Geant4 Hadronic |Physics Models

Geant4 Tutorial
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Gunter Folger

Overview

- Parton String Models – QGS Model
- Binary Cascade
- Precompound Model
- Nuclear de-excitation models
- CHIPS
- Capture

Parton String Models

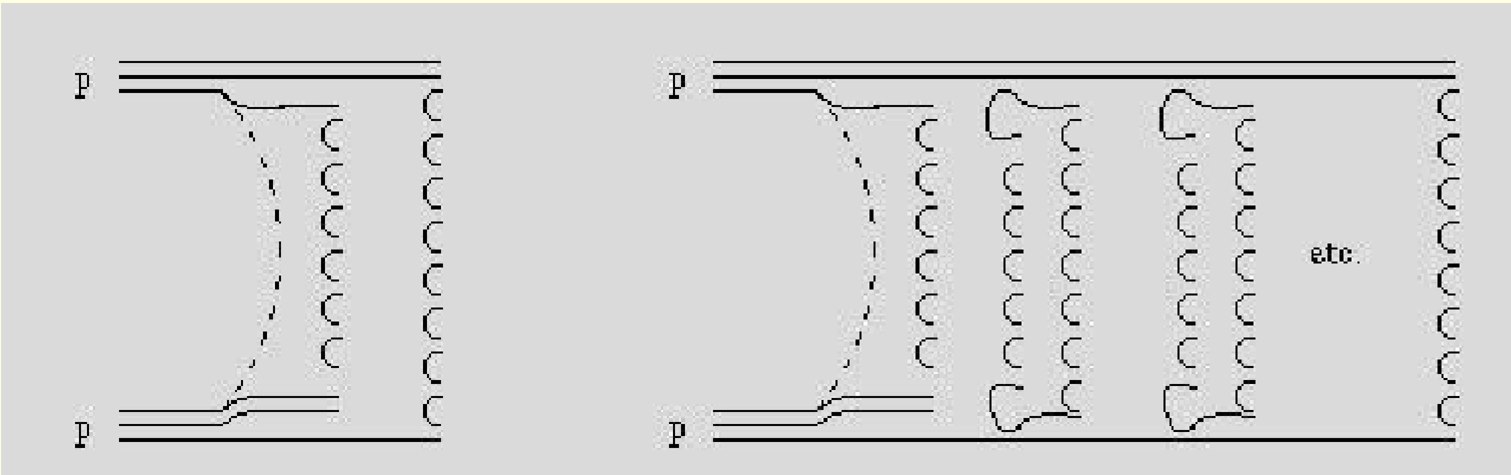
- Quark Gluon String model
- Diffractive String Model

- Models split into
  - Strings excitation part
  - String hadronization

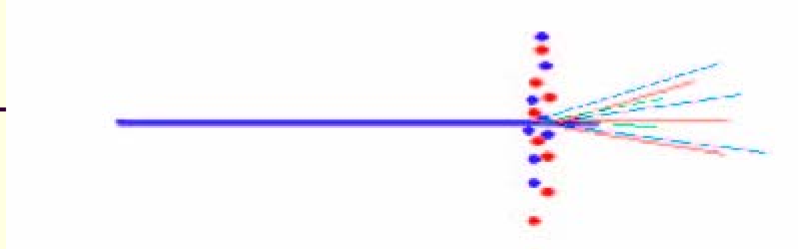
- Damaged nucleus passed to either
  - pre-compound model (QGSP physics list)
  - CHIPS for nuclear fragmentation (QGSC physics list)

Quark Gluon String Model

- Pomeron exchange model
  - Hadrons exchange one or several Pomerons
- Equivalent to color coupling of valence quarks
- Partons connected by quark gluon strings



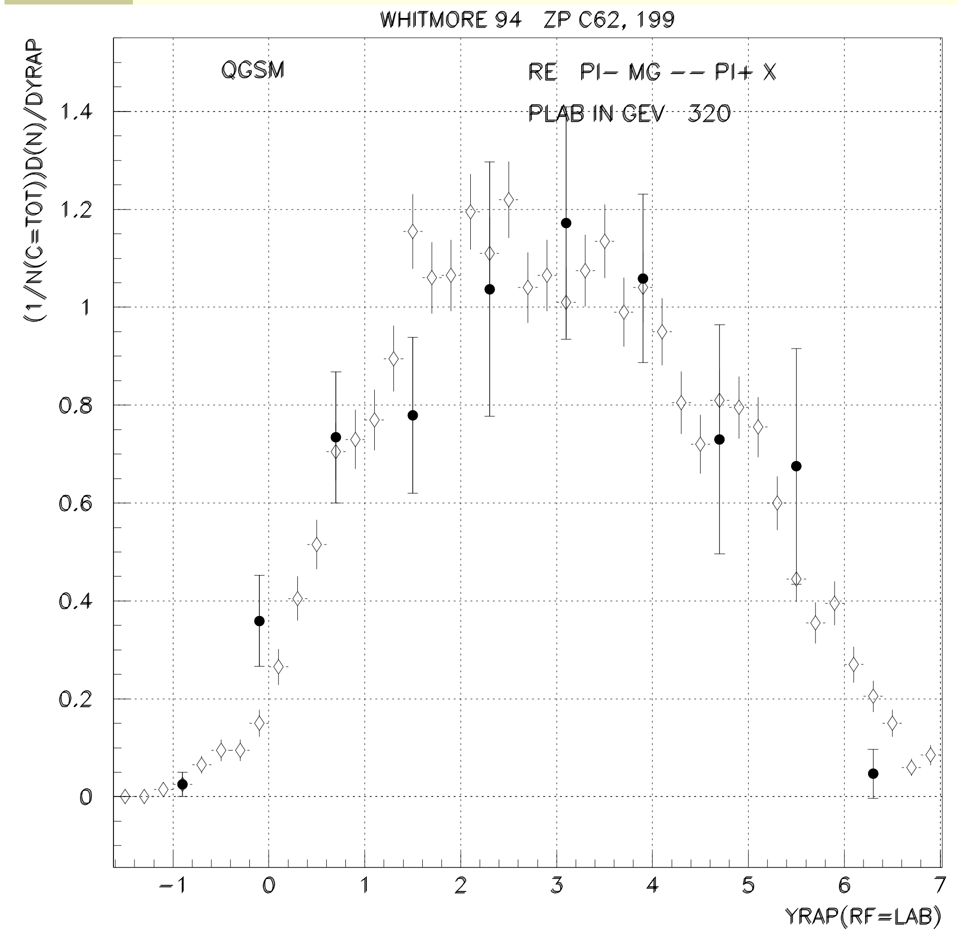
Quark gluon string model Algorithm

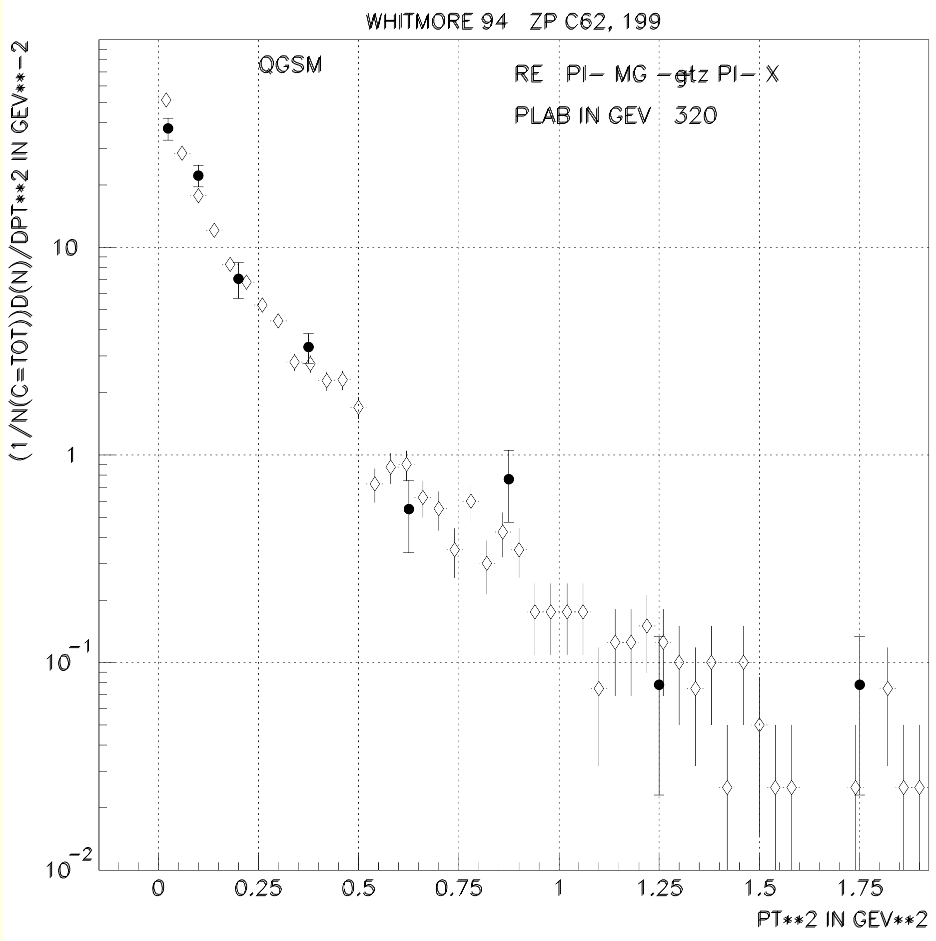


- A 3-dimensional nuclear model is built up
- Nucleus collapsed into 2 dimensions
- The impact parameter is calculated
- Hadron-nucleon collision probabilities calculation based on quasi-eikonal model, using Gaussian density distributions for hadrons and nucleons.
- Sampling of the number of Pomerons exchanged in each collision
- Unitarity cut, string formation and decay.

QGSM - Results

pi- Mg → pi+ X , Plab 320 GeV/c





Rapidity $\eta = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$

P_t^2 [GeV^2]

Binary Cascade

- Modeling interactions of protons, neutrons, pions with nuclei
- Incident particle kinetic energy 50 MeV – 2GeV
- Extension for light ion reactions

- Wounded nucleus passed to pre-compound model and nuclear de-excitation models.

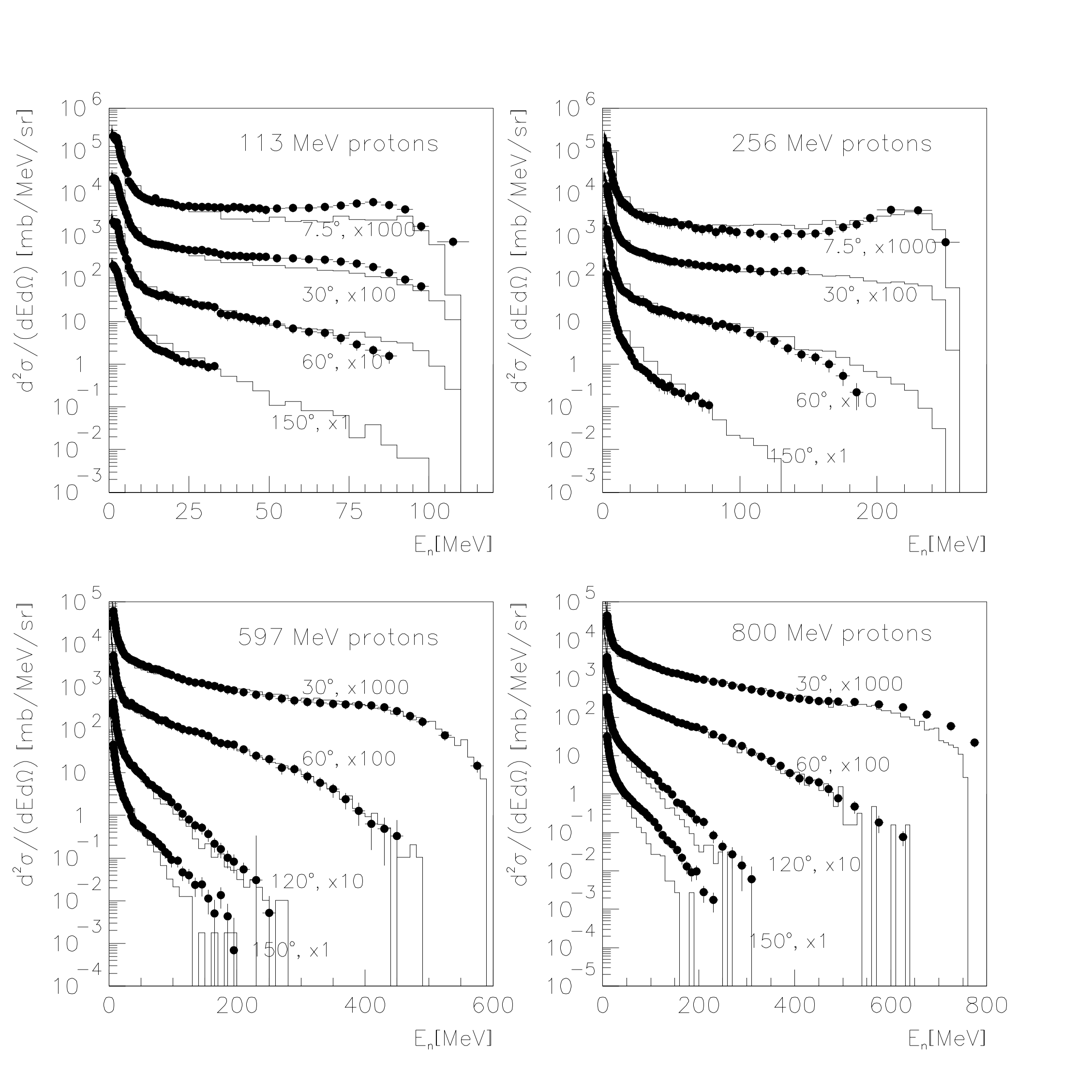
Binary Cascade

- Hybrid between classical cascade and full QMD model
- Detailed model of Nucleus
  - nucleons placed in space according to nuclear density
  - Nucleon momentum according to Fermi gas model
- Collective effect of nucleus on participant nucleons described by optical potential
  - Numerically integrate equation of motion

Binary Cascade

- Interactions between primary (or secondary) with nucleon described as two body reactions
  - E.g. pp -> Δ(1232) N*(2190)
    - Nucleon and delta resonances up to 2GeV included
  - Resonances decay according to lifetime

Binary Cascade - results



p Pb -> n X

Pre-compound model

- The pre-compound nucleus is viewed as consisting of two parts
  - A system of excitons carrying the excitation energy and momentum
  - A nucleus, undisturbed apart from the excitons
- The exciton system is defined by the numbers of excitons, holes, and charged exitons and their total energy and momentum

Pre-compound Model

- The system of excitons and the nucleus evolves through
  - Collisions between excitons ($\Delta n=0, -2$)
  - Collisions between excitons and nucleons ($\Delta n=+2$)
  - Particle and fragment emission (up to helium)
- Until number of excitons is in equilibrium

$$n = \sqrt{2gU}$$

Nuclear de-excitation models

- Nucleus is in equilibrium
  - System is characterised by number of nucleons (A,Z) and excitation energy
  - Excitation energy is distributed over large number of nucleons
- De-excite nucleus through evaporation

Nuclear de-excitation models

- Weisskopf Ewing evaporation
- GEM evaporation
- Photon evaporation
- Internal conversion
- Fission
  - Heavy nuclei ($A \geq 65$)
- Fermi break-up
  - Light nuclei ($A<17$)
- Multifragmentation
  - Large excitation energy $U/A > 3$ MeV

Chiral Invariant Phase Space (CHIPS)

- CHIPS is based on homogeneous invariant phase distribution of mass-less partons
- Quasmon is ensemble of partons
- Quasmon is characterised by mass M_Q
- Critical temperature T_C defines number n of partons in Quasmon
  - T_C is only parameter of model
  - $M_Q \approx 2n\ T_C$
- Nucleus made of nucleon clusters

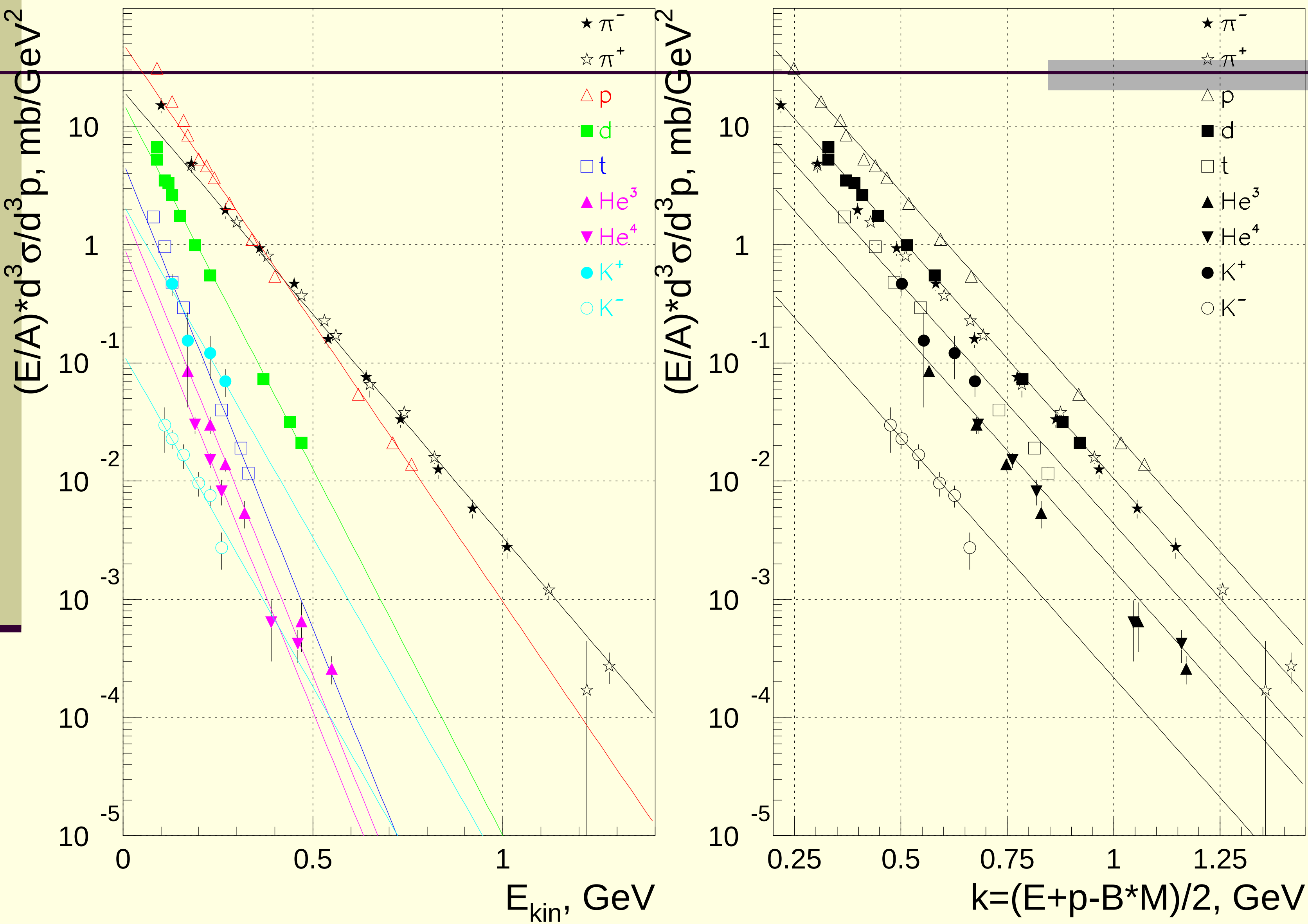
Chiral Invariant Phase Space (CHIPS)

- Critical temperature defines hadronic masses (EPJA-14,265)
- Simulation of proton-antiproton annihilation at rest (EPJA-8,217)
  - Quasmon creation in vacuum
  - quark fusion hadronization mechanism for energy dissipation
- Pion capture and evaporation algorithm (EPJA-9,411)
  - Quasmon creation in nuclear matter
  - Quasmon can exchange quarks with nuclear clusters
  - quark exchange hadronization mechanism
- Photonuclear reactions (EPJA-9, 421)
- Photonuclear absorption cross sections (EPJA-14,377)

Chiral Invariant Phase Space (CHIPS)

- Momentum of primary parton is k=(E-B*m+p)/2
  - B is a baryon number of the secondary hadron,
  - E,p are energy and momentum of the secondary hadron
  - m is mass of nuclear cluster
- measuring E and p of the hadron with known B, one can reconstruct spectra of primary partons.
- In simplified one dimentional case (q momentum of recoil parton):
  - Baryons: k+M=E+q, k=p-q -> k=(E-M+p)/2 (quark exchange)
  - Mesons: k+q=E, k-q=p -> k=(E+p)/2 (quark-antiquark fusion)
  - Antibaryons: k+q=M+E, k-q=p: k=(E+M+p)/2 (antiquark-antidiquark fusion)
- In CHIPS the hadronization is made in three dimensions

p+Ta=h+X, 400 GeV, 90°



Nuclear Capture of Negative Particles at Rest

- This simulation does not need any interaction cross-section
- Parameterised+theoretical models for π^- and K^-
  - Absorption parameterised
  - De-excitatin of nucleus nuclear de-excitation models
- Core code: CHIPS (Chiral Invariant Phase Space) model
  - Valid for μ^-,tau$^-$, π^-, K^-, anti-proton, neutron, anti-neutron, sigma$^-$, anti-sigma+, Xi$^-$, Omega$^-$
- For μ^- and tau$^-$ mesons this is a hybrid model creating
  - Photons and Auger electrons from intra-atomic cascade (electromagnetic process)
  - neutrinos radiated when the meson interacts with the nuclear quark (weak process)
  - hadrons and nuclear fragments, created from the recoil quark interacting with nuclear matter (hadronic process)

Nuclear Capture of Negative Particles at Rest using CHIPS (continued)

- π^- and K^- mesons are captured by nuclear clusters with subsequent hadronization
- Anti-barions (anti-hyperons) annihilate on the surface of nuclei with quasifree nucleons
  - secondary mesons interact with nuclear matter
- neutrons are included for heavy nuclei, which can absorb low energy neutrons and decay.

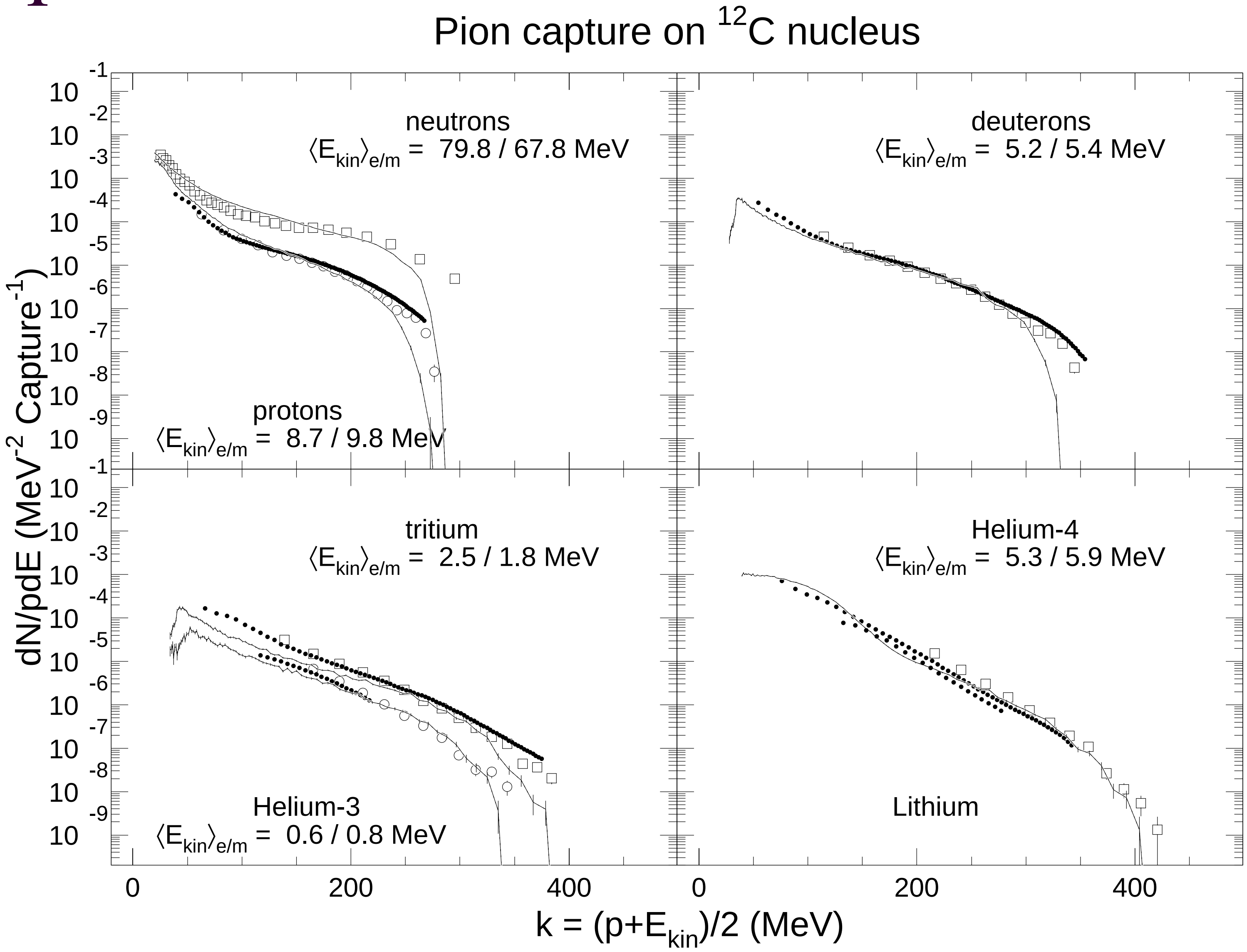
Using Nuclear Capture of Negative Particles at Rest using CHIPS

- The G4QCaptureAtRest process can be used for all negative particles, for negative pions:

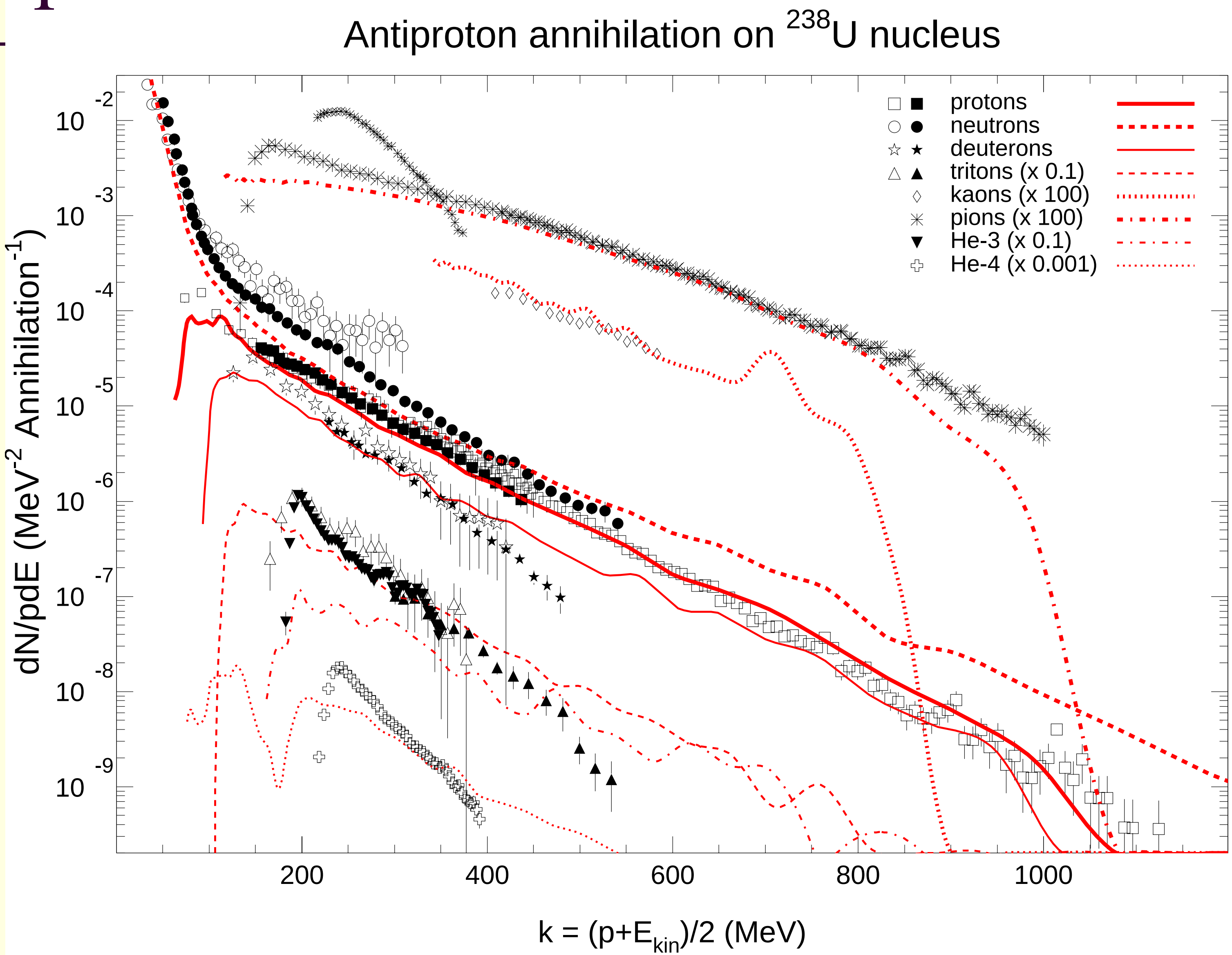
```
G4PionMinusInelasticProcess thePionMinusInelastic;
G4LEPionMinusInelastic* theLEPionMinusModel;
G4MultipleScattering thePionMinusMult;
G4hIonisation thePionMinusIonisation;
G4QCaptureAtRest thePionMinusAbsorption;

pManager = G4PionMinus::PionMinus()->GetProcessManager();
pManager->AddDiscreteProcess(&theElasticProcess);
theLEPionMinusModel = new G4LEPionMinusInelastic();
thePionMinusInelastic.RegisterMe(theLEPionMinusModel);
pManager->AddDiscreteProcess(&thePionMinusInelastic);
pManager->AddProcess(&thePionMinusIonisation, ordInActive,2, 2);
pManager->AddProcess(&thePionMinusMult);
pManager->AddRestProcess(&thePionMinusAbsorption, ordDefault);
```

Validation of CHIPS model for pion Capture at Rest on Carbon



Validation of CHIPS for Anti-Proton Capture at Rest on Uranium



Also…..

- Inelastic Ion reactions
  - Binary Cascade
  - Abrasion/Ablation
  - Electromagnetic dissociation
- Nuclear elastic
- Coherent elastic nucleon-nucleon scattering
- Muon nuclear
- Leading Particle Bias (partial MARS re-write)
- Radioactive decay
- Biasing

Summary

- Validation of physics list for specific use case important
  - For new use cases absolutely needed
- Further reading:
  - Geant4 Physics reference manual
    - Navigate from Geant4 home page http://cern.ch/geant4
  - Geant4 «Results&Publications» web page
  - “Physics of shower simulation at LHC, at the example of Geant4”, J.P. Wellisch, CERN Academic training March 1-4, 2004.
    - http://agenda.cern.ch/fullAgenda.php?ida=a036555