Progress in Hadronic Physics Modeling in Geant4

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For the

Geant4 Hadronic Working Group

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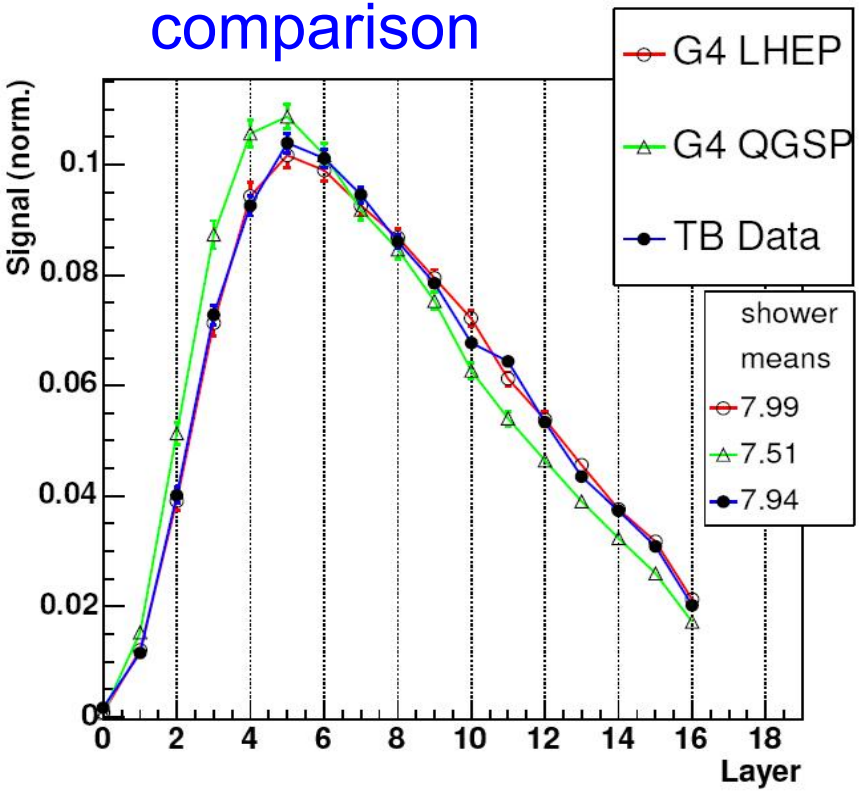
Outline

- Motivation
- Improvements to shower shape
  - Cross section validation
  - Model validation
- Other developments
- Summary

Motivation

- Hadronic development motivated since start (1997) by requirements of LHC detectors
  - Response/linearity (e/pi), resolution, shape, missing E, ..
- 2004-2005 results from ATLAS & CMS test beam indicated that for QGSP physics list
  - **shower shape**, linearity need improvement (LHEP ok)
  - Resolution and e/π were good (LHEP was bad)

- CMS shower shape comparison



300 GeV pions, leaving MIP in ECAL and L0.
Stefan Piperov, Jordan Damgov, Shuichi Kunori, 17-Jul 2006

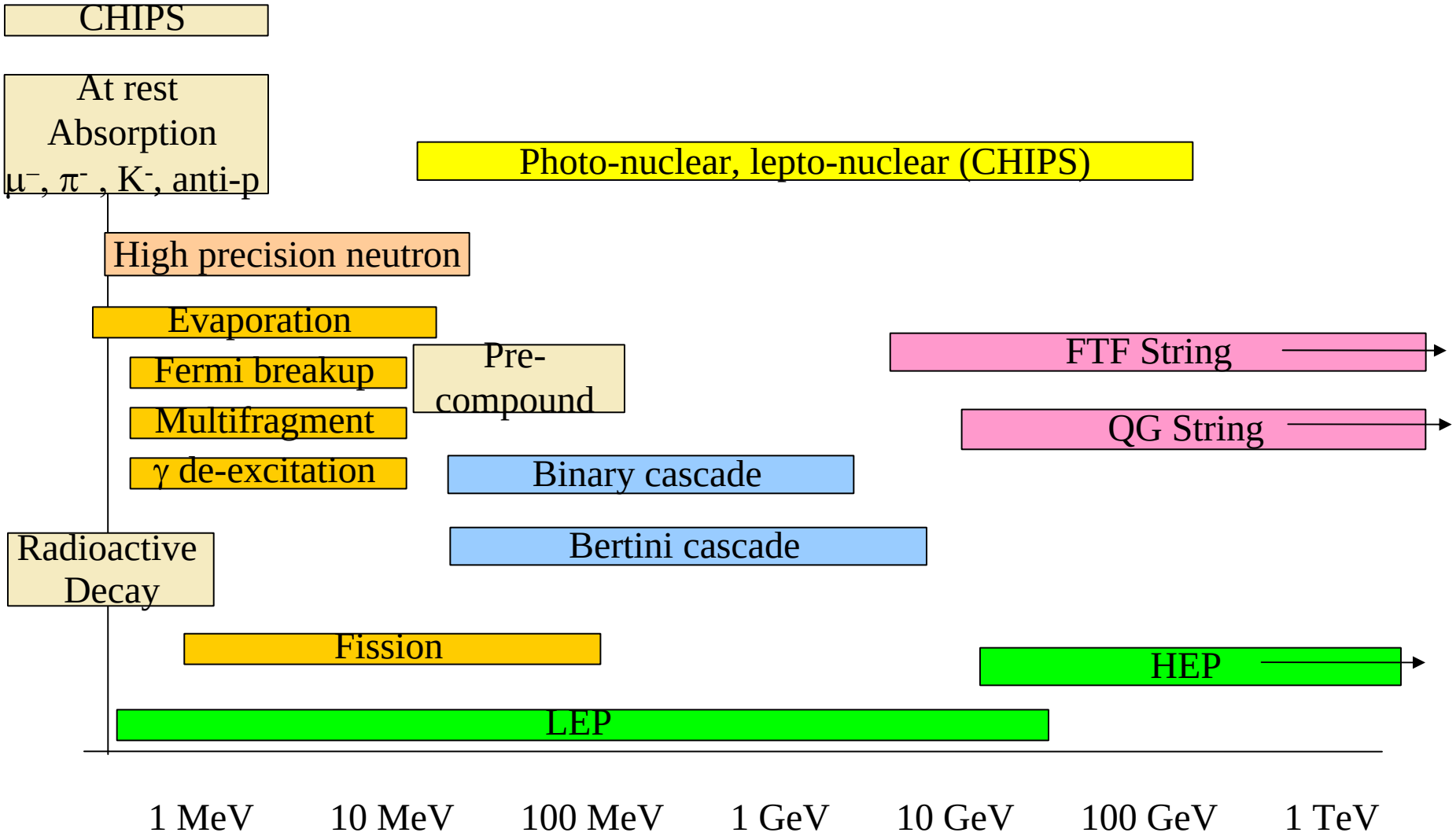
Addressing Shower Shape issue

- Validation effort using microscopic data
  - Cross sections – check vs. data or evaluations
  - Models – check vs. thin target experiments
- Use toy calorimeter to study hadronic shower simulation
  - E.g. Energy deposit per particle type (π^0, p, …)
- **Found a need to:**
  - **Add a proper treatment of quasi-elastic scattering**
  - **use of cascade codes**
  - improve elastic scattering

Ingredients of G4 hadronic physics

- Cross-sections
- Models for interactions
  - Elastic
  - Inelastic **QGSP**
    - String models (~10 GeV – 1 TeV+):
      - Quark Gluon String (**QGS**),
      - Complemented by Quasi-elastic
    - Optional : Cascade (from ~0.2 to 5 or 10 GeV): BIC, Bert
    - Pre-equilibrium and equilibrium models: **P**
    - Capture
    - Decay
  - Inelastic - **LHEP**
    - **H**igh **E**nergy **P**arameterized (~25GeV -
    - **L**ow **E**nergy **P**arameterized (0- ~55 GeV)
    - Capture
    - Decay

Hadronic Inelastic Interactions Models



Physics Lists

Physics List is a set of **consistent physics models** for **each particle** in application

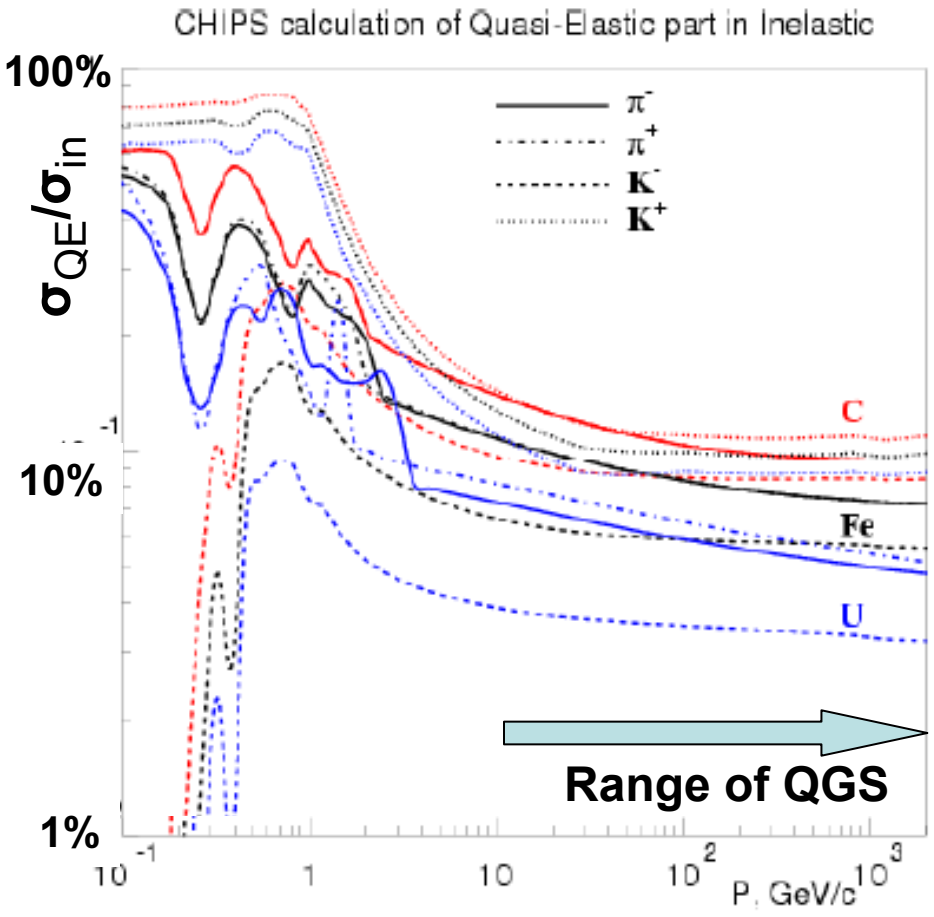
- LHC experiments see developments through Physics Lists
- Follow improvements and developments
  - Update existing configurations
    - Adopt mature options, e.g. elastic,quasi-elastic in **QGSP, QGSP_BERT**, ...
  - Provide new configurations
    - Experimental lists, e.g **FTF_BIC**
- Feedback from experiments is vital

Recent improvements

- Addition of quasi-elastic to Quark Gluon String (QGS) model
- Revised coherent elastic scattering
- Revised inelastic cross sections
- Improvements in Cascade codes
  - Bertini cascade
- Revising FTF model

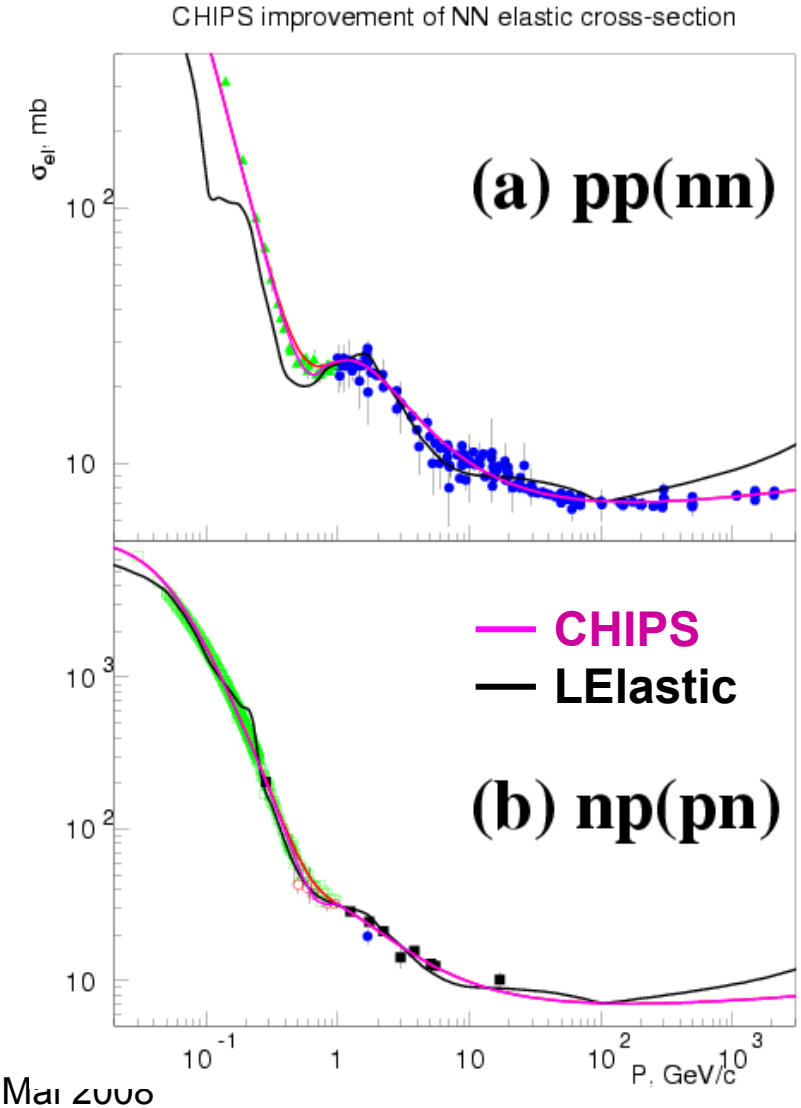
Quasi-elastic in parallel to QGS model

- Elastic scattering of primary on nucleon
- Cross section part of in-elastic cross section
  - about (5-10)% for p > 10GeV/c
- Replaces part of production cross section
  - Longer showers
- Included in all QGS and FTF physics lists



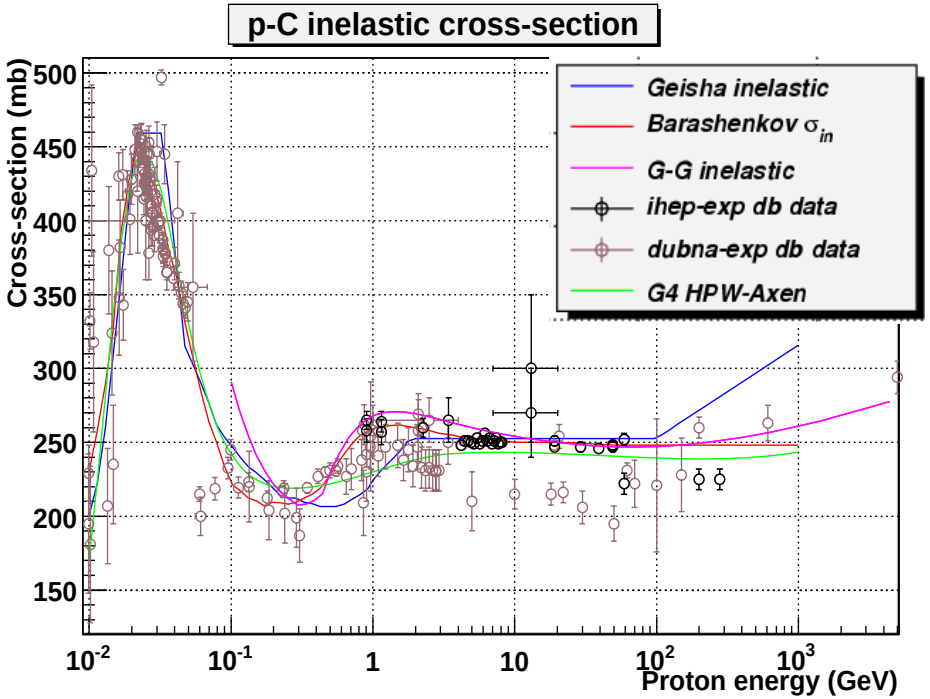
Hadron Elastic Process Developments

- Geant4 elastic scattering was completely reviewed
  - for proton and neutron CHIPS detailed parameterizations are used since G4 8.3
  - for pions and other hadrons above 1 GeV a Glauber model is used since G4 9.1p01
  - for pions and other hadrons below 1 GeV, LElastic model
- Elastic scattering of neutrons off Hydrogen important in sampling calorimeters with plastic scintillator



Revision of Inelastic Cross Sections

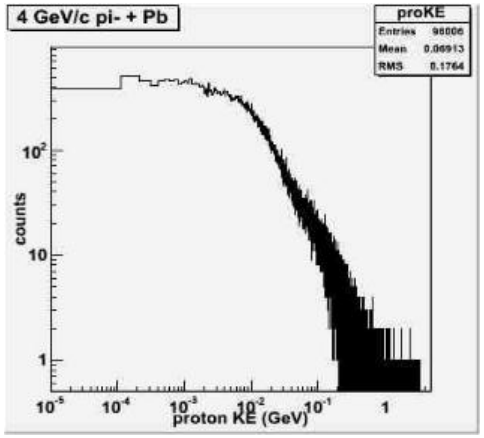
- Pion
  - Revise interpolation of Barashenkov evaluation (optical model fit)
- Proton, neutron
  - Check
- Improved high energy behaviour



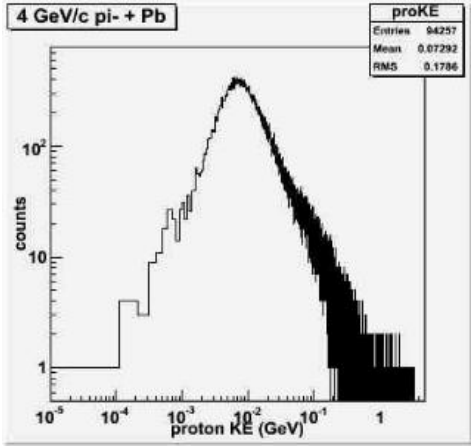
Bertini Cascade Improvements

- Correction enabling Coulomb barrier in evaporation phase

Without barrier



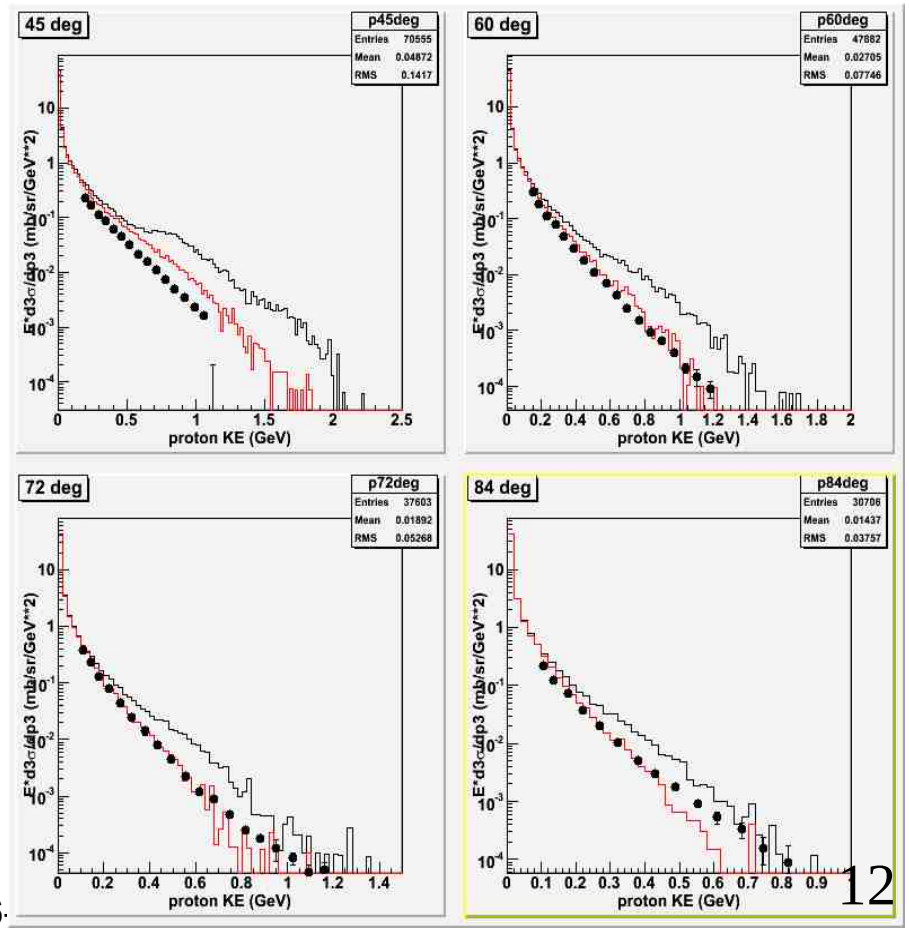
With barrier



- High energy angular distributions fixed:

  4 GeV p+Al → p + X

  black: original, red: fix



Proton kinetic energy

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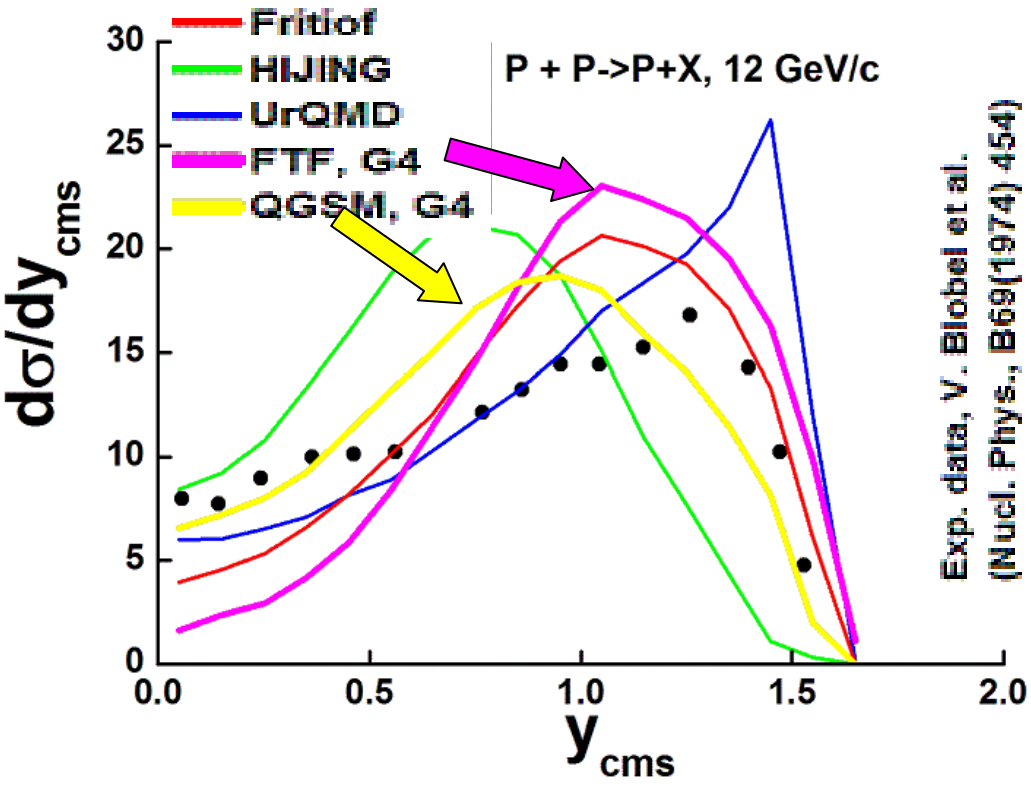
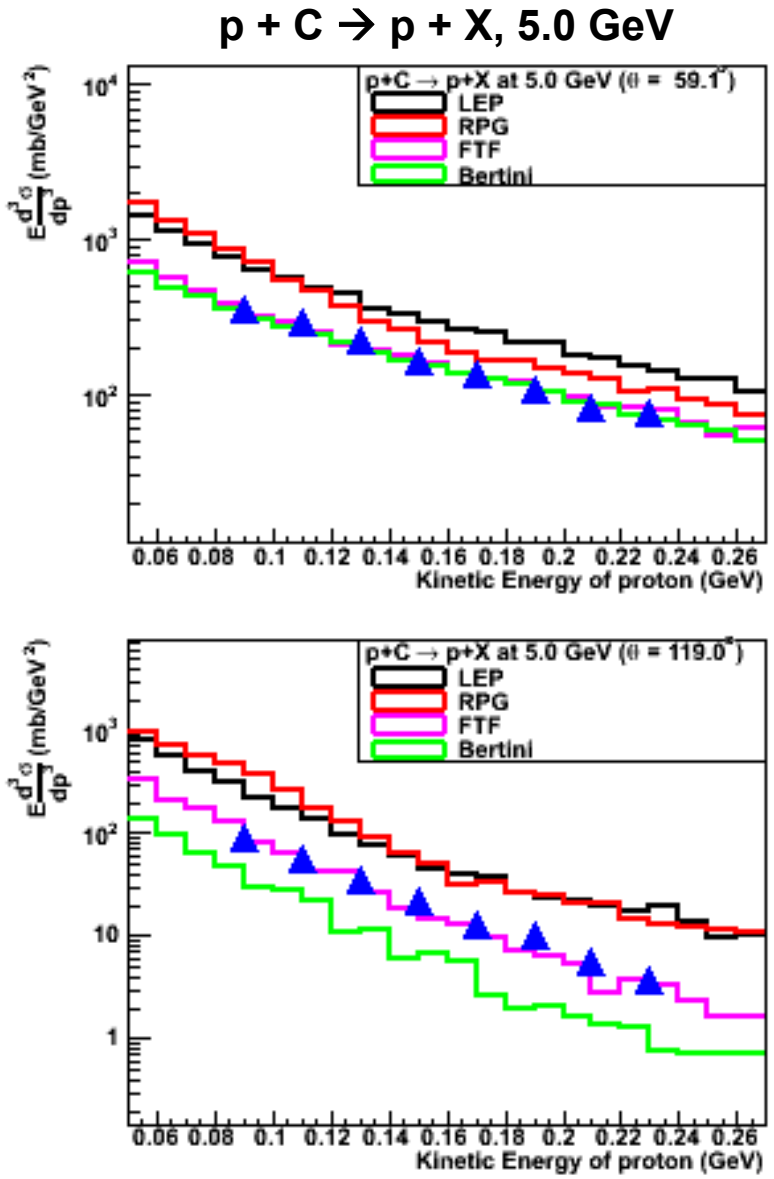
Improvement of Fritiof (FTF) model

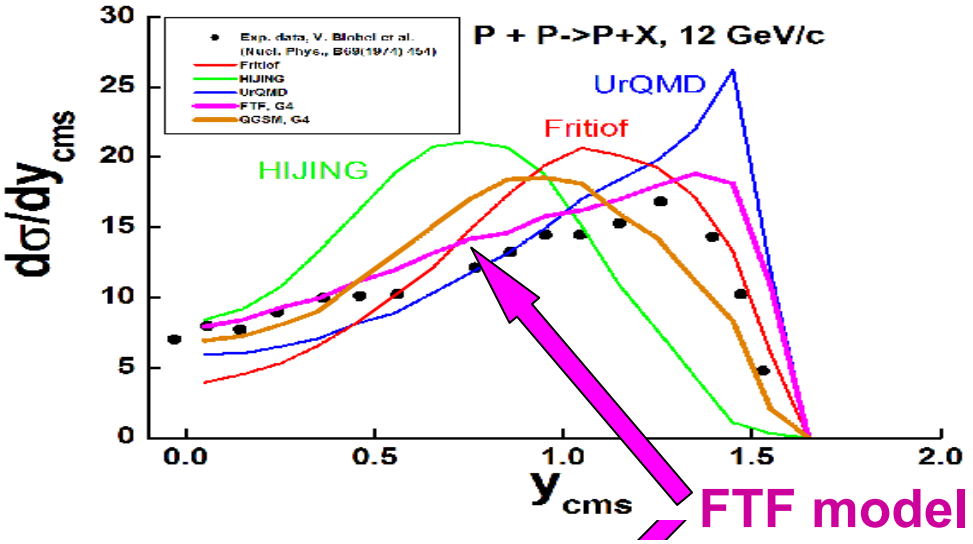
- **Release G4 9.0**
- Geant4 Fritiof model implemention updated to closely correspond to orignal FORTRAN code.
- improved simulation at low energies >2-3 GeV.

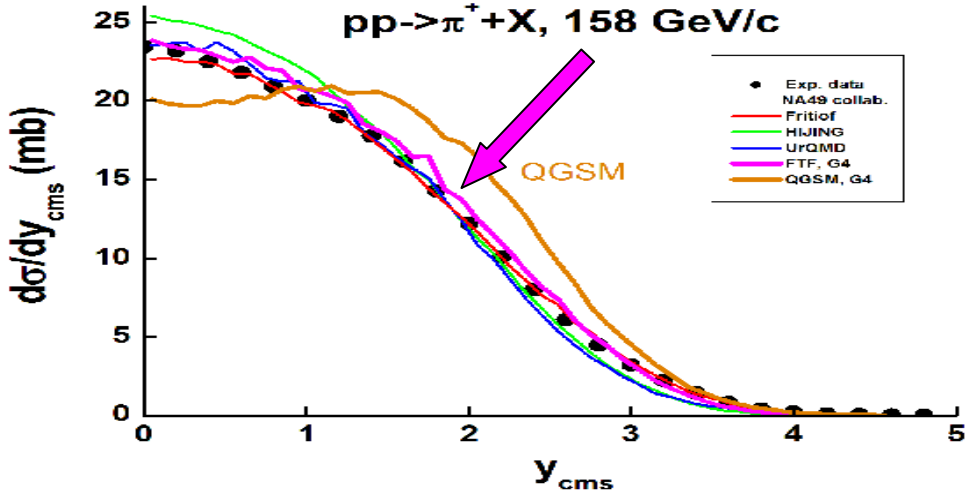




Ongoing improvement of G4 Fritiof (FTF) model

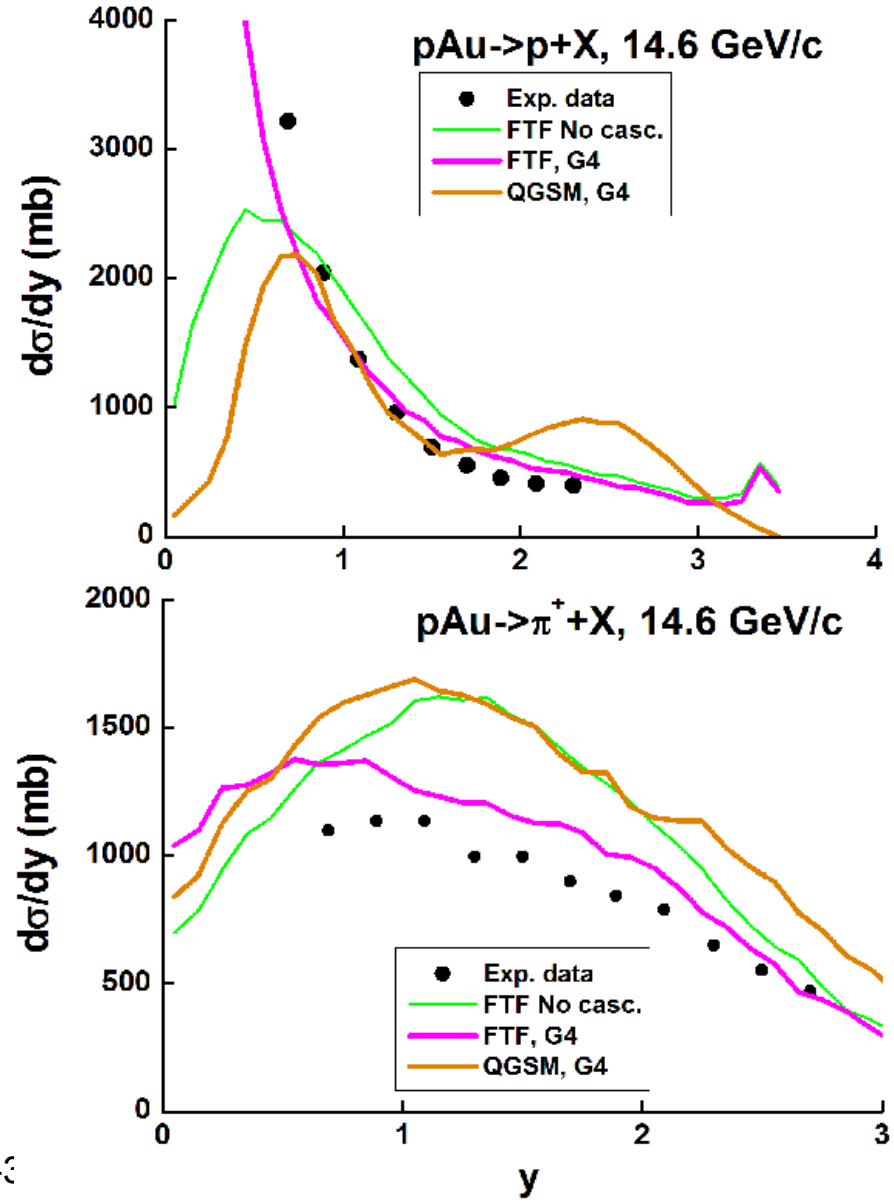
- **Upcoming release**
- Separate simulation of diffractive and non-diffractive nucleon-nucleon interactions
- Implementation of quasi-elastic scattering
  - elastic scattering of projectile on nuclear nucleons
- Accounting of a particle formation time





FTF – a look at heavy nuclei

- **Upcoming release**
- FTF with rescattering using Binary cascade works well for heavy target

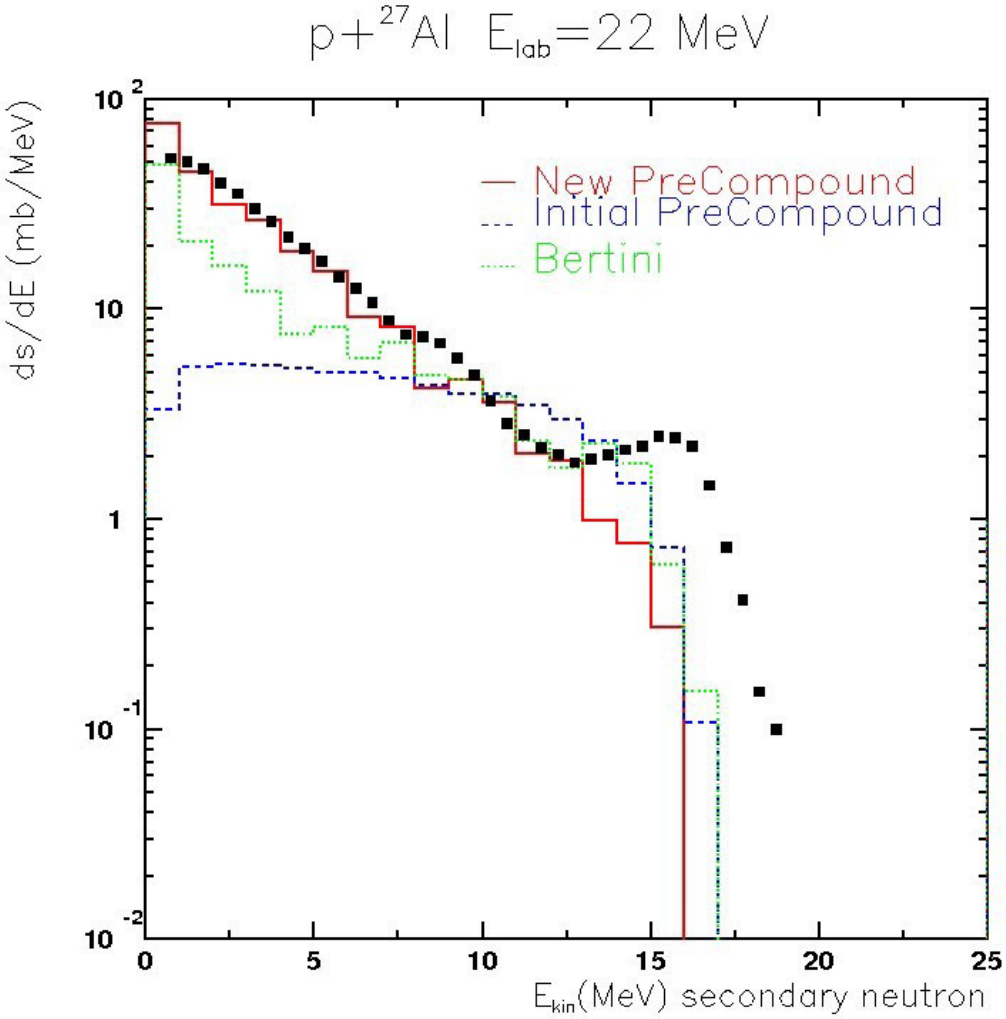


Ongoing work

- Revision of pre-equilibrium and de-excitation models
- Binary cascade
- Reimplementation of INCL/ABLA cascade
- Low energy neutron transport
- Thick target validations
  - TARC
  - Recent results presented at SATIF
- Ion-Ion
- …

Improvements of Preequilibrium and Evaporation Models

- New inverse reaction cross sections for particle emission
- New transition probabilities at preequilibrium
- Physically consistent transition from preequilibrium to equilibrium λ+=λ-
- Several bugs fixed (Coulomb Barrier).
- Statistical processes (preequilibrium & evaporation) are now well described.
- Direct processes (inelastic peak) are out of the scope of statistical methods.



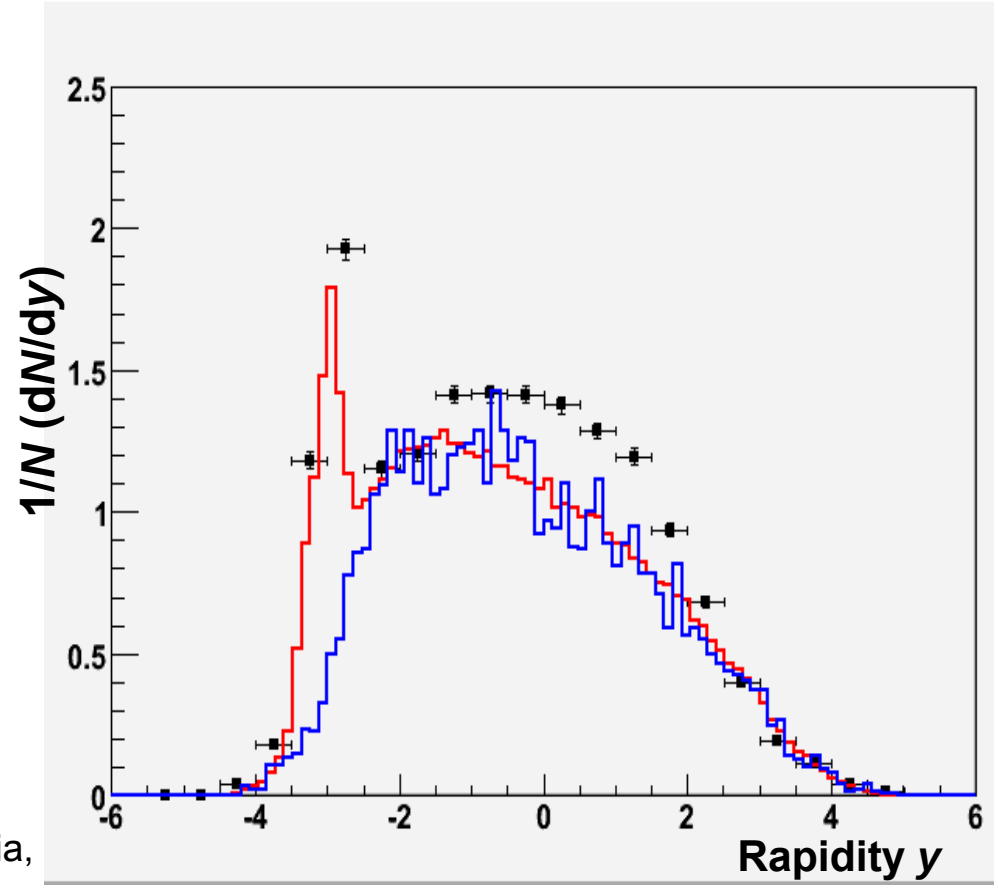
Binary Cascade Improvements

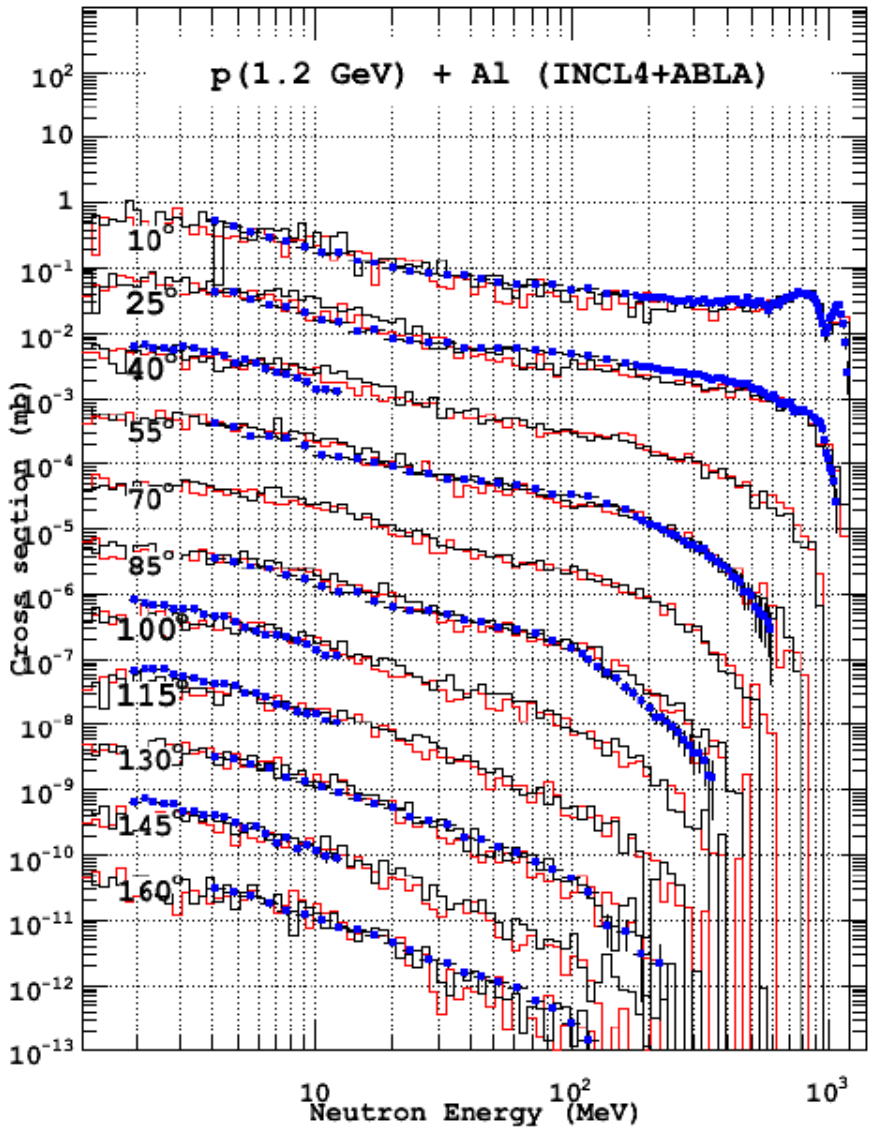
- Added re-scattering interface
  - Allows to re-scatter "slow" particles created by high energy interaction (QGS or FTF)
- Pion incident first release

π^+ Al → x^+ X at 250GeV/c

--- QGS_BIC / --- QGSP

Data: Agababyan et.al., EHS-NA22, Z.Phys.C50, 361(1991)





INCL4.2 **(Liège) intra-nuclear cascade and** ABLA **evaporation-fission**

- *Projectiles:* n,p,$\pi^{0,\pm}$,D,T, ^{3}He, α (0.2-3 GeV)
- *Targets:* C-U
- *Fission:* GSI code SIMFIS
- Optimized for spallation studies:
  - A. Boudard *et al.*, Phys. Rev. C66 (2002) 044615
  - J. Benlliure *et al.*,Nuc.Phys. A628 (1998) 458
- Direct translation of original code is provided; **2009:** INCL5.

Validation of Geant4 9.1 INCL with ABLA (in red) for p(1.2 GeV) on Al target; black: original Fortran code. SATURNE data from S. Leray et al., Phys. Rev. C65, 044621 (2002)

Low energy neutron transport - neutron_hp Overview of recent developments

- Add and replace data to G4NDL
  - Now supported all of officially requested elements
- Many bug fixes and adding new functionalities
- Thermal neutron scattering
  - S (α, β) Models and Cross Sections
- JENDL High Energy Files (2004&2007)
  - up 3 GeV and 106 isotopes (2007)
- ENDL
  - Successor of Neutron HP and G4NDL
  - Adapting new generation neutron libraries such as ENDF7, JEND3.3 and so on.
  - Not Yet included latest release (v9.1.p02)

Summary
Estimate of Readiness for LHC

- Shower shape of hadronic showers has improved
  - Improved modeling – quasi-elastic, elastic
  - Use of Cascade models
- Physics lists
  - stable as ATLAS and CMS settle on **QGSP_BERT**
    - Other lists available for systematics: QGSP, ..
    - Alternatives provide options for future improvement: FTF_BIC, ..
- Challenges remain, e.g.
  - Investigating linearity problem in QGSP_BERT around 10 GeV
- Continuing effort to improve
  - Revising FTF model
  - Review of charge exchange, neutron capture
  - New parameterized model RPG

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The End

- Backup slides follow ….

Quasi-elastic

- Updates since introduction
  - Improved angular distribution
  - Proton Incident
    - Improved angular and momentum distribution
  - Added Fermi momentum
    - Improved handling of low energy secondary

Quasi-elastic scattering in FTF

- New implementation of quasi-elastic scattering in FTF
- There is now no strange structure observed by the HARP collaboration.