Tuning of Geant4 FTF model using NA61/SHINE experimental data

A. Galoyan and V. Uzhinsky, 22.09.2023

Latest data by the NA61/SHINE collaboration

Pi-, PP 20 -158 Eur. Phys. J. C74 (2014) 2794 (Received: 14 October 2013)

Pi,K,P,antiP, PP 20 -158 Eur. Phys. J. C77 (2017) 671 (Received: 9 May 2017)

Pi,K,P,antiP, P+C, 31 Eur. Phys. J. C76 (2016) 84 (Received: 12 October 2015)

Pi-, 7Be+9Be, 13 – 150 Eur. Phys. J. C80 (2020) 961 (Received: 14 August 2020)

Pi,K,P,anti-P, 7Be+9Be Eur. Phys. J. C81 (2021) 73 (Received: 5 October 2020)

Pi-, Ar+Sc , 13 – 150 A GeV/c Eur. Phys. J. C81 (2021) 397 (Received: 22 January 2021)

Arxiv:hep-exp:2308.16683 (31 Aug. 2023)

Measurements of π±, K±, p and anti-p spectra in 40Ar+45Sc collisions at 13A to 150A GeV/c

There are too many comparisons with models!

Tune model parameter: E1= P1 + P2; E2 = P1- P2

Our model developed in Geant4 – Geant4 FTF (Fritiof)

Pi-, PP 20 -158 Eur. Phys. J. C74 (2014) 2794 (Received: 14 October 2013)

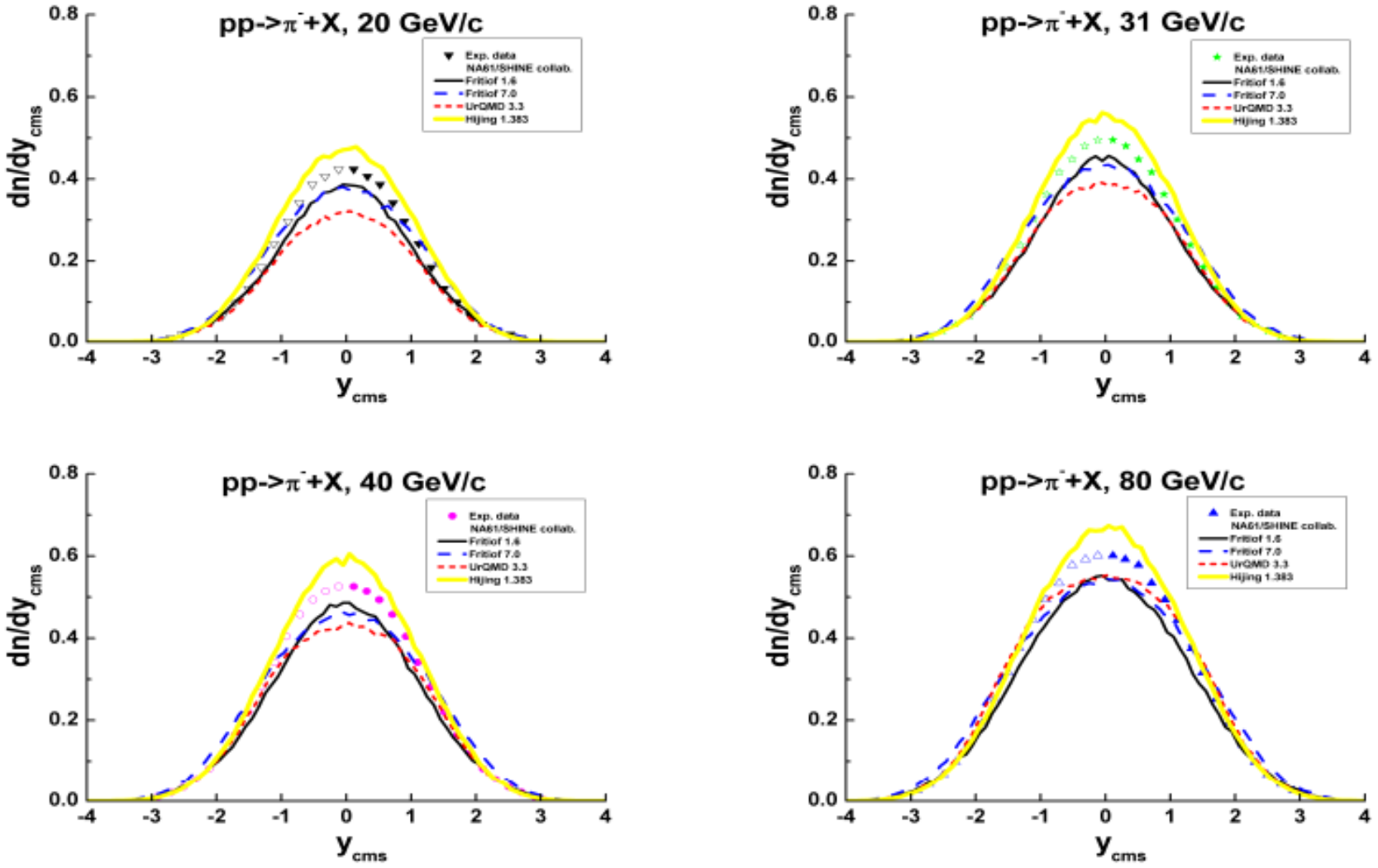
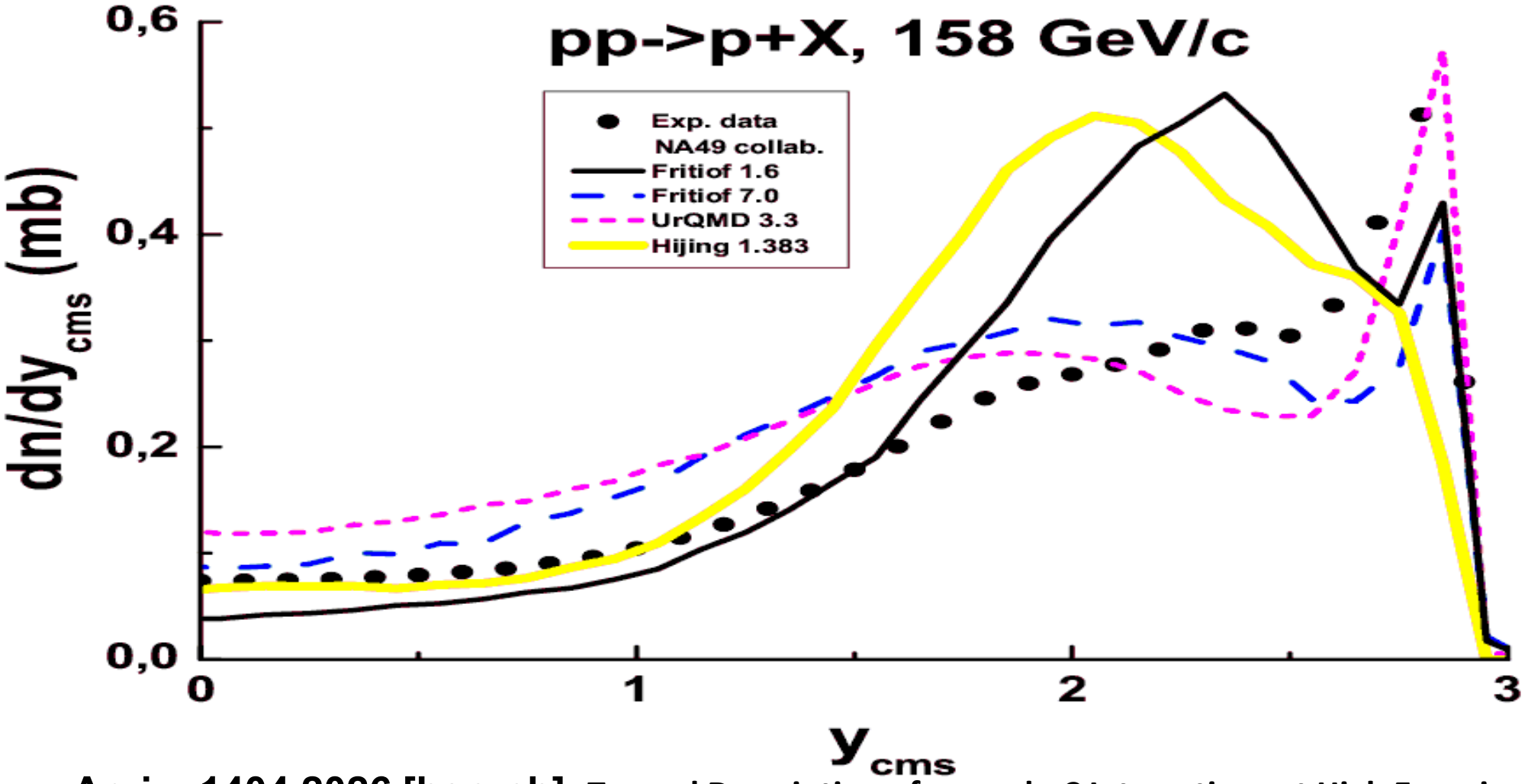


Figure 1: Rapidity distributions of π^--mesons in pp interactions. Closed points are the NA61/SHINE experimental data [1], the open points are the data reflected at mid-rapidity. Lines are model calculations.

Arxiv: 1404.2026 [hep-ph] **Toward Description of pp and pC Interactions at High Energies: Problems of Fritiof-based Models**

Problem

Fritiof 1.6, Fritiof 7.0, Hijing, UrQMD 3.3, pp-interactions NA49 exp. data



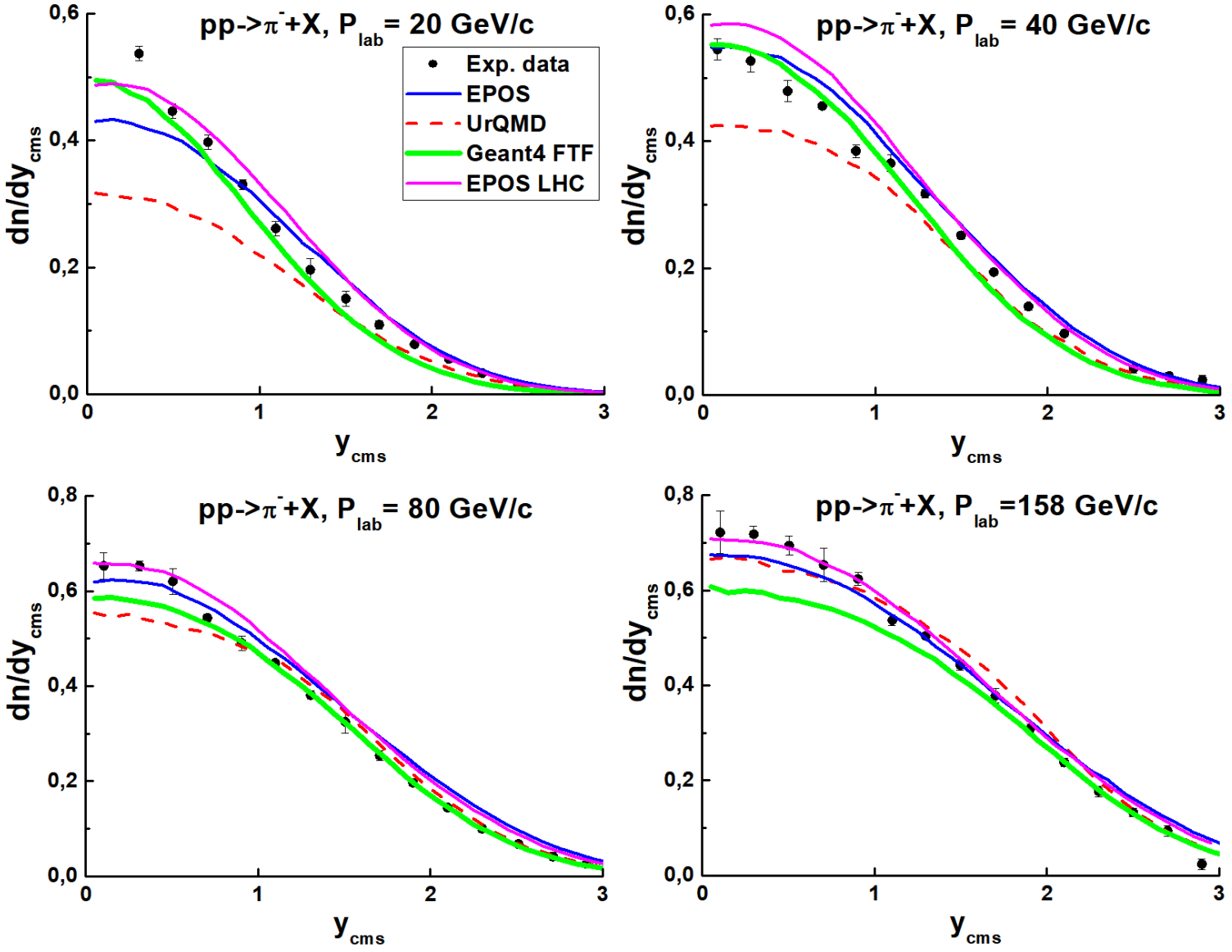
Arxiv: 1404.2026 [hep-ph] **Toward Description of pp and pC Interactions at High Energies: Problems of Fritiof-based Models**

All Fritiof-based models have problems, though, they can be tuned!

NA61/SHINE data on PP interactions at 20 – 158 GeV/c

PP int.

Geant4 FTF
EPOS 1.99
EPOS LHC
UrQMD



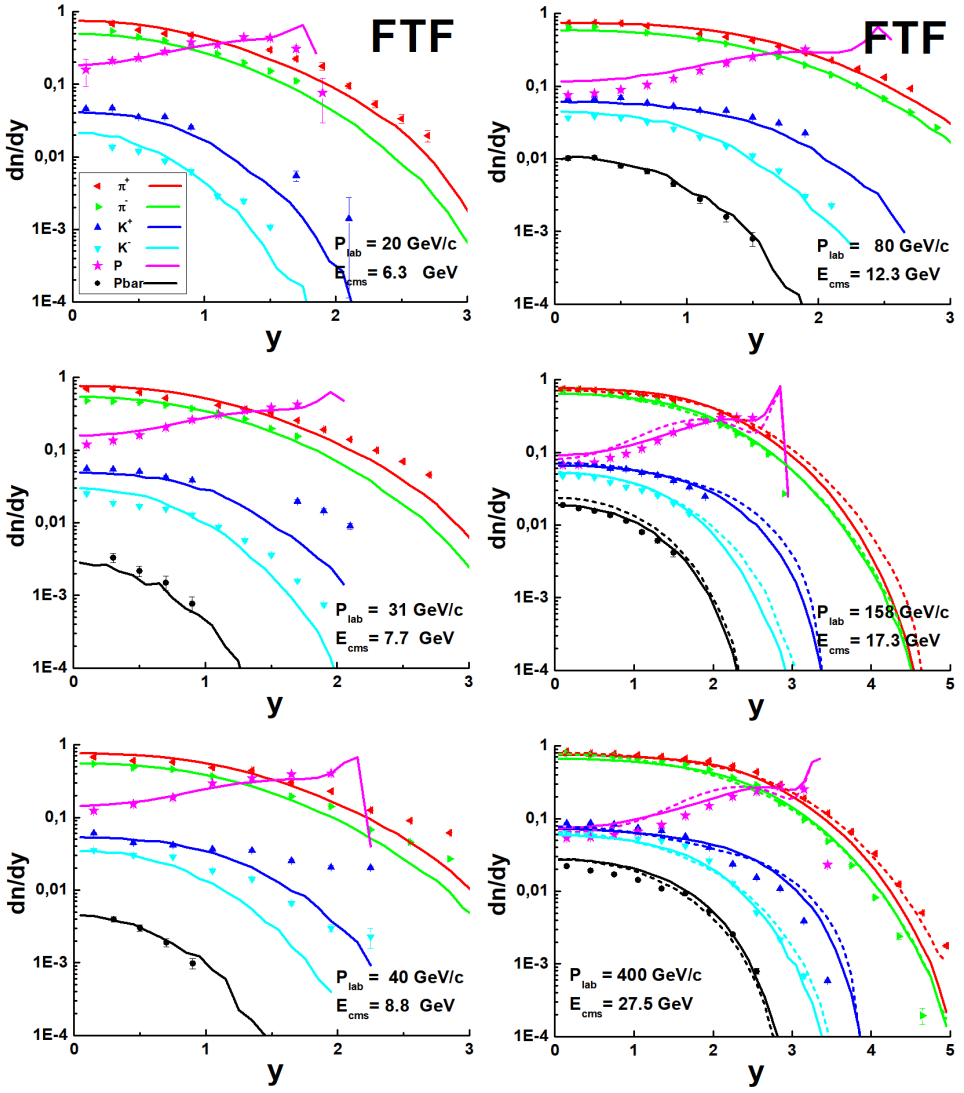
EPOS O.K. Plab > 40 GeV/c. UrQMD 3.3 works only at 158 GeV/c.
Geant4 FTF gives the best results. Only at 159 GeV/c there is a problem.

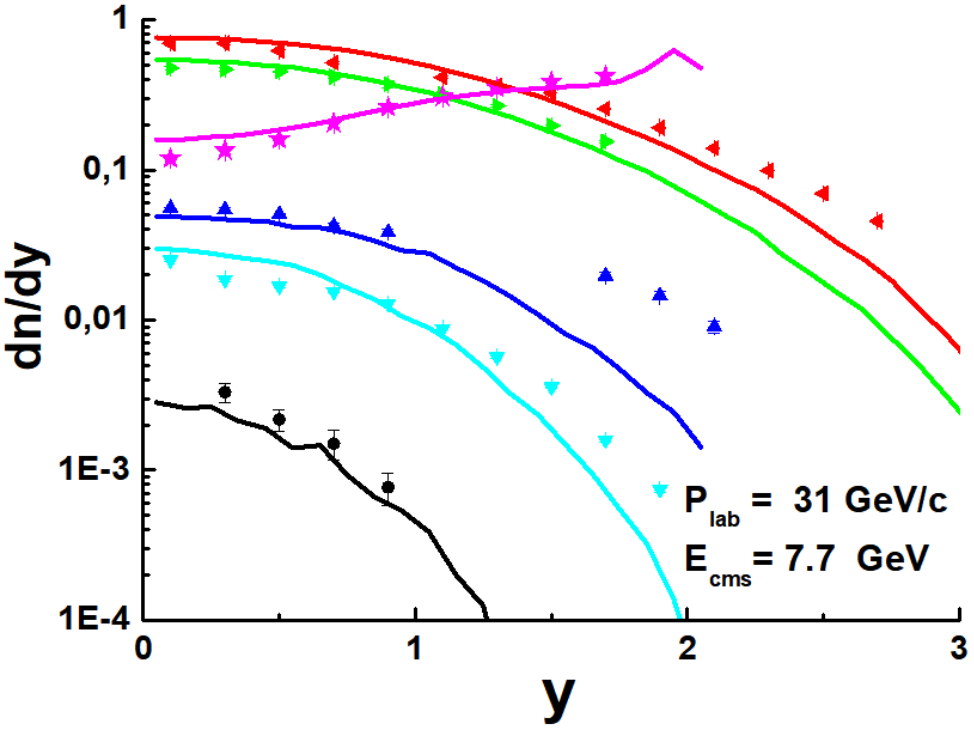
Inclusive one-particle distributions …

Measurements of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/*c* with the NA61/SHINE spectrometer at the CERN SPS

NA61/SHINE Collaboration

Eur. Phys. J. C (2017) 77:671





FTF cannot describe K+, K- production at 20, 31 and 40 GeV/c.
At higher energies all O.K.

What is the matter?

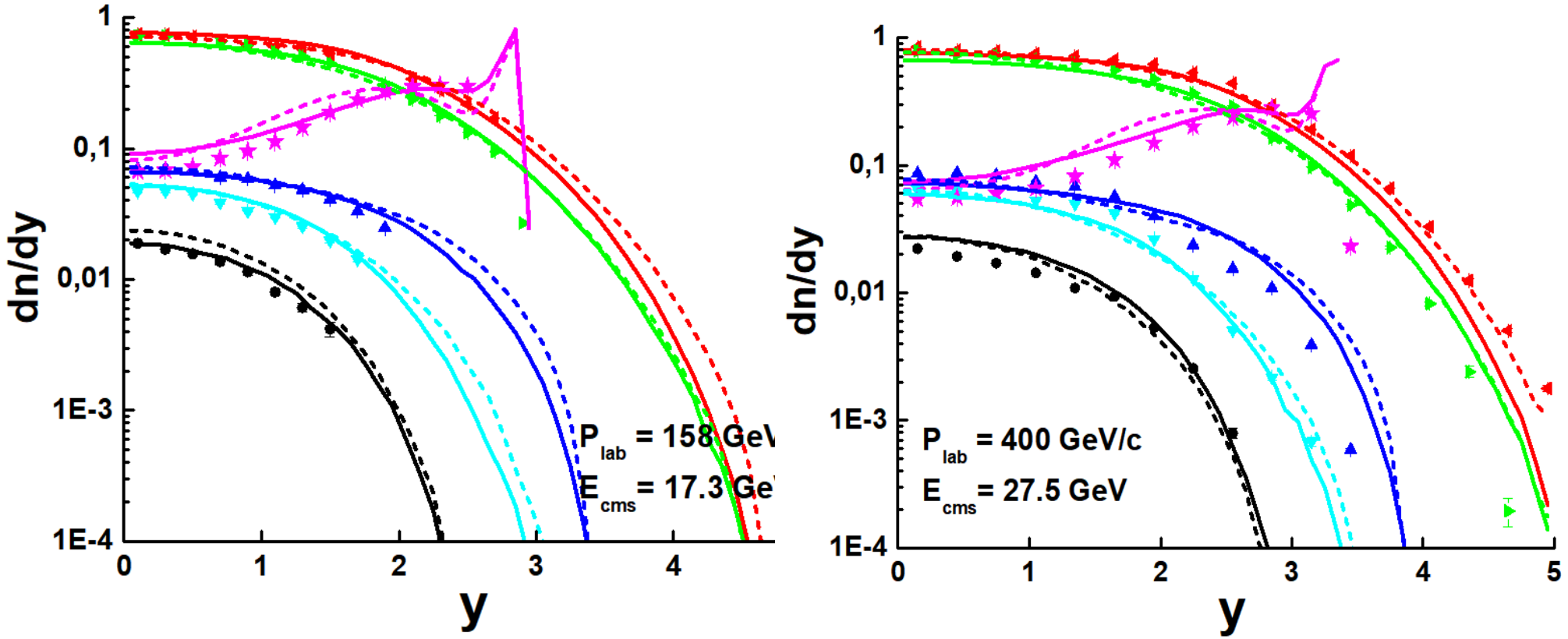
Who is wrong – Exp. Or Theory.?

Inclusive one-particle distributions …

Measurements of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/*c* with the NA61/SHINE spectrometer at the CERN SPS

Eur. Phys. J. C (2017) 77:671

NA61/SHINE Collaboration



Pythia 6.4 – dashed lines, G4 FTF – solid lines

Pythia 6.4 and FTF give close predictions for all energies, except proton spectra.

Proton spectra???

How to improve the description of protons and kaons?

FTF model : basic assumptions

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

Fig. 1: Processes of string's creations considered in the FTF model.

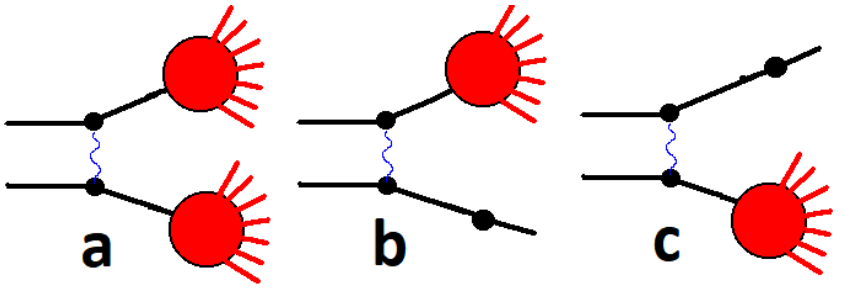
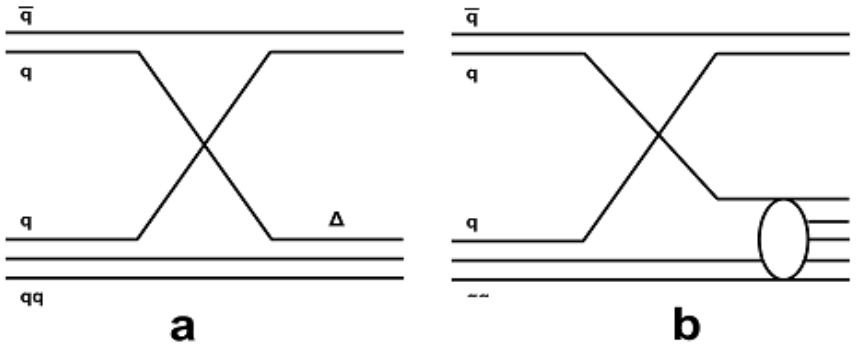


Fig. 2 Additional quark exchange processes in the FTF model.



String mass distribution

$$dW/dP^- = (1-f)\frac{1}{\ln\left(P^-_{max}/P^-_{min}\right)}\,1/P^- + f\frac{1}{P^-_{max}-P^-_{min}},$$

$$P^- = \sqrt{M^2+P_T^2+P_z^2} - P_z \simeq (M^2+P_T^2)/2\,P_z\ (P_z\to\infty) \qquad f = 0.55$$

FTF model: string fragmentation details

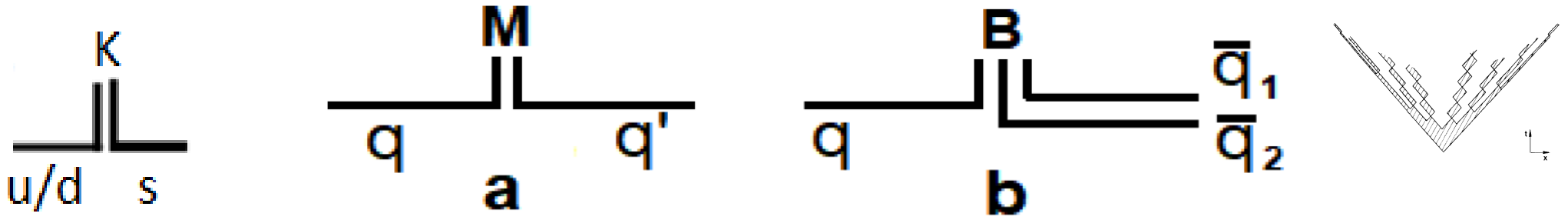


Figure 9: Vertexes of quark fragmentations.

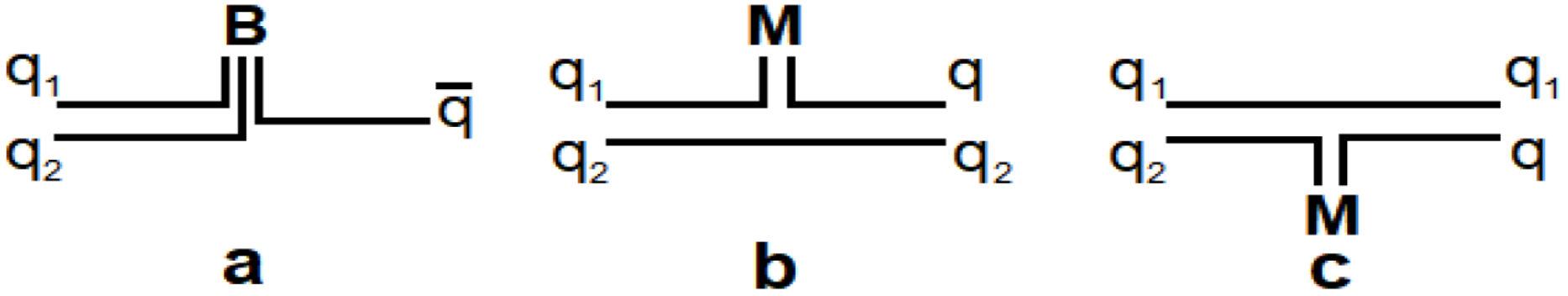
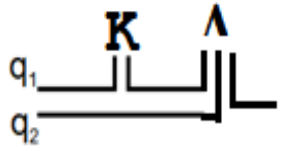


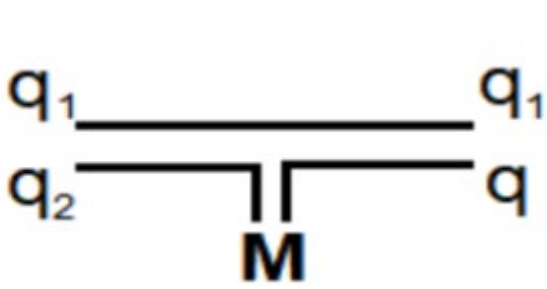
Figure 10: Vertexes of diquark fragmentations.

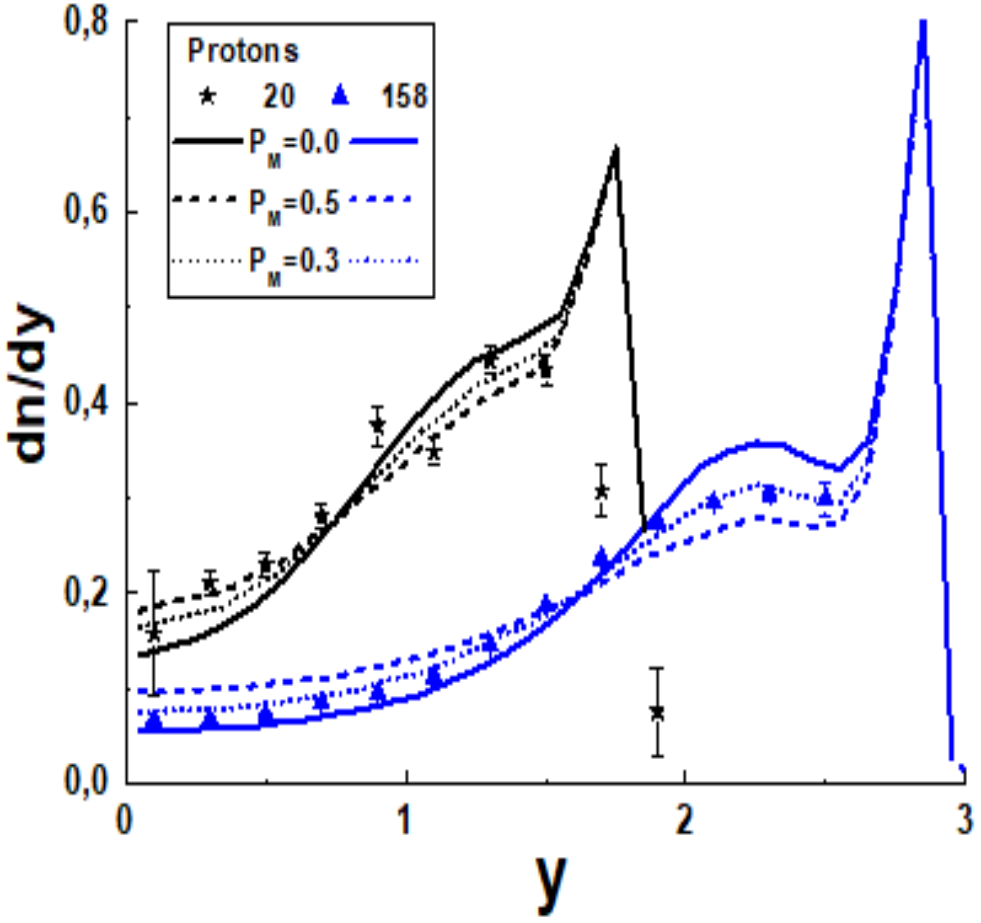


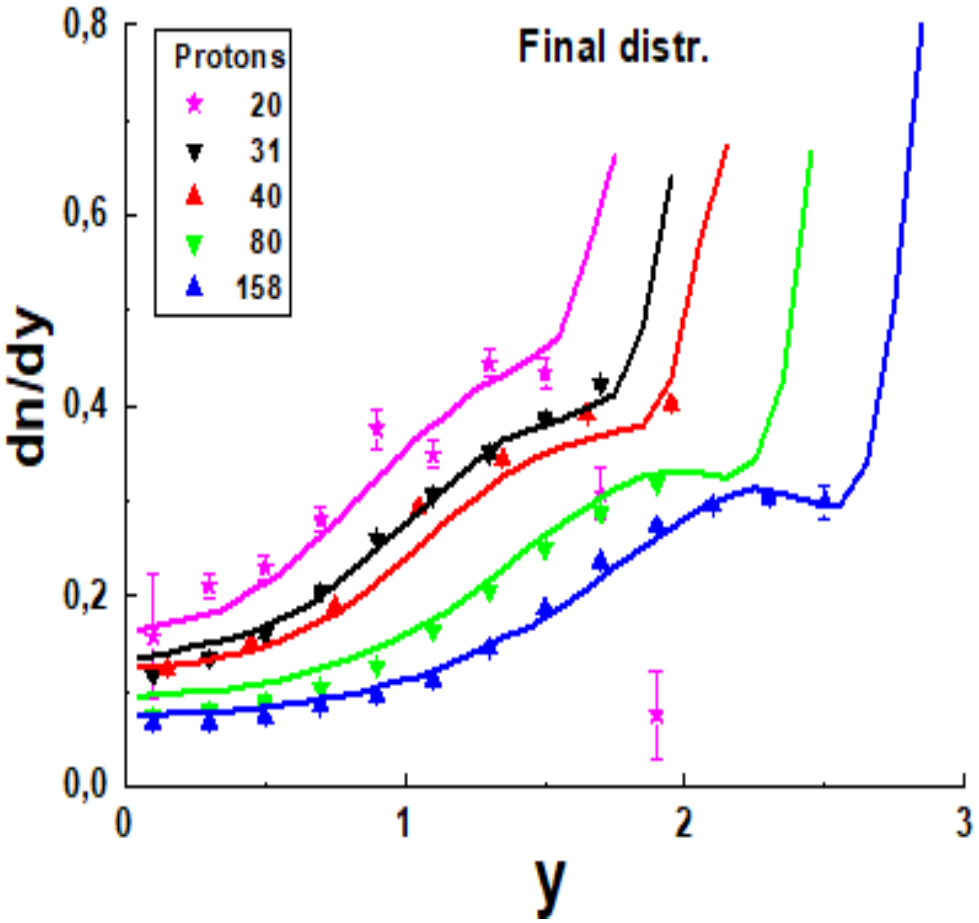
For mesons $f(z) \propto z^{-1}\ (1-z)^a\ \exp\left(-b\ m_T^2/z\right), \quad a = 1, \quad b = 0.7\ (GeV)^{-2}, \quad m_T^2 = m_h^2 + P_T^2.$

For baryons, a'la Kaidalov $f(z) = \dfrac{c}{(z_{max} - z_{min})^c}\ (z - z_{min})^{c-1}, \quad c = 2 + P_T^2.$

Proton production, Geant4 FTF model: tune of P_M





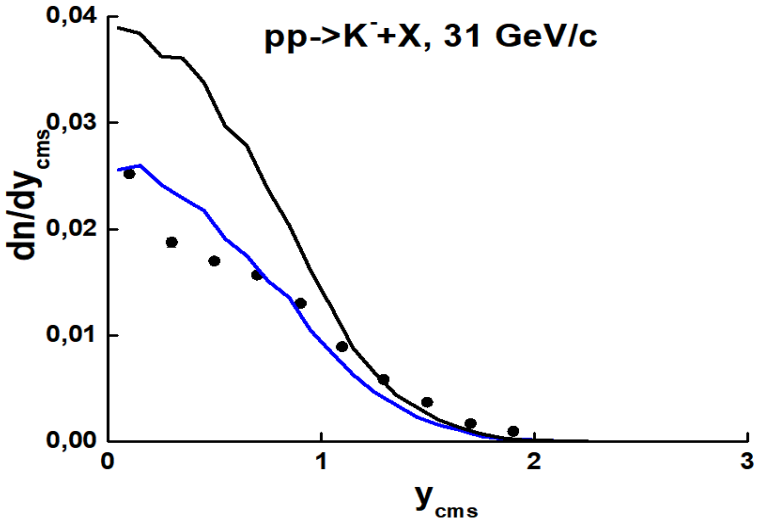


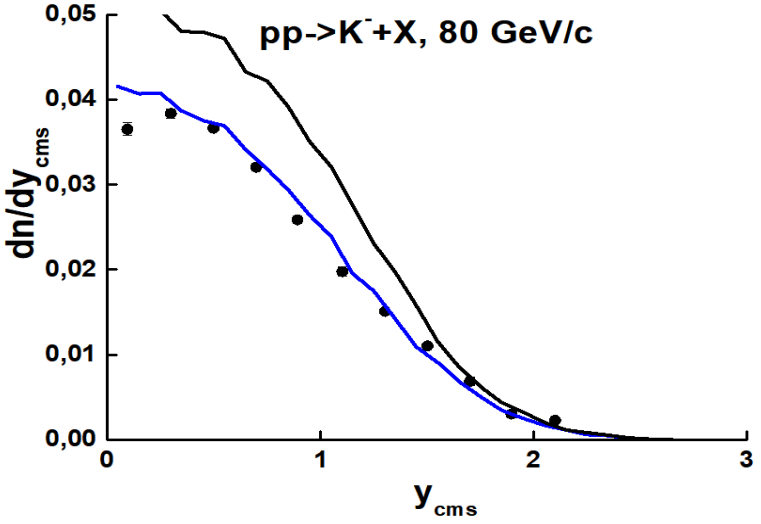
Meson's production by diquarks is the main feature of Geant4 FTF!

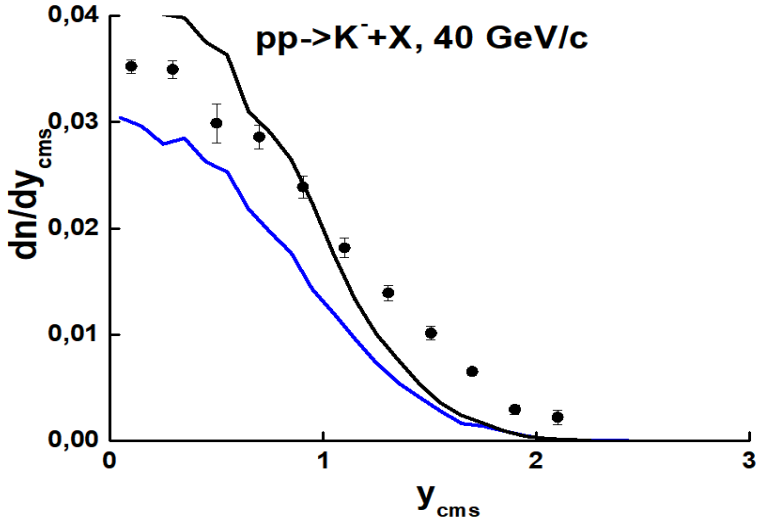
Strange particle production, Geant4 FTF model: tune of Ps-sbar (12 %)

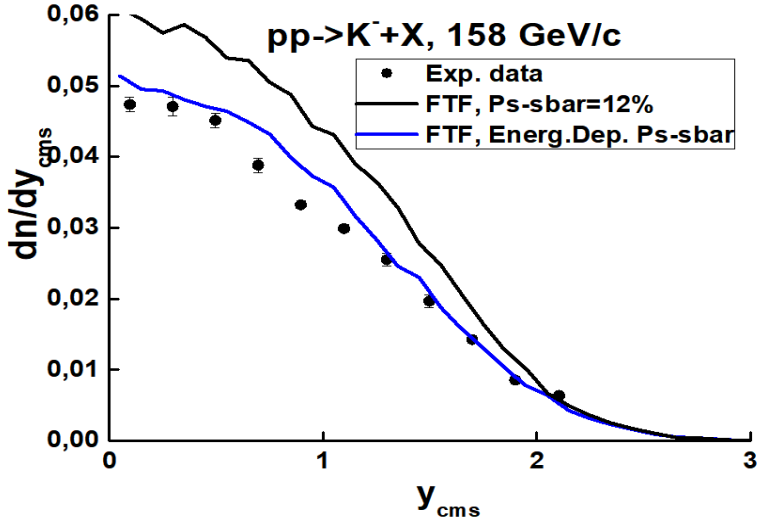
The Schwinger model of quark' pair production from the vacuum in a strong color field.

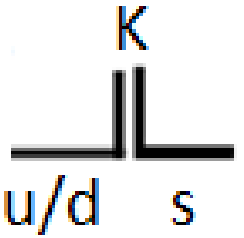
$$\exp\left(-\frac{\pi m_\perp^2}{\kappa}\right) = \exp\left(-\frac{\pi m^2}{\kappa}\right)\exp\left(-\frac{\pi p_\perp^2}{\kappa}\right)$$











Black lines:
Ps-sbar =12 %

Blue lines:
Ps-sbar = 0.12*
[1 – (Mth/Mstr)$^{2.5}$]

Dependence of Ps-sbar on a string mass ?

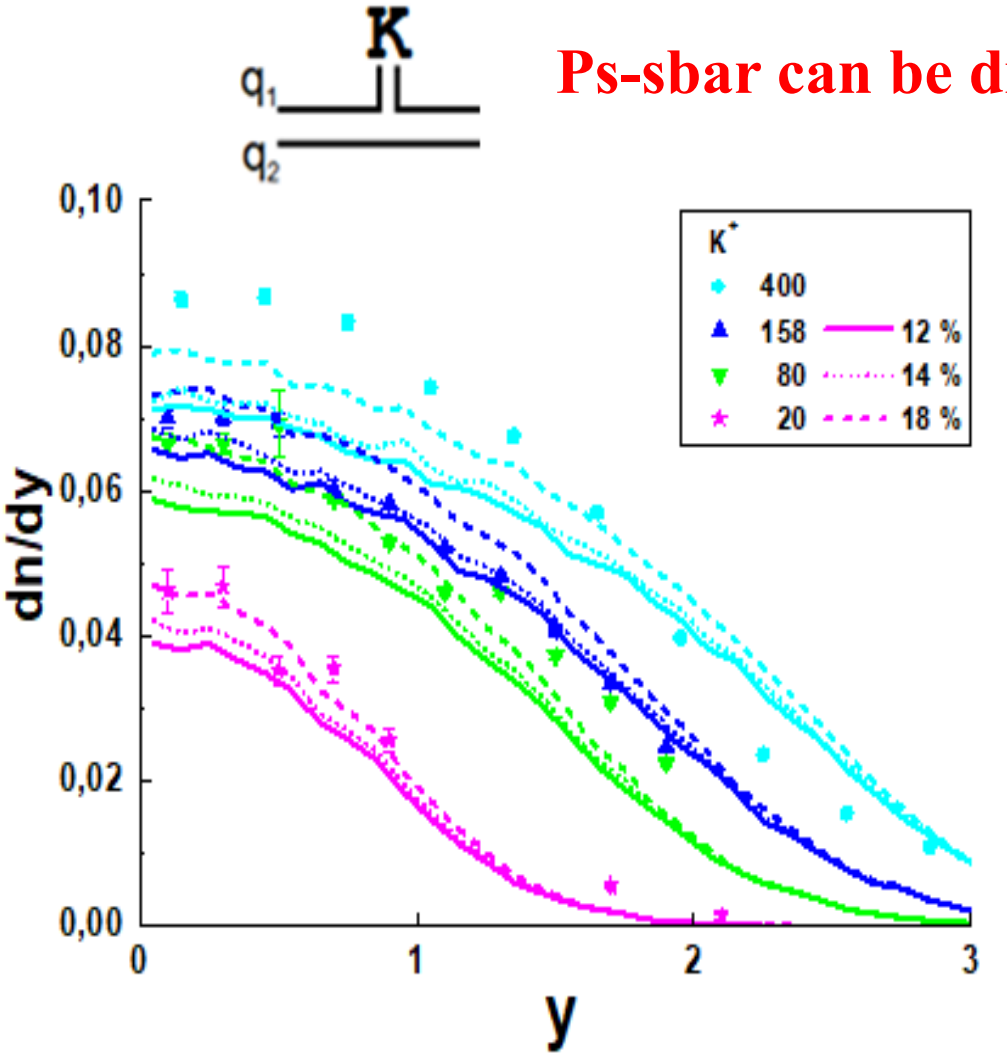
Pi,K,P,antiP, PP 20 -158 Eur. Phys. J. 77 C (2017) 671 (Received: 9 May 2017)

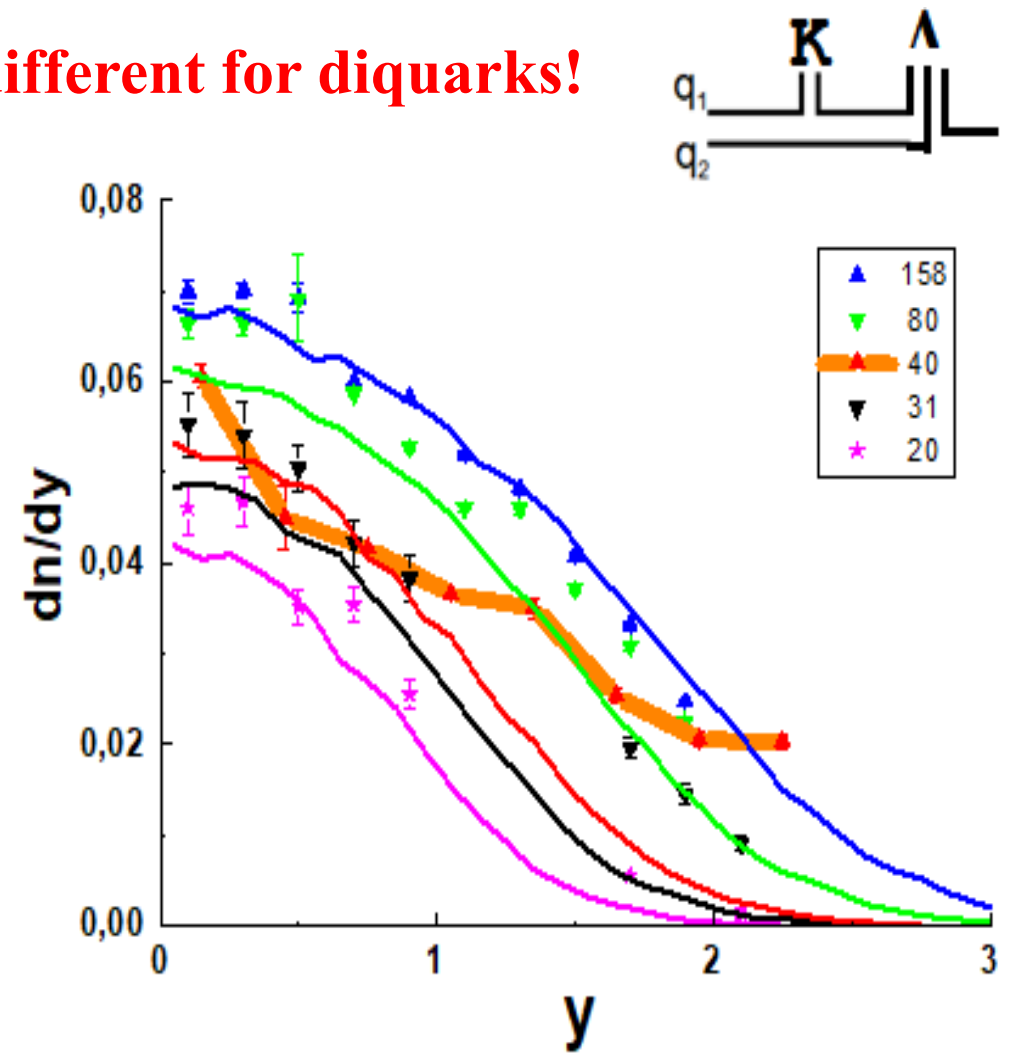
Strange particle production, Geant4 FTF model: tune of Ps-sbar (12 %)

The Schwinger model of quark' pair production from the vacuum in a strong color field.

$$\exp\left(-\frac{\pi m_\perp^2}{\kappa}\right) = \exp\left(-\frac{\pi m^2}{\kappa}\right)\exp\left(-\frac{\pi p_\perp^2}{\kappa}\right)$$

Ps-sbar can be different for diquarks!





It is impossible to choose Ps-sbar! Exp. Data scatter too strongly!

Pi,K,P,antiP, PP 20 -158 Eur. Phys. J. 77 C (2017) 671 (Received: 9 May 2017)

Maybe a consideration of other data will help?

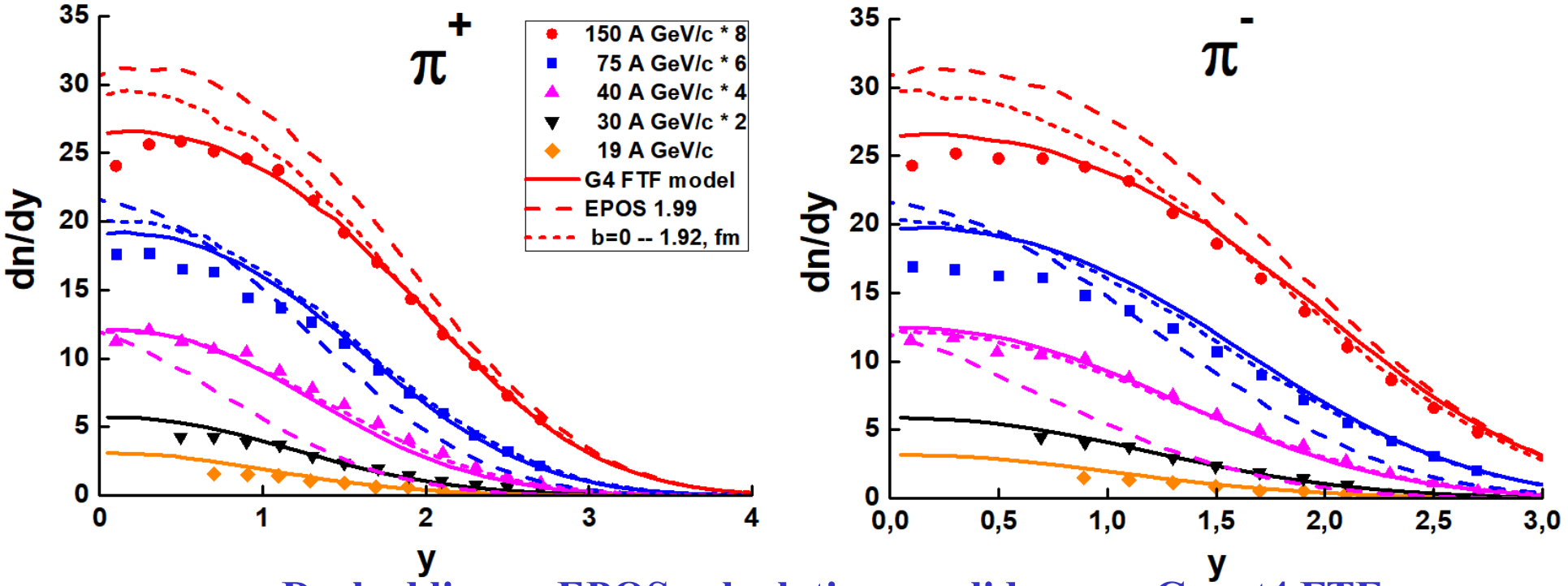
NA61/SHINE data on Be-7 + Be-9

$$\pi B^2_{max} = (C/100)\ \sigma^{in}_{AB}$$

20 % centrality, dn/dy of π mesons

EPOS 1.99 and Geant4 FTF models

EPOS well describes the data at 150 A GeV



Dashed lines – EPOS calculations, solid ones – Geant4 FTF.

Geant4 FTF O.K. EPOS shows a strange energy dependence of the distributions and their form especially at low energies. Changing the centrality selection helps a lot.

Maybe a consideration of other data will help?

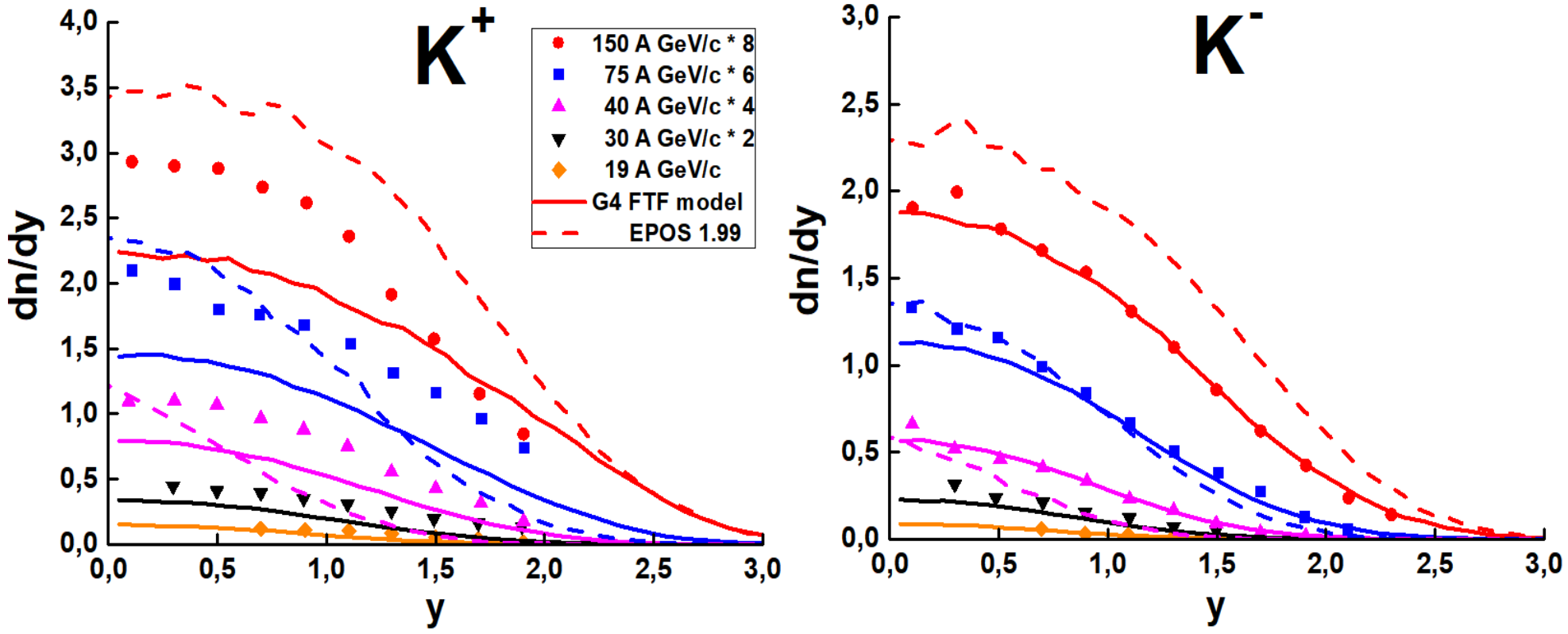
NA61/SHINE data on Be-7 + Be-9

20 % centrality, dn/dy of π mesons

EPOS 1.99 and Geant4 FTF models

cannot describe K+ meson production

Gean4 FTF model well describes K- production

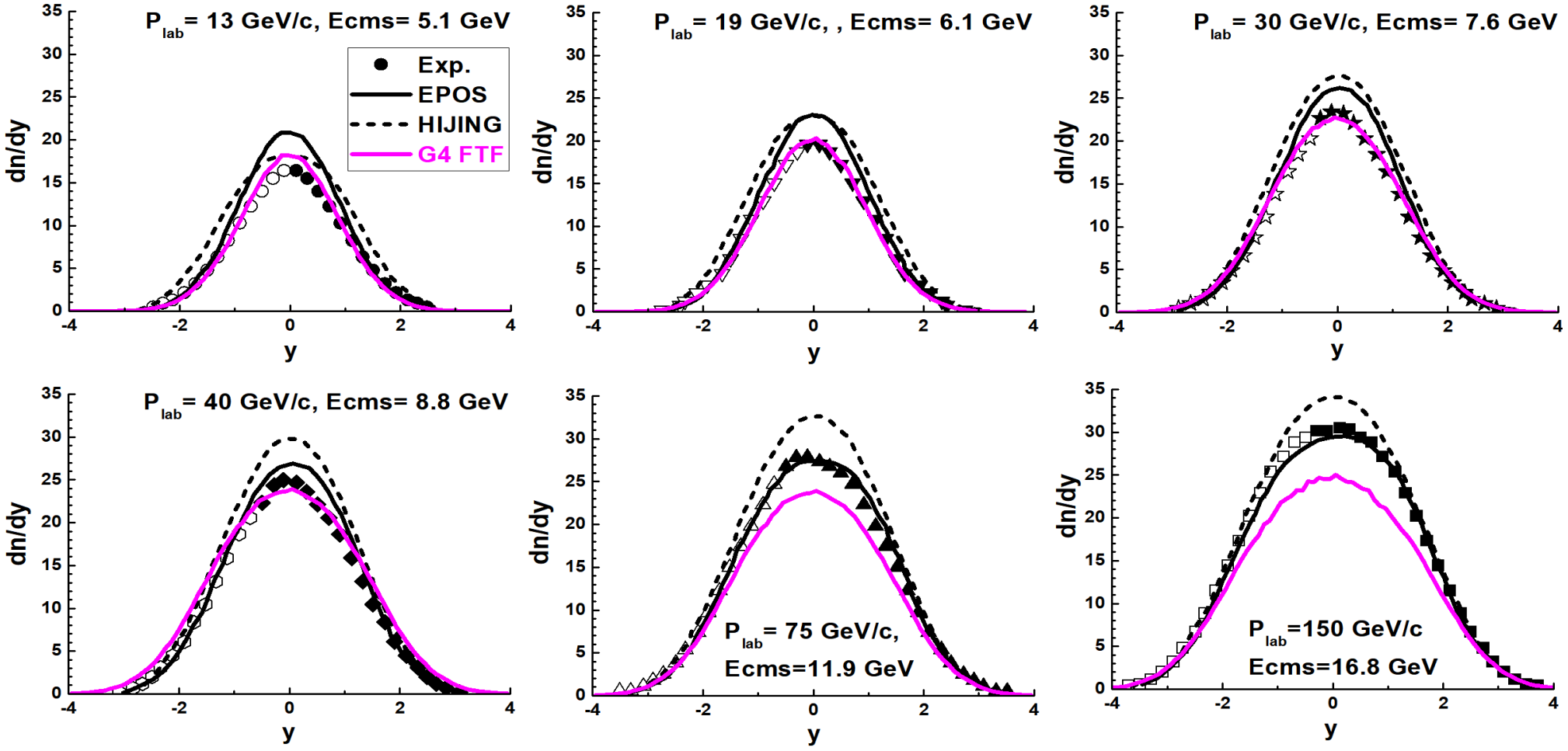


Dashed lines – EPOS calculations, solid ones – Geant4 FTF.

EPOS shows a strange energy dependence of the distributions and their form especially at low energies.

NA61/SHINE data on Ar-40 + Sc-45 and FTF model
5 % centrality, dn/dy of π- mesons

A. Galoyan, A. Ribon, V. Uzhinsky, *Eur.Phys.J.C* 82 (2022) 181



NA61: HIJING overestimates all data. No tuning!

NA61: EPOS overestimates data at Ecmc < 10 GeV, at > 10 GeV – OK.

Geant4 FTF – OK at Ecmc < 10 GeV, underestimates at Ecms > 10 GeV, after improvements.

Main problem – Centrality!

QGP at 7 or 10 GeV?

Latest data: **Arxiv:hep-exp:2308.16683 (31 Aug. 2023)**

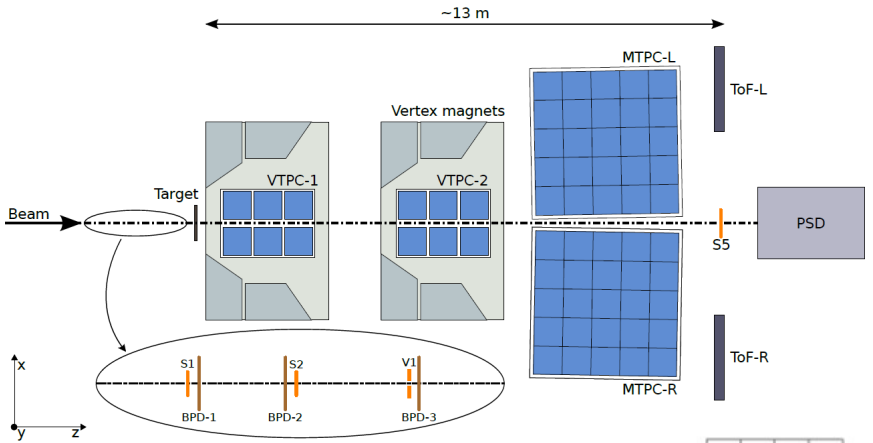
Measurements of π±, K±, p and anti-p spectra in 40Ar+45Sc collisions at 13A to 150A GeV/c

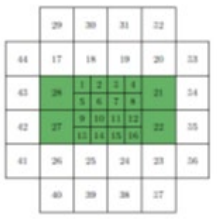
2 questions have to be solved:

a) What is the impact parameter range, or what are criteria for selections of events with various centralities?

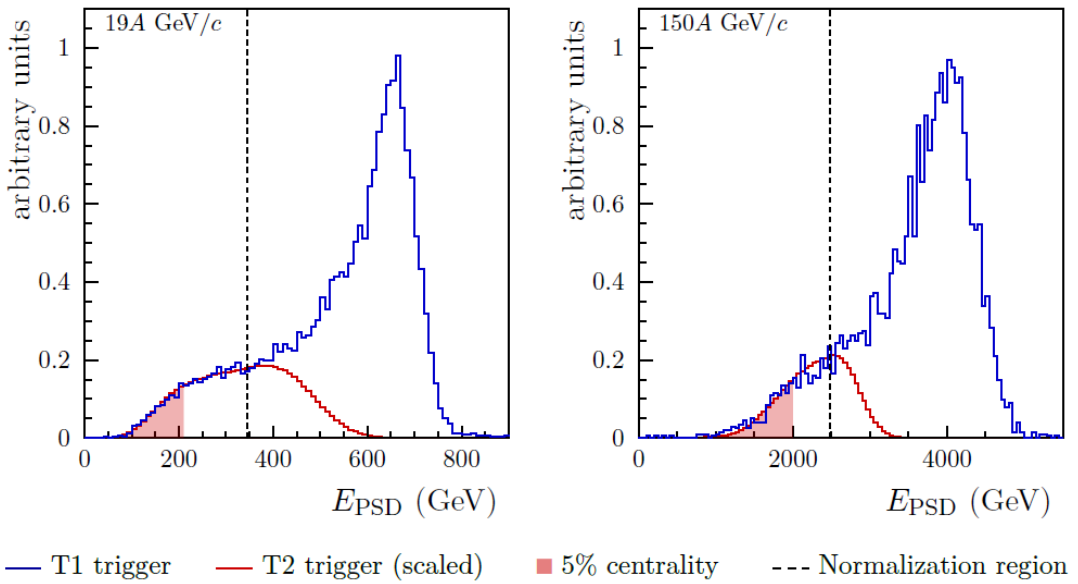
b) Be or not to Be the nucleon diffraction dissociation?

$$\pi B^2_{max} = (C/100)\ \sigma^{in}_{AB}$$ **- 70 GeV** **2000 GeV is missed!**

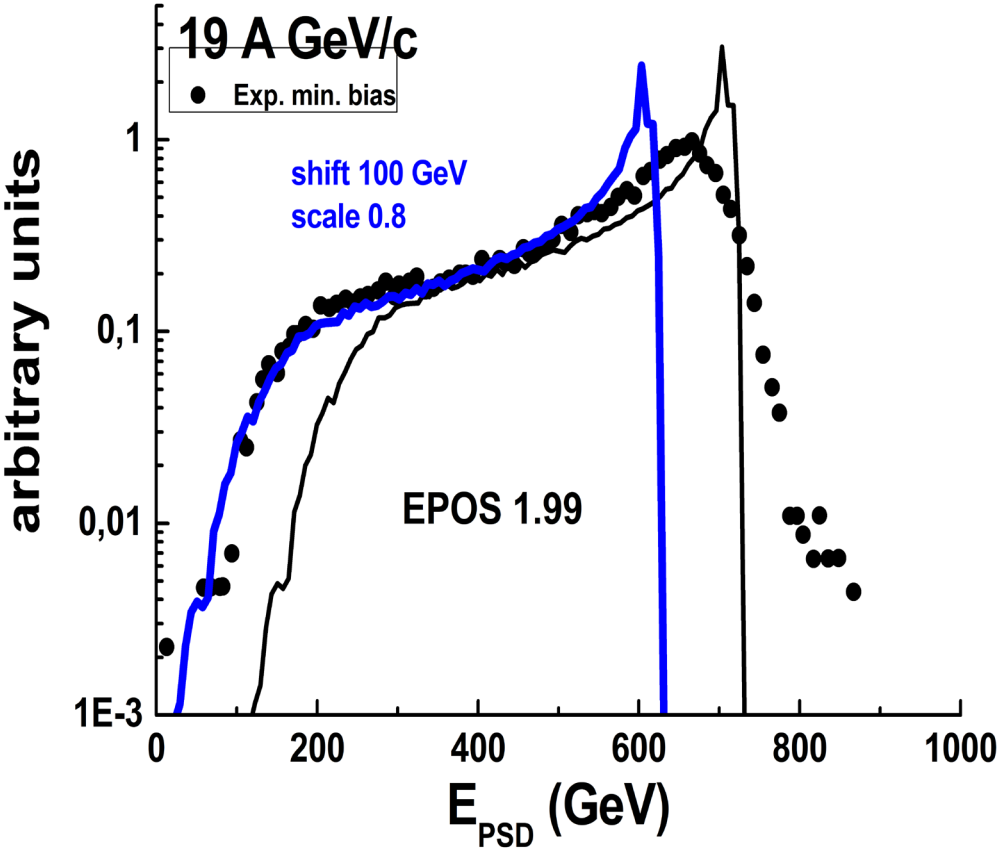


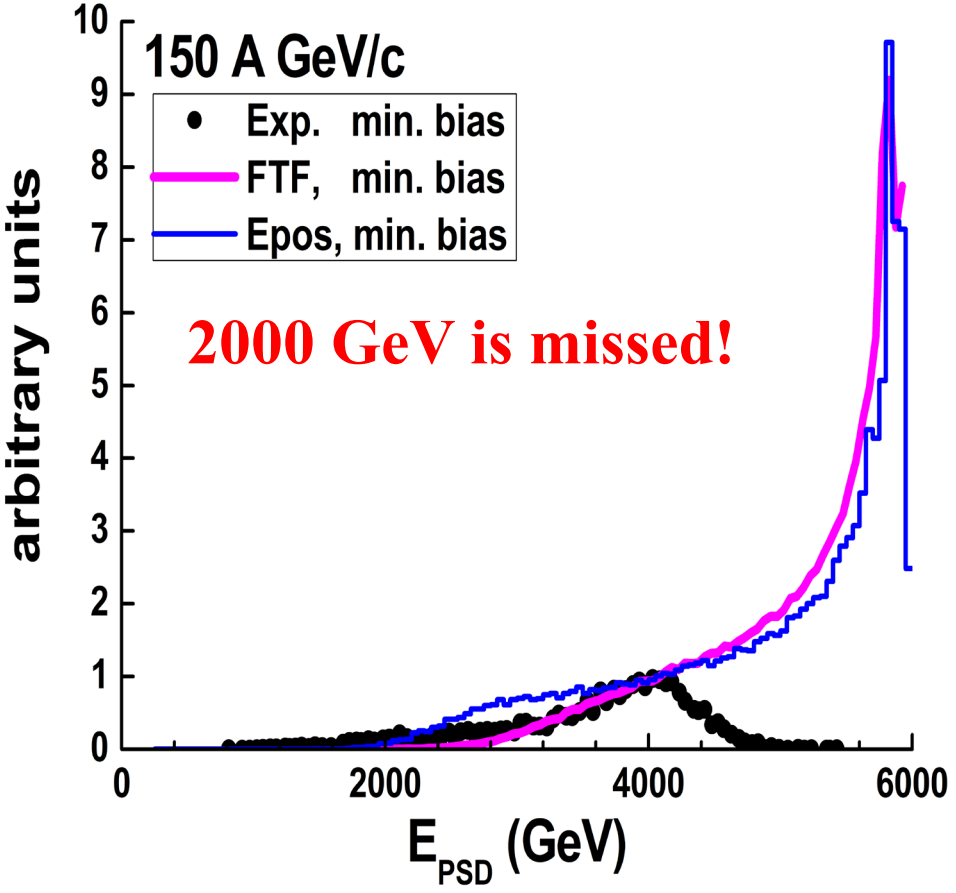


150A GeV/c



Questions? 5 % centrality ? Bmax ?





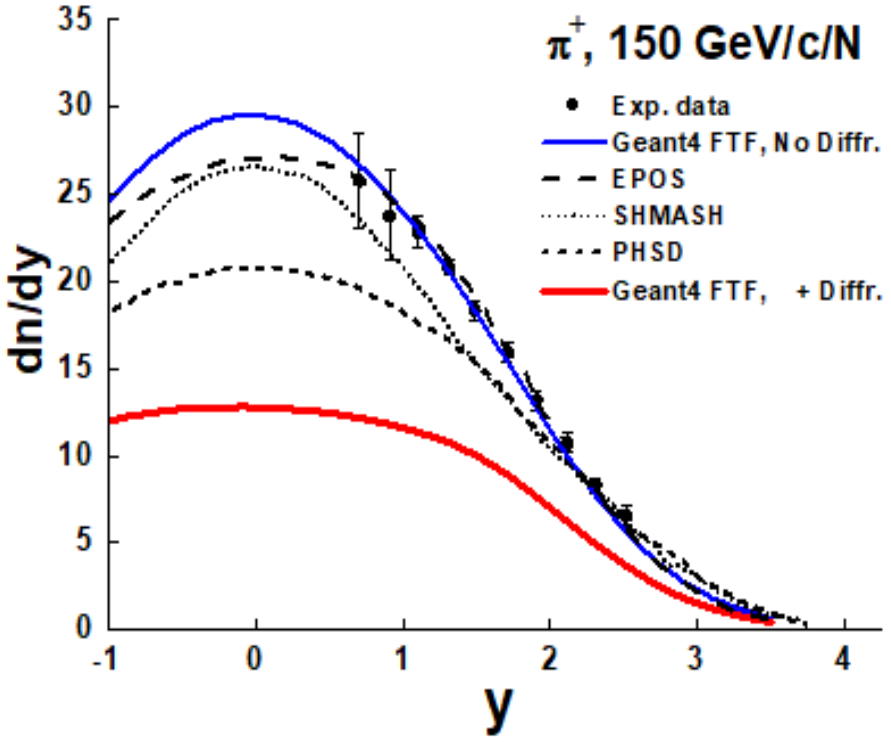
As seen, there is no a correspondence between Exp. data and EPOS one in high part of Epsd after E-shift and scale

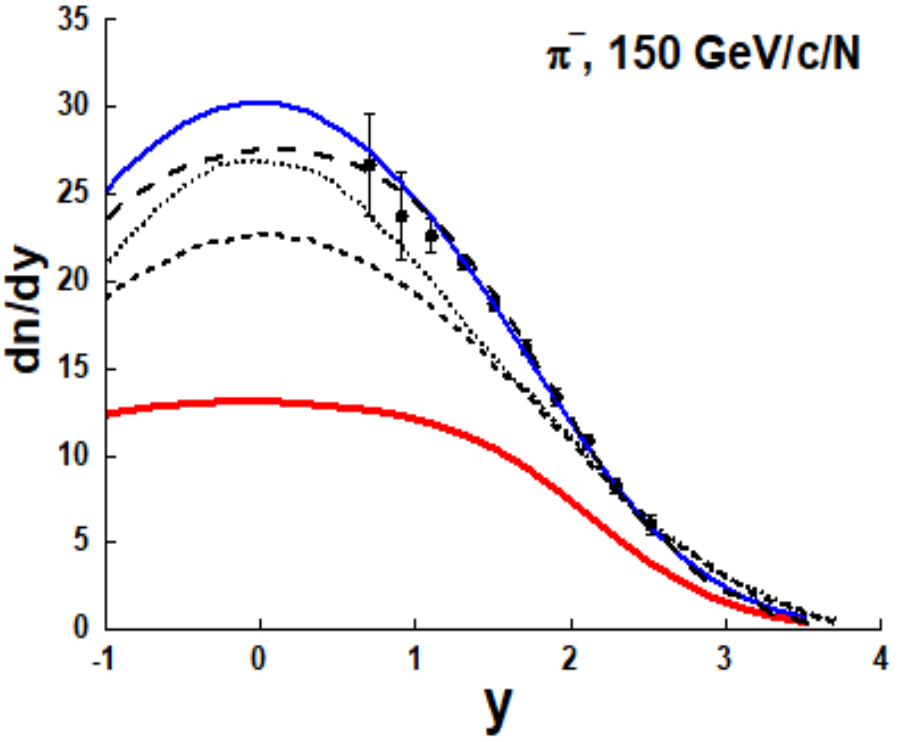
Nuclear residual fragmentation in EPOS is not adequate to Exp.

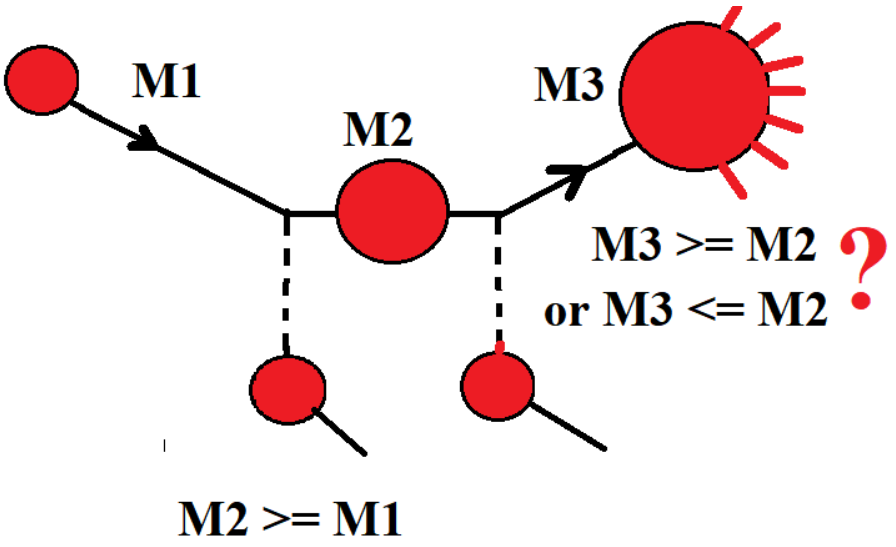
$$\pi B^2_{max} = (C/100)\ \sigma^{in}_{AB}$$

Ar-40 + Sc-45 20 % centrality

The nucleon diffraction in nucleus-nucleus interactions ?





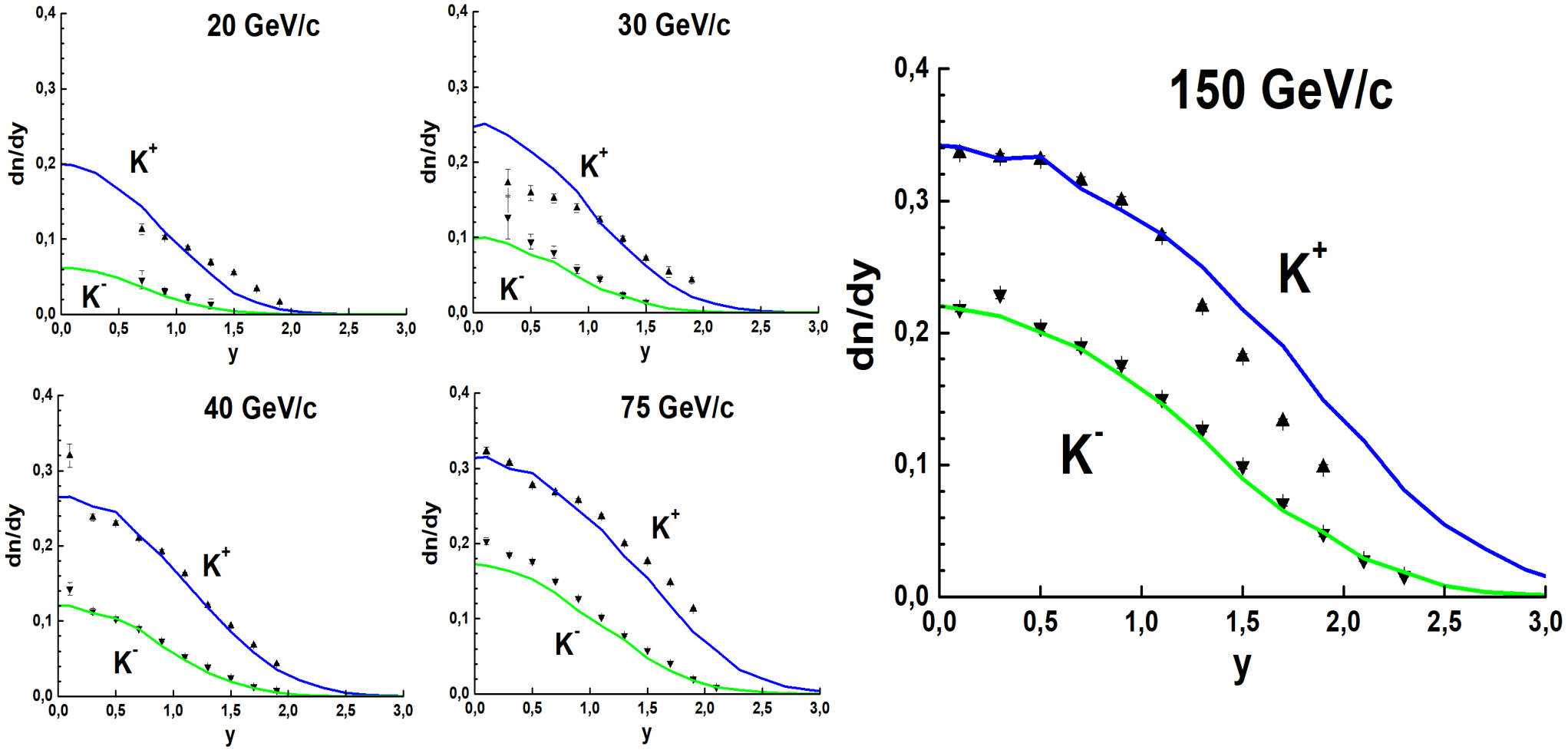


No diffraction at all!?

It is corresponds to QGSM.

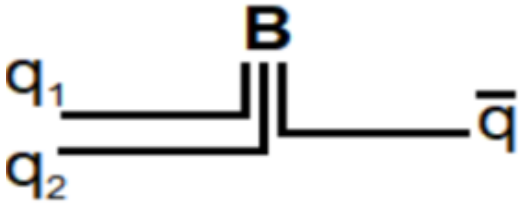
Ar-40 + Sc-45 20 % centrality

Strangeness in the nucleus-nucleus interactions



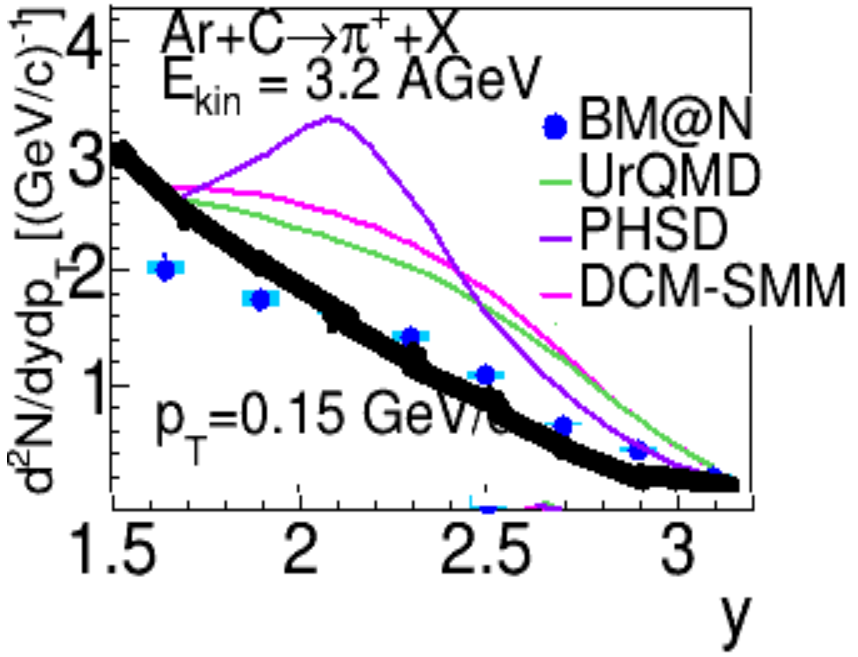
K^- O.K. K^+, we hope, can be better! No QGP!

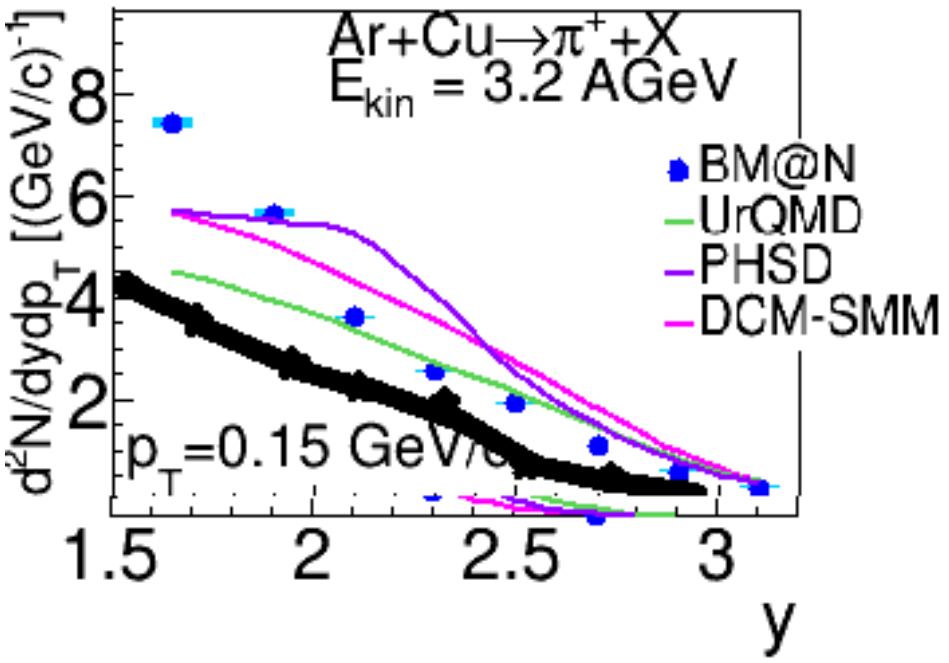
Ps-sbar's are different!

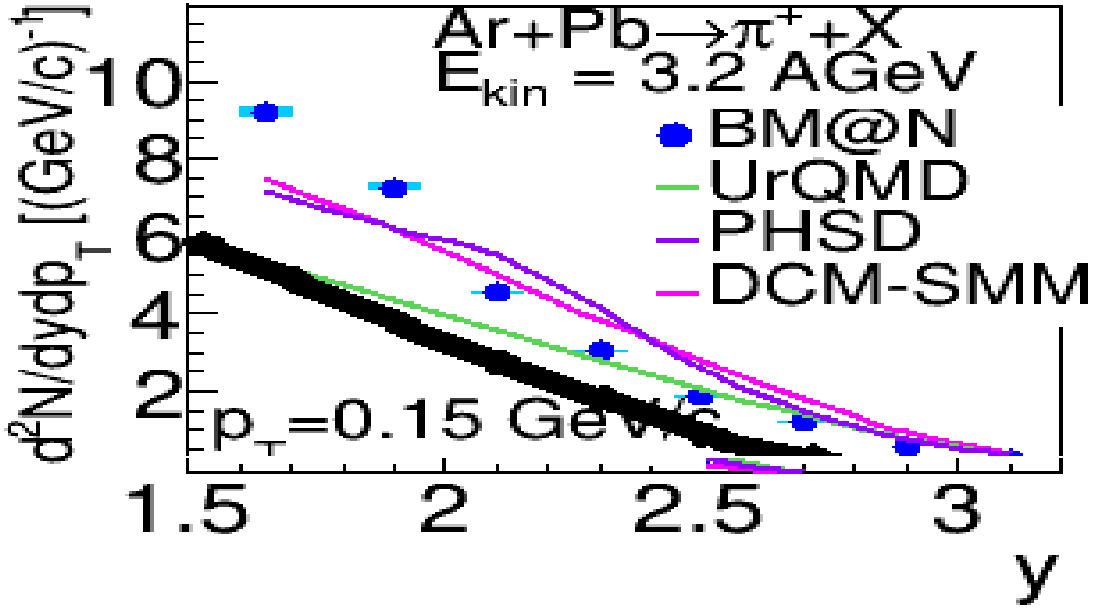


V.Plotnikov, 19 Sept. 2023, BMN Collab. JHEP 07 (2023) 174

Production of π+ and K+ mesons in argon-nucleus interactions at 3.2 AGeV

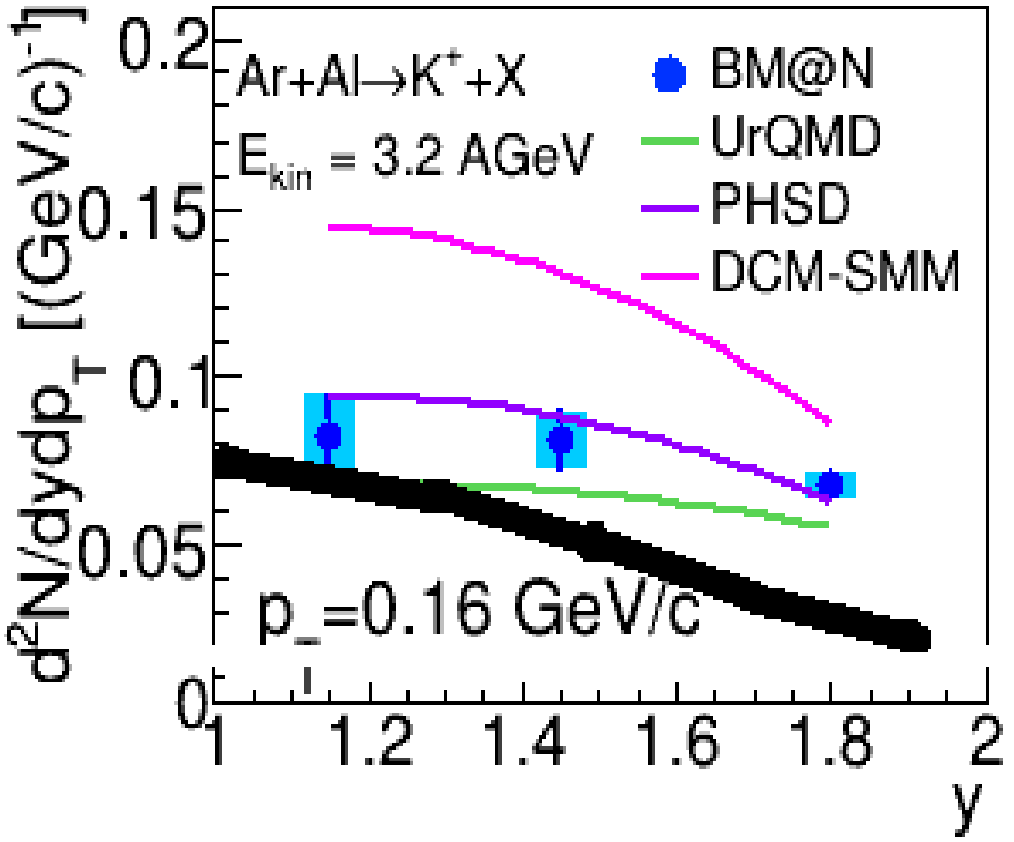


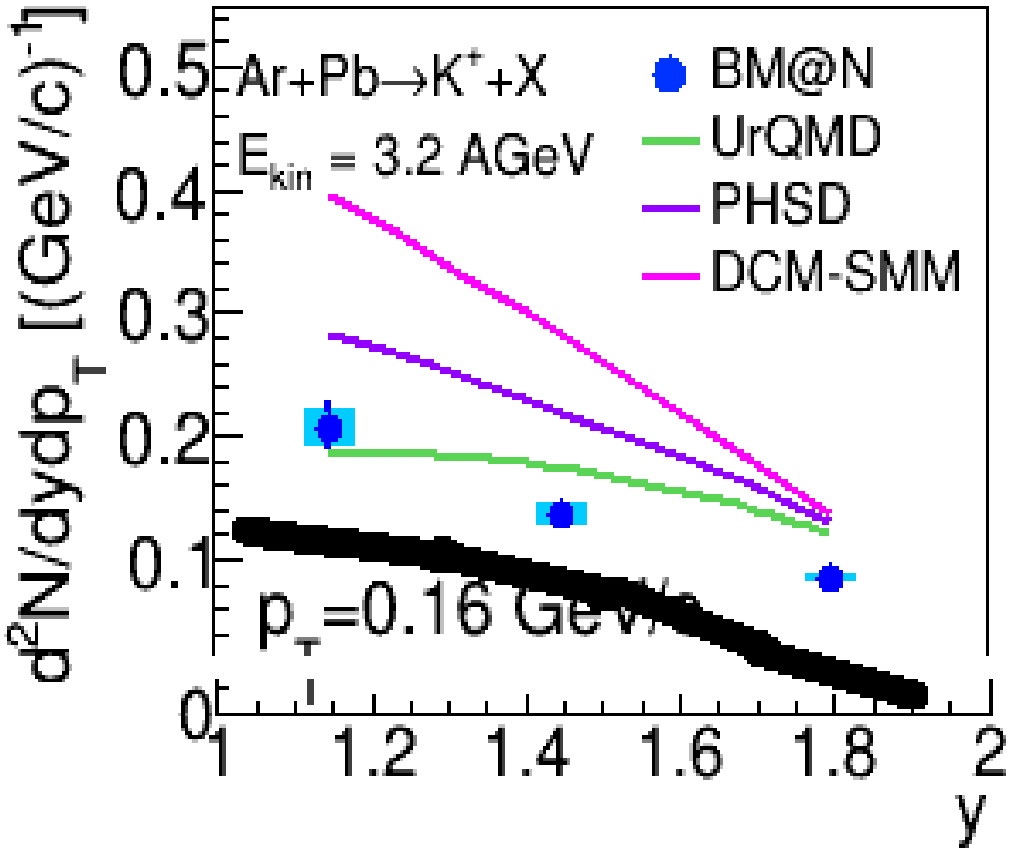


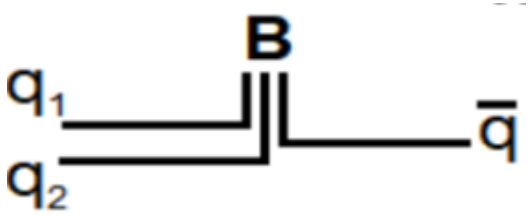


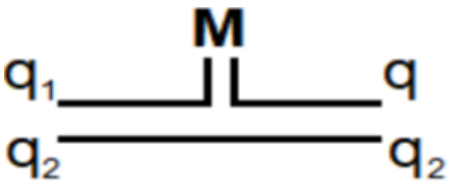
V.Plotnikov, 19 Sept. 2023, BMN Collab. JHEP 07 (2023) 174

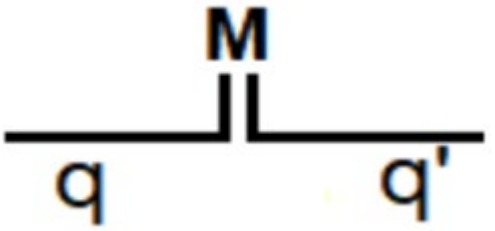
Production of π+ and K+ mesons in argon-nucleus interactions at 3.2 AGeV











Pssbar= 18 % **Pssbar= 20 %** **Pssbar= 12 %**

Summary

1. **Selection of events with various centralities can be a problem in MC models;**
2. **Reproduction of nuclear fragment properties must be checked;**
3. **Description of proton spectra is a problem in all MC model, except GEANT4 FTF;**
4. **Strangeness suppression must be different in various interactions!**

Prob s-sbar: pp – 12 %, pA – 18 %, AA – 30 %

Why?

Strangeness enhancement due to string fluctuations PRD101 (2020)
H. J. Pirner,1 B. Z. Kopeliovich,2 and K. Reygers

Hypotheses:

1. **Misidentification of Pi+ or protons as K+;**
2. **Secondary interactions -- Rho + N → K+, K-, Lambda;**
3. **QGP;**
4. **Nuclear medium effect;**
5. **Change of the string tension parameter in nuclear medium;**
6. **Fragmentation of strings in instantons;**
7. **Color electric Permittivity in a medium.**

Permittivity in electromagnetism

$$F = \frac{1}{4\pi\varepsilon_a} \cdot \frac{|q_1 q_2|}{r_{12}^2}$$

Cornell-like potentials $V_{Cornell} = -\frac{0.641}{r} + 0.113 \cdot r$ $V_{Martin}(r) = -8.054 + 6.870 \cdot r^{0.1}$

Baryons and tetraquarks using instanton-induced interactions; 2308.05638
Nicholas Miesch,* Edward Shuryak,† and Ismail Zahed

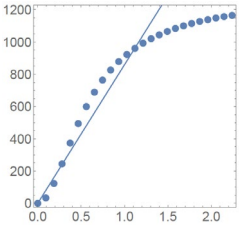
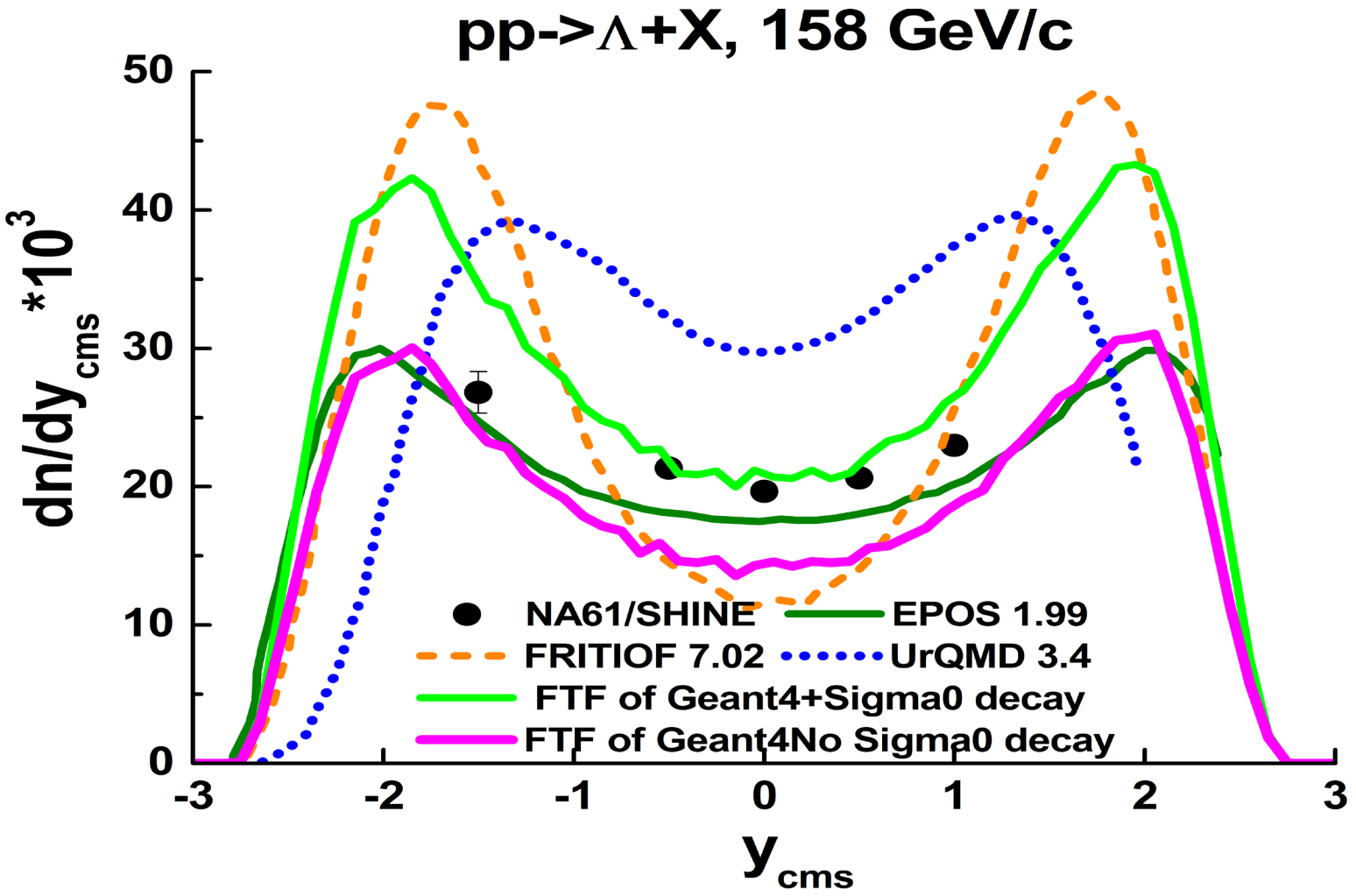


FIG. 5. The points show the instanton-induced effective potential in baryons V (R6), (MeV) vs R6 (fm).. The tension force is of the order of 1 GeV/fm (shown by a line for comparison

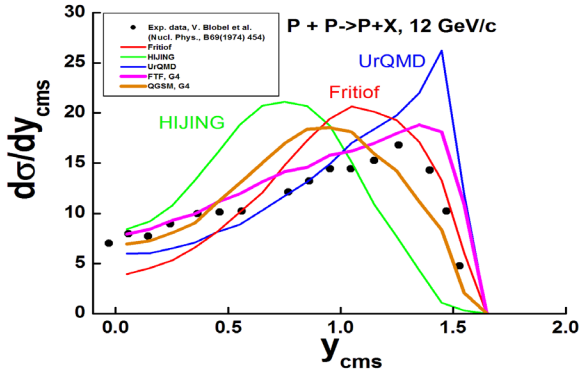
Production of Λ-hyperons in inelastic p+p interactions at 158 GeV/*c*

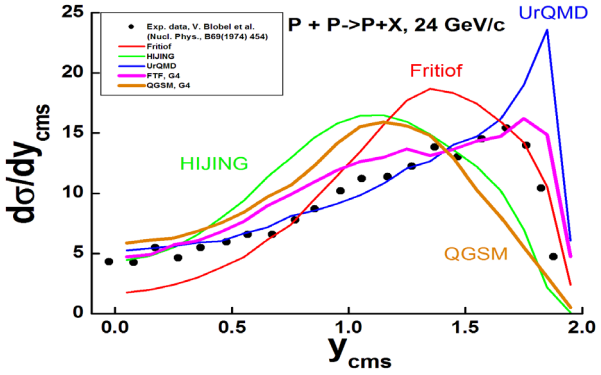
NA61/SHINE Collaboration Eur. Phys. J. C (2016) 76:198

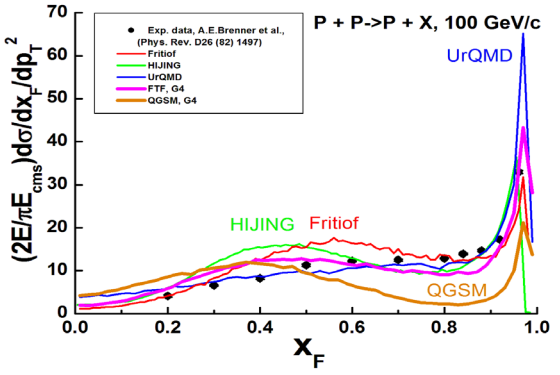


Fritiof 1.6, Fritiof 7.0, Hijing, UrQMD 3.3, pp-interactions

Description of baryon spectra is the problem in all MC models

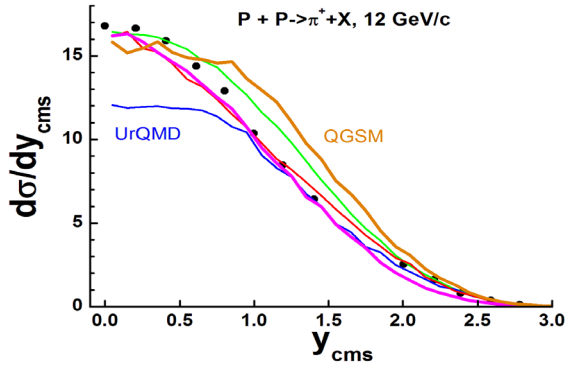


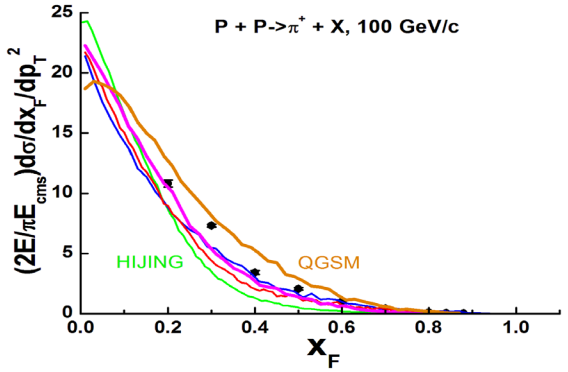


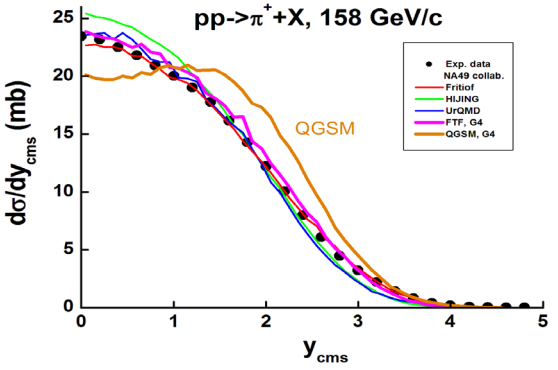


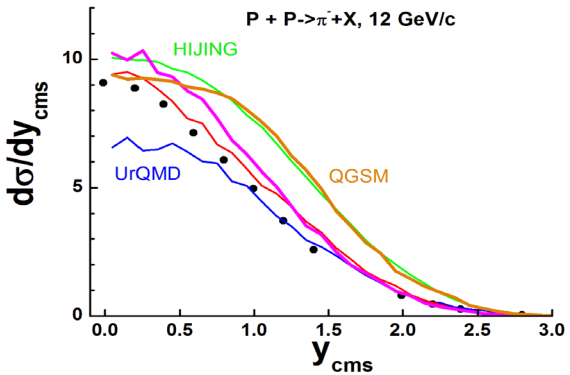
Exp. Data: V. Blobel et al., Nucl. Phys., B69(1974) 454.

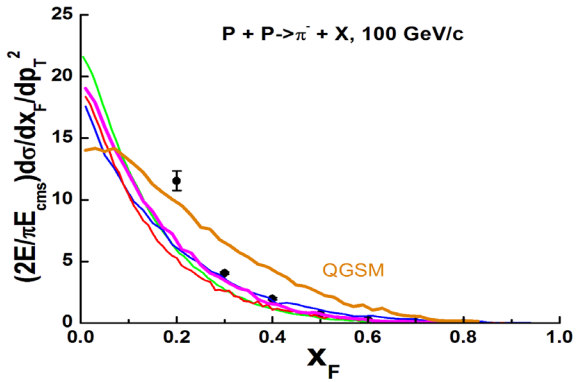
There are some problems with a description of meson spectra

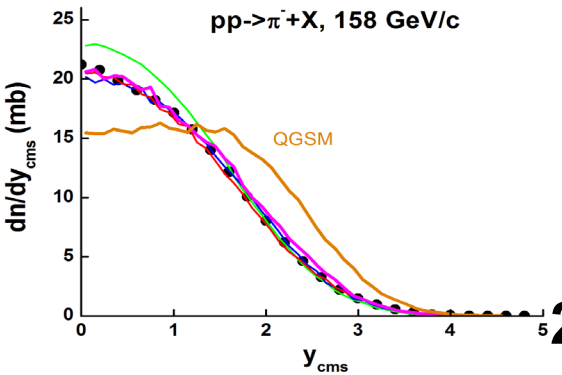




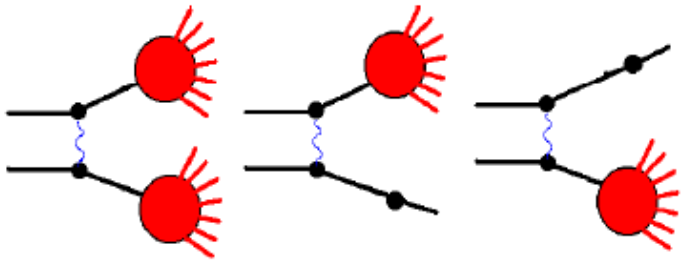




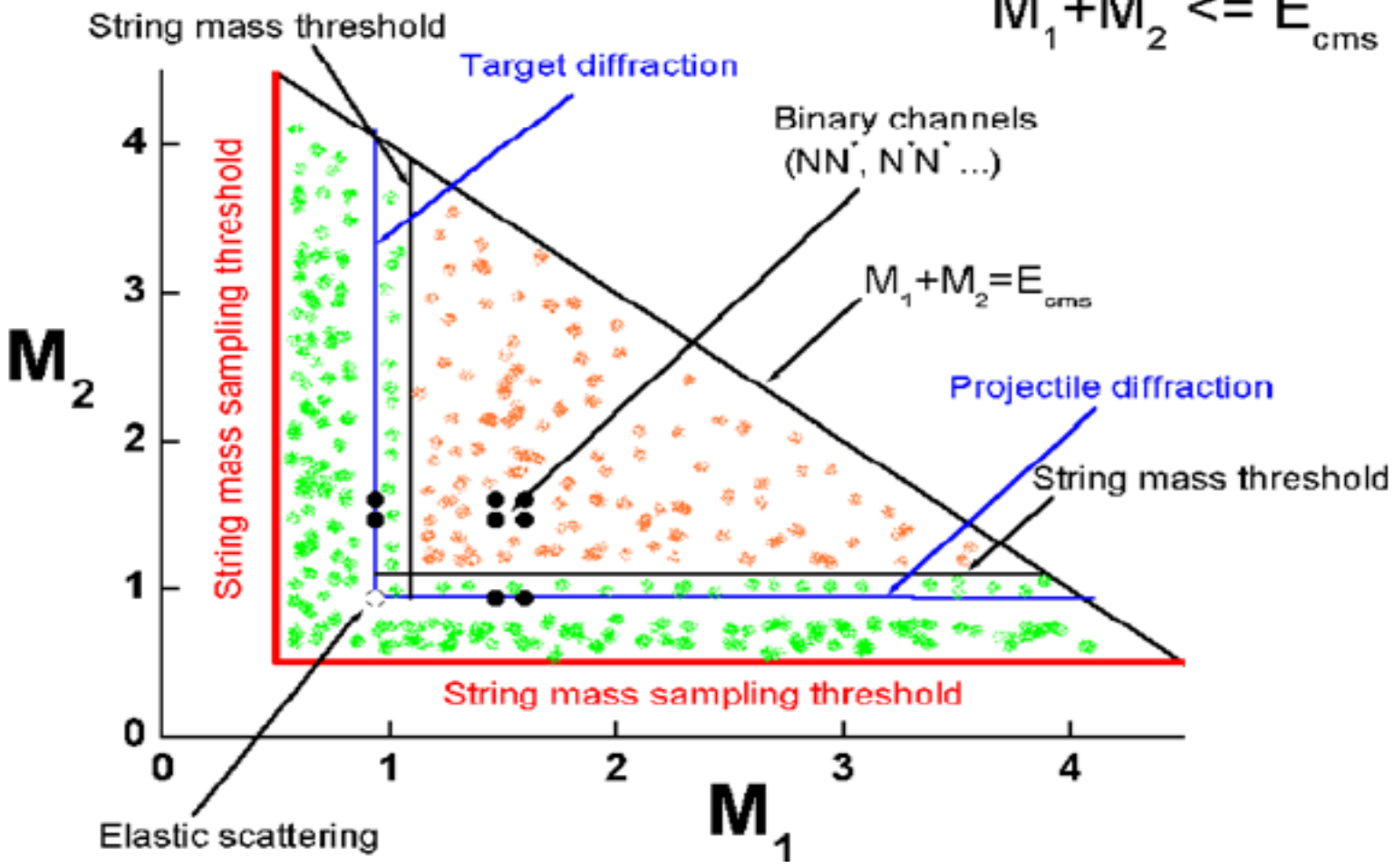




FTF model : basic assumptions



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



UrQMD Md=1.46

$NN \to N\Delta_{1232}$

$NN \to NN^*$

$NN \to N\Delta^*$

$NN \to \Delta_{1232}N^*$

$NN \to \Delta_{1232}\Delta^*$

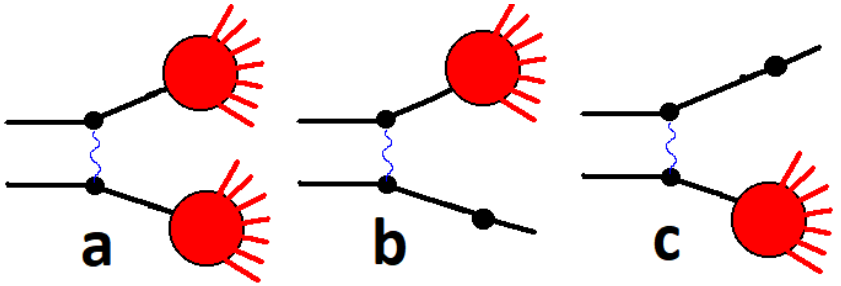
$NN \to \Delta\Delta$ excitation

Fritiof 1.6 – Md=1.2; Fritiof 7.0 Md=1.2; Hijing Md~2 Lines

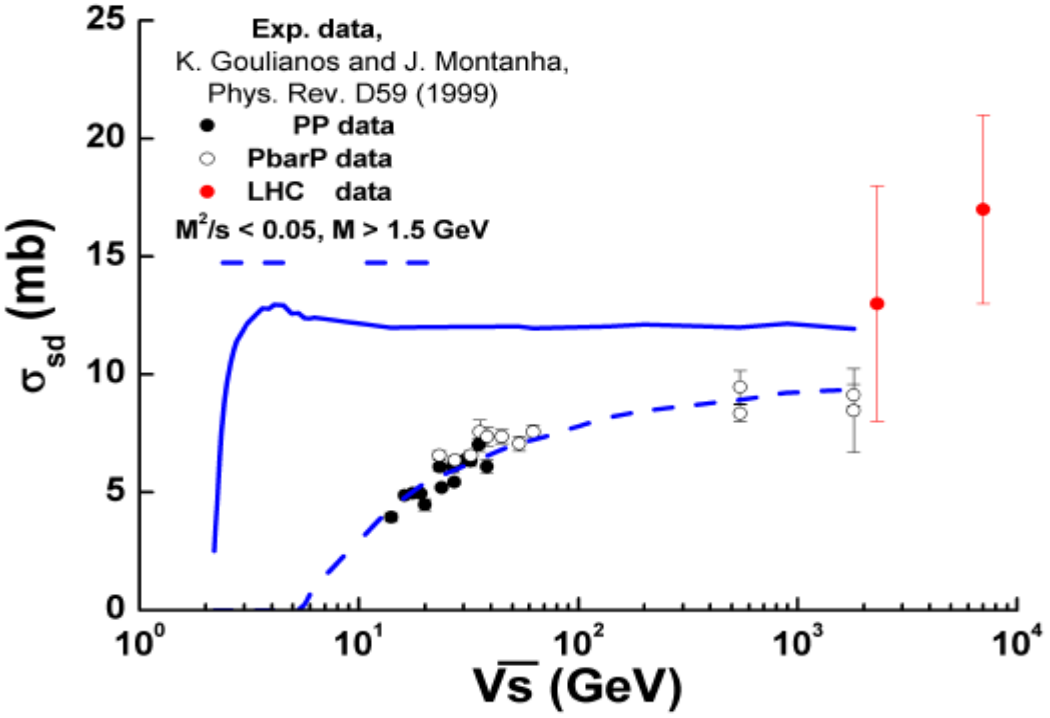
FTF model : basic assumptions

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

Processes of string's creations considered in the FTF model.

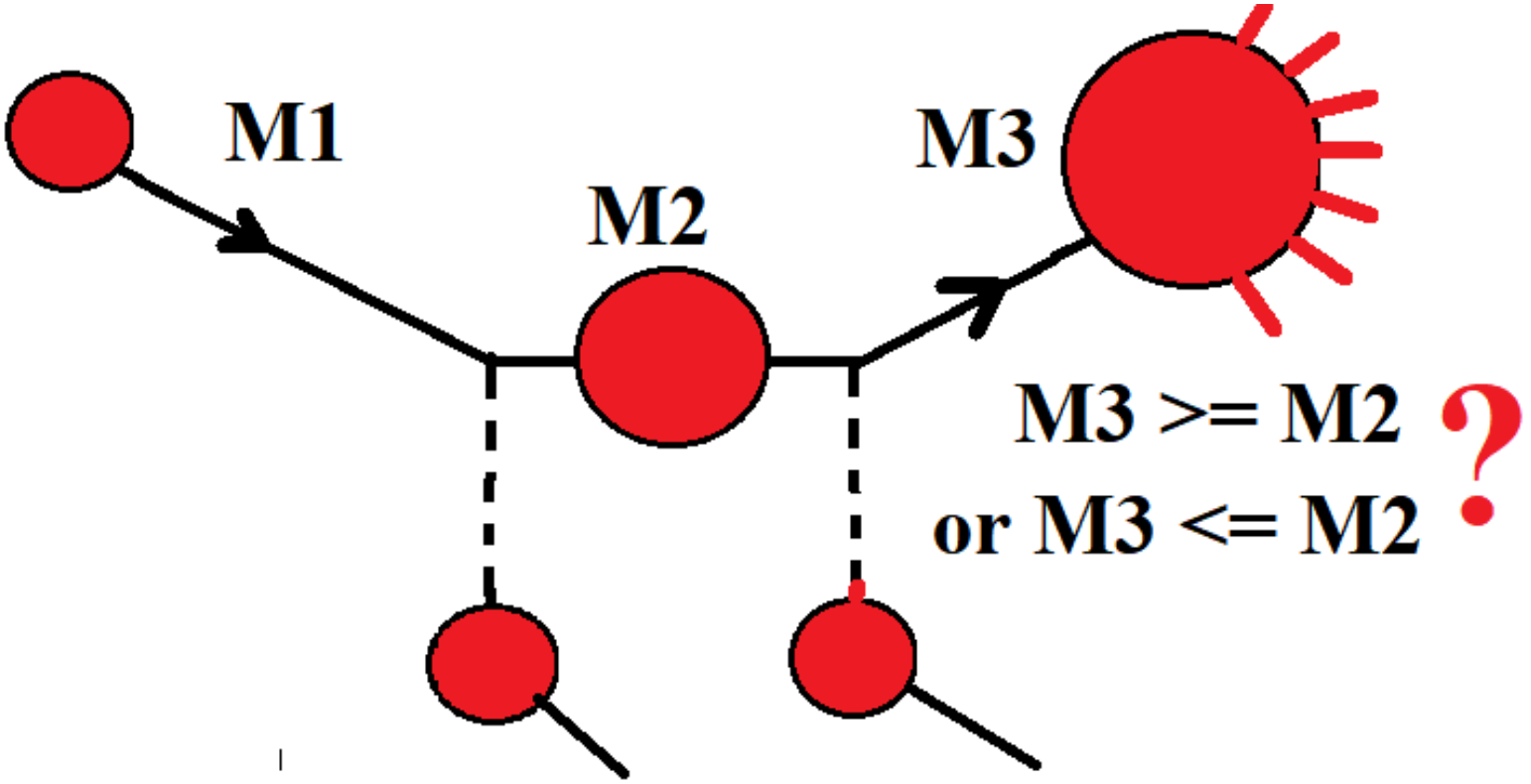


Special parameterizations of the diffraction cross sections are implemented in the HIJING and FTF models.



Energy dependence of the cross section of single one-vertex diffraction in pp interactions. Solid line is FTF model approximation. Dashed line is FTF model calculations with accounting of experimental restrictions on masses of produced systems - M, M^2/s <= 0:05 and M >= 1.5 GeV. Points are experimental data gathered in [22], see there the exact references.

hA and AA interactions?



36 years old question!

Now, M3 => M2 !