Energy dependence of hadron production

NA49 data and string models

Motivation
Models and events
Multiplicities
Particle ratios
Various systems

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# Motivation

NA49 published the energy dependence of π⁺, π⁻ , K⁺ , K⁻ productions in central Pb+Pb collisions (PRC 2002, PRC 2008).

The productions were obtained for full phase space (<π⁺>, <π⁻>, <K⁺>, <K⁻>) as well as at midrapidity dN/dy (y=0) (excluding particles from $\Lambda, \Sigma, \Xi, \Omega$ decays).

Results exhibit rapid changes of hadron production properties with collision energy in the low SPS energy range.

The goal is to compare these results with predictions of several string models.
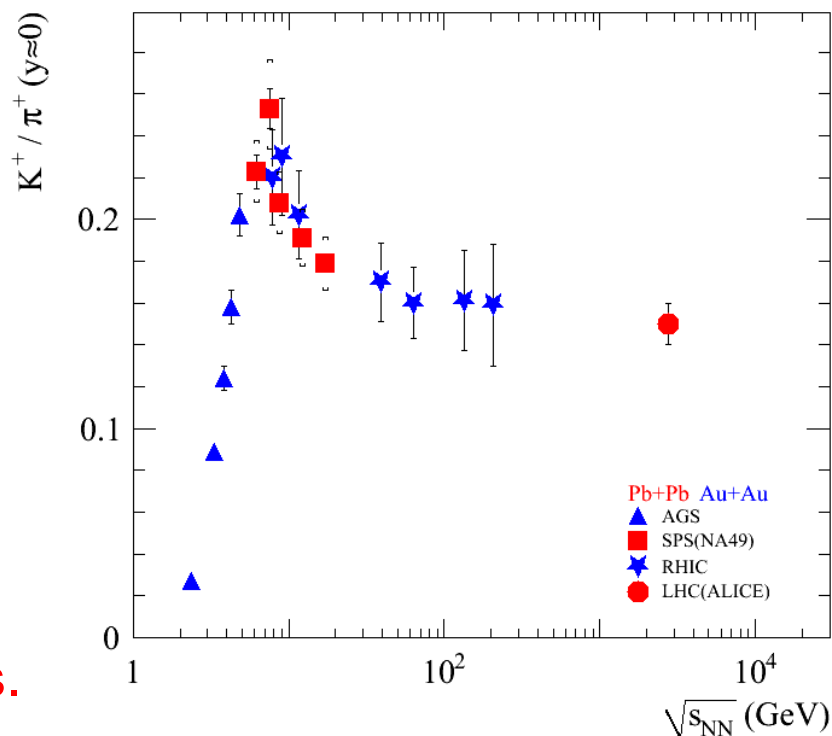
NA49 data samples

Data samples

central Pb+Pb collisions

E(GeV)	Centrality (b)	Number of events
20A	7.2% (b<4.0 fm)	3.5×10^5
30A	7.2% (b<4.0 fm)	3.5×10^5
40A	7.2% (b<4.0 fm)	4.0×10^5
80A	7.2% (b<4.0 fm)	3.0×10^5
158A	5.0% (b<3.4 fm)	4.0×10^5

p+p collisions

158		4.8×10^6

Models

Values calculated from models:

- 4π yields obtained directly from multiplicity distributions

- midrapidity yields using NA49 fitting procedure for rapidity distributions

Three models used:

VENUS 4.12

EPOS 1.99

URQMD 3.3

URQMD 3.4 - ongoing

Generated events *(basic investigation)*

VENUS 4.12

- 5.000 central Pb+Pb VENUS events at 5 SPS beam energies per nucleon E_{lab} = 20, 30, 40, 80 and 158 GeV which corresponds to E_{CM} = 6.27, 7.62, 8,77, 12.32, 17.27 GeV

EPOS 1.99

- 2.500 central Pb+Pb at 5 SPS beam energies and 4 larger „RHIC" energies E_{CM} = 20, 60, 130, 200 GeV

- 100k events of pp collisions at the same energies

- no generation below E_{CM} = 6 GeV

URQMD 3.3

- similar like from EPOS plus collisions at lower AGS/SPS energies E_{CM} = 5.12 GeV (E_{lab} = 13 GeV), E_{CM} = 4.095 GeV (E_{lab} = 8 GeV)

Generated events *(basic investigation) c.d.*

- *ndecay/nodecay* options in VENUS, EPOS switched on
- *stopdecay* Λ, Σ, Ξ, Ω and their anti-particles in URQMD model

- centrality of Pb+Pb collisions

    lower energies (E_{CM} < 17.2 GeV) b < 4.0 fm, 7.2%

    higher enrgies (E_{CM} > 17.2 GeV) b < 3.4 fm, 5.0%
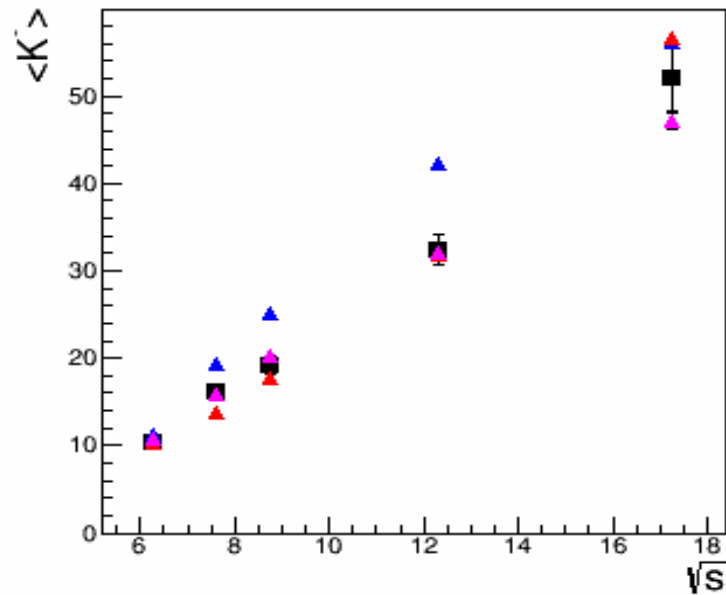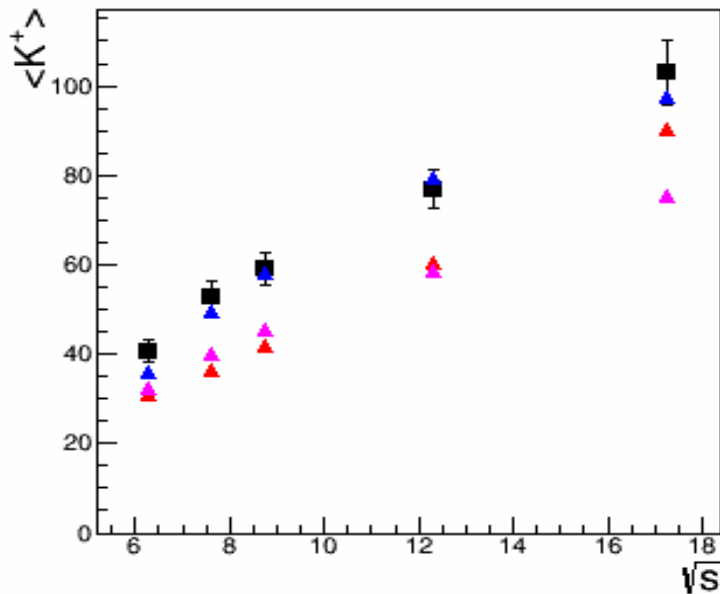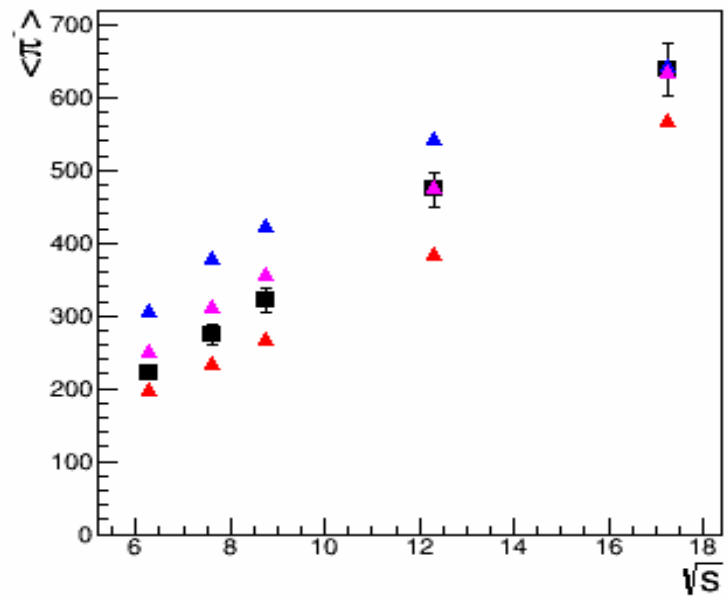
Multiplicities

NA49 and VENUS results

central PbPb collisions (4π mean multiplicities)

E(GeV)	$\langle\pi^+\rangle$	$\langle\pi^-\rangle$	$\langle K^+\rangle$	$\langle K^-\rangle$
20A	190±1±9(173.4)	221±1±11(198.7)	40.7±0.7±2.2(31.07)	10.3±0.1±0.2(10.42)
30A	241±1±12(208.5)	274±1±14(234.3)	52.9±0.9±3.5(36.6)	16.0±0.1±0.2(13.78)
40A	293±3±15(243.2)	322±3±16(269.5)	59.1±1.9±3(42.05)	19.2±0.5±1.0(17.69)
80A	446±5±22(357.5)	474±5±23(384.4)	76.9±2±4(60.54)	32.4±0.6±1.6(31.79)
158A	619±17±31(540)	639±17±31(569)	103±5±5(90.17)	51.9±1.9±3 (56.59)

p+p collisions

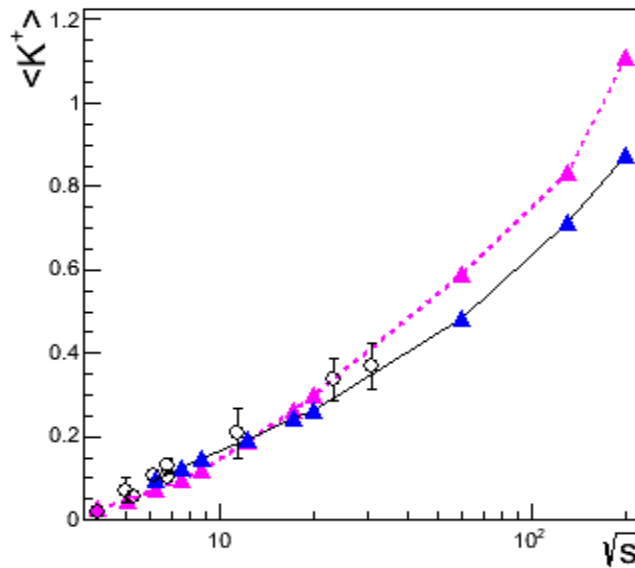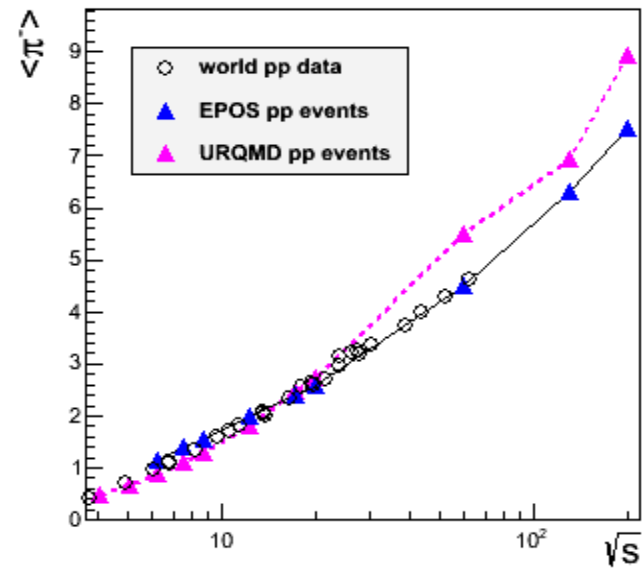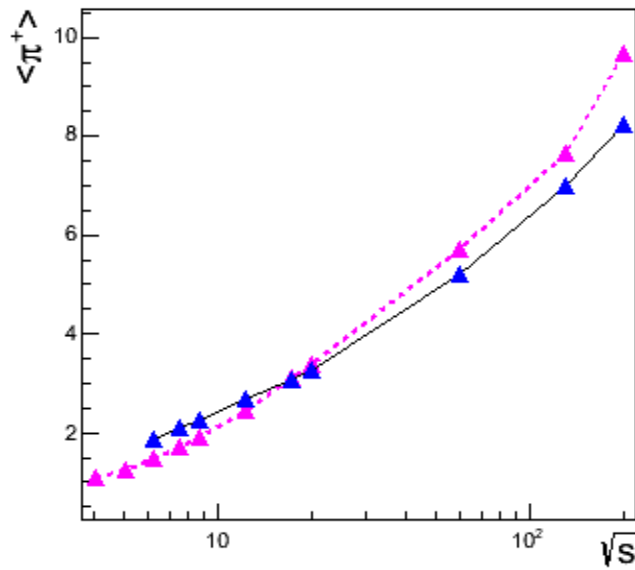|		
158	3.018±1.5%	2.360±1.5%

mean multiplicity (central Pb+Pb)
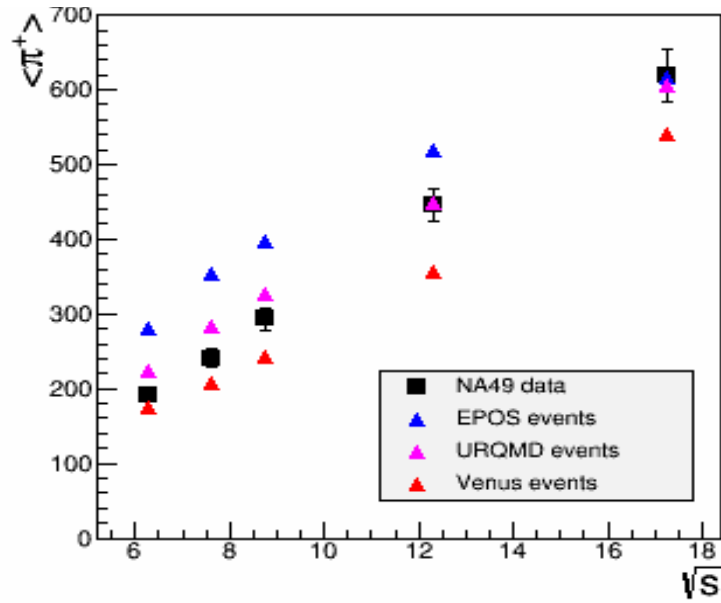
mean multiplicity (pp)
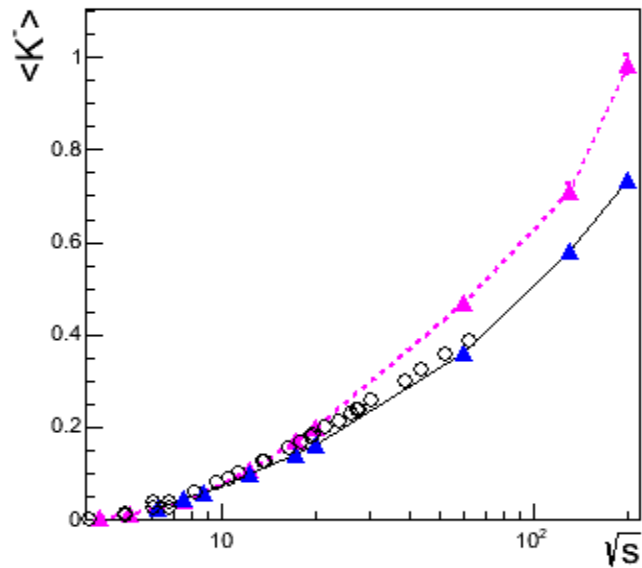
mean multiplicity - summary

Central Pb+Pb collisions

- None of models can reproduce multiplicity of pions and kaons of both charges.

  - π^+ , π^-

- EPOS overestimate (except of top SPS)

- VENUS underestimate

- URQMD slight underestimate (low energy), agreement (top SPS)

  - K^+

- EPOS agreement or slight underestimate

- VENUS, URQMD underestimate

  - K^-

- EPOS overestimate (agreement at low SPS)

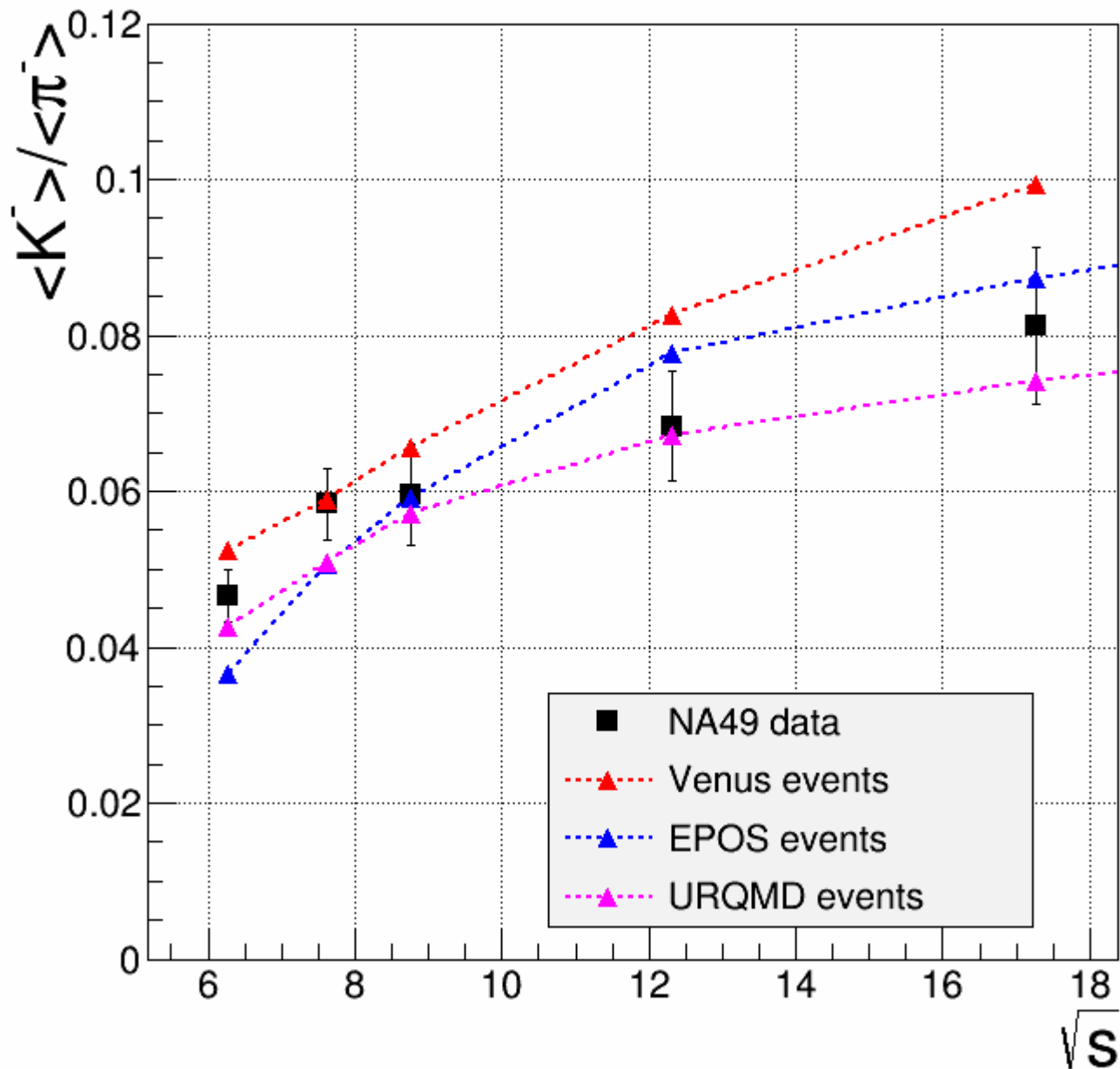- VENUS, URQMD agreement or slight underestimate

p+p collisions

- Sligthly better agreement with world data for EPOS than for URQMD (especially above SPS energy)
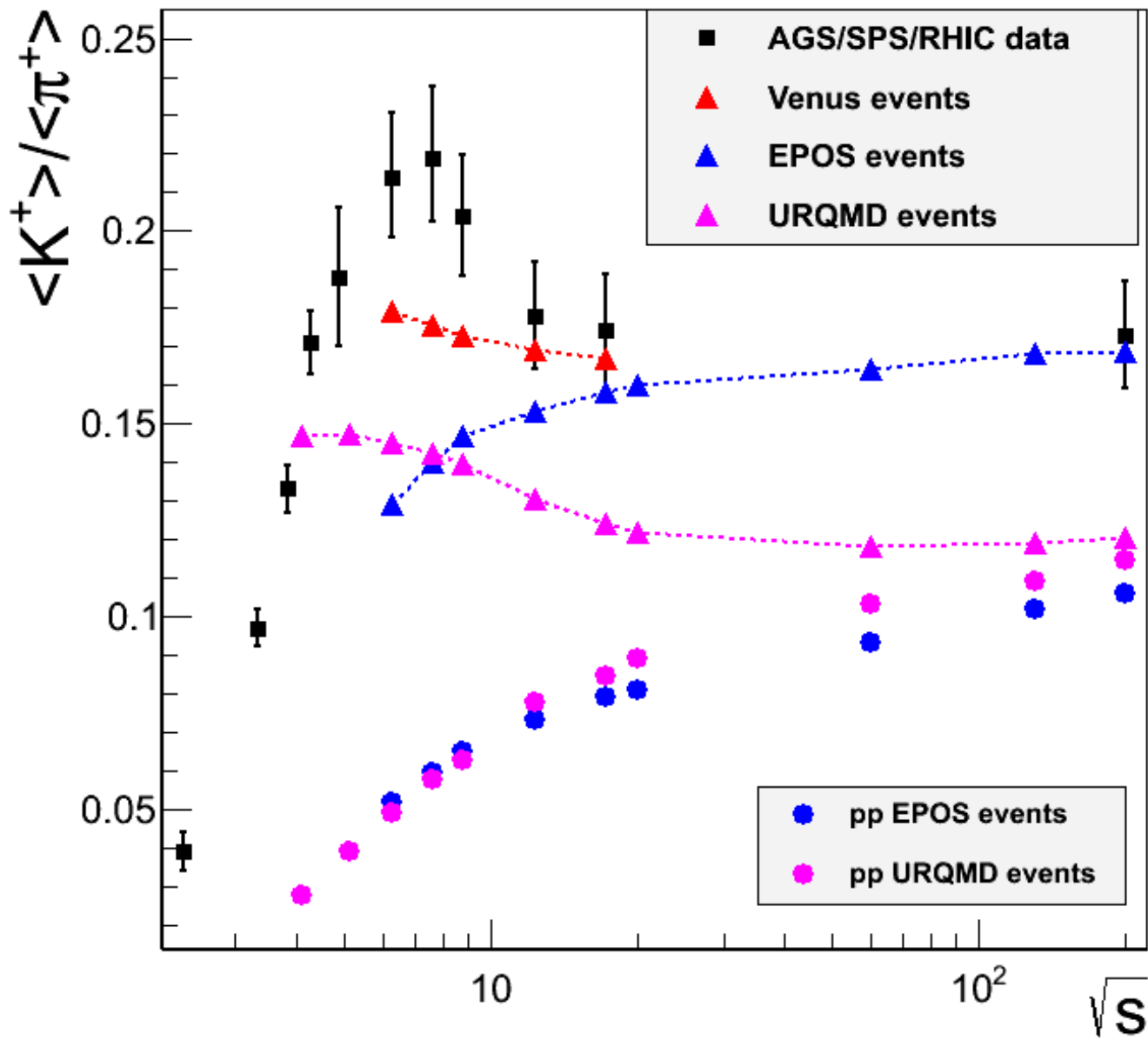
Mean multiplicity ratios
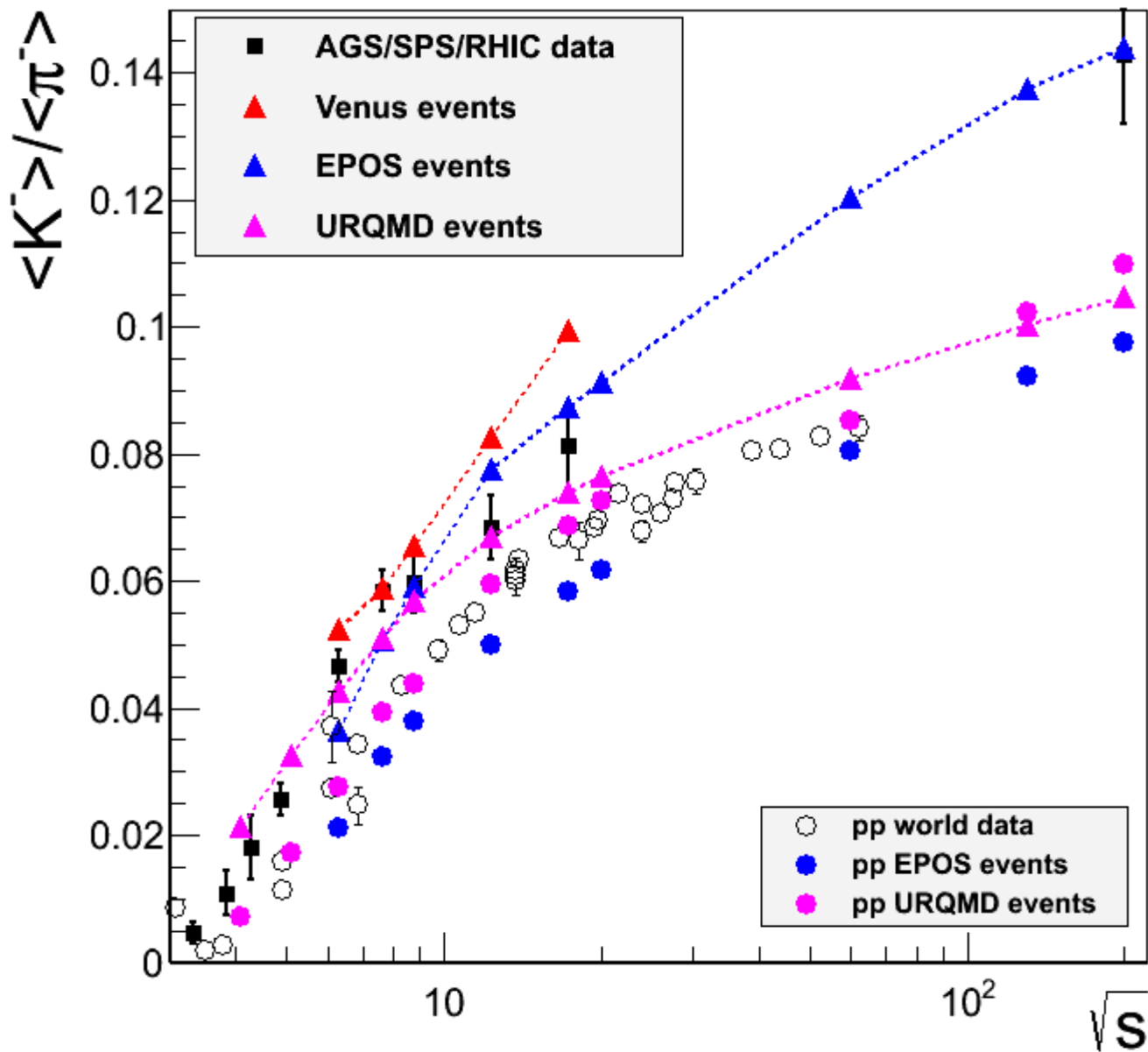
mean multiplicity ratio (positive), SPS
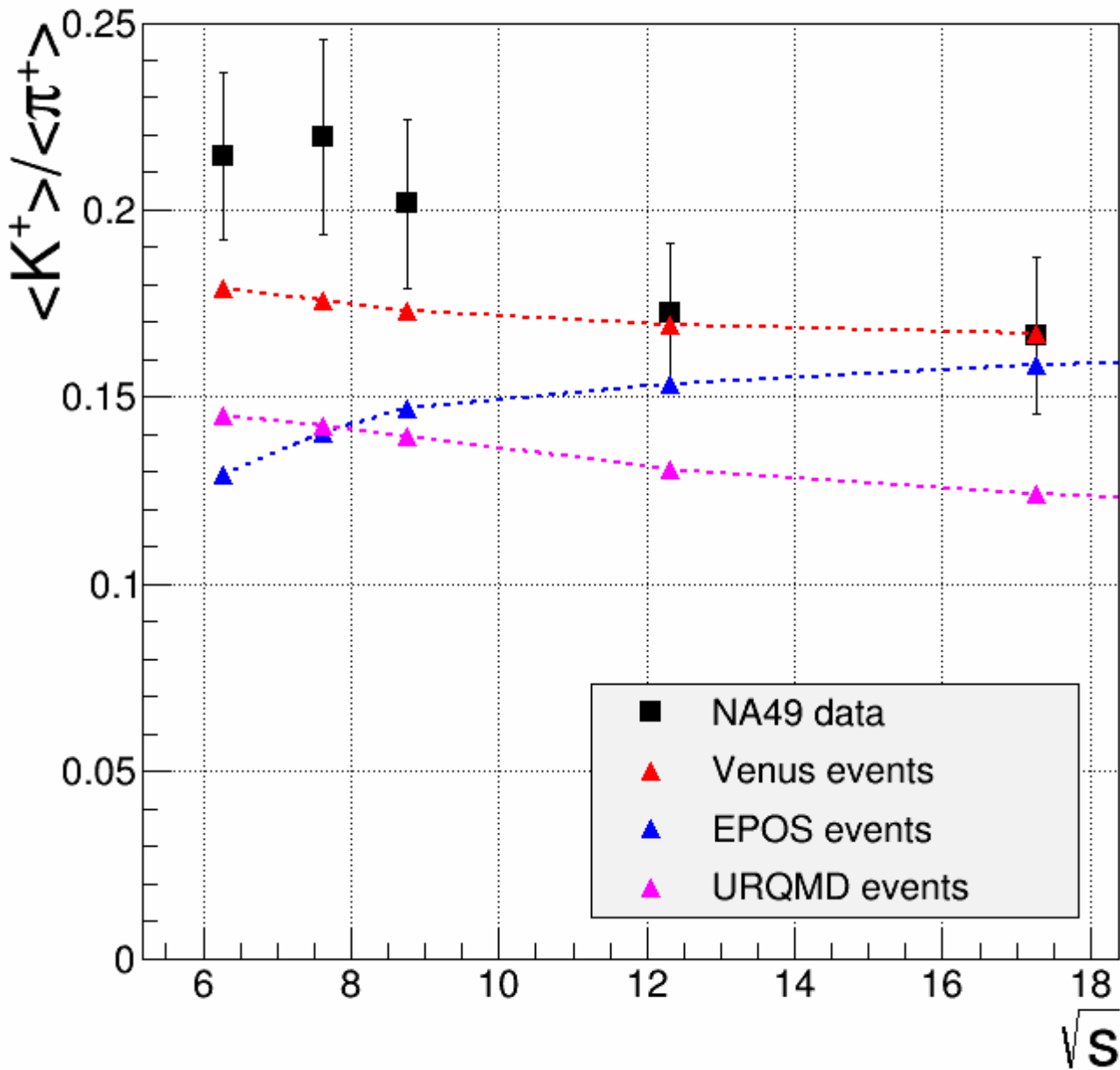
mean multiplicity ratio (negative), SPS

mean multiplicity ratio (positive)

mean multiplicity ratio (negative)

Rapidity distributions
# and
dN/dy (y=0)

(study with EPOS model)

Rapidity distributions and dN/dy (y=0)

- **double Gauss function fitted to rapidity distributions:**

$$\frac{dn}{dy} = \frac{\langle n \rangle}{2\sqrt{2\pi}\sigma} \left\{ \exp\left[-\frac{1}{2}\left(\frac{y - y_0}{\sigma}\right)^2 \right] + \exp\left[-\frac{1}{2}\left(\frac{y + y_0}{\sigma}\right)^2 \right] \right\},$$

- **NA49 data were fitted (measured points only) to guide the eye and check if we reproduce NA49 values published in PRC**

- **dN/dy (y=0) obtained as the value of fit function at y=0 (for E=20, 30A GeV) and as the average from fit function in the range -0.6 < y < 0.6 (for E = 40, 80, 158A GeV)**
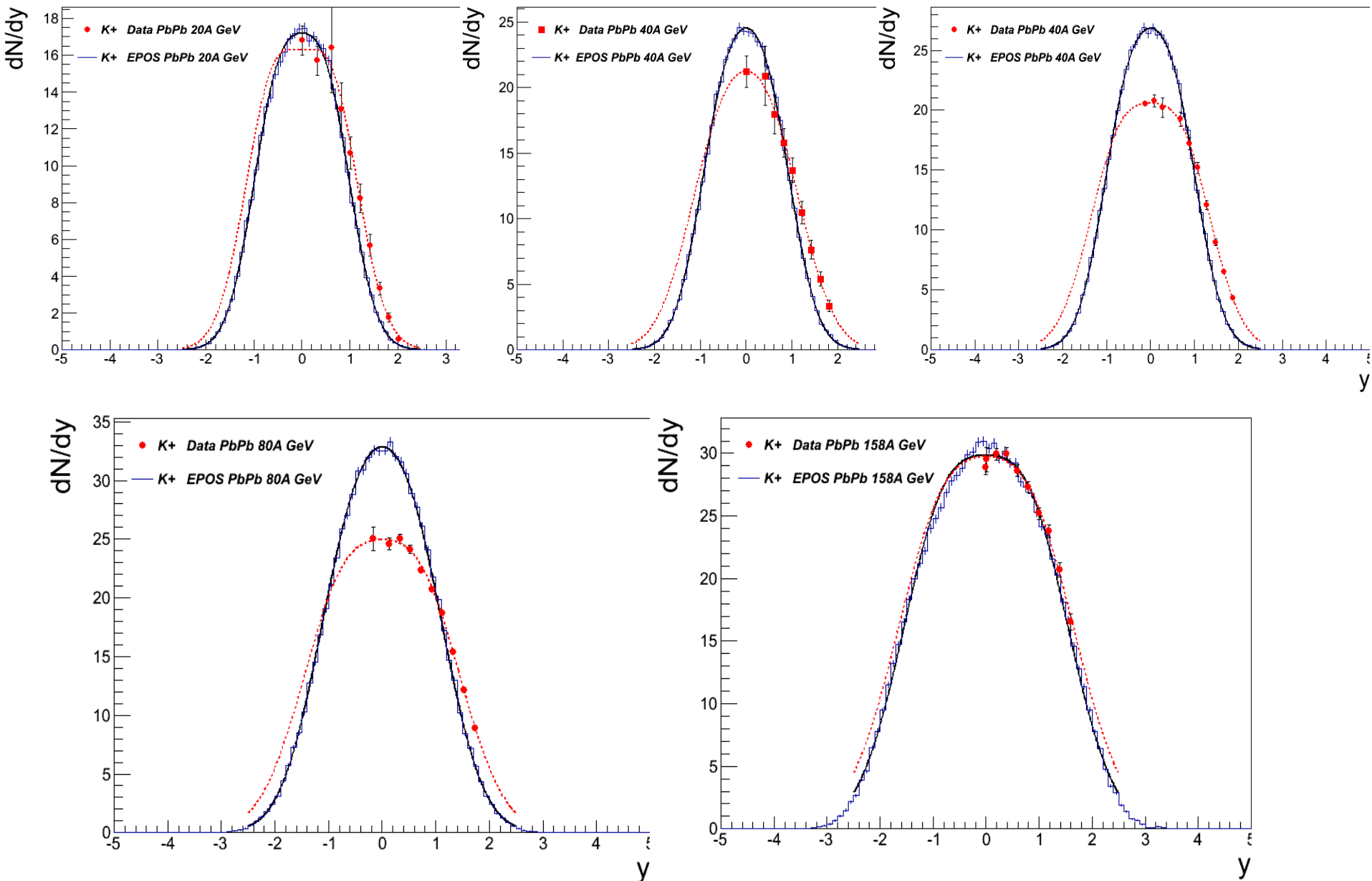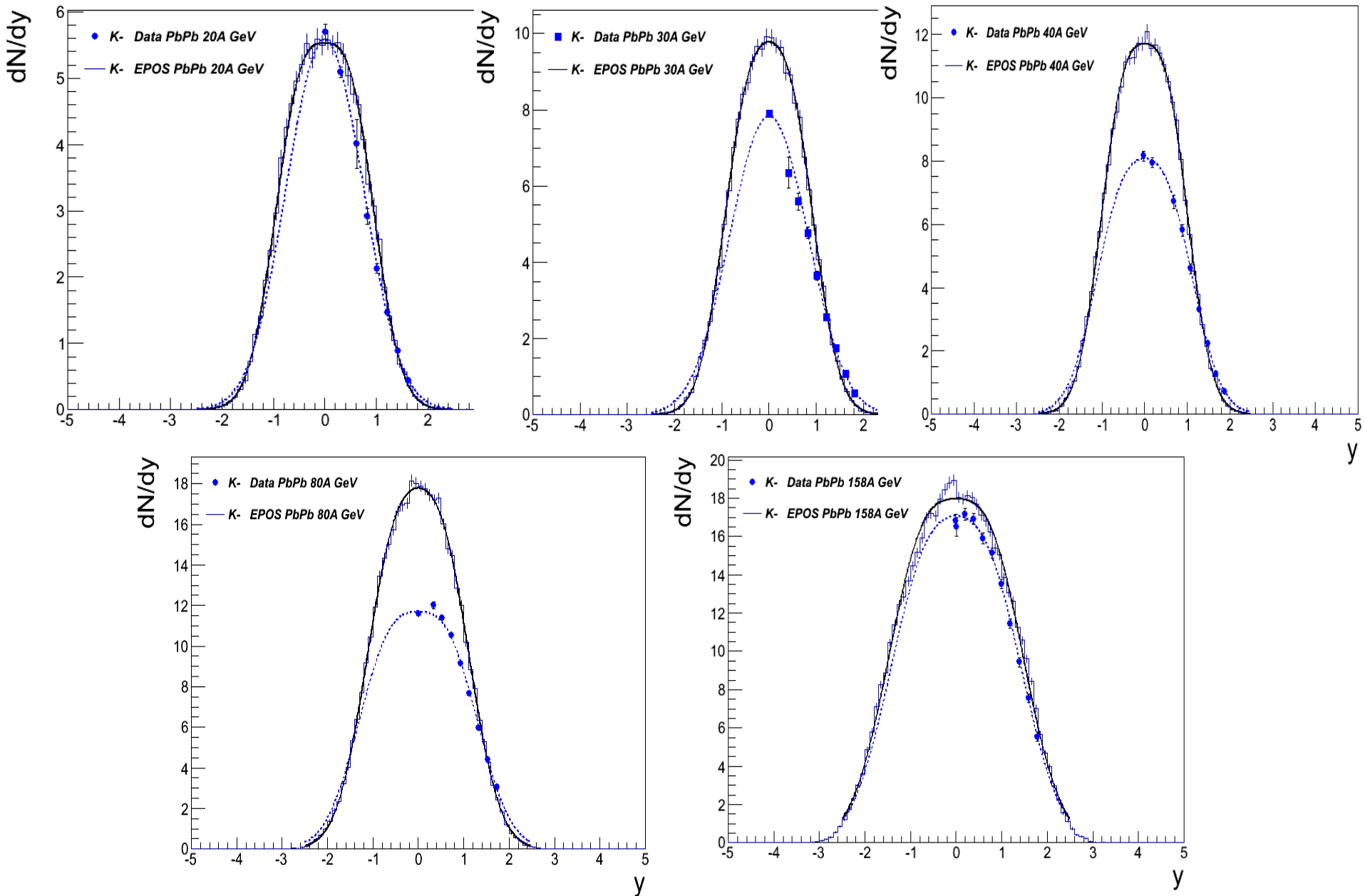
Rapidity distributions - π+
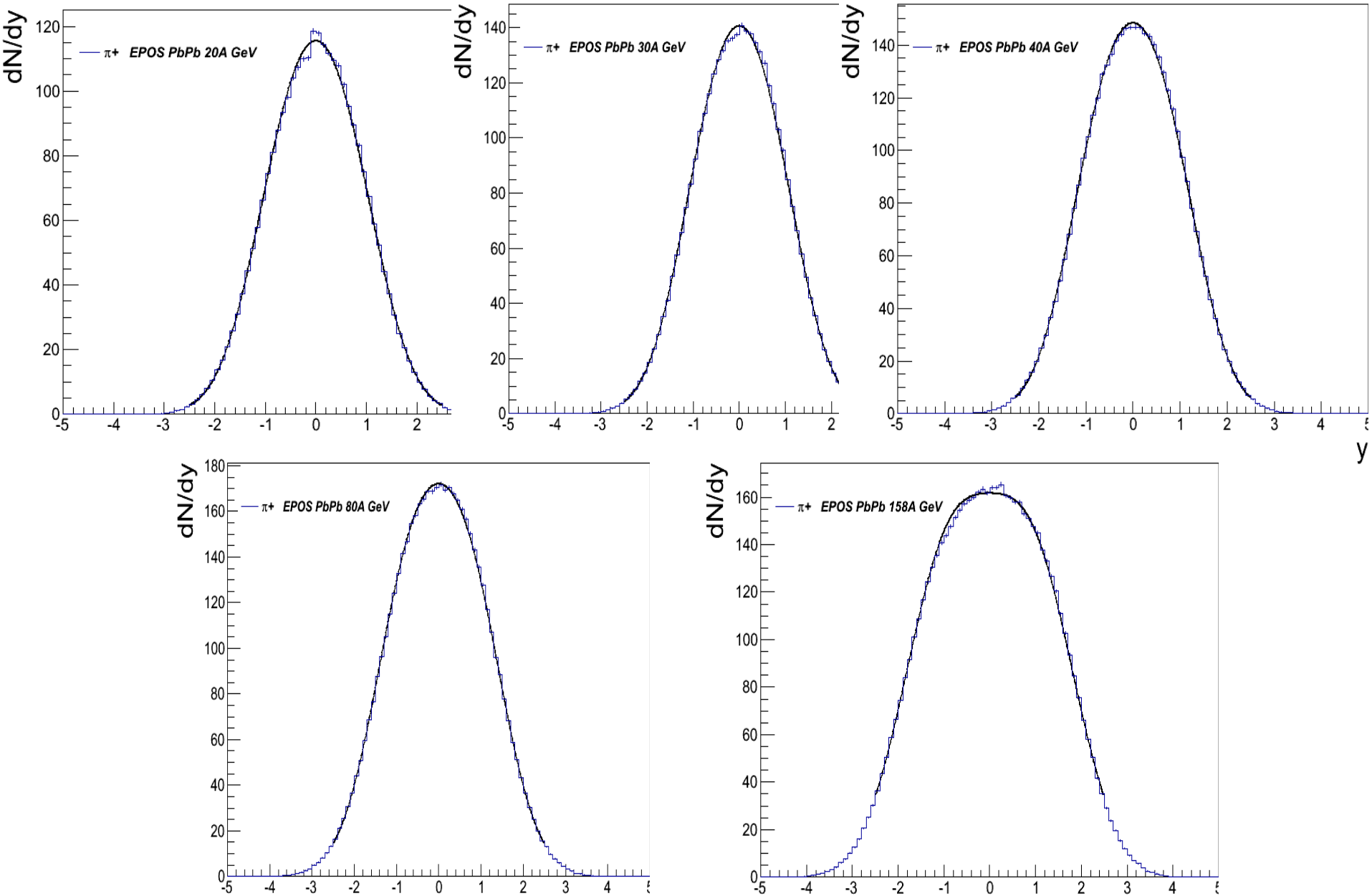
Rapidity distributions - π-
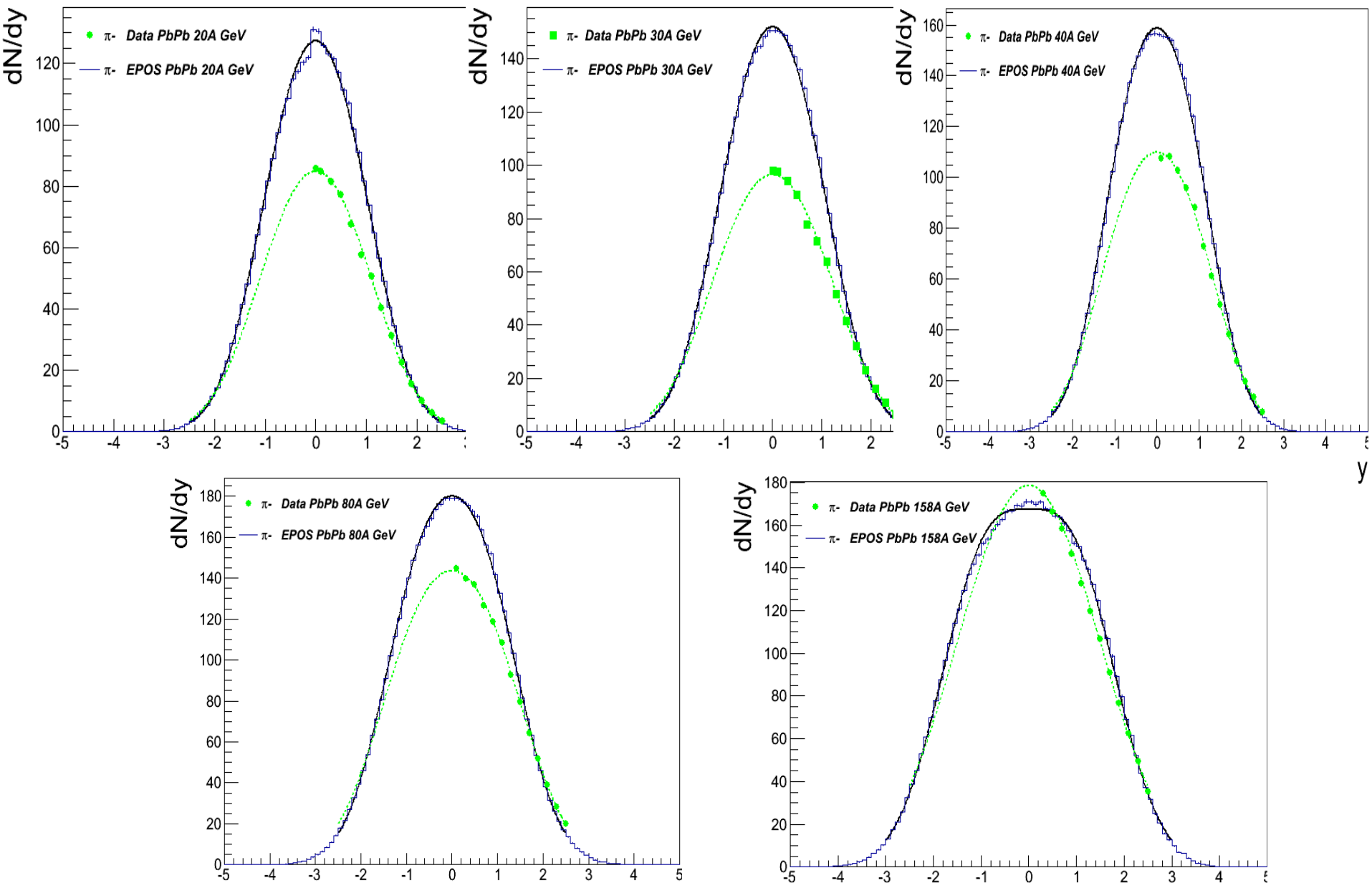
Rapidity distributions - K+

Rapidity distributions - K-

dN/dy (y=0) – ratio K+/π+
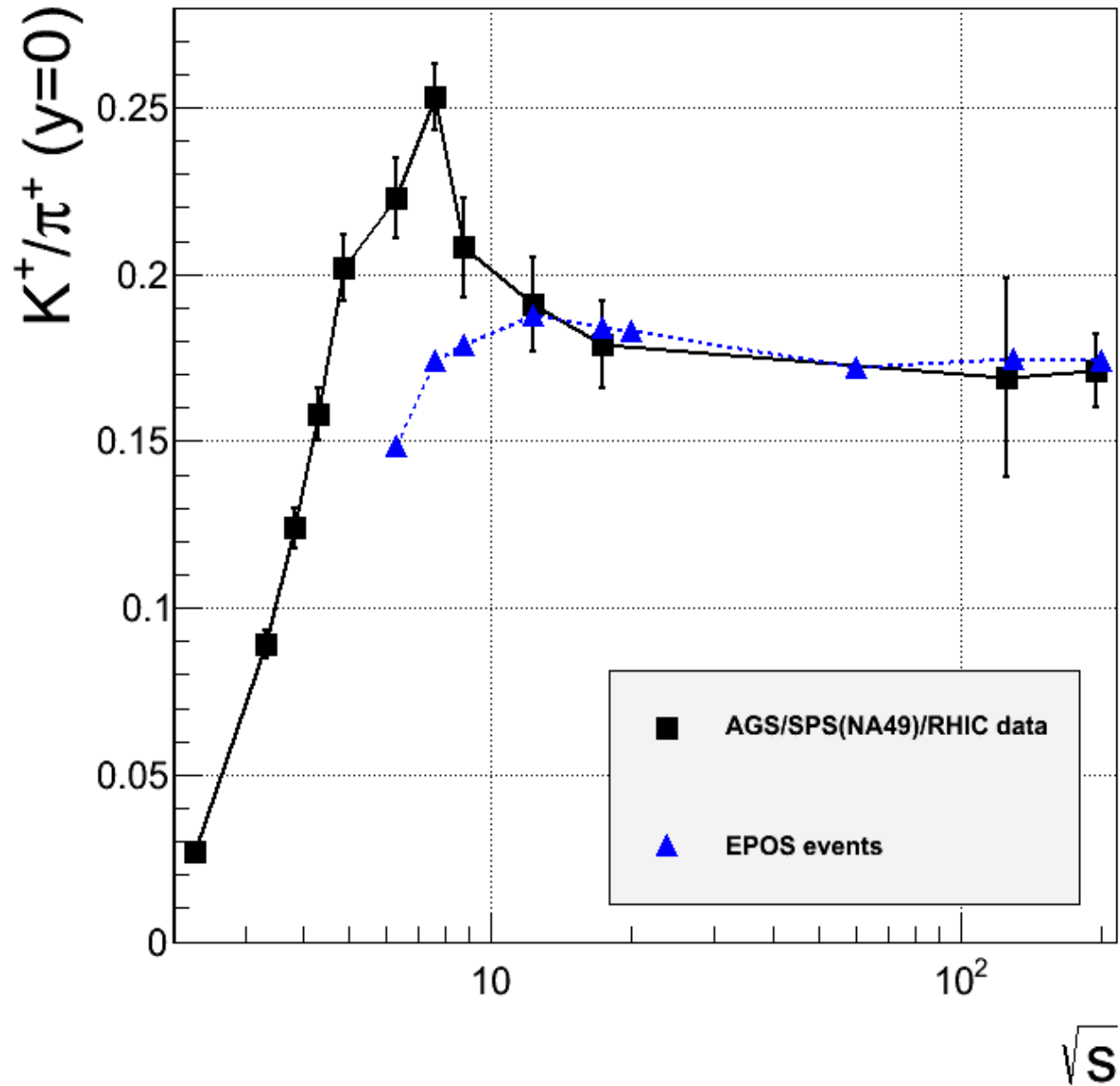
dN/dy (y=0) – ratio K-/π-
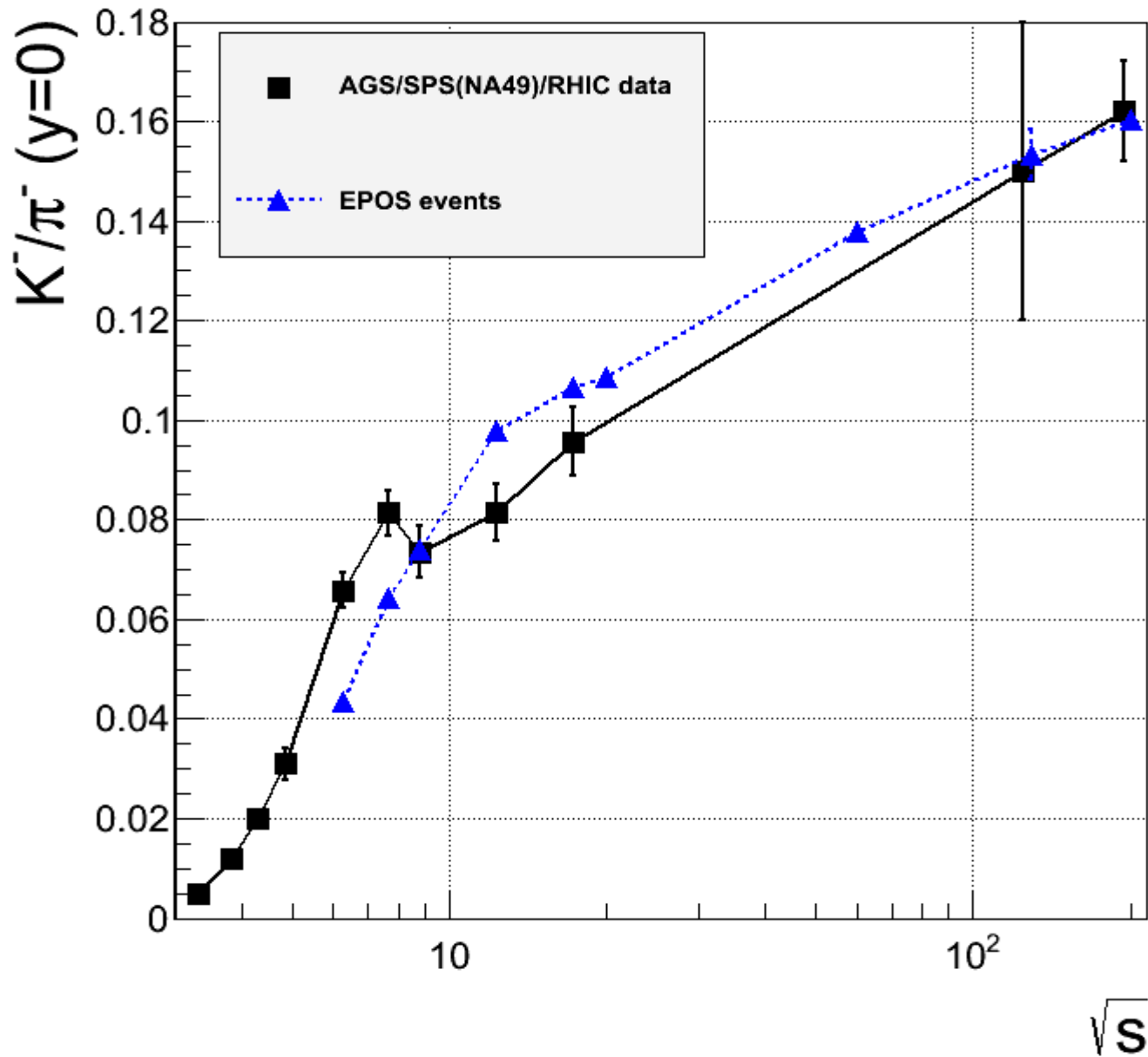
Ratios - summary

Central Pb+Pb collisions at SPS

- $\langle K^+ \rangle / \langle \pi^+ \rangle$ is underestimated and no sharp peak at low SPS

- $\langle K^- \rangle / \langle \pi^- \rangle$ is overestimated in VENUS and mostly reproduced by URQMD; increase in EPOS is stronger than in data

- dN/y (y=0) K^+/π^+ EPOS values decrease at low SPS instead of peak in data

- dN/y (y=0) K^-/π^- EPOS shows no structures at SPS, possible change of slope in SPS energy range

extended investigation

Dependence on colliding system
(study with URQMD model)

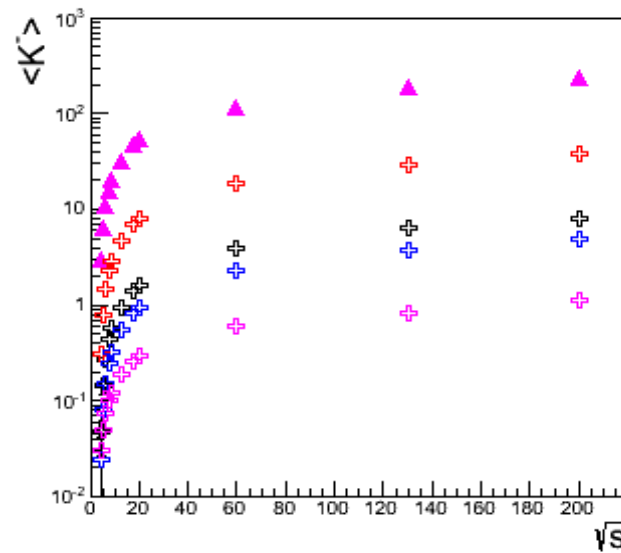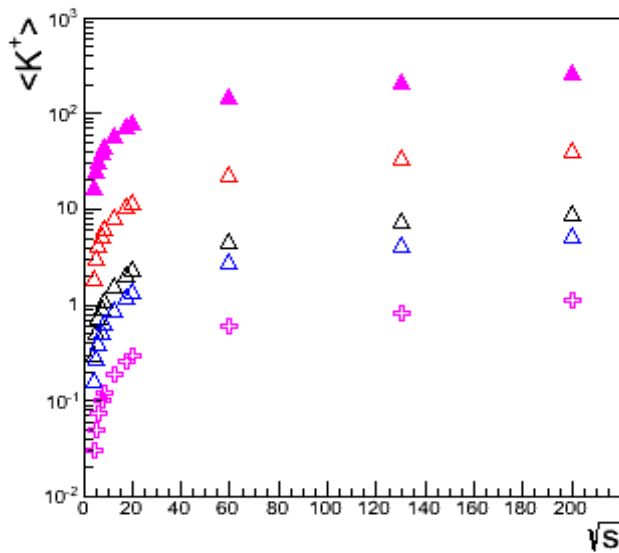# URQMD 3.3 generation (various collisions)
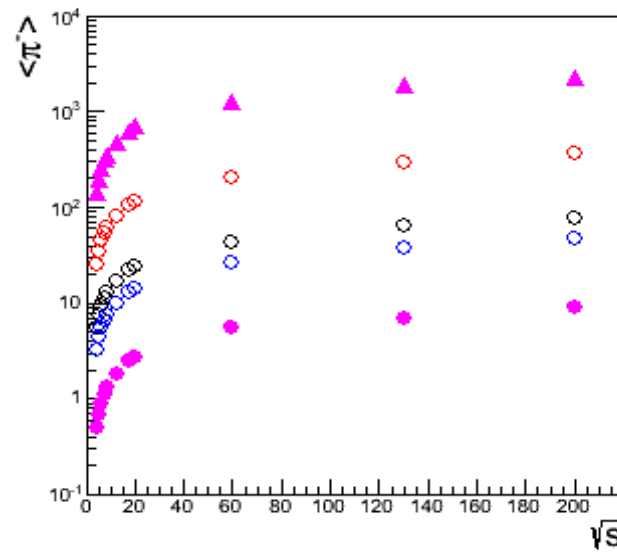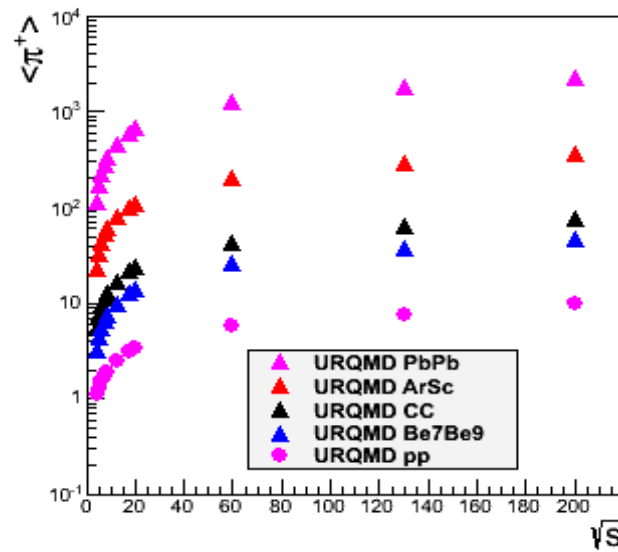
<u>Generated events:</u>

- Central PbPb 2.500 events

- Central (5%) Ar+Sc, C+C, Be7+Be9 10000 events
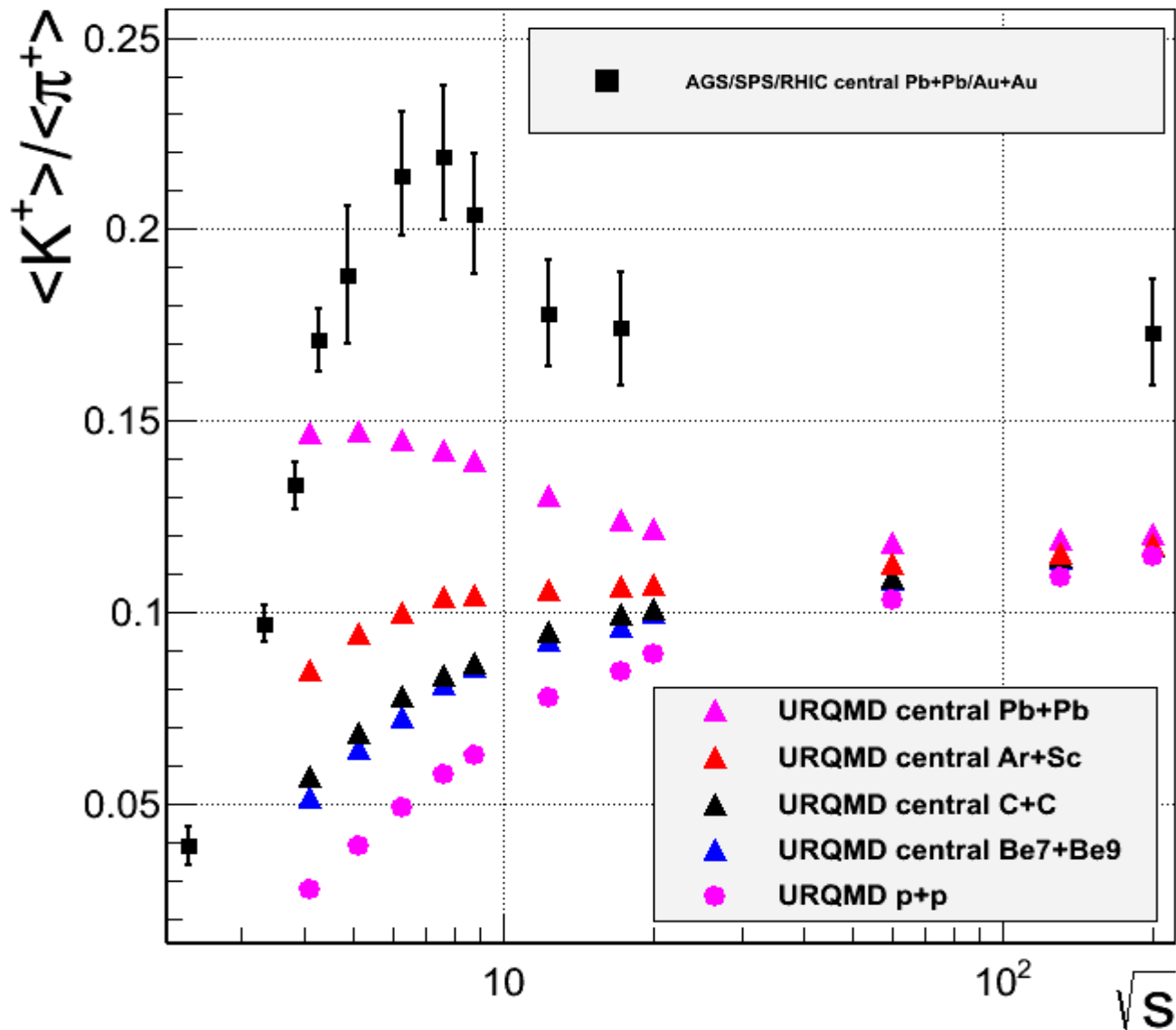
- pp 1mln events (only part of them analysed)

  at E_{cm} = 20, 60, 130, 200 GeV and E_{lab} = 8 (AGS), 13GeV , 20, 30, 40, 80, 158GeV

- The same analysis as the previous one (ie. double gauss fit even though small asymmetry in y-distr in Be7+Be9, Ar+Sc visible)
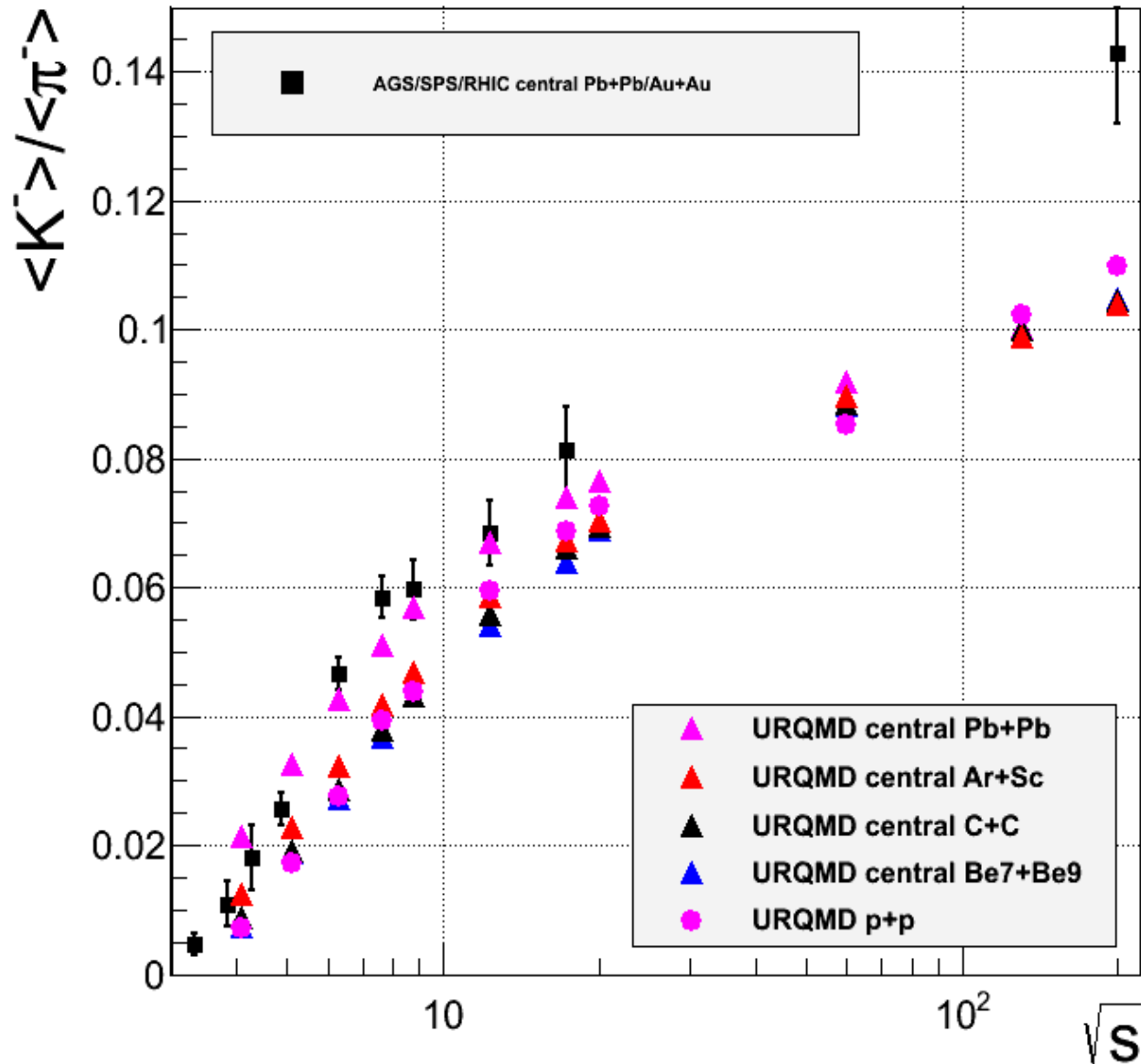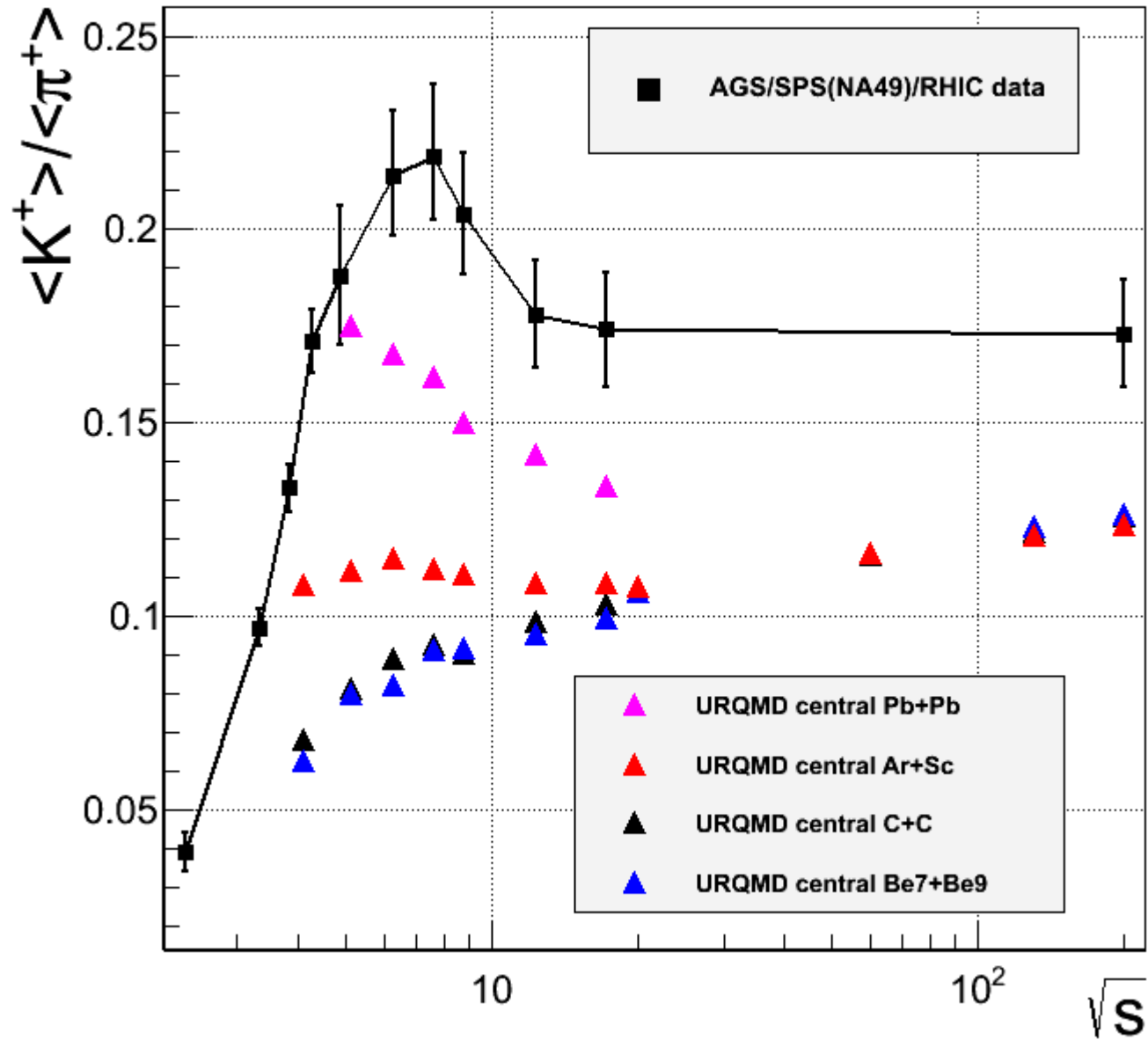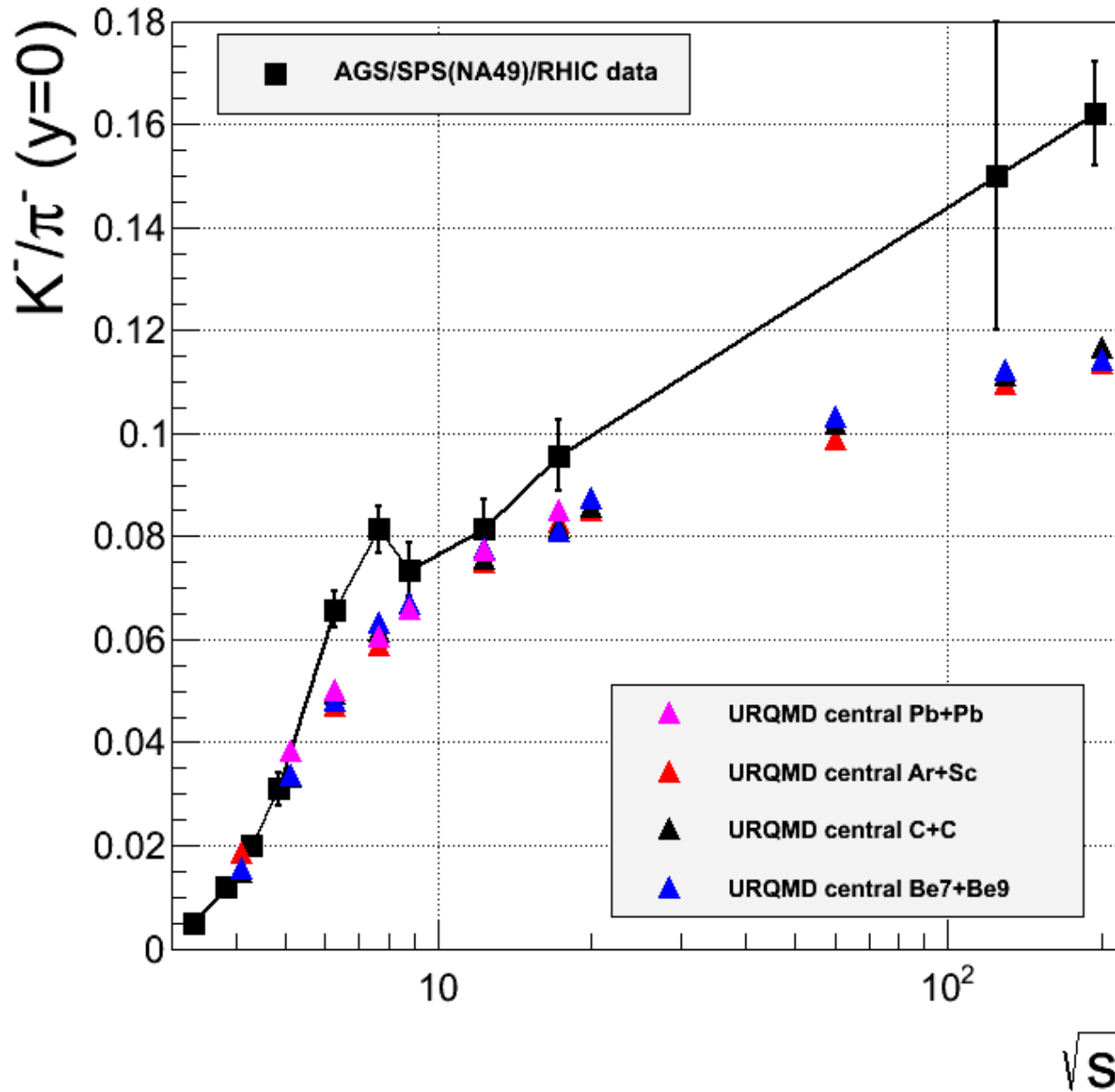
mean multiplicity

mean multiplicity ratio (positive)

mean multiplicity ratio (negative)

dN/dy (y=0) – ratio K+/π+

dN/dy (y=0) – ratio K-/π-

Dependence on colliding system - summary

Increase of mean multiplicity with colliding system observed.

Dependence on colliding energy very similar for all systems

Ratios for positively charged particles in various colliding systems (URQMD) show the decrease at low energies in light systems and the increase for PbPb collisions (no sharp peak)

Ratios for negatively charged particles shows smooth increase with energy for all systems

Thank you