Geometrical scaling from RHIC to LHC energies

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Young Scientist Forum

Outline

- **Physics motivation**

- **Geometrical scaling**

  - $\langle p_T \rangle$ vs. $[(dN/dy)/S_{perp}]^{1/2}$
  - The slope of $\langle p_T \rangle = f(\text{mass})$ vs. $[(dN/dy)/S_{perp}]^{1/2}$
  - $\langle \beta_T \rangle$ from BGBW fits vs. $[(dN/dy)/S_{perp}]^{1/2}$

  - **Au+Au & Cu+Cu - RHIC, Pb+Pb & Xe+Xe – LHC**

    Energy domain: RHIC (BES (7.7 – 39 GeV) + 62.4, 130 & 200 GeV)
    LHC (2.76, 5.02 & 5.44 TeV)

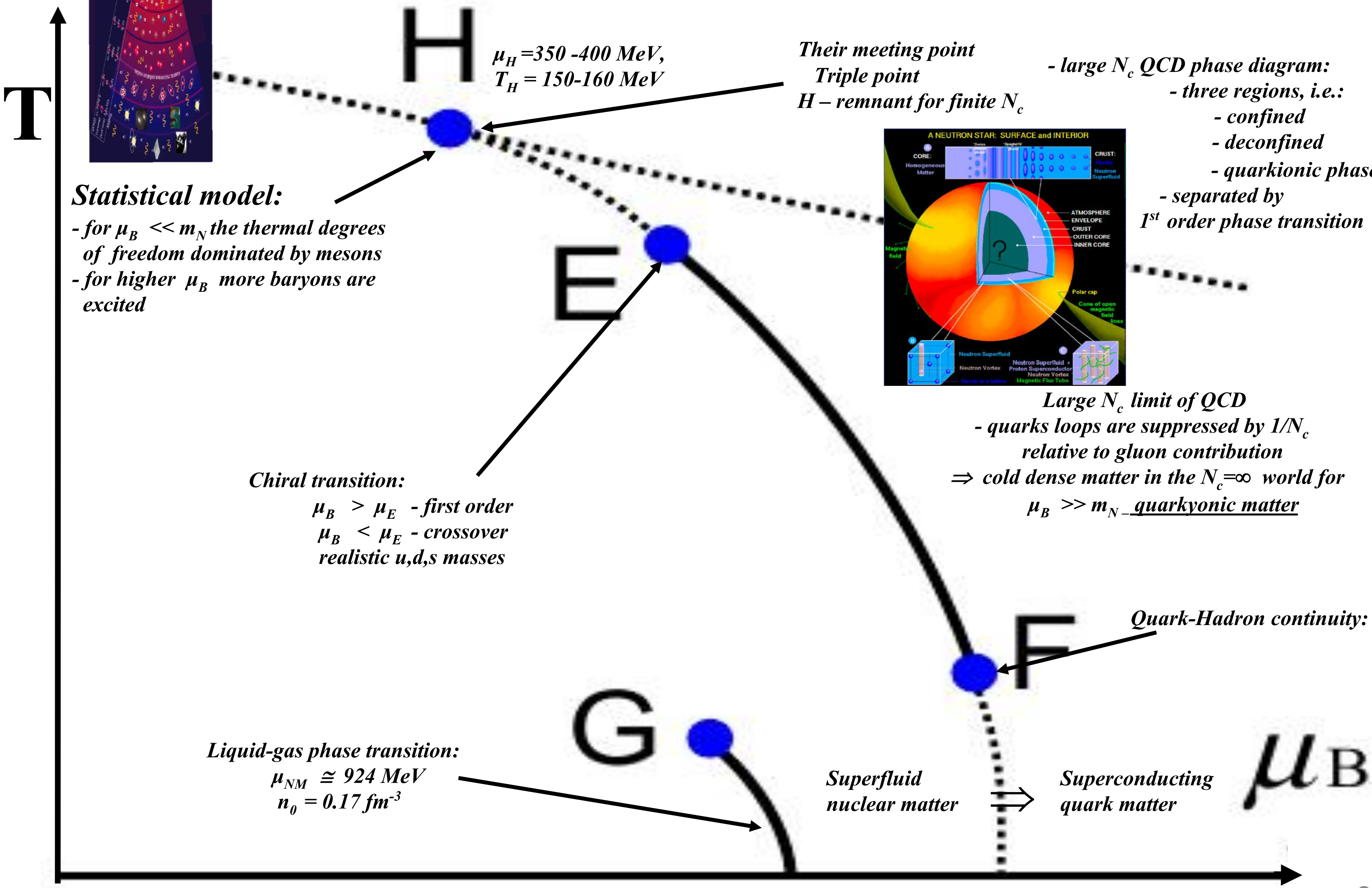
  - **p+p vs. Pb+Pb @ LHC**

    Energy domain: Pb+Pb (5.02 TeV); p+p (7 TeV)

- **Preliminary Results**

- **Conclusions & Perspectives**

Physics motivation



μ_H =350 -400 MeV,
T_H = 150-160 MeV

Their meeting point
Triple point
H – remnant for finite N_c

- large N_c QCD phase diagram:
  - three regions, i.e.:
    - confined
    - deconfined
    - quarkionic phase
  - separated by 1^{st} order phase transition

Statistical model:

- *for $\mu_B \ll m_N$ the thermal degrees of freedom dominated by mesons*
- *for higher μ_B more baryons are excited*

Large N_c limit of QCD
- quarks loops are suppressed by $1/N_c$ relative to gluon contribution
$\Rightarrow$ cold dense matter in the $N_c=\infty$ world for $\mu_B \gg m_N$ – quarkyonic matter

Chiral transition:
$\mu_B > \mu_E$ - first order
$\mu_B < \mu_E$ - crossover
realistic u,d,s masses

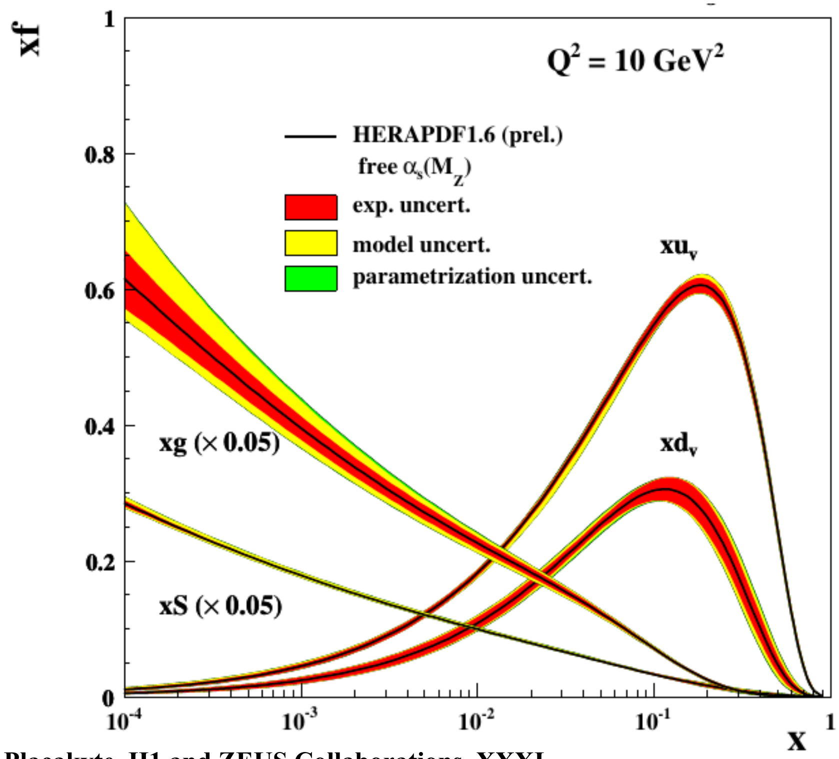
Quark-Hadron continuity:

Liquid-gas phase transition:
$\mu_{NM} \cong 924$ MeV
$n_0 = 0.17\ fm^{-3}$

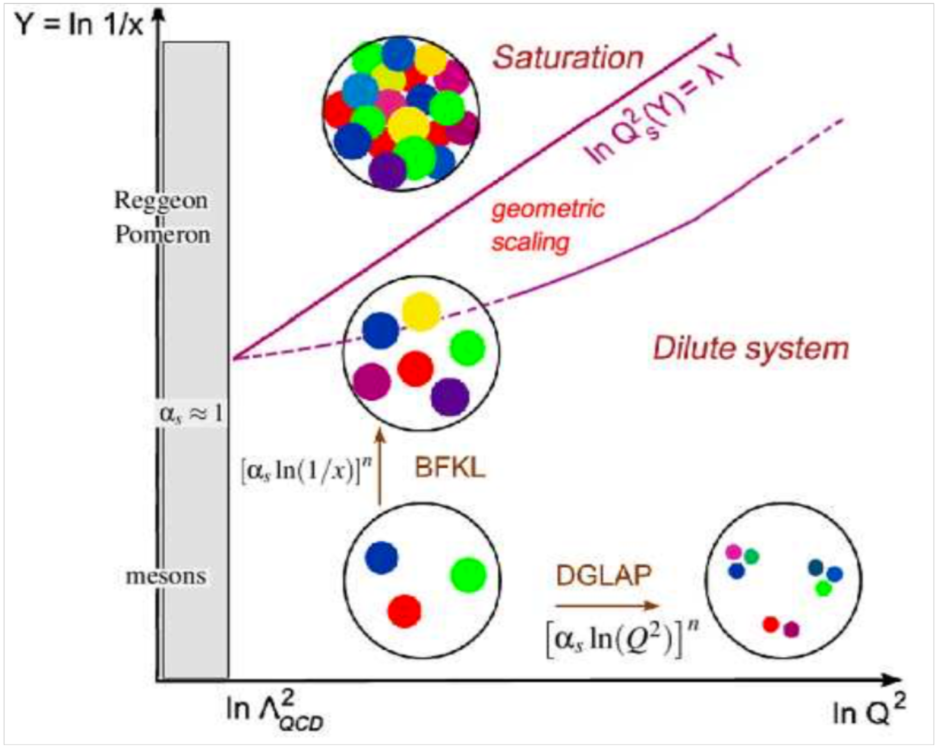
Superfluid nuclear matter $\Rightarrow$ *Superconducting quark matter*

K. Fukushima and T. Hatsuda, Rept.Prog.Phys.74(2011)014001

Physics motivation

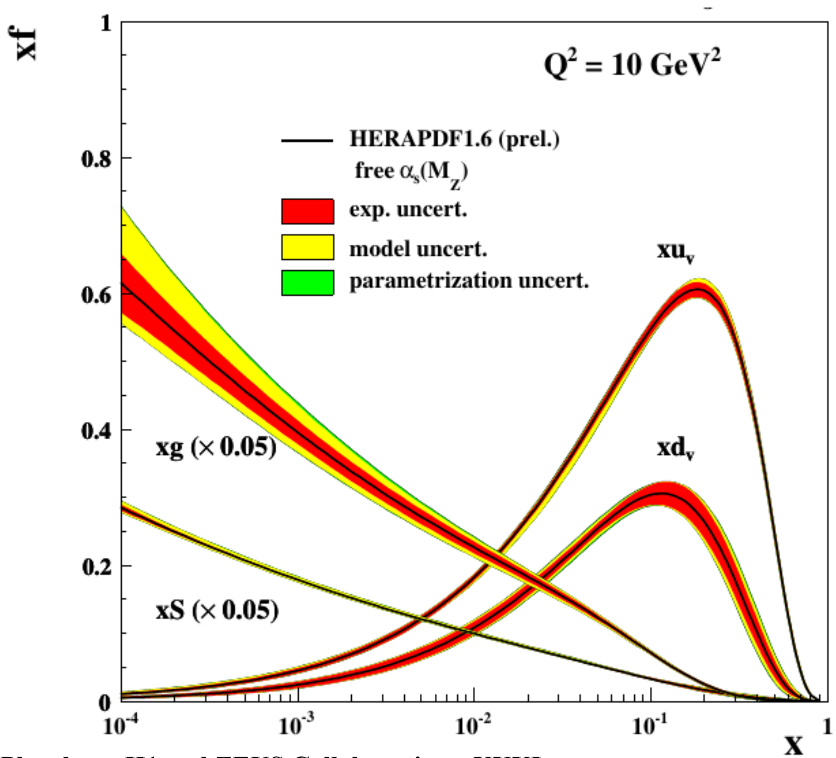


R.Placakyte, H1 and ZEUS Collaborations, XXXI PHYSICS IN COLLISIONS, Vancouver, BC Canada, Aug.28-Sept.1, 2011



D. d'Enterria, Eur.Phys.J. A31(2007)816)

Physics motivation



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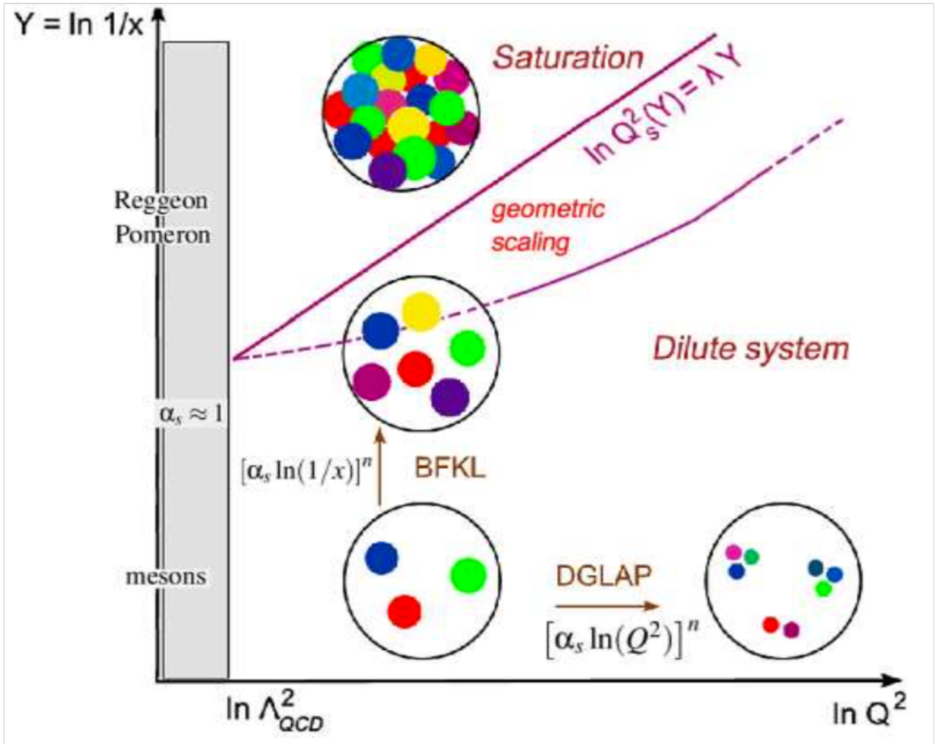


D. d'Enterria, Eur.Phys.J. A31(2007)816)

Geometrical scaling

Local parton-hadron duality picture and dimensionality argument → $\langle p_T\rangle/\sqrt{\frac{dN}{dy}/S_\perp} \sim \frac{1}{n\sqrt{n}}$

n = no. of charged hadrons produced from a gluon fragmentation

$\langle p_T\rangle/\sqrt{\frac{dN}{dy}/S_\perp}$

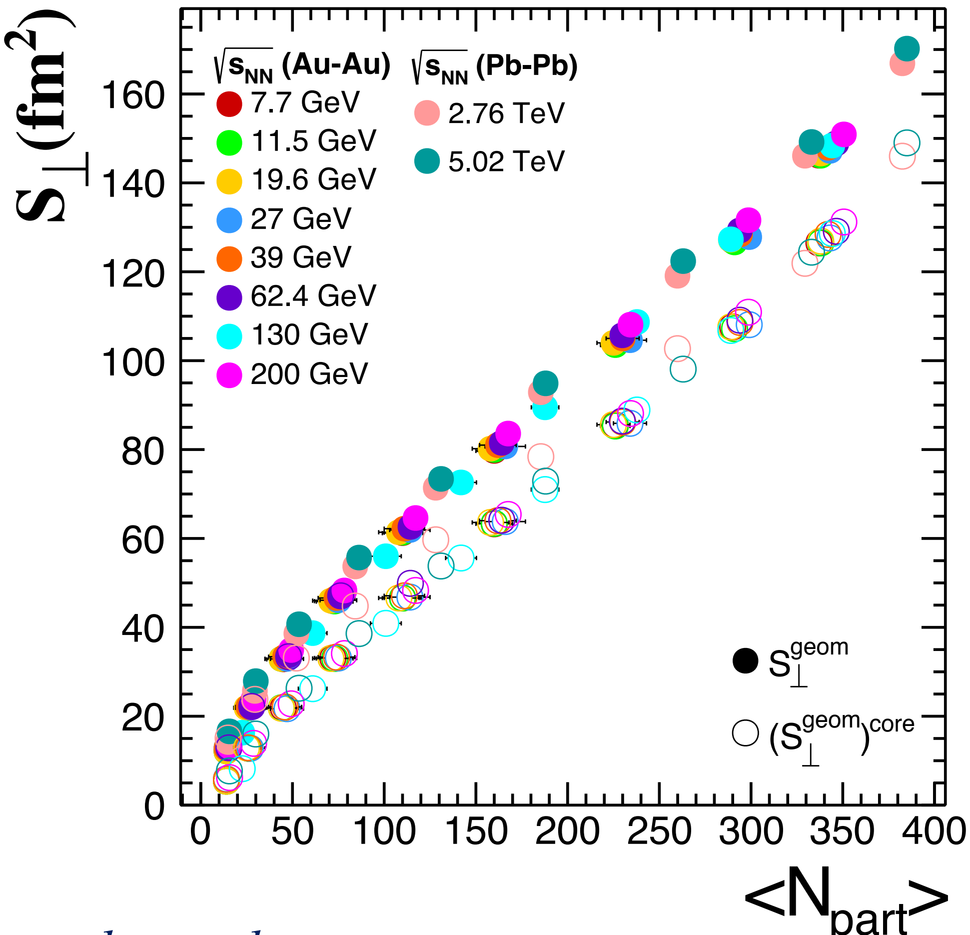
decreases as a function of collision energy and centrality

Y.L.Dokshitzer, V.A.Khoze and S.Troian, J.Phys.G 17 (1991) 1585
T. Lappi, Eur.Phys.J. C71 (2011) 1699
E. Levin and A.H. Rezaeian, Phys.Rev.D 83 (2011) 114001

$S_\perp$ estimates

Scaling variable: $\sqrt{[(dN/dy)/ S_\perp]}$

Glauber Monte Carlo approach



core = the participants that undergo more than a single collision

dN/dy estimates

Scaling variable: √[(dN/dy)/ $S_\perp$]

BES

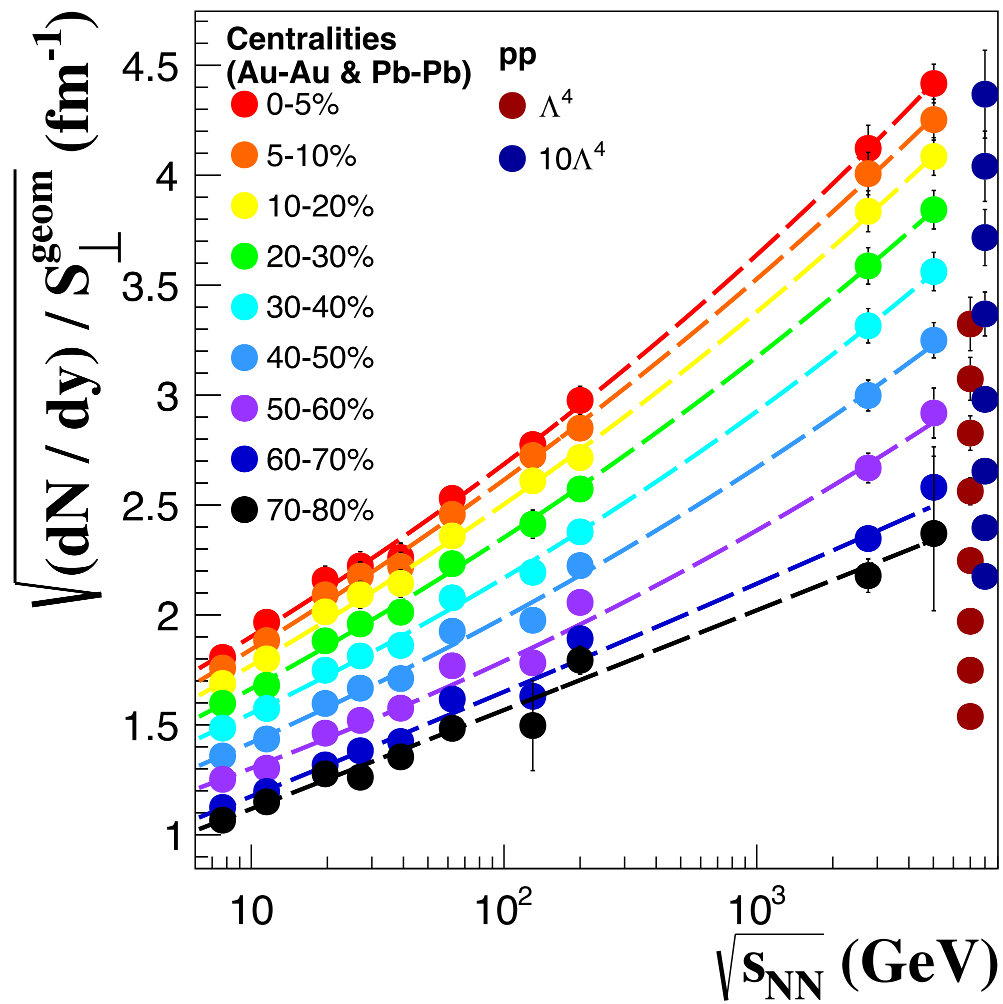
$$\frac{dN}{dy} \simeq \frac{3}{2}\frac{dN^{(\pi^+ + \pi^-)}}{dy} + 2\frac{dN^{(K^+ + K^-, p+\bar{p}, \Xi^- + \bar{\Xi}^+)}}{dy} + \frac{dN^{(\Lambda + \bar{\Lambda})}}{dy}$$

RHIC (62.4; 130 & 200 GeV)

$$\frac{dN}{dy} \simeq \frac{3}{2}\frac{dN^{(\pi^+ + \pi^-)}}{dy} + 2\frac{dN^{(K^+ + K^-, p+\bar{p}, \Xi^- + \bar{\Xi}^+)}}{dy} + \frac{dN^{(\Lambda + \bar{\Lambda}, \Omega^- + \bar{\Omega}^+)}}{dy}$$

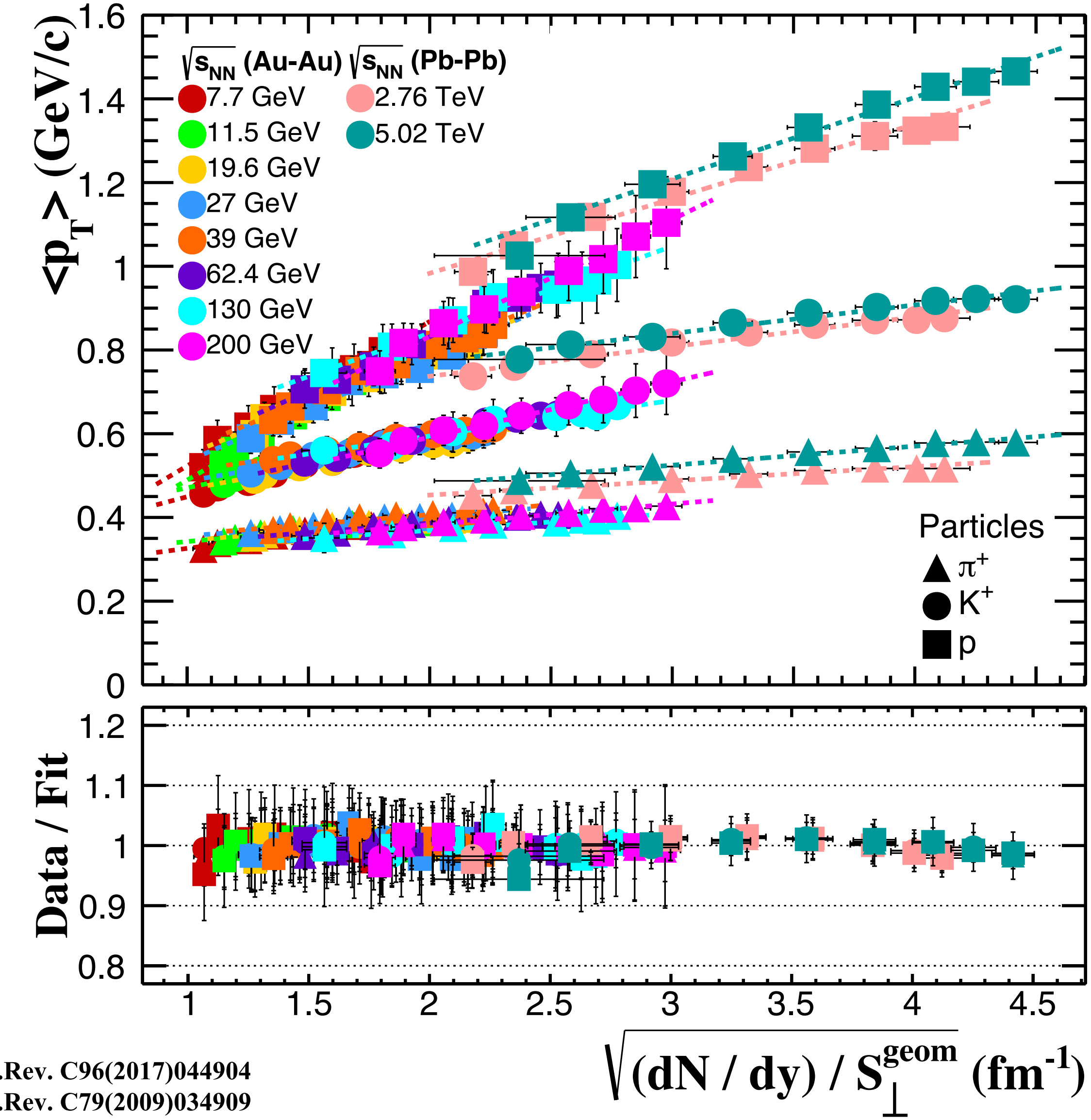
LHC

$$\frac{dN}{dy} \simeq \frac{3}{2}\frac{dN^{(\pi^+ + \pi^-)}}{dy} + 2\frac{dN^{(p+\bar{p}, \Xi^- + \bar{\Xi}^+)}}{dy} + \frac{dN^{(K^+ + K^-, K_S^0 + \bar{K}_S^0, \Lambda + \bar{\Lambda}, \Omega^- + \bar{\Omega}^+)}}{dy}$$



$$\sqrt{(dN/dy)/S_\perp^{geom}} = a + b \cdot (\sqrt{s_{NN}})^{2c}$$

<p_T> vs. √[(dN/dy)/ $S_\perp$]



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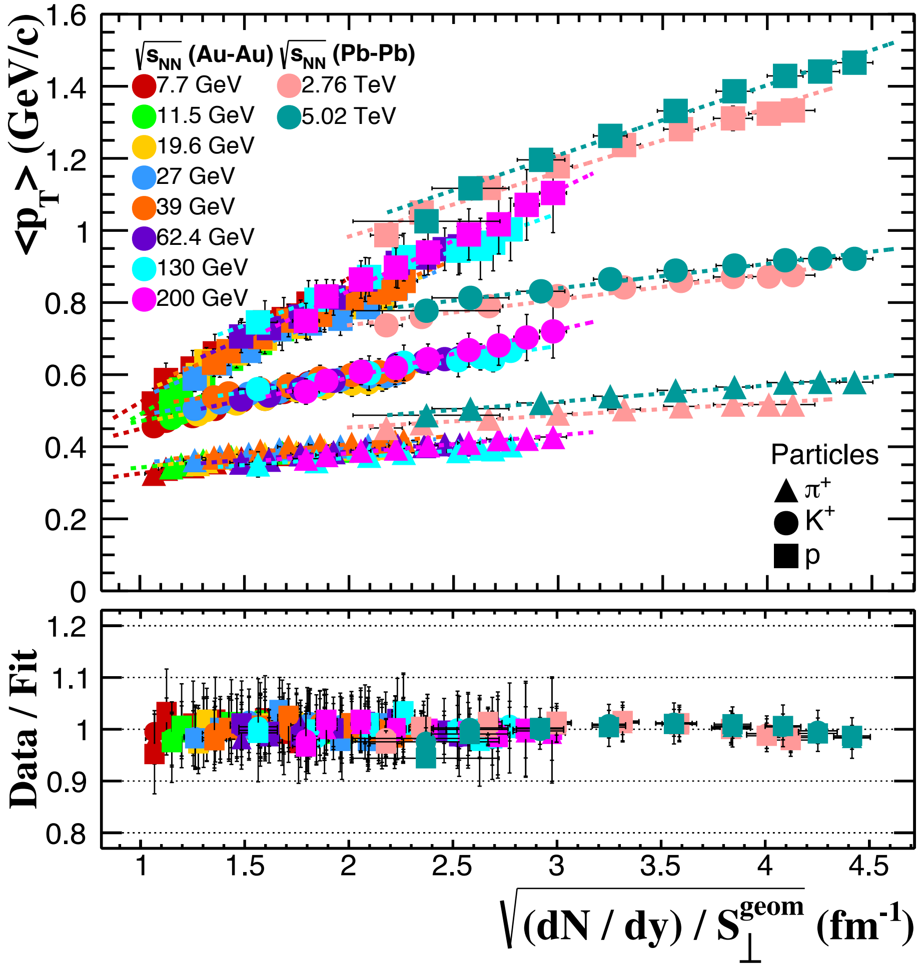
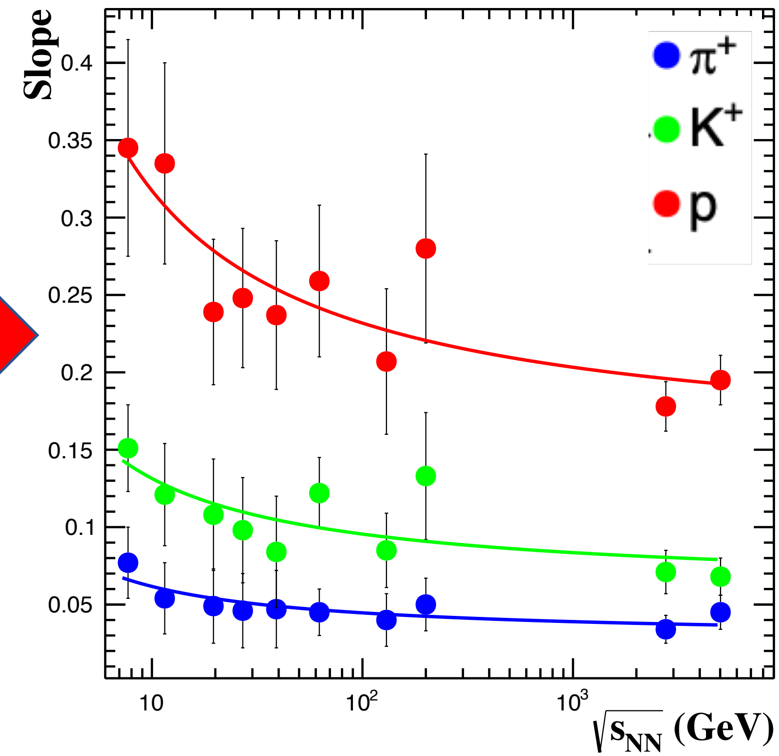
STAR Collaboration, Phys.Rev. C79(2009)034909
ALICE Collaboration, Phys.Rev. C}{88}{2013}{044910}
ALICE Collaboration, Phys.Rev.Lett. 116(2016)222302
ALICE Collaboration, Eur.Phys.J. C75(2015)226
A.K.Dash, ALICE Collaboration , 9th Int. Workshop on MPI at LHC, Dec. 11-15, 2017

$\langle p_T \rangle$ vs. $\sqrt{[(dN/dy)/ S_\perp]}$





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ALICE Collaboration, Phys.Rev.Lett. 116(2016)222302
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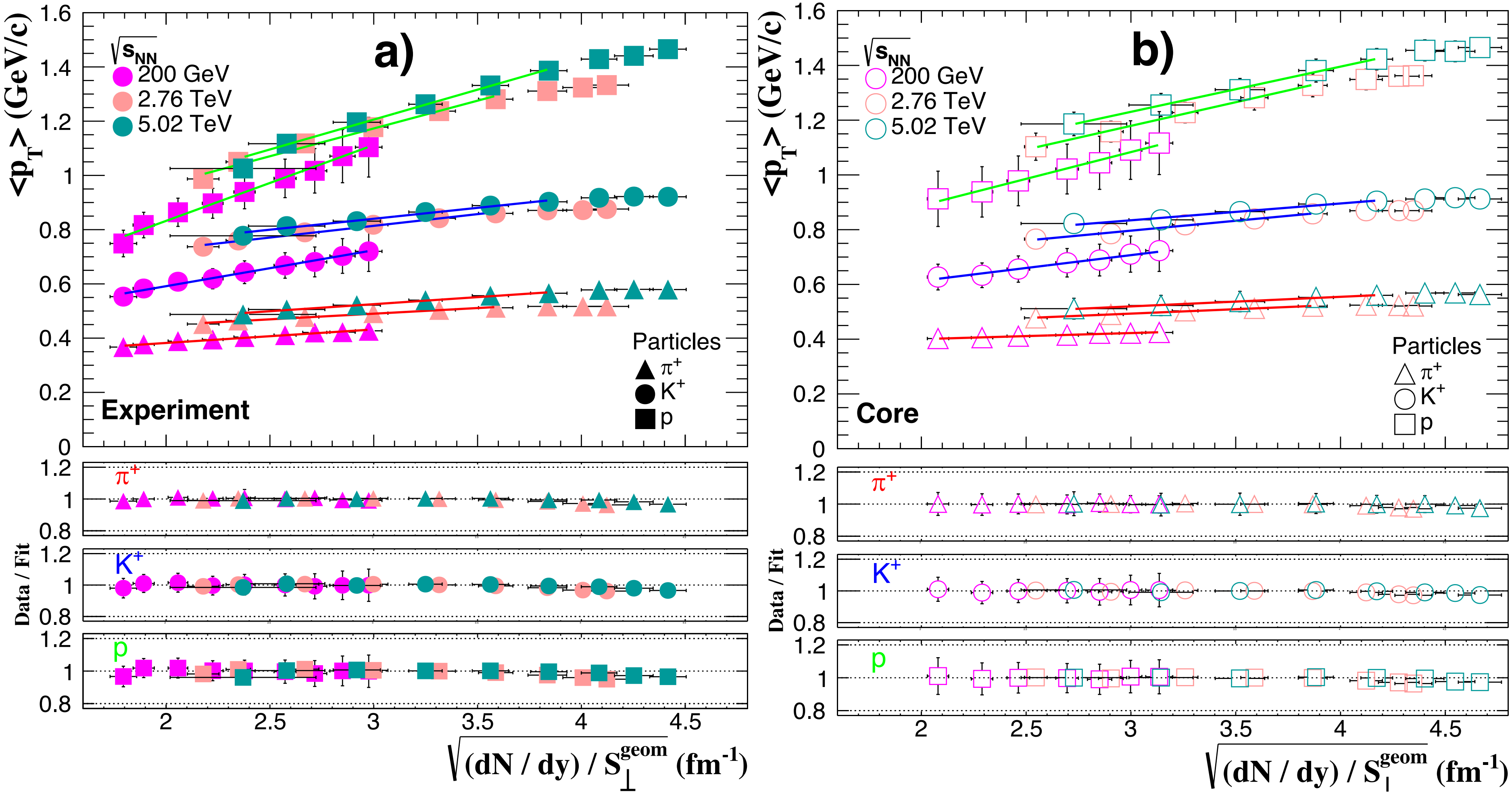
The Core-Corona effect



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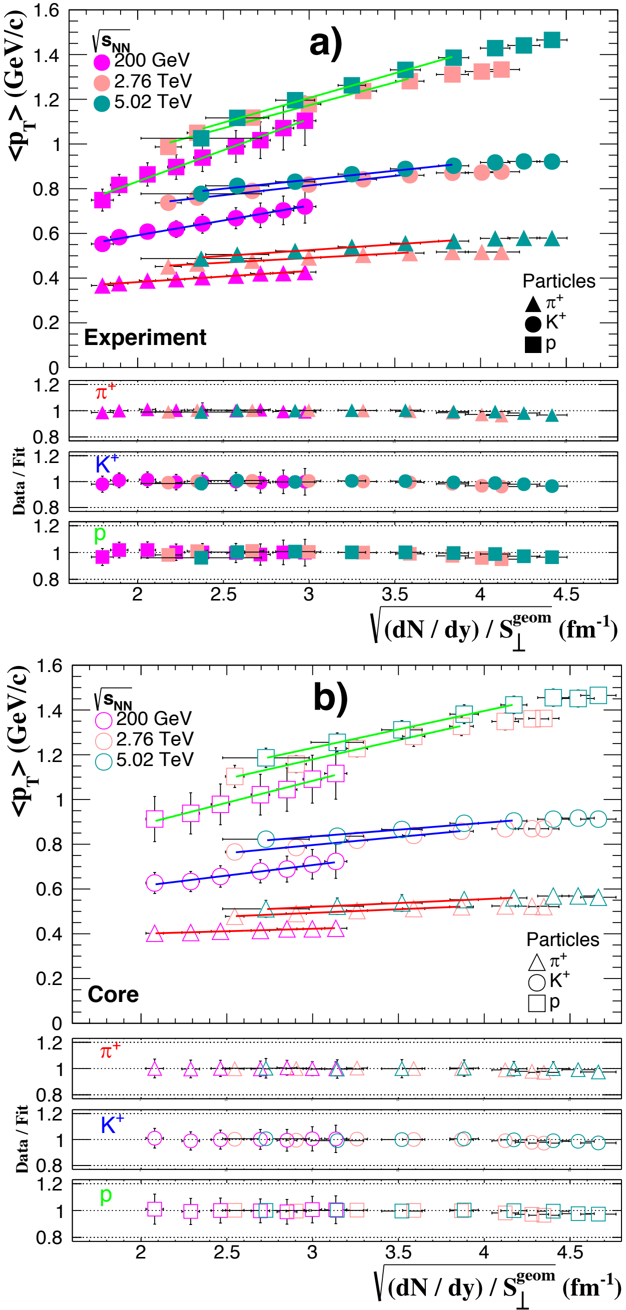
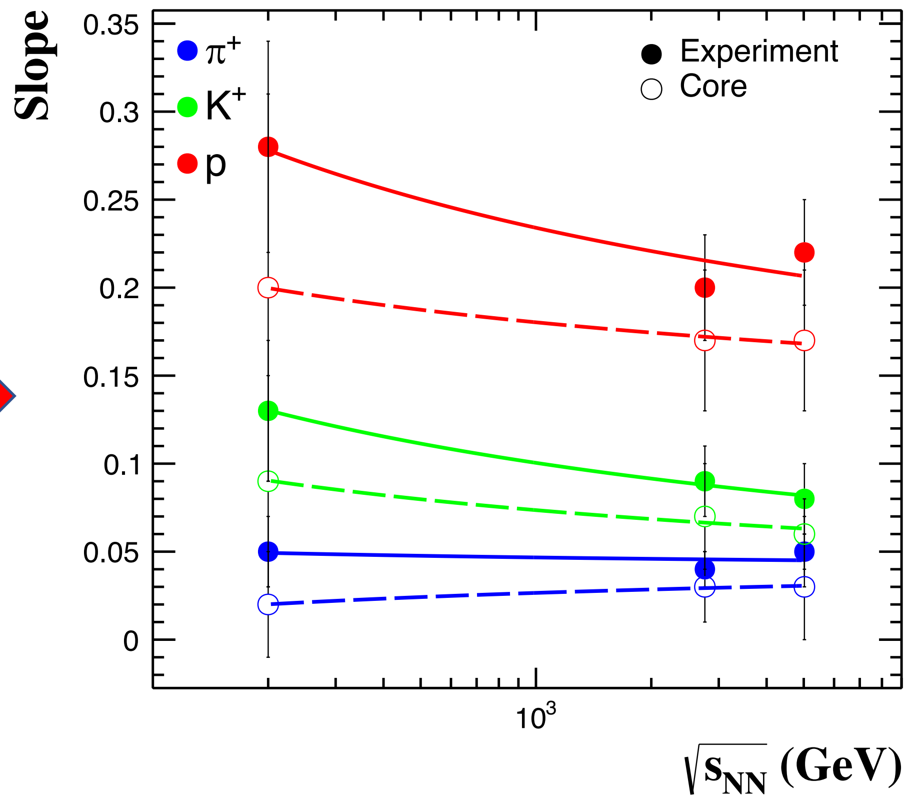
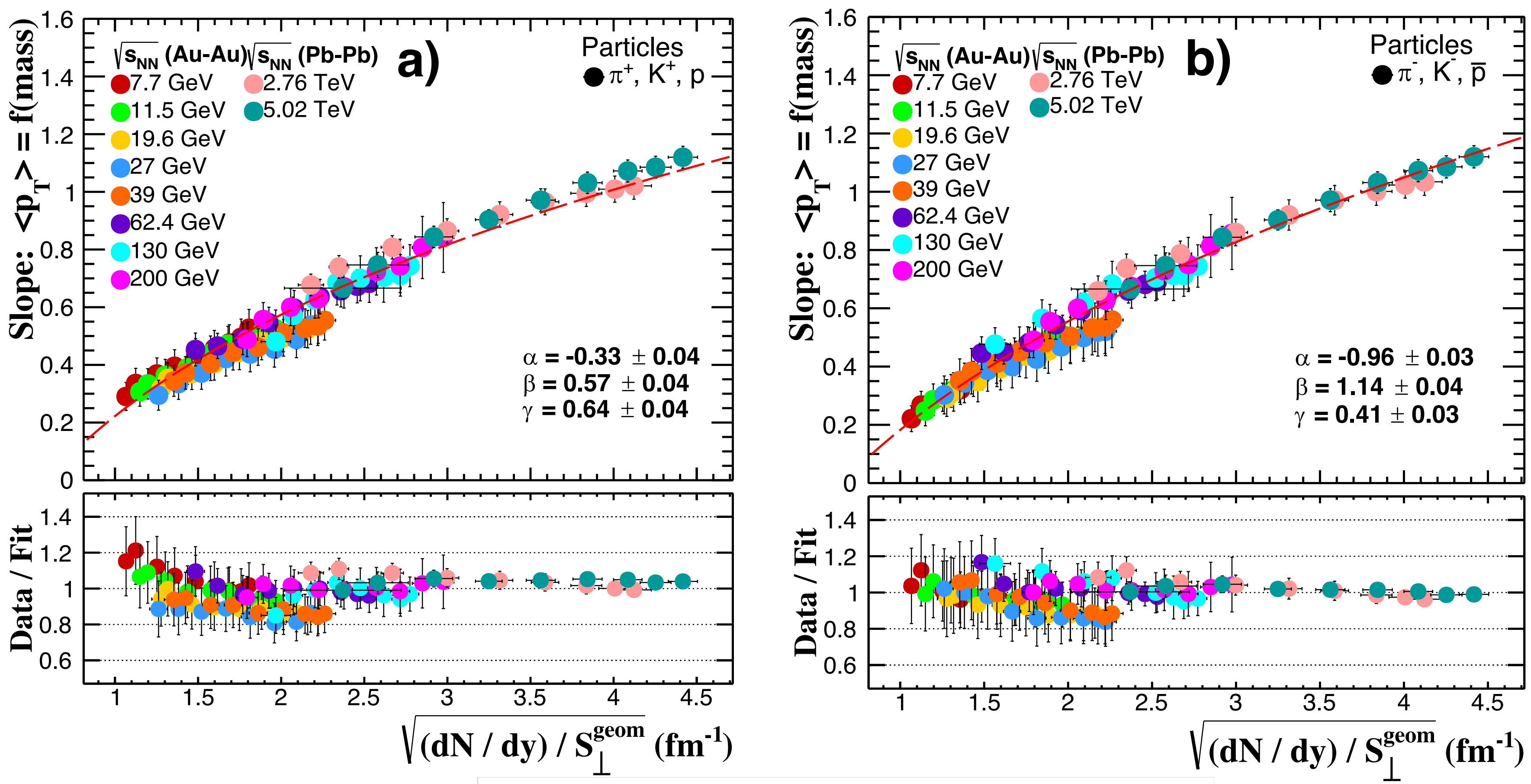


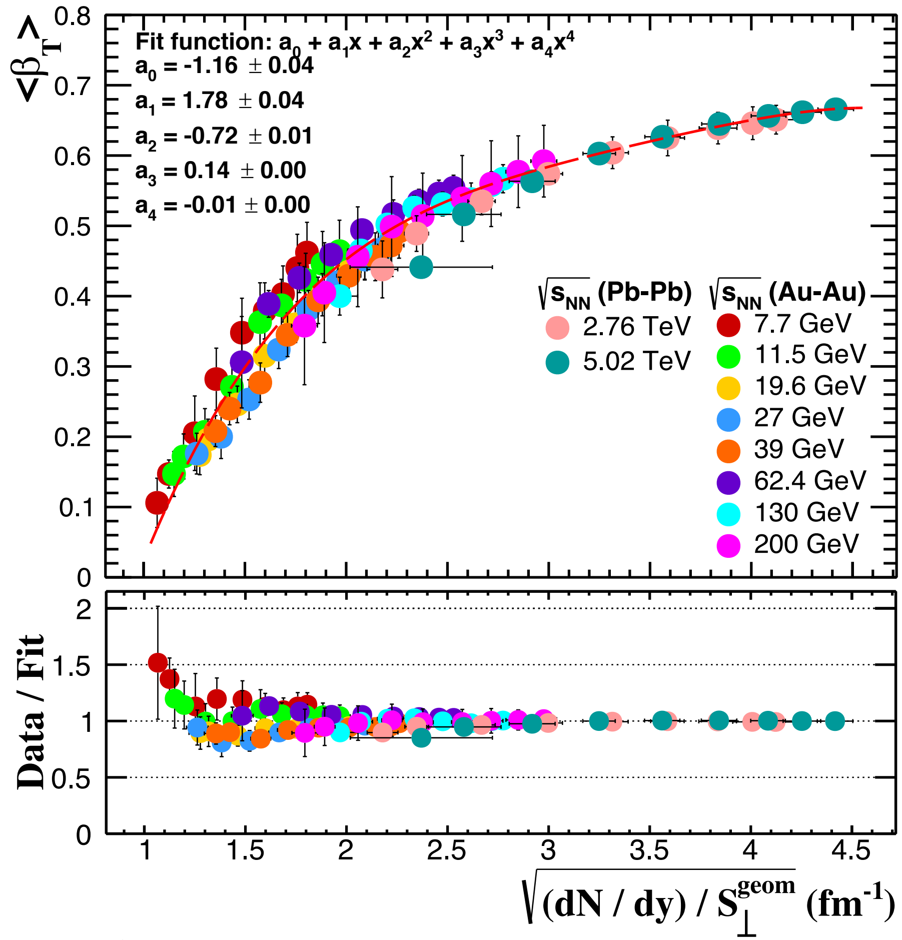


The slope of <p$_T$>=f(mass) vs. √[(dN/dy)/ S$_\perp$]



$$Slope_{\langle p_T \rangle = f(mass)} = \alpha + \beta \left(\sqrt{\frac{dN}{dy} / S_\perp^{geom}} \right)^{\gamma}$$

<βT> from BGBW fits vs. √[(dN/dy)/ S⊥]



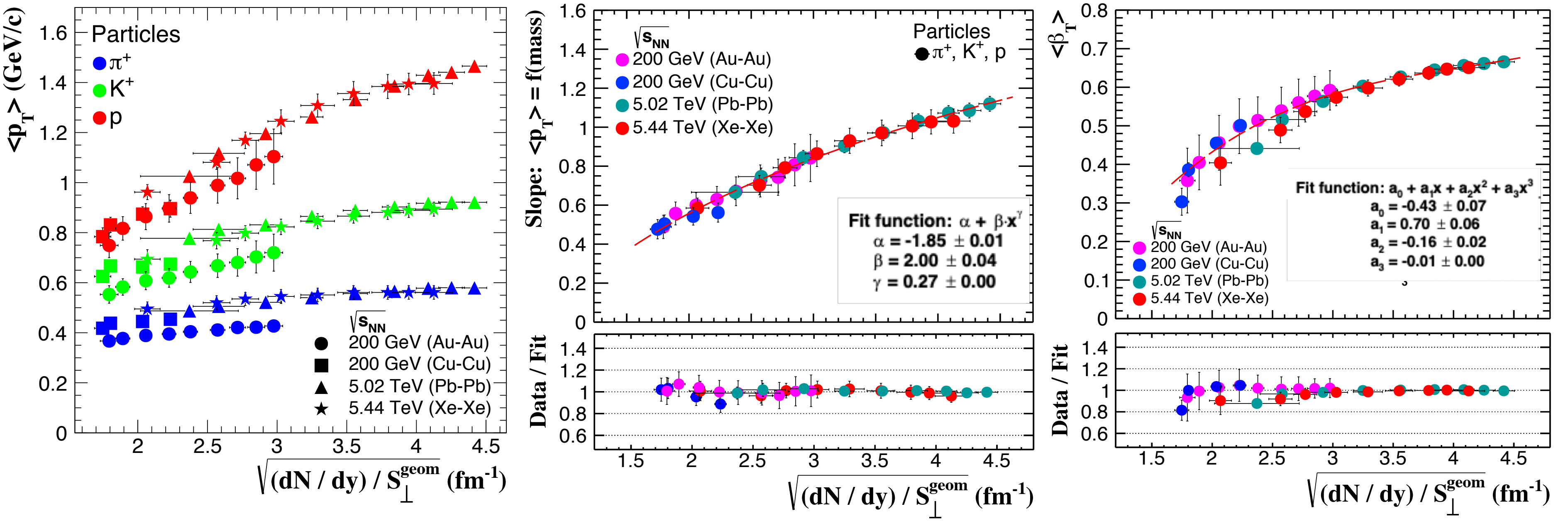
Boltzmann-Gibbs Blast Wave

$$\frac{1}{2\pi p_T}\frac{d^2N}{dydp_T} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh\rho}{T_{kin}}\right) K_1\left(\frac{m_T\cosh\rho}{T_{kin}}\right)$$

$$\rho = \tanh^{-1}\beta_T = \tanh^{-1}\left[\left(\frac{r}{R}\right)^n \beta_s\right]$$

Xe+Xe vs. Pb+Pb @ LHC and Cu+Cu vs. Au-Au @ RHIC

Latest Results



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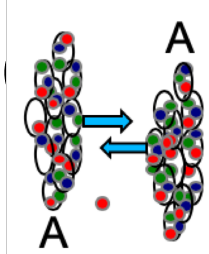
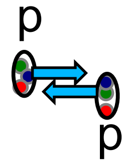
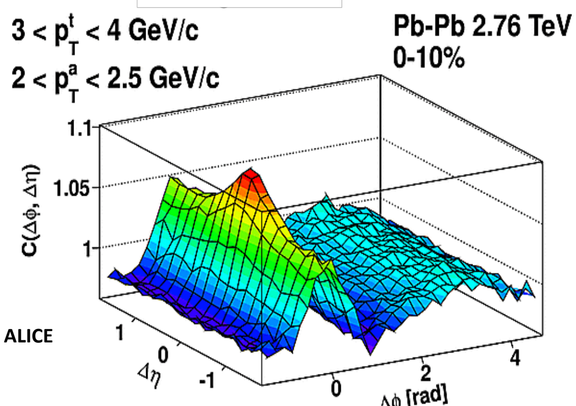
D. S. D Albuquerque, ALICE Collaboration, Quark Matter 2018 STAR Collaboration, Phys.Rev.Lett. 108 (2012) 072301
BRAHMS Collaboration, Phys.Rev.C 94 (2016) 014907
STAR Collaboration, Phys.Rev.Lett. 108 (2012) 072301

p+p vs. Pb+Pb @ LHC

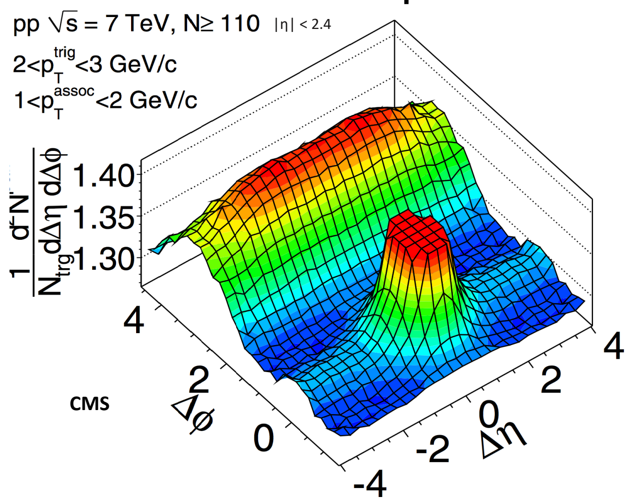


Long range near side correlations



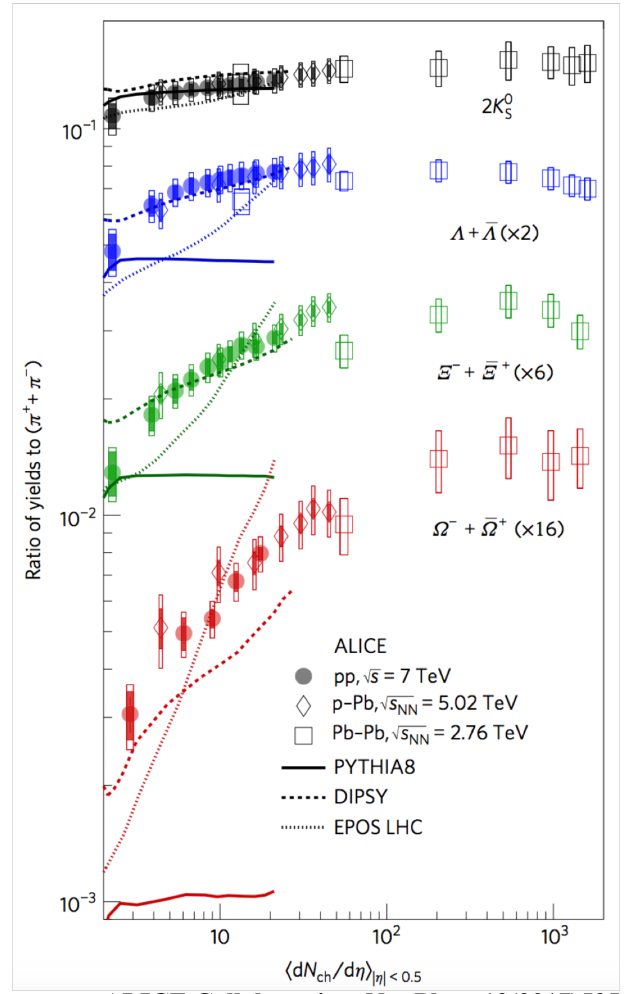


Phys.Lett. B708249(2014)



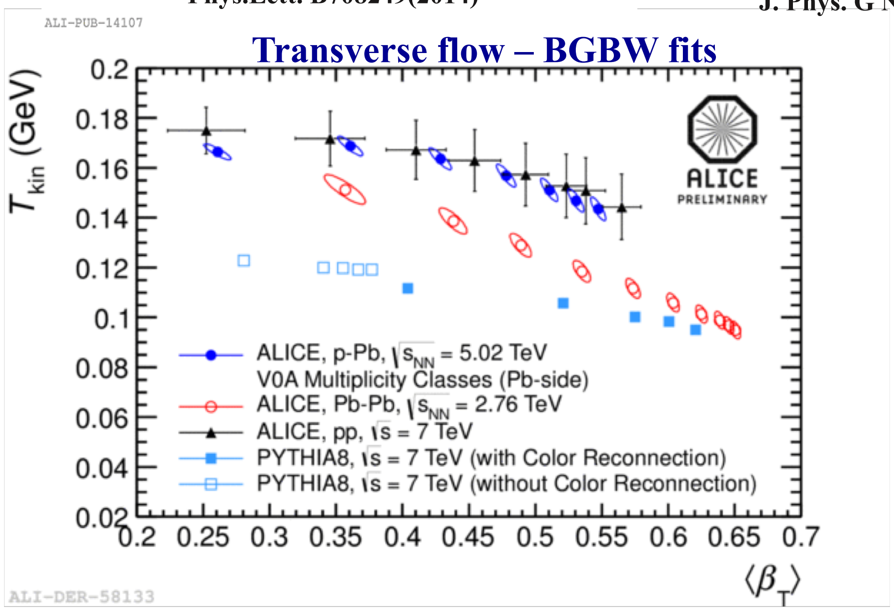
J. Phys. G Nucl. Part. Phys. 38(2011)124051

Strangeness relative yields



ALICE Collaboration, Nat.Phys. 13(2017)535

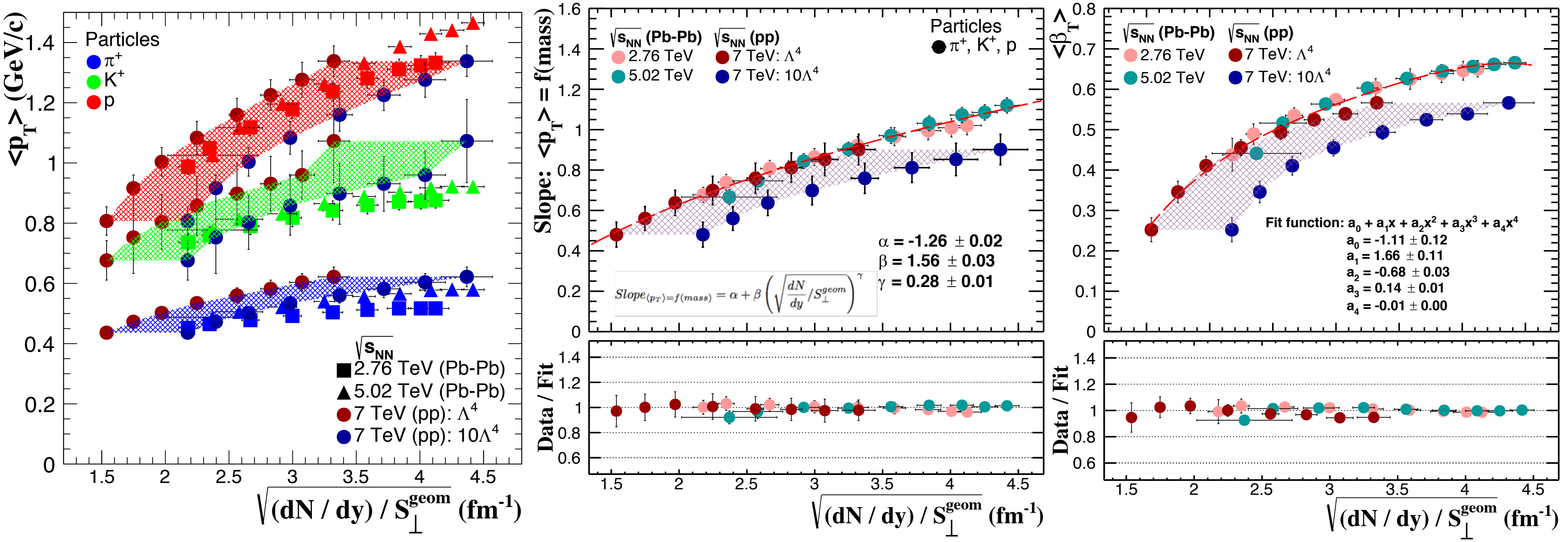
Transverse flow – BGBW fits



C.Andrei, ALICE Collaboration,Nucl.Phys. **A 931 (2014) c888**

p+p vs. Pb+Pb @ LHC

$\langle p_T \rangle$ vs. $[(dN/dy)/S_{perp}]^{1/2}$ — The slope of $\langle p_T \rangle = f(mass)$ vs. $[(dN/dy)/S_{perp}]^{1/2}$ — $\langle \beta_T \rangle$ from BGBW fits vs. $[(dN/dy)/S_{perp}]^{1/2}$



$$S_{\perp}^{pp} = \pi R_{pp}^2 \quad \Longrightarrow \quad \varepsilon = \alpha \Lambda_{QCD}^4$$

α=1

$$f_{pp} = \begin{cases} 0.387 + 0.0335x + 0.274x^2 - 0.0542x^3 & \text{if } x < 3.4 \\ 1.538 & \text{if } x \geq 3.4 \end{cases}$$

α=10

$$f_{pp} = \begin{cases} -0.018 + 0.3976x + 0.095x^2 - 0.028x^3 & \text{if } x < 3.4 \\ 1.17 & \text{if } x \geq 3.4 \end{cases}$$

x$=(dN_g/dy)^{1/3}$

$dN_g/dy \approx dN/dy$

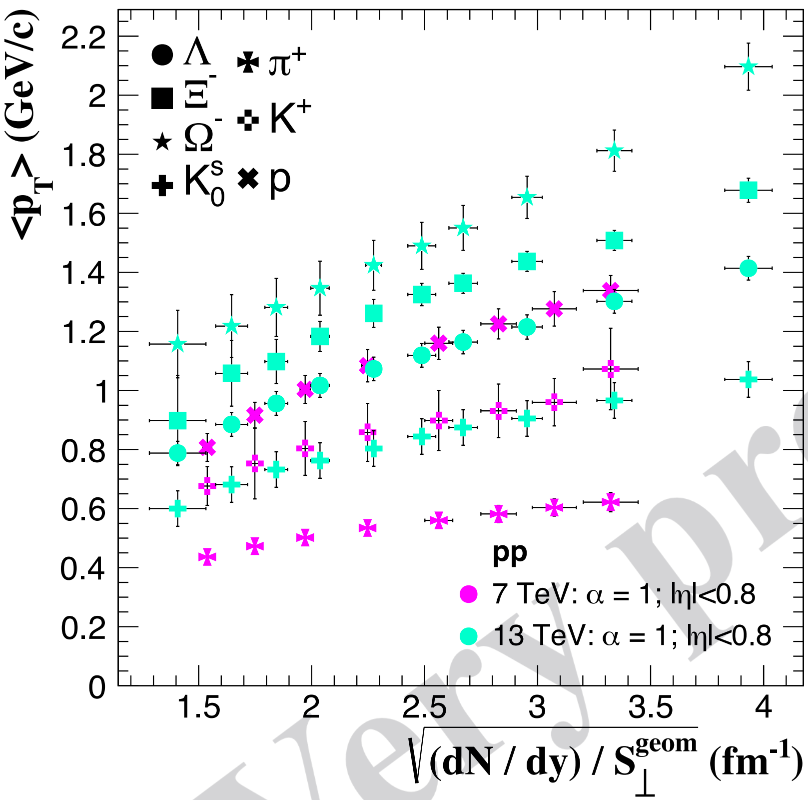
McLarren, M.Praszalowicz and B.Schenke, Nucl.Phys. A916(2013)210

A.Bzdak, B.Schenke, P.Tribedy and R.Venugopalan, Phys.Rev. C87(2013)064906

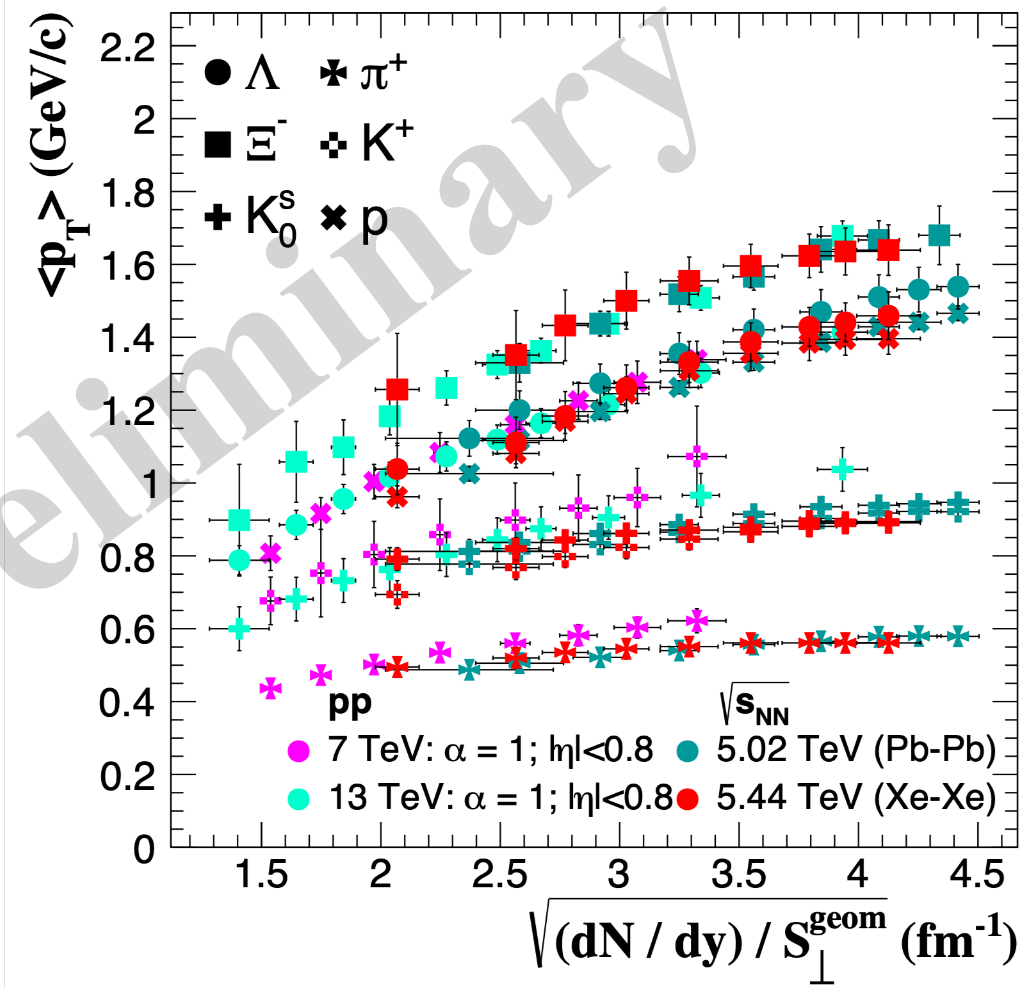
ALICE Collaboration, Nucl.Phys. A931(2014)c888

M. Petrovici, A. Lindner, A. Pop, M. Tarzila and I. Berceanu, Phys. Rev. C 98 (2018) 024904

p+p 13 TeV @ LHC



p+p 7 TeV vs. 13 TeV



p+p 7 TeV & 13 TeV vs. Pb+Pb & Xe+Xe @ LHC

Conclusions

- A very good scaling of different observables as a function of a scaling parameter suggested by the CGC model is found for Cu-Cu, Au-Au Xe-Xe and Pb-Pb for a wide range of energies: *from 7.7 GeV up to 5.44 TeV*
- The scaling is also evidenced for p+p and Pb+Pb at the measured LHC energies

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↓

The global trends at the LHC depend on the properties of the flux tubes of ~ $1/[(dN/dy)/S_{perp}]^{1/2}$ size

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The global trends at the LHC depend on the properties of the flux tubes of $\sim 1/[(dN/dy)/S_{perp}]^{1/2}$ size

↓

System size is playing a minor role at LHC energies

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↓

System size is playing a minor role at LHC energies

Perspectives

- This study will be extended to pp collisions measured at LHC at 13 TeV - preliminary results already obtained
- The strange and multistrange hadrons seems to behave different in A-A relative to pp collisions - detailed analysis and interpretation is in progress

Thank you!