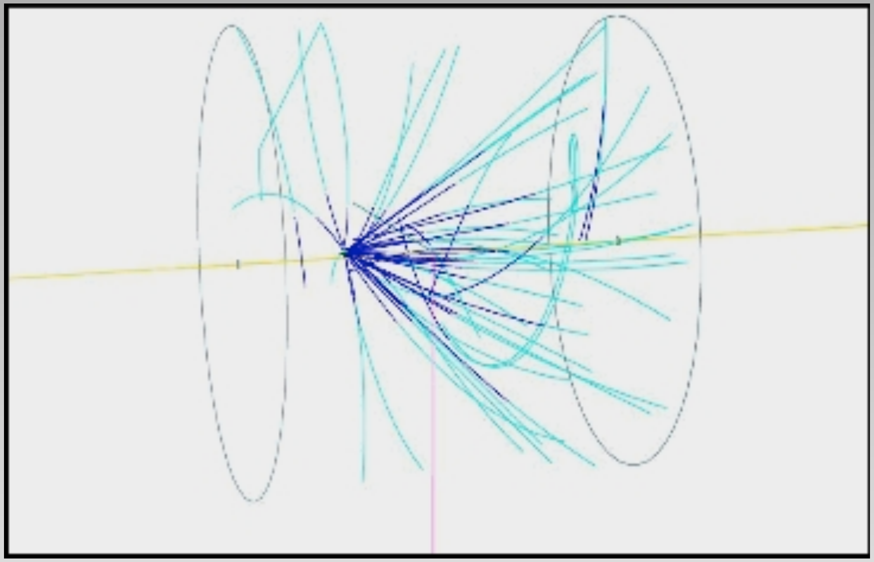
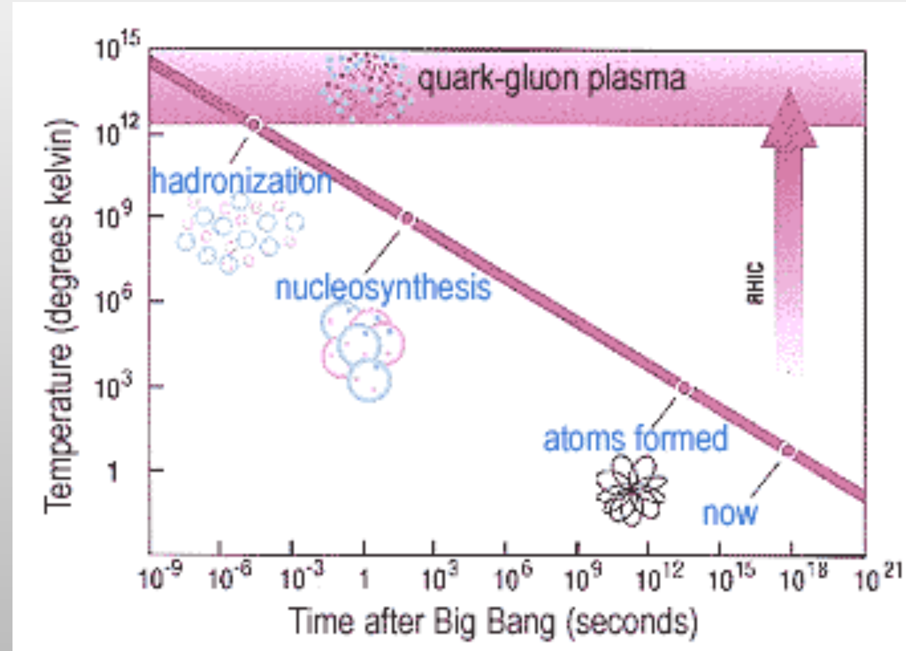
# Analysis of fixed target collisions with the STAR detector



Brooke Haag for the STAR Collaboration
Hartnell College / University of California, Davis
Presented at the Meeting of the California Section of the APS
November 3, 2012

# Creating Mini-Big Bangs in the Lab

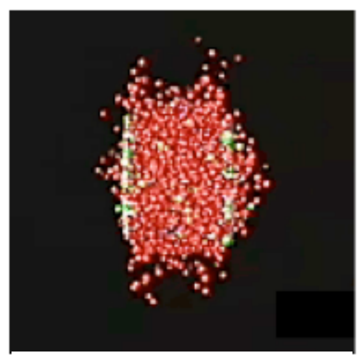
**Goal**: Use relativistic collisions of nuclei to create hot dense matter which reproduces the earliest stages of the universe

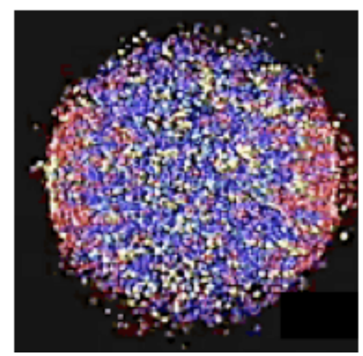




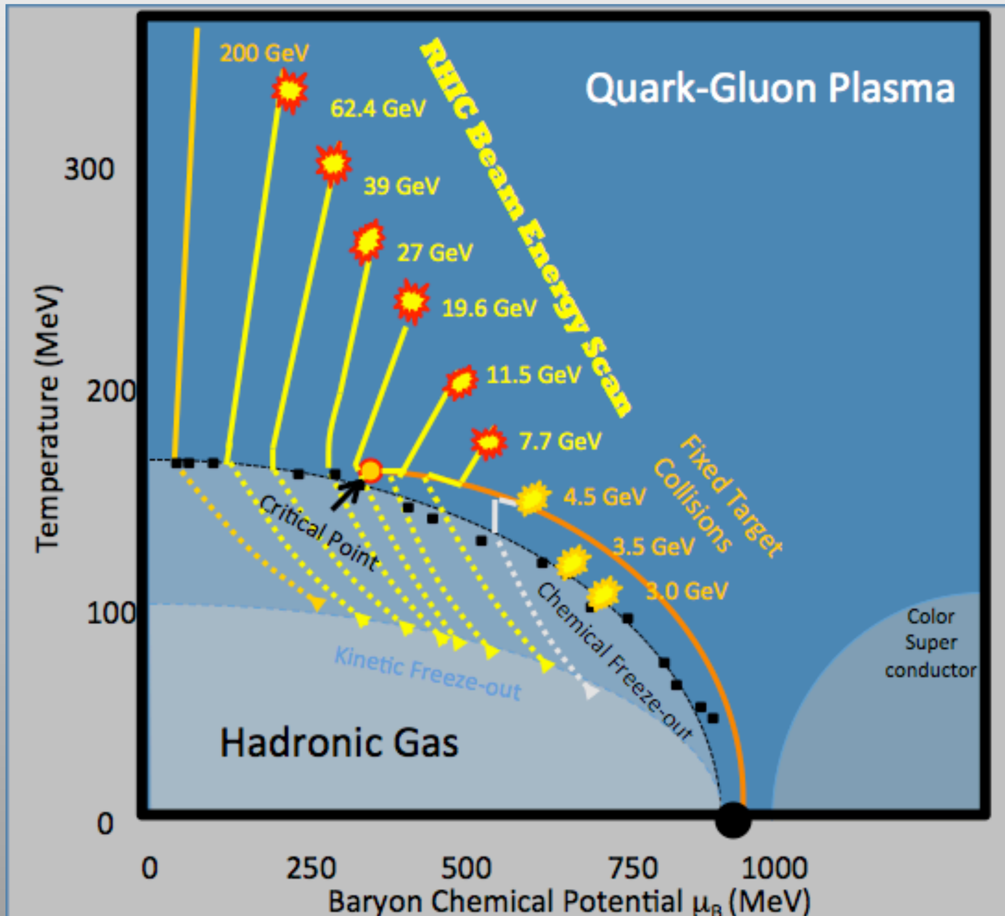
ions about to collide


ion collision


plasma creation

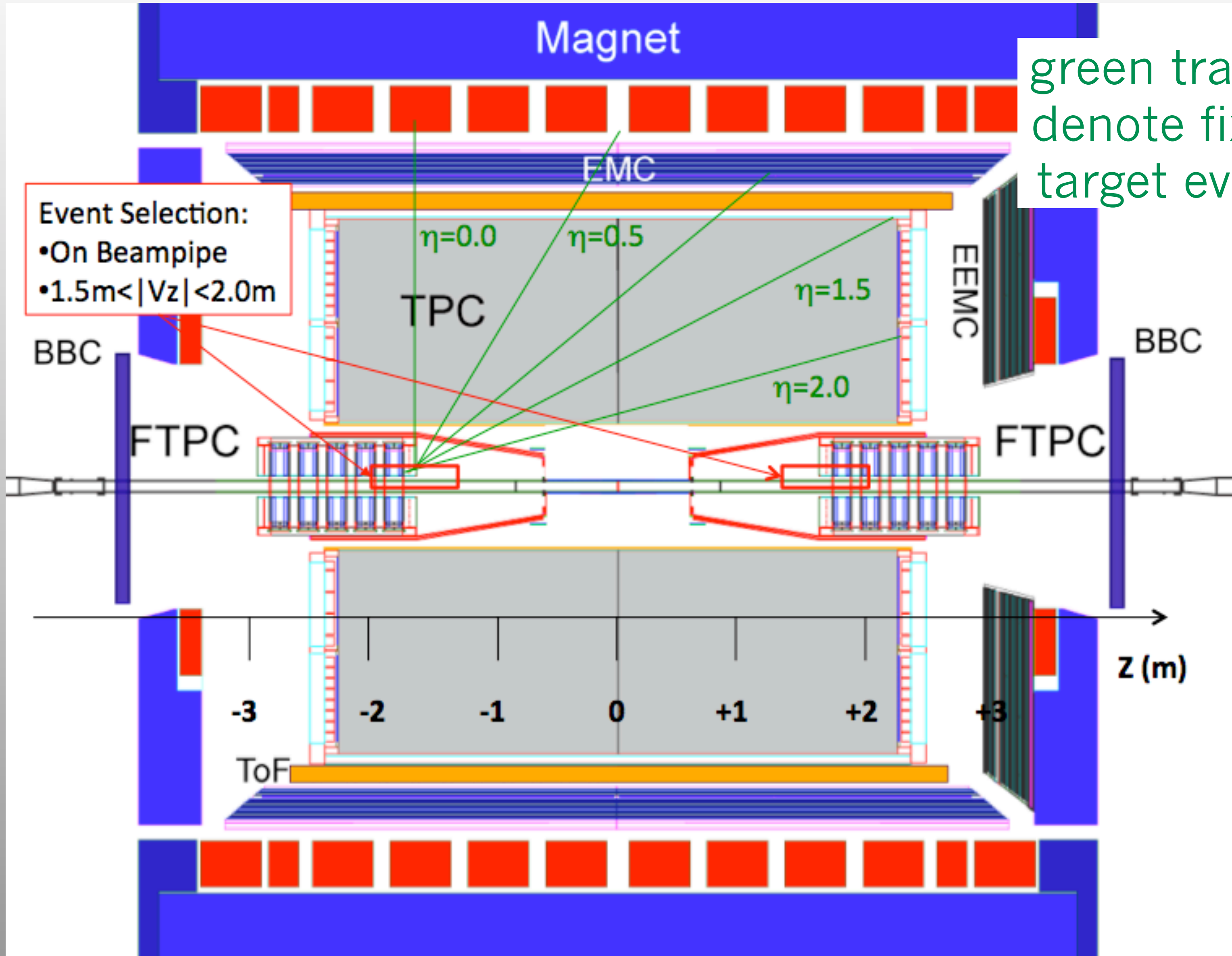

hadron production

# QCD phase diagram




- We have created a new state of matter at $\sqrt{(s_{NN})}$ = 200 GeV consistent with the QGP !
- In 2010 and 2011 an extensive beam energy scan was undertaken at RHIC with a major goal to find the critical point.
- Fixed target collisions will extend the physics analysis to even lower $\sqrt{s}$.

# STAR detector array




green tracks denote fixed target event

# Kinematic Calculations

| Collision Energy (GeV) | Single Beam Energy | Single Beam $P_z$ (GeV/c) | Fixed Target $\sqrt{s}$ | Single Beam Rapidity | Center of Mass Rapidity |
|---|---|---|---|---|---|
| 19.6 Au+Au | 9.8 | 9.76 | 4.47 Au+Al | 3.04 | 1.52 |
| 11.5 Au+Au | 5.75 | 5.67 | 3.53 Au+Al | 2.51 | 1.25 |
| 7.7 Au+Au | 3.85 | 3.74 | 2.99 Au+Al | 2.10 | 1.05 |

$\sqrt{(s_{NN})}$ = center of mass energy

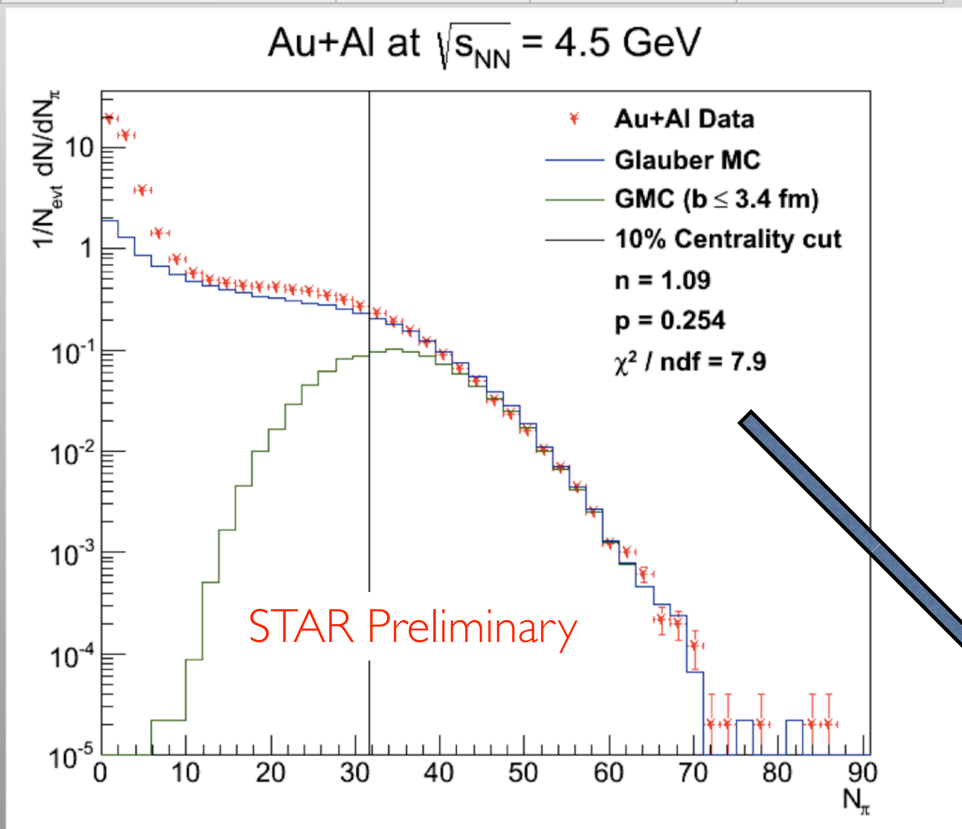
- $\sqrt{(s_{NN})} = \sqrt{(2m^2 + 2Em)}$
  $m = 0.9315$ GeV/$c^2$ ; $E = 9.8$ GeV
- $\sqrt{(s_{NN})} = 4.47$ GeV
- $p_z = \sqrt{(E^2 - m^2)} = 9.76$ GeV/c

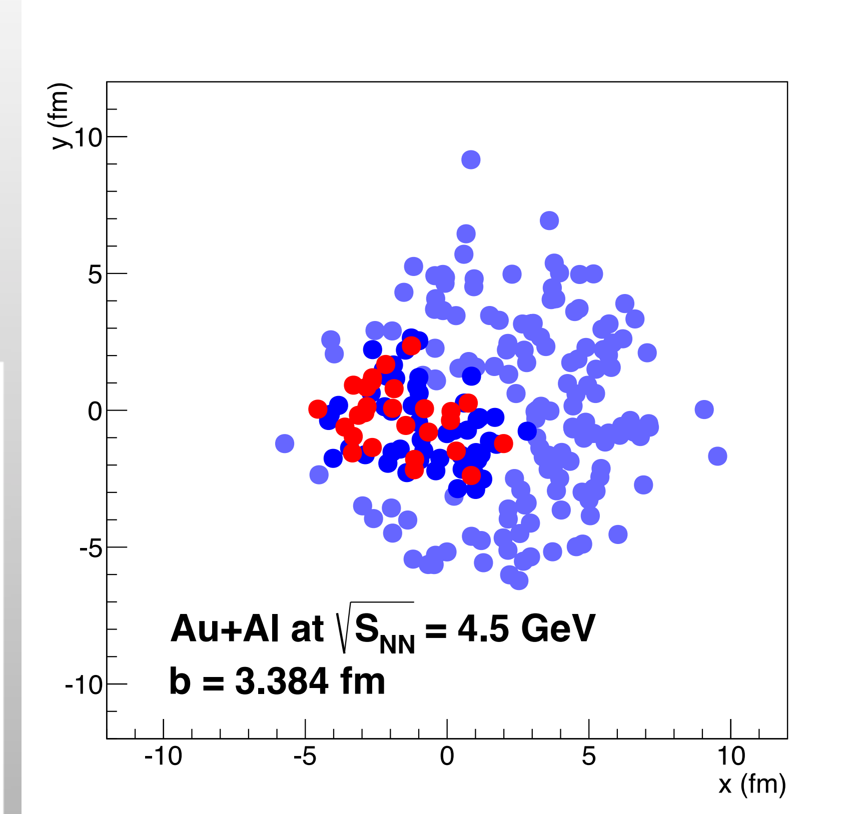
rapidity (y)

- $y_{beam} = 0.5*[\ln(E + p_z)/(E - p_z)]$
- $y_{beam} = 3.0$
- $y_{cm} = 1.5$

# Centrality Determination

| | | | |
|---|---|---|---|
| ***Fixed Target $\sqrt{s}$*** | 2.99 | 3.53 | 4.47 |
| ***Fixed Target $y_{cm}$*** | 1.05 | 1.25 | 1.52 |
| ***Events satisfying fixed target cuts*** | 3.0 M | 4.1 M | 3.1 M |
| ***Au+Al top 10%*** | 78 K | 114 k | 101 k |




- Number of pions is used to determine centrality via Glauber MC predictions

- n, p are parameters of negative binomial fit

# Centrality Determination

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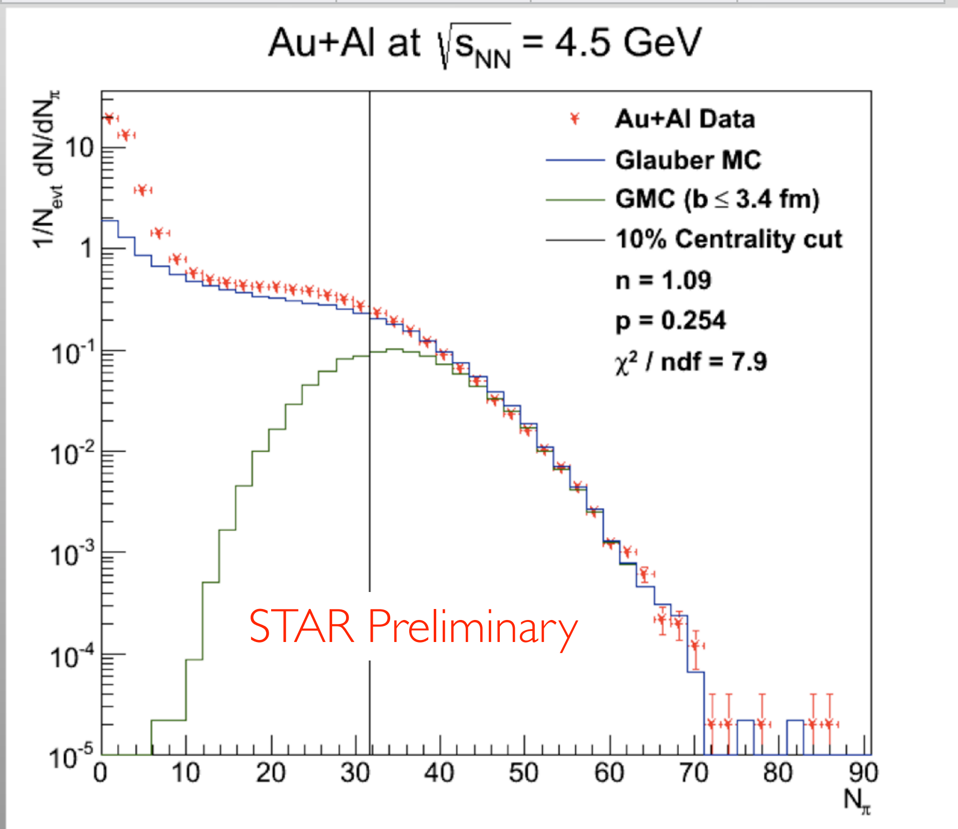
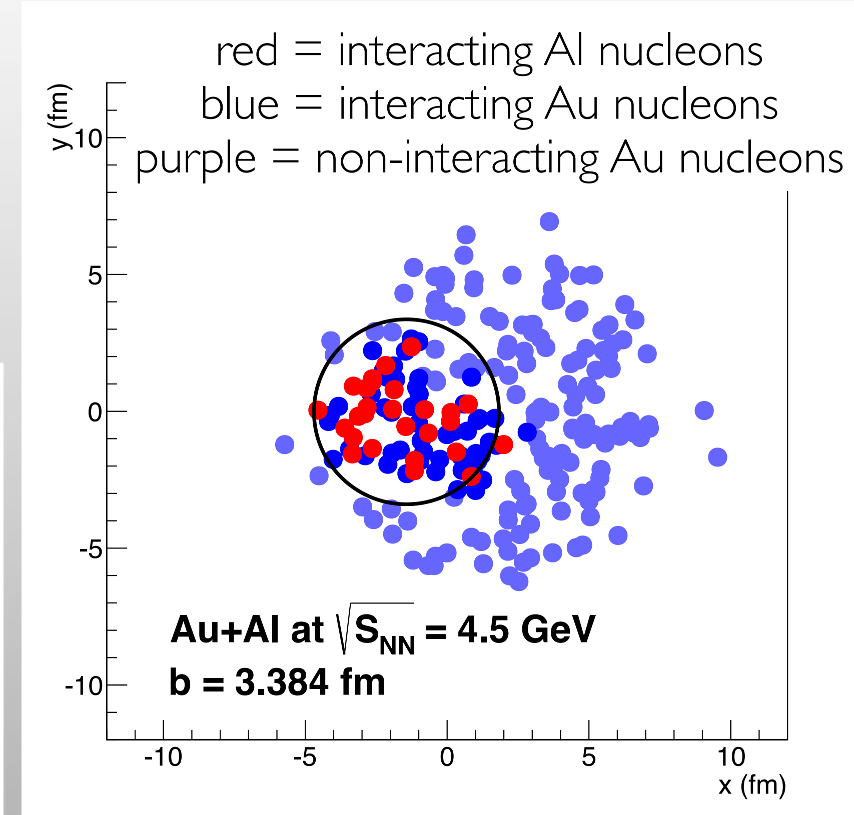


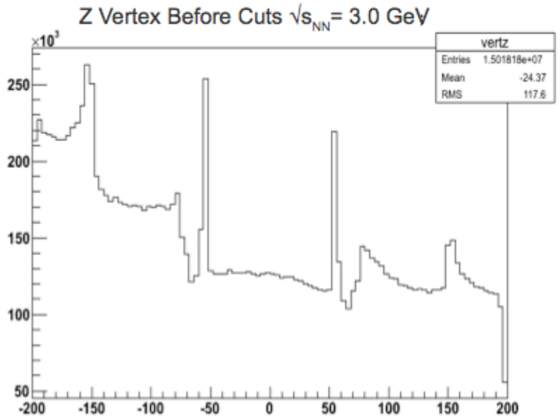



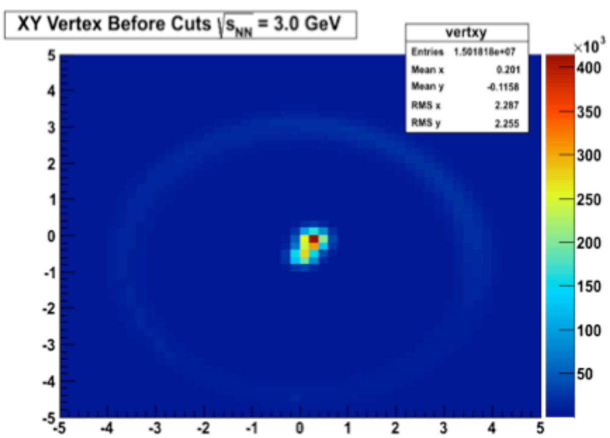

- 37 protons within radius of 3.4 fm → Coulomb potential = 15 MeV

- we will measure Coulomb boost of pions which will allow us to estimate # of interacting protons

# Event Selection

## Before Cuts




## Event Cuts

**- Vertex Requirements -**

200 cm≤ Vz ≤150 cm

$2 \leq V_R \leq 5$ cm

**- Momentum -**

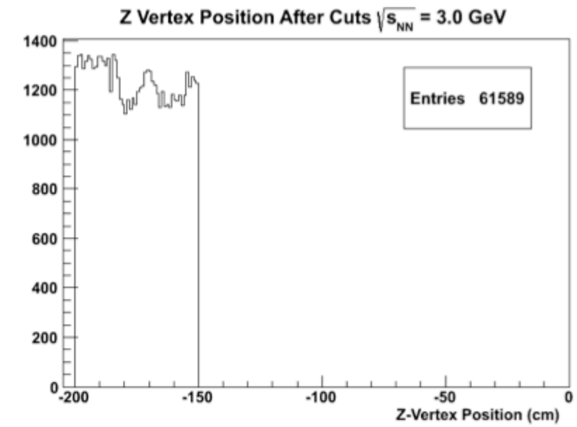
$$\sum_{Tracks} p_z > 0$$

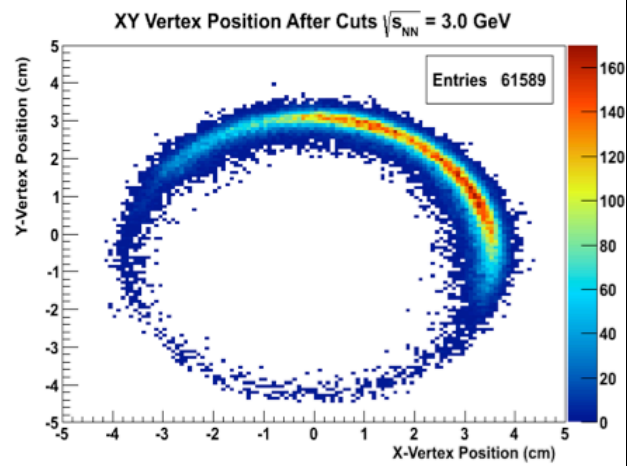
**- Centrality Cut -**

Top 10 %

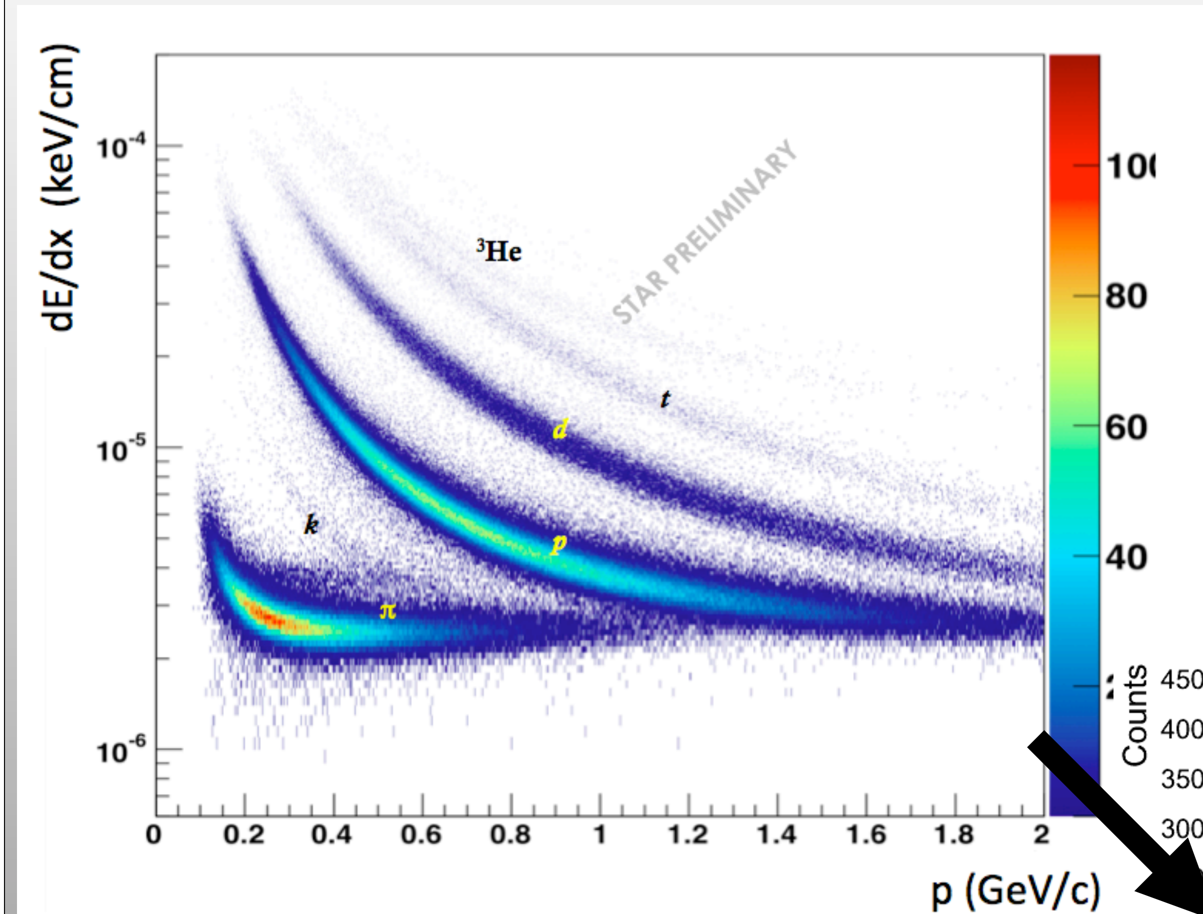
**Apply Cuts**

## After Cuts



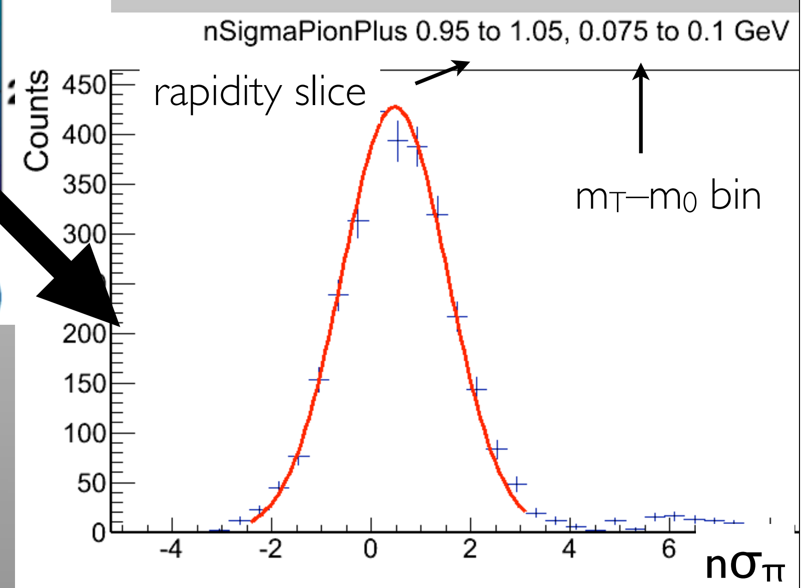
# Particle identification via dE/dx



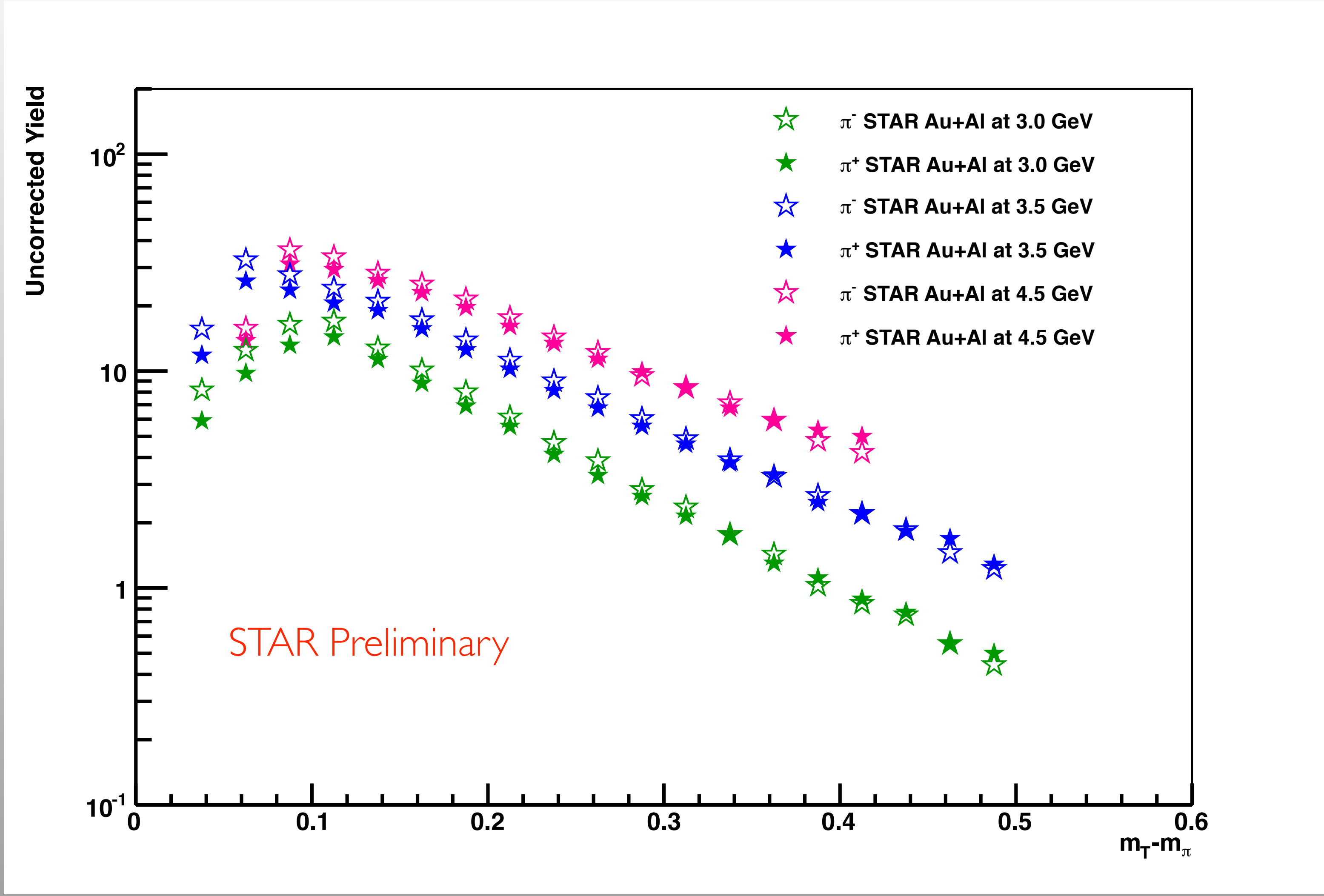

- energy loss in TPC from beampipe events as per event selection criteria

- particle bands are well separated

- Gaussian fits for extracting yields



# pion spectra for $\sqrt{s_{NN}}$ = 3, 3.5, 4.5 GeV




- efficiency corrections pending

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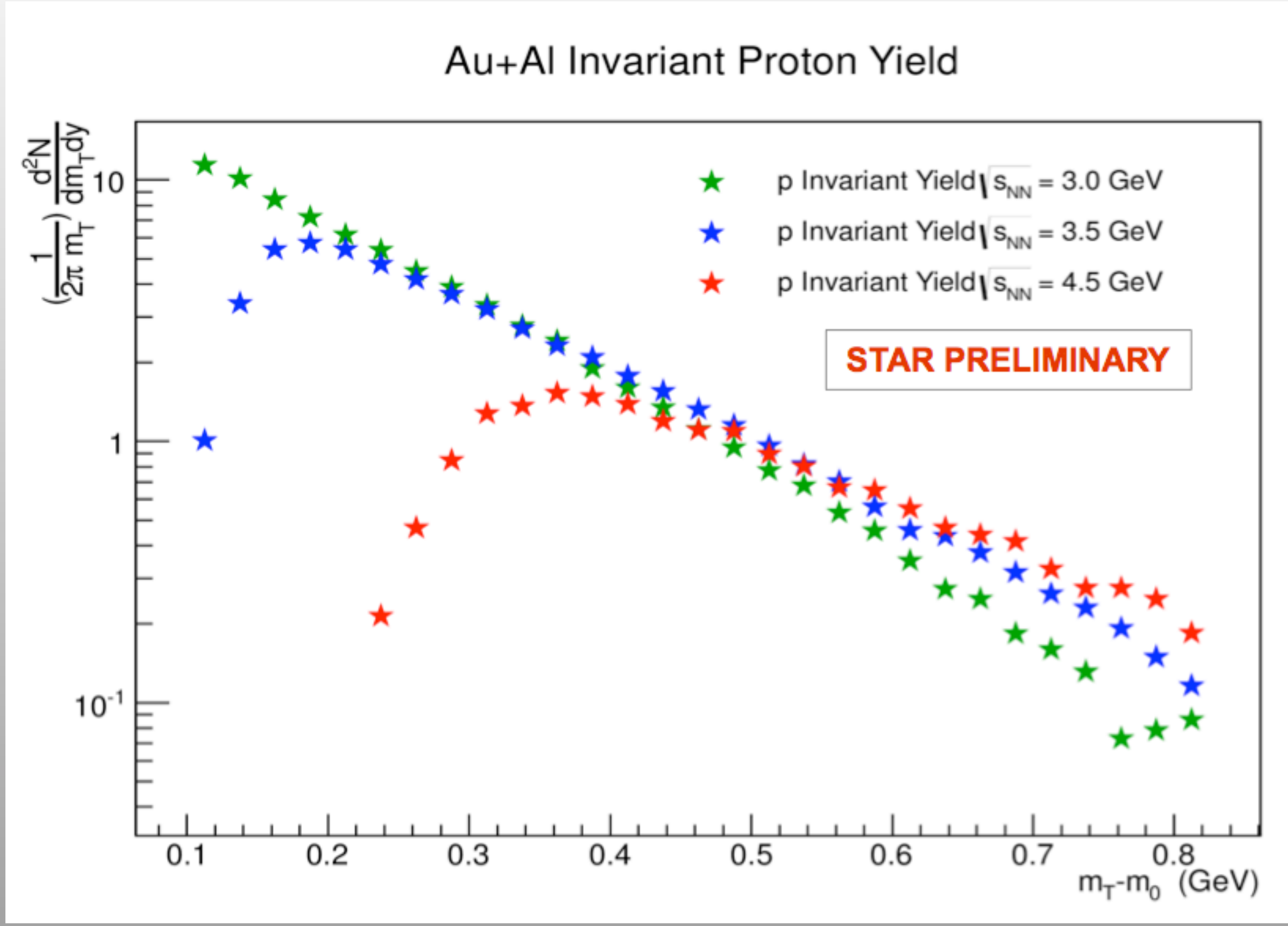
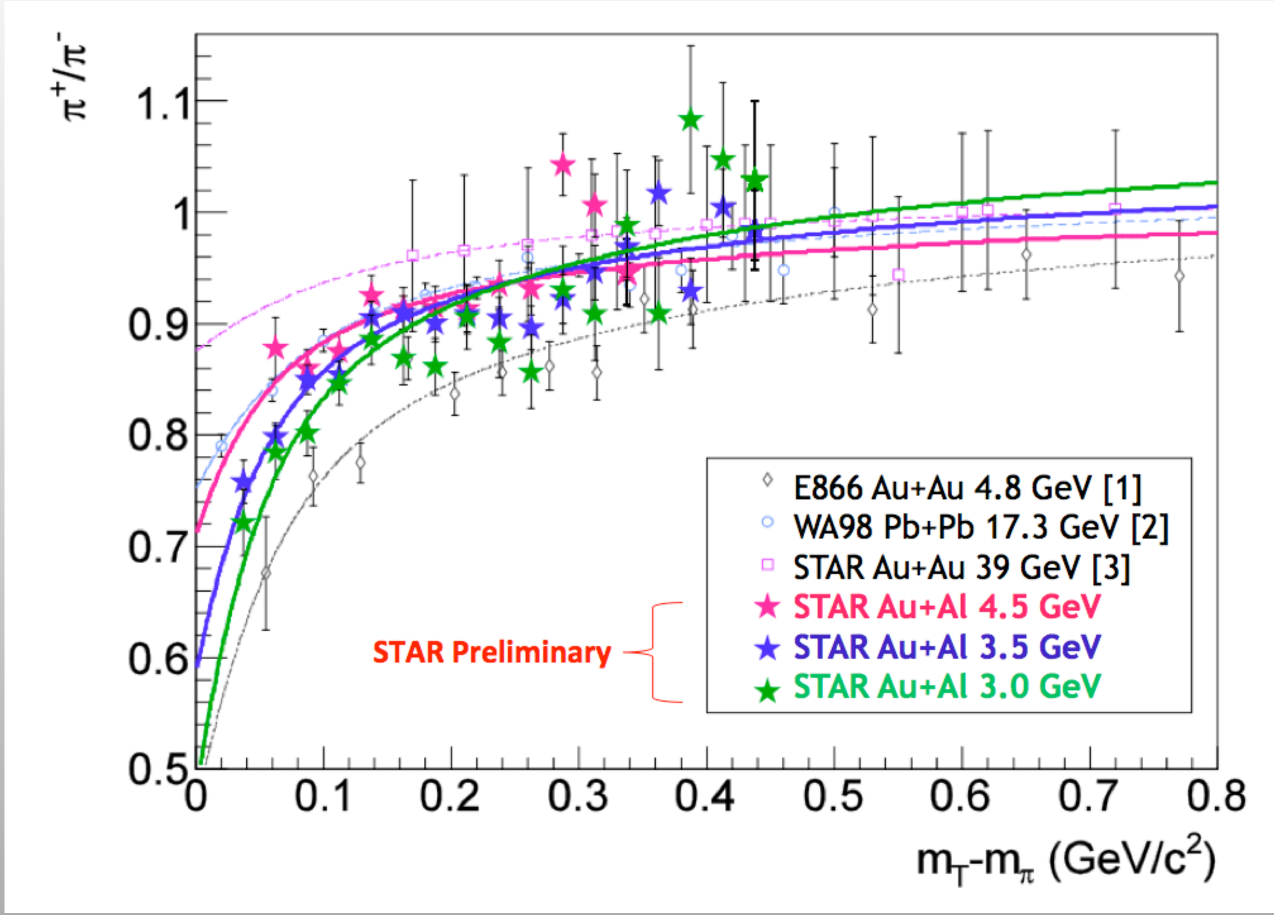



- efficiency corrections pending

# $\pi^+/\pi^-$ yield ratios




- Net positive charge in the collision zone
  - expanding spherical source → effective potential
- Extracted parameters include initial pion ratio and the full coloumb potential
- Coulomb potential of the source modifies momentum distribution
  - greater effect for low–momentum π
- STAR fixed target data is consistent with former measurements and follows expected trends

- only statistical errors on STAR data


[1] L. Ahle *et al.* (E866) Nucl.Phys. **A610,** 139c (1996), and PRC57, R446 (1998).
[2] L. Rosselet *et al.* (WA98) Nucl.Phys. **A698,** 647c (2002).
[3] L. Kumar *et al.* (STAR) J.Phys.G; Nucl.Part.Phys. **38** (2011) 124145.
[4] G. Baym and P. Braun-Munzinger, Nucl. Phys. A610, 286c (1996).

# Conclusions and Outlook

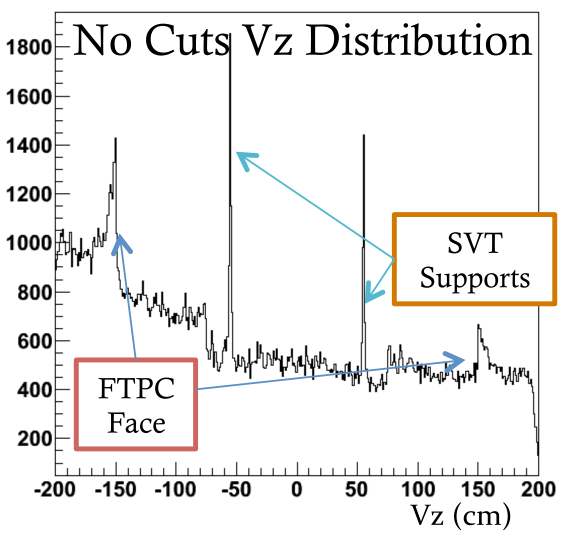
- We have extracted pion and proton spectra for fixed target collisions with the STAR experiment via excellent particle identification in the TPC.
- Currently a fixed target program has approval.  Installation in the next run. (See Daniel Cebra's talk)
- We have carried out fixed target physics with the STAR experiment; a paper is in the works!
- We **can** extend the search for the critical point to lower energies.

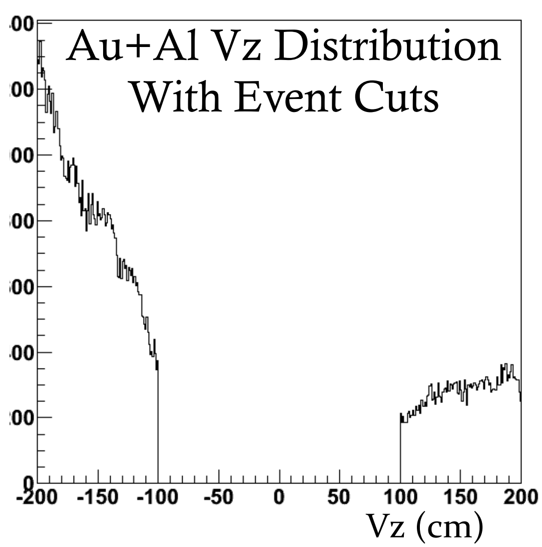
# Backup Slides

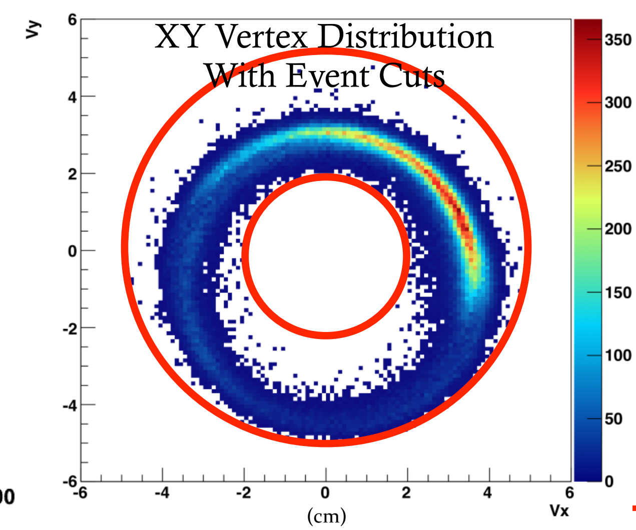
# Au+Al Event Selection

**Sam Brovko**

- Ensure Au+Al collisions
  - Require *z*-vertex position on Al portion of beam pipe via geometric cuts
- Ensure Event is on the beam pipe
  - Require radial vertex position near beam pipe radius
  - Removes vertices on FTPC face and SVT support structures



# Source Coulomb Potential

$$\frac{\pi^+}{\pi^-}(m_T - m_\pi) = R\frac{\exp\left[\left(E+V_{\text{eff}}\right)/T_\pi\right]-1}{\exp\left[\left(E-V_{\text{eff}}\right)/T_\pi\right]-1}\cdot J$$

Ratio as a function of transverse kinetic energy with transformed B-E distribution

$$J = \frac{E-V_{\text{eff}}}{E+V_{\text{eff}}}\frac{\sqrt{\left(E-V_{\text{eff}}\right)^2-m_\pi^2}}{\sqrt{\left(E+V_{\text{eff}}\right)^2-m_\pi^2}}$$

Jacobian of the transformation

$$V_{\text{eff}}(\gamma_\pi\beta_\pi) = V_C\left(1-e^{-E_{\max}(\gamma_\pi\beta_\pi)/T_p}\right)$$

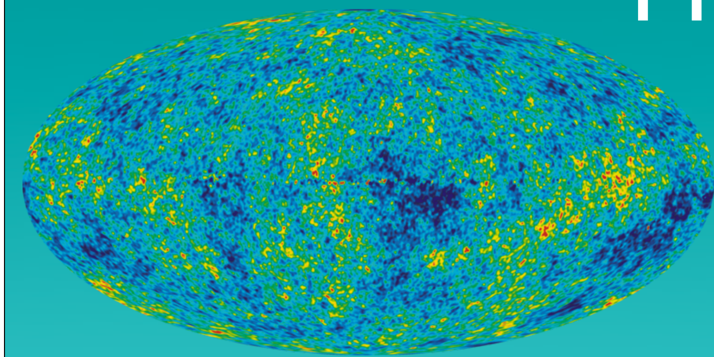
Effective Coulomb potential accounting for the reduced charge seen by low momentum π

$$E_{\max}(\gamma_\pi\beta_\pi) = \sqrt{\left(m_p\gamma_\pi\beta_\pi\right)^2+m_p^2}-m_p$$

Maximum kinetic energy of the corresponding π velocity

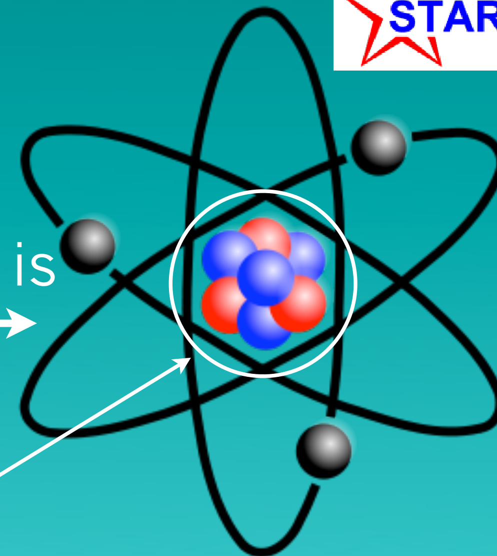
- Net positive charge in the collision zone
  - Expanding spherical source → effective potential
- Coulomb potential ($V_c$) of the source modifies momentum distribution
  - Greater effect for low-momentum π
- R – primordial ratio from initial yields, unmodified by the coulomb source
- Extracted parameters include initial ratio R and the full coulomb potential $V_c$

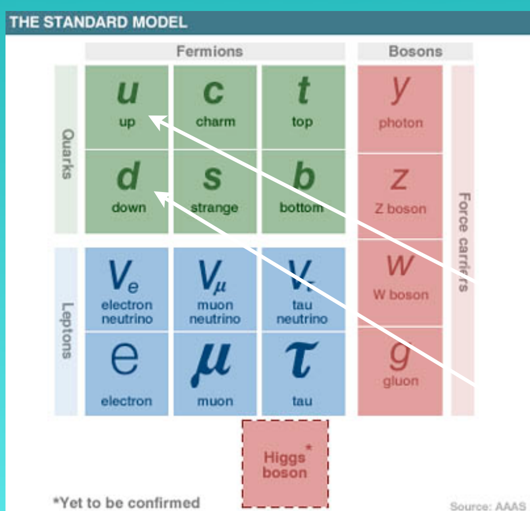
# The Basics



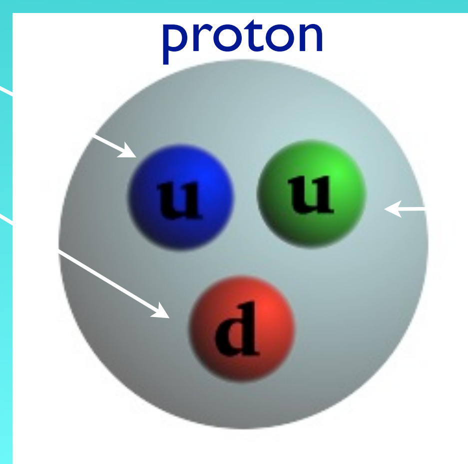
matter in the universe is

made of atoms





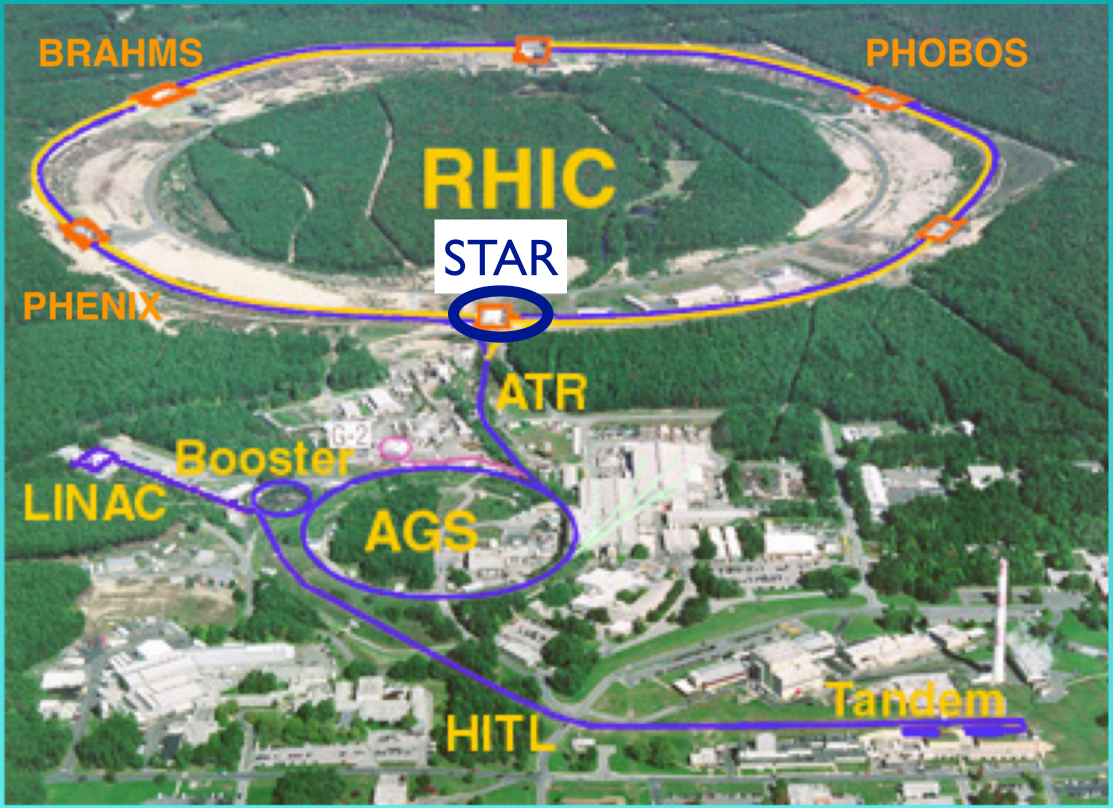

nucleus = protons
+ neutrons



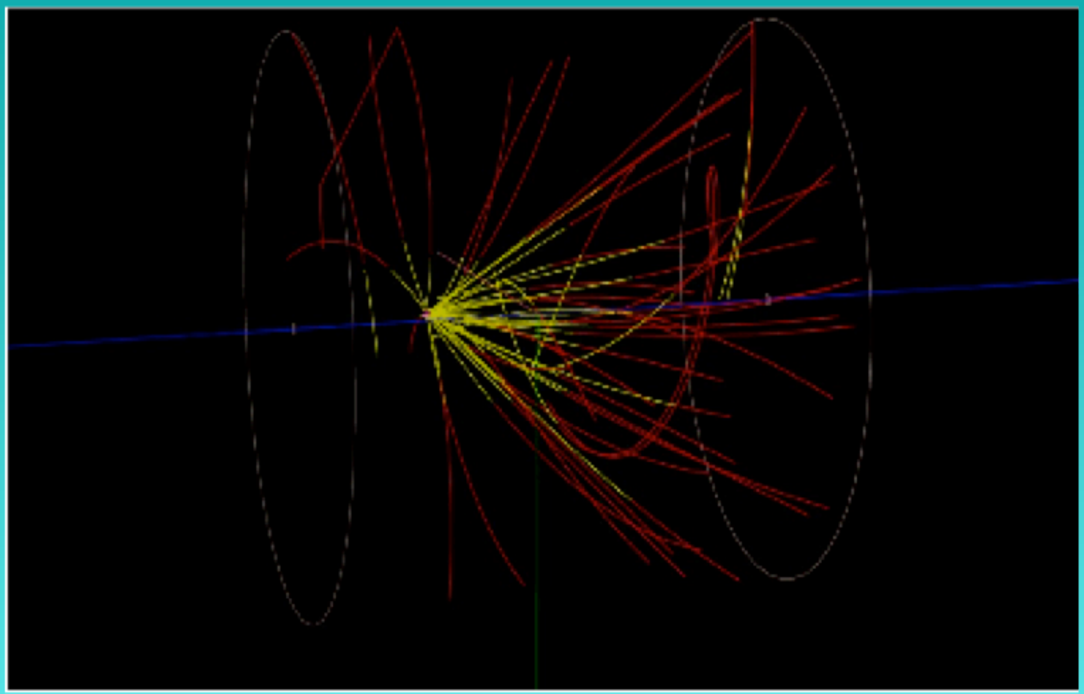

nucleons are hadrons
(made of quarks)

mesons = 2 quarks
baryons = 3 quarks

# The Relativistic Heavy Ion Collider



# STAR has fixed target events



- gold beam ions collide with aluminum beam pipe atoms
- the events are asymmetrical
- acceptance is not optimal ...