Recent CHIPS developments

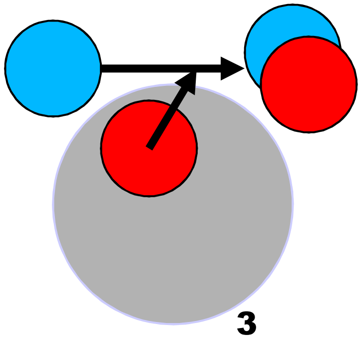
Mikhail Kosov, 14th Geant4 Users and Collaboration Workshop, 2009

Introduction

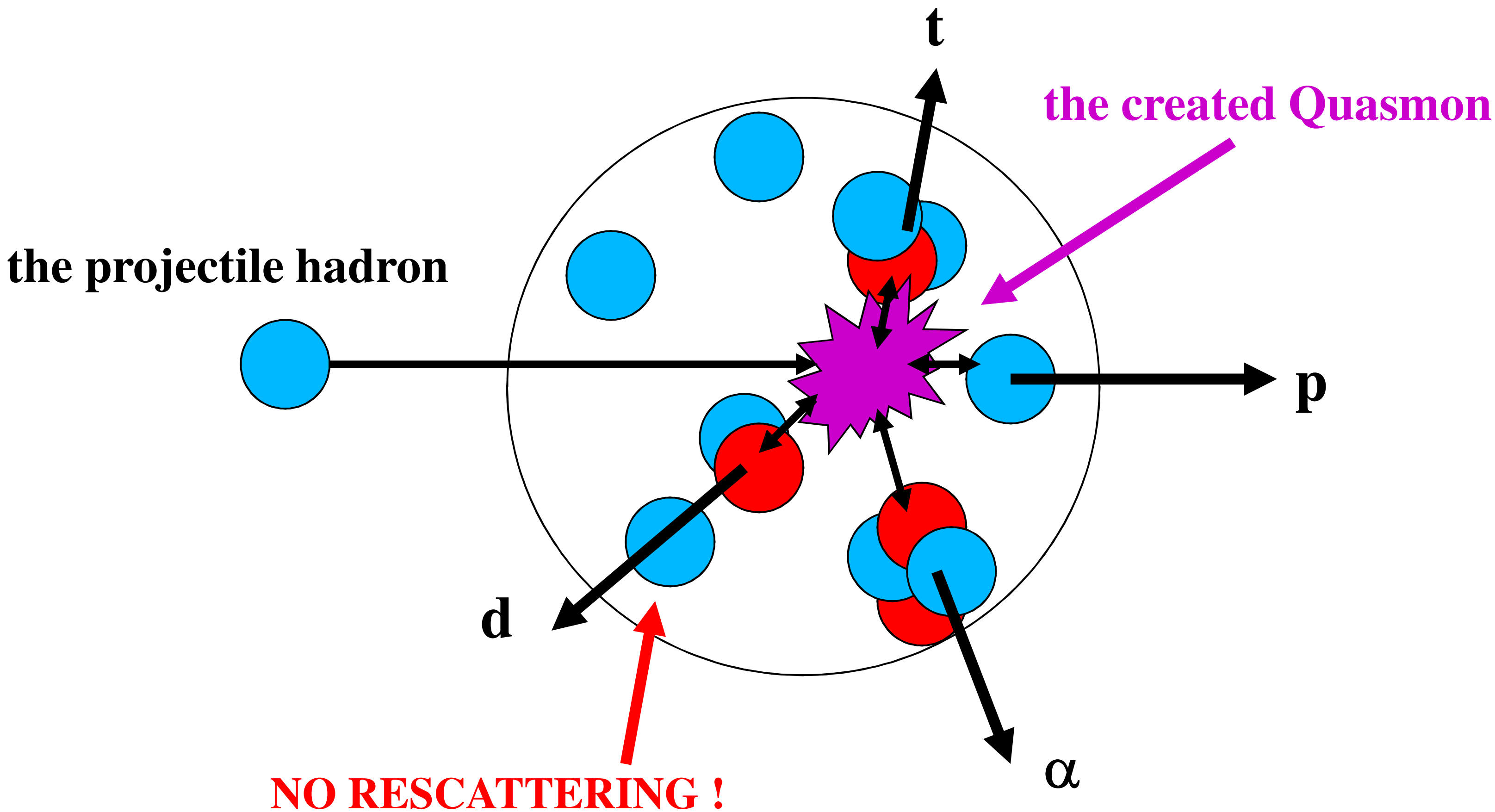
- The main goal of the CHIPS development is creation of a physics list, which is not using any other hadronic model (only CHIPS).
  - The CHIPS package is already unique or the best for the following processes:
    - At rest nuclear capture processes for negative (and neutral) hadrons
    - Neutrino-nuclear, electron-, muon-, tau-nuclear and photo-nuclear reactions
    - Elastic scattering for protons and neutrons
    - Quasi-elastic scattering for the Geant4 QGS model
- New developments:
  - On flight hadron-nuclear interactions
    - Low energy 3-D CHIPS model (excitation and decay of Quasmons)
    - High energy CHIPS string interaction interface extended to low energies
  - Nuclear-nuclear interactions
    - Fast (G4QLowEnergy) simulation appropriate only for low energies
    - All-energies CHIPS ion-ion process (G4QInelastic – under development)
  - CHIPS interaction cross-sections for hadron-nuclear and ion-ion interactions

Algorithm of the low energy CHIPS

- Simulation of the deep inelastic hadron-nuclear interactions is the same as in CHIPS stopping algorithm
  - Nuclei are clusterized (nucleons are in di-baryon, tri-barion etc. states)
  - The projectile hadron joins with one of the clusters and creates a Quasmon
  - By quark-fusion or quark-exchange with other clusters energy is dissipated
  - When the quark level algorithms are exhausted, switch to nuclear evaporation
- A few decoupled processes are added
  - Quasi-elastic scattering of the projectile on nucleons and nuclear clusters
    - G4QElastic process is used for this scattering on nucleons or on clusters
  - Pick up process, which provides high energy forward nuclear fragments
- Final State Interaction of produced secondaries
  - A kind of the nuclear fusion FSI reactions
  - For energy and momentum correction in case of problems



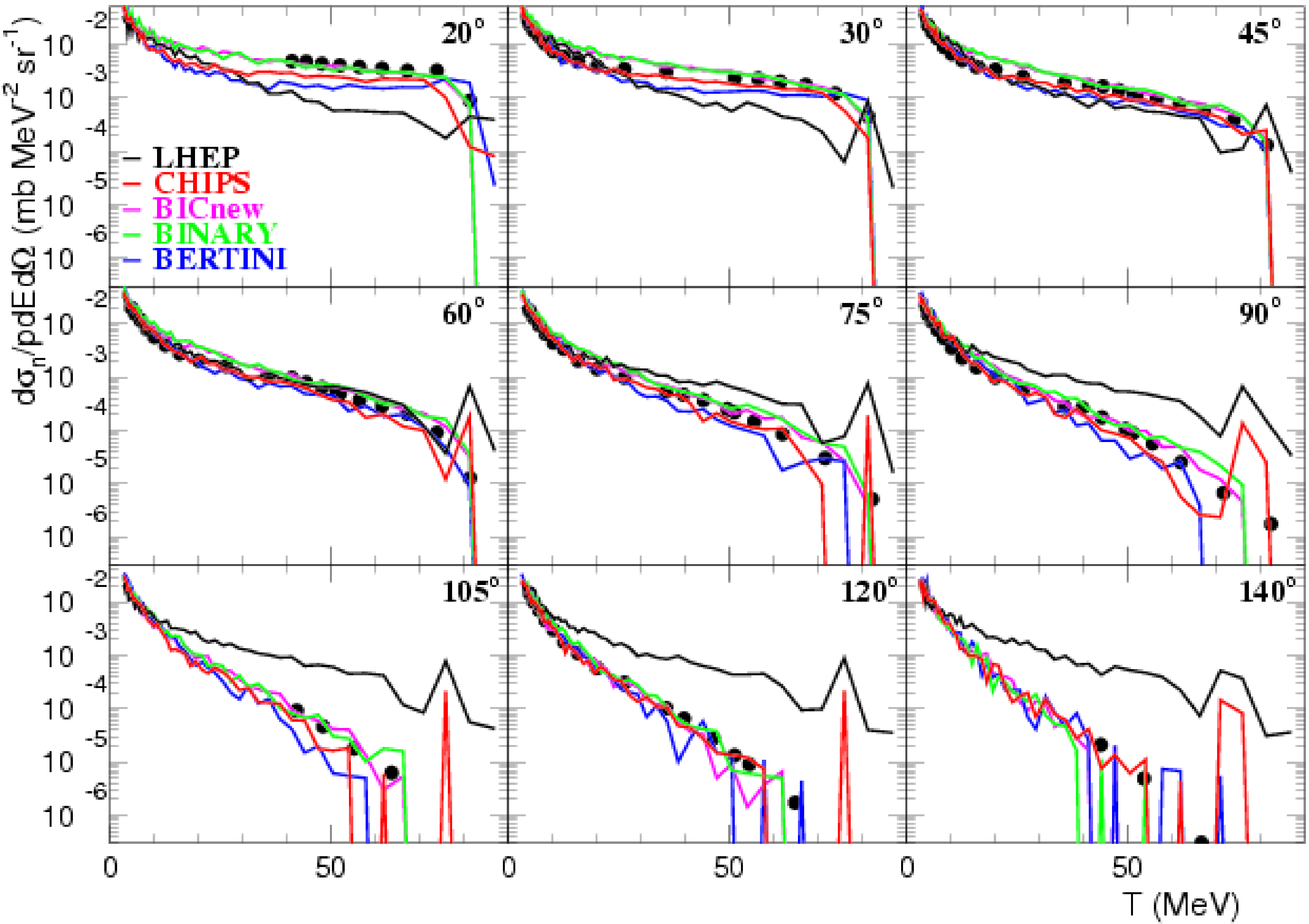
CHIPS algorithm of the deep inelastic hadron-nuclear interaction



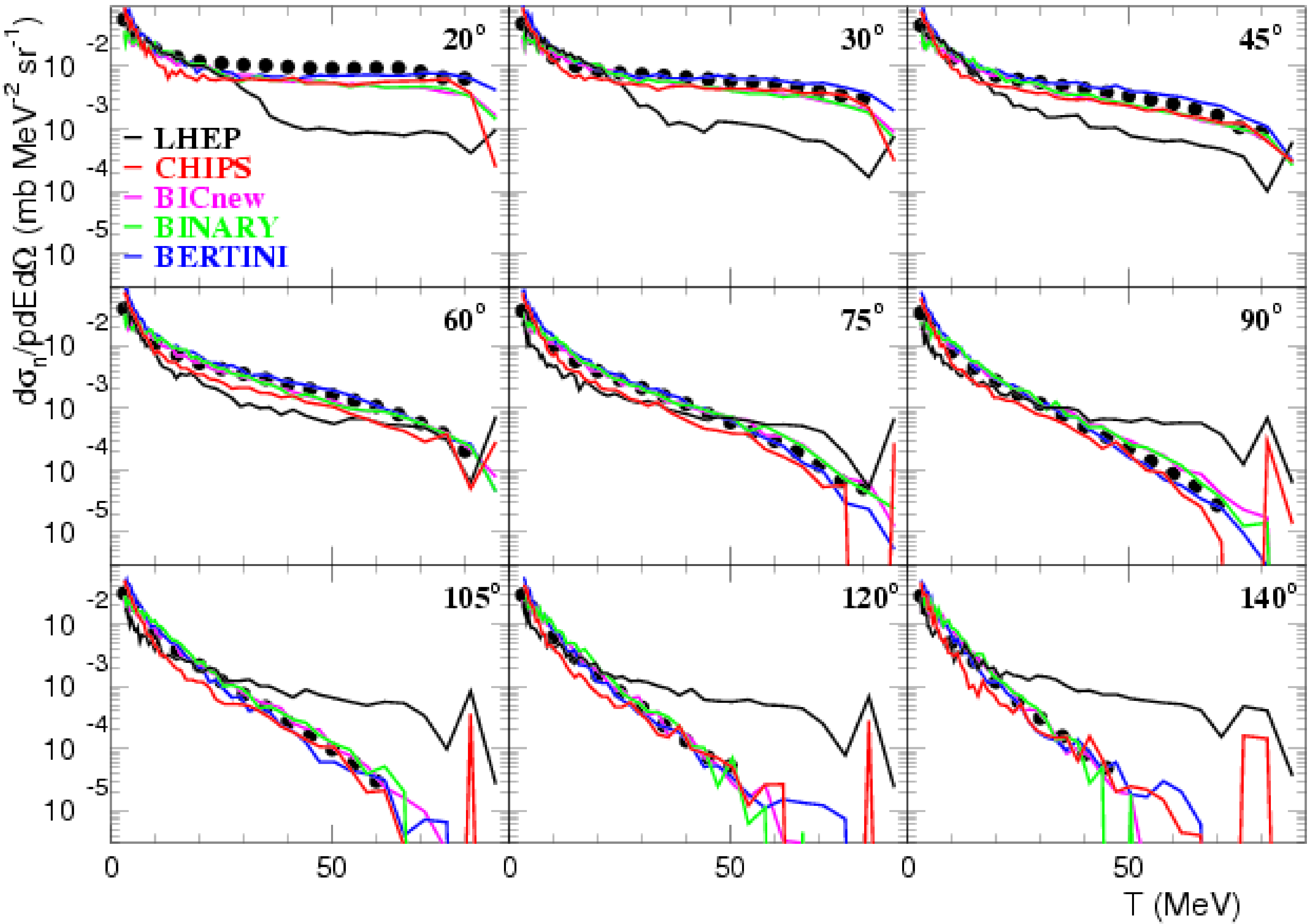
NO CASCADE, JUST A DECAY !

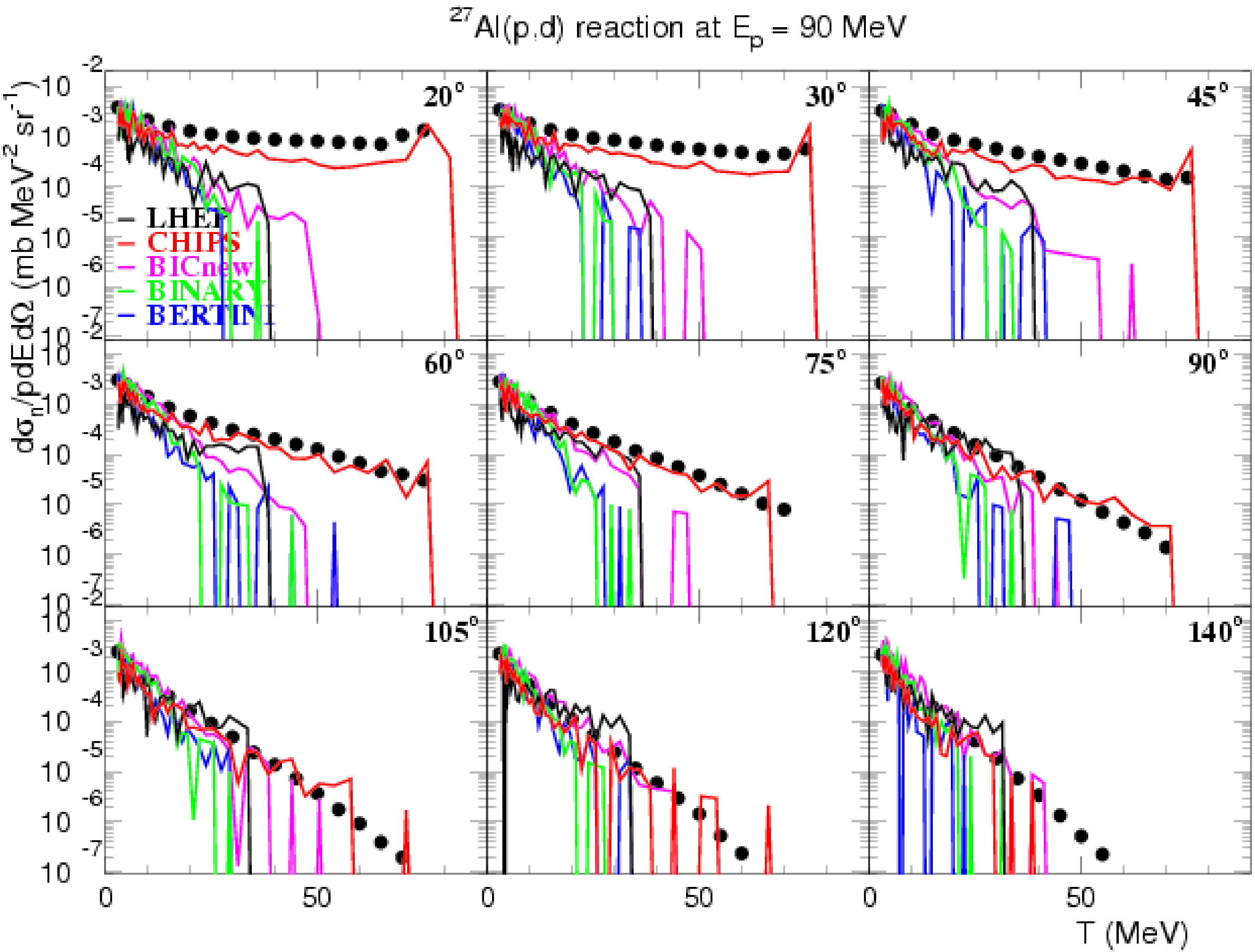
The example for 90 MeV protons on Al and Bi is following

$^{27}Al(p,n)$ reaction at E_p = 90 MeV



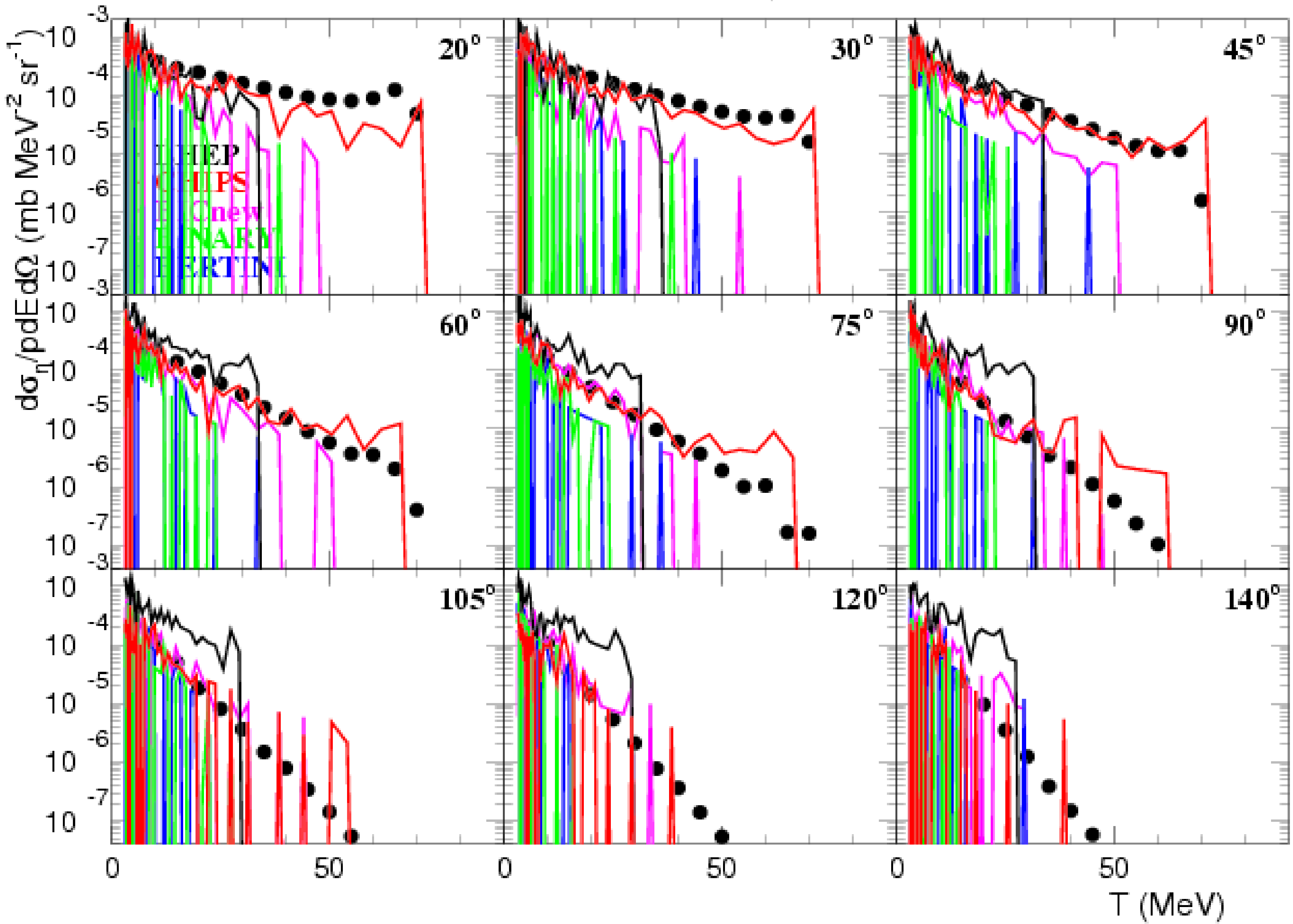
$^{27}Al(p,p)$ reaction at E_p = 90 MeV



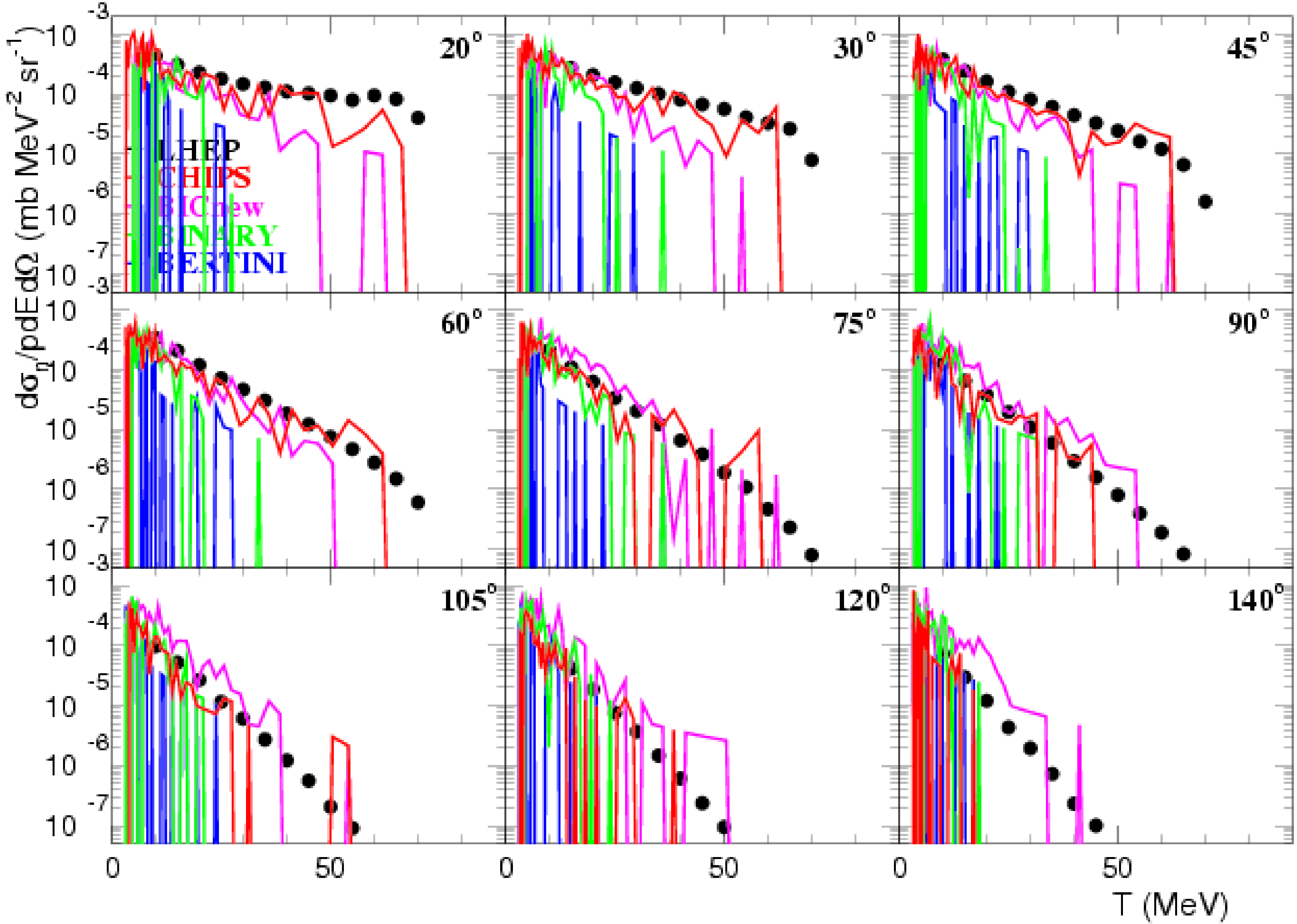


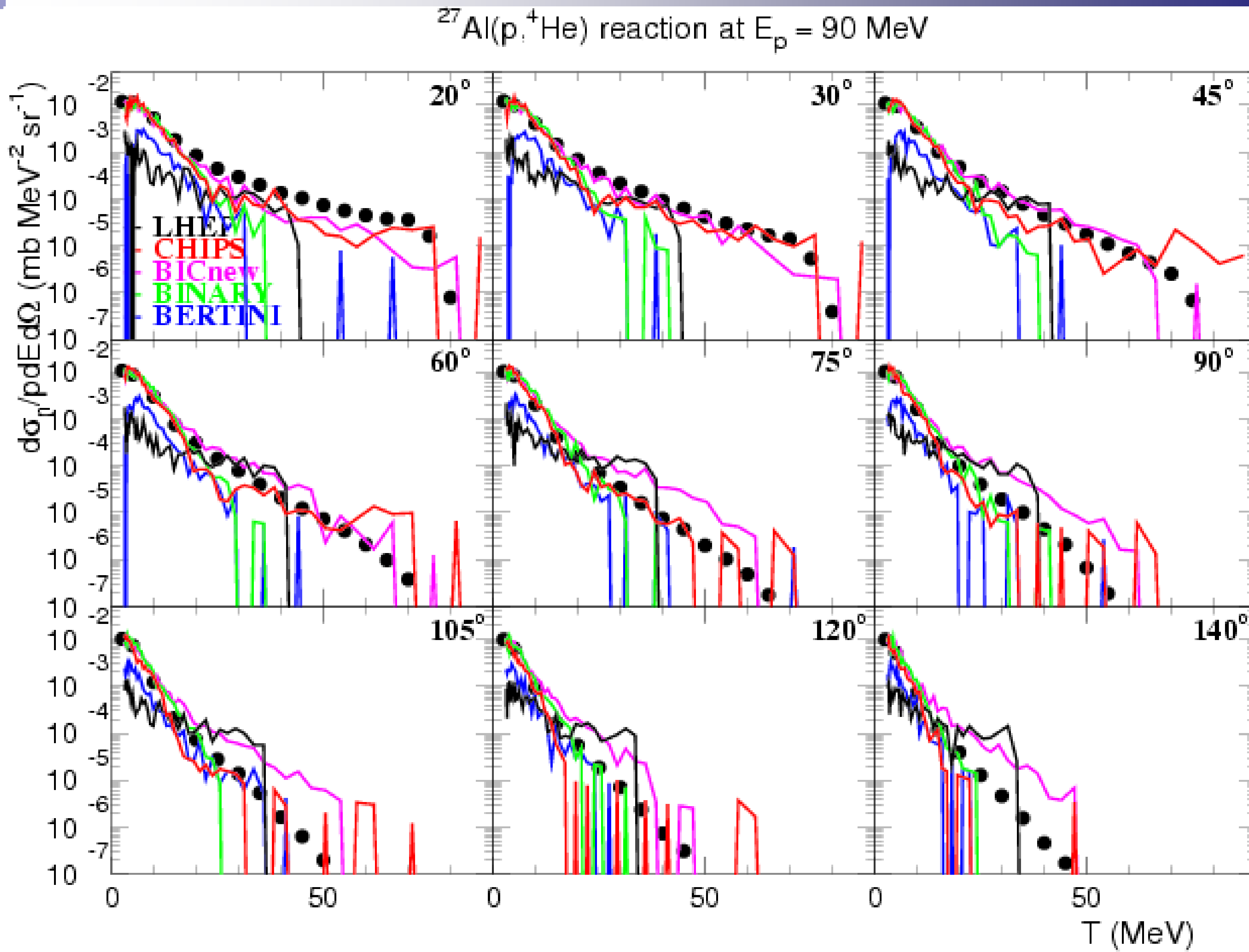
^{27}Al(p,d) reaction at E_p = 90 MeV
$d\sigma_n/pdEd\Omega$ (mb MeV^{-2} sr^{-1})
LHEP
CHIPS
BICnew
BINARY
BERTINI
20°
30°
45°
60°
75°
90°
105°
120°
140°
T (MeV)

^{27}Al(p,t) reaction at E_p = 90 MeV



$^{27}Al(p,^{3}He)$ reaction at E_p = 90 MeV




^{27}Al(p,^{4}He) reaction at E_p = 90 MeV
$d\sigma_\Omega/pdEd\Omega$ (mb MeV^{-2} sr^{-1})
LHEP
CHIPS
BICnew
BINARY
BERTINI
20°
30°
45°
60°
75°
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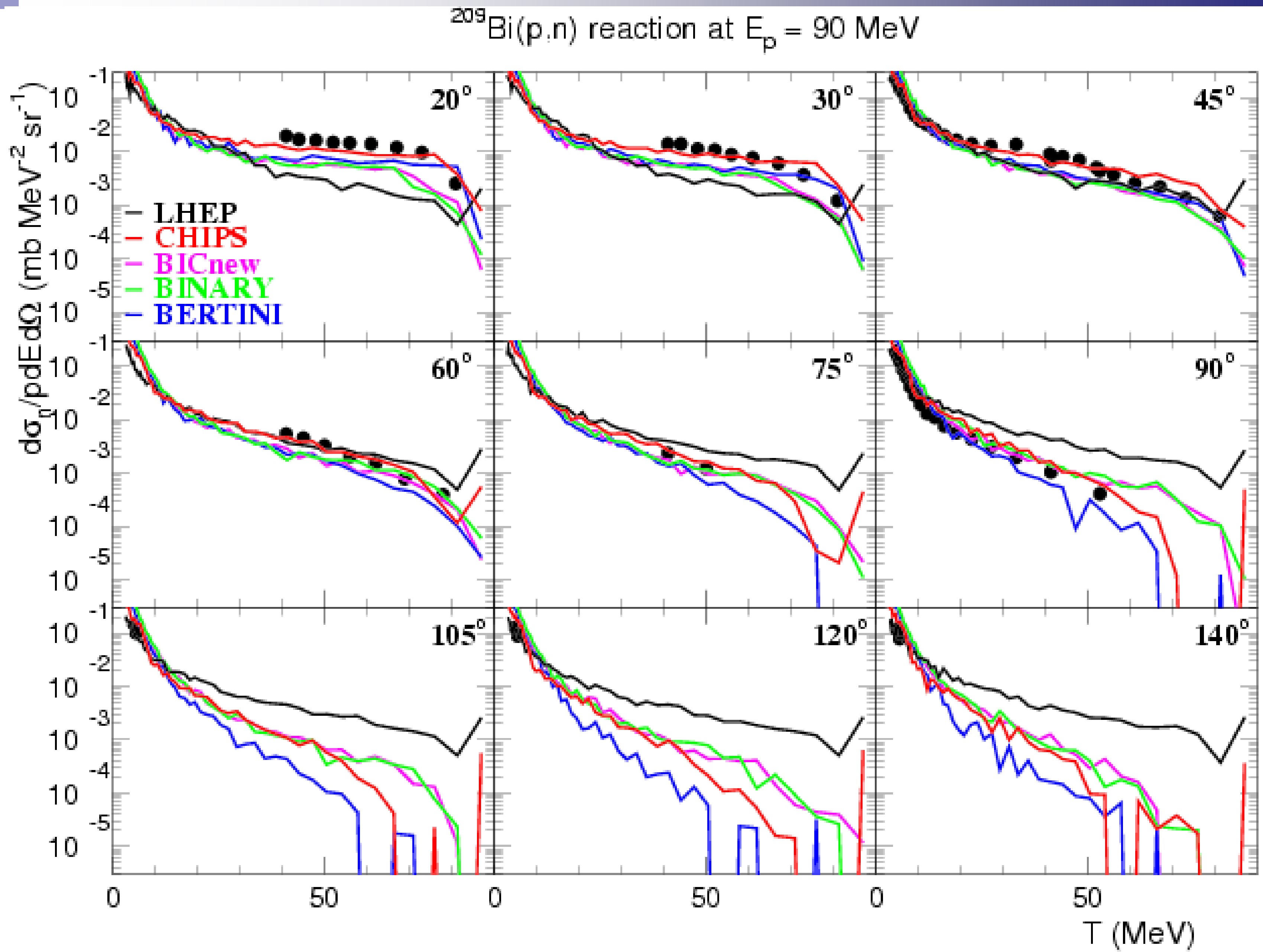
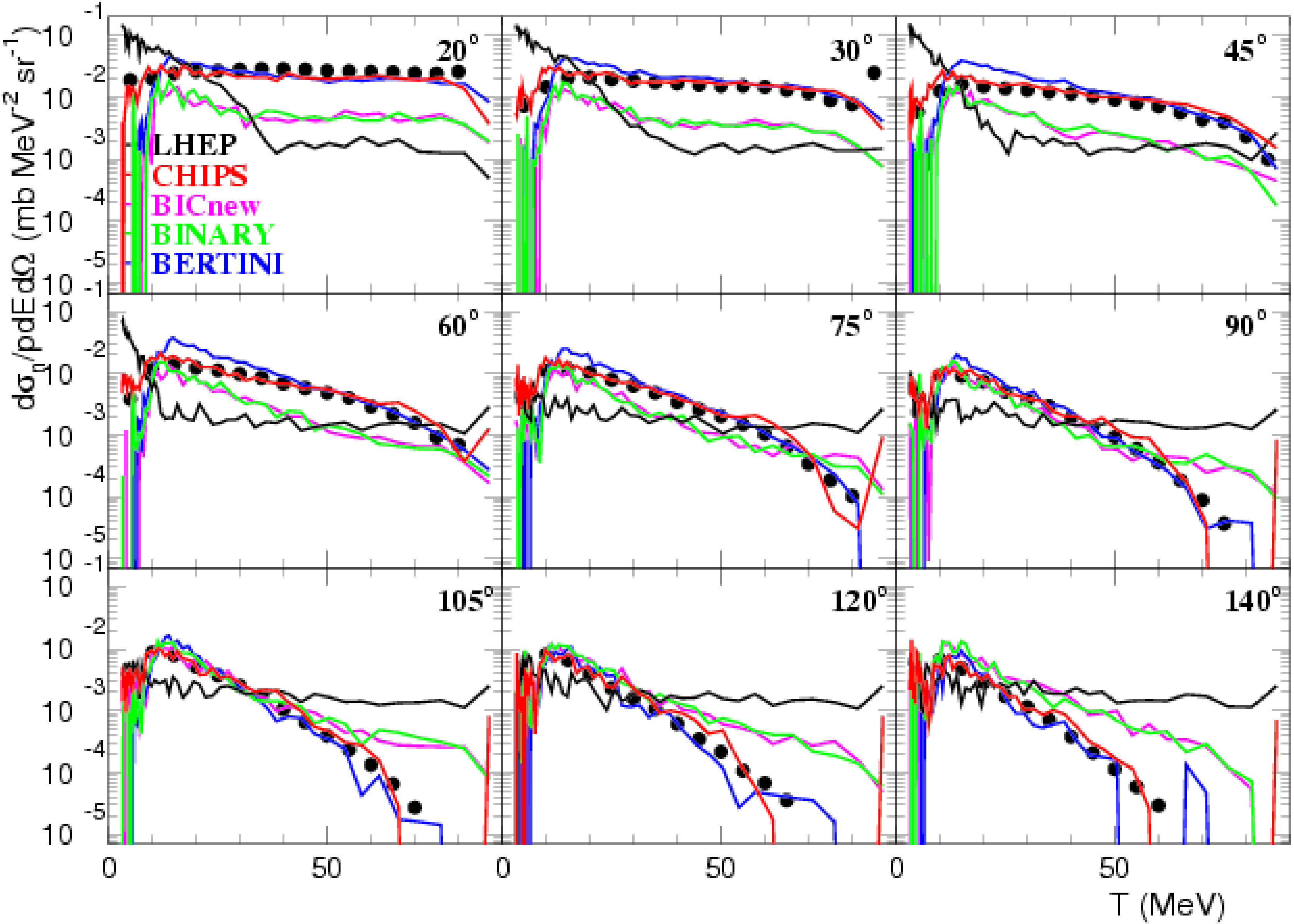
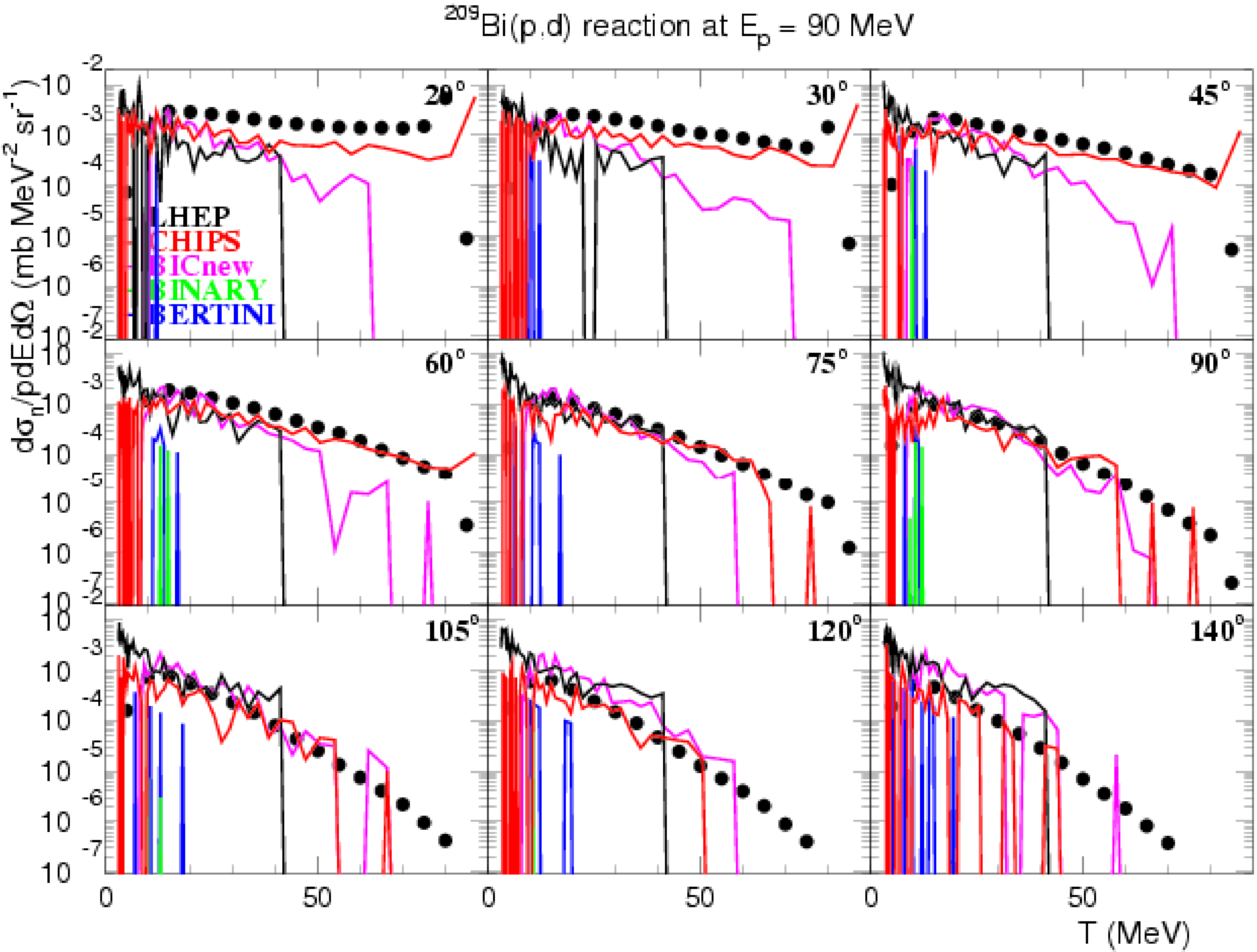
105°
120°
140°
T (MeV)



^{209}Bi(p,n) reaction at E_p = 90 MeV
$d\sigma_n/pdEd\Omega$ (mb MeV^{-2} sr^{-1})
20°
30°
45°
60°
75°
90°
105°
120°
140°
LHEP
CHIPS
BICnew
BINARY
BERTINI
T (MeV)

^{209}Bi(p,p) reaction at E_p = 90 MeV





^{209}Bi(p,d) reaction at E_p = 90 MeV
$d\sigma_n/pdEd\Omega$ (mb MeV^{-2} sr^{-1})
LHEP
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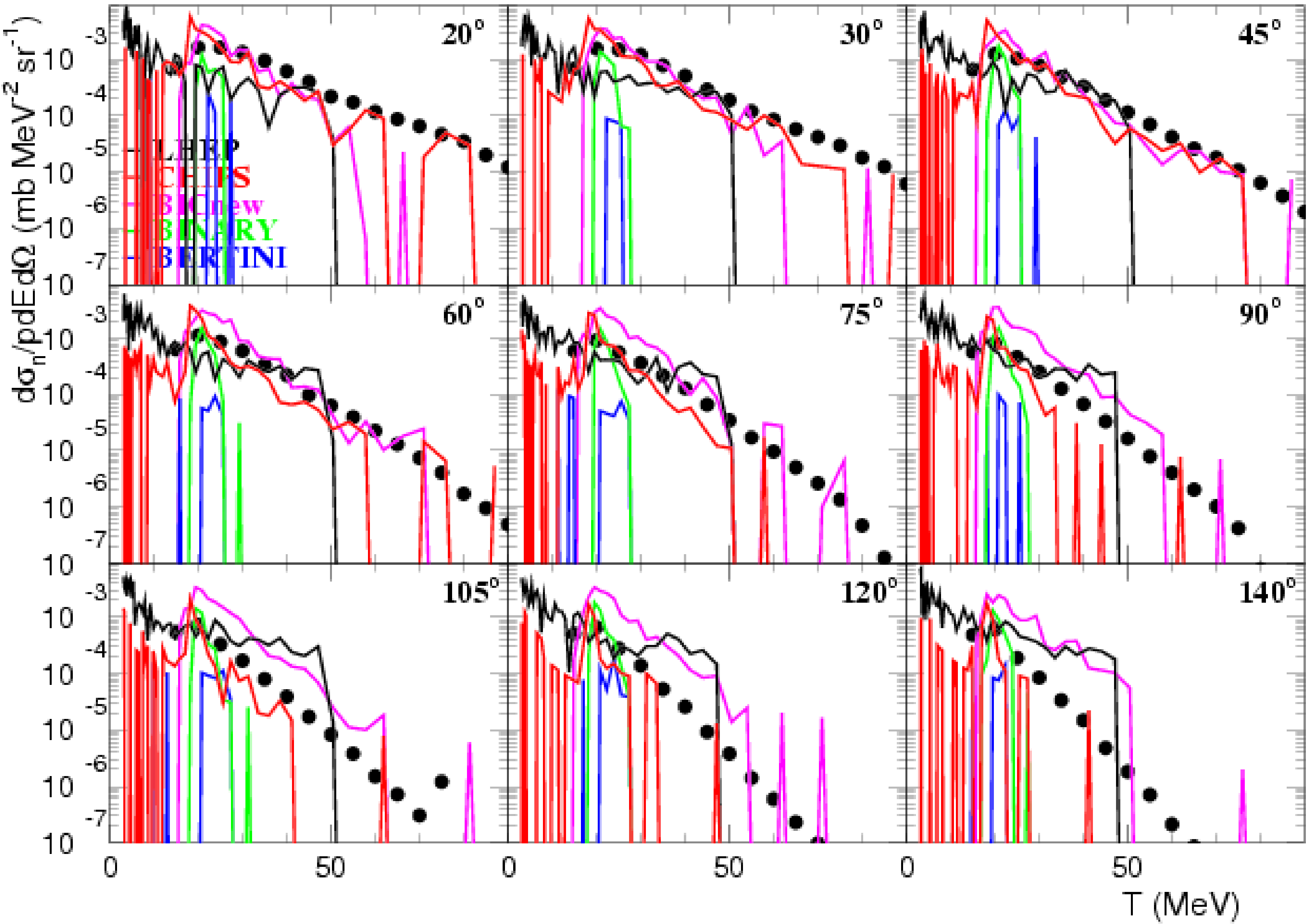
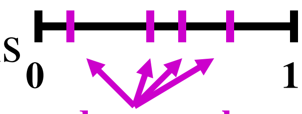
^{209}Bi(p,^{4}He) reaction at E_p = 90 MeV



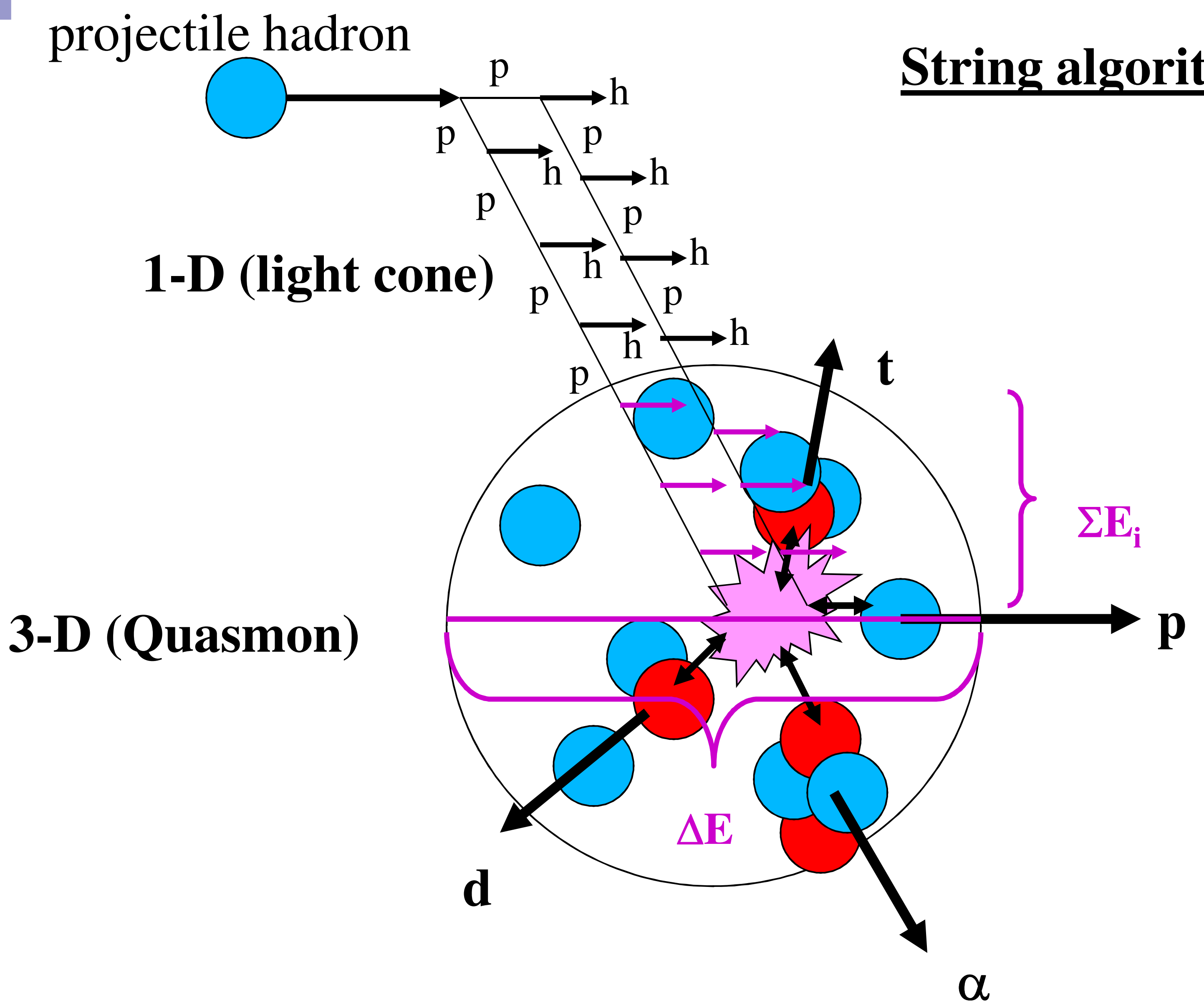
New CHIPS string algorithm

- The 1-D CHIPS String is similar to the QG String, but…
  - All partons are massless (current) instead of heavy (constituent, QGS) ones
  - Thus the CHIPS string algorithm can work from E=0 (formally $E>>m_q$)
  - The hadron splitting in partons is made by the CHIPS algorithm: $(1-x)^{N-2}$
  - If energy is restricted, the strings are fused or converted to hadrons



- Connection to the 3-D CHIPS algorithm
  - In nuclear matter string looses (ΣE_i) about k=1 GeV/fm ($\Delta E=k*T(b)/r(0)$)
    - This energy is converted to the Quasmon excitation
    - The rest (high rapidity part of the string) is hadronized outside of the nucleus
  - If at low energies the projectile energy is smaller than ΔE, string is skipped
- Special cases
  - At low energies the transition to 3-D CHIPS can be used as an emergency
  - Quasi-elastic on nucleons happens at all energies without the string excitation

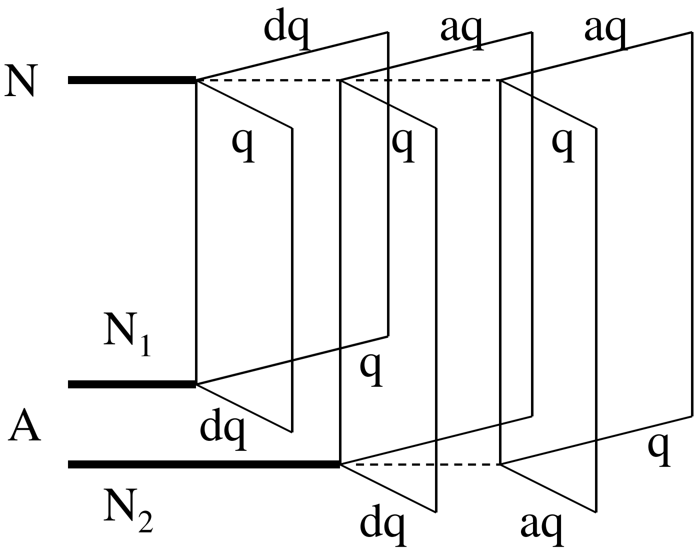
String algorithm



Problems in the string algorithm

- Because of the high transverse momenta of partons the resulting strings can have too low and even imaginary (tachionic) masses.
  - There are a few steps in the CHIPS algorithm to avoid this problem:
    - Try to fuse two or more strings with low masses
    - Scatter on another string with high mass and convert to a GS hadron
    - Scatter on the already produced hadron and convert to a GS hadron
    - Fuse with the already produced hadron and increase the string mass
- Sometimes (at very low energies) the string reduction algorithm converges to elastic scattering, then the interaction is recalculated
  - Be careful with the real threshold for inelastic interactions, as below the threshold the CHIPS algorithm can be looping (with the emergency stop)
- If the strings fusion algorithm fails to get rid of the low mass strings, the string 1-D algorithm is switched to the 3-D algorithm
  - Otherwise the CLHEP 4-vector functions (e.g. boosting to CMS of the string) crashes with the "tachionic" complain.

String fusion algorithm to avoid too low or imaginary mass



There are 6 strings (3 cut cylinders): 3 x q-dq , 3 x aq-q

String fusion examples

aq-q	aq-q	aq-q	q-dq	q-dq
aq-adq	aq-q	dq-adq	q-aq	adq-aq
adq-aq	adq-dq	q-aq	dq-q	aq-q

Emergency flavor reduction: (s – anti-s) → (u/d – anti-u/d) ($\eta \rightarrow \pi^0$)

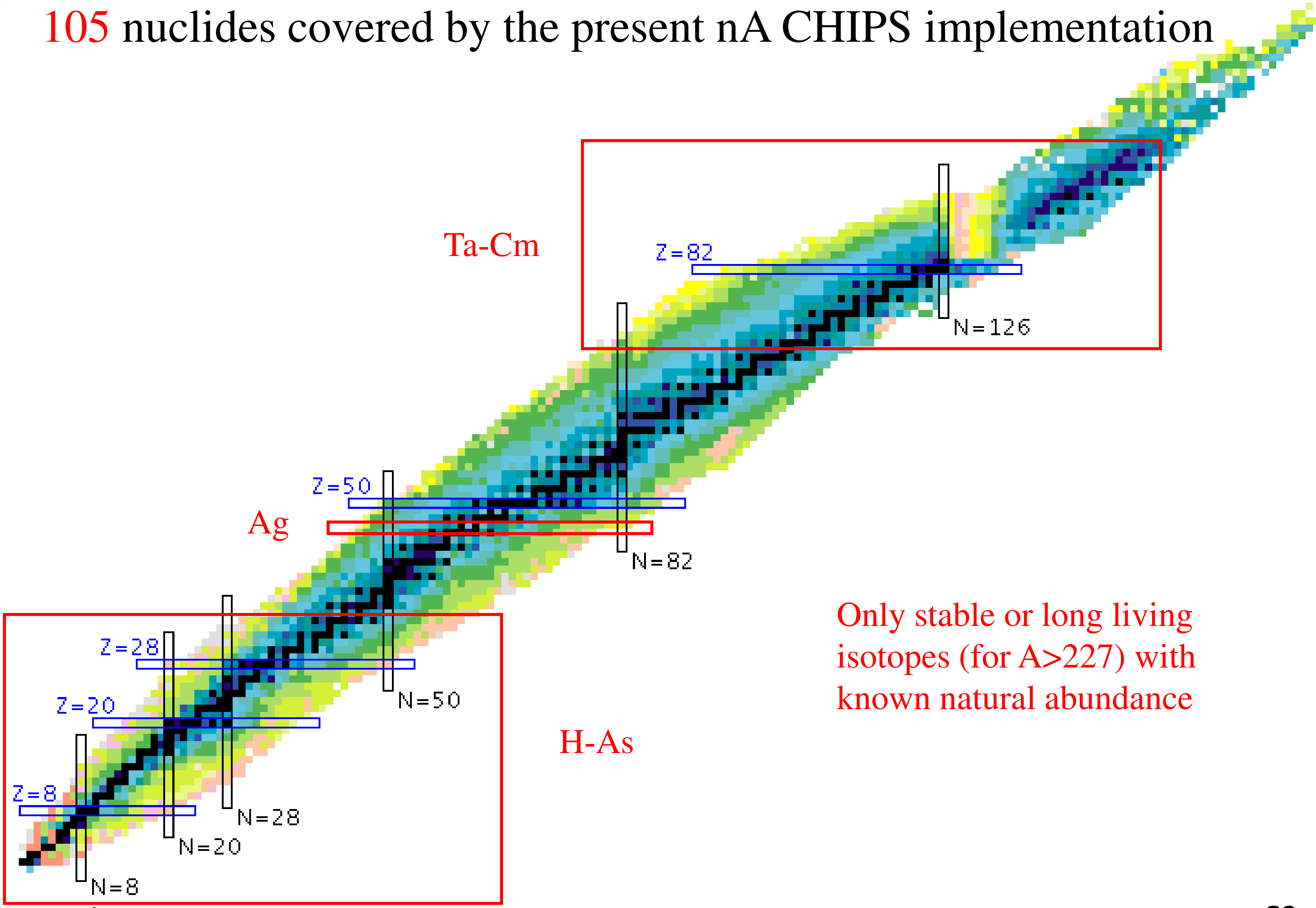
Emergency diquark reduction: (us – anti-d anti-s) → (u – anti-d)

Emergency jump to 3-D CHIPS: (u – anti-d) + N → Quasmon

New CHIPS interaction cross-sections

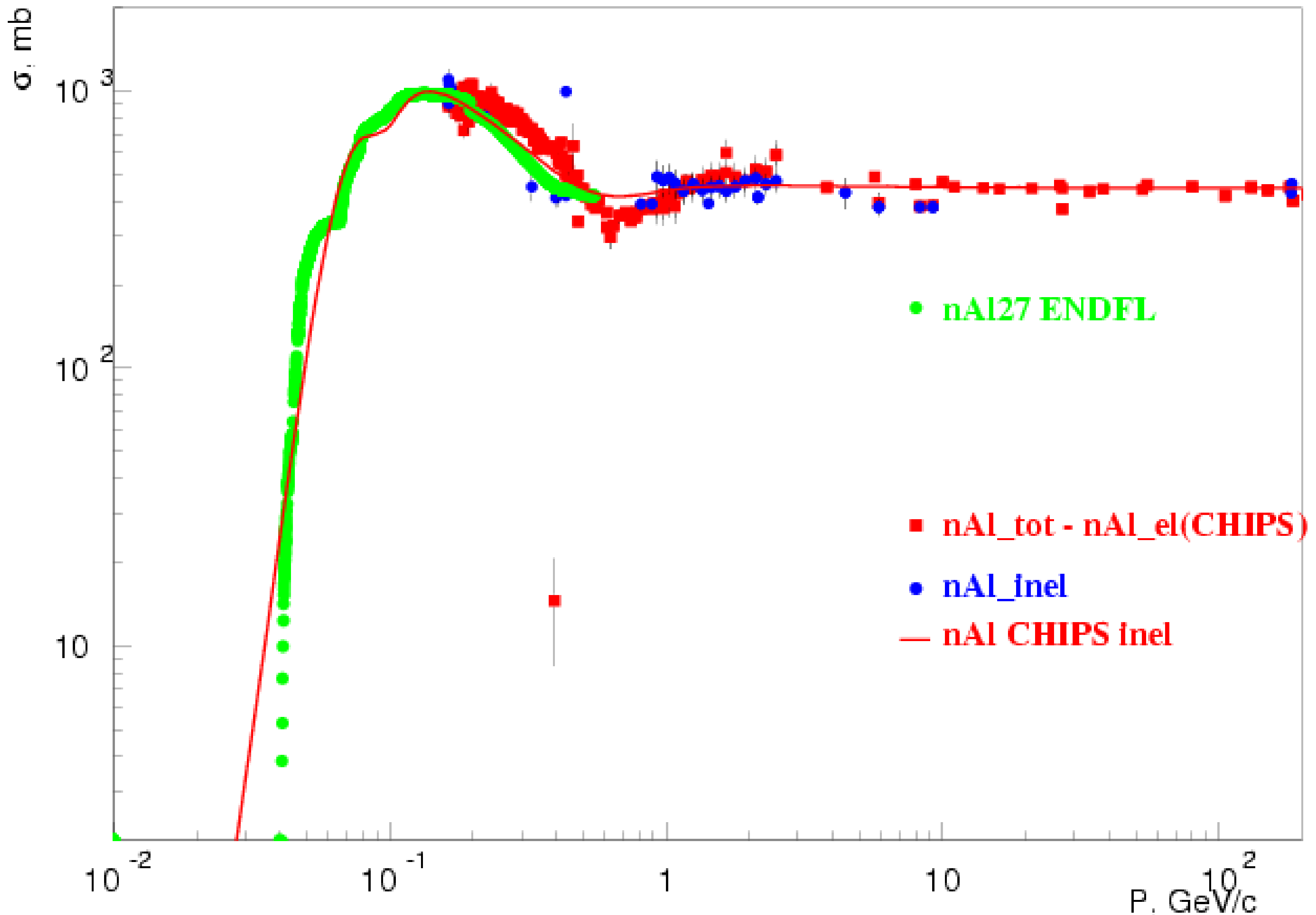
- To avoid usage of the heavy HP package the neutron-nuclear CHIPS cross-sections have been improved for low energies (including (n,γ) capture)
  - There ENDF/B-VII data base was used for the cross-sections
  - Inelastic cross-section is defined as $\sigma_{in}=\sigma_{tot}-\sigma_{el}$
  - The low energy 1/v cross-section is not implemented
  - The cross-sections are parameterized for more than 100 isotopes
- The CHIPS inelastic cross-sections for pion-nuclear, kaon-nuclear, hyperon-nuclear and antiproton-nuclear interactions are calculated
  - The CHIPS cross-sections are discussed in a special presentation
  - A big mistake was found for Geant4 K^+A interactions (= K^-A ?!)

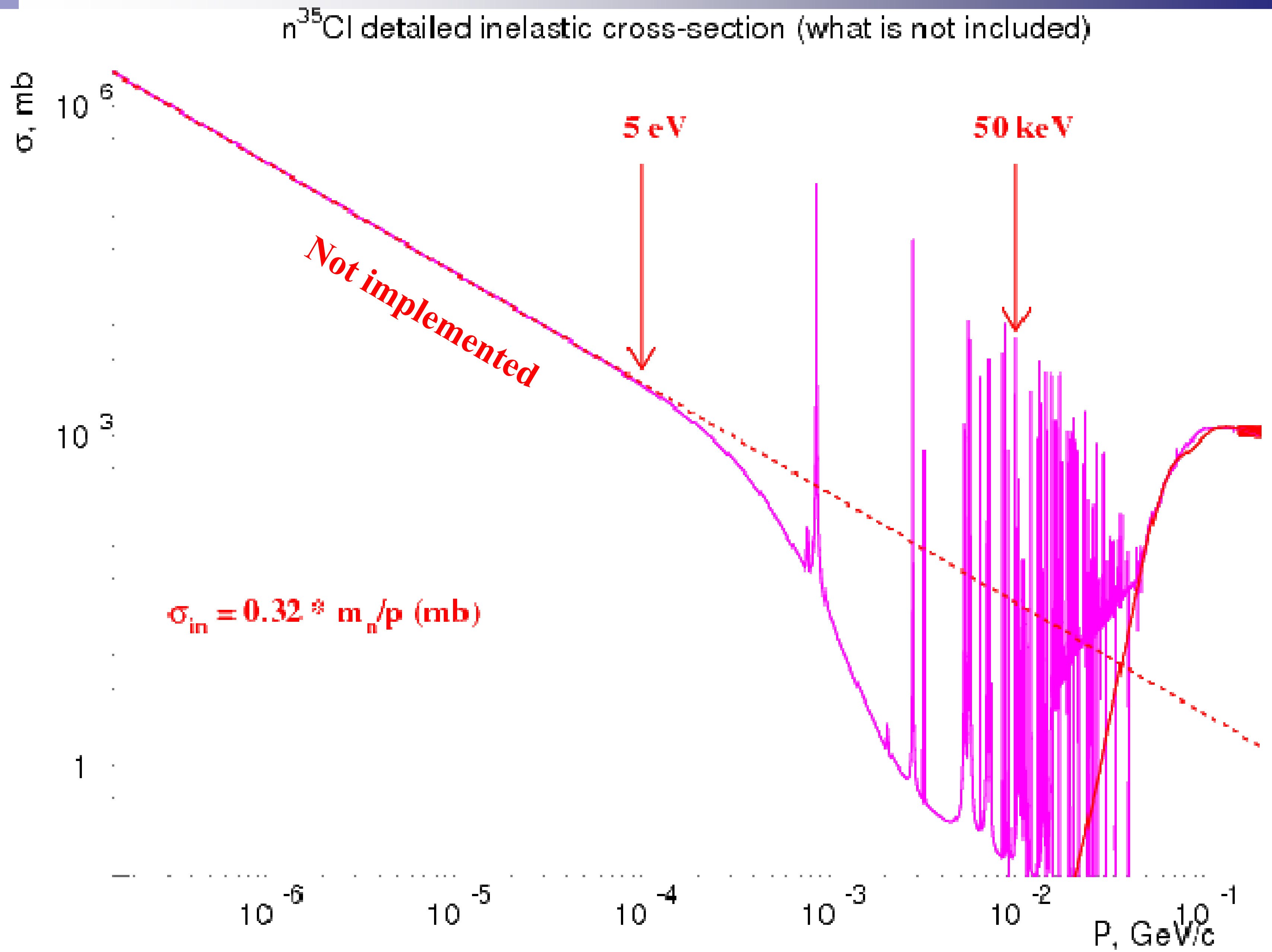
105 nuclides covered by the present nA CHIPS implementation



Only stable or long living isotopes (for A>227) with known natural abundance

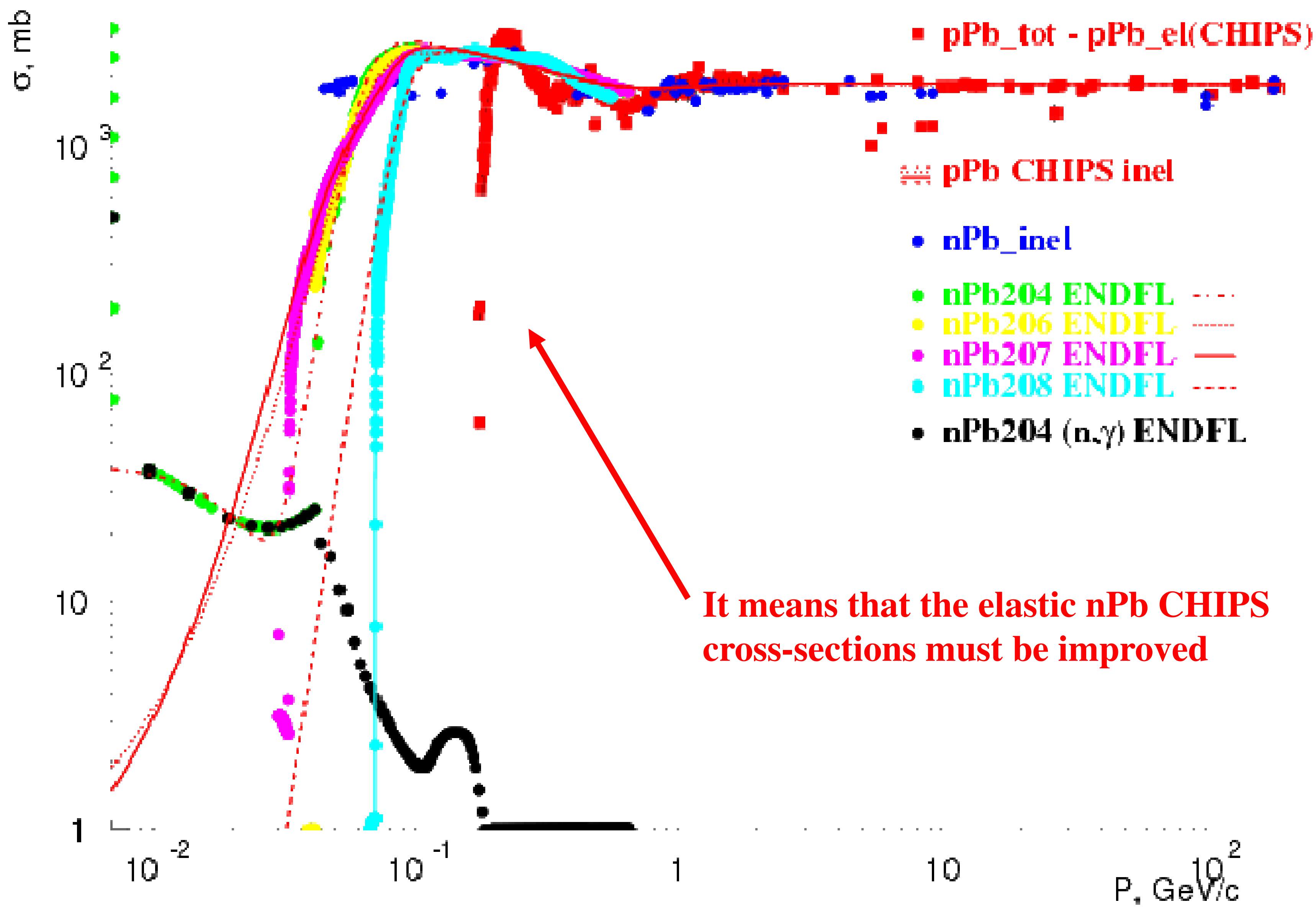
CHIPS improvement of nAl inelastic cross-section





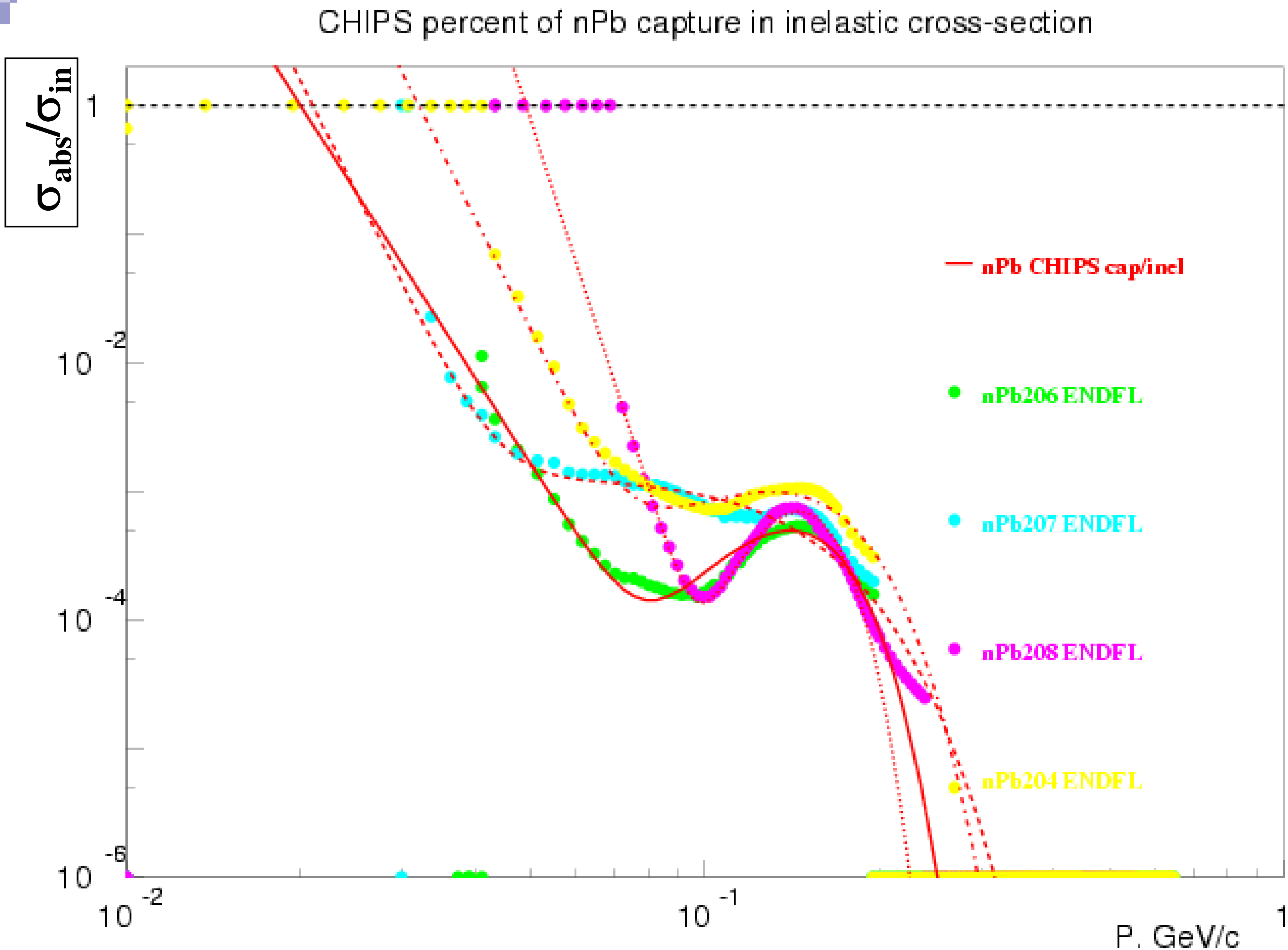
n35Cl detailed inelastic cross-section (what is not included)
σ, mb
10 6
10 3
1
5 eV
50 keV
Not implemented
σin = 0.32 * mn/p (mb)
10 -6
10 -5
10 -4
10 -3
10 -2
10 -1
P, GeV/c

CHIPS improvement of nPb inelastic cross-section



Fit for the absorption contribution σ_{abs}/σ_{in}

- Only ENDF/B VII evaluation data are used
  - $R(p)=\sigma_{abs}/(\sigma_{tot}-\sigma_{el})=\sigma_{abs}/\sigma_{in}$
  - Approximation: $R(p)=(p/B)^{-D}+EXP[C-(p-M)^2/W]$ (if R>1: R=1)
  - The parameter "B" is a threshold of the non-absorption reaction
- Simulation
  - The binary isotropic (n,γ) reaction can be simulated rather fast
  - Simulation of A(n,fission) reactions for A>225 is possible (?)
  - The rest of inelastic reactions are simulated by CHIPS and the simulation is much slower than (n,γ), but…
  - at low energies a big part of the CHIPS simulation is quasi-elastic scattering on quasi-free nucleons and nuclear clusters, so the low energy simulation is expected to be fast enough.



CHIPS percent of nPb capture in inelastic cross-section
σ_{abs}/σ_{in}
1
10^{-2}
10^{-4}
10^{-6}
10^{-2}
10^{-1}
1
P, GeV/c
nPb CHIPS cap/inel
nPb206 ENDFL
nPb207 ENDFL
nPb208 ENDFL
nPb204 ENDFL

Conclusion

- After the new CHIPS inelastic cross-sections are made for all particles, and the all-energies, all-projectiles nuclear fragmentation CHIPS model is debugged, the CHIPS physics list can be done
- A bug (high inelastic cross-section for K^+A interactions at very low energy) was found (LHEP/GEISHA) & corrected by the new CHIPS
- The HP package, in some cases, can be replaced by the new low energy CHIPS nA processes
- The last part of CHIPS to be implemented is the elastic scattering for πA, KA, HyperonA, anti-pA

Backup slides following