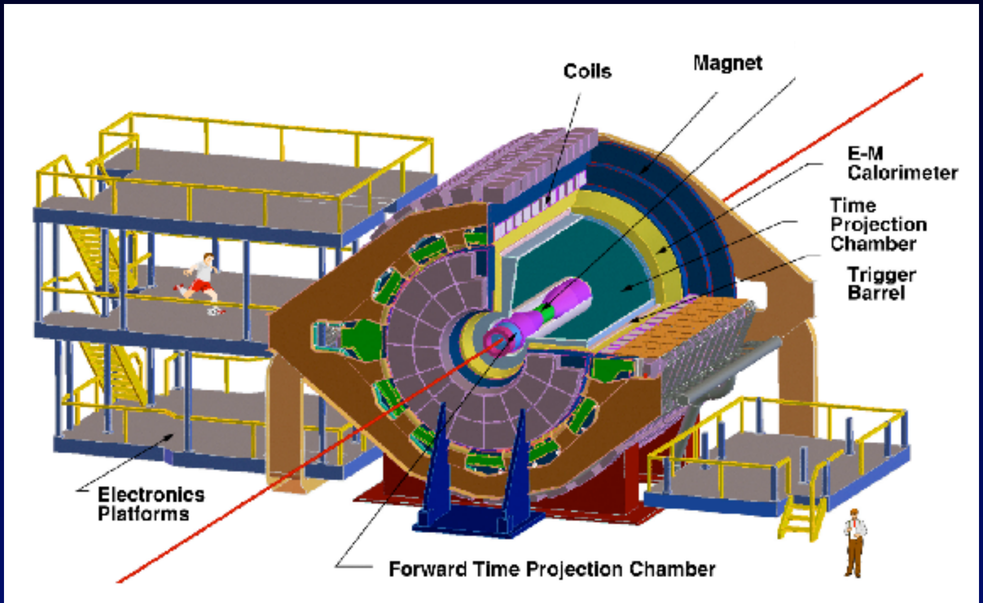
# Analysis of fixed target collisions with the STAR detector





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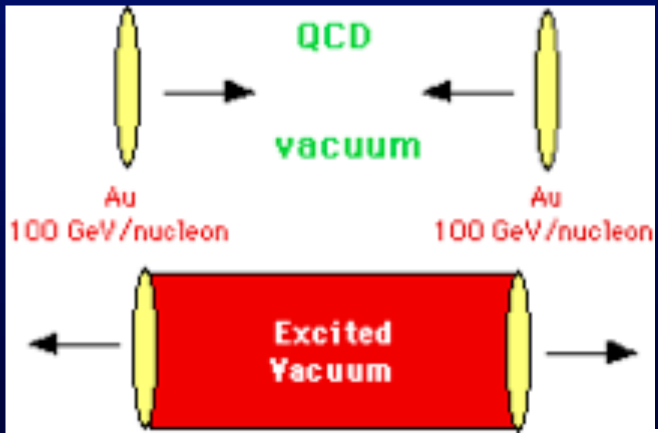
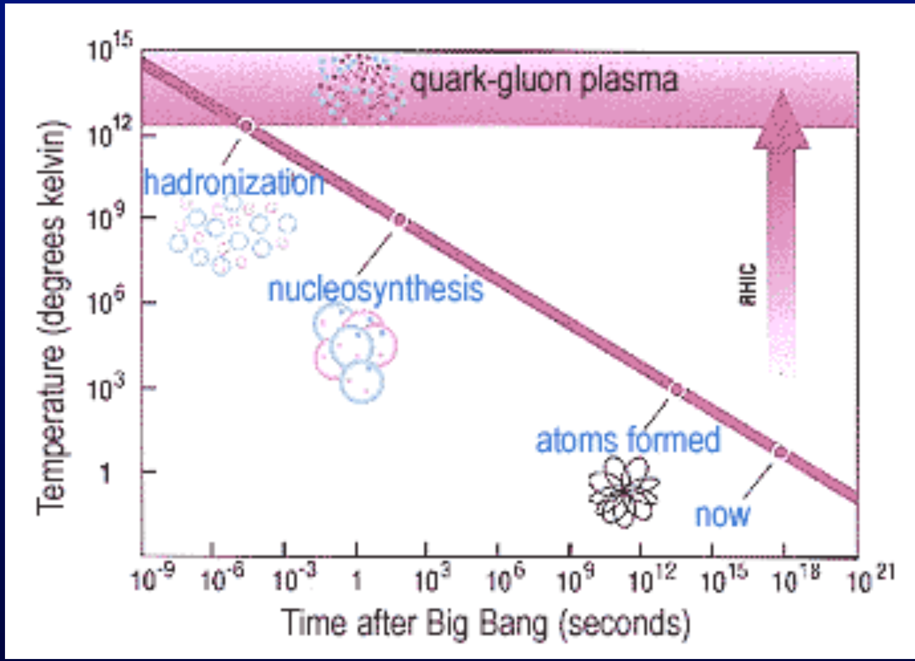
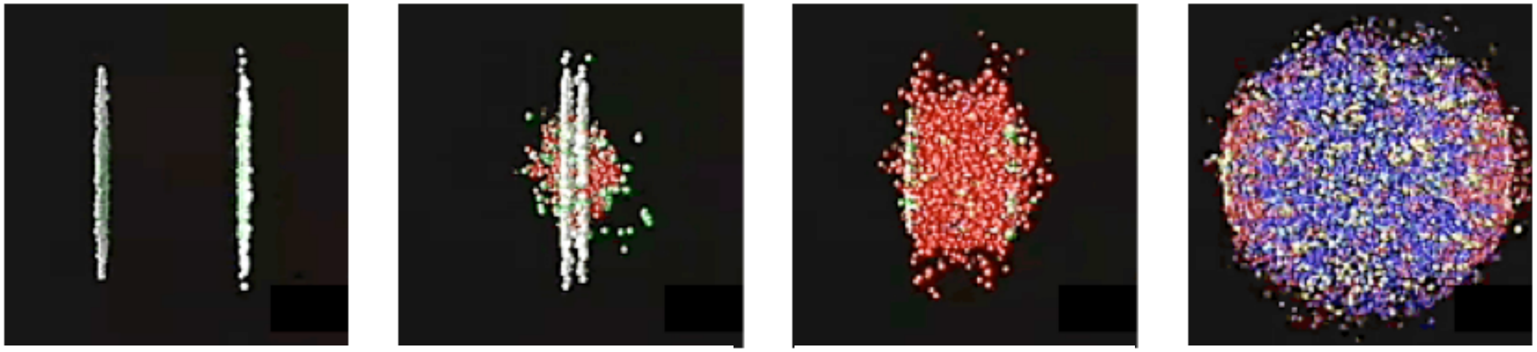
# Creating mini-big bangs in the laboratory

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

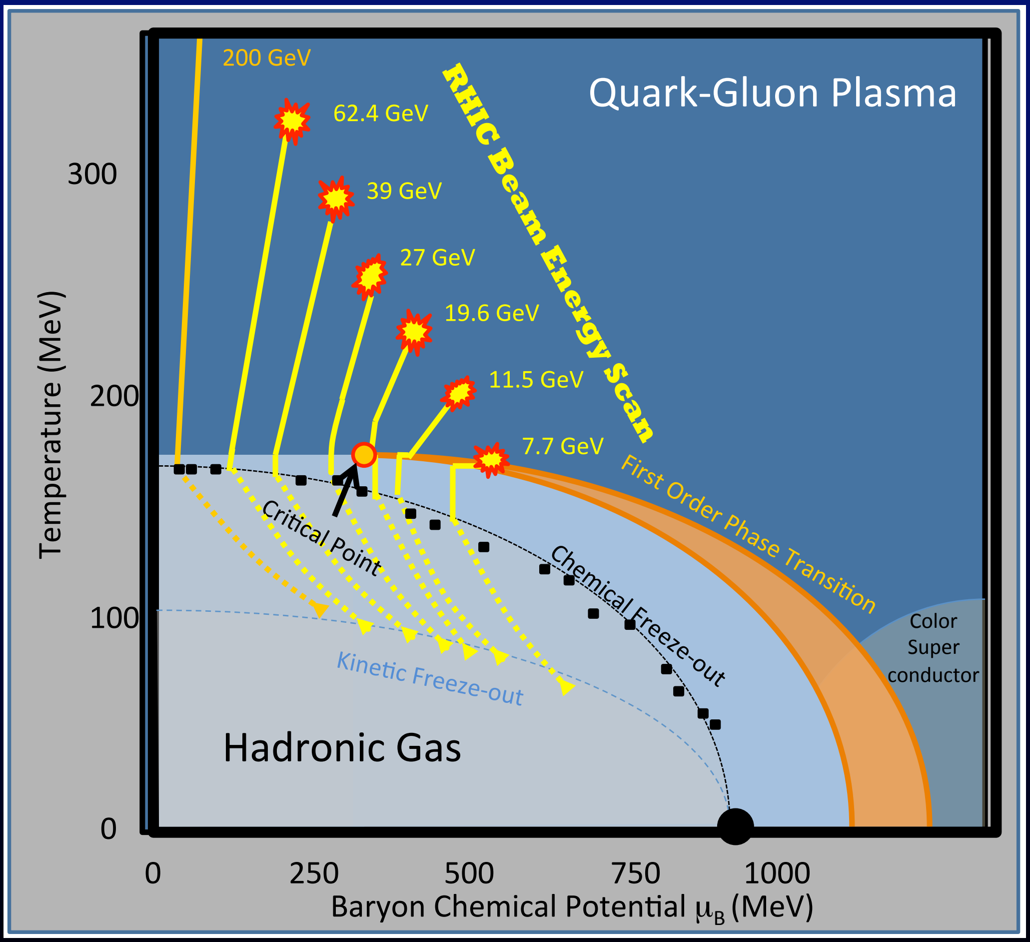


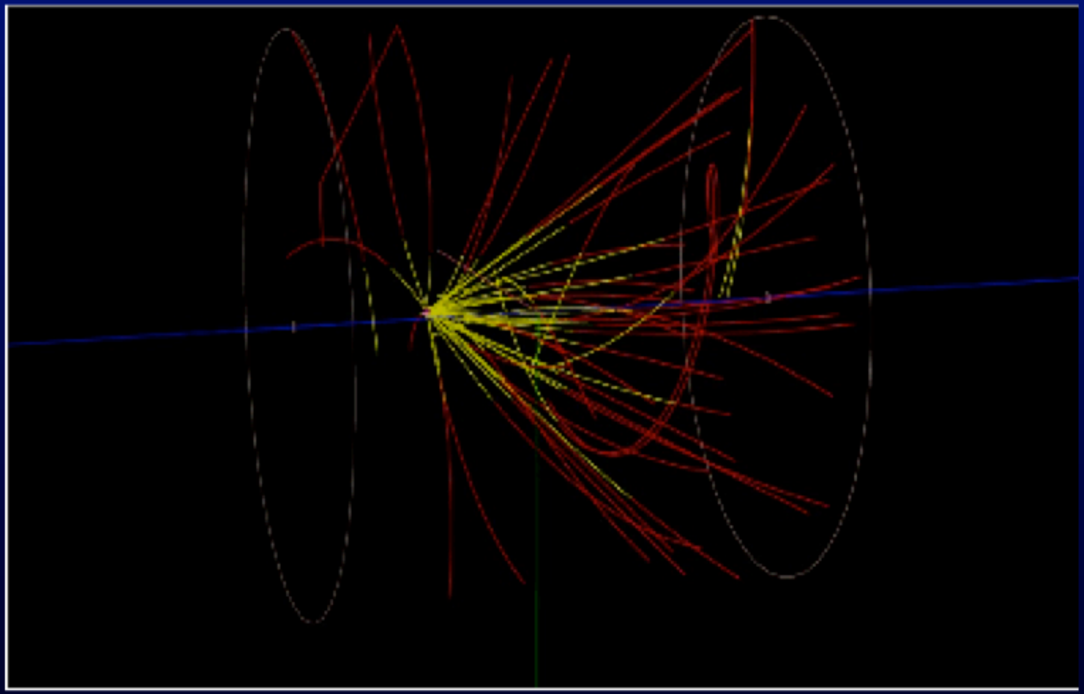
ions about to collide ion collision plasma creation hadron production

# QCD phase diagram



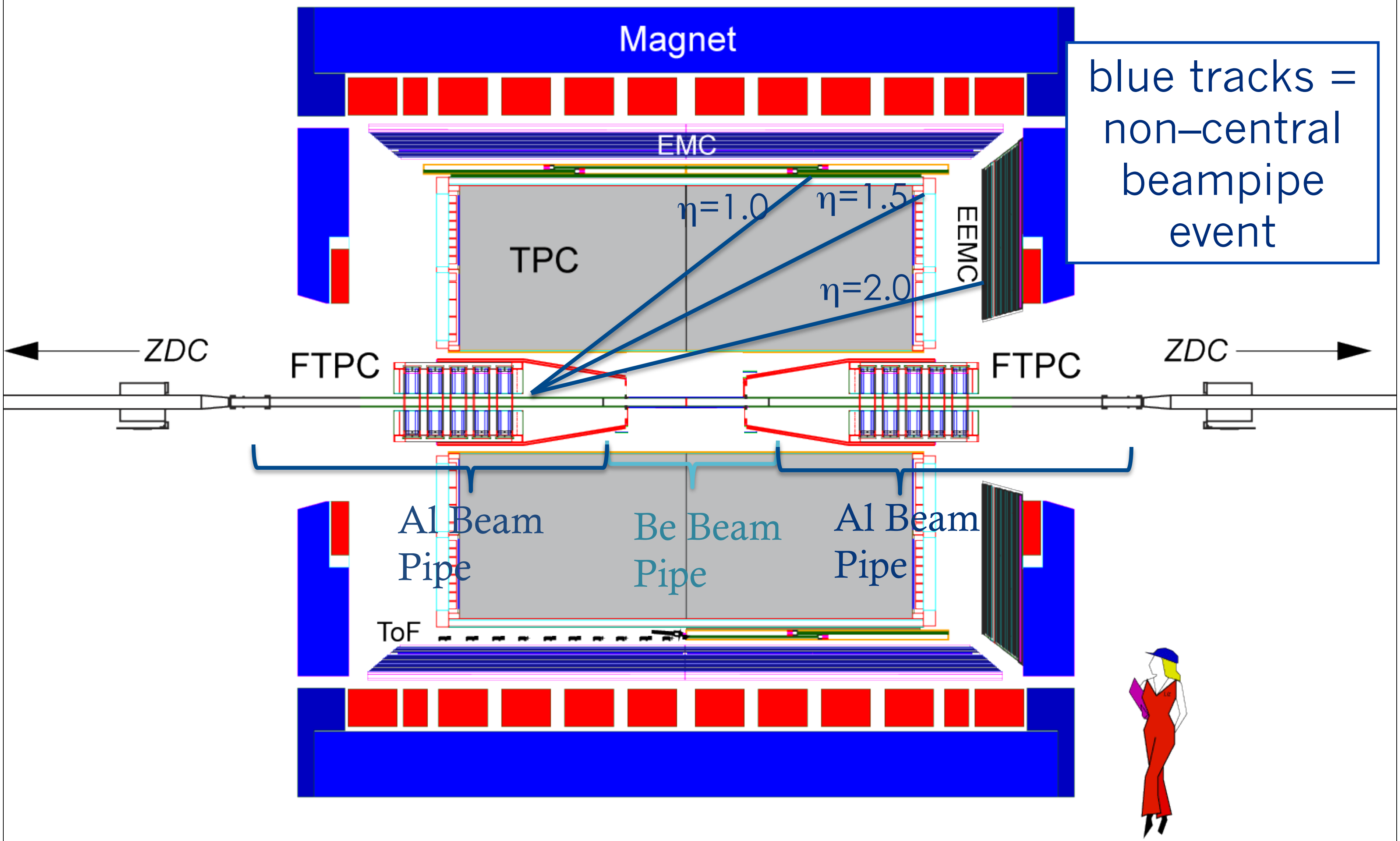

- We have created a new state of matter consistent with the QGP !
- In 2010 (and continuing through 2011) an extensive beam energy scan was undertaken at RHIC with a major goal to find the critical point.
- Fixed target collisions could extend the physics analysis to even lower √s.

# STAR has fixed target events



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

# STAR detector array




blue tracks = non–central beampipe 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

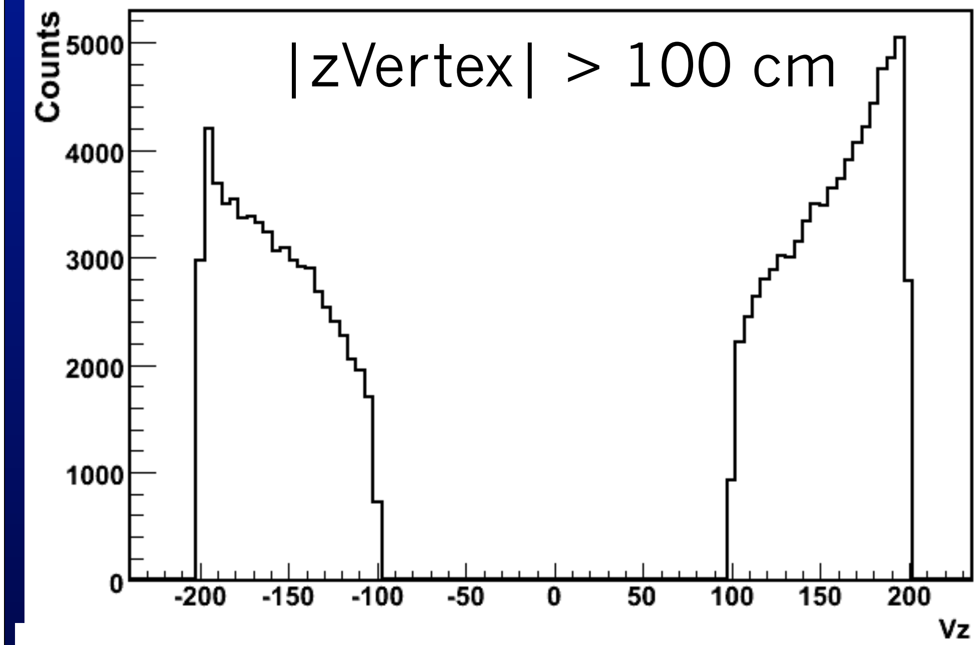
- $\sqrt{(s_{NN})} = \sqrt{(2m^2 + 2Em)}$
  $m = 0.9315\ GeV/c^2$ ; $E = 9.8\ GeV$
- $\sqrt{(s_{NN})} = 4.47\ GeV$
- $p_z = \sqrt{(E^2 - m^2)} = 9.76\ GeV/c$

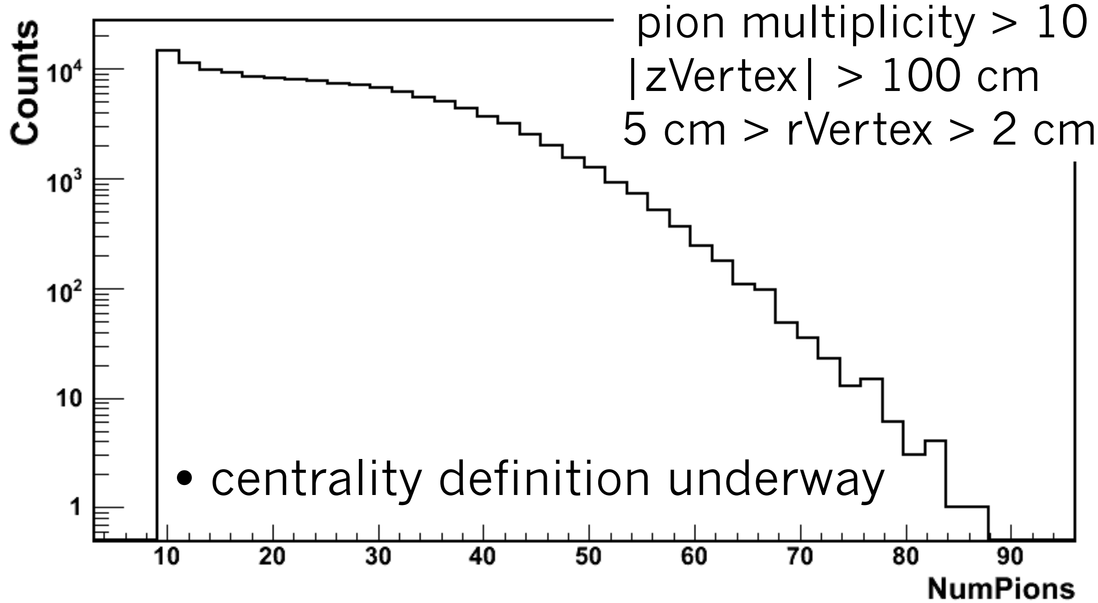
rapidity (y)

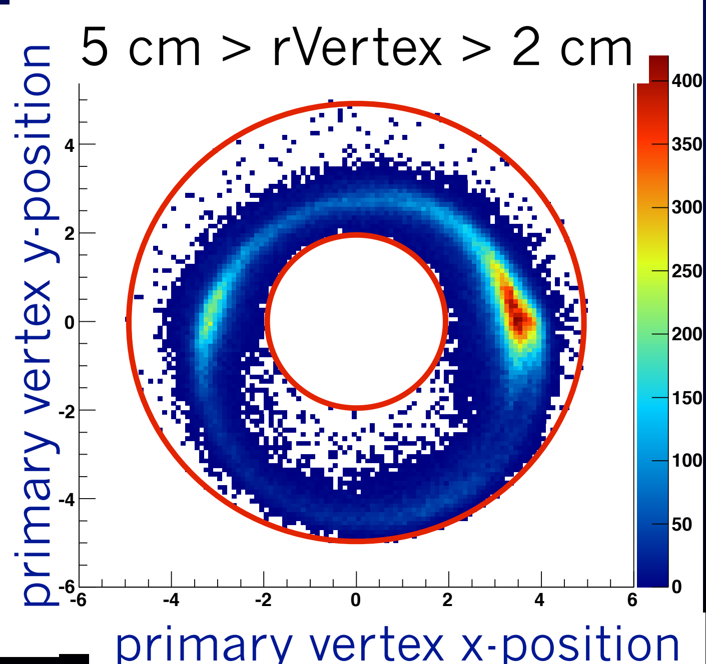
- $y_{beam} = 0.5*[\ln(E + p_z)/(E - p_z)]$
- $y_{beam} = 3.0$
- $y_{cm} = 1.5$

# Event Selection

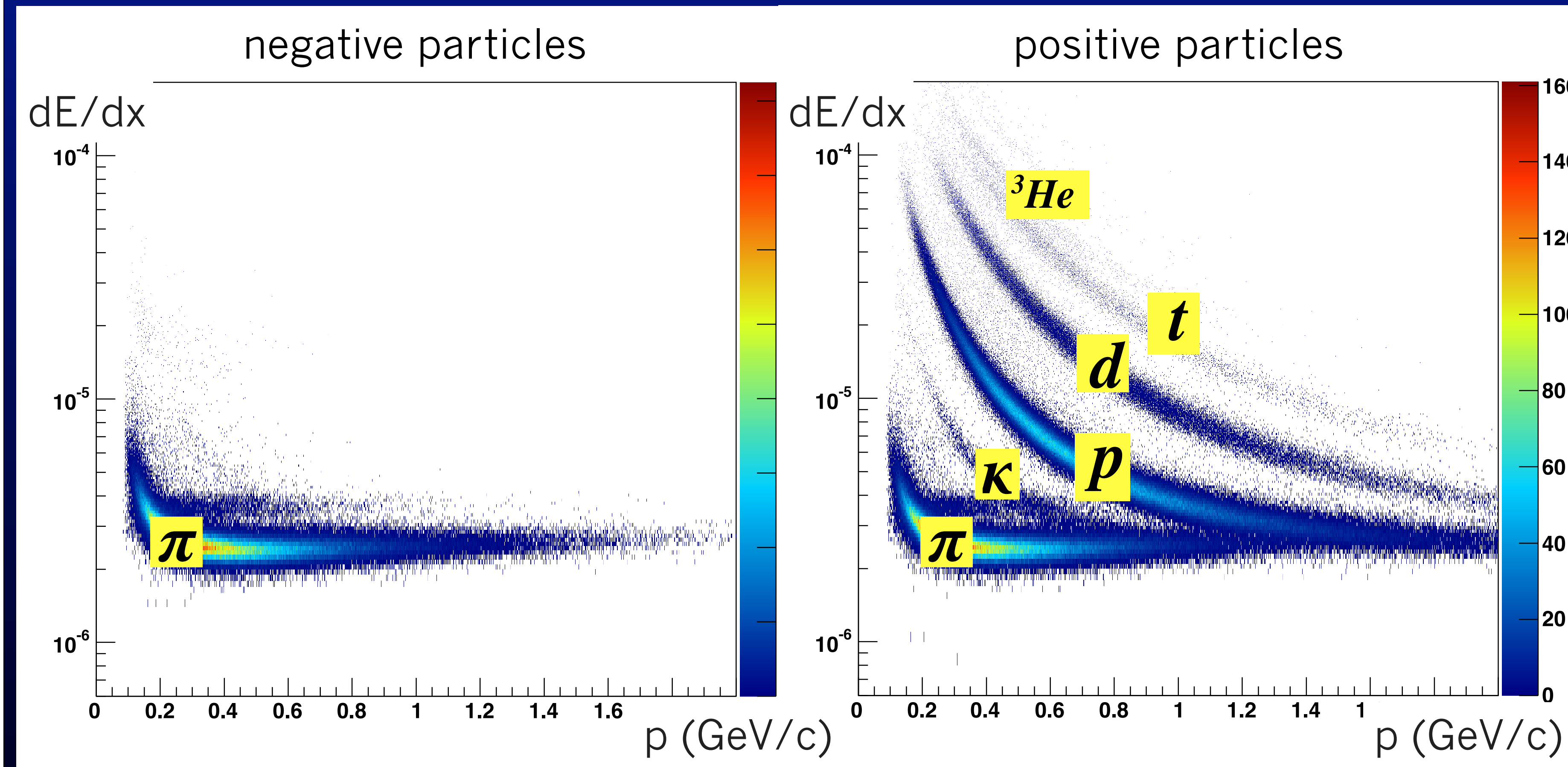
- Run 11 – 19.6 AuAu collider data
- Au+Al $\sqrt{s_{NN}}$ = 4.5 GeV
- 137k events pass selection cuts from 146 M total events



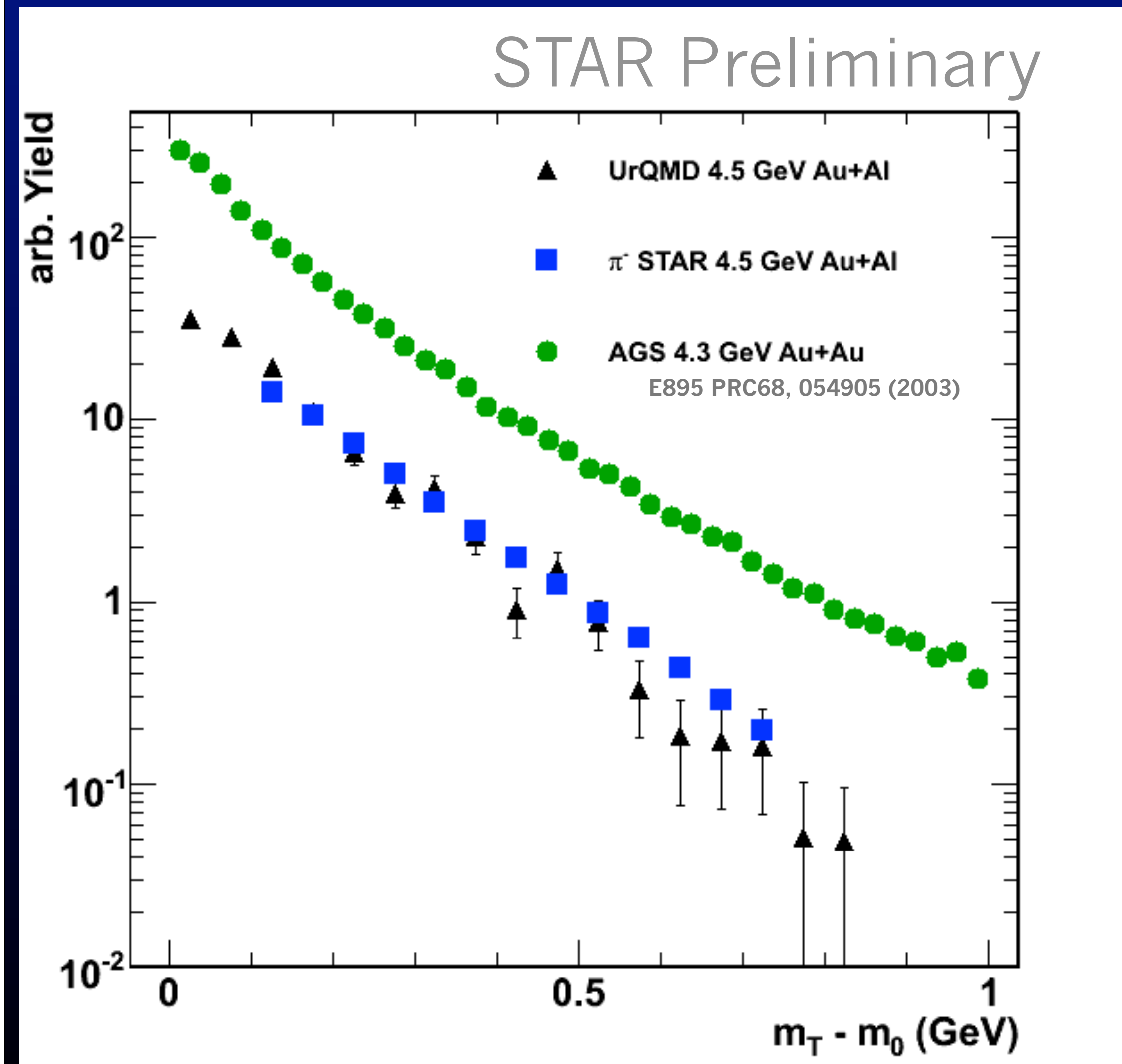



# Particle identification via dE/dx




- dE/dx from beampipe events as per selection criteria in slide 8
- particle bands are well separated

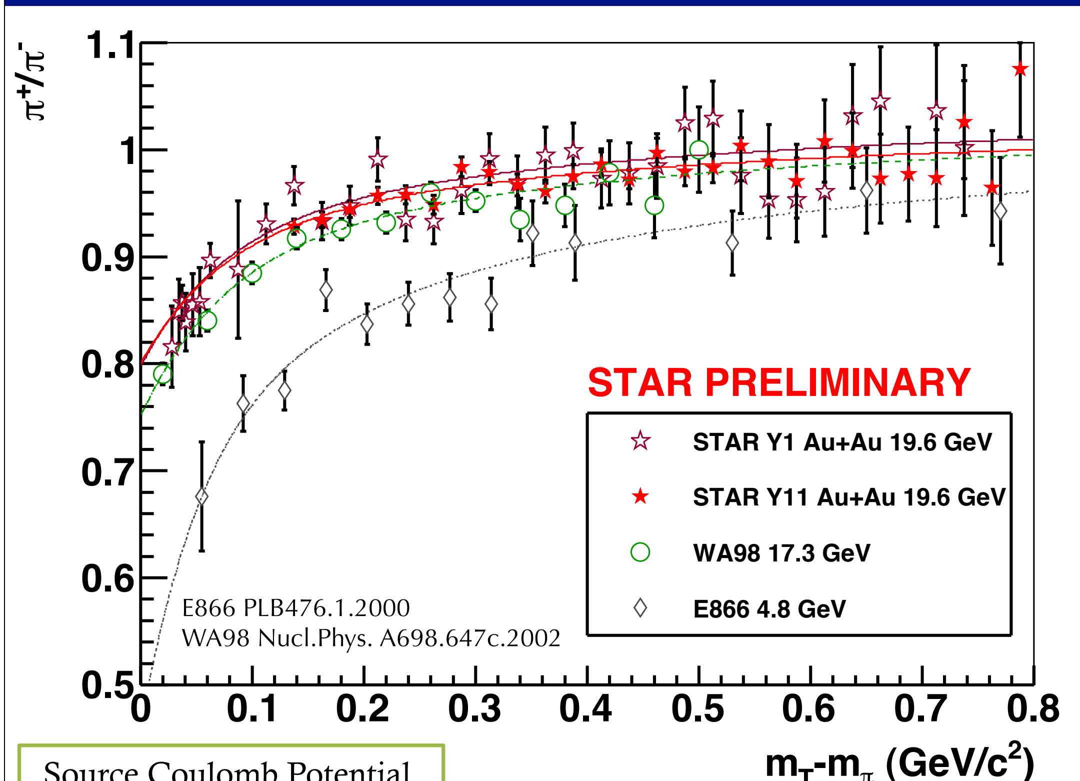
# $\pi^-$ spectra comparisons




- uncorrected STAR data points
- slopes of $\pi^-$ spectra STAR data, AGS data, and UrQMD compare reasonably
- AGS yields are predictably above STAR for Au+Au (AGS) vs. Au+Al (STAR)

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

STAR




<u>Source Coulomb Potential, $V_c$ (MVolts)</u>

Y1: 8.54 +/- 0.78

Y11: 8.07 +/- 0.61

WA98: 9.83 +/- 0.63

E866: 16.32 +/- 1.92

<u>Overall Pion Ratio, R</u>

Y1: 0.960 +/- 0.005

Y11: 0.953 +/- 0.002

WA98: 0.935 +/- 0.004

E866: 0.771 +/- 0.011

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

**STAR Au+Al 4.5 GeV measurement pending**

# Conclusions and Outlook

- We can do physics with STAR as a fixed target experiment !
  - We have been able to extract pion spectra for fixed target collisions at lab rapidity
    - working to understand detector efficiency at high rapidities via simulated events
    - checking pion contamination, stability of multiplicity as a function of zVertex
  - Yields and slopes compare favorably with published data in this energy range
  - We **can** extend the search for the critical point to lower energies
    - We have more fixed target data at $\sqrt{(s_{NN})}$ of 3.0 and 3.5 GeV

# Backup Slides

# 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

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

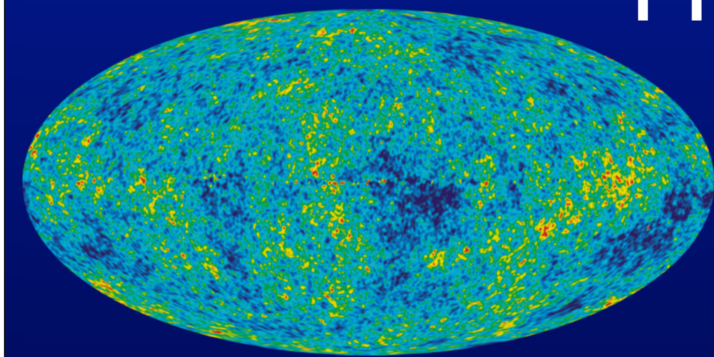
Effective Coulomb potential accounting for the reduced charge seen by low momentum π

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

Maximum kinetic energy of the corresponding π velocity

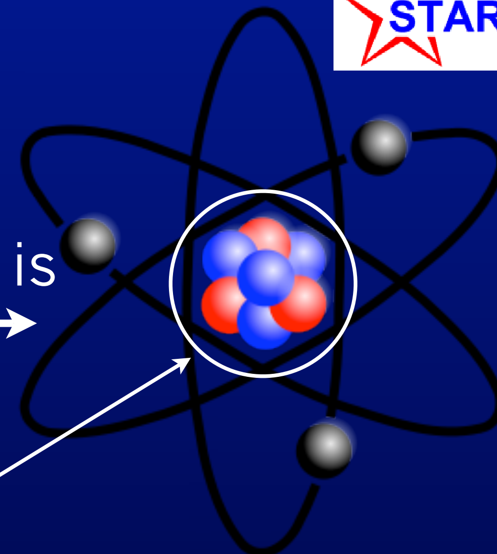
- Net positive charge in the collision zone
  - Expanding spherical source → effective potential
- Coulomb potential ($V_c$) of the source modifies momentum distribution
  - Greater effect for low-momentum π
- R – primordial ratio from initial yields, unmodified by the coulomb source
- Extracted parameters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

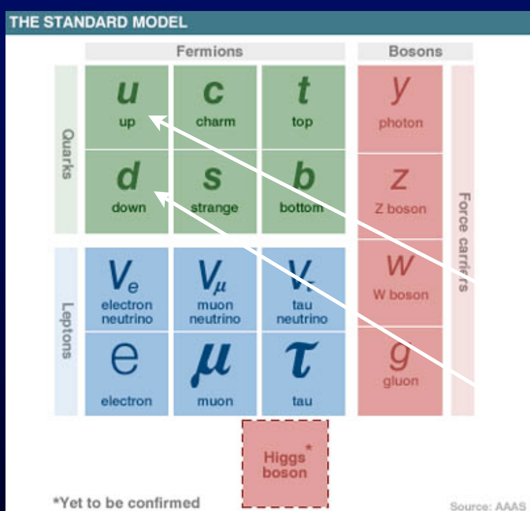
# The Basics



matter in the universe is

made of atoms





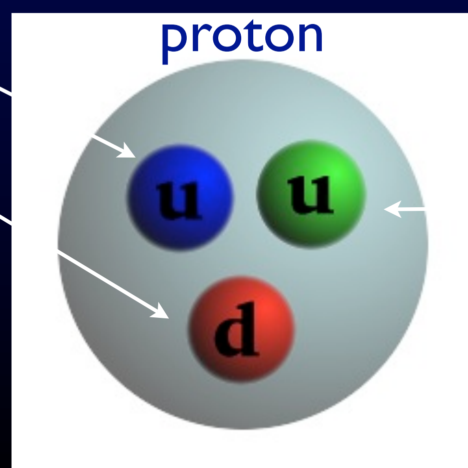
THE STANDARD MODEL

| | Fermions | | | Bosons |
|---|---|---|---|---|
| Quarks | $u$ up | $c$ charm | $t$ top | $\gamma$ photon |
| Quarks | $d$ down | $s$ strange | $b$ bottom | $Z$ Z boson |
| Leptons | $\nu_e$ electron neutrino | $\nu_\mu$ muon neutrino | $\nu_\tau$ tau neutrino | $W$ W boson |
| Leptons | e electron | $\mu$ muon | $\tau$ tau | $g$ gluon |
| | | Higgs* boson | | Force carriers |

*Yet to be confirmed

Source: AAAS

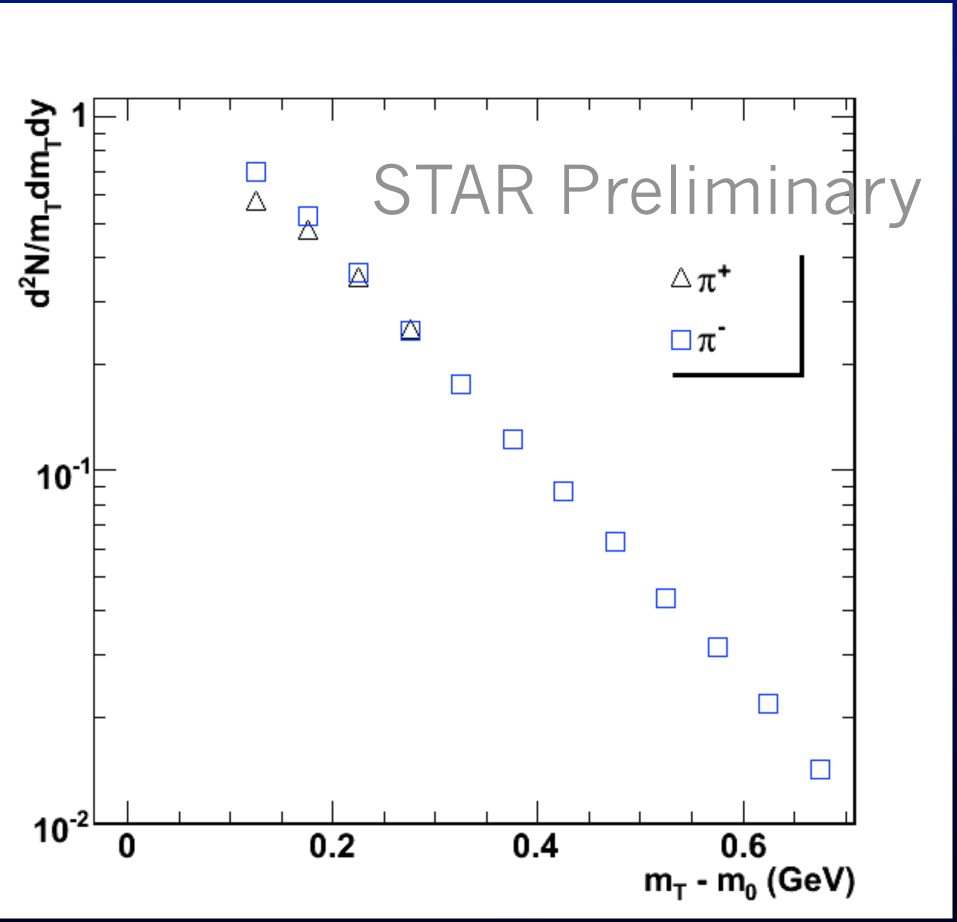
nucleus = protons
+ neutrons




nucleons are hadrons
(made of quarks)

mesons = 2 quarks
baryons = 3 quarks

# π spectra



STAR Preliminary
$d^2N/m_T dm_T dy$
1
$10^{-1}$
$10^{-2}$
0
0.2
0.4
0.6
$m_T$ - $m_0$ (GeV)
$\pi^+$
$\pi^-$