Hadronic Physics 3

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Geant4 V8.3

Outline

- String Models
  - quark-gluon string, Fritiof fragmentation
- Chiral Invariant Phase Space (CHIPS) model
- Other models
  - capture
  - fission
  - isotope production

Acknowledgement:
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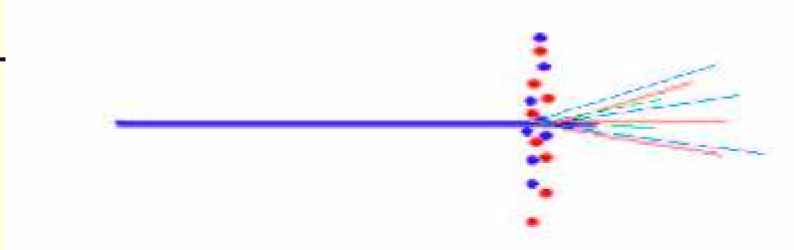
String Models

- For incident p, n, π, K
- $\sim$10 GeV < E < 50 TeV

- Model handles:
  - selection of collision partners
  - formation and excitation of strings
  - string hadronization
- Damaged nucleus remains. Another Geant4 model must be added for nuclear fragmentation and de-excitation
  - pre-compound model, or CHIPS for nuclear fragmentation

- QGS also used for high energy γ nuclear interaction

String Model Algorithm



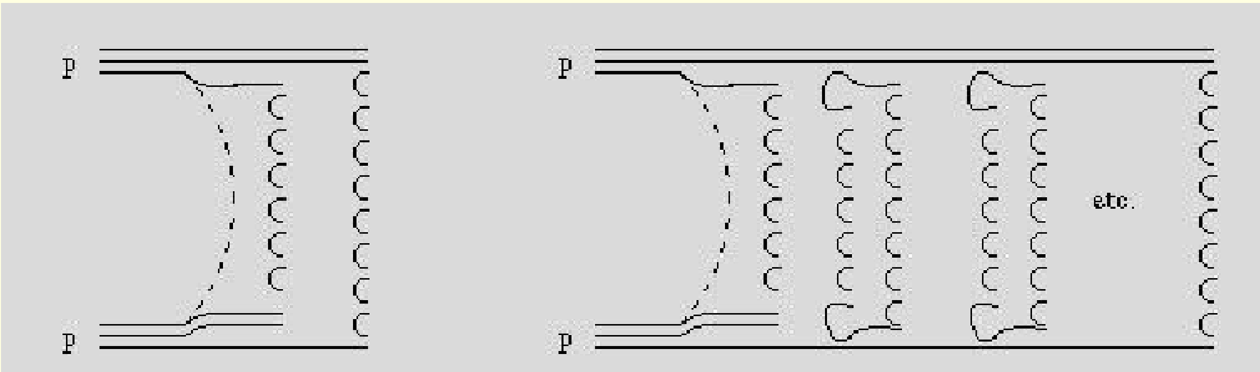
- Build up 3-dimensional model of nucleus
- Large γ-factor collapses nucleus to 2 dimensions
- Calculate impact parameter with all nucleons
- Calculate hadron-nucleon collision probabilities
  - use Gaussian density distributions for hadrons and nucleons
- String formation and fragmentation into hadrons

Longitudinal String Fragmentation

- String extends between constituents
- Break string by inserting q-qbar pair according to
  - u : d : s : qq = 1 : 1 : 0.27 : 0.1
- At break -> new string + hadron
- Created hadron gets longitudinal momentum from sampling fragmentation functions
- Gaussian P_t , $\langle P_t^2 \rangle = 0.5$ GeV

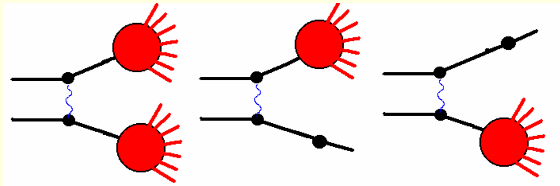
Quark Gluon String Model

- Two or more strings may be stretched between partons within hadrons
  - strings from cut cylindrical Pomerons
- Parton interaction leads to color coupling of valence quarks
  - sea quarks included too
- Partons connected by quark gluon strings, which hadronize



Fritiof Model

- Similar to Quark-Gluon string model, except
  - no partons are exchanged between projectile and target



  - only momentum is exchanged:

$$dW \propto dP^{-}_{proj} / P^{-}_{proj} \times dP^{-}_{tar} / P^{-}_{tar}$$

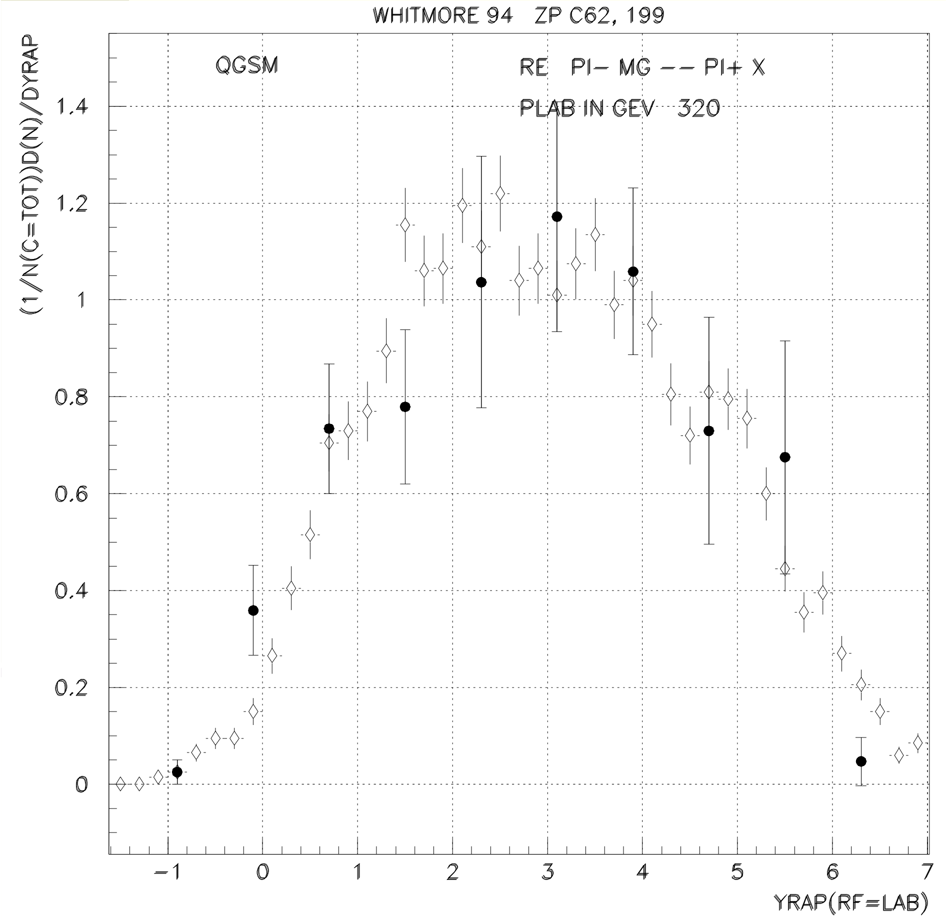
  - has a different set of string fragmentation functions

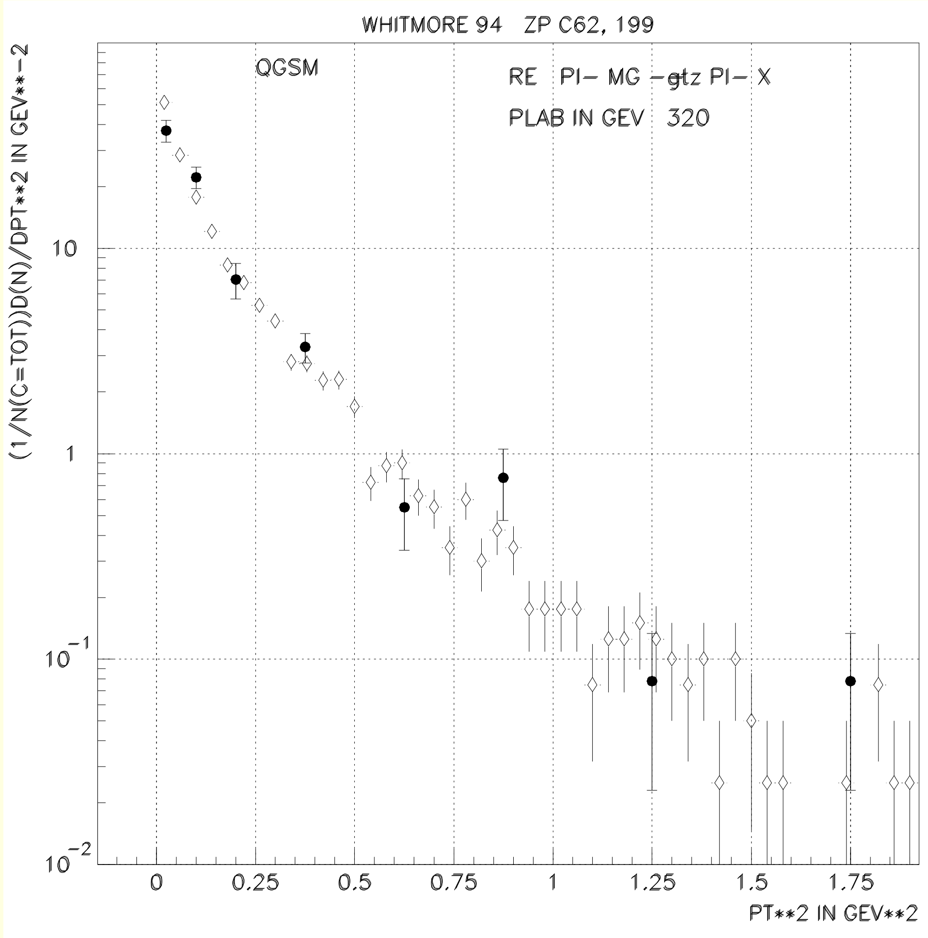
Diffraction

- Both QGS and FTF models include diffraction
  - projectile or target or both break up into hadrons
  - amount of diffraction is adjusted empirically

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]

Chiral Invariant Phase Space (CHIPS)

- Origin: M.V. Kosov (CERN, ITEP)
- Use:
  - capture of negatively charged hadrons at rest
  - anti-baryon nuclear interactions
  - gamma- and lepto-nuclear reactions
  - back end (nuclear fragmentation part) of QGSC model

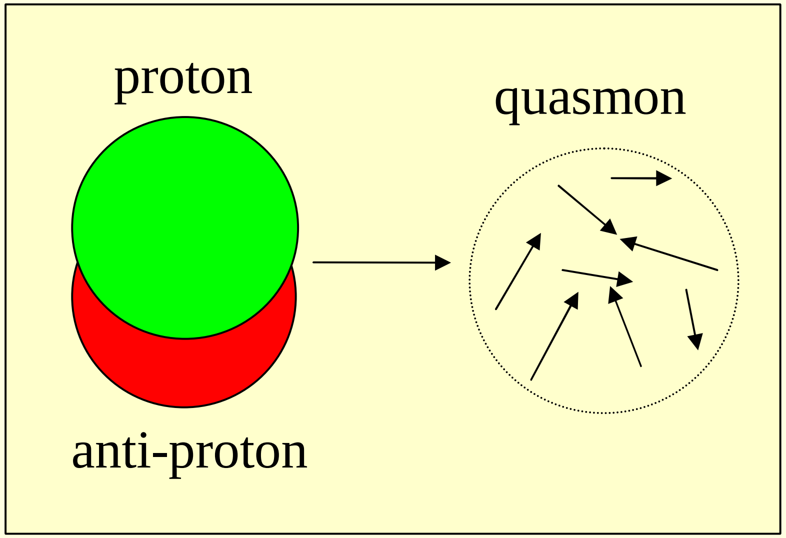
CHIPS Fundamental Concepts

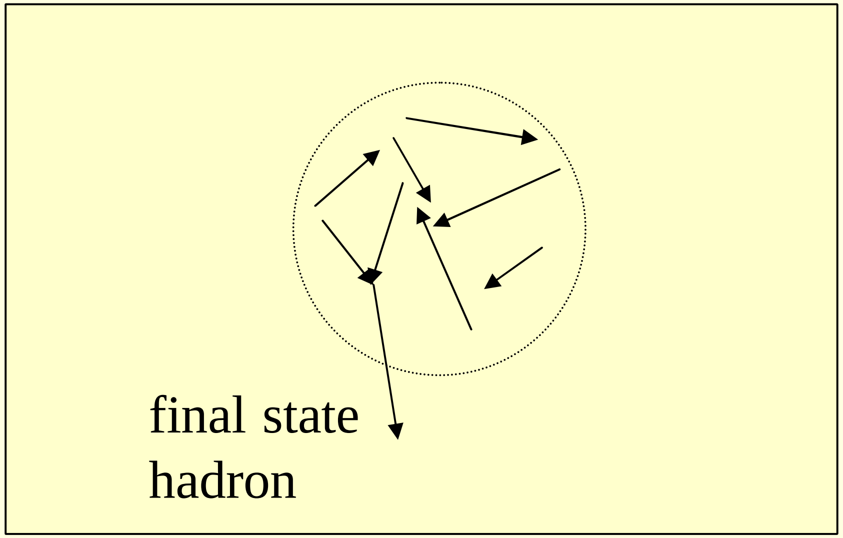
- Quasmon: an ensemble of massless partons uniformly distributed in invariant phase space
  - a 3D bubble of quark-parton plasma
  - can be any excited hadron system or ground state hadron
- Critical temperature T_C : model parameter which relates the quasmon mass to the number of its partons:
  - $M^2_Q = 4n(n-1)T^2_C \Rightarrow M_Q \sim 2nT_C$
  - T_C = 180 – 200 MeV
- Quark fusion hadronization: two quark-partons may combine to form an on-mass-shell hadron
- Quark exchange hadronization: quarks from quasmon and neighbouring nucleon may trade places

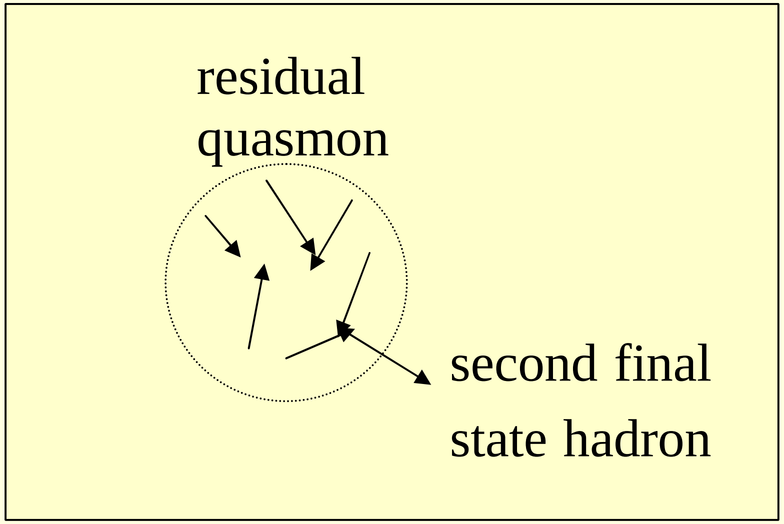
CHIPS Applications

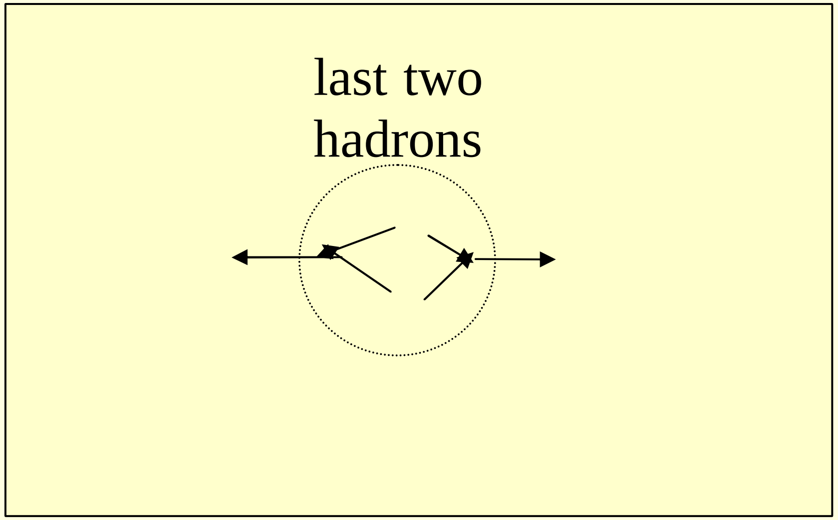
- u,d,s quarks treated symmetrically (all massless)
  - model can produce kaons, but s suppression parameter is needed, η suppression parameter also required
  - real s-quark mass is taken into account by using masses of strange hadrons
- CHIPS is a universal method for fragmentation of excited nuclei (containing quasmons).
- Unique, initial interactions were developed for:
  - interactions at rest such as π^- capture, pbar annihilation
  - gamma- and lepto-nuclear reactions
  - hadron-nuclear interaction in-flight are in progress
- Anti-proton annihilation on p and π^- capture at rest in a nucleus illustrate two CHIPS modelling sequences

Modeling Sequence for Proton – antiproton Annihilation (1)

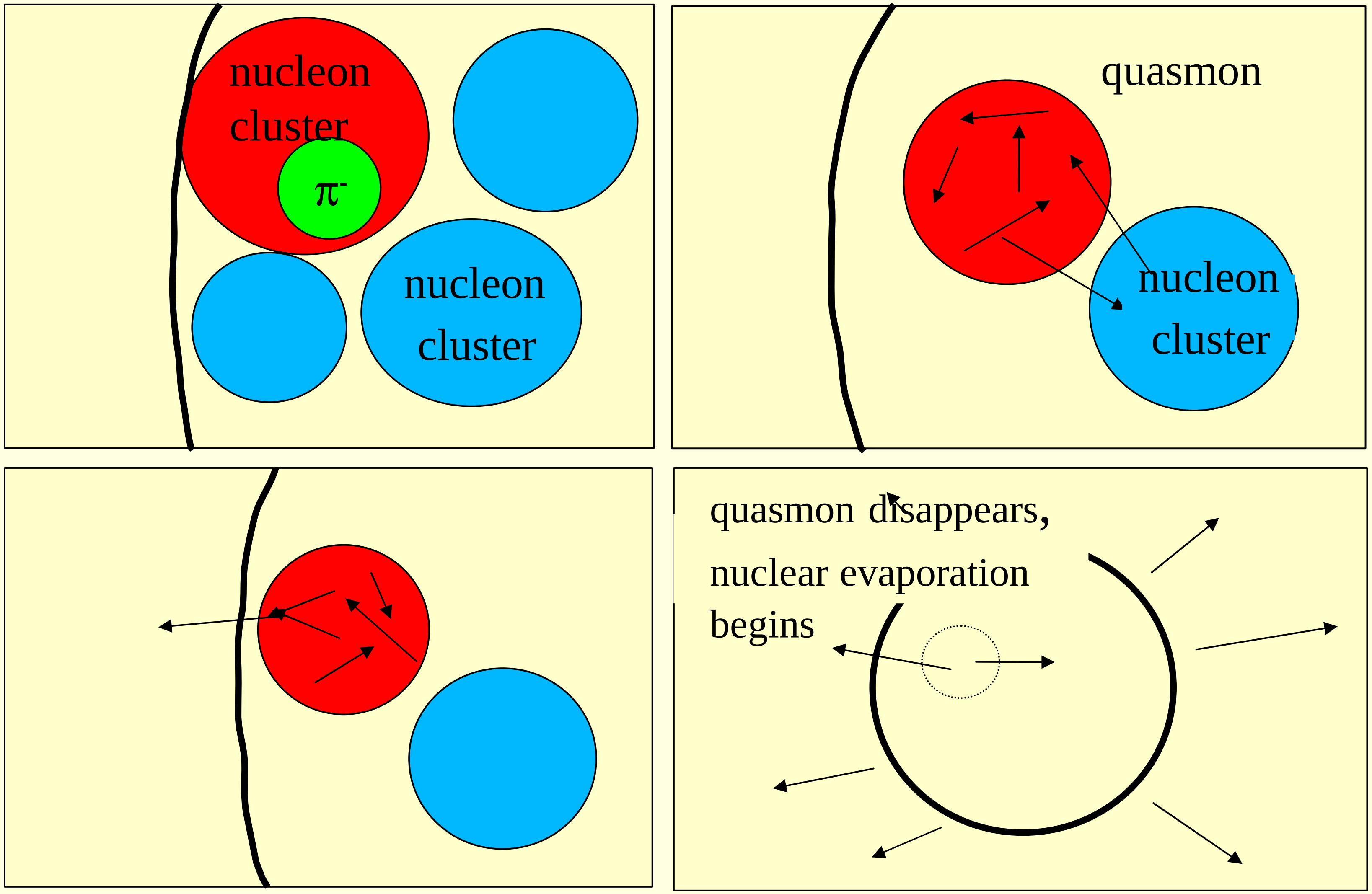








Modeling Sequence for π^- Capture at Rest in a Nucleus (1)



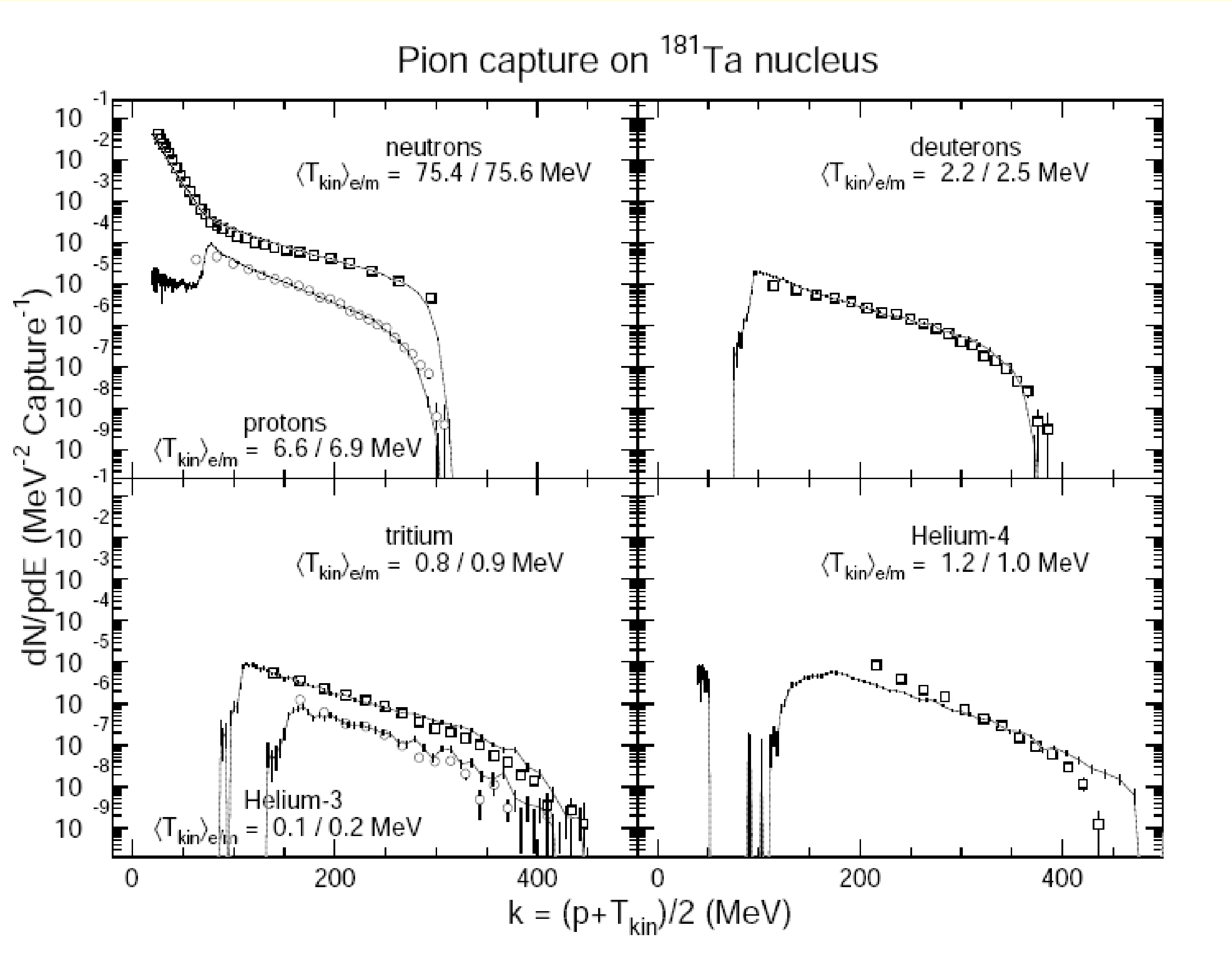
Modeling Sequence for π^- Capture at Rest in a Nucleus (2)

- pion captures on a subset or cluster of nucleons
  - resulting quasmon has a large mass, many partons
  - capture probability is proportional to number of clusters in nucleus
  - 3 clusterization parameters determine number of clusters
- both quark exchange and quark fusion occurs
  - only quarks and diquarks can fuse
  - mesons cannot be produced, so quark-anti-quark cannot fuse as in p-pbar case
  - because q-qbar fusion is suppressed, quarks in quasmon exchange with neighboring nucleon or cluster
    - produces correlation of final state hadrons

Modeling Sequence for π^- Capture at Rest in a Nucleus (3)

- some final state hadrons escape nucleus, others are stopped by Coulomb barrier or by over-barrier reflection
- hadronization continues until quasmon mass reaches lower limit m_{min}
  - in nuclear matter, at this point nuclear evaporation begins
  - if residual nucleus is far from stability, a fast emission of p, n, α is made to avoid short-lived isotopes

Validation of CHIPS Model for Pion Capture at Rest on Tantalum



Capture Processes

- At rest capture on nuclei
  - G4MuonMinusCaptureAtRest
  - G4PionMinusAbsorptionAtRest
  - G4KaonMinusAbsorption
  - G4AntiProtonAnnihilationAtRest
  - G4AntiNeutronAnnihilationAtRest
- In flight
  - G4HadronCaptureProcess uses following models:
    - G4LCapture (mainly for neutrons)
    - G4NeutronHPCapture (specifically for neutrons)

Fission Processes

- G4HadronFissionProcess can use three models:
  - G4LFission (mostly for neutrons)
  - G4NeutronHPFission (specifically for neutrons)
  - G4ParaFissionModel
- New spontaneous fission model from LLNL
  - available soon

Isotope Production

- Useful for activation studies
- Covers primary neutron energies from 100 MeV down to thermal
- Can be run parasitically with other models
- G4NeutronIsotopeProduction is currently available
  - G4ProtonIsotopeProduction not yet completed
- To use:
  - G4NeutronInelasticProcess nprocess;
    G4NeutronIsotopeProduction nmodel;
    nprocess.RegisterIsotopeProductionModel(&nmodel);
- Remember to set environment variable to point to G4NDL (Geant4 neutron data library)

Summary

- Two string models (QGS, FTF) are provided for high energy (>20 GeV) interactions
- The Chiral Invariant Phase Space model is available for:
  - capture at rest
  - anti-baryon annihilation
  - gamma and lepto-nuclear interactions
  - nuclear de-excitation
- Other models/processes available include:
  - capture at rest and in flight
  - fission
  - neutron-induced isotope production