Baryon Stopping and Associated Production of Mesons in Au+Au Collisions at $\sqrt{s_{NN}} = 3.0$ GeV at STAR

10th workshop of the APS Topical Group on Hadron Physics

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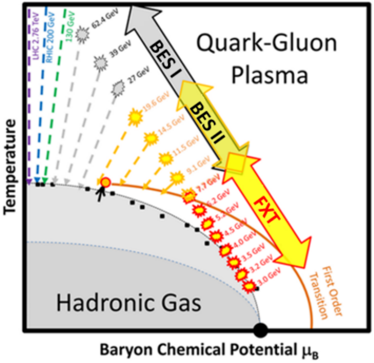
Outline

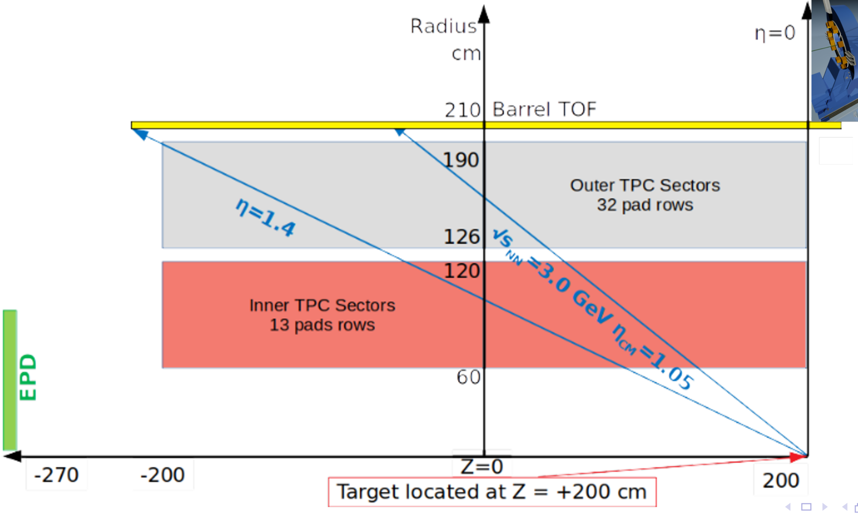
Motivation

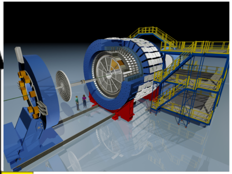
- Models indicate maximum baryon density $\sim \sqrt{s_{NN}} = 7.7$ GeV[1], suggesting changing dynamics of system
- $\pi^{\pm}$, $K^{\pm}$, and p dN/dy in central collisions have been measured at the AGS[2,3,4], SPS[5,6], and SIS[7]
- High statistics data sets collected by STAR extend these measurements to investigate centrality dependence
  - Observed Coulomb potential as a function of centrality is non-spherical
  - Baryon stopping measurements across centrality indicate constant rapidity loss



[1] J. Randrup and J. Cleymans, Phys. Rev.C **74**, 047901 (2006)
[2] J. L. Klay *et al.* (E895 Collaboration), Phys. Rev. C **68**, 054905 (2003)
[3] J. L. Klay *et al.* (E895 Collaboration), Phys. Rev. Lett. **88**, 102301 (2002)
[4] L. Ahle *et al.* (E866 and E917 Collaborations), Phys. Lett. **B490**, 53 (2000)
[5] C. Alt *et al.* (NA49 Collaboration), Phys. Rev. C **77**, 024903 (2008)
[6] S. Afanasiev *et al.* (NA49 Collaboration), Phys. Rev. C **66**, 054902 (2002)
[7] A. Forster et al. (KaoS Collaboration), J. Phys. G **28**, 2011 (2002)

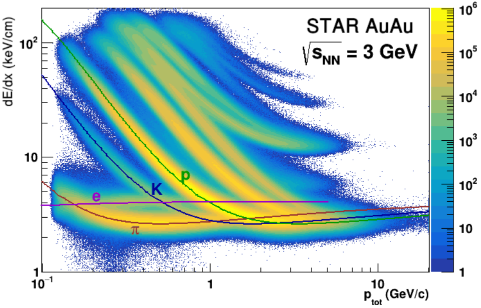
STAR Fixed-Target Acceptance



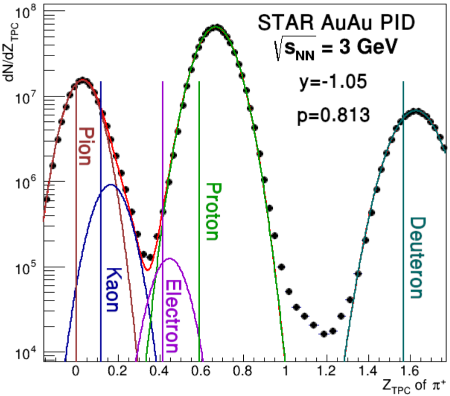


Outline

Particle Identification

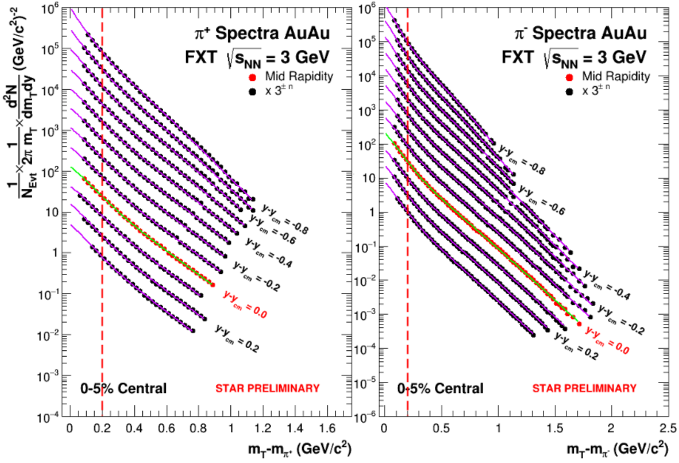


$$Z_{TPC} = ln(\frac{dE/dx_{measured}}{dE/dx_{predicted}})$$



- Slices of dE/dx and m^2 are made in rapidity, $m_T - m_0$, and centrality bins
- Each slice is fit with one or more Gaussians to determine yield of particle of interest, accounting for contamination from other particle species

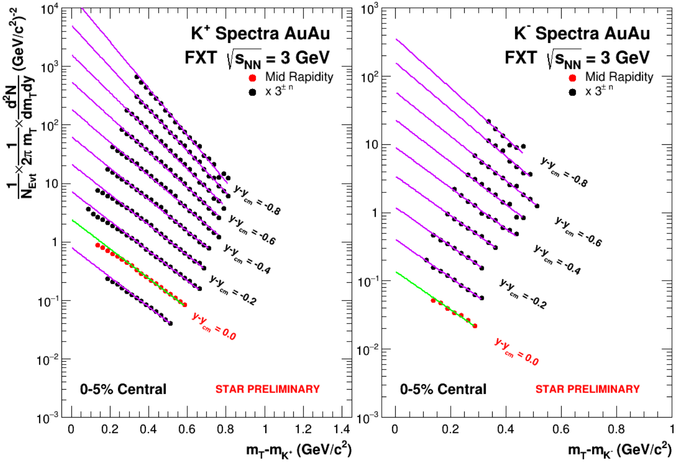
Charged Pion Spectra



- Pion yields extracted from fitting dE/dx from TPC and $1/\beta$ from barrel ToF
- Pion spectrum described well by double thermal function[1], which describes thermal production at high $m_T - m_0$ and production from Δ resonance at low $m_T - m_0$
  - Dashed red line shows where leading production mechanism changes

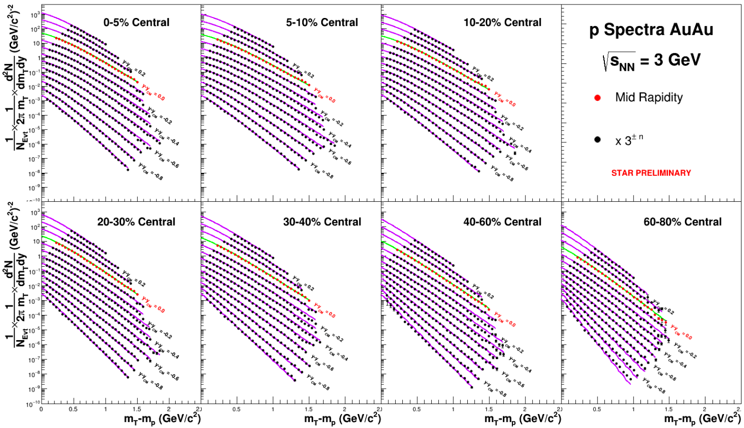
[1] J. Klay et al. (E895 Collaboration), Phys. Rev. C 68, 054905 (2003)

Charged Kaon Spectra



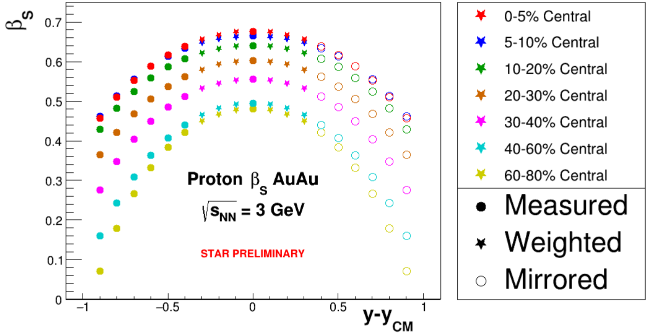
- Kaon yields extracted from fitting dE/dx from TPC and $1/\beta$ from barrel ToF
- ToF identification required at all p, which limits low $m_T - m_0$ reach
- Kaon spectrum fit with m_T exponential function since Bose-Einstein enhancement and radial flow effects mostly cancel

Proton Spectra



- Proton spectra extracted from fitting dE/dx from TPC and m^2 from barrel ToF
- Proton spectra near midrapidity described well using blast-wave function assuming cylindrical expansion of fireball

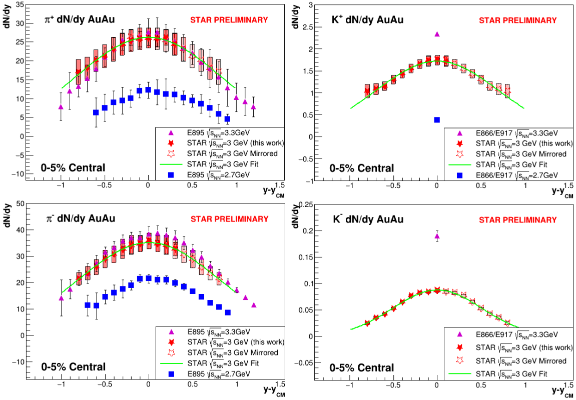
Radial Flow



Surface velocity with linear profile ($n = 1$) from Blast-wave fit with constant temperature for each centrality and assuming Bjorken model

- System is not boost-invariant as there is no plateau around midrapidity and Blast-Wave only used for extrapolation to low $m_T - m_0$
- Non-boost invariant model will be implemented in the future to extract freeze-out parameters

Charged Meson Rapidity Density Distributions



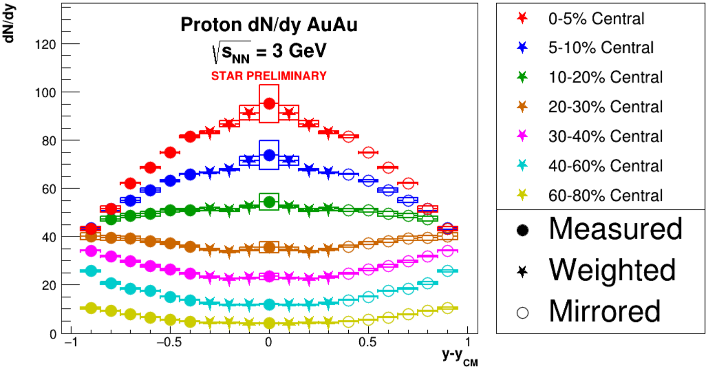
- Yields obtained from spectrum and integration of fits to extrapolate to $m_T - m_0 = 0$
- Kaon yields follow the energy dependence when compared to E866/E917[2], while pion yields are surprisingly close to E895[1] measurements at 3.3 GeV

[1] J. Klay et al. (E895 Collaboration), Phys. Rev. C 68, 054905 (2003)

[2] L. Ahle et al. (E866 and E917 Collaborations), Phys. Lett. B490, 53 (2000)

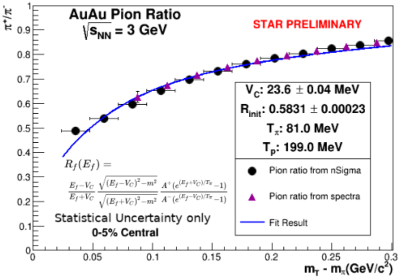
Proton Rapidity Density Distributions

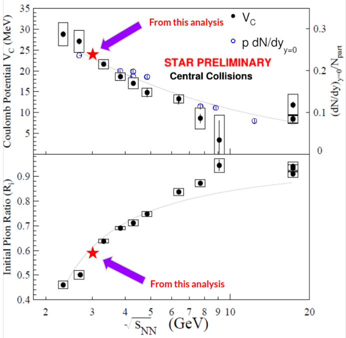
- Yields obtained from spectrum and integration of fits to extrapolate to $m_T - m_0 = 0$
- Centrality dependence shows participant proton peak shifting away from midrapidity for more peripheral collisions, indicating less baryon stopping



Outline

Coulomb Potential in Central Collisions





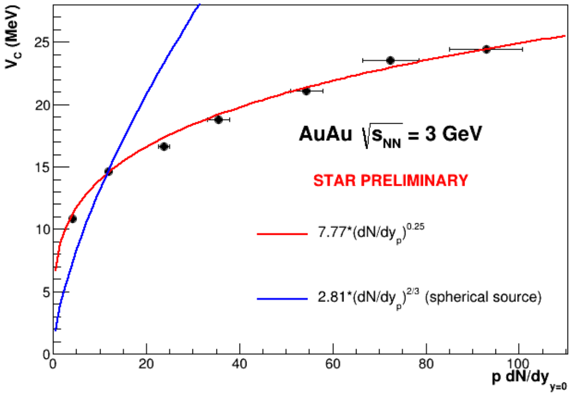
- Pions are susceptible to the Coulomb potential of stopped baryons due to their small mass[1,2]
- Model includes Bose-Einstein nature of pions and an effective potential to account for momentum distribution of stopped protons

[1] D. Cebra *et al.* [arXiv:1408.1369 [nucl-ex]]

[2] J. Adamczewski-Musch *et al.* (HADES Collaboration), [arXiv:2202.12750 [nucl-ex]]

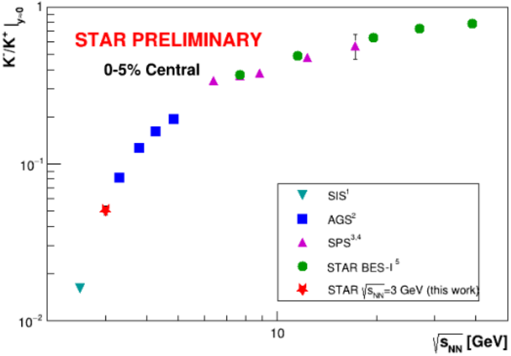
Coulomb Potential Correlation with Proton Yield

- Across centrality, the extracted Coulomb potential tracks monotonically with proton dN/dy
- Indication of less charge deposited in interaction region for peripheral collisions, matching expectations about geometry and baryon stopping
- Power law fit indicates that protons are not acting as a spherical source[1]



[1] J. Adamczewski-Musch *et al.* (HADES Collaboration), [arXiv:2202.12750 [nucl-ex]]

Kaon Production in Central Collisions

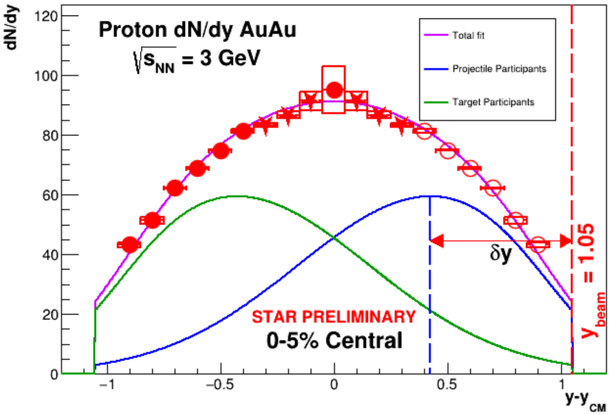


- Results at $\sqrt{s_{NN}} = 3.0$ GeV follow trend seen in SIS, AGS, SPS, and STAR BES-I data
- K^-/K^+ ratio at midrapidity is affected by baryon stopping
  - Production of K^+ in association with Λ baryon
  - Changes in μ_B and μ_S could suppress K^-/K^+ ratio at low collision energy

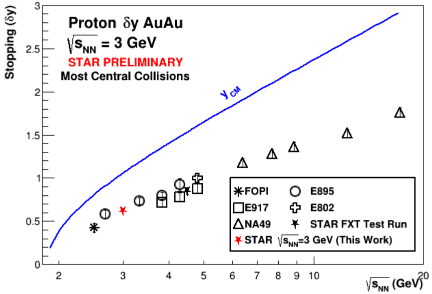
[1] A. Forster *et al.* (KaoS Collaboration), J. Phys. G **28**, 2011 (2002)
[2] L. Ahle *et al.* (E866 and E917 Collaborations), Phys. Lett. **B490**, 53 (2000)
[3] C. Alt *et al.* (NA49 Collaboration), Phys. Rev. C **77**, 024903 (2008)
[4] S. Afanasiev *et al.* (NA49 Collaboration), Phys. Rev. C **66**, 054902 (2002)
[5] L. Adamczyk *et al.* (STAR Collaboration), Phys. Rev. C **96**, 044904 (2017)

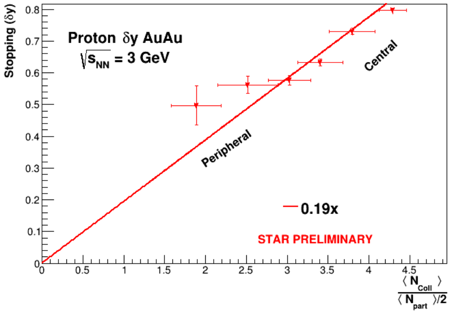
Baryon Stopping

- Proton rapidity density is fit with shape determined by counting the number of collisions each participating nucleon takes part in a Monte-Carlo Glauber model, smoothed using a Gaussian kernel
- The stopping, δy, is defined as the shift of the participant proton peak from beam rapidity



Baryon Stopping Trends





- Stopping at $\sqrt{s_{NN}} = 3.0$ GeV is consistent with measurements at similar energies
- Average loss of 0.19 ± 0.01 units of rapidity per nucleon-nucleon collision[6]

[1] W. Reisdorf *et al.* (FOPI Collaboration), Nucl. Phys. A **848**, 366 (2010)
[2] J. Klay *et al.* (E895 Collaboration), Phys. Rev. Lett. **88**, 102301 (2002)
[3] B. Back *et al.* (E917 Collaboration), Phys. Rev. Lett. **86**, 1970 (2001)
[4] L. Ahle *et al.* (E802 Collaboration), Phys. Rev. C **60** , 064901 (1999)
[5] C. Blume. (NA49 Collaboration) J. Phys. G **34**, S951 (2007)
[6] F.Videbæk and O. Hansen, Phys. Rev. C **52**, 2684 (1995)

Outline

Conclusions

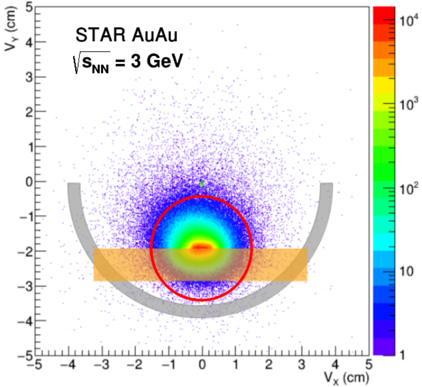
- Rapidity density distributions have been presented at $\sqrt{s_{NN}} = 3.0$ GeV for $\pi^{\pm}$, $K^{\pm}$, and p
- The Coulomb potential from stopped protons has a noticeable effect on the charged pion spectra that correlates with the proton yields and indicates a non-spherical source
- K^{-}/K^{+} ratio at midrapidity is affected by baryon stopping
- Baryon stopping can be modeled as an average rapidity loss of 0.19 ± 0.01 for each binary collision by observing trends in centrality
- Future studies of other STAR Fixed-Target data will identify energy trends in these observables, which will provide a more complete picture of the transition from a baryonic to a mesonic regime

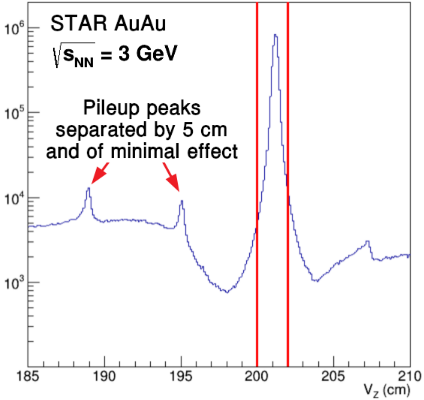
Backup

The STAR Fixed-Target

- Target located at $z = 200$ cm
- Target is 0.25 mm thick - 1% interaction probability
- Target is held 2 cm below center of beam axis
- Collider filled with 12 bunches

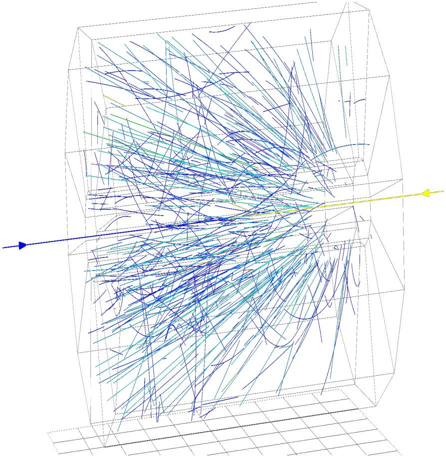
$\sqrt{s_{NN}} = 3.0$ GeV Vertex Position





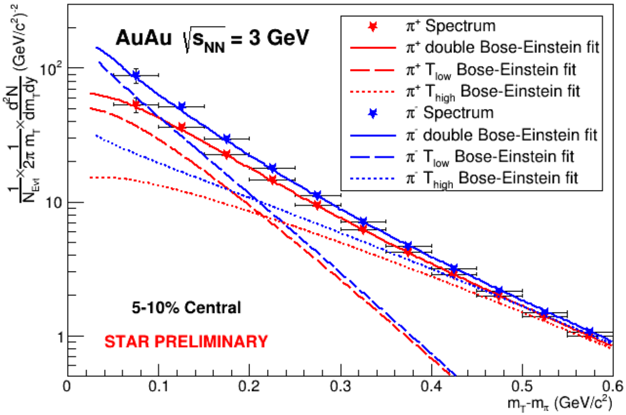
Vertex centered well on target position and out-of-time pileup peaks (offset by 5 cm) easy to separate

Event and Track Selection Cuts



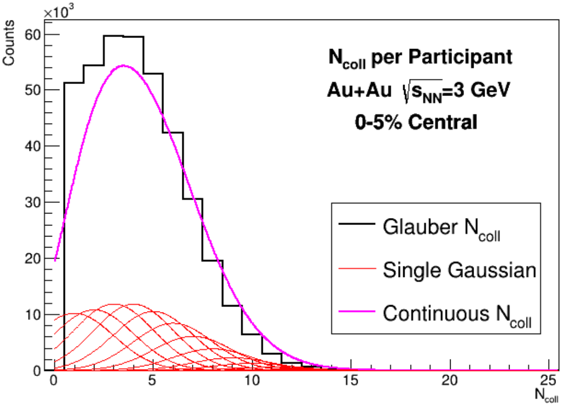
- Event selection
  - Select on minimum-bias events (using mixture of EPD, BBC, and VPD triggers)
  - $198 < V_z < 202$ cm
- Track selection
  - Track projects back to the primary vertex (at target location)
  - Distance of Closest Approach (DCA) ≤ 3

Coulomb-Corrected Double Bose-Einstein



- Coulomb correction applied to Bose-Einstein distribution to account for change in energy of pion
- Change in shape of spectra and fits at low $m_T - m_0$ indicate correction is necessary to describe spectra properly

Proton dN/dy Fit Model



- Glauber Model is used to obtain distribution of N_{coll} for each participant
- Gaussian Kernel Estimator implemented to smooth out discrete distribution and obtain shape of N_{coll}
- Shape is then shifted, stretched horizontally, and scaled vertically to fit proton dN/dy