Latest INCL4-ABLA validations and developments

A. Boudard, S. Leray, S. Lemaire, J.C. David (CEA/SPhN) (+Y. Yariv)
J. Cugnon, T. Aoust, P. Henrotte, S. Pedoux (Univ. Liège - Belgium)
K-H Schmidt, A. Kelic, M-V Ricciardi (GSI), J. Benlliure (Univ. Santiago de Compostella)

INCL
ABLA

➢ **Monte-Carlo** simulation of spallation reactions:

Validity: Projectiles: p,n π,d,t,3he,4he
Beam energy: ~100 MeV - ~3 GeV
Targets: ~Al - U

➢ Reminder of physical content:

Models based on physics,
phenomenology reduced, **predictive power**

Event generators
(INCL4+ABLA already
in LAHET and MCNPX)

↓

Candidates for GEANT-4
(serious contacts in June 06)

➢ Success and difficulties (INCL4-ABLA):

(Already presented in Bordeaux-GEANT4 meeting)

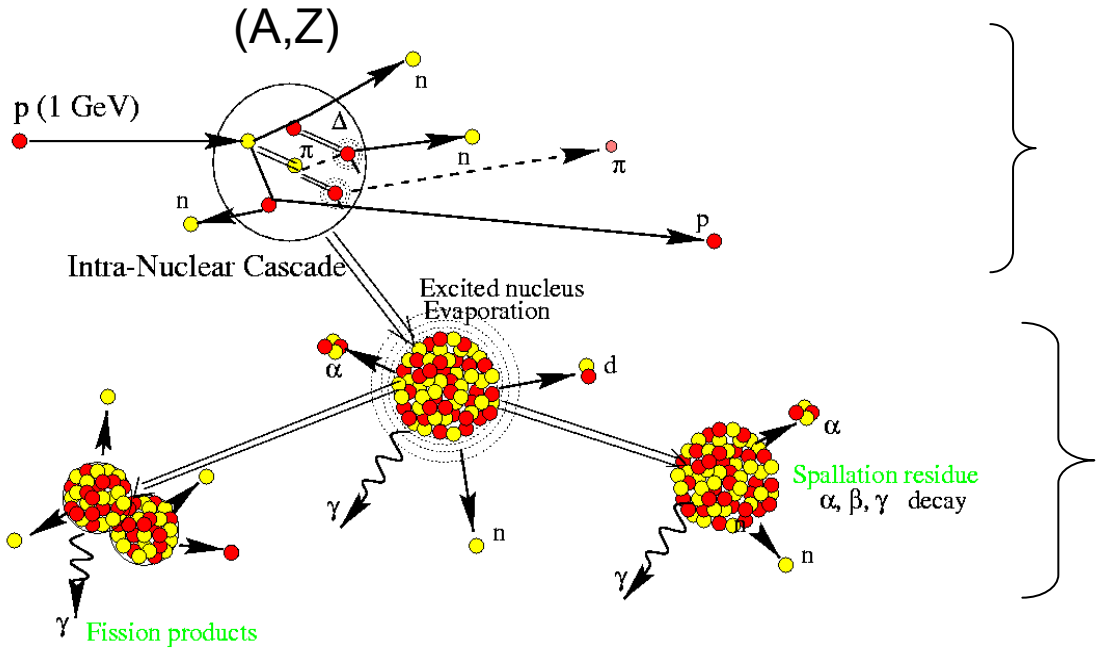
➢ Recent improvements and developments

(Mainly of INCL5 I am working on!)

INCL5-NewABLA New versions; will be coupled during this month.
Detailed tests in 2007.

(International Comparison on Spallation Models (Saclay-Jülich) late 2007)

Physical content in short



Physical module

INCL4

Energetic pions
and nucleons
+ Remnant nucleus
(A,Z,E*,J,P,θ,φ)

Deexcitation module (ABLA)

Evaporated particles,
Fission products,
Residual nuclei.
(No γ and radioactive decay)

INCL4:

Series of indep. NN interactions ($\lambda_b = h/p$) < ($\Lambda=1/\rho.\sigma_{NN}.f$) in a potential

NN->NN; NN->NΔ; Δ<=>Nπ; Δ scattering (No 2π channels)

All particles explicitly followed in time; straight trajectories (no refraction)

r-space density: realistic Wood-Saxon; p-space density: Fermi level.

Pauli blocking (local-statistic) and long range correlation

Stopping time fixed once for ever from emission rates

NO ad hoc PARAMETERS in the MODEL!
(Gives also σ_{Reac} and normalisations)

Physical content in short (De-excitation)

ABLA:

- Evaporation of p, n and α: Weisskopf-Ewing

  Nuclear level densities (GCCI), Inverse (capture) reaction cross sections

- Fission: Bohr-Wheeler (reduced by a viscosity parameter; Kramer factor)
- Sophisticated fission products mass and charge distribution (empirical)
- Competition fission-evaporation

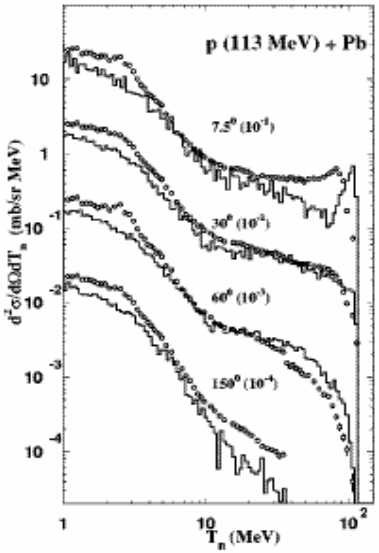
More empirical, but no adjustments or change of parameters here!

(Other de-excitation modules are also coupled to INCL to disentangle the physics):

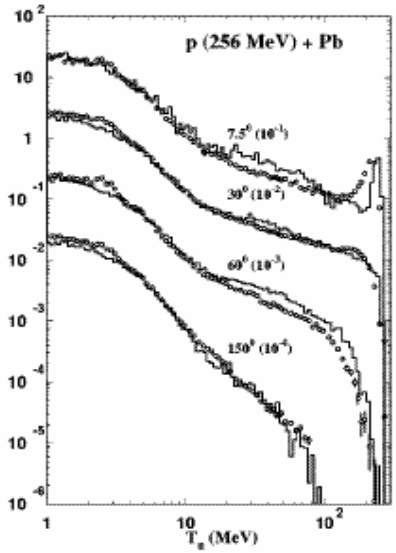
GEM (S. Furihata, K. Niita et al.)	Evaporation up to 24Mg, Atchisson fission
SMM (Botvina)	Multi-fragmentation
GEMINI (Charity)	Transition state model (evapo as very asymmetric fission)

INCL4 + ABLA:Elementary production of neutrons

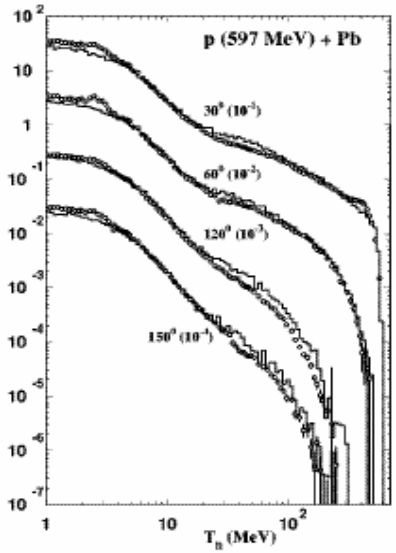
Modèle, voir:
A. Boudard et al, Phys. Rev. C66 (2002) 44615



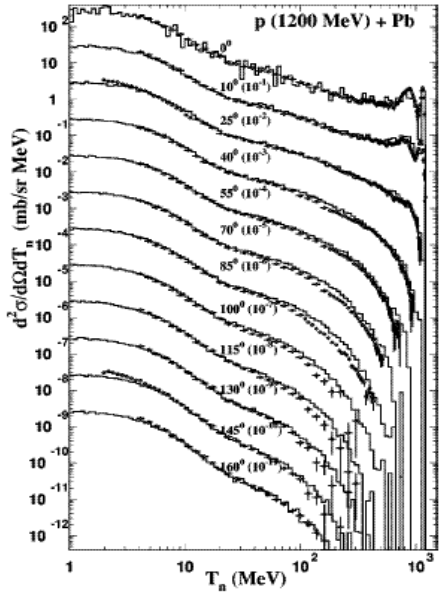
W. Amian et al, Nucl. Sci. Eng 115 (1993) 1

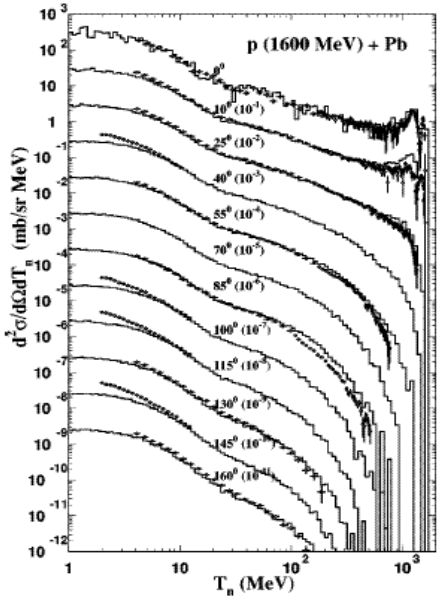


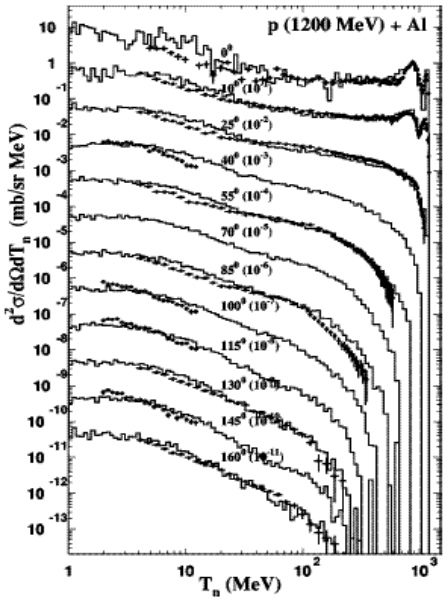
S. Stamer et al, Phys. Rev. C47 (1993) 1647



W. Amian et al, Nucl. Sci. Eng 102 (1989) 310

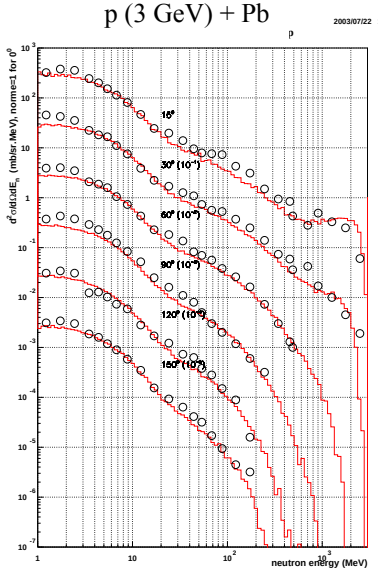






S. Leray et al, Phys. Rev. C65 (2002) 044621

p (3 GeV) + Pb



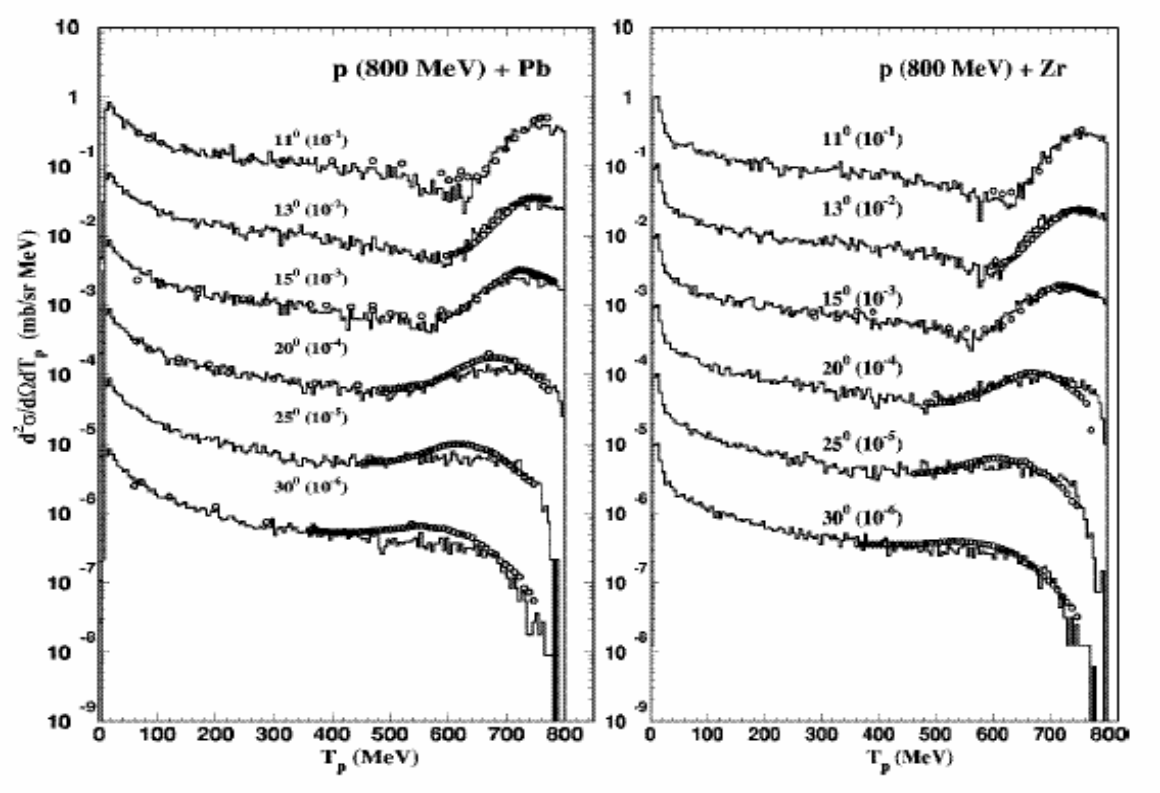
S. Meigo et al (KEK)

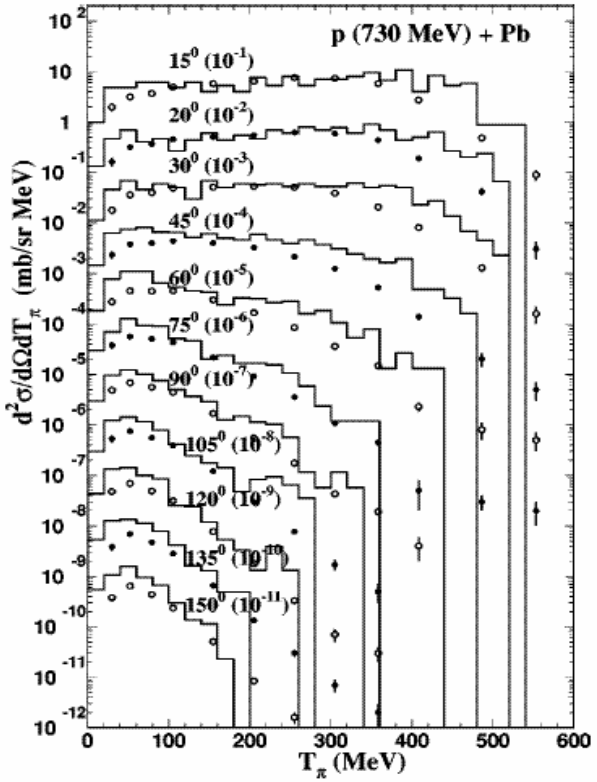
INCL4+ABLA: p, π

R. Chrien et al, Phys. Rev. C21 (1980) 1014

J. McGill et al Phys. Rev. C29 (1984) 204

D. Cochran et al, Phys. Rev. D6 (1972) 3085



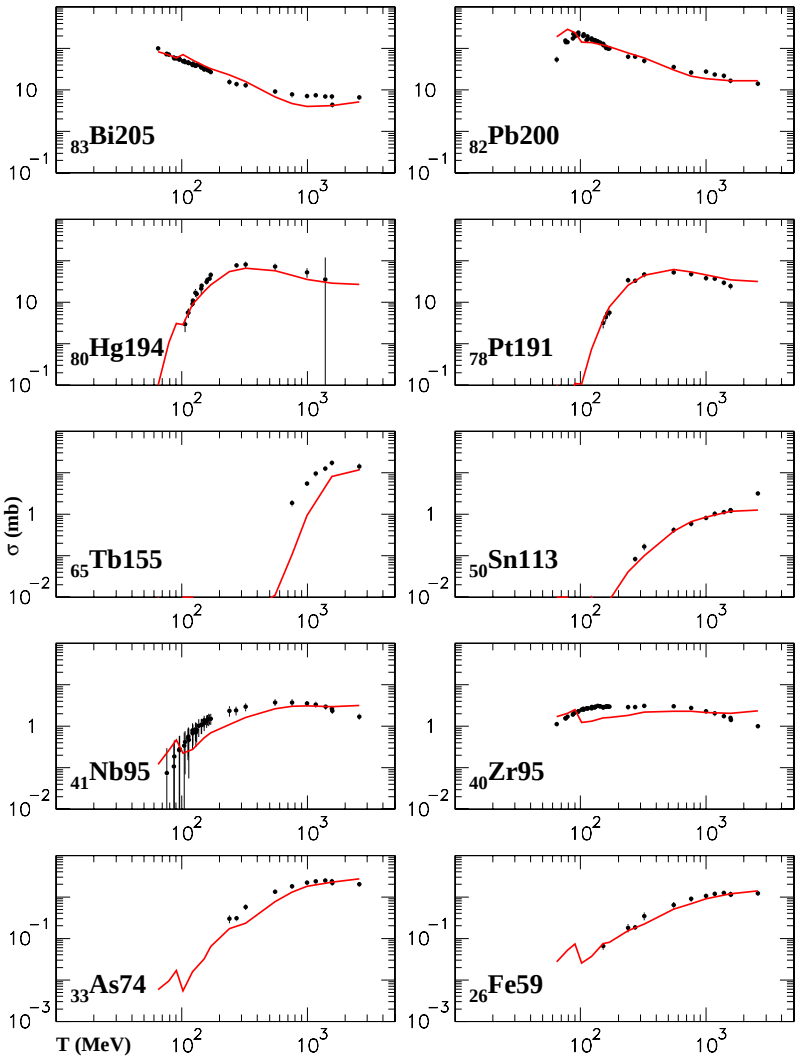


Proton production

π production ok in E and θ dependence, but **too large** (1.6).
(here π+, idem for π-)

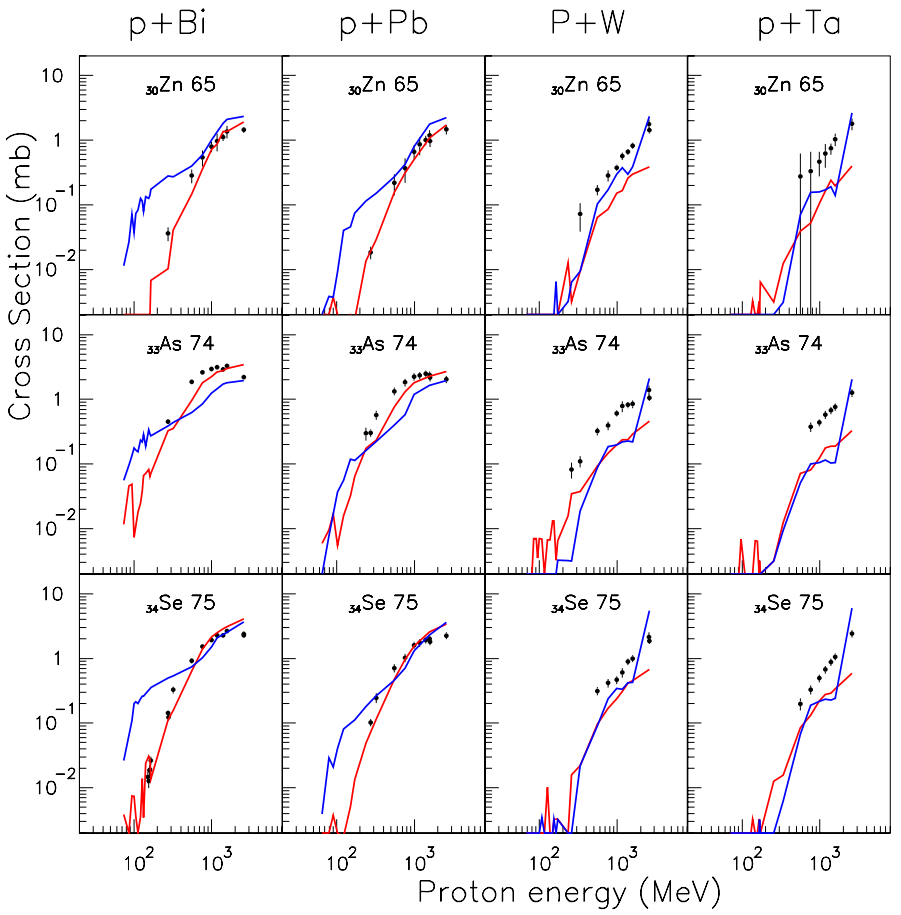
INCL4+ABLA: Residual Nucleus production (from irradiation exp., after radioactive decays)

p (**up to 2.6 GeV**) + Pb -> Residuals



Problems in fission of light nuclei?

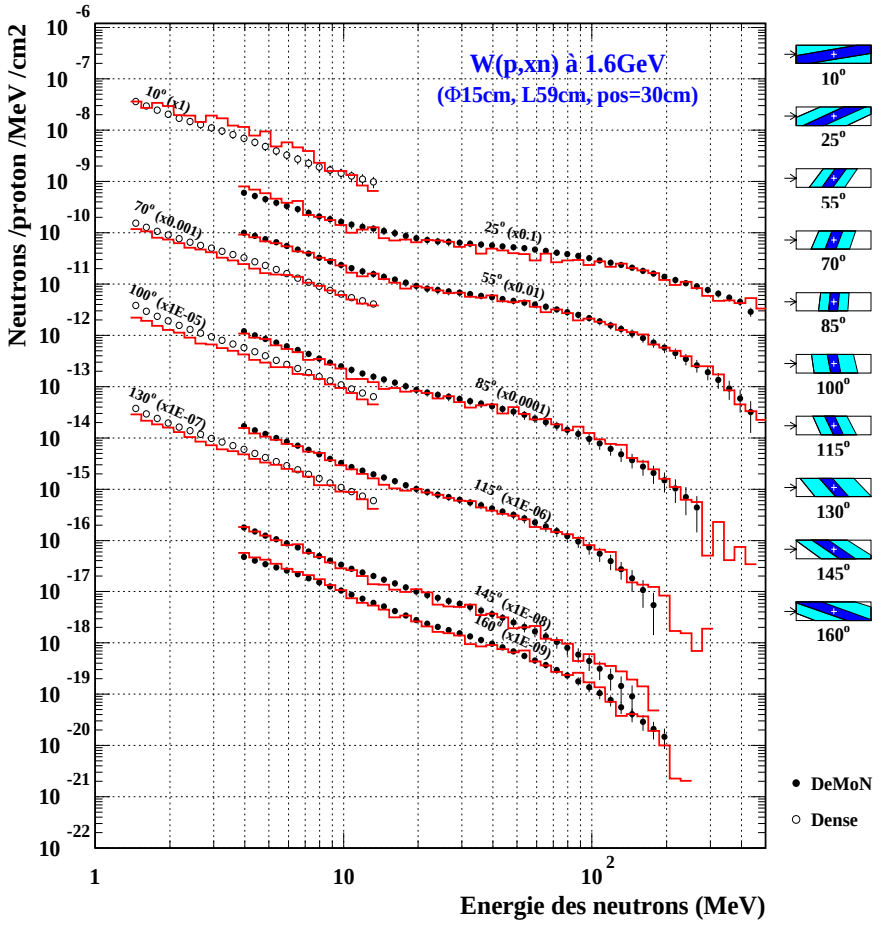
(blue curve is Bertini-Dresner)

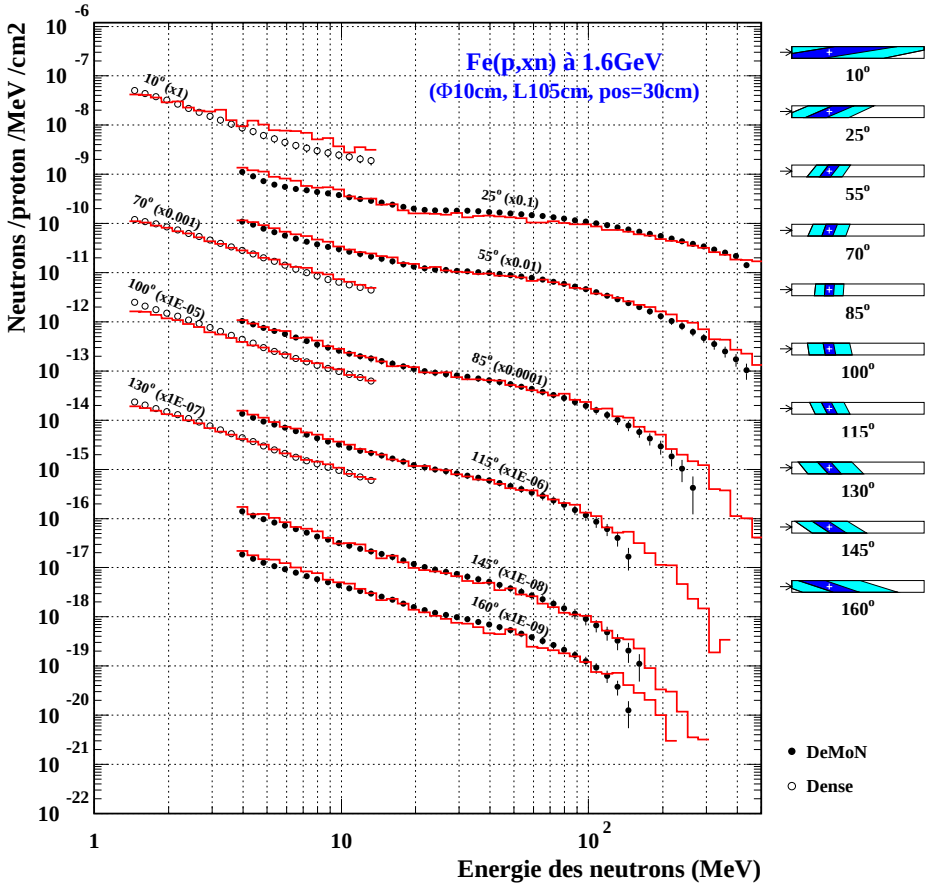


M. Gloris et al, NIM A463 (2001) 593; Michel et al, Nucl. Sci. Tech. Supp 2 (2002) 242

Massive targets (INCL4+ABLA in LAHET)

(S. Leray et al, Lab Nat Saturne experiment)

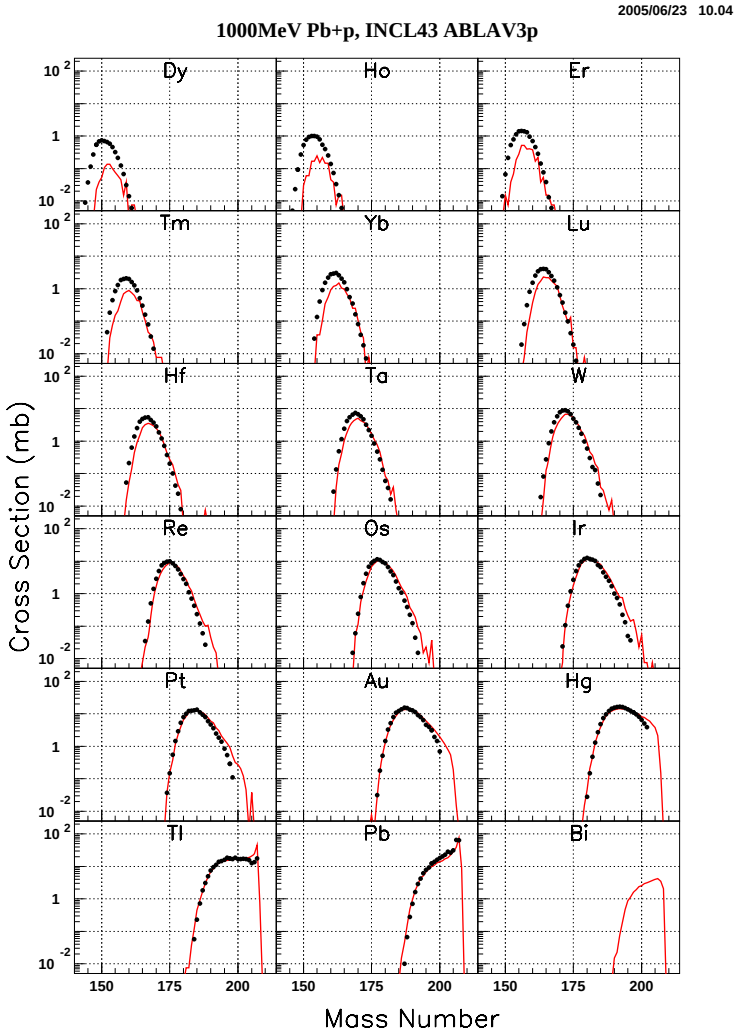




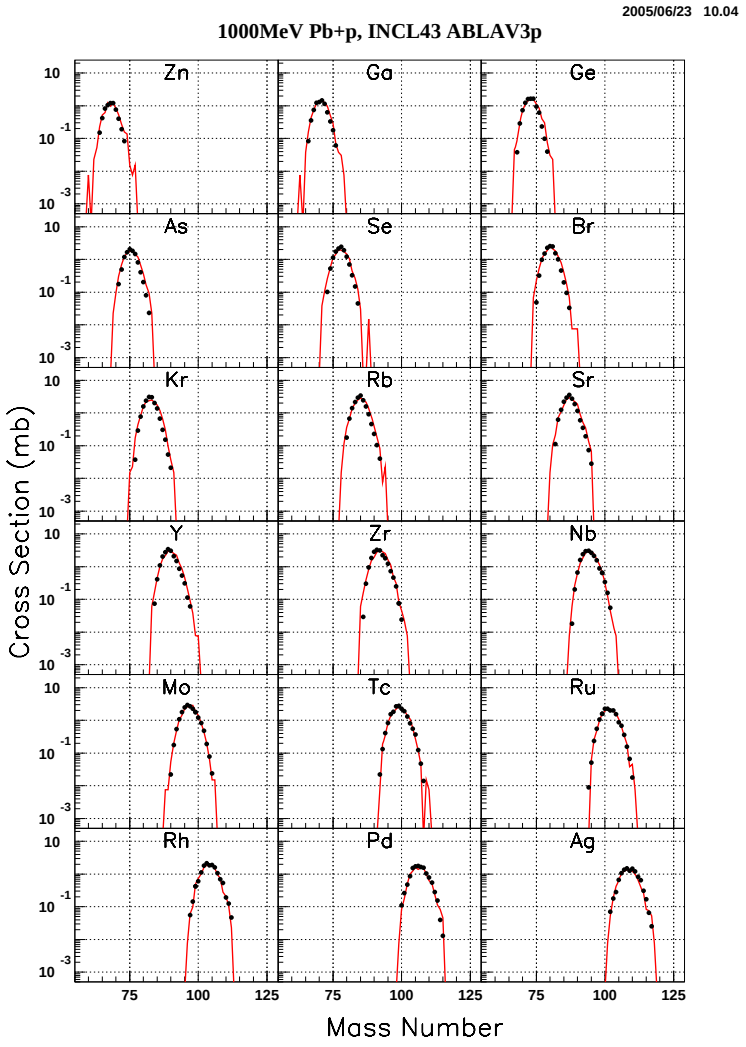
(exemples out of many)

INCL4-ABLA: Residual nucleus production (before decay)

Evaporation residues



Fission Products

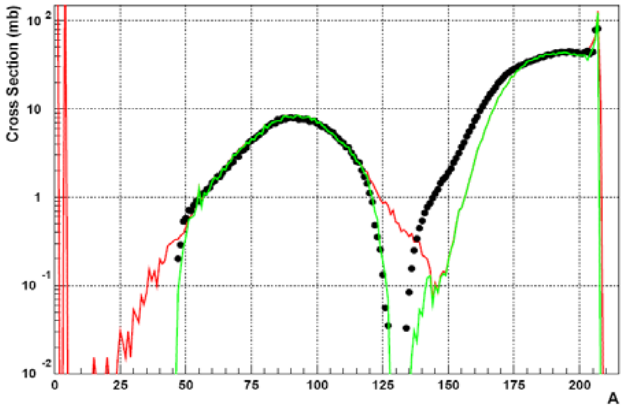


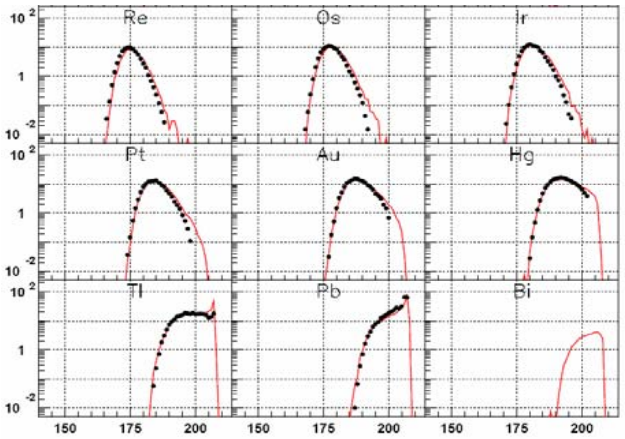
Pb 1 A GeV + p (GSI inverse kinematics)

T. Enqvist et al. Nucl. Phys. A686 (2001) 481

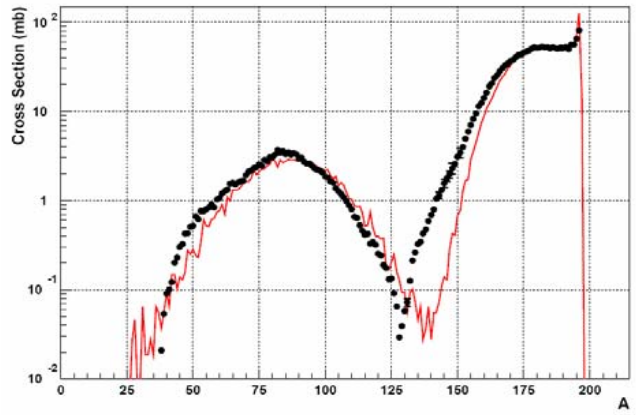
INCL4 + ABLA: Residual nucleus (GSI)

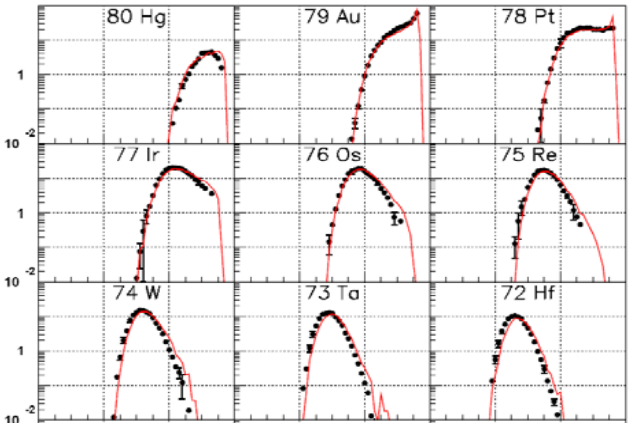
Pb (1 GeV/A) + p





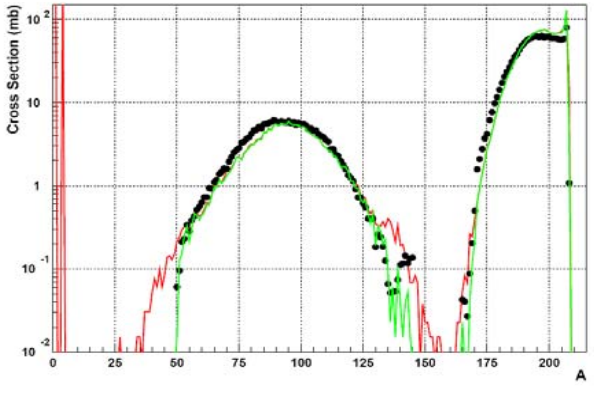
Au (800 MeV/A) + p

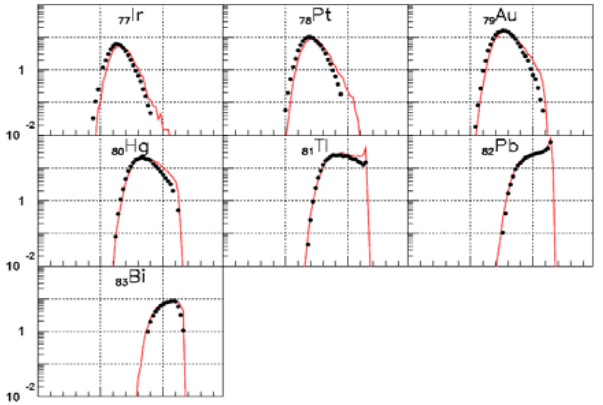




F. Rejmund et al,Nucl. Phys. A683 (2001) 540

Pb (500 MeV/A) + p





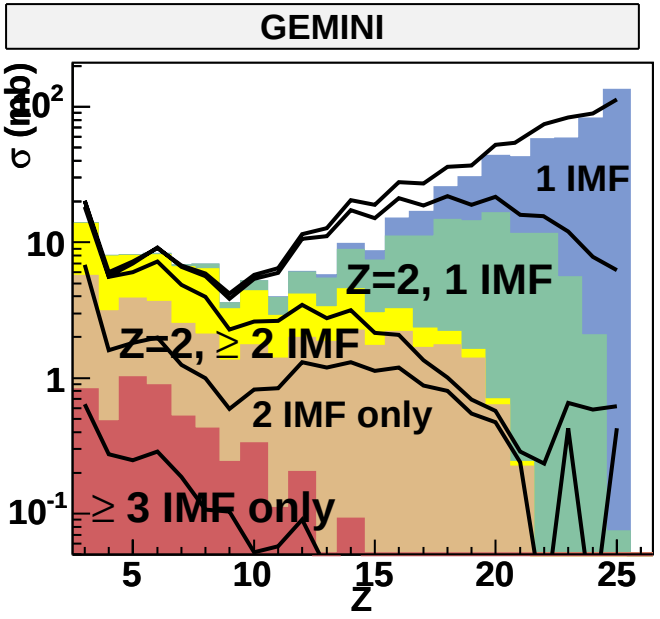
L. Audouin et al, Nucl. Phys. A768 (2006) 1
B. Fernandez et al, Nucl. Phys. A 747 (2005) 227

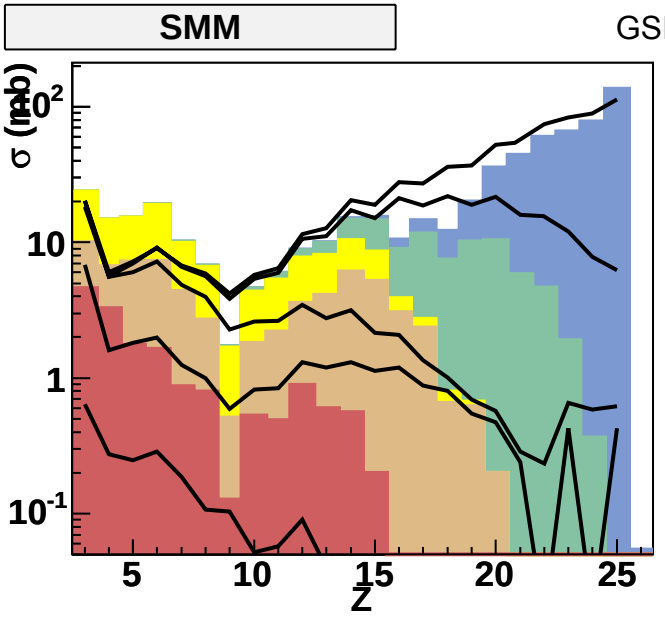
Systematic under estimation of light evaporation residues
(Large excitation energy of the remnant)

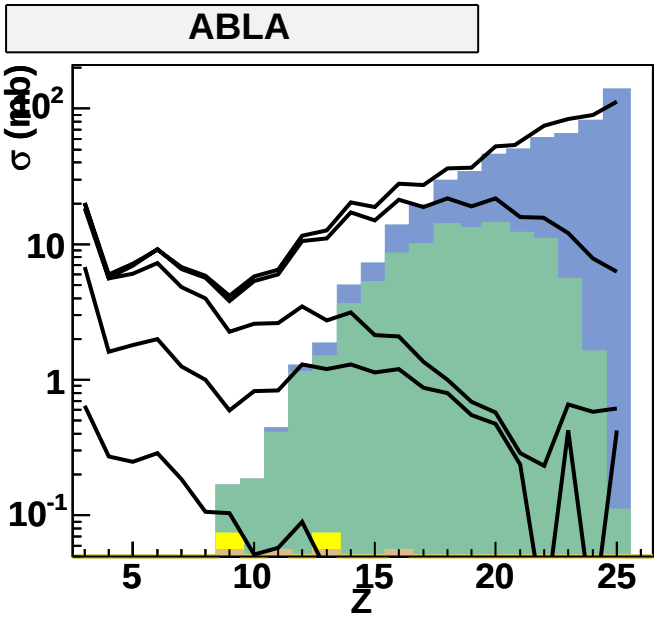
INCL4 +Gemini, SMM, ABLA, GEM)

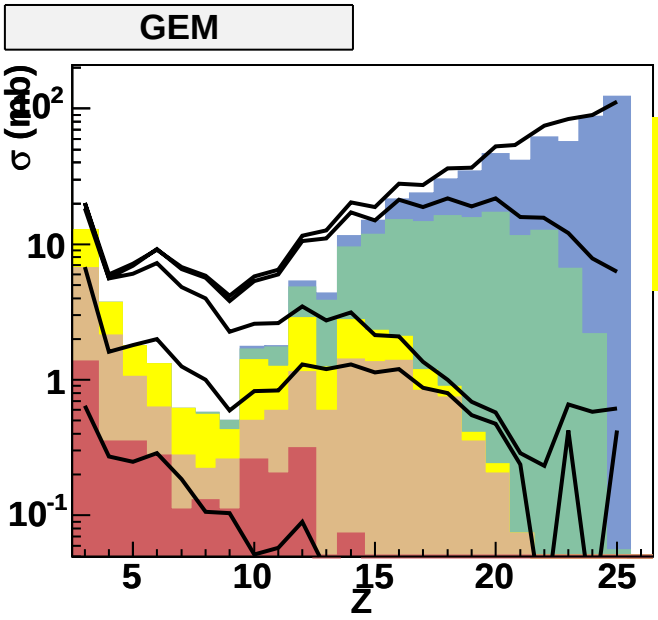
Fe (1 A GeV) + p

E. Legentil (Saclay) PhD,
GSI SPALADIN experiment









Black lines: experiment

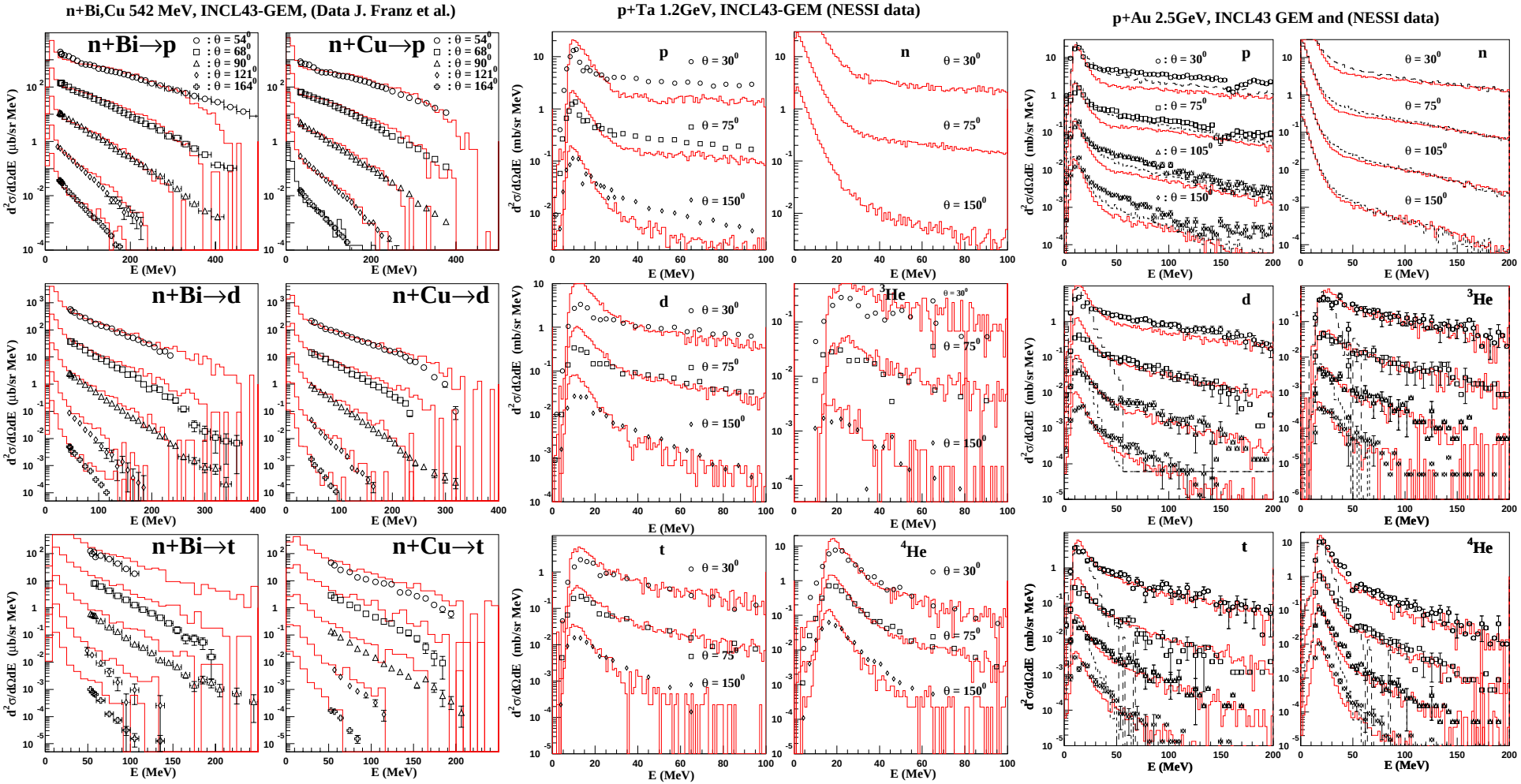
Colored histograms: models

Best agreement with GEMINI
(Hausser-Feshbach Z<5
Evapo as asym fission above)

Contribution missing in evaporation at high E*

Will inspire the NewABLA!

INCL4.3: Production of light charged particles (d, t, 3He,4He)



Extension of strict INC approach: Clusterization at the surface of escaping nucleons

2 Parameters: Distance from R0 (1.75 fm)

Phase space for clusterization ($\Delta r^* \Delta p < 387$ fm*MeV/c)

INCL4.3 + GEMINI: He production

(important for applications; swelling of structures)

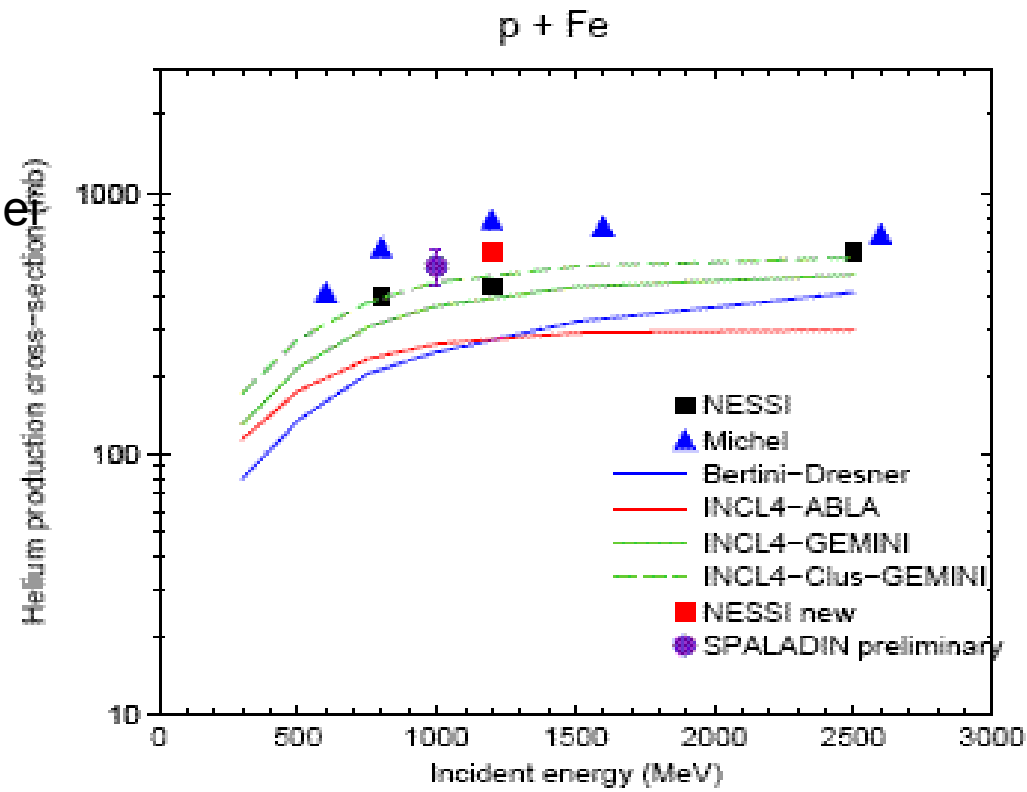
Evolution:

ABLA->GEMINI

Better production of light nuclei
(Very asym. fission)

INCL4->INCL4.3

Production of energetic He
in the INCascade.

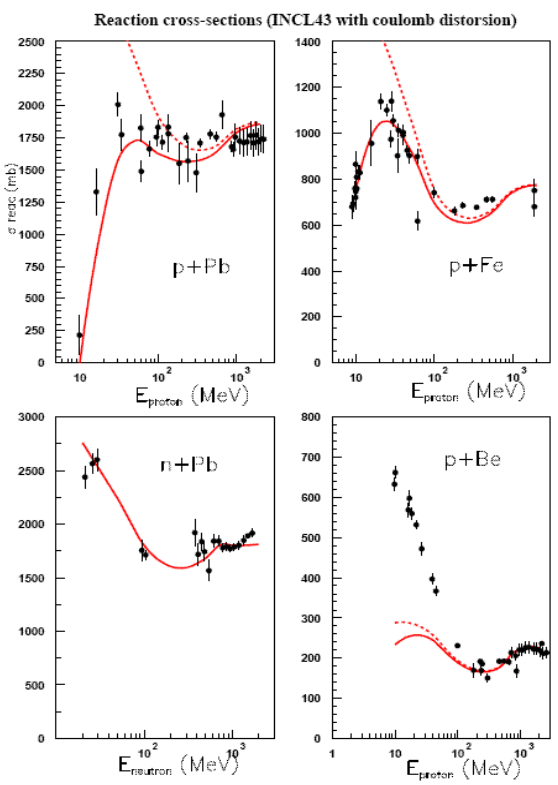


(S. Leray et al, NIM A562 (2006) 806)

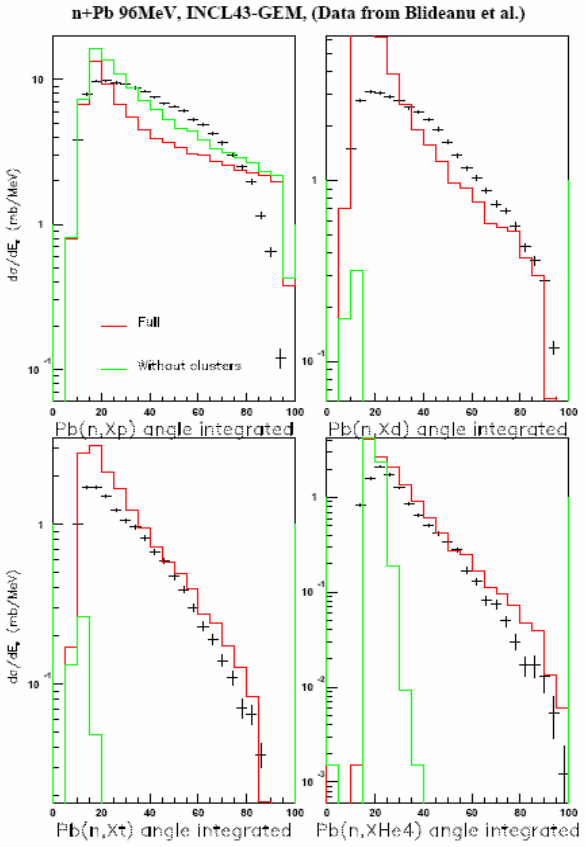
Data: R. Michel et al, NIM B103 (1995) 183
M. Gloris et al, NIM A463 (2001) 593
C.M. Herbach et al, Nucl. Phys. A765 (2006) 426

INCL4.3: Low energy extensions

(should not work below ~150 MeV)



Reaction cross section (normalisation)
OK except on very light nuclei



Green: without clusters in INCL

p (62.9 MeV) + ^{208}Pb

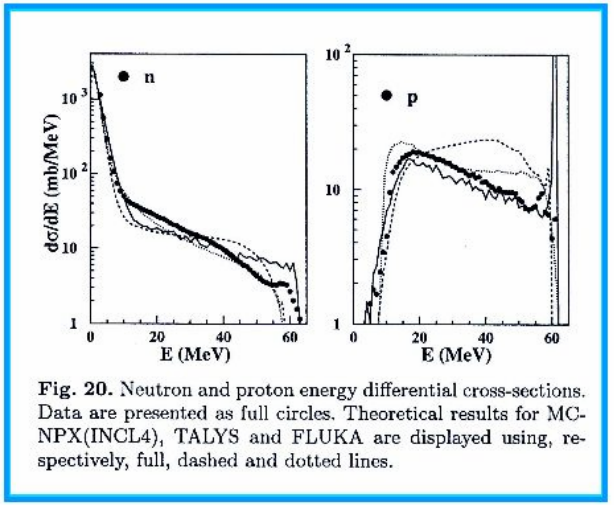


Fig. 20. Neutron and proton energy differential cross-sections. Data are presented as full circles. Theoretical results for MCNPX(INCL4), TALYS and FLUKA are displayed using, respectively, full, dashed and dotted lines.

A. Guertin et al, EPJ A23(2005)49

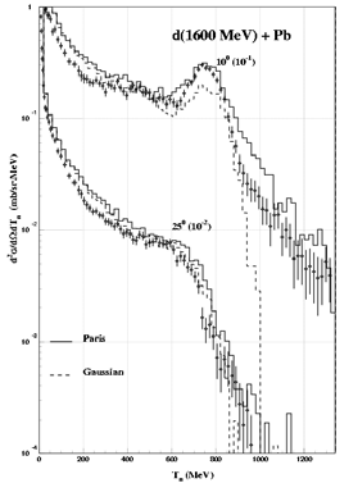
Continuous: INCL4+ABLA
Dashed: TALYS
Dotted: FLUKA

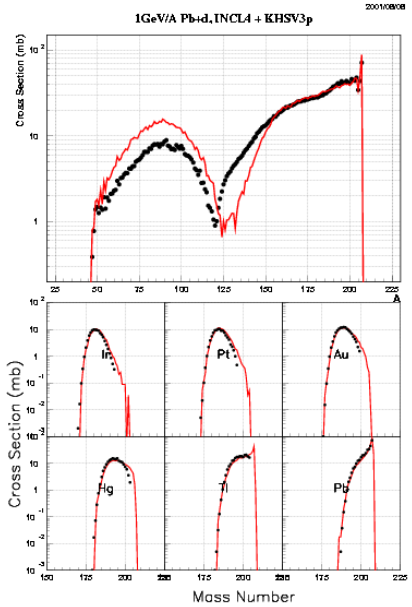
mb	Data	INCL4	TALYS	FLUKA
σ(p)	653	574	914	797
σ(n)	3218	3191	2040	2145

Ingredients: Pauli principle, low kinetic energy of nucleons at the surface.

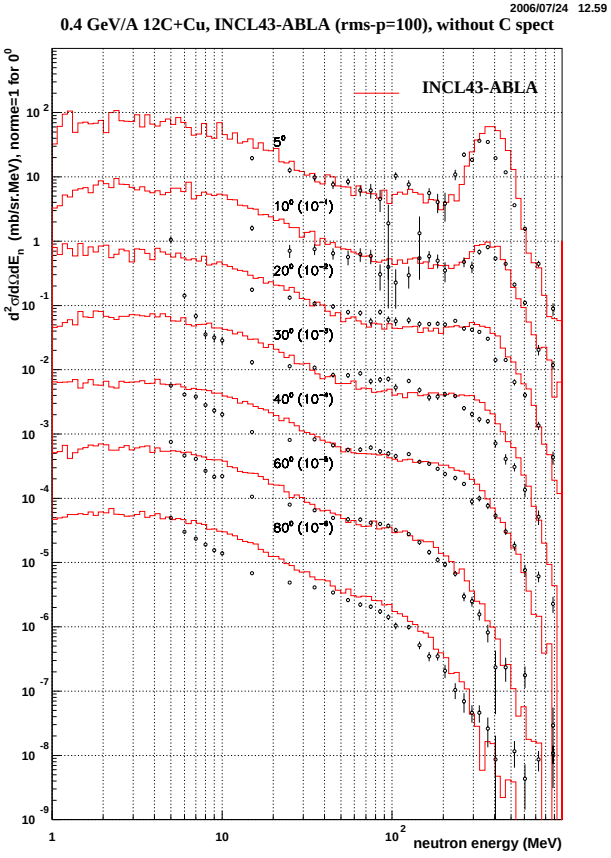
INCL4+ABLA: Composite projectiles (n cross sections)

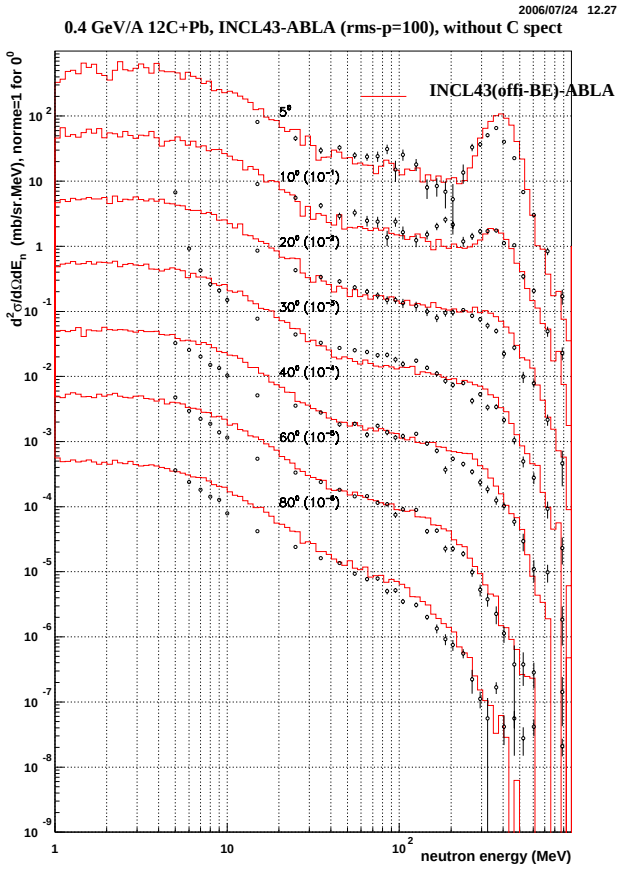
(d beam already in)





Potentiality of extensions: C12 beam



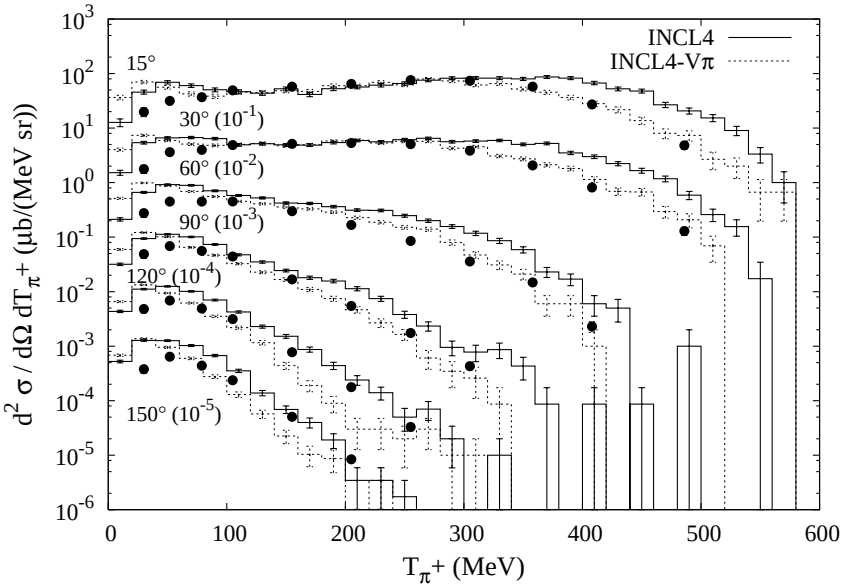


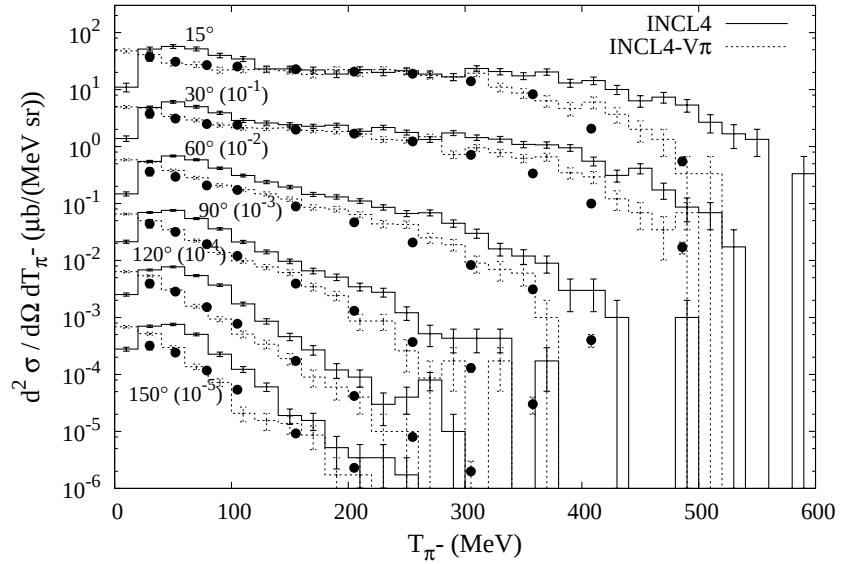
Y. Iwata et al., Phys. Rev. C64 (2001) 54609

Extension for fun: C12 as 12 nucleons in realistic r-space and p-space distrib. + binding energy.

INCL5: Pion production improved

p (730 MeV) + Pb -> π+ (or π-)





D. Cochran et al, Phys. Rev. D6 (1972) 292

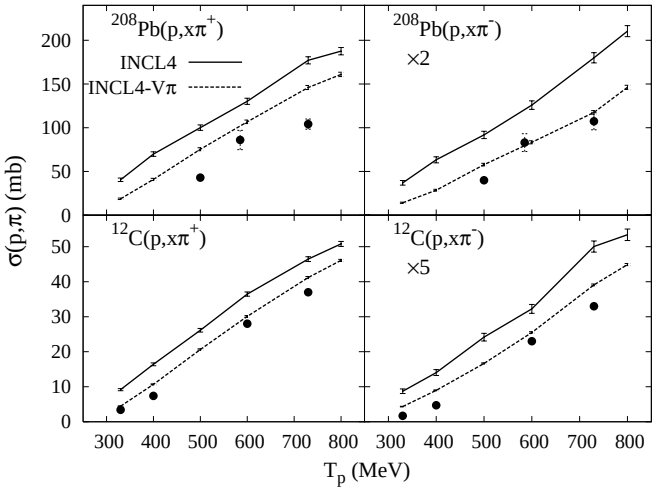
T. Aoust, J. Cugnon, Phys. Rev. C accepted for publication

$V_\pi(t_\pi,(N-Z)/A)$ introduced

Dashed: WITH Vπ (New)

Continuous: WITHOUT (Old)

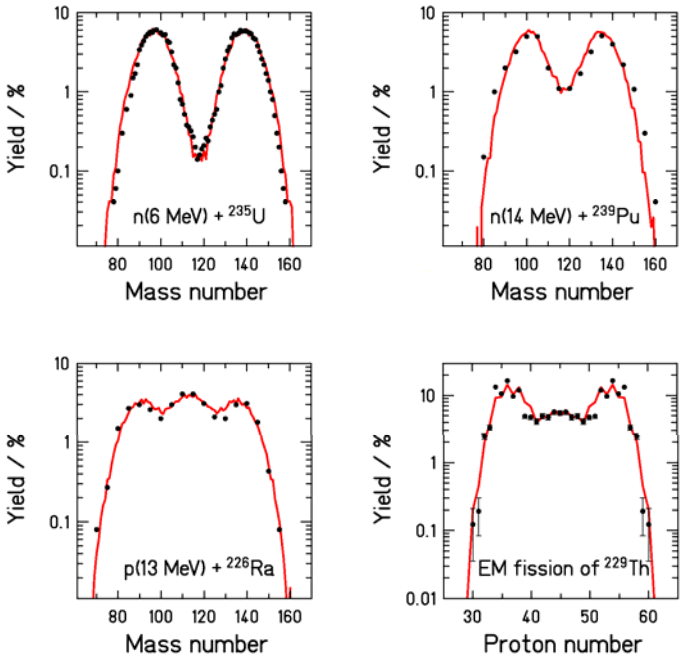
π production significantly better (also π induced reactions)



NewABLA

➢**New content:**

Multifragmentation possible (if E*/A>3MeV)
Evaporation of lcp ((d,t,3He,4He) and IMF
Better coulomb barriers
Time dependent competition fission-evaporation
Fission fragment mass distribution re-adjusted



➢**Will be soon coupled with INCL5 for systematic tests (2007)**

➢**INCL improvement at high energy (up to 10 GeV?)**

PhD starting (Sophie PEDOUX) mentored by J. Cugnon

First step: 2π and 3π channels introduced in the NN interaction

Conclusions

INCL4-ABLA Range of application

Beams: π,p,n,d,t,3He,4He
Energies: ~100 MeV- 3 GeV
Targets: Al (C?) - U

Precisions: 10%-20% except identified defects
((p,n) quasielastic, π production, light nuclei…)

Already in transport codes (LAHET-MCNPX-Hermes)

INCL5-NewABLA Improvements

Low energy (down to 50 MeV?)
π production, π beams
Light evaporation residues, light nuclei

All parts separately tested, to be assembled soon
(International Comparison of Spallation Models; late 2007)

Future

Extension up to ~10 GeV
Beams of light ions

Note: (Models to be complemented by coherent scattering (Glauber type) and nuclear structure at low energy)

As experimentalists, a real will (or wish) to have it in GEANT-4