

PHITS results with **Bertini**, **JAM**, **JQMD**  
+ **GEM**

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# Models in the benchmark

cem03-02

cem03-03

cascade-04

isabel-smm

isabel-gemini++

geant4-bertini

geant4-binary

cascade-asf

incl4.5-abla07

incl4.5-smm

isabel-abla07

incl45-gemini++

cascade-x

mcnpx-bert

phits-bertini

phits-jam

phits-jqmd

# Nuclear models in **PHITS**

- ❖ **Bertini** - the cascade code
- ❖ **JQMD** - a quantum molecular dynamics. Multi-body calculation. Improved nucleon-nucleon inelastic cross sections than Bertini.
- ❖ **JAM** - a cascade including QGP for high-energy reaction. Inelastic reaction of nucleons of JQMD is included.
- ❖ All models are connected to **GEM** de-excitation
  - Bertini** + **GEM**
  - JQMD** + **GEM**
  - JAM** + **GEM**
- ❖ Differences of PHITS results are caused from the differences of **Bertini**, **JQMD**, and **JAM**

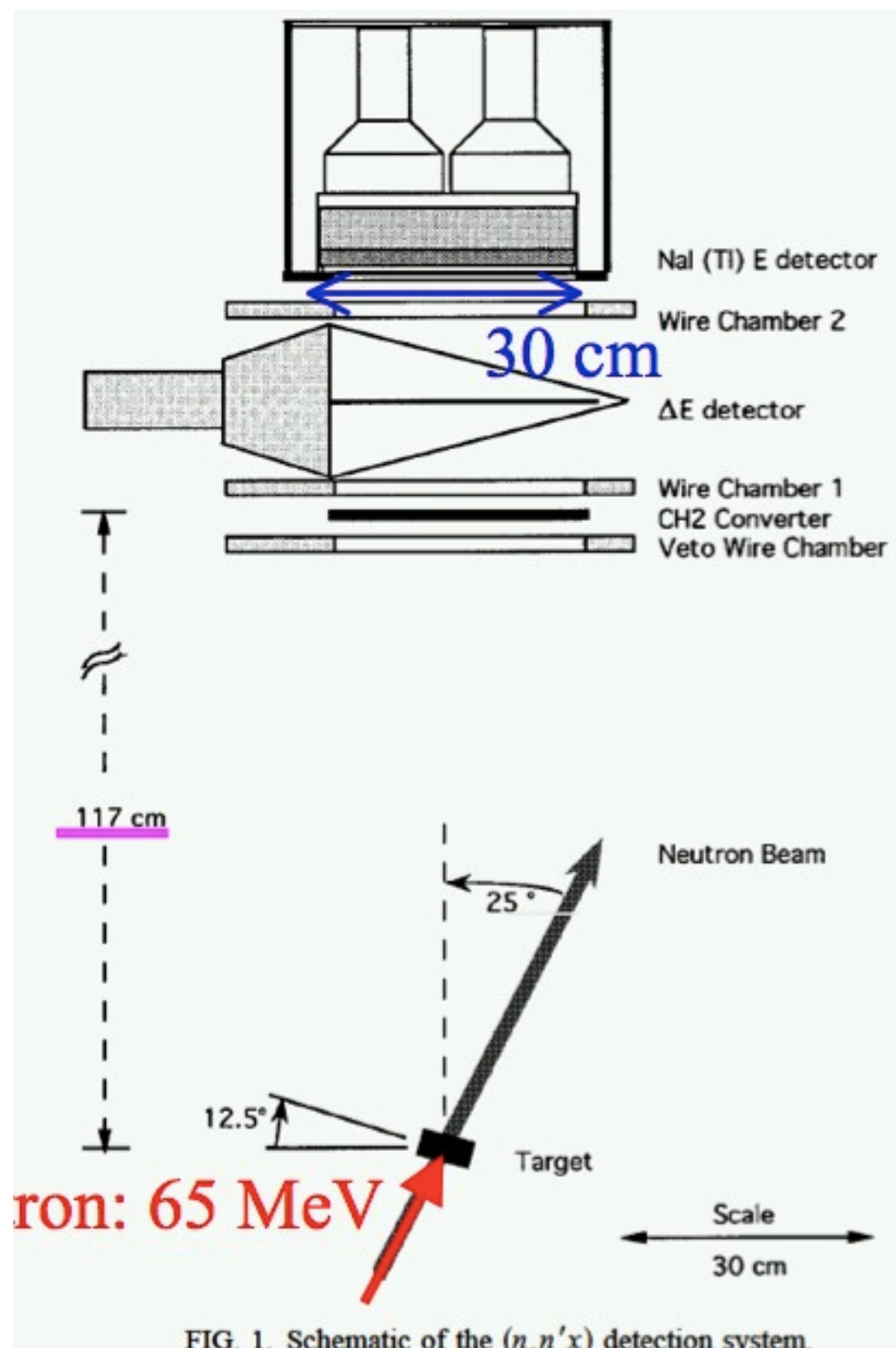
# PHITS parameters

- ❖ since 2003 PHITS changed a **global parameter** only once
- ❖ there is no additional tuning parameters for specific reactions.
- ❖ **JQMD** has produced **reasonably good results to various physical quantities**. Especially **PHITS (JQMD)** as well) was aimed to predict neutron production well (for J-PARC), because neutron production  $\sigma$  is largest.



$n (65 \text{ MeV}) + \text{Fe} \rightarrow n$

data by Hjort

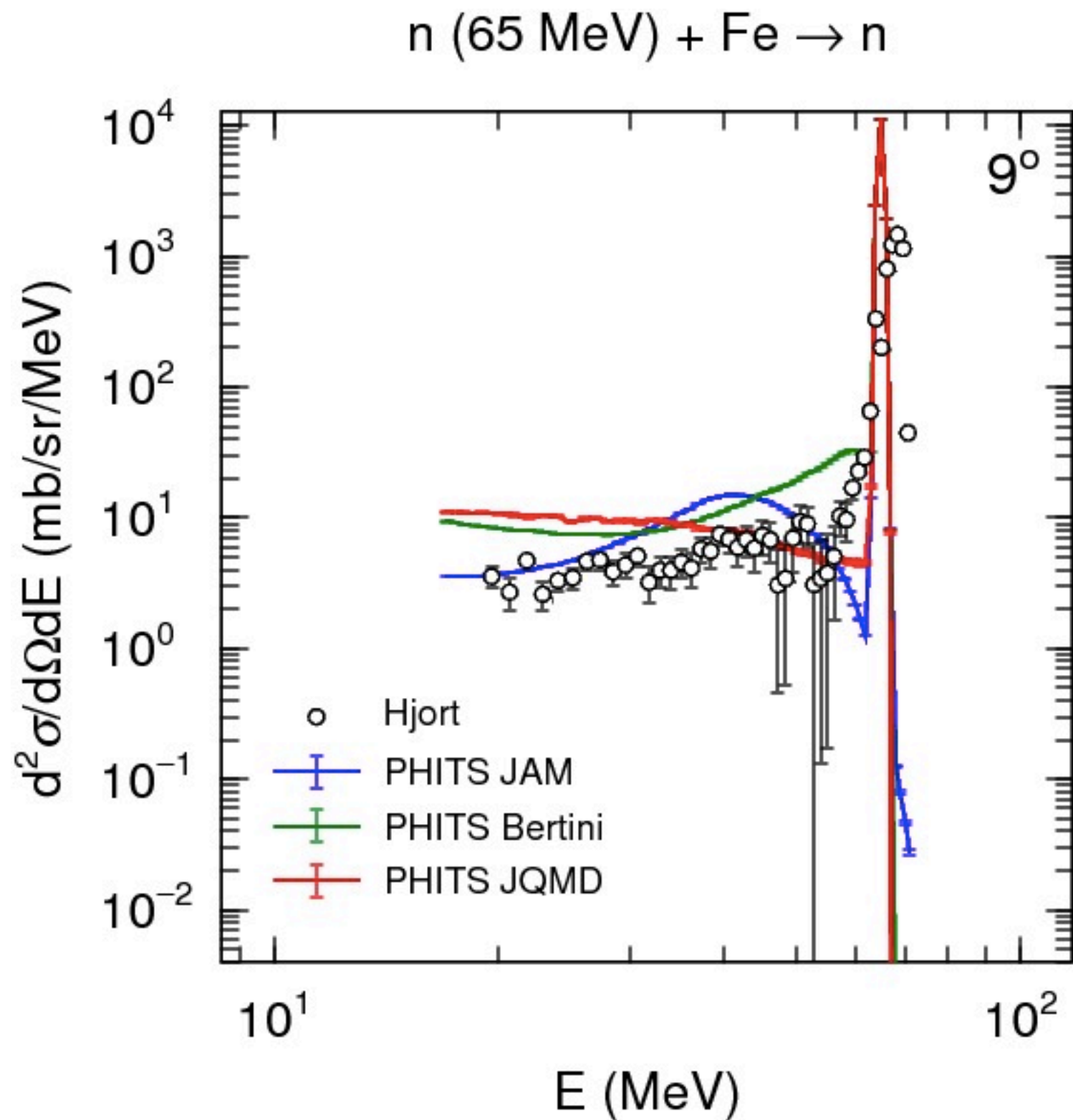


# Expt. and Calc. info. about DDXs01

	Expt.	Calc.
<b>Targets</b>		
Material	Iron	Iron
Size (thickness)	unclear	1.0 cm
Size (width)	unclear	$\phi$ 0.5 cm
Density	---	7.87 g/cm <sup>3</sup>
<b>Detectors</b>		
Size (width)	30 cm	$\pm$ 5.90 degrees
Angle	9.5 to 28 degrees	9.5 to 28 degrees
Distance (T to D)	about 145 cm	10 m

n (65 MeV) + Fe → n

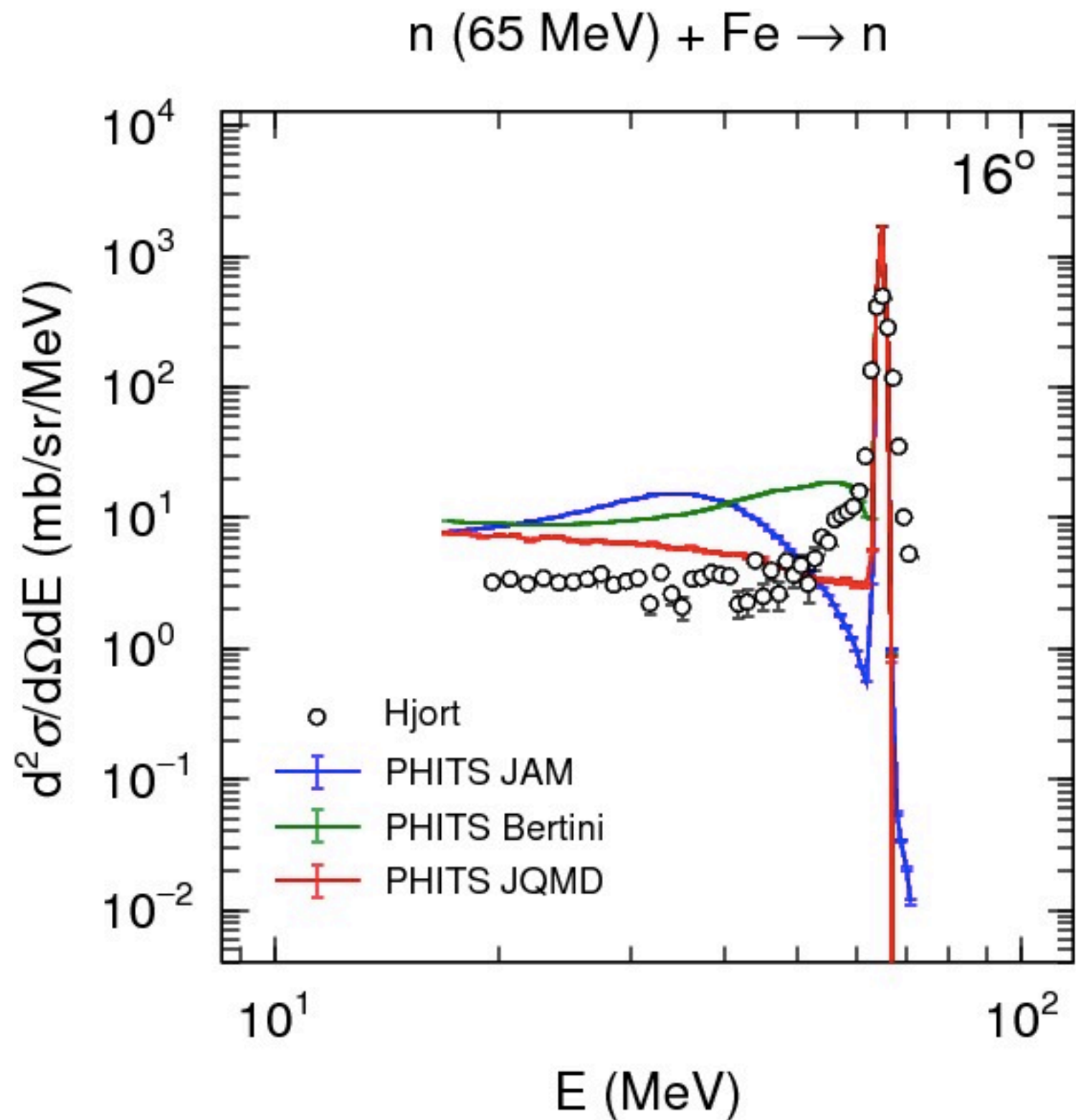
data by Hjort





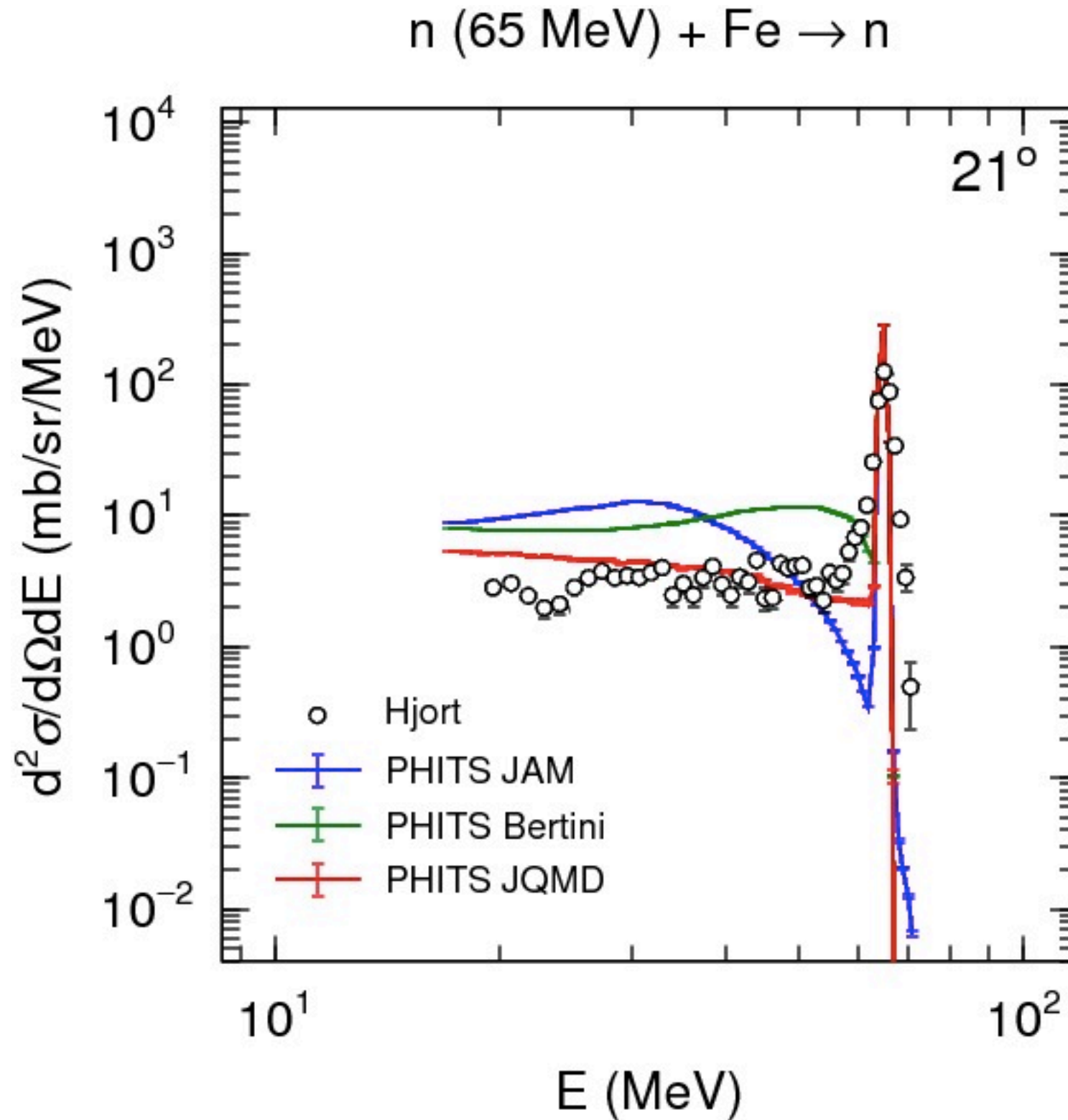
n (65 MeV) + Fe → n

data by Hjort



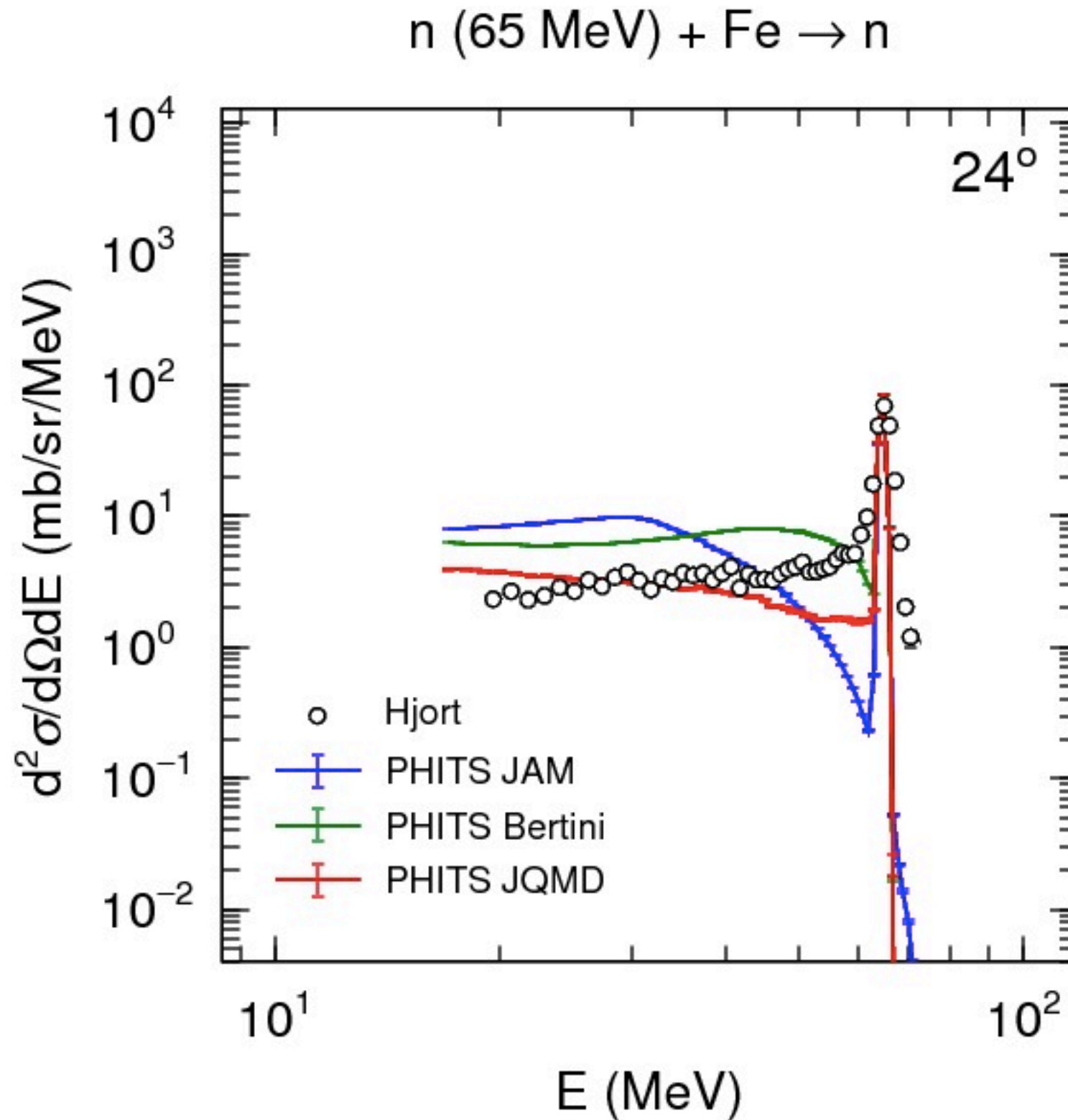
n (65 MeV) + Fe → n

data by Hjort



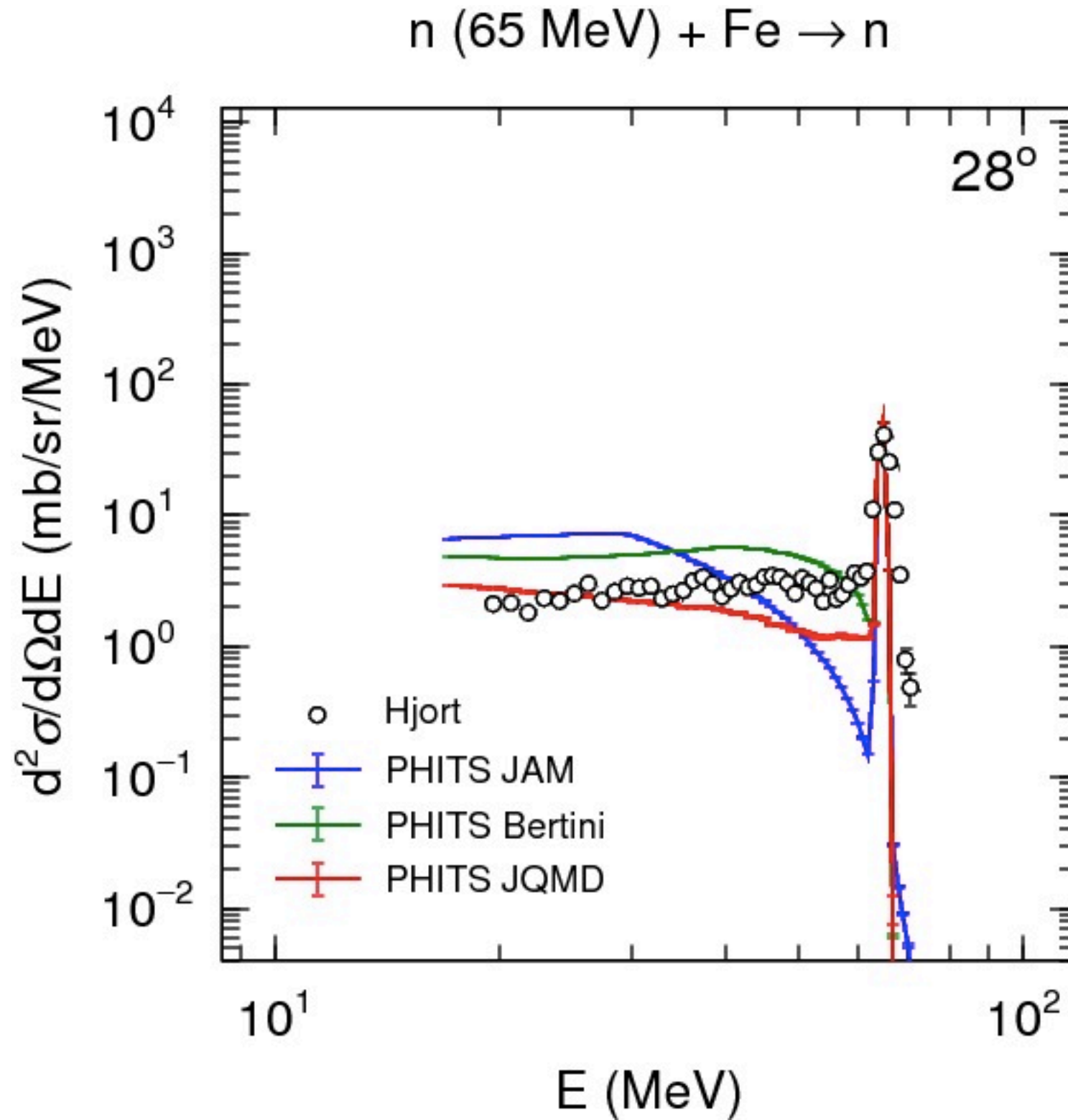
n (65 MeV) + Fe → n

data by Hjort

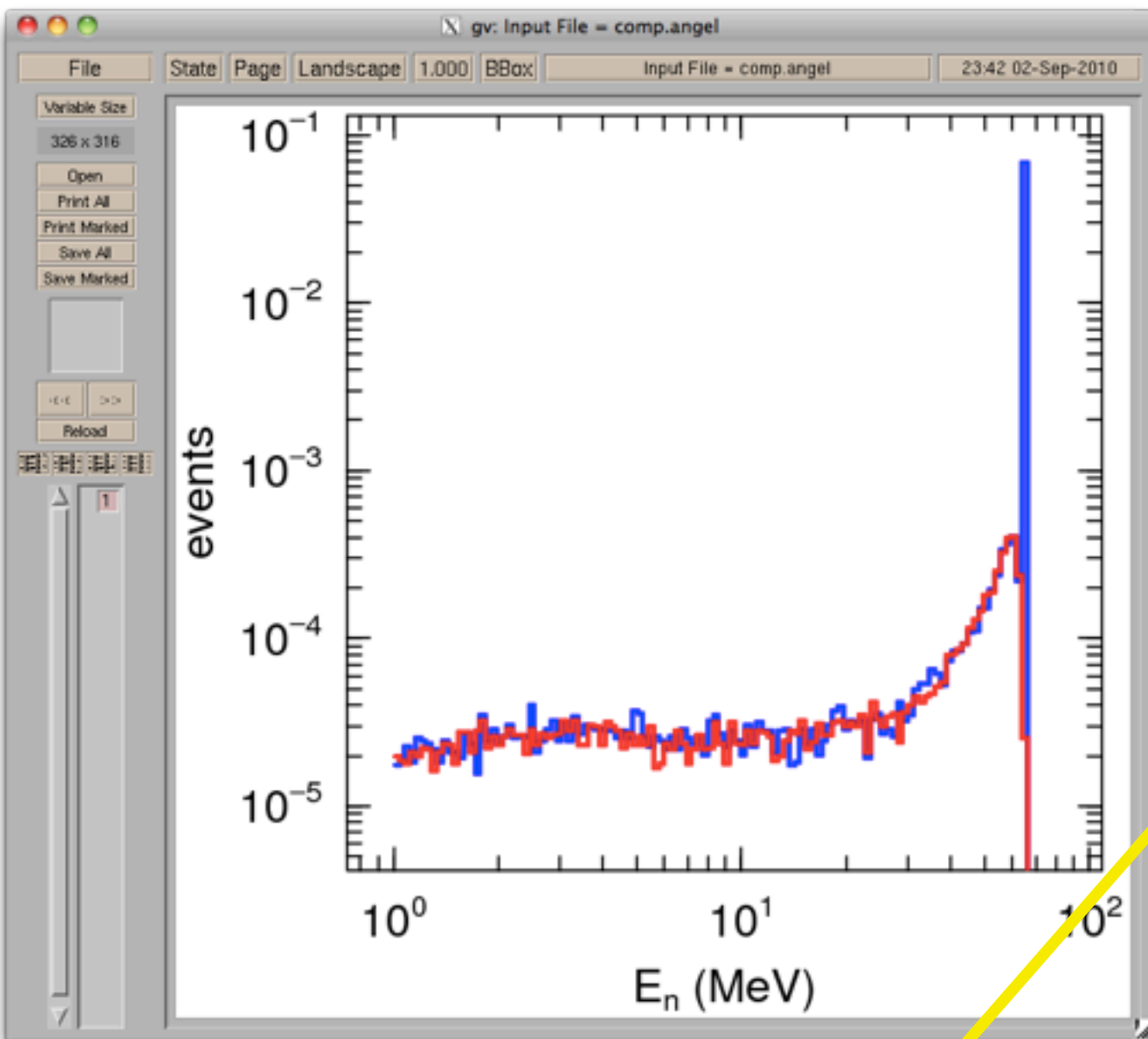


n (65 MeV) + Fe → n

data by Hjort



# repeat calculation@saclay by Iwase



### CPU Summary

	sec	%	count
<i>total cpu time =</i>	49.01	100.00	
<i>set data =</i>	0.00	0.00	
<i>transport =</i>	0.00	0.00	
<i>analysis =</i>	0.00	0.00	6531244.
<i>nevap =</i>	0.00	0.00	279304.
<i>nreac =</i>	0.00	0.00	279311.
<i>other =</i>	0.00	0.00	
<i>hydro =</i>	0.00	0.00	0.
<i>dklos =</i>	0.00	0.00	0.
<i>elast =</i>	0.00	0.00	164604.
<i>ncasc =</i>	0.00	0.00	314564.
<i>n-data =</i>	0.00	0.00	0.
<i>p-data =</i>	0.00	0.00	0.
<i>e-data =</i>	0.00	0.00	0.
<i>h-data =</i>	0.00	0.00	0.
<i>berti =</i>	0.00	0.00	314564.
<i>isoba =</i>	0.00	0.00	0.
<i>JAM =</i>	0.00	0.00	0.
<i>QMD =</i>	0.00	0.00	0.
<i>=== incident particle into bert ===</i>			
<i>proton =</i>	0.32		1000.
<i>neutron =</i>	99.68		313564.
-----			
<i>total</i>			314564.
<i>real</i>			114700.
END			
(END)			

*hydro =*  
*dklos =*  
*elast =*  
*ncasc =*  
*n-data =*



$p$  (800 MeV) + Fe  $\rightarrow$  n

data by Leray

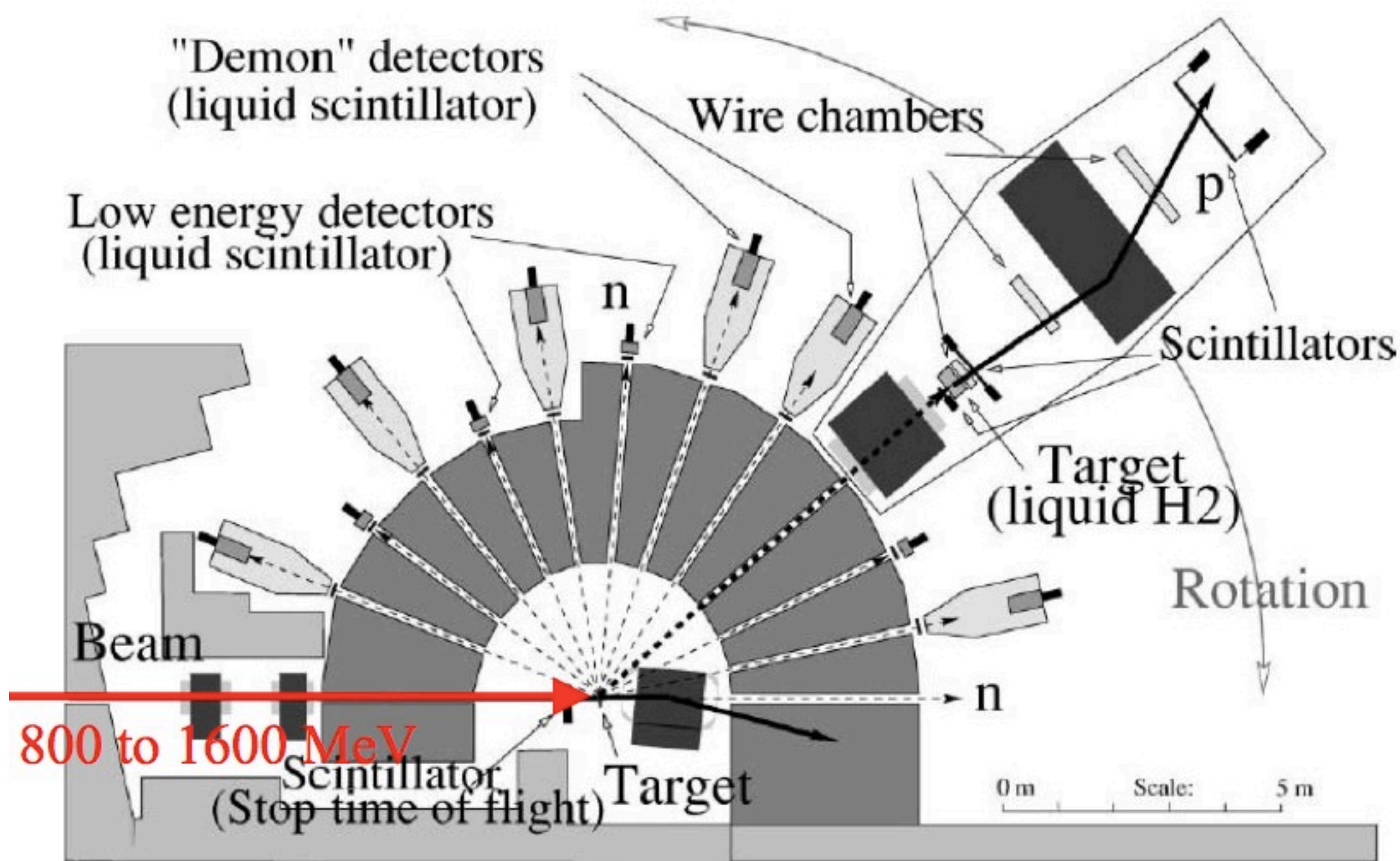
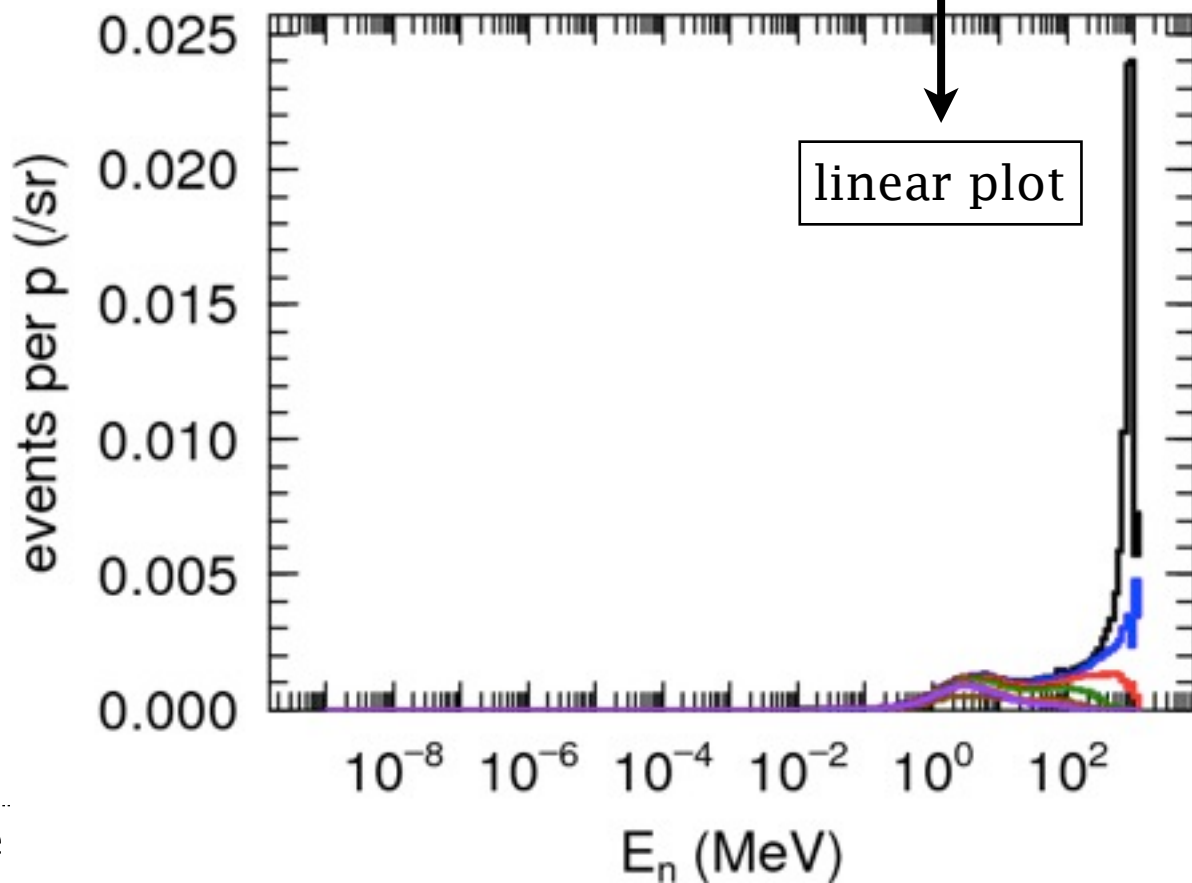
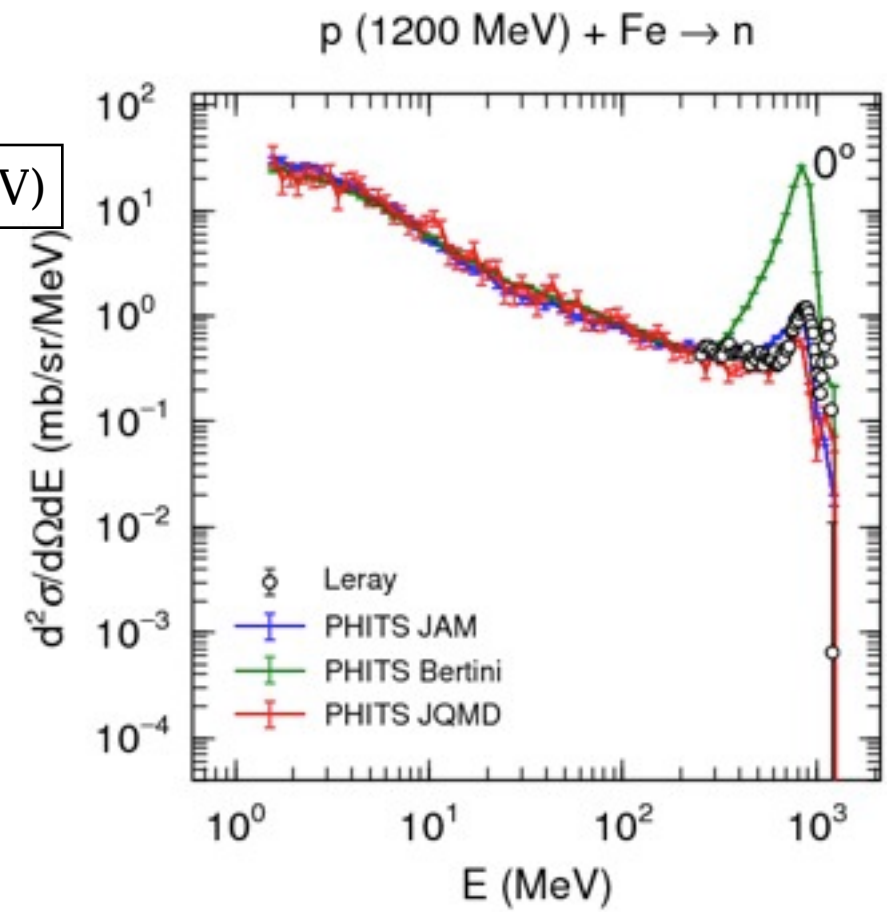
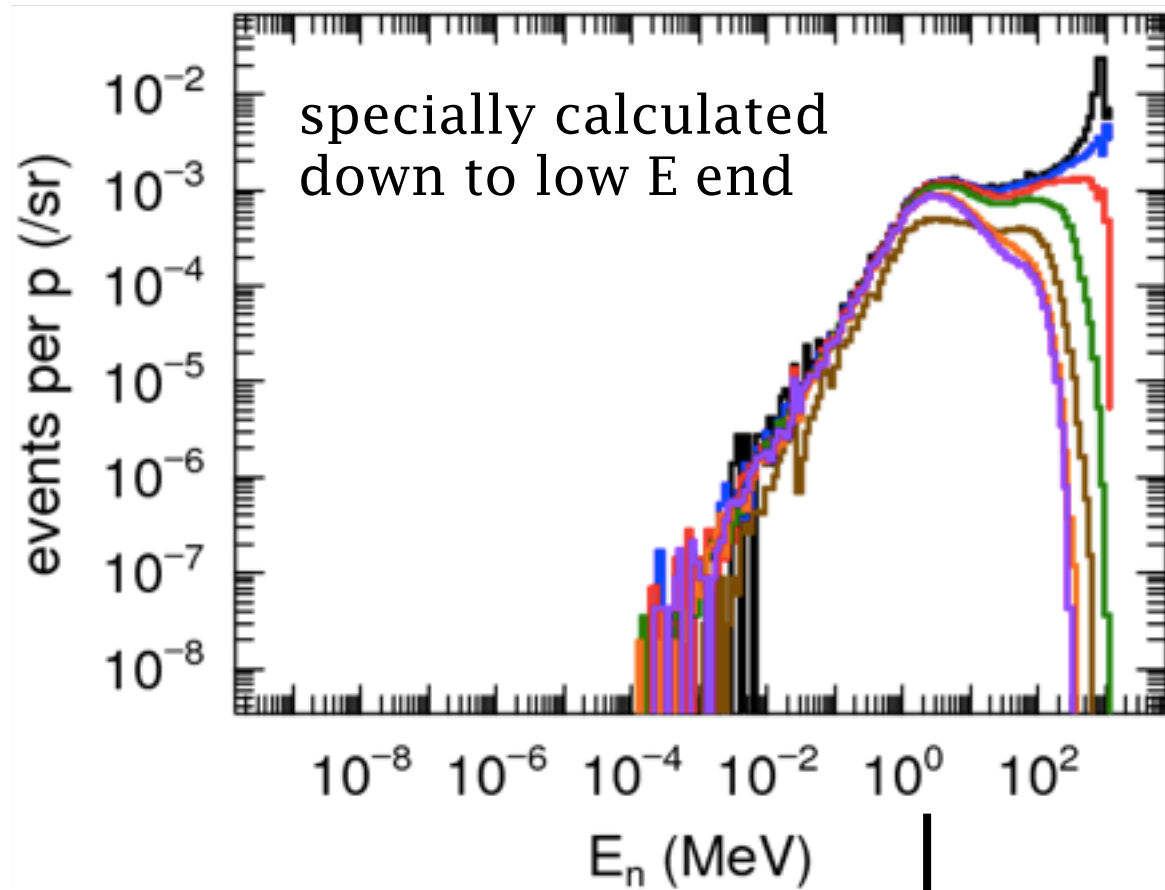


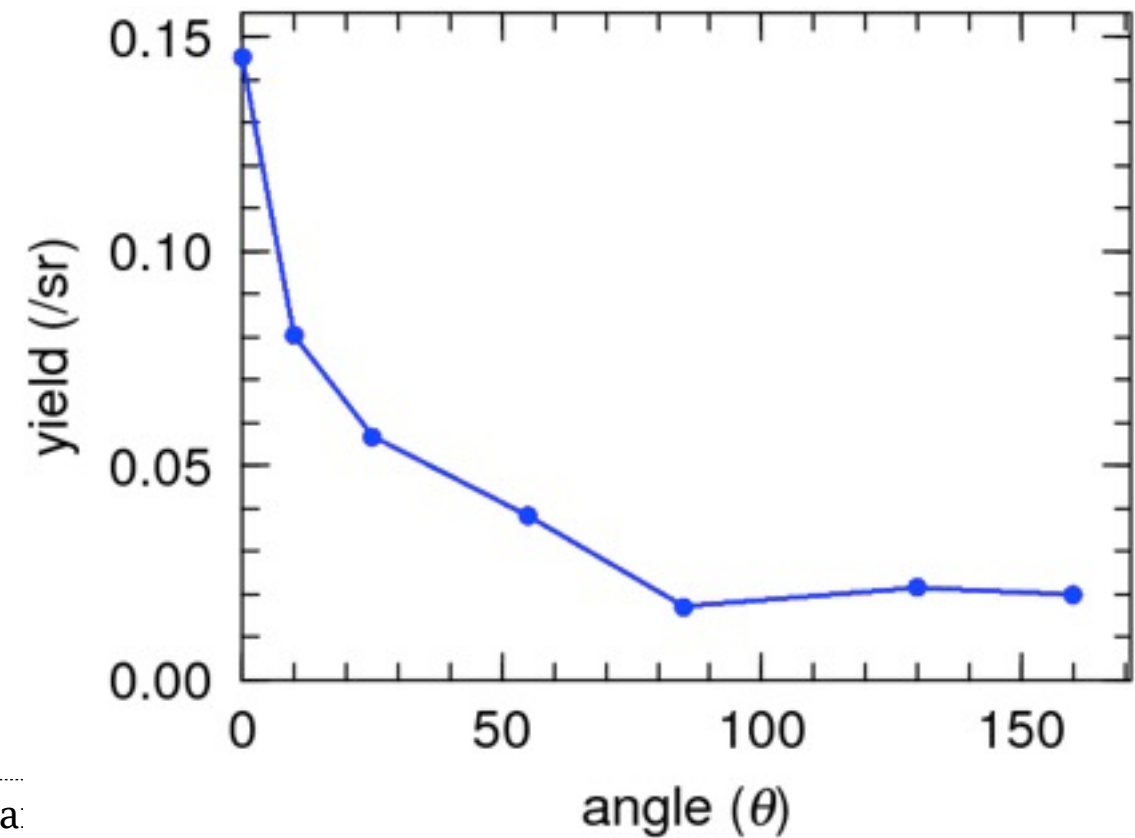
FIG. 1. Experimental area with time-of-flight and spectrometer setup.

# p (1200 MeV) + Fe -> n



integration

angular distribution



Variable Size

Open

Print All

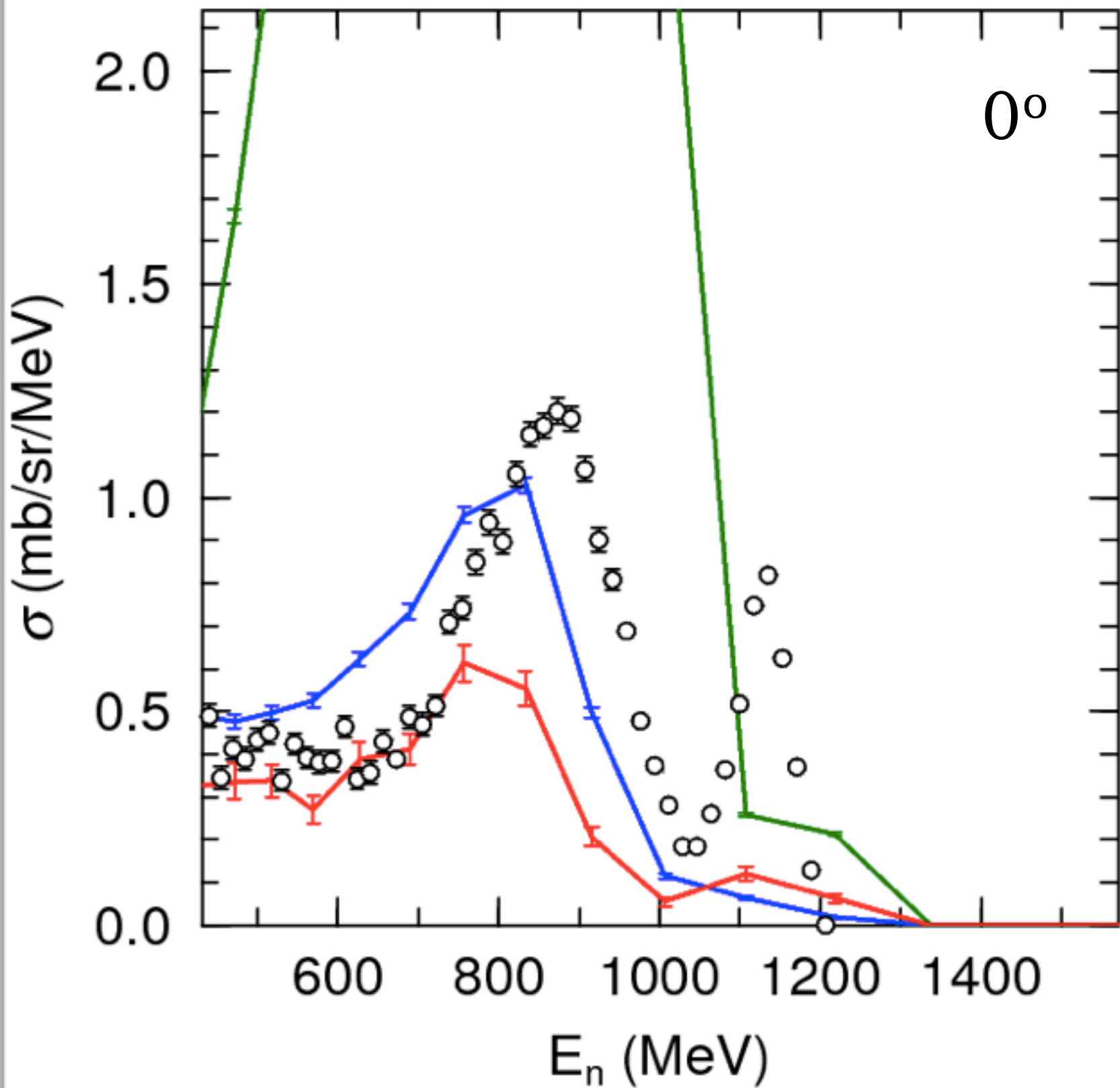
Print Marked

Save All

Save Marked

Reload

# p (1200 MeV) + Fe → n

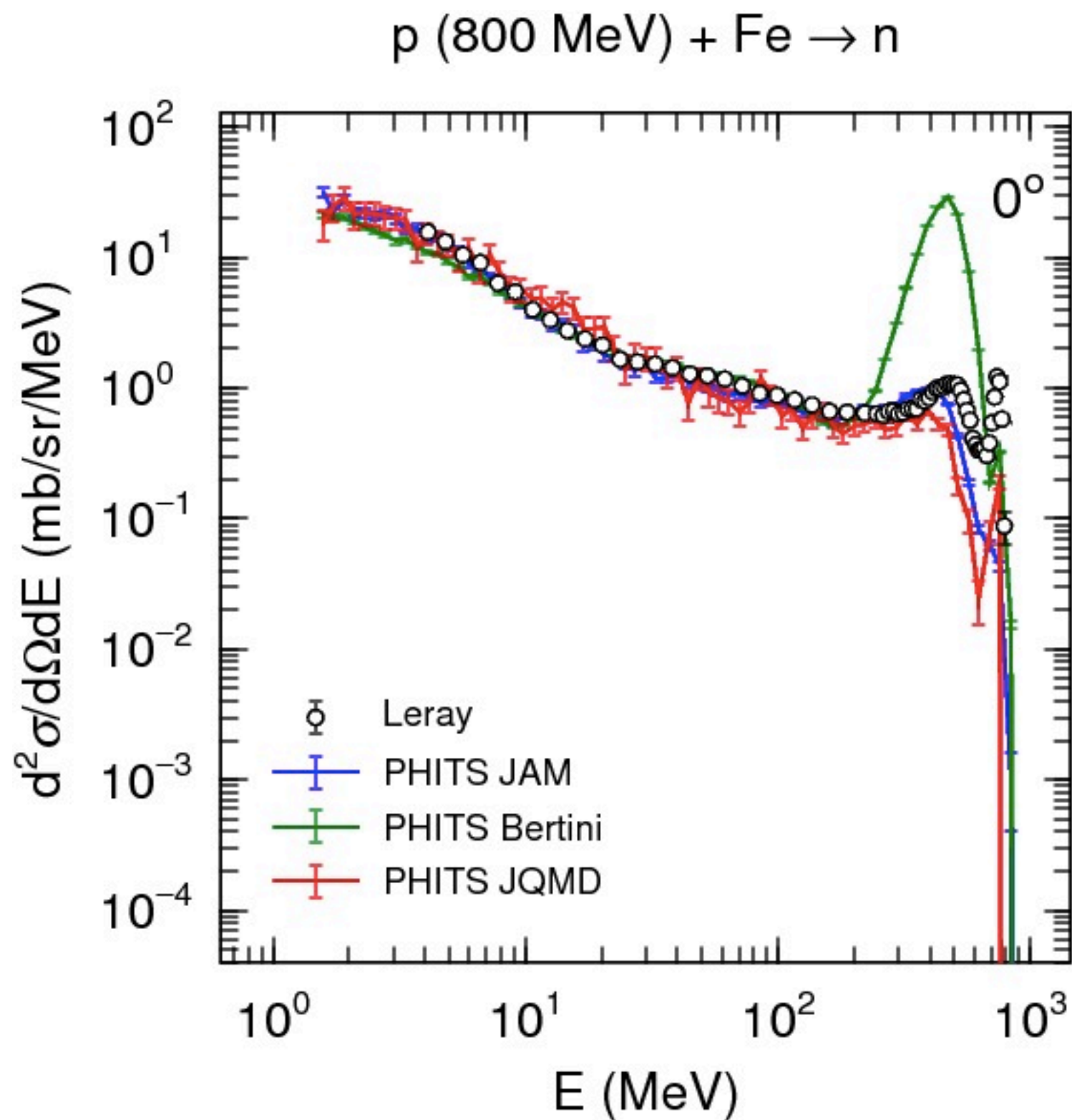


- $\circ$  Leray
- $\text{---}+$  PHITS JAM
- $\text{---}+$  PHITS Bertini
- $\text{---}+$  PHITS JQMD



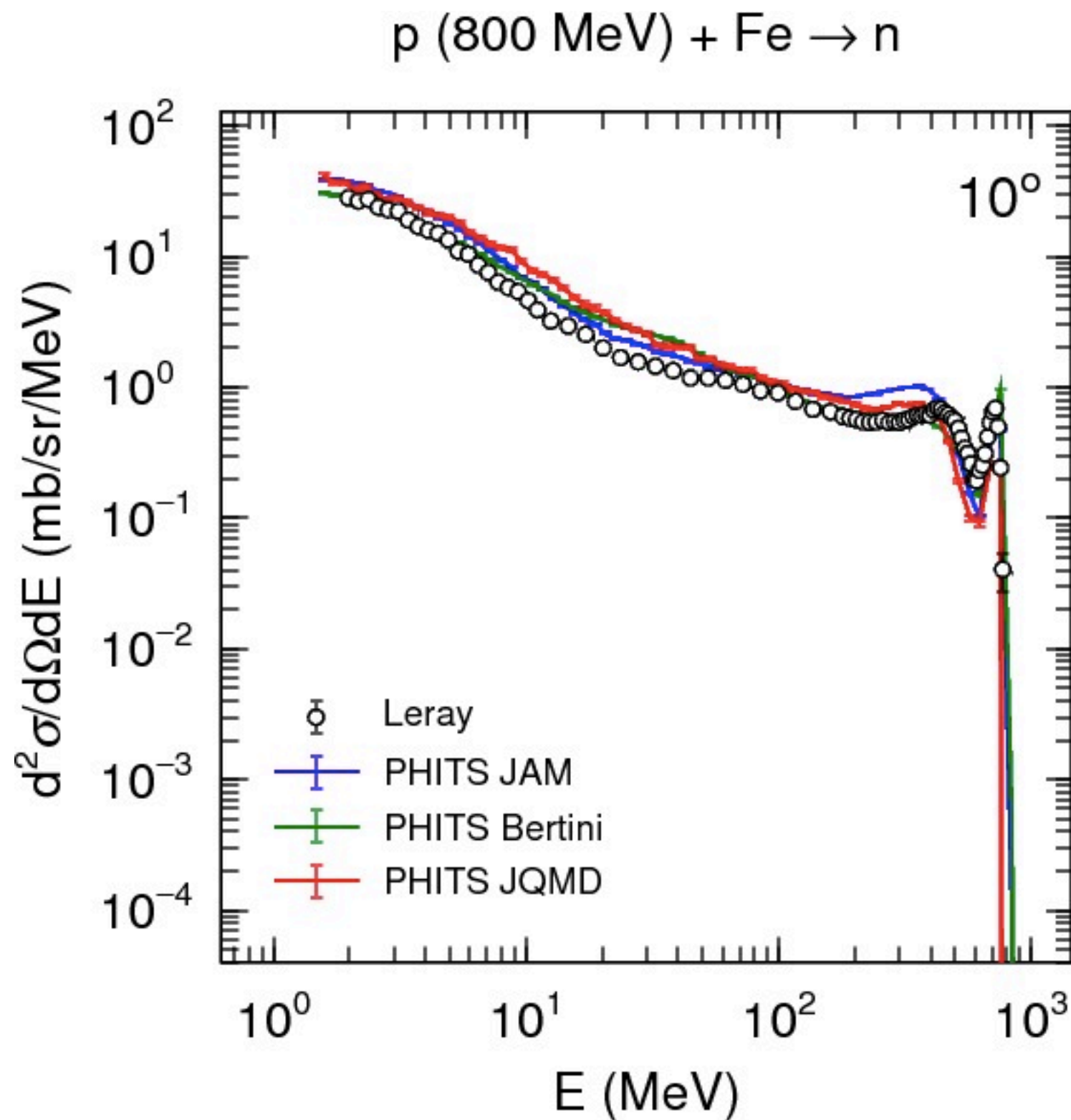
p (800 MeV) + Fe → n

data by Leray



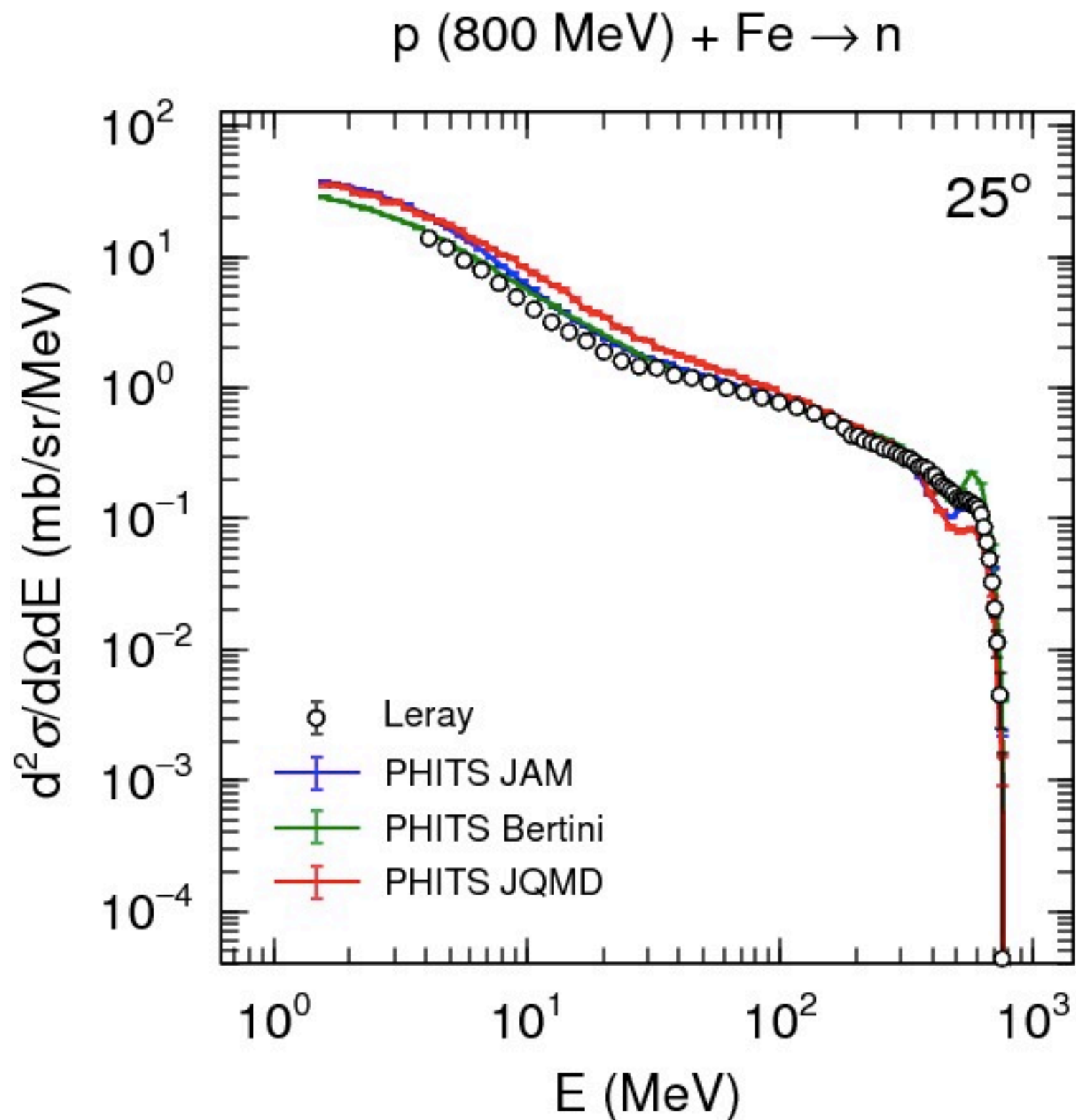
p (800 MeV) + Fe  $\rightarrow$  n

data by Leray

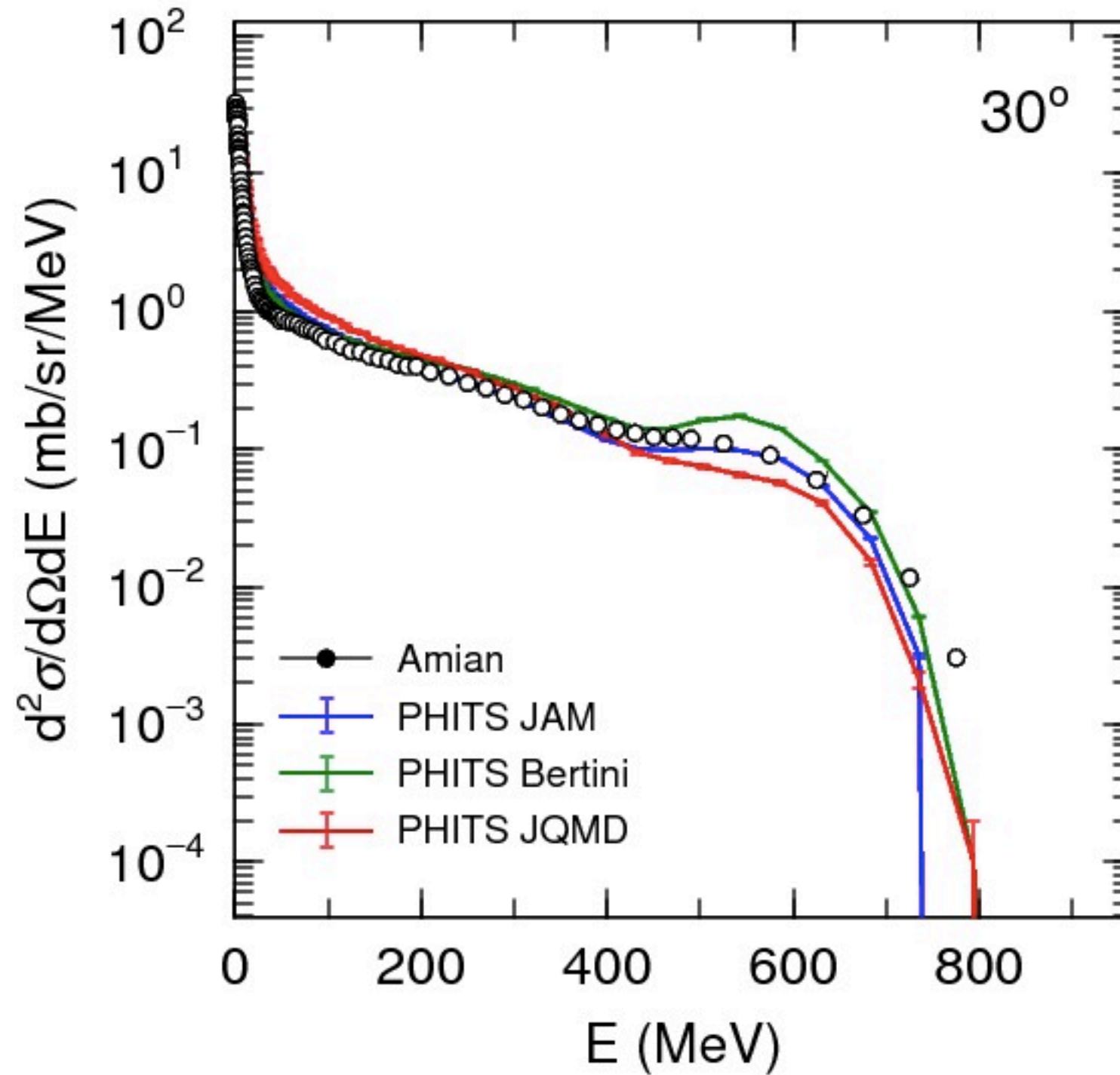


p (800 MeV) + Fe  $\rightarrow$  n

data by Leray

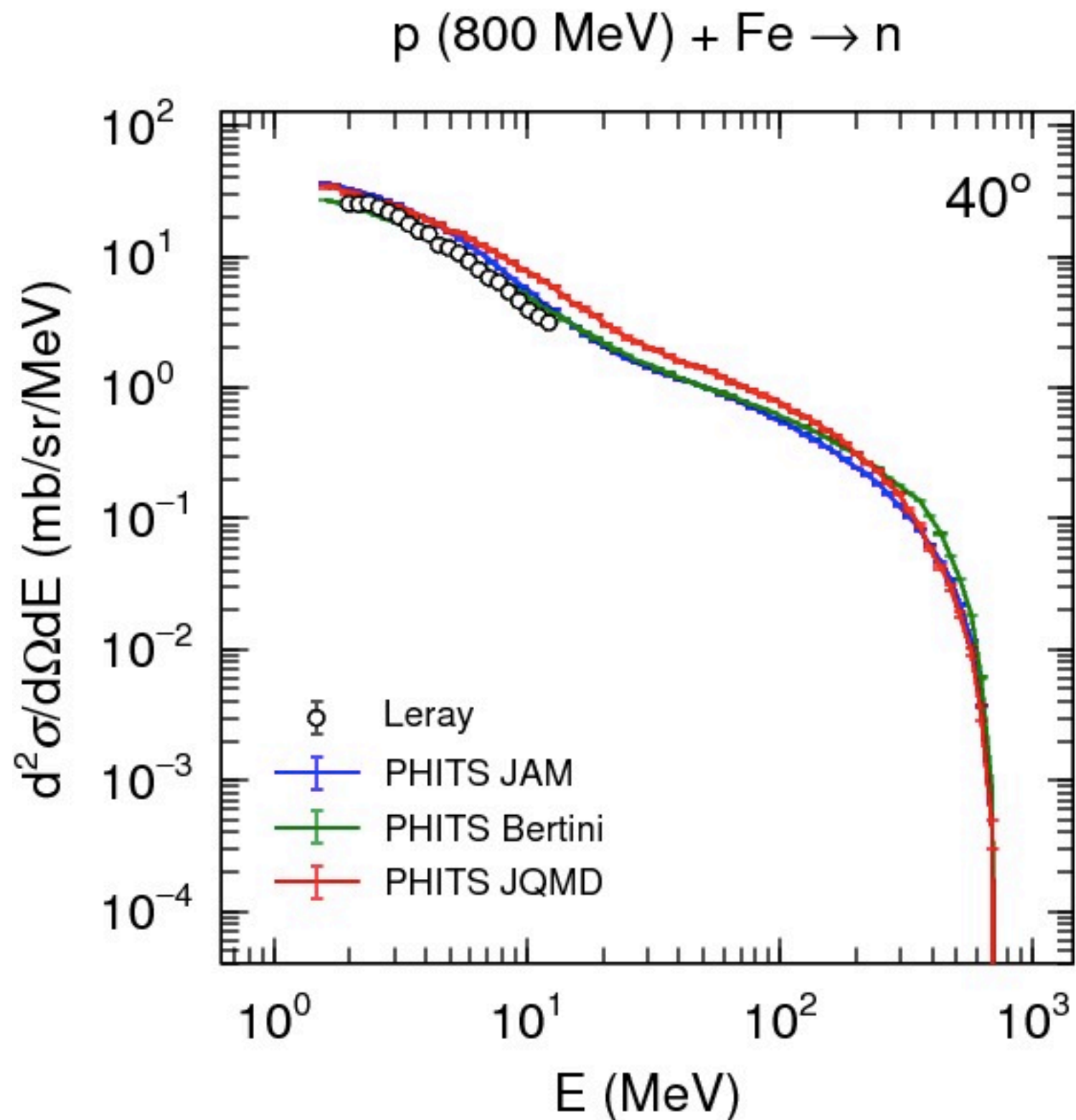


p (800 MeV) + Fe → n



p (800 MeV) + Fe  $\rightarrow$  n

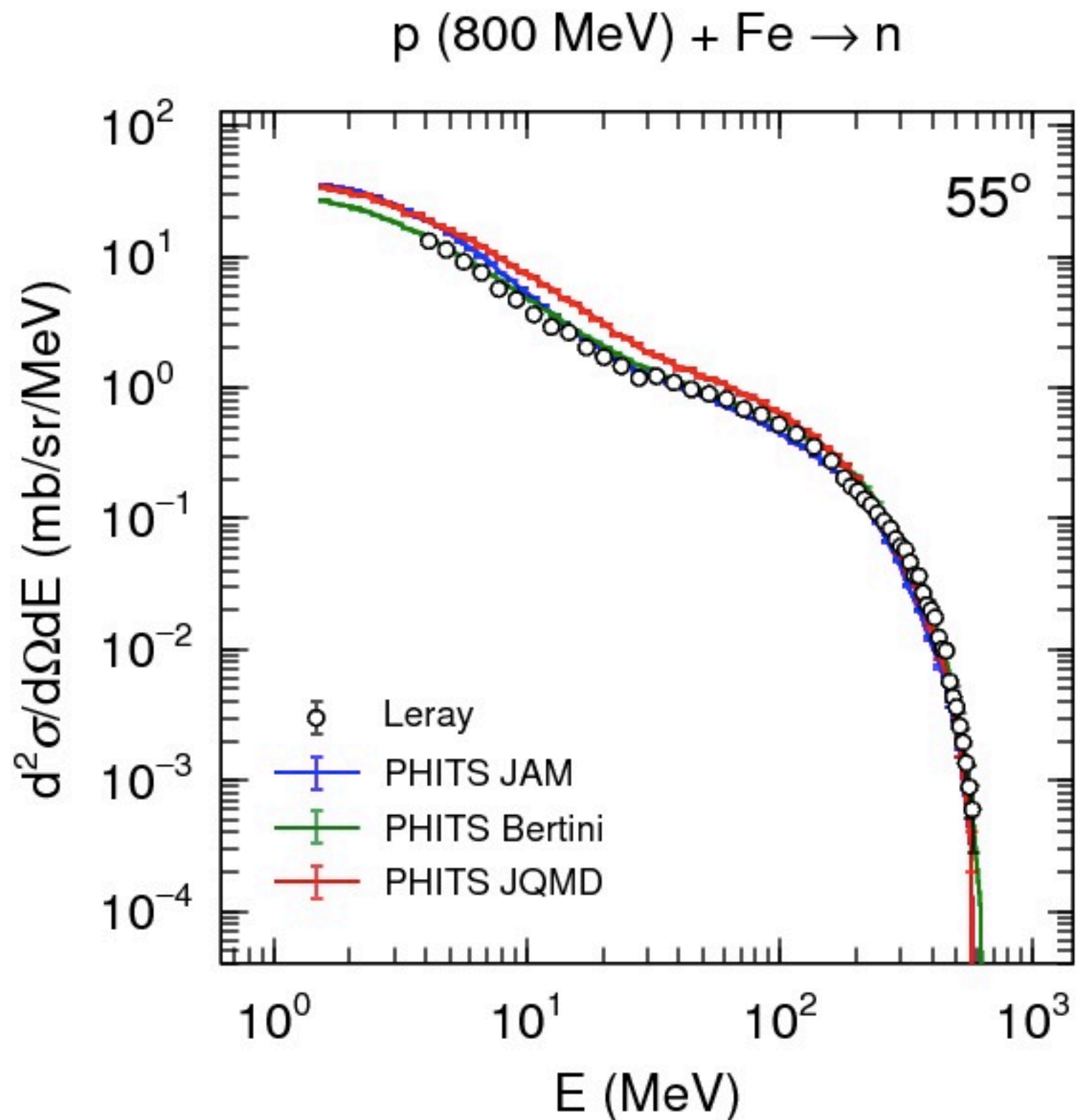
data by Leray





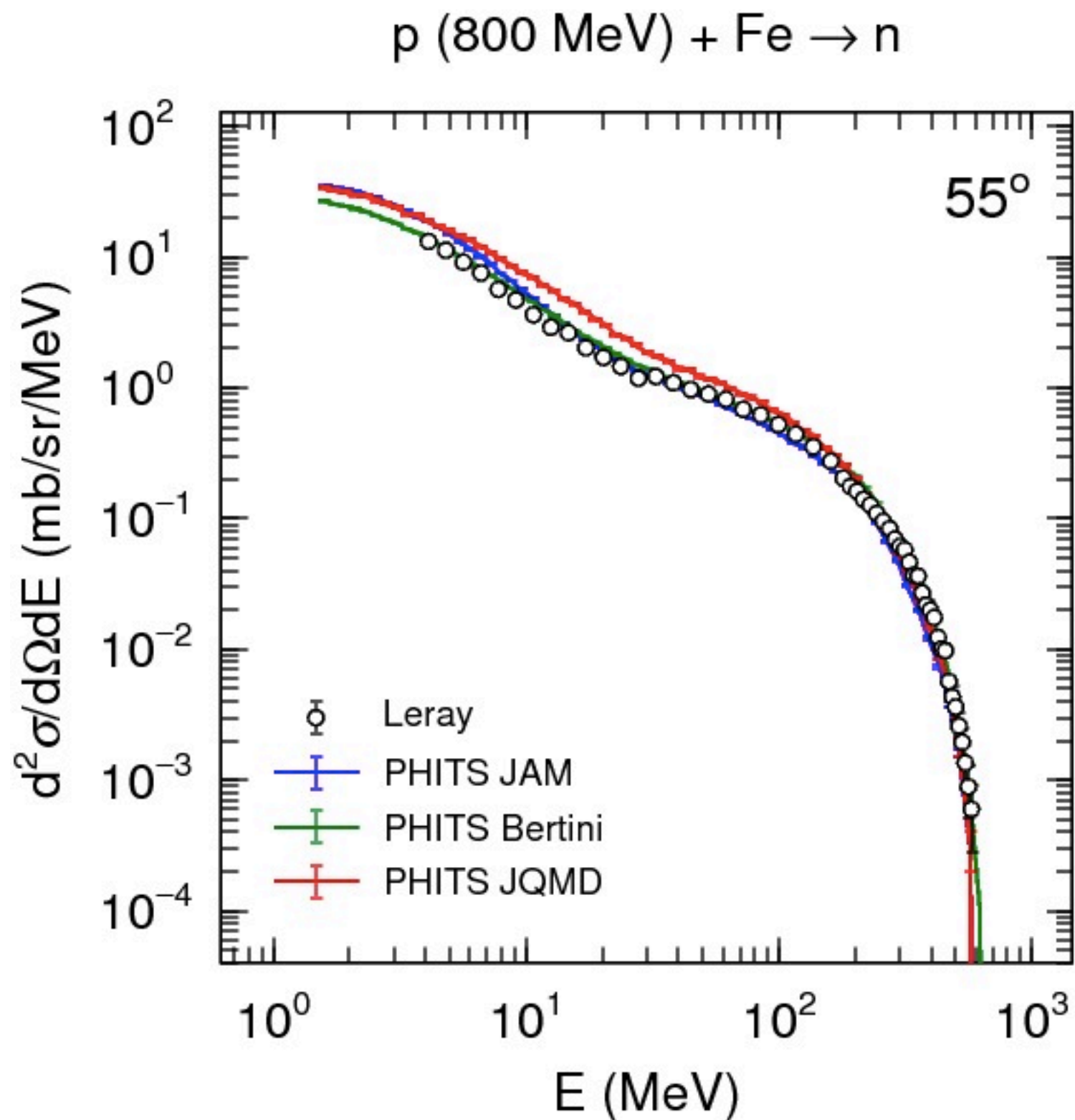
p (800 MeV) + Fe  $\rightarrow$  n

data by Leray



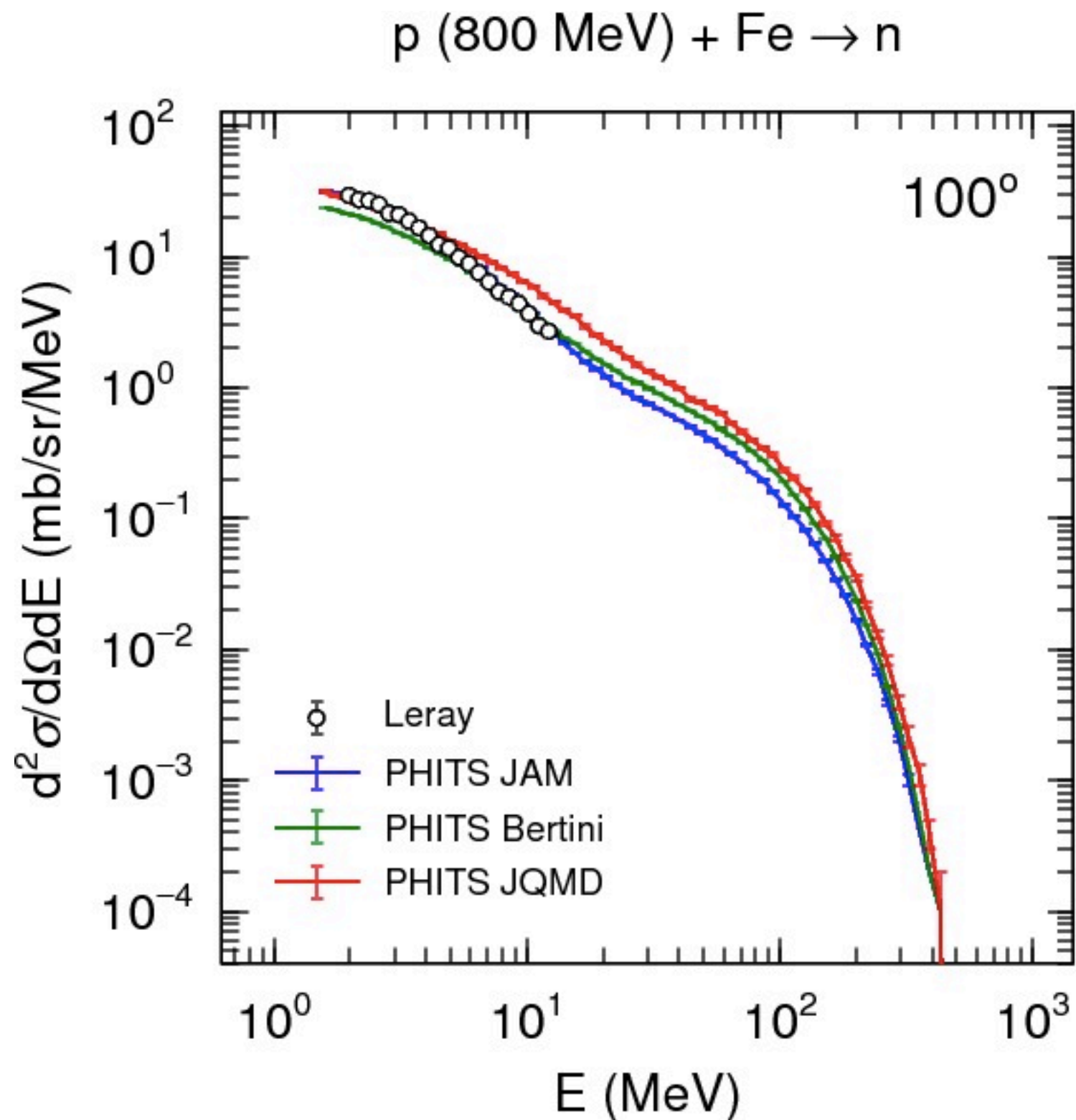
p (800 MeV) + Fe  $\rightarrow$  n

data by Leray



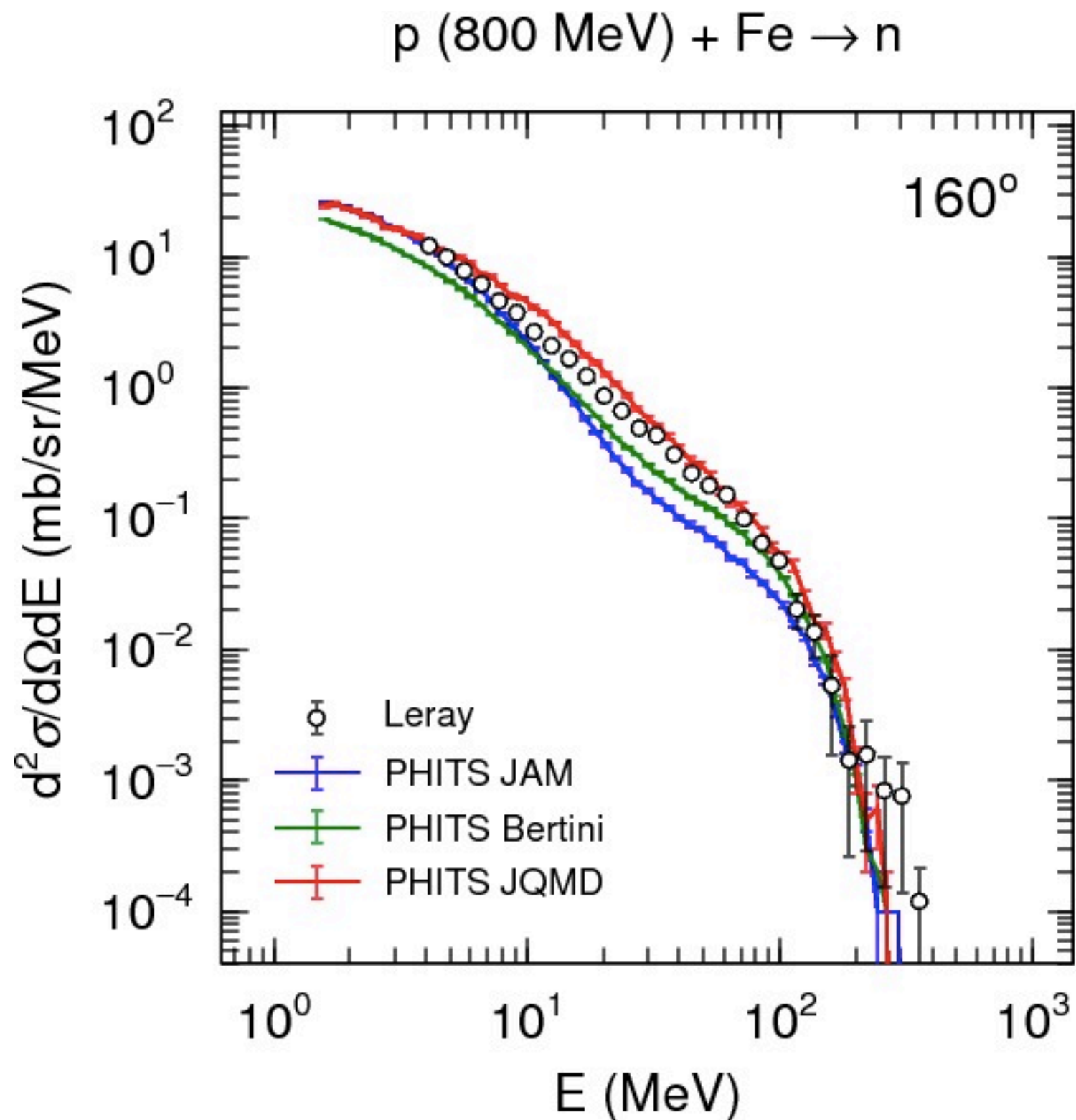
p (800 MeV) + Fe  $\rightarrow$  n

data by Leray

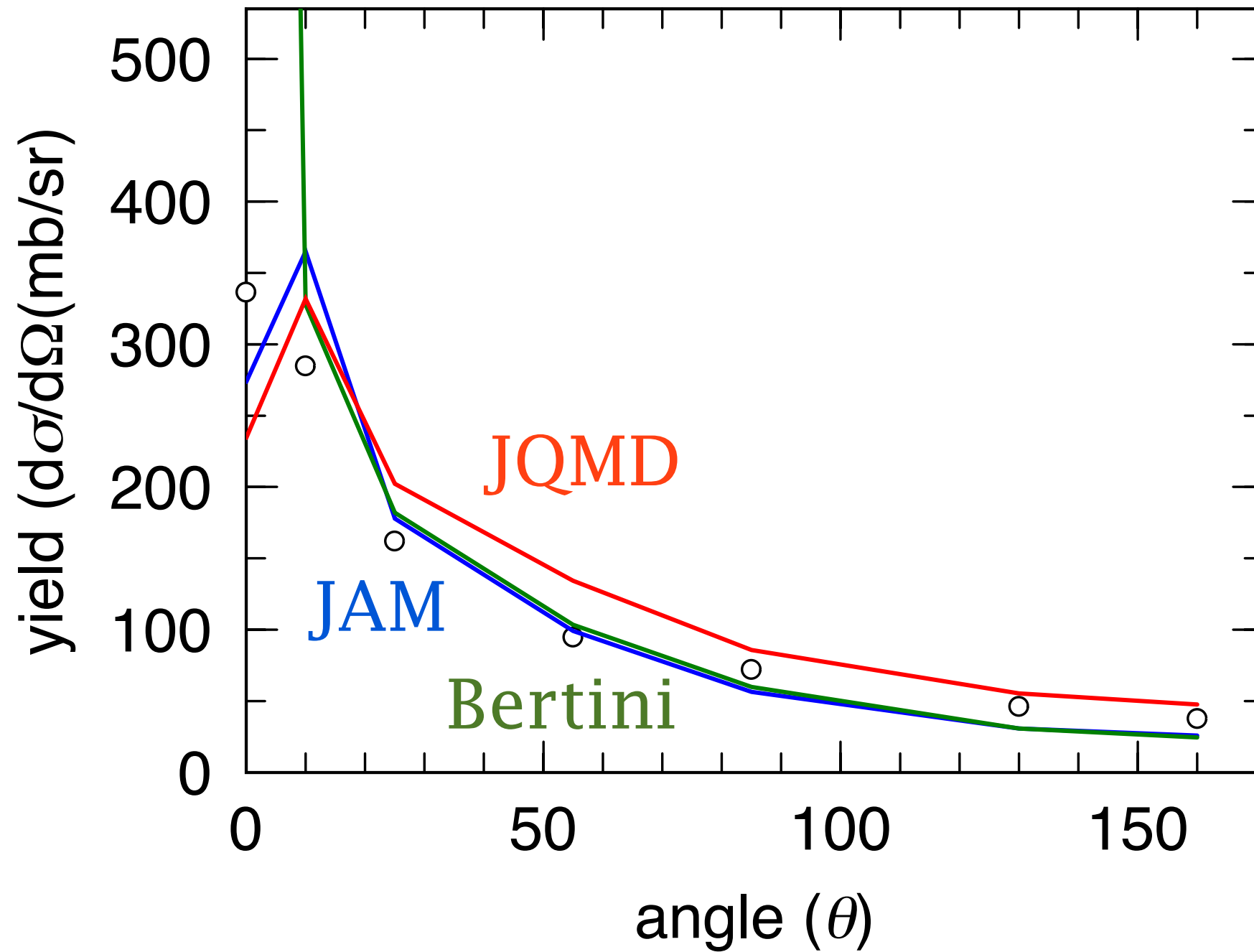


p (800 MeV) + Fe  $\rightarrow$  n

data by Leray



### Angular distribution





$p$  (1200 MeV) + Fe  $\rightarrow$  n

data by Leray

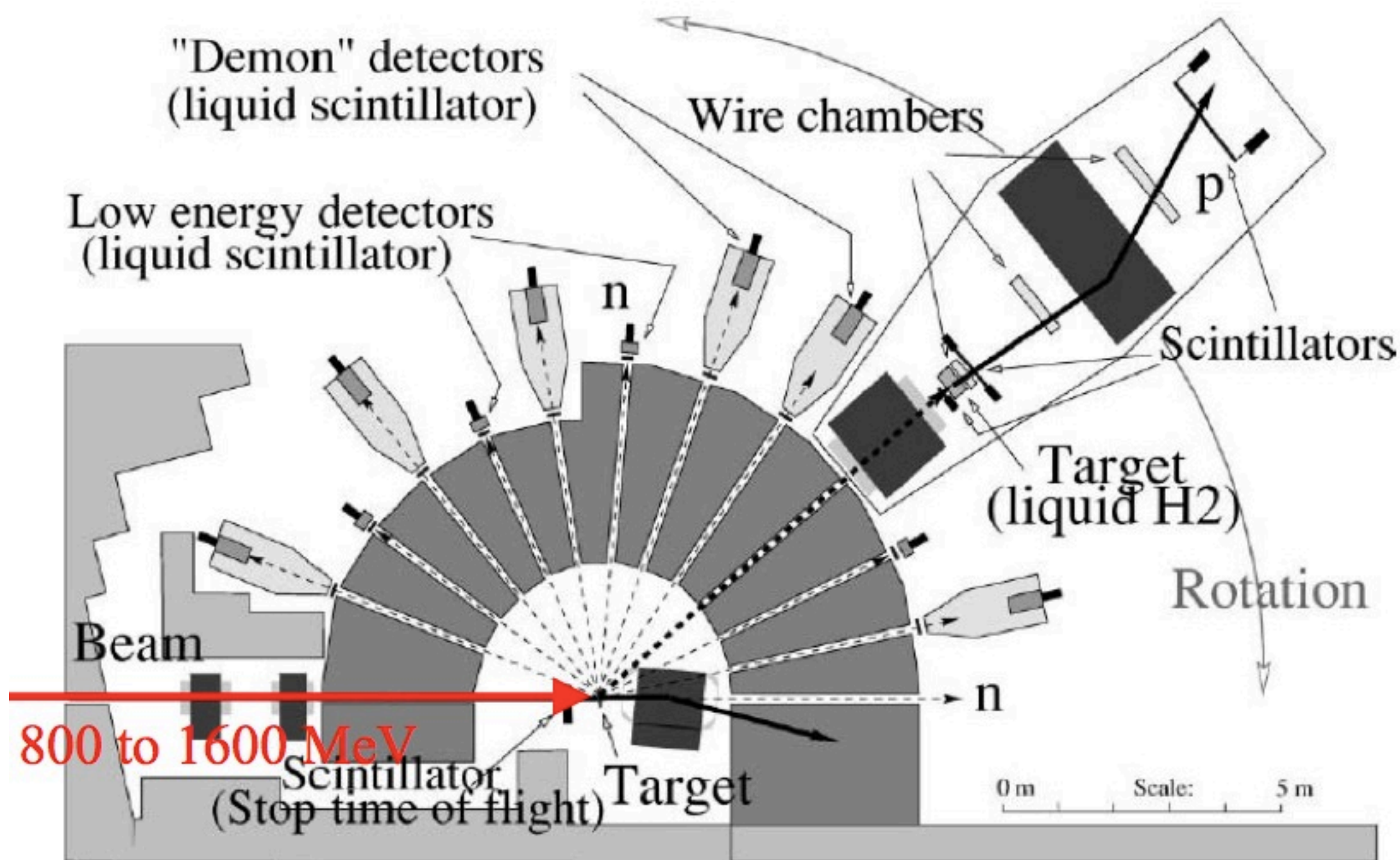
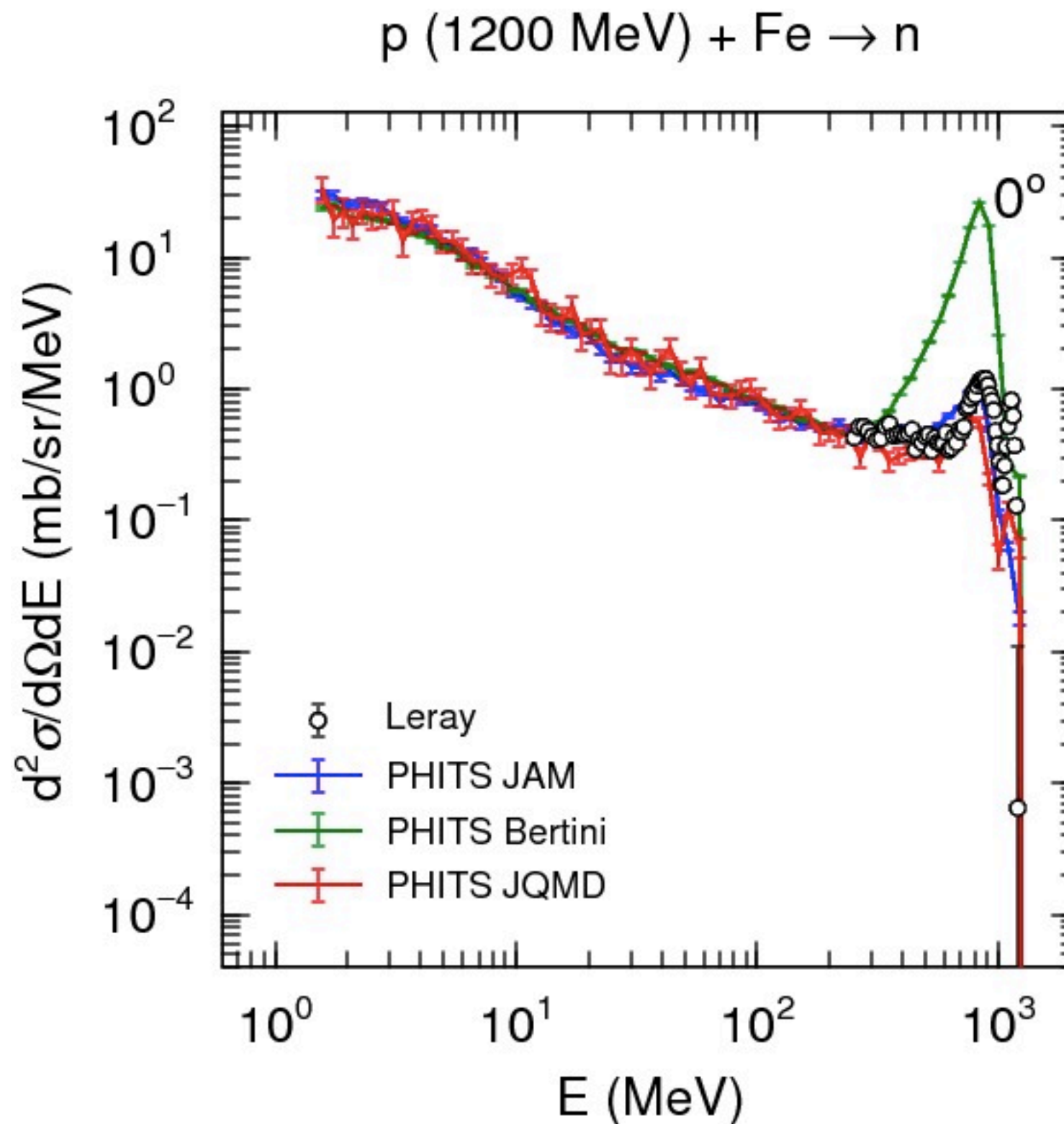


FIG. 1. Experimental area with time-of-flight and spectrometer setup.

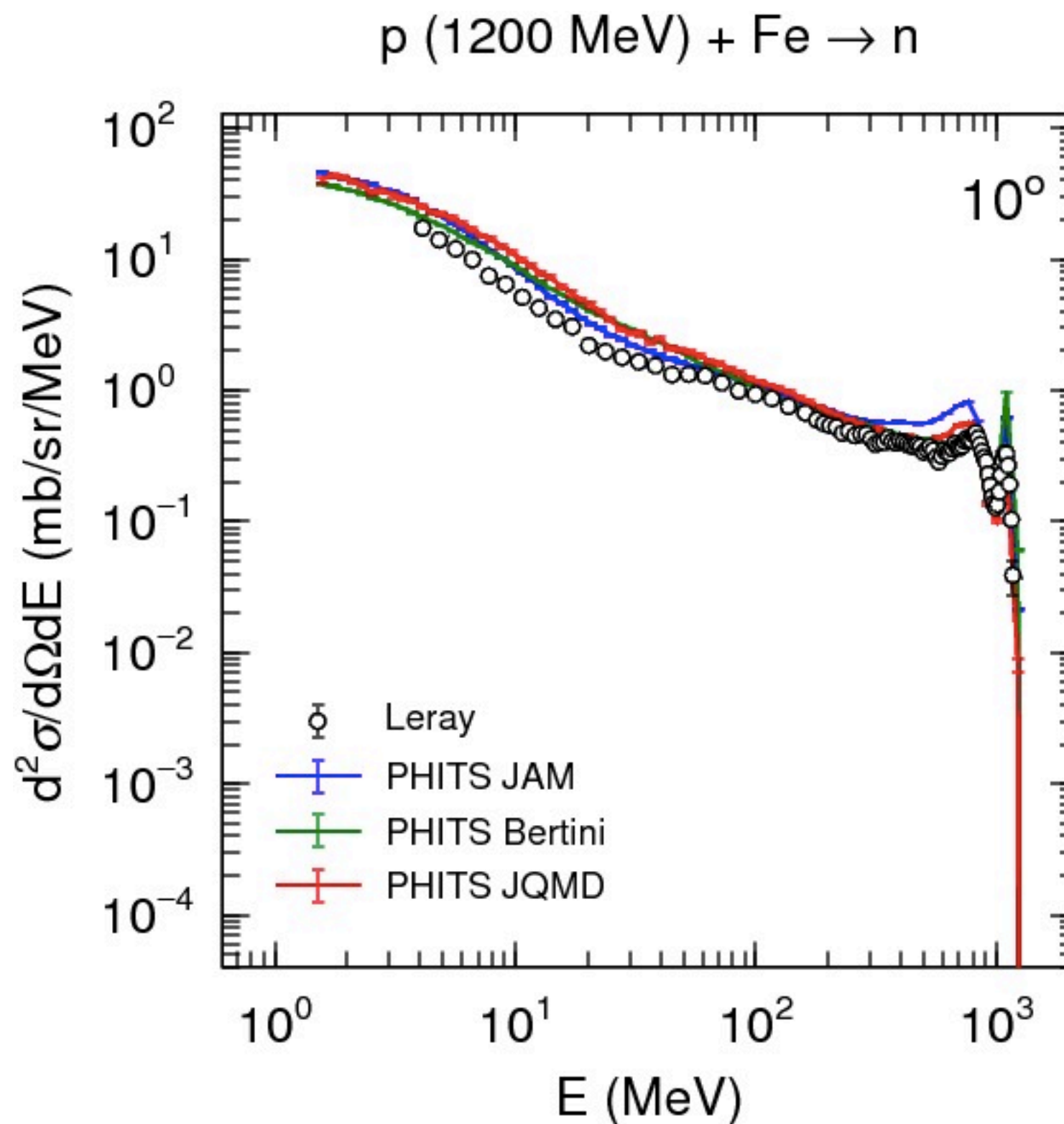
p (1200 MeV) + Fe → n

data by Leray



p (1200 MeV) + Fe  $\rightarrow$  n

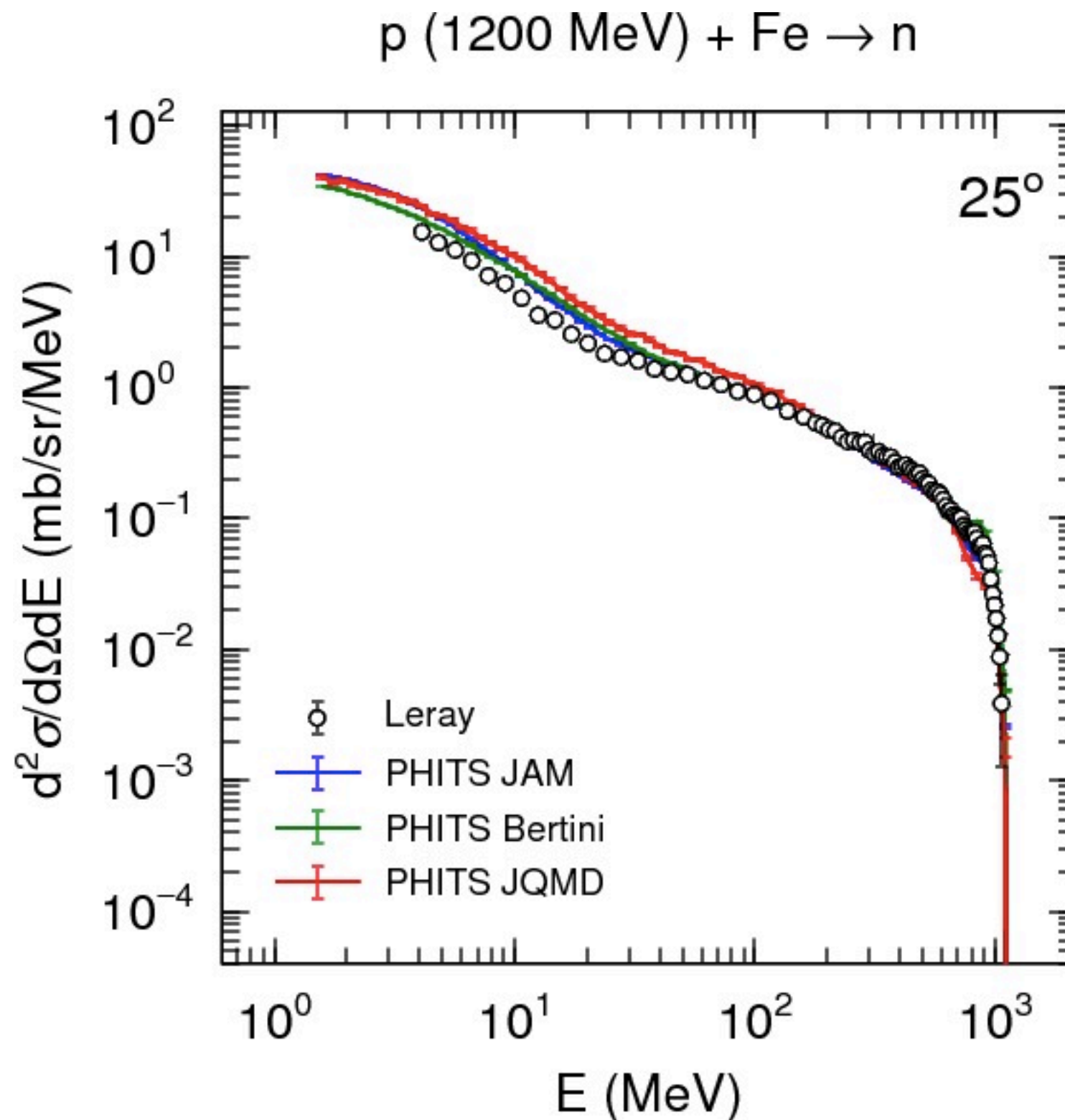
data by Leray





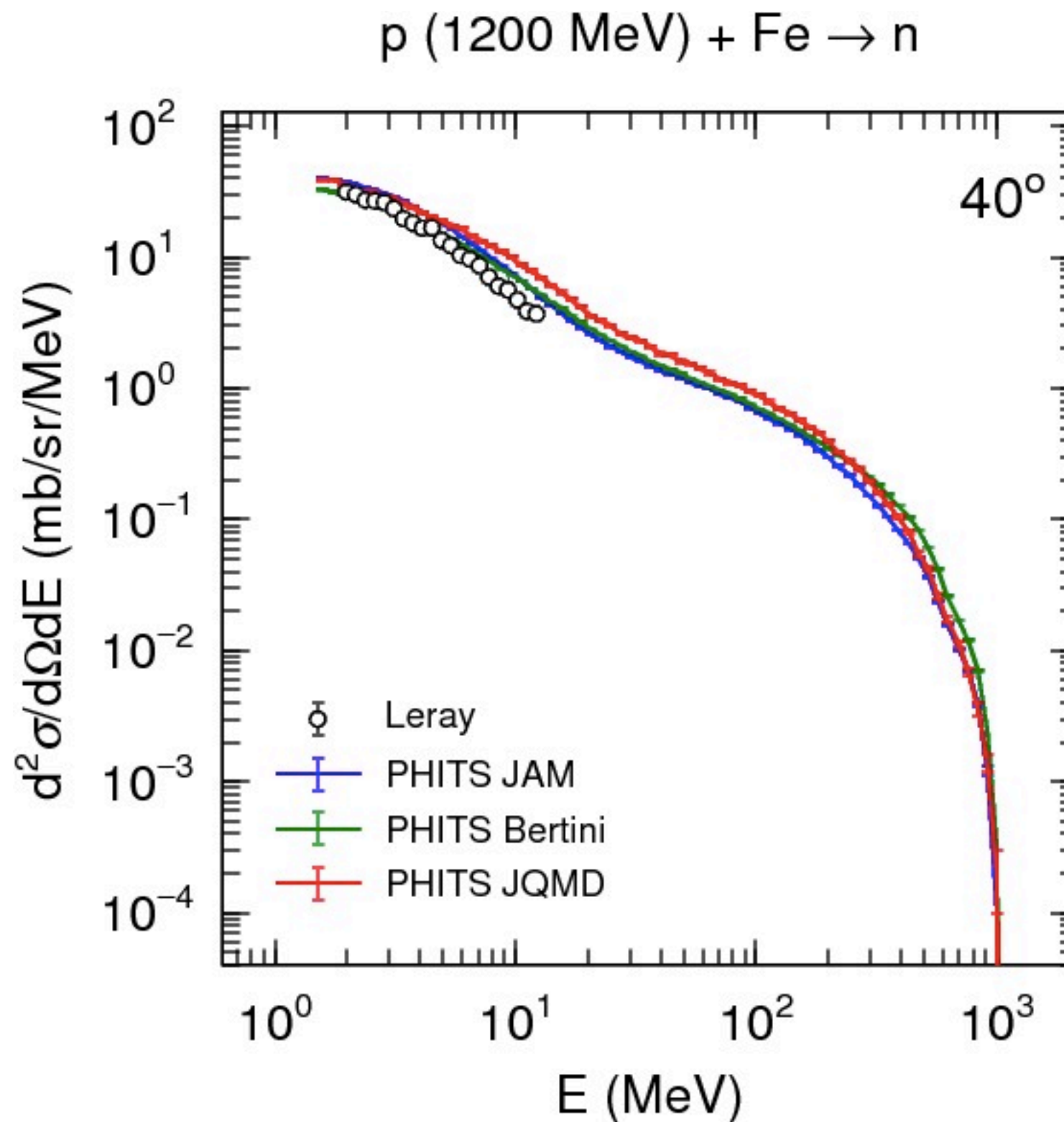
p (1200 MeV) + Fe  $\rightarrow$  n

data by Leray



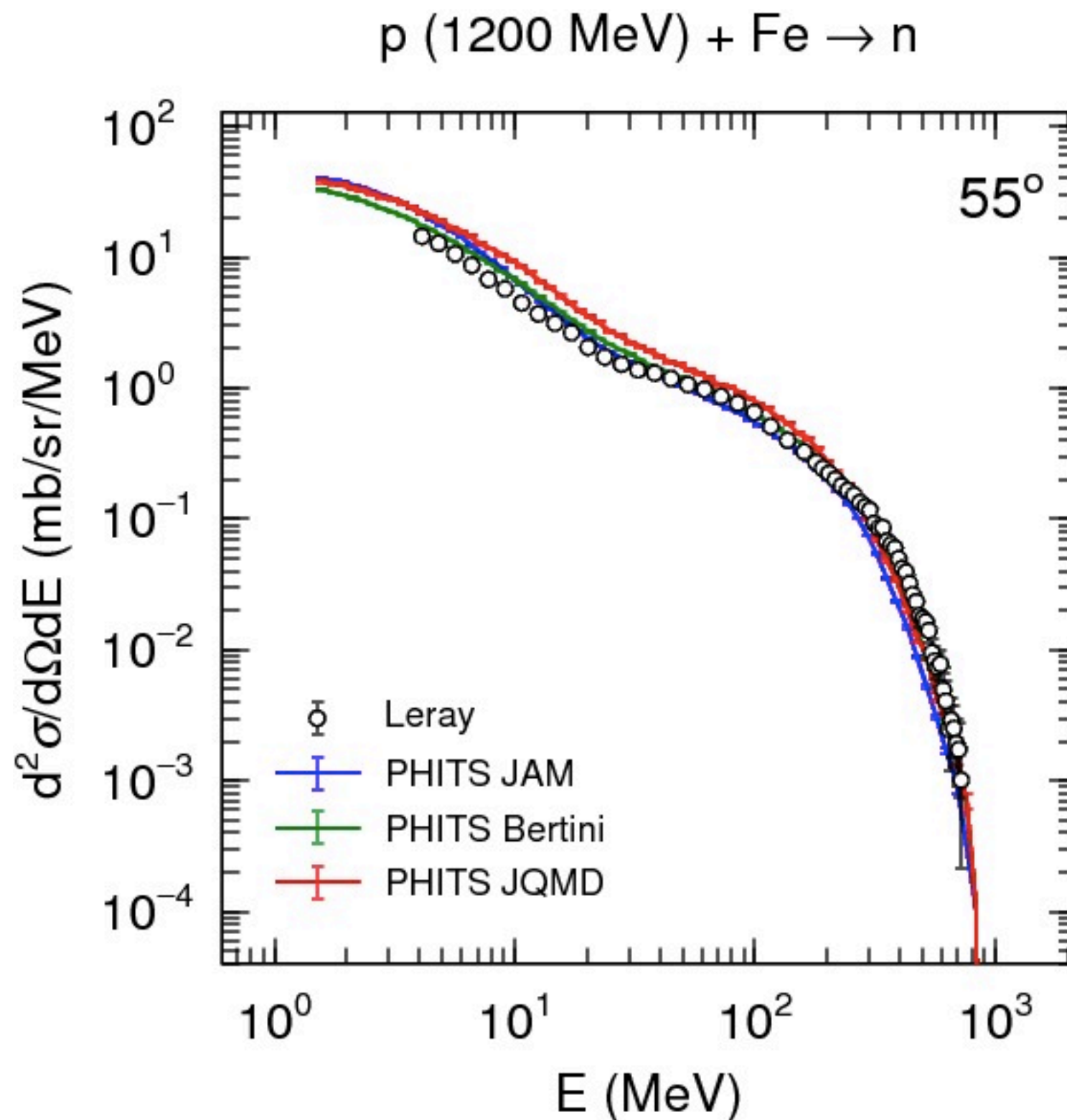
p (1200 MeV) + Fe  $\rightarrow$  n

data by Leray



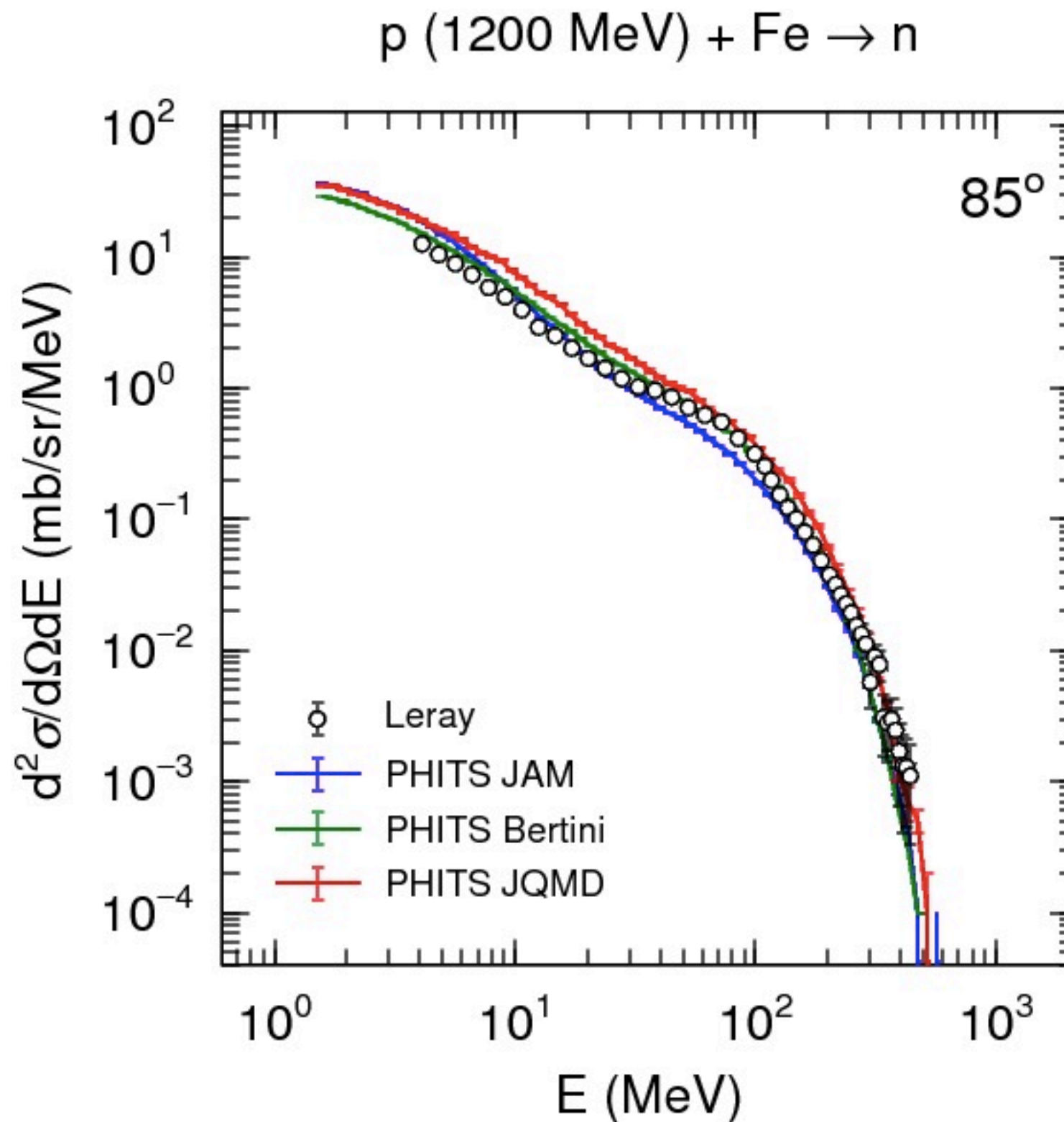
p (1200 MeV) + Fe  $\rightarrow$  n

data by Leray



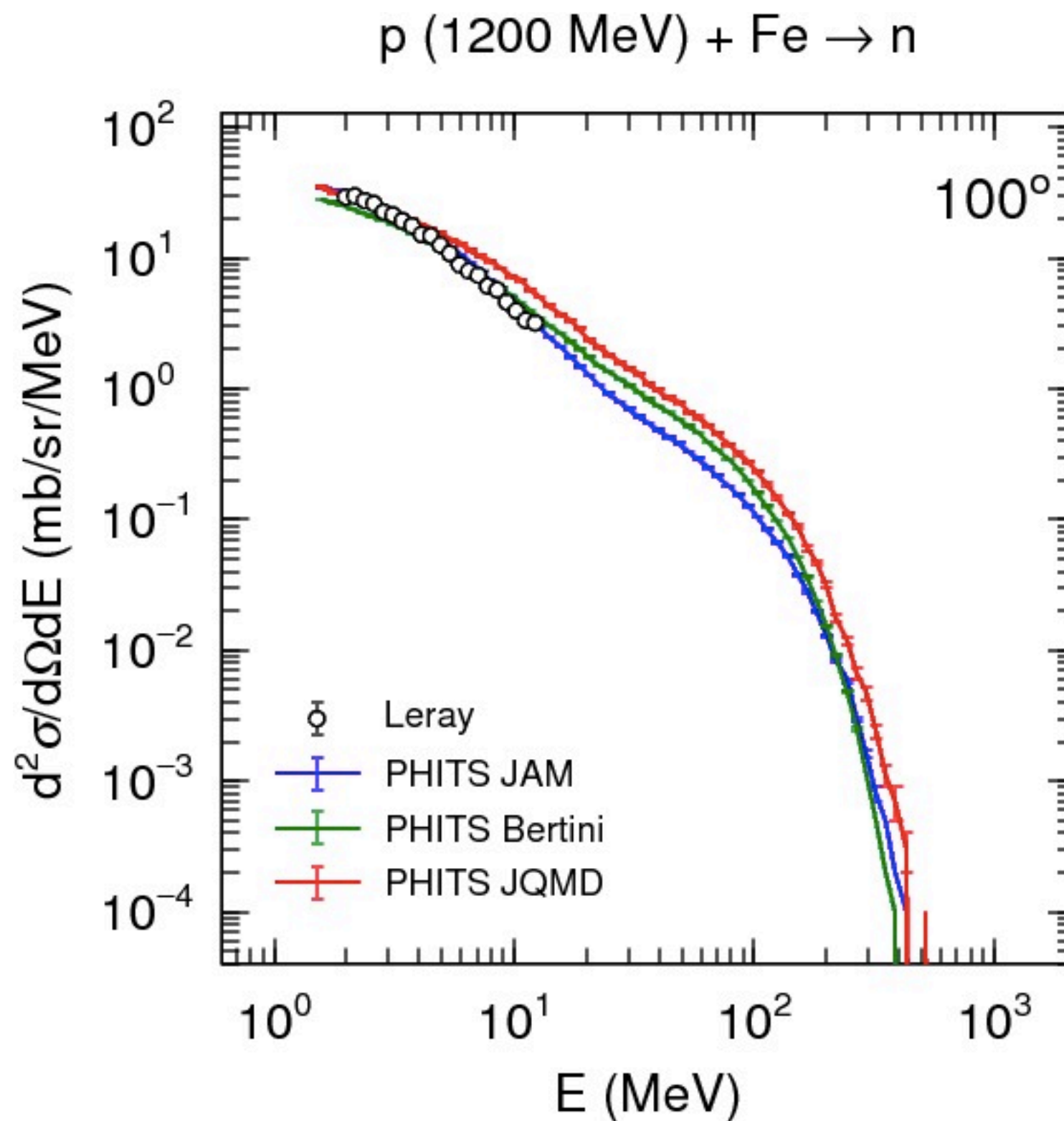
p (1200 MeV) + Fe  $\rightarrow$  n

data by Leray



p (1200 MeV) + Fe  $\rightarrow$  n

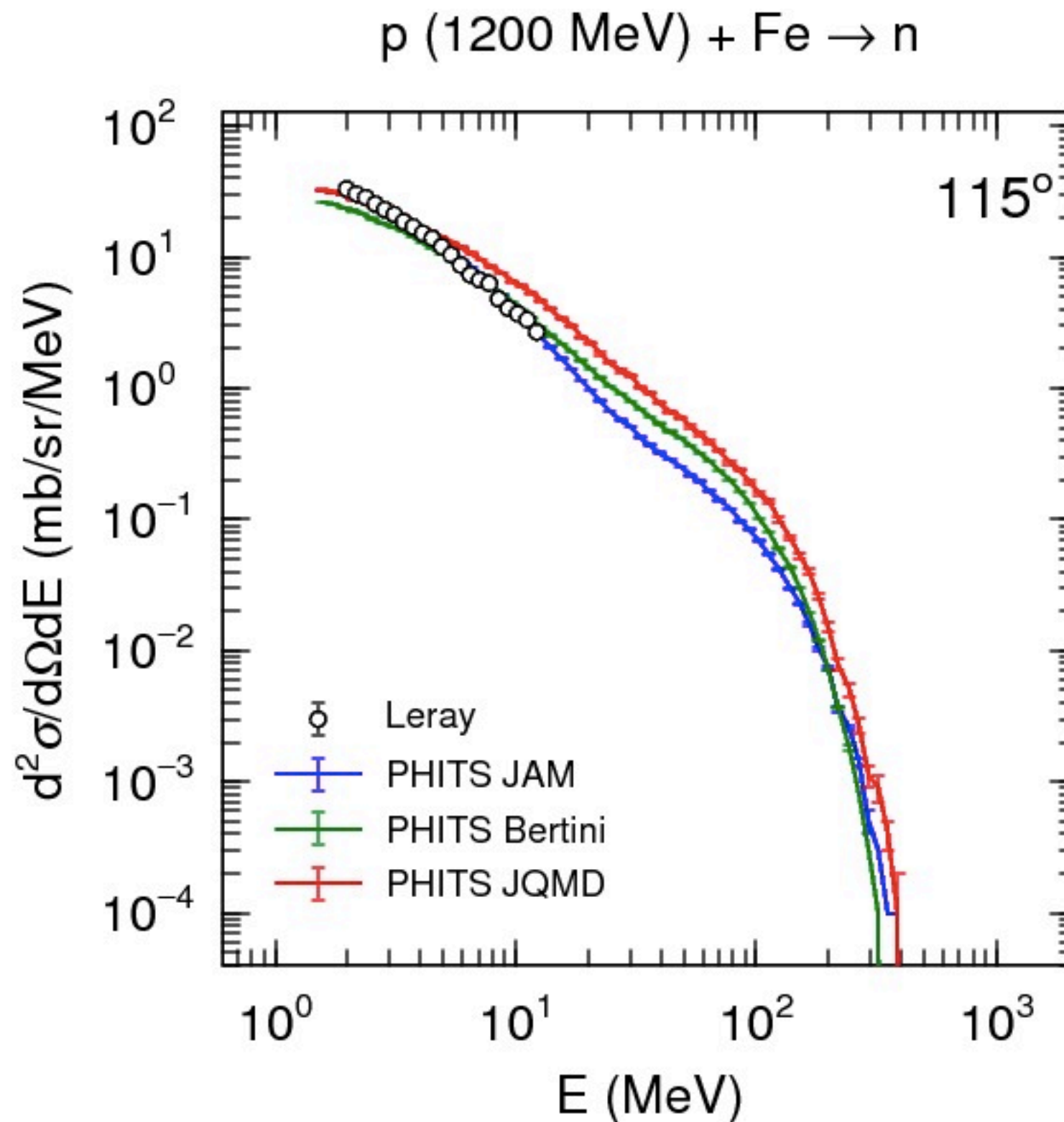
data by Leray





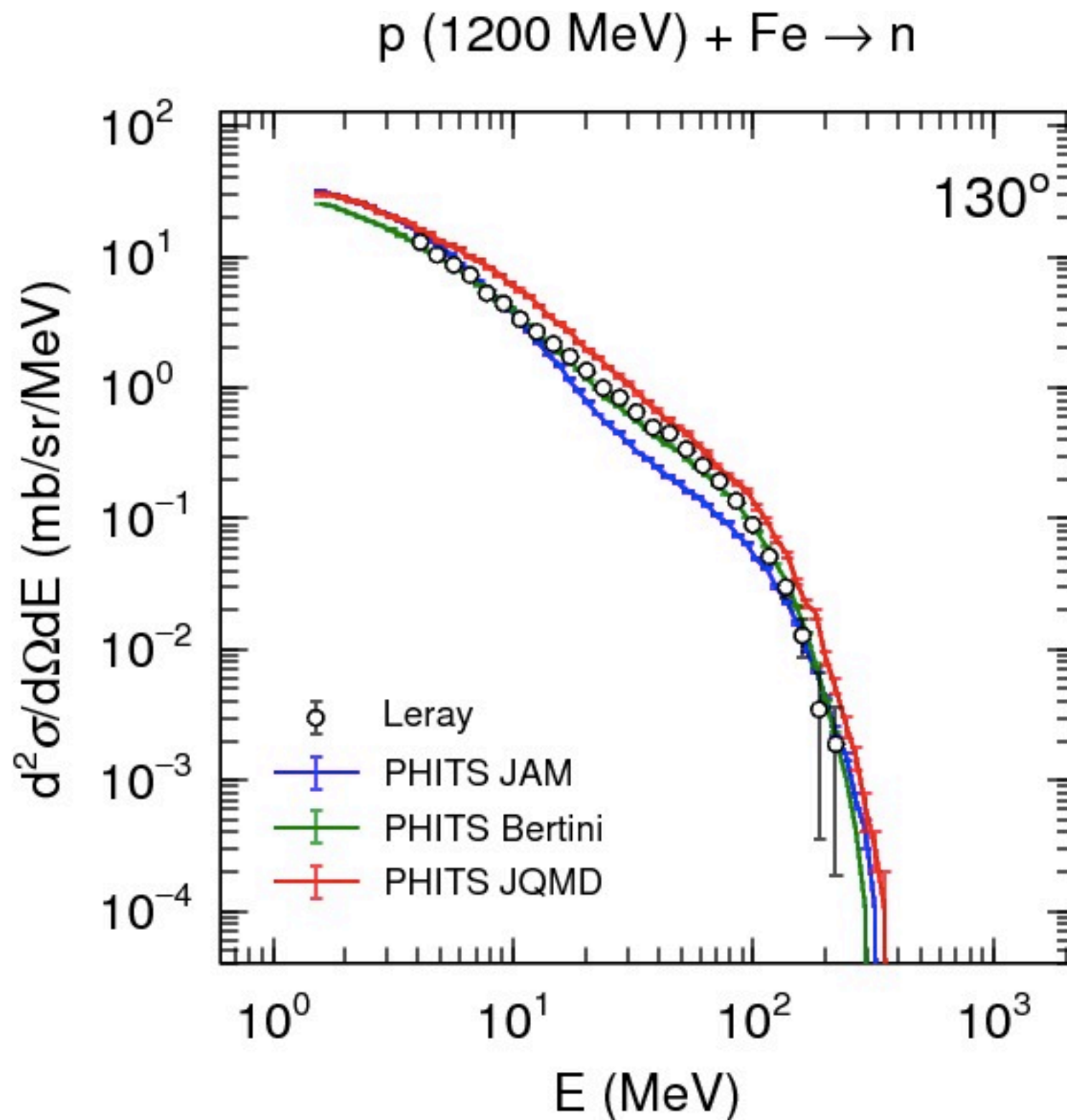
p (1200 MeV) + Fe → n

data by Leray



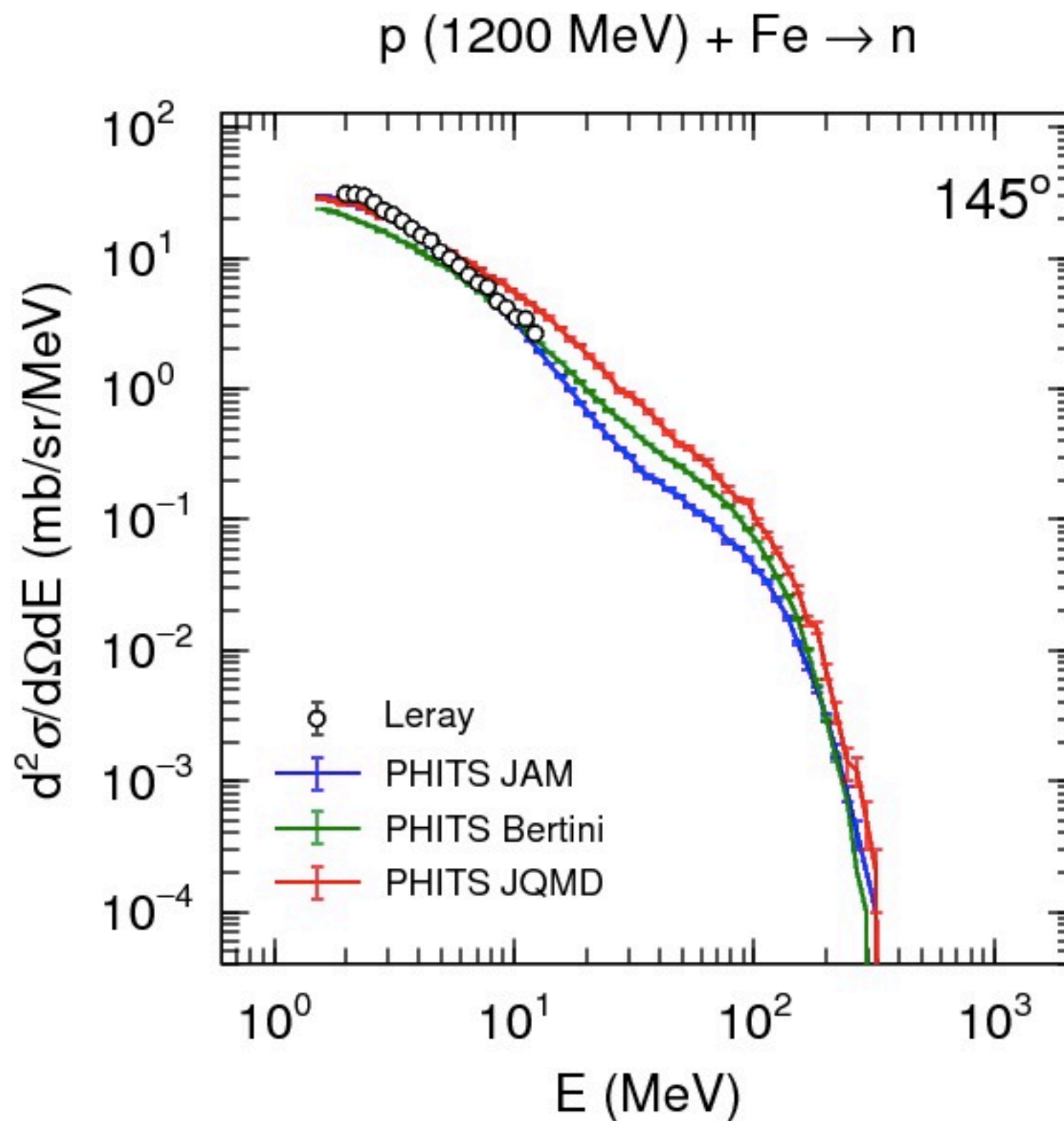
p (1200 MeV) + Fe → n

data by Leray



p (1200 MeV) + Fe → n

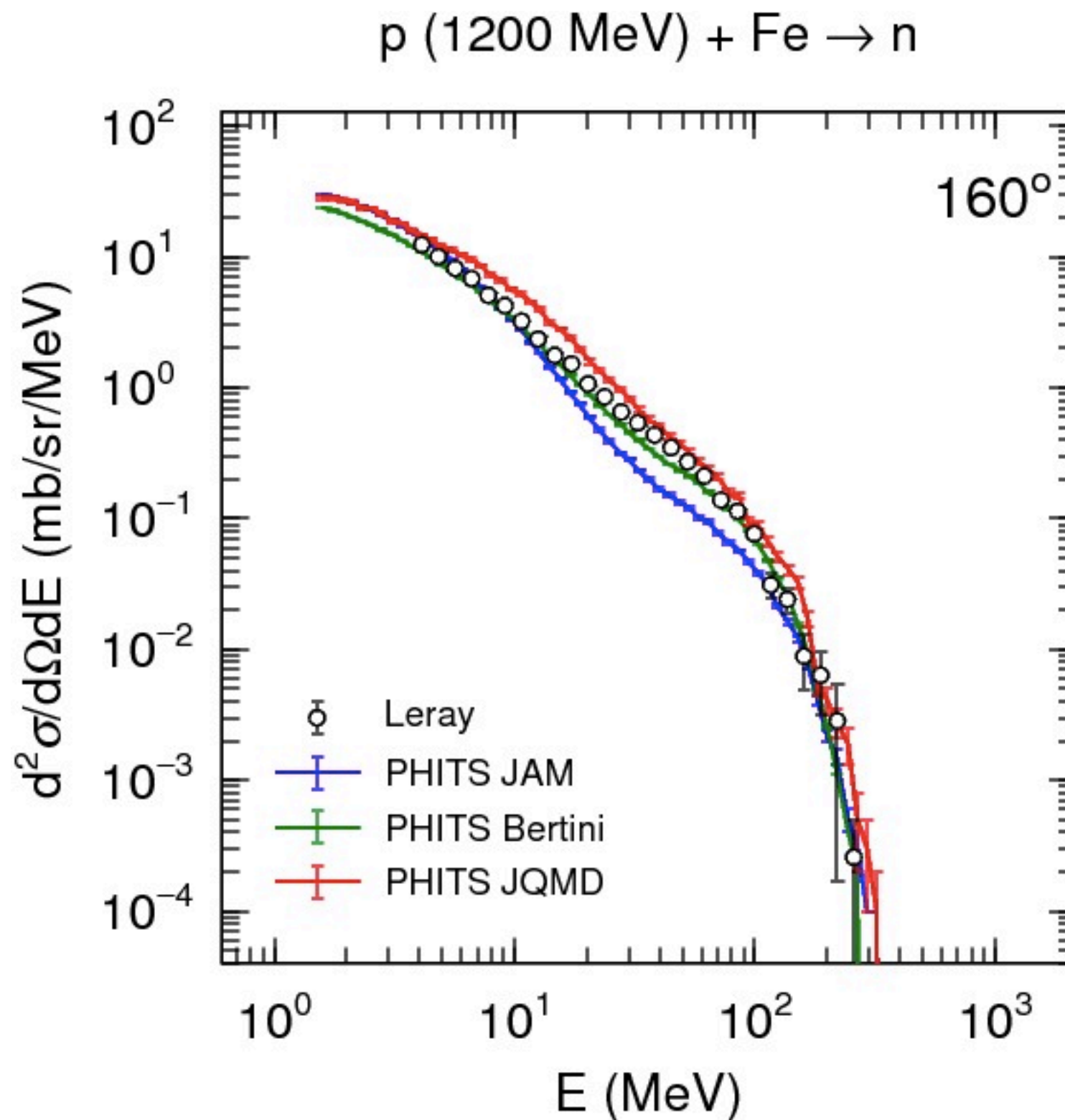
data by Leray



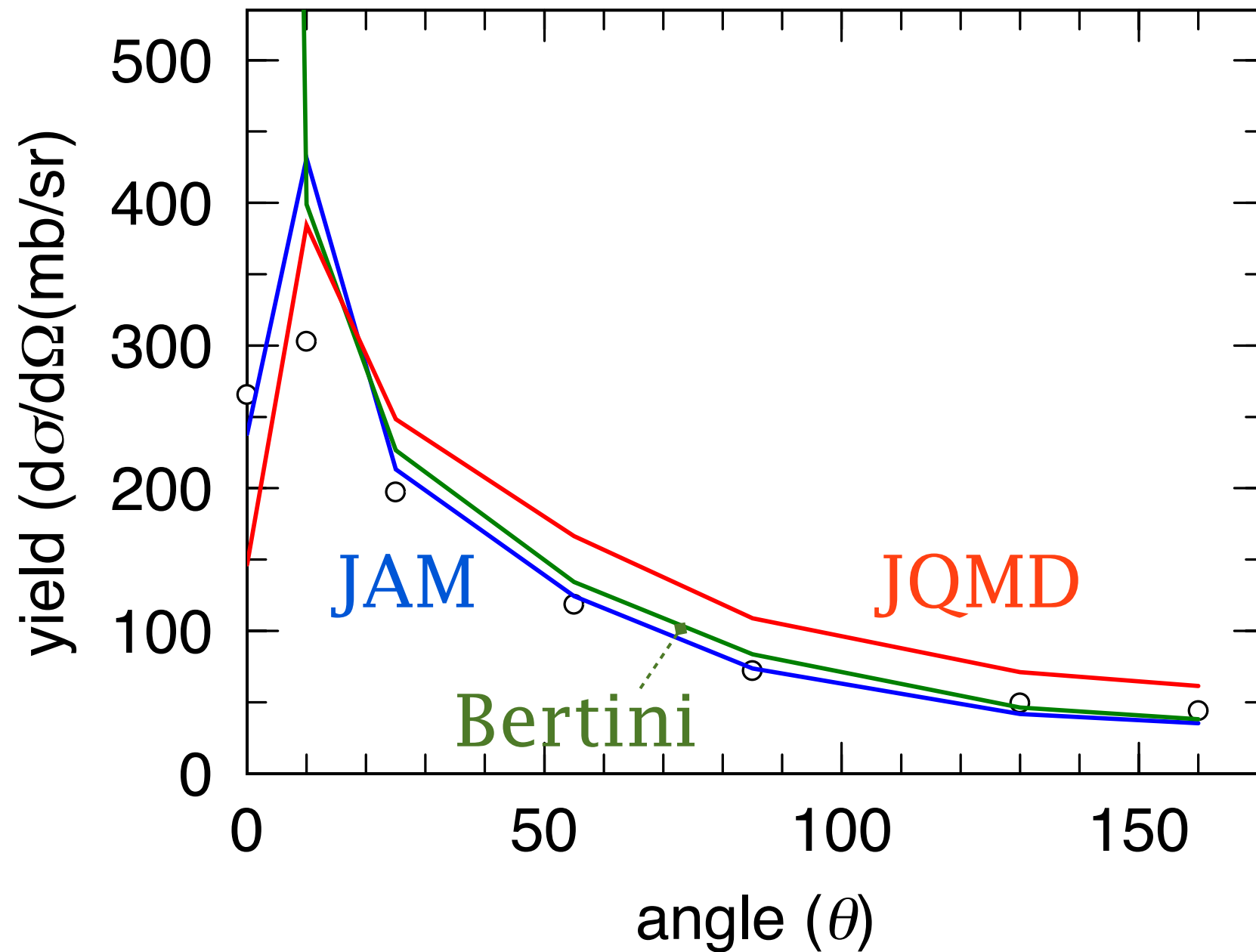


p (1200 MeV) + Fe  $\rightarrow$  n

data by Leray



### Angular distribution



$p$  (1600 MeV) + Fe  $\rightarrow$  n

data by Leray

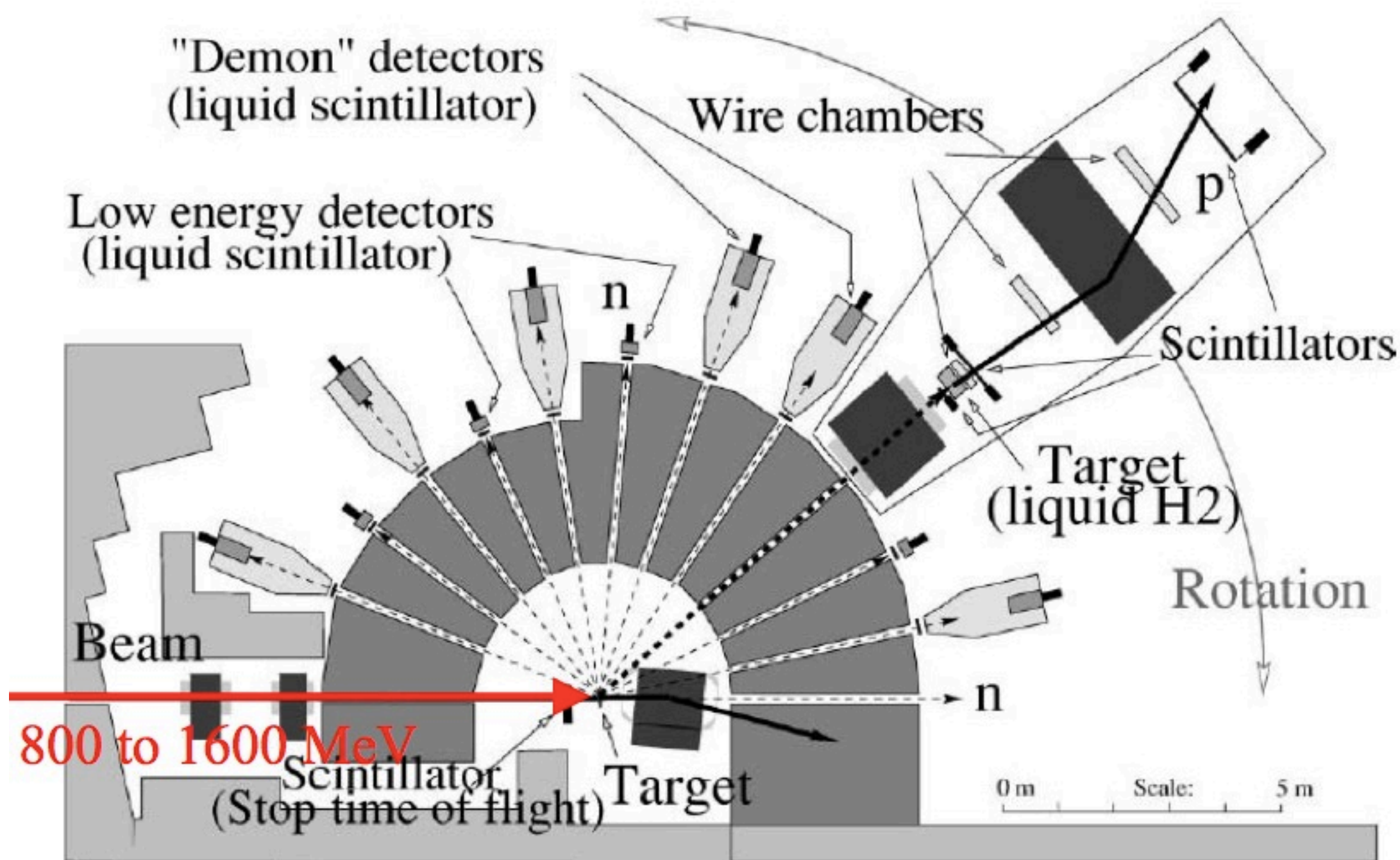
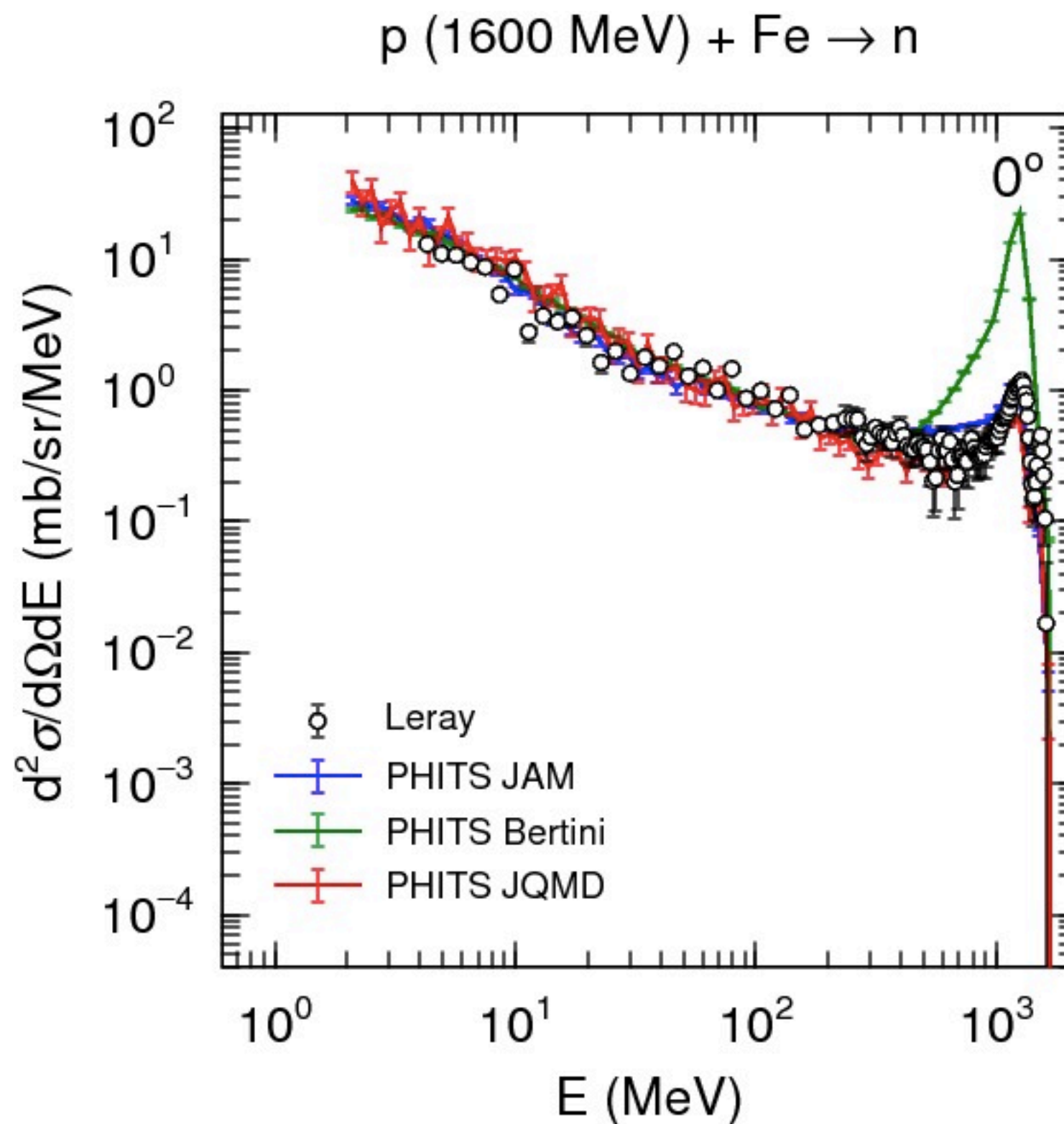


FIG. 1. Experimental area with time-of-flight and spectrometer setup.

p (1600 MeV) + Fe → n

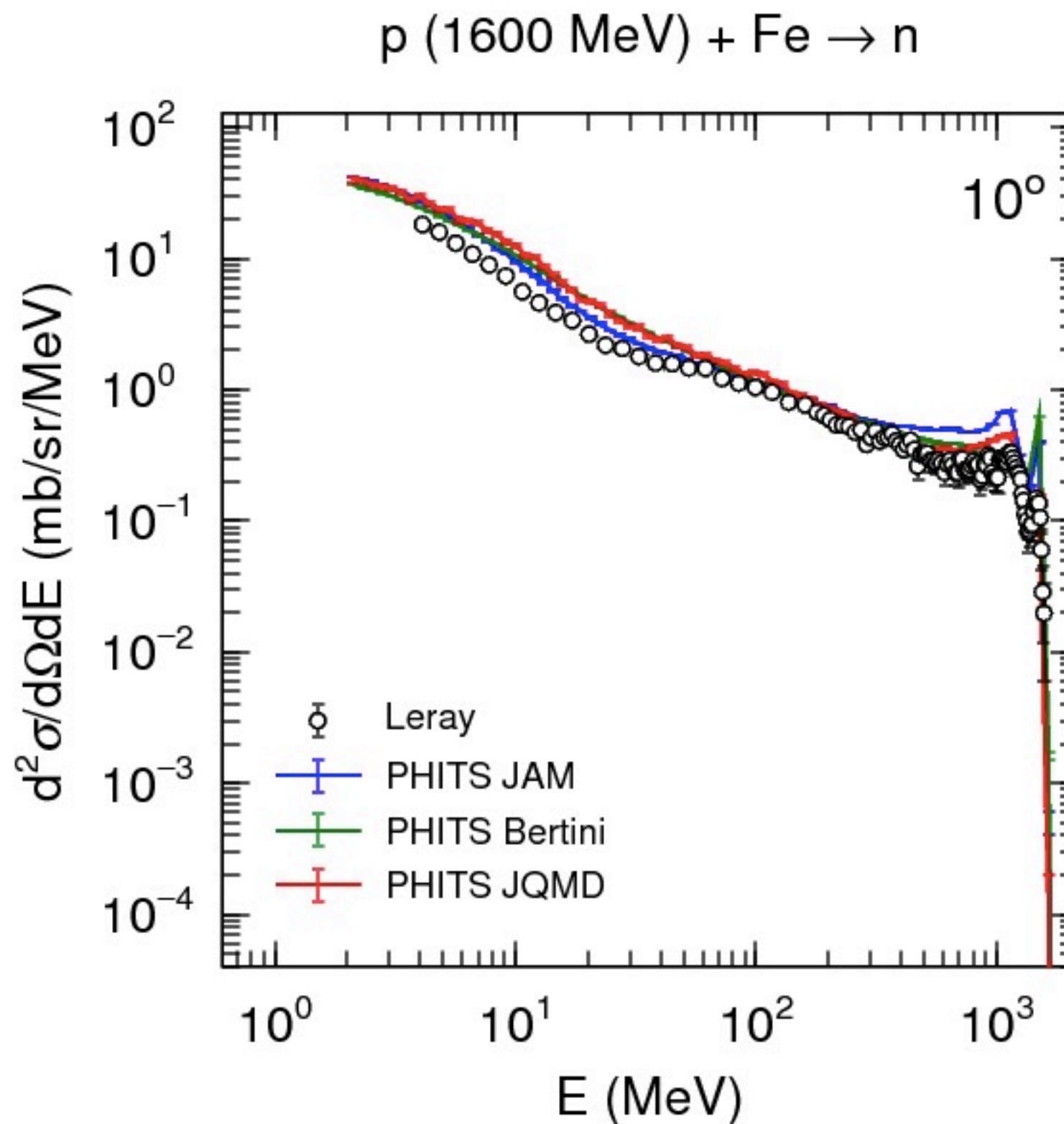
data by Leray





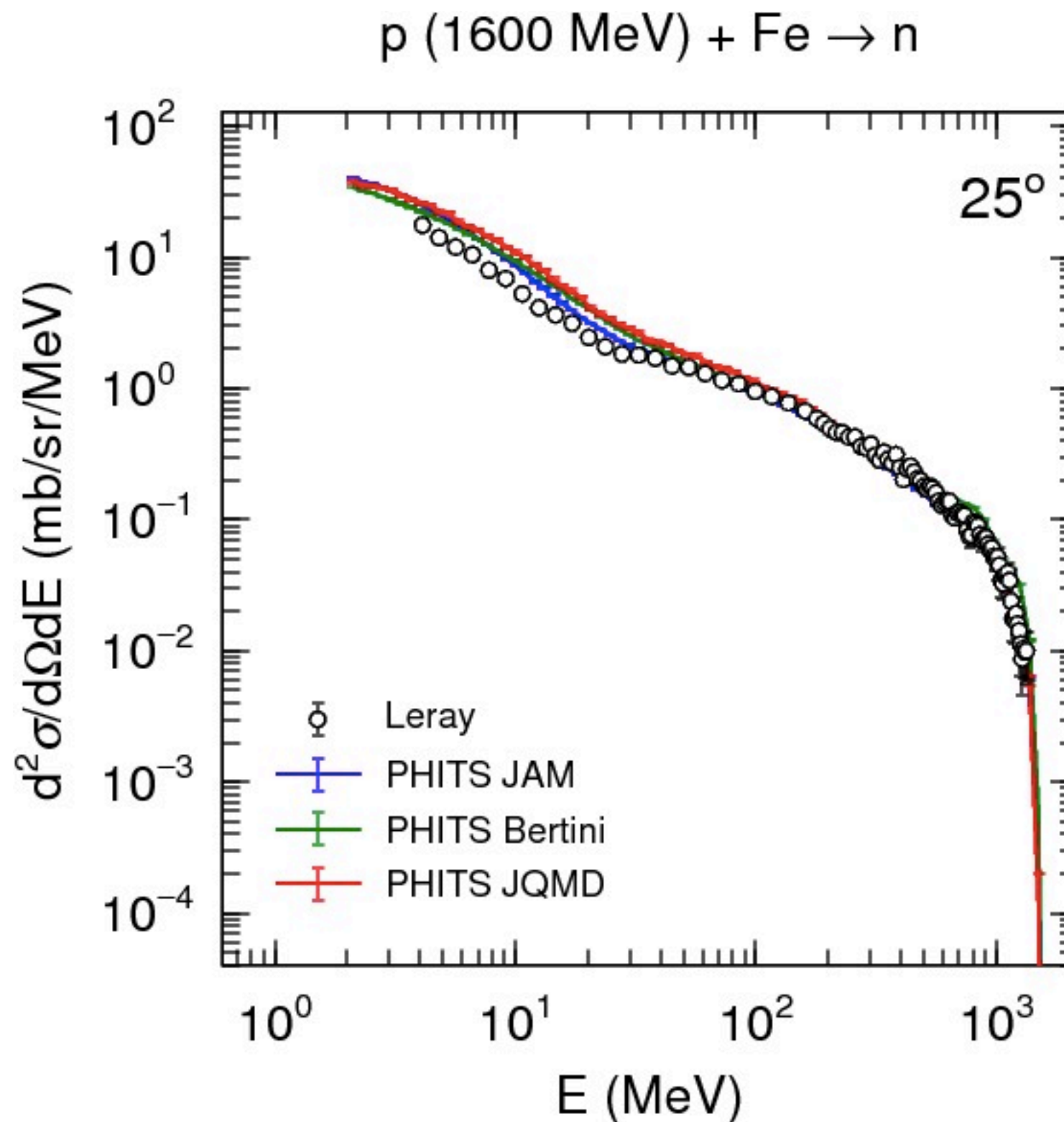
p (1600 MeV) + Fe → n

data by Leray



p (1600 MeV) + Fe  $\rightarrow$  n

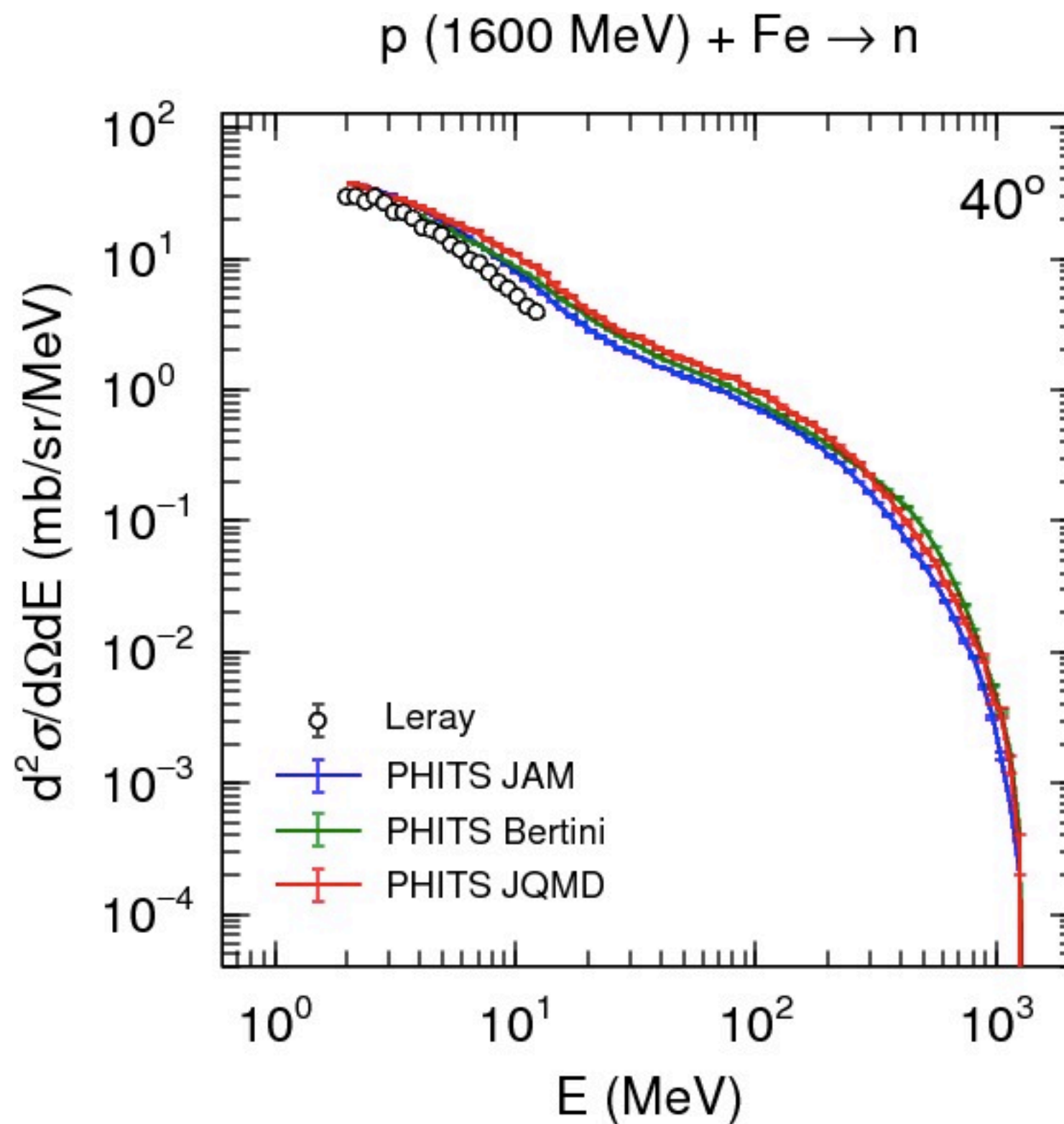
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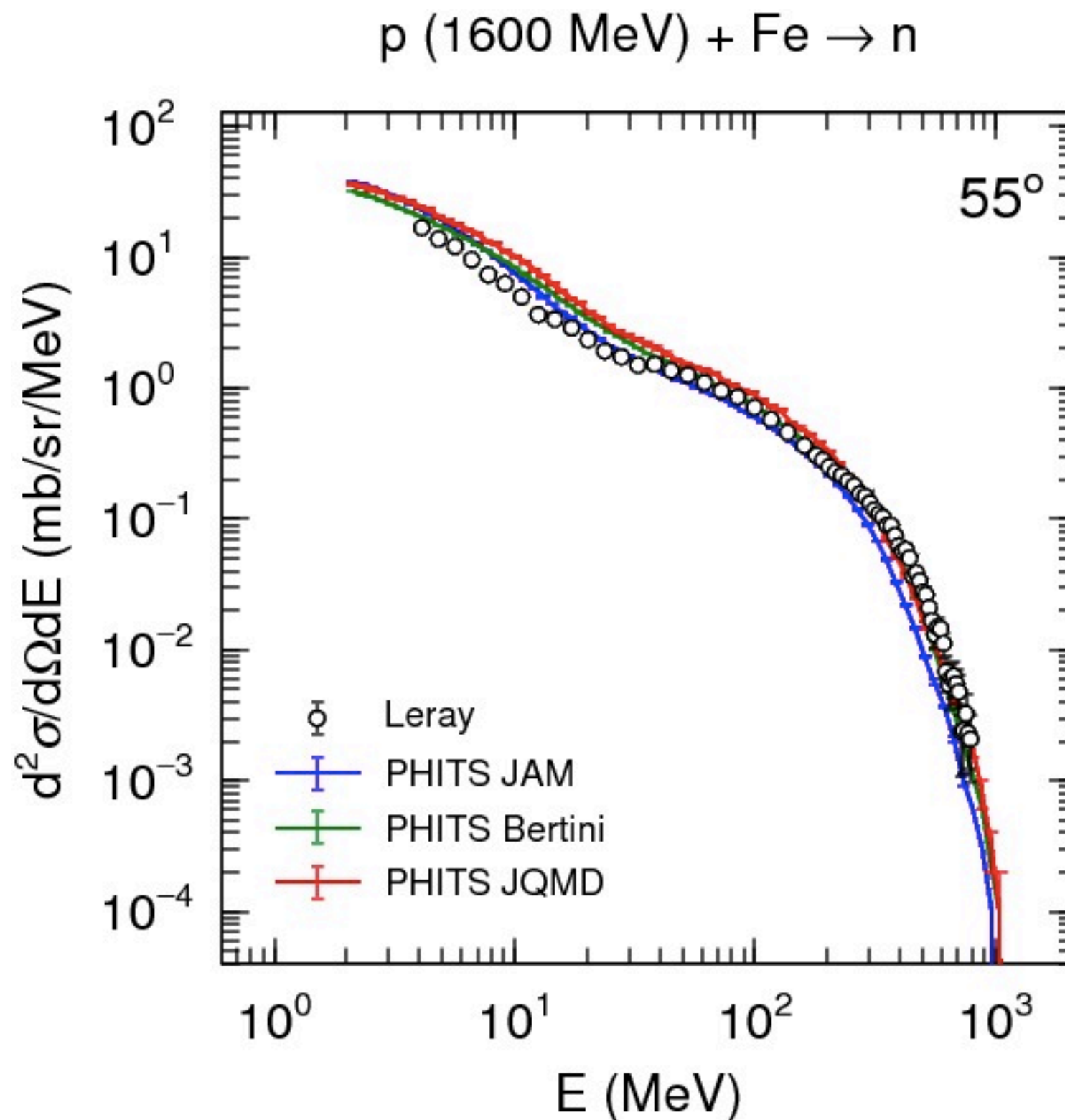
p (1600 MeV) + Fe  $\rightarrow$  n

data by Leray



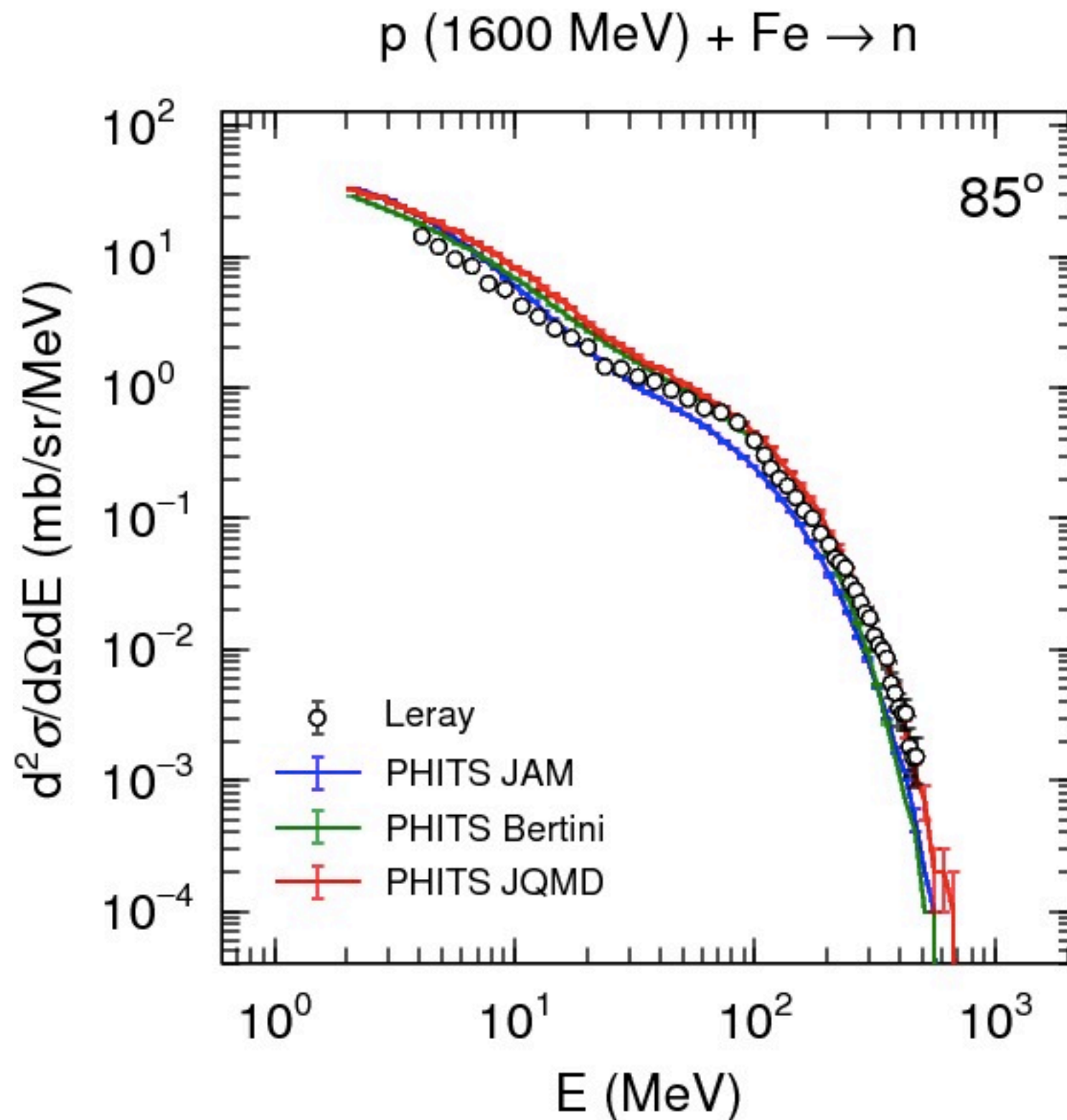
p (1600 MeV) + Fe  $\rightarrow$  n

data by Leray



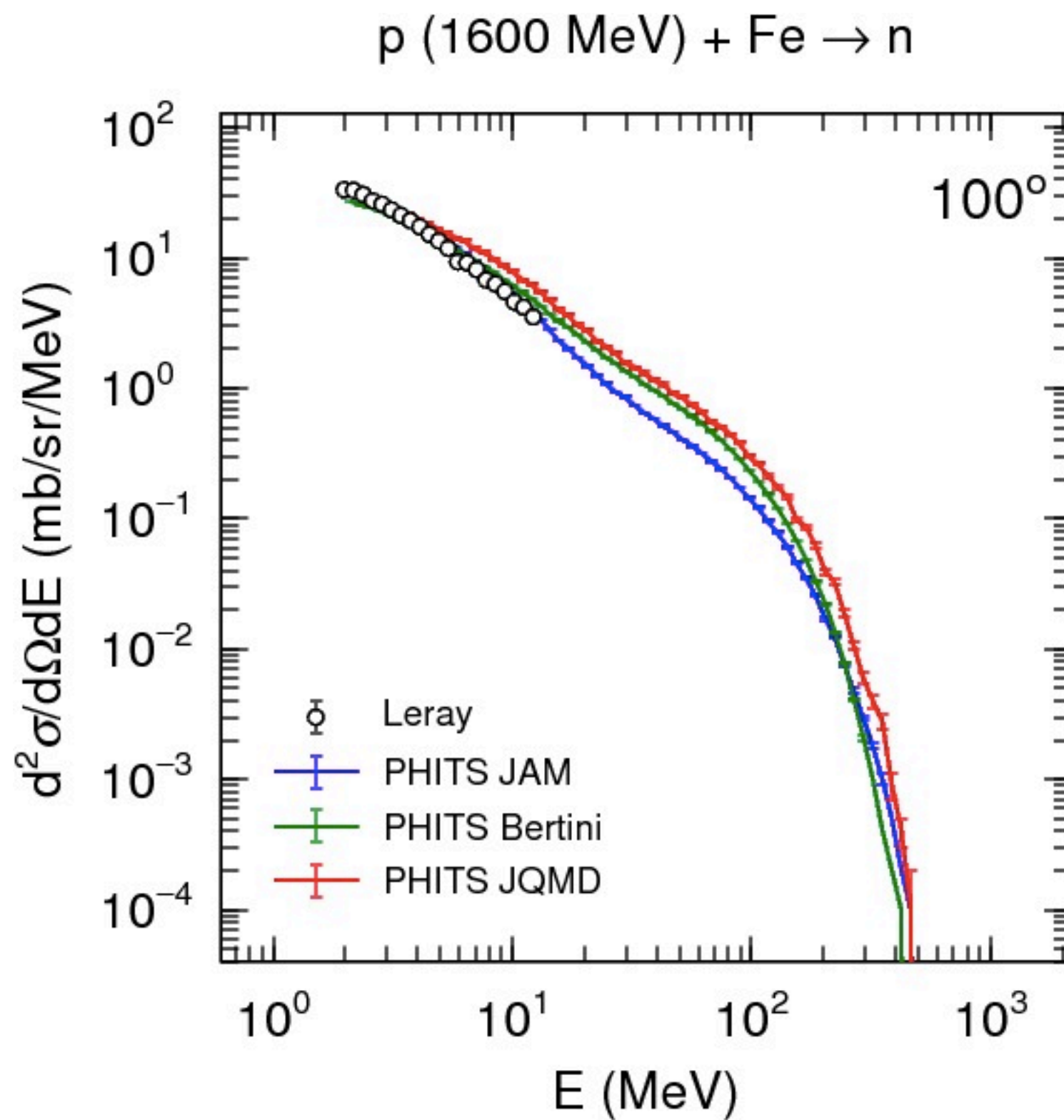
p (1600 MeV) + Fe  $\rightarrow$  n

data by Leray



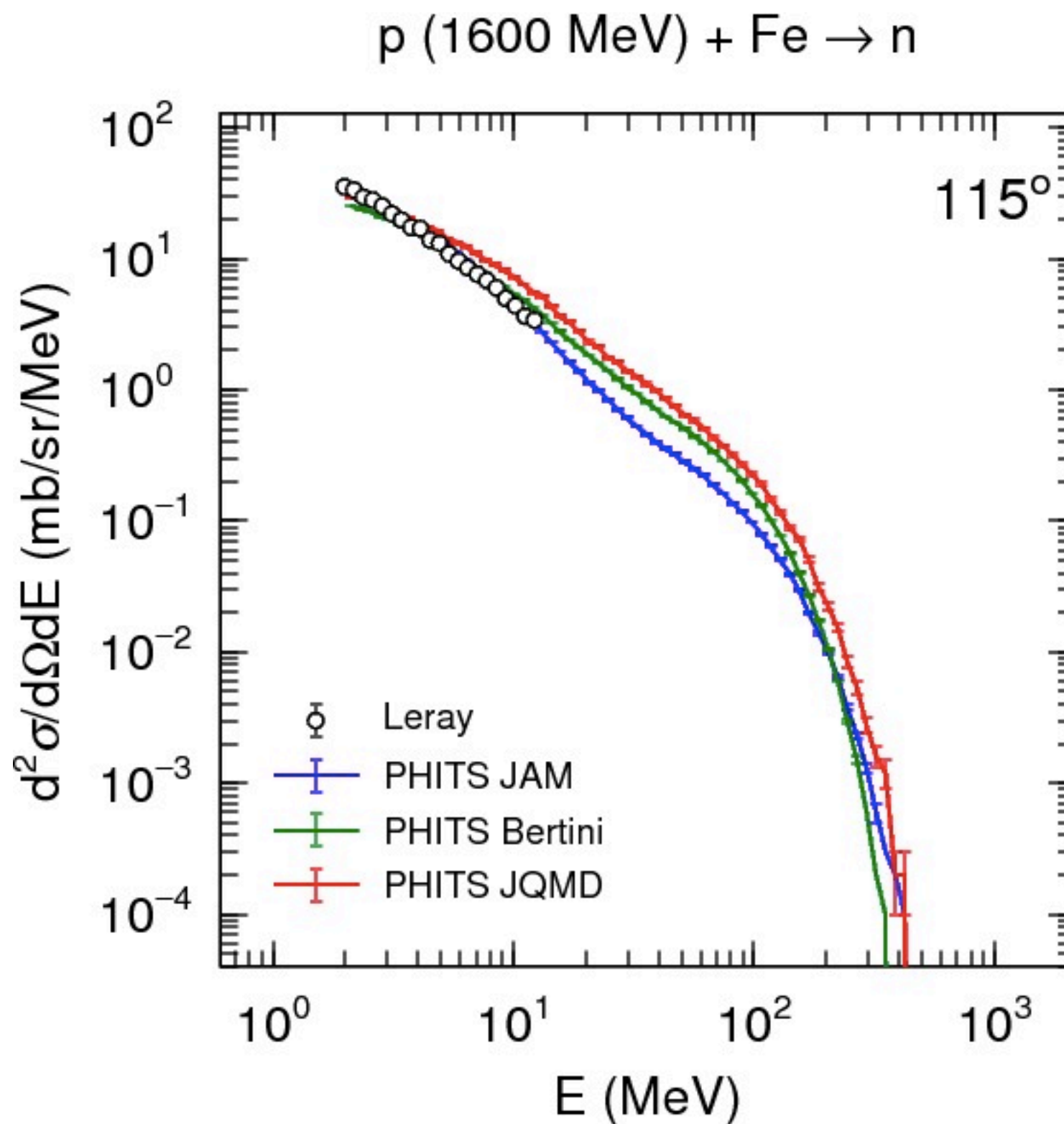
p (1600 MeV) + Fe  $\rightarrow$  n

data by Leray



p (1600 MeV) + Fe → n

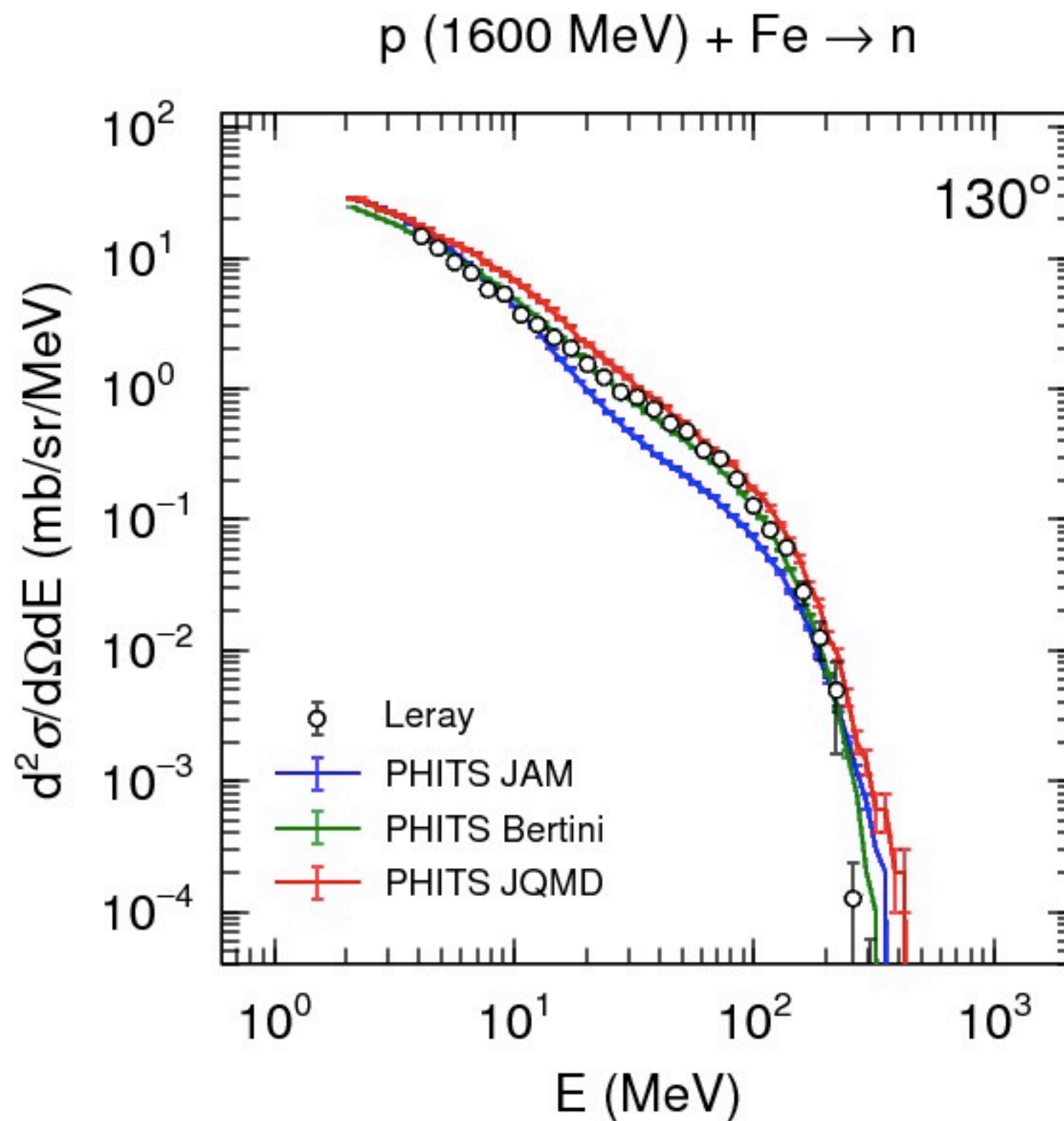
data by Leray





p (1600 MeV) + Fe  $\rightarrow$  n

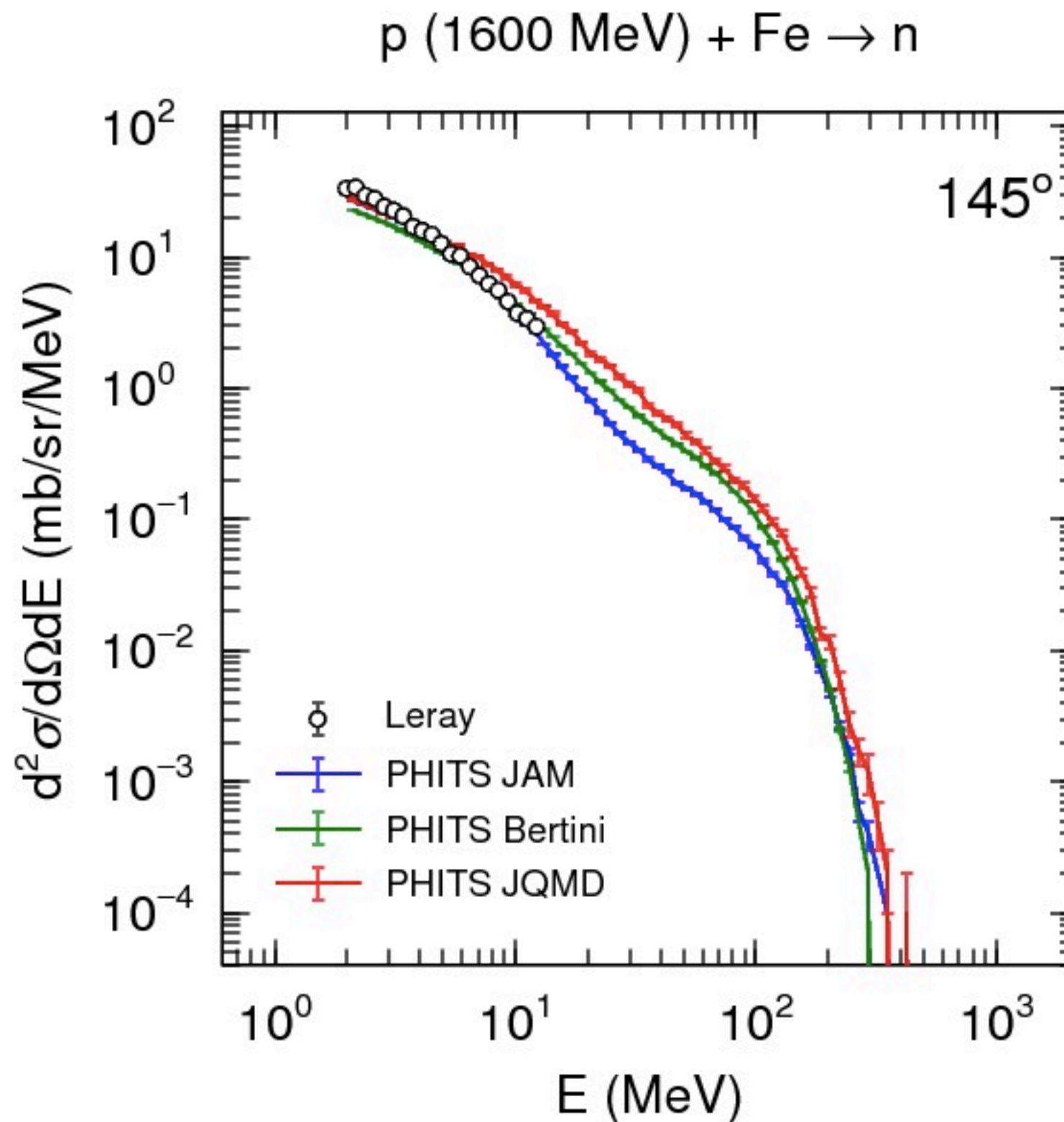
data by Leray





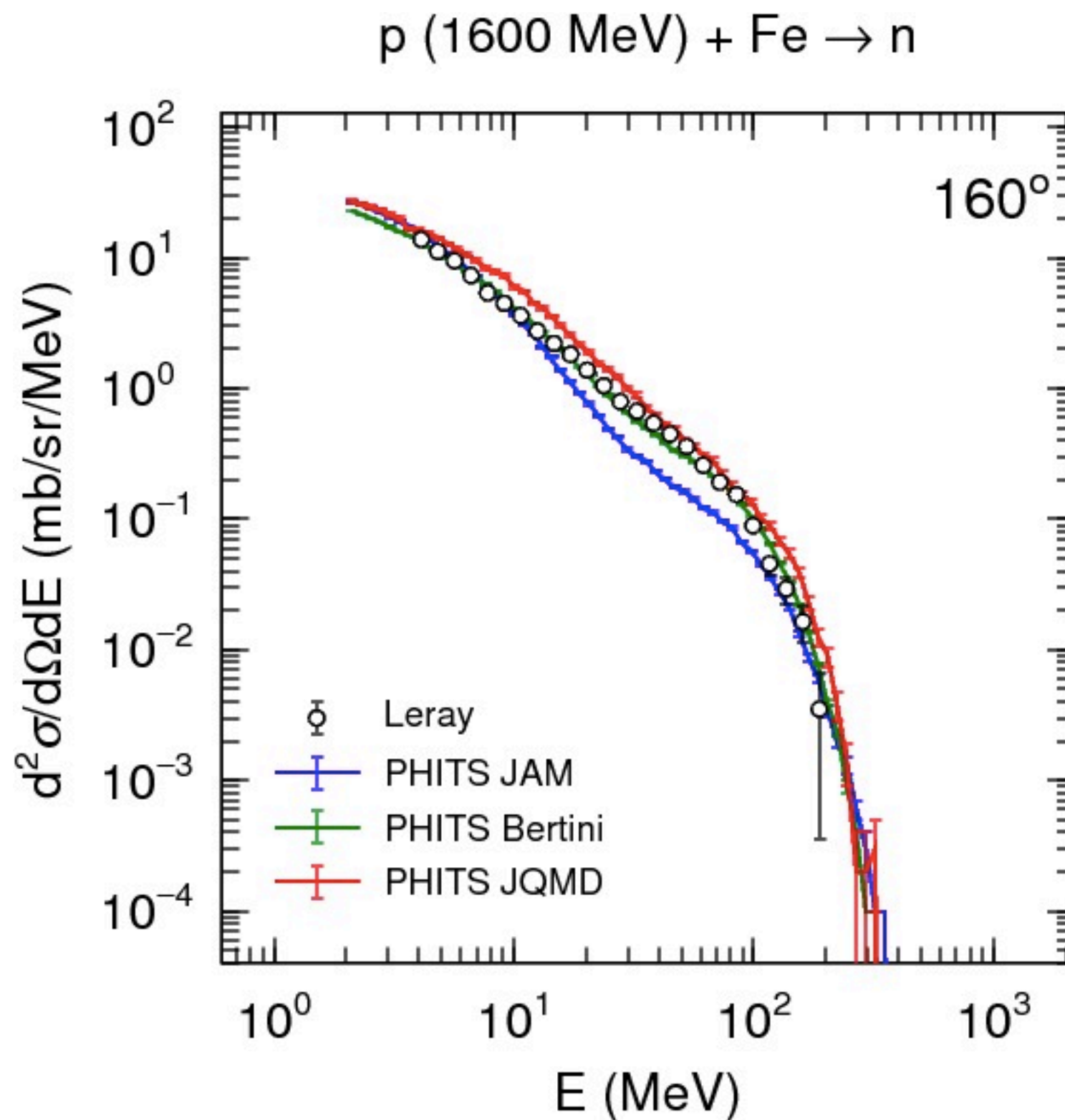
p (1600 MeV) + Fe  $\rightarrow$  n

data by Leray

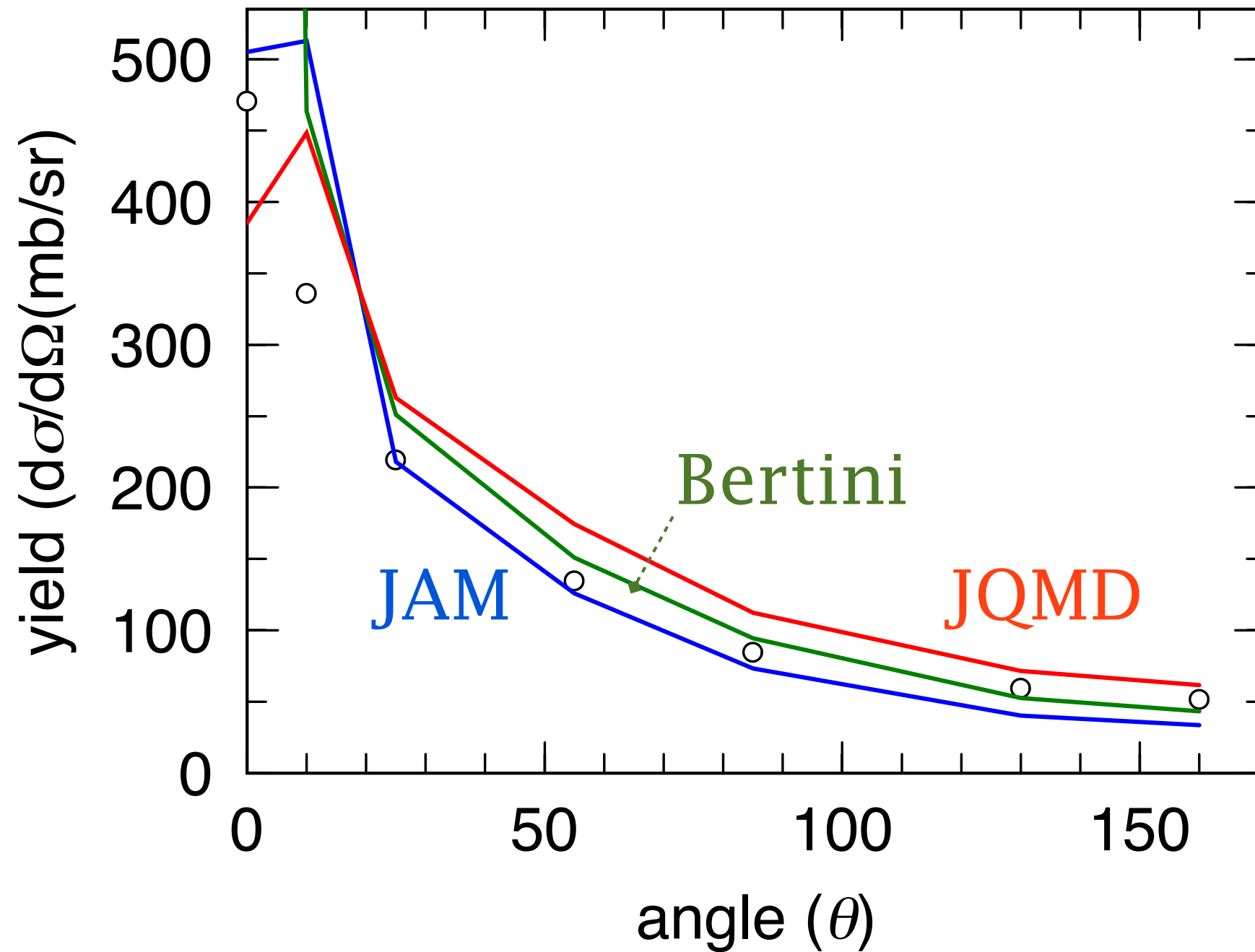


p (1600 MeV) + Fe  $\rightarrow$  n

data by Leray

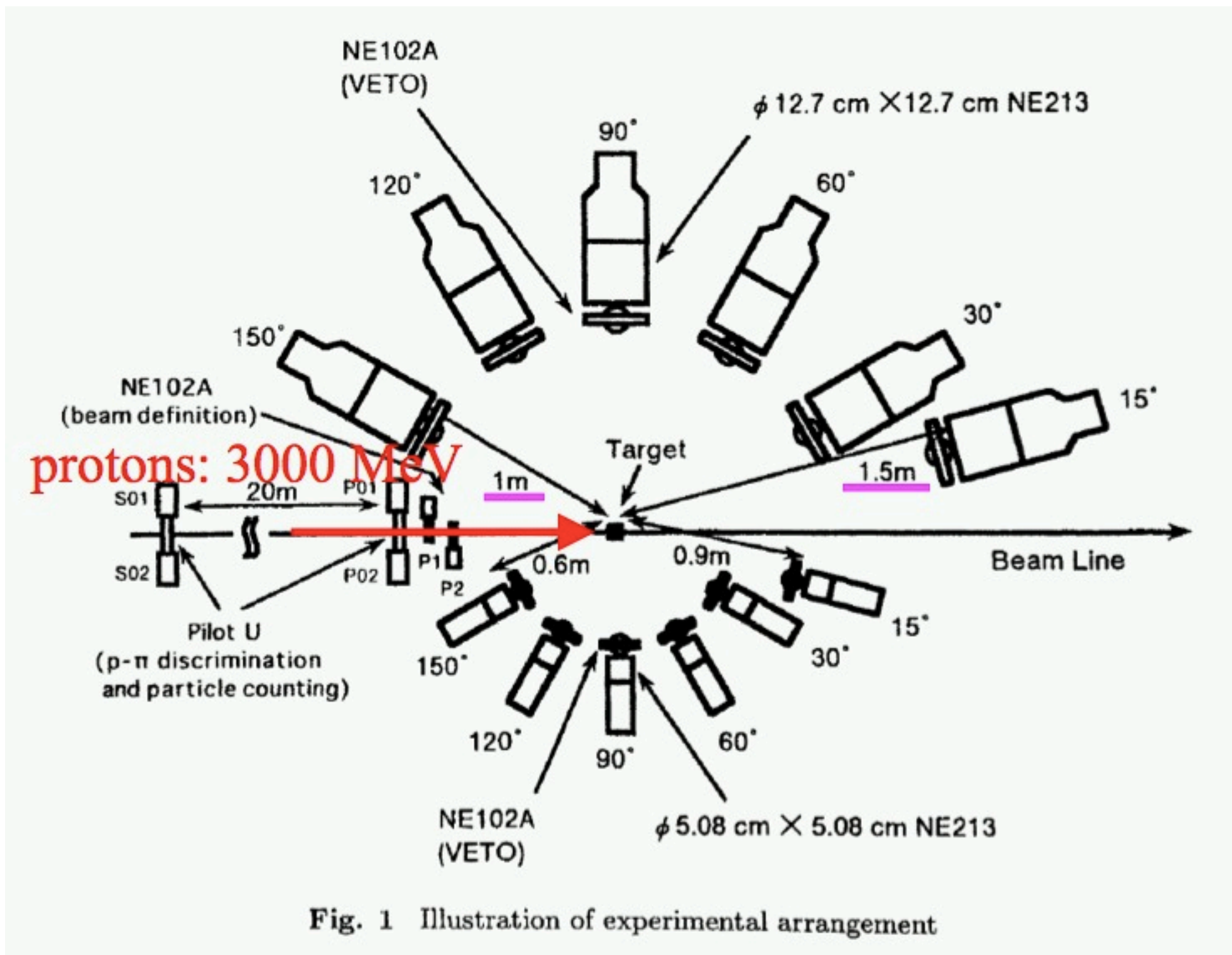


### Angular distribution



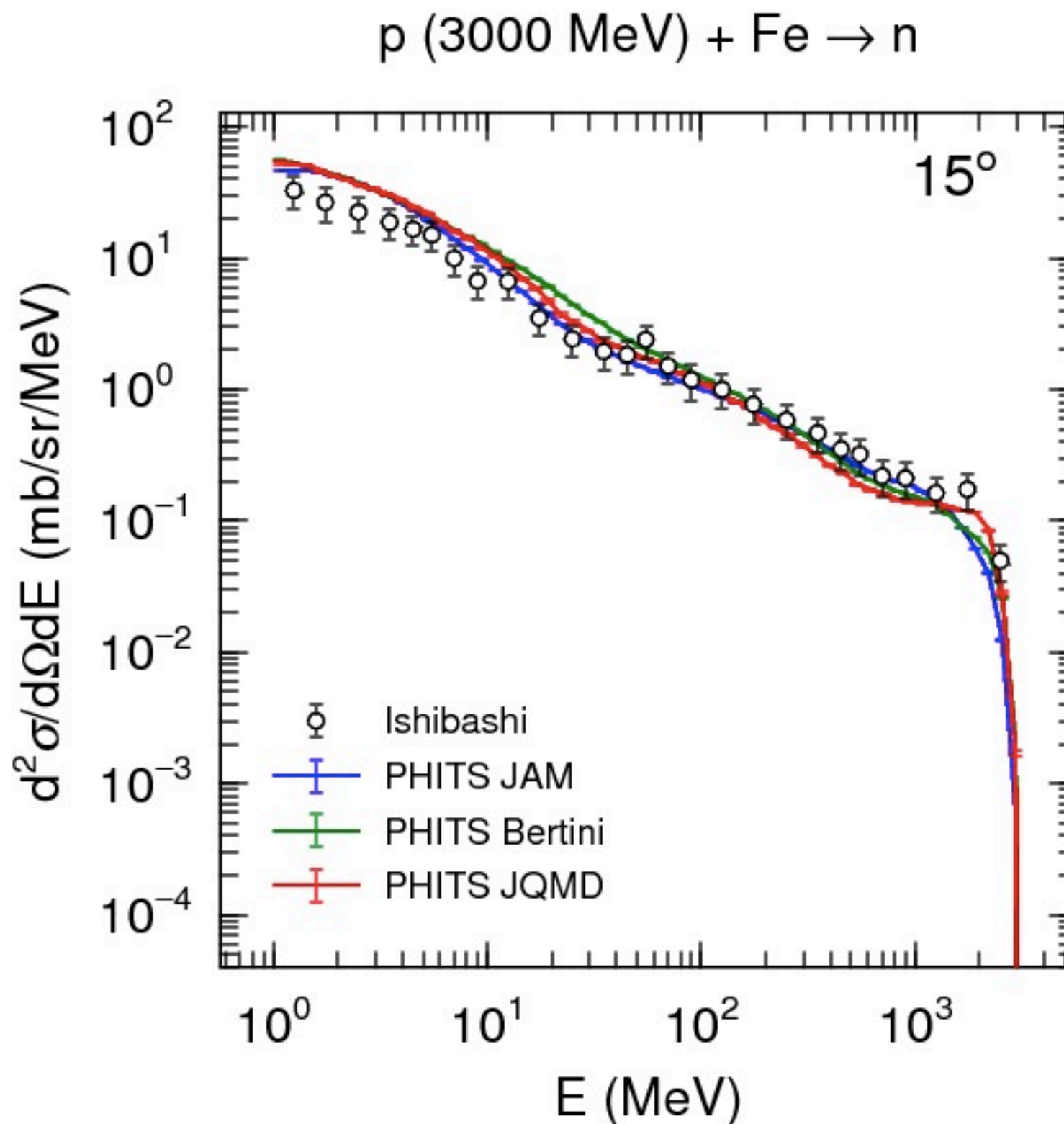
$p$  (3000 MeV) + Fe  $\rightarrow$  n

data by Ishibashi



p (3000 MeV) + Fe → n

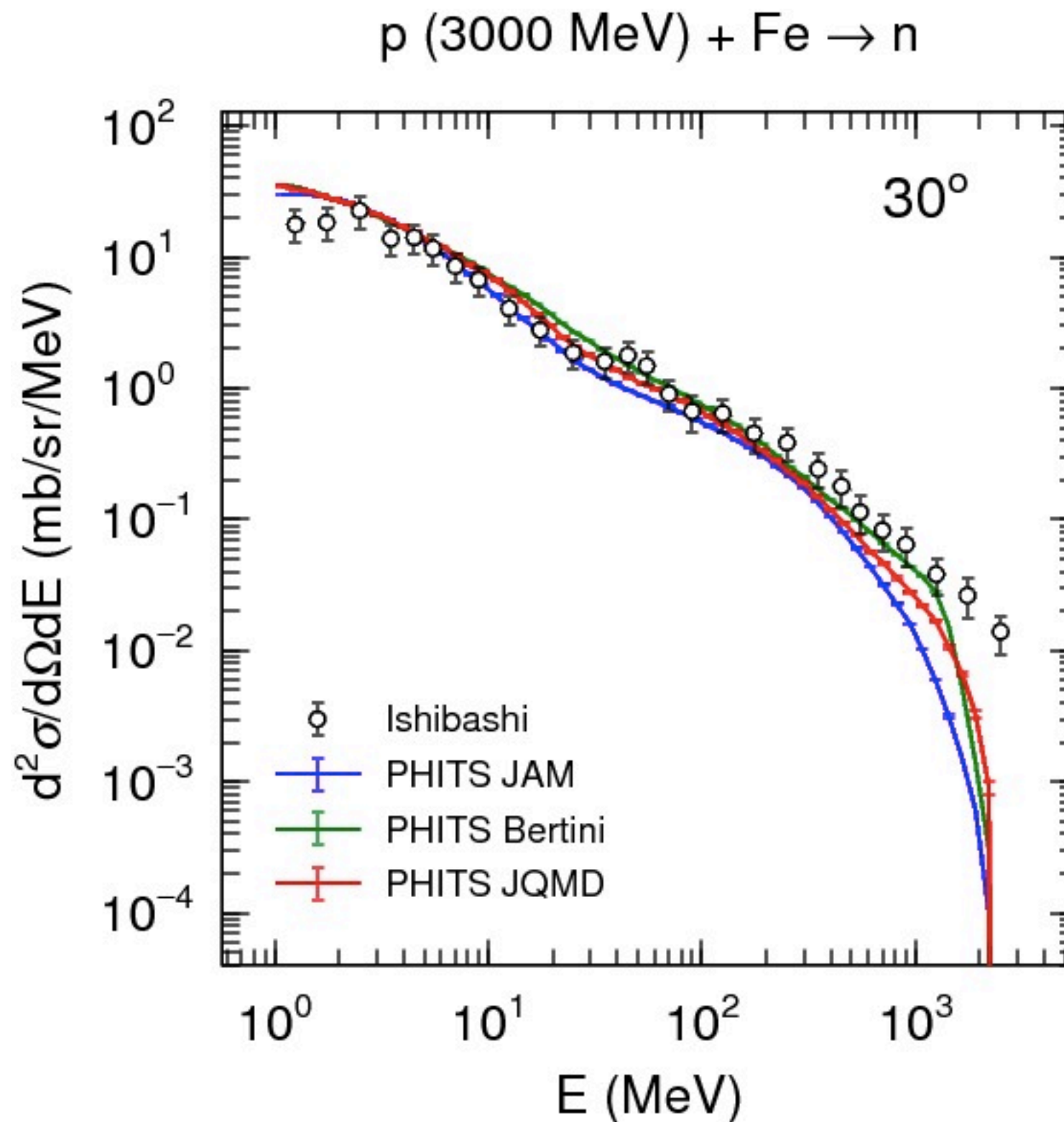
data by Ishibashi





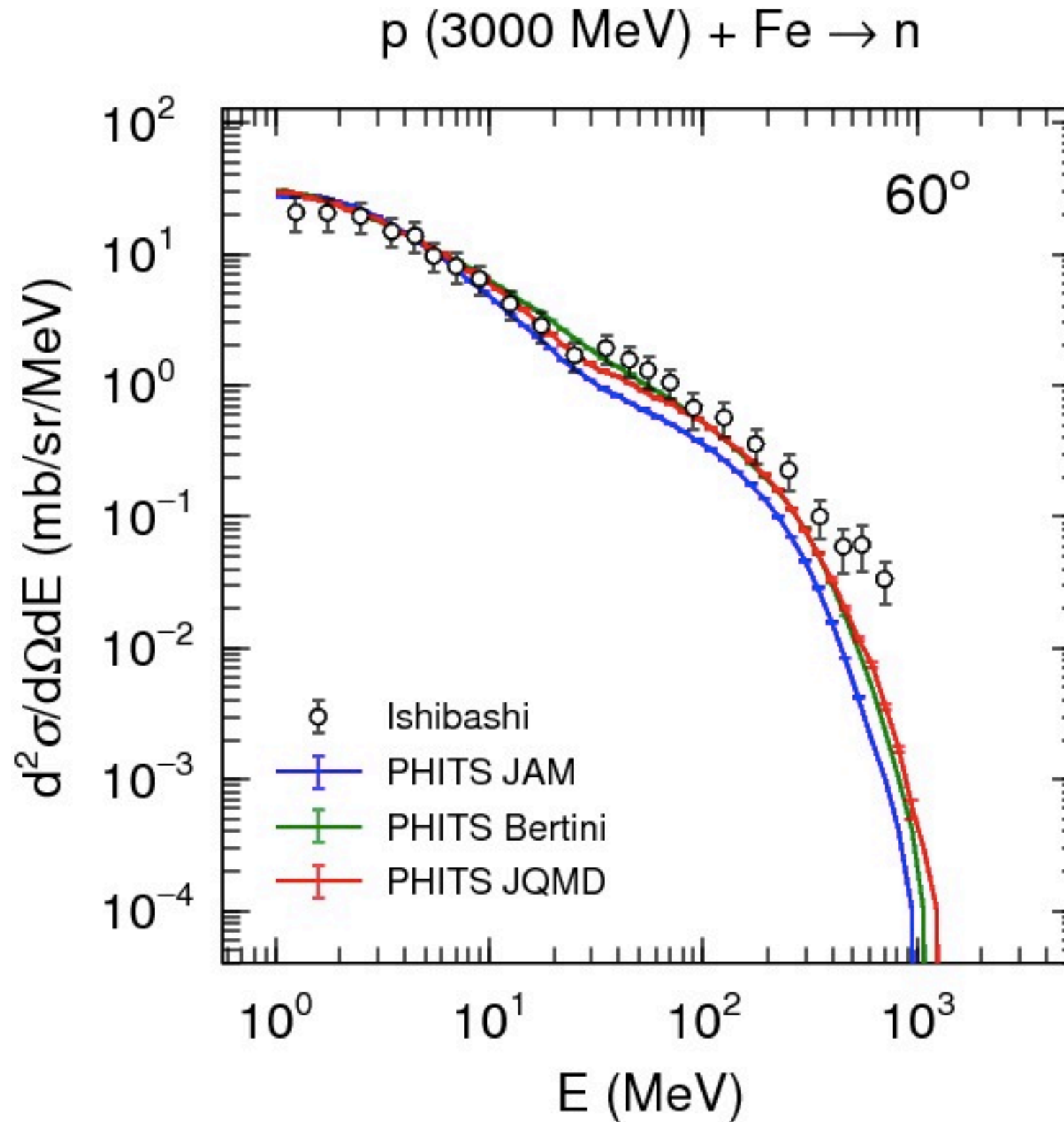
p (3000 MeV) + Fe → n

data by Ishibashi



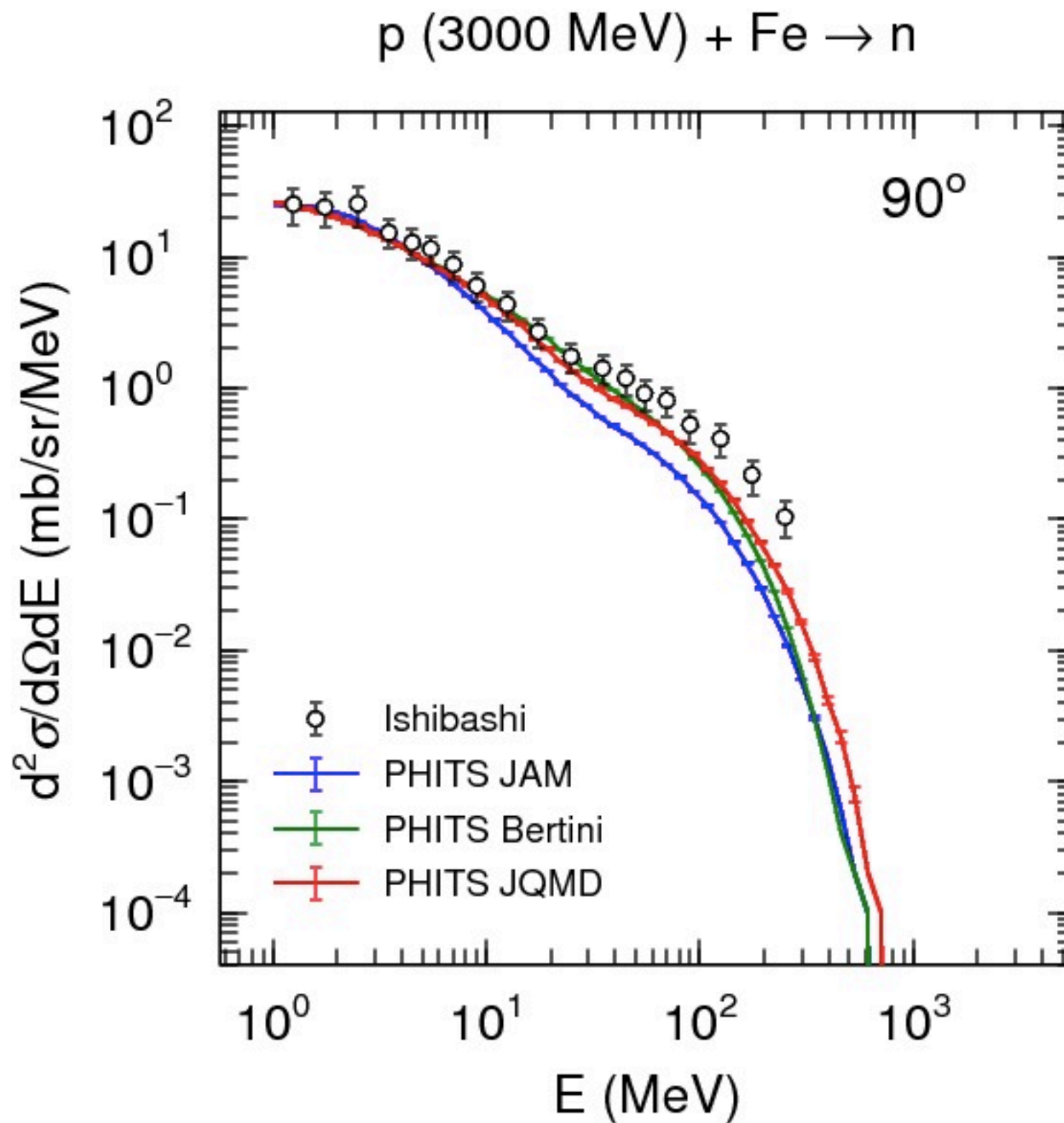
p (3000 MeV) + Fe → n

data by Ishibashi



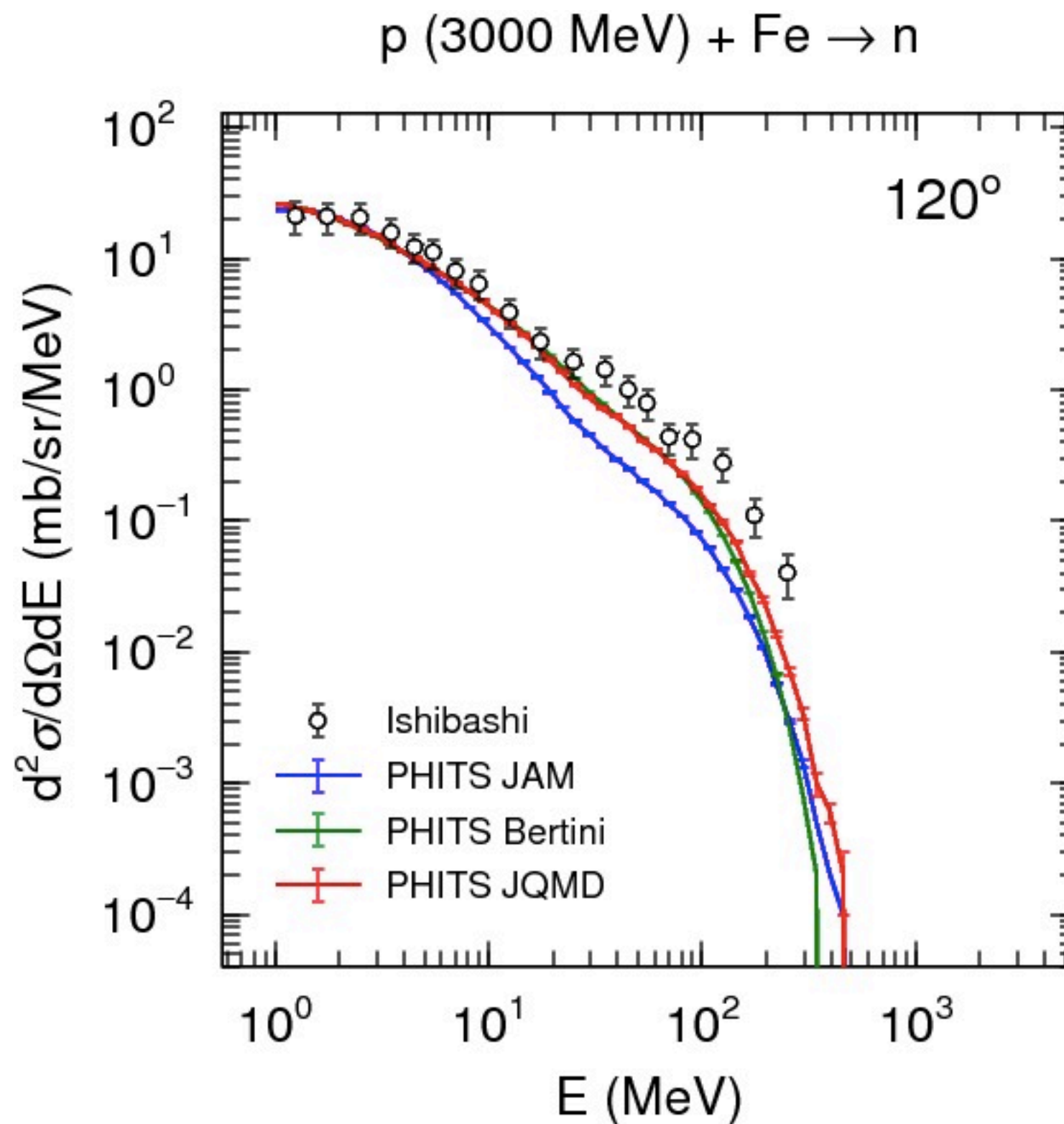
p (3000 MeV) + Fe  $\rightarrow$  n

data by Ishibashi



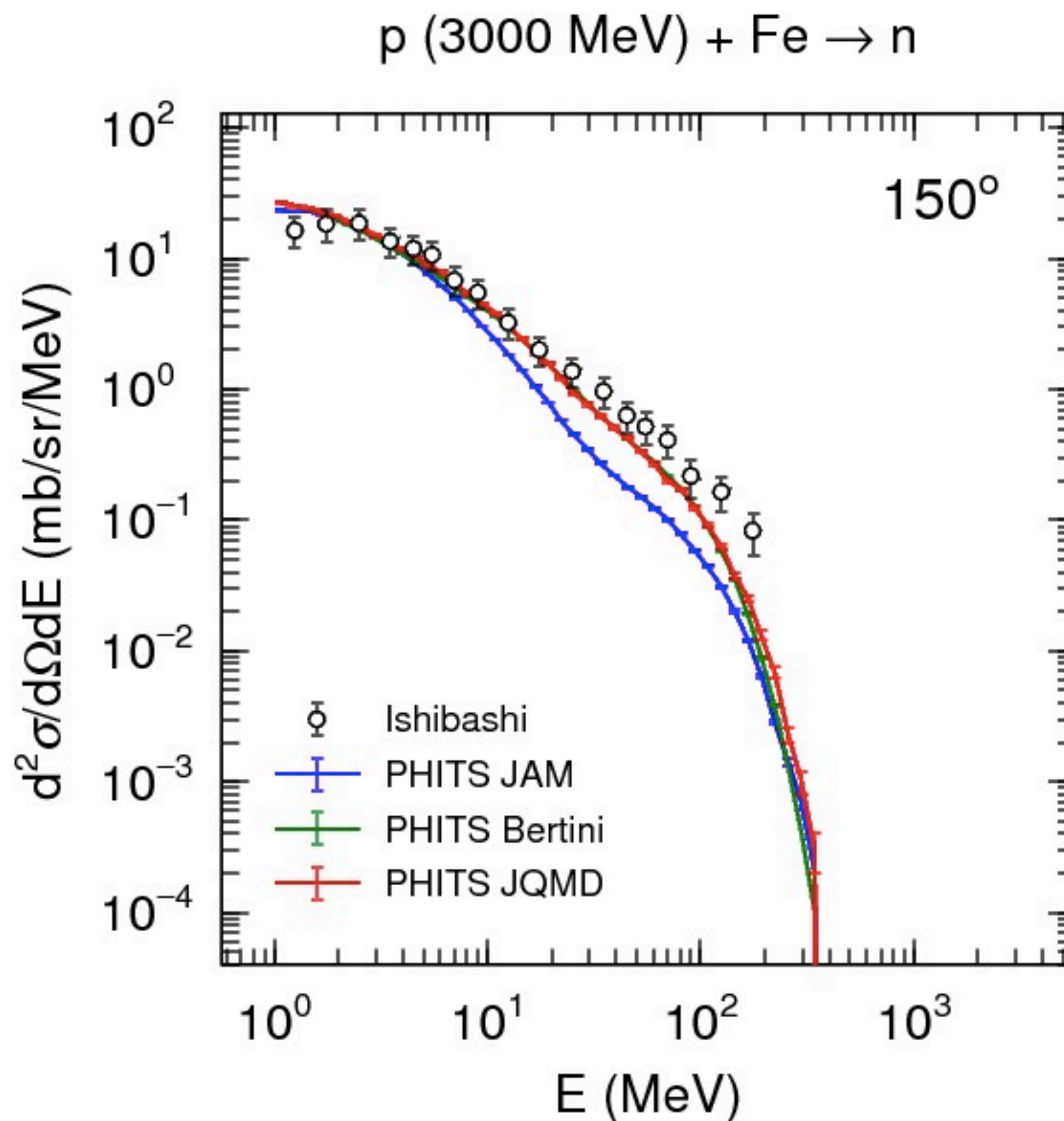
p (3000 MeV) + Fe → n

data by Ishibashi



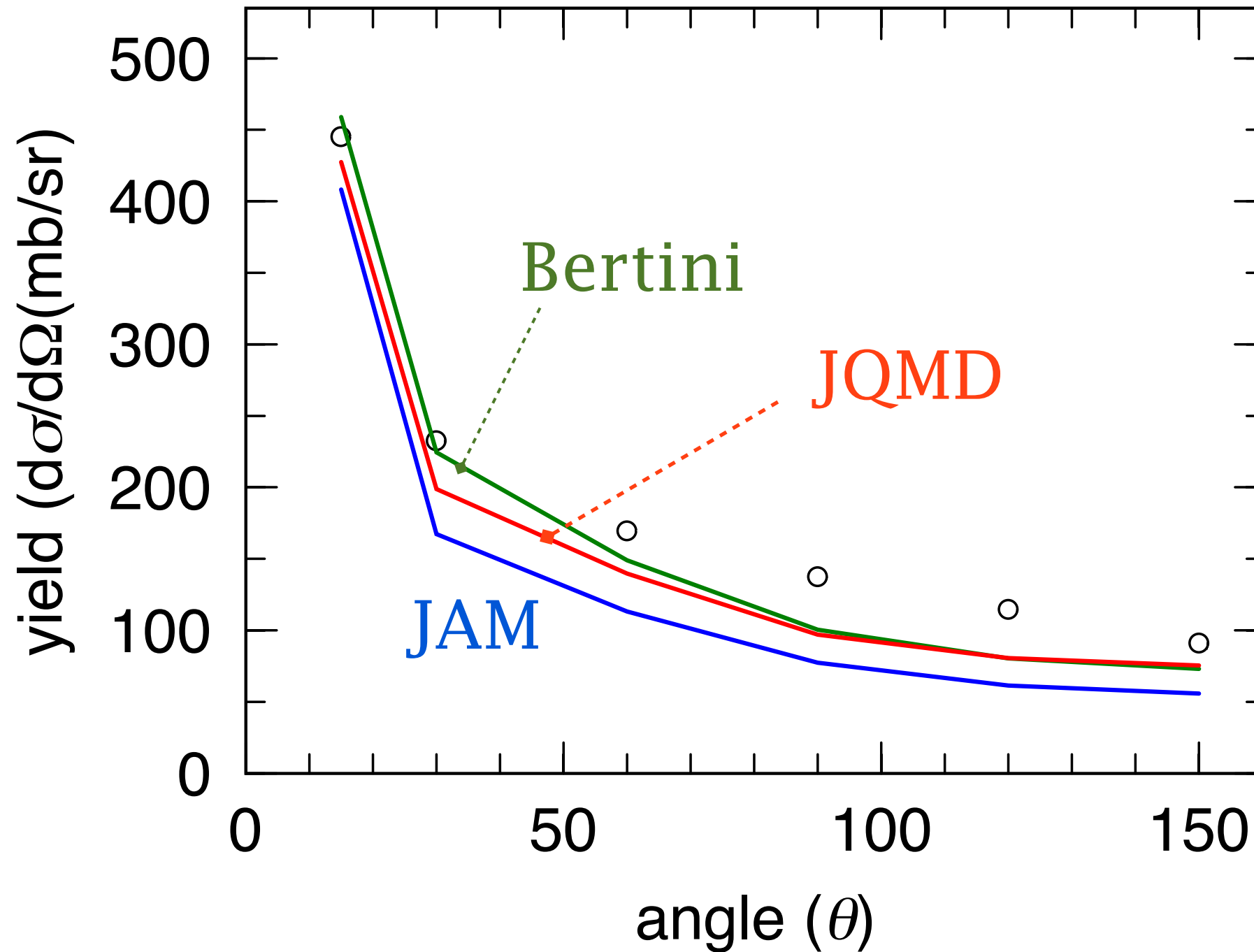
p (3000 MeV) + Fe → n

data by Ishibashi



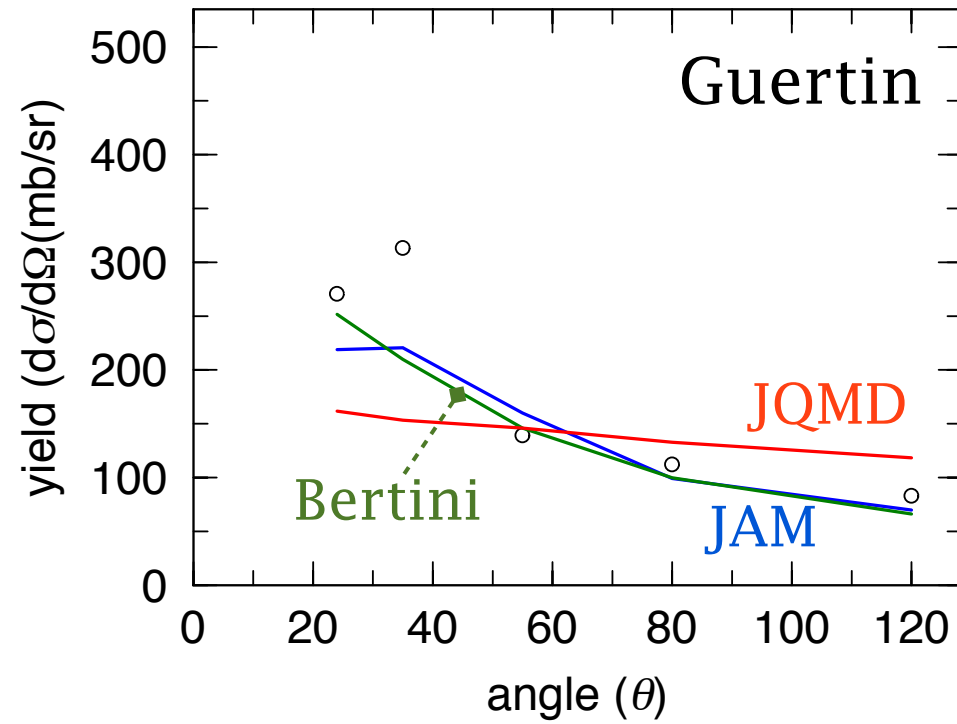


### Angular distribution

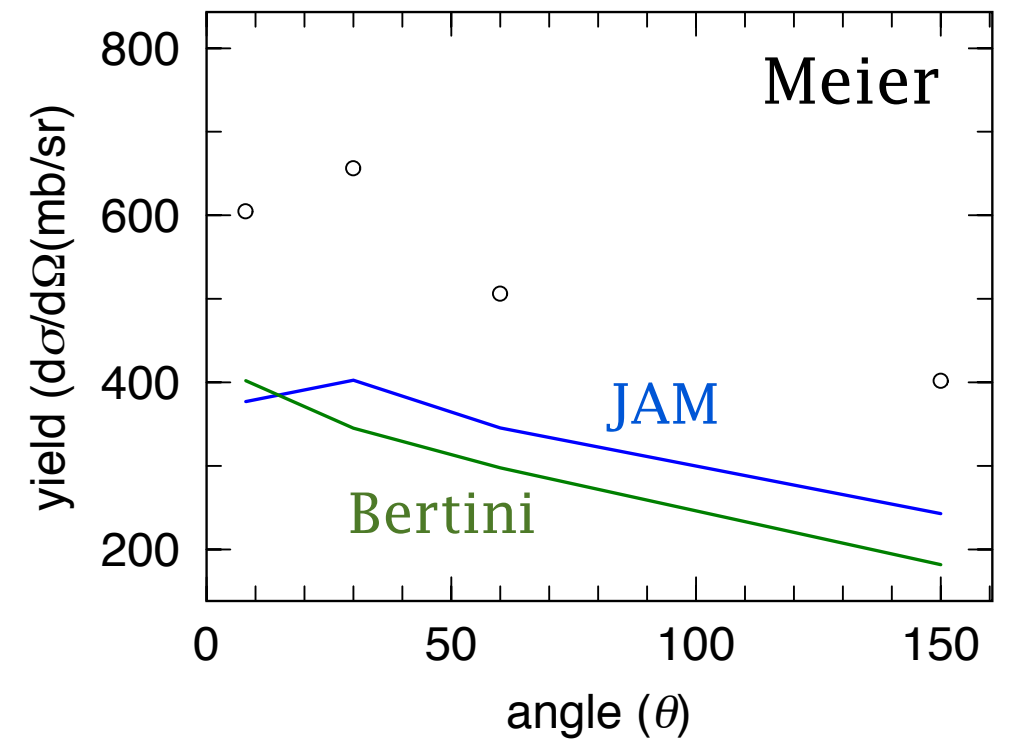


# p + Pb --> n

p (63 MeV) + Pb → n



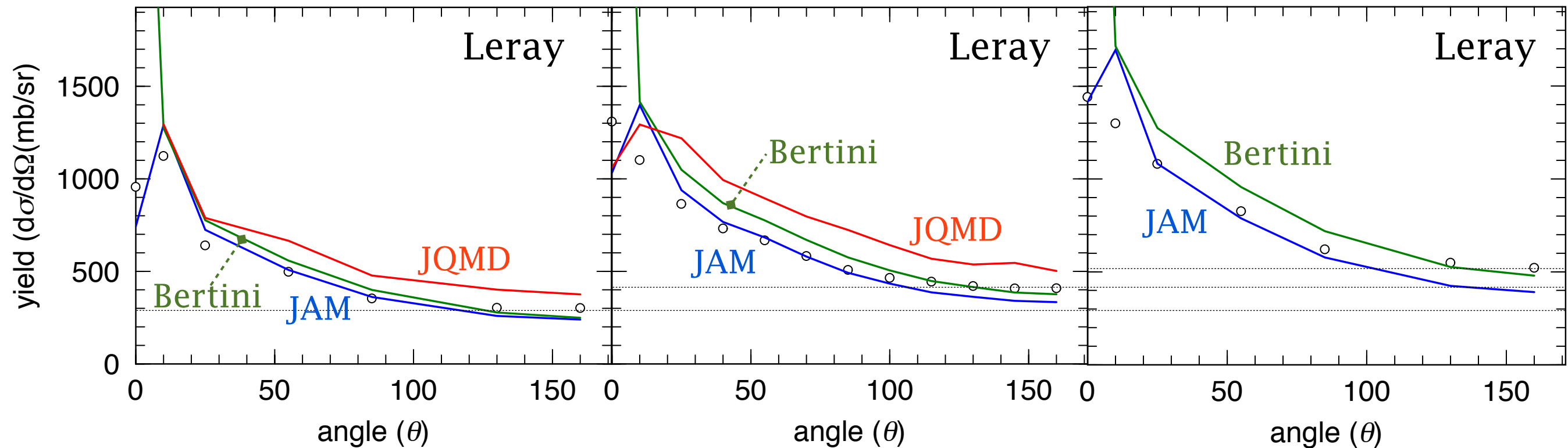
p (256 MeV) + Pb → n



p (800 MeV) + Pb → n

p (1200 MeV) + Pb → n

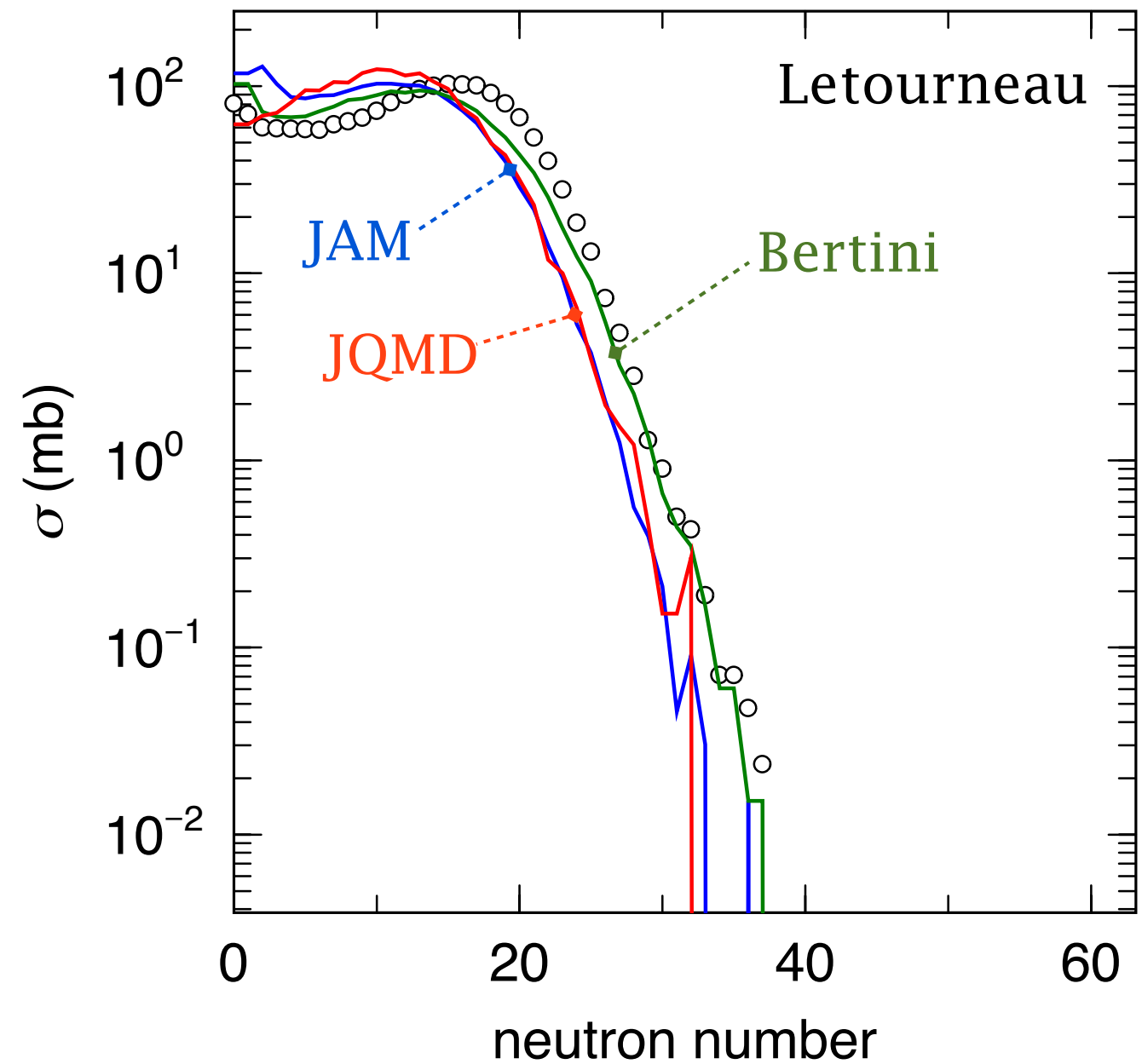
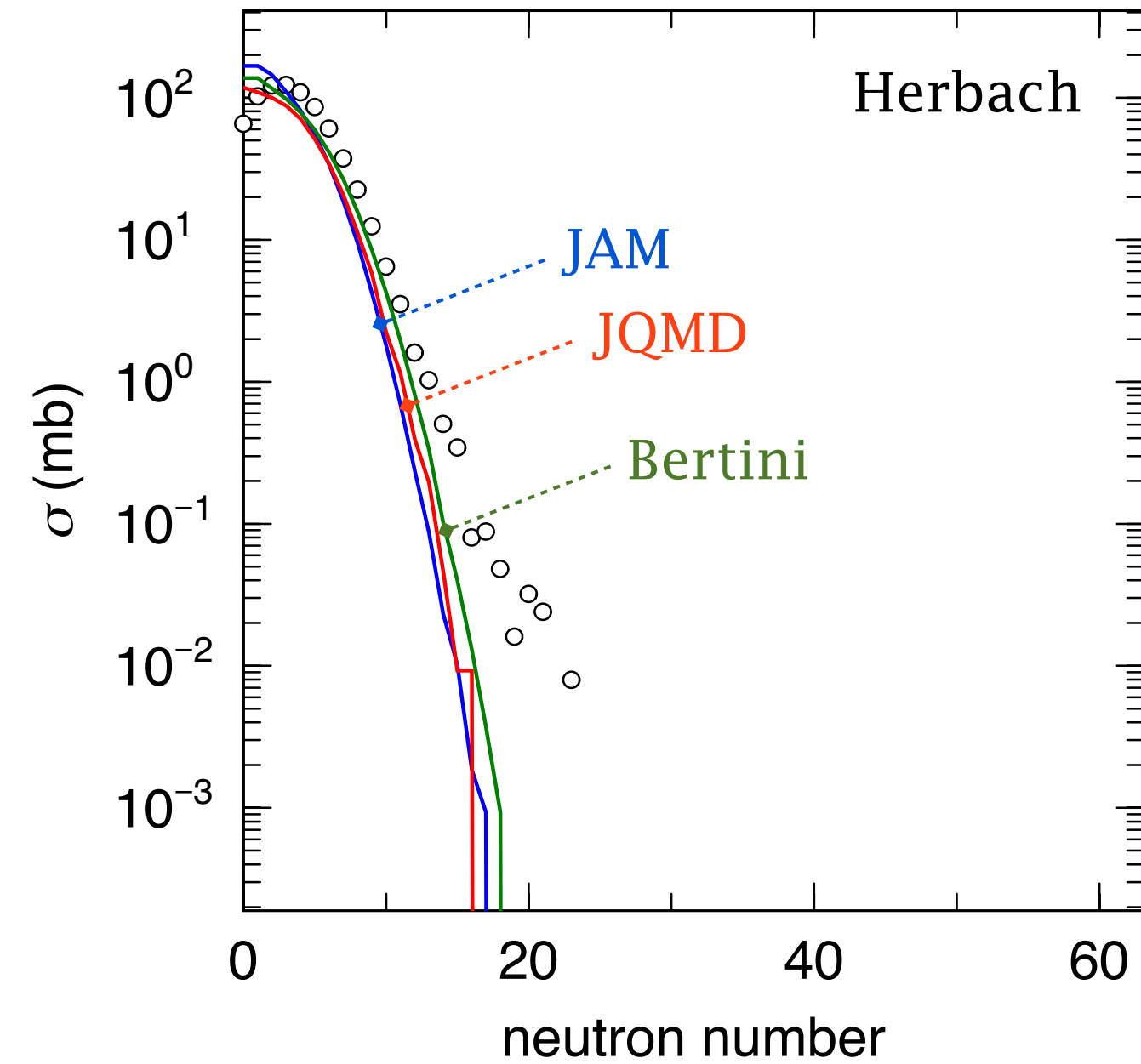
p (1600 MeV) + Pb → n

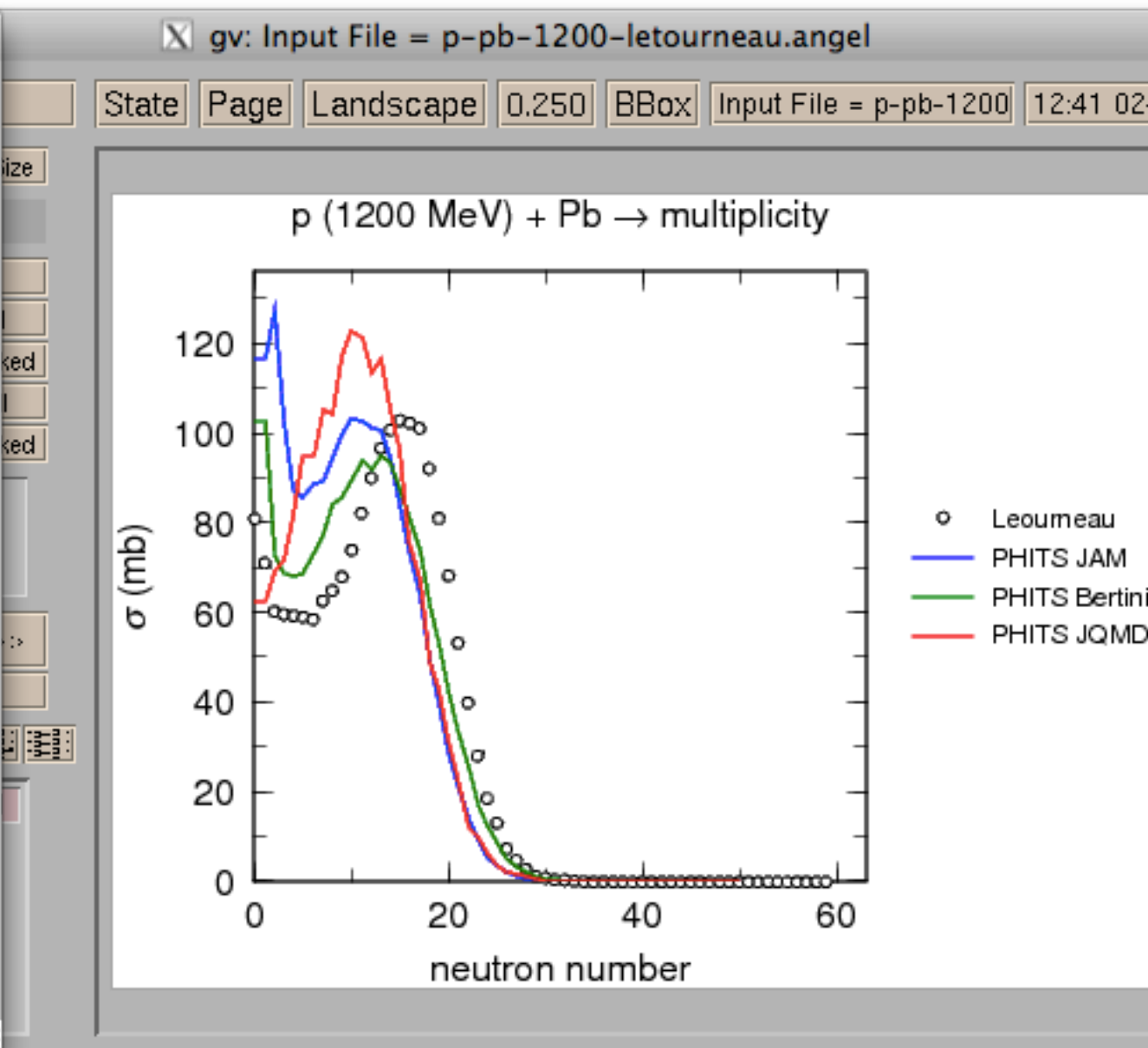
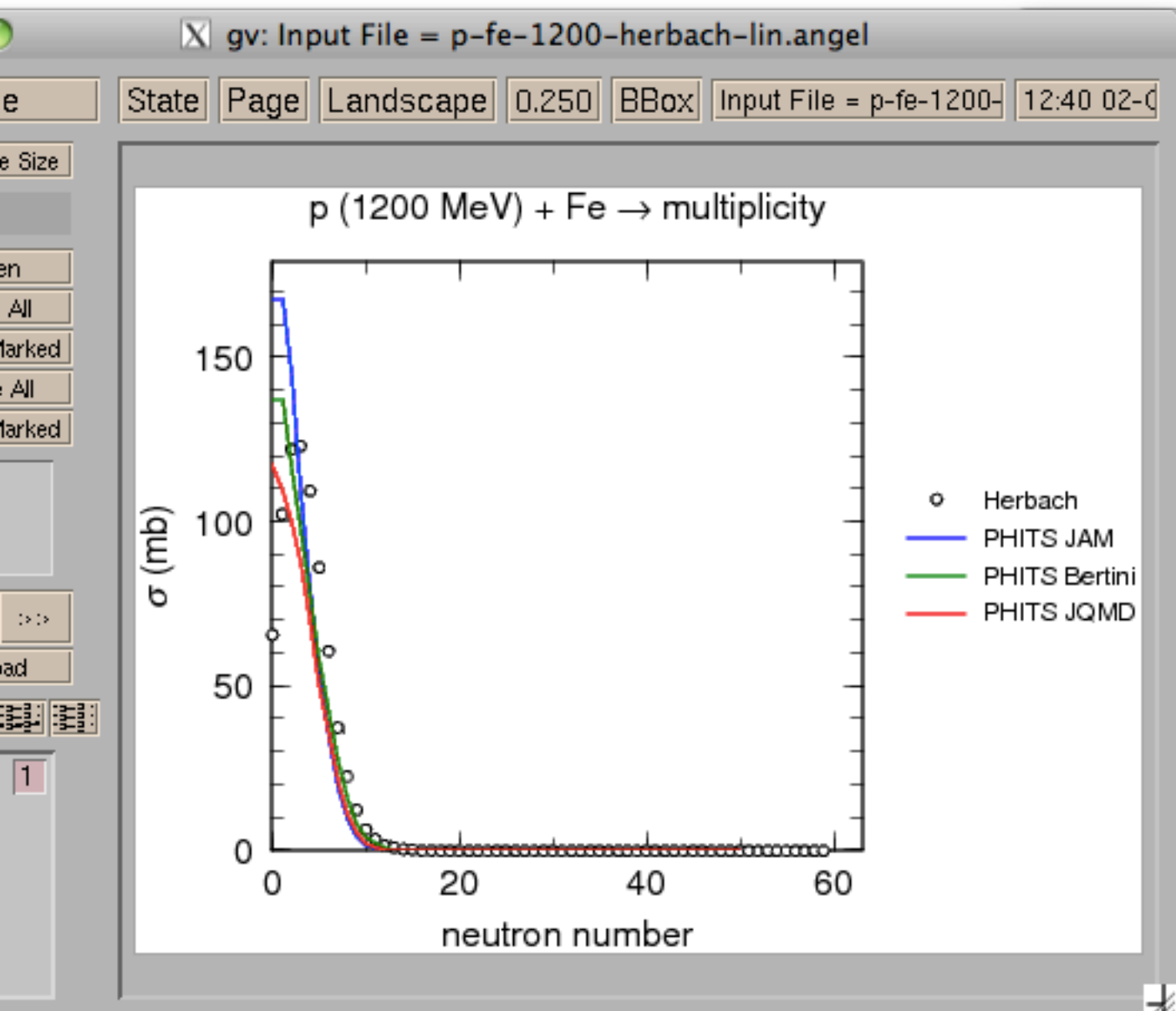


# Multiplicity

p (1200 MeV) + Fe

p (1200 MeV) + Pb





# Benchmark of Spallation Models

ISOTOPIC DISTRIBUTION CROSS-  
SECTION IN INVERSE KINEMATICS  
(IDX)

Summarized by N. MATSUDA

Calculated by N. MATSUDA



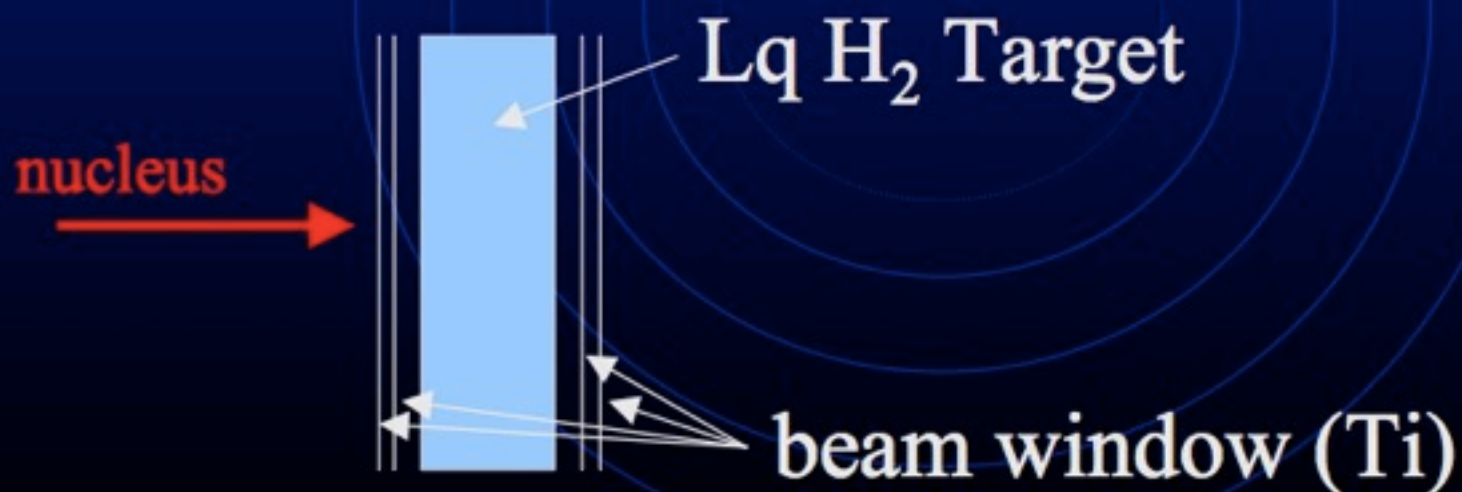
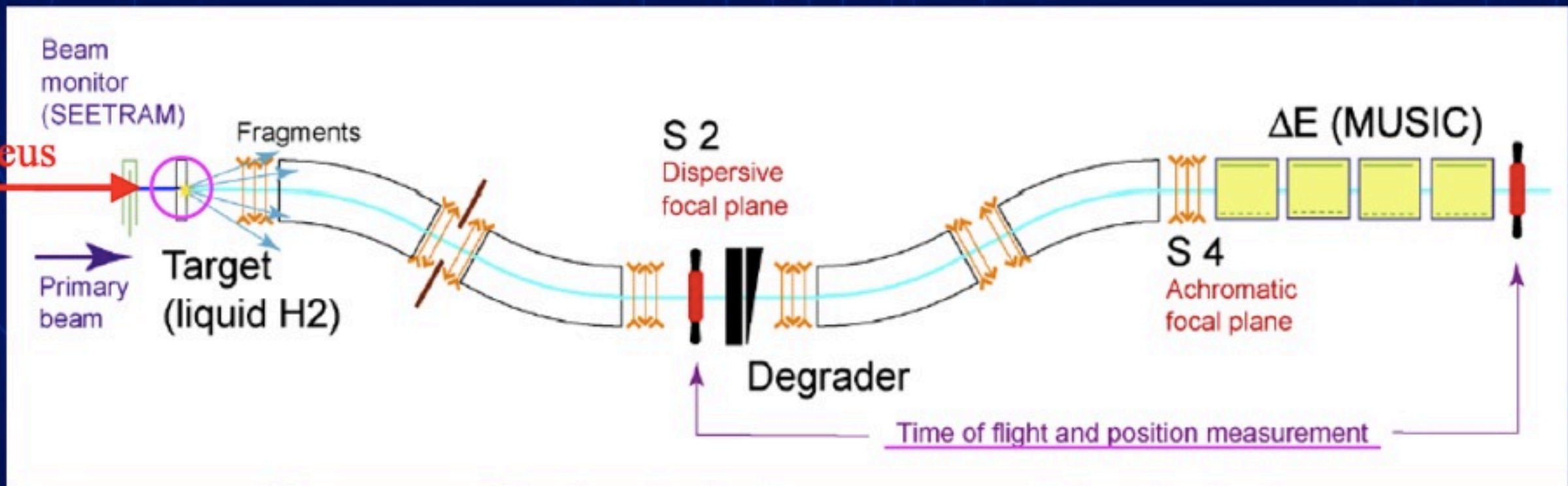
# Problems List (IDX)

Beam	Target	Energy (MeV)	Reference
Fe-56	H	300	<u><a href="#">C. Villagrasa-Canton et al., Phys. Rev. C 75 (2007) 044603</a></u>
Fe-56	H	1000	<u><a href="#">C. Villagrasa-Canton et al., Phys. Rev. C 75 (2007) 044603</a></u> , <u><a href="#">P. Napolitani et al., Phys. Rev. C 70 (2004) 054607</a></u>
Pb-208	H	500	<u><a href="#">L. Audouin et al., Nucl. Phys. A768 (2006) 1</a></u>
Pb-208	H	1000	<u><a href="#">T. Enqvist et al., Nucl. Phys. A686 (2001) 481</a></u>
U-238	H	1000	<u><a href="#">J. Taieb et al., Nucl. Phys. A 724 (2003) 413</a></u> , <u><a href="#">M. Bernas et al., Nucl. Phys. A765 (2006) 197</a></u> , <u><a href="#">M. Bernas et al., Nucl. Phys. A 725 (2003) 213</a></u> , <u><a href="#">M. V. Ricciardi et al., Phys. Rev. C 73 (2006) 014607</a></u>



# Experimental Setup for IDX01~05

- Experimental Geometry (GSI)



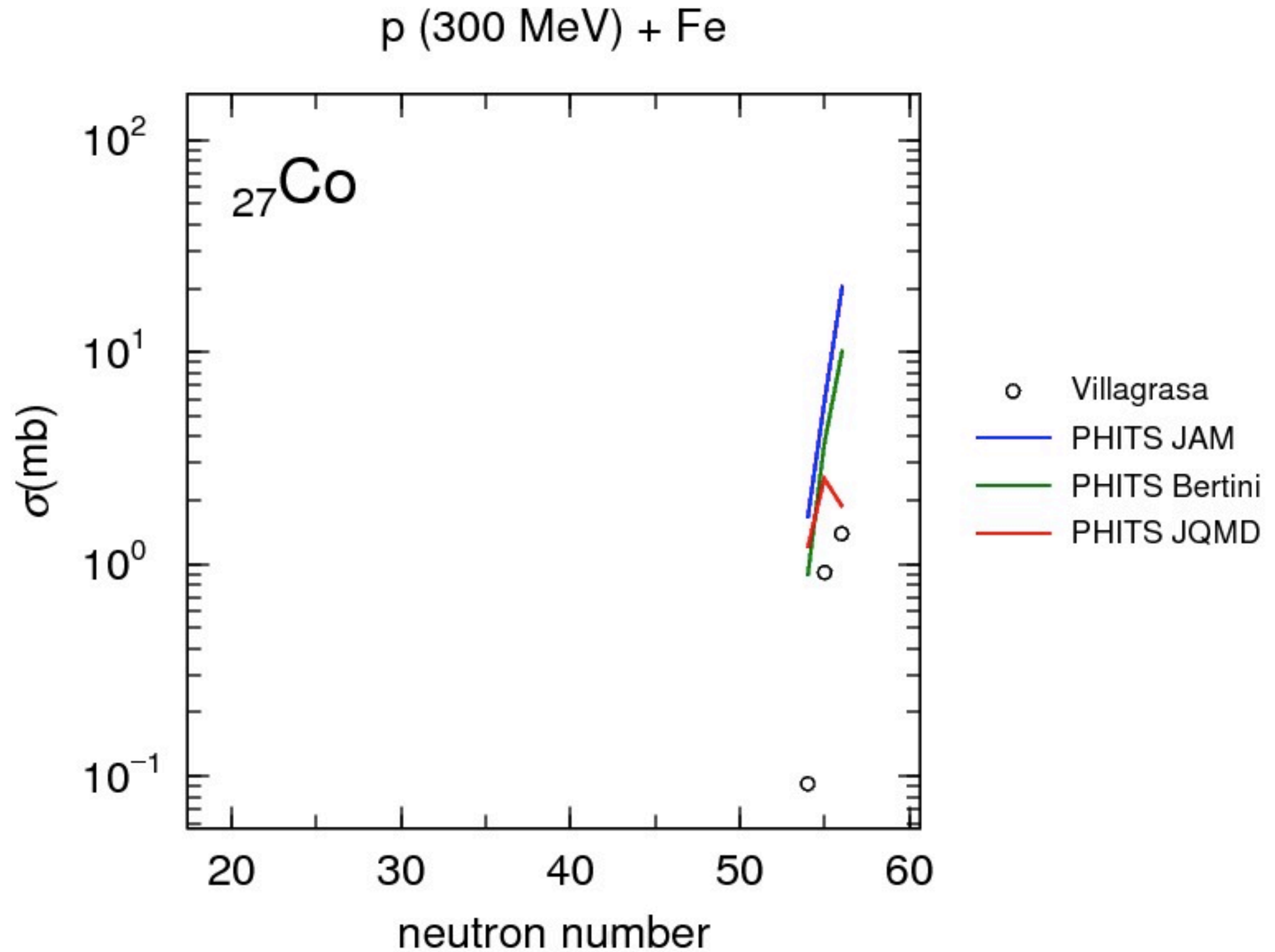


# Expt. and Calc. info. for IDX01~05

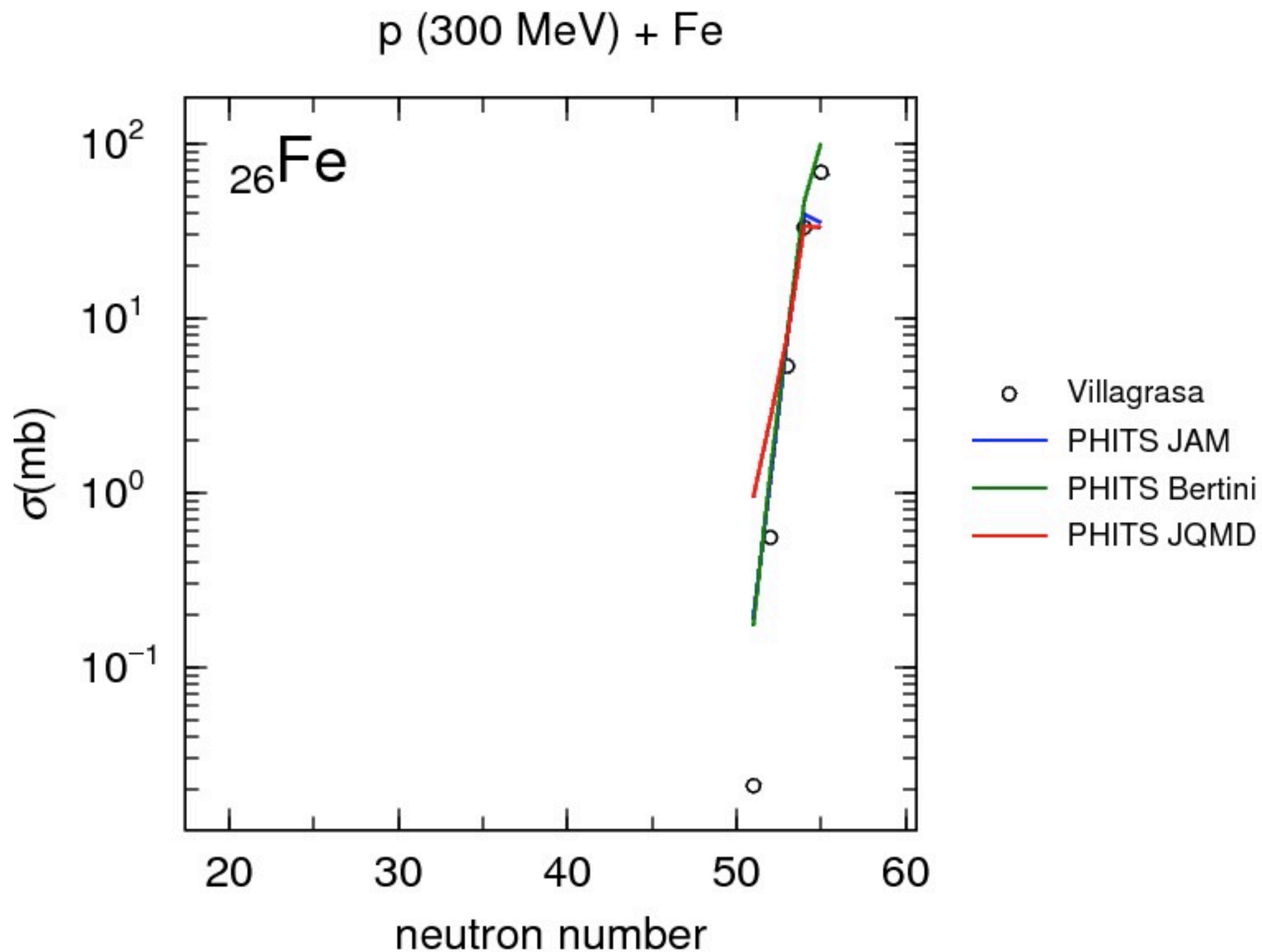
	Expt.	Calc.
<b>Target</b>		
Material	Liquid Hydrogen	Hydrogen
Size (thickness)	87.3 mg/cm <sup>2</sup>	1.22958 cm
Size (width)	unclear	φ 1.22958 cm
Density	---	0.071 g/cm <sup>3</sup>
<b>Beam Window</b>		
Material	Titanium	Titanium
Size (thickness)	36.0 mg/cm <sup>2</sup>	0.00793 cm
Size (width)	unclear	φ 1.22958 cm
Density	---	4.54 g/cm <sup>3</sup>

# 計算では、ターゲット内に生成した核種をTallyした。

# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{27}\text{Co}$

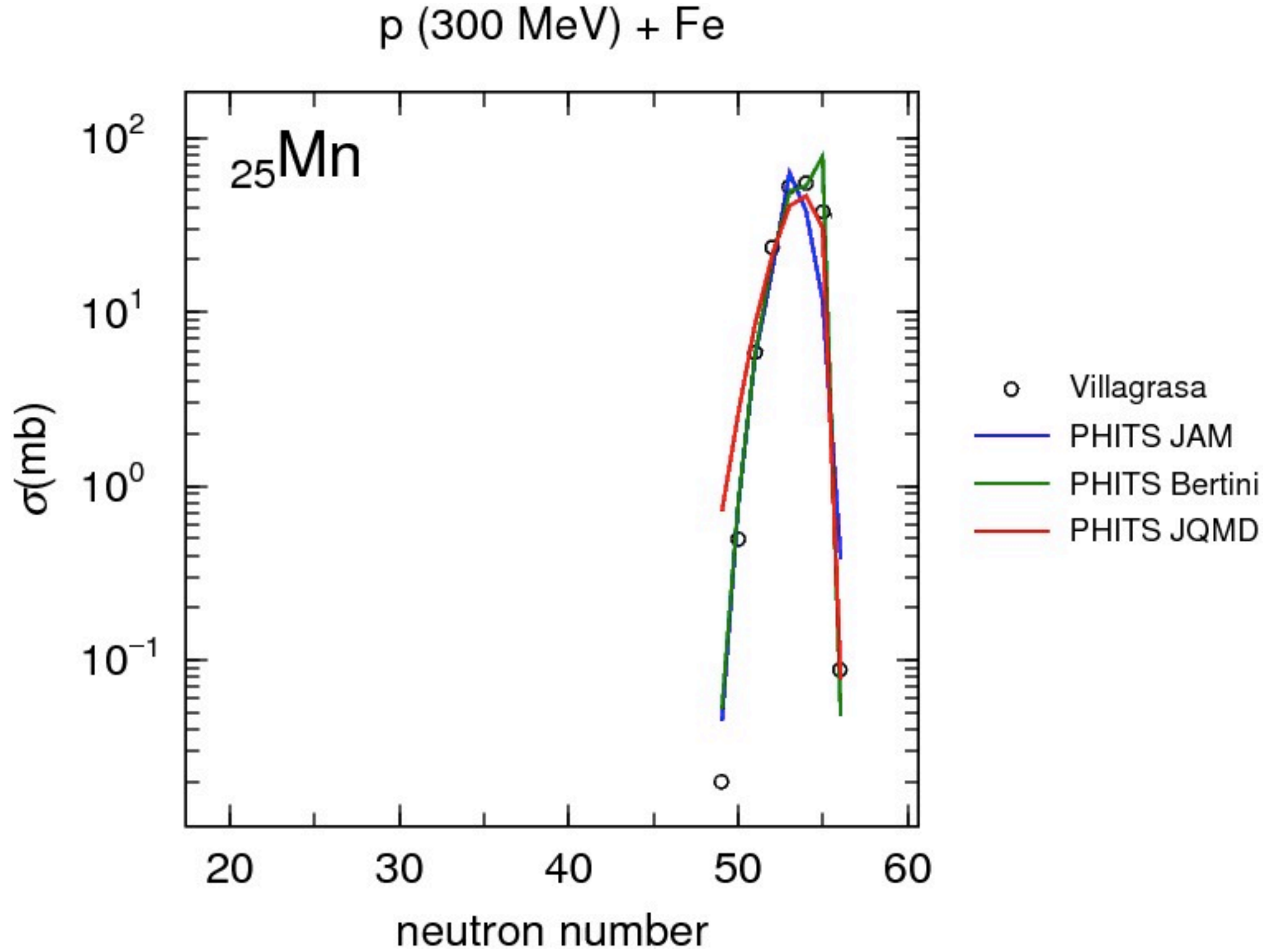


# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{26}\text{Fe}$

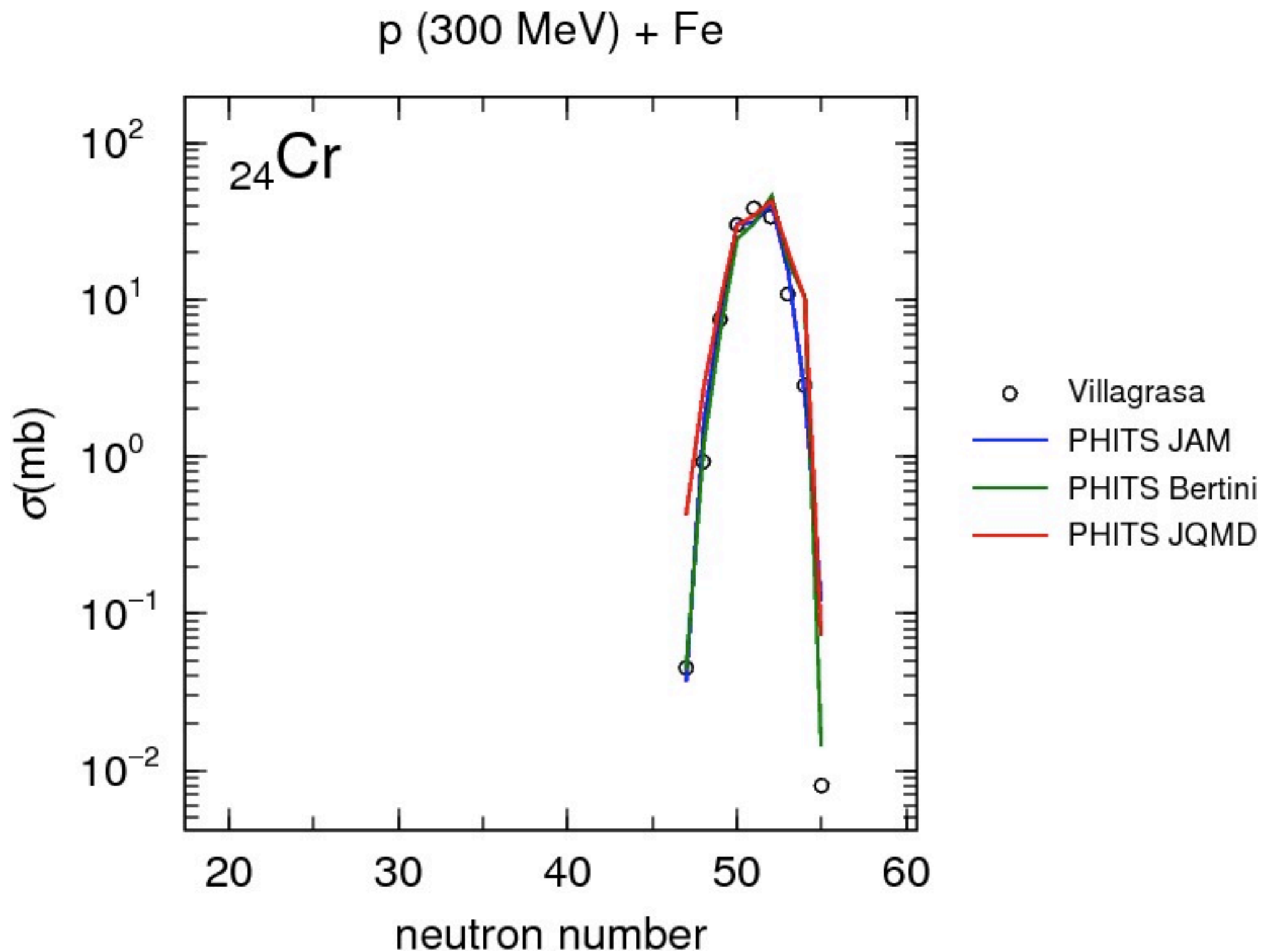




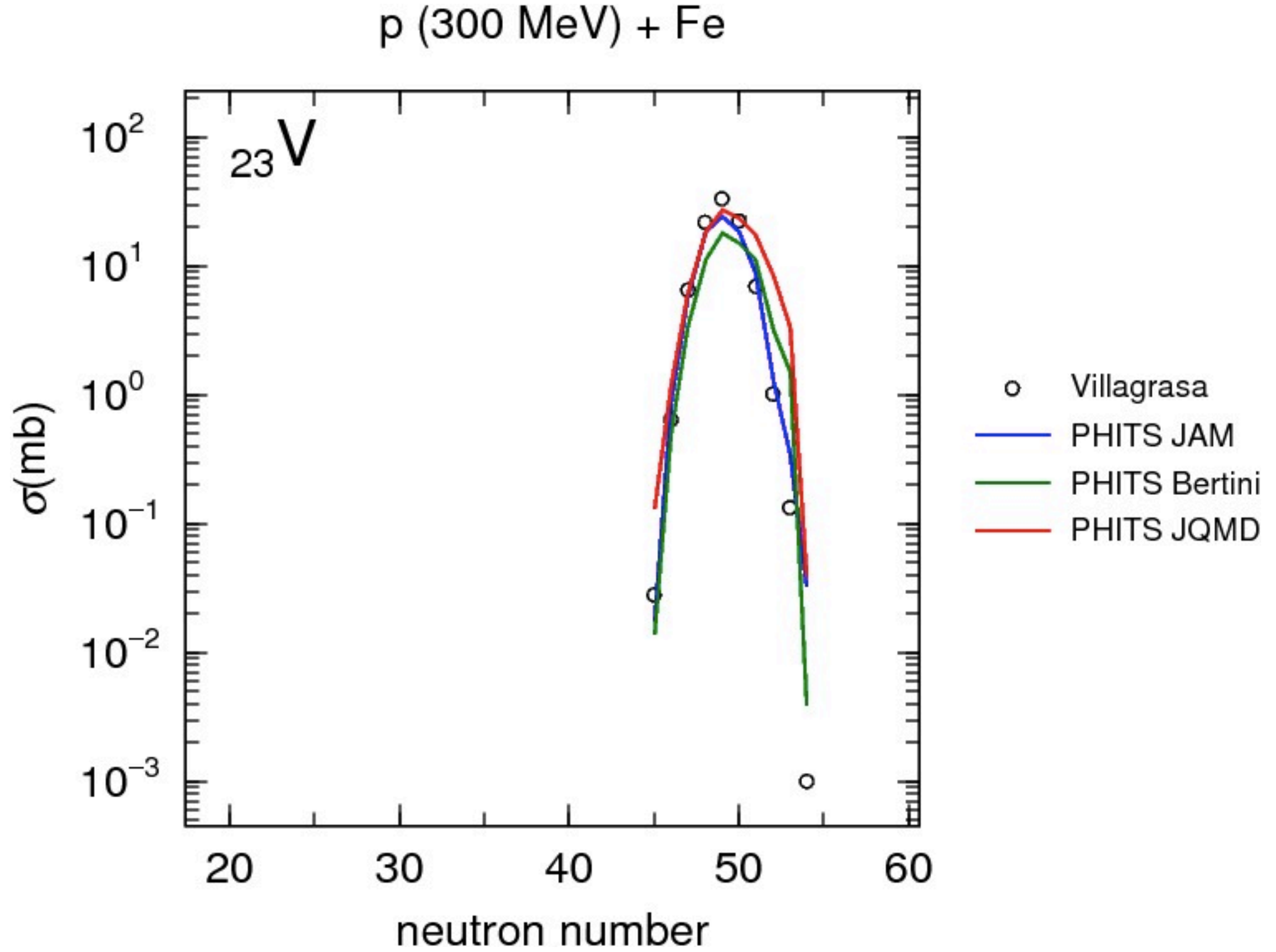
# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{25}\text{Mn}$



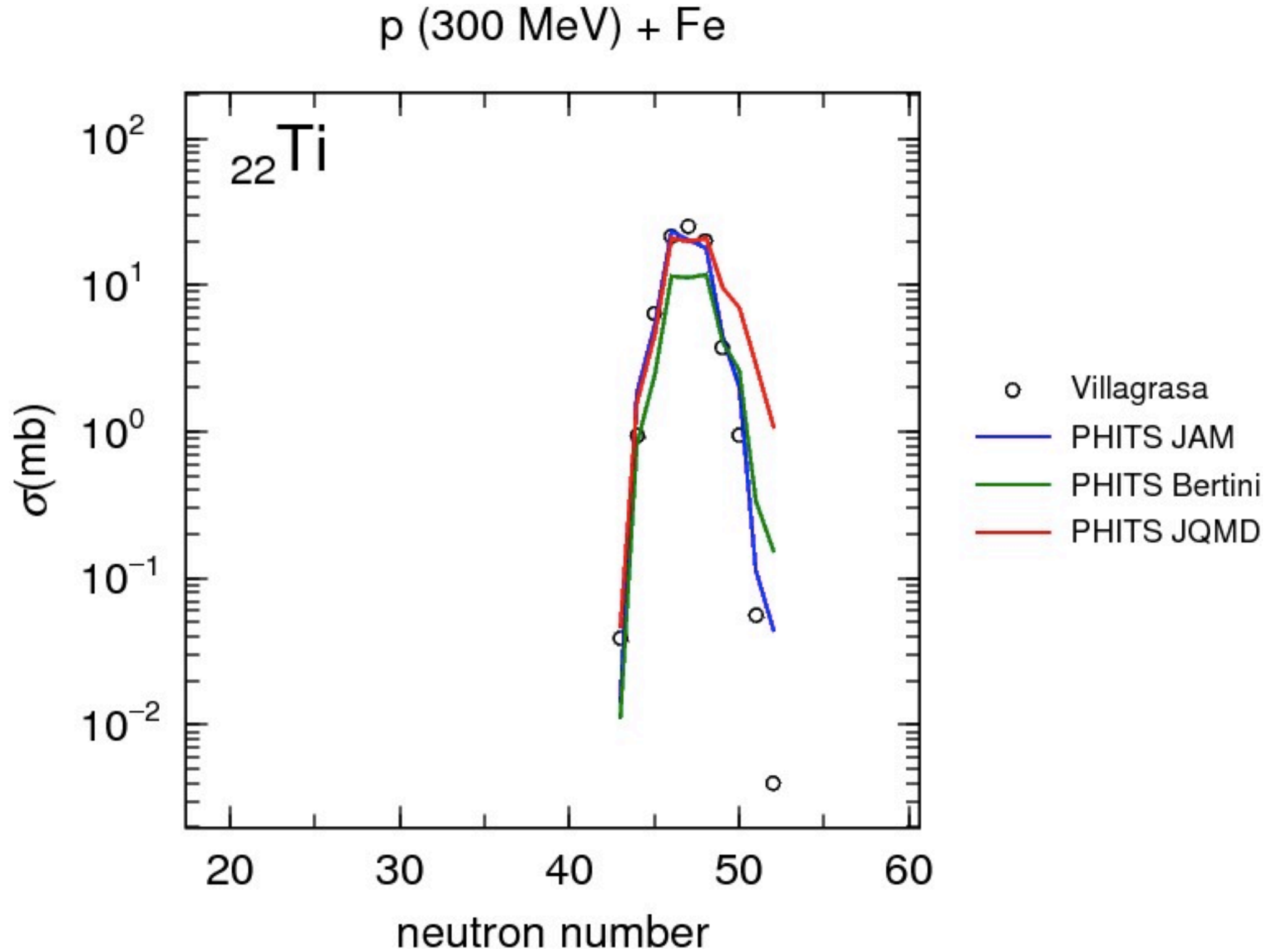
# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{24}\text{Cr}$



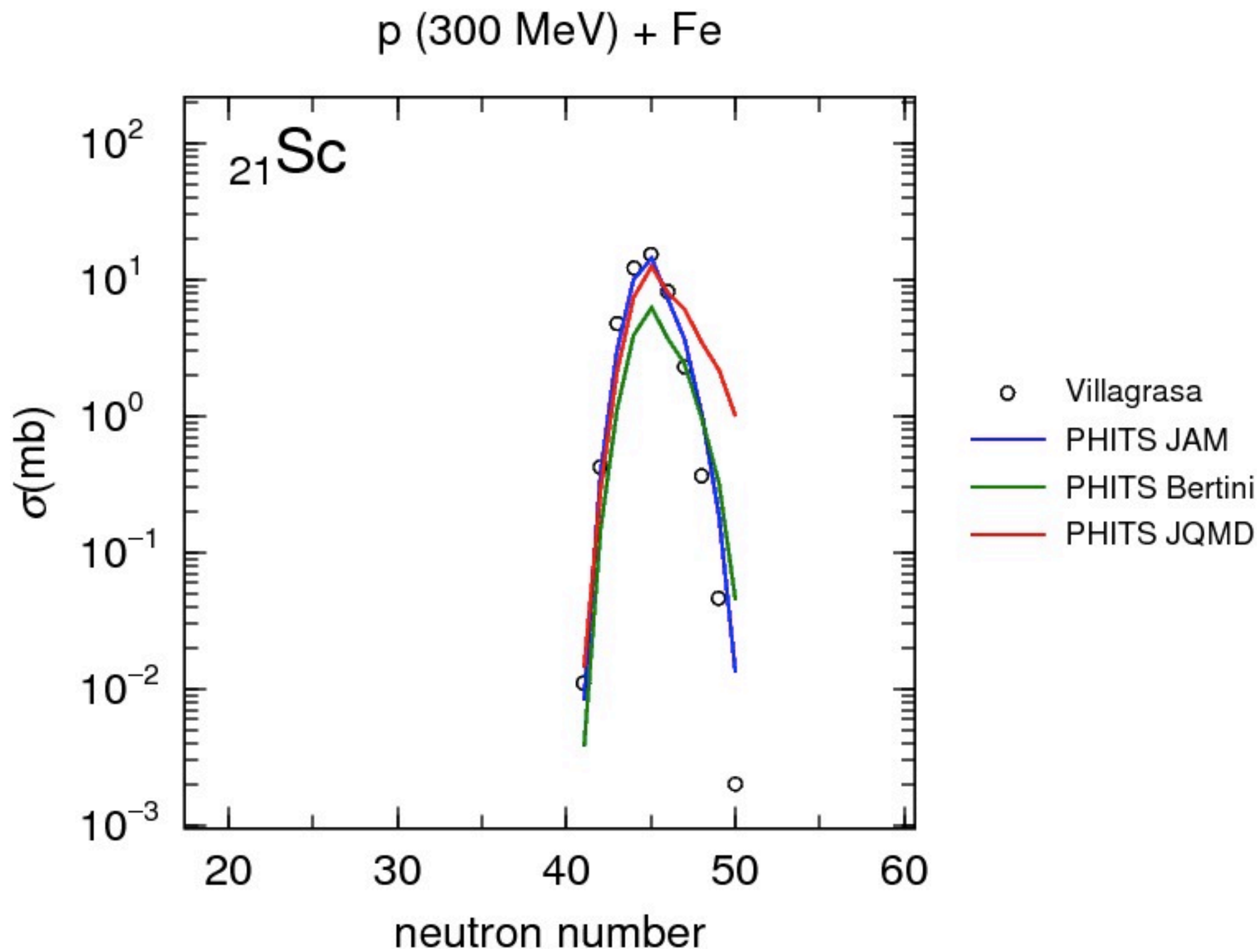
isotropic distribution:  $p$  (300 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{23}\text{V}$



# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{22}\text{Ti}$

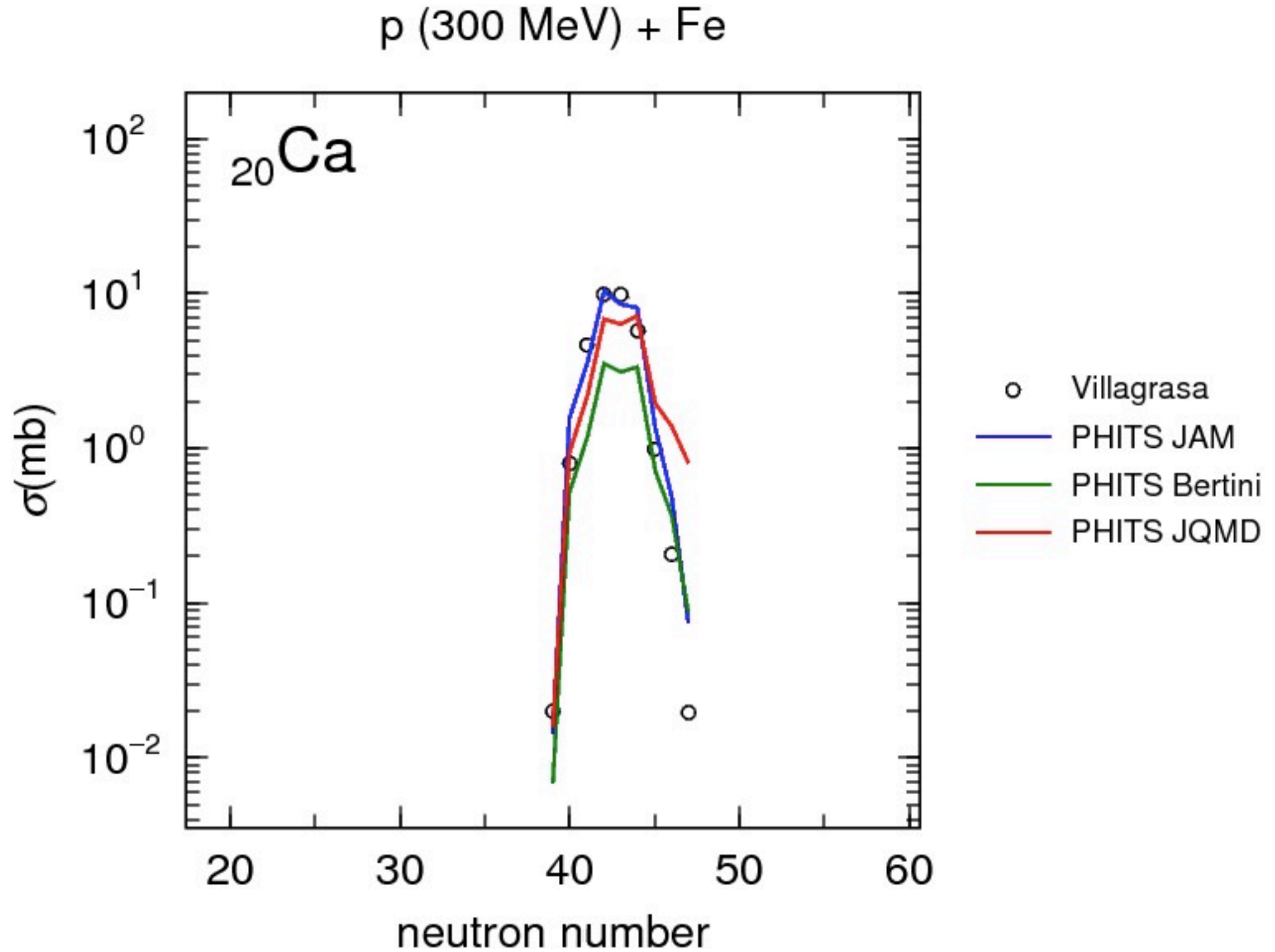


# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{21}\text{Sc}$

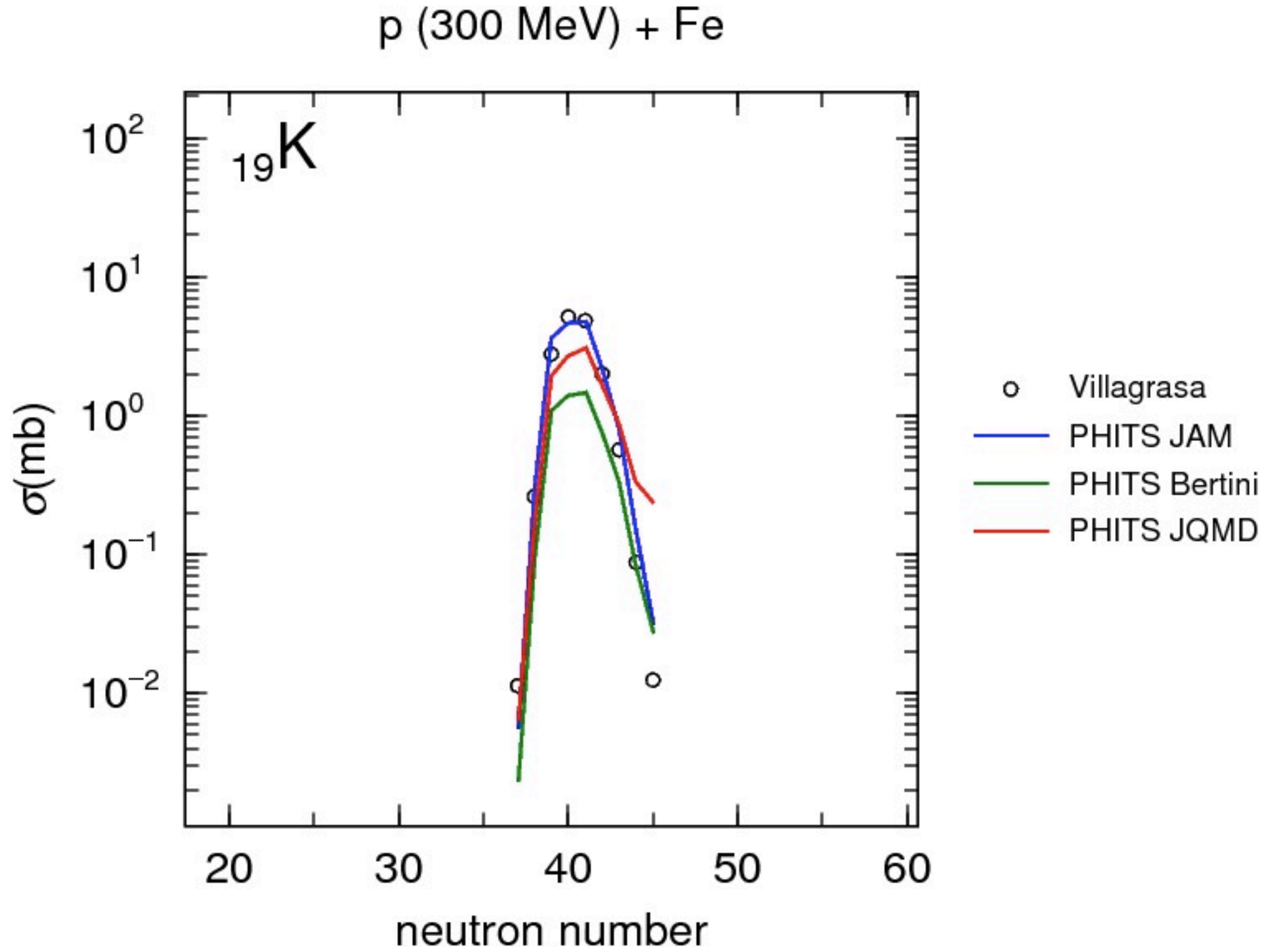




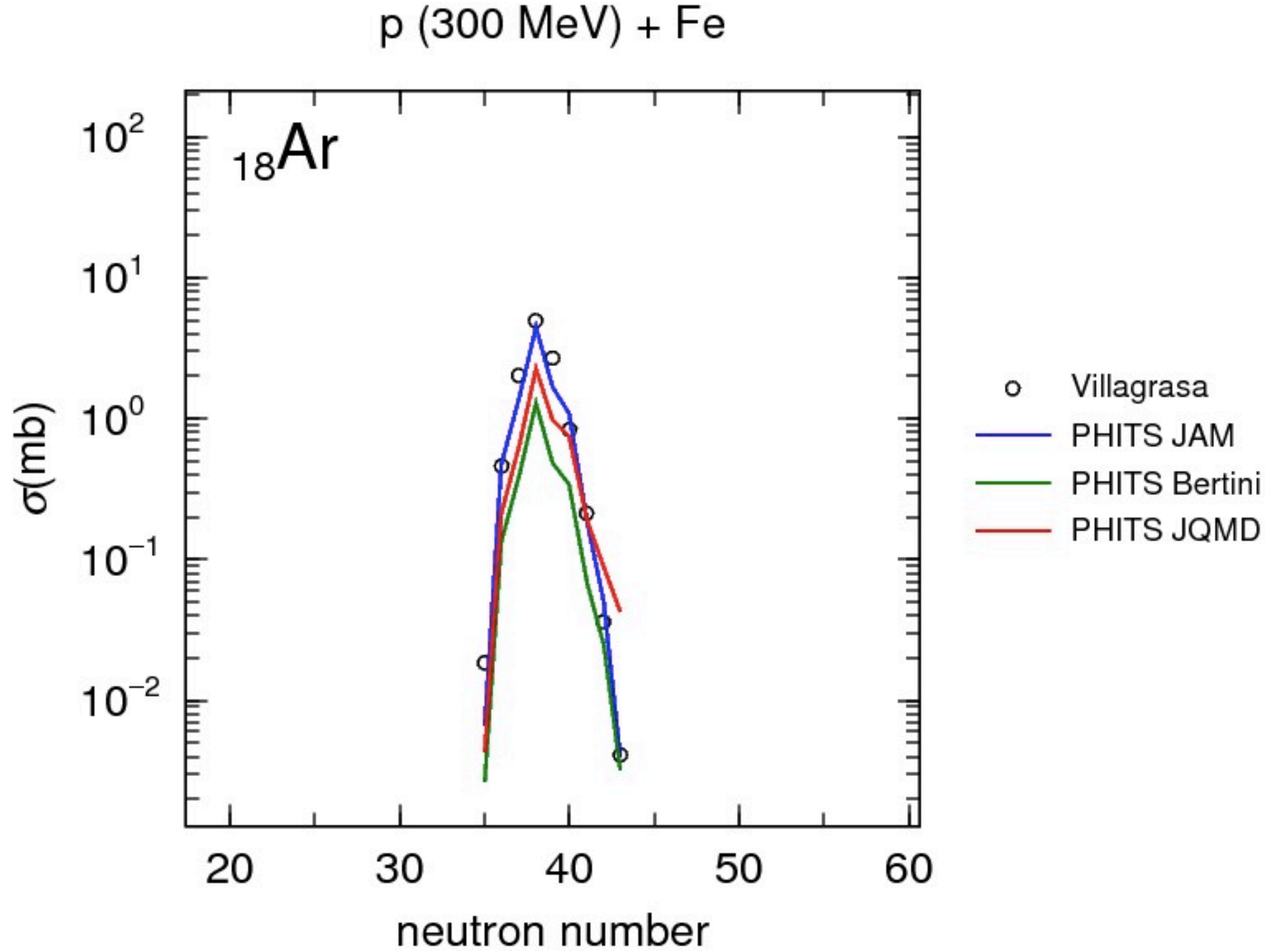
isotropic distribution:  $p$  (300 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{20}\text{Ca}$



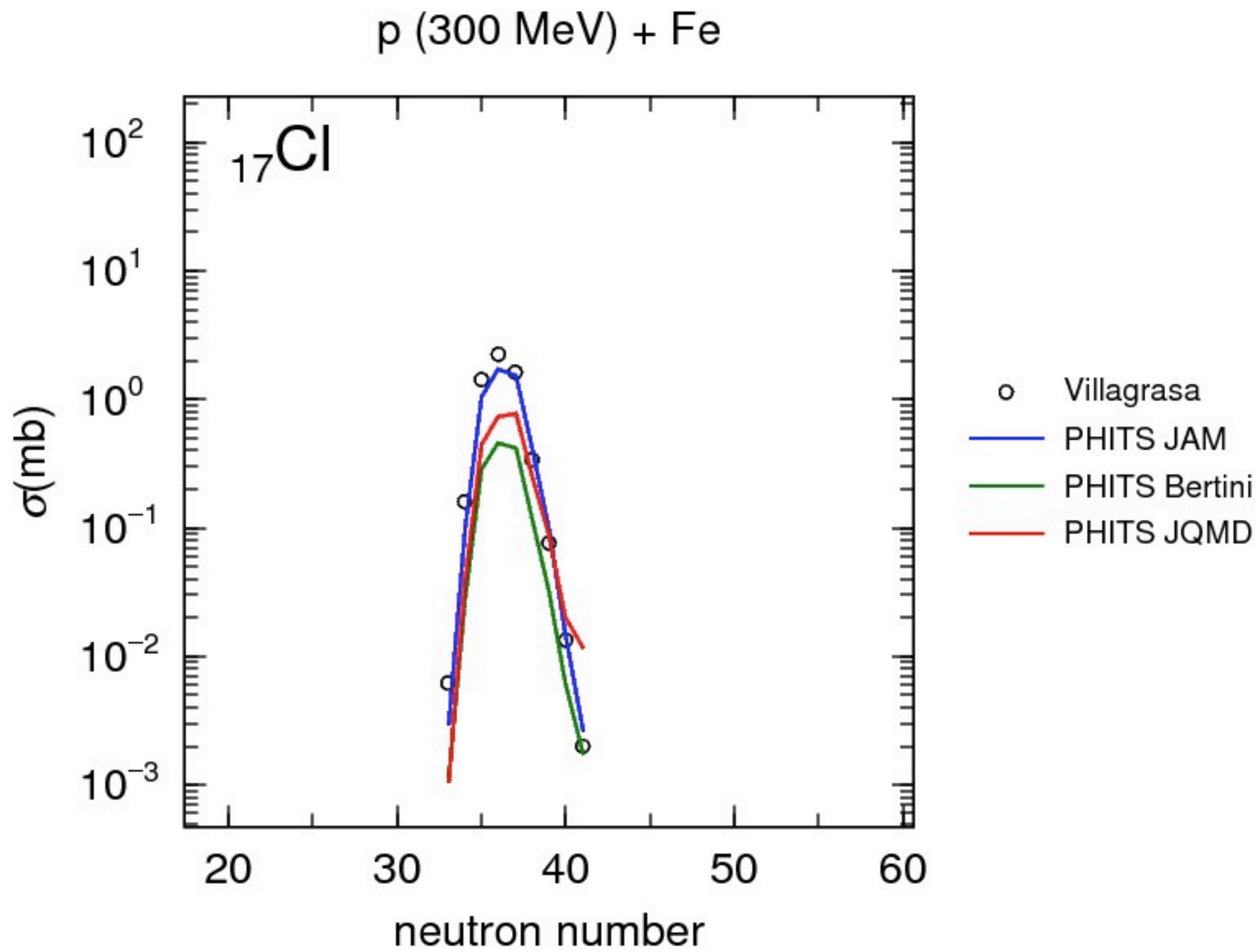
isotropic distribution:  $p$  (300 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{19}\text{K}$



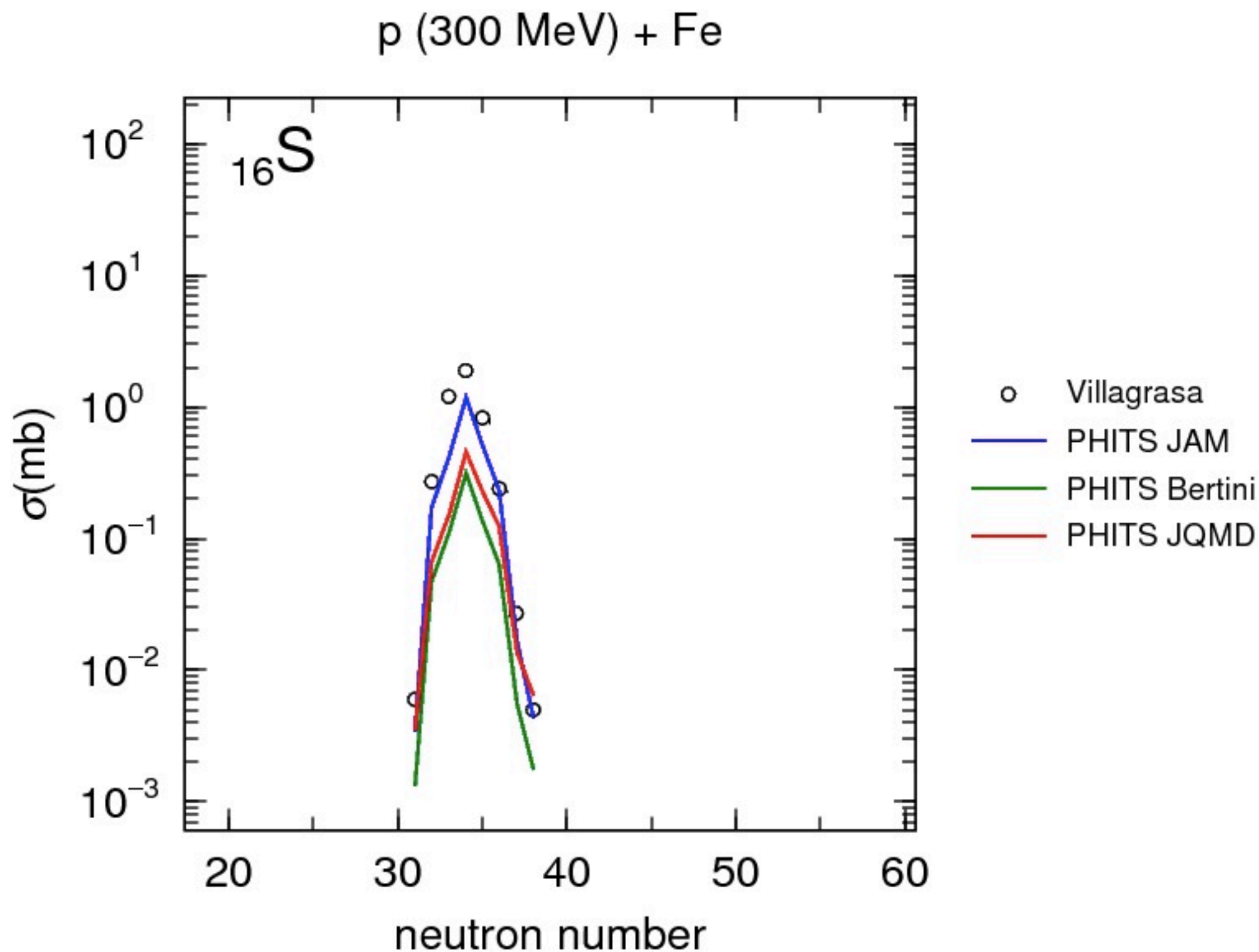
# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{18}\text{Ar}$



# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{17}\text{Cl}$

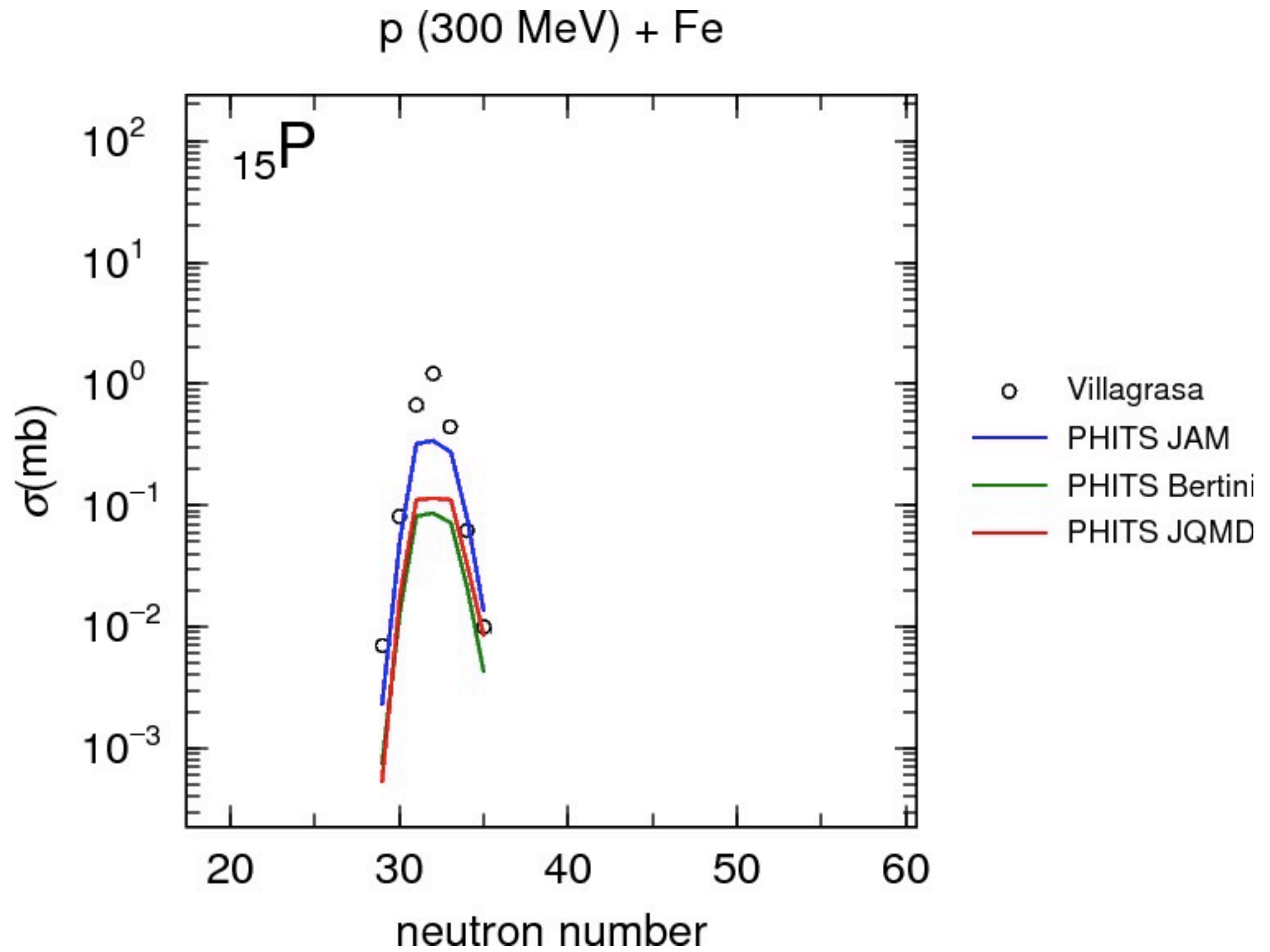


# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{16}\text{S}$

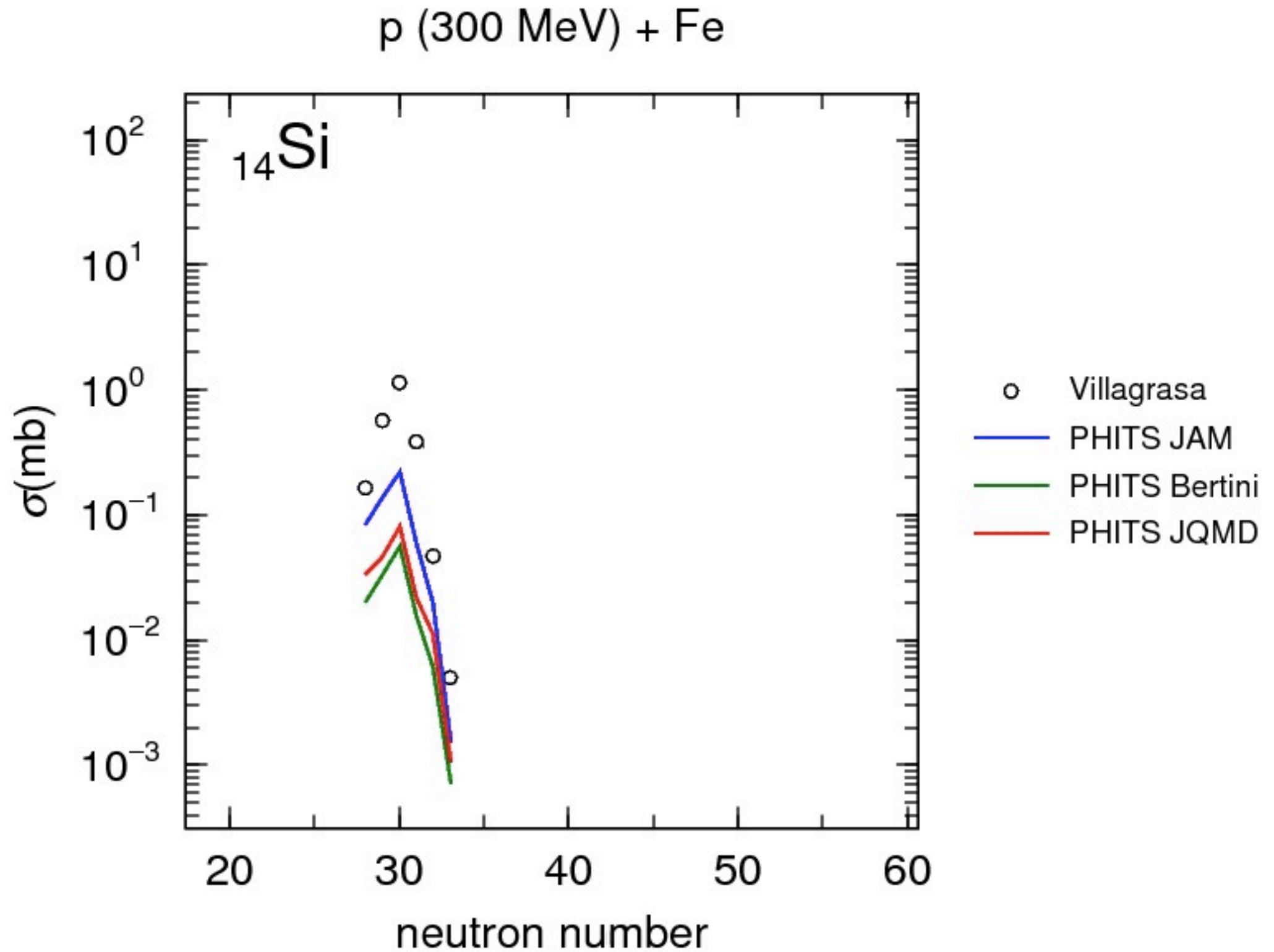




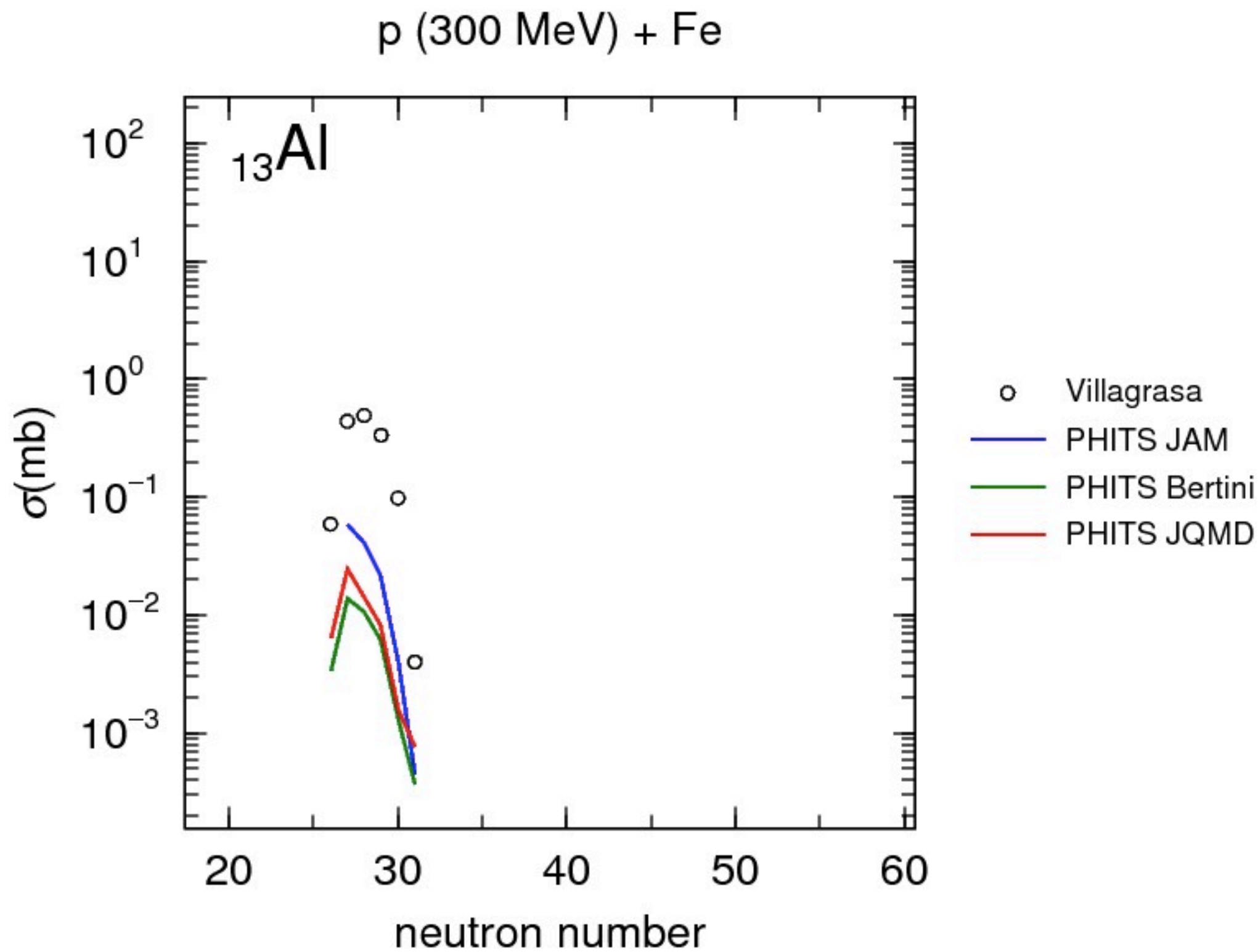
# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{15}\text{P}$



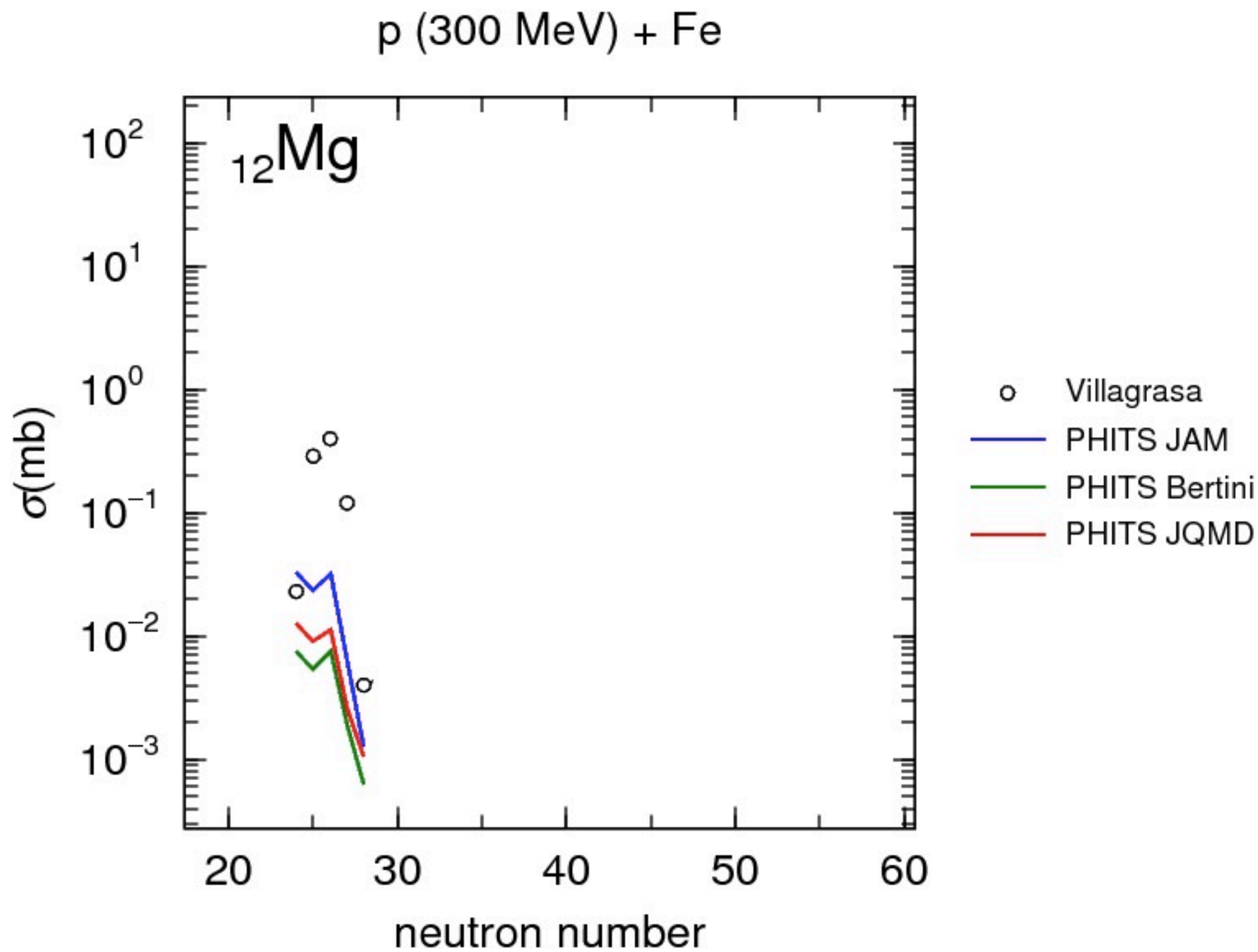
# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{14}\text{Si}$



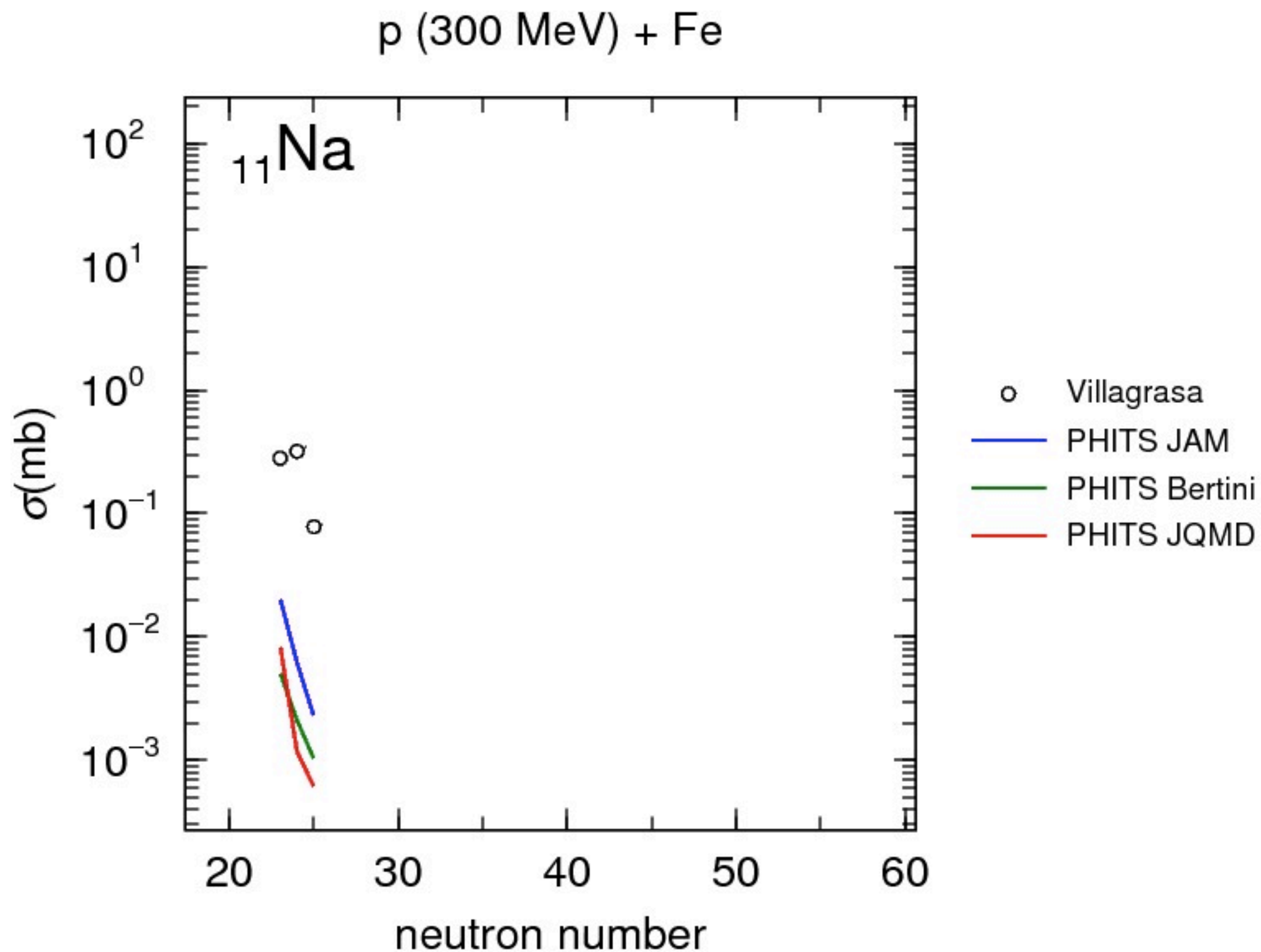
# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{13}\text{Al}$



# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{12}\text{Mg}$

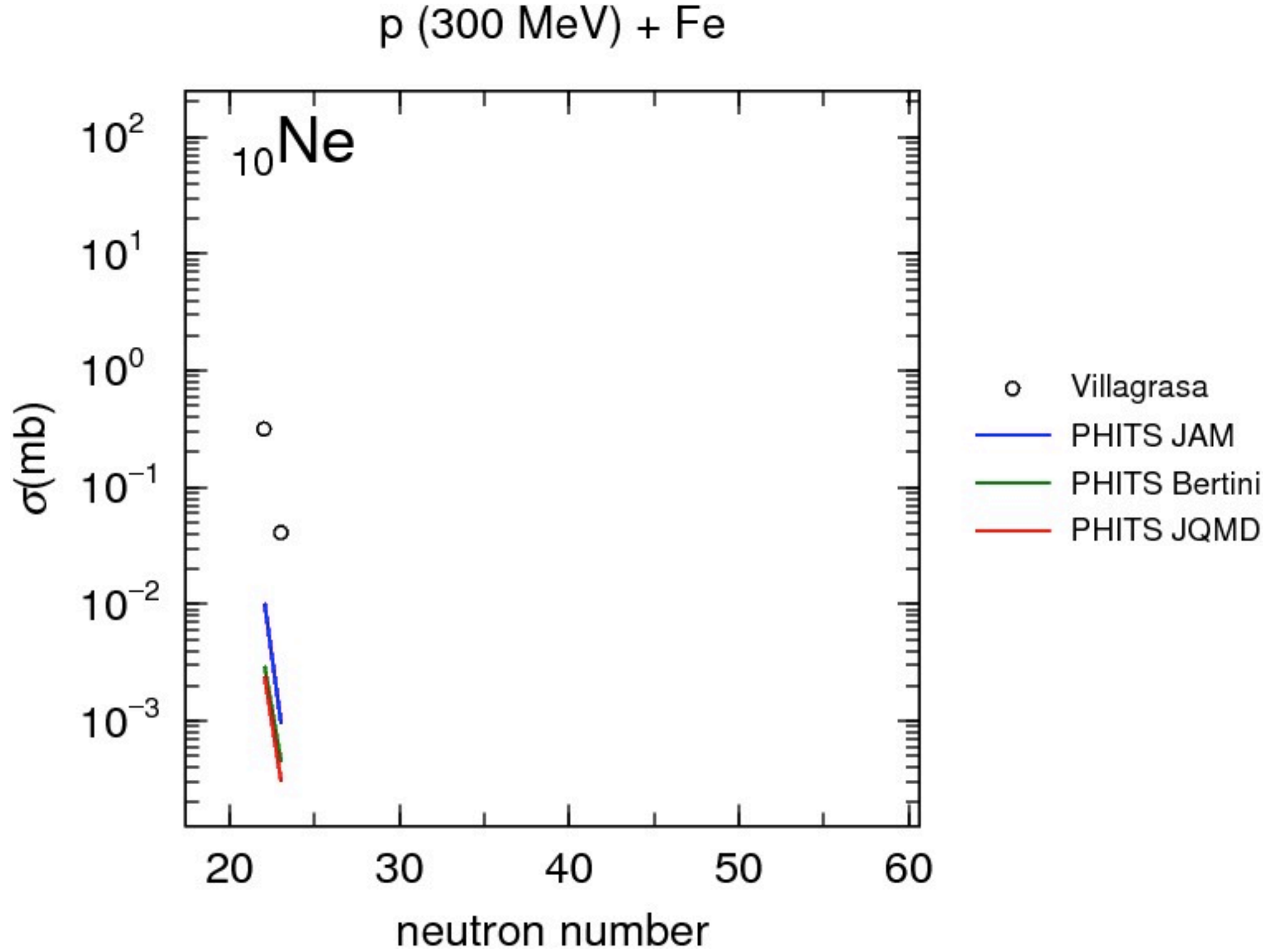


# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{11}\text{Na}$



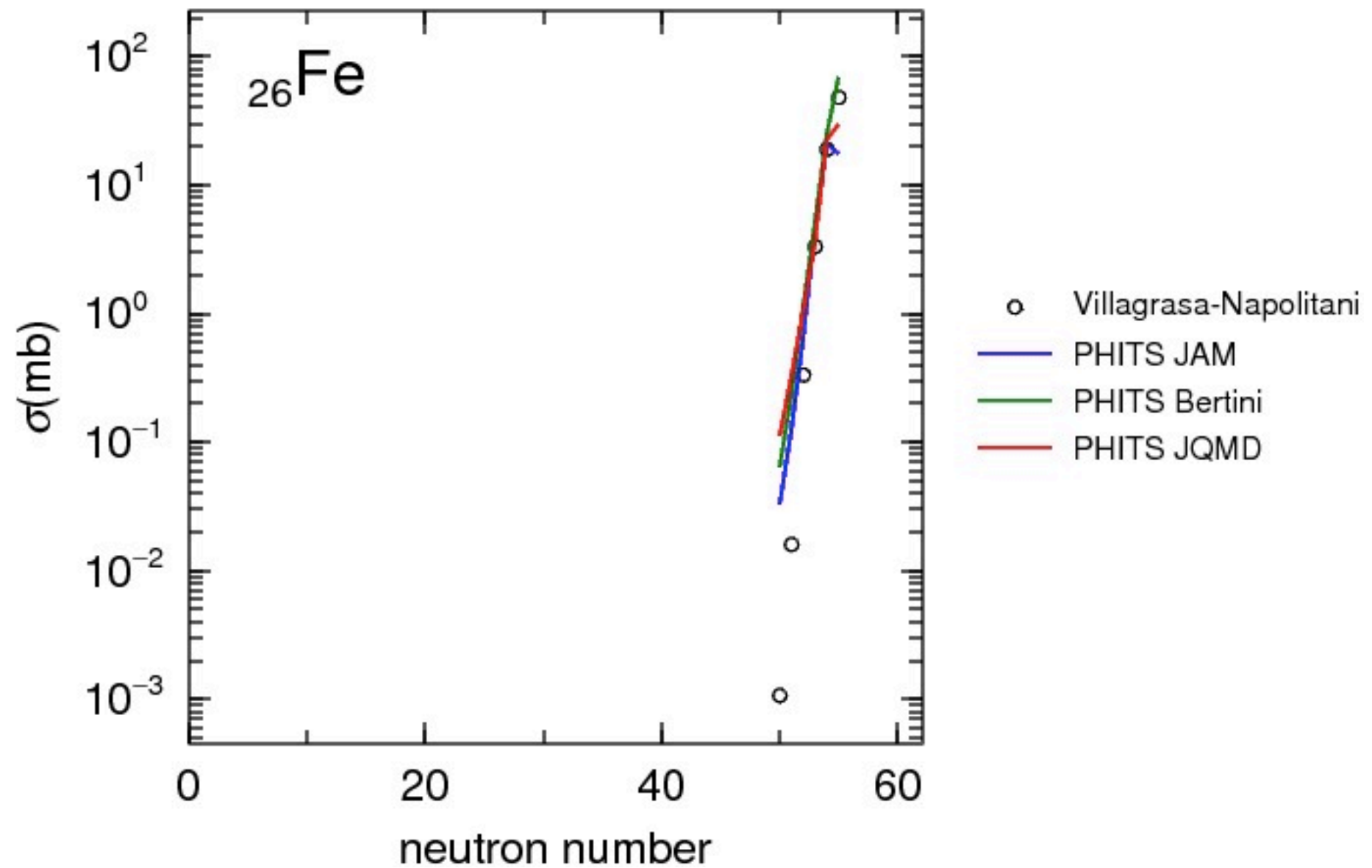


# isotropic distribution: $p$ (300 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{10}\text{Ne}$

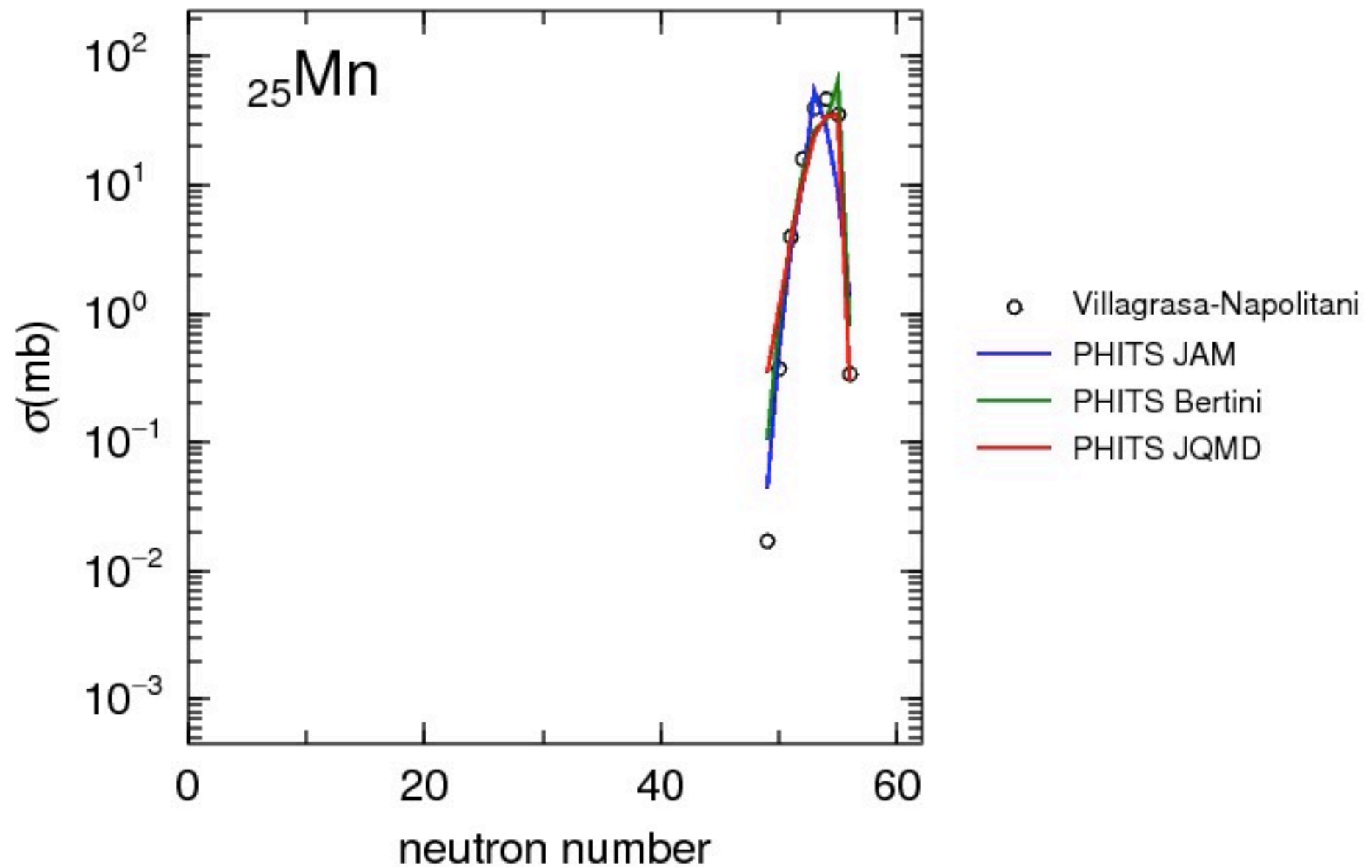




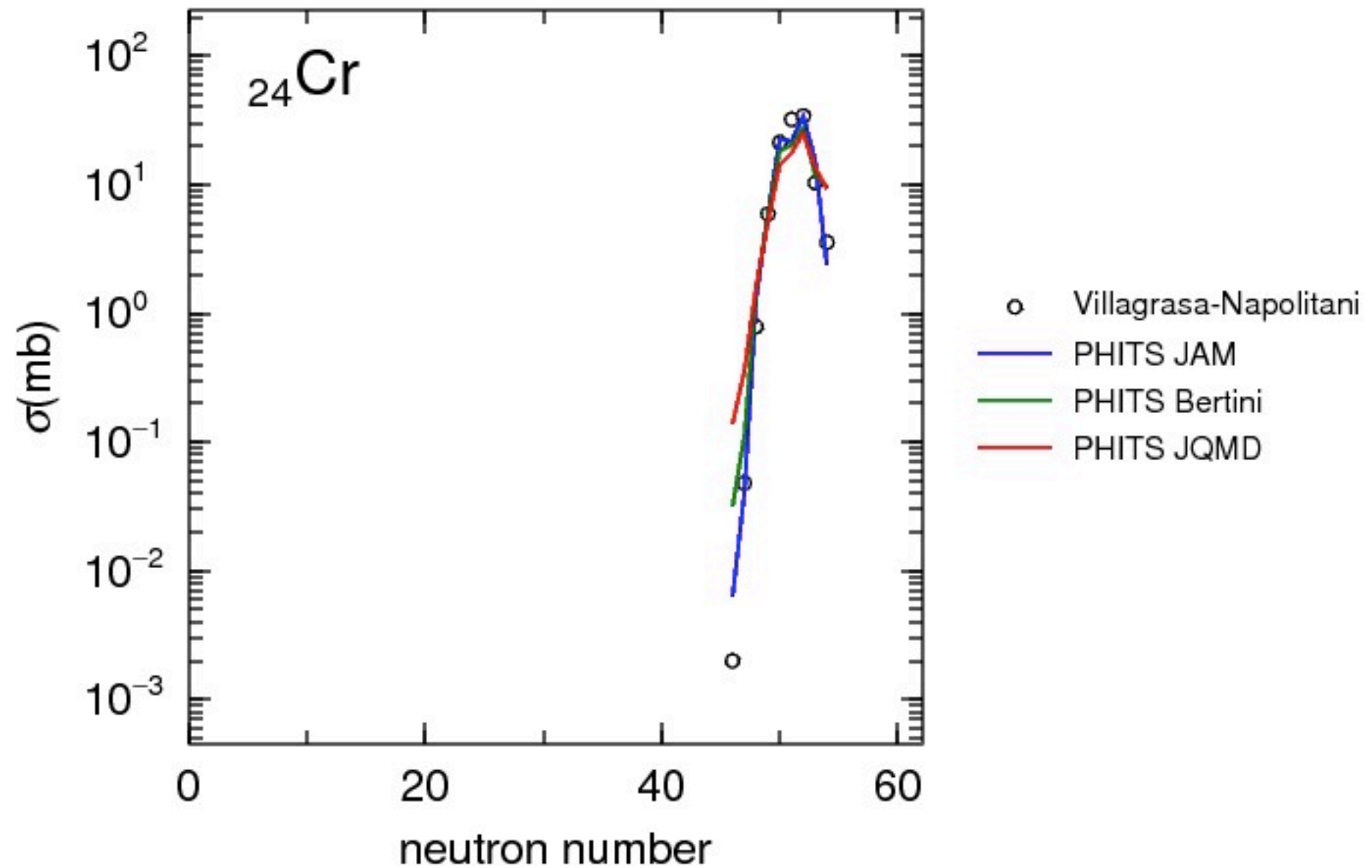
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{26}\text{Fe}$



isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{25}\text{Mn}$

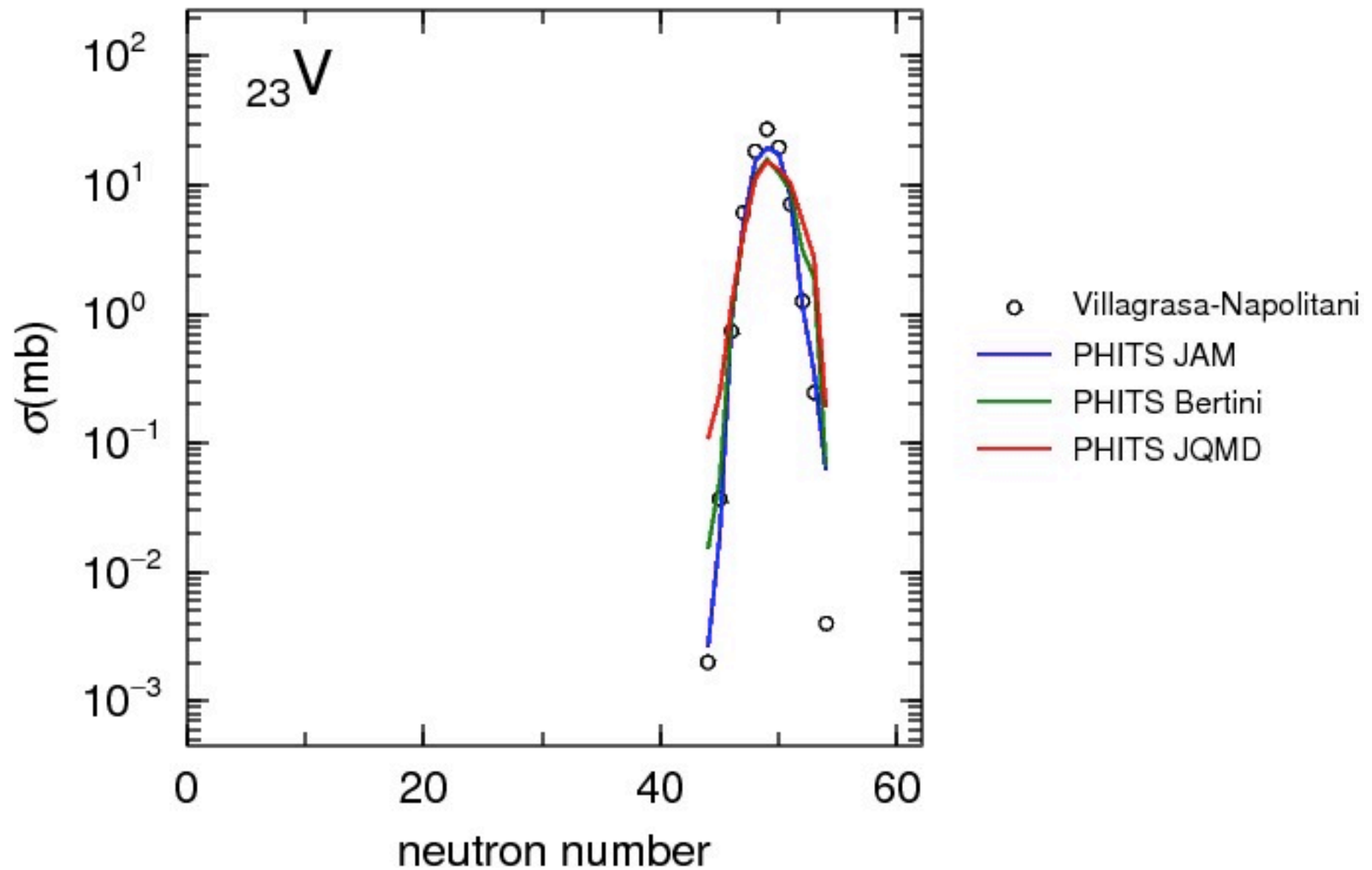


# isotropic distribution: $p$ (1000 MeV) + ${}_{26}^{56}\text{Fe} \rightarrow {}_{24}\text{Cr}$

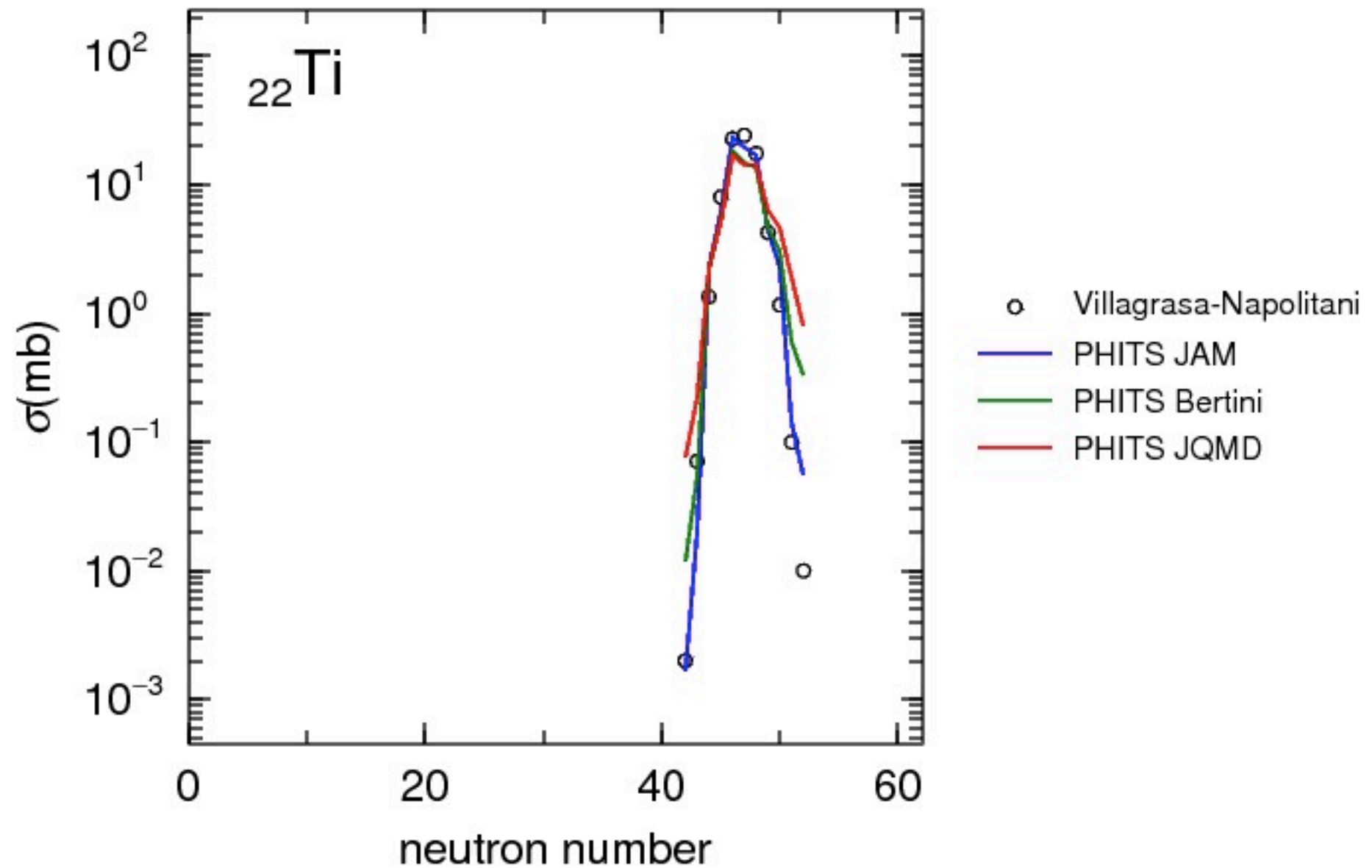




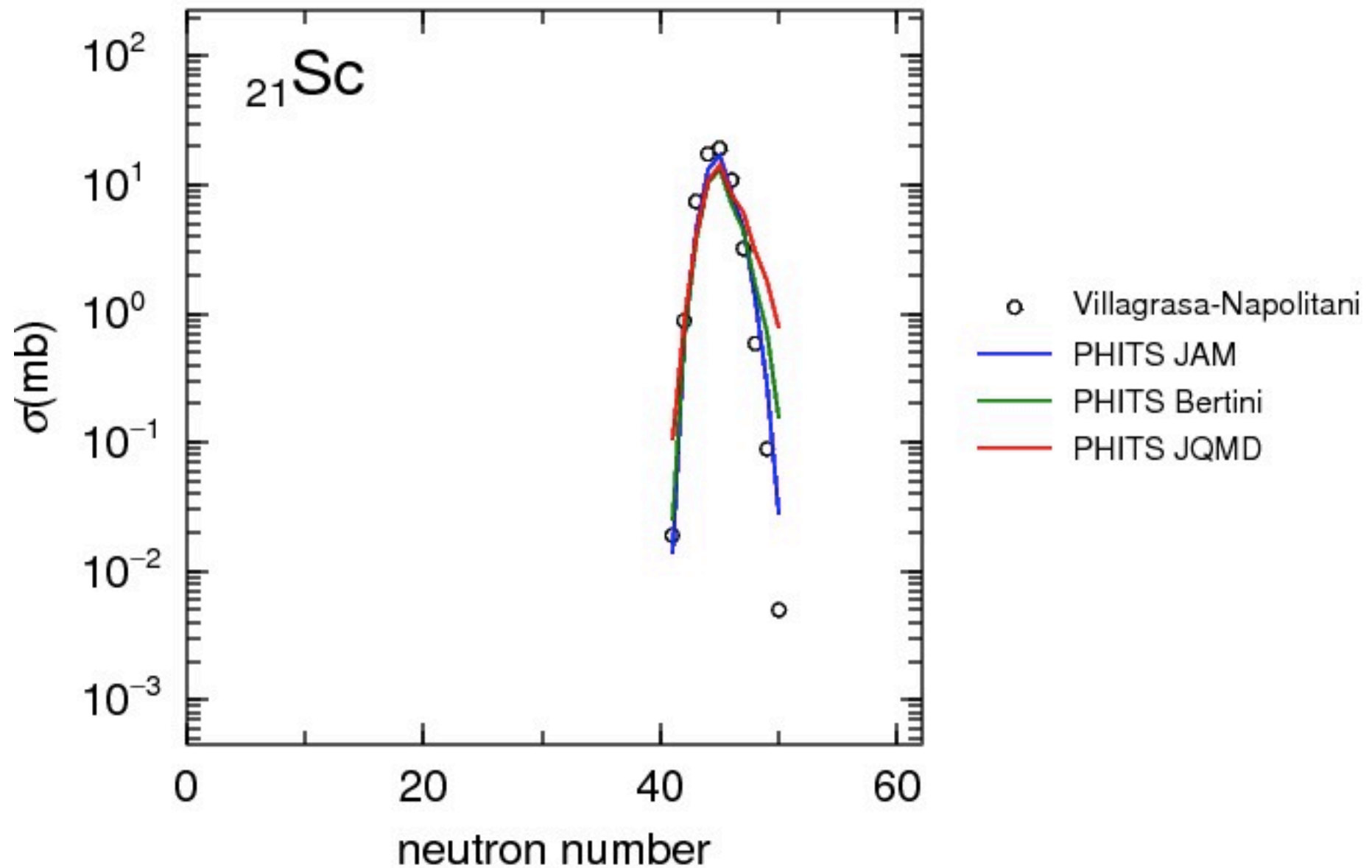
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{23}\text{V}$



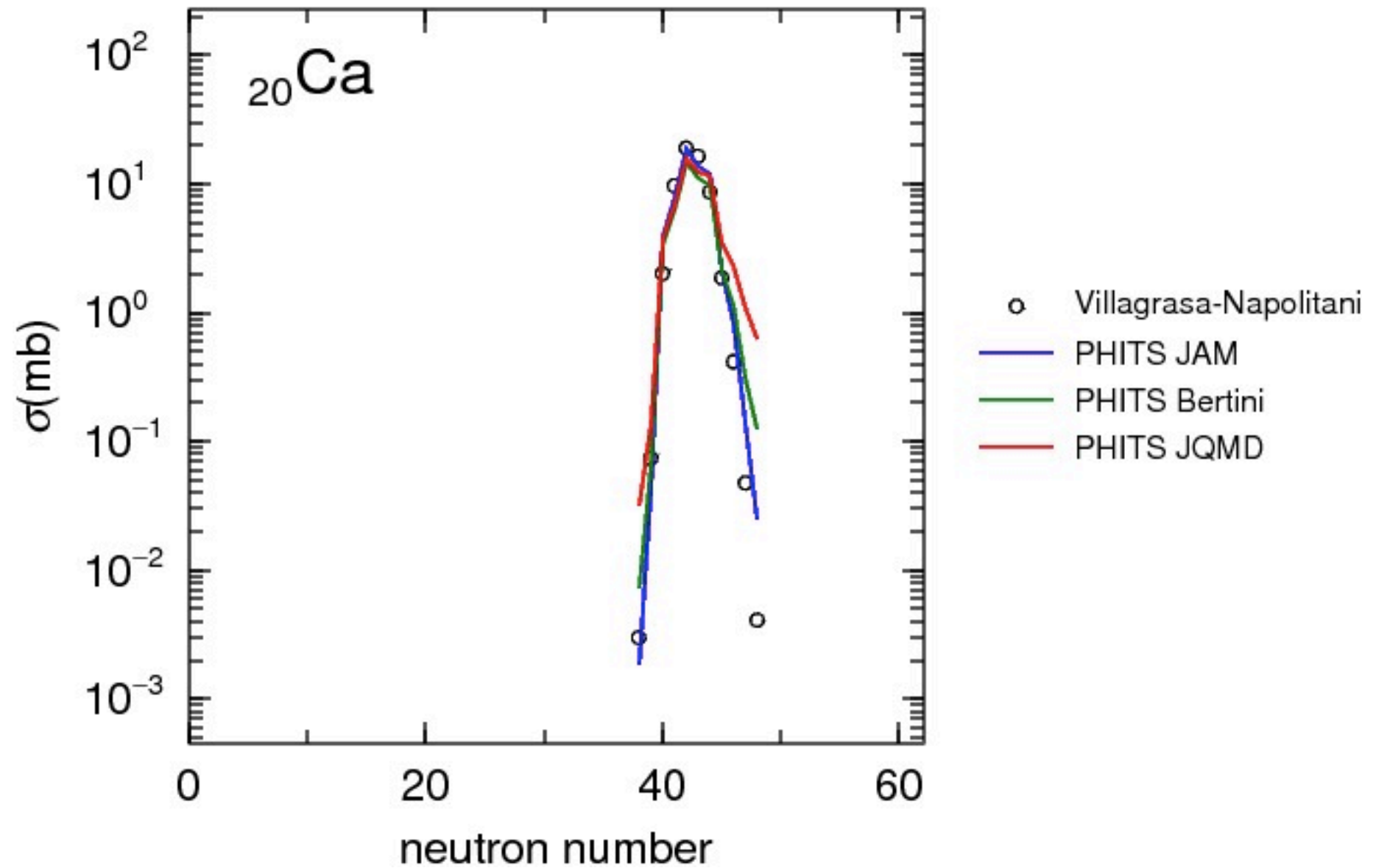
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{22}\text{Ti}$



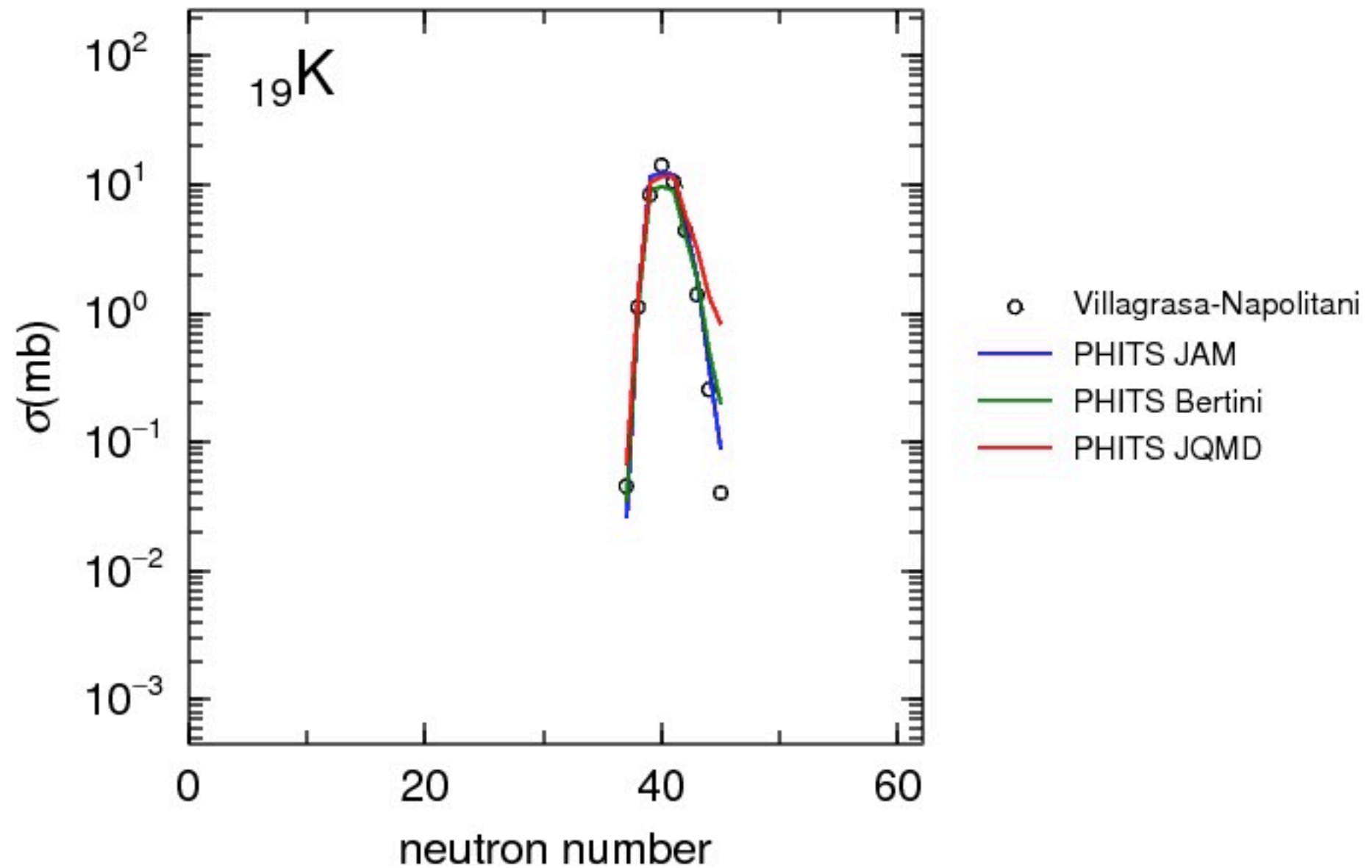
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{21}\text{Sc}$



isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{20}\text{Ca}$

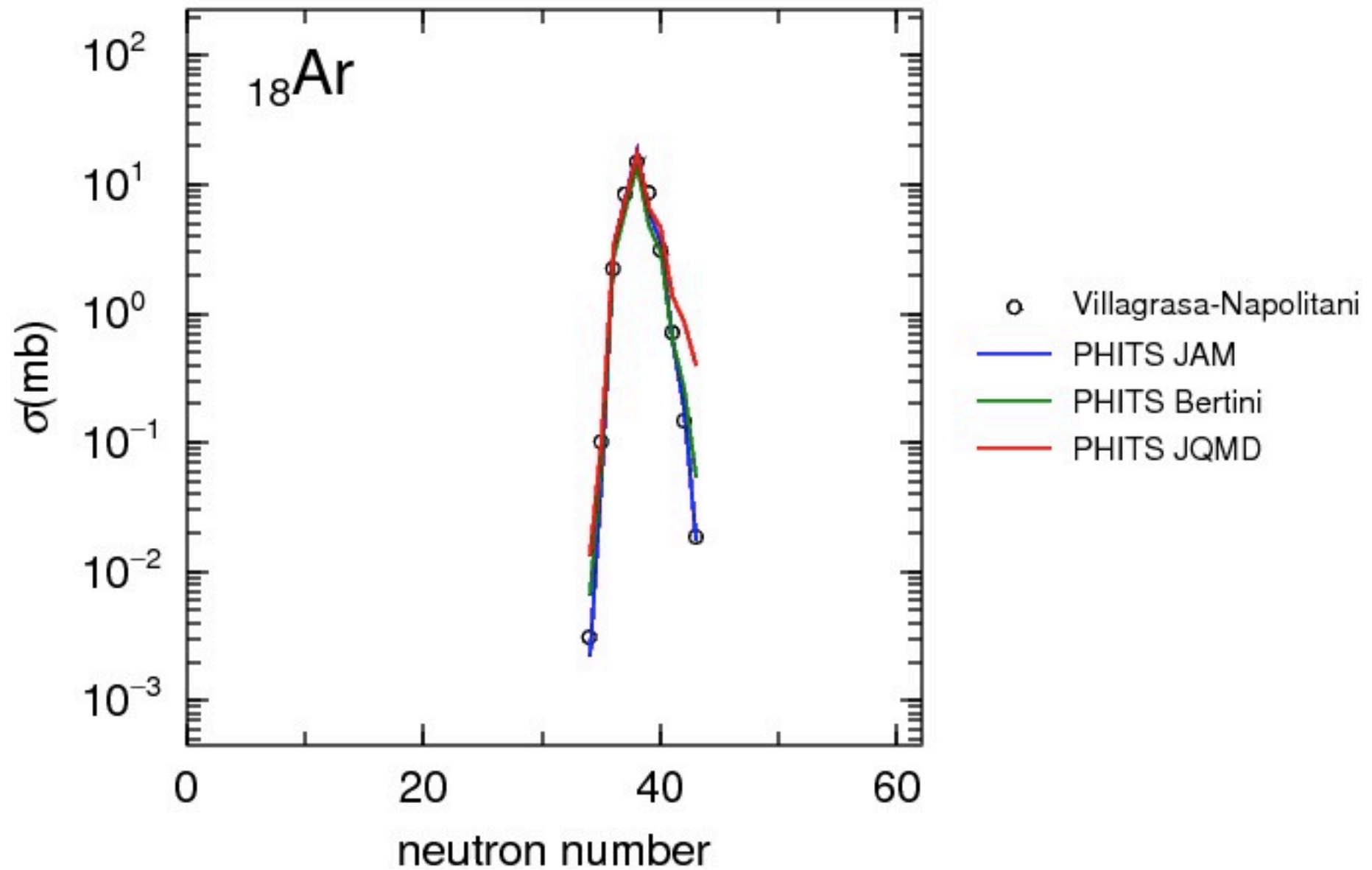


isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{19}\text{K}$

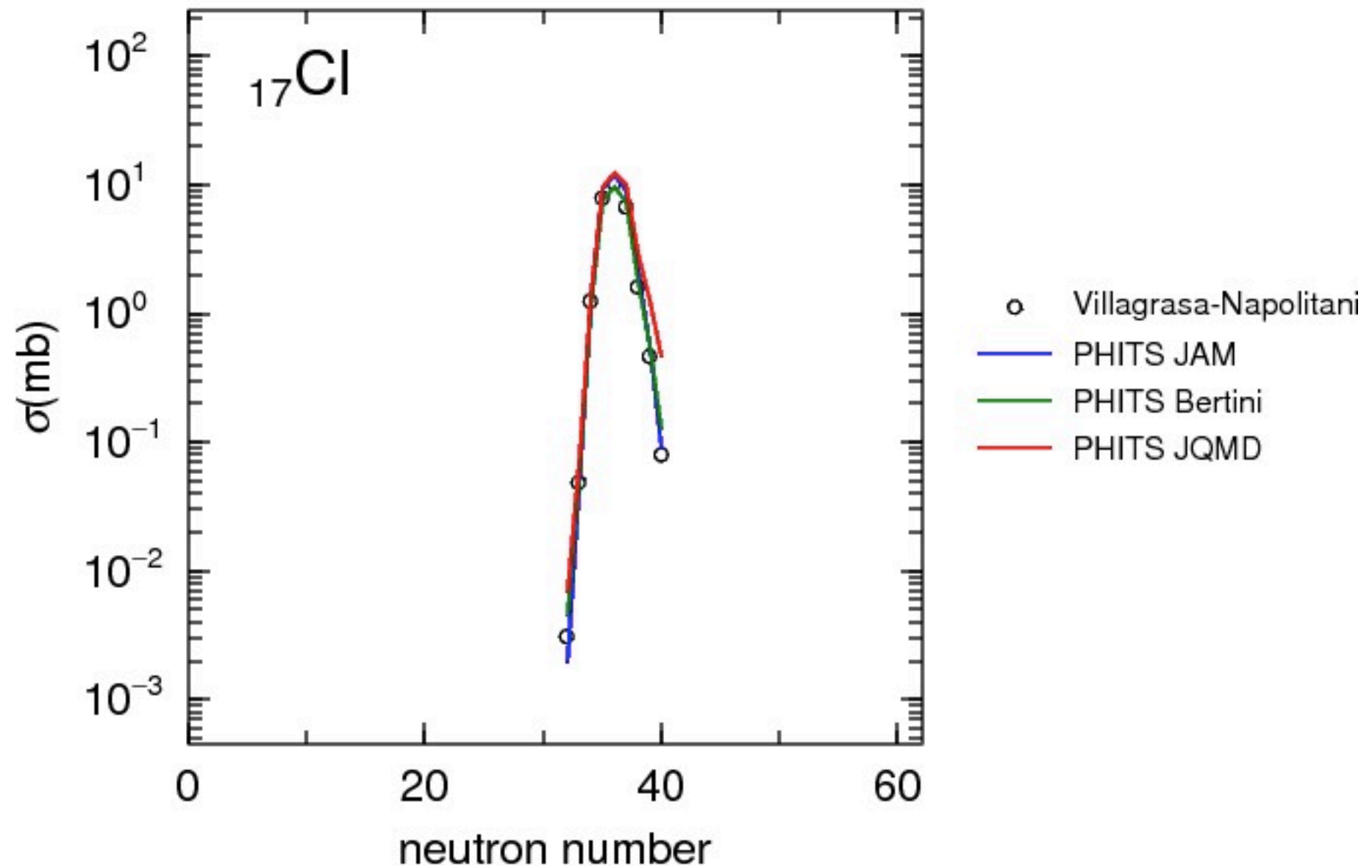




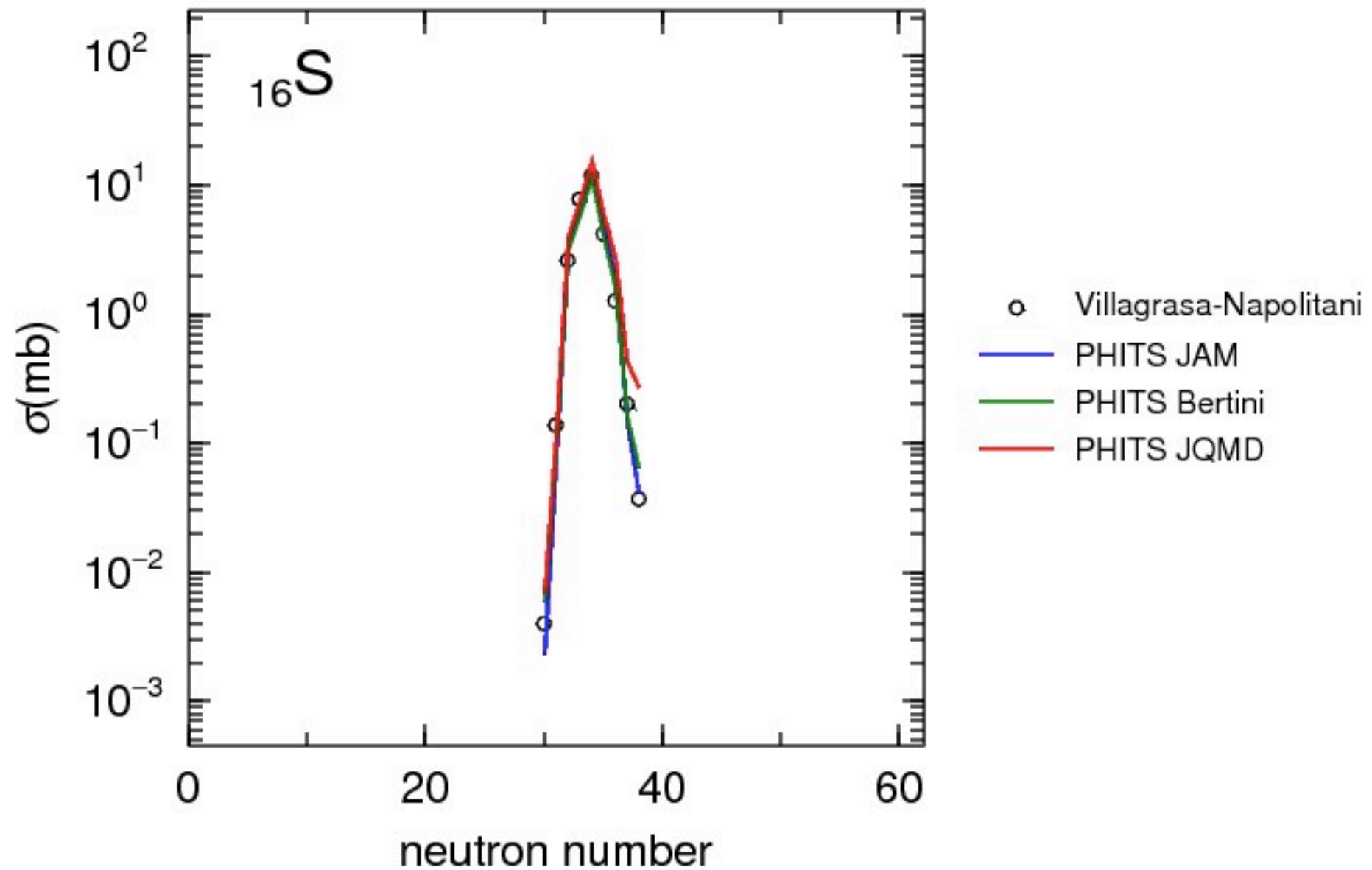
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{18}\text{Ar}$



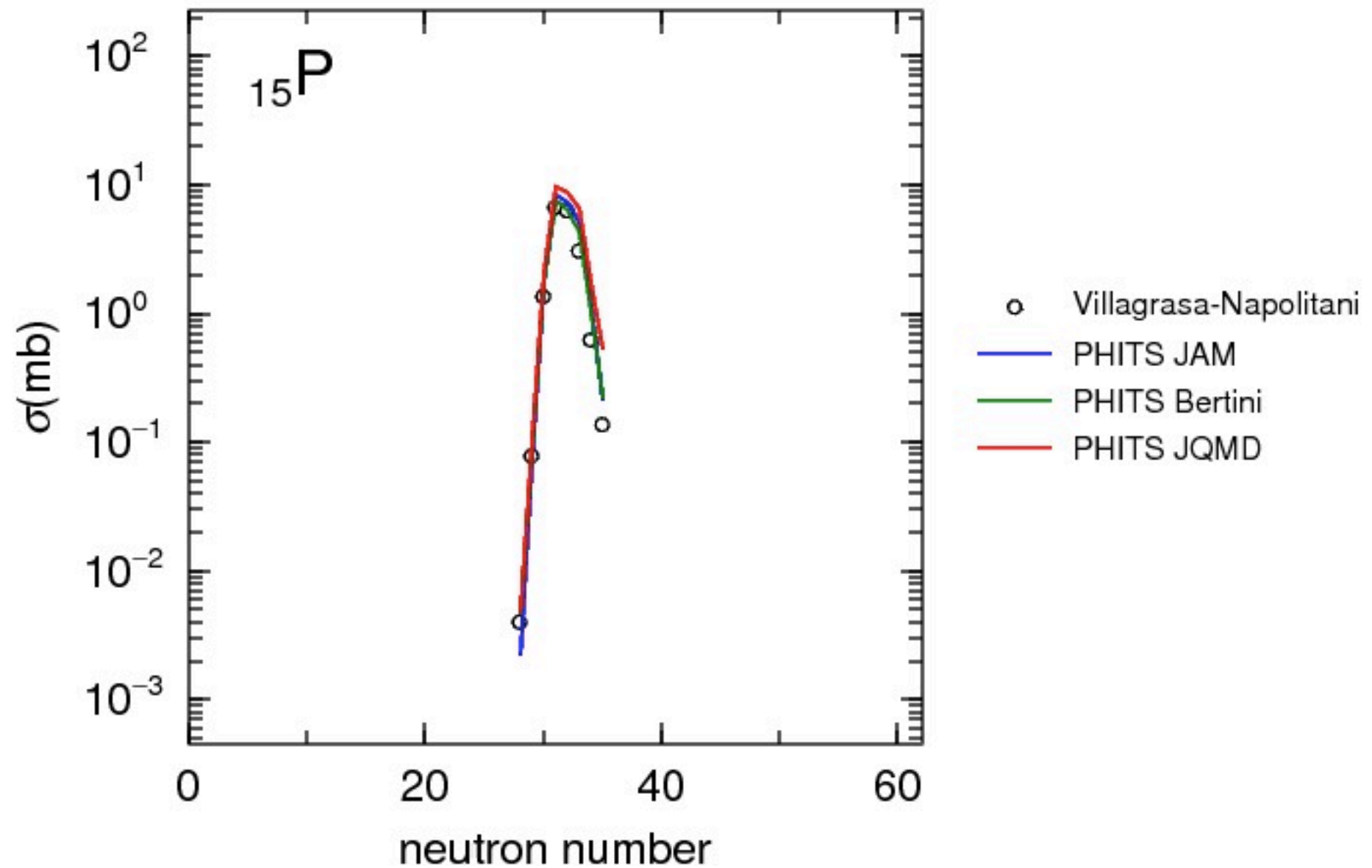
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{17}\text{Cl}$



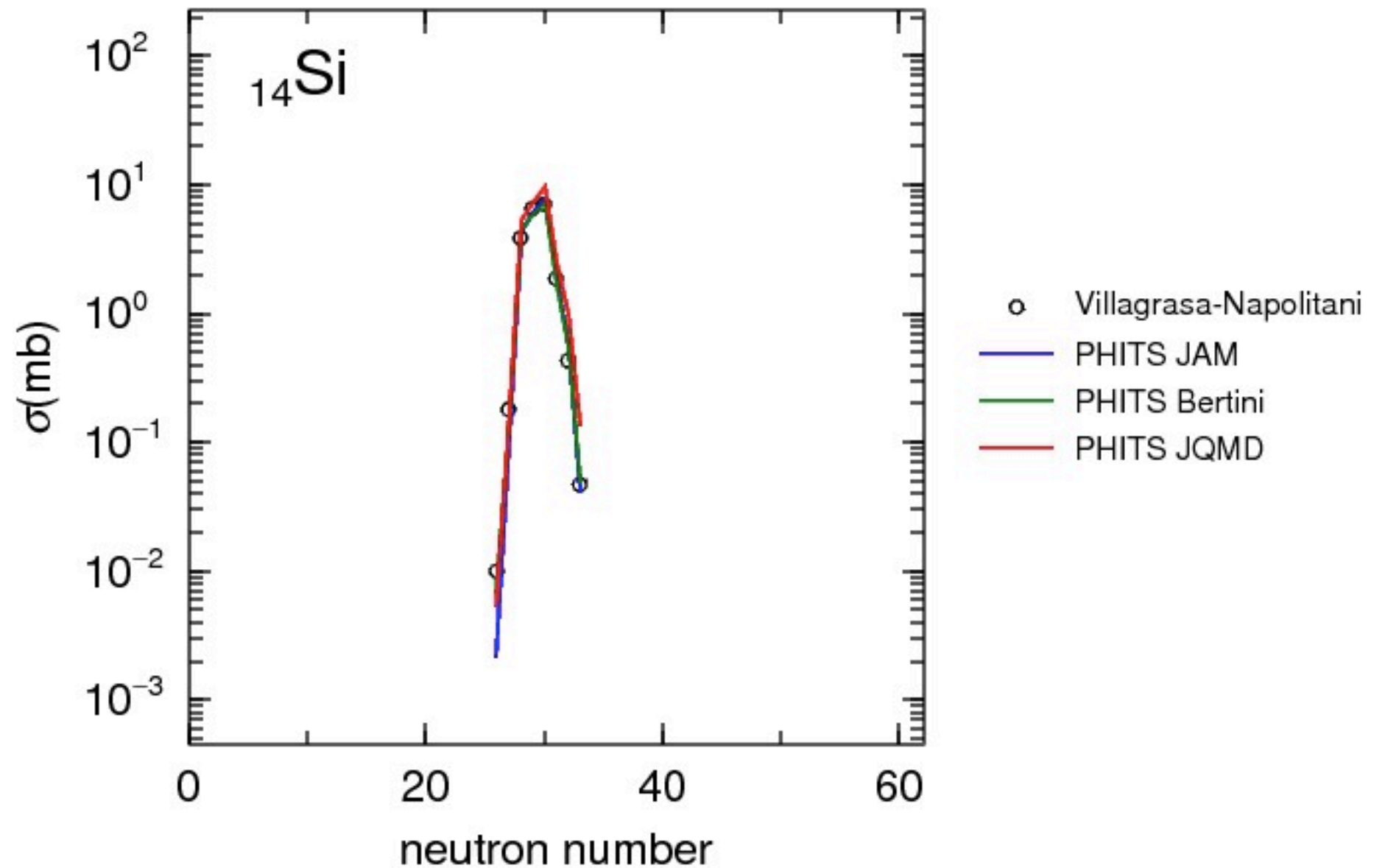
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{16}\text{S}$



isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{15}\text{P}$

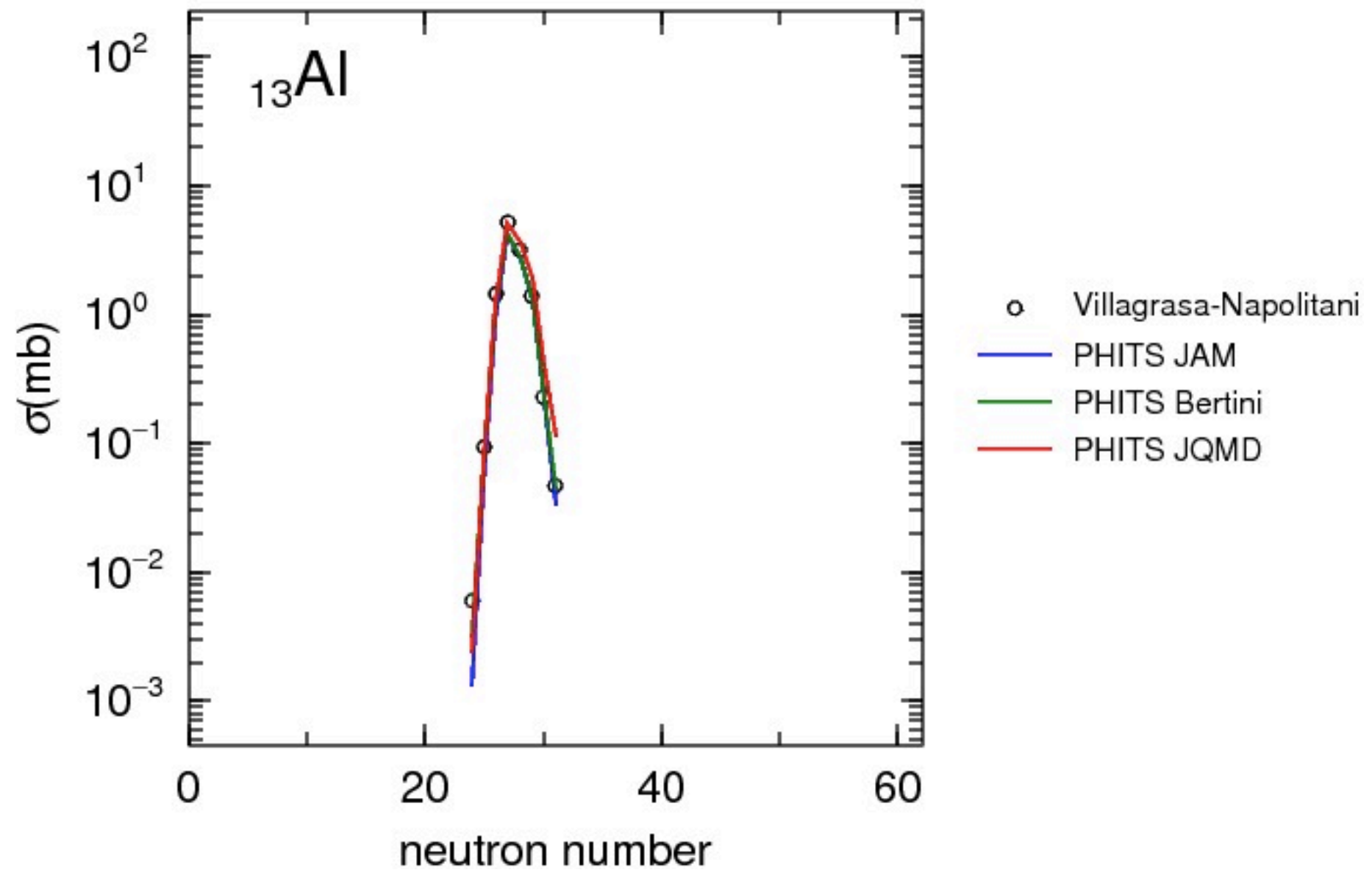


isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{14}\text{Si}$

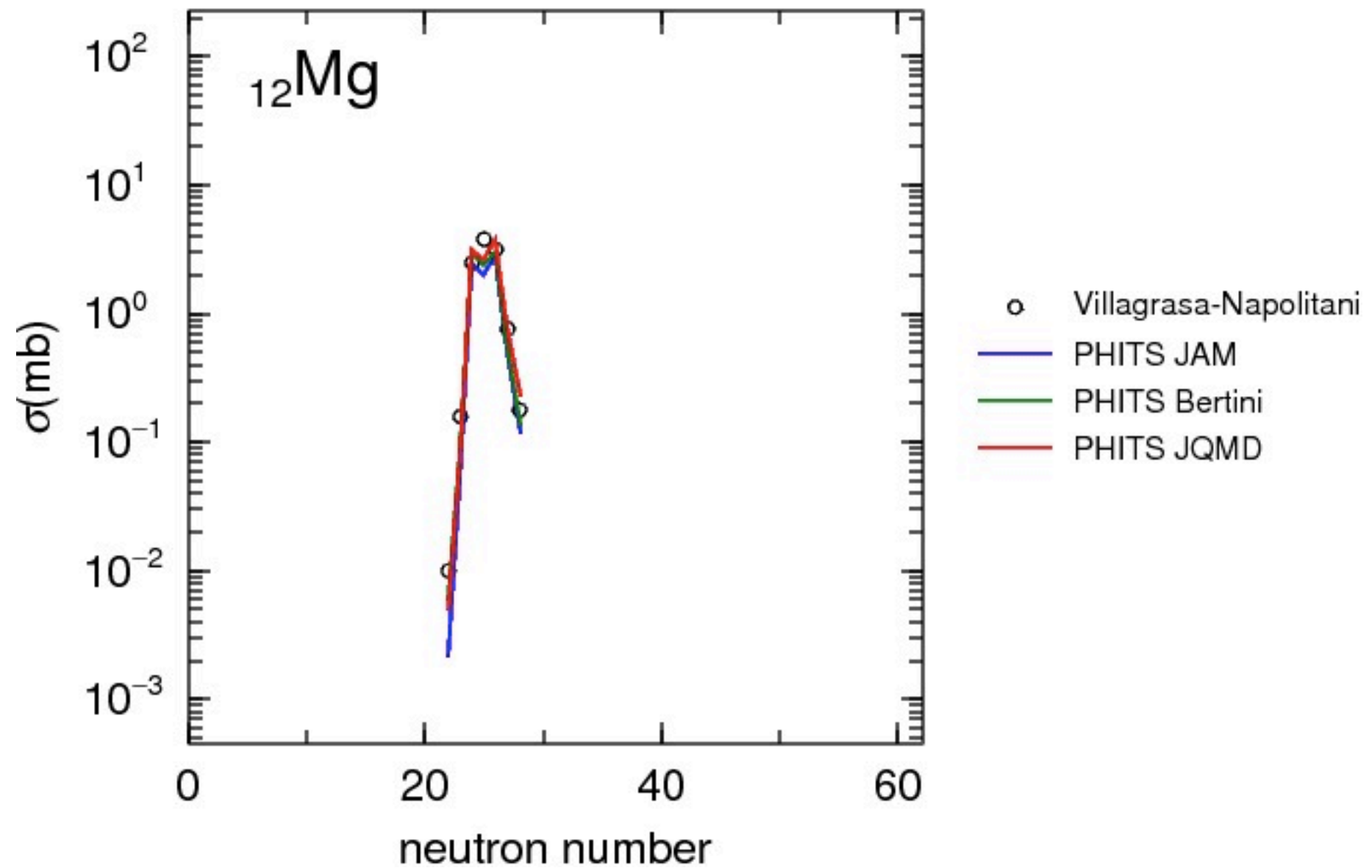




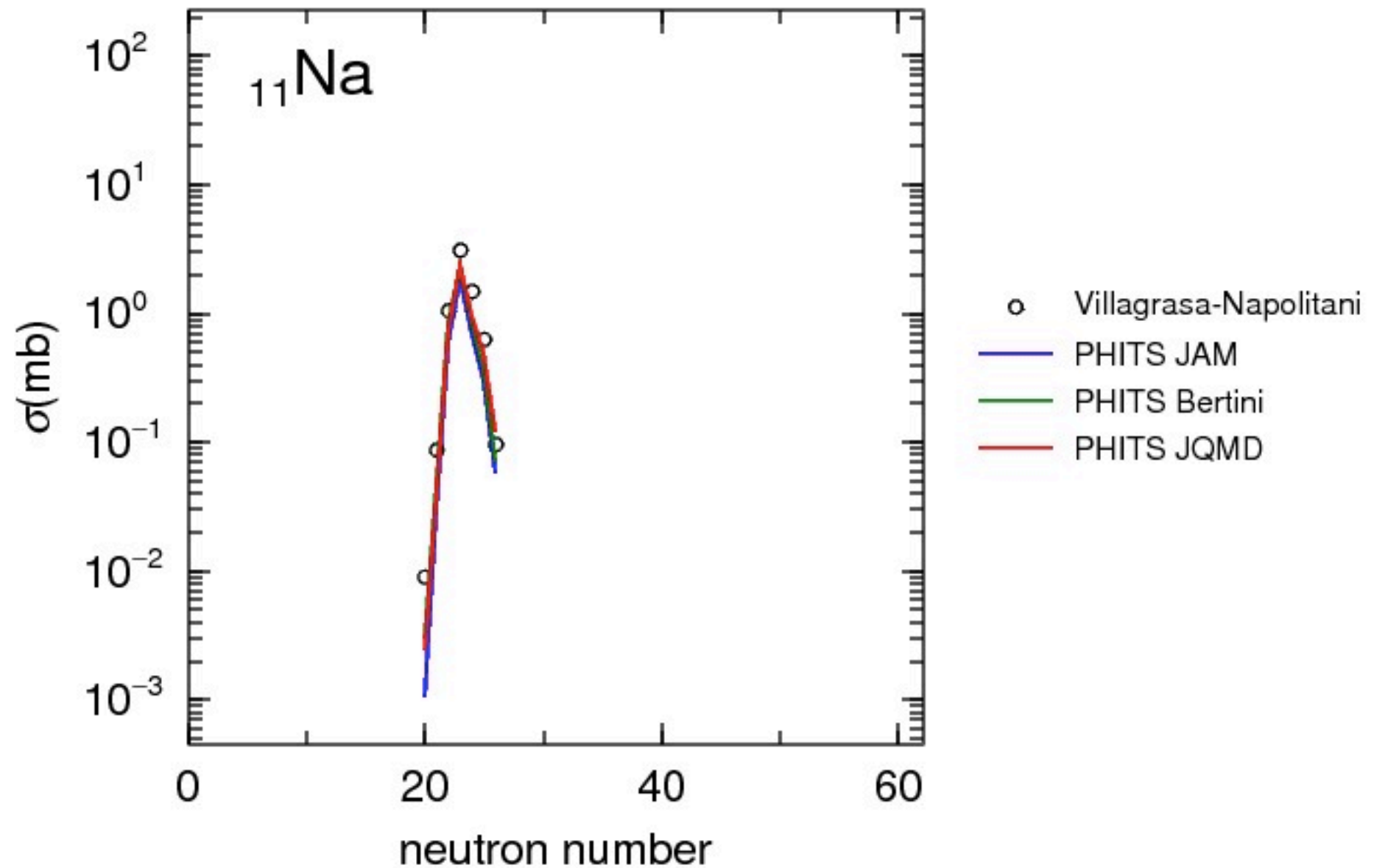
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{13}\text{Al}$



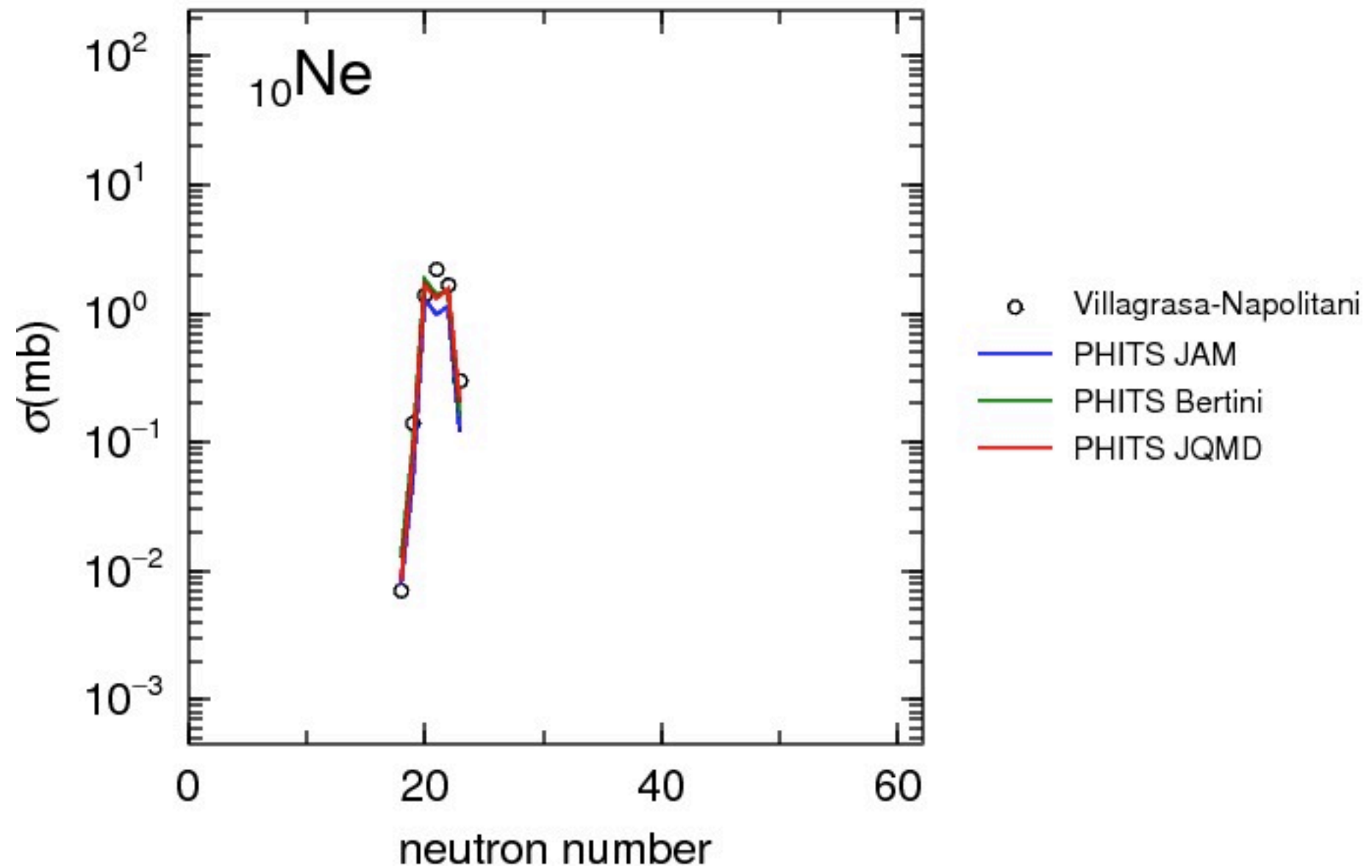
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{12}\text{Mg}$



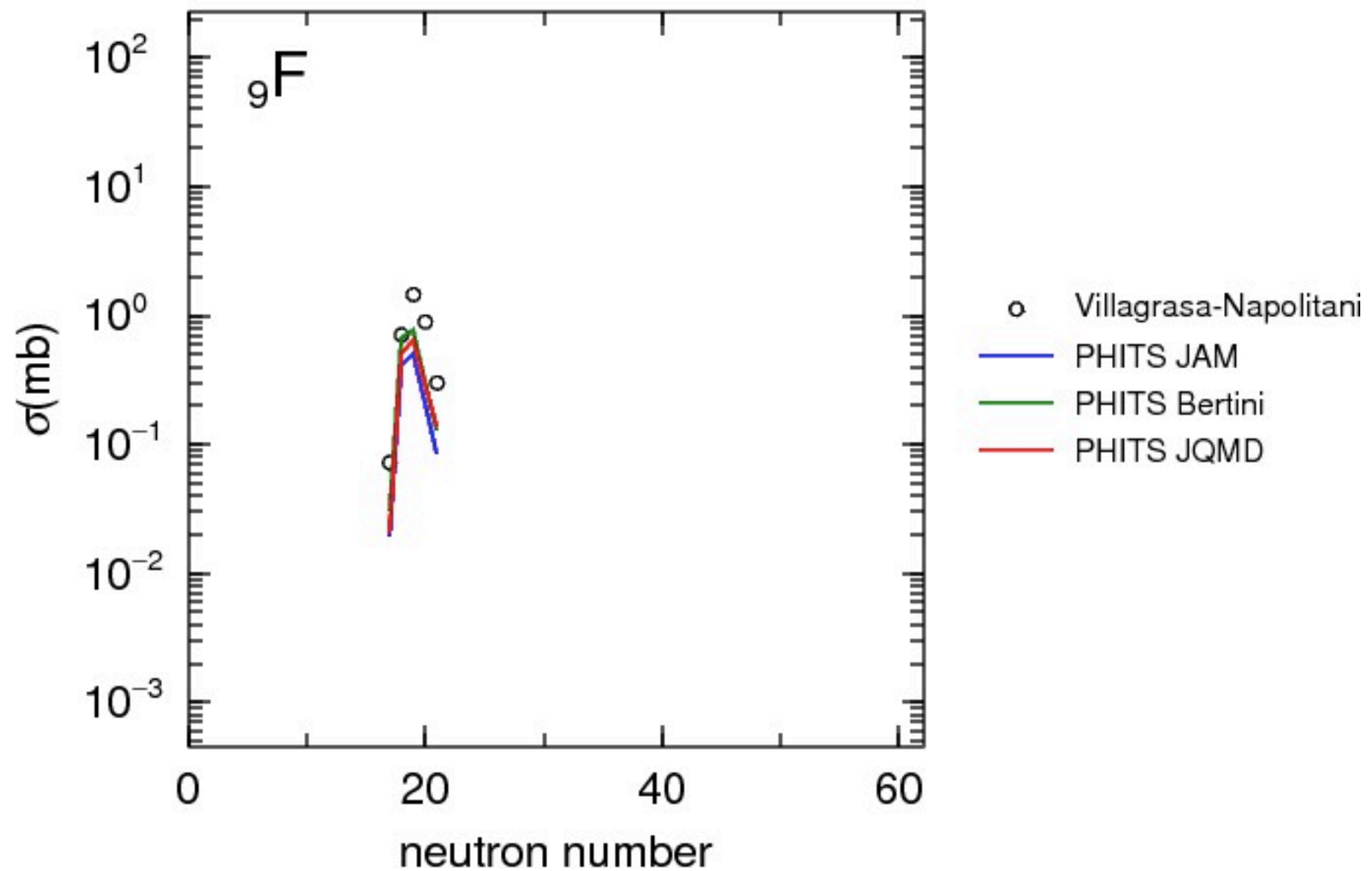
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{11}\text{Na}$



isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_{10}\text{Ne}$

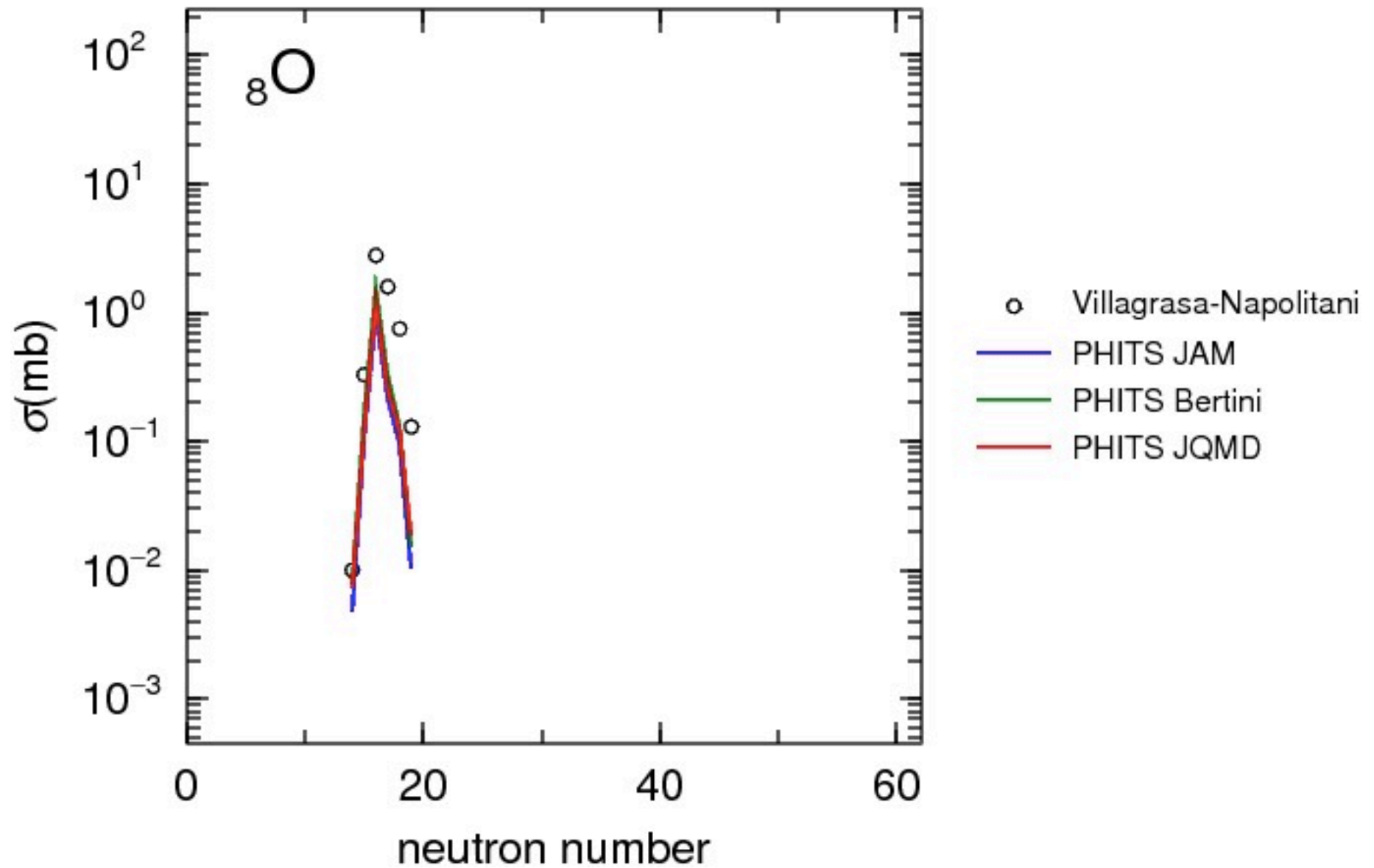


isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_9\text{F}$

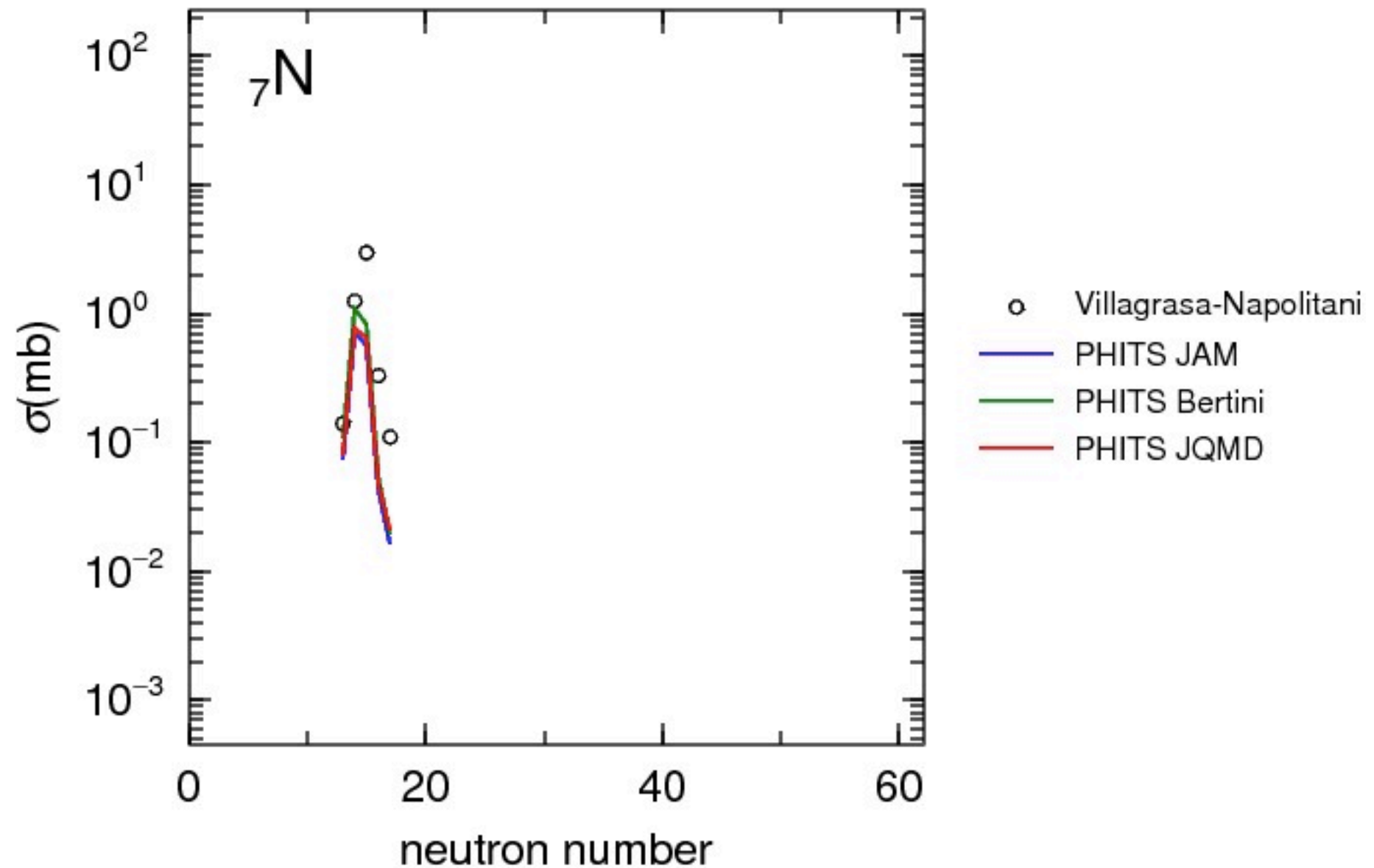




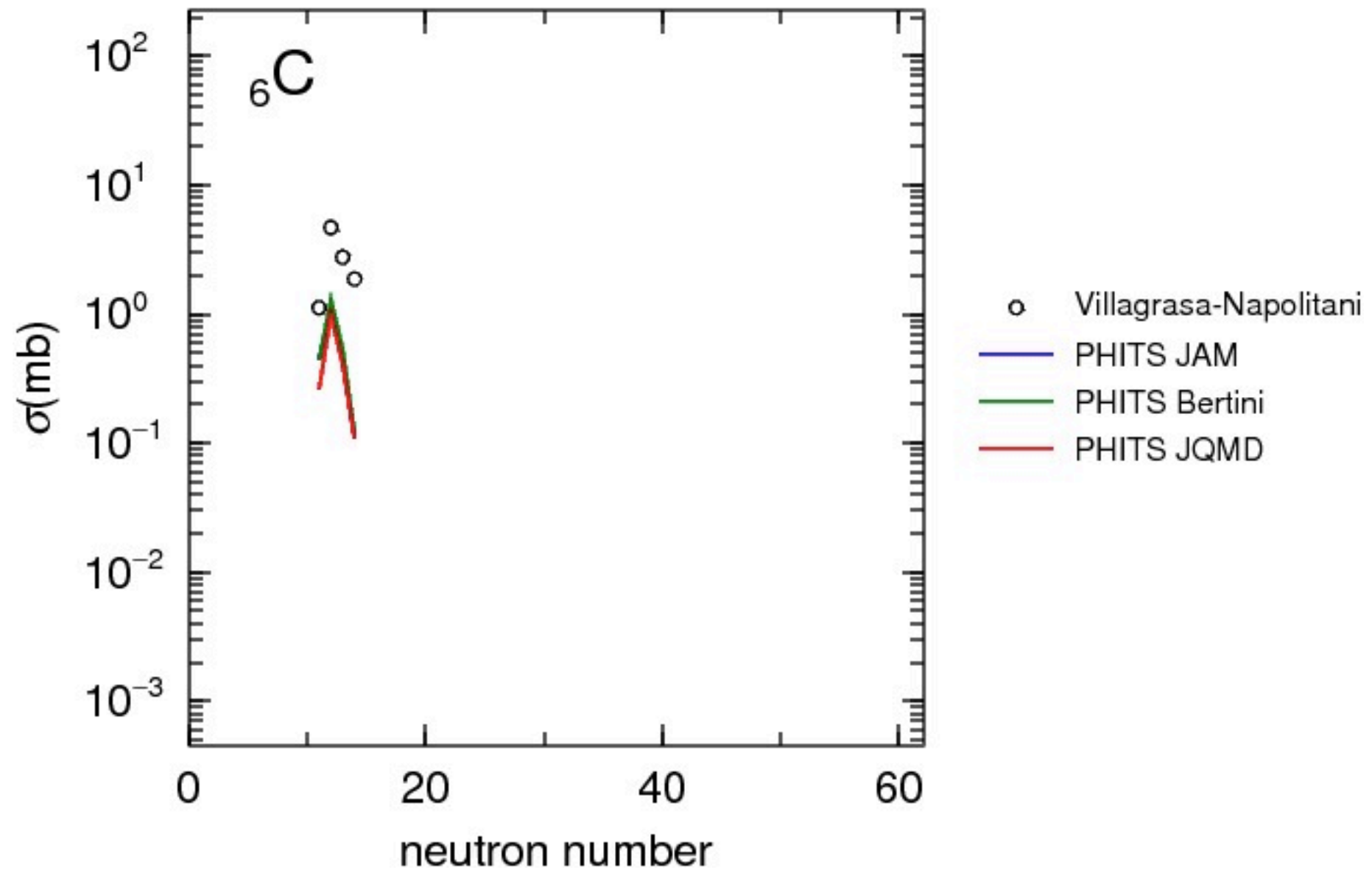
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_8\text{O}$



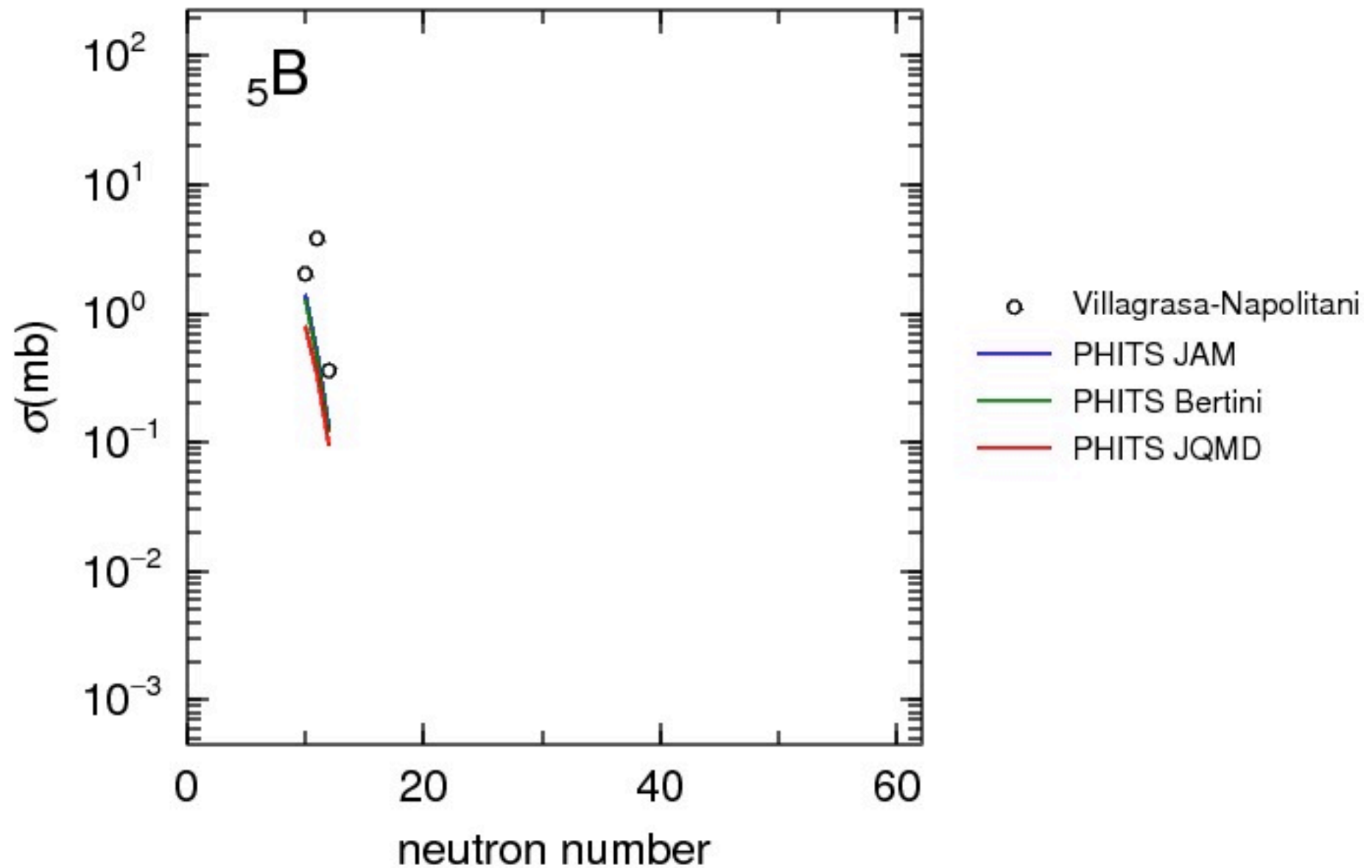
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_7\text{N}$



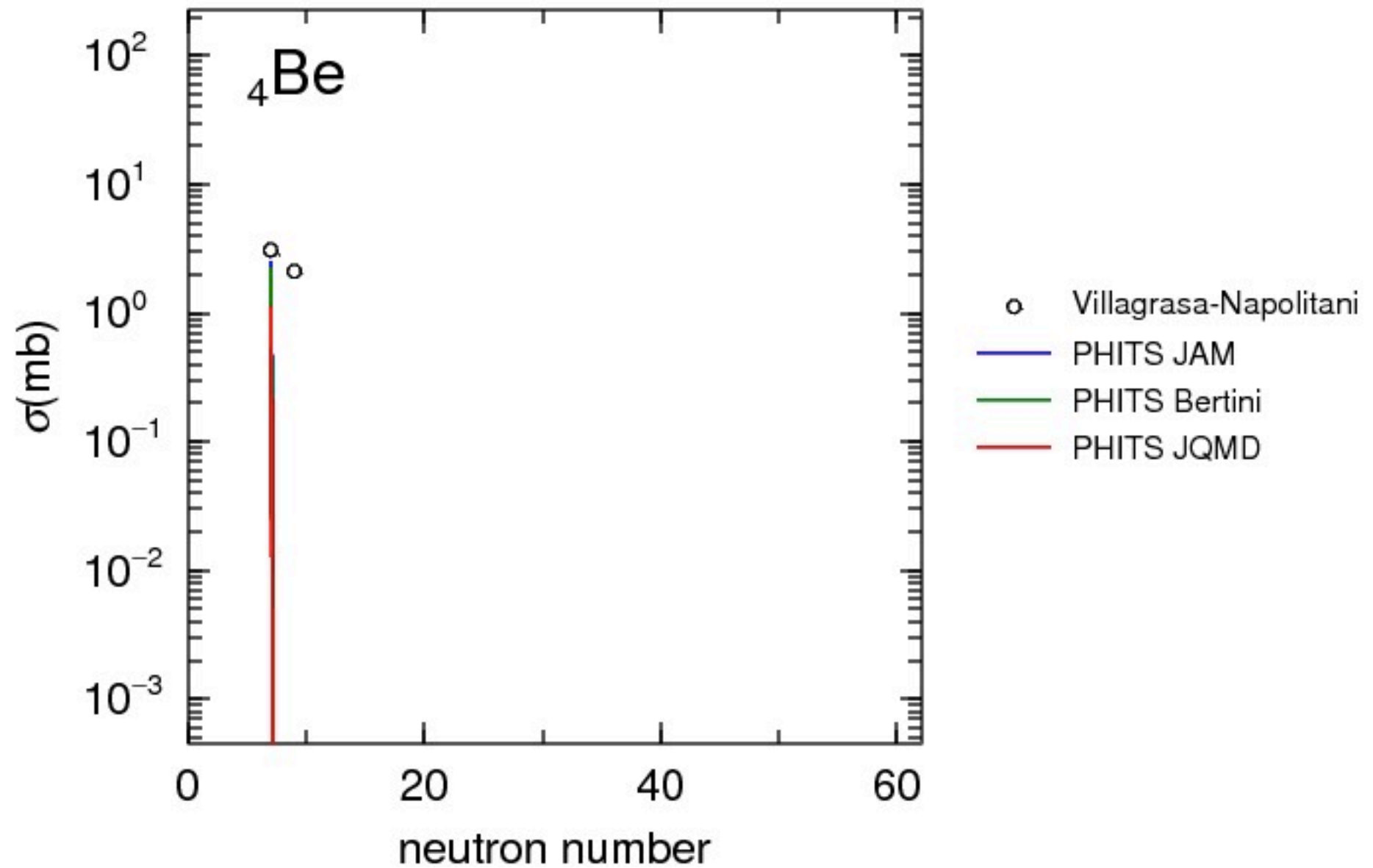
isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_6\text{C}$



isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_5\text{B}$

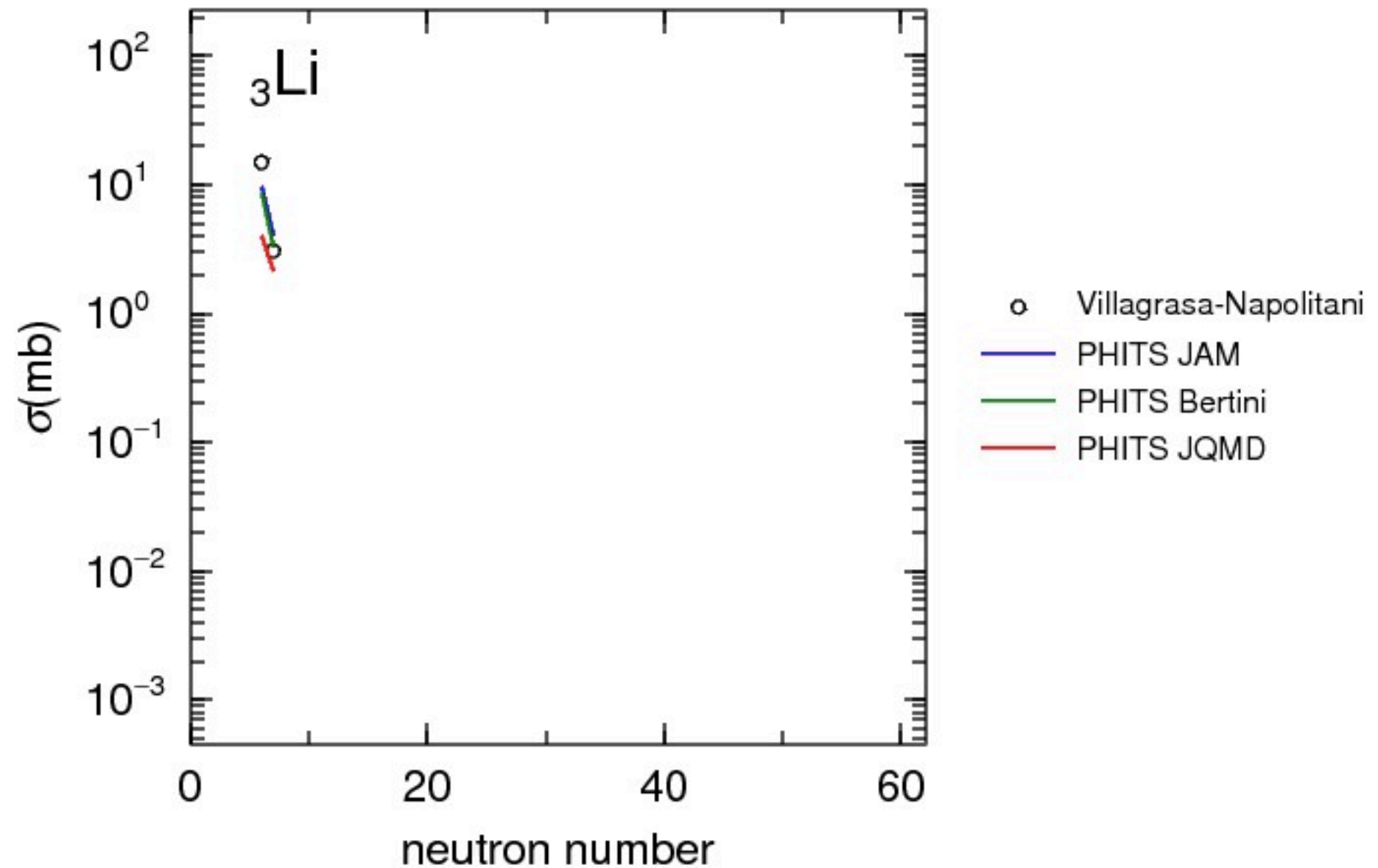


isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_4\text{Be}$



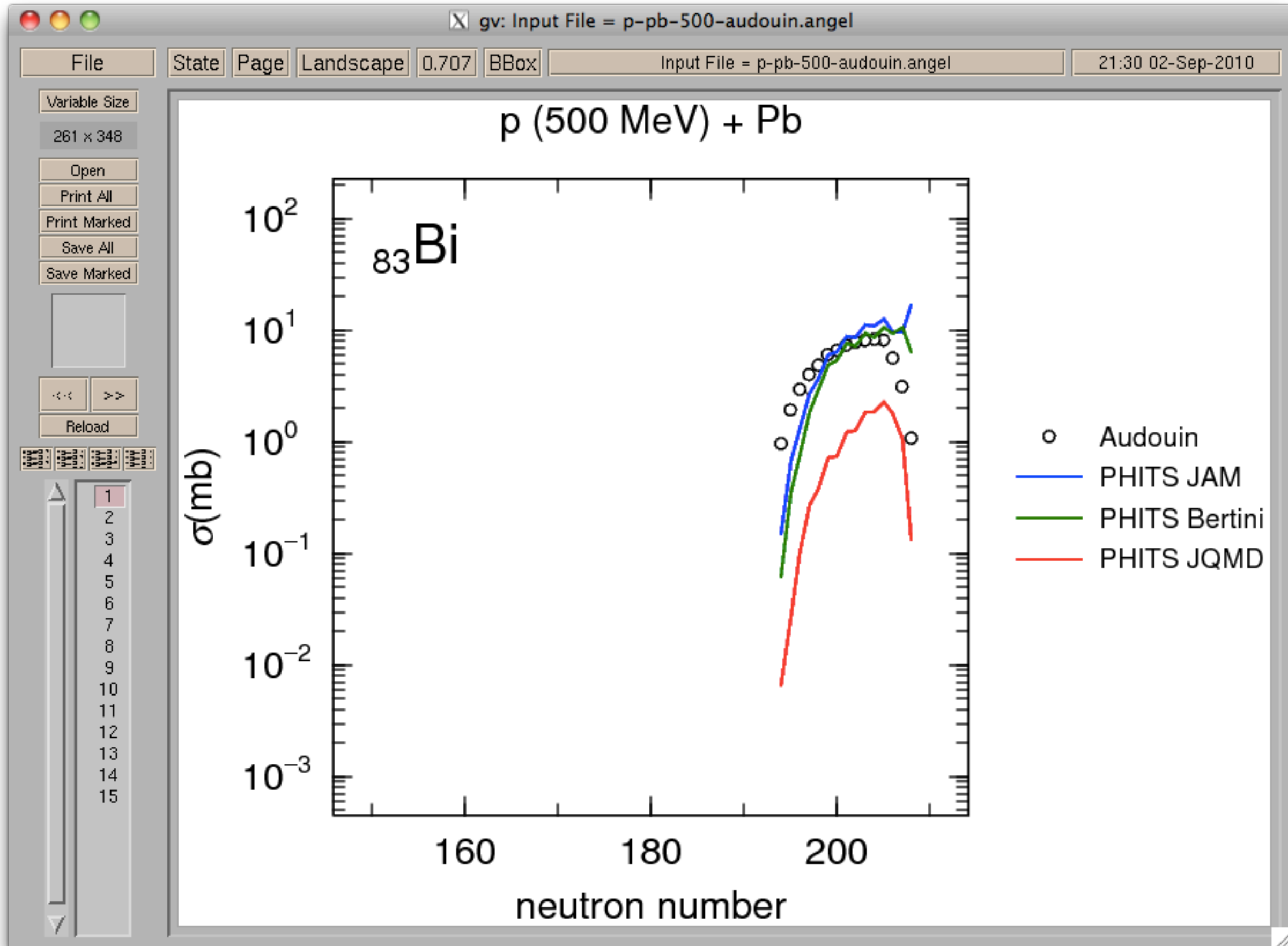


isotropic distribution:  $p$  (1000 MeV) +  ${}_{26}^{56}\text{Fe} \rightarrow {}_3\text{Li}$

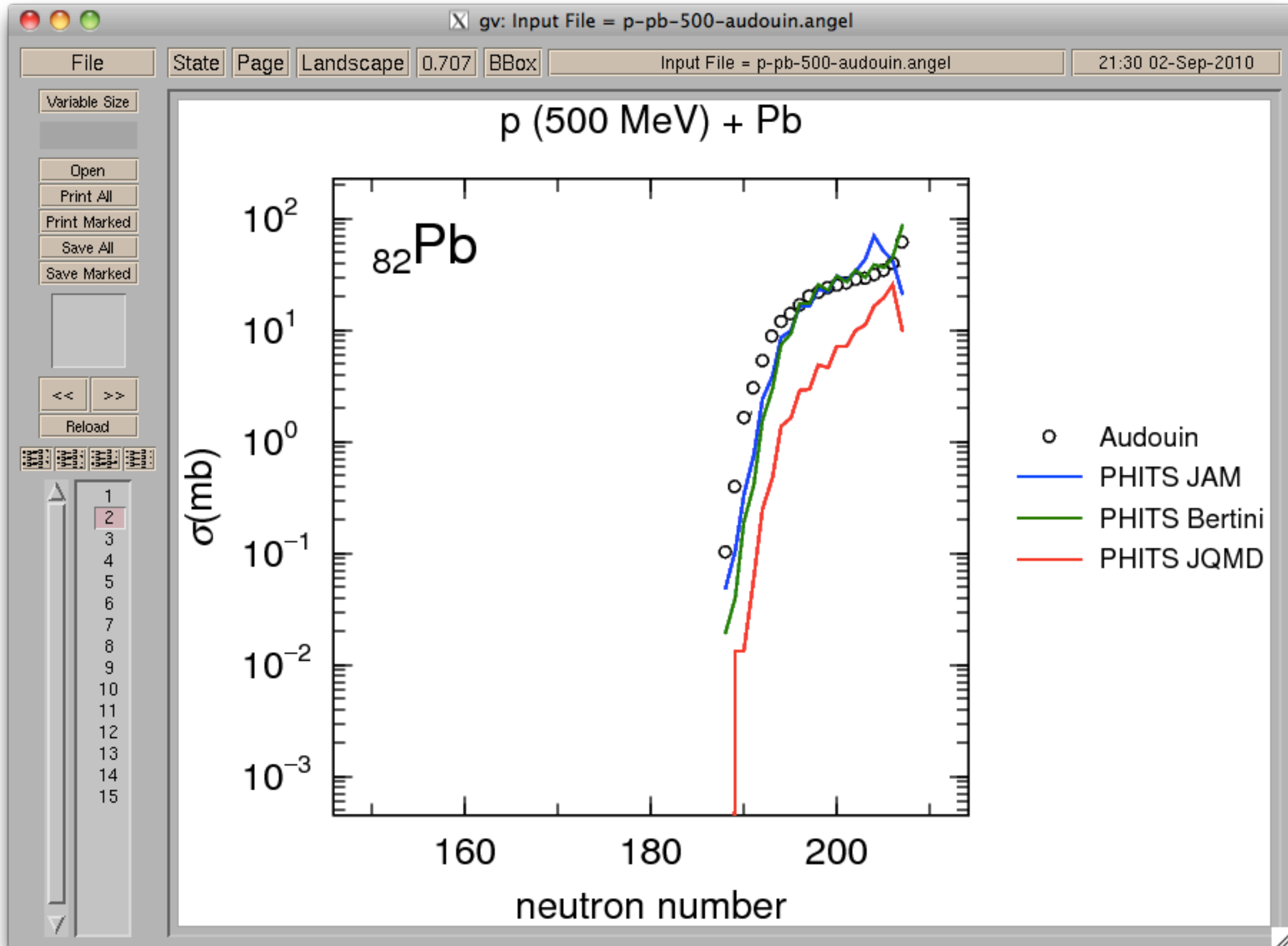




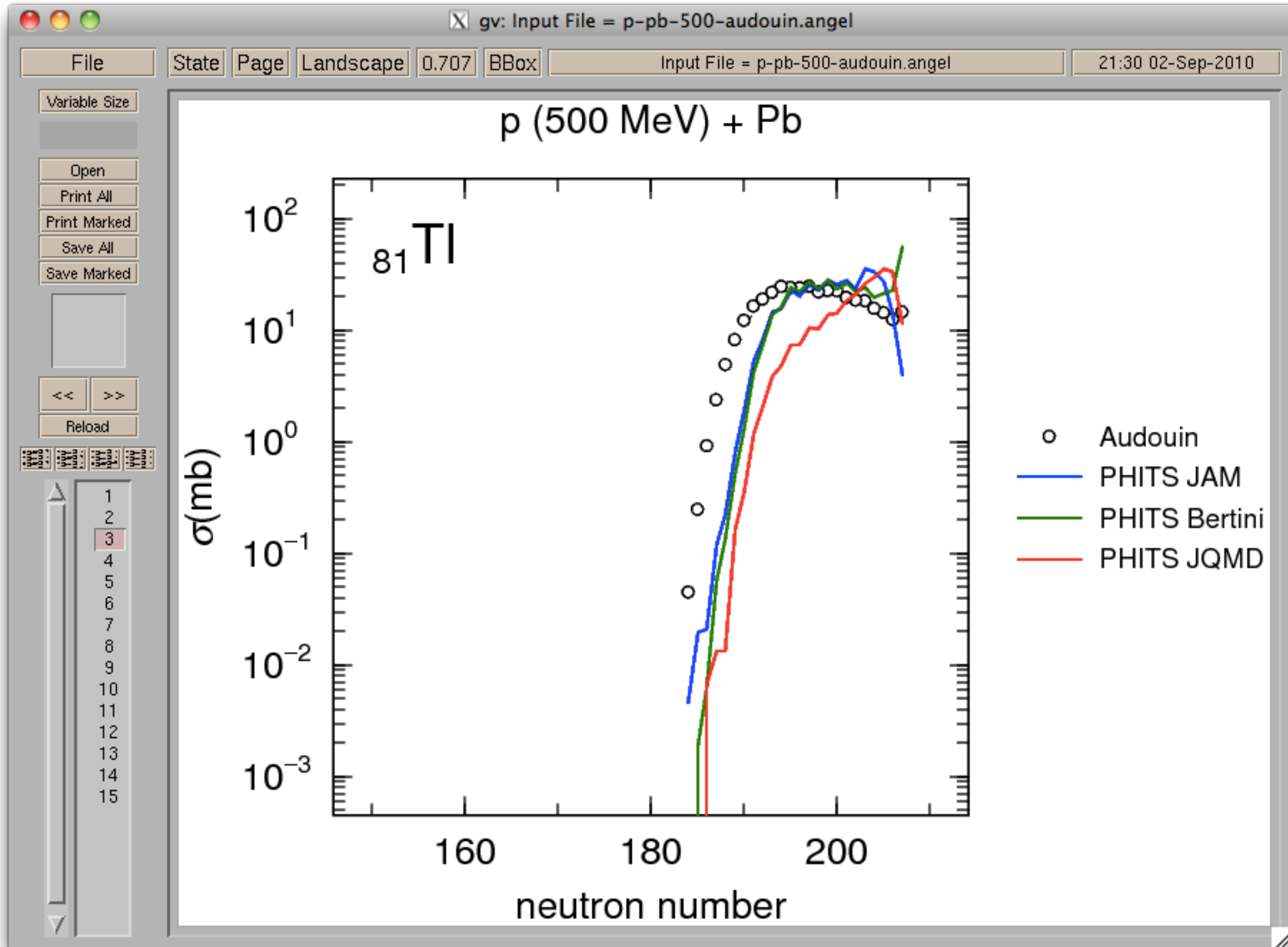
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



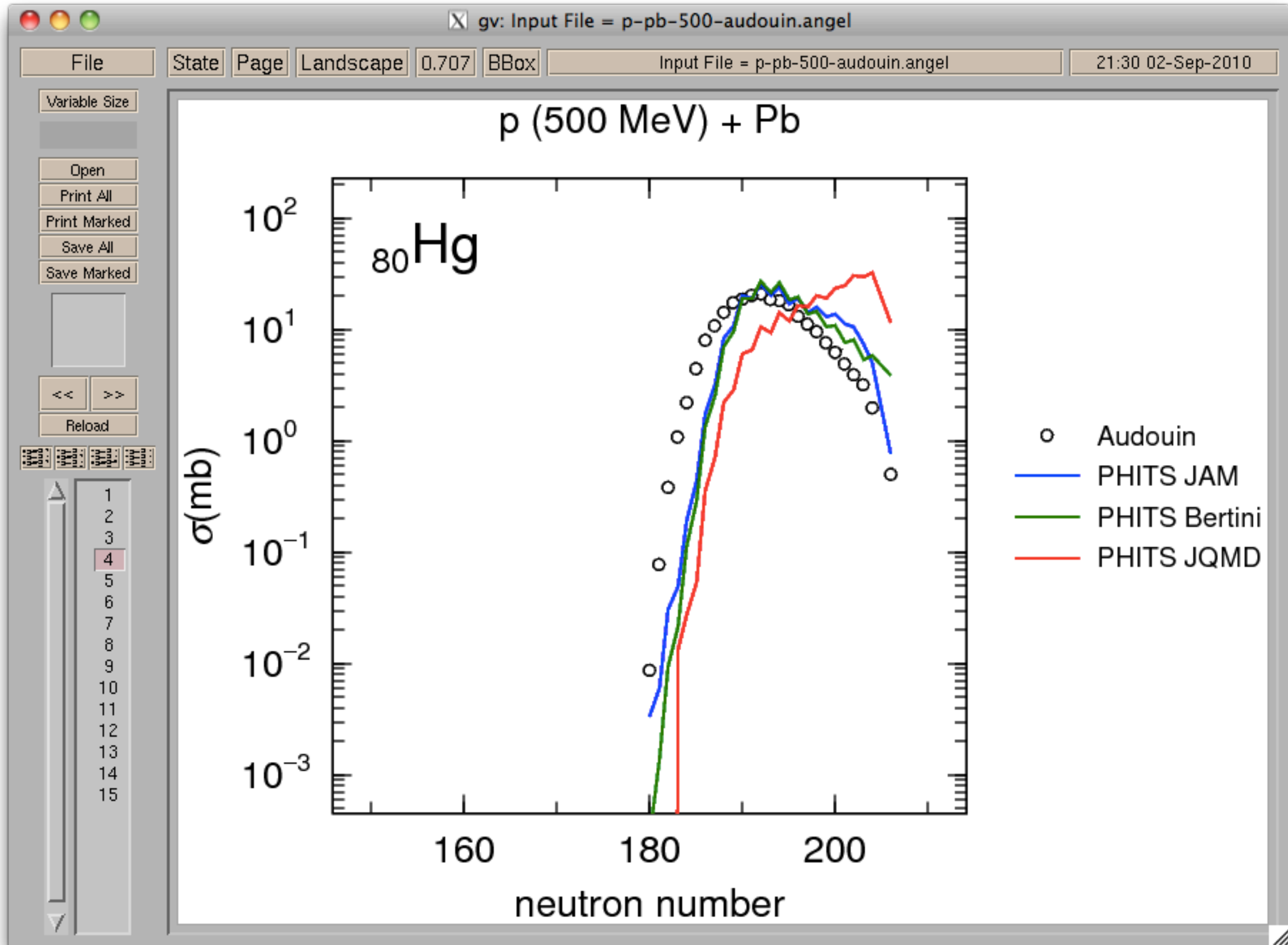
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$

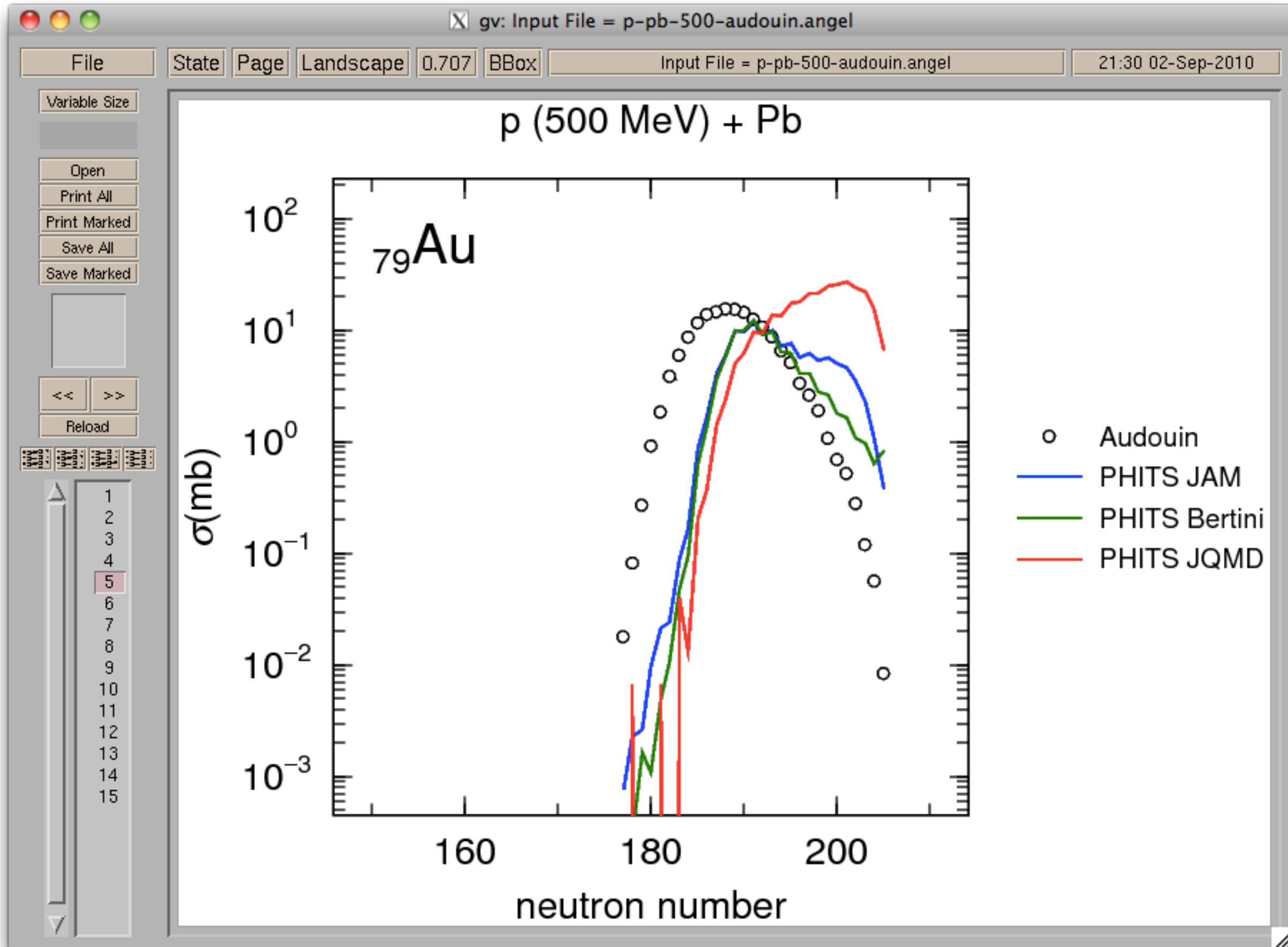


# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$

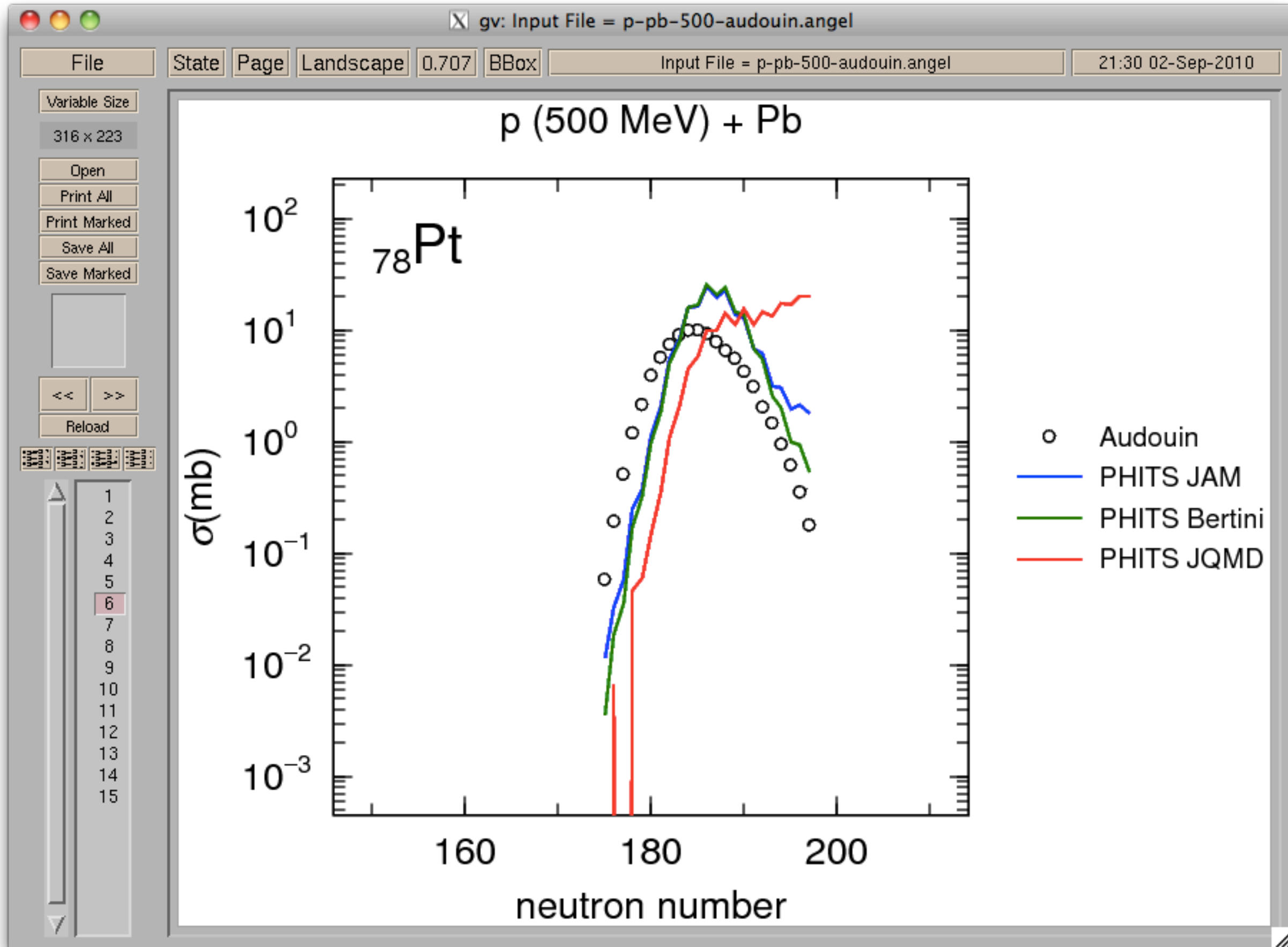




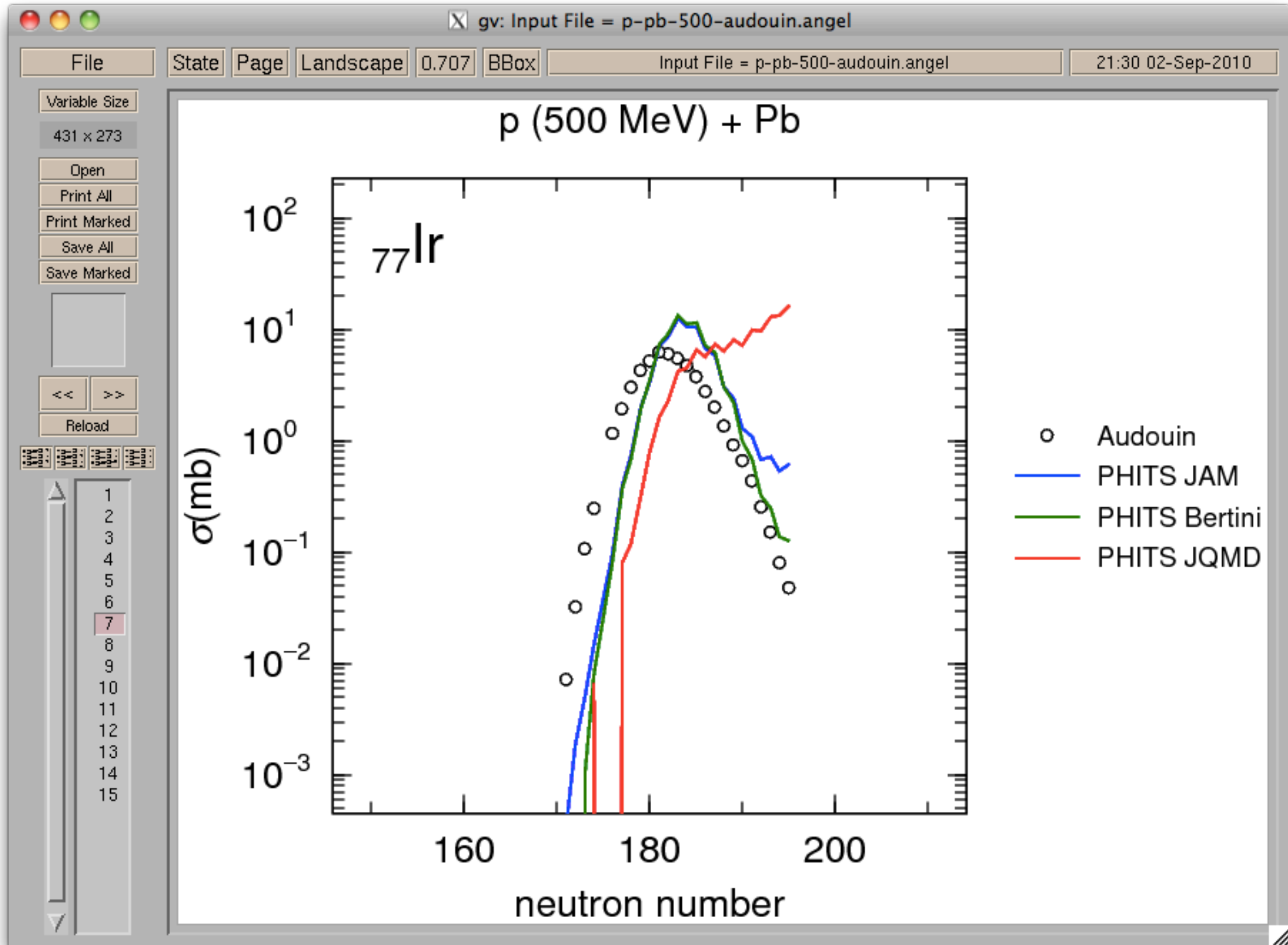
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



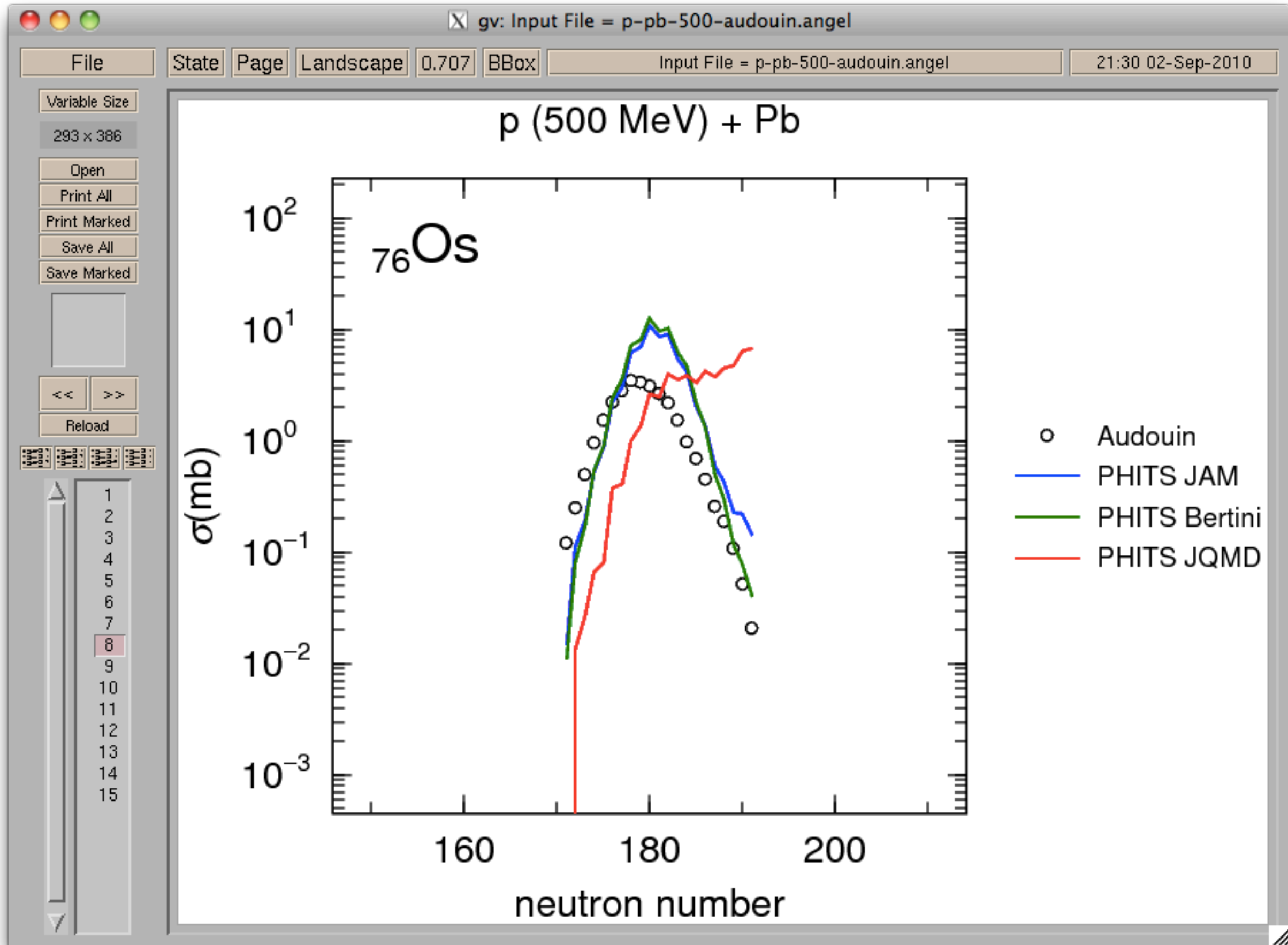
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



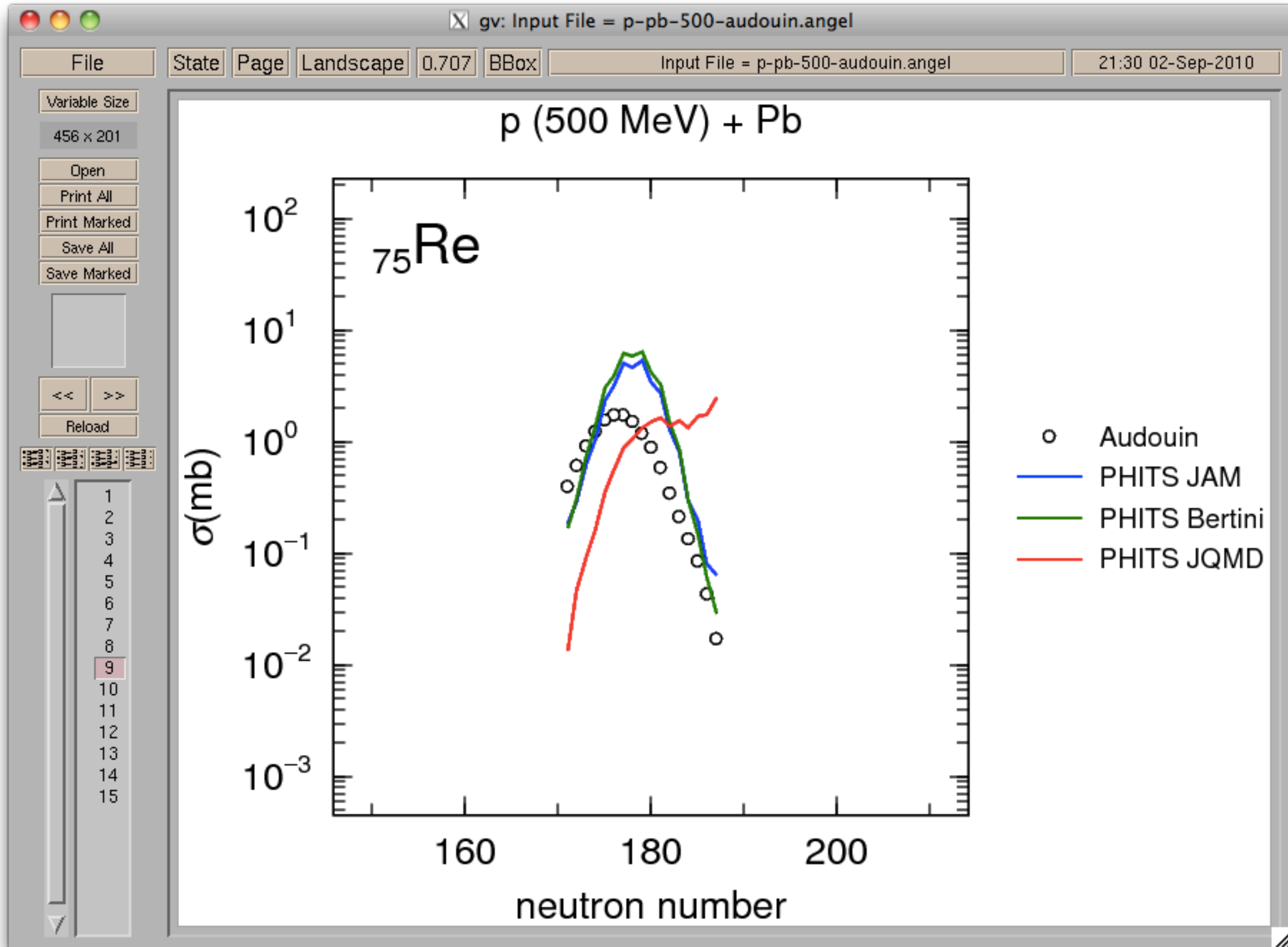
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



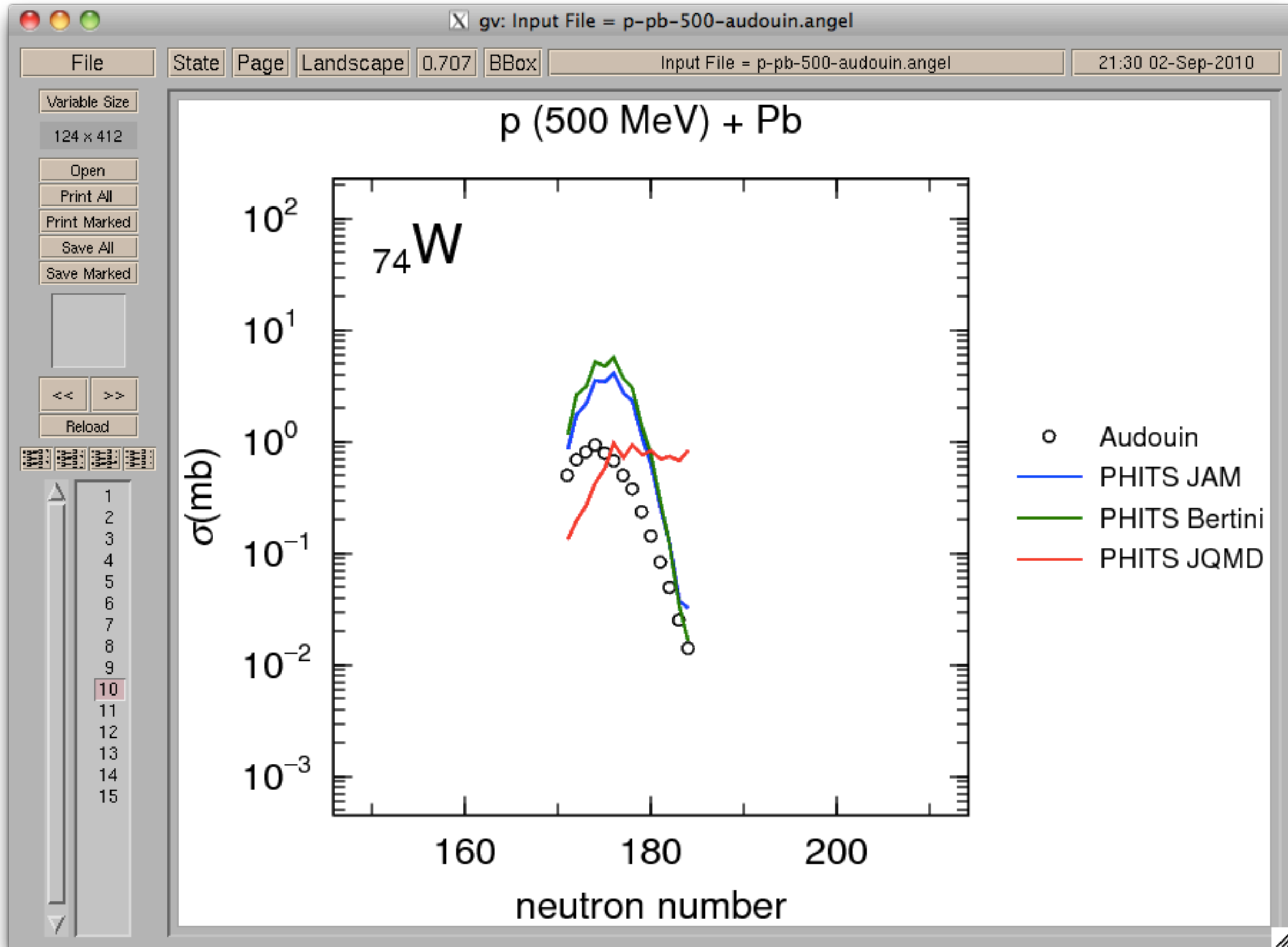
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$

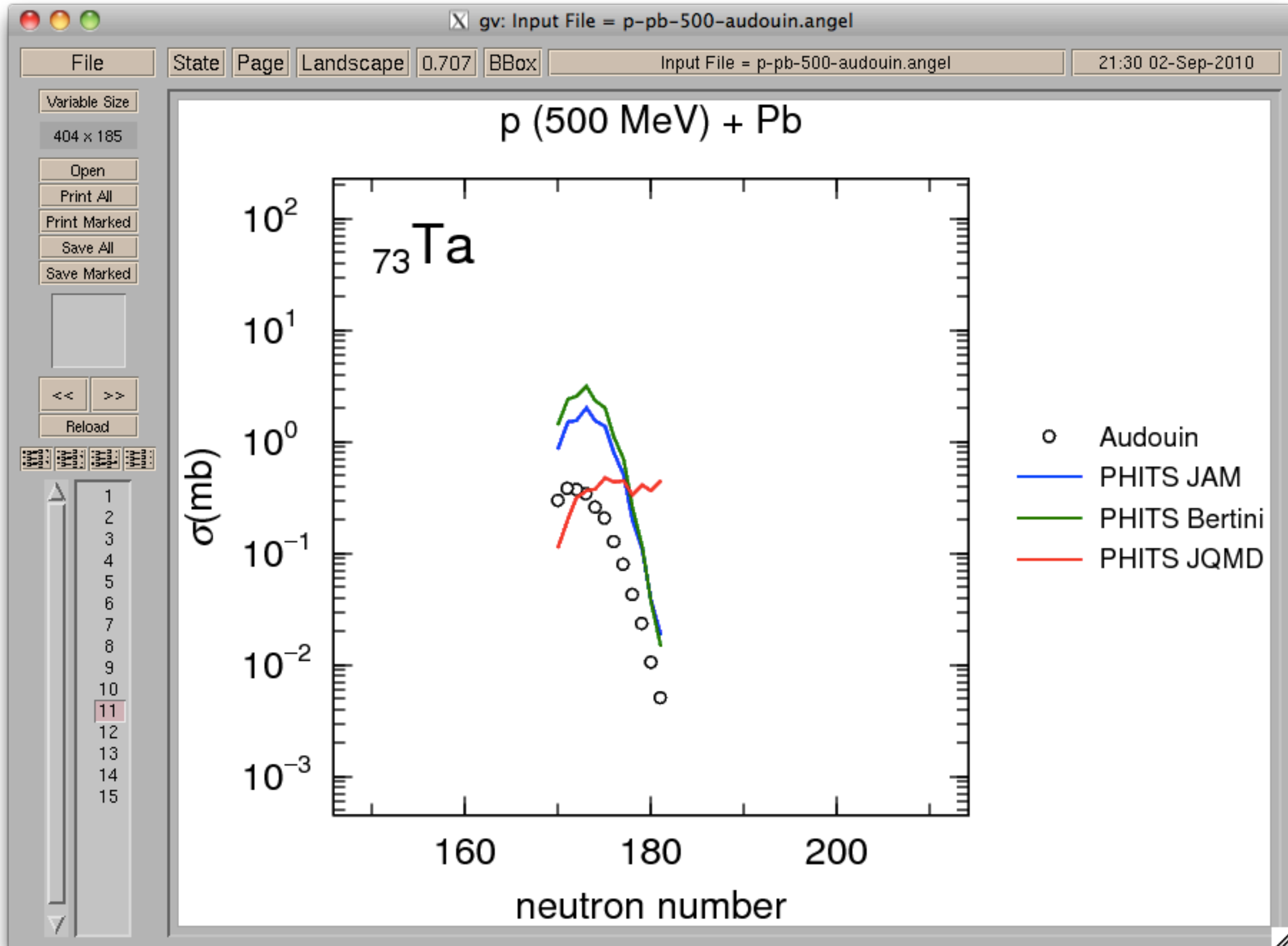


# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$

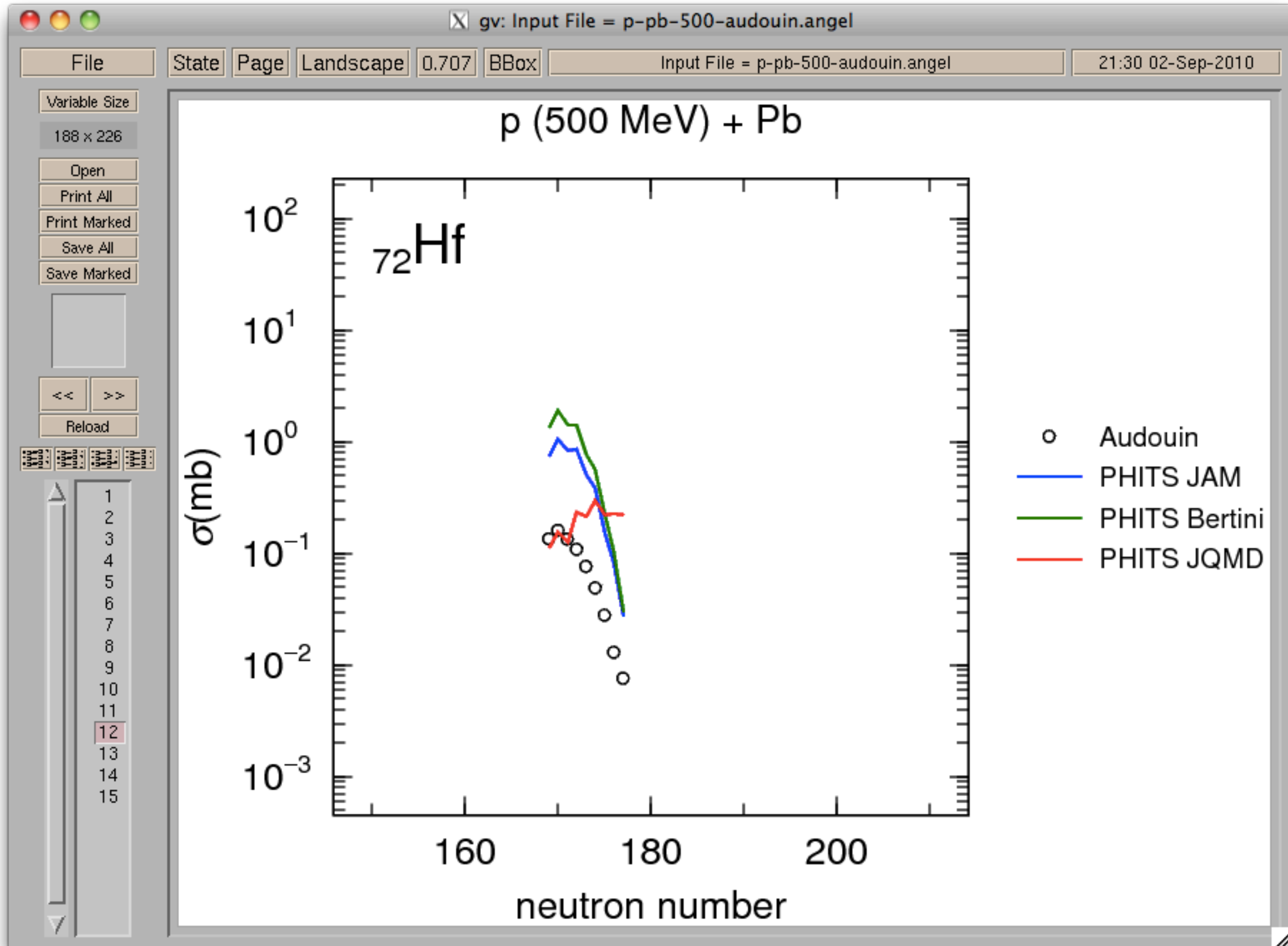




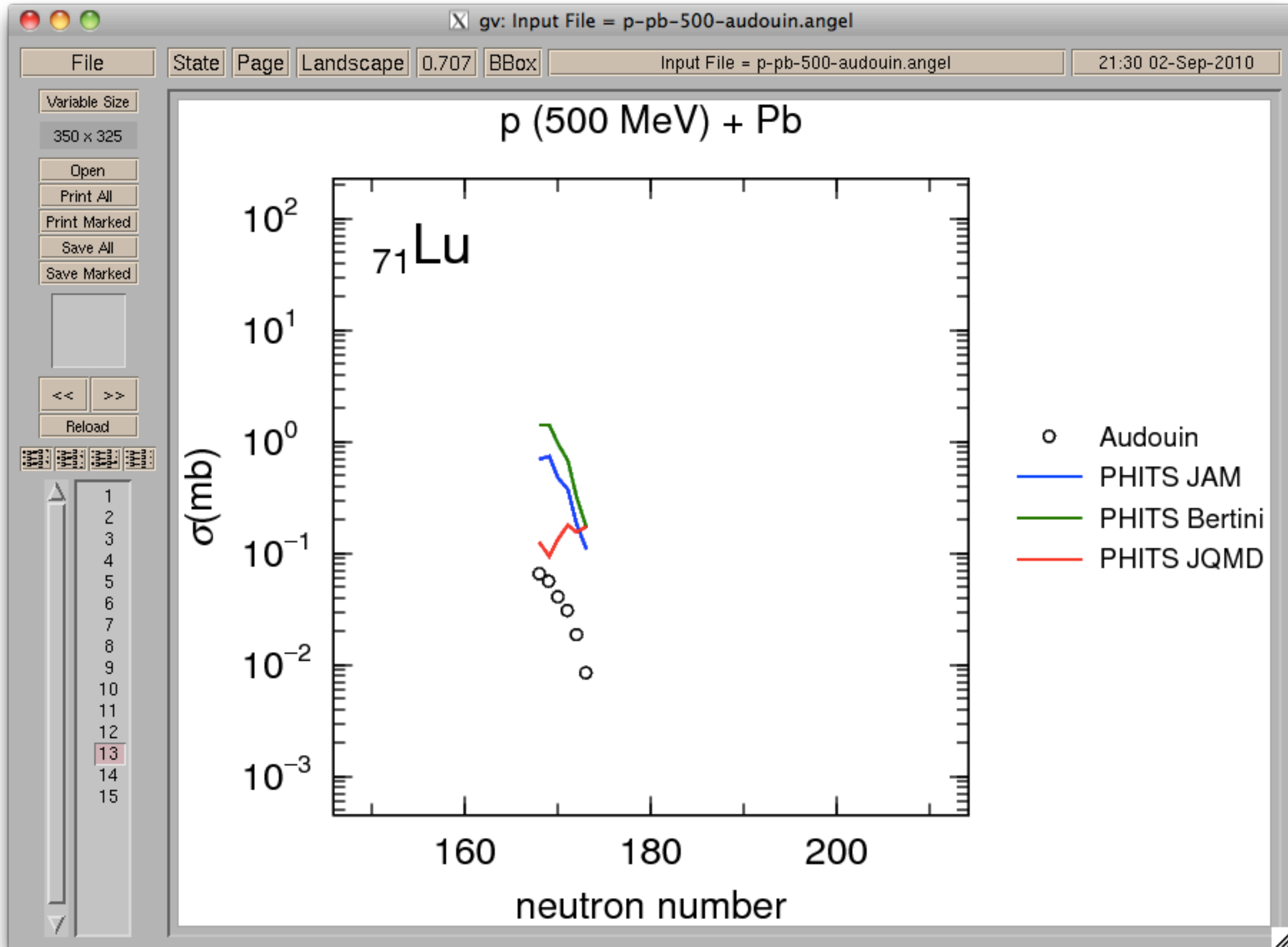
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



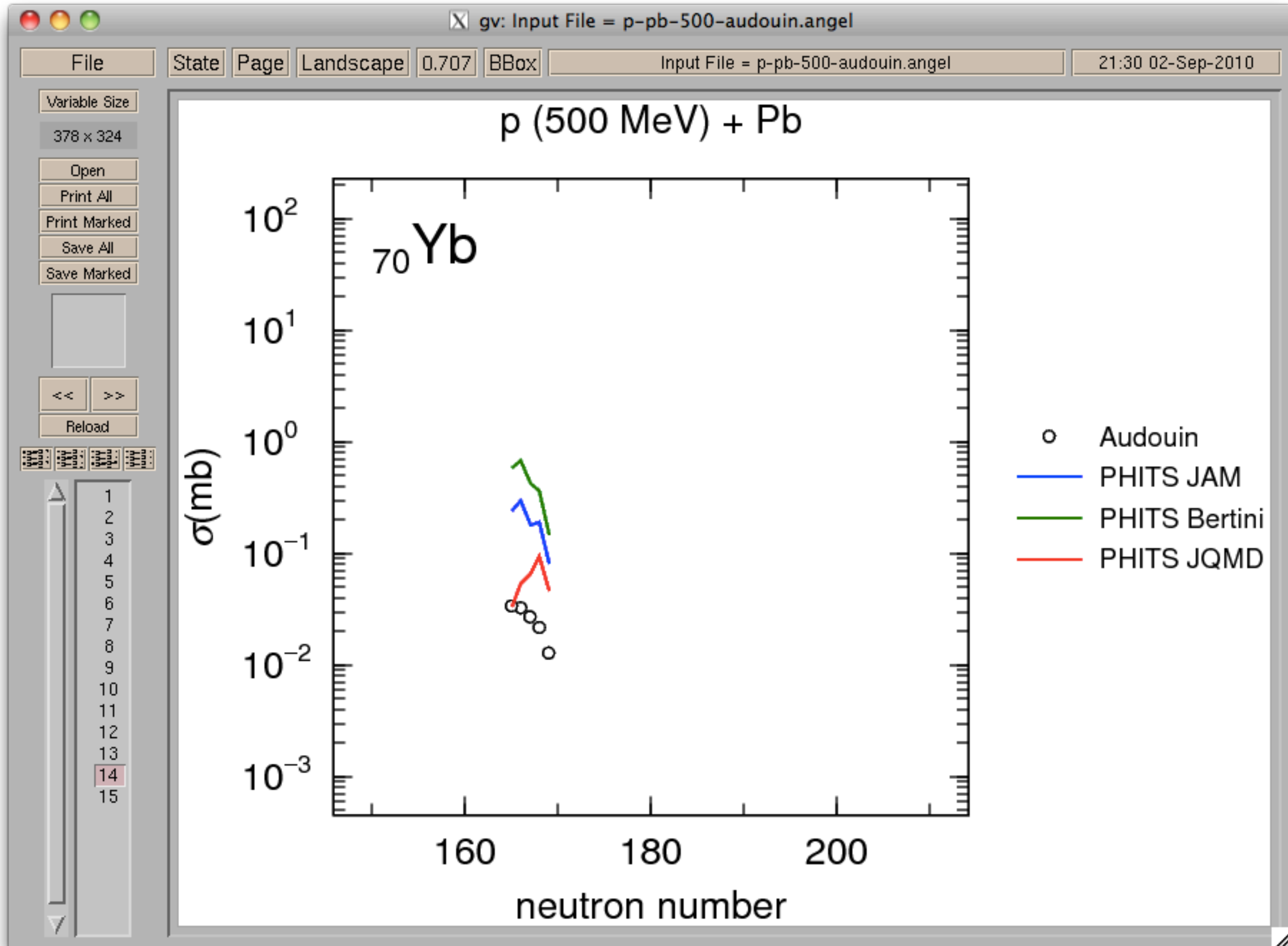
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



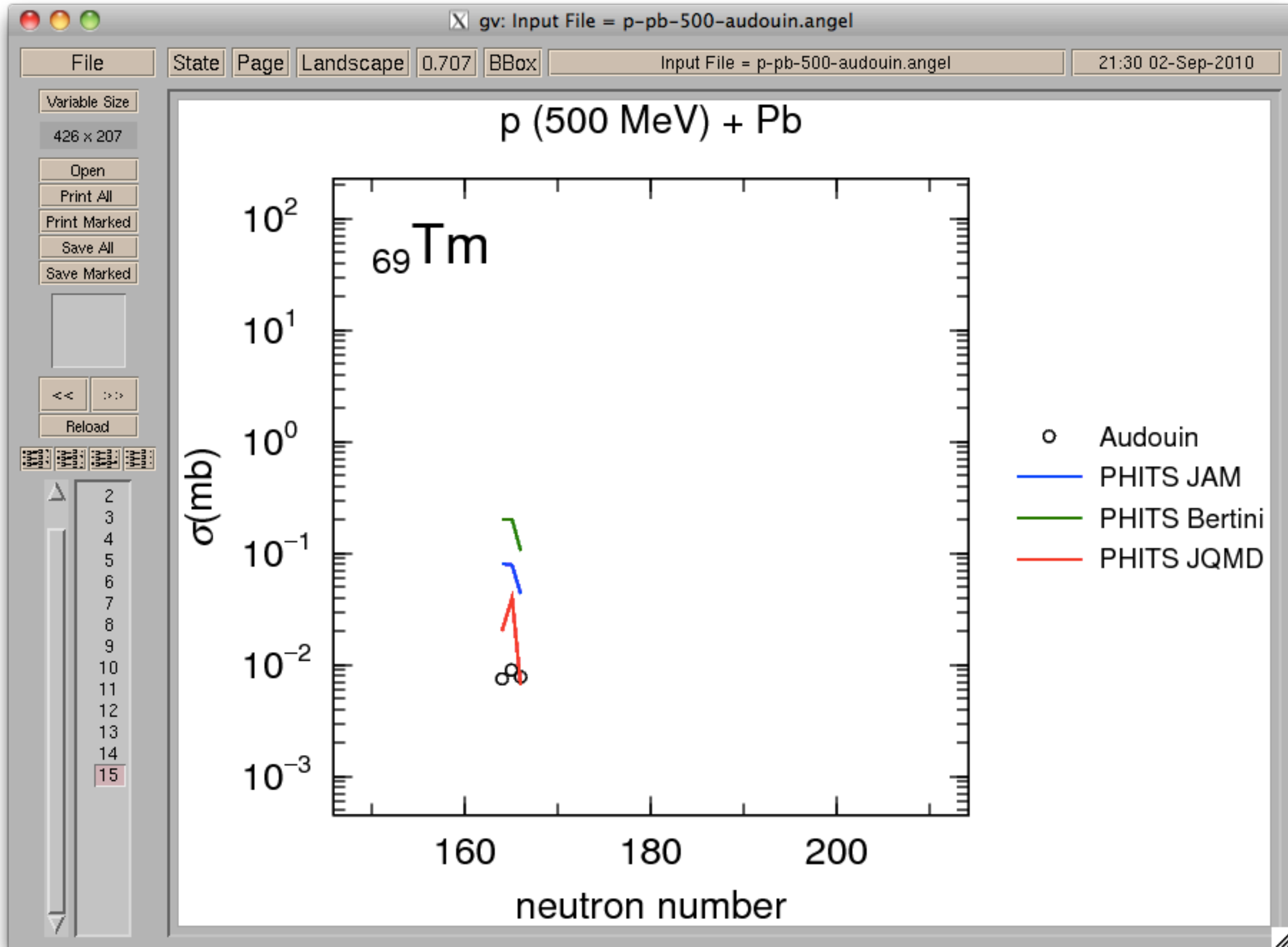
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



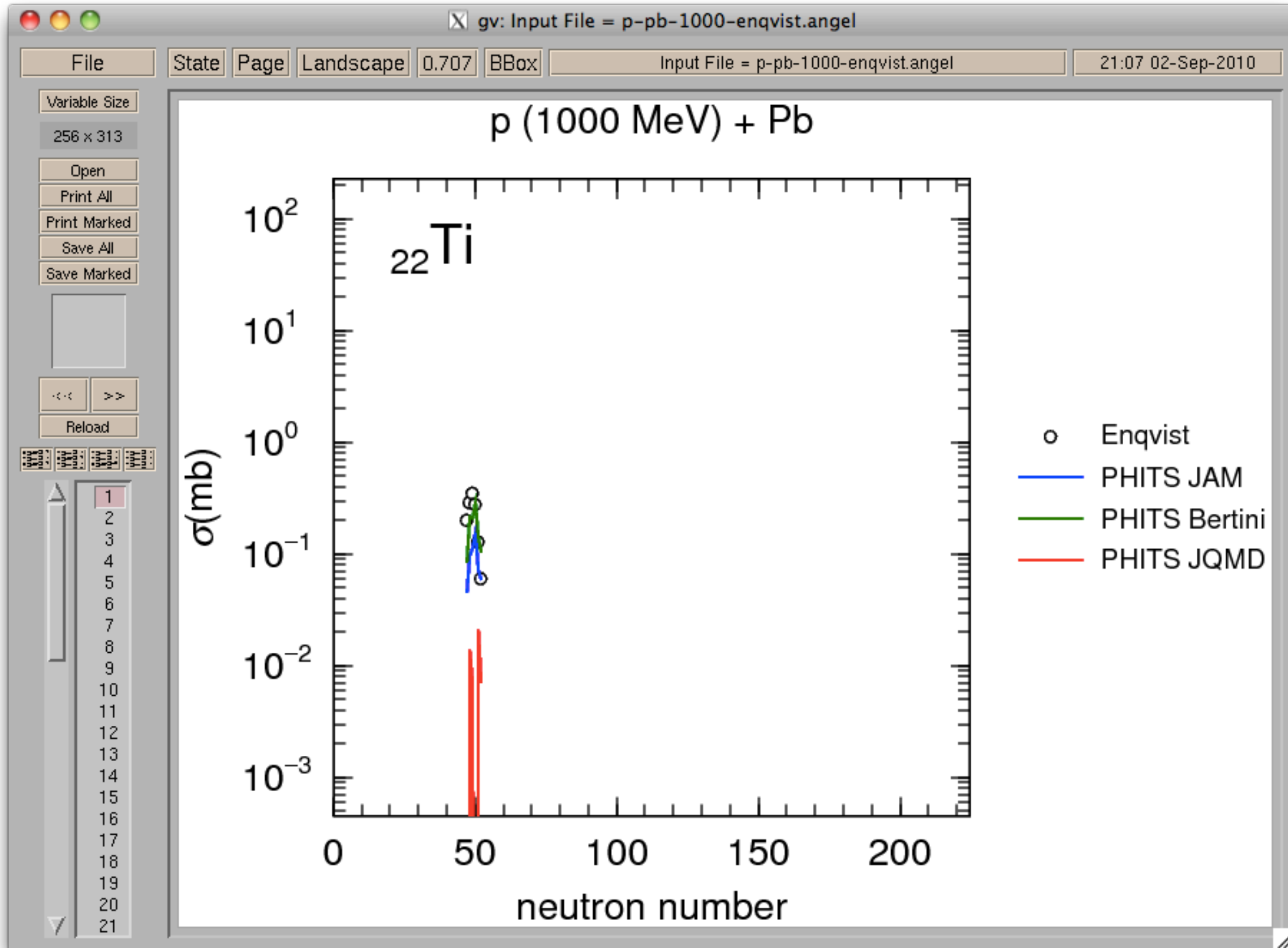
# isotropic distribution: p (500 MeV) + $_{82}^{208}\text{Pb}$



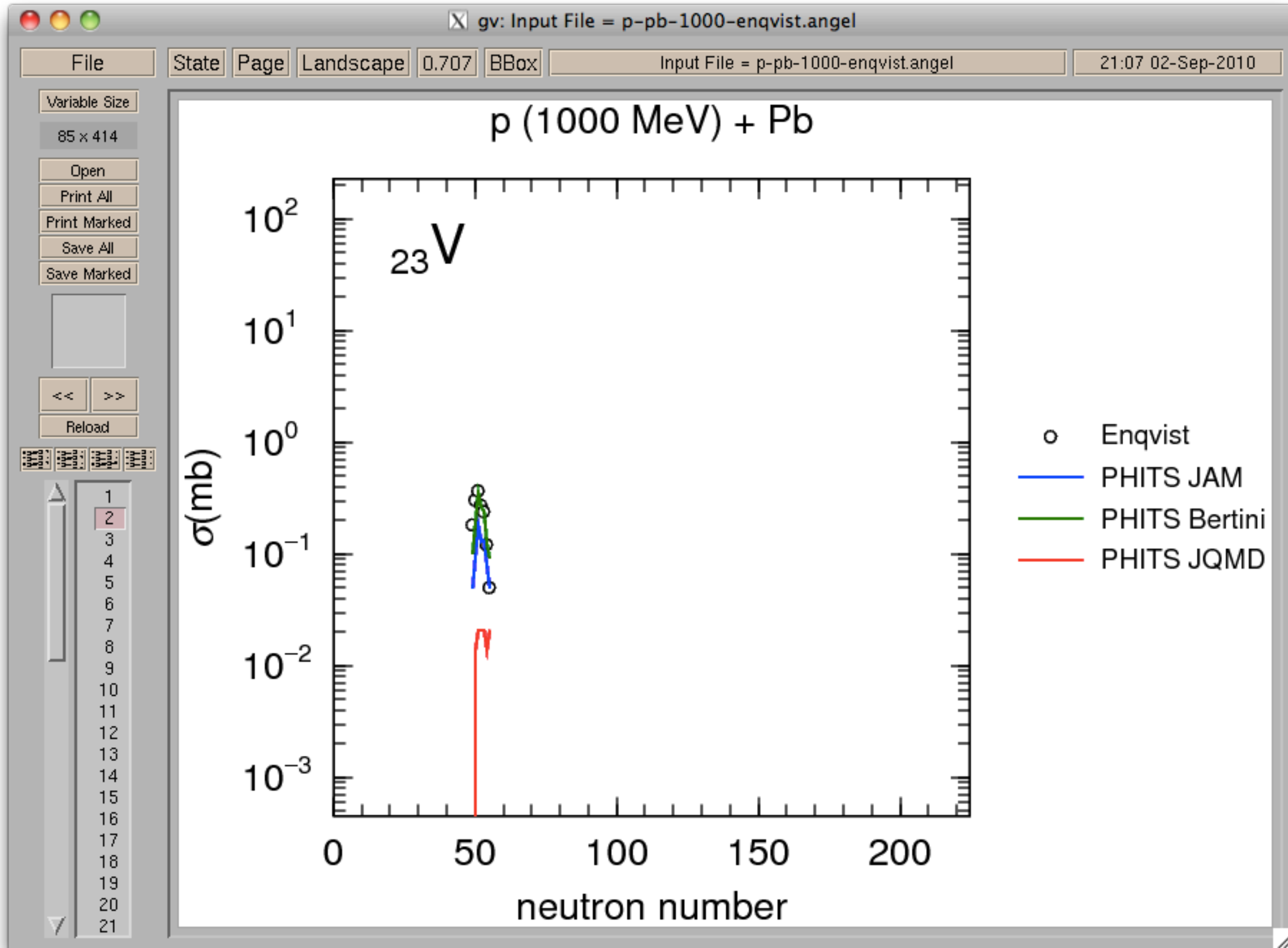




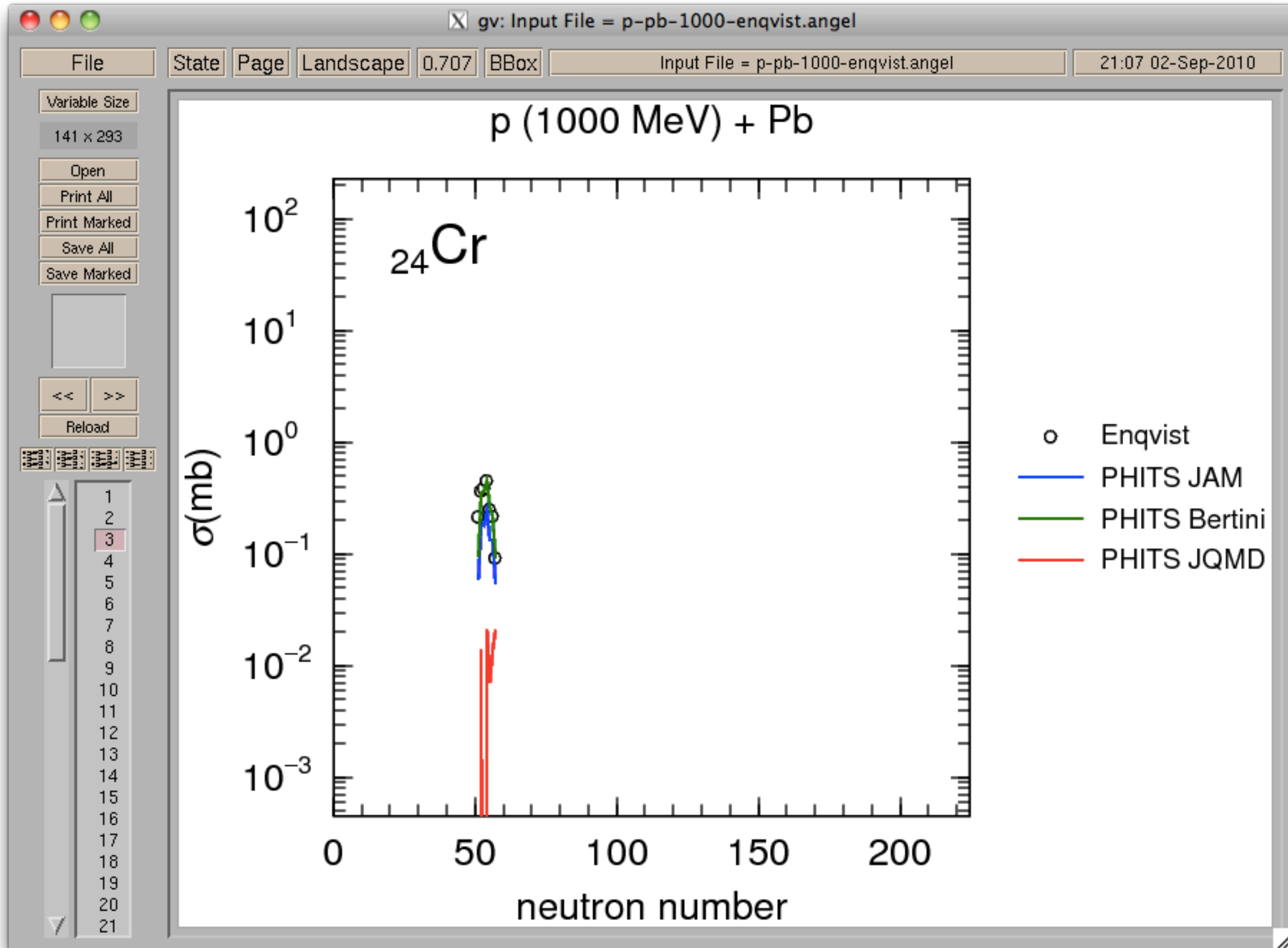
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



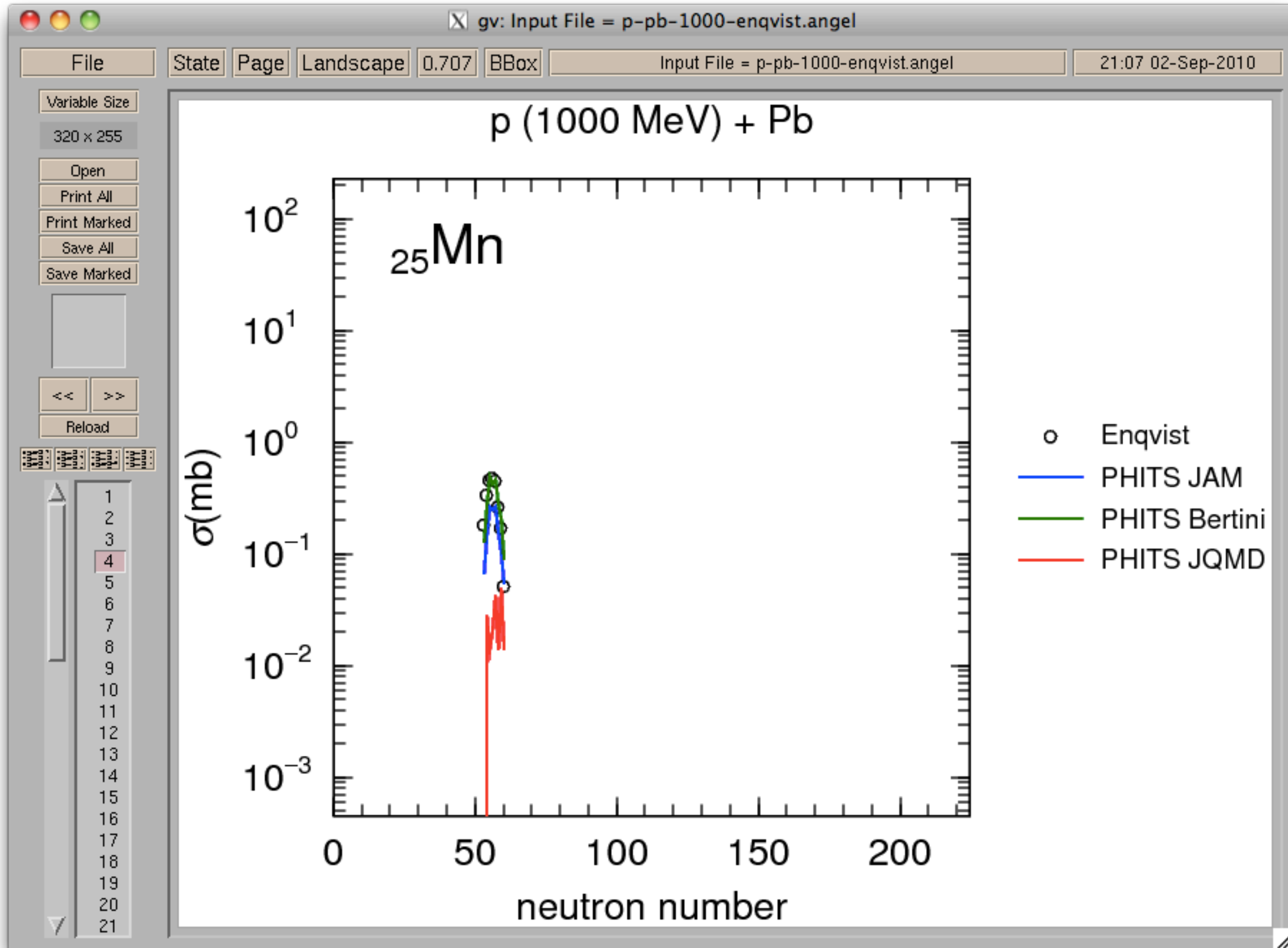
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



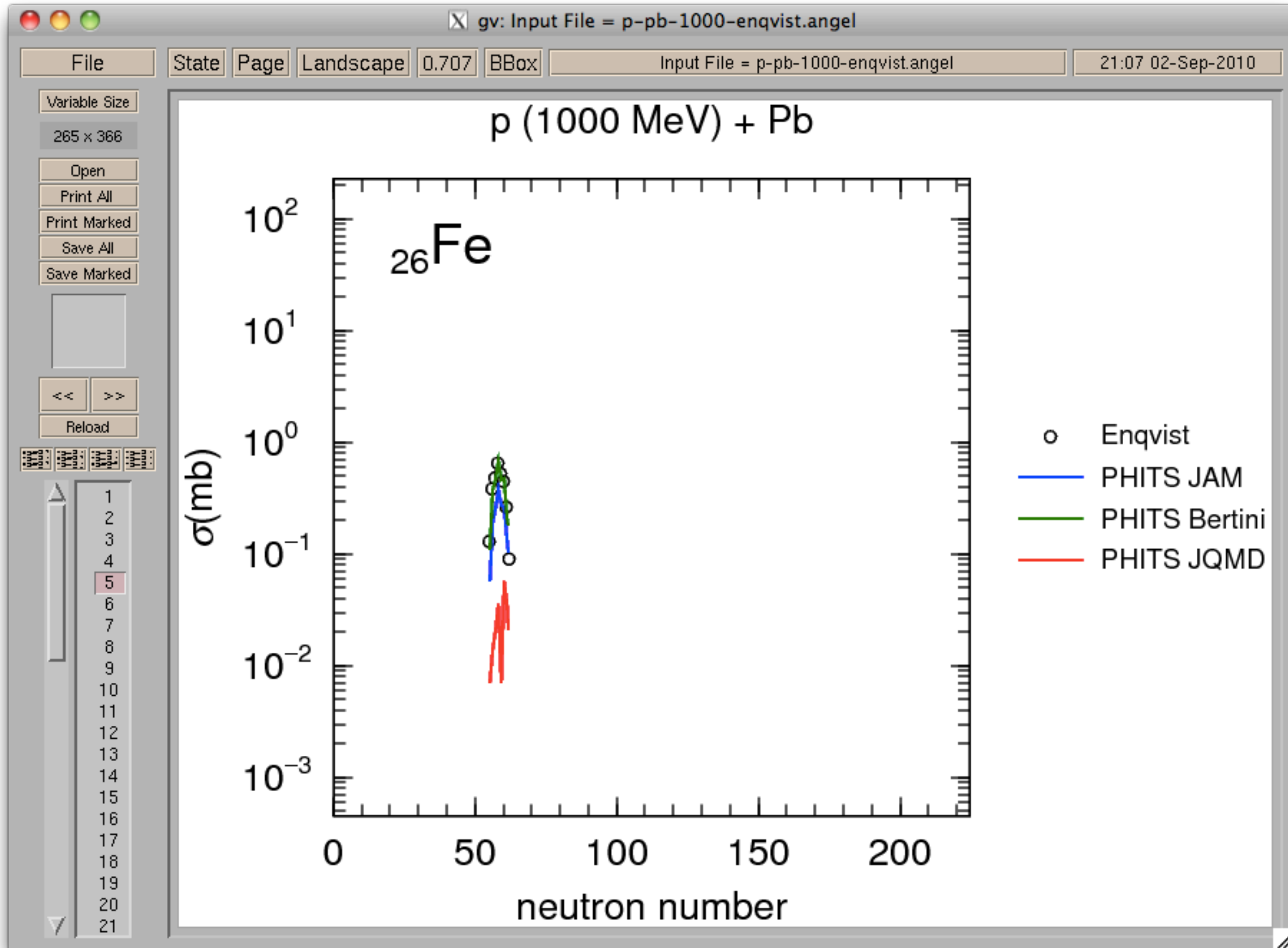
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



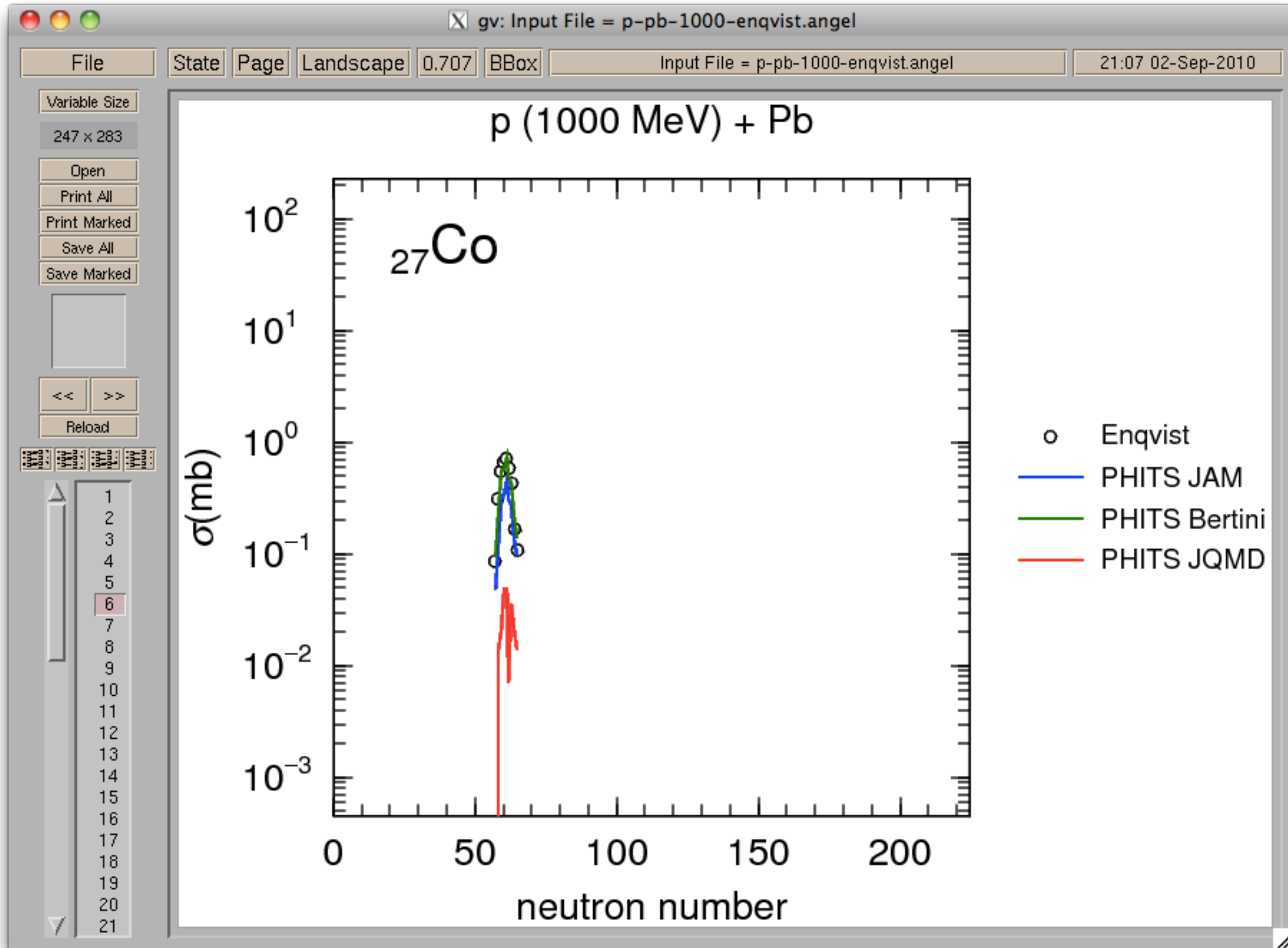
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

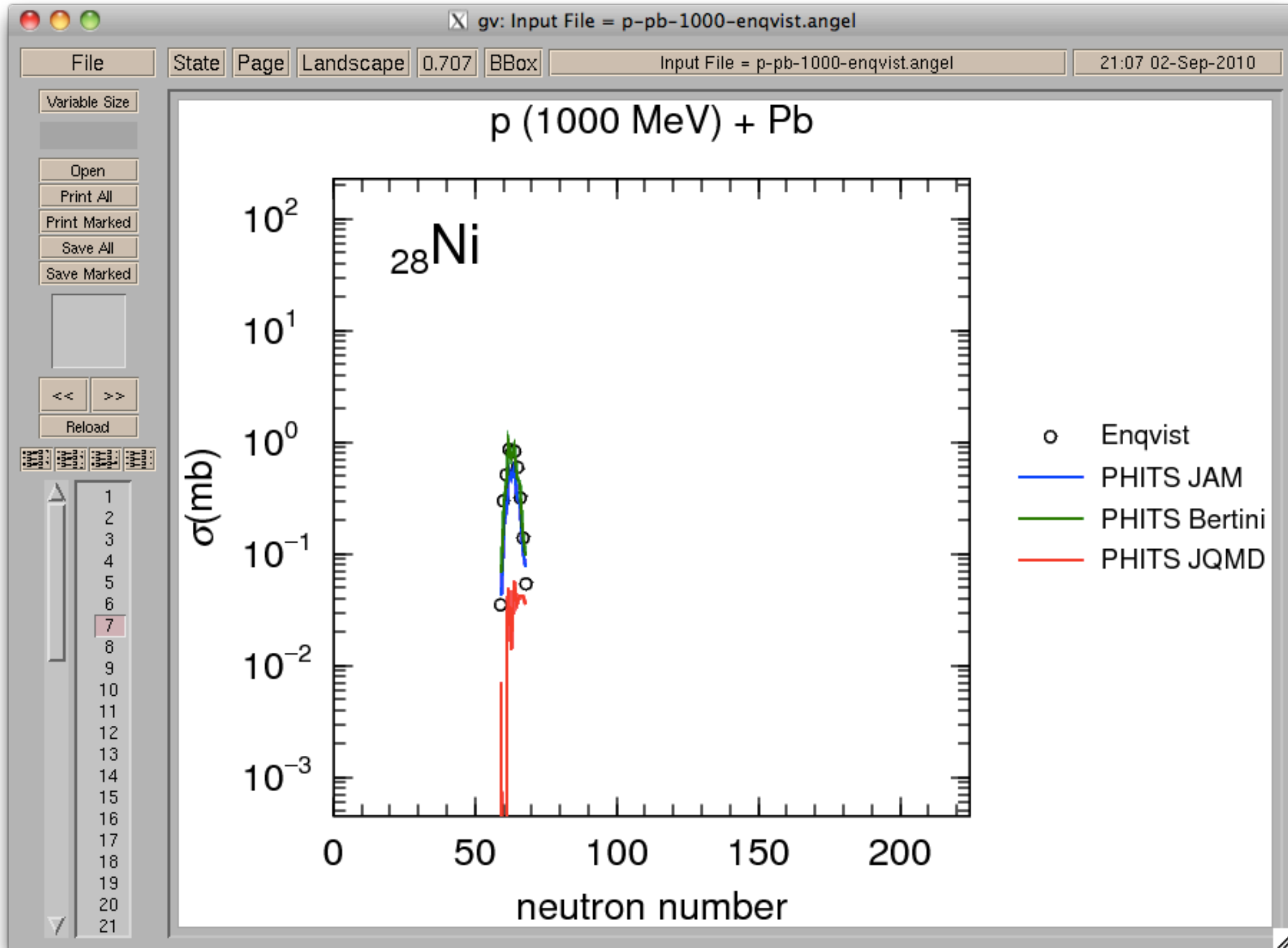


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

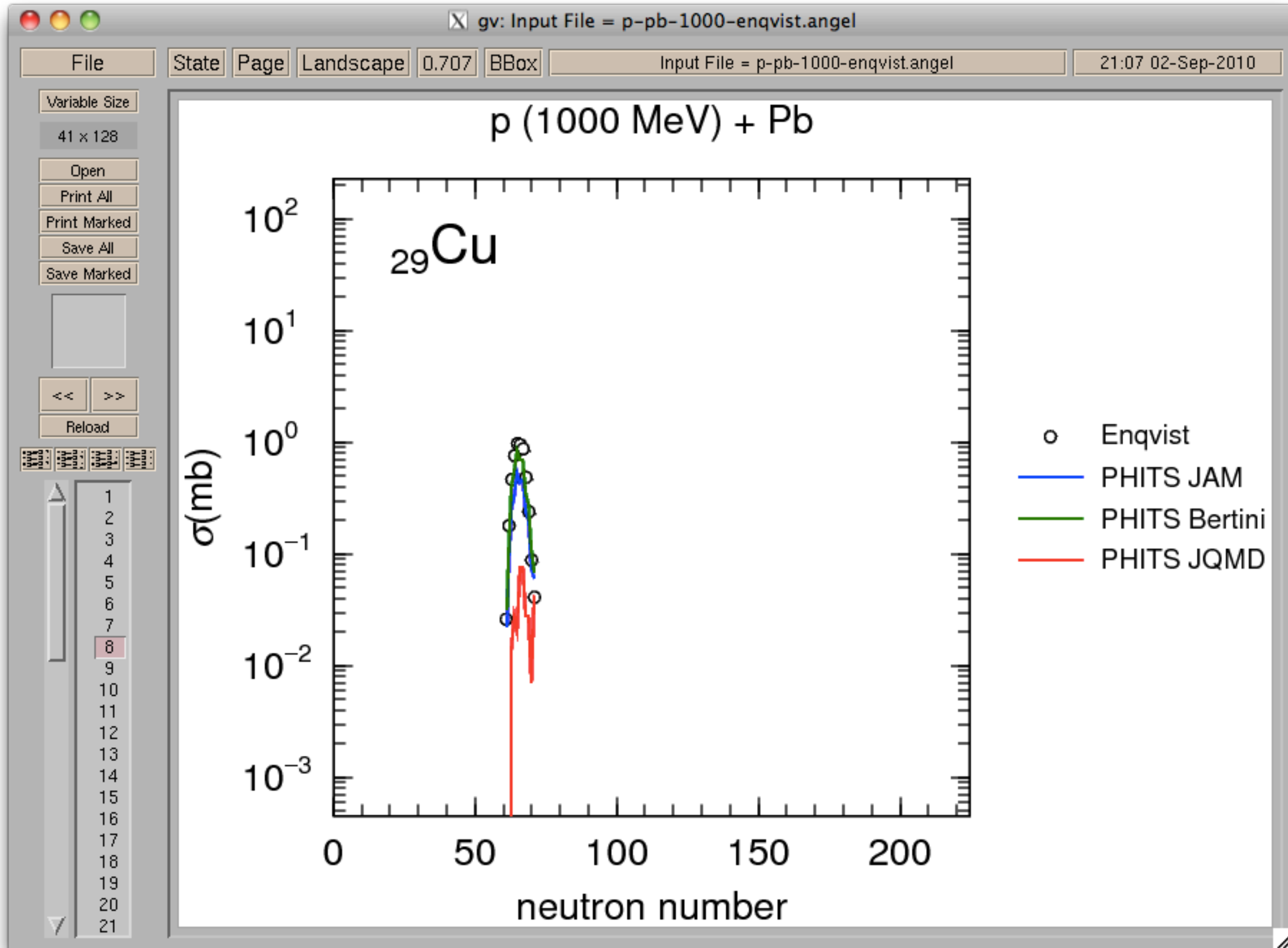




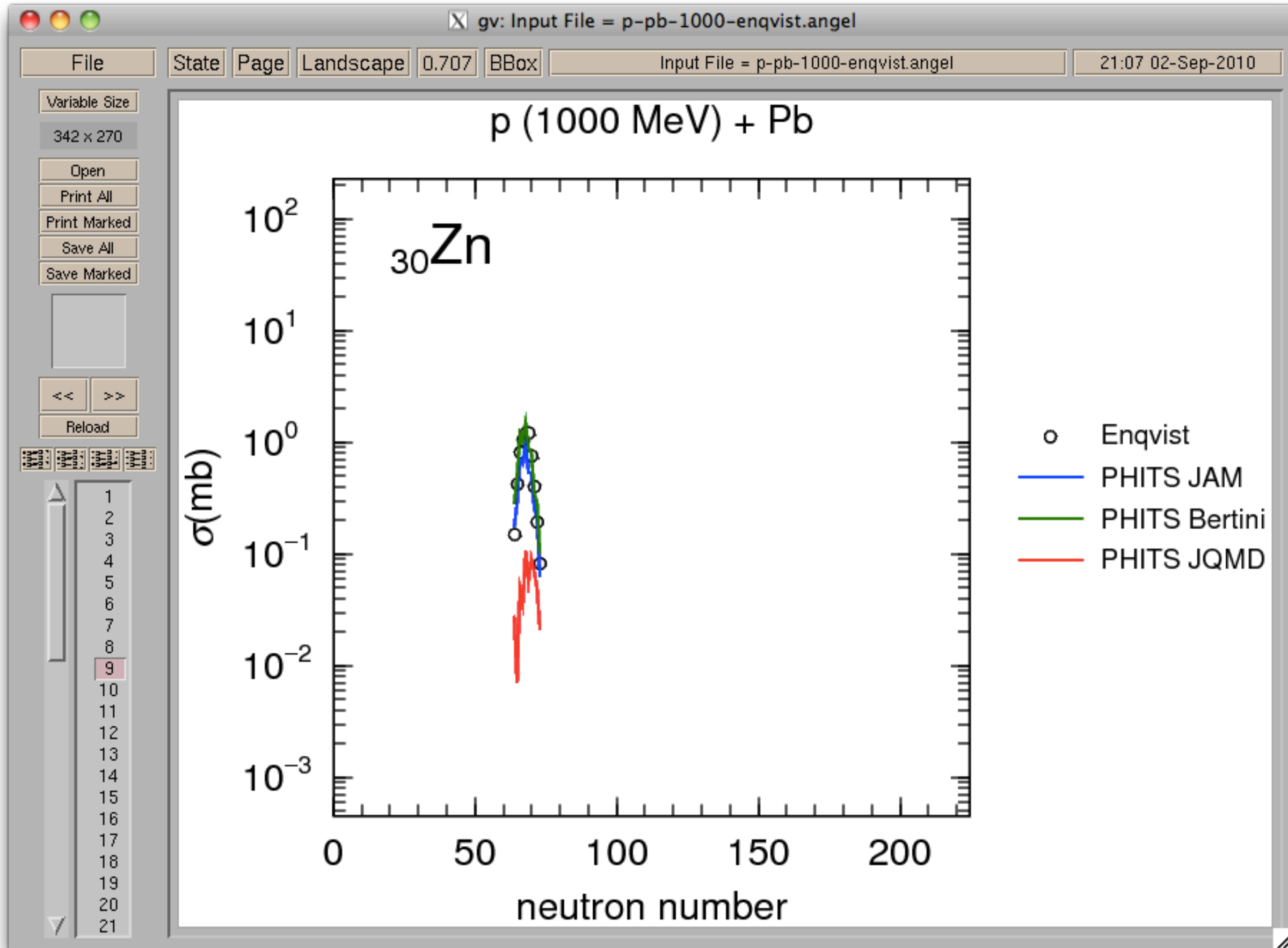
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



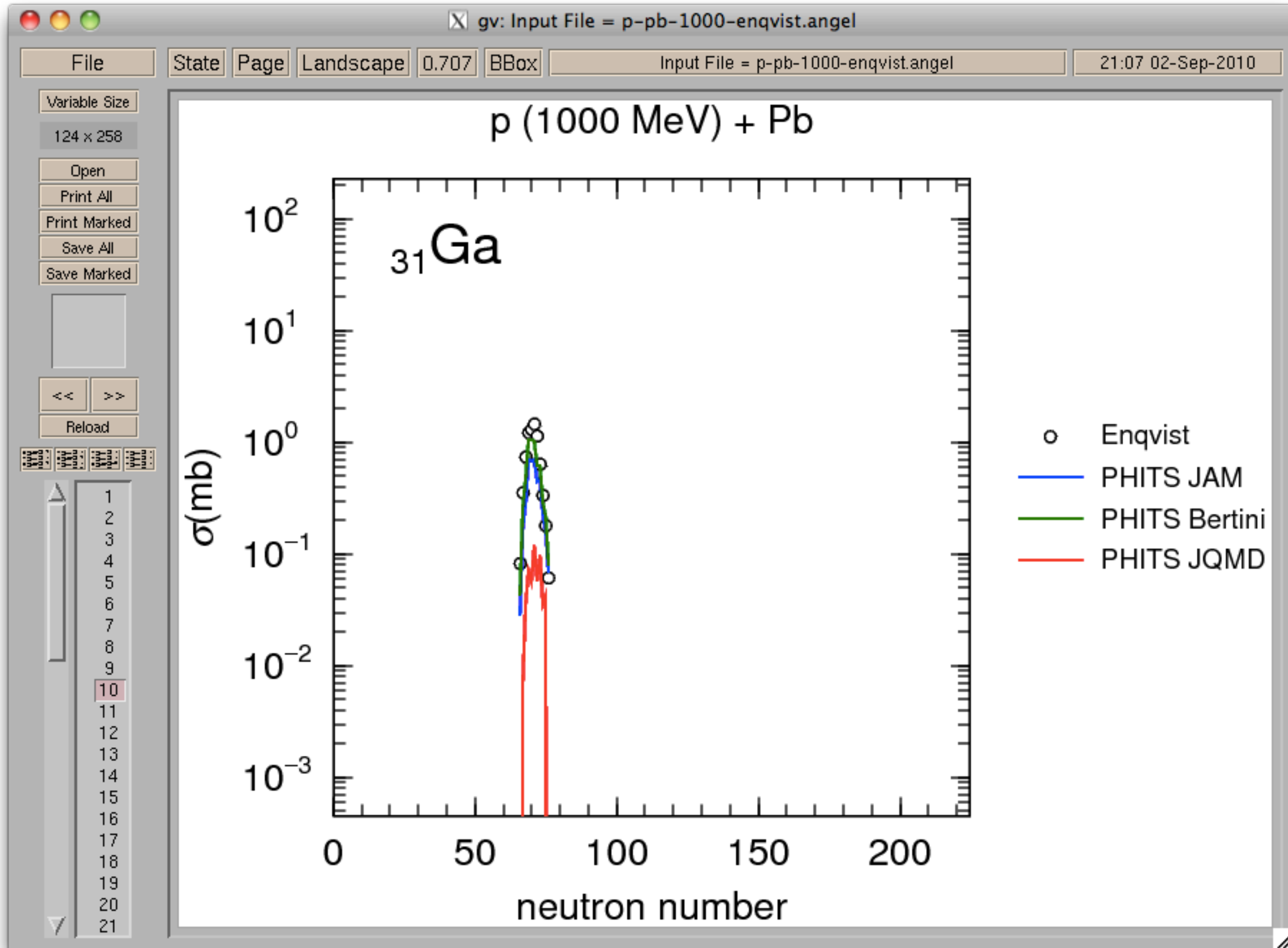
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



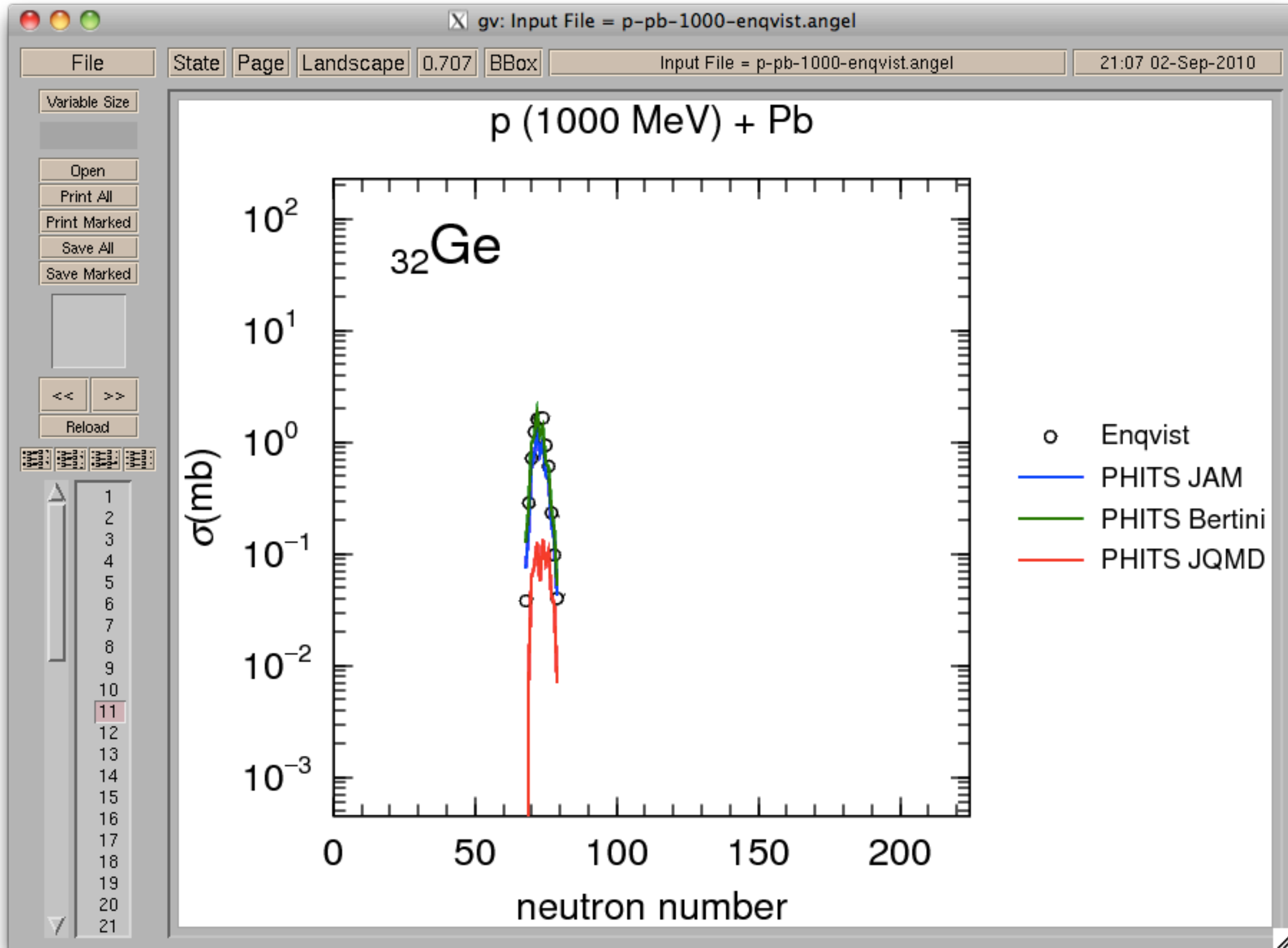
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



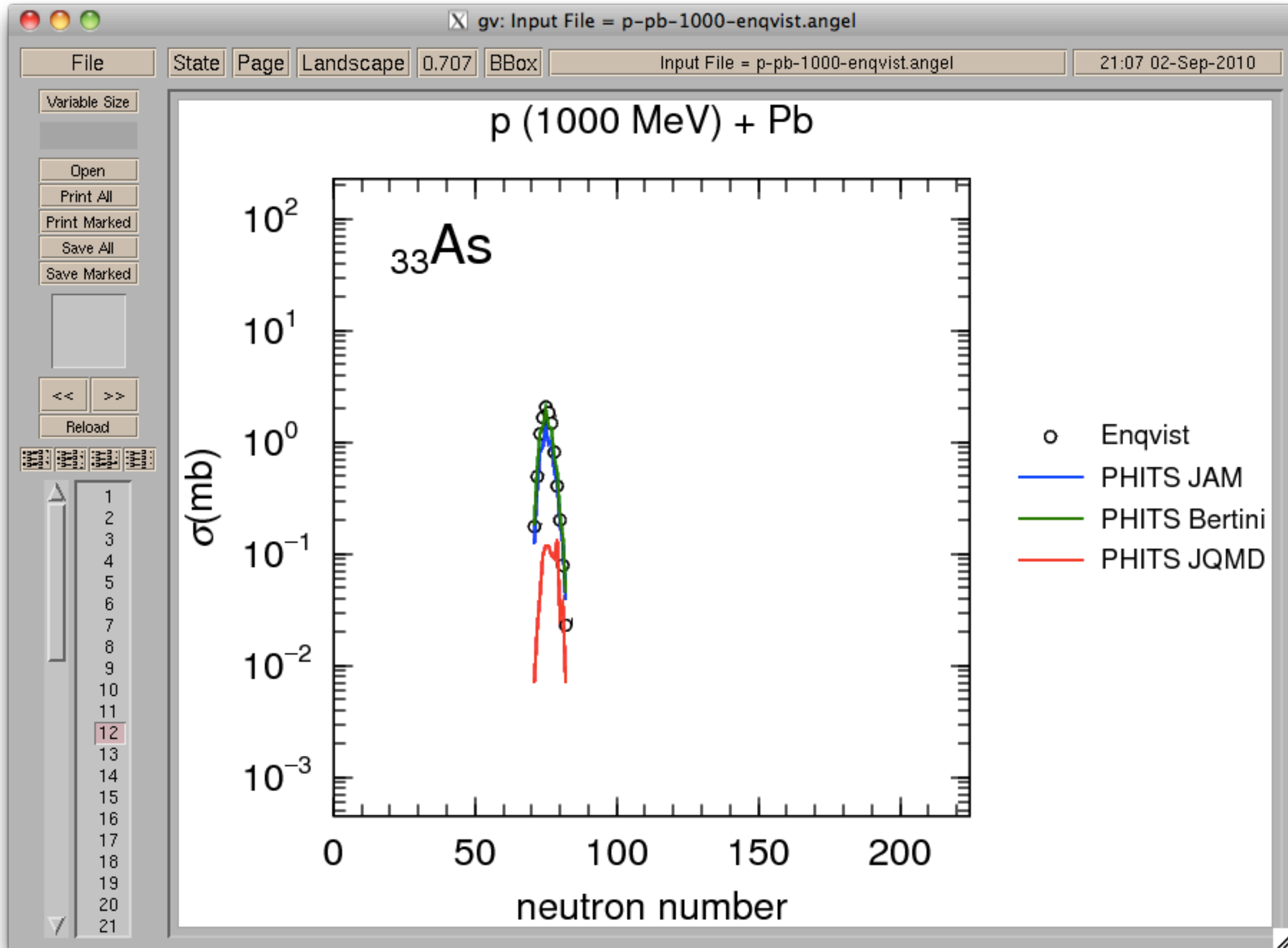
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

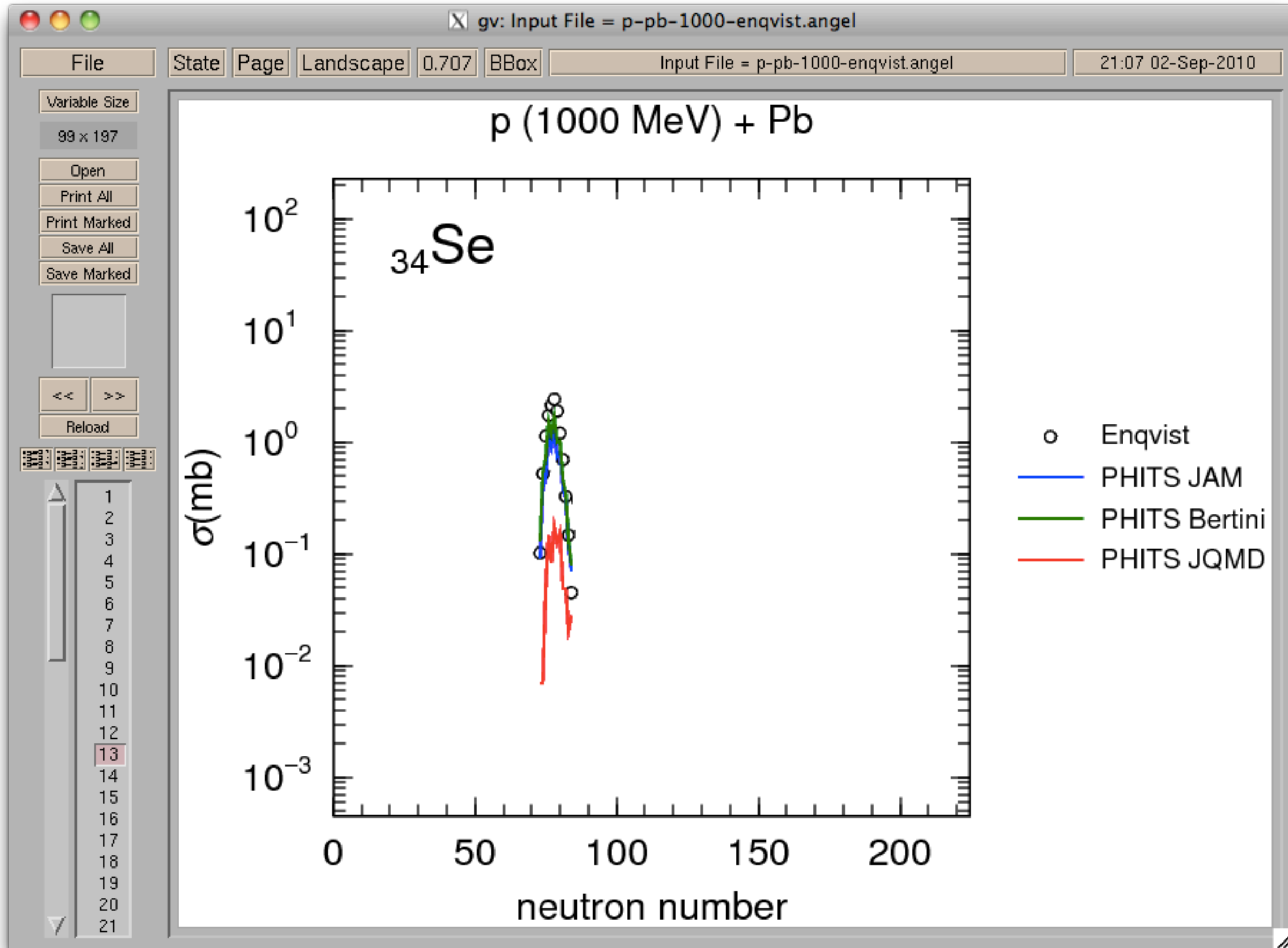


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

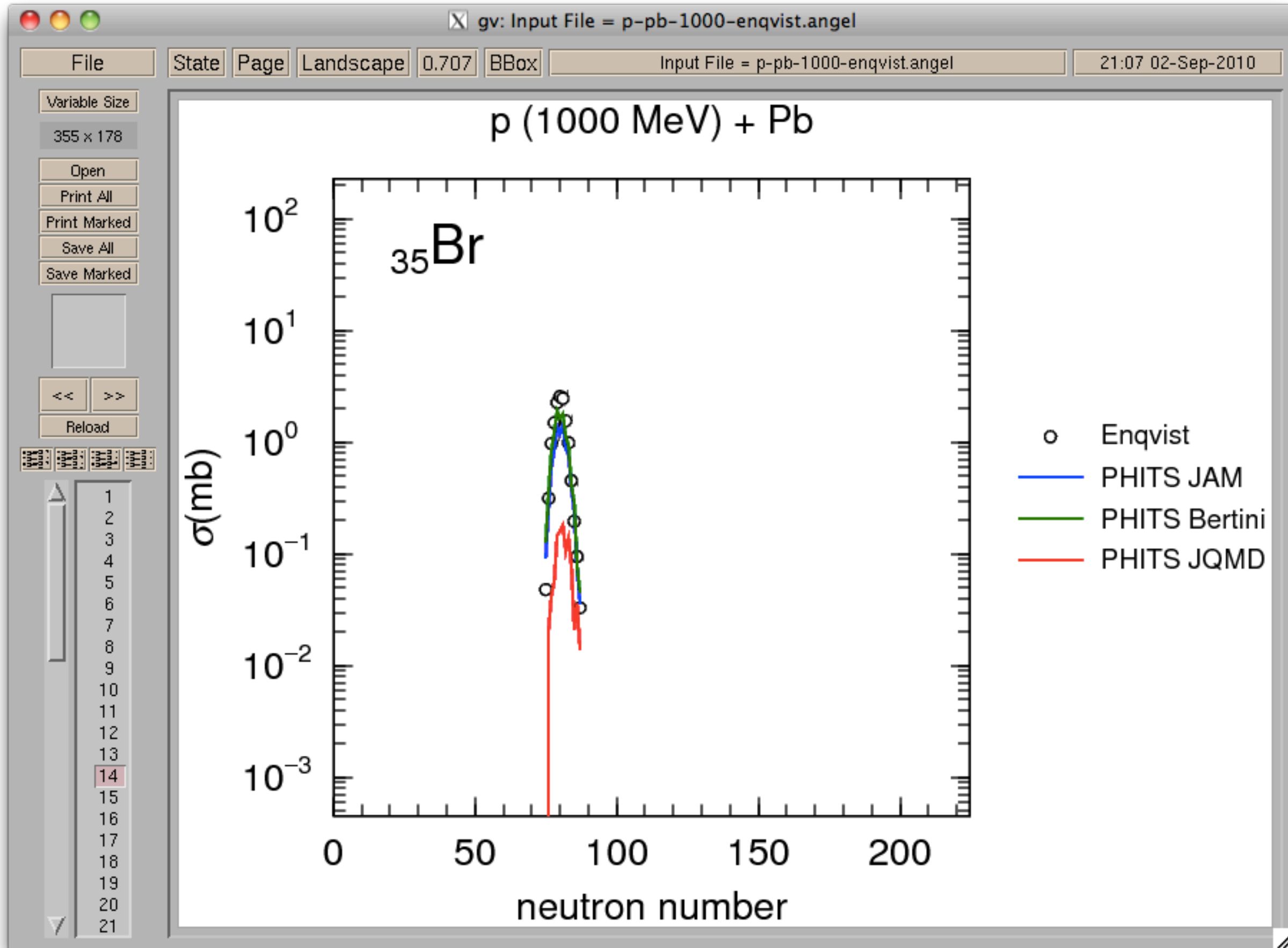




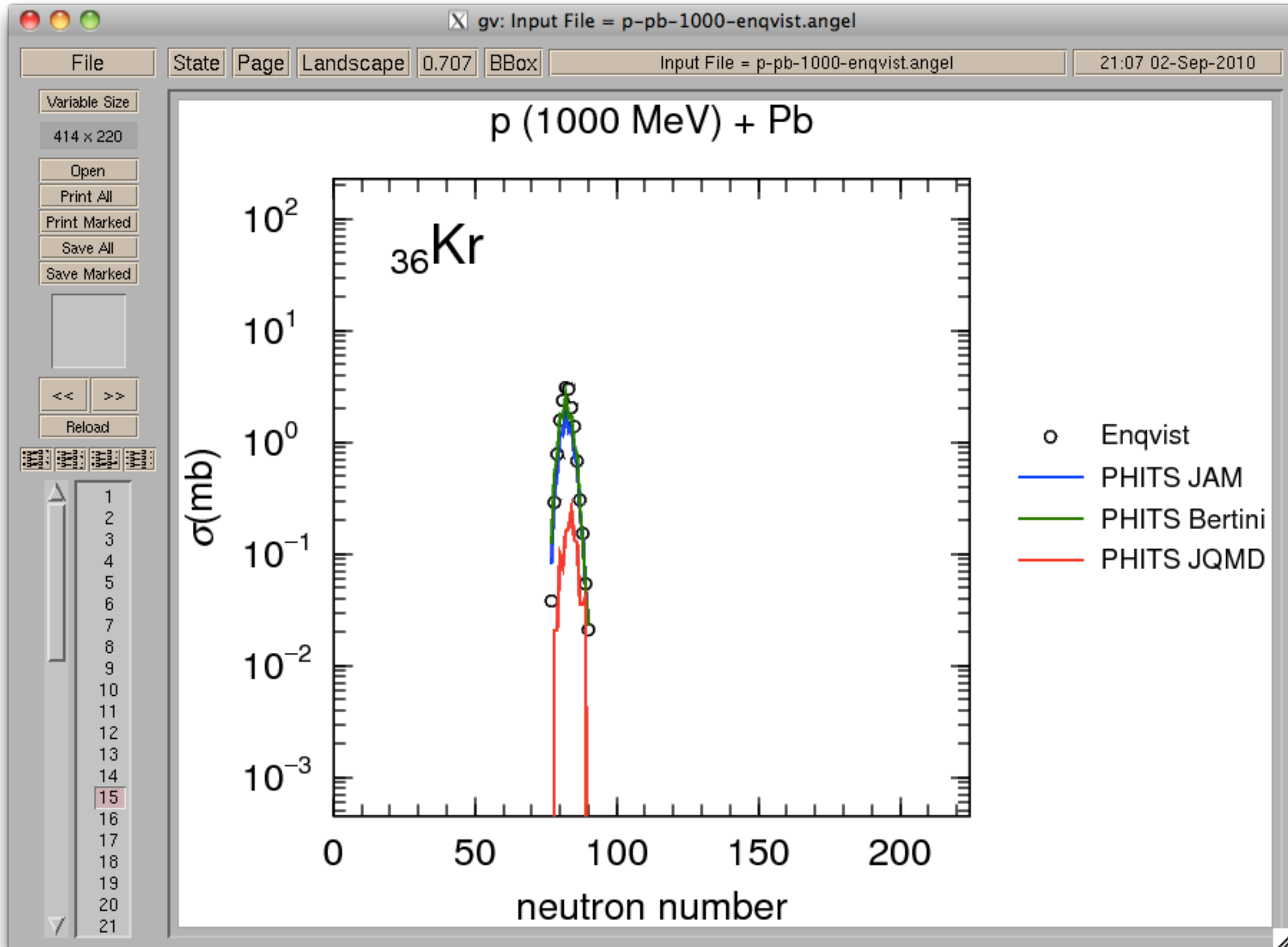
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



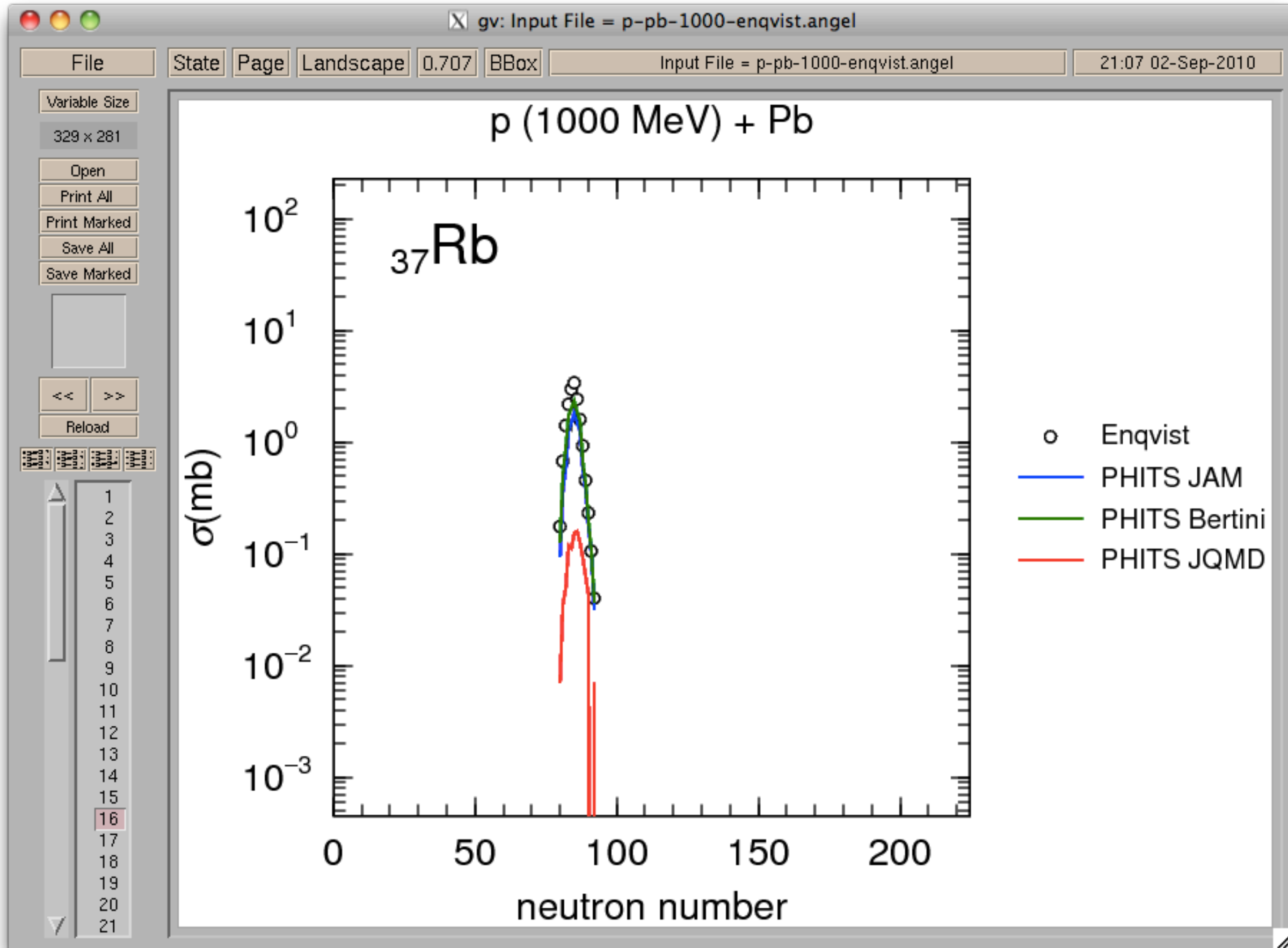
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



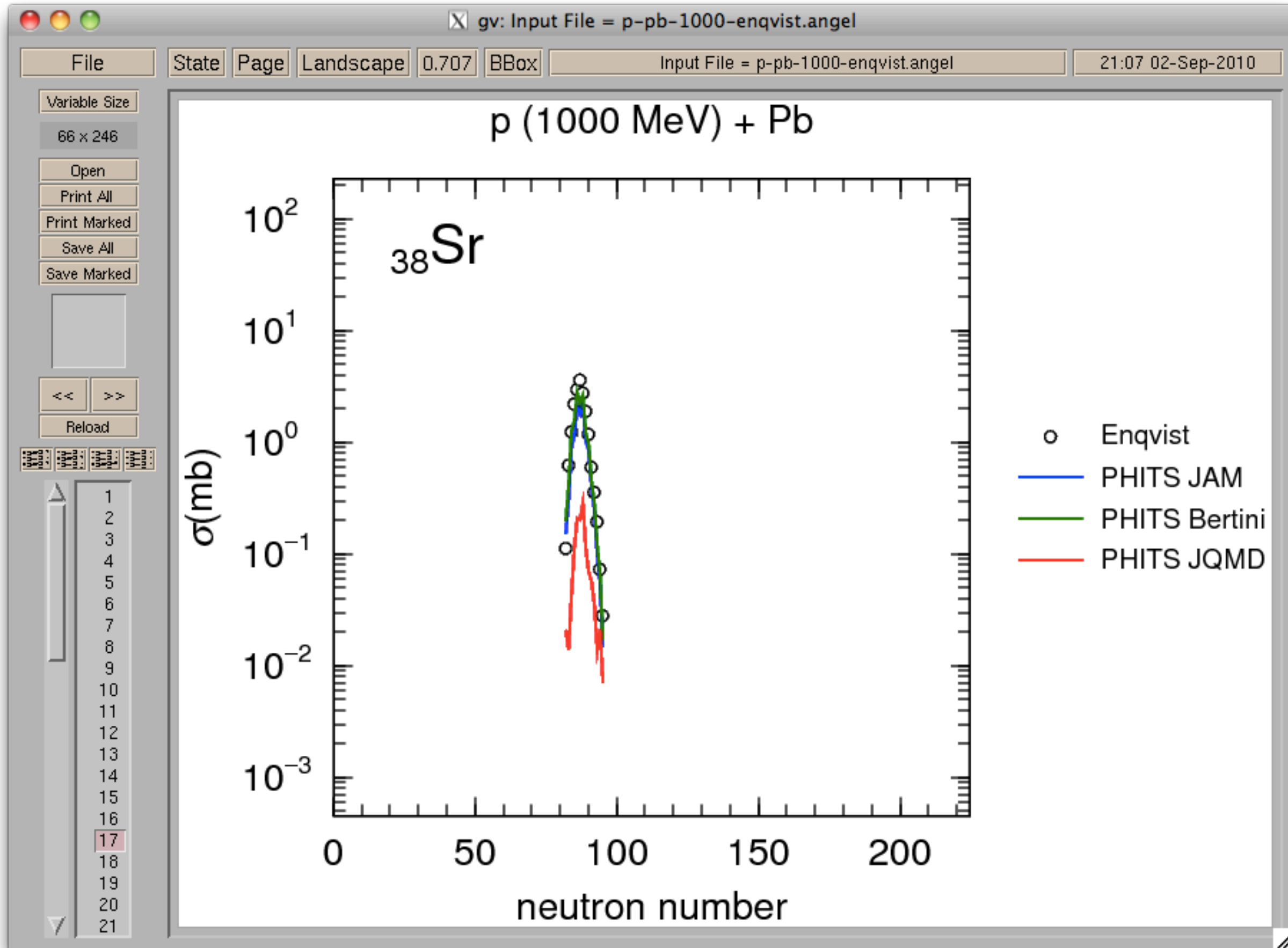
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



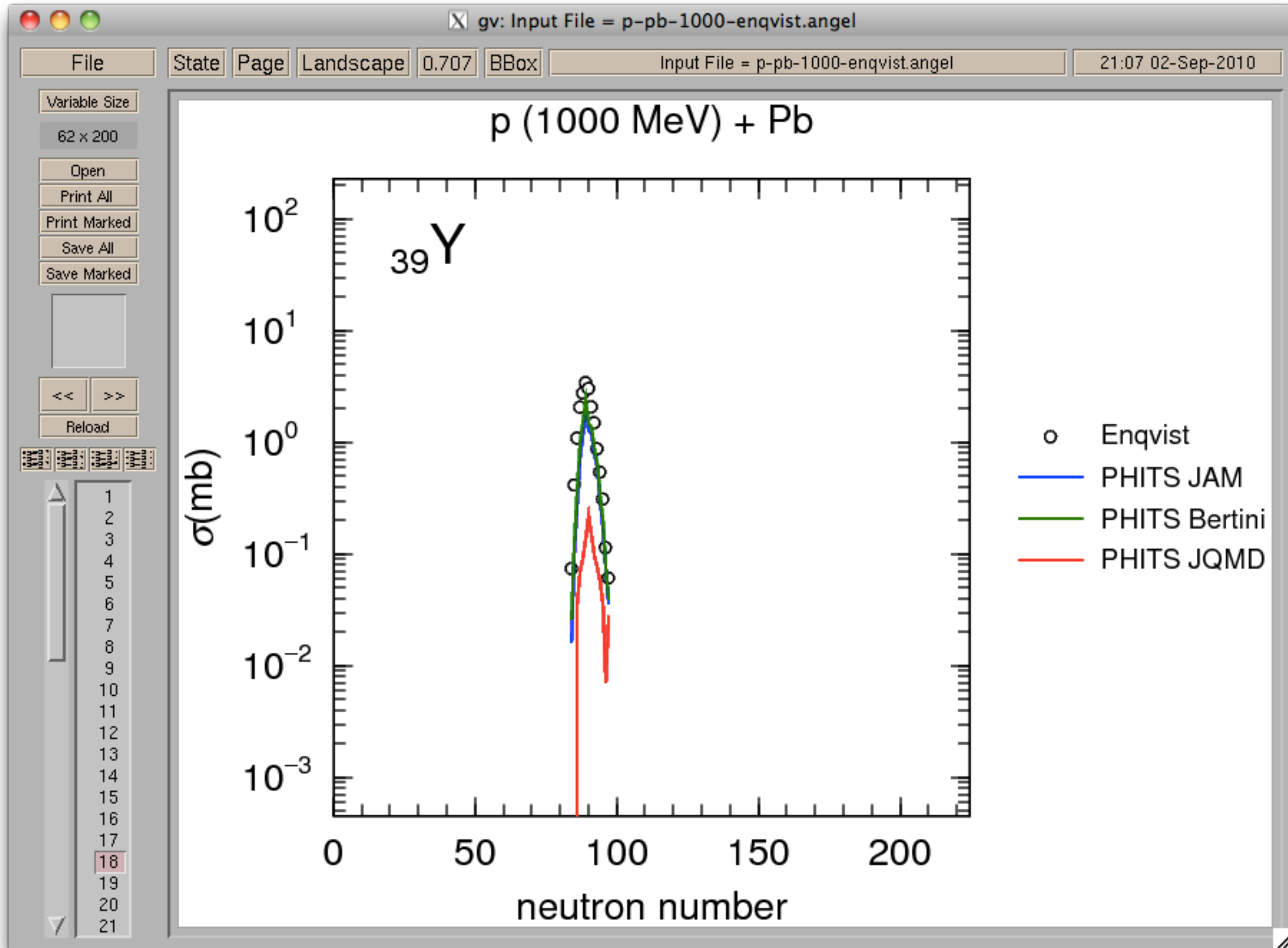
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

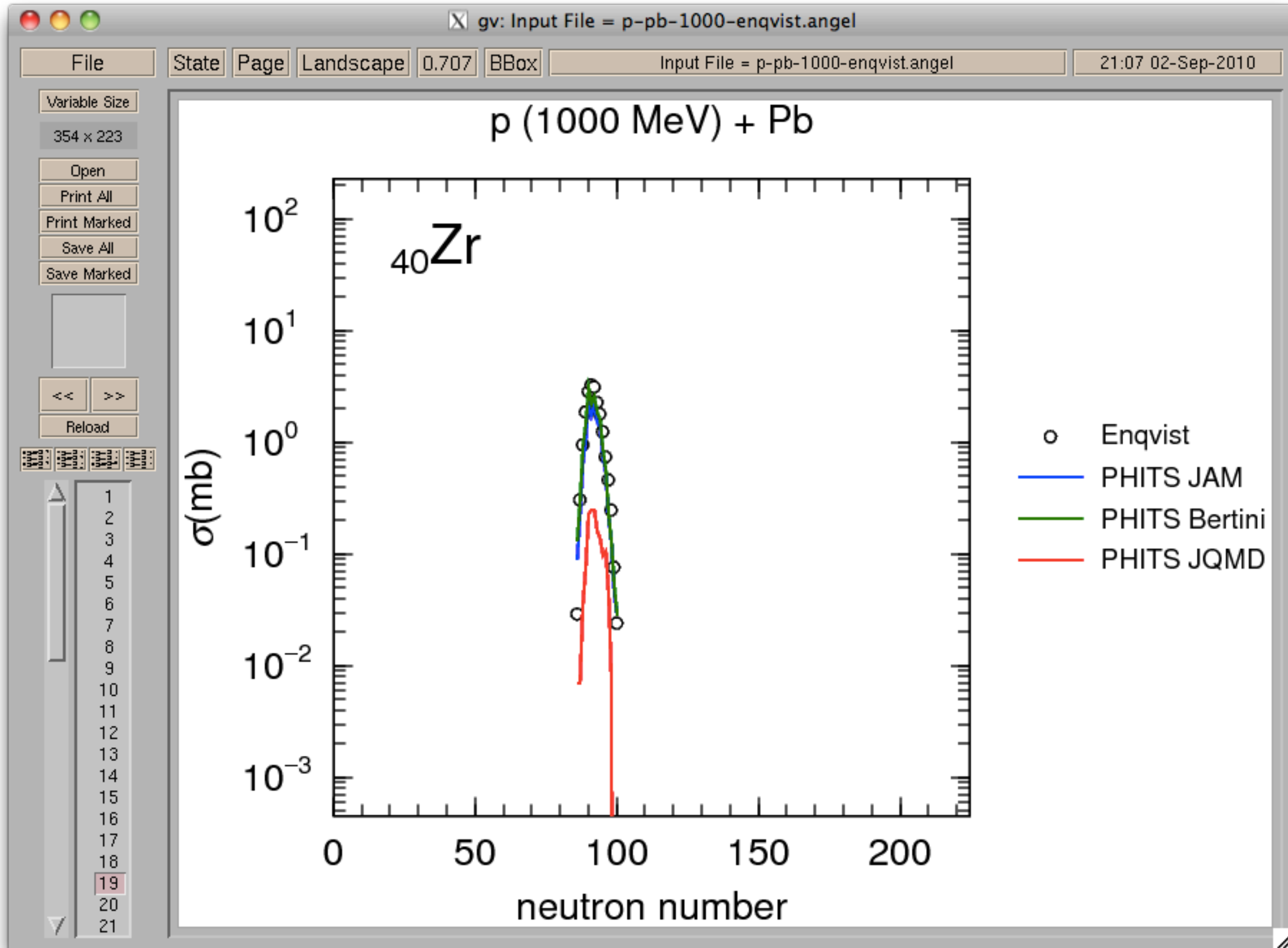


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

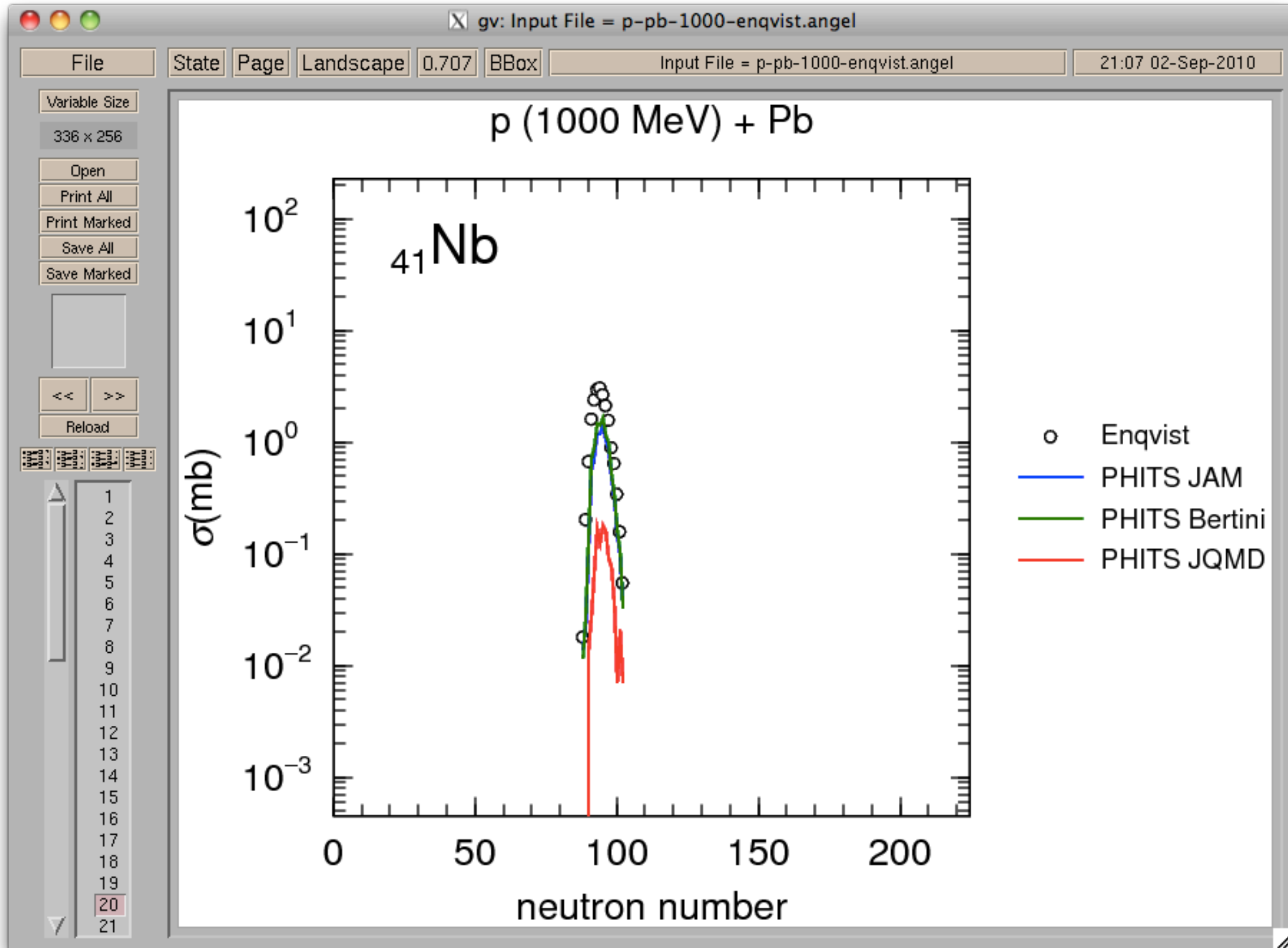




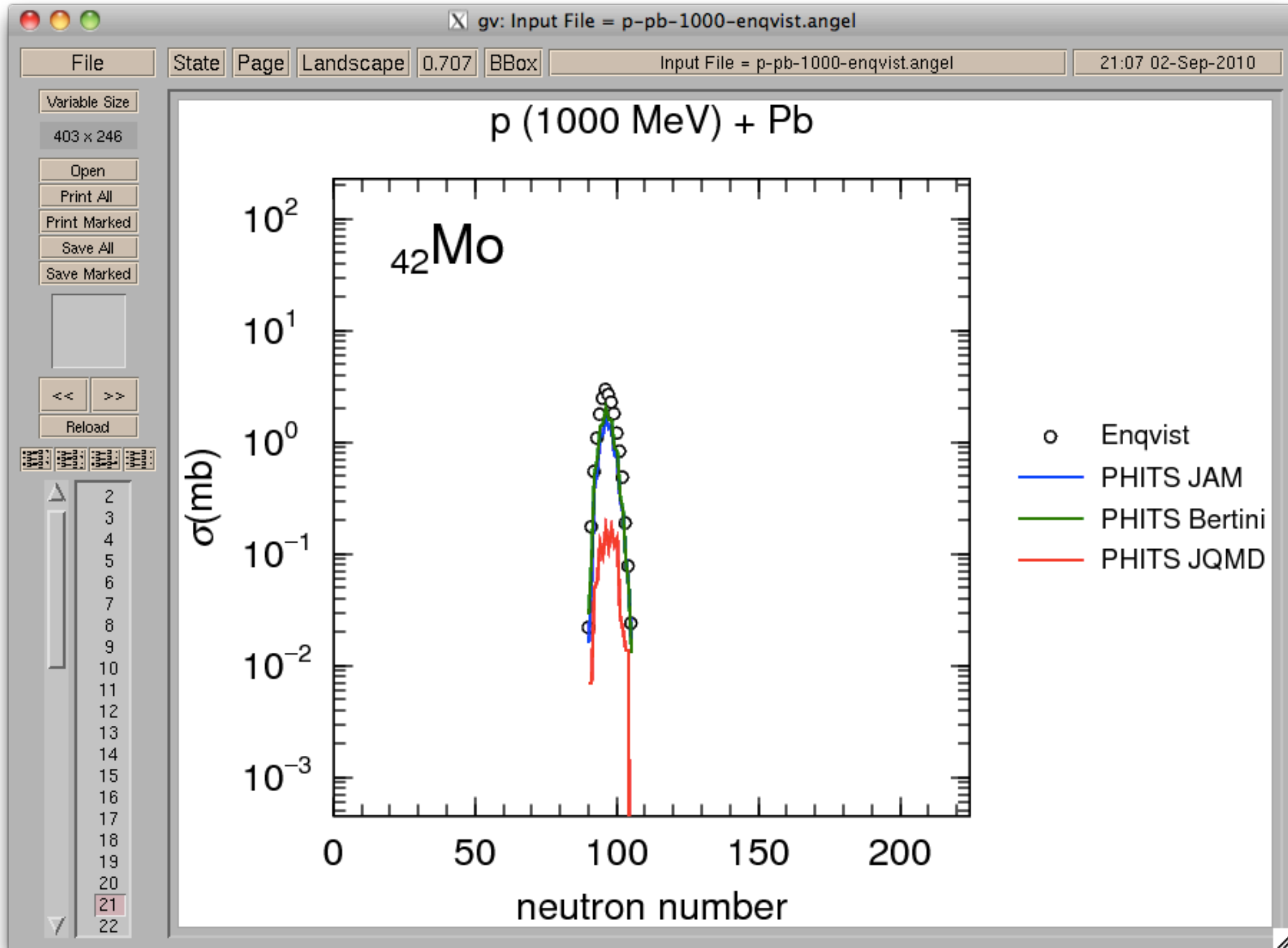
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



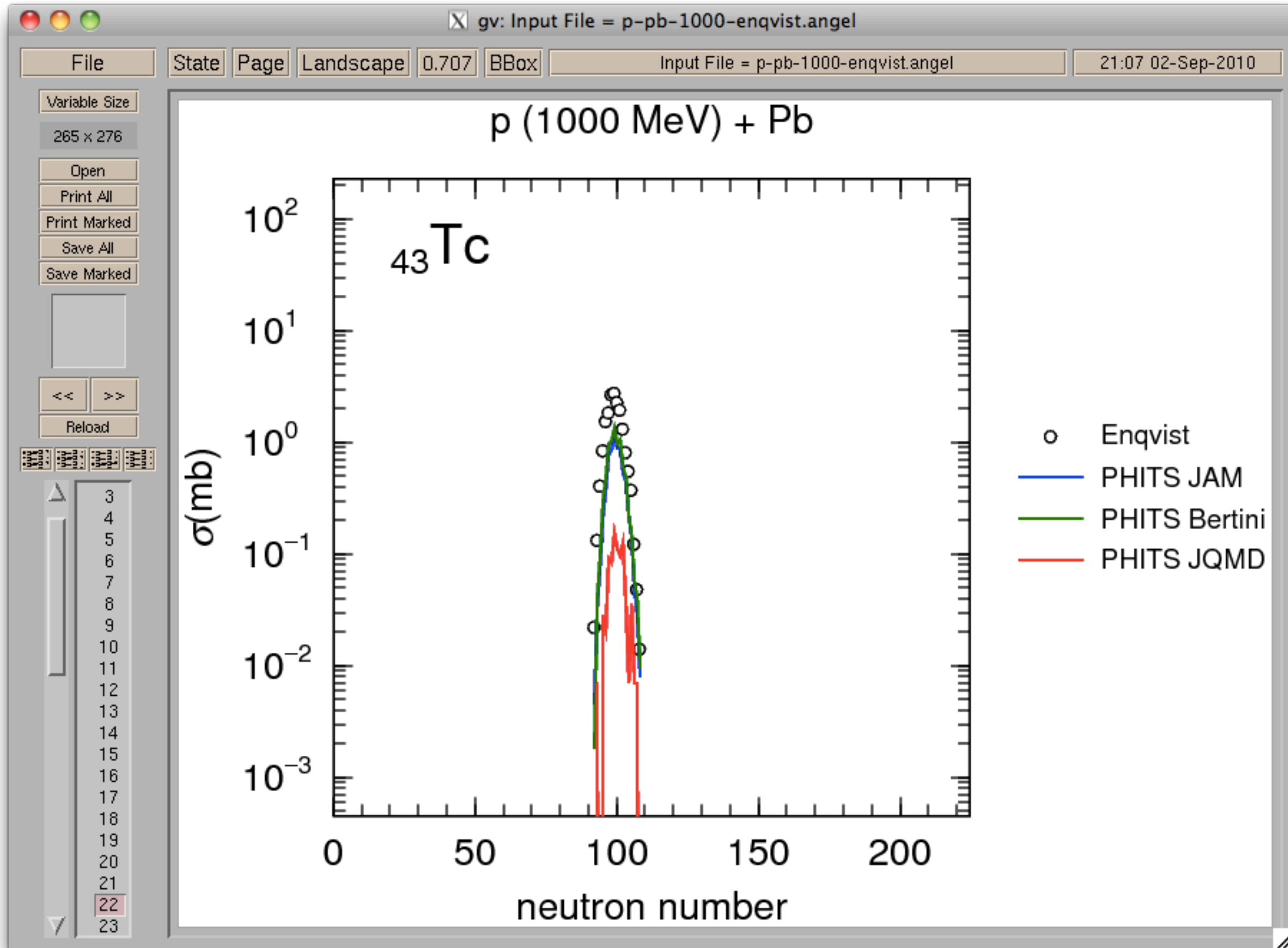
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



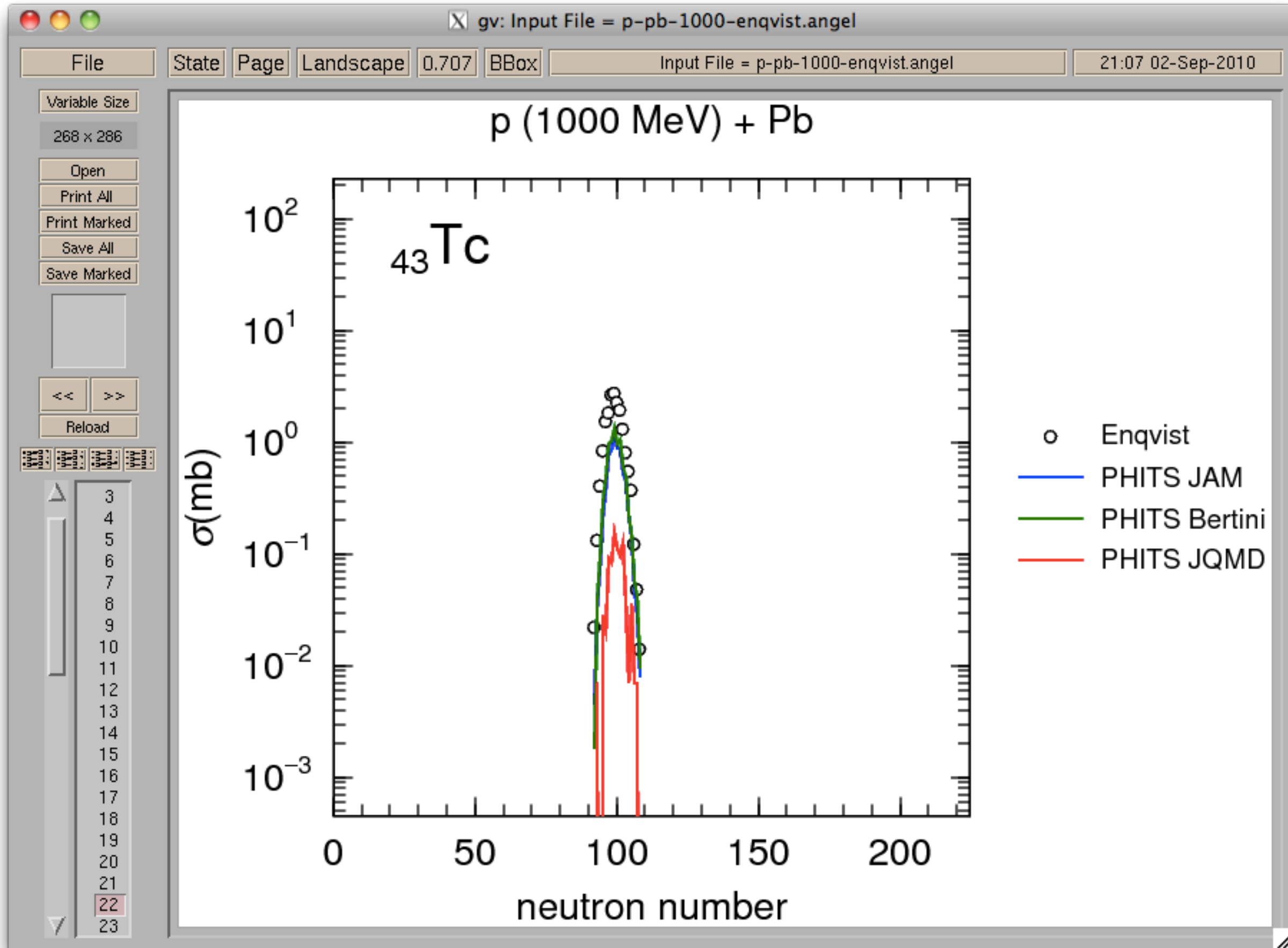
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



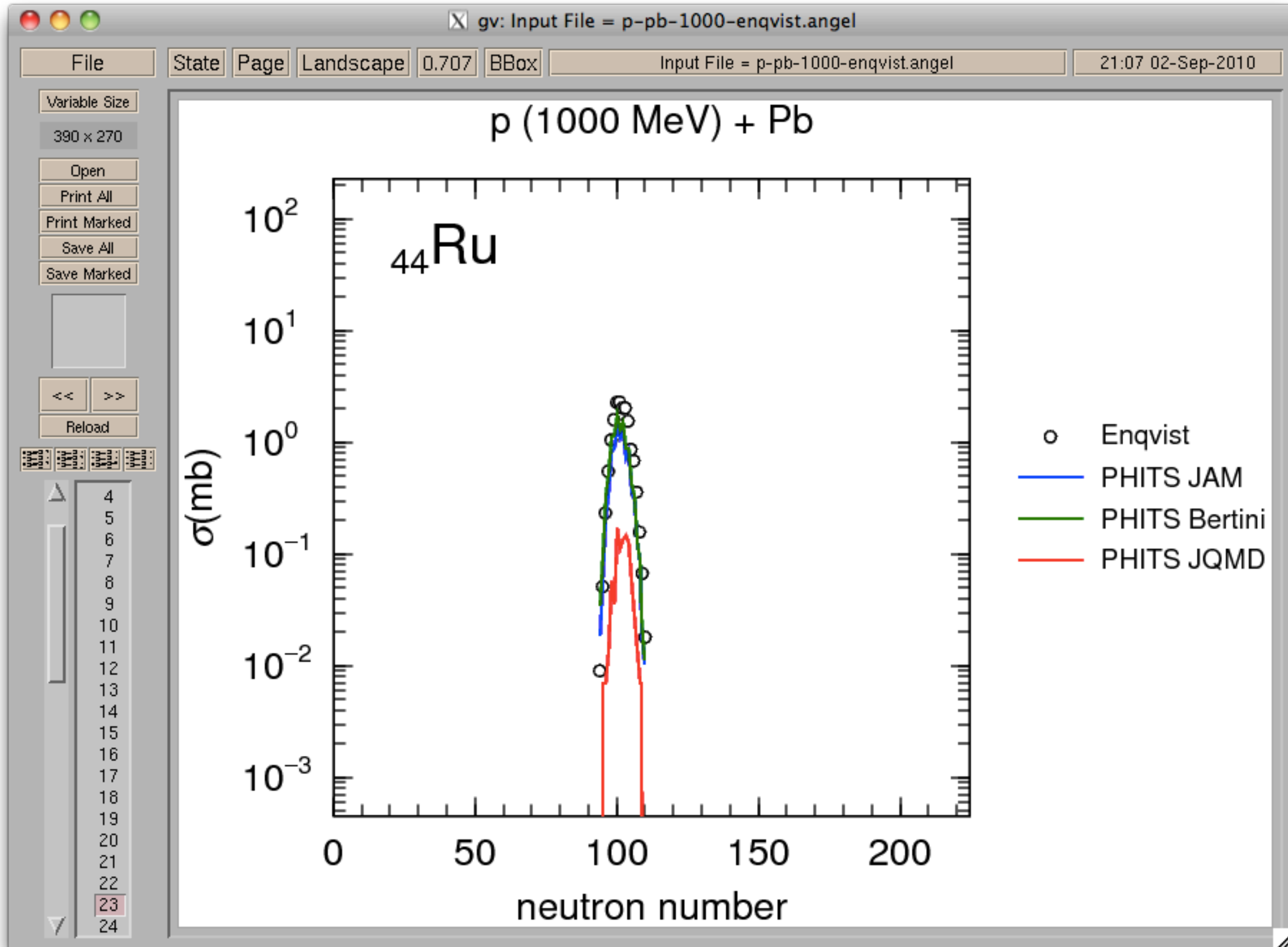
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

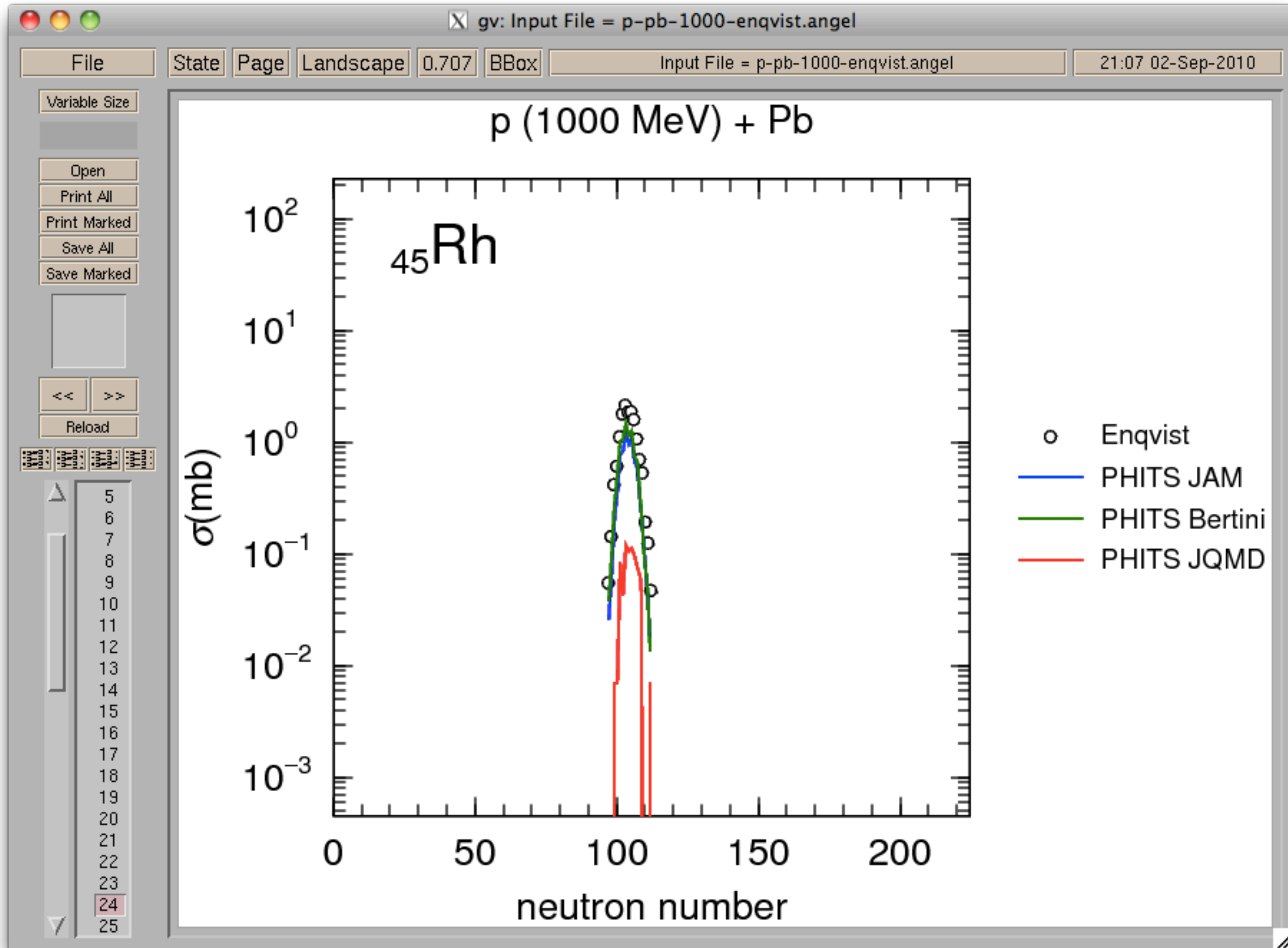


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

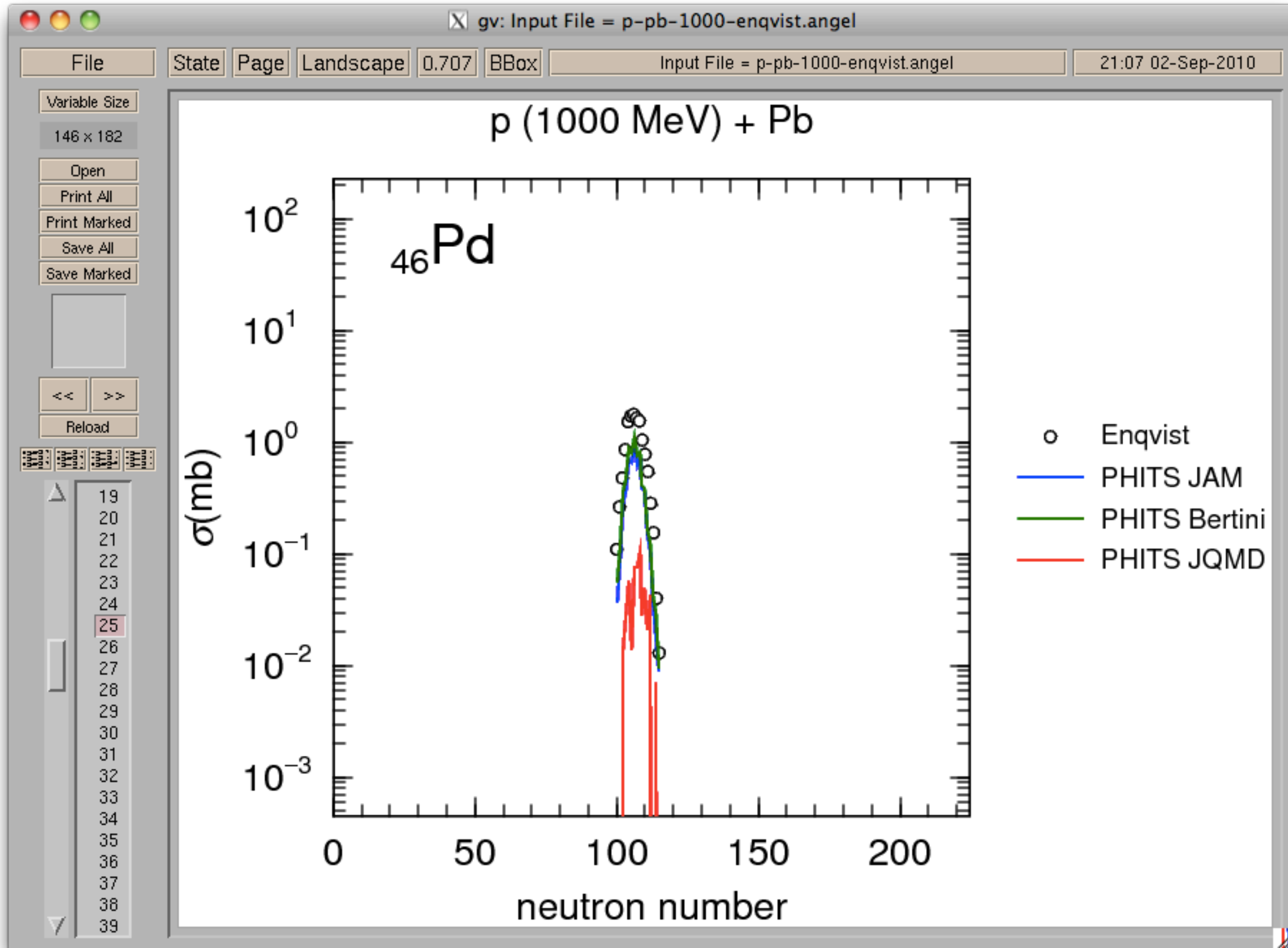




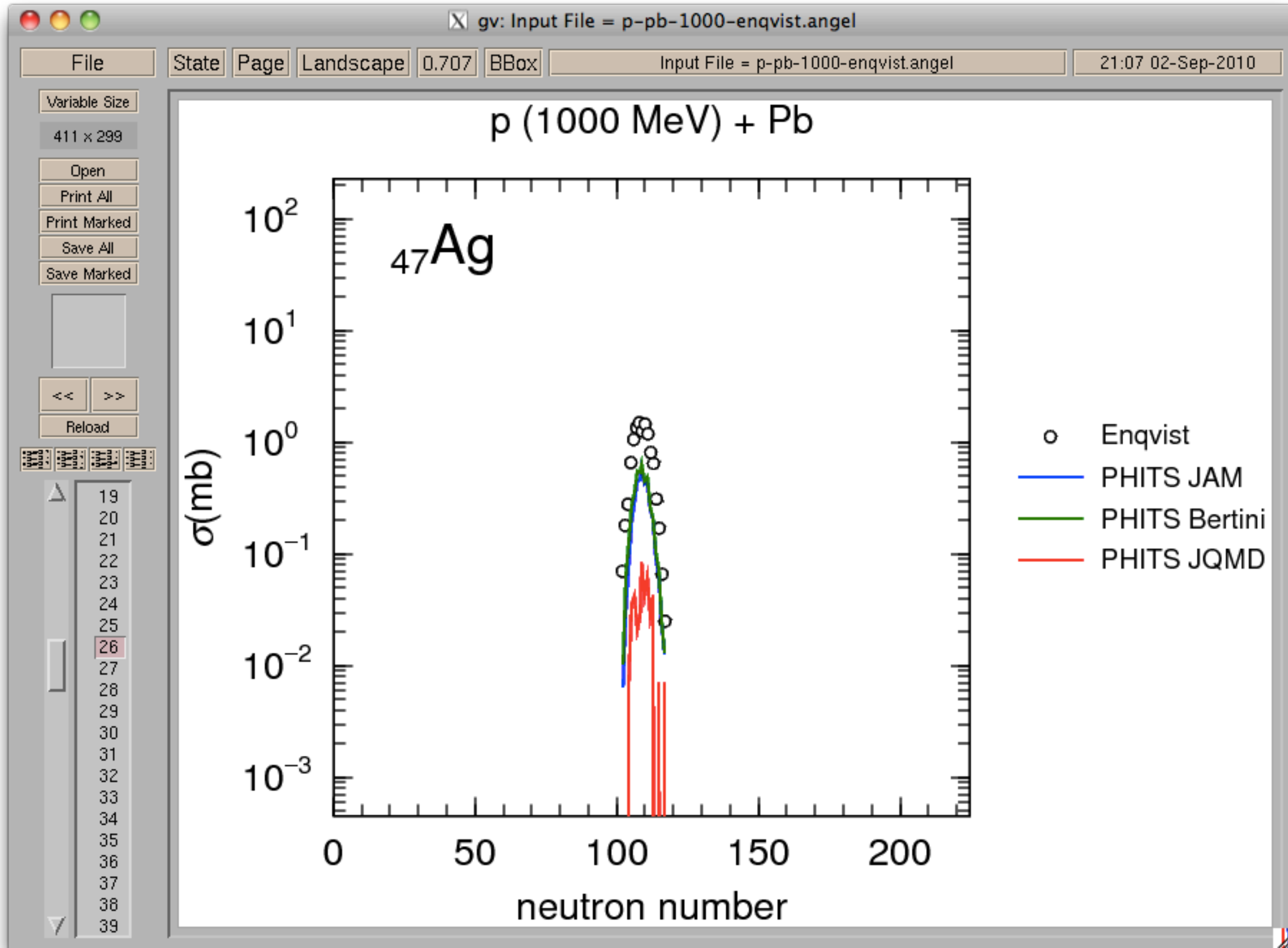
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



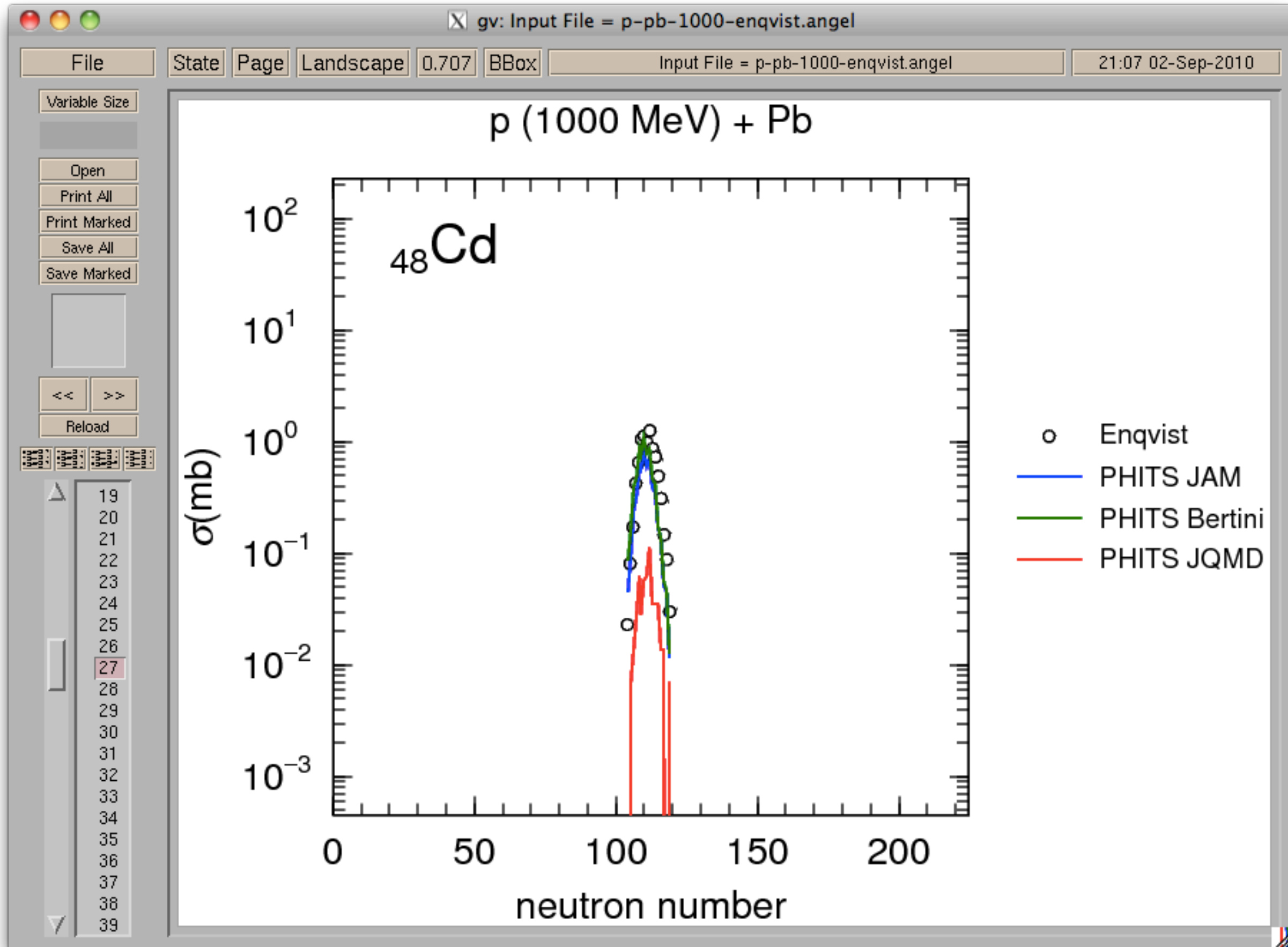
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



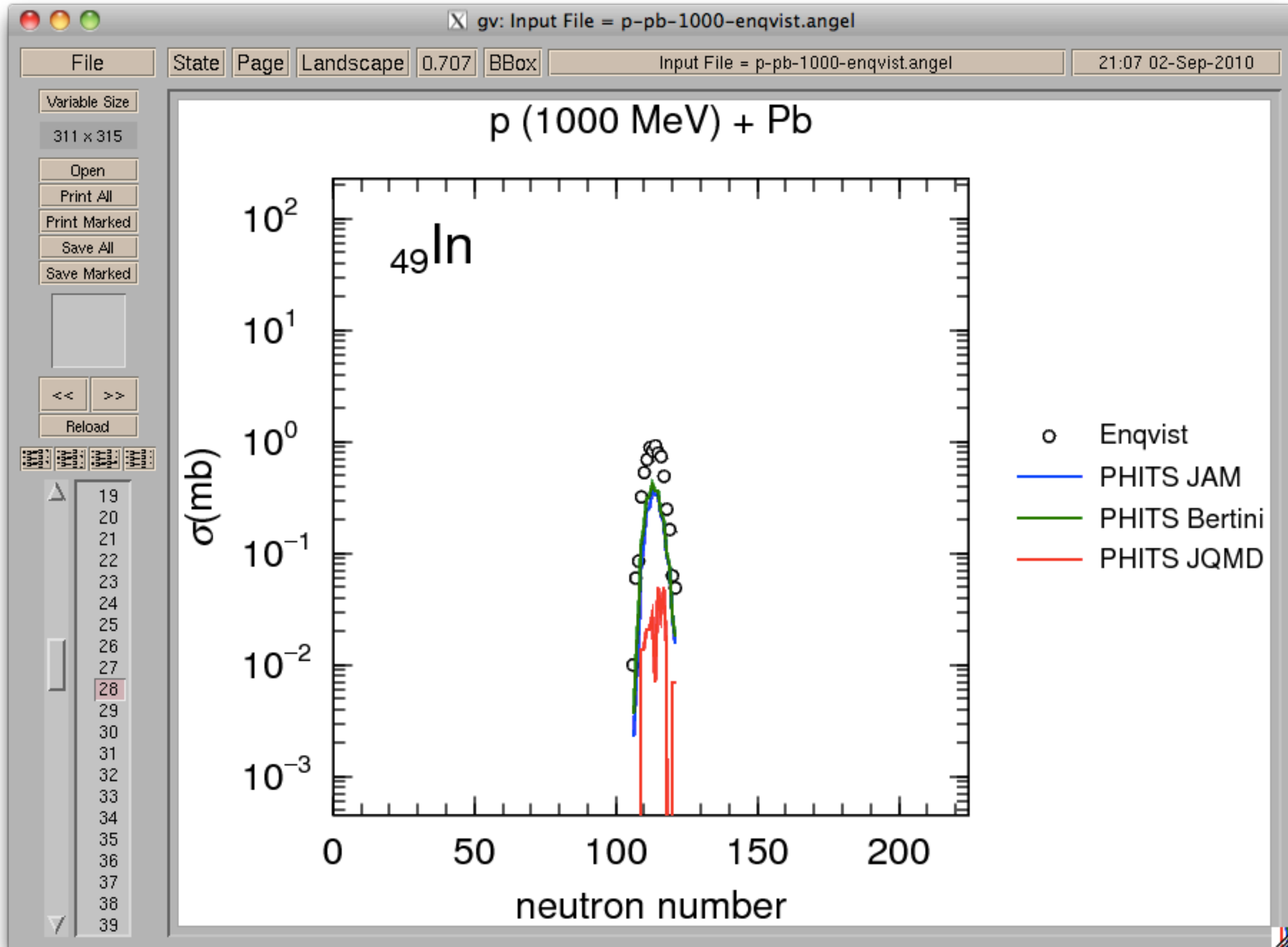
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



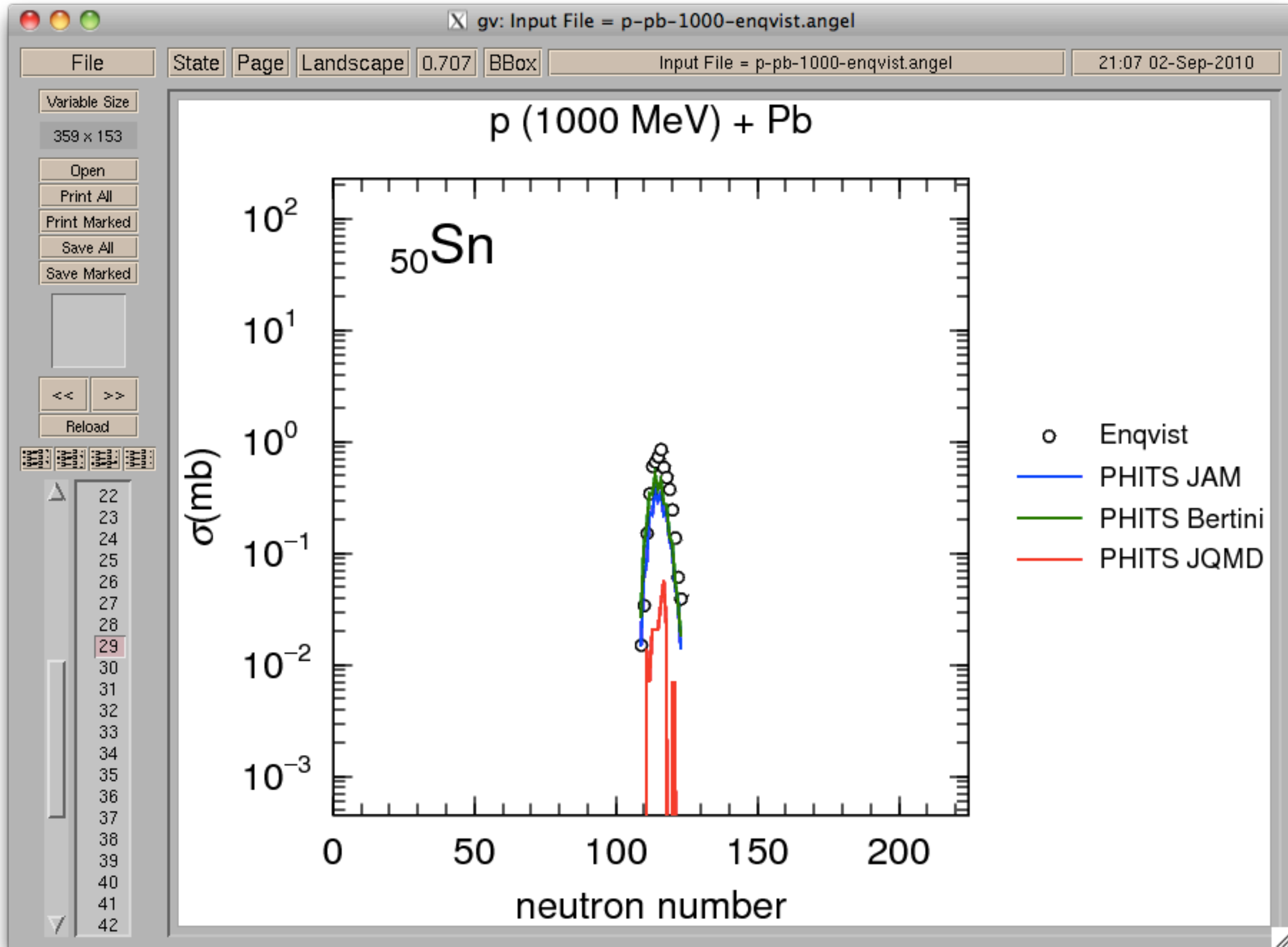
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

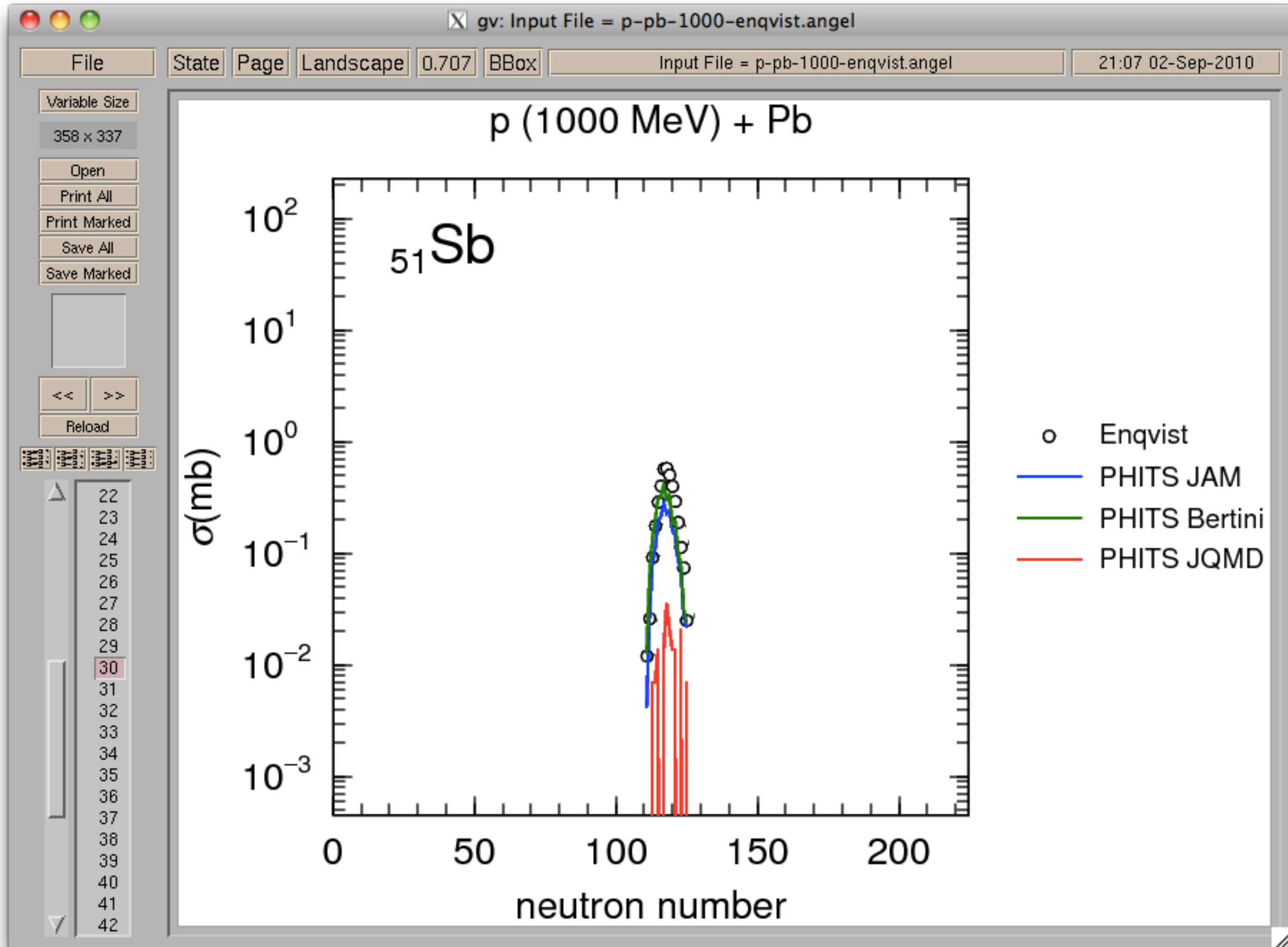


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

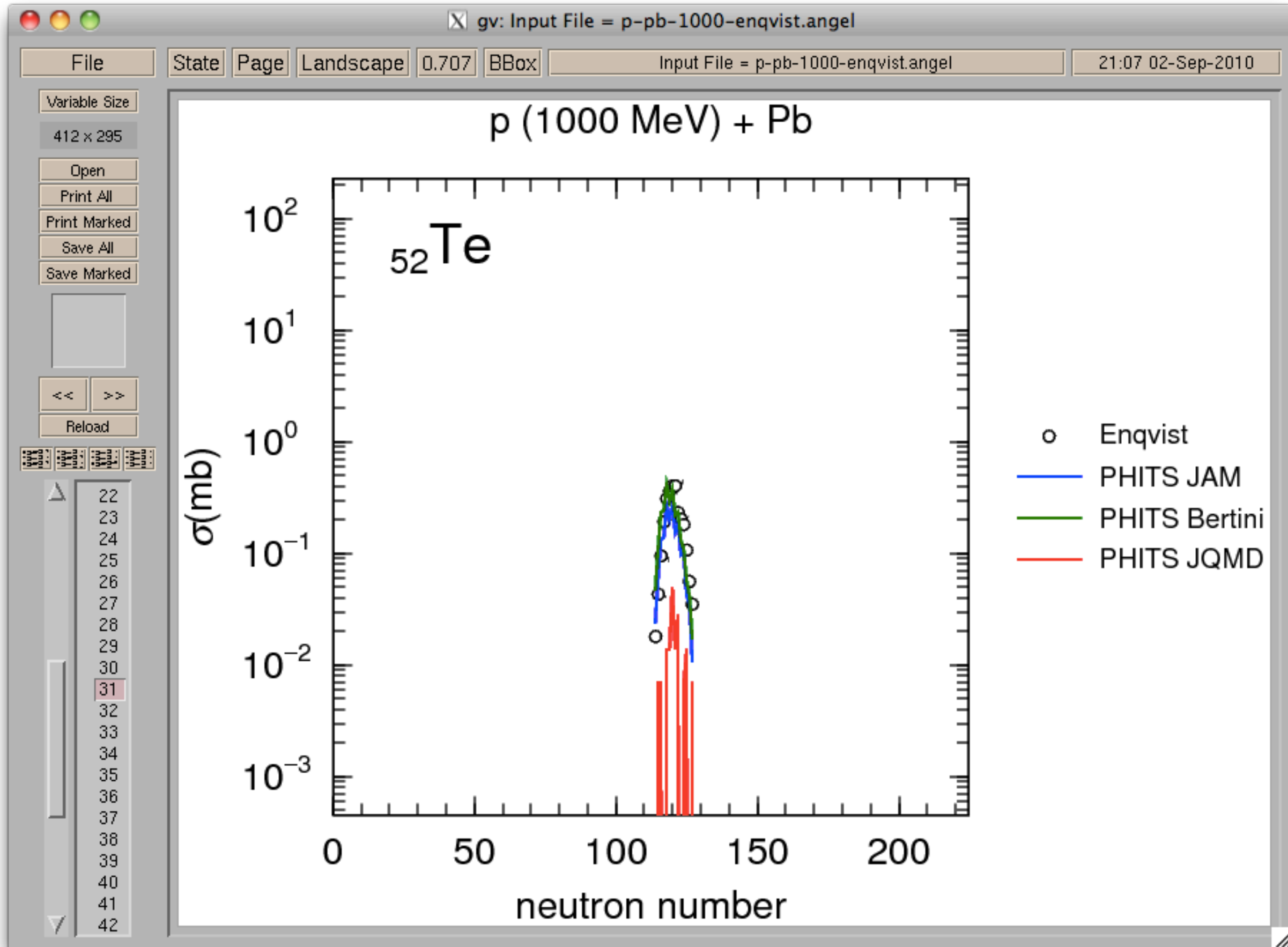




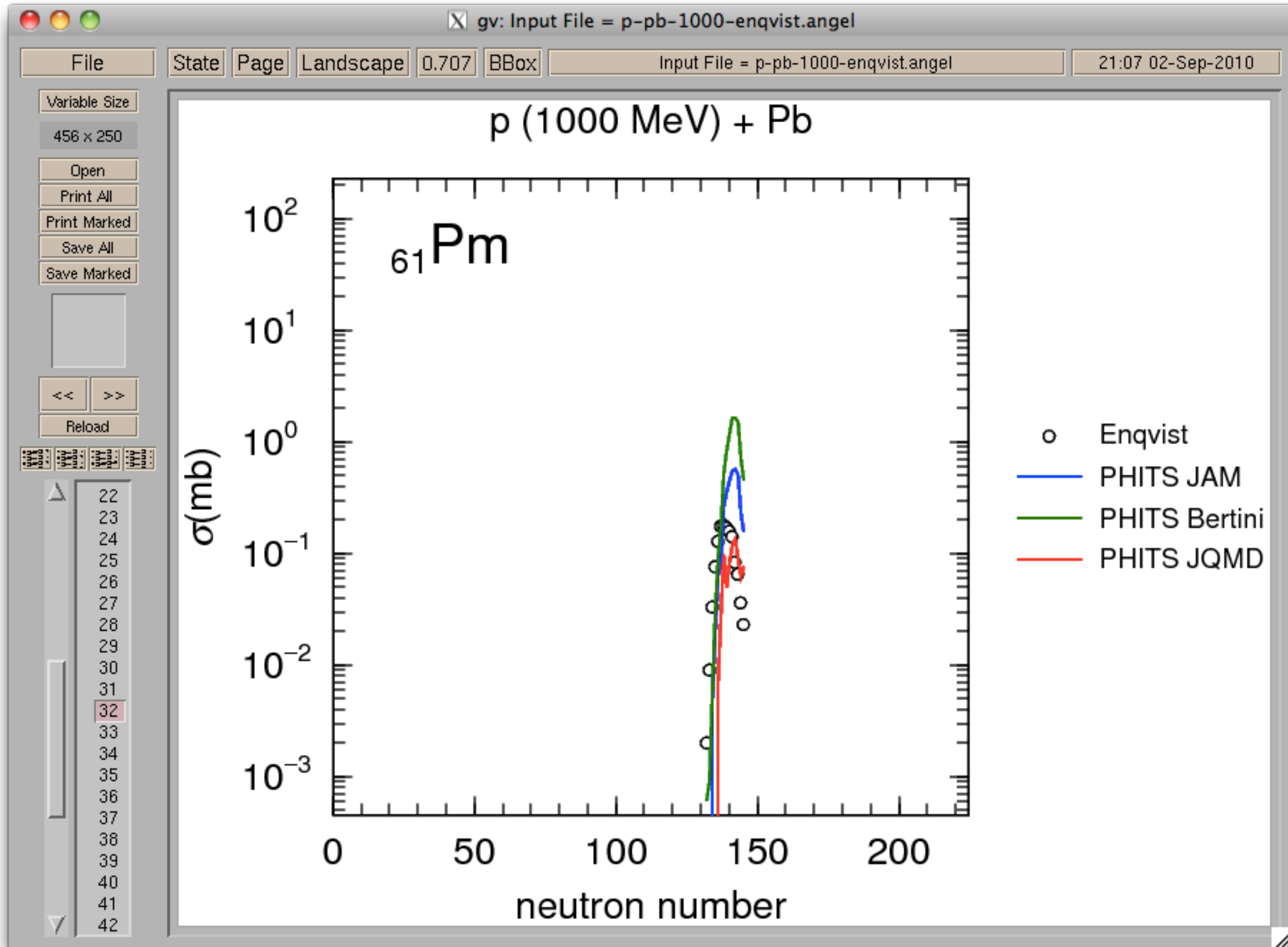
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



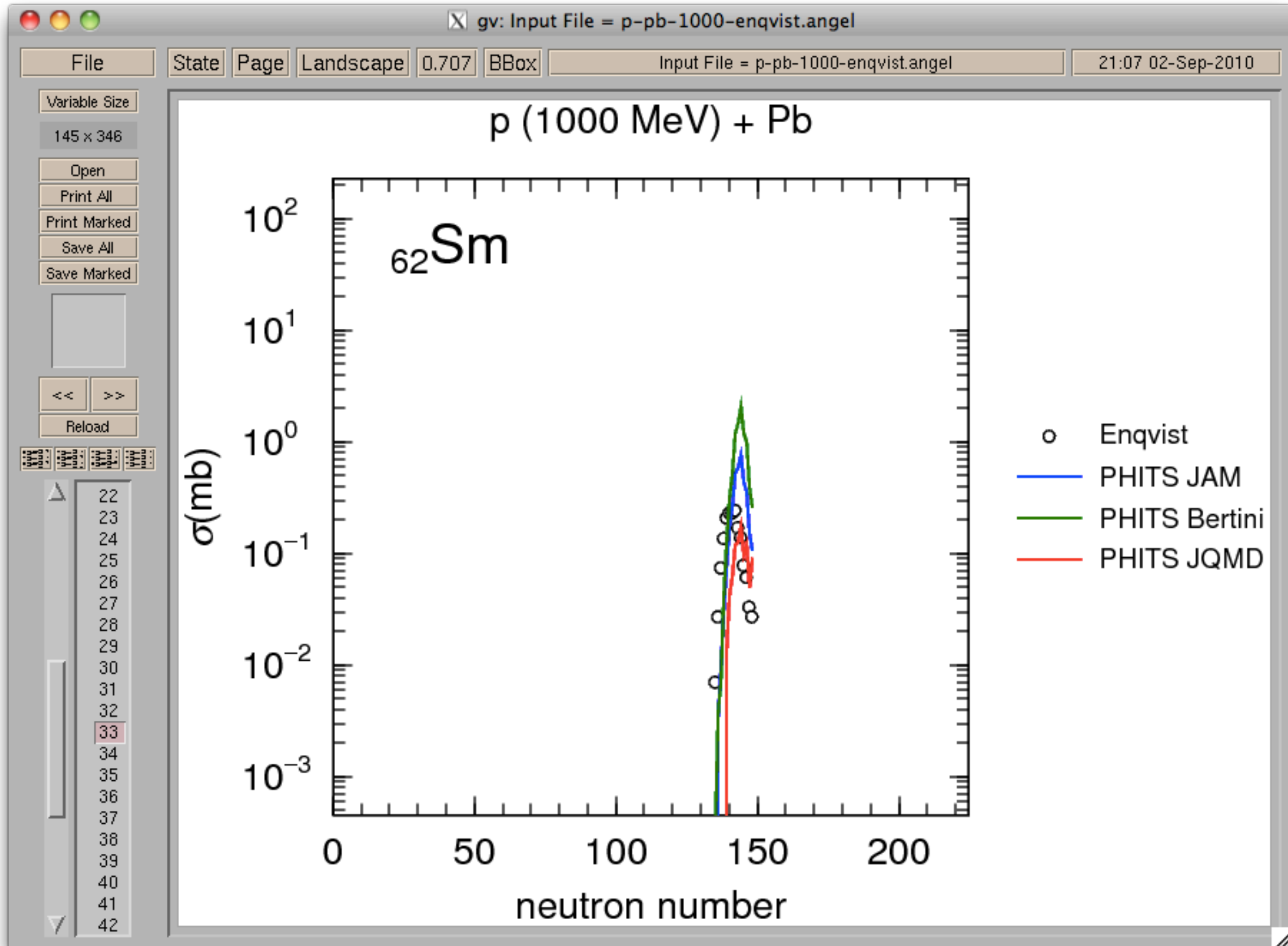
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



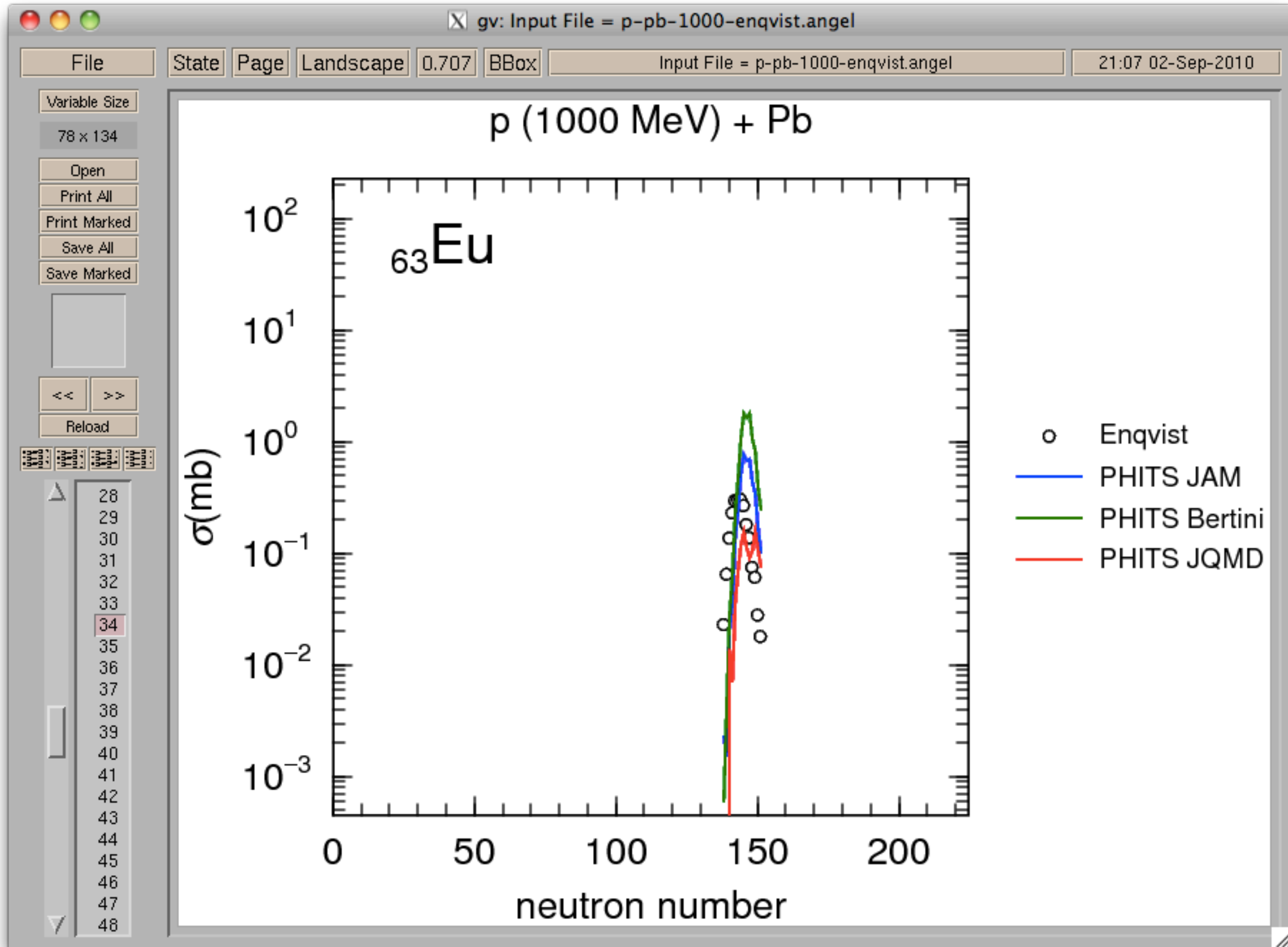
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



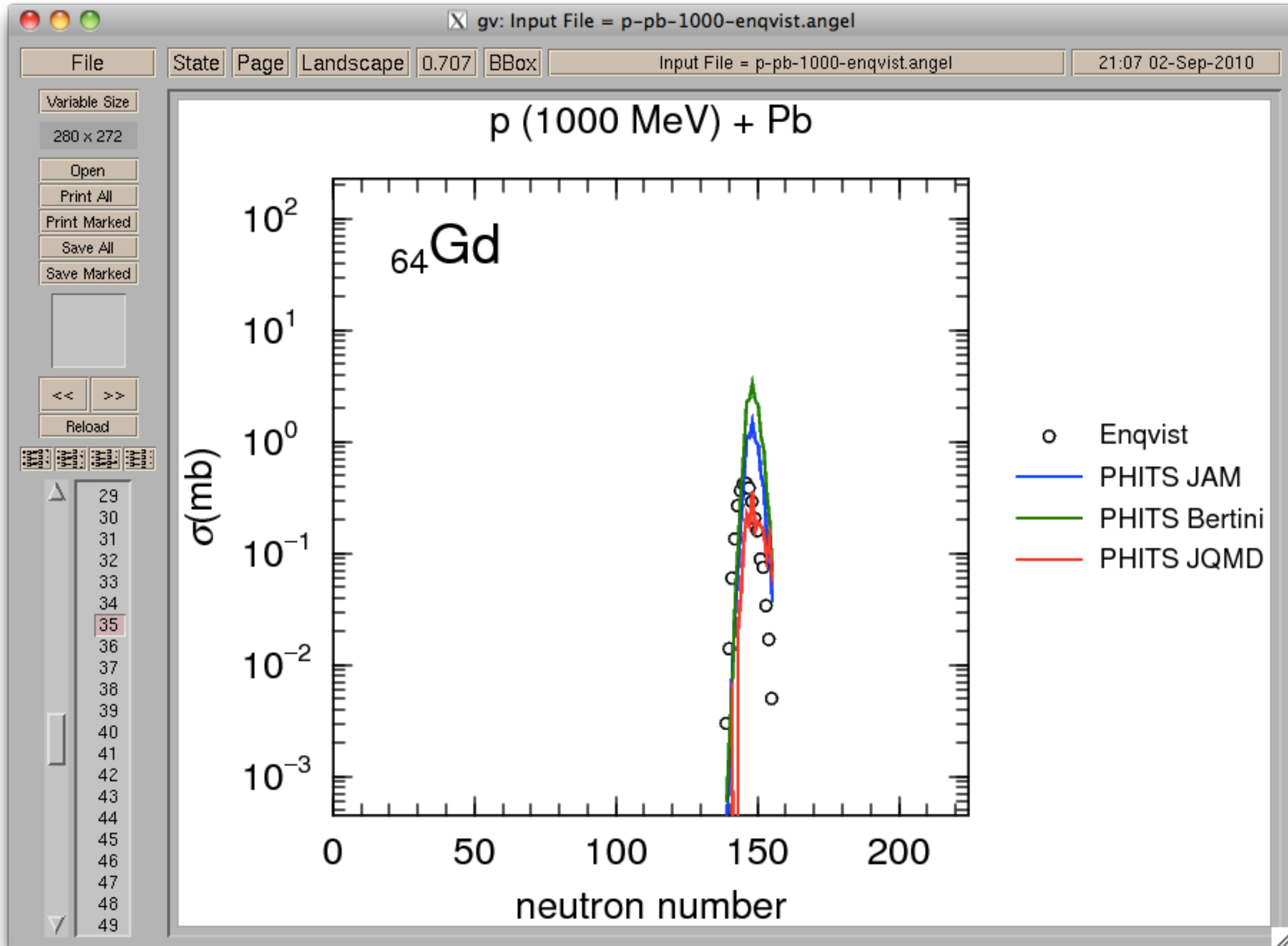
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

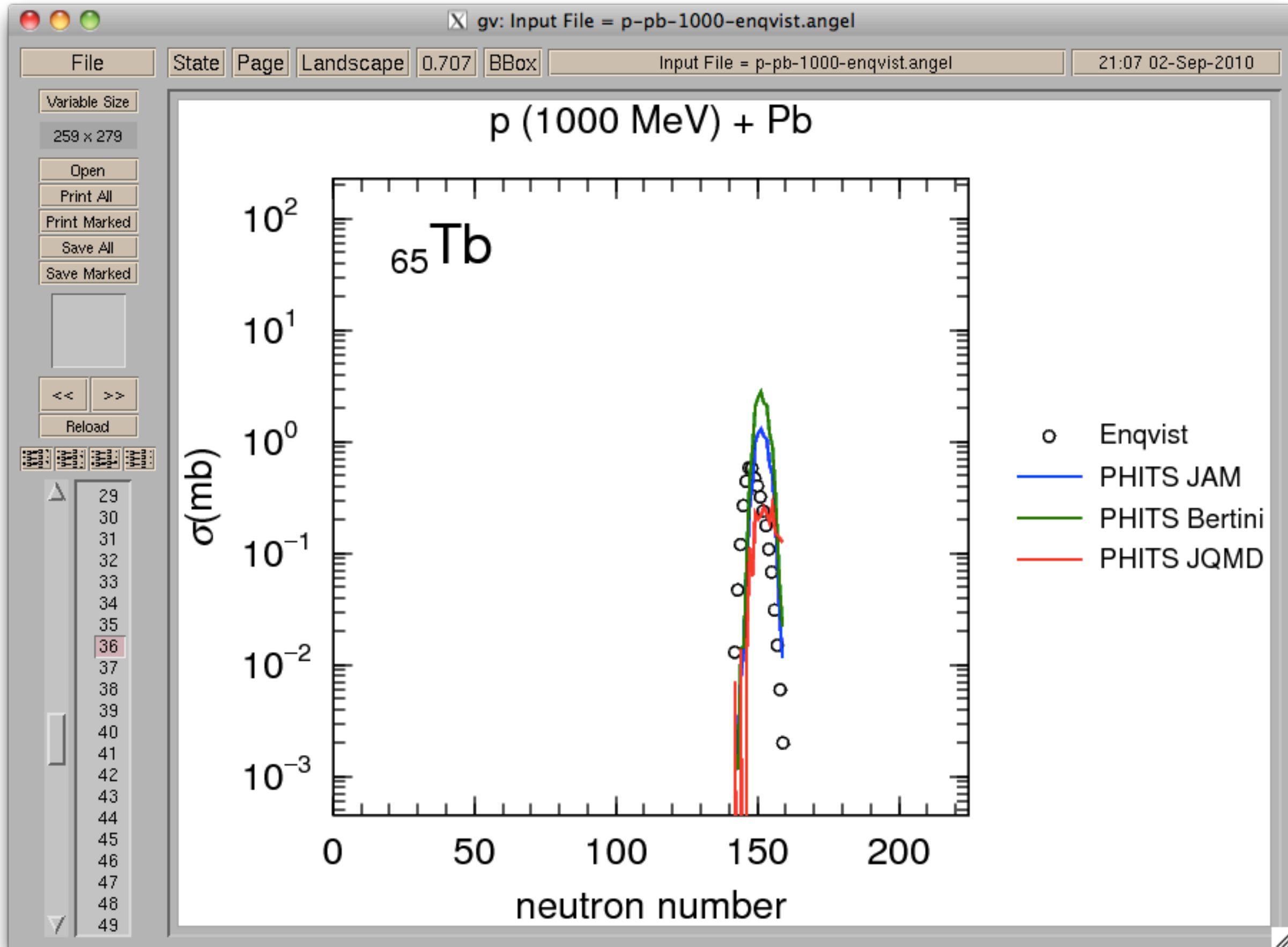


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

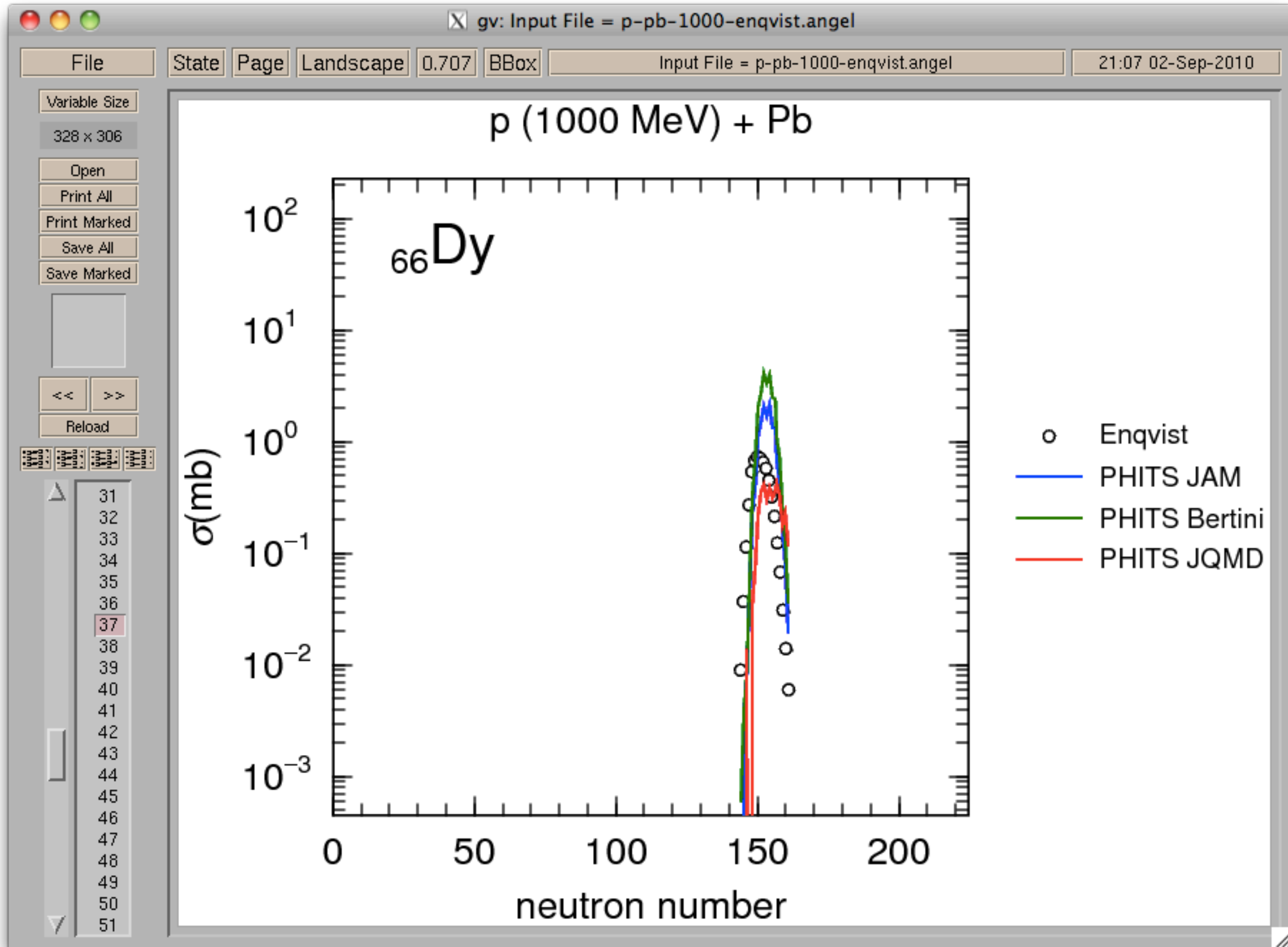




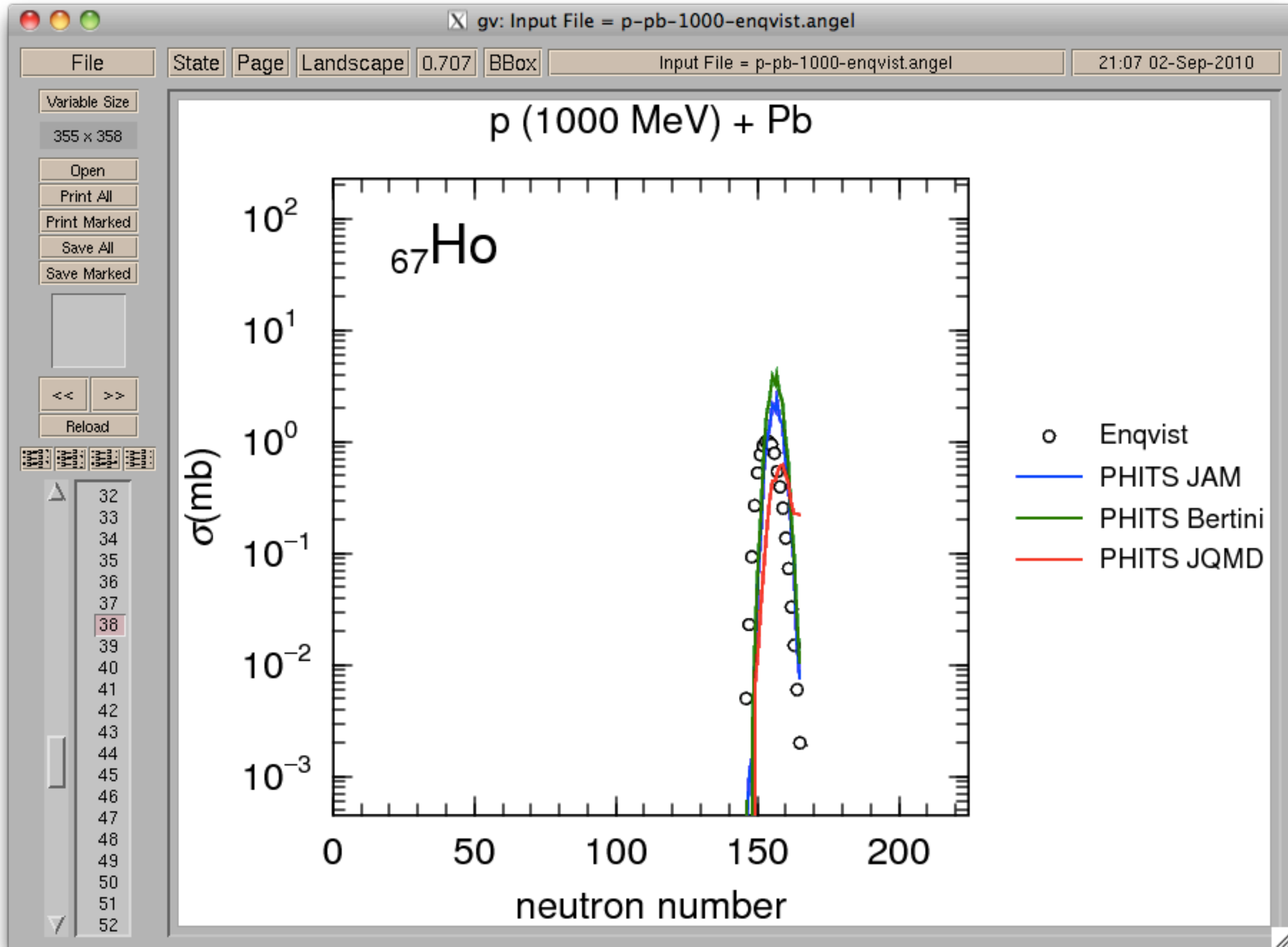
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



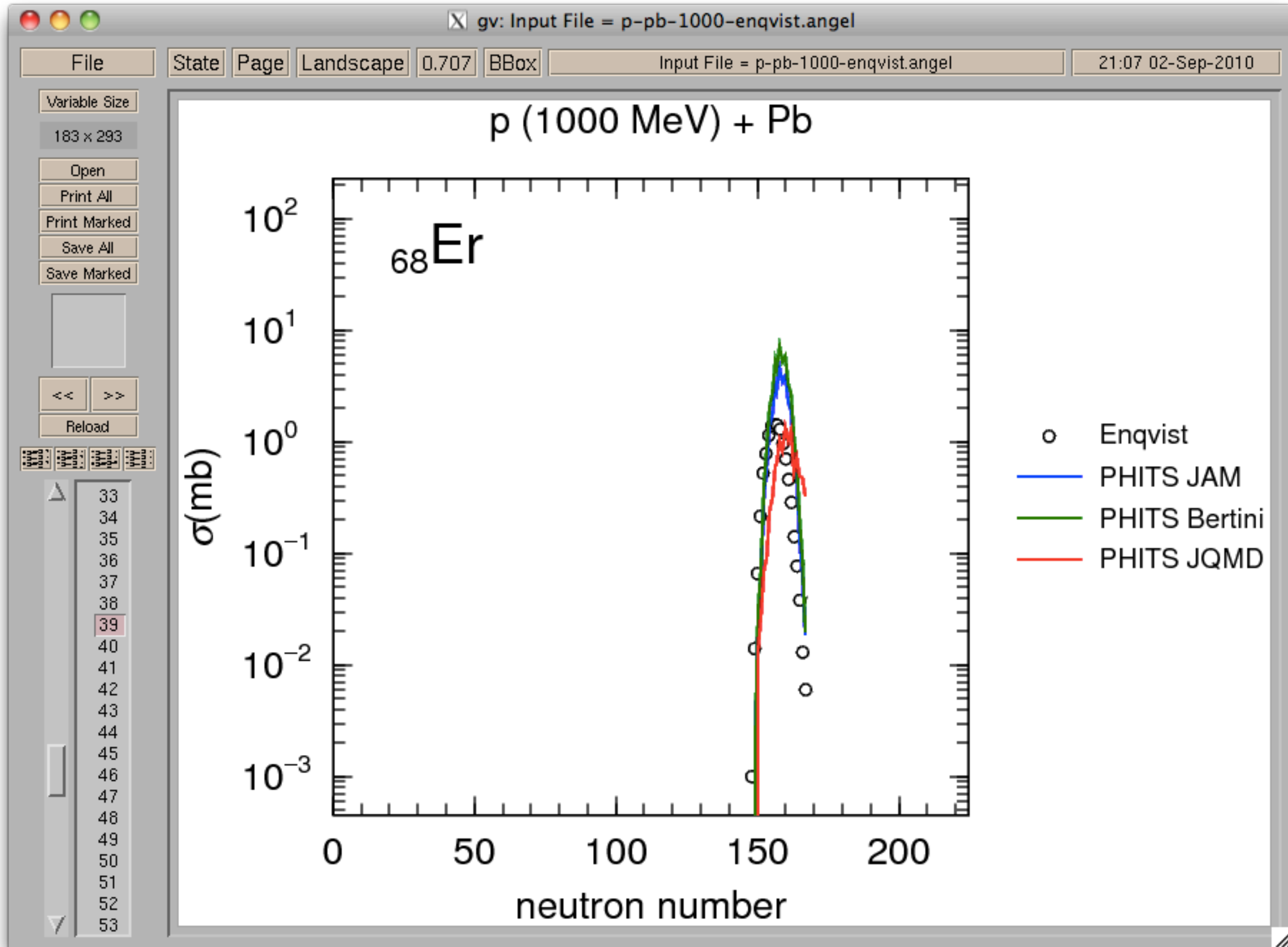
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



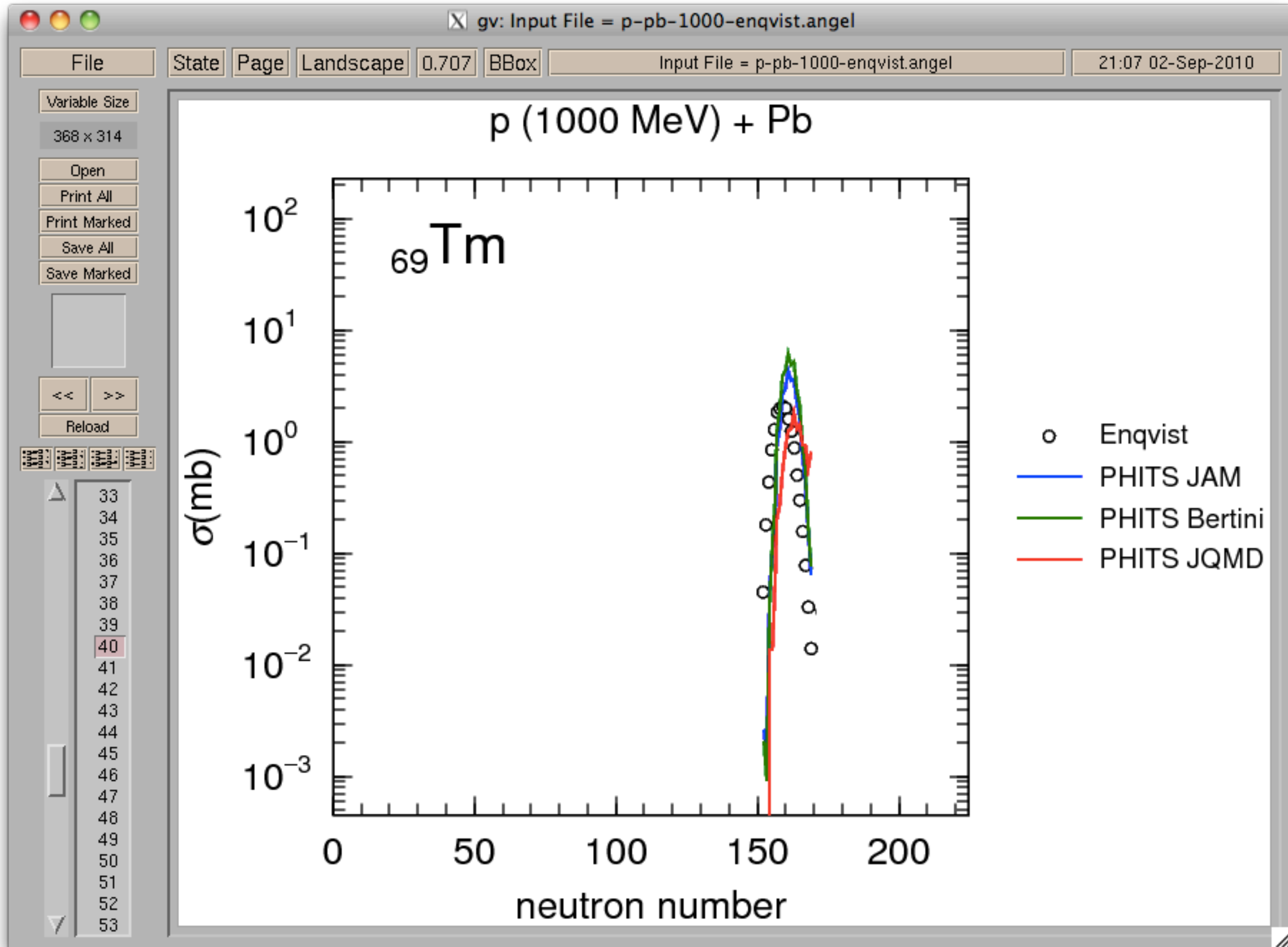
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



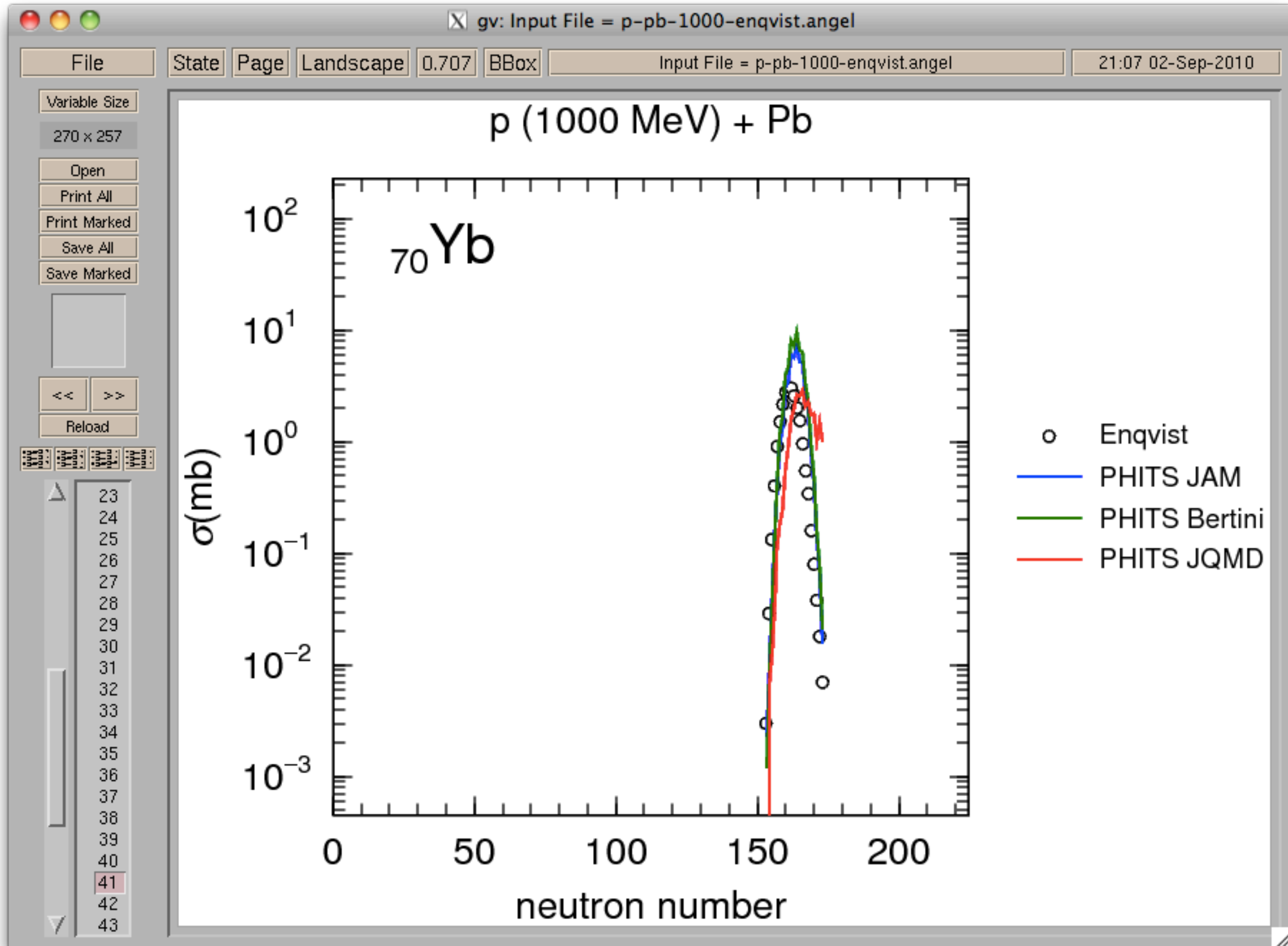
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

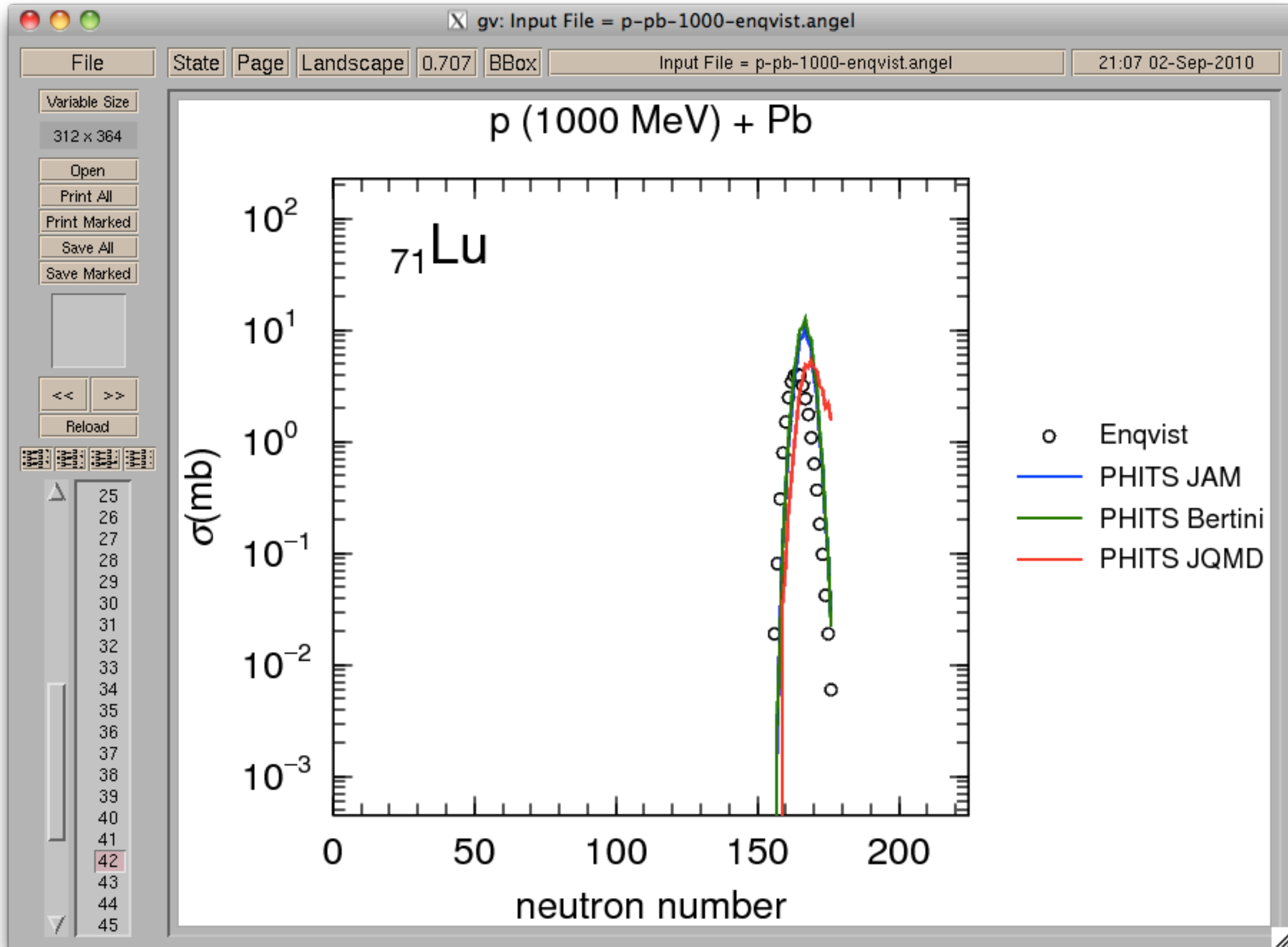


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

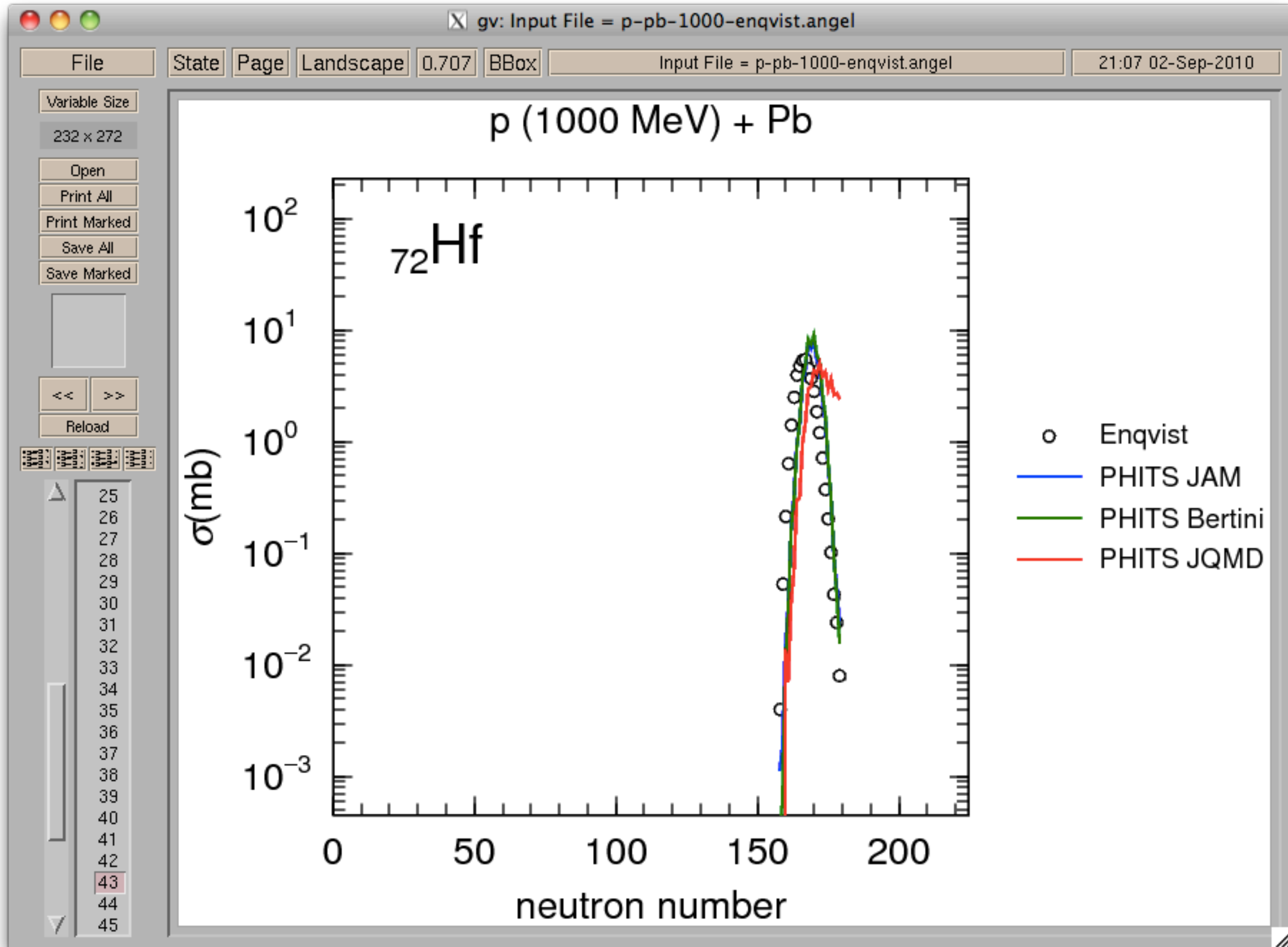




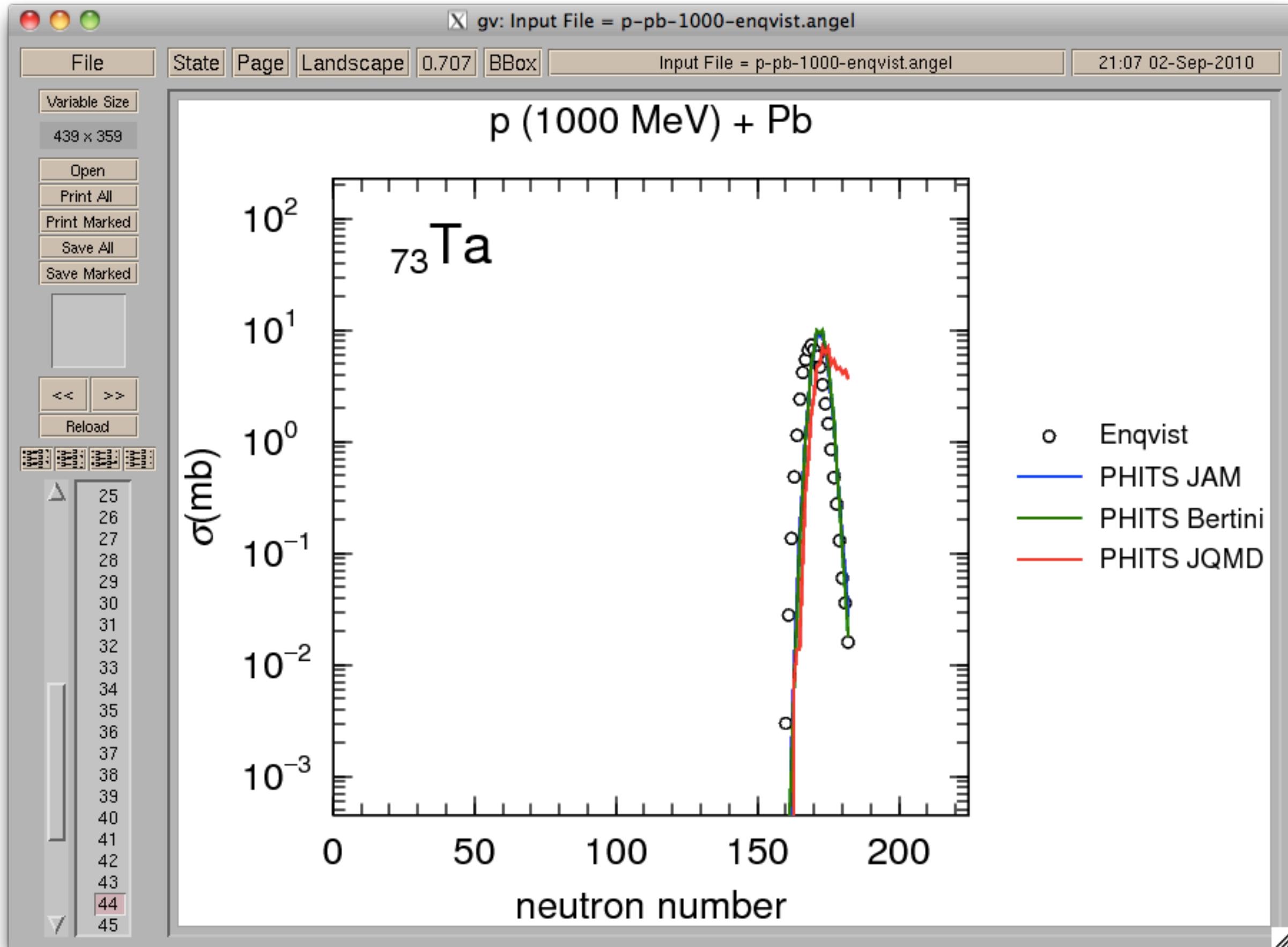
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



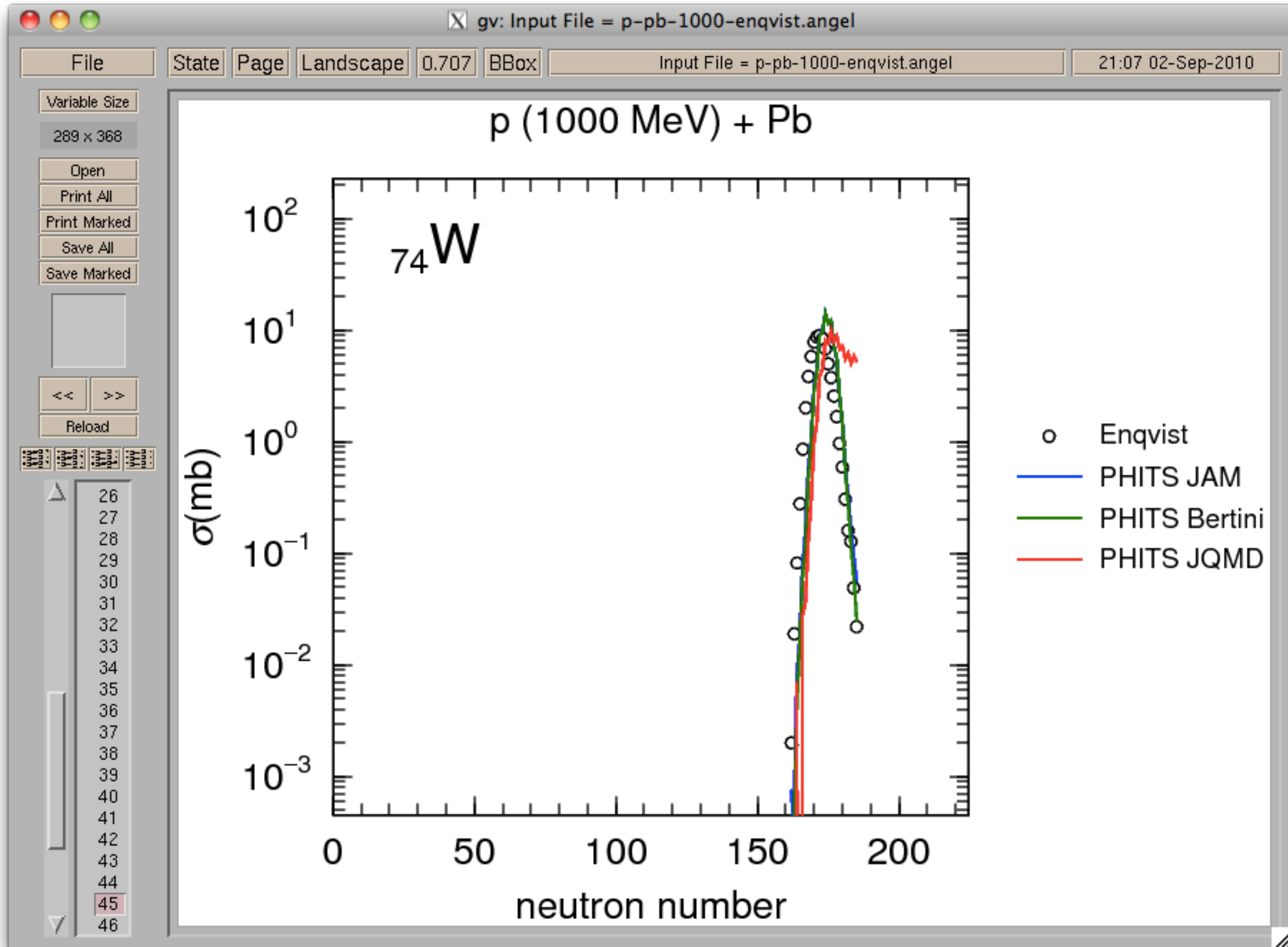
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



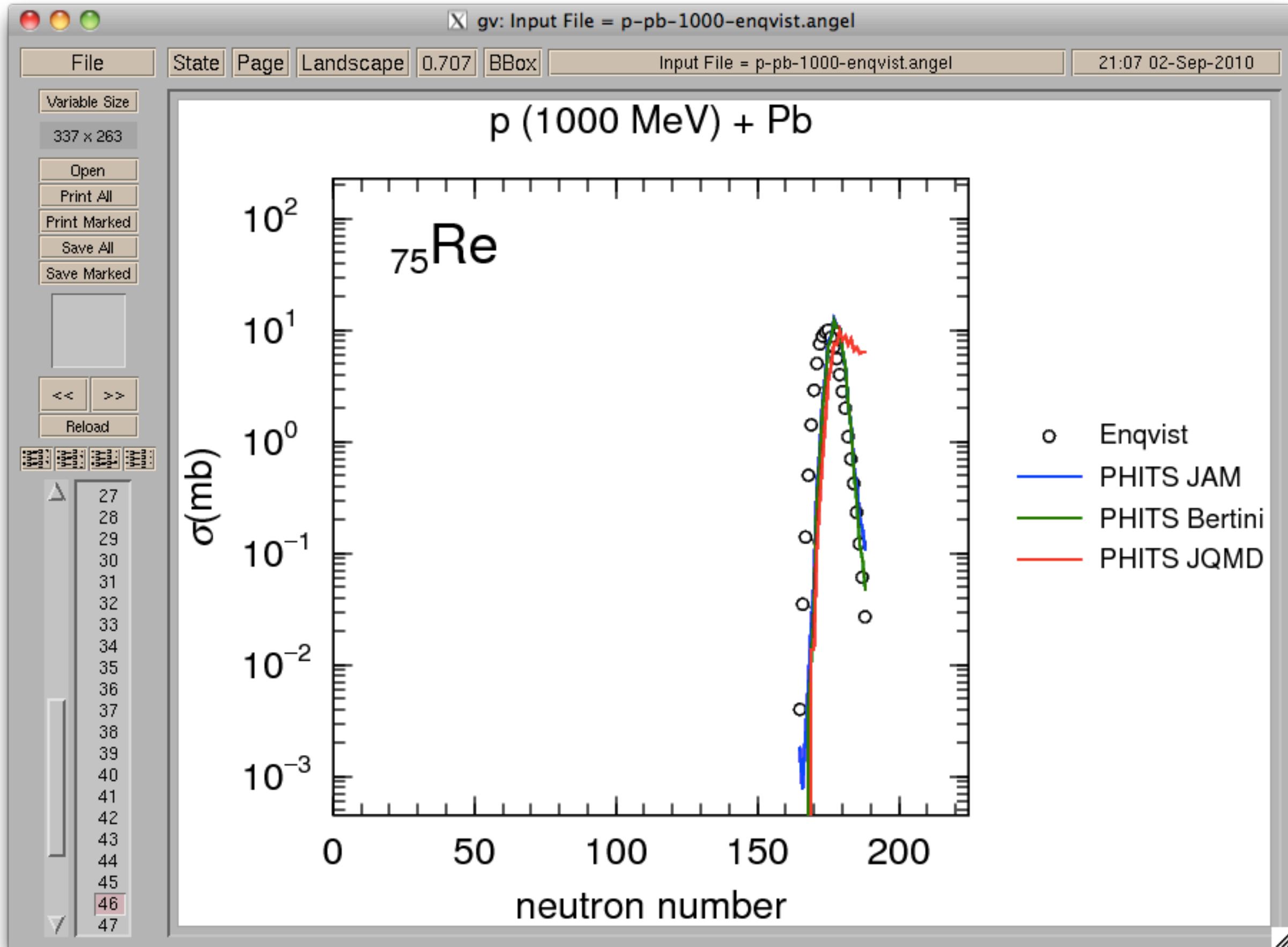
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



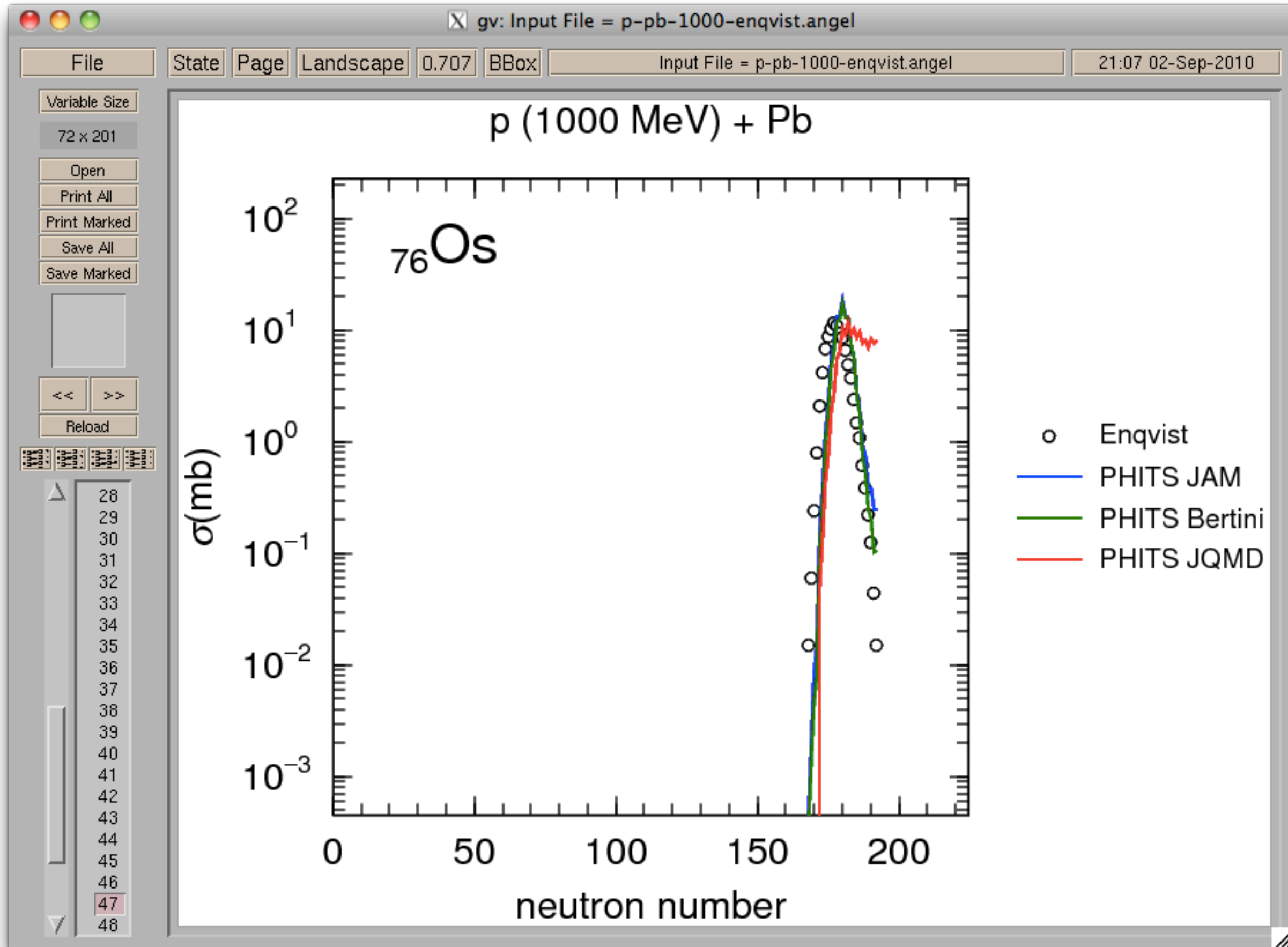
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

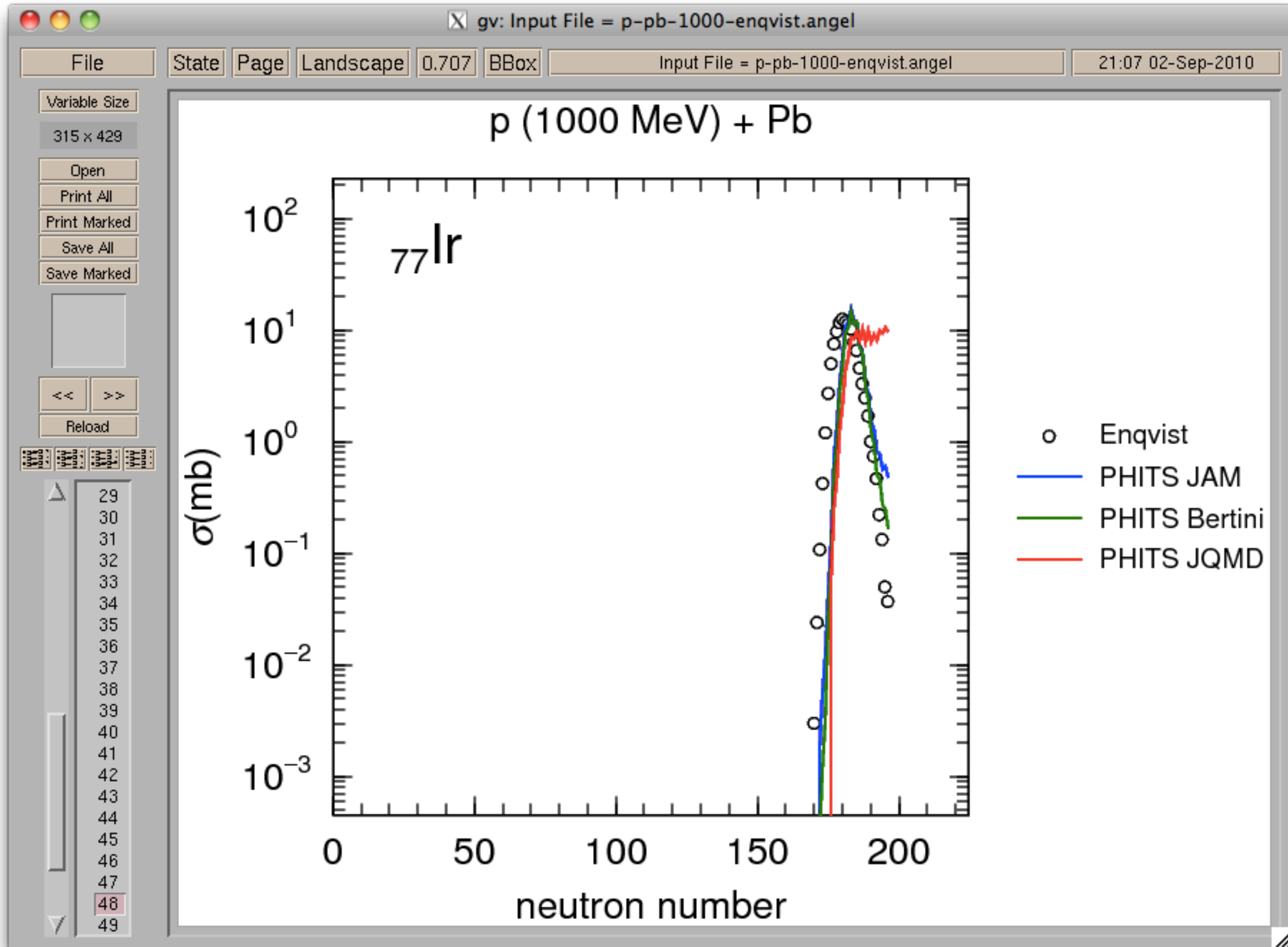


# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

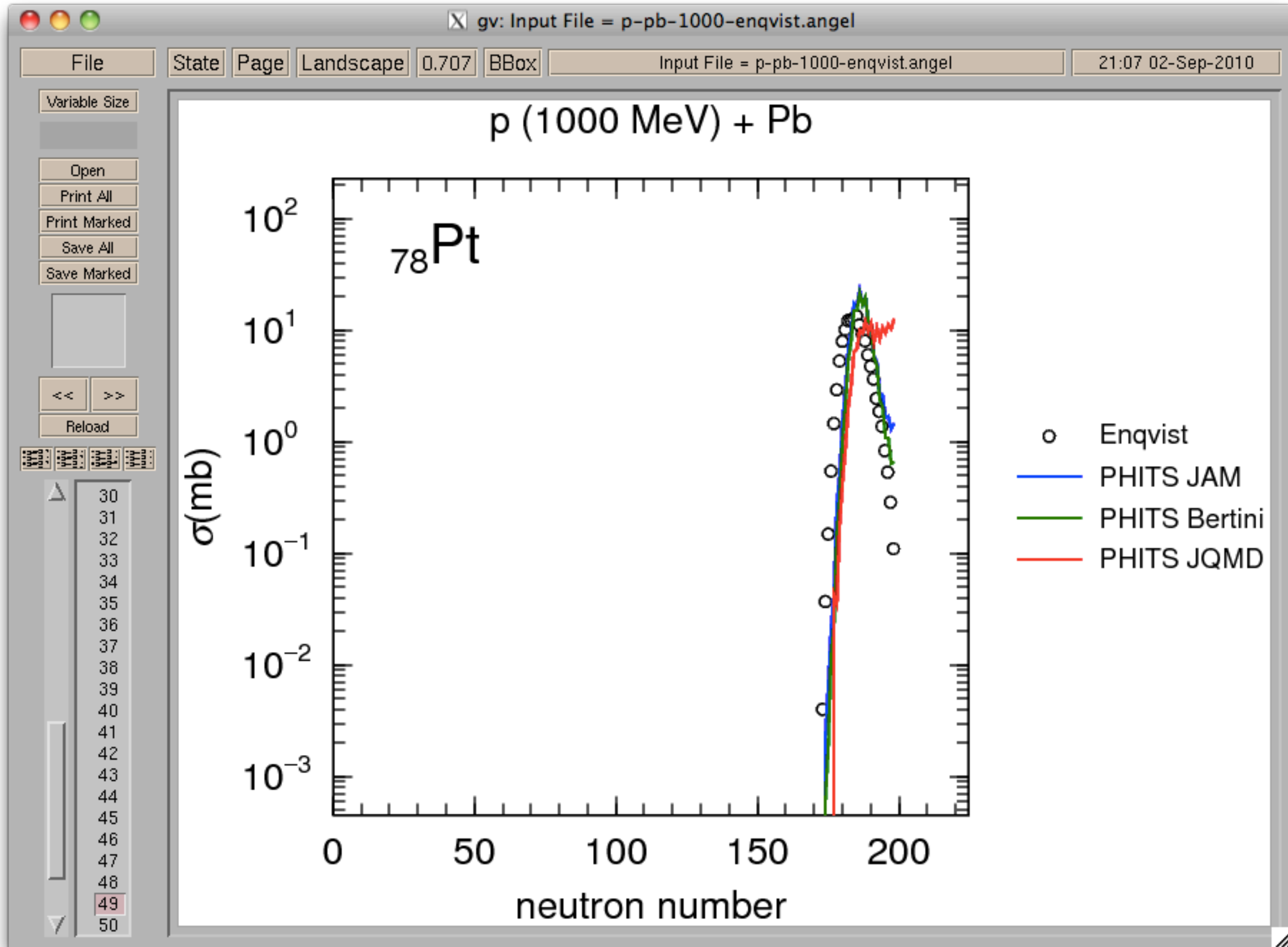




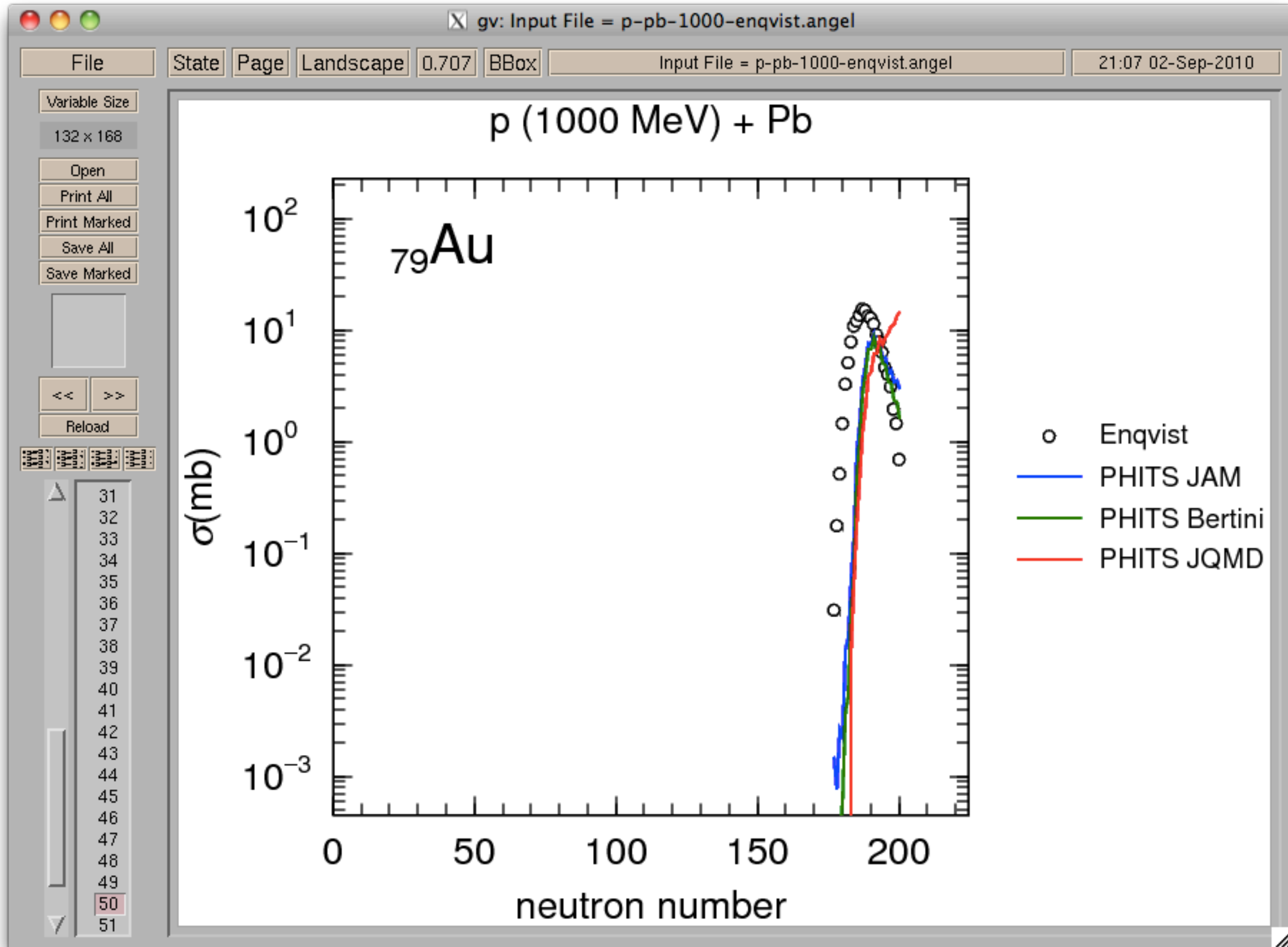
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



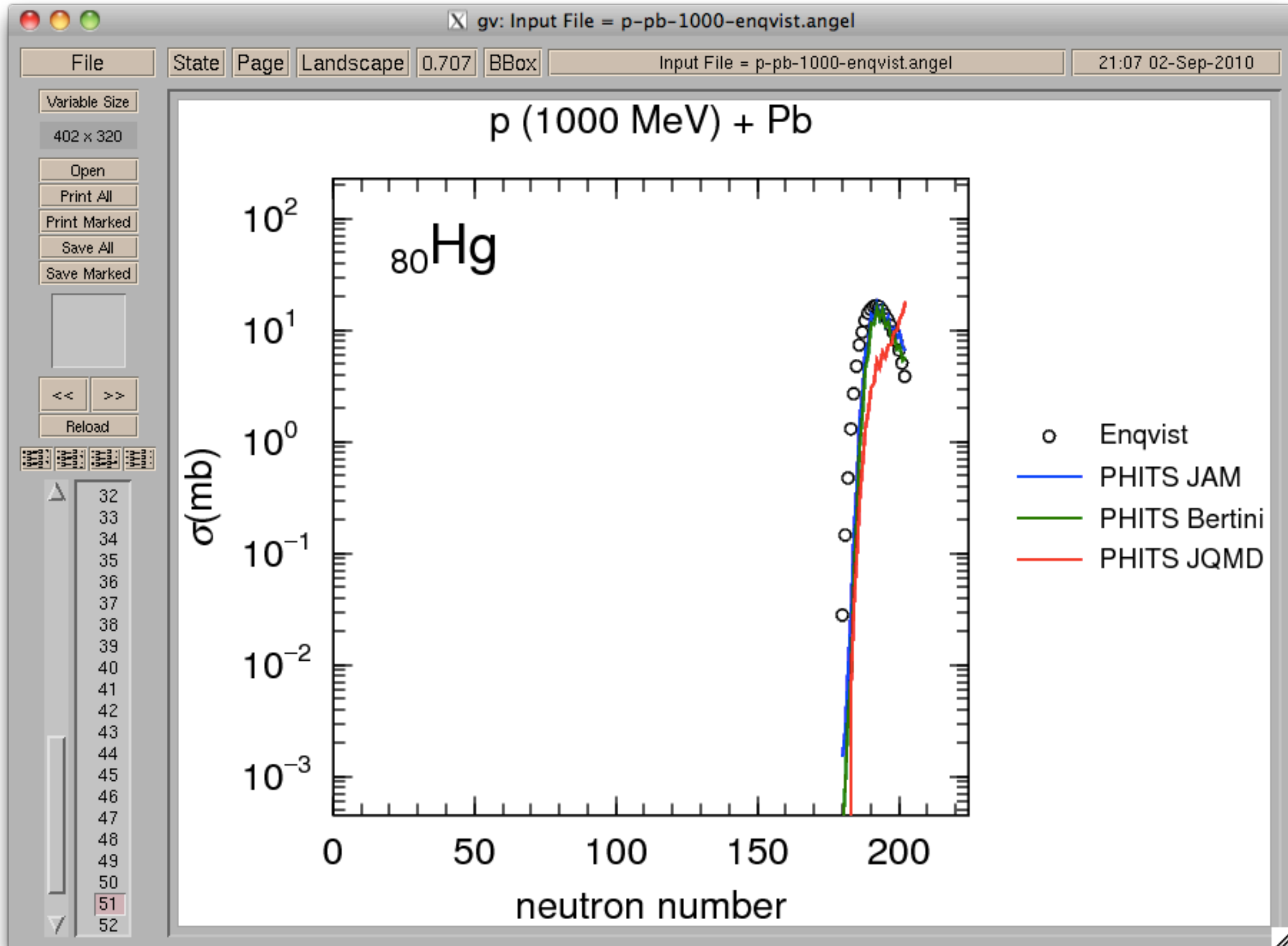
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



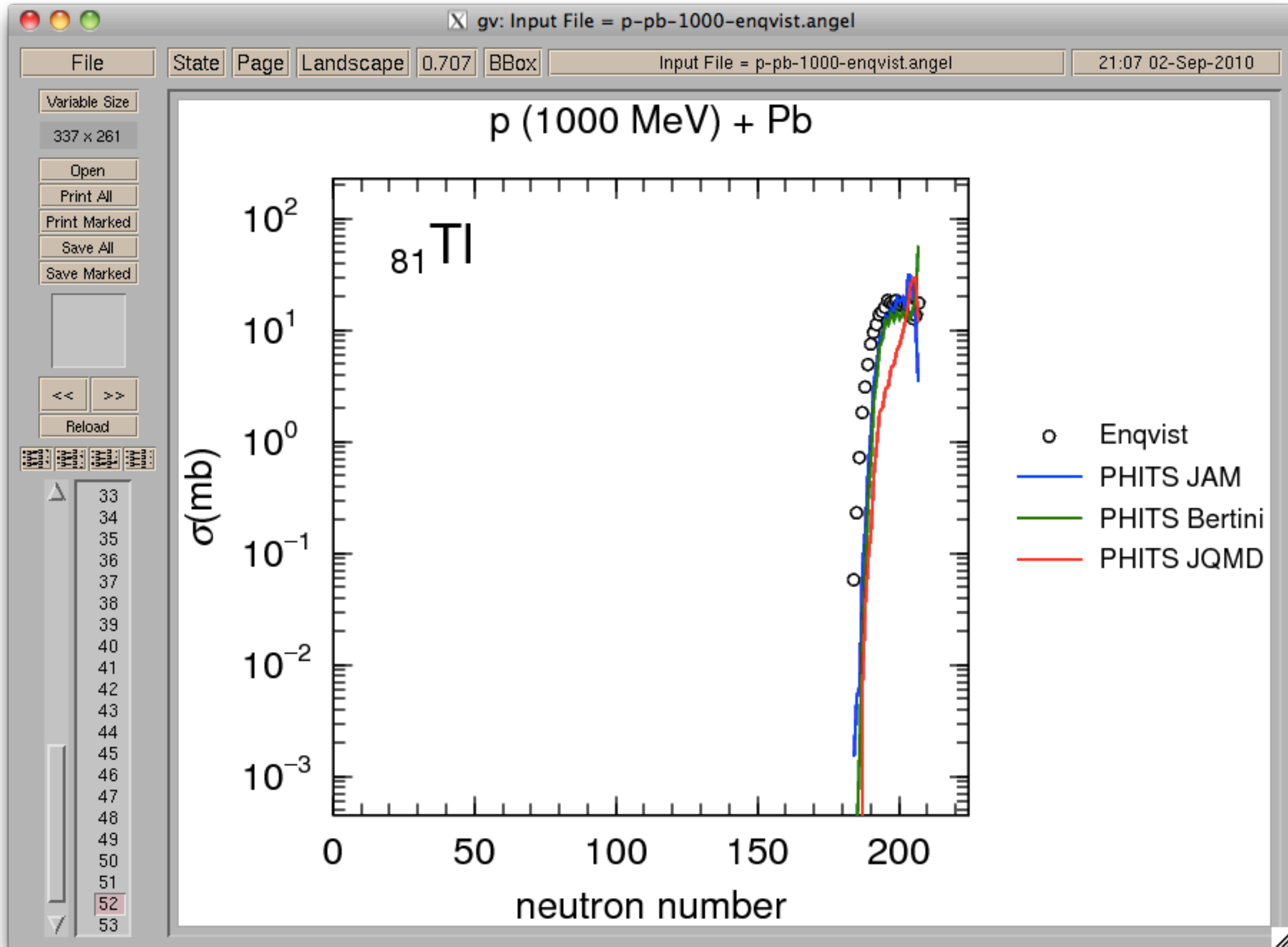
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



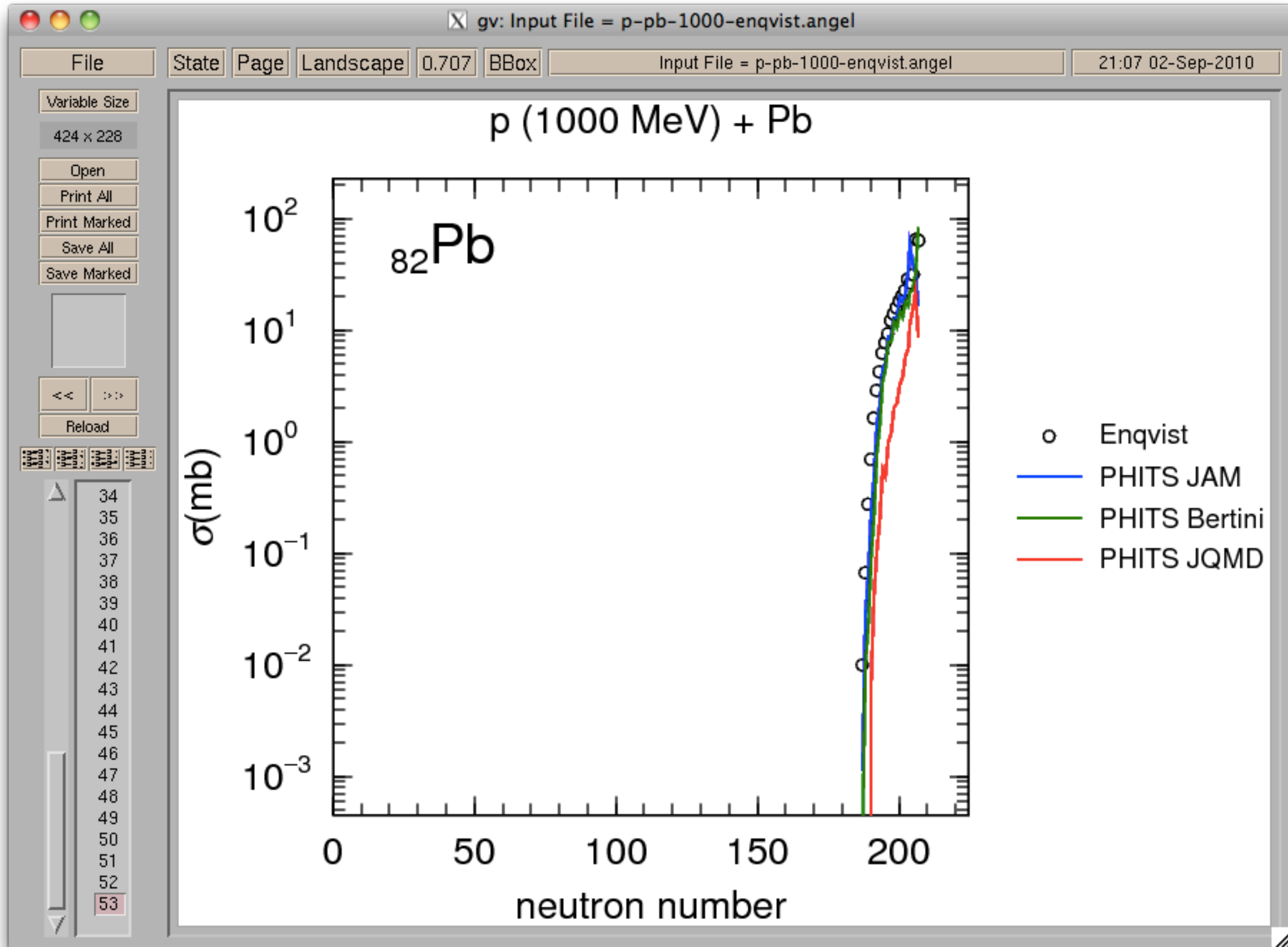
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$



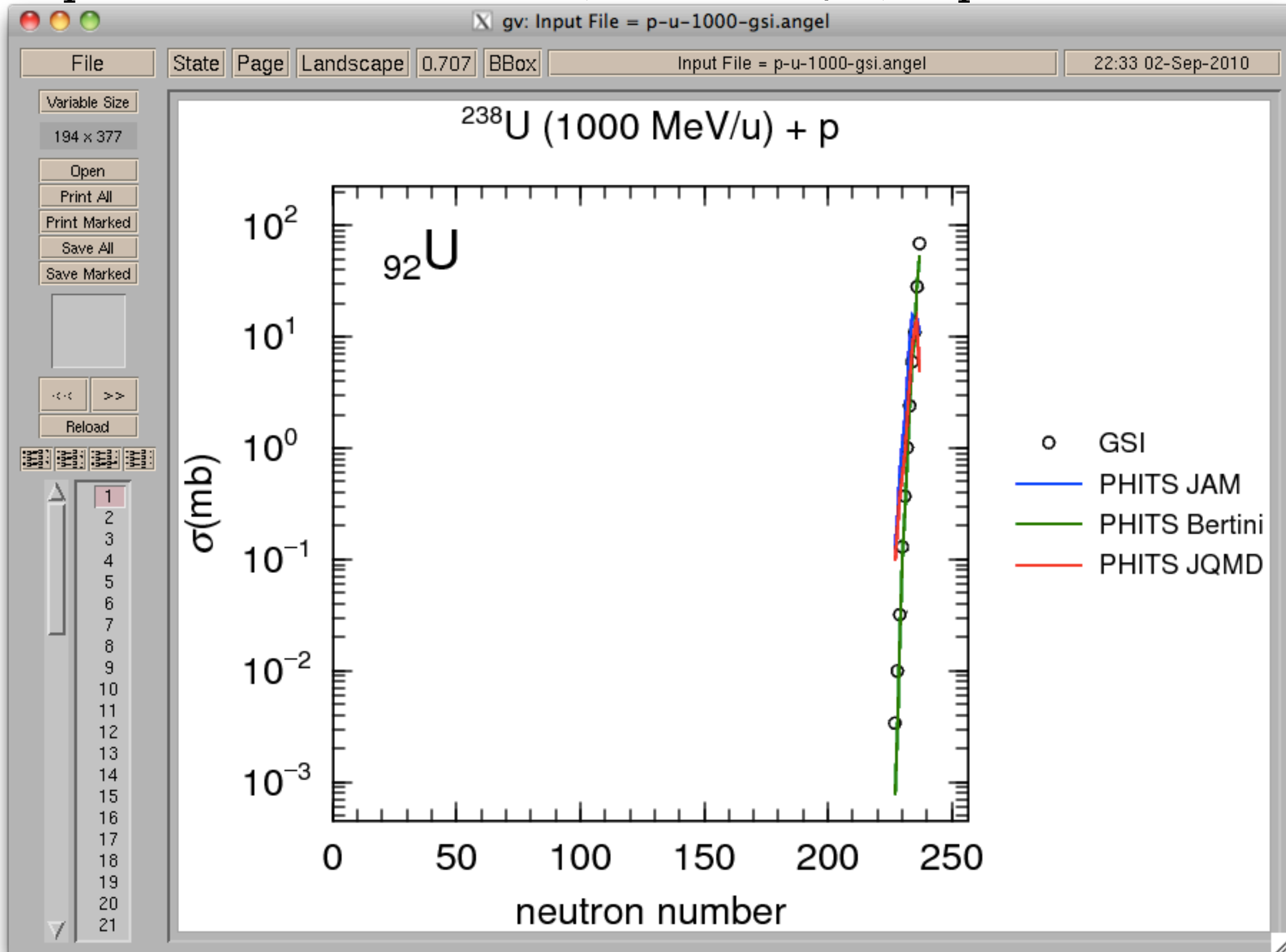
# isotropic distribution: p (1000 MeV) + $_{82}^{208}\text{Pb}$

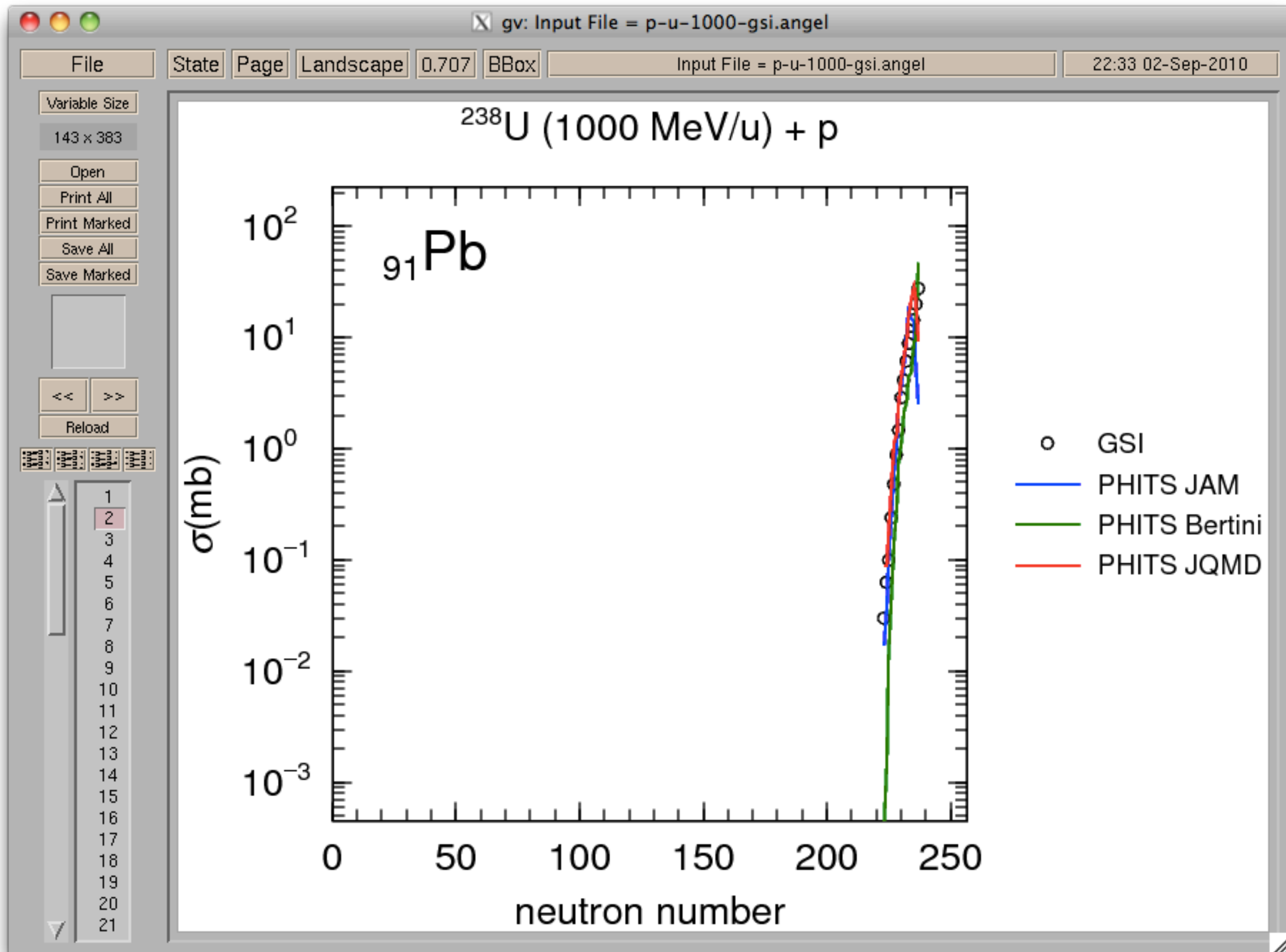




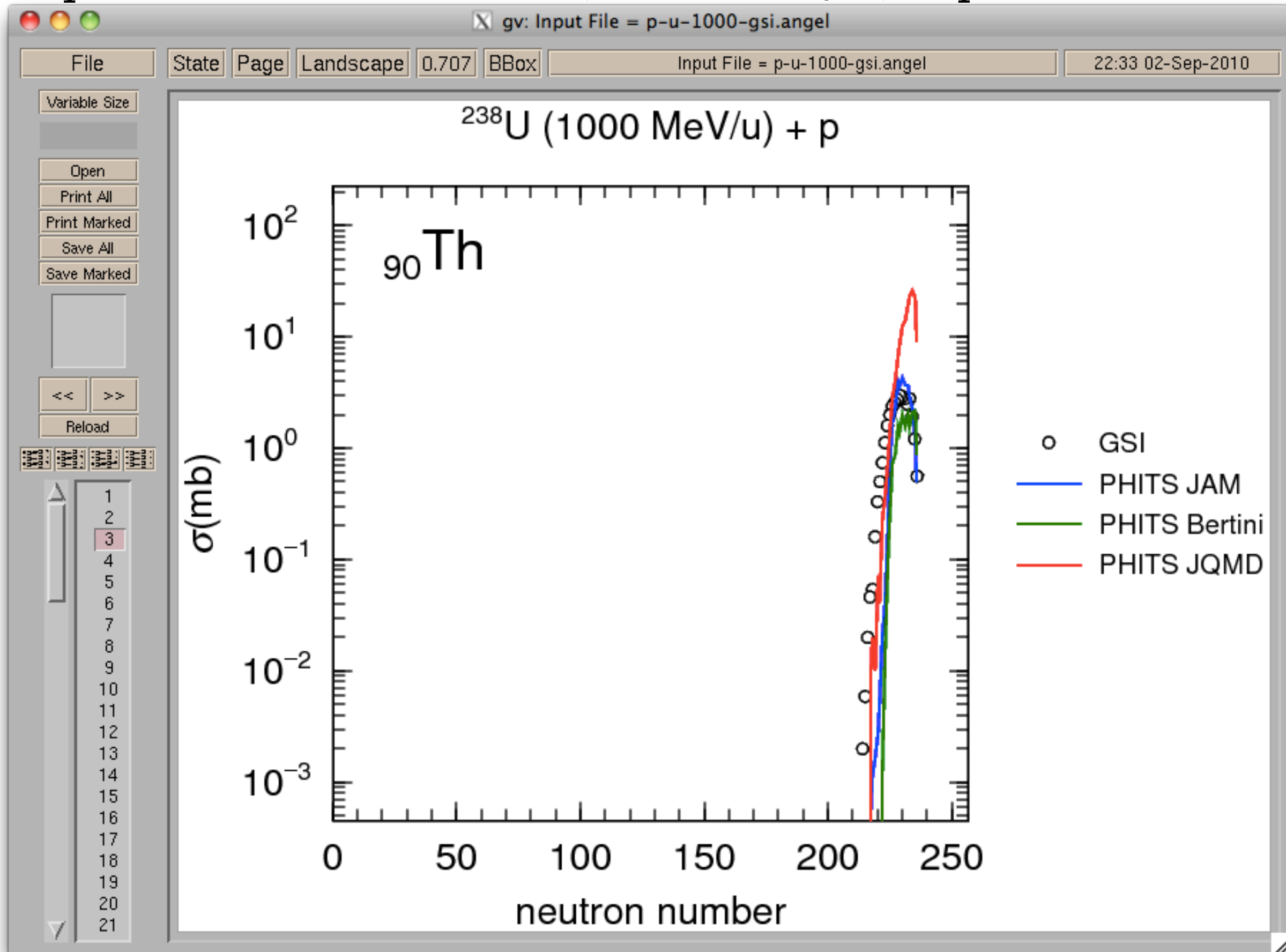


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

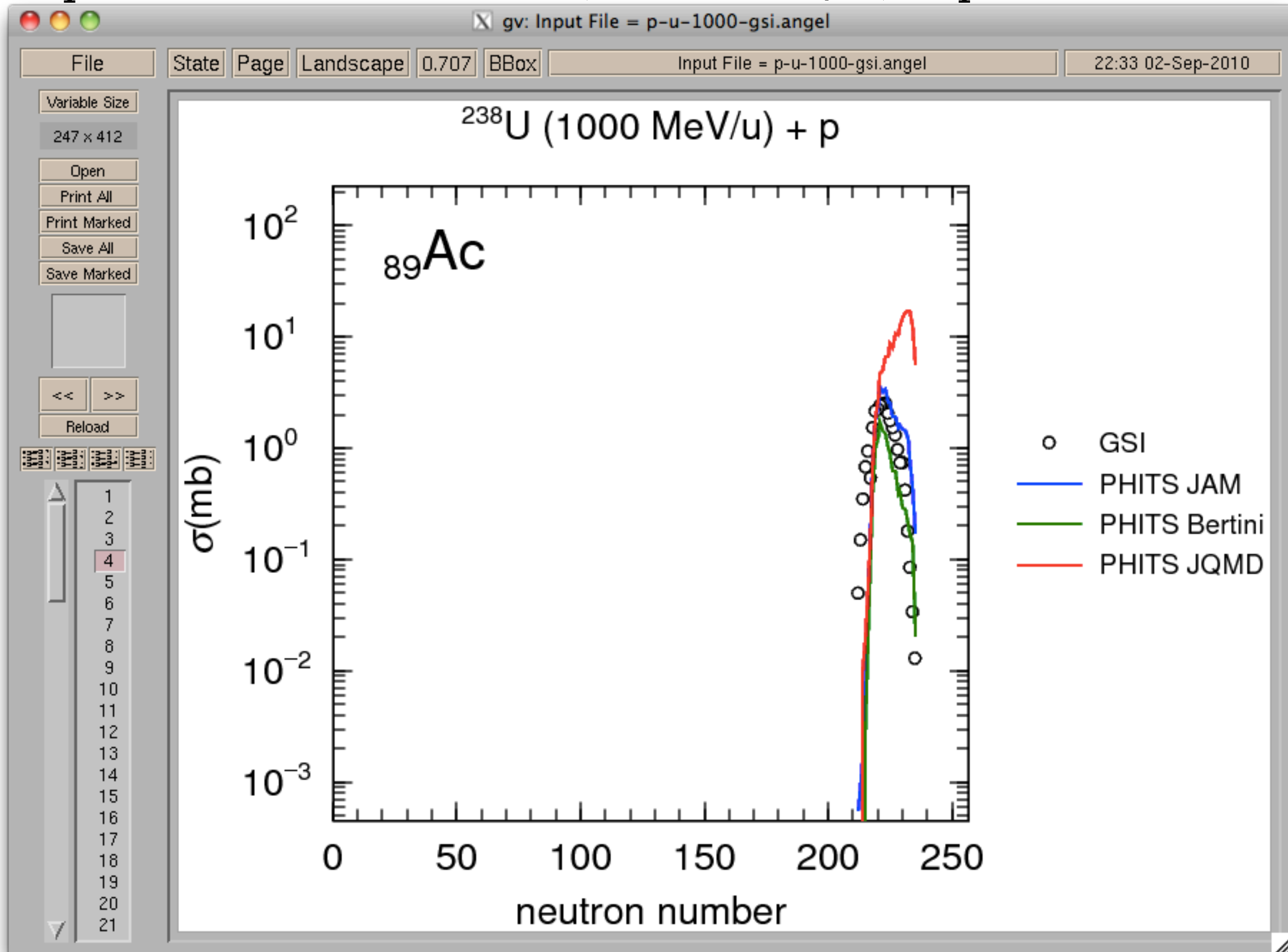




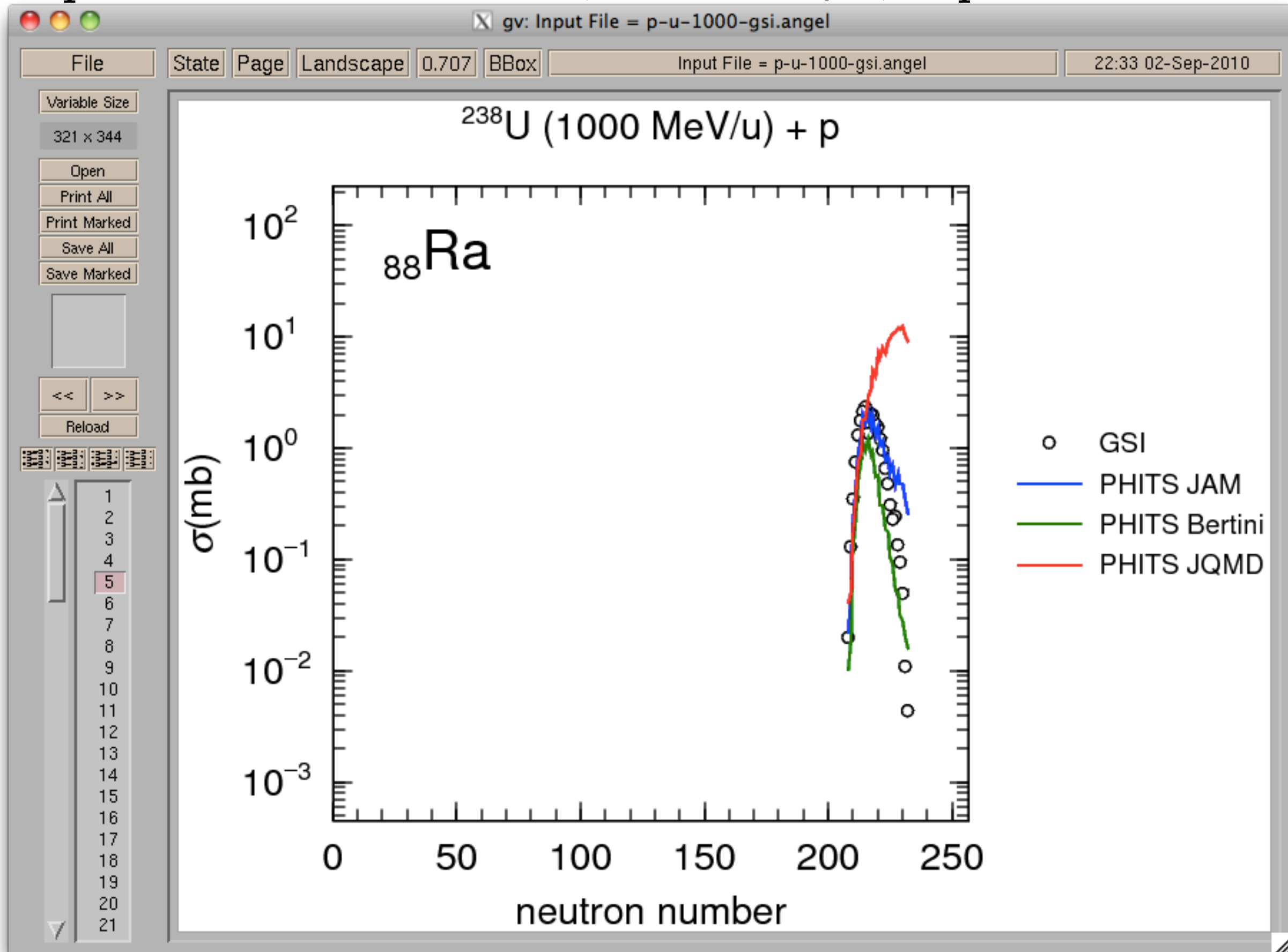
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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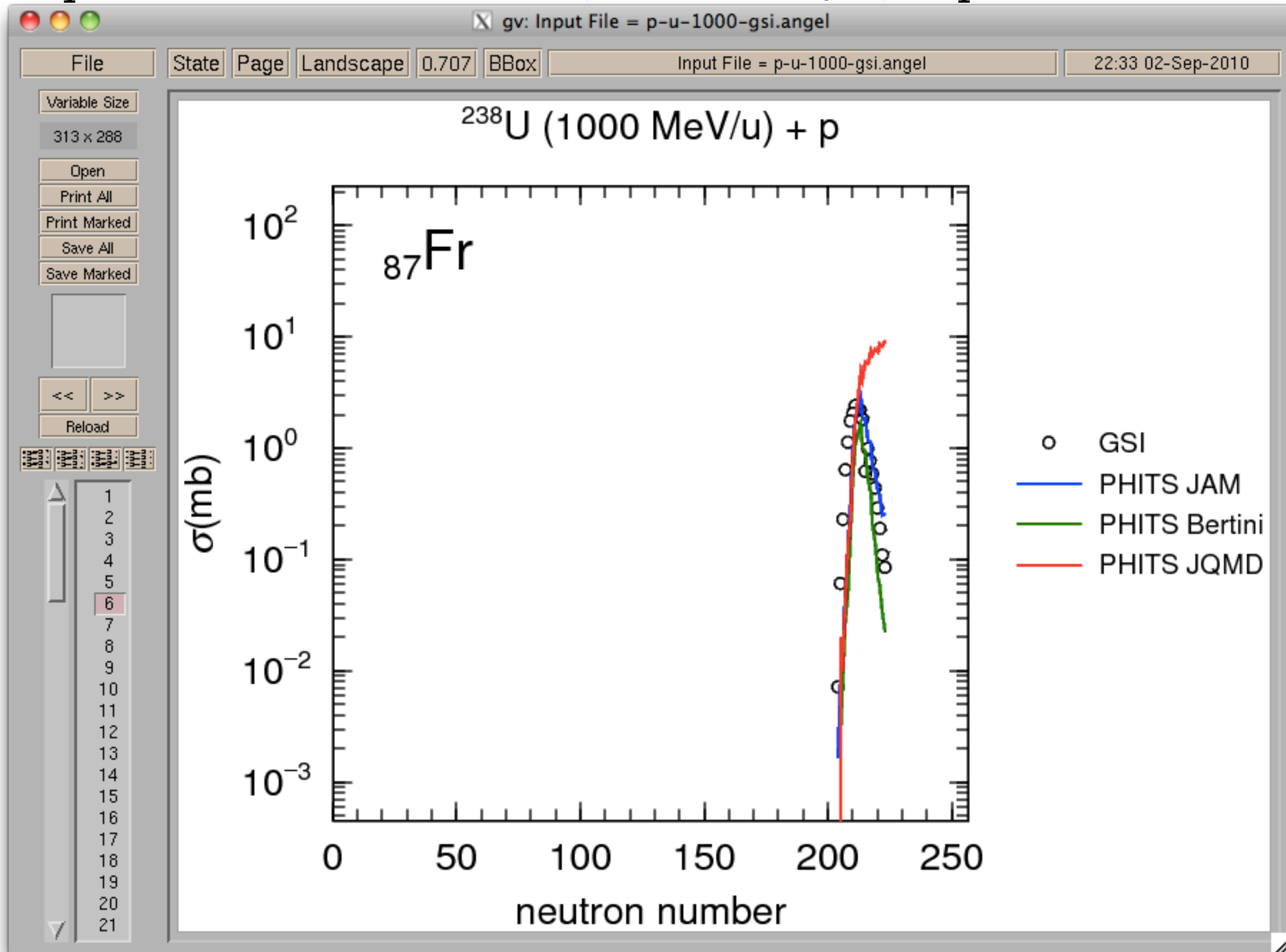


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

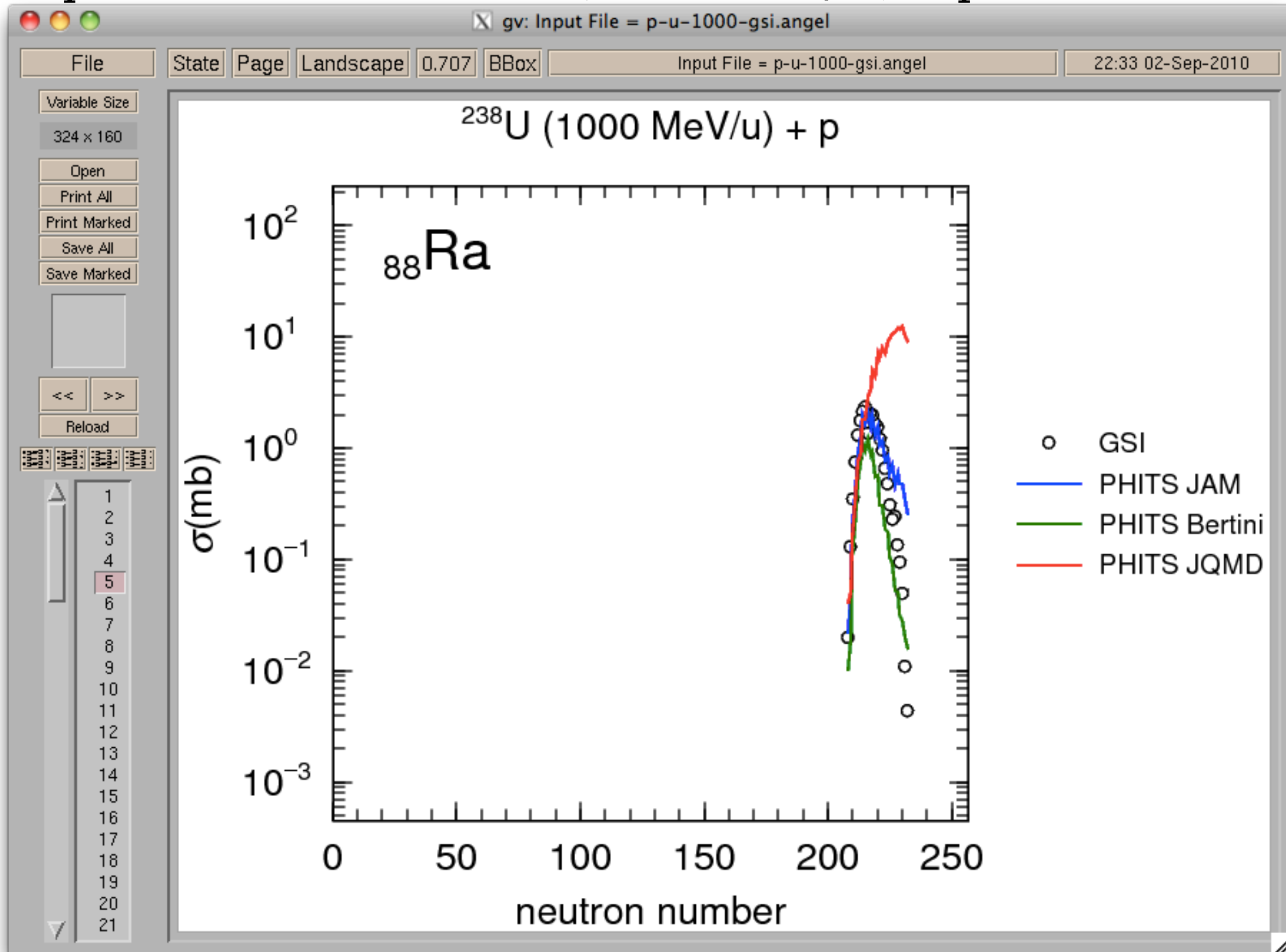




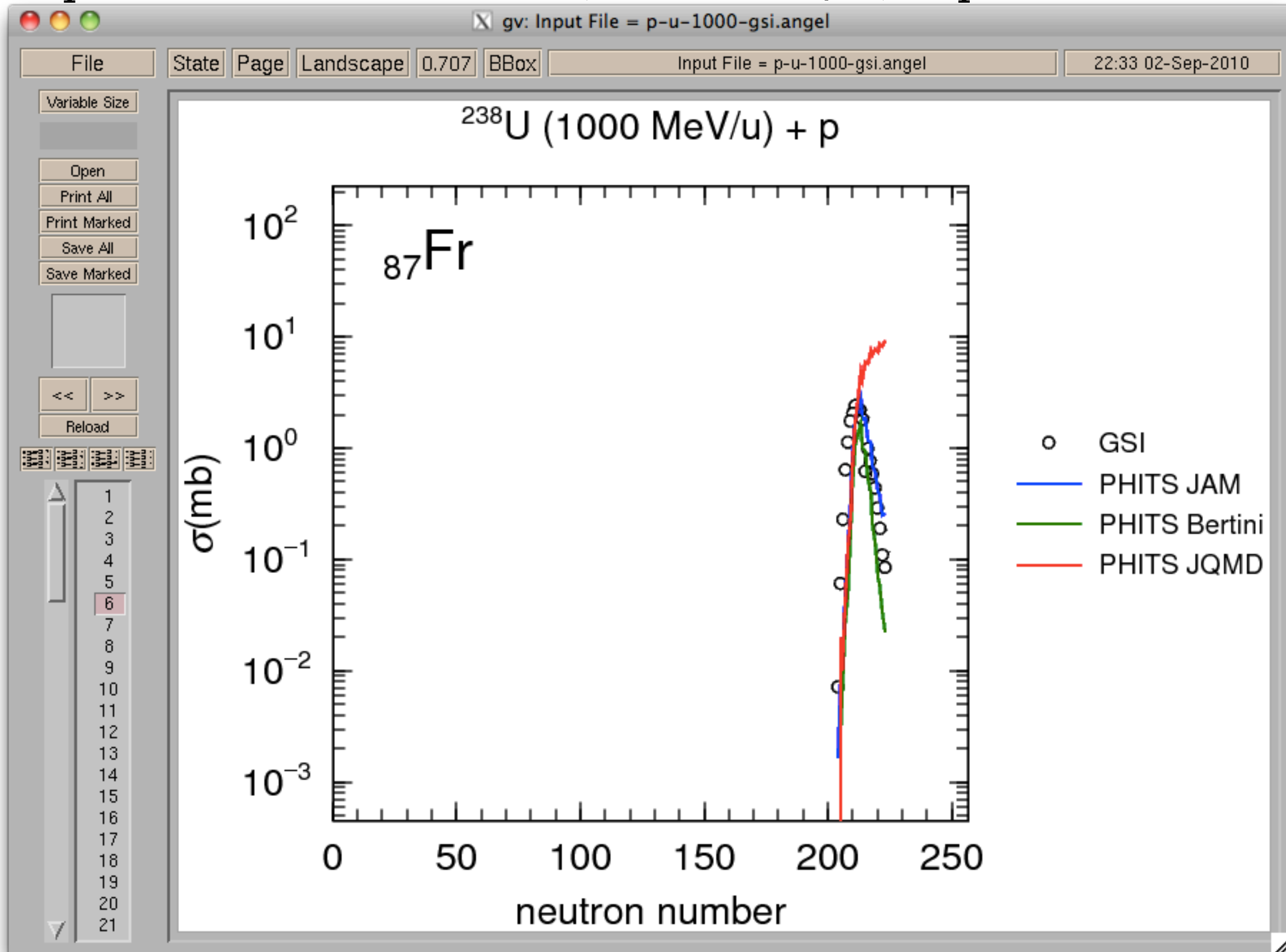
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



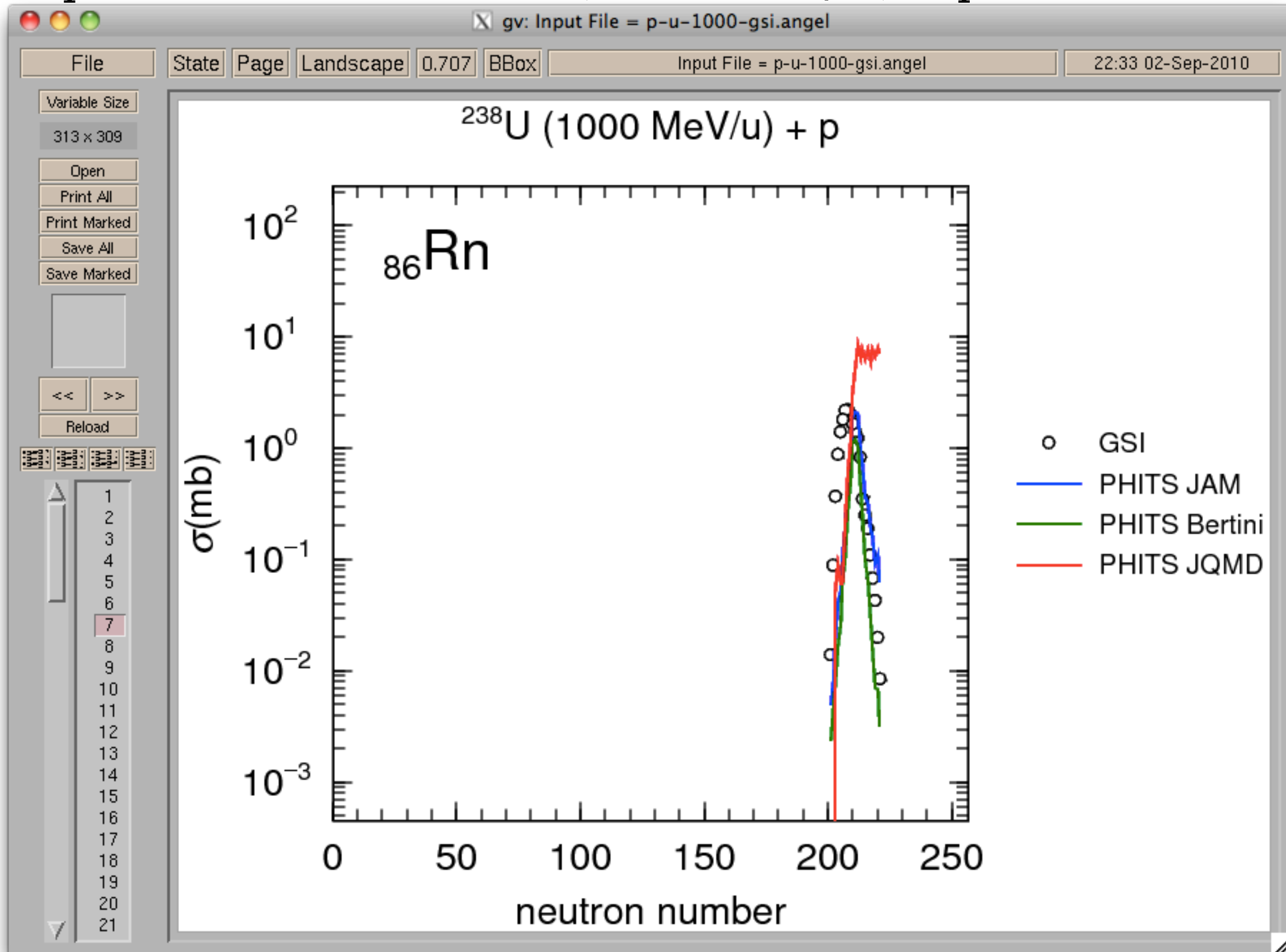
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



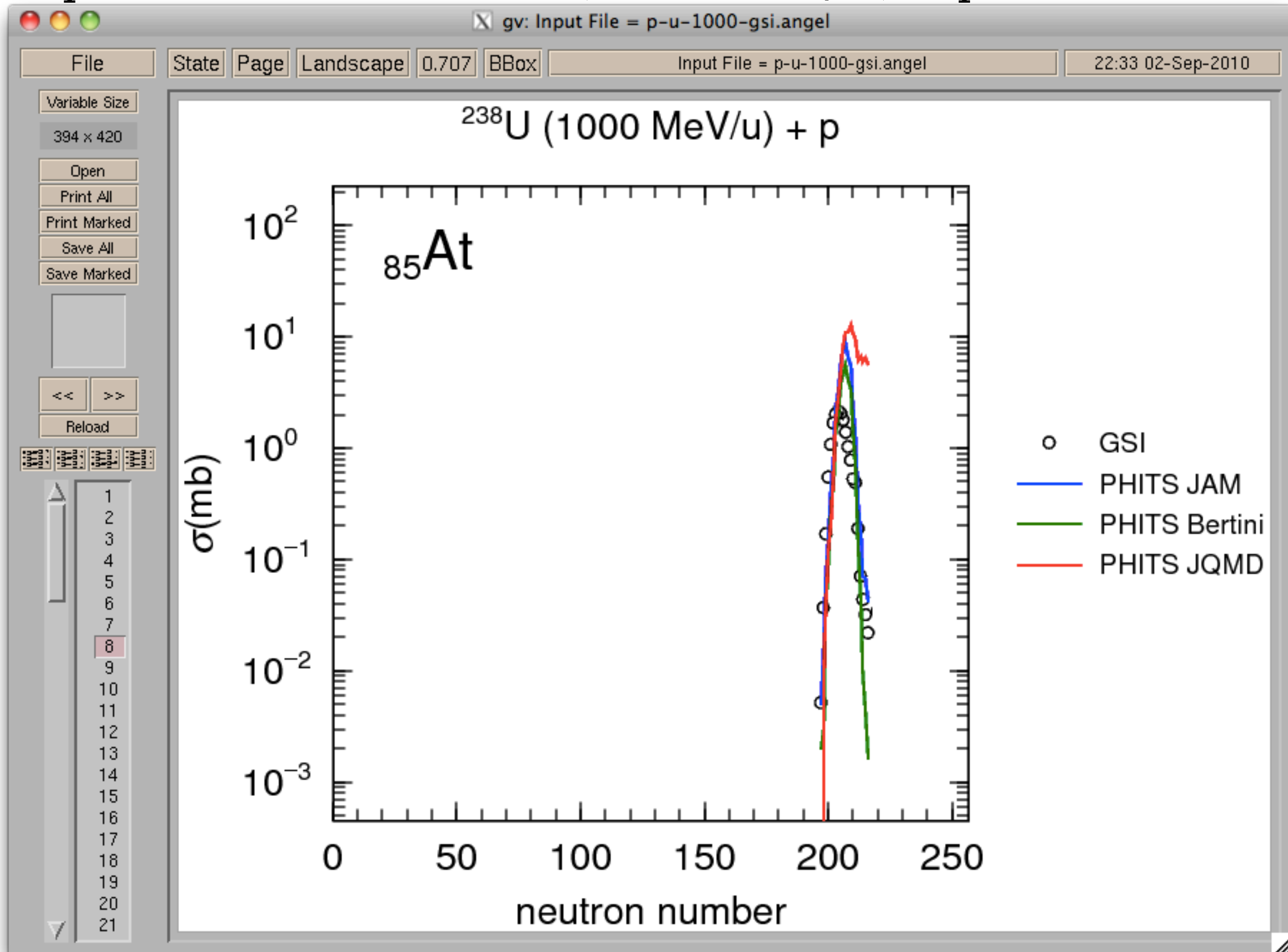
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



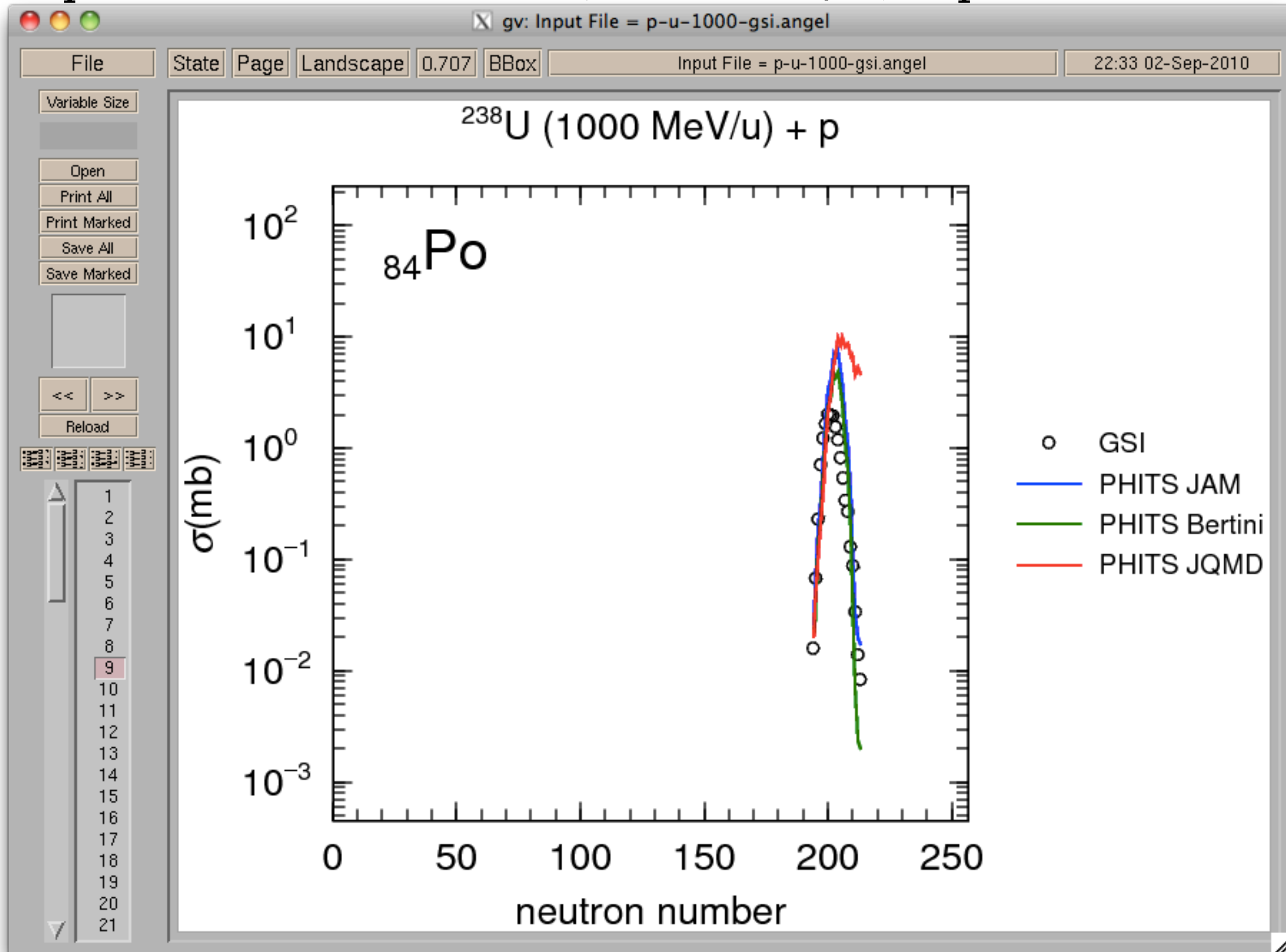
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



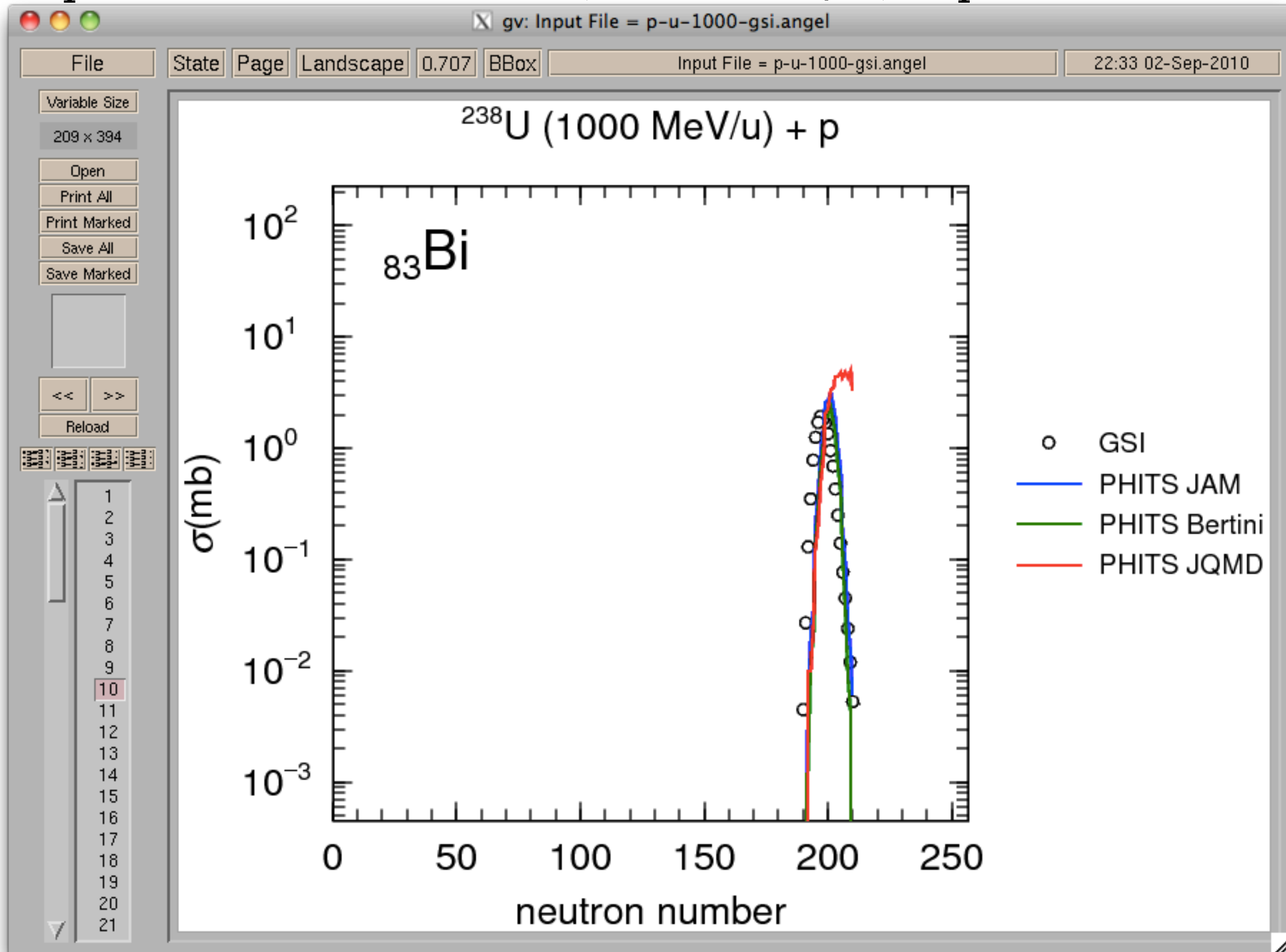
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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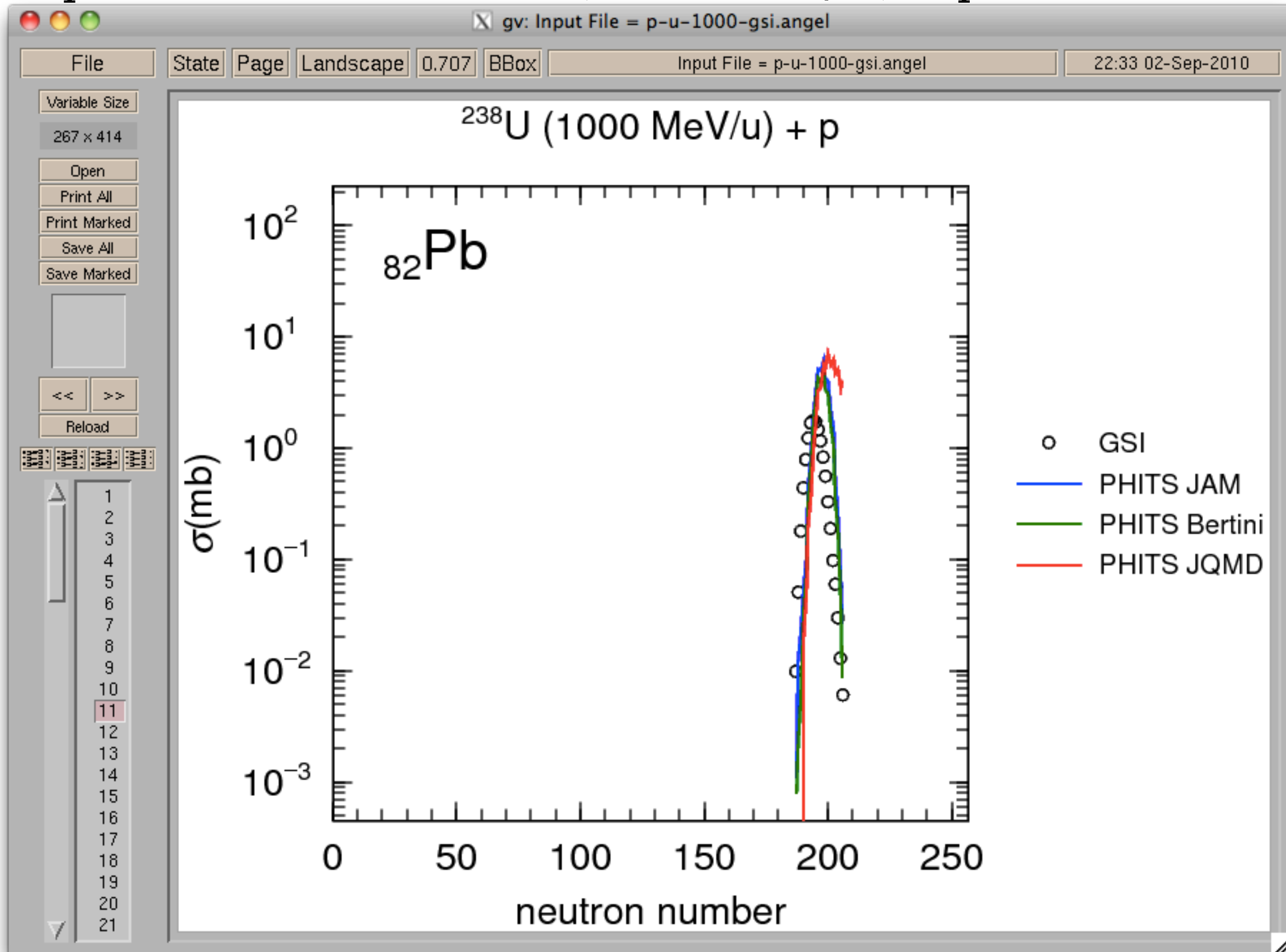


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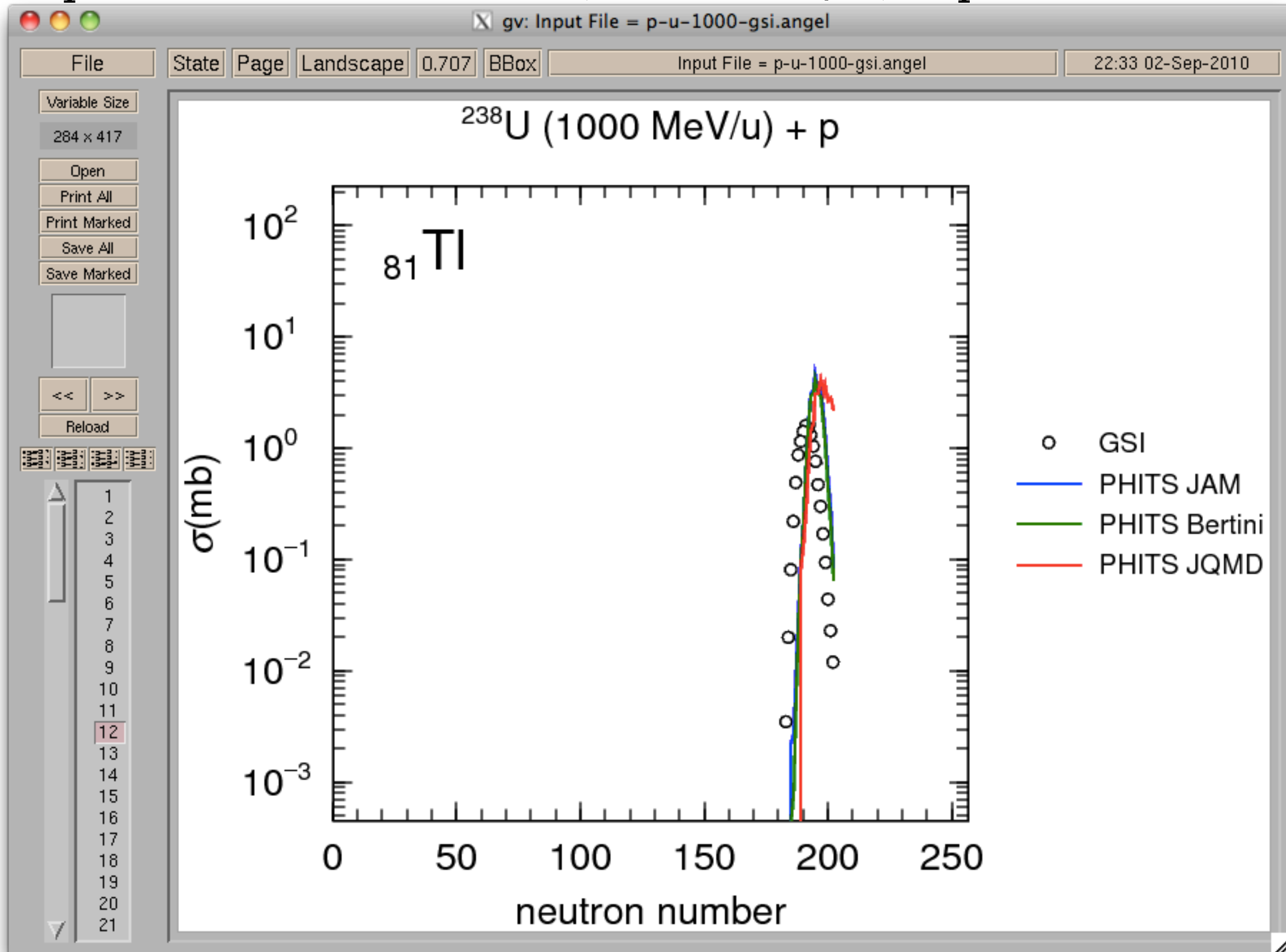




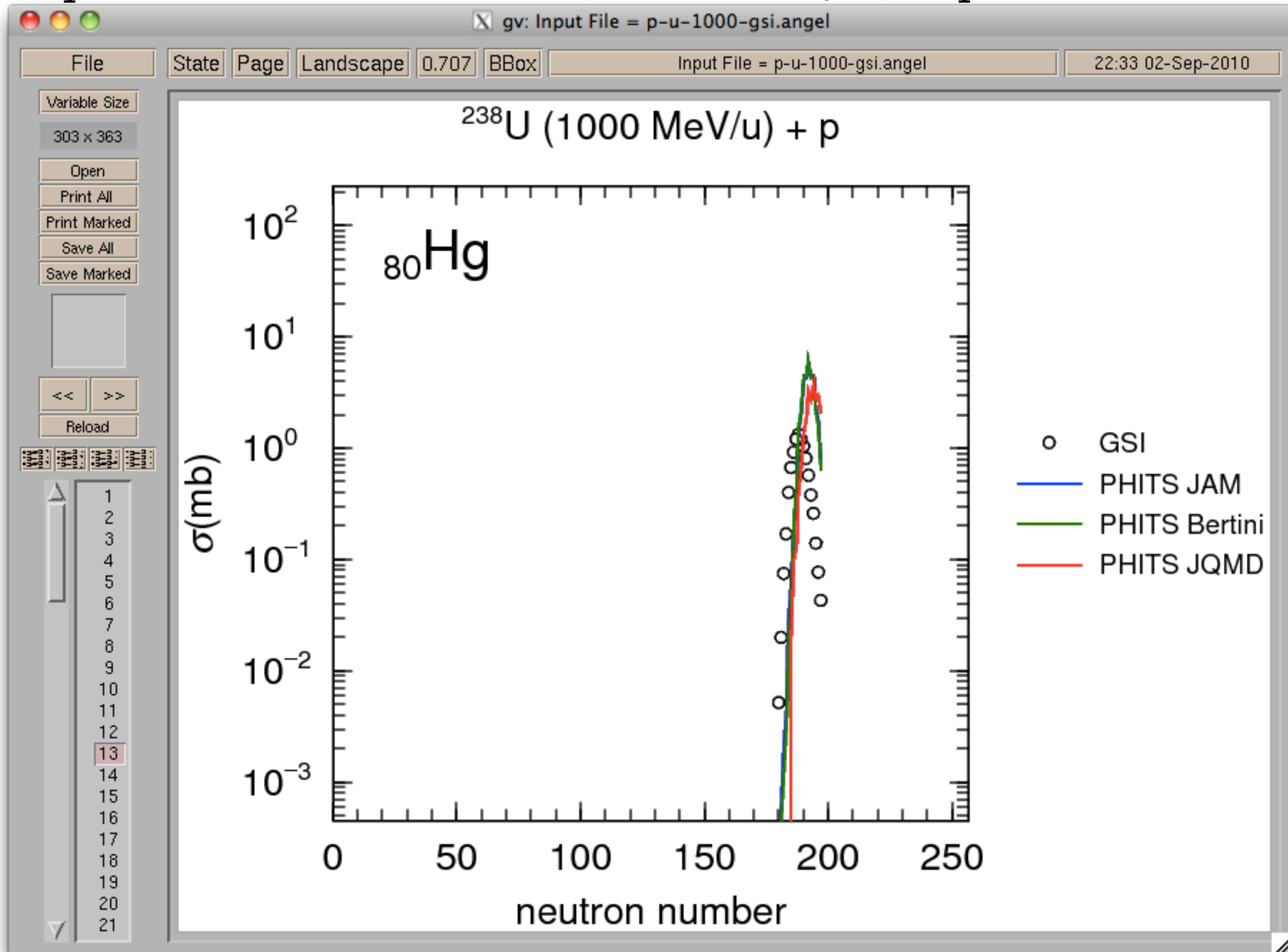
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



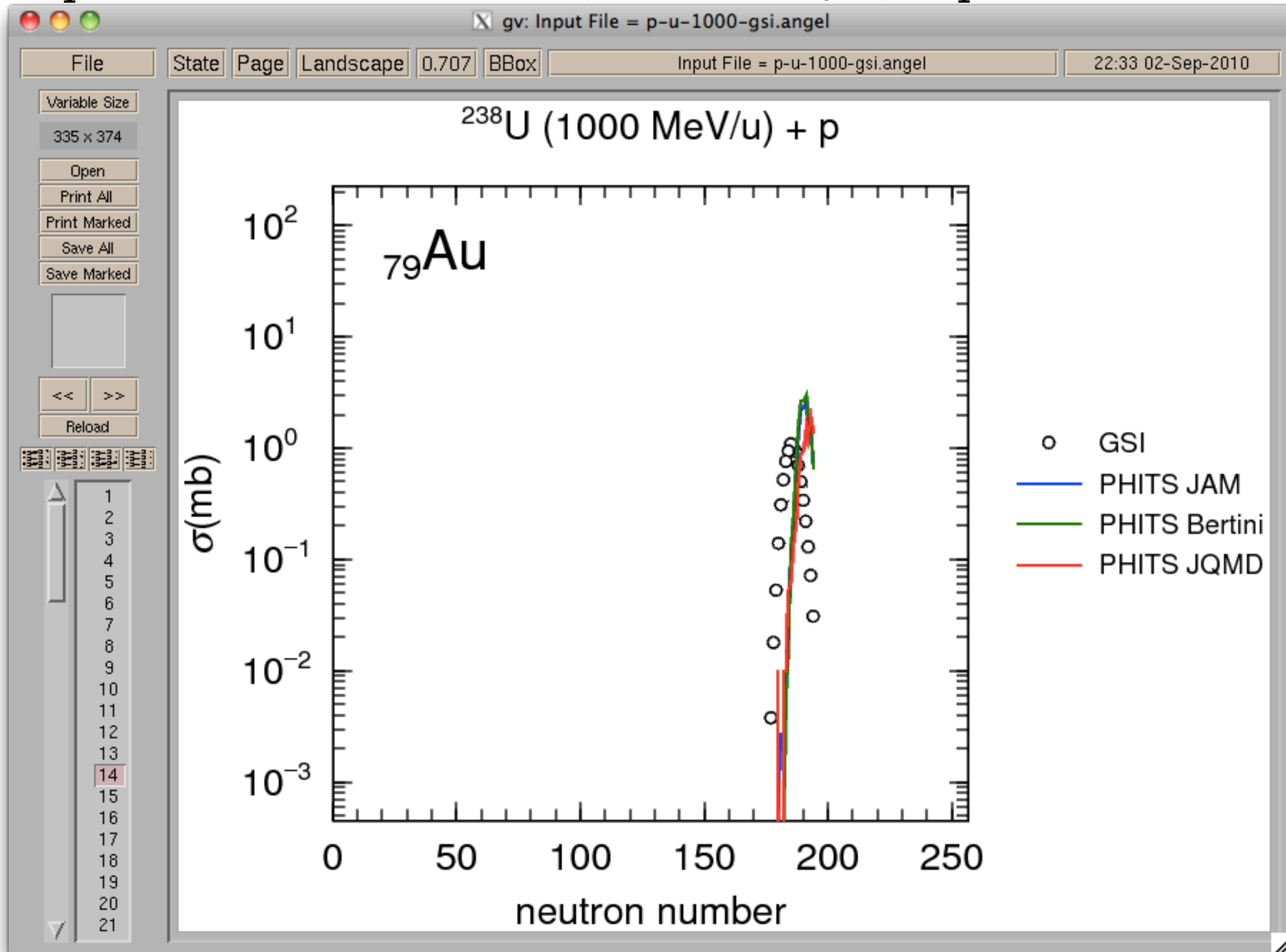
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



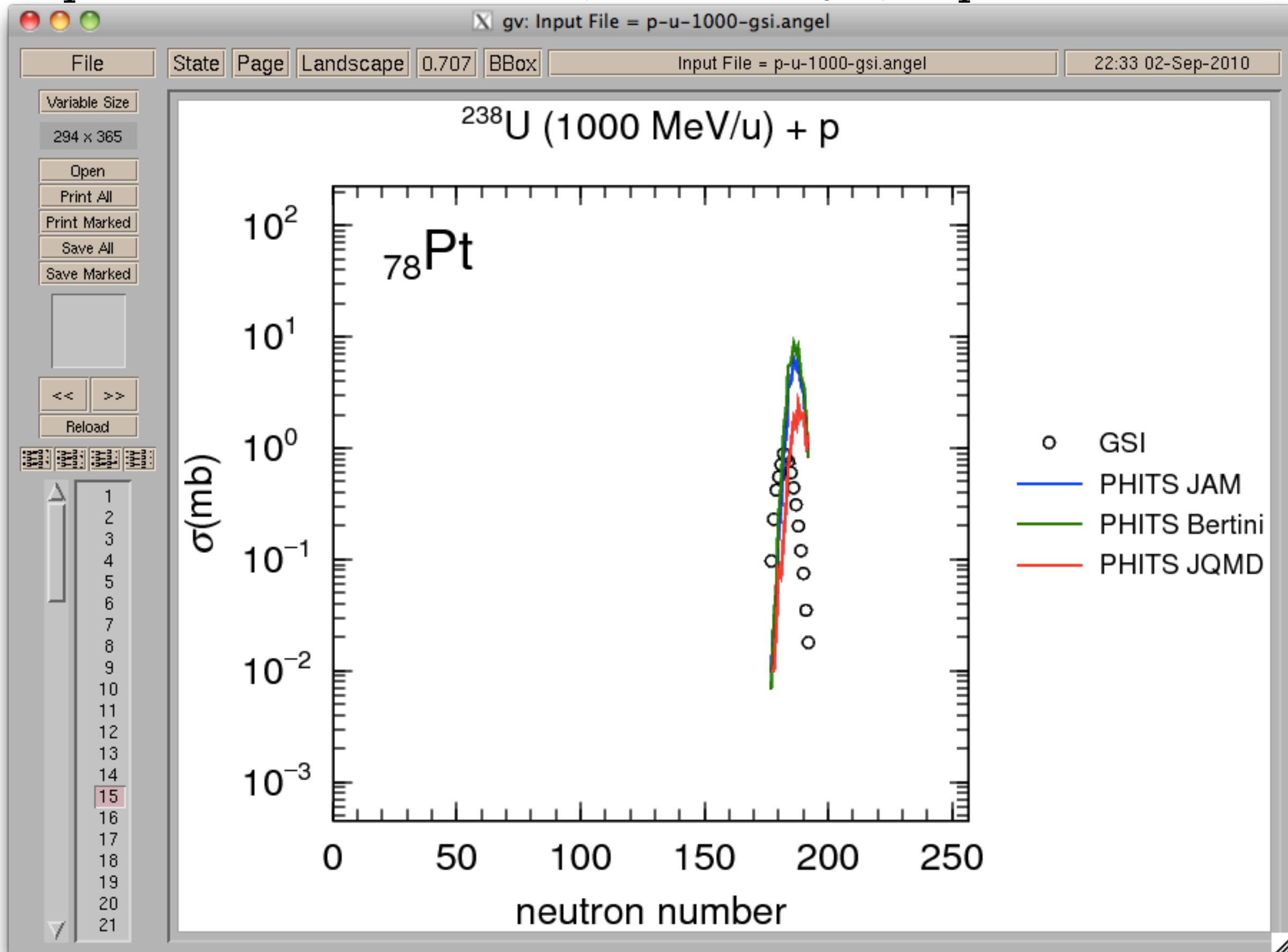
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



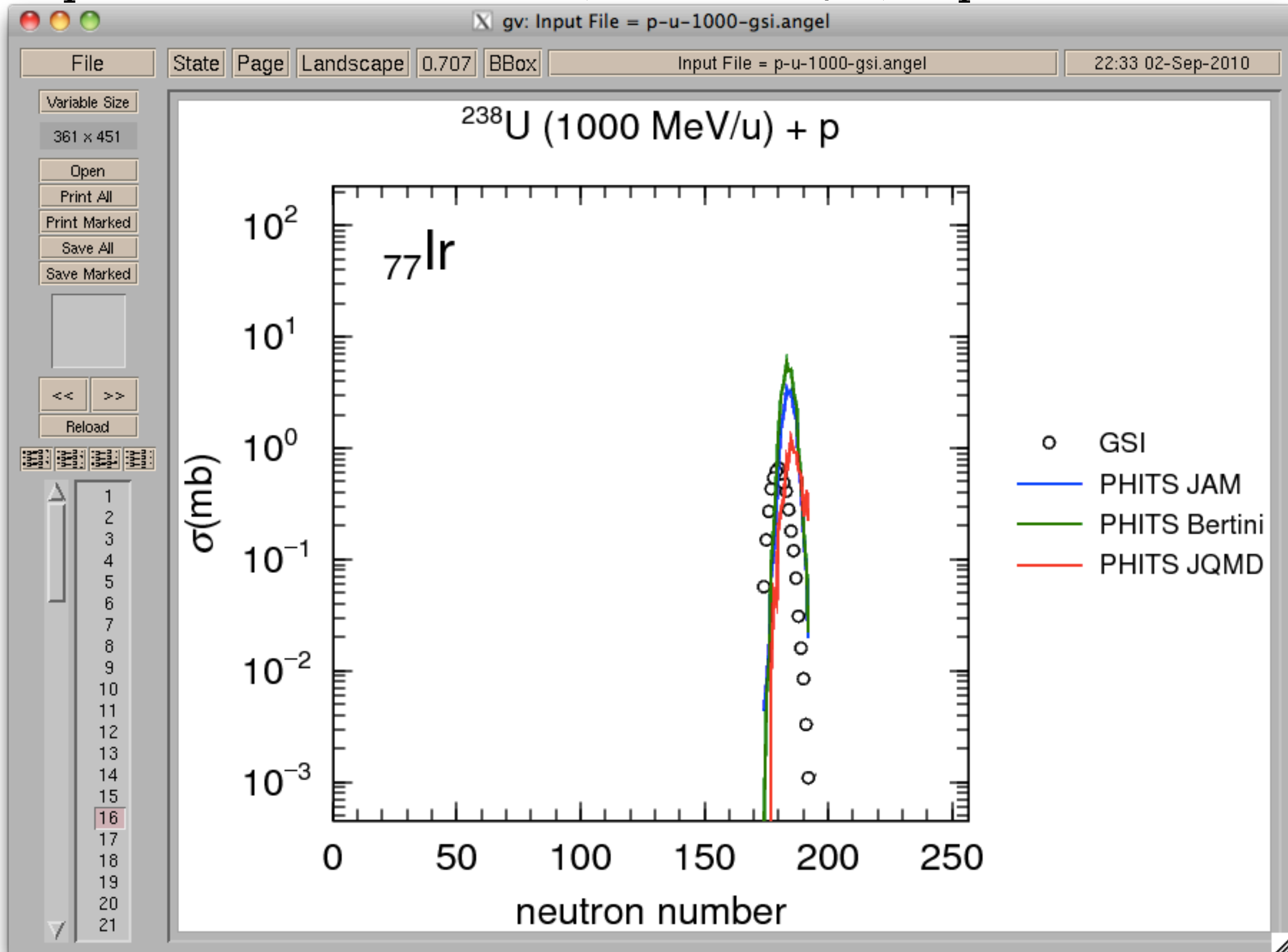
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



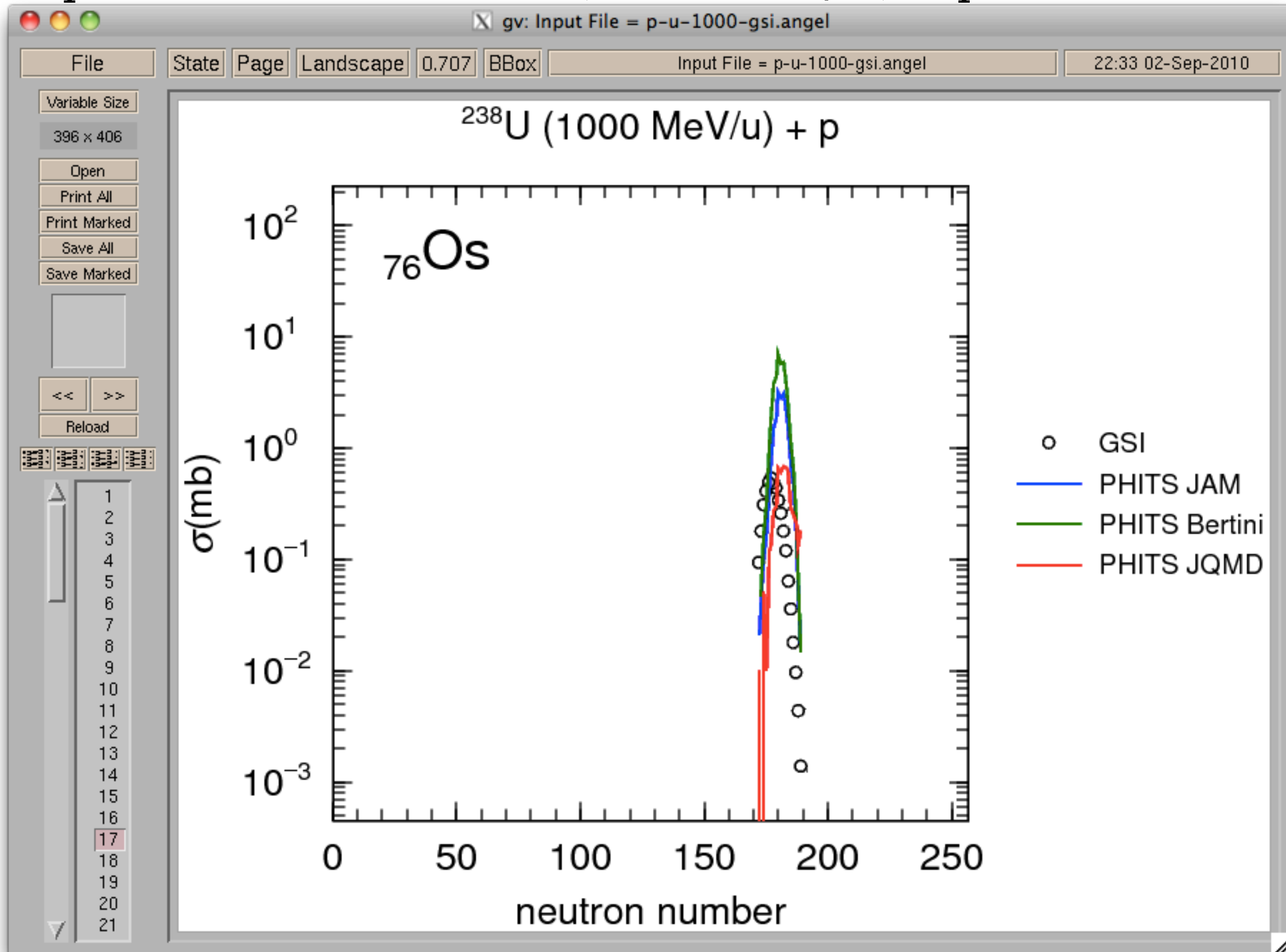
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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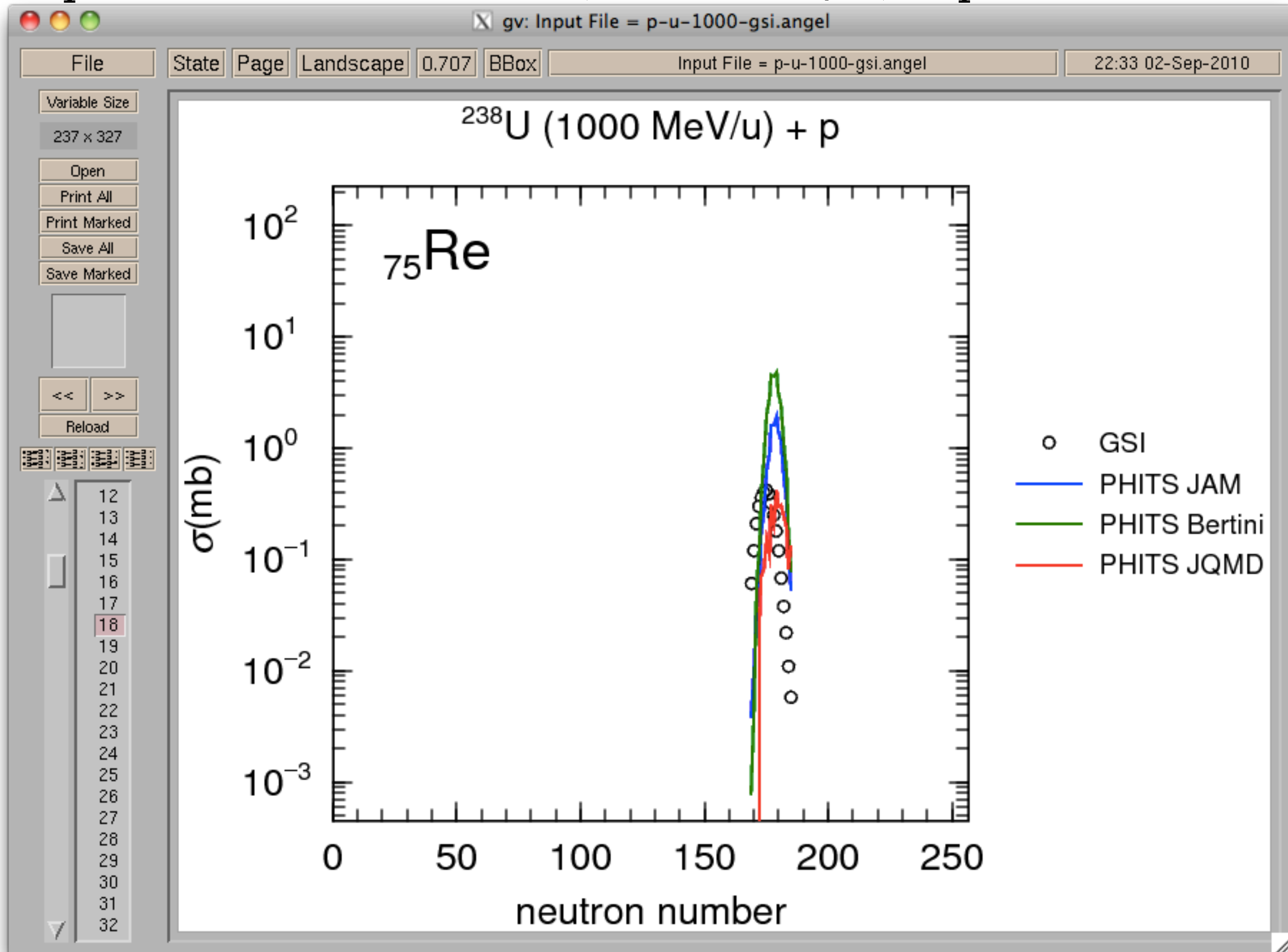


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

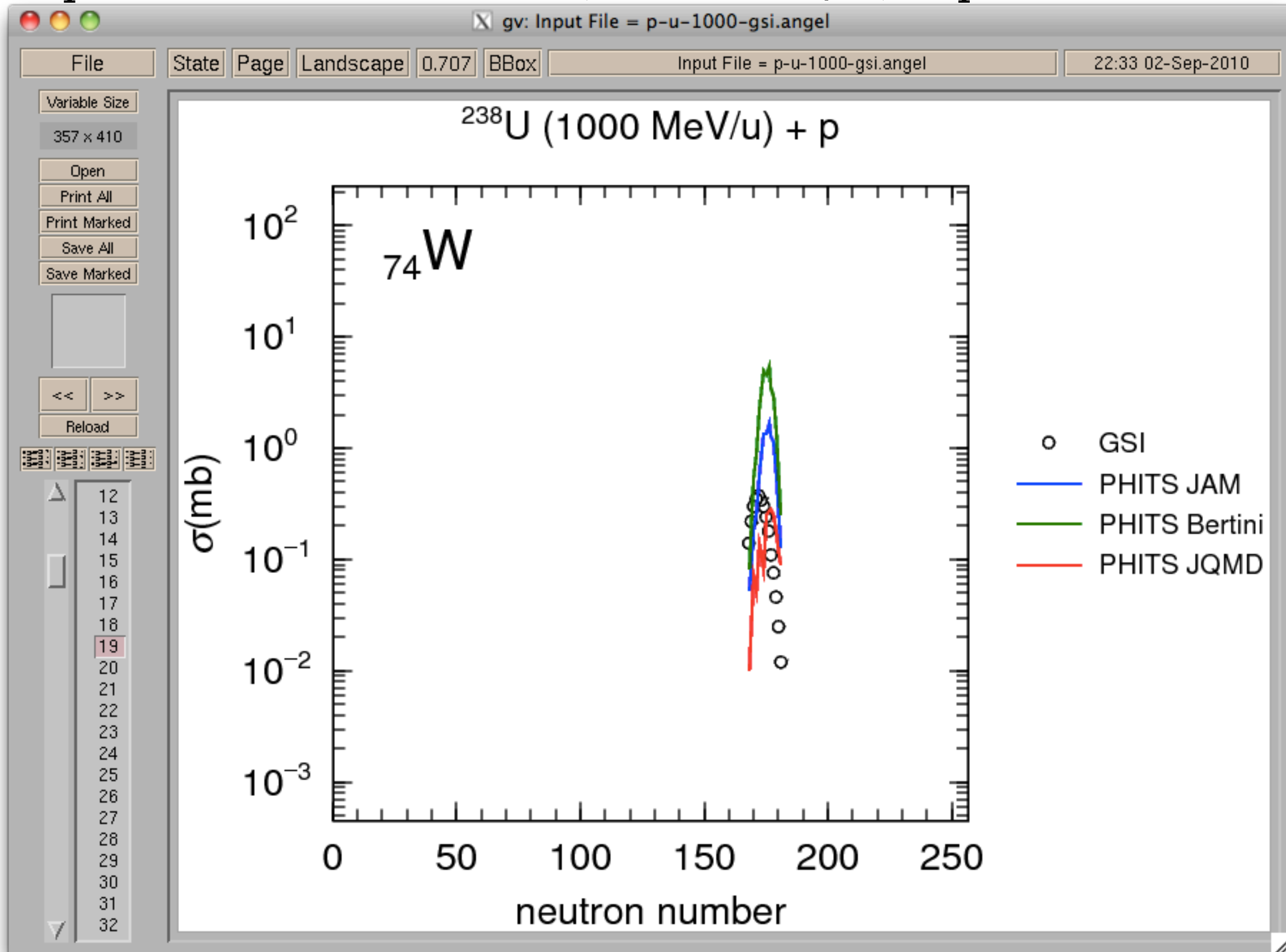




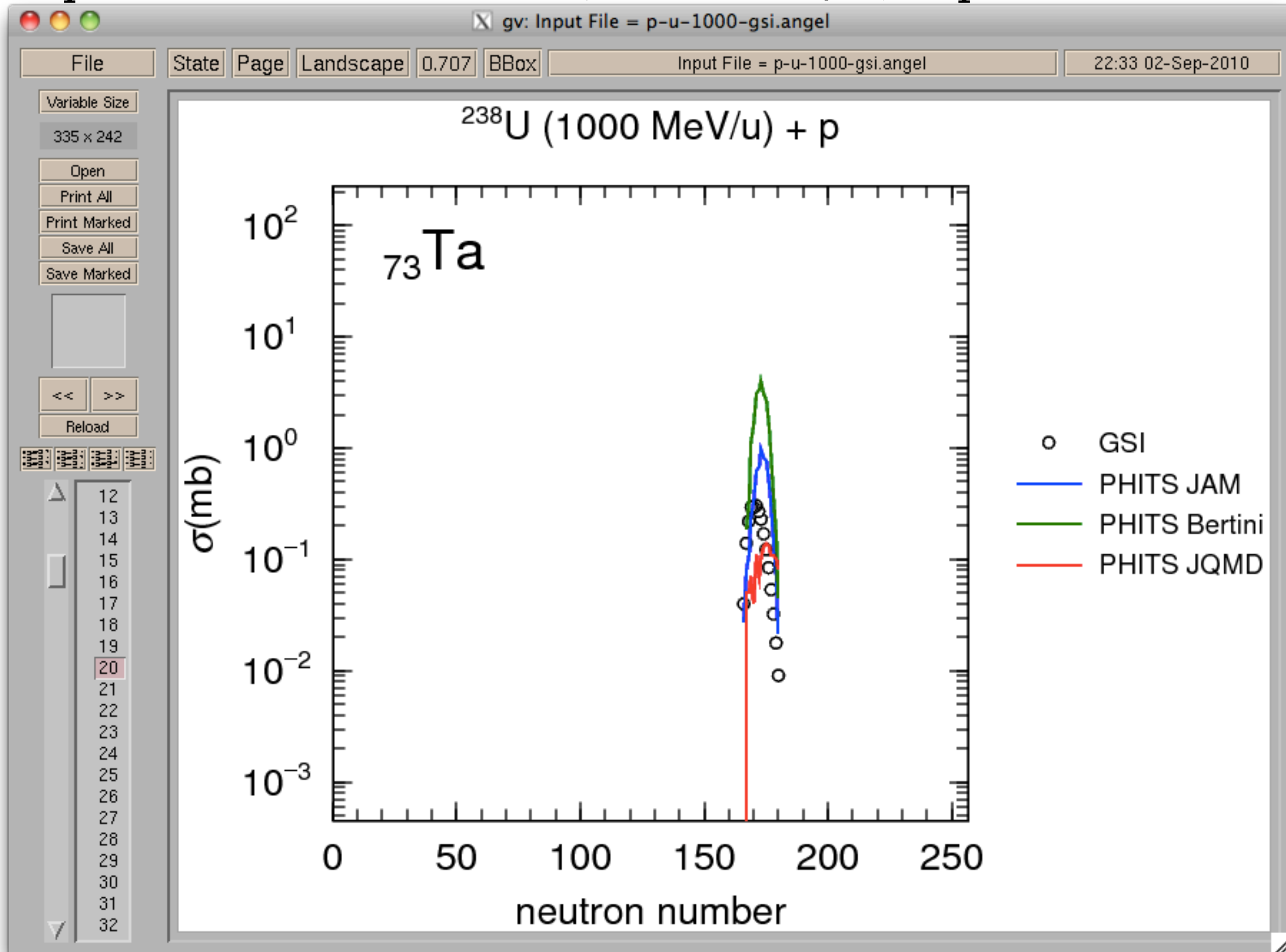
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



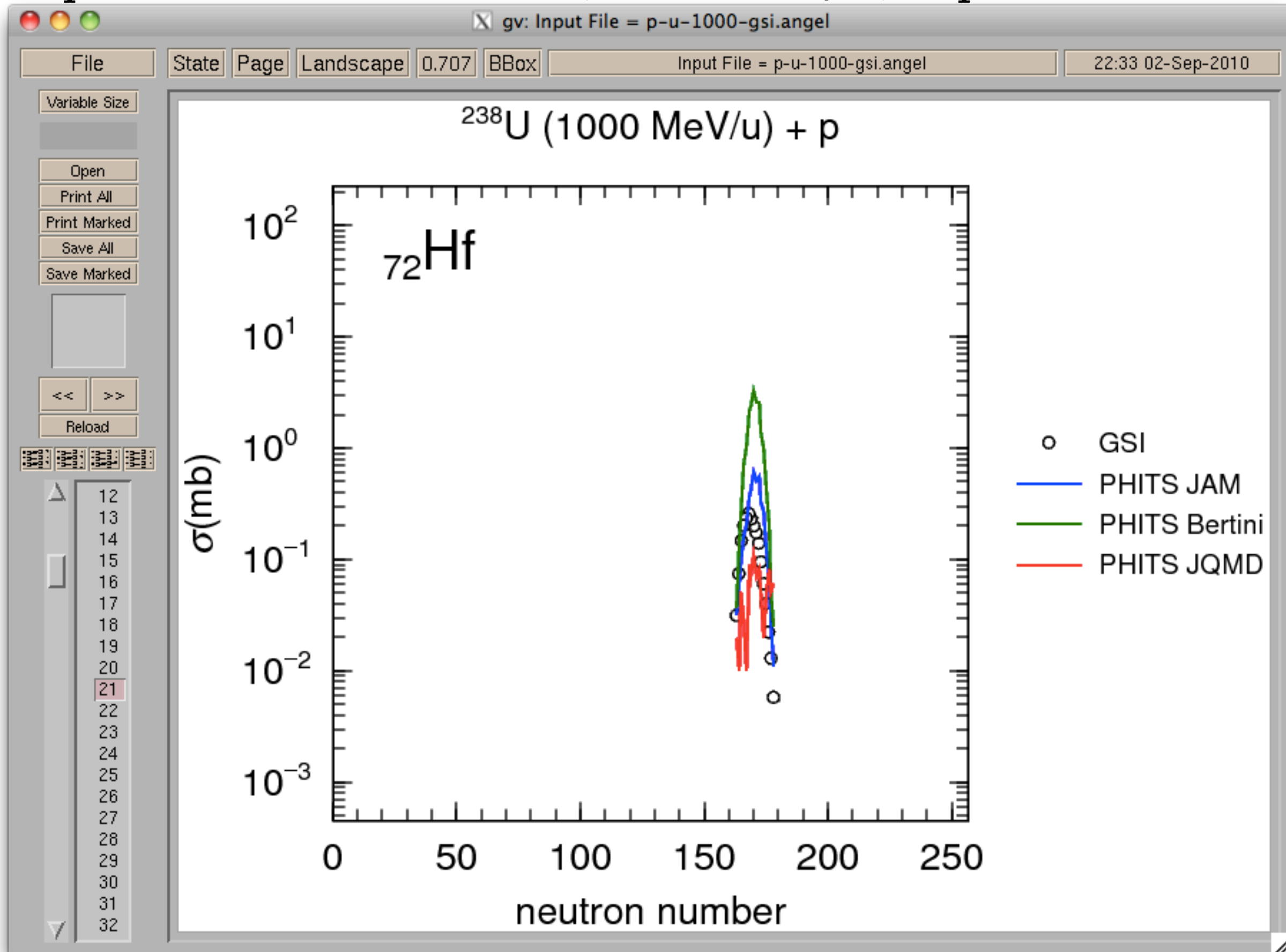
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



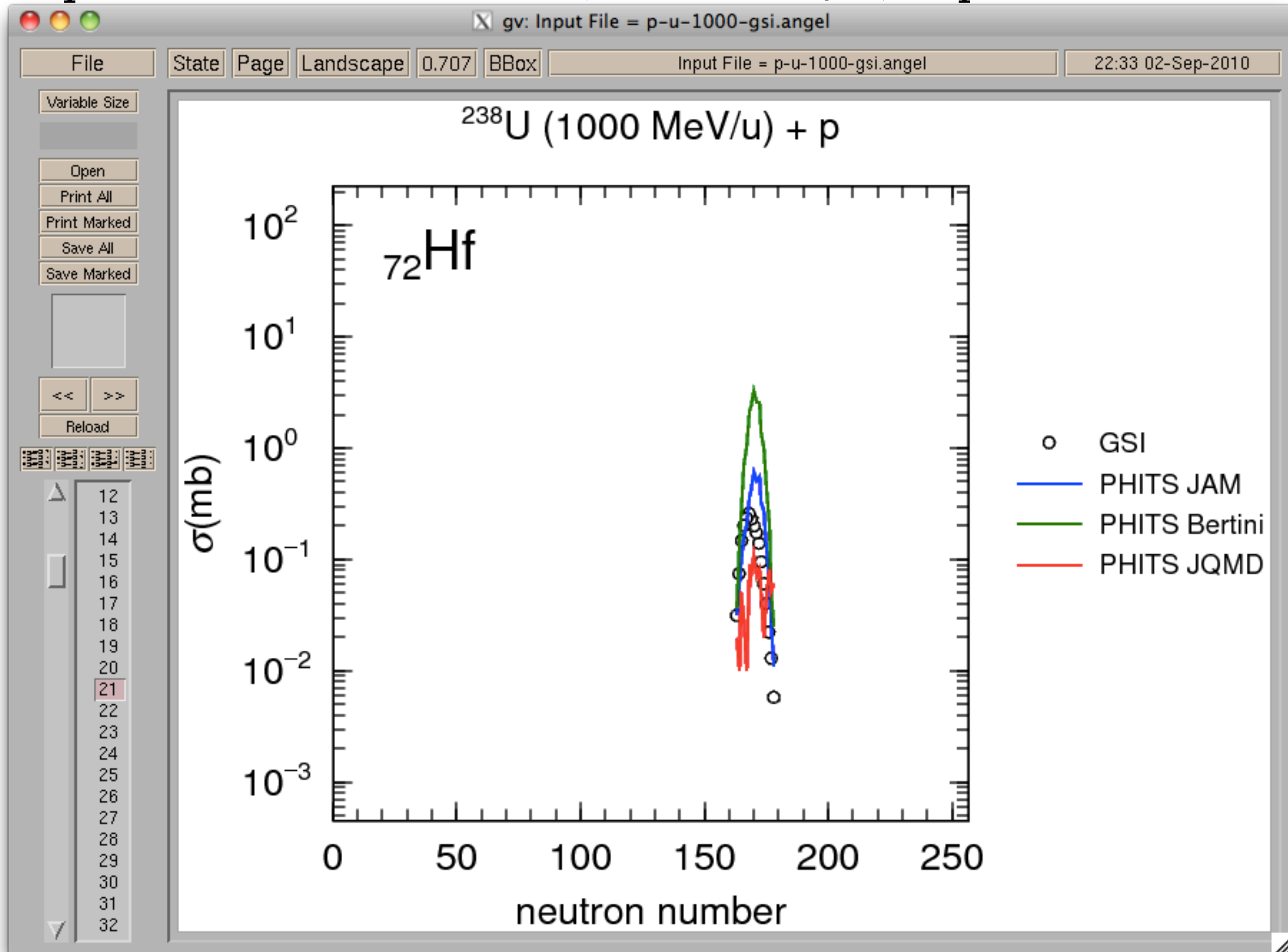
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



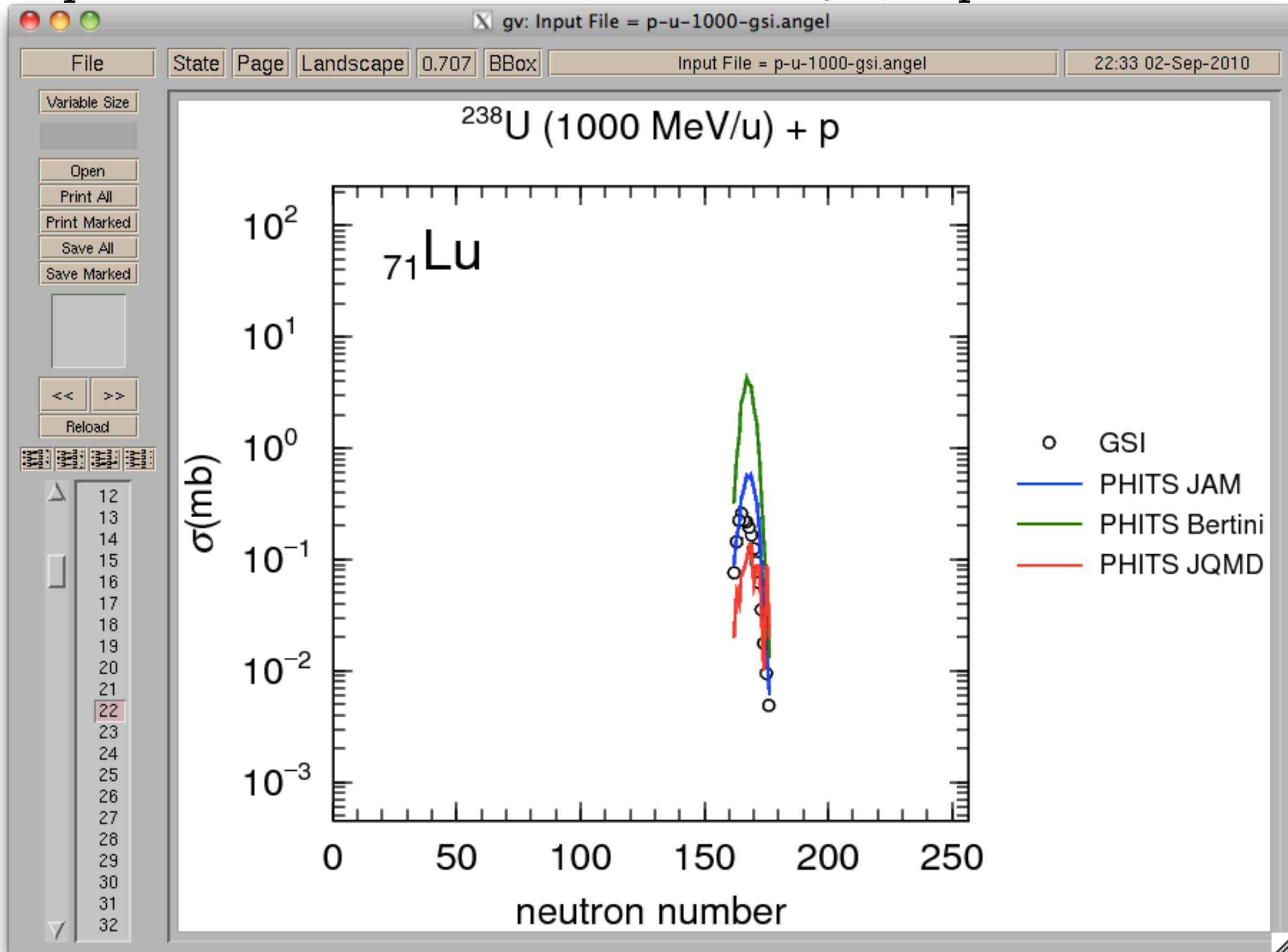
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



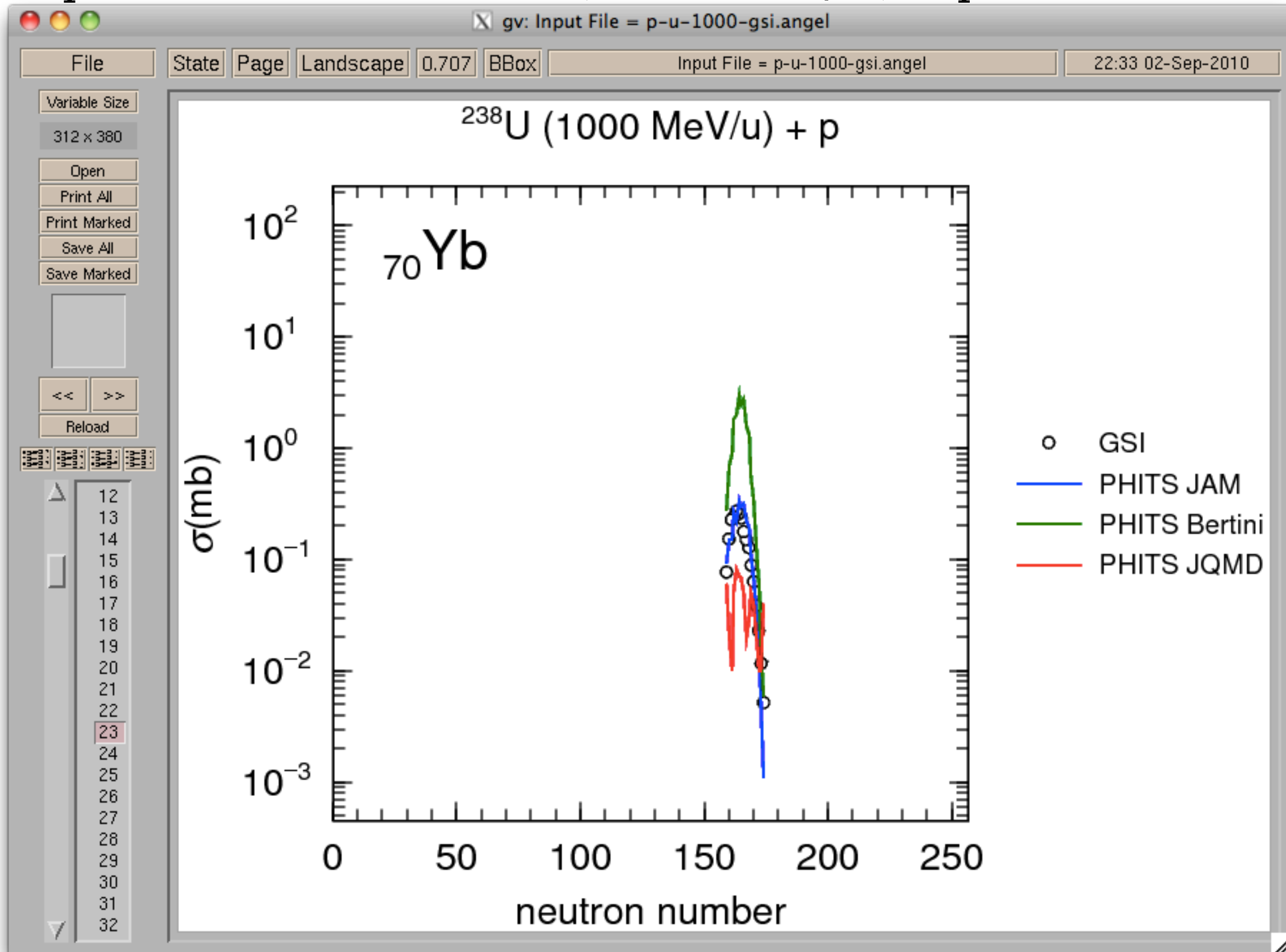
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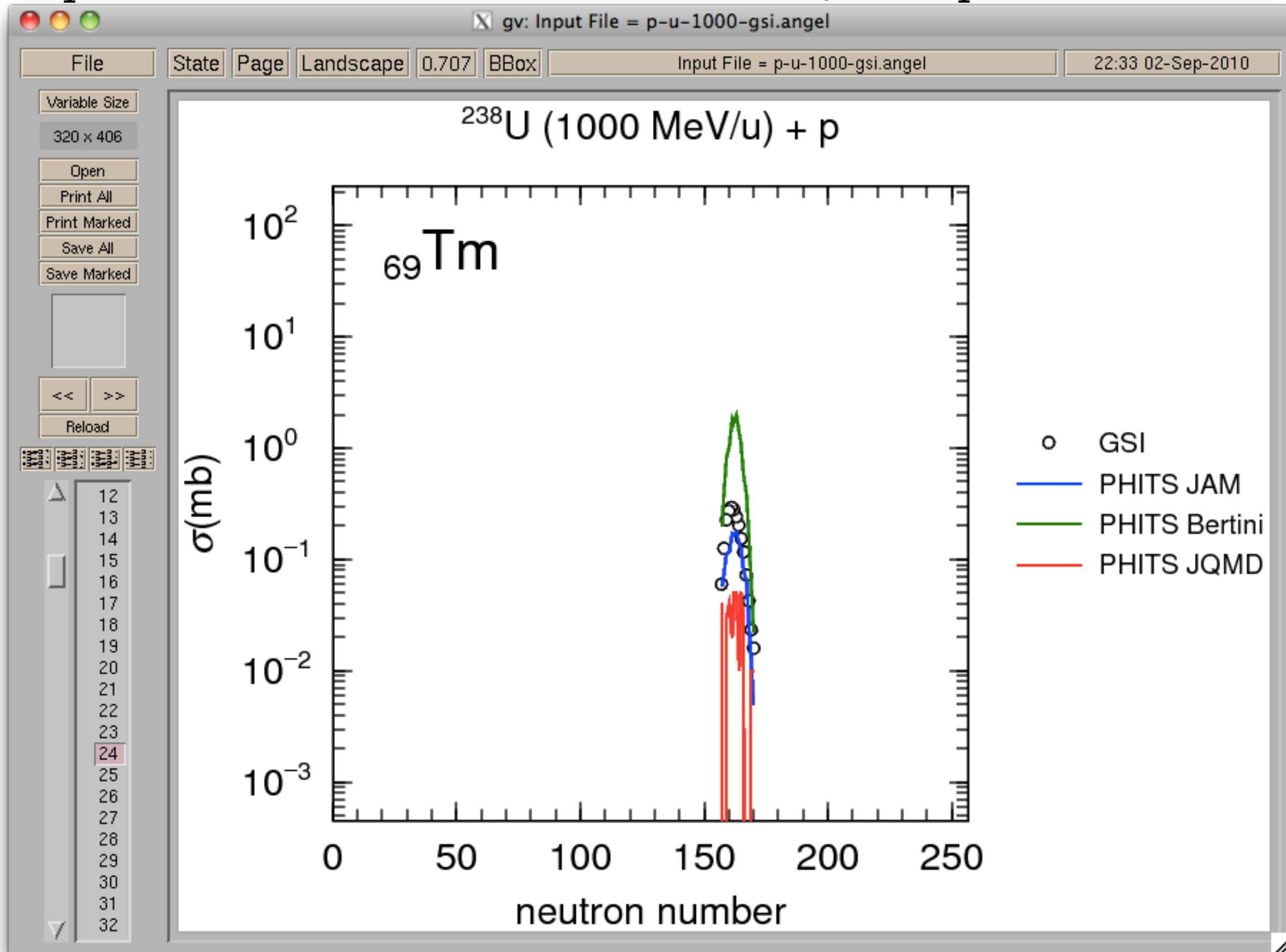


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

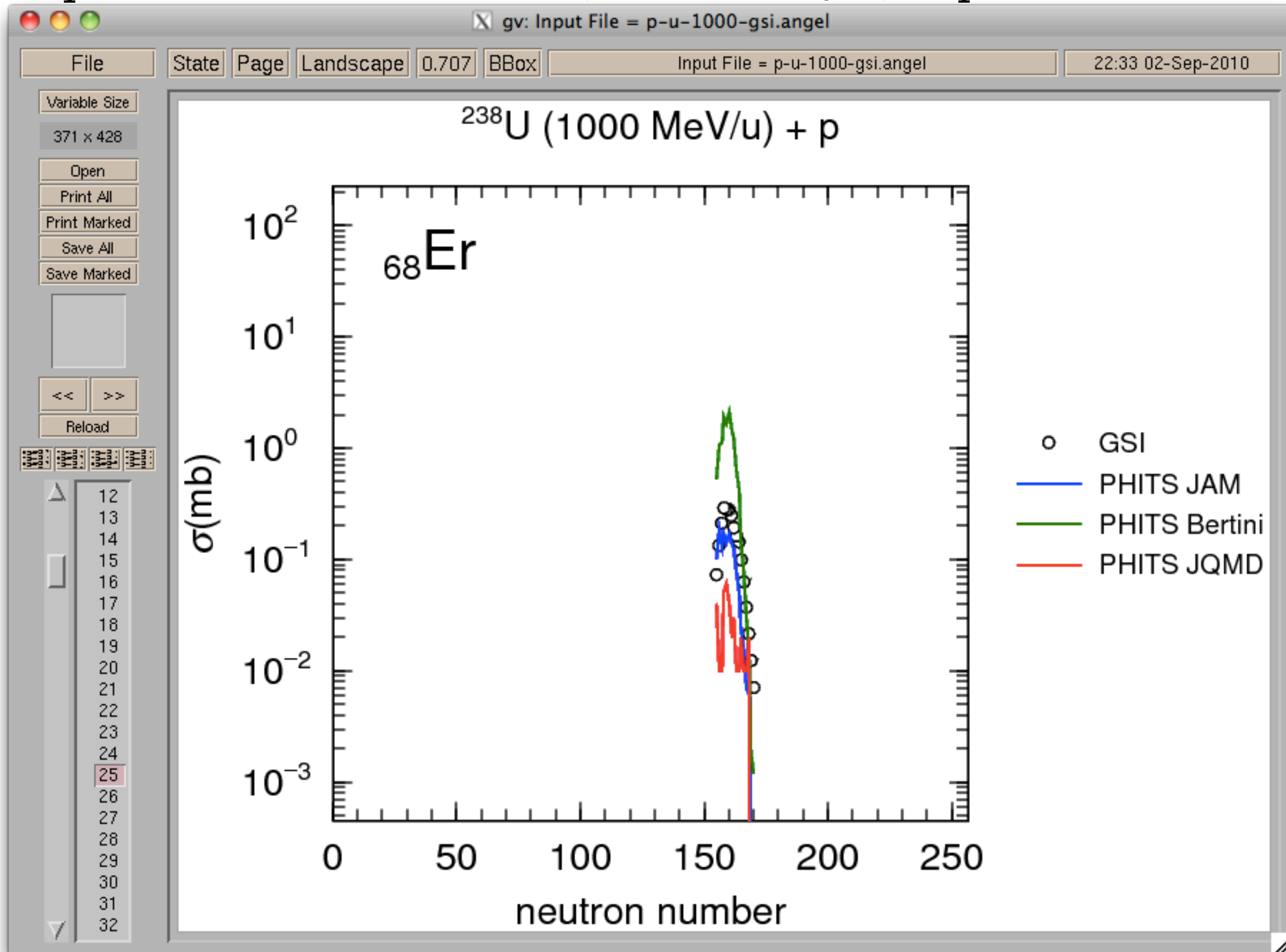




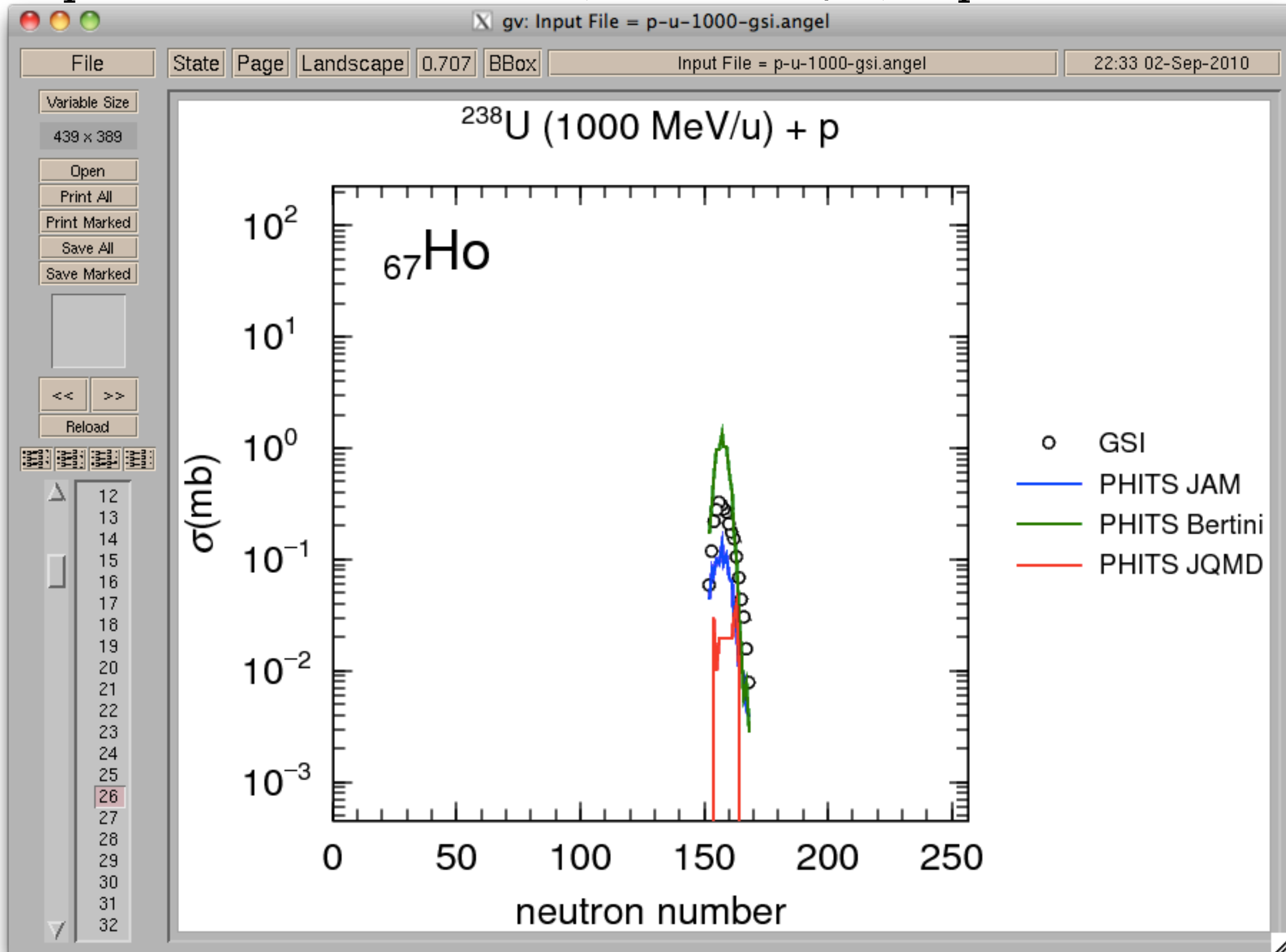
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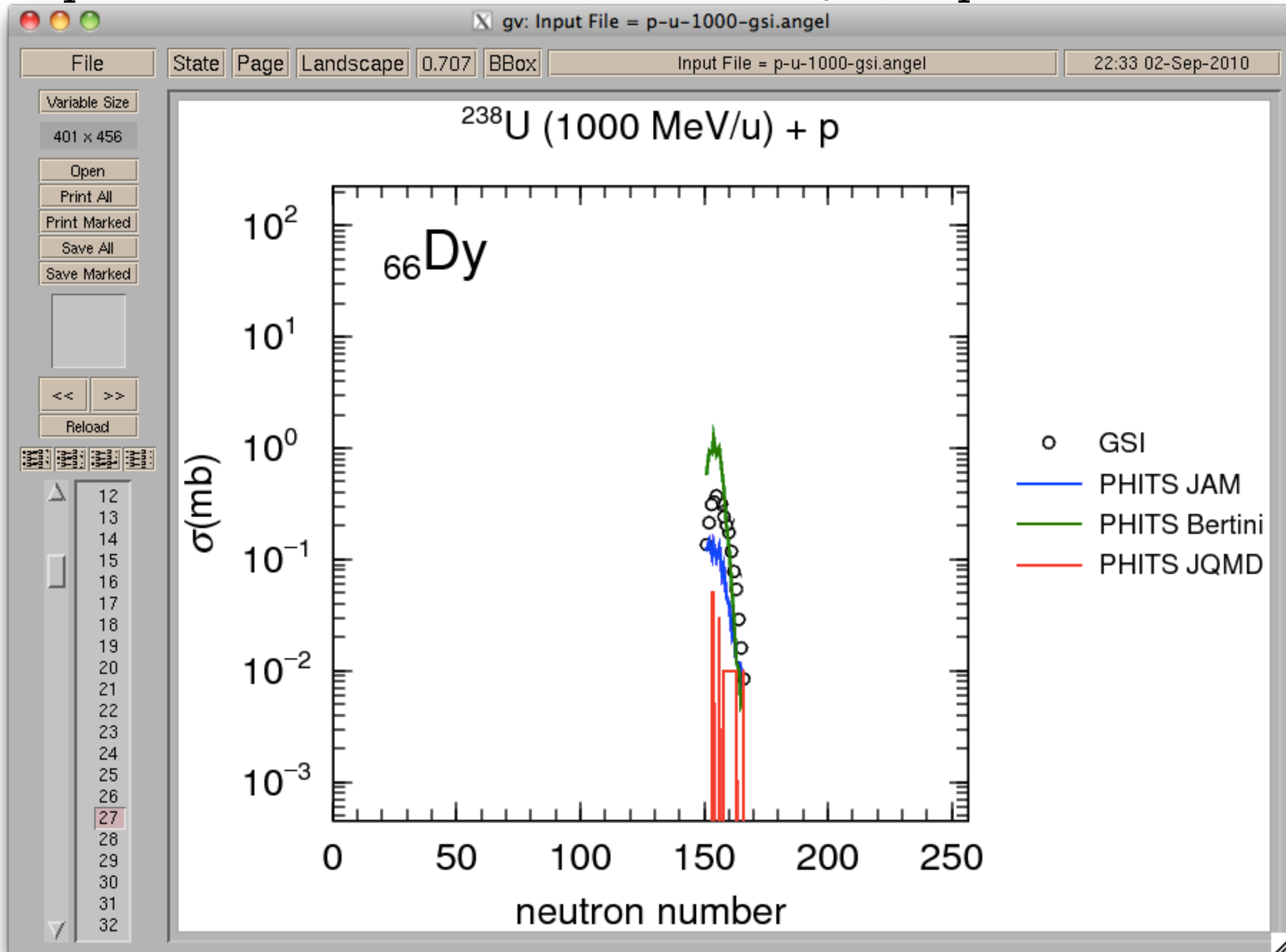
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



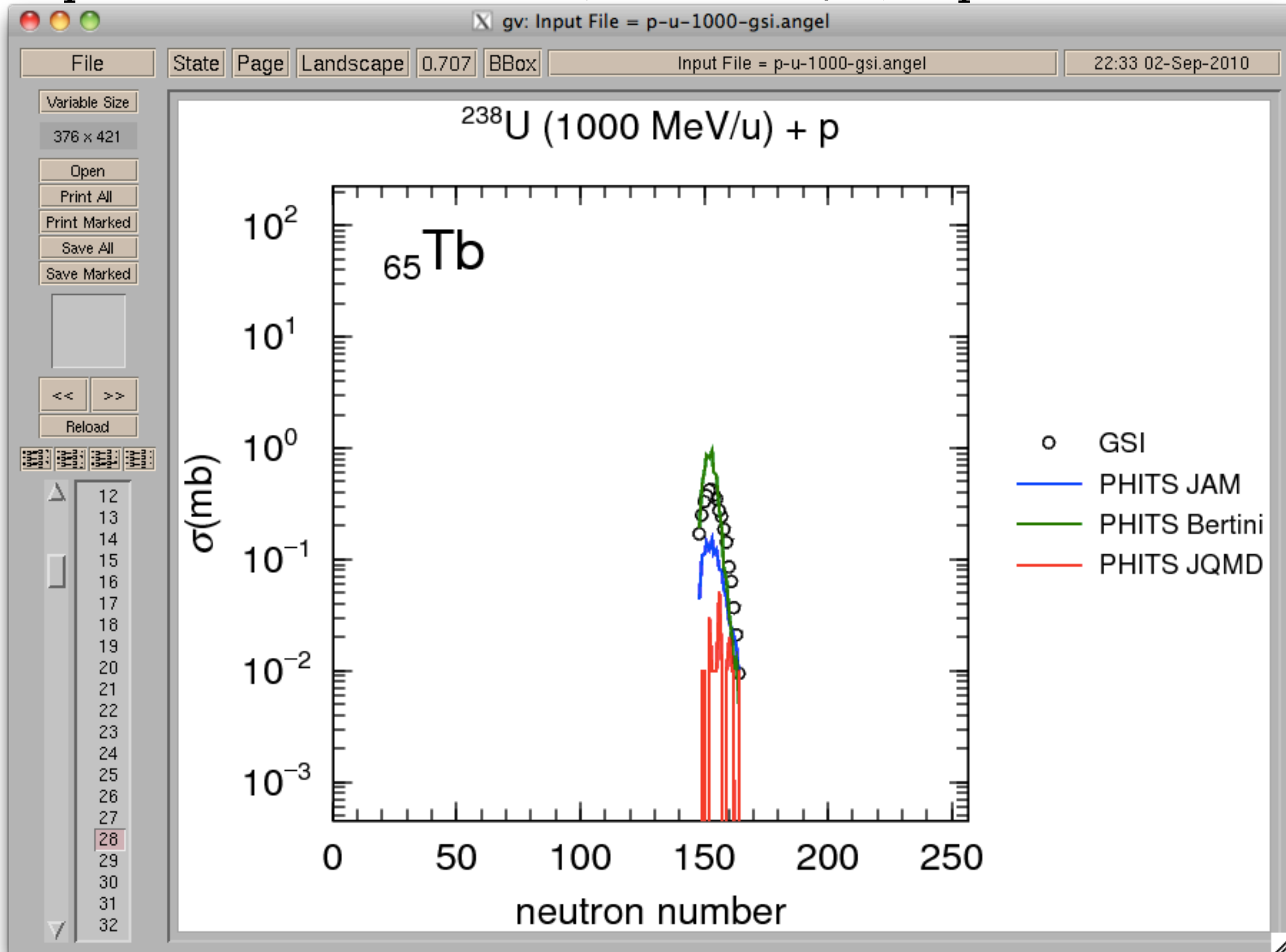
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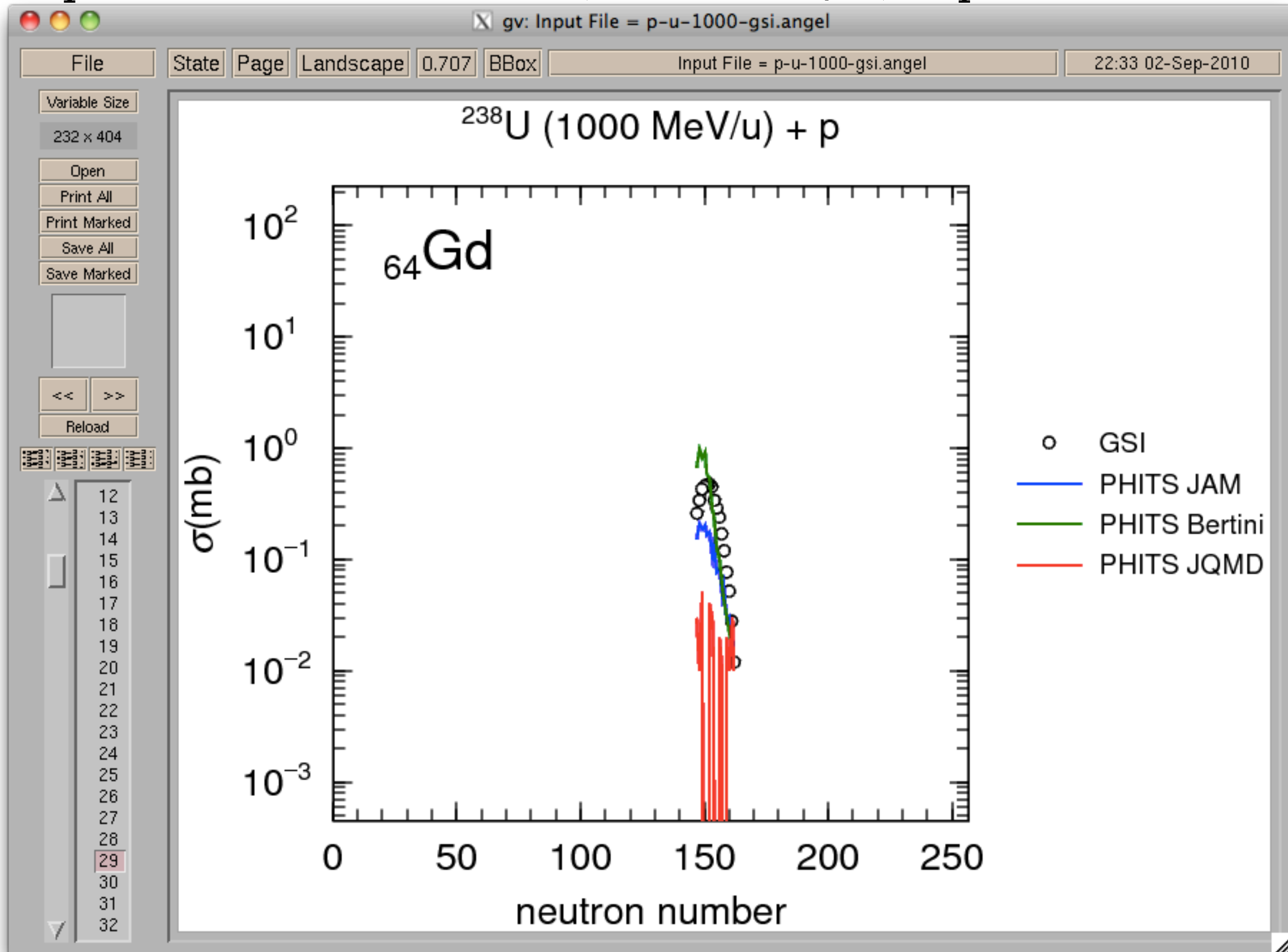
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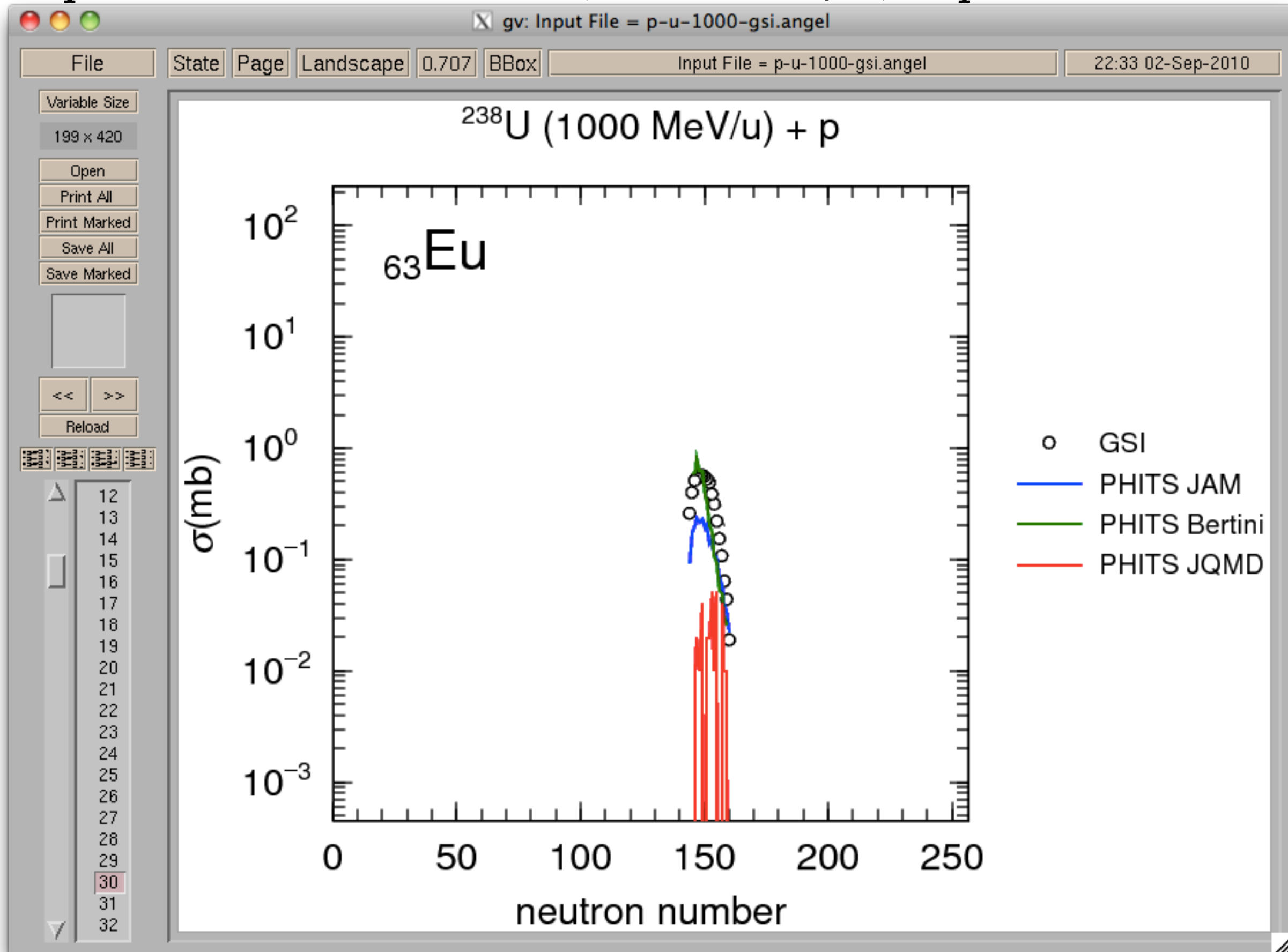
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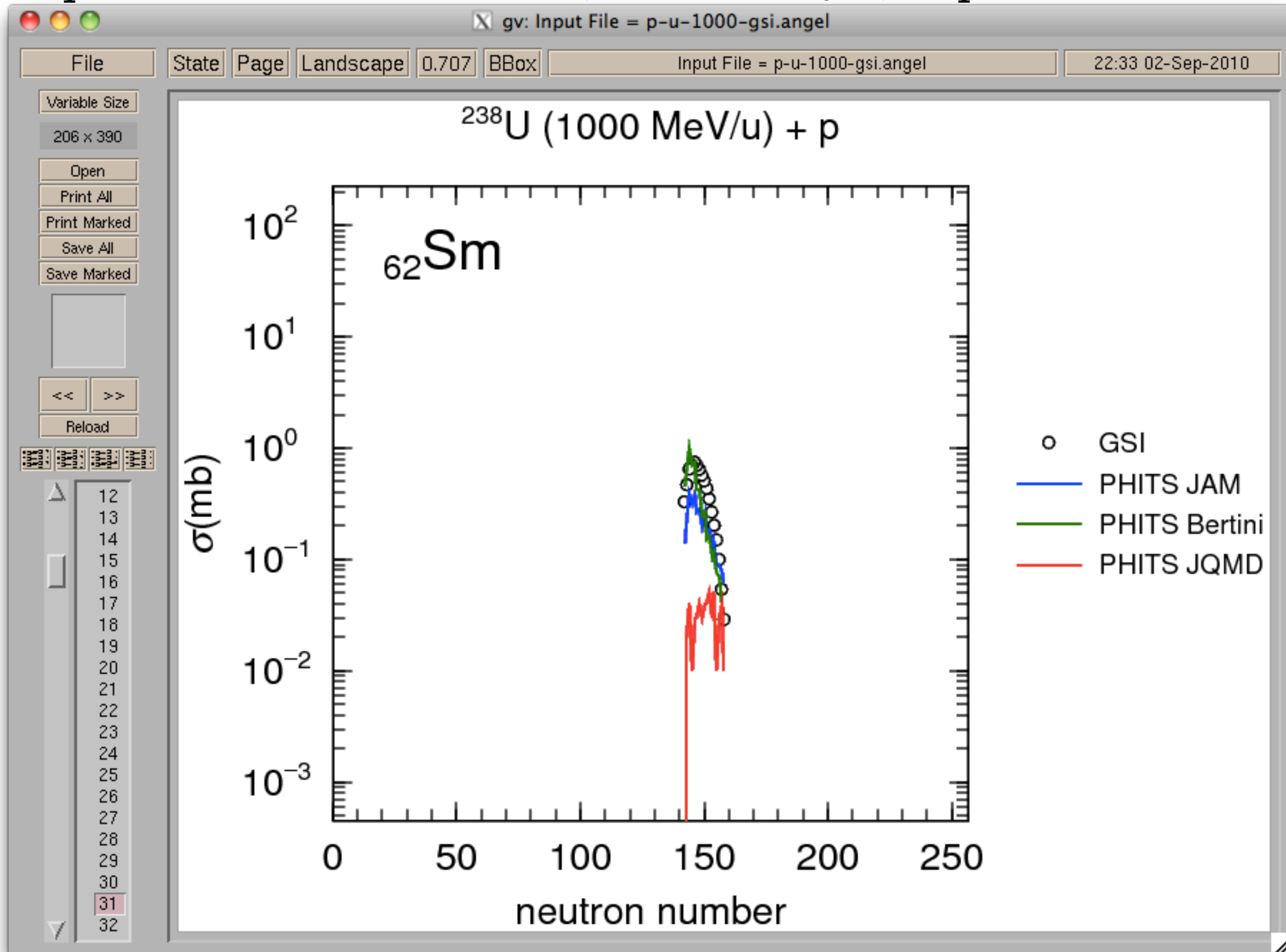


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

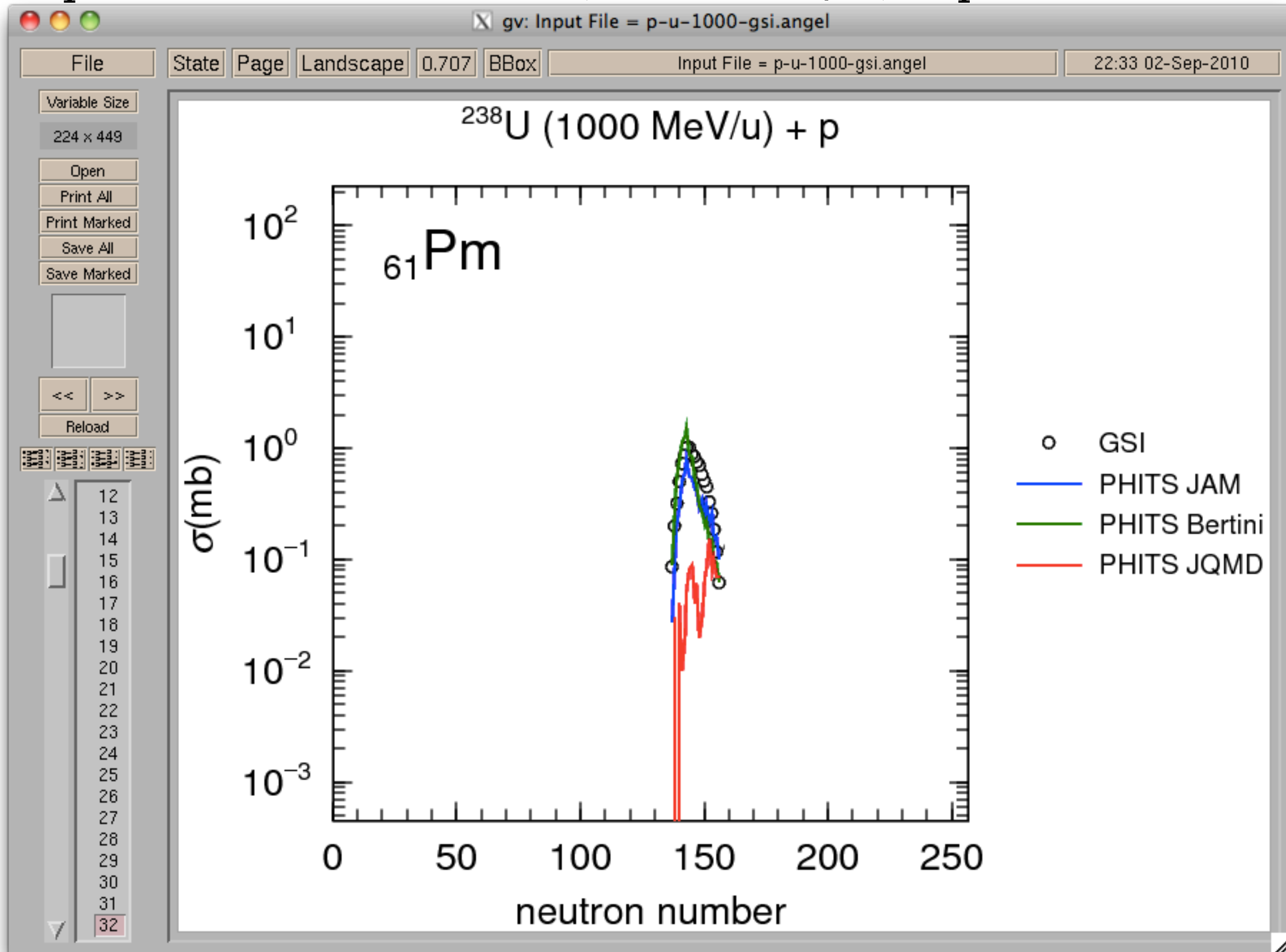




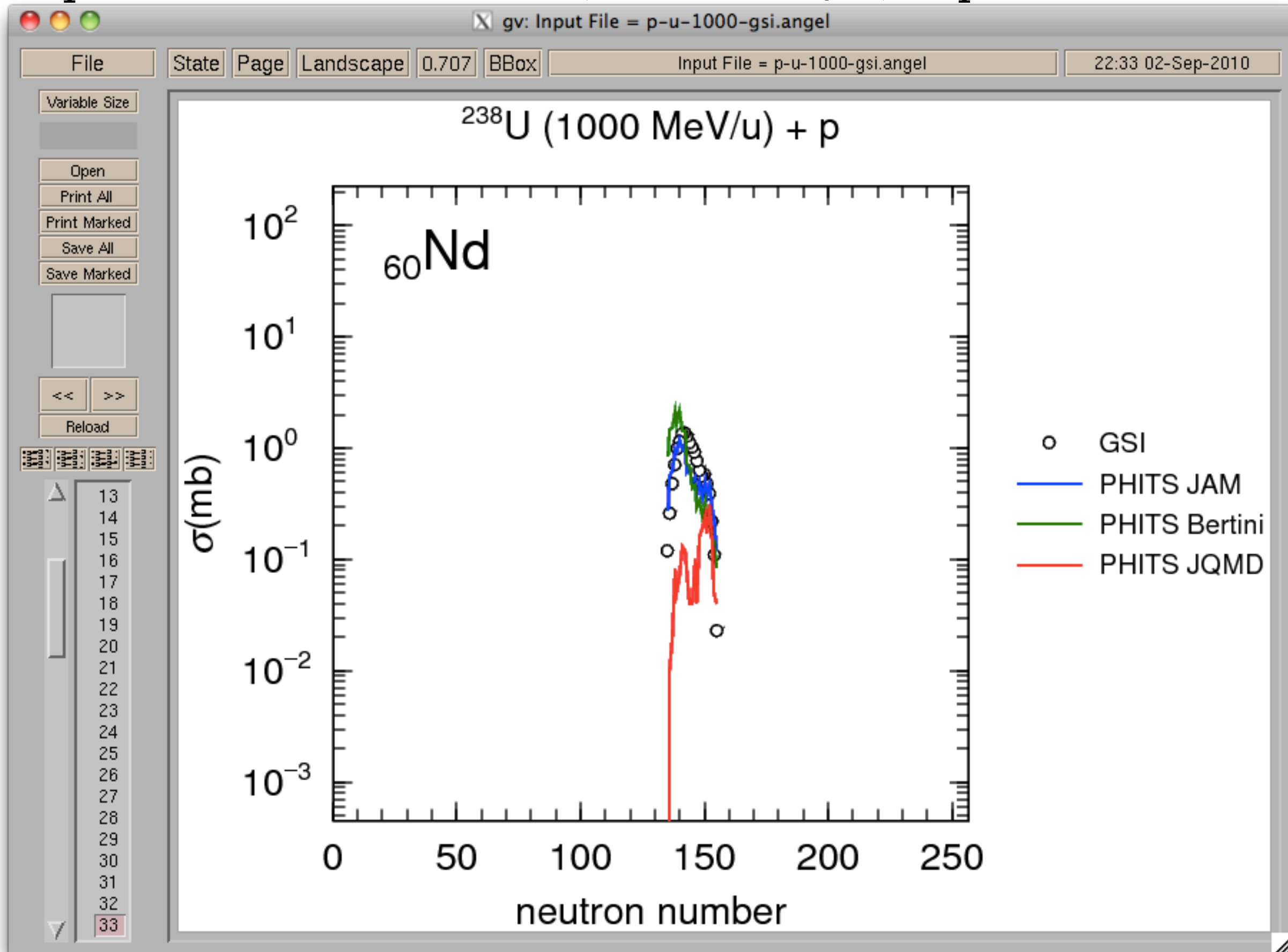
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



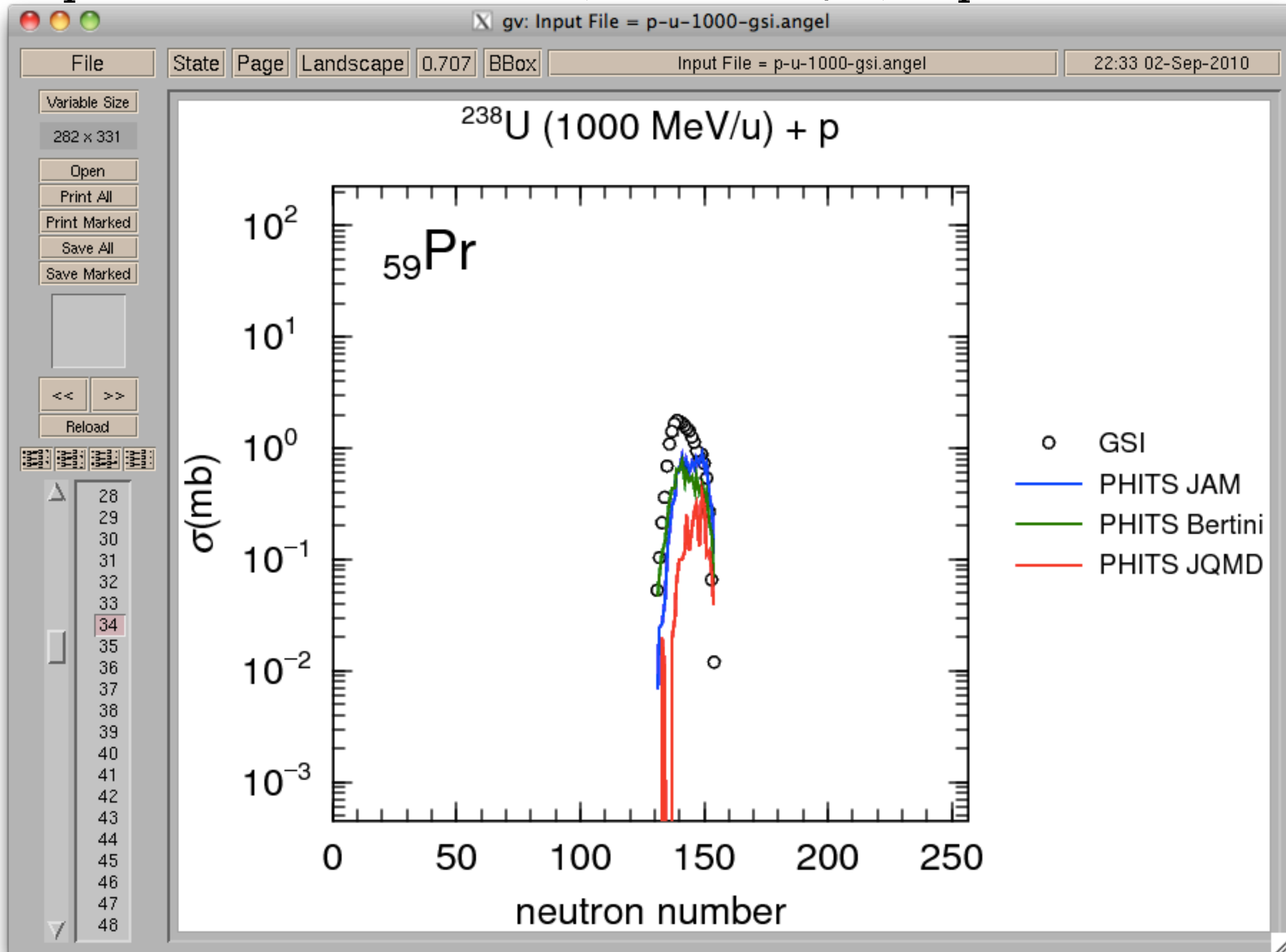
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



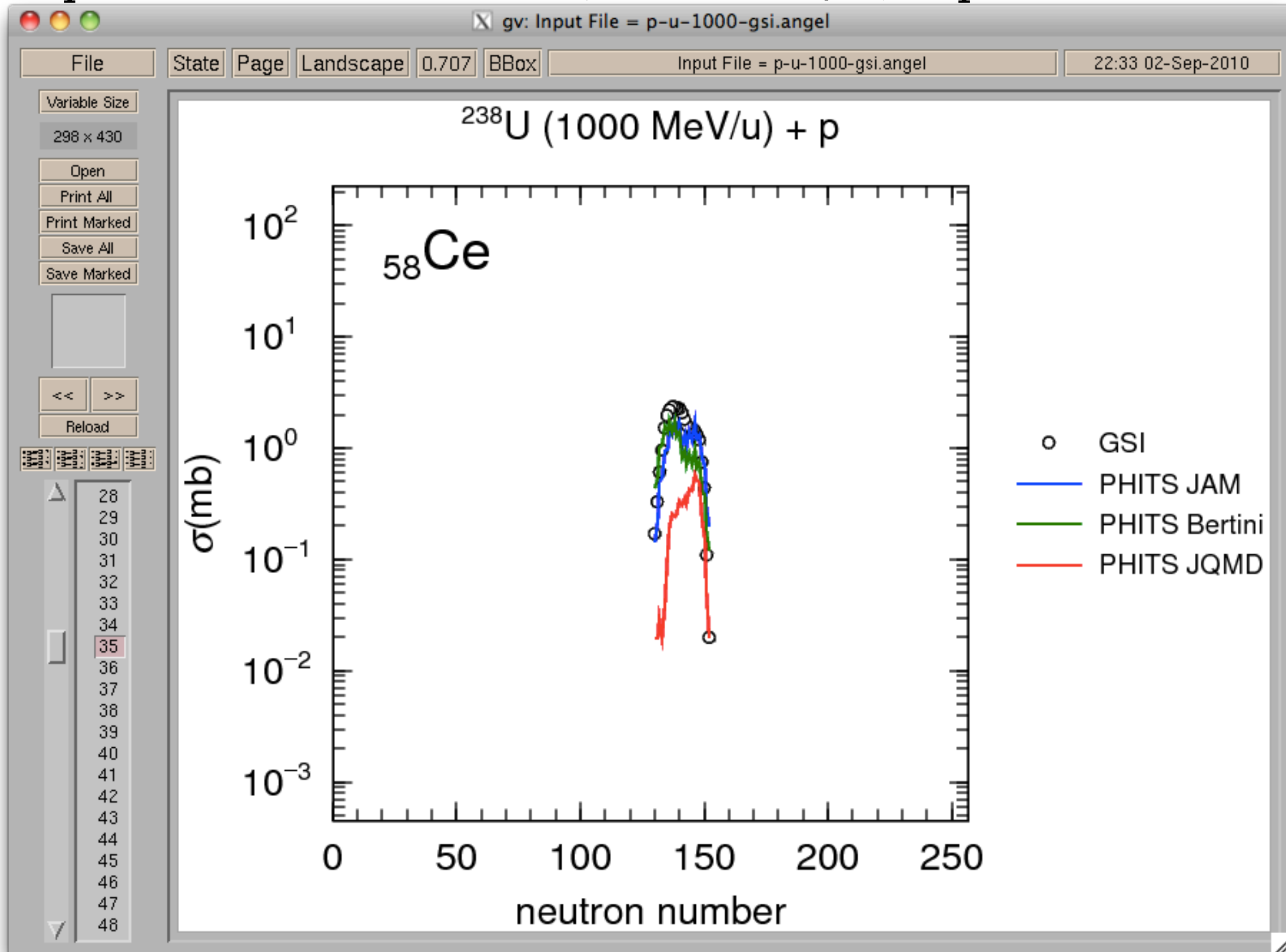
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



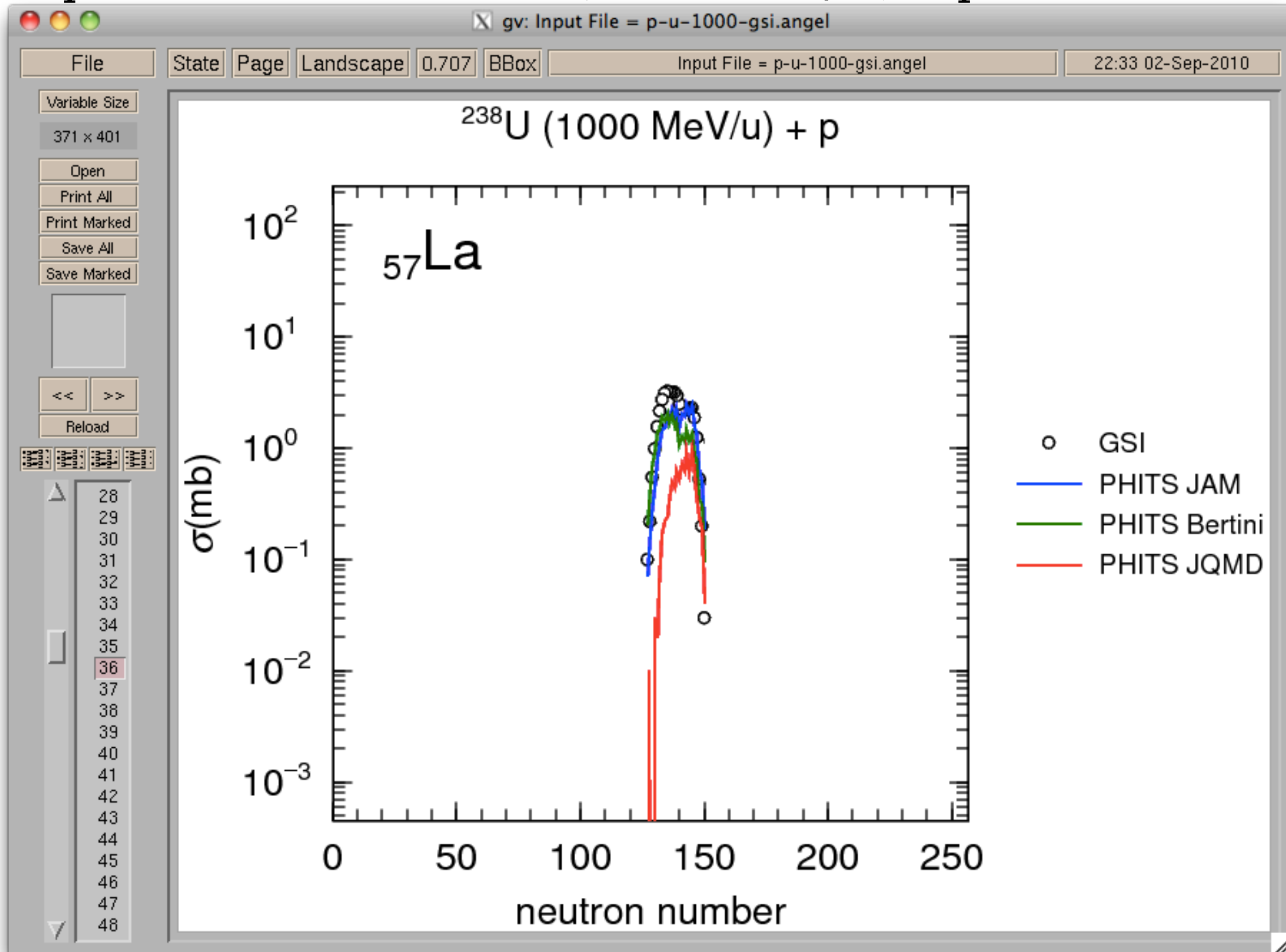
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



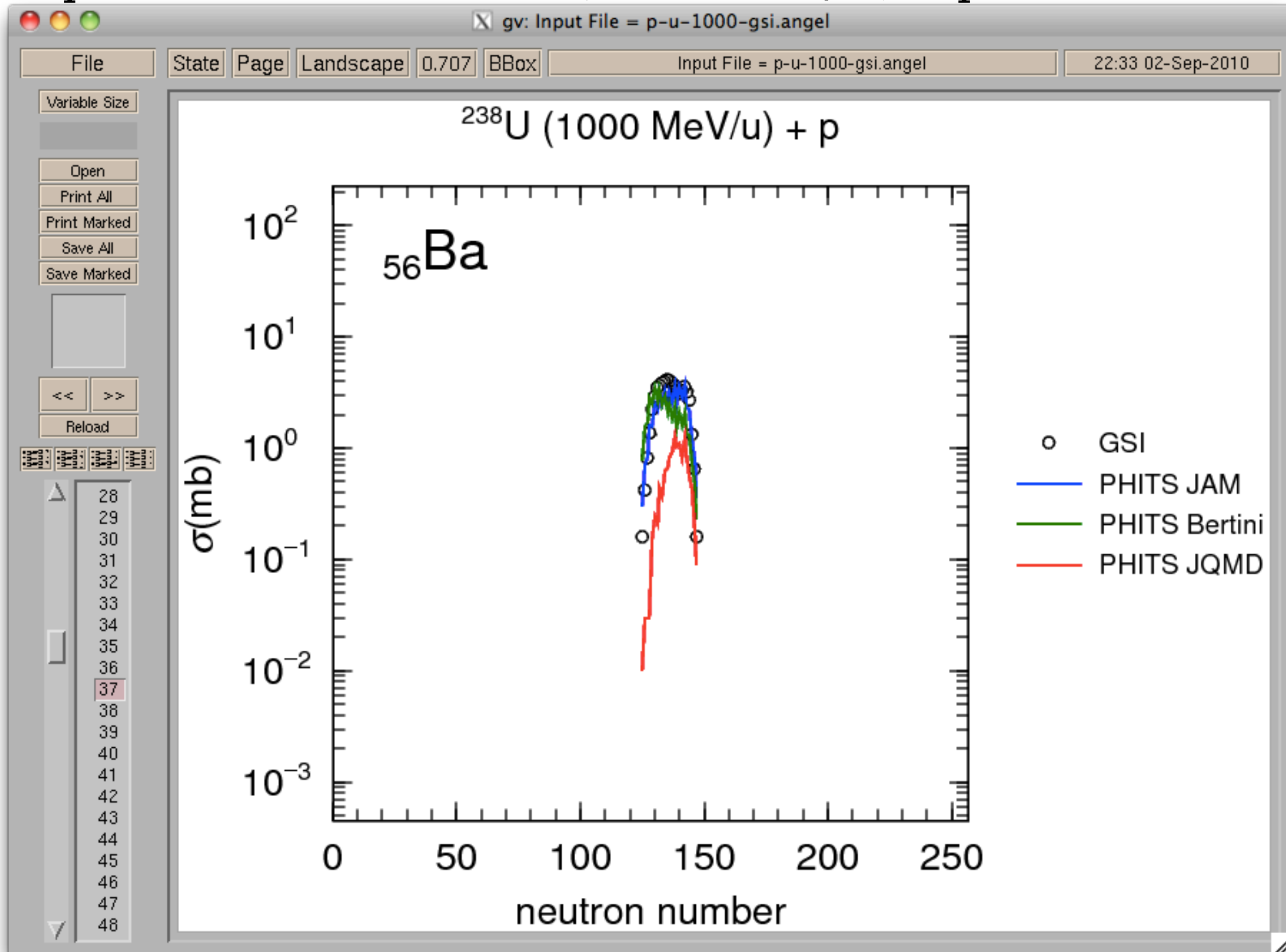
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

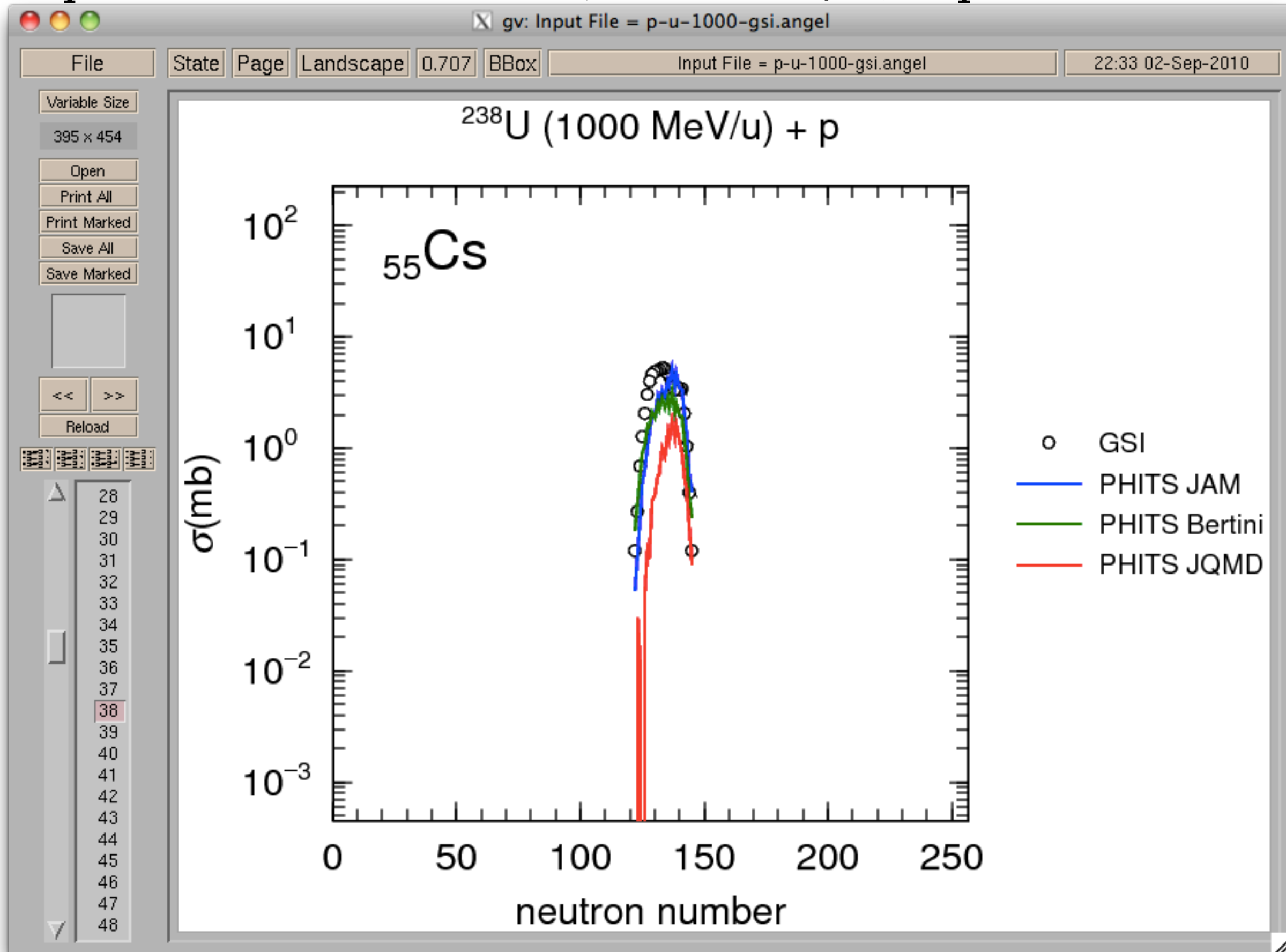


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

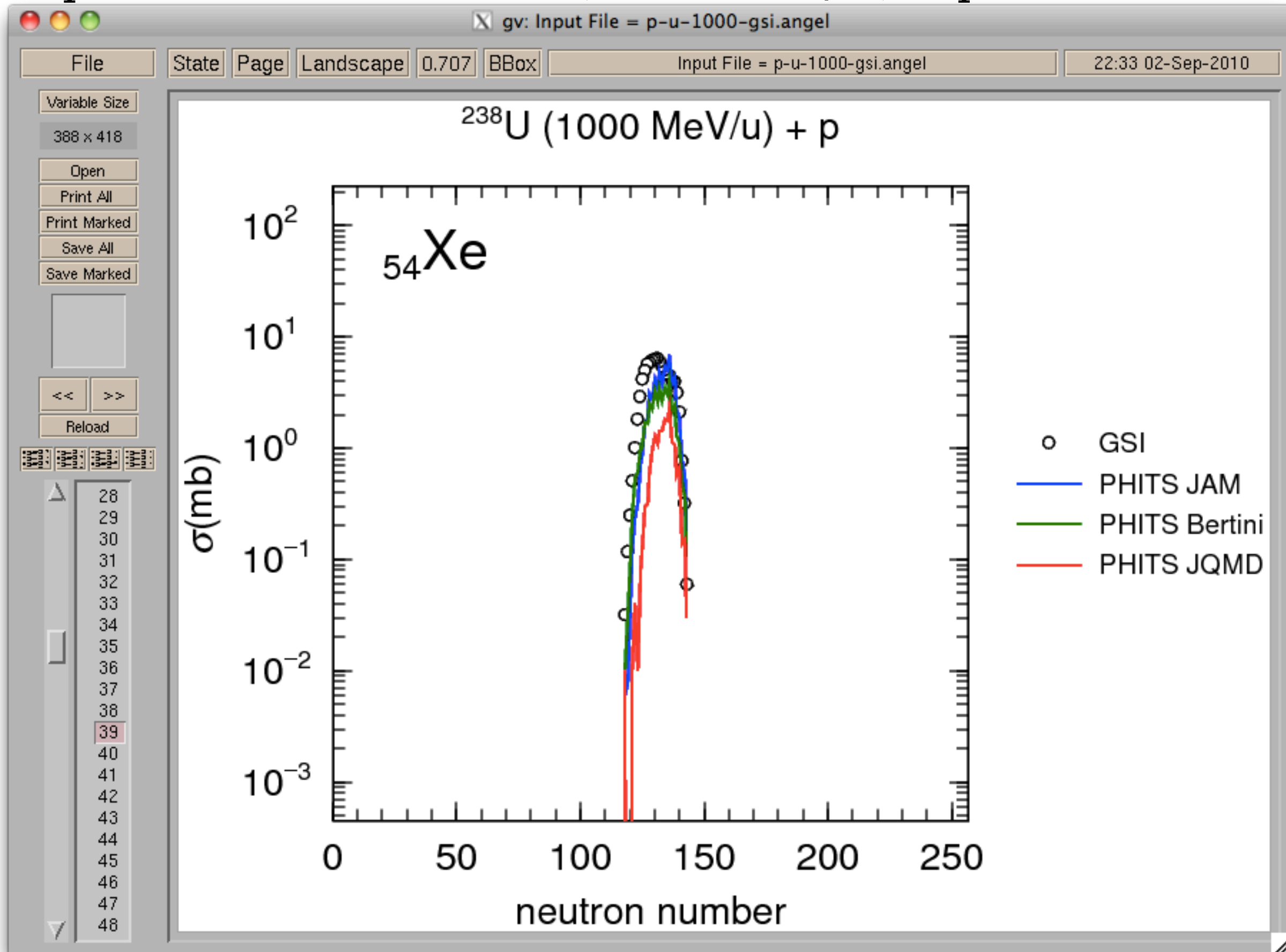




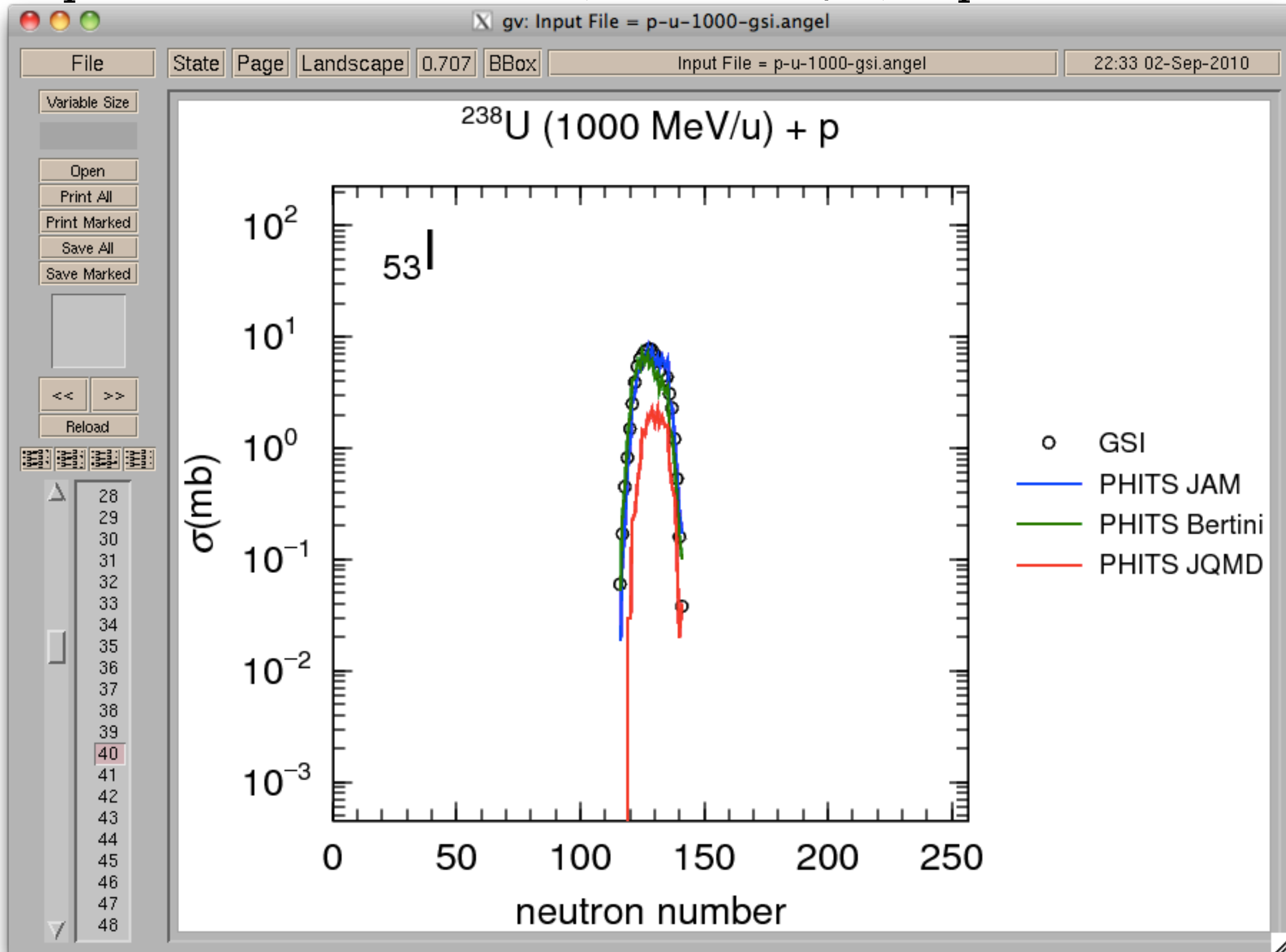
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



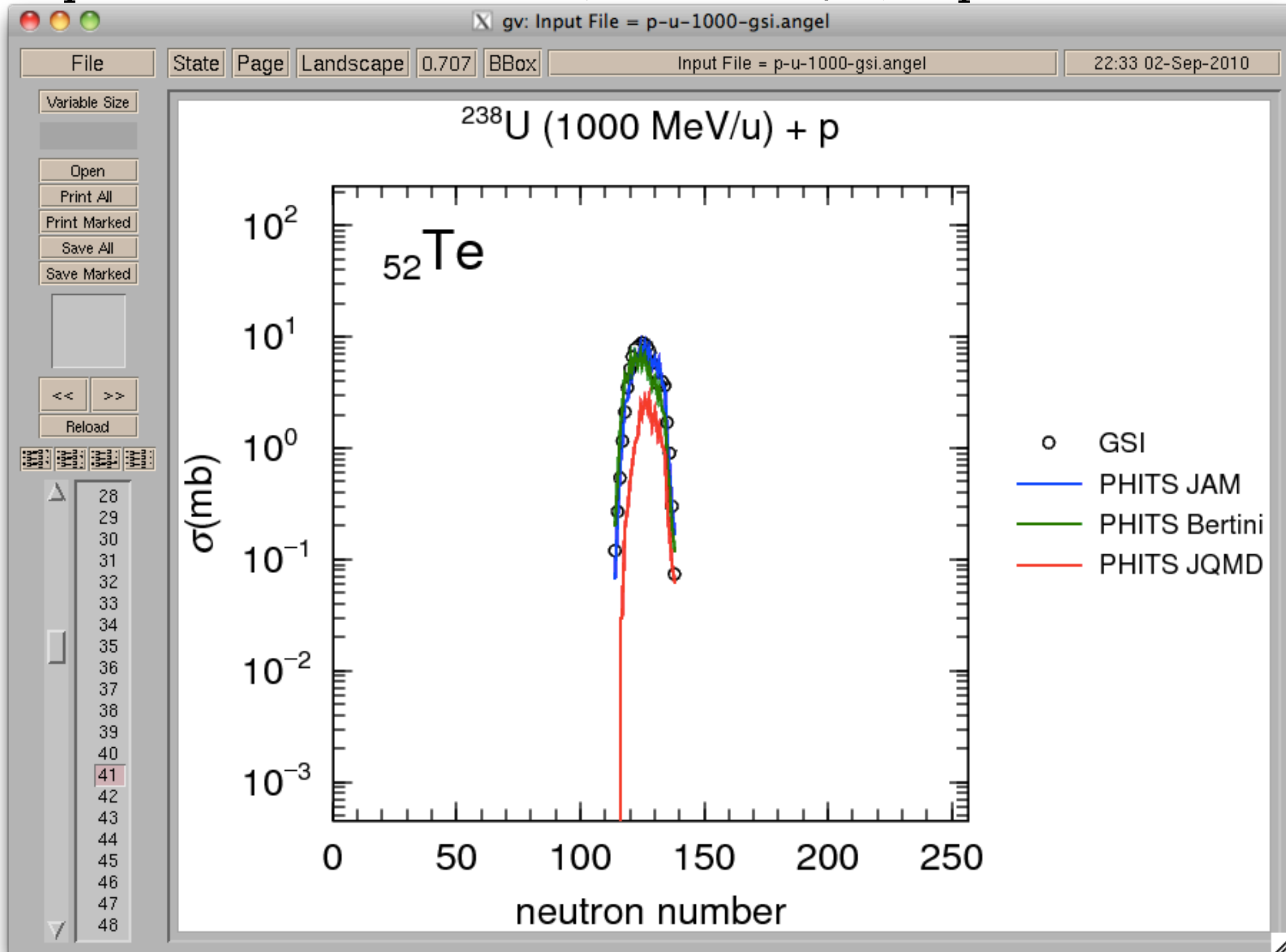
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



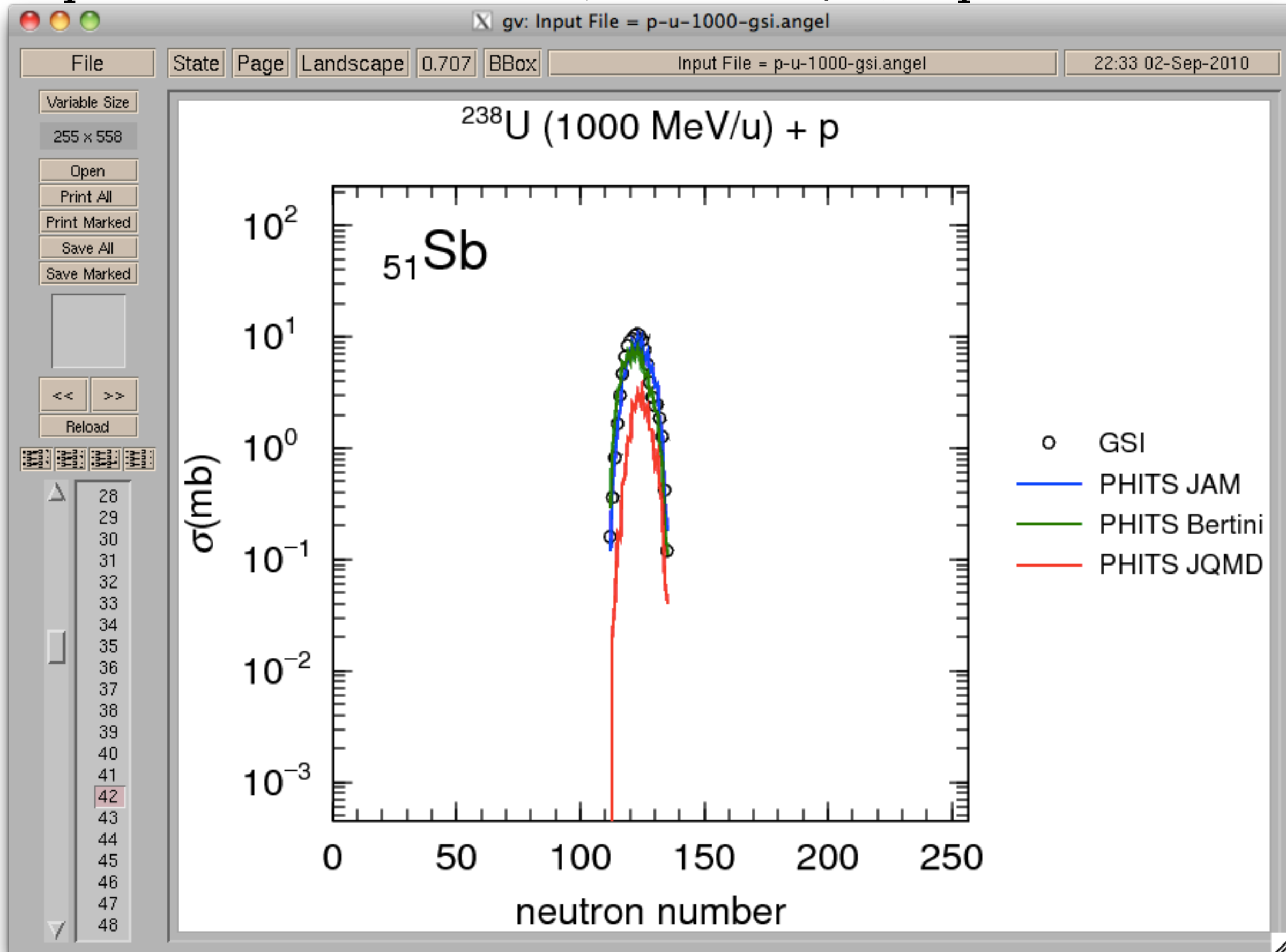
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



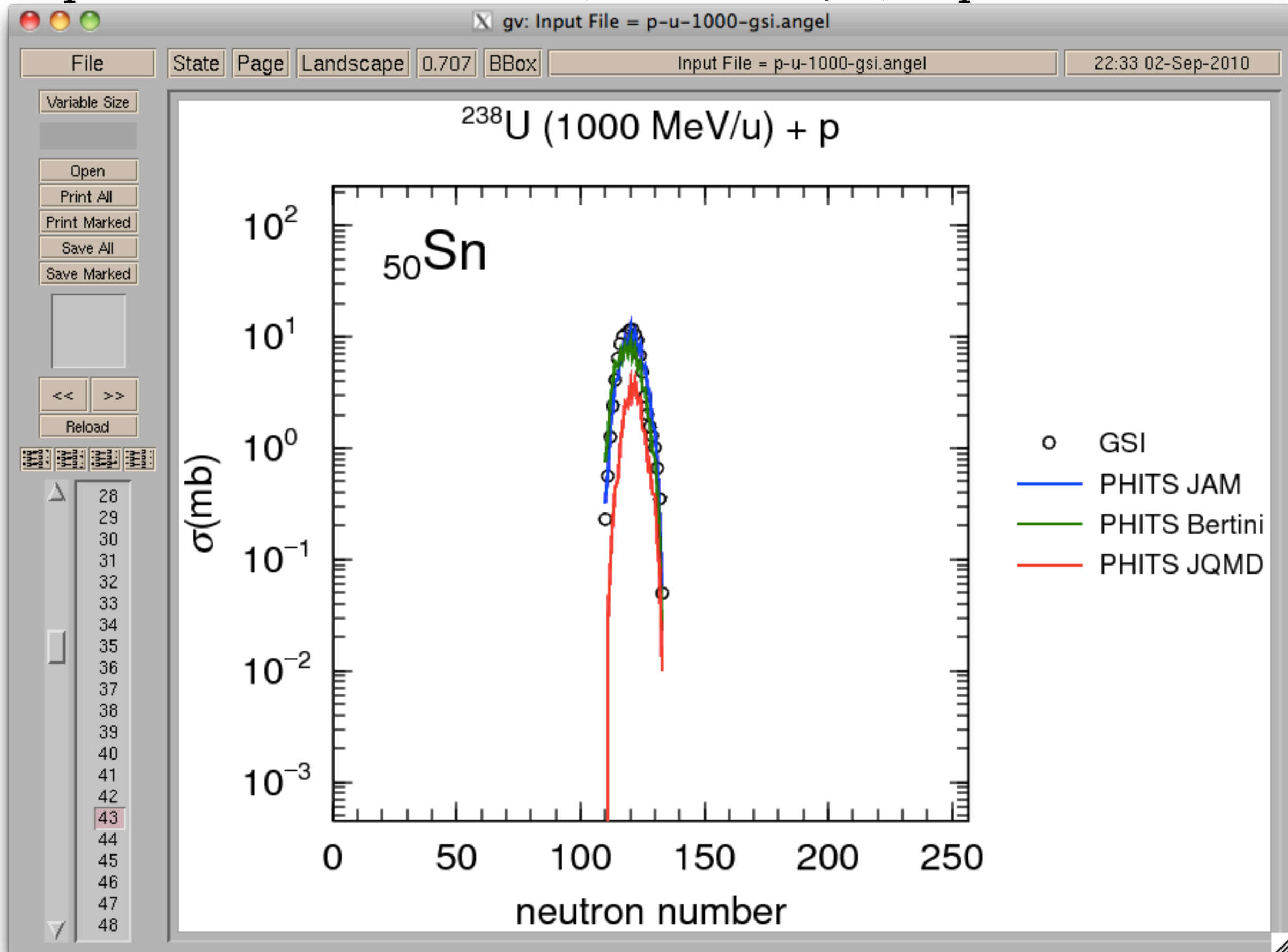
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



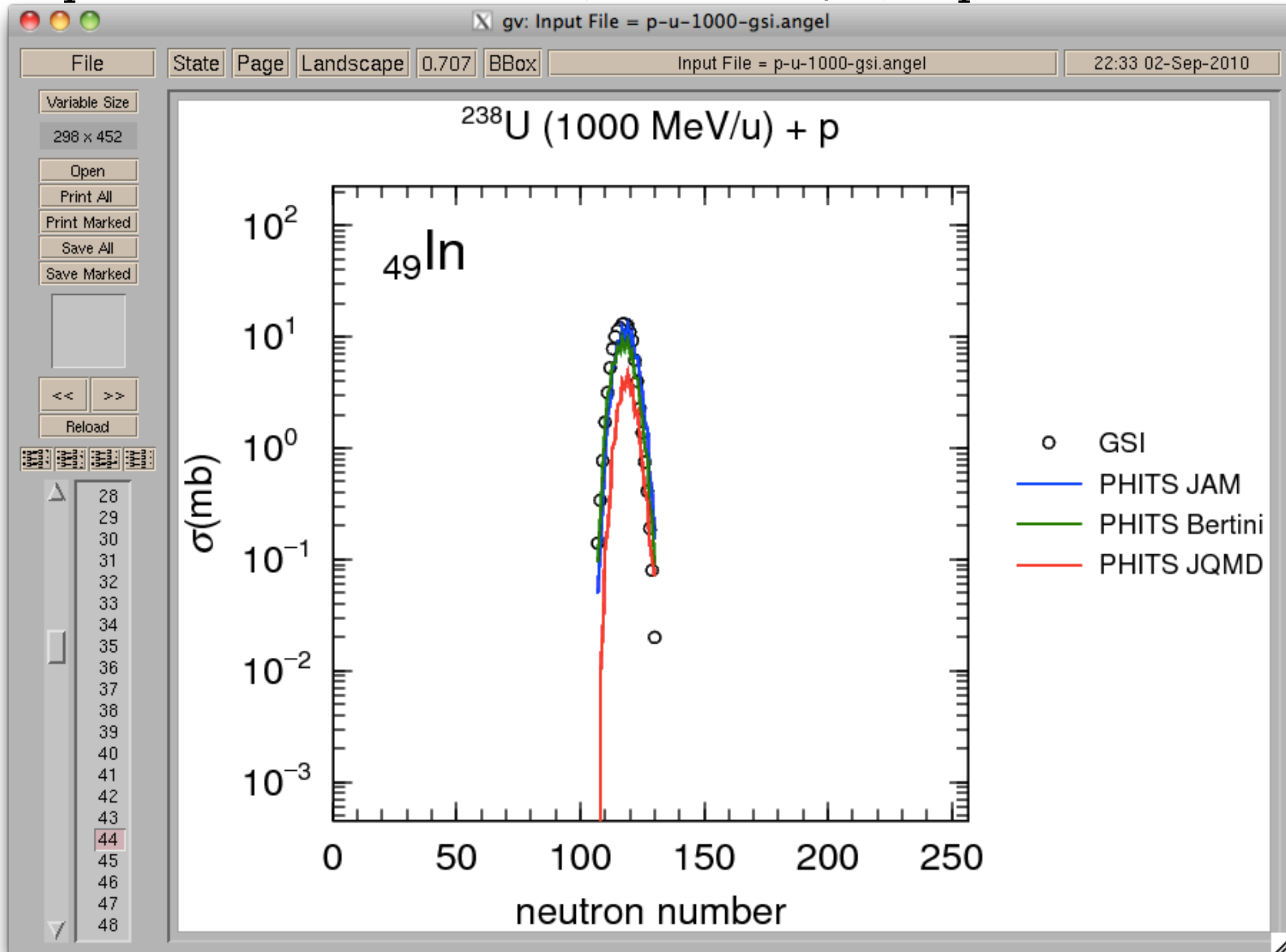
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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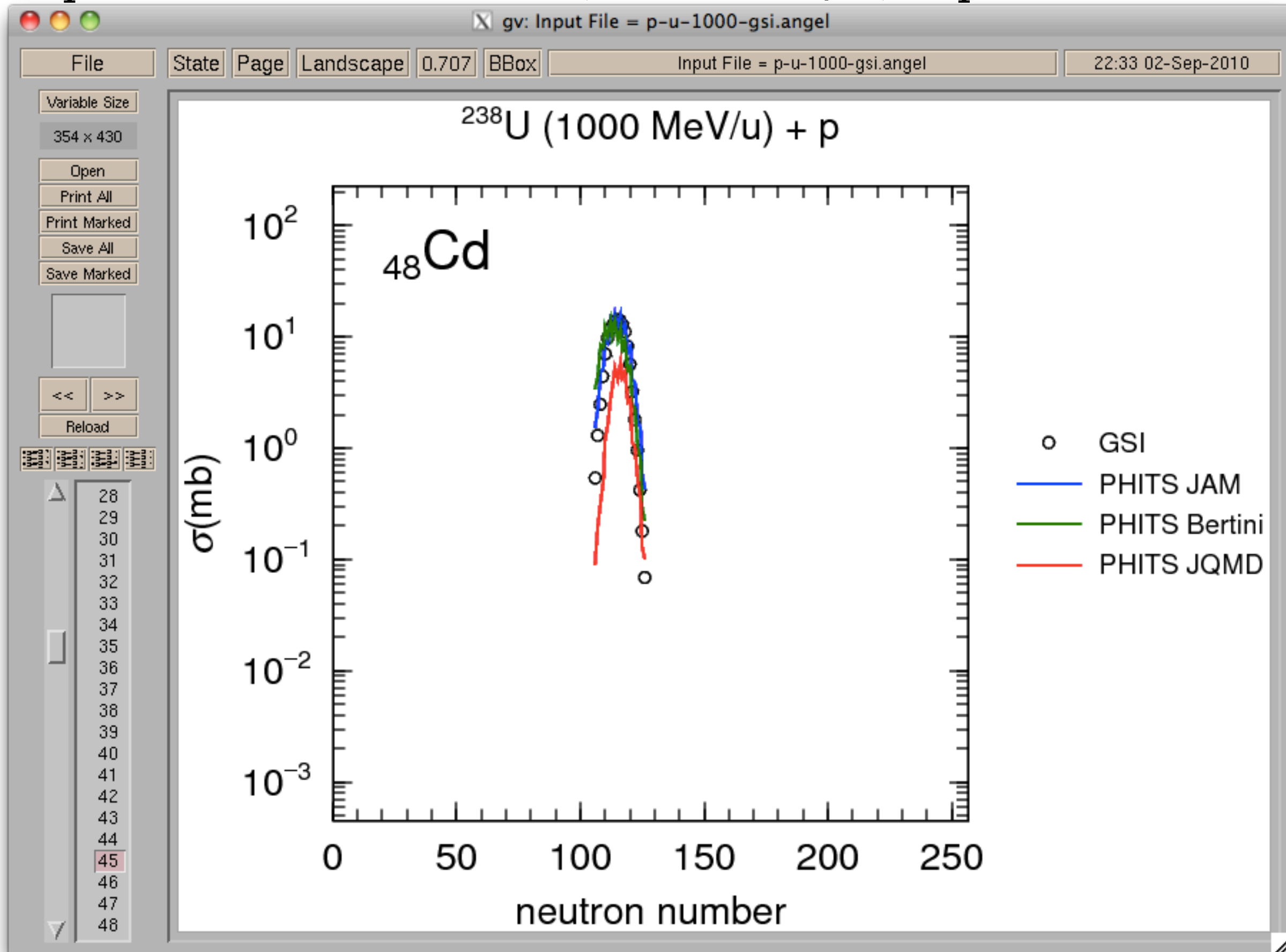


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

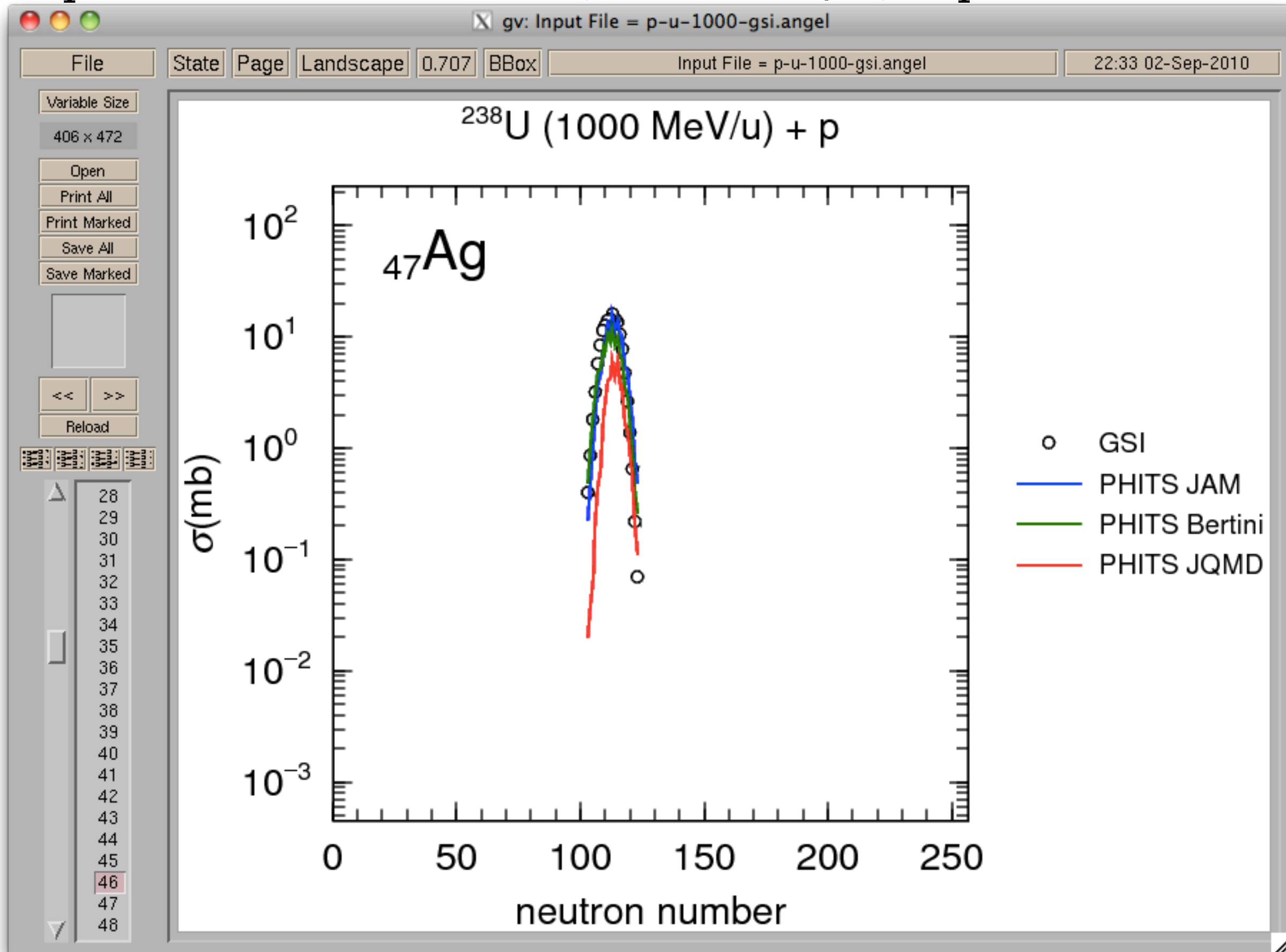




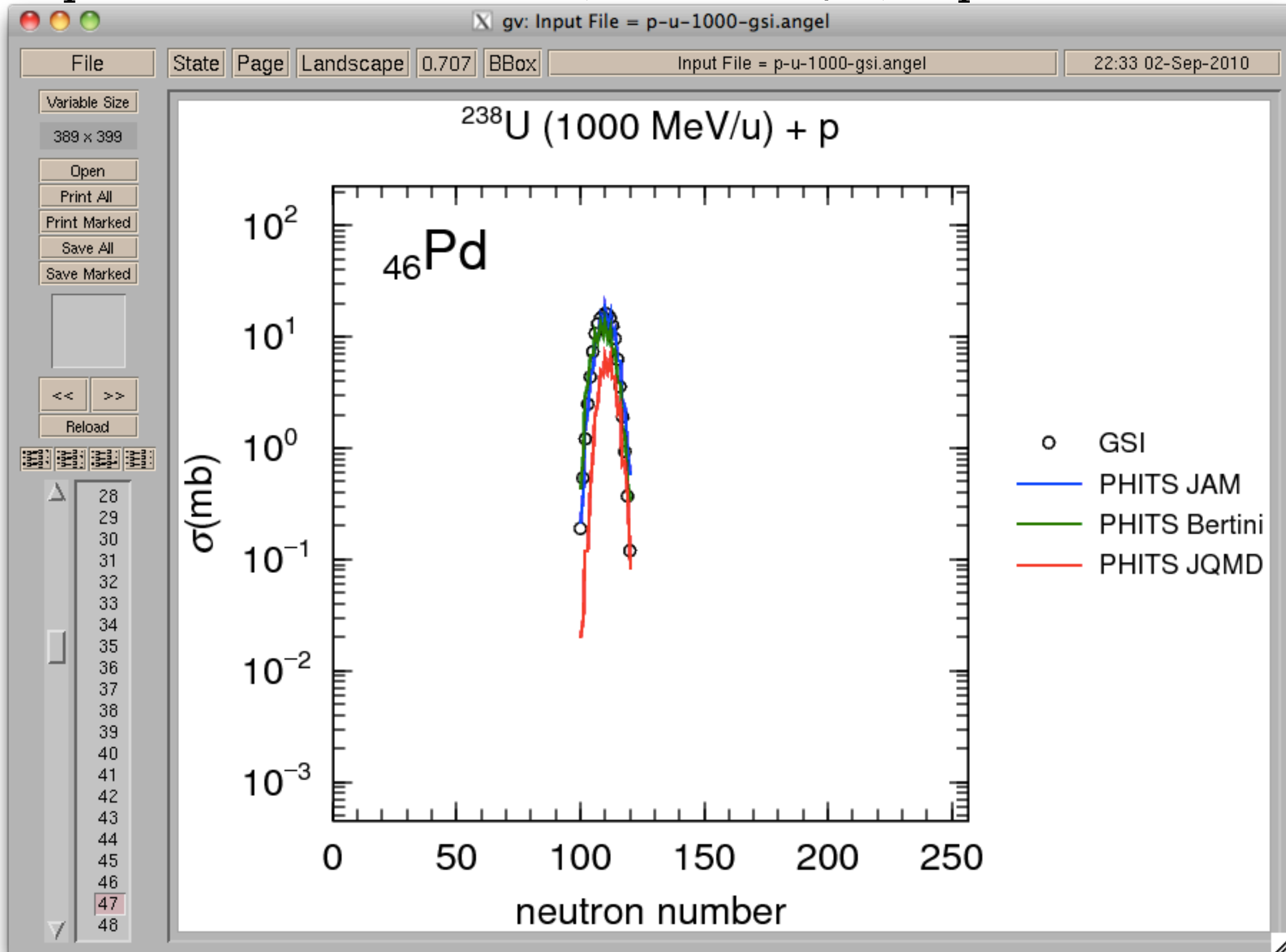
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



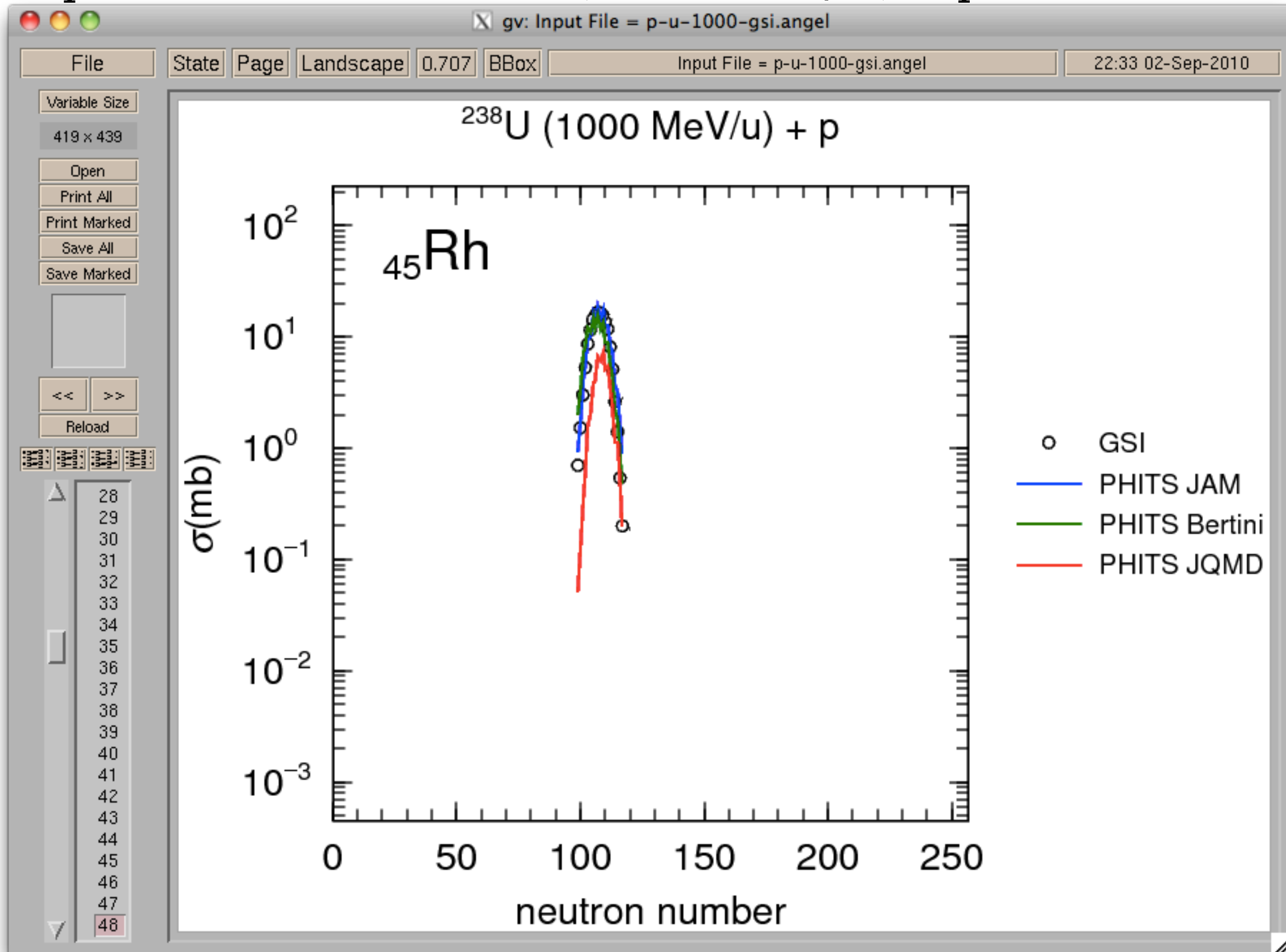
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



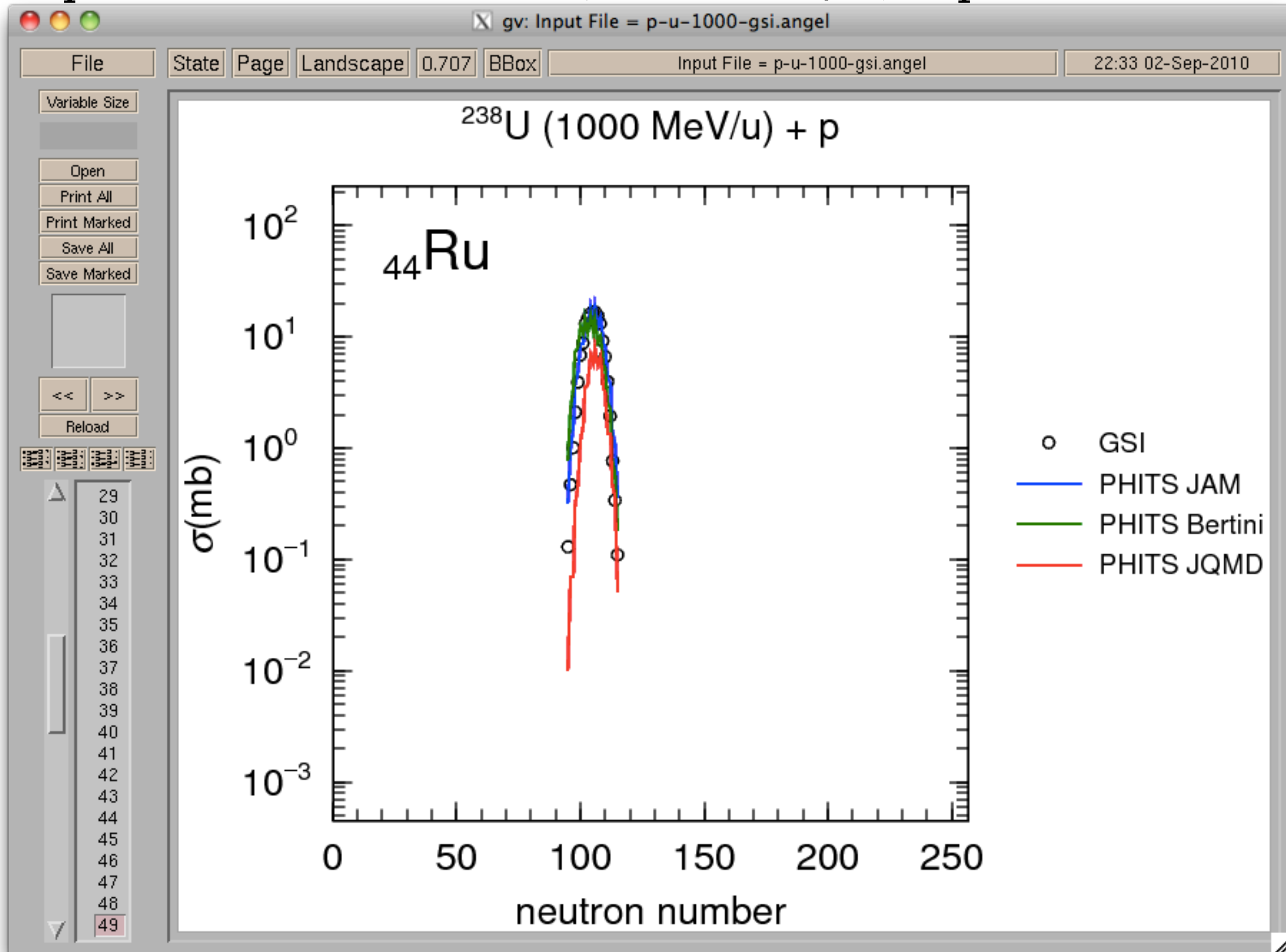
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



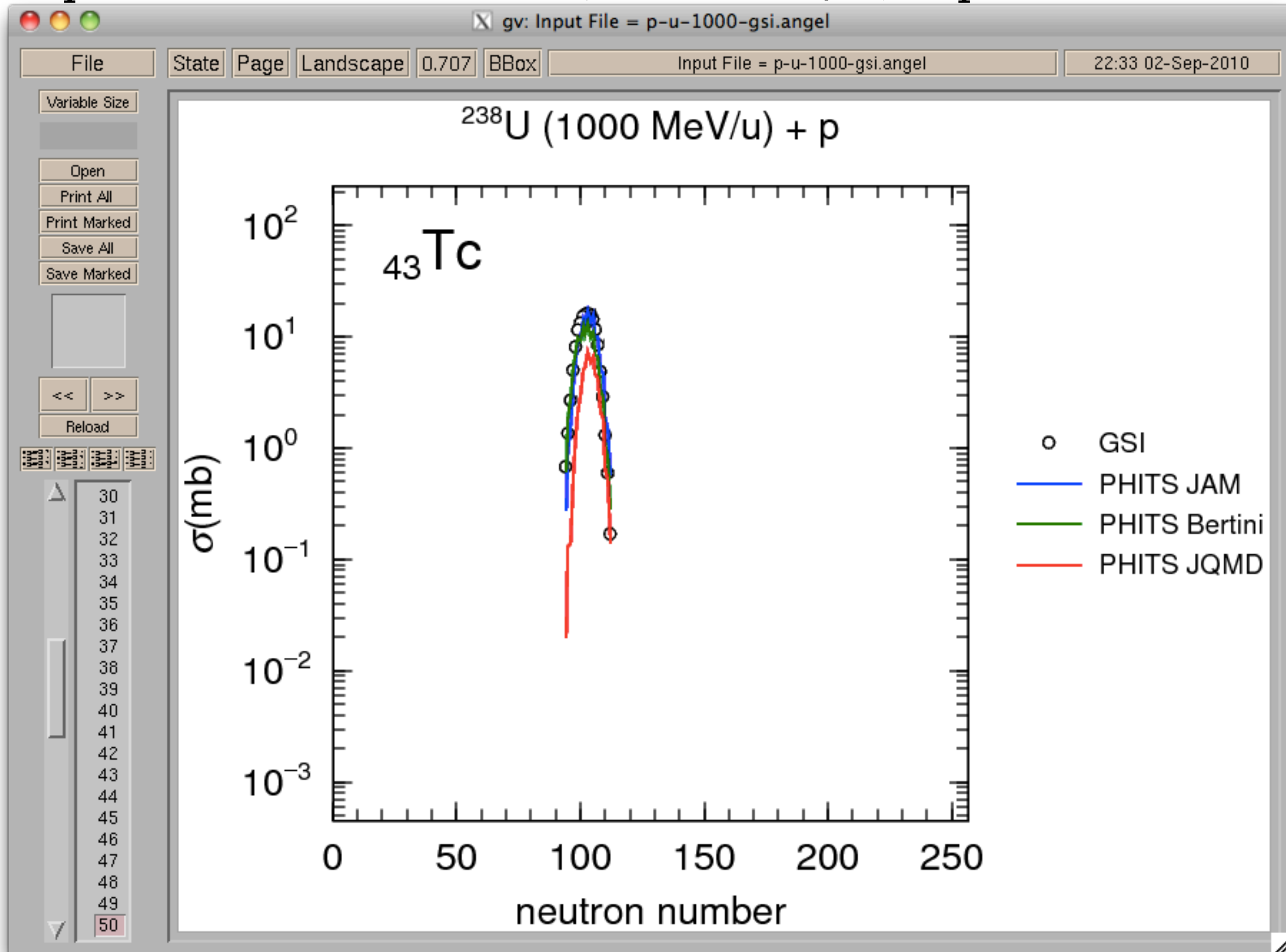
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



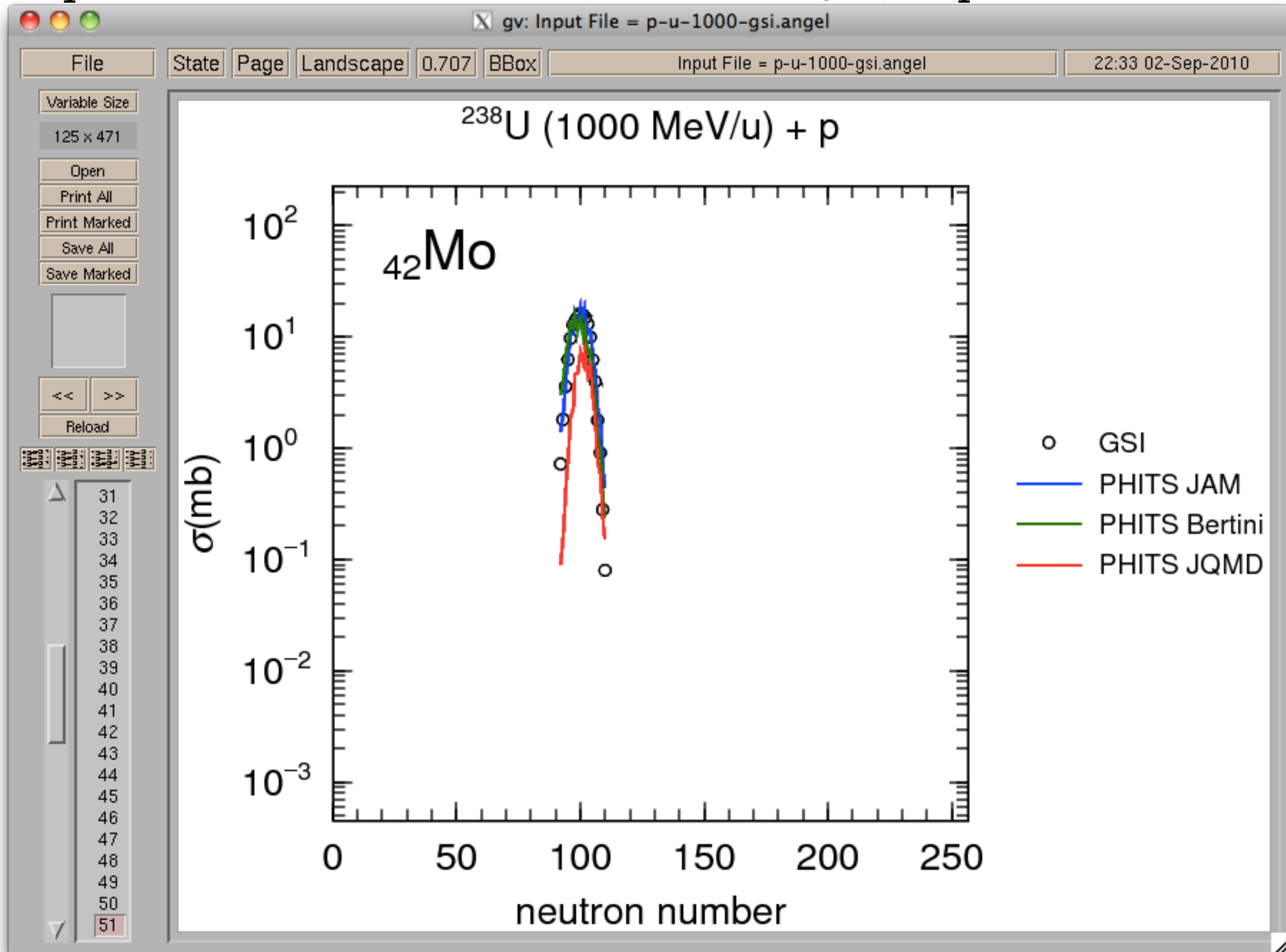
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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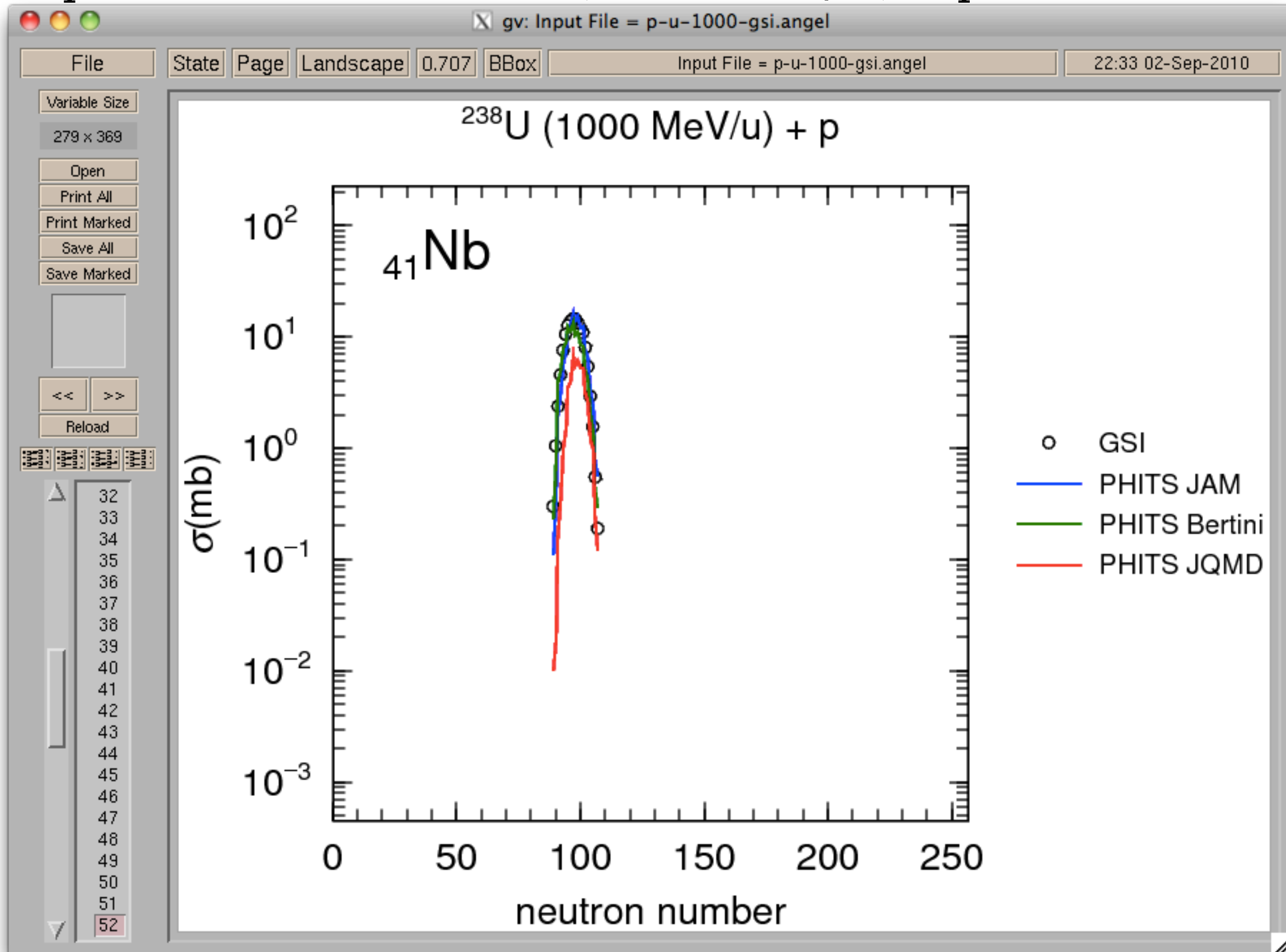


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

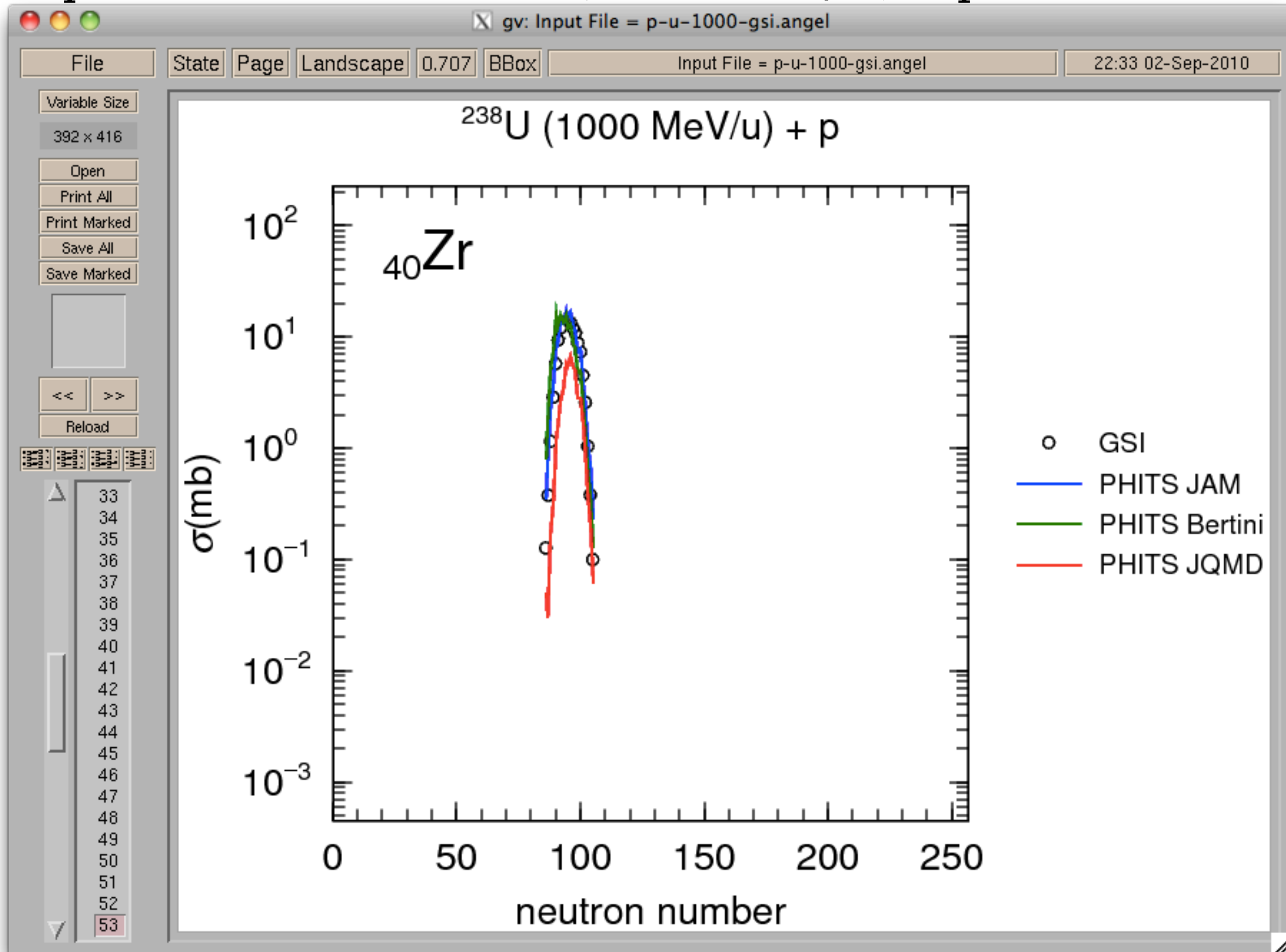




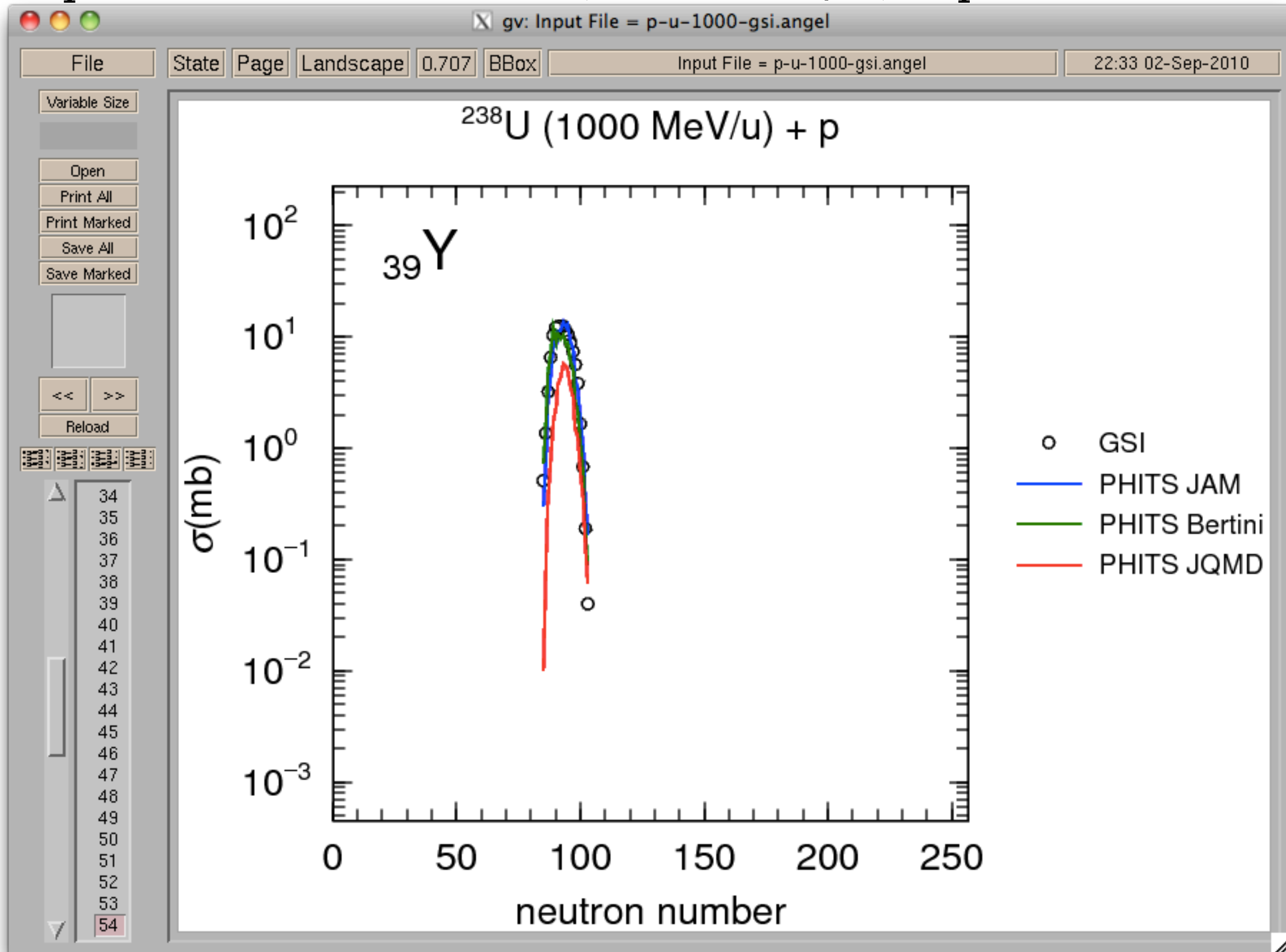
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



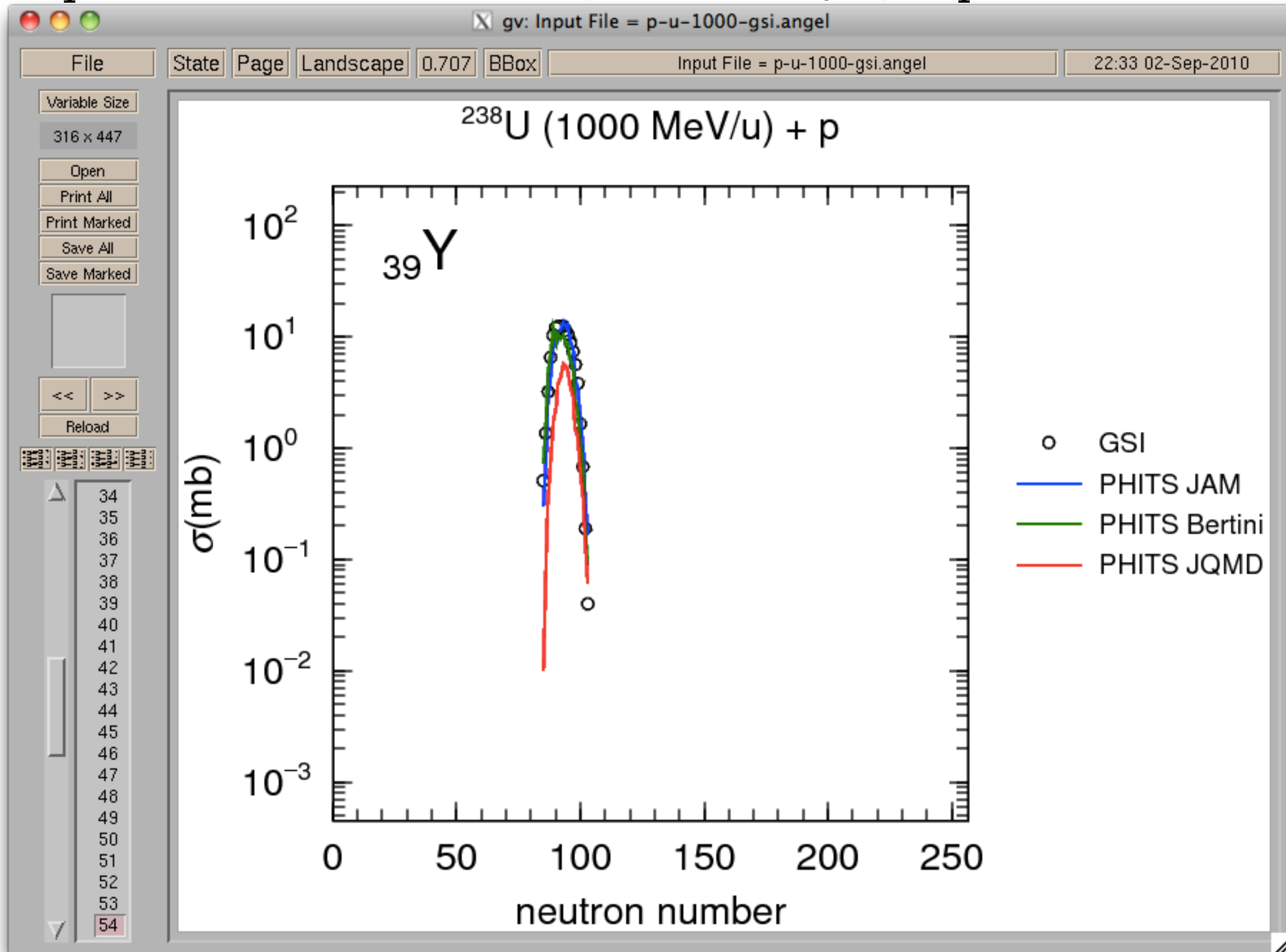
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



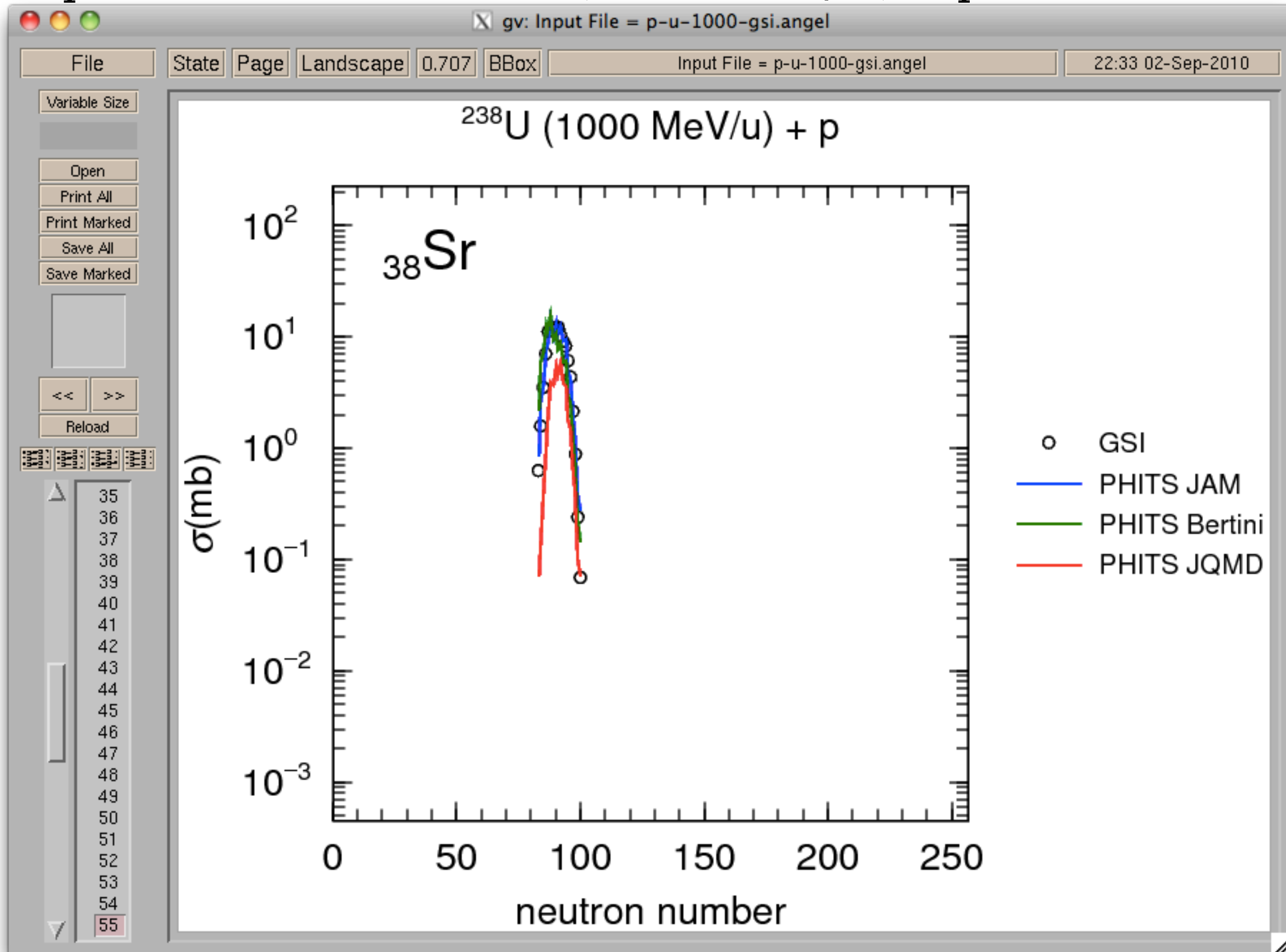
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



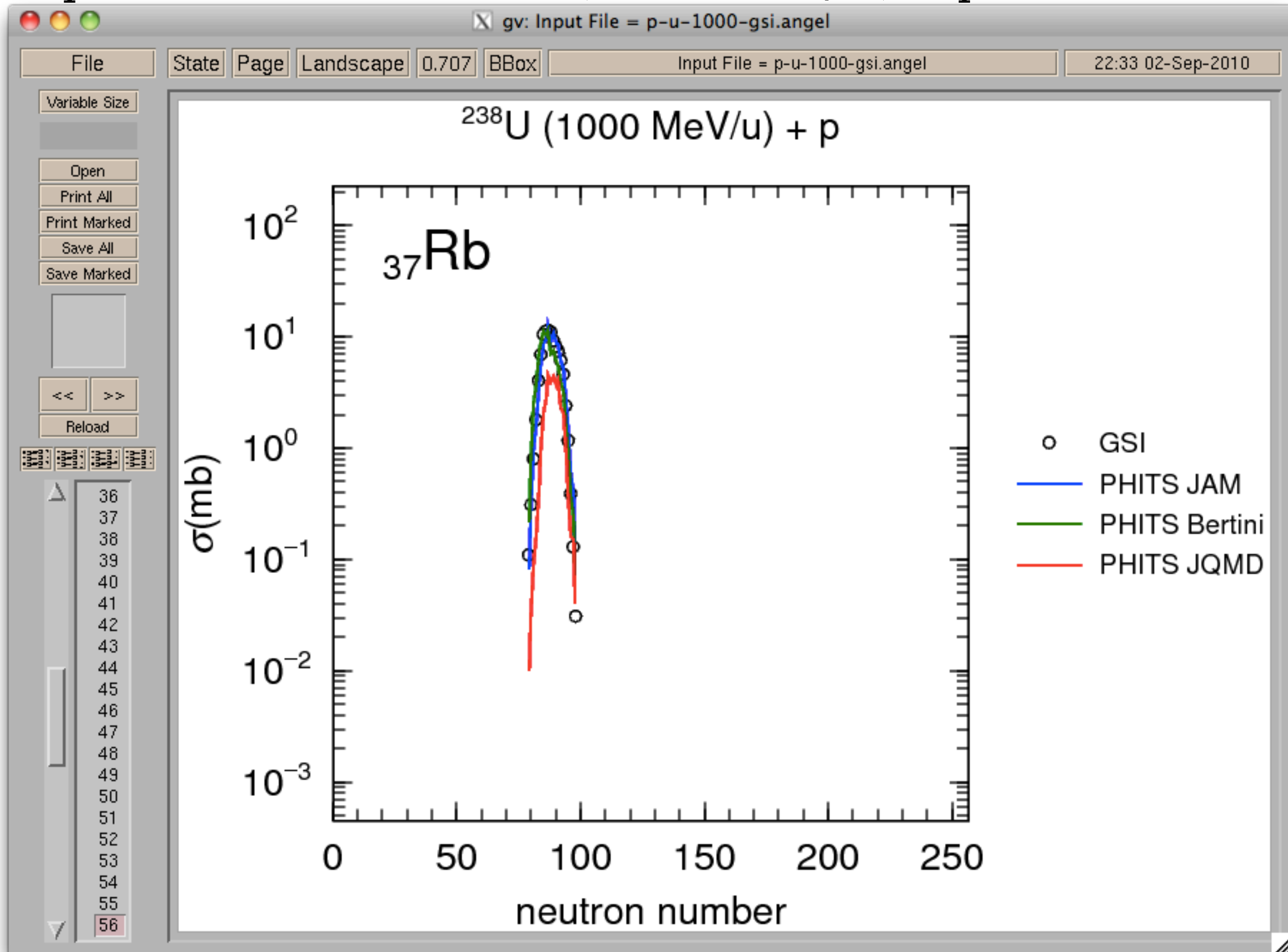
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



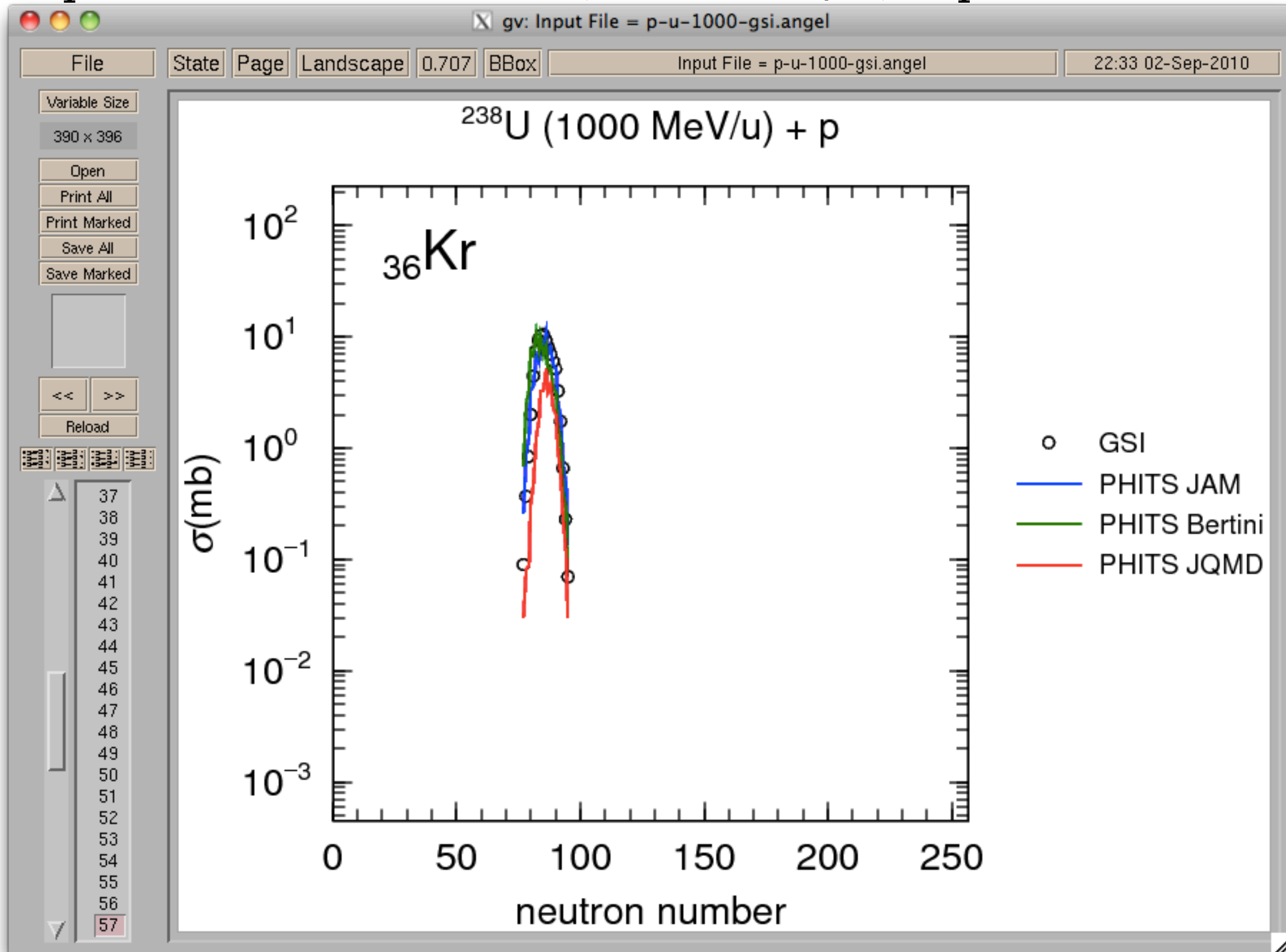
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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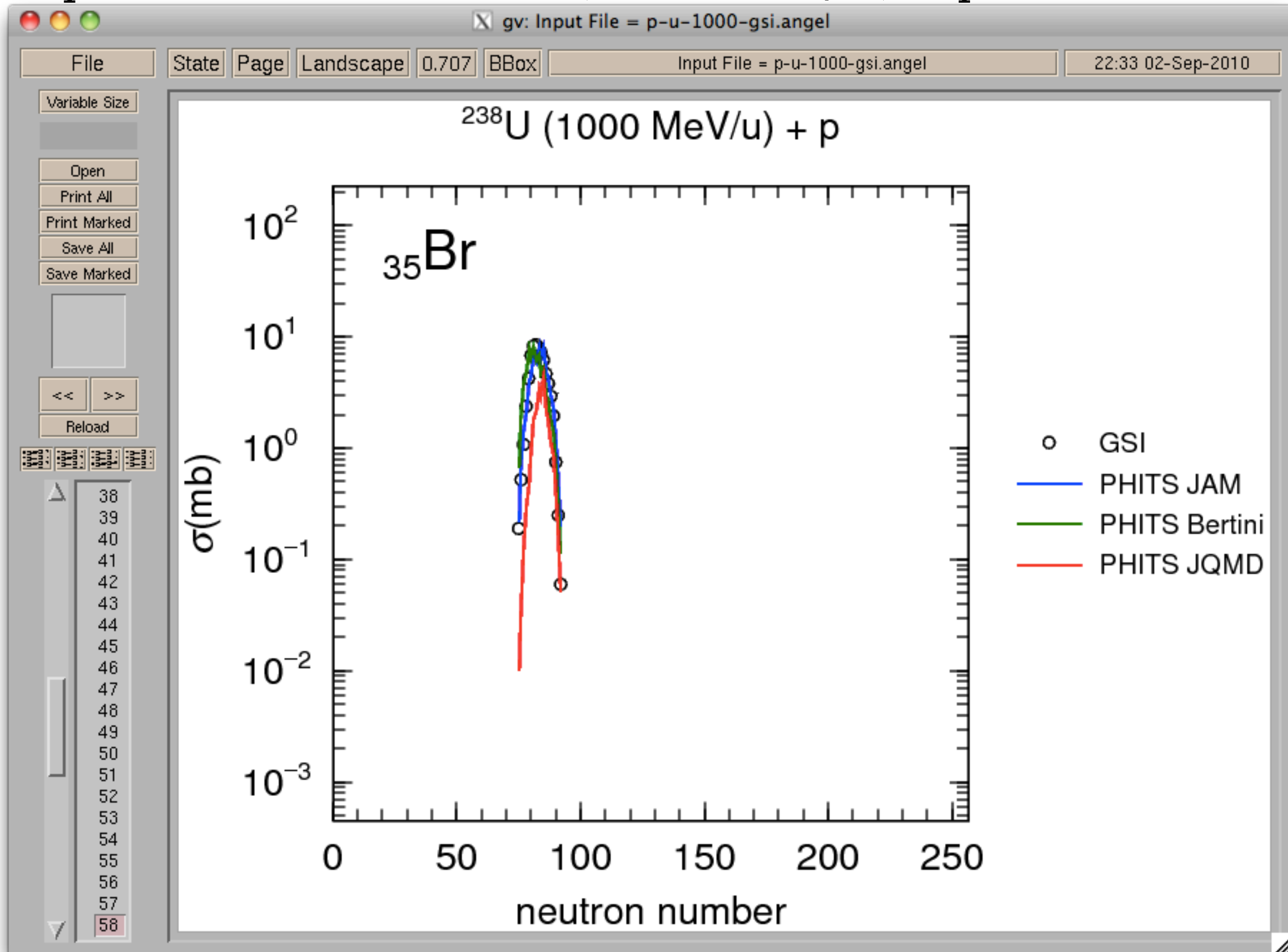


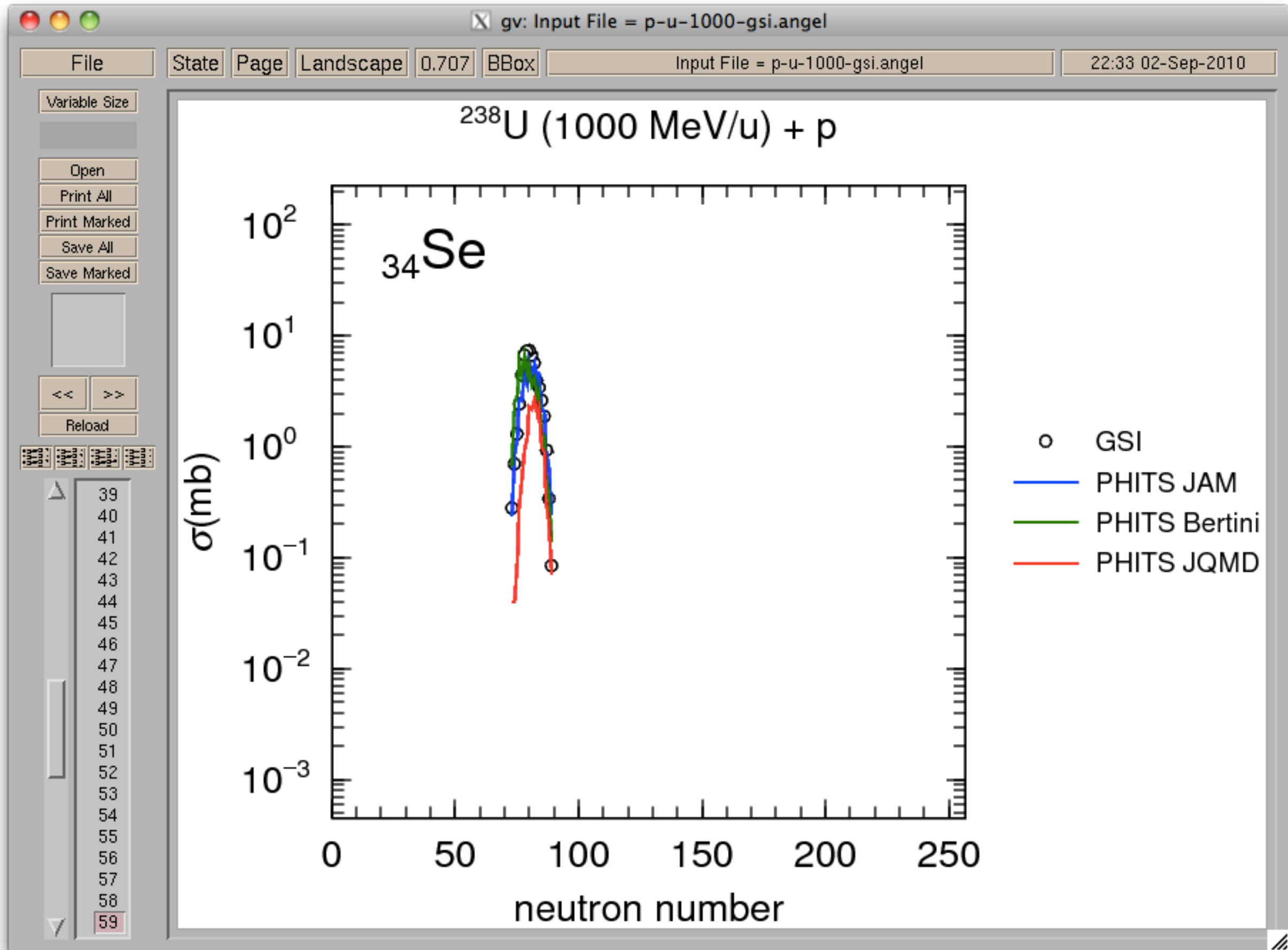
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



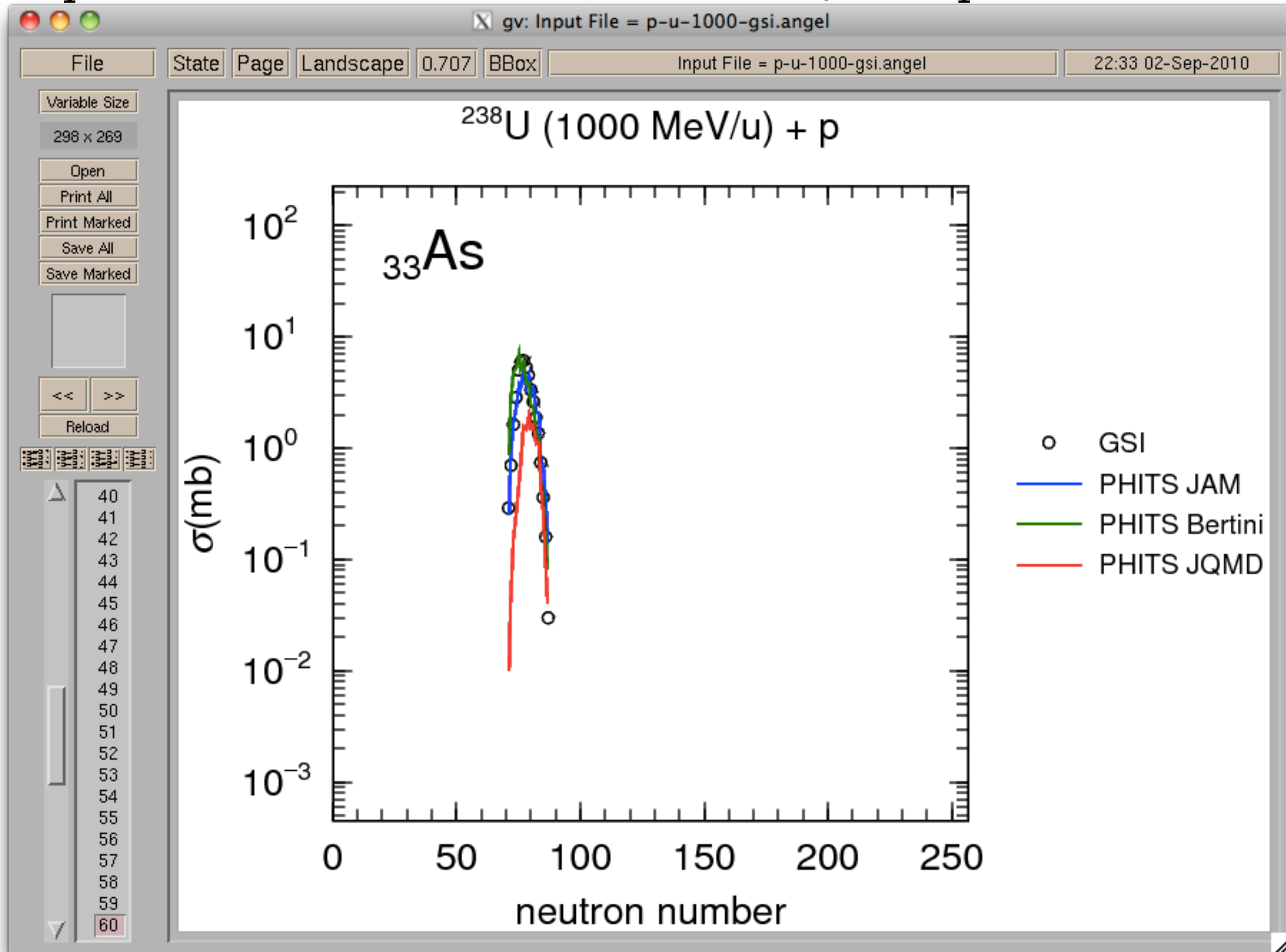


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

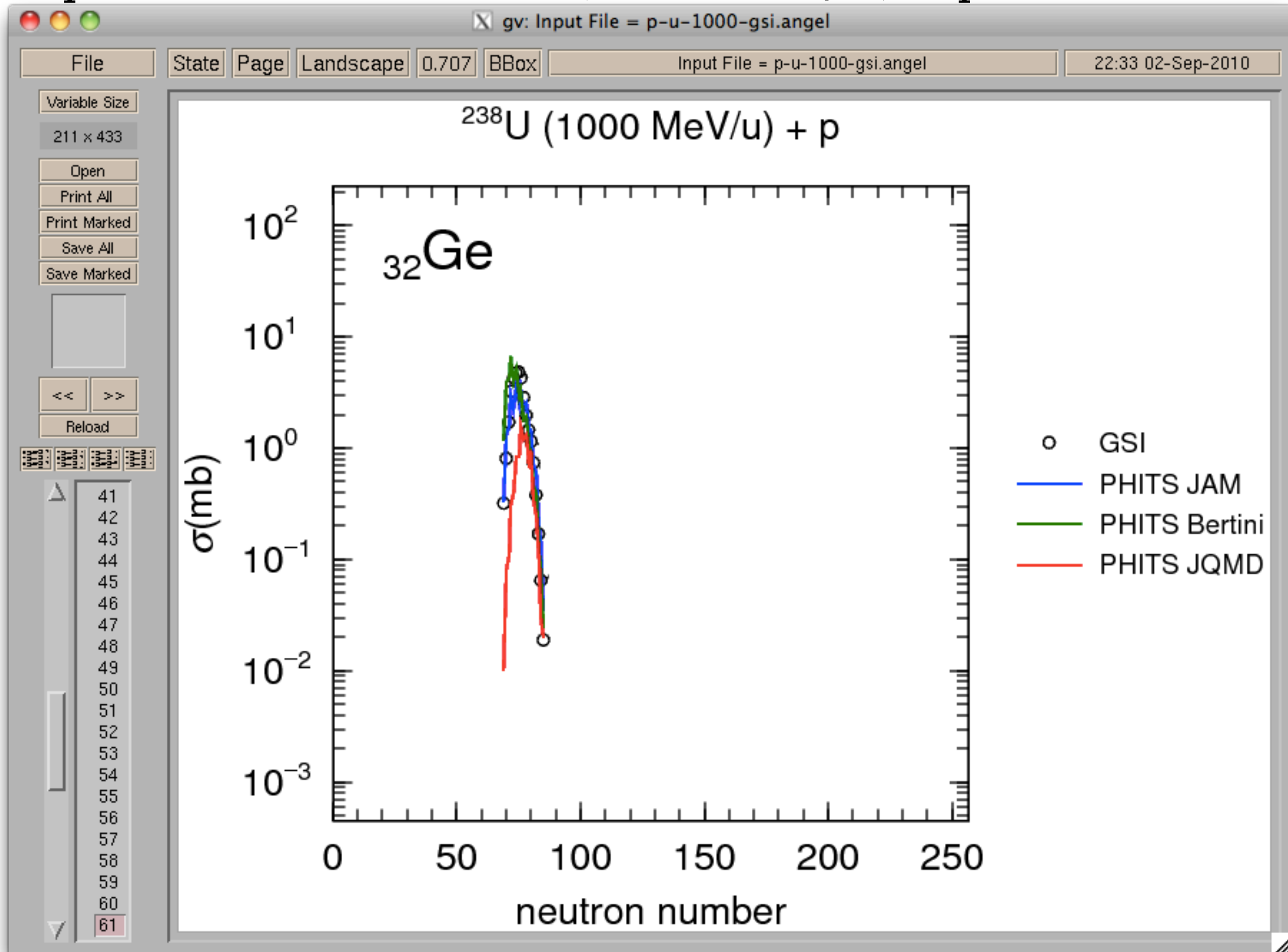




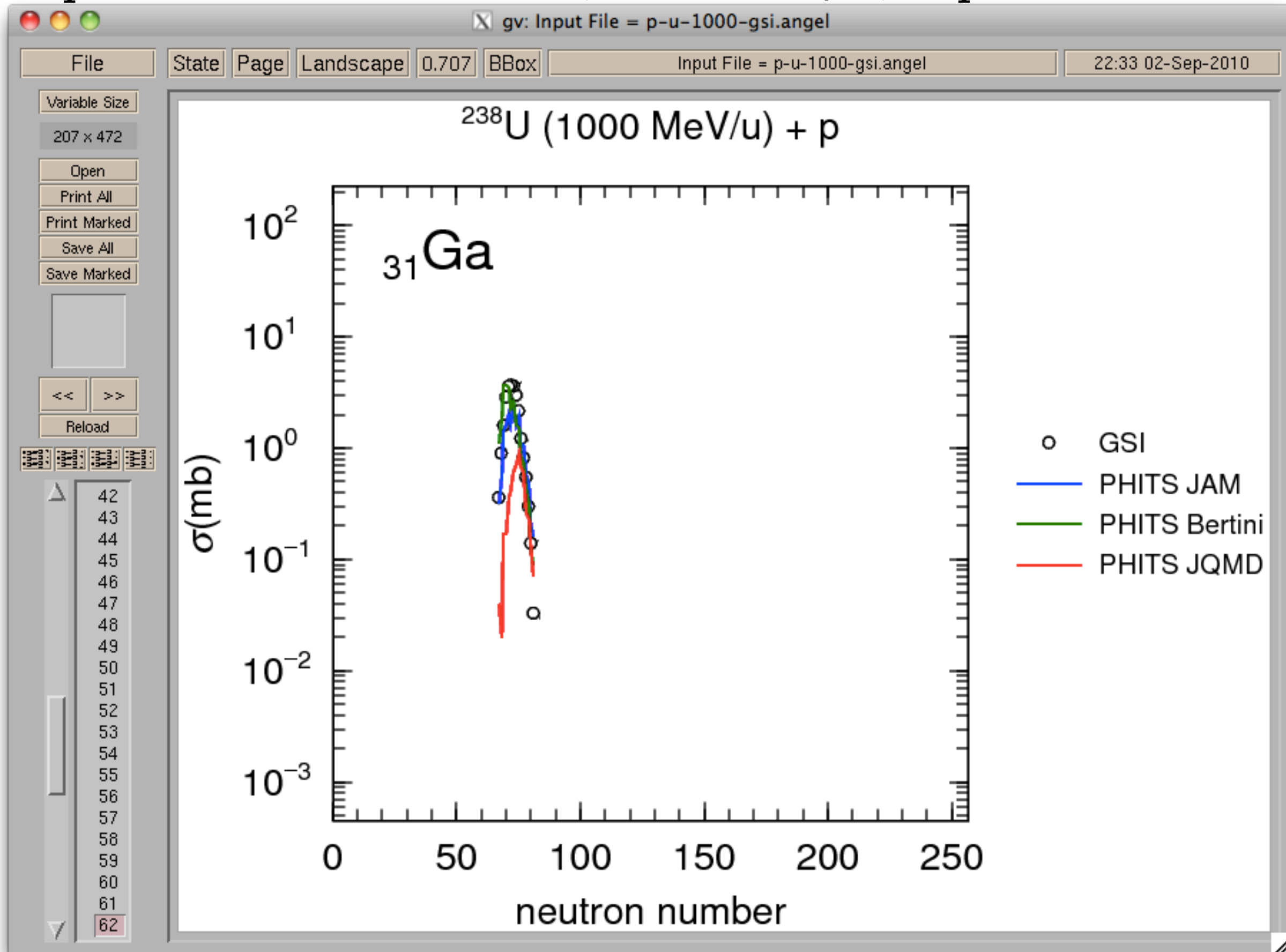
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



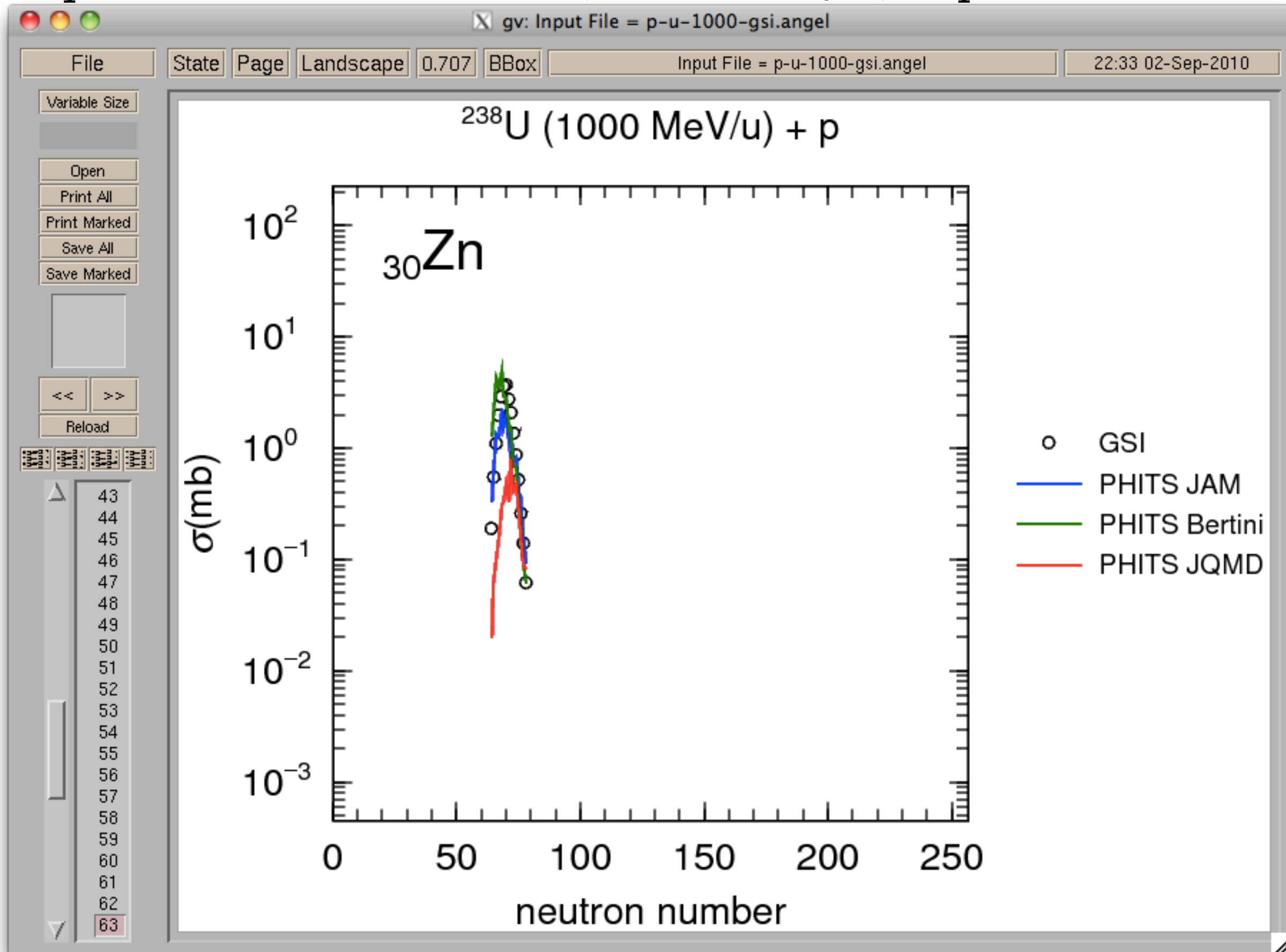
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



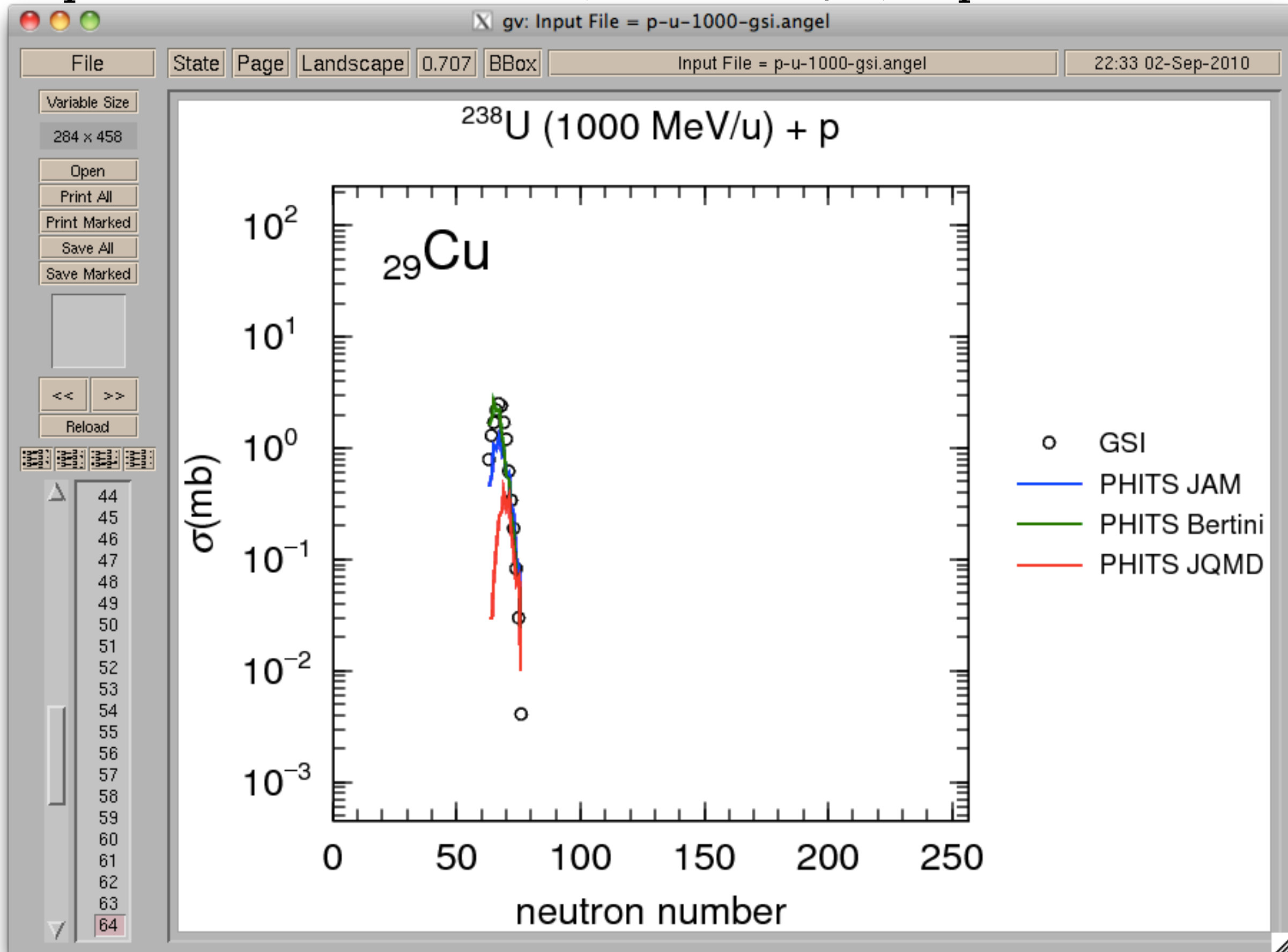
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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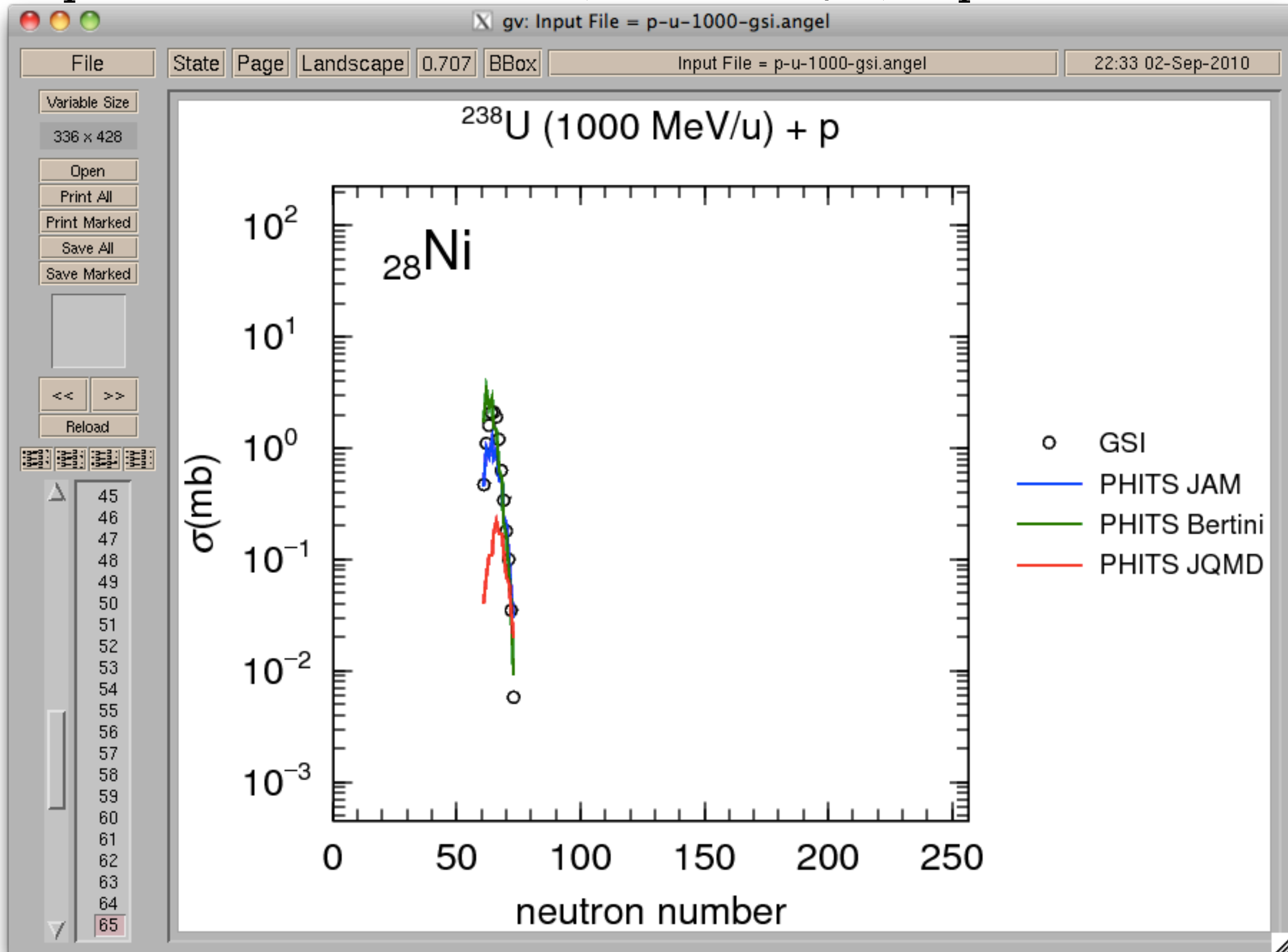


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

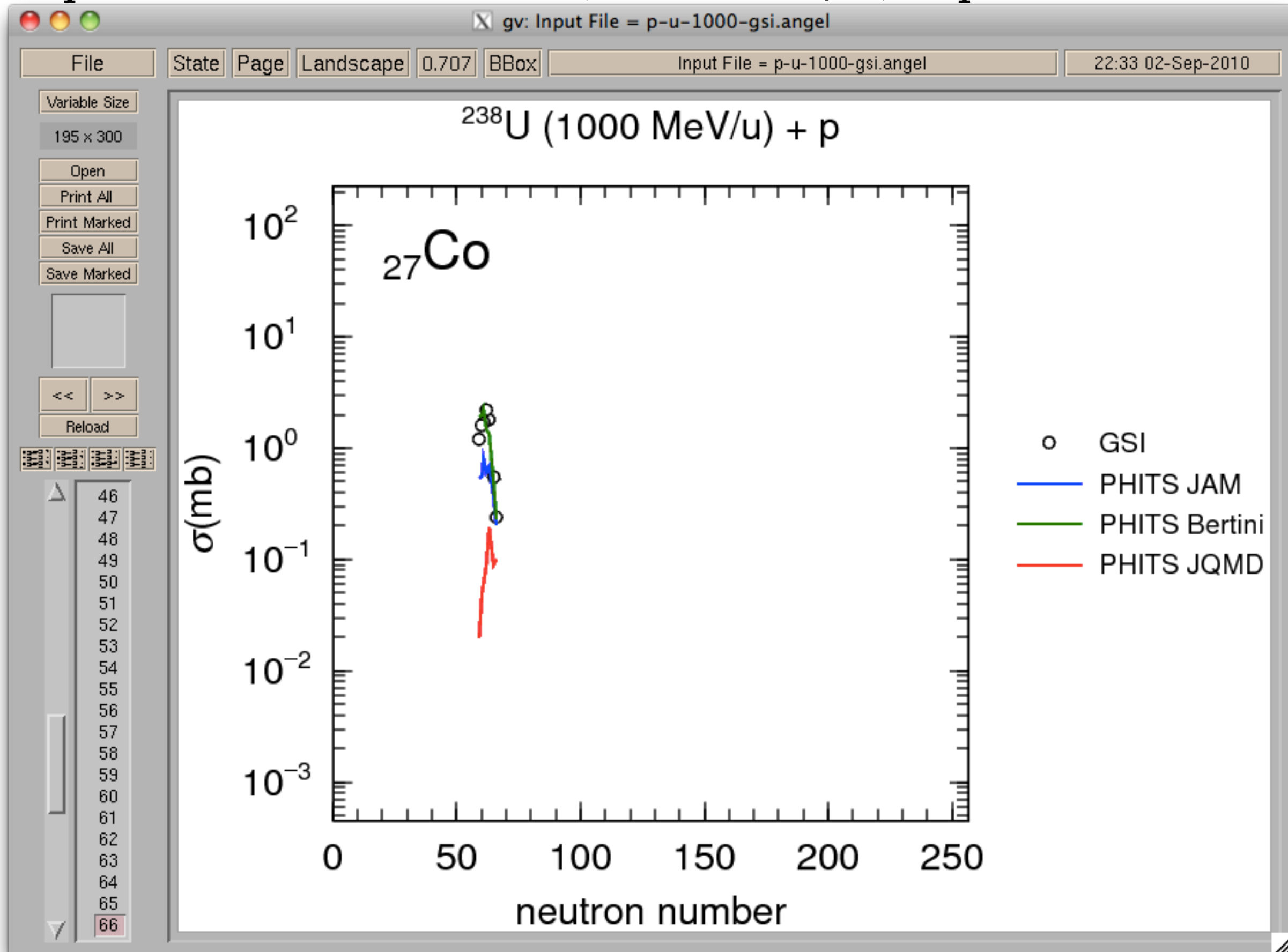




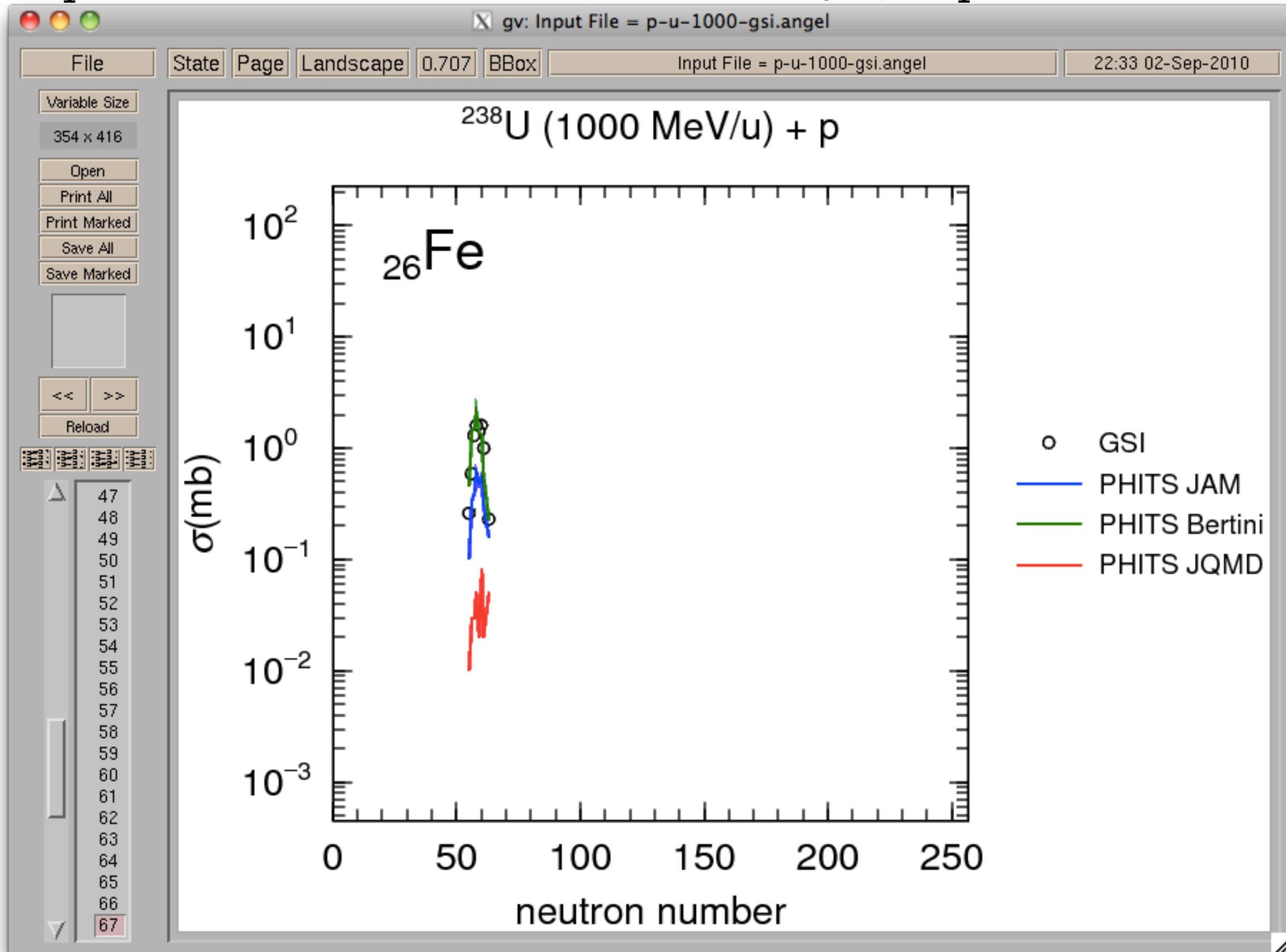
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



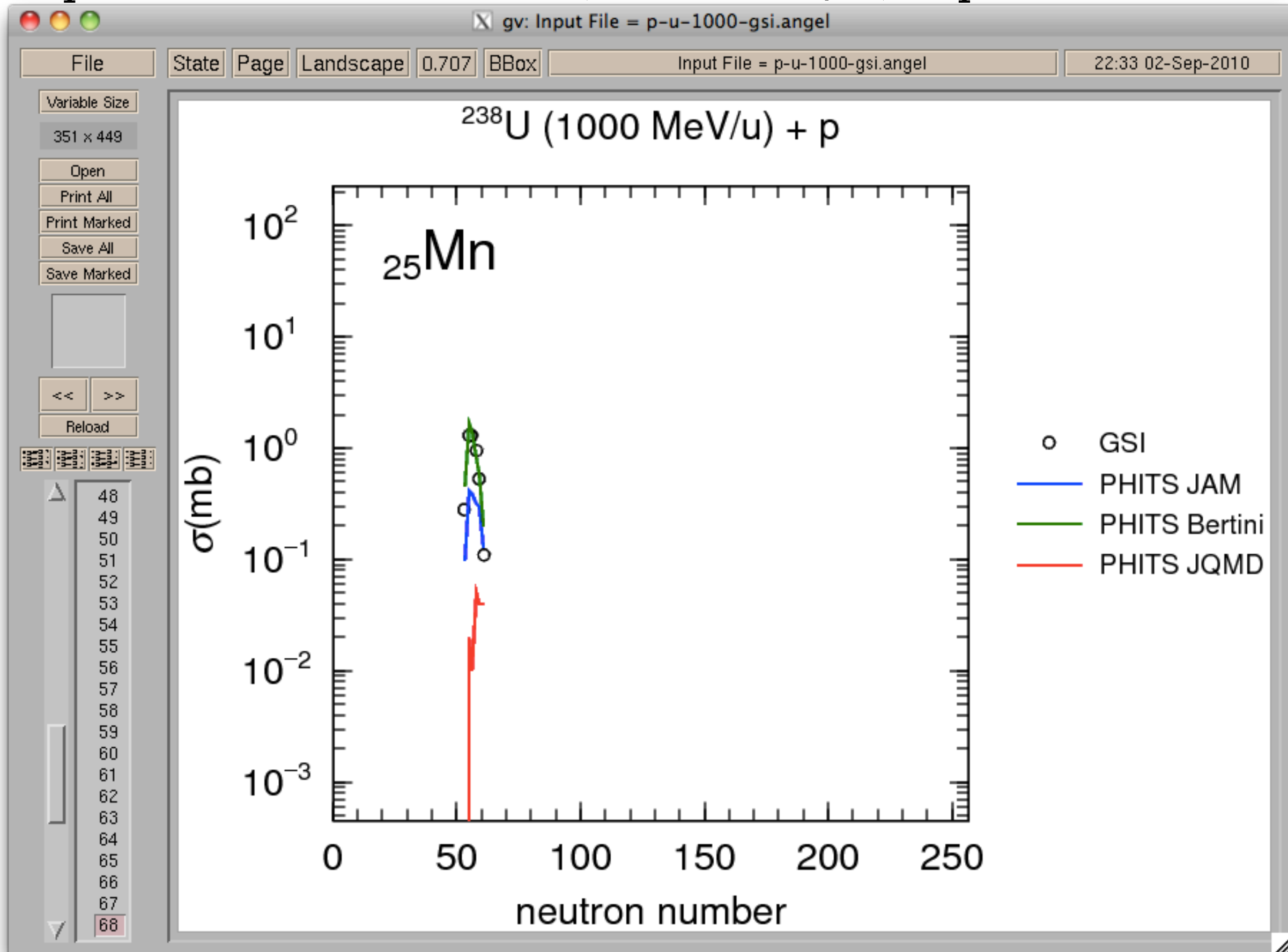
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



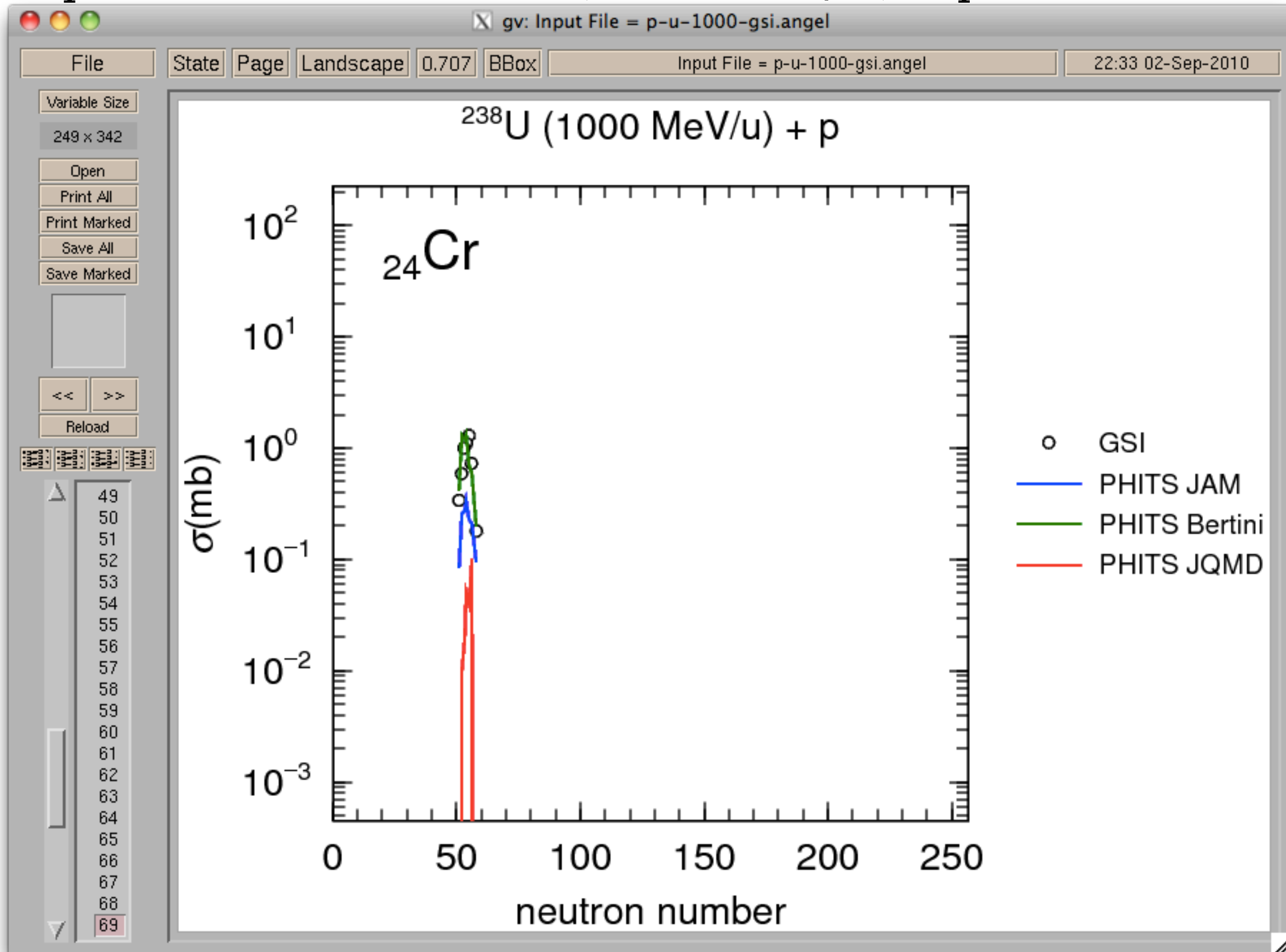
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



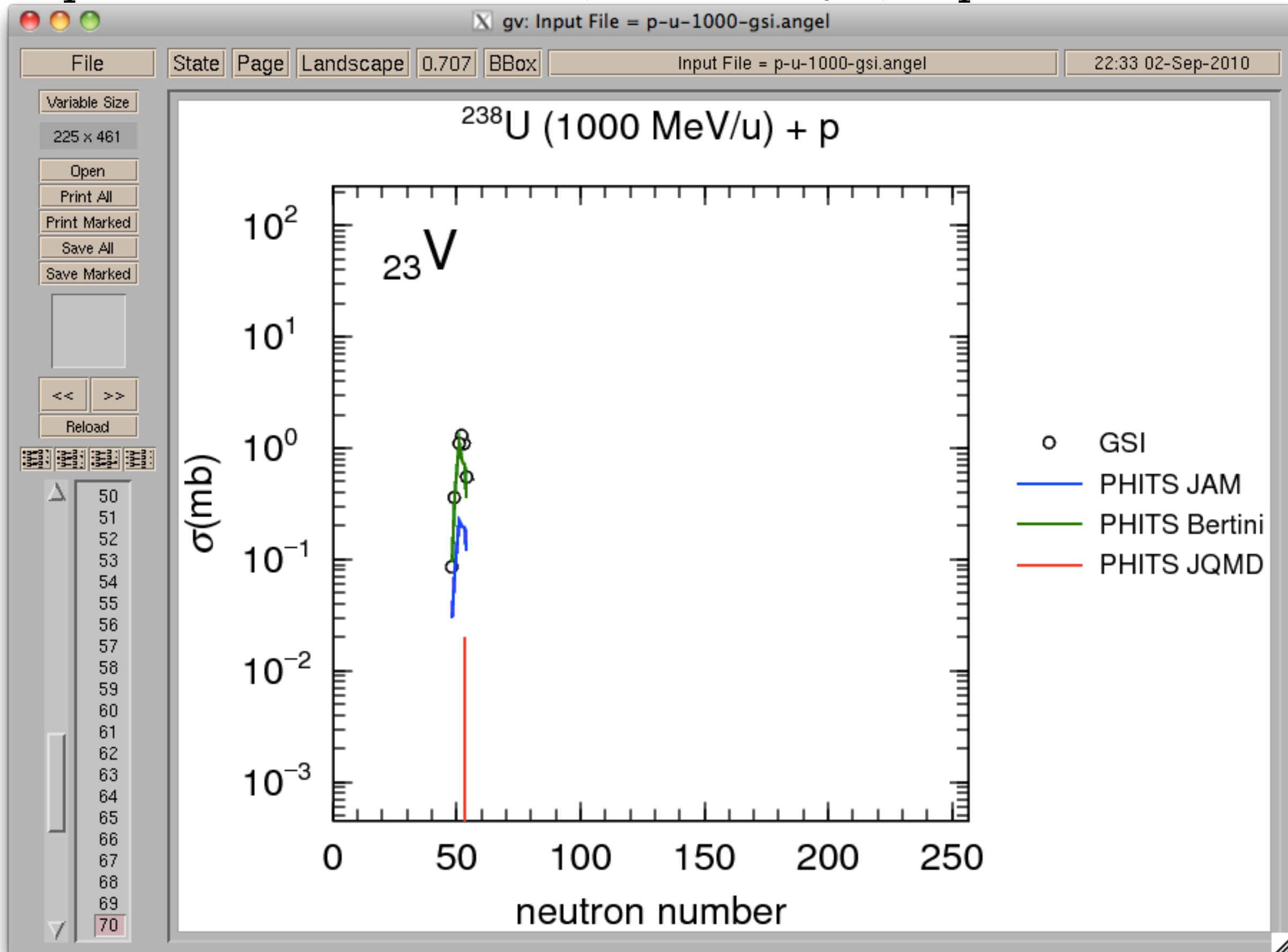
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



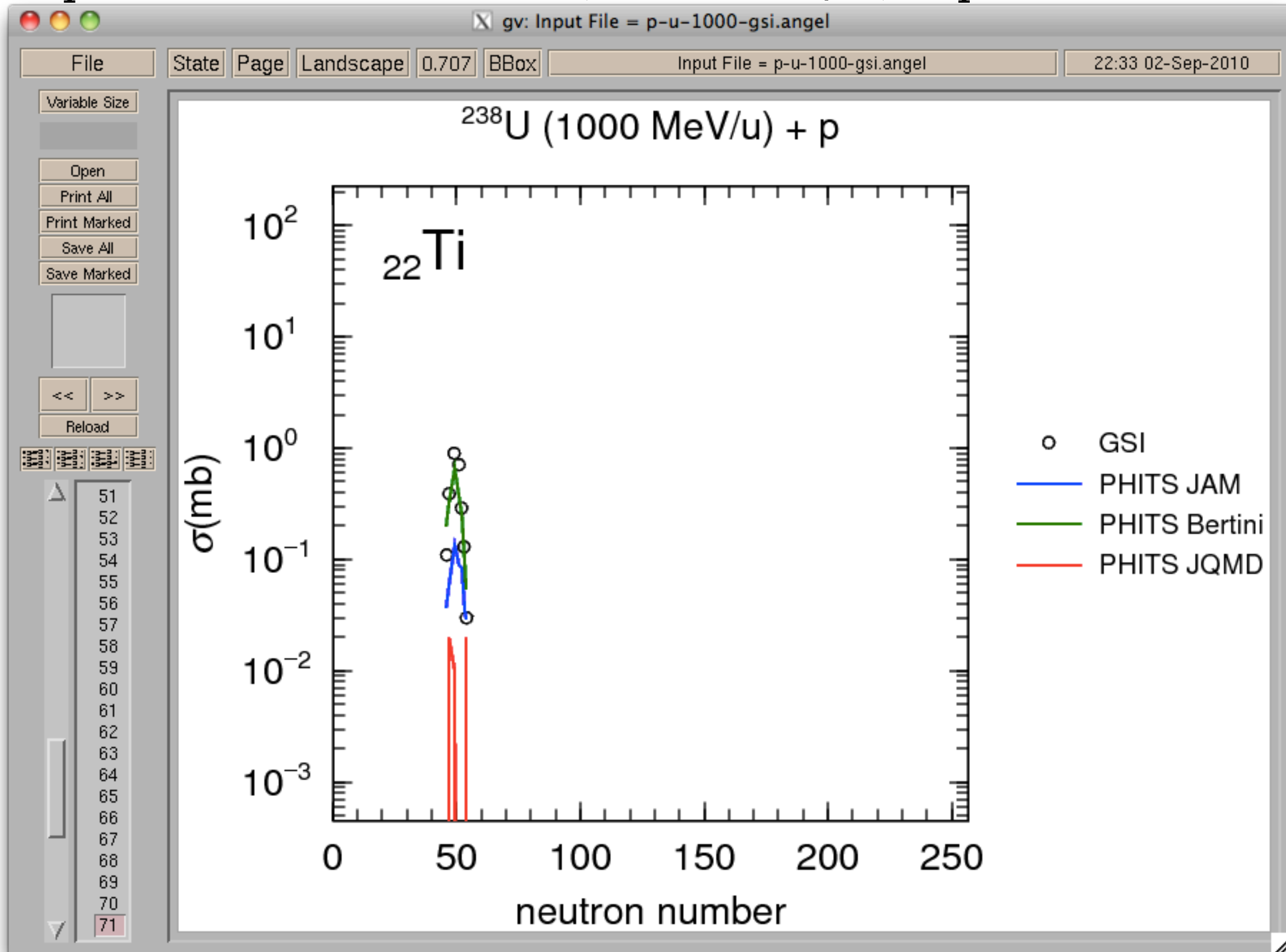
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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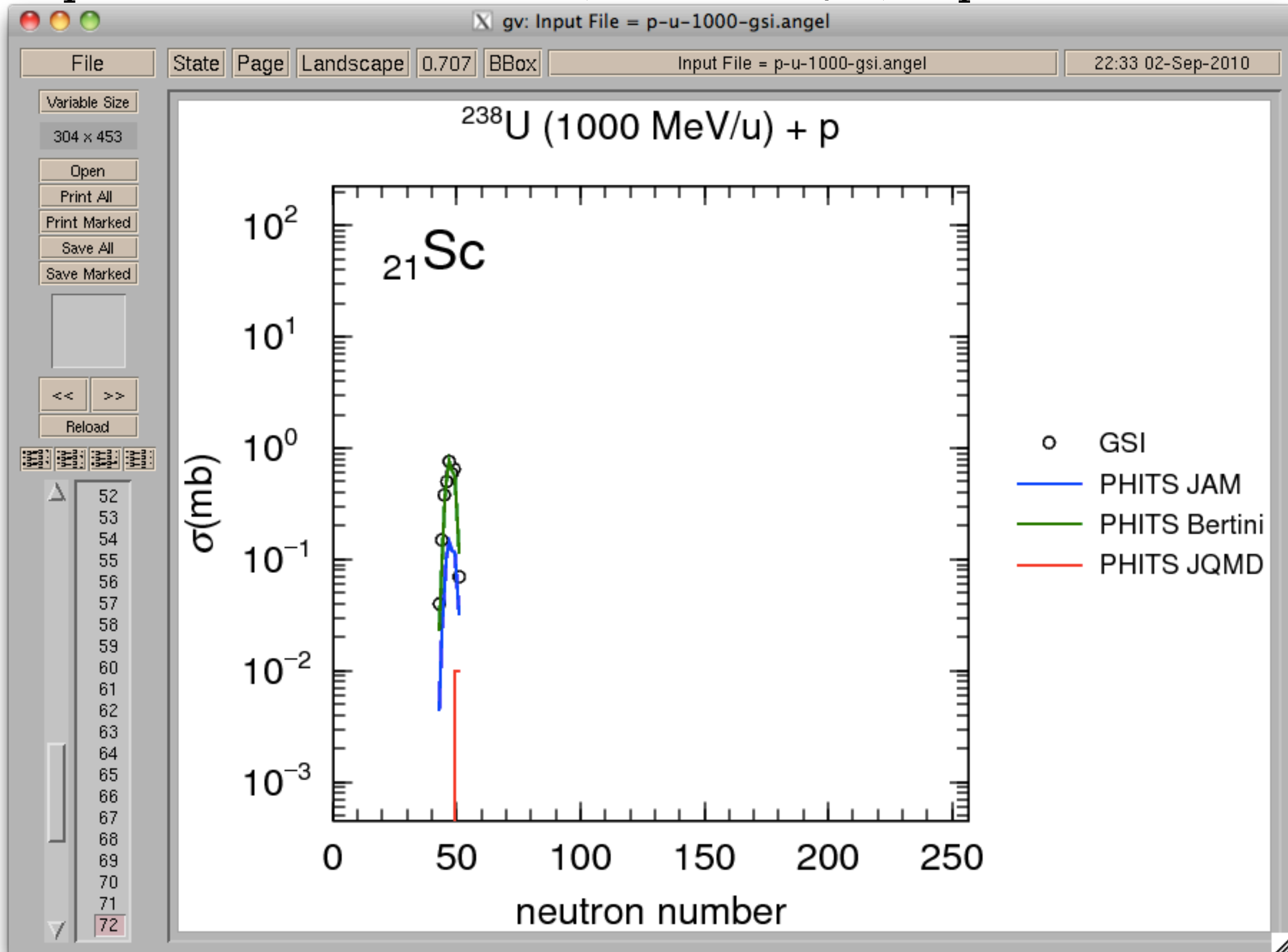


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

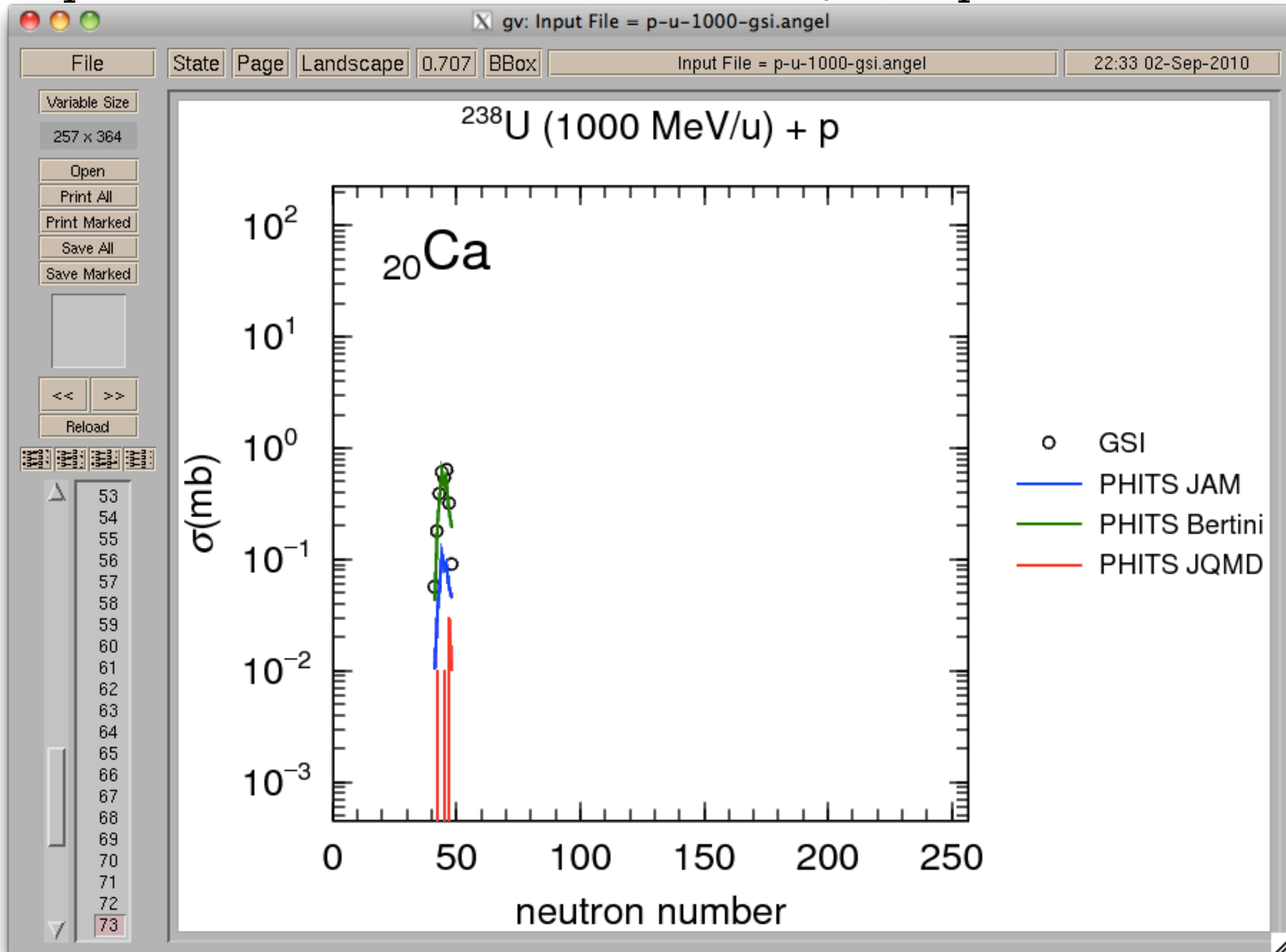




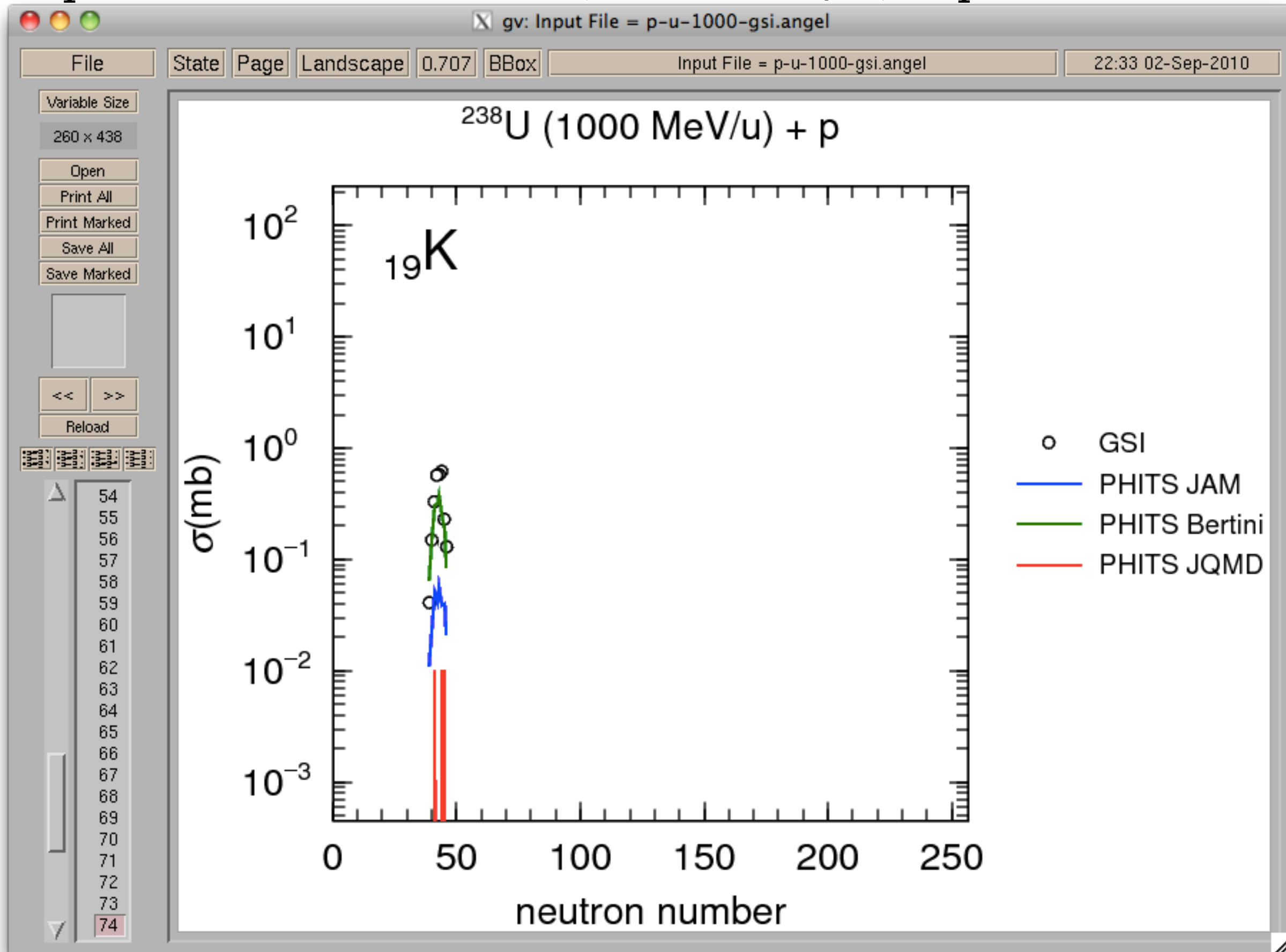
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



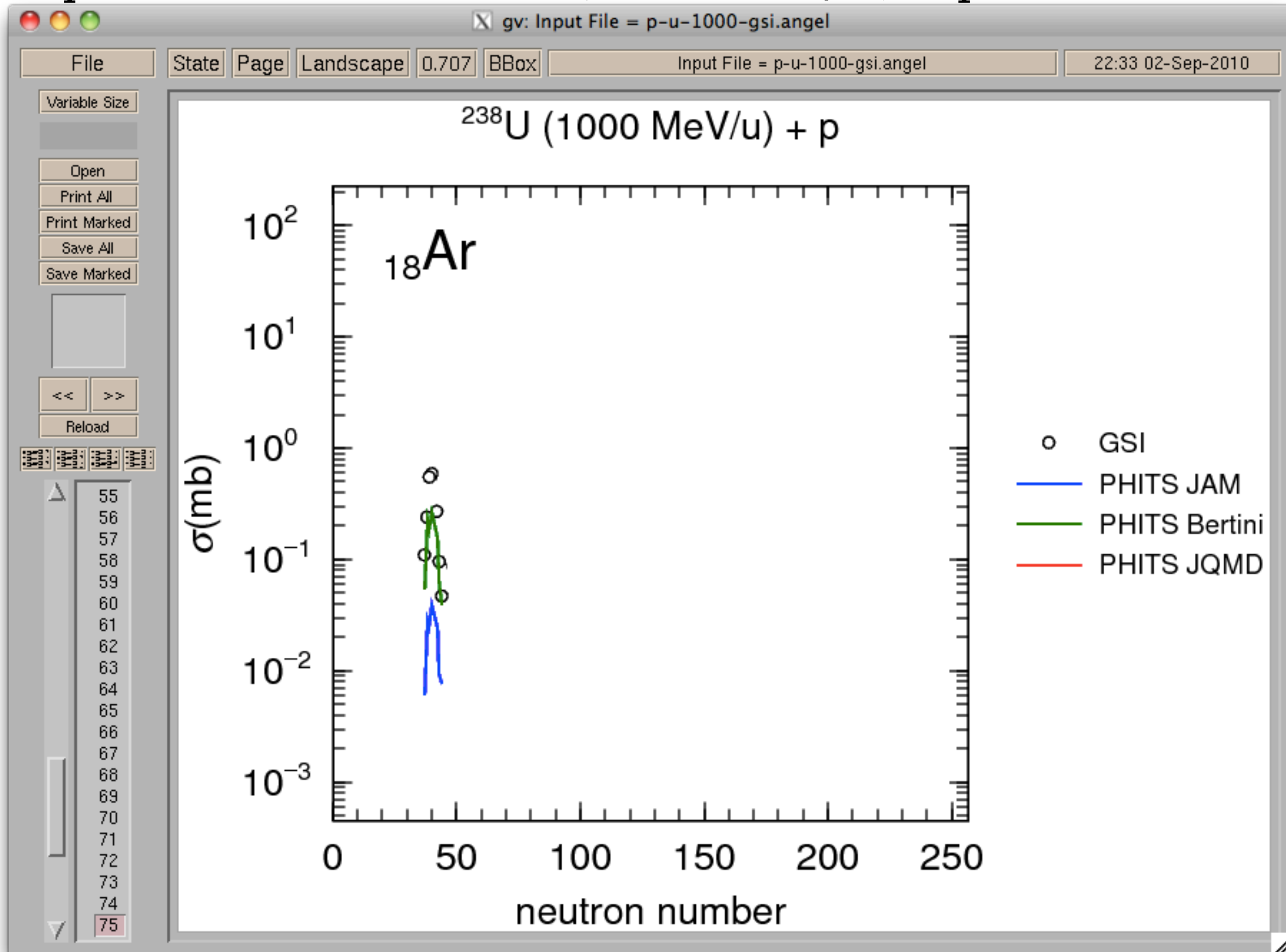
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



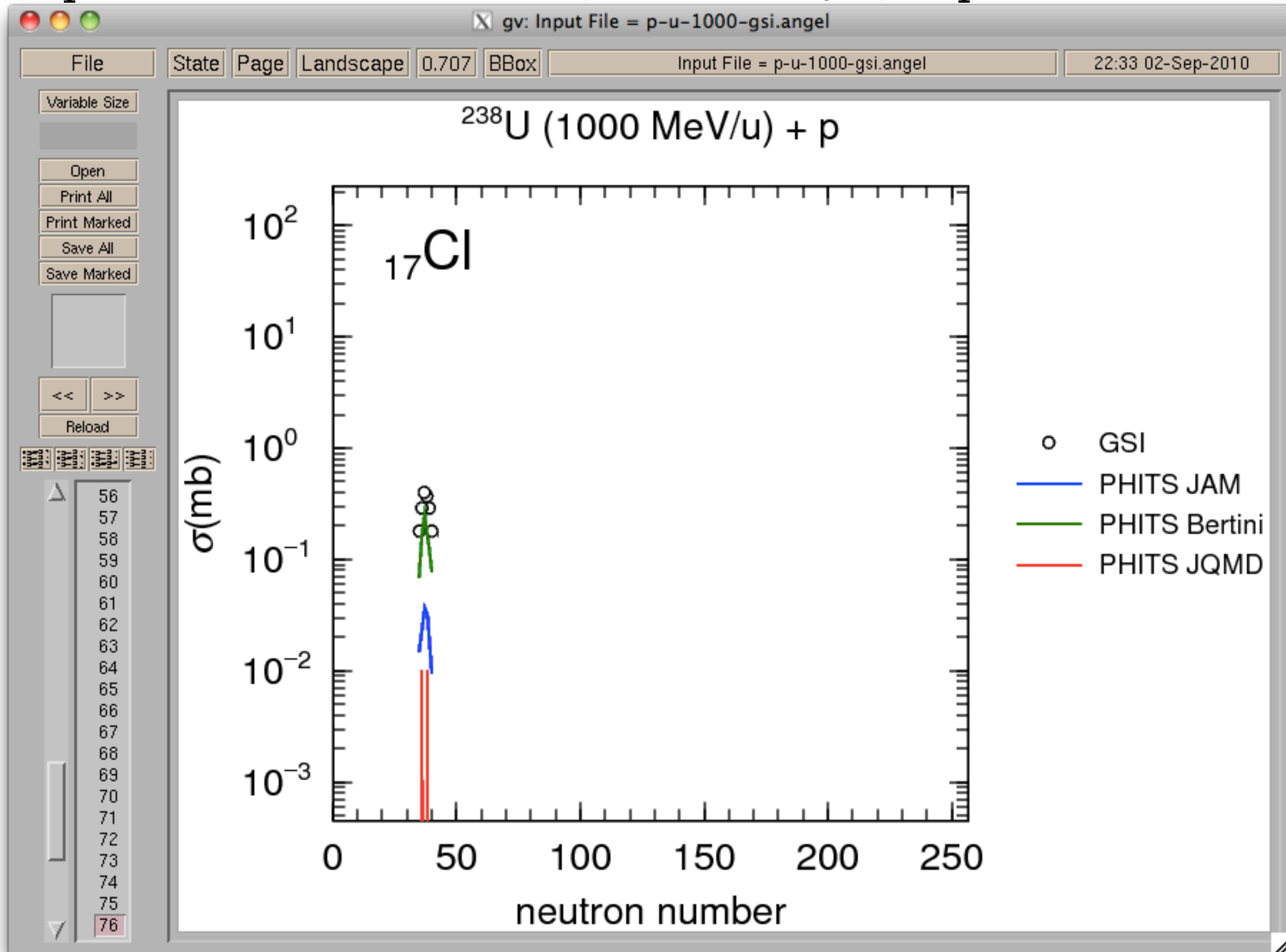
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



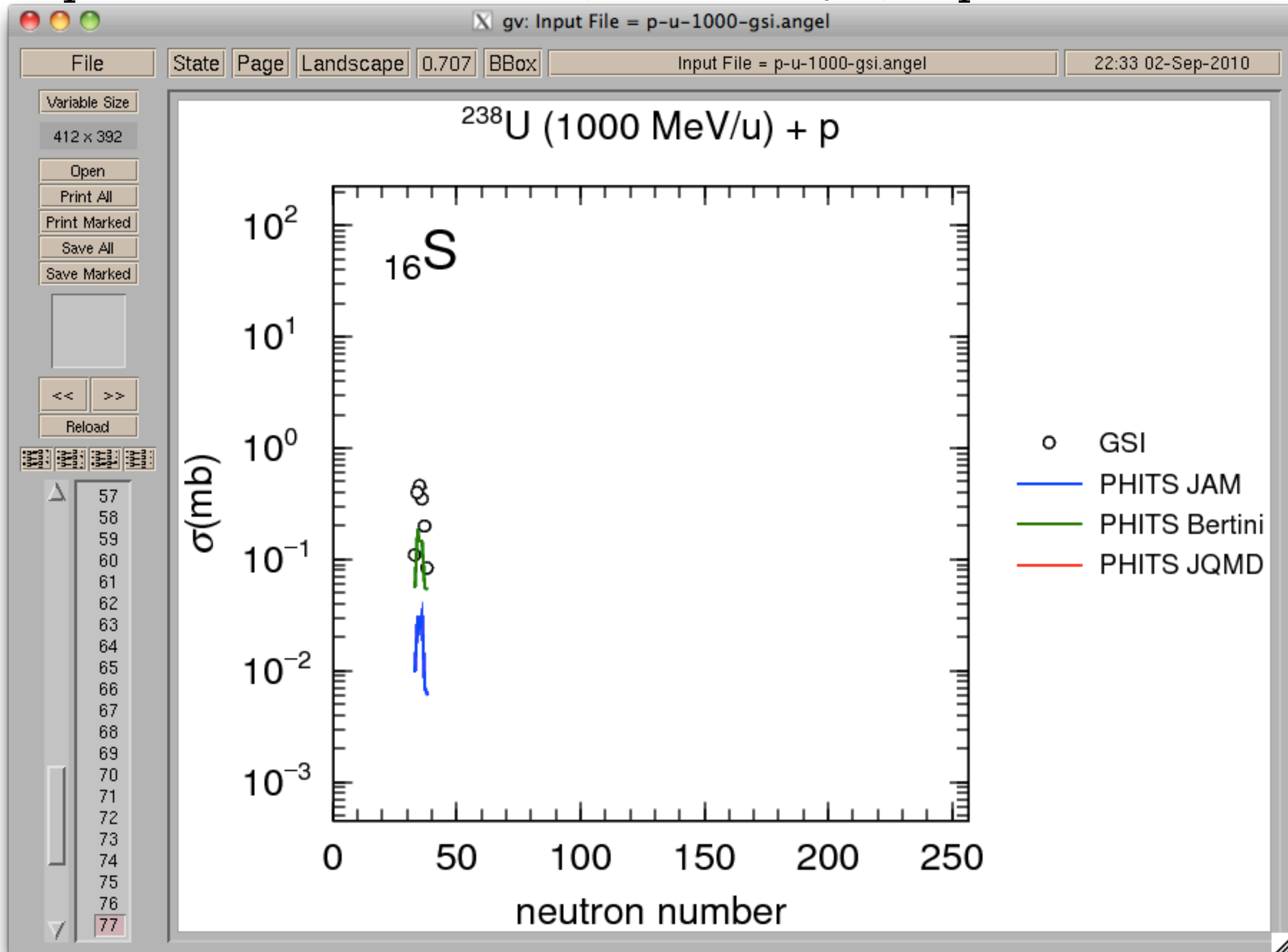
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



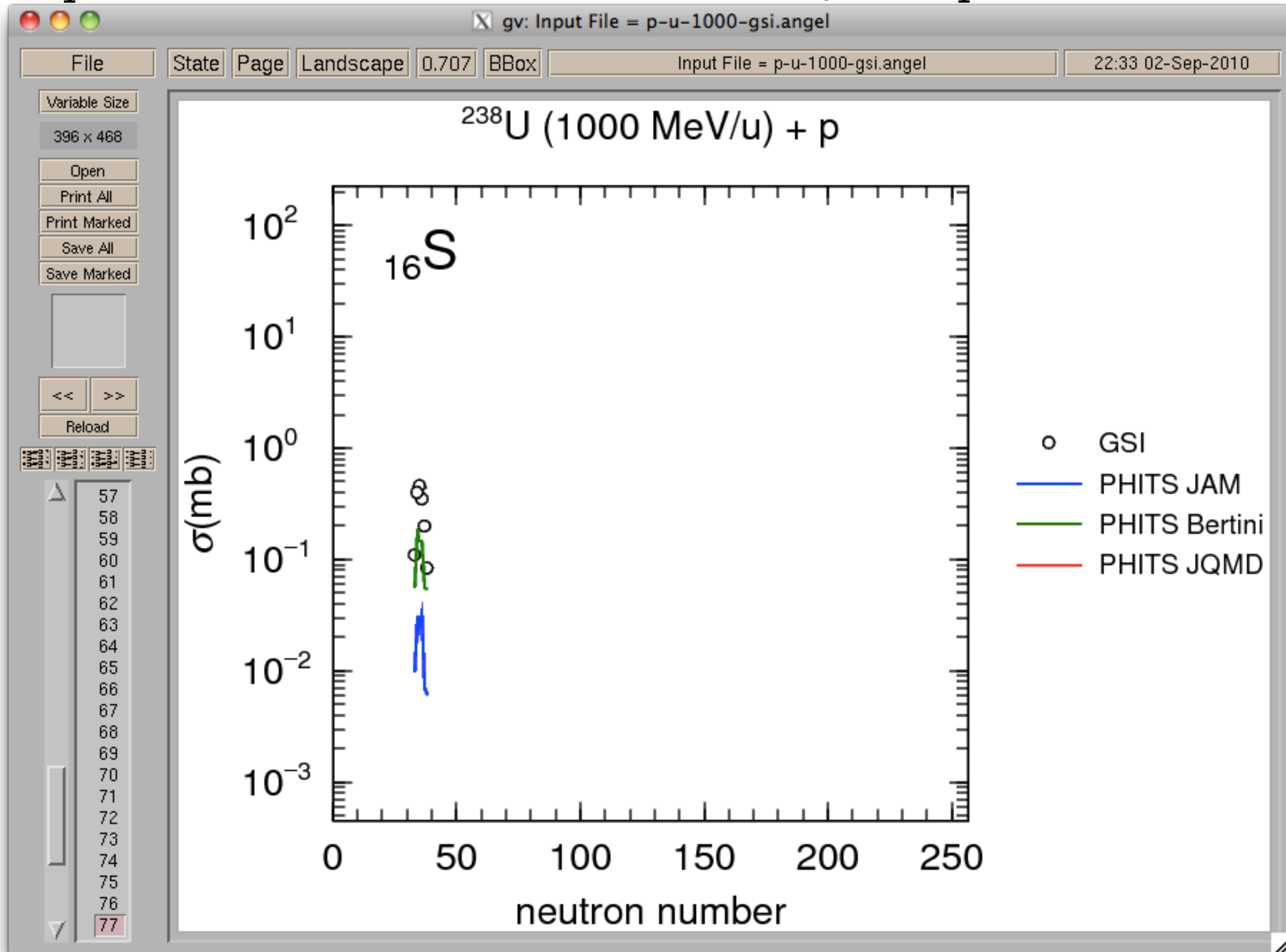
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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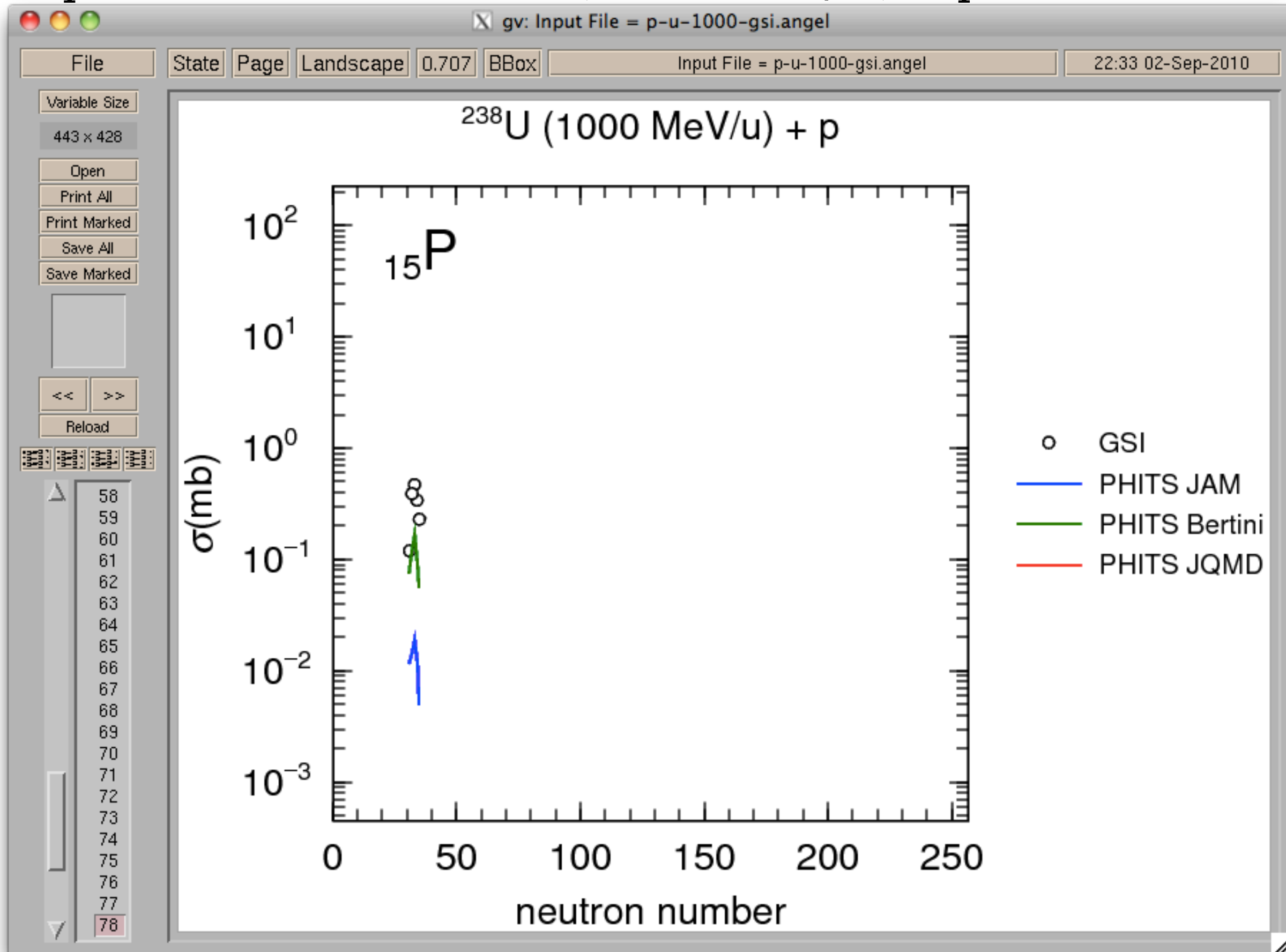


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

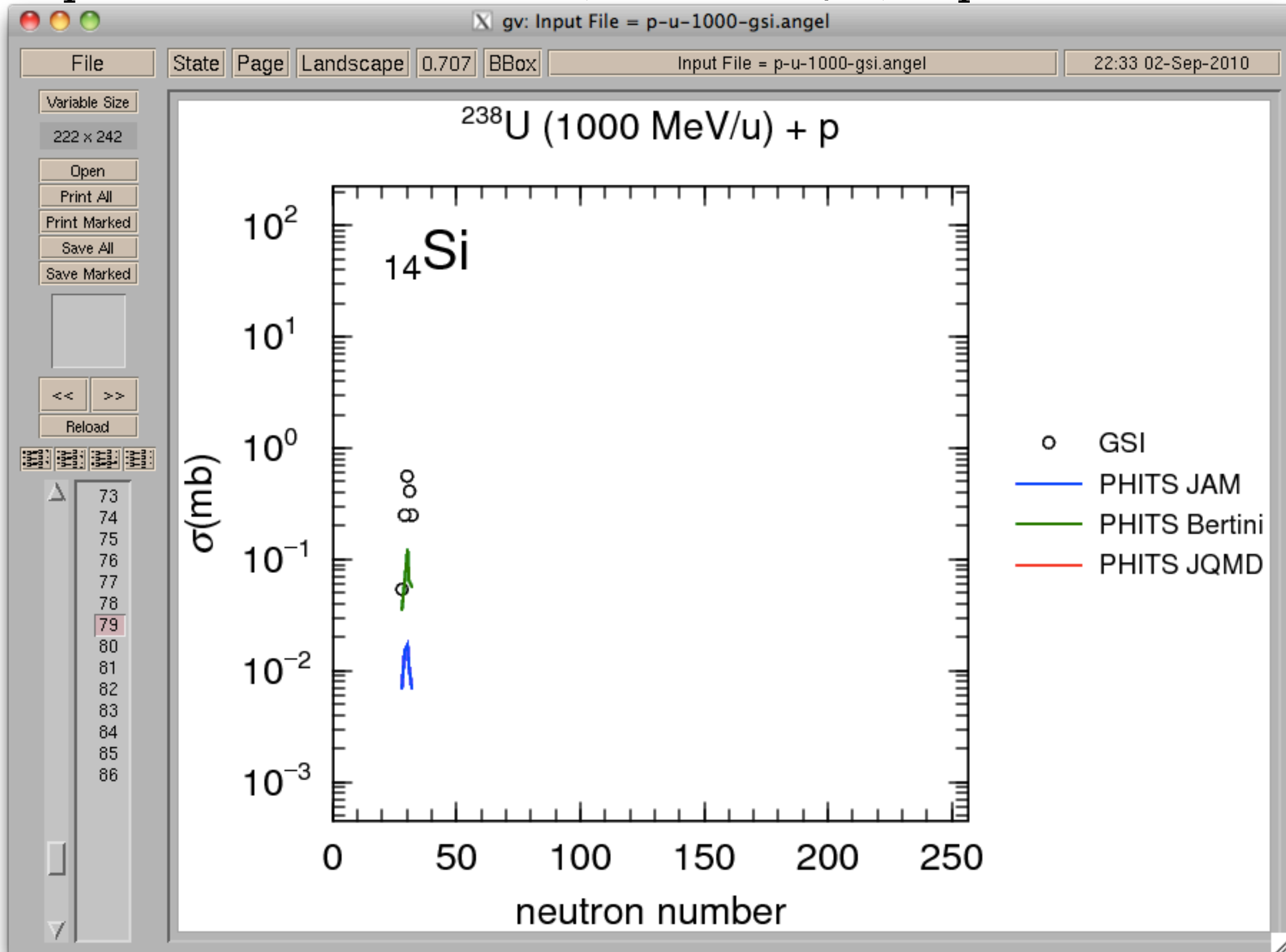




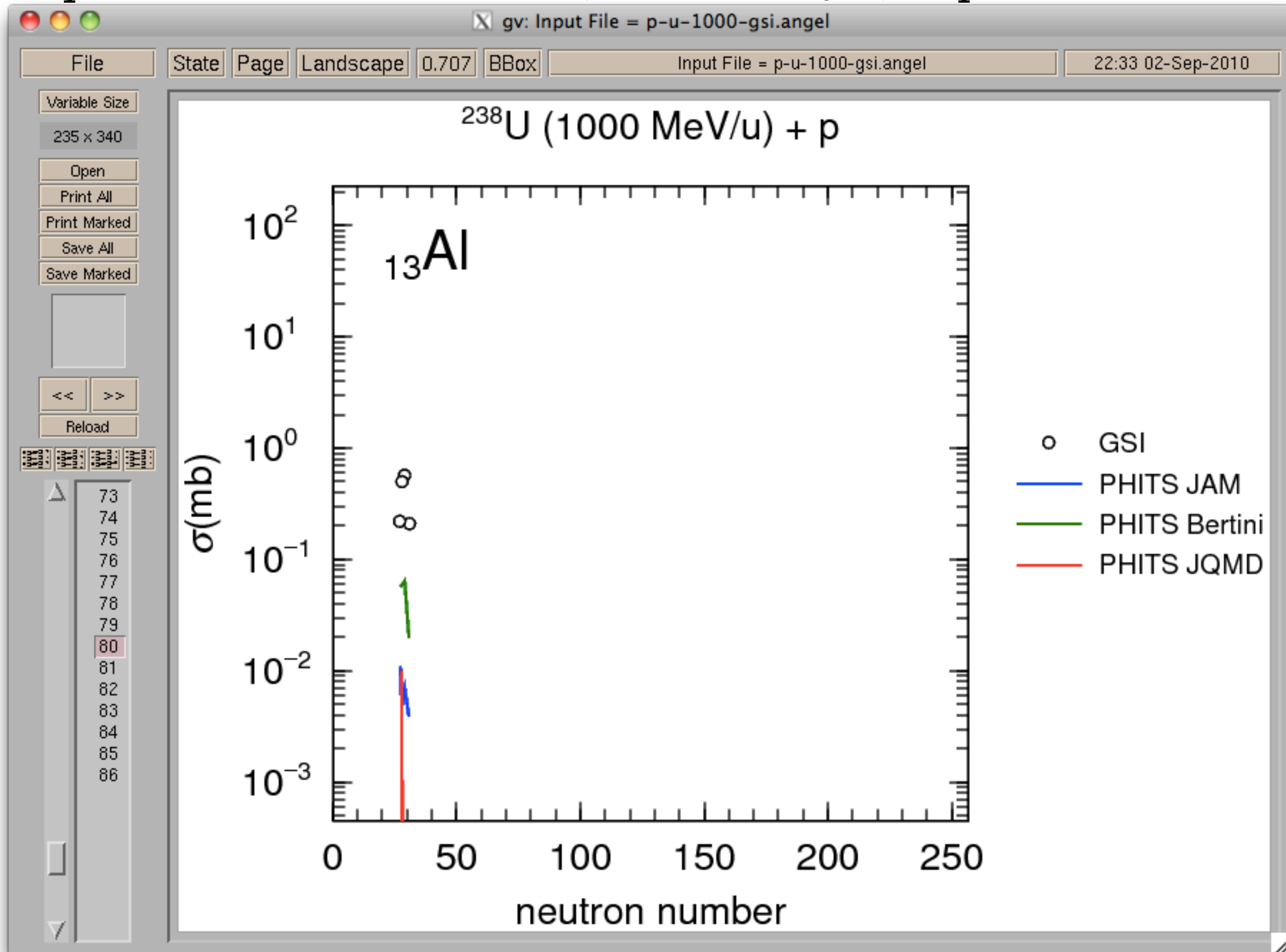
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



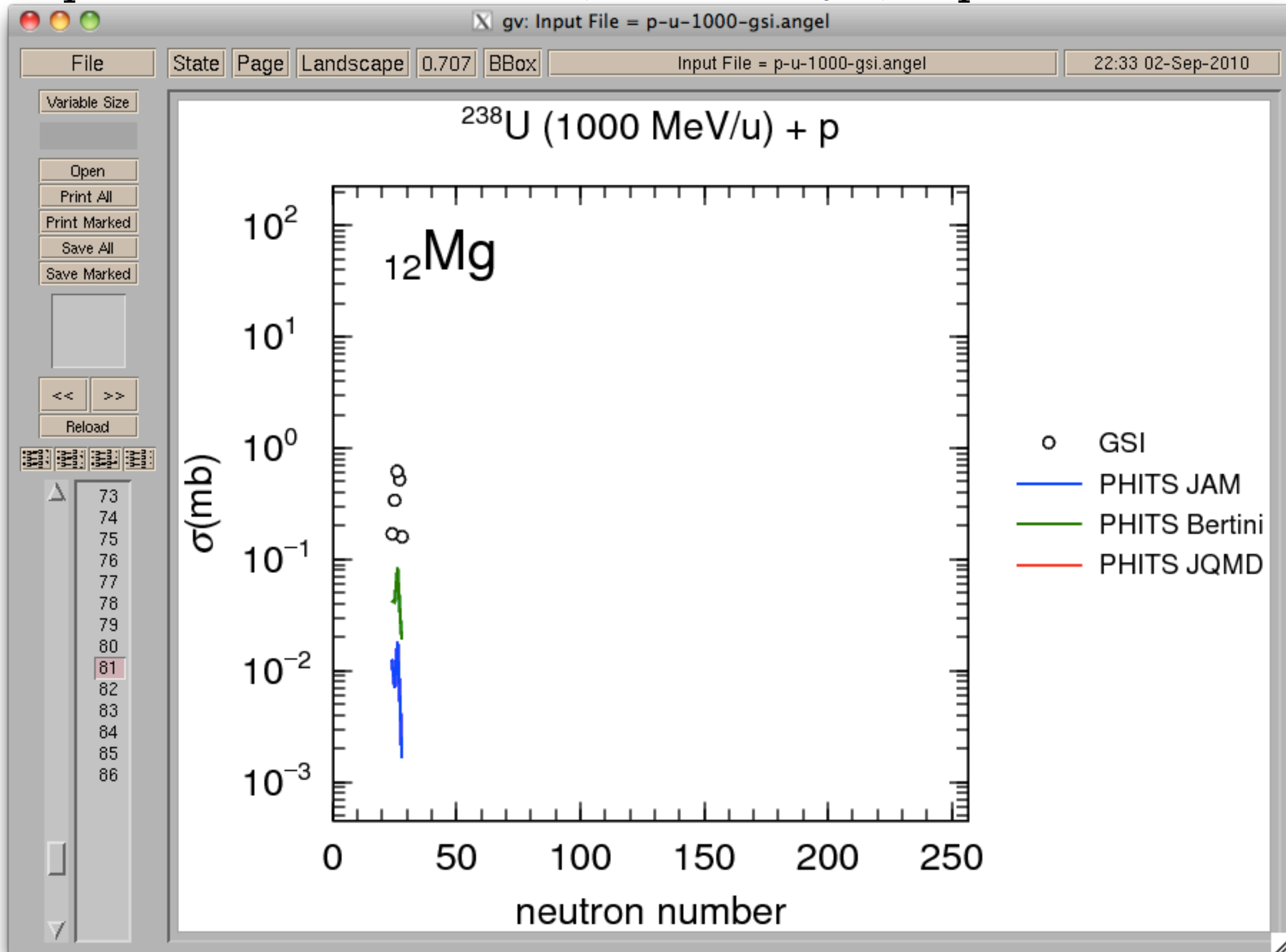
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



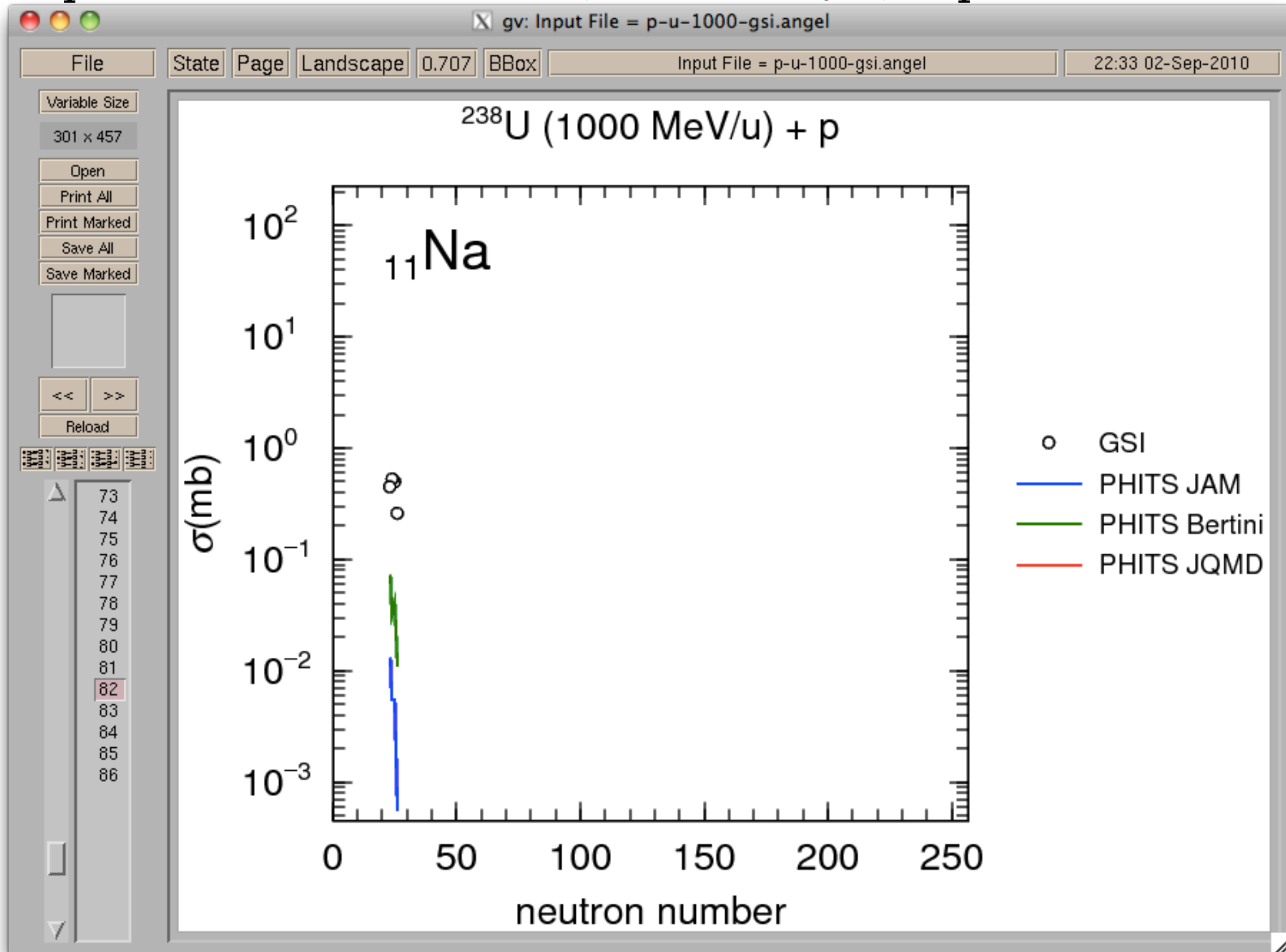
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



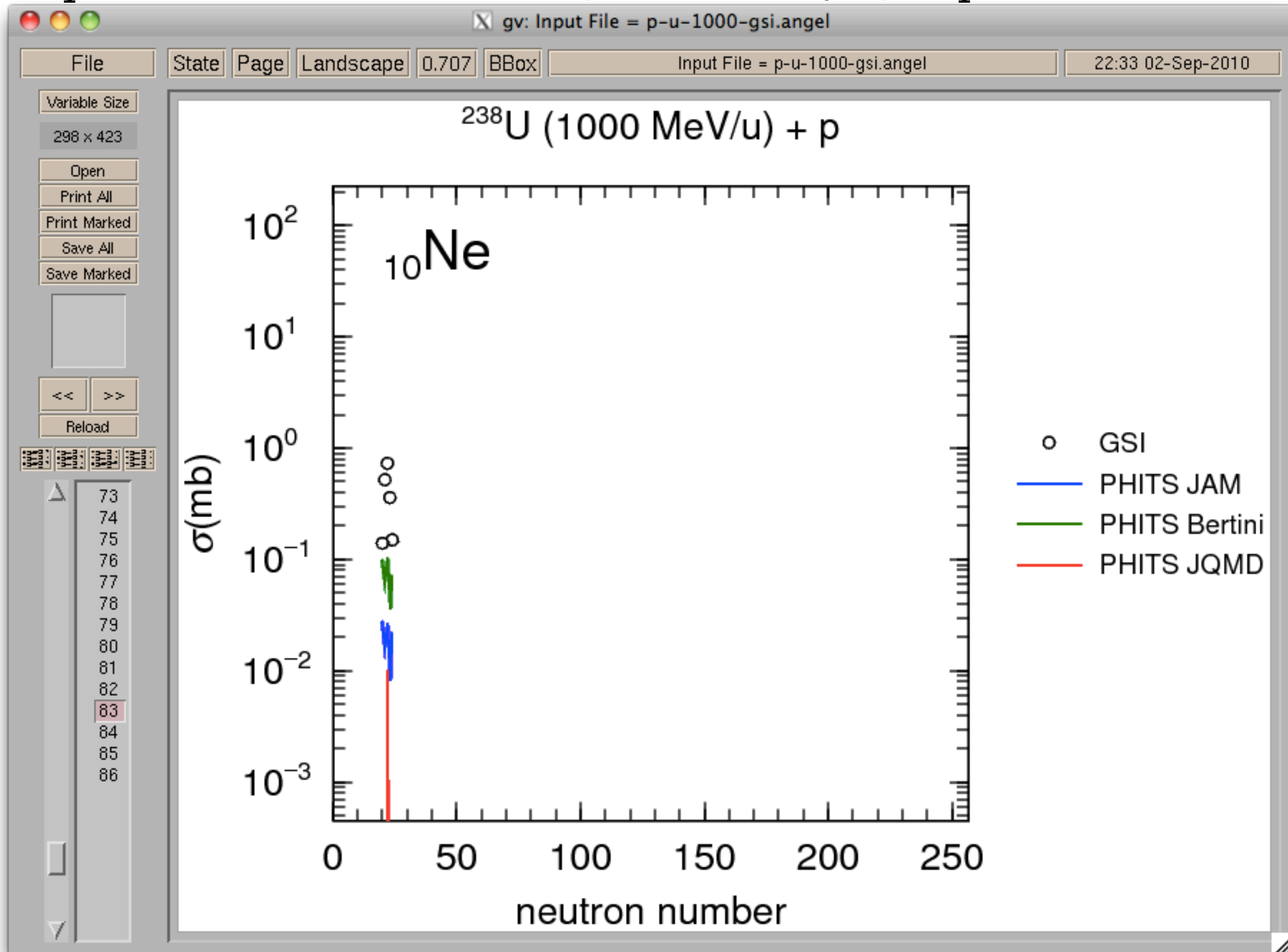
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



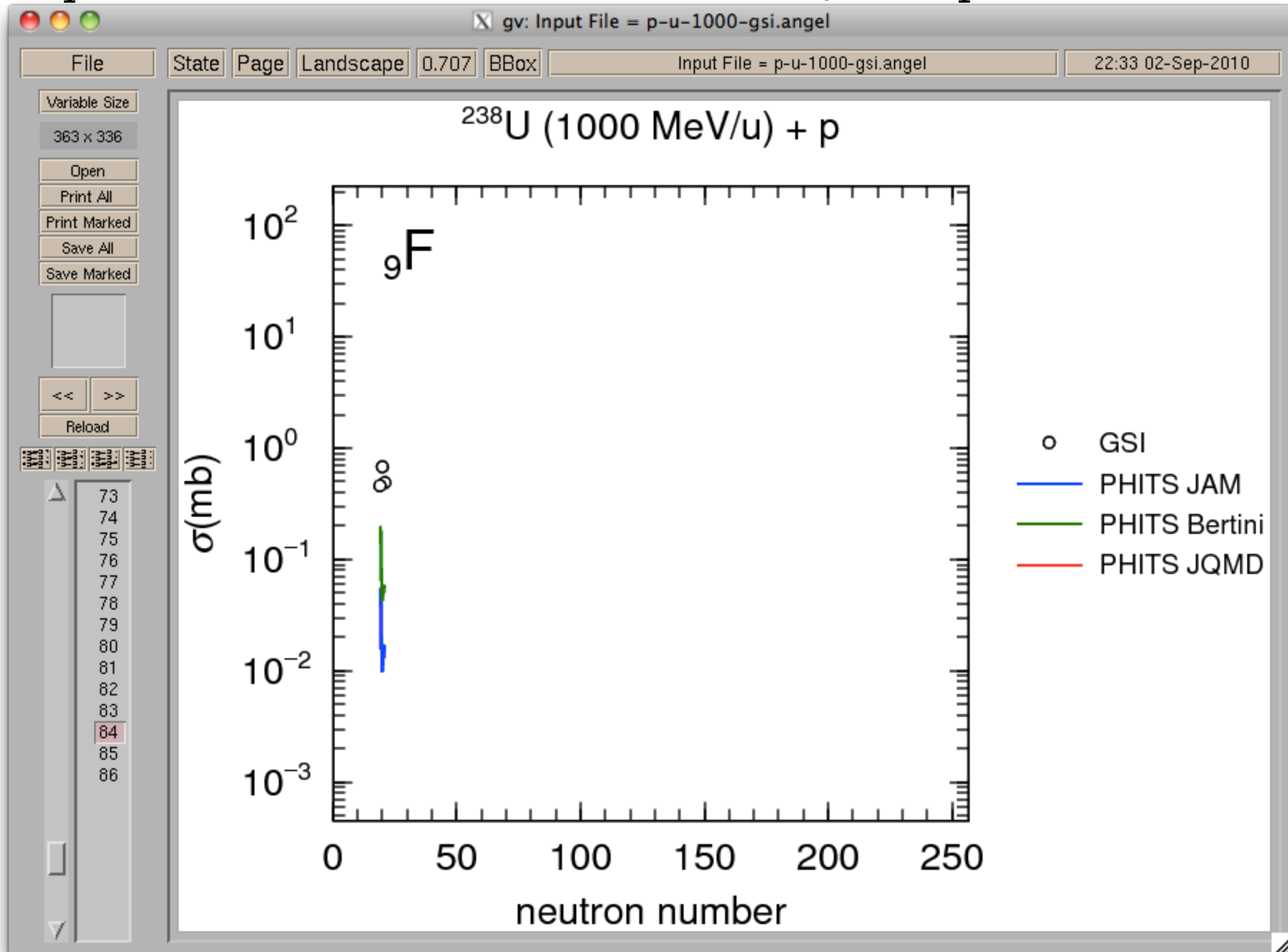
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



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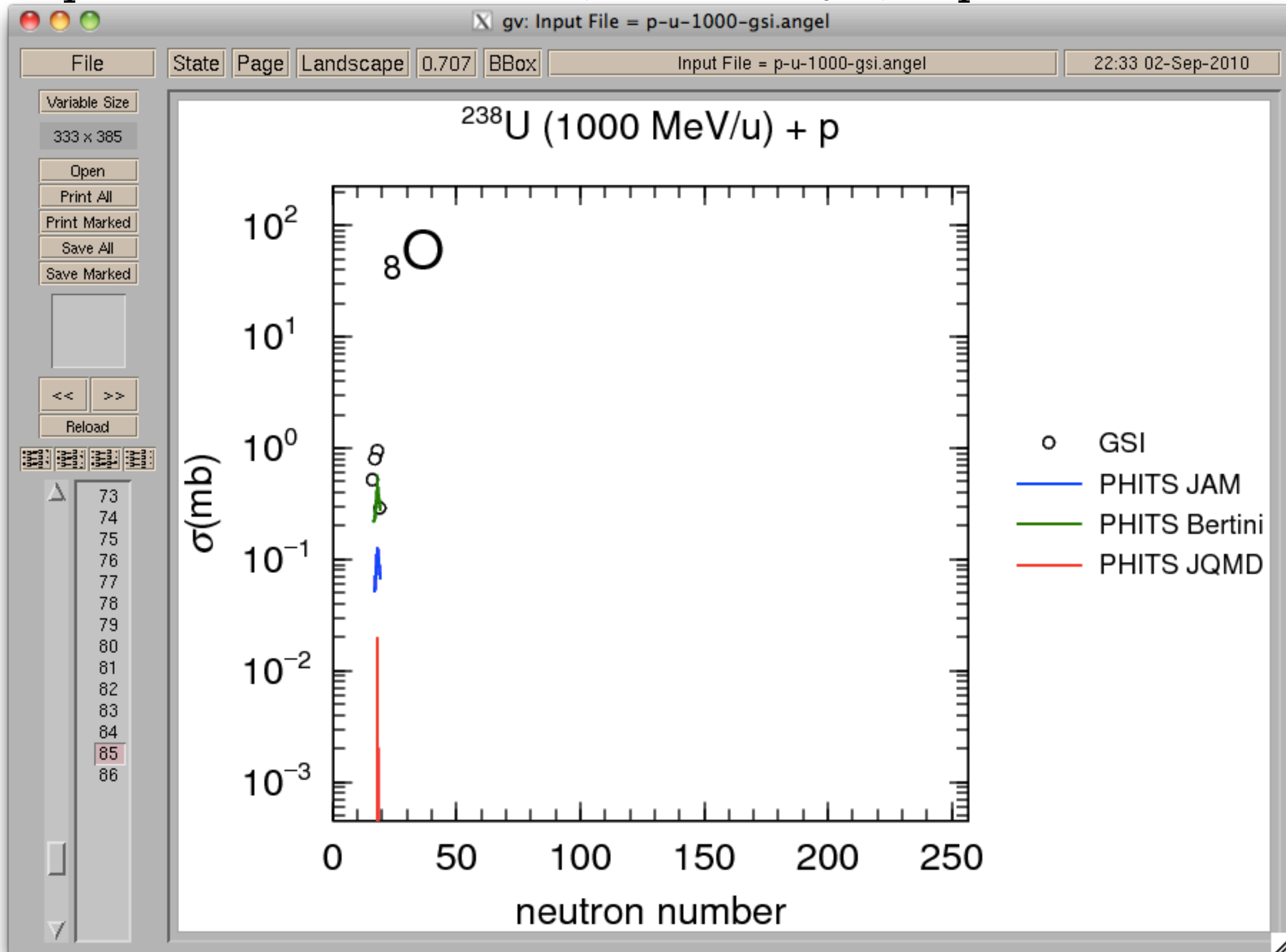


# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p

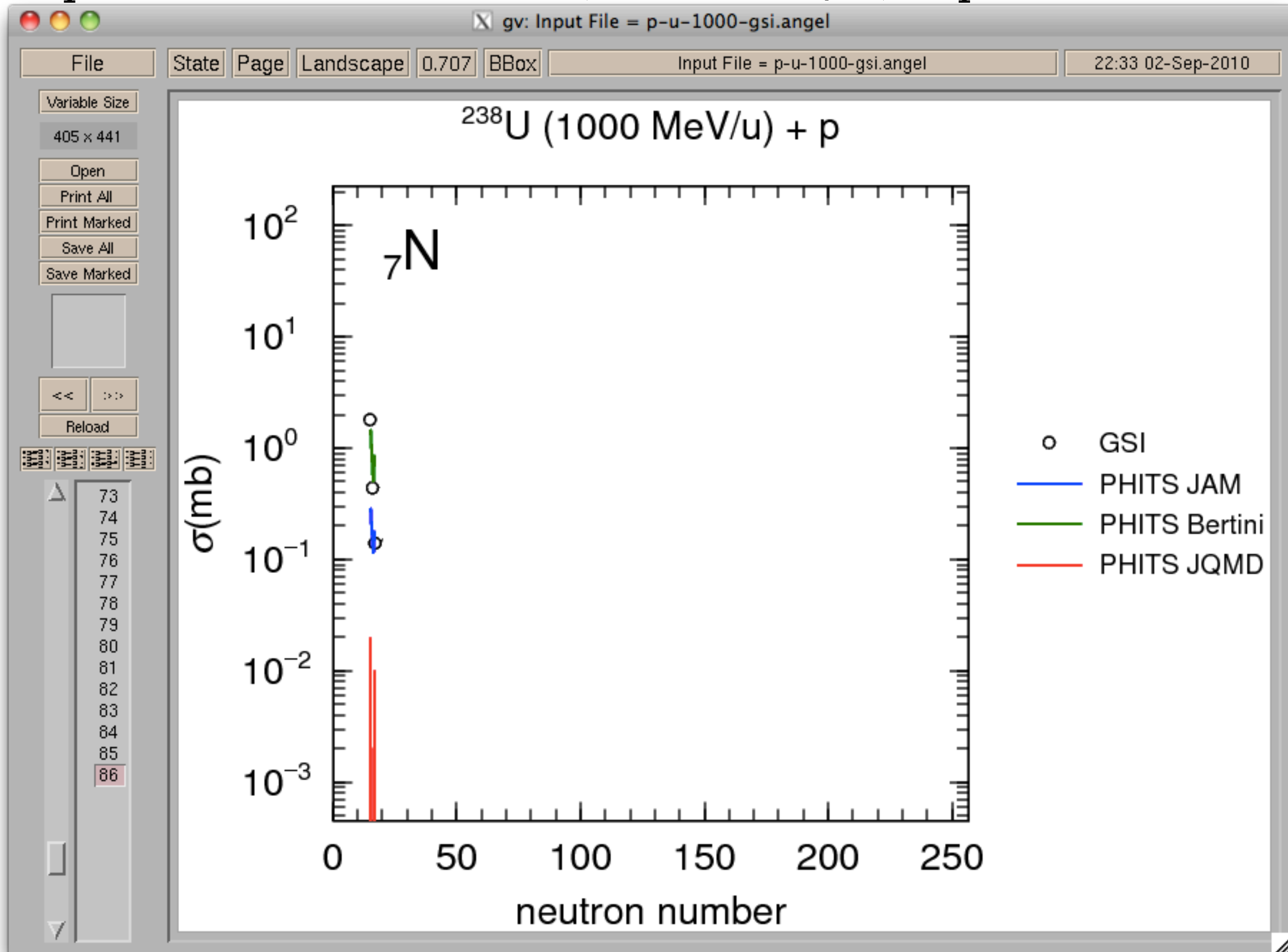




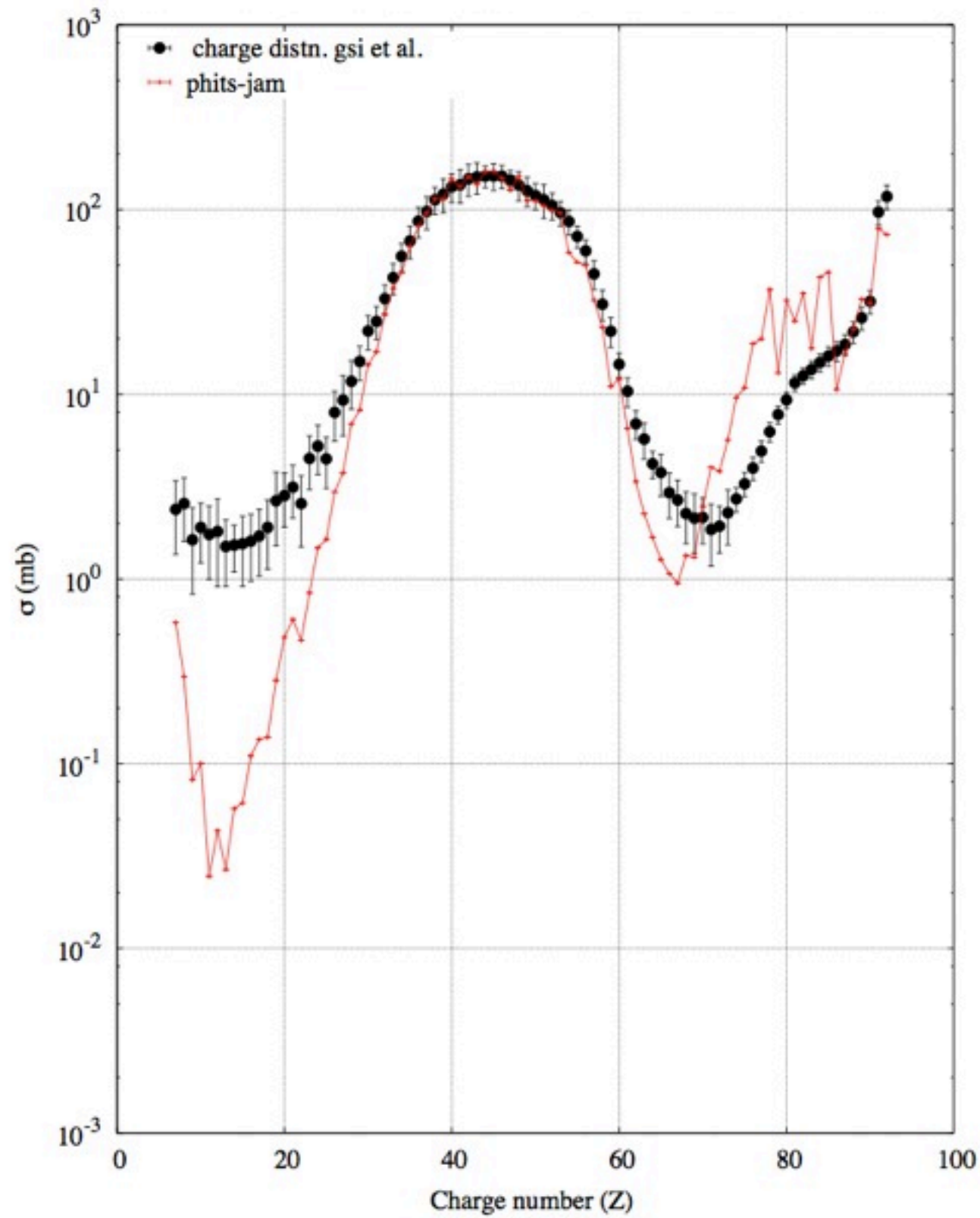
# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



# isotropic distribution: $^{238}\text{U}$ (1000 MeV/u) + p



p (1000 MeV) + U238 -- Residue charge production



# Benchmark of Spallation Models

LIGHT CHARGED PARTICLE  
PRODUCTION (LCPP)

其の一

Summarized by N. MATSUDA

Calculated by N. MATSUDA



# Benchmark Problems (LCPP)

- ❑ **Projectile (Energy):**  
proton (61~1200 MeV)
- ❑ **Target Material:**  
Aluminum (Al), Iron (Fe), Nickel (Ni),  
Tantalum (Ta), Gold (Au), Bismuth (Bi)
- ❑ **Measured Quantities:**  
p, d, t,  $^3\text{He}$  and  $\alpha$  particle double difference  
cross sections (DDX [mb/sr/MeV])

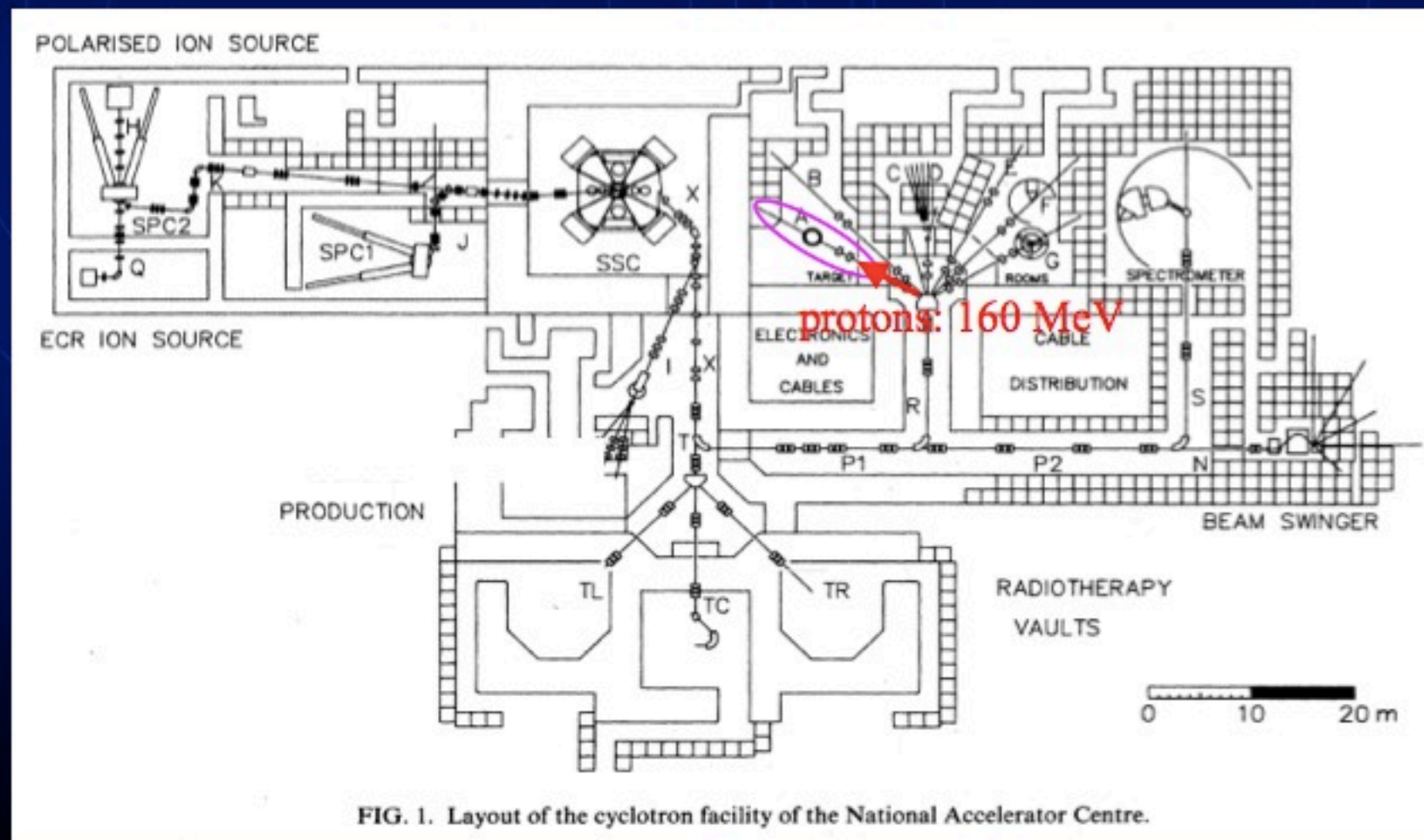
# Problems List (LCPP) 02/02

	Beam	Target	Energy (MeV)	Emitted particles	Reference
04	p	Ni	175	p, d, t, $^3\text{He}$ , $\alpha$	F. Goldenbaum et al. (unpublished)
05	p	Ni-58	175	p	S.V. Förtsch et al., Phys. Rev. C 43 (1991) 691
06	p	Ta	1200	p, d, t, $^3\text{He}$ , $\alpha$	C.-M. Herbach et al., Nucl. Phys. A 765 (2006) 426



# Experimental Setup for LCP02, 07

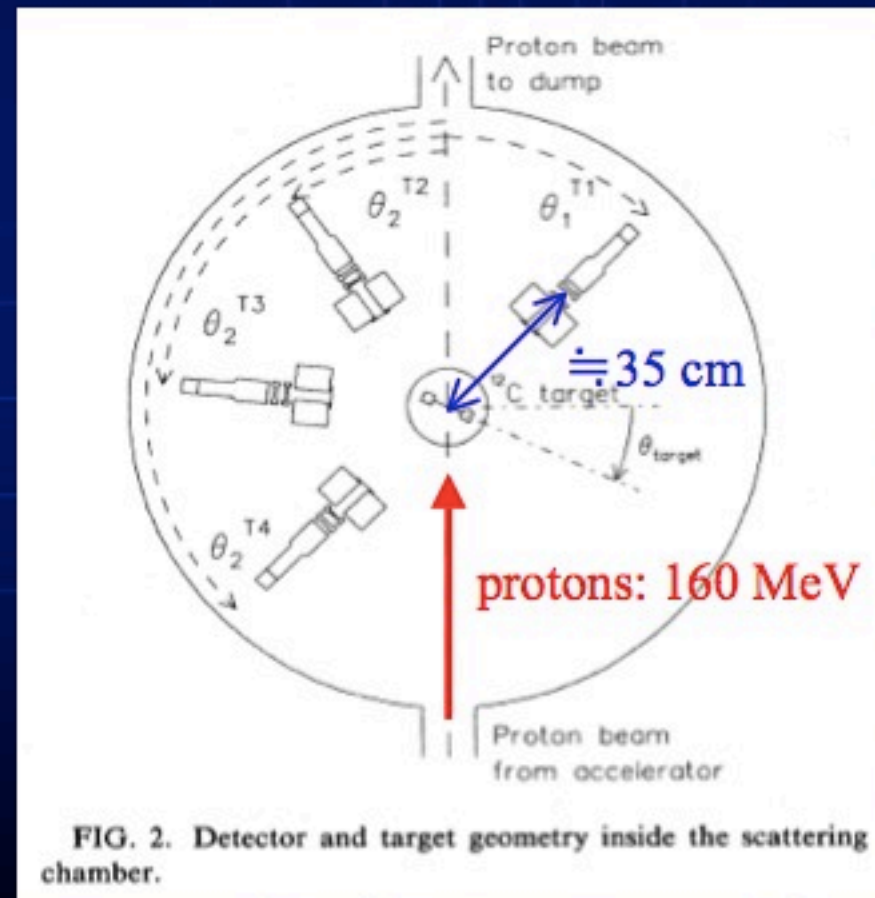
- Experimental Geometry (NAC, South Africa)





# Target and Detectors (LCPP02, 07)

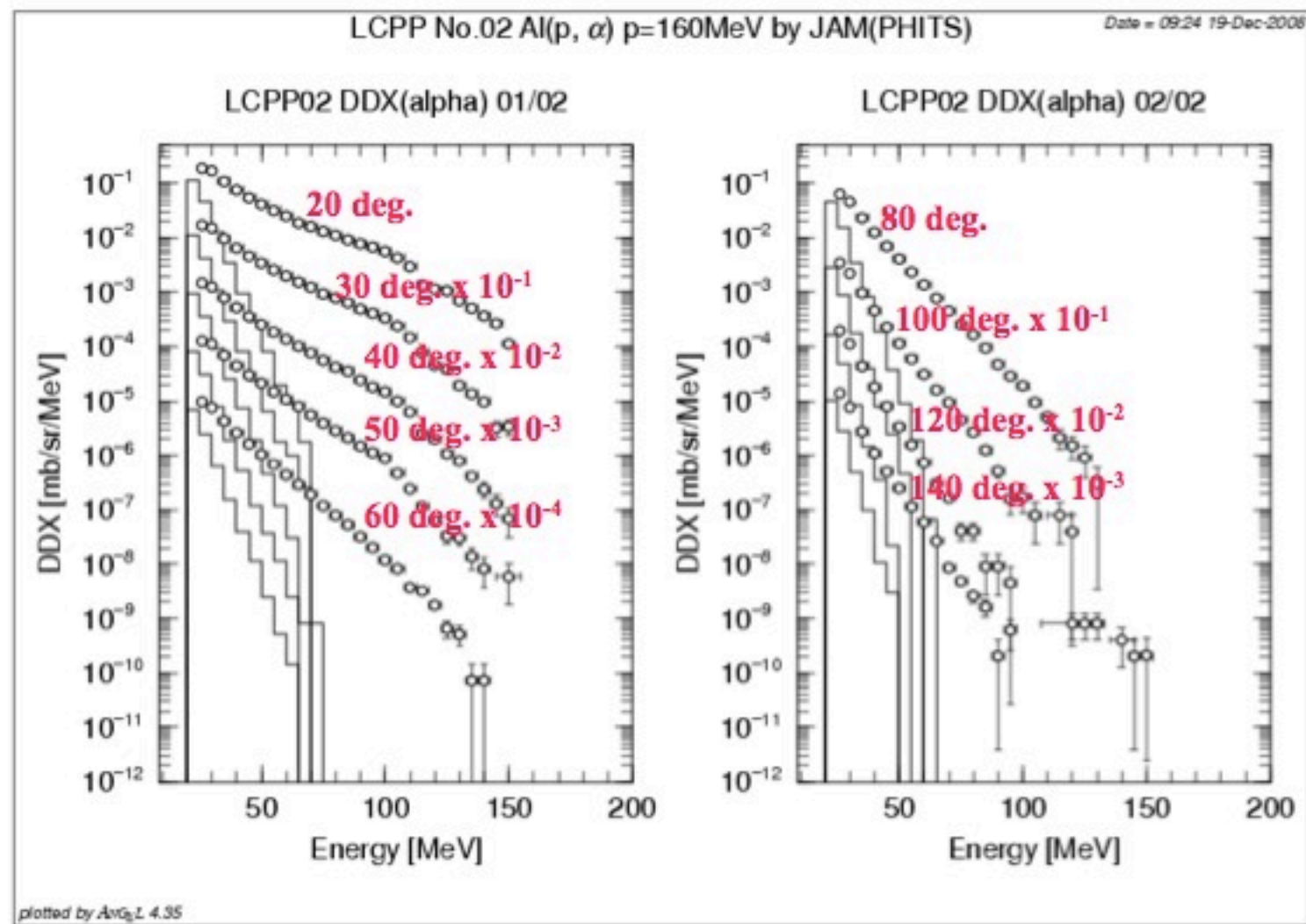
- Target Chamber



# Expt. and Calc. info. about LCPP02

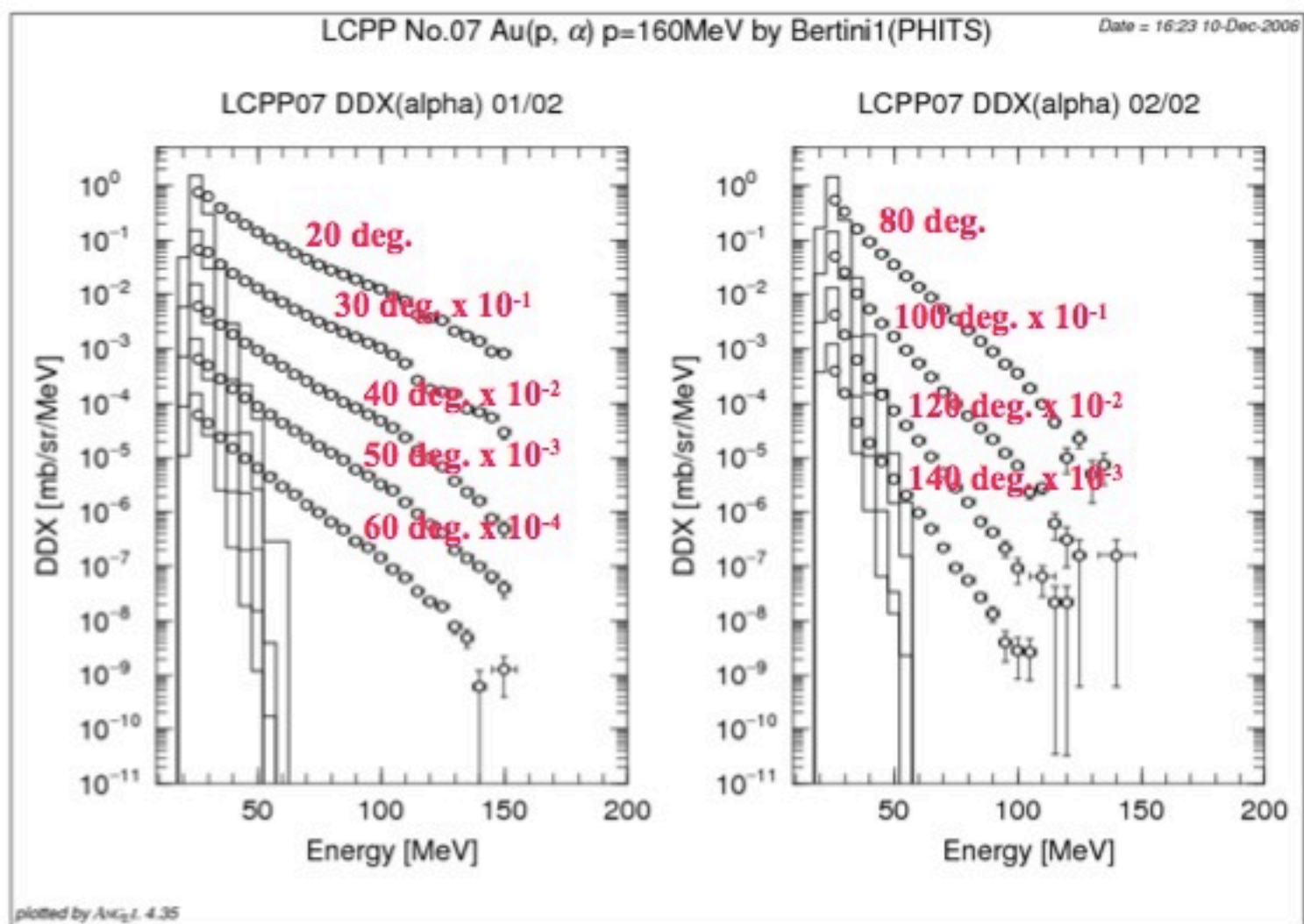
	Expt.	Calc.
<b>Targets</b>		
Material	Aluminum	Aluminum
Size (thickness)	1-4 mg/cm <sup>2</sup>	0.00037 cm (1 mg/cm <sup>2</sup> )
Size (width)	unclear	∅ 0.00037 cm
Density	---	2.6989 g/cm <sup>3</sup>
<b>Detectors</b>		
Size (width)	unclear	± 6.12 degrees
Angle	20 to 140 degrees	20 to 140 degrees
Distance (T to D)	about 35 cm	10 m

# Comparison (LCPP02) Al(p, $\alpha$ ) p (160MeV)





# Comparison (LCPP07) $\text{Au}(p,\alpha)p$ (160MeV)



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# Experimental Setup for LCPP03, 12

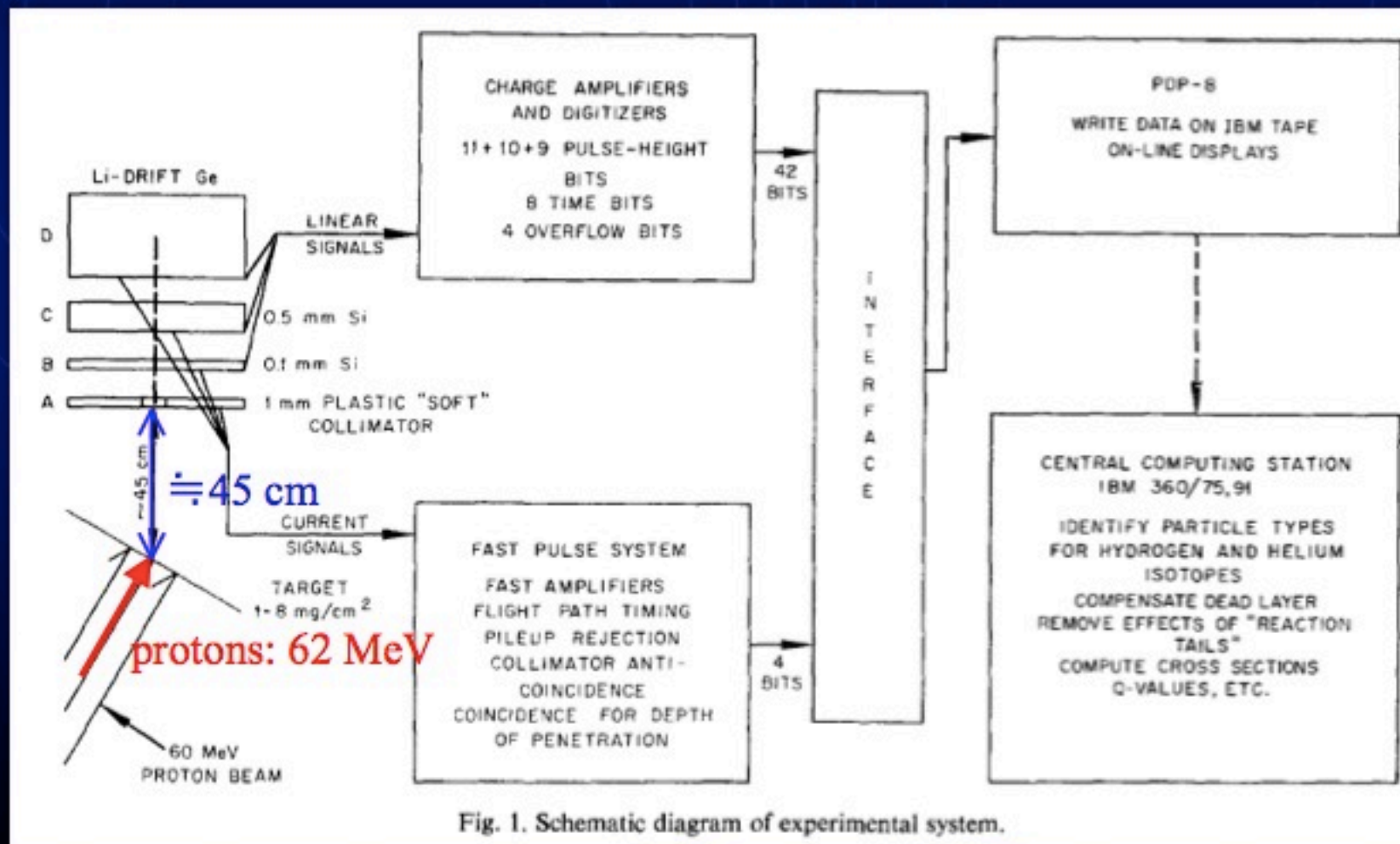
- Experimental Geometry (LANL)



No Photo

# Target and Detectors (LCPP03, 12)

- Experimental procedure



12

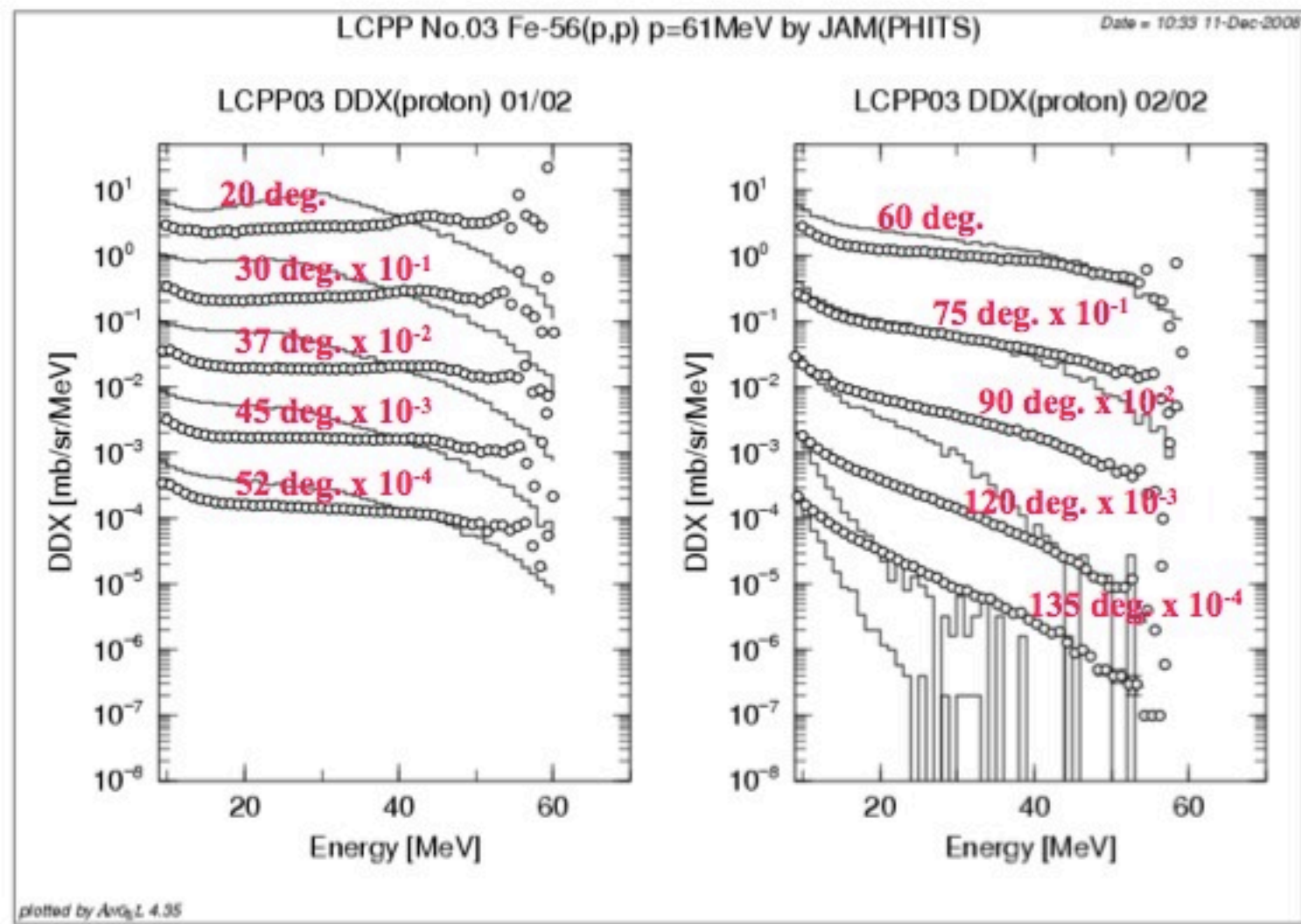


# Expt. and Calc. info. about LCPP03

	Expt.	Calc.
<b>Targets</b>		
Material	enriched $^{56}\text{Fe}$ (99.7%)	$^{56}\text{Fe}$
Size (thickness)	4.16 mg/cm <sup>2</sup>	0.00053 cm
Size (width)	over 8 mm in dia.	$\phi$ 0.00053 cm
Density	---	7.87 g/cm <sup>3</sup>
<b>Detectors</b>		
Size (width)	unclear	$\pm$ 0.21 degrees
Angle	15 to 135 degrees	15 to 135 degrees
Distance (T to D)	about 45 cm	47 cm

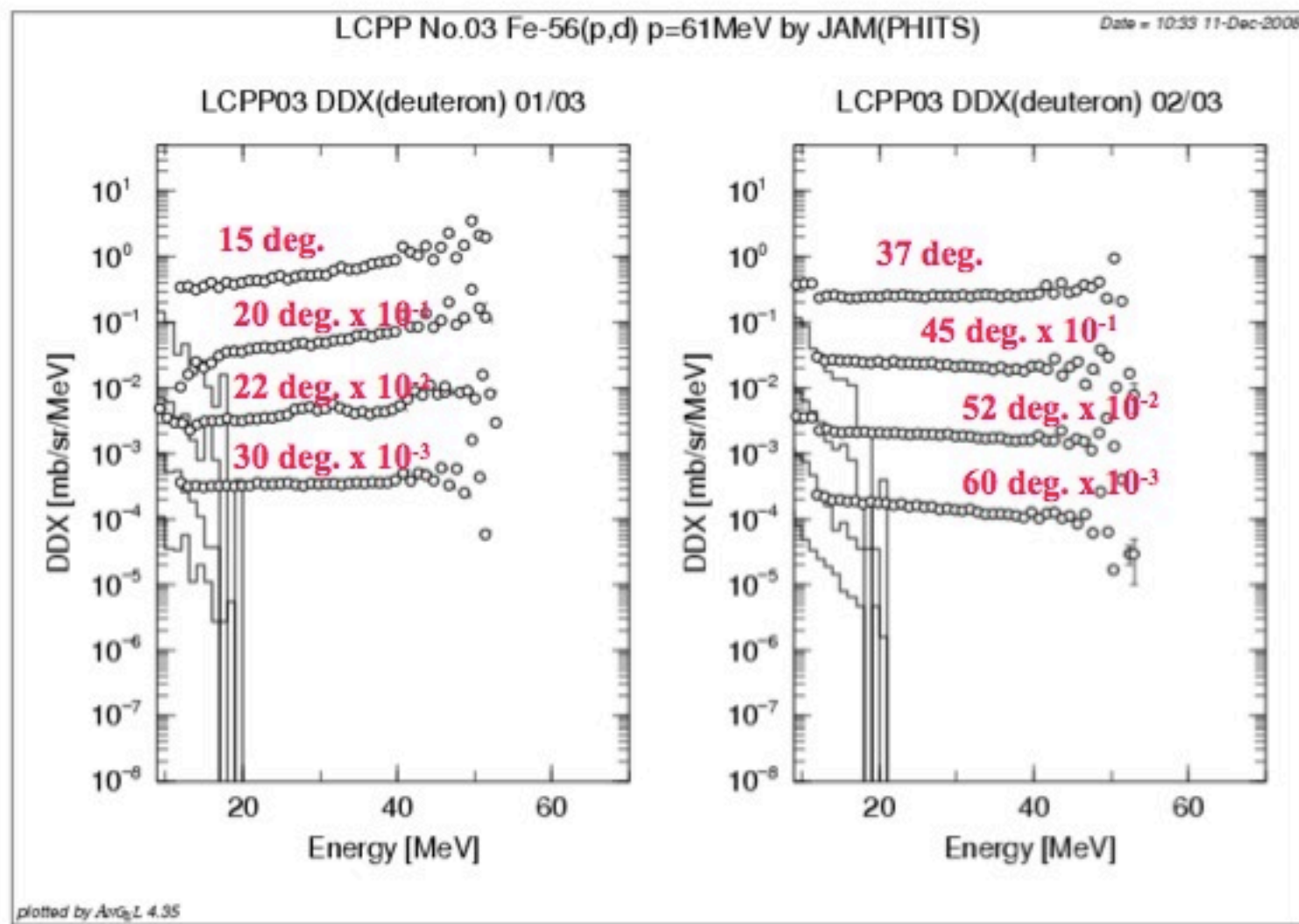


# Comparison (LCPP03) $^{56}\text{Fe}(p,x)p$ (61MeV)



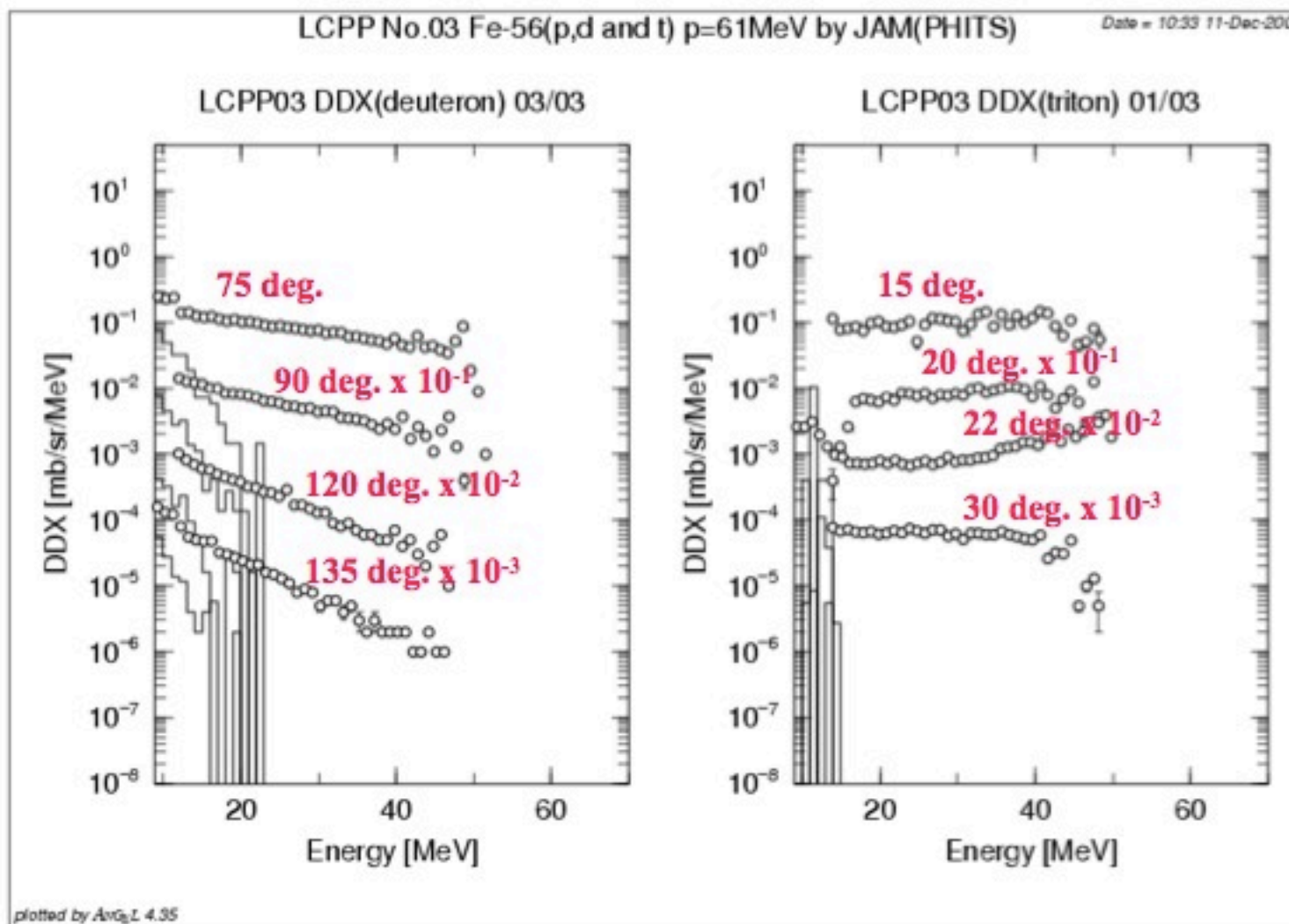
14

# Comparison (LCPP03) $^{56}\text{Fe}(p,x)p$ (61MeV)



15

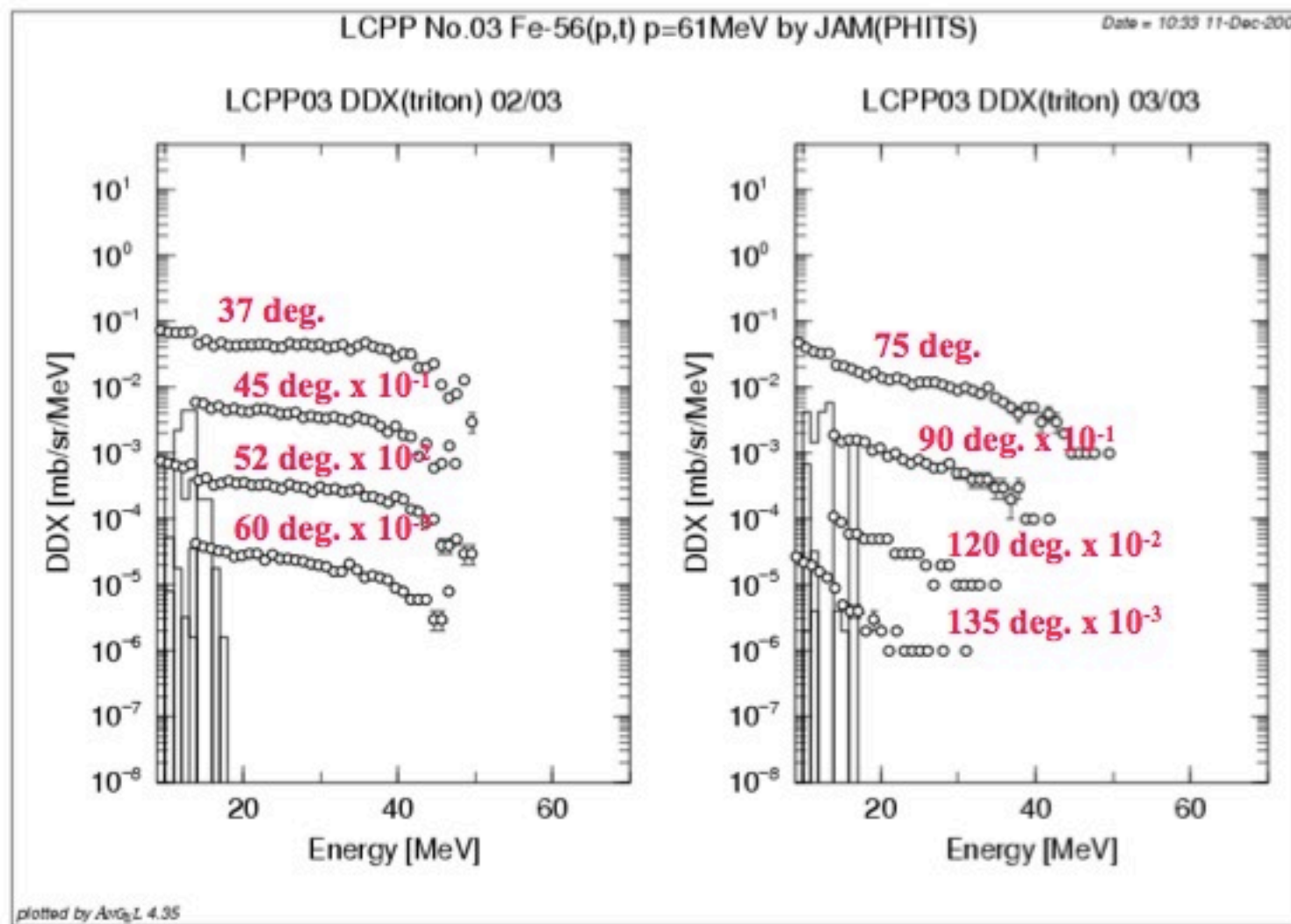
# Comparison (LCPP03) $^{56}\text{Fe}(p,x)p$ (61MeV)



16

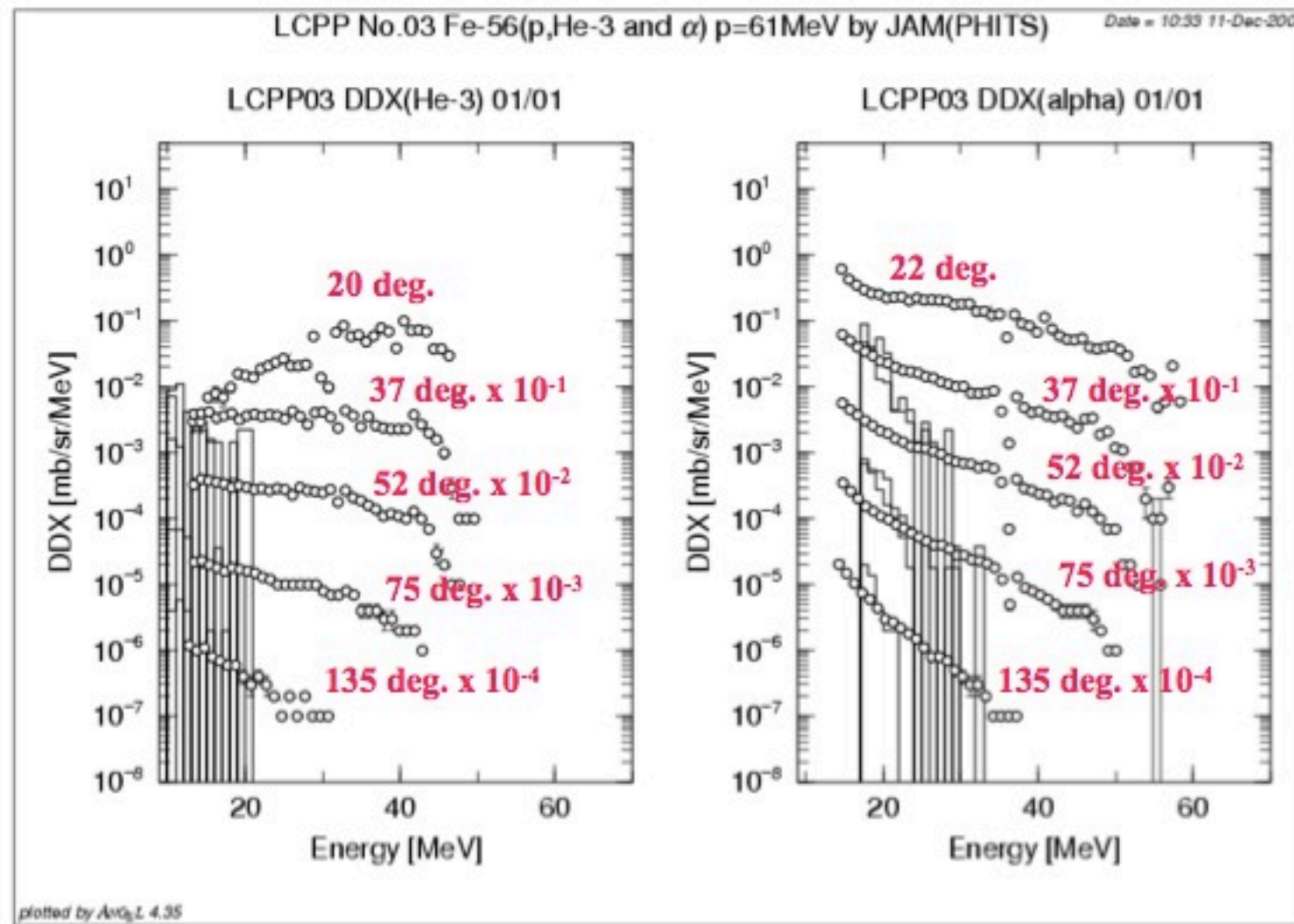


# Comparison (LCPP03) $^{56}\text{Fe}(p,x)p$ (61MeV)



17

# Comparison (LCPP03) $^{56}\text{Fe}(p,x)p$ (61MeV)



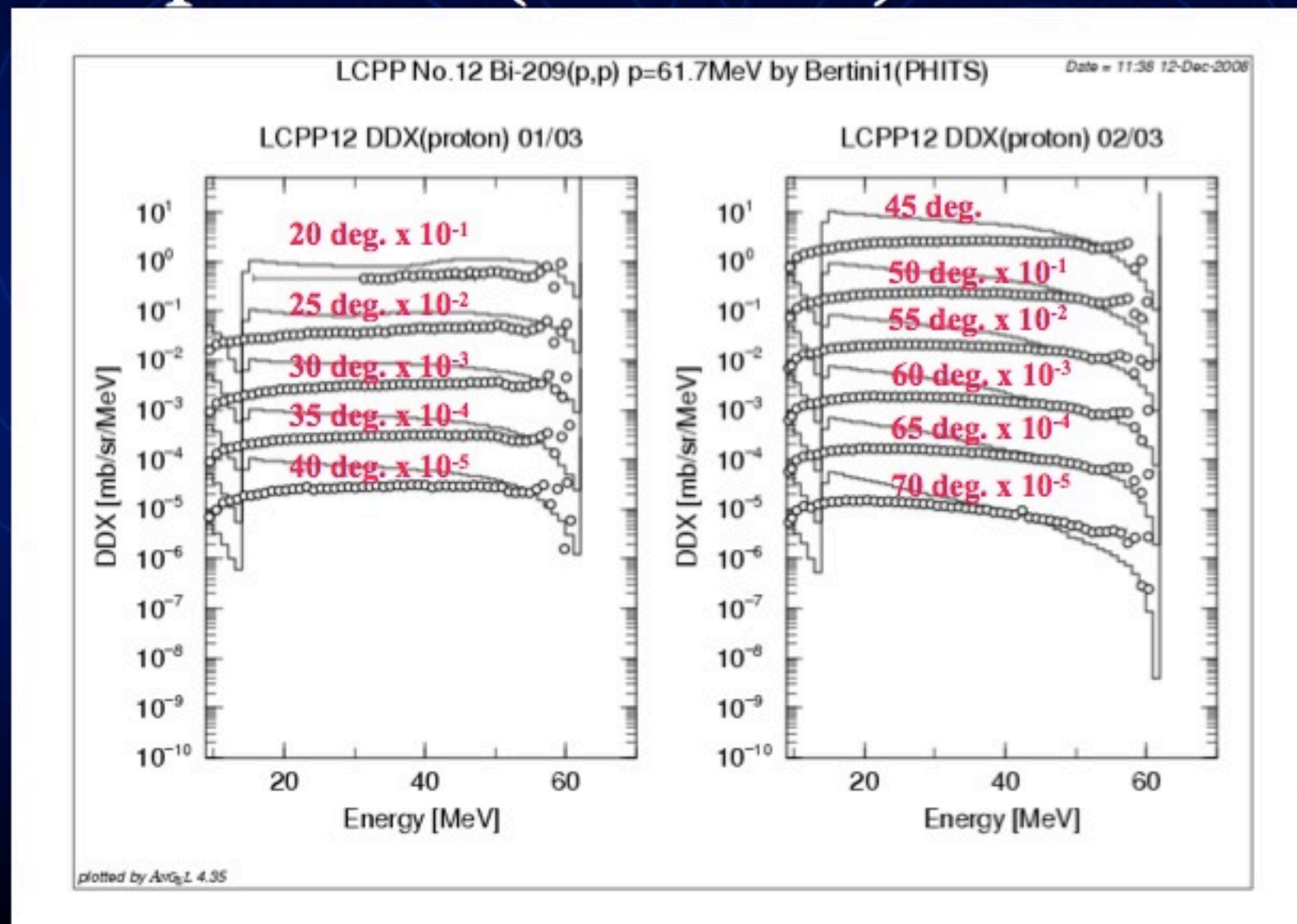
18

# Expt. and Calc. info. about LCPP12

	Expt.	Calc.
<b>Targets</b>		
Material	Bismuth	Bismuth
Size (thickness)	10.3 mg/cm <sup>2</sup>	0.00105 cm
Size (width)	over 8 mm in dia.	∅ 0.00105 cm
Density	---	9.80 g/cm <sup>3</sup>
<b>Detectors</b>		
Size (width)	unclear	± 0.21 degrees
Angle	15 to 160 degrees	15 to 160 degrees
Distance (T to D)	about 45 cm	47 cm



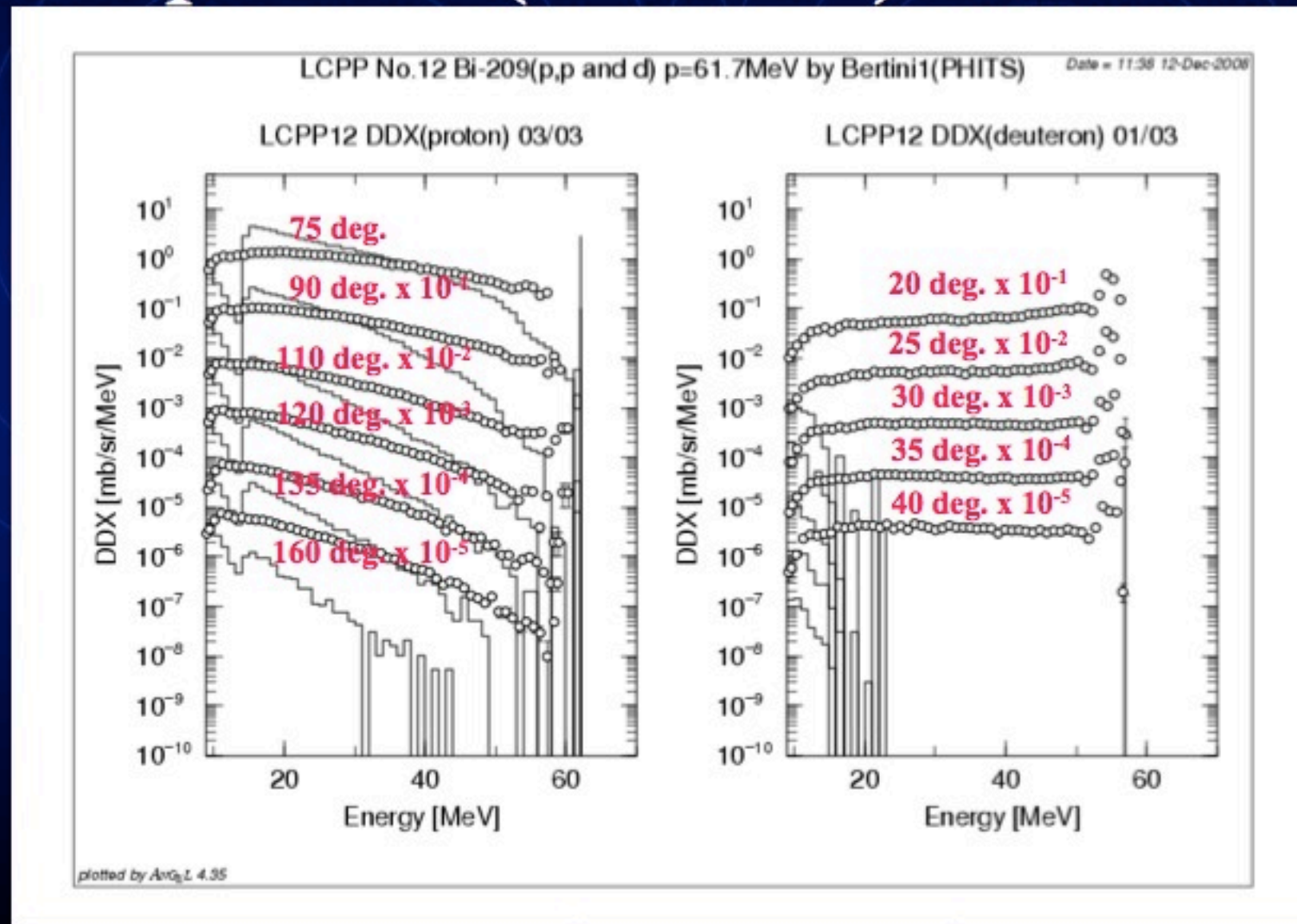
# Comparison (LCPP12) Bi(p,x) p (61.7MeV)



20

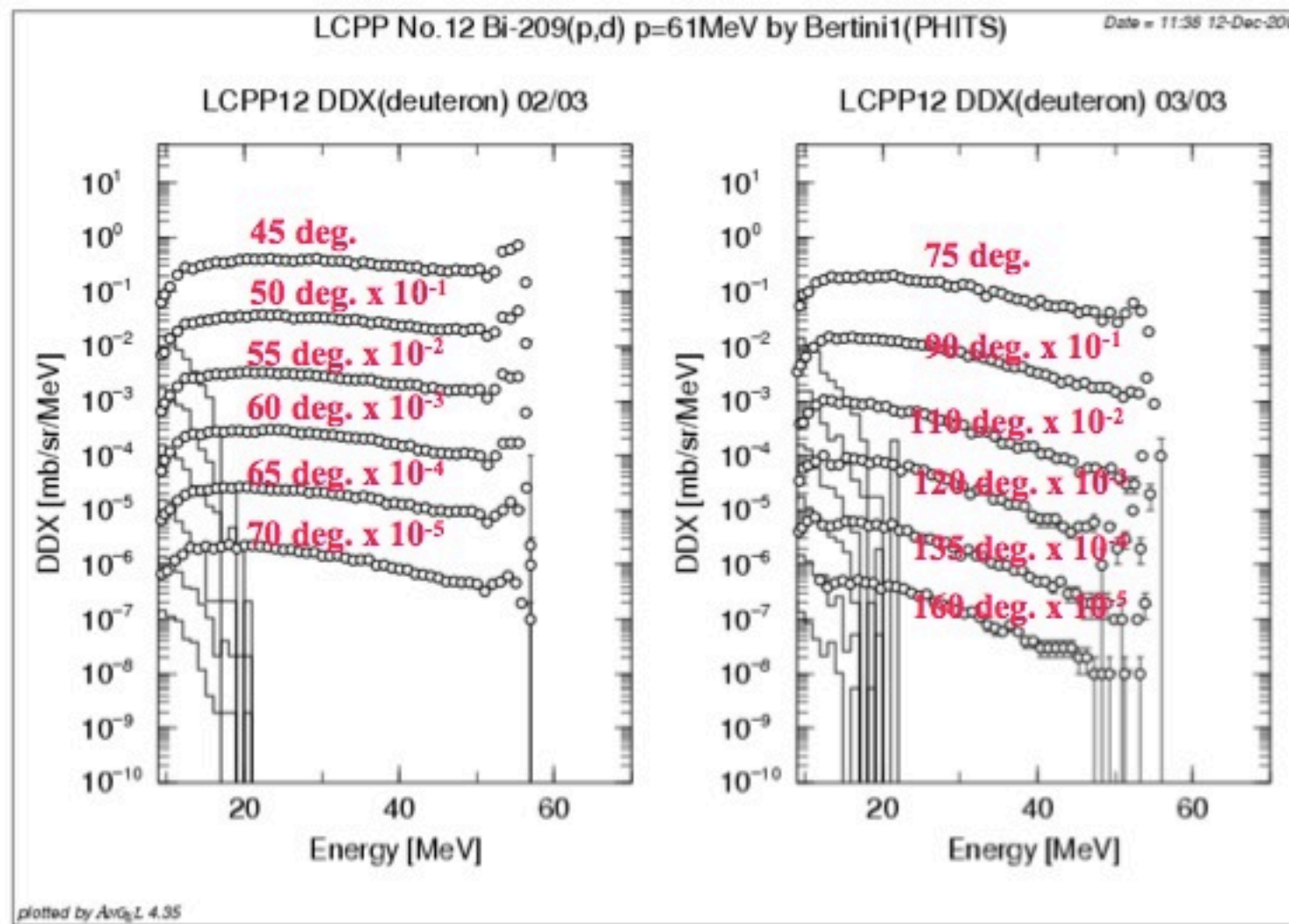


# Comparison (LCPP12) $\text{Bi}(p,x)p$ (61.7MeV)

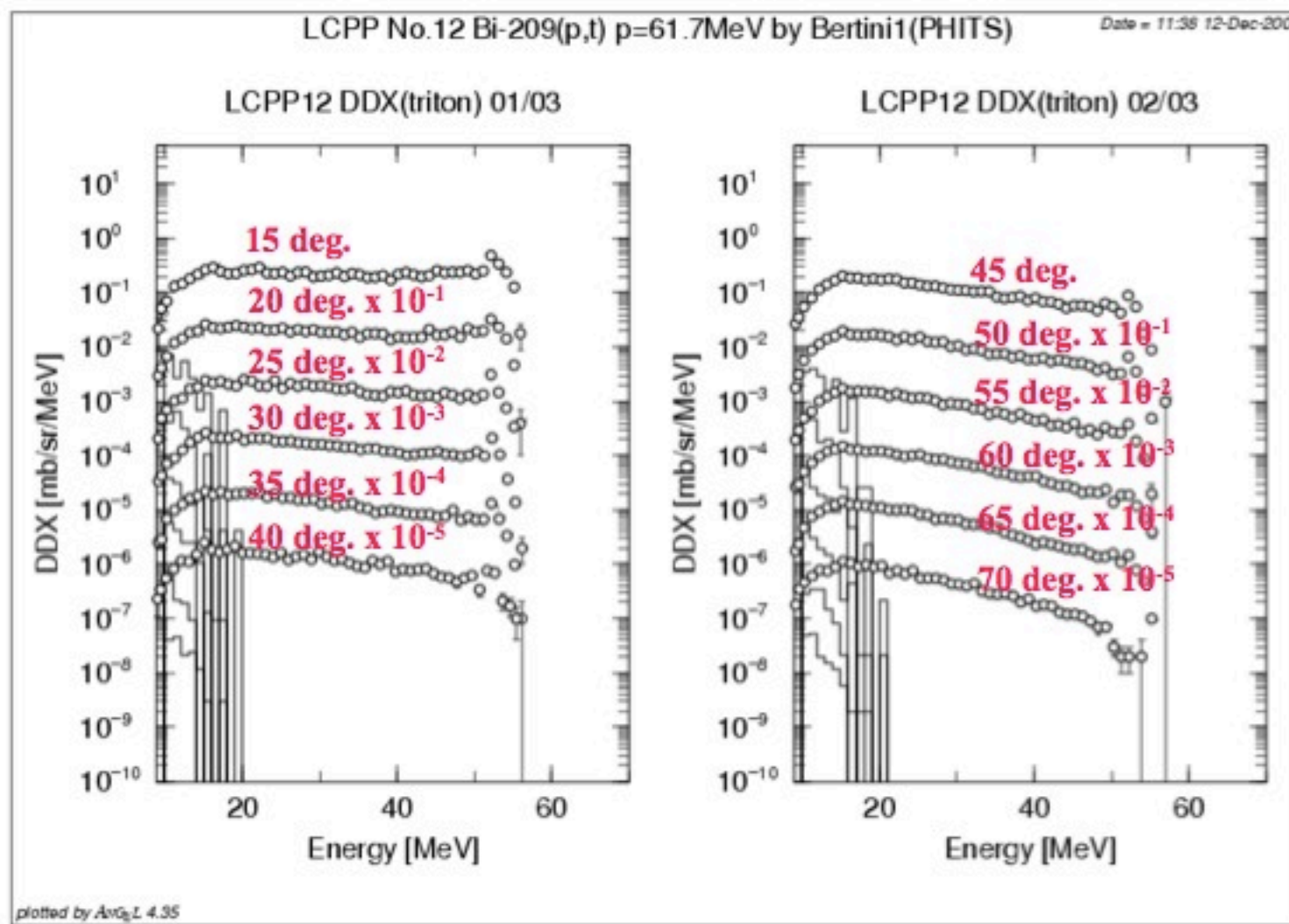


21

# Comparison (LCPP12) Bi(p,x) p (61.7MeV)



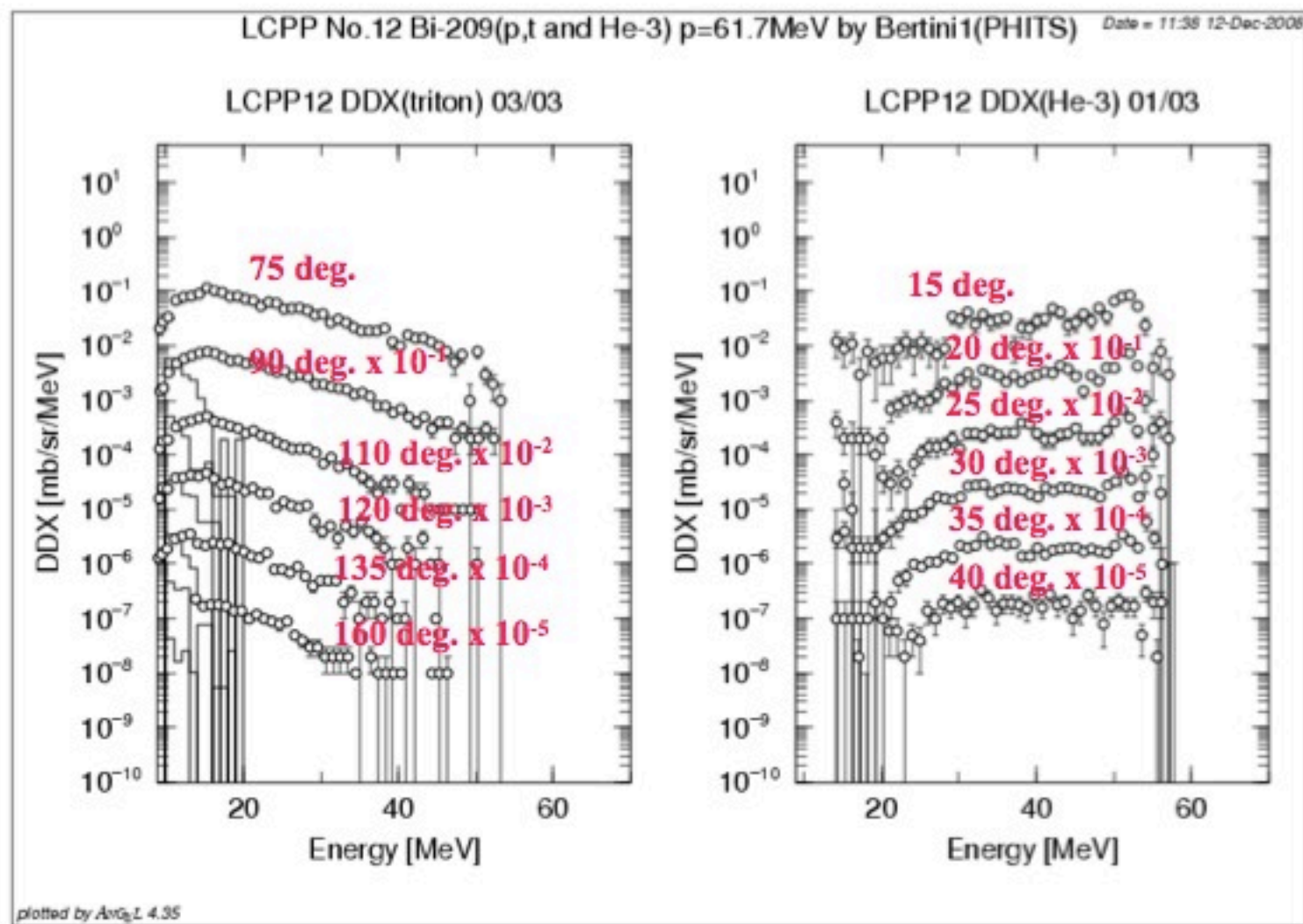
# Comparison (LCPP12) Bi(p,x) p (61.7MeV)



23

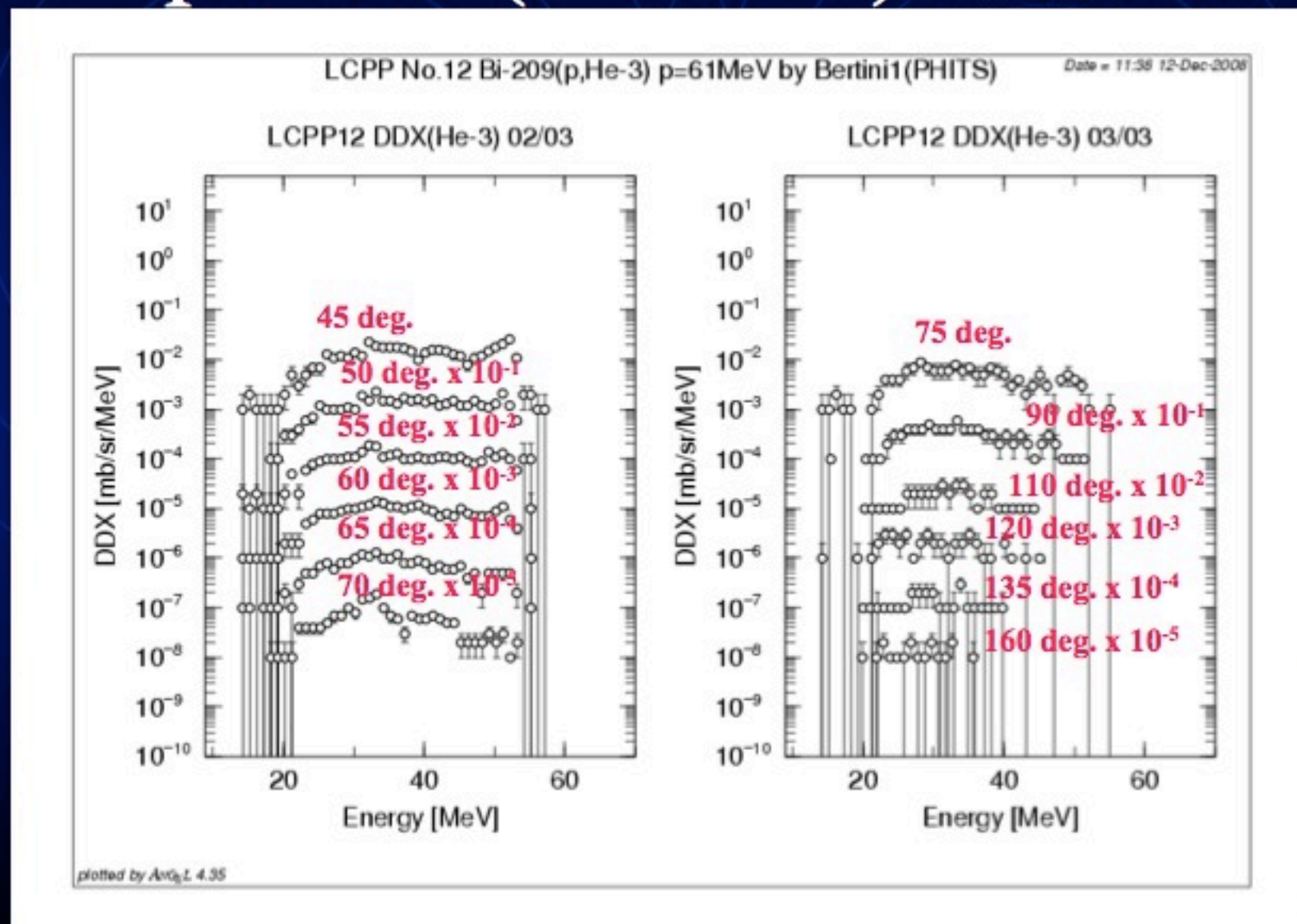


# Comparison (LCPP12) Bi(p,x) p (61.7MeV)



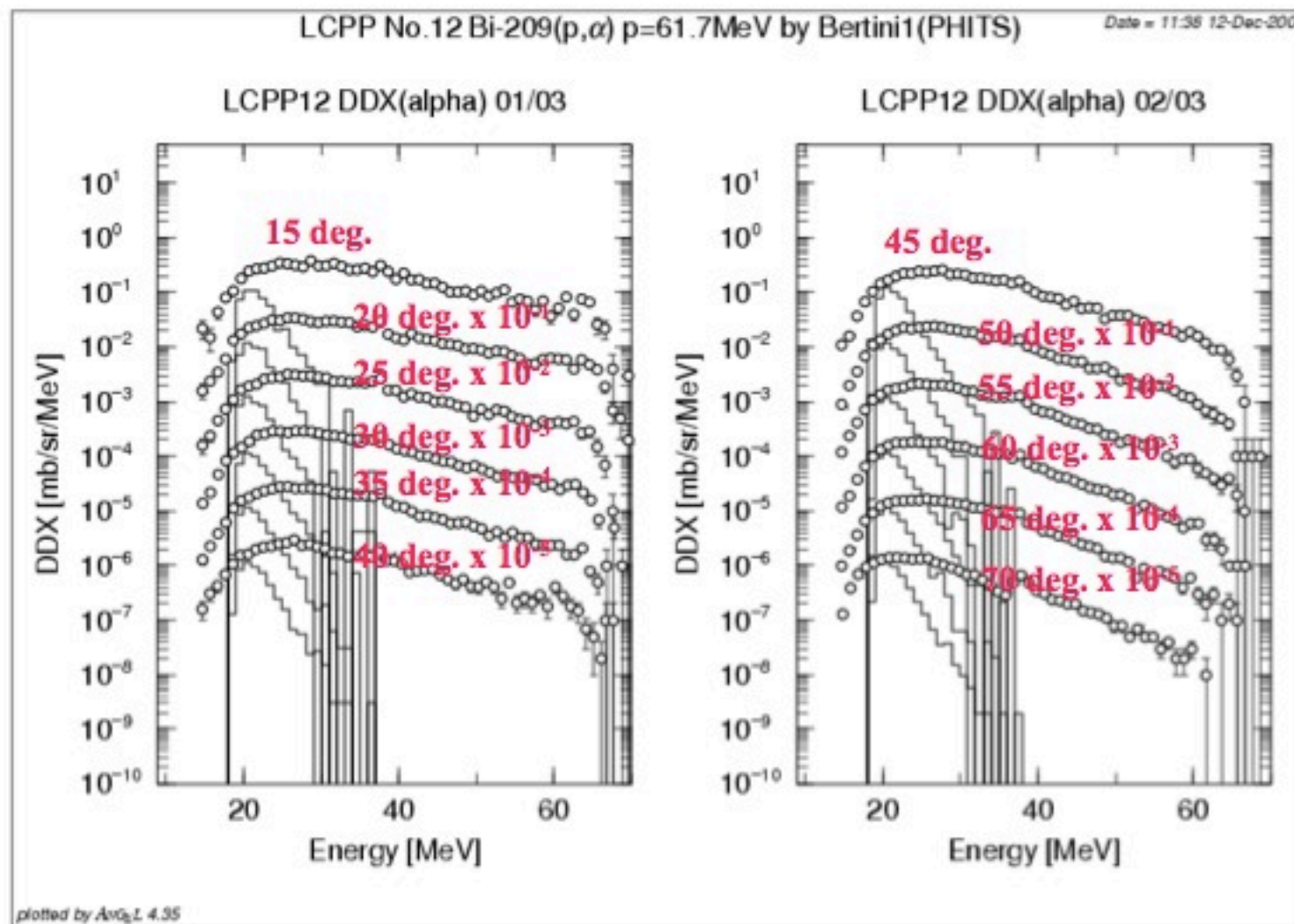
24

# Comparison (LCPP12) Bi(p,x) p (61.7MeV)



25

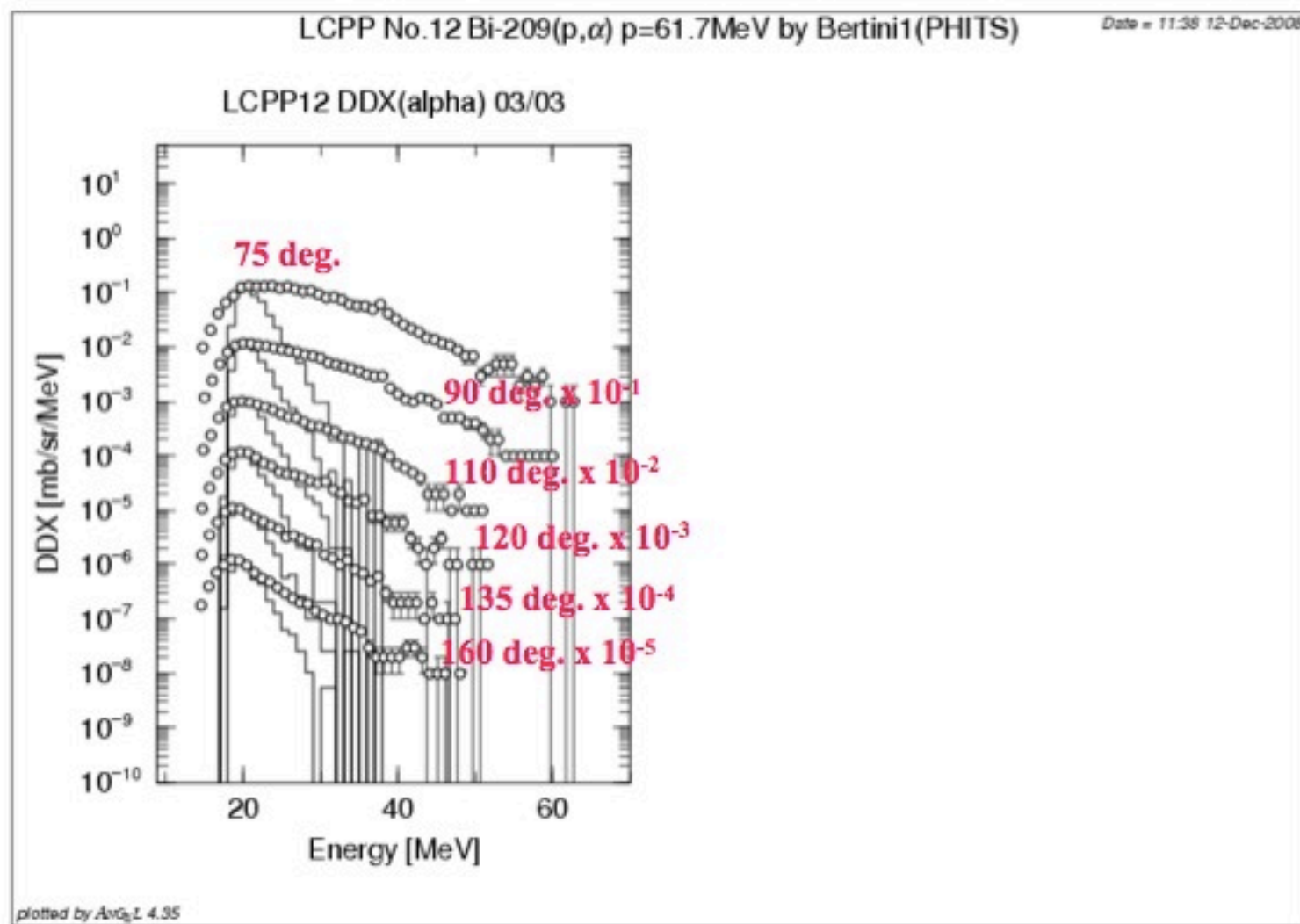
# Comparison (LCPP12) Bi(p,x) p (61.7MeV)



26



# Comparison (LCPP12) Bi(p,x) p (61.7MeV)



27

# Experimental Setup for LCPP04

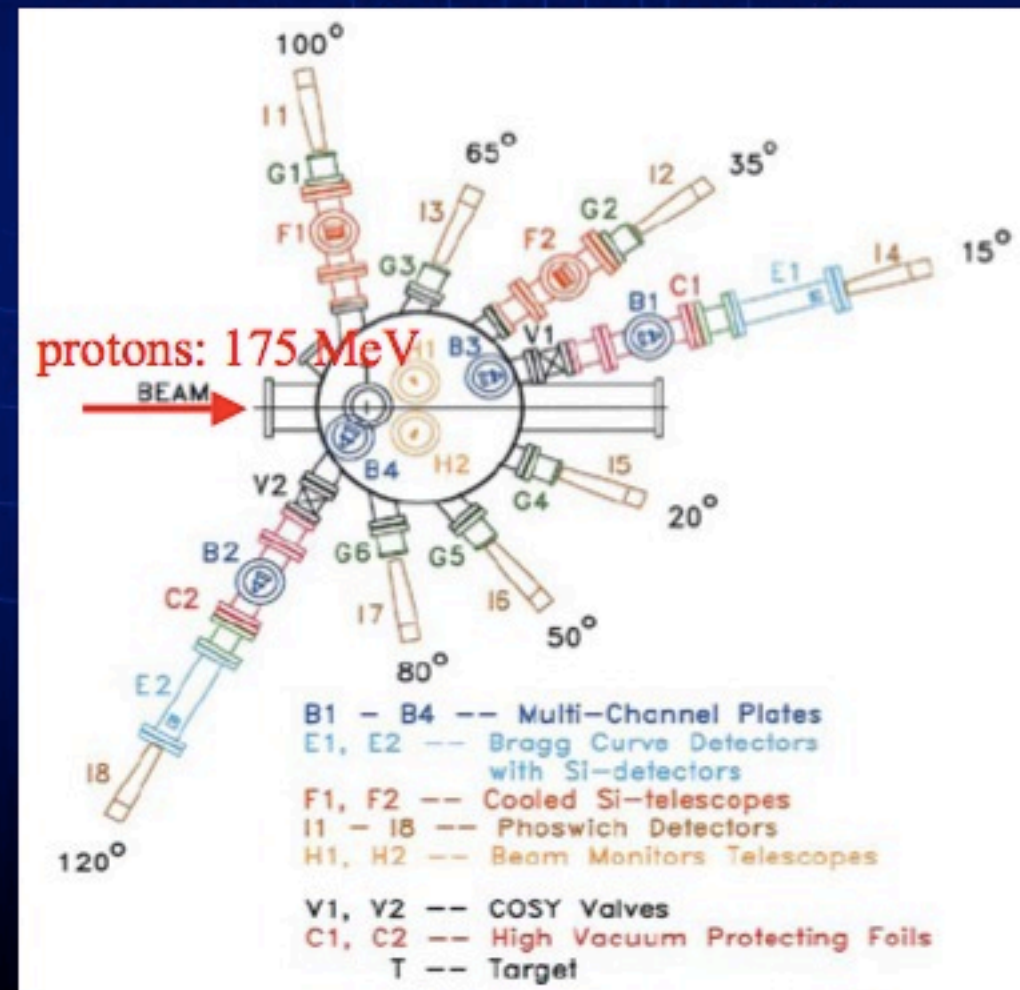
- Experimental Geometry (COSY, Germany)



No Photo

# Target and Detectors (LCPP04)

- Target Chamber (UNCLEAR)

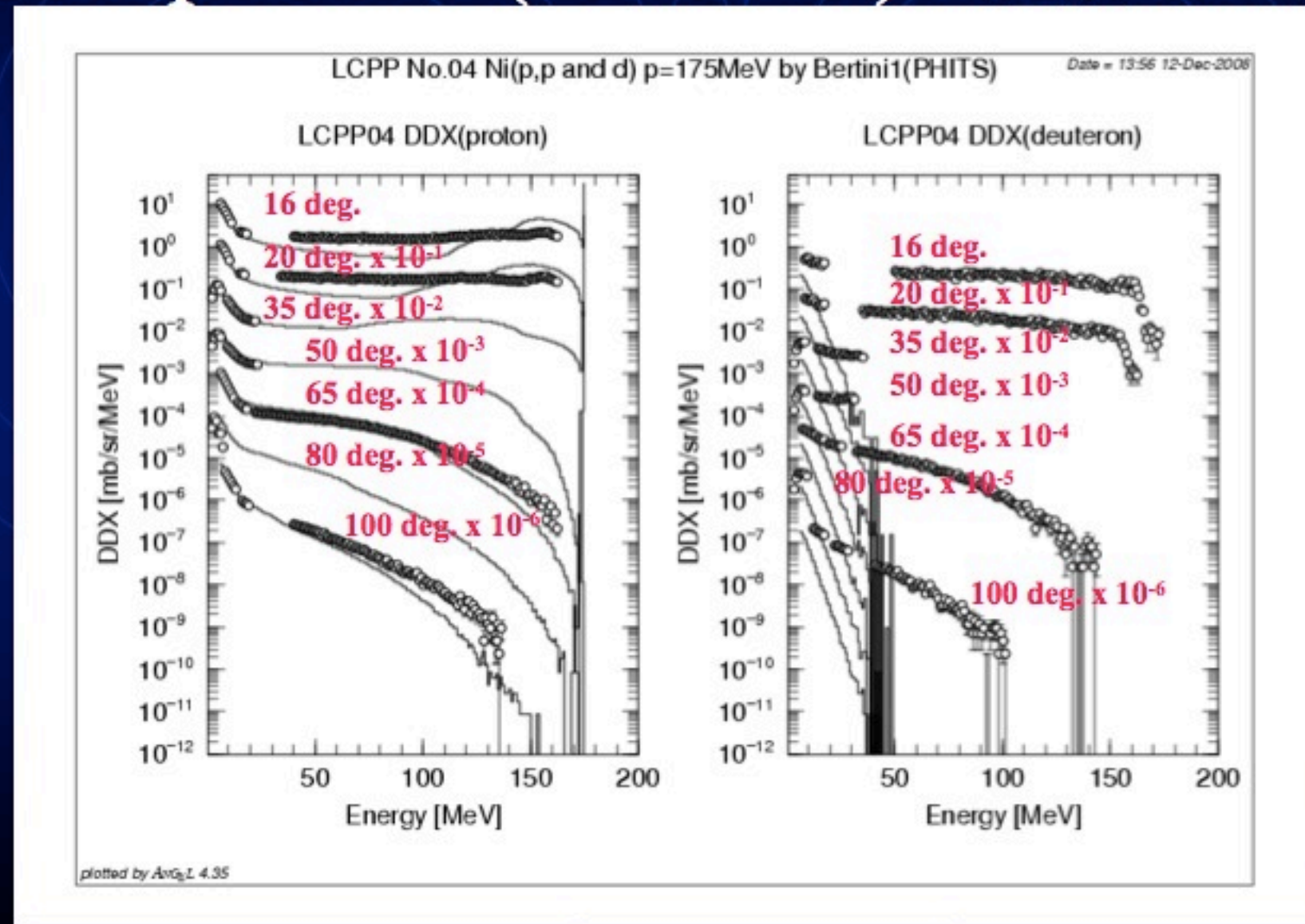




# Expt. and Calc. info. about LCPP04

	Expt.	Calc.
<b>Targets</b>		
Material	Nickel	Nickel
Size (thickness)	unclear	0.000124 cm
Size (width)	unclear	$\phi$ 0.000124 cm
Density	---	8.90 g/cm <sup>3</sup>
<b>Detectors</b>		
Size (width)	unclear	$\pm$ 1 degrees
Angle	16 to 100 degrees	16 to 100 degrees
Distance (T to D)	unclear	30 cm

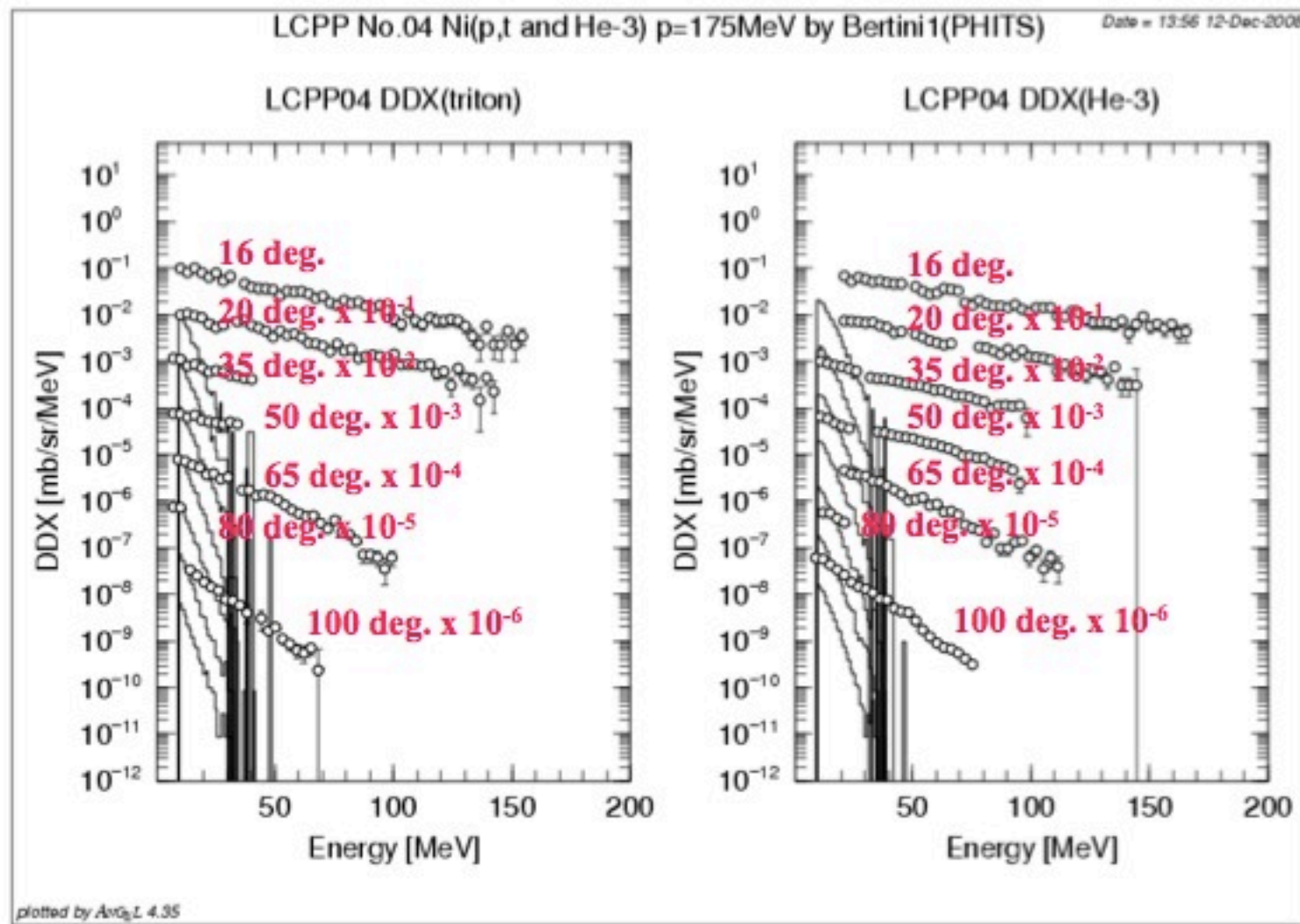
# Comparison (LCPP04) Ni(p,x) p (175MeV)



31



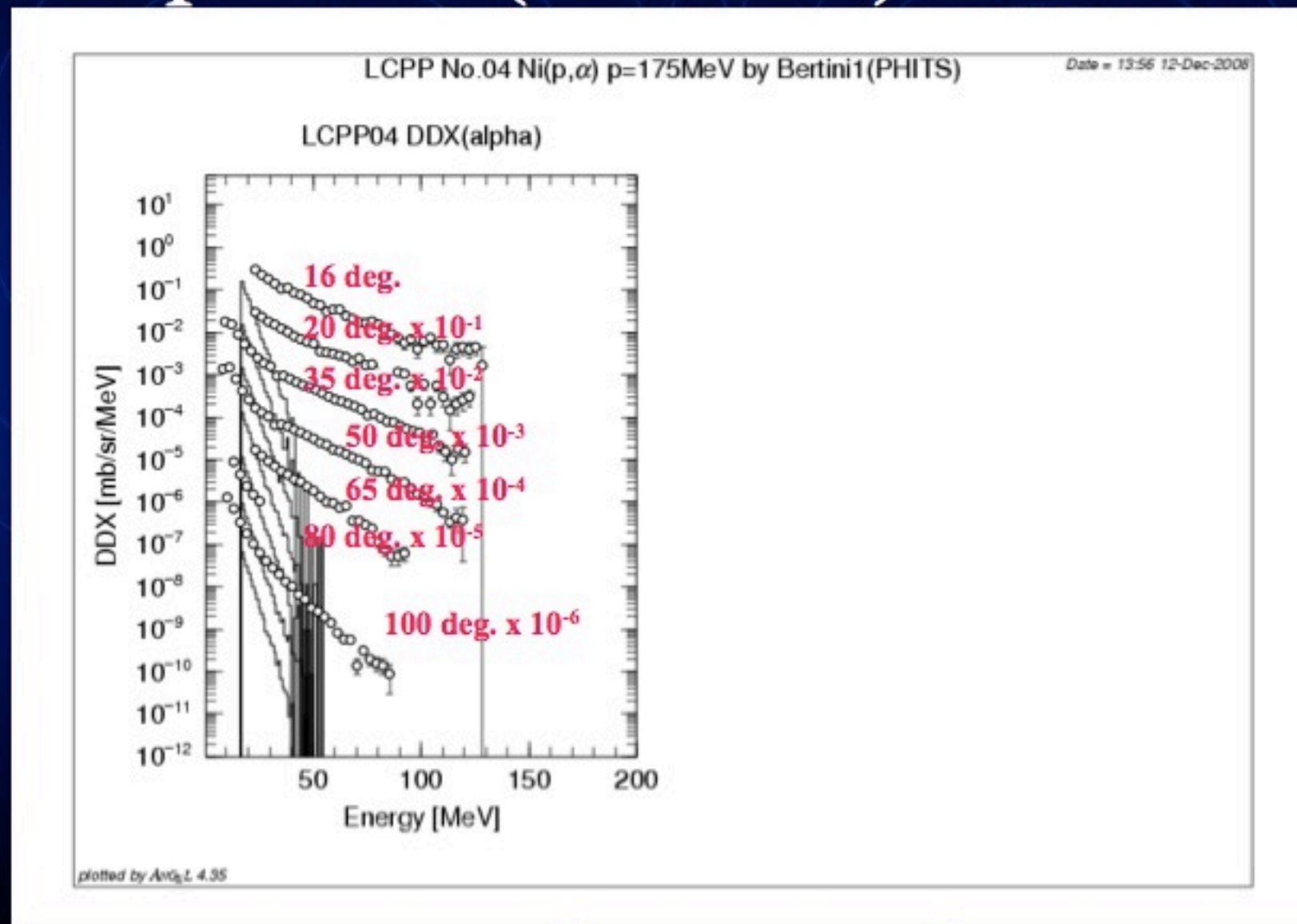
# Comparison (LCPP04) Ni(p,x) p (175MeV)



32



# Comparison (LCPP04) Ni(p,x) p (175MeV)

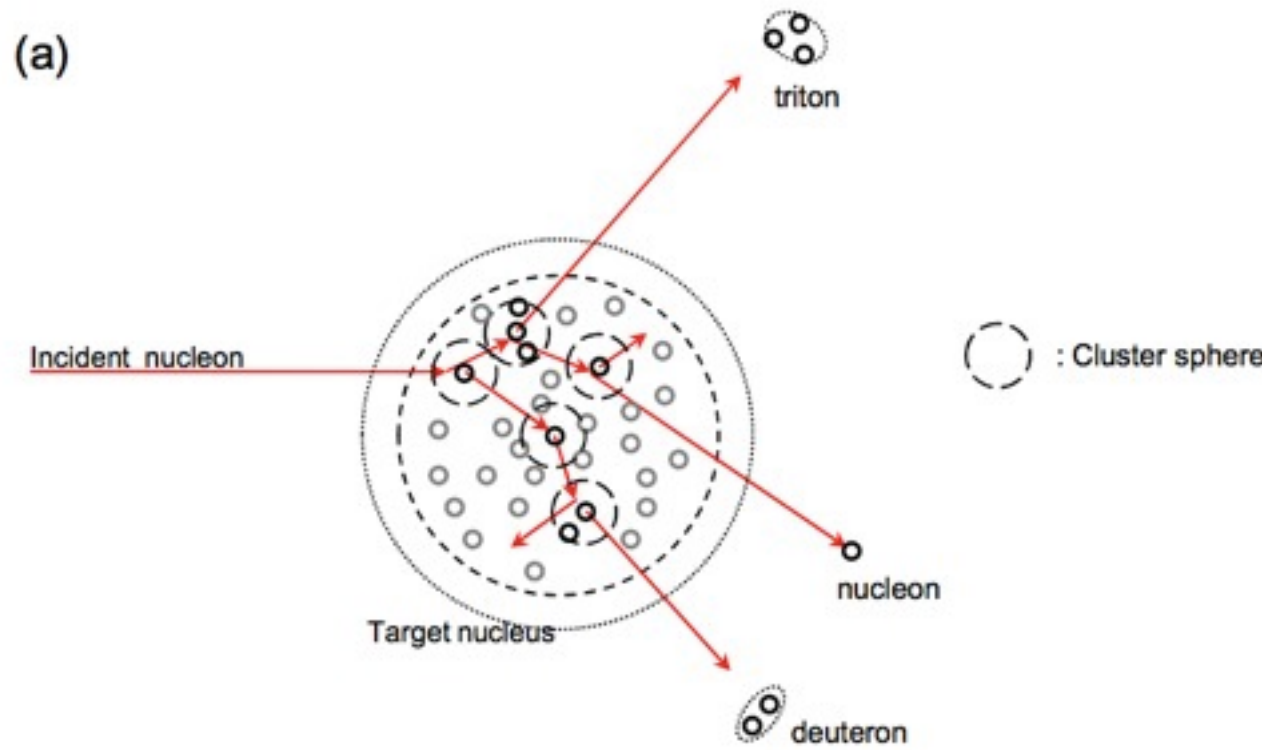


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# charged particles emission

- ❖ the data indicates that light particles of p, d, t, He, etc. are produced mostly from the direct interaction part (not de-excitation).
- ❖ on the other hand no **surface coalescence** model in **Bertini**, (**JQMD**), and **JAM**
- ❖ a cascade model including the surface coalescence model by Kyushu-Univ. will be included in PHITS.

# surface coalescence by D. Iwamoto



Ph.D thesis  
D. Iwamoto

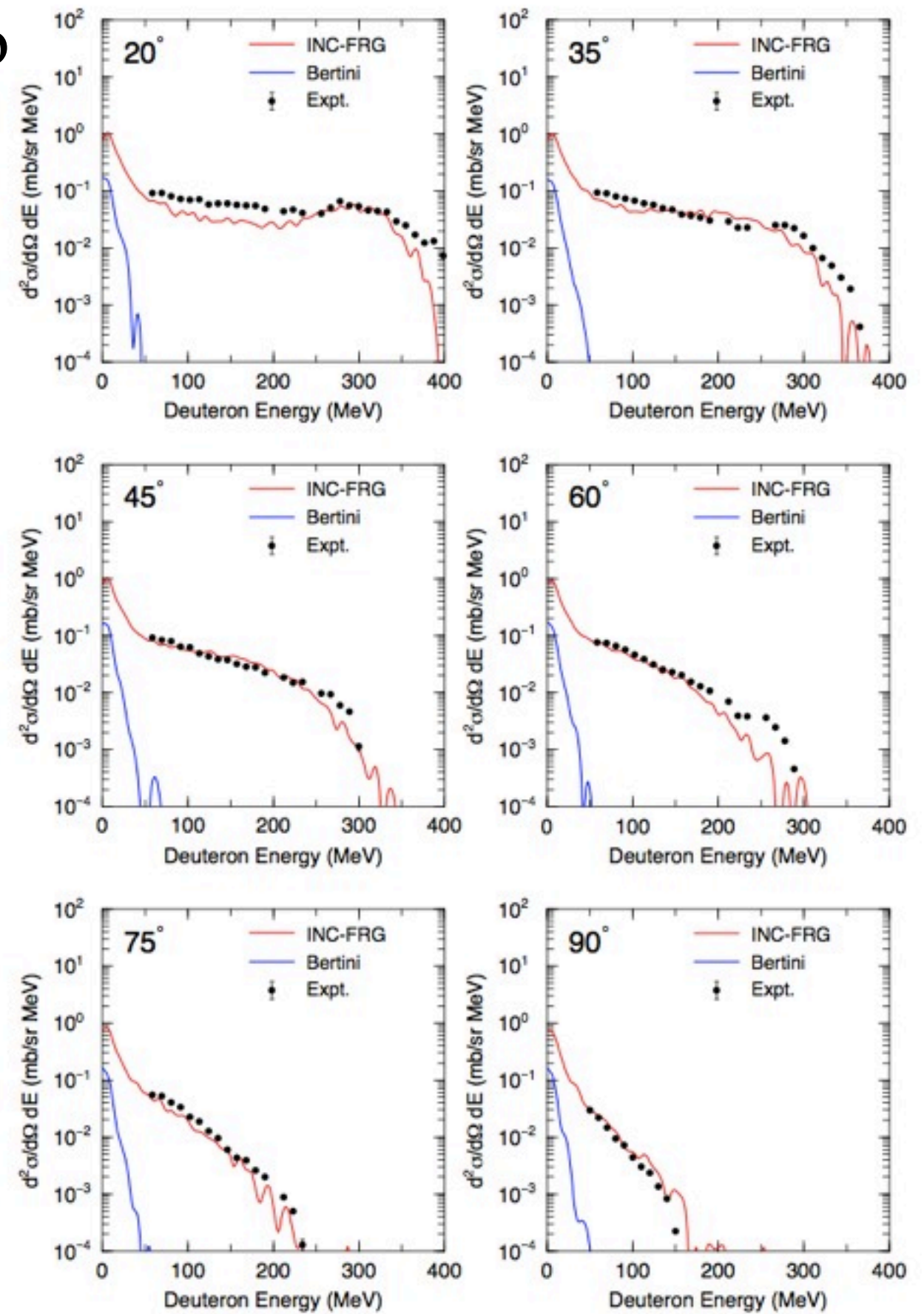


図 4.7 392 MeV 陽子による  $^{27}\text{Al}$  からの重陽子生成二重微分断面積の計算値と実験値の比較。

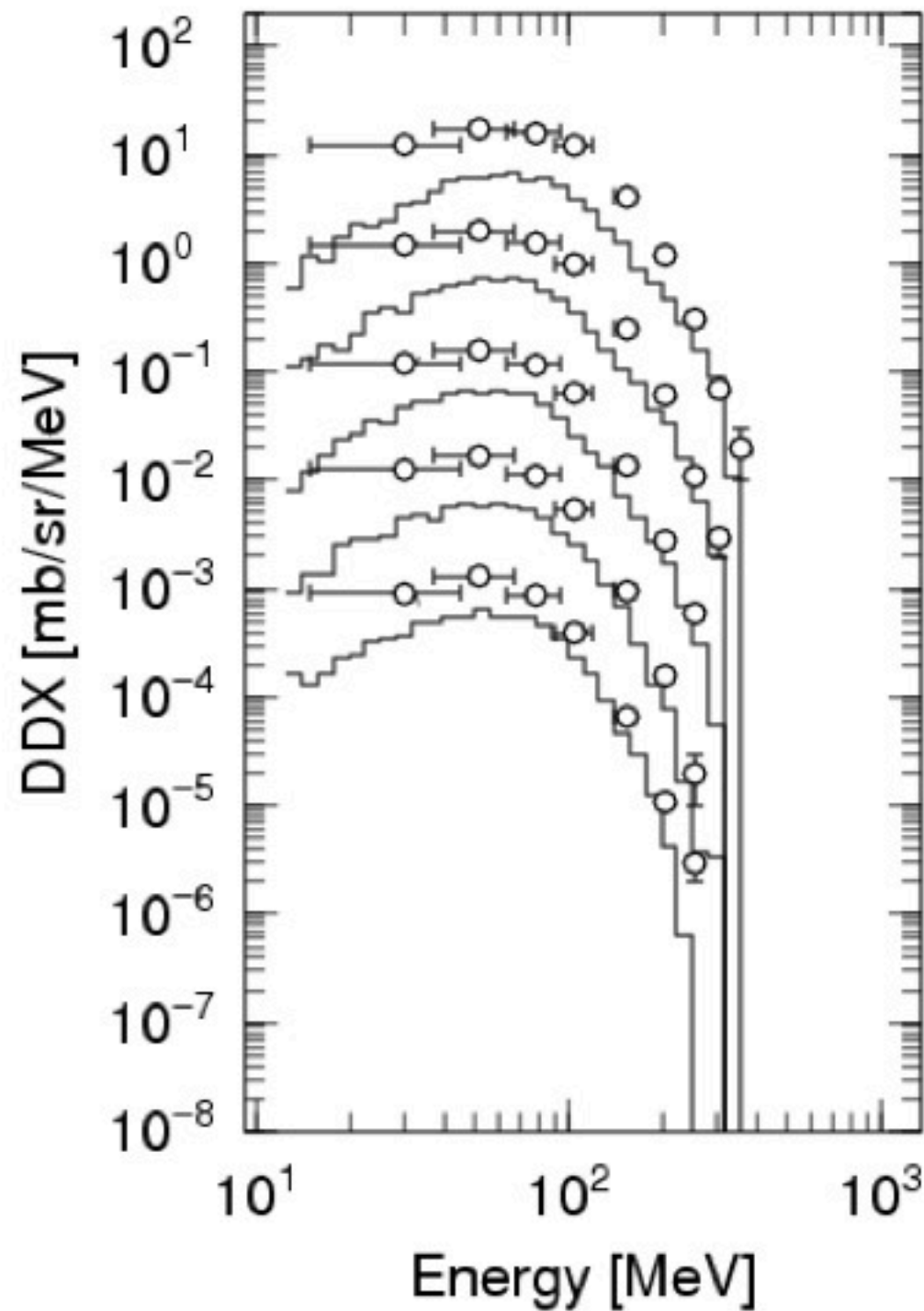
# pion

File = C:\phits\takae\Fermi05\PIP01MB1.txt

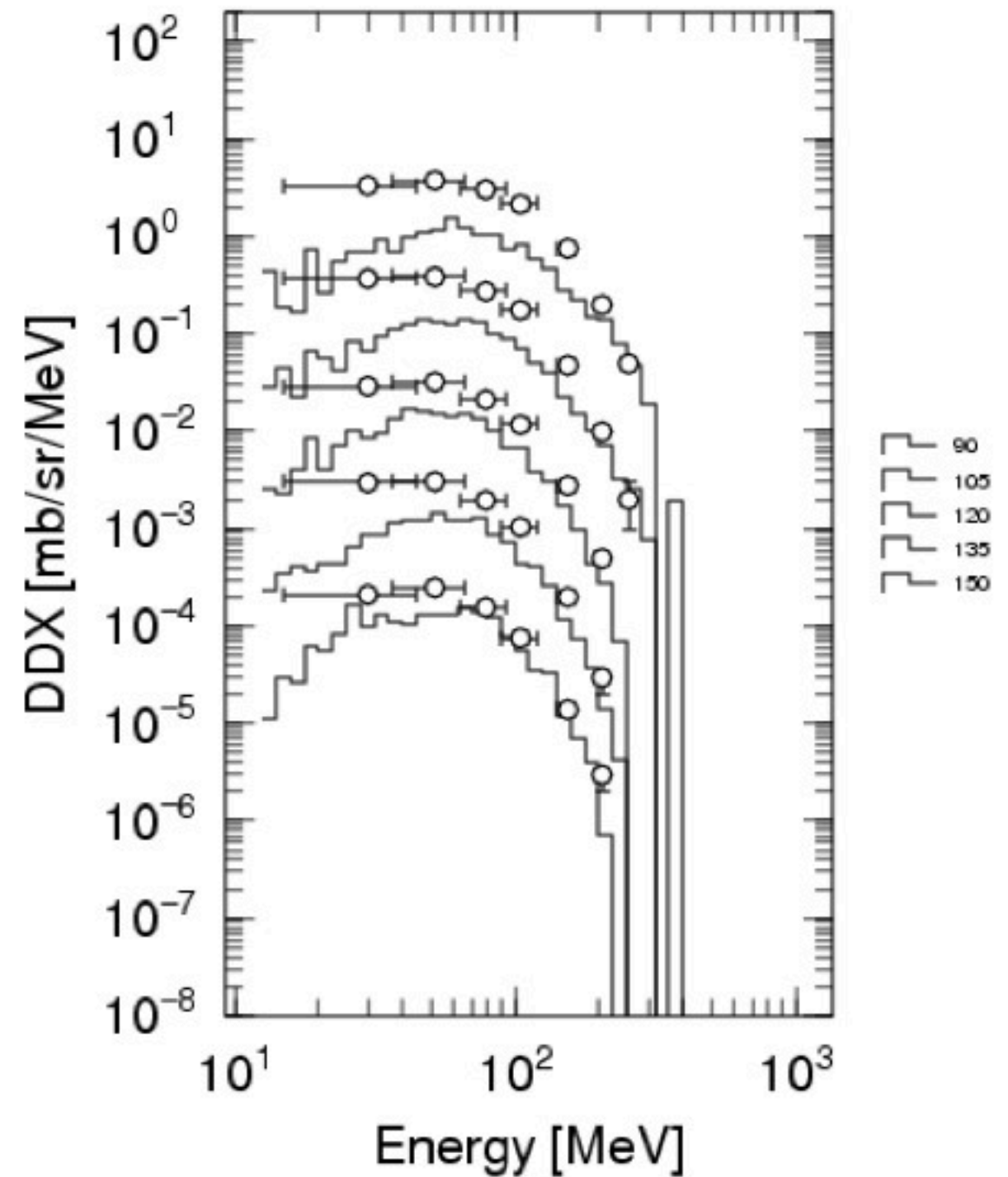
Date = 14:26 19-Nov-2008

PIP01 pion+ 90 to 150 degrees

PIP01 pion- 90 to 150 degrees



98  
105  
120  
135  
150



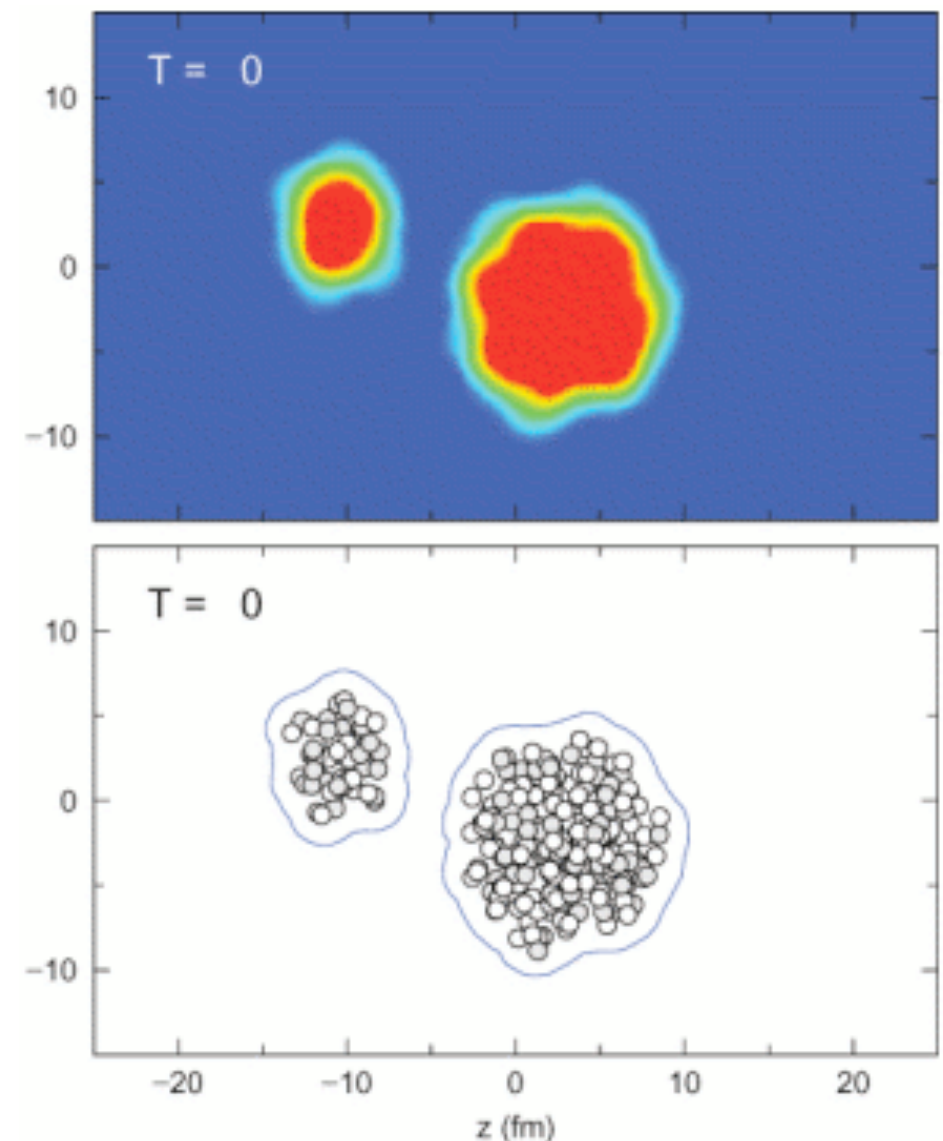
98  
105  
120  
135  
150



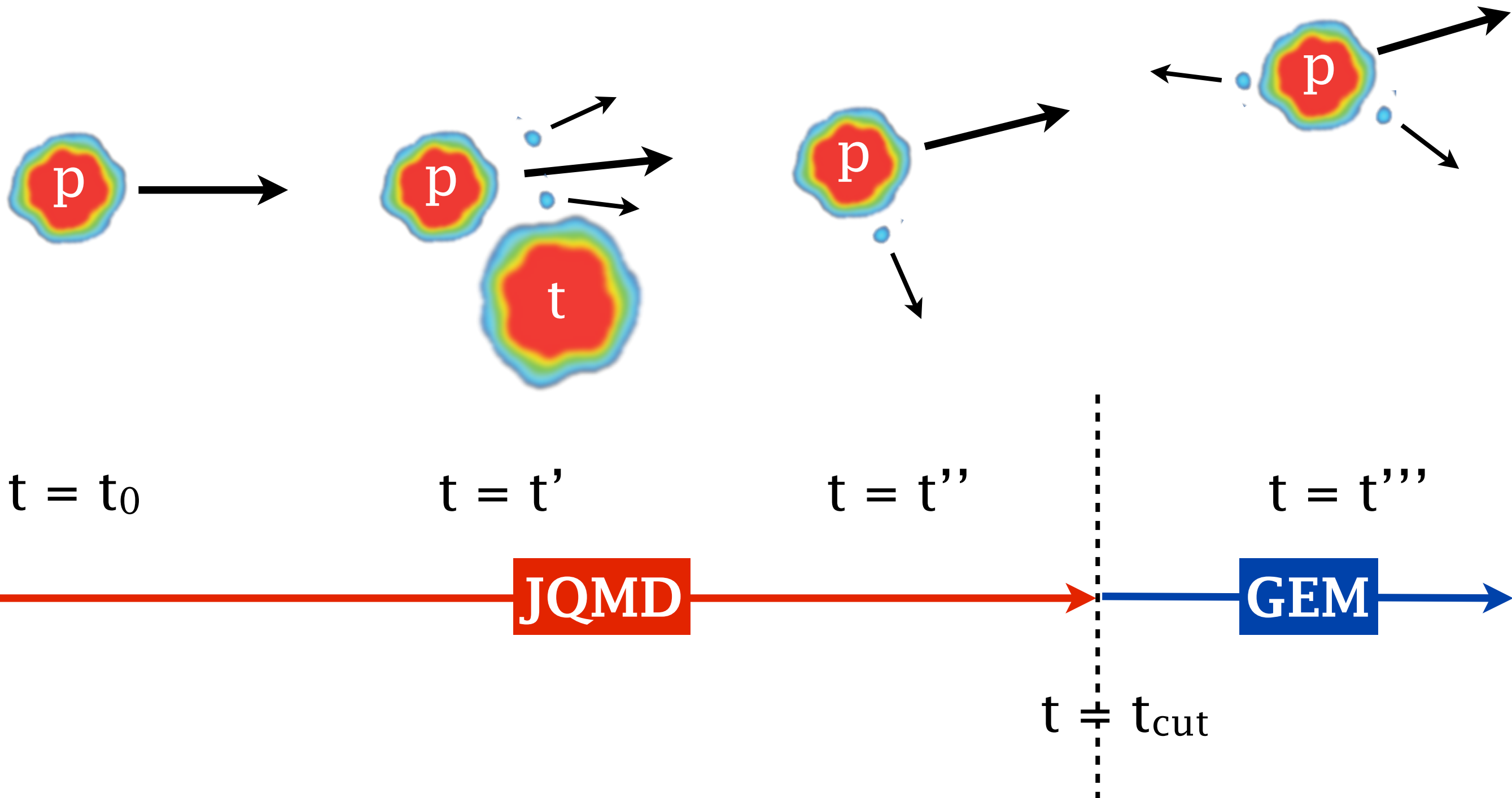
# QMD should help us more

- ❖ the dynamics of QMD potentially should represent pre-equilibrium and **coalescence**.
- ❖ coalescence-like fragments are produced from JQMD but it look less than present coalescence models.

- clusters in QMD?

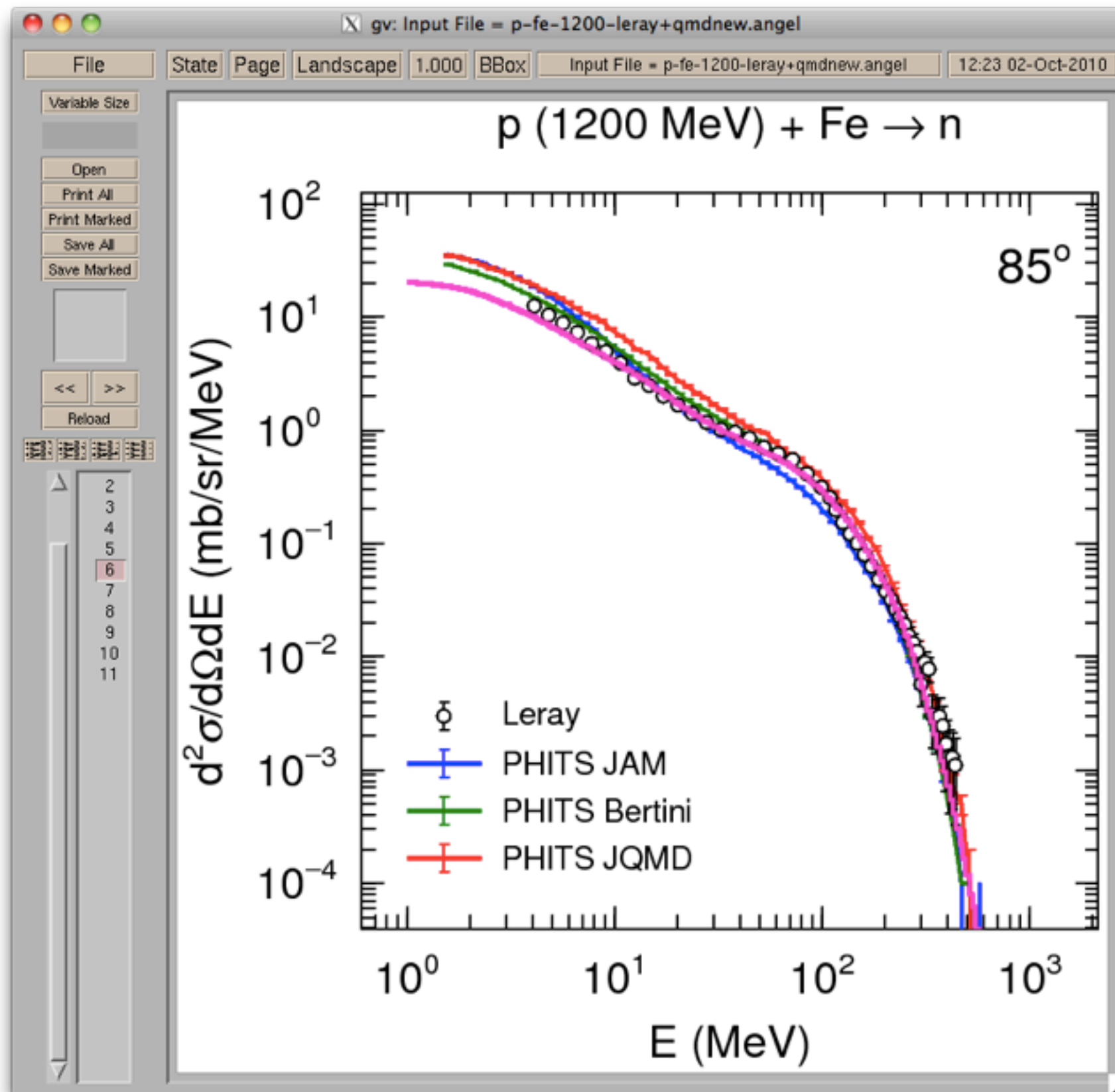


# present status of **JQMD** connected to **GEM** in PHITS





# JQMD with the new default $t_{\text{cut}}$



# Summary

- ❖ good: neutron emission
- ❖ reasonably good: isotropic distribution
- ❖ bad: high energy light charged particle emission, pion
- ❖ there is a big room for improvement on **JQMD**
  
- ❖ benchmarking individual channel is important but benchmarking something integral value, i.e., total dE of fragments in a volume, total activation in Pb irradiated by p, and so on, is also worth to look

# Thank you very much

