Global and Hadronic Observables at BRAHMS
ITP
April 8-12, Santa Barbara

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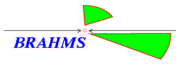
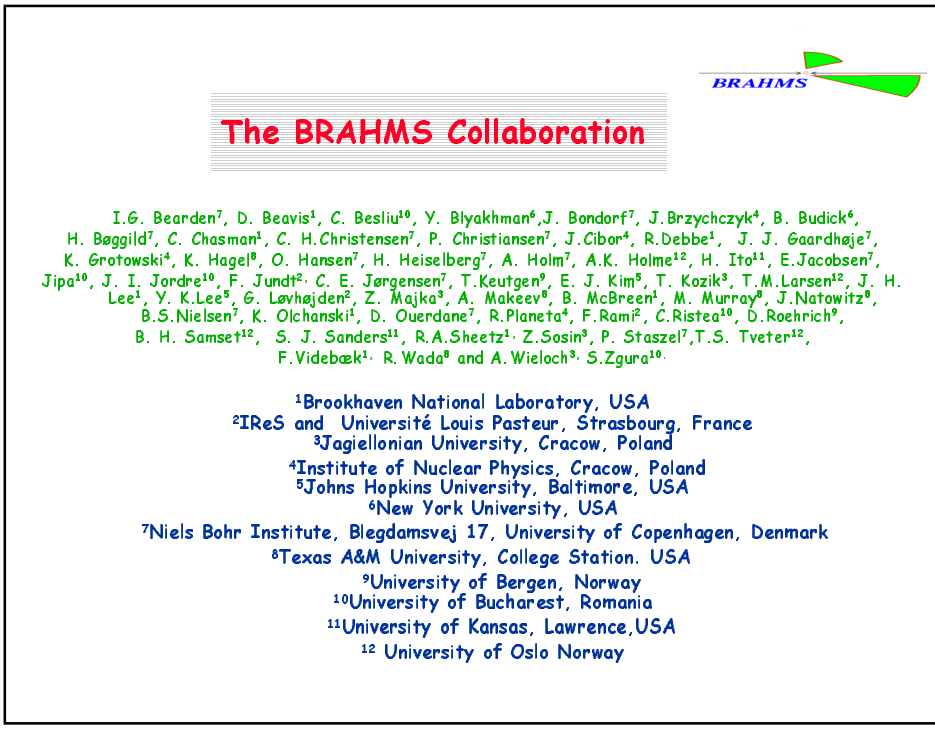
Physics Department, Brookhaven National Laboratory

Overview



- Introduction
- Global Observables (published data)
  - Charged particle multiplicity measurements
  - Comparison to theoretical predictions
- Hadronic Spectra (p.d.+ work in progress)
  - Acceptance and PID.
  - Particle Ratios
  - Particle Spectra
  - Comparison to theoretical predictions
- Summary, outlook


BRAHMS
The BRAHMS Collaboration
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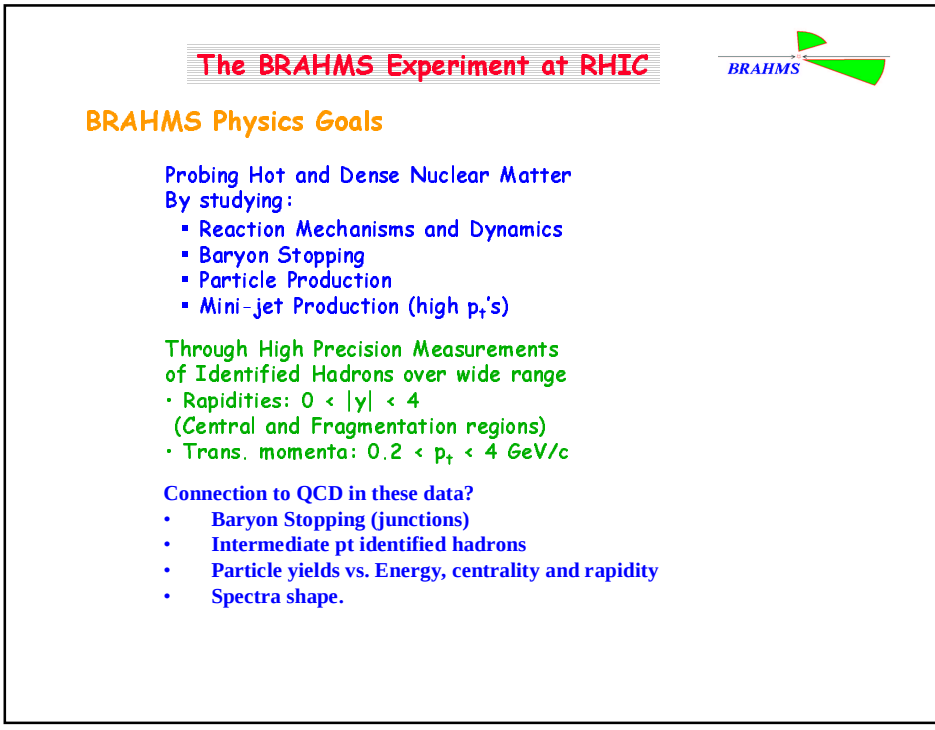
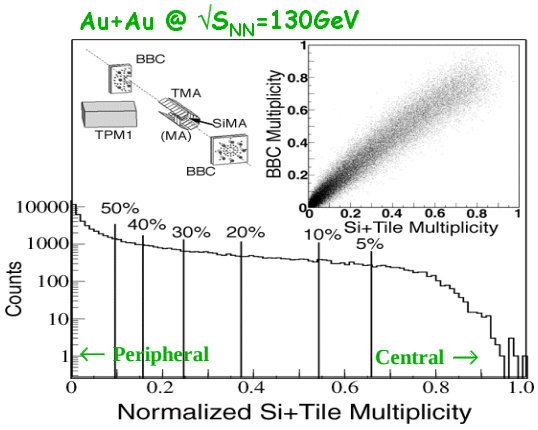

The BRAHMS Experiment at RHIC
BRAHMS
BRAHMS Physics Goals
Probing Hot and Dense Nuclear Matter
By studying:
▪ Reaction Mechanisms and Dynamics
▪ Baryon Stopping
▪ Particle Production
▪ Mini-jet Production (high p_t's)
Through High Precision Measurements
of Identified Hadrons over wide range
· Rapidities: 0 < |y| < 4
(Central and Fragmentation regions)
· Trans. momenta: 0.2 < p_t < 4 GeV/c
Connection to QCD in these data?
• Baryon Stopping (junctions)
• Intermediate pt identified hadrons
• Particle yields vs. Energy, centrality and rapidity
• Spectra shape.

WHAT CAN WE LEARN FROM $dN_{ch}/d\eta$?

- Can be related to entropy production (if expansion leaves entropy unchanged)
- Hadronic re-interactions (shape of $dN_{ch}/d\eta$)
- Relative contributions of hard and soft processes (Centrality/Energy dependence)
- Sensitivity to shadowing and jet-quenching effects (effects of the nuclear medium)

COLLISION CENTRALITY

Au+Au @ $\sqrt{S_{NN}}$=130GeV

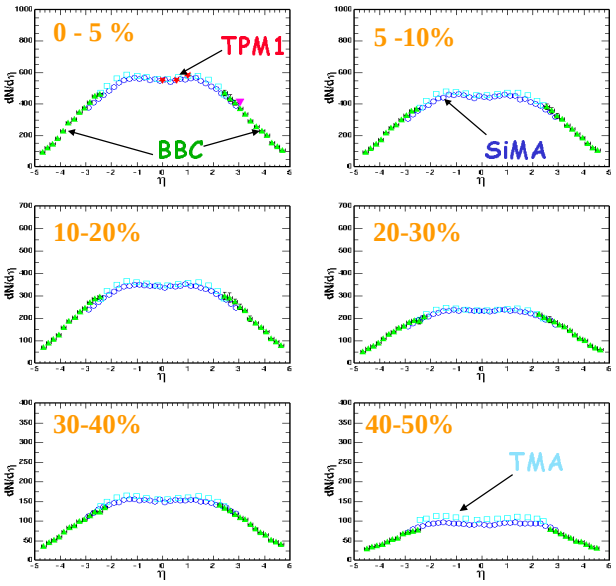


- Measured with TMA and SiMA
- Corrected for missing fraction of cross section (~3%) in the peripheral region. Using GEANT and HIJING

- Define Event Centrality Classes
  → Slices corresponding to different fractions of the cross section
- For each Centrality Cut
  → Evaluate the corresponding number of participants N_{part} (from HIJING simulations)

$dN_{ch}/d\eta$ measurements in BRAHMS

Au+Au @ $\sqrt{s_{NN}}$=130GeV



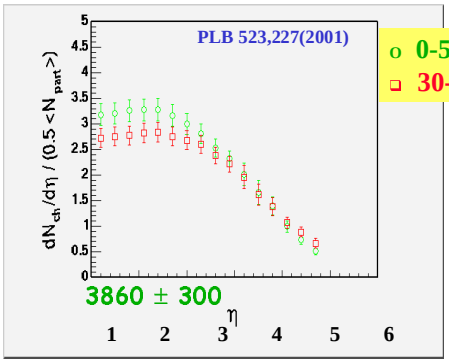
- Data from different detectors → Consistency
- By combining all results → Cover wide η range $-4.7 \le \eta \le 4.7$

Take weighted average → Reduce Syst. Errors

Backward/Forward Symmetry

$dN_{ch}/d\eta$ - Experimental Results

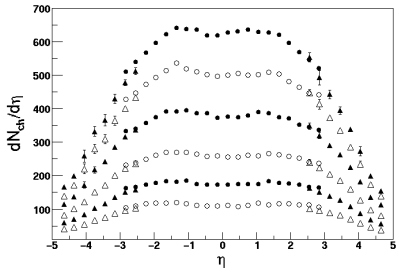
$\sqrt{s_{NN}}$=130GeV Au+Au



Scaled Multiplicity distributions
$dN_{ch}/d\eta/(0.5<N_{part}>)$

- Centrality Dependence
  - Mid-rapidity ($\eta \approx 0$) ⇒ Increase with centrality
  - Forward η's ⇒ No significant change

$\sqrt{S_{NN}}$=200GeV data



Accepted for publication PRL
Nucl-ex/0112001

Centrality bins shown are for
0-5%,5-10,10-20,..
40-50%.
Statistical errors only.

Increased width – scales approximately with y_B
Total Nch increases to ~ 4630+-370 (by 21%)

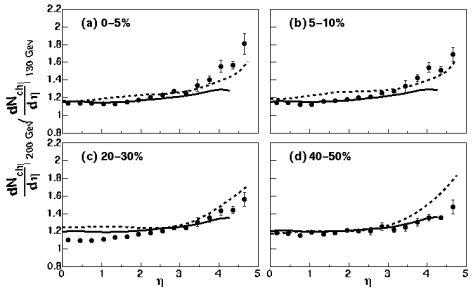
$dN_{ch}/d\eta$ around η=0 – Energy Dependence

- $dN_{ch}/d\eta/(0.5<N_{part}>)$ at η~0

  3.10 ± 0.20 at 130GeV
  3.50 ± 0.30 at 200GeV

  ⇒ Increase by 13+-4%

The increase at large eta reflects the Change in width of $dN_{ch}/d\eta$. Increase in beam rapidity (see later)



Limiting Fragmentation Picture

BRAHMS

Benecke et al, PRC 188(1969)2159

⇒ at high energies the number of particles produced by the "wounded projectile" nucleons is independent of the details of the target, the projectile and the beam energy

Observed in several reactions
(pp, pp, p-emulsion, π-emulsion)

Seems to work also for AA collisions at SPS energies

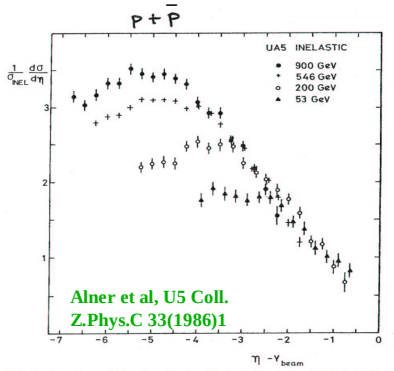


Fig. 5. Pseudorapidity density for inelastic events plotted against $y_{beam} = \eta - Y_{beam}$ as a test of scaling in the fragmentation region, $y_{beam} \gtrsim -2.5$

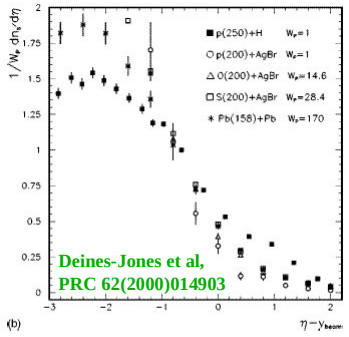


FIG. 3. Scaling of target and projectile regions with the number of target and projectile participants. Note that the two vertical axes are different. The target region (a) is normalized by W_T, while the projectile region (b) is normalized by W_P.

Limiting Fragmentation: from SPS to RHIC

BRAHMS

- Fragmentation region

  Translate to the beam's reference frame →

  $\eta' = \eta - y_{beam}$

  (assuming $\eta \approx y$)

- When shifed by y_{beam}

  ⇒ No Energy Dependence
  (130GeV → 200GeV)

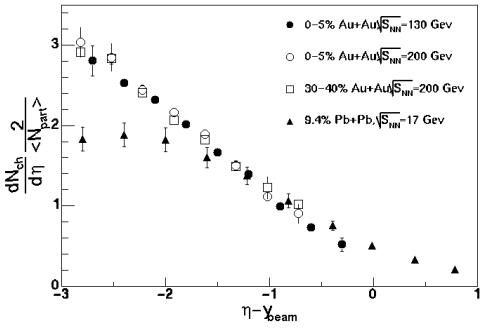
- Consistent with the limiting fragmentation picture

  ↔ No Dependence on System size and Energy

  - Observed in pp, pp, p-emulsion, π-emulsion data
  - Also in AA collisions at SPS

Alner et al, Z.Phys.C33(1986)1
Deines-Jones et al, PRC(2000)4903

Central Collisions (5%)

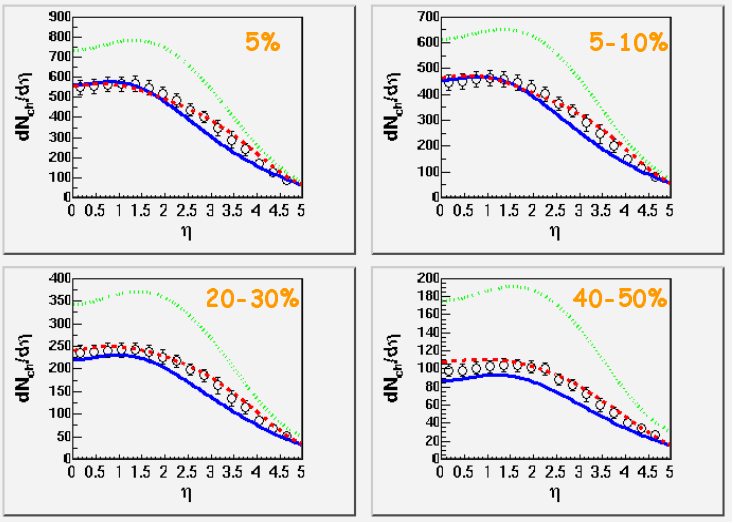


Limiting fragmentation holds from SPS → RHIC

$dN_{ch}/d\eta$ - Comparison to Model Predictions

BRAHMS

$\sqrt{s_{NN}}$=130GeV



UrQMD
Bass et al, Prog. Part Nuc. Phys. 41(98)255

HIJING
Wang and Gyulassy, PRD44(91)3501

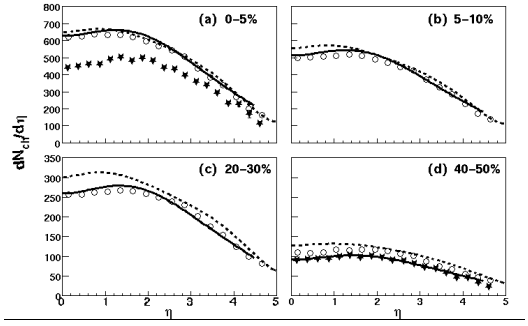
AMPT
Zhang et al, PRC61(2001)067901
Lin et al, PRC64(2001)011902

- Parton scattering models give a good description of the data
- AMPT → wider distributions (includes hadronic rescattering)

$dN_{ch}/d\eta$ - Comparison to Model Predictions

BRAHMS

$\sqrt{s_{NN}}$=200GeV

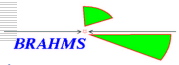


AMPT

High density QCD gluon saturation
Kharzeev and Levin, PLB523(2001)79

Differences for Peripheral Collisions but Small effect !

Global Observables



- $dN_{ch}/d\eta$ Measurements in Au+Au Collisions at two energies
  $\sqrt{S_{NN}}$=130GeV and $\sqrt{S_{NN}}$=200GeV

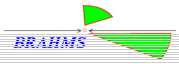
- Combining different sub-detectors in BRAHMS
  ⇒ Cover a wide range $-4.7 \leq \eta \leq 4.7$
  ⇒ Reduce Systematic Errors

Around η=0

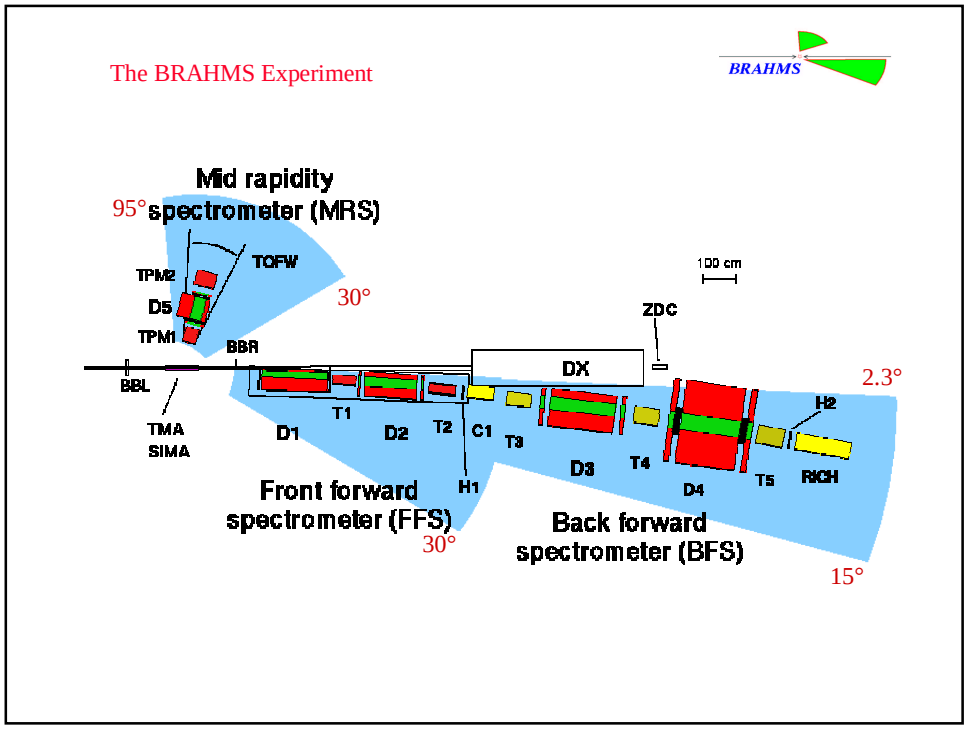
→$dN_{ch}/d\eta/(0.5<N_{part}>)$ = 3.10±0.20 at $\sqrt{S_{NN}}$=130GeV
3.50±0.30 at $\sqrt{S_{NN}}$=200GeV (13%+-4% increase)

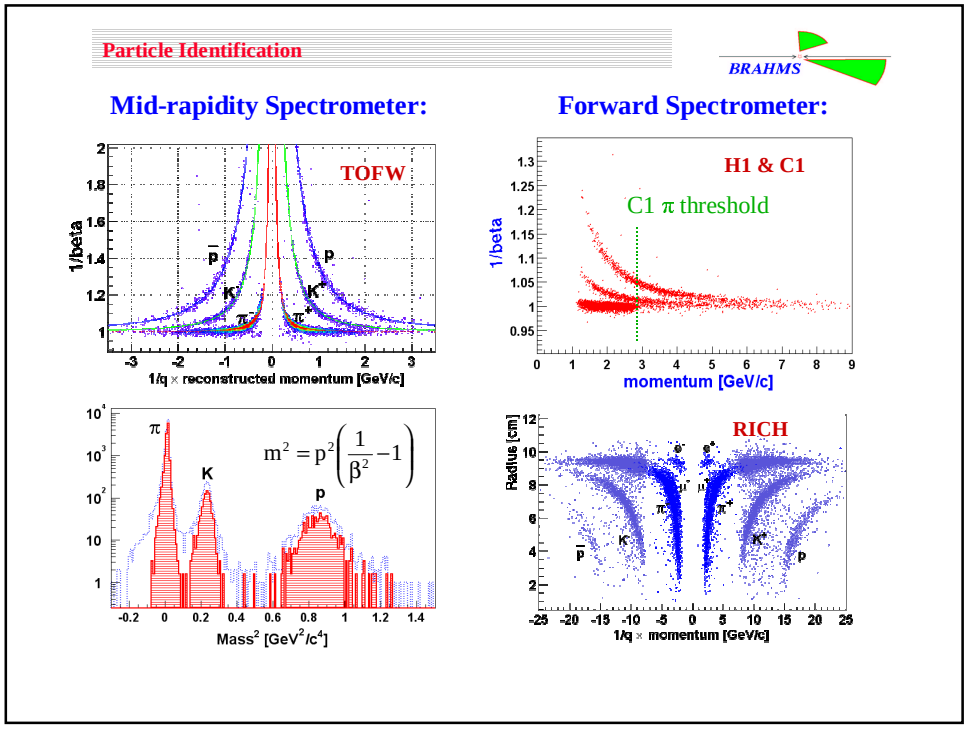
Forward η's → No Dependence on Centrality
→ No Dependence on Energy (Limiting Fragmentation)
Partonic Models → good general agreement with data

Hadronic Spectra



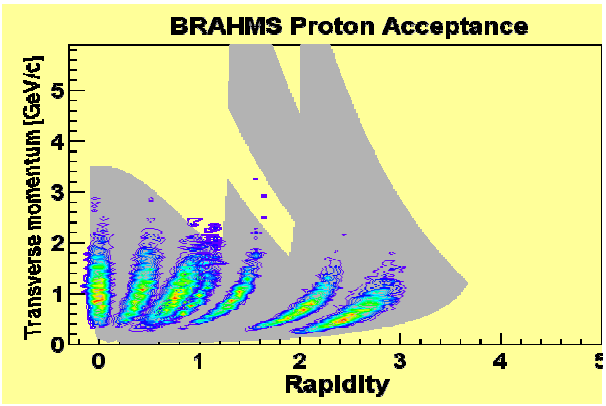
- **Particle ID and coverage (experimental)**
- **Pt, centrality, and rapidity dependence of pbar-p**
- **Model comparisons**
- **Even particle ratios (thermal)**
- **Energy dependence and comparison with pp**
- **P_t/m_t dependence of particle species,**
- **Spectra.**


The BRAHMS Experiment
BRAHMS
Mid rapidity
spectrometer (MRS)
95°
TOFW
30°
TPM2
D5
TPM1
BBR
BBL
TMA
SIMA
100 cm
ZDC
DX
2.3°
H2
D1
T1
D2
T2
C1
T3
D3
T4
D4
T5
RICH
H1
Front forward
spectrometer (FFS)
30°
Back forward
spectrometer (BFS)
15°

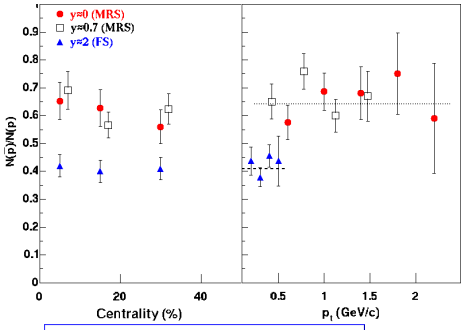

Particle Identification
BRAHMS
Mid-rapidity Spectrometer:
Forward Spectrometer:
TOFW
1/beta
1/q × reconstructed momentum [GeV/c]
H1 & C1
C1 π threshold
1/beta
momentum [GeV/c]
m² = p²(1/β² − 1)
Mass² [GeV²/c⁴]
RICH
Radius [cm]
1/q × momentum [GeV/c]

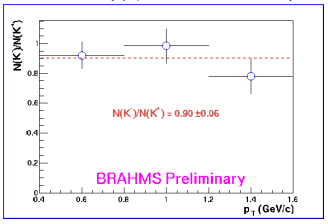
BRAHMS acceptance

Shown to illustrate that the particle ratios are from specific are from <y> and <p_t>



Particle Ratios from BRAHMS (130 GeV data)





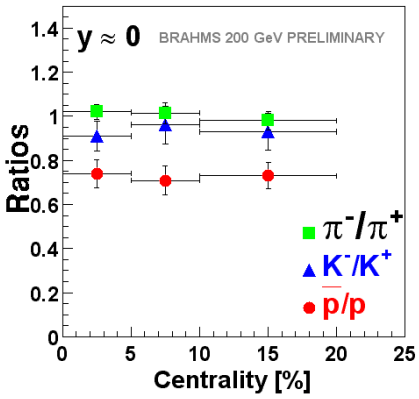
Centrality and and p_t dependence of particle ratios

At y~0

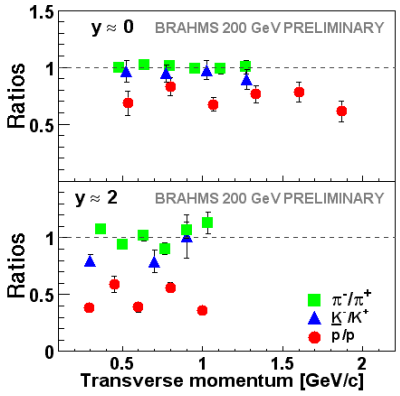
- pbar/p: 0.64+-0.04+-0.06
- $N(K^-)/N(K^+)$: 0.90

Particle Ratios from BRAHMS (200 GeV data)

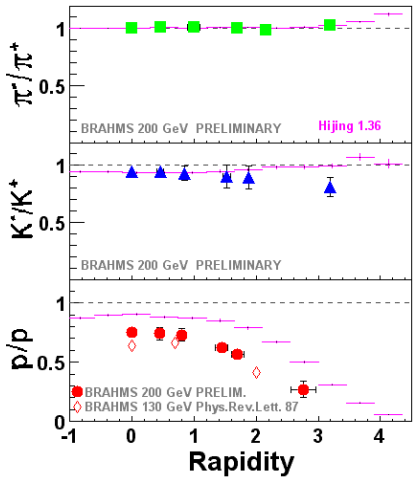
Ratios vs Centrality (top 25%)



…and Transverse Momentum



Rapidity dependence

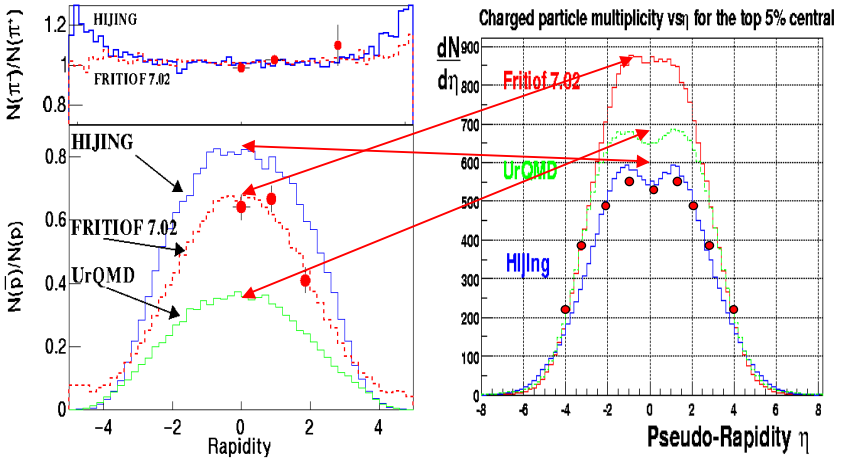


Rather smooth change from 130 to 200 GeV.

Ratios ~identical over +-1 unit around mid-rapidity.

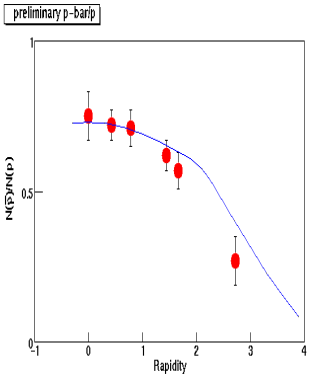
How consistent are the models?

BRAHMS



Rapidity dependence of pbar/p

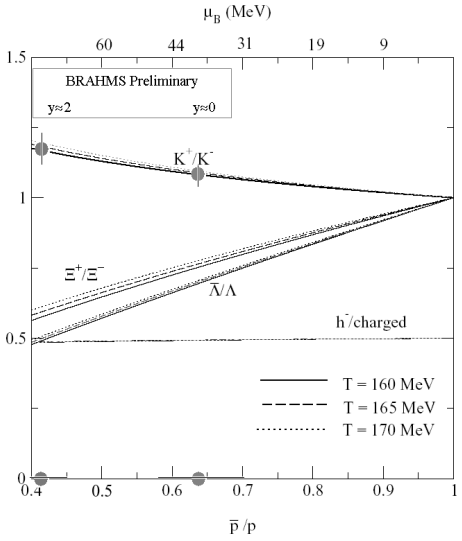
BRAHMS



Brahms 200 GeV

Comparison with AMPT (…) calculations including modification to string breaking (pop-corn) mechanism and re-scattering in hadronic phase.
nπ<->NN channels simulated by ρ and ω 2-body channels.

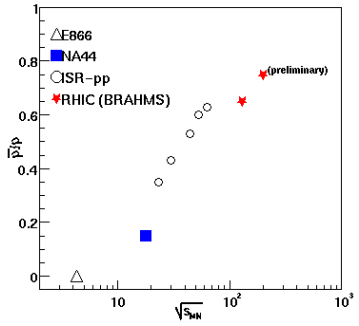
Thermal description of yields



Comparison at 130 GeV ratios with model by Becattini et al (PRC64,024901 (01))

The change in K/K and p/p to forward rapidities is consistent with the thermal description.

Energy Dependence of p/pbar ratio

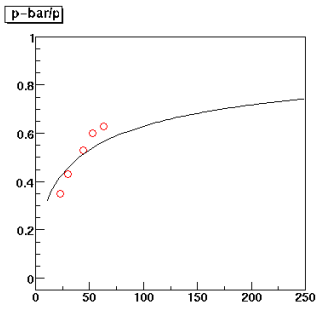


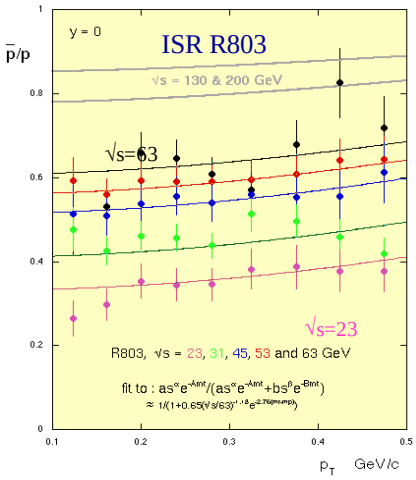
Summary of pp and AA data.

Large symmetry of baryons achieved at RHIC. Never the less still significant net baryon yield at y~0 at 200 GeV.

Look in more details on the pp. What can we learn.

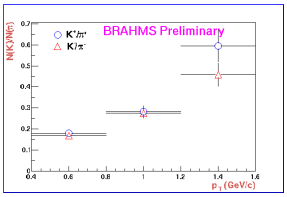
From pp to AA

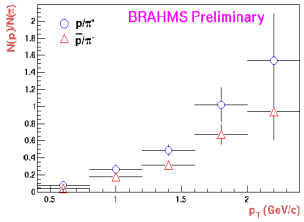




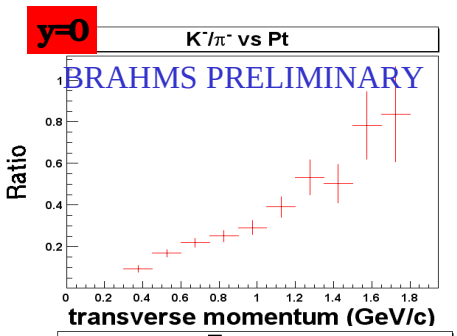
D.Kharzeev proposed to study Baryon Junctions and evaluate magnitude from pp. (Physics Letter B378,238) description with P-bar/p $= s^{\Delta}/(s^{\Delta}+s^{1/4+\Delta/2}) = 0.08$ c =8.5. Second component should dominate stopping at higher energy

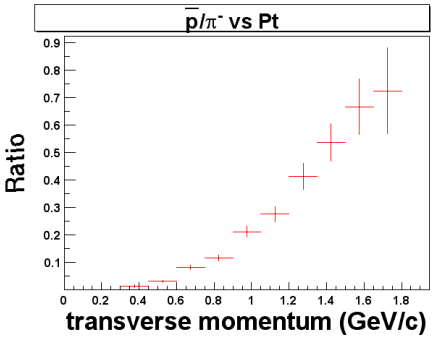
Unlike particle ratio's

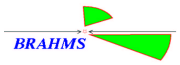




- N(K)/N(π): 0.2 – 0.5
- N(p)/N(π): 0.1 – 1.4
  increasing with p_t
- pbar(p) > $\pi^-(\pi^+)$ at $p_t > 2$



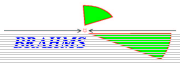




K/π=0.17+–0.04
pbar/π=0.08+-0.02

BRAHMS PRELIMINARY

As for 130 GeV the charged hadron yields are dominated by protons, anti-protons at pt ~2.



Particle spectra for cent 0-25%

T(π+) = 225 ± 3 (stat) ± 15 (syst)

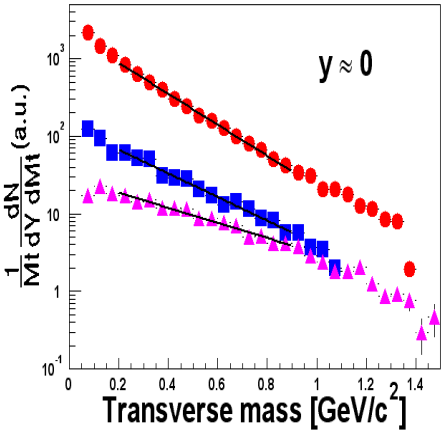
T(π-) = 227 ± 3 (stat) ± 15 (syst)

T(K+) = 284 ± 20 (stat) ± 25 (syst)

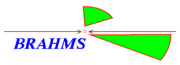
T(K-) = 269 ± 17 (stat) ± 25 (syst)

K/pi ~0.17+-0.04

Are the spectral shapes fully described by radial flow? Do we need gluonic degree of freedom for the data? How can this be distinguished?

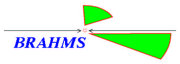


Hadron observables Summary



- pbar/p =0.75 y~0
  - Net baryon transport important
- Pbar/p approximately constant over +-1 unit of y
  - falls with y, for y>1
- Models need to include rescattering to reproduce ratios(pbar/p). (AMPT)
- K/π=0.17; pbar/p=0.08 at y=0.
- P-bar/ π increases with p_t reaching ~1 at p_t > 2 GeV/c
- Large inverse slopes (T) for K,p T(p) >T(K)> T(π)
  - Radial expansion seems important

Outlook



To come from analysis of 2001 data

- Spectra π, K , p, pbar for centralities in range 0-25%.
- p- up to ~ 3.5 GeV/c.
- Net-Baryon rapidity distributions (0-3).
- pp comparison data at modest pt (< 2 GeV/c). The hadron spectra in pp are much softer than in AuAu.
- First look at HBT at y~2;