Ministerul Cercetării și Inovării

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Core-Corona
Geometrical scaling from RHIC to LHC energies
pp - (A-A) similarities

Mihai Petrovici

Work done in collaboration with:

C.Andrei, I.Berceanu, A.Lindner, A.Pop, M.Tarzila, V.Topor Pop

HADRON PHYSICS DEPARTMENT

Outline

- Physics motivation

- Core-corona interplay - impact on the experimental trends

- Geometrical scaling

<u>Au-Au @ RHIC, Pb-Pb @ LHC</u>

- $<p_T>$ vs. $[(dN/dy)/S_{perp}]^{1/2}$

- The slope of $<p_T>=f(mass)$ vs. $[(dN/dy)/S_{perp}]^{1/2}$

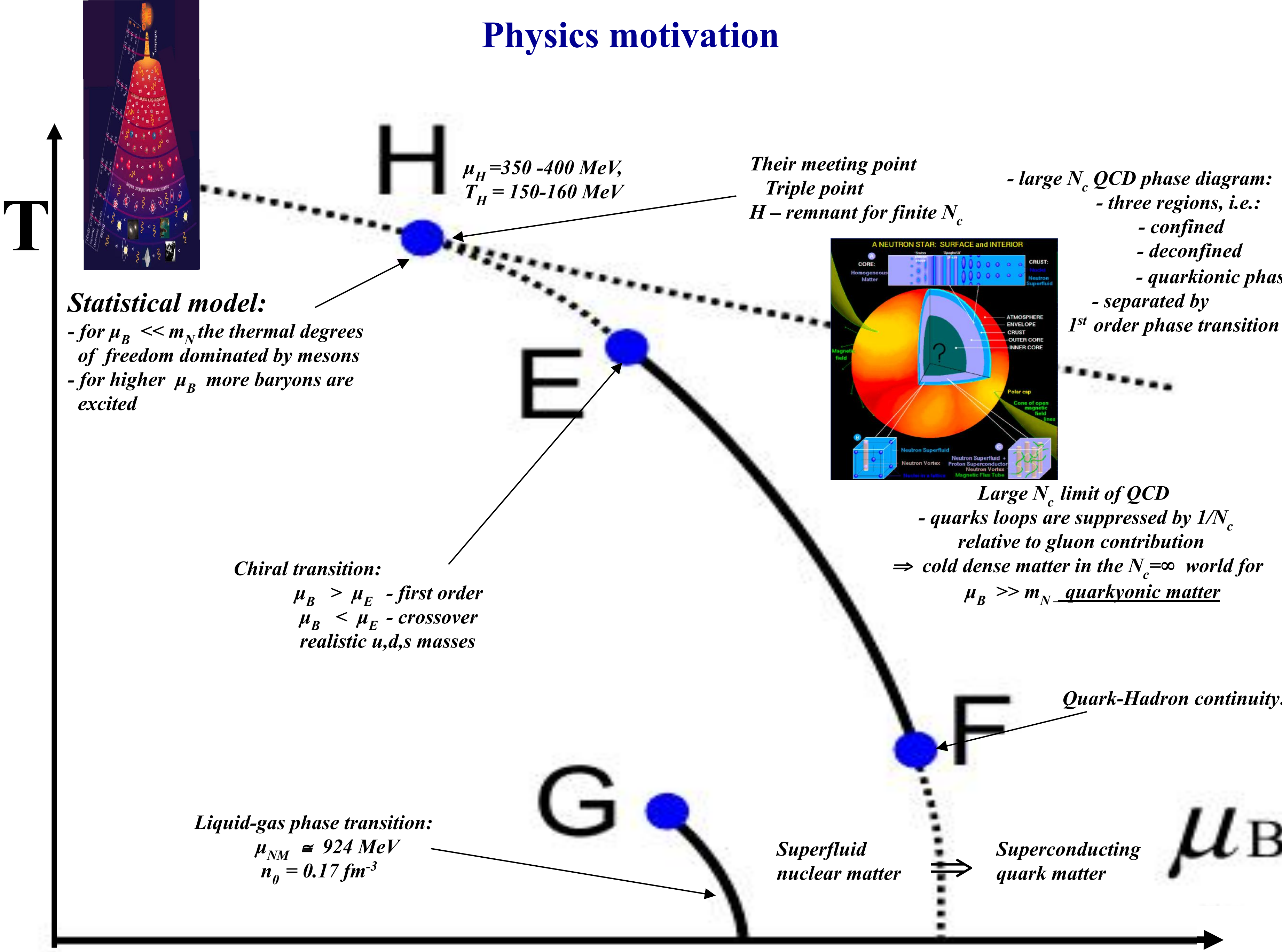
- $<\beta_T>$ from BGBW fits vs. $[(dN/dy)/S_{perp}]^{1/2}$

<u>Au-Au & Cu-Cu @ RHIC, Pb-Pb & Xe-Xe @ LHC</u>

<u>p+p vs. Pb-Pb @ LHC</u>

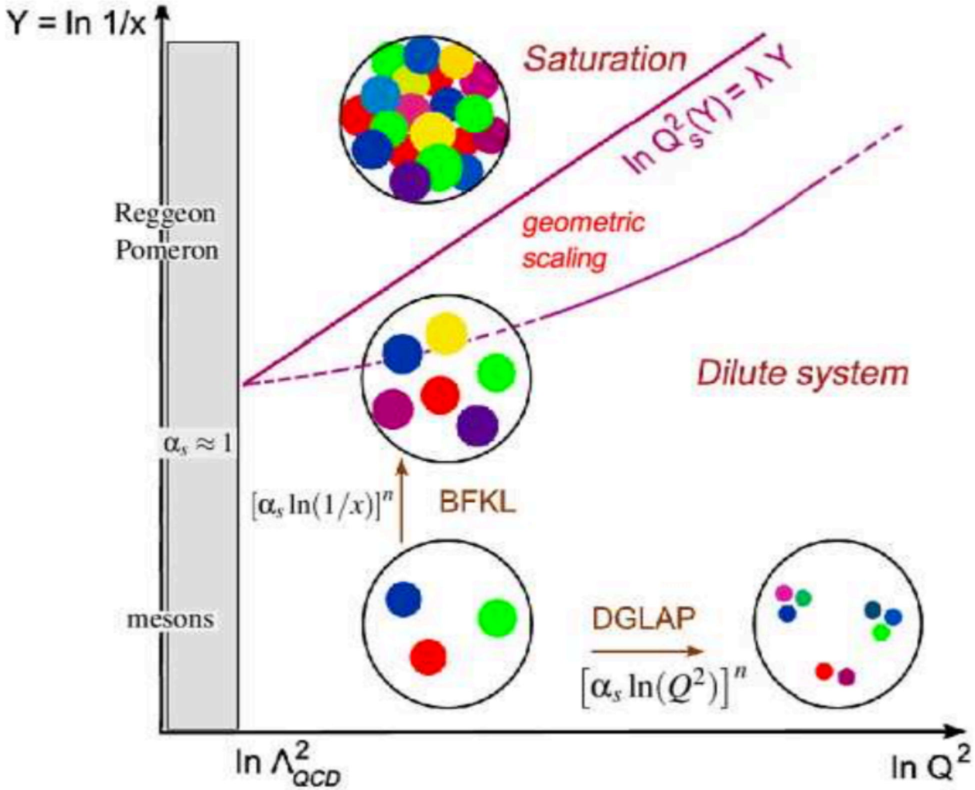
- Outlook

Physics motivation

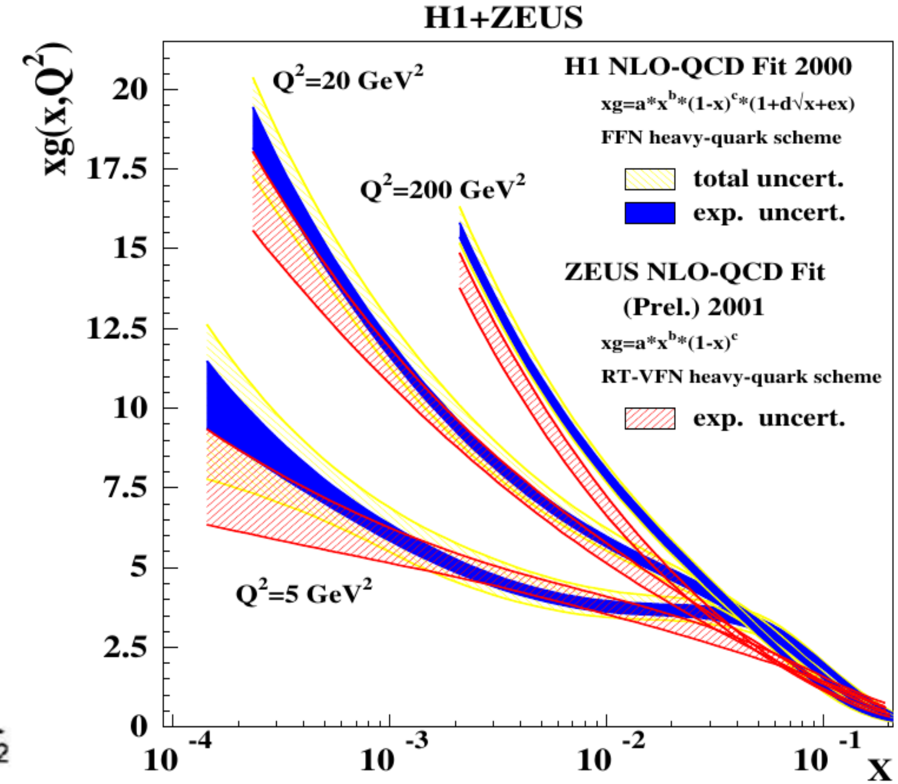


K. Fukushima and T. Hatsuda, Rept.Prog.Phys.74(2011)014001

Physics motivation



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



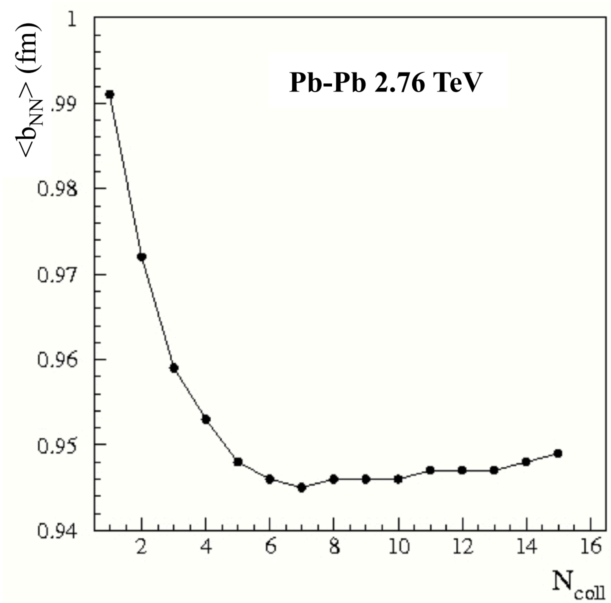
M.Dittmar et al., Proceedings HERA-LHC Workshop
arXiv:[hep-ph]0511119

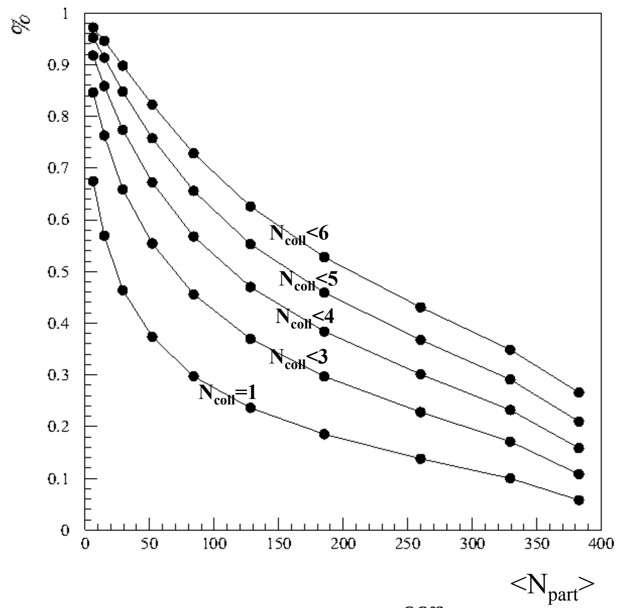
Following A.H. Mueller approximations NP A715(2003)20

System	*Au-Au*	*Pb-Pb*	*Pb-Pb*	*pp*
$\sqrt{s}(GeV)$	*200*	*2700*	*5020*	*7000*
$\frac{dN_g^{in}}{dyd^2b}(fm^{-2})$	≈4.7	≈11.8	≈15.9	≈18.7
f_{in}^g	≈0.9	≈2.3	≈3.1	≈3.6

Core-Corona effect

Glauber MC



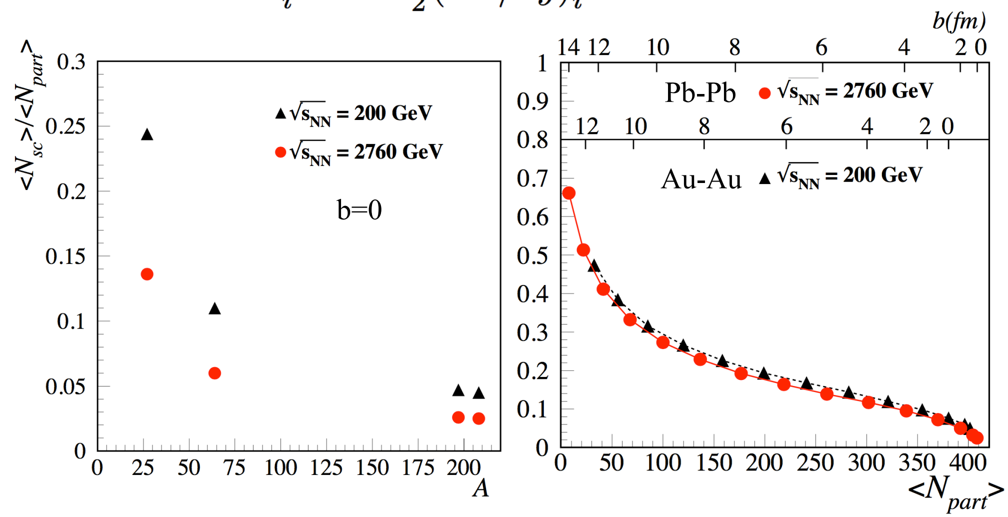


$$\left(\frac{dN}{dy}\right)_i^{cen} = N_{part}[(1-f_{core})M_i^{ppMB} + f_{core}M_i^{core}]$$

$$M_i^{ppMB} = \frac{1}{2}(dN/dy)_i^{ppMB}$$

How should we define "Corona" ?

F.Becattini, J.Manninen, J.Phys.G 35 (2008) 104013, Phys.Lett.B 673(2009)19
J.Aichelin, K.Werner, Phys.Rev.C 79(2009)064907,
J.Phys.G 37(2010)094006,
Phys.Rev.C 82(2010)034906
P.Bozek, Phys.Rev.C 79 (2009) 054901
C.Schreiber, K.Werner, J.Aichelin, Phys.Atom.Nucl. 75(2012)640
M.Gemard and J.Aichelin, Astron.Nachr. 335(2014)660



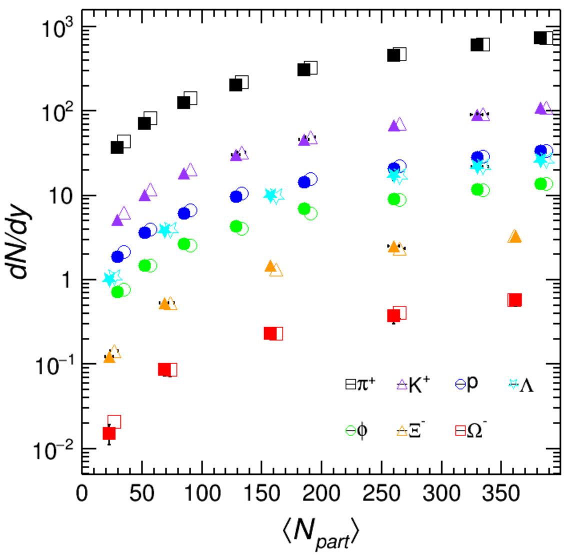
M. Petrovici, I. Berceanu, A. Pop, M. Târzila, and C. Andrei, Phys.Rev. C96(2017)014908

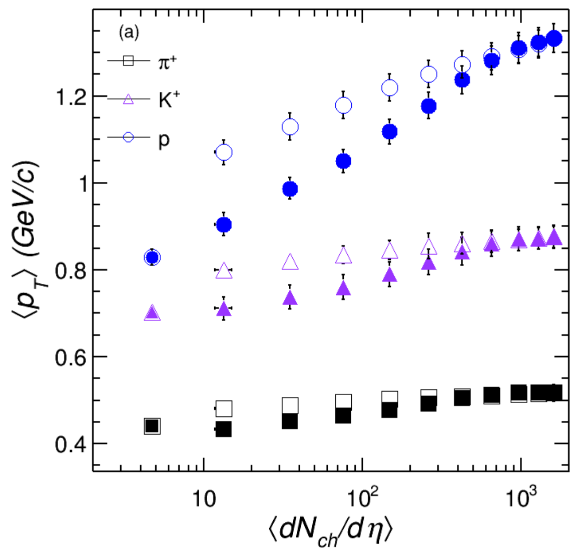
Core-Corona effect

$$\left(\frac{dN}{dy}\right)_i^{cen} = N_{part}[(1-f_{core})M_i^{ppMB} + f_{core}M_i^{core}] \qquad (1)$$

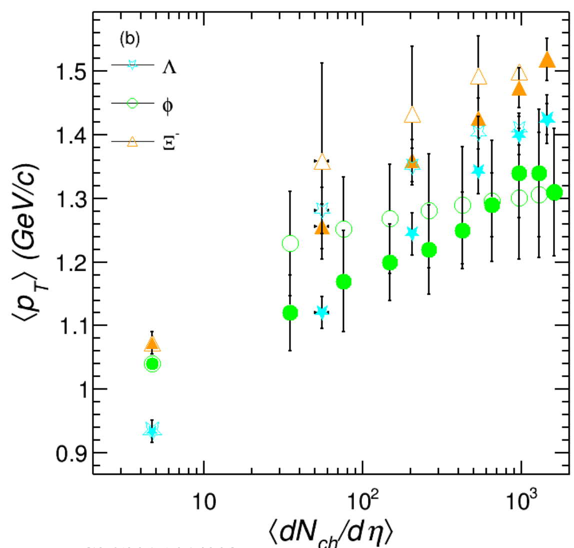
$$M_i^{ppMB} = \tfrac{1}{2}(dN/dy)_i^{ppMB} \qquad (2)$$

$$\langle p_T\rangle_i^{cen} = \frac{f_{core}\langle p_T\rangle_i^{core}M_i^{core} + (1-f_{core})\langle p_T\rangle_i^{ppMB}M_i^{ppMB}}{f_{core}M_i^{core} + (1-f_{core})M_i^{ppMB}} \qquad (3)$$



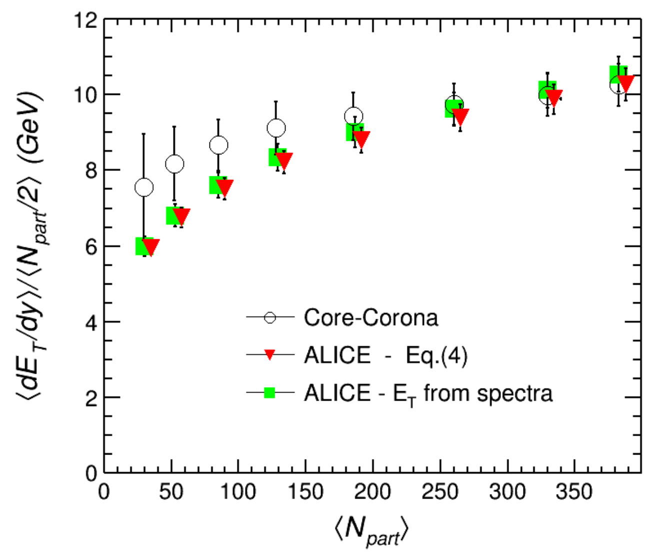


Full symbols - experiment
Open symbols – core-corona interplay



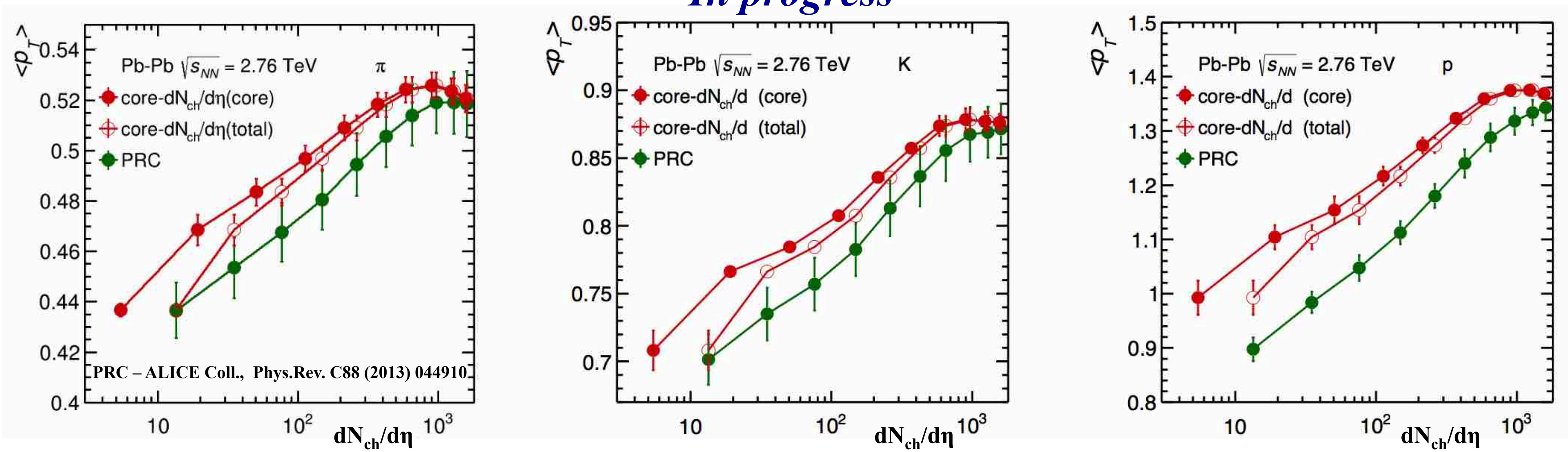
$$\frac{dE_T}{dy} \approx 3\left(\frac{dE_T}{dy}\right)_{\pi^+} + 4\left(\frac{dE_T}{dy}\right)_{K^+,p,\Xi^-} + 2\left(\frac{dE_T}{dy}\right)_{\Lambda,\Omega^-} \quad (4)$$

$$\frac{dE_T}{dy} = \langle m_T\rangle\frac{dN}{dy} \qquad \langle m_T\rangle = \sqrt{\langle p_T\rangle^2 + m^2}$$

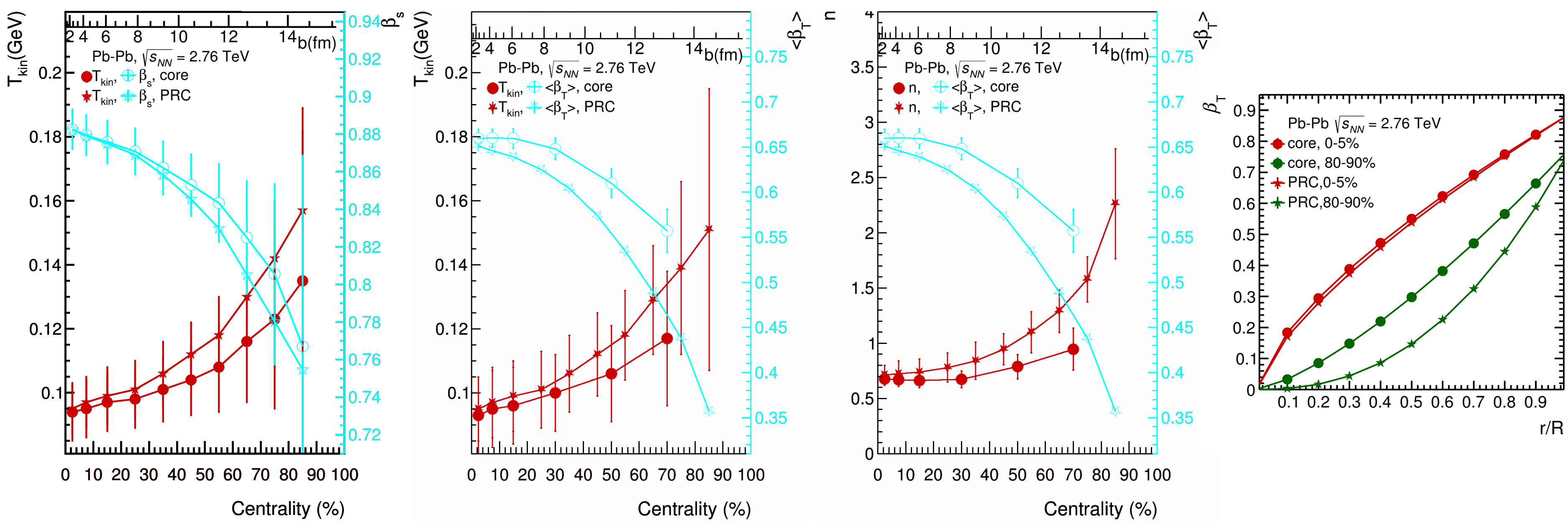


ALICE Coll., Phys.Rev. C88(2013)044910
ALICE Coll., Phys.Rev.Lett 111(2013)222301
ALICE Coll., Phys.Lett. B728(2014)216
ALICE Coll., Phys.Rev. C91(2015)024609
M. Petrovici, I. Berceanu, A. Pop, M. Târzila, and C. Andrei, Phys.Rev. C96(2017)014908

Core properties
In progress



BGBW
$$\frac{1}{2\pi p_T}\frac{d^2N}{dydp_T} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh\rho}{T_{kin}}\right) K_1\left(\frac{m_T \cosh\rho}{T_{kin}}\right) \qquad \rho = \tanh^{-1}\beta_T = \tanh^{-1}\left[\left(\frac{r}{R}\right)^n \beta_s\right]$$



Based on ALICE data, see references in:
M. Petrovici, I. Berceanu, A. Pop, M. Târzila, and C. Andrei, Phys.Rev. C96(2017)014908

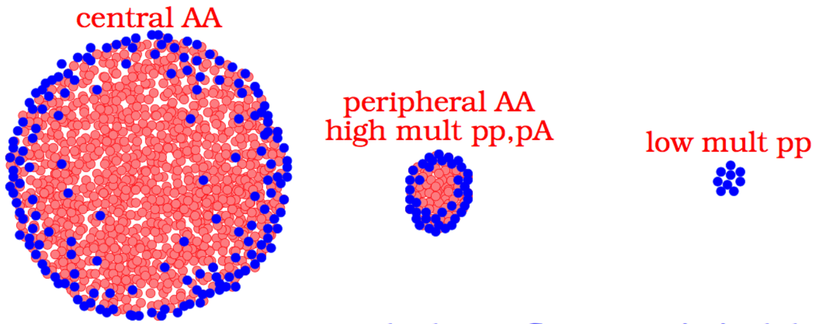
Core-corona in pp

Core-corona picture in EPOS

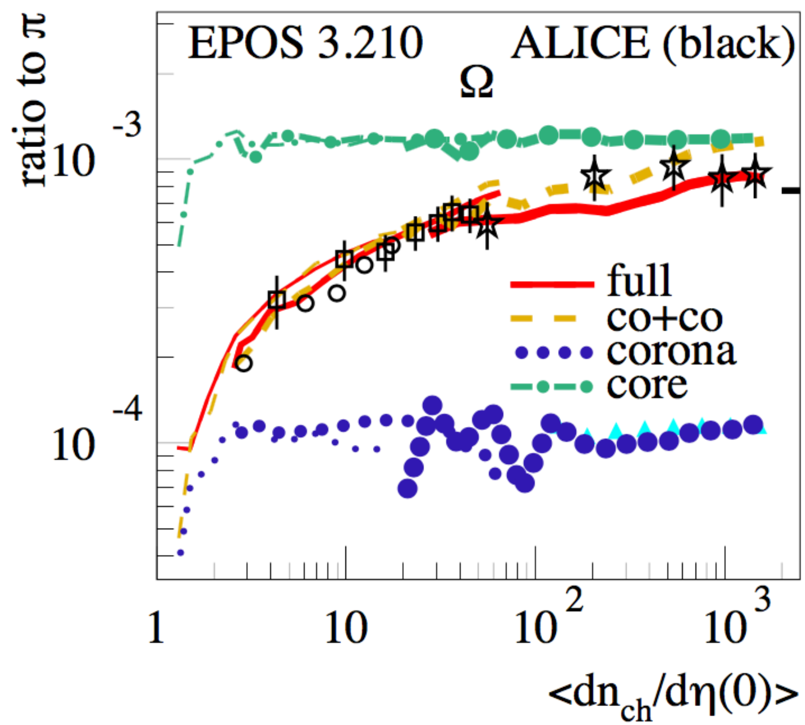
Phys.Rev.Lett. 98 (2007) 152301, Phys.Rev. C89 (2014) 6, 064903

K. Werner, SQM 2017, July 10-15 2017, Utrecht

Gribov-Regge approach => (Many) kinky strings
=> core/corona separation (based on string segments)



core => hydro => flow + statistical decay
corona => string decay



thin lines = pp (7TeV)
intermediate lines = pPb (5TeV)
thick lines = PbPb (2.76TeVVV)

circles = pp (7TeV)
squares = pPb (5TeV)
stars = PbPb (2.76TeV)

Geometrical scaling

Local parton-hadron duality picture and dimensionality argument

- 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

$$\langle p_T \rangle / \sqrt{\frac{dN}{dy}/S_\perp} \sim \frac{1}{n\sqrt{n}}$$

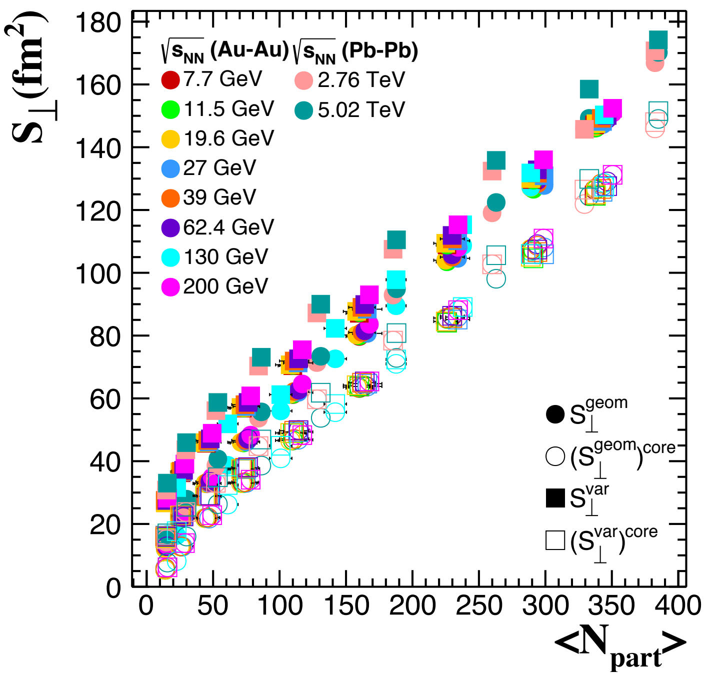
n - *no. of charged part. from a gluon fragmentation*

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

<u>**decreases as a function of:**</u>
- <u>**collision energy**</u>
- <u>**centrality**</u>

S_{perp} & dN/dy estimates

Glauber Monte Carlo approach



$$S_\perp^{var} \sim \pi\sqrt{\sigma_x^2\sigma_y^2 - \sigma_{xy}^2}$$

BES

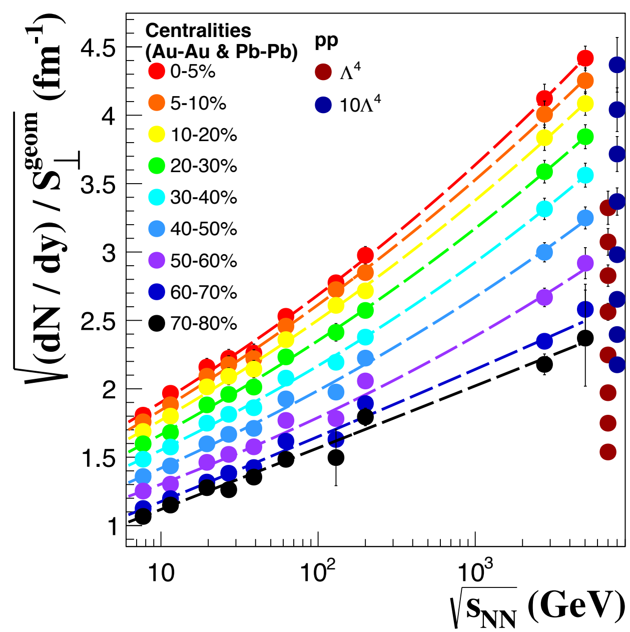
$$\frac{dN}{dy} \simeq \frac{3}{2}\frac{dN^{(\pi^+ + \pi^-)}}{dy} + 2\frac{dN^{(K^+ + K^-, p+\bar{p}, \Xi^- + \bar{\Xi}^+)}}{dy} + \frac{dN^{(\Lambda+\bar{\Lambda})}}{dy}$$

RHIC 62.4; 130; 200 GeV

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

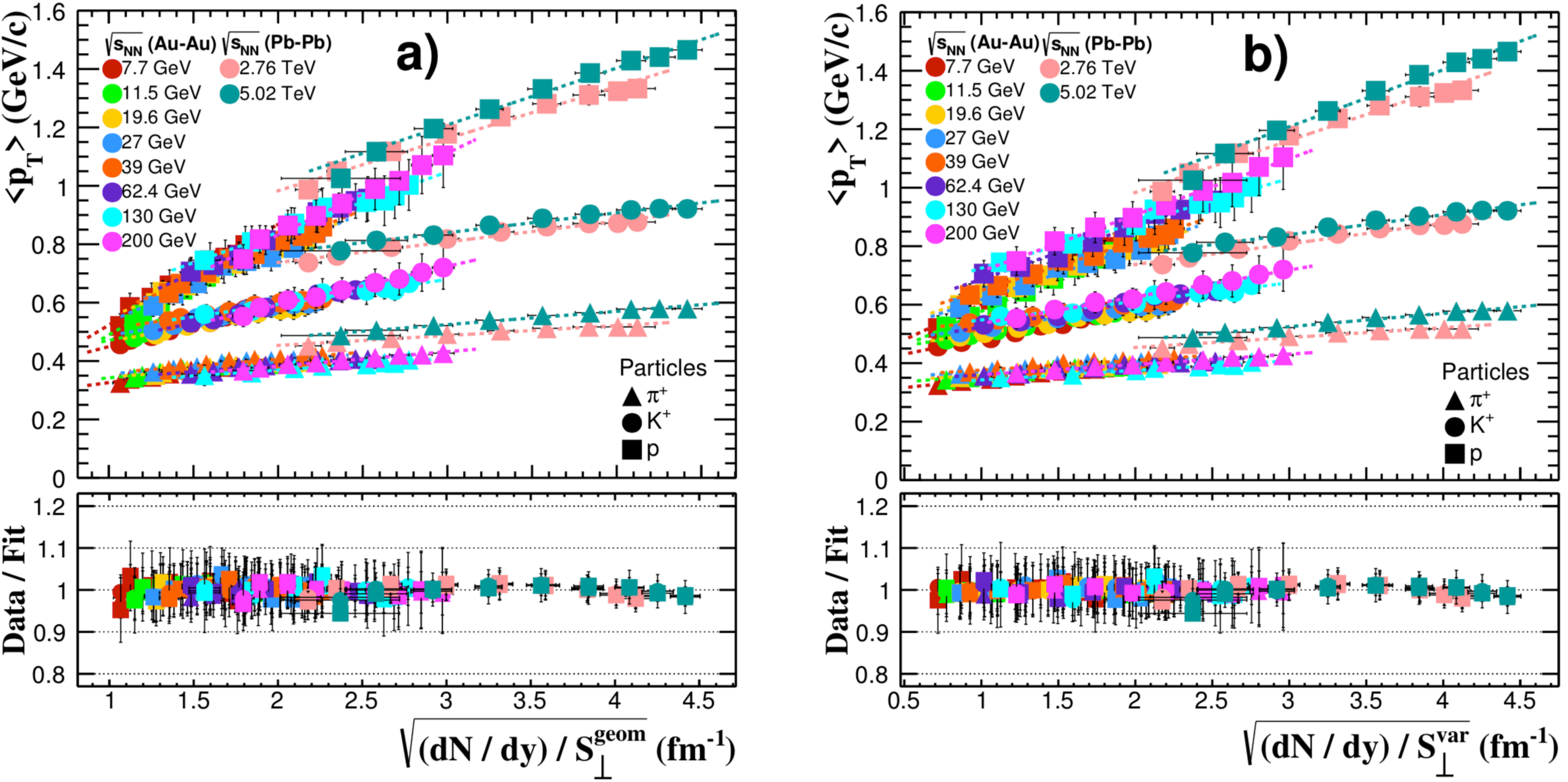
LHC

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



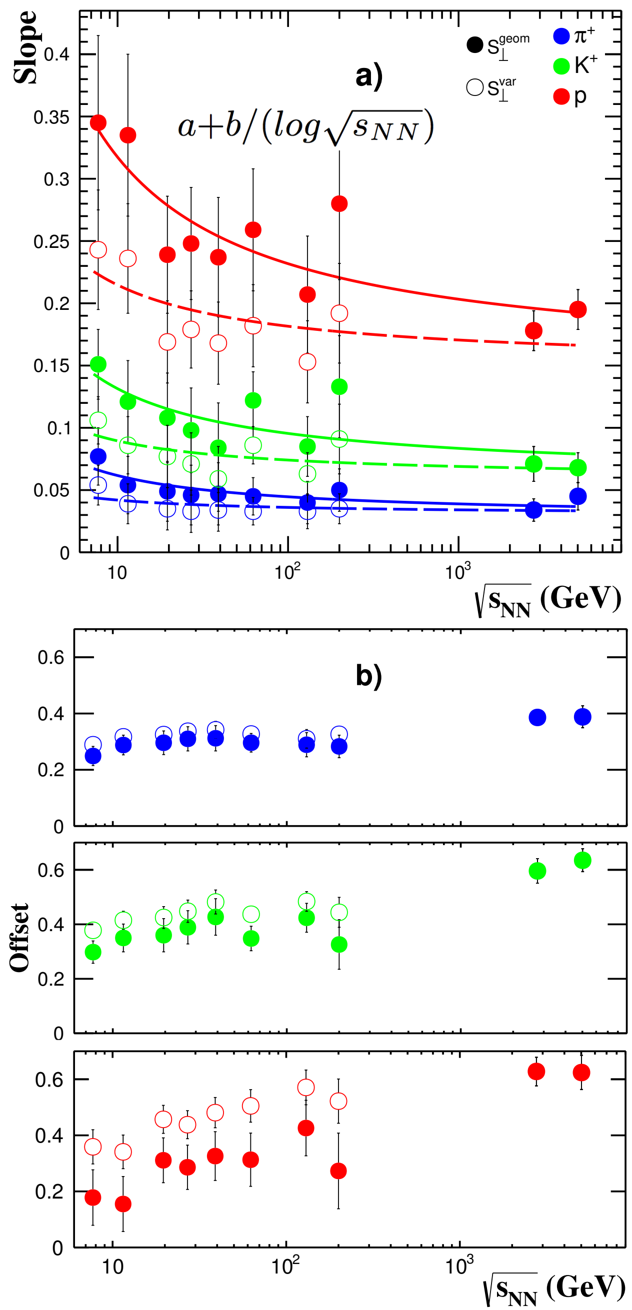
M. Petrovici, A.Lindner, , A. Pop, M. Târzila, and I.Berceanu, arXiv:[hep-ph]1805.04060

$\langle p_T \rangle$ vs. $[(dN/dy)/S_{perp}]^{1/2}$



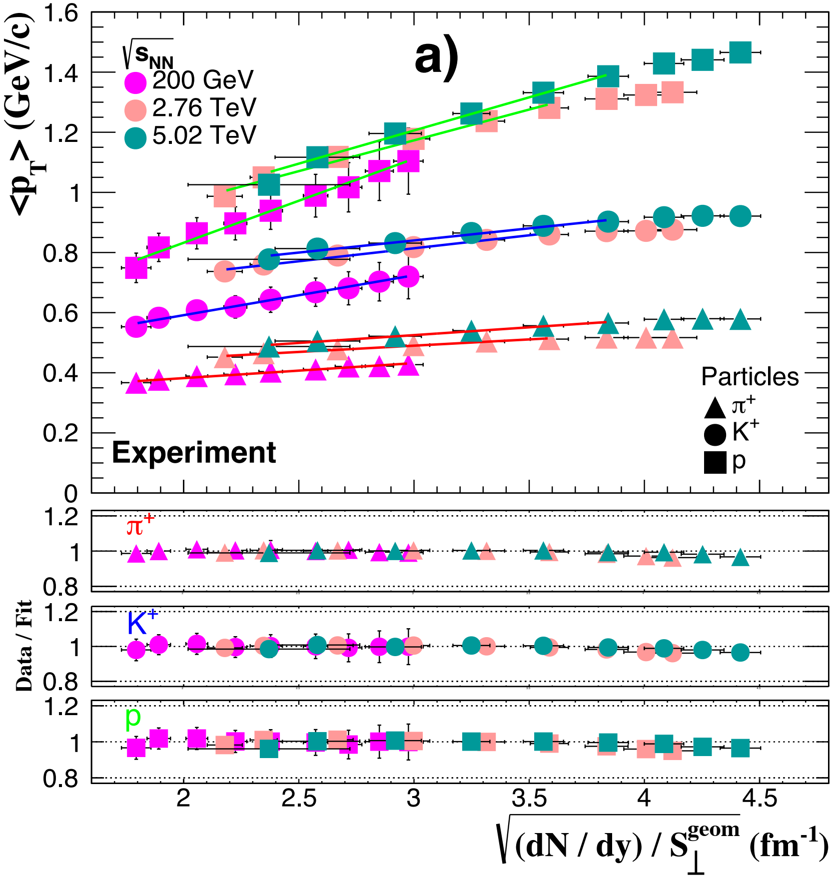
STAR Collaboration, Phys.Rev. C96(2017)044904
STAR Collaboration, Phys.Rev. C79(2009)034909
ALICE Collaboration, Phys.Rev. C}{88}{2013}{044910}
ALICE Collaboration, Phys.Rev.Lett. 116(2016)222302
ALICE Collaboration, Eur.Phys.J. C75(2015)226
A.K.Dash, ALICE Collaboration , 9th Int. Workshop on MPI at LHC, Dec. 11-15, 2017

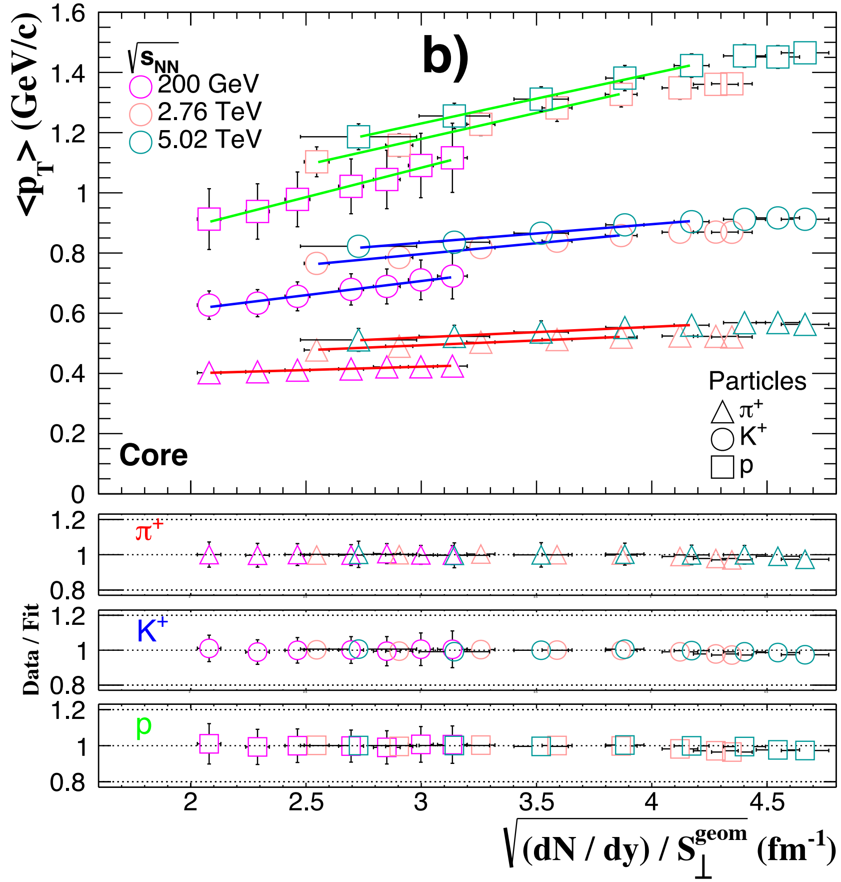
$\langle p_T \rangle$ vs. $[(dN/dy)/S_{perp}]^{1/2}$



$\langle p_T \rangle$ vs. $[(dN/dy)/S_{perp}]^{1/2}$

Core-Corona effect





$\sqrt{s_{NN}}$ (GeV)	Slope			Offset		
	π^+	K^+	p	π^+	K^+	p
200	0.05 ± 0.02	0.13 ± 0.04	0.28 ± 0.06	0.28 ± 0.04	0.33 ± 0.09	0.27 ± 0.13
2760	0.04 ± 0.01	0.09 ± 0.02	0.20 ± 0.03	0.37 ± 0.04	0.56 ± 0.07	0.56 ± 0.08
5020	0.05 ± 0.02	0.08 ± 0.02	0.22 ± 0.03	0.37 ± 0.06	0.60 ± 0.07	0.54 ± 0.10

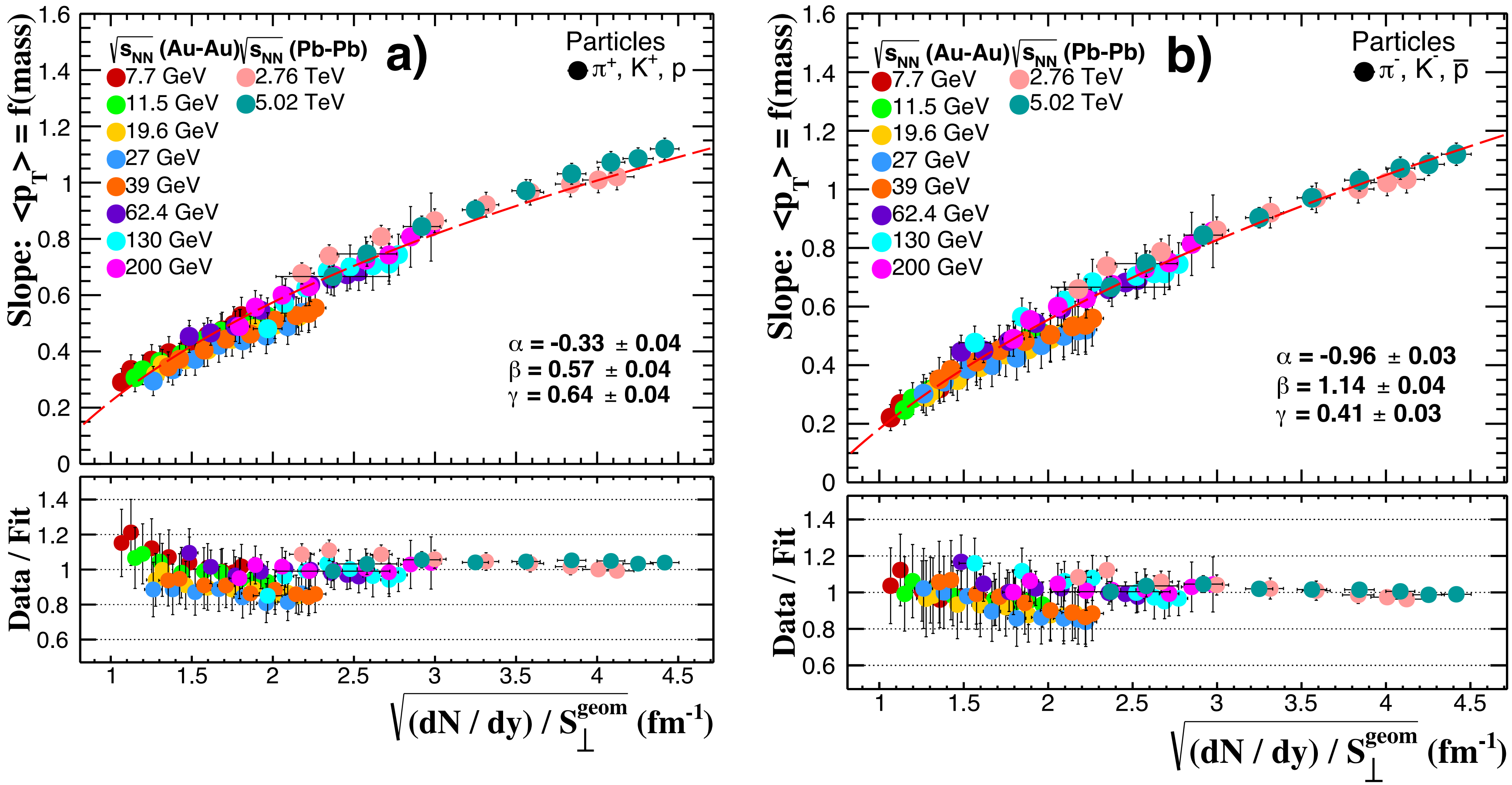
$\sqrt{s_{NN}}$ (GeV)	Slope			Offset		
	π^+	K^+	p	π^+	K^+	p
200	0.02 ± 0.03	0.09 ± 0.06	0.20 ± 0.11	0.36 ± 0.07	0.43 ± 0.15	0.50 ± 0.29
2760	0.03 ± 0.02	0.07 ± 0.03	0.17 ± 0.04	0.40 ± 0.06	0.58 ± 0.10	0.66 ± 0.14
5020	0.03 ± 0.03	0.06 ± 0.02	0.17 ± 0.04	0.41 ± 0.11	0.65 ± 0.08	0.73 ± 0.16

$$\langle p_T \rangle_i^{cen} = \frac{f_{core} \langle p_T \rangle_i^{core} M_i^{core} + (1 - f_{core}) \langle p_T \rangle_i^{ppMB} M_i^{ppMB}}{f_{core} M_i^{core} + (1 - f_{core}) M_i^{ppMB}}$$

$$\left(\frac{dN}{dy} \right)_i^{cen} = \langle N_{part} \rangle [(1 - f_{core}) M_i^{ppMB} + f_{core} M_i^{core}]$$

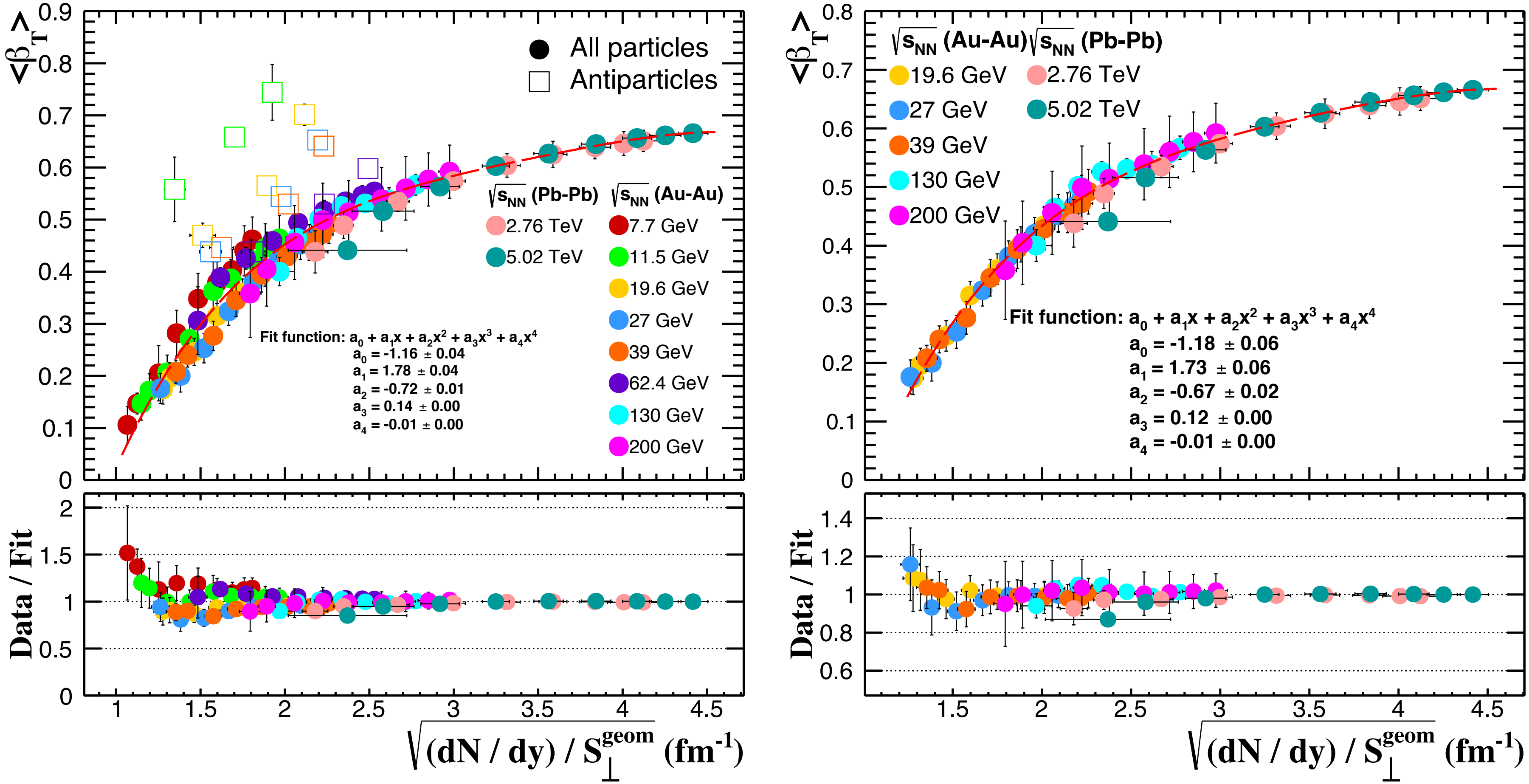
$$M_i^{ppMB} = \tfrac{1}{2} (dN/dy)_i^{ppMB}$$

The slope of $<p_T>=f(mass)$ vs. $[(dN/dy)/S_{perp}]^{1/2}$



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

$\langle\beta_T\rangle$ from BGBW fits vs. $[(dN/dy)/S_{perp}]^{1/2}$



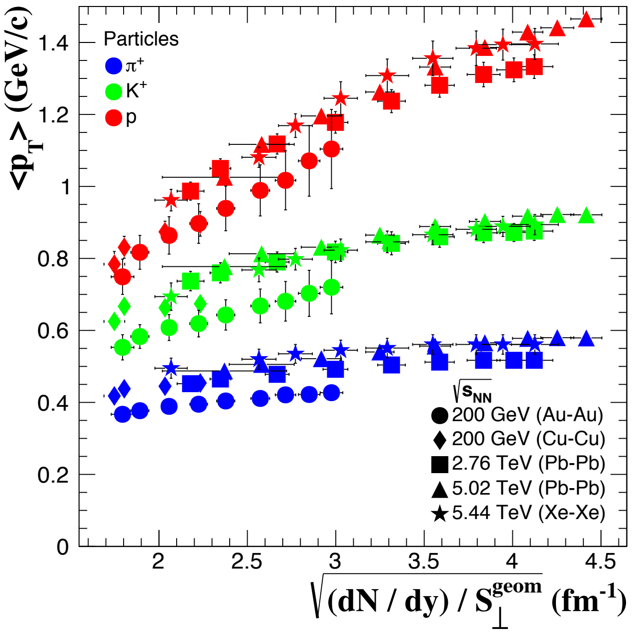
Boltzmann-Gibbs Blast Wave

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

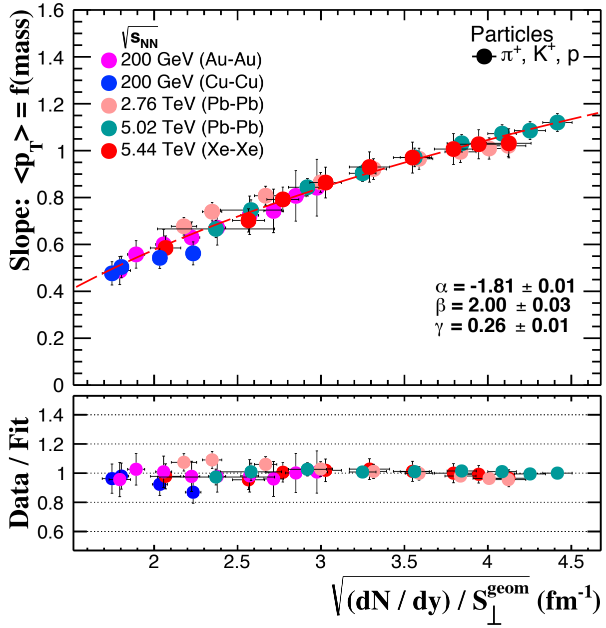
$$\rho = \tanh^{-1}\beta_T = \tanh^{-1}\left[\left(\frac{r}{R}\right)^n \beta_s\right]$$

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

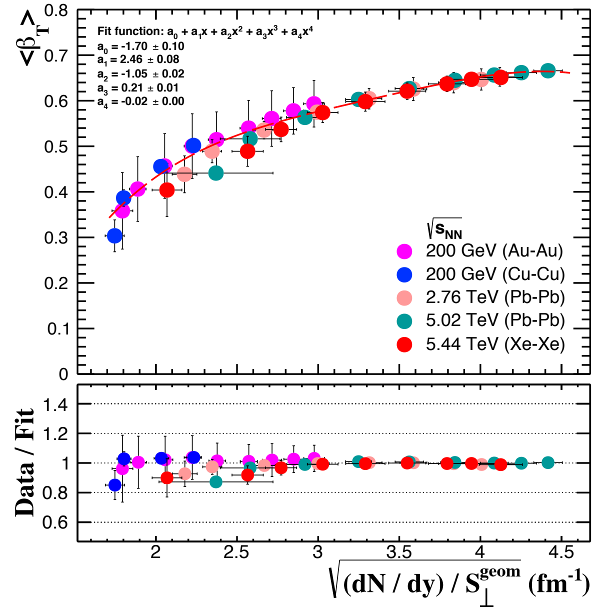
$<p_T>$ vs. $[(dN/dy)/S_{perp}]^{1/2}$



The slope of $<p_T>=f(\text{mass})$ vs. $[(dN/dy)/S_{perp}]^{1/2}$



$<\beta_T>$ from BGBW fits vs. $[(dN/dy)/S_{perp}]^{1/2}$



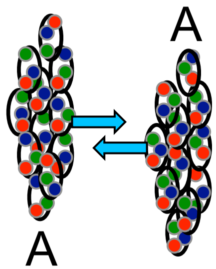
BRAHMS Collaboration, arXic:[nucl.ex]1602.01183

F.Bellini, ALICE Collaboration, QM2018

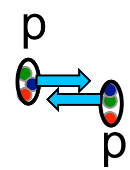
STAR Collaboration, Phys.Rev. C79(2009)034909

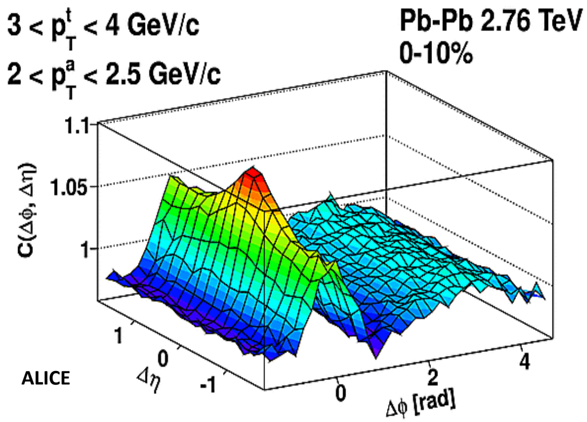
ALICE Collaboration, Phys.Rev. C}{88}{2013}{044910}

p+p vs. Pb+Pb @ LHC



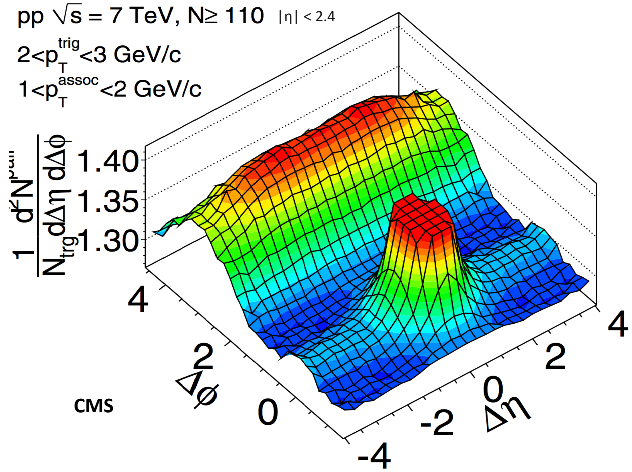
Long range near side correlations





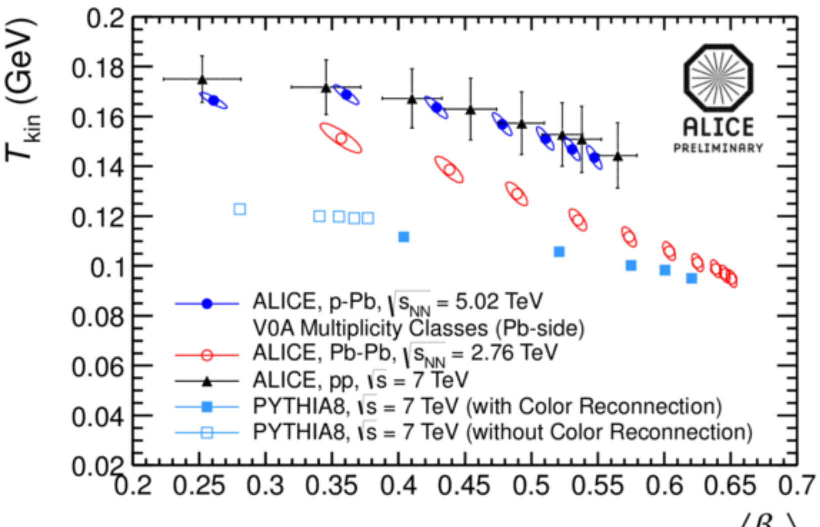
Phys.Lett. B708(2014)249

ALI-PUB-14107



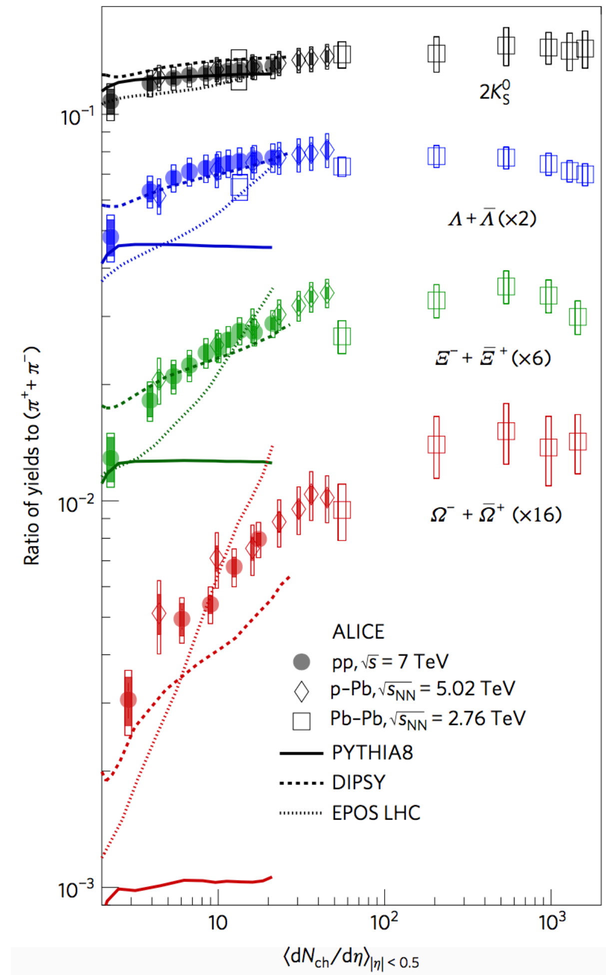
J. Phys. G Nucl. Part. Phys. 38(2011)124051

Transverse flow – BGBW fits



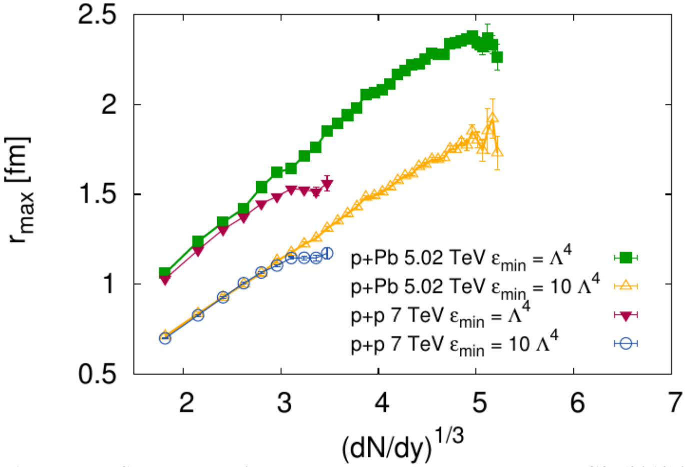
ALICE Collaboration,Nucl.Phys. A 931 (2014) c888

Strangeness relative yields



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

p+p vs. Pb+Pb @ LHC



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

$S_{\perp}^{pp}=\pi R_{pp}^2$ $\quad R_{pp}=1fm \bullet f_{pp}$ - maximal radius for which the energy density of the Yang-Mill fields is larger than $\varepsilon = \alpha \Lambda_{QCD}^4 \ (\alpha \in [1,10])$

α=1 $$f_{pp} = \begin{cases} 0.387 + 0.0335x + 0.274x^2 - 0.0542x^3 & \text{if } x < 3.4 \\ 1.538 & \text{if } x \geq 3.4 \end{cases}$$

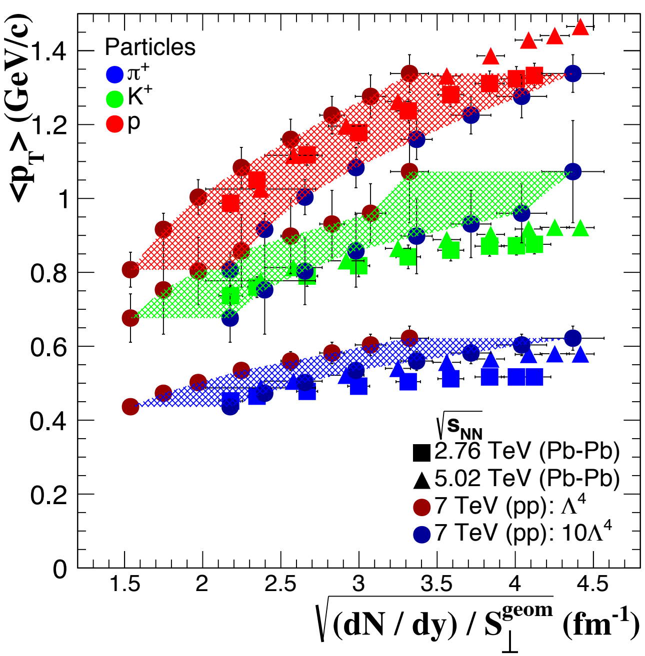
$$x=(dN_g/dy)^{1/3}$$

$$dN_g/dy \approx dN/dy$$

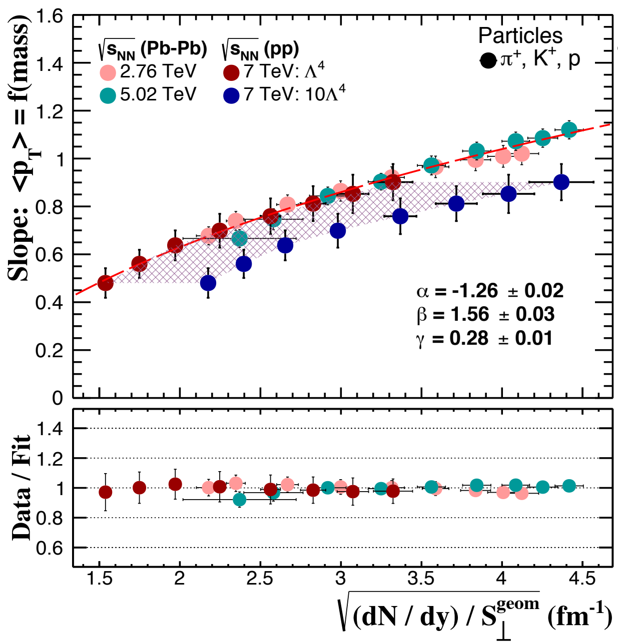
McLarren, M.Praszalowicz and B.Schenke, Nucl.Phys. A916(2013)210

α=10 $$f_{pp} = \begin{cases} -0.018 + 0.3976x + 0.095x^2 - 0.028x^3 & \text{if } x < 3.4 \\ 1.17 & \text{if } x \geq 3.4 \end{cases}$$

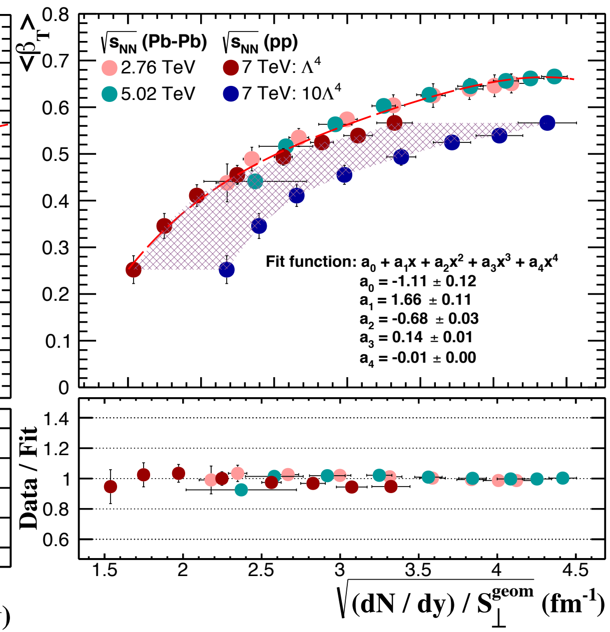
$\langle p_T \rangle$ vs. $[(dN/dy)/S_{perp}]^{1/2}$



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



$\langle \beta_T \rangle$ from BGBW fits vs. $[(dN/dy)/S_{perp}]^{1/2}$

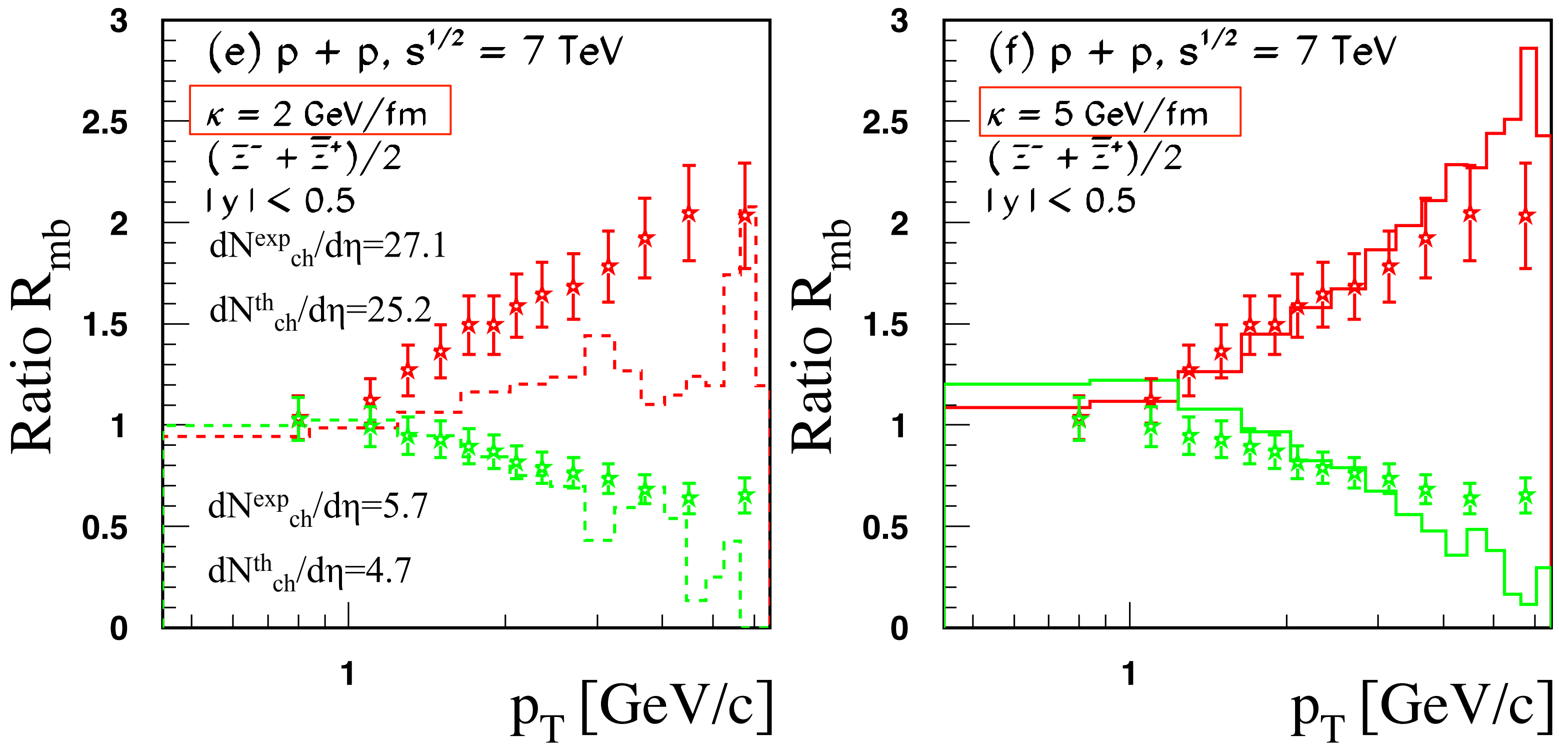


$$Slope_{\langle p_T \rangle = f(mass)} = \alpha + \beta \left(\sqrt{\frac{dN}{dy} / S_{\perp}^{geom}} \right)^{\gamma}$$

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

pp - Pb+Pb similarities @ LHC within HIJING/B$\bar{\text{B}}$ v2.0 model

$$R_{mb}\ (cen) \ = \ \left(\frac{\frac{d^2N}{dydp_T}}{\langle\frac{dN_{ch}}{d\eta}\rangle}\right)_i^{cen} \Big/ \left(\frac{\frac{d^2N}{dydp_T}}{\langle\frac{dN_{ch}}{d\eta}\rangle}\right)_i^{ppMB}$$



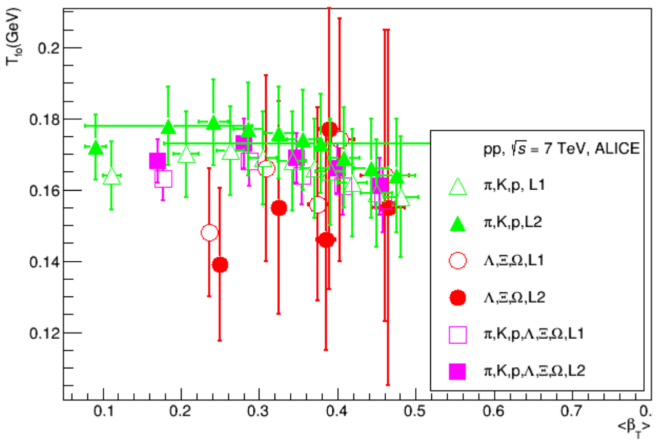
V.Topor Pop and M.Petrovici, arXiv:[hep-ph]1806.00359

ALICE Collaboration, Phys.Lett. 712B(2012)309

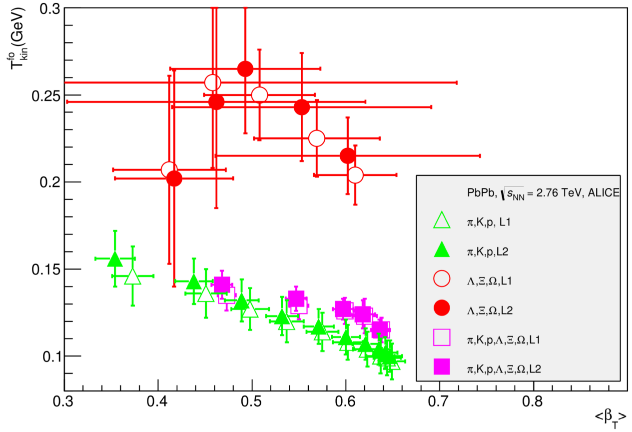
R. Derradi de Souza , ALICE Collaboration, J. Phys. Conf. Ser. 779, no. 1(2017)012071

There are still some differences between pp & A-A BGBW - fits

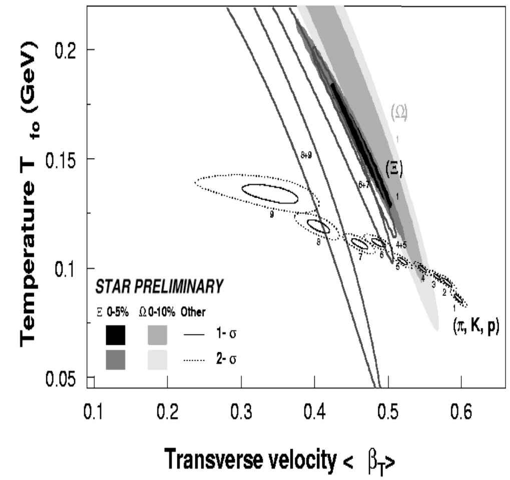
pp 7 TeV



Pb-Pb 2.76 TeV



Au-Au 200 GeV



M.Estienne, STAR Coll. arXiv:nucl-ex/0411034

L1
π: 0.5-1.15 GeV/c;
K: 0.2-1.25 GeV/c;
p: 0.3-2.30 GeV/c
Λ: ≤ 2.75 GeV/c;
Ξ: ≤ 3.25 GeV/c ;
Ω: ≤ 3.0 GeV/c

L2
π: 0.5-1.35 GeV/c;
K: 0.2-1.65 GeV/c;
p: 0.3-2.45 GeV/c
Λ: ≤ 2.50 GeV/c;
Ξ: ≤ 2.70 GeV/c ;
Ω: ≤ 3.40 GeV/c

M.Petrovici et al. AIP Conf.Proc. 1852, 050003-1 (2017)

Outlook

- larger statistics => multi-differential analysis

- very good PID as low as possible in p_T

- charged particle multiplicity

- event-shape

- different ranges in $\Delta\eta$ and $\Delta\Phi$ relative to L(T)P

- Core-corona interplay in A-A and pp - plays an important role in understanding the origin of different experimentally evidenced trends

- pp as high as possible in charged particle multiplicity

- Understanding the similarities and differences between pp and A-A at high f_g^{in}

- lower mass A-A collisions ?