Towards understanding of enhanced production of strange particles in nucleus-nucleus interactions at high energies

V. Uzhinsky (JINR), A. Galoyan (JINR), N. Chalyi (TGU)

Content

1. Problem formulation – NA61/SHINE exp. Data on Ar+Sc interactions at 13 – 150 GeV/c/Nucleon (February 2024)
2. Hypothesis
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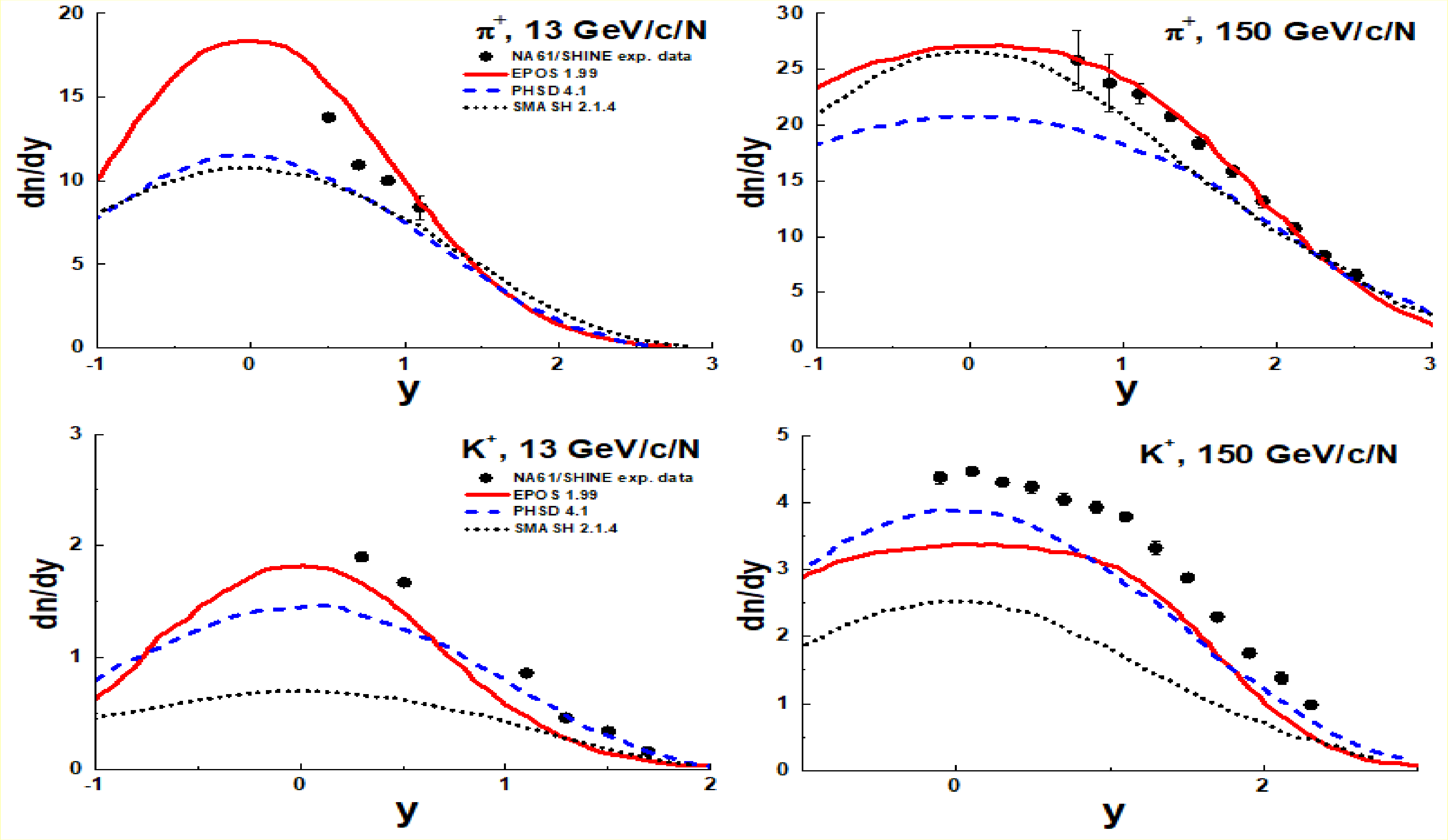
4. Calculations results
5. Conclusions

Problem formulation – NA61/SHINE exp. Data on Ar+Sc interactions at 13 – 150 GeV/c/Nucleon

Measurements of π+-, K+-, p and anti-P spectra in **Ar-40 + Sc-45 collisions at 13A to 150A GeV/c**
NA61/SHINE Collaboration H. Adhikary(Jan Kochanowski U.) et al. Eur. Phys. J. C 84 (**2024**) 4, 416
0 – 30 % centrality



The most actual models cannot describe K+ and K- meson production in Ar+Sc interactions !

Hypothesis

1. **Quark-Gluon Plasma (It is impossible at 13 GeV/c/N)**
2. **Intrinsic strangeness (It is forgotten)**
3. **Secondary interactions -- N+N->Y + K (UrQMD model**
4. **String fusion ?**
5. **EPOS: Core + Corona ?**
6. **Quark-Gluon String Model** -- QGSM **?**

Gevorg H. Arakelyan Carlos Merino Yuli M. Shabelski

SciPost Phys.Proc. **15 (2024) 024 ISMD2022, 024**

Centrality dependence of multistrange baryon production in high-energy heavy-ion collisions

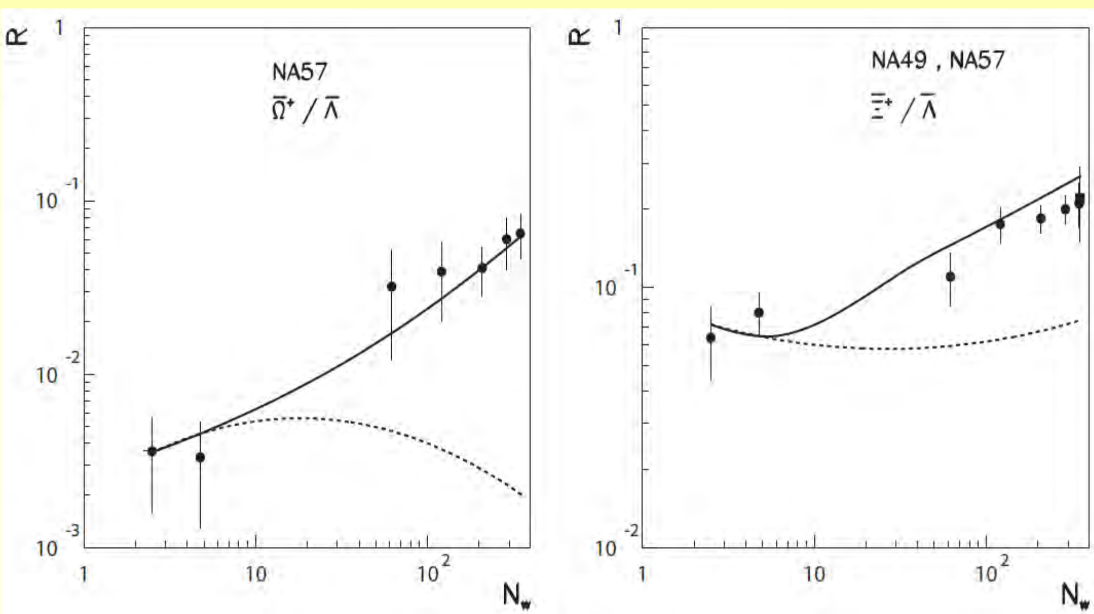


Figure 1: Experimental SPS ratios $\overline{\Omega}^+/\overline{\Lambda}$ (left panel), and of $\overline{\Xi}^+/\overline{\Lambda}$ (right panel), in Pb+Pb collisions, as function of the number of wounded nucleons, N_W, compared with the corresponding QGSM results. The full lines show the result of QGSM calculation obtained with the value λ_s=0.32 at the left end, and with larger values of λ_s at its right end, while the dashed lines show the result of QGSM calculation obtained with a constant value λ_s=0.32, disregarding of the value of the number of wounded nucleons (centrality).

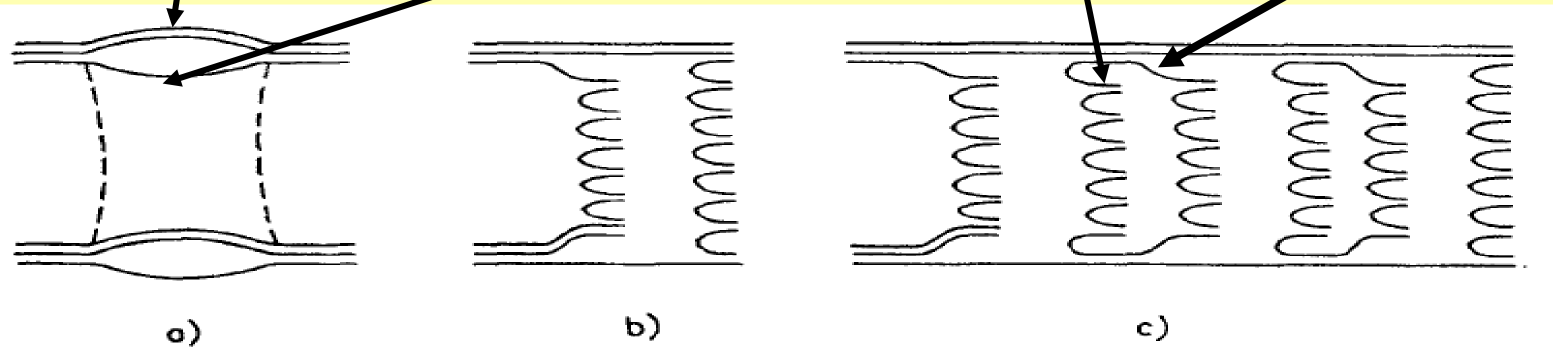
λs=0.36 ?

Possibilities of the Quark-Gluon-String Model (QGSM)

A.B. Kaidalov, Phys. Lett. B 116 (1982) 459: A.B. Kaidalov and K.A. Ter-Martirosian, Phys. Lett. B 117 (1982) 247

Constituent di-quark Constituent quark Sea quark **λs ?** Sea anti-quark

Nucl. struct.



λs

String frag.

Fig. 7. – QGSM diagrams corresponding *a*) to the one-pomeron exchange contribution to the elastic pp scattering (cylindrical dyagram), *b*) to the cut of one pomeron (which determines the contribution to the inelastic pp cross-section) and *c*) to the cut of three pomerons.

$$\begin{aligned}\phi_k^h(x) &= f_{qq}^h(x_+,k)\cdot f_q^h(x_-,k) + f_q^h(x_+,k)\cdot f_{qq}^h(x_-,k)\\ &+ 2(k-1)\cdot f_s^h(x_+,k)\cdot f_s^h(x_-,k) \quad ,\end{aligned}$$

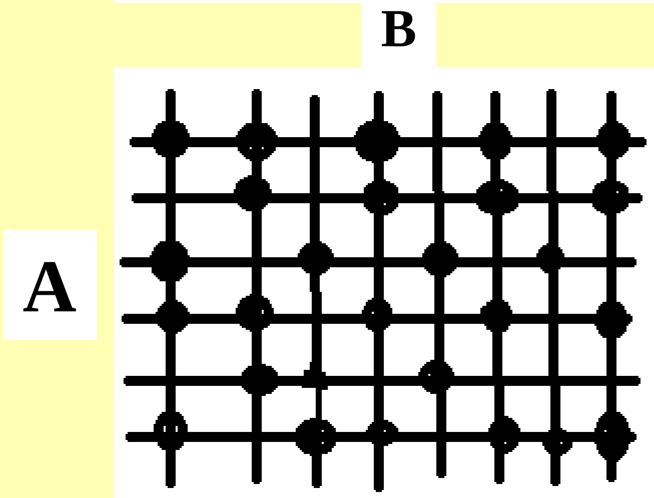
$$f_i^h(x_\pm,k) = \int_{x_\pm}^{1} u_i(x_1,k)G_i^h(x_\pm/x_1)dx_1 \quad ,$$

A.B. Kaidalov and O.I. Piskunova, Z. Phys. C - Particles and Fields 30, 145-150 (1986

$$\begin{aligned}F_{q_{\rm sea}}^{h(n)} = \frac{1}{4+2\delta}\int_x^1 dx_1 \Big[& f_p^{u_{\rm sea}(n)}(x_1)G_u^h\left(\frac{x}{x_1}\right)\\ &+ f_p^{\bar u_{\rm sea}(n)}(x_1)G_{\bar u}^h\left(\frac{x}{x_1}\right) + f_p^{d_{\rm sea}(n)}(x_1)G_d^h\left(\frac{x}{x_1}\right) + f_p^{\bar d_{\rm sea}(n)}(x_1)G_{\bar d}^h\left(\frac{x}{x_1}\right) + \delta\left(f_p^{s_{\rm sea}(n)}(x_1)G_s^h\left(\frac{x}{x_1}\right)\right.\\ &\left.+ f_p^{s_{\rm sea}(n)}(x_1)G_{\bar s}^h\left(\frac{x}{x_1}\right)\right)\Big].\end{aligned}$$

δ=0.25 → λs=0.11

Possibilities of the Quark-Gluon-String Model (QGSM) for nucleus-nucleus interactions



Max number of wounded nucleons = A+B
Max number of binary collisions = A*B!

In nucleus-nucleus interactions as in high multiplicity PP interactions multiplicity of sea-quark-sea-antiquark pairs (2ν) can be essentially larger then multiplicity of constituent quark-diquark pairs (2A+2B). For the first ones strangeness suppression Ps-anti-s/Pu-anti-u ~ 1, as in QGP according to our rough estimation!

How can one check the assumption?

EPOS ?, QGSJET +,

AGT (Amelin-Gudima-Toneev) Model,

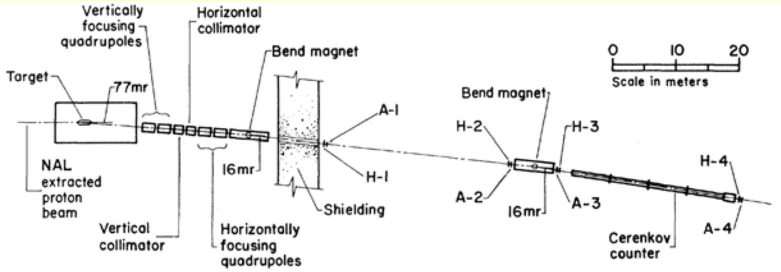
DCM (Dubna Cascade Model (used in NICA project).

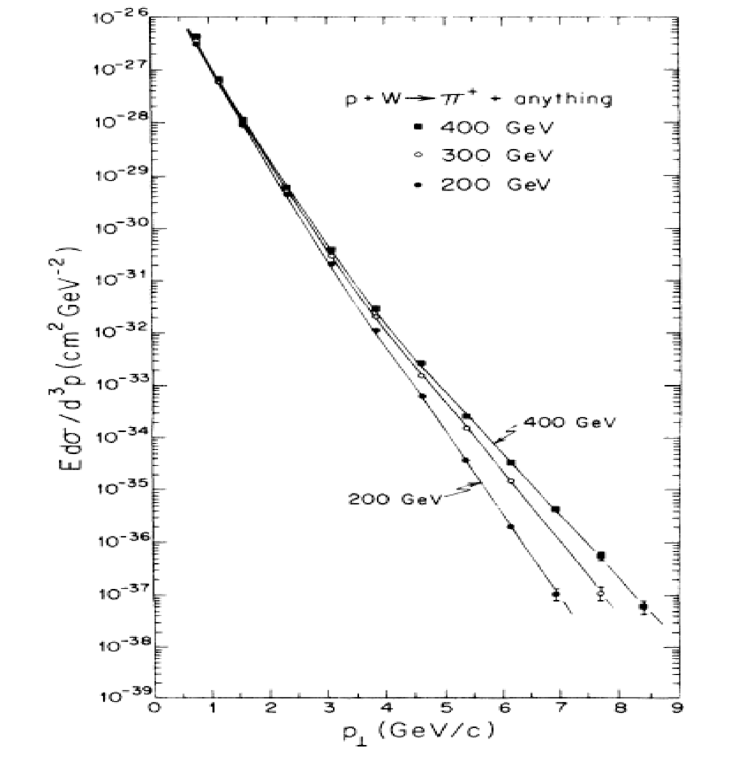
Geant4 QGSM for h+A interactions (our implementation)

Calculations results: Cronin's exp., Geant 4 QGSM

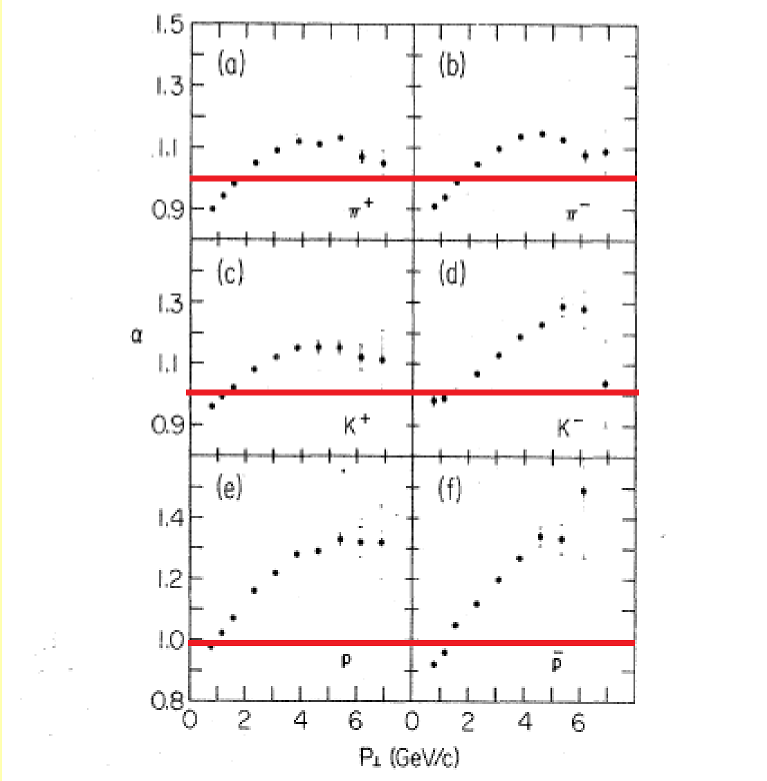
J.W. Cronin et al *Phys. Rev. Lett.* 31 (1973) 1426, 218 citations
E100 Collaboration: J.W. Cronin et al. *Phys. Rev. D* 11 (1975) 3105, 1 151 citations
D. Antreasyan et al. *Phys. Rev. D* 19 (1979) 764, 686 citations

P + P, H-2, Be, Ti, W at 200, 300 and 400 GeV/c





Invariant cross section per W nucleus *divided by 40.9* (see text) for π^+ mesons produced at 90° c.m. in p-W collisions.



The power α of the A dependence of the invariant cross section versus $p_\perp$ for the production of hadrons by 400-GeV protons; (a) π^+, (b) π^-, (c) K^+, (d) K^-, (e) p, and (f) $\bar{p}$. Unless indicated, the errors are smaller than or equal to the size of the points.

It was expected that hard scattered hadrons will have A^1.
The results were very unexpected!
Double partons scattering !?

There were a lot of considerations.

For us it is important that the data are the most exact data on hadron-nucleus interactions.

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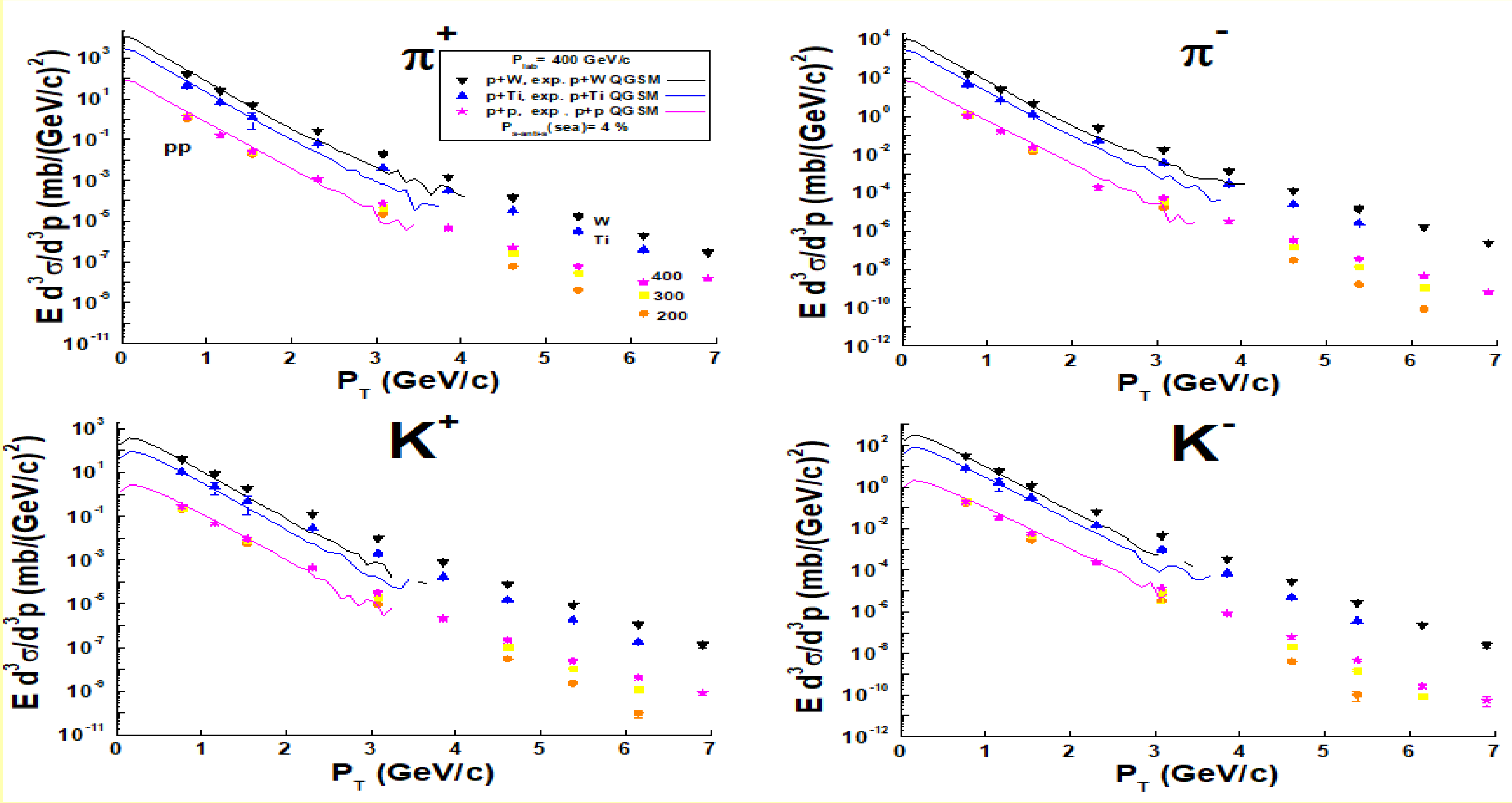

Geant 4 QGSM does not include hard interactions which are at $P_T > 2 – 3$ GeV/c.

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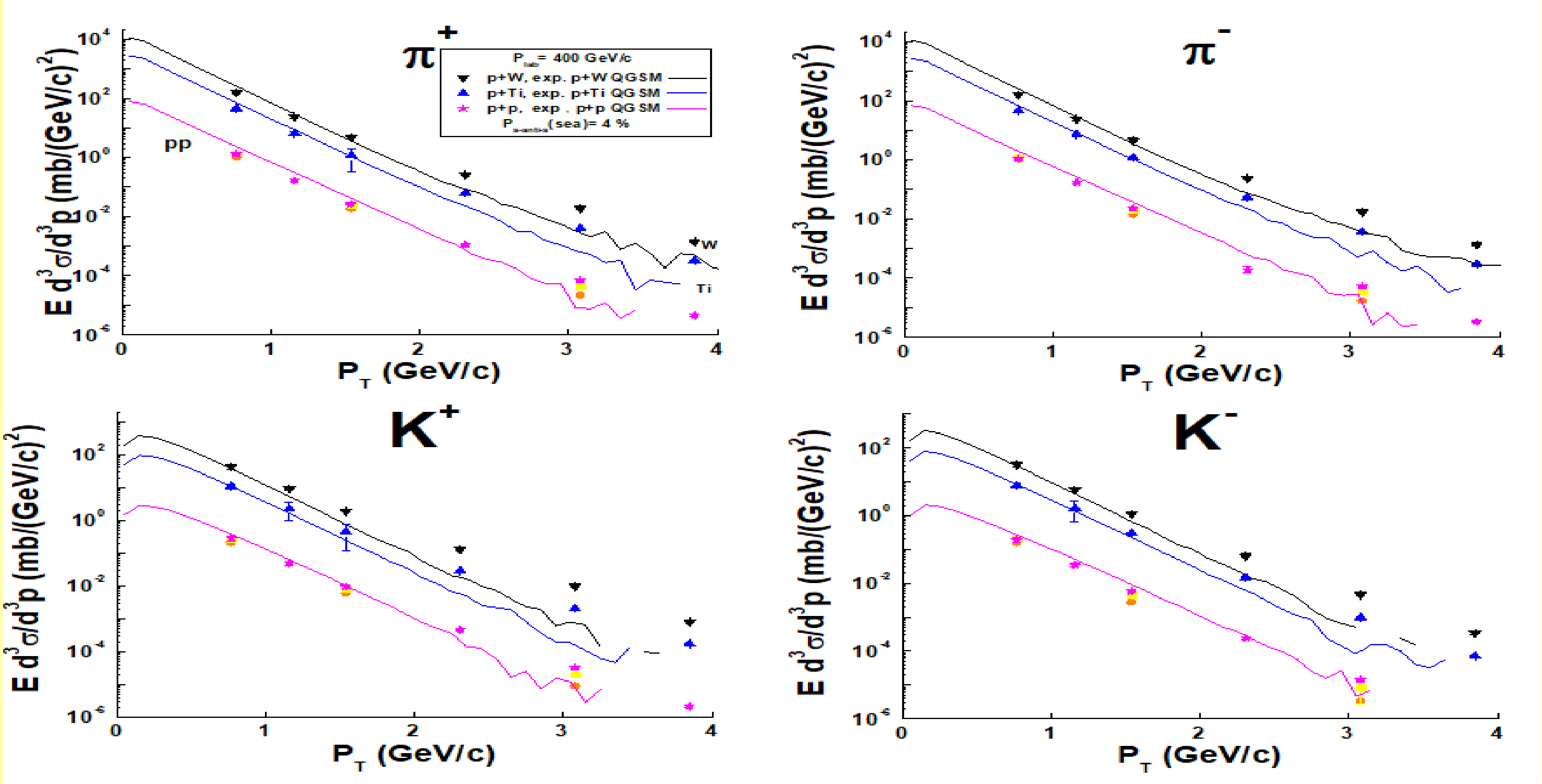

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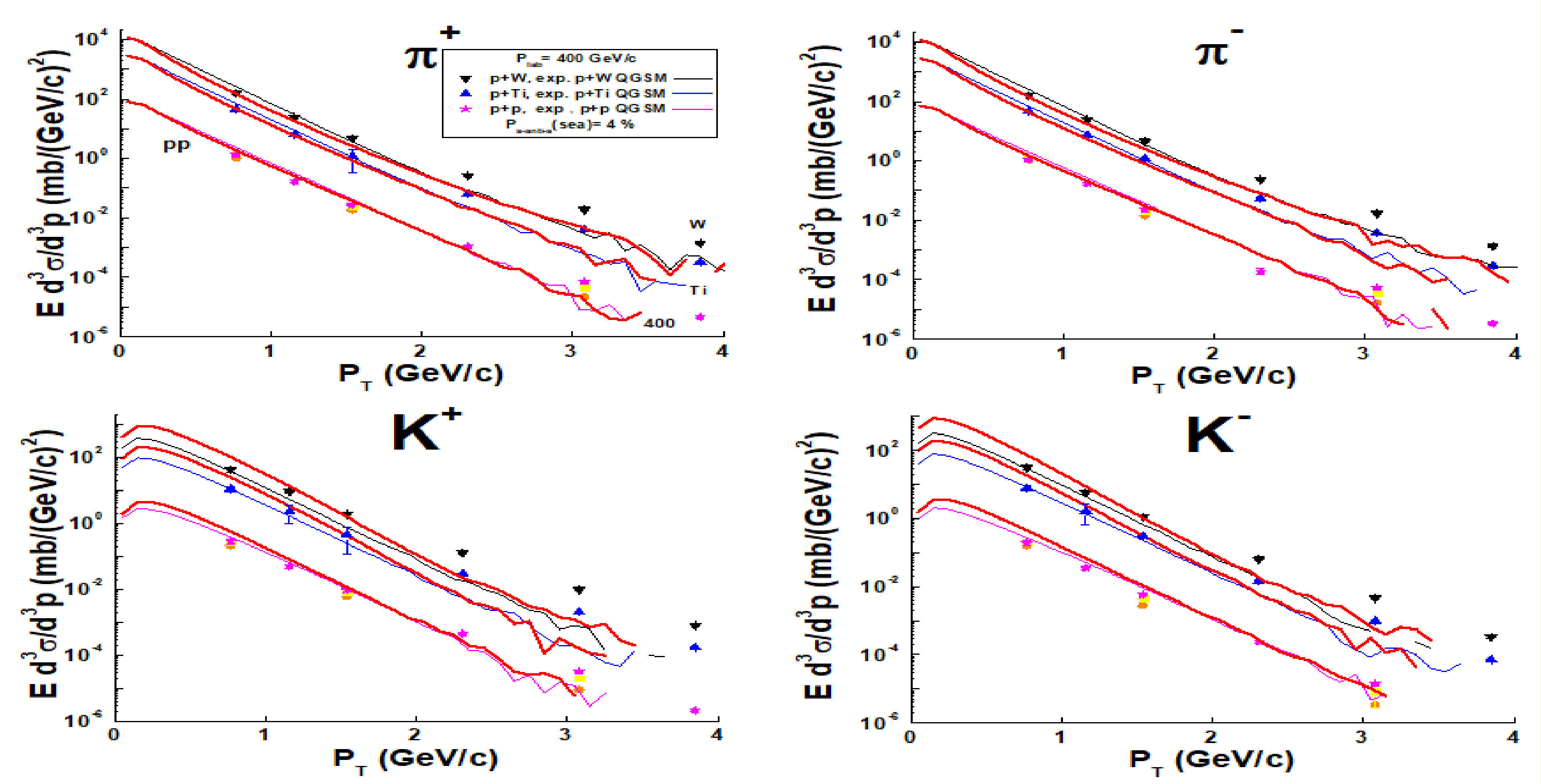
Extreme suggestion – $P_{s\text{-}anti\text{-}s} = 1$!



Effect of the strange sea quarks can be seen at $P_T < 2$ GeV/c.

Possibilities of the Quark-Gluon-String Model (QGSM)

QGSM – Quark-Gluon String Model by A.B. Kaidalov implemented in DCM – Dubna-Cascade Model

AGT – Amelin-Gidima-Toneev model,
N. S. Amelin, Yad. Fiz. **51**, 512 (1990)
N. S. Amelin, et al, Yad. Fiz. **52**, 272 (1990)

a previous version of DCM.

SHIELD – a Monte Carlo Hadron Transport Code
A.V. Dementyev, N.M. Sobolevsky,
IAI, 2017

SHIELD-HIT12A - a Monte Carlo particle transport program for ion therapy research
N. Bassler, D.C. Hansen, A.Luhr, B. Thomsen, J.B. Petersen, N Sobolevsky
Jour. Of Phys. 489 (2014) 12004

User Manual for the Code LA QGSM
K.K. Gudima, S. Mashnik, A.J. Sierk
Los Alamos, December, 2001

DCM - Dubna Cascade Model (NICA)
Monte-Carlo Generator of Heavy Ion Collisions DCM-SMM,
M. Baznat, A. Botvina, G. Musulmanbekov, V. Toneev, V. Zhezher
Phys. Part. Nucl. Lett. 17 (2020) 3, 303

A.S. Botvina, K. K. Gudima, J.Steinheimer, M. Bleicher, and J. Pochodzalla
Phys. Rev. C ***95****, 014902 (2017*)

Calculations results: AGT and DCM

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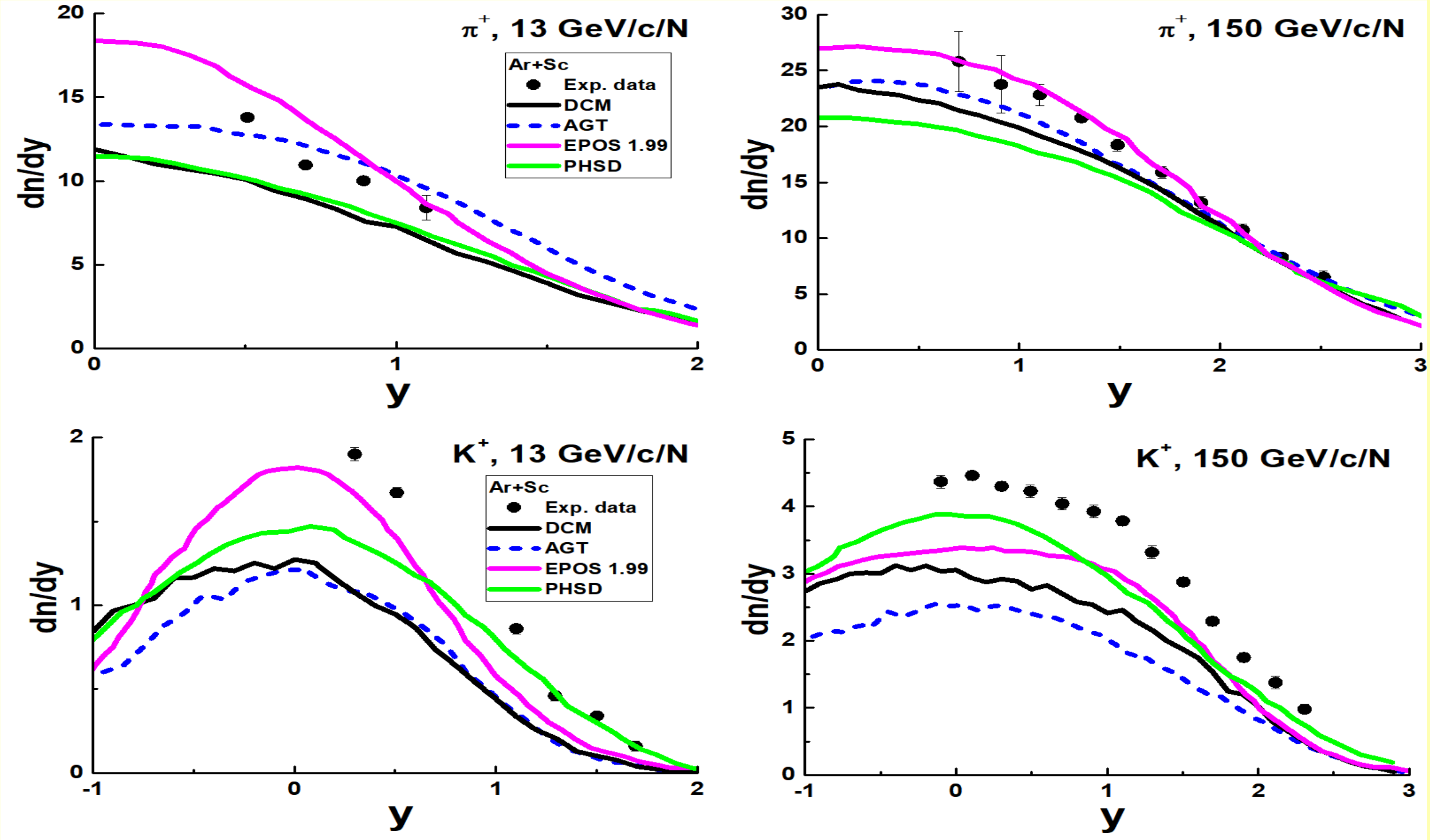


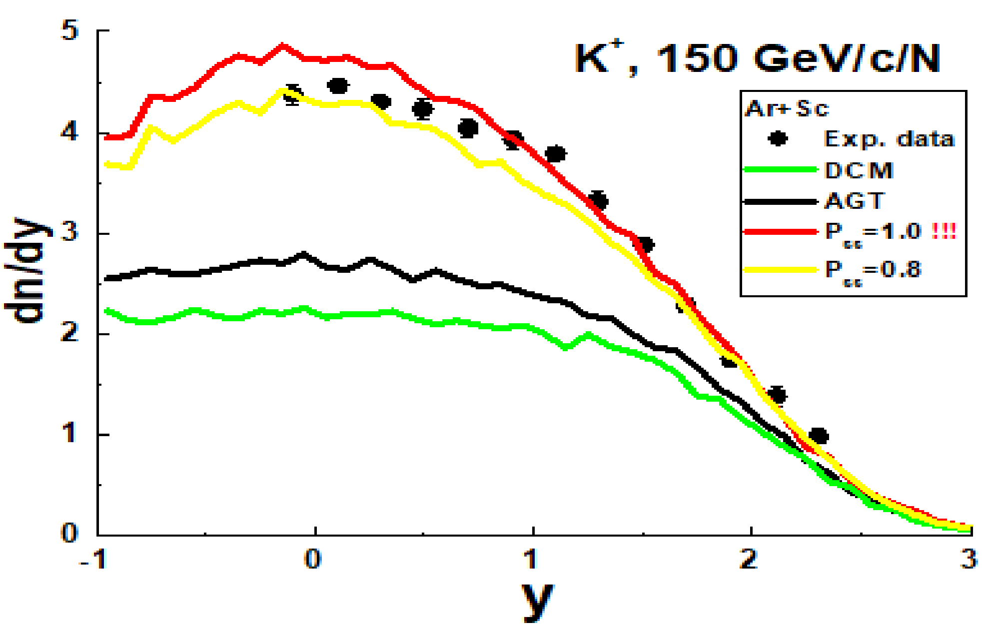
Default versions of AGT and DCM models cannot reproduce K-meson yields!

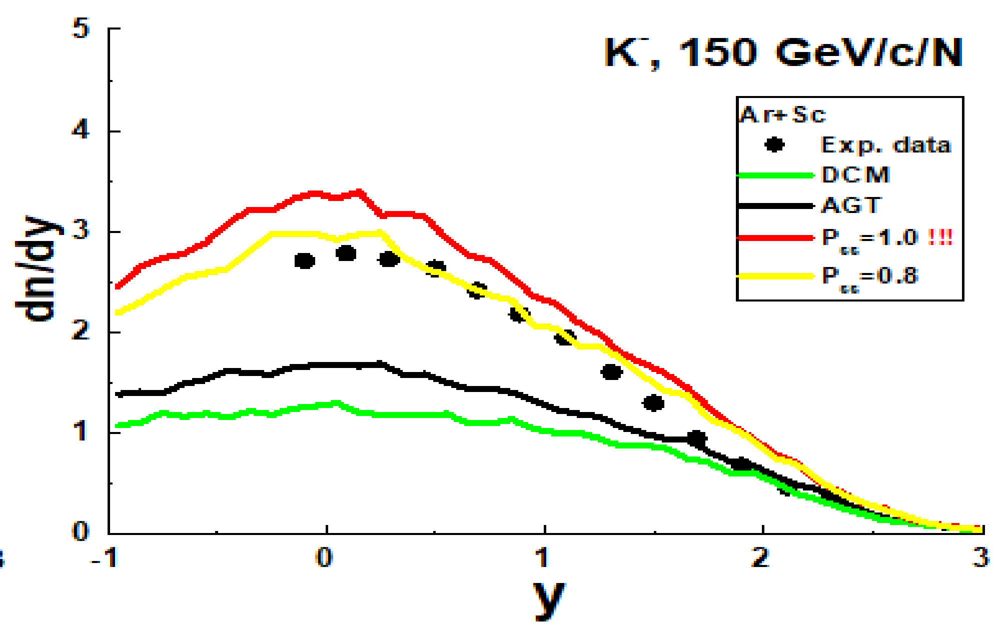
Calculations results: AGT and DCM

```
SUBROUTINE CHAINS

IF(NAVAL.EQ.0) GO TO 2
      IF(NUAVAL.NE.IPAR) GO TO 1
      IAA=1
      NASEA=NASEA+1
      JS1=NASEA
      IFLAS(NASEA)=1+INT(RNDM(-1.)/PUD) ! PUD=0.42  ! Uzhi
      GO TO 3
  1    CONTINUE
2     NAVAL=NAVAL+1
```

```
 IF(NAVAL.EQ.0) GO TO 2
      IF(NUAVAL.NE.IPAR) GO TO 1
      IAA=1
      NASEA=NASEA+1
      JS1=NASEA
c       IFLAS(NASEA)=1+INT(RNDM(-1.)/PUD)  ! Uzhi
     IFLAS(NASEA)= 3                                  ! Uzhi
GO TO 3
  1    CONTINUE
2     NAVAL=NAVAL+1
```

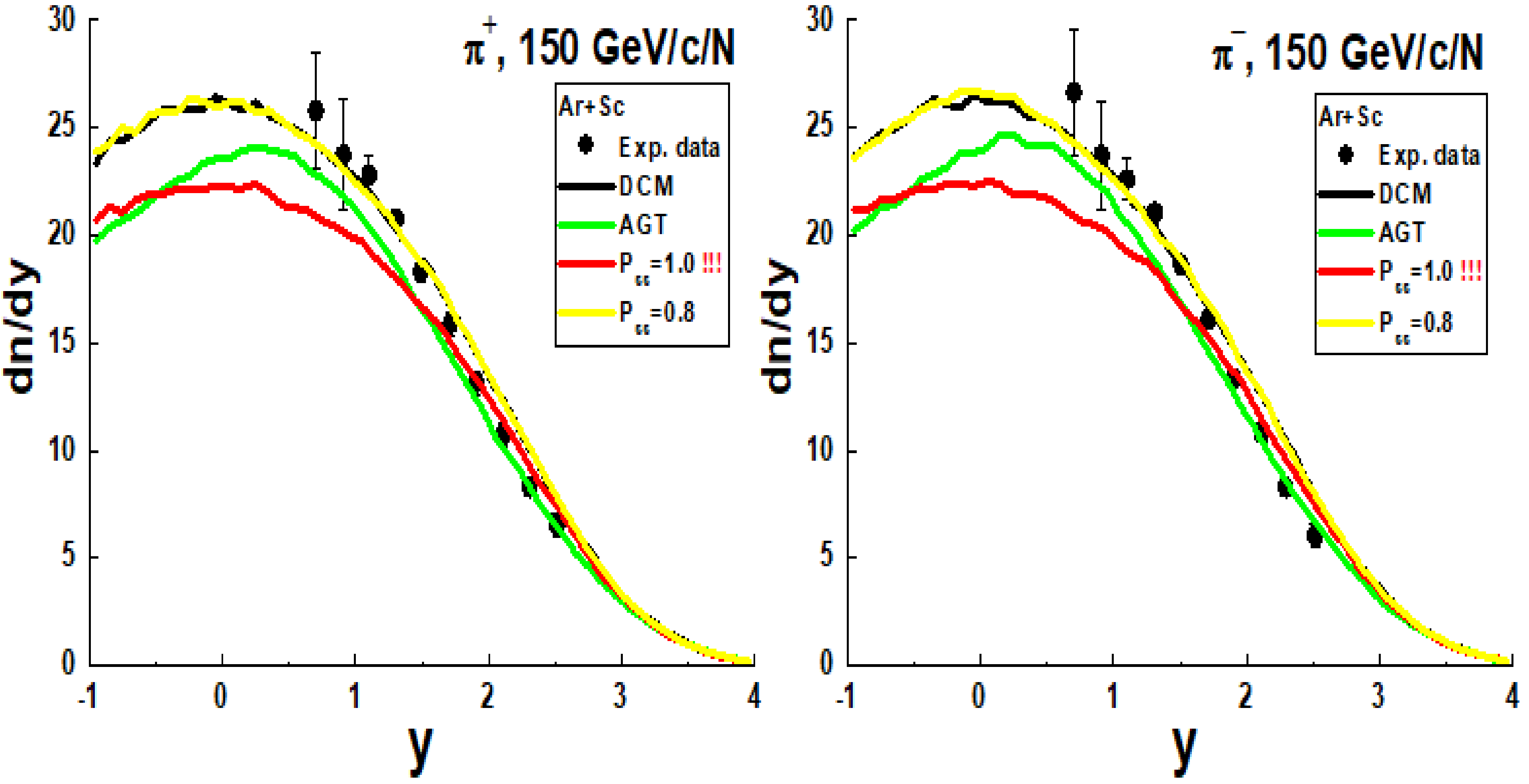




Calculations results

We propose a possible explanation in QGS model.

At the same time a problem with Pi+ and Pi- appeared.



Ps-sbar = 80 % Too much! If QGP would be added, Ps-sbar could be lower.

It would be well to improve the DCM model!

Conclusions

1. **The enhancement of the strange particle production in Ar+Sc interactions can be reproduced increasing the strange quark production probability at the ends of sea strings.**
2. **It would be well to improve DCM and reach a well description of the strange particle production in AA interactions on a solid basis.**
3. **It would be well to obtain analogous results in QGSJET III. Model.**

The research was carried out with the support of a grant from the Government of the Russian Federation (Agreement No. 075-15-2025-009 of 28 February 2025)

Measurements of π+-, K+-, p and pbar 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 (A. Aduszkiewicz(Warsaw U.) et al. Eur. Phys. J. C77 (2017) 10, 671

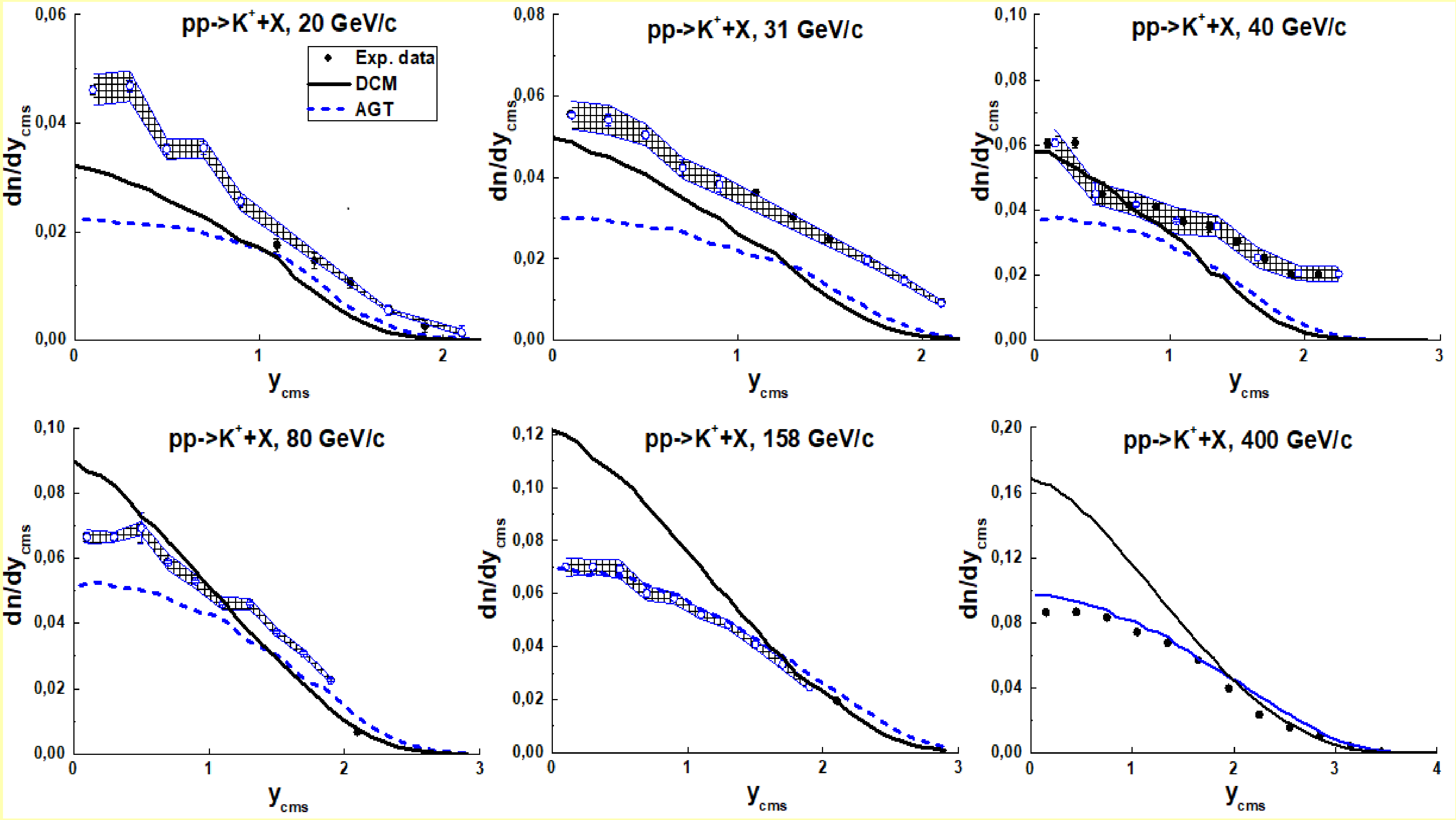


Fig. 3 Rapidity distributions of K^+-mesons in PP-interactions.

AGT approximately reproduces the energy dependence of the spectra.
DCM essentially overestimate the data at high Plab!

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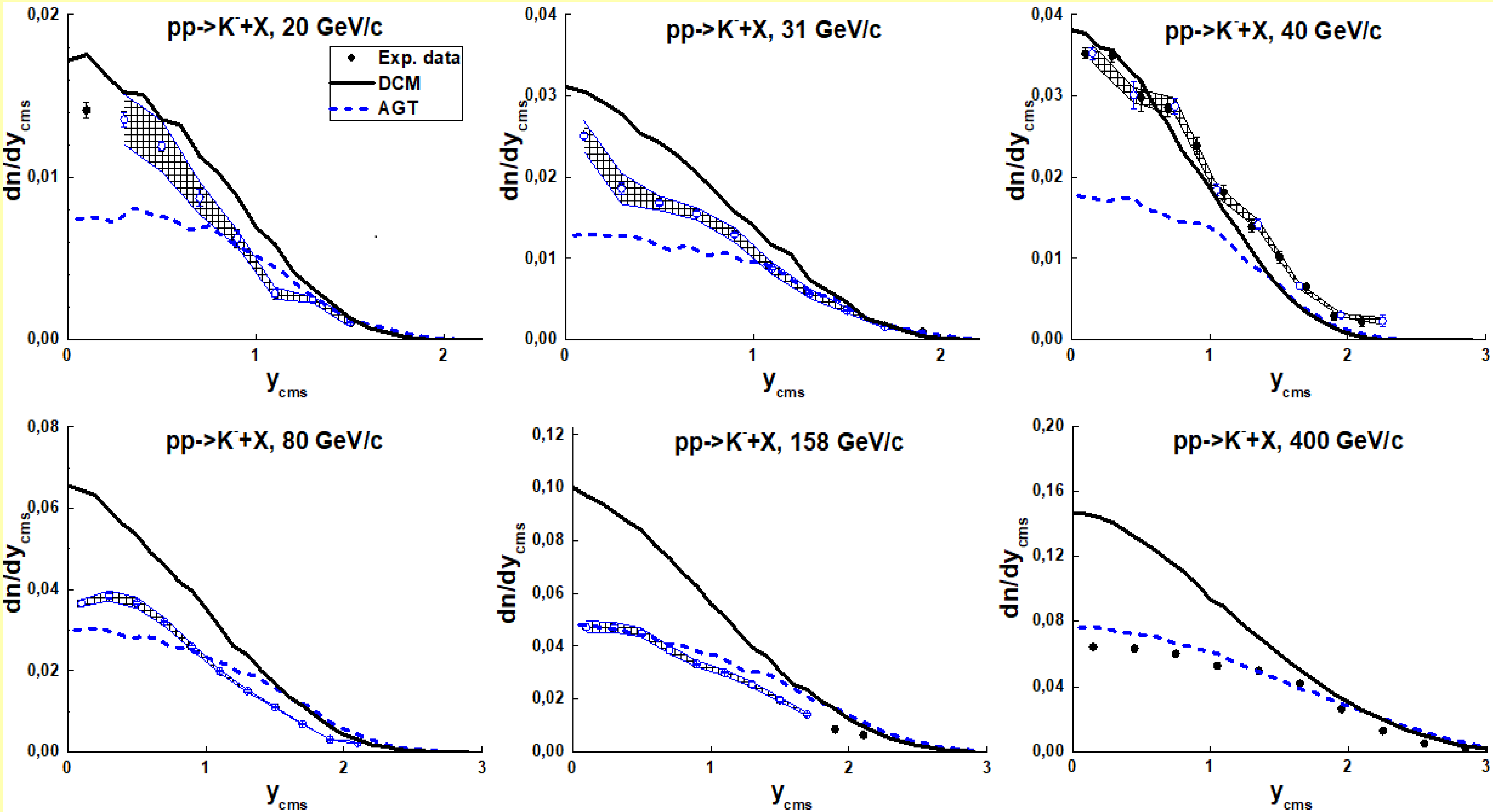
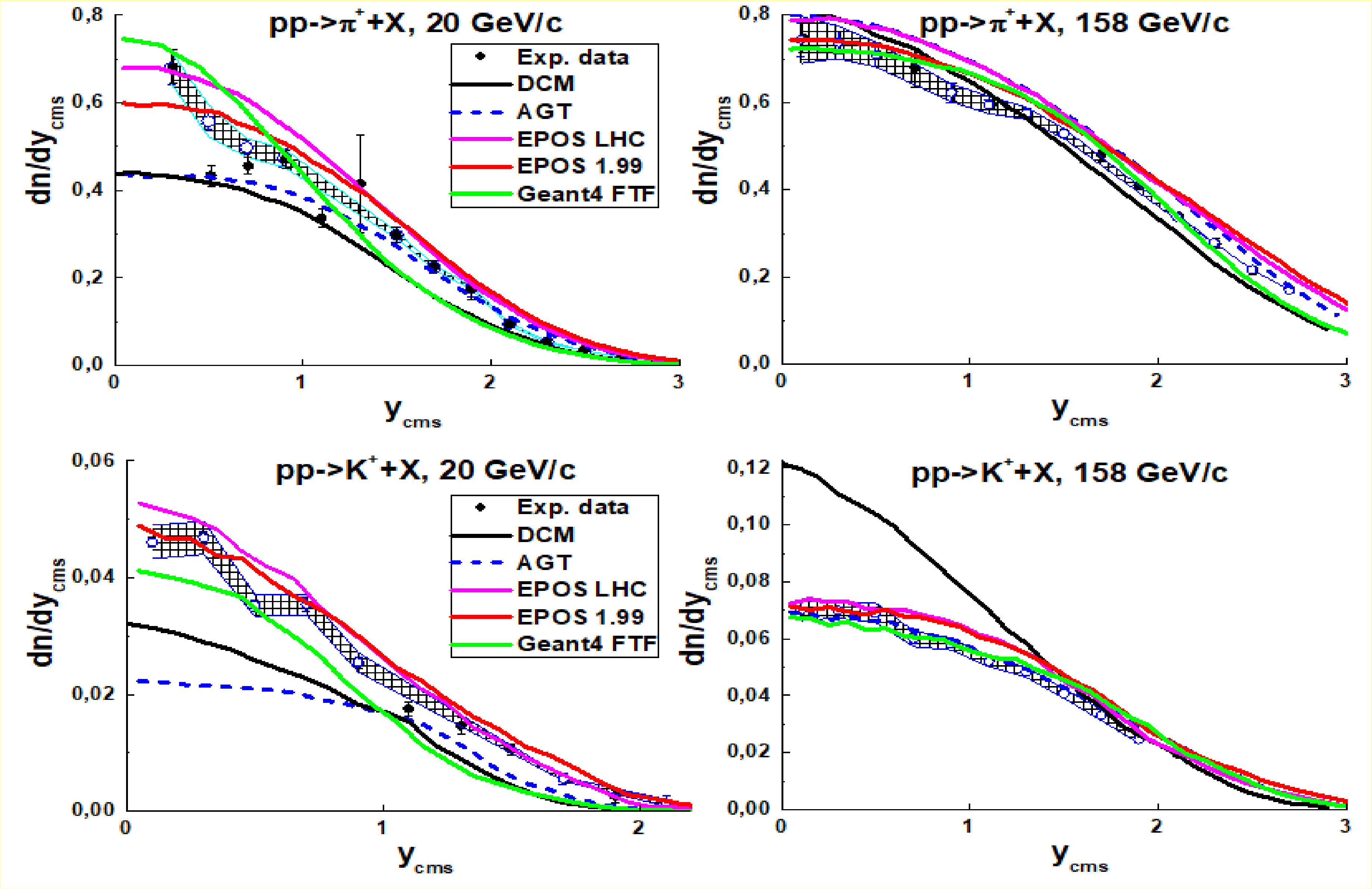


Fig. 4 Rapidity distributions of K^--mesons in PP-interactions.

AGT approximately reproduces the energy dependence of the spectra.

DCM essentially overestimate the data at high Plab!

DCM/AGT and other models, PP interactions



AGT is ~ among the other models
DCM has to be improved!

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NA61/SHINE Collaboration (A. Aduszkiewicz(Warsaw U.) et al. Eur. Phys. J. C77 (2017) 10, 671

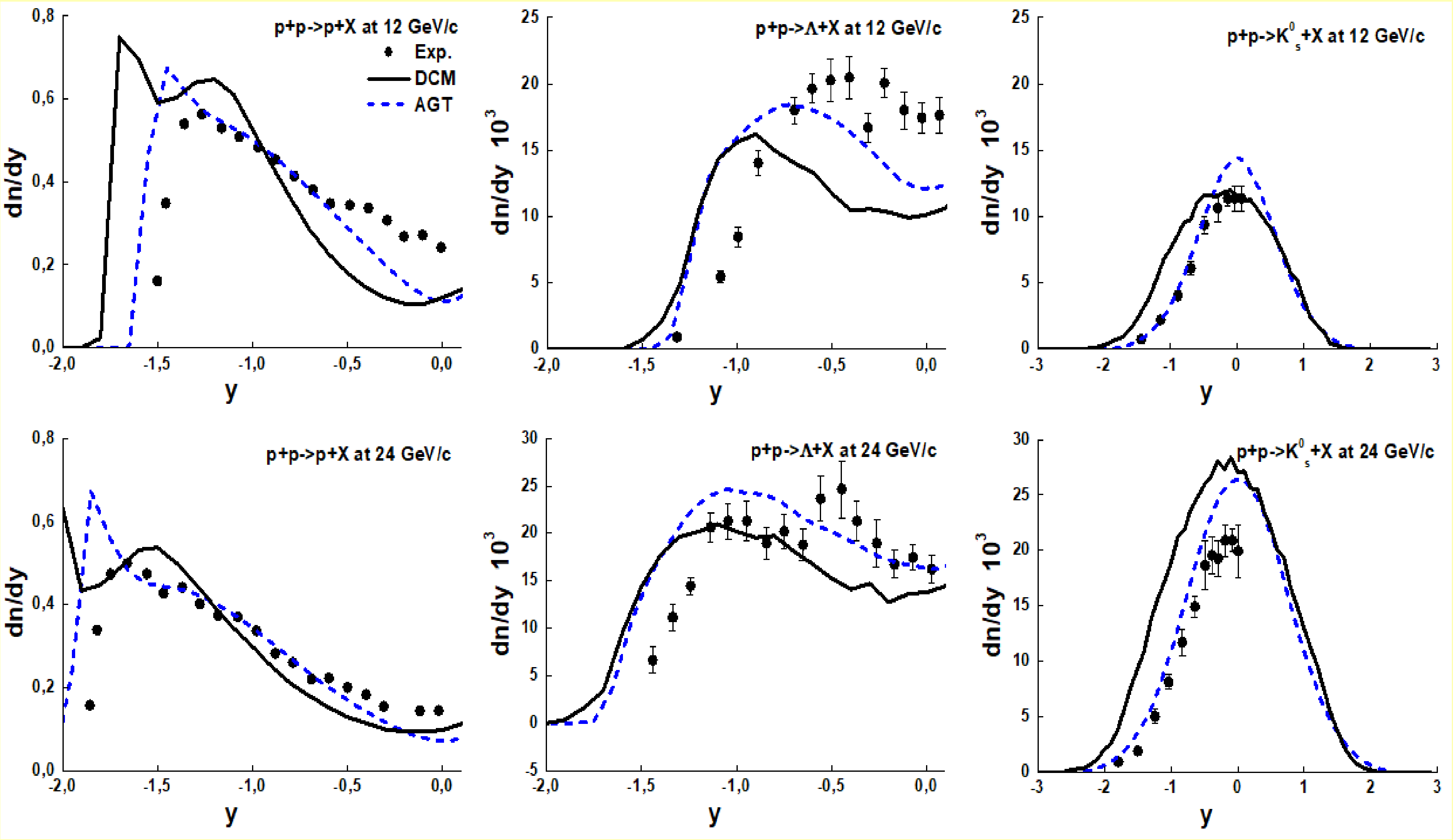

Fig. 8 Rapidity distributions of protons, Λ-hyperons and K^0_s -mesons in PP-interactions.

AGT is a little bit better than DCM.