Status of Geant4 Hadronics

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on behalf of the Hadronics Working Group
Geant4 Workshop
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Outline

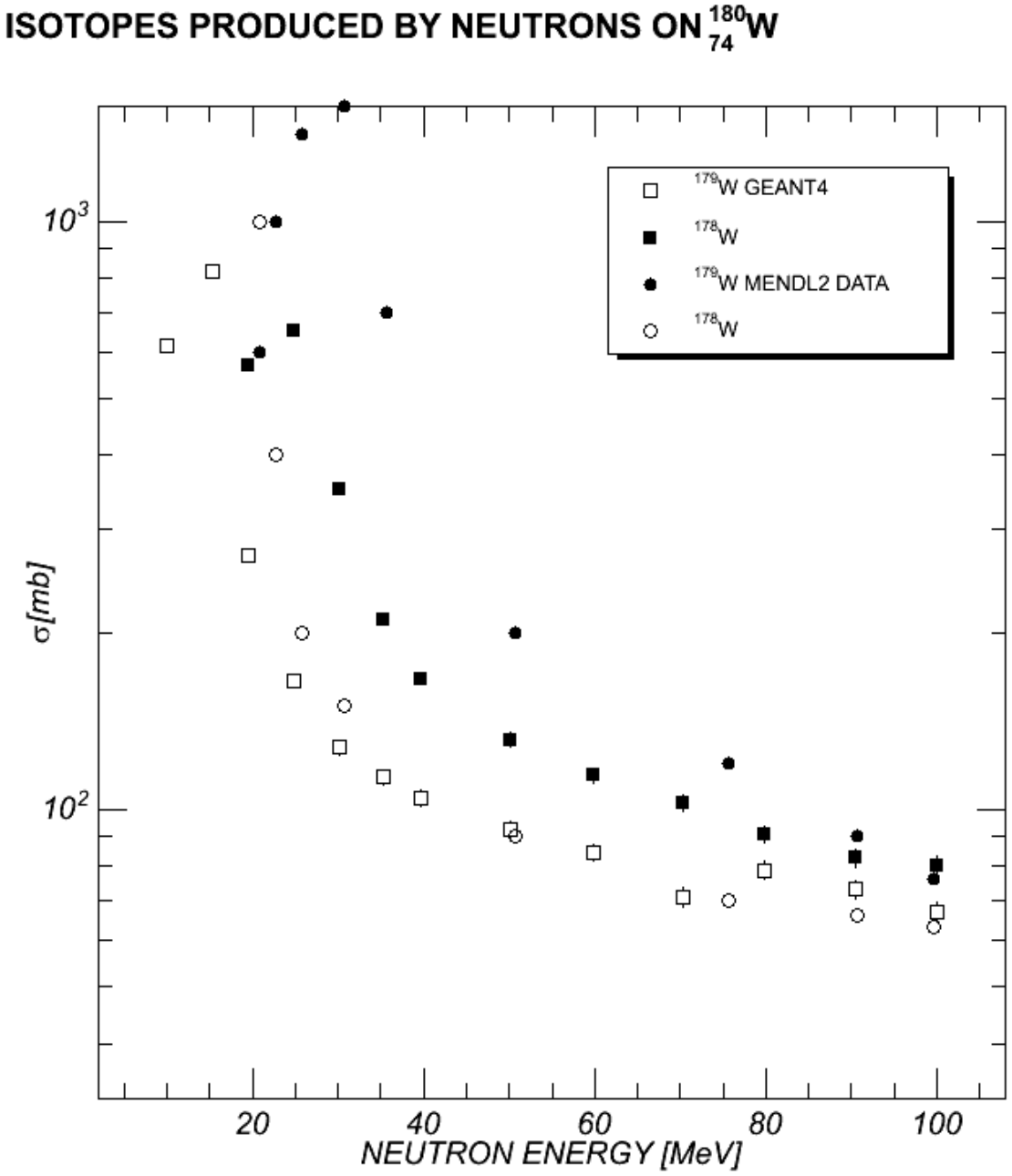
- Bertini cascade
- CHIPS
- Validation
- Abrasion/ablation models
- High precision neutrons

Bertini Cascade

- Isotope production
  - Proton and neutron induced
- Elastic scattering interface for release 7.2
  - G4CascadeElasticInterface (for < 1 GeV)
- Kaon extensions
- Validation
- Optimization for speed, model tuning
- Ion-ion interactions (future)

Bertini hadronic models in Geant4 7.1

- Submodels implemented for proton, neutron, pion bullets:
  - `G4ElementaryParticleCollider`
  - `G4IntraNucleiCascader`
  - `G4NonEquilibriumEvaporator (pre-euilibrium)`
  - `G4EquilibriumEvaporator`
  - `G4Fissioner`
  - `G4BigBanger`
- Latest Bertini extension (June, 2005)
  - First partial release providing elastic part of intra-cascade treatment for kaon, lambda, sigma, and xi by Dennis Wright (SLAC)
    - Now stable and available at CVS (use KAON-flag)
    - This SLAC-tag is to be released fully in Geant4 7.2 release



Low-energy neutron induced isotope production is usually treated with Geant4 isotope production model using of evaluated data libraries

Yet in some cases Bertini model performs quite well and might be useful

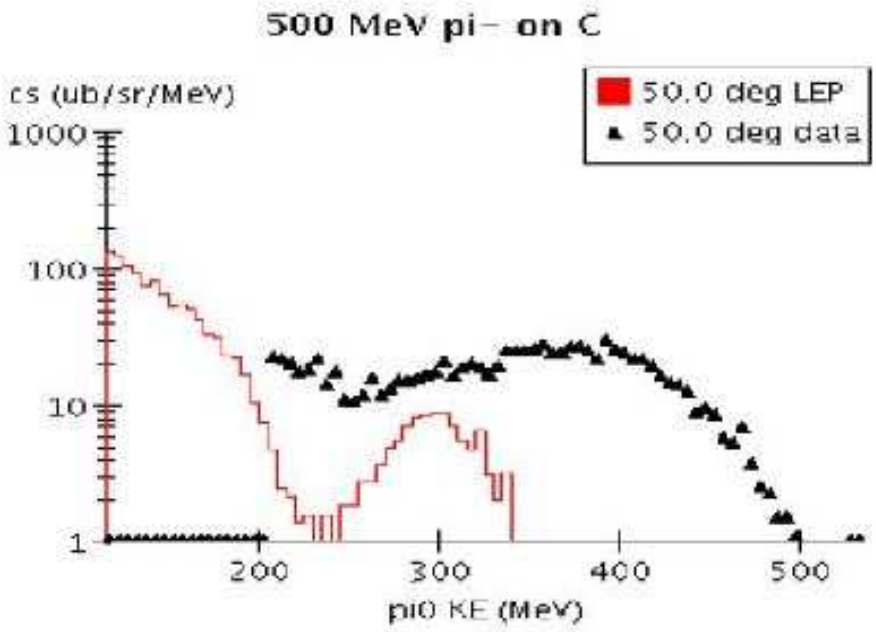


Figure 1: Current GEANT4 LEP physics list setting against data (Ouyang, Peterson 1992)

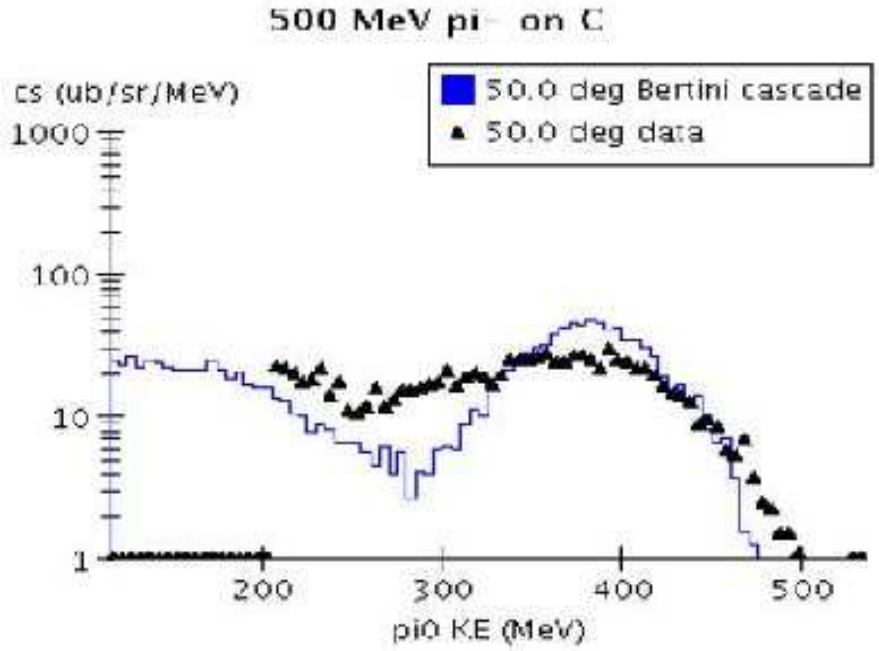
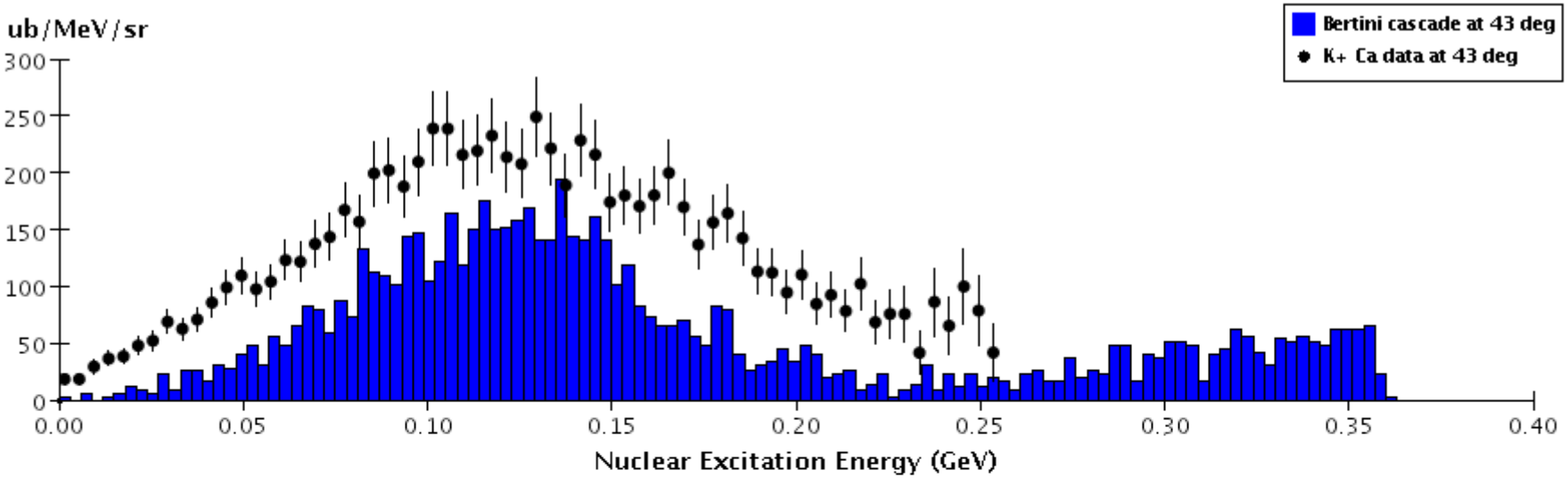
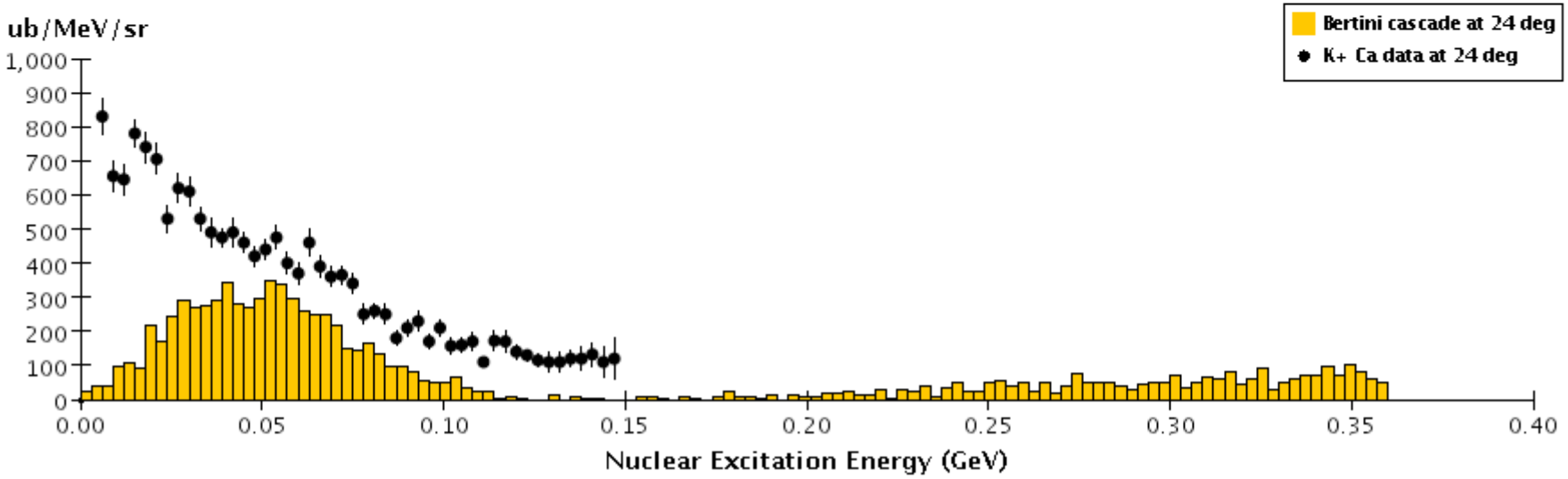


Figure 2: Bertini cascade model

705 MeV/c K+ quasi-elastic scattering from Ca

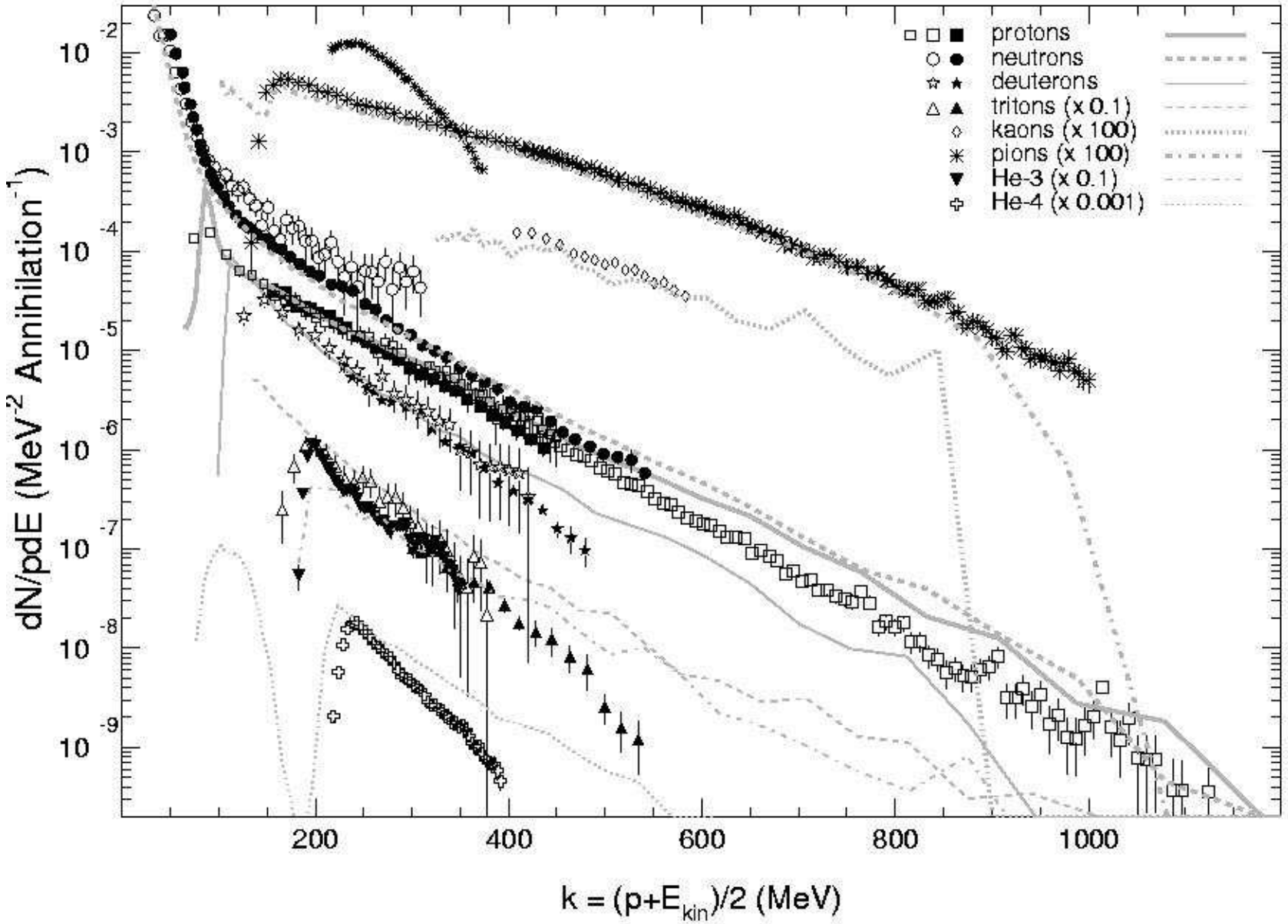




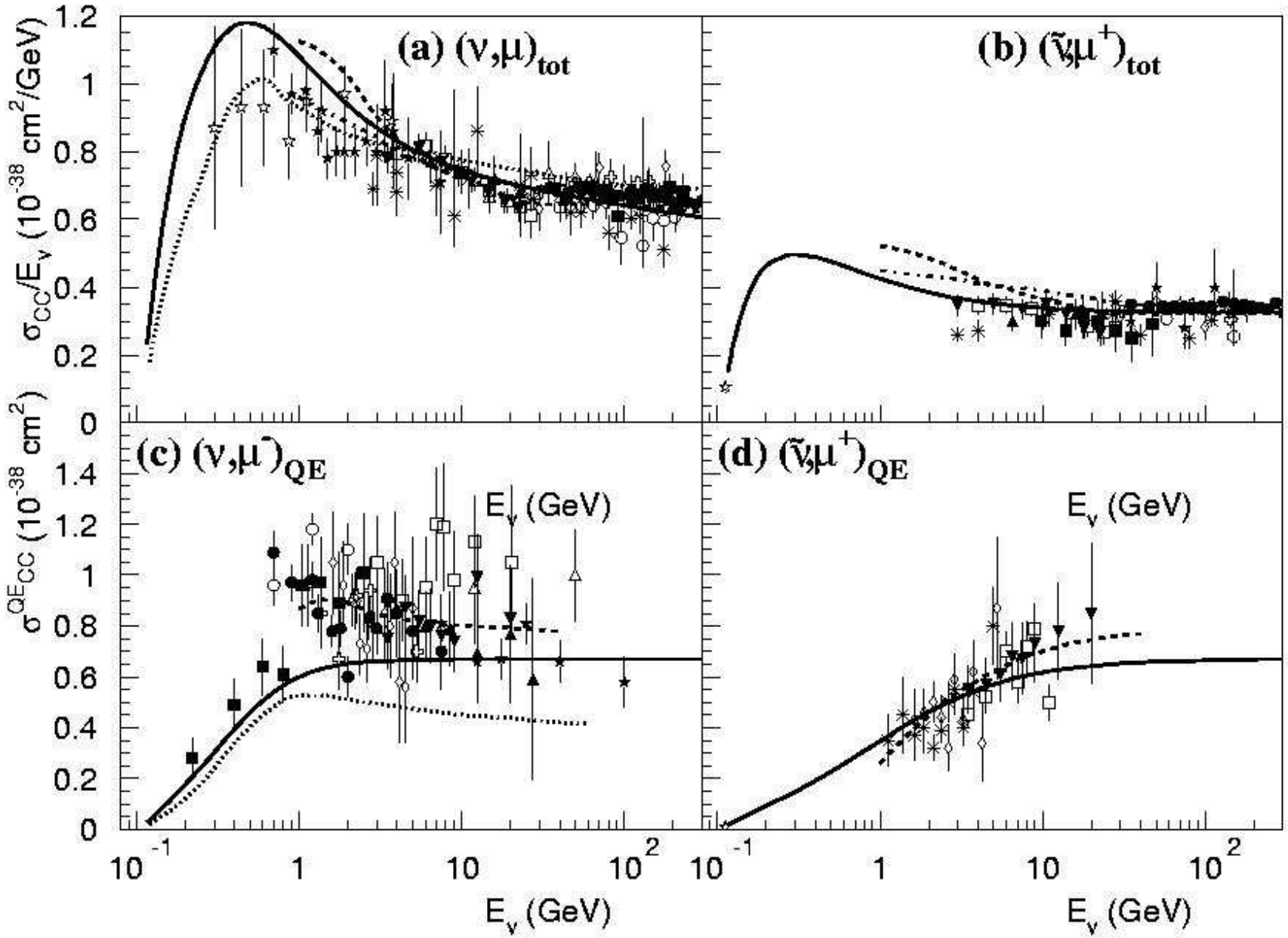
New Developments in CHIPS

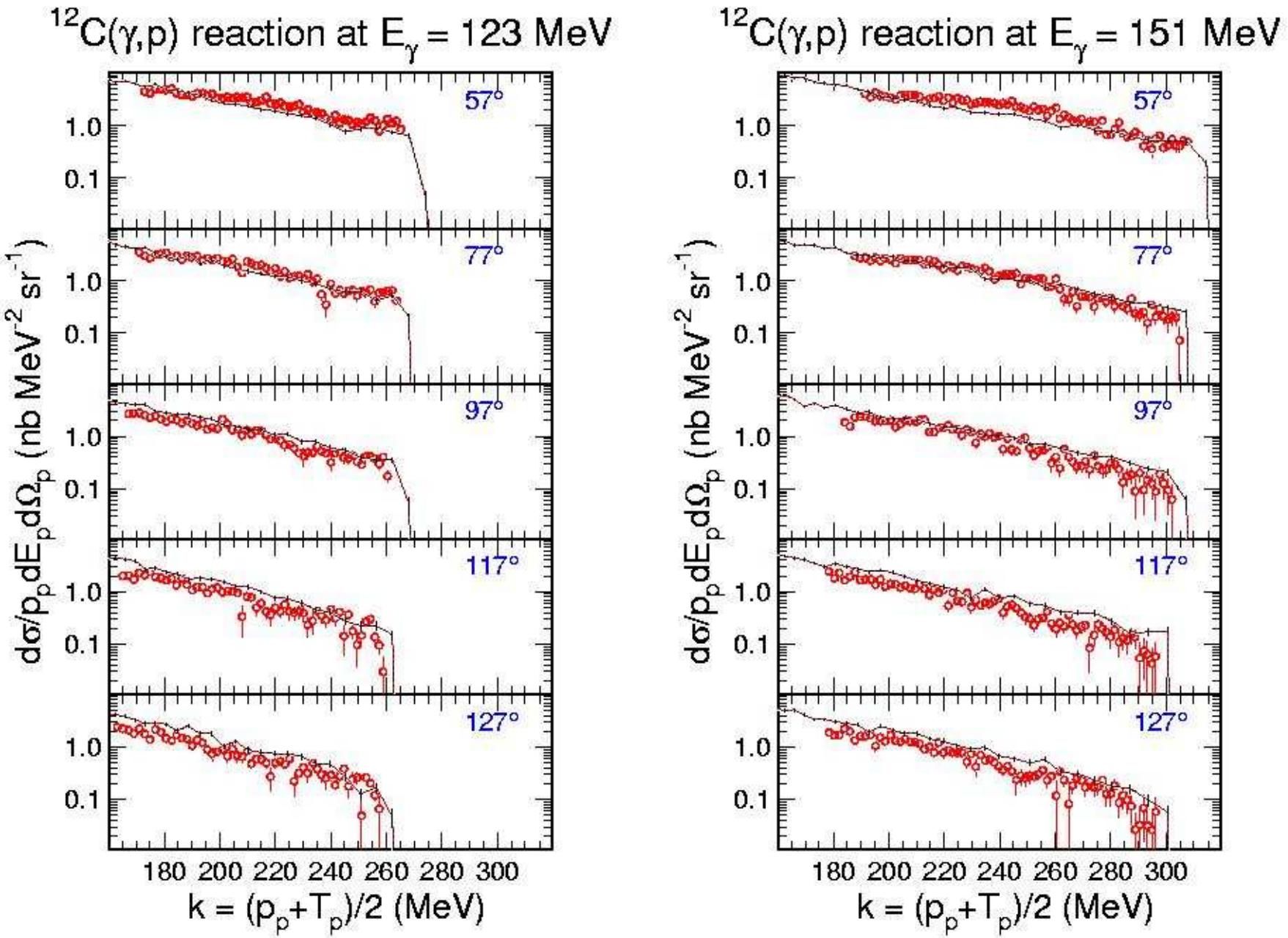
- G4QCaptureAtRest for nuclear capture of negative hadrons, muons, and low energy neutrons/antineutrons.
- G4QCollision for photo- and lepto-nuclear reactions with DIS simulation of neutrino-nuclear reactions.
- Process level tests for comparison of simulated parameters with experimental data (test19/test29).
- New debugged version of CHIPS for QGSC and FTFC.
- Prototype of internal Physics Lists with reengineering of the external Physics Lists and New Modular Physics List

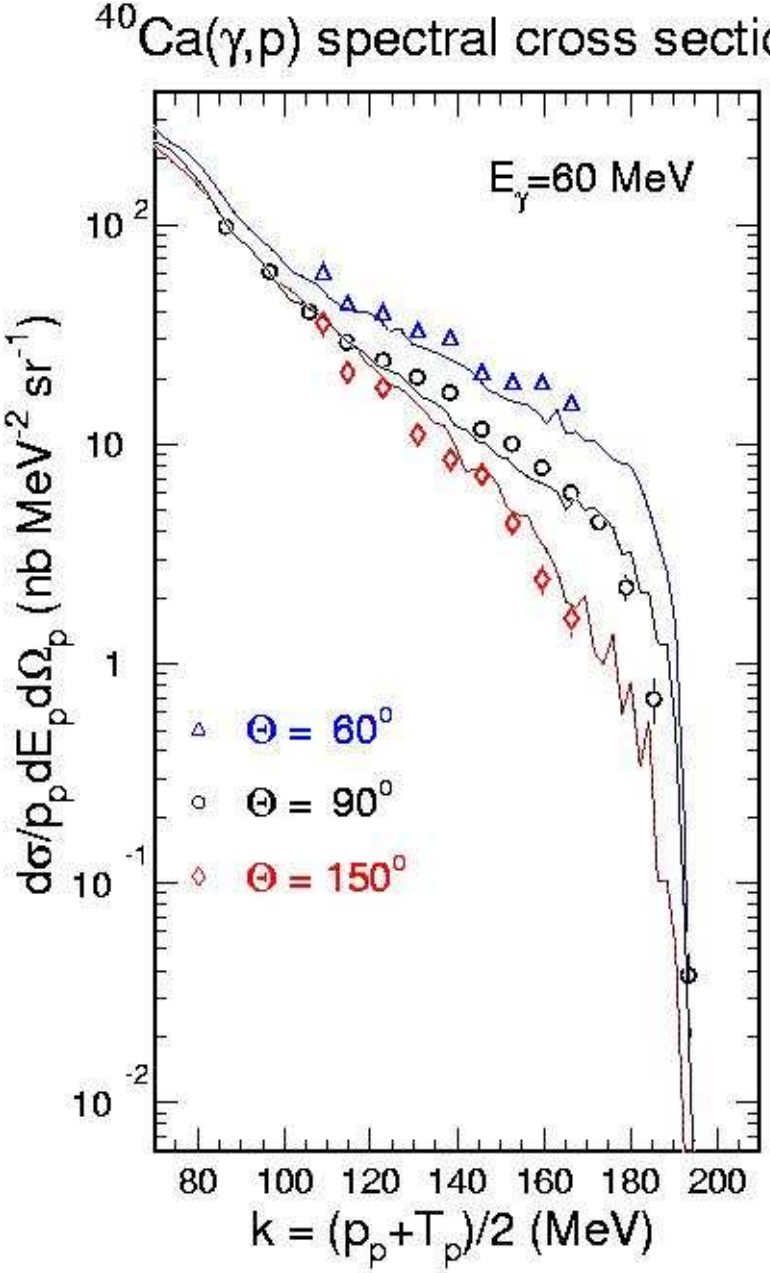
Antiproton capture at rest for CERN AD

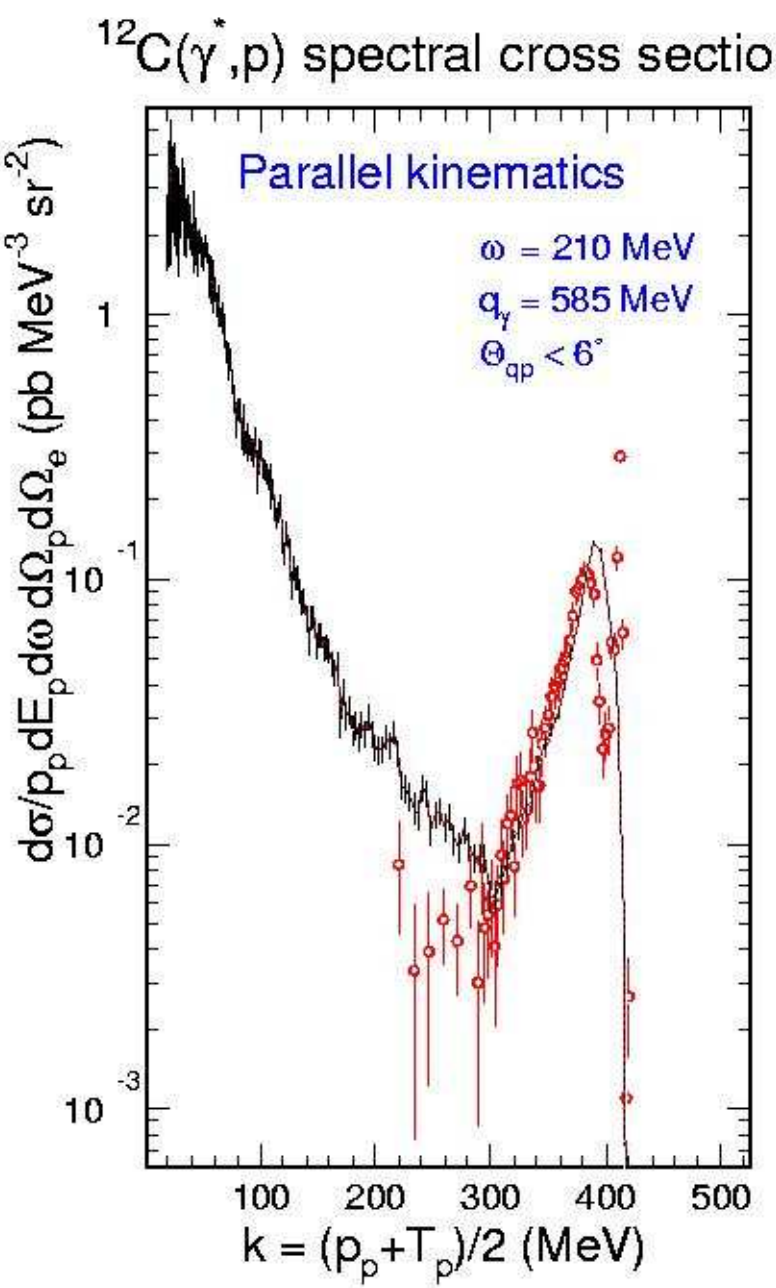


Neutrino-nuclear interactions for CNGS




^{12}C(γ,p) reaction at E_γ = 123 MeV
^{12}C(γ,p) reaction at E_γ = 151 MeV
57°
77°
97°
117°
127°
1.0
0.1
180 200 220 240 260 280 300
$k = (p_p+T_p)/2$ (MeV)
$d\sigma/p_p dE_p d\Omega_p$ (nb MeV^{-2} sr^{-1})


^{40}Ca(γ,p) spectral cross section
E$_\gamma$=60 MeV
Θ = 60°
Θ = 90°
Θ = 150°
dσ/p$_p$dE$_p$dΩ$_p$ (nb MeV^{-2} sr^{-1})
k = (p$_p$+T$_p$)/2 (MeV)


^{12}C(γ*,p) spectral cross section
Parallel kinematics
ω = 210 MeV
q$_\gamma$ = 585 MeV
Θ$_{qp}$ < 6°
dσ/p$_p$dE$_p$dω dΩ$_p$dΩ$_e$ (pb MeV^{-3} sr^{-2})
k = (p$_p$+T$_p$)/2 (MeV)

CHIPS applications in Geant4

- CHIPS is a unique package for all applications
- Simulation of at rest processes for negative hadrons, muons, neutrons and antineutrons
- Photo- and lepto-nuclear interactions in Geant4
- Nuclear fragmentation induced by absorption of low energy neutrons (competitor of HP package)
- Final state nuclear fragmentation induced by the projectile fragmentation (QGS or FTF models)
- Low energy ($E \leq A^{1/3}$GeV) interaction of hadrons

Validation

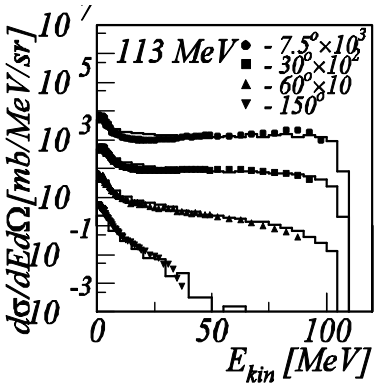
- Validation suite (V. Ivantchenko)
- Hadronic validation effort by potential new working group members
  - ions, medical applications
- Validation proceeding for high energy models
  - LHC detectors (A. Ribon)
  - pp cross sections (T. Koi)
- Cascade models validation
  - G. Folger, V. Ivantchenko, T. Koi, A. Heikkinen, D. Wright

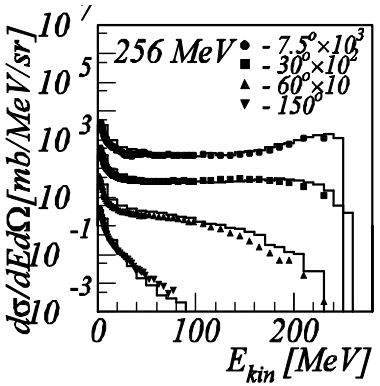
Verification Suite for the Cascade Energy Region

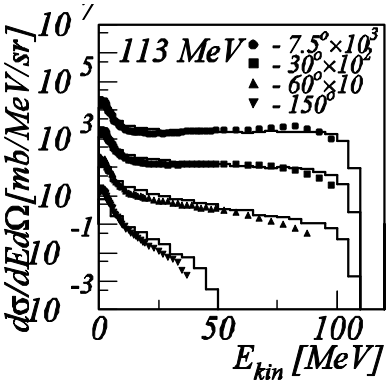
- Neutron production by p, d, α with E < 1 GeV
  - P + A -> n + X
  - d + A -> n + X
  - α + A -> n + X
- 45 thin target experiments with reasonably small systematic
- Inclusive pion production by protons
  - P + A -> π^{+-} + X

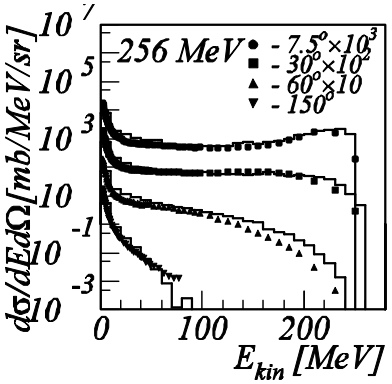
- Binary Cascade
- Binary Ion cascade
- Bertini Cascade
- Wilson-Abrasion model
- LHEP
- Control on differential spectra
- The number of problems have been fixed for the previous Geant4 releases

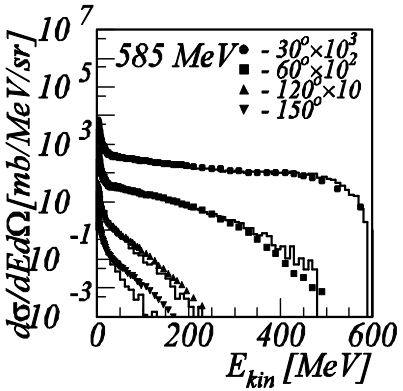
Neutron spectra by protons below 1 GeV in Al and Fe Binary Cascade G4 7.0

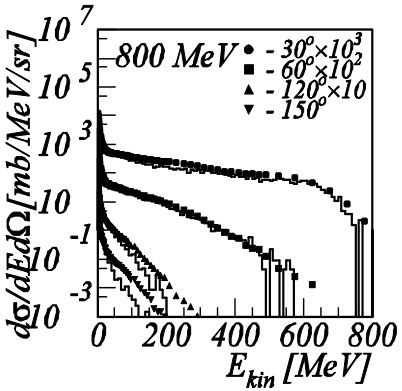


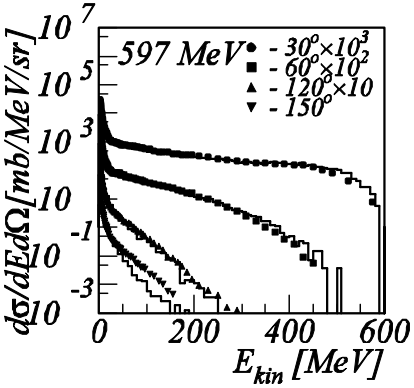


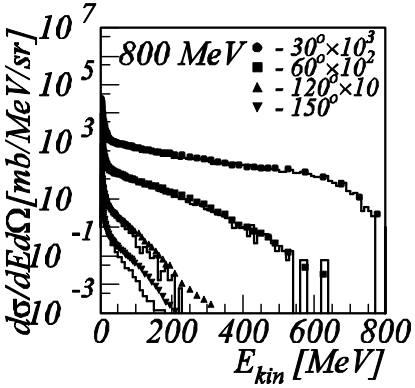




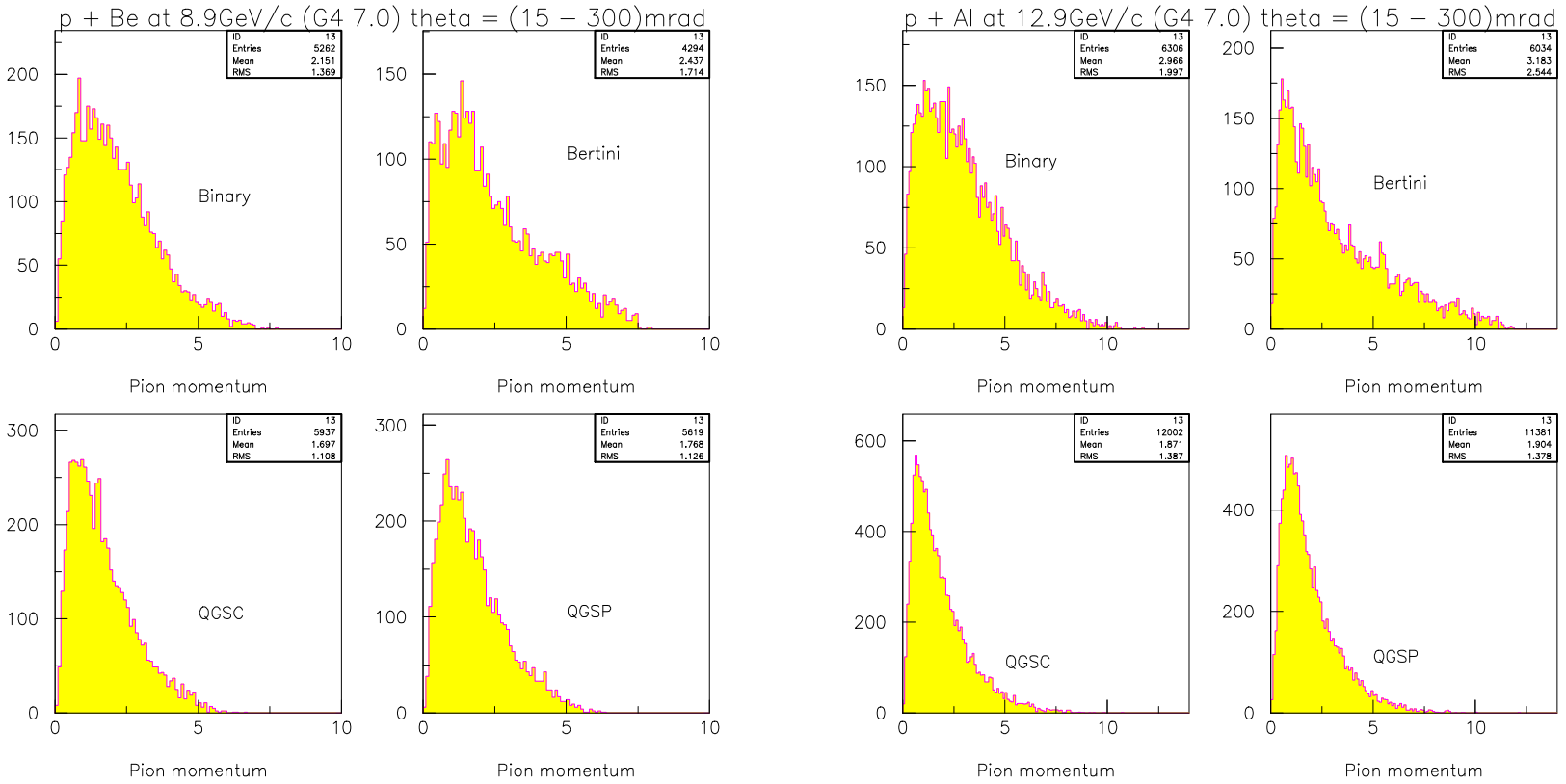








HARP test: Pion production by protons of 8.9 GeV/c in Be and 12.9 GeV/c in Al G4 7.0



Abrasion, Ablation and EMD

- Nuclear-nuclear models implemented in Geant4 for :
  - Abrasion model to simulate macroscopic production of pre-fragments
  - Version of Wilson's ablation model
  - EM dissociation model simulating production of protons/neutrons for highly relativistic collisions
- Models complement other nuclear-nuclear physics developments in Geant4 (G4BinaryLightIonReaction, JQMD, QGSM)
- Abrasion model provides more accurate prediction of nuclear fragment production
- Geant4 EM dissociation model generally within 5-42% of experiment
- Improved / easier-to-use total interaction cross-section classes (*e.g.* G4TripathiLightCrossSection, G4GeneralSpaceNNCrossSection)

Radioactive Decay

- Model to simulate α, β^+, β^- and EC decay, *e.g.* produced as spallation products
- Simulates the decay chain through multiple nuclide generations - if you start at ^{228}Ra, it creates all the appropriate daughter nuclides
- Uses ENSDF database (based on Lawrence Berkley on-line data)
- Linked to photoevaporation to treat subsequent isomeric transition
  - photoevaporation model and database correspondingly updated to treat internal conversion as well as γ-emission
- Includes variance reduction methods to:
  - increase statistical significance or force decay events to occur at user-defined times of observation (with corresponding decrease in statistical weight)
  - enhance events which have a low-probability of occurring, but produce a disproportionately large effect for the application

High Precision Neutrons

- "Missing isotopes"
  - Gaps in G4NDL: Gd, Hg, Sm, Nd, ….
  - Gd entry to be provided soon
- Hybrid neutron process
  - There may always be gaps
  - Currently if HP neutron model encounters a missing isotope -> error
  - New model: if HP neutron model encounters missing isotope then use LEP model (not as precise)
- Documentation of G4NDL format

Thanks to:

- Gunter Folger (Binary cascade)
- Aatos Heikkinen (Bertini cascade)
- Vladimir Ivantchenko (validation suite)
- Mikhail Kossov (CHIPS)
- Pete Truscott (Abrasion/ablation/EMD, radioactive decay)