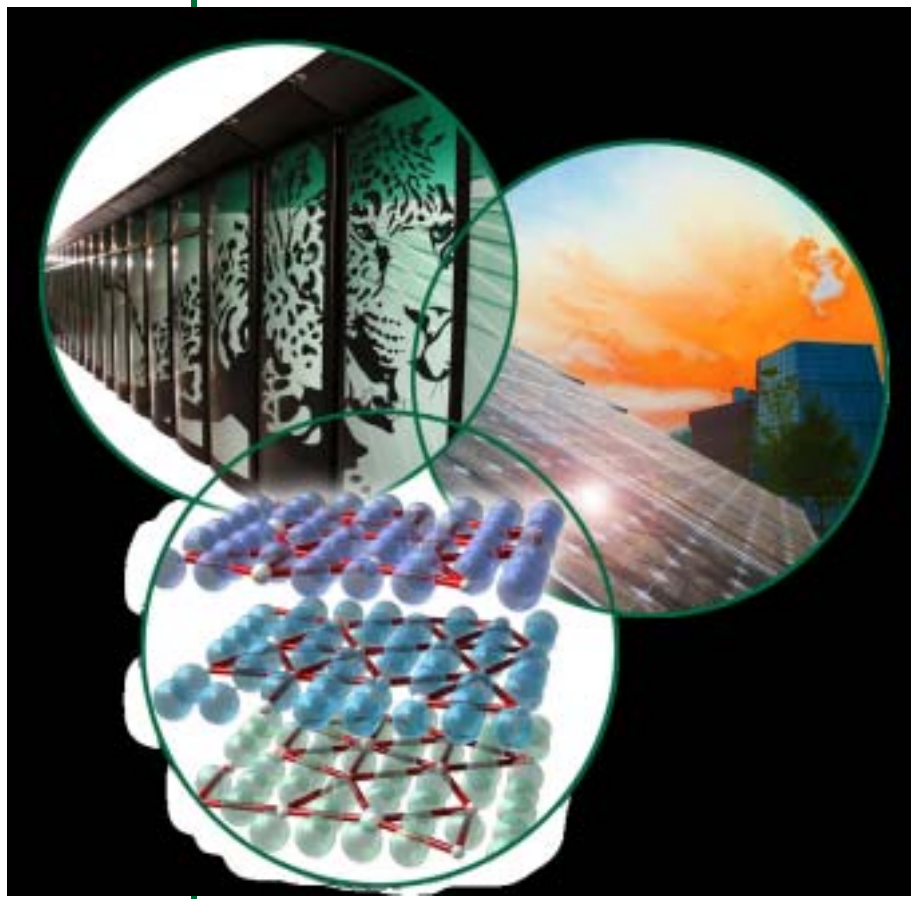
The Light Charged Particle Benchmark Evaluation



Workshop on Spallation Model Benchmark

February 8-11, 2010

Franz Gallmeier

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

Outline

- Previous benchmark effort
- Experimental data
- Contributing codes and code combinations
- Rating scheme
- General Findings
- Specific findings

Previous Benchmarking efforts

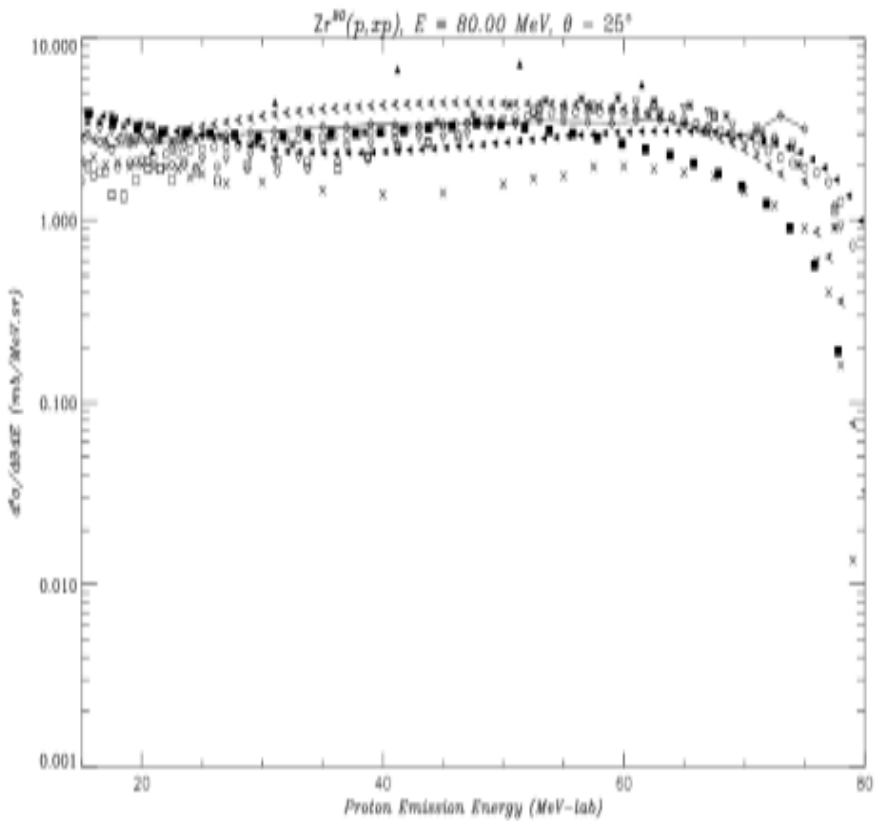
- **NEA: "International Code Comparison for Intermediate Nuclear Data" Blann et al, 1993**

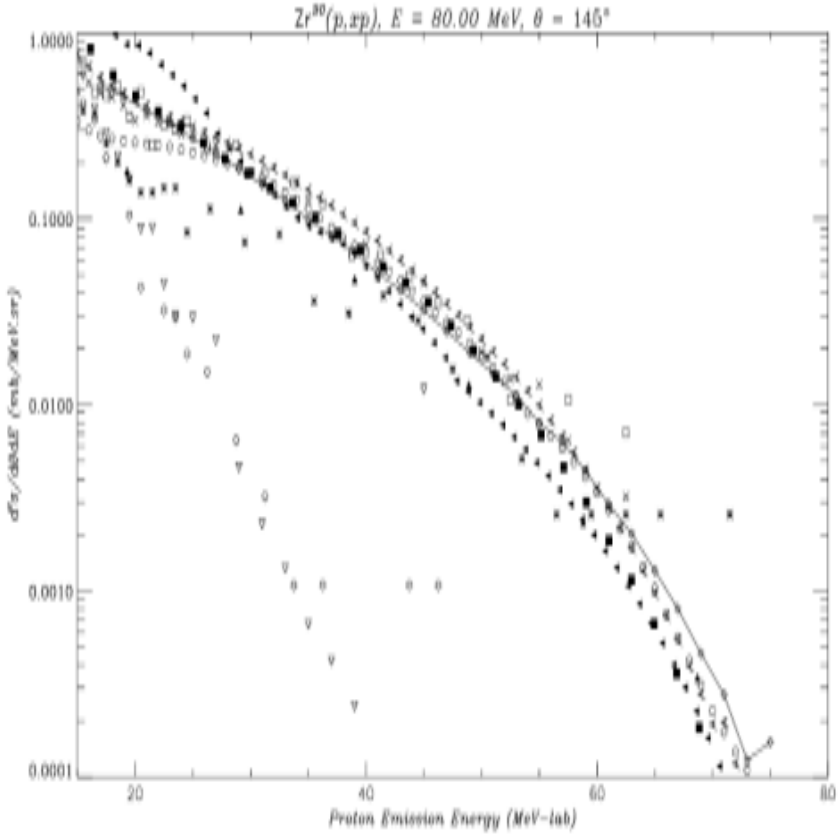
"Emphasis has been placed on thin target double differential cross sections, for which ^{90}Zr and ^{208}Pb target nuclei were selected. Experimental double differential cross section data are compared with calculated results at incident proton energies of 25, 45, 80, 160, 256 and 800 MeV for (p, xn) reactions, and at incident energies of 80 and 160 MeV for ^{90}Zr (p, xp) reactions. Calculated (p, xp) double differential spectra are presented at 25, 45, 256, 800 and 1600 MeV, and (p, xn) double differential cross sections are presented at 1600 MeV; however, no comparisons with experimental data are made for these cases."

- **NEA: Summary and Recommendations for Microscopic Nuclear Physics Development: Thin target benchmark**

Blann: "We feel that there may not be a good theory for predicting yields of clusters (deuterons and heavier) beyond those which evaporate at equilibrium. It is therefore premature to try to benchmark codes for this aspect…."

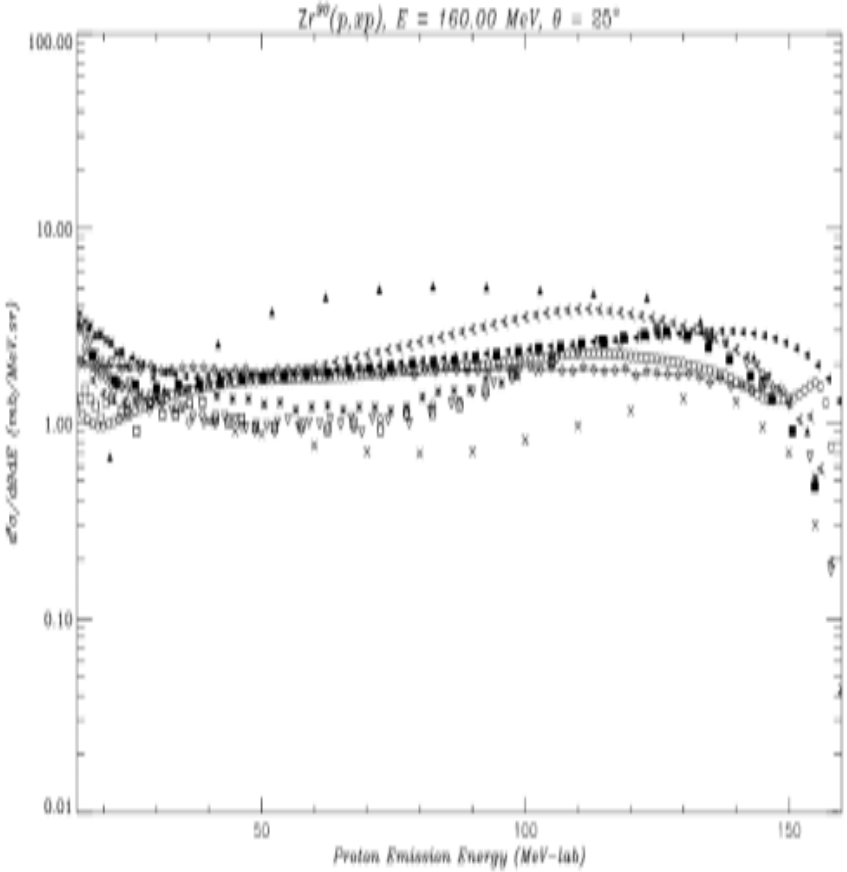
Previous benchmark efforts (cont.)

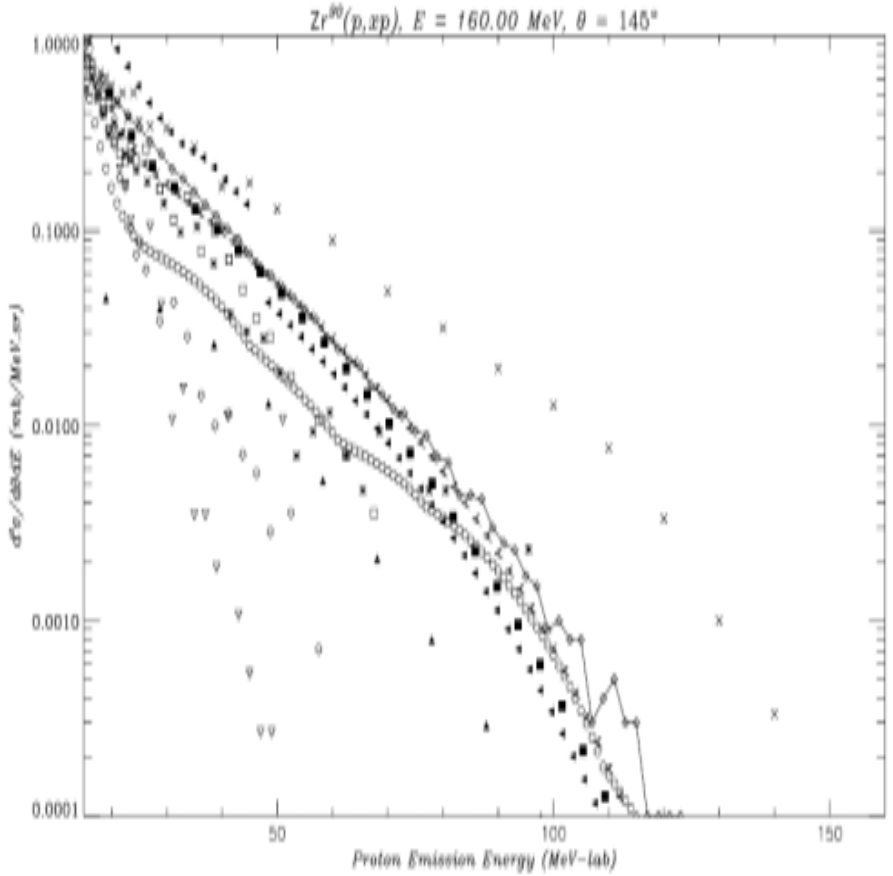




- **Many of the contributors at low incident energies were semi-classical precompound models**

Previous benchmark efforts (cont.)



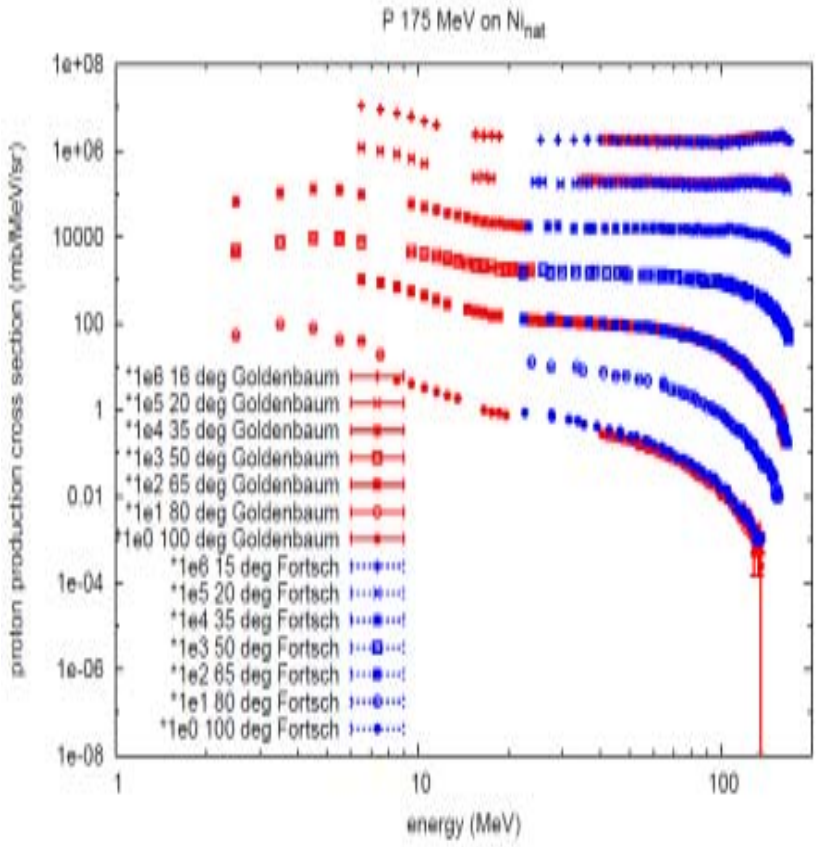


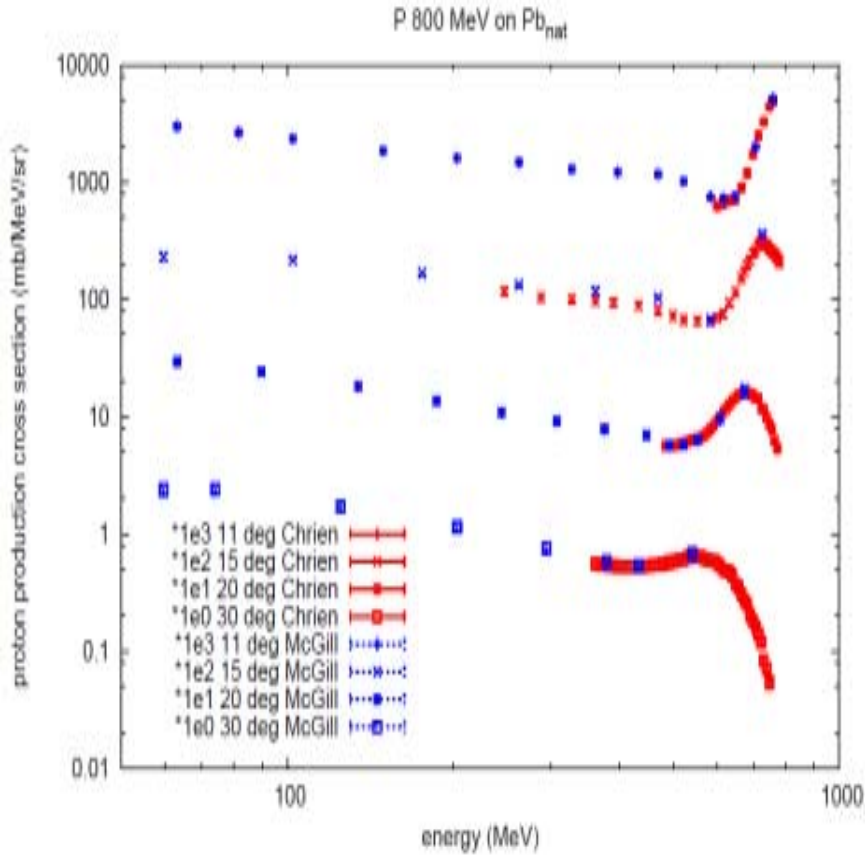
- **LAHET physics is very close to MCNPX-Bertini-Dresner (x)**
- **CEM92 has developed to CEM03 (Δ)**
- **GEANT3 concerted to GEANT4 (▼)**

Experimental data

Beam	Target	Beam Energy [MeV]	Emitted particles	Emission angles [deg]	Emission energies [MeV]	Reference
n	Bi	542	p, d, t	54 -164	20-500	J. Franz et al., Nucl. Phys. A 510 (1990) 774
p	Al	160	α	20-140	20-160	A. Cowley et al., Phys. Rev. C 54 (1996) 778
p	Fe	62	p, d, t, ^{3}He, α	20-135	5-62	F.E. Bertrand and R.W. Pelle, Phys. Rev. C 8 (1973) 1045
p	Ni	175	p, d, t, ^{3}He, α p	16-100 15-120	2-175 20-175	F. Goldenbaum et al., (unpublished) S.V. Förtsch et al., Phys. Rev. C 43 (1991) 691
p	Ta	1200	p, d, t, ^{3}He, α	30-150	2-100	C.-M. Herbach et al., Nucl. Phys. A 765 (2006) 426
p	Au	160	α	20-140	20-160	A. Cowley et al., Phys. Rev. C 54 (1996) 778
p	Au	1200	p, d, t, ^{3}He, α	16-100	2-250	A. Budzanowski et al., Phys. Rev. C 78 (2008) 024603
p	Au	2500	p, d, t, ^{3}He, α	30-150 16-100	2-150 2-150	A. Letourneau et al., Nucl. Phys. A 712 (2002) 133 A. Bubak et al., Phys. Rev. C 76 (2007) 014618
p	Pb	63	p, d, t, ^{3}He, α	25-155	5-60	A. Guertin et al., Eur. Phys. J. A 23 (2005) 49
p	Pb208	800	p	11-30 5-30	200-800 50-800	R. Chrien et al., Phys. Rev. C 21 (1980) 1014 J.A. McGill et al., Phys. Rev. C 29 (1984) 204
p	Bi	62	p, d, t, ^{3}He, α	15-160	5-60	F.E. Bertrand and R.W. Pelle, Phys. Rev. C 8 (1973) 1045

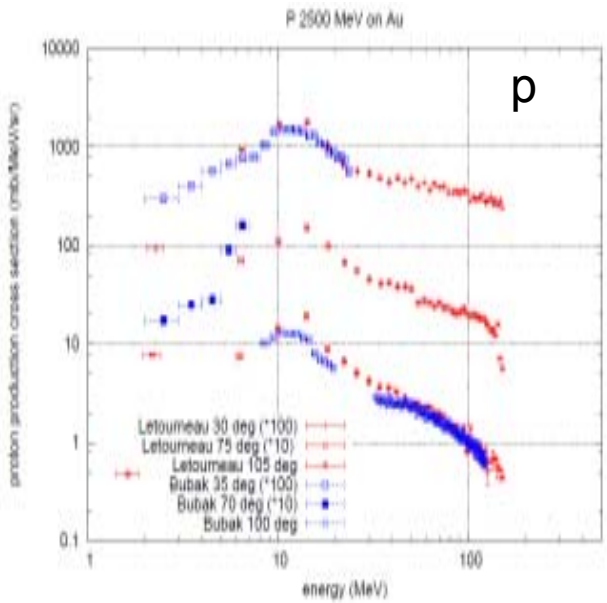
Experimental Data (cont.)

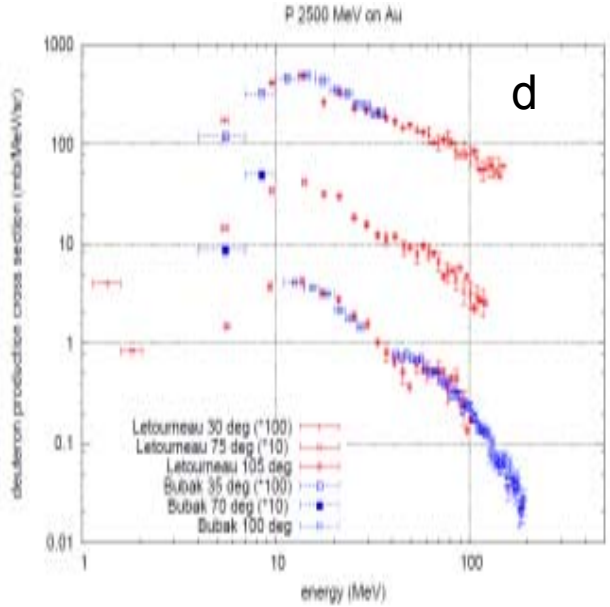


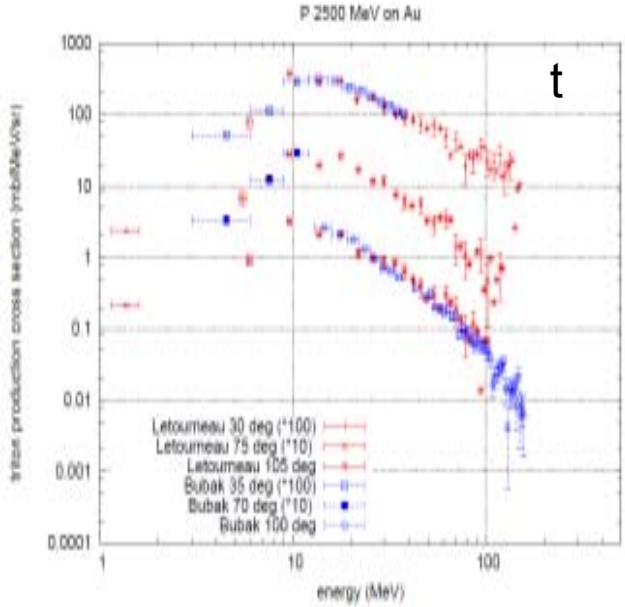


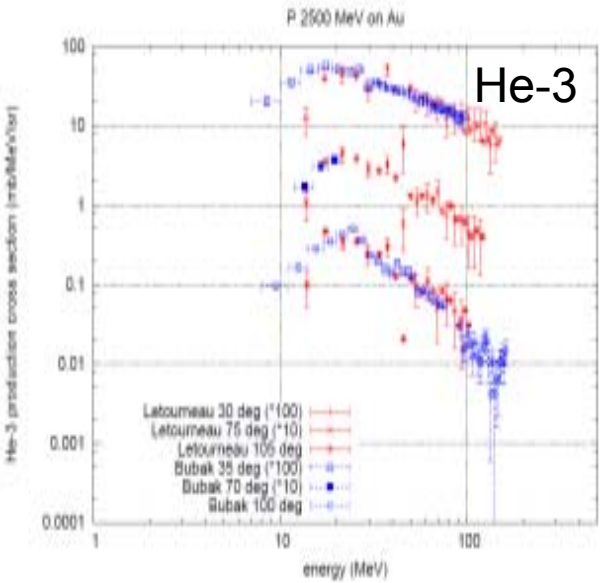
- **Overlap in experimental data sets allows comparison**
  - **Goldenbaum-Frötsch; Chrien-McGill**

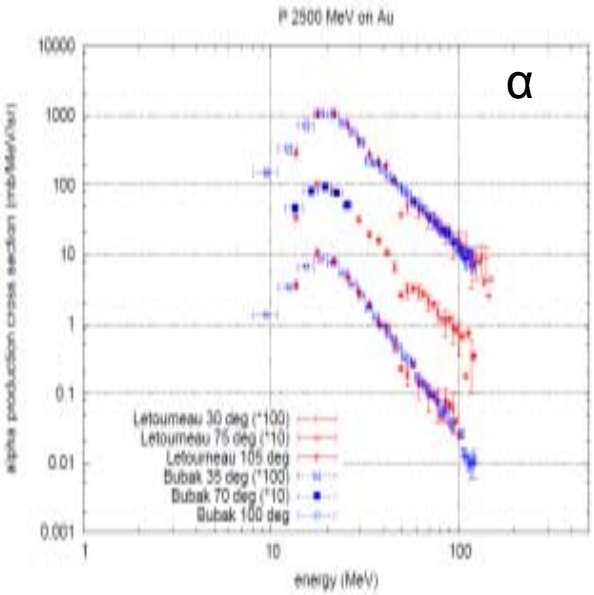
Experimental Data (cont.)











- **Bubak vs Letourneau 2500 MeV protons on Au**

Experimental data (cont.)

- **Wishlist:**
  - **Data for medium mass targets at high incident energies**
  - **Data for high mass targets at high energies extending the emission energy range to higher energies**
  - **Multiplicity data**
  - **Extending the light charged particle list to lithium, boron and beryllium isotopes**
  - **Light mass targets**

Contributing Codes

Model	Abreviation	Contributors
Cascade04	cascade04	H. Kumawat
Cascade-ASF	Cascadeasf	A. Konobeyev
CEM0302	cem0302	S. Mashnik
CEM0303	cem0303	A. Gudima
Geant4-Bertini	g4bert	D. Wright
Geant4-BIC	g4bic	D. Wright
INCL4.5-ABLA07	incl45-abla07	J. Cugnon/ A. Boudard/ A. Kelic/ V. Ricciardi/ D. Mancusi
INCL4.5-Gemini	incl45-gemini++	J. Cugnon/ A. Boudard/ R. Charity / D. Mancusi
INCL4.5-SMM	incl45-smm	J. Cugnon/ A. Boudard/ A. Botvina/ D. Mancusi
Isabel-ABLA07	isabel-abla07	Y.Yariv / A. Kelic / V. Ricciardi / D. Mancusi
Isabel-Gemini	isabel-gemini	Y.Yariv / R. Charity / D. Mancusi
Isabel-SMM	isabel-smm	Y.Yariv / A. Botvina / D. Mancusi
MCNPX-Bertini-Dresner	mcnpx-bert	F. Gallmeier/ W. Lu
PHITS-Bertini	phits-bertini	N. Matsuda
PHITS-jam	phits-jam	N. Matsuda
PHITS-JQMD	phits-jqmd	N. Matsuda

Rating Scheme

- **Coarse eye-guided rating**
- **Rated double differential production cross sections in two energy bands for each angular subset of a set of benchmark data:**
  - **1-150 MeV (wished I had split this range into 1-20 and 20-150 MeV)**
  - **Above 150 MeV**
- **Points earned for achieving an acceptance band around the experimental values:**

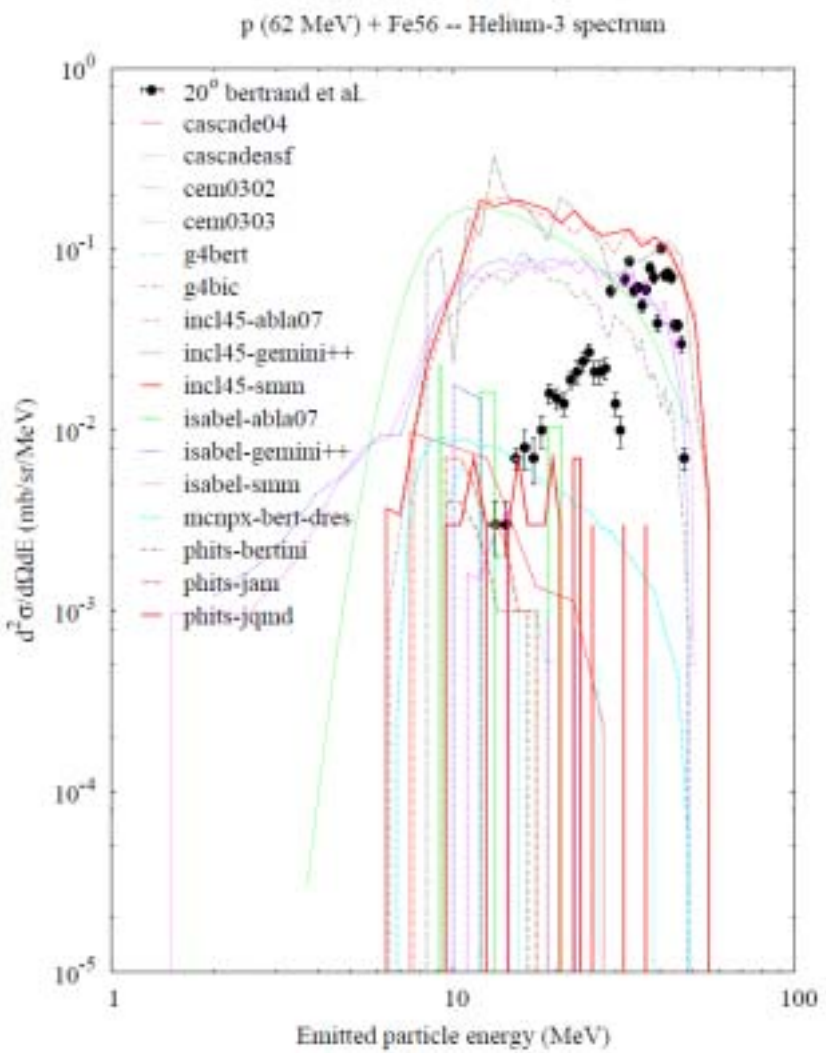
Acceptance band [eval/x ; eval*x]	Earned points
x=5	1
x=3	2
x=2	3
x=1.4	4

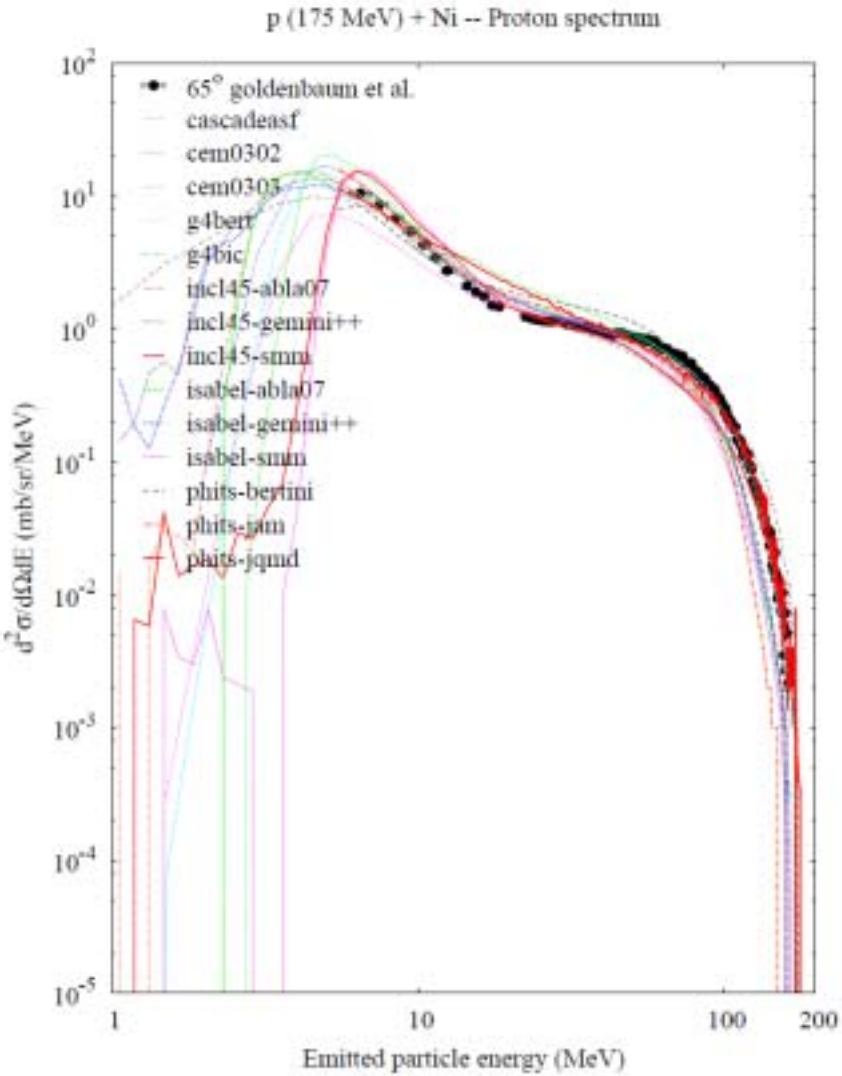
Rating Scheme (cont.)

- **Intention to switch to a mathematical approach close to FOM P**
- **Hope I can get hold of evaluation scripts used to do the FOMs**

Rating Scheme (cont.)

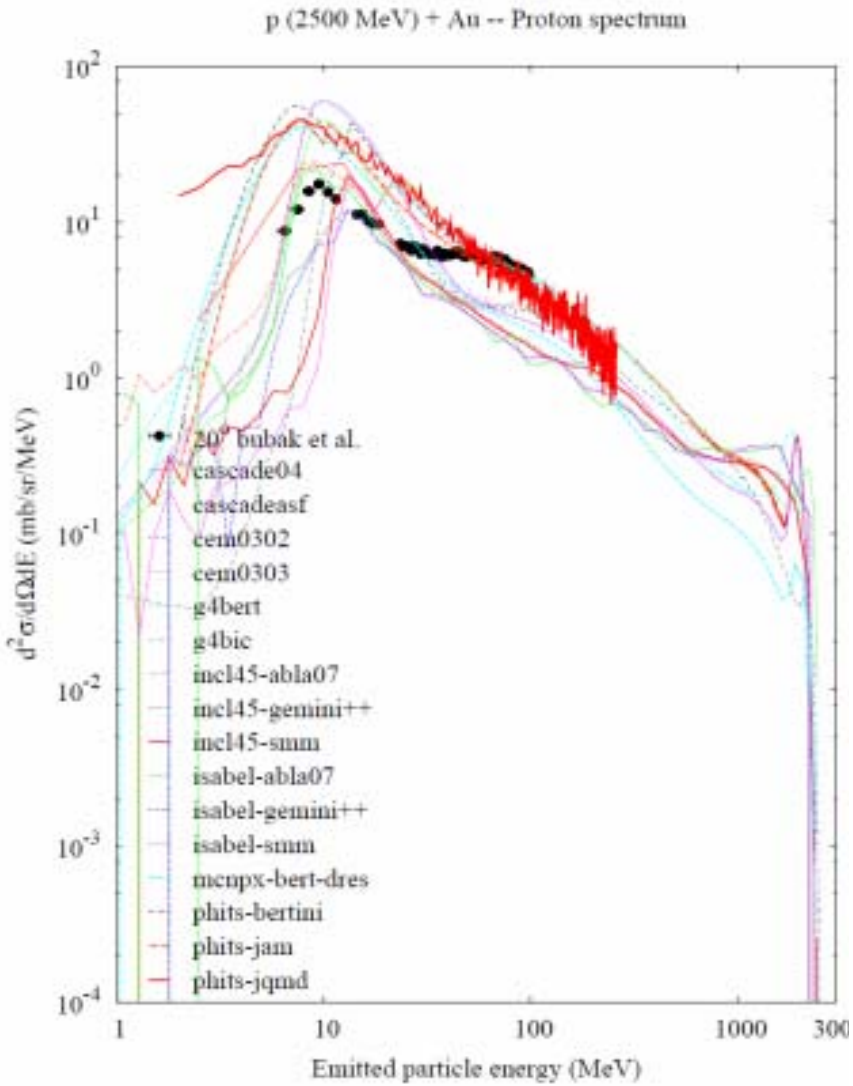
- **Extreme cases**

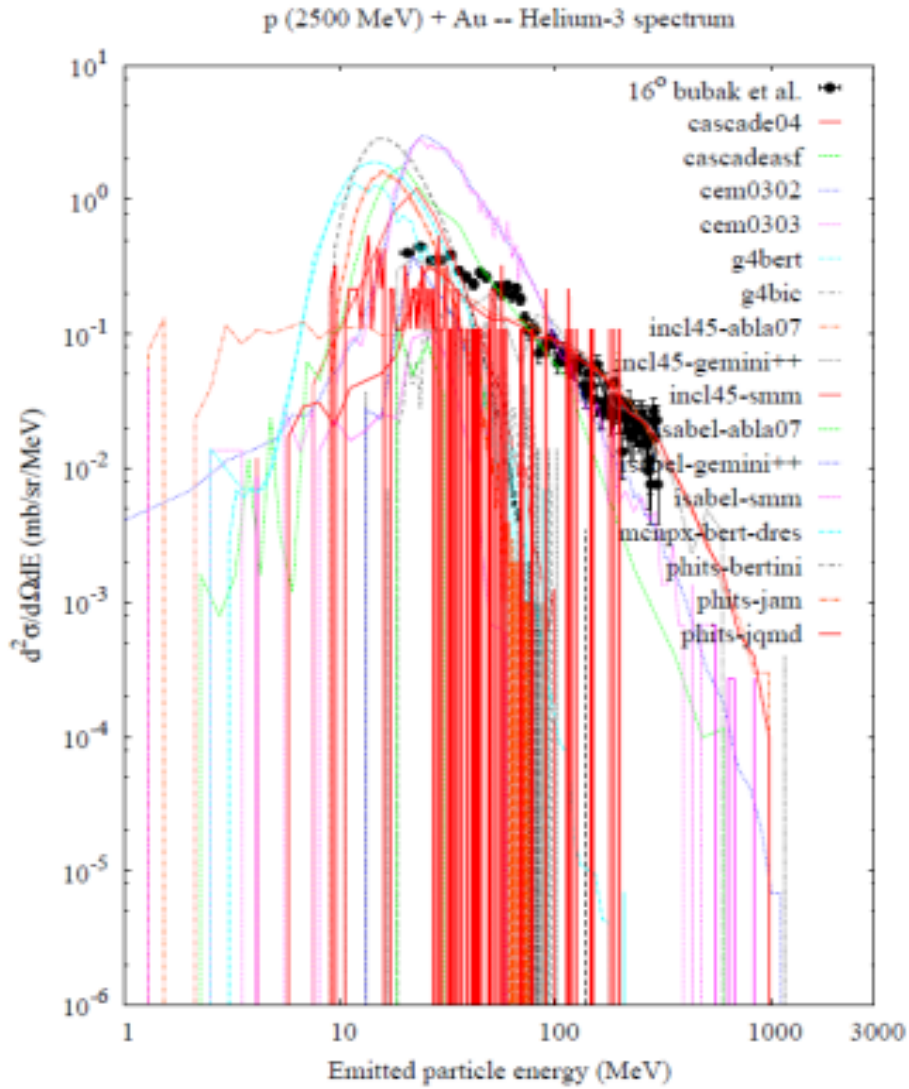




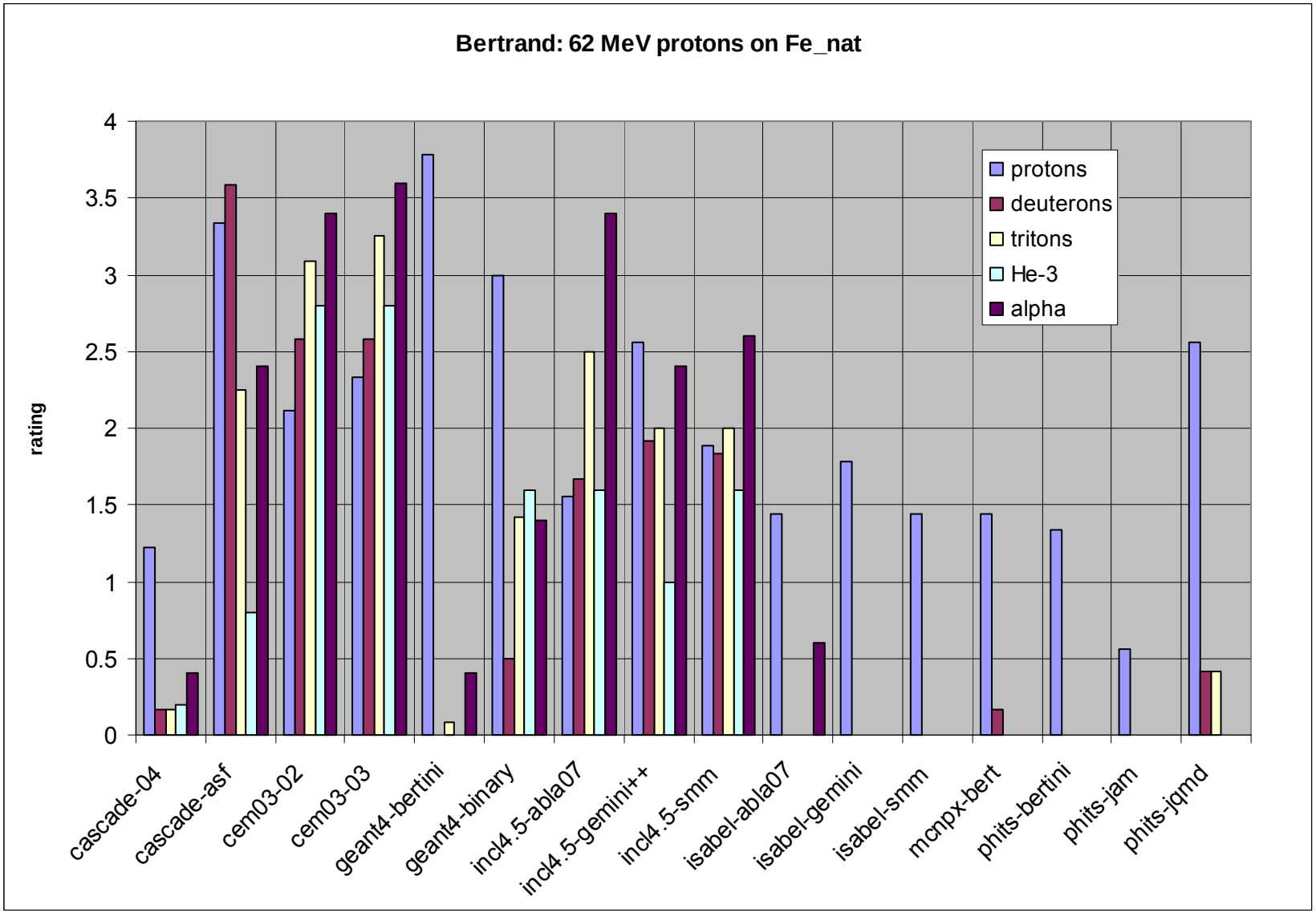
Rating Scheme (cont.)

- **Typical cases**

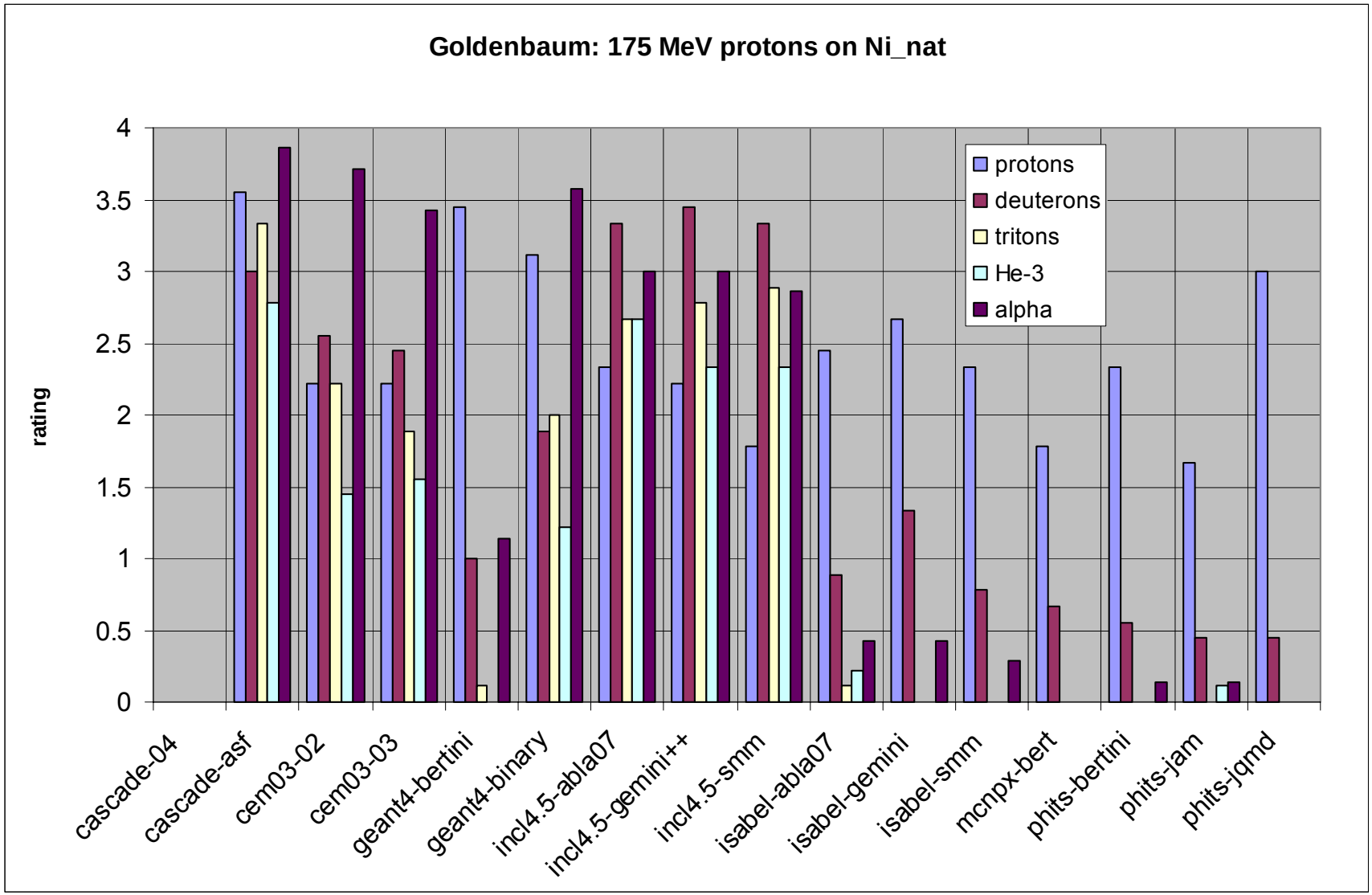




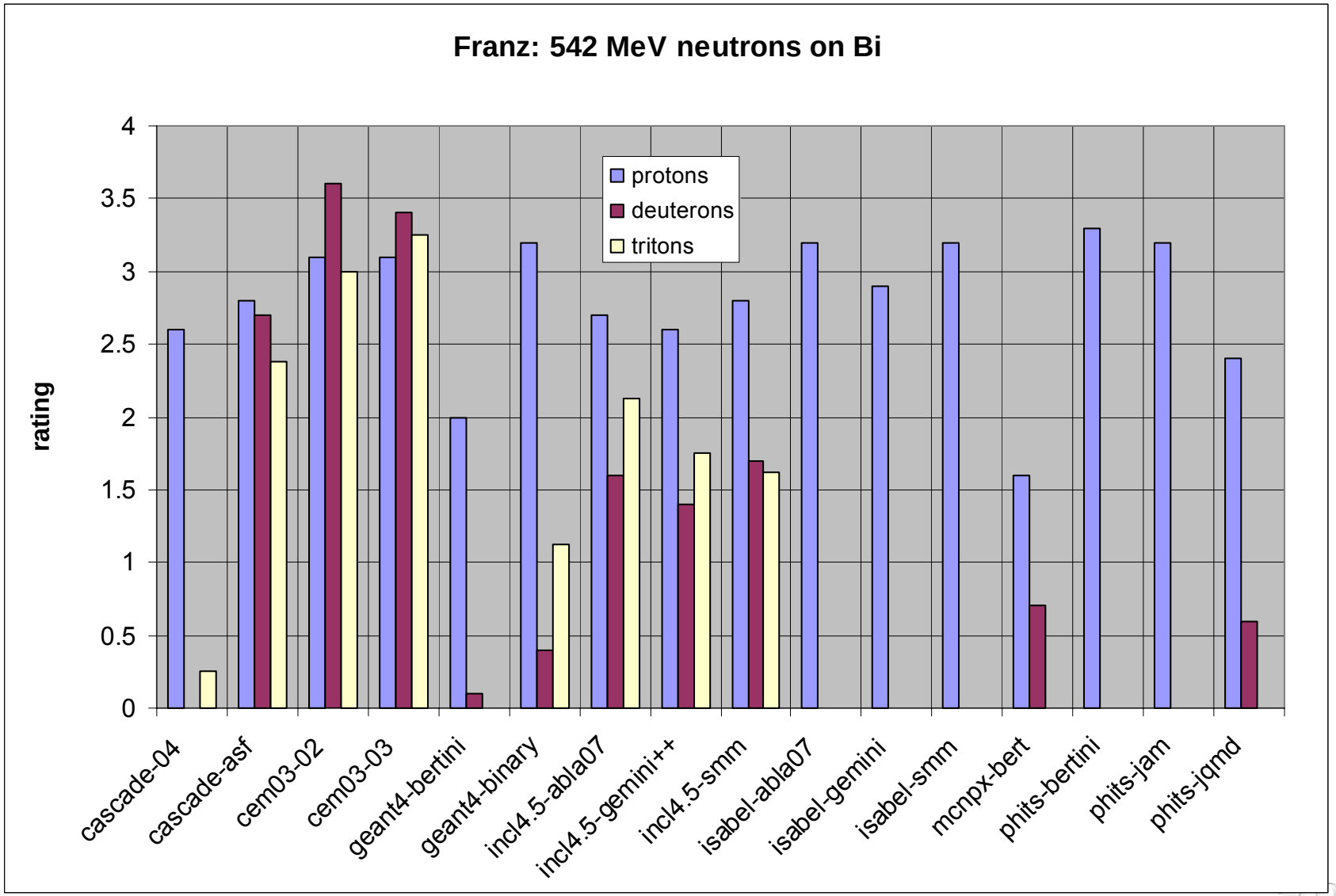
Bertrand 62 MeV protons on Fe-nat



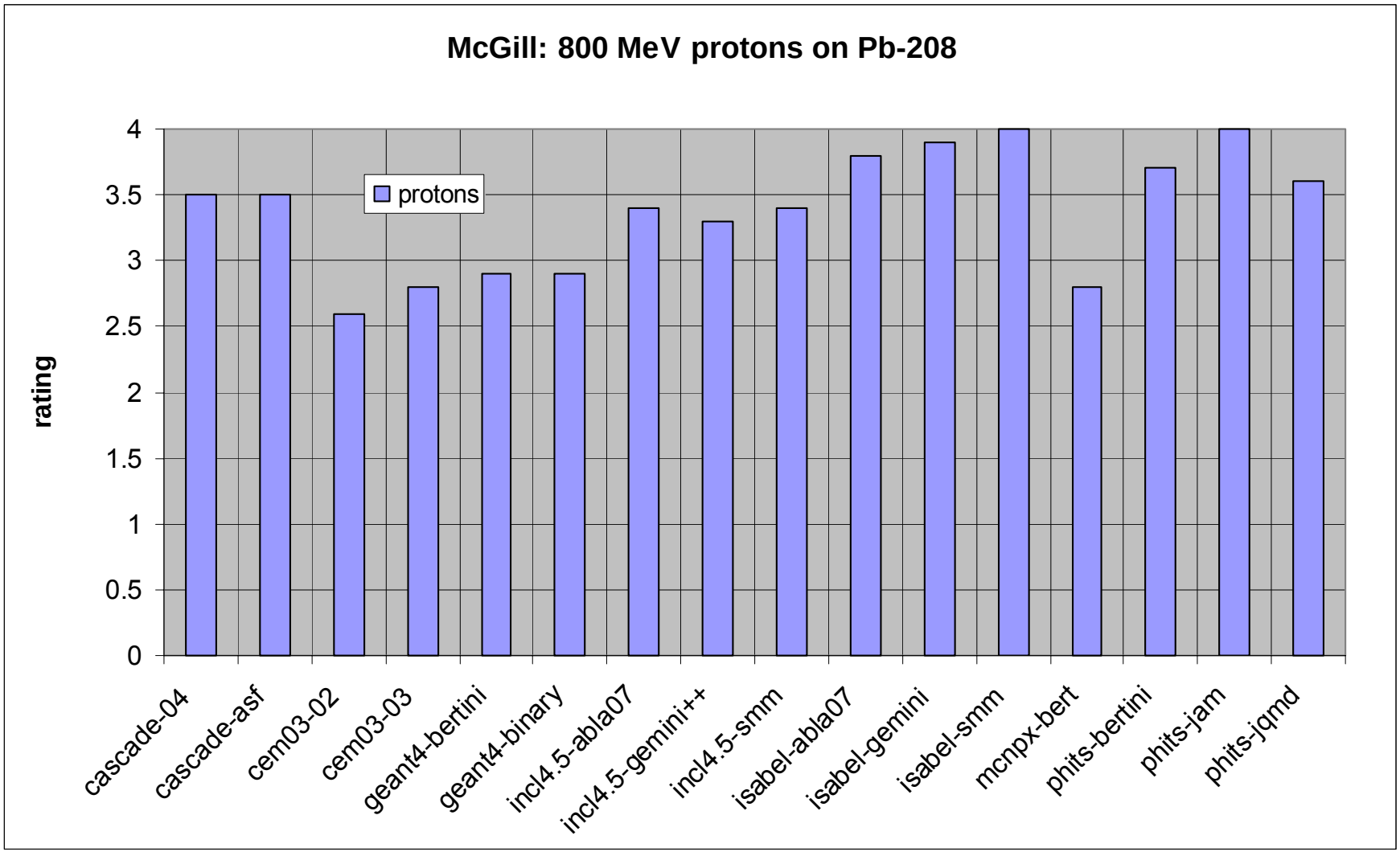
Goldenbaum: 175 MeV protons on Ni-nat



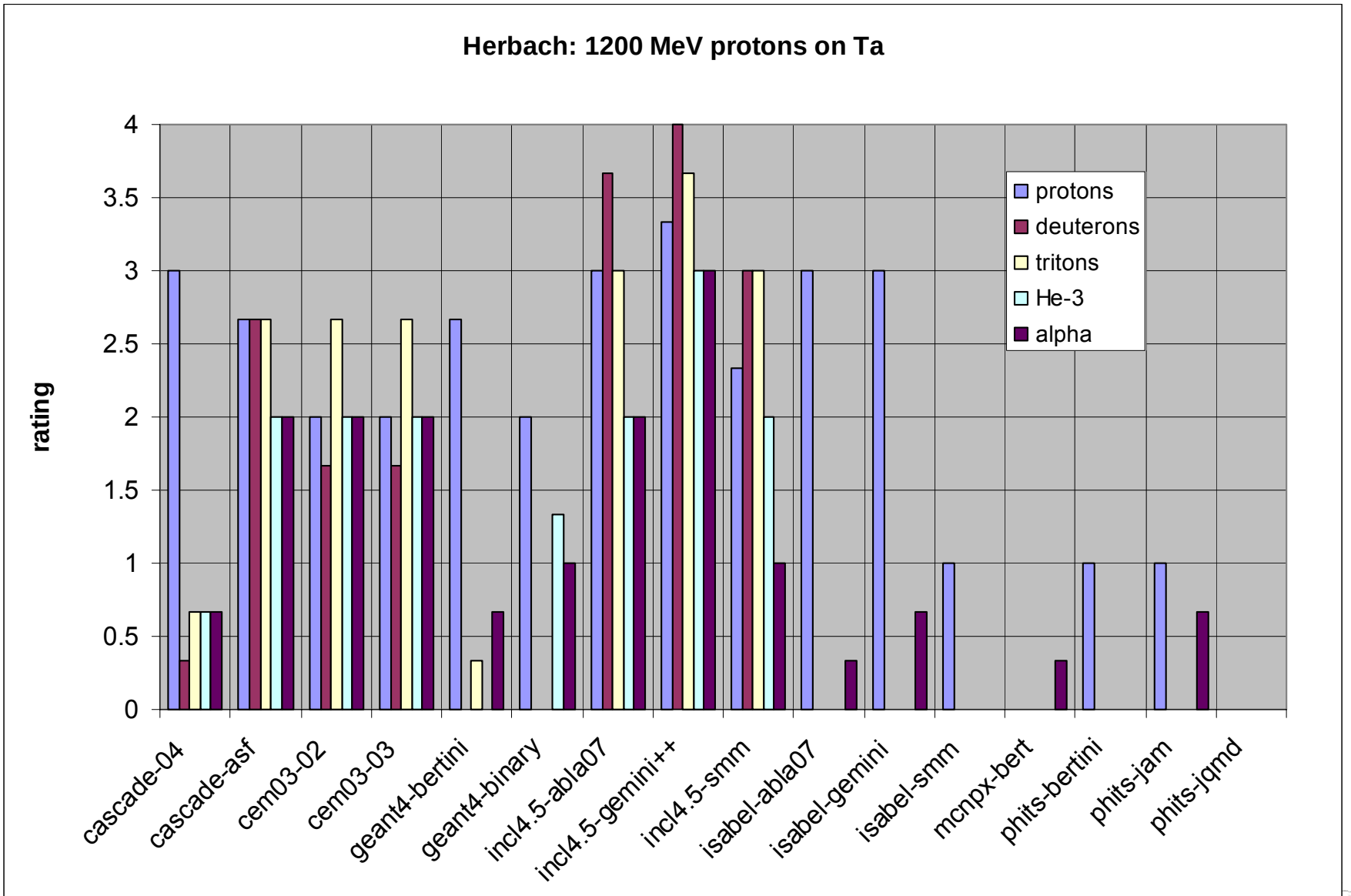
Franz: 542 MeV neutrons on Bi



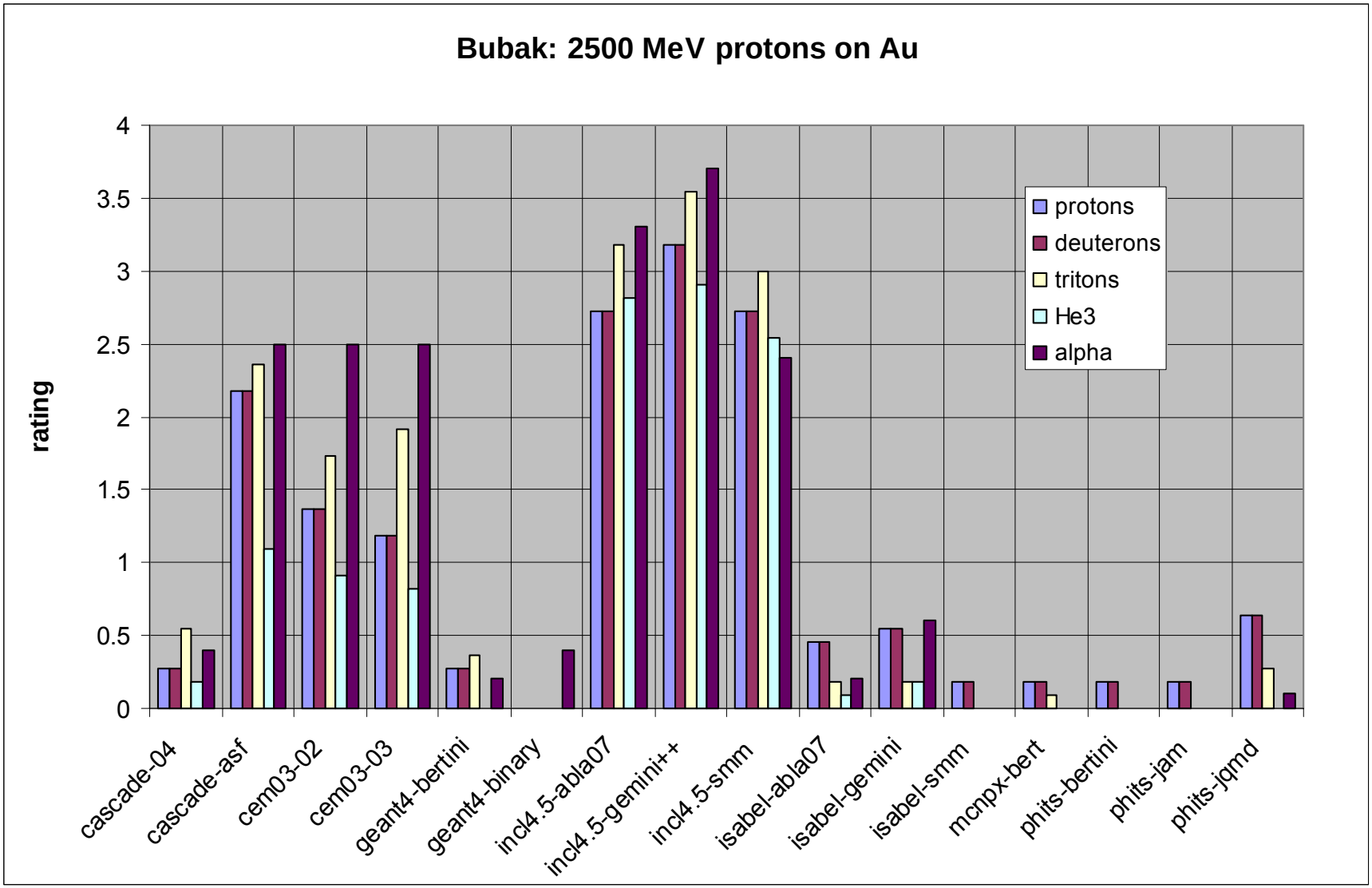
McGill: 800 MeV protons on Pb-208



Herbach: 1200 MeV protons on Ta



Bubak: 2500 MeV protons on Au



General Findings

- **No code is able to predict the benchmark data within a factor of 3 (corresponds to rating 2).**

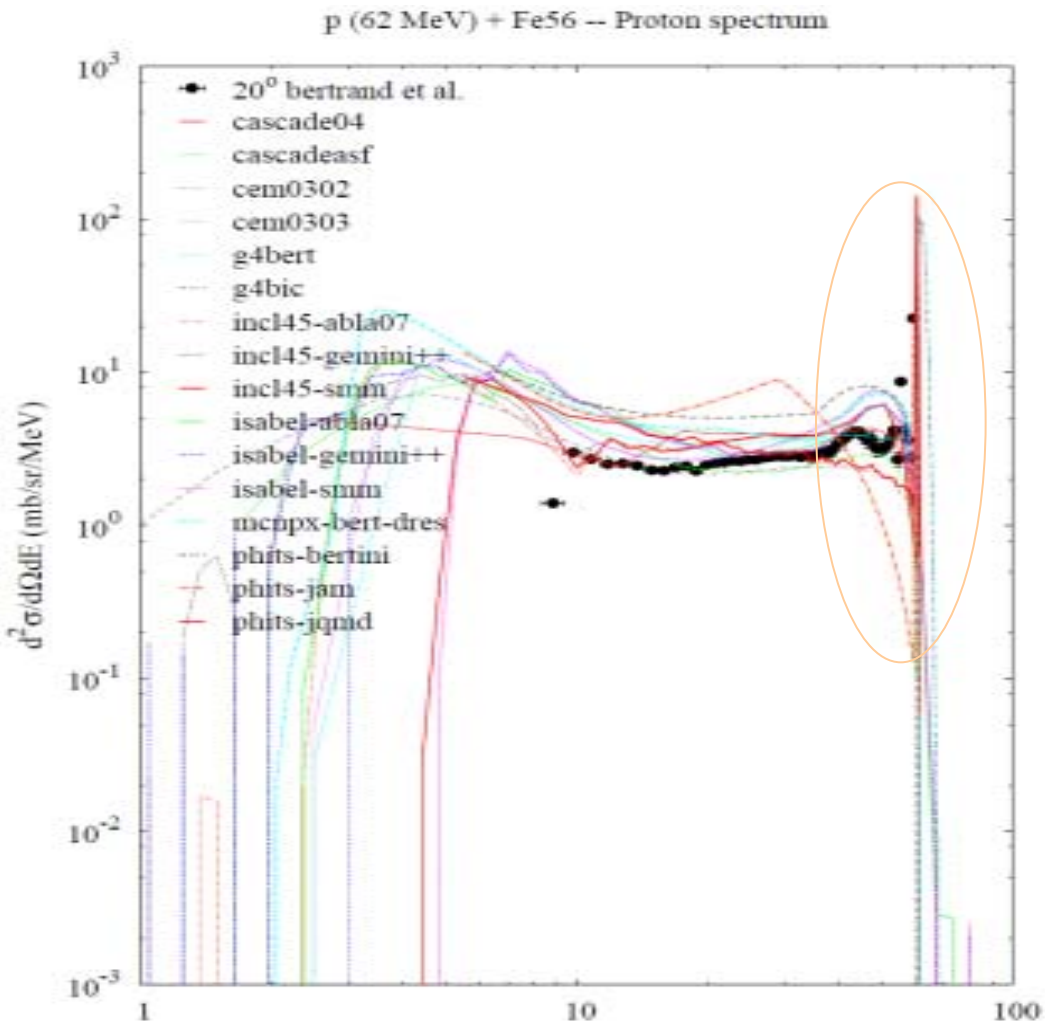
Emitted particle	Code-Data Averaged rating
protons	2.4
deuterons	1.2
tritons	1.2
He-3	0.9
alpha	1.3

General Findings (cont.)

- **7+ of the codes lack emission of composite particles in INC phase and are not able to describe the spectra at all**
- **There is a trend that CASCADE-ASF and CEM03 codes perform best under 1 GeV incident and show weaknesses above**
- **There is a trend that INCL4.5 codes perform weaker below 1GeV and improve above 1GeV**

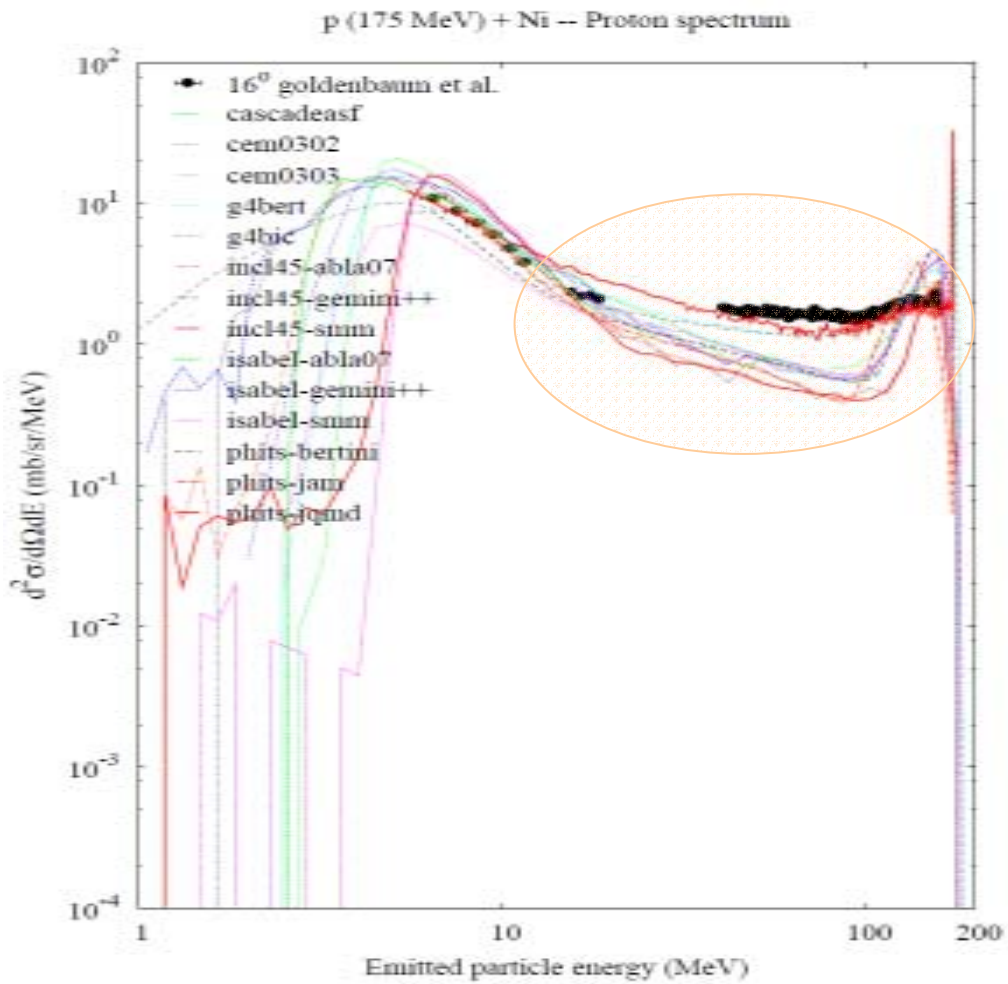
Specific Findings: 62 MeV p on Fe-56

- **The quasi-elastic peaks are generally not well captured**
- **The large discrepancies for the He-3 emission was shown already earlier**



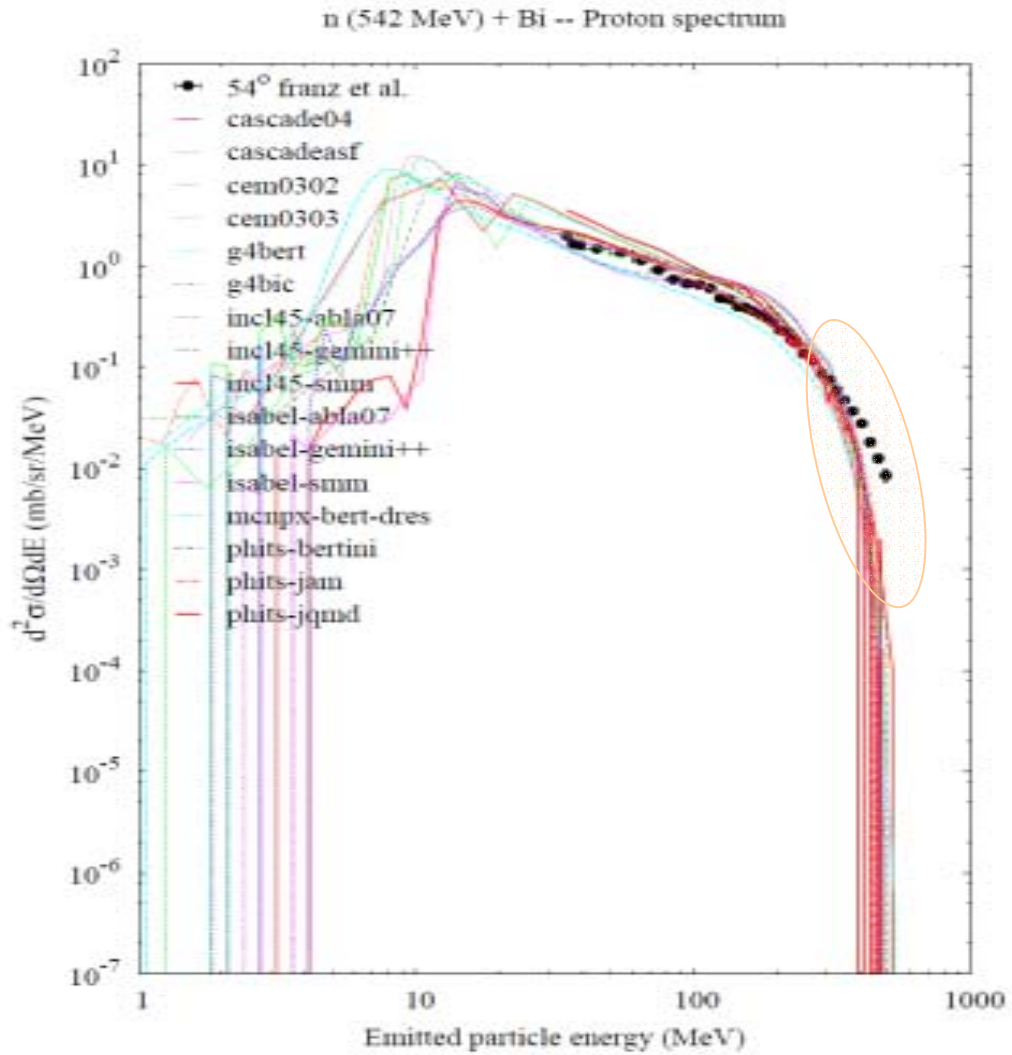
Specific Findings: 175 MeV p on Ni-nat

- **Bathtub-like depression at 20-80 MeV entering into a broad high-E peak in forward direction found in almost all calculations (except PHITS-JQMD and GEANT4-BIC)**



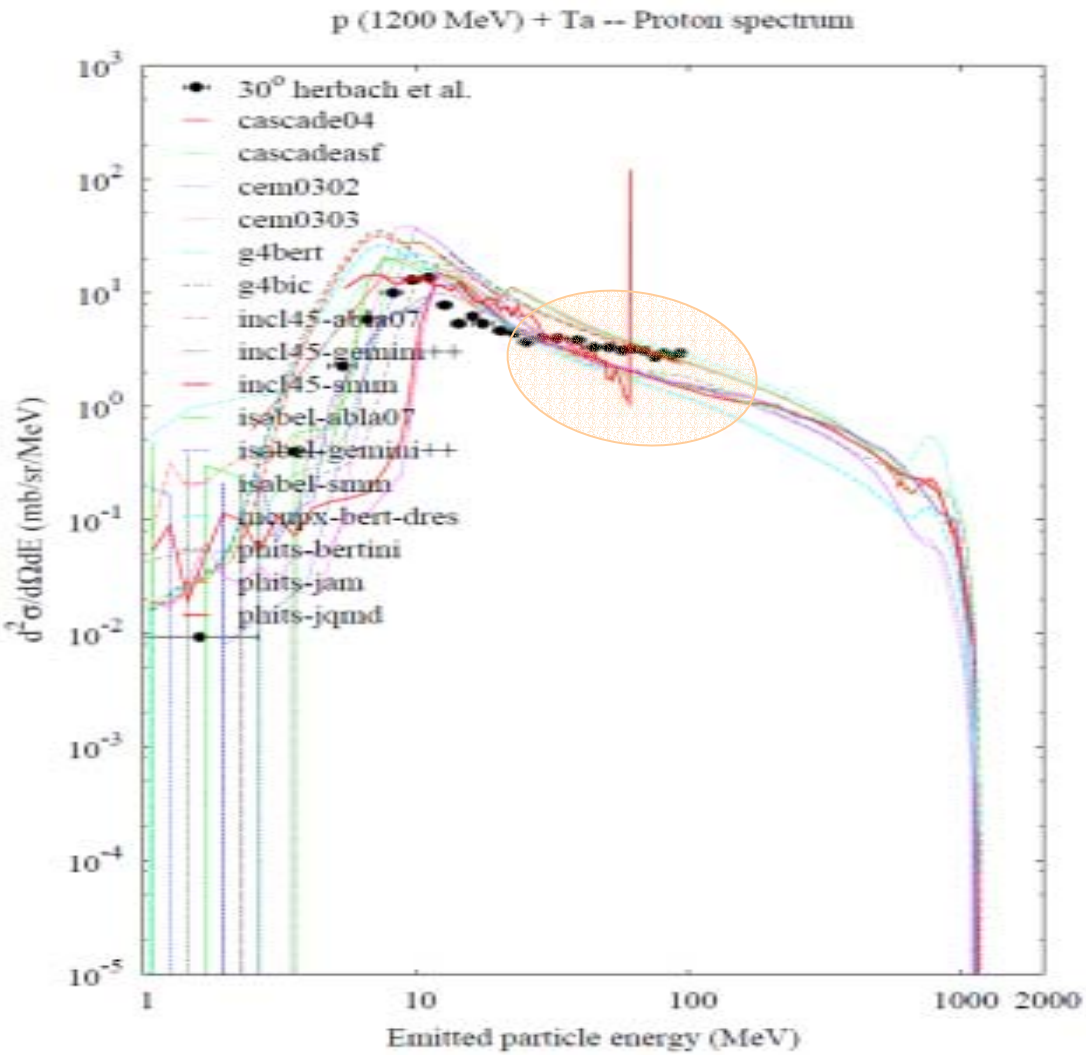
Specific Findings: 542 MeV n on Bi

- **Incident neutron energy is a distribution peaking at 542 MeV but extending to 590 MeV**
- **This may explain the deviations at high E**



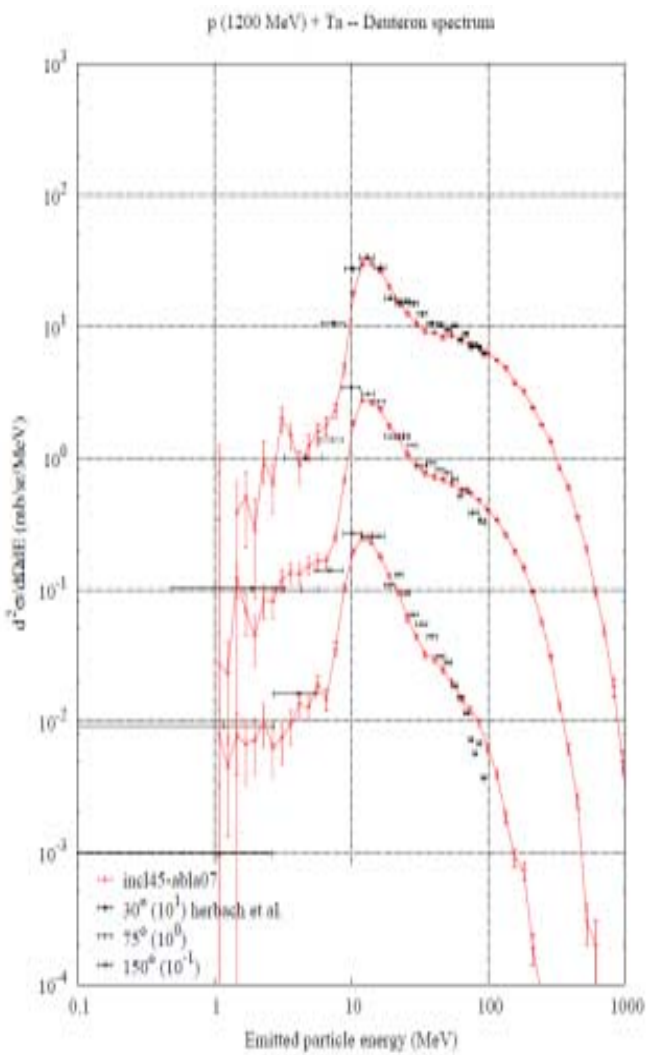
Specific Findings: 1200 MeV p on Ta

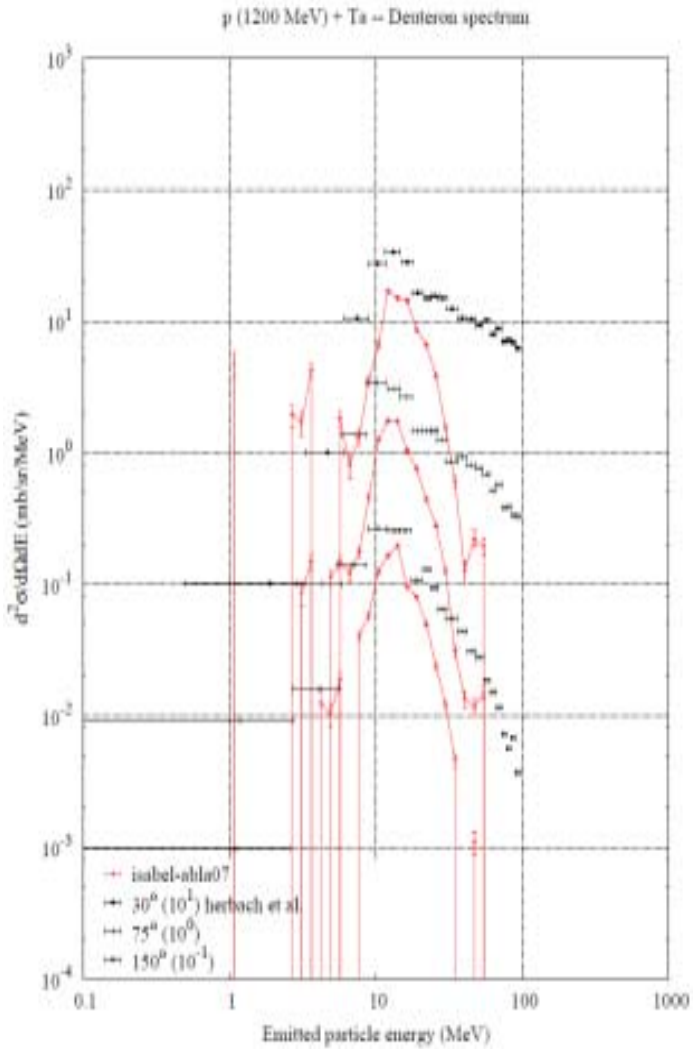
- **None of the codes describe the slope between 10 and 100 MeV for the most forward angle**



Specific Findings: 1200 MeV p on Ta

- **INCL4.5-ISABEL comparison both with ABLA07**
- **Pre-equilibrium emission is important**





Specific Findings: 2500 MeV p on Au

- **Again the transition from equilibrium emission to pre-equilbrium emission is starting almost flat.**
- **Data extending to higher energy would be nice to have.**