# Exploring the Quark-Gluon Plasma with ALICE at the LHC

Physics background: 20 years after start of fixed target program at AGS and SPS and 8 years after start of RHIC next huge step in collision energy

$\sqrt{s_{NN}}$ = 5/19 GeV -> 200 GeV -> 5400 GeV

truely macroscopic energy ⟷ what's the difference?

J. Stachel – Physikalisches Institut der Universität Heidelberg

Int. School of Nuclear Physics, 30th course 'Heavy Ion Collisions from the Coulomb Barrier to the Quark-Gluon Plasma'

Erice, September 27, 2008

# expected initial conditions in central nuclear collisions at LHC

initial conditions from pQCD+saturation of produced gluons

$$N_{AA}(\mathbf{0}, p_0, \Delta y = 1, \sqrt{s}) \cdot \pi / p_0^2 = \pi R_A^2$$

using pQCD cross sections find for central PbPb at LHC $p_0 = p_{sat} = 2$ GeV

and a formation time of $\tau_0 = 1/p_{sat} = 0.1$ fm/c

and with Bjorken formula:

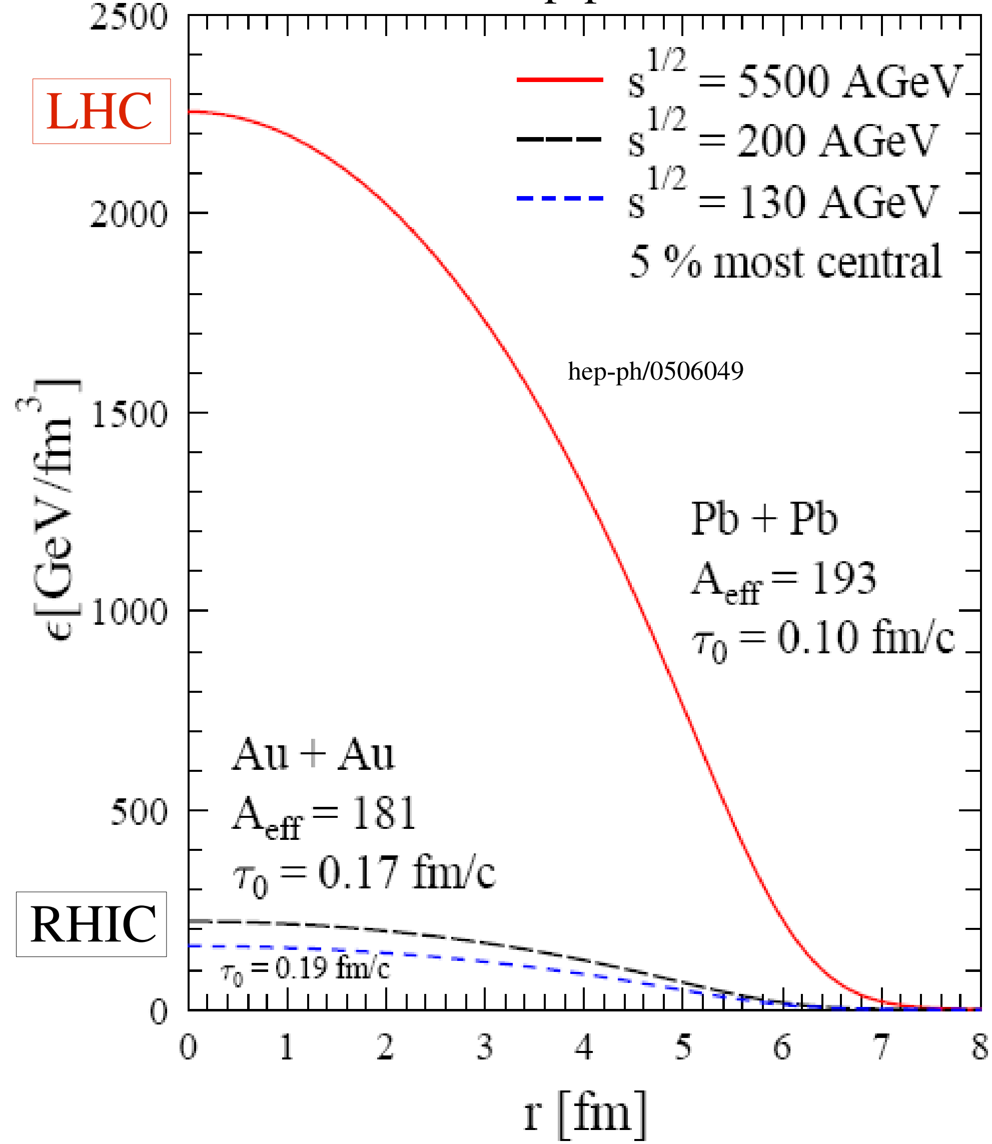
$\epsilon_0 = \mathrm{dE_t}/\mathrm{d}\eta/(\tau_0 \pi \mathrm{R}^2)$ w. Jacobian $d\eta/dz = 1/\tau_0$

as compared to RHIC: more than order of magnitude increase in intial energy density

initial temperature $T_0 \approx 1$ TeV

(factor 2-3 above RHIC)

K. Eskola et al., hep-ph/0506049



# expected evolution of QGP fireball at LHC

K. Eskola et al.

after fast thermalization hydrodynamic expansion of fireball and cooling $T \propto \tau^{-1/3}$

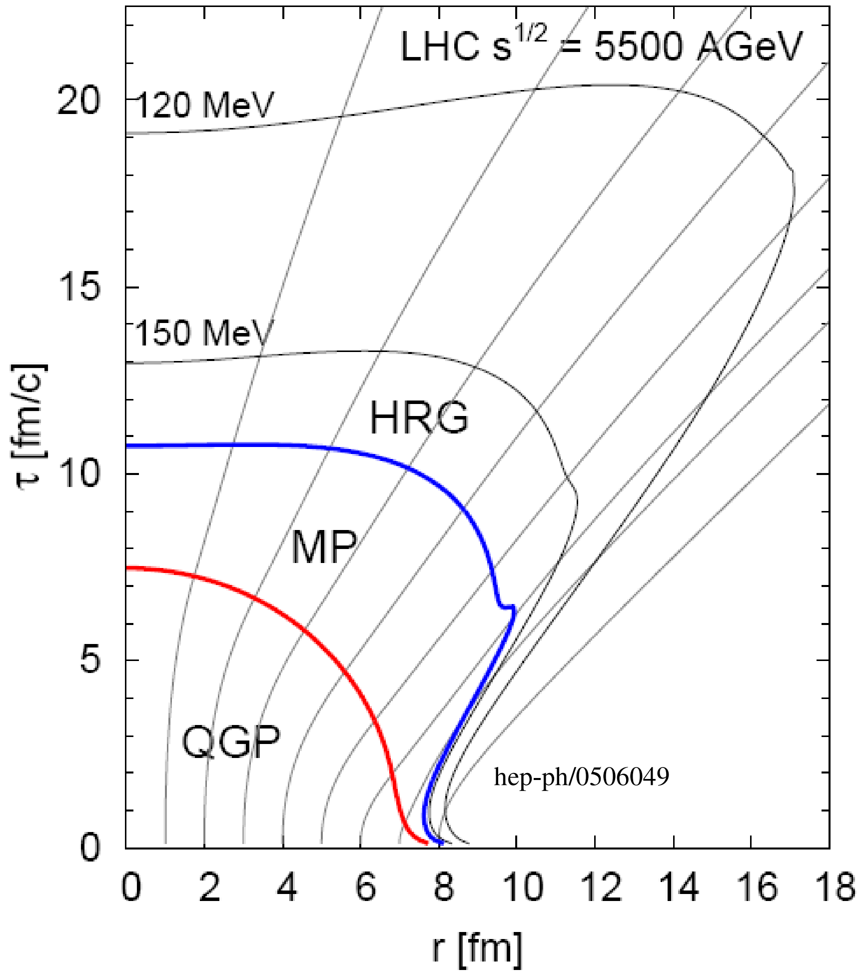
hadronization starts at when $T_c$ is reached (165 MeV)

duration hadronization:

# degrees of freedom drops by factor 3.5

-> volume has to grow accordingly -> 3-4 fm/c

(this is independent of order of phase transition)



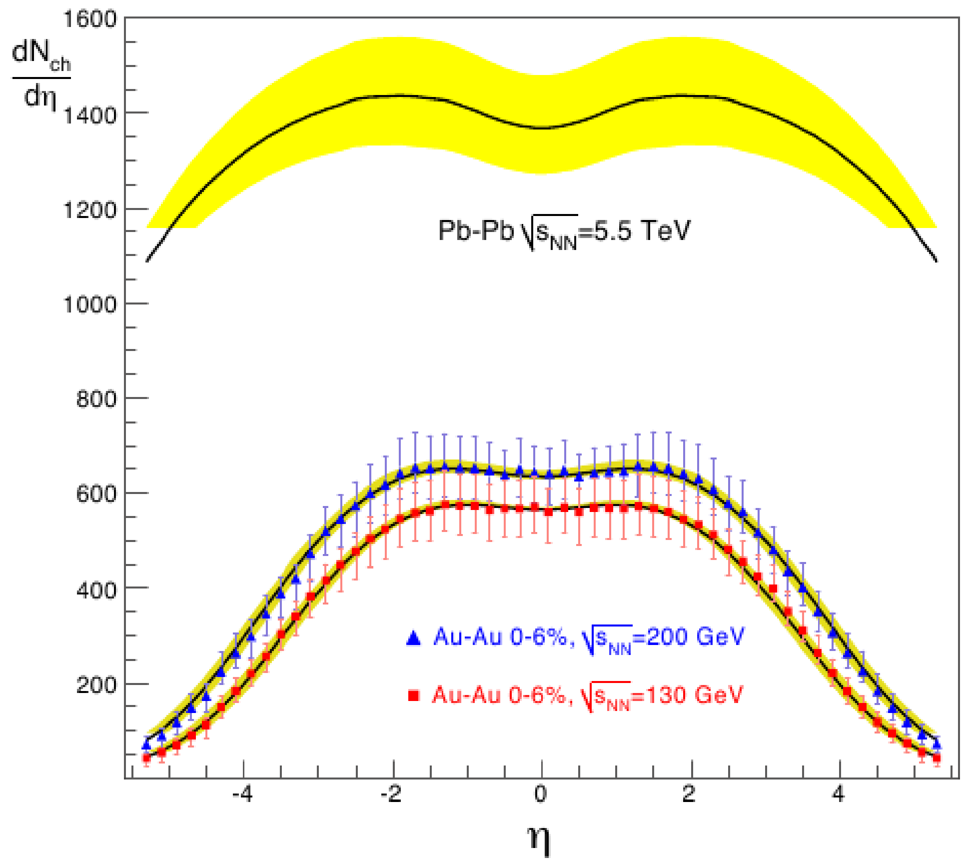

initial $N_{AA}$ determines final multiplicity

estimate (Eskola) $dN_{ch}/d\eta = 2600$

overall several 10 k hadrons produced

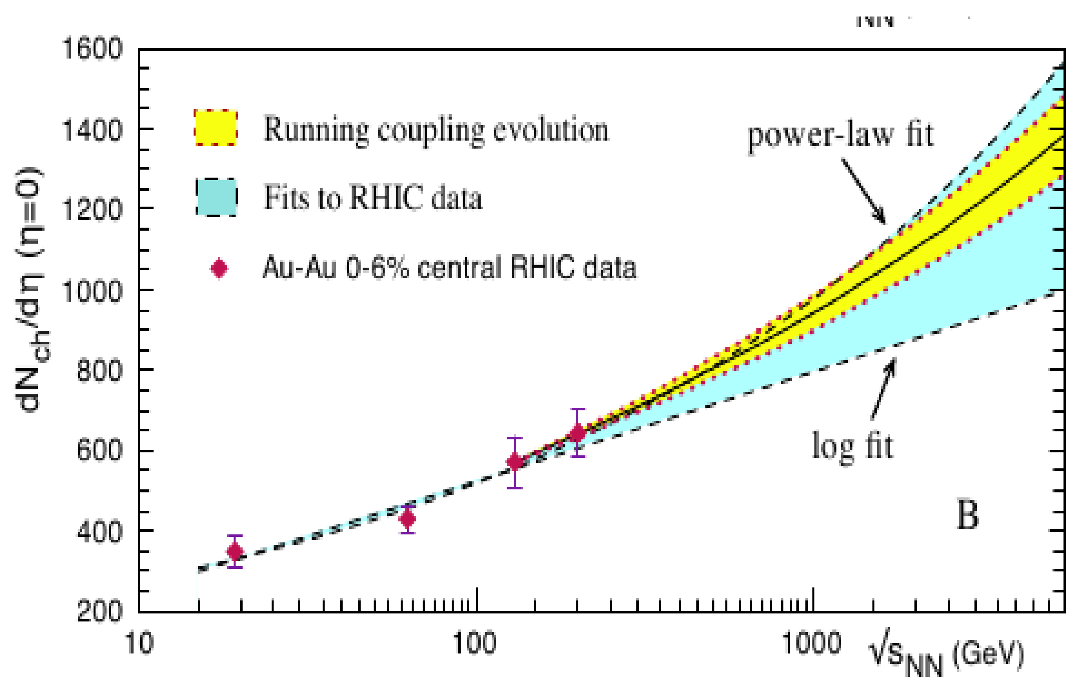
**'macroscopic state'**

# expected charged particle rapidity density at LHC




J.L.Albacete 0707.2545 [hep-ph]
within $k_t$ factorization framework

depending on evolution of saturation scale
get $dN_{ch}/d\eta$ = 1000 – 2500



# task of heavy ion program at LHC

- unambiguous proof of QGP
- determine properties of this new state of matter

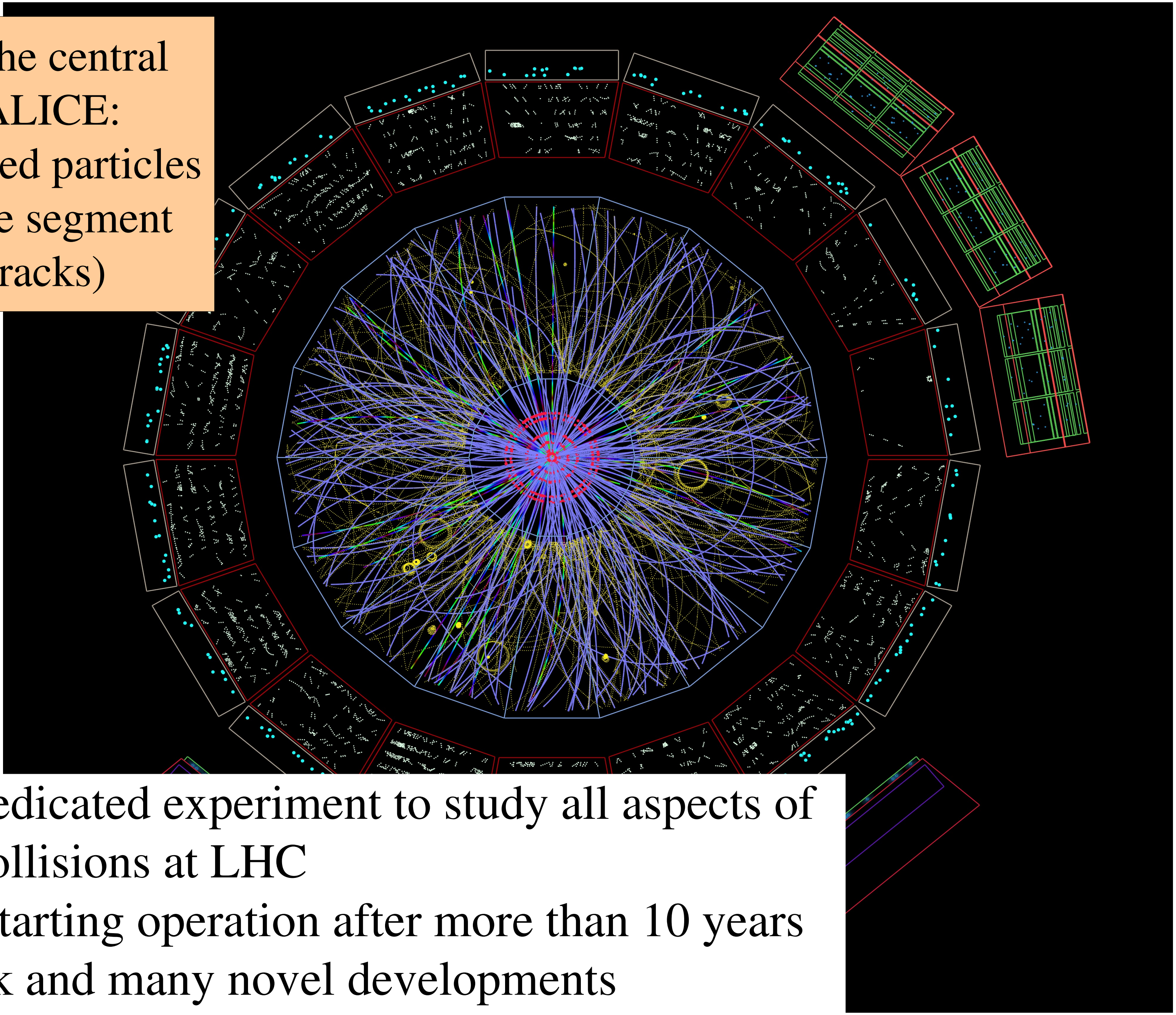
equation of state – energy density ↔ temperature ↔ density ↔ pressure
heat capacitance /entropy – number degrees of freedom
viscosity (Reynolds number) – flow properties under pressure gradient
velocity of sound – Mach cone for supersonic particle
opacity / index of refraction / transport coeff. - parton-energy loss
excitations / quasi particles - correlations
susceptibilities – fluctuations
characterisation of phase transition
....

**unusual quantities in particle physics – but we want to characterize matter!**

- be open for the unexpected

## the challenge: identification and reconstruction of 5000 (up to 15000) tracks of charged particles

cut through the central barrel of ALICE: tracks of charged particles in a 1 degree segment (1% of tracks)



- ALICE is dedicated experiment to study all aspects of heavy ion collisions at LHC
- detector is starting operation after more than 10 years of hard work and many novel developments

# 1. The hadro-chemical composition of the fireball

what are the 7500 hadrons observed in final state at RHIC?

analysis in terms of statistical ensemble (grand canonical) successful for central PbPb (AuAu) collisions from top AGS energy

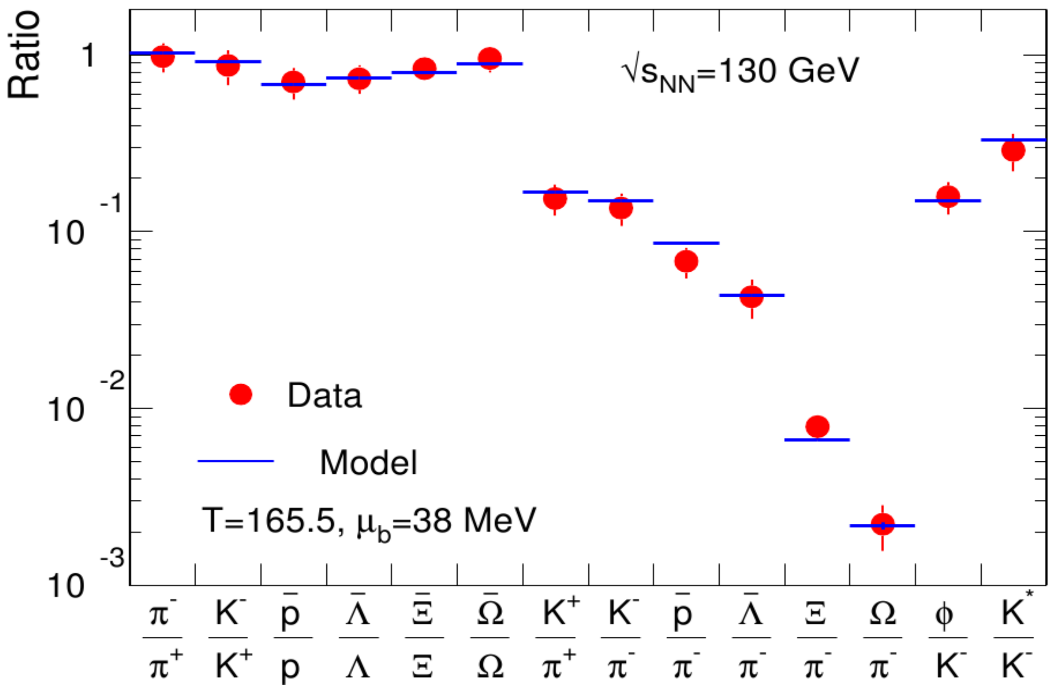
a new look at e+e-

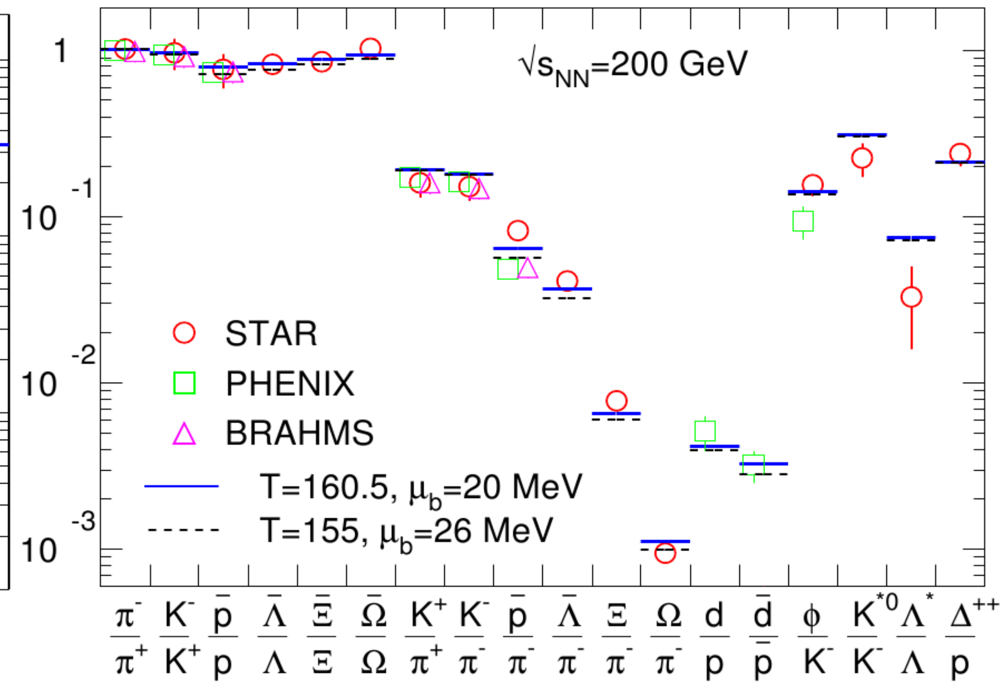
what do we expect at the LHC?

# hadron yields at RHIC compared to statistical model (GC)

130 GeV data in excellent agreement with thermal model predictions

prel. 200 GeV data fully in line
still some experimental discrepancies



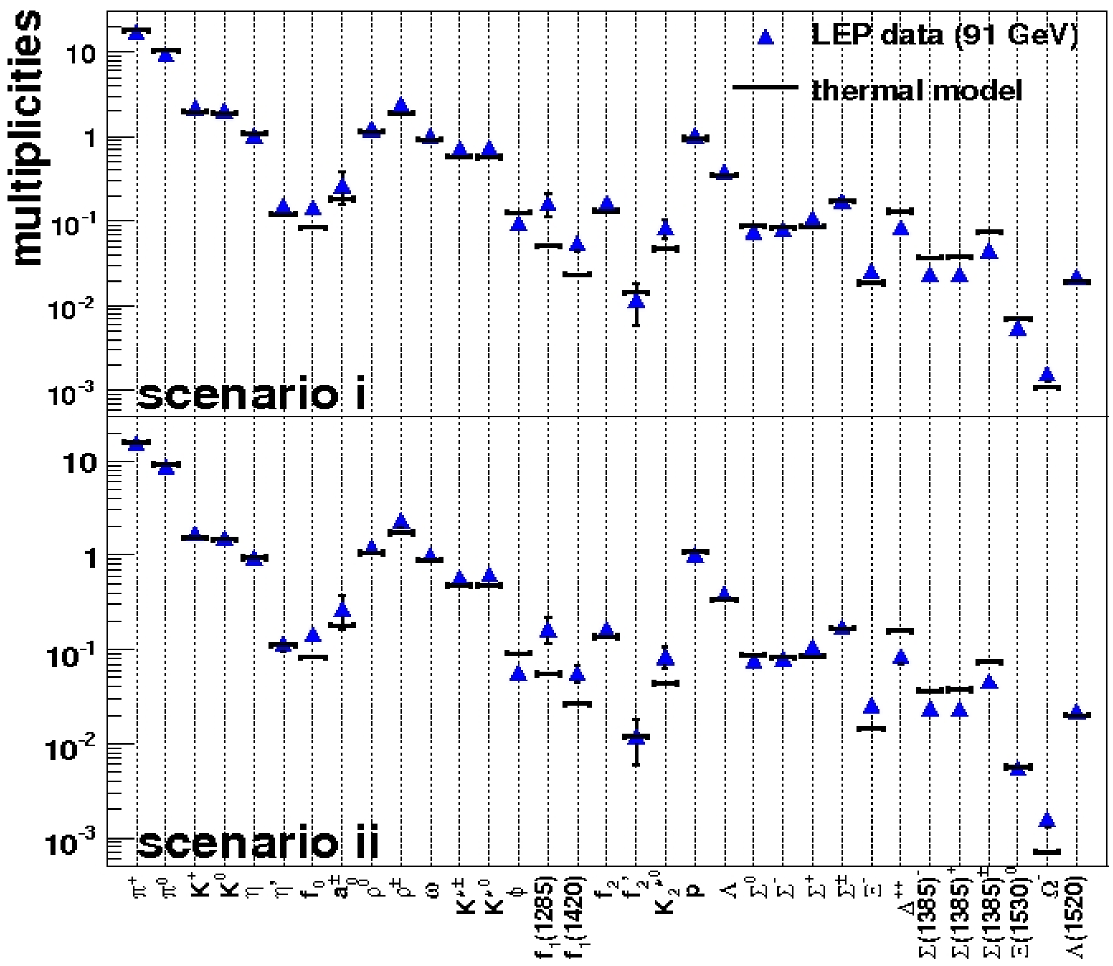




chemical freeze-out at: $T = 165 \pm 5$ MeV

P. Braun-Munzinger, D. Magestro, K. Redlich, J. Stachel, Phys. Lett. B518 (2001) 41
A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 (2006) 167

# is success of statistical description unique to heavy ion collisions or generic feature of hadronization?

study of high quality final LEP data – F. Beutler, Heidelberg, diploma thesis 2008
full canonical treatment with conservation of A, Q, S, C, B and quantum statistics



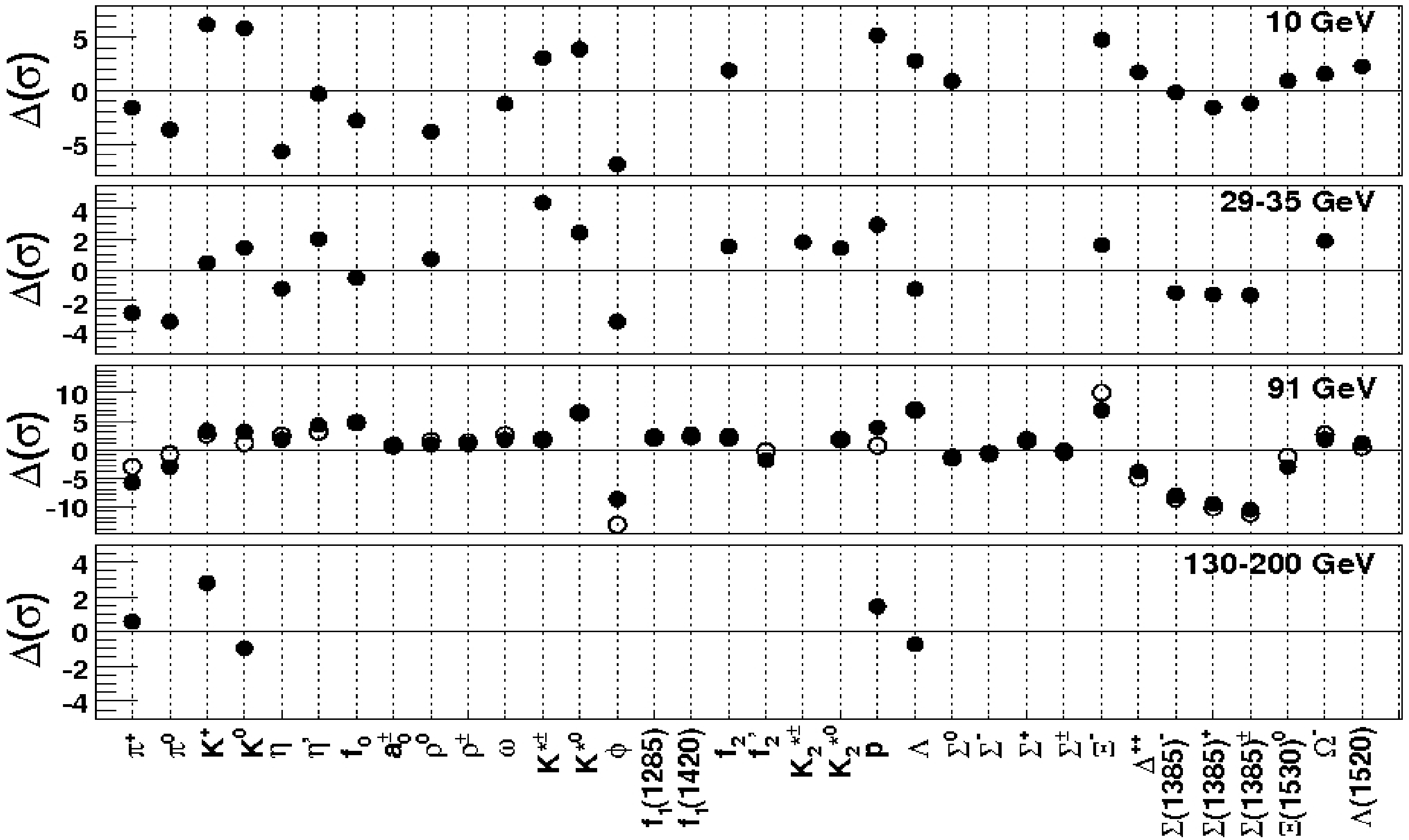

i) quantum numbers 0 in each jet
ii) quantum numbers 0 in sum of both jets

decay from charm and beauty subtracted – production not thermal

A. Andronic, P. Braun-Munzinger, F. Beutler, K. Redlich, J. Stachel, arXiv 0804.4132

# these are not good fits...

difference between data and model in standard deviations




quite some points differ by 5 or more standard dev.

A. Andronic, P. Braun-Munzinger, F. Beutler, K. Redlich, J. Stachel, arXiv 0804.4132

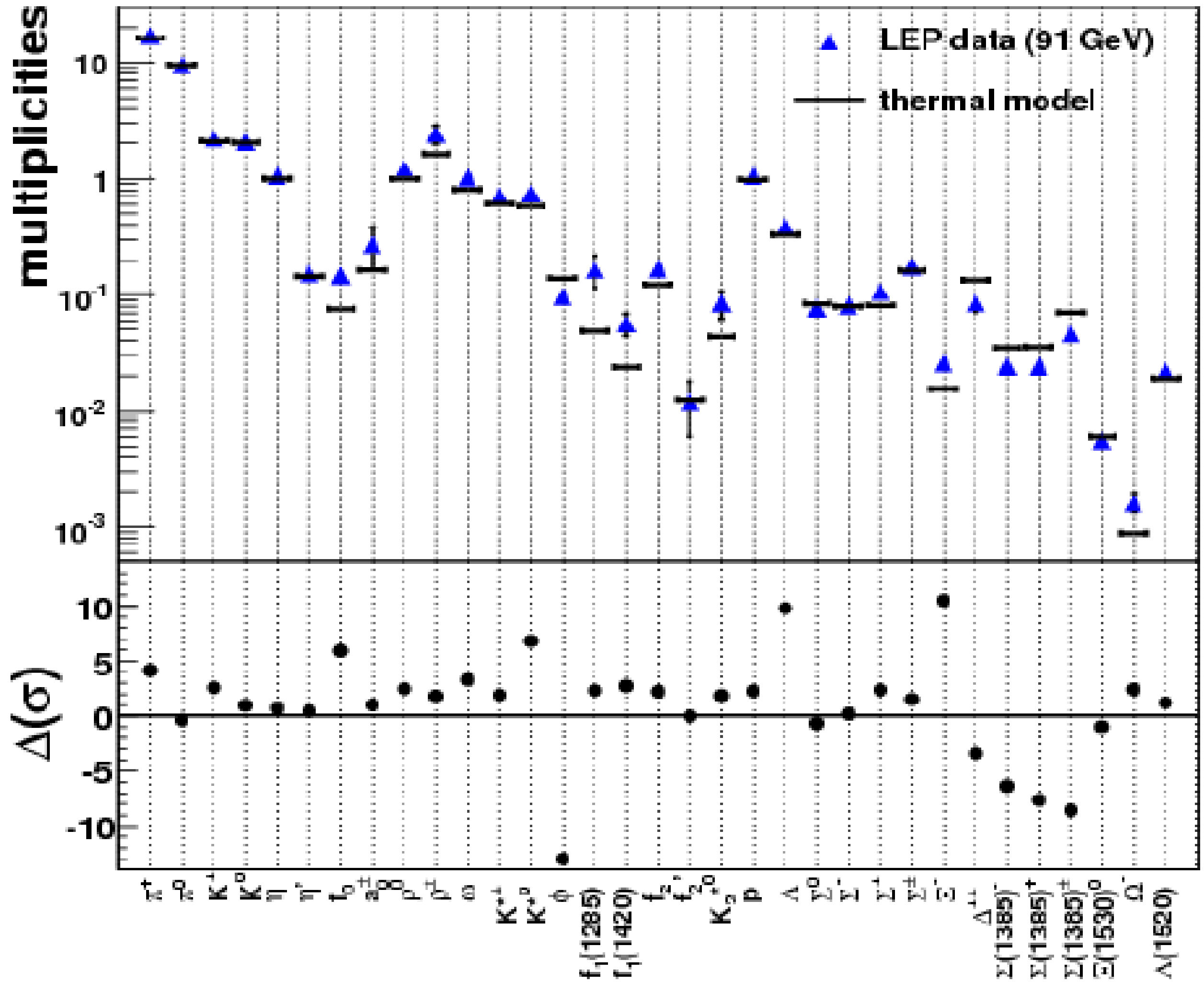
# Statistical Model Fit Results for LEP hadron yields

| $\sqrt{s}$[GeV] | T[MeV] | V[fm$^3$] | $\gamma_s$ | $\chi^2$/dof |
|---|---|---|---|---|
| 10 | 159±1.7 | 14±1.5 | 0.80±0.02 | 318/21 |
| 29-35 | 160±1.7 | 18±1.4 | 0.96±0.03 | 101/18 |
| 91 (all) | 157±0.50 | 32±1 | 0.78±0.007 | 630/30 |
| 91 (-c,b) | 166±0.50 | 20±1 | 0.66±0.01 | 708/30 |
| 130-200 | 154±2.8 | 42±4.3 | 0.78±0.03 | 11/2 |

- fits not good, in particular to best data set on Z-pole
  in part, because LEP data are very precise
- 'T' indeed similar to heavy ion collisions at high energy
- strangeness significantly suppressed (gamma_s = 0.66 implies deviation for Omega of factor 3.5)

# initialize thermal model with u,d,s,c,b – jets according to measurement (weak isospin)

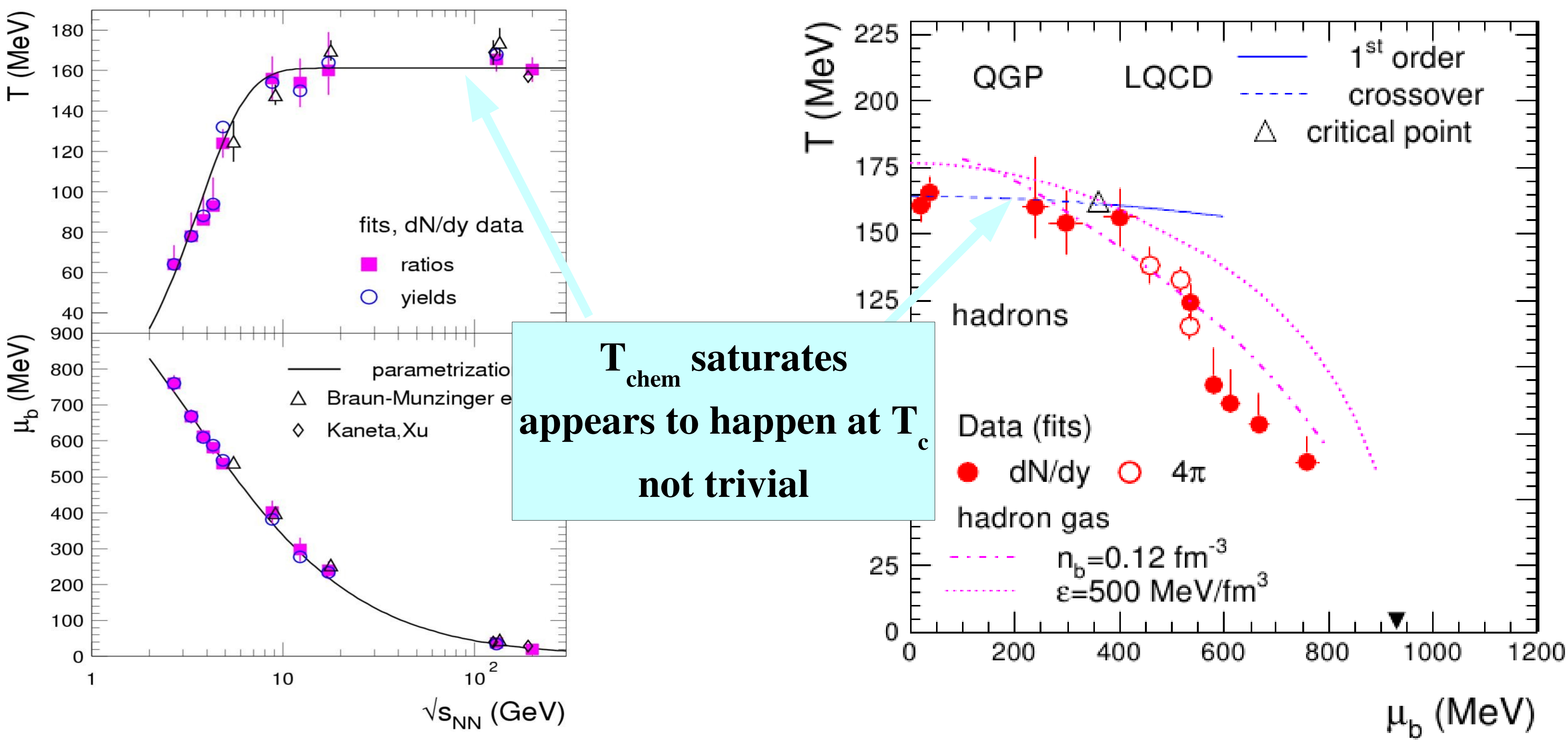
A. Andronic, P. Braun-Munzinger, F. Beutler, K. Redlich, J. Stachel, arXiv 0804.4132




parameter set: T=164 MeV, V=20 $fm^3$, $\gamma_s$=0.72 with $\chi^2$=718/30

# hadrochemical freeze-out points and the phase diagram

A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 (2006) 167



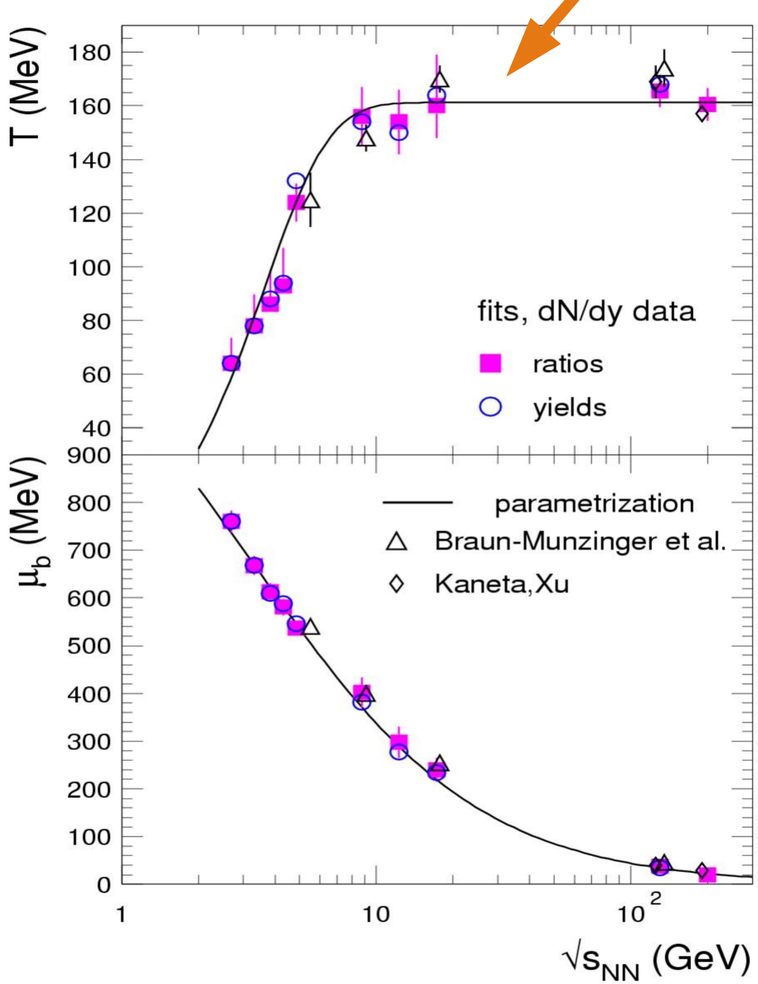

Johanna Stachel

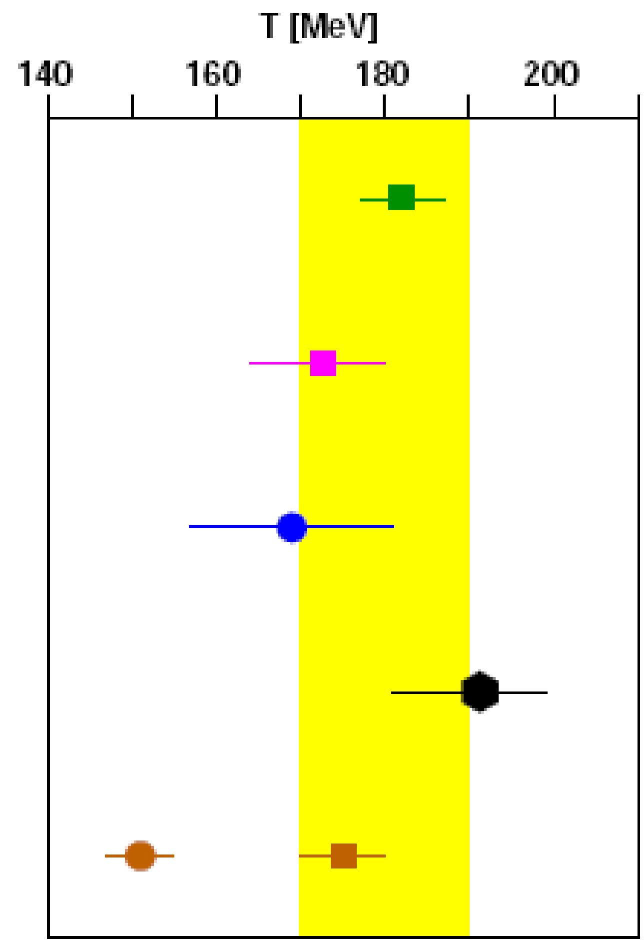
RUPRECHT-KARLS-UNIVERSITÄT H

# equilibration driven by high densities near $T_c$

rapid equilibration within a narrow temperature interval around $T_c$ by multiparticle collisions ⇨ **requires $T_c \approx 170$ MeV**

P. Braun-Munzinger, J. Stachel, C. Wetterich, Phys. Lett. B596 (2004)61




synopsis of different lattice QCD results - F.Karsch

# predicted hadron abundancies for LHC PbPb collisions

A. Andronic,P. Braun-Munzinger, J. Stachel arXiv 0707.4046 [nucl-th]

$T_c$=161 +-4 MeV, $\mu_b$ = 0.8+1.2-0.6 MeV

| $\pi^-/\pi^+$ | $K^-/K^+$ | $\bar{p}/p$ | $\bar{\Lambda}/\Lambda$ | $\bar{\Xi}/\Xi$ | $\bar{\Omega}/\Omega$ |
|---|---|---|---|---|---|
| 1.001(0) | 0.993(4) | $0.948^{-0.013}_{+0.008}$ | $0.997^{-0.011}_{+0.004}$ | $1.005^{-0.007}_{+0.001}$ | 1.013(4) |

| $p/\pi^+$ | $K^+/\pi^+$ | $K^-/\pi^-$ | $\Lambda/\pi^-$ | $\Xi^-/\pi^-$ | $\Omega^-/\pi^-$ |
|---|---|---|---|---|---|
| 0.074(6) | 0.180(0) | 0.179(1) | 0.040(4) | 0.0058(6) | 0.00101(15) |

interesting question: what about strongly decaying resonances – sensitive to existence of hadronic fireball after hadronization of QGP

| $\phi/K^-$ | $K^{*0}/K^0_S$ | $\Delta^{++}/p$ | $\Sigma(1385)^+/\Lambda$ | $\Lambda^*/\Lambda$ | $\Xi(1530)^0/\Xi^-$ |
|---|---|---|---|---|---|
| 0.137(5) | 0.318(9) | 0.216(2) | 0.140(2) | 0.075(3) | 0.396(7) |

due to their width **very** difficult to measure
RHIC results not conclusive

# 2. Indications for hydrodynamic expansion

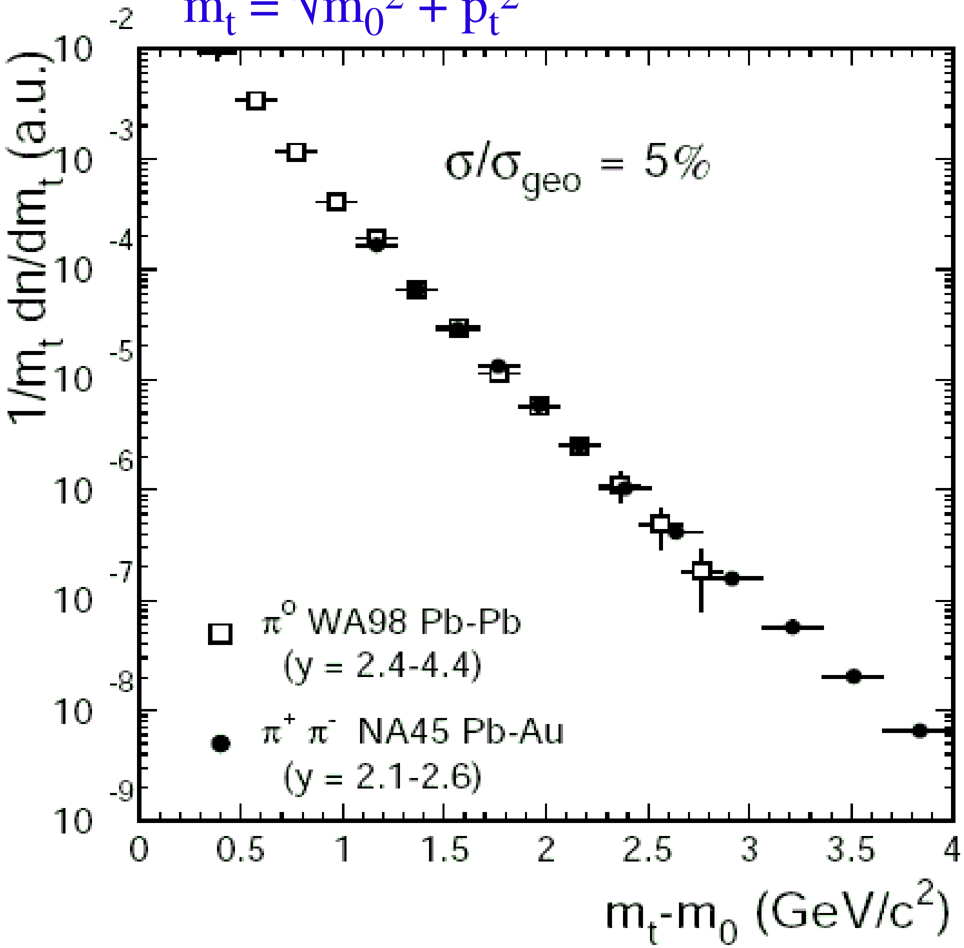
consider

- particle transverse momentum spectra
- azimuthal correlations
- momentum correlations

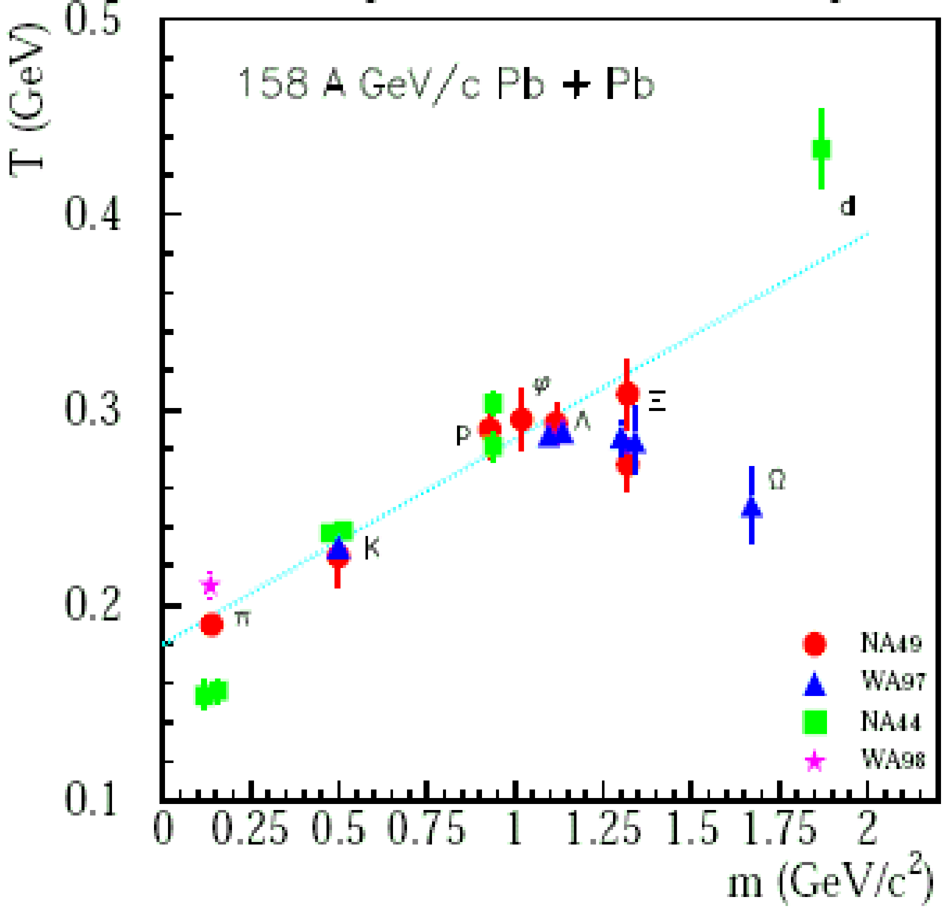
# hydrodynamic expansion to understand transverse spectra already needed for fixed target data at AGS and SPS

typical transverse mass spectrum

$m_t = \sqrt{m_0^2 + p_t^2}$




mass dependence of inverse slopes

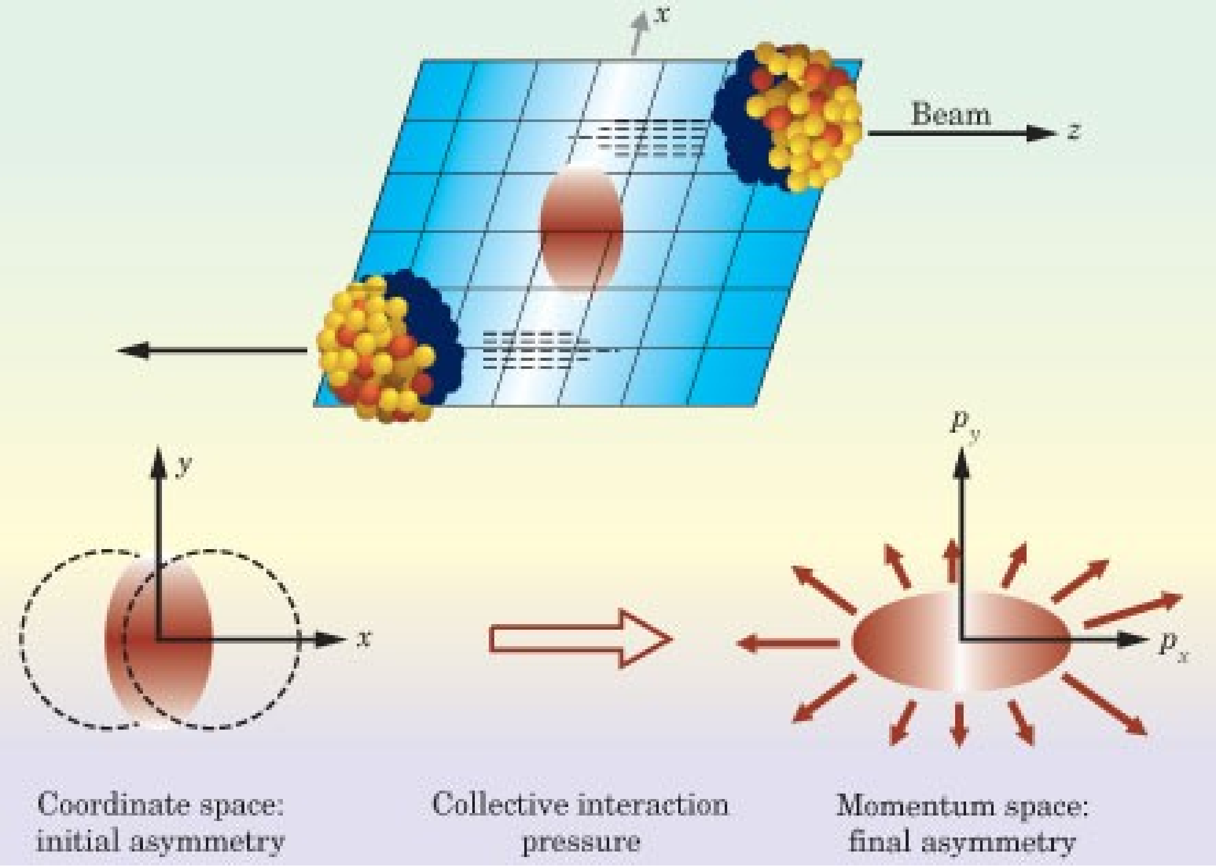



slope constants grow with mass - much too large to be temperatures!

Hubble Expansion of Nuclear Fireball

expansion velocity at surface 2/3 c at SPS, 4/5 c at RHIC

# Azimuthal Anisotropy of Transverse Spectra




Fourier decomposition of momentum distributions rel. to reaction plane:

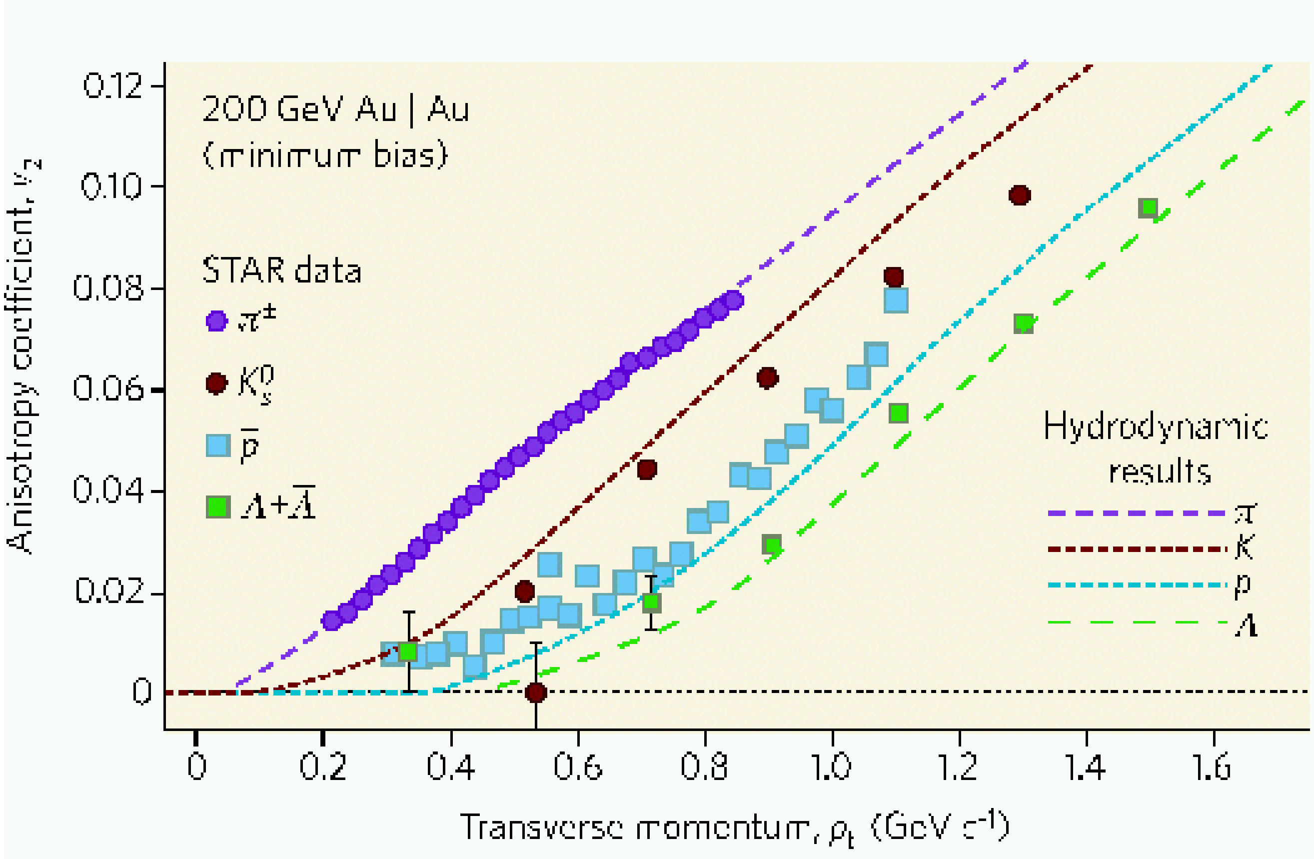
$$\frac{dN}{dp_t\, dy\, d\phi} = N_0 \cdot \left[ 1 + \sum_{i=1} 2\, v_i \left( y, p_t \right) \cos\left( i\, \phi \right) \right]$$

quadrupole component $v_2$

"elliptic flow"

effect of expansion (positive $v_2$) seen from top AGS energy upwards

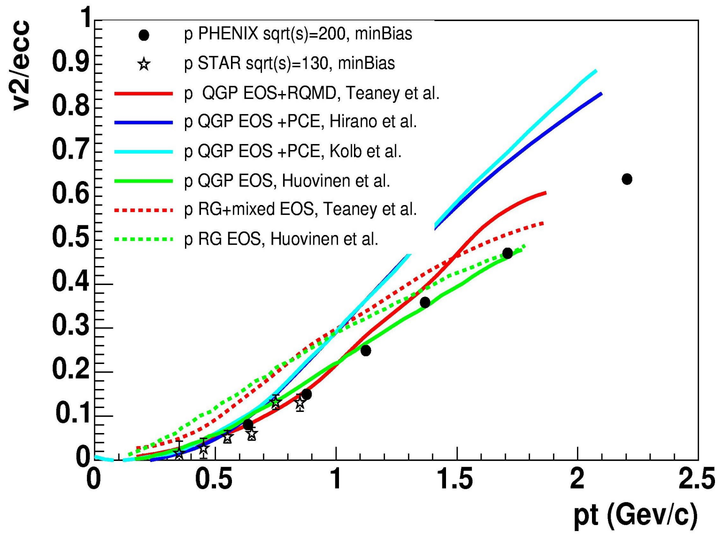
# elliptic flow for different particle species and $p_t$ at RHIC

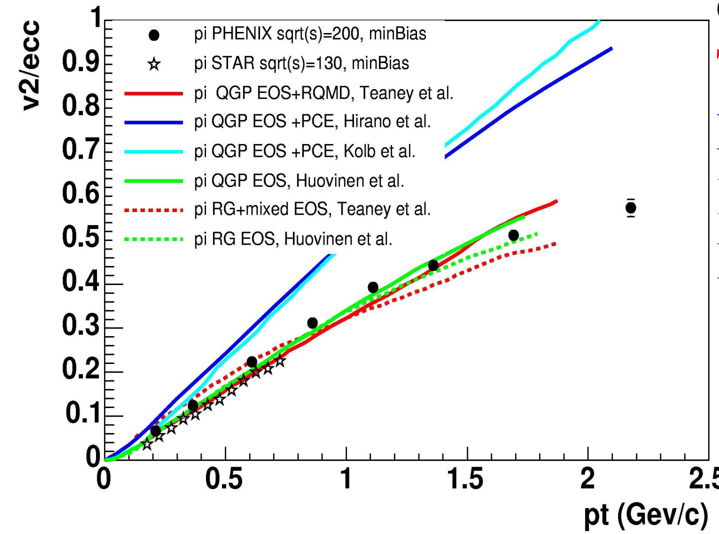



mass ordering typical effect of hydrodynamic expansion
ideal (nonviscous) hydrodynamics describes azimuthal asymmetries up to about 2 GeV/c at sub % level

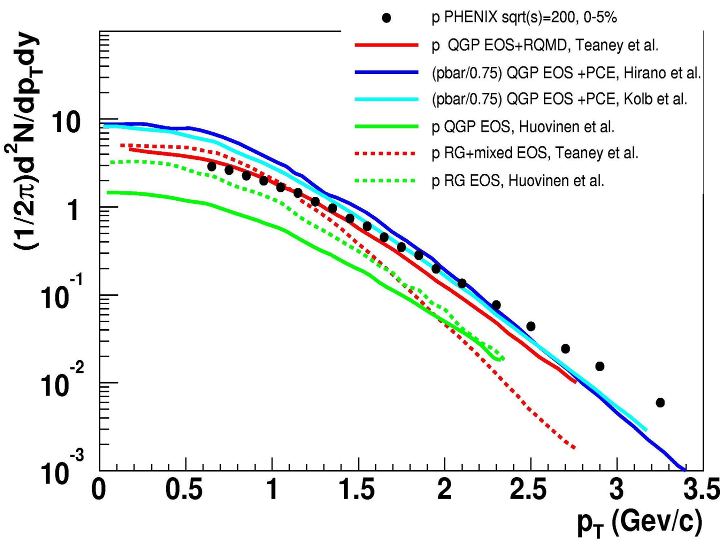
# hydrodynamics describes spectra and elliptic flow

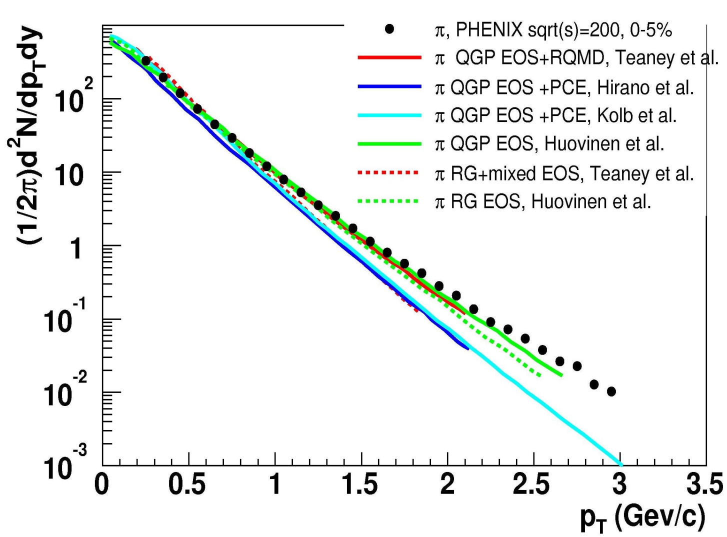
proton | pion




different hydrodyn. models:
Teaney *(w/ & w/o RQMD)*
Hirano *(3d)*
Kolb
Huovinen *(w/& w/oQGP)*



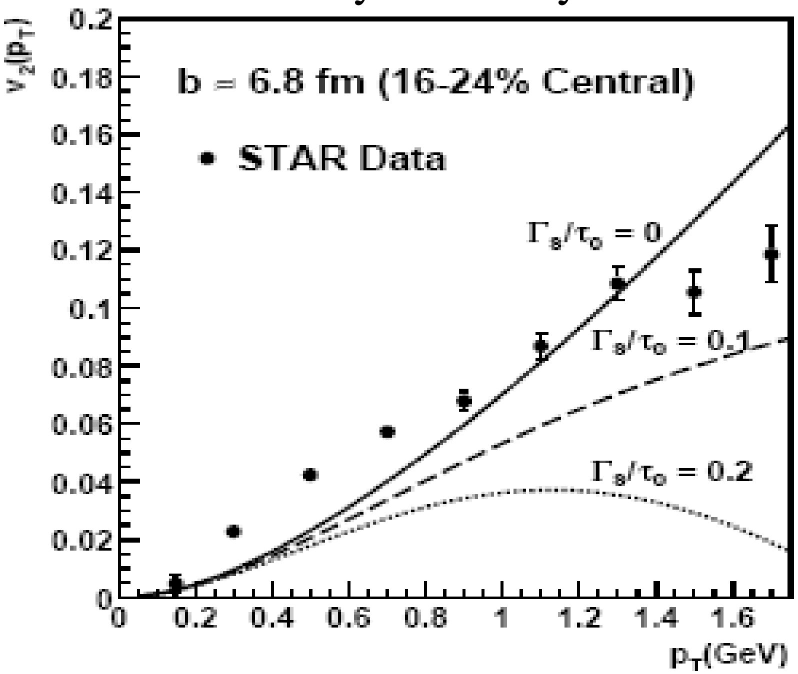




works up to $\simeq$ 2 GeV/c
but not perfectly
requires very fast equilibration (< 1 fm/c)
strong interactions
at short times
origin?

# sQGP

low viscosity (maybe zero?) implies strong interactions
not ideal gas - actually this was realized from lattice results a long time
conjecture: QGP produced at RHIC is strongly interacting
lately a lot of excitement connected to AdS/CFT equivalence
what about LHC? does this change at higher T?

D. Teaney, PRC68, 034913 (2003)
first order hydro 'wo dynamics'




not enough work on viscous hydro
in the last 5 years, but more is starting ...
see e.g. Romatschke arXiv 0706.1522
& Teaney's talk today & Son/Heinz
qualitative trends established
still many open issues when it comes to
quantitative comparison to data

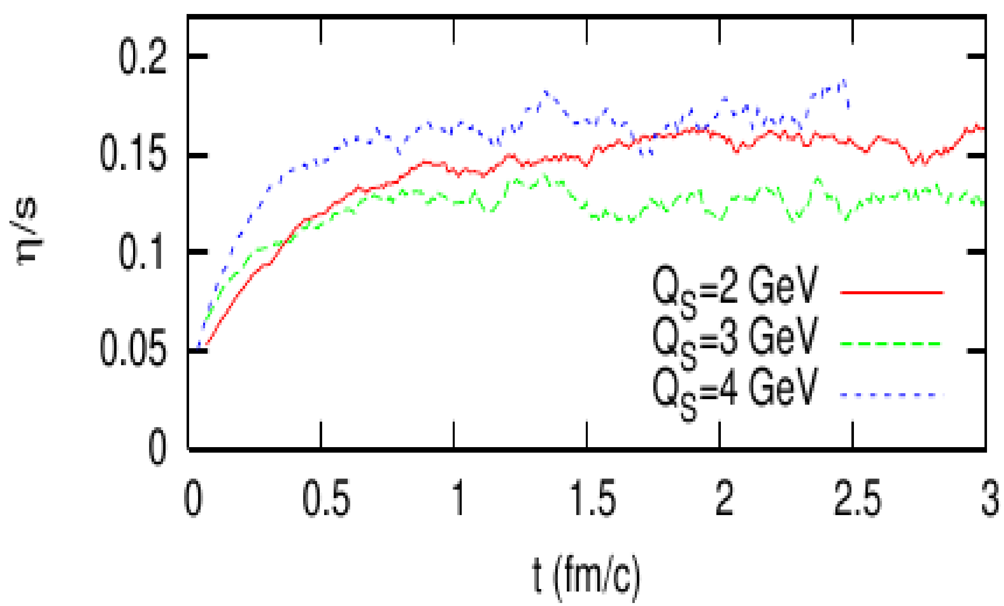
# alternatively: theoretical determination of viscosity

determination of viscosity/entropy density from lattice QCD via correlation function of energy-momentum tensor
H.B.Meyer arXiv 0704.1801 [hep-lat]

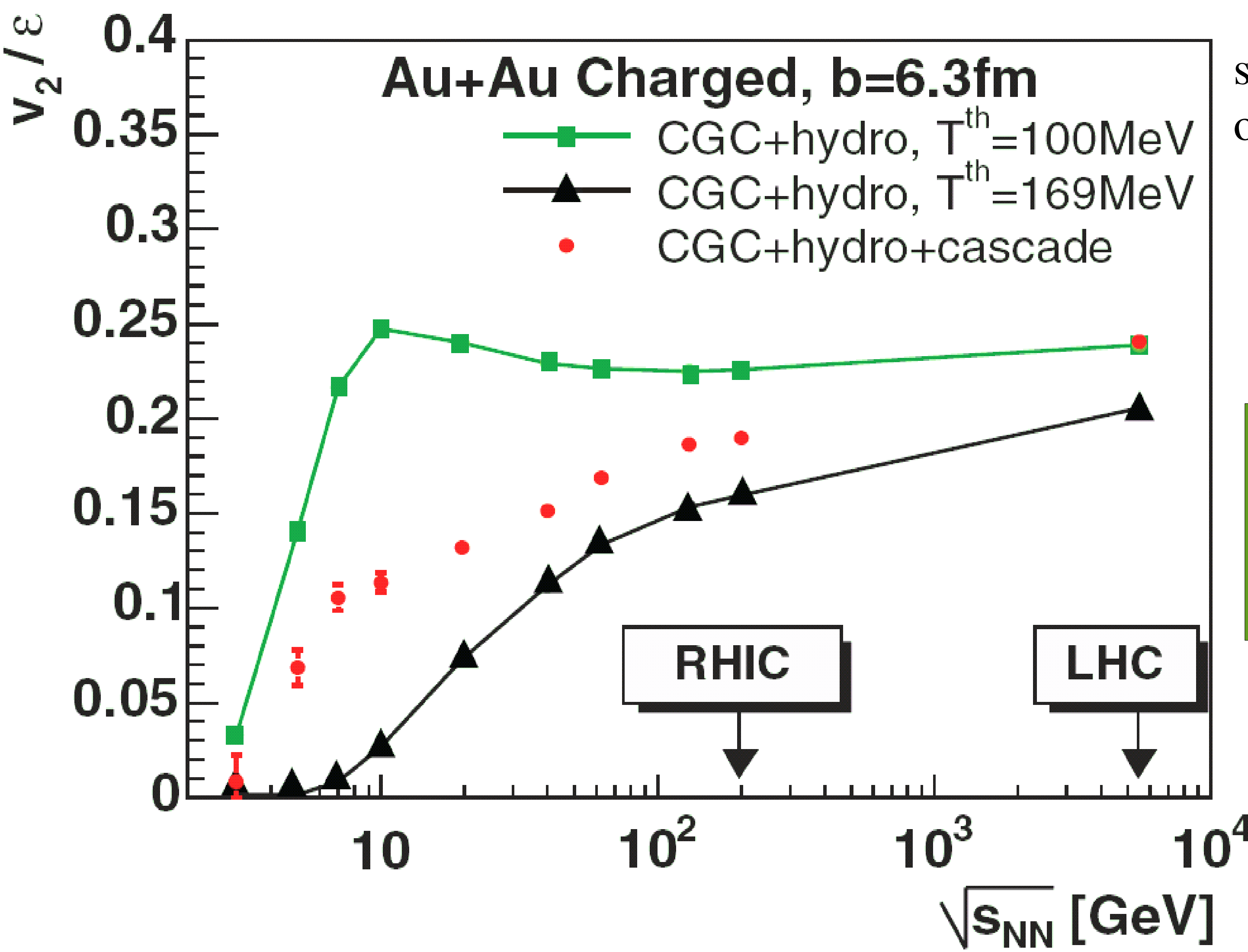
$\eta/s$ = 0.134(33) at T=1.65 Tc
0.101(45) 1.24

C. Greiner et al. using perturbative kinetic parton cascade get

$\eta/s = 0.15$



# elliptic flow at LHC: most models predict stronger effects – sensitivity to initial and final condition and to EOS



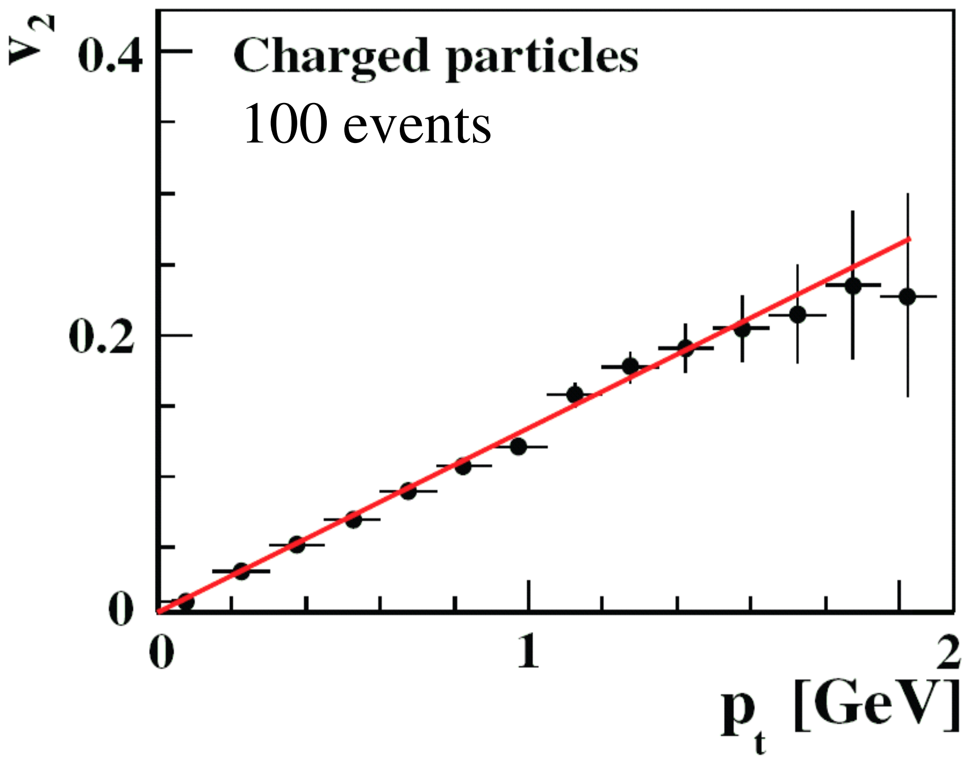

scaled to eccentricity of overlap region

$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

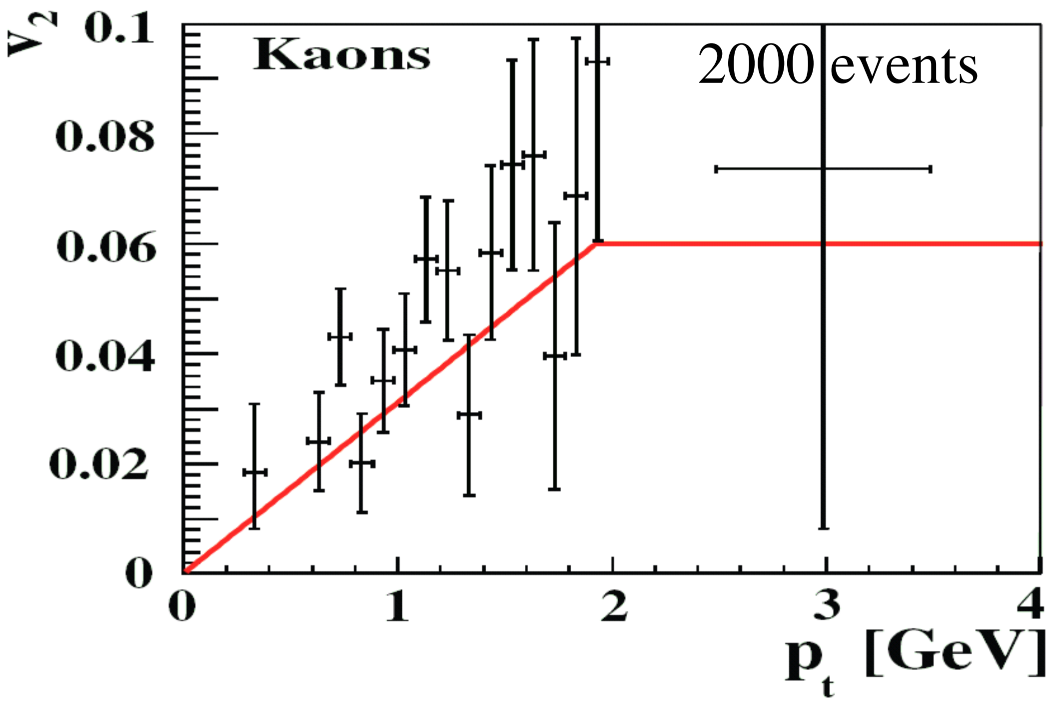
but at very high T the plasma could become weakly interacting

T. Hirano et al., J.Phys.G34 (2007)S879

# how well will elliptic flow be measured in ALICE at LHC?




for 2000 charged particles:
reaction plane resolution 8°
statistics plentiful
good particle identification



# 3. Charmonia as signature for deconfinement

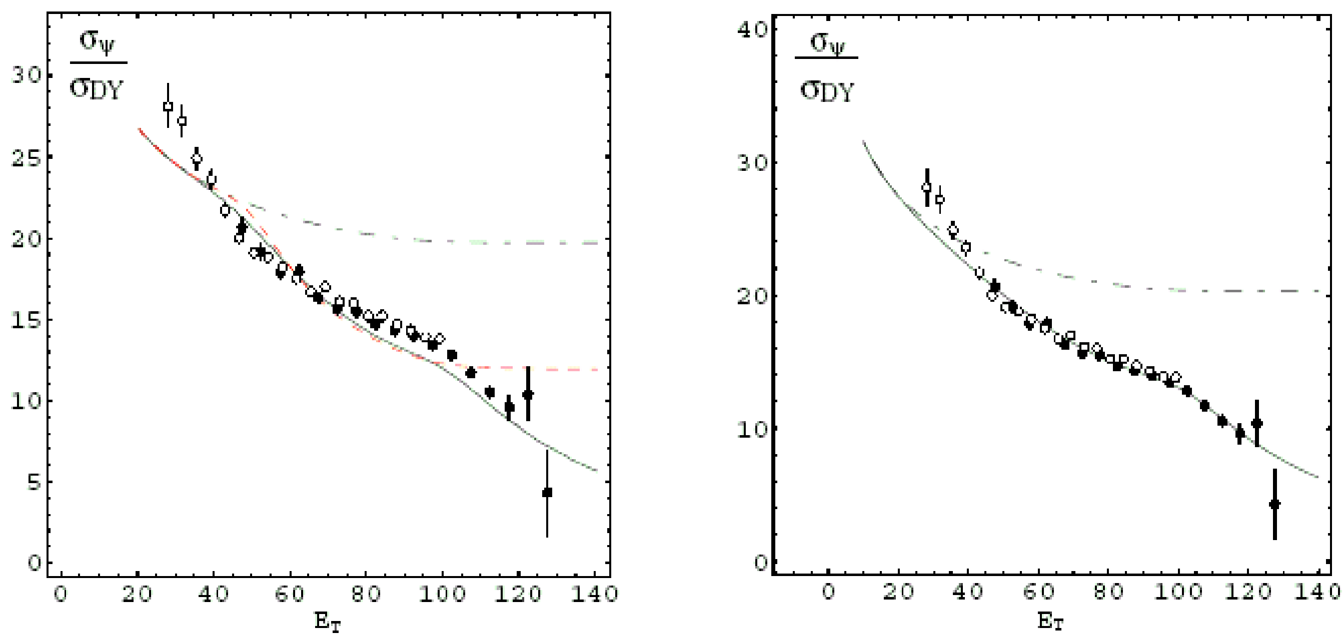
- T. Matsui and H. Satz (PLB178 (1986) 416) predict J/ψ suppression in QGP due to Debye screening
- significant suppression seen in central PbPb at top SPS energy (NA50) in line with QGP expectations

J.P. Blaizot, P.M. Dinh, J.Y. Ollitrault, Phys.Rev.Lett.85(2000)4012

Dissolution in QGP at critical density $n_c$ (dashes)

and with energy density fluctuations (solid)

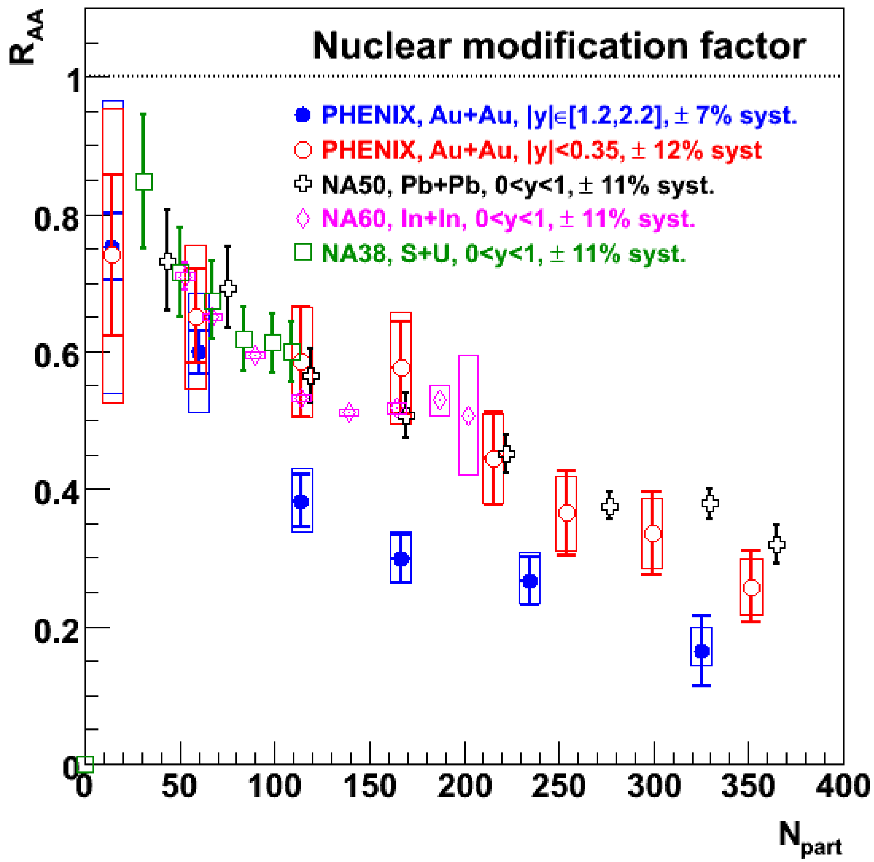
$n_c$=3.7/fm$^2$ $n_{c1}$=3.3 and $n_{c2}$=4.2/fm$^2$




DELBERG

# J/ψ production in AuAu collisions at RHIC

PRL 98 (2007) 232301



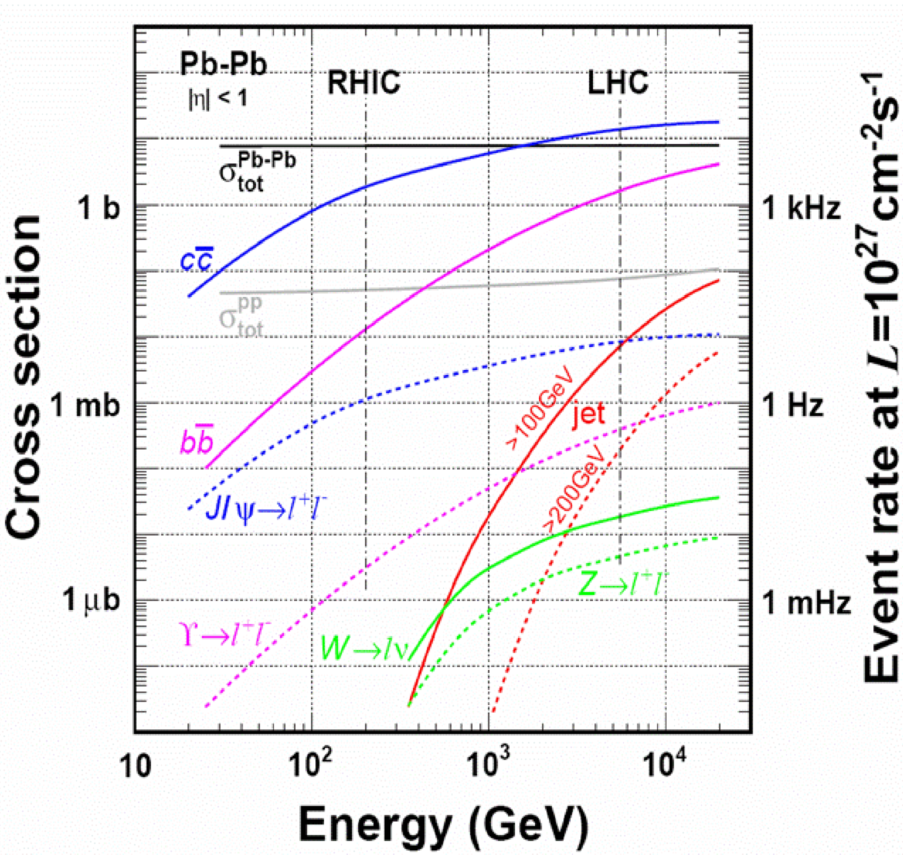

$R_{AA}$: J/ψ yield in AuAu / J/ψ yield in pp times $N_{coll}$

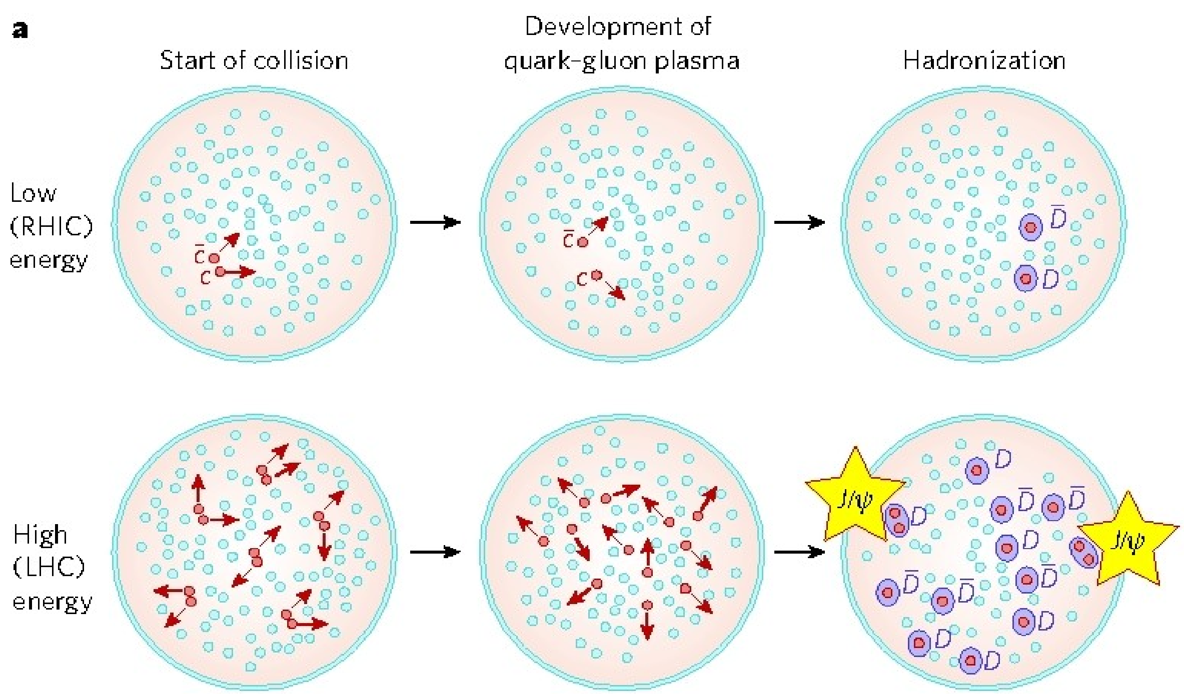
at mid-rapidity suppression at RHIC very similar to SPS

suppression at forward/backward rapidity stronger!

- but prediction:
  at hadronization of QGP J/ψ can form again from deconfined quarks, in particular if number of ccbar pairs is large
  $N_{J/\psi} \propto N_{cc}^{2}$
  (P. Braun-Munzinger and J.Stachel, PLB490 (2000) 196)

## what happens at higher beam energy when more and more charm-anticharm quark pairs are produced?



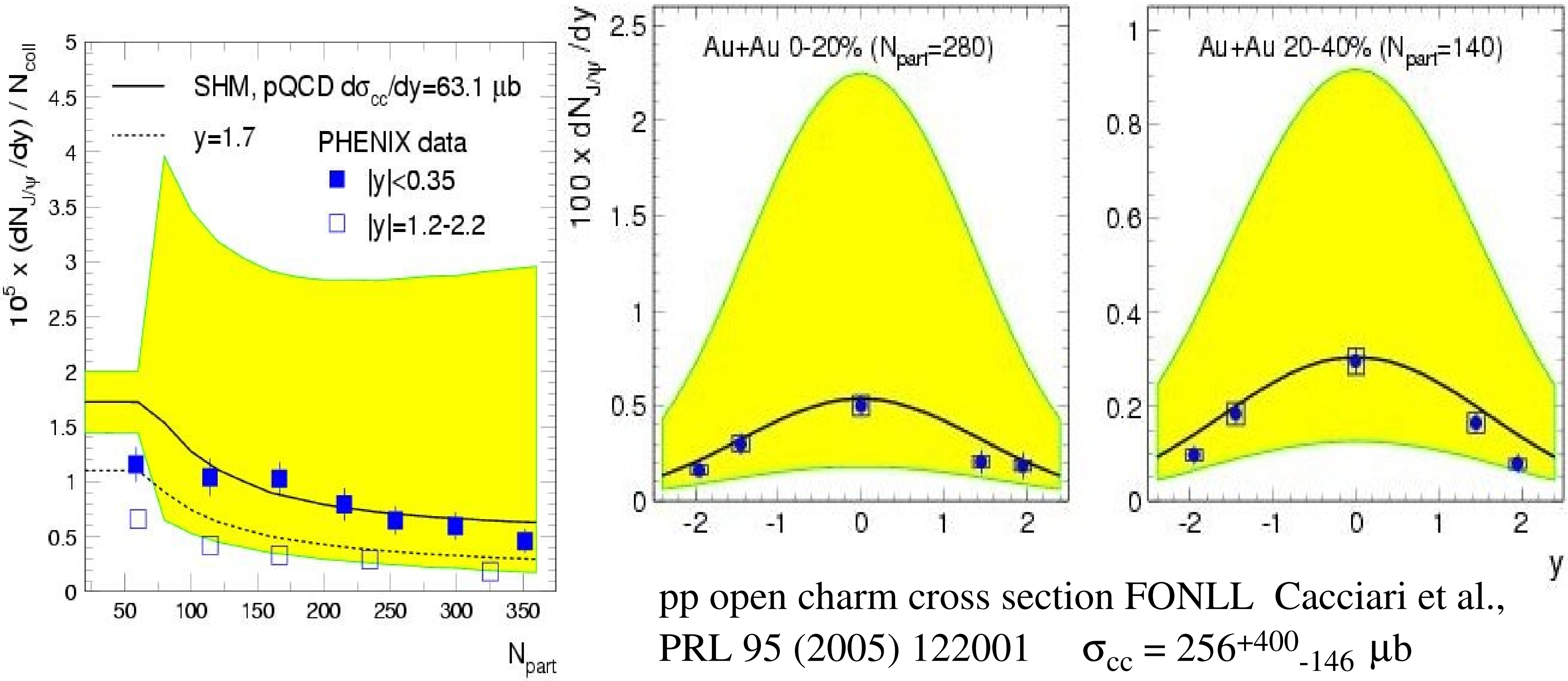

low energy: few c-quarks per collision → **suppression** of J/ψ

high energy: many " " → **enhancement** "

**unambiguous signature for QGP!**

# comparison of model predictions to RHIC data: centrality dependence and rapidity distribution

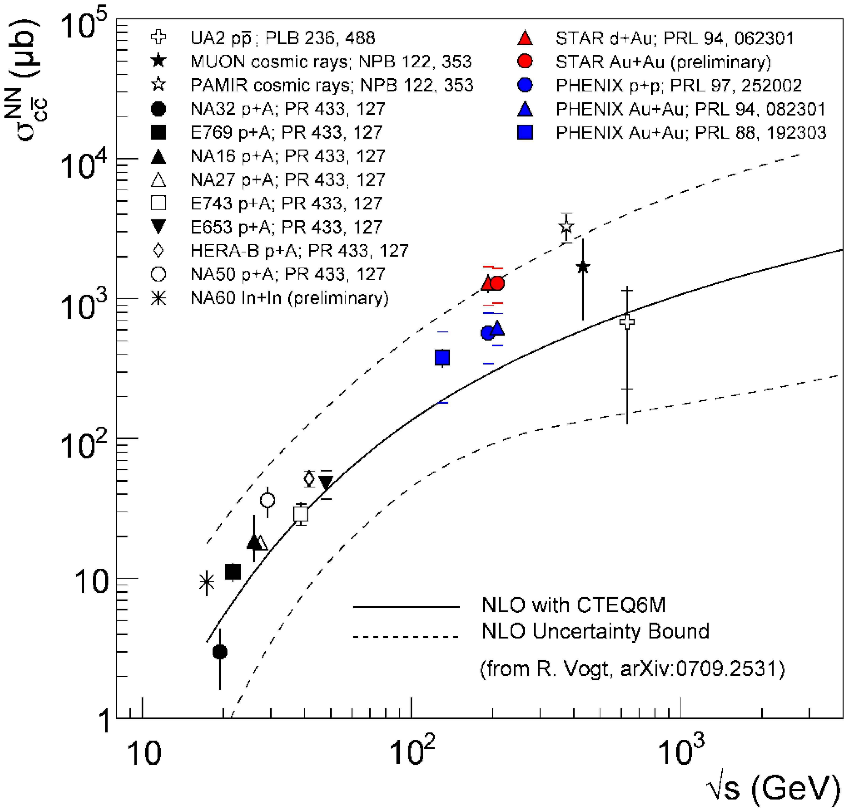
P. Braun-Munzinger, K. Redlich, J. Stachel, Nucl. Phys. A789 (2007) 334 nucl-th/0611023




pp open charm cross section FONLL Cacciari et al., PRL 95 (2005) 122001 $\sigma_{cc} = 256^{+400}_{-146}$ μb

good agreement, no free parameters ⟷ but need for good open charm measurement obvious (this is a lesson for LHC as well!)

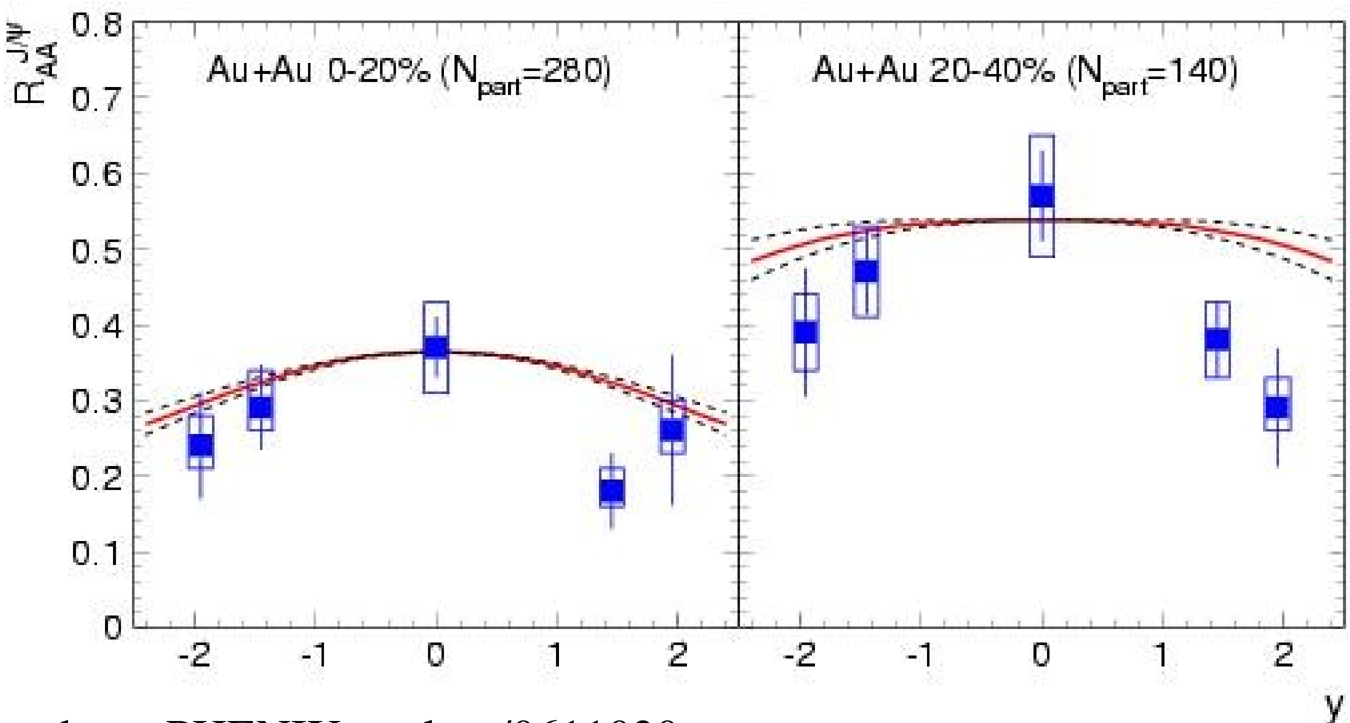
# systematics of charm cross section compared to NLO pQCD




pQCD cross section consistent with data
(modulo discrepancy between STAR and PHENIX)
only in spectra at higher pt some deviation

# but there is a more revealing normalization:

$R_{AA}$: J/ψ yield in AuAu / J/ψ yield in pp times $N_{coll}$




quantitative agreement!

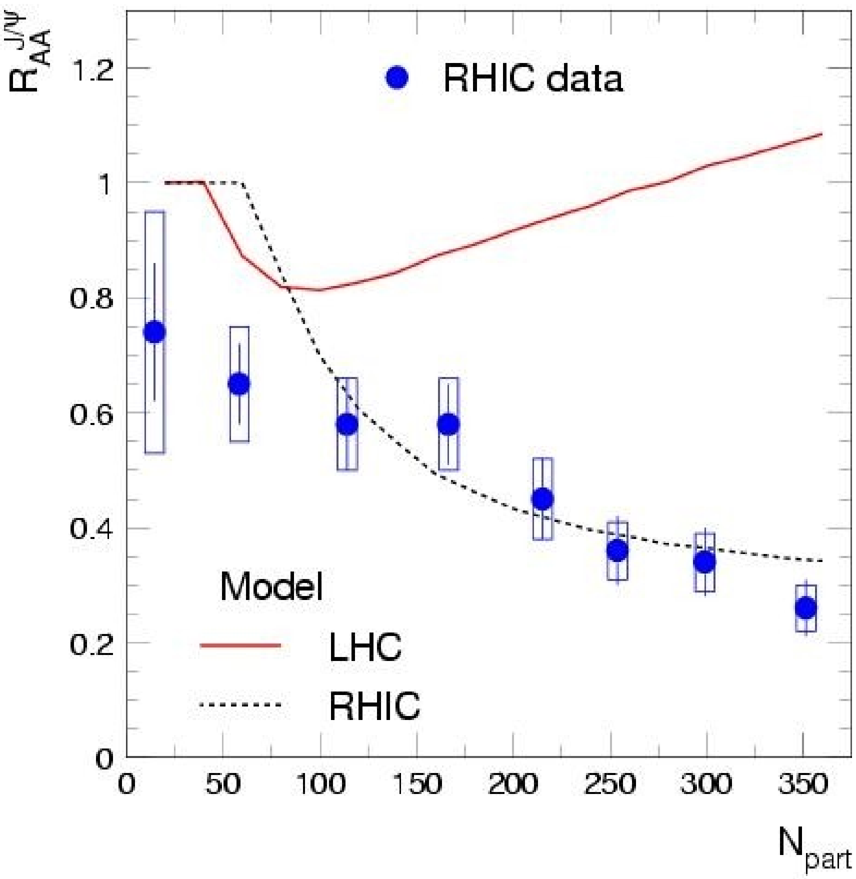
data: PHENIX nucl-ex/0611020
additional 14% syst error beyond shown

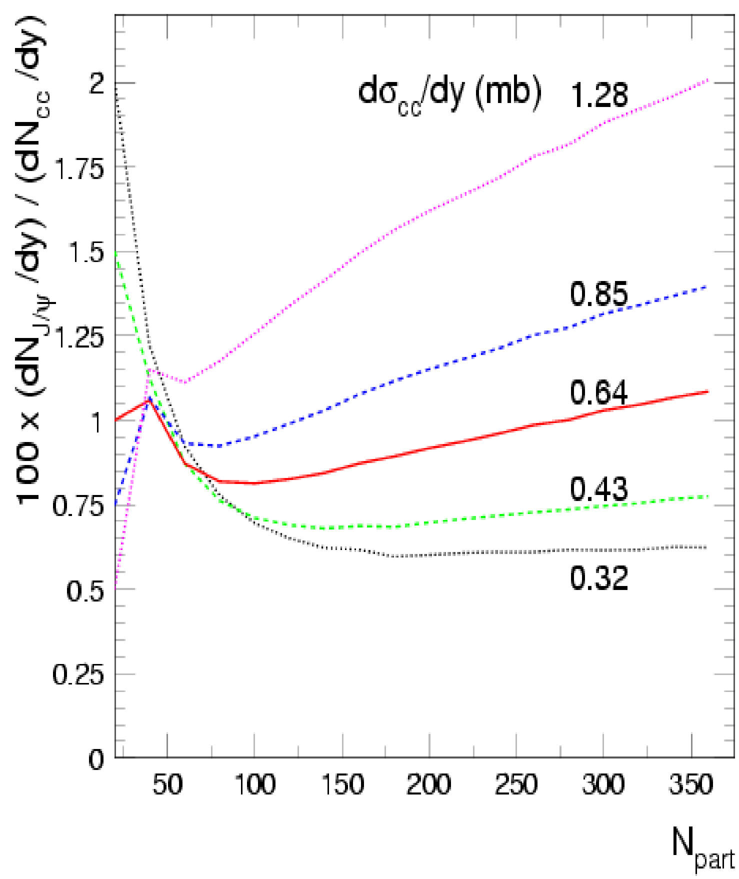
model: A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B652 (2007) 259

remark: y-dep opposite in 'normal Debye screening' picture; suppression strongest at midrapidity (largest density of color charges)

# energy dependence of quarkonium production in statistical hadronization model

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B652 (2007) 259



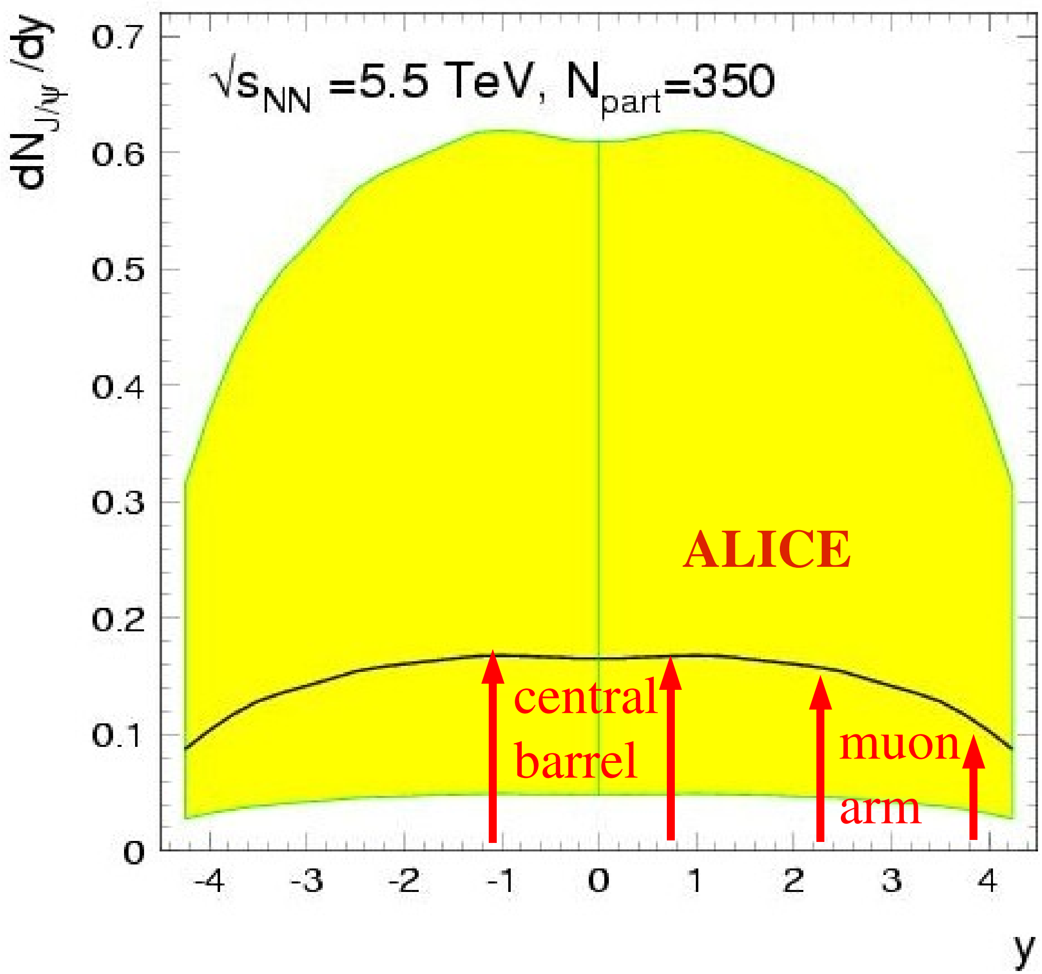



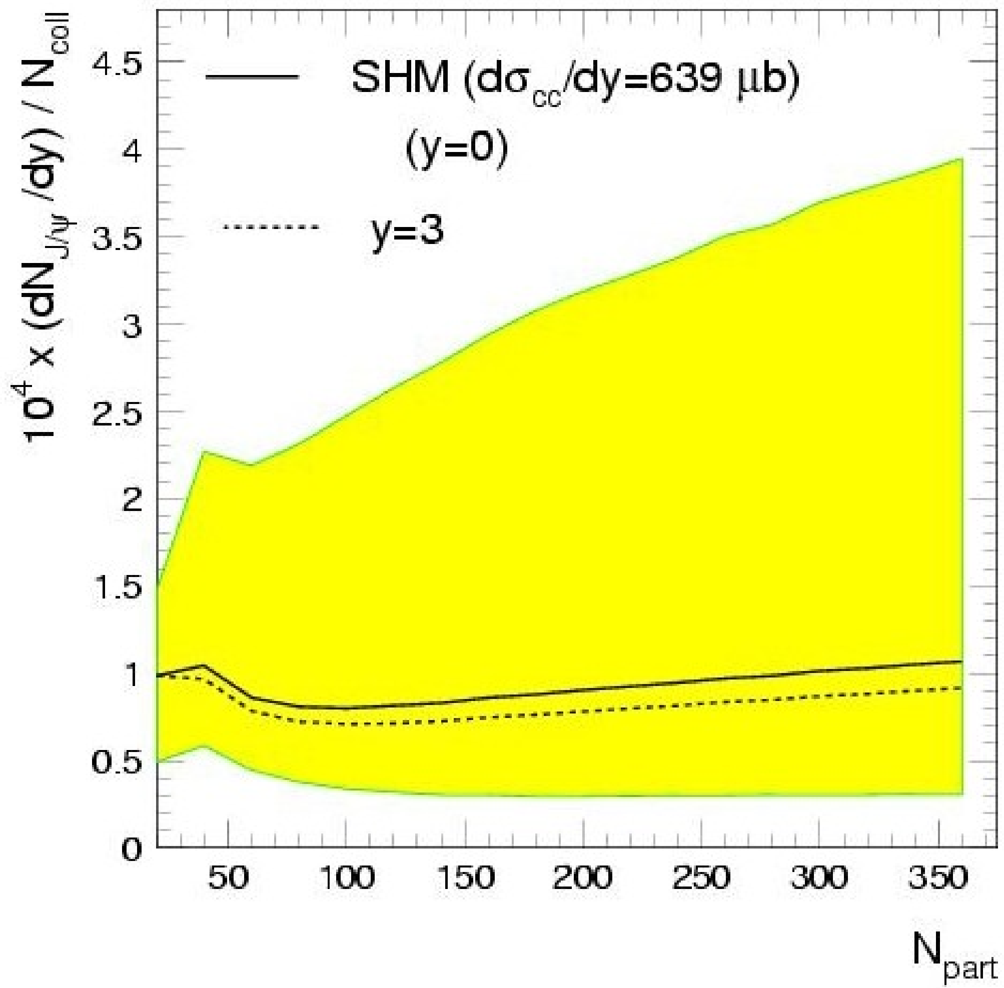

centrality dependence and enhancement beyond pp value will be fingerprint of statistical hadronization at LHC

**-> direct signal for deconfinement**

# predictions for charmonium rapidity and centrality distributions at LHC

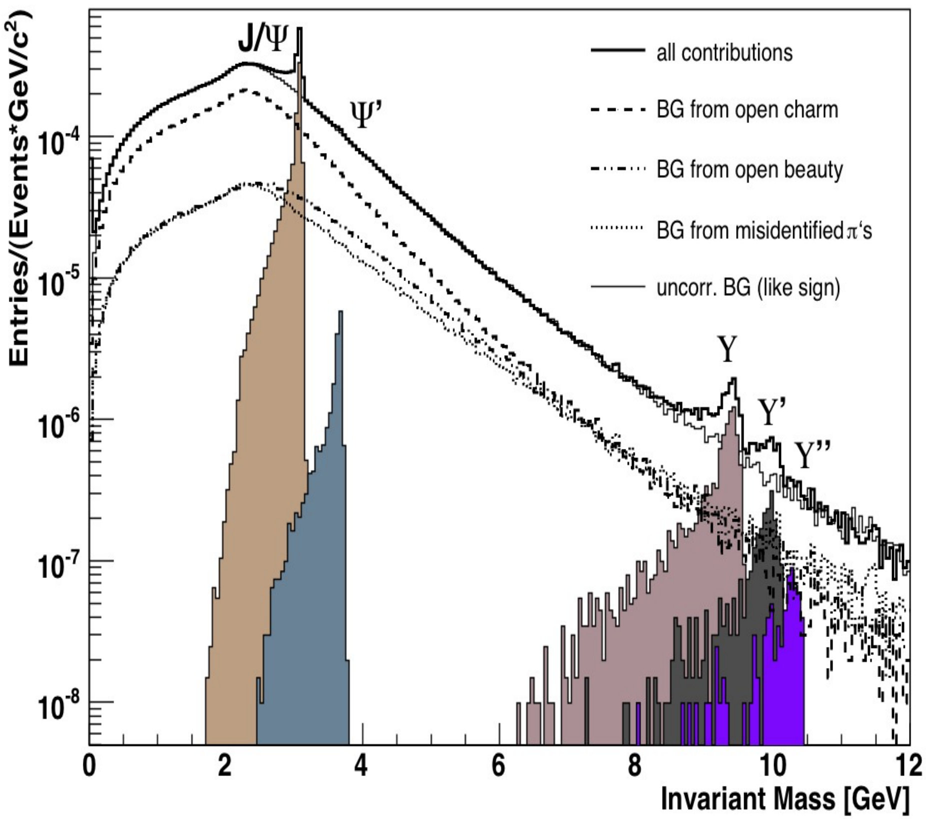
yellow band: uncertainty of pQCD prediction for ccbar prod.     line: central value

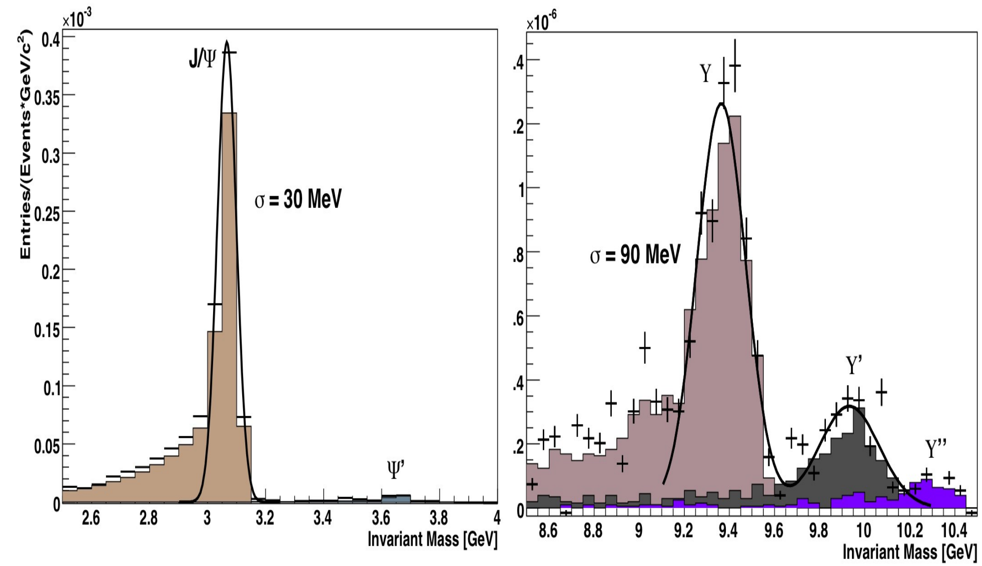


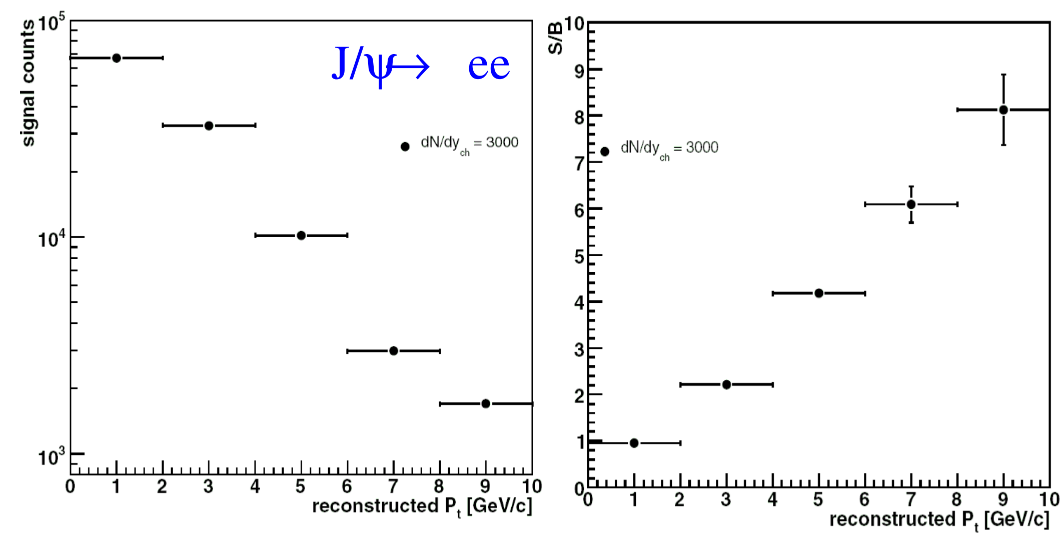



# measurement of charmonia in ALICE at mid-rapidity

electron identification with TPC and TRD



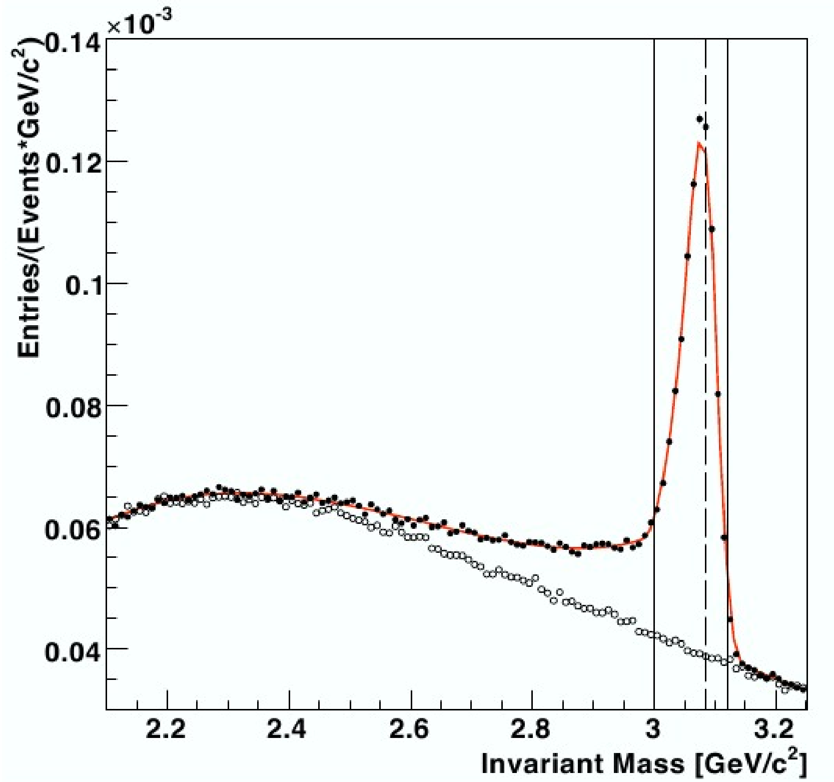




Simulation: W. Sommer (Frankfurt) $2{\cdot}10^8$ central PbPb coll.

Good mass resolution and signal to background
expect w full TRD and trigger 2500 Upsilon per PbPb year

# full simulation of central barrel performance

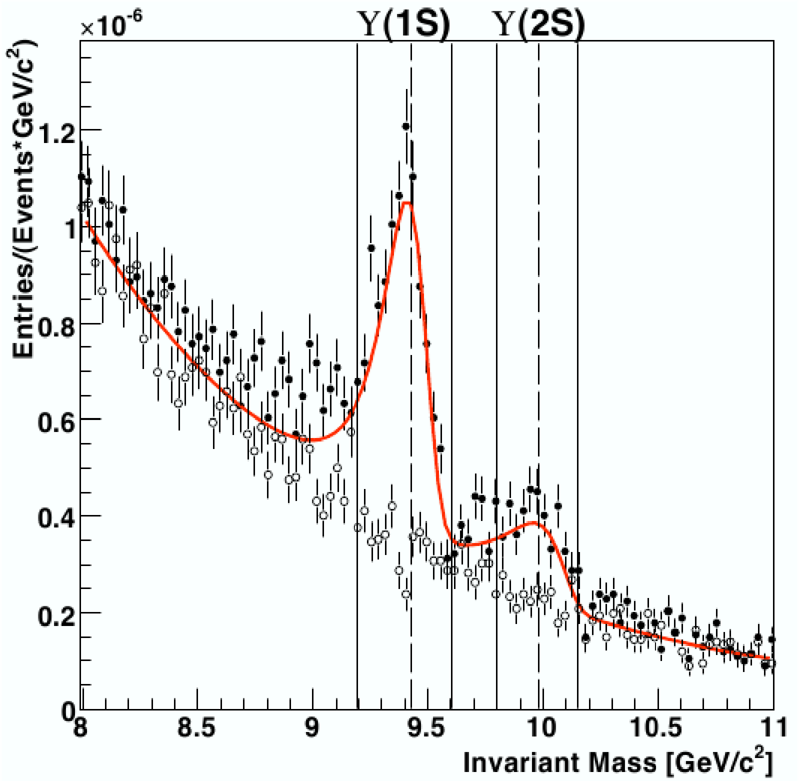
$2\times10^8$ central (10%) events, $10^6$ sec (1 year run)




**J/ψ:**
S/B = 1.47
sgn = 284
signal = 1.3 × $10^5$
FWHM = 65 MeV/$c^2$

**ψ':**
S/B = 0.05
sgn = 10.5
signal = 23

$2\times10^8$ central (10%) events, $10^6$ sec (1 year run)




**ϒ:**
S/B = 1.03
sgn = 25.0
signal = 1378
FWHM = 200 MeV/$c^2$

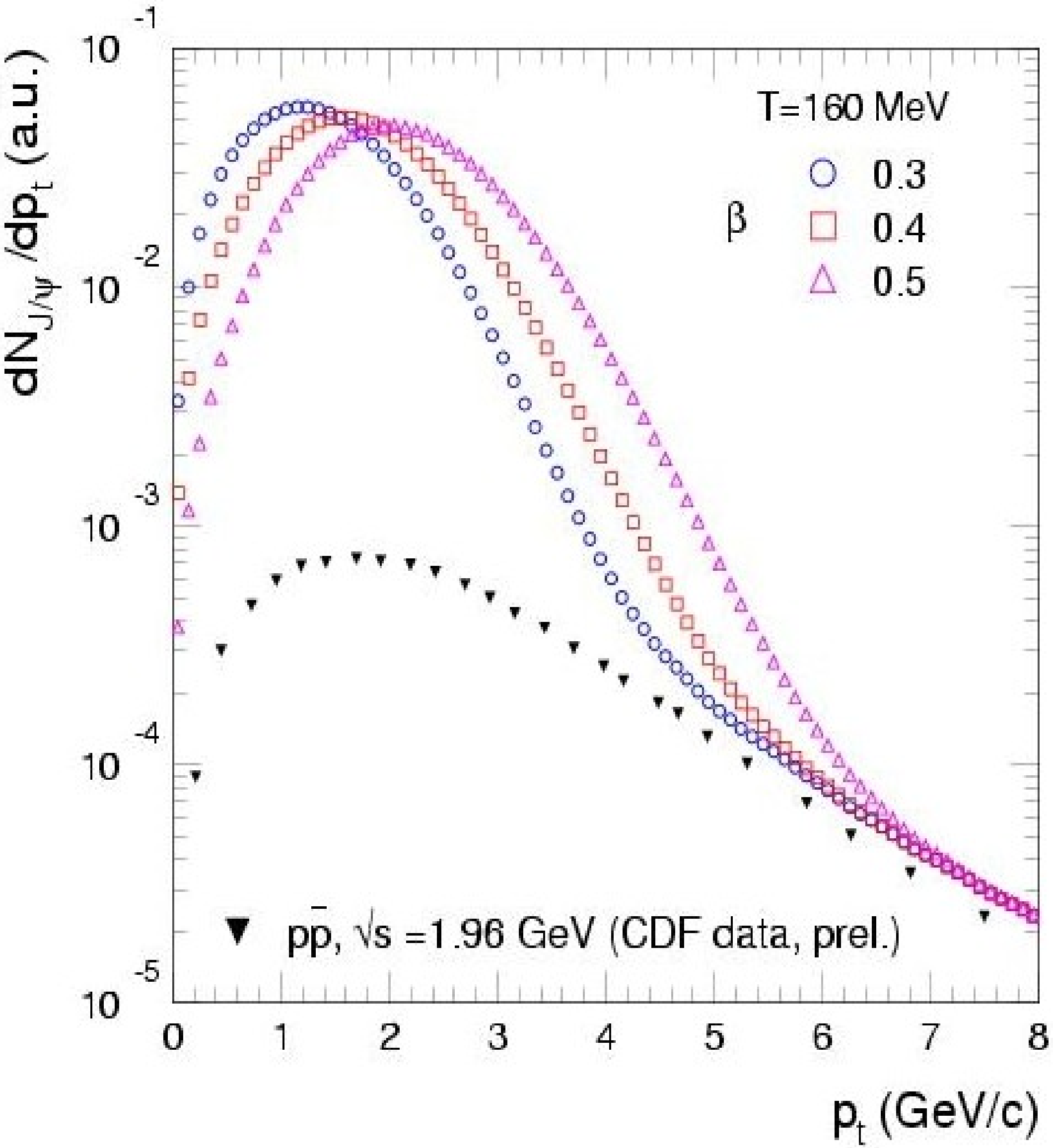
D. Krumbhorn, Heidelberg

# flow of quarkonia at LHC?

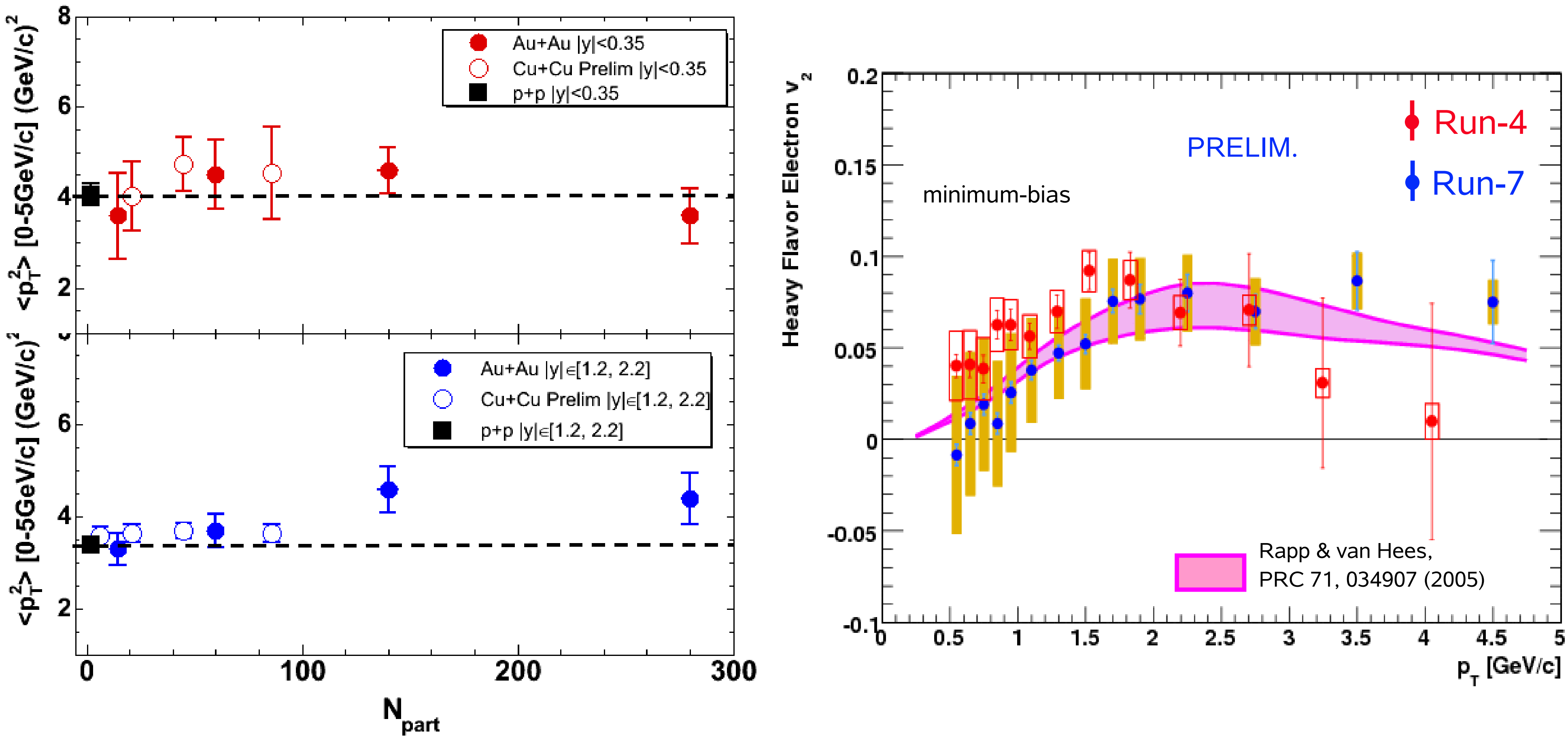
there is evidence from RHIC that fireball is expanding hydrodynamically
do heavy quarks follow?

$p_t$ spectra with flow are very different for charmonia from those measured in pp_bar e.g. at Fermilab or expected for pp at LHC

should be easy to discriminate at LHC

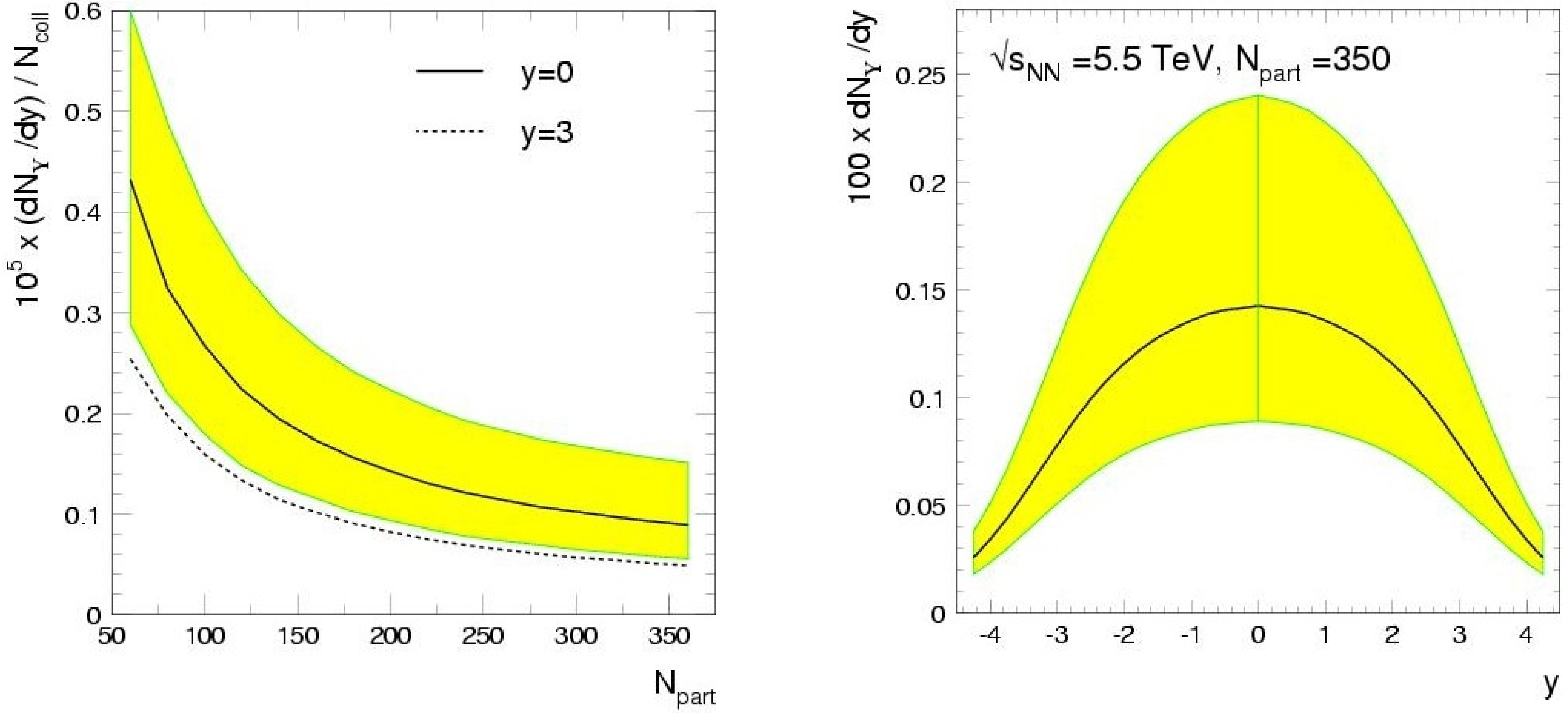


# charm quarks at RHIC: spectra don't show initial state scattering effects - follow elliptic flow



# bottomonium at LHC

predictions with statistical hadronization model




in terms of number of produced quarks, beauty at LHC like charm at RHIC

do they thermalize and hadronize statistically??

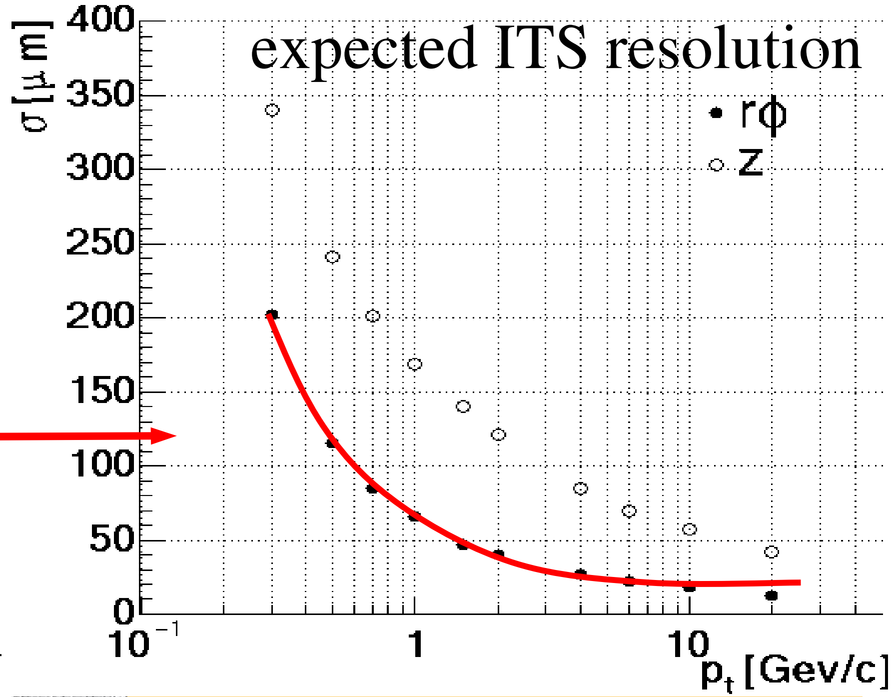
if yes, population of 2s and 3s states completely negligible (exp-Δm/T)

hydrodynamic flow? need to measure spectrum to 15 GeV

# open/hidden heavy flavor measurements in ALICE

- Hadronic decays: $D^0 \rightarrow K\pi$, $D^{+-} \rightarrow K\pi\pi$, $D_s \rightarrow K K^*$, $D_s \rightarrow \phi\pi$, …
- Leptonic decays:
  - $B \rightarrow l$ (e or μ) + anything
  - Invariant mass analysis of lepton pairs: BB, DD, $BD_{same}$, J/Ψ, Ψ', ϒ family, B →J/Ψ + anything
  - BB →μ μ μ (J/Ψ μ)
  - e-μ correlations

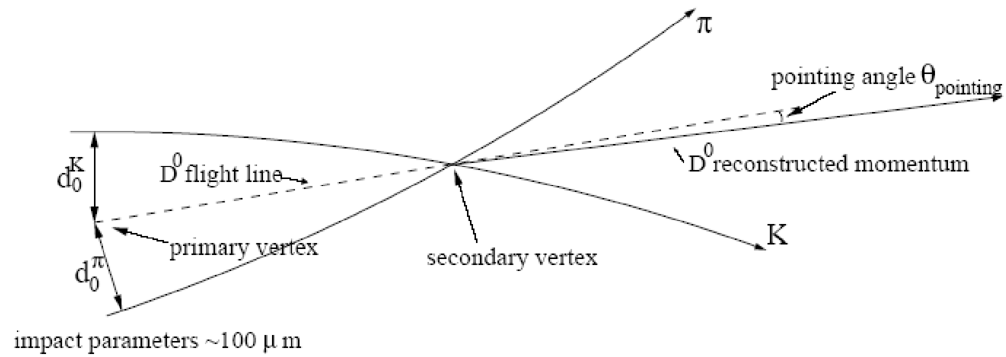
id. hadrons, electrons: -0.9 < y < 0.9
muons: y=2.5-4.0
in central barrel: vertex cut effective for heavy quark identification



# $D^0 \rightarrow K\pi$ channel

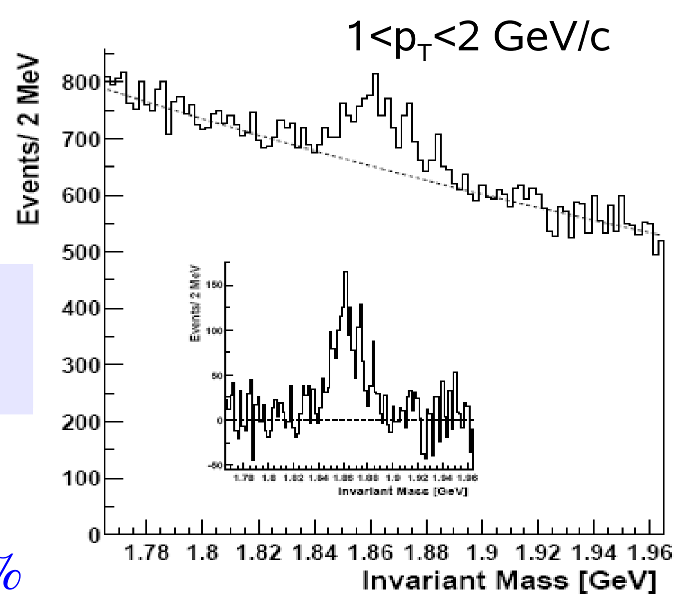
ALICE PPR vol2 JPG 32 (2006) 1295

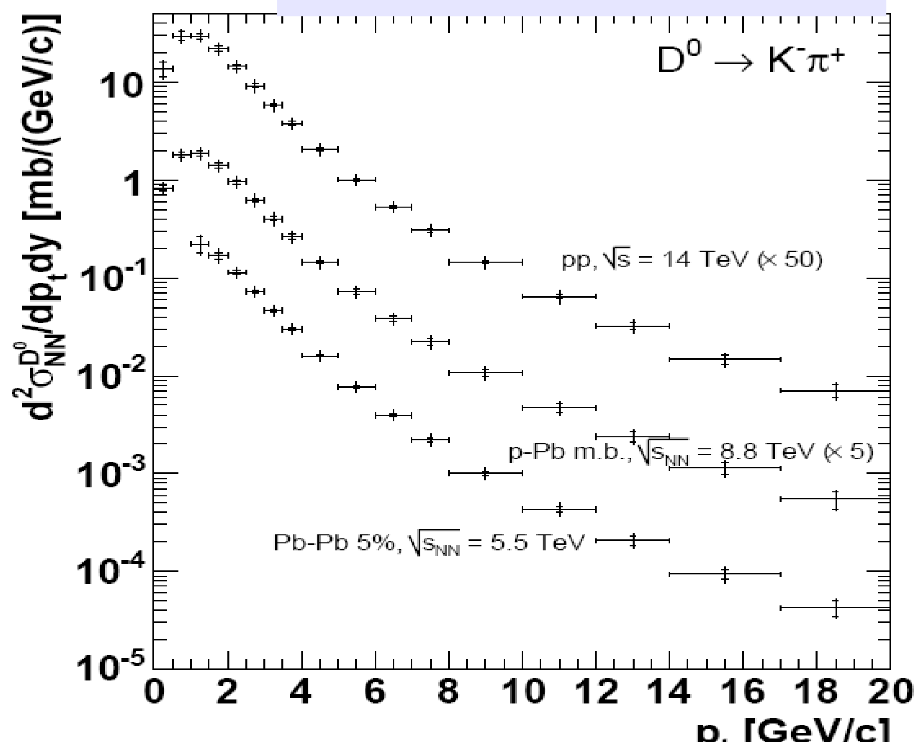
- high precision vertexing, better than 100 μm (ITS)
- high precision tracking (ITS+TPC)
- K and/or π identification (TOF)




$10^9$ pp  $10^8$ pPb  $10^7$ PbPb

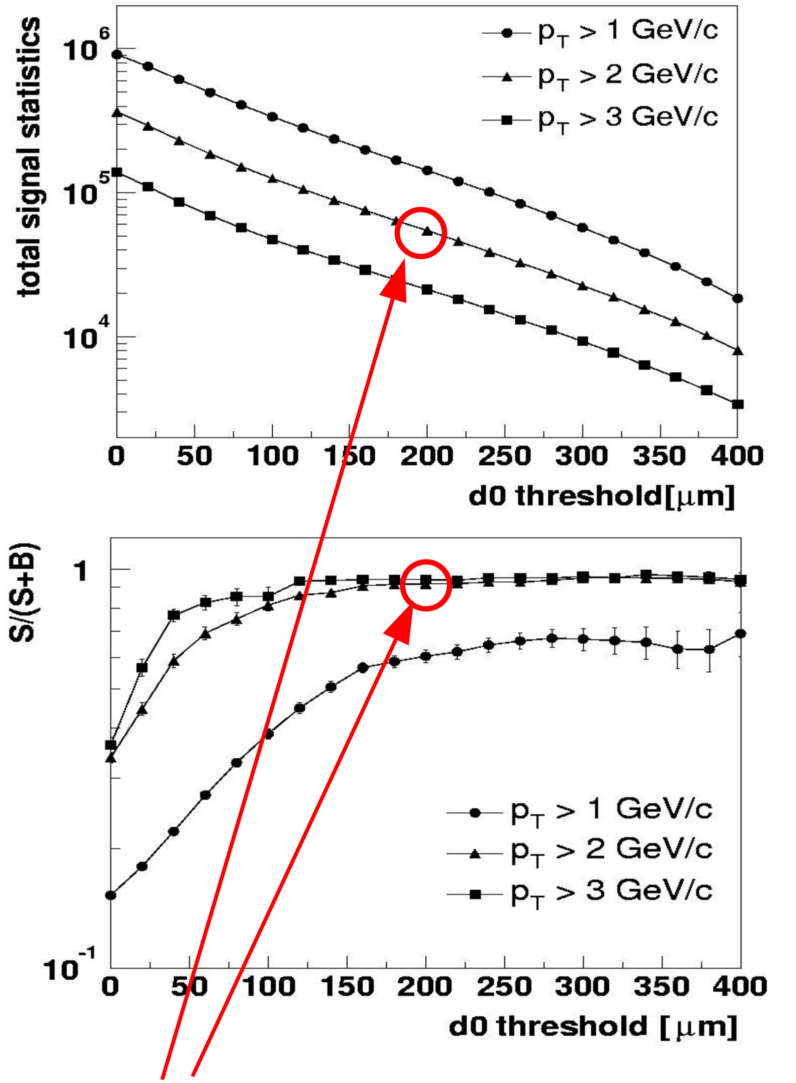
$10^7$ central PbPb

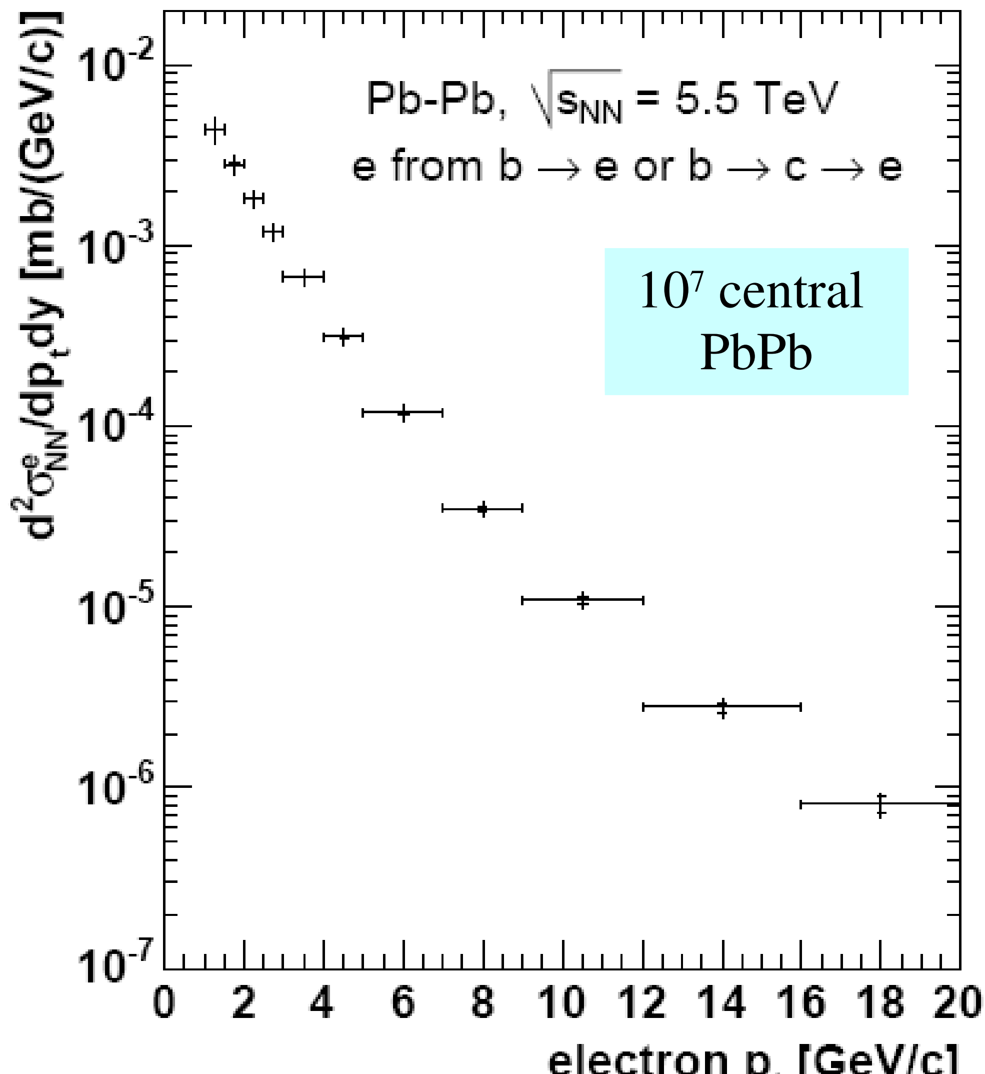



S/B = 10%
$S/\sqrt{(S+B)} = 40$

# open beauty from single electrons




$B \rightarrow e^{x}$ in ALICE ITS/TPC/TRD
$p_t > 2$ GeV/c & $d_0 = 200$ - $600$ μm:
80 000 electrons with S/(S+B) = 80%

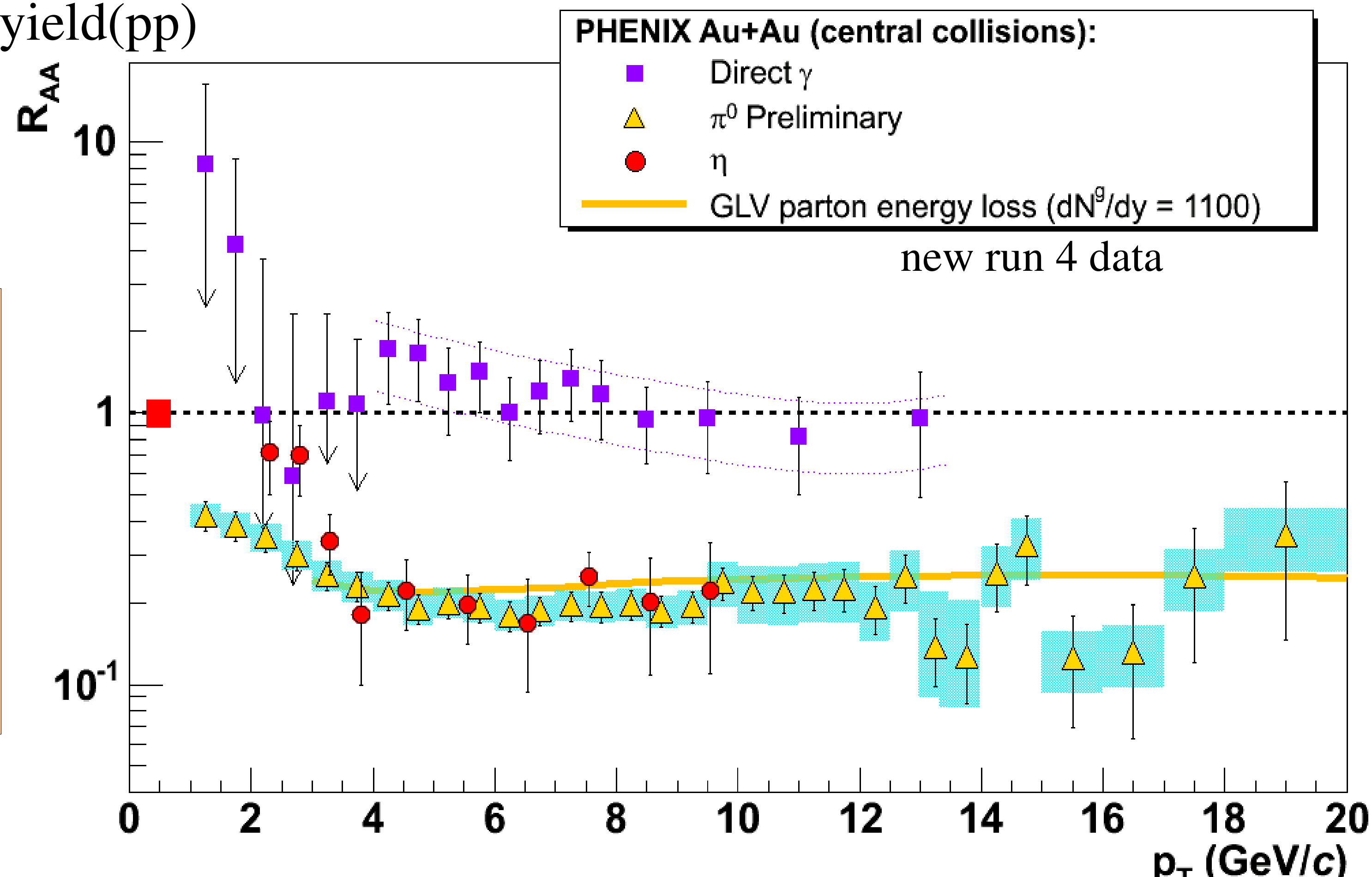
ALICE PPR vol2 JPG 32 (2006) 1295

# 4. high $p_t$ partons as probe of the medium, i.e. the QGP

prediction: in dense partonic matter a jet is losing energy rapidly
order several GeV/fm

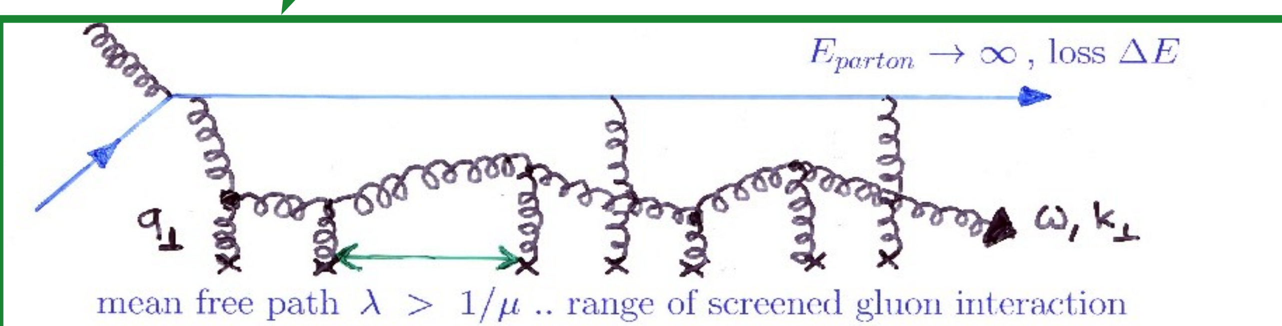
# RHIC result: jet quenching

$R_{AA}$=yield(AuAu)/$N_{coll}$ yield(pp)




high gluon density of the plasma induces energy loss of partons

most calculations based on radiation



# jet quenching indicative of high gluon rapidity density

I. Vitev, JPG 30 (2004) S791

| | $\tau_0[fm]$ | $T[MeV]$ | $\varepsilon[GeV/fm^3]$ | $\tau_{tot}[fm]$ | $dN^g/dy$ |
|---|---|---|---|---|---|
| **SPS** | **0.8** | **210-240** | **1.5-2.5** | **1.4-2** | **200-350** |
| **RHIC** | **0.6** | **380-400** | **14-20** | **6-7** | **800-1200** |
| **LHC** | **0.2** | **710-850** | **190-400** | **18-23** | **2000-3500** |

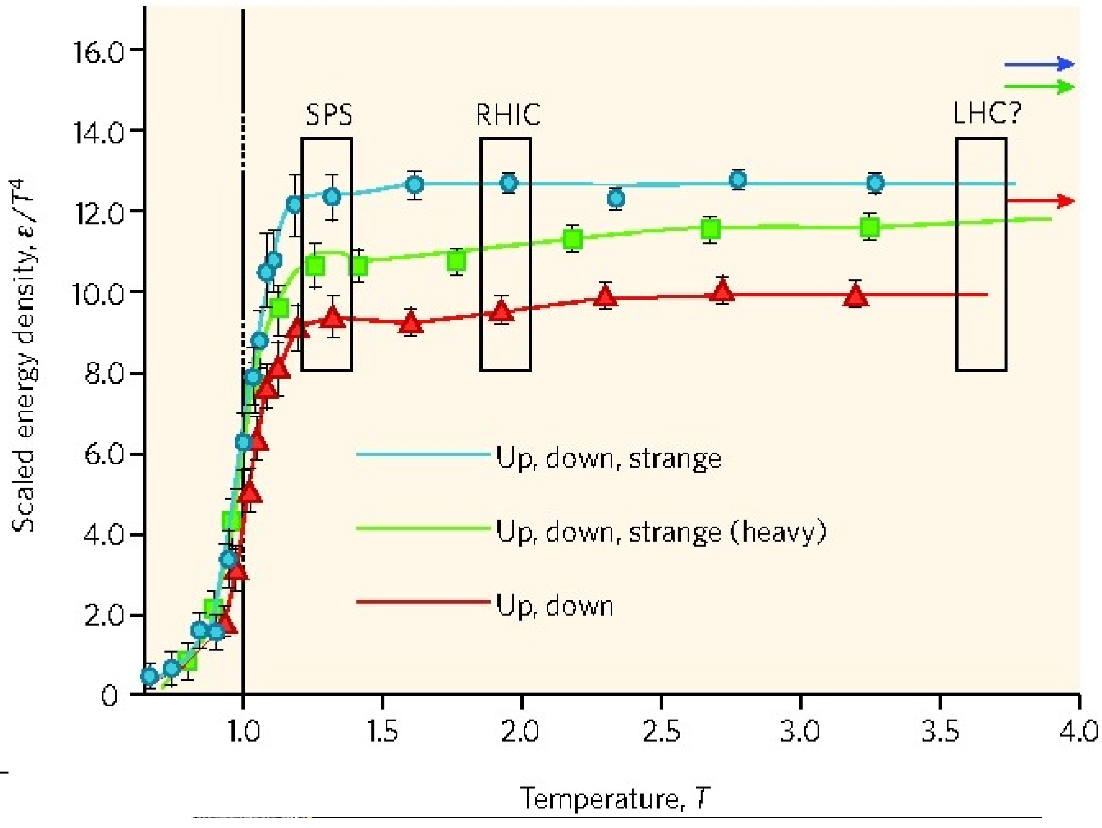
- **Consistent estimate with hydrodynamic analysis**

several mechanisms describe jet quenching at RHIC -> predictions for LHC span very wide range

- $R_{AA}$ stays at 0.2 out to 100 GeV or so
- $R_{AA}$ rises slowly toward high pt
- $R_{AA}$ much smaller than at RHIC

need to cover large $p_t$ range

go beyond leading particle analysis identified jets, frag. function, ...



# jet measurements in ALICE

**2 GeV** **20 GeV** **100 GeV** **200 GeV**

**Mini-Jets 100/event** **1/event** **1 Hz** **100k/month**

**at p > 2 GeV/c :**

**- leading particle analysis**

**- correlation studies**

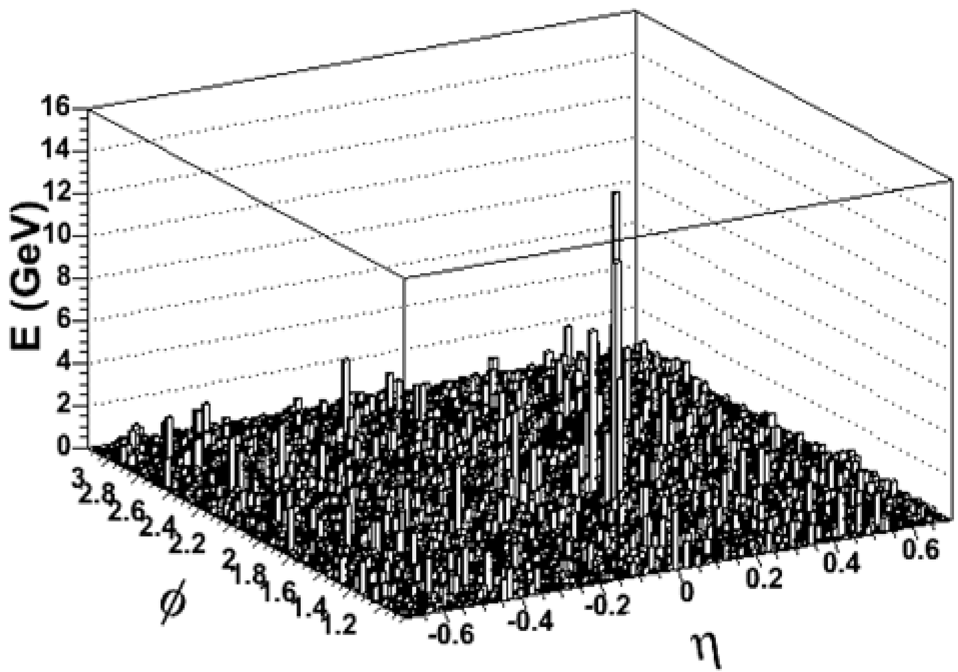
**(similar to RHIC)**

**at high p:**

**- reconstructed jets**

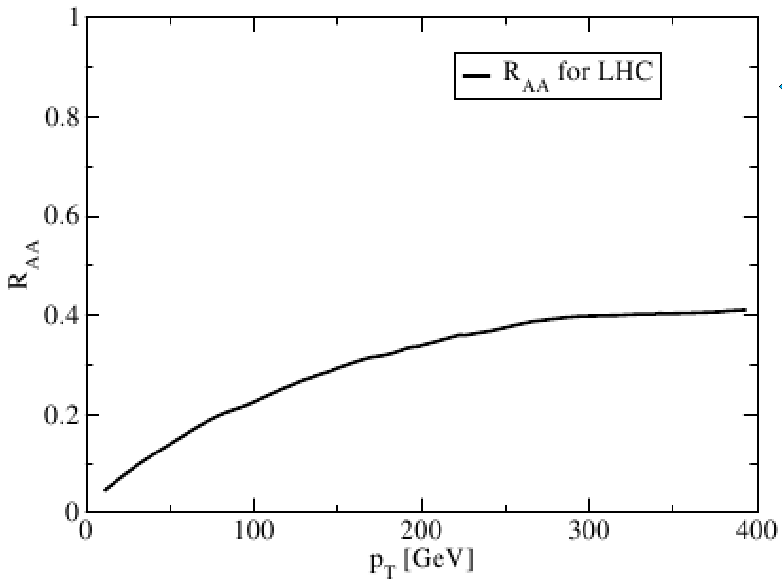
**- event-by-event well distinguishable objects**

Example :
100 GeV jet +
underlying event



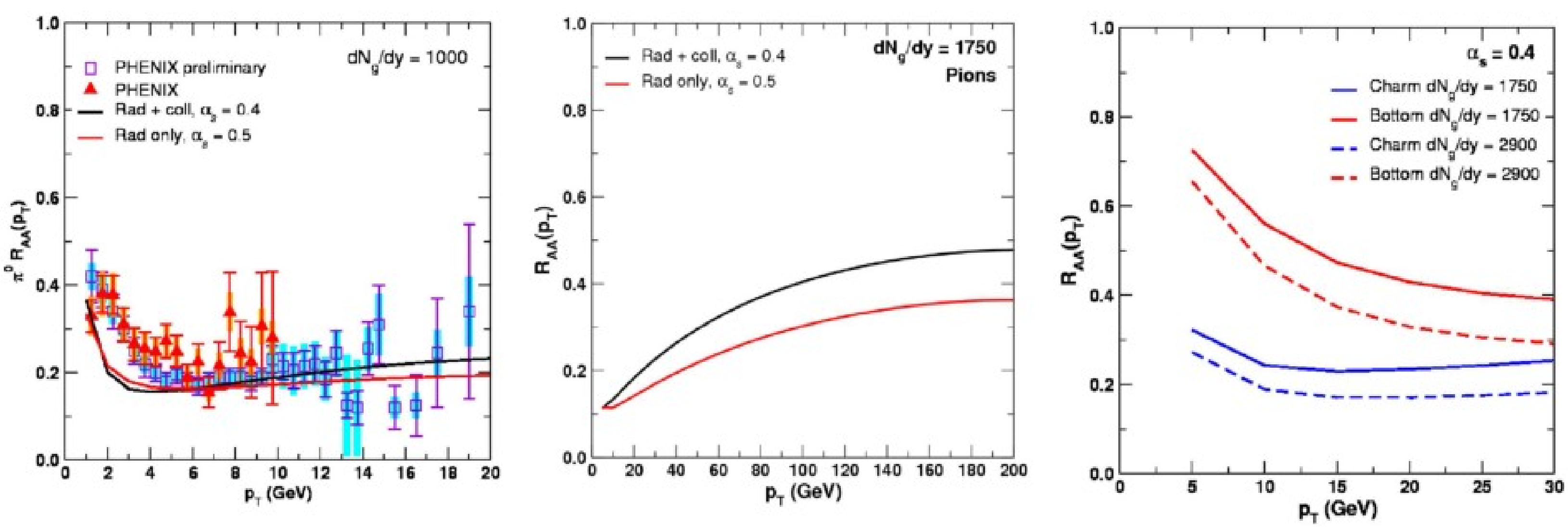

for jet physics recently added EmCal will play important role in conjunction with existing charged particle tracking

# LHC: increase in gluon density and very high jet energy reach to pin down energy loss mechanism



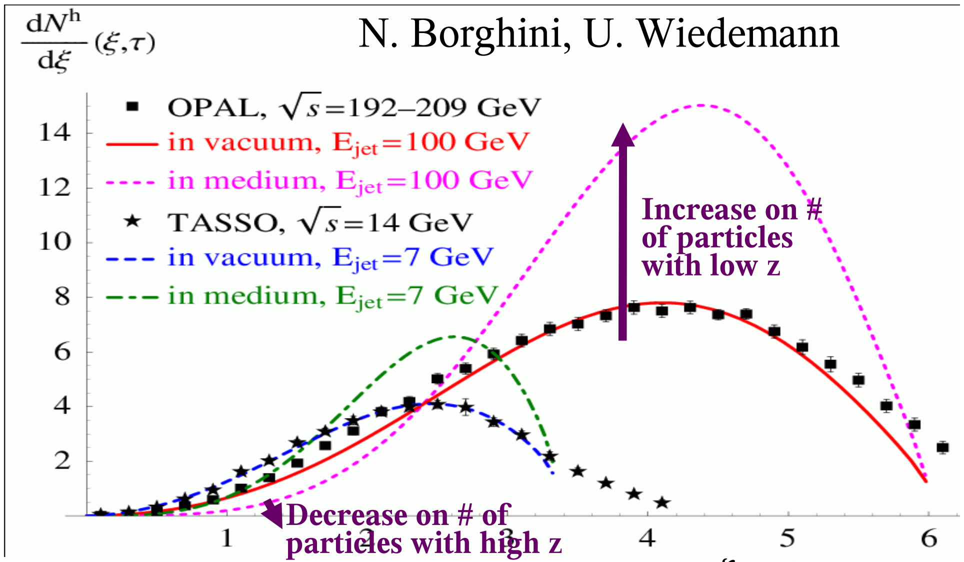

Renk and Eskola, expanding QGP
BDMPS energy loss; midrapidity at LHC

Wicks and Gyulassy, sensitivity to gluon dens. and E-loss mechanism

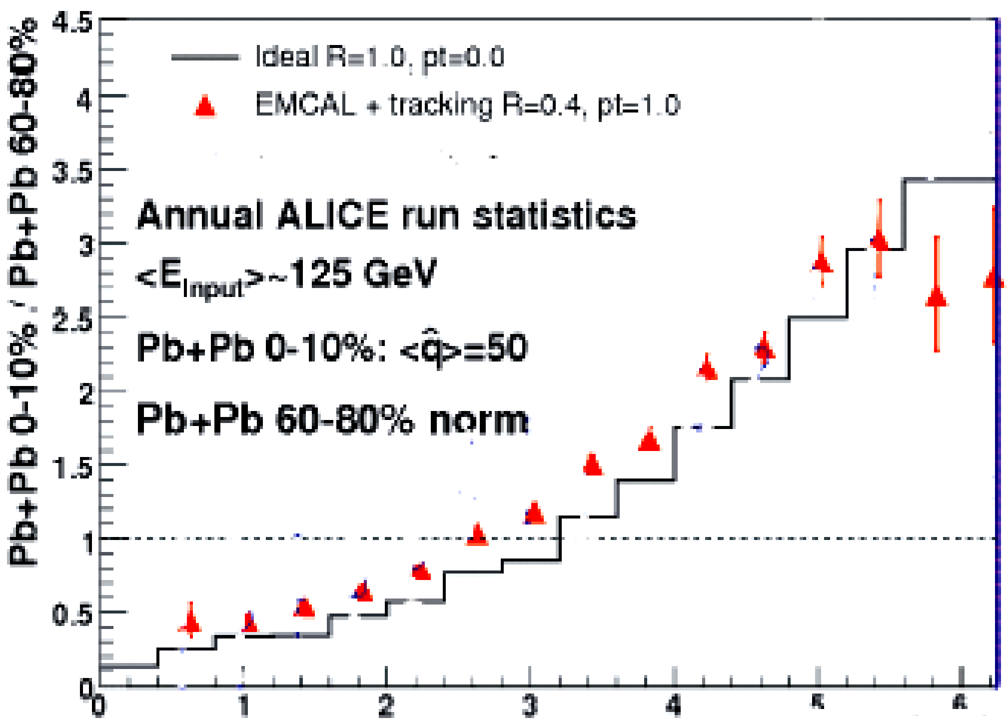


# measurement of jet fragmentation function

sensitive to energy loss mechanism




$\xi = \ln(1/z)$



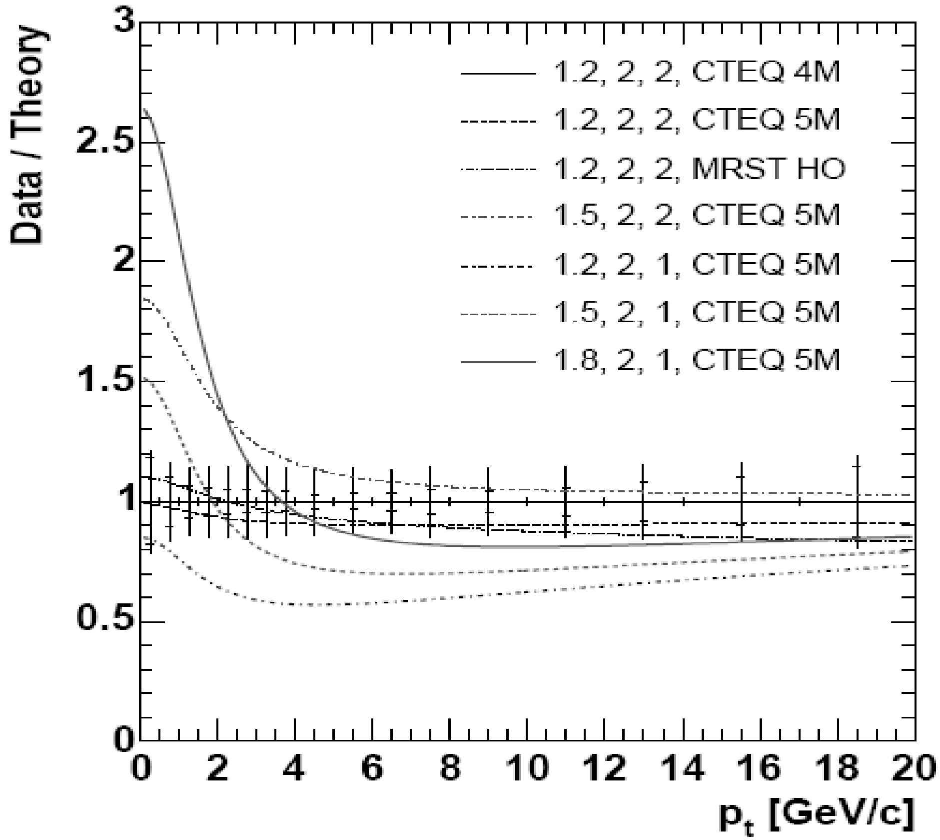

$\xi = \ln(1/z)$

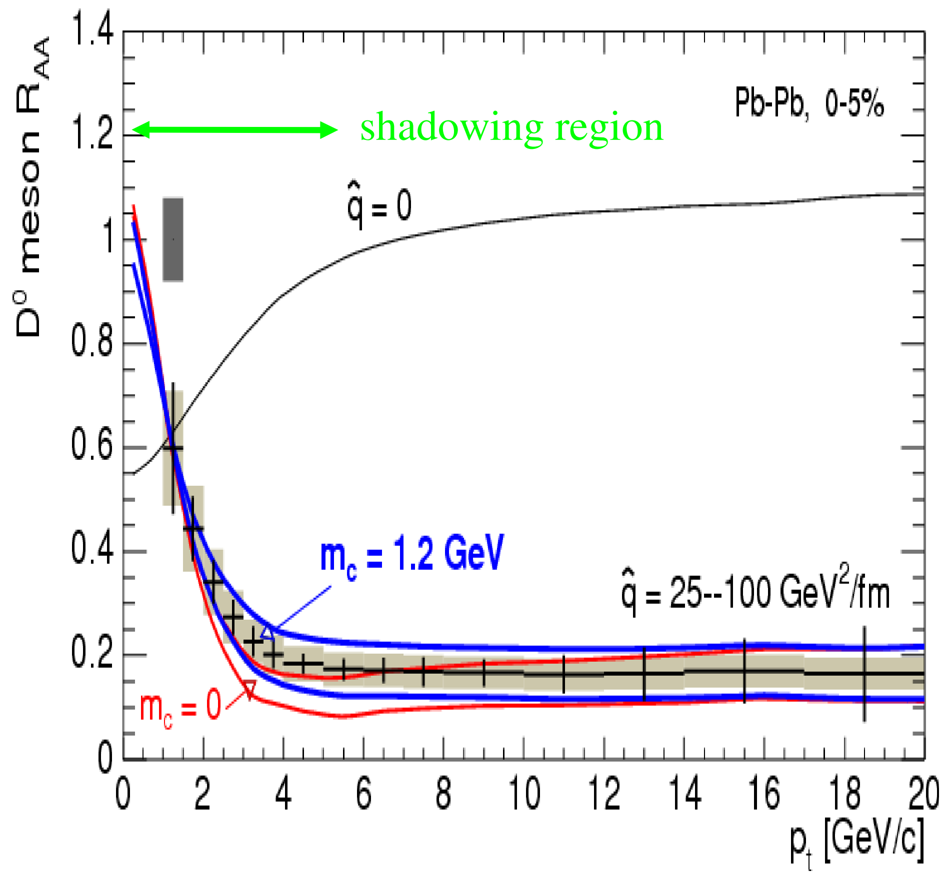
good reconstruction in ALICE

# high precision charm measurement

pp at 14 TeV
sensitivity to PDF's

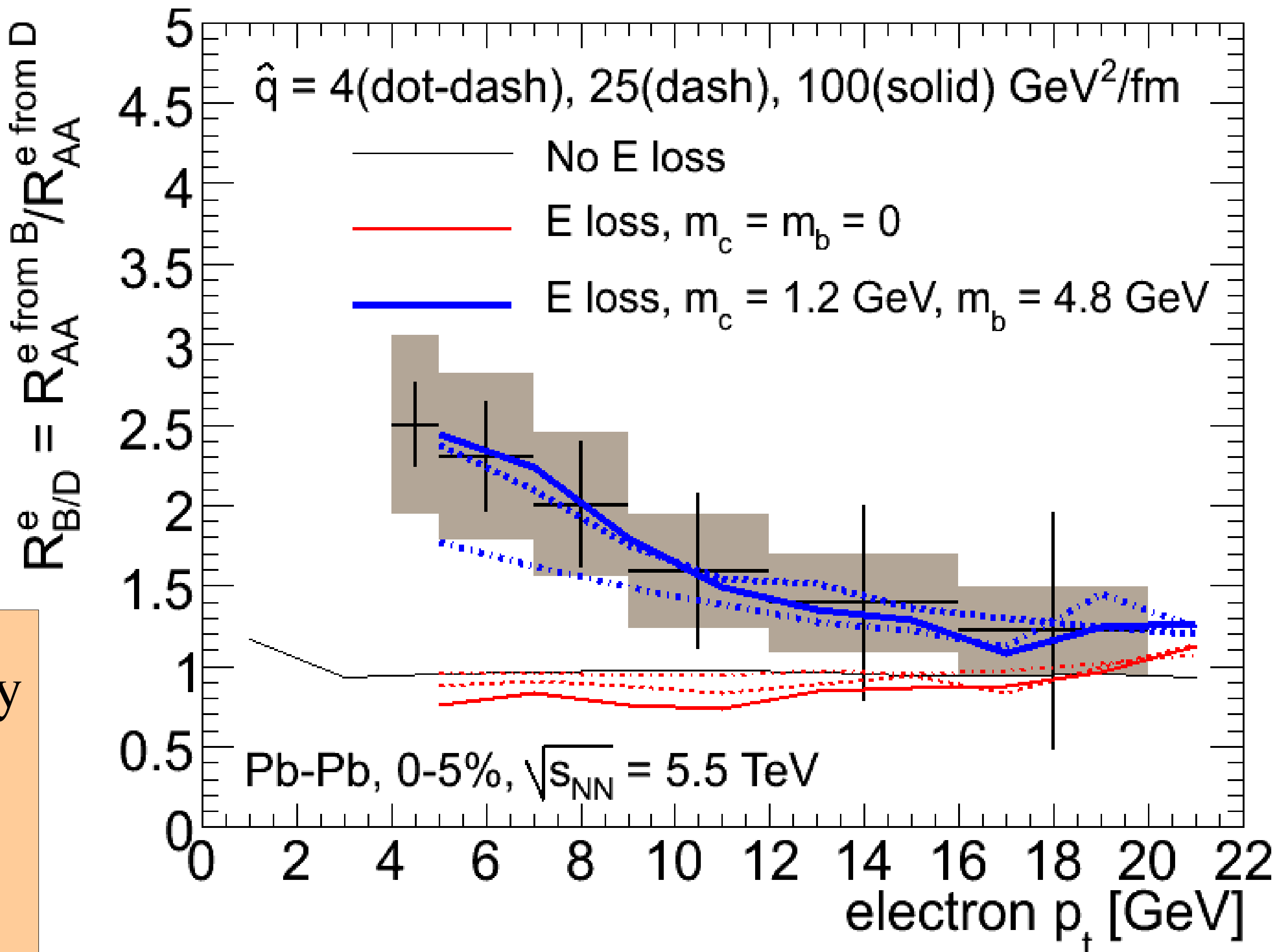
Central PbPb
shadowing + $k_T$ + energy loss



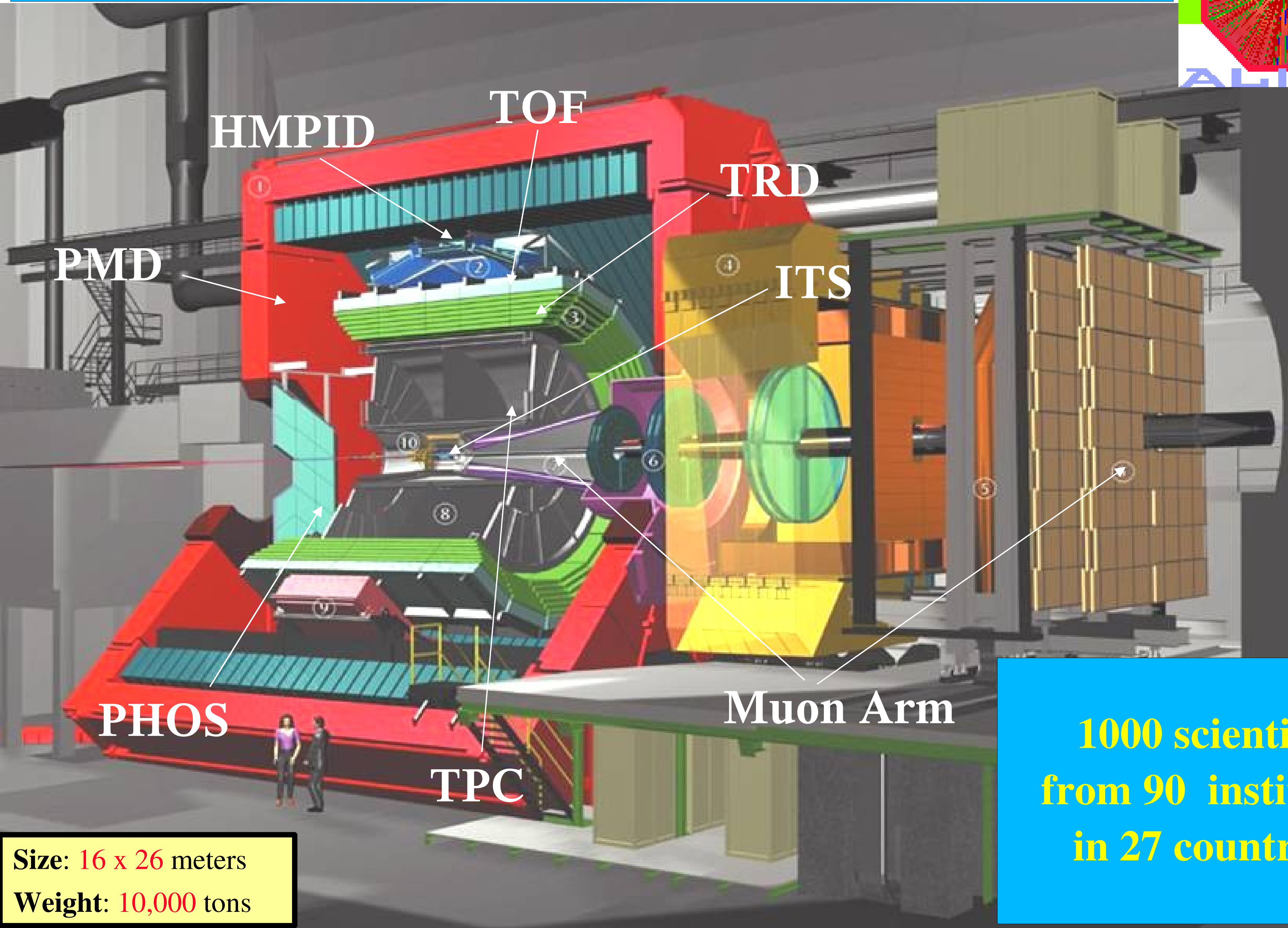

ALICE PPR vol2 JPG 32 (2006) 1295

# jet quenching for b-quarks relative to c-quarks




data of one full luminosity PbPb run ($10^6$ s) should clarify heavy flavor quenching story

# ALICE



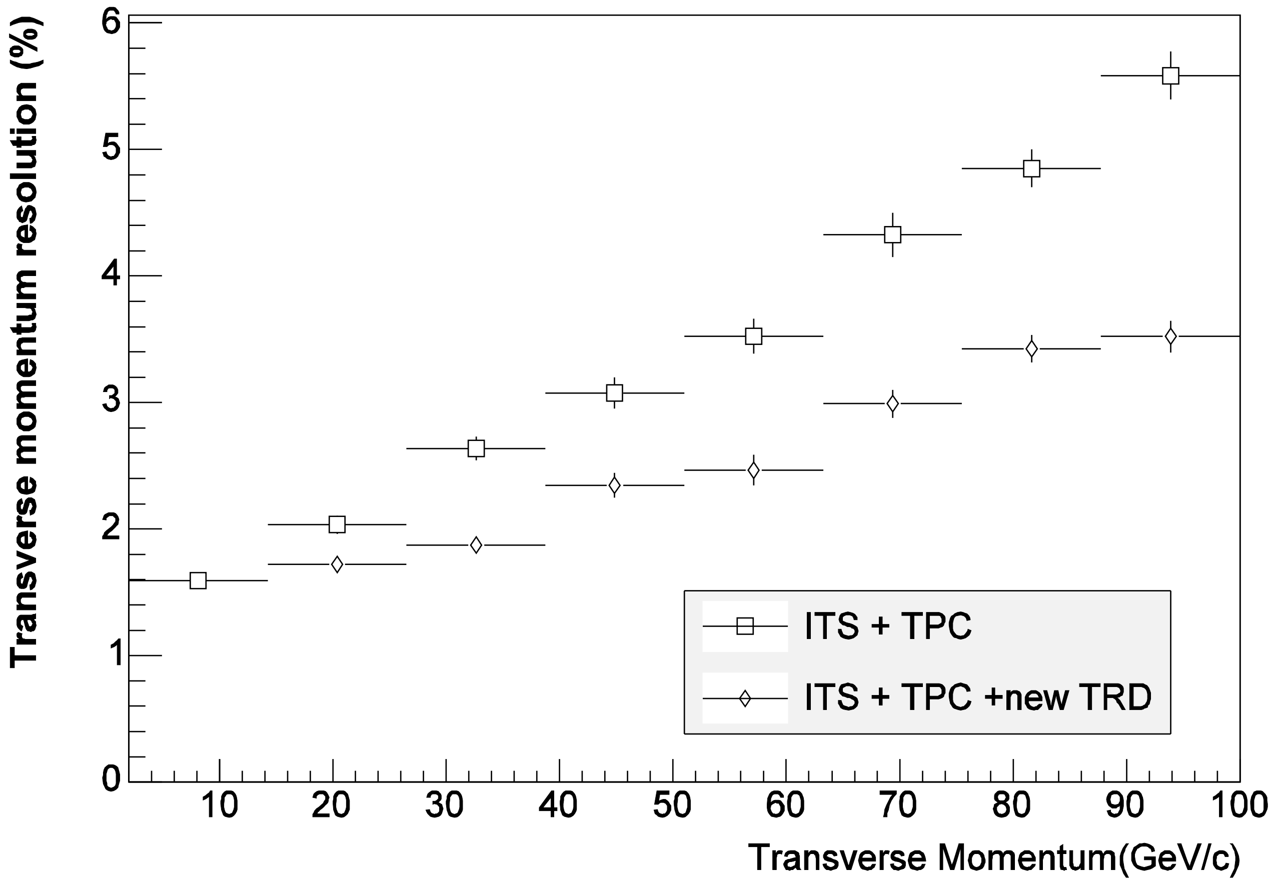

**Size**: 16 x 26 meters
**Weight**: 10,000 tons

**1000 scientists from 90 institutes in 27 countries**

# Combined Momentum Resolution in ALICE Central Barrel

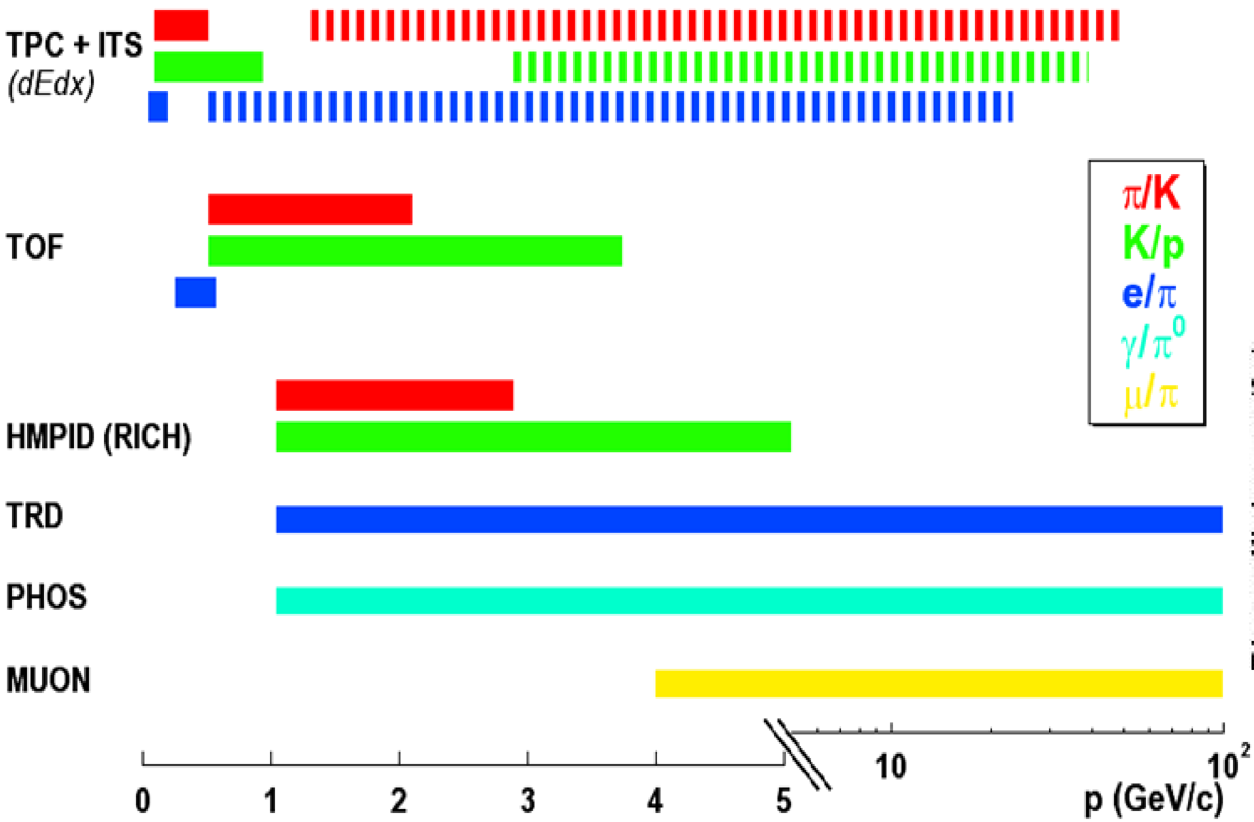
$dN_{ch}/dy \sim 5000$

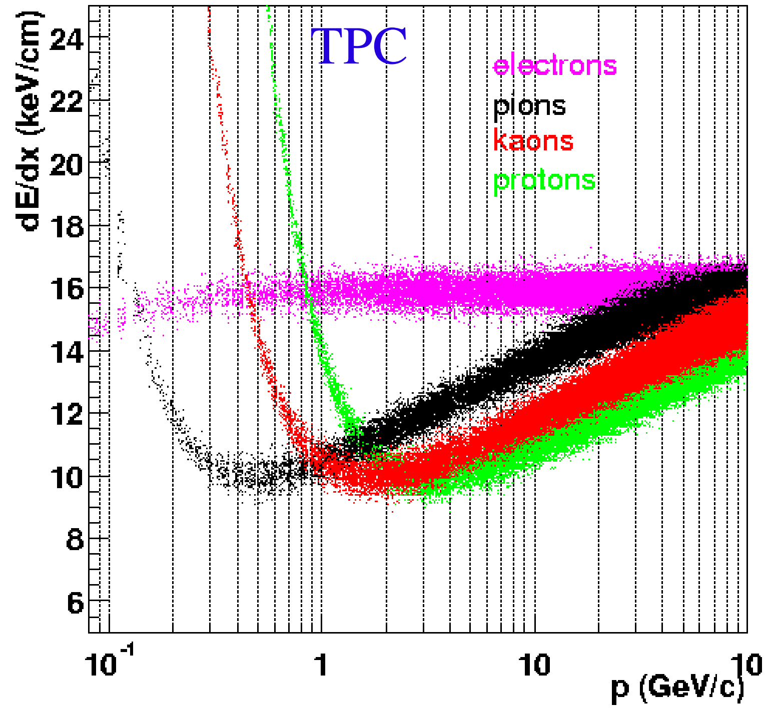
ALICE physics performance report

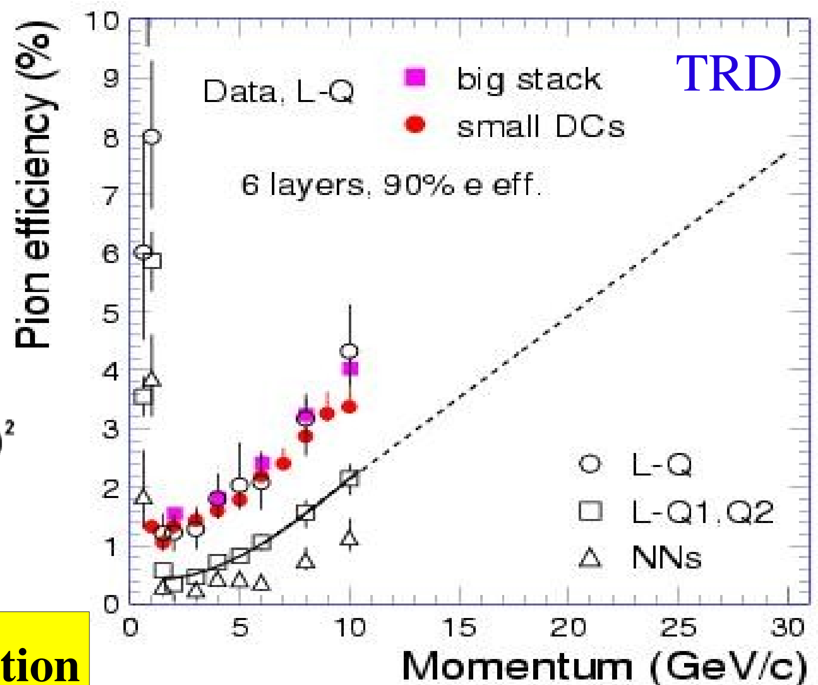



**resolution ~ 3% at 100 GeV/c**
**excellent performance in hard region!**

# Particle Identification in ALICE



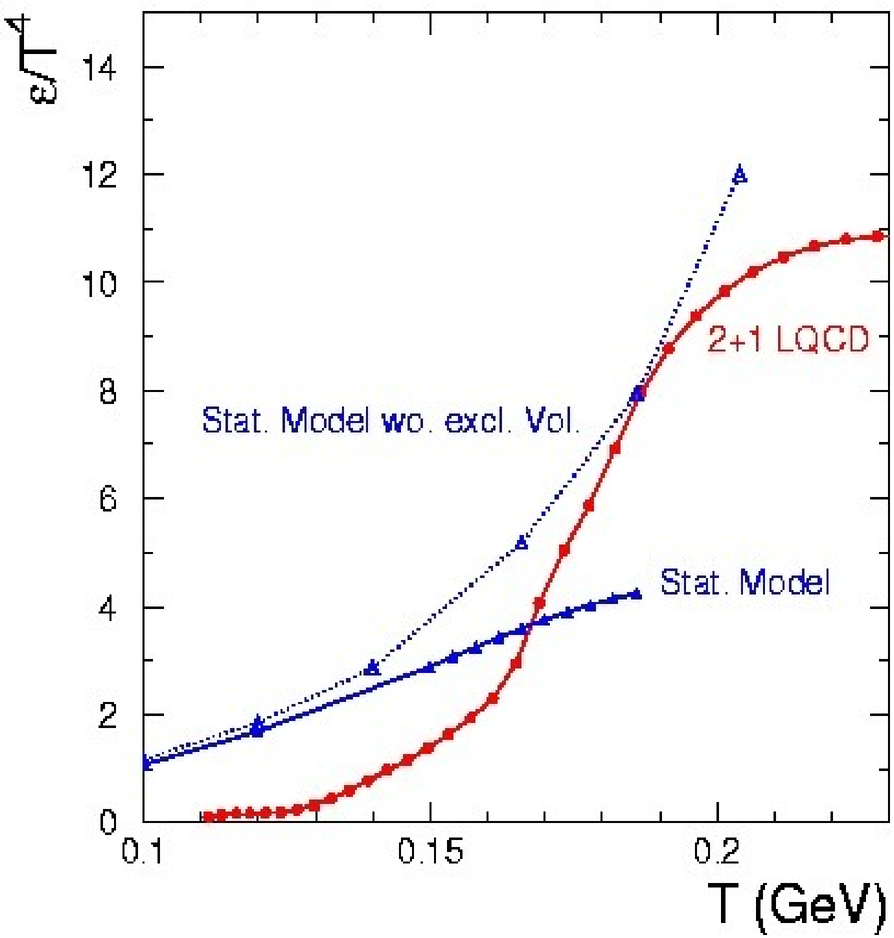




**From test beam data: at 2 GeV and 90 % e eff → $10^5$ π rejection**

# Backup slides

# rapid hadrochemical equilibration at phase boundary

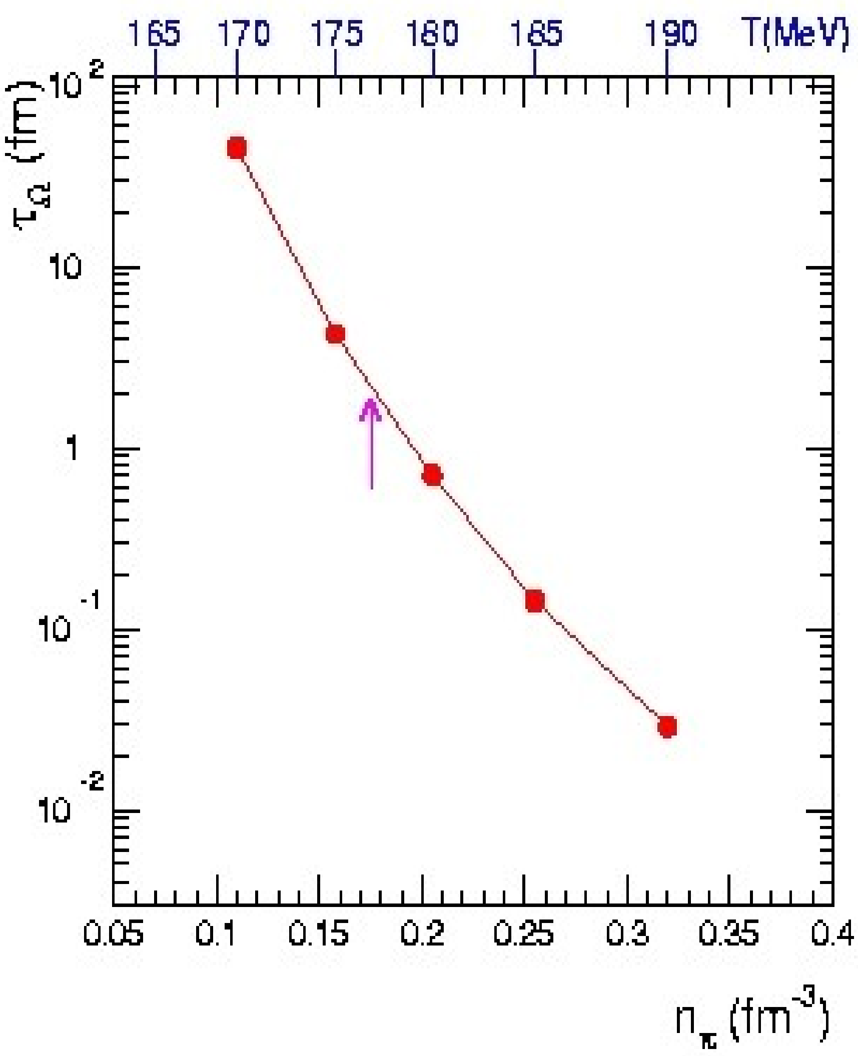



Lattice QCD calcs. F. Karsch et al.

- Known since years: two-body collisions are not sufficient to bring multi-strange baryons into equilibrium.
- The density of particles varies rapidly with T near the phase transition.
- Multi-particle collisions are strongly enhanced at high density and lead to chem. equilibrium very near to $T_{c.}$

P. Braun-Munzinger,
J. Stachel, C. Wetterich
Phys. Lett. B596 (2004) 61
nucl-th/0311005

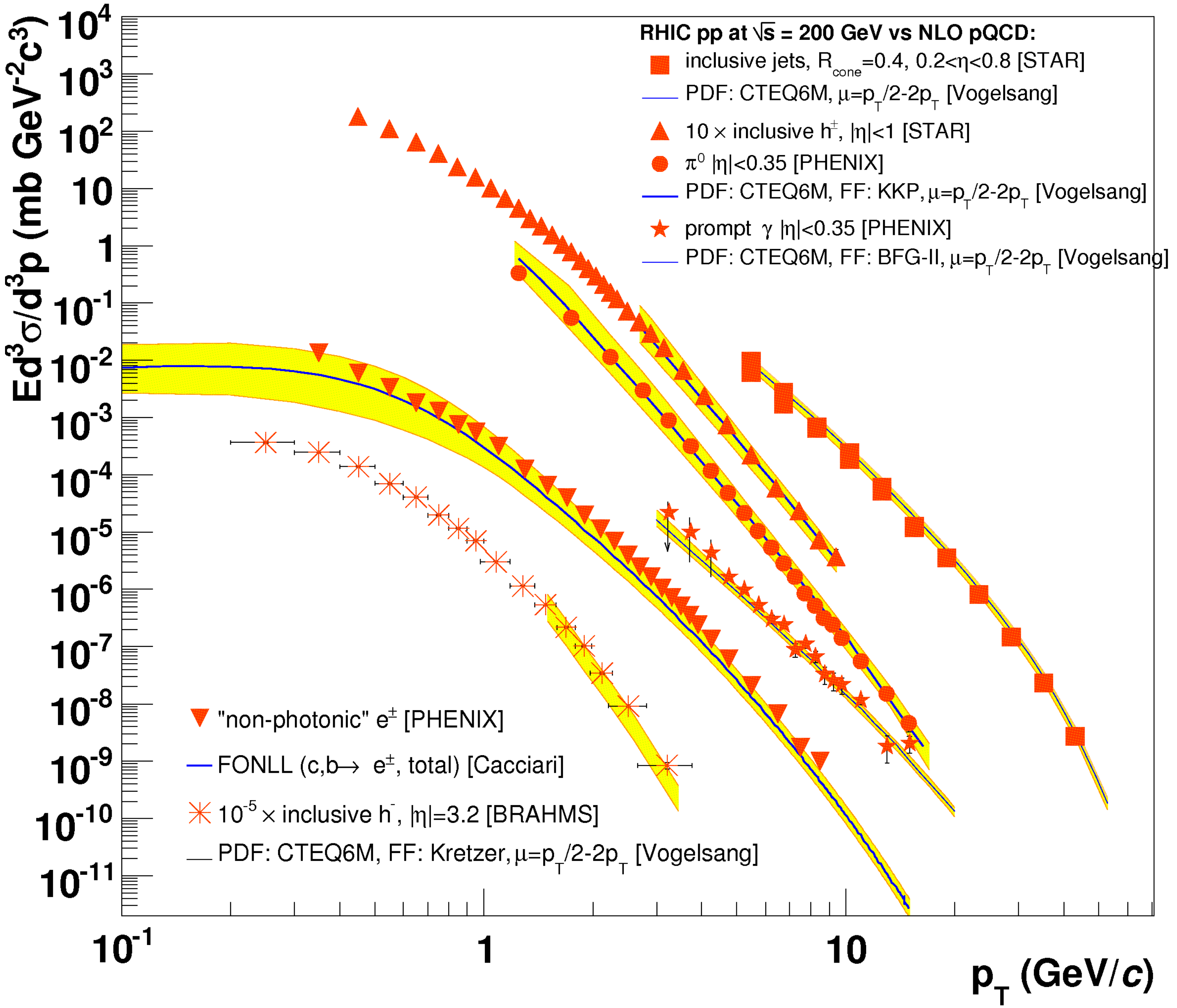
# chemical freeze-out takes place at $T_c$



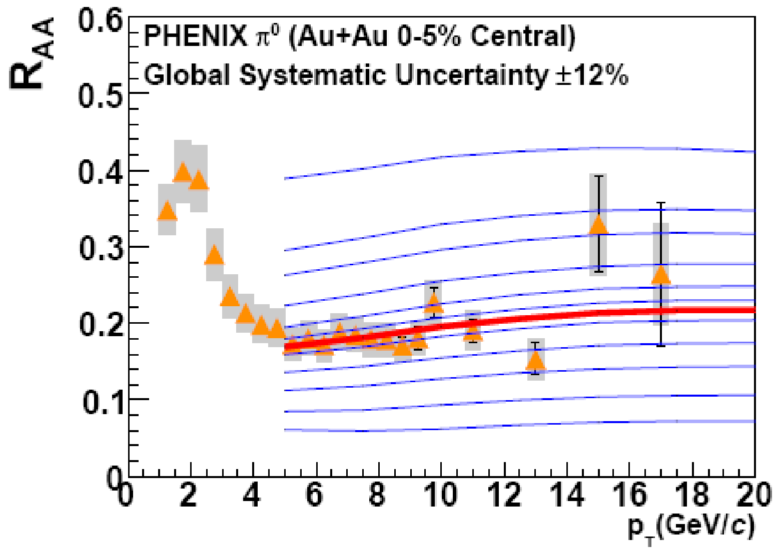

- rate of change of density due to multiparticle collisions $\propto n(T)^{n_{in}} |M|^2 \Phi$
- example: for small $\mu_b$, reactions such as $KKK\pi\pi \rightarrow \Omega N_{bar}$ bring multi-strange baryons close to equilibrium.
- Equilibration time $\tau \propto T^{-60}$ !
- All particles freeze out within a very narrow temperature window close to $T_c$.

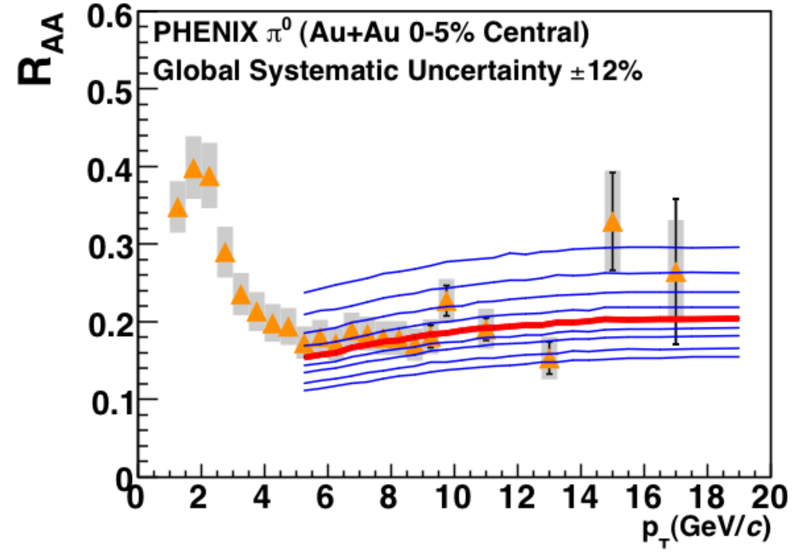
P. Braun-Munzinger,
J. Stachel, C. Wetterich
Phys. Lett. B596 (2004) 61
nucl-th/0311005

# High $p_T$ Spectra in p-p Collisions (II)



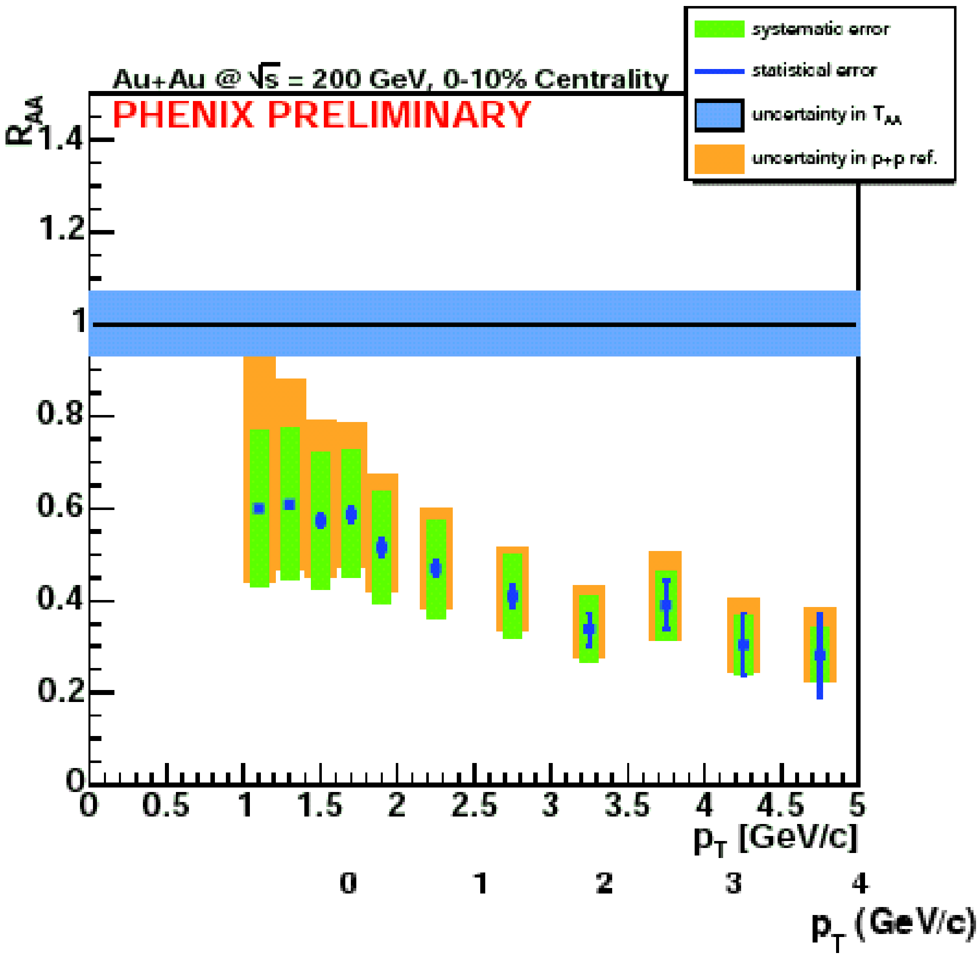
# Quantitative Constraints on Medium Parameters

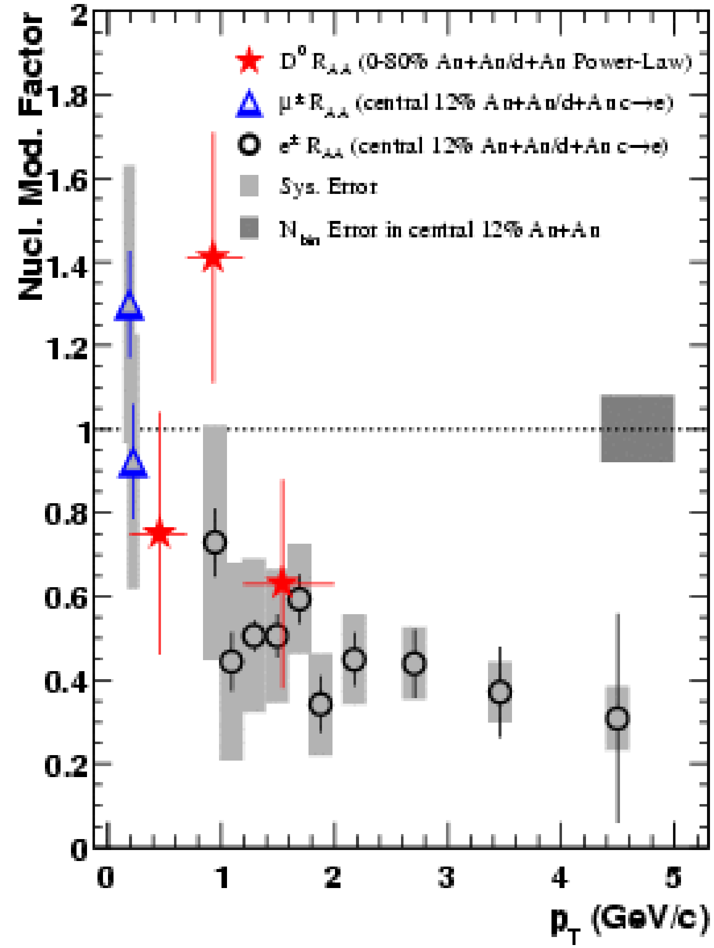



| PQM | GLV | WHDG | ZOWW |
|---|---|---|---|
| $\hat{q} = 13.2^{+2.1}_{-3.2}$ GeV$^2$/fm | $dN^g / dy = 1400^{+270}_{-150}$ | $dN^g / dy = 1400^{+200}_{-540}$ | $\varepsilon_0 = 1.9^{+0.2}_{-0.5}$ GeV/fm$^3$ |

# heavy quark distributions from inclusive electron spectra



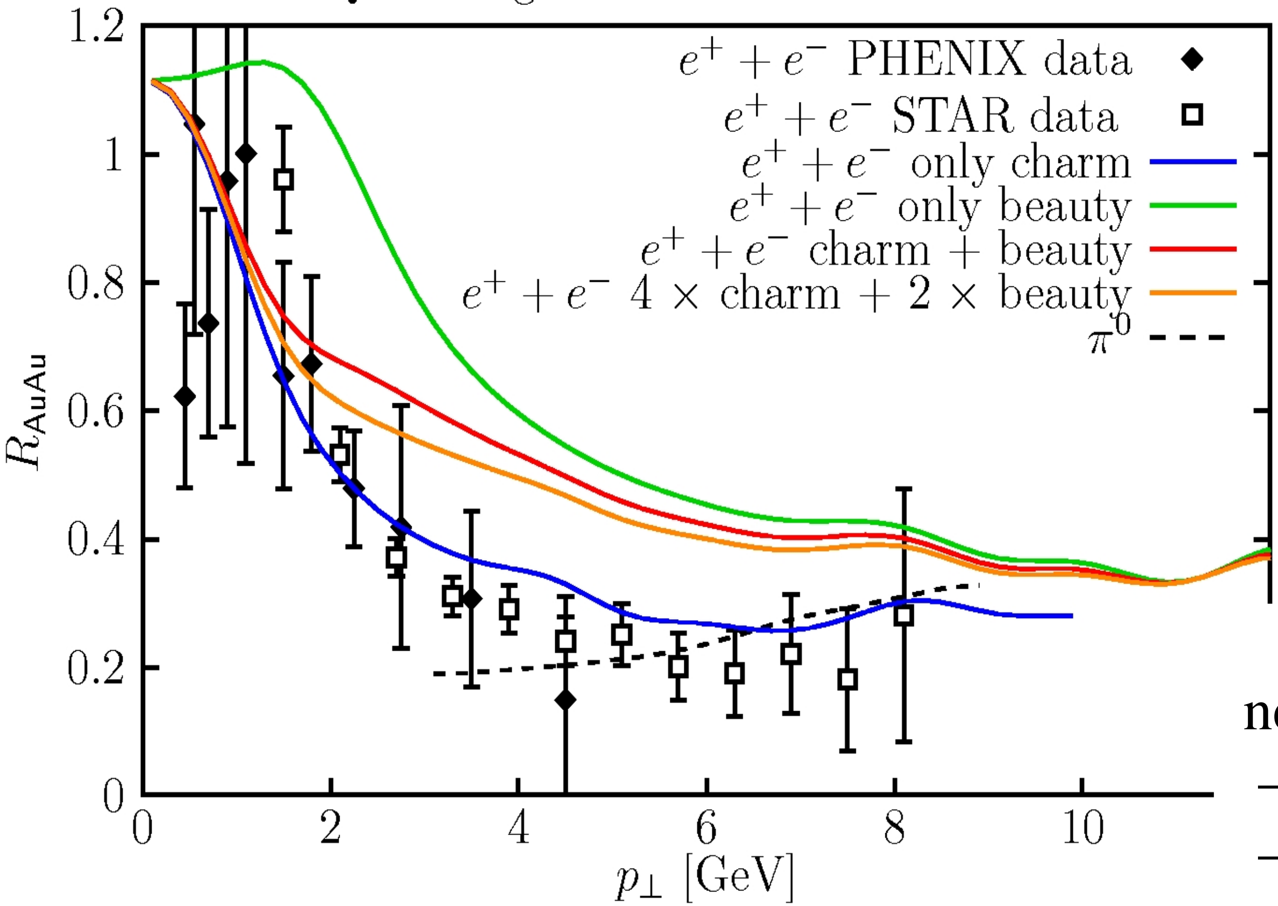

STAR
preliminary

**surprize:** suppression very similar to pions
prediction (Dokshitzer, Kharzeev) less energy loss for heavy quarks (radiation suppr.)

# radiation fails, is scattering the solution for heavy quarks?

recently shown by Korinna Zapp (U. Heidelberg) that scattering also important for parton energy loss; implementation in nonperturbative approach - SCI jet quenching model (K. Zapp, G. Ingelman, J. Rathsman, J. Stachel, PLB637 (2006) 179

apply same approach to c and b 0-10% centr. σ=5.2 mb ← σ to match pion data



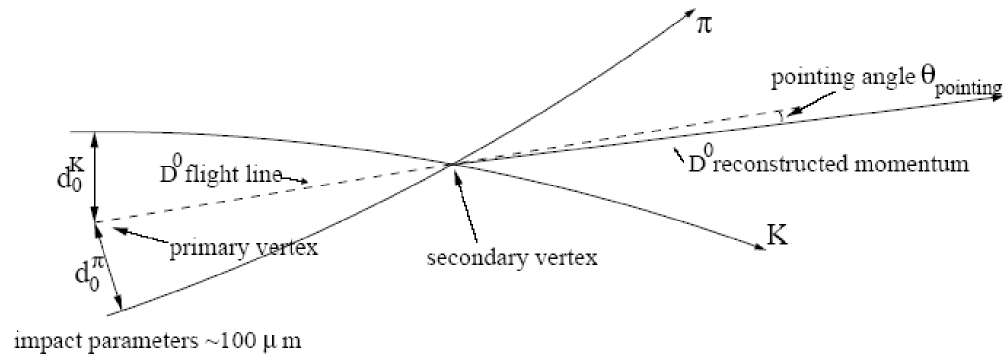

charm contribution indeed suppressed as much as pions but adding beauty data are not reproduced

need improved heavy quark data
– to come with RHIC upgrades
– or even earlier from ALICE

# $D^0 \rightarrow K\pi$ channel

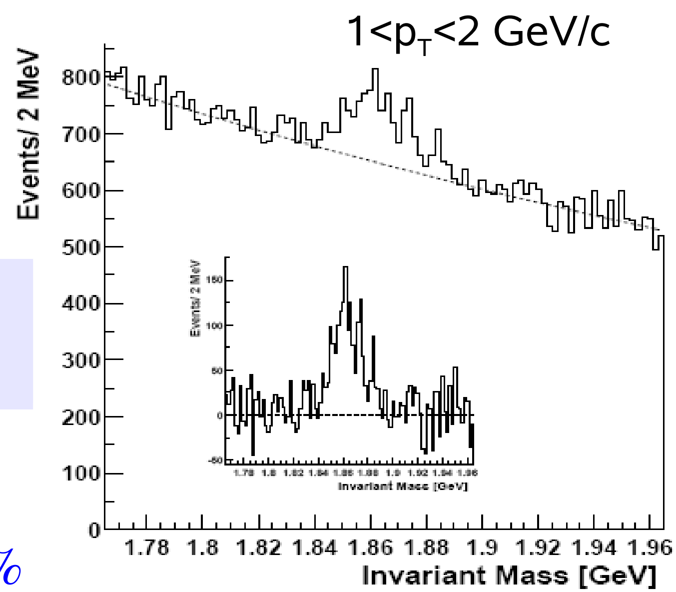
ALICE PPR vol2 JPG 32 (2006) 1295

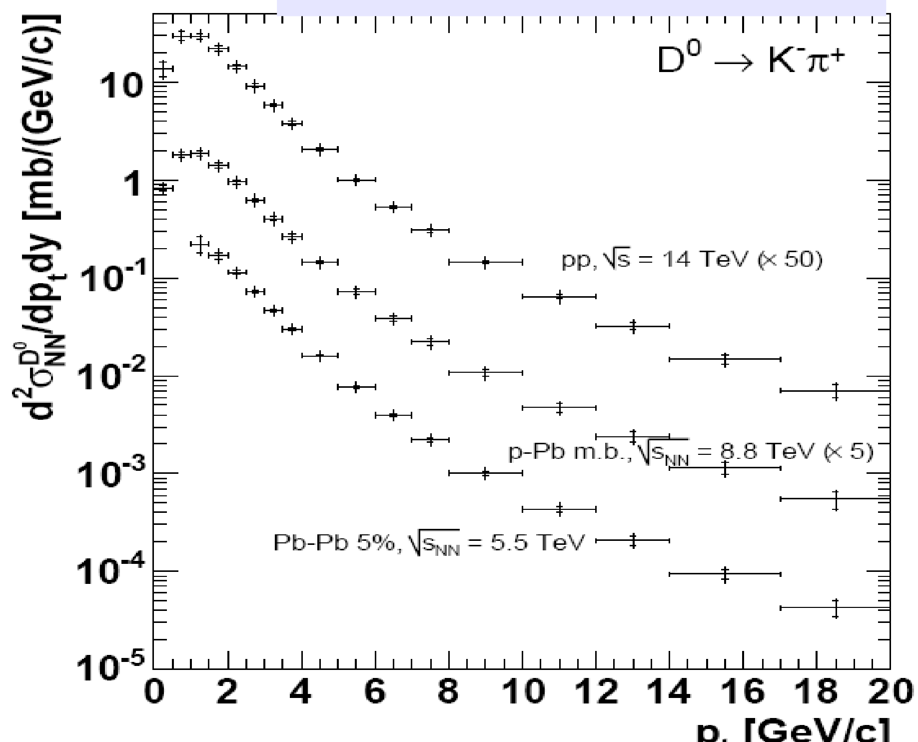
- high precision vertexing, better than 100 μm (ITS)
- high precision tracking (ITS+TPC)
- K and/or π identification (TOF)




10⁹ pp 10⁸ pPb 10⁷ PbPb

10⁷ central PbPb



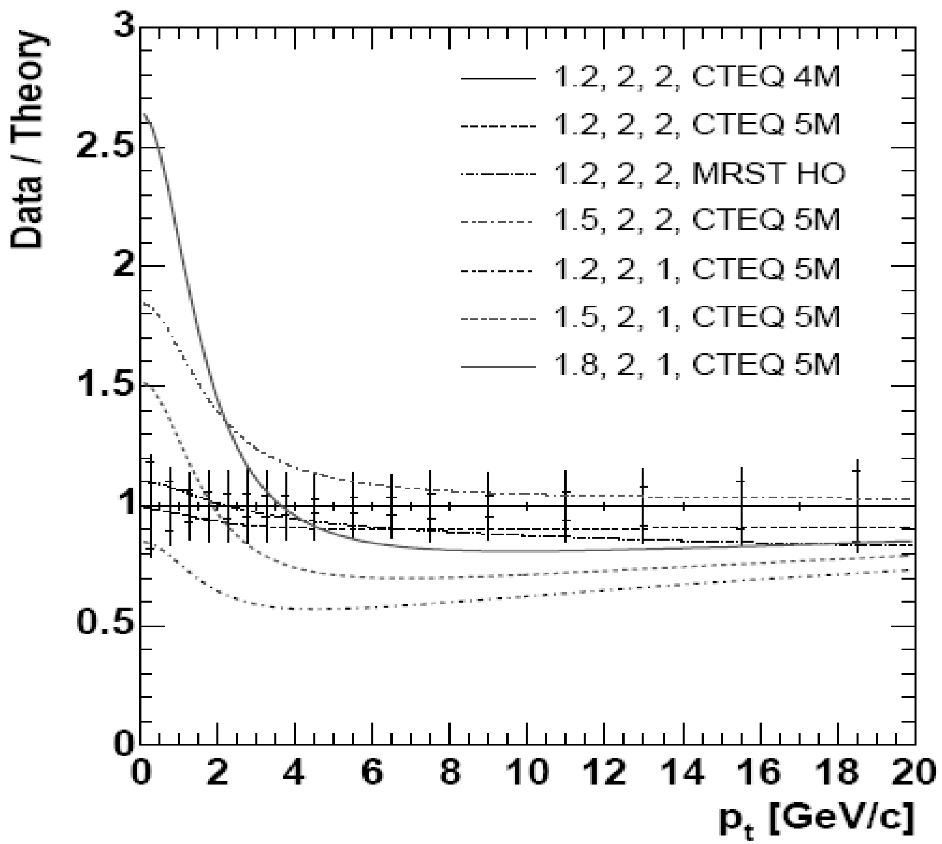



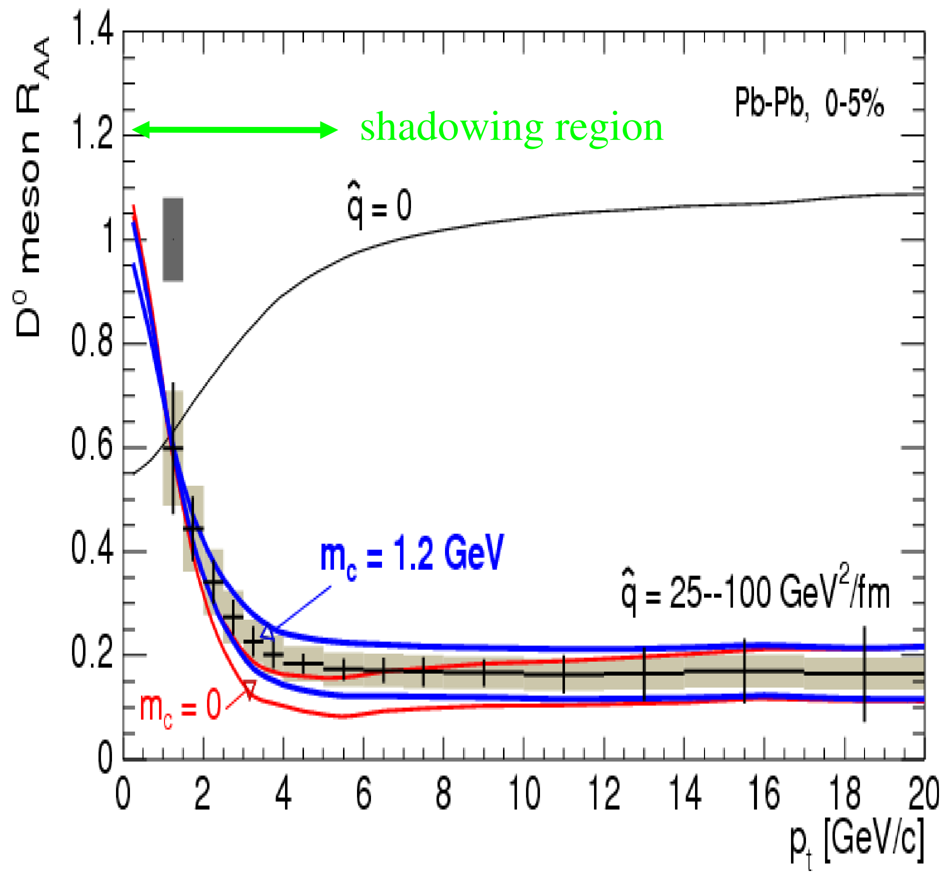

S/B = 10%
$S/\sqrt{(S+B)} = 40$

# high precision charm measurement

pp at 14 TeV
sensitivity to PDF's

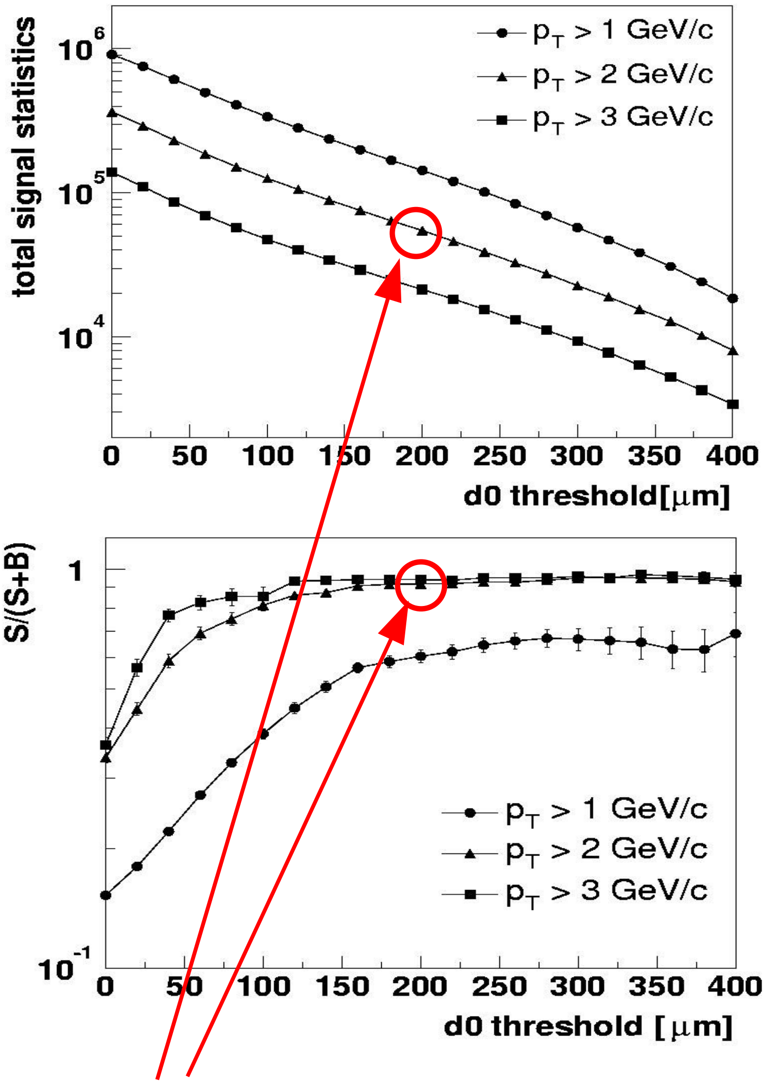
Central PbPb
shadowing + $k_T$ + energy loss

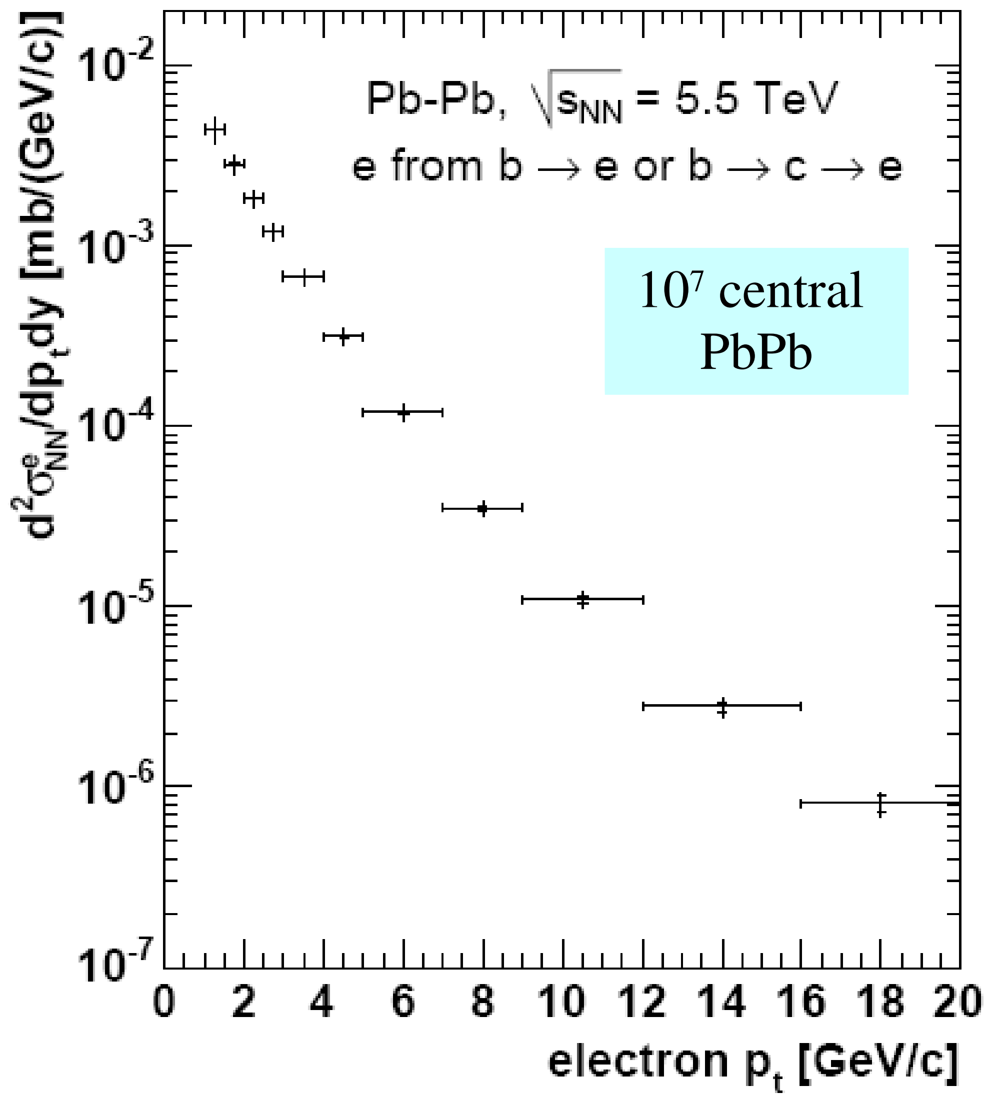



ALICE PPR vol2 JPG 32 (2006) 1295

# open beauty from single electrons

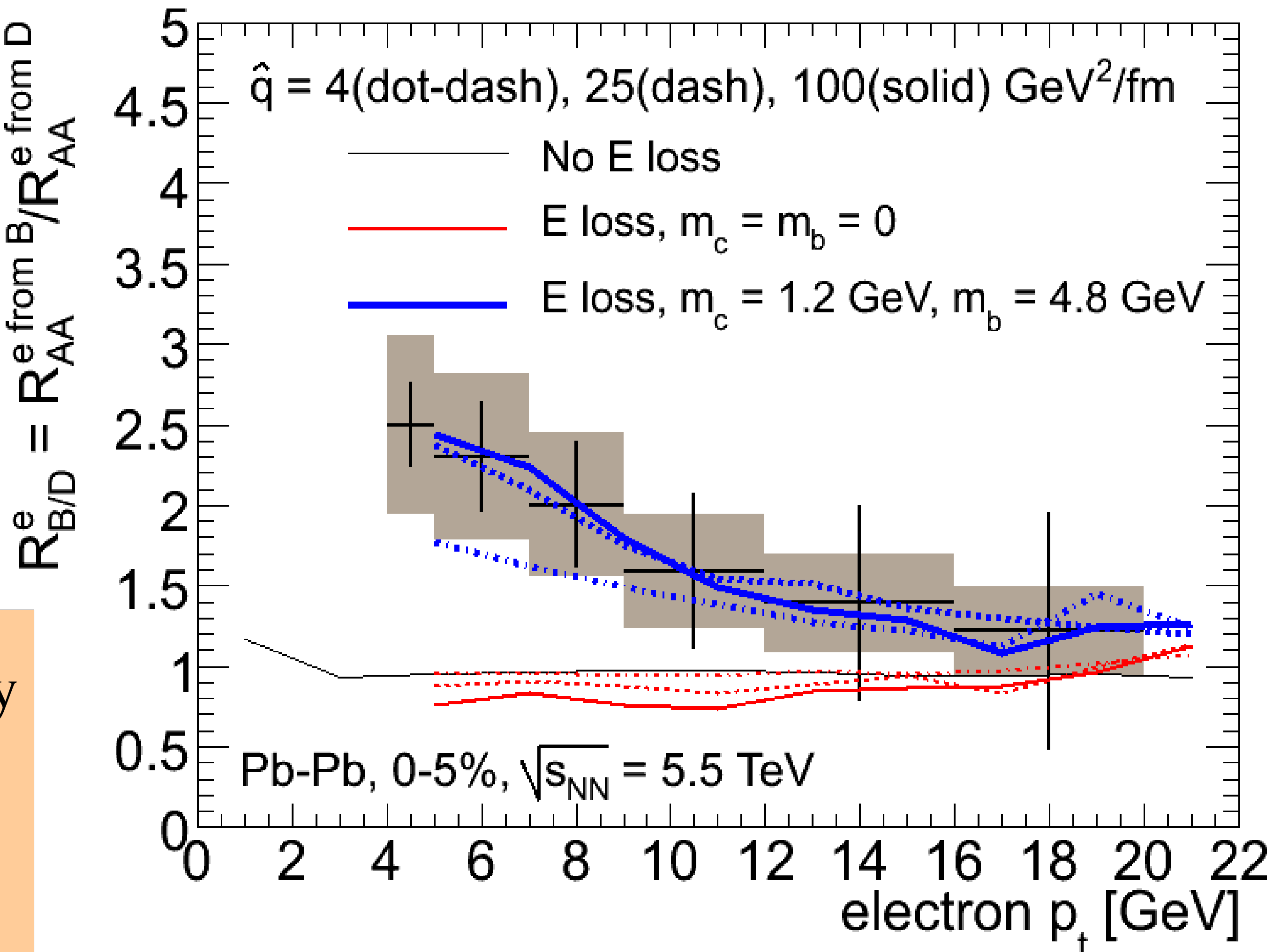



**B →fie in ALICE ITS/TPC/TRD**
**$p_t$ > 2 GeV/c & $d_0$ = 200 -600 μm:**
**80 000 electrons with S/(S+B) = 80%**

ALICE PPR vol2 JPG 32 (2006) 1295

# jet quenching for b-quarks relative to c-quarks




data of one full luminosity PbPb run ($10^6$ s) should clarify heavy flavor quenching story