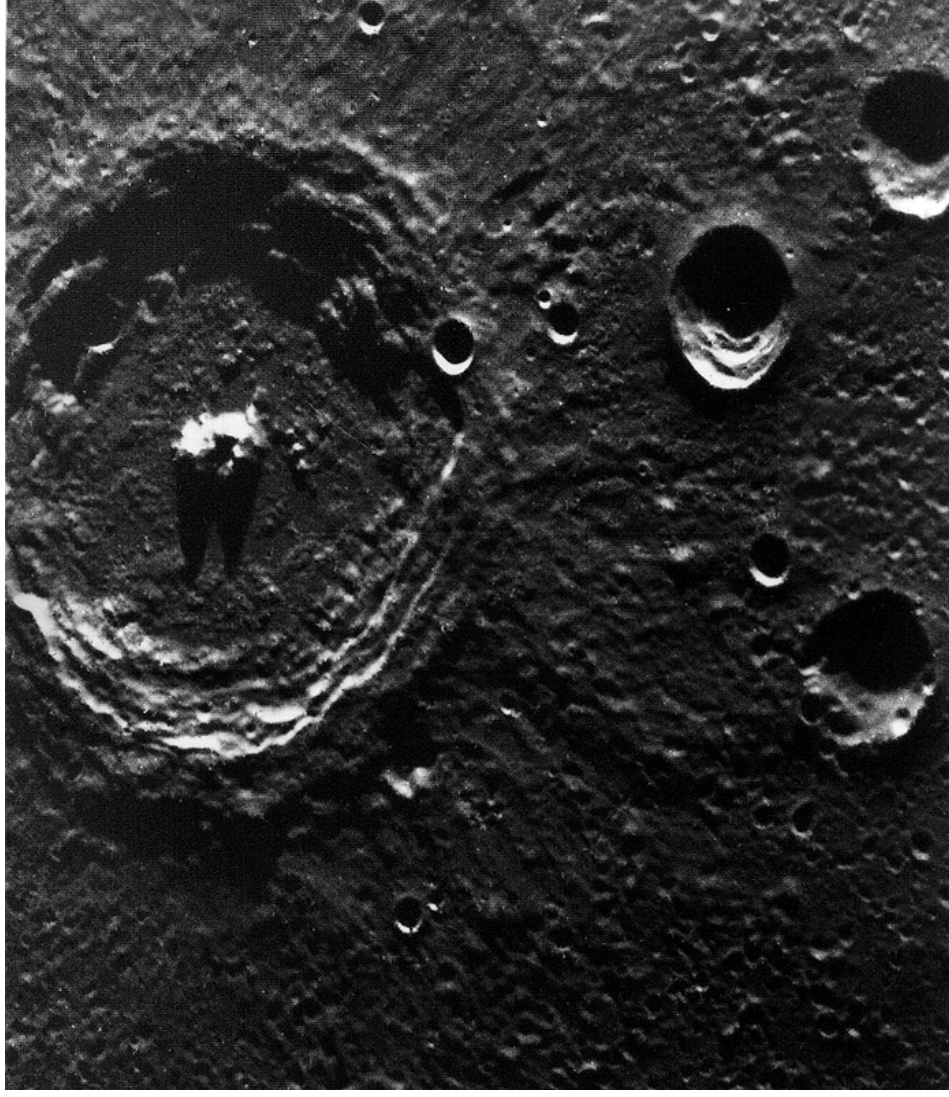


Transverse dynamics at $y=0$ in BRAHMS



Bjørn H. Samsø

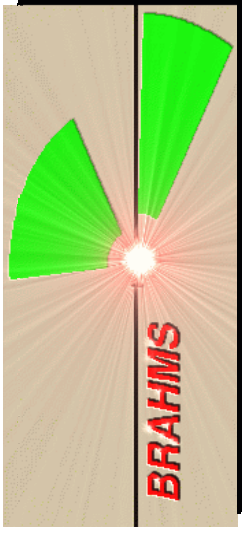
Transverse dynamics
at RHIC, March 2003



A story of
centrality dependent
pt spectra of identified
charged hadrons
measured with the

BRAHMS
experiment at
RHIC

Data from AuAu
collisions at
 $\sqrt{s_{NN}} = 200 \text{ GeV}$

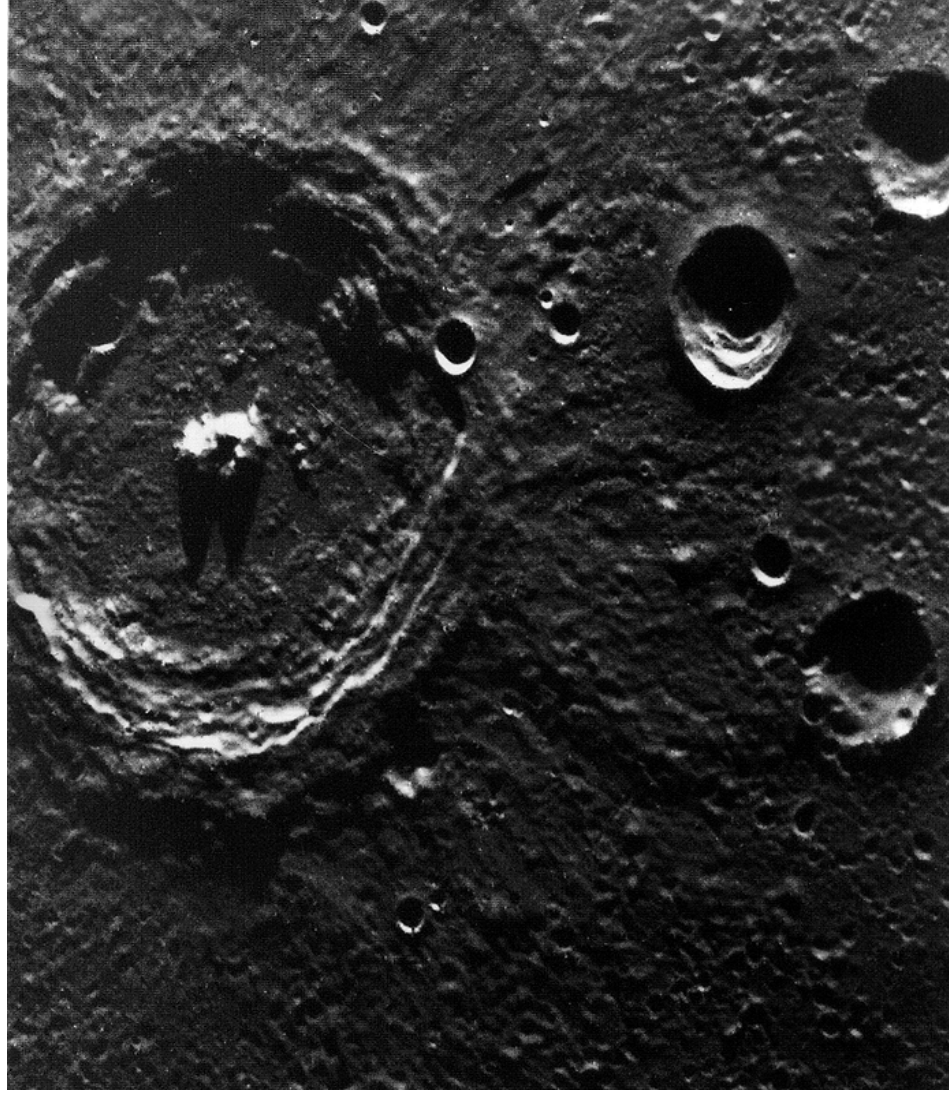


Transverse dynamics at $y=0$ in BRAHMS



Bjørn H. Samset

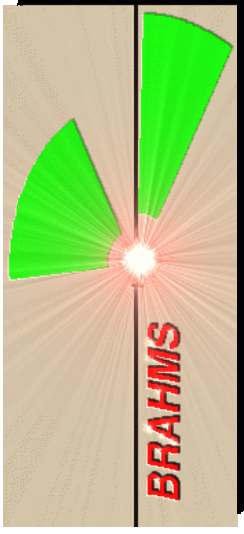
Transverse dynamics
at RHIC, March 2003



A story of
centrality dependent
pt spectra of identified
charged hadrons
measured with the

BRAHMS
experiment at
RHIC

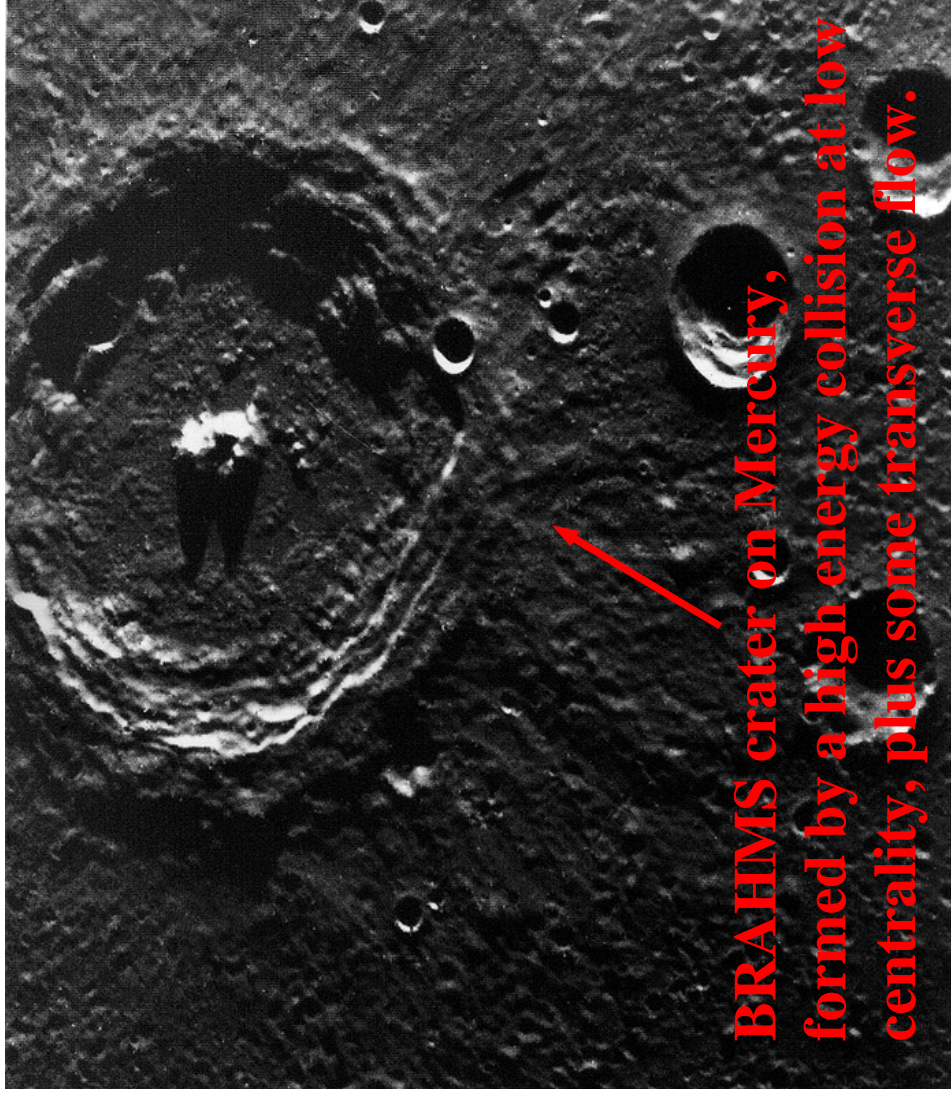
Bjørn H. Samset
PhD student,
University of Oslo, Norway
Been with BRAHMS for 4 years...



Transverse dynamics at $y=0$ in BRAHMS



Bjørn H. Samsøt
Transverse dynamics
at RHIC, March 2003



A story of
centrality dependent
pt spectra of identified
charged hadrons
measured with the
BRAHMS
experiment at
RHIC

Bjørn H. Samsøt
PhD student,
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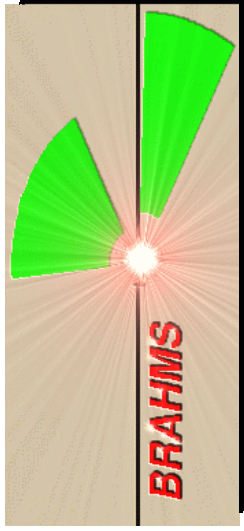
Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

Outline

- The BRAHMS experiment at RHIC
- The analysis - extracting particle yields from BRAHMS data
- $\langle p_t \rangle$ and centrality dep. of $dN_{ch}/d\eta$ at $y=0$
- $\langle p_t \rangle$ and centrality dep. of identified hadron p_t spectra at $y=0$
- Centrality dependence of like and unlike particle ratios
vs. p_t at $y=0$
- Conclusions and future visions

The



experiment at



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003





The BRAHMS collaboration

Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

I.G. Bearden⁷, D. Beavis¹, C. Besliu¹⁰, Y. Blyakhman⁶, J.Brzychczyk⁴, B. Budick⁶,
H. Bøggild⁷, C. Chasman¹, C. H. Christensen⁷, P. Christiansen⁷, J.Cibor⁴, R.Debbe¹,
J. J. Gaardhøje⁷, M. Germinario⁷, K. Grotowski⁴, K. Hagel⁸, O. Hansen⁷,
A.K. Holme¹², E. Enger¹², H. Ito¹¹, E. Jacobsen⁷, A. Jipa¹⁰, J. I. Jordre¹⁰, F. Jundt²,
C.E.Jørgensen⁷, T. Keutgen⁹, E. J. Kim⁵, T. Kozik³, T.M.Larsen¹², J. H. Lee¹,
Y. K.Lee⁵, S. Lindal¹², G. Løvnhøjden¹², Z. Majka³, A. Makeev⁸, B. McBreen¹, M. Mikkelsen¹²,
M. Murray⁸, J. Natowitz⁸, B.S.Nielsen⁷, K. Olchanski¹, D. Ouerdane⁷, R.Planeta⁴, F. Rami²,
D. Roehrich⁹, B. H. Samsø¹², S. J. Sanders¹¹, I. S. Sgura¹⁰, R.A.Sheetz¹, Z.Sosin³,
P. Staszal⁷, T.S. Tveter¹², F. Videbæk¹, R. Wada⁸ and A. Wieloch³

¹Brookhaven National Laboratory, USA, ²IReS and Université Louis Pasteur, Strasbourg, France
³Jagiellonian University, Cracow, Poland, ⁴Institute of Nuclear Physics, Cracow, Poland

⁵Johns Hopkins University, Baltimore, USA, ⁶New York University, USA

⁷Niels Bohr Institute, Blegdamsvej 17, University of Copenhagen, Denmark

⁸Texas A&M University, College Station, USA, ⁹University of Bergen, Norway

¹⁰University of Bucharest, Romania, ¹¹University of Kansas, Lawrence, USA

¹² University of Oslo Norway



Bjørn H. Samsø

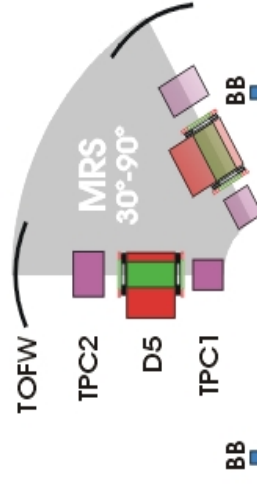
Transverse dynamics
at RHIC, March 2003

The BRAHMS experiment

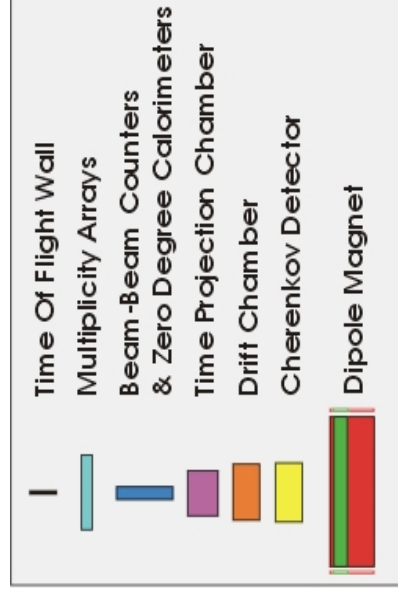
Setup used for AuAu data in 2001

BRAHMS Experimental Setup

Mid Rapidity Spectrometer



100 cm



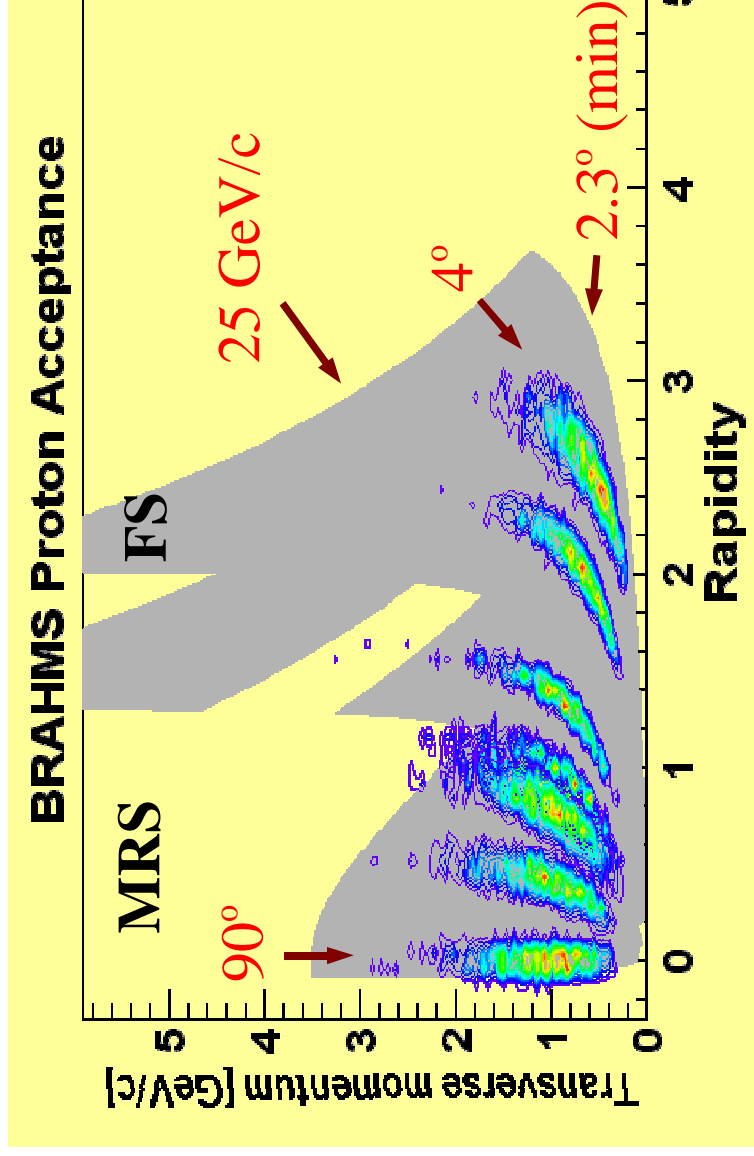
Forward Spectrometer (FS)

Center of the RHIC Ring

BRAHMS coverage for the AuAu run of 2001



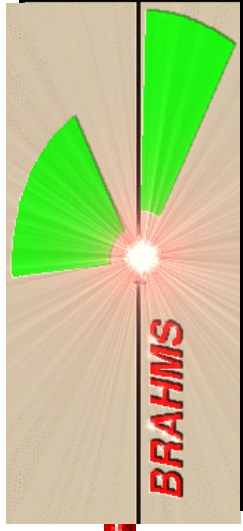
Bjørn H. Samsøe
Transverse dynamics
at RHIC, March 2003



Coverage of the y -pt plane is achieved by rotating the two spectrometer arms and changing magnetic fields.

Angles covered in 2001: 90°, 60°, 45°, 40°, 35°, 20°, 12°, 8°, 4°, 3°

Data analysis in



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

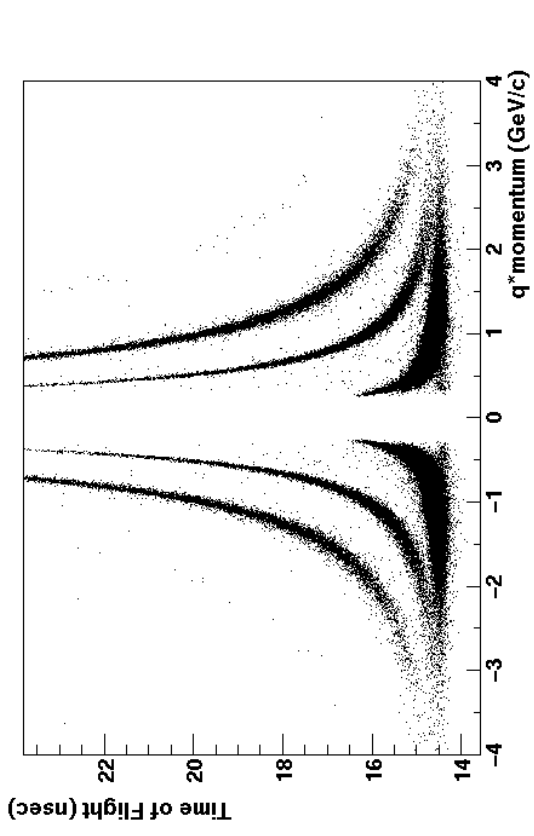
heading towards Centrality dependence of charged particle production at midrapidity

Analysis mainly by E. J. Kim and J. H. Lee

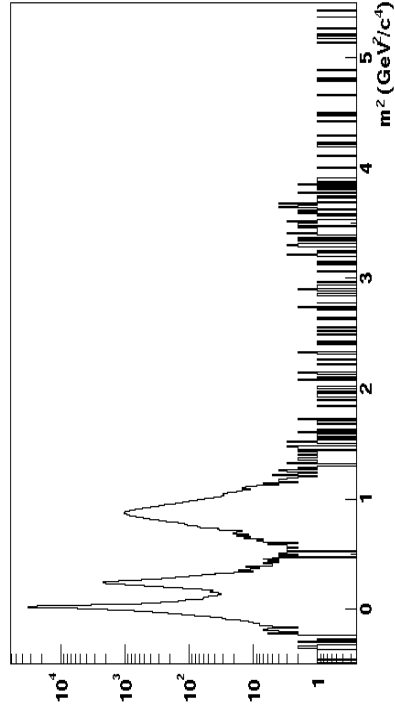
Particle identification in BRAHMS



Bjørn H. Samsøe
Transverse dynamics
at RHIC, March 2003



TOFW

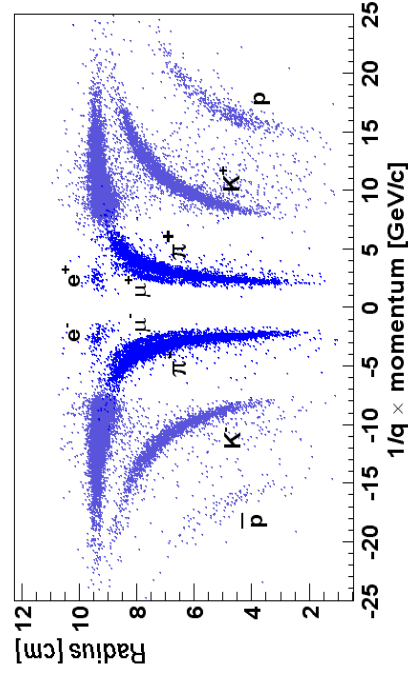


Midrapidity performance:

- Time-of-flight resolution of ~ 75 psec
- π /K separation up to ~ 2.5 GeV/c
- K/p separation up to ~ 4.0 GeV/c

Forward spectrometer (example):

- RICH gives PID up to 25 GeV/c

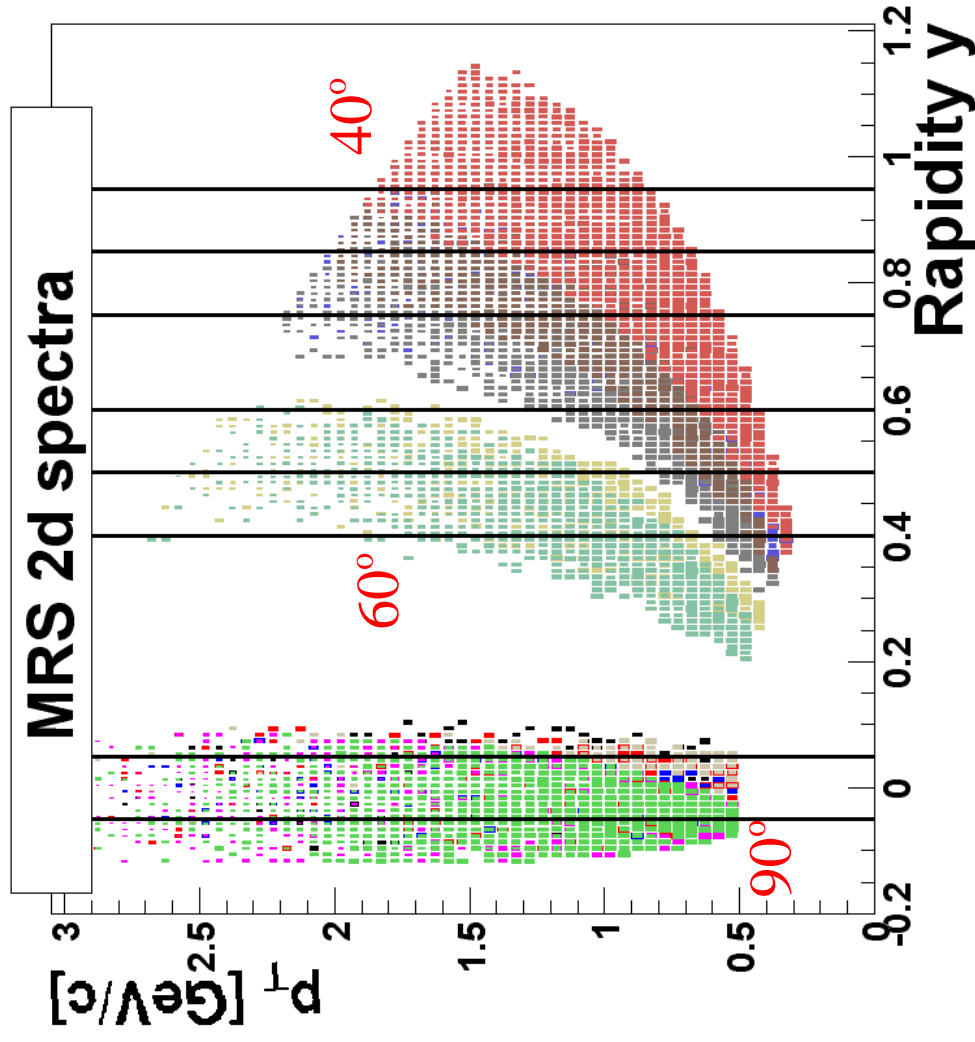


Select data from y - p_t plots



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

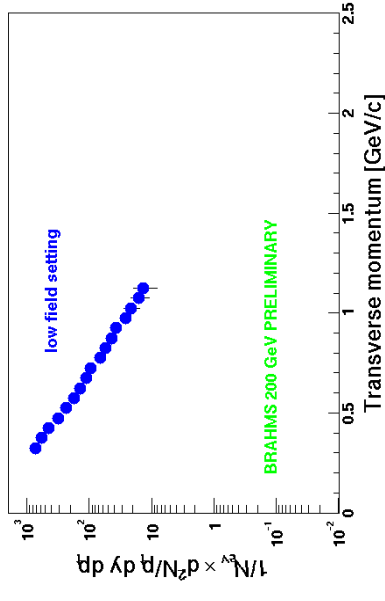
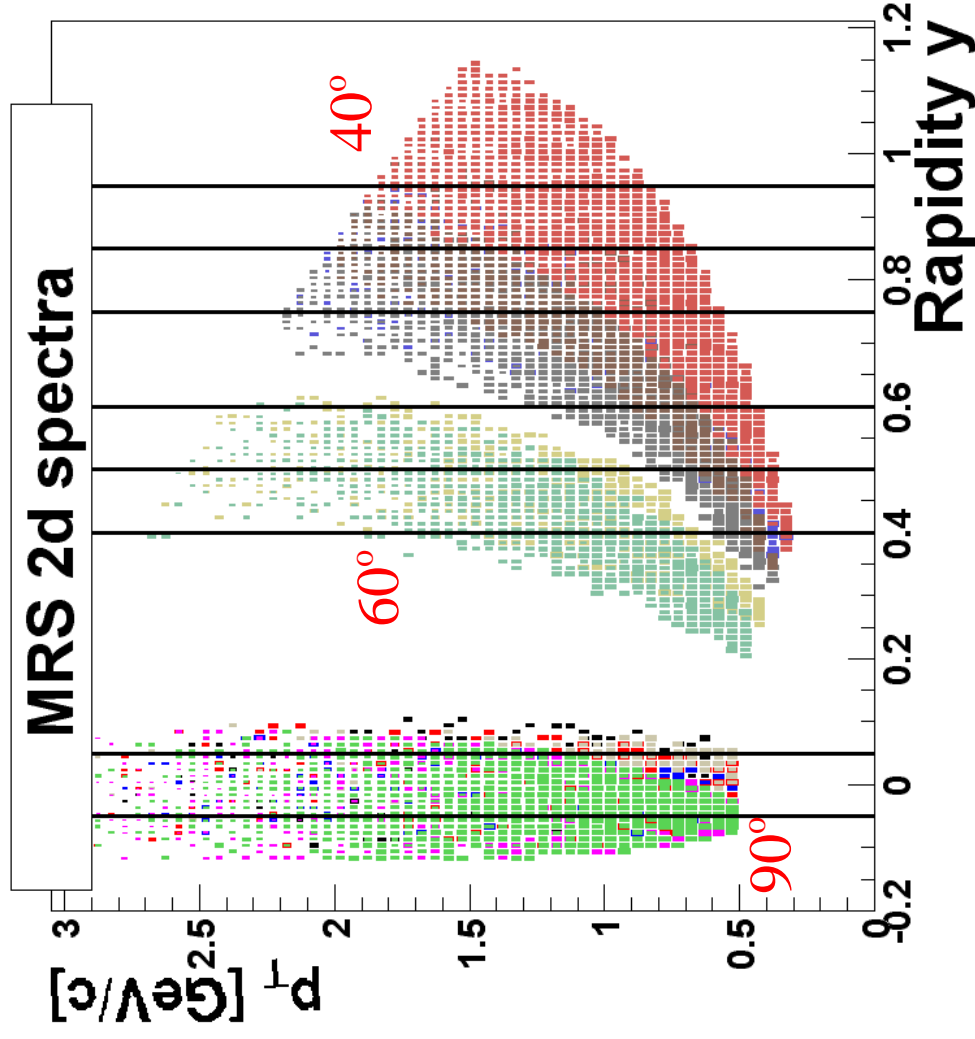


Select data from y - p_t plots



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

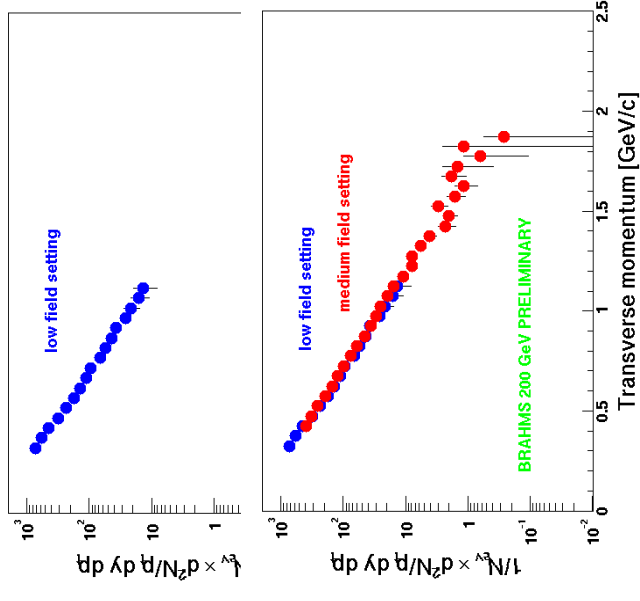
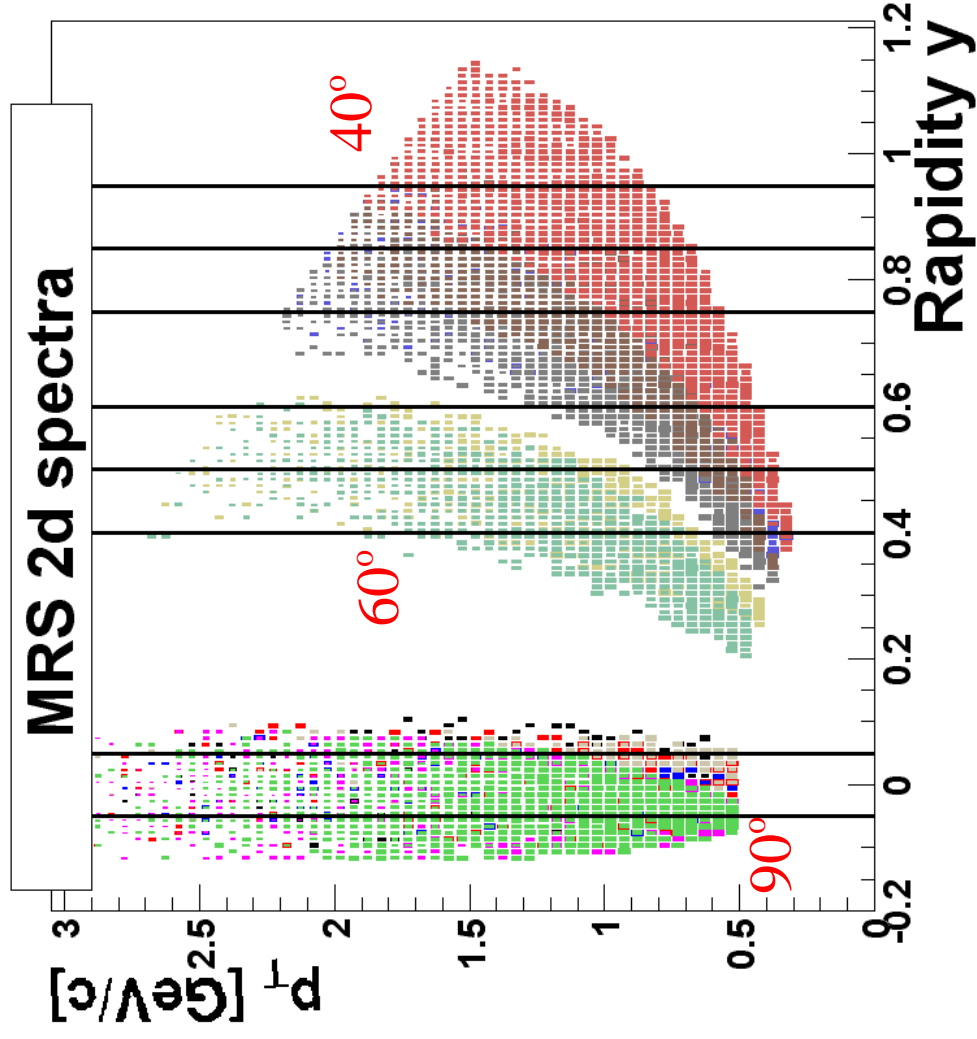


Select data from y - p_t plots



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

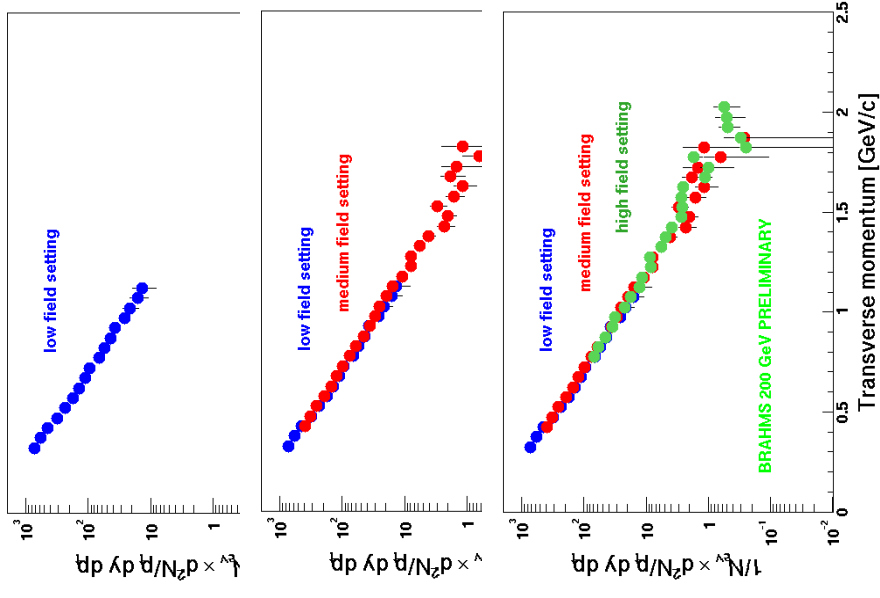
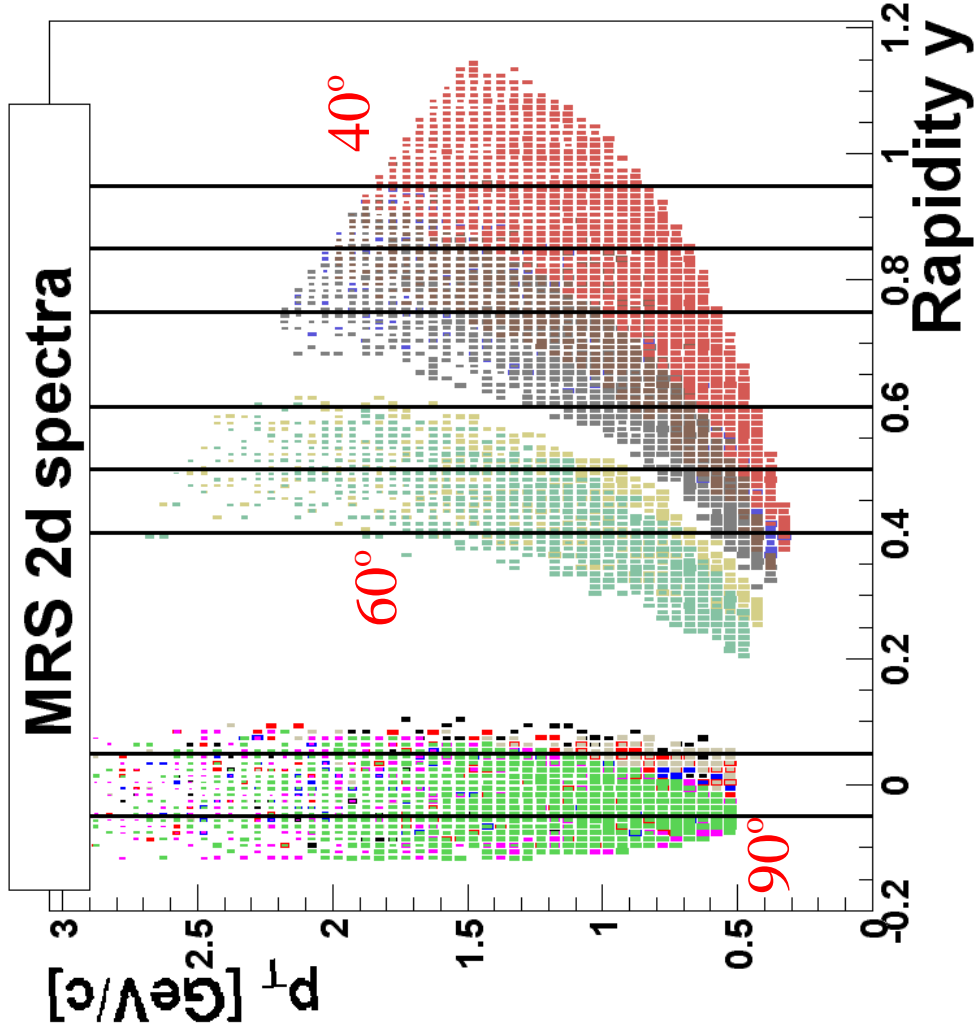


Select data from y - p_t plots



Bjørn H. Samsøe

Transverse dynamics
at RHIC, March 2003



A word on extracting a yield from a p_t spectrum



Bjørn H. Samsø

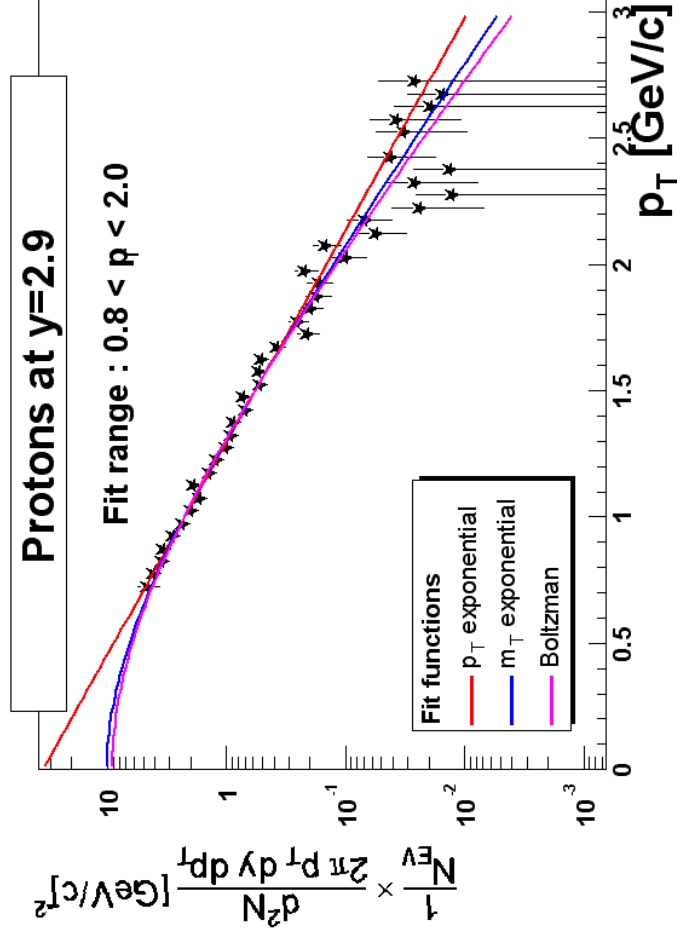
Transverse dynamics
at RHIC, March 2003

We need to extrapolate to integrate the spectra, and here we have to make an assumption about the spectral shape:

- Boltzman?
- p_t exponential?
- m_t exponential?

There is a 20% difference in the yields extracted via the different fits - this goes into our systematic uncertainty.

In the following we have used m_t exponential fits unless otherwise noted.



Centrality dependence of charged particle production at midrapidity



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

-
- Analysis of total $y \sim 0$ data set from Run-2 (Au-Au $\sqrt{s_{NN}} = 200 \text{ GeV}$)
Approx. 30M events

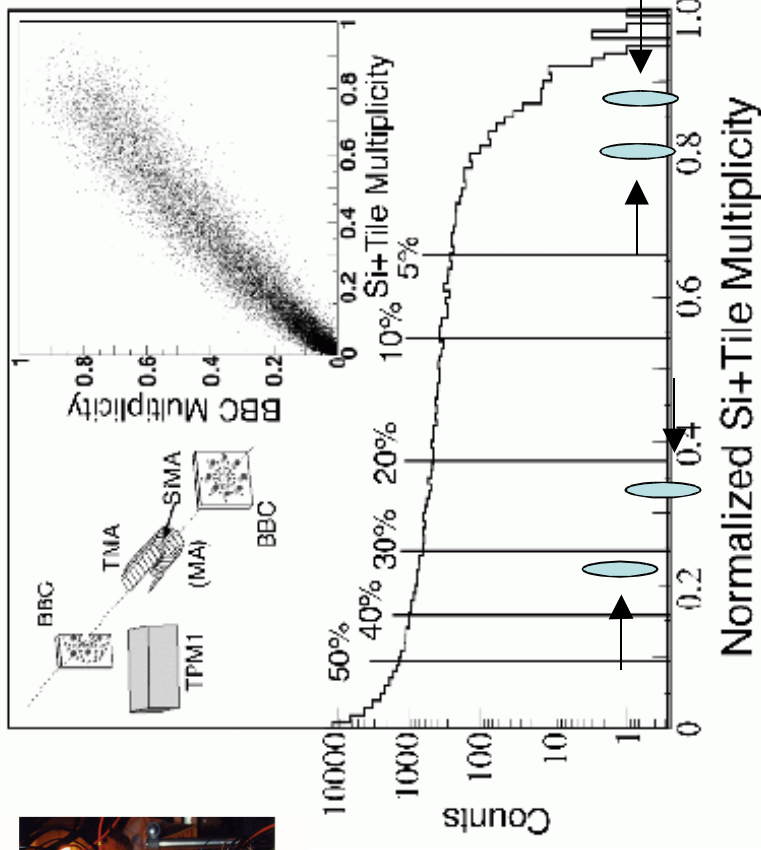
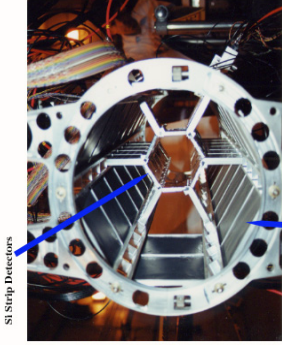
Centrality dependence of charged particle production at midrapidity



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

- Analysis of total $y \sim 0$ data set from Run-2 (Au-Au $\sqrt{s_{NN}} = 200 \text{ GeV}$)
- Events divided into centrality classes (0-10, 10-20, 20-40, 40-60 %)
as determined by Multiplicity detector ($-2.2 < \eta < 2.2$).



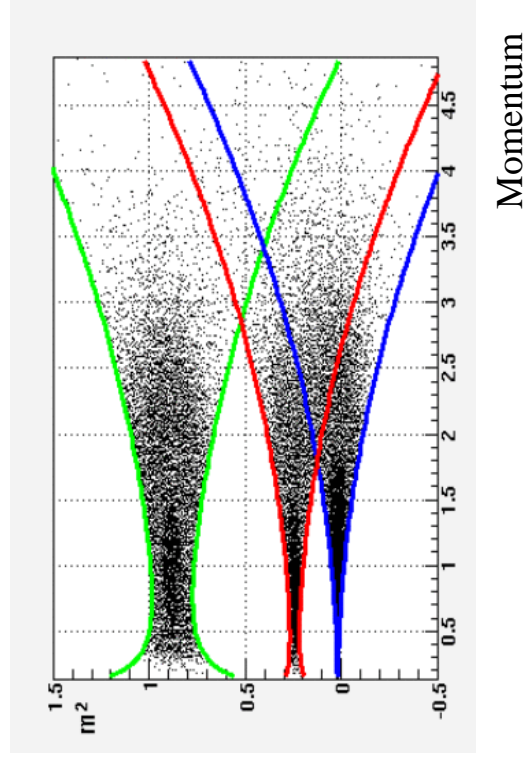
Centrality dependence of charged particle production at midrapidity



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

- Analysis of total $y \sim 0$ data set from Run-2 (Au-Au $\sqrt{s_{NN}} = 200 \text{ GeV}$)
- Divided into centrality classes (0-10, 10-20, 20-40, 40-60 %) as determined by Multiplicity detector ($-2.2 < \eta < 2.2$).
- PID by Time-Of-Flight, 3σ cut with respect to our momentum and tof resolutions



Corrections applied to the data



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

We need to apply a number of corrections to our raw number of particles to get the correct yield. We've corrected for:

- tracking efficiency, using a track embedding technique
- efficiency in matching spectrometer tracks to hits in the time-of-flight systems
- geometrical acceptance, using GEANT3.21
- physics effects like multiple scattering, proton knockout from the beam pipe etc., also evaluated with GEANT3.21

Caveats:

The numbers I will show have not been corrected for Λ feed-down, and I will only show statistical errors.

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Bjørn H. Samsø

Transverse dynamics
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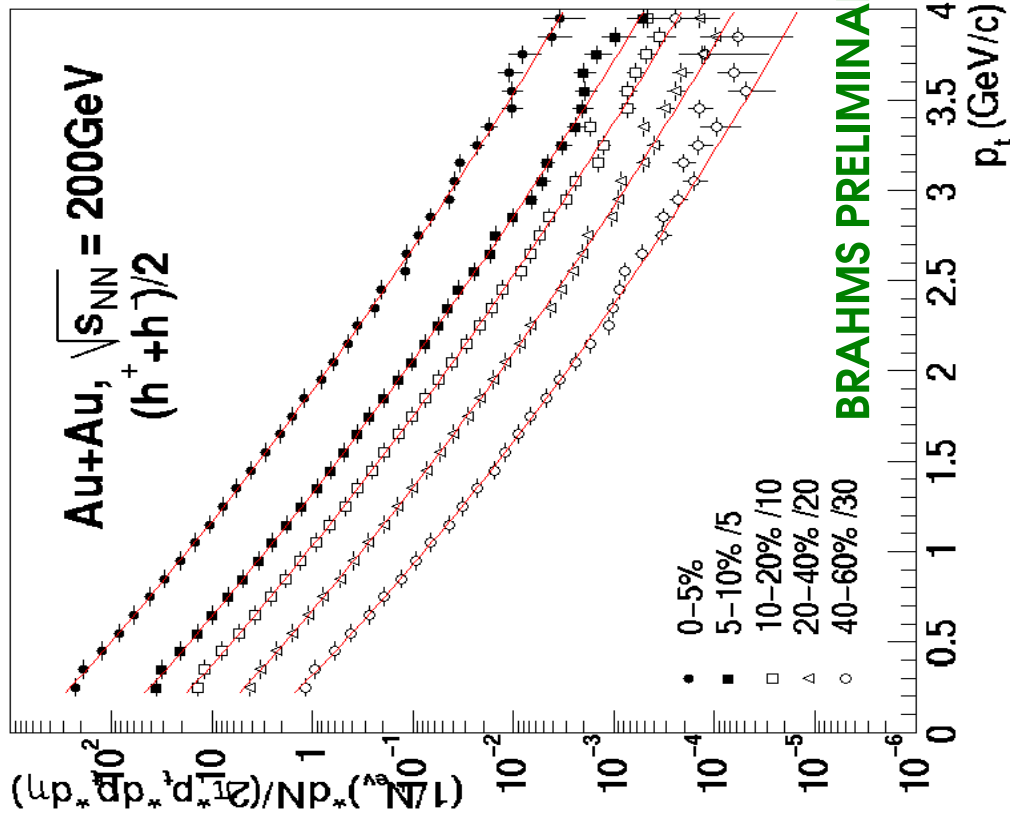
Now for the data...

Centrality dependence of charged hadron spectra at $y=0$



Bjørn H. Samsøe

Transverse dynamics at RHIC, March 2003



- The charged hadron spectra have been fitted to a power law formula:

$$f = \frac{C}{\left(1 + \frac{p_t}{p_0}\right)^n}$$

in the range $0.2 < p_t < 4.0 \text{ GeV}/c$

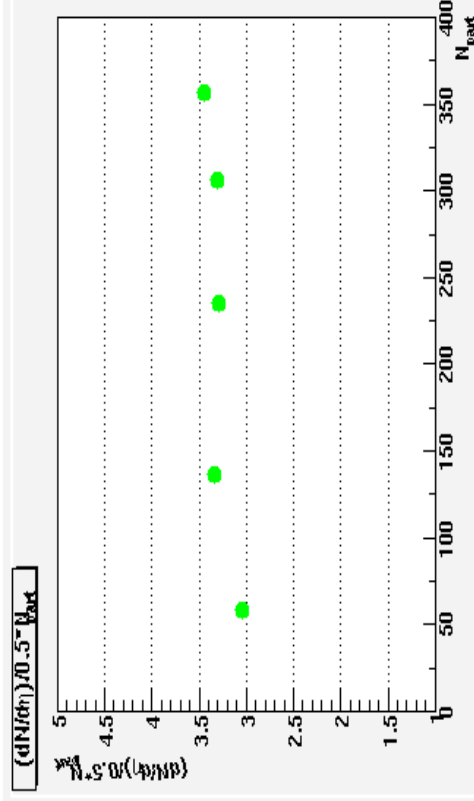
- $dN/d\eta$ and $\langle p_t \rangle$ values are calc. from the fit parameters, with

$$\langle p_t \rangle = \frac{2p_0}{(n-3)}$$

$dN/d\eta$ at $\eta=0$ from charged hadrons

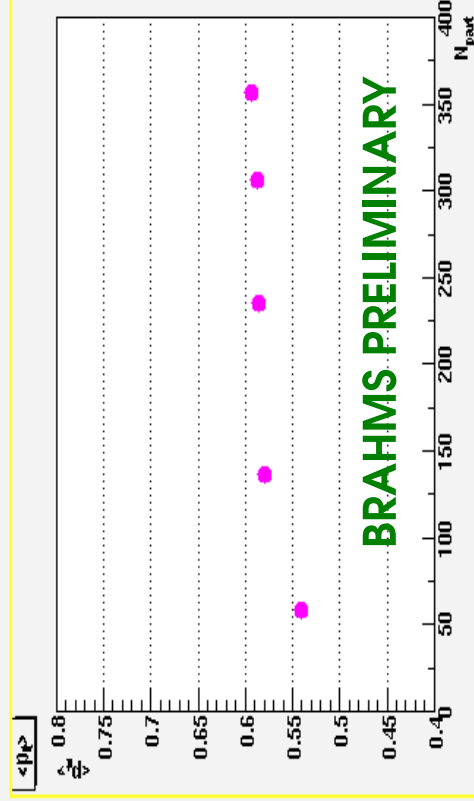


Bjørn H. Samsøe
Transverse dynamics
at RHIC, March 2003



$dN/d\eta$ per participant pair increases from 3.0 for peripheral collisions to 3.5 for central.

This is consistent with what we showed in Phys.Rev.Lett.88:202301,2002



$\langle p_T \rangle$ rises from ~ 0.55 GeV/c for peripheral collisions to ~ 0.60 GeV/c for central.

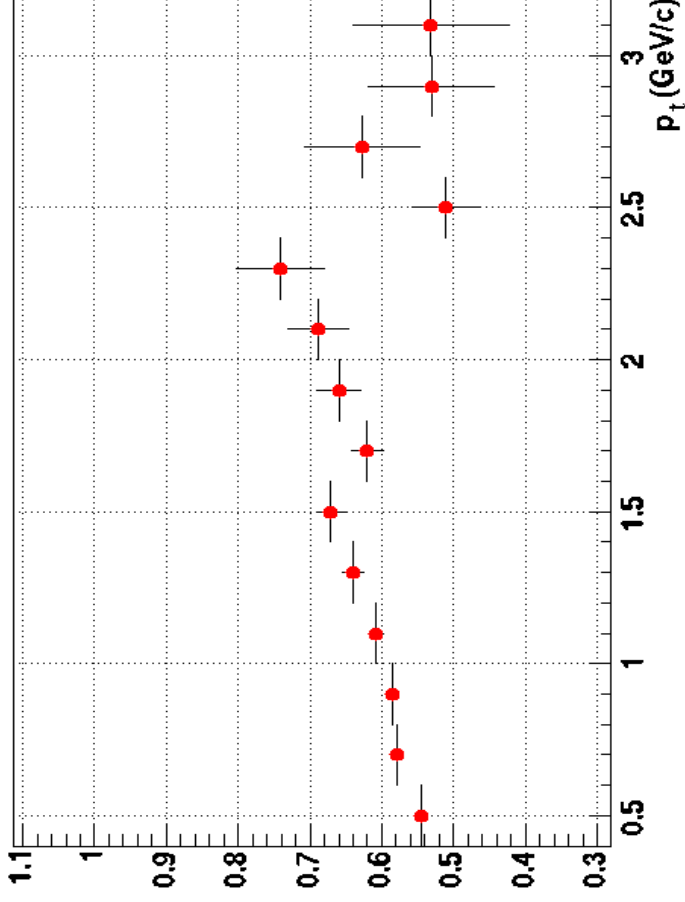
Charged hadron yield per N_{coll} ,

comparison between central and peripheral



Bjørn H. Samsøe
Transverse dynamics
at RHIC, March 2003

$$\frac{Y(\frac{d^+d^-}{2})/N_{\text{coll}} (0-5\%)}{Y(\frac{d^+d^-}{2})/N_{\text{coll}} (40-60\%)}$$



The ratio between the yield of charged hadrons from central and peripheral collisions

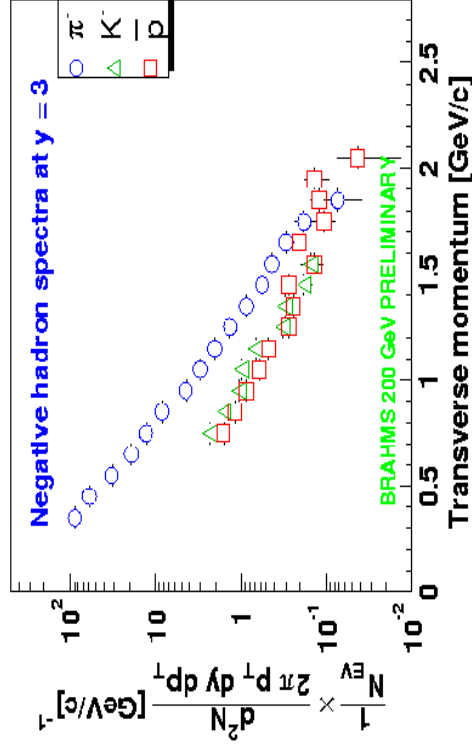
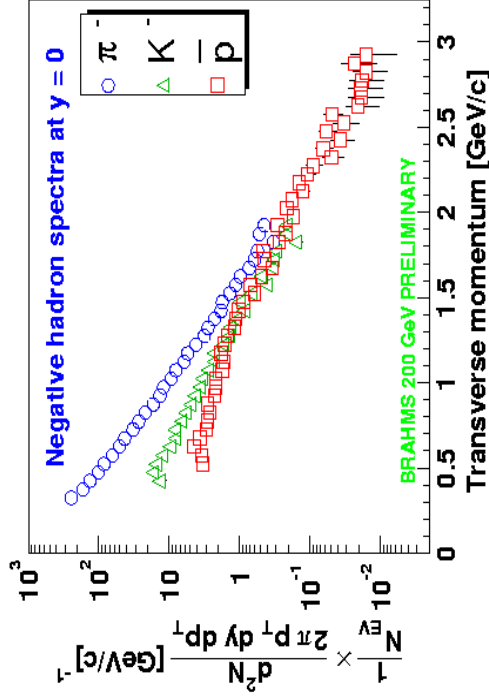
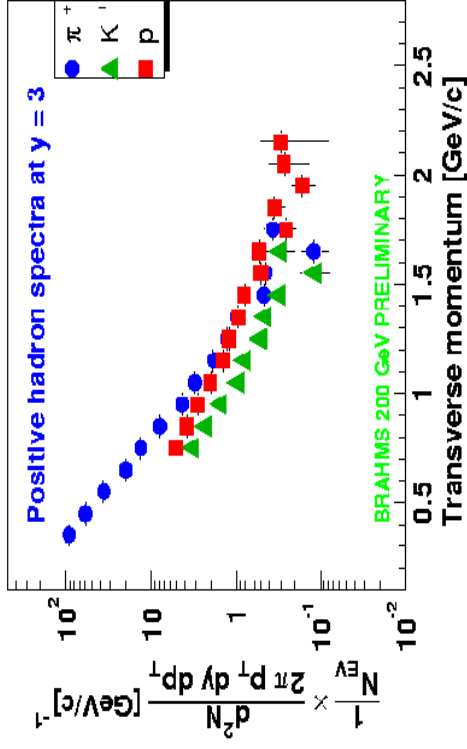
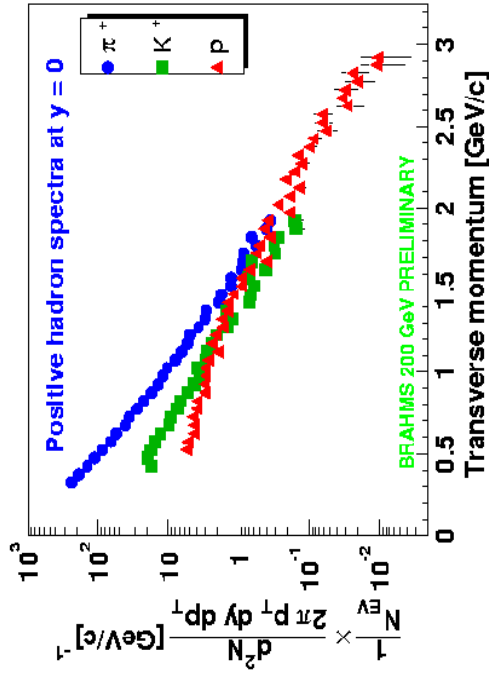
- increases up to $p_t \sim 2.3$
- drops as p_t increases beyond this value

BRAHMS PRELIMINARY

Particle spectra from central AuAu collisions



Bjørn H. Samsøe
 Transverse dynamics
 at RHIC, March 2003



Cent:
 0-10%

Analysis by
 D. Ouerdane

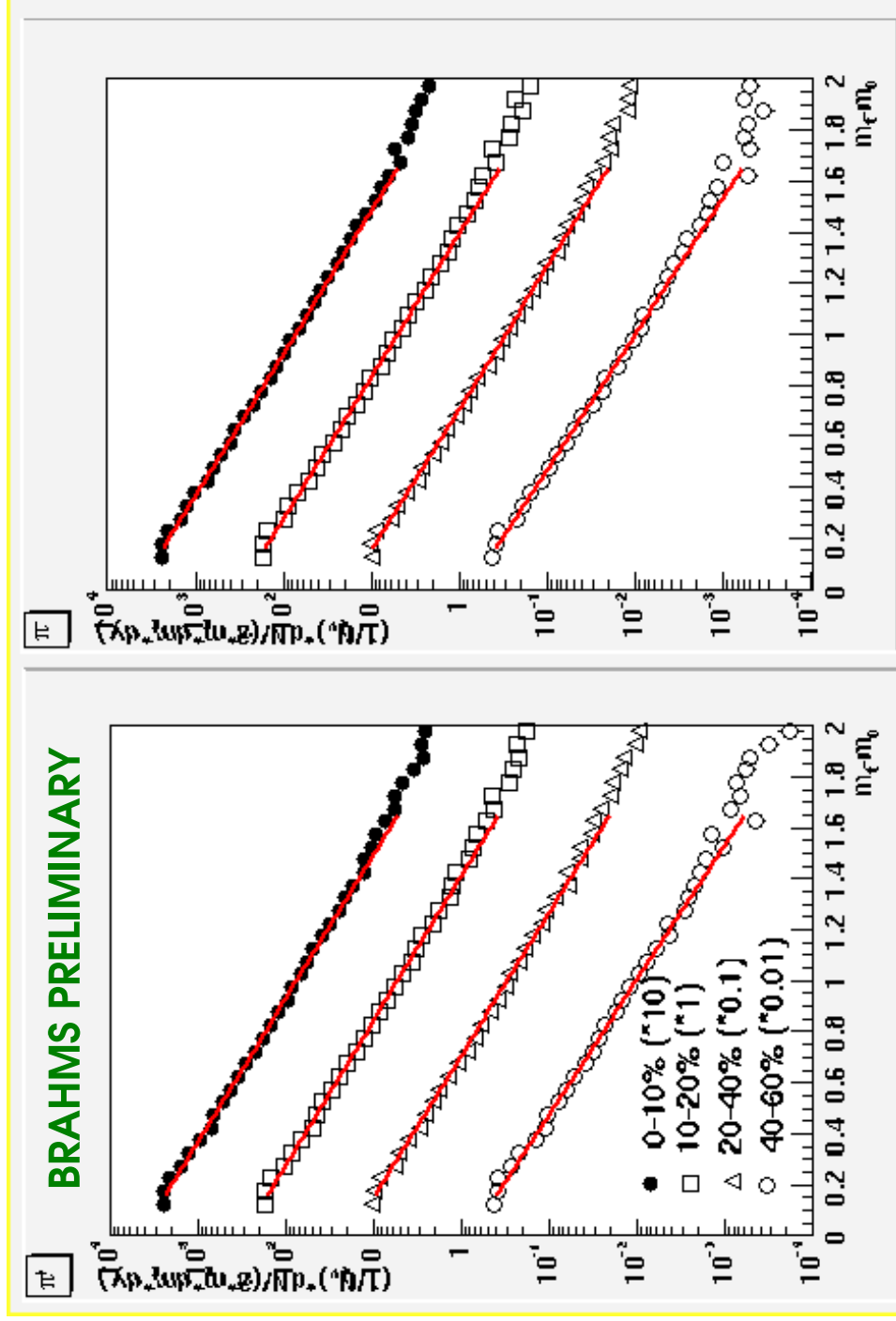
Charged hadron spectra:

π^+ , π^-



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at RHIC, March 2003

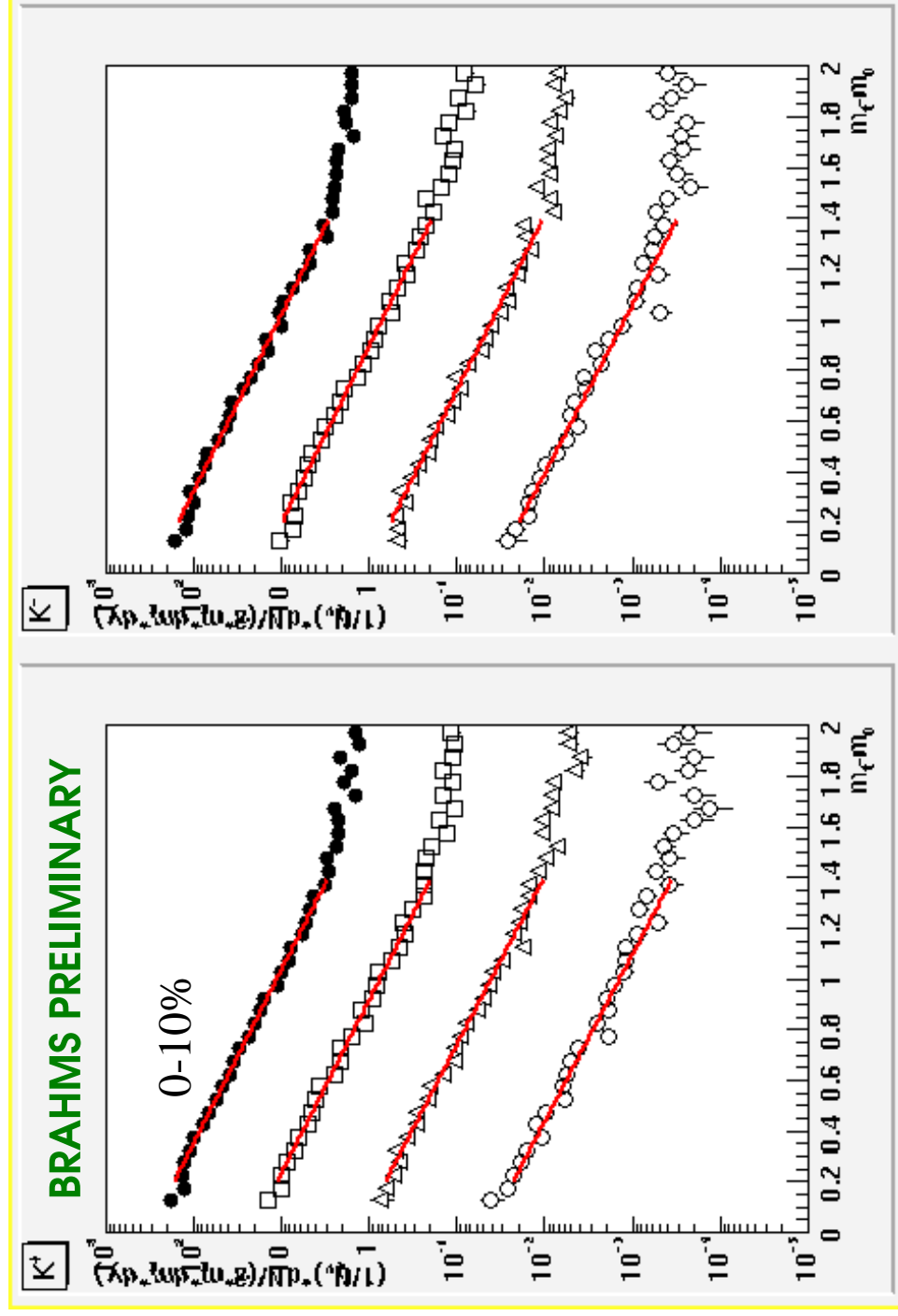


Charged hadron spectra: K^+ , K^-



Bjørn H. Samsø

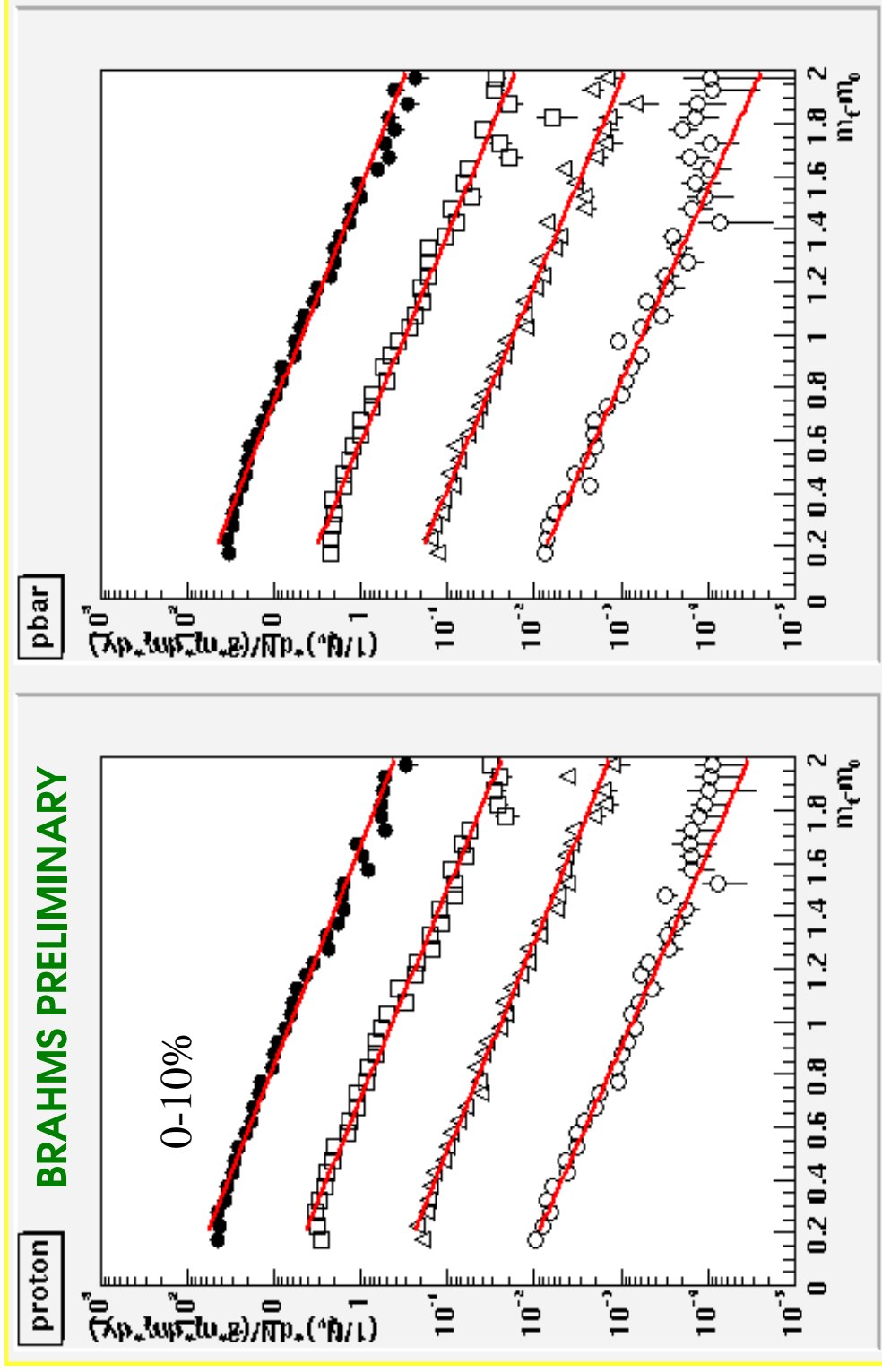
Transverse dynamics
at RHIC, March 2003



Charged hadron spectra: p, \bar{p}



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 Transverse dynamics
 at RHIC, March 2003

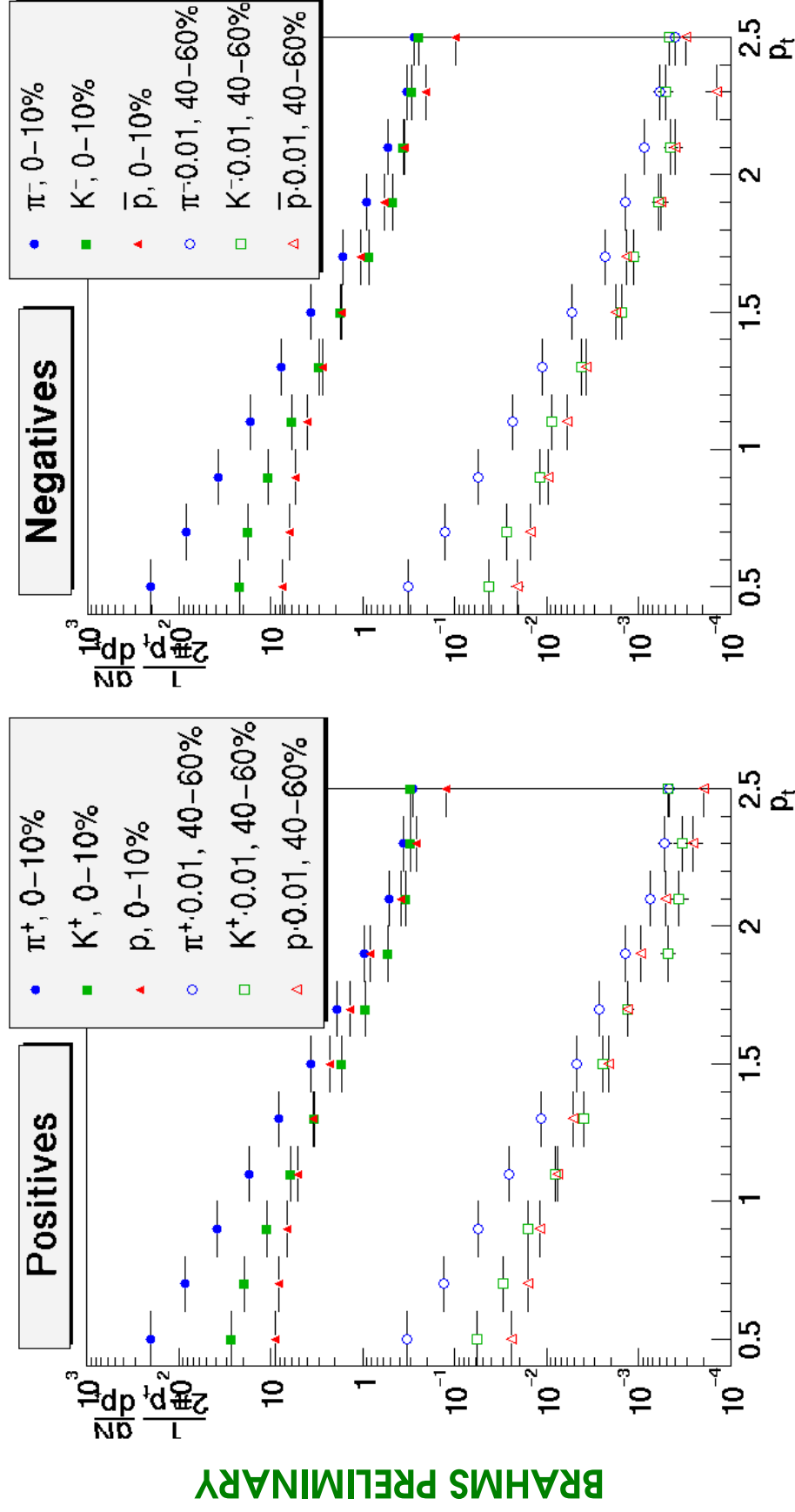




Comparison: 0-10% vs. 40-60%

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at RHIC, March 2003

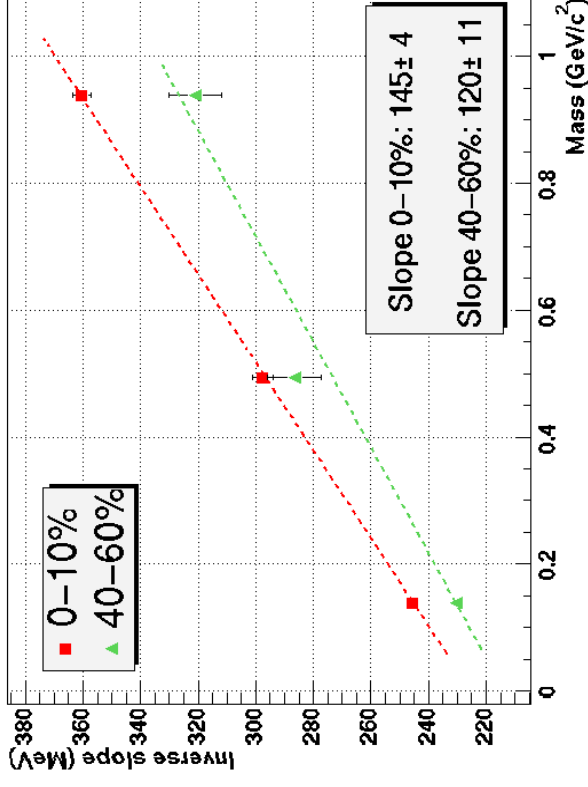
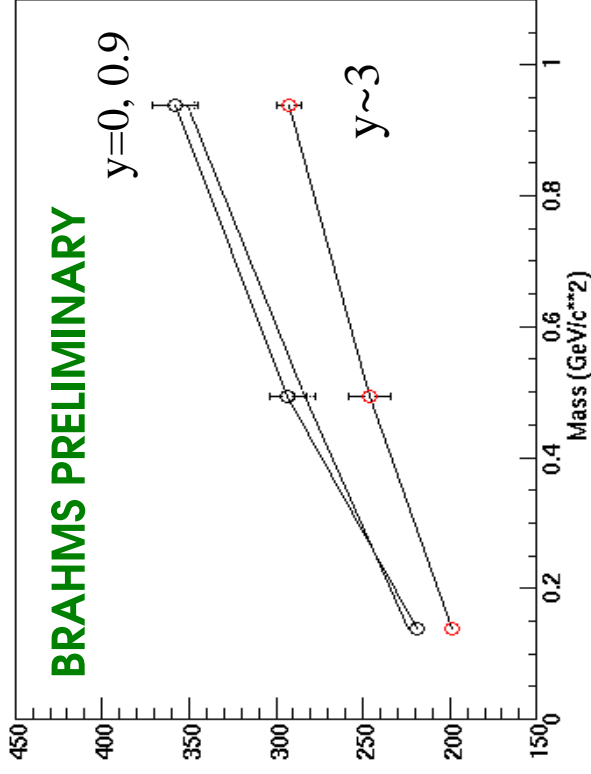


We see no significant difference between the behaviors of p_t spectra for central and peripheral events.

Inverse slope vs. mass and centrality



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Transverse dynamics
at RHIC, March 2003

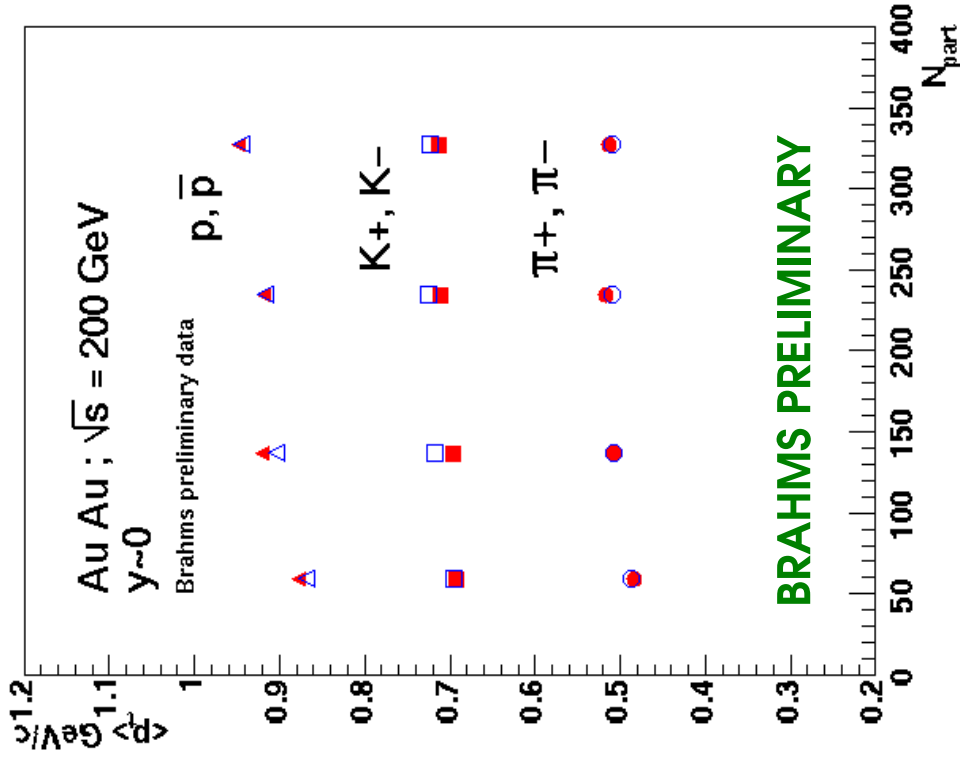


- We see transverse flow at all rapidities, and all centralities at $y=0$
- Inverse slope decreases with increasing rapidity
- Inverse slope decreases somewhat for less central events

$\langle p_t \rangle$ for π , K, p at $y=0$



Bjørn H. Samsøe
 Transverse dynamics
 at RHIC, March 2003



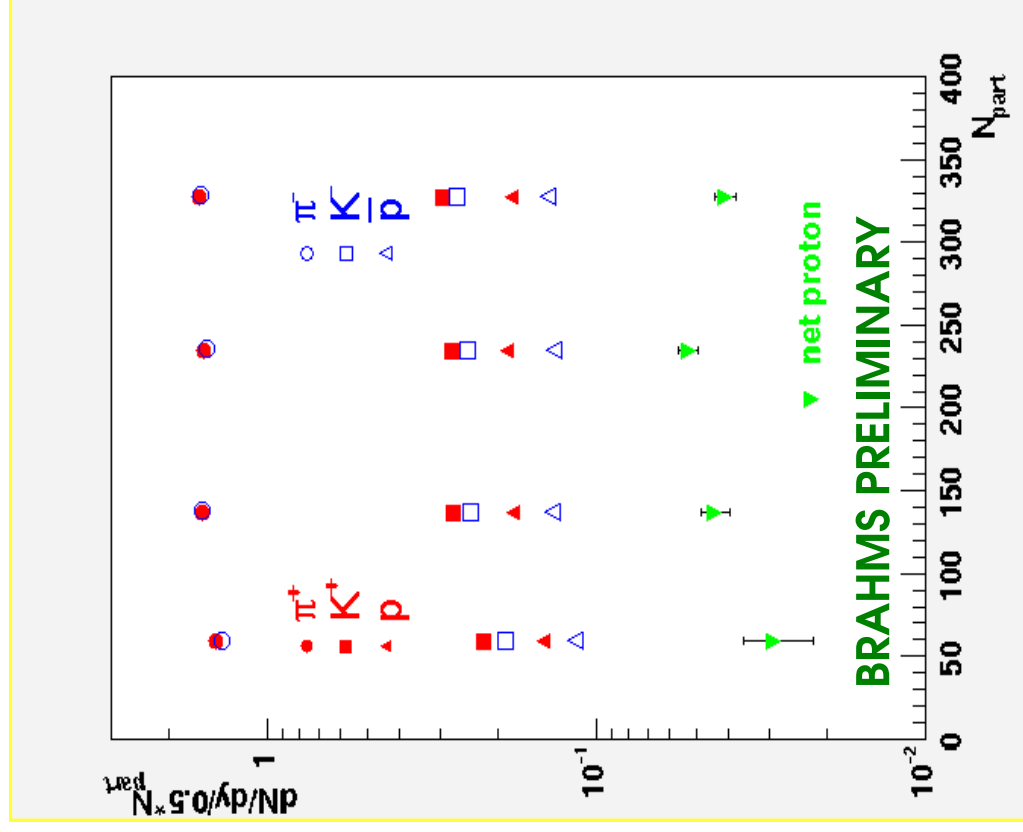
- The mean p_t is evaluated from the exponential m_t fits.
- $\langle p_t \rangle$ for all particle species increases from peripheral to central events
- Values and centrality dependence is good agreement with preliminary Phenix data, except for the pions. Ours are higher, likely because of the m_t fit.

dN/dy per participant pair at y=0



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

Bjørn H. Samsøe
 Transverse dynamics
 at RHIC, March 2003



- The yield per participant pair increases with participant number for all particle species

- K and p yields rise faster than π

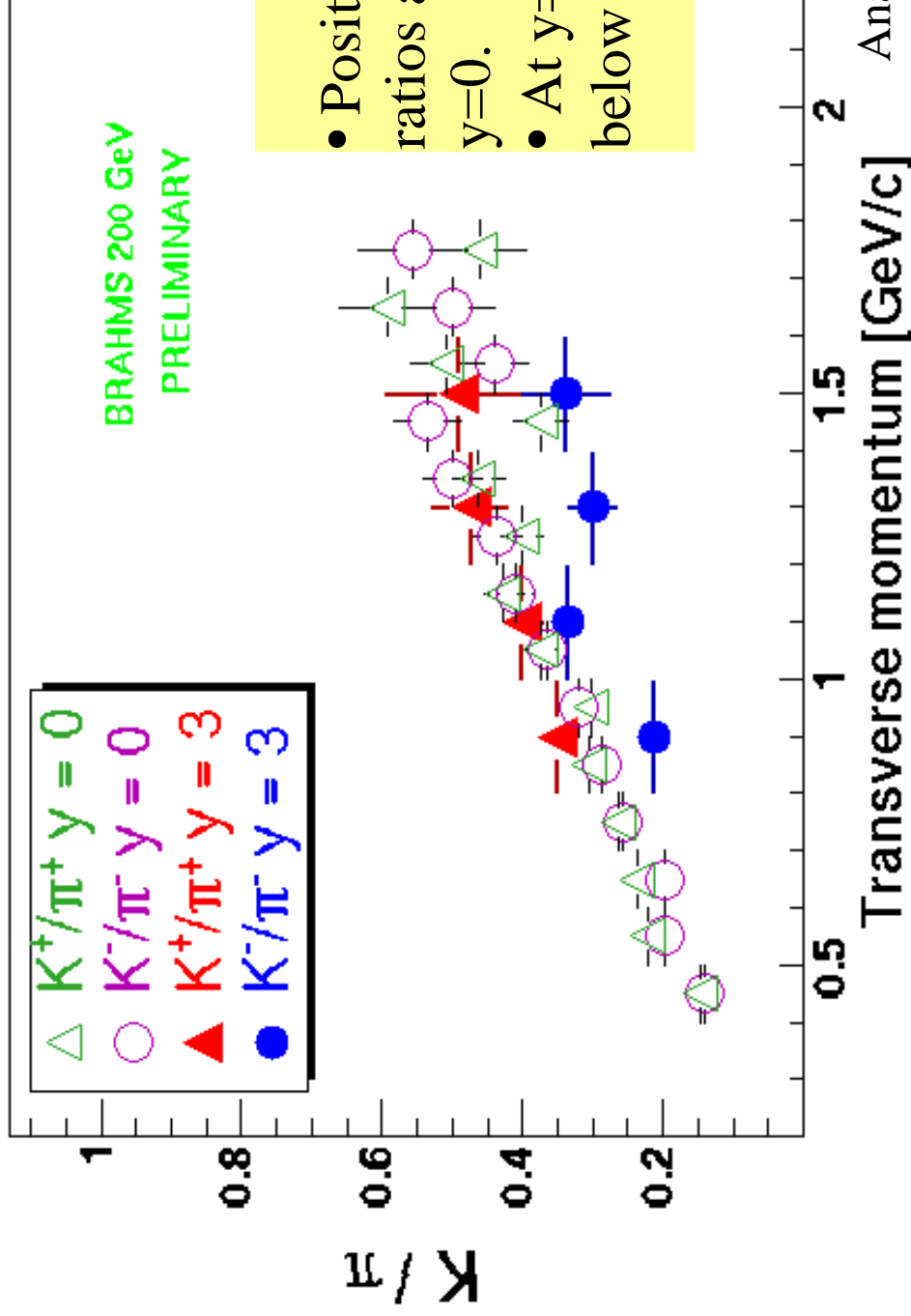
Statistical errors only. Dominant sources of systematic errors are N_{part} numbers and extraction of yields.

K/ π ratio at $y=0, 3$



Bjørn H. Samsø

Transverse dynamics
 at RHIC, March 2003



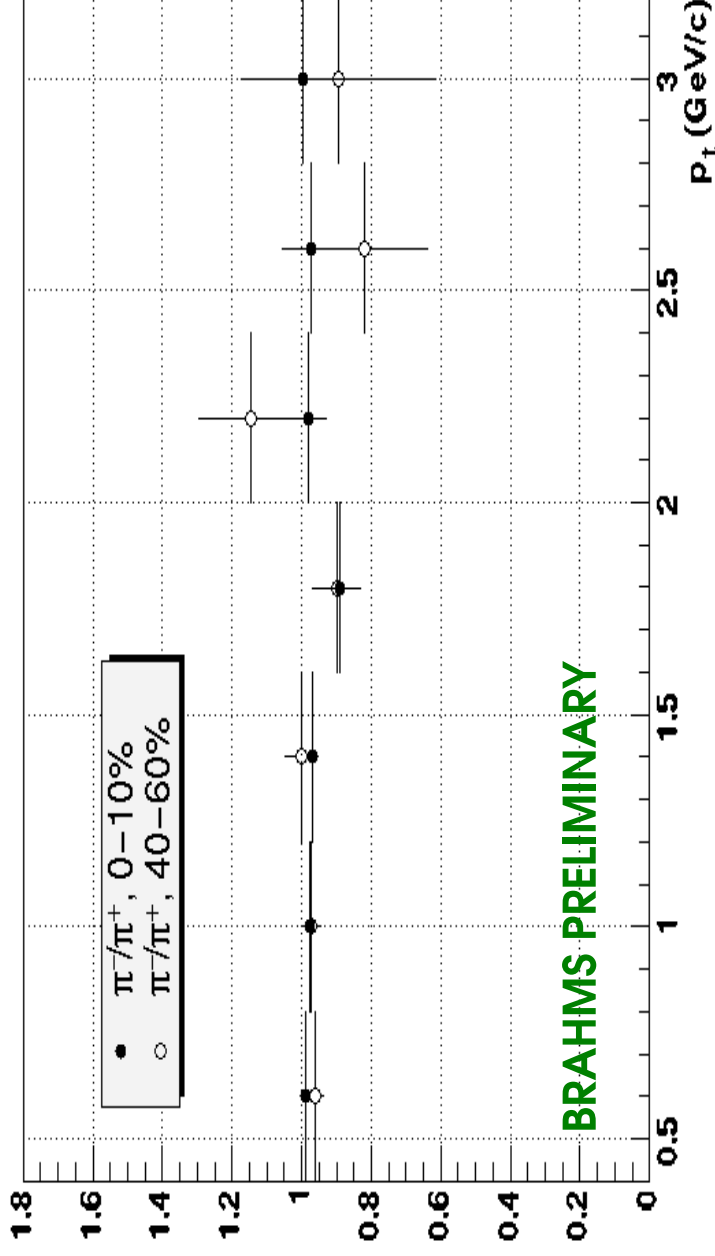
- Positive and negative ratios are identical at $y=0$.
- At $y=3$ K^-/π^- drops below the positives

Analysis by
 D. Ouerdane

Centrality dependent π^-/π^+ ratios at $y=0$



Bjørn H. Samsøe
Transverse dynamics
at RHIC, March 2003

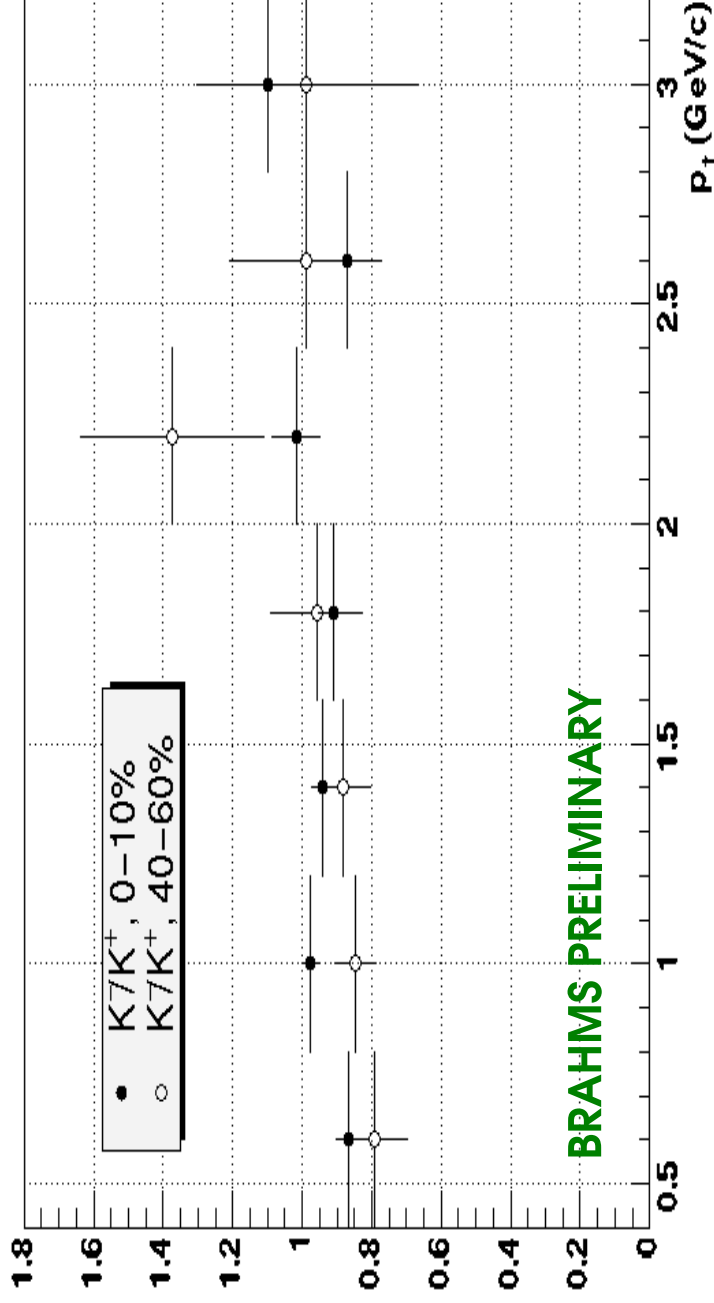


- The π^-/π^+ ratio is flat over the range $0.5 < p_T < 3.5$ GeV/c.
- R(central) is equal within errors to R(peripheral)

Centrality dependent K^-/K^+ ratios at $y=0$



Bjørn H. Samsøe
Transverse dynamics
at RHIC, March 2003

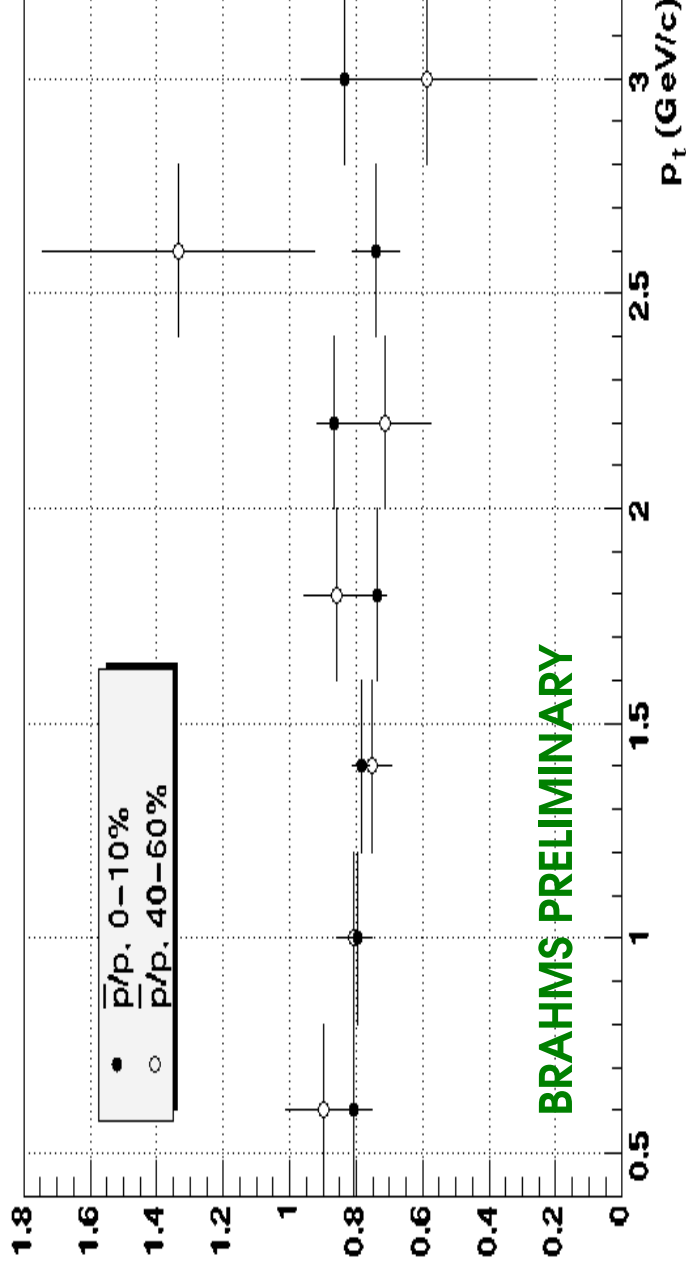


- The K^-/K^+ ratios are almost flat over the range $0.5 < p_t < 3.5$ GeV/c. There may be a dip at low p_t
- R(central) is again equal within errors to R(peripheral)

Centrality dependent \bar{p} / p ratios at $y=0$



Bjørn H. Samsøe
Transverse dynamics
at RHIC, March 2003



- The \bar{p} / p ratios for central events are flat over the range $0.5 < p_t < 3.5 \text{ GeV}/c$.
- $R(\text{central})$ is equal within errors to $R(\text{peripheral})$

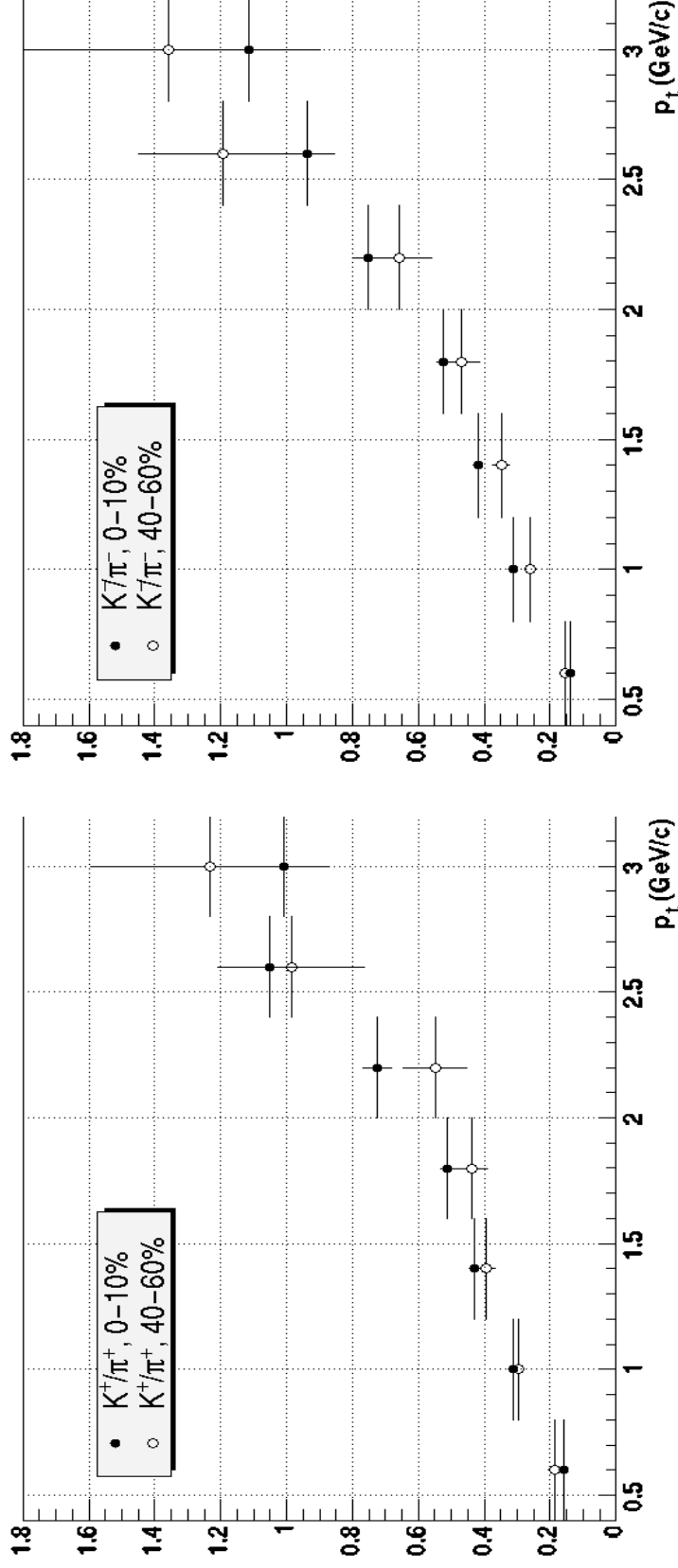


K / π ratios at $y=0$

Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

BRAHMS PRELIMINARY



- K^-/π^- , K^+/π^+ ratios show an increase with p_t
- There is no significant difference between central and peripheral events.

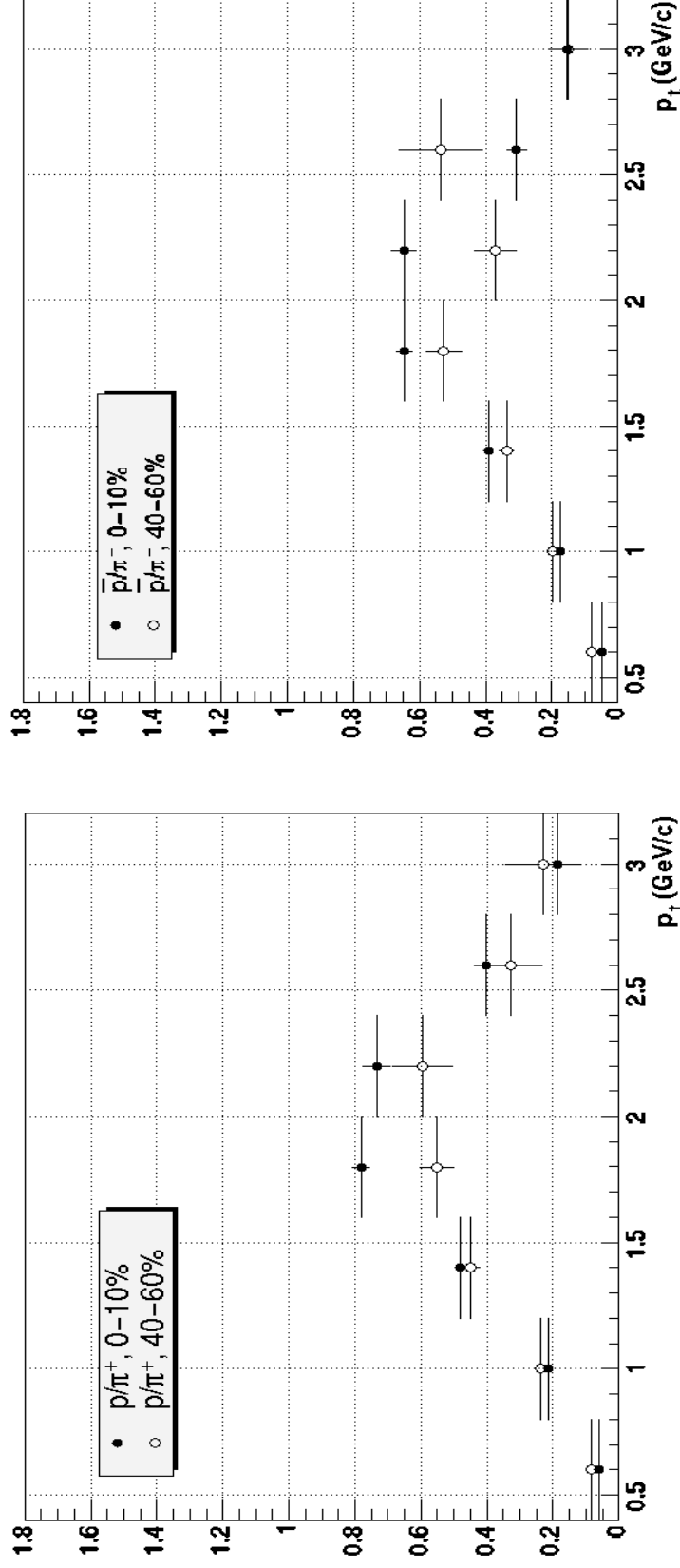


p / π ratios at $y=0$

Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

BRAHMS PRELIMINARY



- \bar{p}/π^- , p/π^+ ratios show an increase with centrality.
- The ratios in central events reach 0.7~0.8 at 2GeV/c, while in peripheral events the ratios go up to 0.4~0.5.

The BRAHMS experiment

Additions since 2001

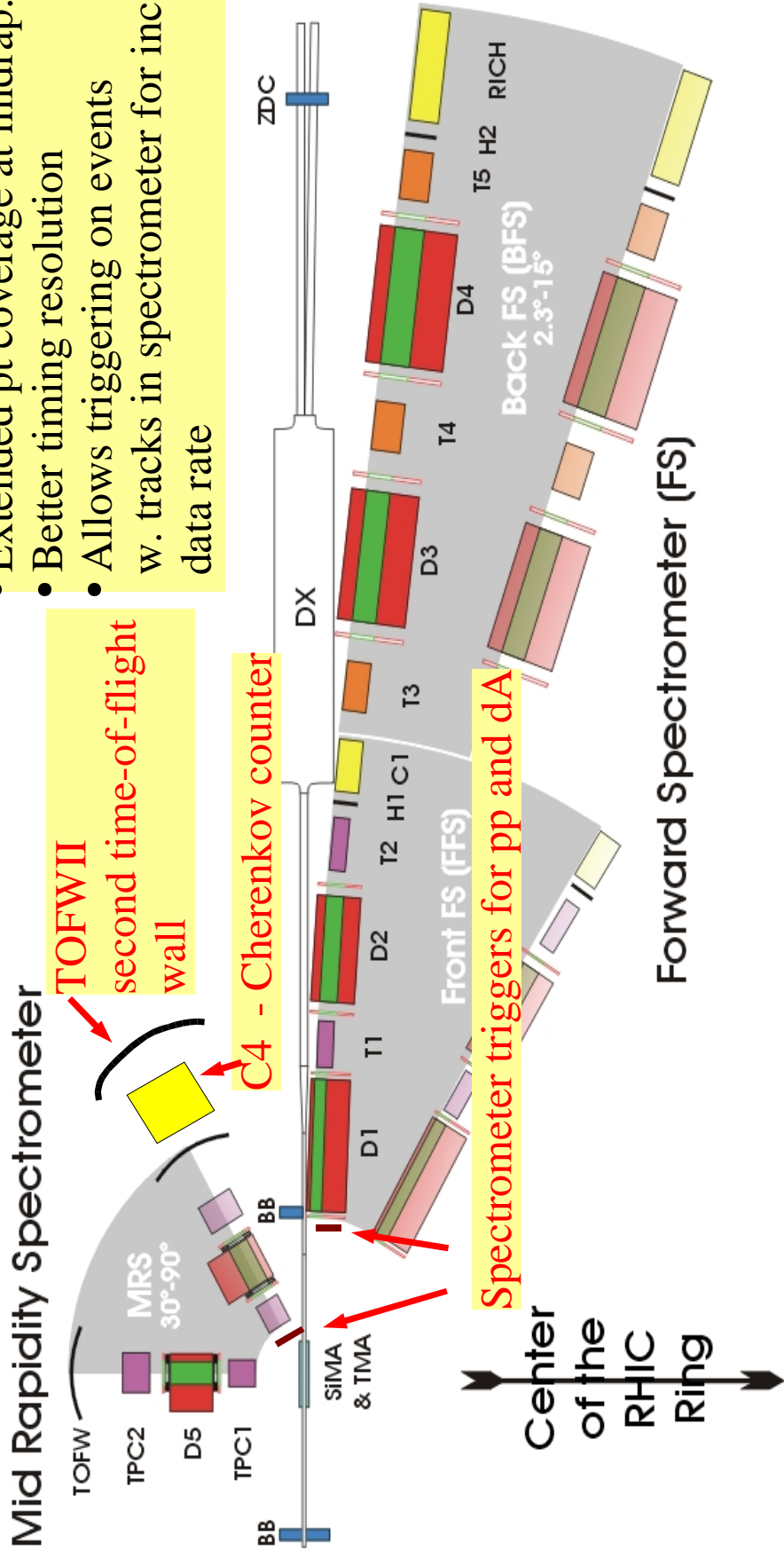


Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

BRAHMS Experimental Setup

- Extended pt coverage at midrap.
- Better timing resolution
- Allows triggering on events w. tracks in spectrometer for inc. data rate



What to expect from BRAHMS in the near future



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

Existing AuAu data:

- Analysis is ongoing away from midrapidity
- Our centrality dependent spectra will be extended out to $y \sim 3$

pp and dAu data:

- pp data are being analyzed to serve as baseline for our AuAu data
- dAu data are being taken and analyzed as we get them. Now we only need the machine to deliver enough beam for a good high pt sample!

A future AuAu run at full RHIC energy:

- C4 and TOFWII extend our capabilities at midrapidity, allowing for an even better comparison between mid and high rapidities
- Our p_t coverage at midrapidity will go increase, nicely complementing the data we already have



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

Conclusions

BRAHMS has measured the transverse dynamics of charged hadrons at midrapidity from AuAu collisions at $\sqrt{s_{NN}} = 200 \text{ GeV}$

In brief, we have shown that

- for charged hadrons, $\langle p_t \rangle$ increases as a function of centrality
- this also applies to each particle species individually
- the global behavior of identified particle spectra does not change with centrality
- like-particle ratios are constant as a function of p_t and centrality
- the p/π ratio shows an increase for more central events

Conclusions



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Thank you for listening

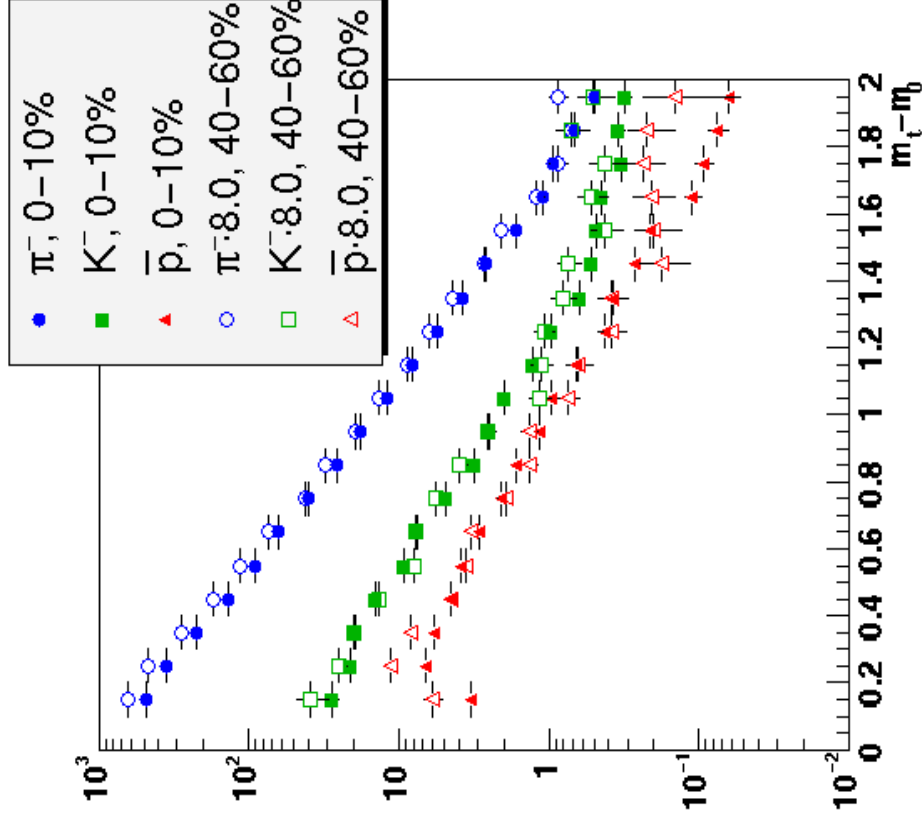
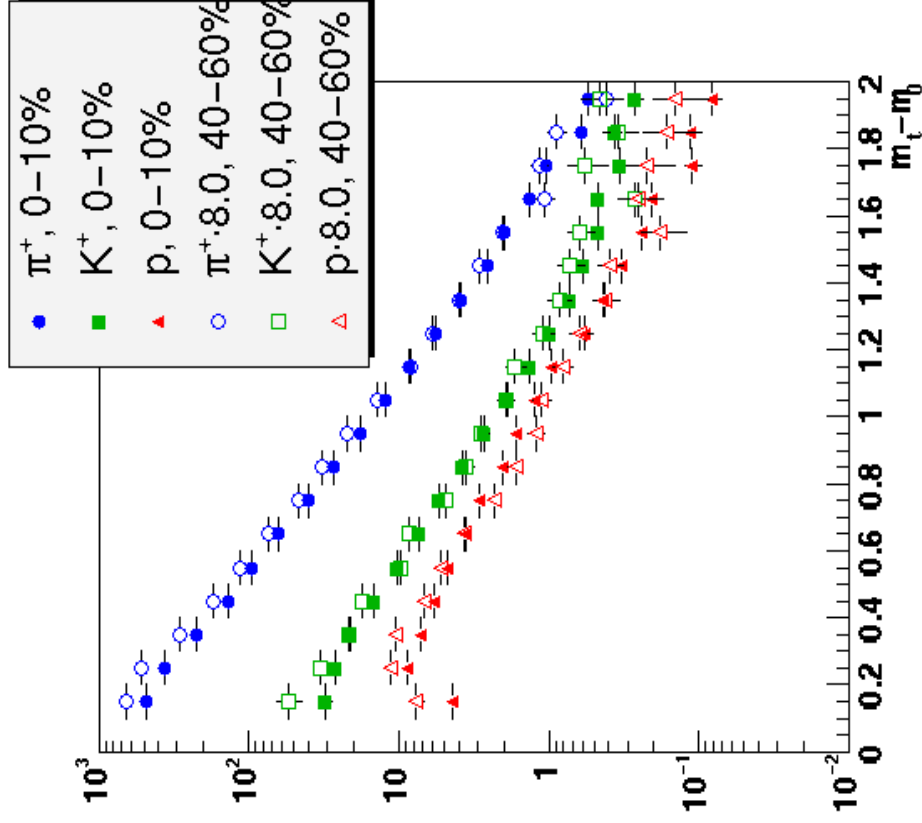
Comparison: 0-10% vs. 40-60%

$$m_t - m_0$$



Bjørn H. Samsø

Transverse dynamics
at RHIC, March 2003

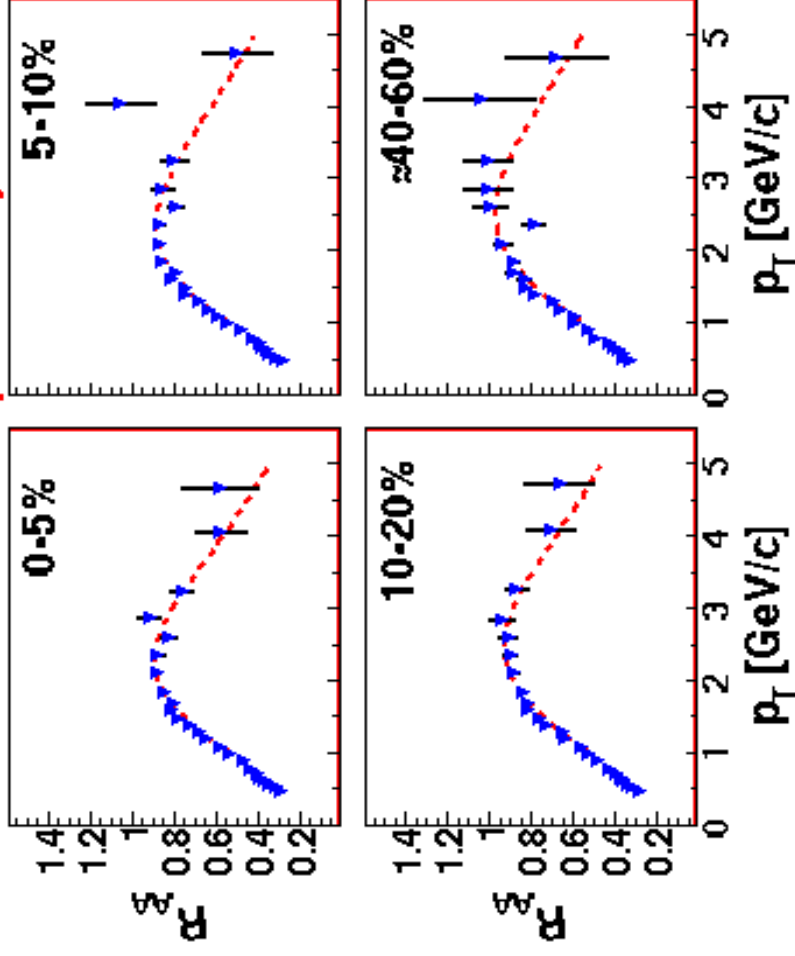


High pt, nuclear modification factor



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 at RHIC, March 2003

BRAHMS preliminary



$$R_{AA} = \frac{d^2 N^{A+A} / dp_T d\eta \sigma^{N+N}}{d^2 \sigma^{N+N} / dp_T d\eta \langle N_{bin} \rangle}$$

cent.	$\langle N_{binary} \rangle$
0-5%	965
5-10%	764
10-20%	551
~40-60%	~ 150

Numbers from
nucl-ex/0206011

The **.....** lines show ratios of fits.

Calculating $\langle p_t \rangle$ from m_t spectra



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We've fit our spectra with an m_t exponential to extract the inverse slope.

Using the fit functions for p_t :

$$\frac{dN}{dp_t} = p_t \cdot e^{-\frac{\sqrt{p_t^2 + m^2}}{T}}$$

$$p_t \cdot \frac{dN}{dp_t} = p_t^2 \cdot e^{-\frac{\sqrt{p_t^2 + m^2}}{T}}$$

we can extract the mean p_t by integrating:

$$\langle p_t \rangle = \frac{\int p_t^2 \cdot \frac{dN}{dp_t}}{\int p_t \cdot \frac{dN}{dp_t}}$$



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Analysis details 1: Track and event selection

- All MRS 90 degree data set
 - > run4692 - run5983
 - > BB, TPC, TOFW, BbVertex calibration
- No specific Trigger selection
- Centrality cut from latest calibration from DB
- Select Good MrsTracks
- Magnet Fiducial cut : 1cm (x,y) from edge
- Run-by-Run fitting
 - Diff(Vzdc-Vbb) : 4σ cut
 - matching (Dang,Dy,Daly,Ty) : 3σ cut

Analysis details 2:

Acceptance maps



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- Flat distributions : p, θ
 - > 10M at each setting
 - > $-17.5\text{cm} < z < 17.5\text{cm}, \Delta z = 5\text{cm}$
- New TPM2 geometry for 2001 data setting
- Selection : same as used in data
 - > remove bad TOFW slats
 - > Magnet Fiducial cut : 1cm (x,y)
- y- η , y-pt map for π, K, p
 - > Acceptance values below 4.5(5.5) are applied to data. (reduce edge effect)

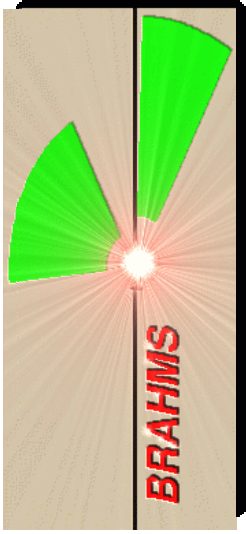
Analysis details 3:

Corrections



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- **Track-by-Track corrections**
- **TPC efficiency : ~ 89%, 96%**
 - > as a function of # of clusters
- **TOFW : remove bad slats**
- **Corrections for particle species**
 - > **Multiple scattering : π , K, p**
 - > **Decay correction : π , K**
 - > **Absorption : pbar**
 - > as a function of momentum

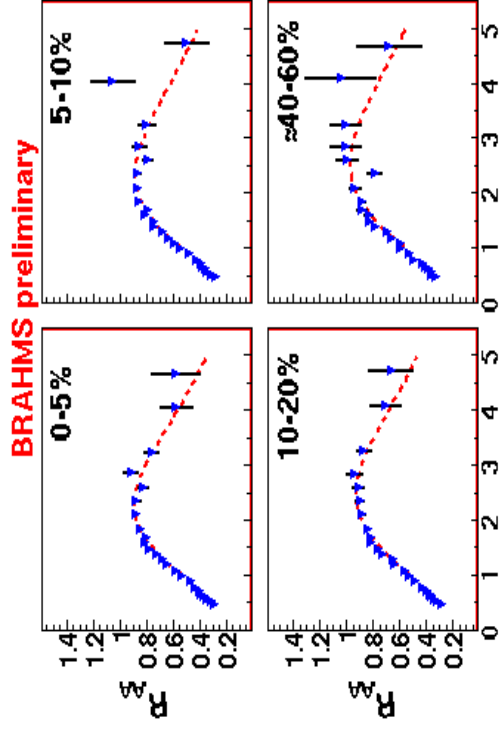
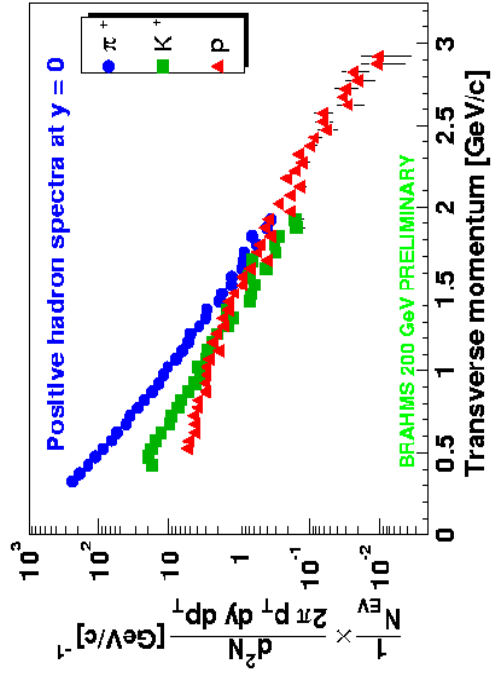


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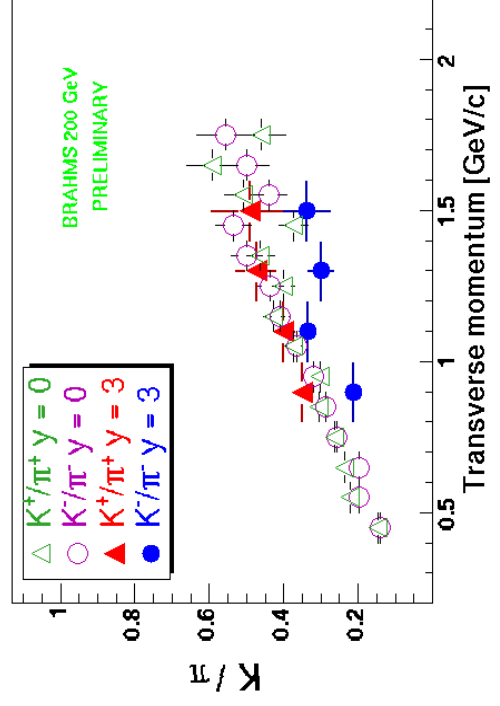
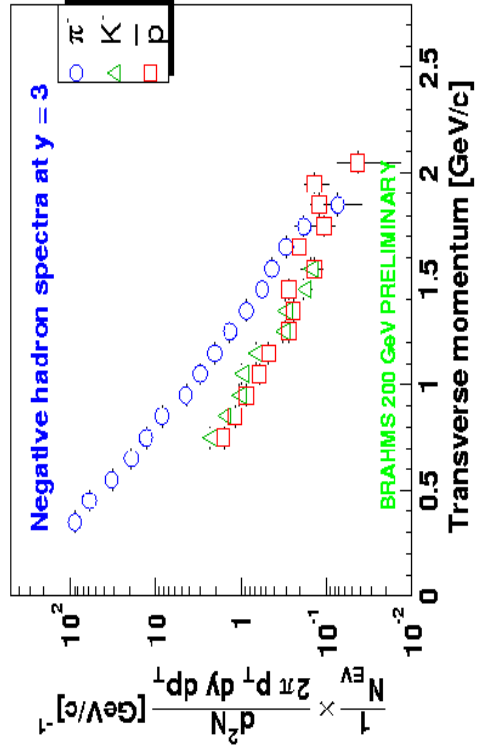
Quark Matter 2002



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Cent:
 0-10%



Centrality dependence of charged particle production at midrapidity



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- Analysis of total $y \sim 0$ data set from Run-2 (Au-Au $\sqrt{s_{NN}} = 200 \text{ GeV}$)
- Divided into centrality classes (0-10, 10-20, 20-40, 40-60 %)
as determined by Multiplicity detector ($-2.2 < \eta < 2.2$).
- PID by Time-Of-Flight, 3σ cut with respect to our momentum
and tof resolutions

...and now for the data:

- 1) Yields and $\langle p_t \rangle$ from charged hadrons
- 2) Yields and $\langle p_t \rangle$ from identified hadrons
- 3) Centrality and p_t dependence of like and unlike particle ratios