Survey on the hadron spectra

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- Total yield (ratios)
- Pt and Y-distribution
- HBT Interferometry
- Elliptic Flow, Directed Flow
- Summary

4th HIM 2005.2.24 보광

Ratios, experiment vs. a model

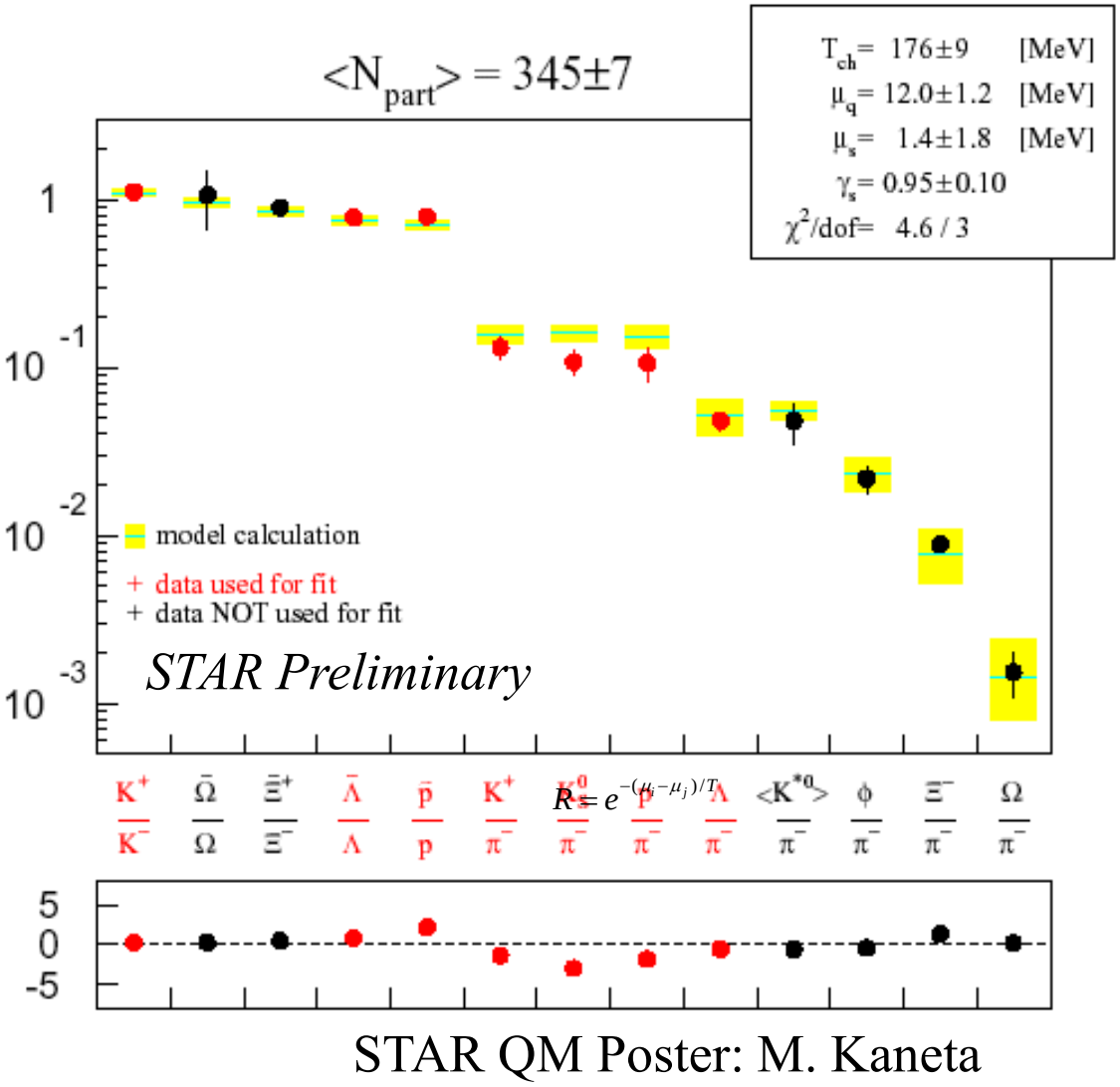
Central
130 GeV Au+Au
Preliminary Data

Agreement between model and data is very good!

$$R = e^{-(\mu_i - \mu_j)/T}$$

Strangeness saturation factor

γ



STAR QM Poster: M. Kaneta

Particle Spectra – single derivative

Invariant cross section

$$E\frac{d^3N}{dp^3} = \frac{d^3N}{p_t dp_t dy\, d\varphi} = \int p_\mu d\sigma_\mu e^{-p_\mu v_\mu / T}$$

$$\approx e^{-\gamma E/T}$$

Cooper-Frye formula

freeze-out scheme
–sudden or continuous ?

Transverse momentum spectrum

$$\frac{dN}{p_t dp_t} = \int dy d\varphi \left(\frac{d^3N}{p_t dp_t dy\, d\varphi}\right)$$

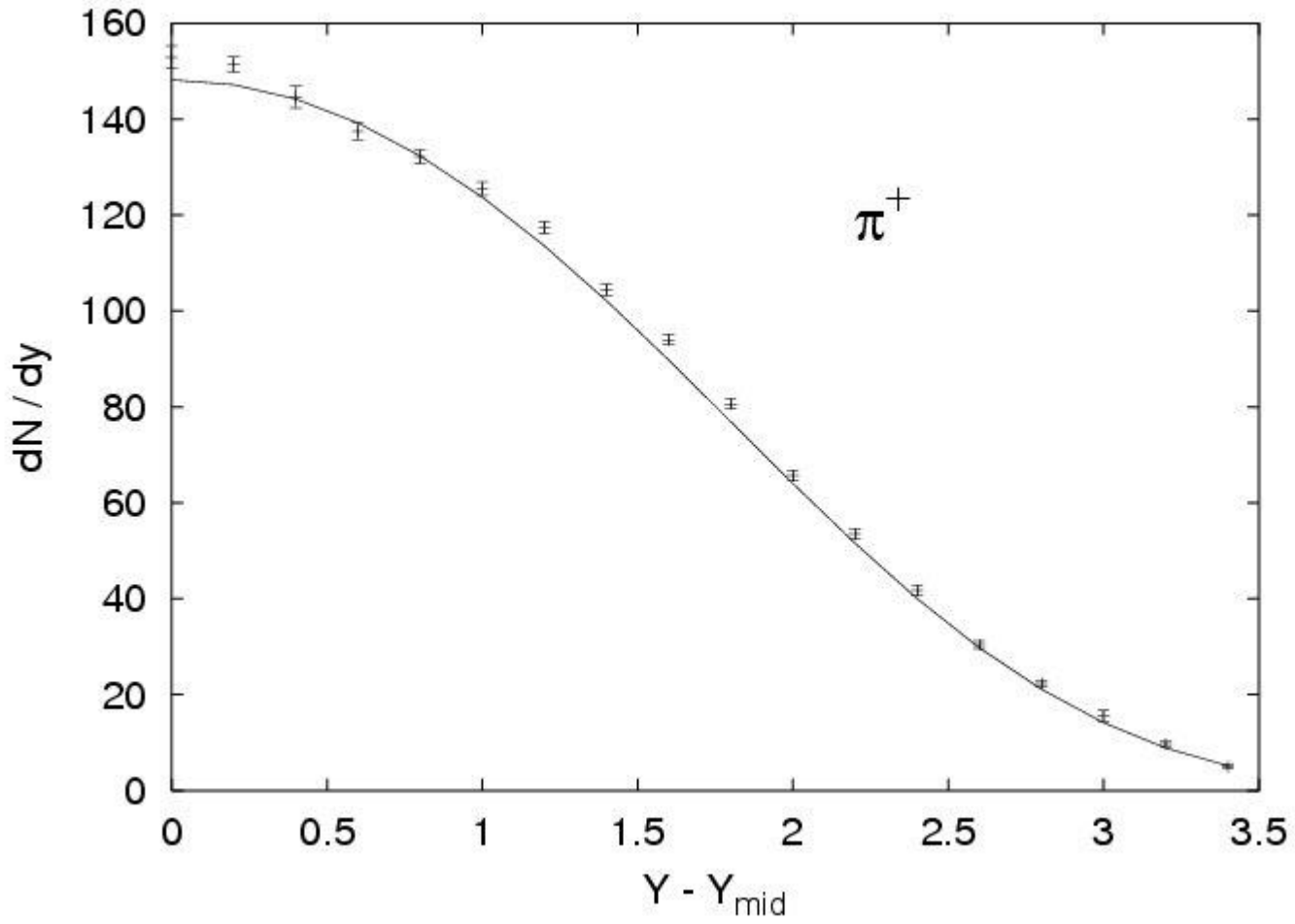
What to plot?

Cooper-Frye formula

Rapidity distribution

$$\frac{dN}{dy} = \int p_t dp_t d\varphi \left(\frac{d^3N}{p_t dp_t dy\, d\varphi}\right)$$

Rapidity distribution of pions at Pb+Pb at 158GeV A



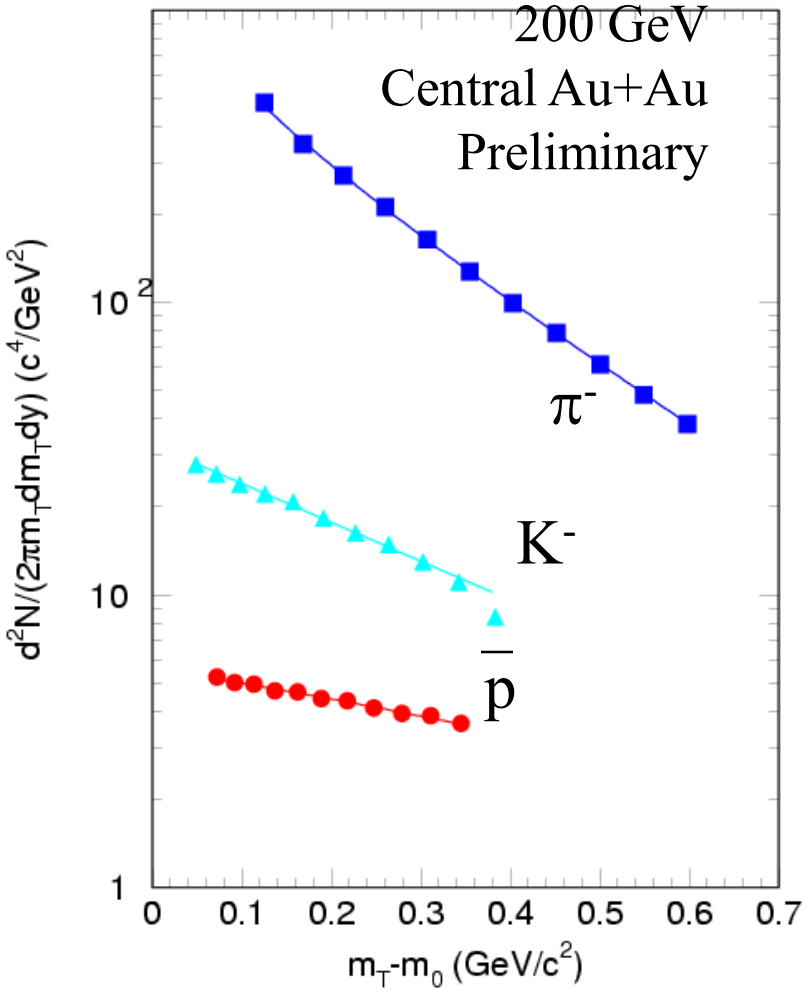
Y-distribution cannot be fitted simultaneously with Pt distribution.

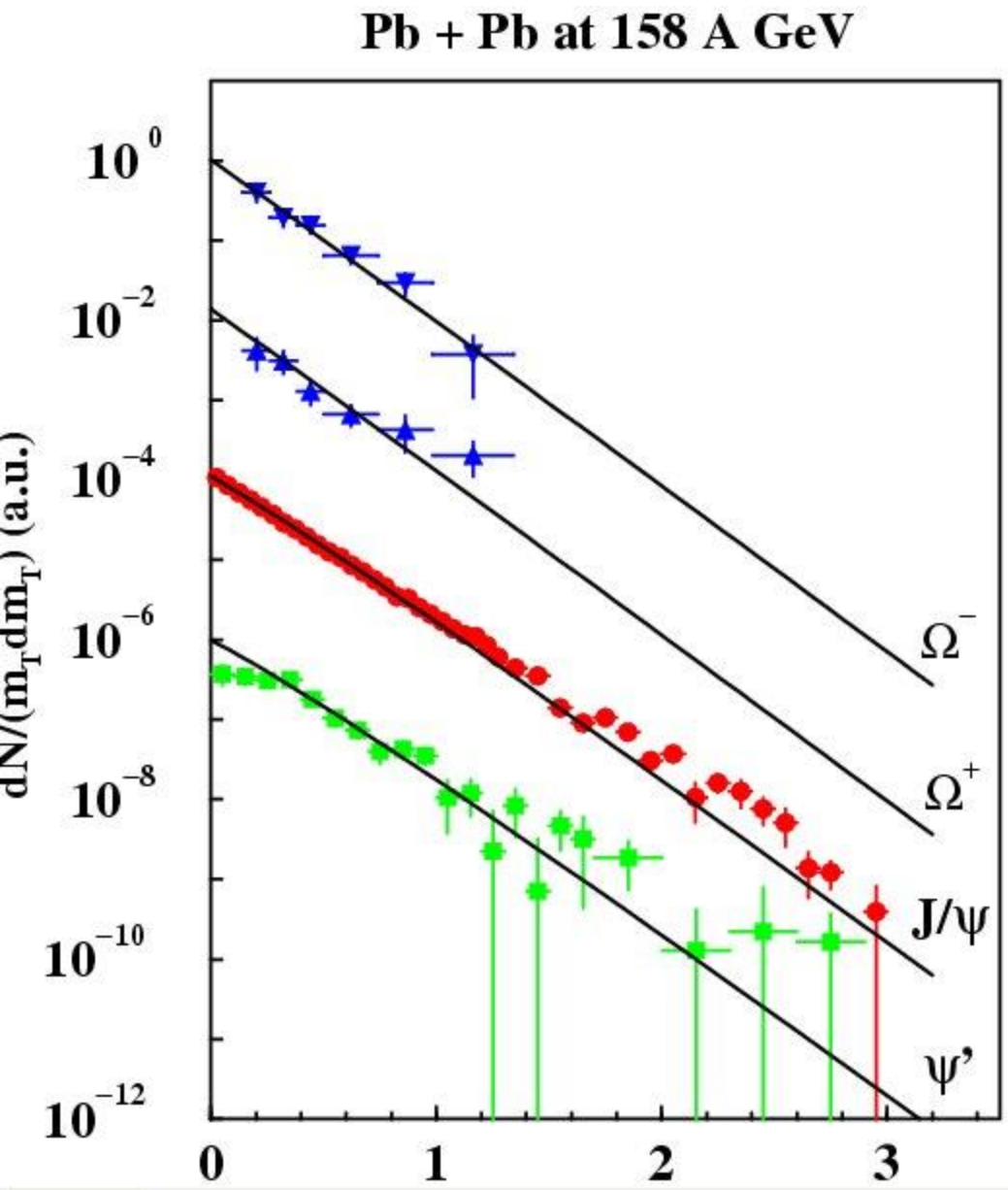
Different collision dynamics? stopping or transparency

π^-, K^-, p: radial flow

- Exponential shape
- Higher the mass, flatter the slope
- Radial expansion

$$e^{-p_\mu u_\mu / kT} \approx e^{-\gamma E / kT}$$

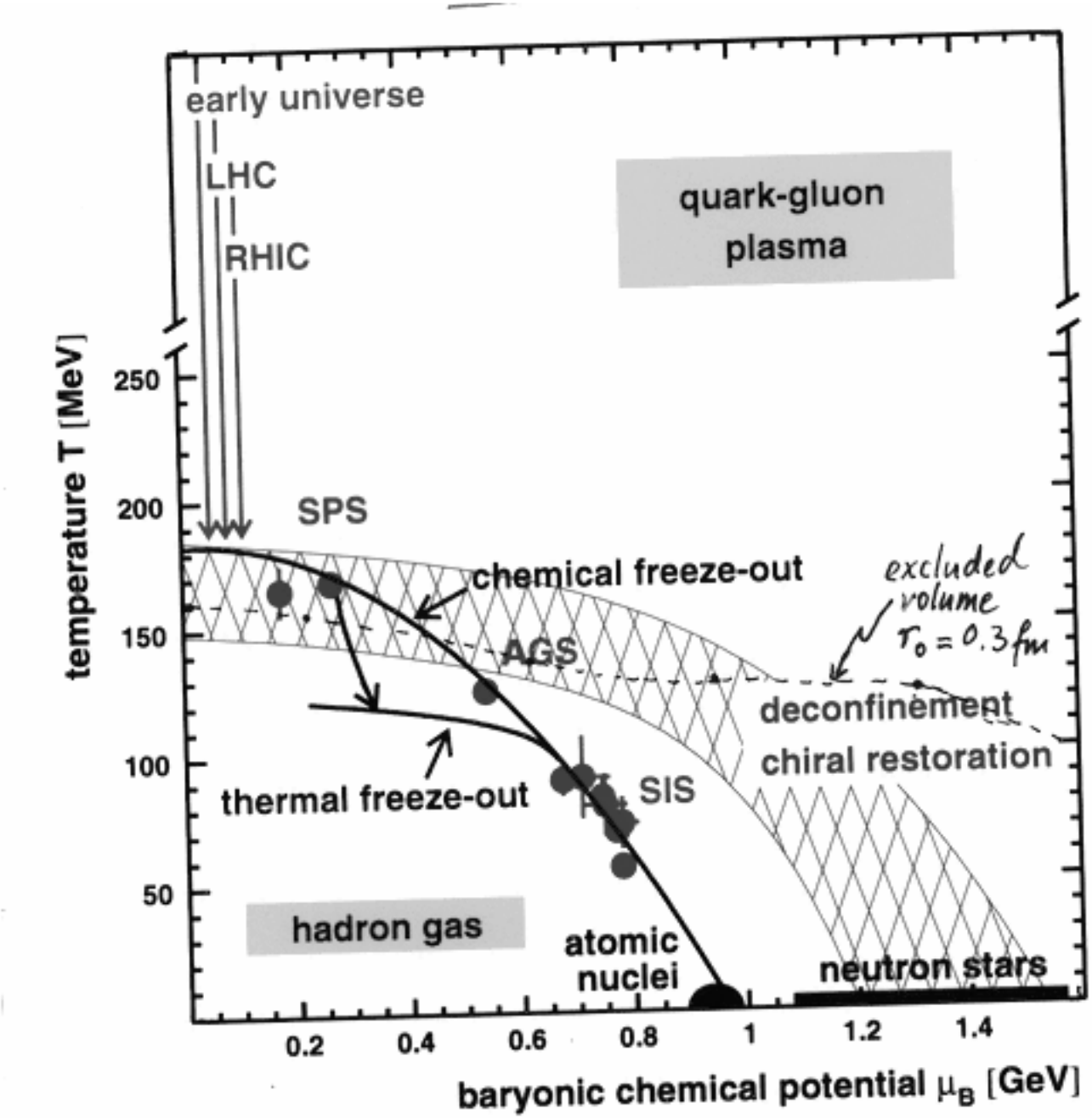




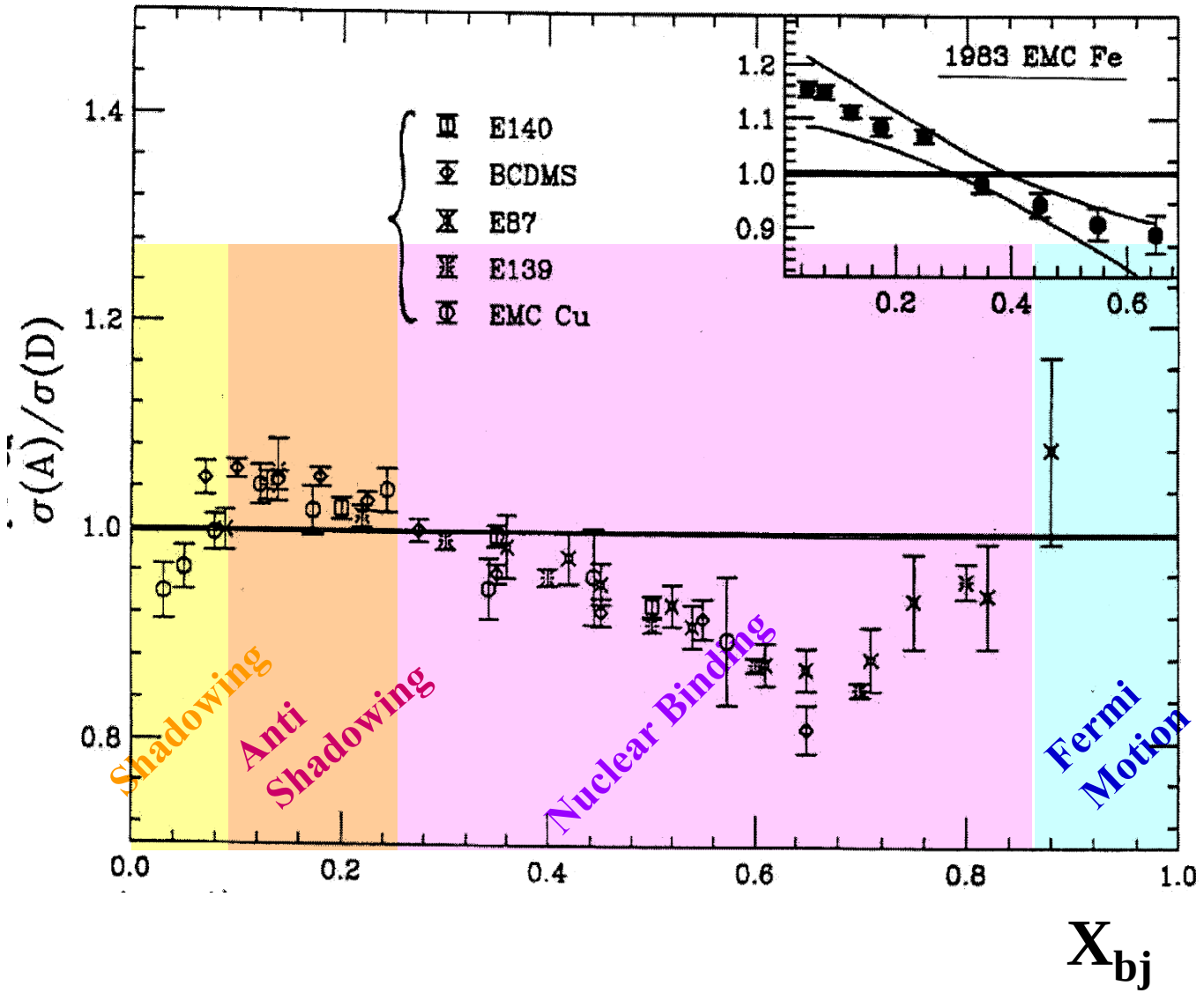
K.A. Bugaev et al., PLB 523(01)255
M.I. Gorenstein et al., PRL 88(02)1323011
K.A. Bugaev et al., hep-ph/0206109

simultaneous fit with
$T_H = 170$ MeV
gives $\bar{v}_T \sim 0.2$

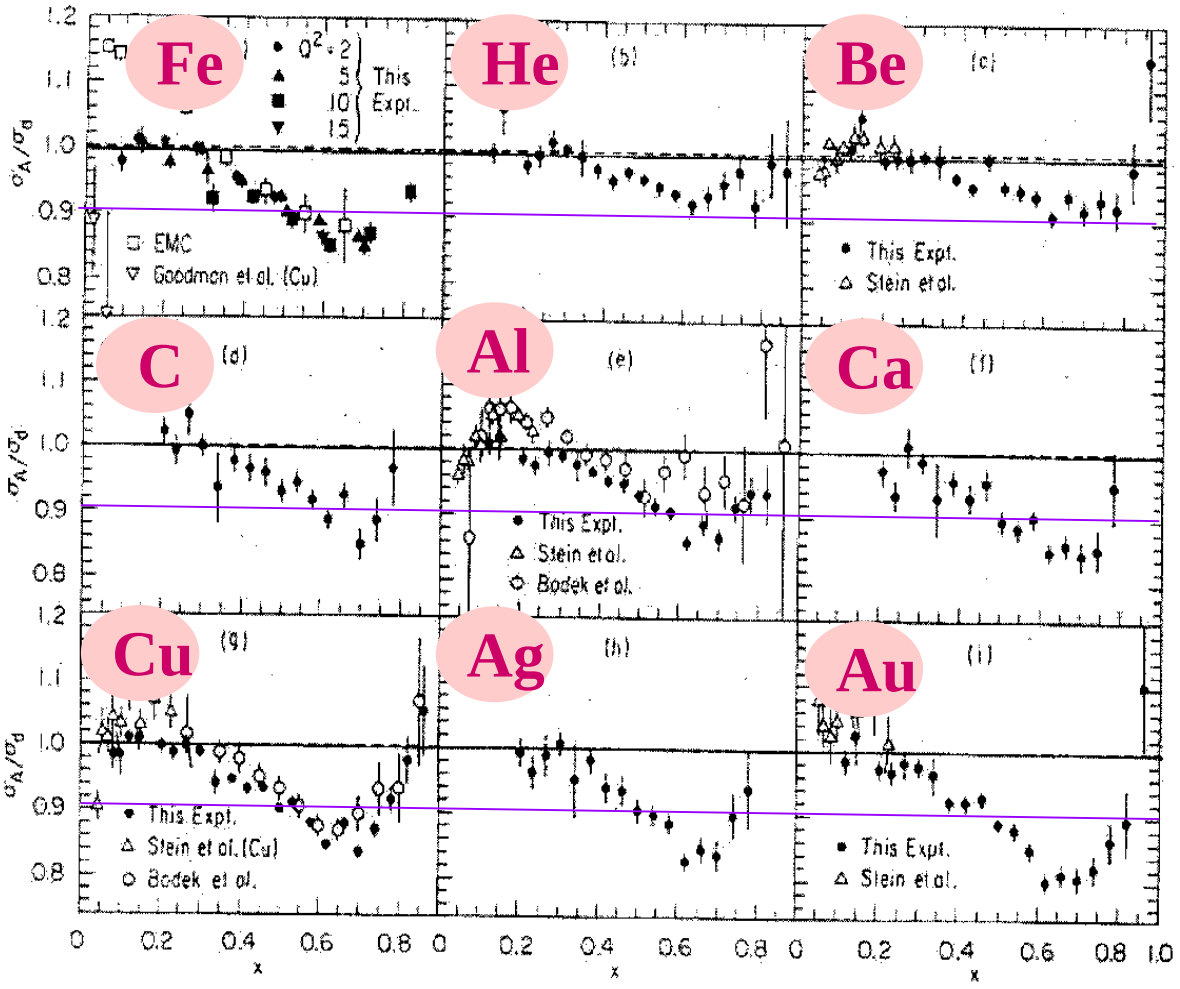
Radial flow for heavier particles ?


early universe
LHC
RHIC
quark-gluon plasma
temperature T [MeV]
250
200
150
100
50
SPS
chemical freeze-out
AGS
excluded volume
$r_0 = 0.3$ fm
deconfinement
chiral restoration
thermal freeze-out
SIS
hadron gas
atomic nuclei
neutron stars
0.2
0.4
0.6
0.8
1
1.2
1.4
baryonic chemical potential μ_B [GeV]

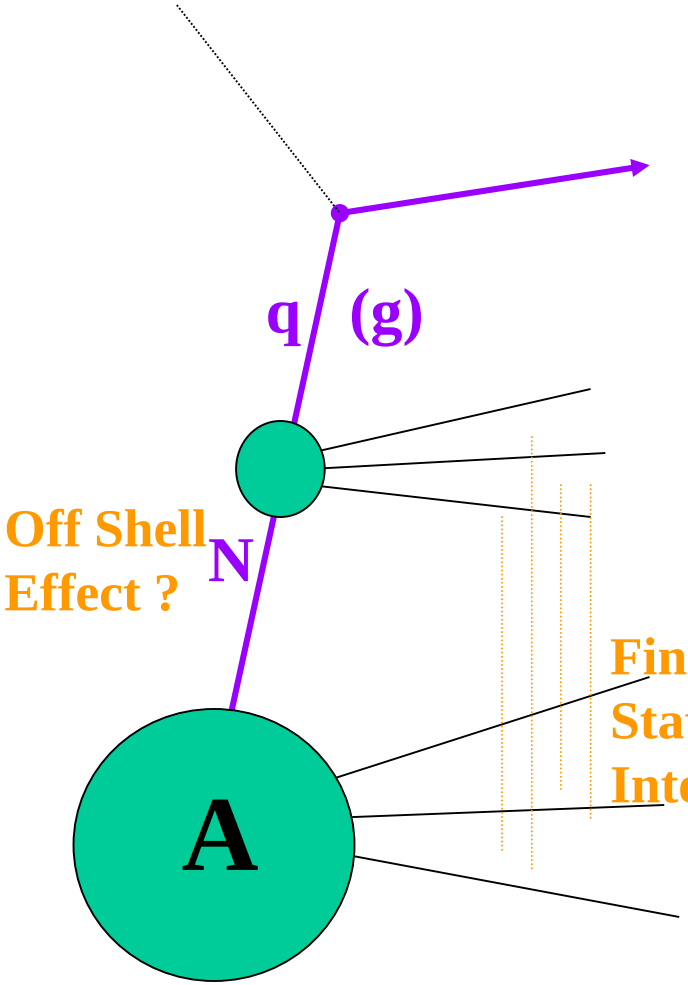
EMC effect

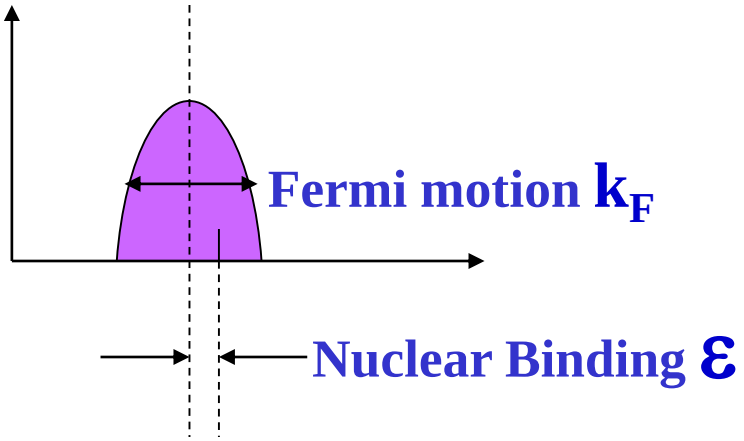

1983 EMC Fe
E140
BCDMS
E87
E139
EMC Cu
σ(A)/σ(D)
Shadowing
Anti Shadowing
Nuclear Binding
Fermi Motion
X_bj

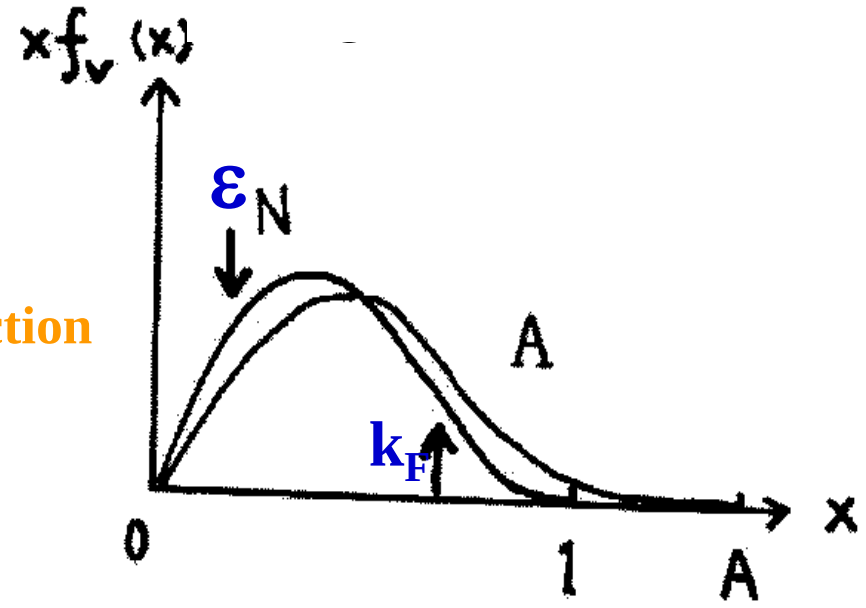
EMC effect is seen any nucleus



EMC effect, Not Fundamental?



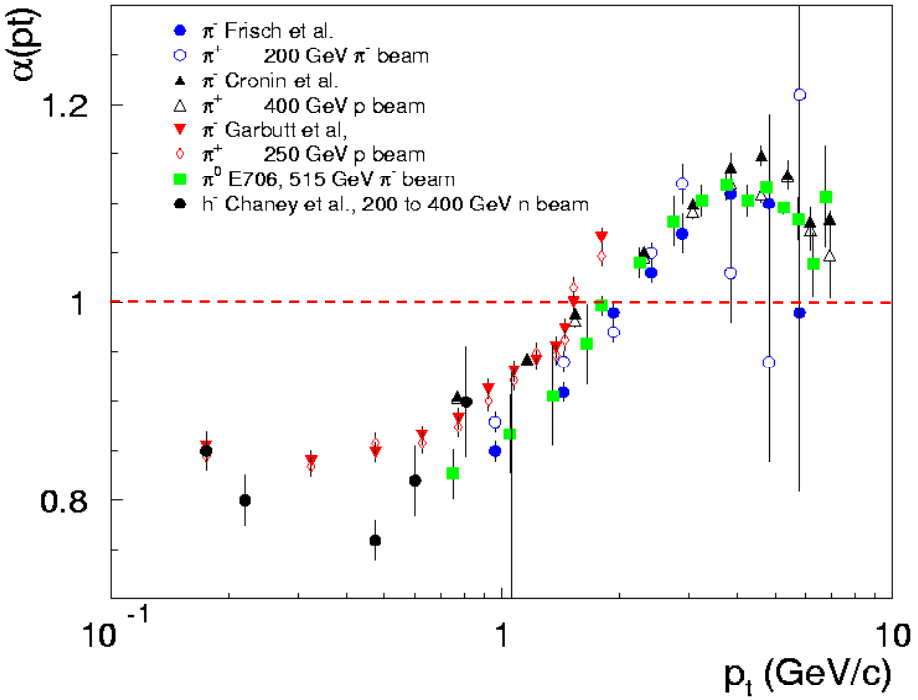




Initial State Multiple Scattering: "Cronin effect"

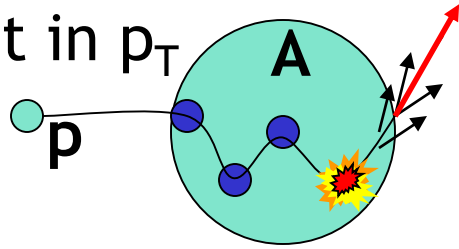
Experimental observation:

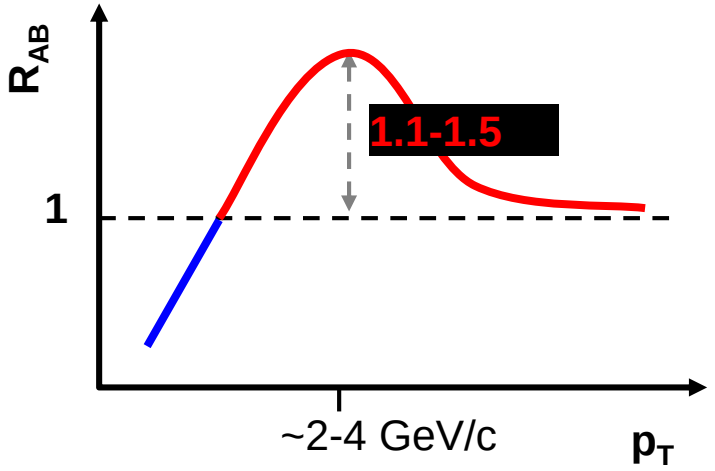
p+A collisions: $\sigma_{pA} = A^{\alpha(p_t)}\sigma_{pp}$



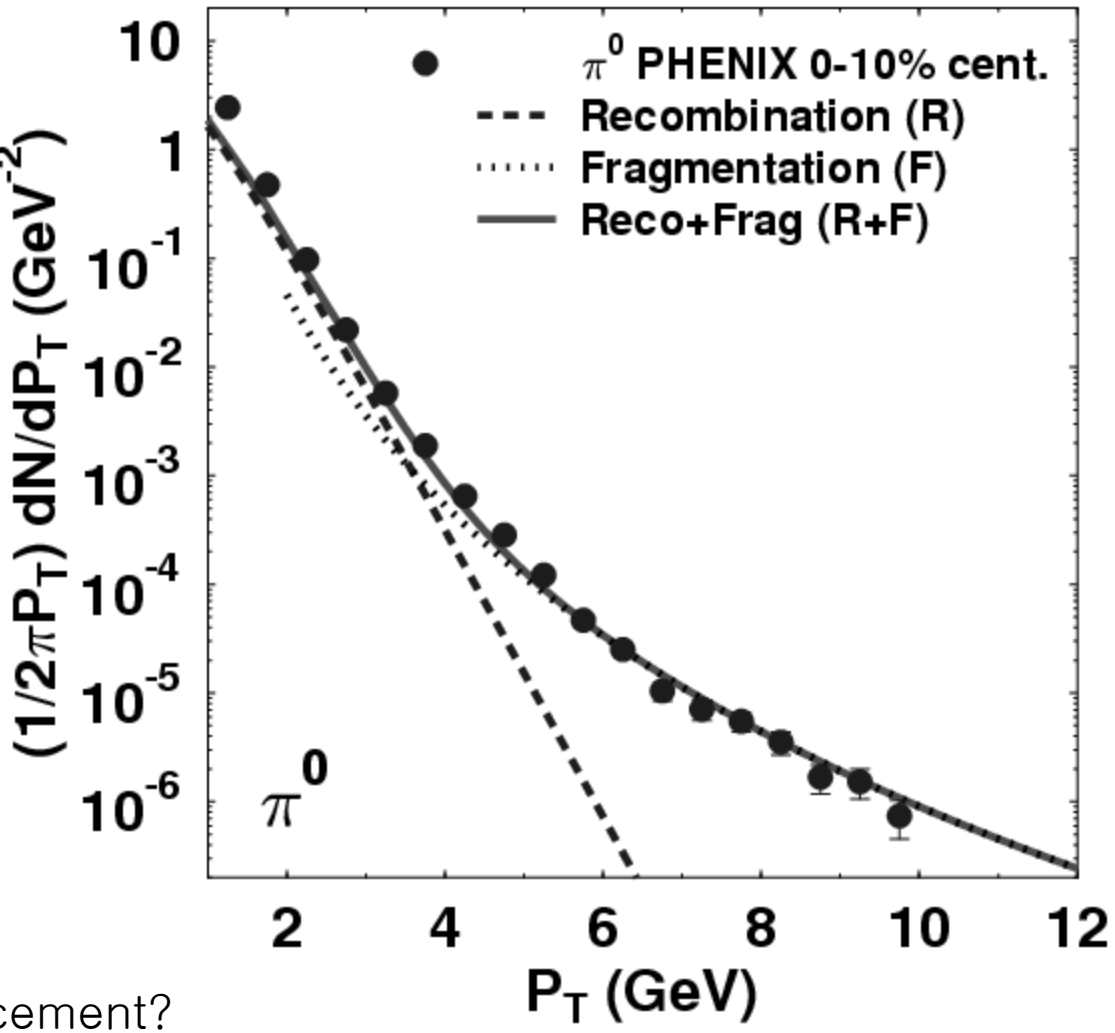
Theoretical explanation:

Partons can undergo soft scatters prior to the hard collision ⇒ spreads the spectrum out in p_T



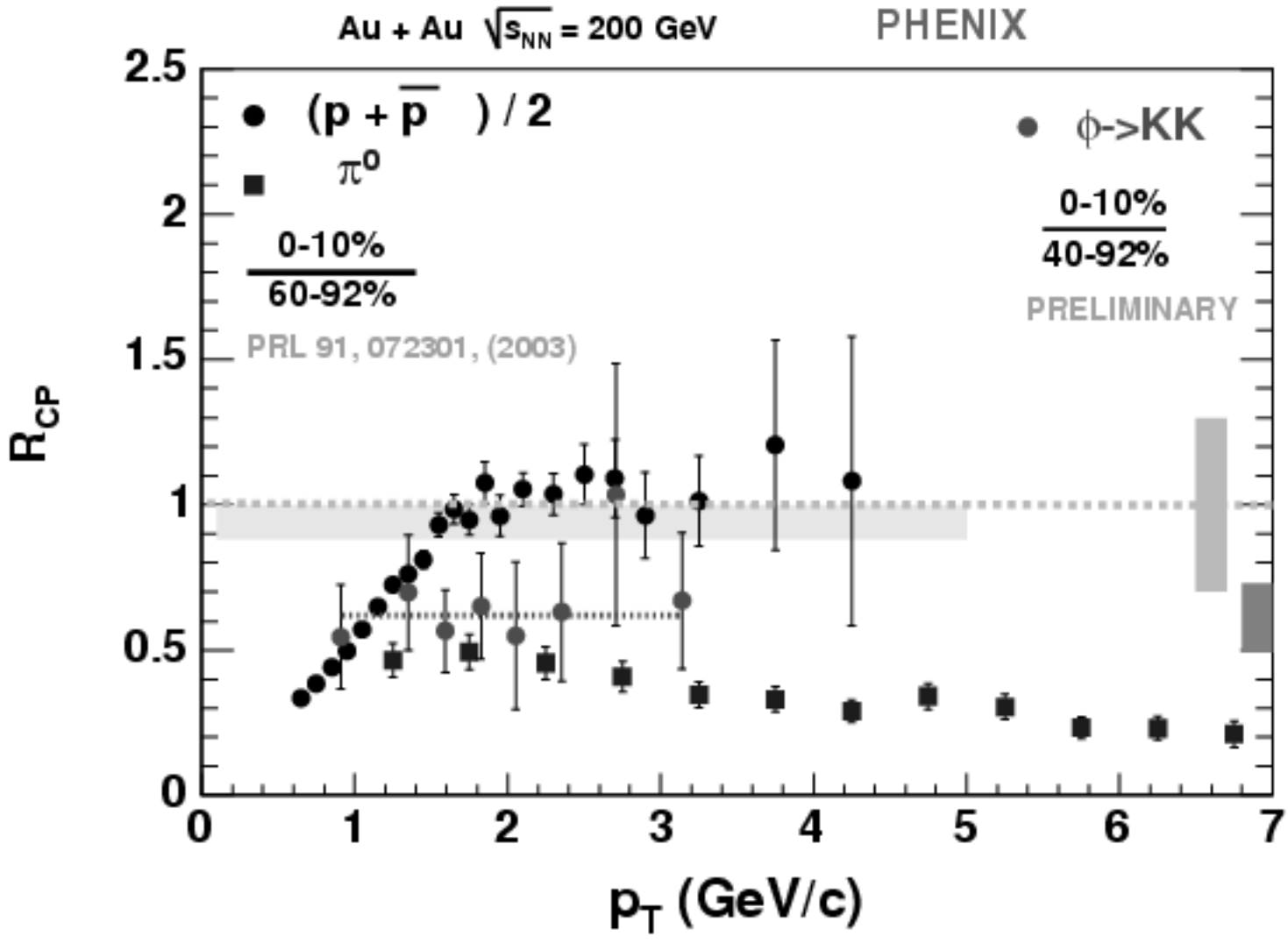


A+A collisions

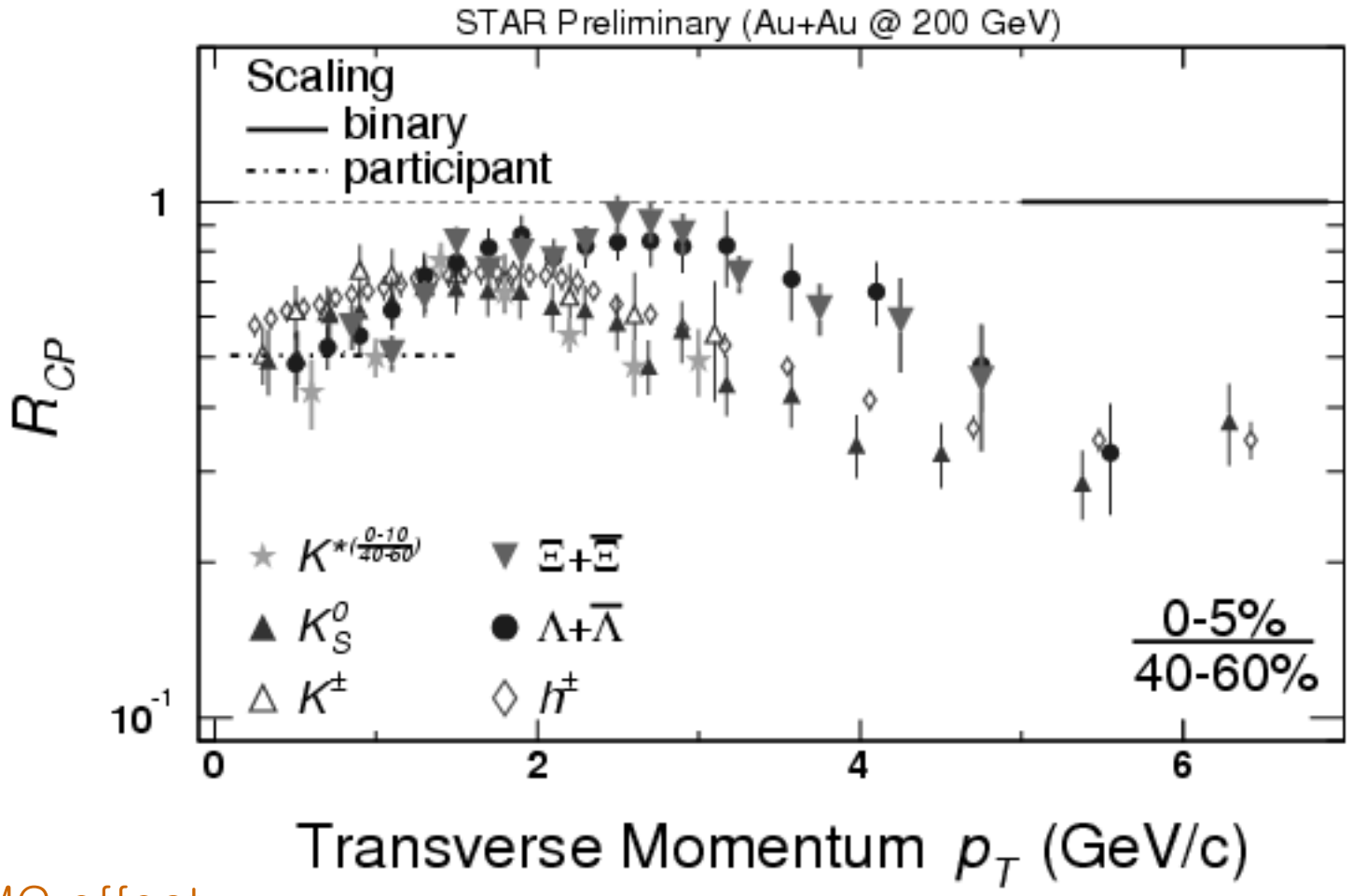


High Pt enhancement?

When scaled by N_part, they are suppressed.


Au + Au $\sqrt{s_{NN}}$ = 200 GeV
PHENIX
$(p + \bar{p}) / 2$
π^0
0-10%
60-92%
PRL 91, 072301, (2003)
ϕ->KK
0-10%
40-92%
PRELIMINARY
R_{CP}
p_T (GeV/c)
0
0.5
1
1.5
2
2.5
0
1
2
3
4
5
6
7

Suppression of high pt particles



EMC effect

J/Psi suppression

J/Psi production in pp, pA and AA

$$\sigma = A^{\alpha(p_t)}$$

$2/3 < \alpha(p_t) < 1$ without nuclear absorption

$\alpha(p_t)$ similar to Rcp

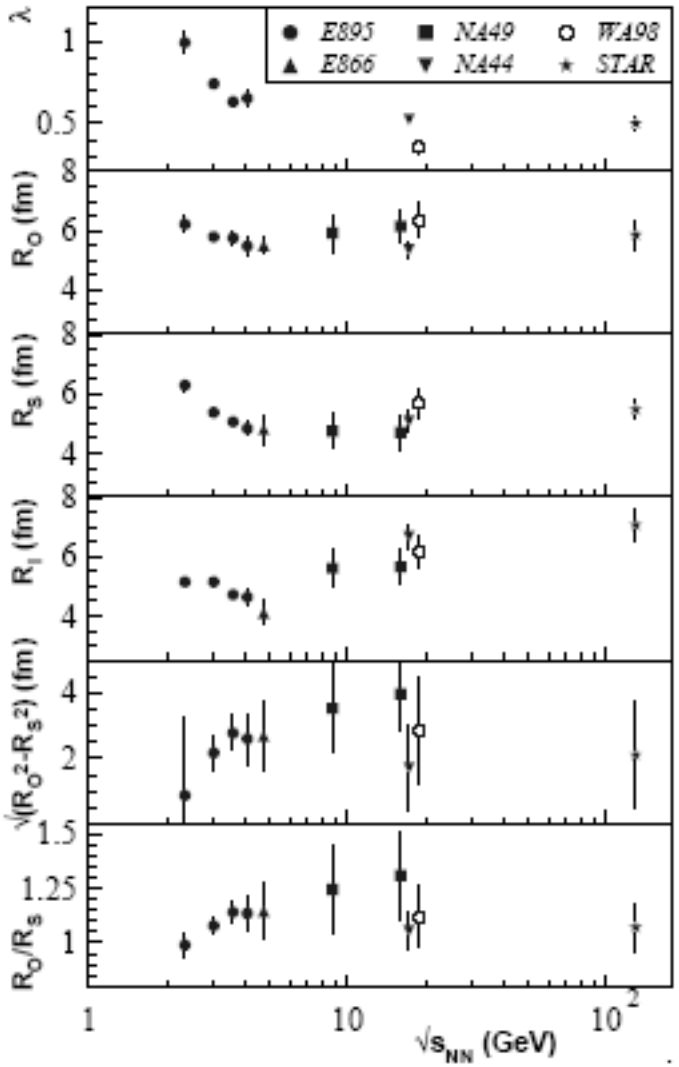
Correlation Function (HBT)

$$C_2 = \frac{\frac{d\ N}{dp^3{}_1 dp^3{}_2}}{\frac{d\ N_1}{d^3 p_1}\frac{d\ N_2}{d^3 p_2}}$$

$$C_2 = 1 + \lambda e^{-R_x^2 q_x^2 - R_y^2 q_y^2 - R_z^2 q_z^2 - R_t^2 q_t^2}$$

Particle interferometry: HBT correlations

But: HBT radii nearly constant with energy

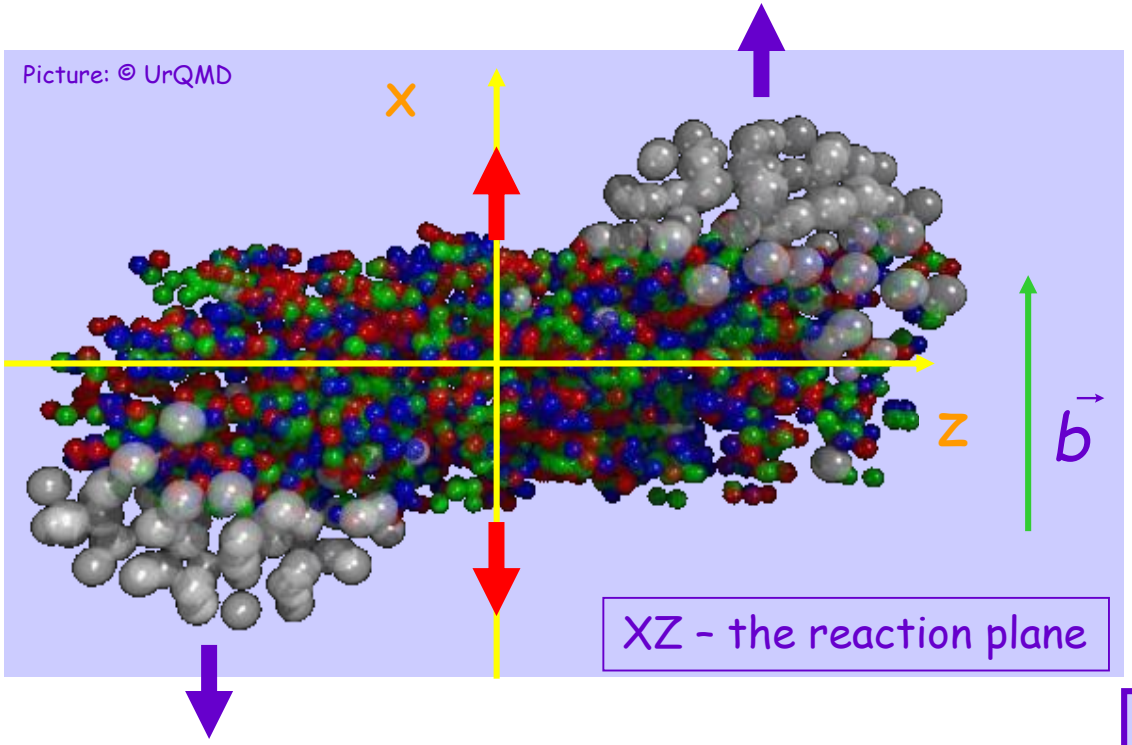


C. Adler et al. (STAR Coll.), nucl-ex/0206001

HBT puzzle :

No differences in the radius from SPS to RHIC, contrary to the hydrodynamic prediction

Anisotropic flow from AGS to RHIC

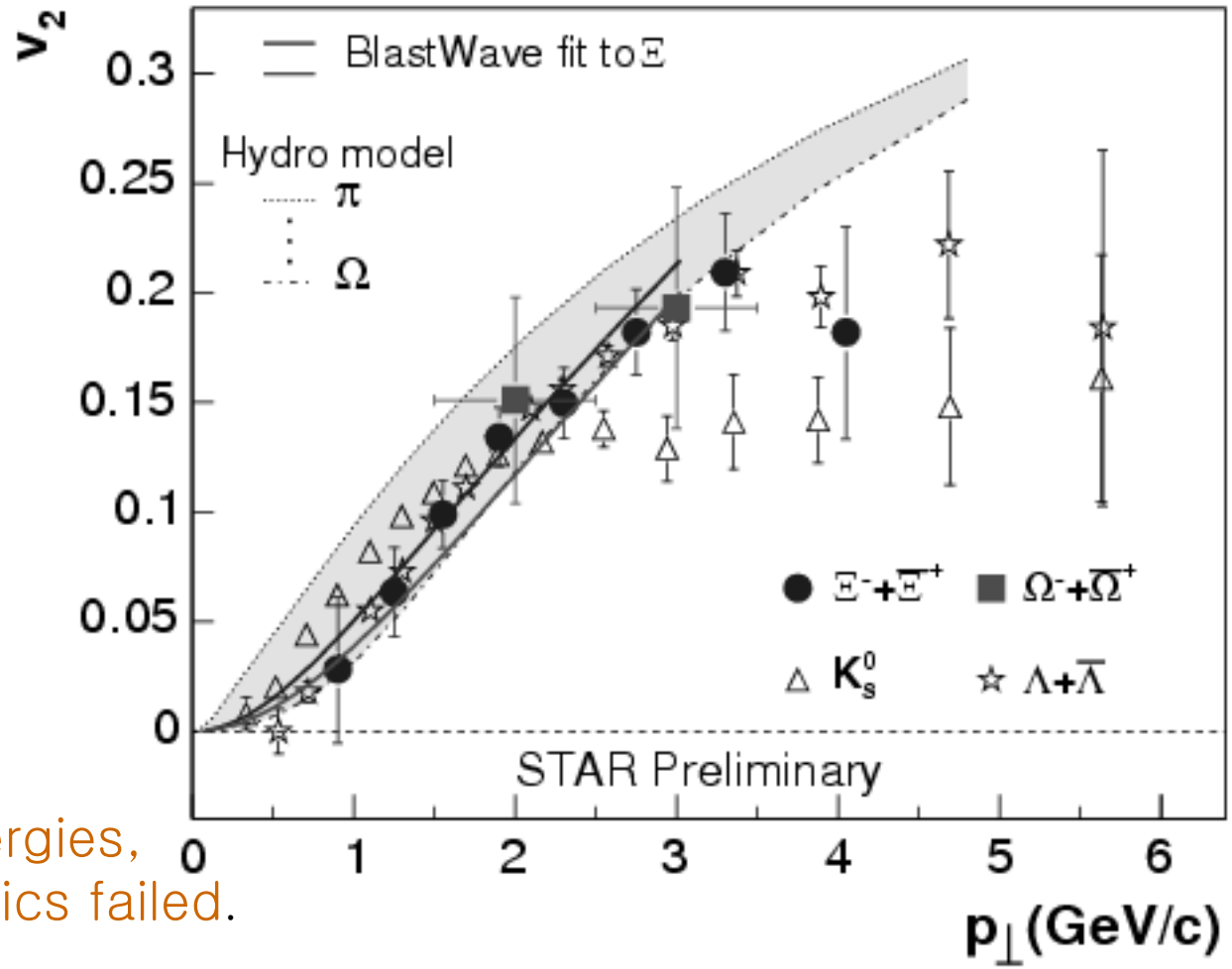


Anisotropic flow ≡ correlations with respect to the reaction plane

$$\frac{d^3N}{dp_t\,dy\,d\varphi} = \frac{d^2N}{dp_t\,dy}\frac{1}{2\pi}(1+2v_1\cos(\varphi)+2v_2\cos(2\varphi)+\ldots)$$

Directed flow

Elliptic flow



At lower energies, hydrodynamics failed.

Perfect hydrodynamic condition reached only at RHIC?

Jet Asymmetry

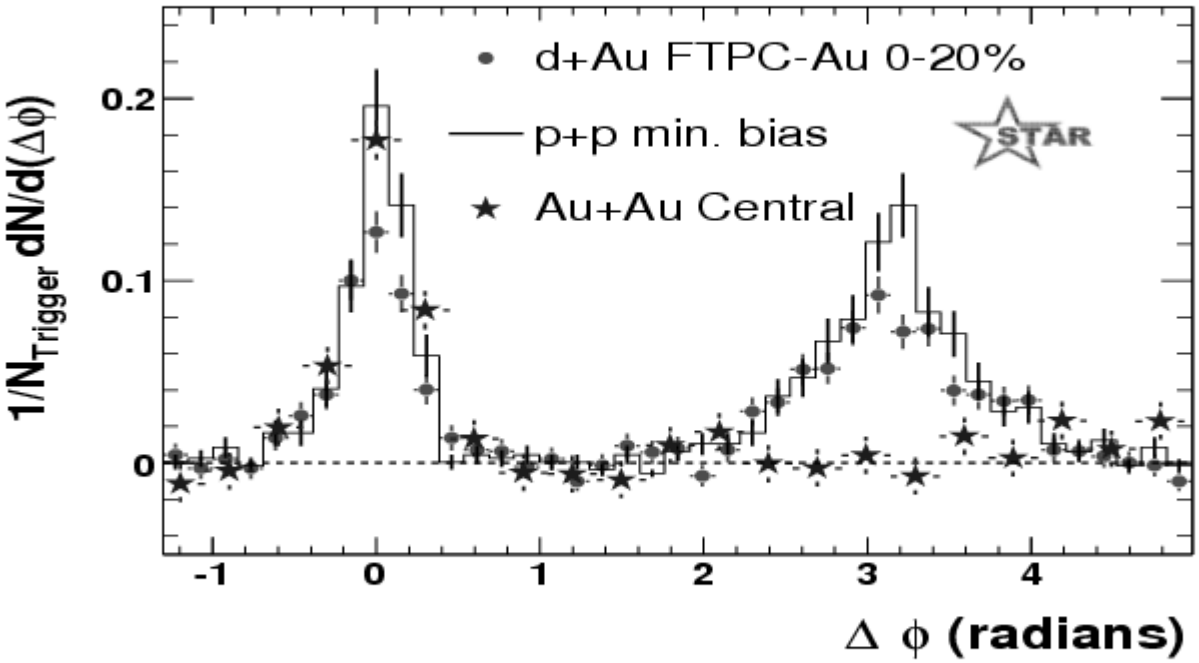


Figure 13: The **dA** "Return of the Jeti": Dijet fragment azimuthal correlations from STAR [97] in DAu are unquenched relative to the mono jet correlation observed in central $AuAu$.

summary

- Many features of hadron spectra in agreement with hydrodynamic concept.

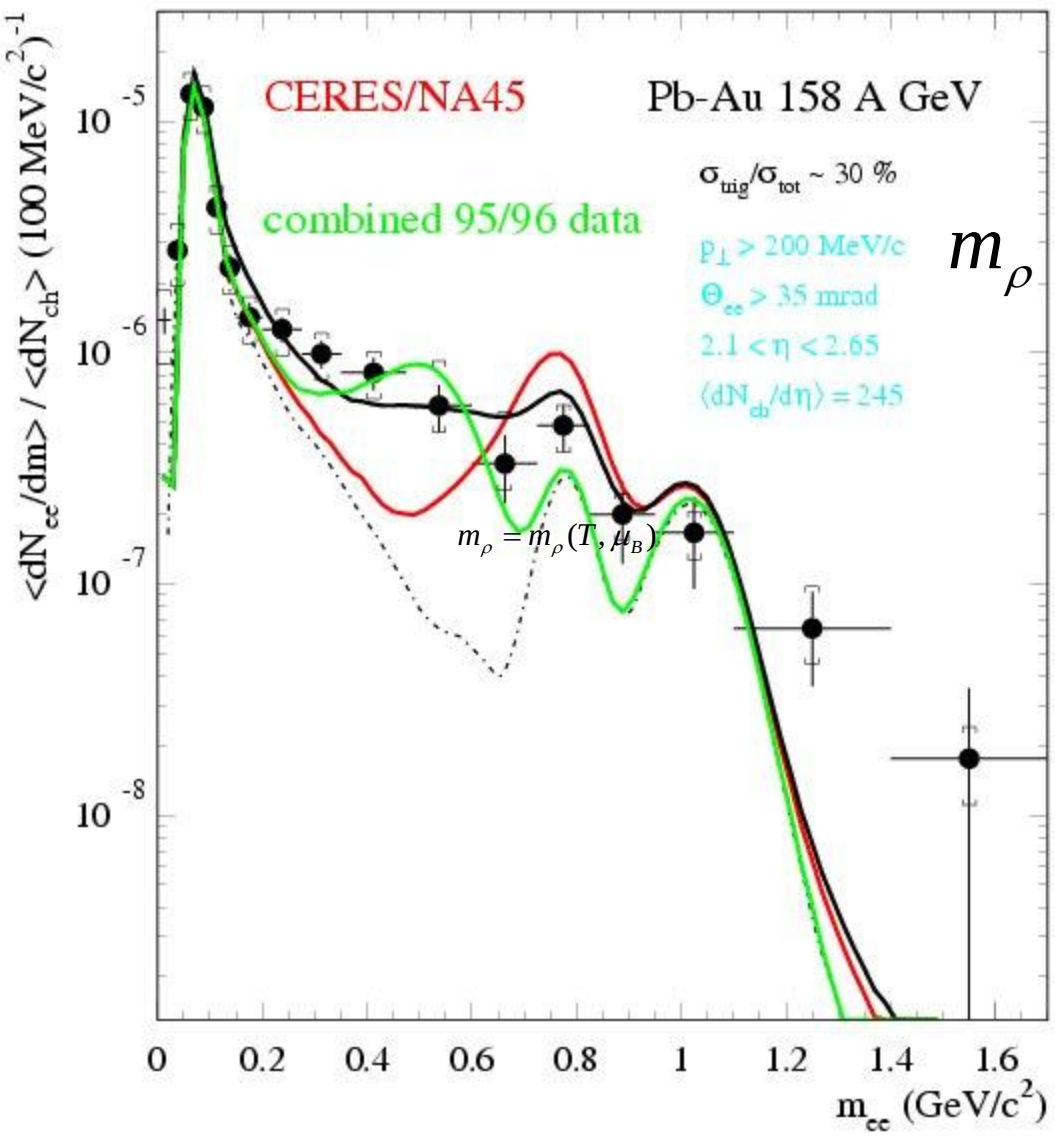
- But there is HBT puzzle.

Hadron spectra reveals many interesting features

- strangeness enhancement
- ratios, radial flow, y-distr.
- HBT
- high pt suppression
- elliptic flow
- fluctuation

- Not yet understood comprehensively

Dimuon excess in the mid mass range



$$m_\rho = m_\rho(T, \mu_B)$$

Lee, Hatsuda
Brown, Rho