Forward Physics in BRAHMS at RHIC

- Why Forward?
- BRAHMS
- Selected Results in Au+Au 200 GeV
- Future Measurements and Considerations

J.H. Lee (BNL)
For the BRAHMS Collaboration

Forward Physics in R.H.I. Collisions: Mapping Space-time Evolution

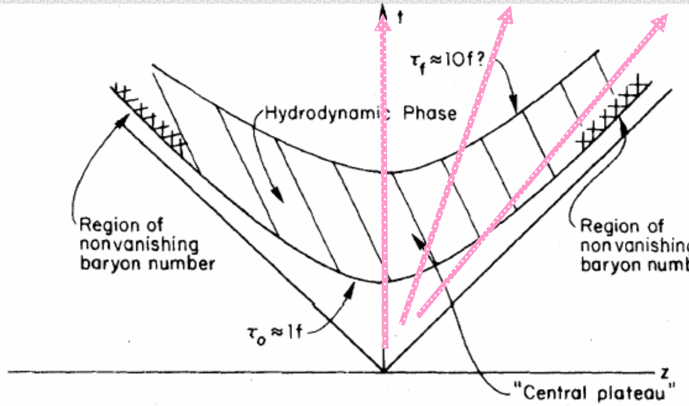
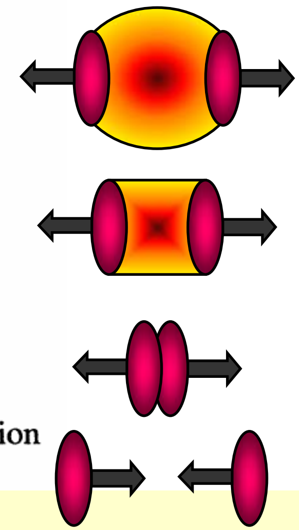


FIG. 3. Space-time diagram of longitudinal evolution of the quark-gluon plasma. (Bjorken 1982)



Formation of Hot Matter, QGP?

-Identifying and Characterizing the Hot Matter

- How does the system extend/develop? Transverse and longitudinal dynamics

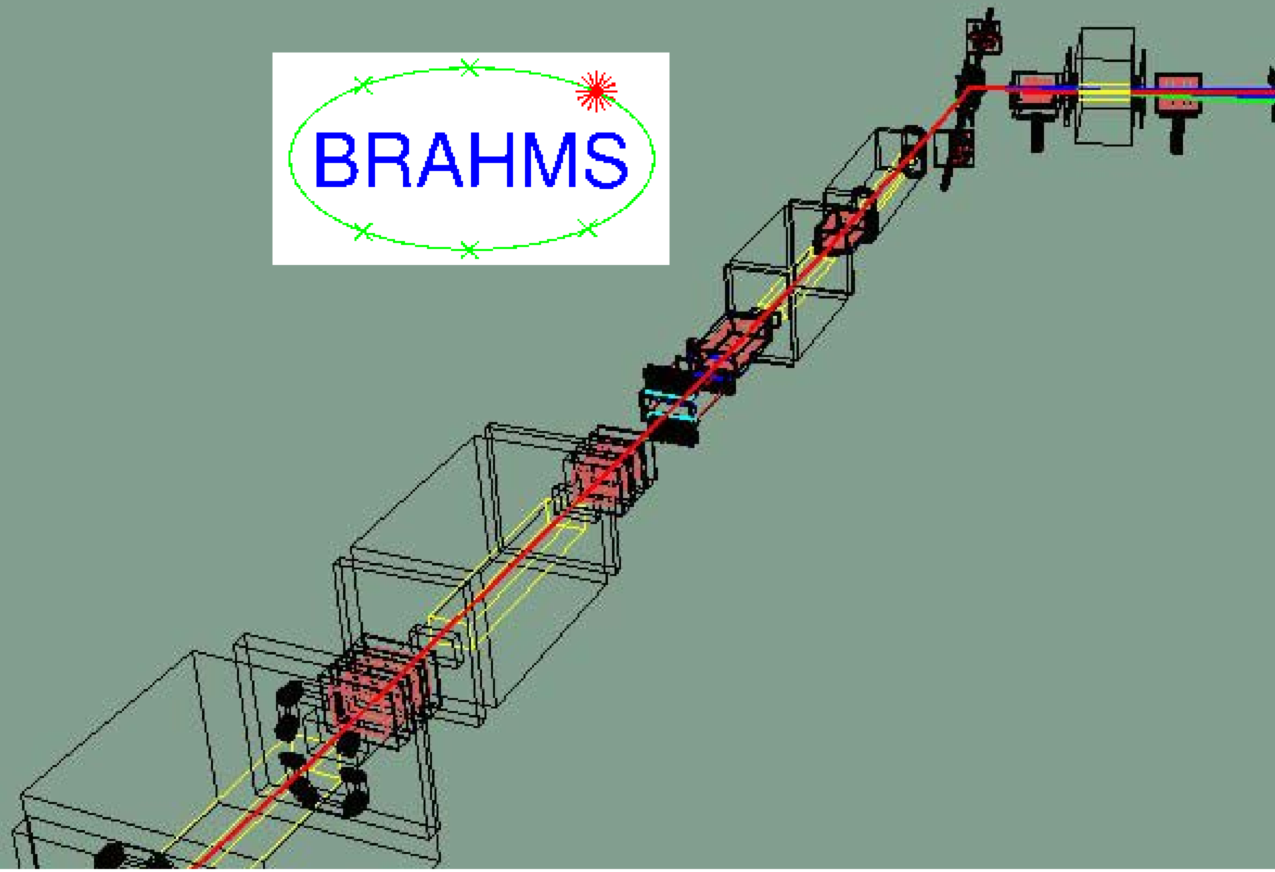
- Strong constraints for theoretical modeling/interpretation

- Initial Conditions/Partonic Dynamics: High-p_T vs y
- Collective Hydro-dynamics: Flow (radial and elliptic) vs y
- Thermodynamic and freeze-out properties: Temperatures, Ratios, HBT vs y
- Baryon Transport: Net-baryon vs y
- Bulk Properties: dN/dy

Large Rapidity Measurements: Limits and Challenges

- Kinematic limits:
  - $p_T \sim 4$ GeV/*c* for p = 100 GeV/c
    at BRAHMS' current limit (FS@2.3deg/$y_\pi \sim 4$)
  - $p_T \sim 7$GeV/*c* at FS@4deg
- High track density
- High particle momentum
  - Momentum/Energy determination
  - Particle identification
- Background
- Limitations in instrumentation: Beam pipe+magnets

BRAHMS



Braod RAnge Hadron Magnetic Spectrometers

- Designed to study nuclear reactions in broad kinematic range (y-p_T)
- 2 movable spectrometers with small solid angle measuring charged identified hardrons precisely
- Centrality detectors (Si+Scintillator Tiles) to characterize events
- 53 people from 12 institutions from 5 countries

BRAHMS

Highlights of BRAHMS Measurements in Au+Au Collisions

- Bulk properties

  Particle production: $dN/d\eta$, $dN/dy(\pi,K,p)$
- Thermodynamic/Hydrodynamic properties

  Chemical: particle ratios, strangeness production

  Thermal: identified particle spectra in a wide range of p_T

  T ,$\langle P_T \rangle$ vs Y
- Baryon transport

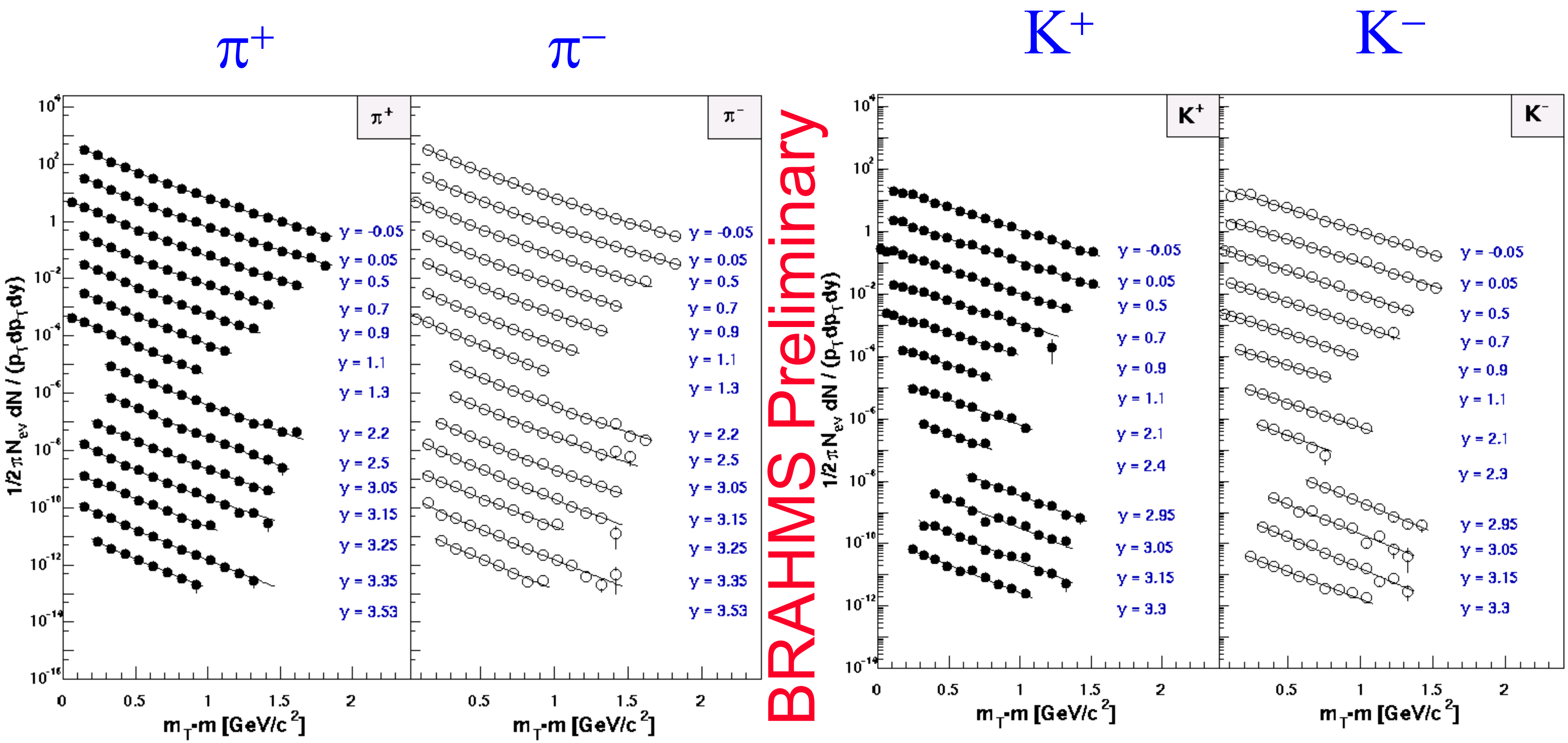
  Net-proton distributions in $0<Y<\sim 3$
- High-p_T probe

  p_T-dependent particle production (High-p_T suppression) at $y\sim 0$, $y\sim 2$

All as a function of rapidity

BRAHMS

Pion and Kaon spectra in y = 0 – 3.5 for 0-5% central Au+Au

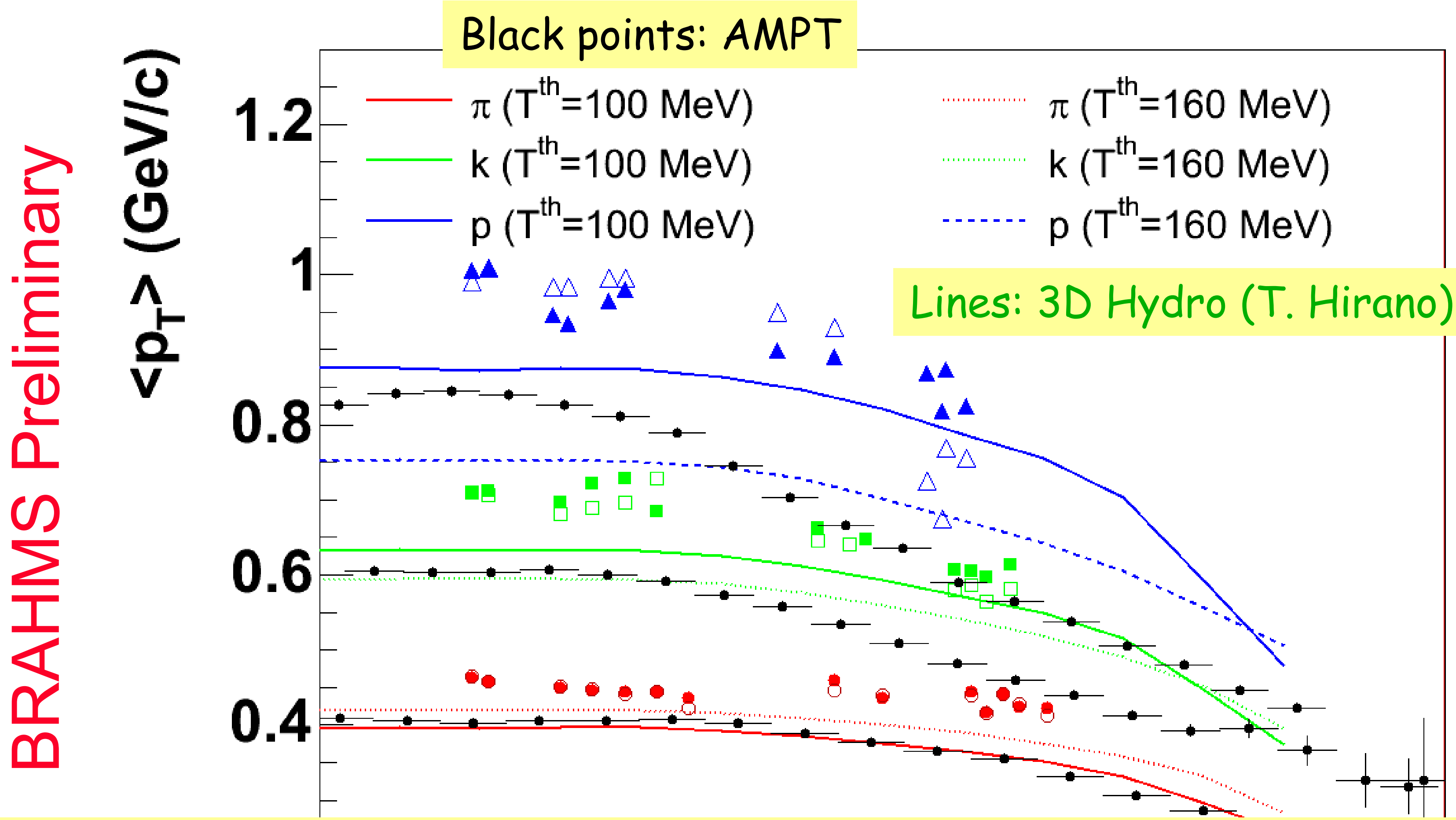


Pion: Power law fit

Kaon: m_T single exponential fit

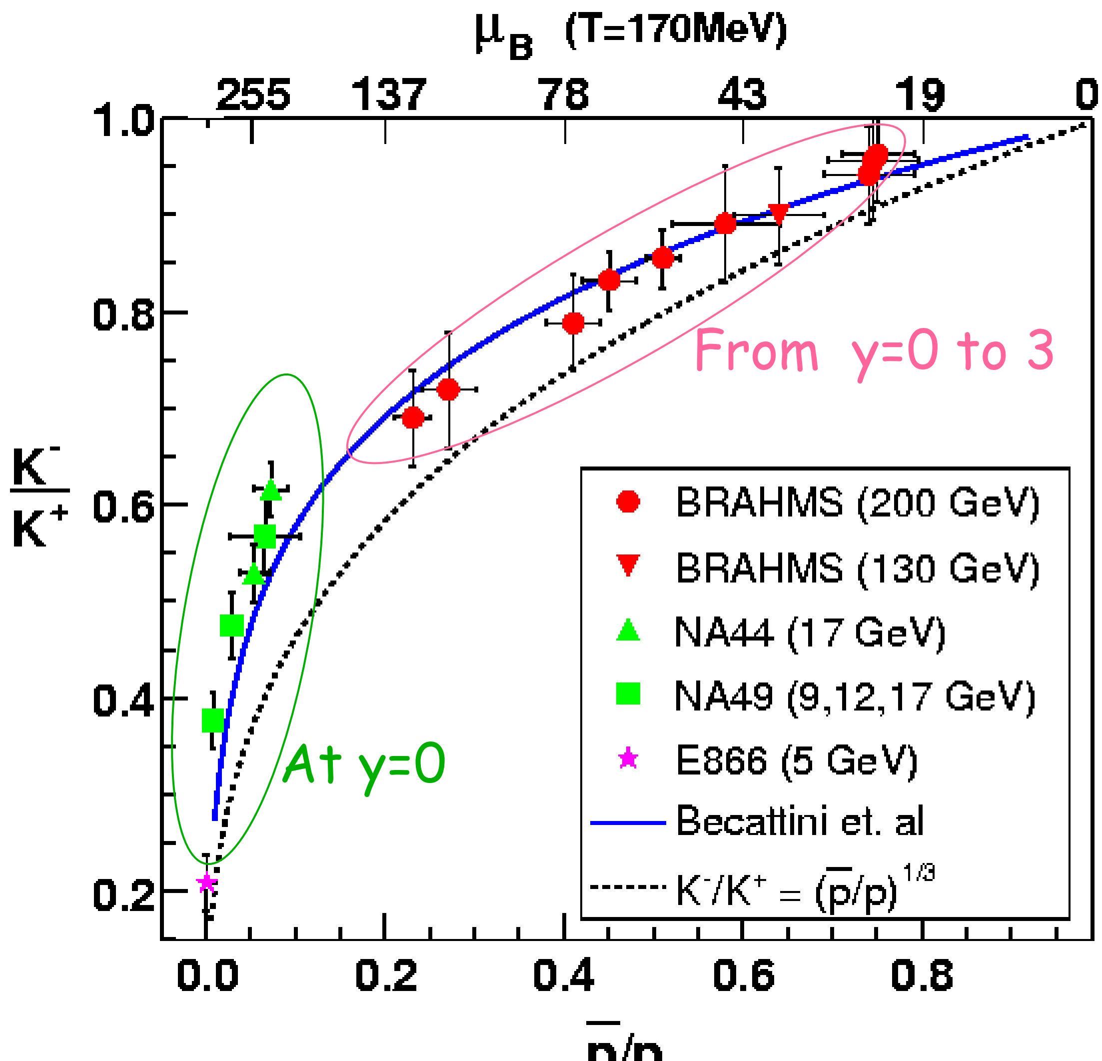
D. Ouerdane (NBI) Thesis

<p_T> vs rapidity



- AMPT (HIJING + Re-scattering) shows stronger y dependence then data
- 3D-Hydro describe y-dependence of data with a single T_{th} value at~< 100 MeV (initial condition is tuned for dN/dη and T_{ch} = 170 MeV)
- Strong Radial Flow in 0< y<~3 (Blast-Wave Fit gives T~120 MeV β~0.6 at y=0)

"Universal" Correlation in K^-/K^+ vs pbar/p?

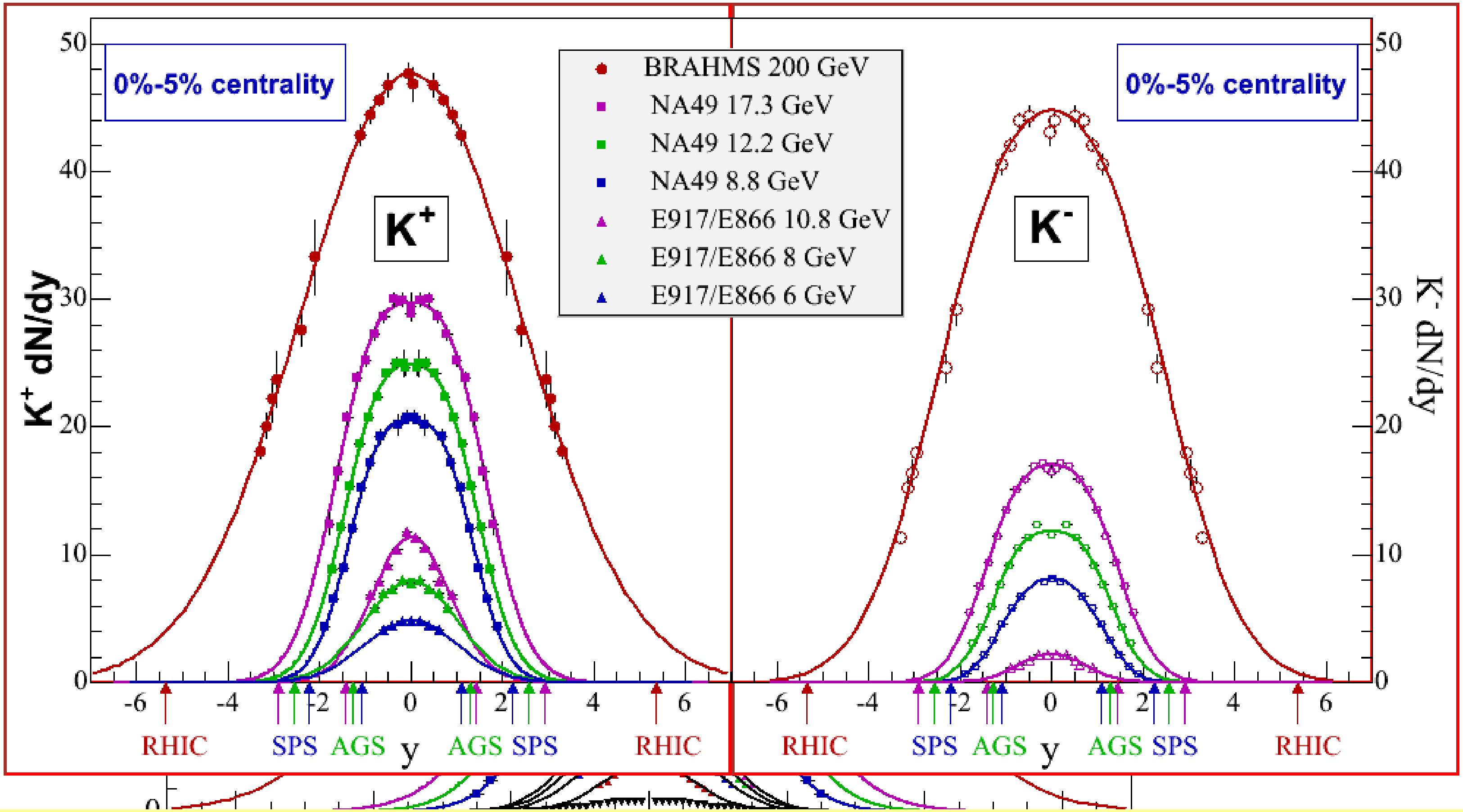


- By simple quark counting in quark recombination K^-/K^+ $= \exp(2\mu_s/T)\exp(-2\mu_q/T)$ $= \exp(2\mu_s/T)(\text{pbar}/p)^{1/3}$ $= (\text{pbar}/p)^{1/3}$ by assuming local (in y) strangeness conservation
- $K^-/K^+ = (\text{pbar}/p)^{\alpha}$
  $\alpha = 0.24 \pm 0.02$ for BRAHMS
  $\alpha = 0.20 \pm 0.01$ for SPS
- Good agreement with the statistical-thermal model prediction by Beccatini et al. (PRC64 2001): Based on SPS results and assuming T_{ch}=170 MeV

PRL 90 102301 Mar. 2003

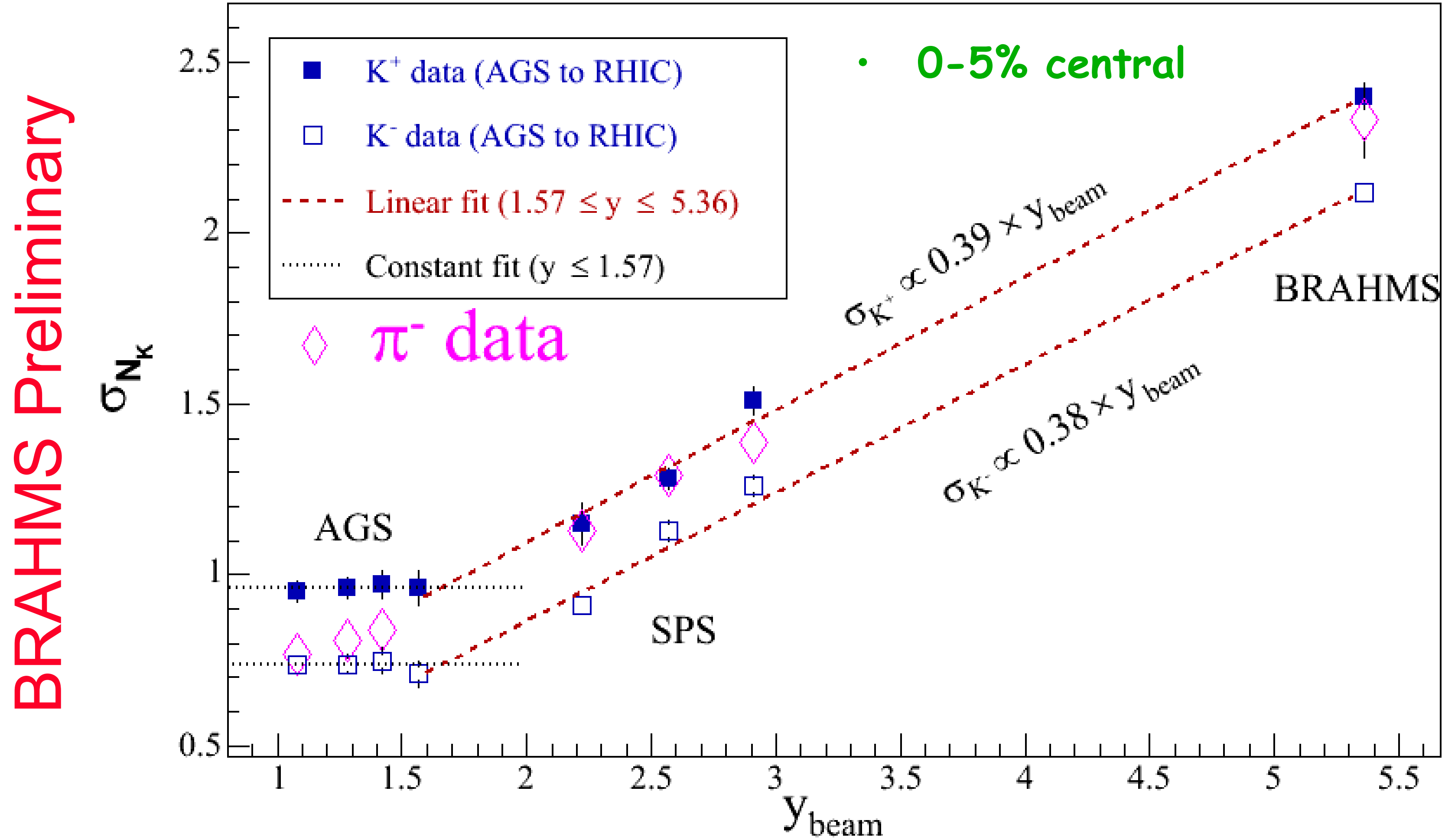
S. V. Afanasiev *et al.*, NA49 Collaboration, nucl-ex/0205002, nucl-ex/0208014; M. Van Leeuwen, Proc. Quark Matter 2002. P. Seyboth, private comm.
I. G. Bearden *et al.*, NA44 Collaboration, Phys. Rev. C66, 044907 (2002).

Energy dependence of dN/dy: π and K



- No clear "plateau" observed for π and K
- Rapidity dendities : Close to a Gaussian shape ($\sigma(\pi^+) \sim \sigma(K^+) \sim 2.4$)
- Yield is extrapolated from a double Gaussian (better description of data)
- SPS->RHIC: dN/dy for π^+ gets narrower, K^+ similar or wider

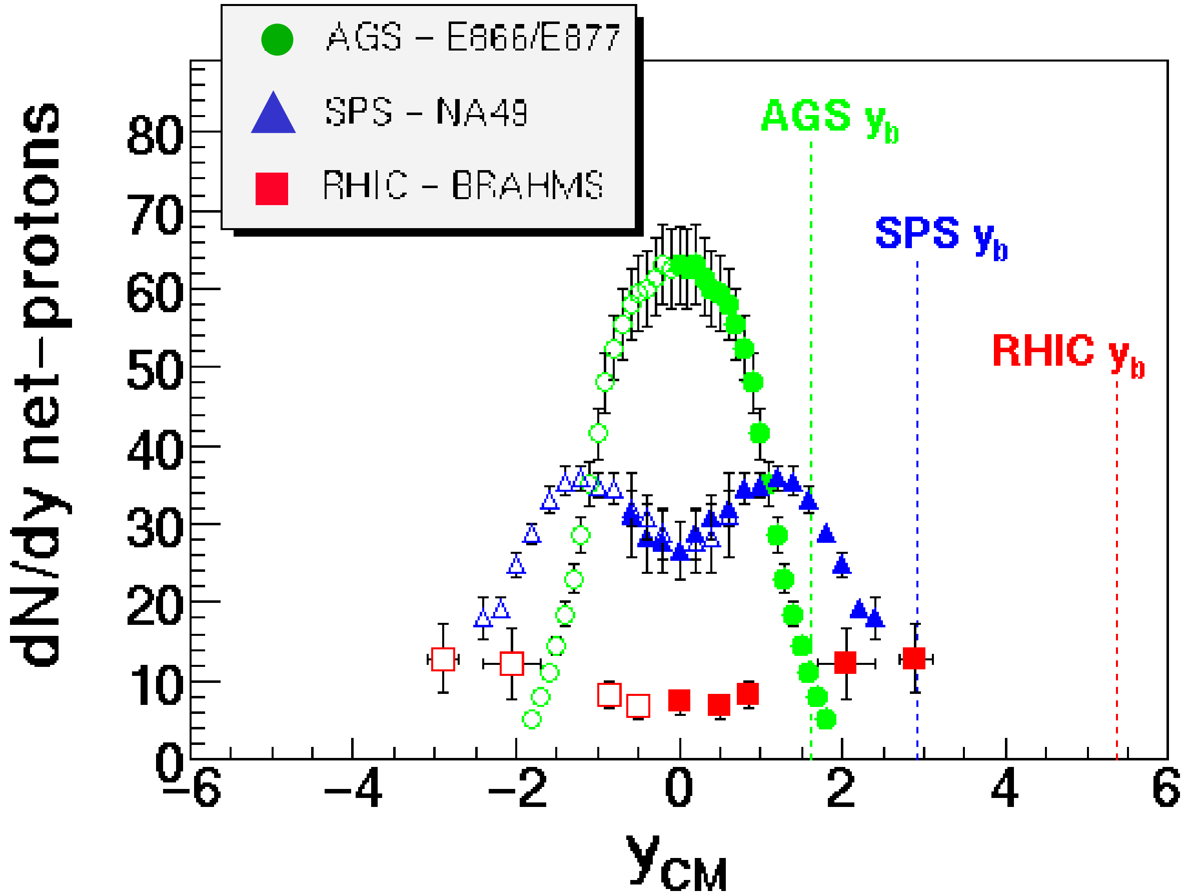
Energy dependence of Rapidity distributions



AGS->RHIC: σ(K) and σ(π) scale approximately linearly with ybeam

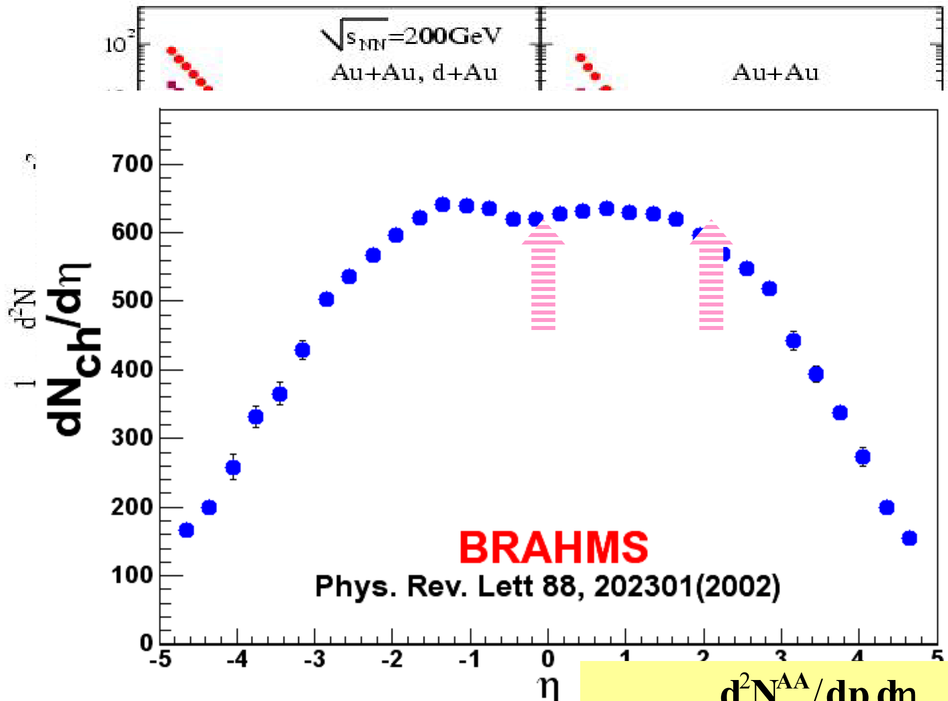
BRAHMS

Energy dependent Net-proton

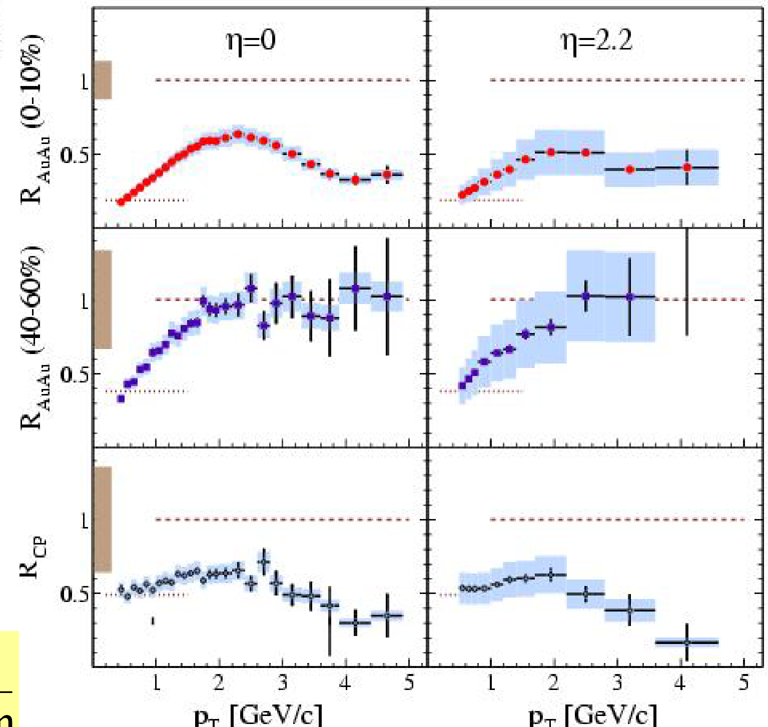


- AGS->RHIC : Stopping -> Transparency
- Net proton peak > y ~ 2

Rapidity Dependent high-p_T Suppression



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



- The Au-Au data from RUN2 show similar suppression effects at η~0 and η~ 2.2 (different at High p_T? Need more data.)
- Medium Density scales to Multiplicity?
- Need to measure at higher rapidities with identified particles

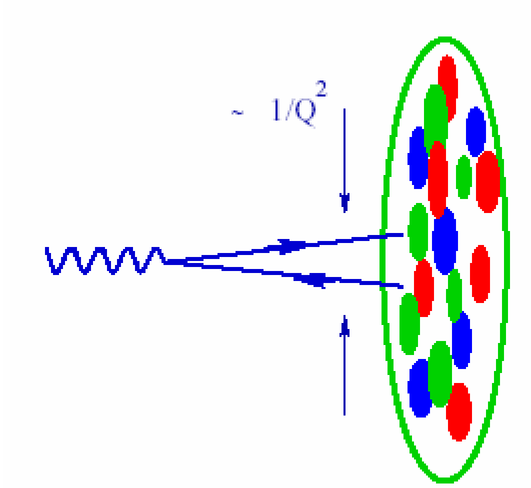
Summary of 200 GeV results I

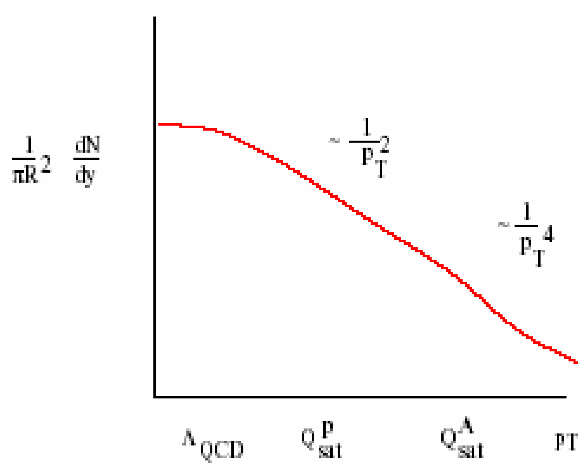
- Bulk properties and Baryon transport
  - Rapidity distributions for π, K are near Gaussian with σ ~ 2.4 linearly scales with y_{beam}
  - near flat net-proton yield in y < ~ +-1 (dN/dy(net-baryon) ~16 at y=0) Increasing transparency with energy
- Thermodynamic properties
  - Statistical model describe system with a chemical freeze-out for rapidity 0-3.5 with T = 170 MeV
  - System freeze-out thermally with T ~ 100-130 MeV with strong radial flow (β ~ 0.6)
  - Thermal and Chemical properties are similar in y = 0-3.5 for the particles produces with a narrow Gaussian distribution: Is something missing in the interpretation?

Summary of 200 GeV results II

- Hard Probe
  - High-p_T suppression at η=0, 2.2 due to medium effect
  - $R_{(\eta=0)}/R_{(\eta=2.2)} \sim [dN/d\eta_{(\eta=0)}]/[dN/d\eta_{(\eta=2.2)}] \sim 1$
  - R for Identidied Particles in AuAu, dAu: Limited statistics/Analysis in progress
- Rapidity dependent measurements and Theoretical Models
  - Different parameters measured have different "plateau" region
  - No models can describe all observables well
  - **Constraint for theoretical ingredients for models**
- More New Physics Opportunities in Forward?

Forward Physics II: Proving QCD at small-x





The p_T distribution for particles produced in a pA collision.

- Proving initial state gluon saturation/coherence at small-x (CGC)
- $Q_s^2(s;\pm y) = Q_s^2(s;y=0)\ \exp(\pm\lambda y).$
- Saturation Scale Q_{sat} can be more easily reached at high-y
- BRAHMS took data in d-Au (RUN2)
  - At y=3 pt ~ 3-4 GeV/c (x~ 10^{-3})
  - Current Data set being analyzed might not have sufficient kinematic coverage to address CGC based on the latest predictions
- Need more data depending on the results of the analysis and theoretical development

BRAHMS

Forward Measurements in the Future I

Measurements Planned in Run4

- More high-p_T measurement at different (higher) rapidities

  at $y \sim 3$ up to $p_T \sim 4$ GeV/*c* for **identified** particles

- More detailed measurements of hydrodynamic properties: Elliptic Flow (reaction plane-p_T-centrality-**rapidity**-particle)

  with a limited p_T coverage. (need more run time for high-p_T v2

- Correlation measurements at Forward: HBT, Coalescence

  With a limited acceptance (only R_T at Forward) and p_T ranges

Forward Measurements (considered) in the Future II

- Physics interests in beyond the current BRAHMS forward limit ?
  - Lowing saturation scale in CGC with y [d(p)-Au]
  - Limiting Fragmentation of identified particles
  - More high rapidity baryons: More complete understanding of Baryon Transport
- Missing pieces of net-baryon measurements
  - n, lambda,
- More direct Hard probe (Wang: nucl-th/037036)
  - Centrality Dependent Forward jets (leading particle identification by tracking and/or RICH + Calorimeter)
- … Di-lepton at Forward?

Needed for the Future Measurements in Forward

- Larger Acceptance
  - Statistics: High-p_T particles, Flow measurements,...
  - Two-particle acceptance: HBT, Resonances
- Additional Detectors
  - Reaction plane (existing Si +)
  - Jets (Calorimeter)
  - More Forward (new magnet, Si tracking...)
- More theoretical inputs for forward regime

BRAHMS

The BRAHMS Collaboration

I.Arsene[10], I.G. Bearden[7], D. Beavis[1], C. Besliu[10], B. Budick[6],H. Bøggild[7],
C. Chasman[1], C. H. Christensen[7], P. Christiansen[7],J.Cibor[4], R.Debbe[1],E.Enger,
J. J. Gaardhøje[7],M. Germinario[7] , K. Hagel[8], O. Hansen[7], H. Ito[1], A. Jipa[10], J. I. Jordre[10], F. Jundt[2],
C.E.Jørgensen[7], E. J. Kim[11], R.Karabowisz[3], T. Kozik[3], T.M.Larsen[12], J. H. Lee[1], Y. K.Lee[5],
S. Lindal, G. Lystad, G. Løvhøjden[2], Z. Majka[3], A. Makeev[8], M. Mikelsen, M. Murray[11], J. Natowitz[8],
B. Neuman[11],B.S.Nielsen[7], D. Ouerdane[7], R.Planeta[3], F. Rami[2], C.Ristea[10], O.Ristea[10],
D. Roehrich[9], B. H. Samset[12], D.Sandberg, S. J. Sanders[11],, R.A.Sheetz[1],
P. Staszel[3], T.S. Tveter[12], F.Videbæk[1], R. Wada[8], Z. Yin[9] and I. S. Zgura[10]

[1]Brookhaven National Laboratory, USA, [2]IReS and Université Louis Pasteur, Strasbourg, France
[3]Jagiellonian University, Cracow, Poland, [4]Institute of Nuclear Physics, Cracow, Poland
[5]Johns Hopkins University, Baltimore, USA, [6]New York University, USA
[7]Niels Bohr Institute, Blegdamsvej 17, University of Copenhagen, Denmark
[8]Texas A&M University, College Station. USA, [9]University of Bergen, Norway
[10]University of Bucharest, Romania, [11]University of Kansas, Lawrence,USA
[12] University of Oslo, Norway

- 53 people from 12 institutions, 5 Countries