Hadronic Physics Highlights

Alberto Ribon

CERN PH/SFT

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Outline

- A few technical aspects of hadronics
- Status of String models (FTF, QGS)
- Status of Intranuclear Cascade models (BERT, BIC, INCLXX)
- Status of Precompound/de-excitation
- Status of Elastic scattering
- Status of Cross Sections
- Status of Radioactive Decay –-> *see Dennis talk*
- Status of NeutronHP & ParticleHP –-> *see Pedro talk*
  Status of GND/LEND –-> *see Tatsumi talk*

Maintenance

- As expected for a mature software, a significant fraction of the time spent by the hadronic developers of Geant4 goes to maintenance:
  - Questions & results by users
  - Bug fixes
  - Memory-leak fixes
  - Coverity fixes
  - MT-related fixes or refinements
  - ...

Checking of Unending Loops

- ATLAS required to check all *while* loops in Geant4 code to be sure that they will never produce infinite loops
- If a *while* loop is not guaranteed to end, a counter should be introduced in such a way to exit the loop when a specified threshold in the number of loops is reached
- When the check is done, this is marked in the code, e.g.

  while (condition) / Loop checking, 10.08.2015, A.Ribon */*

- The goal is to complete these checks for G4 10.2
- Most of hadronic packages
  - *e.g.* string models, Bertini, Precompound/de-excitation, *etc.*

  are ready in 10.1.ref08

Migration to Fast Math

- To speed up the simulation, we have started a campaign to replace, whenever possible, the following mathematical functions with the corresponding faster (VDT) versions
  - **std::exp –-> G4Exp**
  - **std::log –-> G4Log**
  - **std::pow –-> G4Pow**
    - *G4Pow::GetInstance()->powA(double, double);*
      G4Pow::GetInstance()->powN(double, int); *// int exponent*
      G4Pow::GetInstance()->Z13(int); *// int^(1/3)*
      G4Pow::GetInstance()->A13(double); *// double^(1/3)*
      G4Pow::GetInstance()->Z23(int); *// int^(2/3)*
      G4Pow::GetInstance()->A23(double); *// double^(2/3)*
- The goal is to complete the migration for G4 10.2
- Mos of hadronic packages
  - e.g. string models, Bertini, Precompound/evaporation, etc.

  are ready in 10.1.ref08

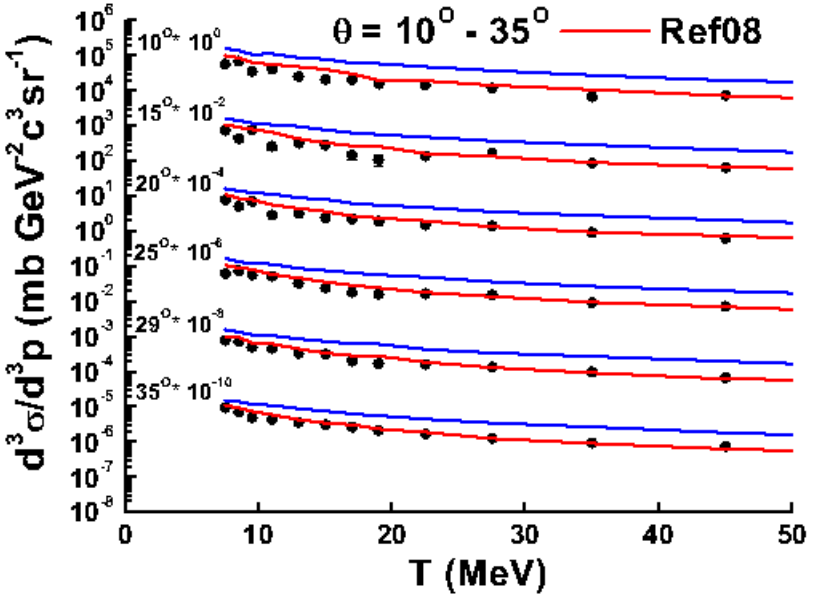
Status of **FTF** (Fritiof) Model

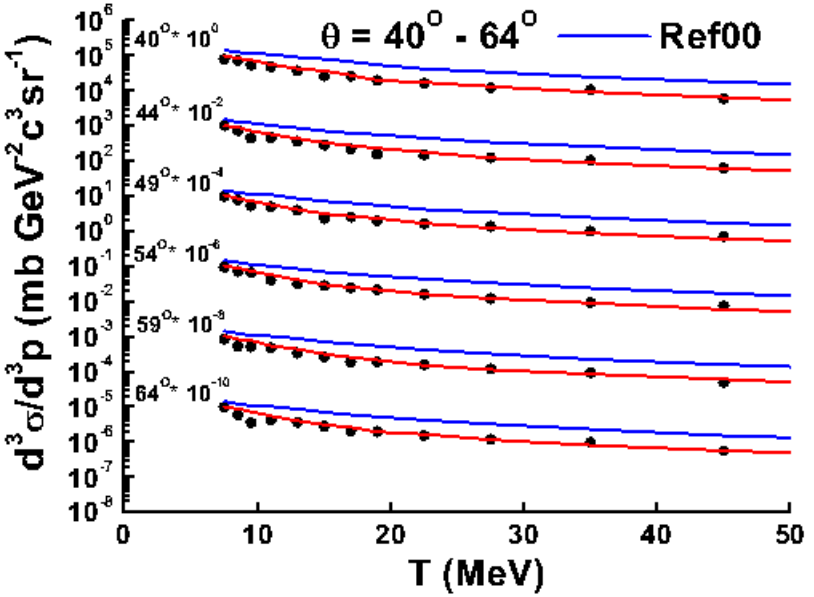
- The only part of FTF that was not yet tuned on data was the lowest energy sector, related to the preparation of the excited nuclear remnant, which is then passed to the Precompound/evaporation model
- This part is particularly important for the production of slow nucleons, *i.e.* low energy, below few tens of MeV
  - But energy conservation implies also an indirect effect on the production of the other particles, faster and more energetic, produced by FTF, either in the Glauber approach or in the Reggeon Cascade
- V. Uzhinsky has used the ITEP thin-target data to peek into this sector of FTF
  - Paper just published in JETP Lett. Vol. 102, N° 6

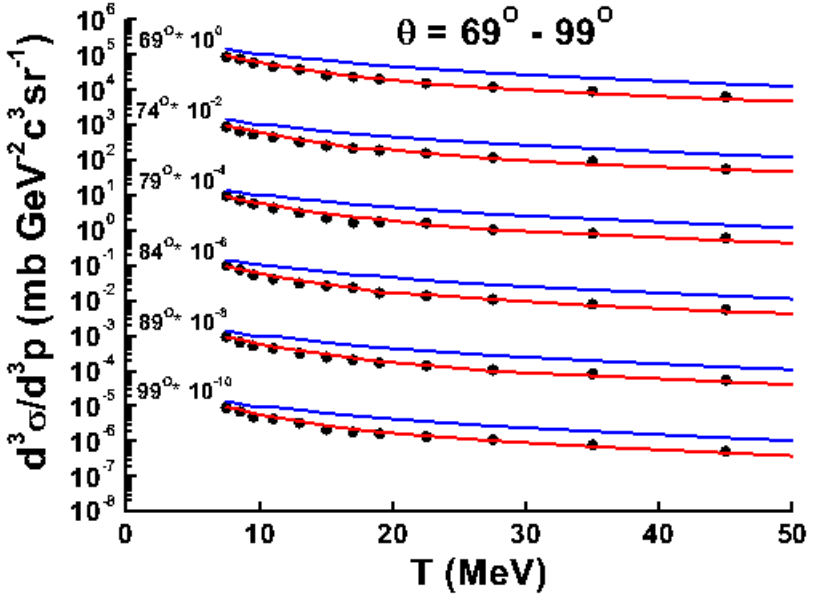
- *See talk in Parallel Session **3A** by A. R.*

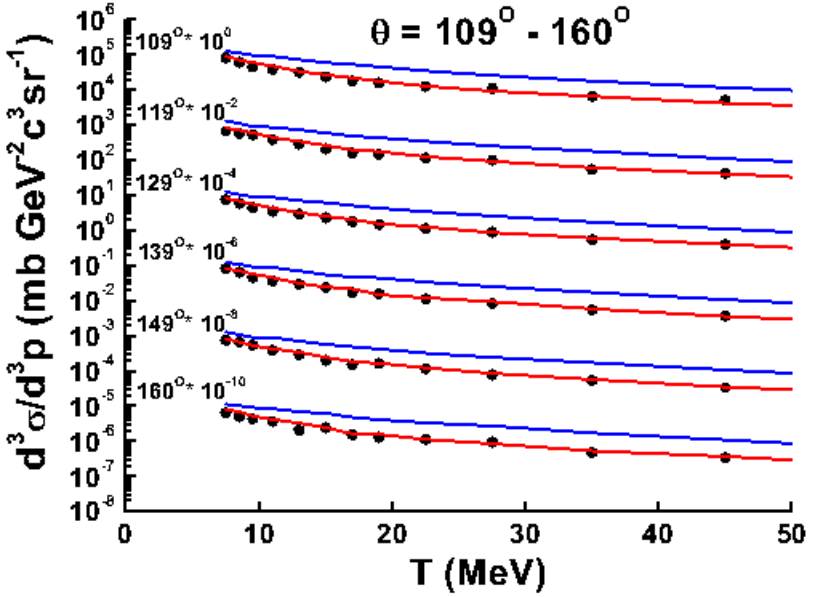
Experimental Data: 7.5 GeV/c p Cu

G4 10.1.**ref08** vs 10.1.**ref00**

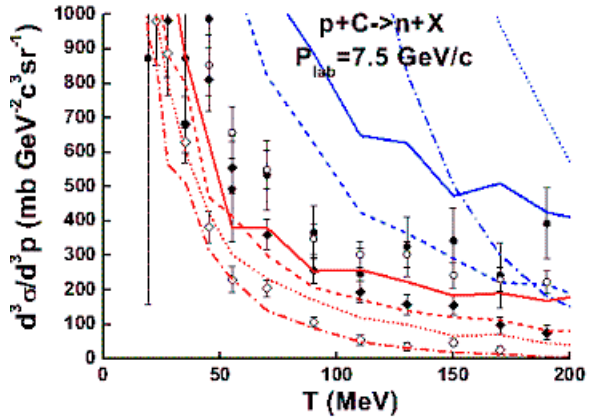


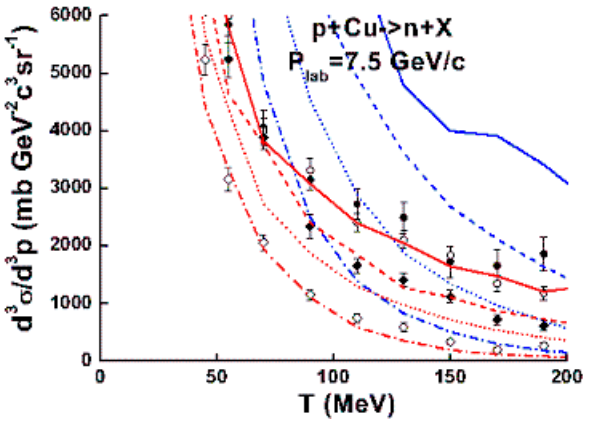


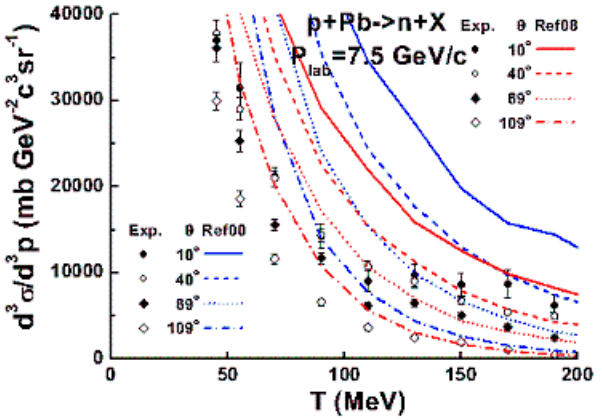


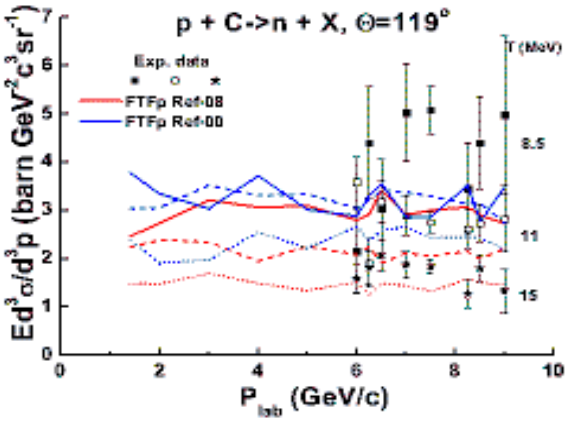


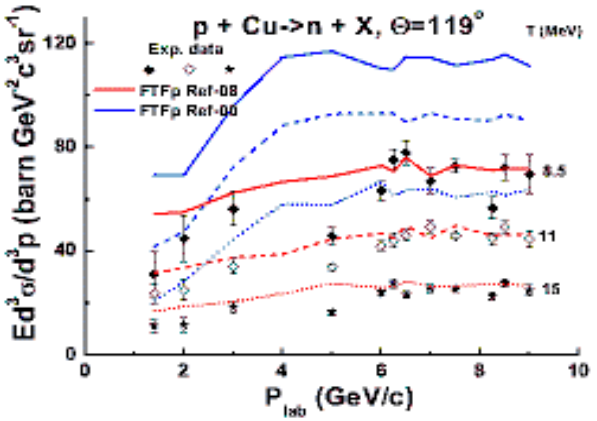
G4 10.1.**ref08** vs 10.1.**ref00**

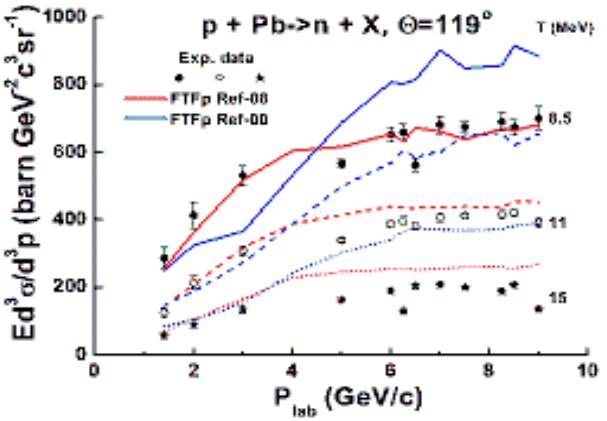


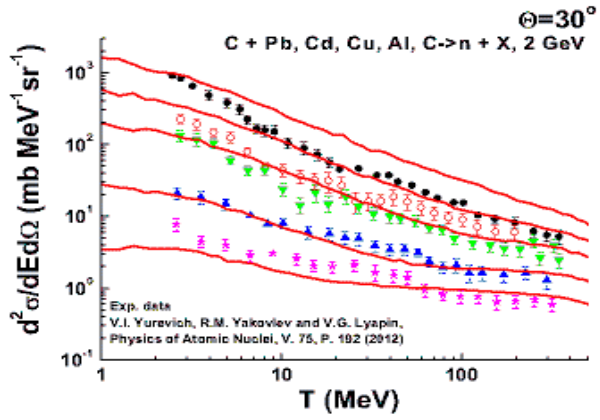


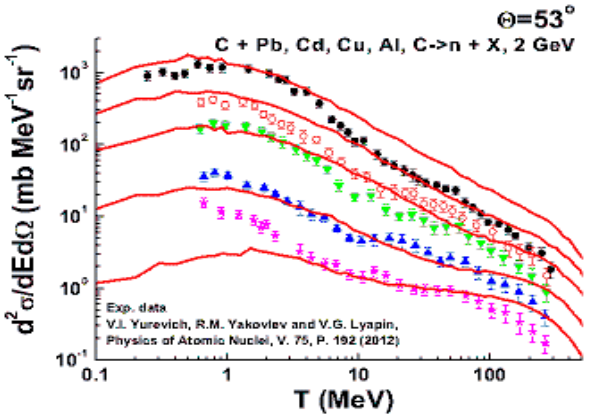


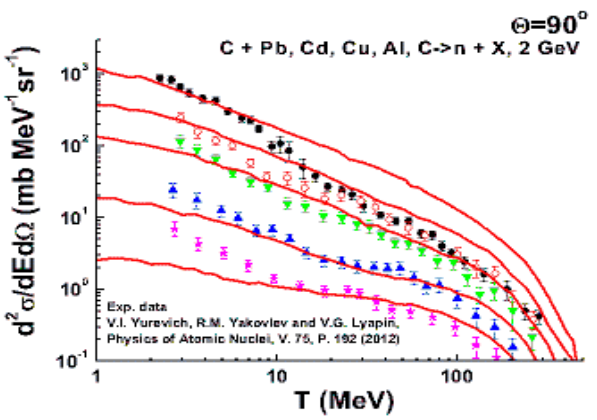




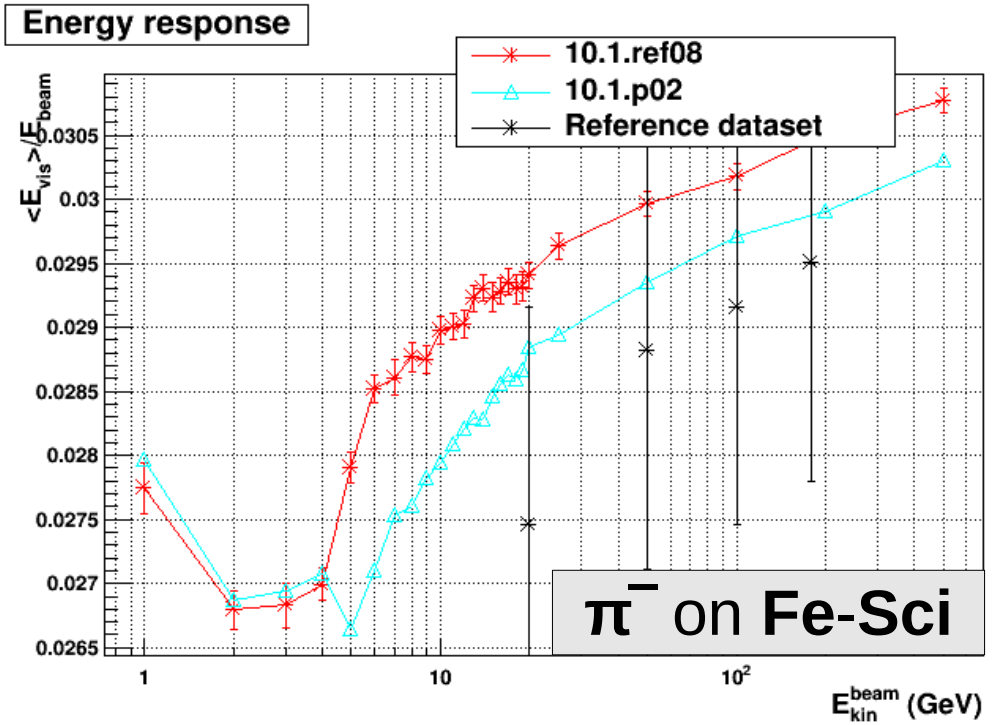


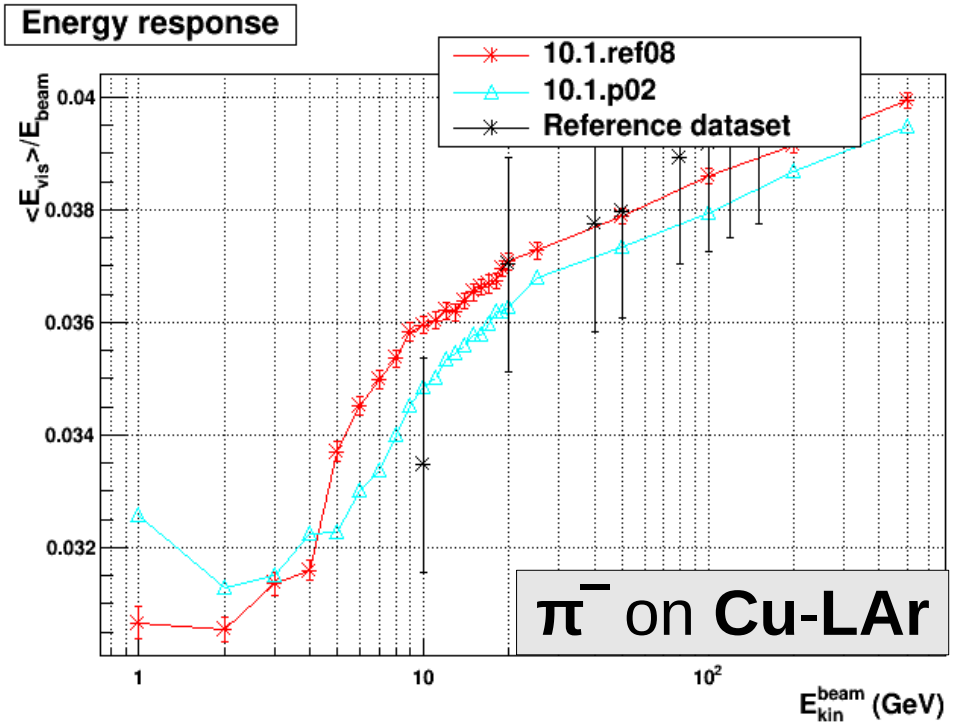


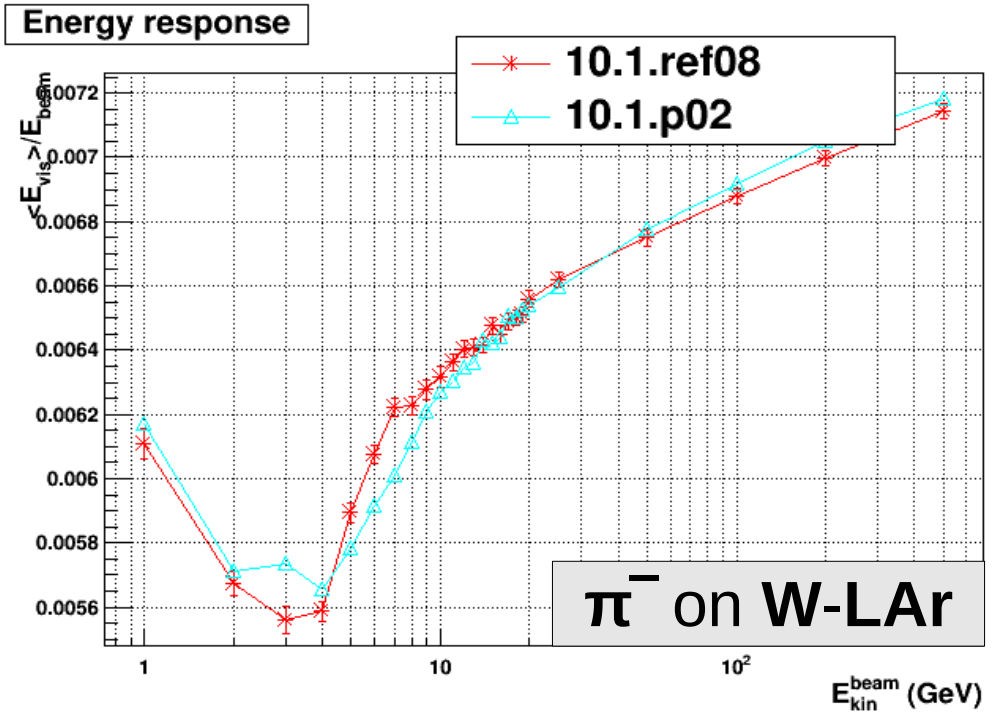


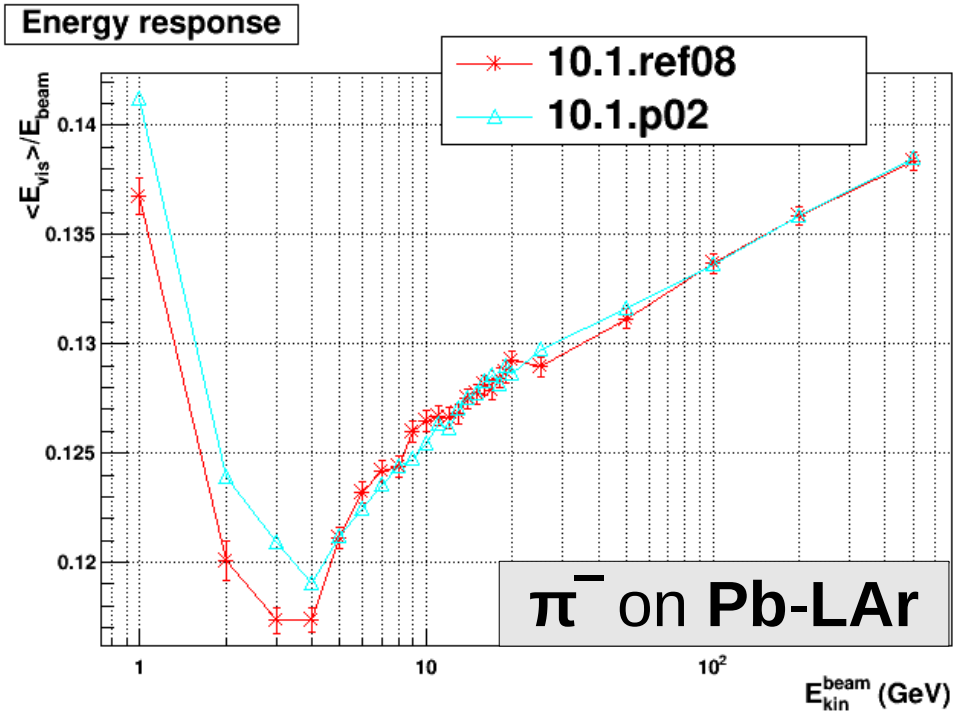


FTFP_BERT : Energy Response

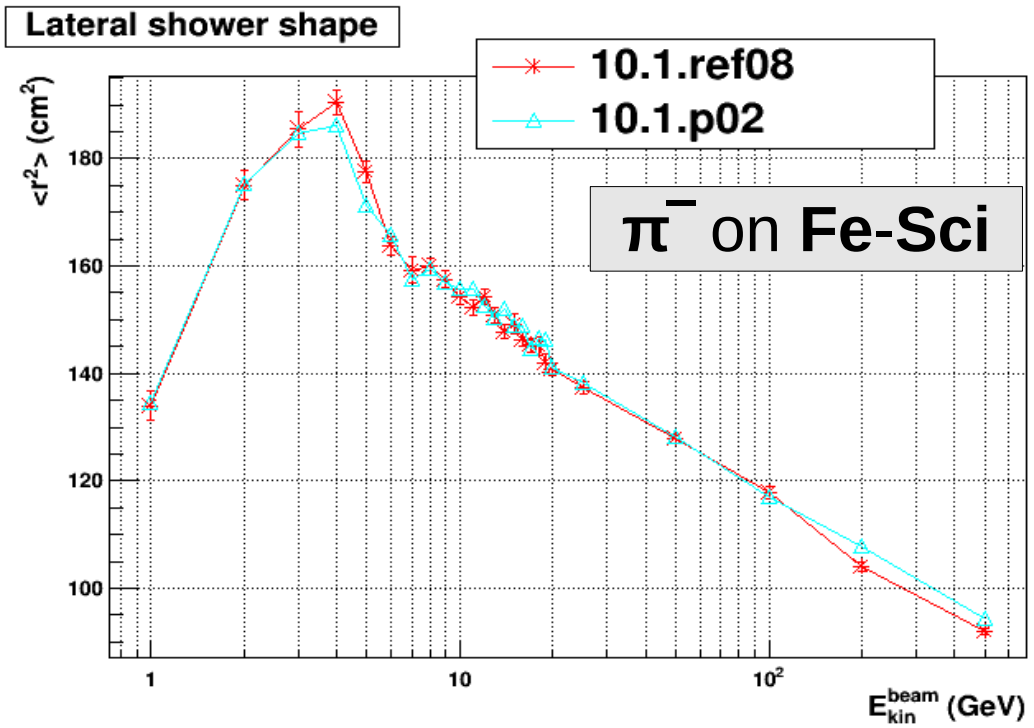


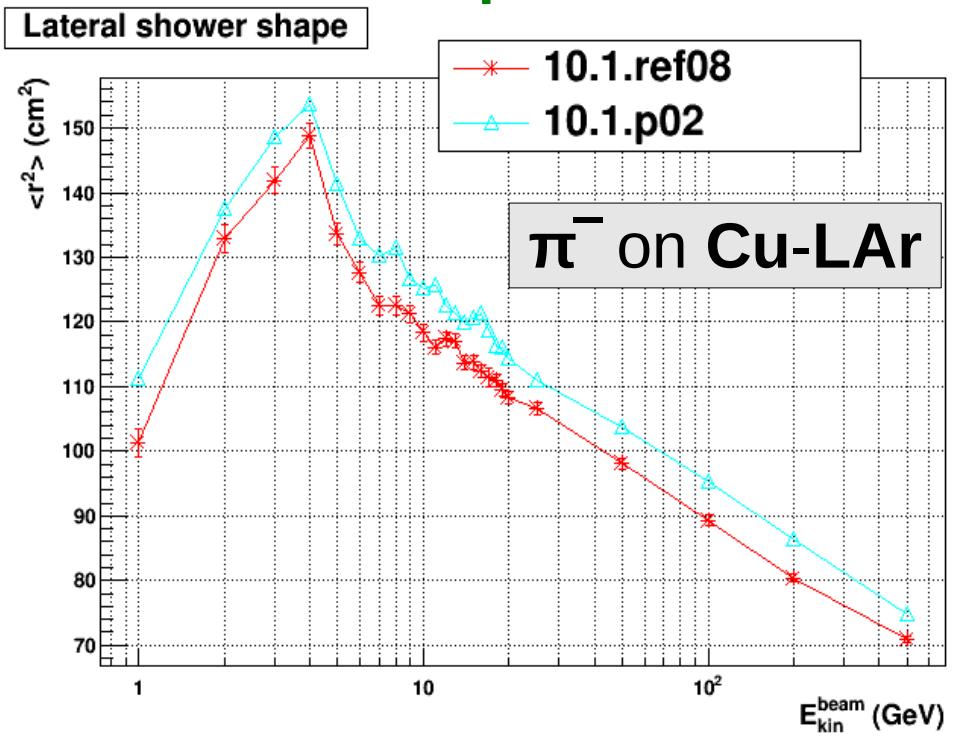


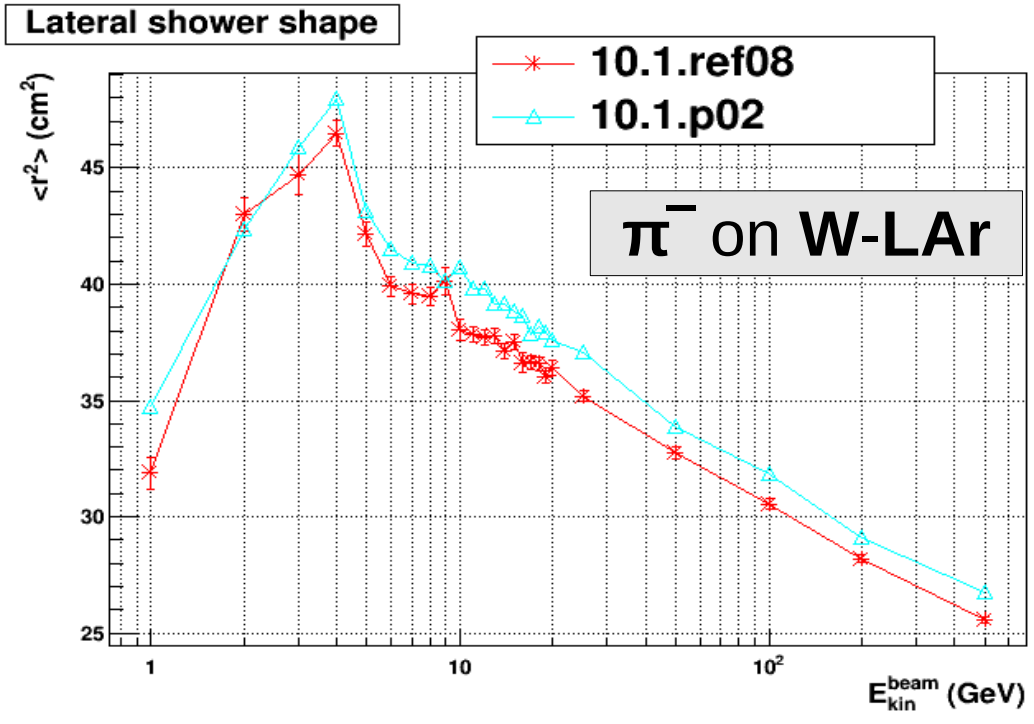


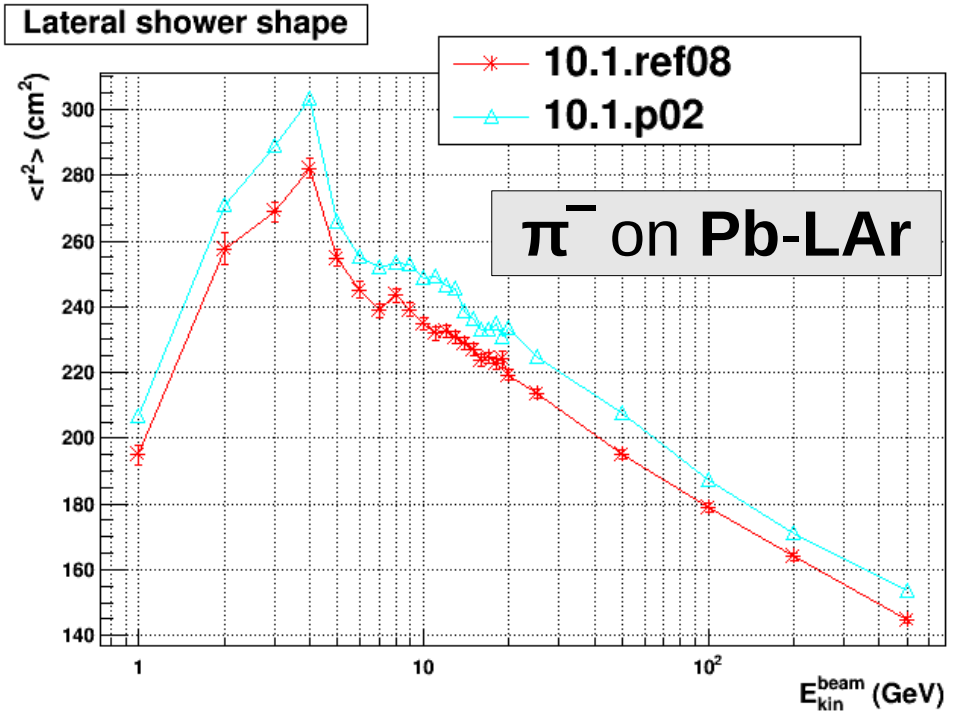


FTFP_BERT : Lateral Shape









Summary of **FTF**

- Preparation of the excited nuclear remnant by the FTF model to hand over to Precompound/evaporation has been revised
  - Improved description of slow neutron production in thin-target ITEP data
  - Little effect on the other thin-target observables

- Significant (few %) impact on FTFP_BERT hadronic showers
  - Higher energy response in Fe and Cu
    - More optimistic energy resolution
  - Narrower shower shapes

  both likely in the wrong direction !

Status of **QGS** (Quark Gluon String) Model

- The QGS model of Geant4 has been successfully used in production for several years by ATLAS and CMS simulations
  - In particular for all Run 1 analyses, including the Higgs discovery
- After the improvements and low-energy extensions of FTF model made by V. Uzhinsky, FTF became the recommended string model in Geant4 for high-energy applications
  - It will be used for Run 2 analyses by all LHC experiments
- Still, there are two main reasons to keep developing QGS

1. For evaluation of systematic errors, to compare against FTF
2. For its potential applicability up to slightly higher energy than FTF
   - QGS is more theoretically motivated than the phenomenological FTF model
   - Important for the increased LHC energy: 7-8 TeV --> 13-14 TeV
   - But QGS cannot be applied to much higher energies than few TeV : it does not included hard scattering (*i.e.* jet production) (the same applies for FTF as well)

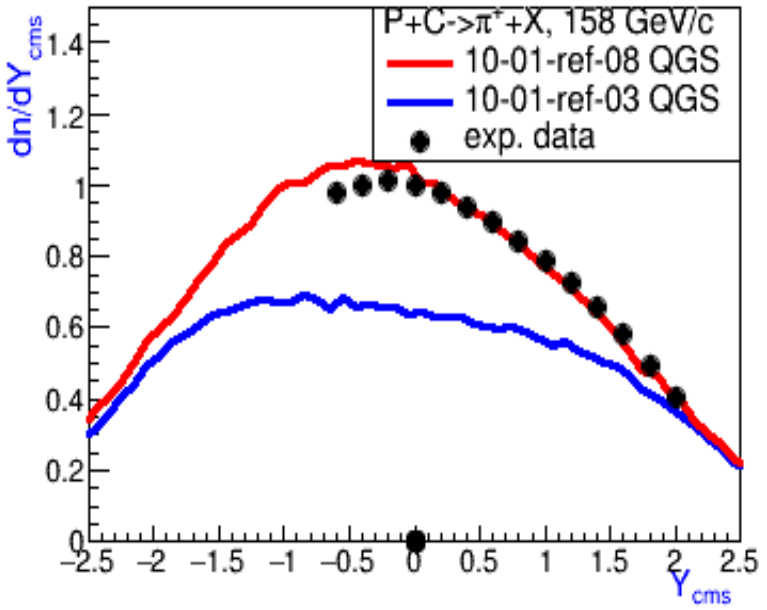
QGS String Fragmentation

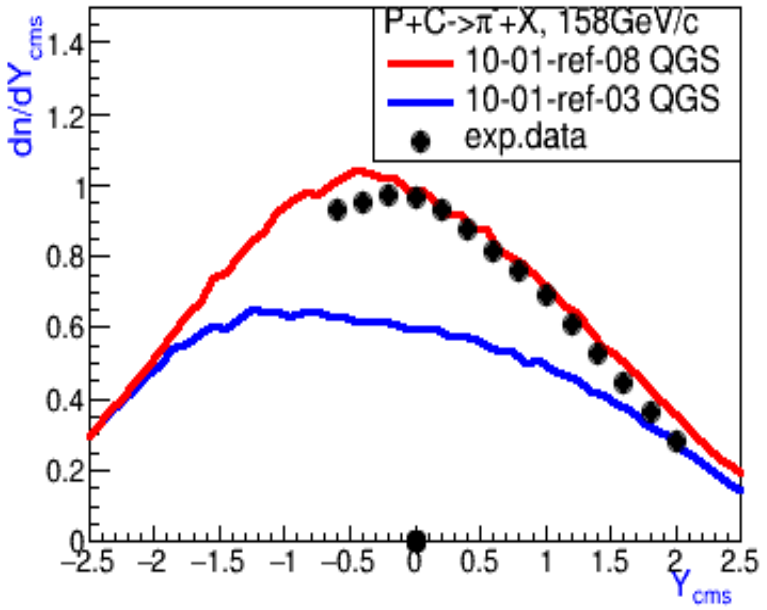
- In Autumn 2014, V. Uzhinsky made the first step in the revision of the Geant4 QGS model: the string fragmentation
  - The quark and diquark fragmentation functions (in G4 10.0) were significantly different with respect to Kaidalov's prescription
  - Kaidalov argued that the use of fragmentation functions extracted from e+ e- annihilation or in deep inelastic scattering is not justified in soft processes, and inconsistent with Reggeon theory
  - Vladimir changed the fragmentation functions of Geant4 QGS to bring them consistent with those recommended by Kaidalov
  - This development was included in G4 10.1
  - Although not driven by experimental data, the new QGS string fragmentation improved the description of some thin-target data
- Significant impact on hadronic showers
  - lower energy response, longer and wider showers
  - closer to the hadronic showers of FTF model

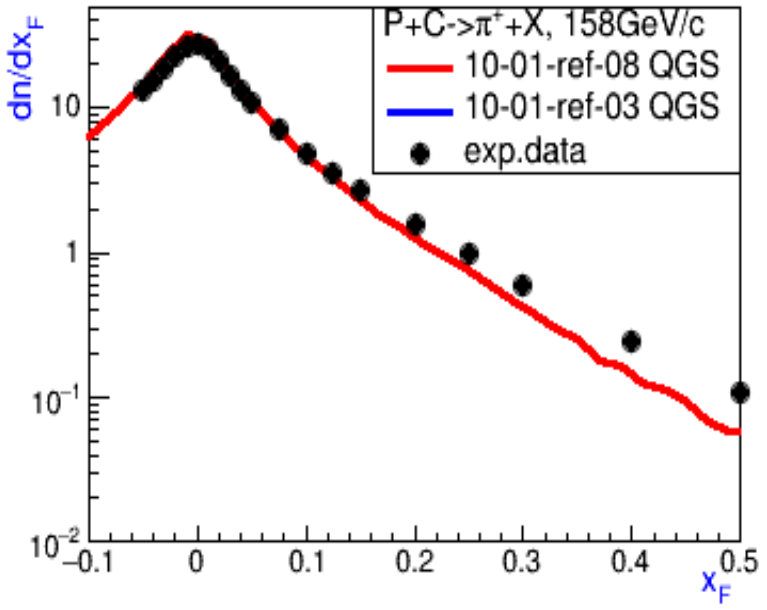
QGS String Formation

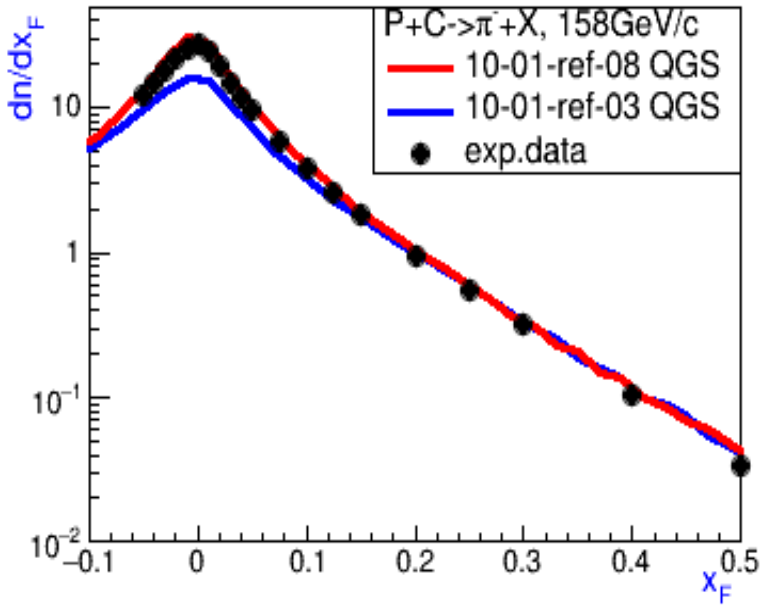
- In the first half of 2015, V. Uzhinsky has improved, re-written, and extended the whole of the QGS model related to the formation of quark strings
  - Inclusion of the Reggeon Cascade, as in FTF
  - Rewriting of the sampling of parton momenta
  - Improvement of the Fermi motions of target nucleons
  - Inclusion of the multi-pomeron exchange
  - More accurate preparation of the excited nuclear remnant
  - These developments have been included in G4 10.2.beta
- A very important thing which is still **missing** – planned for 2016 – is the **tuning of the parameters**
  - Currently the parameters are left as they were, often quite different from the values used in other modern QGS implementations
    - *e.g.* pomeron intercept: 0.98 *vs* 1.08

p C interactions at 158 GeV/c (NA49)

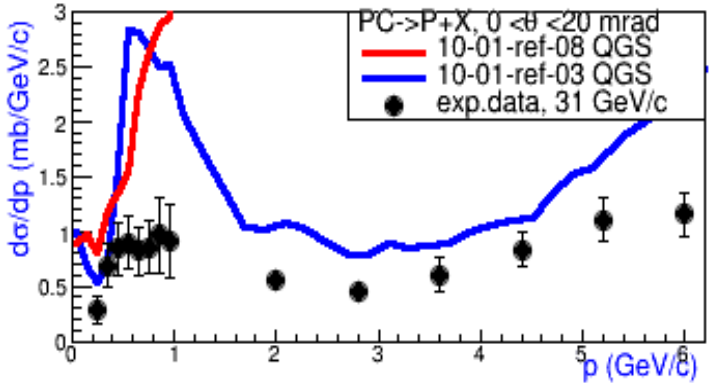


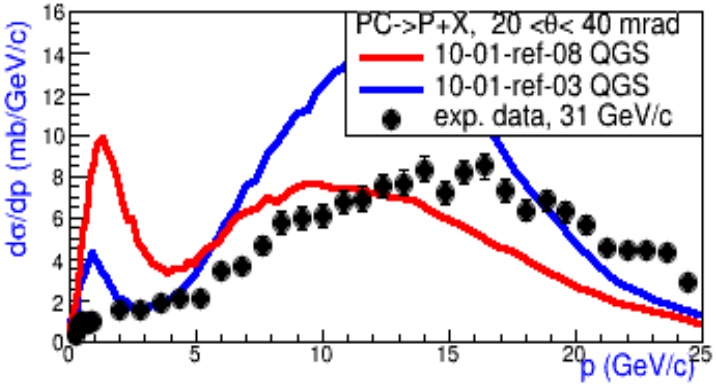


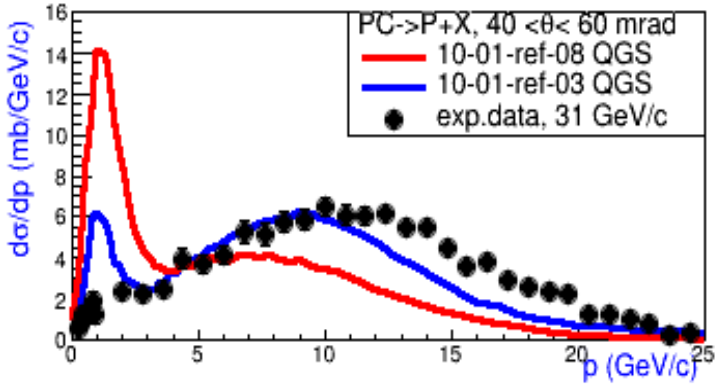


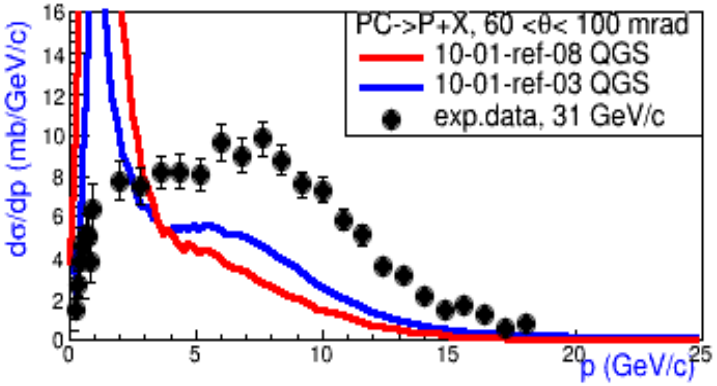


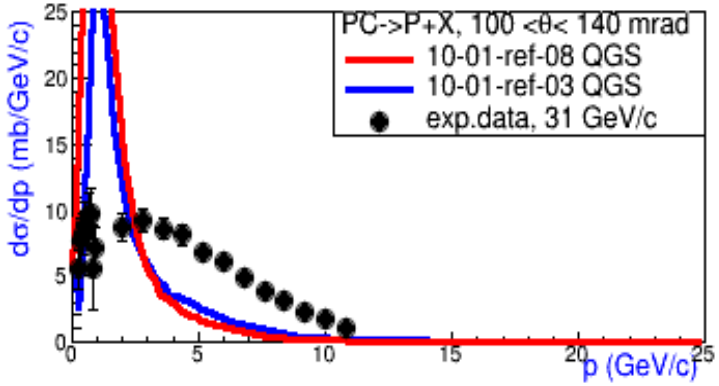
p C interactions at 31 GeV/c (NA61)

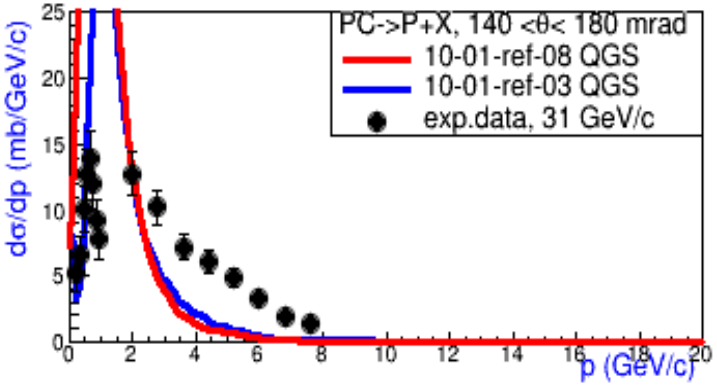








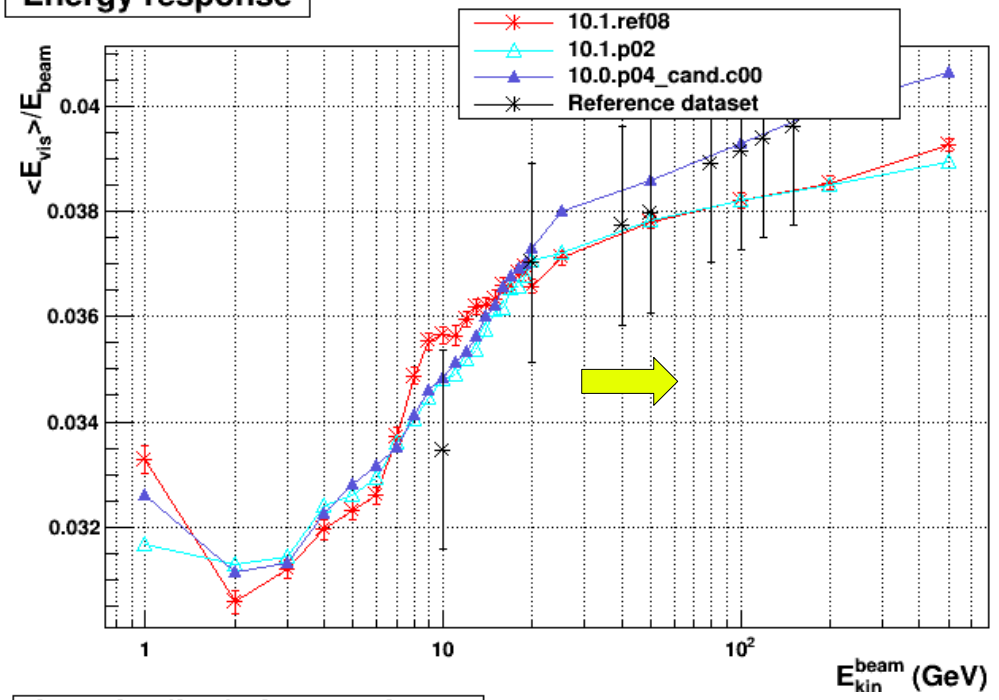




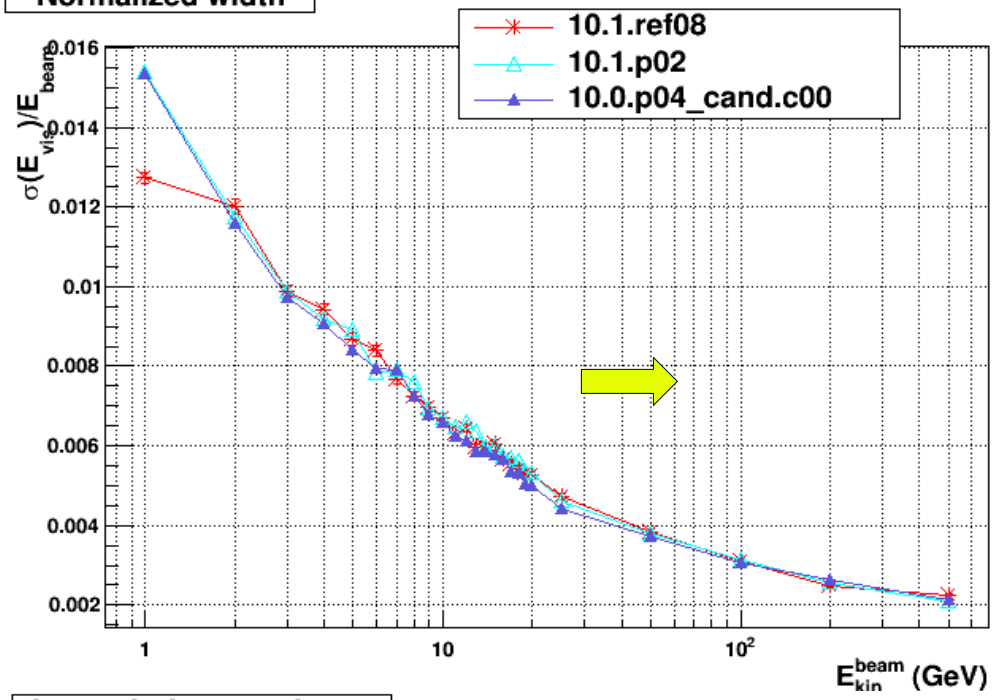
QGSP_FTFP_BERT

π^- on Cu-LAr

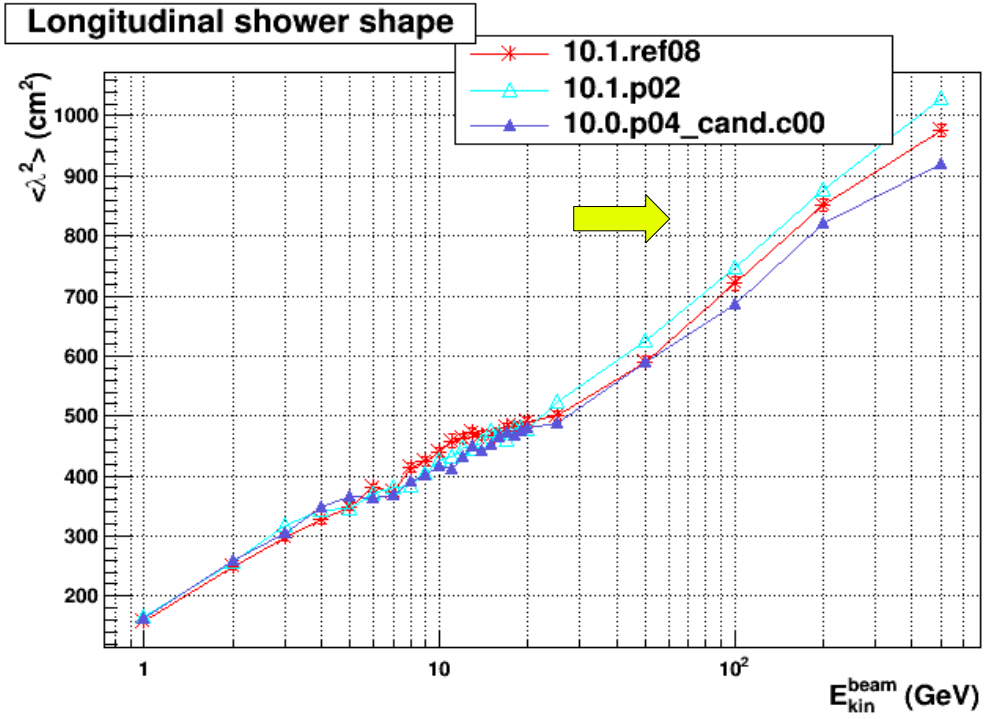
Energy response



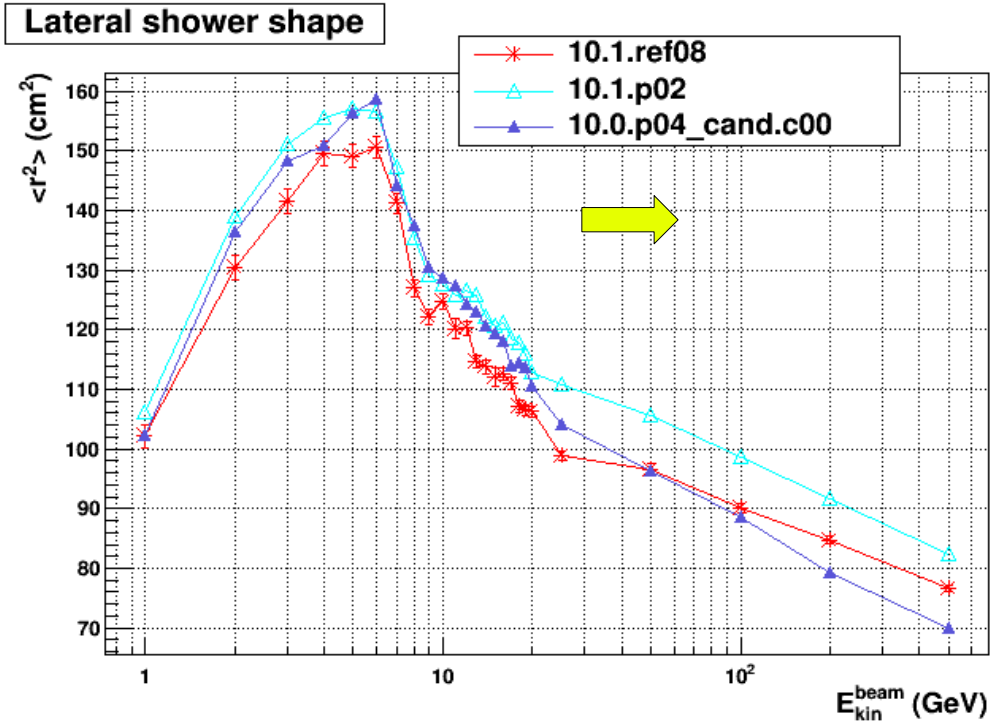
Normalized width



Longitudinal shower shape



Lateral shower shape



Summary and Outlook of **QGS**

- **Significant improvements in the model implementation**
- The main **two missing pieces** are:

  1. Tuning of the parameters with thin-target data

  2. Extension to lower energies by including the non-vacuum reggeon contribution (main problem)

- Test22 thin-target data validation favor the new QGS in most cases; but there are cases, *e.g.* NA61 data, where QGS in G4 10.1 is better...
  - Either we release in G4 10.2 the current version of QGS, with eventually a warning in the release notes
    - Easier from the code management point of view
    - Could be a push to CMS to migrate from QGSP_FTFP_BERT to FTFP_BERT
  - Or we release in G4 10.2 the version of QGS as it was in G4 10.1
    - More conservative choice: no risk of users finding worse results
    - After the release, we bring back the new version (*i.e.* in G4 10.2.ref01)

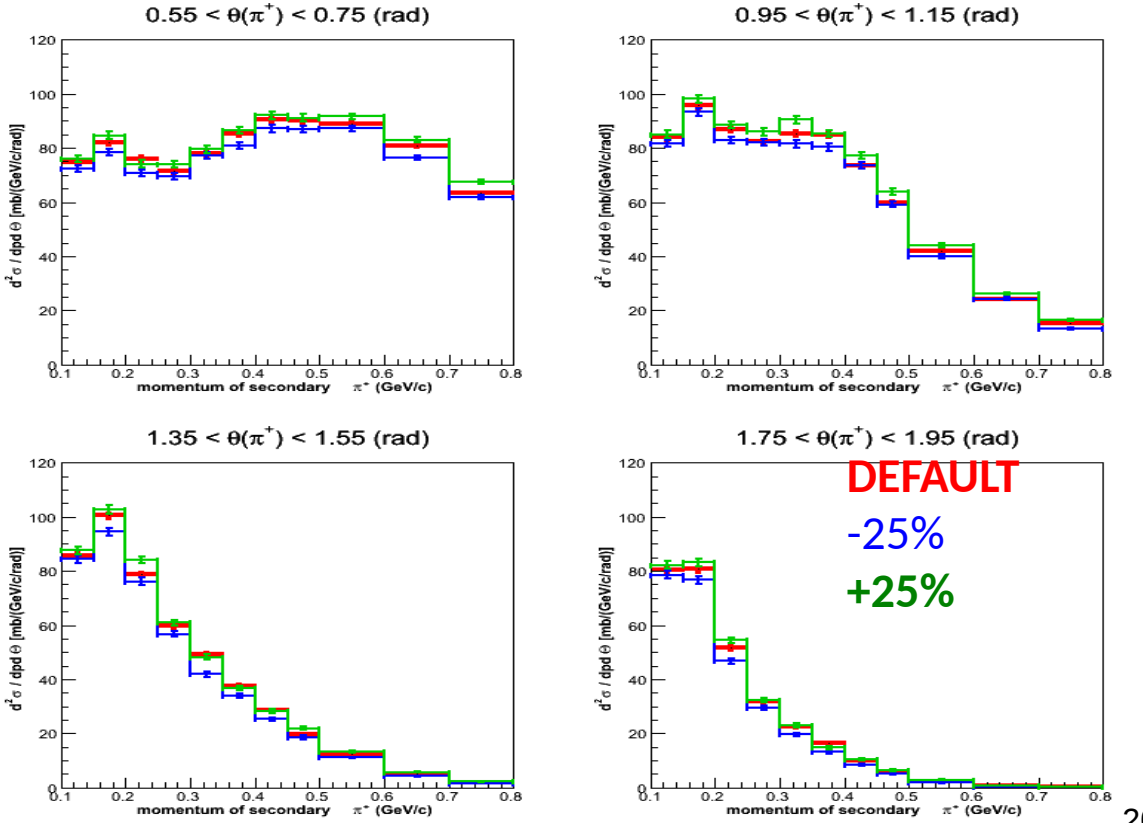
Status of Intranuclear Cascade Models

- BERT
  - Extended K+n and K+p up to 32 GeV and 9-body "final" states
  - Introduced (optional) improved nucleon evaporation from giant dipole resonance excitation (Bugzilla #1680)
  - Exploring systematic variation of BERT parameters (see next slide)
- INCLXX
  - No developments
- BIC
  - No developments
- *See talks in Parallel Session **3A** by M. Kelsey and J. Yarba*

Varying Parameters of Geant4 Hadronic Models (Bertini as the 1st use-case)

Derive systematic uncertainty band for Geant4 predictions
Help to optimize model parameters

Proof of principle:
Varying Bertini Fermi Scale by ±25%
Impact on momentum spectra of secondary π+
coming from p+Be at 5 GeV/c



Ideas/Plans

- Develop software tools to vary intentionally exposed parameters in a controlled way, without recompiling the code
- Develop software tools to comprehensively analyze the impact of varying model parameters on the simulated results
- Fermilab and SLAC teams

Status of Precompound/de-excitation

- Revised the computation of evaporation cross sections, unifying between Precompound and de-excitation
- New structure of gamma levels, used by all de-excitation models
- New gamma de-excitation model
- *See talk in Parallel Session **3A** by V. Ivanchenko*

Elastic Scattering

- Not yet completed the validation of the new elastic scattering G4HadronHElasticPhysics, for the time being used only in FTFP_BERT_TRV
- Early this year, we have activated in FTFP_BERT_TRV , through G4HadronHElasticPhysics , the recent model of V. Grichine on low-mass single diffraction, G4LMsdGenerator
  - It uses a fraction of the elastic cross section
  - It is still in development
  - There are still problems in the hadronic showers, therefore we have temporarily disabled it for the release G4 10.2
  - *See talk in Parallel Session **7A** by V. Grichine*
- TARC benchmark
  - Resumed by A. Howard, in progress. *See talk in **6A***

Hadronic Cross Sections

- Update on LHCb kaon cross section asymmetry
  - LHCb reported a bad K+/K- inelastic cross setion asymmetry obtained with G4ChipsKaonMinus(Plus)InelasticXS
  - Vladimir Grichine has recently done some development in **G4ComponentGGHadronNucleusXsc** and, with this class, LHCb gets good results for the K+/K- asymmetry
  - More validation is in progress: let's keep the JIRA task open...

- Recent fixes in NeutronXS cross sections
  - Brings FTFP_BERT showers closer to FTFP_BERT_HP ones for heavy absorbers (Pb, W)