Heavy ions at the LHC:
personal predictions & overview of the CERN TH Institute

Nicolas BORGHINI

Universität Bielefeld

Heavy ion collisions at the LHC

- "Personal" predictions:

mostly, agnostic extrapolations of trends observed in the data

N.B., U.A.Wiedemann, arXiv:07070564 [hep-ph]

- CERN Theory Institute:

Heavy Ion Collisions at the LHC

Last Call for Predictions

Monday May 14th to Friday June 8th 2007

organized by N.Armesto, N.B., S.Jeon & U.A.Wiedemann

http://fpaxp1.usc.es/nestor/predhiclhc.html

What are the more elaborate predictions of the community?
(19 seminars + 85 talks... I shall present a biased overview!)

Heavy ion collisions at the LHC

When at last the accelerator people inject Pb^{82+} nuclei into the LHC, what will ALICE, ATLAS and CMS first measure?

the multiplicity of charged particles

... as a function of the position in their detectors

pseudorapidity $\eta \equiv -\ln\tan\left(\frac{\theta}{2}\right) = \frac{1}{2}\ln\left(\frac{|\mathbf{p}|+p_z}{|\mathbf{p}|-p_z}\right)$

(z beam axis)

Charged hadron multiplicity

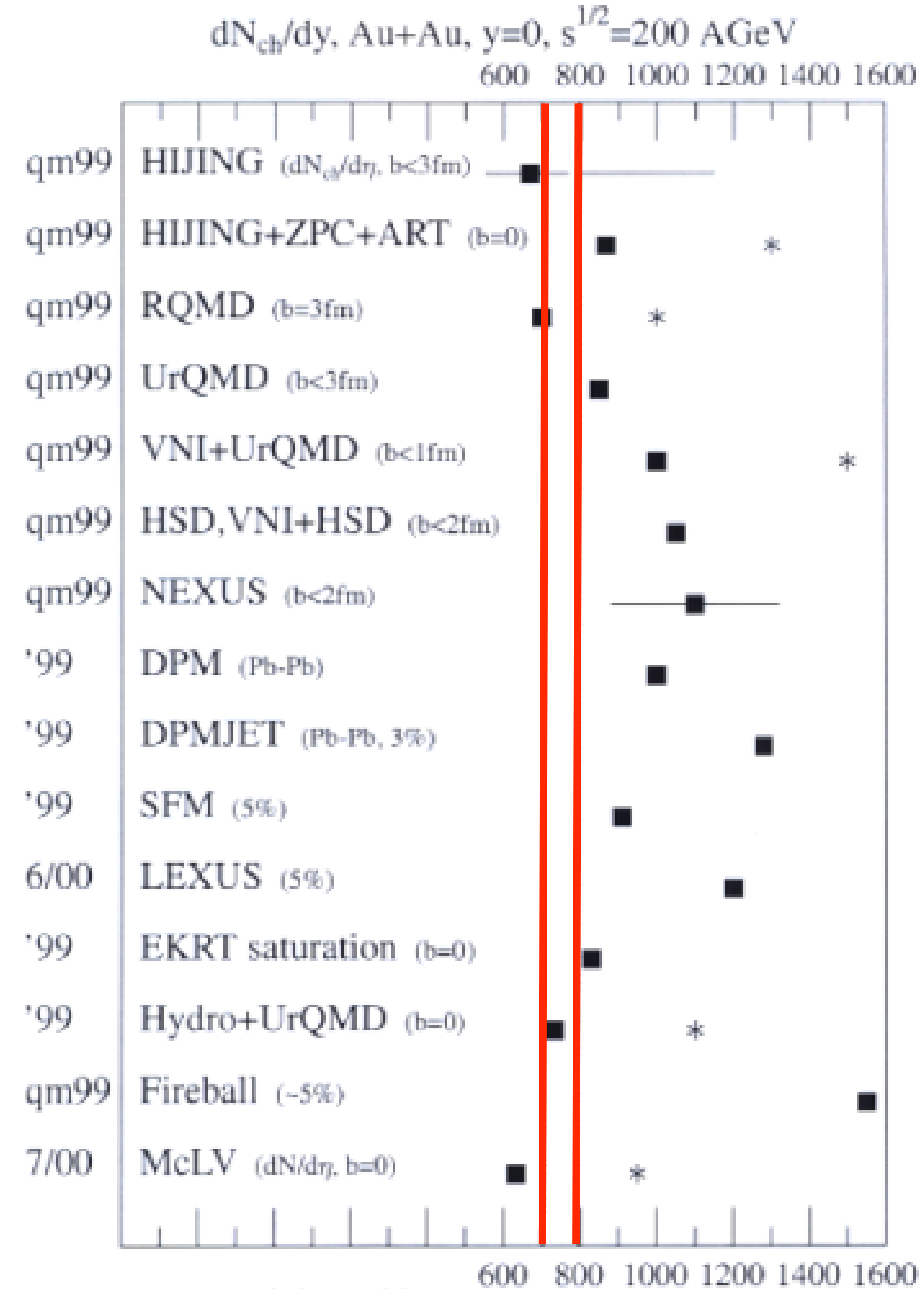
What is the multiplicity of charged hadrons at midrapidity $\eta = y = 0$?
(i.e., hadrons emitted at $\theta = 90°$ from the beam)

A number... not so trivial to predict:

cf. the range of RHIC predictions...

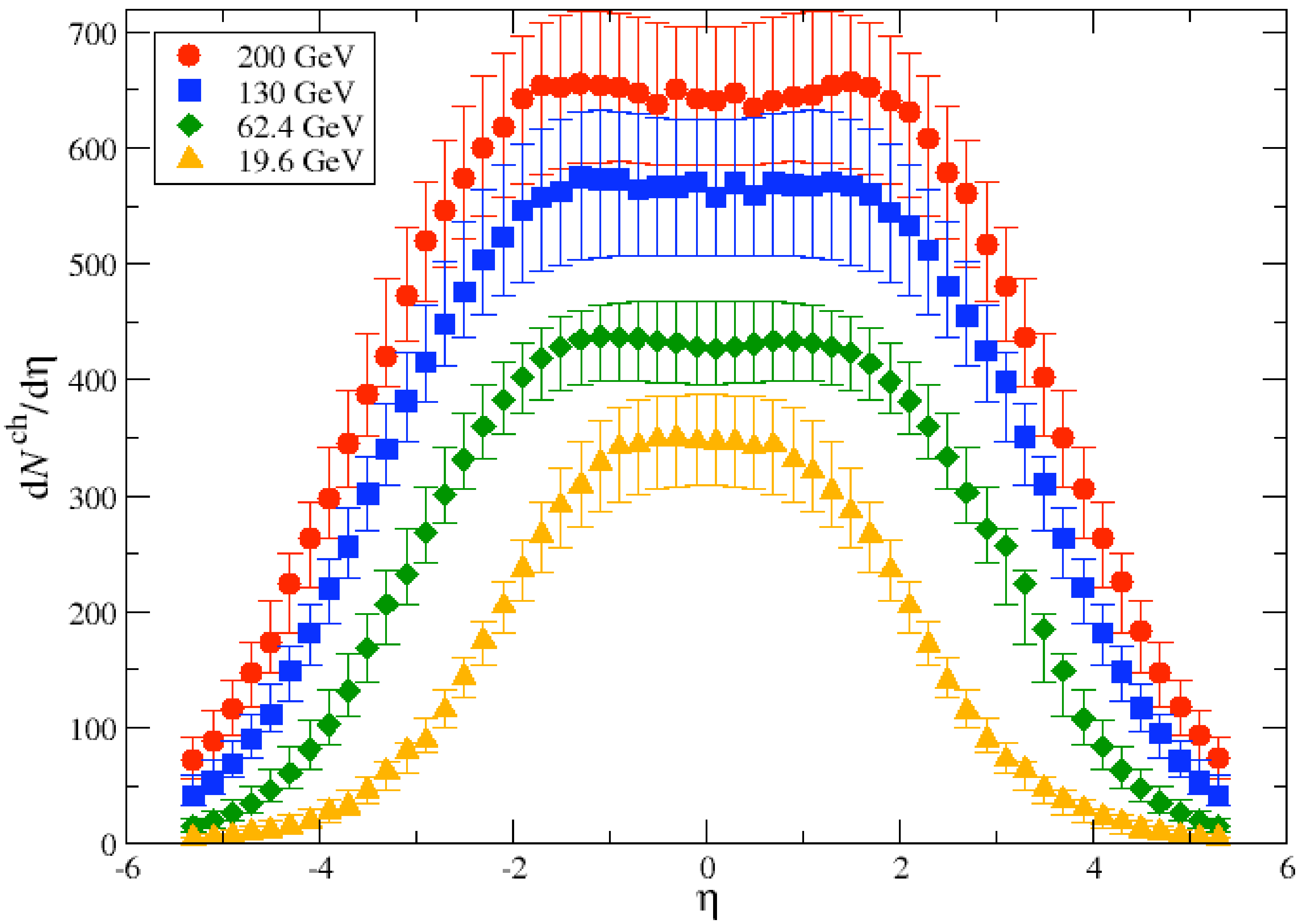
and the measured value

(taken from K.Eskola @ QM'01)

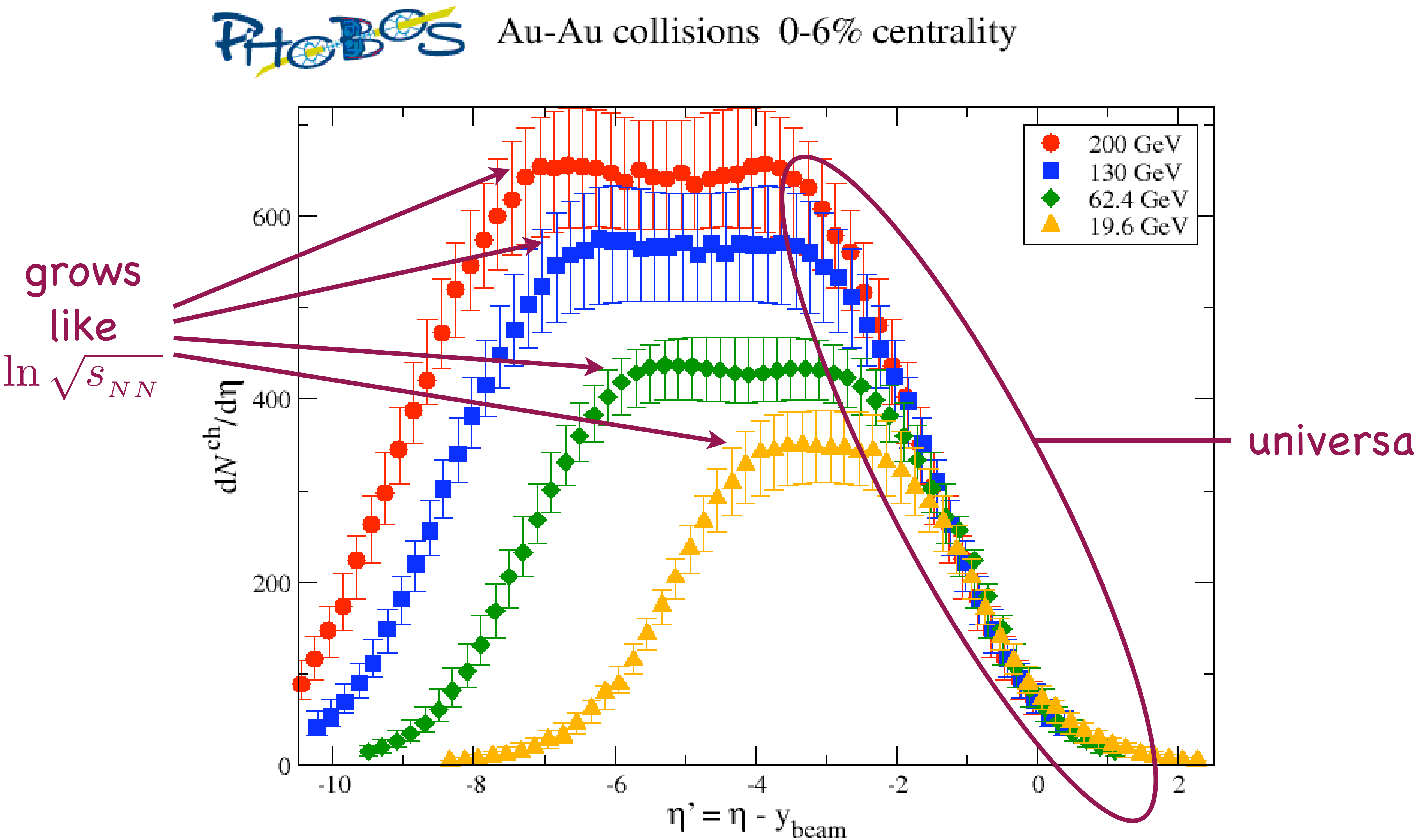


Charged hadron multiplicity

Au-Au collisions 0-6% centrality



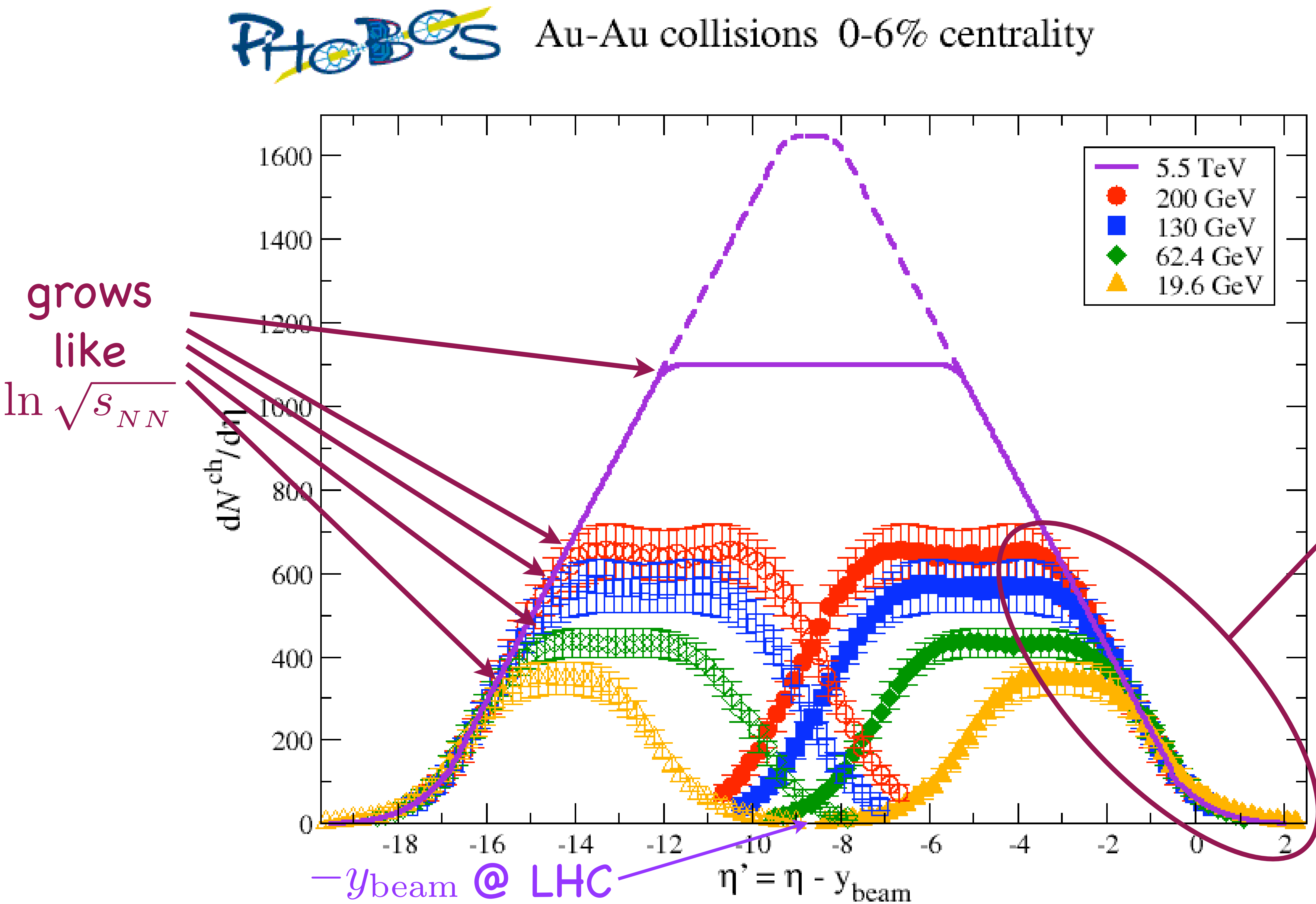
Charged hadron multiplicity



We boost everything to the rest frame of one nucleus ("projectile")

☞ "limiting fragmentation"

Charged hadron multiplicity



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☞ "limiting fragmentation"

Busza 2004; N.B. & Wiedemann 2007

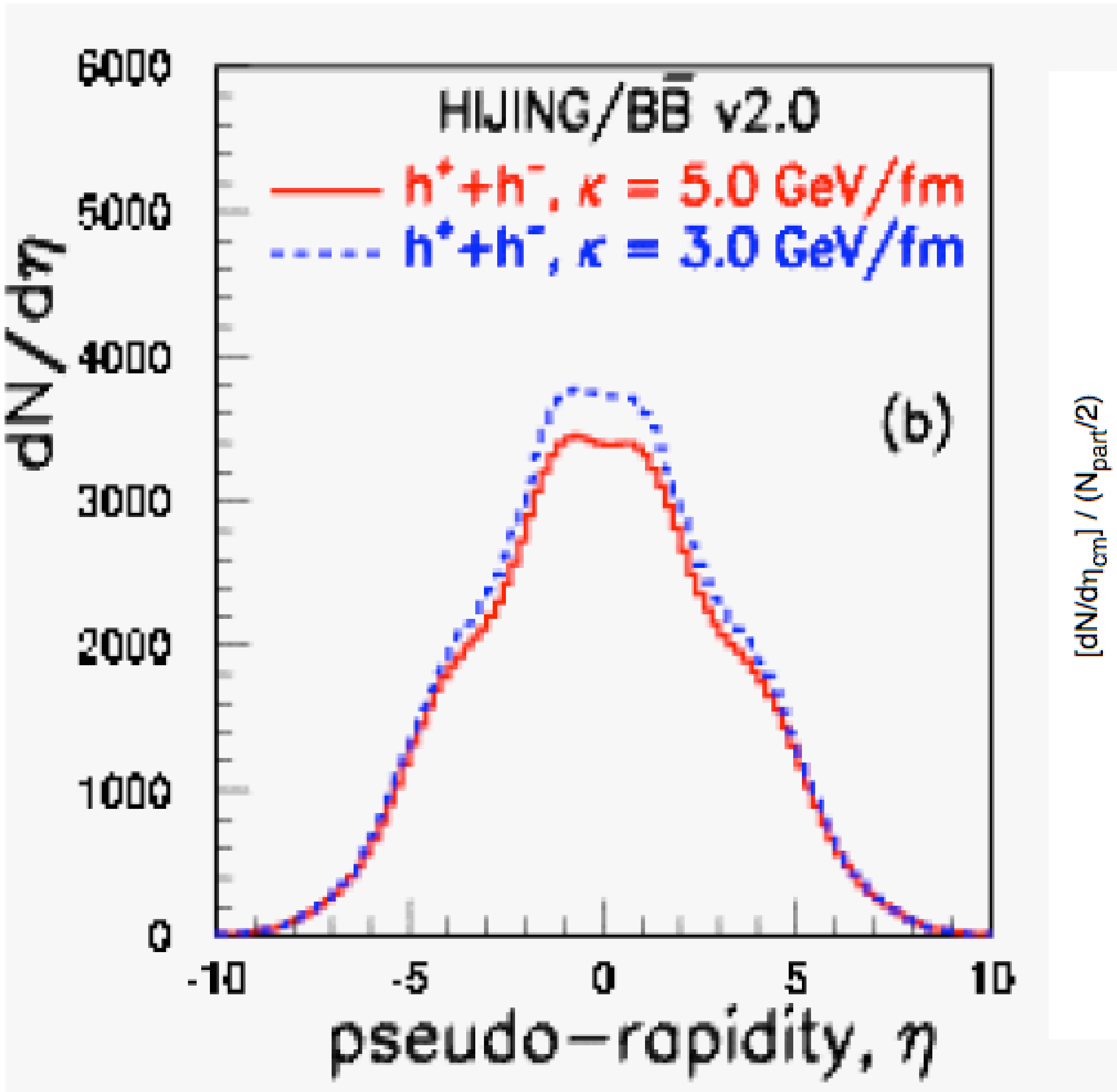
Charged hadron multiplicity

The naive extrapolation of RHIC data yields $\frac{dN^{ch}}{d\eta} \approx 1100$ at $\eta = 0$

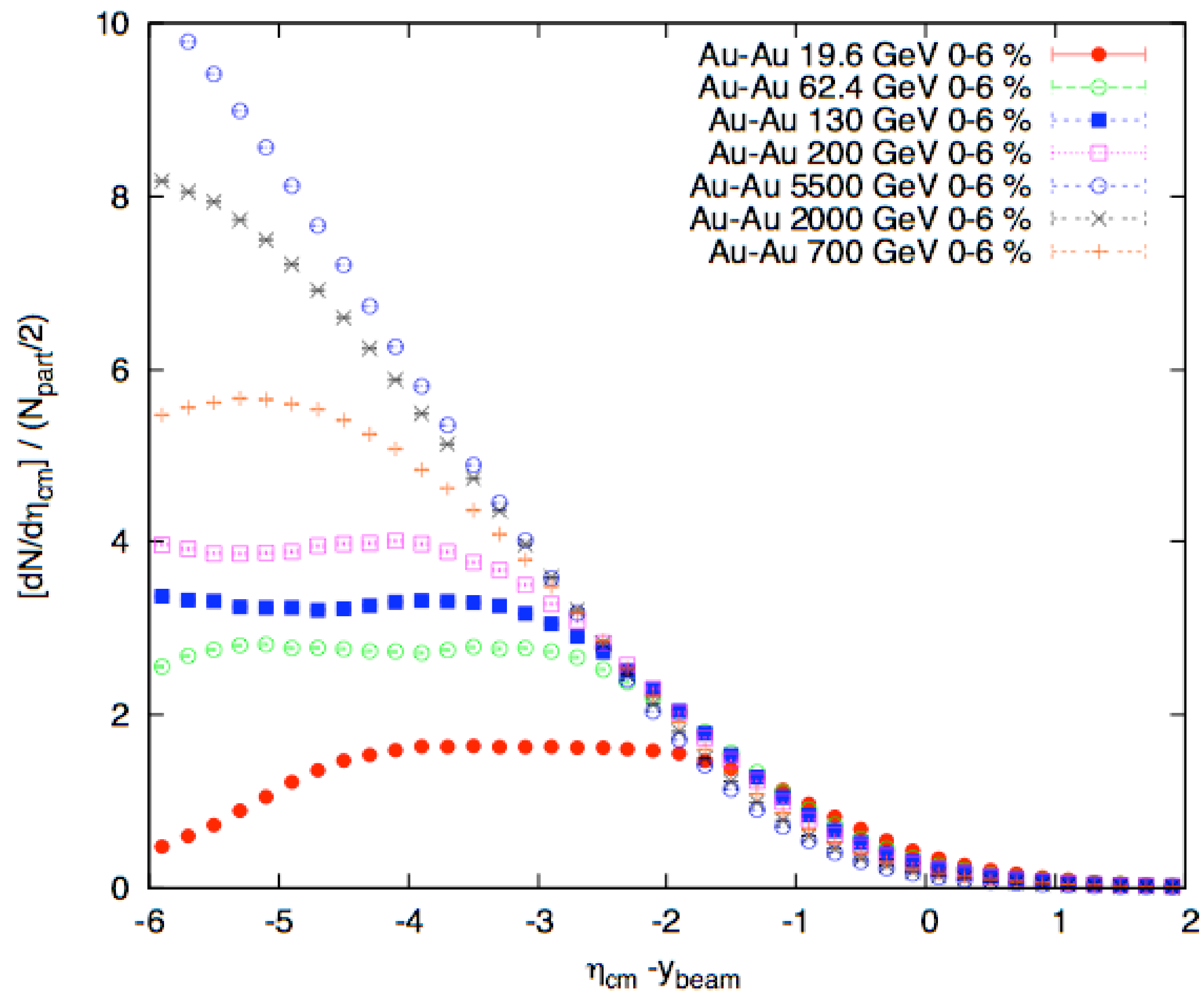
☞ $\ln\sqrt{s_{NN}}$ -increase, in opposition to conventional power-law rise

- Hijing + baryon junctions: 3500
- EPOS (multiple scattering): 2500
- pQCD minijets + saturation (EKRT) of produced gluons: 2570
- AMPT (Hijing+ZPC): ≈2500
- Percolating strings:
  - DMPJET III: ≈1900
  - Pajares et al.: 1500–1600
- 2-component + shadowing: ≈1700
- "Geometric scaling" (Armesto, Salgado, Wiedemann): 1700–1900
- Gluon saturation (Kharzeev, Levin, Nardi 2000–05): 1800–2100
- B-K eq.+ running coupling (Albacete, Kovchegov): ≈1400
- "CGC" (Gelis, Stasto, Venugopalan): 1000–1400
- ALCOR (quark-antiquark plasma + recombination): 1250–1830 = $\frac{dN^{ch}}{dy}$

Charged hadron multiplicity

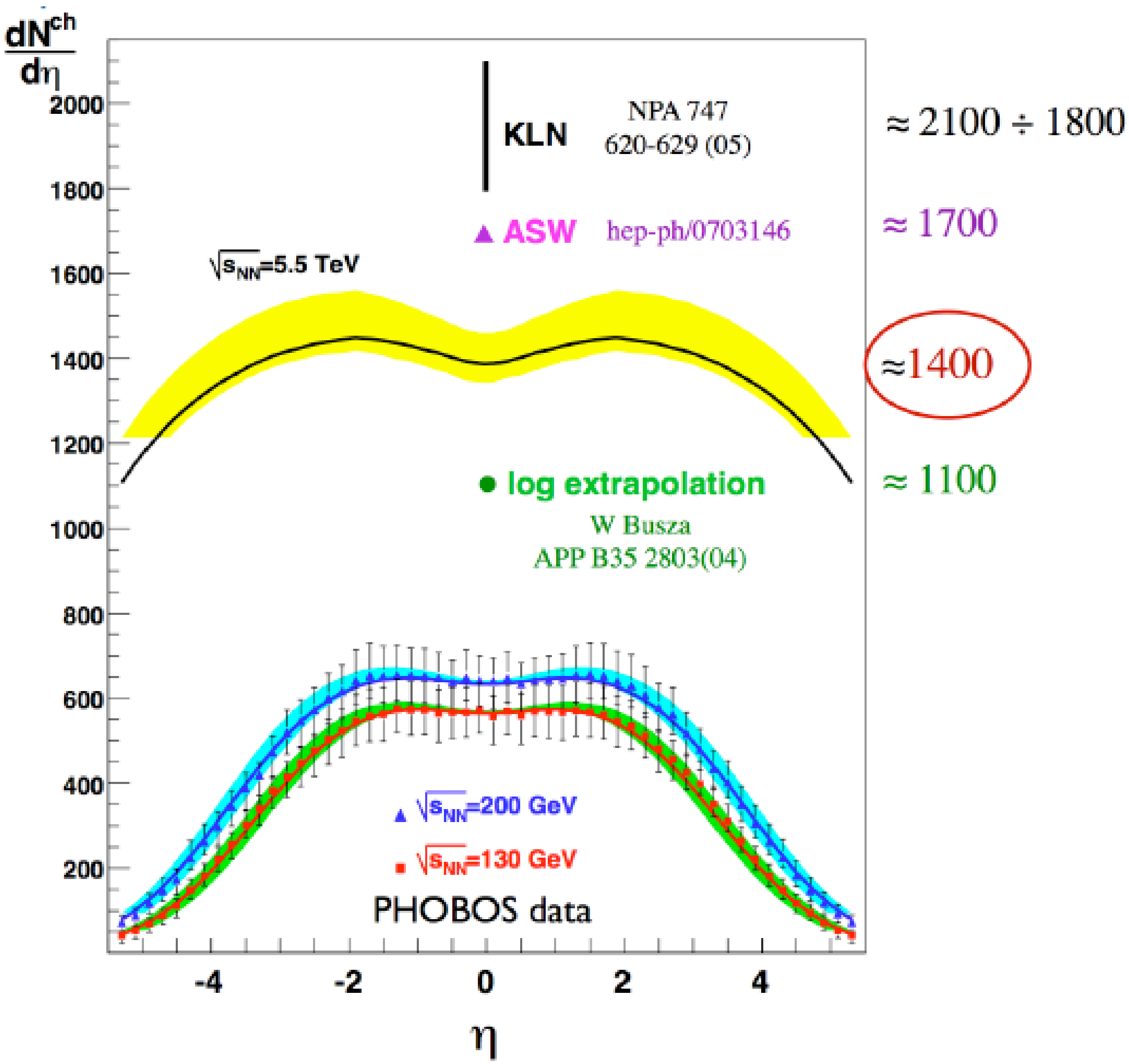


modified Hijing: Topor Pop et al.

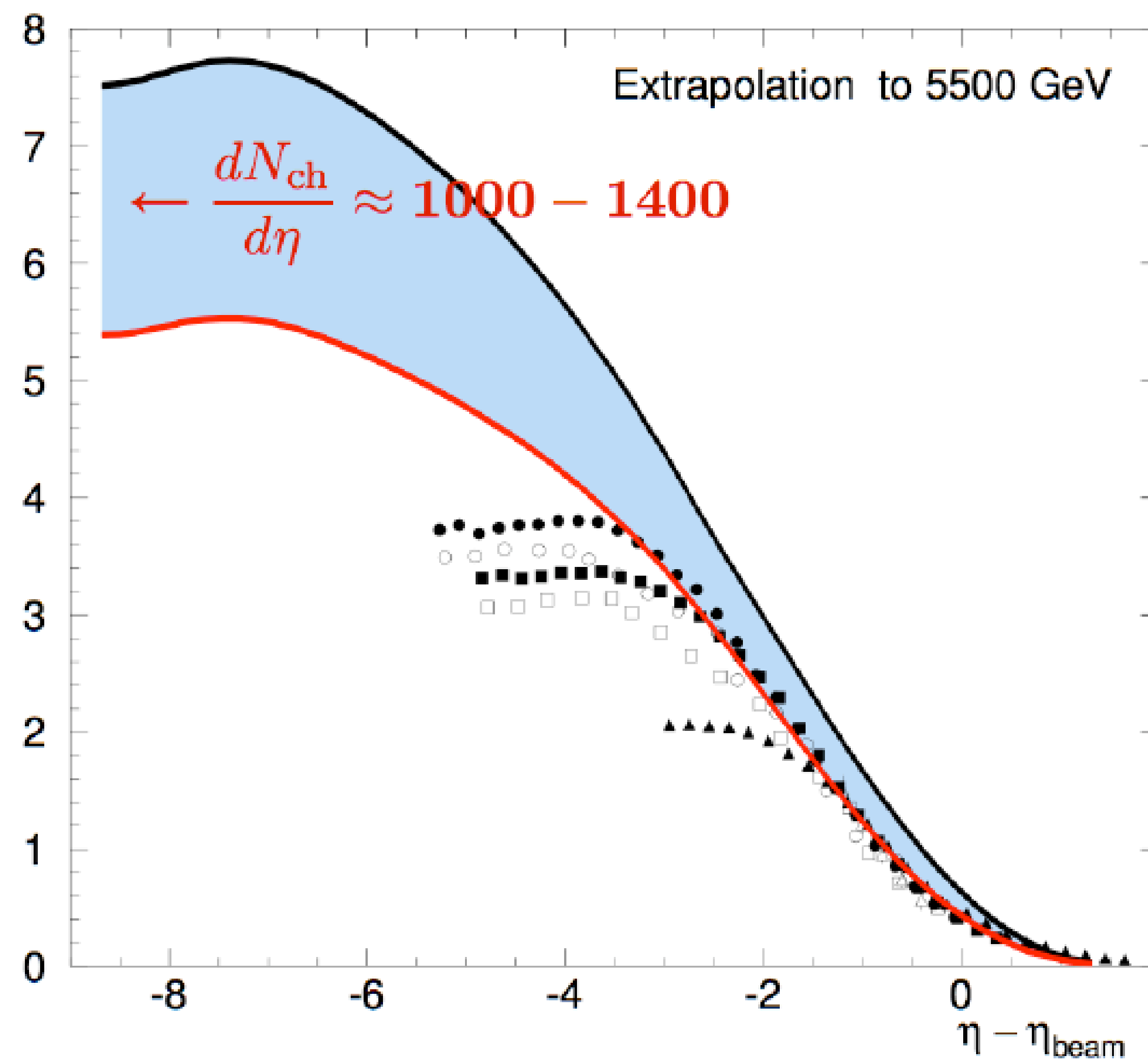


DPMJET III: Bopp, Engel, Ranft, Roesler

Charged hadron multiplicity



B-K+running coupling: Albacete



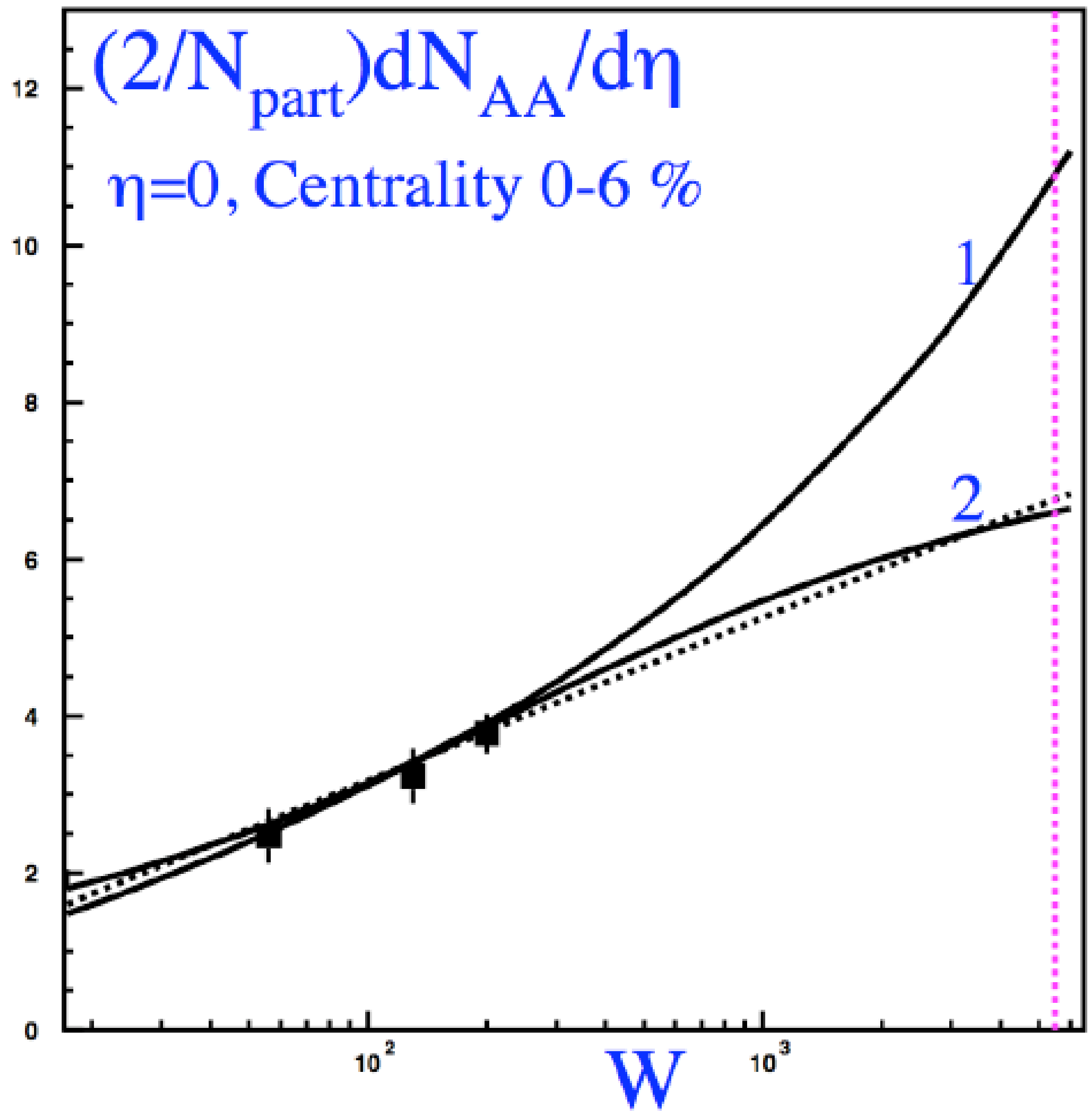
CGC: Gelis, Stasto, Venugopalan

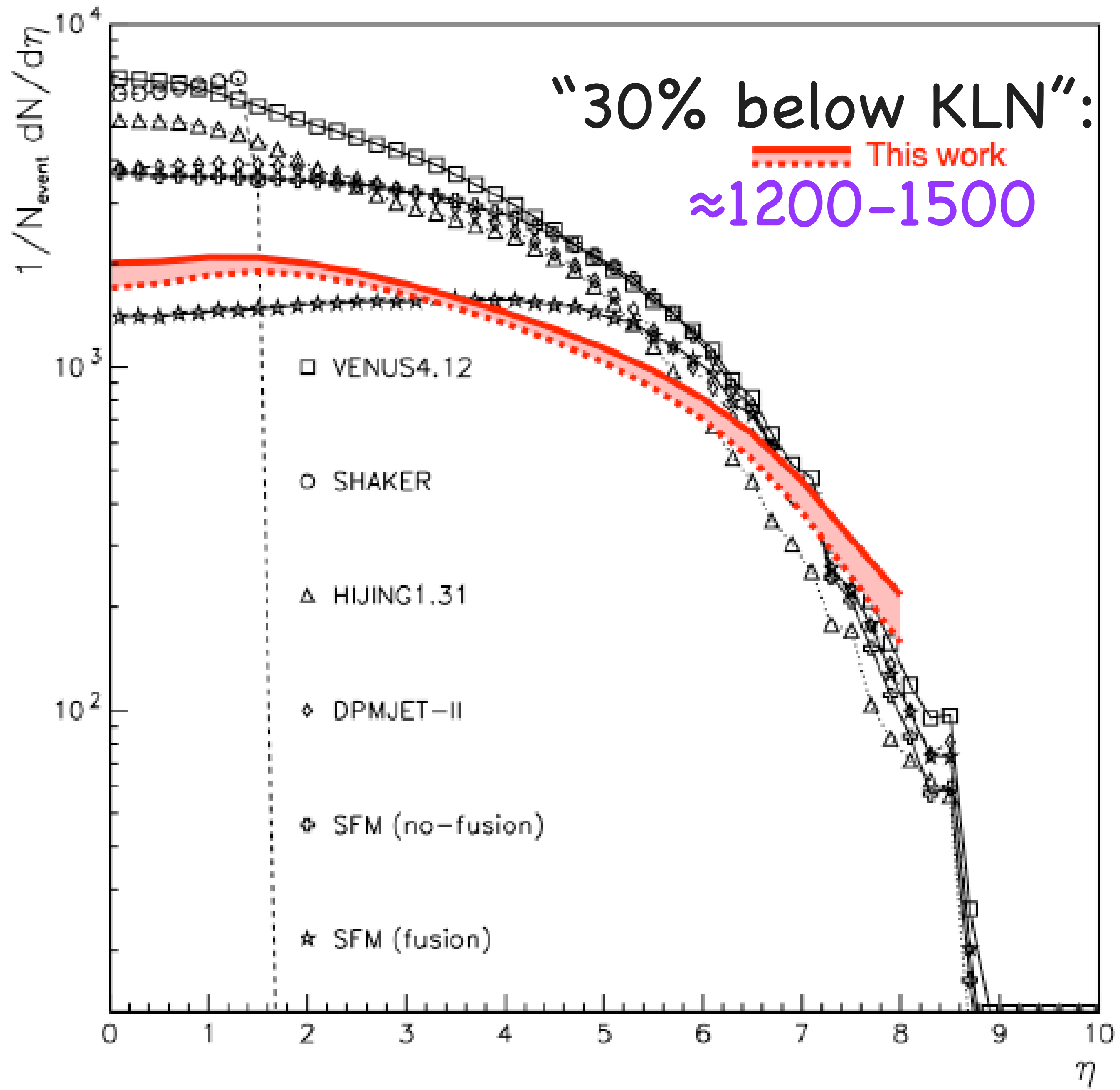
Charged hadron multiplicity

Saturating the saturation scale Q_s^2?

$$\frac{4}{\alpha_S \pi} \frac{d\,Q_s^2(Y)}{dY} = Q_s^2(Y) - B\,Q_s^4(Y)$$

Kharzeev, Levin





Heavy ion collisions at the LHC

Then our experimental friends will get to know their detectors better and provide us with

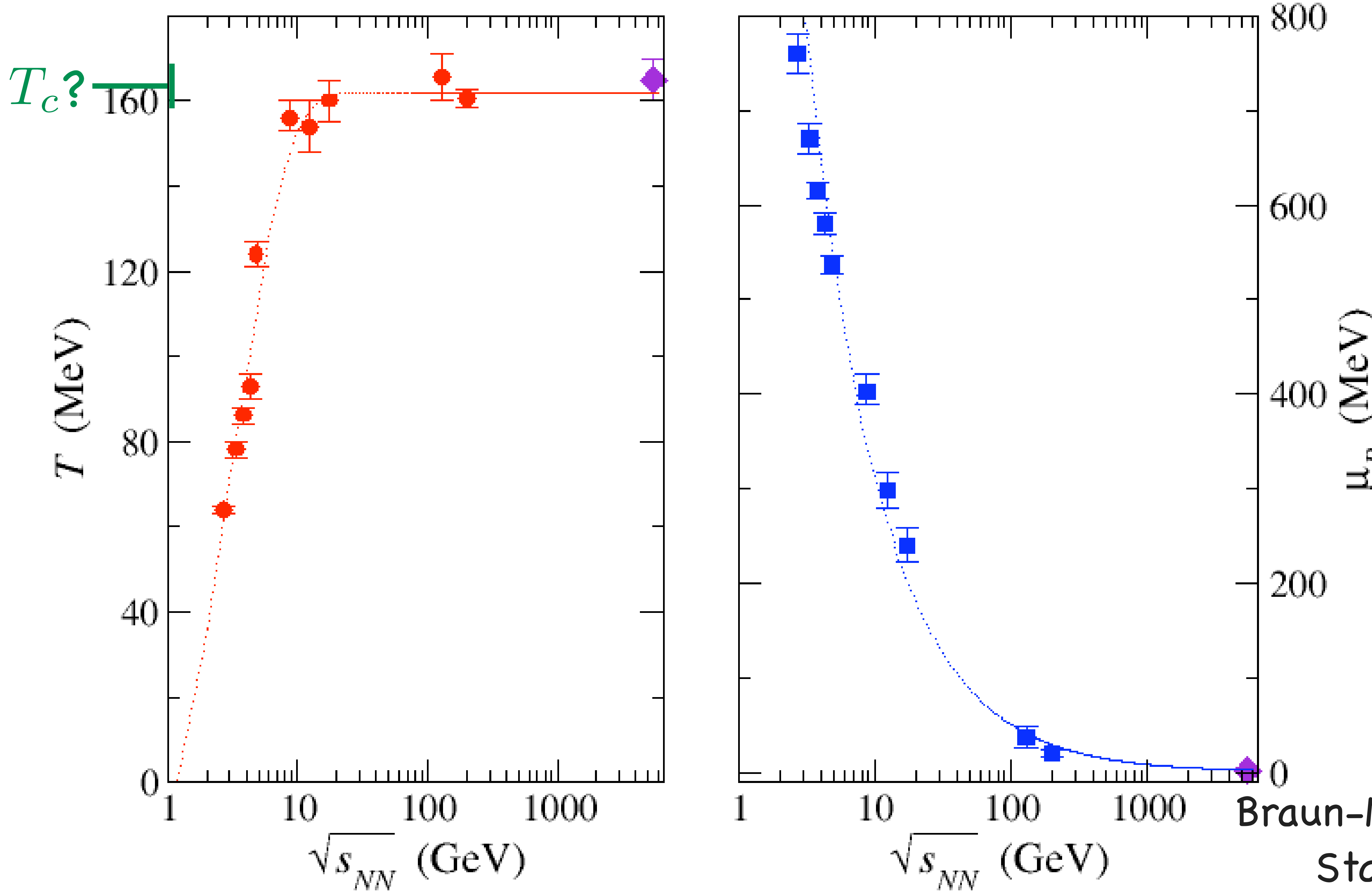
the p_T-spectra of charged particles

(not much to say... the spectra will be stiffer — "more radial flow" — than at RHIC)

the relative abundances ("chemistry") of identified hadrons

Hadrochemistry

From SIS@GSI energies onwards, the relative abundances of hadrons are well described by a statistical distribution: 2 parameters T, μ_B



Andronic, Braun-Munzinger, Stachel 2006

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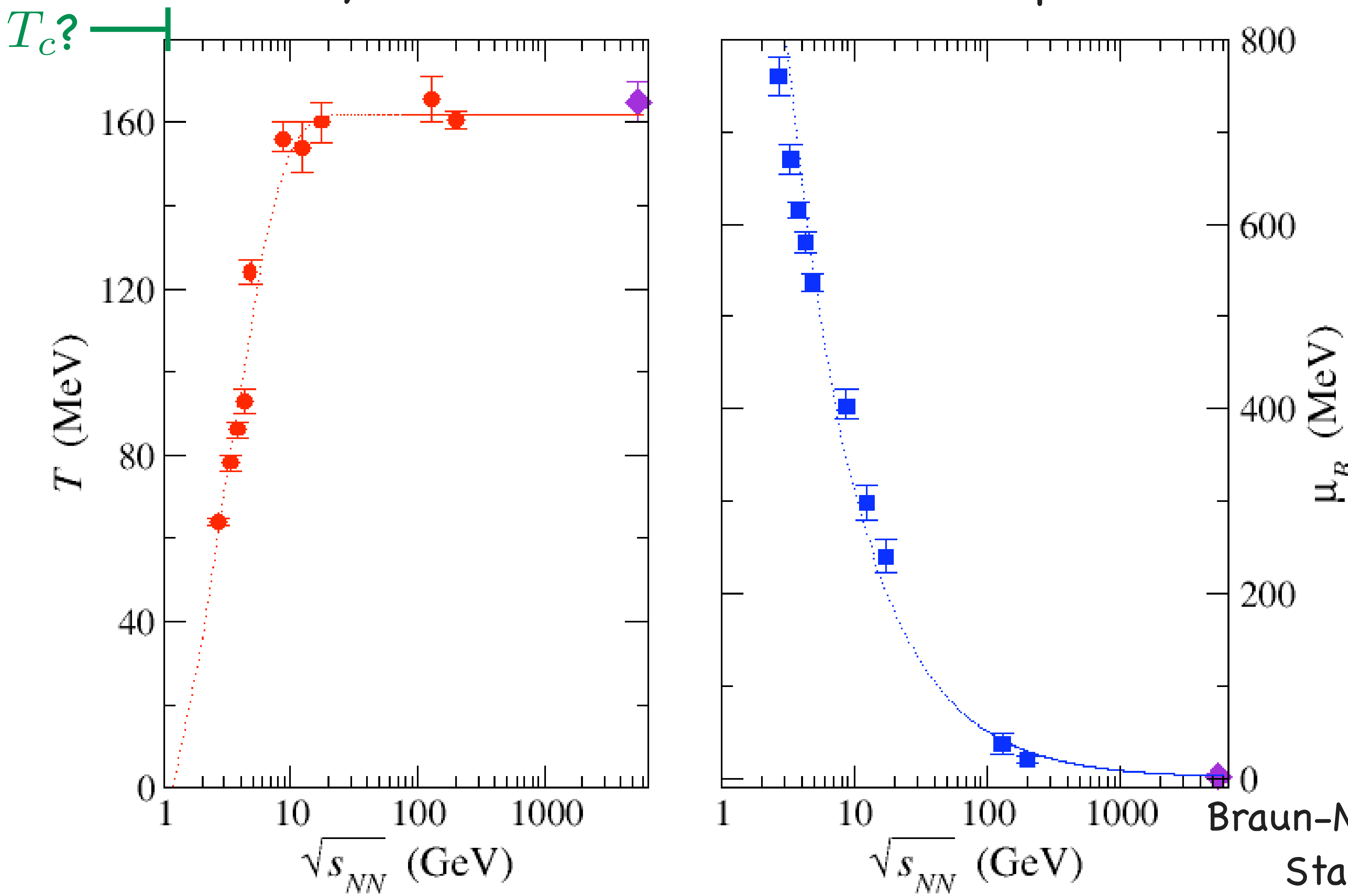


Andronic, Braun-Munzinger, Stachel 2006

What with the relative yields of D- & B-mesons? (canonical suppression?)

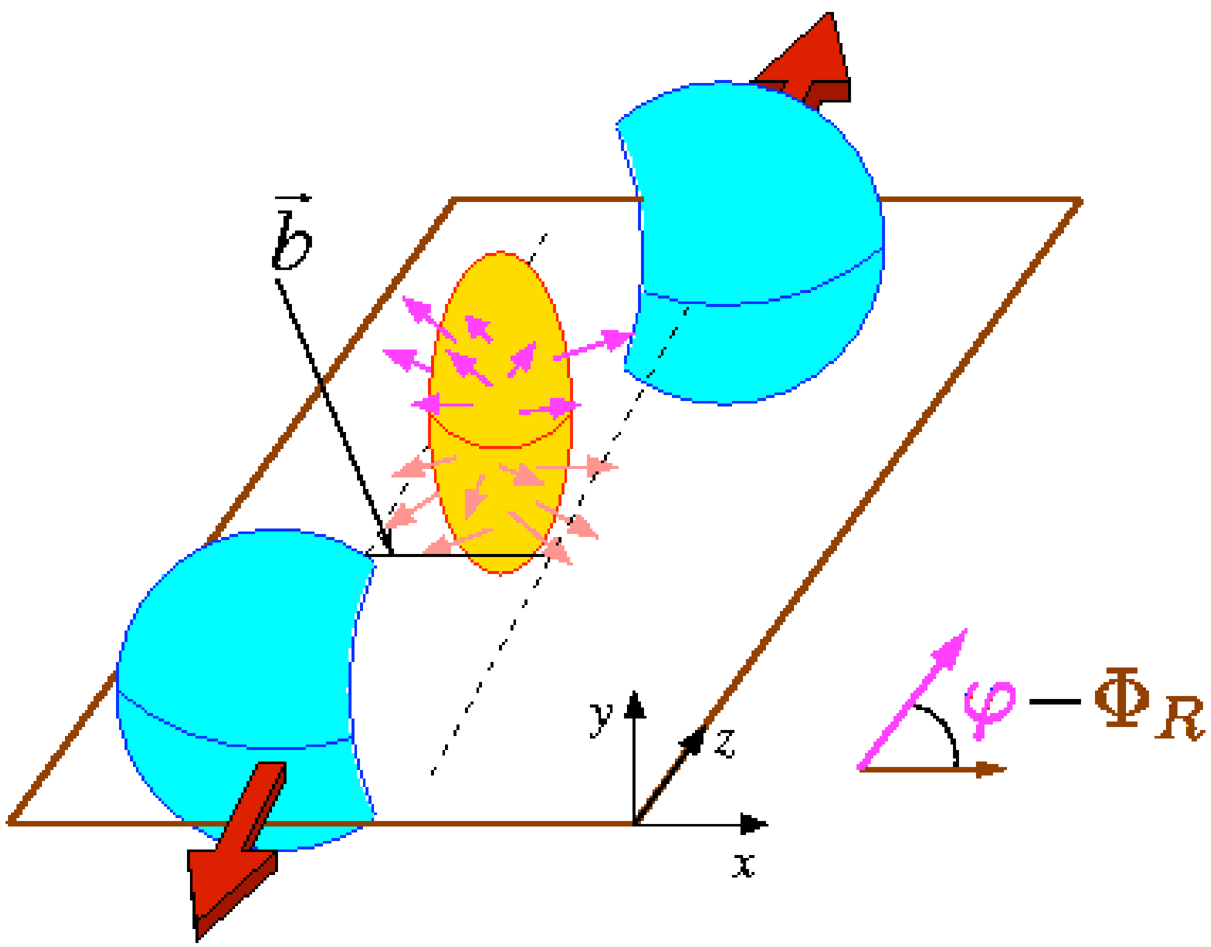
Heavy ion collisions at the LHC

The data from the first year (= month) of Pb-Pb collisions will be sufficient to obtain measurements of

the anisotropy in particle emission
"anisotropic collective flow"

Anisotropic (collective) flow

Consider a non-central collision:



anisotropy of the source (in the plane transverse to the beam)

⇒ anisotropic emission of particles

"anisotropic collective flow"

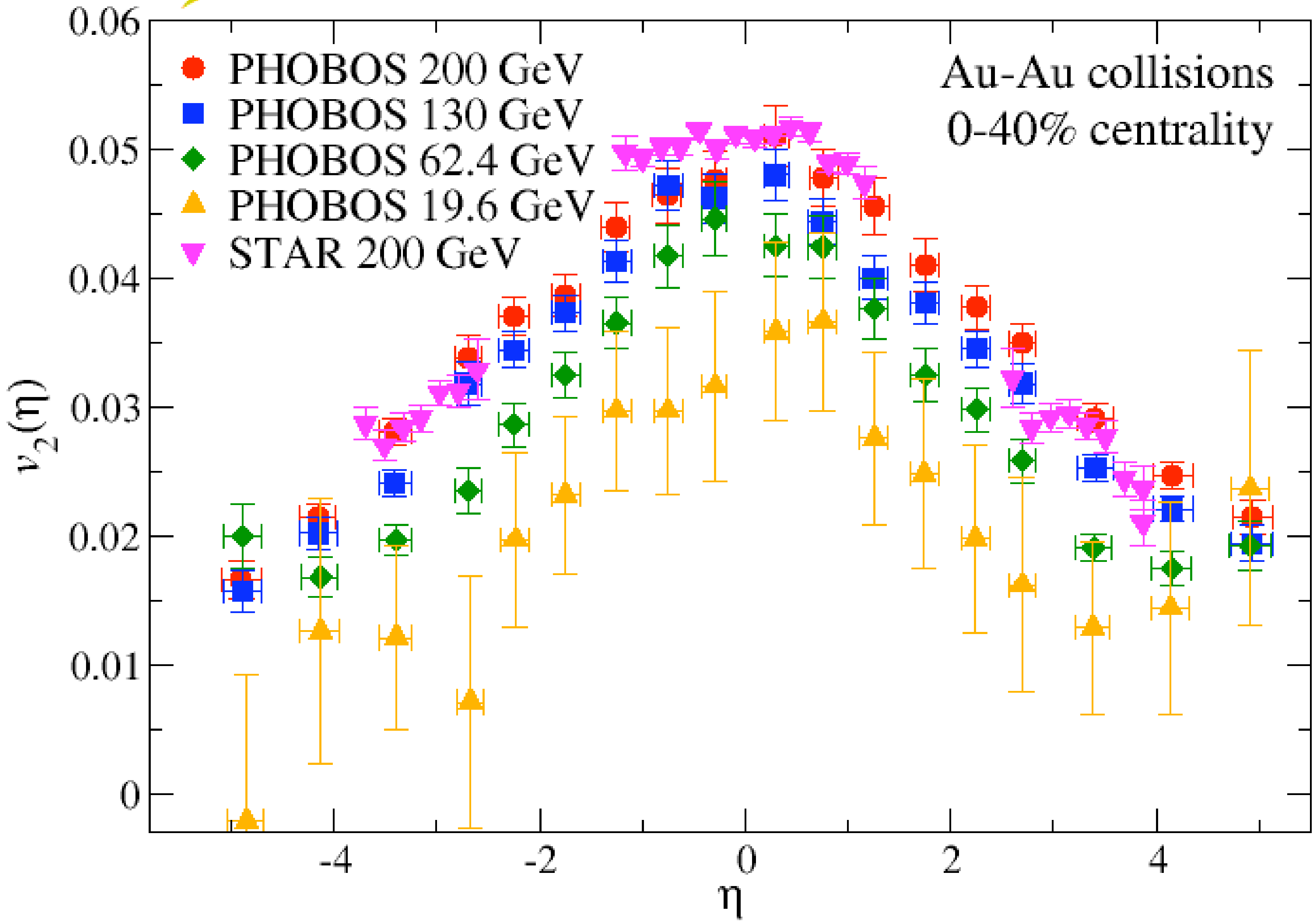
$$E\frac{\mathrm{d}N}{\mathrm{d}^3\mathbf{p}} \propto \frac{\mathrm{d}N}{p_T\,\mathrm{d}p_T\,\mathrm{d}y}\left[1 + 2\,v_1\cos\left(\varphi - \Phi_R\right) + 2\,v_2\cos 2(\varphi - \Phi_R) + \cdots\right]$$

More particles along the impact parameter ($\varphi - \Phi_R = 0$ or 180°) than perpendicular to it ☞ "elliptic flow" $v_2 \equiv \langle\cos 2(\varphi - \Phi_R)\rangle > 0$.

average over particles

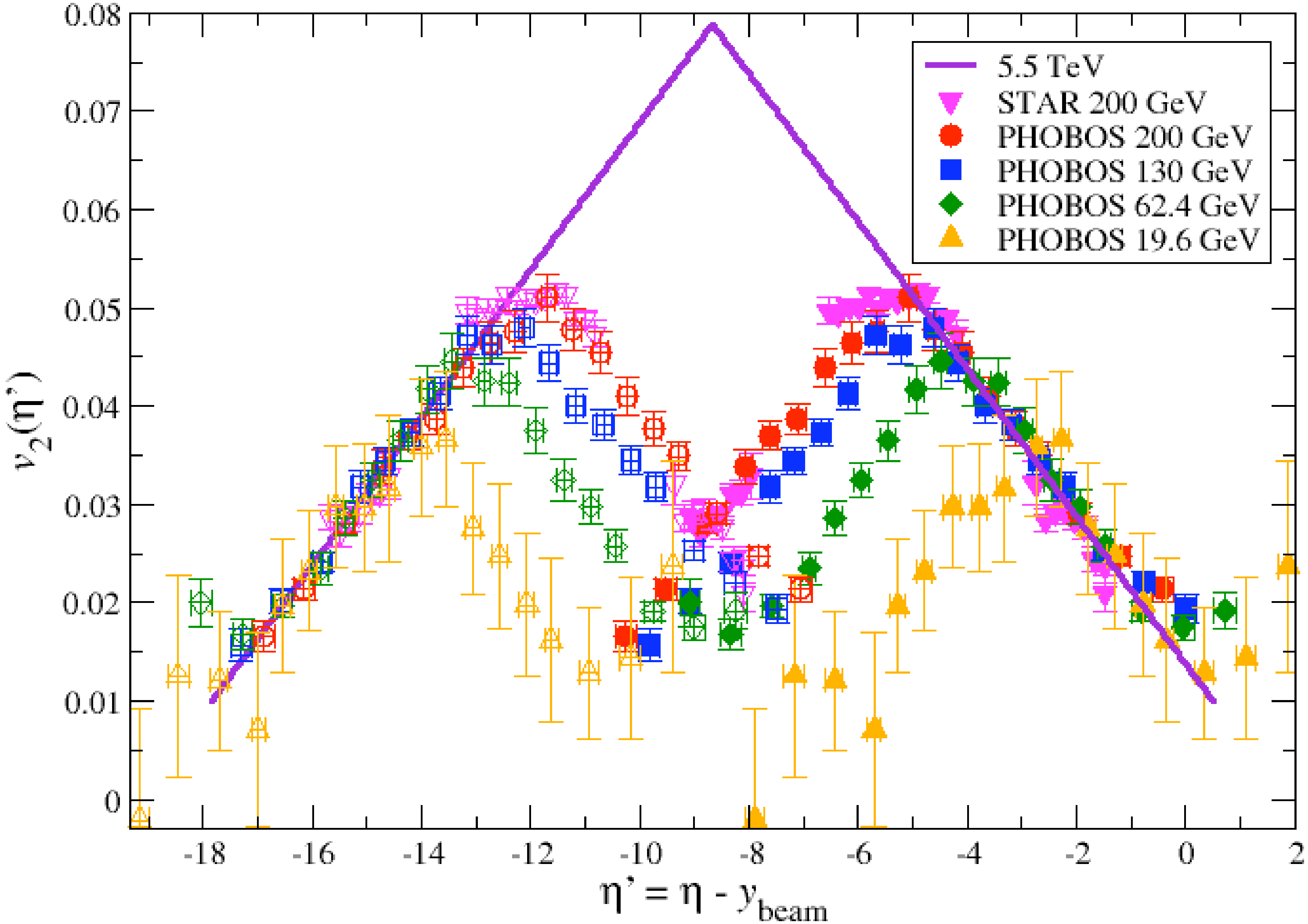
Anisotropic (collective) flow

Au-Au collisions, 0-40% centrality



Anisotropic (collective) flow

STAR PHOBOS Au-Au collisions, 0-40% centrality



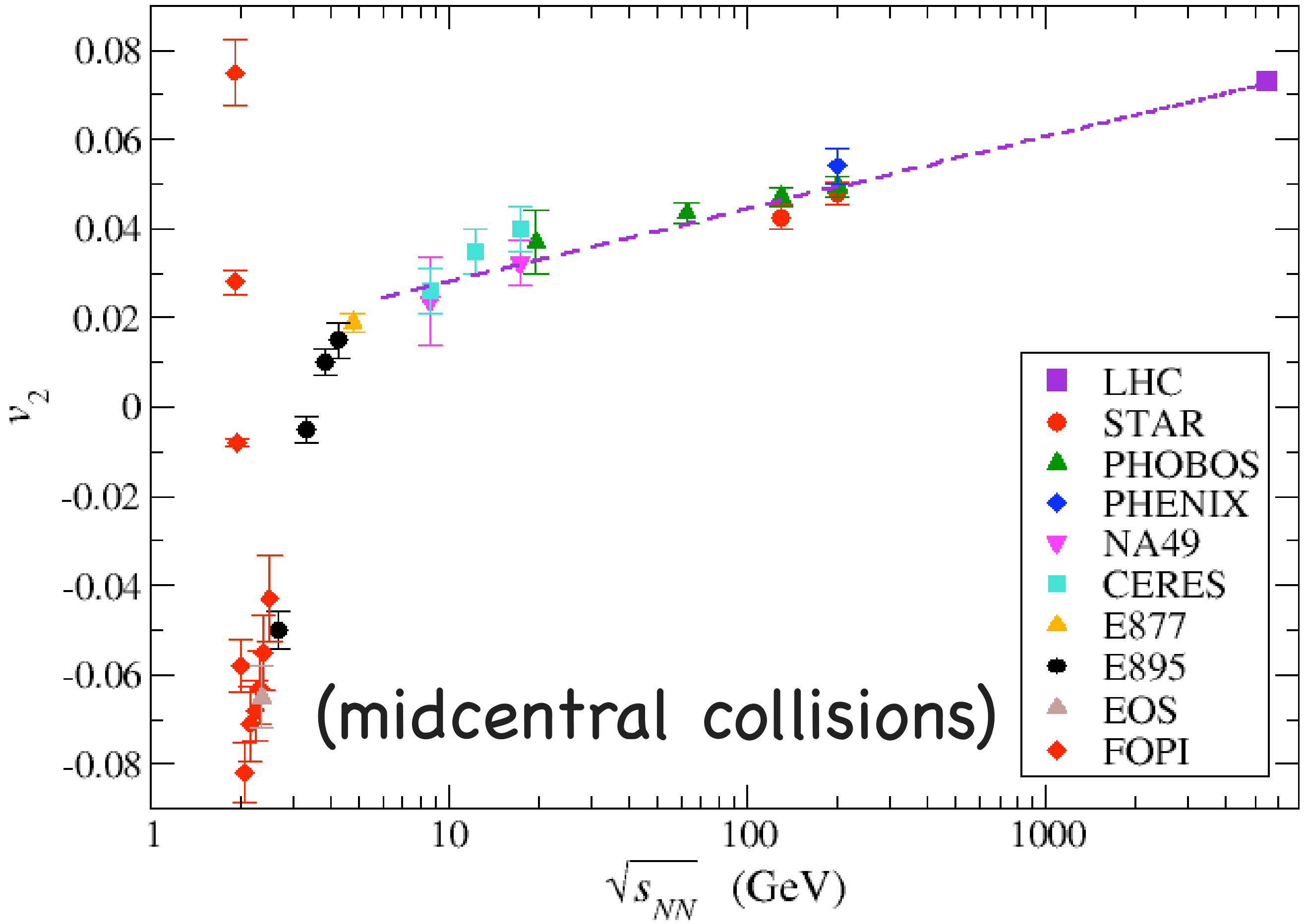
☞ use "limiting fragmentation" again

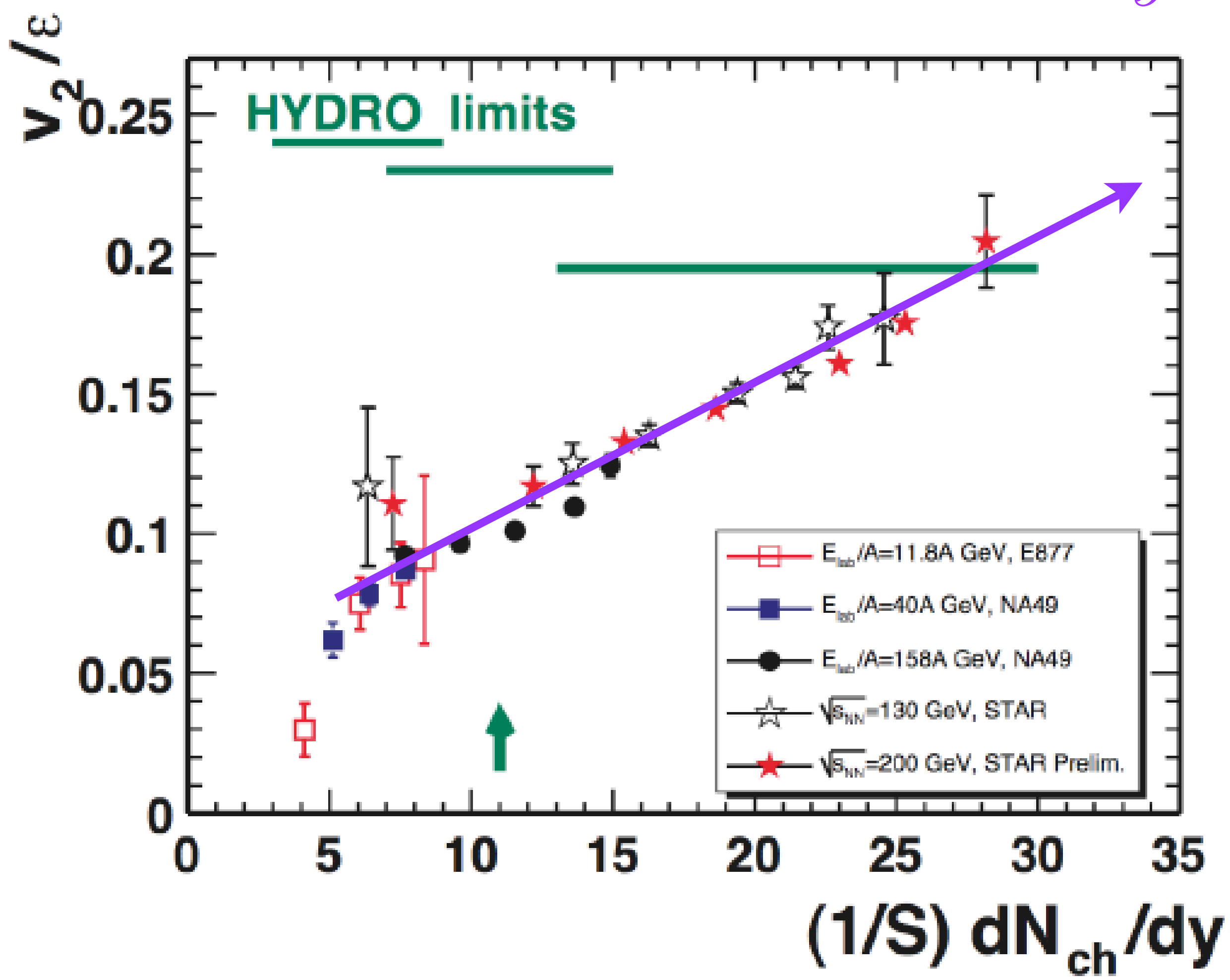
N.B. & Wiedemann 2007

Anisotropic (collective) flow

Alternative views: v_2 increases linearly with $\ln\sqrt{s_{NN}}$;

v_2 / ϵ (eccentricity) increases linearly with $\dfrac{1}{S}\dfrac{\mathrm{d}N^{\mathrm{ch}}}{\mathrm{d}y}$





Anisotropic (collective) flow

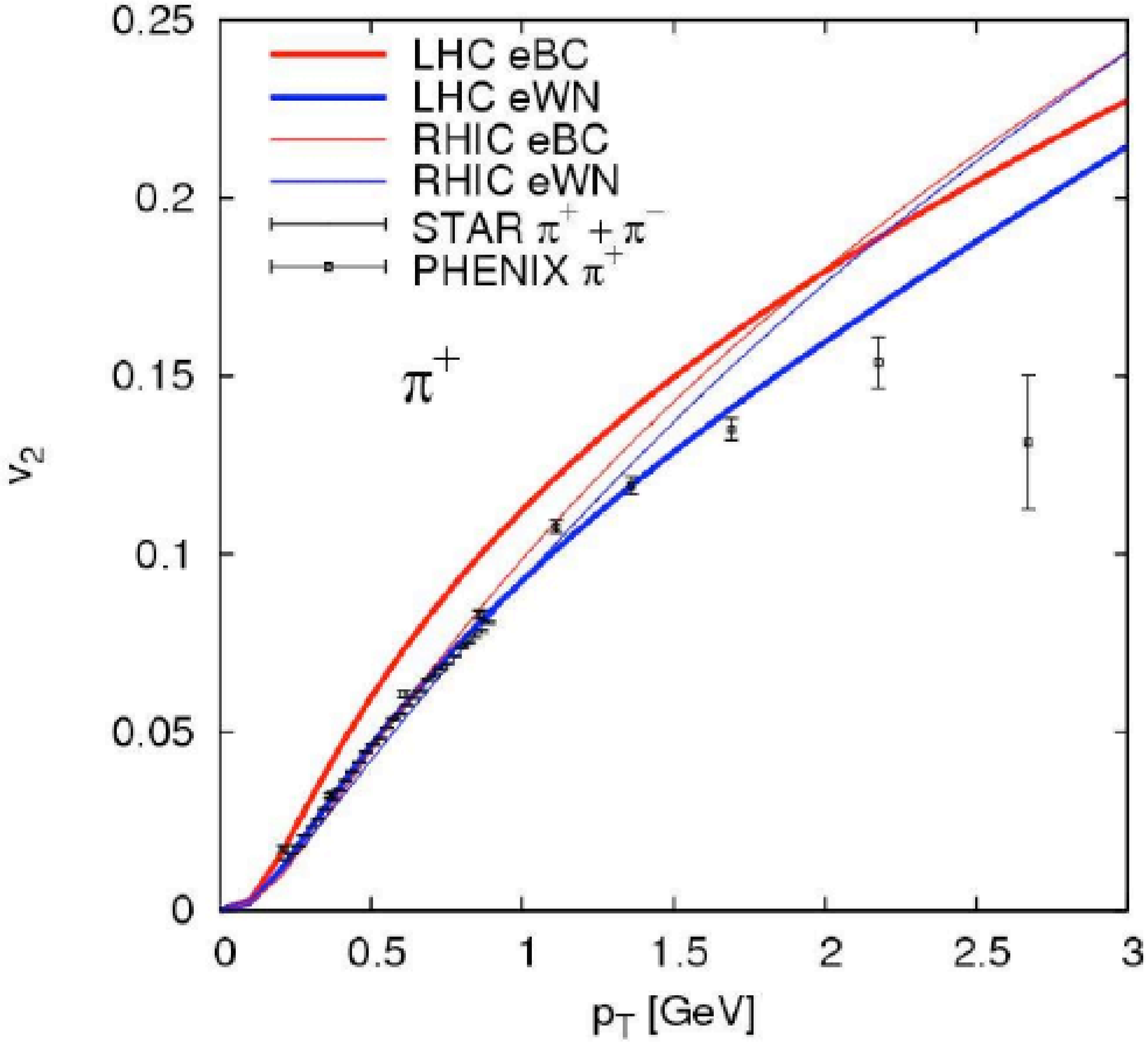
Naive predictions: v_2 increases linearly with $\ln\sqrt{s_{NN}}$;
v_2 / ϵ (eccentricity) increases linearly with $\frac{1}{S}\frac{\mathrm{d}N^{\mathrm{ch}}}{\mathrm{d}y}$

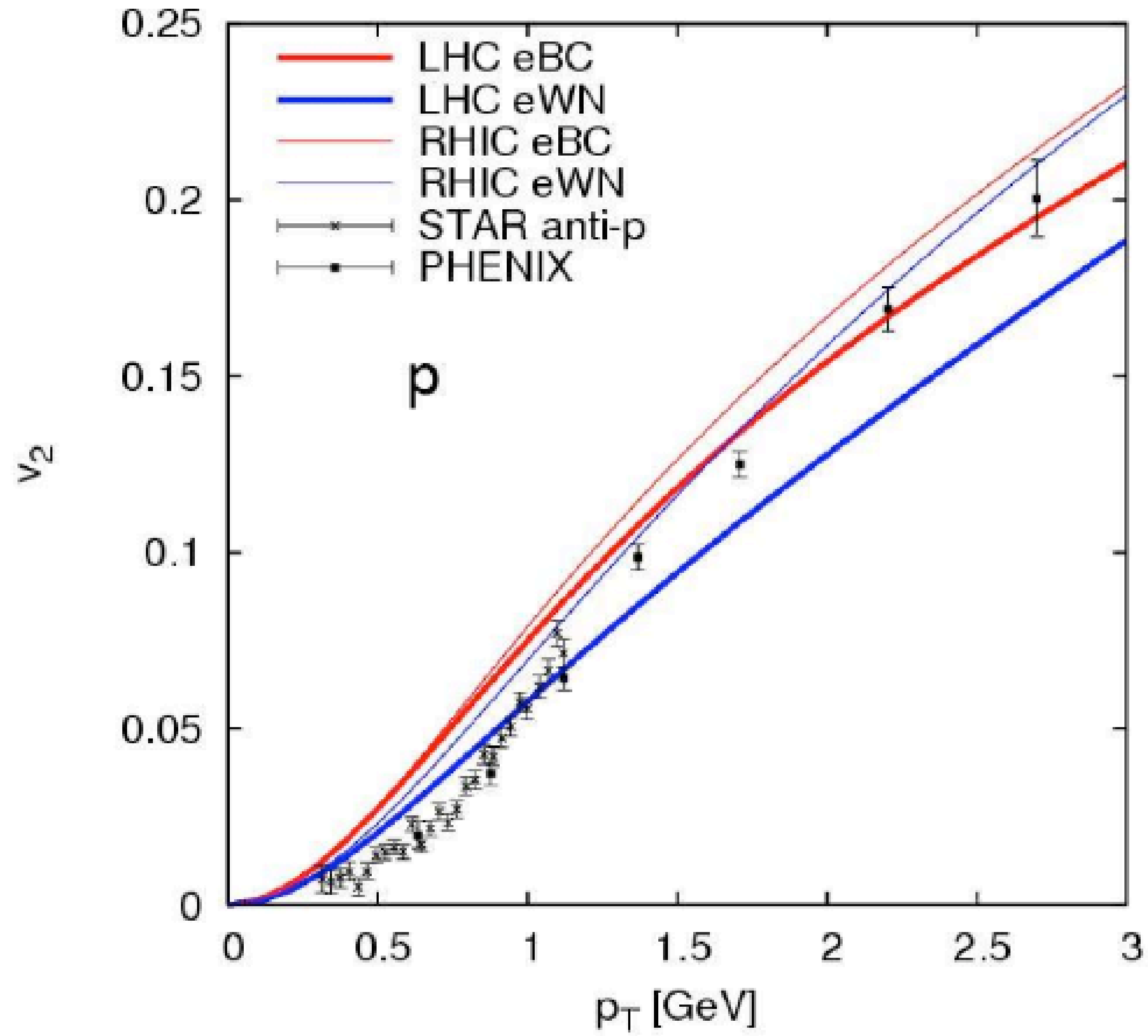
- Transport model I (Molnár): $v_2(p_T)$ increases from RHIC to LHC

$$v_2^{LHC,5500}(p_T) \approx v_2^{RHIC,200}(p_T \cdot k) \qquad k = \frac{Q_s^{RHIC}}{Q_s^{LHC}} \approx 1.5$$

- Transport model II (Ko): $v_2(p_T)$ increases for $\pi^{\pm}$, decreases for p
- Transport model III (Ollitrault): v_2 / ϵ increases; still 12-20% the hydro limit in central Pb-Pb @ LHC
- Hydro I (Bluhm): $v_2(p_T)$ decreases
- Hydro II (Eskola, Niemi, Ruuskanen): $v_2(p_T)$ increases for pions, decreases for protons
- Hydro III (Heinz): $v_2(p_T)$ decreases for pions; yet the average v_2 increases, by at most 20% (less then $\ln\sqrt{s_{NN}}$ -linear rise)

Anisotropic (collective) flow





Eskola, Niemi, Ruuskanen

Heavy ion collisions at the LHC

The next, much expected (due to the increased available phase space) measurements will be that of

spectra at high transverse momentum

(remember, however, that we shall miss a proton-proton reference at the same energy $\sqrt{s_{NN}}$ = 5.5 TeV)

High-p_T hadron spectra

Conveniently characterized by the "nuclear modification factor"

$$R^h_{AB} \equiv \frac{\mathrm{d}N^{AB\to h}}{\mathrm{d}\,\mathbf{p}_T\mathrm{d}y} \bigg/ \left(\langle N^{AB}_{\text{coll}} \rangle \frac{\mathrm{d}N^{pp\to h}}{\mathrm{d}\mathbf{p}_T\,\mathrm{d}y} \right)$$

average number of inelastic nucleon-nucleon collisions

High-p_T hadron spectra

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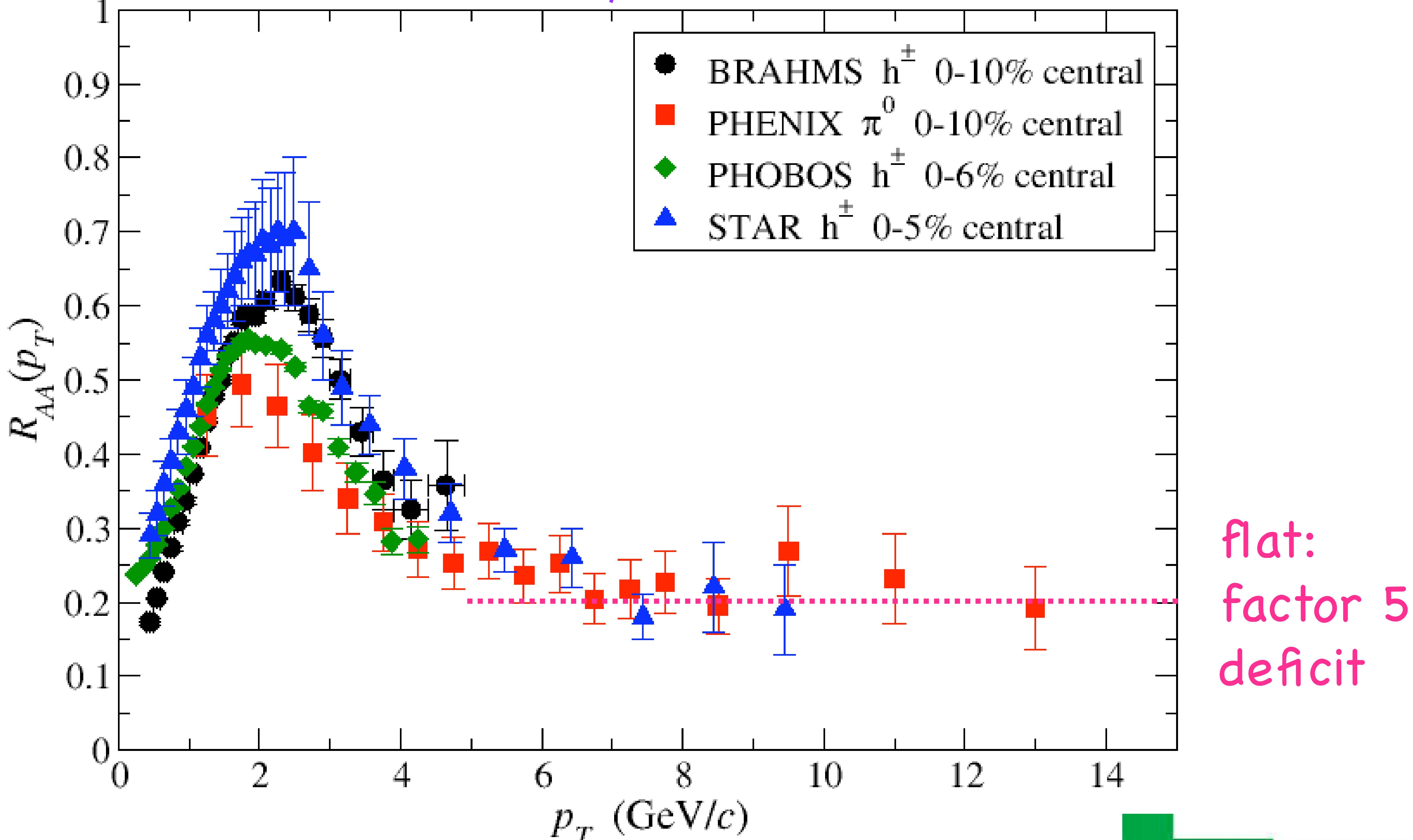

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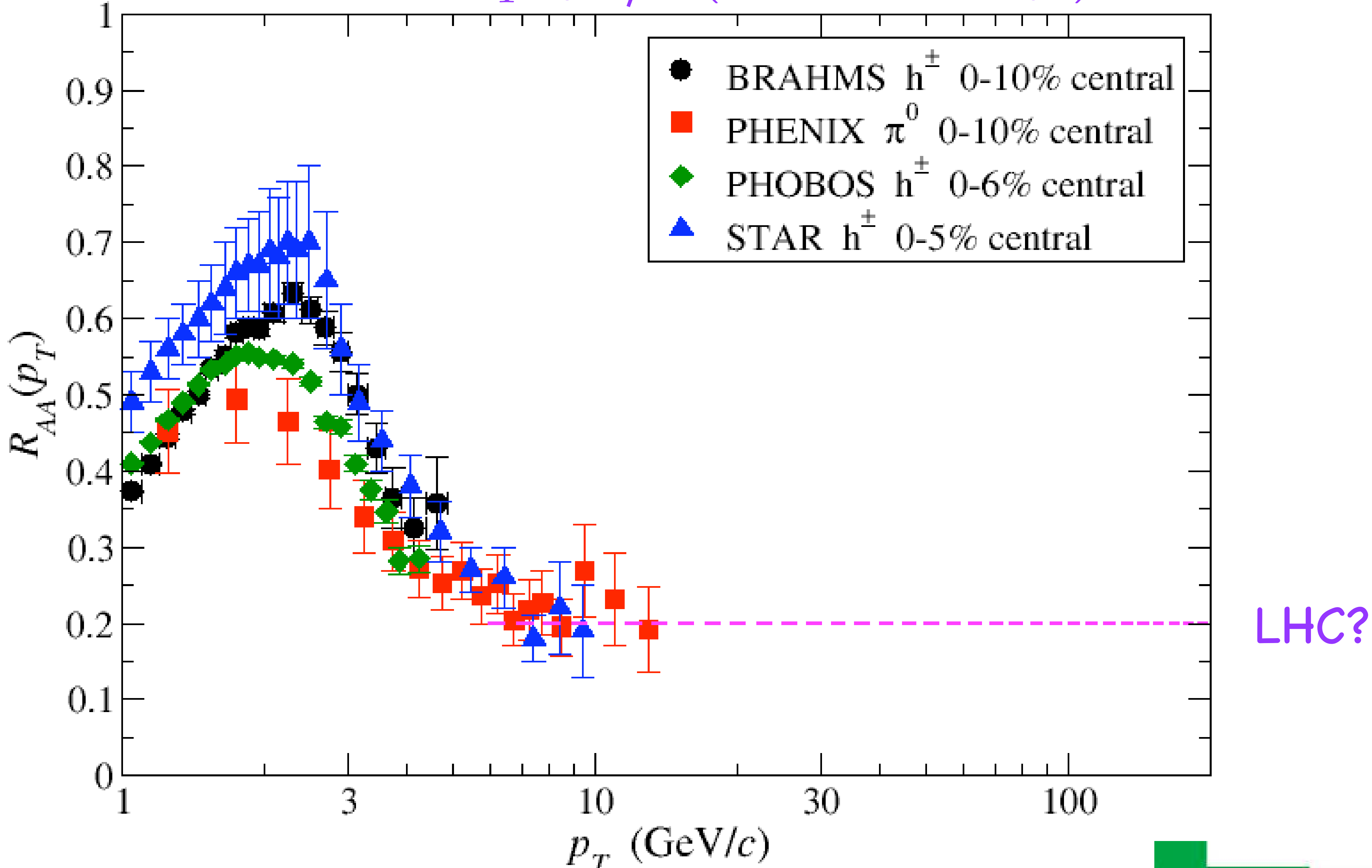
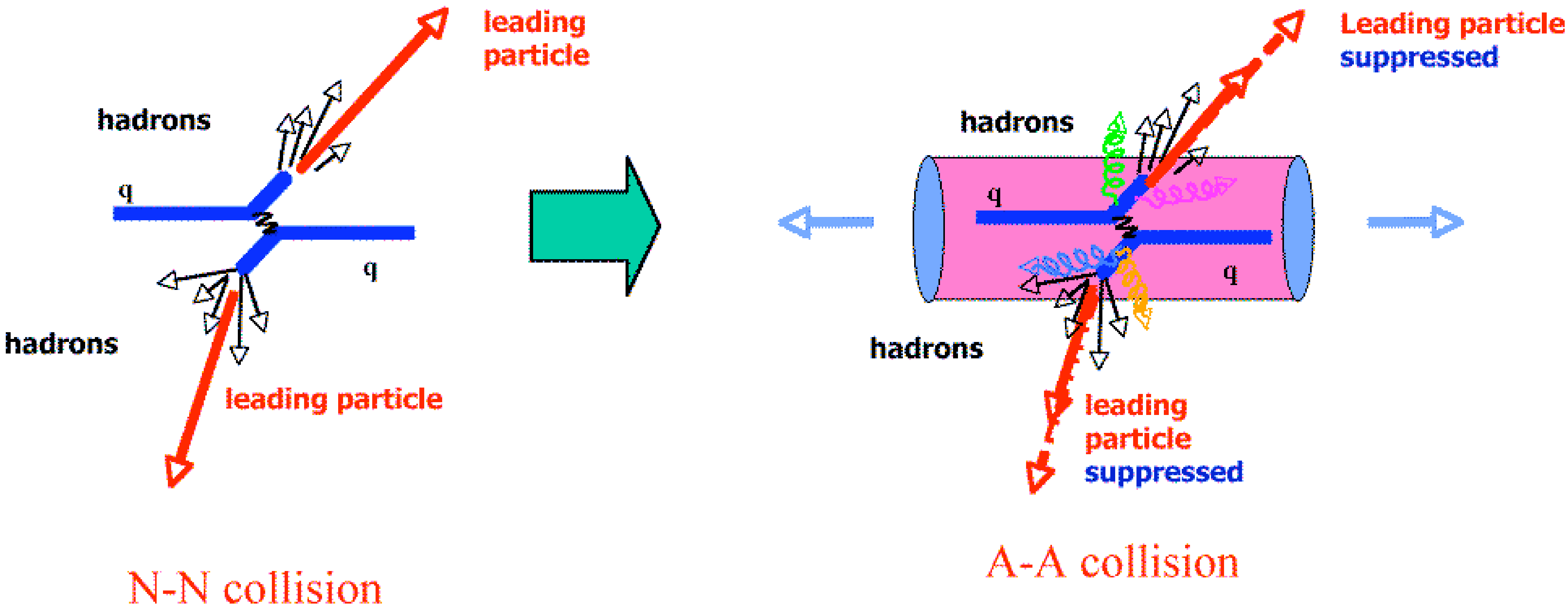


High-p_T hadron spectra

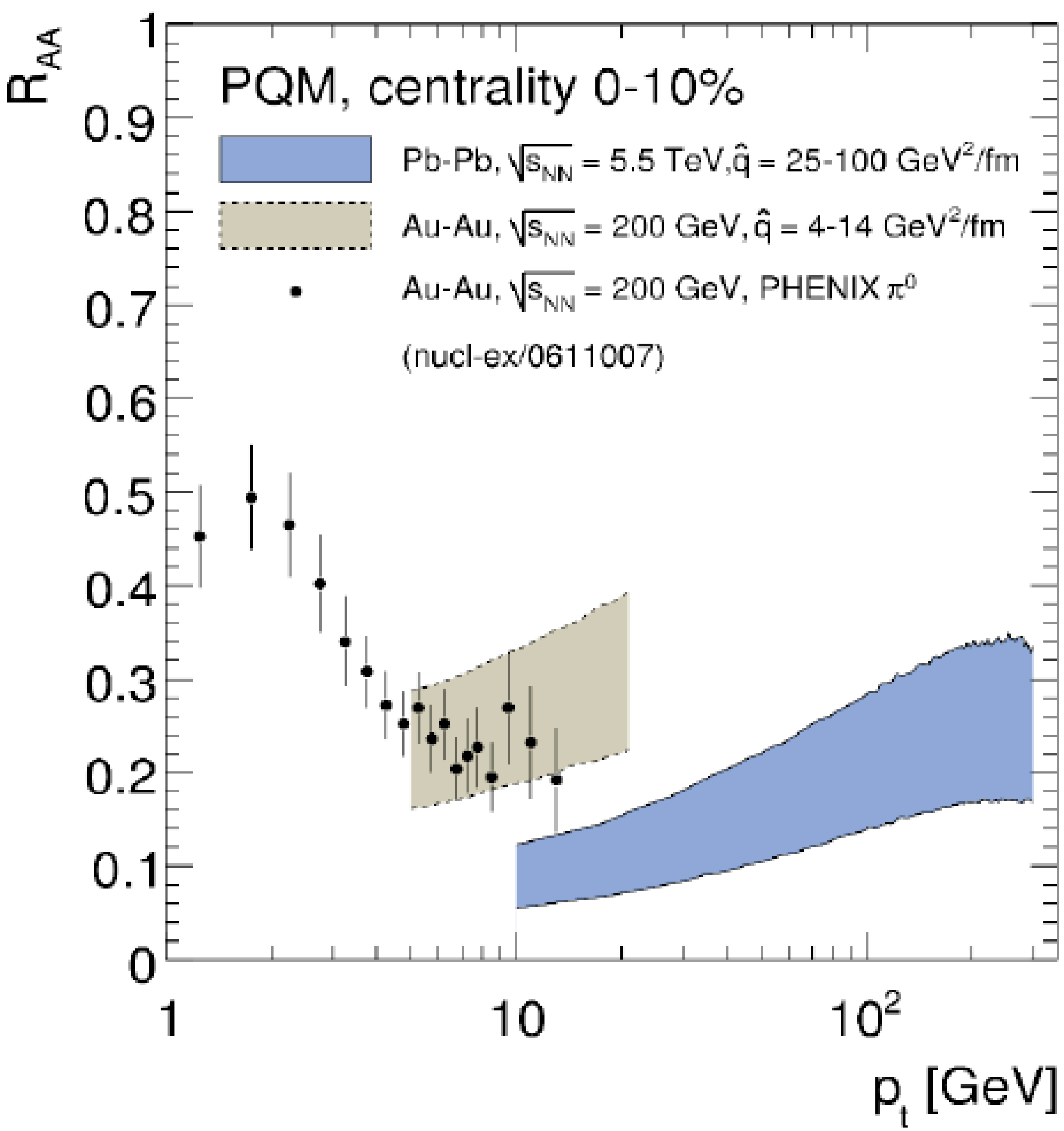
The picture: while traversing the hot & dense medium, a fast parton loses energy (through collisions & radiation): “jet quenching”



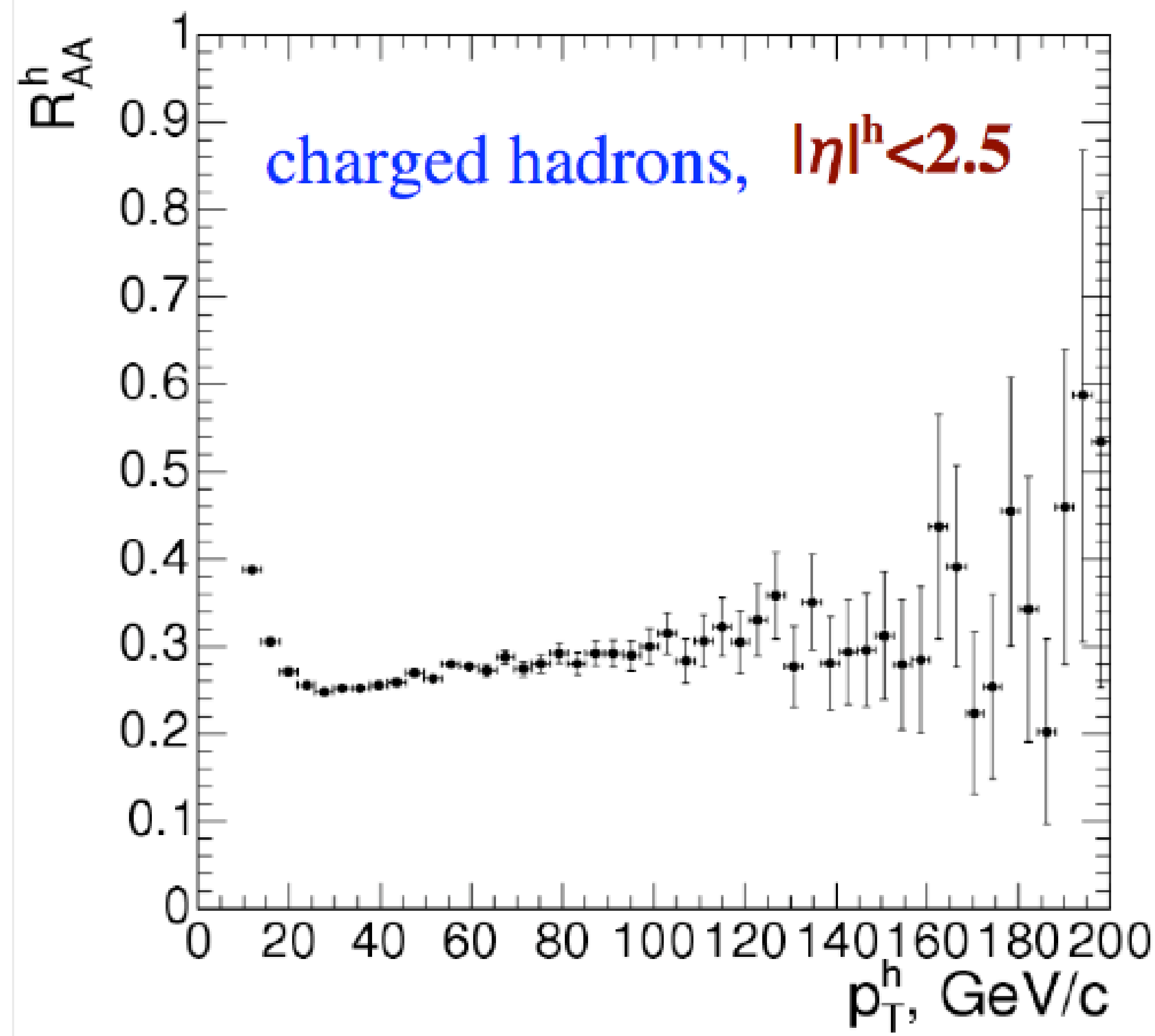
☞ the final spectrum depends on

1. the initial parton spectrum
2. the jet-quenching parameter $\hat{q}$

High-p_T hadron spectra

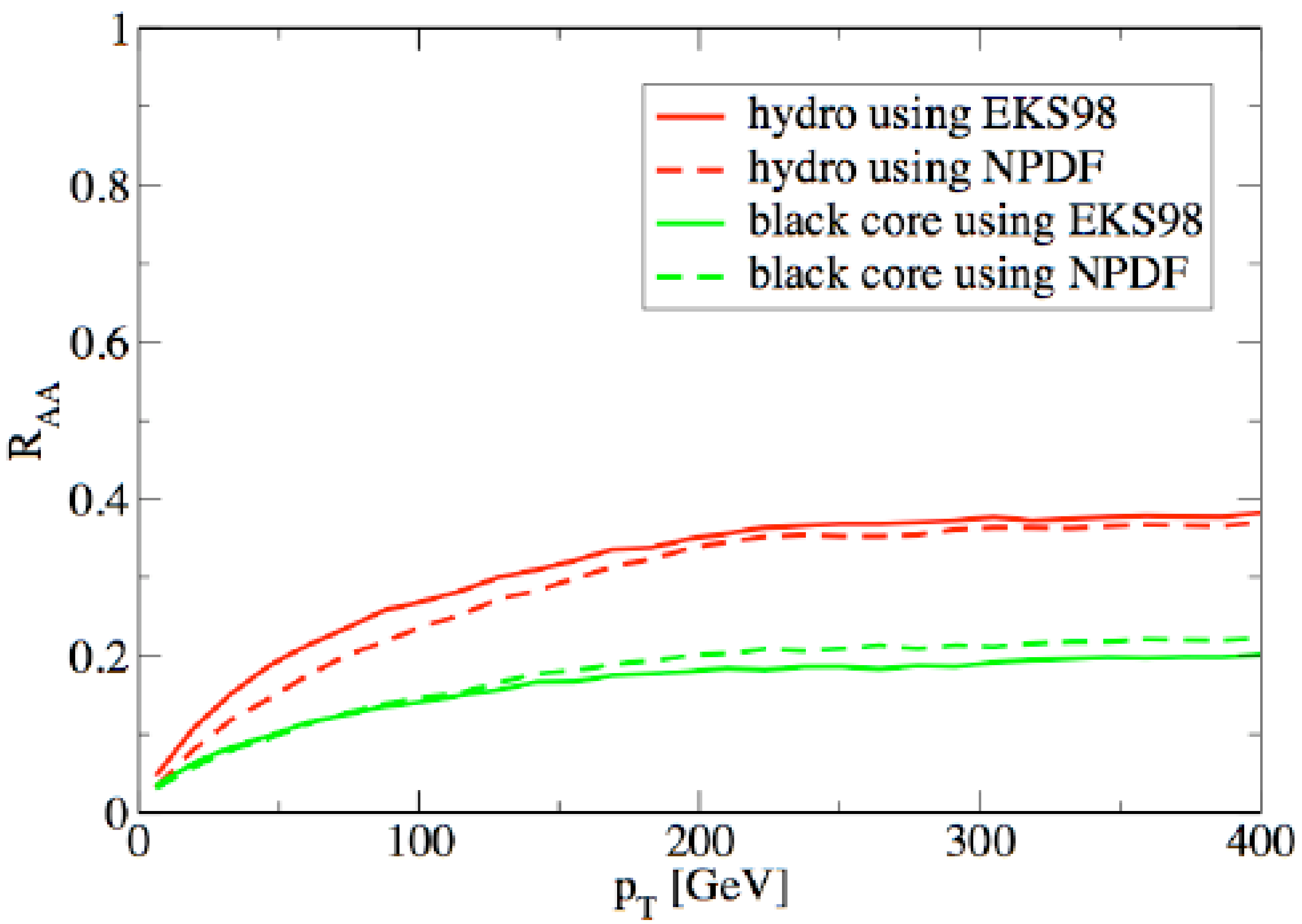


"Parton quenching model":
Dainese, Loizides, Paic

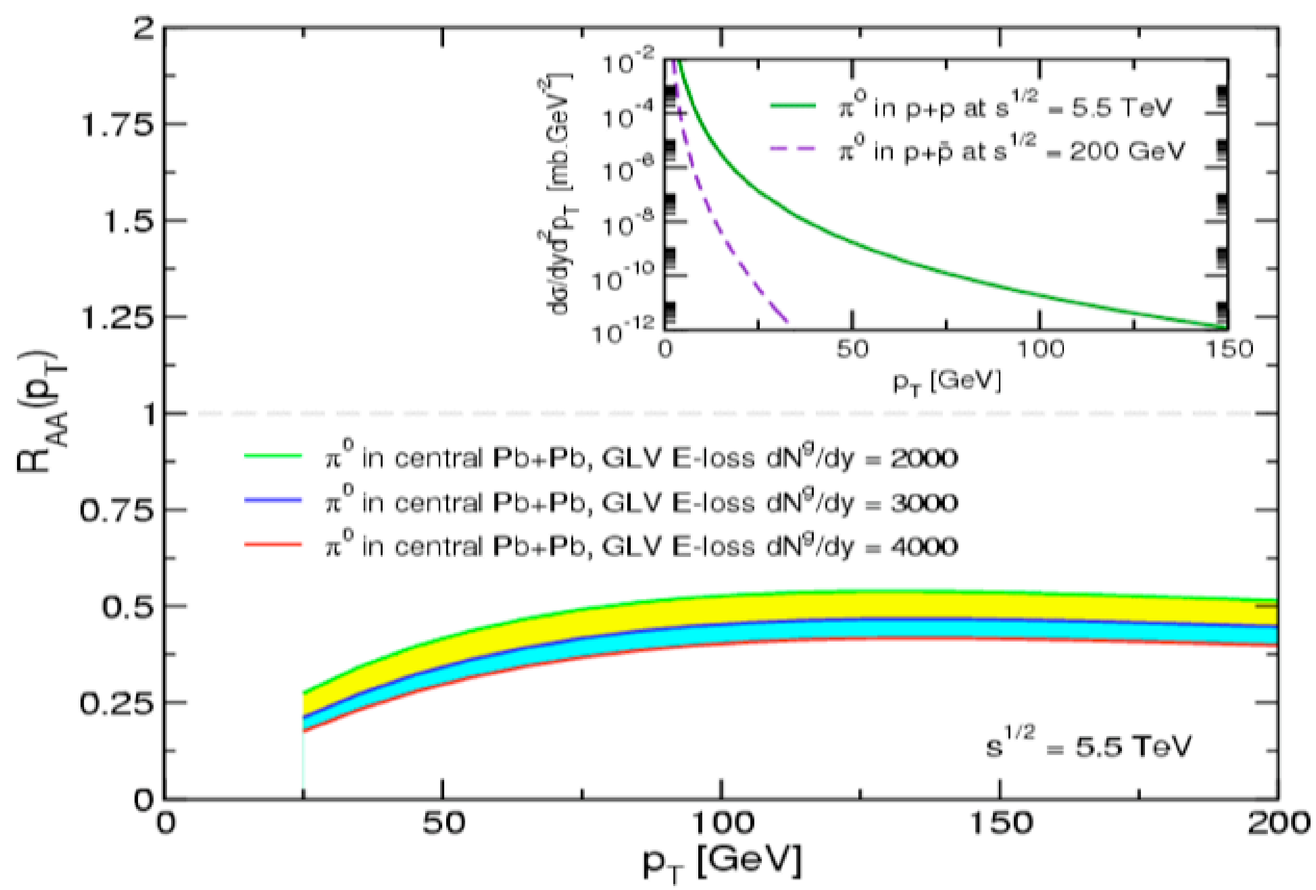


Pyquen: Lokhtin, Snigirev

High-p_T hadron spectra

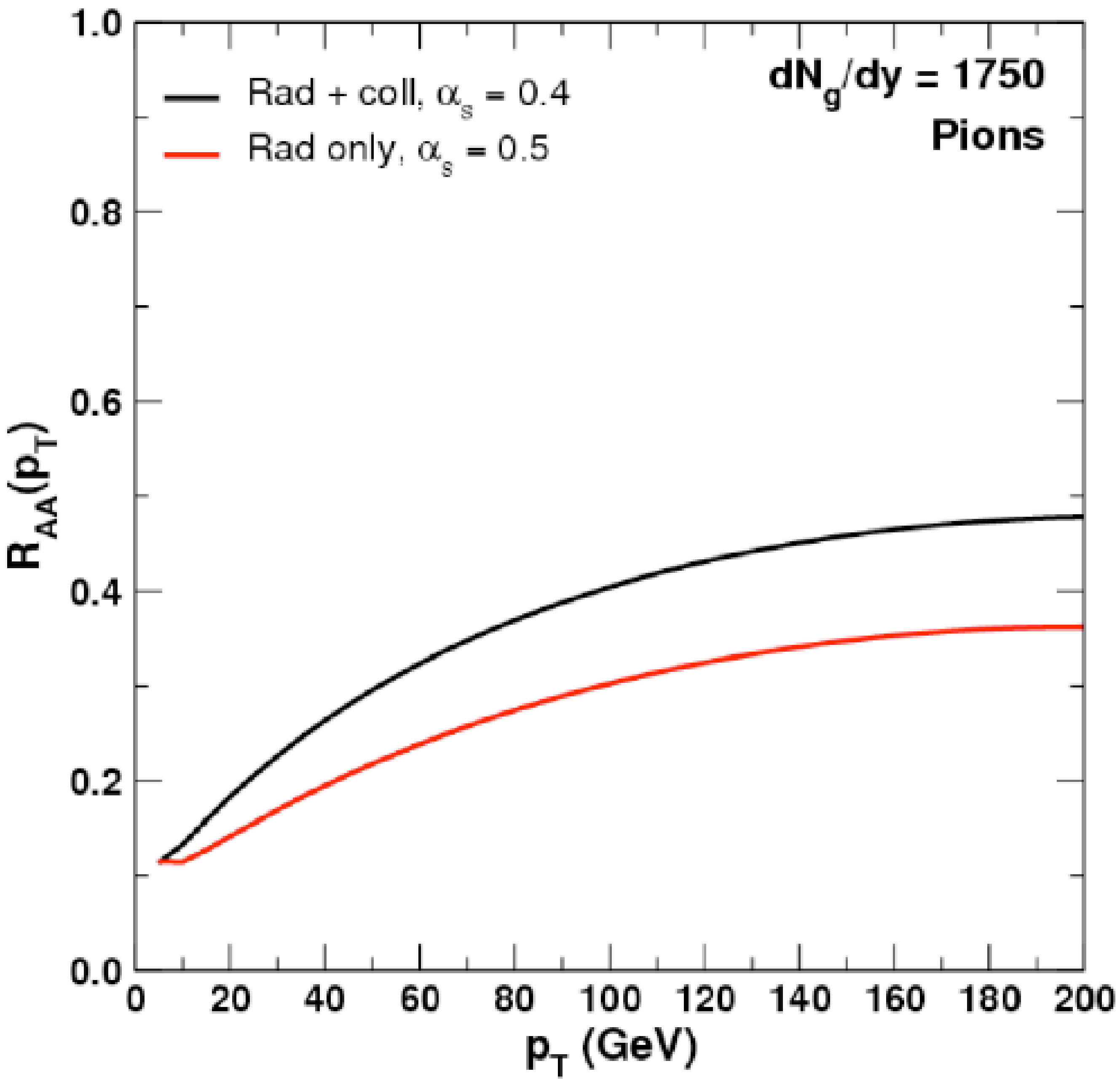


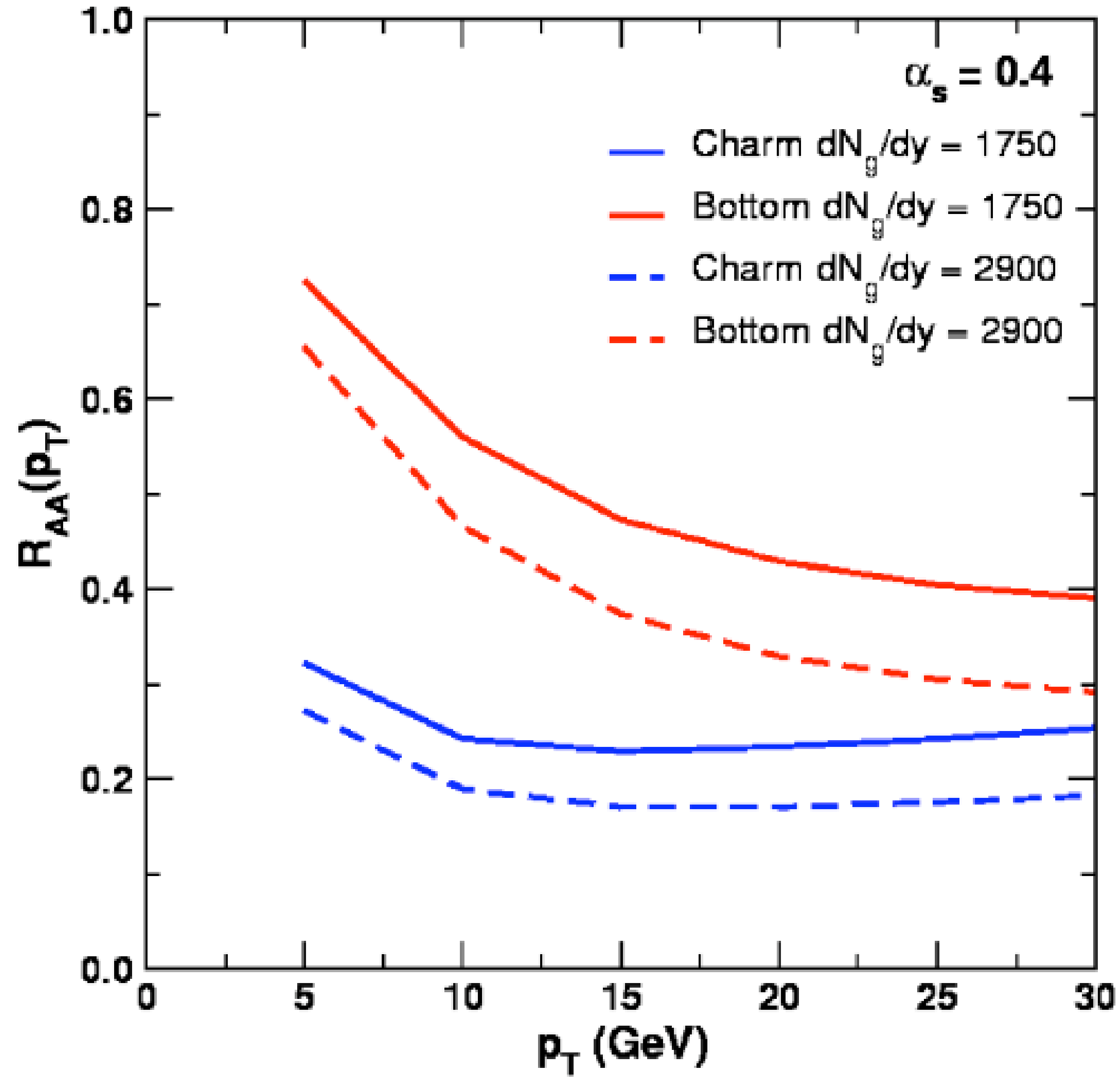
Renk



Gyulassy, Lévai, Vitev

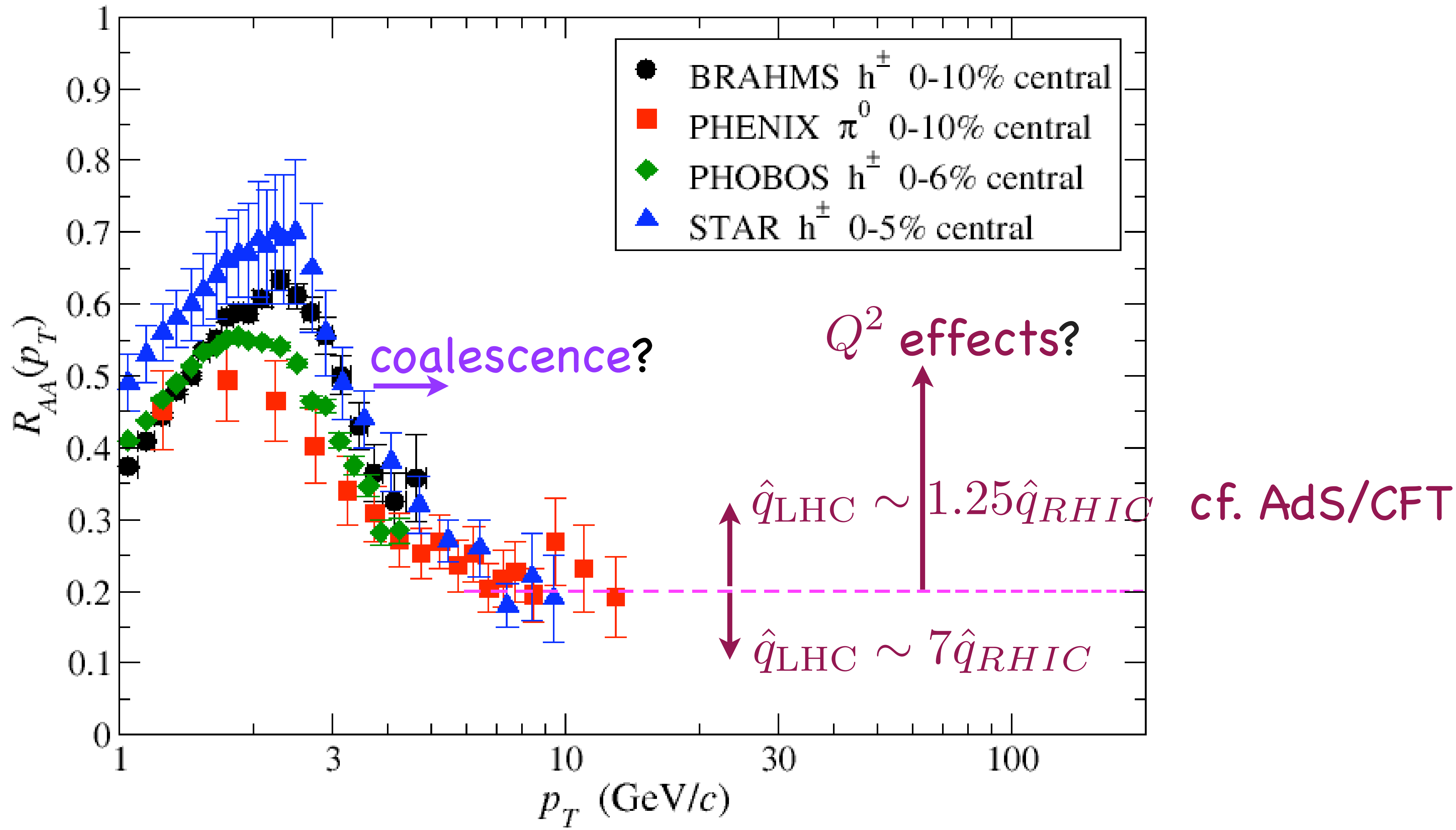
High-p_T hadron spectra





Gyulassy, Wicks et al.

High-p_T hadron spectra



N.B. & Wiedemann 2007

Heavy ion collisions at the LHC

Eventually, after a few years' data taking, we shall see results on

charmonium & bottomonium

Charmonium & bottomonium

Should we believe Agnes and Péter?

lattice data does not necessarily imply survival of quarkonia

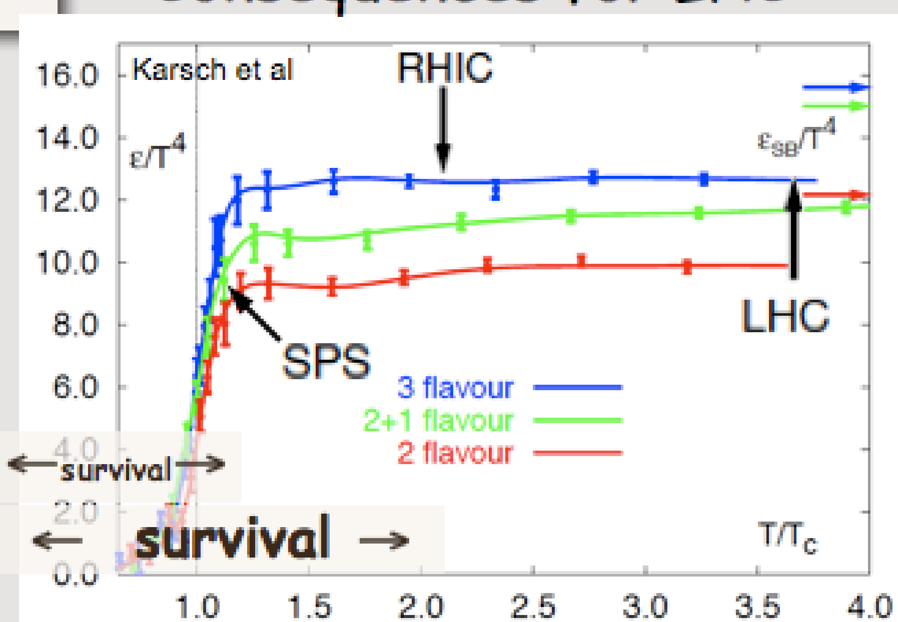
all states except Υ and η_b are dissolved by 1.2 T_c

Dissociation condition:
thermal width > 2 binding energy
upper limits

J/ψ	Υ'	χ_b	Υ
$1.2T_c$	$1.2T_c$	$1.3T_c$	$2T_c$

Upsilon suppressed at LHC
but less suppressed at RHIC

Consequences for LHC

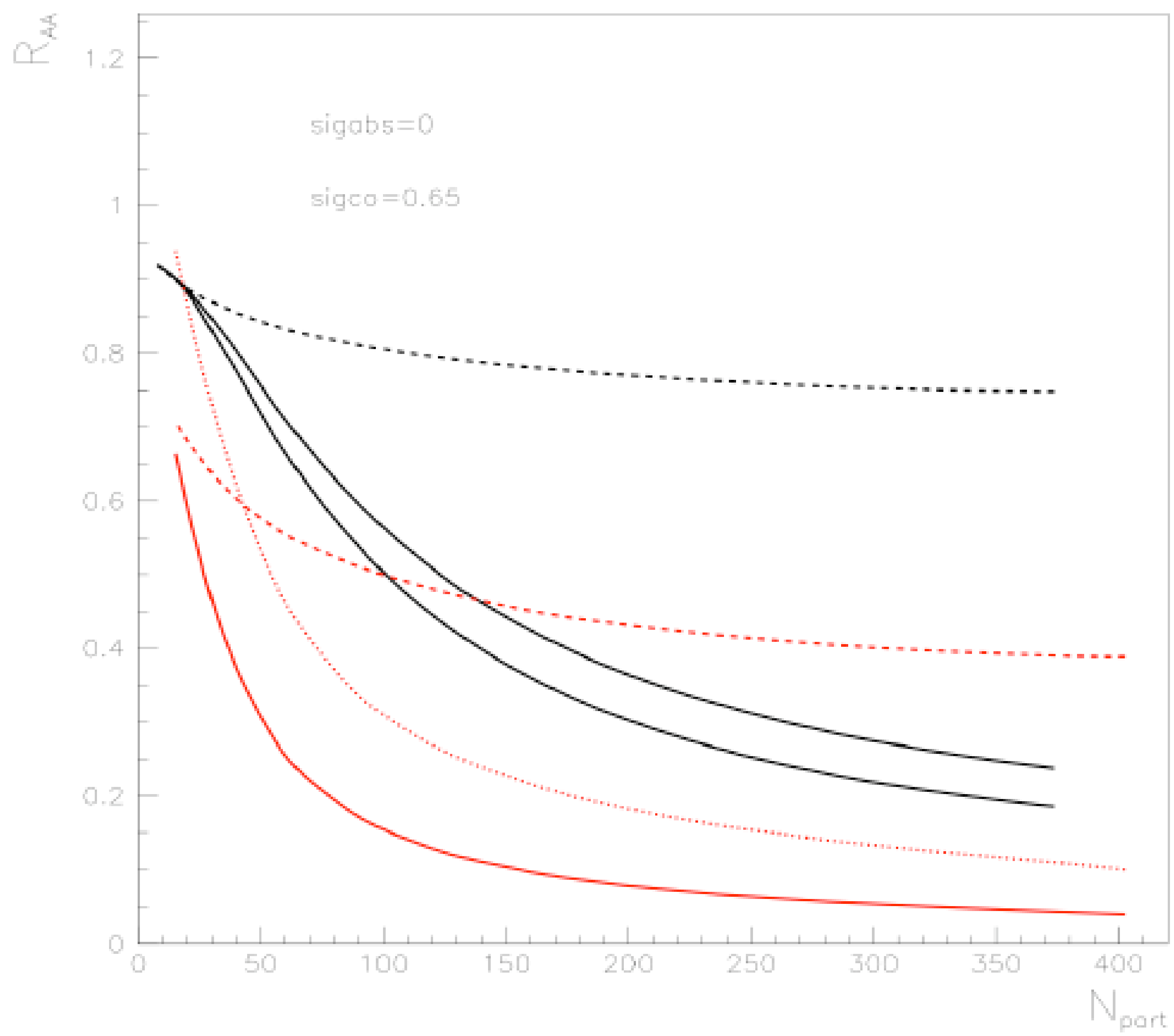


Threshold is enhanced over free propagation
=>> correlations between Q-Qbar may remain strong
regeneration from primordially correlated, not independent Q-Qbar

Mócsy, Petreczky

Charmonium & bottomonium

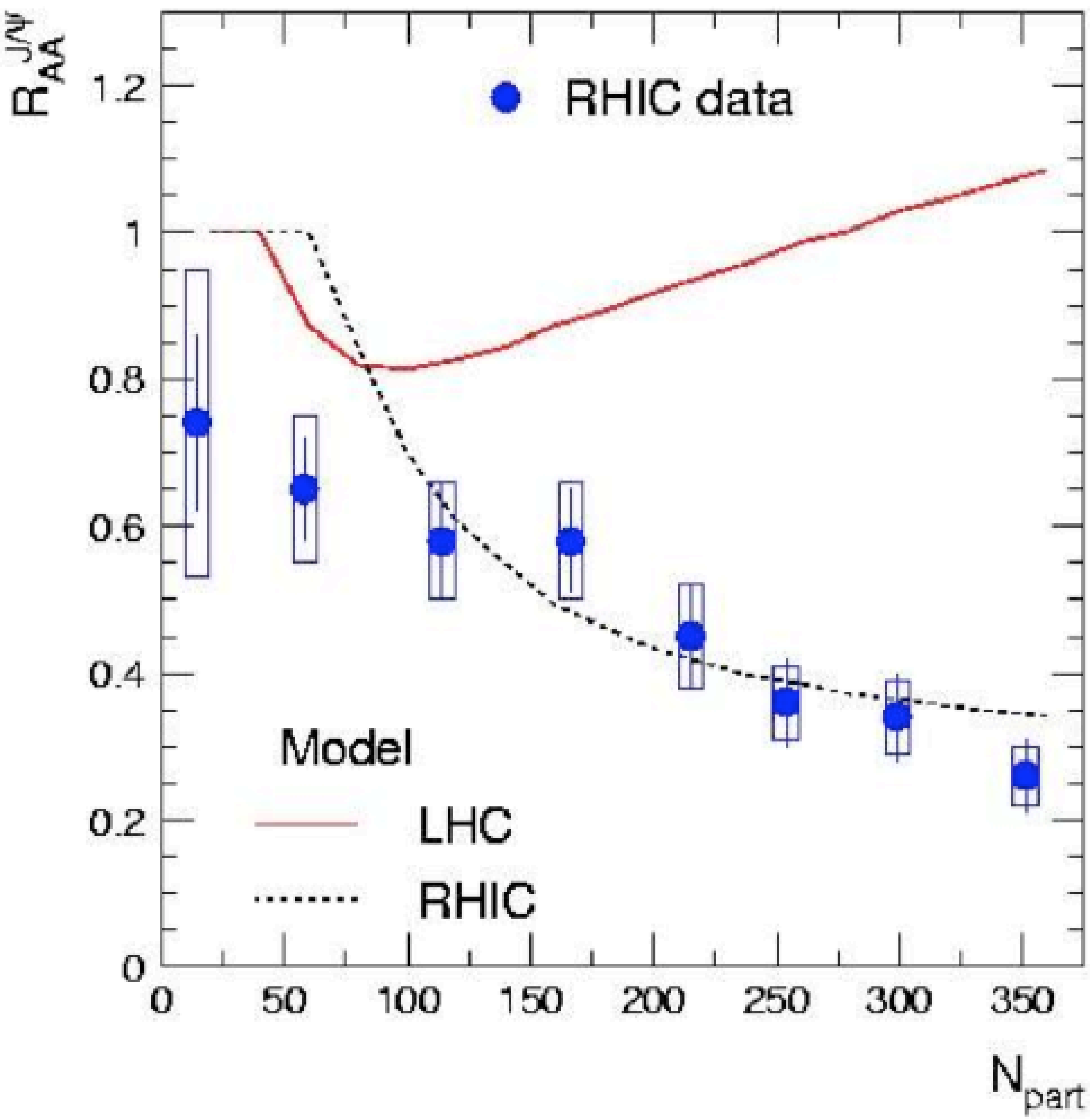
Shall we have suppression of the J/ψ?

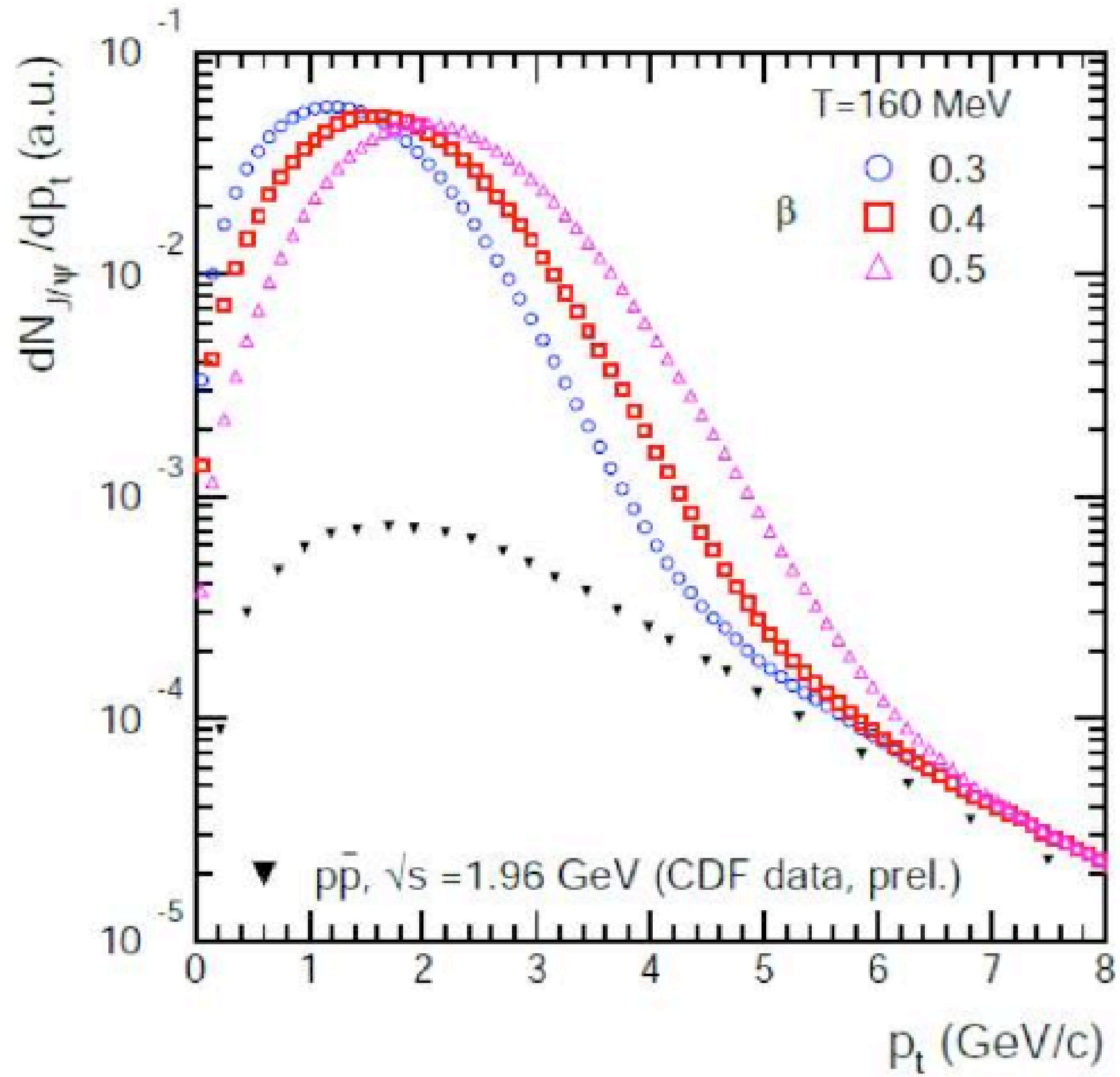


Cappella, Ferreiro

Charmonium & bottomonium

… or an enhancement of the J/ψ?





Andronic, Braun-Munzinger, Redlich, Stachel

Heavy ion collisions at the LHC

Sorry for the omitted topics...

- "femtoscopy": various predictions of the "HBT radius parameters", within transport (Ko), hydro (Heinz), and mixed (Bass, Sinyukov) models
- fluctuations: of baryon number & strangeness (Karsch), of charge density (Redlich), or of abundance ratios (Torrieri)
- jets: beyond the leading particle, away from midrapidity, reponse of the traversed medium... see session 6!
- electromagnetic/-weak probes: photons (Arleo, d'Enterria; Fries; Rezaeian; Sinha), dileptons (Fries; Sinha; van Hees); no Z^0 talk
- "exotica": black holes (Sarcevic; Stöcker), pentaquarks (Lee)
- predictions for p-Pb collisions (Iancu, Jalilian-Marian, Kopeliovich, Kozlov, Tuchin, Wessels)

The end

Many thanks...

to Urs Wiedemann (for our lasting correlation)

to Néstor Armesto, Sangyong Jeon, & Urs (again) for the fun we had

and to the many theorists / phenomenologists / experimentalists who dared make predictions

and to you, for your patience!