Particle Production Studied with **BRAHMS**

I.G. Bearden,

Niels Bohr Institute

For

The BRAHMS collaboration

BRAHMS

The BRAHMS Collaboration

- 12 institutions-

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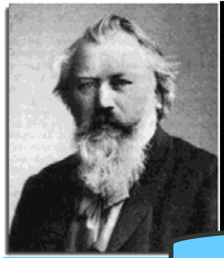
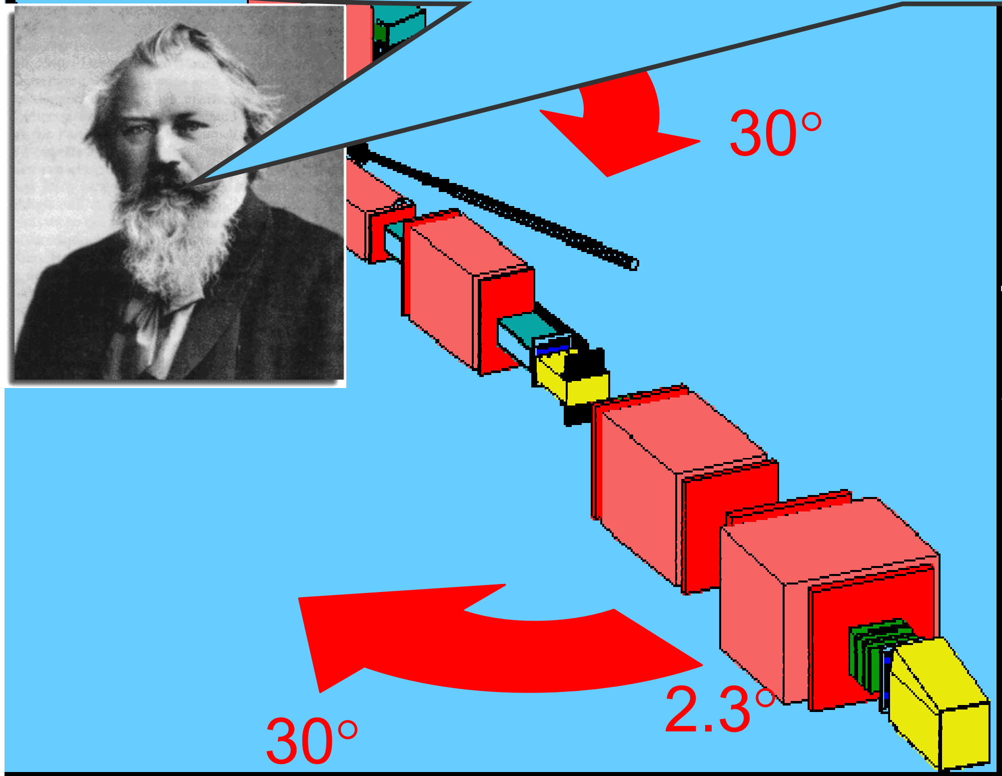


The BRAHMS Experiment

It's **B**road **RA**nge **H**adron **M**agnetic **S**pectrometers!

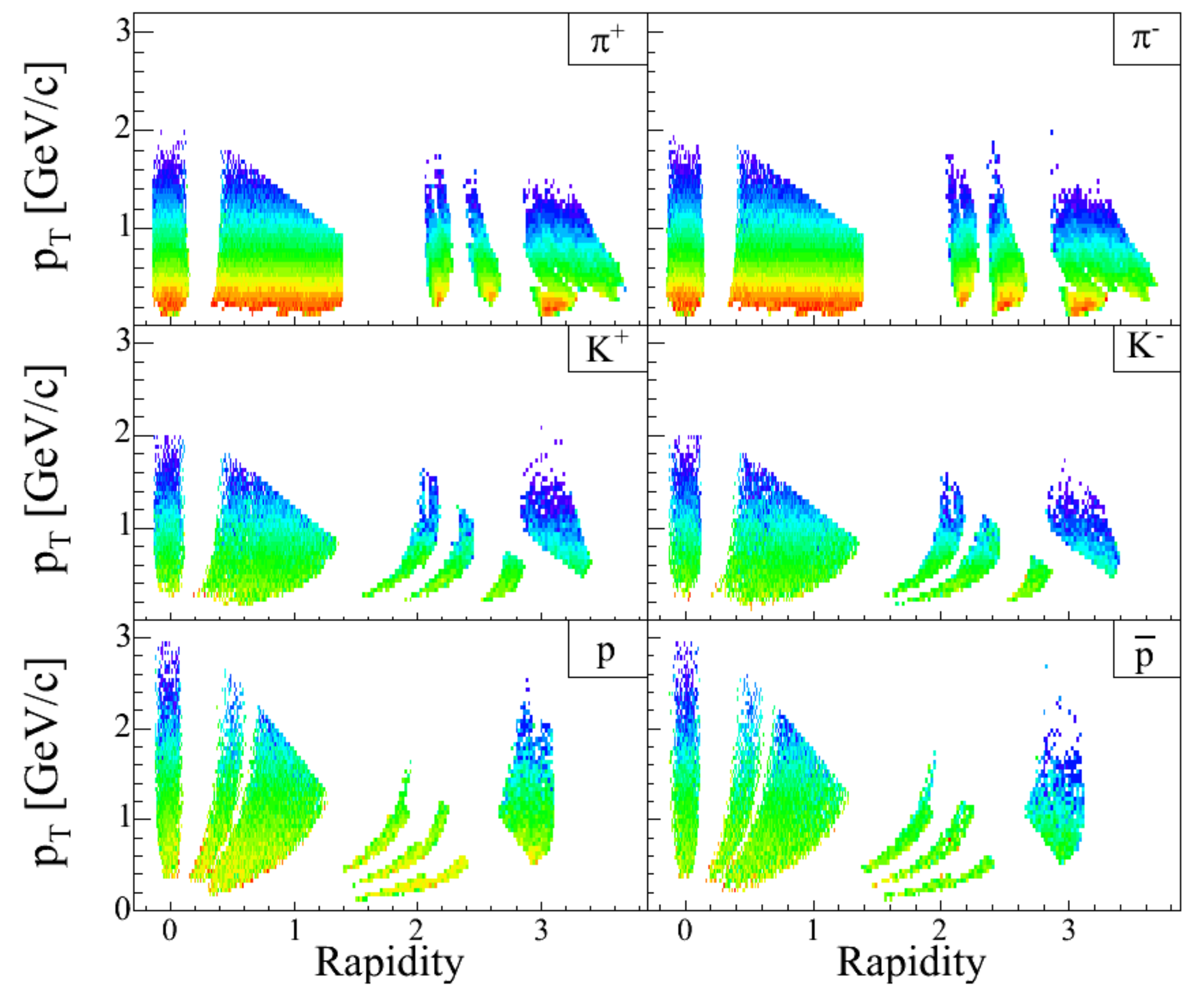


Two small solid angle spectrometers (FS and MRS)

that can rotate from 2.3° to 30° and 30° to 90° (MRS)

provide excellent PID over broad range in y-p_T

BRAHMS Acceptance:

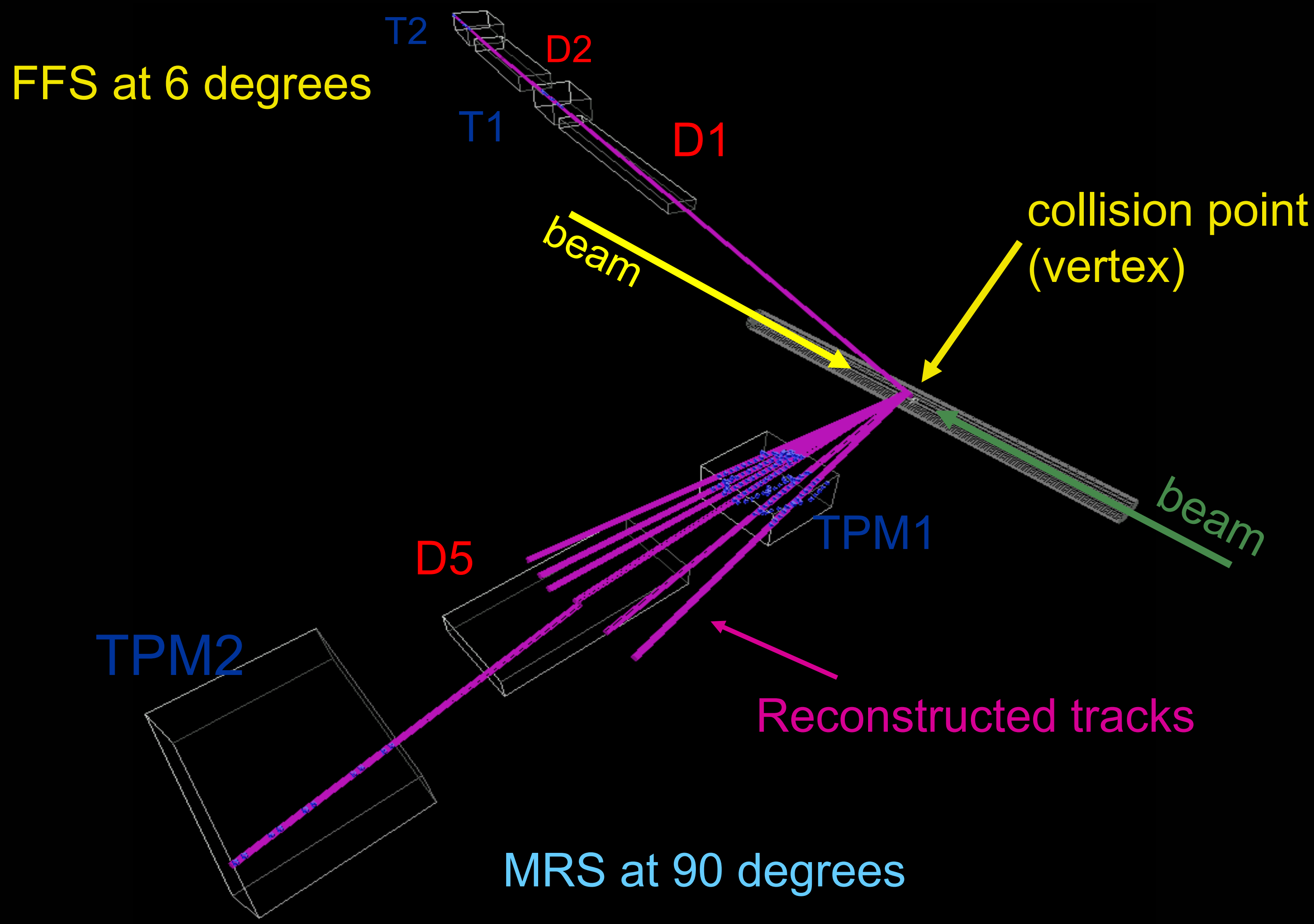


π

K

p

A BRAHMS Event



T2

D2

FFS at 6 degrees

T1

D1

collision point (vertex)

beam

beam

TPM1

D5

TPM2

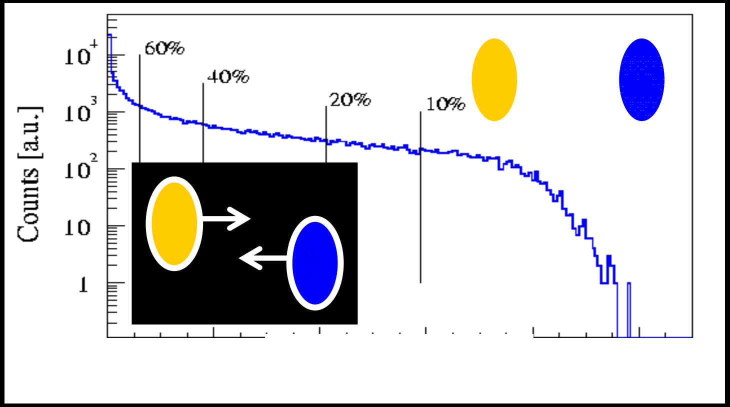
Reconstructed tracks

MRS at 90 degrees

Event Counting

We measure (almost) all the collisions and counting is easy!

…still we need the centrality from the multiplicity (MA)…

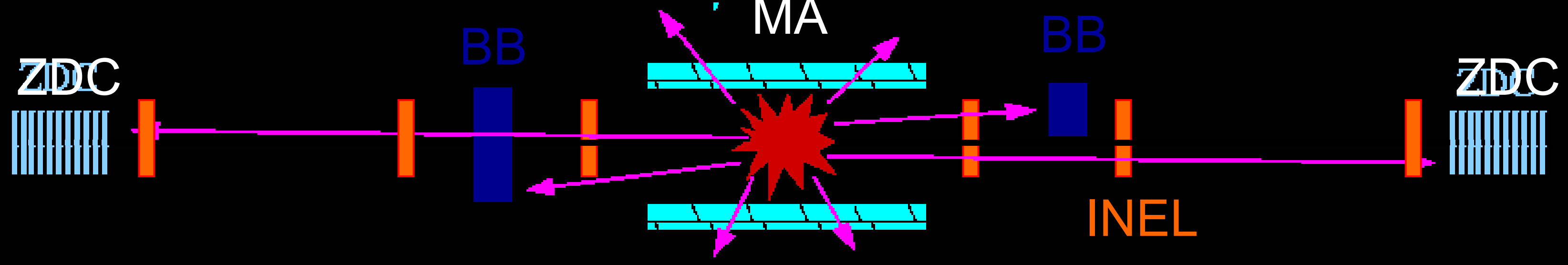


We want to make spectra,

$$\frac{1}{N_{events}}\frac{1}{2\pi p_T}\frac{dN_{tracks}}{d\eta dp_T}$$

⇒ we need to count the number of collisions (events) N_{events} and the number of tracks N_{tracks}

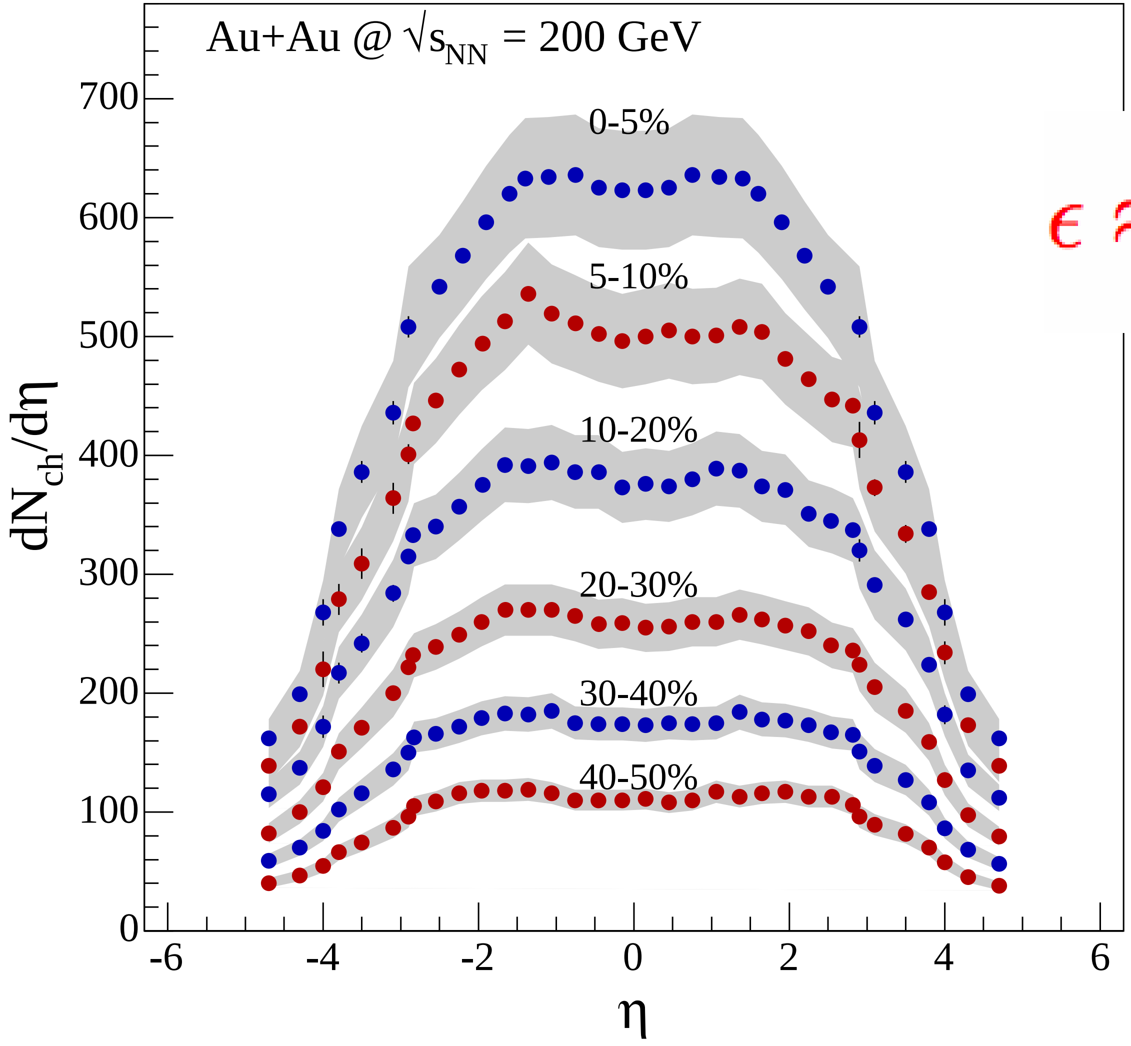
…and the collision point (vertex) from the BB, ZDC and INEL counters.



Charged Particle Multiplicity

BRAHMS

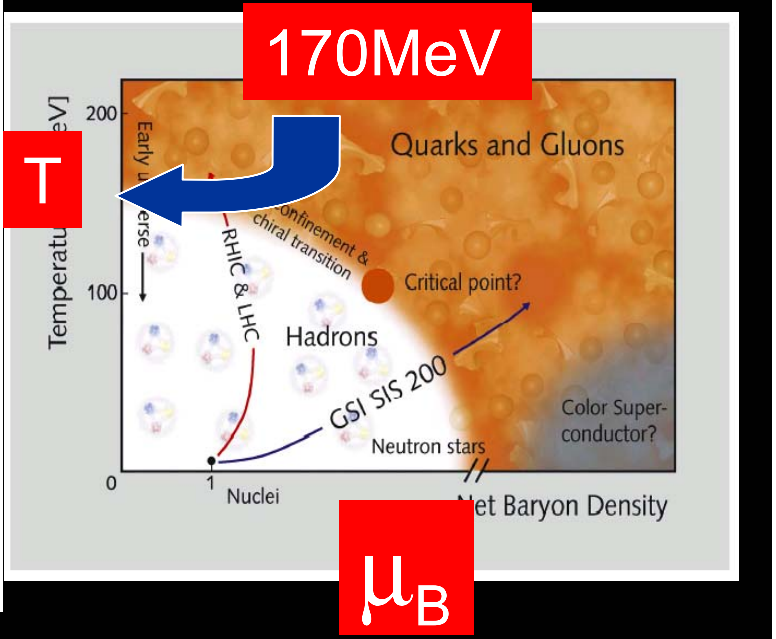
dN/dη



According to Bjorken,

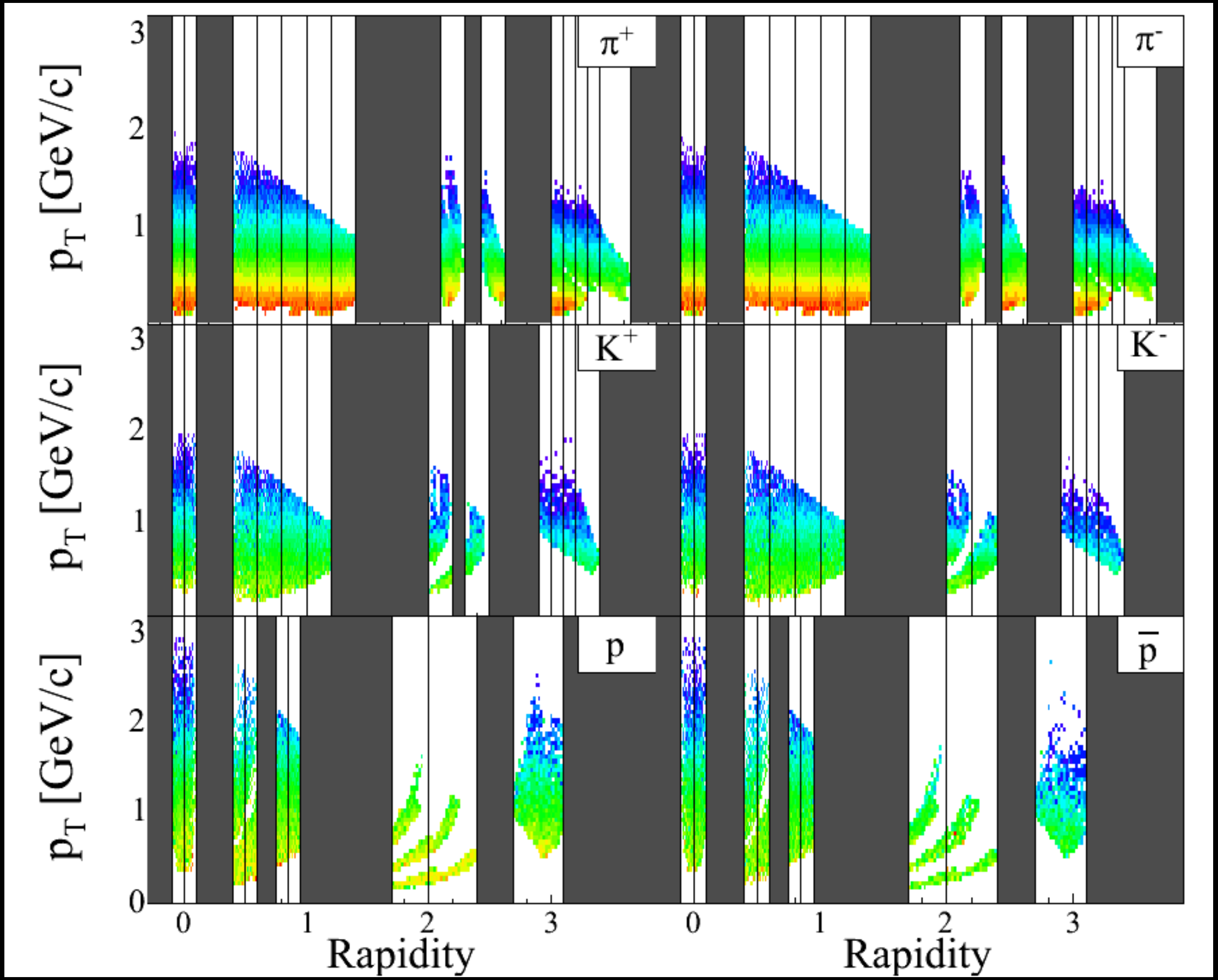
$$\epsilon \approx \frac{1}{A_t}\frac{dN}{d\eta}\frac{1}{\tau} < E_t >$$

$\varepsilon > 5 \mathrm{GeV/fm}^3$



Particle Spectra

After appropriate corrections, we combine all data sets to obtain final invariant yields over a broad range of rapidity and p_T



π

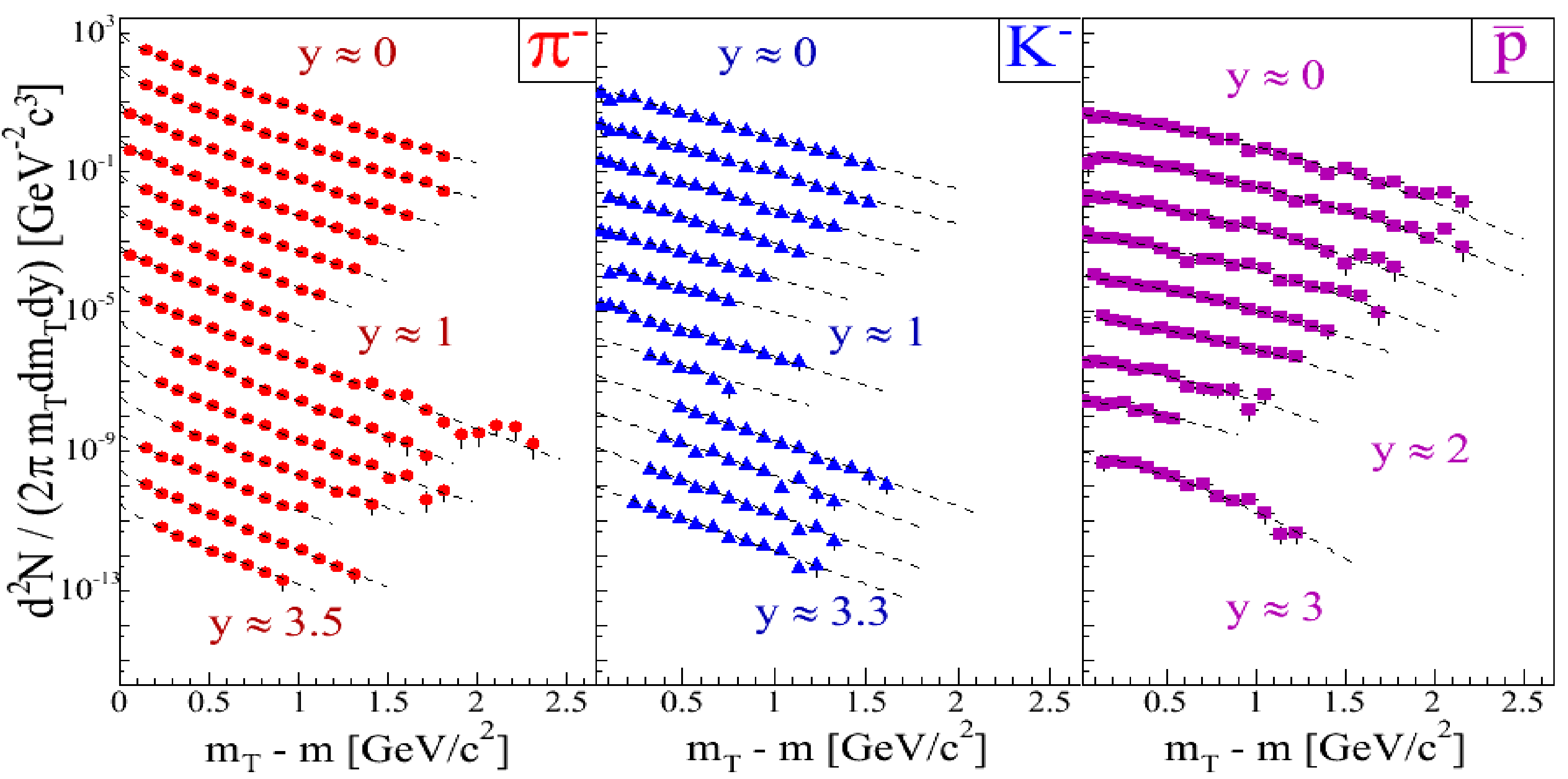
K

p

Spectra:

BRAHMS

Top 5% central collisions



Pions: power law

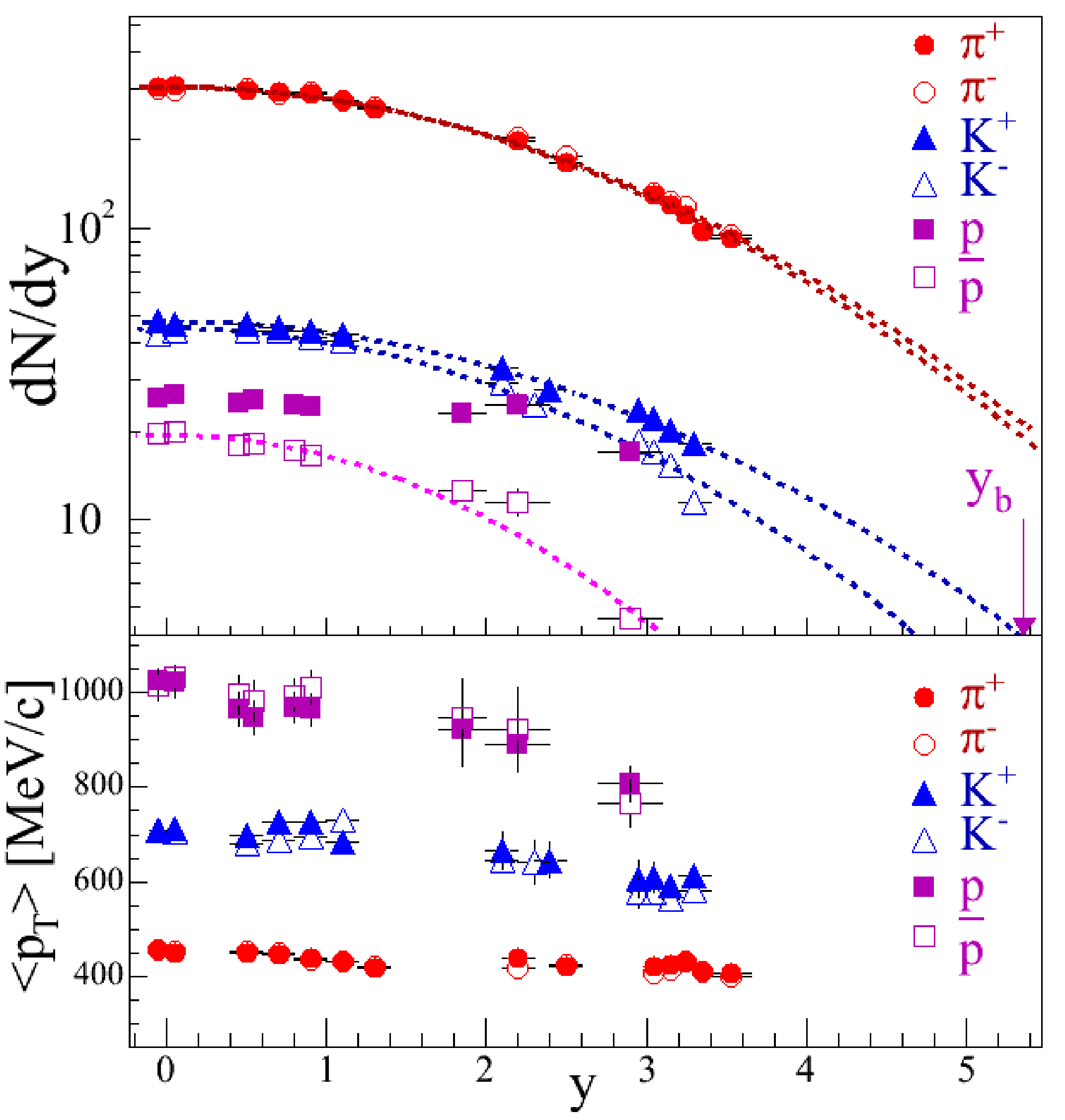
$$A\left(1+\frac{p_T}{p_0}\right)^{-n}$$

Kaons:exponential

$$A\exp\left(-\frac{m_T-m}{T}\right)$$

Protons: Gaussian

$$A\exp\left[-\frac{p_T^2}{2\sigma^2}\right]$$



At y ~ 0, dN/dy is

~ 300 (300) for π^+ (π^-)

~ 47 (44) for K^+ (K^-)

~ 27 (20) for p (pbar)

N(π) >> N(K) > N(p)

N(π^+) = N(π^-)

N(K^+) > N(K^-) and

N(p) > N(pbar) systematically

Integrated multiplicities

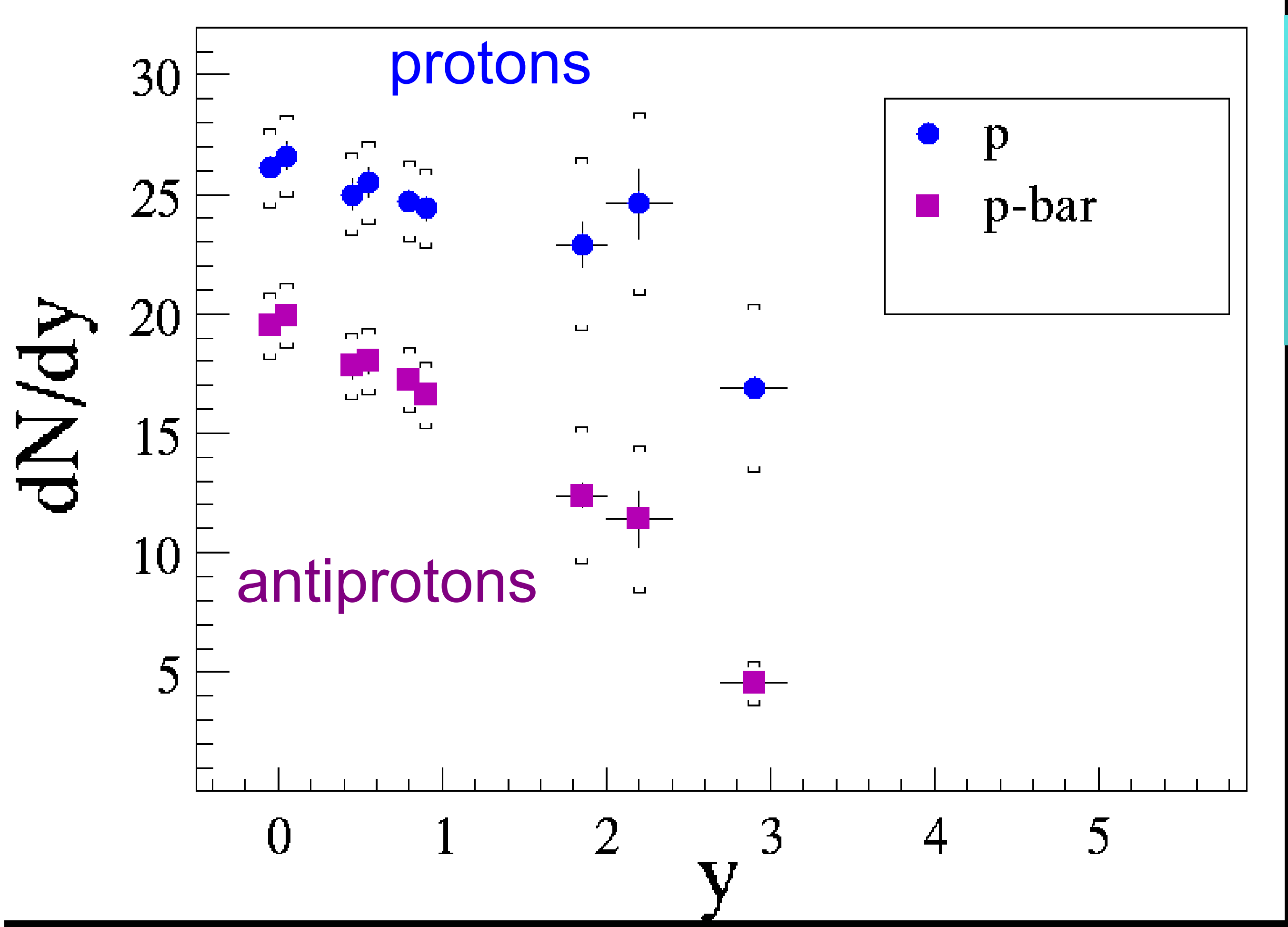
(Gaussian fit)

N(π^-) ~ 1780 N(π^+) ~1760

N(K^+) ~ 290 N(K^-) ~ 240

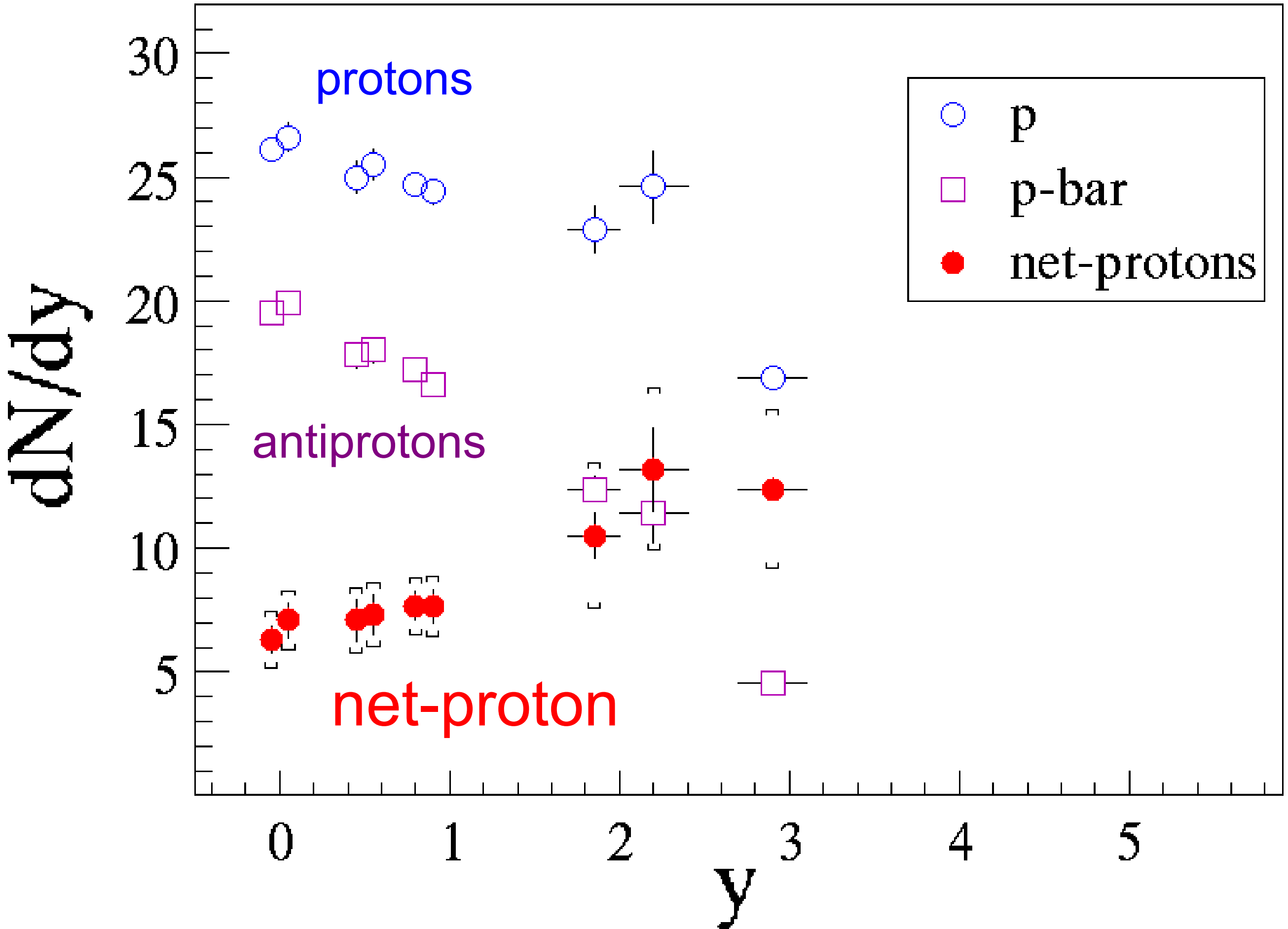
N(pbar) ~ 85

Proton & antiproton dN/dy (5% central)



BRAHMS, submitted
to PRL, 31/12/03
nucl-ex/0312023
P. Christiansen
Ph.D. Thesis, København's
Universitet

"Net" Proton= proton - antiproton dN/dy (5% central)



BRAHMS, submitted to PRL, 31/12/03
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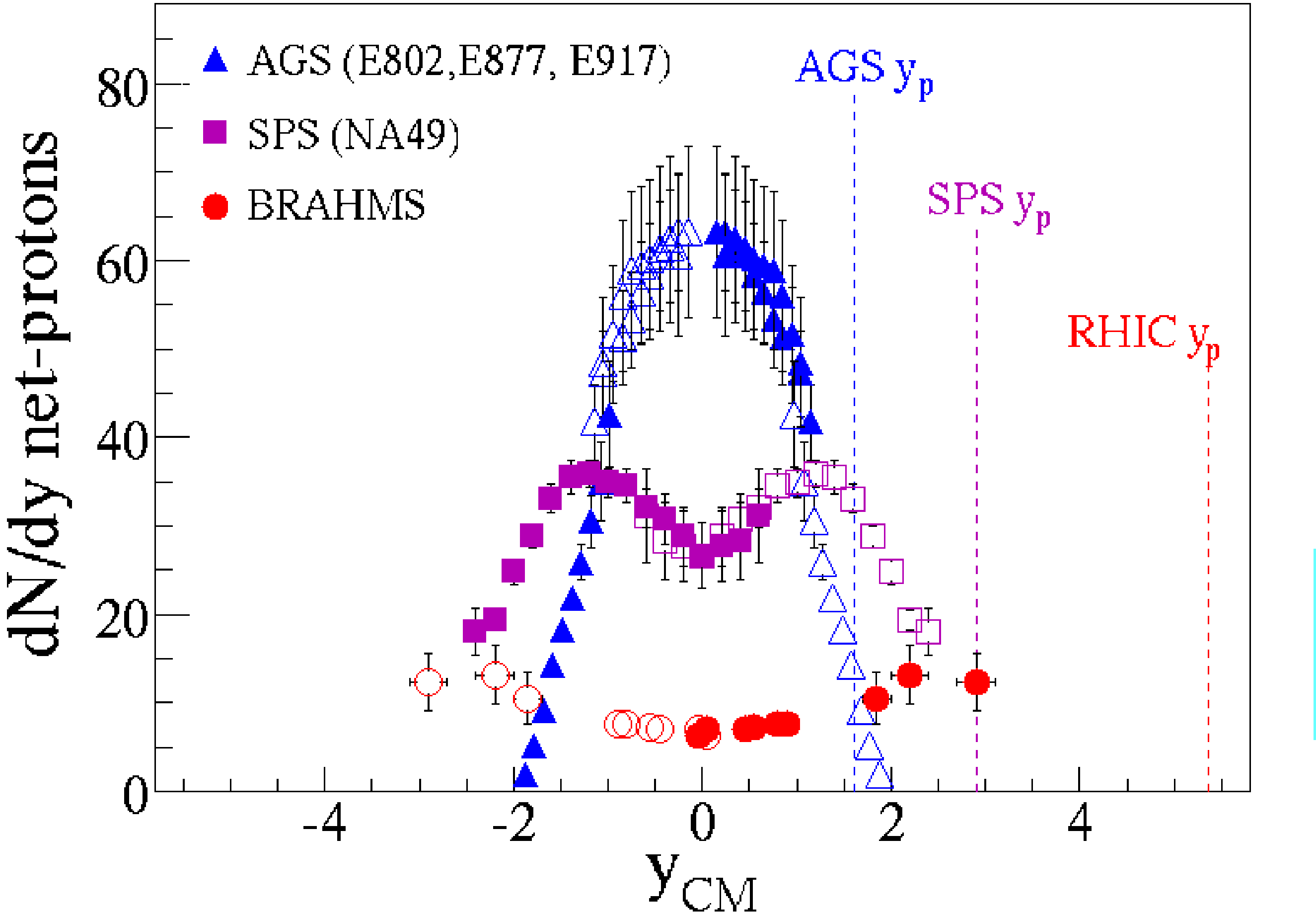
BRAHMS

RHIC vs. AGS,SPS:



BRAHMS, submitted to PRL,
nucl-ex/0312023
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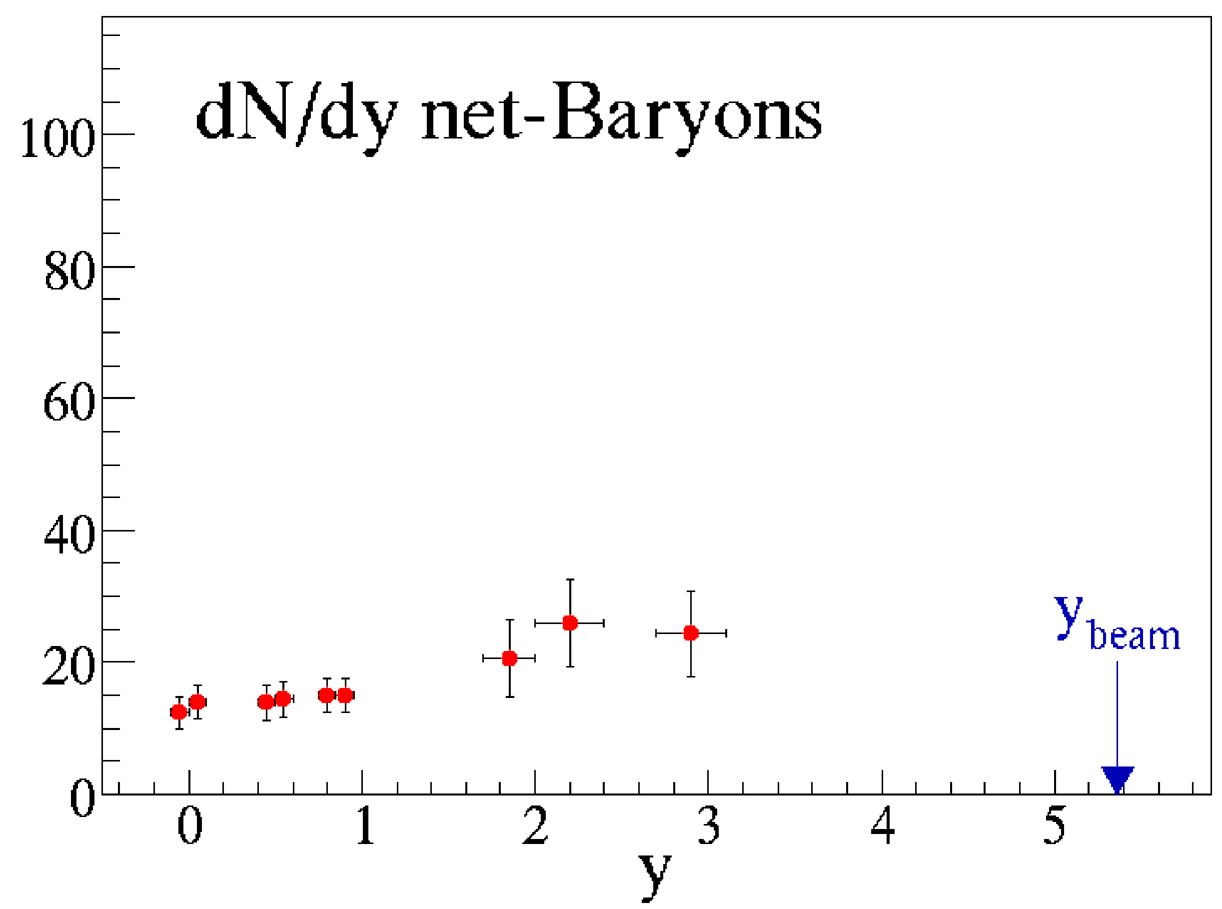
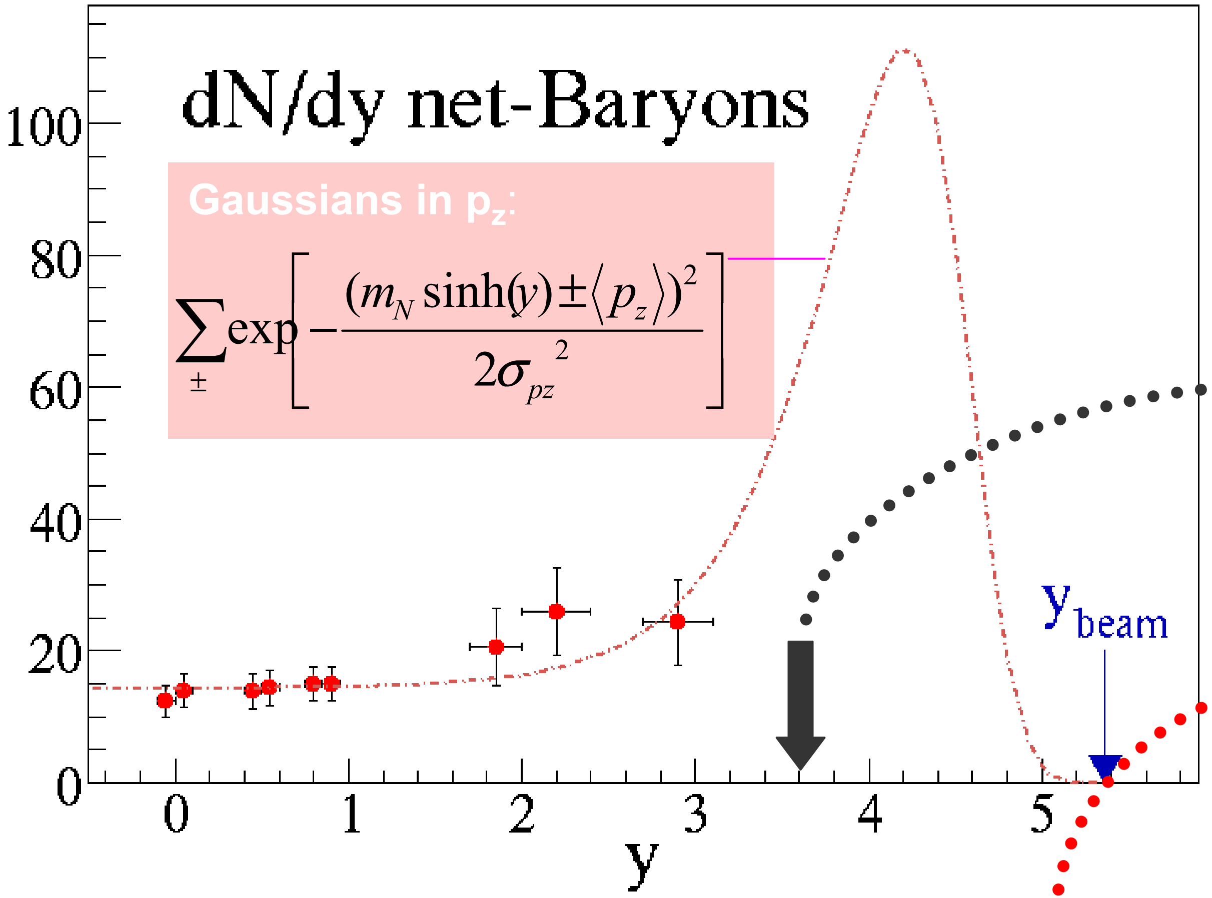
AGS : high stopping
RHIC: more
transparent

Net Baryon dN/dy



Calculate net-baryon distribution from net-protons (and y=0 yields of Λ, and Hijing…)

Rapidity loss: gaussian in p_z



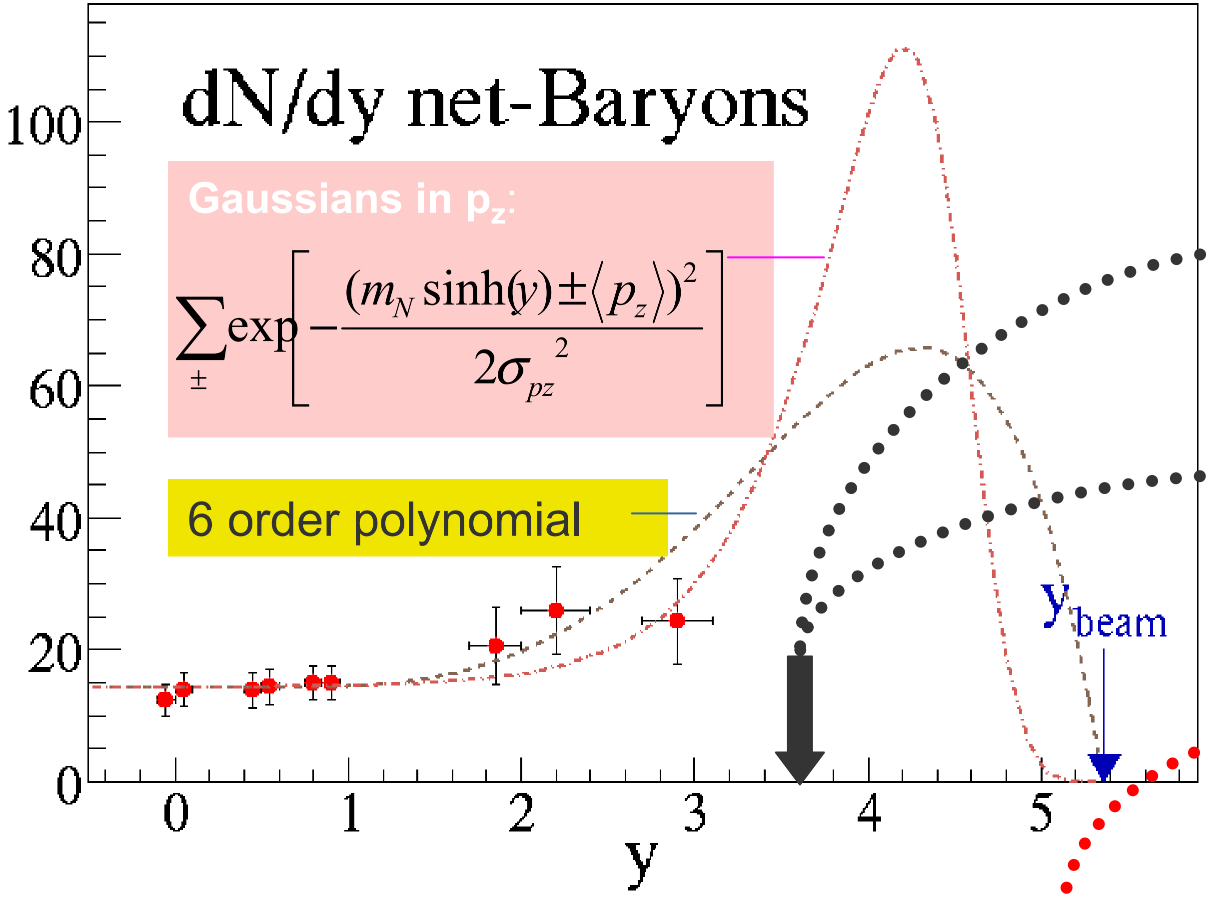
Gaussians in p_z:

$$\sum_{\pm} \exp\left[-\frac{(m_N \sinh(y) \pm \langle p_z \rangle)^2}{2\sigma_{pz}^{\;2}}\right]$$

$$\langle \delta y \rangle = \quad 2.03 \pm 0.16$$

Rapidity loss:
$$\langle \delta y \rangle = y_p - \langle y \rangle = y_p - \frac{2}{N_{part}} \int_0^{y_p} y \frac{dN_{(B-\overline{B})}}{dy} dy$$

Rapidity loss: 6th order polynomial



$\langle \delta y \rangle = 2.03 \pm 0.16$

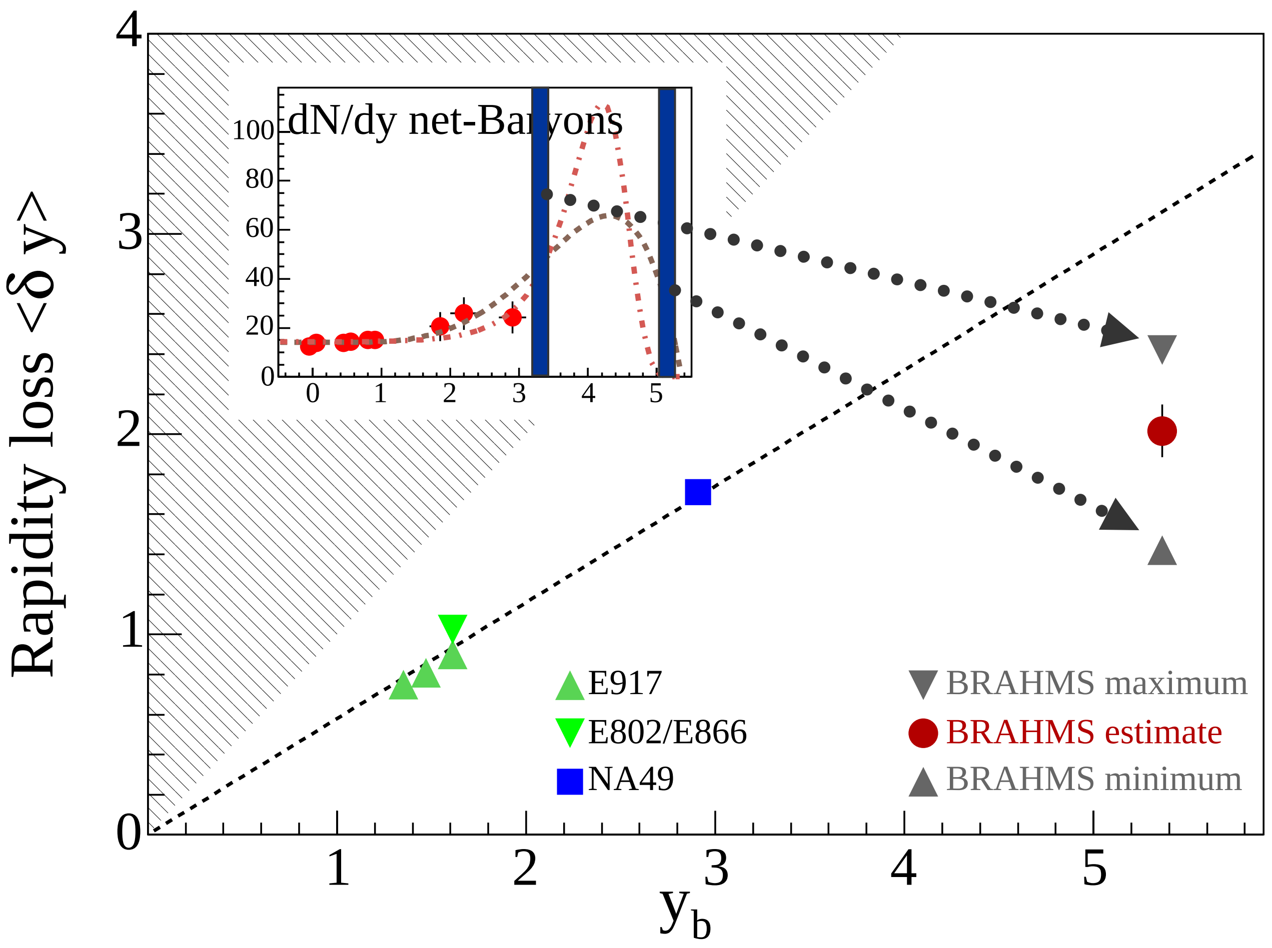
$\langle \delta y \rangle = 2.00 \pm 0.10$

$$\int_{-y_p}^{y_p} \langle m_T \rangle_y \frac{dN_{(B-\bar{B})}}{dy} \cosh y \, dy$$

Total ΔE=25.7±2.1TeV

Rapidity loss: $\langle \delta y \rangle = y_p - \langle y \rangle = y_p - \frac{2}{N_{part}} \int_0^{y_p} y \frac{dN_{(B-\bar{B})}}{dy} dy$

δy vs. y_{beam}



Even (unphysically) extreme approximations don’t change conclusions: scaling broken, large energy available

Total ΔE=25.7±2.1TeV

$$\int_{-y_p}^{y_p} \left\langle m_T \right\rangle_y \frac{dN_{(B-\bar{B})}}{dy} \cosh y \, dy$$

Energy Balance…

- Fit π, K and p distributions (dN/dy and $\langle m_T \rangle$ vs y)
  $\Rightarrow$ total energy of π, K and p
- Assume reasonable distribution for particles we don't detect (π^0,n,Λ…)
- Calculate the total energy…

$$E_{total} = \sum_{specie}\left[\int \frac{dN}{dy}\langle m_T \rangle \cosh(y)\, dy\right]$$

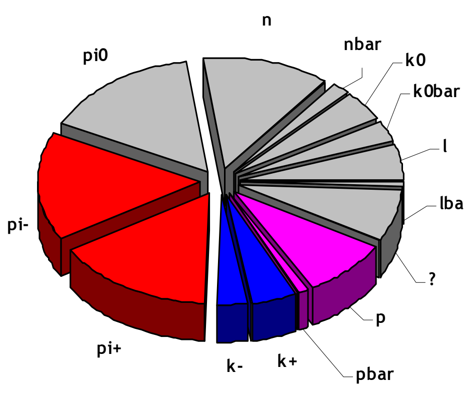
Energy (in GeV)

p	: 3108	π^0	: 6004
$\bar{p}$	: 428	n	: 3729
K^+	: 1628	$\bar{n}$	: 513
K^-	: 1093	K^0	: 1628
π+	: 5888	$\bar{K}^0$	: 1093
π-	: 6117	Λ	: 1879
		$\bar{\Lambda}$	: 342

sum: 33.4 TeV
produced: 24.8TeV

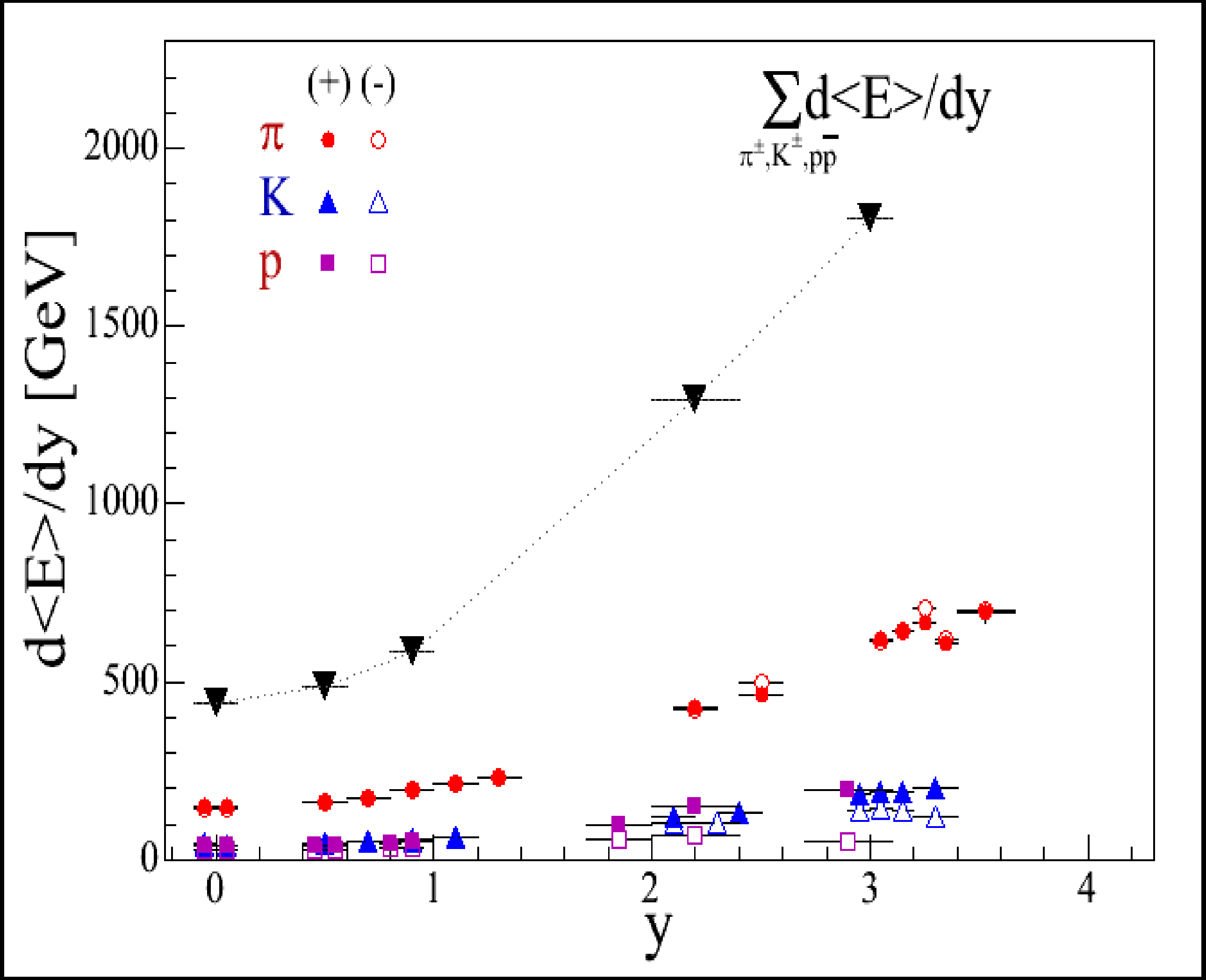
NB: the method is very sensitive to the tails of the dN/dy dist. (±10-15%)

≈35 TeV ($E_{beam} \times N_{part}$)
of which ≈25 TeV are carried by produced particles.



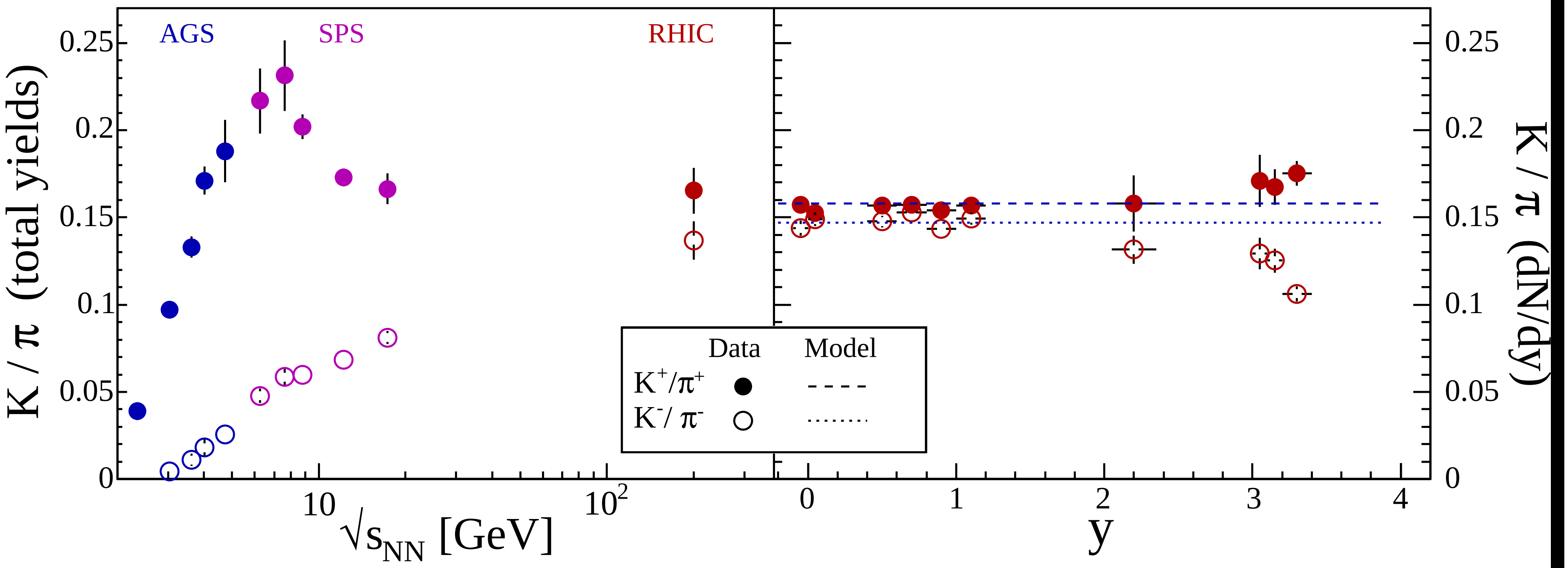
BRAHMS

Where is the energy?



≈9TeV in produced particles in the covered y range -3<y<3

Strange to non-strange meson ratios



$K^-/\pi^- \approx K^+/\pi^+$ at midrapidity

Depend strongly on baryochemical potential

Strangeness with Kaons

RAPIDITY DEPENDENCE

Y < 1 : consistent with Hadron Gas Stat. Model

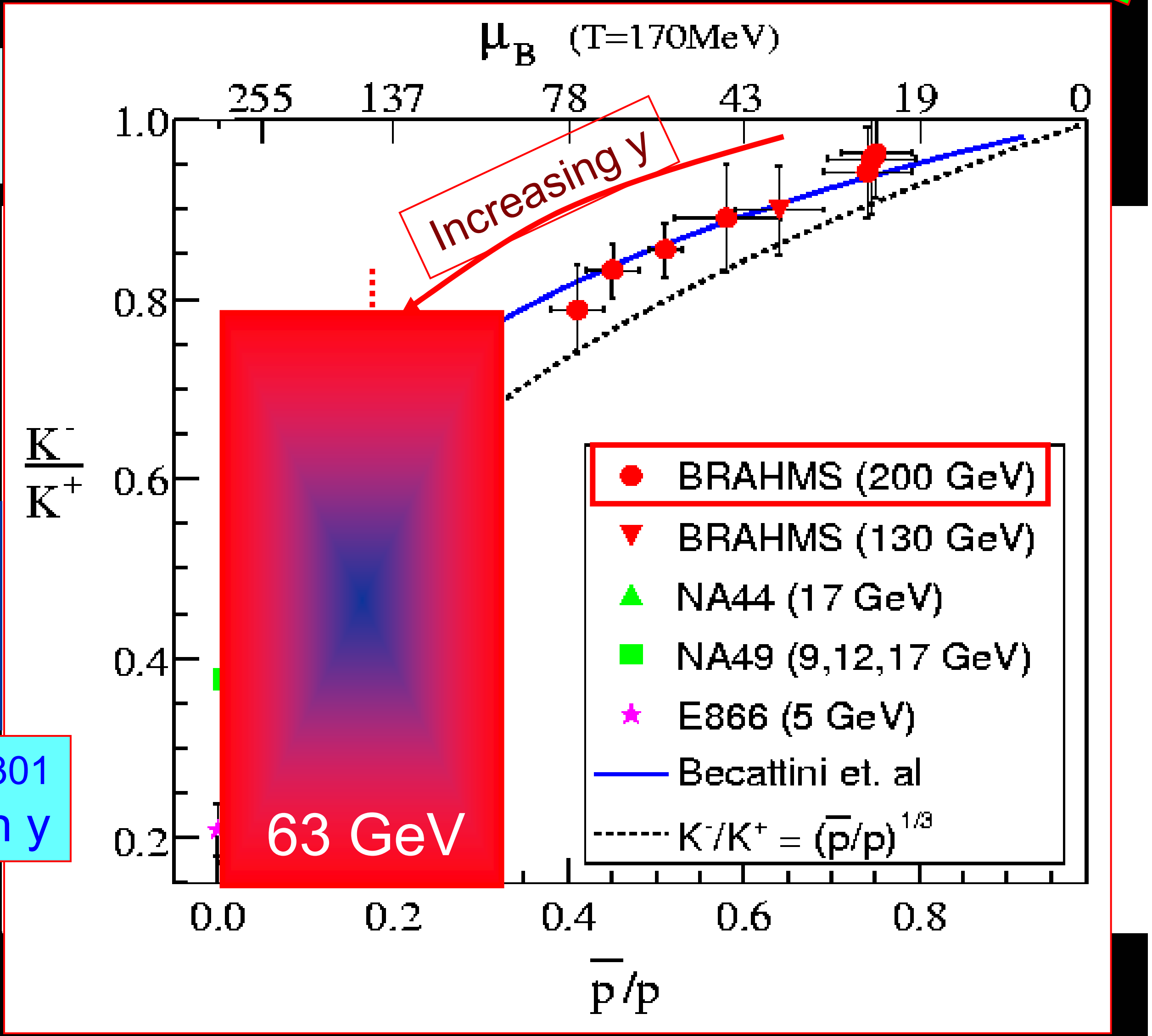
K^+/π^+ : 15.6 ± 0.1 % (stat)

K^-/π^- : 14.7 ± 0.1 % (stat)

[Phys. Lett. B 518 (2001) 41]

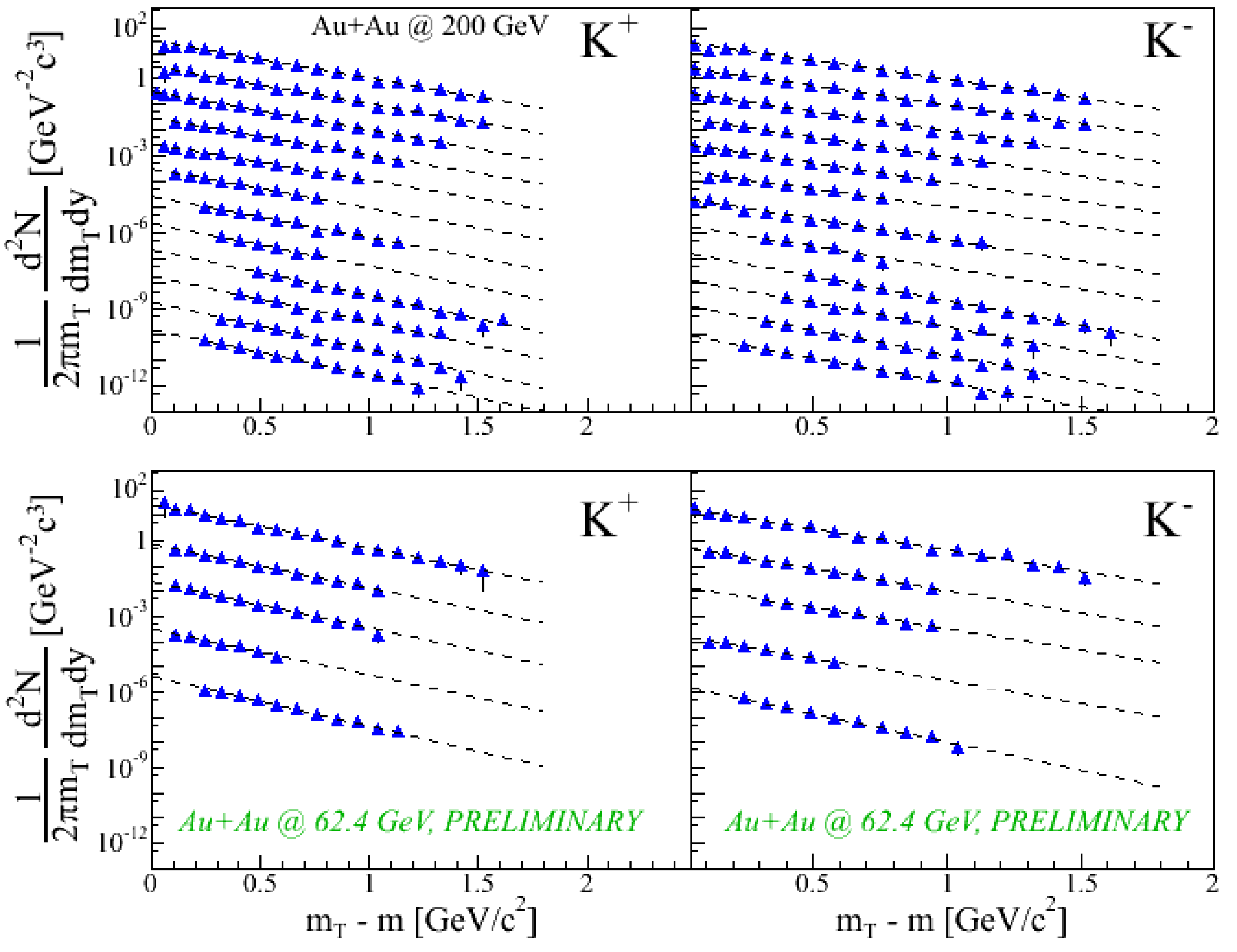
Divergence at higher y :
Associated K^+ production
No single source with
unique T and μ_B

BRAHMS, PRL90 (2003) 102301
T~constant, μ_B varies with y

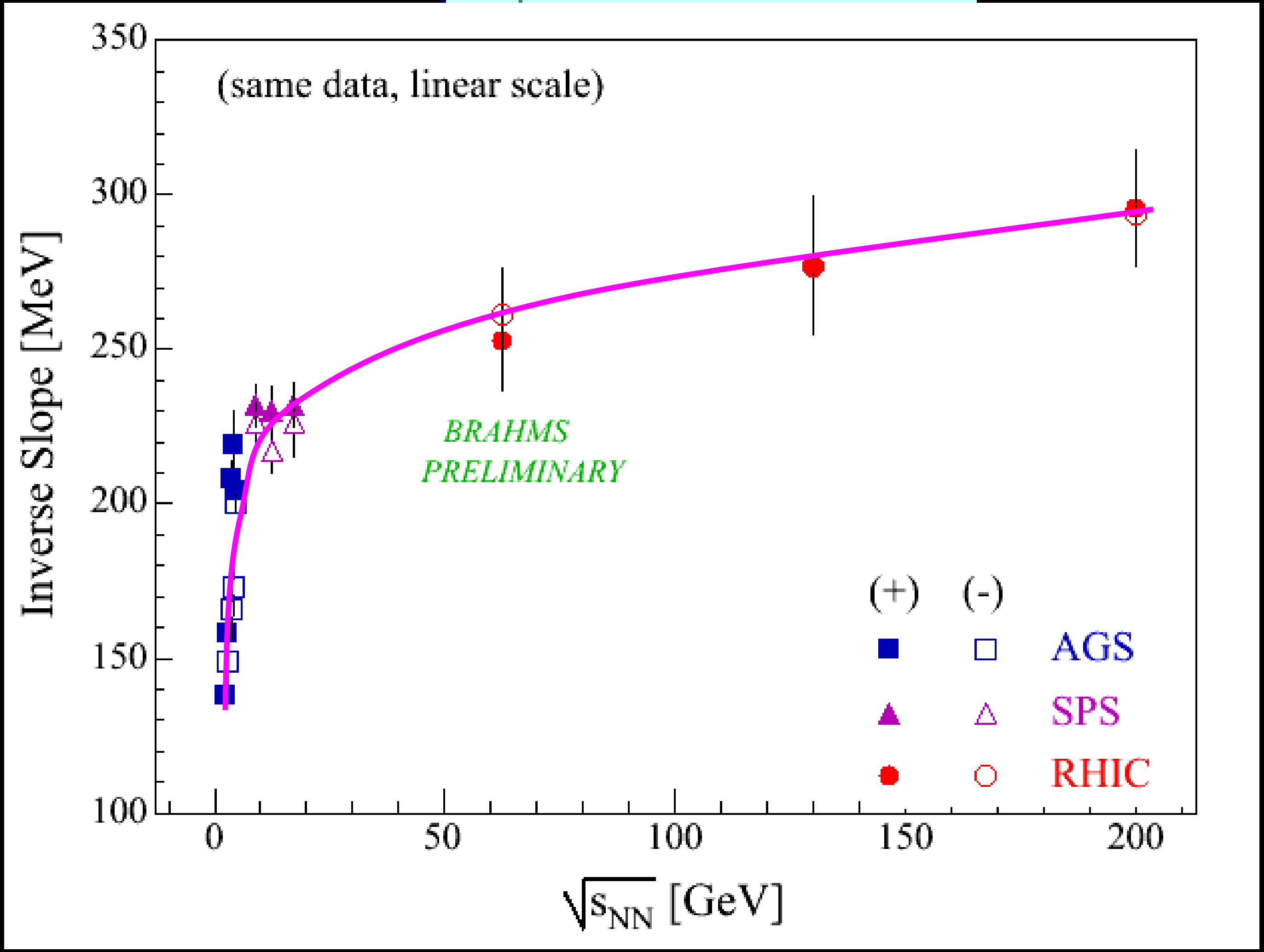


Kaon Spectra

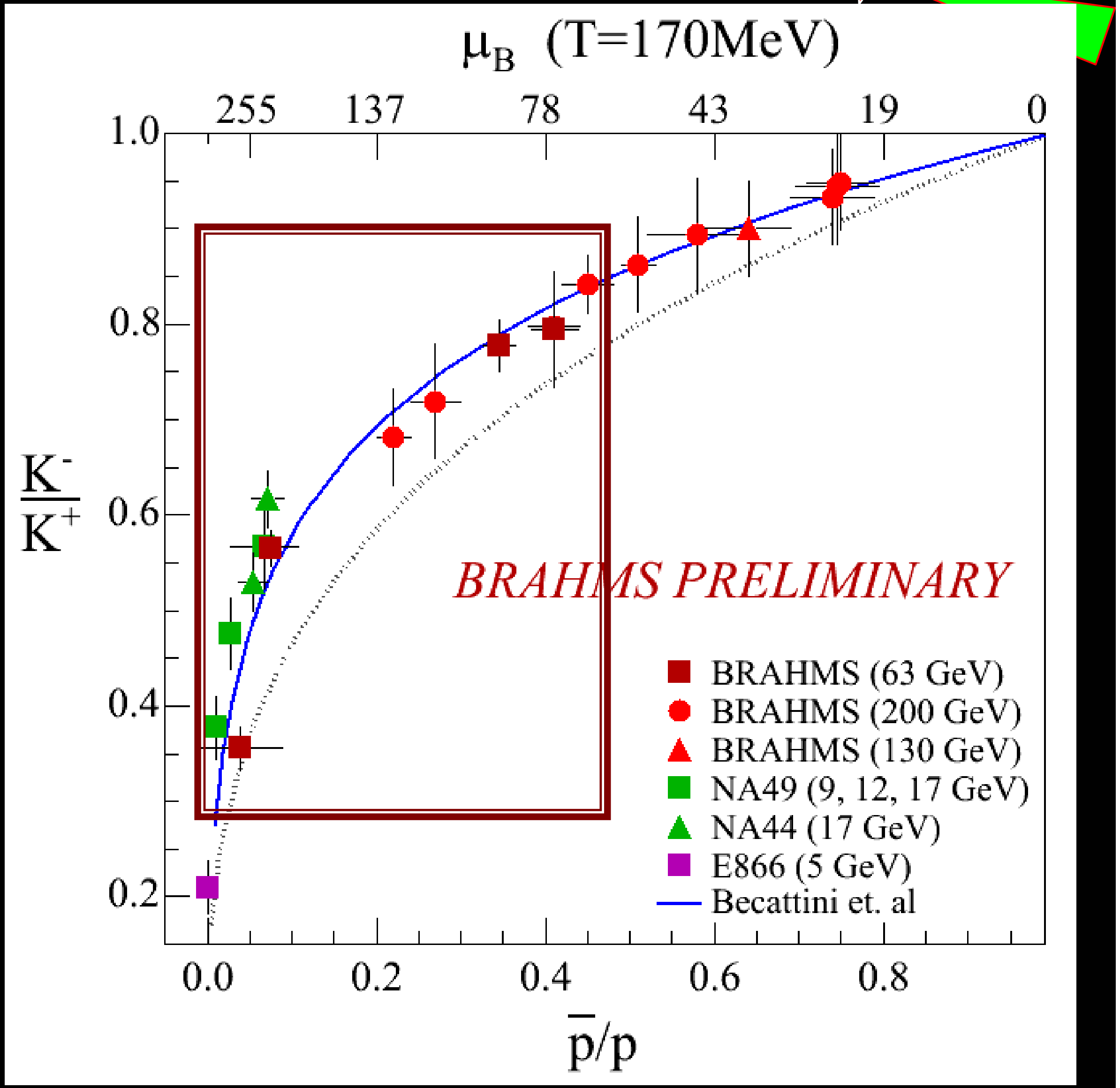
Top 5% central collisions



Top 5% central collisions

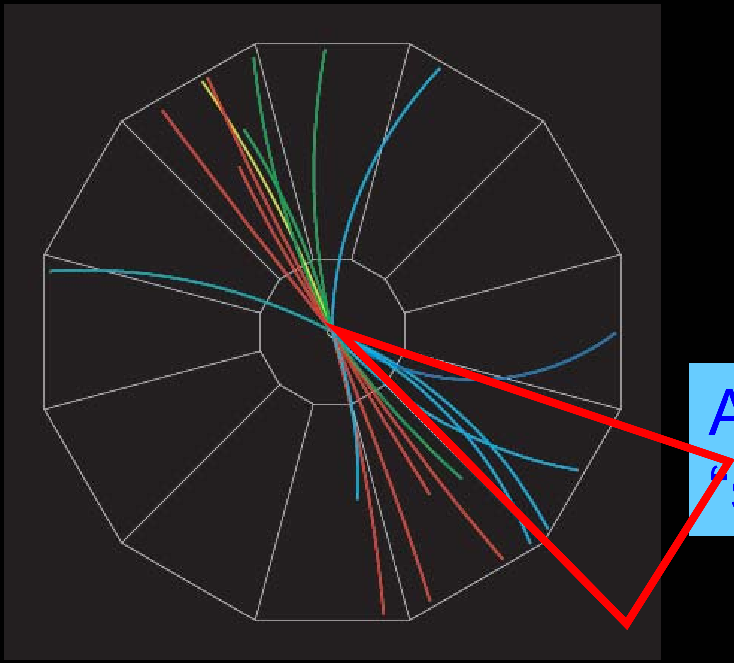


Cover “peak” of strange matterhorn



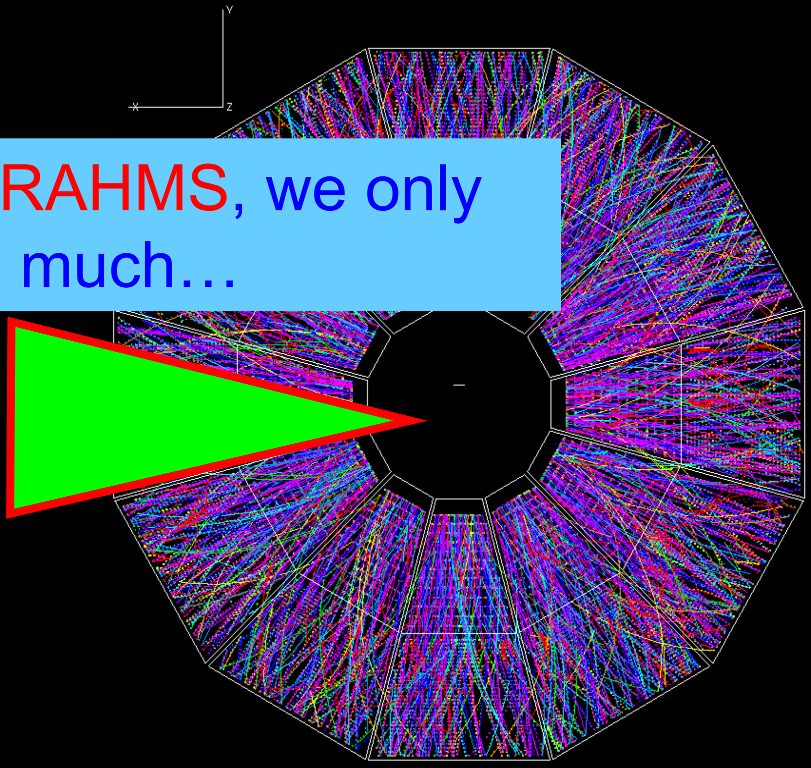
Jets at RHIC

Find this……….in this

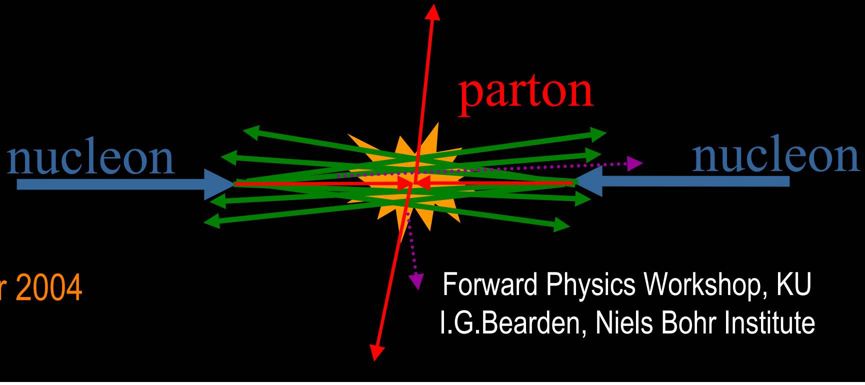


p+p →jet+jet
(STAR@RHIC)

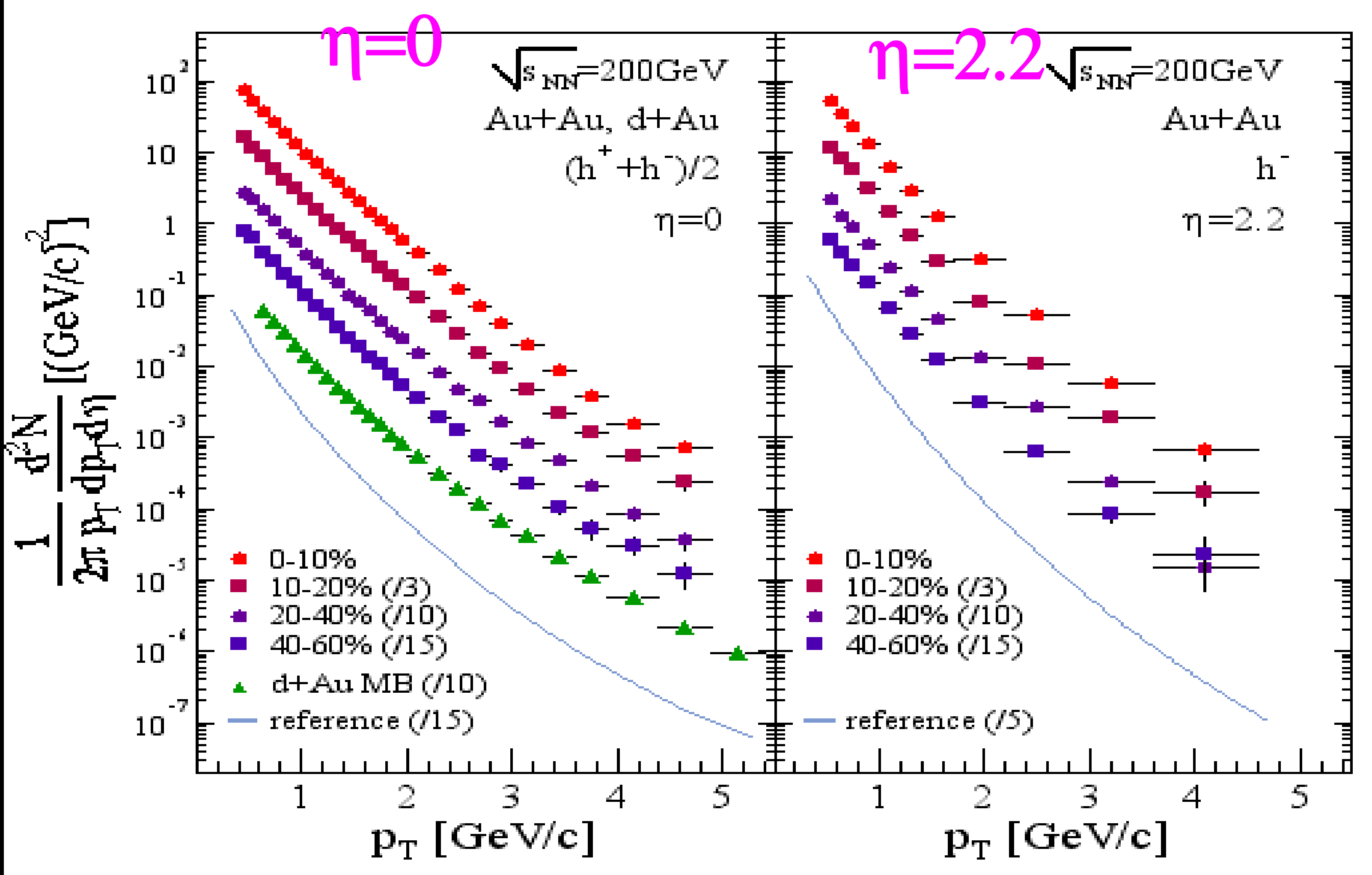
And, in BRAHMS, we only "see" this much…



Au+Au →???
(STAR@RHIC)



Characterize “high” p_T by single particle spectra



Nuclear Modification

Quantified by:

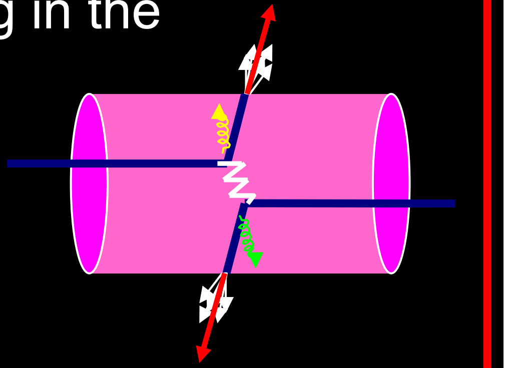
$$R_{AB} = \frac{d^2N^{AB}/dp_T d\eta}{\langle N_{bin}\rangle d^2N^{NN}/dp_T d\eta}$$

- yield relative to that from N+N collisions, scaled for the nuclear geometry (N_{bin})

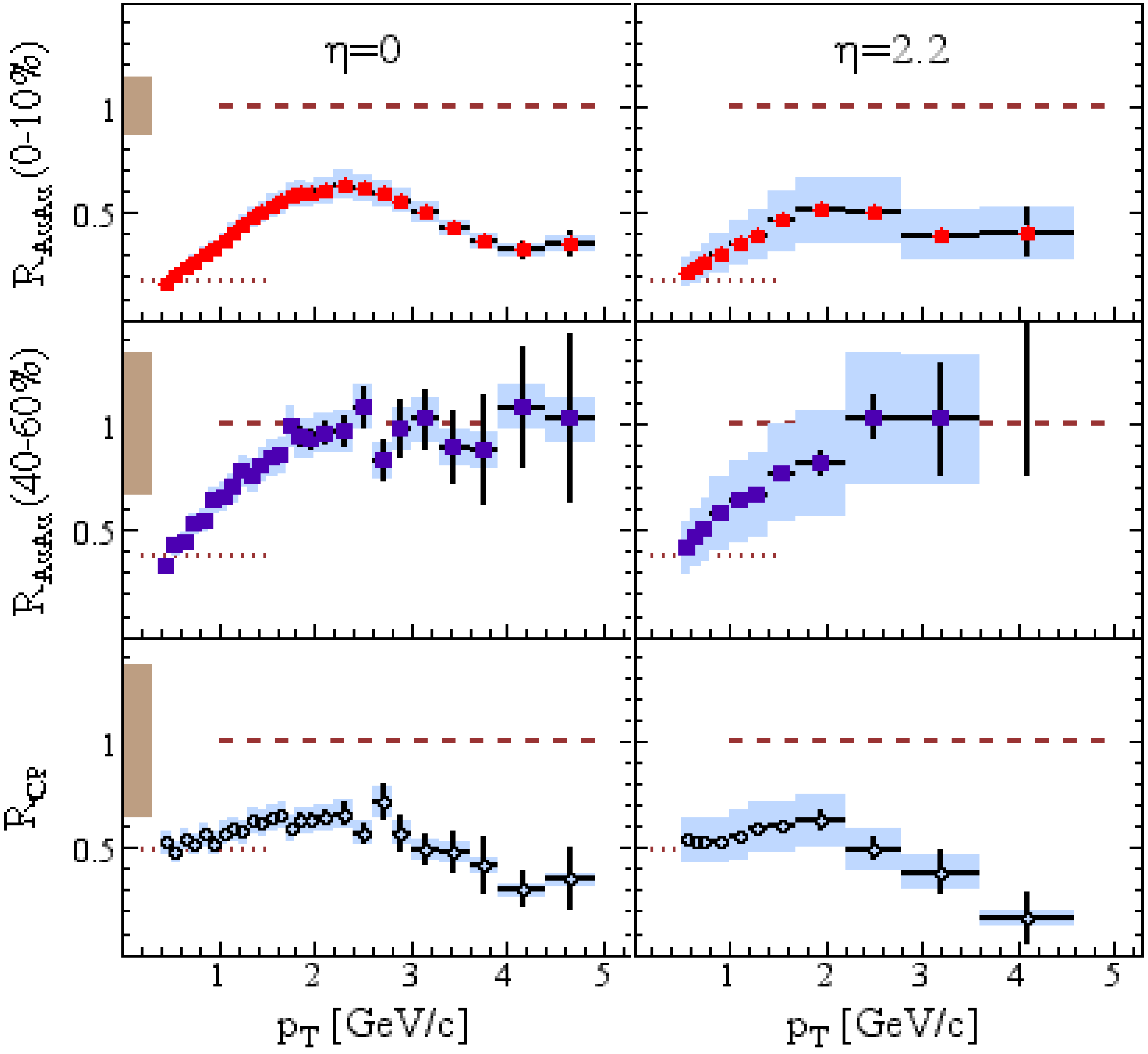
- Cronin Enhancement
- Shadowing/Saturation
- Jet-quenching

Jet-quenching

energy loss of high momentum particles in the dense medium due to
- gluon brehmstralung in the colored medium
- hadronic multiple scattering

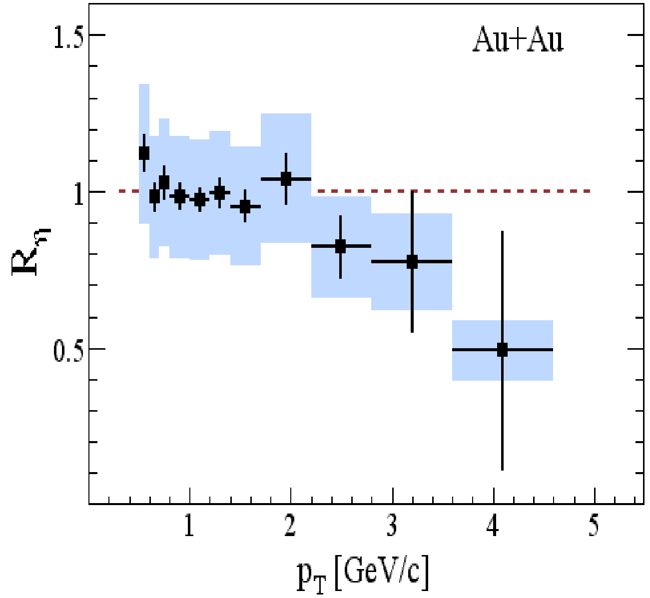


⇒suppression of leading hadrons
- Au+Au at $\sqrt{s_{NN}}$ = 130GeV and 200GeV
- next: energy+rapidity dependence



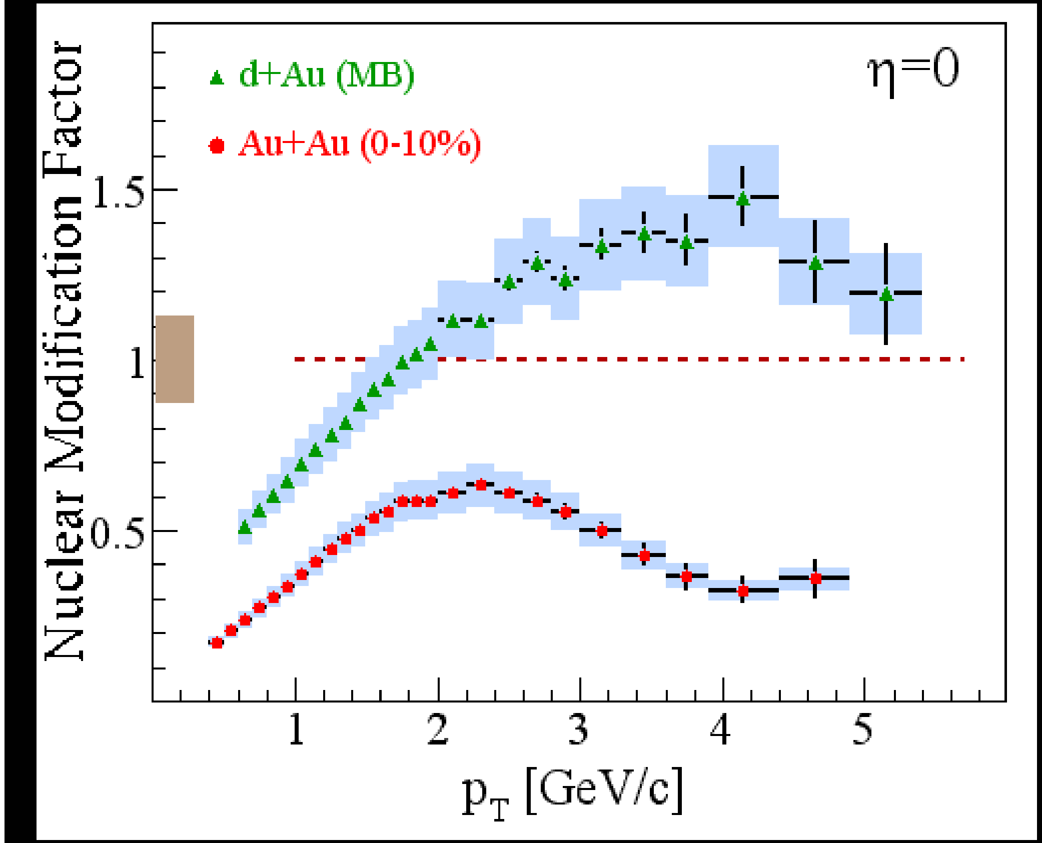
To look at ‘only’ data, form ratio

$R_\eta = R_{cp}(\eta=2.2)/R_{cp}(\eta=0)$



Arsene et al.
PRL2003

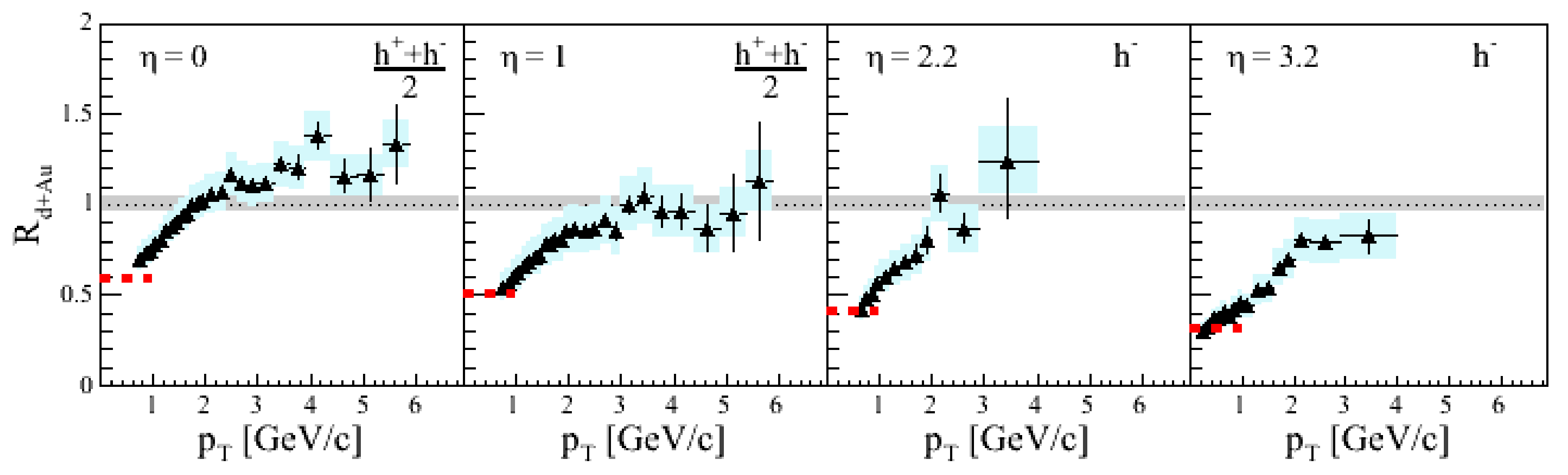
d+Au Nuclear Modification η =0



High p_T enhancement observed in d+Au collisions at $\sqrt{s_{NN}}$=200 GeV.

Comparing Au+Au to d+Au
⇒ strong effect of dense medium

R_{dAu} at $\sqrt{s_{NN}}$ = 200 GeV



Cronin enhancement at η=0

- the “null” experiment that ruled out initial state effect as explanation for Au+Au suppression

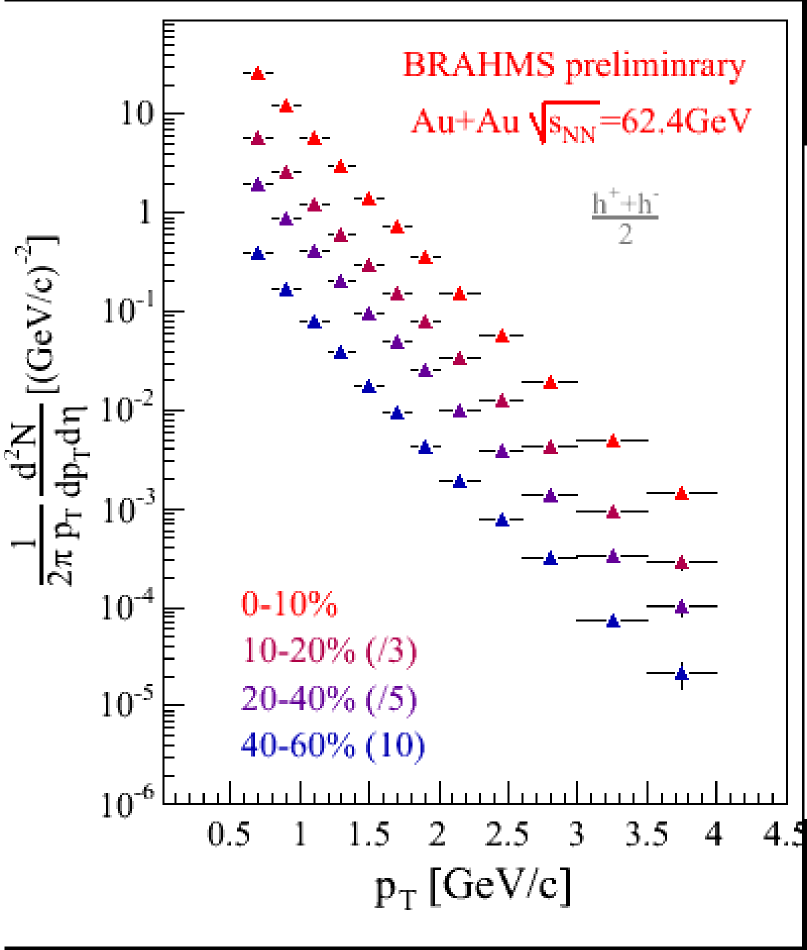
submitted to PRL

Increasing suppression for $\eta \rightarrow 3$

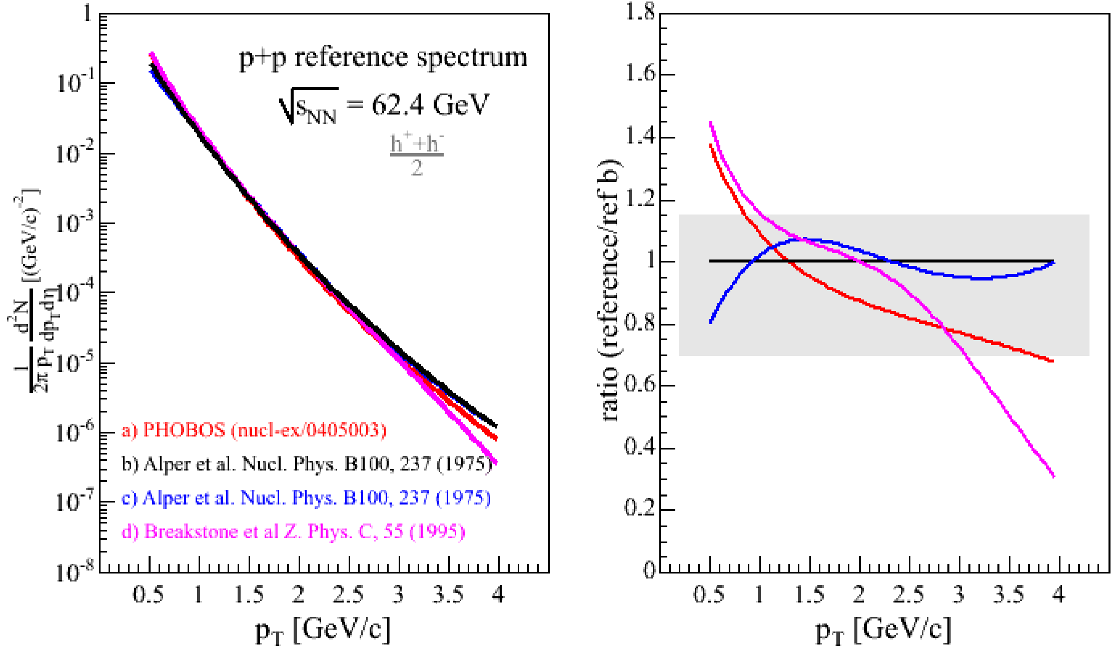
- window to the low-x partons in the Au nuclei ($Q_S \sim A^{1/3} e^{-\alpha y}$)
- consistent with CGC prediction

one week of 62.4 GeV running…

New BRAHMS results

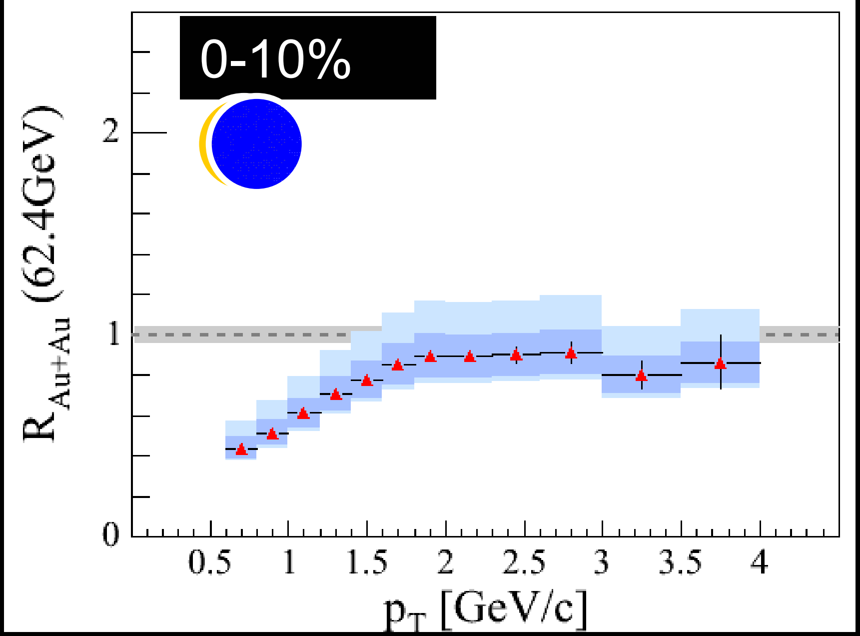


No RHIC p+p running at this energy:
- what should we use as reference?

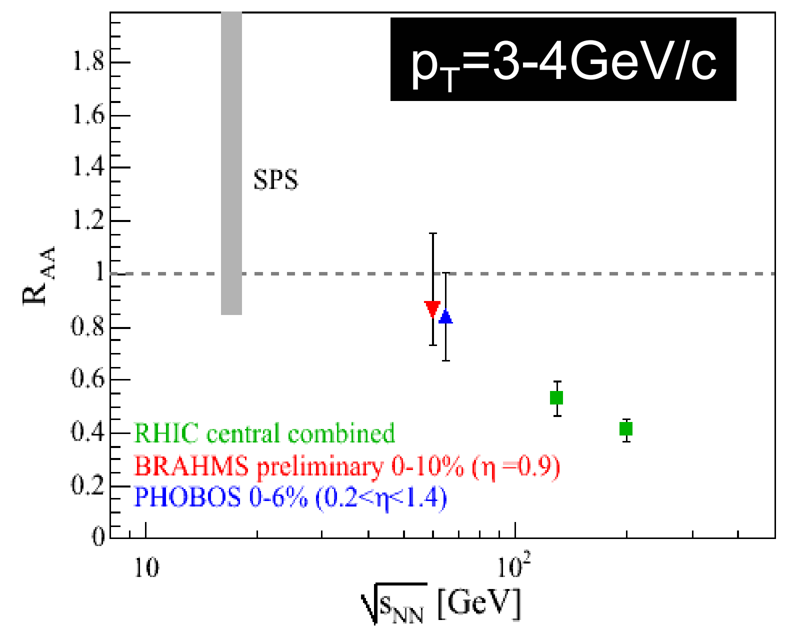


R_{AuAu} at $\sqrt{s_{NN}}$ = 62.4 GeV

Nuclear modification factor R_{AuAu}
- different centrality classes



Energy dependence (SPS→RHIC)
p_T=3-4GeV/c



Conclusions

- High energy density
- 70% of energy available for particle production
- Source (nearly) same over >1 unit rapidity
- 63 GeV data: climb the K/π “matterhorn”?
- High p_T suppression persists to high y in Au+Au
- More saturation as y increases in d+Au
- Gluon saturation describes data, though not uniquely
- Lots left to do…

In 'BT' (Danish morning tabloid) Feb. 2004

That you can recreate the Big Bang in a particle accelerator is simply a fantastic and earth shattering….

discovery!

At the same level .....

…….as plastic slippers with acrylic lining