BECHMARKIG THE CODES AGAIST RESIDUAL NUCLIDE SPALLATION DATA OBTAINED RECENTLY

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Brief Summary ADS-related works

	THIN Targets	THICK Targets	Critical experiments (fuel cycle, …)
ISTC Projects	#839-0, #839 (1997-2001) #2002 (2002-2004) #3266 (2006-2009)	#1145 (W-Na,1999-2001) #2405 (Pb, 2005-2007)	#017 (1994-1996) #1145 (1999-2001)
Current Results	More than 14000 CRS's measured and published in IAEA and OECD web sites. Data are used for: 1)designs 2)physics models verification	More than 2500 reaction rates measured. Data are used for verification of: activation excitation functions; neutron yield; target activation	• ^{237}Np RI's; • Th-cycle major reactions; • MA fission rates in NaF+ZrF4 salt mixure • Subcriticality
Perspe-ctives	#3880: Mo, Ti, Zr, Sn, In	1)Th-target activation rates. 2)Actinide(n,f) CRS in ADS-spectrum	Th-cycle in ADS

Major facilities at ITEP:

- Proton synchrotron (E_p=40-2600MeV, <I_p>~10^{11}p/pulse)
- MAKET critical facility (heavy water zero-power reactor, ~100W power)

Publications in 2008-2009.

- **http://www-nds.iaea.org/reports-new/indc-reports/indc-ccp/:**
  - Titarenko Yu.E., Batyaev V.F., Borovlev S.P., et.al. Measurements Relevant to Simulating Subcriticality in ADS Facilities with «Thermal» Blanket. **INDC(CCP)-0450**, IAEA, October 2009
  - Titarenko Yu.E.,Batyaev V.F., Zhivun V.M., et.al. Measuring the Neutron Field Characteristics of the Outside Surface of the 0.8 GeV Proton-irradiated «Thick» W-Na Target. **INDC(CCP)-0449**, IAEA
  - Titarenko Yu.E., Batyaev V.F., Zhivun V.M., et.al. Measurements of the neutron field characteristics inside and on the surface of the Pb target micromodel exposed to 0.8 GeV protons. **INDC(CCP)-0448**, IAEA, October 2009
  - Titarenko Yu.E., Batyaev V.F., Zhivun V.M., et.al. Experimental and Theoretical Studies of the Yields of Residual Product Nuclei Produced in Thin Pb and Bi Targets Irradiated by 40 – 2600 MeV Protons. **INDC(CCP)-0447**, IAEA, October 2009
  - Titarenko Yu.E., Konev V.N., Batyaev V.F., et.al. Study of the multiplication and kinetic effects of salt mixtures and salt blanket micromodels on thermal neutron spectra of heavy water MAKET facility. **INDC(CCP)-0446**, IAEA, October 2009
  - Titarenko Yu.E., Batyaev V.F., Zhivun V.M., et.al. Experimental and Theoretical Study of the Yields of Residual Product Nuclei Produced in Thin Targets Irradiated by 100-2600 MeV, **INDC(CCP)-434**, IAEA, February 2001.
- **АЭ (Atomnaya Energiya), ВАНТ (VANT):**
  - V.F. Batyaev , M.A. Butko, K.V. Pavlov et al, Analysis of Main Nuclear Physics Parameters of Proton Beam Interactions with Heavy Metal Targets, **AE, 2008**, vol. **104**, issue 4, pp. 242-249.
  - Yu.E. Titarenko, V.F. Batyaev , A.Yu. Titarenko et al., Experimental and Theoretical Study of Threshold Reaction Rates in the 0.8 GeV Proton Irradiated Extended Lead target, **AE**, vol. **107,** issue **1**, pp. 37-46, **2009**.
  - Yu.E. Titarenko, V.F. Batyaev , A.Yu. Titarenko, V.M. Zhivun, Detailed Data on the threshold reaction rates outside and inside the 0.8 GeV proton-irradiated thick Pb target, – **VANT,** Nuclear Constants and Parameters, **2009**, issue 1-2.
- **Nuclear Technology, Phys. Rev.:**
  - Titarenko Yu., Batyaev V., Butko M, et al. Residual radioactive nuclide formation in 0.8-GeV proton-irradiated extended Pb-target. **Nuclear Technology**, v.**168**, p.p.631-636, Dec., 2009.
  - Titarenko Yu., Batyaev V., Titarenko A.Yu, et al. Beam dump and local shielding layout around the ITEP radiation test facility, **Nuclear Technology**, v.**168**, p.p.472-476, Nov., 2009
  - Titarenko, Yu.E., Batyaev V., Titarenko A.Yu, et al. , **Phys.Rev. C 78**, 034615 (2008). Cross sections for nuclide production in a 56Fe target irradiated by 300, 500, 750, 1000, 1500, and 2600 MeV protons compared with data on a hydrogen target irradiated by 300, 500, 750, 1000, and 1500 MeV/nucleon 56Fe ions

ISTC Project #3266 (2006-2009, funded by EC)

Experimental and theoretical study of the residual nuclide production in 40-2600 MeV proton-irradiated thin targets of ADS structure materials

Targets	Proton energies (MeV)										
	40	70	100	150	250	400	600	800	1200	1600	2600
^{56}Fe +	18	21	24	25	33	37	38	38	39	38	38
^{nat}Cr	14	17	19	22	28	31	33	33	33	33	33
^{nat}Ni	20	22	27	28	37	36	40	43	43	46	46
^{93}Nb	19	28	37	46	58	64	75	85	96	106	107
^{181}Ta	9	17	31	40	53	82	101	105	143	151	166
^{nat}W	19	31	45	53	69	83	104	110	155	163	181

+ ^{56}Fe is also measured at 300, 500, 750, 1000, and 1500 MeV (36, 33, 38, 38, 38 products, respectively) to be compared with recent GSI measurements (P. Napolitani et al., PRC (2007)

Isotopic composition of the targets

Isotope	Number of samples	Isotopic composition, %
^{56}Fe	15	^{54}Fe-0.3, ^{56}Fe-99.5±0.1, ^{57}Fe-0.2, ^{58}Fe-<0.05.
^{nat}Cr	11	^{50}Cr-4.345 , ^{52}Cr-83.789 , ^{53}Cr-9.501, ^{54}Cr-2.365 .
^{nat}Ni	11	^{58}Ni-68.077, ^{60}Ni-26.223, ^{61}Ni-1.140, ^{62}Ni-3.634, ^{64}Ni-0.926
^{93}Nb	10	^{93}Nb > 99.9
^{181}Ta	15	^{180}Ta-0.012, ^{181}Ta-99,988.
^{nat}W	14	^{180}W-0.12, ^{182}W-26.50, ^{183}W-14.31, ^{184}W-30.64, ^{186}W – 28.43.

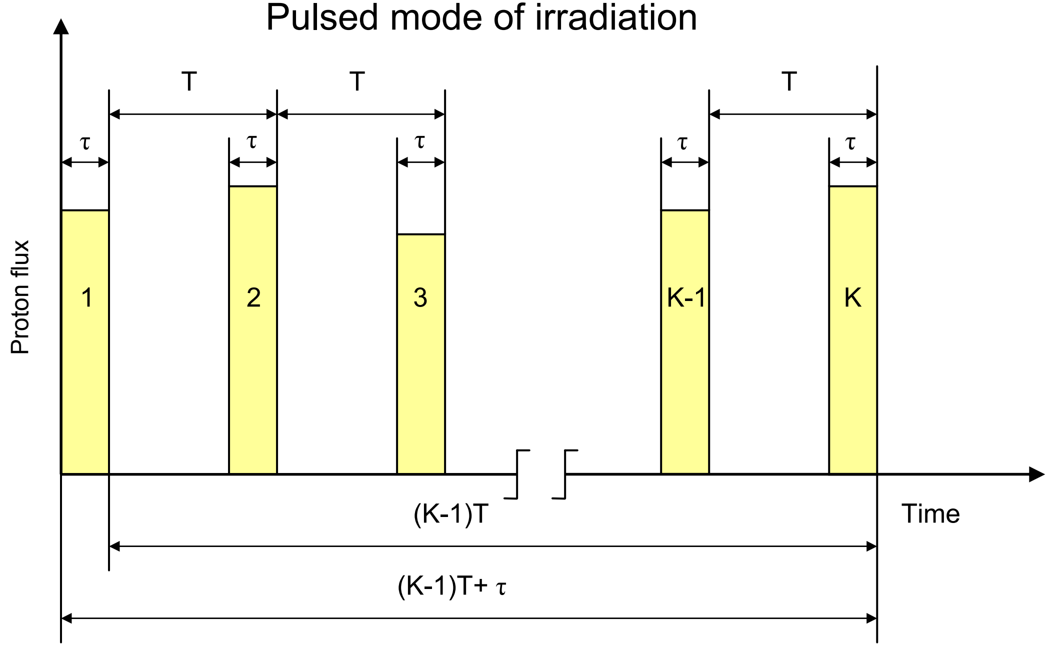
List of irradiation runs for alpha-active nuclide (^{148}Gd) production measurements.

Targets	Proton energies (MeV)				
	600	800	1200	1600	2600
^{181}Ta	x	x	x	x	x
^{nat}W	x	x	x	x	x

3848 products, including ^{56}Fe at GSI energies + 12 ^{148}Gd.

REACTION RATES and CROSS SECTION DETERMINATION

Pulsed mode of irradiation



Instability proton flux correction

$$\zeta_i = \frac{1-e^{-\lambda_i \cdot t_{irr}}}{\lambda_i \cdot T \cdot \sum_{j=1}^{k} \xi_i \cdot e^{-\lambda_i \cdot (k-j) \cdot T}} = \frac{1-e^{-\lambda_i \cdot t_{irr}}}{\lambda_i \cdot t_{irr} \cdot \sum_{j=1}^{k} \Phi_j \cdot e^{-\lambda_i \cdot t_j}} \cdot \sum_{j=1}^{k} \Phi_j$$

Cross sections

$$\sigma_i^{cum/ind} = \frac{R_i^{cum/ind}}{\hat{\Phi}_{st}} \qquad \frac{\Delta\sigma_i^{cum/ind}}{\sigma_i^{cum/ind}} = \sqrt{\left(\frac{\Delta R_i^{cum/ind}}{R_i^{cum/ind}}\right)^2 + \left(\frac{\Delta\hat{\Phi}_{st}}{\hat{\Phi}_{st}}\right)^2}$$

Reaction rates:

$$R_1^{cum/ind} = \frac{\hat{A}_1}{N_{Tag} \cdot \eta_1 \cdot \varepsilon_1} \cdot \frac{1}{F_1} \qquad R_1^{cum/ind} = \frac{\hat{A}_2^1}{N_{Tag} \cdot \eta_2 \cdot \varepsilon_2 \cdot \nu_{12}} \cdot \frac{\lambda_2 - \lambda_1}{\lambda_2} \cdot \frac{1}{F_1}$$

$$R_2^{ind} = \left(\frac{\hat{A}_2^2}{F_2} + \frac{\hat{A}_2^1}{F_1} \cdot \frac{\lambda_1}{\lambda_2}\right) \cdot \frac{1}{N_{Tag} \cdot \eta_2 \cdot \varepsilon_2}$$

$$R_2^{cum} = R_2^{ind} + \nu_{12} \cdot R_1^{cum/ind} = \left(\frac{\hat{A}_2^1}{F_1} + \frac{\hat{A}_2^2}{F_2}\right) \cdot \frac{1}{N_{Tag} \cdot \eta_2 \cdot \varepsilon_2}$$

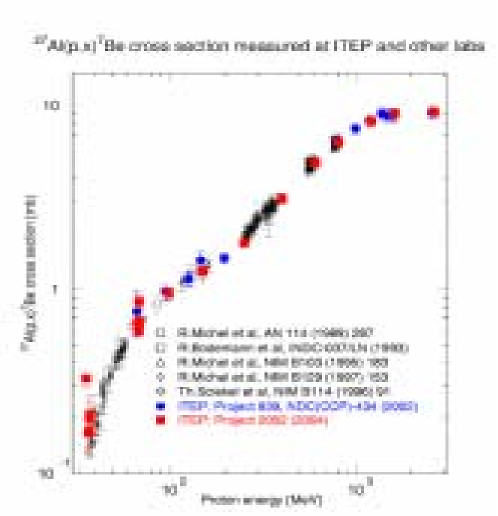
$$R_2^{cum*} = R_2^{ind} + \frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot \nu_1 \cdot R_1^{cum} = \frac{\hat{A}_2^2}{N_{Tag} \cdot \eta_2 \cdot \varepsilon_2 \cdot F_2}$$

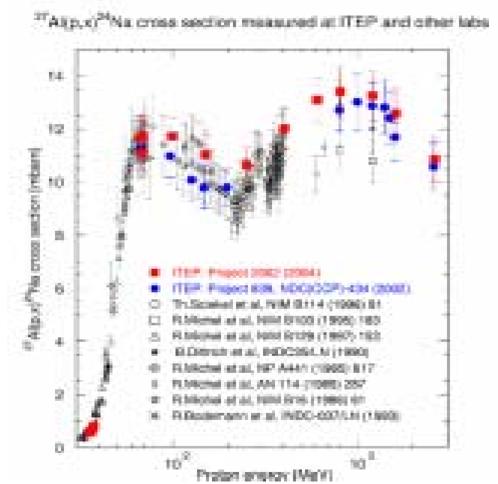
$$F_1 = \lambda_1 \cdot T \cdot \sum_{j=1}^{k} \xi_j \cdot e^{-\lambda_1 \cdot (k-j) \cdot T} \qquad F_2 = \lambda_2 \cdot T \cdot \sum_{j=1}^{k} \xi_j \cdot e^{-\lambda_2 \cdot (k-j) \cdot T}$$

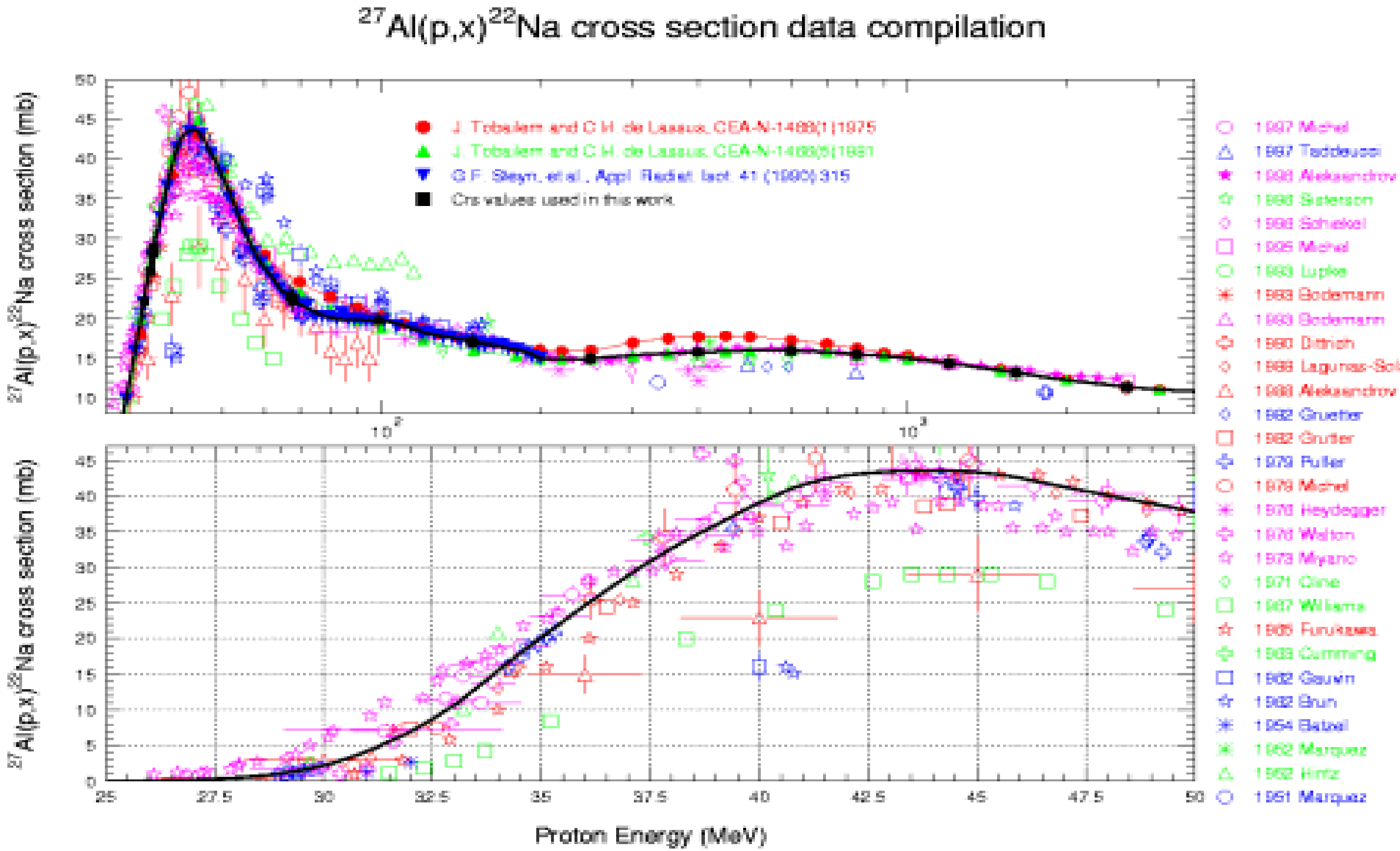
Reaction rates uncertainties

$$\Delta\overline{R}_i^{cum/ind} = \overline{R}_i^{cum/ind} \cdot \sqrt{\left(\frac{\Delta\, {}^{rel}\overline{R}_i^{cum/ind}}{{}^{rel}\overline{R}_i^{cum/ind}}\right)^2 + \left(\frac{\Delta k_{\gamma_i}}{k_{\gamma_i}}\right)^2 + \left(\frac{\Delta k_{\varepsilon}}{k_{\varepsilon}}\right)^2 + \left(\frac{\Delta N_{tag}}{N_{tag}}\right)^2}$$

Monitor reactions cross sections

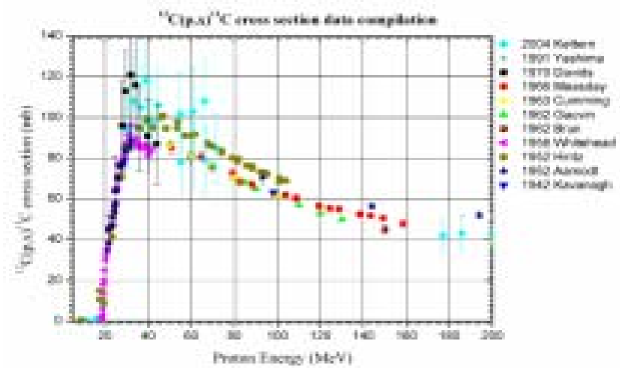






$$\Phi = \frac{R_{mon}}{\sigma_{mon}}$$

$$\Delta\Phi/\Phi = \sqrt{\left(\Delta R/R\right)^2 + \left(\Delta\sigma/\sigma\right)^2}$$



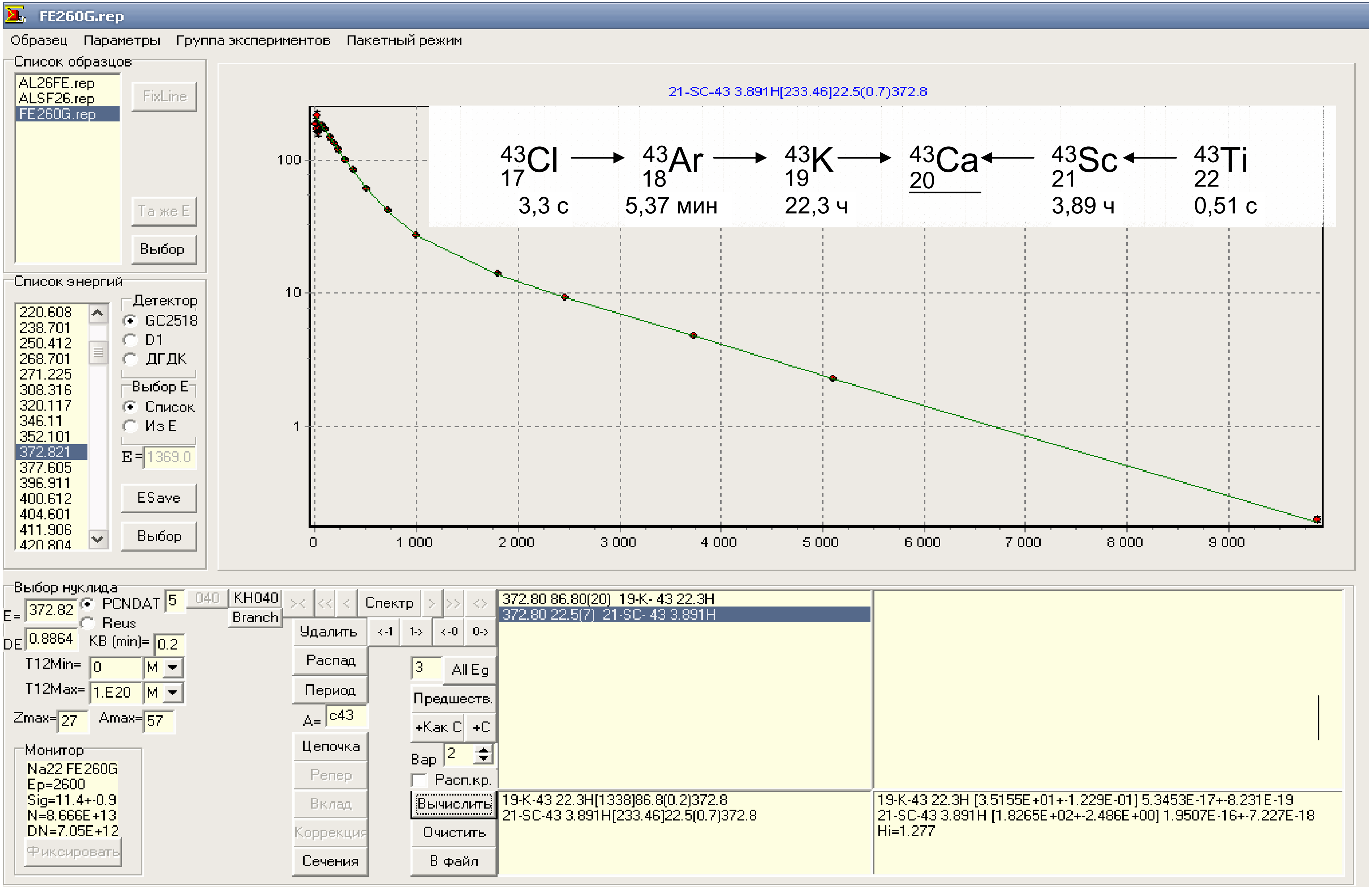
Irradiation of thin targets

U10 Synchrotron at ITEP:

- Proton energy: 40-10000 MeV;
- Beam section: a circle of ~10 mm diameter;
- Intensity: ~$1 \cdot 10^{11}$ protons per pulse;
- Extraction runs: 4 100-ns bunches of 1 μs total duration.

The transport channel schematic together with the elements of proton beam fast extraction. 1 - The table to place the irradiated samples. 2 – Current transformer. 3 – Outlet flange of the vacuum proton guide. 4 – Bending magnet. 5,6 – The doublet of quadrupole lenses to provide beam focusing. 7 – Septum magnet. 8,9 – Magnetic units of the accelerating ring. 10 – Kicker magnet with a 15 mrad bending angle

Reaction rate determination via ZHSIGMA code.

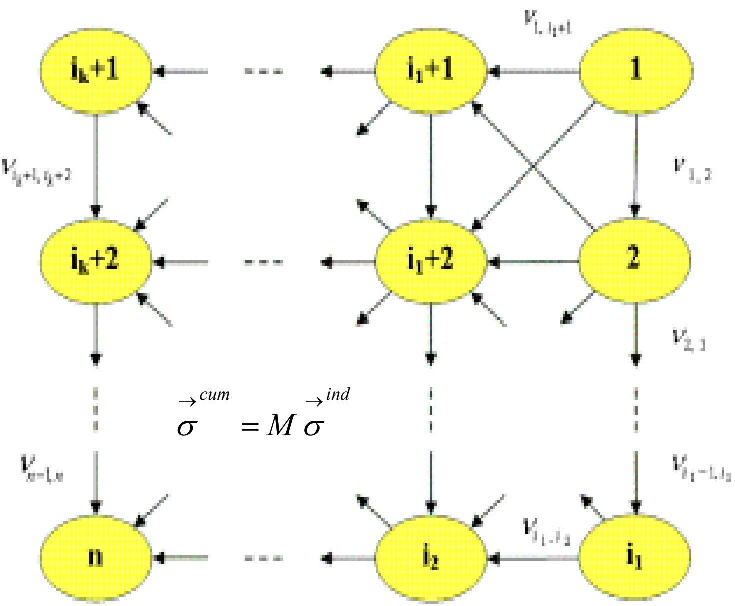


Comparison with GSI data

^{56}Fe

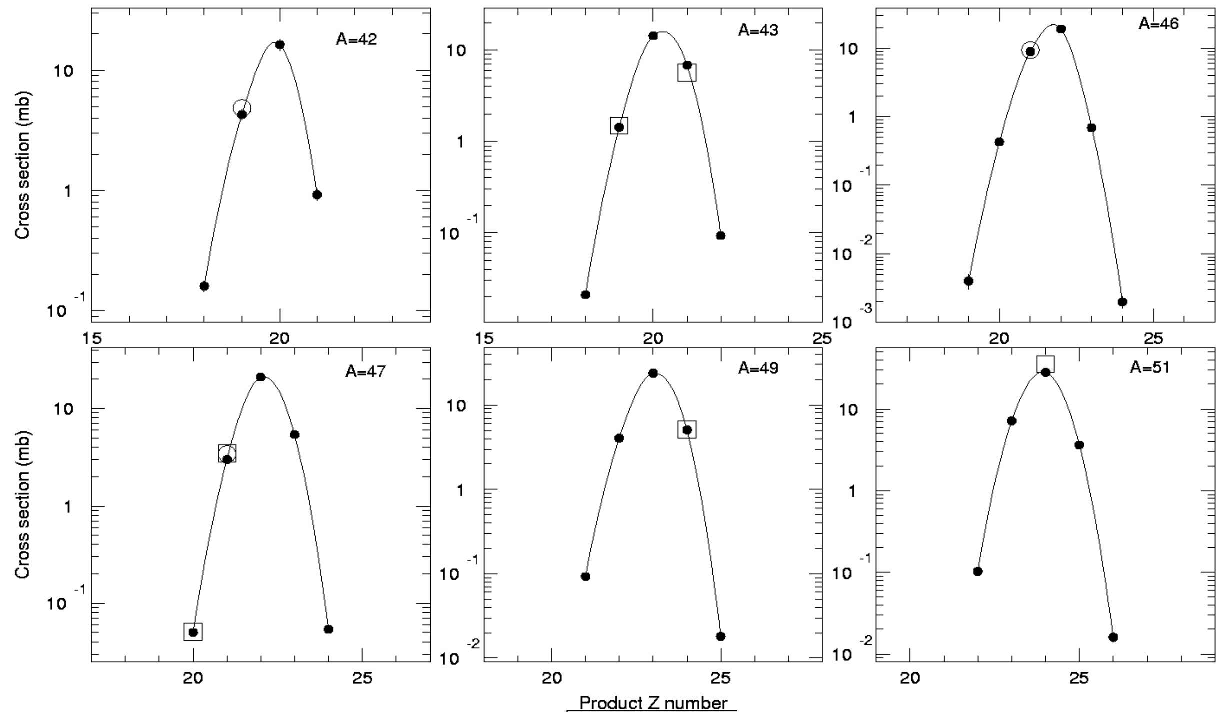
	Type	Number of CRS's at energies (MeV)				
		300	500	750	1000	1500
GSI	i	**128**	**136**	**148**	**152**	**157**

	Type	Number of CRS's at energies (MeV)				
		300	500	750	1000	1500
ITEP	i	**9**	**9**	**9**	**9**	**9**
	i(m)	**3**	**3**	**3**	**3**	**3**
	i(m+g)	**3**	**2**	**3**	**3**	**3**
	c	**19**	**21**	**23**	**23**	**23**
	Total	**34**	**35**	**38**	**38**	**38**



$$\vec{\sigma}^{cum} = M\vec{\sigma}^{ind}$$

□ - ITEP (cum), ○ - ITEP(ind), ● - GSI(ind)



$$m_{kj} = \begin{cases} \sum_{i=j}^{k-1} \nu_{ik} \cdot m_{ik} \; for \; k > j; \\ 1 \; for \; k = j; 0 \; for \; k < j. \end{cases}$$

$$F = 10^{\sqrt{\left\langle \left(\log\left(\frac{\sigma_{cal_i}}{\sigma_{\exp_i}} \right) \right)^2 \right\rangle}}$$

	<F> at proton energy (MeV)					
	300	500	750	1000	1500	All energies, all products
ITEP – GSI (A<30)	3.14	1.67	1.33	1.25	1.14	**1.34**
ITEP – GSI (A>30)	1.34	1.28	1.28	1.28	1.25	
ITEP – GSI (all A)	1.53	1.37	1.28	1.28	123	

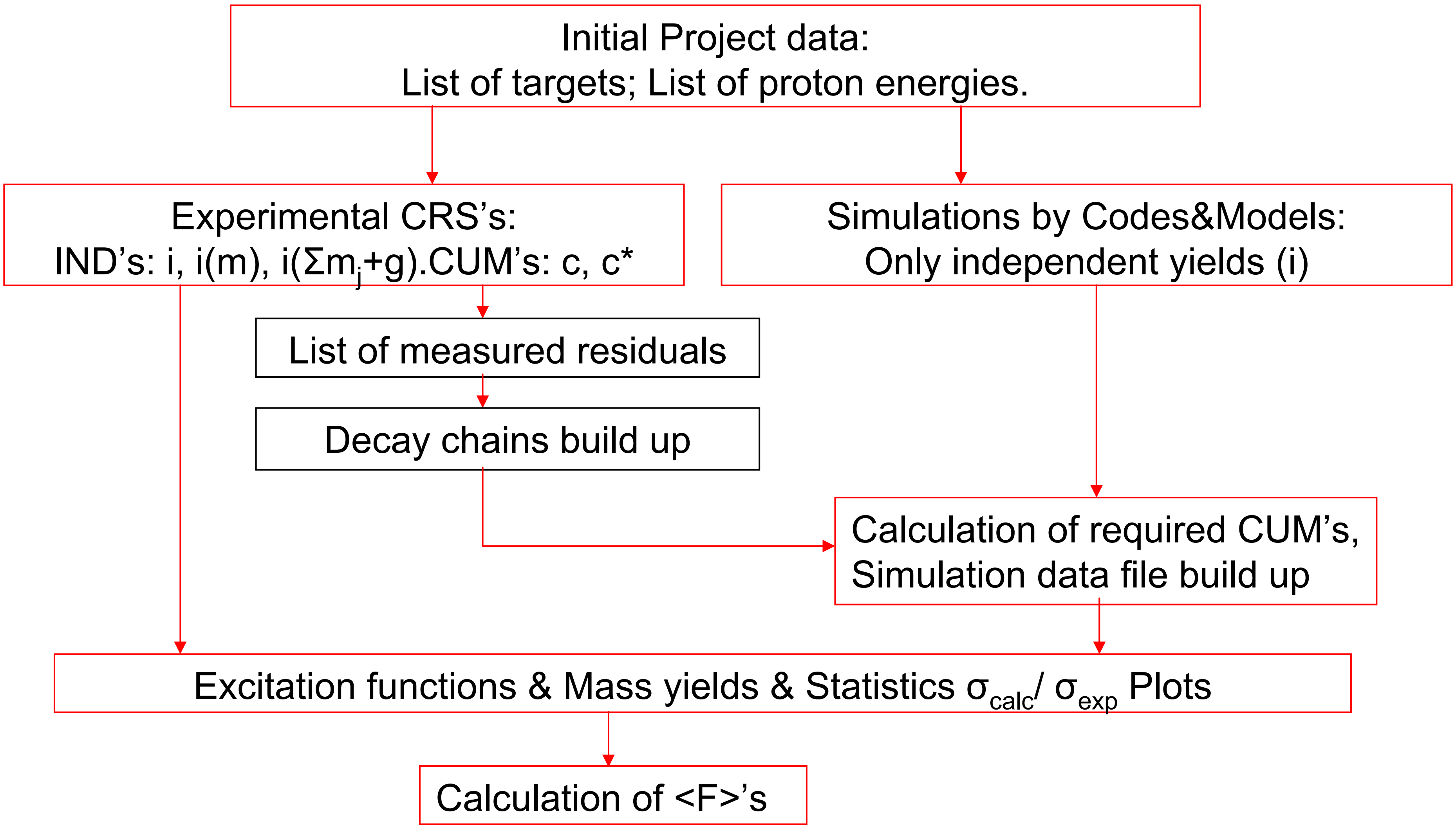
In case of ^{208}Pb (1.0GeV) and ^{197}Au (0.8GeV): <F>(ITEP-GSI, all A)= 1.30 (^{208}Pb); 1.40 (^{197}Au)

The codes used for simulation

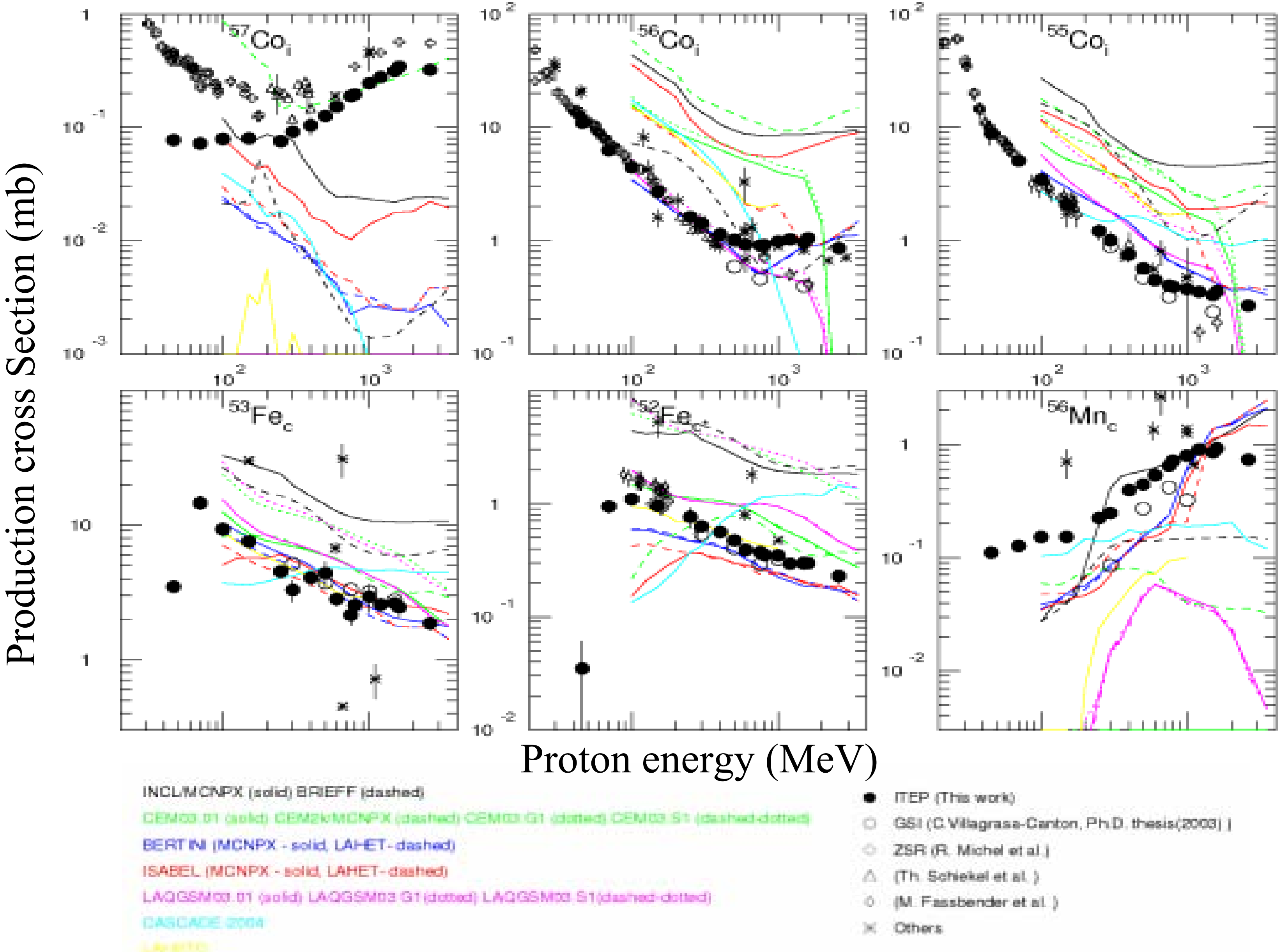
Code	Author	Models
CEM03	**S.G. Mashnik, LANL**	**Improved Dubna INC* (exciton), Preequilibrium Modified Exciton Model, Evaporation (Weisskopf-Ewing), Competition between Fission (Bohr-Wheeler) and Evaporation**
LAHET	**R.E. Prael, LANL**	**Bertini/ISABEL INC, Multustep Preequilibrium Exciton Model, Evaporation (Weisskopf-Ewing, Dresner's code) or Fermi Breakup Model for light nuclei, Fission (RAL/ORNL models)**
MCNPX	**LANL**	**Improved LAHET + CEM2k+INCL INC**
LAQGSM+GEM2	**S.G. Mashnik et al., LANL**	**Los Alamos modification of Guark-Gluon String Model initially realized at Dubna, improved Dubna INC, improved pre-equlibrium model, refined Fermi break-up and coalescence models, improved Generalized Evaporation-fission Model (GEM2)**
INCL4+ABLA	**J. Cugnon et al., Liege, Sacley ; Schmidt et al, GSI**	**Liege INC, GSI evaporation/fission model**
CASCADE-2004	**V.S. Barashenkov, Dubna**	**Dubna INC, Evaporation (Bohr-Wheeler), Fission (Dubna version of Fong model)**
LAHETO, CASCADO	**A. Ignatyuk, Obninsk**	**Obninsk modification of LAHET and CASCADE: fission barriers updated, liquid drop model parameters adjusted, pre-equilibrium parameters modified.**
BRIEFF	**H. Duarte, CEA Bruyeres-le-Chatel**	**BRIC INC, Evaporation (Weisskopf-Ewing), Fermi break-up, Atchison (RAL) fission model**

Simulations were made at 25 proton energies from 0.03 to 3.5 GeV to get smooth excitation functions

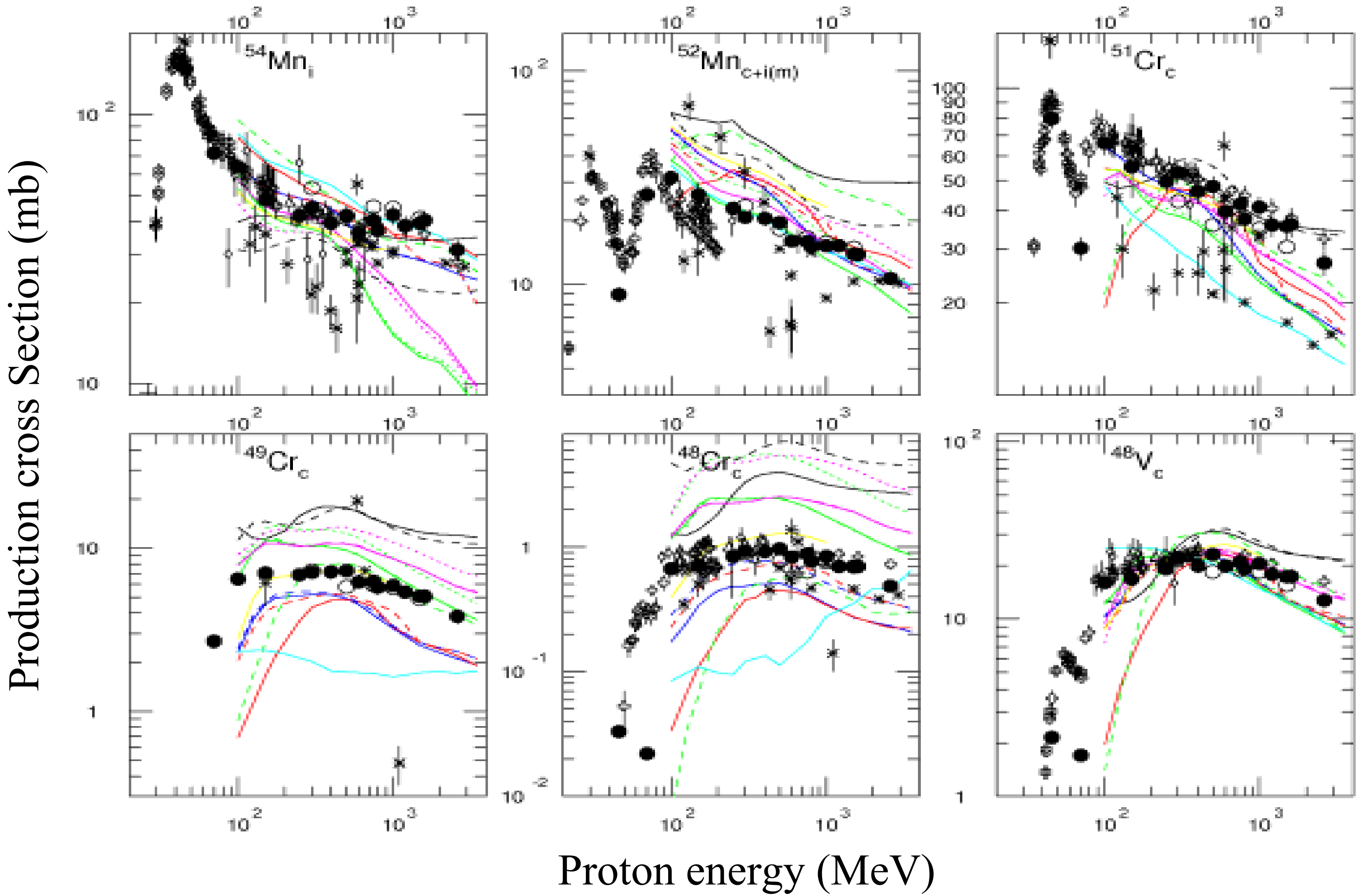
Theory – to – Experiment comparison



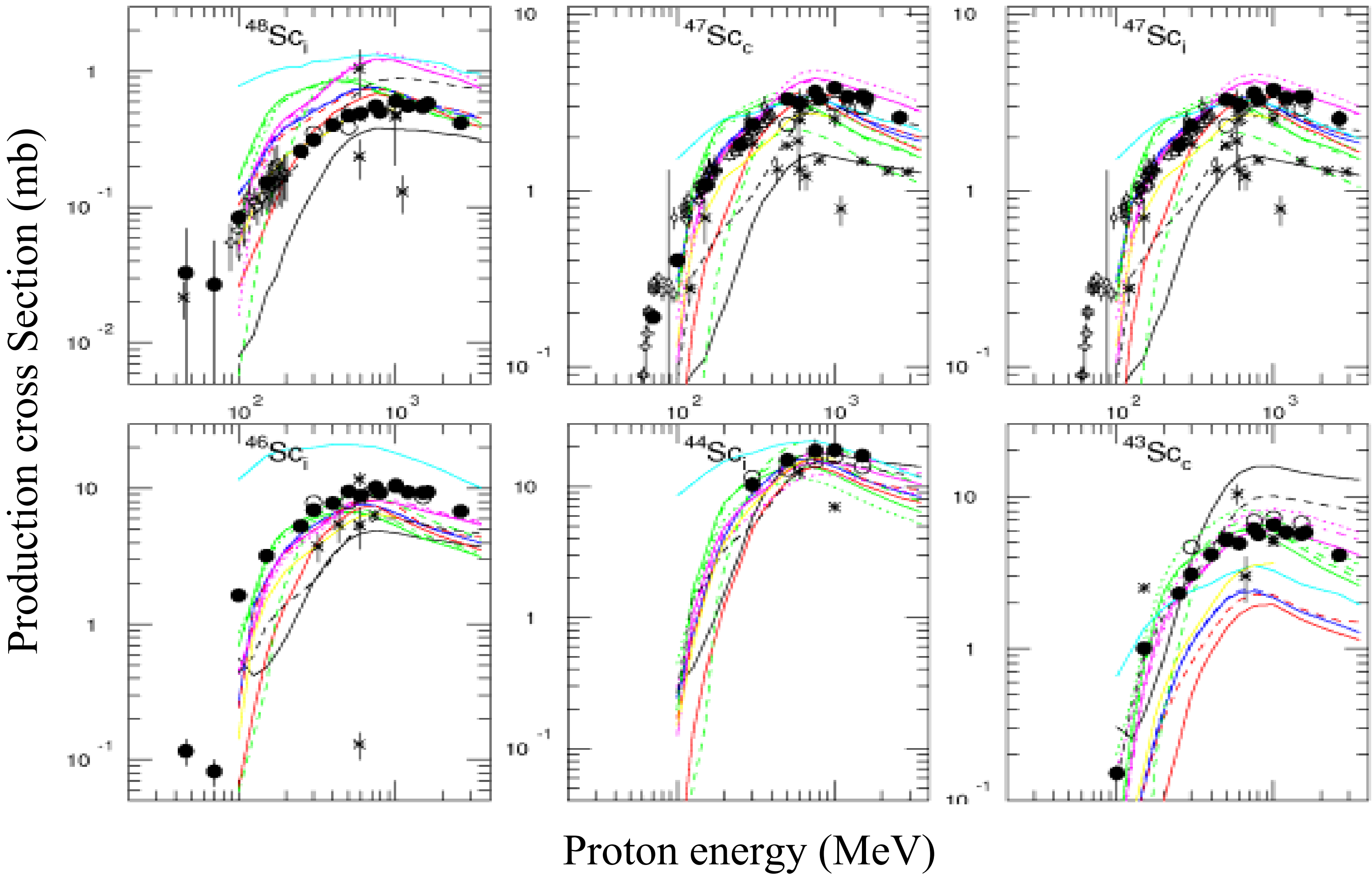
^{56}Fe(p,x) excitation functions



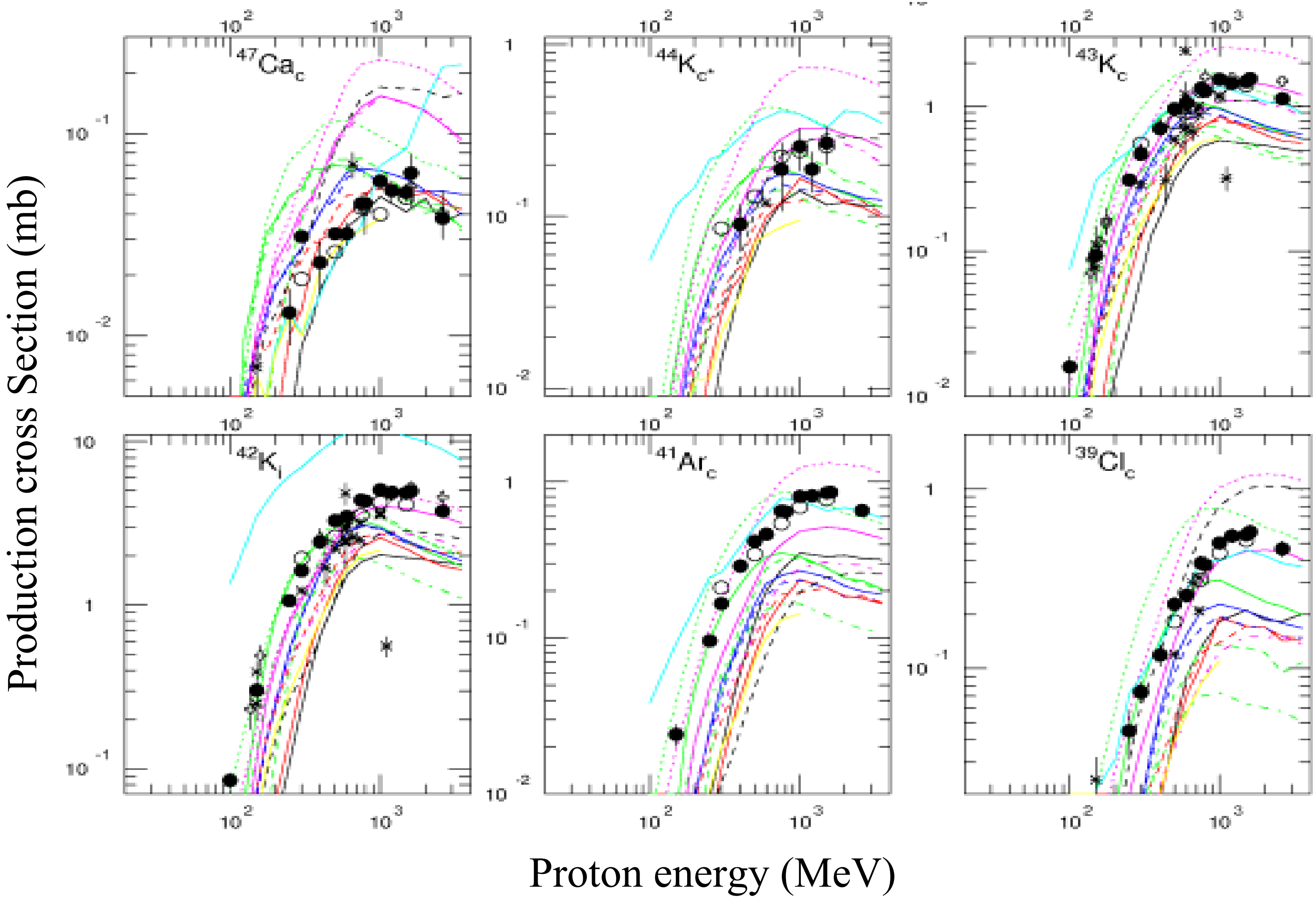
$^{56}Fe(p,x)$ excitation functions



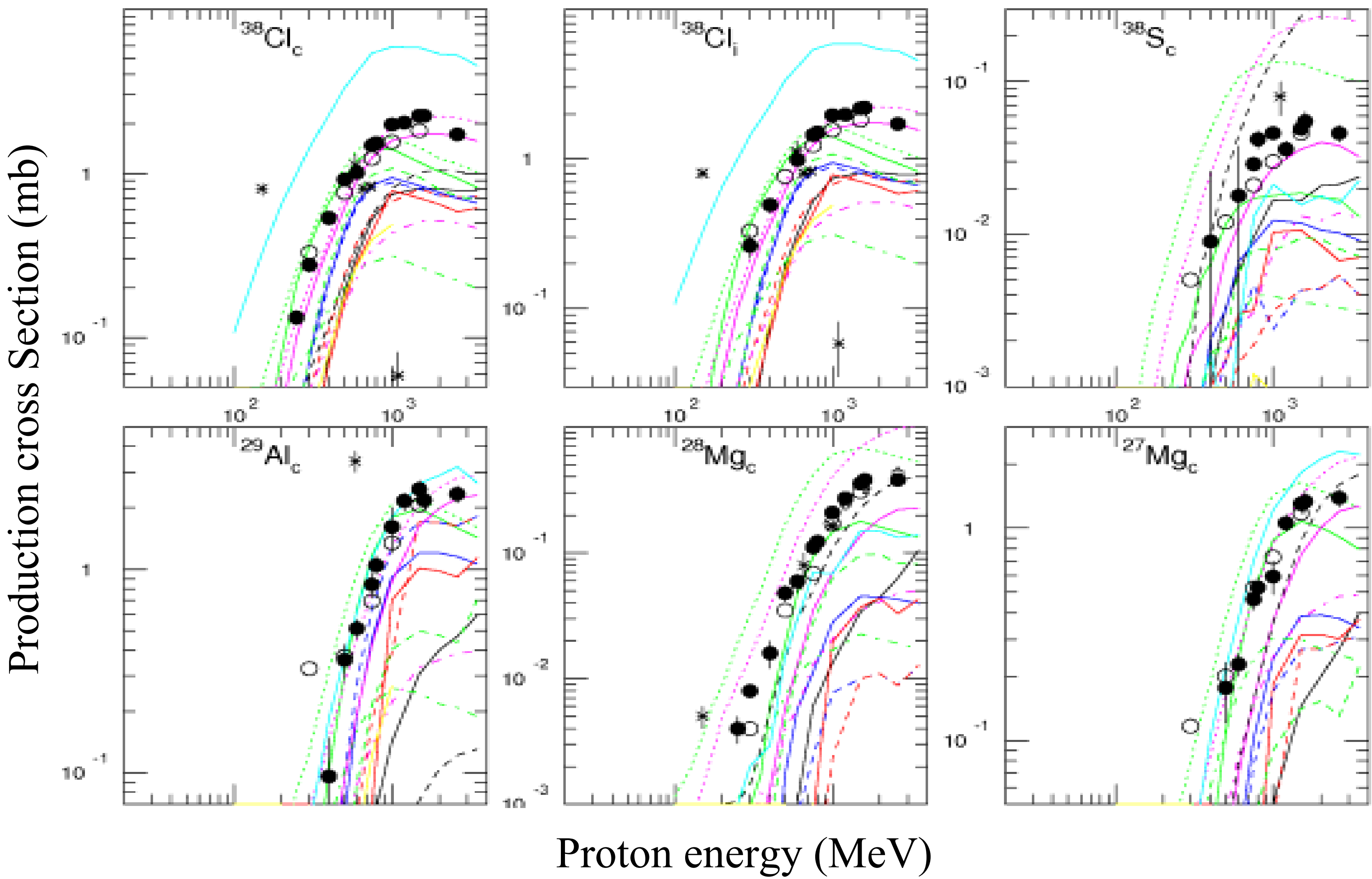
$^{56}Fe(p,x)$ excitation functions



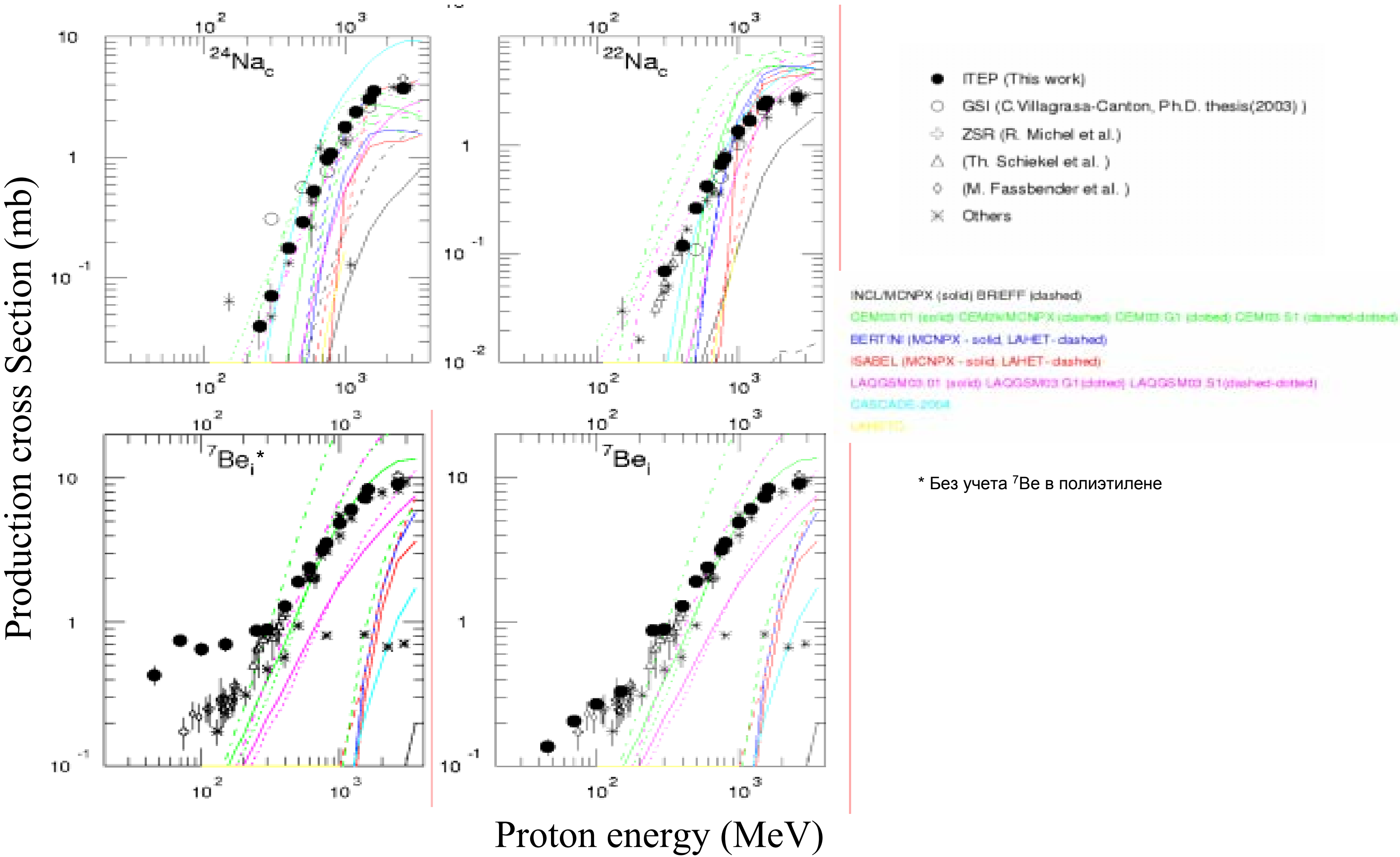
$^{56}Fe(p,x)$ excitation functions



$^{56}Fe(p,x)$ excitation functions



$^{56}Fe(p,x)$ excitation functions



* Без учета ^{7}Be в полиэтилене

Mean squared deviation factors <F> for $^{56}Fe(p,x)$ products predictions

ITEP data

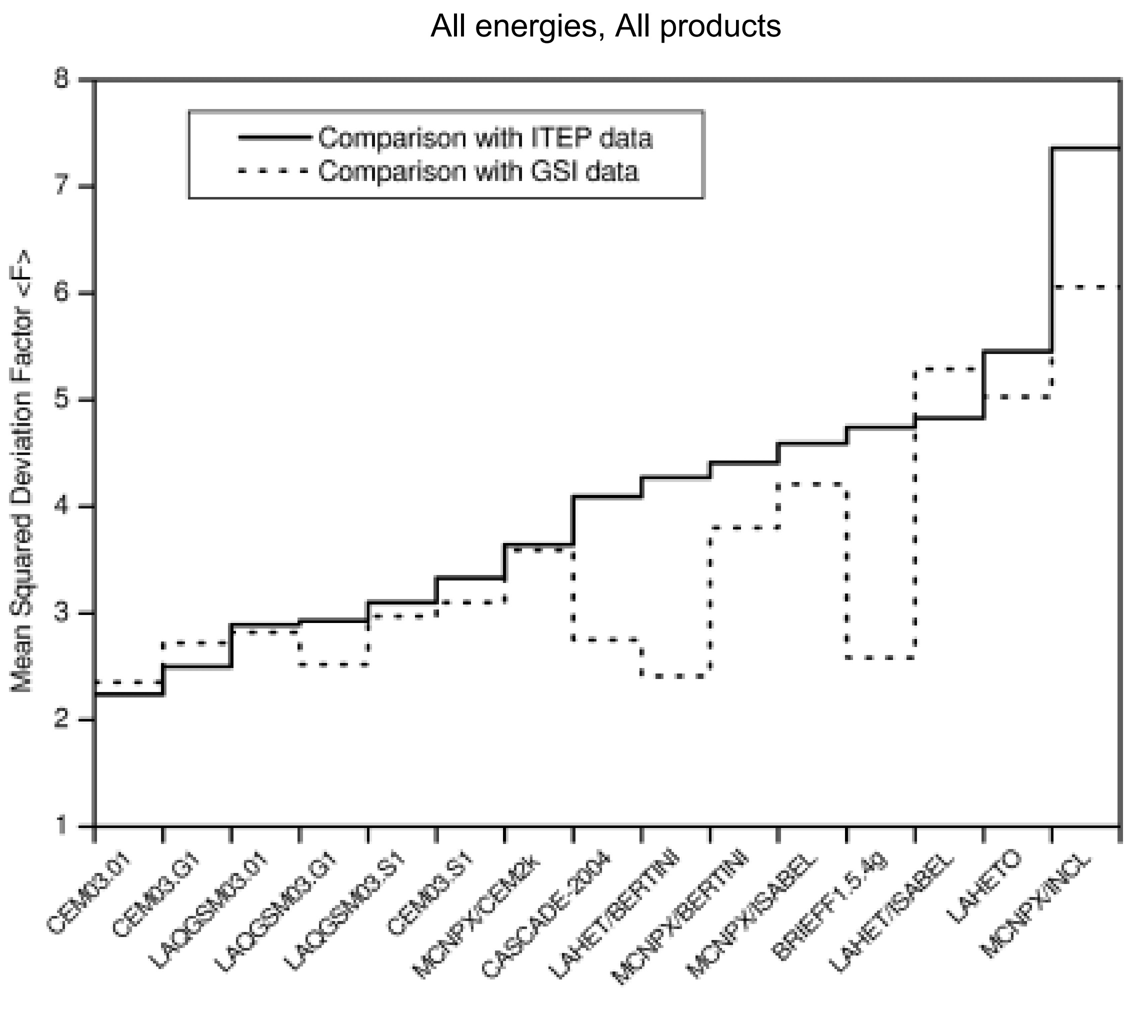
Code/Model	Product mass (A), Proton energy (MeV)												All energies, All products
	300		500		750		1000		1500		2600		
	A<30	A>30	A<30	A>30	A<30	A>30	A<30	A>30	A<30	A>30	A<30	A>30	
MCNPX/INCL	**233**	**5.04**	**141**	**3.19**	**51.5**	**3.09**	**38.1**	3.08	**26.1**	3.30	**12.1**	3.47	**7.36**
MCNPX/CEM2k	--	2.73	17.2	2.49	21.1	**2.57**	7.83	2.72	4.87	2.88	4.02	3.15	3.64
MCNPX/BERTINI	**1035**	2.27	19.4	2.27	**50.5**	2.73	13.8	2.85	4.93	3.16	3.35	3.19	4.41
MCNPX/ISABEL	--	4.04	**158**	2.82	**49.1**	2.99	**17.1**	2.62	**5.99**	2.83	4.02	**2.99**	4.59
LAHET/BERTINI	**542**	2.29	24.9	**2.26**	6.98	2.66	16.5	3.15	**7.34**	**3.37**	**5.69**	**3.14**	4.09
LAHET/ISABEL	--	2.86	100	2.60	44.6	3.00	15.4	**3.43**	**7.34**	**3.37**	**5.69**	**3.14**	**4.83**
CEM03.01	13.0	**1.81**	**1.99**	**1.88**	**1.32**	**1.88**	**1.49**	**1.92**	**1.58**	**2.04**	1.72	3.17	**2.24**
CEM03.G1	**2.82**	2.54	2.35	2.59	**2.42**	2.60	**2.15**	**2.34**	**1.67**	**2.31**	**1.57**	**3.10**	**2.50**
CEM03.S1	**3.35**	**2.20**	3.73	2.32	4.21	2.68	4.94	2.94	6.19	3.25	**6.98**	**4.34**	3.33
LAQGSM03.01	45.3	**2.07**	6.98	**1.94**	3.15	**2.02**	2.43	**2.09**	1.98	**2.19**	**1.46**	3.74	**2.89**
LAQGSM03.G1	**2.43**	**4.00**	**1.85**	2.47	**1.73**	2.76	**1.66**	2.77	**1.50**	2.90	**1.60**	**4.22**	2.93
LAQGSM03.S1	4.64	2.79	4.35	2.41	3.75	2.67	3.89	2.67	4.17	2.66	3.59	4.13	3.10
CASCADE-2004	4.69	2.70	**1.87**	**2.84**	12.4	**3.13**	8.00	**3.72**	4.55	**5.43**	3.04	**6.48**	4.27
LAHETO	--	**4.07**	**108**	2.43	22.8	2.83	**38.9**	3.24	--	--	--	--	**5.45**
BRIEFF 1.5.4g	208	2.47	12.5	**3.00**	8.01	**3.51**	6.41	**3.71**	5.15	**3.89**	3.84	3.82	4.74

Mean squared deviation factors <F> for $^{56}Fe(p,x)$ products predictions

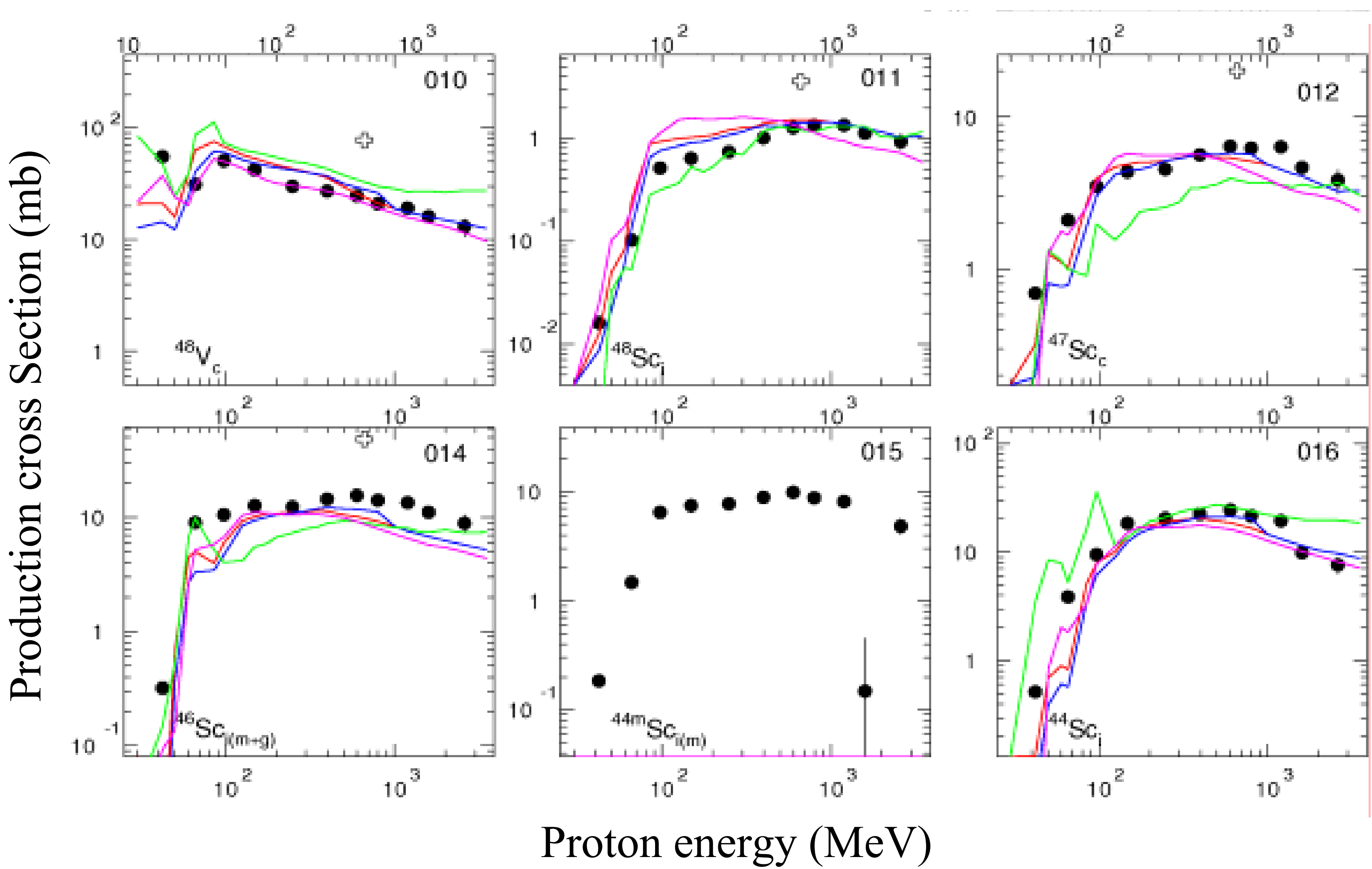
GSI data

Программа/Модель	Масса продукта (A), энергия протонов (Ep, ГэВ)										Все энергии, все продукты
	300		500		750		1000		1500		
	$A<30$	$A>30$	$A<30$	$A>30$	$A<30$	$A>30$	$A<30$	$A>30$	$A<30$	$A>30$	
MCNPX/INCL	153	**5.85**	52.0	**3.30**	15.8	**3.10**	**10.2**	2.25	**6.63**	**3.27**	**6.06**
MCNPX/CEM2k	**1598**	3.09	17.7	2.70	3.96	2.66	3.54	1.96	3.88	**2.69**	3.59
MCNPX/BERTINI	**534**	2.45	18.8	**1.66**	3.48	**1.54**	2.80	**1.70**	3.00	**1.95**	2.75
MCNPX/ISABEL	--	**4.76**	**124**	**2.81**	**39.3**	2.57	3.54	**1.79**	3.42	2.69	4.21
LAHET/BERTINI	**1369**	2.78	22.7	**1.82**	5.75	**1.66**	4.67	2.07	**5.44**	2.18	3.80
LAHET/ISABEL	1224	2.90	**91.4**	2.52	**35.5**	2.23	**13.7**	2.06	**5.44**	2.18	**5.29**
CEM03.01	27.6	**1.86**	**2.20**	2.08	**1.58**	2.09	**1.69**	**1.58**	**1.59**	2.18	**2.35**
CEM03.G1	**3.49**	2.65	3.23	**3.11**	3.36	**2.95**	2.61	2.15	1.77	2.52	2.72
CEM03.S1	5.42	2.68	4.91	2.62	4.07	2.70	4.83	**2.51**	**5.50**	**3.28**	3.10
LAQGSM03.01	97.9	**1.93**	7.59	**1.89**	2.66	1.93	2.06	1.90	**1.69**	**1.61**	2.82
LAQGSM03.G1	**4.22**	**2.26**	**1.97**	2.64	**1.77**	**2.85**	**1.53**	**2.76**	**1.48**	2.46	**2.52**
LAQGSM03.S1	13.4	3.16	5.69	2.54	3.76	2.44	4.15	2.35	4.17	2.04	2.97
CASCADE-2004	**4.90**	2.65	**1.54**	**2.95**	**1.69**	2.27	**1.94**	2.04	1.76	2.24	**2.41**
LAHETO	--	**3.65**	**107**	2.36	**20.2**	2.67	**34.7**	**2.72**	--	--	**5.03**
BRIEFF 1.5.4g	42.2	3.38	4.86	2.19	3.18	1.96	2.99	1.89	2.62	**1.81**	2.58

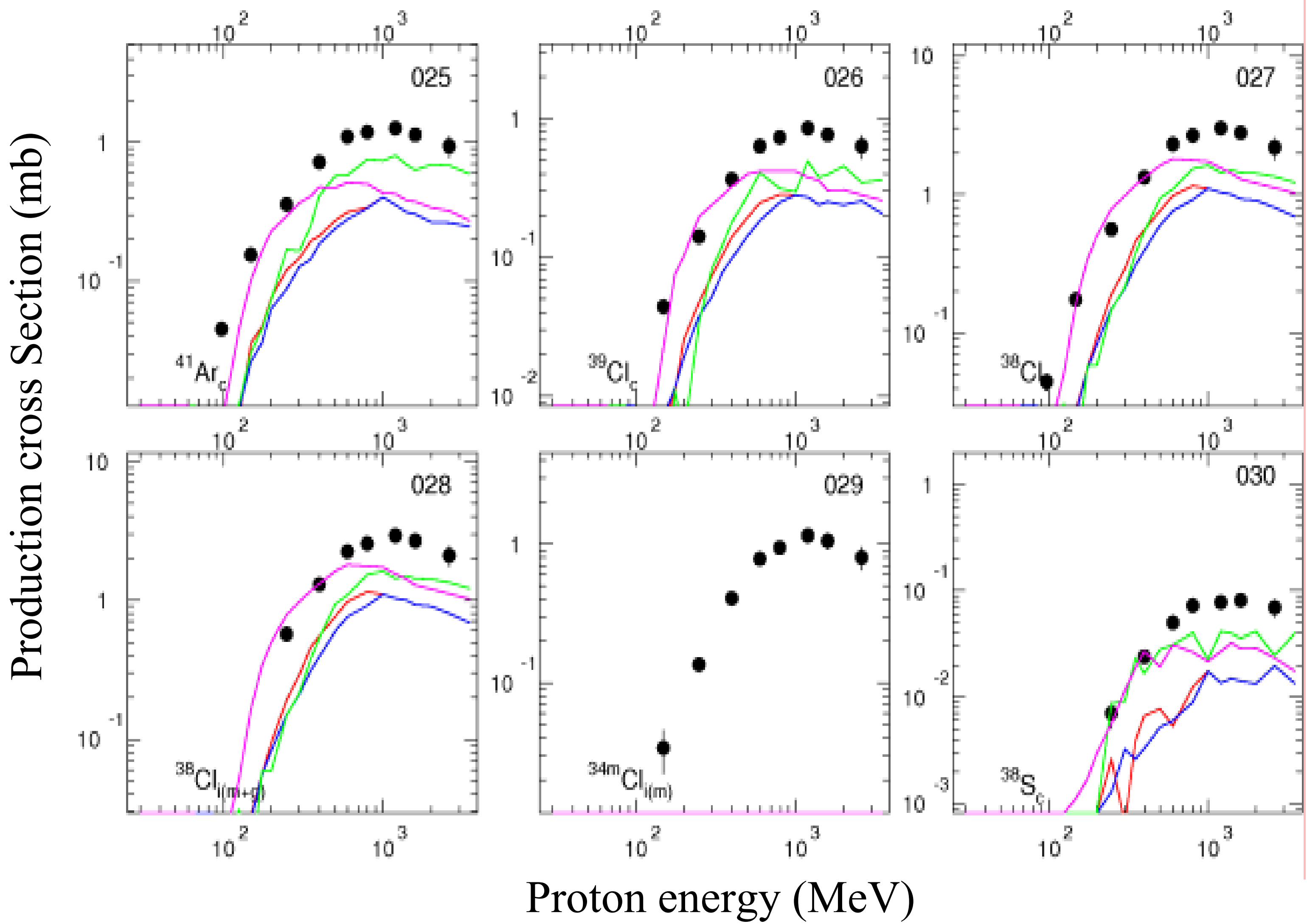
Mean squared deviation factors <F> for $^{56}Fe(p,x)$ products predictions



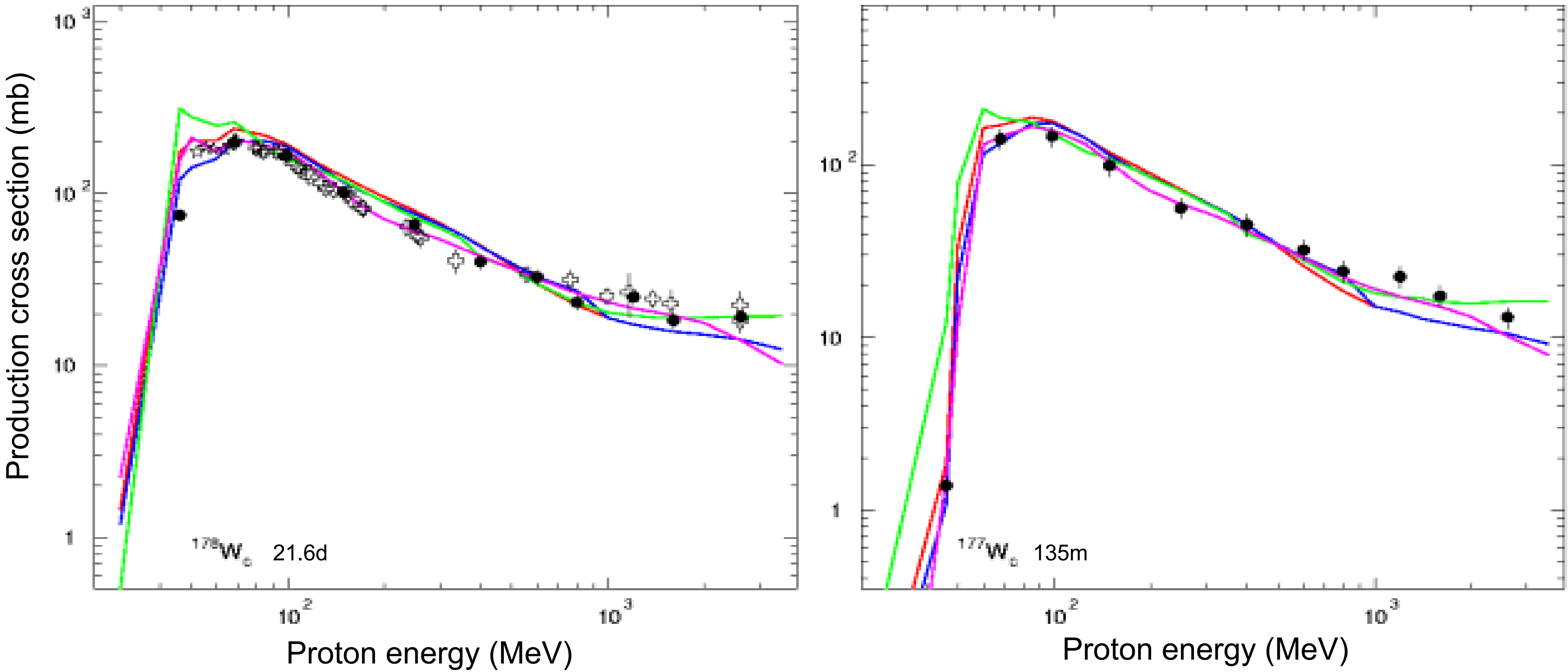
$^{nat}Cr(p,x)$ excitation functions



$^{nat}Cr(p,x)$ excitation functions



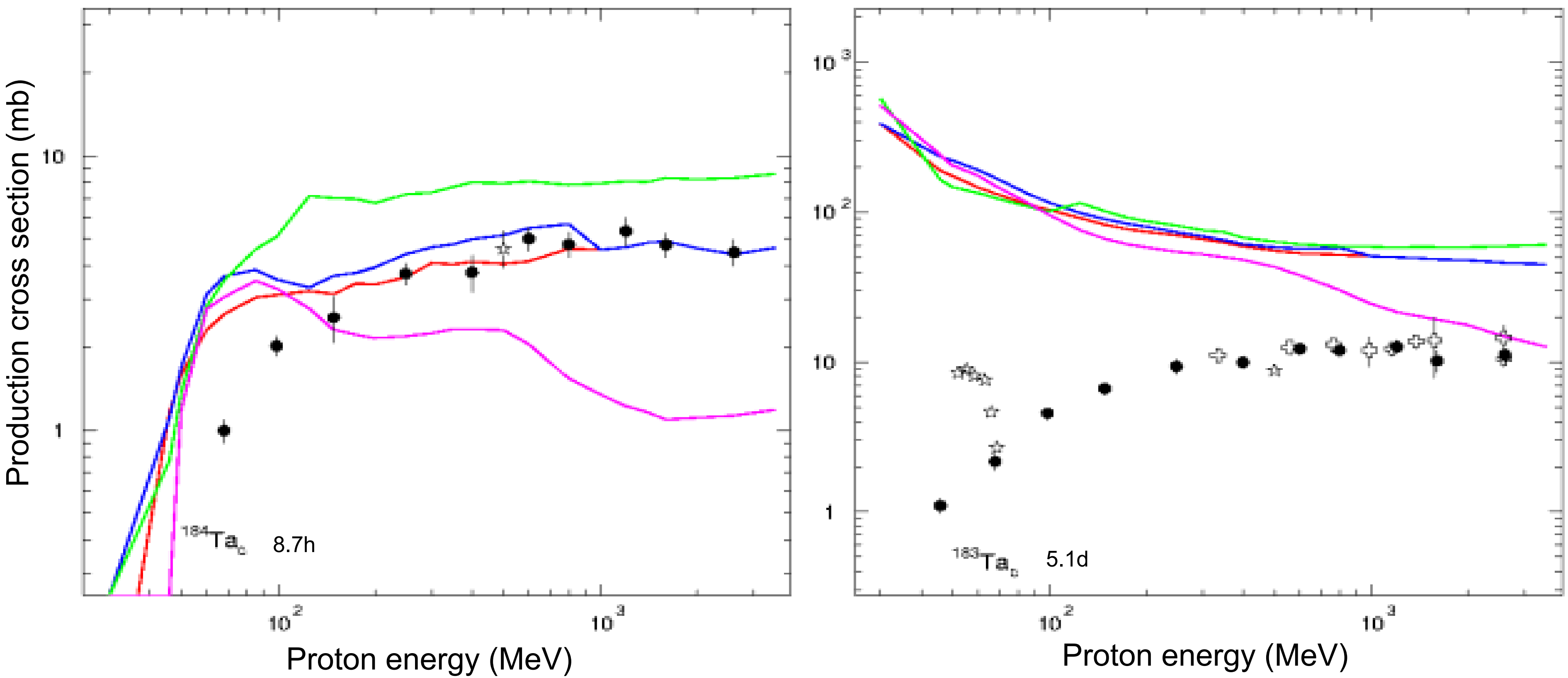
$^{nat}W(p,x)$ products (1)



Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚- ZSR (R.Michel et al., 2002)

$^{nat}W(p,x)$ products (2)

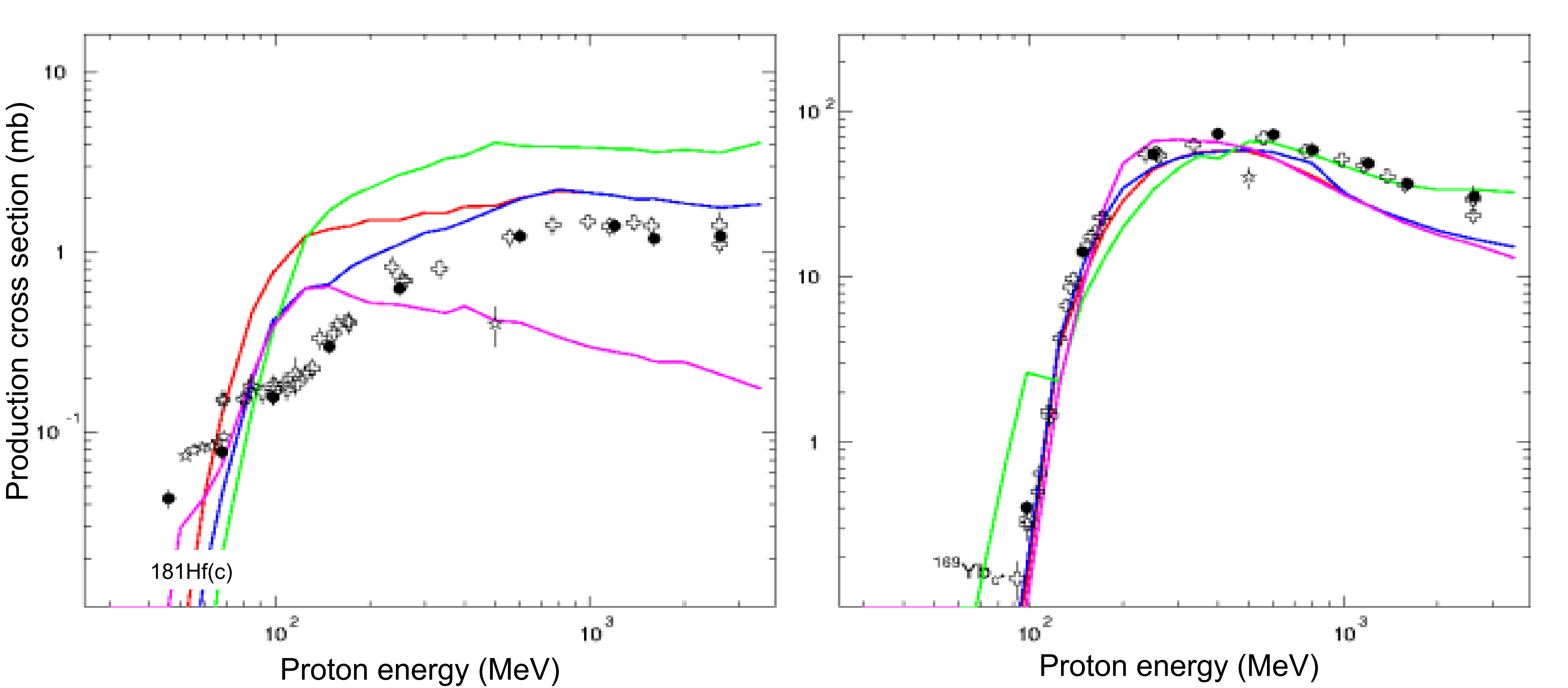


Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., (2002)

☆ - Y. Asano (1985)

$^{nat}W(p,x)$ products (3)

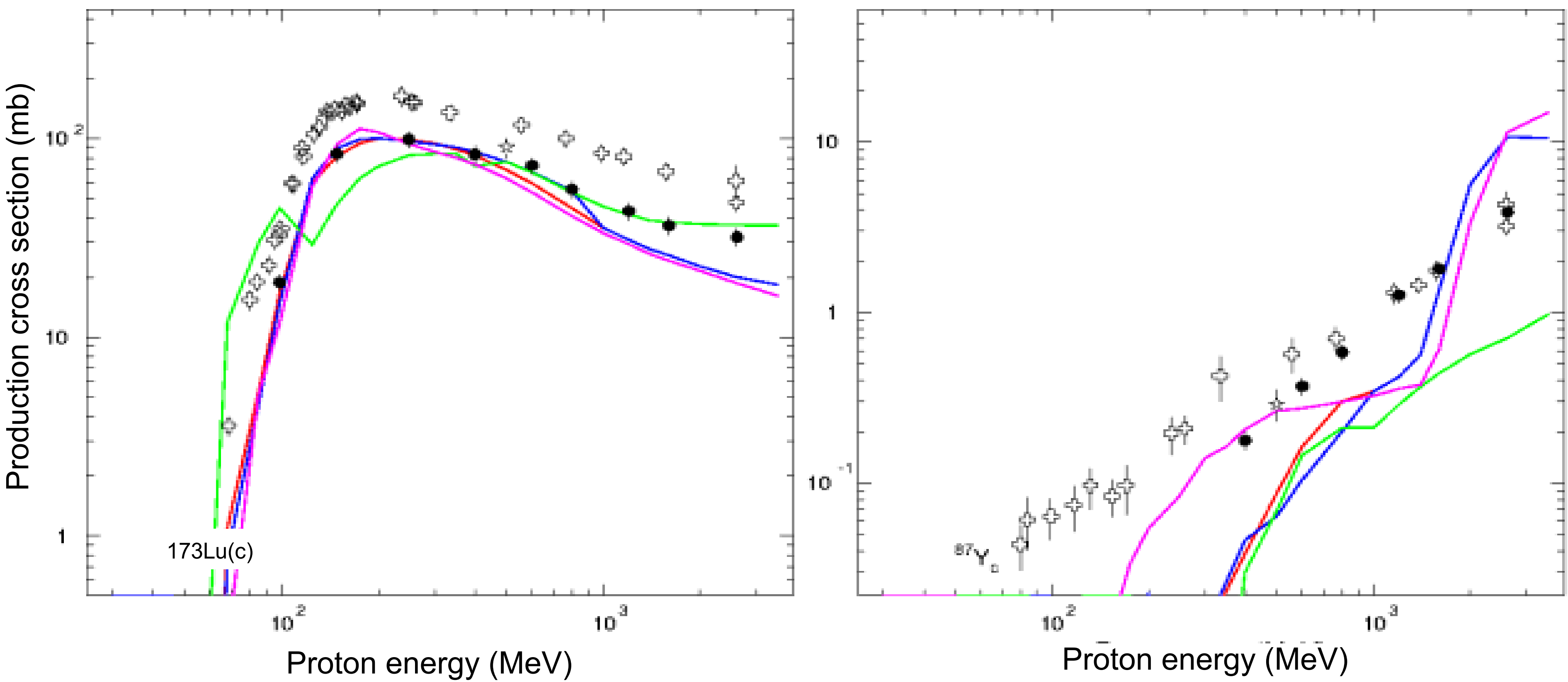


Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., 2002)

☆ - Y. Asano (1985)

$^{nat}W(p,x)$ products (4)

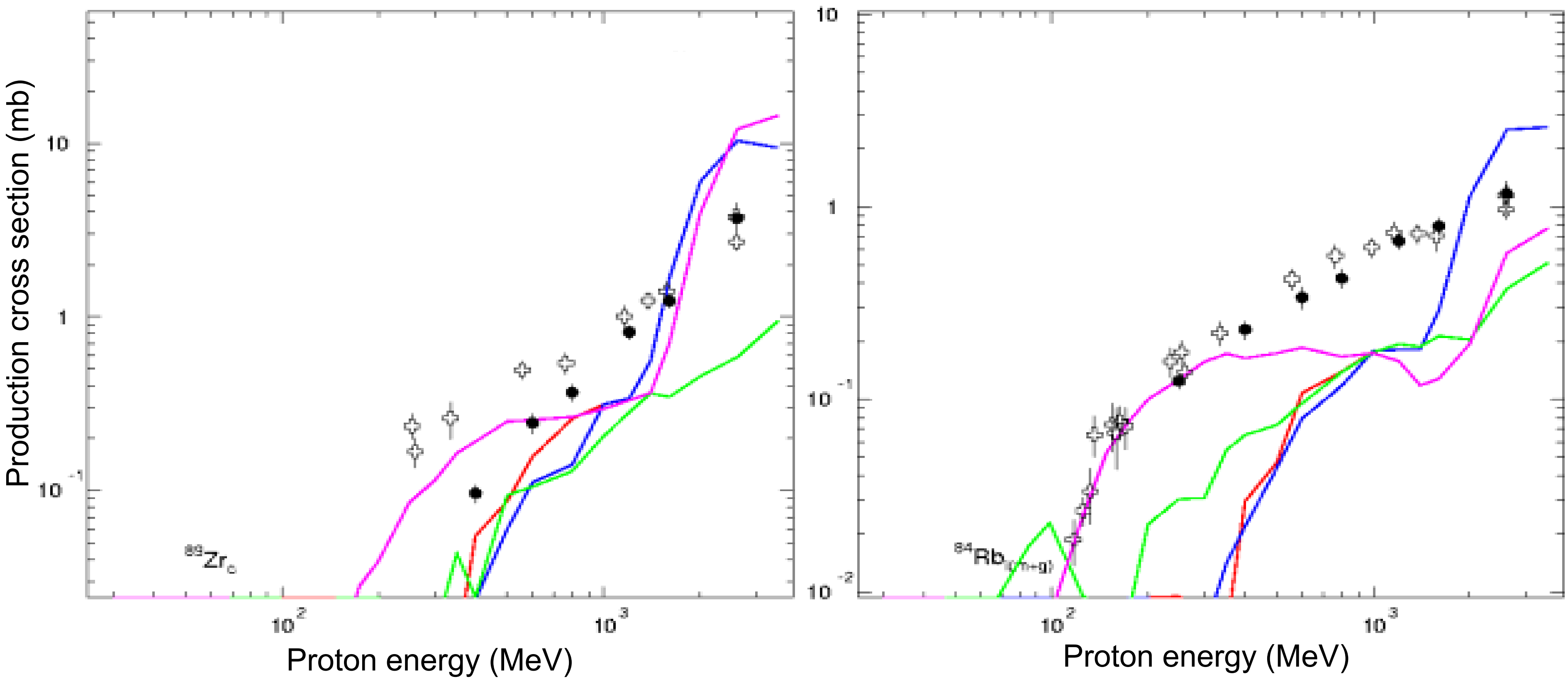


Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., 2002)

☆ - Y. Asano (1985)

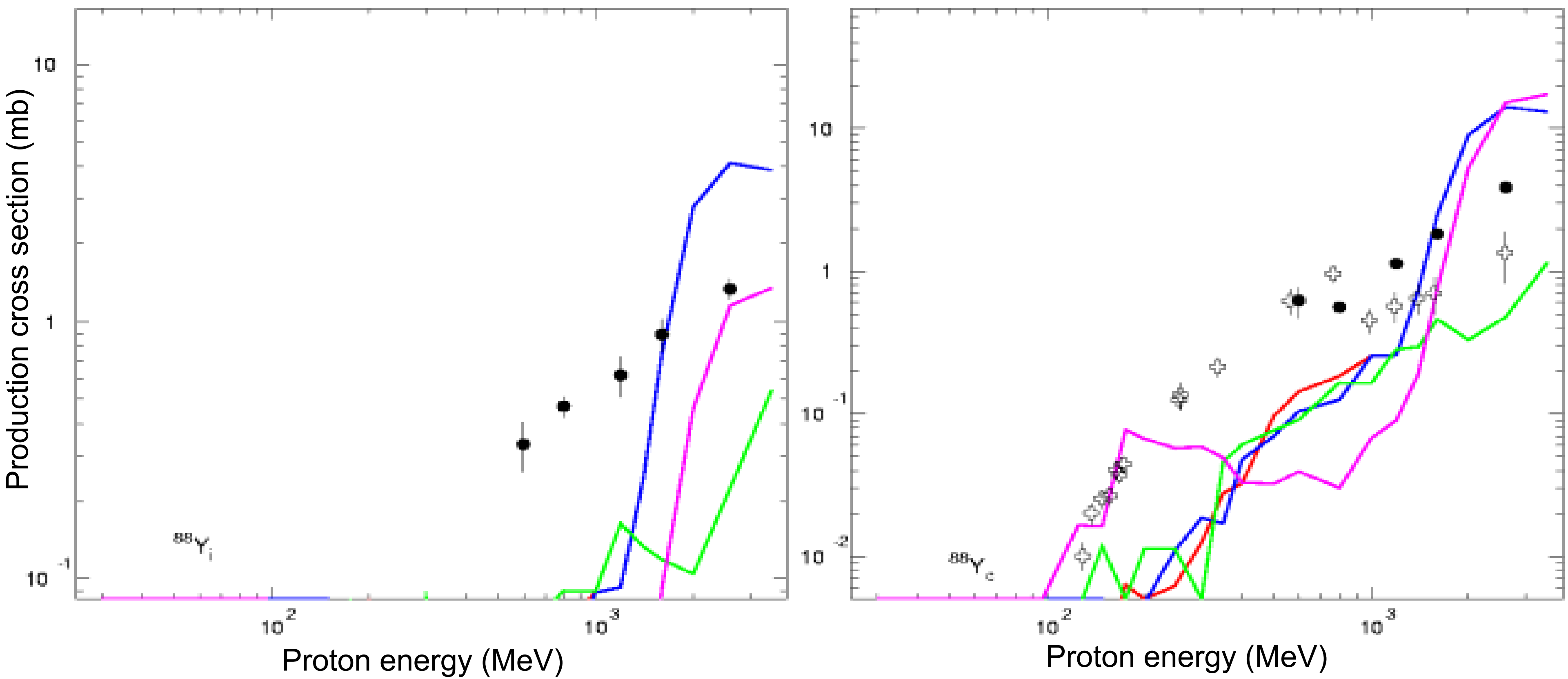
$^{nat}W(p,x)$ products (5)



Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., 2002)

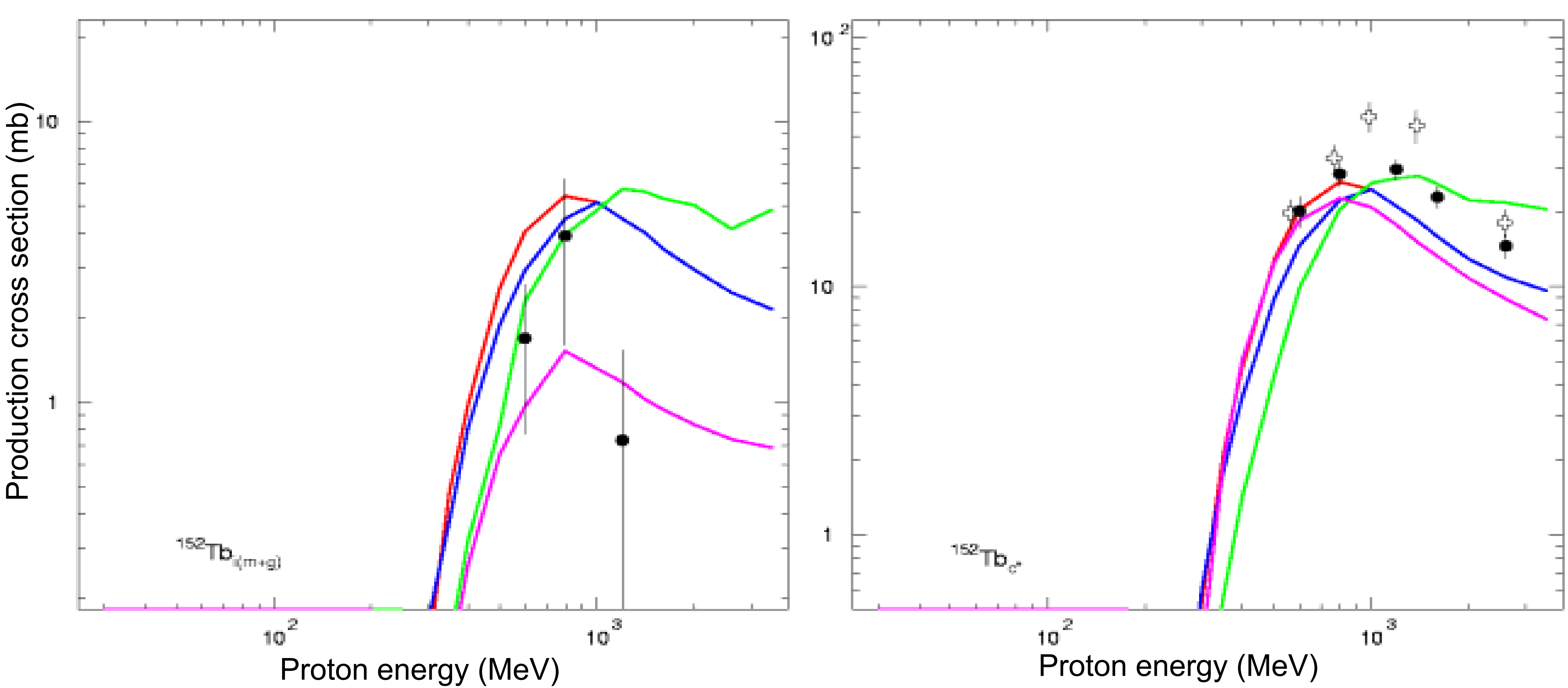
$^{181}Ta(p,x)$ products (1)



Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✣- ZSR (R.Michel et al., 2002)

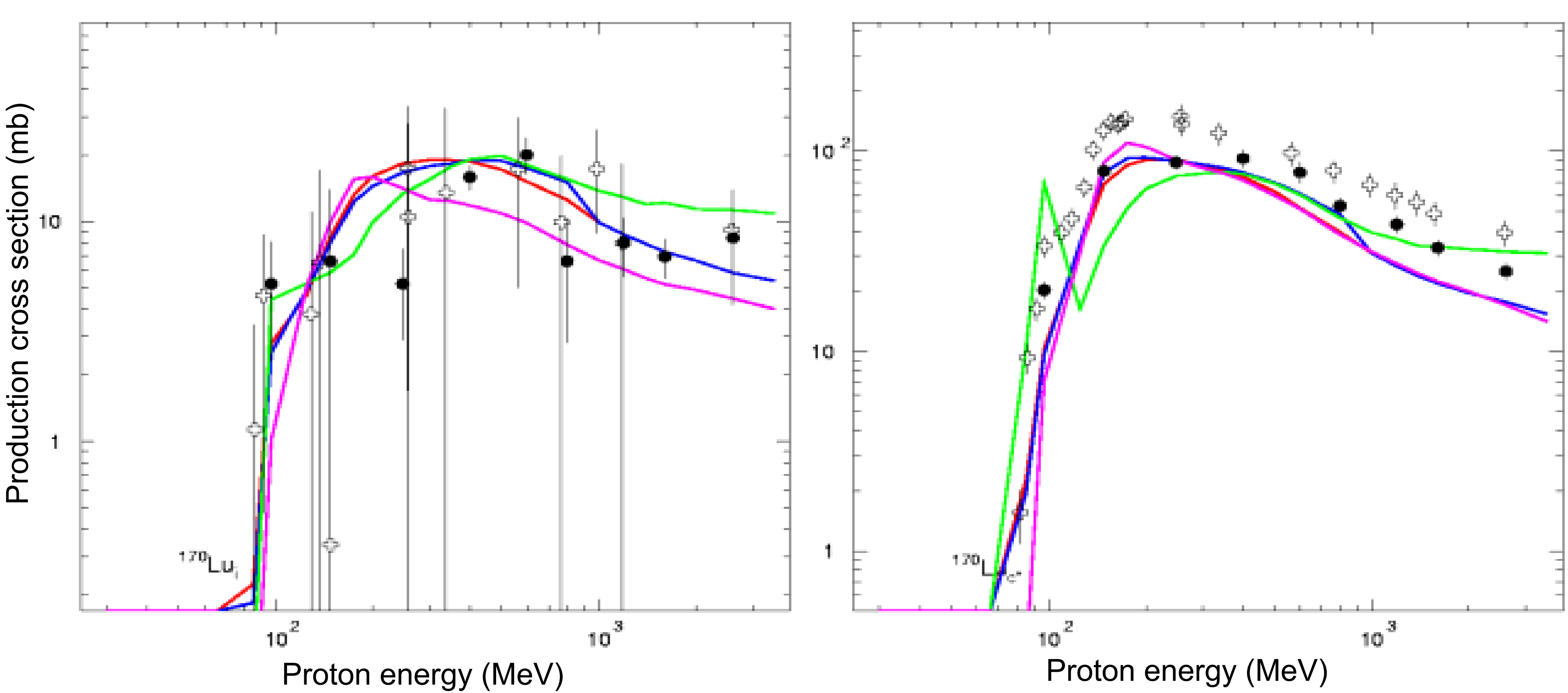
$^{181}Ta(p,x)$ products (2)



Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., 2002)

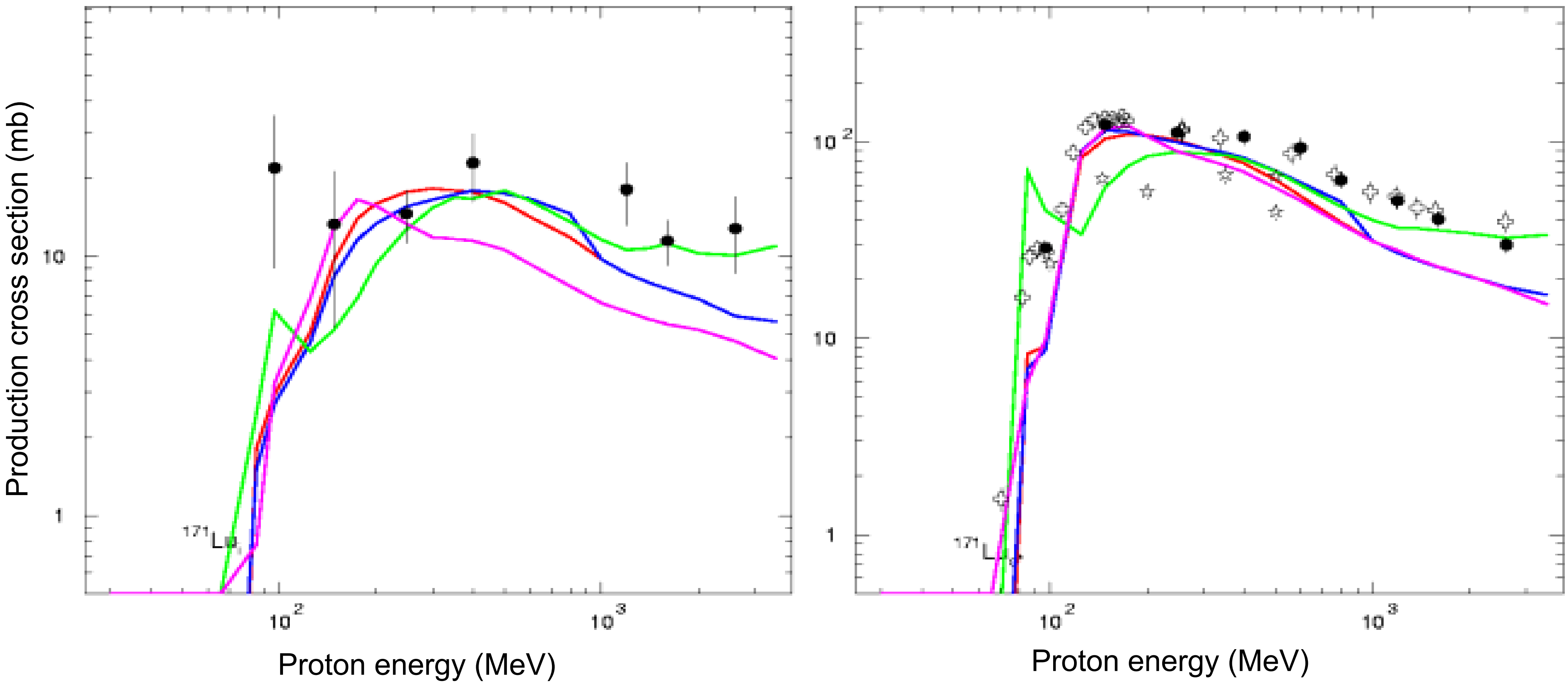
$^{181}Ta(p,x)$ products (3)



Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✜- ZSR (R.Michel et al., 2002)

^{181}Ta(p,x) products (4)

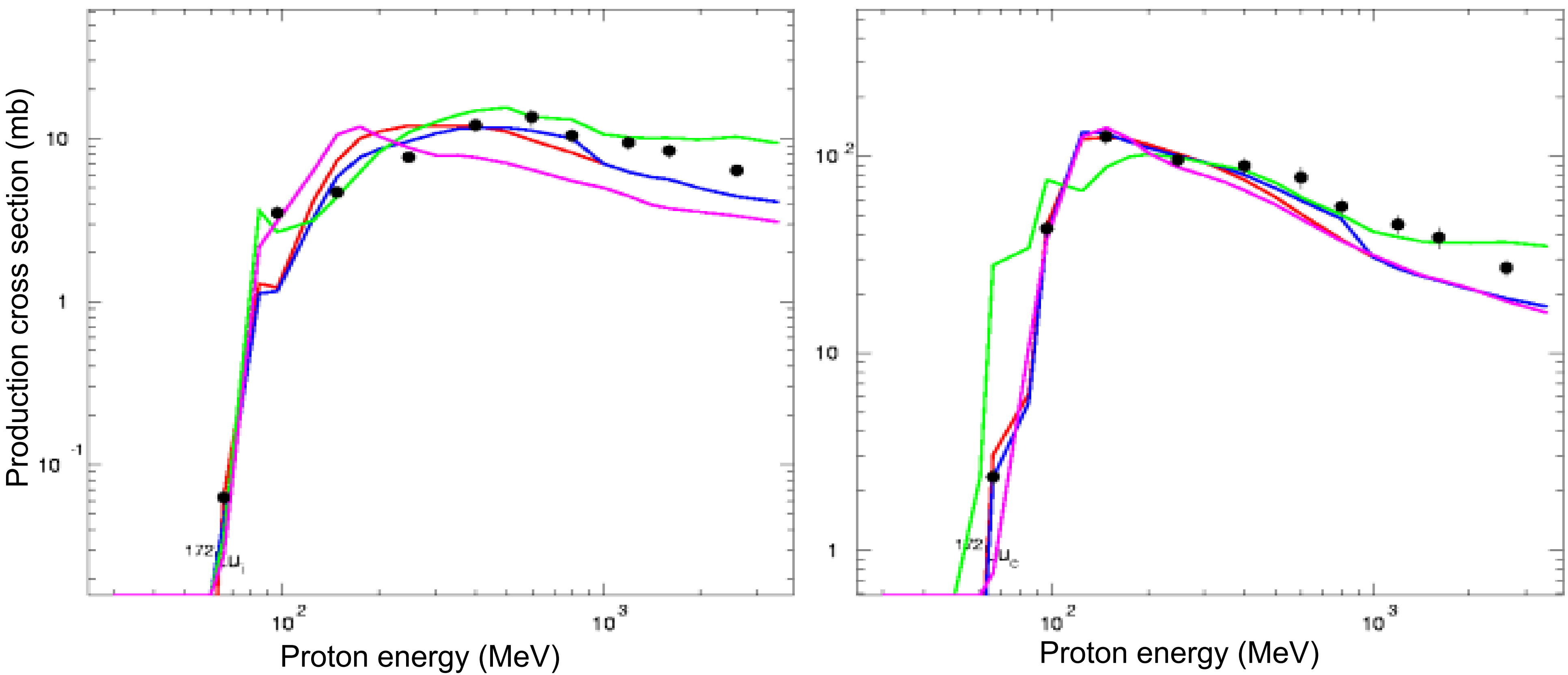


Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., 2002)

☆ - Y. Asano (1985)

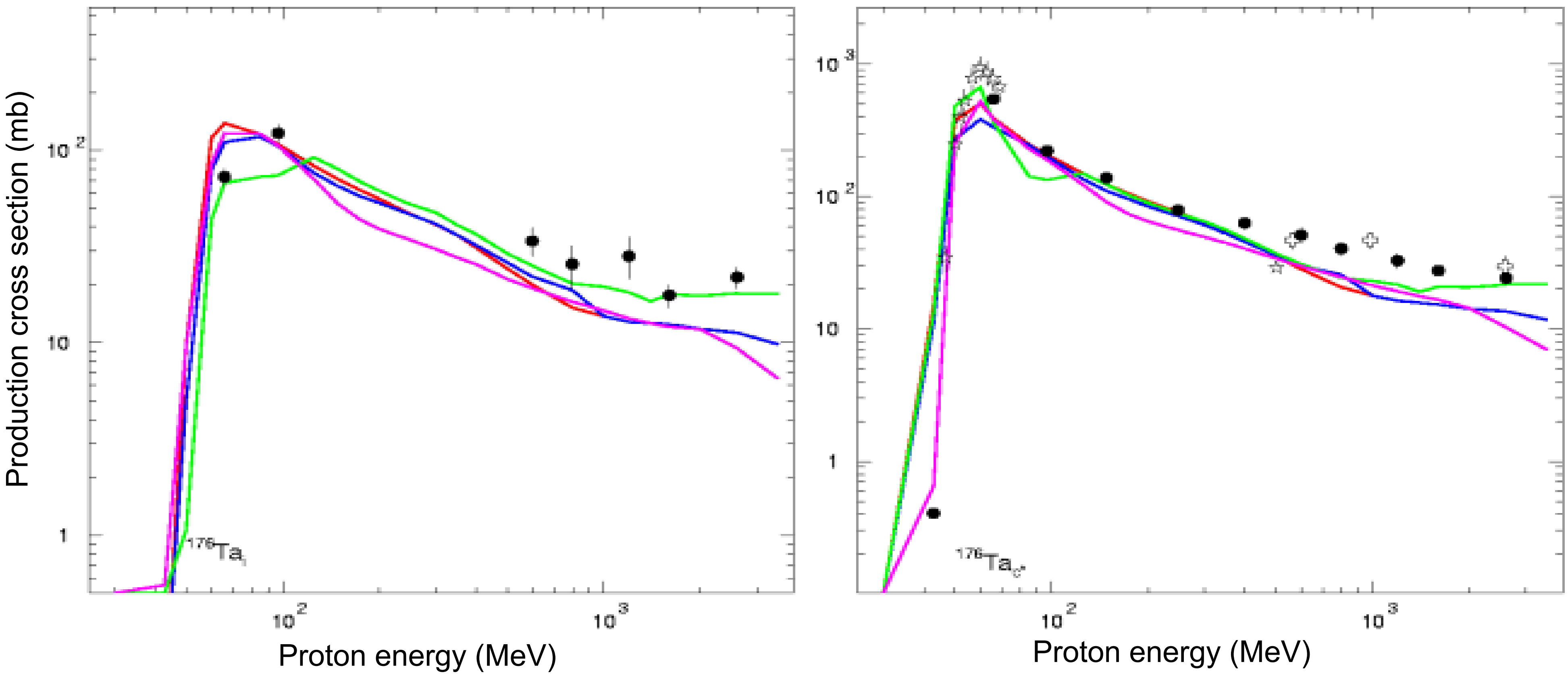
^{181}Ta(p,x) products (5)



Codes: Bertini Isabel INCL4 CEM03.02

Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., 2002)

$^{181}Ta(p,x)$ products (6)

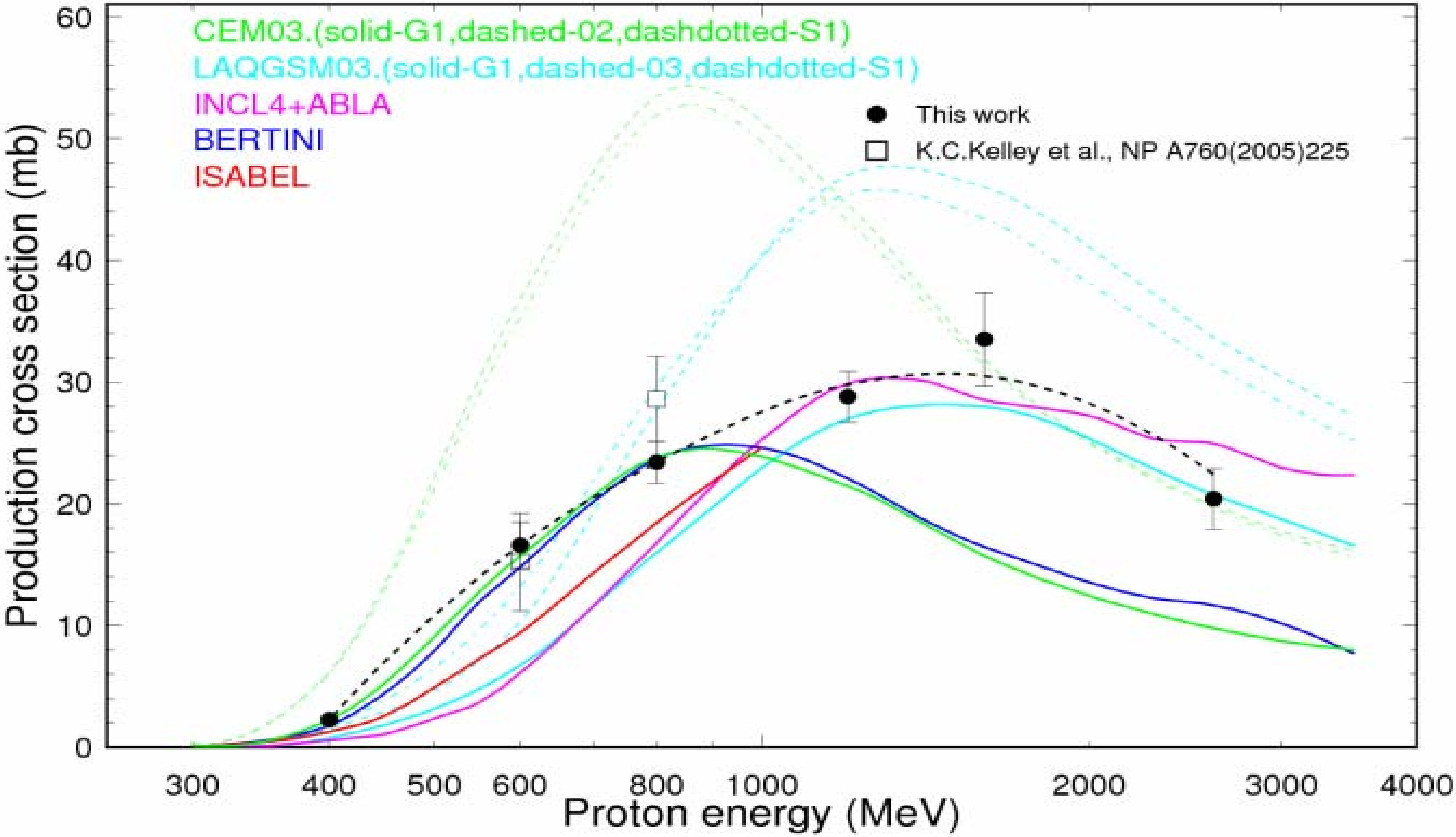


Codes: Bertini Isabel INCL4 CEM03.02

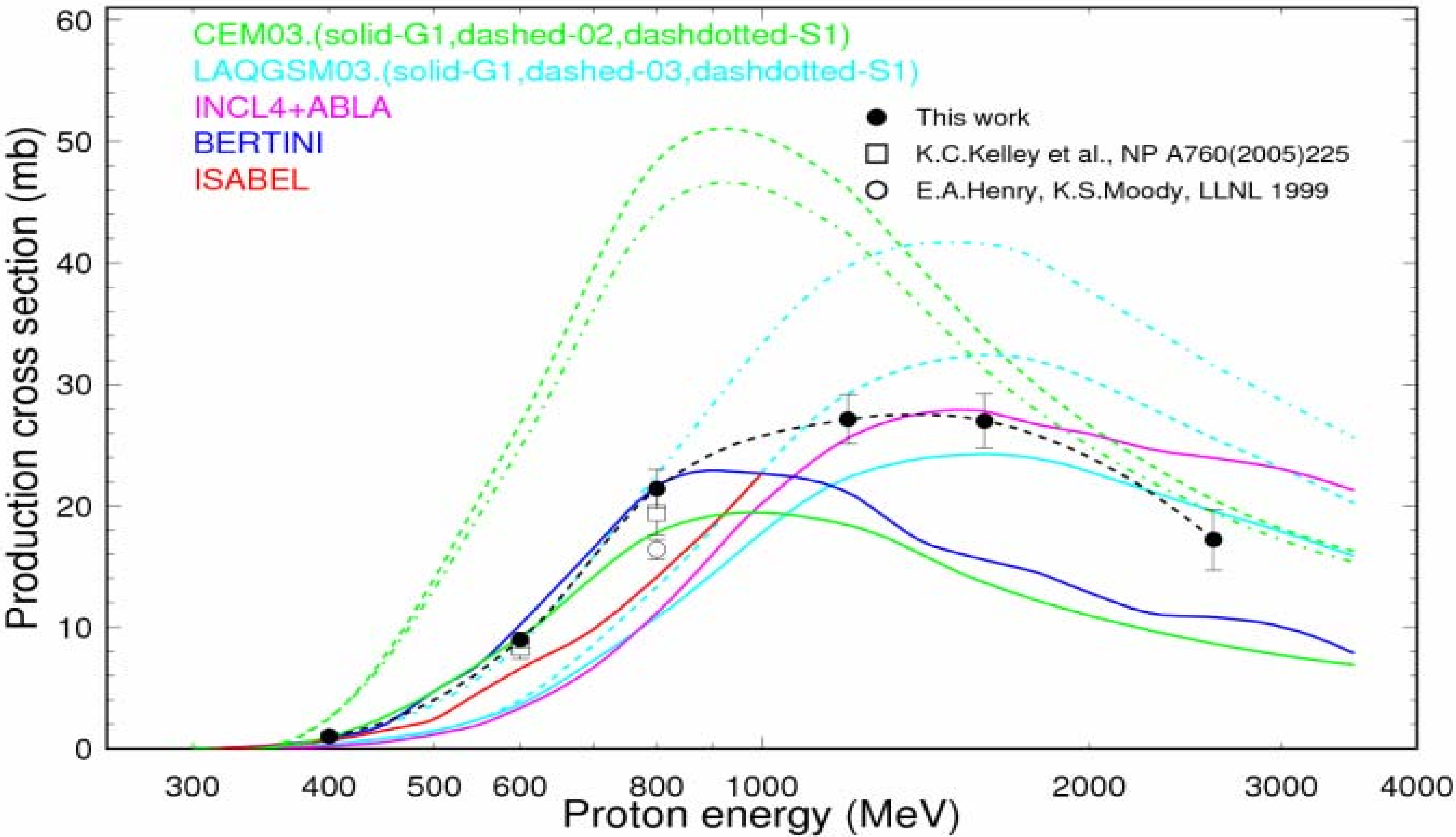
Exp.data: ● - ITEP (ISTC3266), ✚ - ZSR (R.Michel et al., 2002)

☆ - Y. Asano (1985)

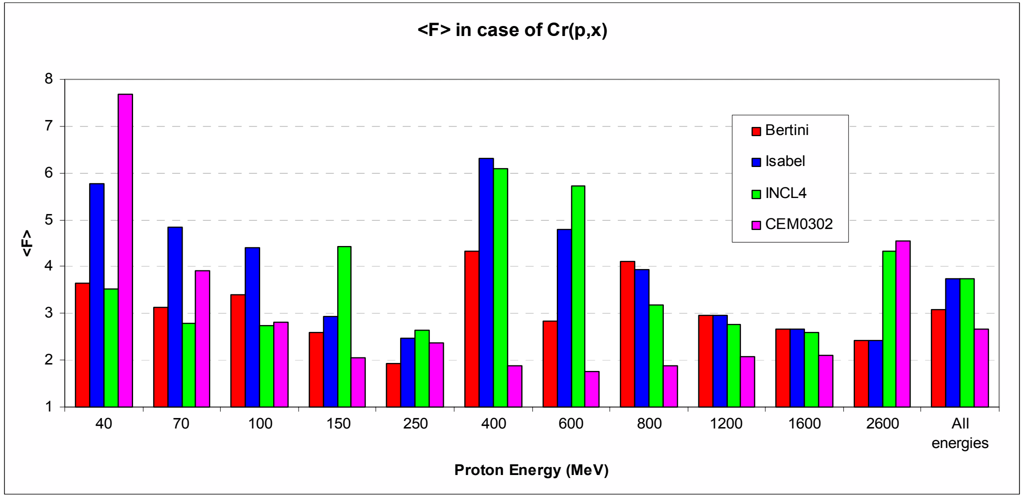
$^{181}Ta(p,x)^{148}Gd$: Theory vs. Experiment

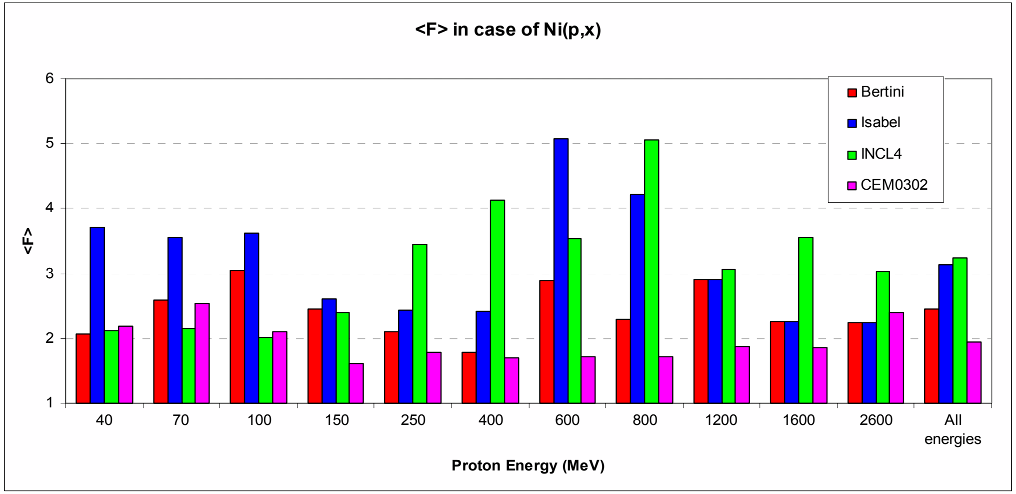


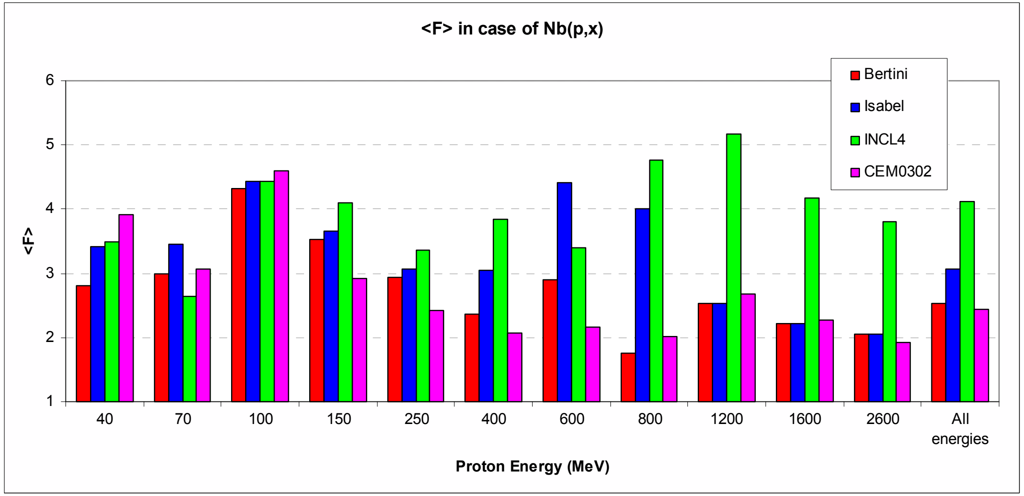
$^{nat}W(p,x)^{148}Gd$: Theory vs. Experiment

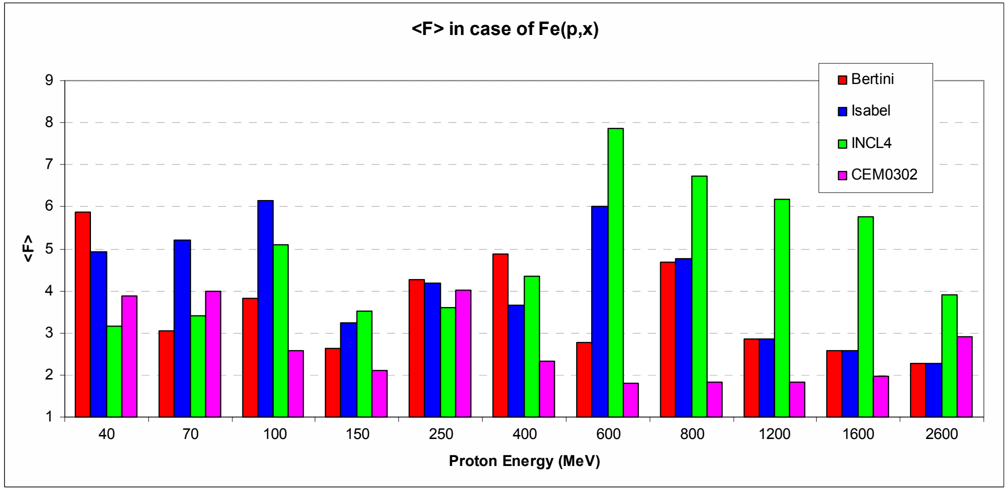


<F> for “structure materials” targets

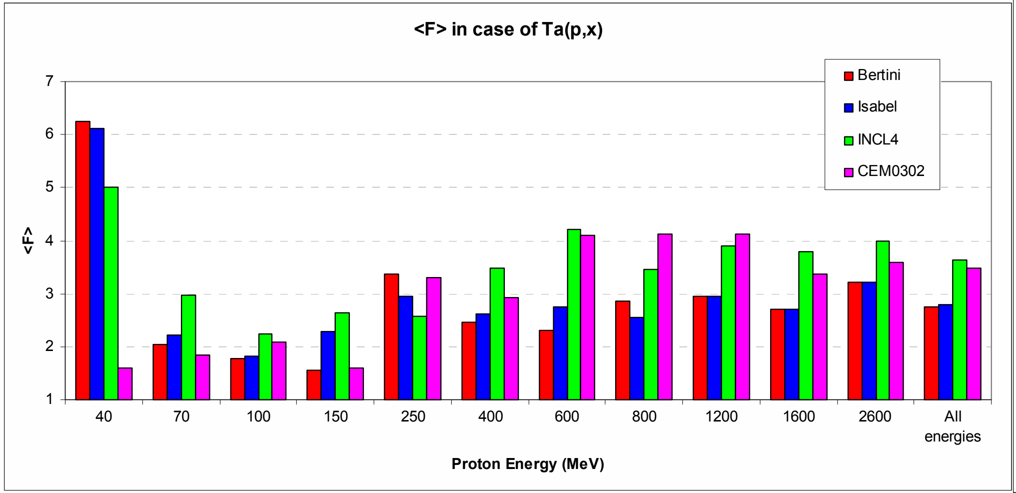


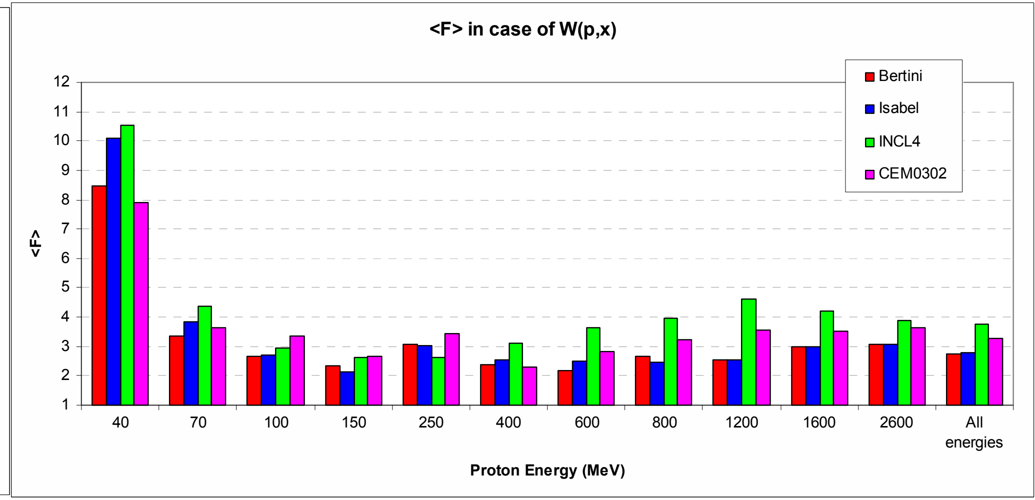


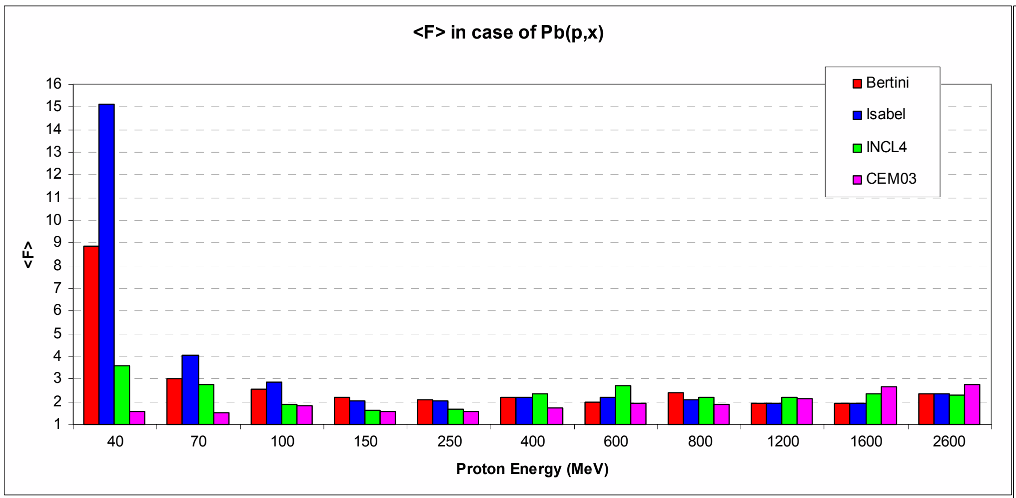


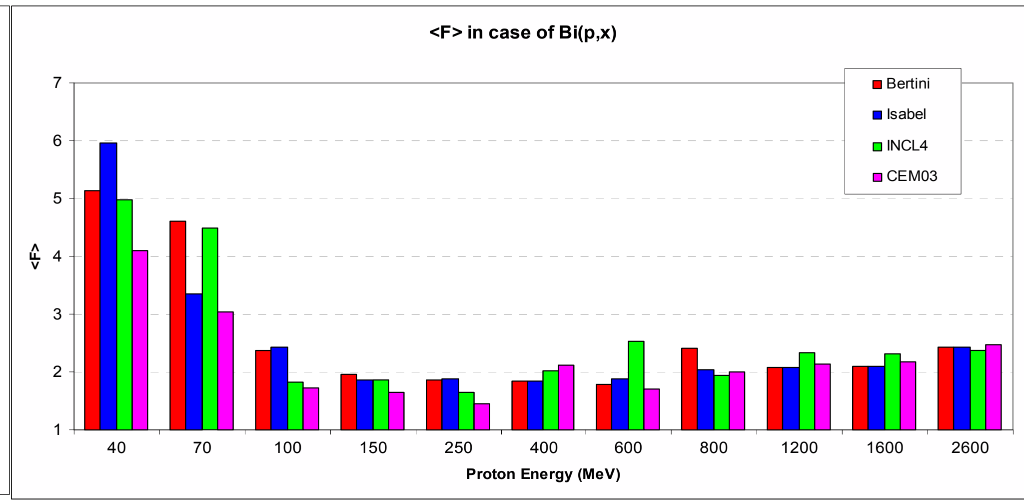


<F> for "target materials"

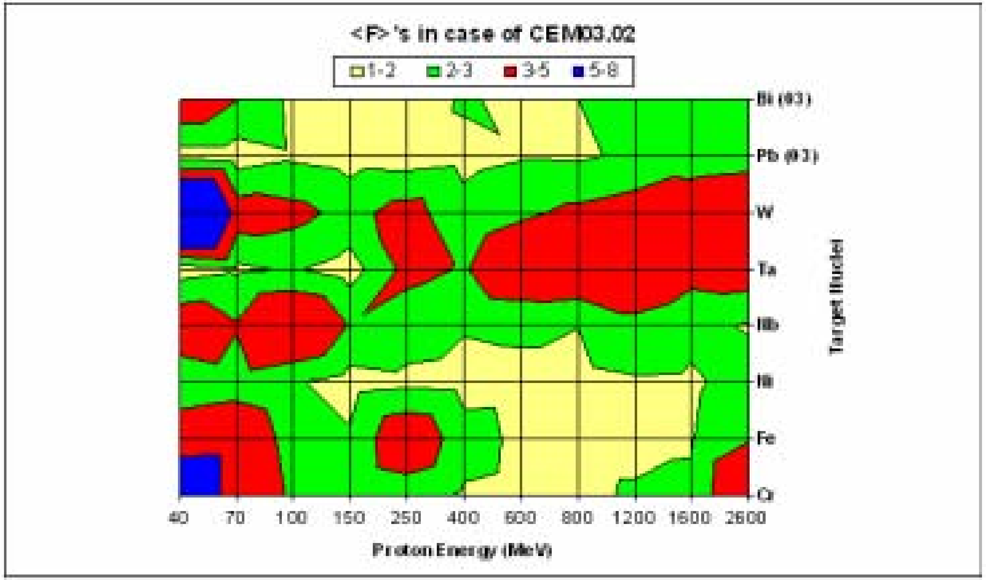




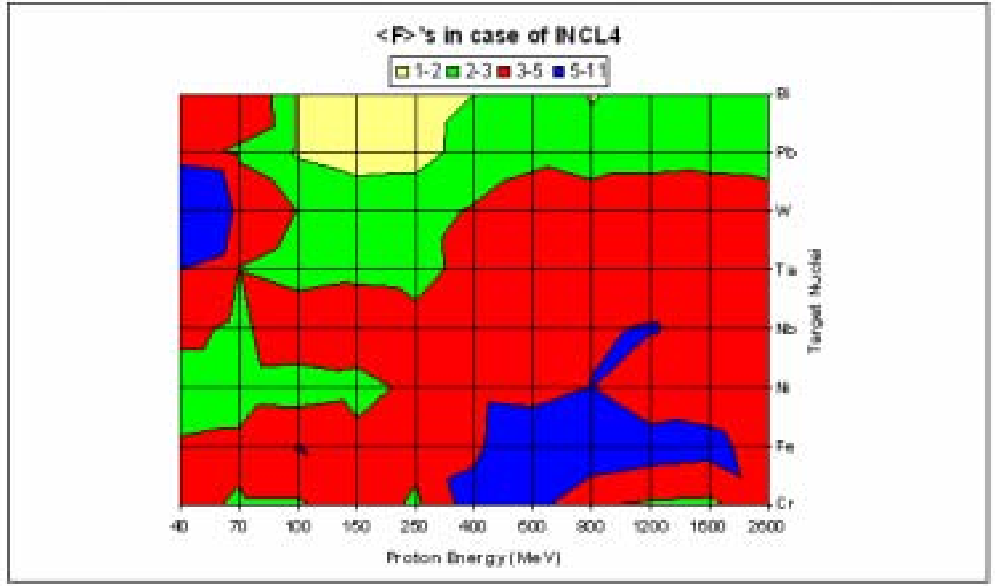




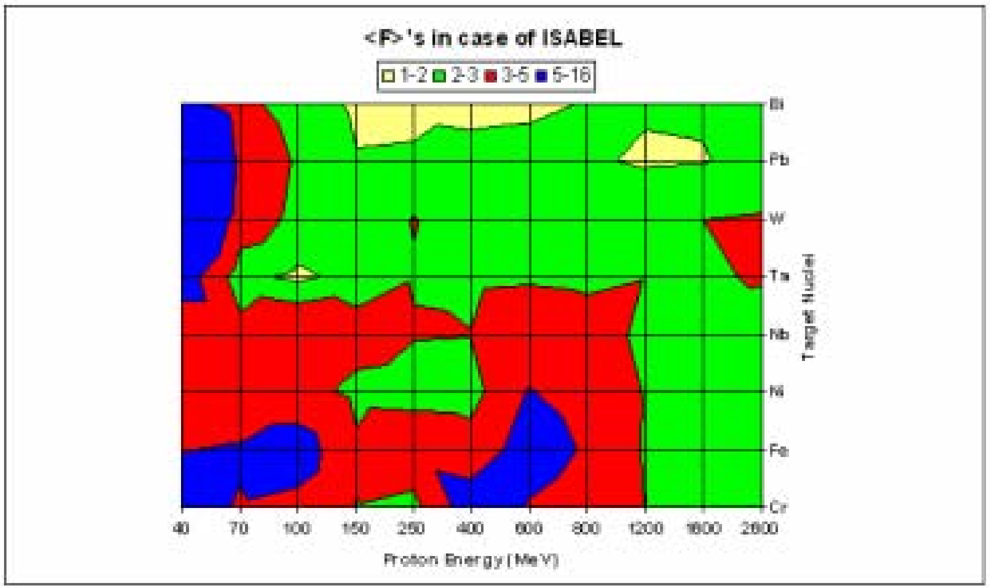
<F> map



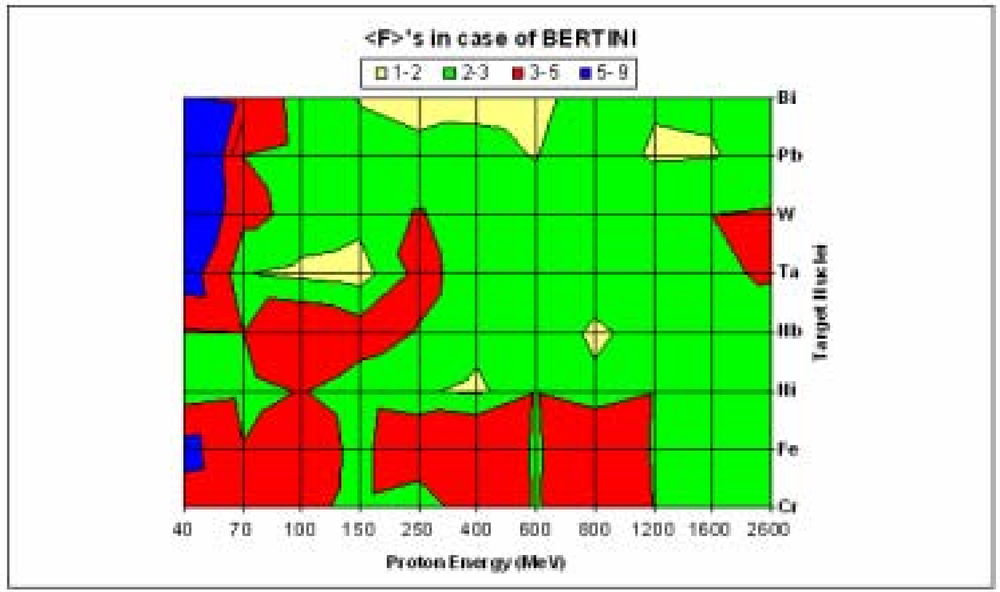
<F>'s in case of CEM03.02
1-2 2-3 3-5 5-8
Bi (03)
Pb (03)
W
Ta
Nb
Ni
Fe
Cr
Target Nuclei
40 70 100 150 250 400 600 800 1200 1600 2600
Proton Energy (MeV)



<F>'s in case of INCL4
1-2 2-3 3-5 5-11
Bi
Pb
W
Ta
Nb
Ni
Fe
Cr
Target Nuclei
40 70 100 150 250 400 600 800 1200 1600 2600
Proton Energy (MeV)



<F>'s in case of ISABEL
1-2 2-3 3-5 5-16
Bi
Pb
W
Ta
Nb
Ni
Fe
Cr
Target Nuclei
40 70 100 150 250 400 600 800 1200 1600 2600
Proton Energy (MeV)



<F>'s in case of BERTINI
1-2 2-3 3-5 5-9
Bi
Pb
W
Ta
Nb
Ni
Fe
Cr
Target Nuclei
40 70 100 150 250 400 600 800 1200 1600 2600
Proton Energy (MeV)

Conclusions

- 14518 residual nuclides were measured during 1997-2009:

Proton energy (GeV)	Targets																				
	^{nat}Cr	^{56}Fe *	^{nat}Ni	^{59}Co	^{63}Cu	^{65}Cu	^{93}Nb	^{99}Tc	^{181}Ta	^{182}W	^{183}W	^{184}W	^{186}W	^{nat}W	^{nat}Hg	^{206}Pb	^{207}Pb	^{208}Pb	^{nat}Pb	^{209}Bi	^{232}Th	^{nat}U
0.04	14	18	20				19		9					19		13	9	8	18	13		
0.07	17	21	22				28		17					31		28	29	28	28	35		
0.1	19	24	27				37	18	31					45	44	46	42	36	43	50	87	108
0.13				25	11	6										22	22	20		26		
0.15	22	25	28				46		40					53		65	65	63	63	71		
0.2				29	29	29		39		32	35	36	36		65						128	123
0.25	28	33	37				58		53					69		94	94	94	95	106		
0.4	31	37	36				64		82					83		112	112	113	116	128		
0.6	33	38	40				75		101					104		139	140	141	141	147		
0.8*	33	38	43				85	72	105	70	76	77	60	110	103	156	152	154	154	162	130	195
1.0		38						64										114				
1.2	33	39	43	41	47	54	96	67	143					155		170	170	170	171	183	214	226
1.5		38			35	36										92	93	94	93	99		
1.6	33	38	46	41	42	47	106	78	152	109	111	114	119	164		180	180	182	181	192	212	231
2.6	33	38	46	41	42	48	107	85	166					181	141	171	171	172	178	198		

* - Moreover, ^{197}Au was irradiated at 0.8GeV (101 product measured) and ^{56}Fe at 0.3, 0.5 and 0.75GeV (107 products)

x – high flux irradiations to measure 148Gd.

Results: #839: http://www-nds.iaea.org/reports/indc-ccp-434.pdf; EXFOR Data files#: O0781, O0782, O0978-O0987, O1018-O1021

#2002: http://www.nea.fr/html/science/egsaatif/ISTC2002-final-report.pdf

- <F> for “structure” materials is much higher <F> for “target materials” (only CEM03.02 can reproduce Fe, Cr, Ni at 0.5-1.0 GeV with <F> below 2);
- Further experimental activity should be shifted to low and middle mass targets (for instance, Mo, Ti, Zr, Sn, In)