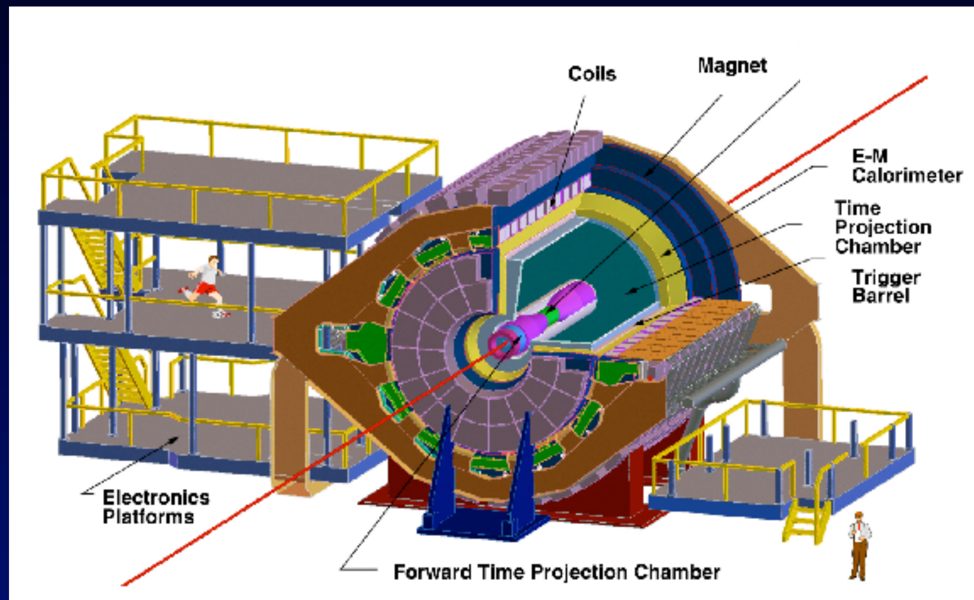
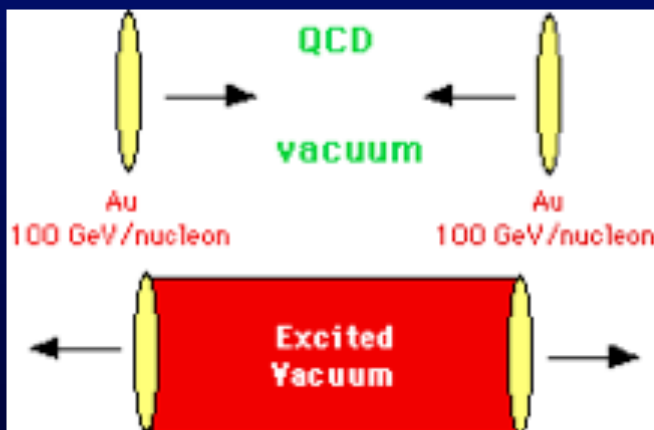
Analysis of fixed target collisions with the STAR detector

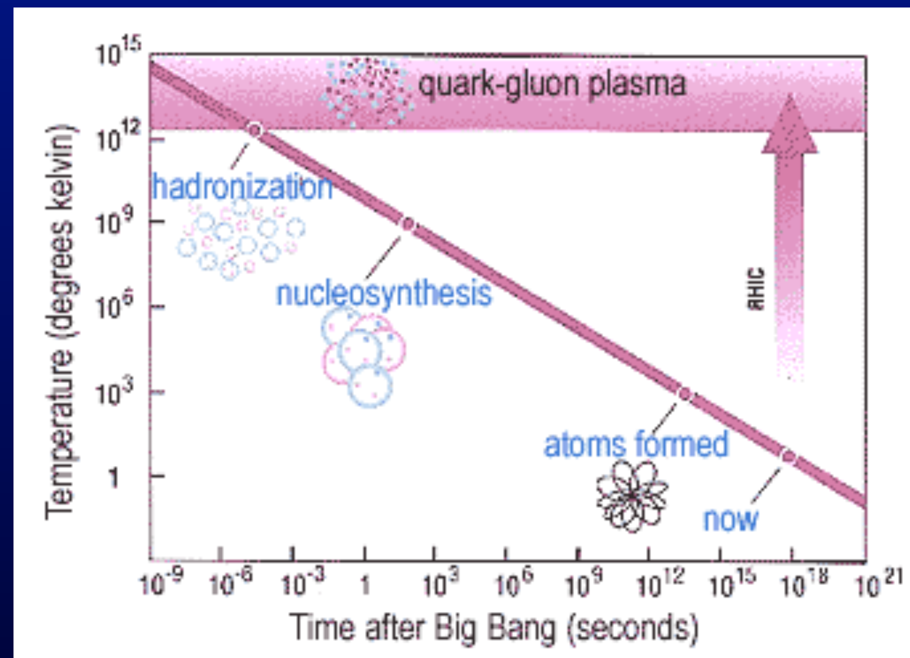


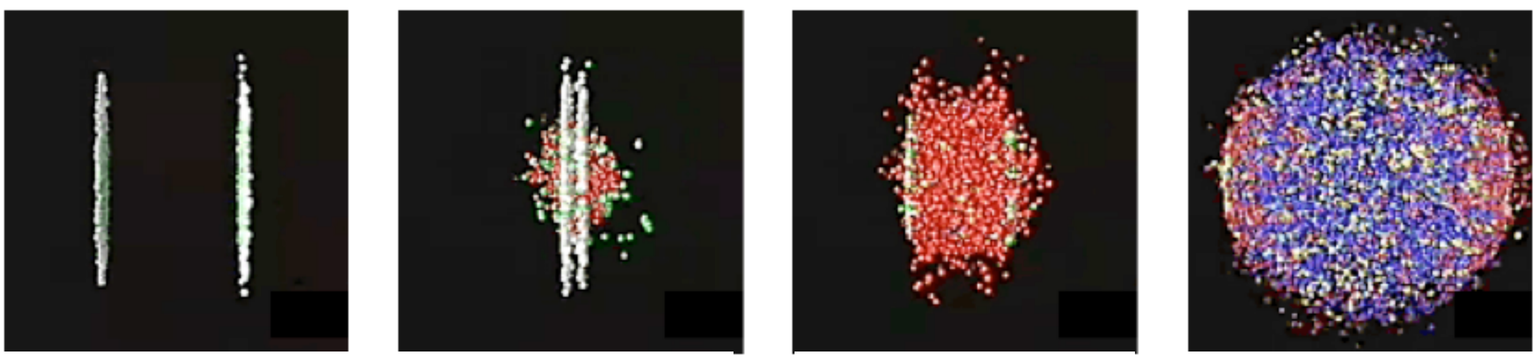
Brooke Haag for the STAR Collaboration
Hartnell College / University of California, Davis
Presented at the Meeting of the California Section of the APS
November 11, 2011

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

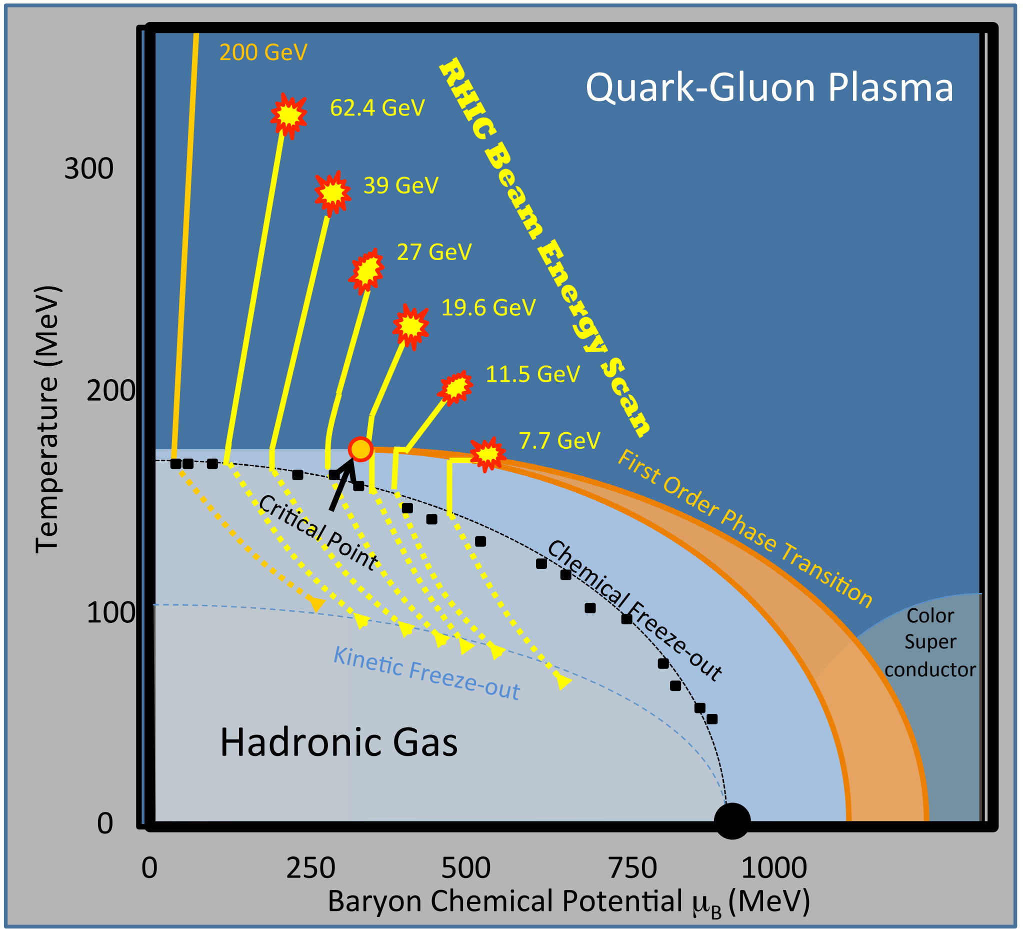






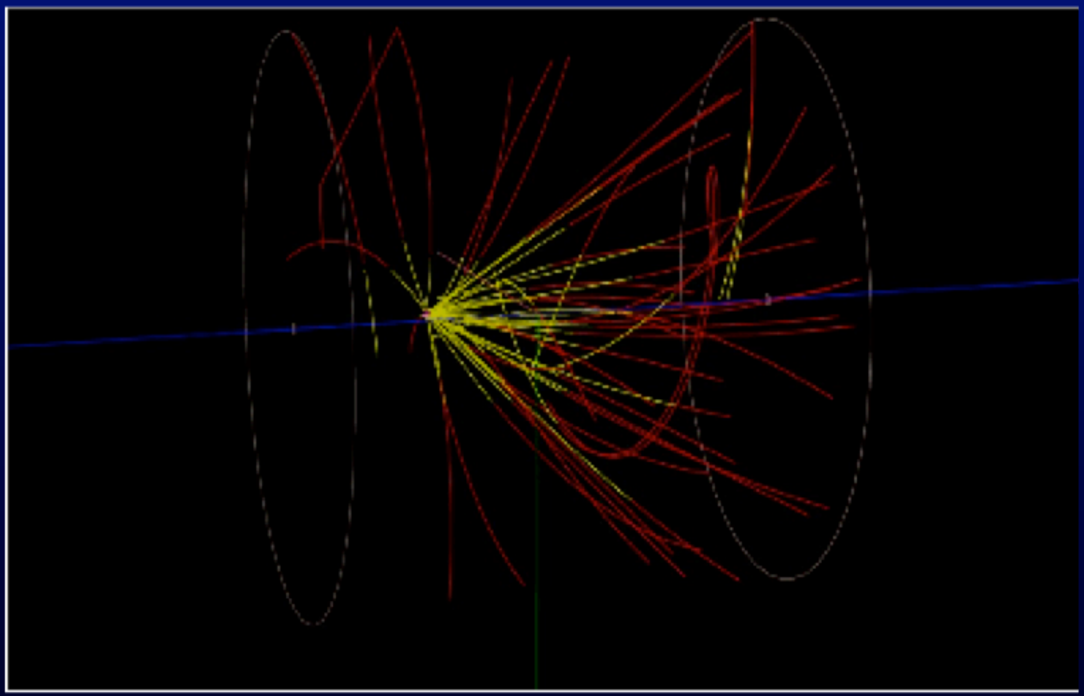
ions about to collide | ion collision | plasma creation | hadron production

QCD phase diagram



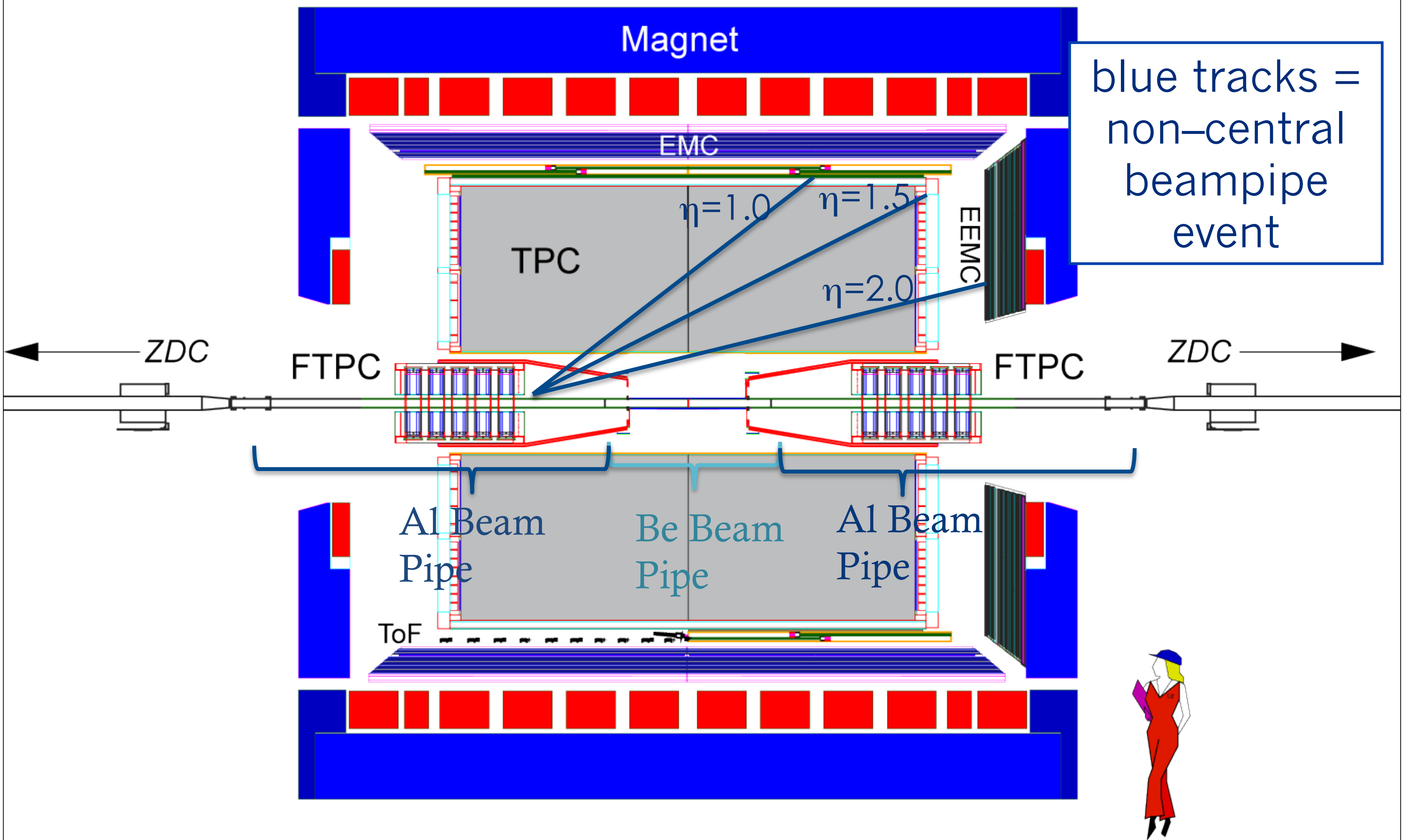
- We have created a new state of matter consistent with the QGP !
- In 2010 (and continuing through 2011) an extensive beam energy scan was undertaken at RHIC with a major goal to find the critical point.
- Fixed target collisions could extend the physics analysis to even lower $\sqrt{s}$.

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

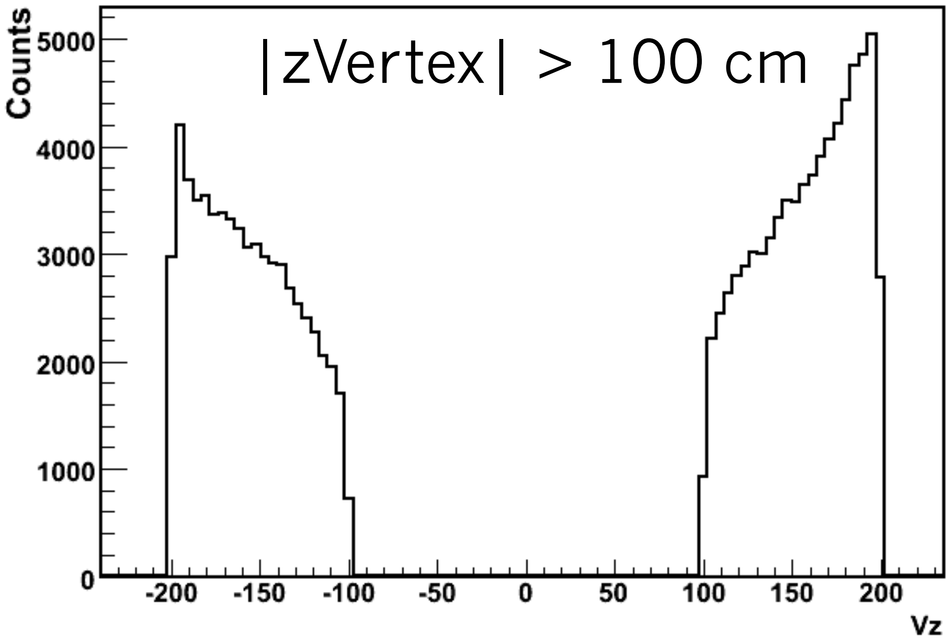
- $p_z = \sqrt{(E^2 - m^2)} = 9.76$ GeV/c

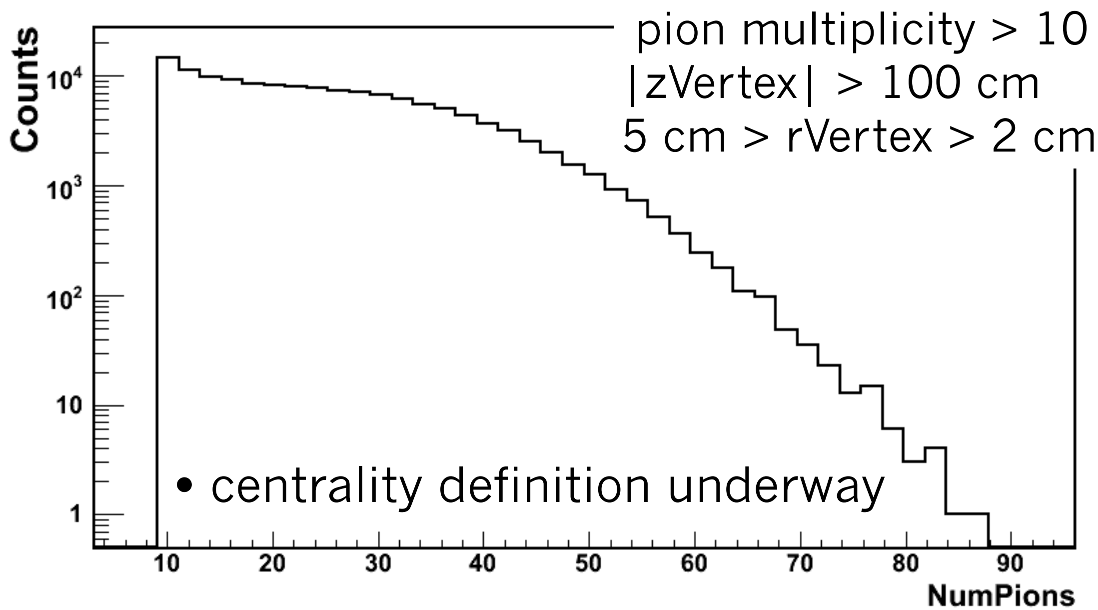
rapidity (y)

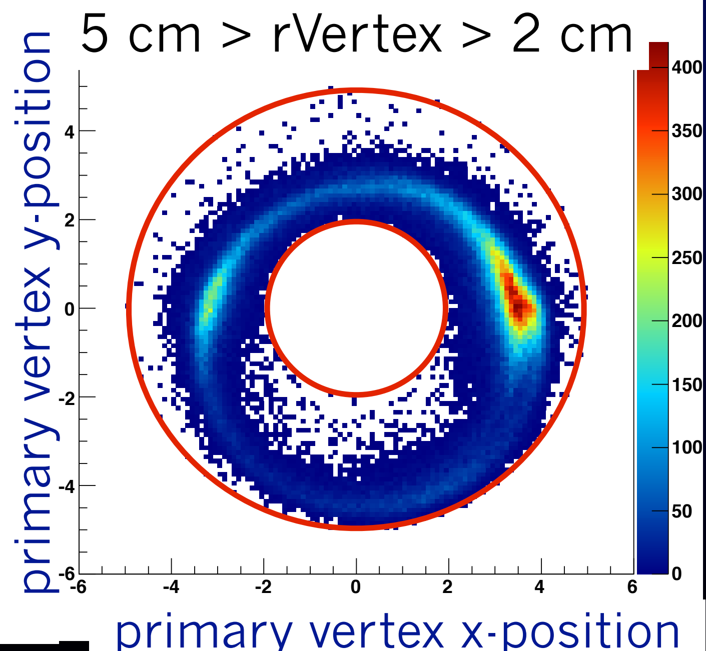
- $y_{beam} = 0.5*[\ln(E + p_z)/(E - p_z)]$
- $y_{beam} = 3.0$
- $y_{cm} = 1.5$

Event Selection

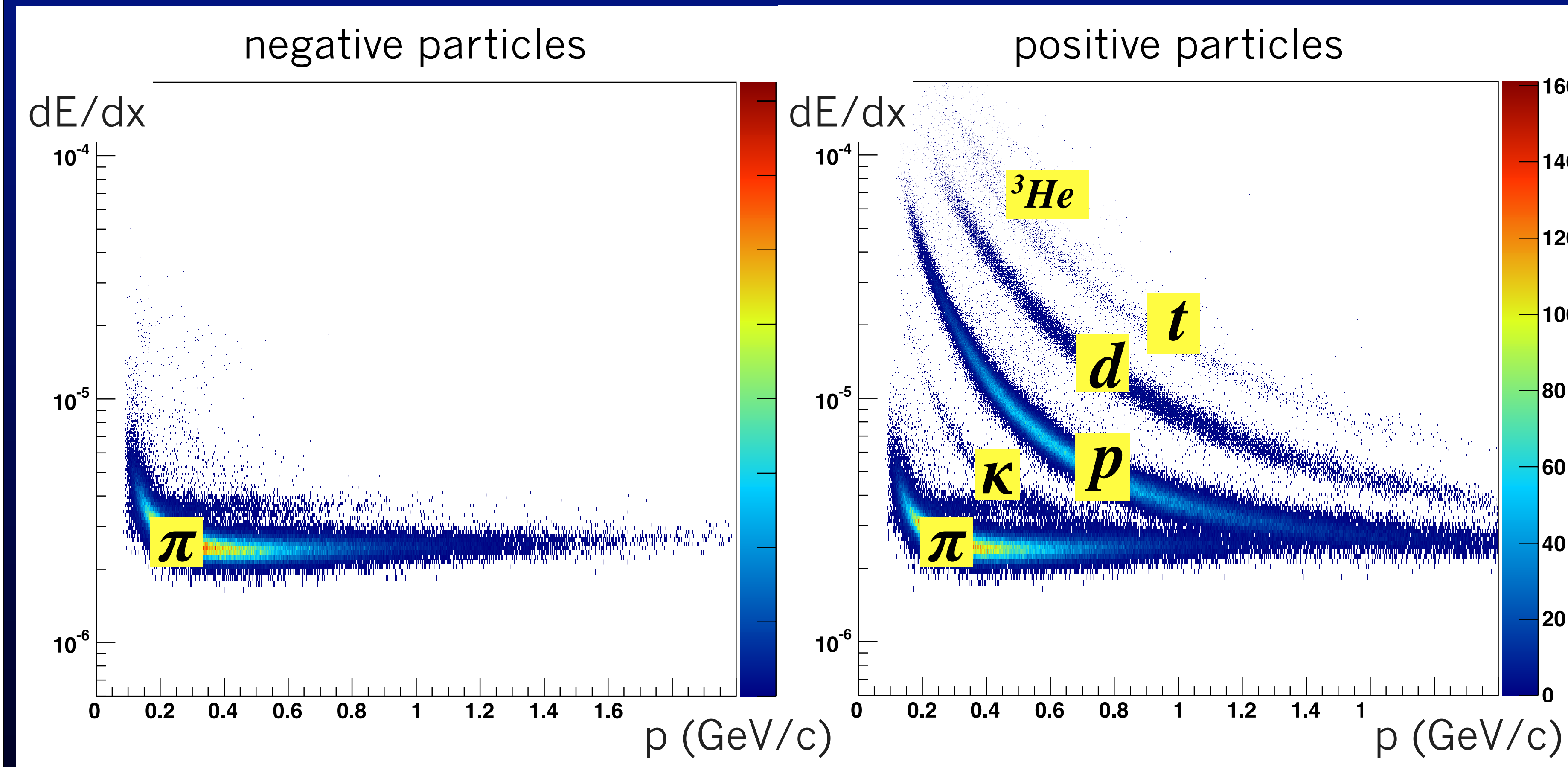
- Run 11 – 19.6 AuAu collider data
- Au+Al $\sqrt{s_{NN}}$ = 4.5 GeV
- 137k events pass selection cuts from 146 M total events







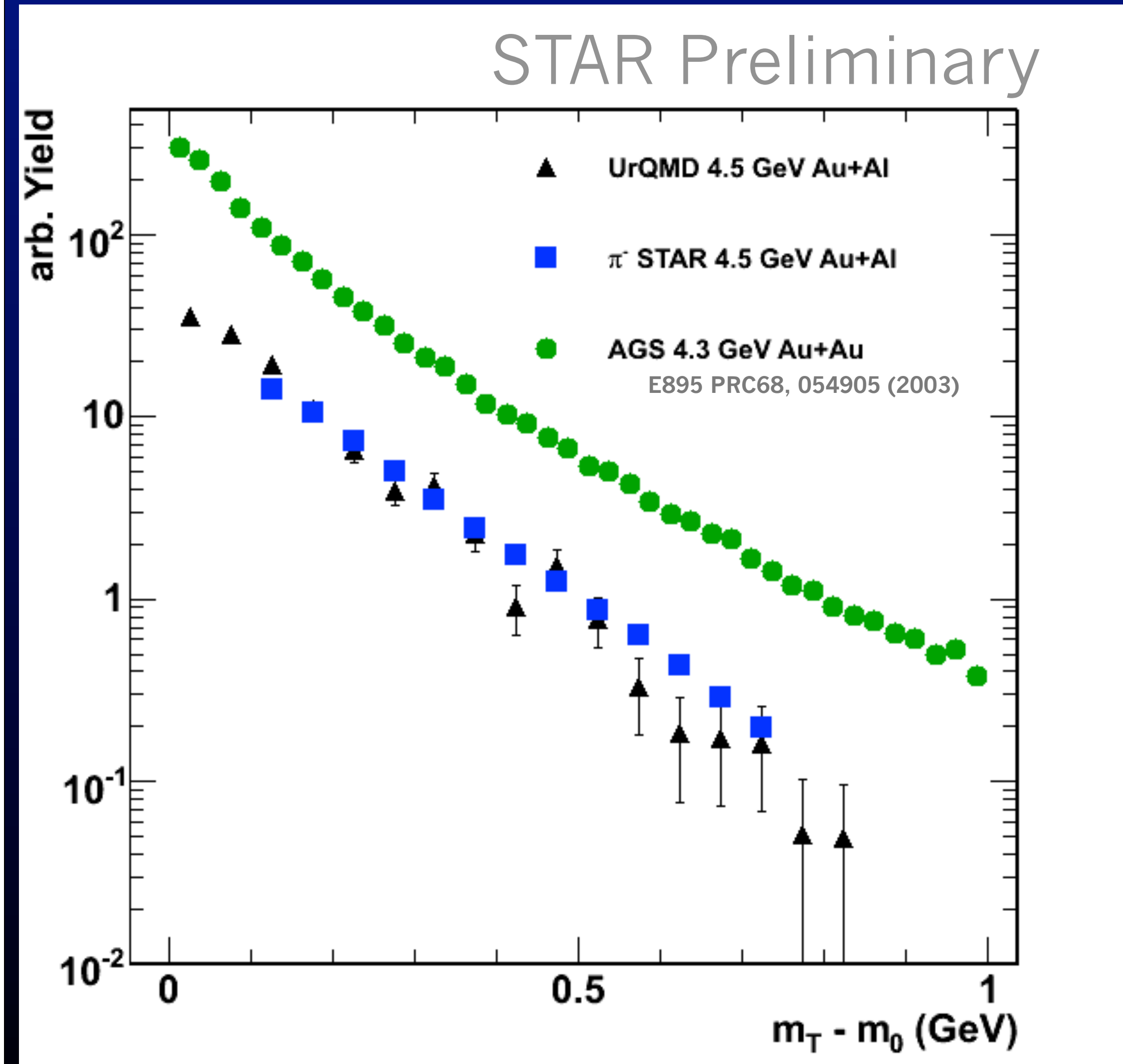
Particle identification via dE/dx



• dE/dx from beampipe events as per selection criteria in slide 8

• particle bands are well separated

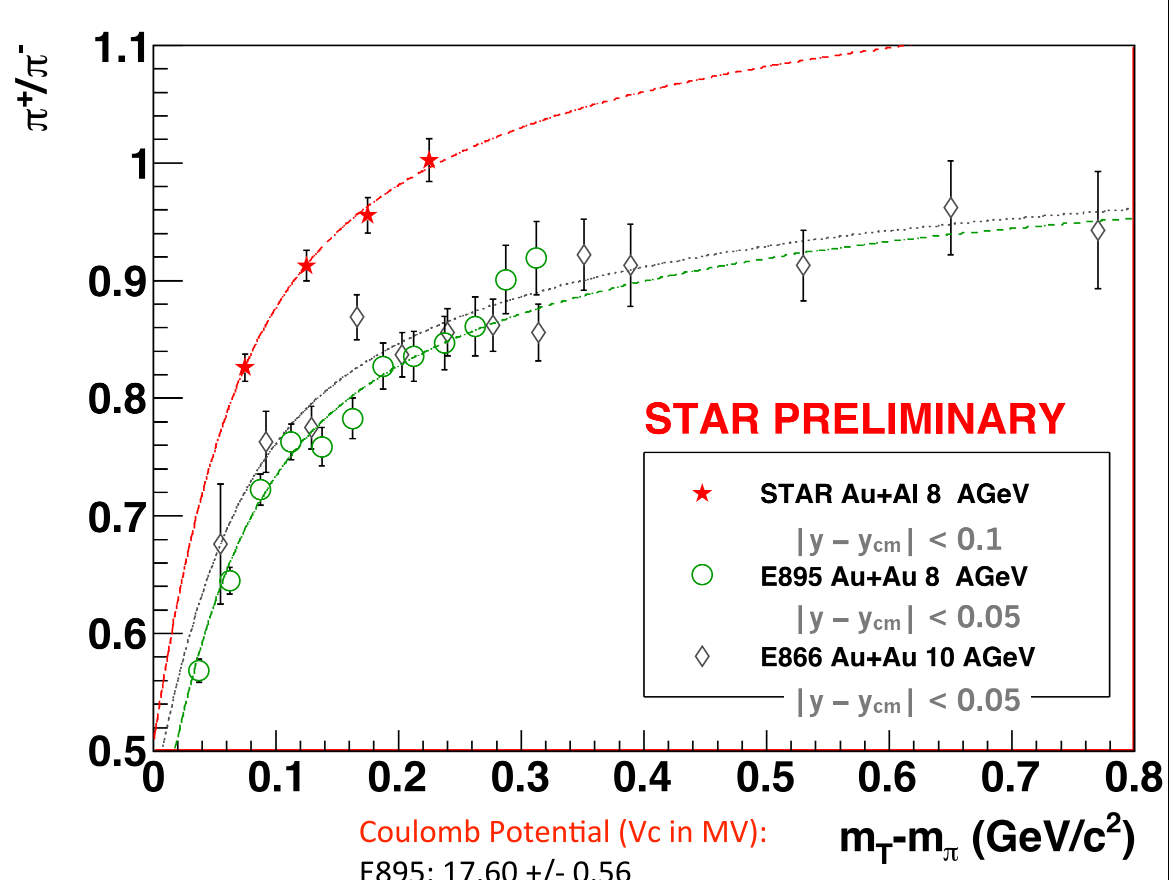
π^- spectra comparisons



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

π^+/π^- yield ratios

- Net positive charge in the collision zone
  - expanding spherical source → effective potential
- Extracted parameters include initial ratio R and the full coloumb potential Vc
- Coloumb 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



Coulomb Potential (Vc in MV):
E895: 17.60 +/- 0.56
E866: 16.32 +/- 1.92
Au+Al: 16.45 +/- 1.74

Ratios:
E895: 0.717 +/- 0.004
E866: 0.771 +/- 0.011
Au+Al: 0.858 +/- 0.008

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

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

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

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

Jacobian of the transformation

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

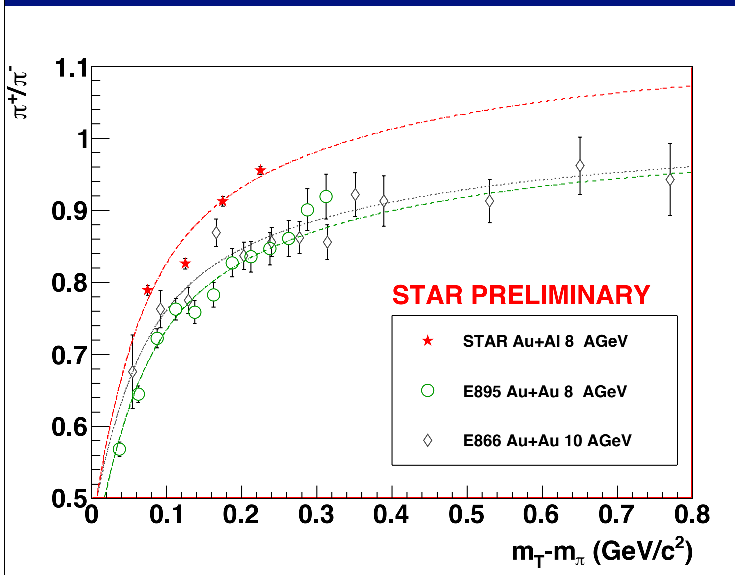
Effective Coulomb potential accounting for the reduced charge seen by low momentum π

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

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

π^+/π^- yield ratios fit parameters




```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  p0        7.71114e-01   1.14871e-02   1.22945e-05  -5.15275e-04
  2  p1        1.63202e+01   1.92414e+00   2.05922e-03  -1.39505e-05
  3  p2        1.12800e-01     fixed
  4  p3        0.00000e+00     fixed
  5  p4        2.28900e-01     fixed
```

E866 Chi^2 1.20046

```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  p0        7.17317e-01   4.43901e-03   8.06105e-06  -5.22883e-05
  2  p1        1.75996e+01   5.60205e-01   1.01731e-03   8.87560e-07
  3  p2        9.80000e-02     fixed
  4  p3        0.00000e+00     fixed
  5  p4        2.25000e-01     fixed
```

E895 Chi^2 1.17822

```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  p0        8.58428e-01   8.42426e-03   3.77270e-06  -1.17553e-04
  2  p1        1.64496e+01   1.74370e+00   7.80892e-04   1.14995e-06
  3  p2        9.80000e-02     fixed
  4  p3        0.00000e+00     fixed
  5  p4        2.25000e-01     fixed
```

STAR Au+Al Chi^2 0.184964

Coulomb Potential:

E895: 17.60 +/- 0.56

E866: 16.32 +/- 1.92

Au+Al: 17.60 +/- 0.86

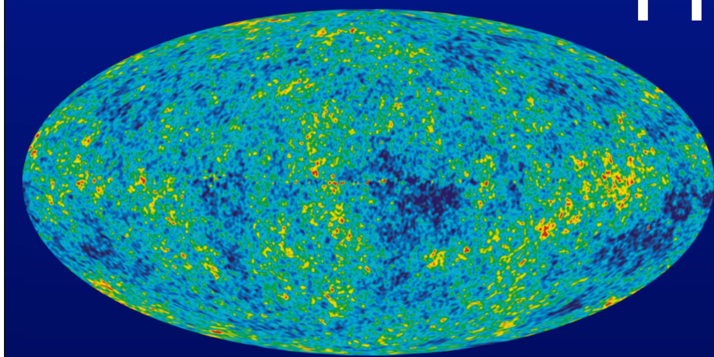
Ratios:

E895: 0.72 +/- 0.00

E866: 0.77 +/- 0.01

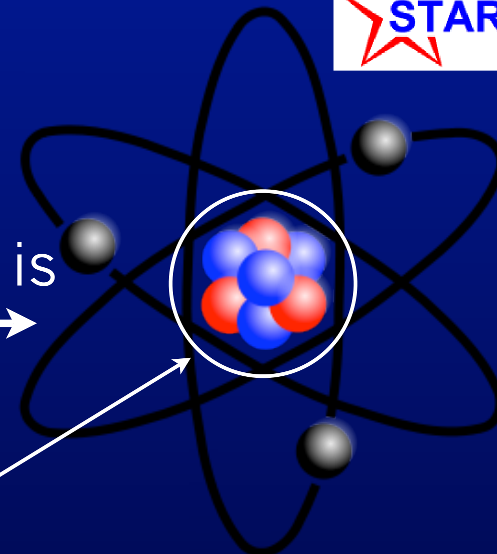
Au+Al: 0.81 +/- 0.00

The Basics

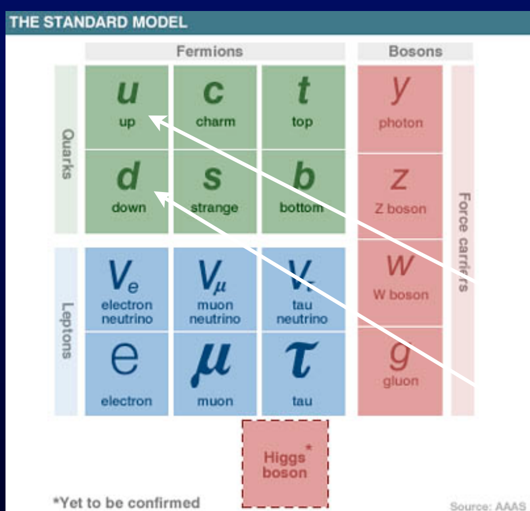


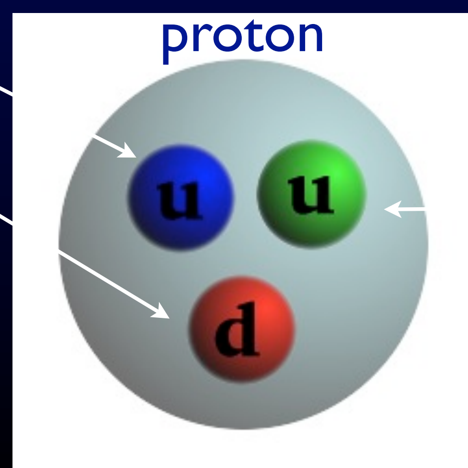
matter in the universe is

made of atoms



nucleus = protons + neutrons

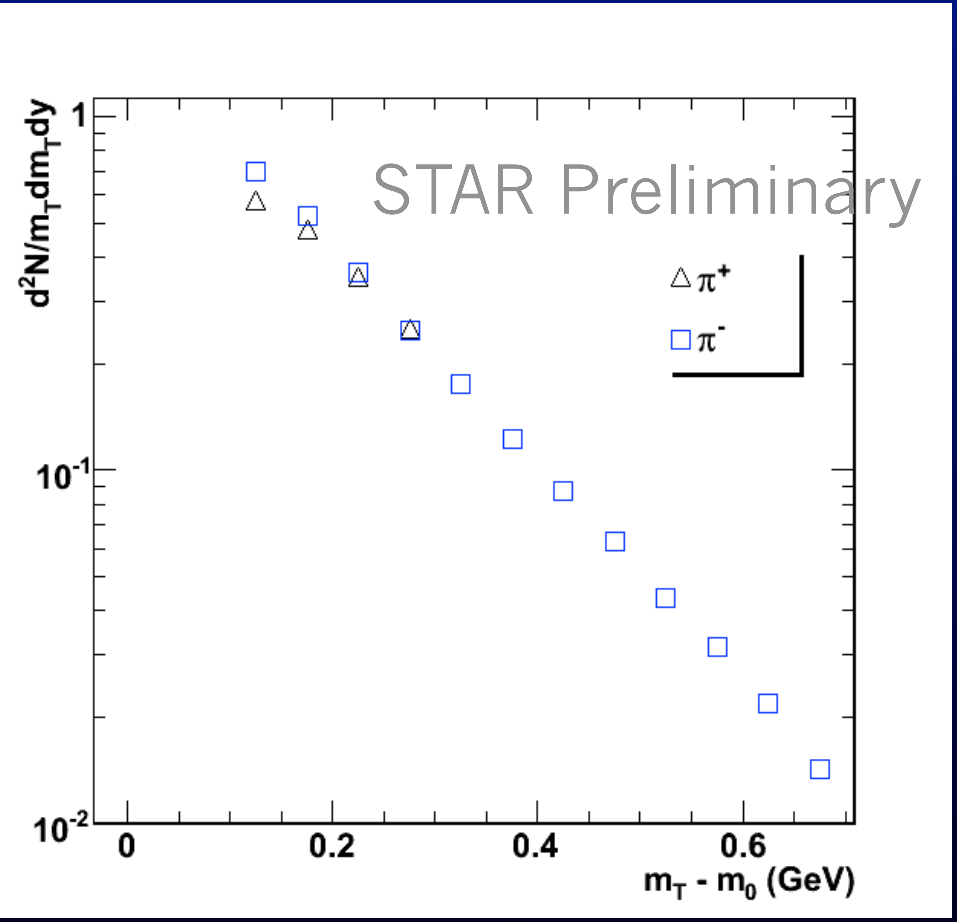




nucleons are hadrons (made of quarks)

mesons = 2 quarks
baryons = 3 quarks

π spectra



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