Quark-Gluon Plasma is appeared in collisions of medium nuclei at higher energies than in heavy ion interactions

V. Uzhinsky and A. Galoyan (JINR, Dubna)

Lates experimental data

The NA61/SHINE Collaboration, Eur. Phys. J. C (2021) 81:73 (22 Jan. 2021)
Measurements of $\pi\pm$, $K\pm$, p and anti-p spectra in 7Be+9Be collisions at beam momenta from 19A to 150A GeV/c with the NA61/SHINE spectrometer at the CERN SPS

The results were compared with predictions of the models:
Epos 1.99, Urqmd 3.4, Ampt 1.26, Phsd 4.0 and Smash 1.6.

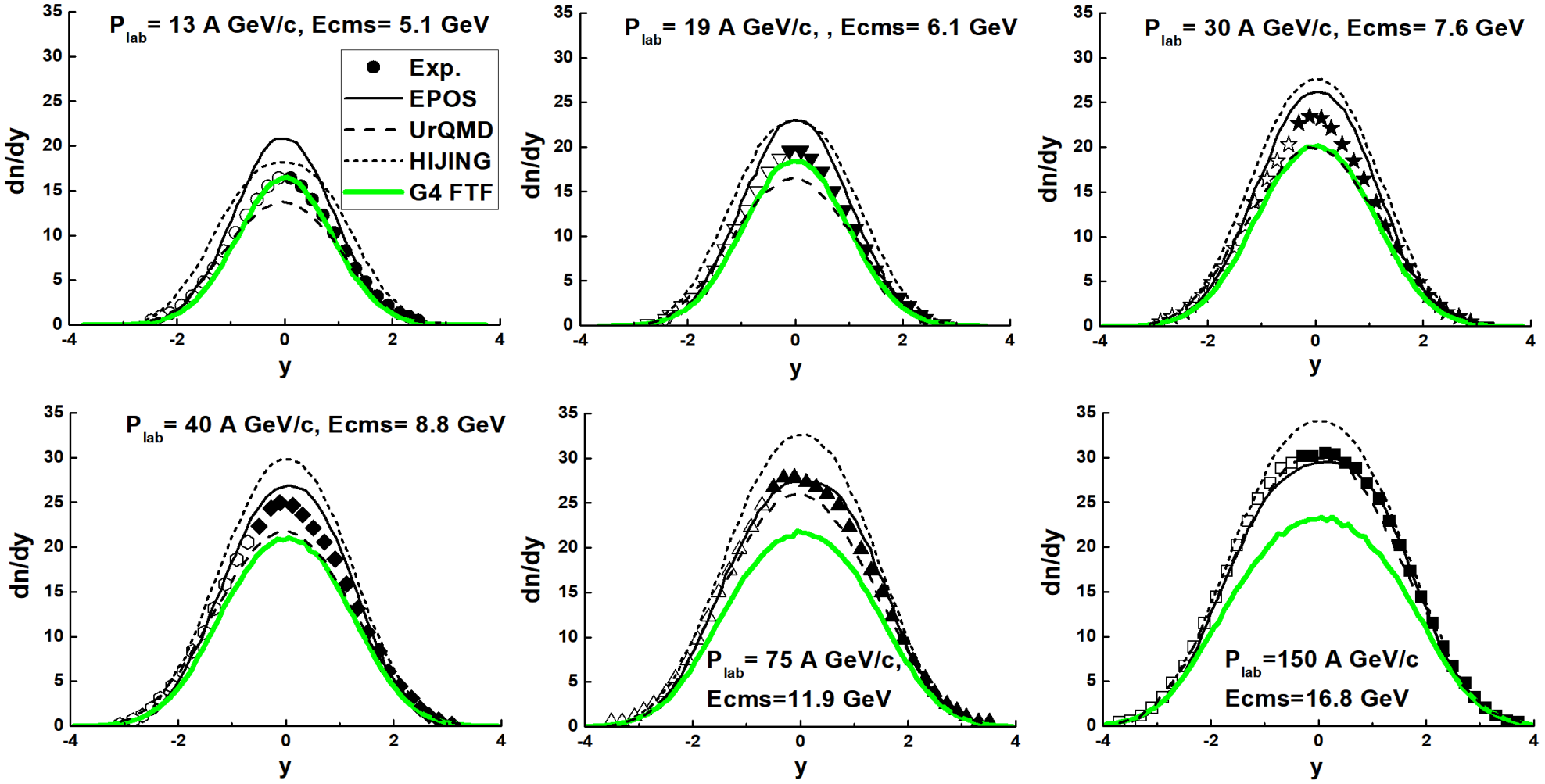
None of the models reproduces all features of the presented results.

The NA61/SHINE Collaboration, Eur. Phys. J. C (2021) 81:397 (7 May 2021)
Spectra and mean multiplicities of $\pi-$ in *central* Ar-40+Sc-45 collisions at 13A, 19A, 30A, 40A, 75A and 150AGeV/c beam momenta measured by the NA61/SHINE spectrometer at the CERN SPS

The results (Exp.) represent the first measurements on pion production in an intermediate size collision system at SPS energies.

The new measurements were compared to predictions of Epos1.99, Urqmd3.4 and Hijing models. None of them provides a consistent description of the new NA61/SHINE measurements in Ar+Sc collisions.

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



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

HIJING overestimates all data.

Geant4 FTF – OK at Ecmc < 8 GeV, underestimates at Ecms > 8 GeV, with accounting of the acceptance maps

QGP at 7 or 10 GeV?

None of the Monte Carlo models can describe the data!
Is something wrong in our understanding of Physics or experiment?

HIJING model was widely used at RHIC and LHC for design studies of nucleus-nucleus experiments. Its new reincarnation is AMPT. Is it wrong!?

EPOS model is well know in Cosmic Ray Physics.
There is also EPOS-LHC for LHC experiment.

UrQMD is a workhorse at FAIR and NICA! Is it OK?

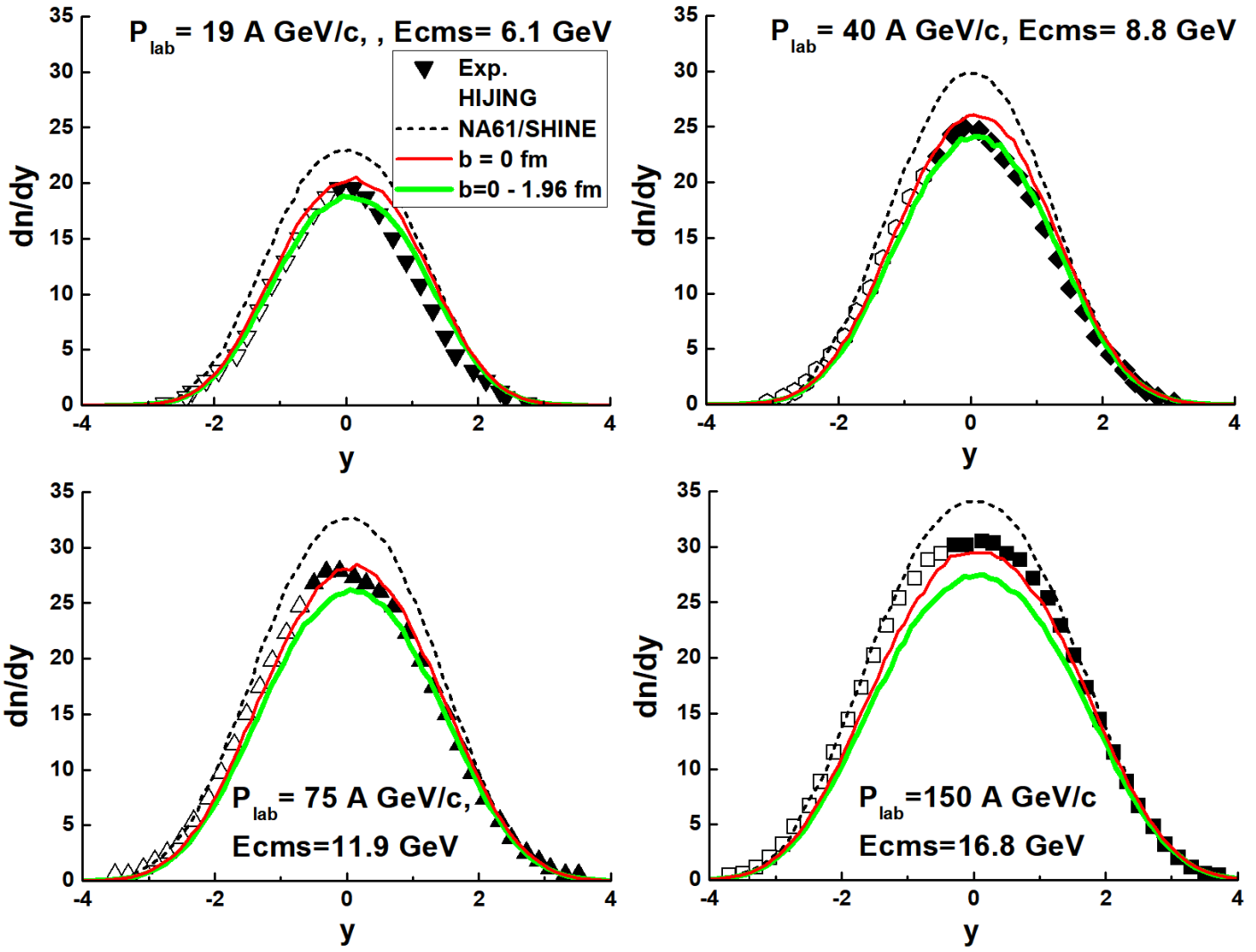
All of the models are pure hadronic models!
They do not consider Quark-Gluon Plasma (QGP) creation!

Two questions: Are the model calculations correct?
Is the discrepancy a signature of QGP?

NA61/SHINE data on Ar-40 + Sc-45

5 % centrality, dn/dy of π-mesons $\pi b^2_{max} = (C/100)\ \sigma^{in}_{AB}$

HIJING



Hijing predictions for pure central events (b=0) are below NA61/SHINE calculations!

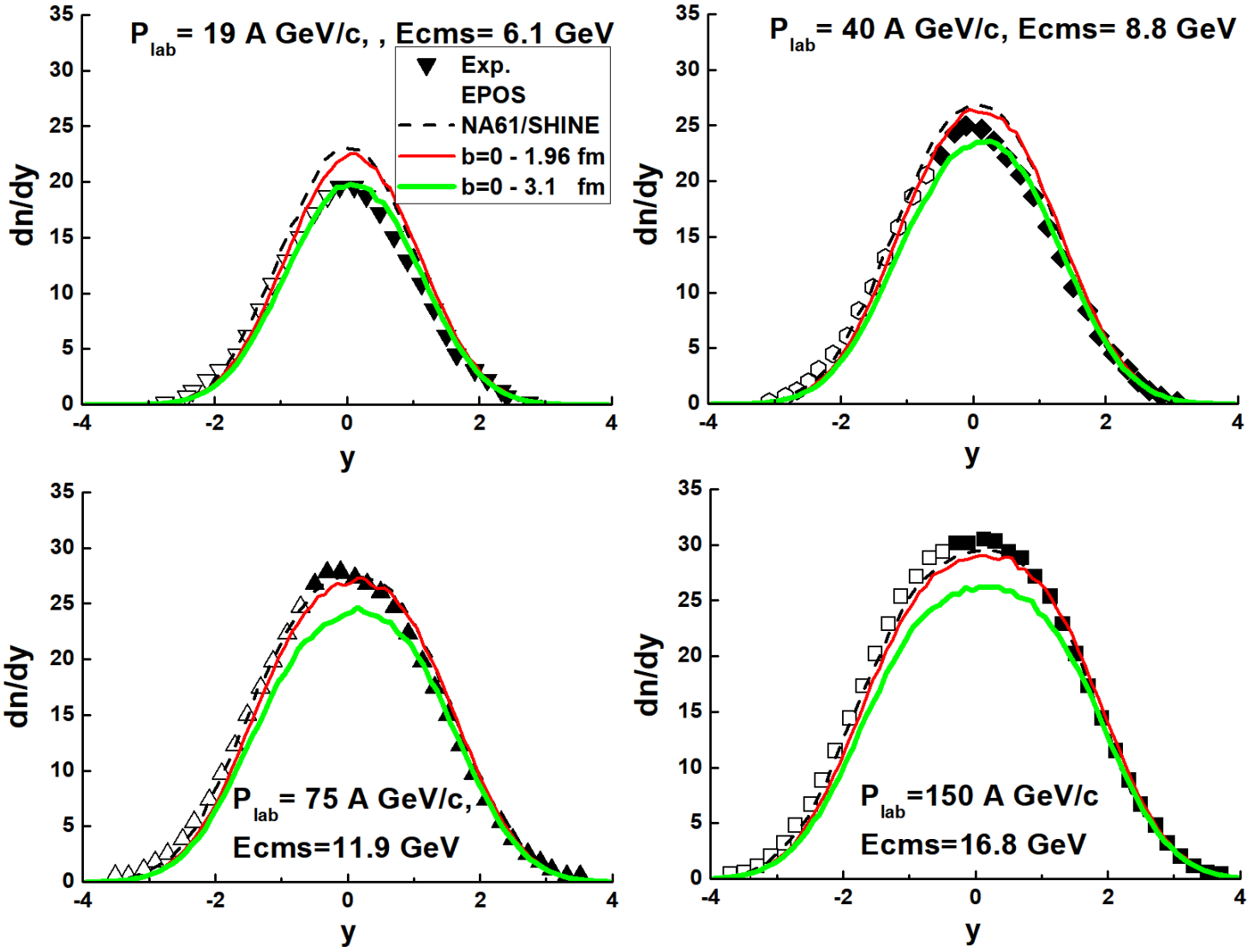
At b= 0 – 1.96 fm, there is a freedom for developments!

NA61/SHINE data on Ar-40 + Sc-45
5 % centrality, dn/dy of π-mesons 20 % !?

EPOS 1.99

non-vacuum exchanges?

Fragmentation of nuclear residuals?



EPOS model with a simplified centrality selections gives good results at high energies.

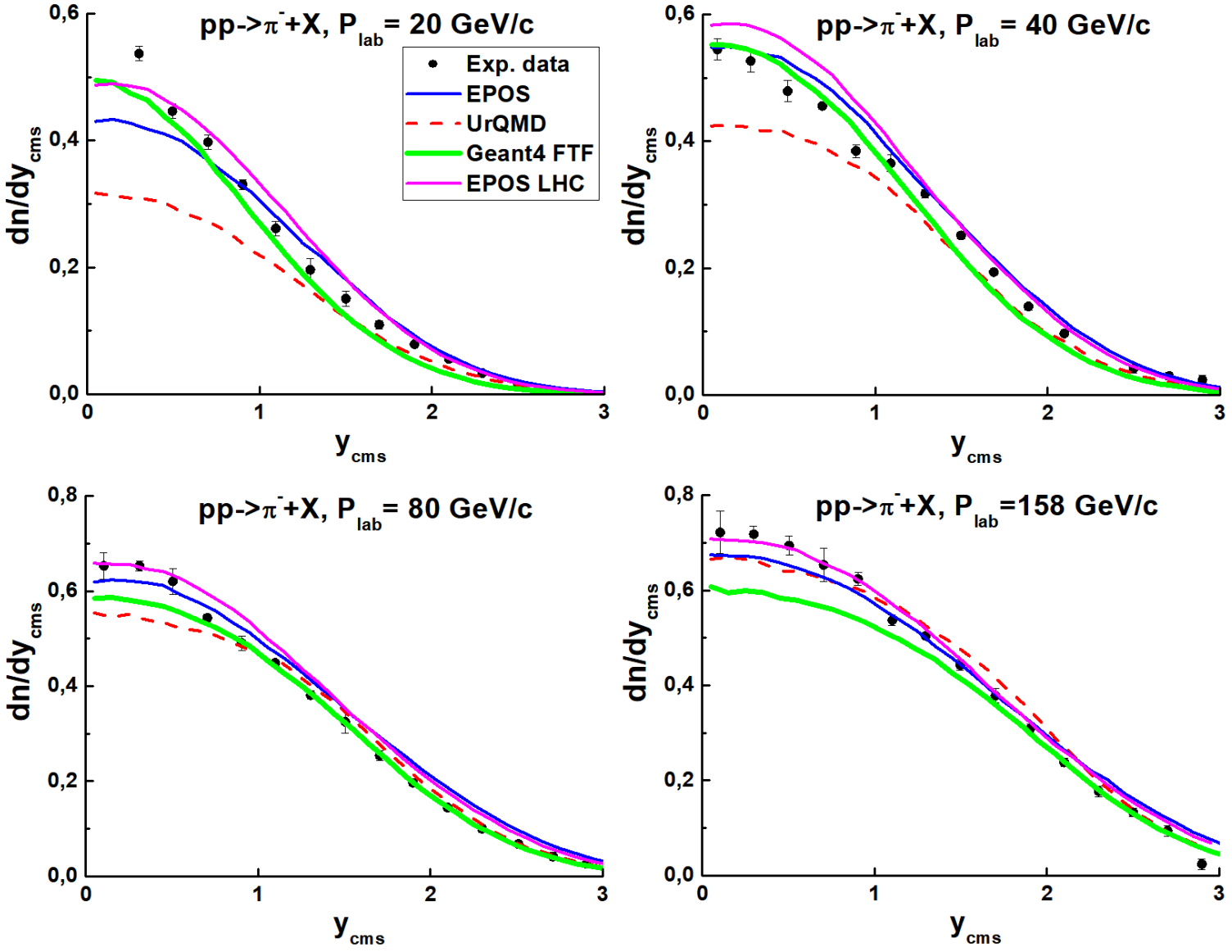
Changing the selections, we obtain the freedom!

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

PP int.

Geant4 FTF
EPOS 1.99
EPOS LHC
UrQMD

V. Uzhinsky,
Toward Description of pp and p C Interactions at High Energies: Problems of Fritiof-based Models. arXiv::1404.2026 [hep-ph] (2014).



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.

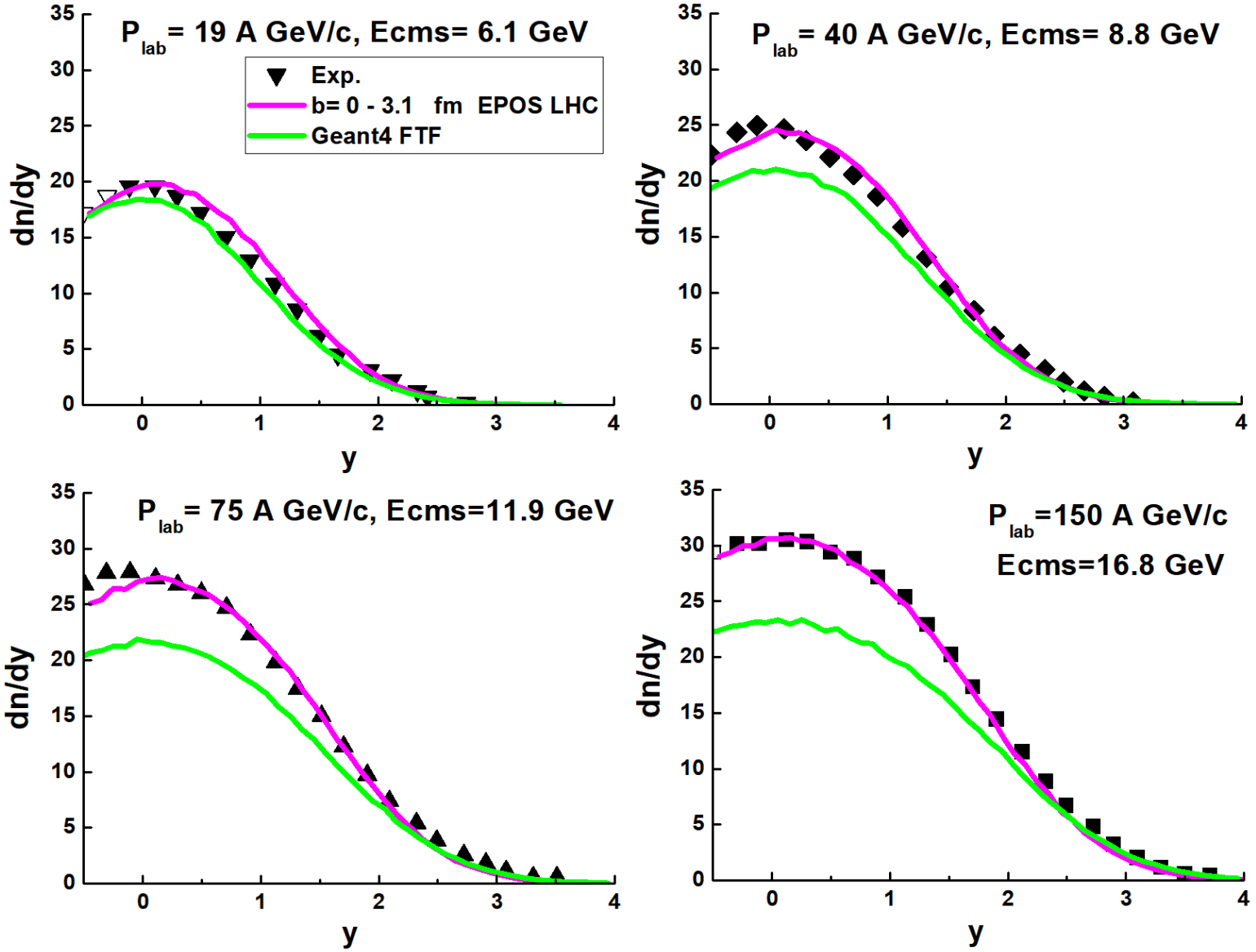
NA61/SHINE data on Ar-40 + Sc-45
5 % centrality, dn/dy of π-mesons 20 % !?

EPOS LHC

Collective fragmentation

non-vacuum exchanges?

Fragmentation of nuclear residuals?



EPOS LHC gives promising results!

^{7}Be + ^{9}Be interactions

Eur. Phys. J. C81 (2021) 73

Measurements of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra in ^{7}Be+^{9}Be collisions at beam momenta from 19A to 150A GeV/c with the NA61/SHINE spectrometer at the CERN SPS

The NA61/SHINE Collaboration

0 – 20 % centrality

The results were compared with predictions of the models:
Epos 1.99, Urqmd 3.4, Ampt 1.26, Phsd 4.0 and Smash 1.6.

None of the models reproduces all features of the presented results.

What's about Geant4 FTF (Fritiof) model?

***Central* collisions refer to events selected by a cut on the total energy emitted into the forward direction as defined by the acceptance maps for the PSD given in :**

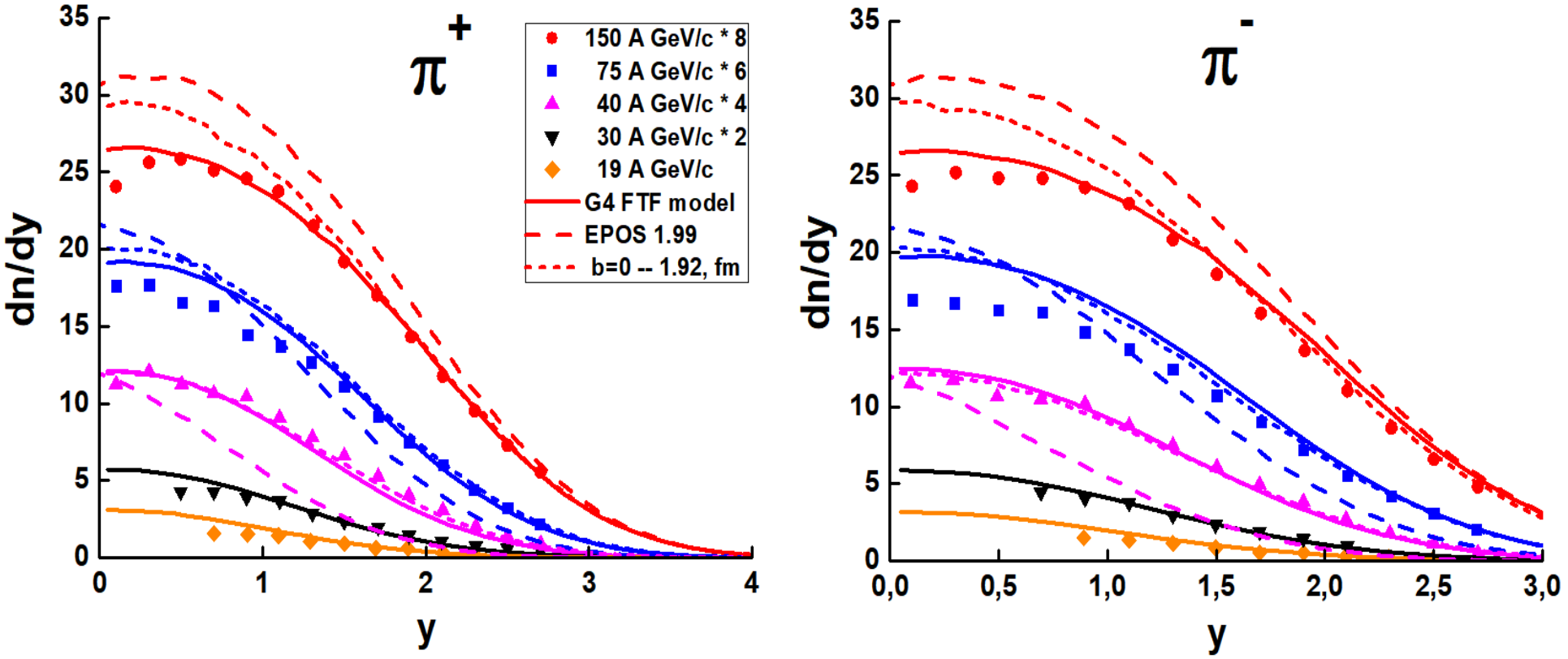
A. Seryakov. PSD acceptance maps for event selection. https://edms.cern.ch/document/1867336/1, 2017. CERN EDMS

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

20 % centrality, dn/dy of π mesons $\pi B_{max}^2 = (C/100)\ \sigma_{AB}^{in}$

EPOS 1.99 and Geant4 FTF models

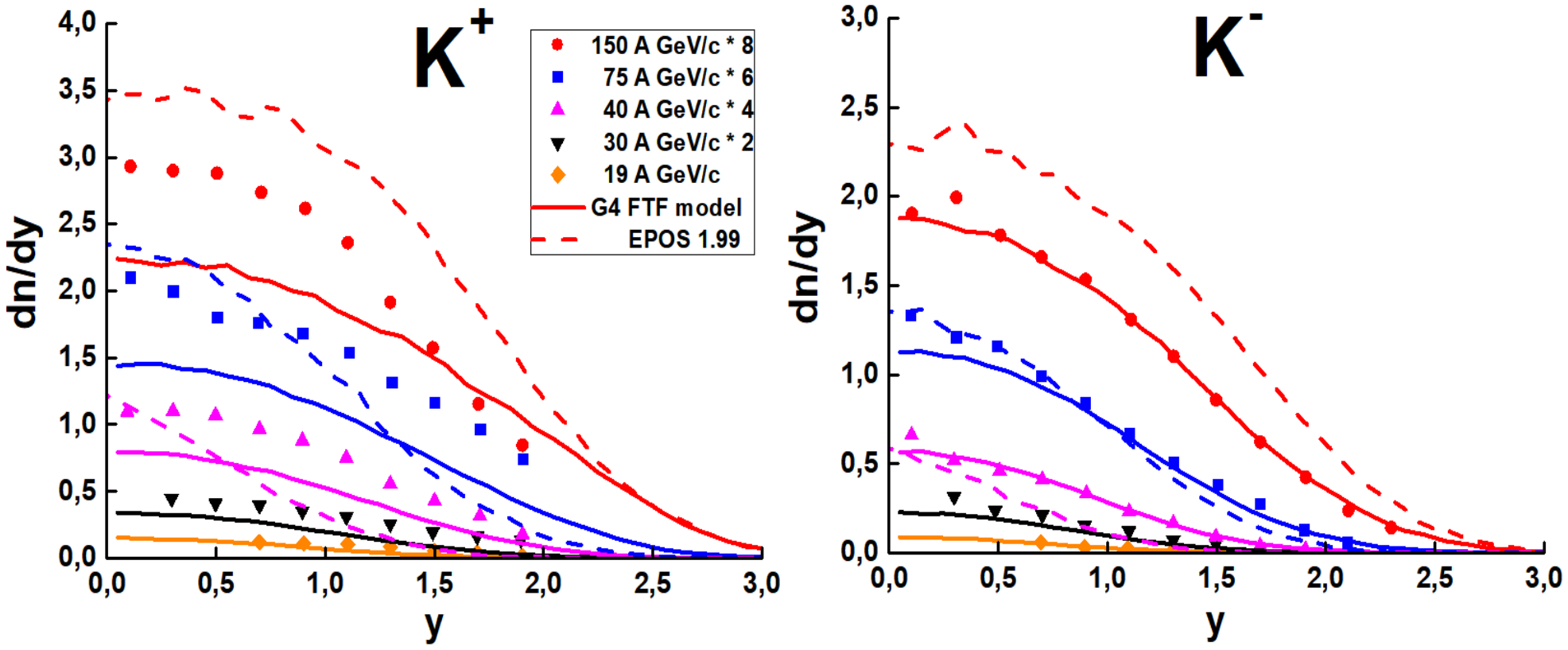
EPOS well describes the data on Ar+Sc at 150 A GeV



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.

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



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

Conclusion

1. **Geant4 FTF model describes well latest data of NA61/SHINE collaboration on π- meson production in Ar-40 + Sc-45 interactions at Ecms < 8 GeV.**

2. **It is needed an additional source of particle production in Ar+Sc interactions (QGP?) in Geant4 FTF at high energies, Ecms> 8 GeV.**

3. **Only Geant4 FTF model reproduces main features of π- mesons and proton spectra in Be-7 + Be-9 at Ecms= 6.1 – 17.8 GeV.**

No need QGP!

Quark-Gluon Plasma is appeared in collisions of medium nuclei at higher energies than in heavy ion interactions

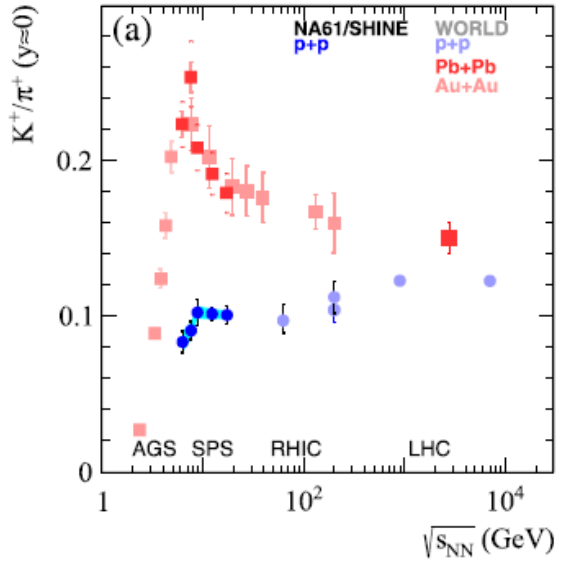
4. **There is the old problem with K+ meson production!**

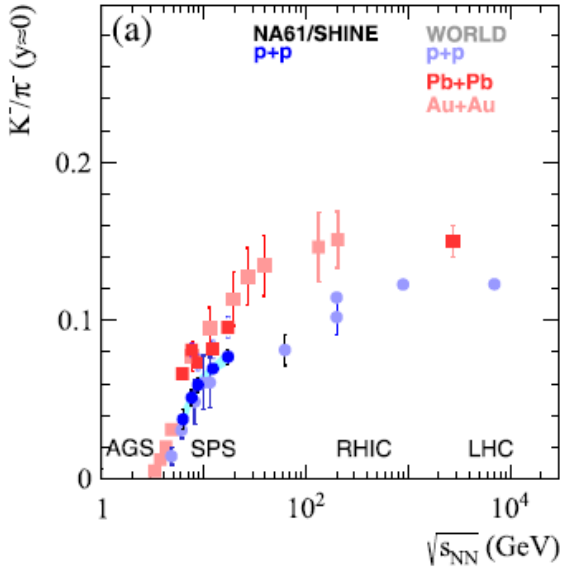
5. **Monte Carlo models should be applied with some cautions! At least, adequate centrality selection should be implemented!**

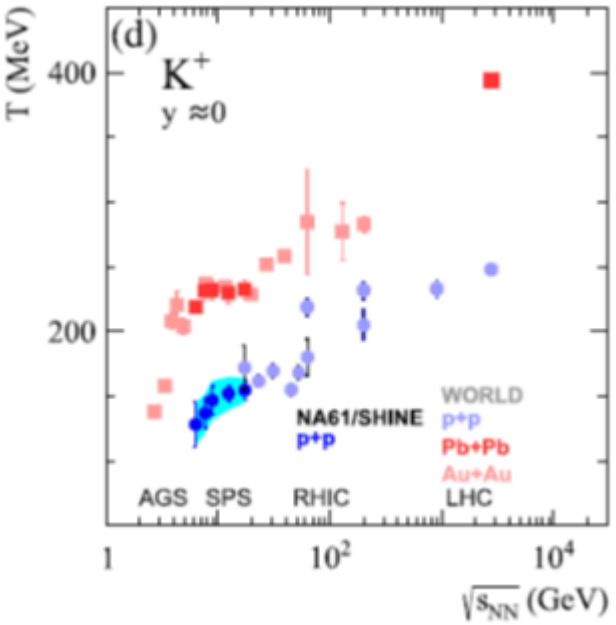
PHYSICAL REVIEW C **102**, 011901(R) (2020)

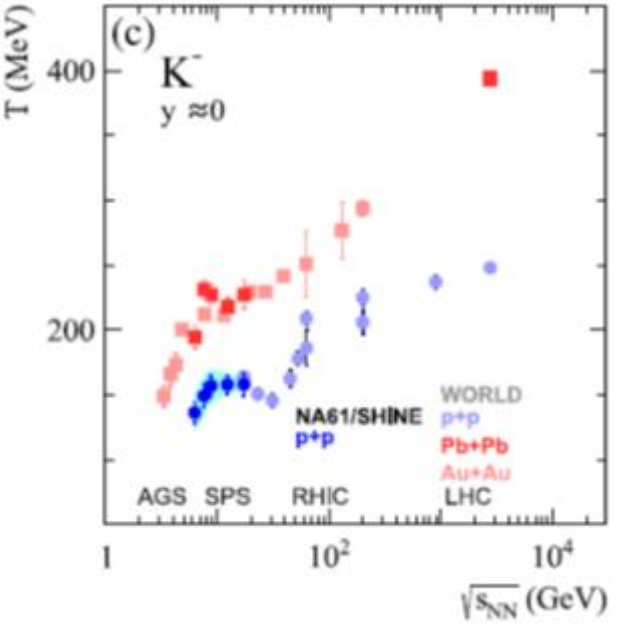
Proton-proton interactions and onset of deconfinement

(NA61/SHINE Collaboration)









How is PSD working?

Eur. Phys. J. C81 (2021) 73

Measurements of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra in ^{7}Be+^{9}Be collisions at beam momenta from 19A to 150A GeV/c with the NA61/SHINE spectrometer at the CERN SPS

The NA61/SHINE Collaboration

Central **collisions refer to events selected by a cut on the total energy emitted into the forward direction as defined by the acceptance maps for the PSD given in :**

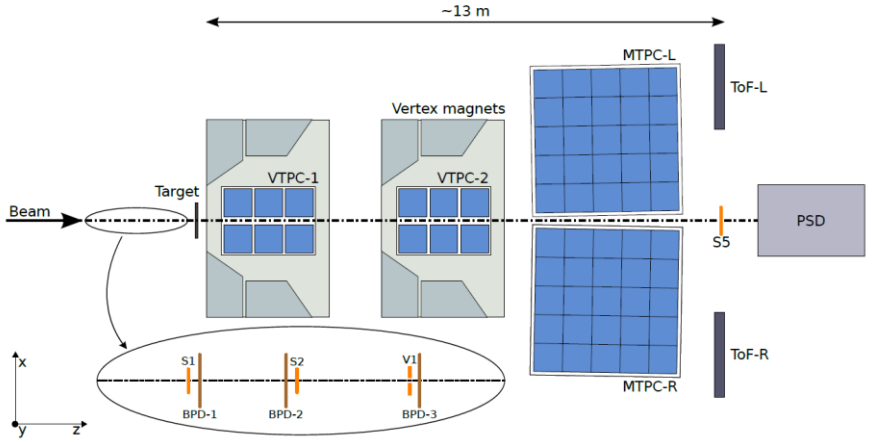
A. Seryakov. PSD acceptance maps for event selection. https://edms.cern.ch/document/1867336/1, 2017. CERN EDMS

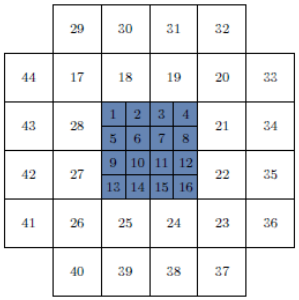
E. Kaptur [NA61/SHINE Collab.],
Analysis of collision centrality and negative pion spectra in Be-7 +Be-9 interactions at CERN SPS energy range.
Ph.D thesis (2017).
https://edms.cern.ch/document

Our special thanks to Michal Naskret!

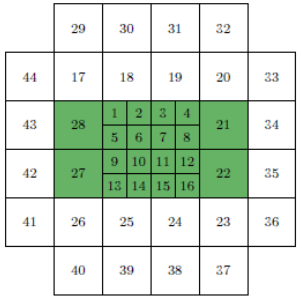
NA61/SHINE data on Ar-40 + Sc-45 and FTF model

5 % centrality ?

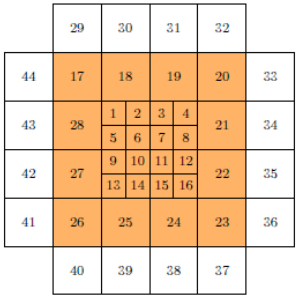




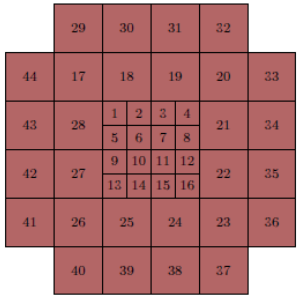
T2 trigger



150A GeV/c



75A, 40A, 30A GeV/c



19A, 13A GeV/c

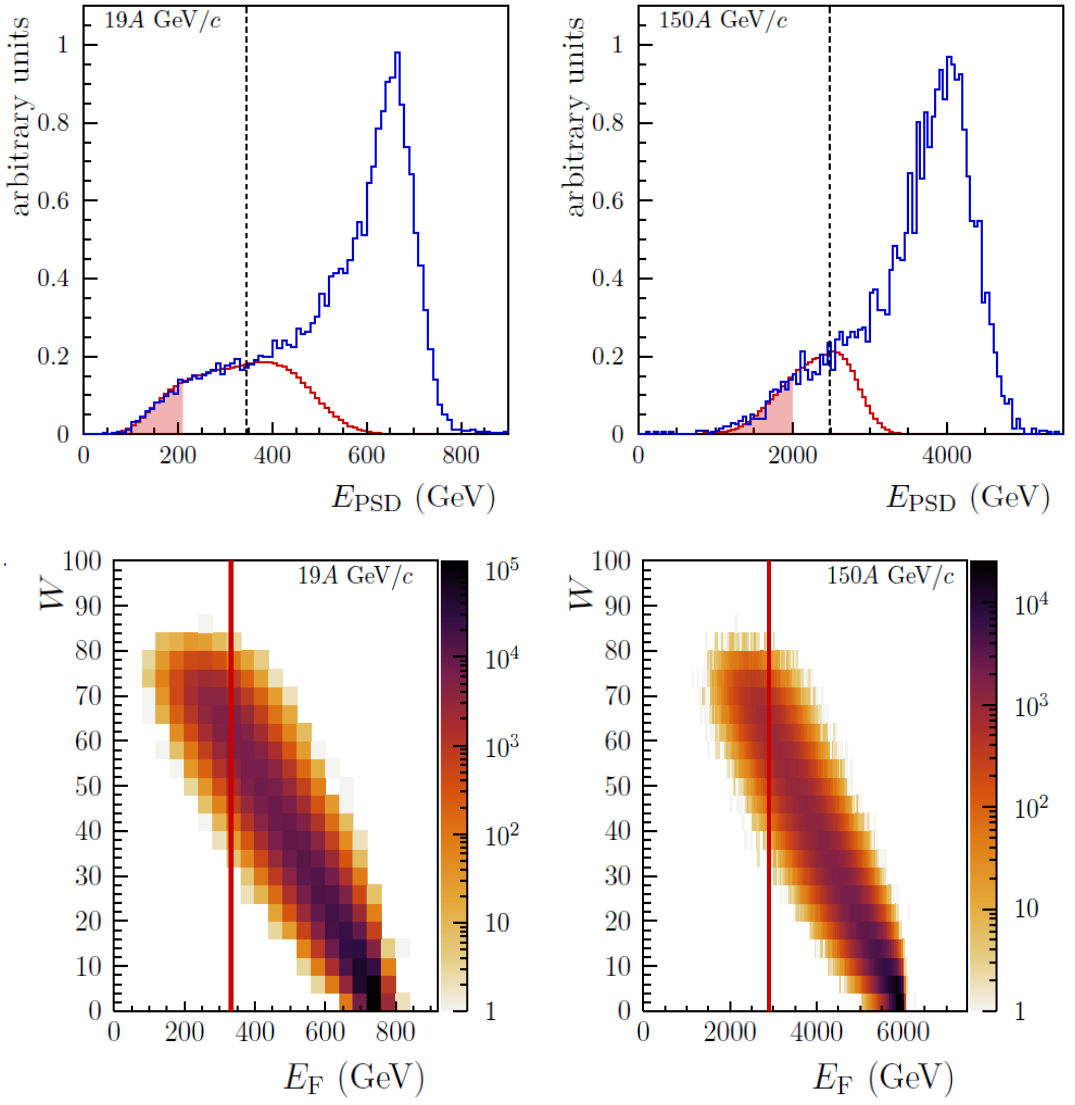


Figure 4: Distributions of W versus E_F for all inelastic collisions at 19A (*left*) and 150A GeV/c (*right*) beam momenta calculated from the EPOS1.99 model. The vertical red lines show the value of the cut on E_F for selecting the 5% most *central* collisions.

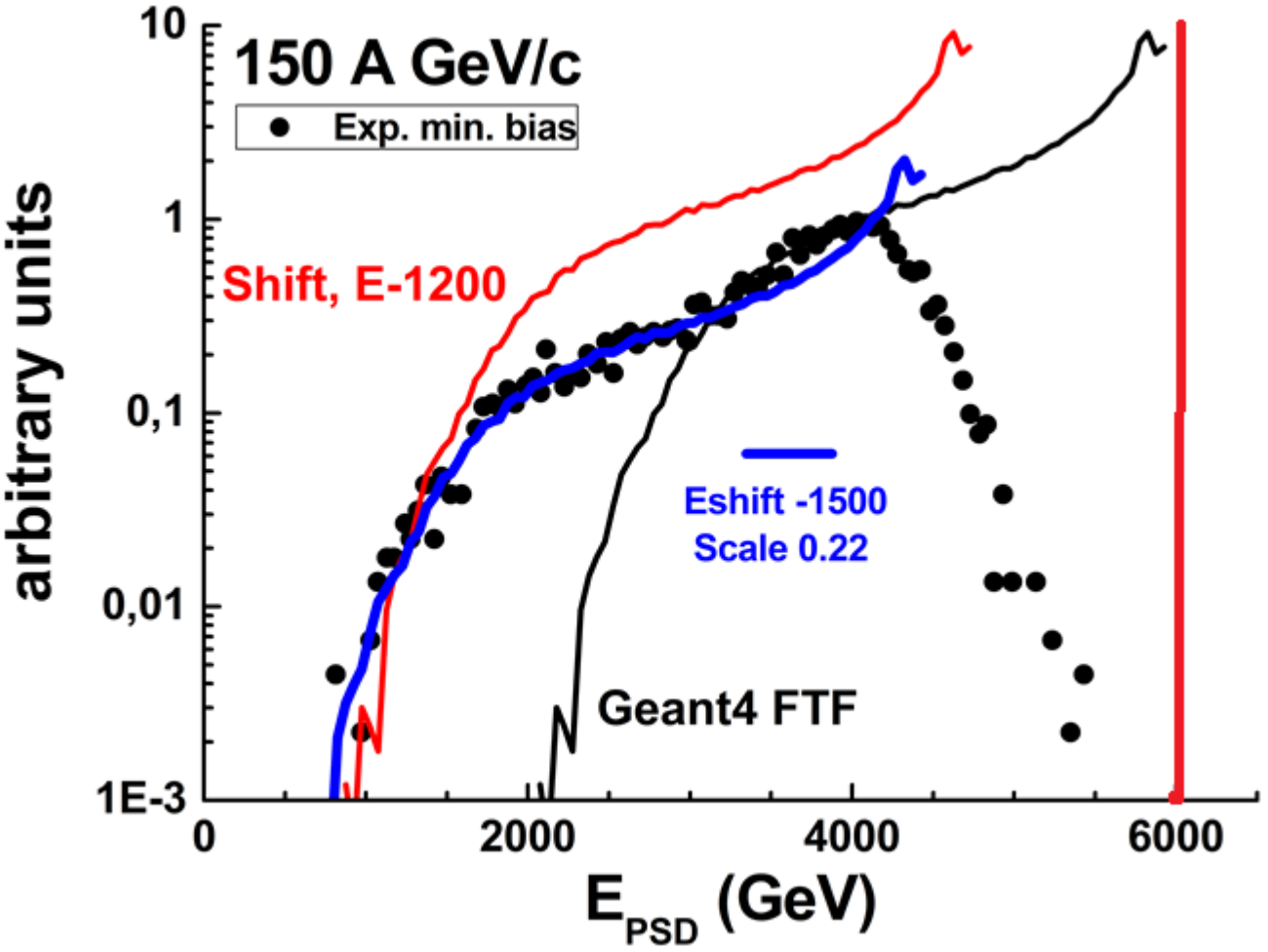
Questions? 5 % centrality ? Bmax ?

Beam energy 19*40 = 760 GeV, Exp. max ~ 650 GeV ?

Beam energy 150*40 = 6000 GeV, Exp. max ~ 4000 GeV ?

Why?

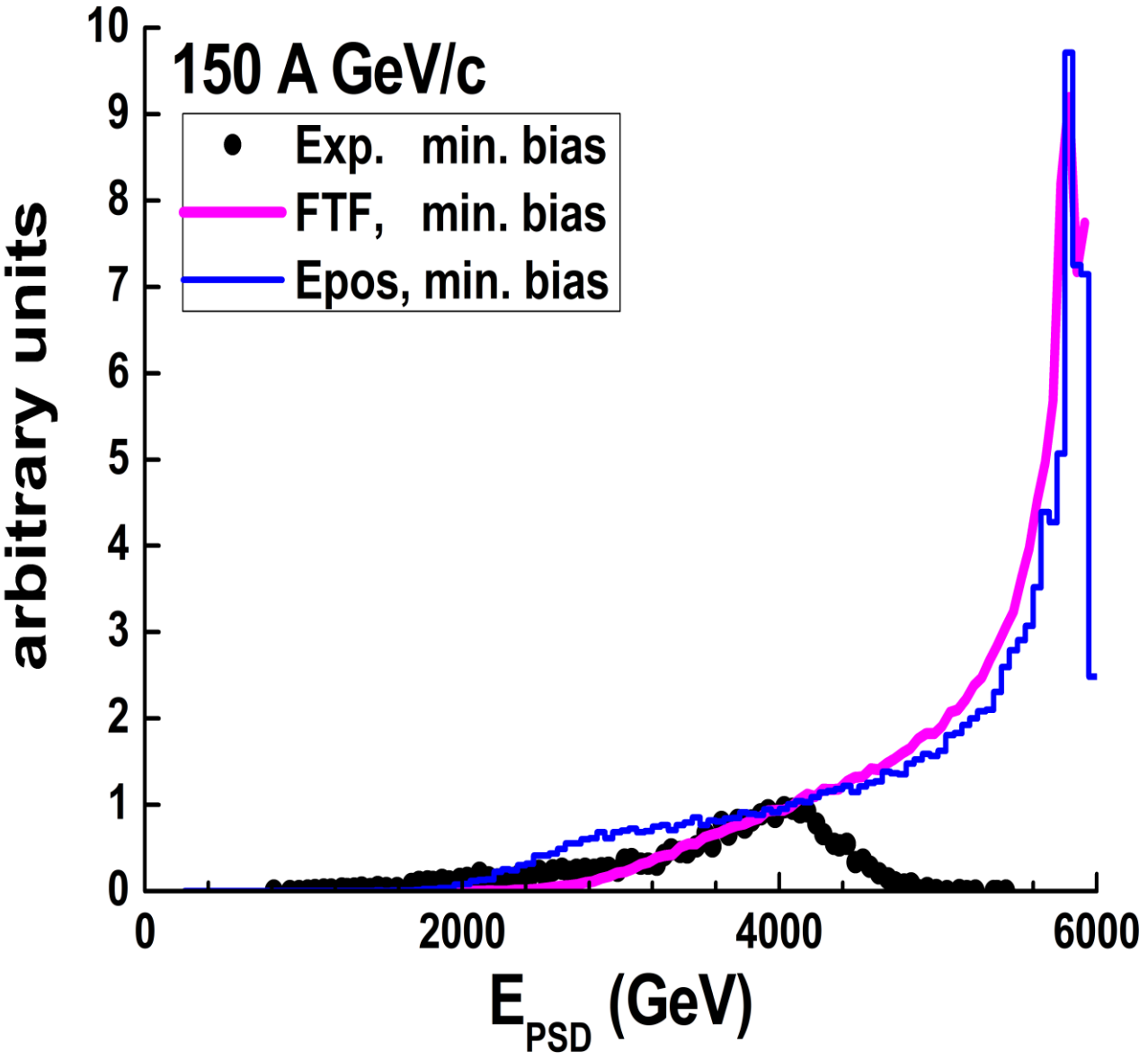
Theory and other experiments give Epsd Max close to the beam energy!



As seen, there is a correspondence between Exp. data and theor. one in low part of Epsd after E-shift and scale

Nature of this? Estimation of the shift?

Questions? 5 % centrality ? Bmax ?

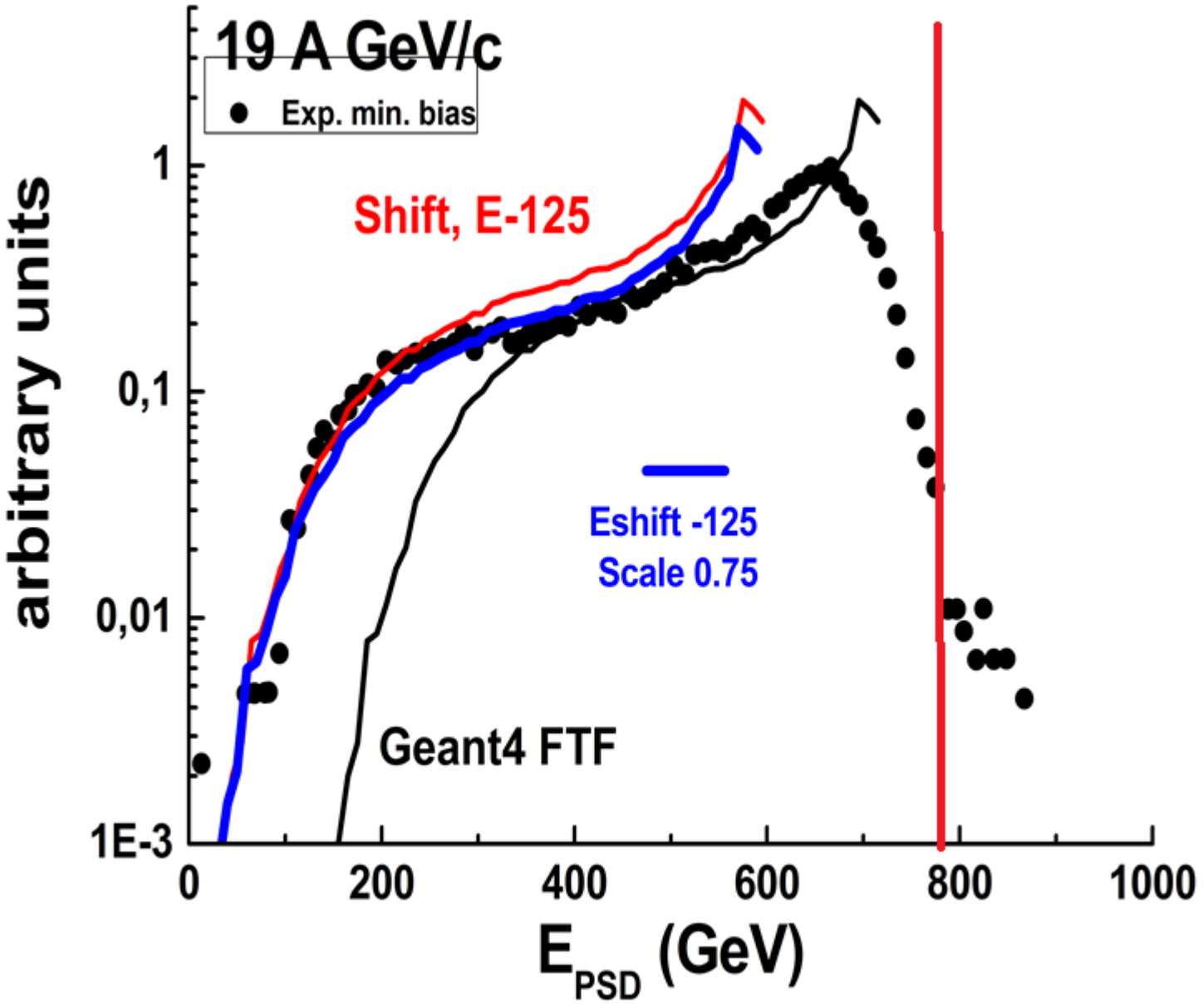


As seen, there is no a correspondence between Exp. data and EPOS one.

Nuclear residual fragmentation in EPOS is not adequate to Exp.

Questions? 5 % centrality ? Bmax ?

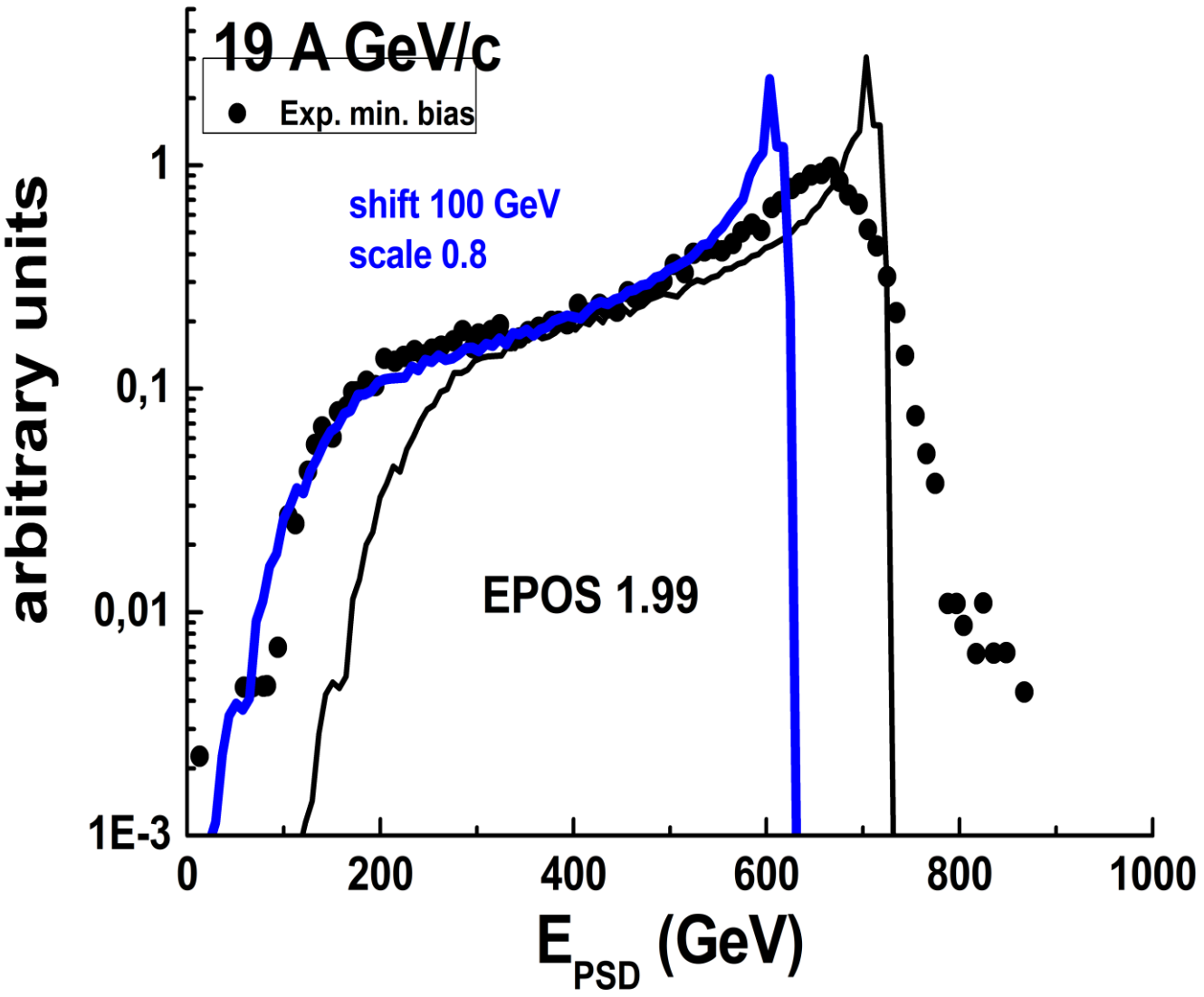
Why?



As seen, there is a correspondence between Exp. data and theor. one in low part of Epsd after E-shift and scale

Nature of this?
Estimation of the shift?

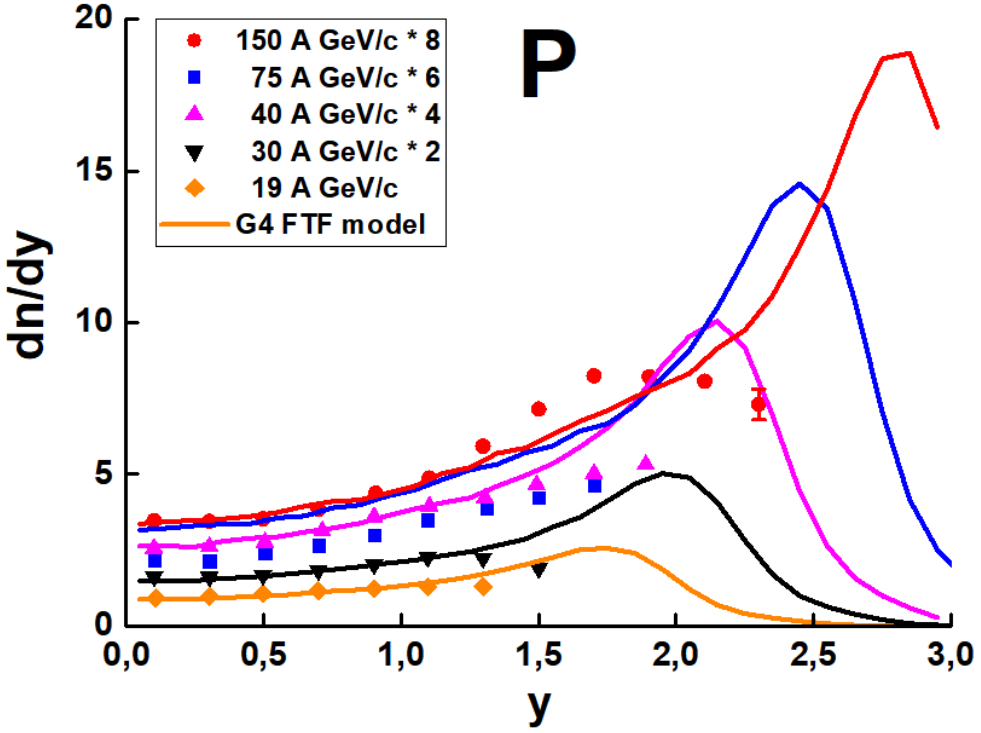
Questions? 5 % centrality ? Bmax ?

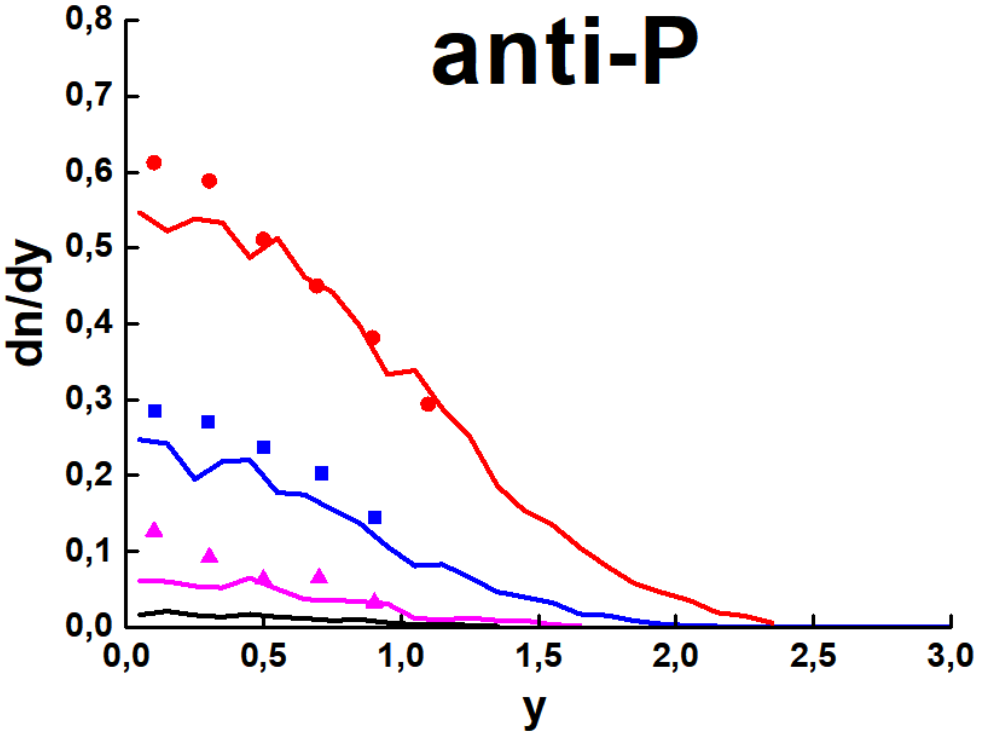


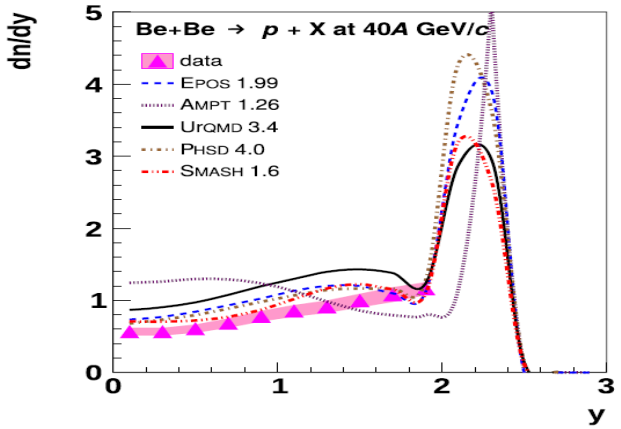
As seen, there is no a correspondence between Exp. data and EPOS one in high part of Epsd after E-shift and scale

Nuclear residual fragmentation in EPOS is not adequate to Exp.

NA61/SHINE data on Be-7 + Be-9 and FTF model
20 % centrality. Bmax = 2.1 fm







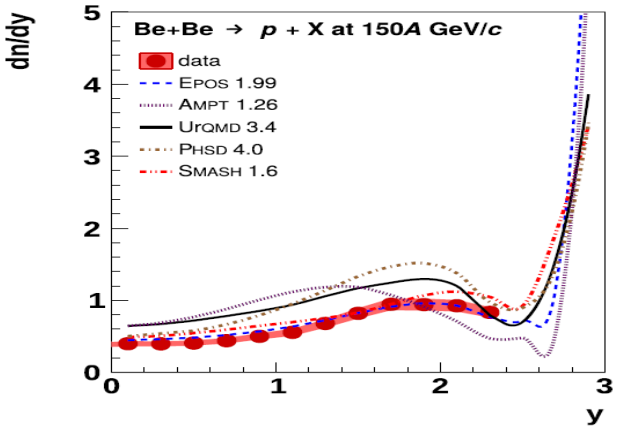


Fig. 31 Proton rapidity distribution in the 20% most *central* Be+Be collisions at 40*A* and 150*A* GeV/*c* compared with predictions of the EPOS 1.99 [16,31] (blue dashed line), URQMD 3.4 [33,34] (black solid line), AMPT 1.26 [35–37] (violet dotted line), PHSD 4.0 [38,39] (brown dashed-dotted line) and SMASH 1.6 (red dashed-double dotted line) [40,41] models

NA61/SHINE data on Be-7 + Be-9 and FTF model 20 % centrality. Bmax = 2.1 fm

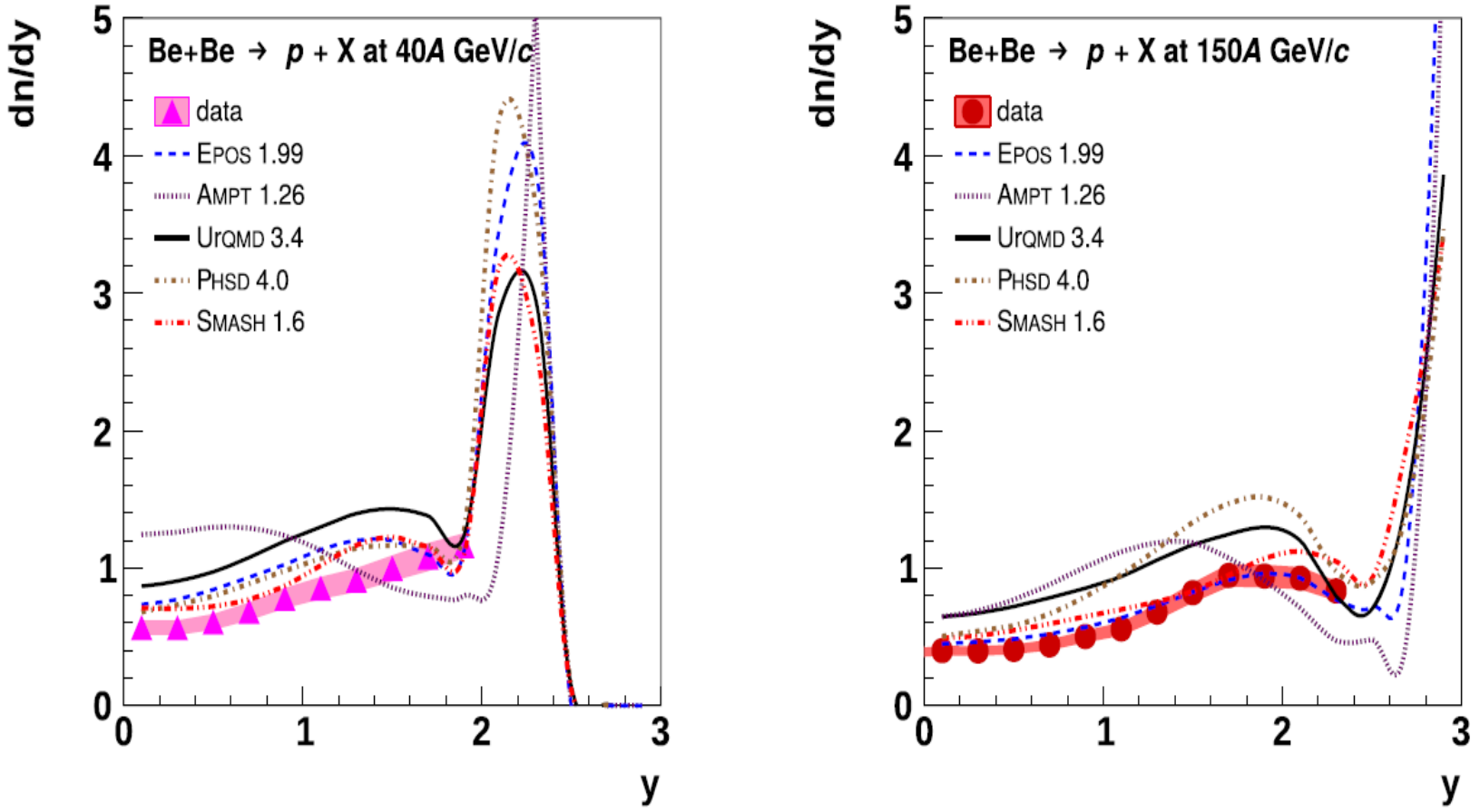


Fig. 31 Proton rapidity distribution in the 20% most *central* Be+Be collisions at 40*A* and 150*A* GeV/*c* compared with predictions of the EPOS 1.99 [16,31] (blue dashed line), URQMD 3.4 [33,34] (black solid line), AMPT 1.26 [35–37] (violet dotted line), PHSD 4.0 [38,39] (brown dashed-dotted line) and SMASH 1.6 (red dashed-double dotted line) [40,41] models