Second Advanced Workshop on Model Codes for Spallation Reactions

CEA-Saclay (France)
8 - 11 February 2010

Result global analysis: Neutrons

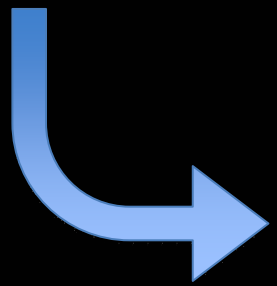
Jean-Christophe David

Objectives of this benchmark

- To assess the prediction capabilities of the spallation models
- To understand the reason for the success or deficiency of the models
- To reach a consensus, if possible, on some of the physics ingredients that should be used in the models

Objectives of this talk

• To assess the prediction capabilities of the spallation models on neutron production



- General Trends
- Each model

- **Methodology**
- **Results (and Open questions to developers)**

- **Data**
  - **17 models**
  - **4 average multiplicities**
  - **2 multiplicity distributions**
  - **13 (11) DDXS (3 energy ranges * 3 angle regions + peak = 10)**

→ ≈ 2000 Data (≈ 116 per model)

- **Data**
  - **17 models**
  - **4 average multiplicities**
  - **2 multiplicity distributions**
  - **13 (11) DDXS (3 energy ranges * 3 angle regions + peak = 10)**

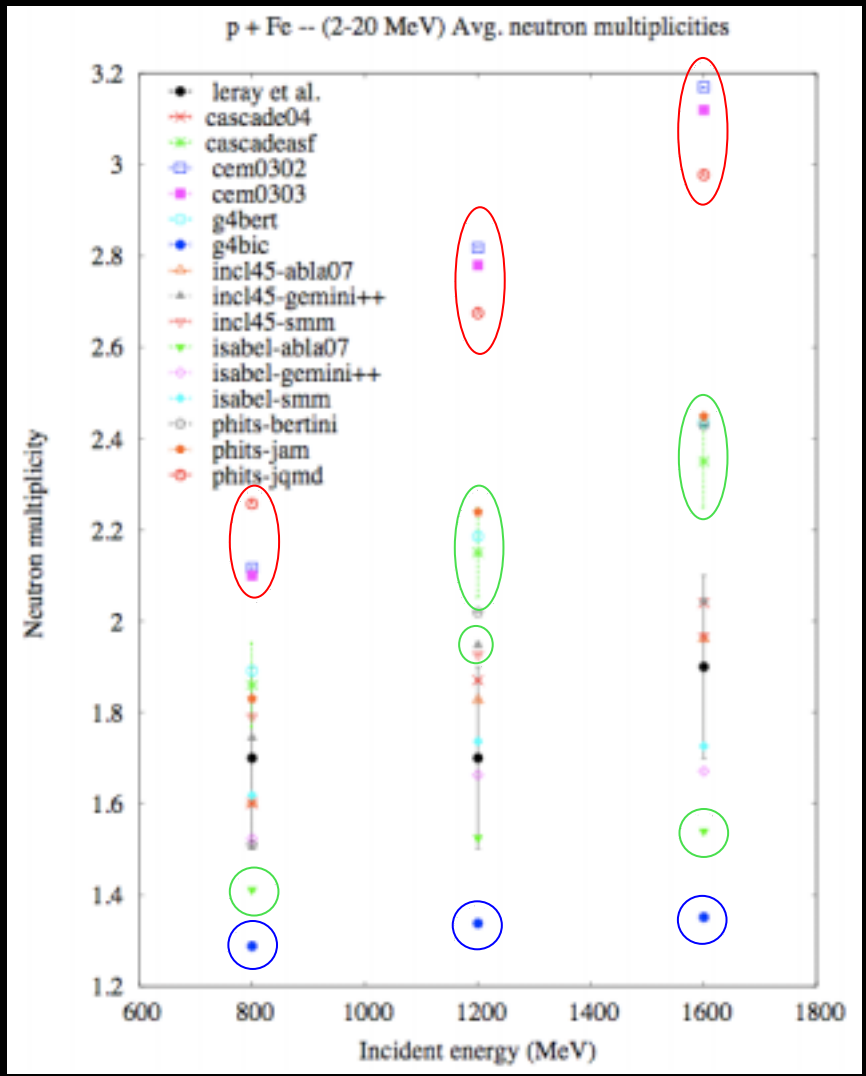
→ ≈ 2000 Data (≈ 116 per model)

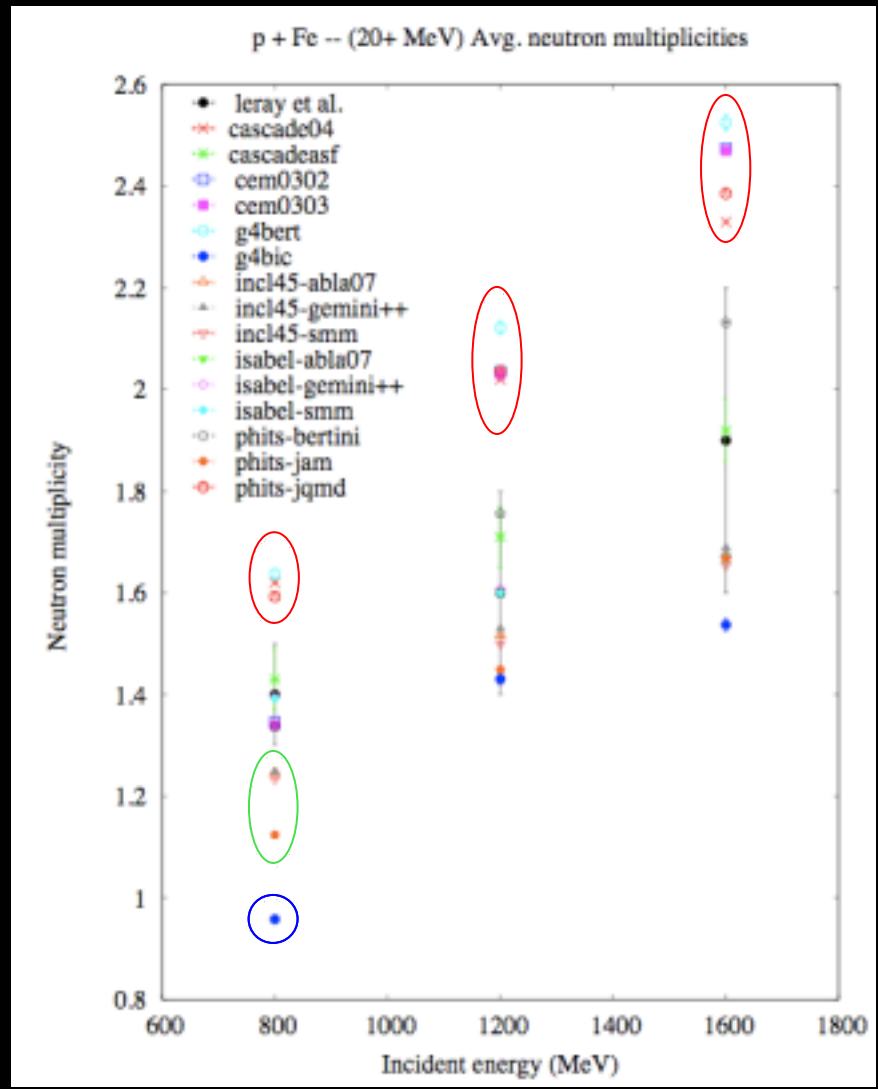
- **Tools**
  - **Figures**
  - **Deviation factors (or Figures of Merit) : 6**
    - **H Chi-square (0)**
    - **R Mean ratio - overestimation is penalized (1)**
    - **F Mean ratio - same weight over/under-estimation (1)**
    - **S ≈ F weighted by exp. relative uncertainties (1)**
    - **M Intrinsic discrepancy (≈ F + shape) (0)**
    - **P_x Percentage of points within a factor x (100)**

- **Qualitative analysis**
  bad, good, worse, better, under/overestimation, shape, etc.

- **And Quantitative (attempt) with ratings** (as done by R. Michel for residues)**:**
  2 good
  1 moderately good, minor problems
  -1 moderately bad, particular problems
  -2 unacceptably bad, systematically wrong

Fe


p + Fe -- (2-20 MeV) Avg. neutron multiplicities
leray et al.
cascade04
cascadeasf
cem0302
cem0303
g4bert
g4bic
incl45-abla07
incl45-gemini++
incl45-smm
isabel-abla07
isabel-gemini++
isabel-smm
phits-bertini
phits-jam
phits-jqmd
Neutron multiplicity
Incident energy (MeV)


p + Fe -- (20+ MeV) Avg. neutron multiplicities
leray et al.
cascade04
cascadeasf
cem0302
cem0303
g4bert
g4bic
incl45-abla07
incl45-gemini++
incl45-smm
isabel-abla07
isabel-gemini++
isabel-smm
phits-bertini
phits-jam
phits-jqmd
Neutron multiplicity
Incident energy (MeV)

Fe

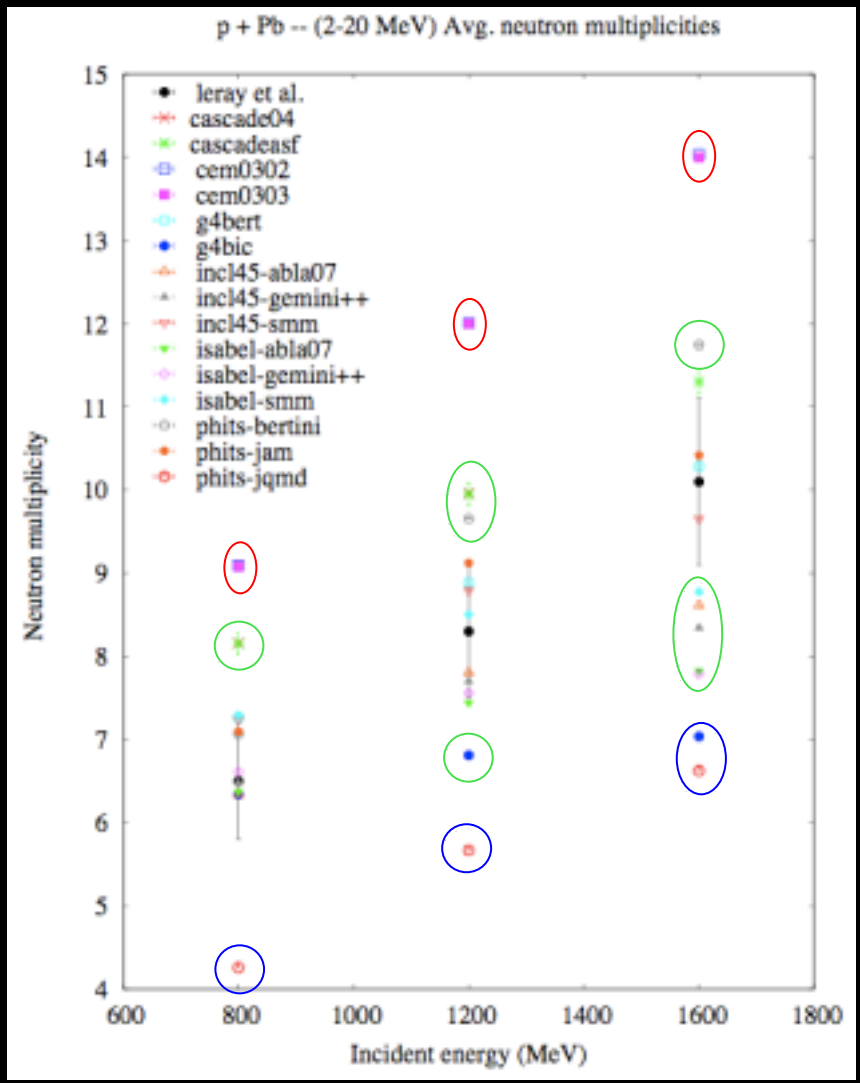
- Better than a factor 2 (low E) and 30% (high E)

- CEM, Phits-JQMD, G4-bert → overestimation
- G4-bic → underestimation

- Low E: Phits-Jam, Cascade-asf → overestimation
- High E: Phits-Jam, Cascade-04 → underestimation

- Isabel: Too much E*? (→ E*/N too high → other channels open)
- INCL4.5: Not enough n emitted? (balanced by evaporation…)

Pb


p + Pb -- (2-20 MeV) Avg. neutron multiplicities
leray et al.
cascade04
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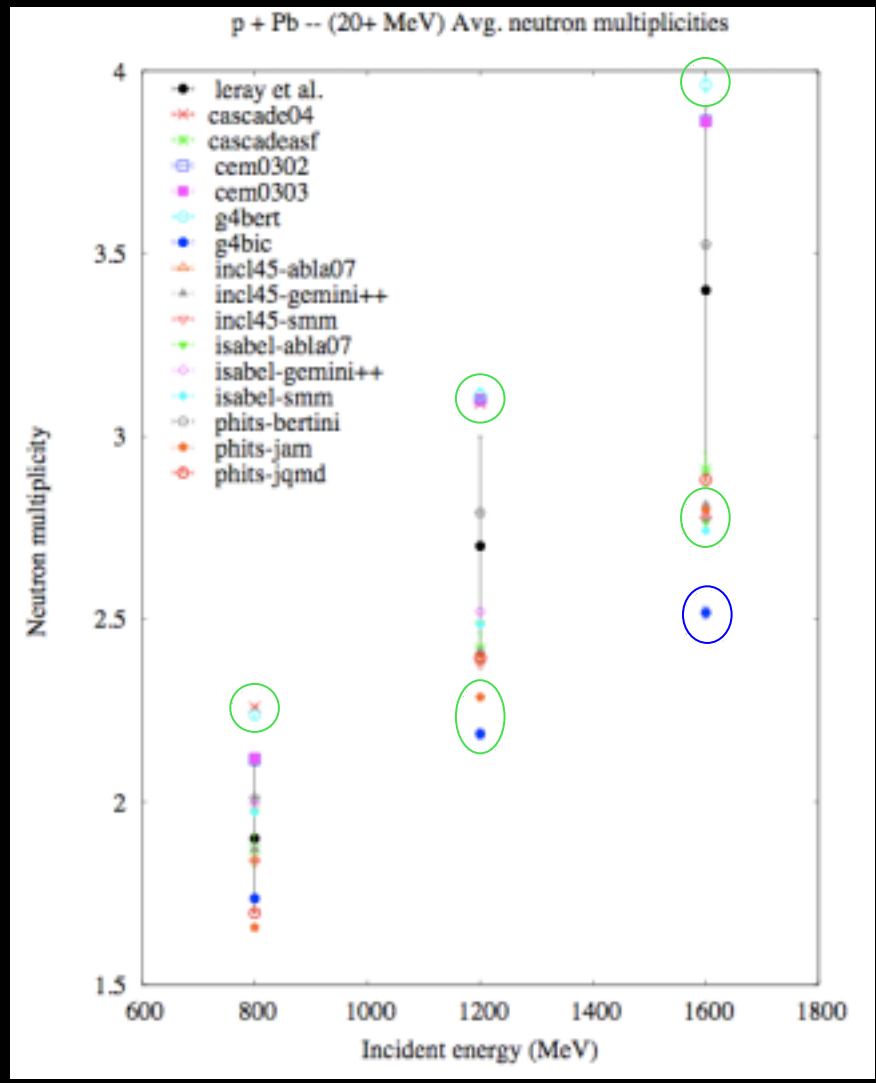
isabel-gemini++
isabel-smm
phits-bertini
phits-jam
phits-jqmd
Neutron multiplicity
Incident energy (MeV)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isabel-gemini++
isabel-smm
phits-bertini
phits-jam
phits-jqmd
Neutron multiplicity
Incident energy (MeV)

Pb

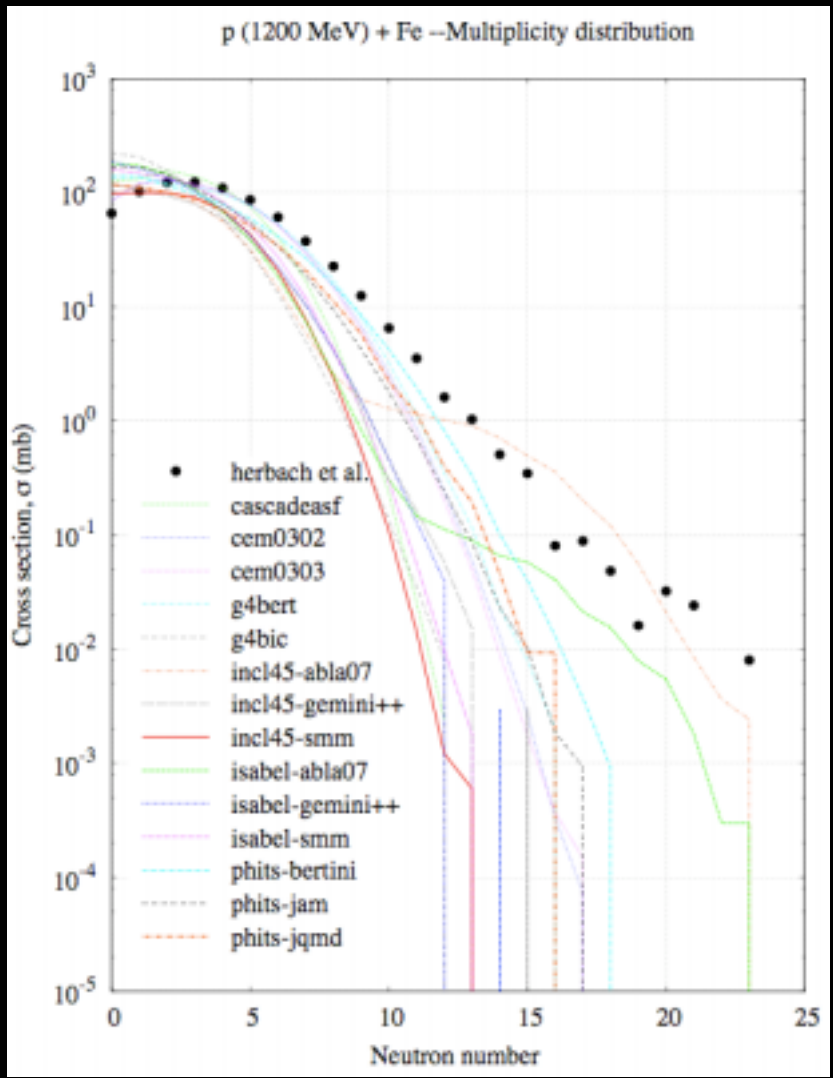
- Better than 30% (but more models outside the error bars compared to Fe)

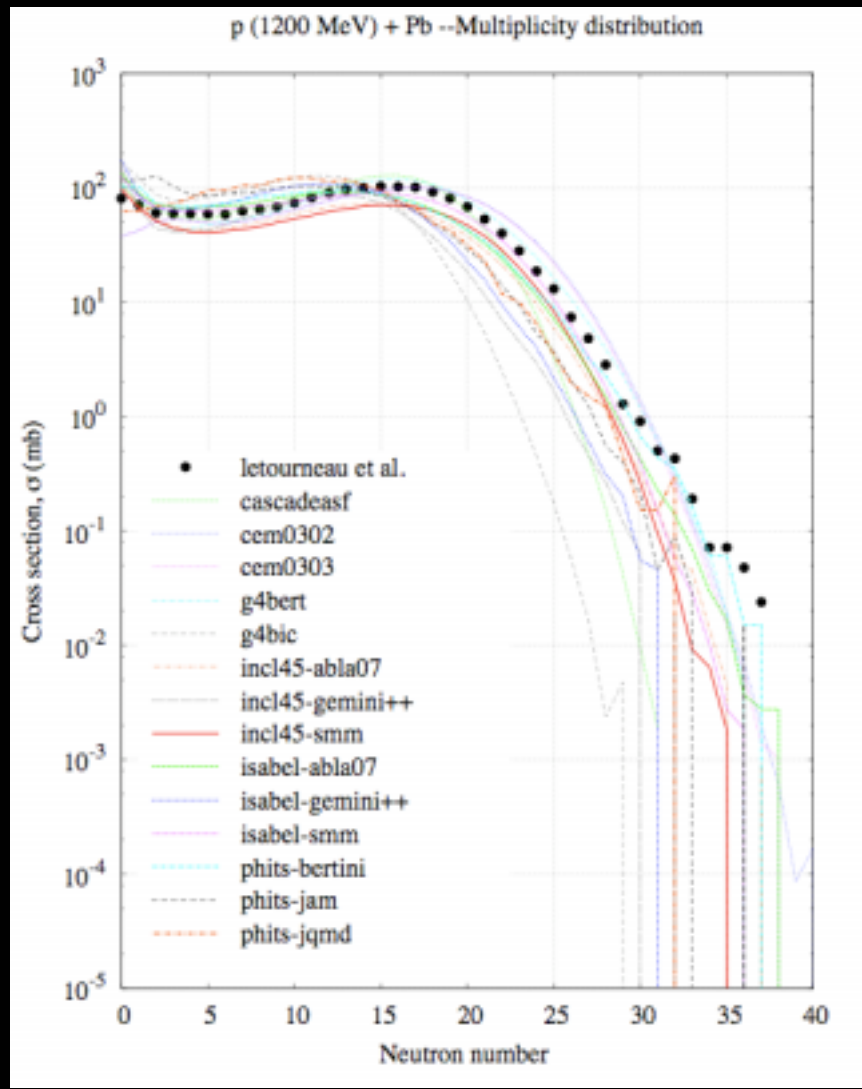
- CEM → overestimation
- G4-bic, Phits-JQMD → underestimation

- Low E: Cascade-04, Cascade-asf → overestimation
- High E: G4-Bert → underestimation

- Phits-Bert: Low E : overpredict / High E: Good
- Phits-Jam: Low E : Good / High E: underpredict

- When E ↗, INCL and Isabel underestimate…


p (1200 MeV) + Fe --Multiplicity distribution
Cross section, σ (mb)
Neutron number
herbach et al.
cascadeasf
cem0302
cem0303
g4bert
g4bic
incl45-abla07
incl45-gemini++
incl45-smm
isabel-abla07
isabel-gemini++
isabel-smm
phits-bertini
phits-jam
phits-jqmd


p (1200 MeV) + Pb --Multiplicity distribution
Cross section, σ (mb)
Neutron number
letourneau et al.
cascadeasf
cem0302
cem0303
g4bert
g4bic
incl45-abla07
incl45-gemini++
incl45-smm
isabel-abla07
isabel-gemini++
isabel-smm
phits-bertini
phits-jam
phits-jqmd

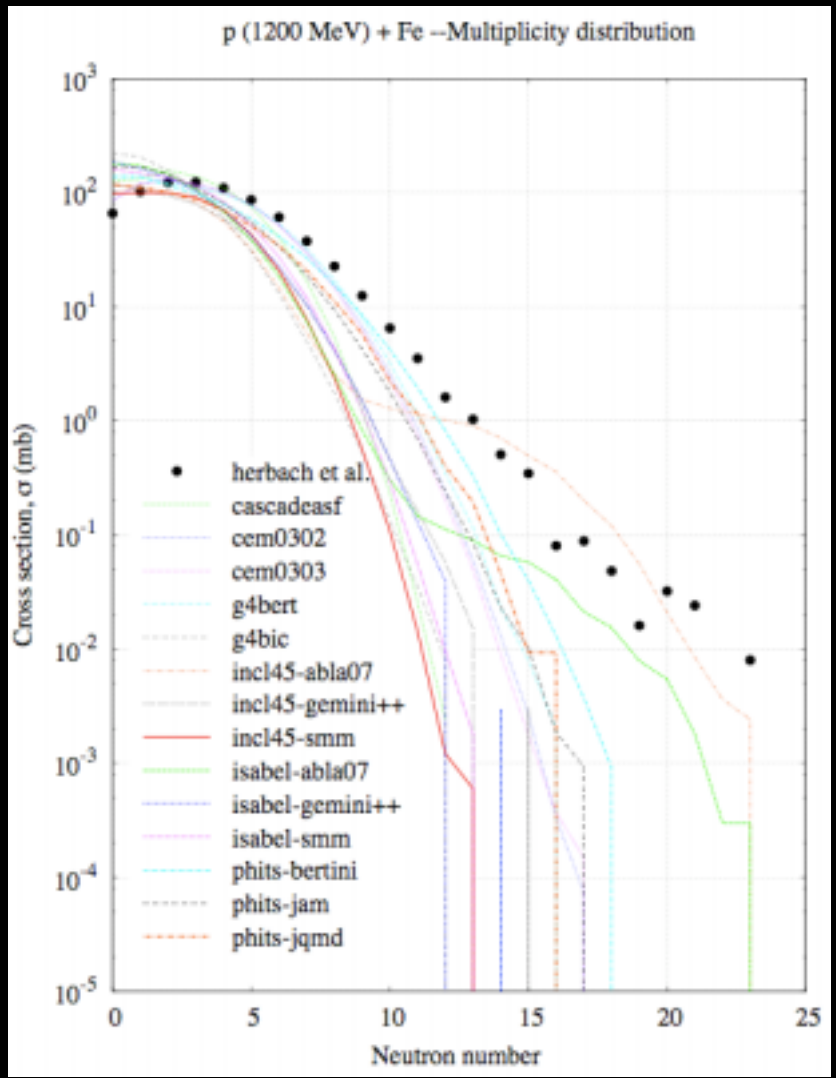
General trends

- Overestimation Low Multiplicities
- Underestimation High Multiplicities (Fe fall down faster, earlier than Pb)

- Pb better reproduced than Fe (lower E*/N…? Deexcitation more important?)
- Fe: balance for average multiplicity

- Difficulty for INC to reproduce neutron emission (especially low multiplicities)?

Fe



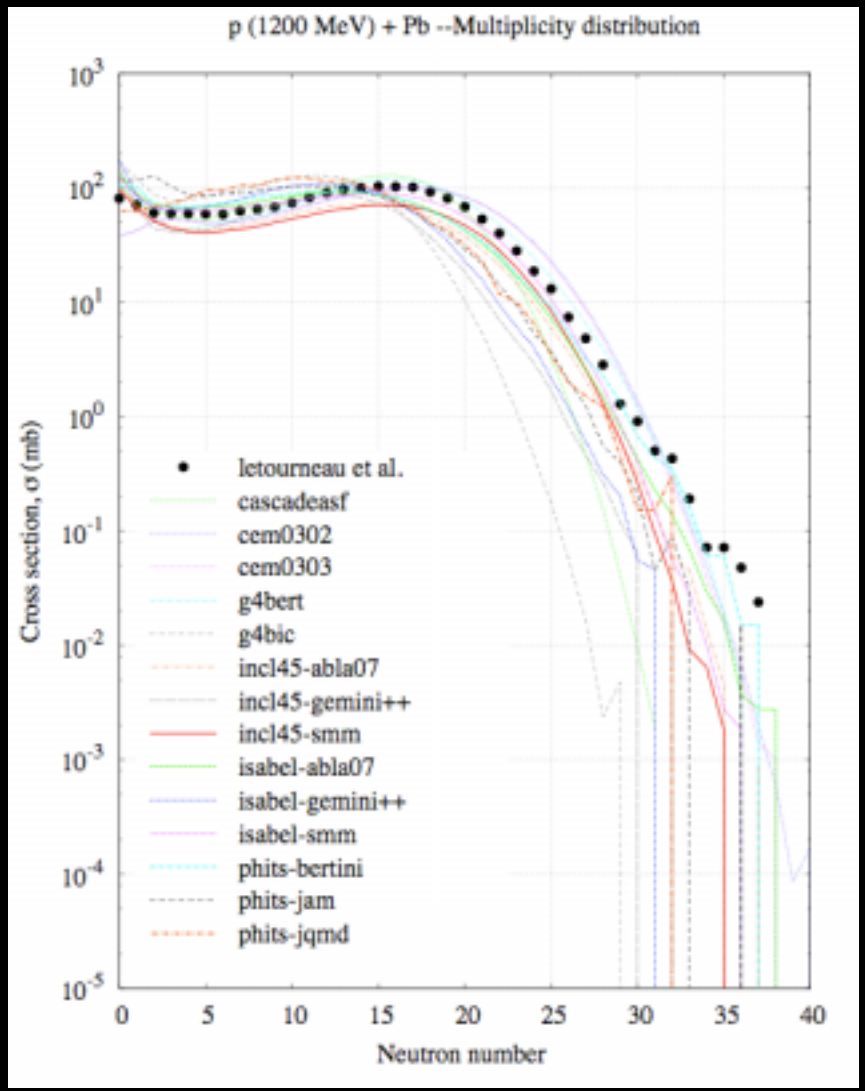
- **CEM**
  best shape at low and medium multiplicities (so no balance for average mult.) -- The right way?

- **Phits-JQMD, G4-Bert**
  fall down slowly (no balance also → overpred. average mult.)

- **G4-bic**
  too much low multiplicities and fall down very early (underestimate average mult.)

- **Abla07**
  What happens around Mult=10? What type of mechanism?

Pb



- see Fe, except:
- CEM
  underpredict at low and
  overpredict at high
- Abla07
  No more shoulder

Rating

1 model

model : isabel-geneist++

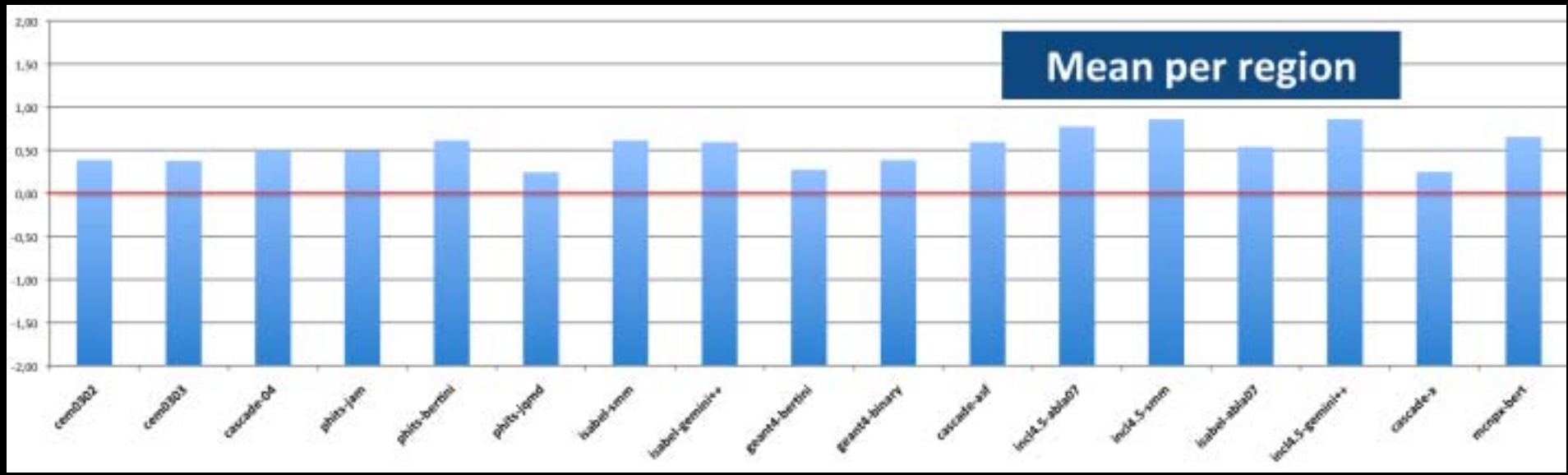
reaction	0-20 MeV			20-150 MeV			> 150 MeV			quasi-elastic peak	number of region	reaction taken into account	Total	reaction
	θ < 45°	45° < θ < 135°	θ > 135°	θ < 45°	45° < θ < 135°	θ > 135°	θ < 45°	45° < θ < 135°	θ > 135°					
n(65 MeV) + Fe				1						-2	2		-1	n(65 MeV) + Fe
p(800 MeV) + Fe	2	1	1	1	1	1	1	1	1	2	10		12	p(800 MeV) + Fe
p(800 MeV) + Fe	1	1	1	2	2	1	-1	1	2		9		10	p(800 MeV) + Fe
p(1200 MeV) + Fe	1	1	1	1	1	1	-1	1	-1	-1	10		4	p(1200 MeV) + Fe
p(1600 MeV) + Fe	1	1	1	-1	-1	-1	1	2	1	-1	10		3	p(1600 MeV) + Fe
p(3000 MeV) + Fe	1	1	2	-1	-1	-1	-2	-1			8		-2	p(3000 MeV) + Fe
p(63 MeV) + Pb208	1	1		-1	-2					-2	5		-3	p(63 MeV) + Pb208
p(256 MeV) + Fe	1	1	1	1	1	-2		1		1	8		5	p(256 MeV) + Fe
p(800 MeV) + Pb	1	2	1	1	1	1	-1	1		1	9		8	p(800 MeV) + Pb
p(800 MeV) + Pb	1	1	1	1	1	-1	-1	1	1		9		6	p(800 MeV) + Pb
p(1200 MeV) + Pb	2	2	2	-1	1	-1	1	2		1	9		9	p(1200 MeV) + Pb
p(1600 MeV) + Pb	1	1	1	1	1	-1	1	2		-1	9		6	p(1600 MeV) + Pb
p(3000 MeV) + Pb	2	2	2	-1	-1	-1	1	2			9		6	p(3000 MeV) + Pb
Total	15	15	14	6	6	-6	-1	13	5	-2	106	13	63	Total
													4,85	Mean per reaction
													0,59	Mean per region
													4,43	standard deviation (mean per reaction)
													1,14	standard deviation (mean per region)

all models

model : all

reaction	nem0302	nem0303	cascade-04	phits jam	phits bertini	phits jqmd	isabel-sinem	isabel-geneist++	geant4-bertini	geant4-binary	cascade-stp	incl4.5-abla07	incl4.5-sinem	isabel-abla07	incl4.5-gemmin++	cascade-x	recoga-bert	reaction
p(65 MeV) + Fe	-1	-1	-1	-1	-1	-1	-1	-1	0	2	0	-1	-1	-1	-1	-1	-1	p(65 MeV) + Fe
p(800 MeV) + Fe	7	8	6	7	7	8	12	12	8	7	13	12	12	11	12	-3	13	p(800 MeV) + Fe
p(800 MeV) + Fe	5	8	6	8	10	-1	11	10	-1	4	13	12	14	10	12	-7	8	p(800 MeV) + Fe
p(1200 MeV) + Fe	3	1	-1	8	11	9	6	4	-1	-1	11	6	9	6	9	-1	8	p(1200 MeV) + Fe
p(1600 MeV) + Fe	4	3	3	14	10	11	5	3	-1	-1	6	5	5	7	5	4	8	p(1600 MeV) + Fe
p(3000 MeV) + Fe	-4	-4	7	8	7	6	-1	-2	6	5	7	5	5	-1	5	6	-7	p(3000 MeV) + Fe
p(63 MeV) + Pb208	-2	-2	-4	-4	-4	-6	-5	-5	-4	-3	-3	-6	-8	-8	-6	-7	-8	p(63 MeV) + Pb208
p(256 MeV) + Pb	-2	-5	4	-7	-3	6	5	5	1	1	4	-3	-3	5	5	5	6	p(256 MeV) + Pb
p(800 MeV) + Pb	2	3	3	7	7	8	9	8	2	8	1	8	9	8	9	8	12	p(800 MeV) + Pb
p(800 MeV) + Pb	0	5	7	7	6	-7	6	6	-1	1	2	11	12	6	12	1	7	p(800 MeV) + Pb
p(1200 MeV) + Pb	3	3	4	3	7	2	9	9	2	7	4	12	12	9	12	4	15	p(1200 MeV) + Pb
p(1600 MeV) + Pb	11	11	0	13	13	8	7	6	6	-1	8	9	12	8	9	8	6	p(1600 MeV) + Pb
p(3000 MeV) + Pb	12	13	13	2	-1	-4	6	6	16	12	13	13	13	8	13	13	3	p(3000 MeV) + Pb
Total	41	48	44	52	65	21	65	63	29	41	63	82	91	57	91	24	70	
Mean (per reaction)	3,15	3,69	3,67	4,00	5,00	1,75	5,00	4,85	2,23	3,15	4,85	6,31	7,00	4,38	7,00	2,00	5,38	
Mean (per region)	0,39	0,48	0,49	0,49	0,61	0,24	0,61	0,59	0,27	0,39	0,59	0,77	0,86	0,54	0,86	0,25	0,65	
Standard deviation (Pop)	5,01	5,25	4,52	5,94	6,32	6,41	5,08	4,43	5,42	4,72	4,65	6,41	6,74	4,81	5,94	5,83	6,82	
Standard deviation (Pop)	1,15	1,17	1,25	1,31	1,31	1,27	1,18	1,14	1,21	1,15	1,19	1,07	1,12	1,14	1,04	1,31	1,25	
Number of reactions	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	12	13	
Number of region	100	108	88	108	106	86	106	108	108	108	108	108	108	106	108	97	107	

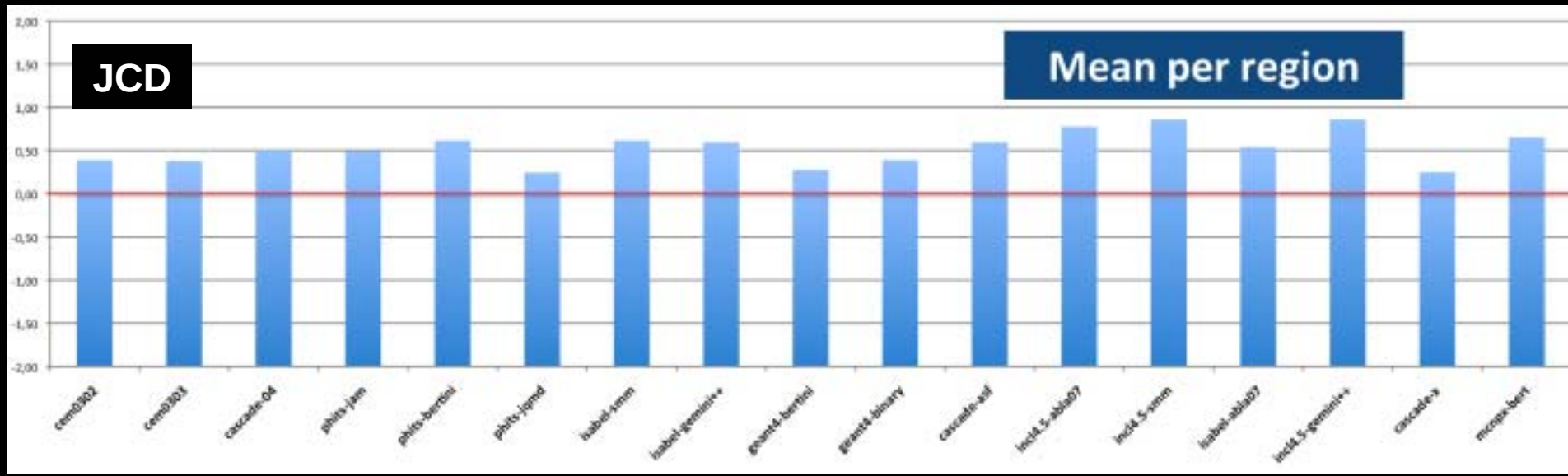
Rating

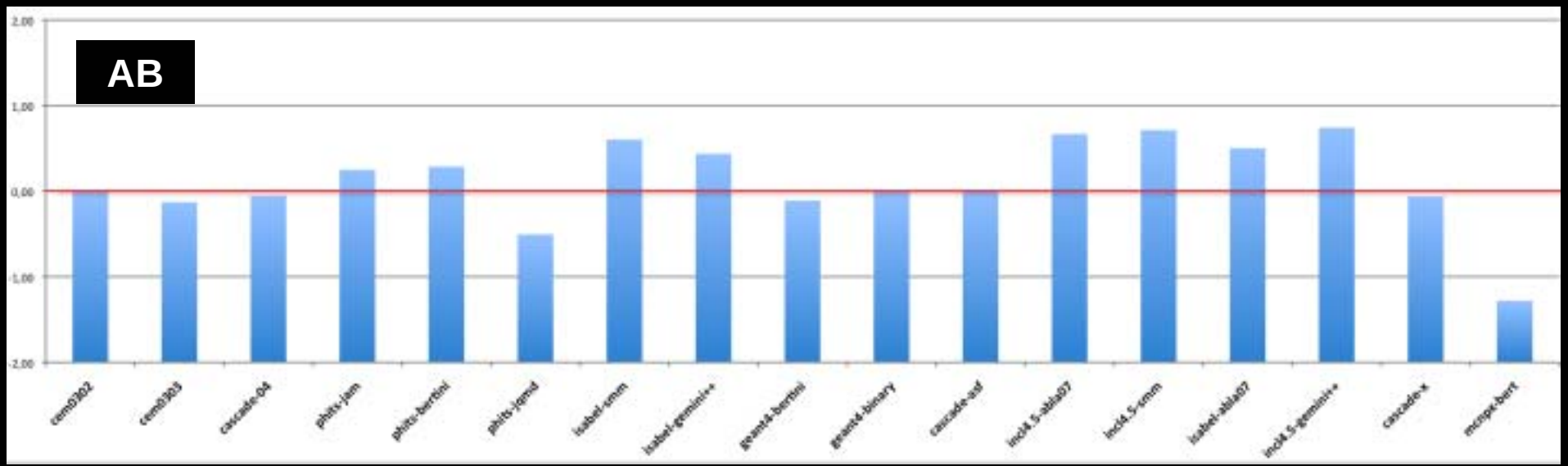


all models

reaction	cem03t2	cem03t3	cascade-04	phits-jam	phits-bertini	phits-jqmd	isabel-smm	isabel-gemini++	geant4-bertini	geant4-binary	cascade-asf	incl4.5-abla07	incl4.5-smm	isabel-abla07	incl4.5-gemini++	cascade-x	mcnpx-bert	reaction
p(68 MeV) + Fe	-3	-3	-3	-4	-3	-3	-3	-3	0	2	0	-1	-1	-1	-1	-3	-4	p(65 MeV) + Fe
p(800 MeV) + Fe	7	8	6	7	7	8	12	12	0	7	13	12	12	11	12	-3	13	p(800 MeV) + Fe
p(800 MeV) + Fe	5	8	4	8	16	-5	11	10	-3	4	13	12	14	10	12	-7	8	p(800 MeV) + Fe
p(1200 MeV) + Fe	3	3	-3	8	11	9	6	4	-3	-1	11	6	9	6	9	-1	8	p(1200 MeV) + Fe
p(1600 MeV) + Fe	4	3	3	14	10	11	5	3	-3	-3	6	5	7	5	7	5	8	p(1600 MeV) + Fe
p(3000 MeV) + Fe	-4	-4	7	8	7	8	-3	-2	6	5	7	5	7	5	8	5	7	p(3000 MeV) + Fe
p(63 MeV) + Pb208	-3	-3	-4	-4	-4	-4	-3	-3	-4	-3	-3	-3	-3	-3	-4	-3	-4	p(63 MeV) + Pb208
p(256 MeV) + Pb	-2	-3	4	-3	-3	0	5	5	1	3	4	-3	5	5	5	5	6	p(256 MeV) + Pb
p(800 MeV) + Pb	2	3	3	7	7	8	9	8	2	8	7	8	9	8	9	8	12	p(800 MeV) + Pb
p(800 MeV) + Pb	0	1	7	7	6	-3	6	6	-3	1	2	11	12	6	12	1	9	p(800 MeV) + Pb
p(1200 MeV) + Pb	3	3	4	3	7	2	9	8	2	7	4	12	12	9	12	4	15	p(1200 MeV) + Pb
p(1600 MeV) + Pb	11	11	6	13	13	8	7	6	6	-1	8	9	12	8	9	8	9	p(1600 MeV) + Pb
p(3000 MeV) + Pb	12	13	13	2	-3	-4	6	8	16	12	13	13	13	8	13	10	3	p(3000 MeV) + Pb
Total	41	48	44	52	65	21	65	63	29	41	63	82	91	57	91	24	92	
Mean (per reaction)	3,15	3,69	3,67	4,00	5,00	1,75	5,00	4,85	2,23	3,15	4,85	6,31	7,00	4,38	7,00	2,00	5,58	
Mean (per region)	0,39	0,46	0,50	0,49	0,61	0,24	0,61	0,59	0,27	0,39	0,59	0,77	0,86	0,54	0,86	0,25	0,65	
Standard deviation (Res)	5,01	5,25	4,52	5,94	6,32	6,41	5,08	4,43	5,42	4,72	4,65	6,41	6,74	4,81	5,94	5,83	6,82	
Standard deviation (Reg)	1,15	1,17	1,25	1,31	1,31	1,27	1,18	1,14	1,21	1,15	1,19	1,07	1,12	1,14	1,04	1,31	1,25	
Number of reactions	13	13	12	13	13	12	13	13	13	13	13	13	13	13	13	12	13	
Number of region	100	108	88	108	106	86	106	108	108	108	108	108	108	106	108	97	107	

Rating


JCD
Mean per region
2,00
1,50
1,00
0,50
0,00
-0,50
-1,00
-1,50
-2,00
cem03r2
cem03r3
cascade-04
phits-jam
phits-bertini
phits-jqmd
isabel-smm
isabel-geminix
geant4-bertini
geant4-binary
cascade-asf
incl4.5-abla07
incl4.5-smm
isabel-abla07
incl4.5-geminix
cascade-x
mcnpx-bert


AB
2,00
1,00
0,00
-1,00
-2,00
cem03r2
cem03r3
cascade-04
phits-jam
phits-bertini
phits-jqmd
isabel-smm
isabel-geminix
geant4-bertini
geant4-binary
cascade-asf
incl4.5-abla07
incl4.5-smm
isabel-abla07
incl4.5-geminix
cascade-x
mcnpx-bert

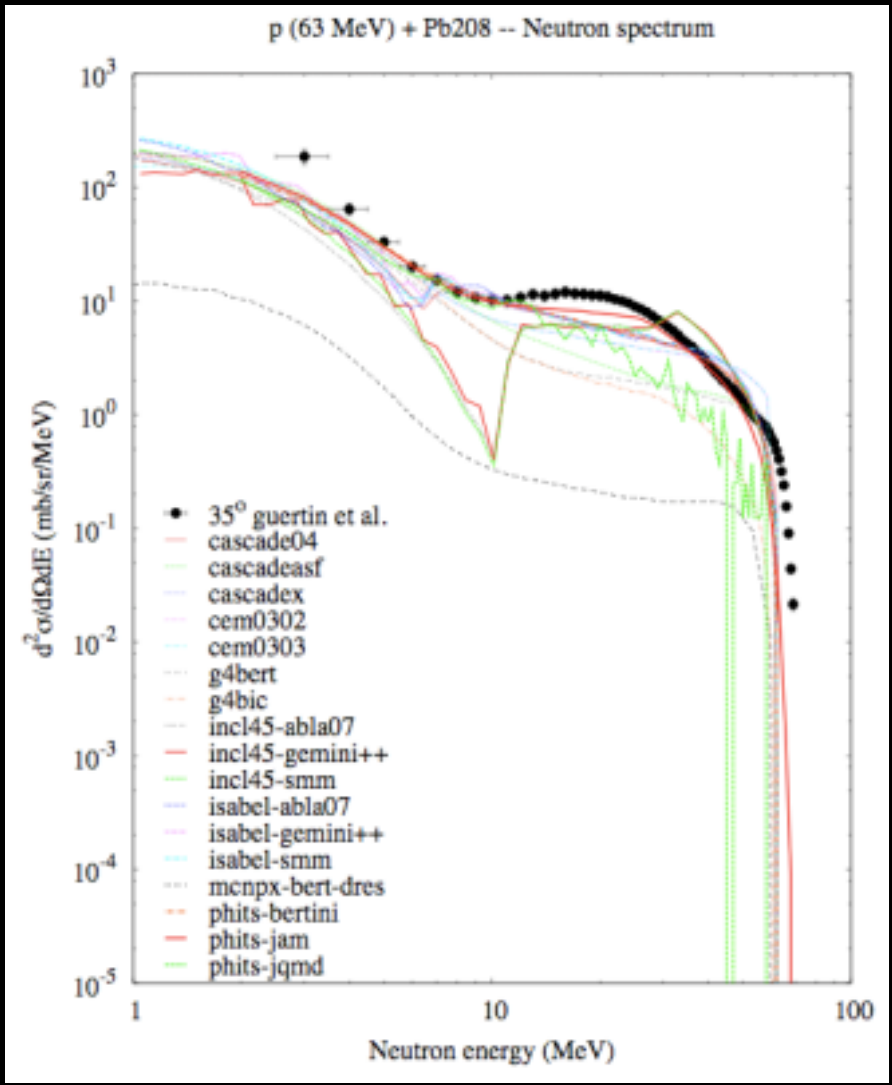
Quantitative analysis attempt

- Two people did it (AB – JCD) --- 2 ways to proceed
  - AB: from -2 to 2 (the worst to the best) --- only neutron
  - JCD: smaller range (all can get the same mark) --- residue in mind

- NEVERTHELESS the same trends
  - All rather good (no one bad, no one wonderful)
  - INCL4.5 seems the best
  - But Isabel is close, with other models

- Differences occur for
  - Phits-JQMD: Low statistic, so difficult to rate
  - Cascade-asf: Large error bars, and a lot of 1 and -1 (gap = 2!!!)

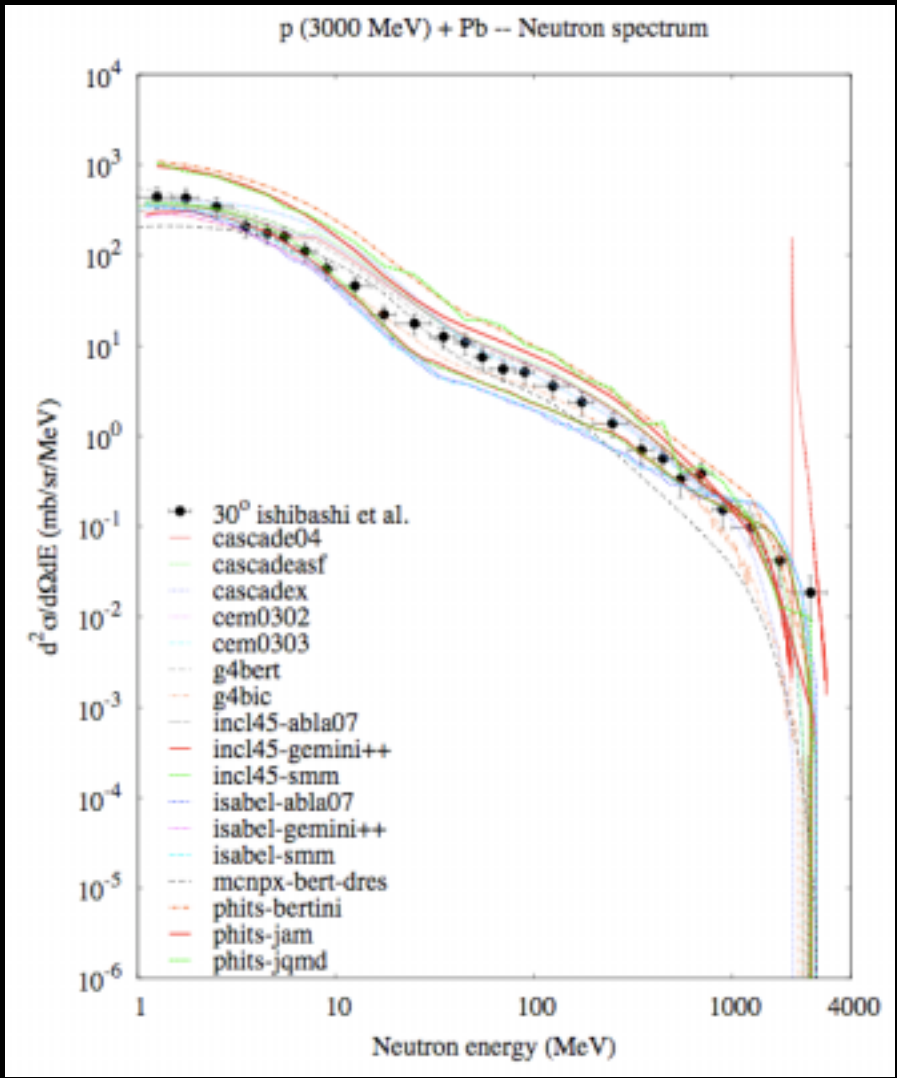
Low Energy projectile



- **No model able to reproduce these low energies**
  …But out of spallation realm

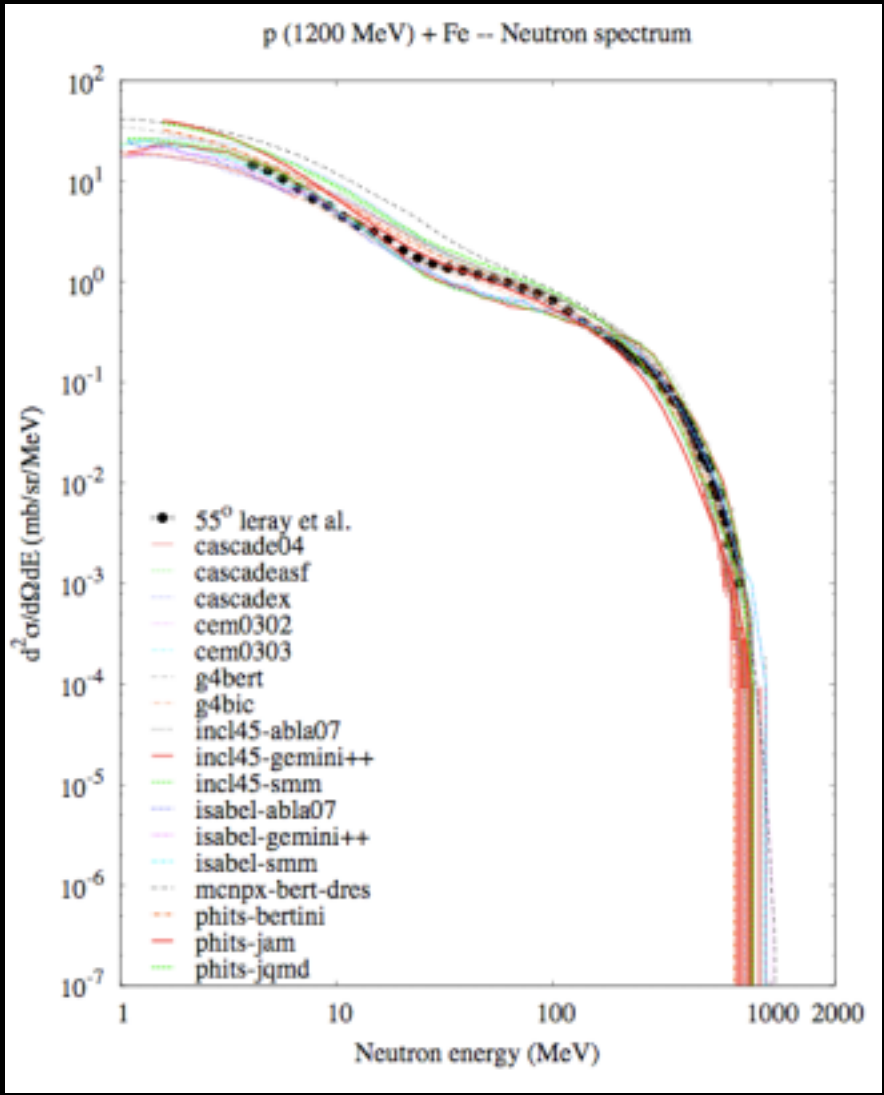
. What happens with INCL4.5 (≈10 MeV)?

High Energy projectile



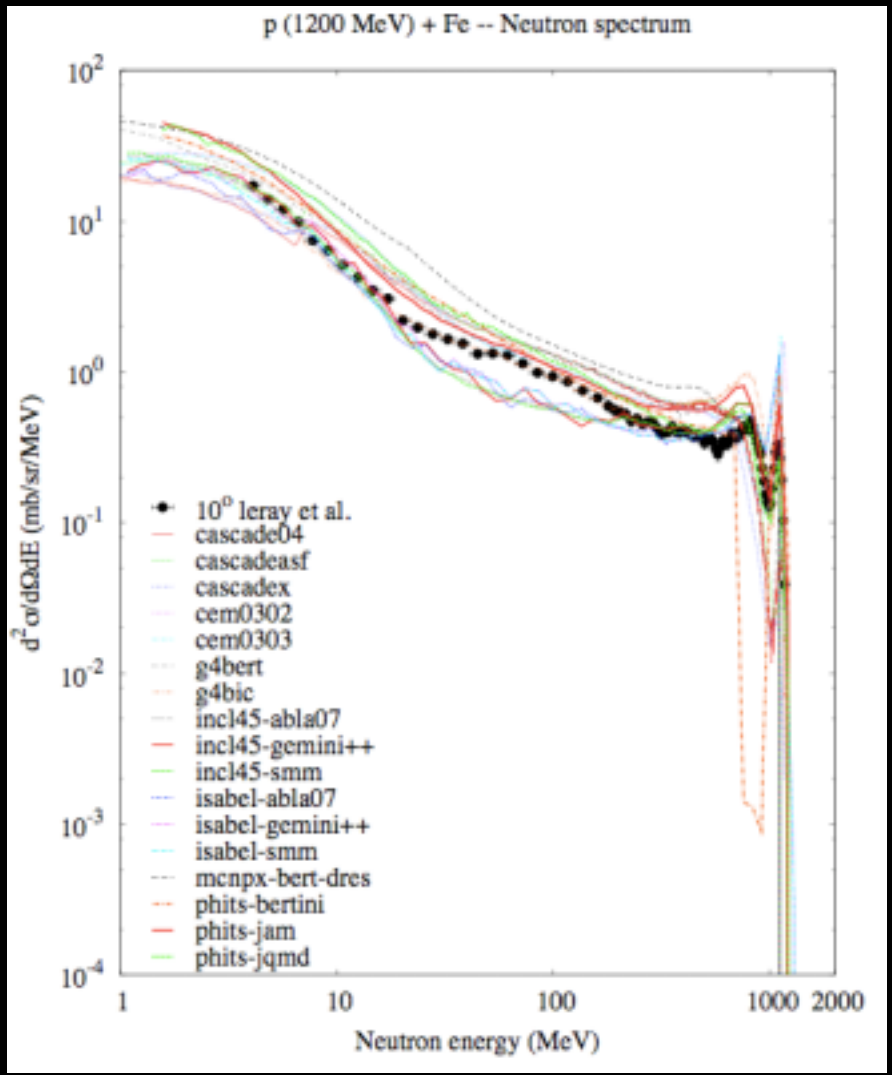
- **All models are quite OK, except Phits at Low E (evap.) and cascade-04 (strange peak)**

Medium Energy projectile (transverse angle)



- All models are good
- Some slight improvements possible
  - at medium energy
  - or in evaporation

Medium Energy projectile (forward angle)



- All models are quite OK for the shape
- But improvements can be done
- Especially for the peaks
- And for the quasi inelastic peak

CEM0302 -- CEM0303

BAD

- Low E forward direction
- Fe, 3000 MeV
- Peaks

GOOD

- Medium E (in average…)
- Pb 1600/3000 MeV – Fe 800 MeV

Comments

- sometimes good in average, but not the shape (Fe low/medium E)

Cascade-04

BAD

- **Peak**
- **Forward, High E**
- **Kick at E ≈ 6-7 MeV (all Cascade models)**

GOOD

- **Backward, Low/Medium E**
- **Medium E**

Comments

- **Peak, 3 GeV (Fe and Pb) strange!**

Cascade-asf

BAD

- **Kick at E ≈ 6-7 MeV (all Cascade models)**

GOOD

- **Medium E**
- **Pb 1600/3000 MeV – Fe 800 MeV**

Comments

- **Difficulties to have a compromise…**

CascadeX

BAD

- Kick at E ≈ 6-7 MeV (all Cascade models)
- Low E forward direction
- Peaks (…)

GOOD

- Medium E
- High E, transverse direction

Comments

- Sometimes (Fe 800 MeV, 3000 MeV) fall down below 4 MeV!?!?

Phits-Jam

BAD

- **Peak**
- **Medium E, backward direction**

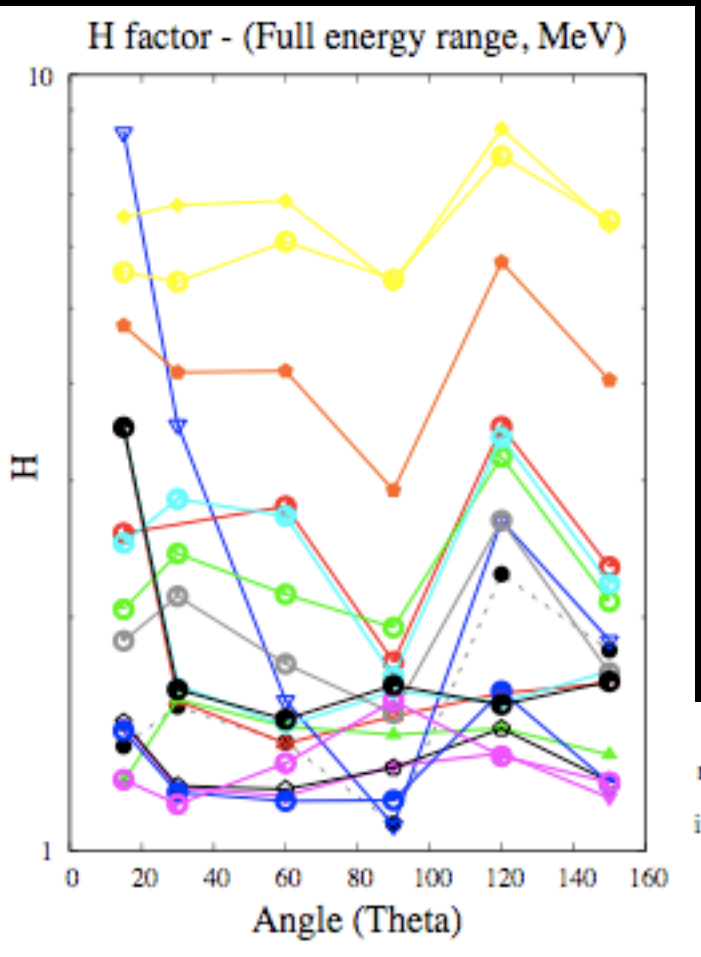
GOOD

- **… Elsewhere**
- **Especially at Low E**

Comments

- **Pb, 3000 MeV Bad evap or Normalisation ?!?!**
- **n, Fe, 65 MeV Peak seems too narrow**

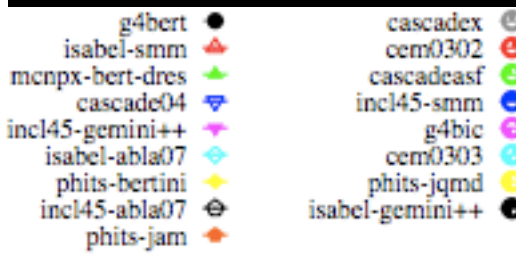
Phits **Pb, 3000 MeV** **Bad evap or Normalisation ?!?!**

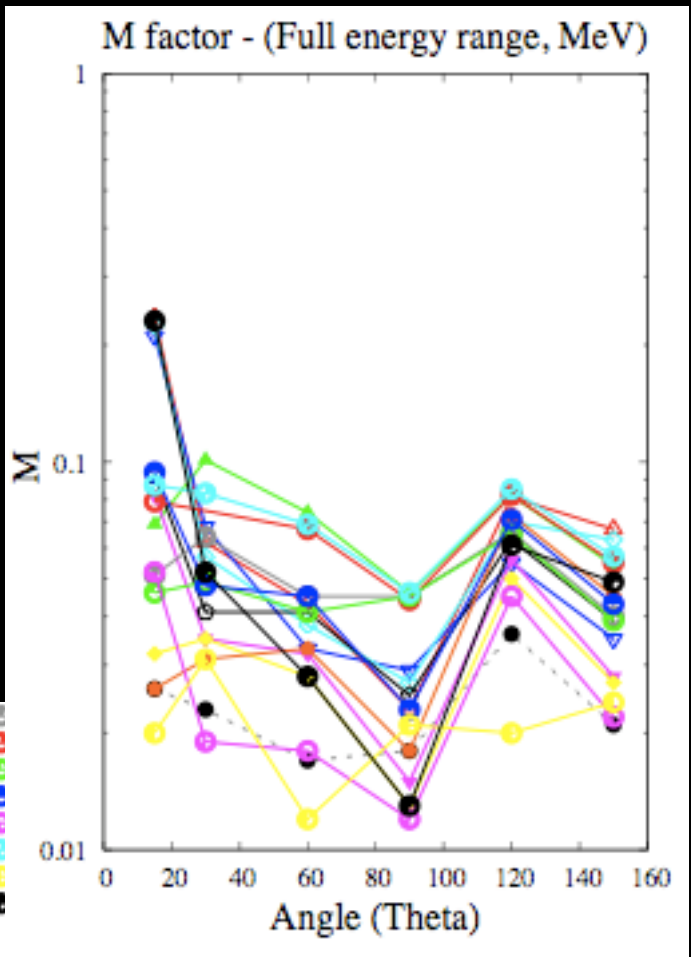


H:
Does not reproduce the data

M:
But the shape is OK

→ Maybe Normalisation





Phits-Bertini

BAD

- **Peak!!!**
- **High E, forward direction**

GOOD

- **… Elsewhere**
- **Especially at Low and Medium E**

	Comments
• Pb, 3000 MeV	Bad evap or Normalisation ?!?!
• n, Fe, 65 MeV	Peak seems too narrow

Phits-JQMD

BAD

- **Medium E**

GOOD

- **High E**
- **Peak not so bad**

	Comments
• Low statistic	difficulties to decide
• Pb, 3000 MeV	Bad evap or Normalisation ?!?!
• n, Fe, 65 MeV	Peak seems too narrow

Geant4-Bertini

BAD

- **High E (except transverse angle)**
- **Peak**

GOOD

- **Low E**
- **Medium E**

Comments

- **n, Fe, 65 MeV Peak seems too large**

Geant4-Bic

BAD

- **High E (backward angle)**

GOOD

- **Low E**
- **Medium E (except backward direction)**
- **Peak**

Comments

- **One of the best for the Peaks**
- **n, Fe, 65 MeV Peak seems too large**
- **Better than Geant4-Bertini**

Isabel

BAD

- Low projectile Energy (E=6-7MeV)
- Medium E (especially backward angle)

GOOD

- High E
- Low E with Abla07, SMM or Gemini++

Comments

- Peak can be improved

INCL4.5

BAD

- **Low projectile Energy (E=10MeV!!!)**
- **Medium E**

GOOD

- **High E**
- **Low E with Abla07, SMM or Gemini++**

Comments

- **Peak can be improved**

Abla07

BAD

- Low projectile Energy
- Very Low n Energy

GOOD

- Yes

Comments

- Maybe Backward angles with isabel…

SMM

BAD

- Low projectile Energy
- Very Low n Energy

GOOD

- Yes

Comments

Gemini++

BAD

- Low projectile Energy
- Very Low n Energy

GOOD

- Yes

Comments

- Better with INCL4.5 than Isabel

MCNPX-Bertini-Dresner

BAD

- **Low E**
- **. Low projectile energy**

GOOD

- **Medium E**
- **High Energy**

Comments

- **Peaks not so bad,**
  except quasi inelastic very forward angle (position, but too high)
- **n, Fe, 65 MeV Problem?!?!**

Thank You!