Development and Validation of Geant4 hadronic models

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VALSIM project in the Collaboration with the Geant4

Hadronic models in G4: QGSM, E > 10 GeV:
Fritiof (FTF) model, E > 3-5 GeV:
the binary cascade model, E < 9 GeV:
the Bertini cascade model, E < 9 GeV.

Content

Motivation

CMS - TB2004/ 2006

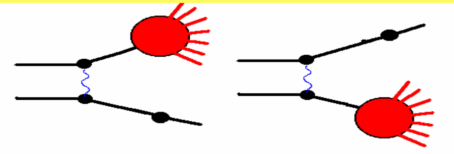
QGS is today the main model for hadronic interactions, used in QGSP & QGSP_BERT physics lists. It has good validation above ~15 GeV (?). A key need is a model spans down to energy ceiling of Geant4 'cascades' (3-10 GeV)

We hoped that an improvement of the Fritiof model would help to solve problems.

There are in the model:

Diffraction dissociation;
Quasi-elastic scattering could be inserted;
It works at Plab > 3-5 GeV/c.
(See V.Uzhinsky et al. Yad. Fiz.)

Diffraction dissociation =



Quasi-elastic scattering – elastic scattering of a projectile on intra-nuclear nucleons. It was included previously in the inelastic cross section. This lead to an increase of secondary particle multiplicity. Starting from 8.3 it is simulated separately.

All of these could improve the shower shape

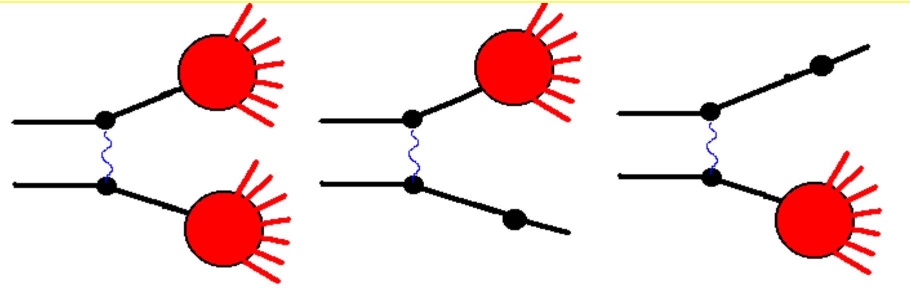
1 Ingredients of the Fritiof model

B. Andersson et al., Nucl. Phys. B281 (1987) 289;
B. Nilsson-Almquist and E. Stenlund, Comp. Phys. Commun. 43 (1987) 387.

Hadron-hadron interactions are modeled as binary kinematics

$$a + b \rightarrow a' + b', \quad m_a' > m_a \quad m_b' > m_b$$

where a' and b' are excited states of the initial hadrons a and b.



In hadron-nucleus interactions the excited hadrons can interact with other nucleons of nucleus and increases mass. The probability of multiple collisions is calculated in Glauber approach. The variant used in the Fritiof model is enlarged with elastic re-scatterings of hadrons. The excited states are considered as QCD-strings, and the LUND model is used for their fragmentation.

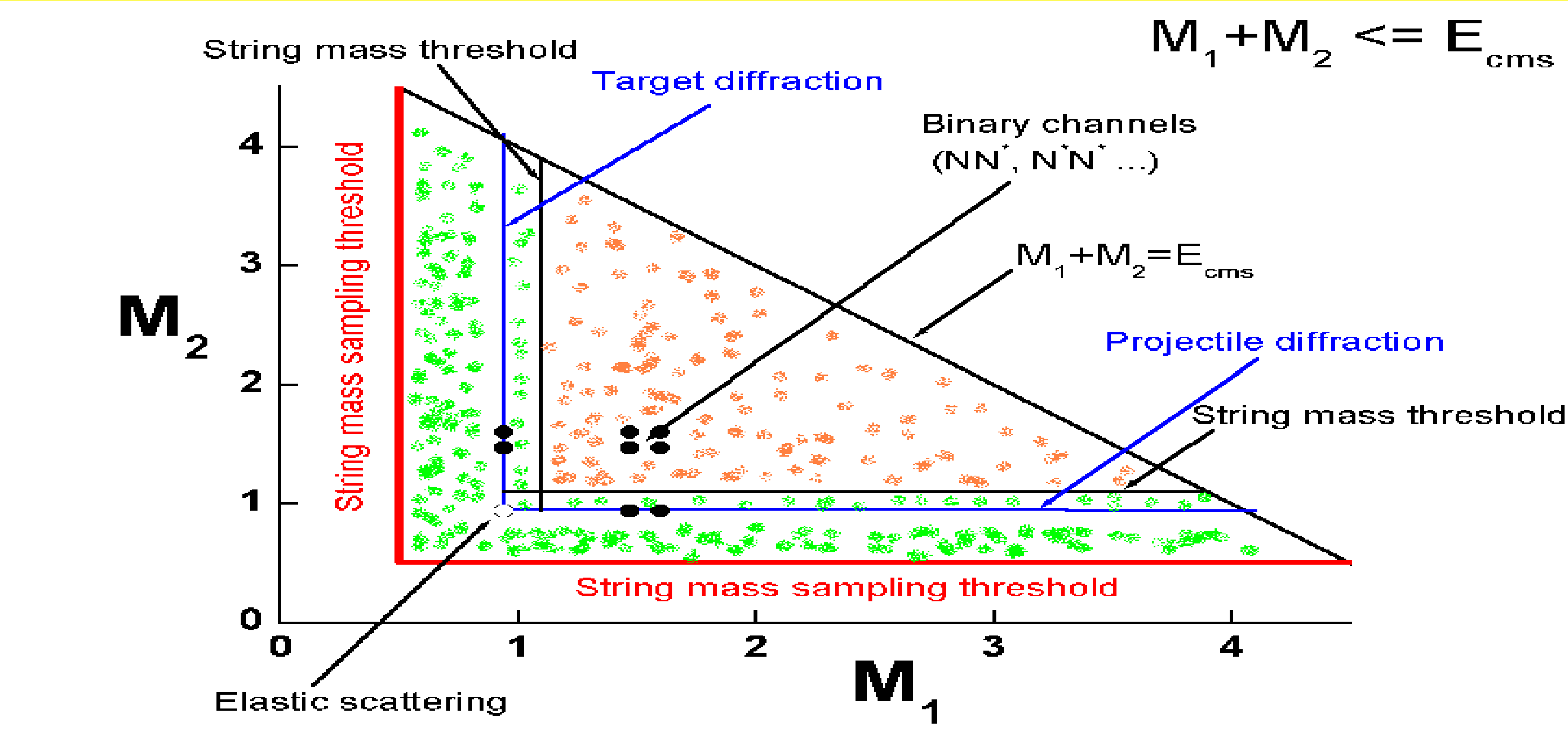
HIJING model

HIJING – RHIC and LHC, AA interactions

UrQMD model

UrQMD – FAIR, GSI (future experiments)

HSD model (new one, W. Cassing et al.)



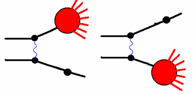
Key parameters

$$dW \propto \frac{dM_1}{M_1}, \qquad dW \propto \frac{dM_2}{M_2}$$

$$M_{string} = 1.1\ GeV\ (N), \quad 1\ GeV\ (\pi), \quad 1.1\ GeV\ (K)$$

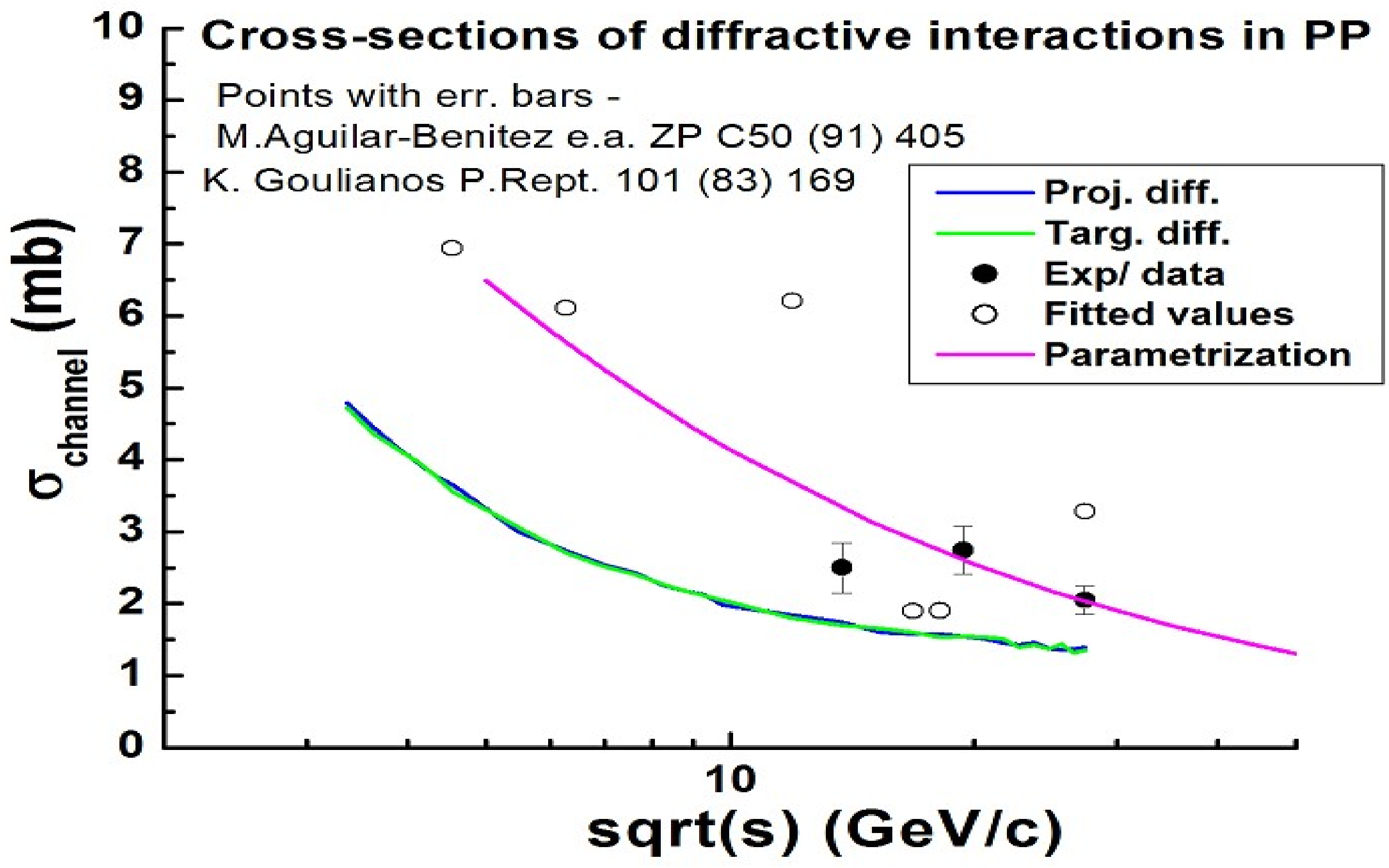
$$M_{sampling} = 0.94\ GeV\ (N), \ 0.75\ GeV\ (\pi), \ 0.85\ GeV\ (K)$$

Diffraction dissociation



1 Ingredients of the Fritiof model

The model was implemented in Geant4 but it was not tuned and validated.

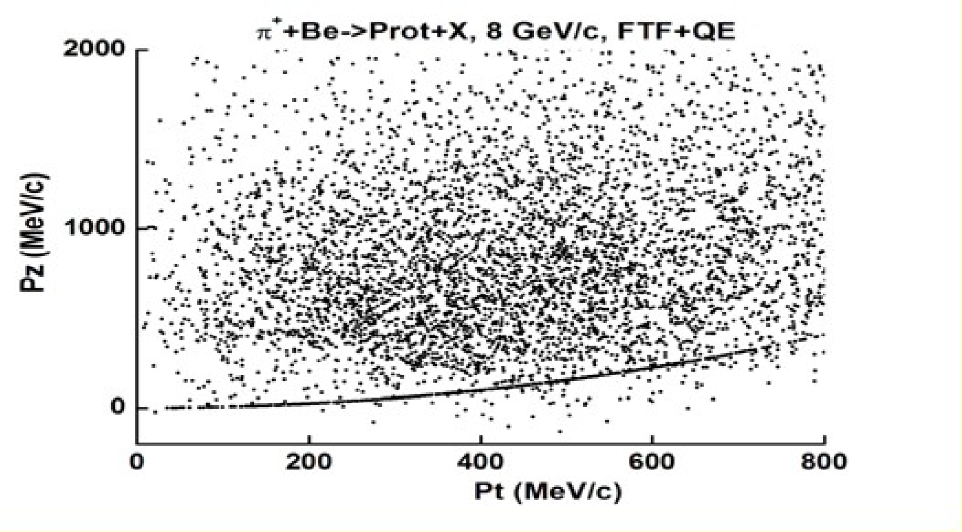


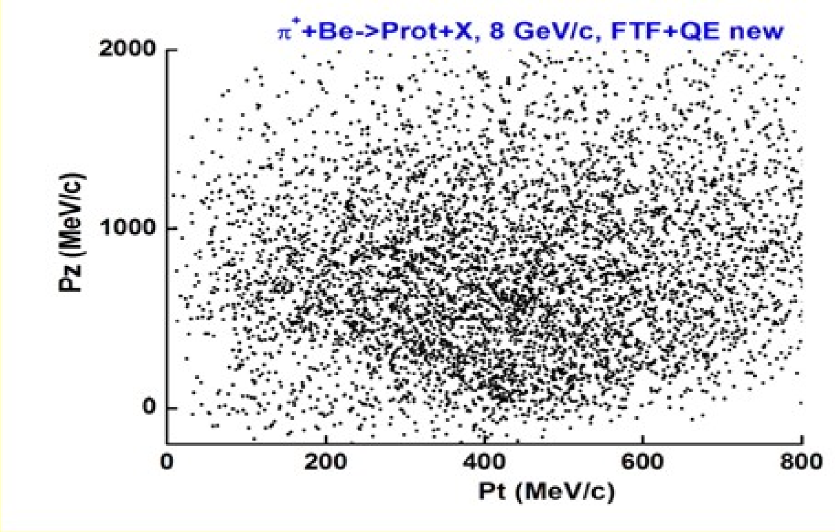
We simulate separately diffractive and non-diffractive interactions.

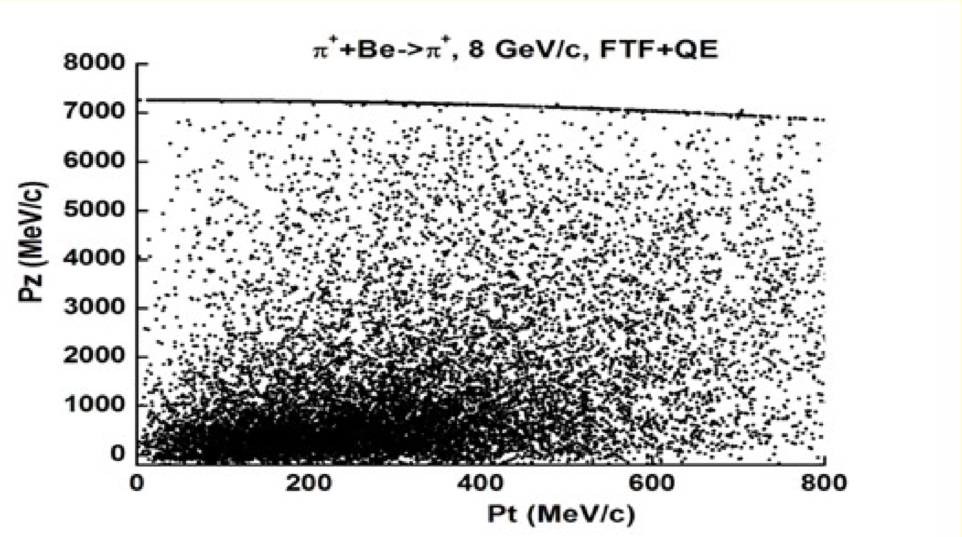
Inclusion of the process allows to make the shower longer

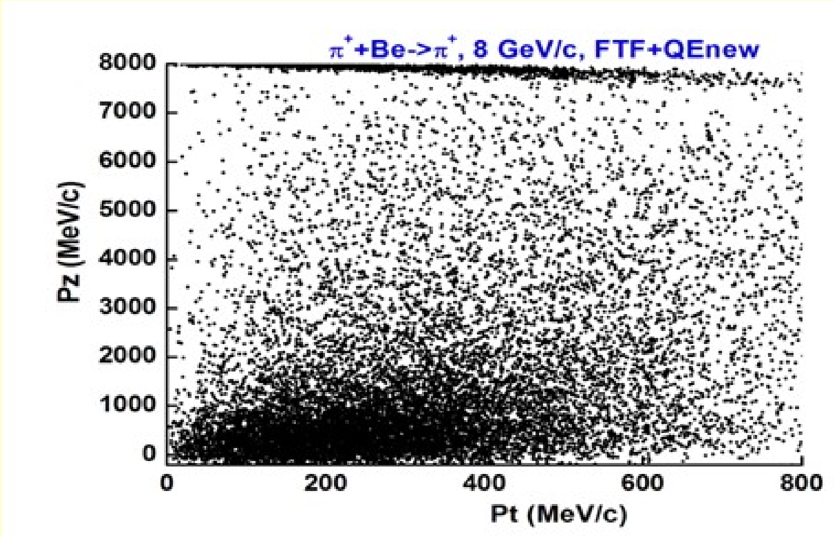
Without Fermi-motion

With Fermi-motion (9.2putch)





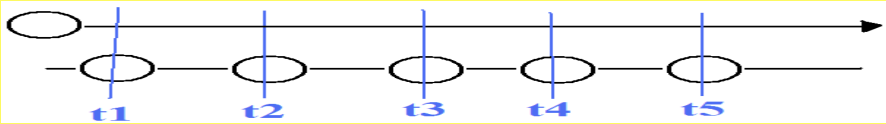


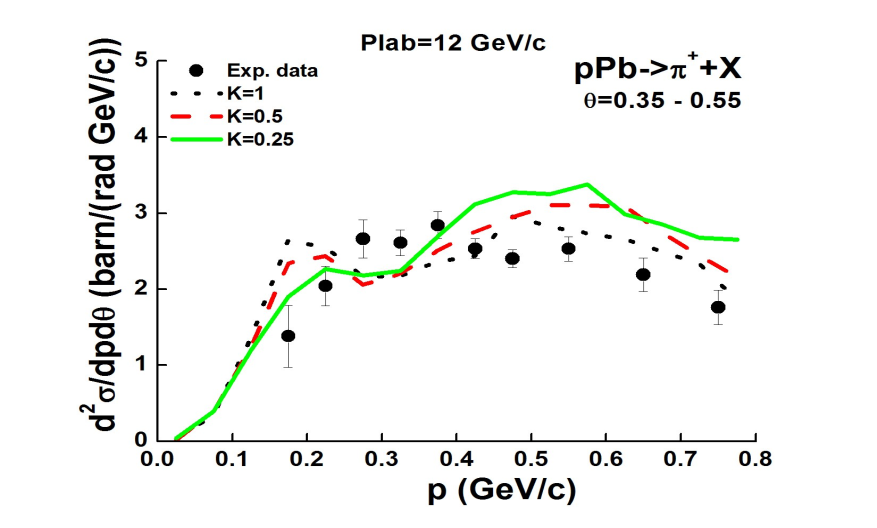


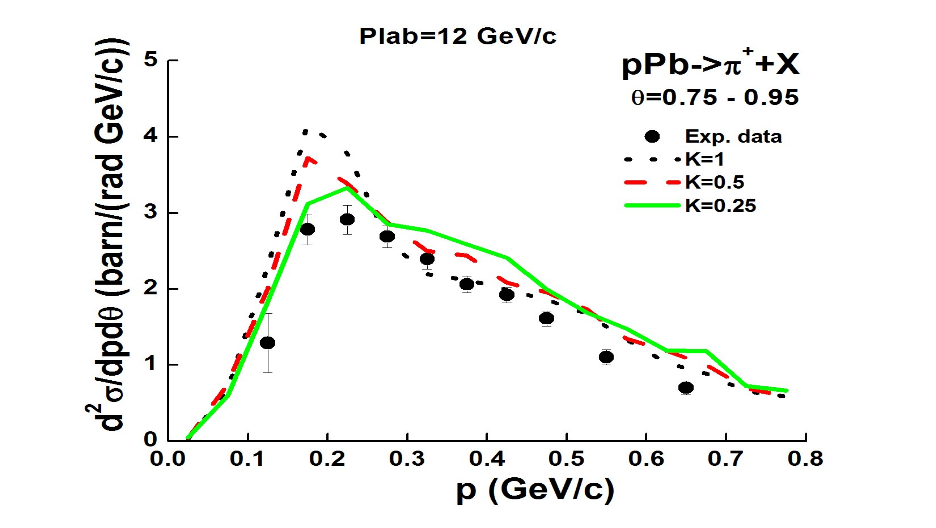
Inclusion of quasi-elastic scattering allows to make the shower longer

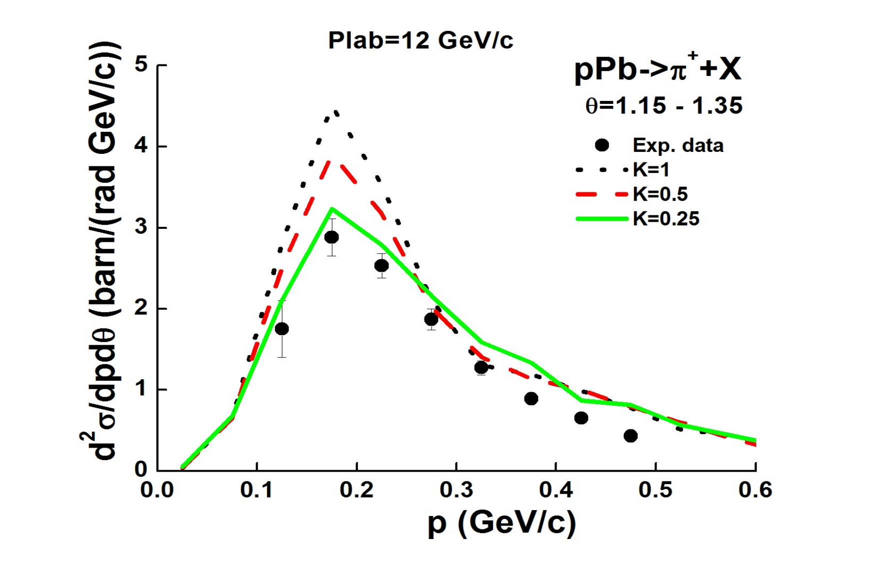
Implementation of formation time in FTF, HARP experimental data for pPb, large angles, Pi+.

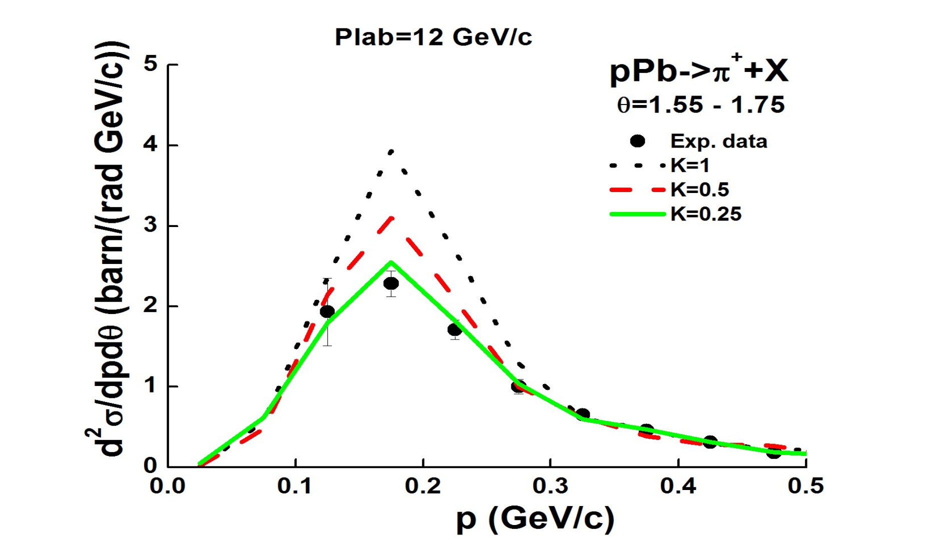
1 Ingredients of the Fritiof model





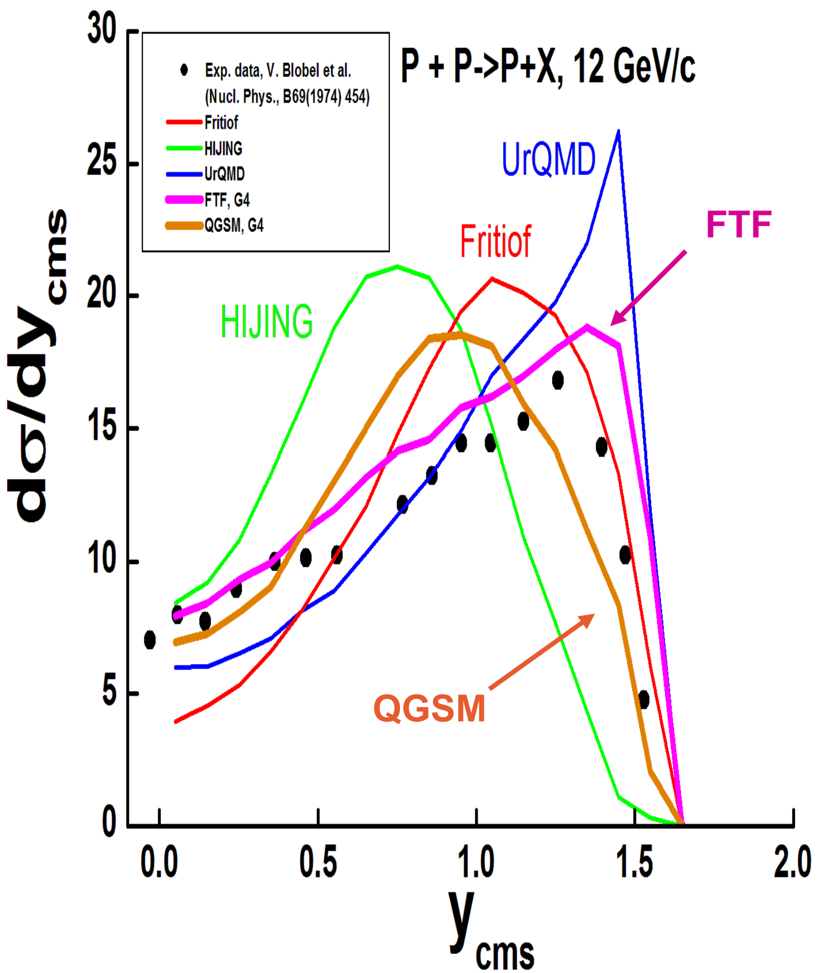


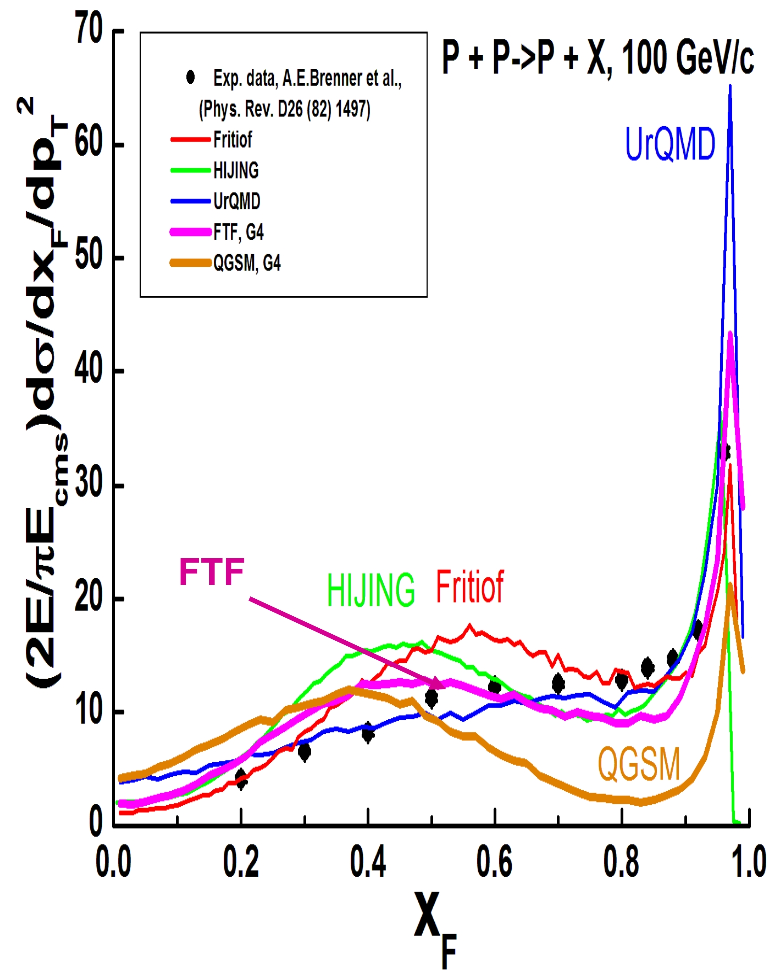




Formation time at string fragmentation was implemented before.

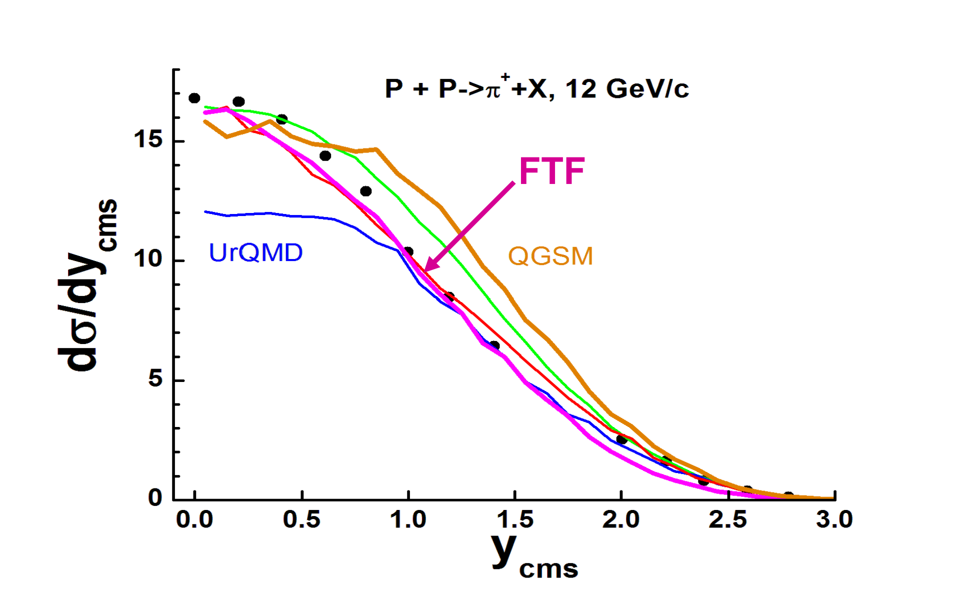
2 Testing and validation of the model

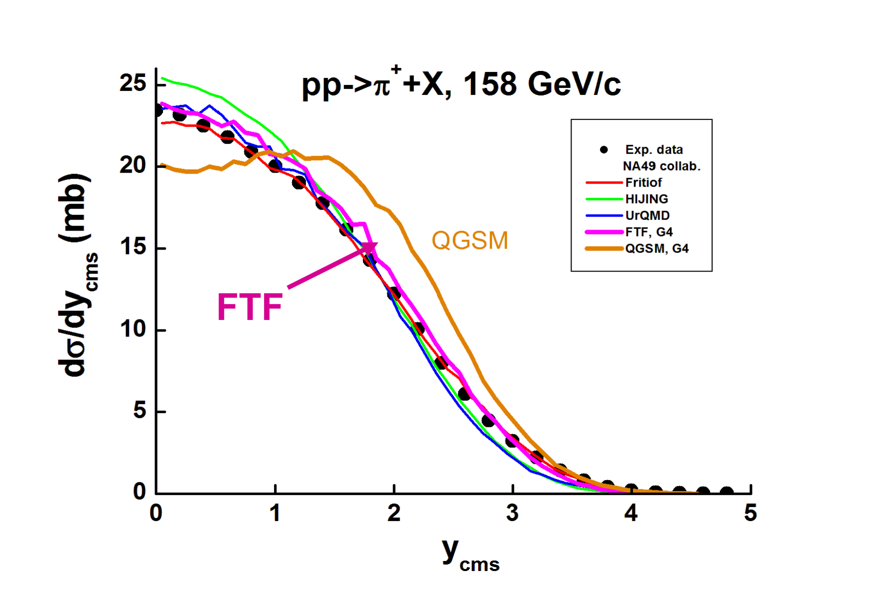


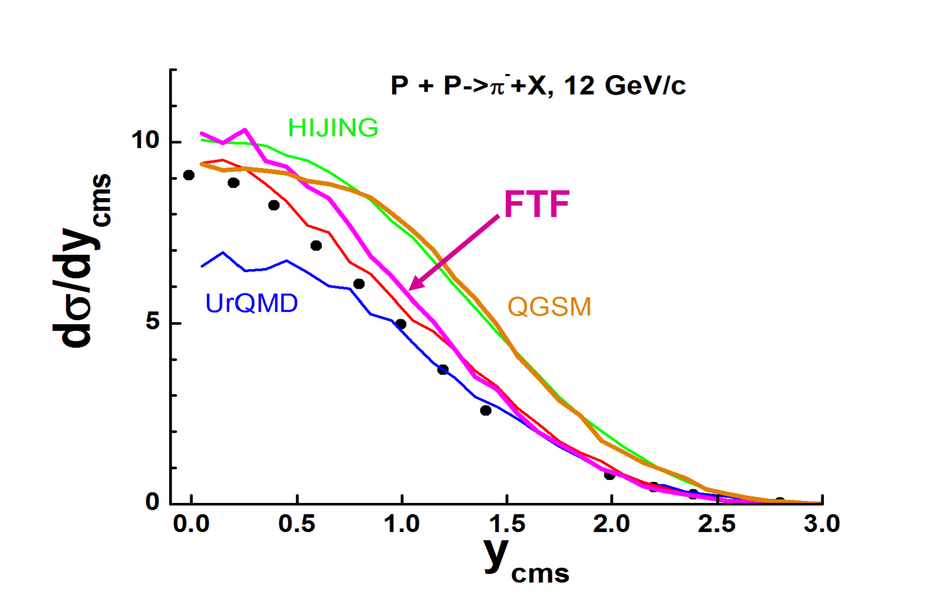


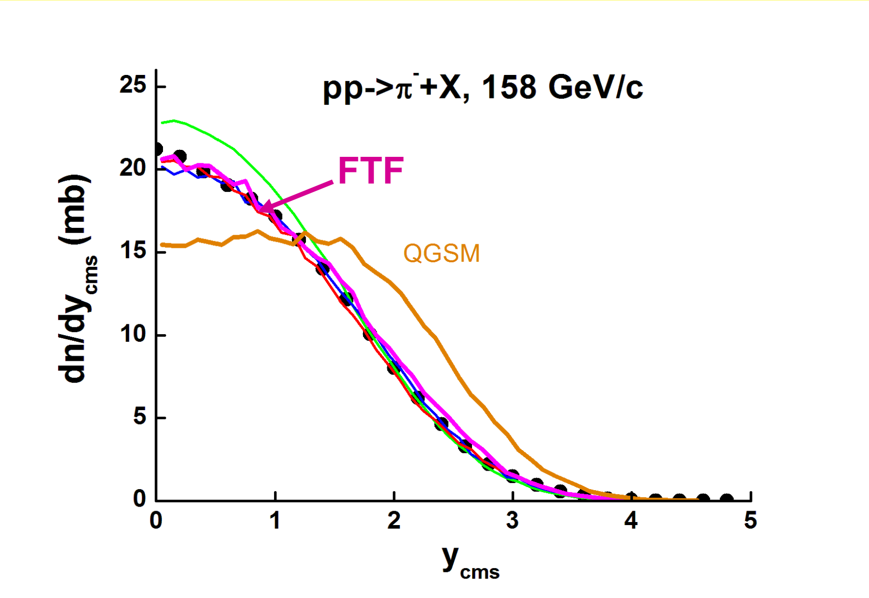
Description of baryon spectra is a problem in all MC models. We have a good solution in FTF.

2 Testing and validation of the model



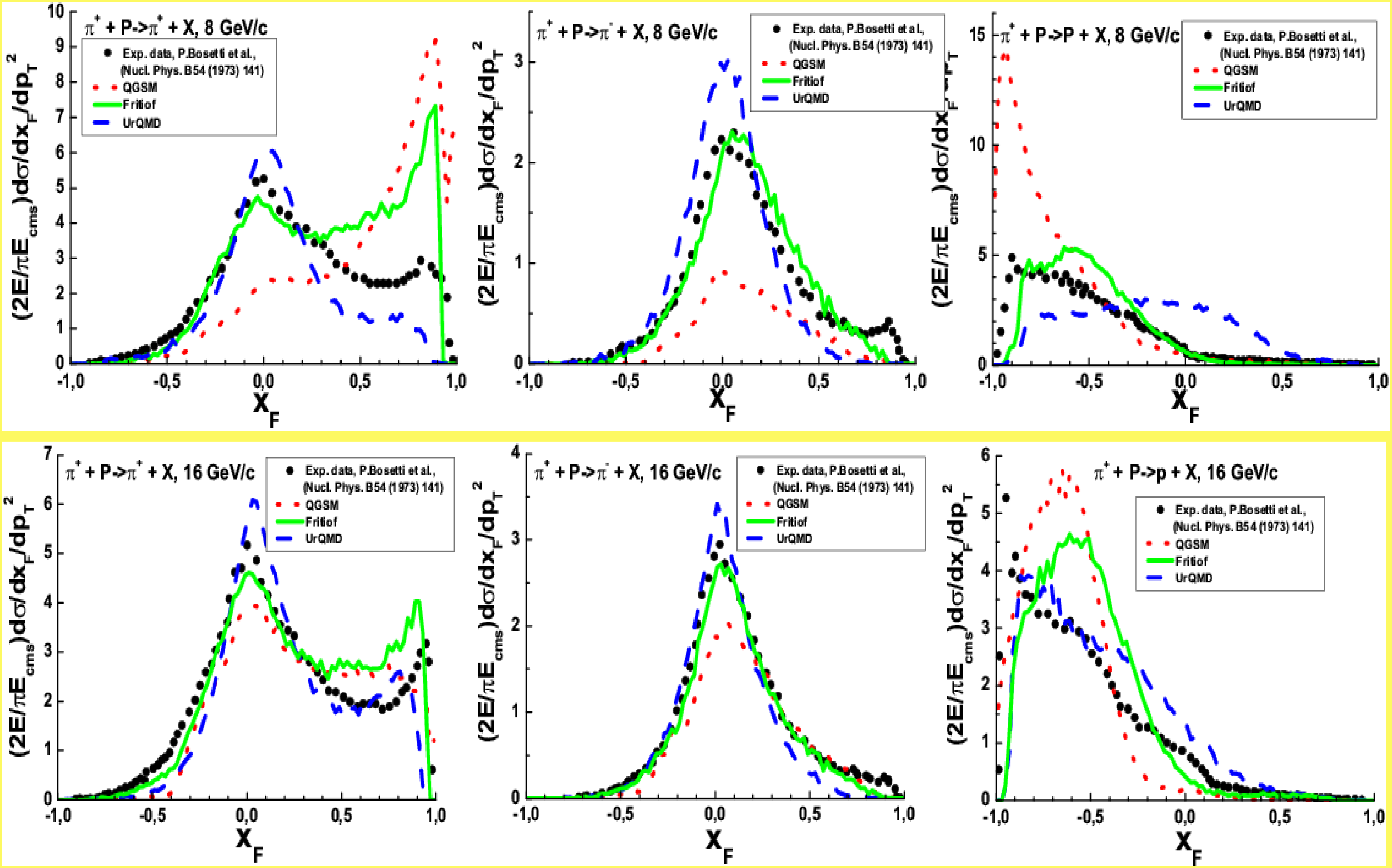




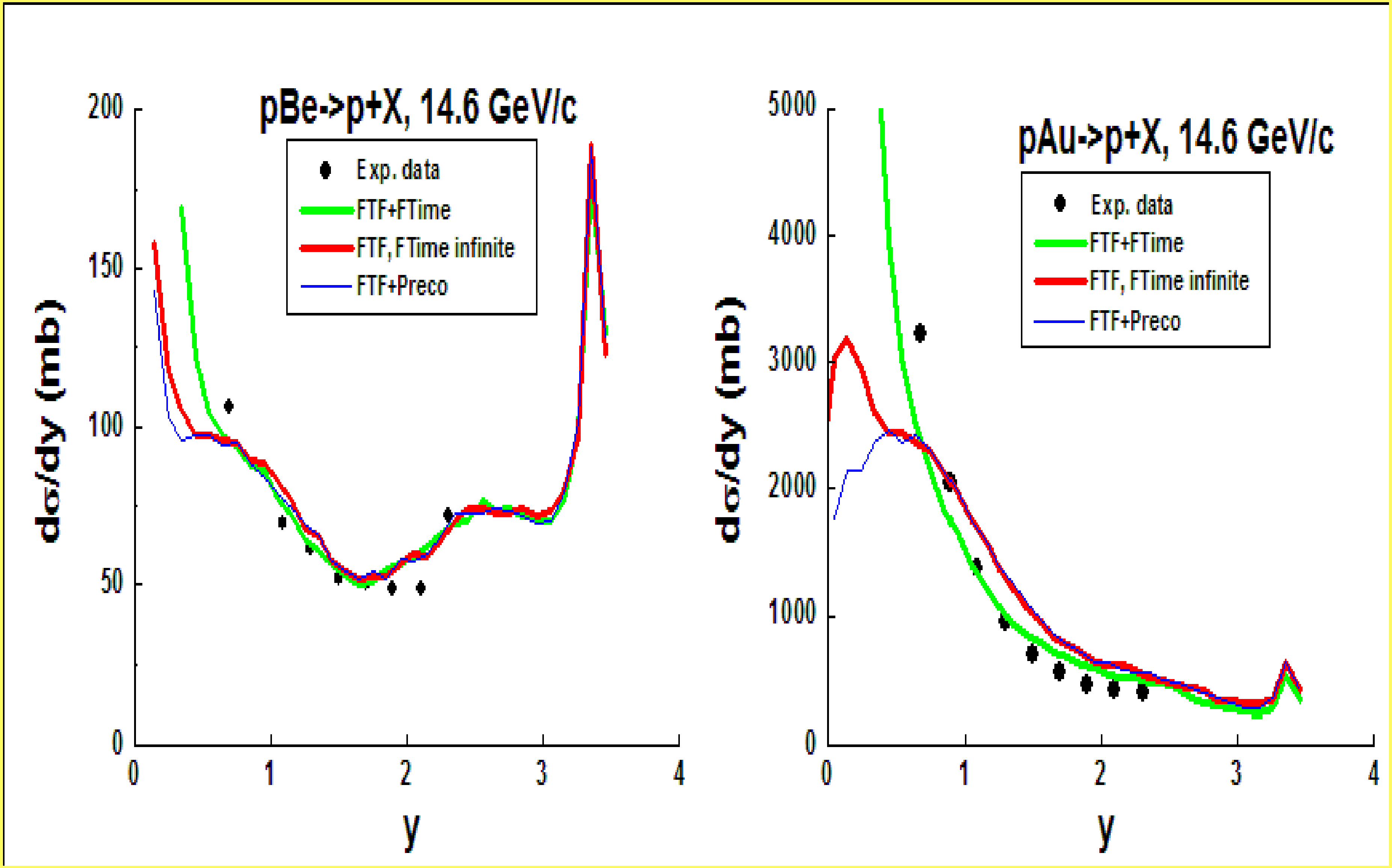


There are some problems with a description of meson spectra

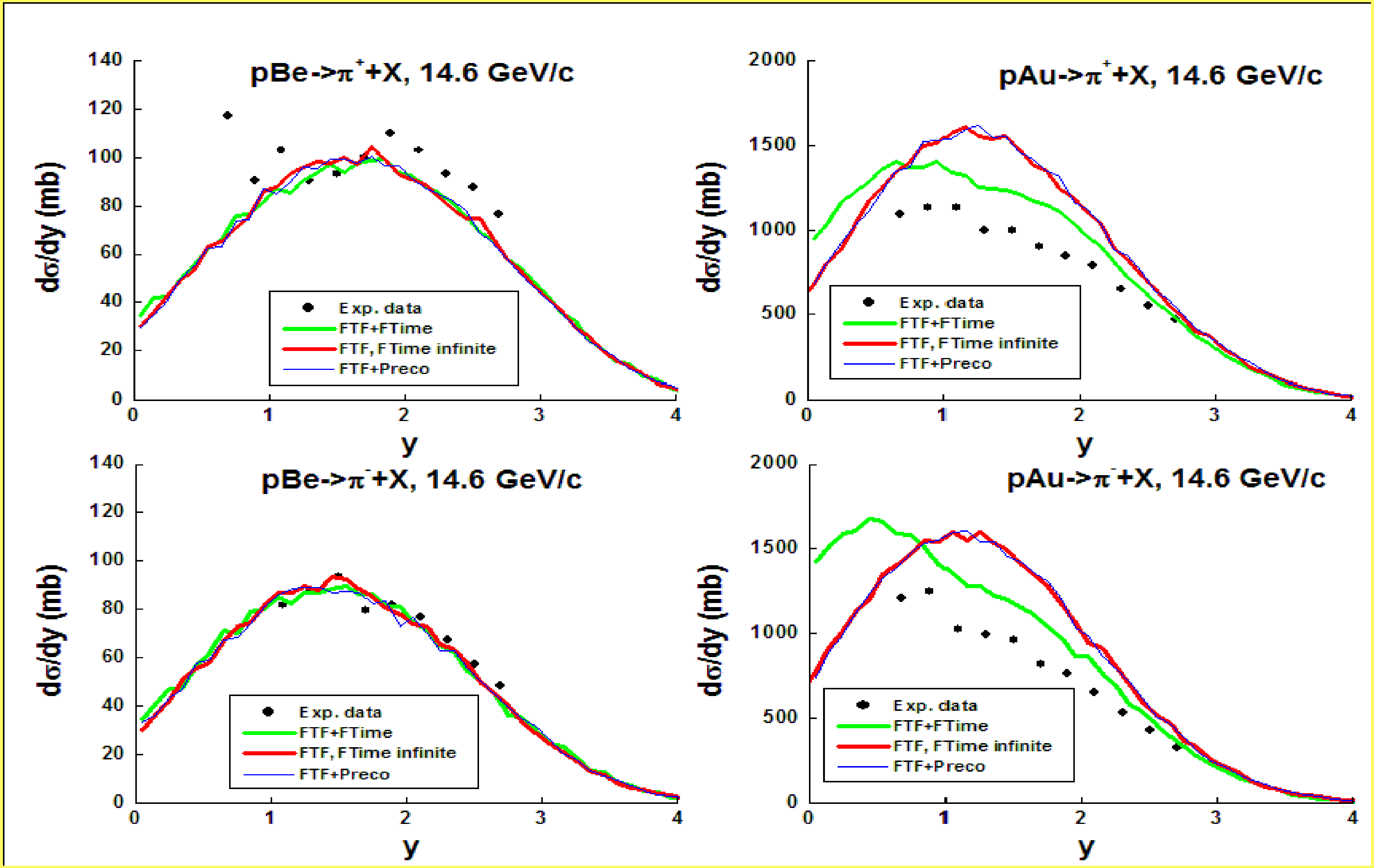
2 Testing and validation of the model



No model gives satisfactory results!
UrQMD crashed for Pi+A interactions!



FTF + binary cascade works well!

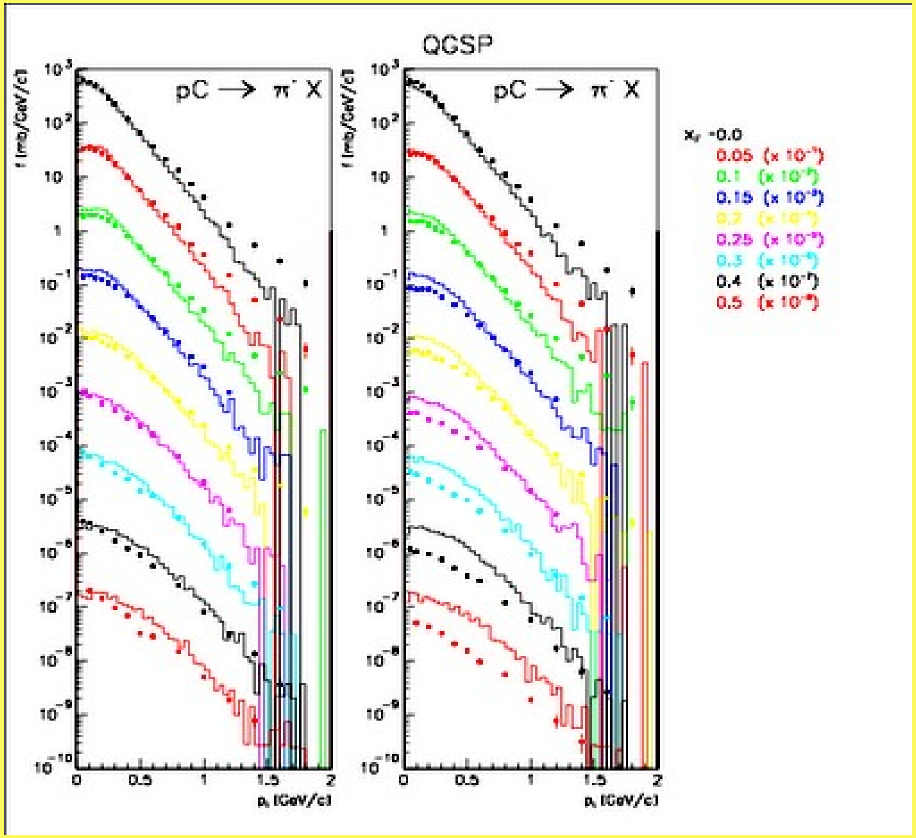


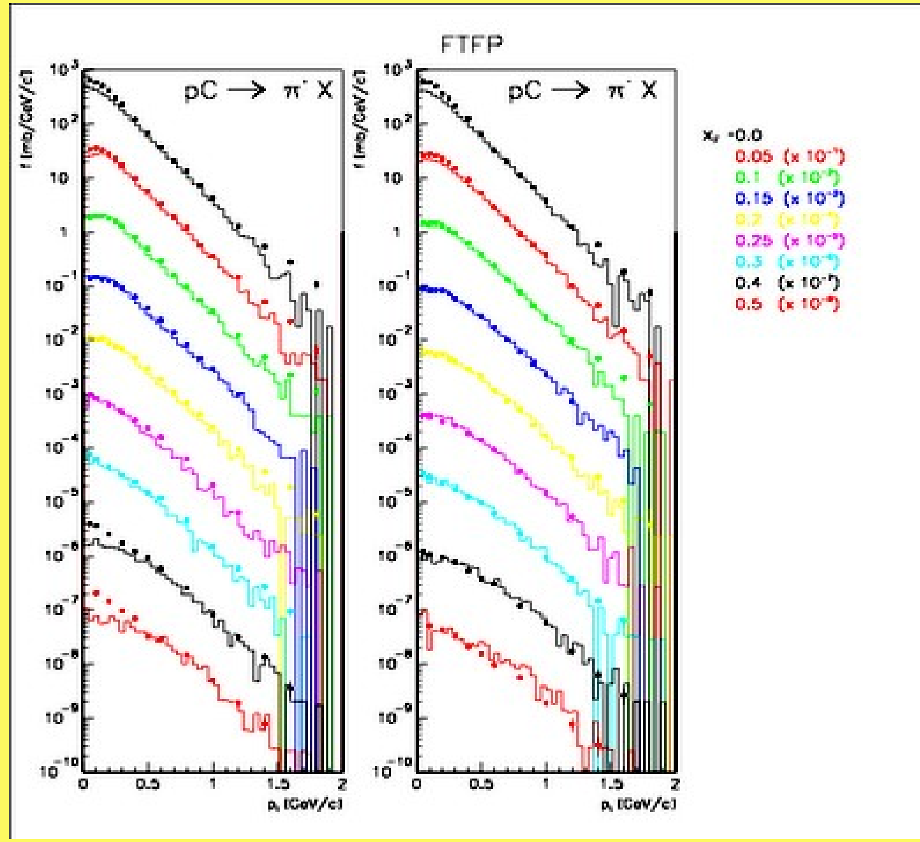
FTF + binary cascade works well!

Results for pA-interactions

2 Testing and validation of the model

Comparison of QGSP and FTFP models in release geant4.9.2-beta. Points – NA49 data.



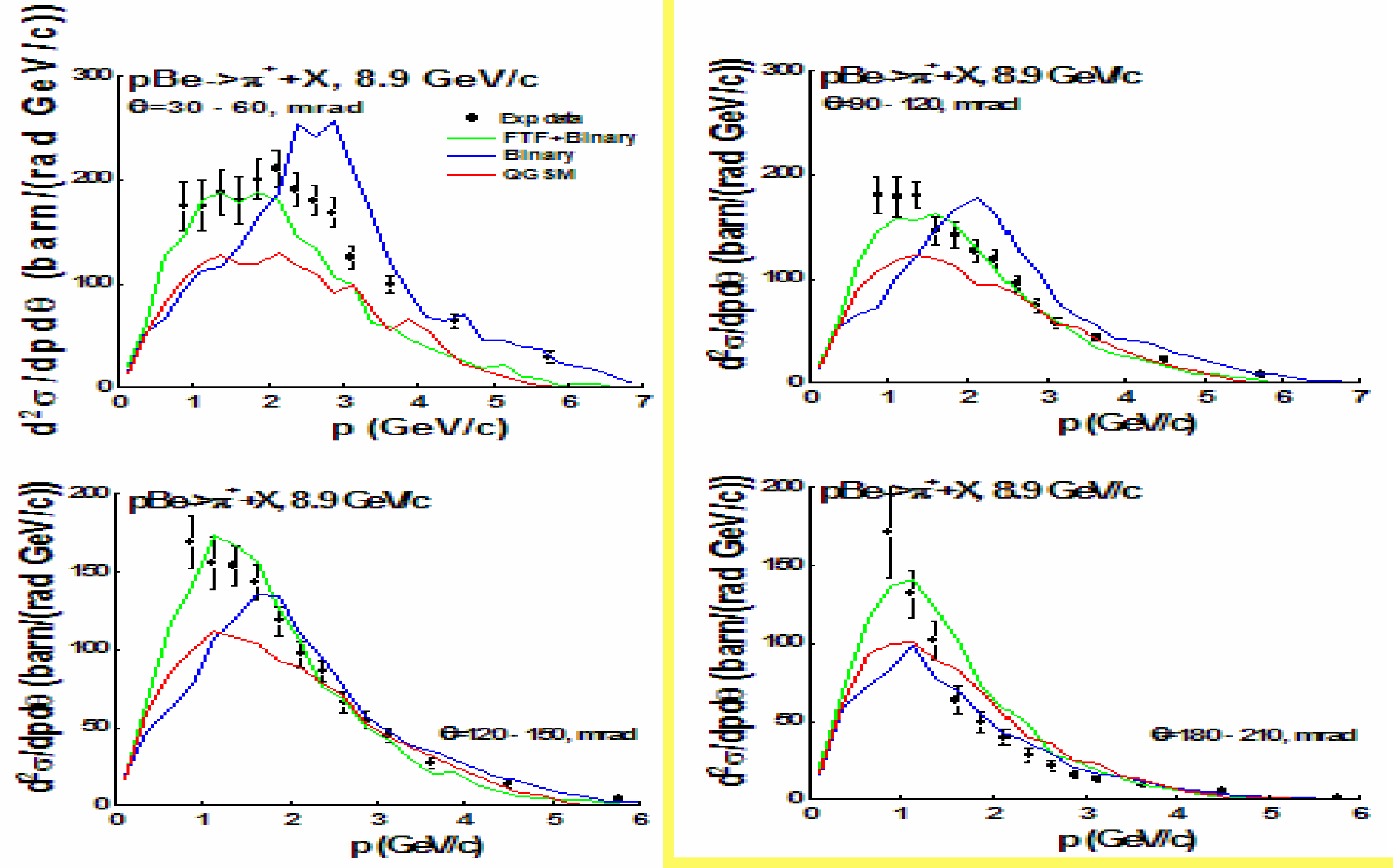


The revised versions of FTFP first released in Geant4.9.2-beta describes the data rather well (right figure). Small differences can be seen for the *xF=0* at small *pT*, and for positive pions for large *xF* again at small *pT*. The QGSP model is unchanged to previous releases (left figure).

More plots see at http://gunter.web.cern.ch/gunter/thin_tgt/

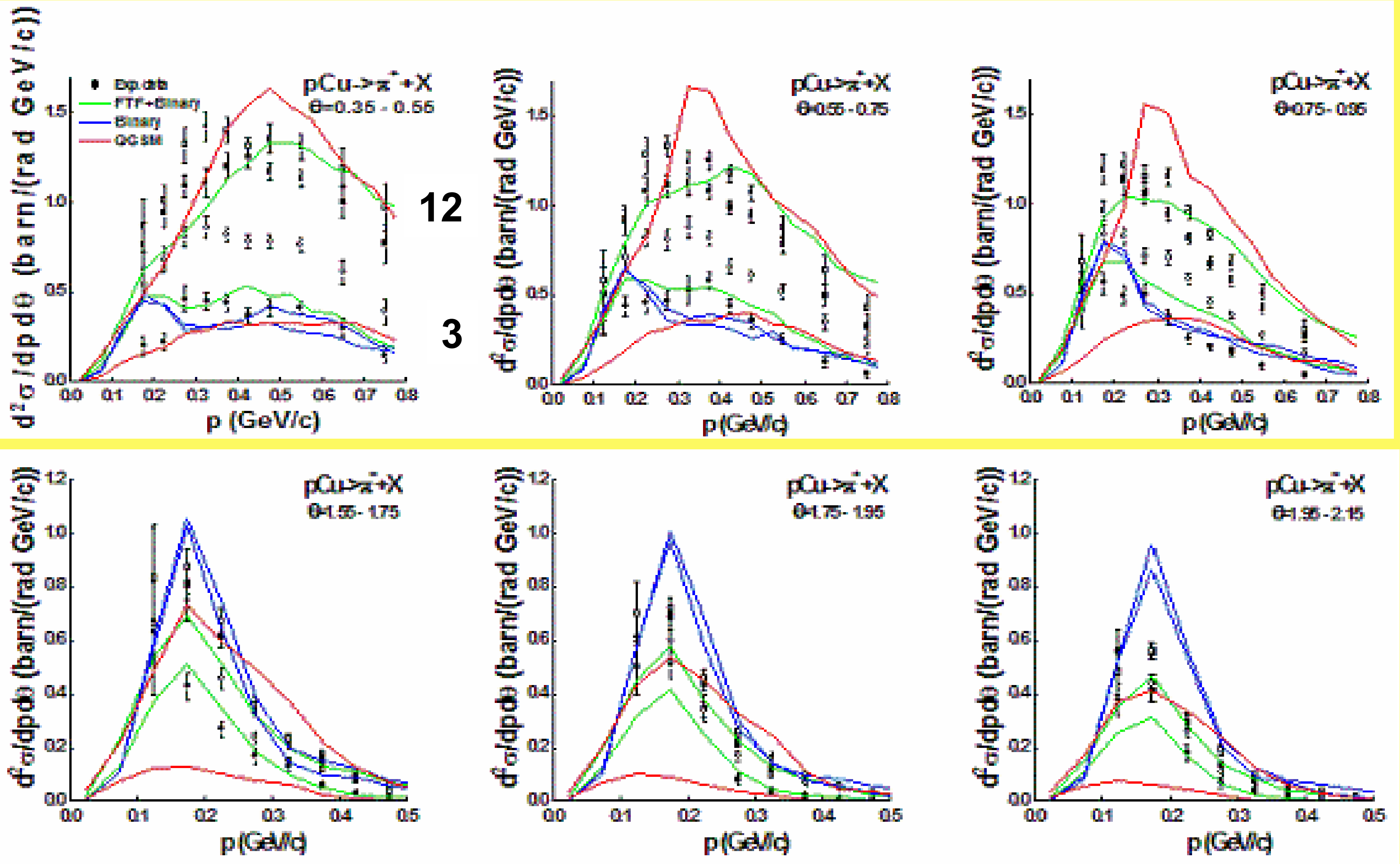
FTF + binary cascade works well!

HARP experimental data for pBe, small angles, Pi+.



HARP experimental data, pCu, Pi+, large angles

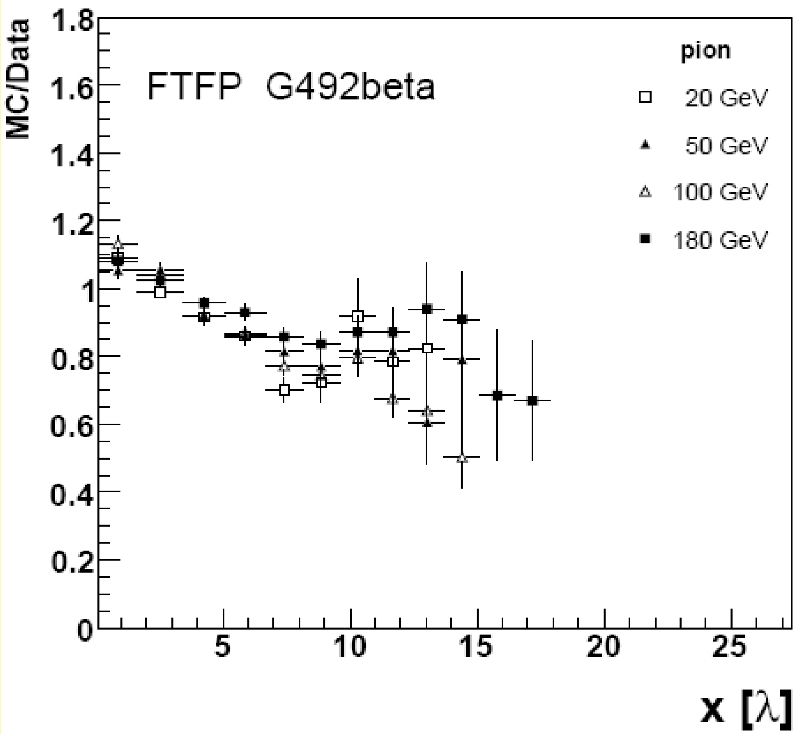
2 Testing and validation of the model

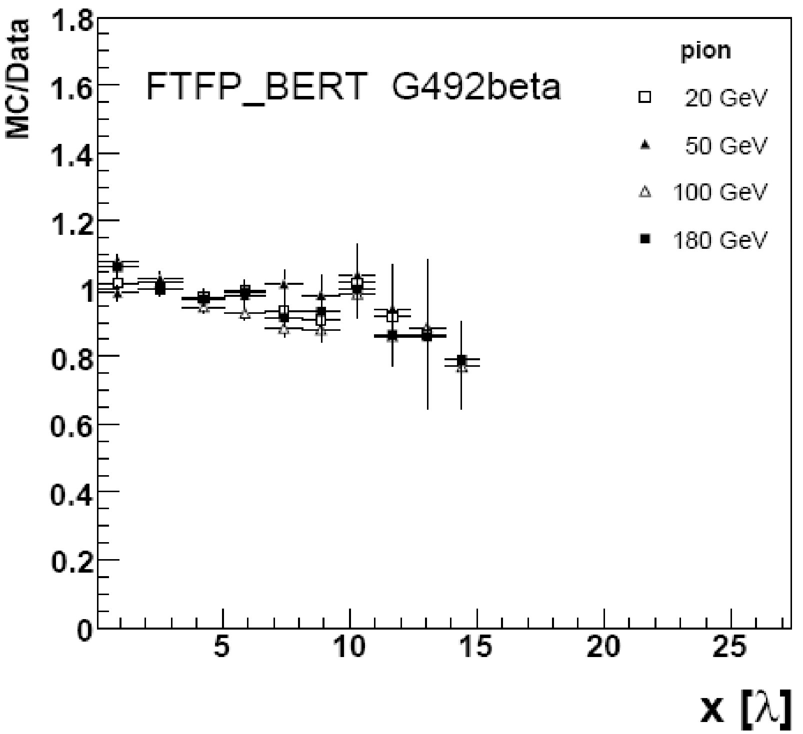


More plots see at http://cern.ch/vnivanch/verification/hadronic/ and At Geant4 “Testing and Validation” WEB-page

Comparison of results of Geant4.9.2-beta to ATLAS TileCal test beam data, Margar Simonyan (*LAPP)* Calor 2008

Longitudinal Profile, dE/dx(Monte Carlo)/dEdx(Exp.data)= MC/Data

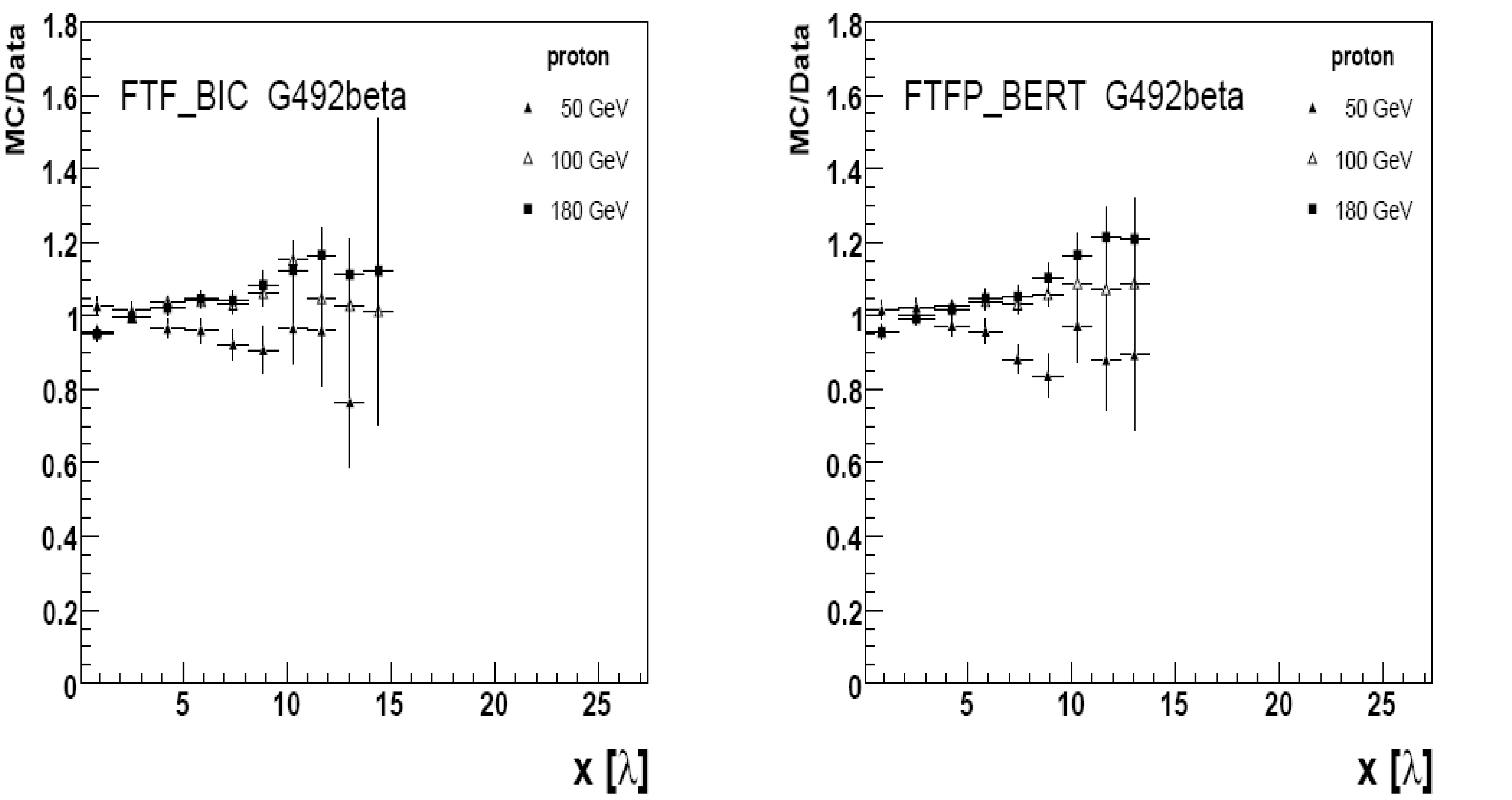




- With Fritiof model showers are a bit shorter, up to 10λ within $\pm$20%.
- With Bertini cascade MC describes data up to 10λ within $\pm$10%.

Comparison of results of Geant4.9.2-beta to ATLAS TileCal test beam data, Margar Simonyan (*LAPP)* Calor 2008

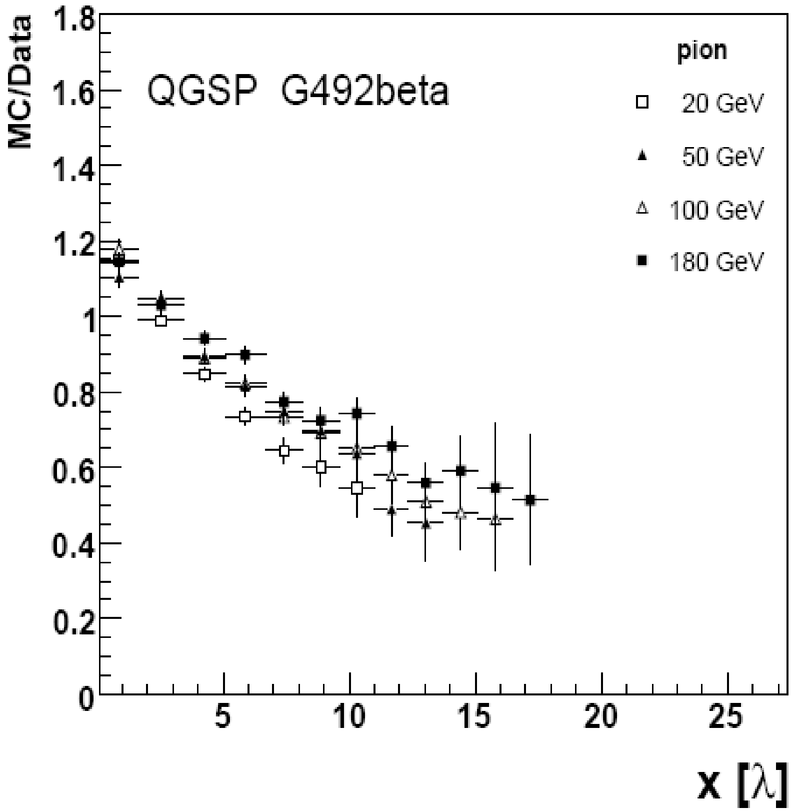
Longitudinal Profile, dE/dx(Monte Carlo)/dEdx(Exp.data)= MC/Data

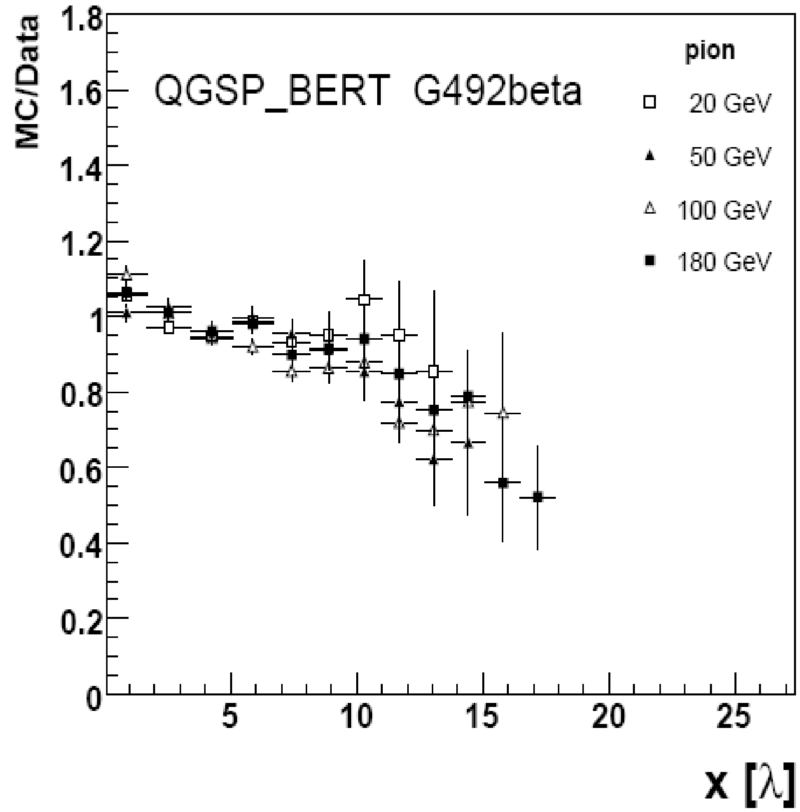


- Up to 10λ ±20% agreement.
- Good description at high energies.

Comparison of results of Geant4.9.2-beta to ATLAS TileCal test beam data, Margar Simonyan (*LAPP)* Calor 2008

Longitudinal Profile, dE/dx(Monte Carlo)/dEdx(Exp.data)= MC/Data





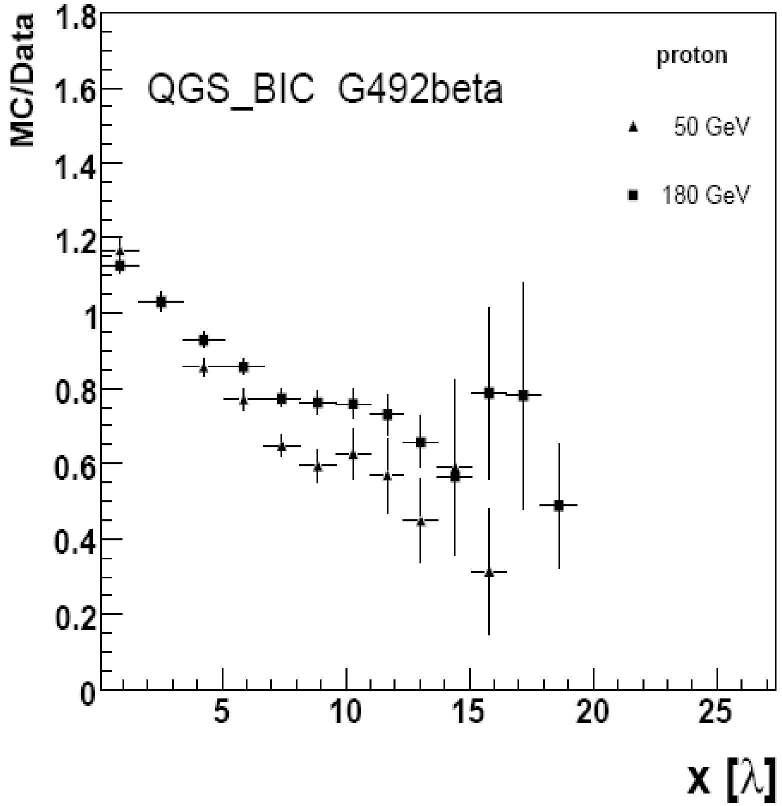
- Showers simulated with QGSP are too short, 20 – 40% less energy at 10λ.
- Adding Bertini makes showers longer, up to 10λ within $\pm 15\%$.

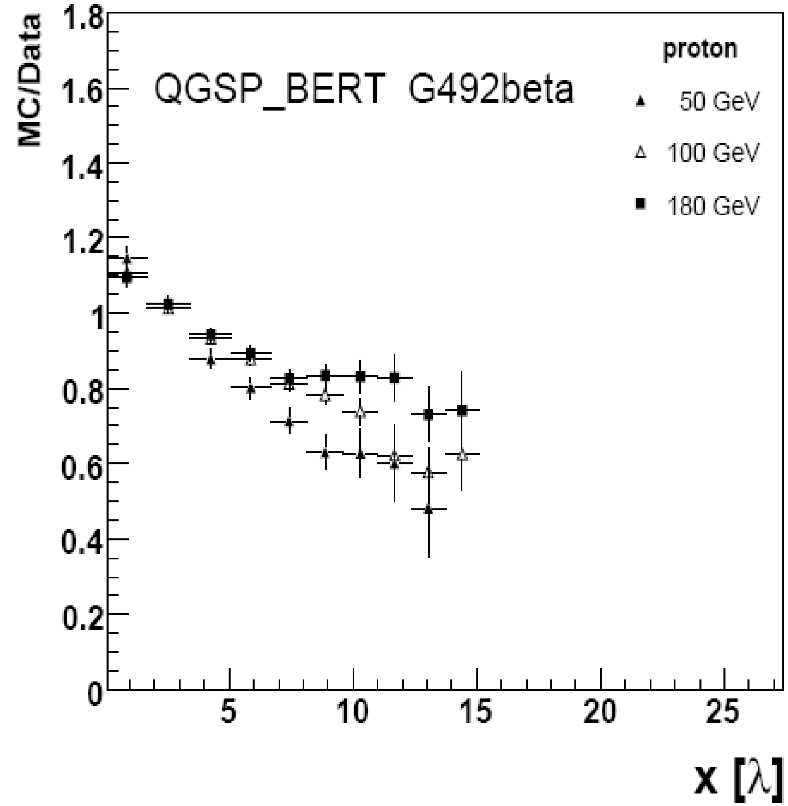
Shower shape

2 Testing and validation of the model

Comparison of results of Geant4.9.2-beta to ATLAS TileCal test beam data, Margar Simonyan (*LAPP)* Calor 2008

Longitudinal Profile, dE/dx(Monte Carlo)/dEdx(Exp.data)= MC/Data





- Simulated showers are too short, at 10λ 20 – 40% less energy.
- With Bertini at 10λ 20-40% less energy.
- Protons are described worse than pions.

3 Improvement of LHEP

arXiv.org > hep-ex > arXiv:0804.3013

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All papers Go!

High Energy Physics - Experiment

Comparison of Geant4 hadron generation with data from the interactions with beryllium nuclei of +8.9 GeV/c protons and pions, and of -8 GeV/c pions

A. Bolshakova, et al

(Submitted on 18 Apr 2008)

Hadron generation in the Geant4 simulation tool kit is compared with inclusive spectra of secondary protons and pions from the interactions with beryllium nuclei of +8.9 GeV/c protons and pions, and of -8.0 GeV/c pions. The data were taken in 2002 at the CERN Proton Synchrotron with the HARP spectrometer. We report on significant disagreements between data and simulated data especially in the polar-angle distributions of secondary protons and pions.

Comments:	15 pages, 13 figures
Subjects:	**High Energy Physics - Experiment (hep-ex)**
Report number:	CERN-PH-EP/2008-007
Cite as:	arXiv:0804.3013v1 [hep-ex]

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References & Citations

- SLAC-SPIRES HEP (refers to, cited by, arXiv reformatted)
- CiteBase

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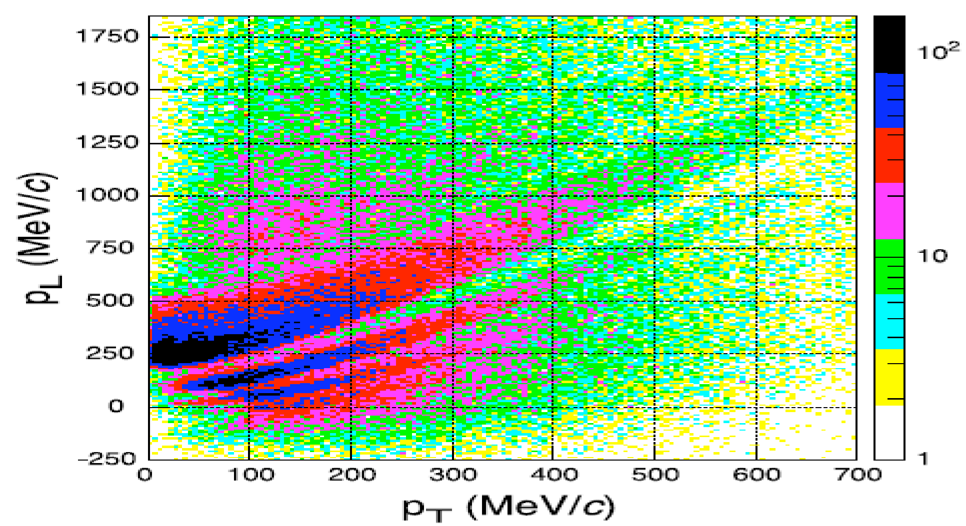
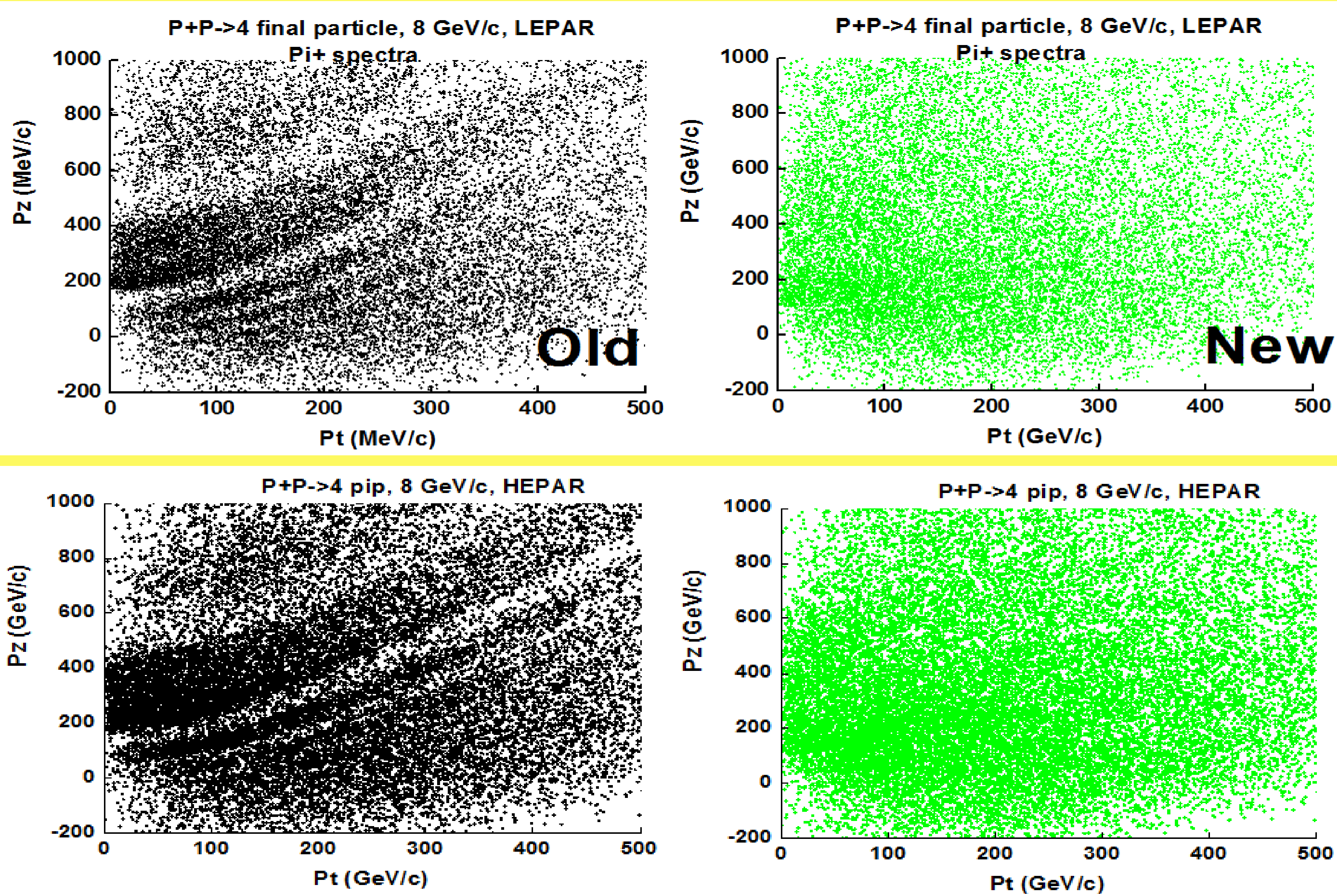


Fig. 1: Longitudinal momentum p_L versus transverse momentum p_T, as generated by Geant4's LHEP physics list for secondary π^+ from the interactions of $+8.9$ GeV/c beam π^+ with beryllium nuclei at rest.

The structure is presented in hadron-hadron interactions.

The bug is fixed!

3 Improvement of LHEP



Conclusion

x. **Fritiof (FTF) model in Geant4 has been essential improved.**
There were:
a. Tuning of the FTF parameters;
b. Implementation of the quasi-elastic scattering;
c. Improvement of the formation time treating.

2. Combination of the FTF and the binary cascade model gives a good results compatible with the results of the QGSP_Bert.

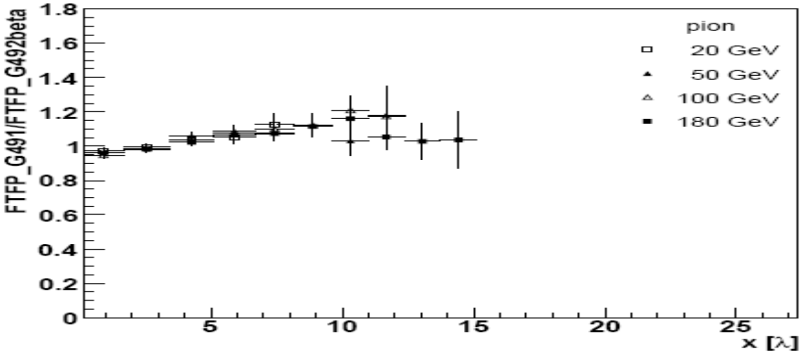
3. Bug was fixed in low and high energy parameterized models.

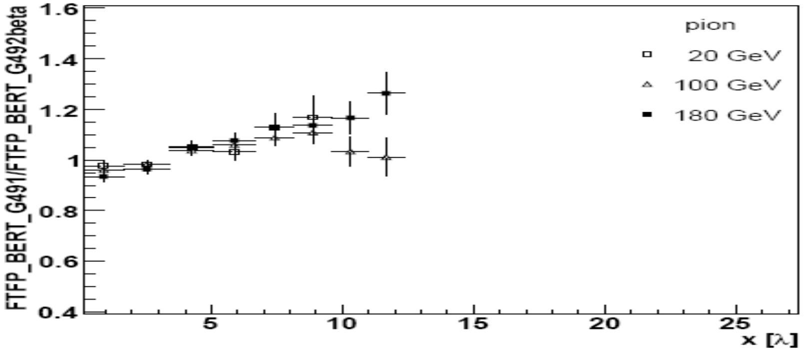
Results

1. Description of meson and proton spectra in PP-interactions, O.K..
2. Experimental results by the HARP Collaboration are described quite well.
3. Shower shape was improved, but there stll some problems.
"Non-smooth energy response dependence on beam energy is observed within QGSP_BERT physics list in the interaction model transition regions. FTF_BIC has significantly less discontinuities"

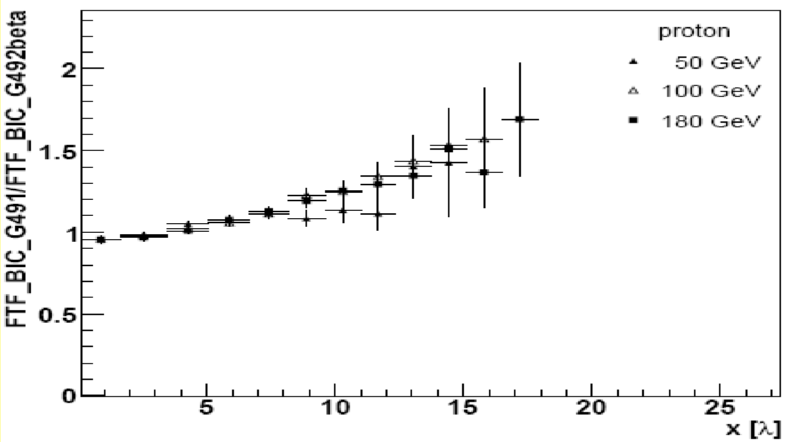
Comparison of results of Geant4.9.2-beta to ATLAS TileCal test beam data, Margar Simonyan (*LAPP)* Calor 2008

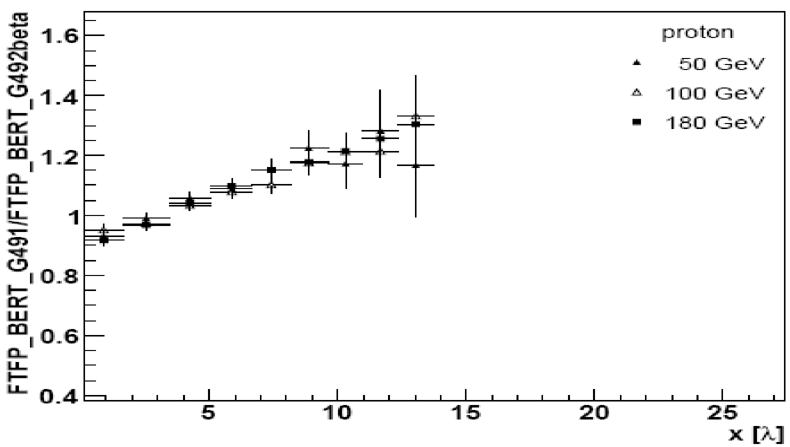
Comparison G4.9.1 and G4.9.2





- Showers became longer in G4.9.2 with respect G4.9.1 in FTFP based physics lists.





- Proton induced showers became longer in G4.9.2 with respect G4.9.1 in FTFP based physics lists.

Is the structure appearing in the hadron-hadron interactions?

3 Improvement of LHEP

LEP, LEPAR, Gheisha

Yes!

Program steps:

2) Sampling of multiplicity of produced particles;
3) Sampling of Pt of the particles;
4) Sampling of Xf of the particles.

geant4-09-01-ref-02/source/processes/hadronic/models/low_energy/src/

CVS		G4LEKaonZeroInelastic.cc	G4LCapture.cc
G4LELambdaInelastic.cc	G4LEAlphaInelastic.cc	G4LElastic.cc	G4LEAntiKaonZeroInelastic.cc
G4LENeutronInelastic.cc	G4LEAntiLambdaInelastic.cc	G4LEOmegaMinusInelastic.cc	G4LEAntiNeutronInelastic.cc
G4LEPionMinusInelastic.cc	G4LEAntiOmegaMinusInelastic.cc	G4LEPionPlusInelastic.cc	G4LEAntiProtonInelastic.cc
G4LEProtonInelastic.cc	G4LEAntiSigmaMinusInelastic.cc	G4LEProtonInelastic.cc~	G4LEAntiSigmaPlusInelastic.cc
G4LESigmaMinusInelastic.cc	G4LEAntiXiMinusInelastic.cc	G4LESigmaPlusInelastic.cc	G4LEAntiXiZeroInelastic.cc
G4LETritonInelastic.cc	G4LEDeuteronInelastic.cc	G4LEXiMinusInelastic.cc	G4LEKaonMinusInelastic.cc
G4LEXiZeroInelastic.cc	G4LEKaonPlusInelastic.cc	G4LFission.cc	

No!

geant4-09-01-ref-02/source/processes/hadronic/util/src

CVS	G4HadSignalHandler.cc	G4ReactionDynamics.cc~	G4Bessel.cc
G4HadTmpUtil.cc	G4ReactionDynamics.ccPrint	G4HadFinalState.cc	G4IsoResult.cc
G4ReactionKinematics.cc	G4HadProjectile.cc	G4LightMedia.cc	G4ReactionProduct.cc
G4HadronicWhiteBoard.cc	G4Nucleus.cc	G4StableIsotopes.cc	G4HadSecondary.cc
G4ReactionDynamics.cc			

Yes!

```
while( ++innerCounter < 7 )      {
     ran = G4UniformRand()*dndl[19];
     l = 1;
     while( ( ran >= dndl[l] ) && ( l < 20 ) )l++;
     l = std::min( 19, l );
//     x = std::min( 1.0, pt*(binl[l-1] + G4UniformRand()*(binl[l]-binl[l-1])/2.) ); //Uzhi
       x = std::min( 1.0, pt*(binl[l-1] + G4UniformRand()*(binl[l]-binl[l-1])   ) ); //Uzhi
```

Here it is!