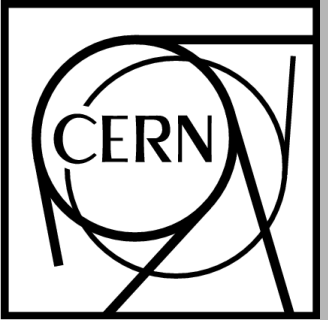
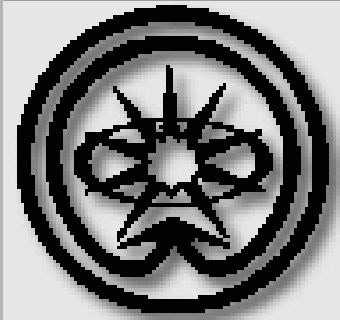




CHIPS physics list in Geant4

Mikhail Kosov, EUDET Annual meeting, September 29, 2010

Introduction (CHIPS Phys. List status)

- The CHIPS physics list is an experimental physics list, which simulates (** in all physics lists, * in many other physics lists):
  - all inelastic hadron-nuclear reactions (all particles, all energies)
  - photo/lepto-nuclear reactions**(including neutrino-nuclear reactions)
  - elastic hadron-nuclear reactions (all particles, all energies)*
  - stopping for all negative hadrons** + μ^- and τ^- leptons
  - synchrotron radiation (all particles, not only for e^-/e^+) important for γ-nuclear
- All processes are based on the original CHIPS model with the unique CHIPS approximation for reaction cross-sections http://indico.cern.ch/getFile.py/access?contribId=2&resId=1&materialId=slides&confId=69548
- The CHIPS physics list is robust, but it is not complete yet…
  - The ion-ion interactions are still not finished (not very important).
  - The low energy (LE) neutron cross-sections are not implemented because the low energy inelastic nA cross-sections can not be implemented in the open code toolkit ($\rightarrow$ callorimeter response overestimation).
  - The CHIPS inelastic reactions are not tuned to thin-target data.

CHIPS interaction cross-sections

- Elastic hadron-nuclear and ion-ion cross-sections
  - Elastic hA reaction cross-sections are complete in Geant4 (EUDET support)
    - low energy neutron-nuclear elastic cross-sections http://indico.cern.ch/getFile.py/access?contribId=3&resId=1&materialId=slides&confId=84659
    - hadron-nuclear elastic cross sections for all energies, all hadrons http://indico.cern.ch/getFile.py/access?contribId=0&resId=1&materialId=slides&confId=80049
  - Not completeness: detailed approximation of differential cross-section is made only for protons, and it is used for neutrons and all other hadrons
  - Elastic ion-ion cross-sections (reaction and differential) are calculated theoretically and approximated without comparison with data
- Inelastic hadron-nuclear cross-sections
  - Ion-ion inelastic process in **CHIPS PL** is taken from **G4Had** (or G4QLowE)
  - Inelastic reaction cross-sections are made for all hadrons, all energies
  - Exception for LE nA, which are temporary implemented for 105 of 411 isotopes (inelastic and (n,γ) reactions, no fission) without thermal part and with “corresponding” exaggeration of the intermediate absorption part, which overestimates immediate neutron absorption in matter, overestimates the CHIPS simulation of calorimeter responses and make the response too fast: http://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=105232

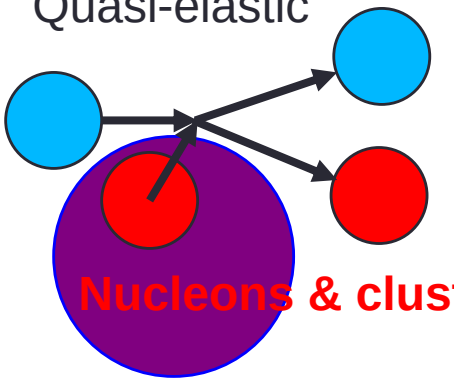
Existing CHIPS LE nA cross-sections

- In spite of the open source restrictions the CHIPS fit for low energy nA non-elastic cross-sections was presented
  - Non-elastic means inelastic + (n,γ), whilst fission is a part of inelastic
  - 411 isotopes for inelastic, (n,γ), and fission reactions are covered
  - Presentation of the CHIPS LE (n,γ), inelastic, fission cross-sections: http://indico.cern.ch/getFile.py/access?contribId=2&resId=0&materialId=slides&confId=93377
- All approximations are 2D functions of A and momentum
  - A-dependent coefficients for the momentum dependent functions
  - In the very low energy region: individual coefficients for each isotope
- The CHIPS approximations are compared with ENDF/B-VII and other modern data bases, including “high energy” DB (411 pictures for each of inelastic & (n,γ) reactions + 70 for fission)
- The CHIPS approximation covers 3 times more separate isotopes than the existing G4Had HP data base
- It is working much faster than the HP package

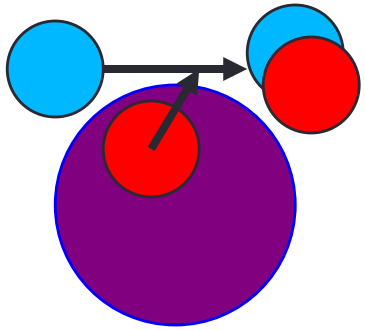
LE inelastic CHIPS model (all hadrons)

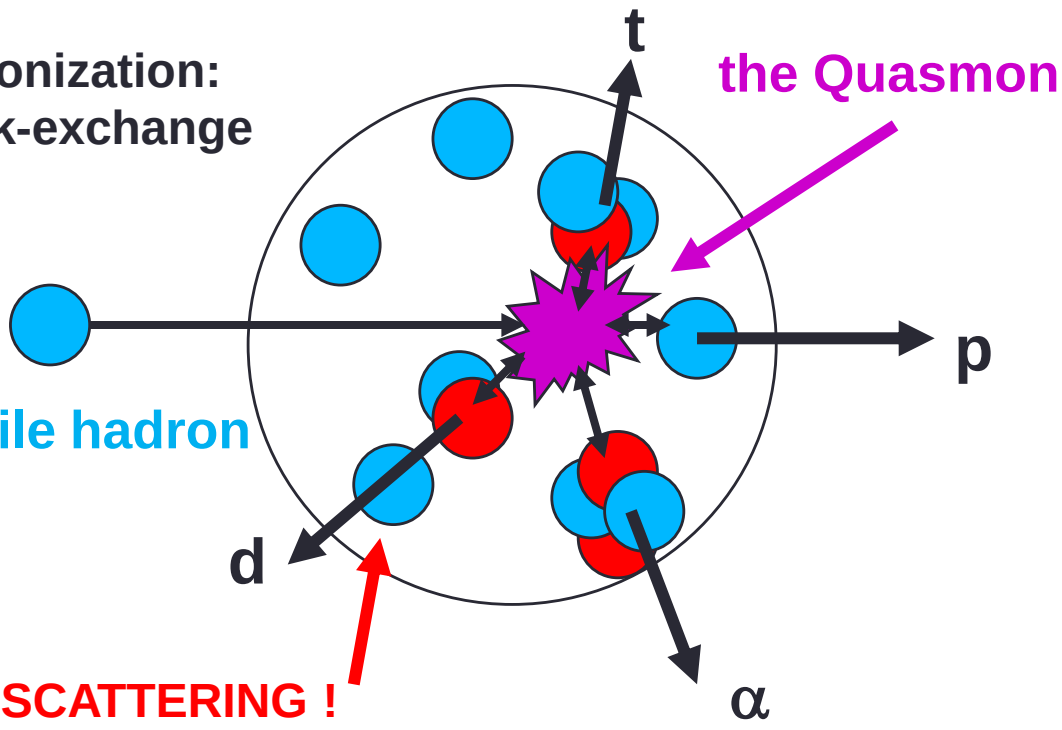
- Absorption of projectiles by nuclei with creation of Quasmons + quasi-elastic & pick-up reactions on nucleons & clusters
  http://indico.cern.ch/getFile.py/access?contribId=1&resId=1&materialId=slides&confId=50798

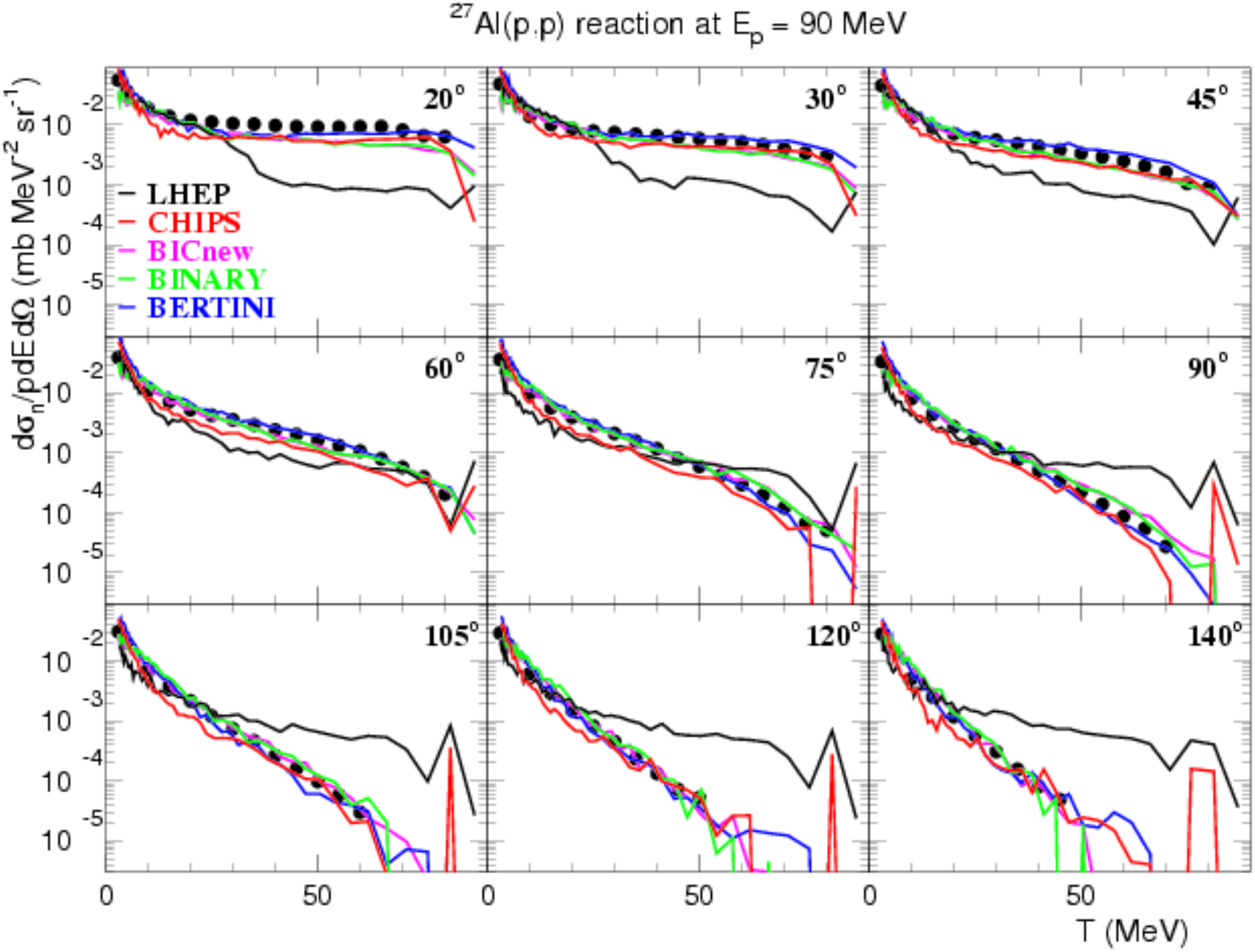
Quasi-elastic

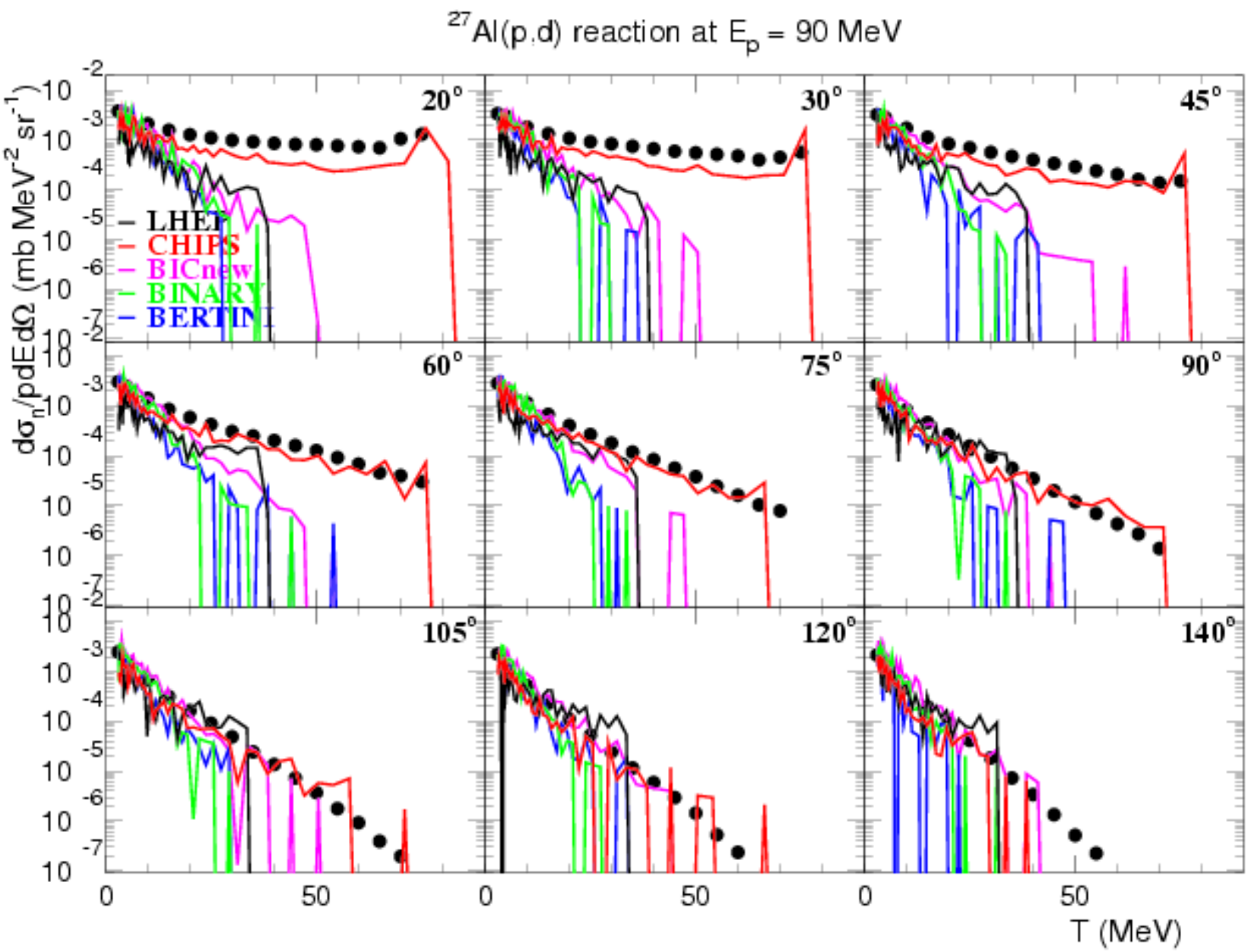


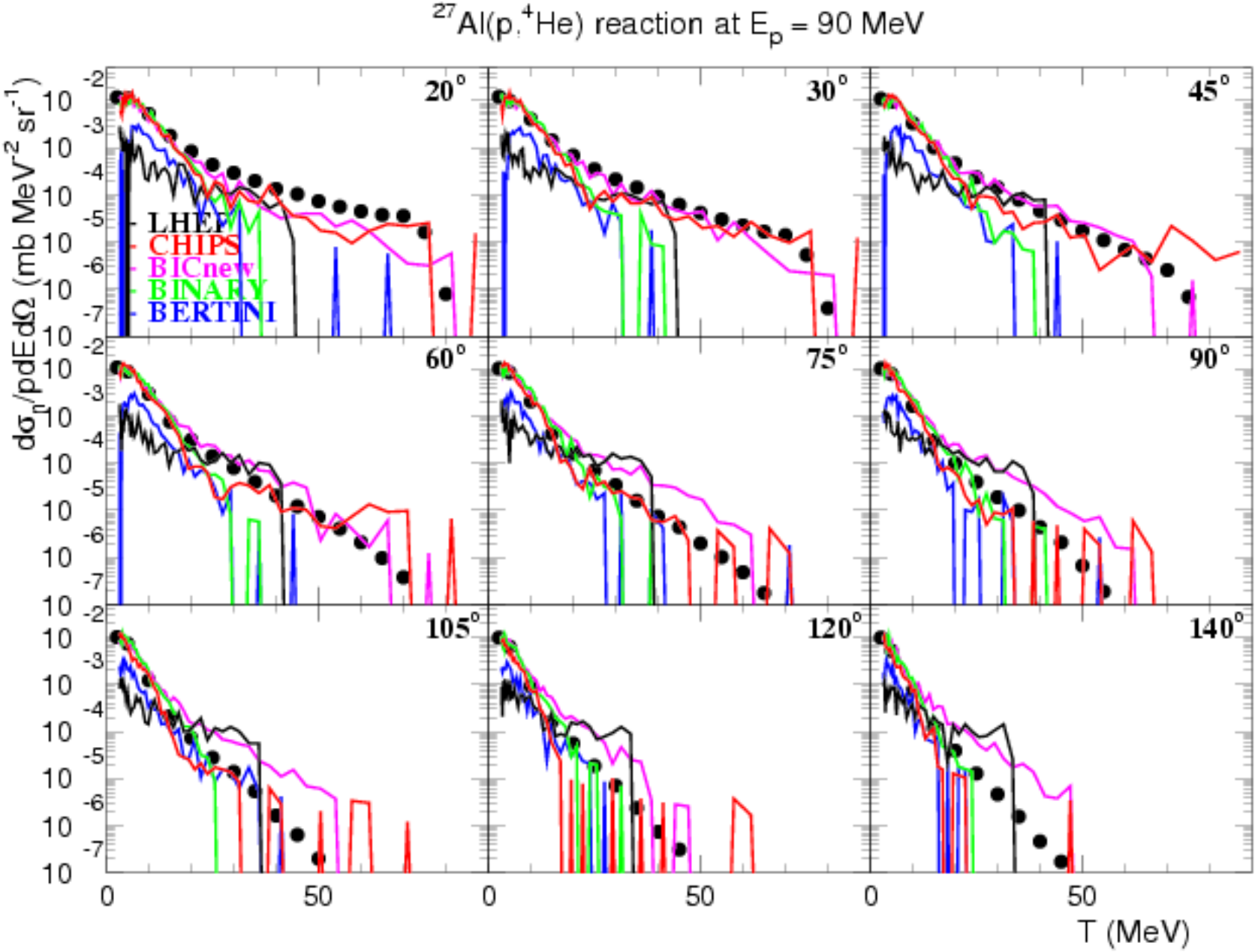
Pick-up process

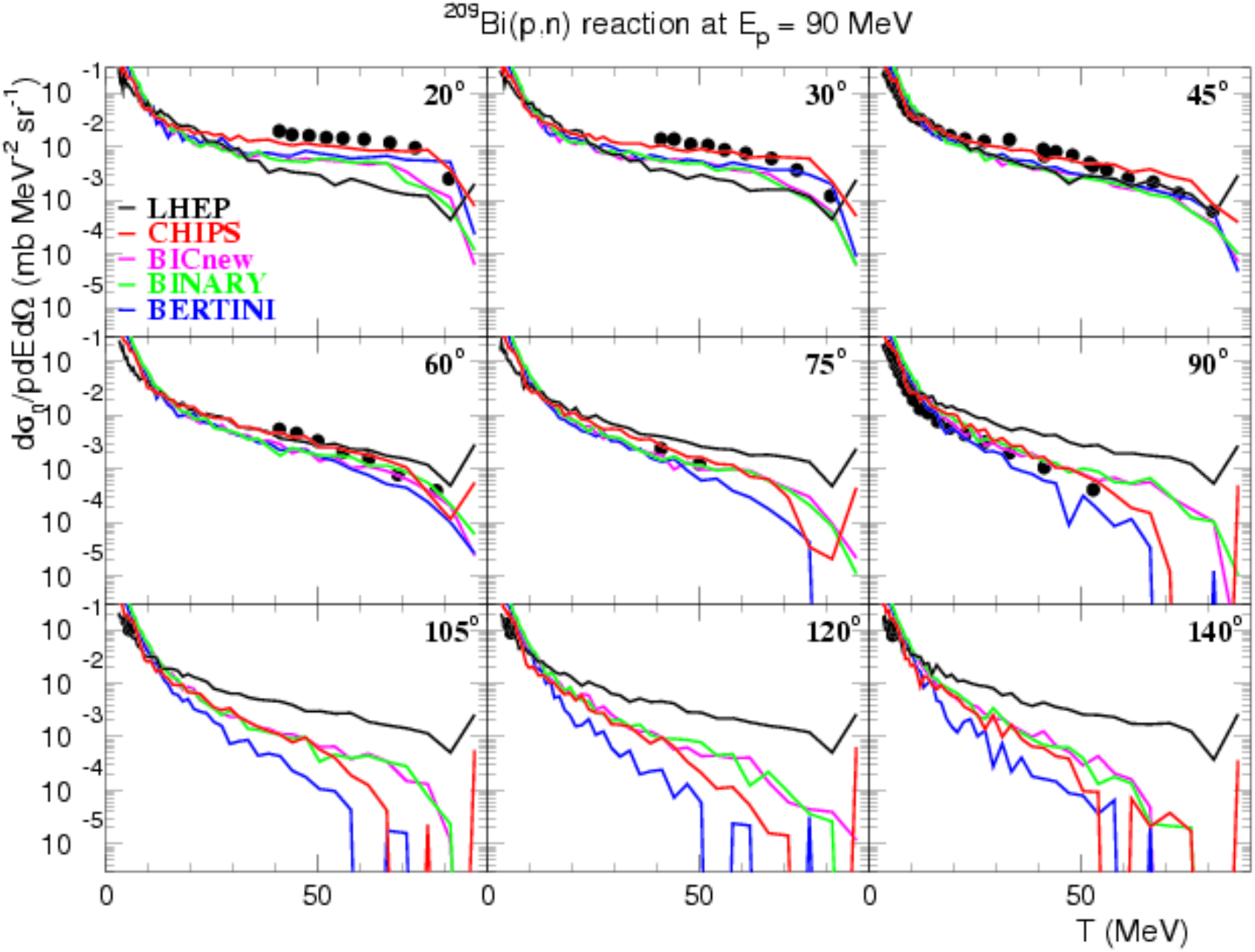


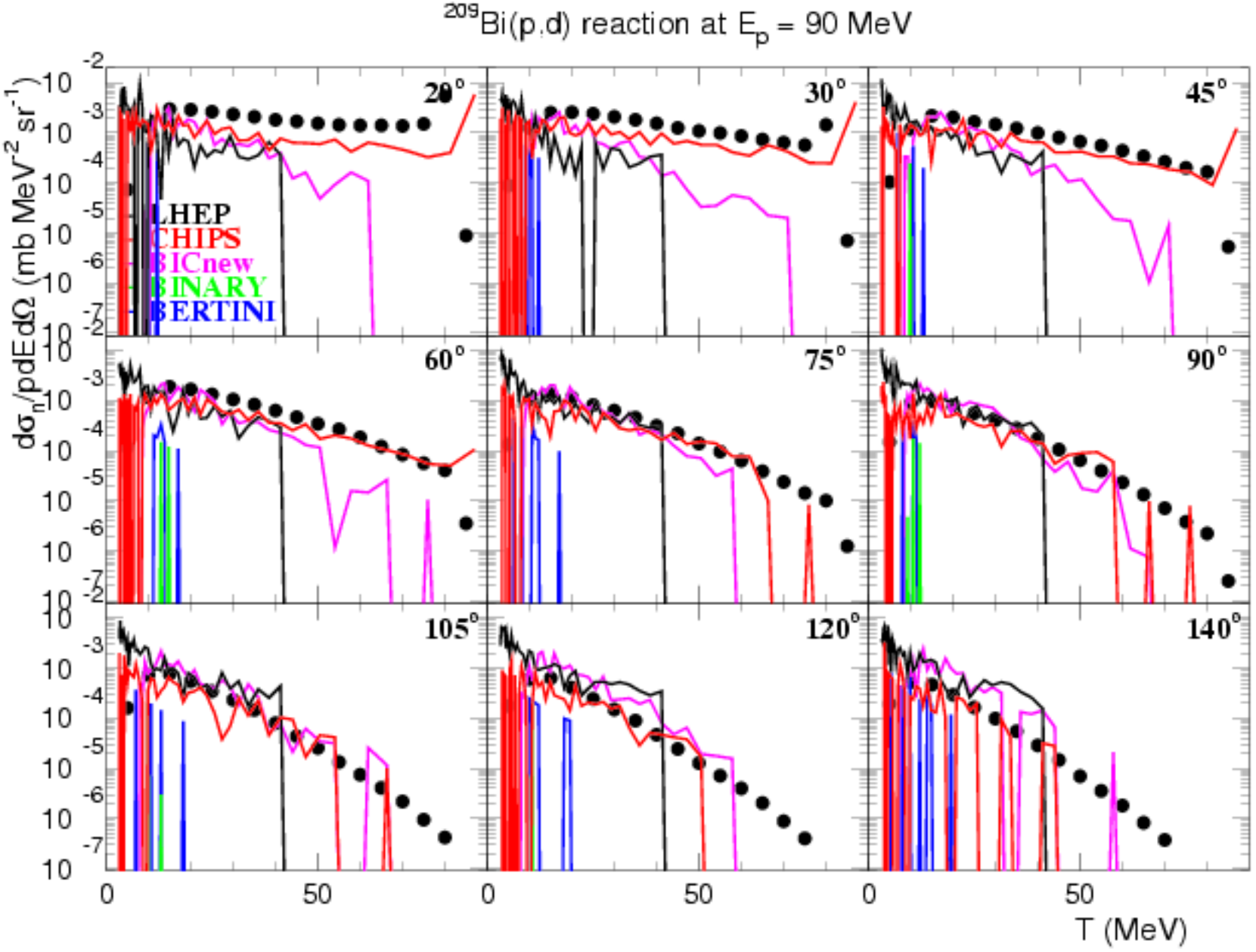


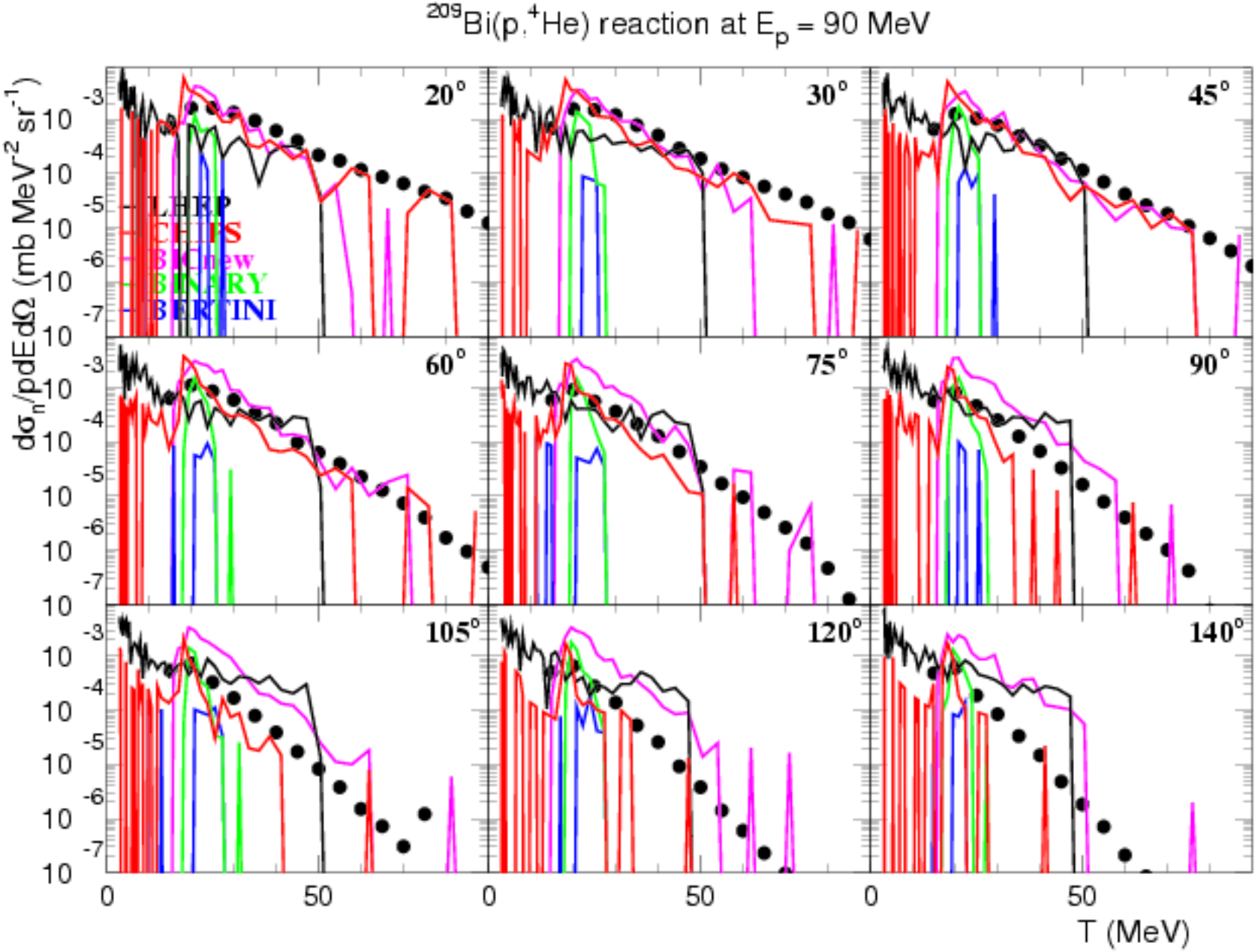

^{27}Al(p,p) reaction at E_p = 90 MeV
$d\sigma_n/pdEd\Omega$ (mb MeV^{-2} sr^{-1})
LHEP
CHIPS
BICnew
BINARY
BERTINI
20°
30°
45°
60°
75°
90°
105°
120°
140°
T (MeV)


^{27}Al(p,d) 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°
LHET
CHIPS
BICnew
BINARY
BERTINI
T (MeV)


^{27}Al(p,^{4}He) 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)


209Bi(p,n) reaction at Ep = 90 MeV
dσn/pdEdΩ (mb MeV-2 sr-1)
T (MeV)
20°
30°
45°
60°
75°
90°
105°
120°
140°
LHEP
CHIPS
BICnew
BINARY
BERTINI


209Bi(p,d) reaction at Ep = 90 MeV
dσn/pdEdΩ (mb MeV-2 sr-1)
T (MeV)
20°
30°
45°
60°
75°
90°
105°
120°
140°
LHEP
CHIPS
BICnew
BINARY
BERTINI


^{209}Bi(p,^{4}He) 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
BIC new
BINARY
BERTINI
T (MeV)

Simulation is made using the test49 tool with specific CHIPS tuning parameters

Time performance for 29 MeV and 90 MeV protons

protons 29 MeV (2009)

Model	Al	Au
PreCom	1.5	4.4
Binary	1.9	4.7
Bertini	0.40	0.42
CHIPS	2.7	2.8
LHEP	0.06	0.07
QLowE	0.10	0.10

protons 90 MeV (2009)

Model	Al	Bi
PreCom	2.2	5.2
Binary	3.1	8.2
Bertini	0.48	0.62
CHIPS	2.5	3.1
LHEP	0.10	0.11
QLowE	0.12	0.14

HE inelastic CHIPS model (all hadrons)

Projectile

(effective γ or W for lepto-nuclear reactions)

1-D (light cone)

3-D (Quasmon)

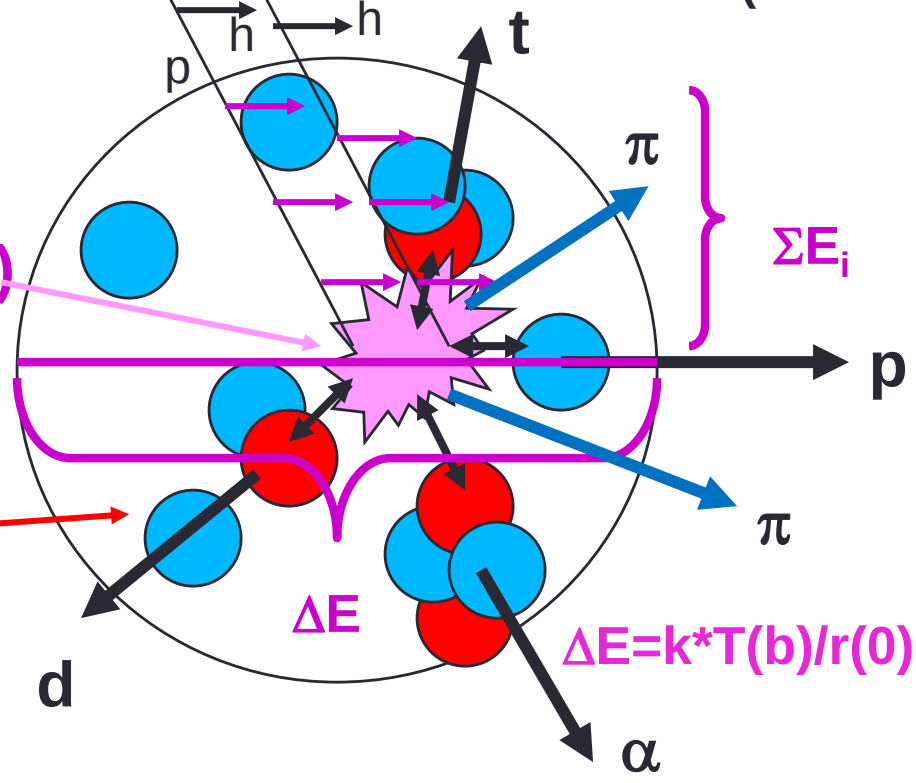
No rescattering

Hadronization:
quark-exchange,
quark-fusion

Parton (p) string algorithm

String fusion for low energies, when hadrons (h) can not be produced + Quasmon finish

(similar to QGS string)



ΔE=k*T(b)/r(0) (k=1.5 GeV/fm)

Important issues for calorimeter simulation

- Production of γ's in hadron EM decays of π^0,η, η', ω, Σ^0 etc., switching distributed hadronic energy to short range electromagnetic cascades
  - usually a source of γ's are π^0's; in CHIPS + direct γ's & massive mesons (η, ω)
  - π^0+γ+η energy is better for the short range deposition estimate than just π^0's energy.
- Significance of the correct simulation of low energy neutrons.
  - They can be killed after some "gate" time (model dependent, detector dependent).
  - They can be (as in the present CHIPS implementation) absorbed too fast
    - conversion to gamma adds to visible energy even more than the kinetic energy of neutrons
    - inelastic reactions spend energy for separation of nucleons and nuclear fragments
  - Elastic scattering of neutrons contributes to the visible energy by stopping of the recoil nuclei (correct in CHIPS implementation to Geant4)
  - Correct evaporation of neutrons in the HE inelastic generator is important.
- The quasi-elastic and diffraction parts of the inelastic cross-sections
  - In CHIPS both problems are solved in the first order, and can be improved.
  - Quasi-elastic & diffraction are very important for the longitudinal shower shape
    - Both quasi-elastic and diffraction effectively reducing the real inelastic cross-section
    - That is why sometimes an artificial reduction of the inelastic cross-section to the "production" cross-section level helps to improve simulation results.
- Tuning of p_T-distribution in 1D strings is important for lateral shower shapes

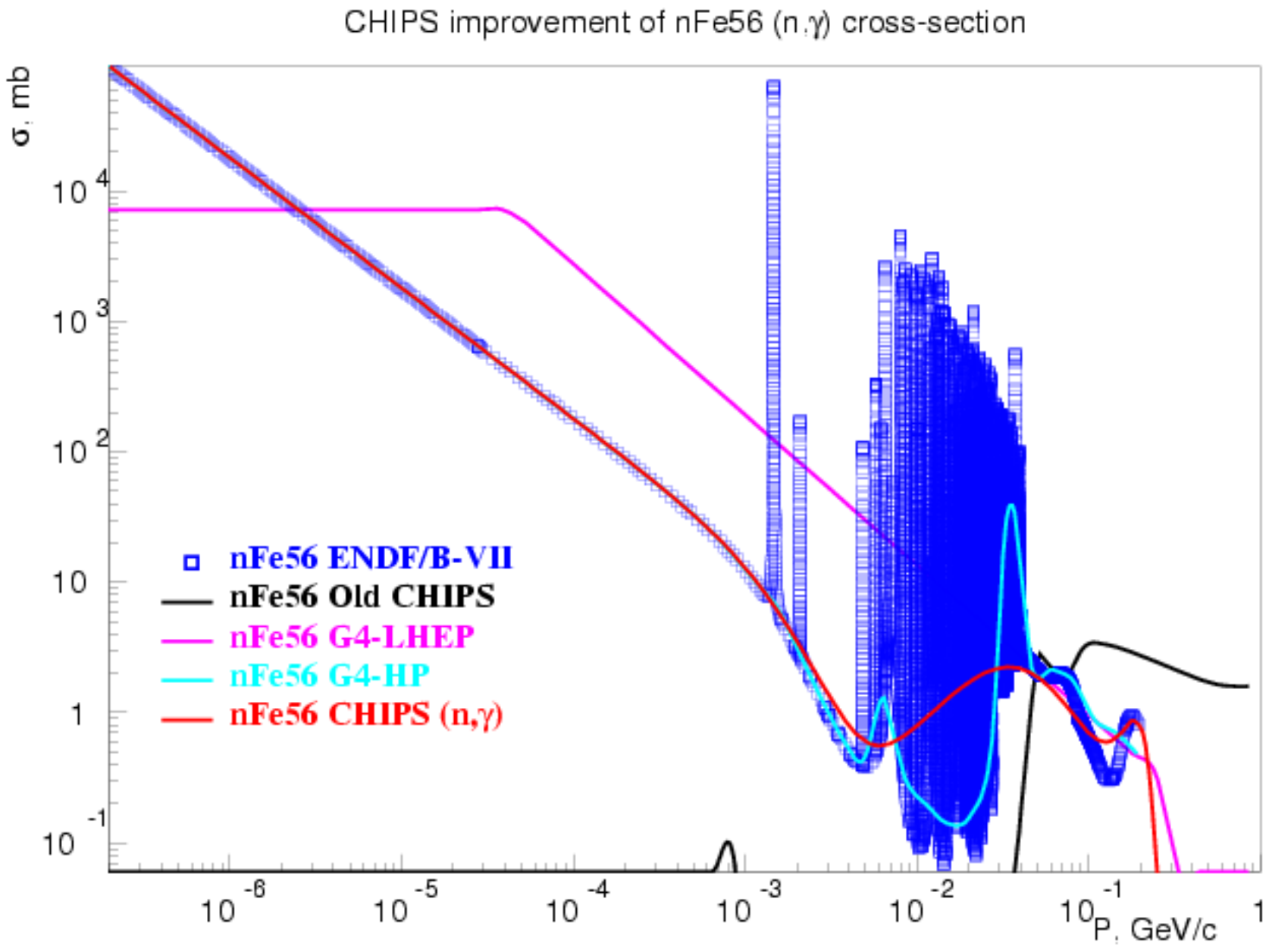
Future plans (CUDA C/C++ CHIPS)

- Detailed simulation of hadronic processes takes a lot of calculation time, which contradicts to the user's requirements
- To meet the requirements of medical, astro- and LHC users it is necessary to use new CUDA technology, which uses GPU's for parallel calculations and can accelerate simulation by an order of magnitude (to say nothing about visualization).
- A project for conversion of the C++ Geant4 toolkit to the CUDA C/C++ CHIPS (**C**ell **H**ierarchy **I**nterface for **P**hysics **S**imulation) toolkit based on the CHIPS Physics Package is started in ITEP
- All tuning and development of the CHIPS physics package are planned only within this new CUDA C/C++ CHIPS project
- On each step of the CUDA C/C++ CHIPS development the time performance improvement is planned to be reported

Conclusion

- Geant4 CHIPS physics list is an experimental physics list, which needs tuning and further development
- A big disadvantage of the present CHIPS physics list is the fast absorption of neutrons, which overestimates simulated responses for calorimeters (consequently reduces σ/E). Whilst the correct LE nA CHIPS approximation exist, it can not be implemented in the open source toolkit Geant4
- Other details of the CHIPS inelastic model should be tuned, using the thin-target data (inclusive spectra of hadrons)
- Quasi-elastic and diffraction CHIPS ratios should be tuned
- CHIPS physics list is a bit slower than other Geant4 physics lists, so evolution of the CHIPS physics package in the parallel algorithm direction (CUDA) can be a reasonable strategy
- A parallel Geant4$\rightarrow$CHIPS toolkit can be not an open source project with correct LE neutron inelastic/(n,γ) cross-sections.

Thank you


CHIPS improvement of nFe56 (n,γ) cross-section
σ, mb
10 4
10 3
10 2
10
1
10 -1
nFe56 ENDF/B-VII
nFe56 Old CHIPS
nFe56 G4-LHEP
nFe56 G4-HP
nFe56 CHIPS (n,γ)
10 -6
10 -5
10 -4
10 -3
10 -2
10 -1
1
P, GeV/c

CHIPS (CHiral Invariant Phase Space) publications

0. Thermodinamic quark-parton model: Preprint ITEP-165-84
1. Light SU(3) hadron masses: Eur.Phys.J. A14 (2002) 265
2. Proton-antiproton annihilation at rest: Eeur.Phys.J.A8(2000)217
3. Nuclear p^- capture at rest: Eur.Phys.J. A9 (2000) 414
4. Nuclear m^- capture at rest: Eur.Phys.J. A33 (2007) 7
5. Anti-proton capture at rest: IEEE Trans.Nucl.Sci. 52 (2005)2832
6. Low energy γA reactions: Eur.Phys.J. A9 (2000) 421
7. Cross-sections of γA/eA reactions: Eur.Phys.J. A14 (2002) 377
8. Nucleon structure functions: Eur.Phys.J A34 (2007) 283
9. Drell-Yan $\mu^+\mu^-$ pair production: Eur.Phys.J A36 (2008) 289

Official Page with more information about CHIPS:
http://mkossov.home.cern.ch/mkossov/Welcome.html