Geant4 FTF Model Description of the NA61/SHINE Collaboration Data on Strange Particle Production in pp-interactions

A. Galoyan and V. Uzhinsky, 12.07.2022

Latest data by the NA61/SHINE collaboration

Measurement of ϕ meson production in $p + p$ interactions at 40, 80 and 158 GeV/c with the NA61/SHINE spectrometer at the CERN SPS Eur. Phys. J. C (2020) 80:199 (Received: 17 August 2019)

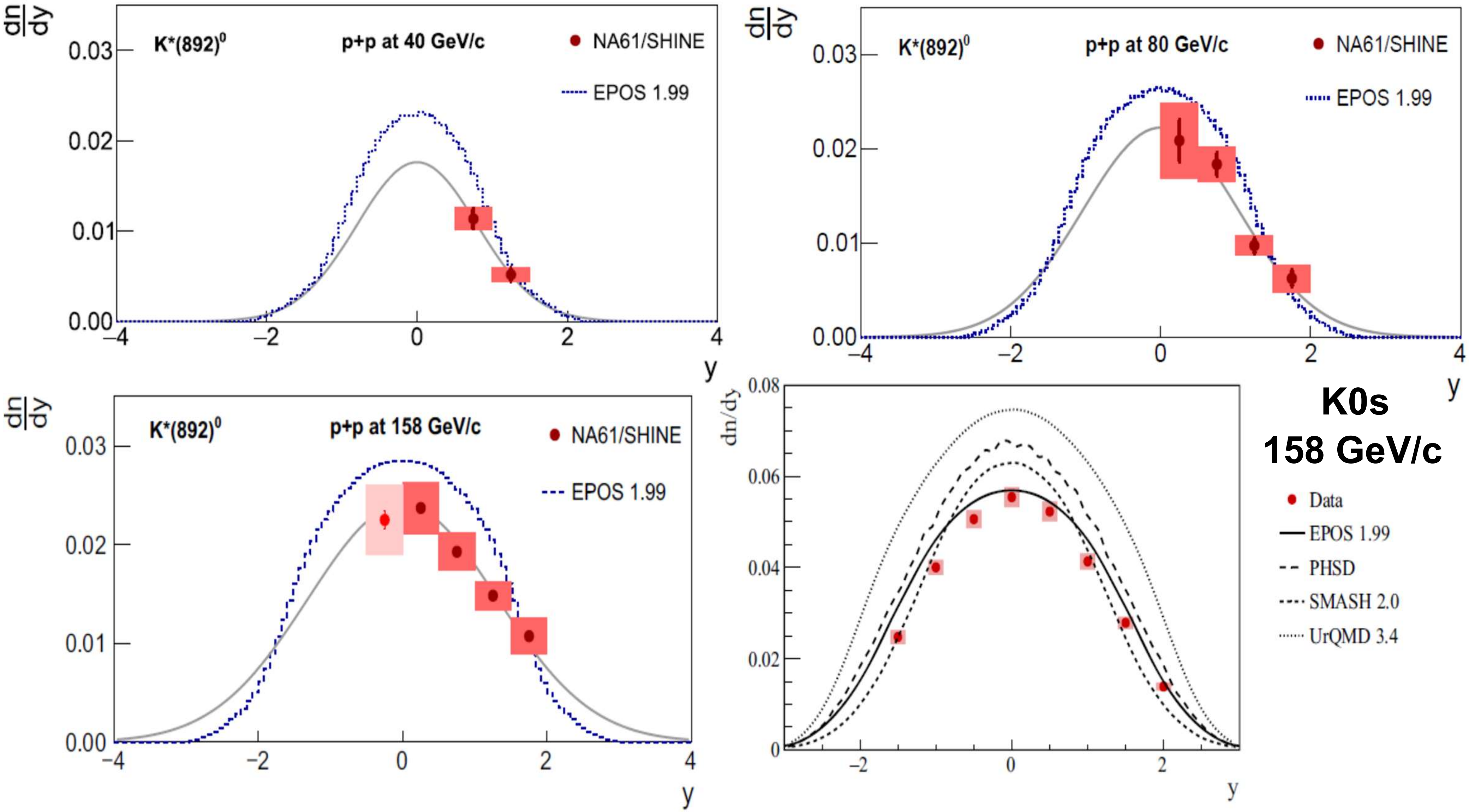
$K^*(892)^0$ meson production in inelastic p+p interactions at 158 GeV/c beam momentum measured by NA61/SHINE at the CERN SPS Eur. Phys. J. C (2020) 80:460 (Received: 20 January 2020)

$K^*(892)^0$ meson production in inelastic $p+p$ interactions at 40 and 80 GeV/c beam momenta measured by NA61/SHINE at the CERN SPS

Eur. Phys. J. C (2022) 82:322(Received: 22 December 2021)

Measurements of Ξ^- and $\overline{\Xi}^+$ production in proton–proton interactions at $\sqrt{s_{NN}} = 17.3$ GeV in the NA61/SHINE experiment
Eur. Phys. J. C (2020) 80:833 (Received: 4 June 2020)

*K**(892)^0 meson production in inelastic p+p interactions at 158 GeV/*c* beam momentum measured by NA61/SHINE at the CERN SPS



EPOS cannot describe the K*0 data!

There is no model able to describe the data on K0s except EPOS!

Measurement of φ meson production in $p+p$ interactions at 40, 80 and 158 GeV/c with the NA61/SHINE spectrometer at the CERN SPS

Eur. Phys. J. C (2020) 80:199

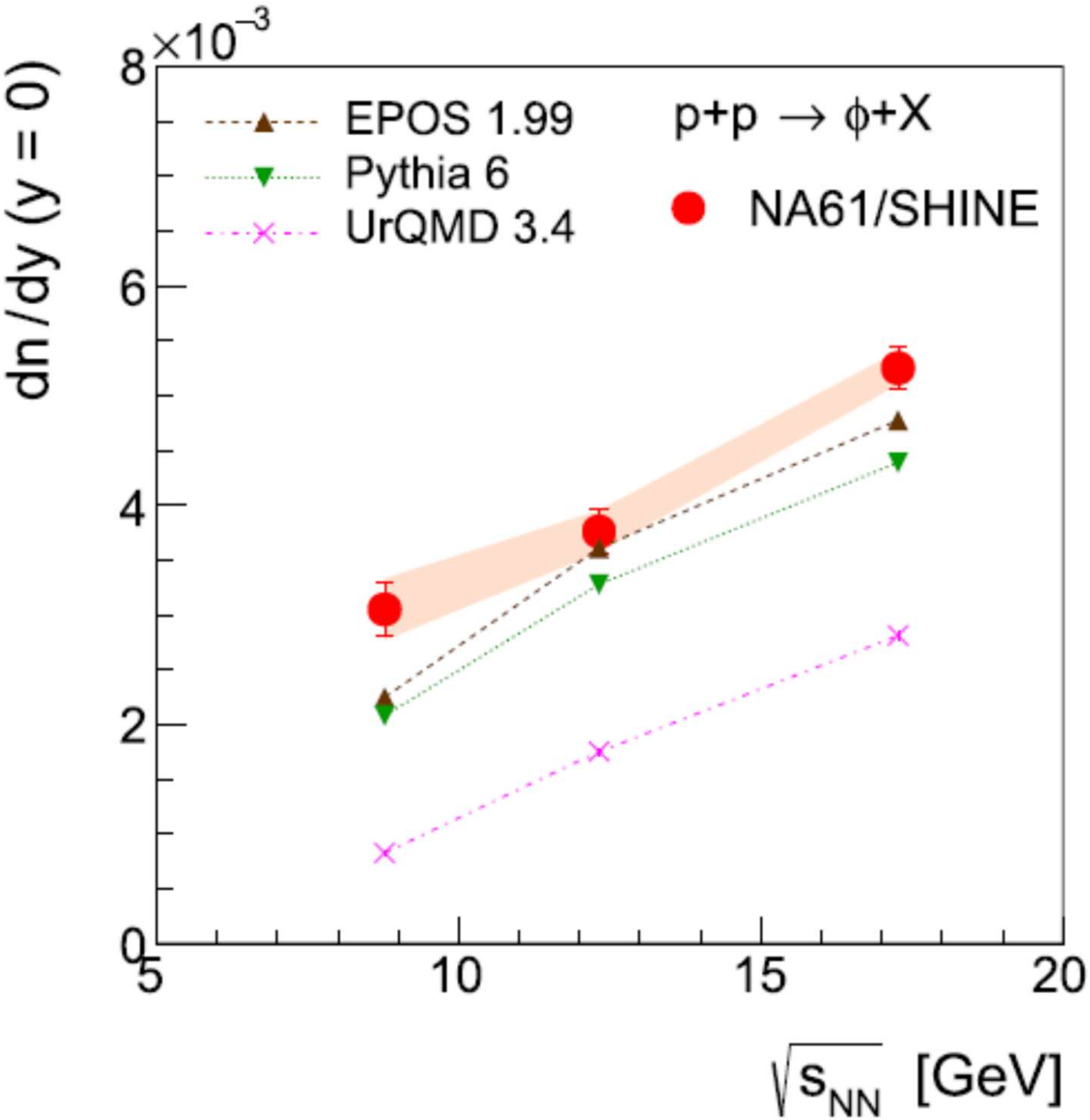
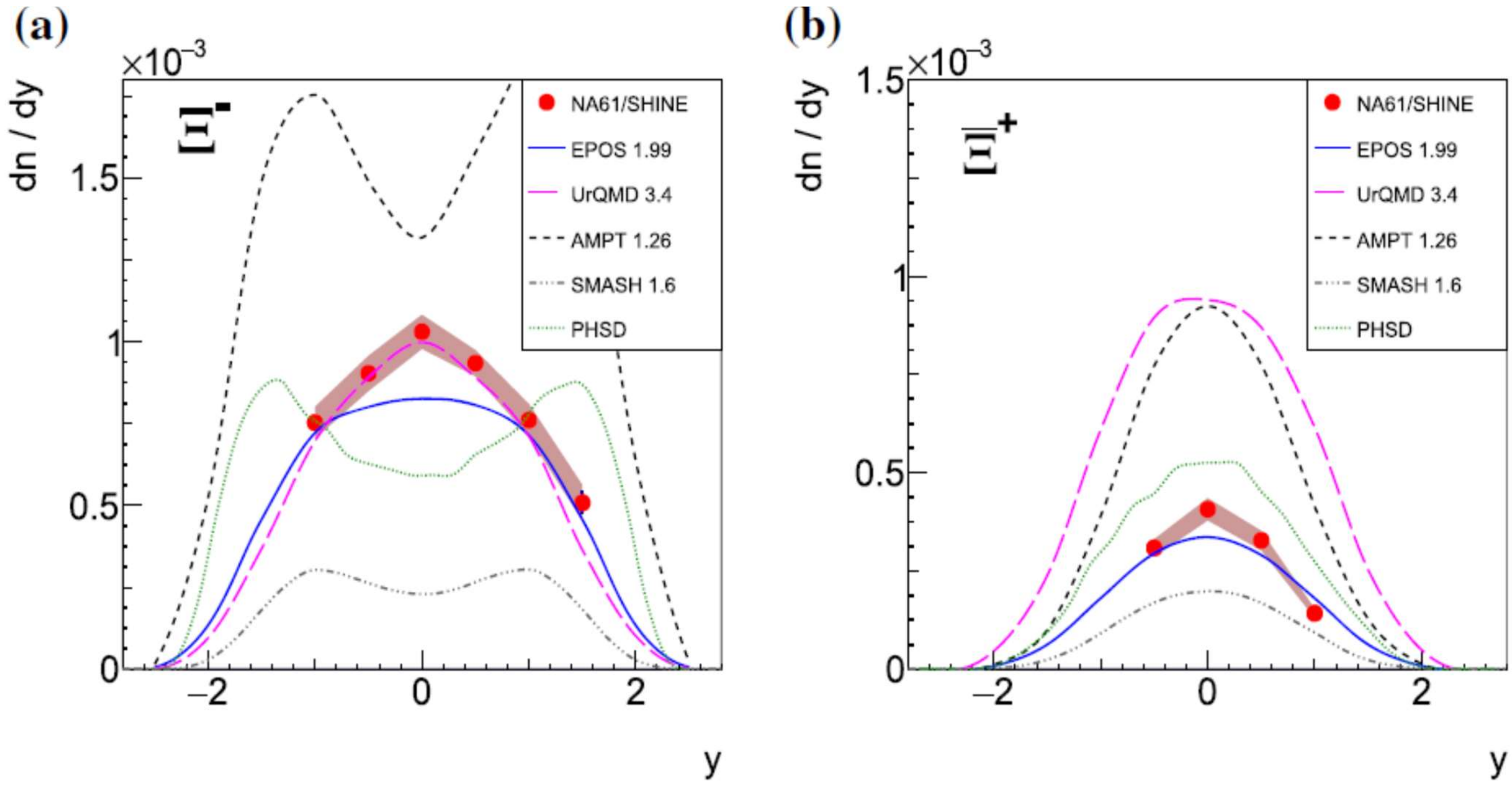


Fig. 17 Energy dependence of midrapidity yields of φ mesons in $p+p$ collisions at SPS energies. Also shown are the results of microscopic model calculations (Epos, Pythia, UrQMD)

EPOS, Pythia and UrQMD models cannot describe the high of φ meson rapidity distributions in the central region!

Measurements of Ξ^- and $\overline{\Xi}^+$ production in proton–proton interactions at $\sqrt{s_{NN}}$ = 17.3 GeV in the NA61/SHINE experiment

Eur. Phys. J. C (2020) 80:833



No MC model able to describe production of vector mesons and Xi hyperons!

We are responsible for the development of the Geant4 hadronic models – FTFp (Fritiof) and QGSp (Quark-Gluon String) models. We were going to tune the model parameters using the exp. data.

The main idea:

Yield of K*0 ≈ Ps-sbar * Pvec,
Yield of K+- ≈ Ps-sbar * Ppsm + Decay prod. of K*'s

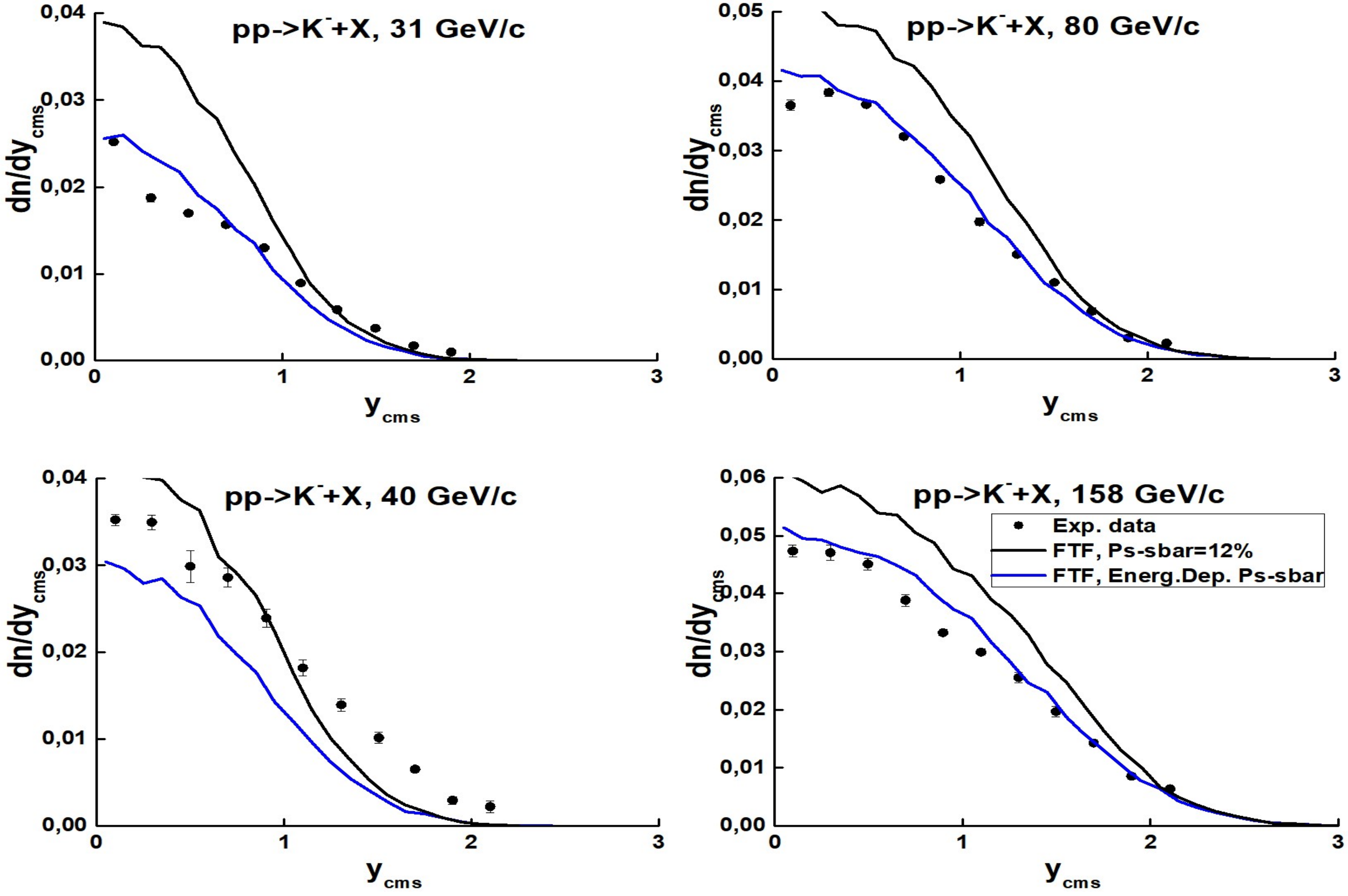
Ps-sbar – probability of pair of strange quark prod.	12 %
Ppsm – probability of pseudoscalar meson production	0.5
Pvec = 1-Ppsm - probability of vector meson production	0.5

A Parametrization of the Properties of Quark Jets

R.D. Field, R.P. Feynman *Nucl.Phys.B* 136 (1978) 1

2. 7.1. Recursive scheme
(iii) One decides on the spin-parity of the primary meson, according to (2.45), (i.e., pseudoscalar or vector with equal probabilities.

Geant4 FTF model: tune of Ps-sbar (12 %)



Black lines:
Ps-sbar =12 %

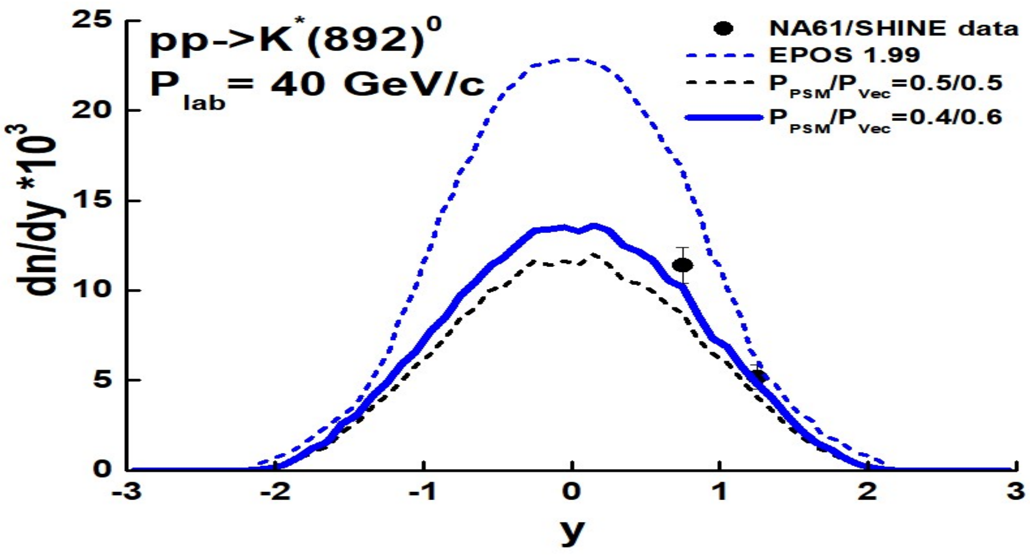
Blue lines:
Ps-sbar = 0.12*
$[1 – (Mth/Mstr)^{2.5}]$

Dependence of Ps-sbar on a string mass ?

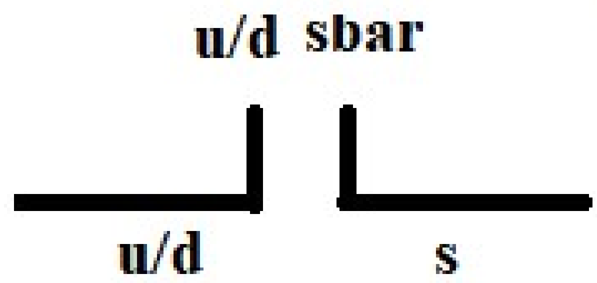
Measurements of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/*c* with the NA61/SHINE spectrometer at the CERN SPS

NA61/SHINE Collaboration, Eur. Phys. J. C (2017) 77:671

Geant4 FTF model: tune Ppsm

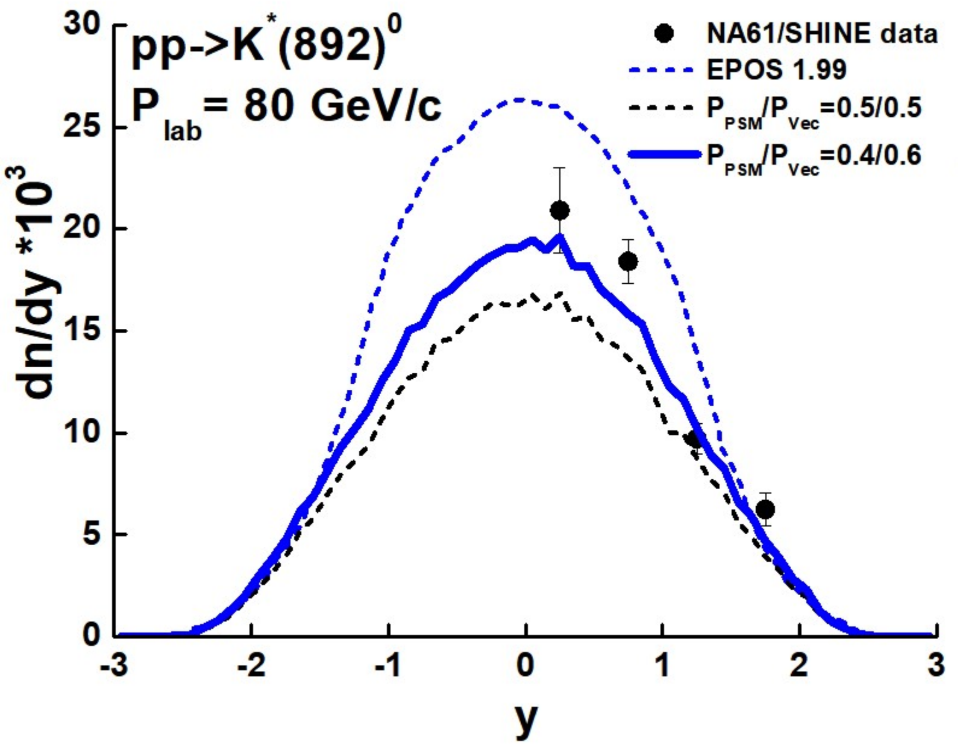


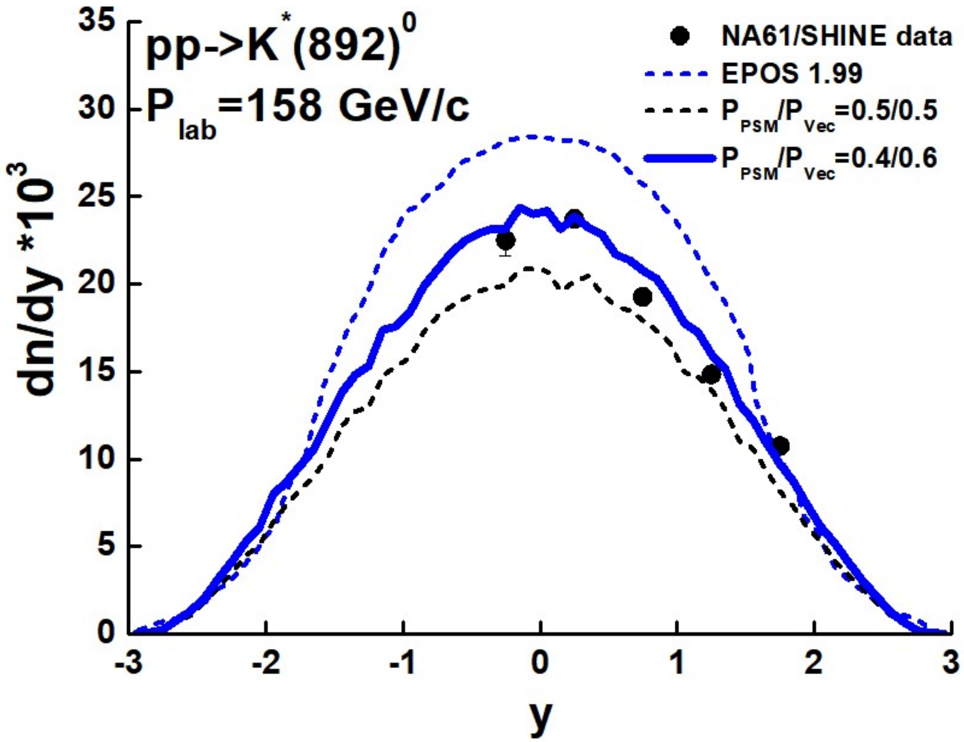
Meson - PS/V (0.5/0.5 Std)



Ps-sbar = 12% (Std.)

New PS/V - 0.4/0.6



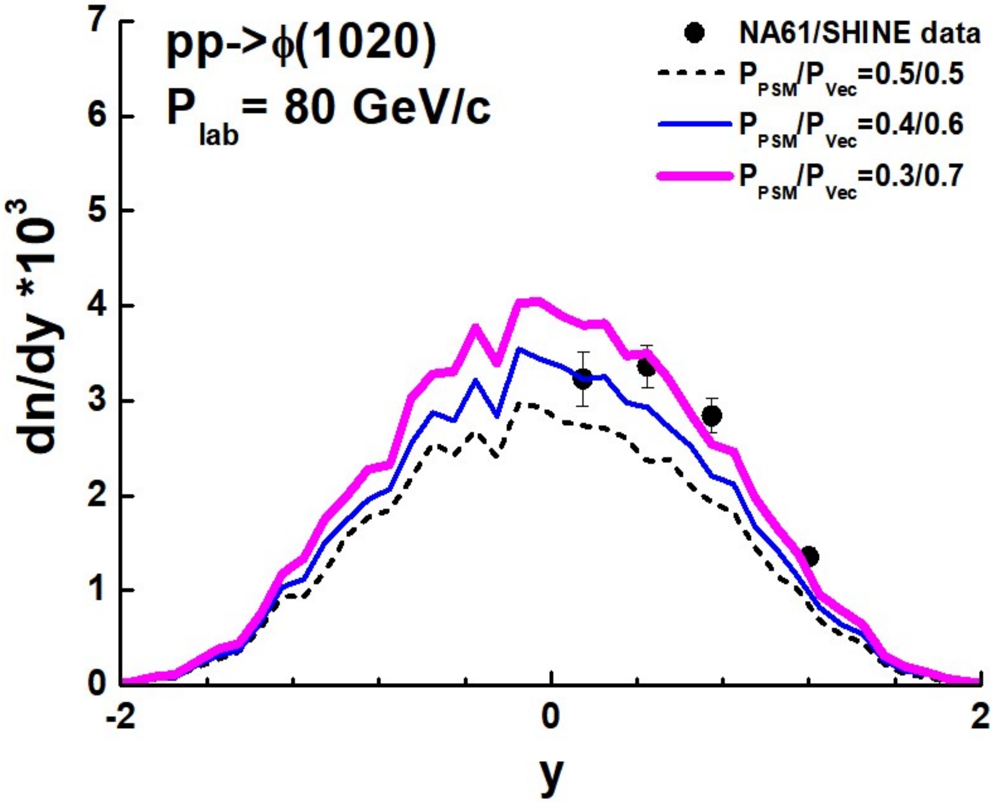


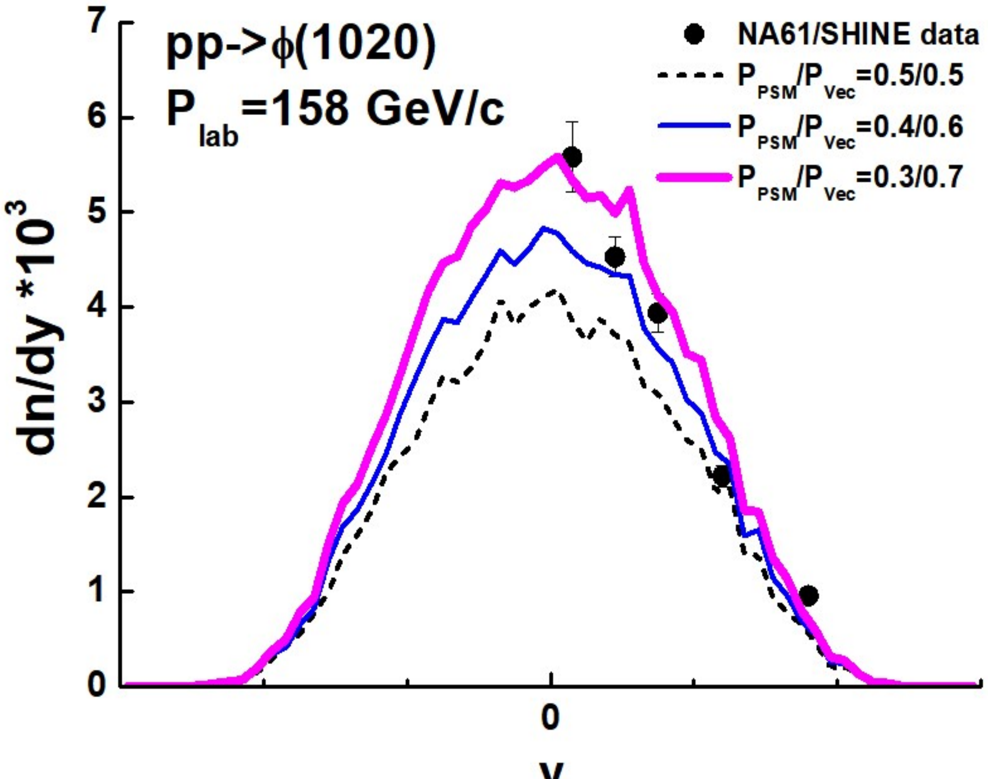
New Ppsm/Pvec = 0.4/0.6

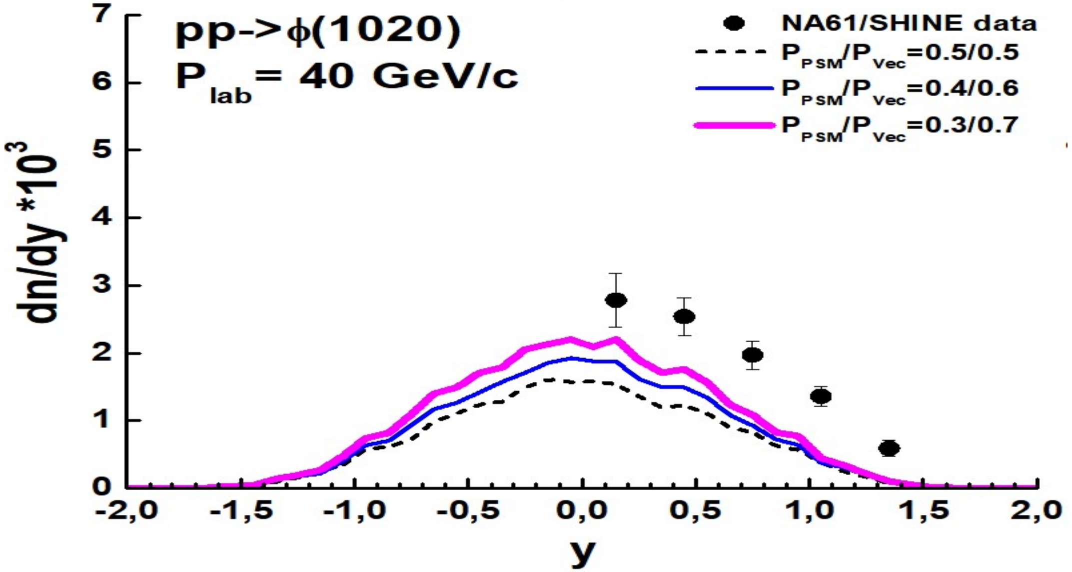
Слайд 7

L72 Lenovo 78; 09.07.2022

Problem of Phi meson description, Ppsm/Pvec=0.3/0.7

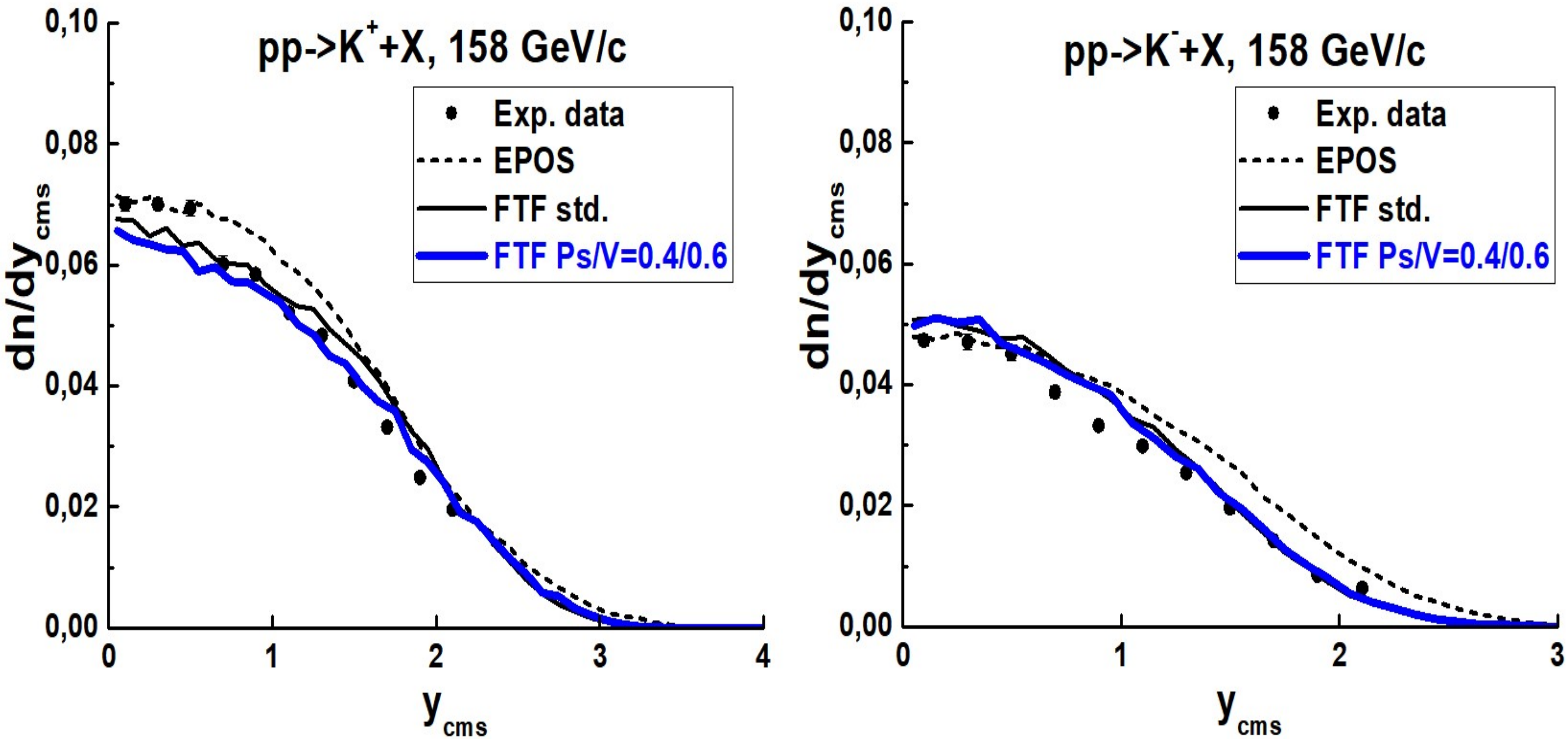






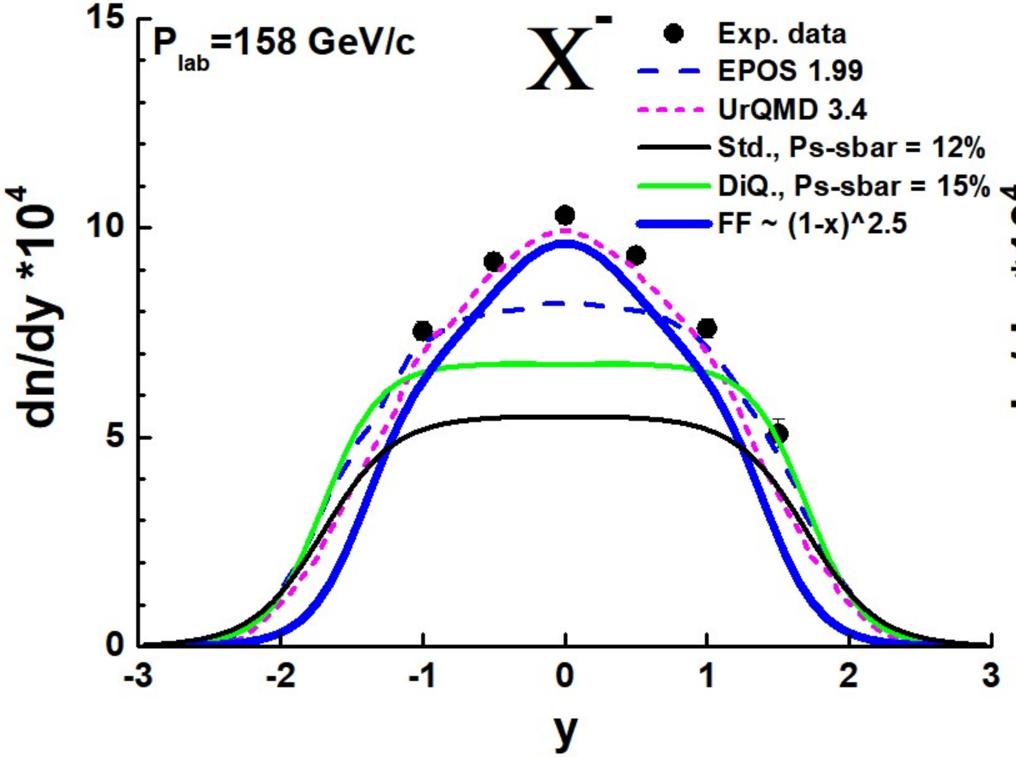
Pythia 6.4 In the program, the spin S is first chosen to be either 0 or 1. This is done according to parameterized relative probabilities, where the probability for spin 1 by default is taken to be **0.5** for a meson consisting only of u and d quark, **0.6** for one which contains s as well, and **0.75** for quarks with c or heavier quark, in accordance with the deliberations above.

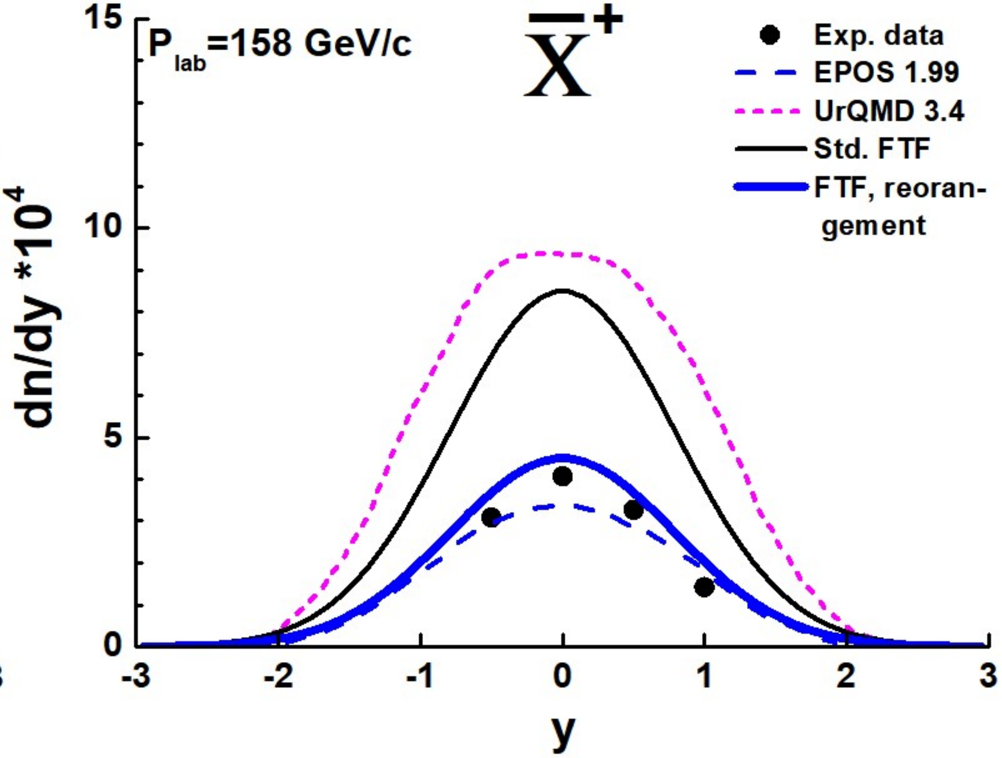
Standard K+ and K- production



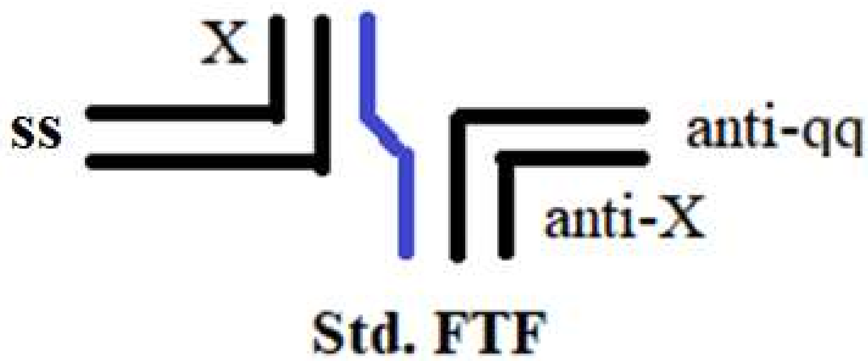
Small changes,
as it was expected.

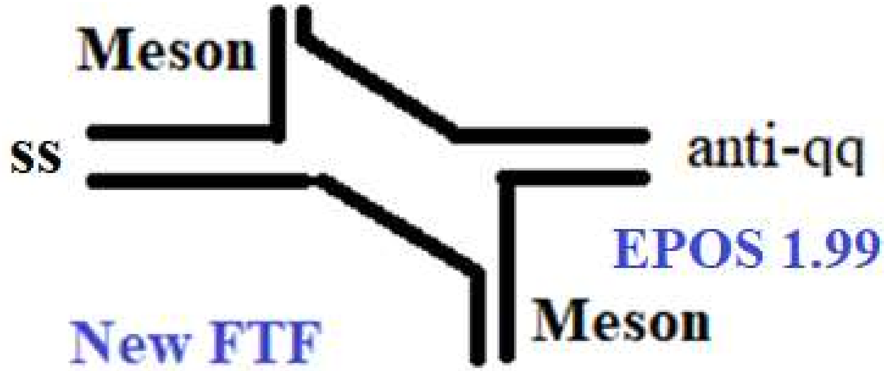
Problem of Hi-hyperon production



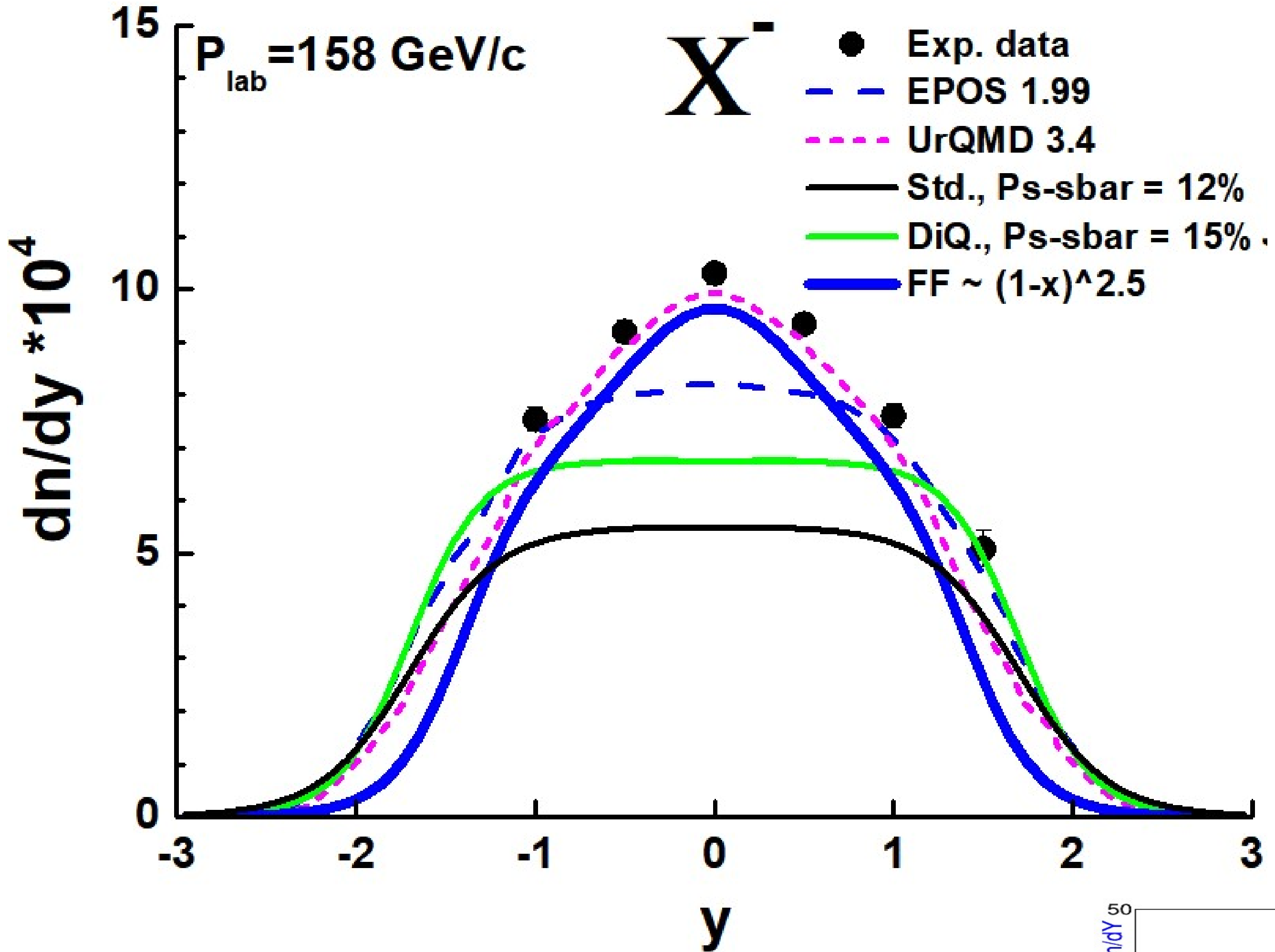


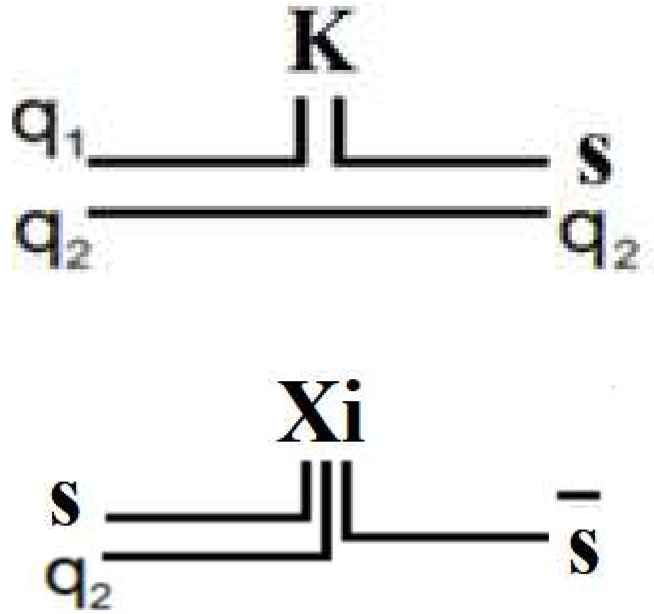
Anti-X is mainly produced at Last String Decay!





Problem of Hi-hyperon production





Ps-sbar ?

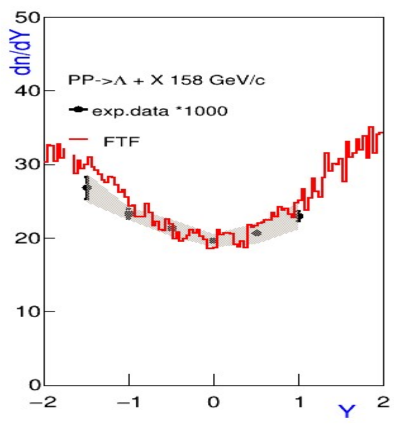
12 or 15 %?

LUND symmetric fragmentation function

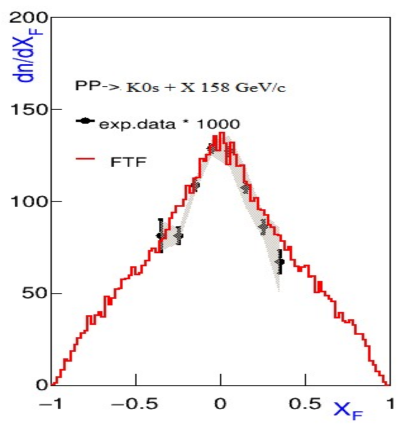
For mesons $f(z) \propto \frac{1}{z} z^{a_\alpha} \left(\frac{1-z}{z} \right)^{a_\beta} \exp\left(-\frac{b m_\perp^2}{z} \right)$

For baryons, a'la Kaidalov $f(z) = \frac{c}{(z_{max} - z_{min})^c} (z - z_{min})^{c-1}$

New FF for Hi - $f(z) \sim (z_{max} - z)^{c-1}$



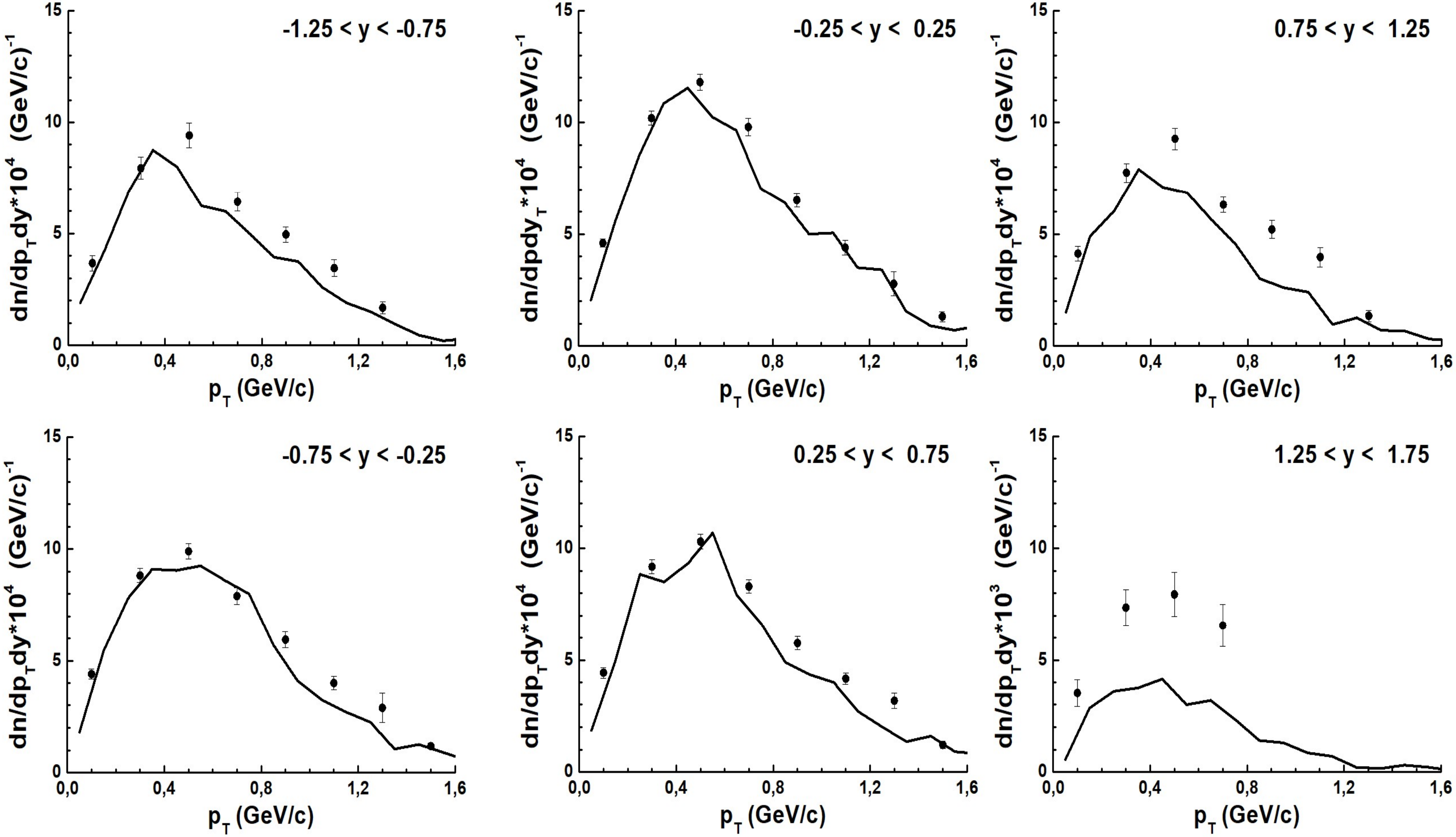
Lambda



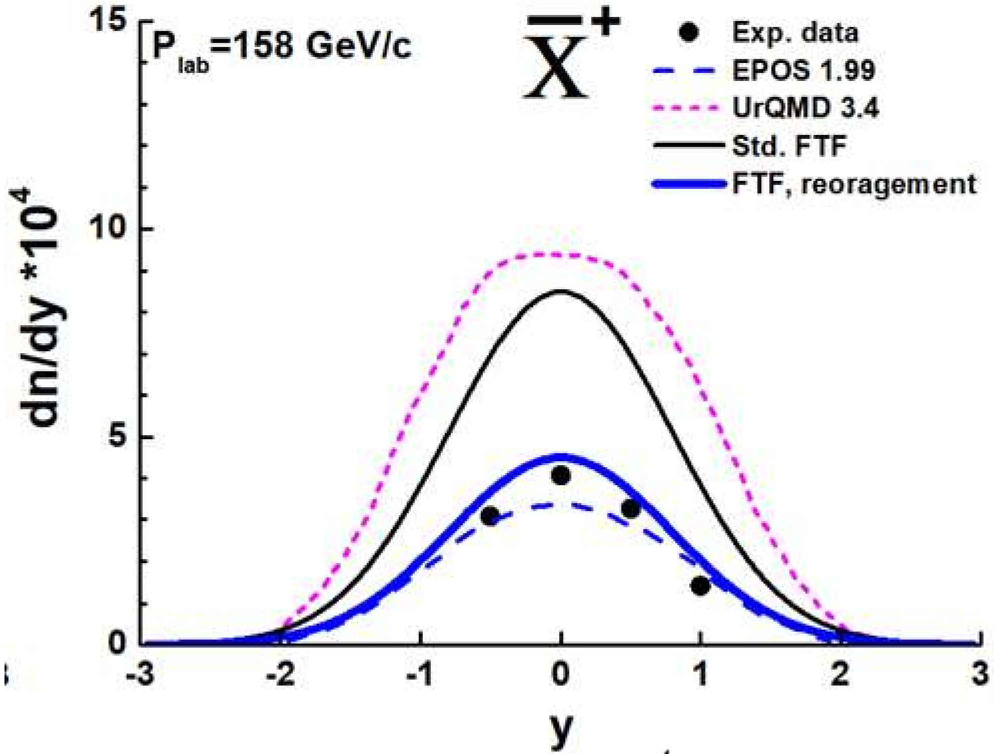
K0s

Problem of Hi-hyperon production

Pt distribution are approximately correct!



Problem of Hi-hyperon production



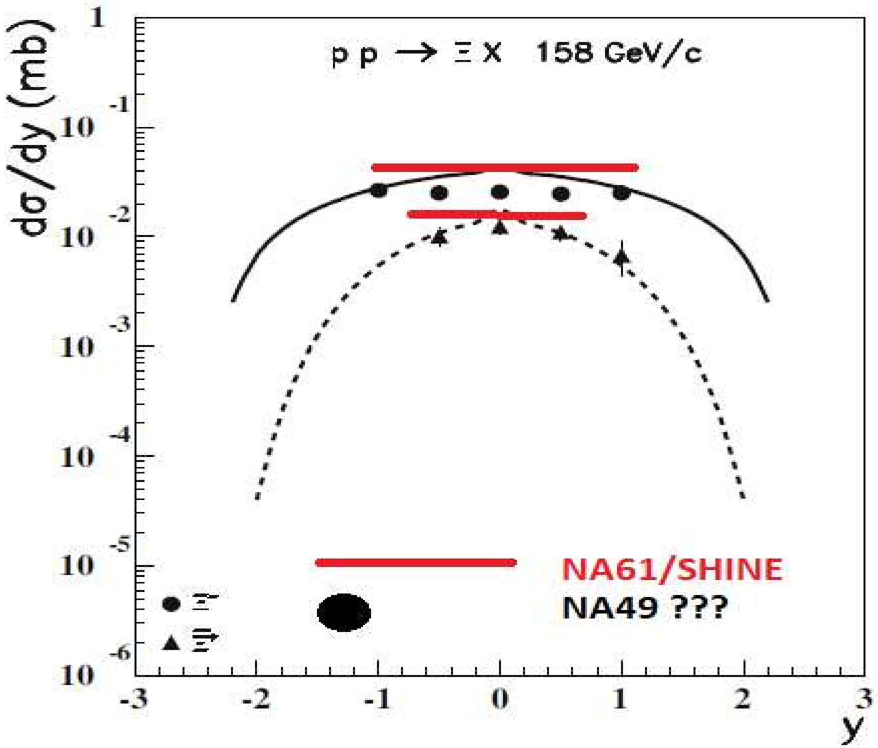
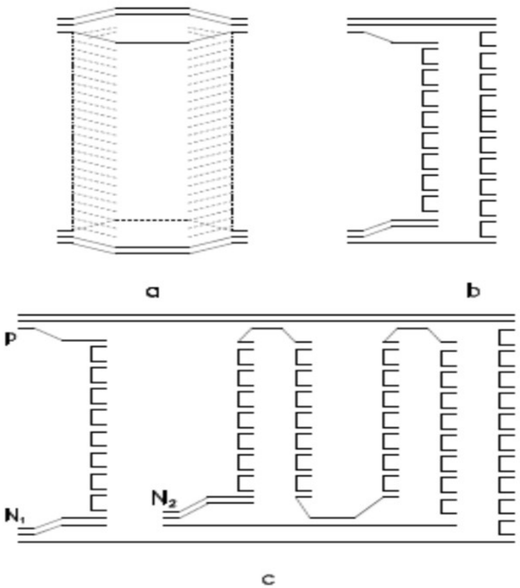
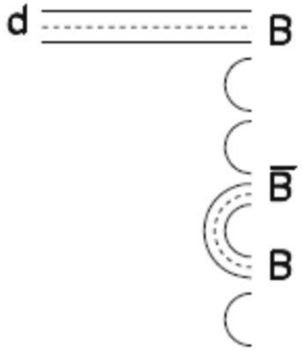
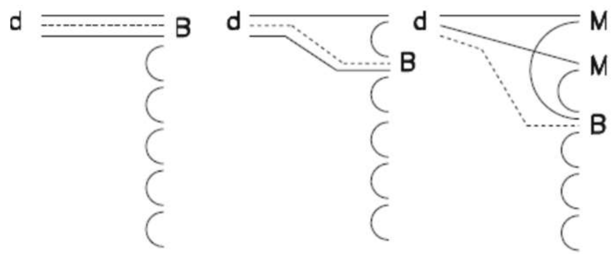


Fig. 7. The QGSM results for the rapidity dependence of the inclusive cross section $d\sigma/dy$ of Ξ^- and $\bar{\Xi}^+$ productions in pp collisions at 158 GeV/c, and their comparison with the experimental data [64]. The full curve corresponds to Ξ^- and the dashed curve to $\bar{\Xi}^+$ production.



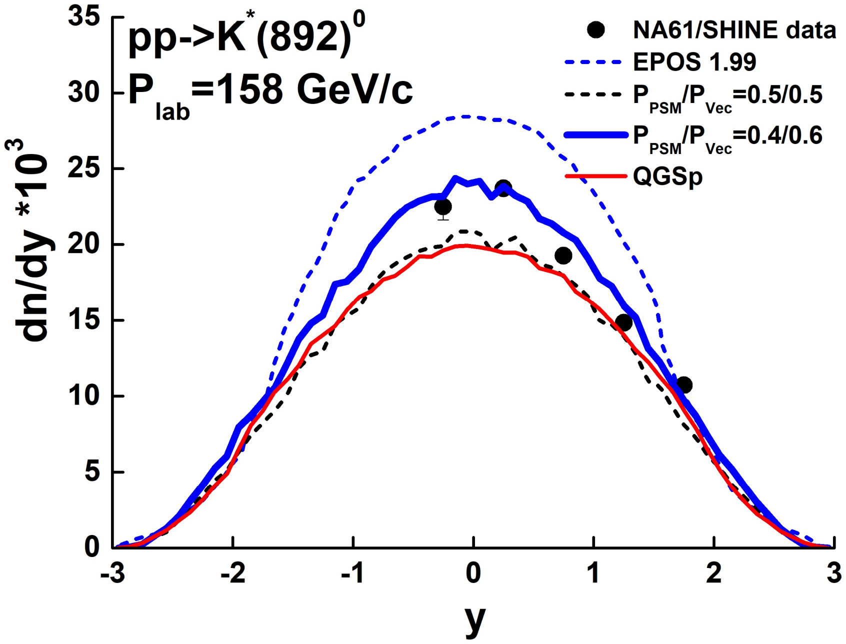


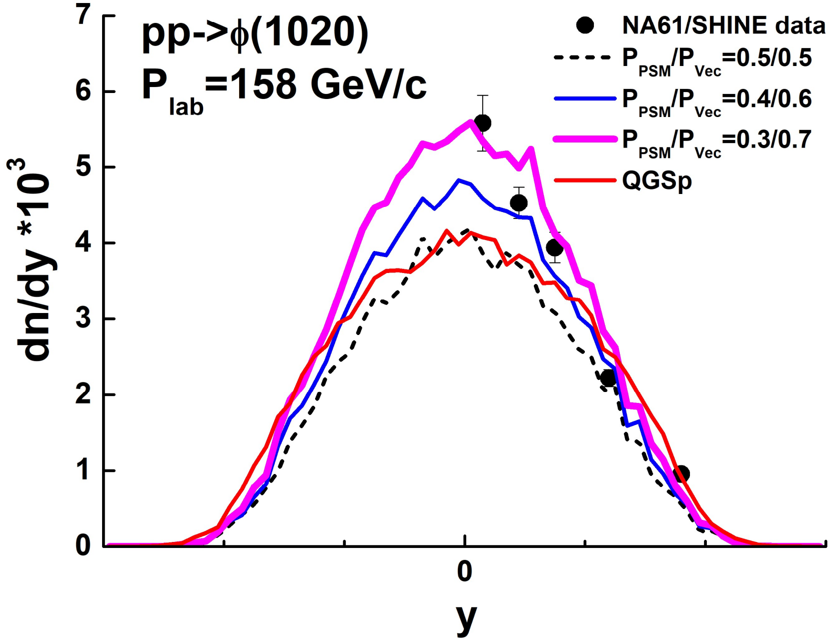
G.H. Arakelyan, C. Merino, and Yu.M. Shabelski
Eur. Phys. J. A (2016) 52: 9
Midrapidity hyperon production in pp and pA collisions from low to LHC energies

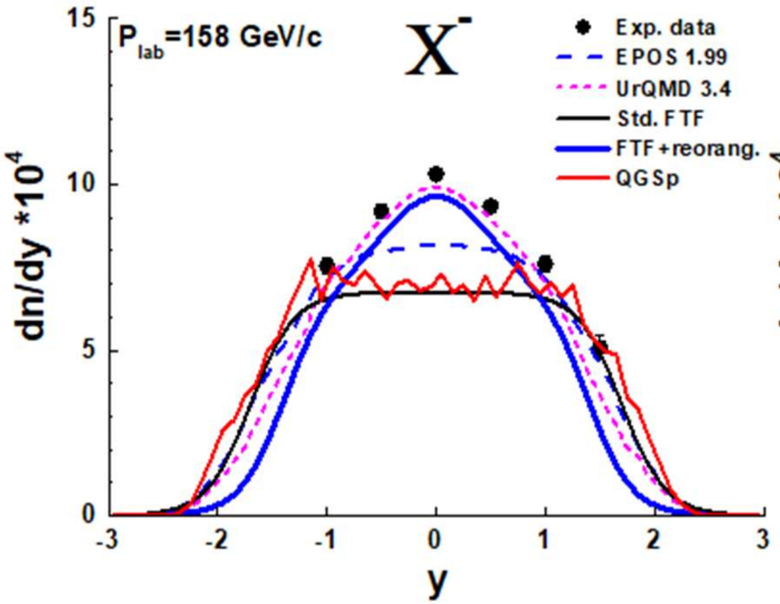


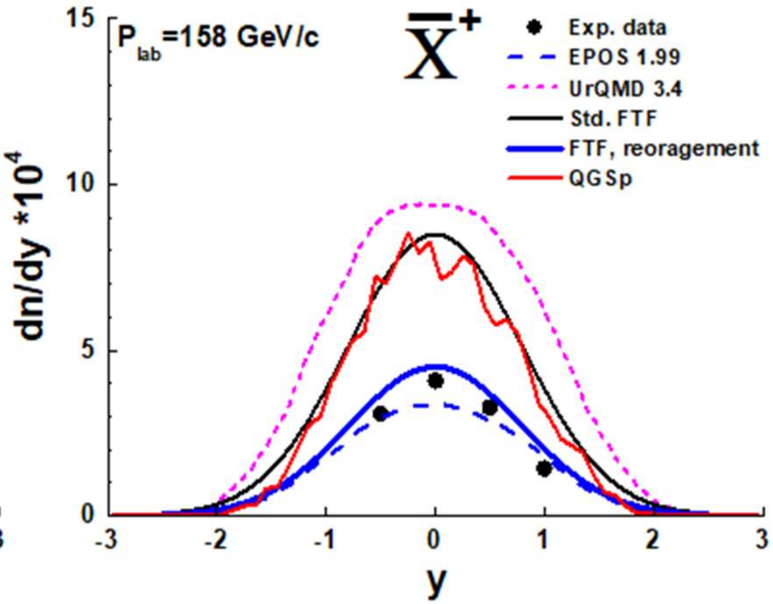
The predictions of QGSM were realistic ones!

Geant4 QGS model





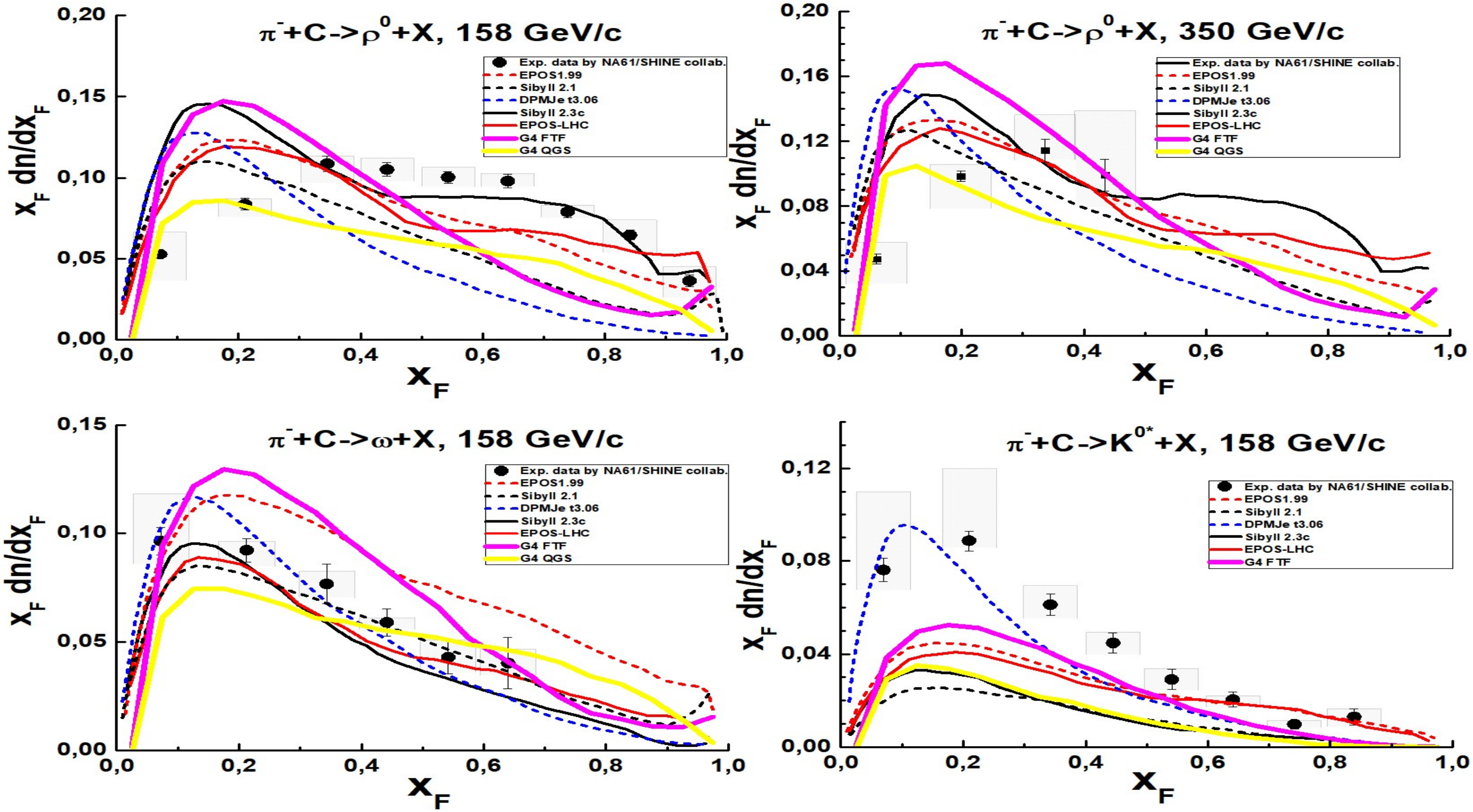




Some work has to be done!

Problem of Rho, omega, K*0 production in pi- C interactions

The NA61/SHINE Collaboration, Measurement of meson resonance production in π^{-}+ C interactions at SPS energies, Eur. Phys. J. C (2017) 77:626



The situation is very unclear!

Problem of Rho, omega, K*0 production in pi- C interactions

The NA61/SHINE Collaboration, **Measurement of meson resonance production in π^{-}+ C interactions at SPS energies,** Eur. Phys. J. C (2017) 77:626

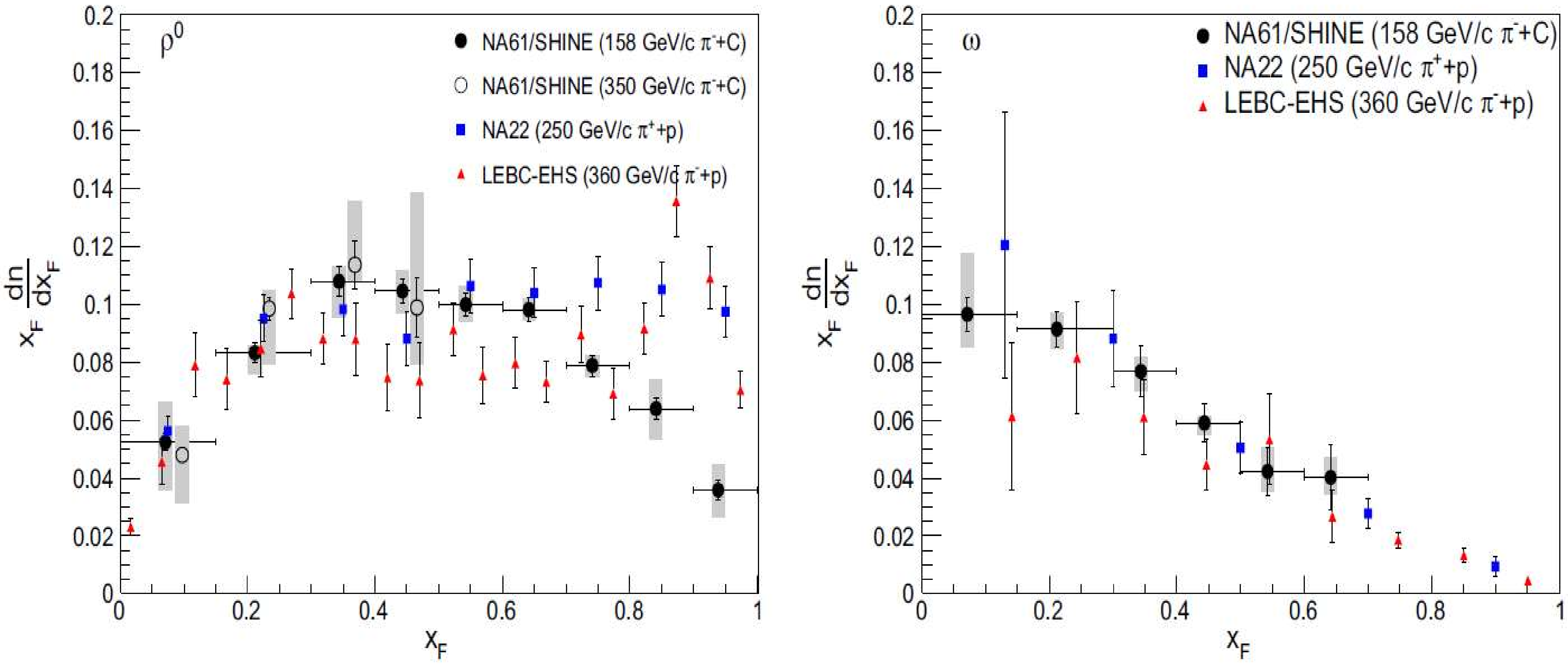
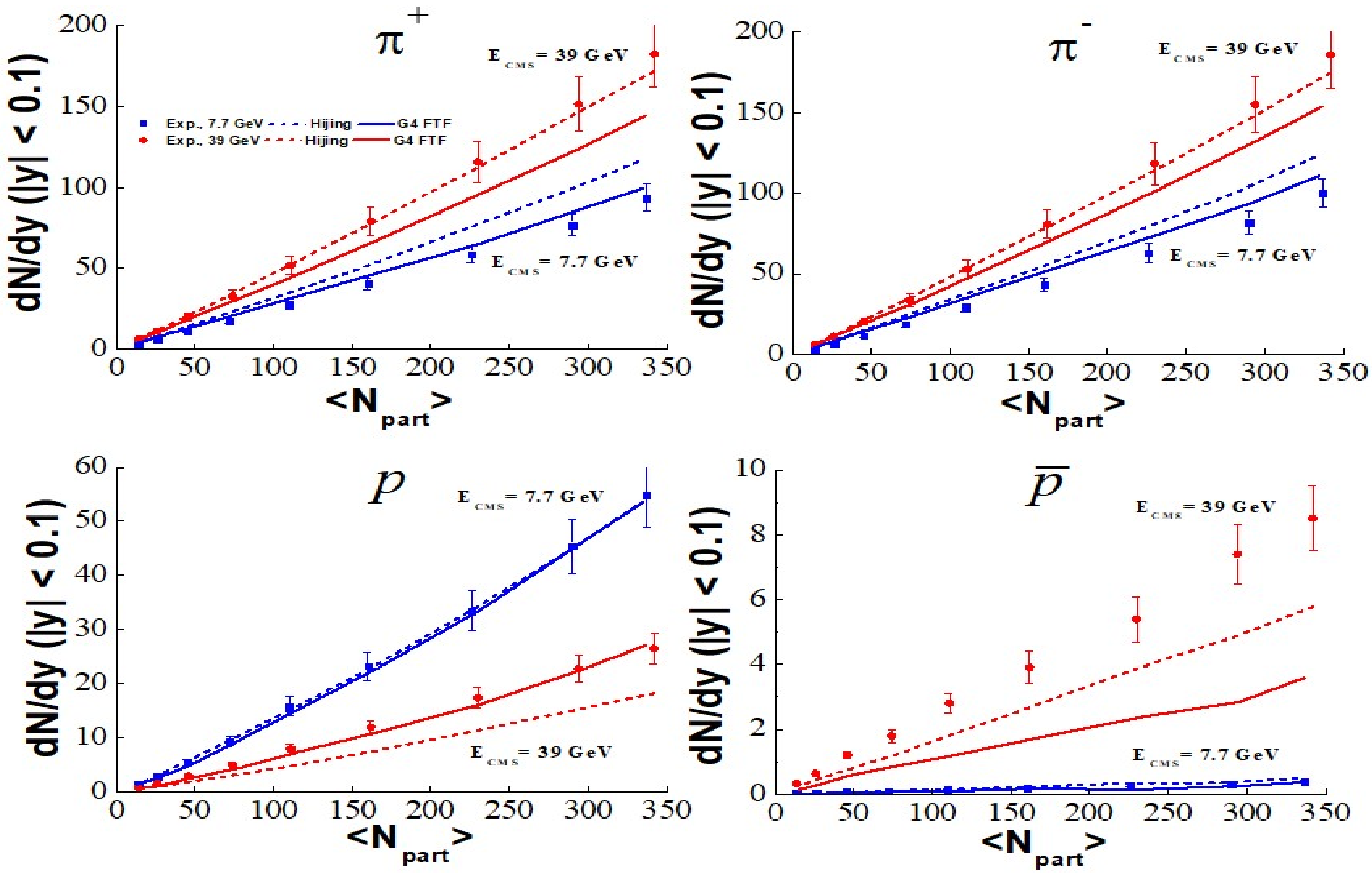


Fig. 14 Scaled x_F-spectra of meson production in π^- + C production interactions at 158 and 350 GeV/c (350 GeV/c shifted by 0.035). The error bars show the statistical, the bands indicate systematic uncertainties (where available). The black points are from this experiment, blue squares are from NA22 [17], red triangles are from LEBC-EHS (NA27) [57]. ρ^0 spectra are shown on the left and ω spectra on the right

Results of FTF for BES of RHIC

Bulk properties of the medium produced in relativistic heavy-ion collisions from the beam energy scan program, PRC 96, 044904 (2017) STAR Collaboration (L. Adamczyk et al.) Ecms= 7.7, 11.5, 19.6, 27, and 39 GeV



FTF: Pi+, Pi-, P – OK at 7.7 GeV; Pi+ and Pi- underestimated at 39 GeV. We have not QGP!
Solid Lines – G4 FTF calculations, dashed ones – HIJING.

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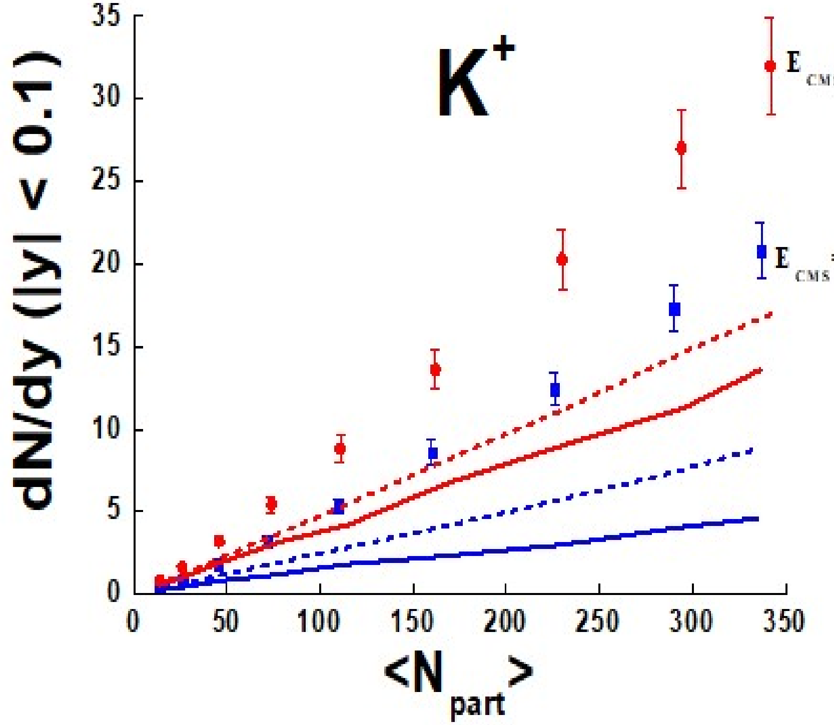
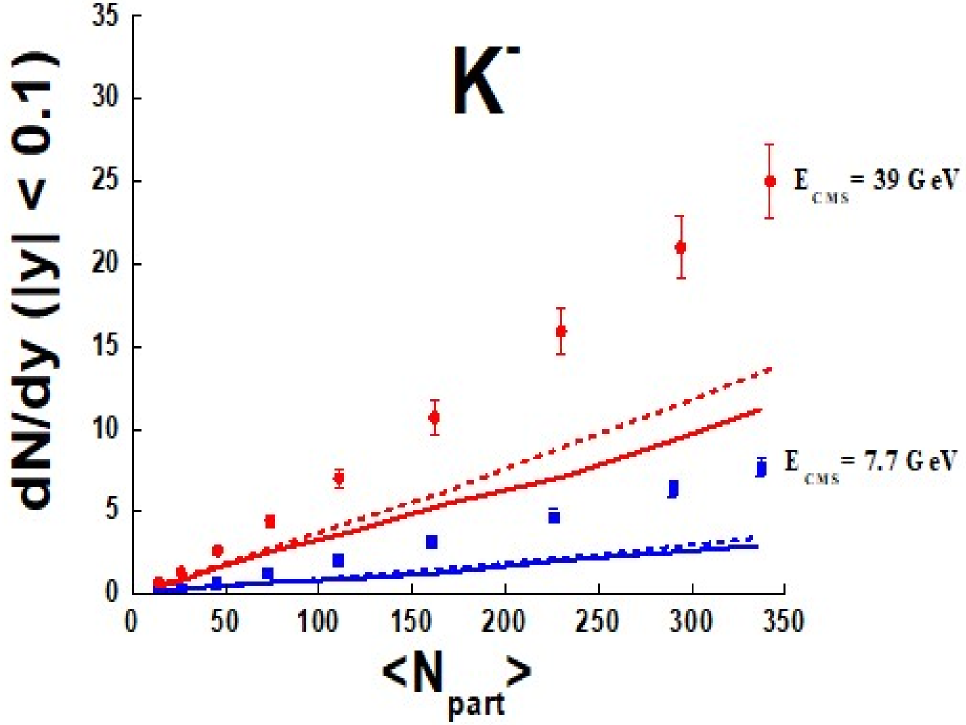
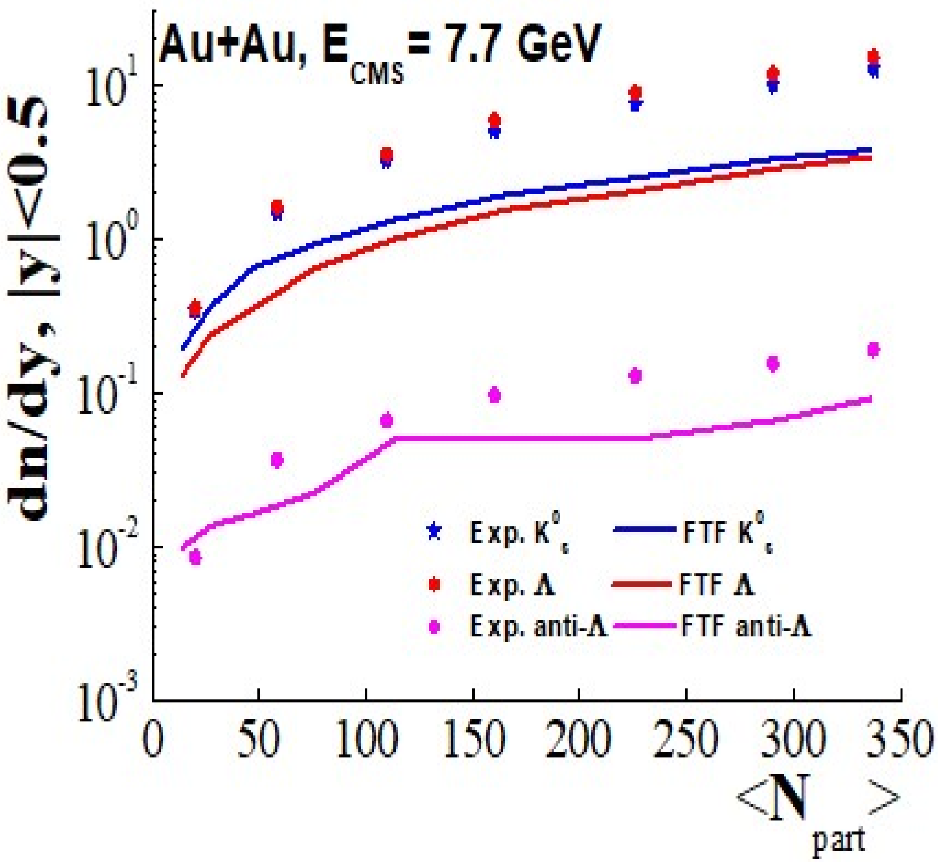


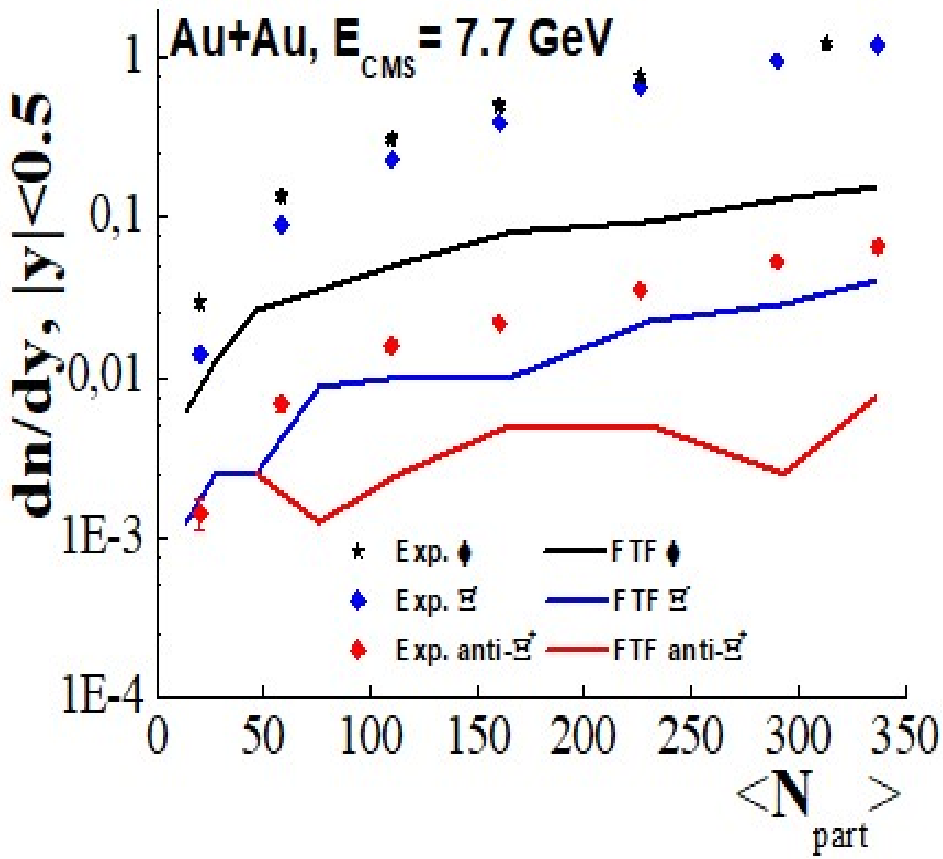


G4 FTF and HIJING model essentially underestimate strange particle production!
QGP at this energy?

Results of FTF for BES of RHIC

Strange hadron production in Au + Au collisions at √sNN = 7.7, 11.5, 19.6, 27, and 39 GeV
STAR collaboration, Phys. Rev. C102, 034909 (2020)





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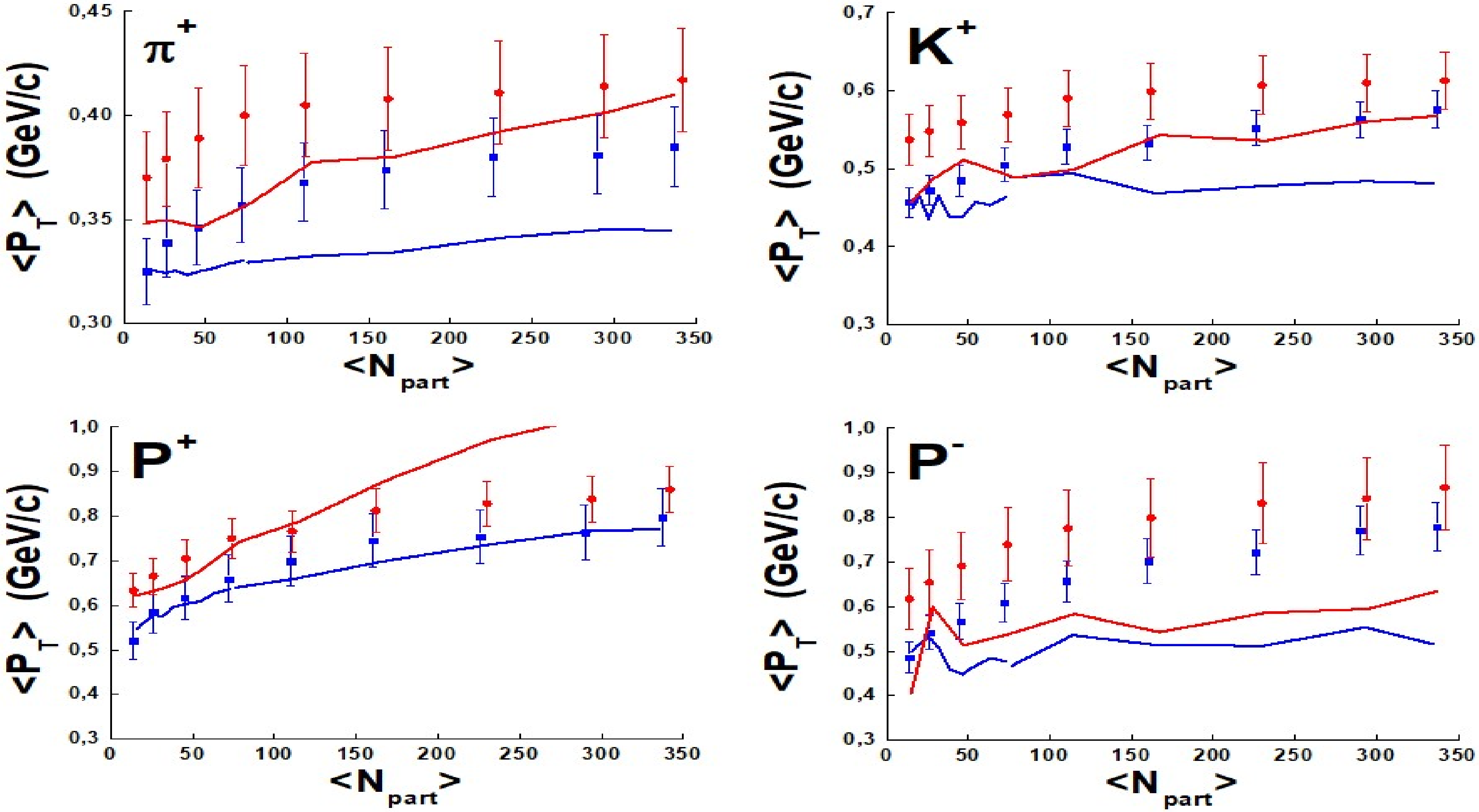
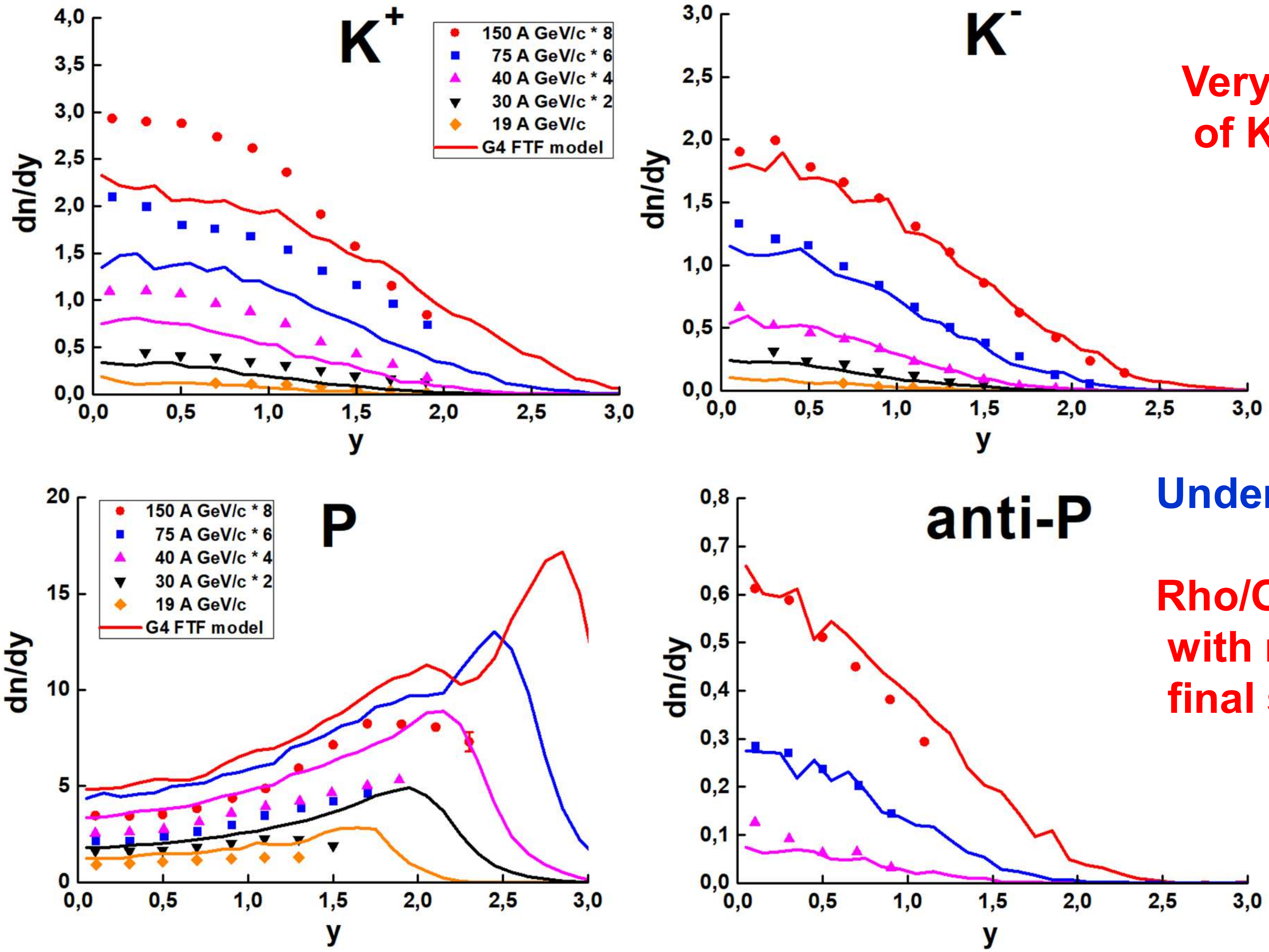


FTF: Pi+, Pi-, P – OK at 7.7 GeV; Pi+ and Pi- underestimated at 39 GeV. We have not QGP!

Solid Lines – G4 FTF calculations, dashed ones – HIJING.

It's not all bad though!

NA61/SHINE data on Be-7 + Be-9 and FTF model
20 % centrality + acceptance maps
NA61/SHINE Collaboration, Eur. Phys. J. C81, 73 (2021)



Very good description
of K- and anti-protons!

Underestimation of K+!

Rho/Omega/Pi interact.
with nucleons in the
final states!

Conclusion

1. Geant4 models – FTF and QGS, are evolved.
2. For description of K*0 meson production it is needed to choose Ppsm/Pvec=0.4/0.6
3. For a description of phi meson production Ppsm/Pvec must be 0.3/0.7!
4. For anti-Hi, last string decay has to be changed. (Rearrangement)
5. For Hi, di-quark fragmentation functions to baryons has to be changed.

Something has to be done for heavy ion collisions! QGP at low energies or rescattering?

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.

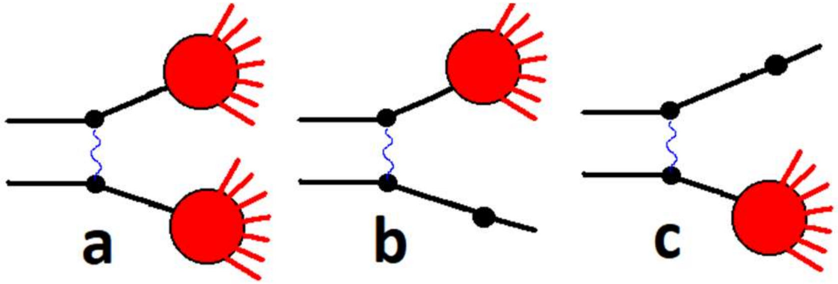
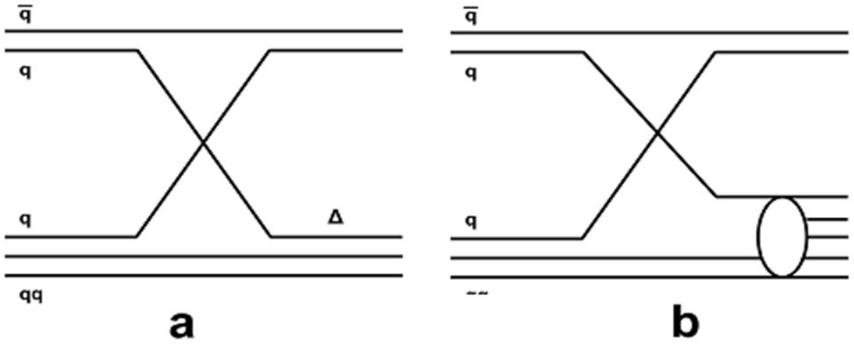


Fig. 2 Additional quark exchange processes in the FTF model.



String mass distribution

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

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