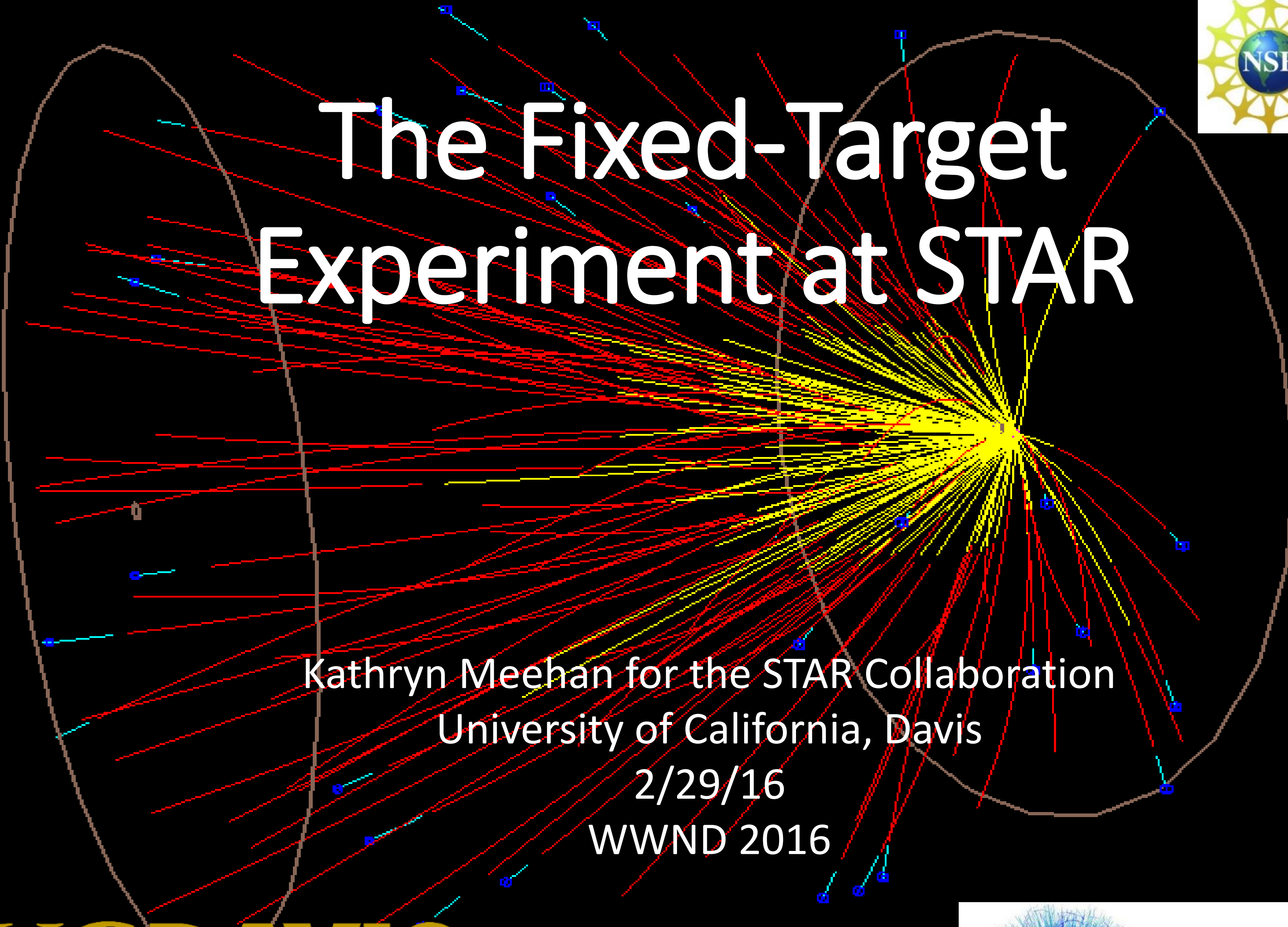


The Fixed-Target Experiment at STAR

Kathryn Meehan for the STAR Collaboration
University of California, Davis

2/29/16

WWND 2016

Outline

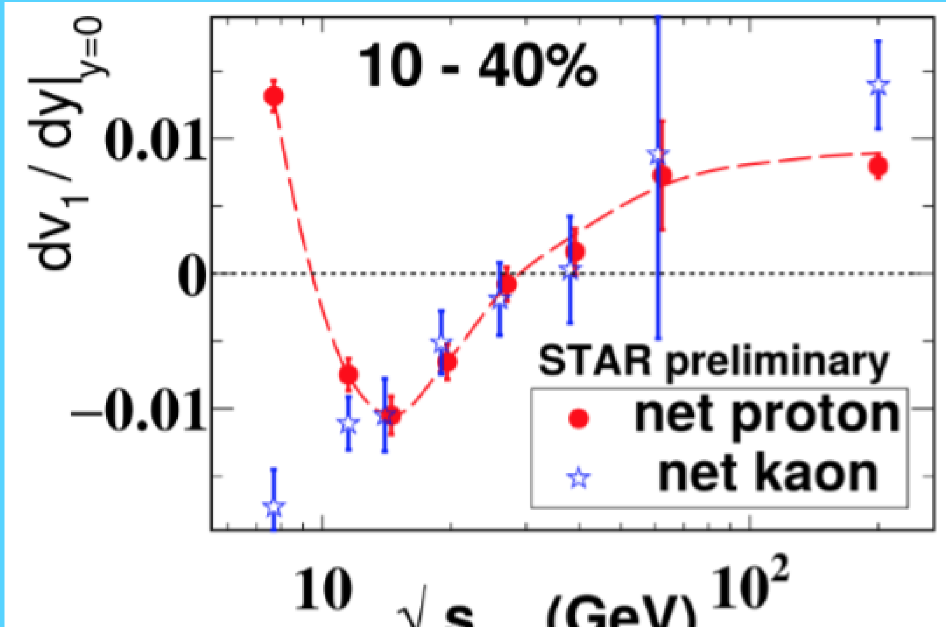
I. Introduction to STAR's Fixed Target (FXT) Program
II. FXT Test Run Results
III. Future & Detector Upgrades
IV. Conclusions

Why a Fixed-Target (FXT) Program?

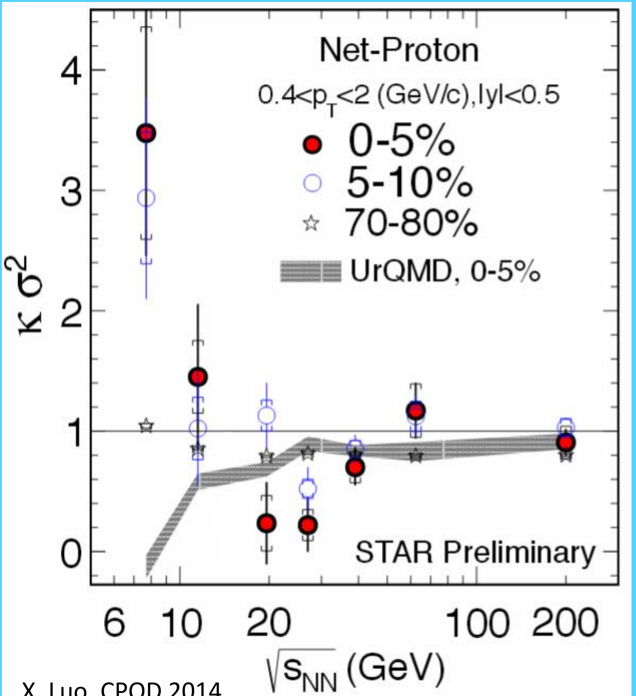
- STAR Beam Energy Scan (BES-I) results suggest a softening of the equation of state (EOS) and hints at critical fluctuations
- To help clarify these hints, STAR needs to access energies below 7.7 GeV where we expect no QGP formation
- At these lower energies the luminosity of RHIC is too low, making it impractical to take data in collider mode

The goals of BES-I:

1) Observe the disappearance of QGP signatures
2) **Find evidence of the first-order phase transition**
3) Find the possible Critical Point



STAR, PRL 112, 162301 (2014)



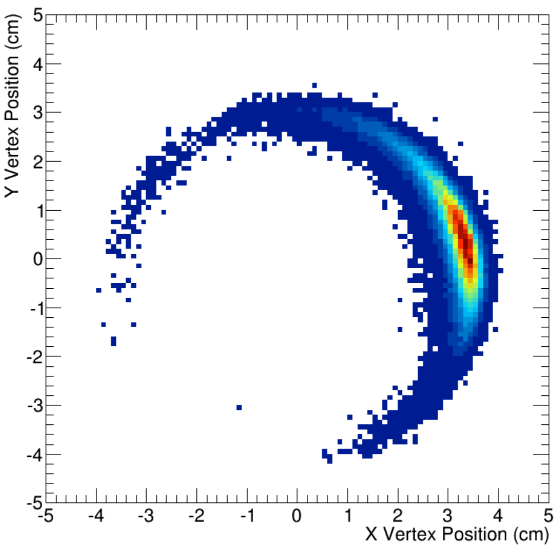
X. Luo, CPOD 2014

RHIC Runs at or Below Nominal Injection Energy:

1. Au+Au 19.6 GeV 2001 (Test Run)	100 k events
2. Cu+Cu 22.4 GeV 2005 (Test Run)	250 k events
3. Au+Au 9.0 GeV 2007 (Test Run)	0 events
4. Au+Au 9.2 GeV 2008 (Test Run)	3 k events
5. Au+Au 7.7 GeV 2010 (Physics)	4 M events
6. Au+Au 11.5 GeV 2010 (Physics)	12 M events
7. Au+Au 5.5 GeV 2010 (Test Run)	0 events
8. Au+Au 19.6 GeV 2011 (Physics)	36 M events
9. Au+Au 5.0 GeV 2011 (Test Run)	1 event
10. Au+Au 14.5 GeV 2014 (Physics)	20 M events

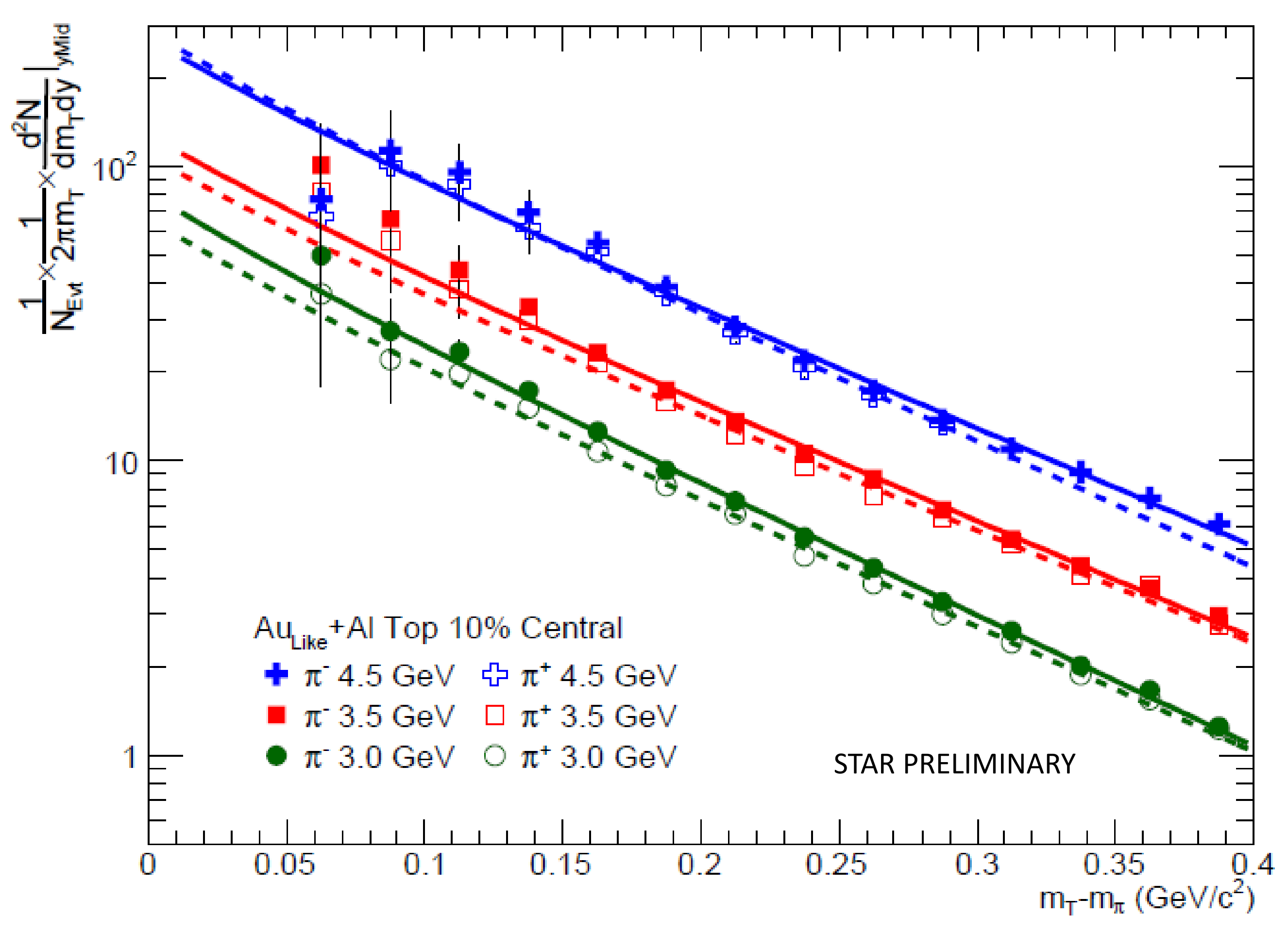
Proof of Principle: Au + Al Beam Pipe Studies

Vertex Distribution of Au + Al Beam Pipe Events



Energy	Particle	T (MeV)
3.0 GeV	π^+	103 ± 3 ± 5
	π^-	99 ± 3 ± 3
3.5 GeV	π^+	115 ± 3 ± 9
	π^-	111 ± 3 ± 8
4.5 GeV	π^+	102 ± 8 ± 10
	π^-	110 ± 4 ± 6

Pion Spectra for the Au + Al Data at $\sqrt{s_{NN}} = 3.0$, 3.5 and 4.5 GeV



- Curves are Bose-Einstein Fits to Spectra

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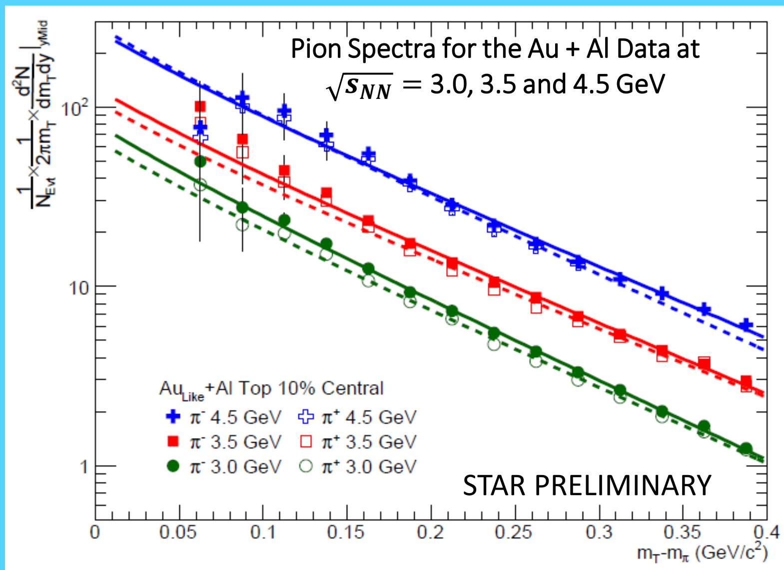
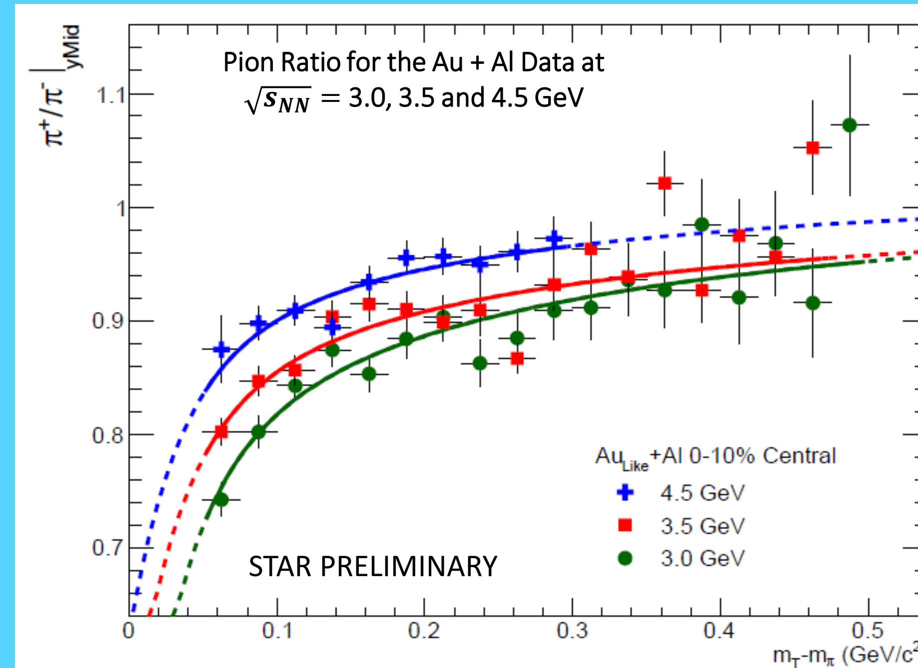
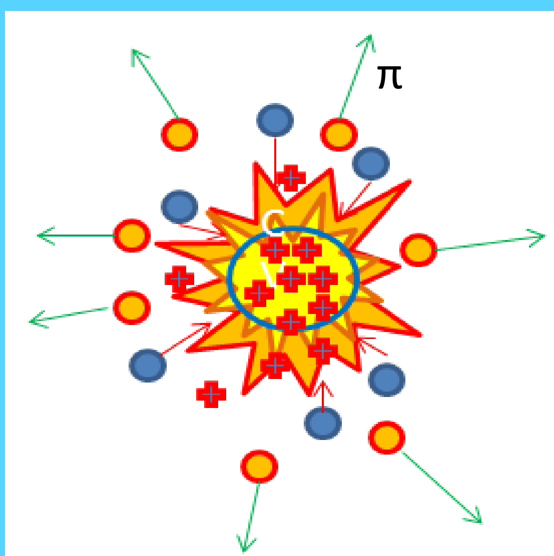
Coulomb Potential







(1) $E_f = E_i \pm V_C$ ← Coulomb Potential

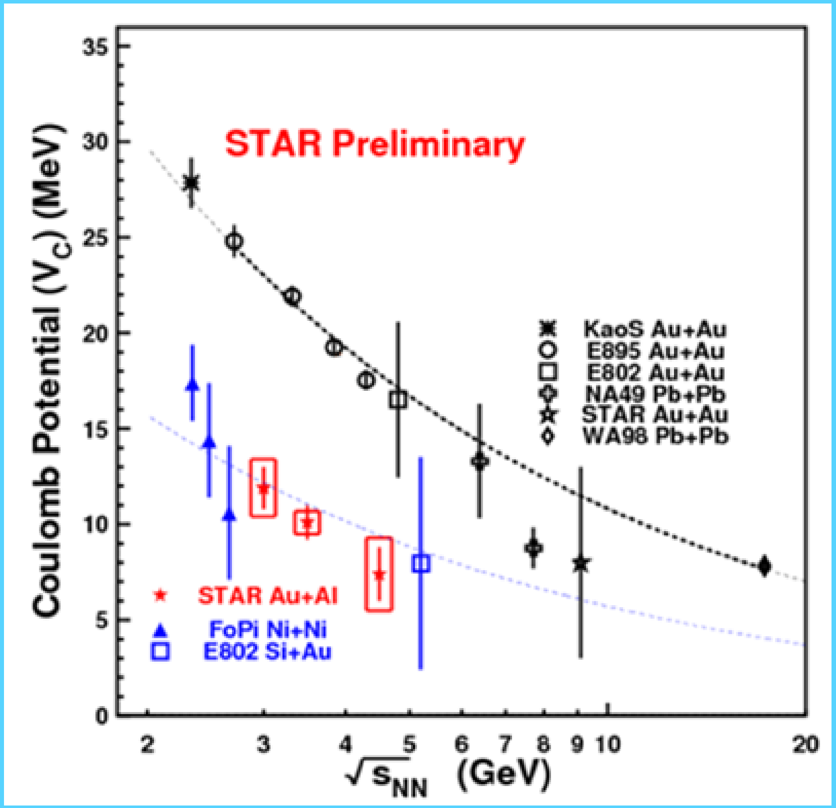
(2) $R_f(E_f) = \frac{E_f - V_C}{E_f + V_C} \frac{\sqrt{(E_f - V_C)^2 - m^2}}{\sqrt{(E_f + V_C)^2 - m^2}} \frac{n^-(E_f - V_C)}{n\ (E_f + V_C)}$ ← Jacobian

(3) $\frac{n^+(E_f - V_C)}{n^-(E_f + V_C)} = \frac{A^+(e^{(E_f + V_C)/T_\pi} - 1)}{A^-(e^{(E_f - V_C)/T_\pi} - 1)}$ ← Bose-Einstein Formulae

(4) $V_{eff} = V_C(1 - e^{-E_{max}/T_p})$

$E_{max} = \sqrt{(m_p p_\pi / m_\pi)^2 + m_p^2} - m_p$ ← Energy where the proton is faster then the pions with a given momentum

Proof of Principle: Au + Al Beam Pipe Studies



- **Coulomb Potential has been extracted and shown to be consistent with previous experiments**

- **STAR software framework can successfully reconstruct fixed target vertices and has good acceptance and PID capabilities up to mid-rapidity**

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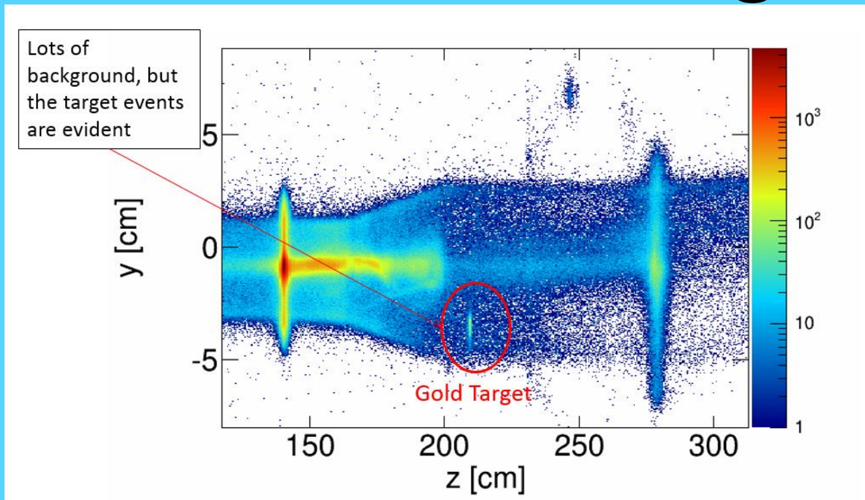
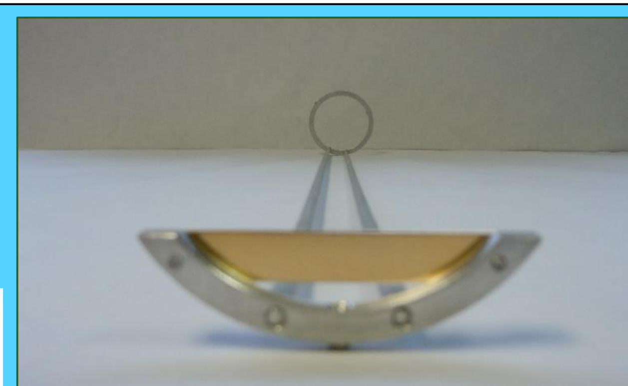
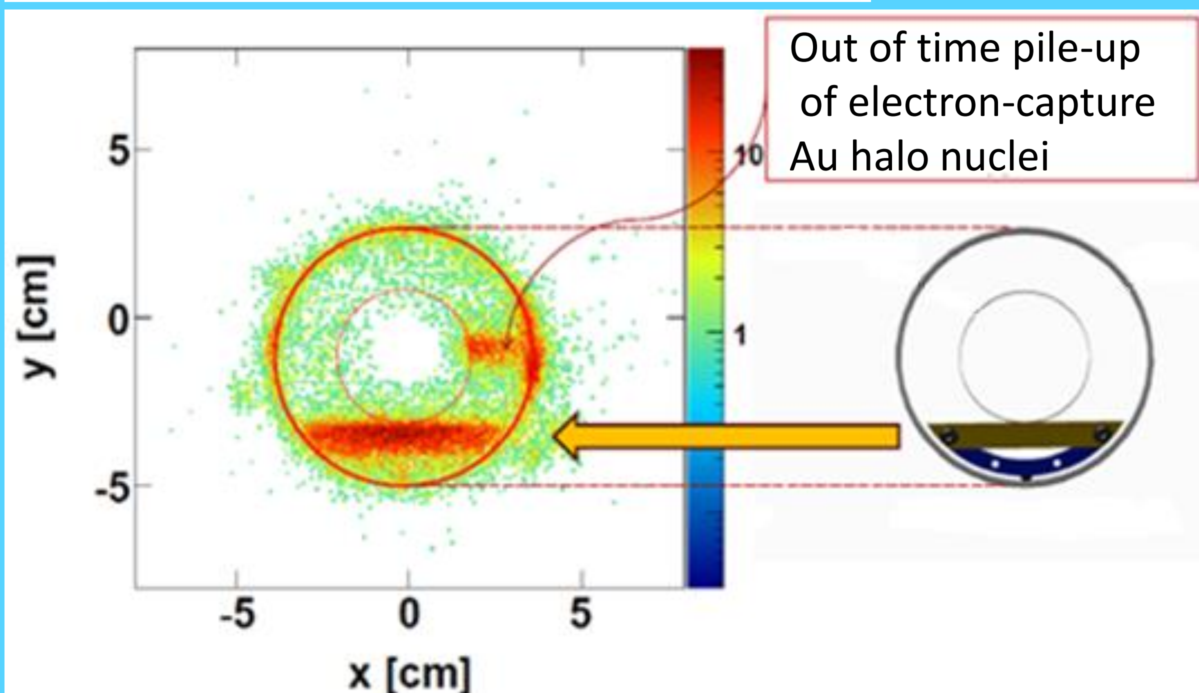
Gold Target Installed for Run 14

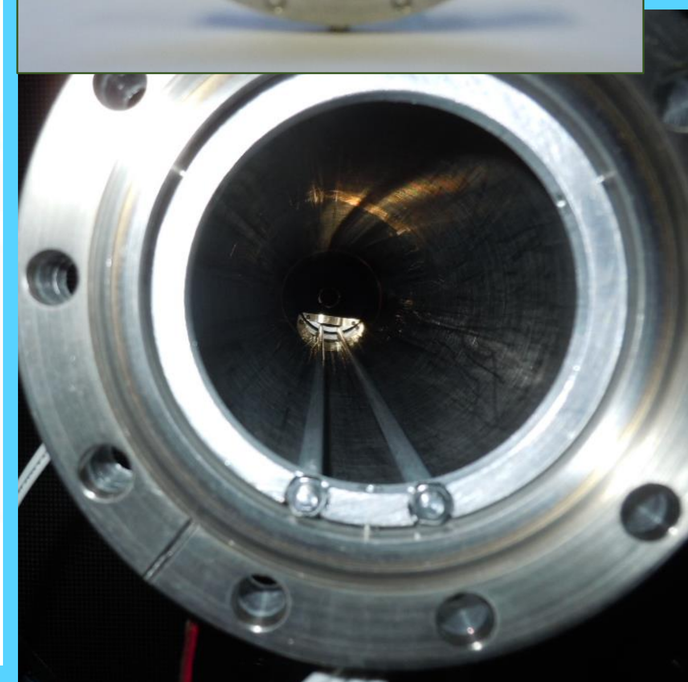


Run 14 details:

- Fixed Target 3.9 GeV data taken concurrently with 14.5 GeV Au + Au collider events
- The target foil is held 2 cm below of the beam axis.
- The foil is 1 mm thick (4%).

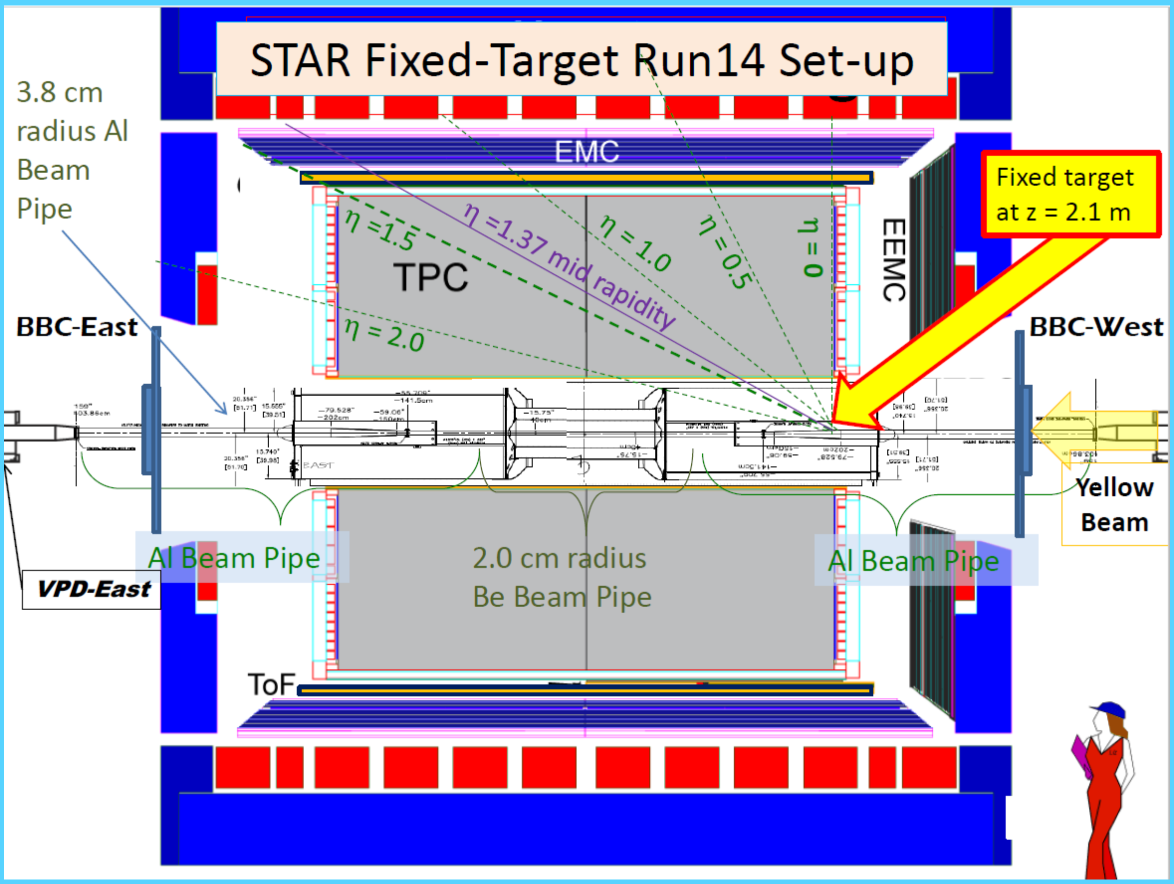


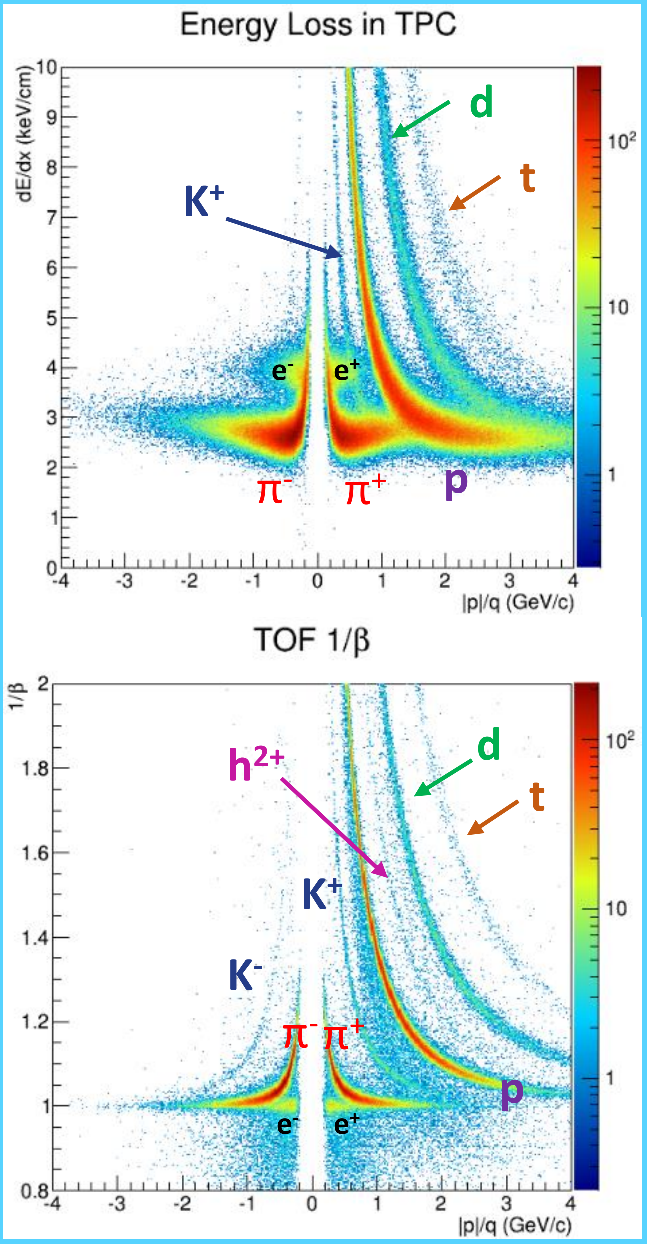




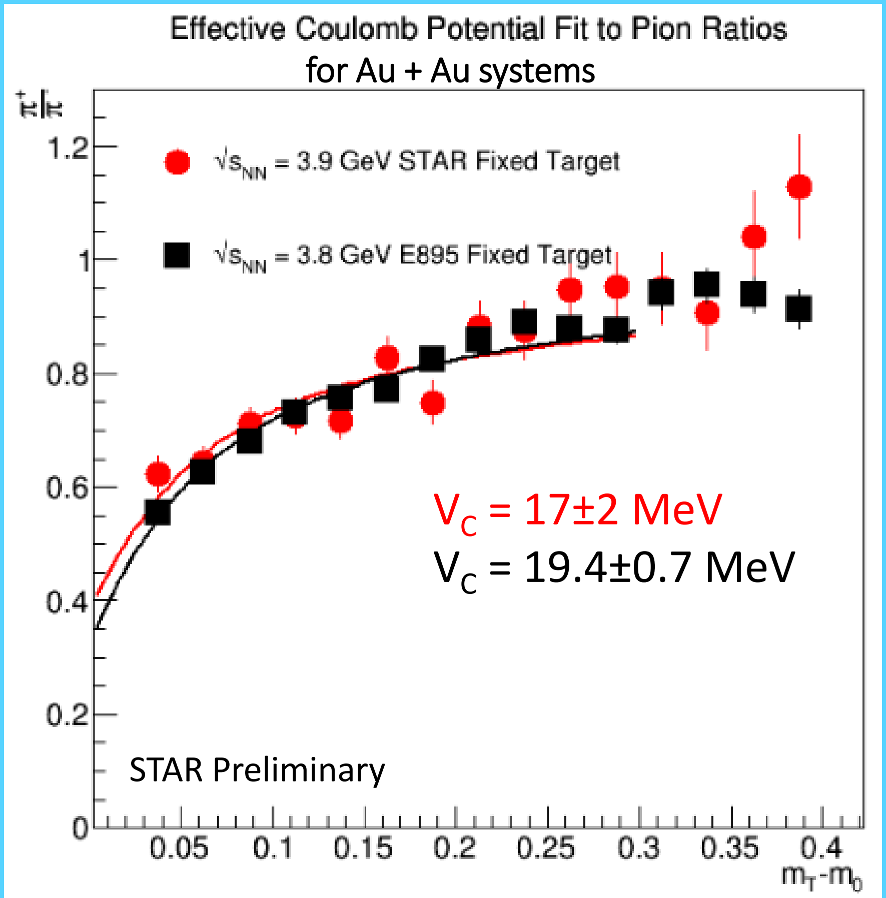
3.9 GeV Au + Au Test Run

Excellent PID with Time Projection Chamber (TPC) and Time of Flight (TOF) detectors for fixed target events

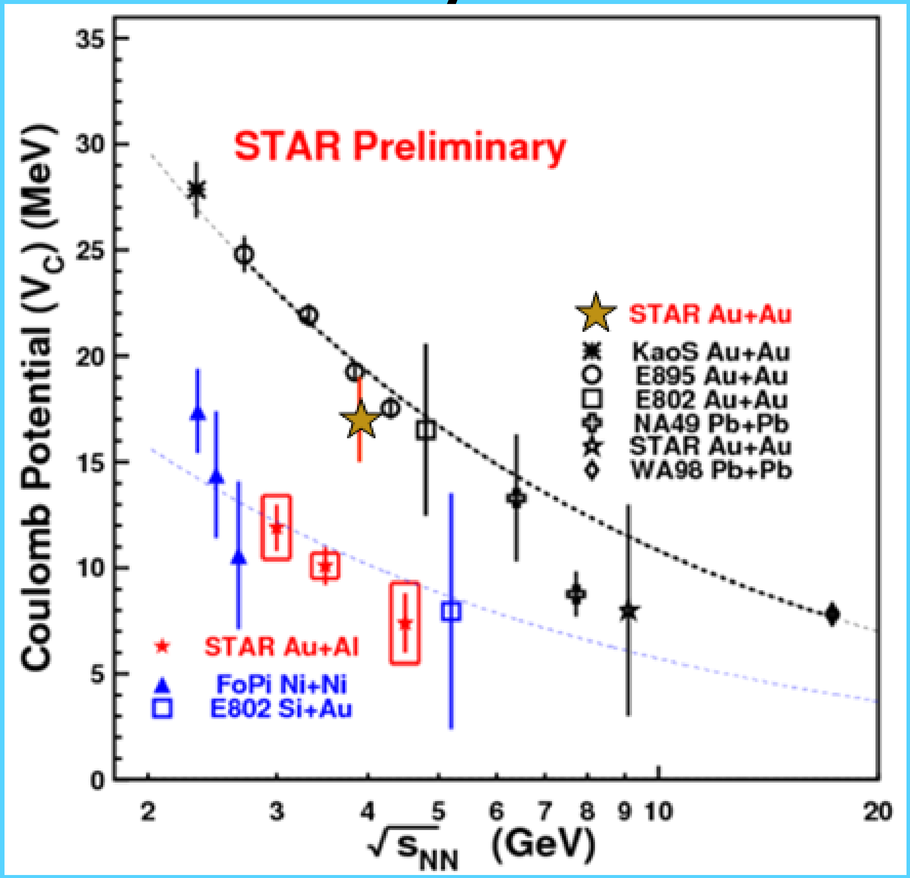




Coulomb Potential Analysis



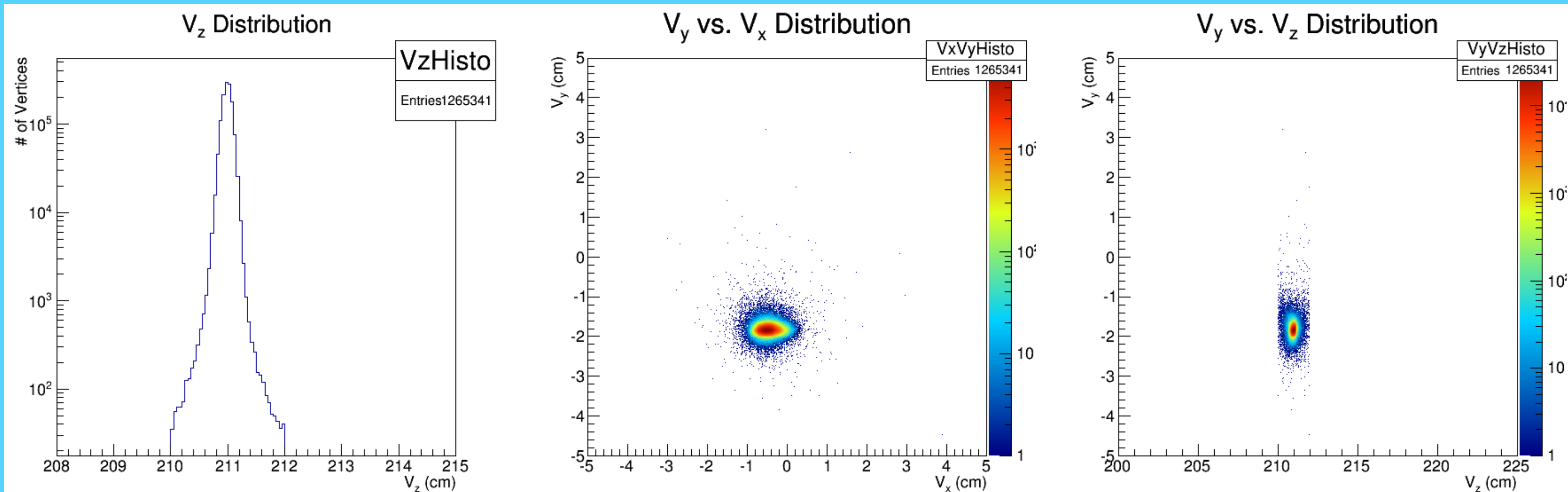
J. Klay et al.(E895 Collaboration), Phys. Rev. C 68,054905 (2003)

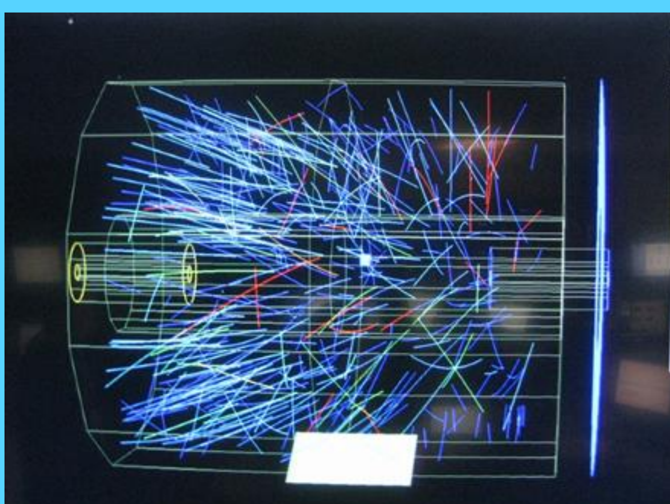


arXiv:1408.1369

- **Our result for Coulomb potential is consistent with previous experiments**
- **Projectile is consistent with gold ion**

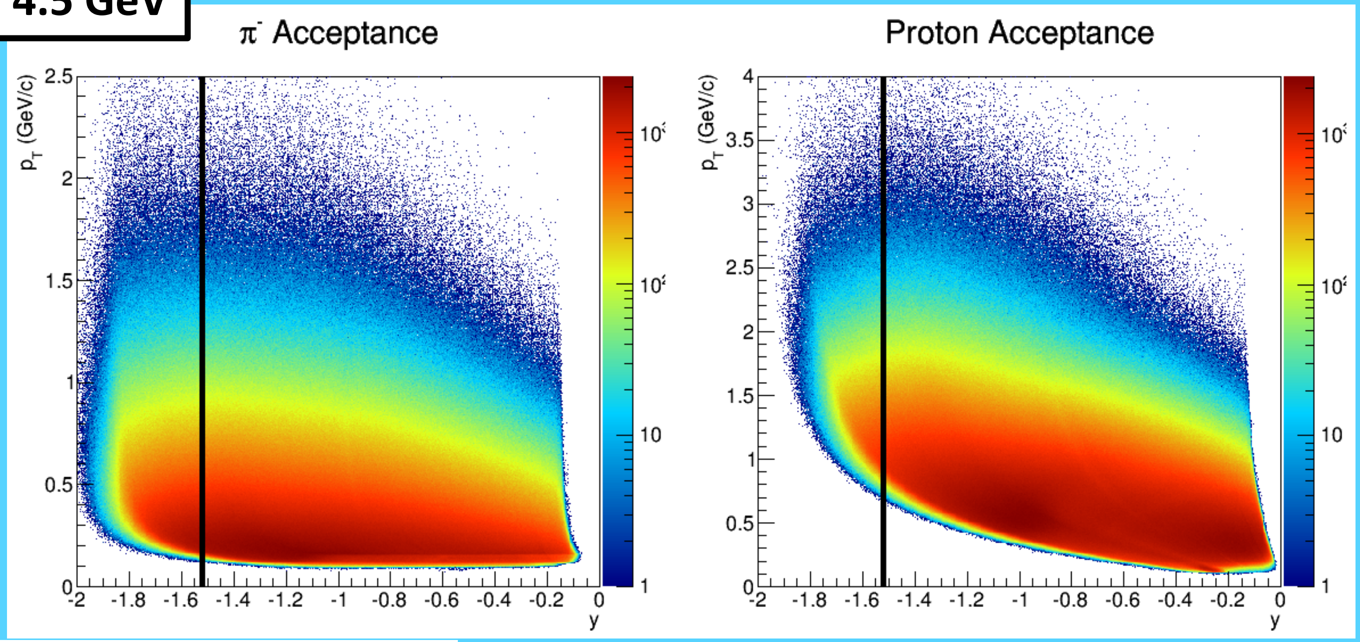
Au + Au $\sqrt{s_{NN}}$ = 4.5 GeV 2015 Test Run Performance

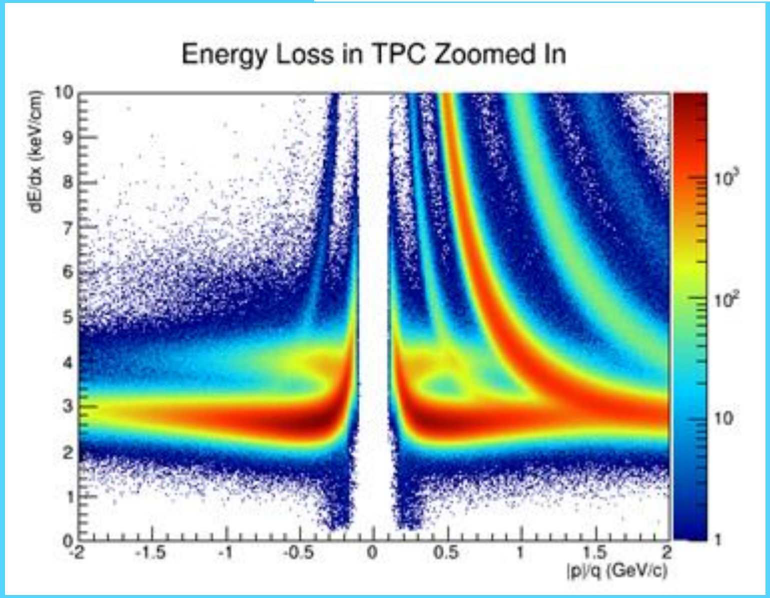




- May 20th, 2015 4 hour test run
- Dedicated FXT test run (not concurrent running)
- 6 bunches, ~1.3 million triggers
- Beam lowered to graze the top edge of the target

Au + Au $\sqrt{s_{NN}}$ = 4.5 GeV





- Can take ~1 million events in half an hour, as opposed to ~5000 events in 3 weeks
- Dedicated fixed target runs are a better conduct of operations than concurrent runs
- Official production completed, awaiting embedding
- Coming soon: HBT, fluctuation, spectra, flow results…

STAR

Paper Proposal for FXT 4.5 GeV

- Broad paper to reproduce AGS results and establish STAR's FXT Program
- Further studies with newer analyses techniques and draw deeper conclusions will most likely need separate papers

At AGS there was a scan of energies done with gold beams:

1993 11.7 AGeV/c ($\sqrt{s_{NN}}$ = 4.9)

1994 & 1995 2, 4, 6, and 8 AGeV ($\sqrt{s_{NN}}$ = 2.7, 3.3, 3.8, 4.3)

Fixed-target experiments:

E866/E917 (Spectrometer) [Previously E802/E859]

E891 (MPS TPC) [Previously E810]

E877 (Forward Calorimeter) [Previously E814]

E895 (EOS TPC) [Only 2, 4, 6, and 8 AGeV]

AGS Results: Spectra

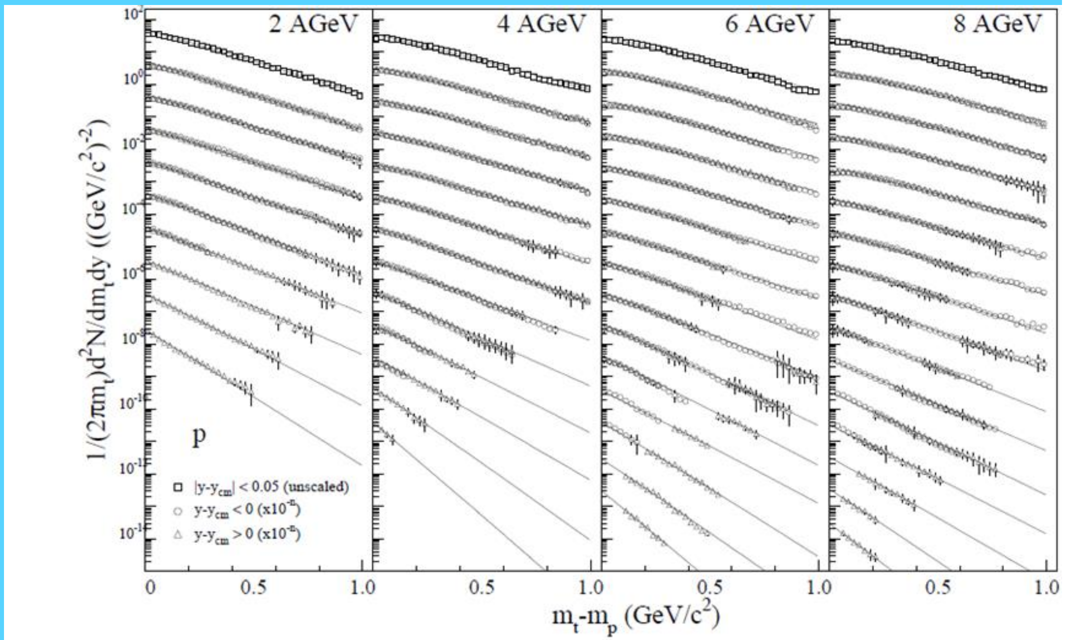


FIG. 1: Invariant yield per event as a function of m_t-m_0 for protons in central Au+Au collisions at 2, 4, 6, a
Midrapidity is shown unscaled, while the 0.1 unit forward/backward rapidity slices are scaled down by successive f

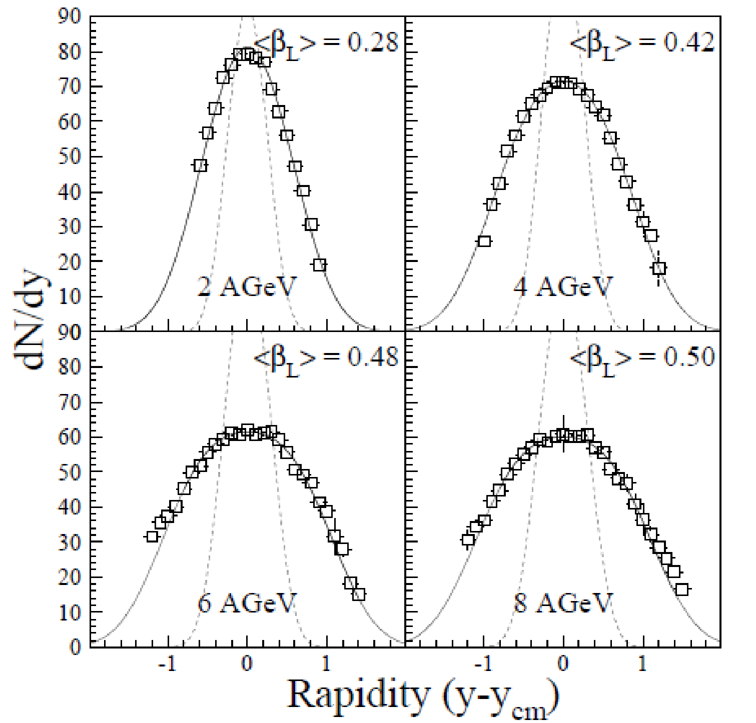
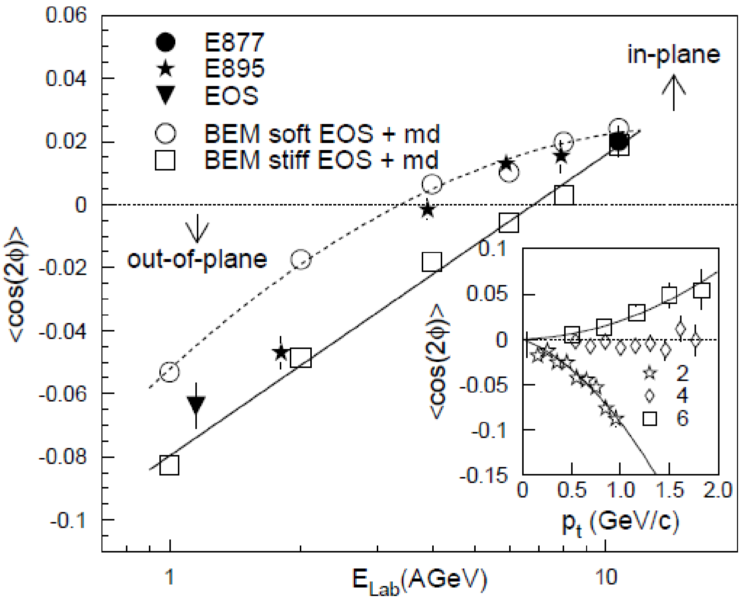


FIG. 2: Proton rapidity distributions in central Au+Au collisions at 2, 4, 6, and 8 AGeV. The dashed curves correspond to isotropic emission from a stationary thermal source with temperatures given by the mid-rapidity inverse slope parameters from the transverse mass fits (Eq. (2)), whereas the solid curves indicate fits with longitudinal flow (Eq. (3)).

E895_PRL88(2002)102301

- Measurements of the Coulomb potential and the rapidity density distributions contain information about stopping and size of the thermal source

AGS Results: Flow



E895_PRL83(1999)1295

E895_PRL84(2000)5488

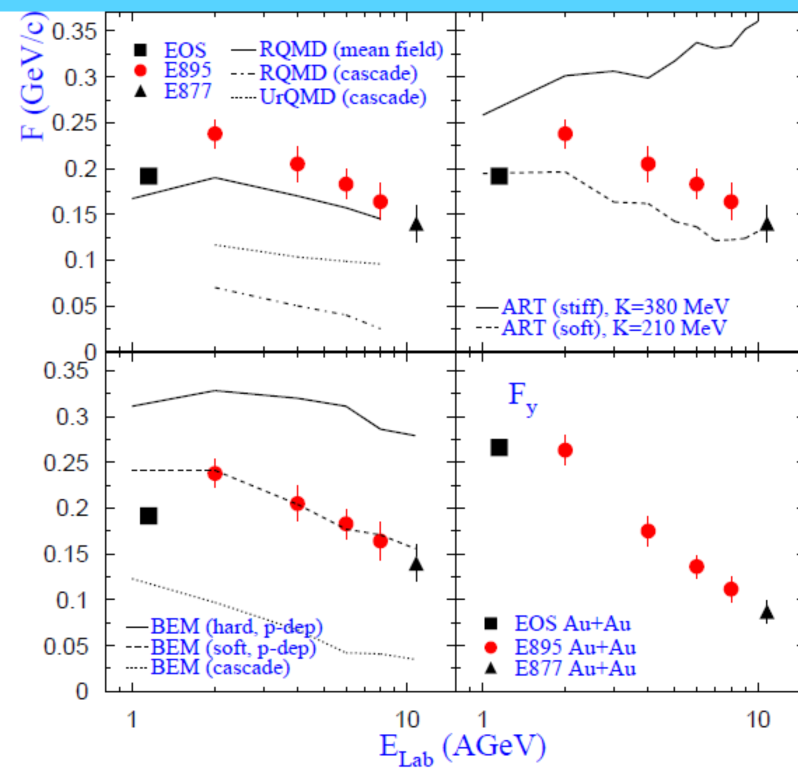


FIG. 2. Proton flow magnitude as a function of beam energy; the lower right panel shows the measured F_y, while the other three panels show identical measurements of the parameter F, with different transport model calculations superimposed. The error bars include systematic uncertainties.

- Comparing flow measurements with models can help distinguish between different equations of state. If a softening of an equation of state is detected, this is consistent with a phase transition

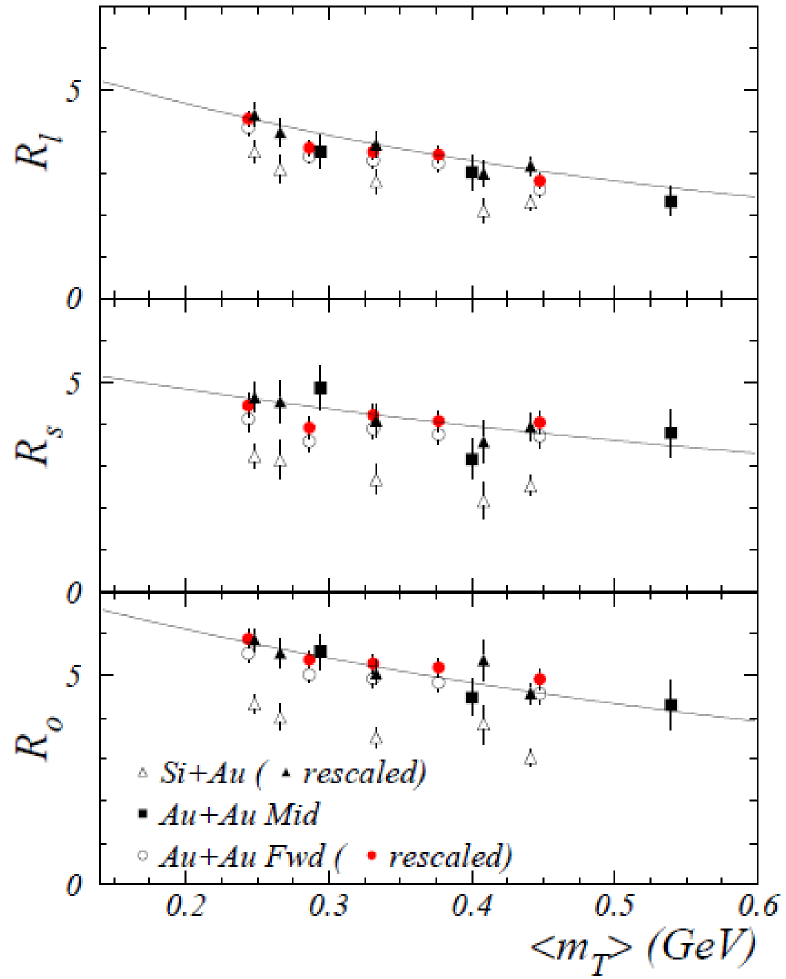


FIG. 8: m_T dependence of Bertsch-Pratt radii for Si+Au, Au+Au, Au+Au at forward rapidity [44], and for Si+Au rescaled by $N_{\text{total}}^{1/3}$ to match Au+Au. The solid line is a fit of the form $e^{(a+bm_T)}$ to the Si+Au points, rescaled according the $N_{\text{total}}^{1/3}$ for Au+Au. The Au+Au forward rapidity data are also shown after being rescaled to match the mid-rapidity centrality condition.

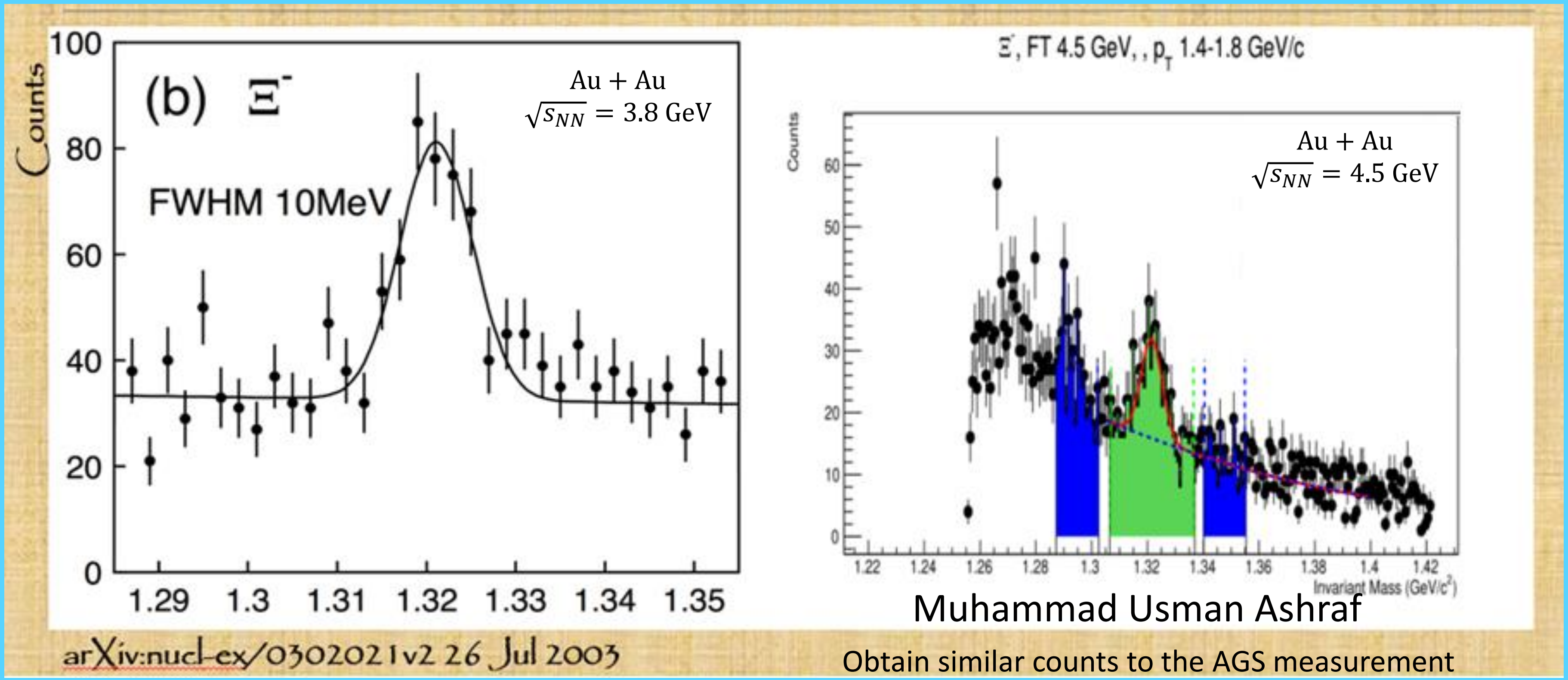
AGS Results: HBT

- Correlations of identical pions are sensitive to the source dimensions
- R_{long} is along the beam axis
- R_{out} is in the direction of the average of the two particle's momenta
- R_{side} is then perpendicular to the other two axes.

E802_PRC66(2002)054096

Hyperons and Hypernuclei in FXT

Comparison of Xi (Ξ) signal with E895 Collaboration

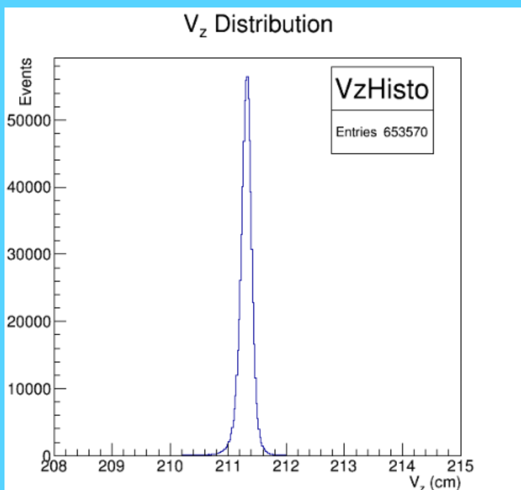


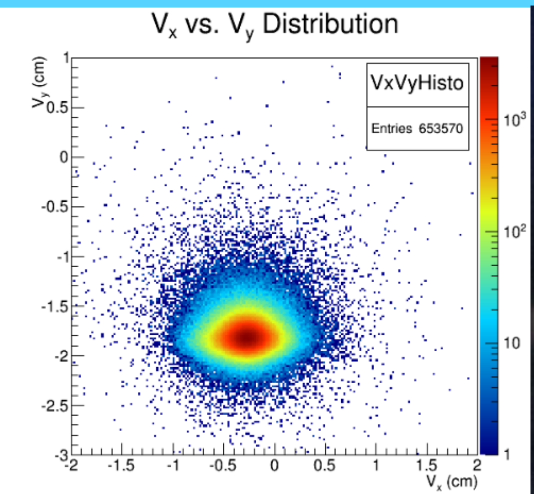
Muhammad Usman Ashraf

Obtain similar counts to the AGS measurement

- Expect to be able to reconstruct cascades and singly-strange hypernuclei
- Expect integrated luminosity to be too low for measurement of omegas, doubly-strange hypernuclei

Al + Au $\sqrt{s_{NN}}$ = 4.9 GeV





June 16, 2015

- 2 hour test run
- ~ 3 million triggers
- $\sqrt{s_{NN}}$ = 4.9 GeV, y_{mid} = -1.62

➢ Can obtain second half of phase space to complement beam pipe studies

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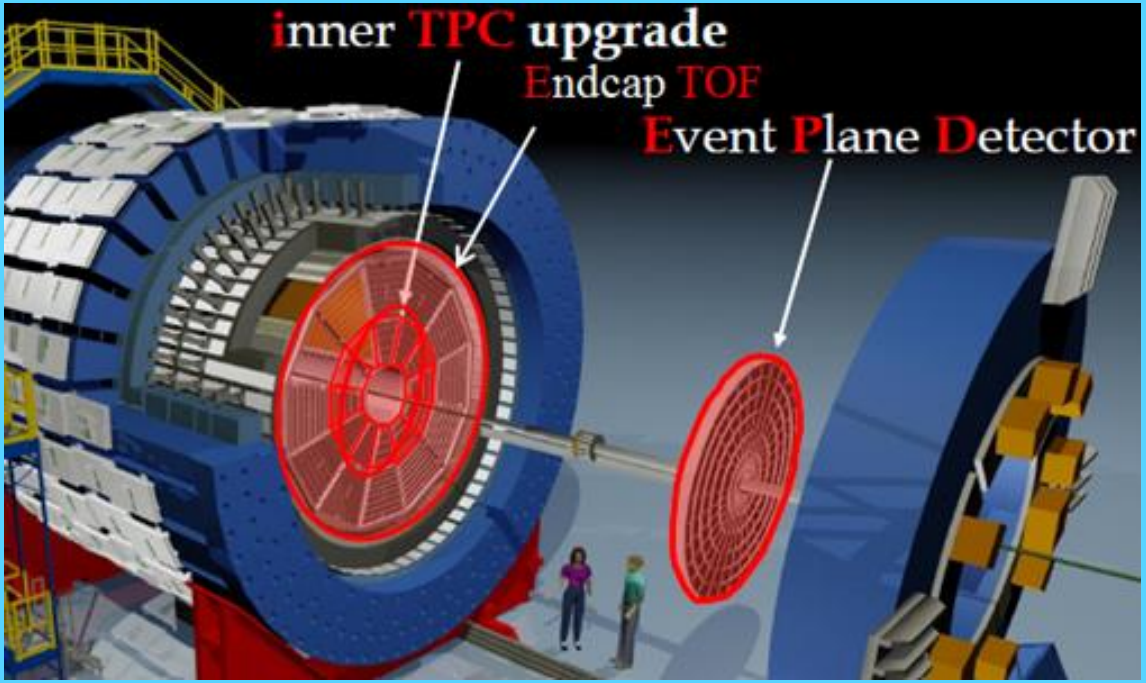
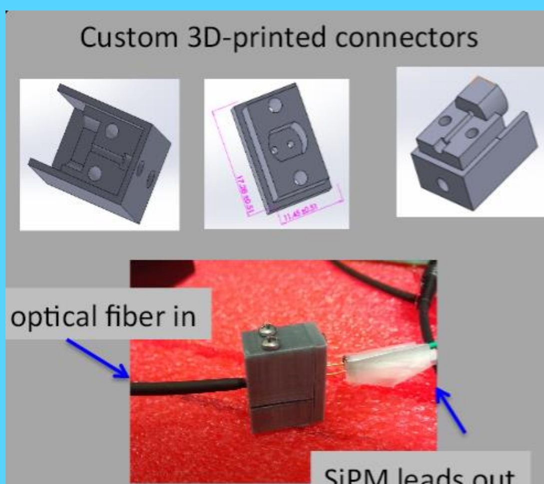
Future: BES-II

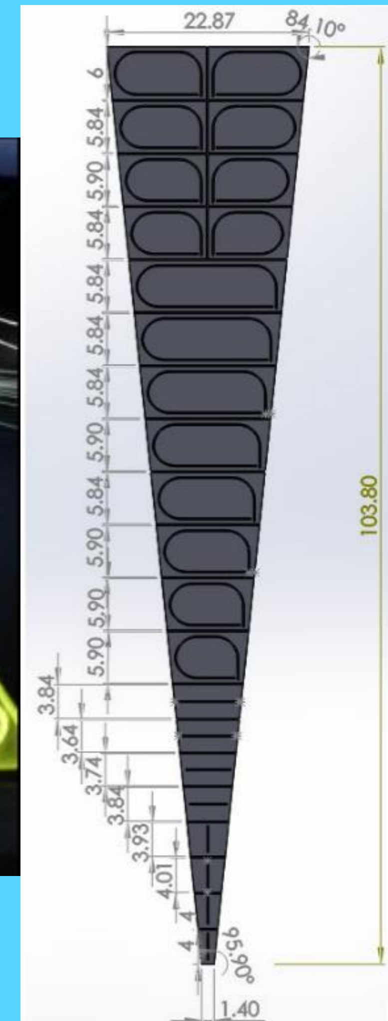


- FXT Program will collect huge statistics up to ~50 million events per day
- 1-2 days of dedicated fixed target running at each energy would collect sufficient statistics to extend BES-II to lower energies
- Detector upgrades would extend our midrapidity acceptance for additional fixed target energies
- Physics goals include looking for a 1st order phase transition (eg. dv_1/dy…) and clarifying evidence for a critical point (eg. kurtosis…)

Event Plane Detector (EPD)

- To improve event plane resolution
- Can be used for triggering in FXT
- Full coverage to beam rapidity
- Prototype has 24 sectors, 16 tiles/sector

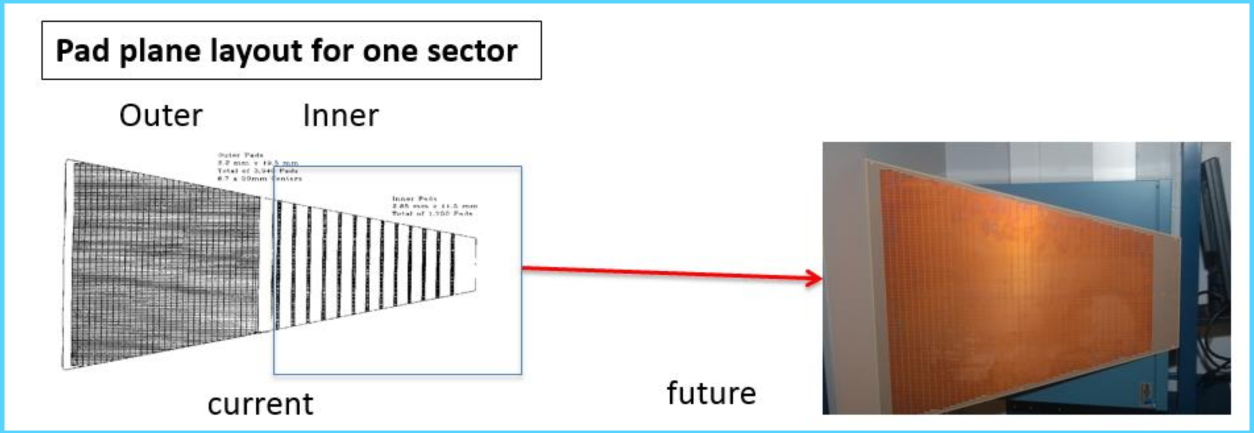




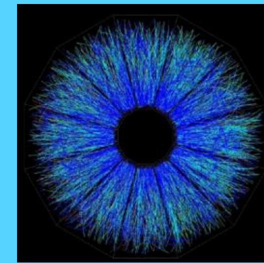
Current status: Prototype installed on STAR's East side

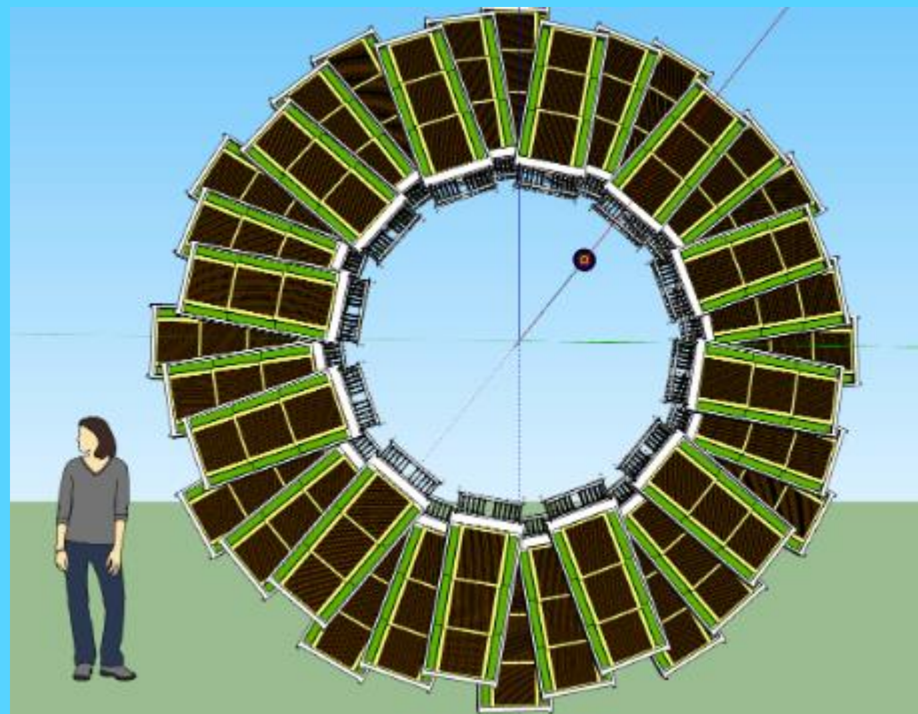
inner Time Projection Chamber (iTPC)

- Upgrade to inner sectors of TPC: electronics are now smaller an can pack them denser, increasing # of pad rows from 13 to 40 → can have continuous pad row coverage
- Increases track path length sampled by inner pads from 20% to 95%
- Provides better momentum resolution and dE/dx resolution
- Extends acceptance from $|\eta| \leq 1.0$ to $|\eta| \leq 1.5$



eTOF: +





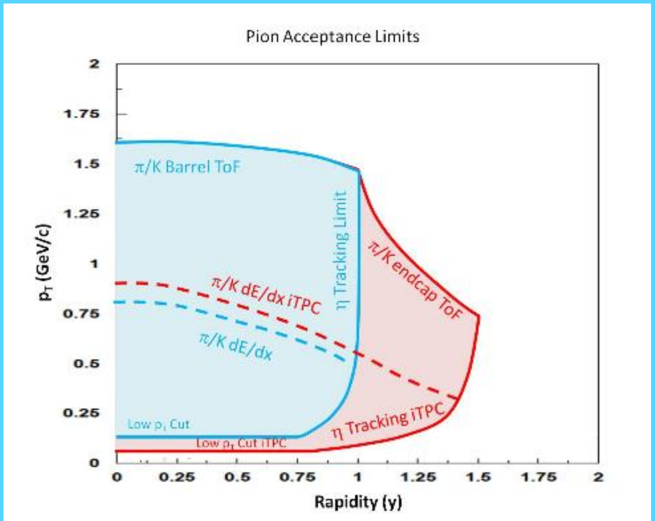
CBM and STAR in cooperative agreement:

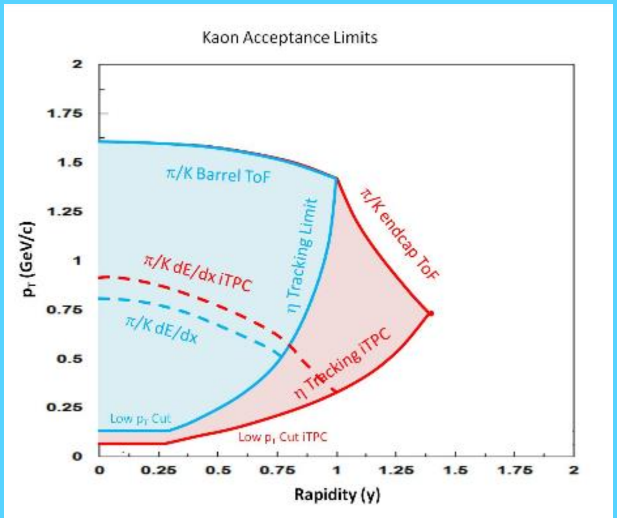
STAR-> gets an endcap TOF for BES-II

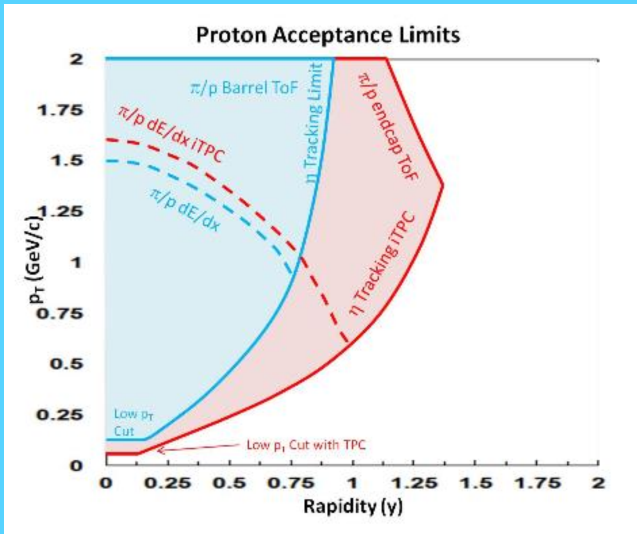
CBM-> gets a large-scale integration test of their TOF system

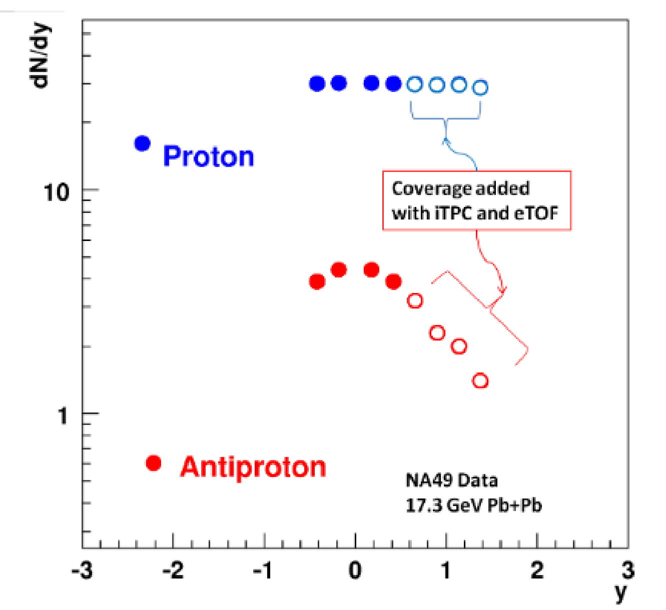
108 of 1376 CBM MRPCs will be used in STAR for BES-II, then returned to CBM

eTOF + iTPC in BES-II:





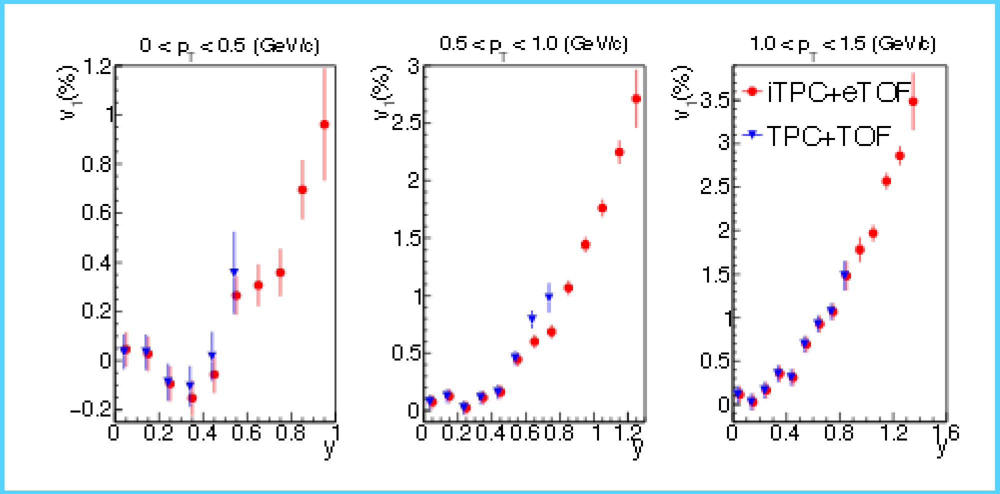




- Increases acceptance for tracking and PID

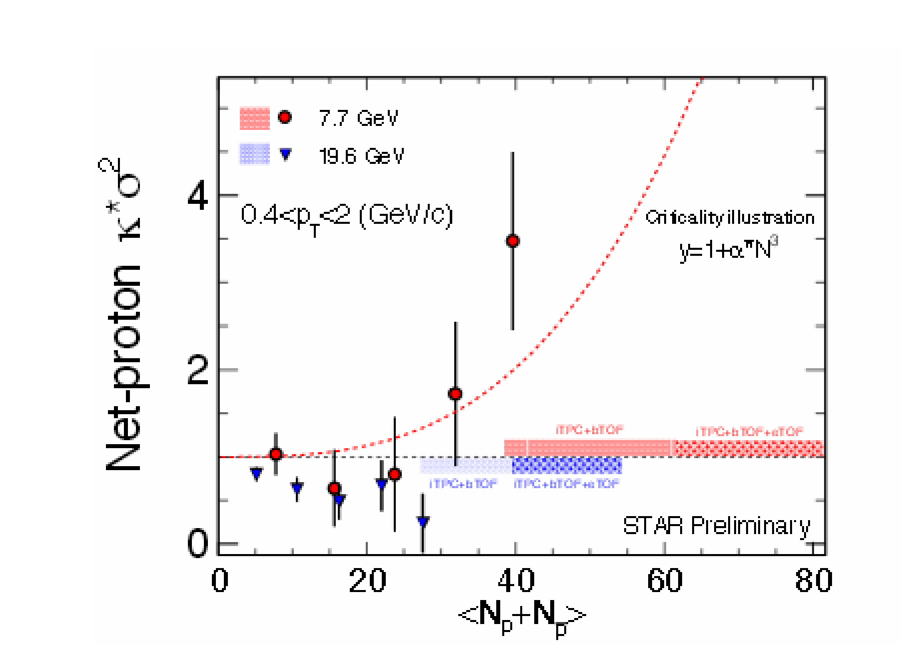
STAR

eTOF + iTPC in BES-II:

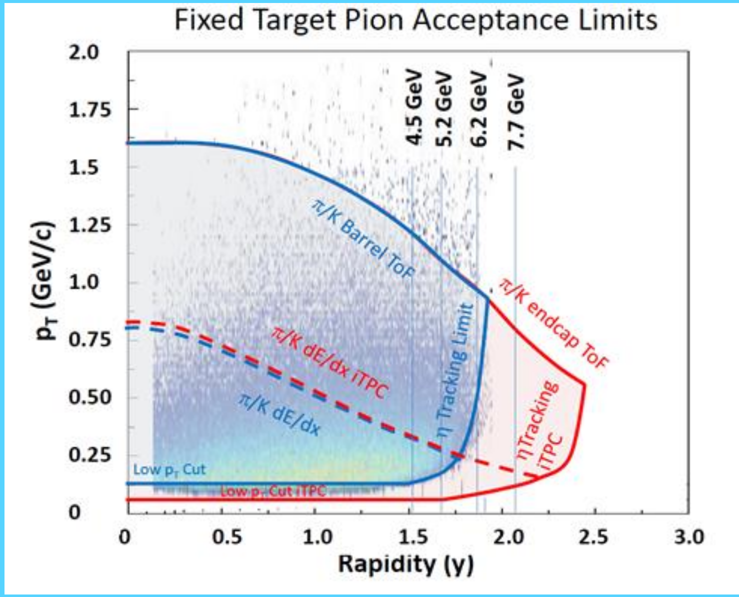


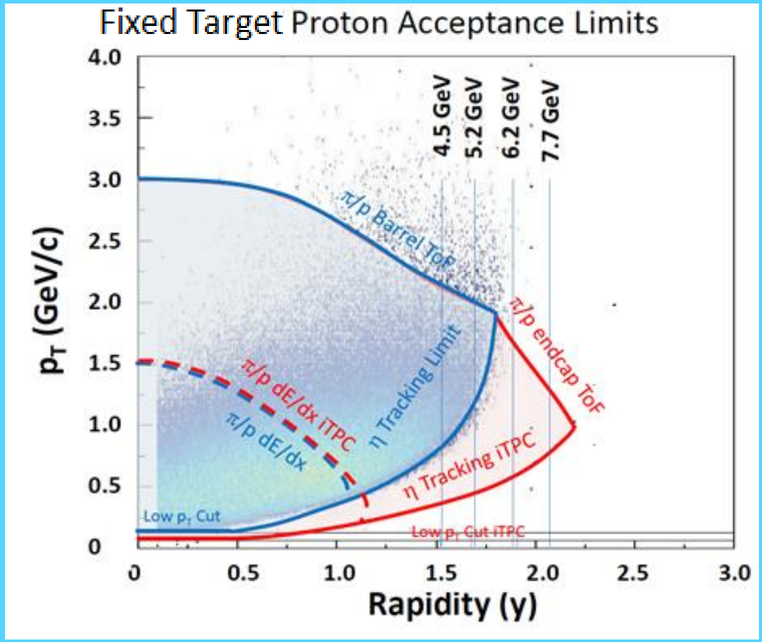
UrQMD simulations show v_1 signal before and after improvements in acceptance and PID from iTPC and eTOF.

Acceptance improvements for net-proton kurtosis with iTPC+bTOF and iTPC+eTOF



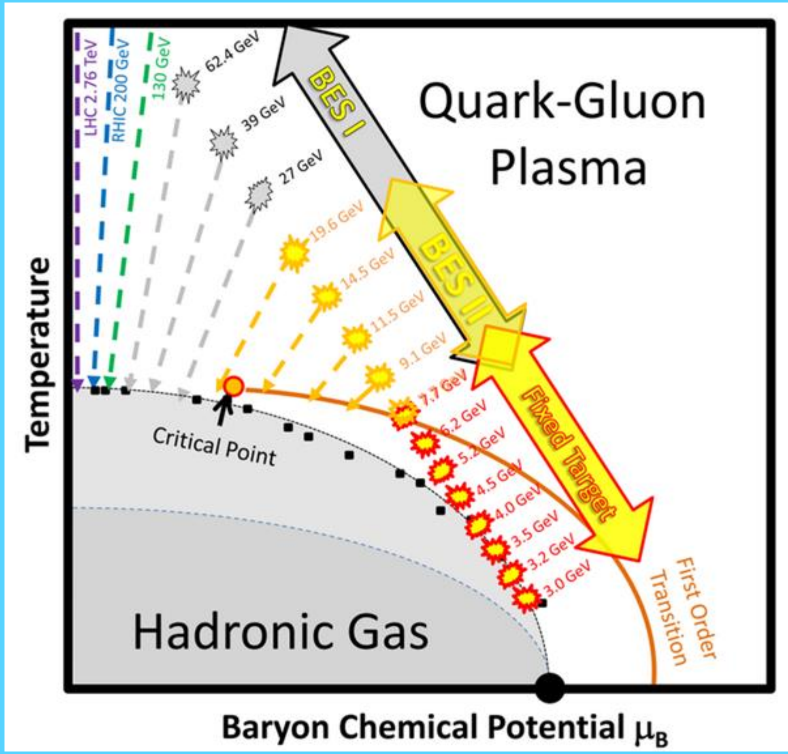
eTOF + iTPC in FXT:





- **Increased acceptance for tracking and PID allows the FXT experiment to extend its energy range to 7.7 GeV allowing comparisons with collider analyses.**

Conclusions



- Successful FXT test runs demonstrated that dedicated runs are a preferable conduct of operations to concurrent runs
- Coulomb potentials were also measured and are consistent with previous experiments
- The detector upgrades will extend the FXT program up to $\sqrt{s_{NN}} = 7.7$ GeV which will allow for comparison with collider mode analyses at the same energy
- The FXT program will allow us to extend BES-II down to $\sqrt{s_{NN}} = 3.0$ GeV