The Fixed-Target Experiment at STAR

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RHIC & AGS Users Meeting

UCDAVIS

STAR

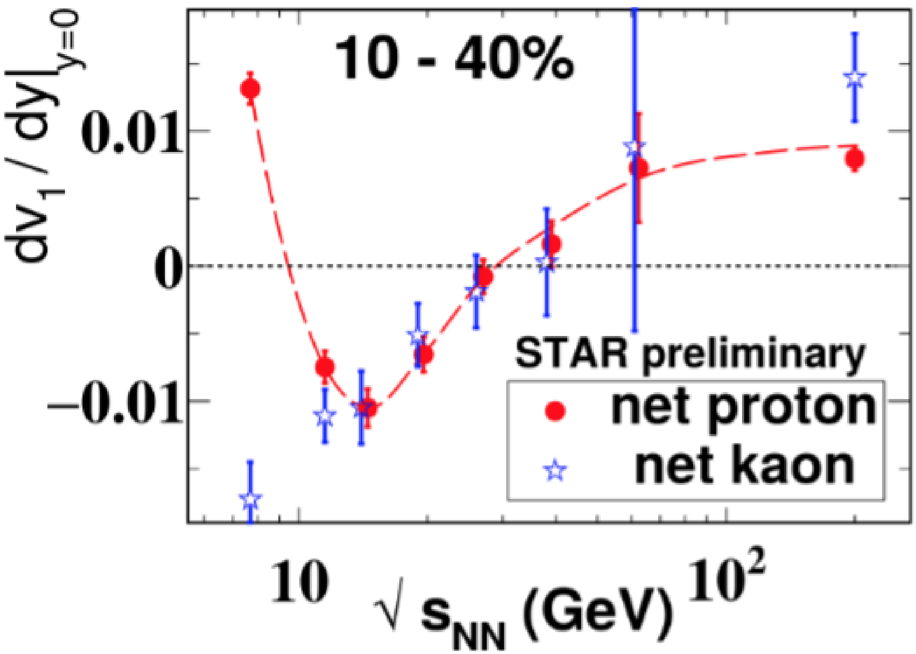
Outline

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

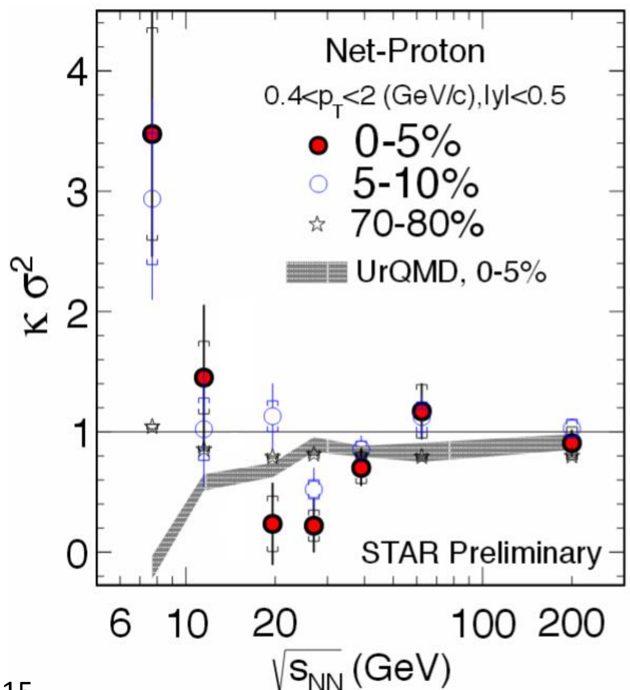
Why a Fixed-Target (FXT) Program?

- 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 possible first-order phase transition**
3) Find the possible Critical Point



P. Shanmuganathan for the STAR Collaboration, Quark Matter 2015.



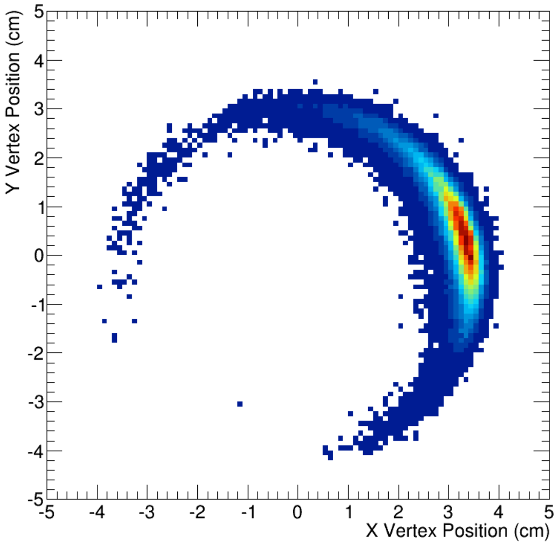
X. Luo, J. Phys.: Conf. Ser. 599, 012023 (2015). [arXiv:1501.03010].

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

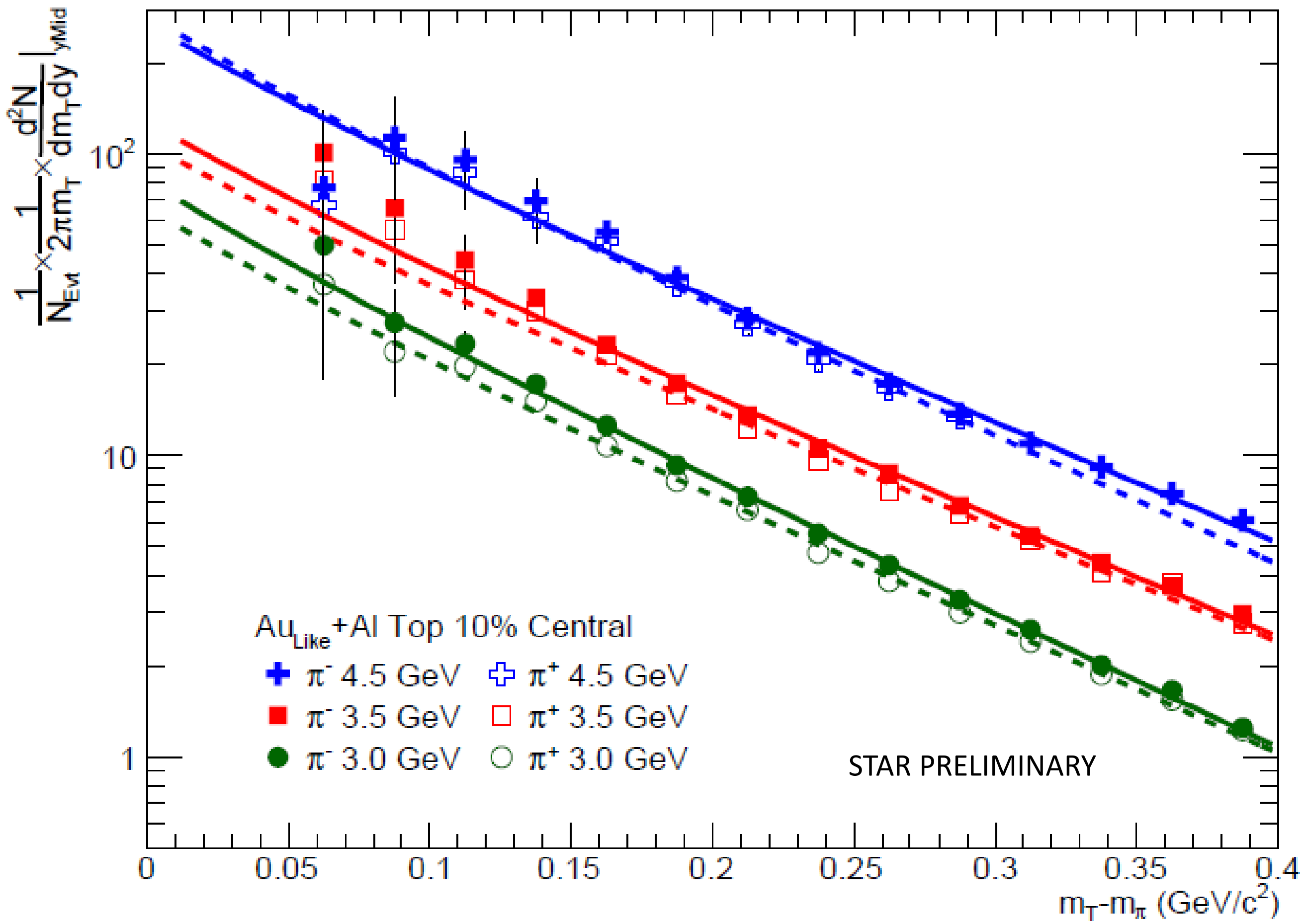
Proof of Principle: Au + Al Beam Pipe Studies

Vertex Distribution of Au + Al Beam Pipe Events



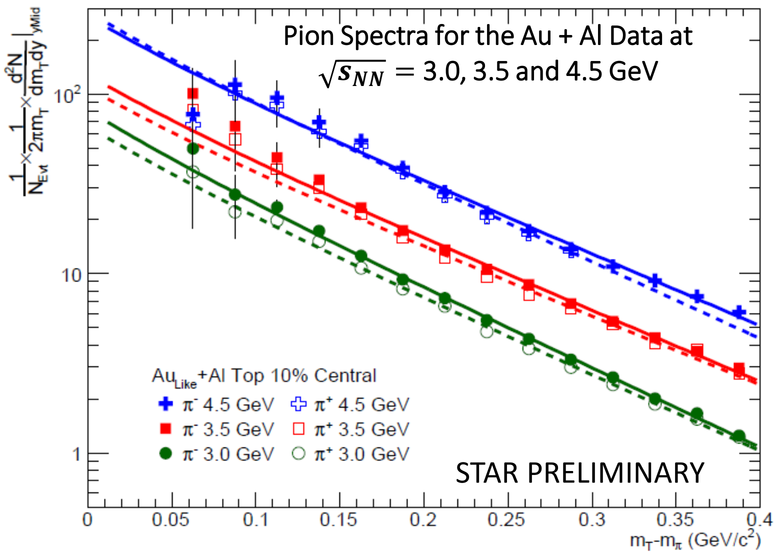
Energy	Particle	T (MeV)
3.0 GeV	π^+	103 ± 3 ± 5
	π^-	99 ± 3 ± 3
3.5 GeV	π^+	115 ± 3 ± 9
	π^-	111 ± 3 ± 8
4.5 GeV	π^+	102 ± 8 ± 10
	π^-	110 ± 4 ± 6

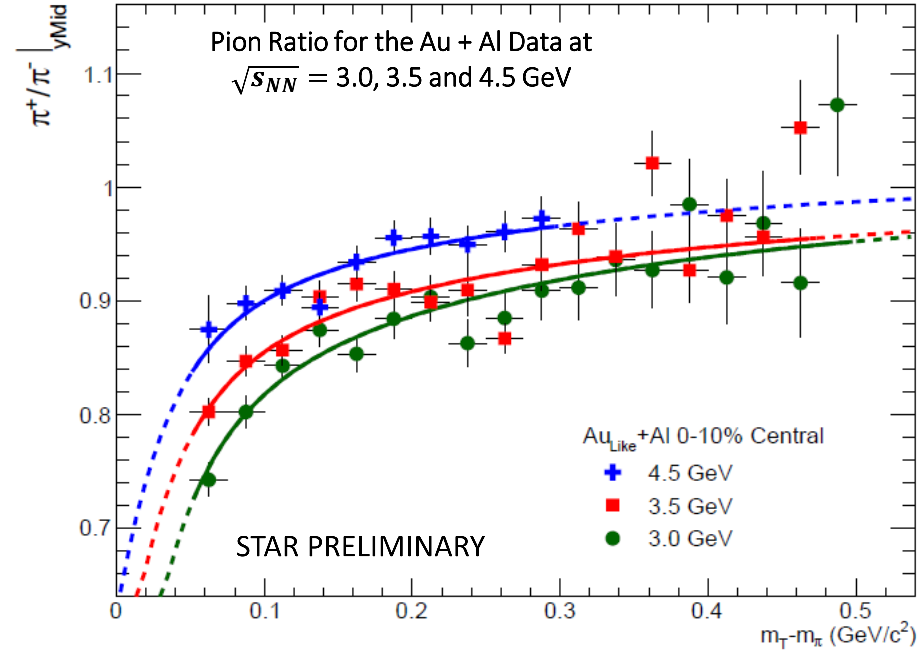
Pion Spectra for the Au + Al Data at $\sqrt{s_{NN}} = 3.0$, 3.5 and 4.5 GeV

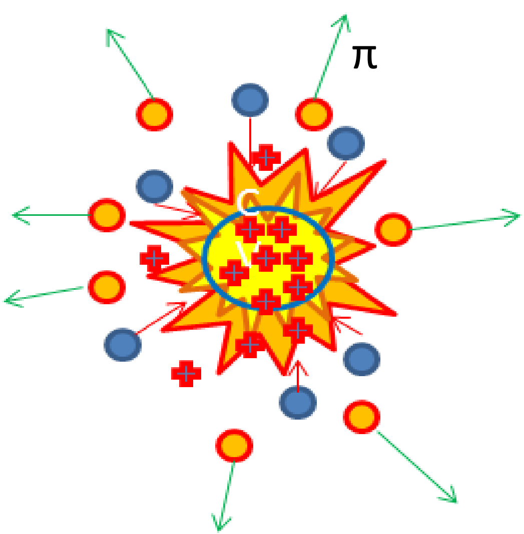


- Curves are Bose-Einstein Fits to Spectra

Coulomb Potential







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

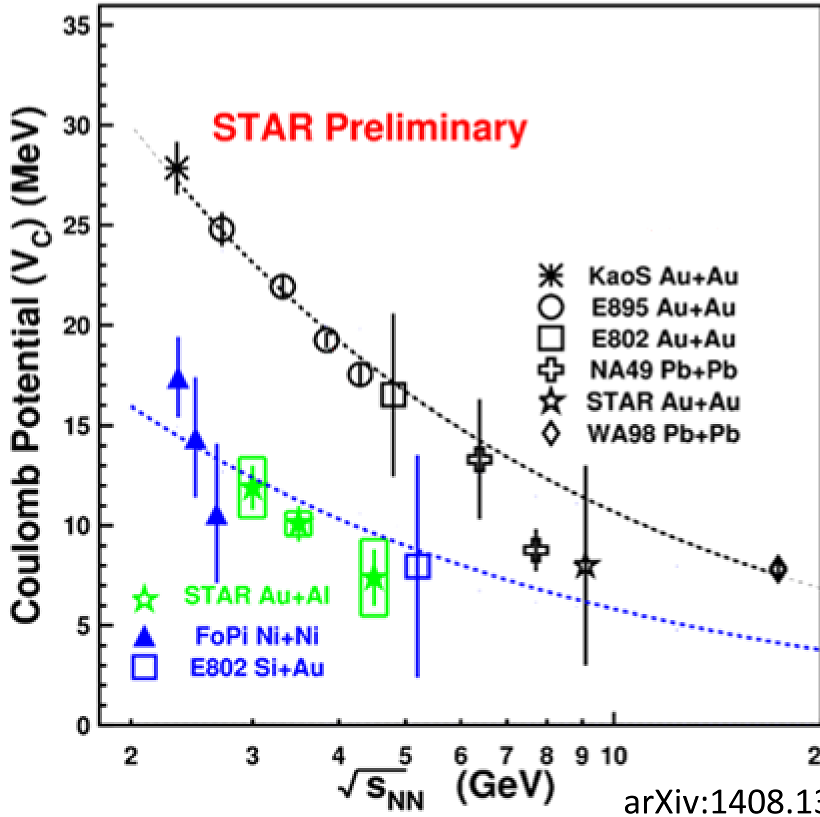
(2) $R_f(E_f) = \frac{E_f - V_C}{E_f + V_C}\frac{\sqrt{(E_f - V_C)^2 - m^2}}{\sqrt{(E_f + V_C)^2 - m^2}}\frac{n^-(E_f - V_C)}{n^+(E_f + V_C)}$ ← Jacobian

(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 than the pions with a given momentum

Proof of Principle: Au + Al Beam Pipe Studies

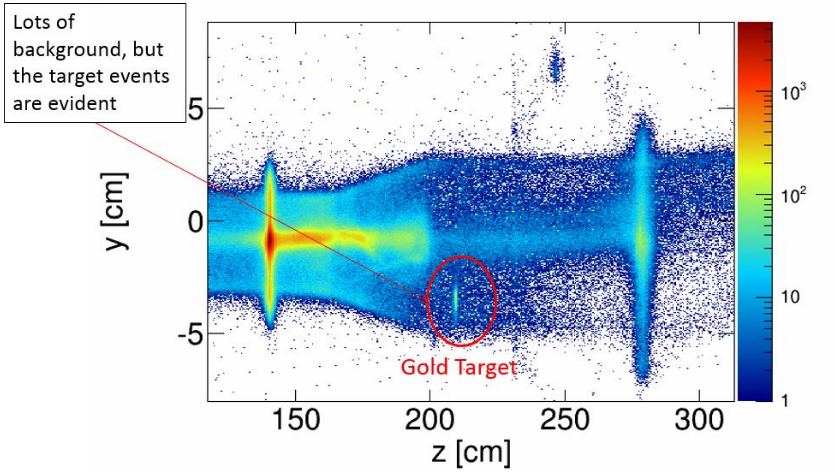


arXiv:1408.1369

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

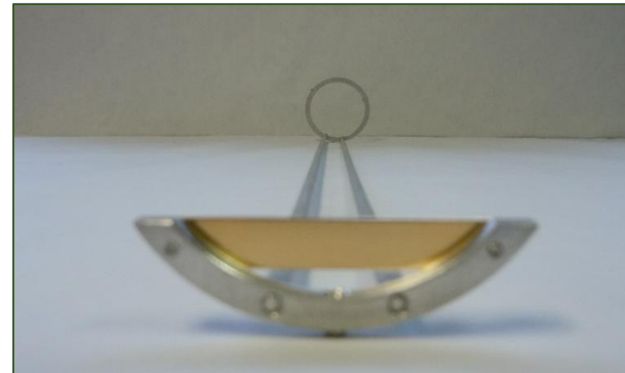
- STAR software framework can successfully reconstruct fixed target vertices and has good acceptance and PID capabilities up to mid-rapidity

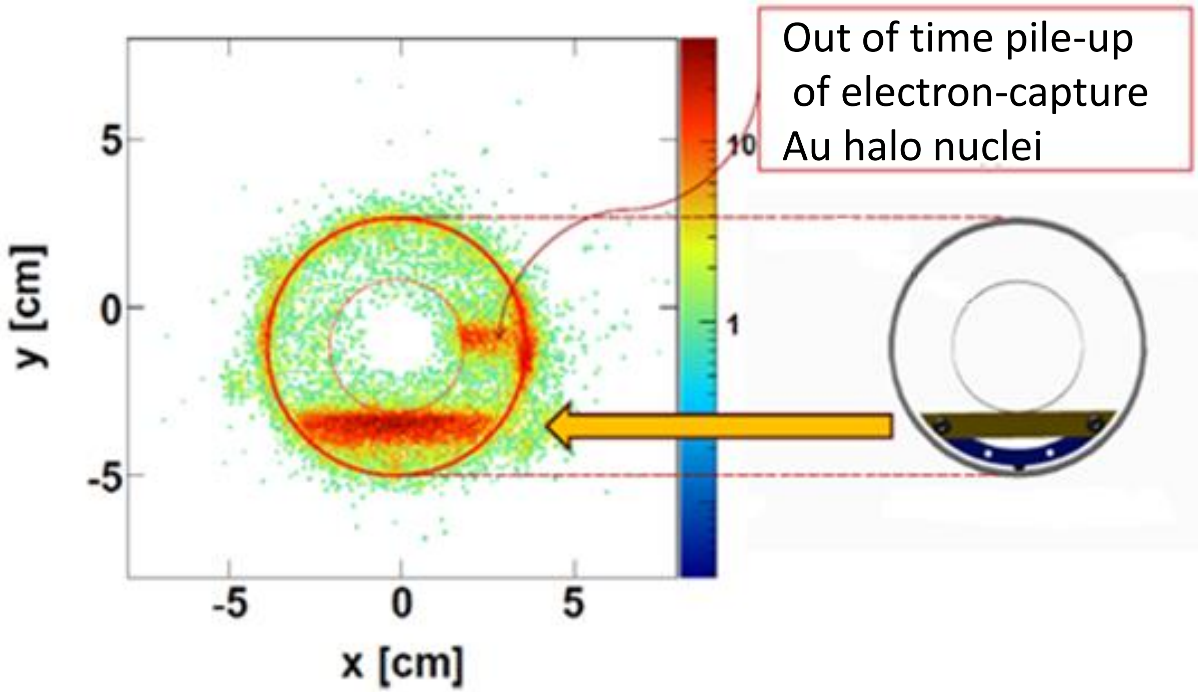
Gold Target Installed for Run 14

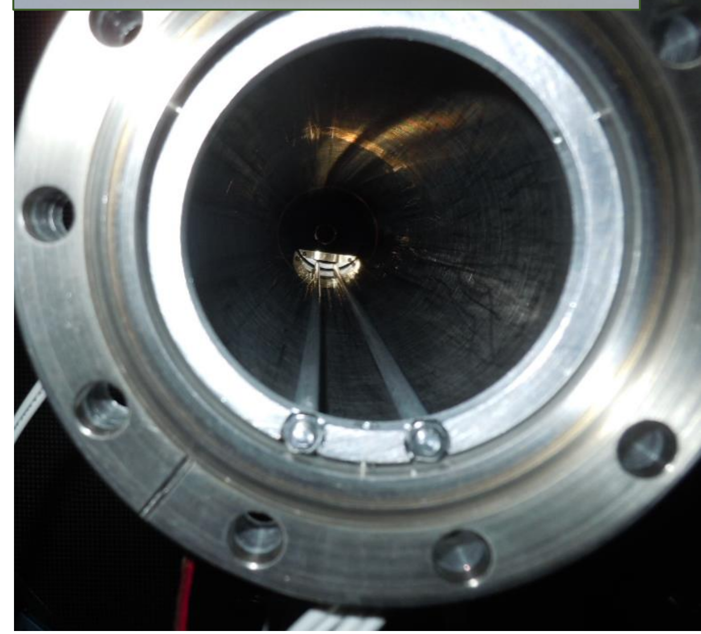


Run 14 details:

- 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%).

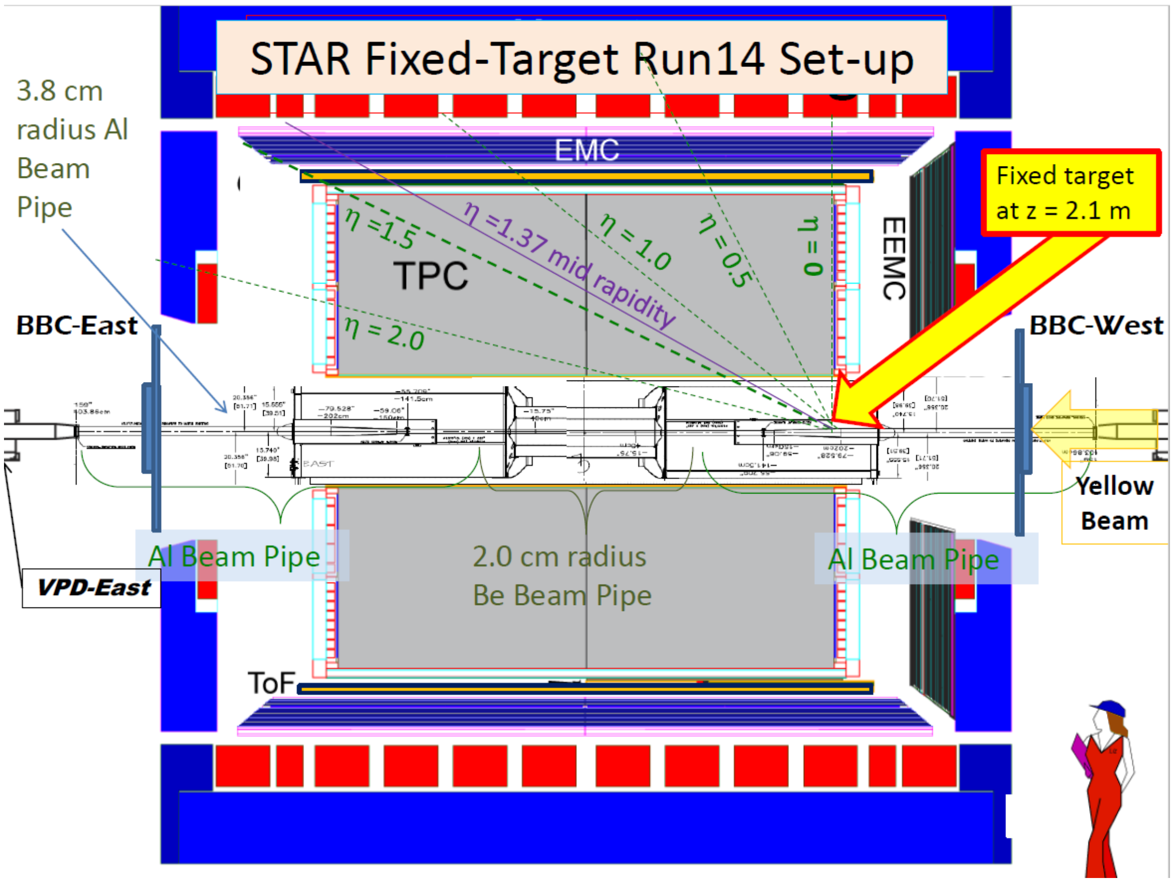


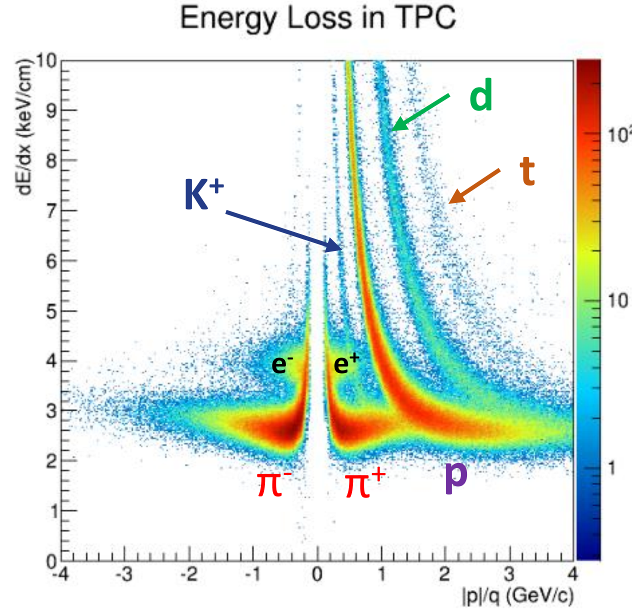


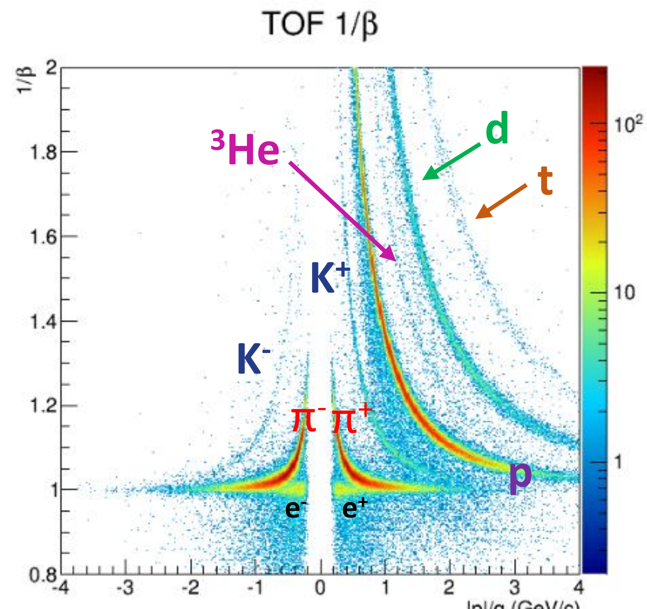


3.9 GeV Au + Au Test Run

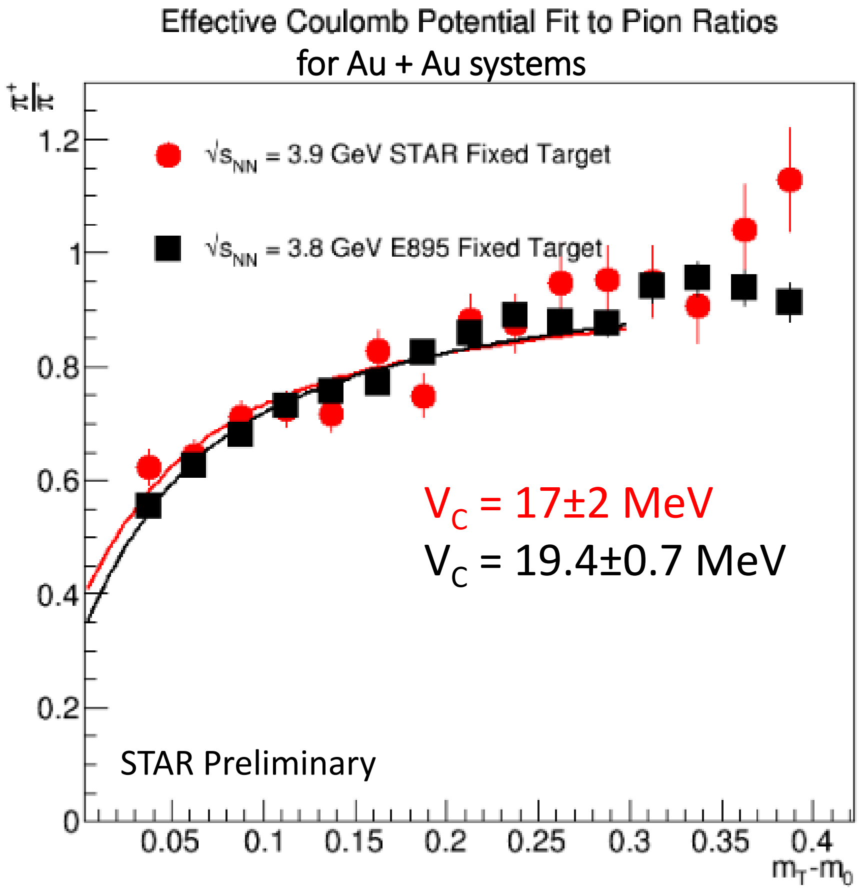
Excellent PID with Time Projection Chamber (TPC) and Time of Flight (TOF) detectors for fixed target events



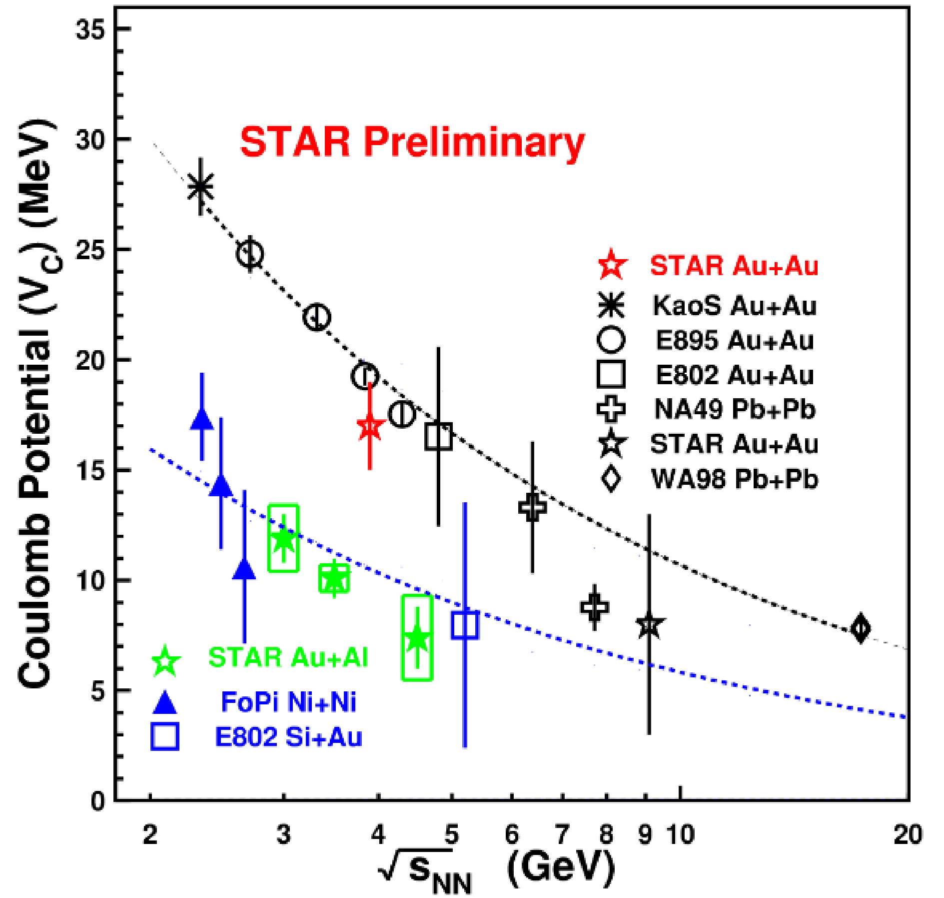




Coulomb Potential Analysis



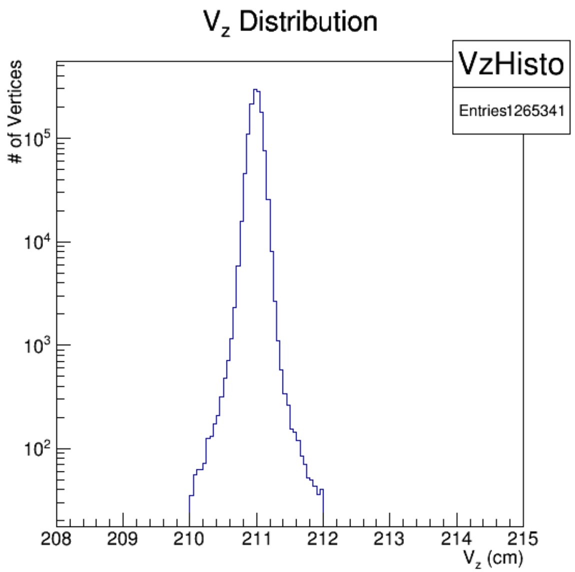
J. Klay et al.(E895 Collaboration), Phys. Rev. C 68,054905 (2003)

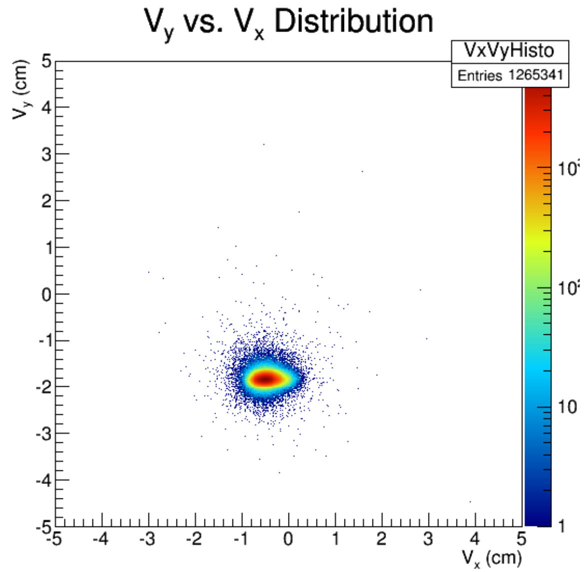


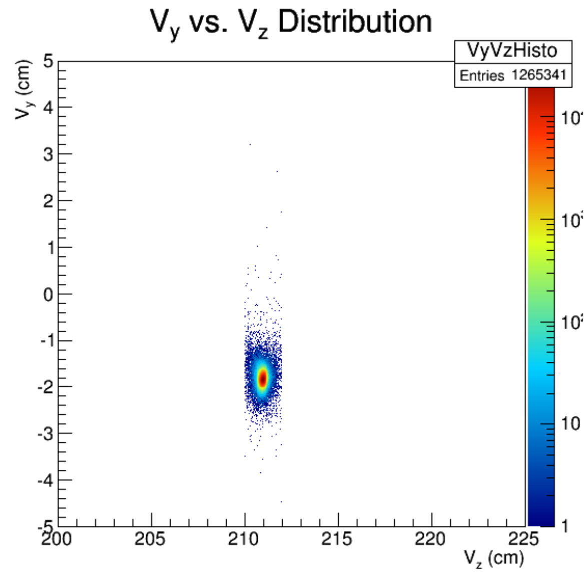
arXiv:1408.1369

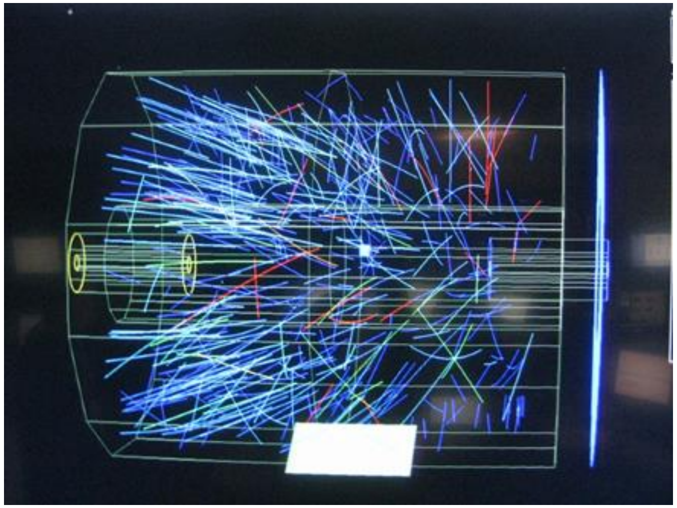
- **Our result for Coulomb potential is consistent with previous experiments**
- **Projectile is consistent with gold ion**

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



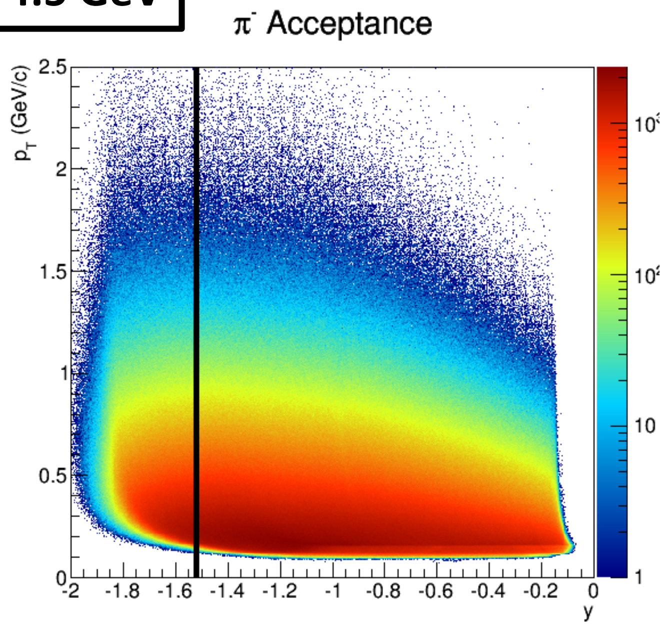


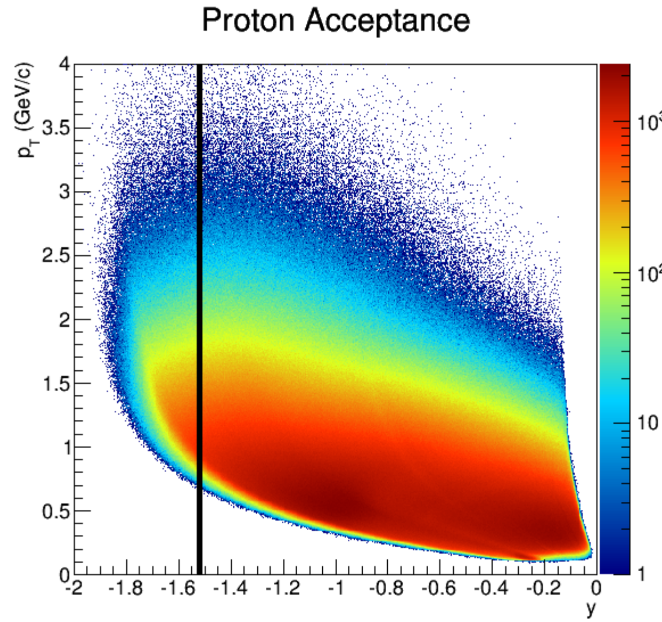


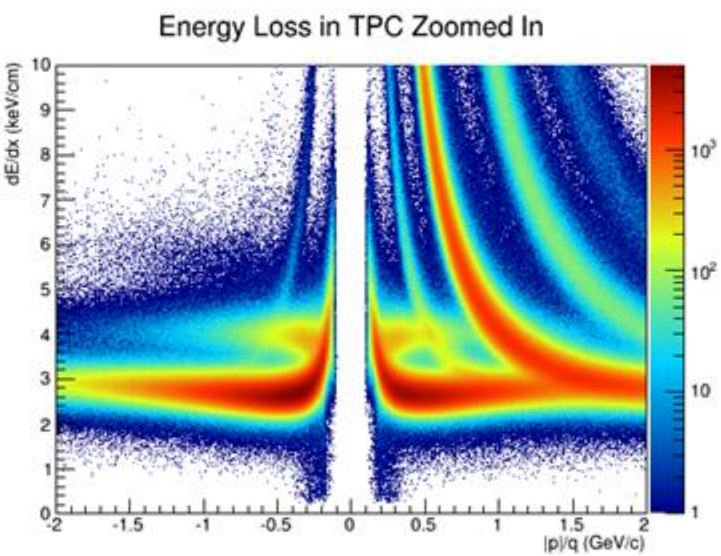


- May 20th, 2015 4 hour test run
- Dedicated FXT test run (not concurrent running)
- 6 bunches, ~1.3 million triggers
- Beam lowered to graze the top edge of the target

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

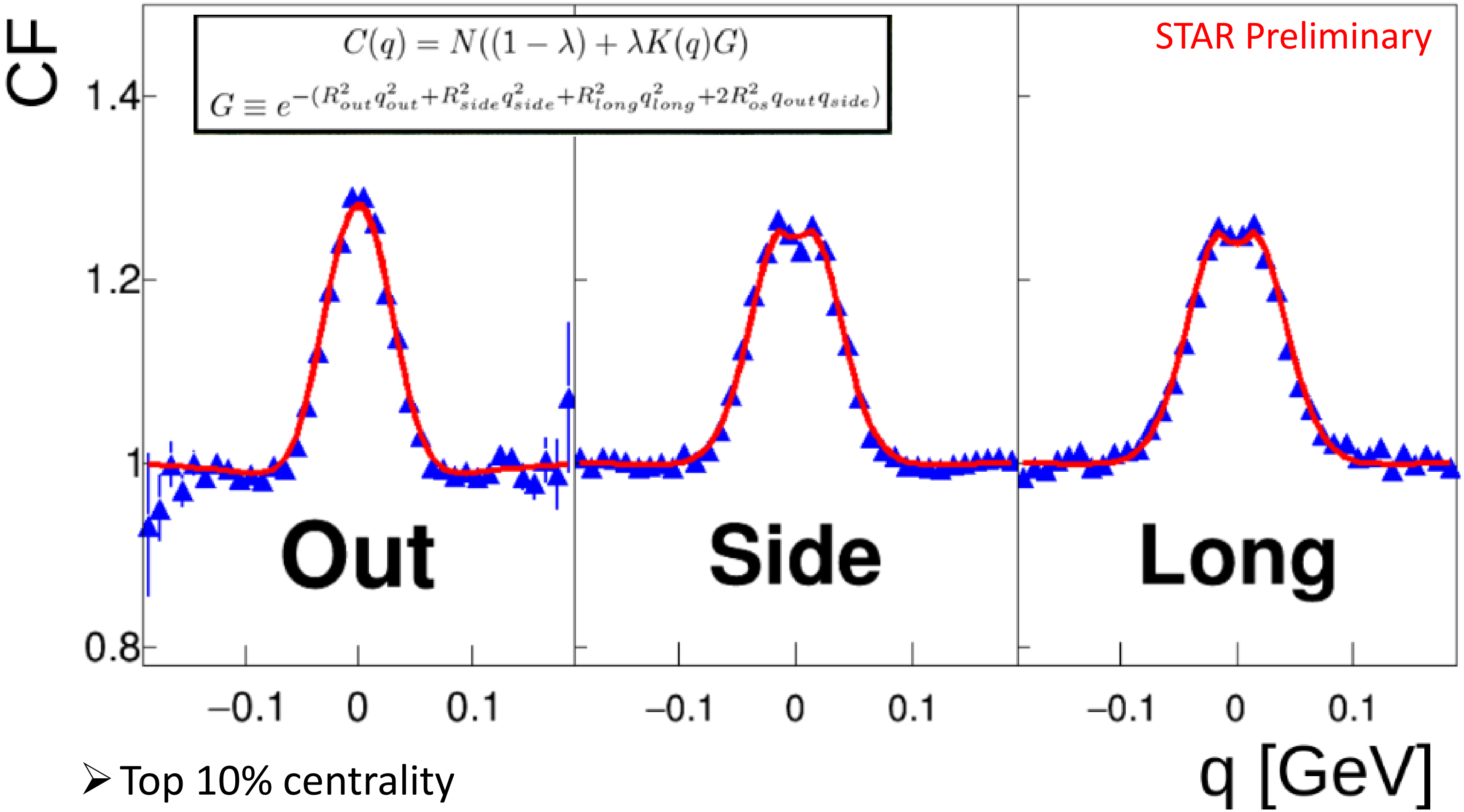






- Can take ~1 million events in half an hour, as opposed to ~5000 events in 3 weeks
- Dedicated fixed-target runs are a better conduct of operations than concurrent runs
- Official production completed, awaiting embedding
- Coming soon: HBT, fluctuation, spectra, flow comparison paper with AGS

FXT HBT Results

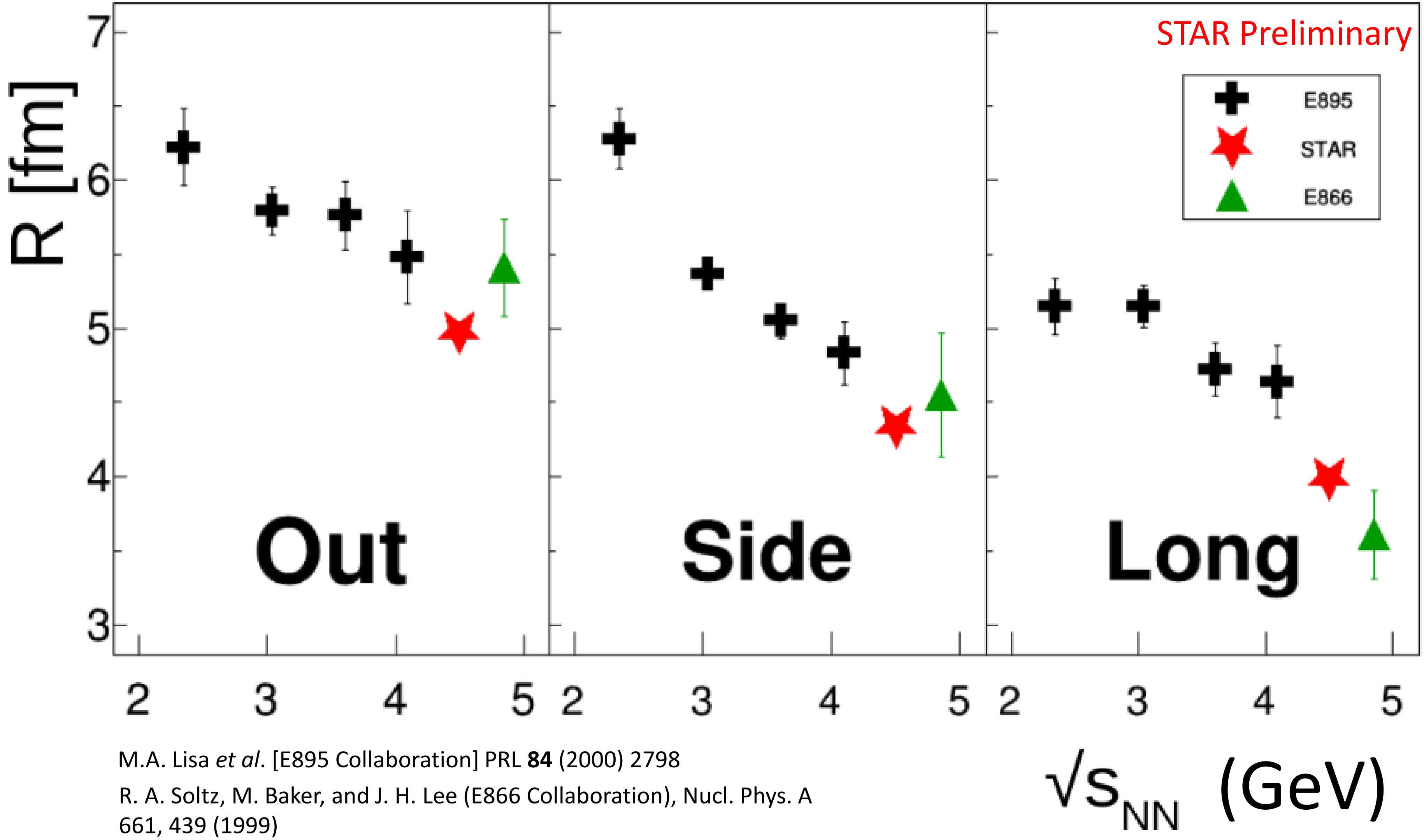


- Top 10% centrality
- Fit CF with Gaussian to extract 5 parameters:

R^2_{out}, R^2_{side}, R^2_{long}, λ, and a normalization

FXT HBT Comparison with AGS

Top 10% Centrality, 0.1 GeV < p_T < 0.3 GeV, only using π^-

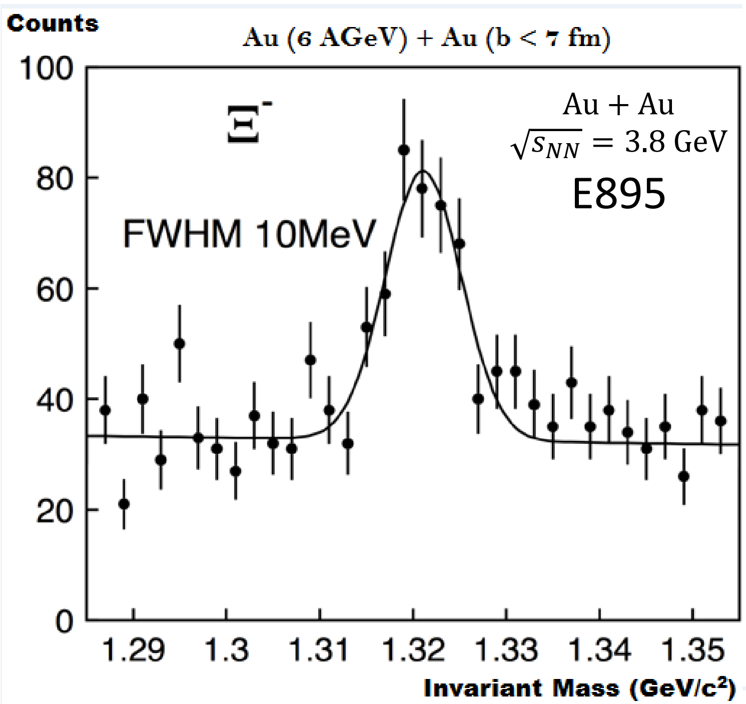


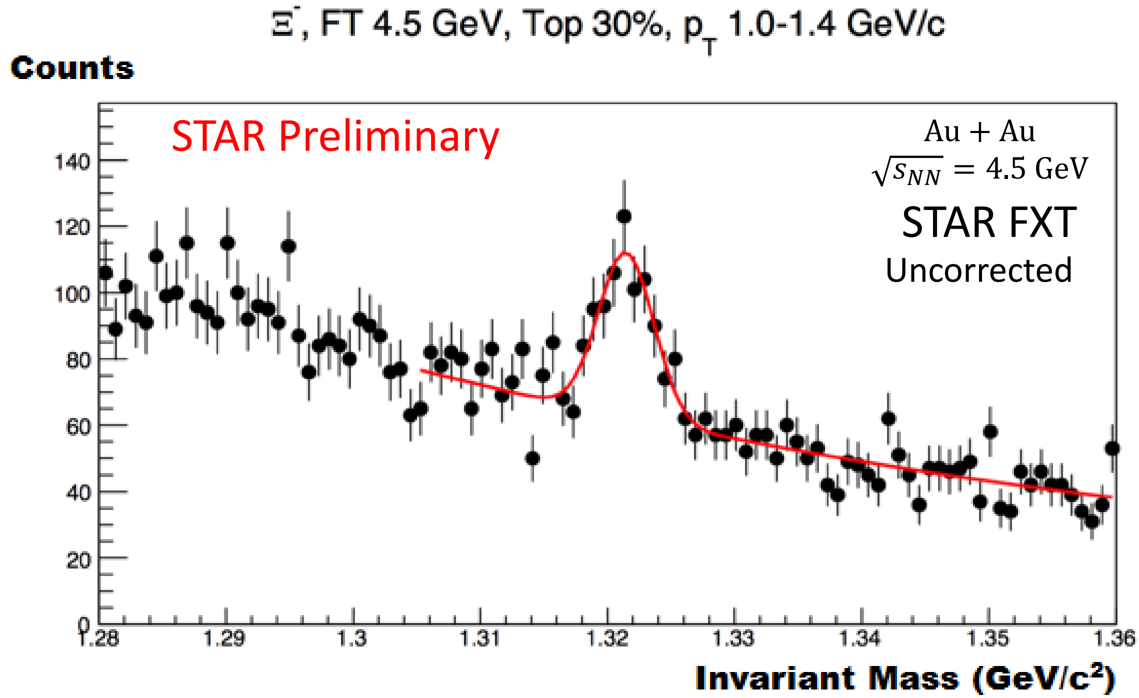
M.A. Lisa *et al*. [E895 Collaboration] PRL **84** (2000) 2798

R. A. Soltz, M. Baker, and J. H. Lee (E866 Collaboration), Nucl. Phys. A 661, 439 (1999)

FXT Cascade Measurement

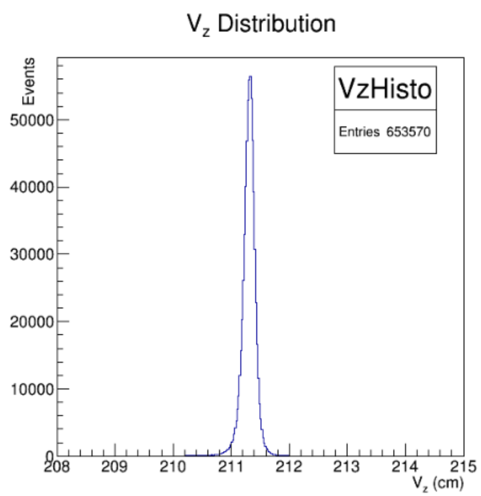
Comparison of Xi (Ξ) signal with E895 Collaboration

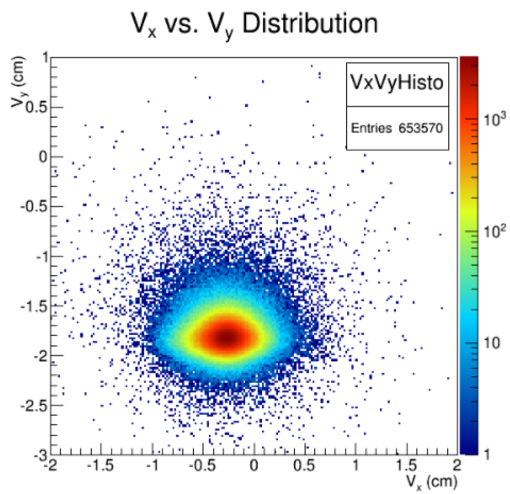


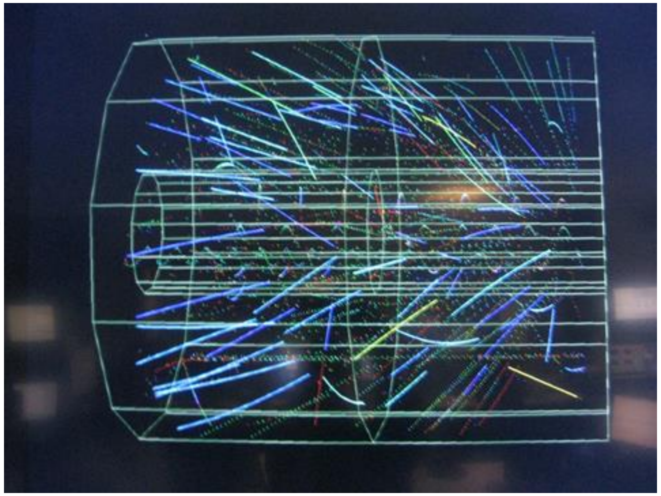


- Efficiency corrections still needed for official physics result
- Peaks have similar width, expect physics result with similar statistical significance as AGS result

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





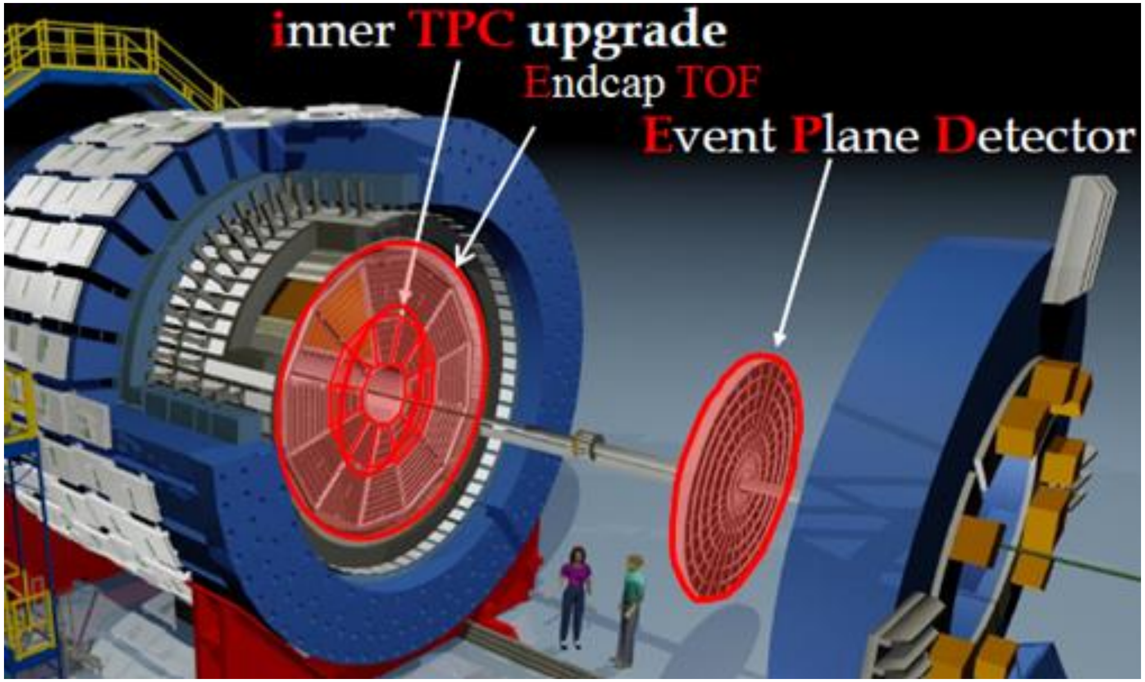


June 16, 2015

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

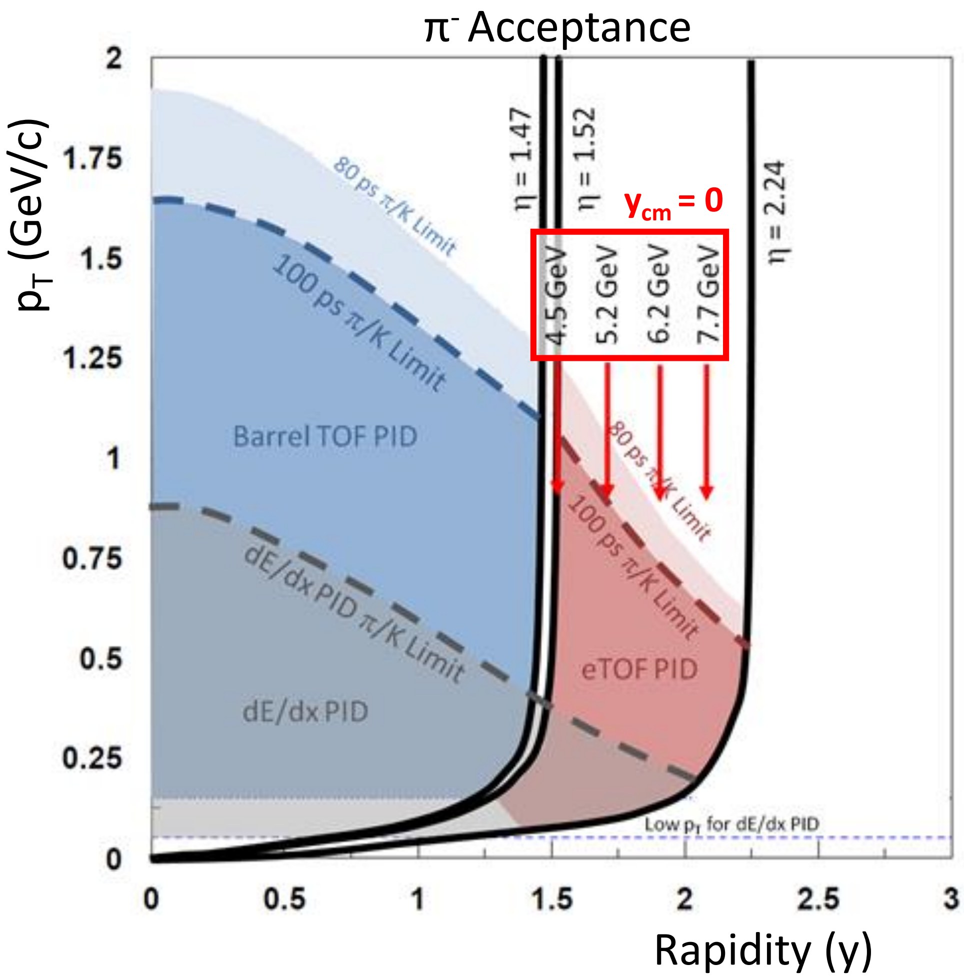
➢ Can obtain second half of phase space to complement beam pipe studies

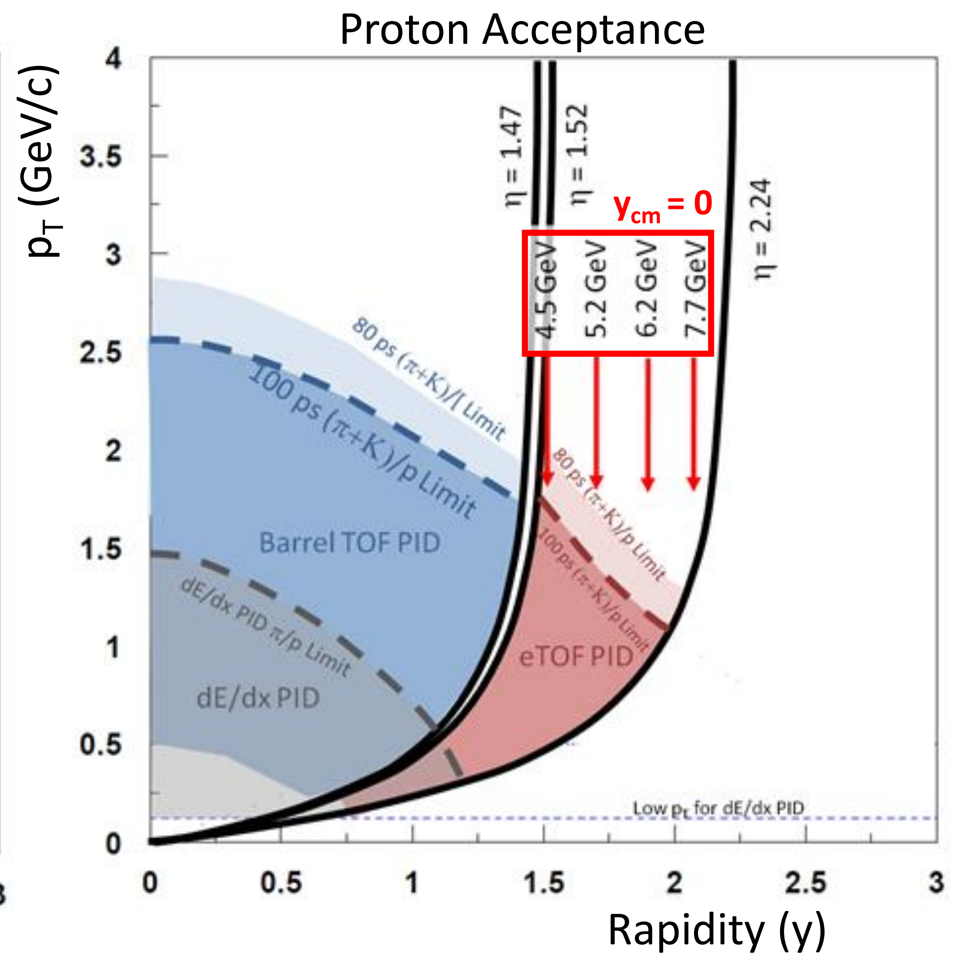
Future: BES-II



- 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 possible evidence for a critical point (eg. kurtosis…)

eTOF + iTPC in FXT:



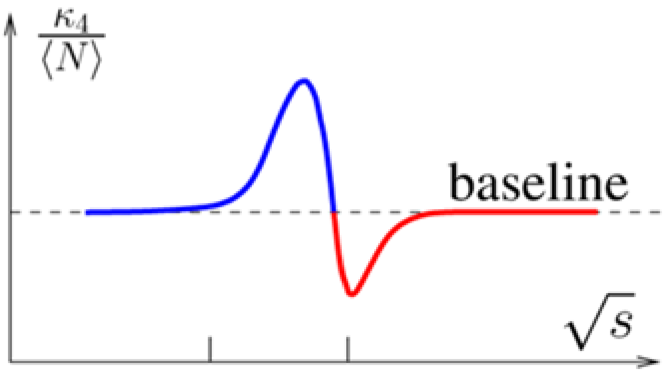


- **Increased acceptance for tracking and PID allows the FXT program to extend its energy range to 7.7 GeV allowing comparisons with collider analyses.**

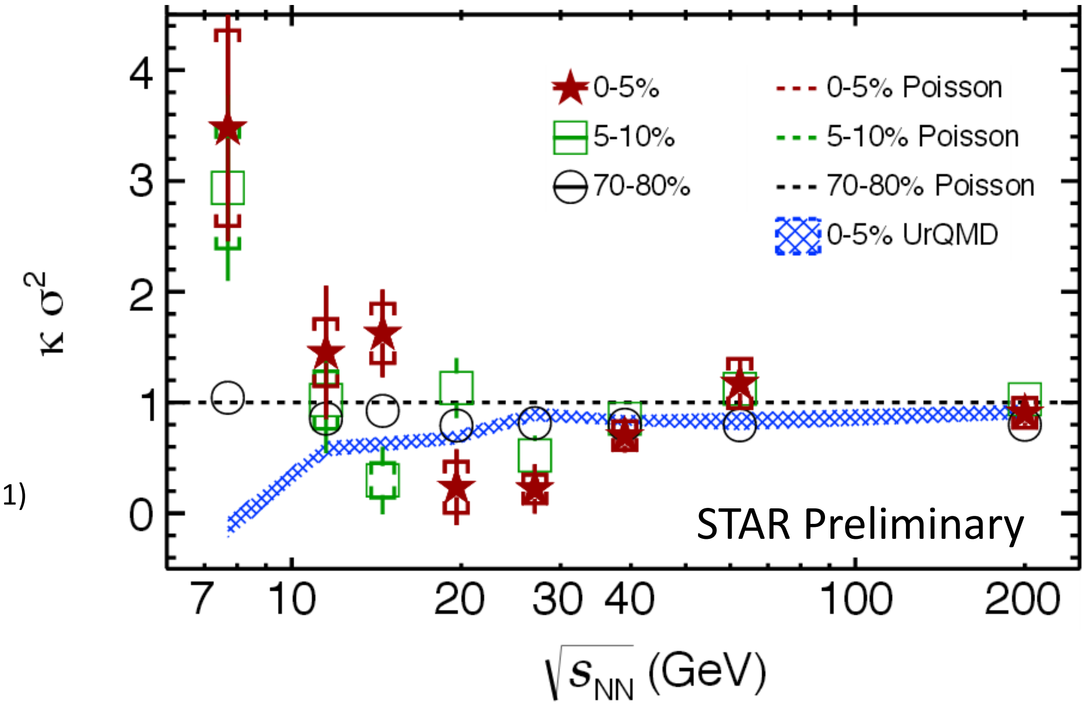
Kurtosis in FXT

- Probing lower energies can clarify this signature

J. Thaeder for the STAR Collaboration. Quark Matter 2015.

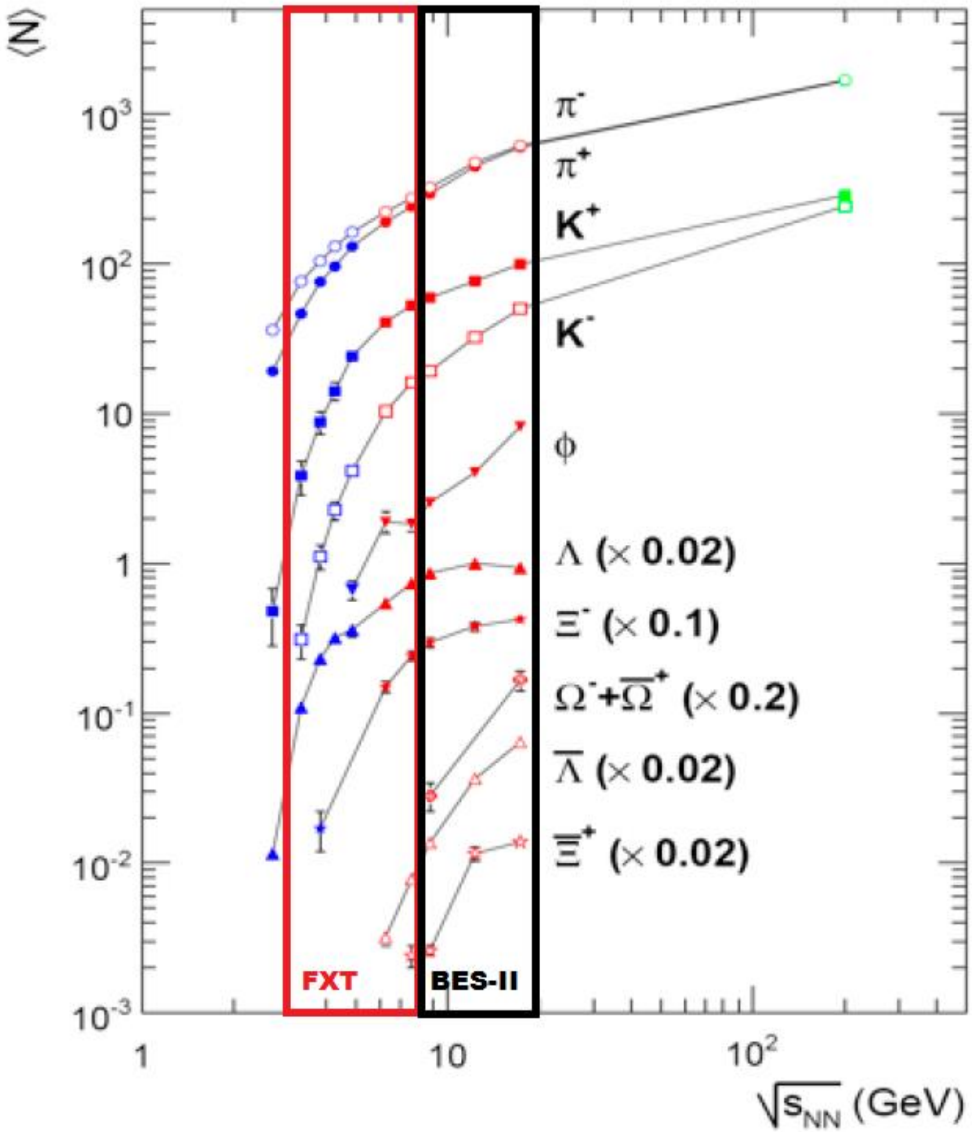


M. Stephanov. J. Physics G.: Nucl. Part. Phys. ***38*** (2011) 124147



➢ Need to go to lower energies to confirm a return to baseline values

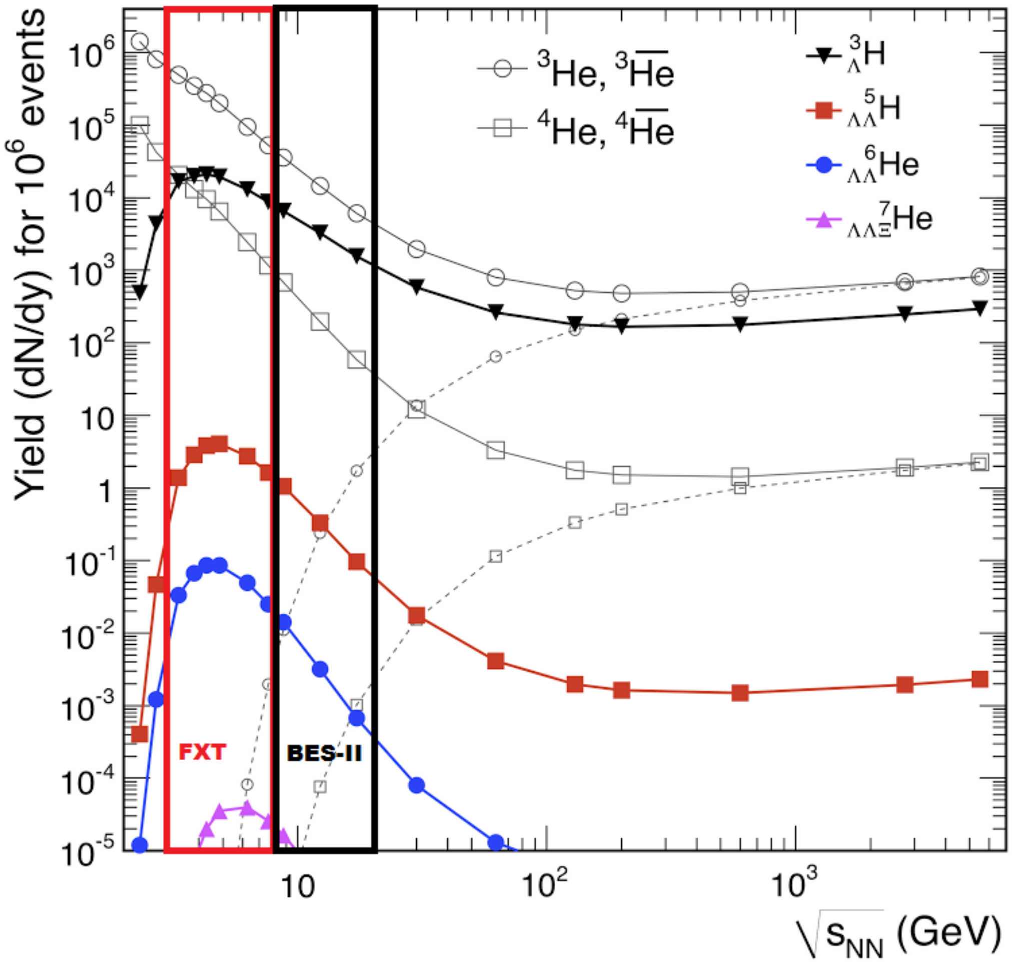
Hyperons in FXT



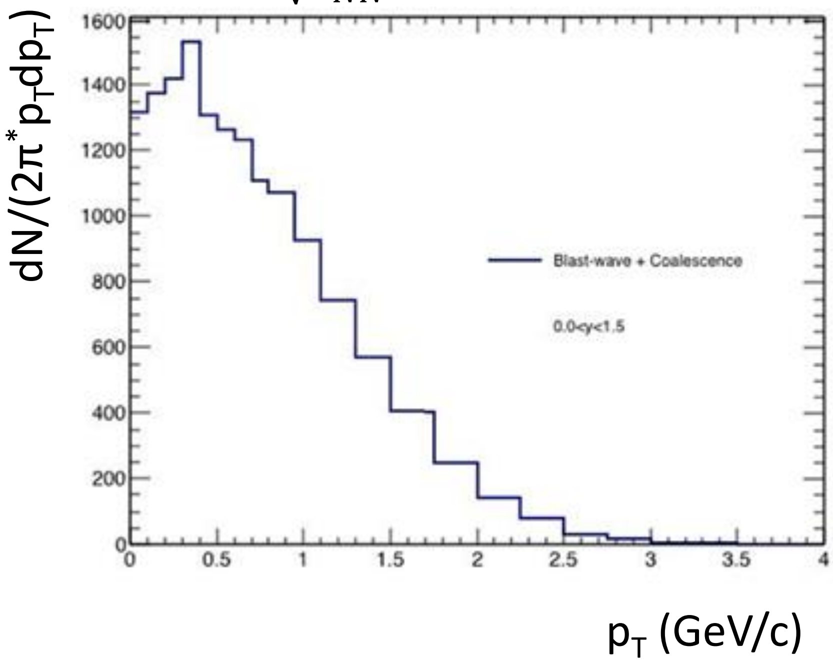
C. Blume, J. Phys. G31, S57 (2005).

- Expect to be able to measure turn-on of lambdas and cascades
- Might be able to measure omegas and anti-lambdas

Hypernuclei in FXT



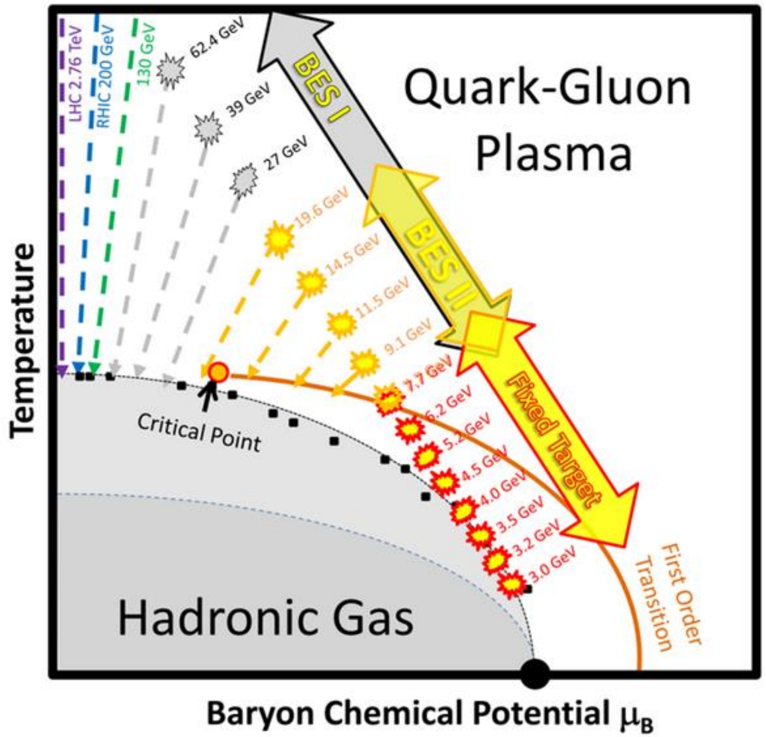
Simulated Yield of Hypertritons
1 day of FXT running
$\sqrt{s_{NN}} = 4.5$ GeV



STAR FXT could improve world hypertriton lifetime measurement

A. Andronic, P. Braun-Munzinger, J. Stachel, and H. Stocker, Phys. Lett. B697, 203 (2011), arXiv:1010.2995 [nucl-th].

Conclusions



- Successful FXT test runs demonstrated that dedicated FXT runs are a preferable conduct of operations to concurrent FXT runs
- Coulomb potentials and preliminary HBT radii were also measured and are consistent with previous experiments
- The detector upgrades will allow the FXT program to run at $\sqrt{s_{NN}} = 7.7$ 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