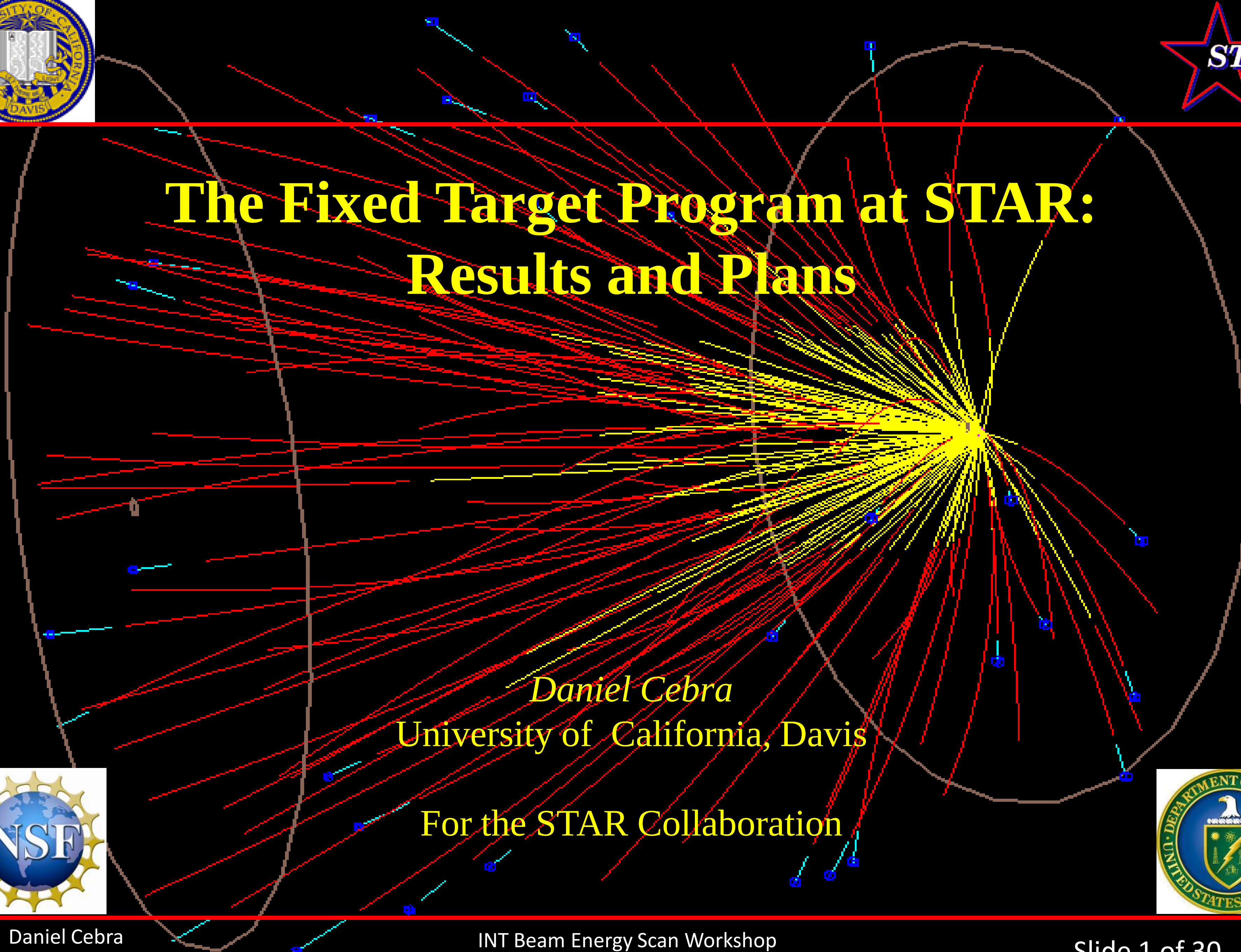


The Fixed Target Program at STAR: Results and Plans

Daniel Cebra
University of California, Davis

For the STAR Collaboration

Disclaimers

Important Caveats:

1) The STAR Fixed-target program has not yet been officially proposed or approved

2) Most of the results to date come from the analysis of background collisions

3) Data taking during the 2015 test runs was limited to roughly half an hour

4) The possible future directions that will be presented are only my opinions of what would make a good program, not the official view of the STAR collaboration

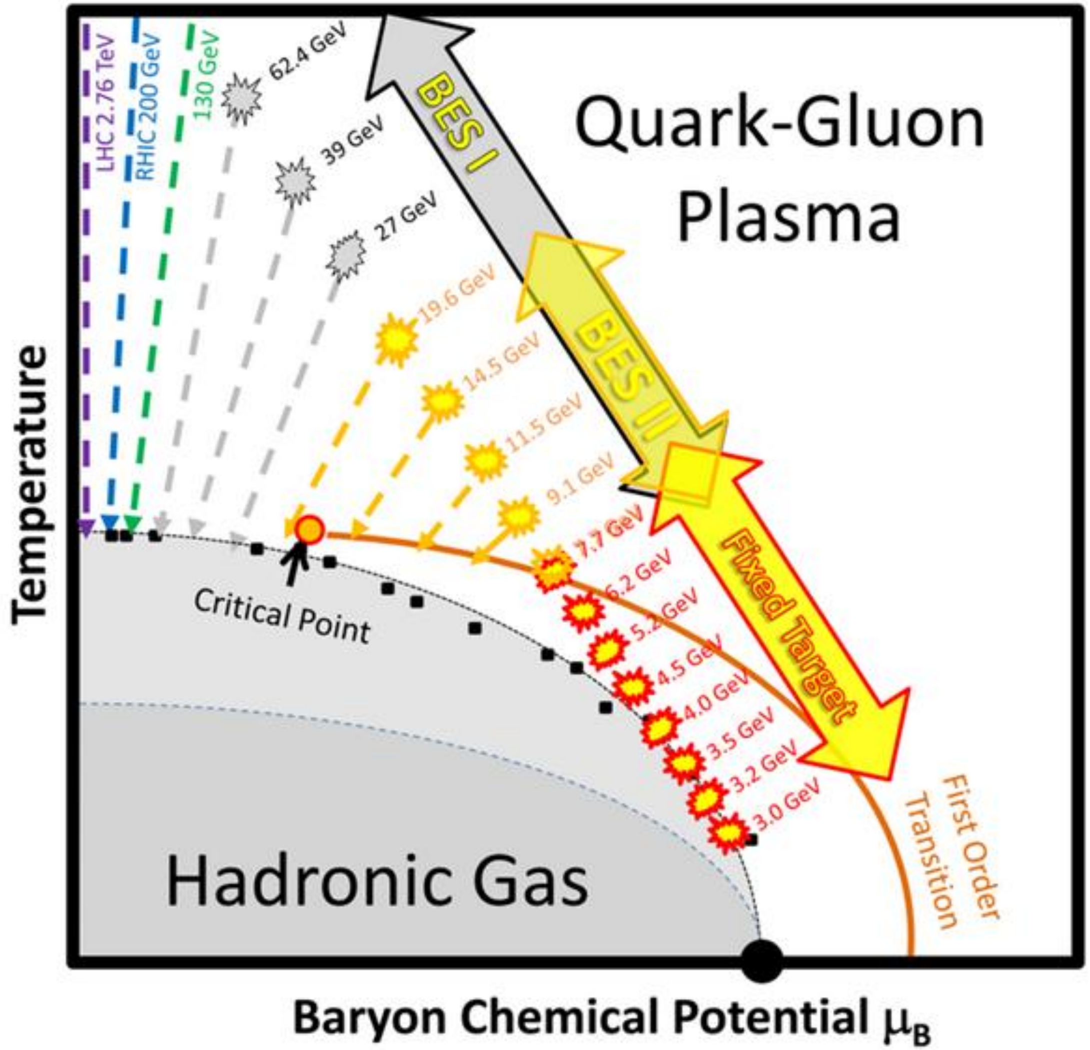
5) It is expected that the STAR fixed-target proposal will be included in the next Beam Use Request in May of 2017

Fixed-Target Program

The Fixed-Target Program will extend the reach of the RHIC BES to higher μ_B.

Goals:

1) Search for evidence of the first entrance into the mixed phase
2) Control measurements for BES collider program searches for Onset of Deconfinement
3) Control measurements for Critical Point searches



History of Low Energy Running at RHIC

RHIC Runs at or Below Nominal Injection Energy:

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

We learned that background was a serious concern

We conclude that RHIC can not achieve a useful collider event rate at 5.0 GeV

STAR and RHIC recognized the importance to run at energies down to and below 7.7 GeV

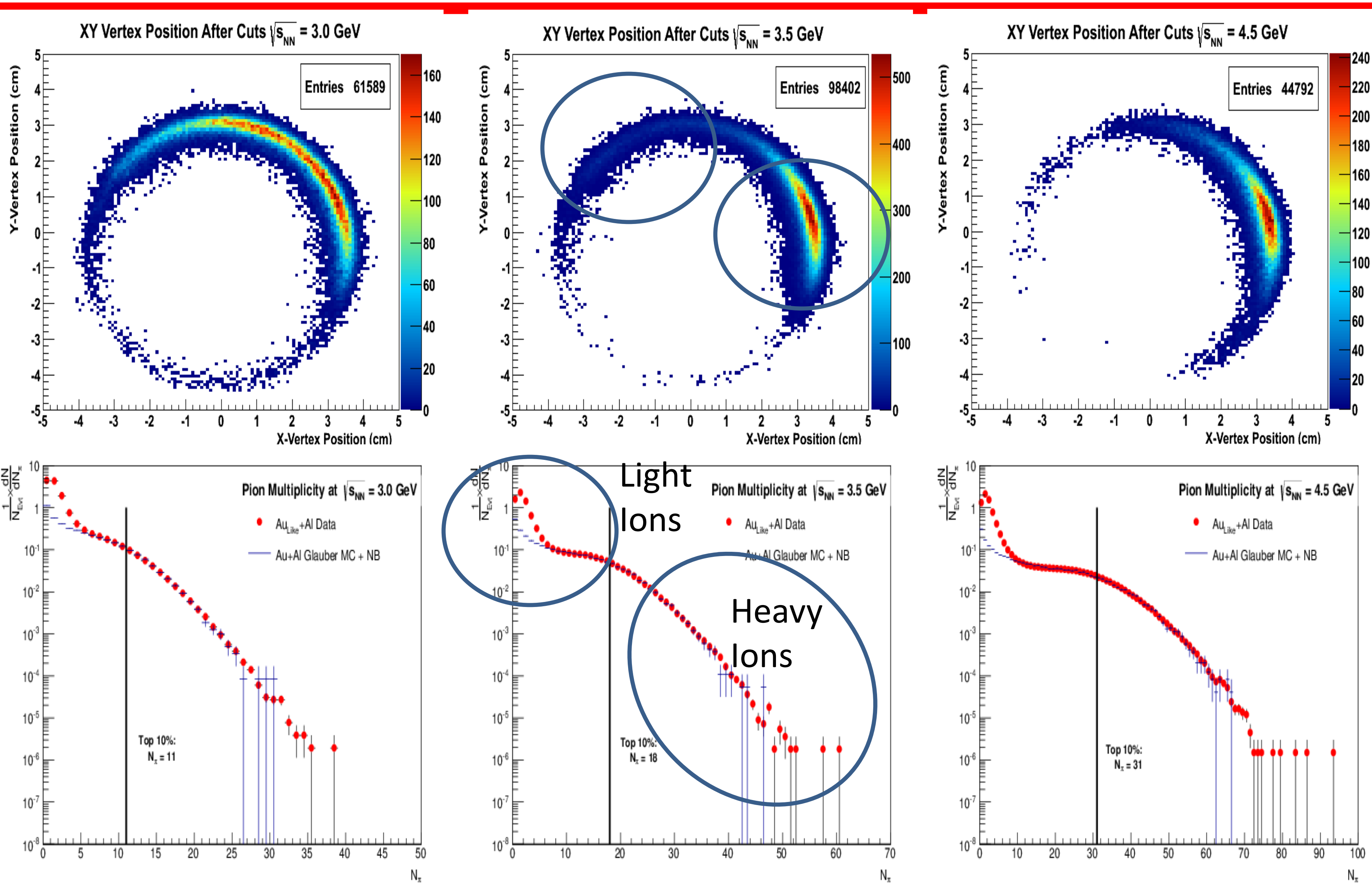
Studies using Beam Halo Background

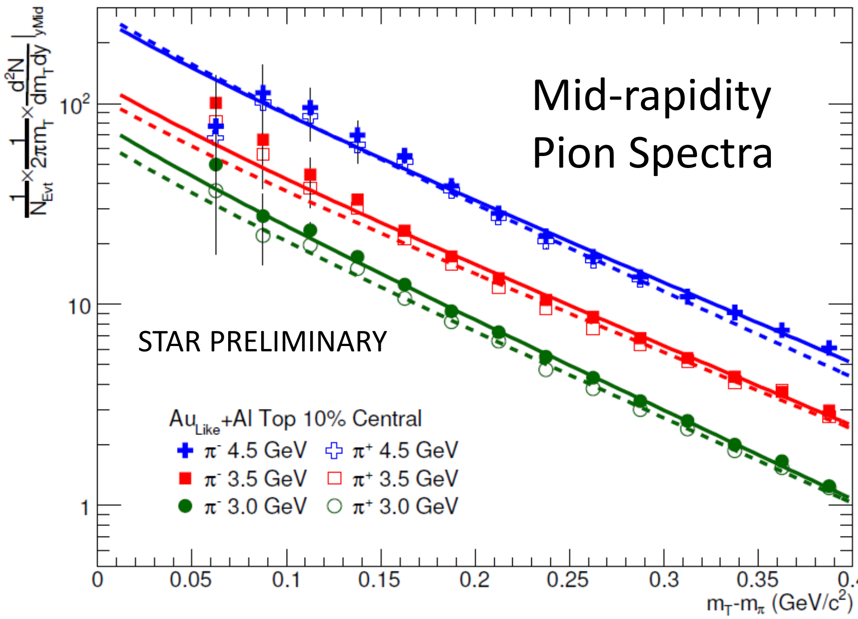
2010 - 2014

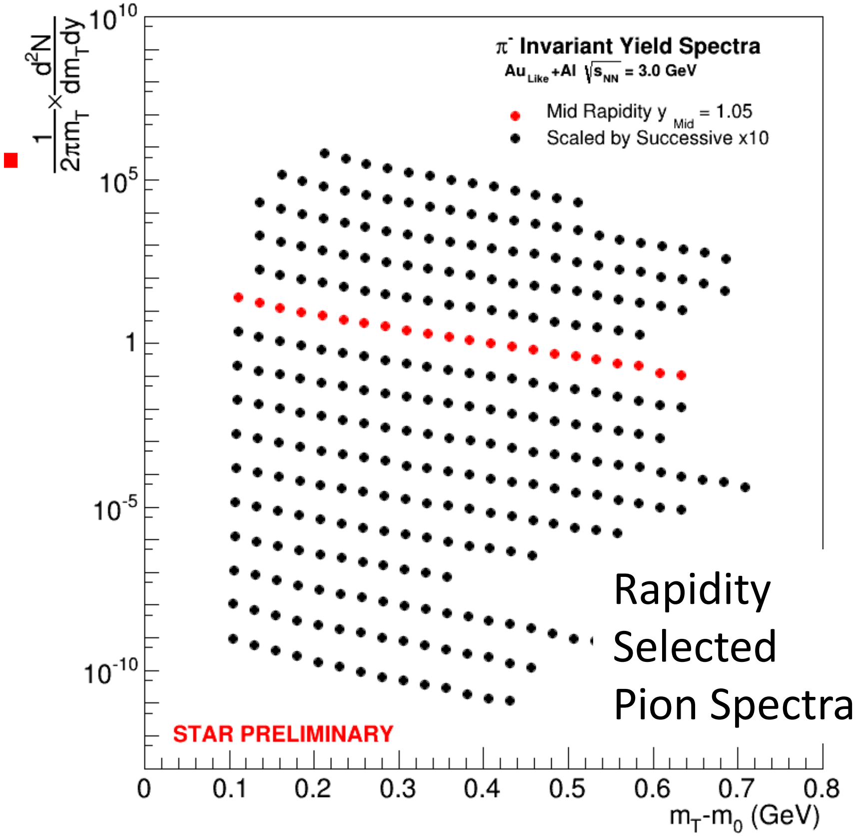
Goals:

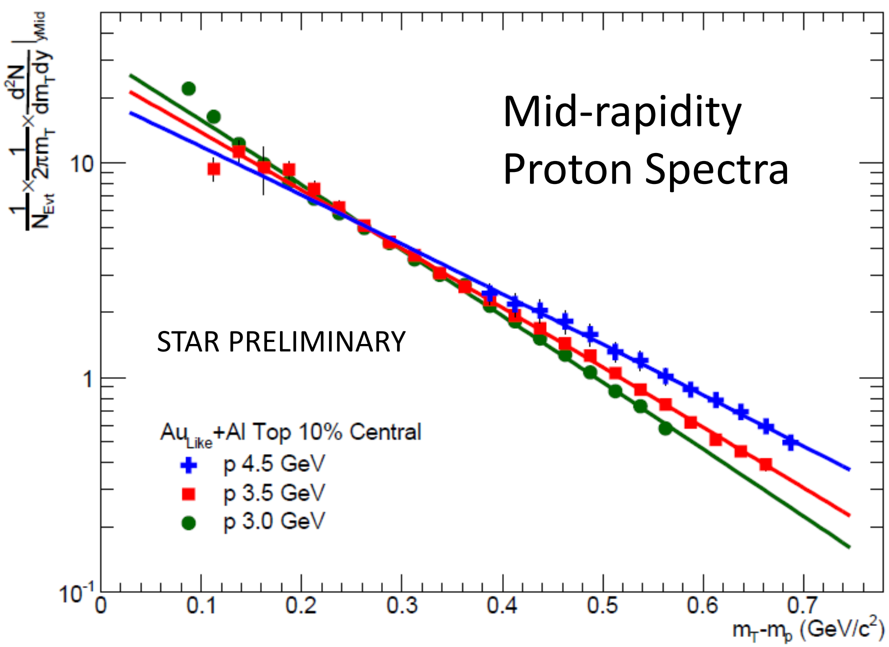
•Understand the Beam Halo Background
•Determine the applicability of STAR for fixed target
•First publication of FXT results → Au+Al

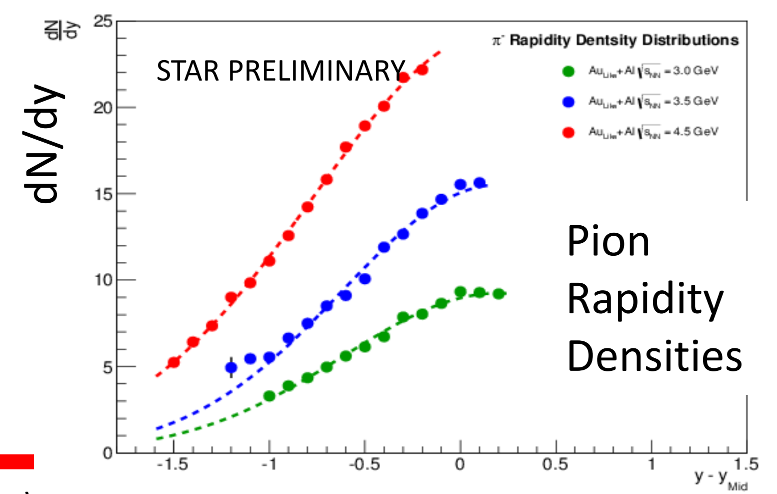
Beam Halo on Al Vacuum Pipe




Mid-rapidity
Pion Spectra
STAR PRELIMINARY
Au_Like+Al Top 10% Central
π⁻ 4.5 GeV π⁺ 4.5 GeV
π⁻ 3.5 GeV π⁺ 3.5 GeV
π⁻ 3.0 GeV π⁺ 3.0 GeV
m_T-m_π (GeV/c²)


π⁻ Invariant Yield Spectra
Au_Like+Al √s_NN = 3.0 GeV
Mid Rapidity y_Mid = 1.05
Scaled by Successive x10
Rapidity
Selected
Pion Spectra
STAR PRELIMINARY
m_T-m_0 (GeV)


Mid-rapidity
Proton Spectra
STAR PRELIMINARY
Au_Like+Al Top 10% Central
p 4.5 GeV
p 3.5 GeV
p 3.0 GeV
m_T-m_p (GeV/c²)

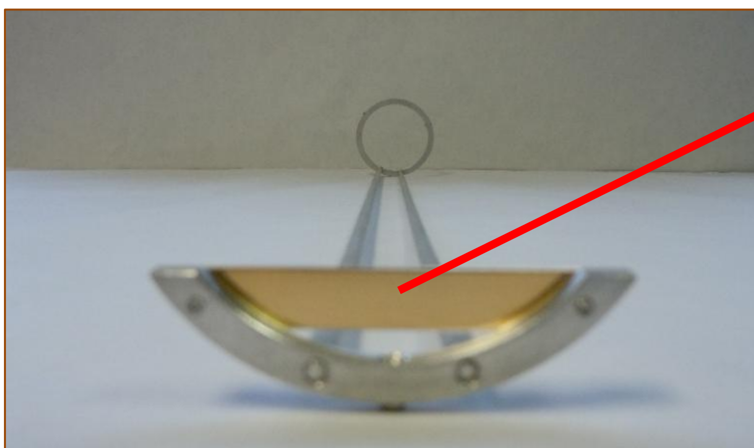

dN/dy
STAR PRELIMINARY
π⁻ Rapidity Dentsity Distributions
Pion
Rapidity
Densities
y - y_Mid

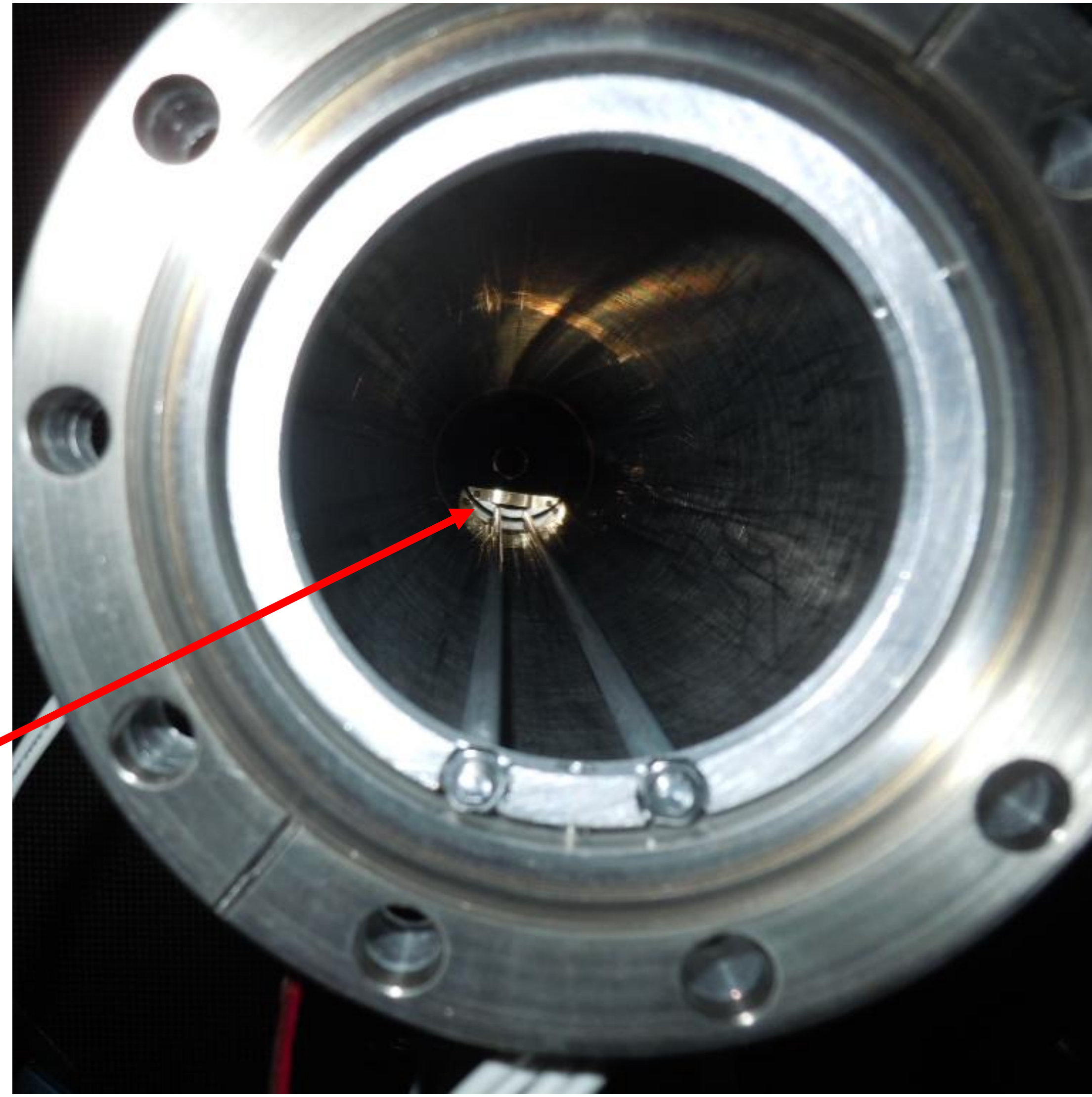
Target Design 2014 and 2015

The success of the beam pipe studies motivated installing an internal gold target

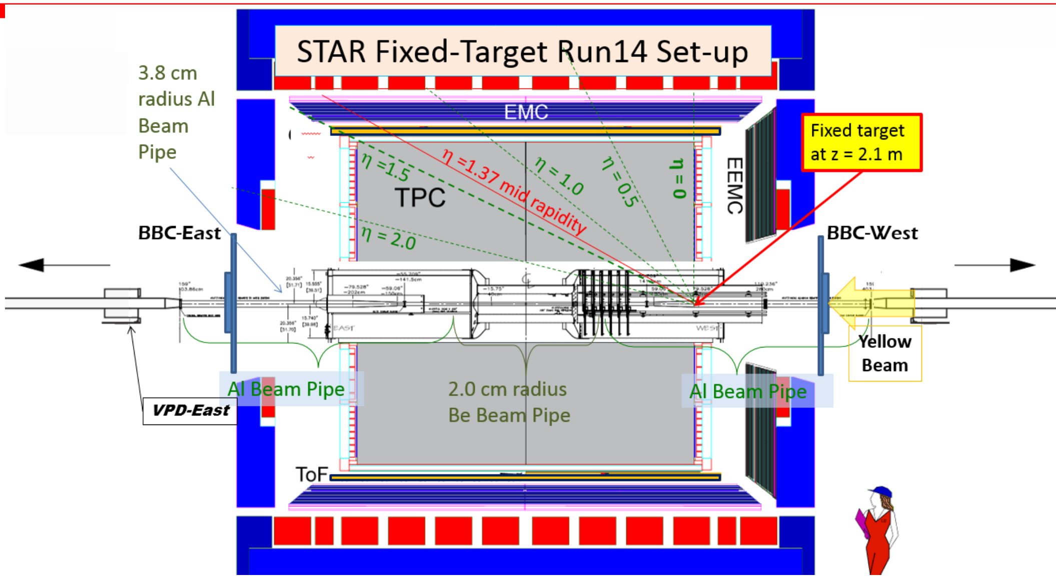
Target design:

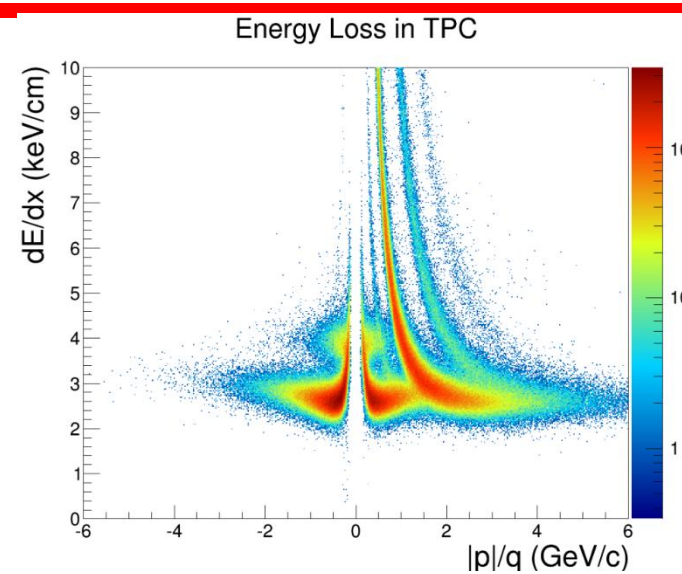
Gold foil
1 mm Thick (4%)
~1 cm High
~4 cm Wide
~2 cm below beam axis
210 cm from IR



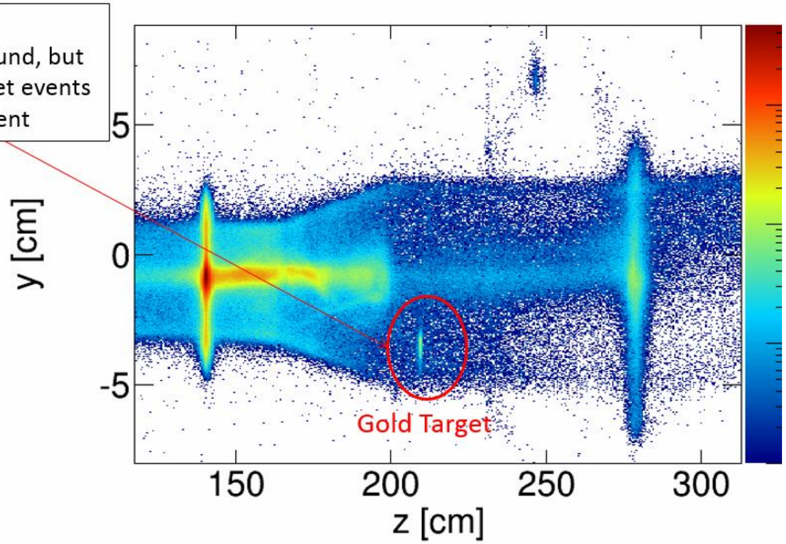


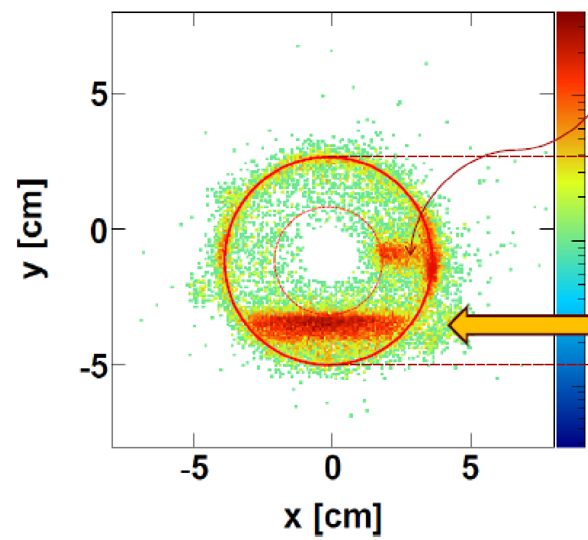
3.9 GeV Au halo + Au target



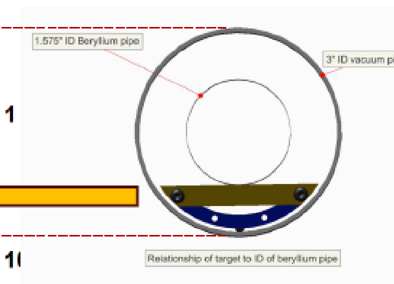


Lots of background, but the target events are evident

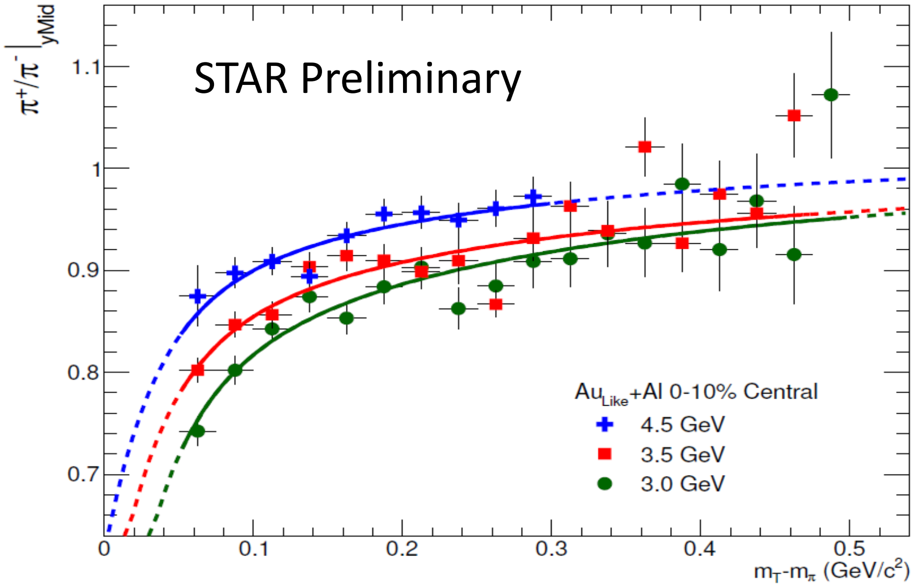


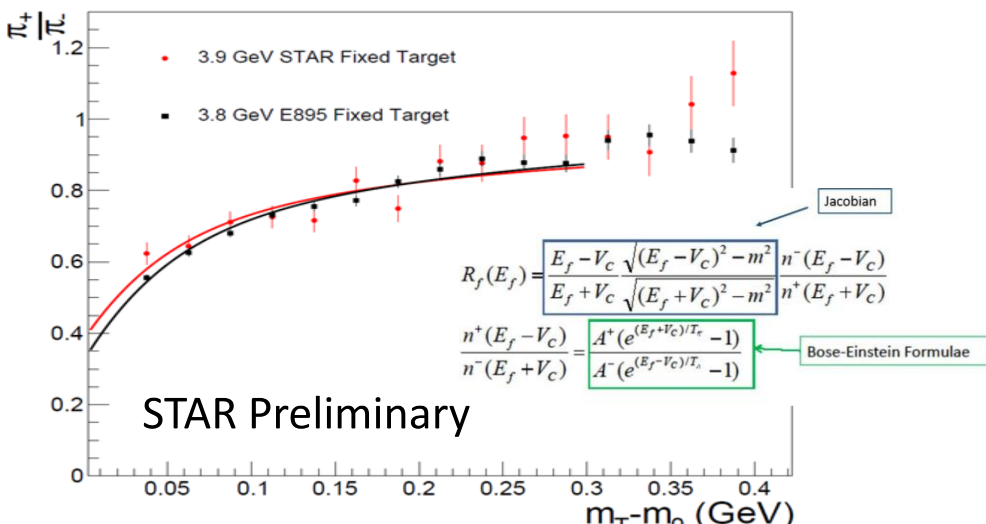


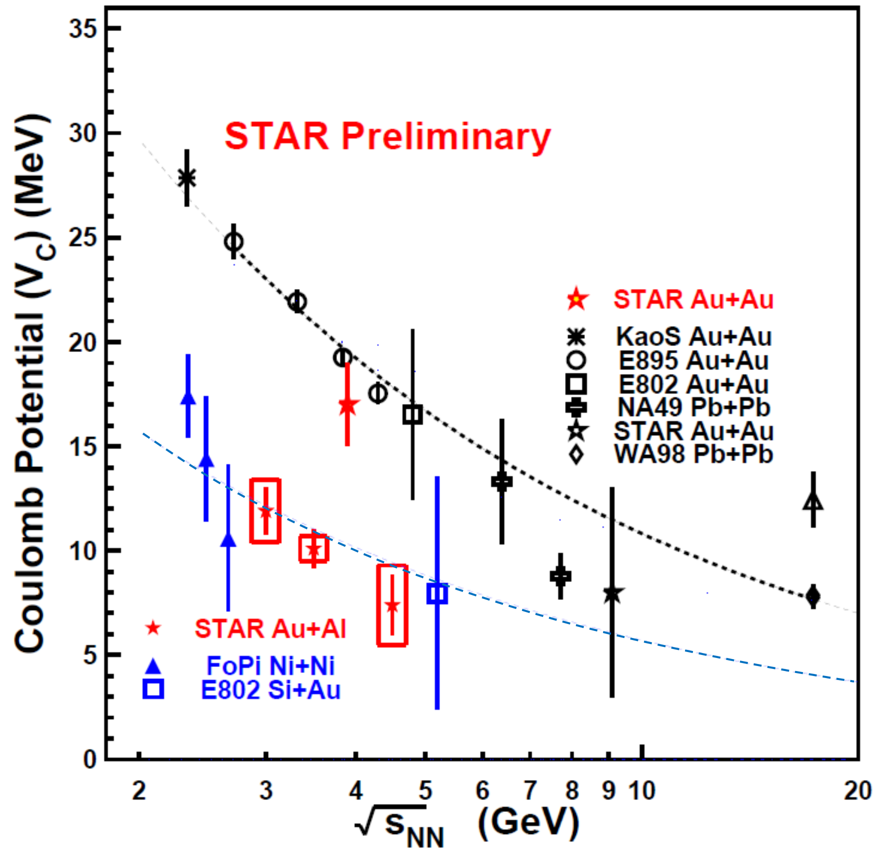
The most intense beam halo is deflected by the dipole magnets in the positive *x* direction. These are $Au_{Halo}+Al_{Beampipe}$ background



Coulomb Analysis







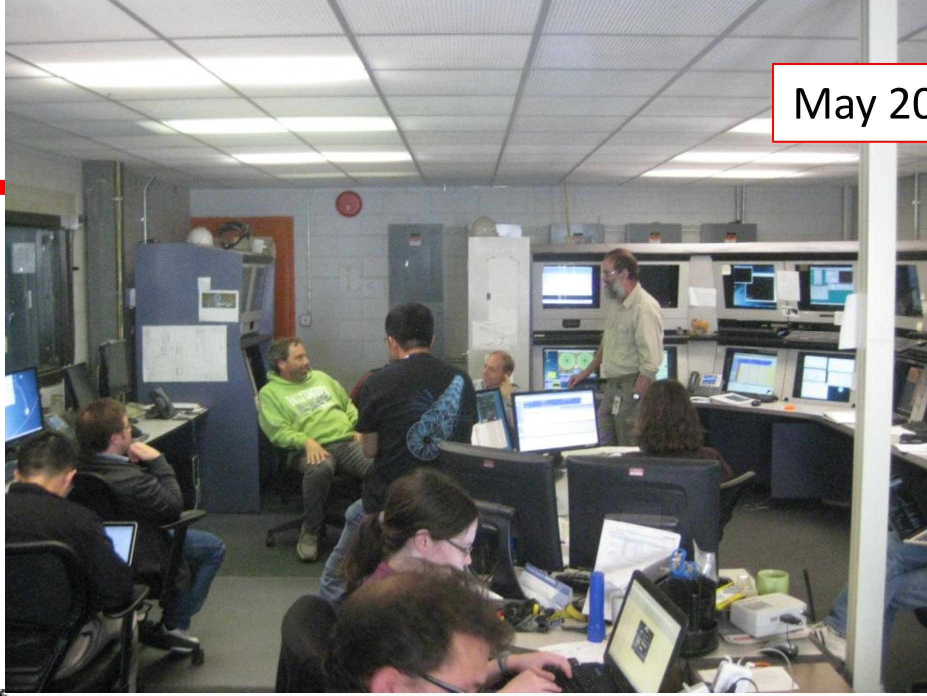
Conclusions from background studies:

- Beam halo contains Au^{like} ions
- Detector performance is fine
- Paper draft is in collaboration review

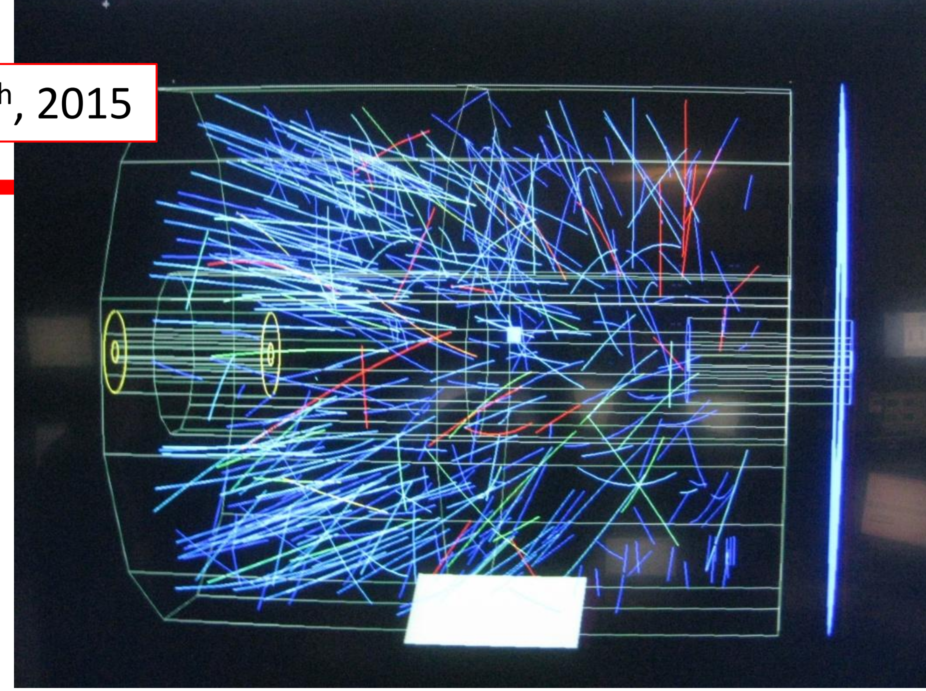
Direct Beam Test Run 2015

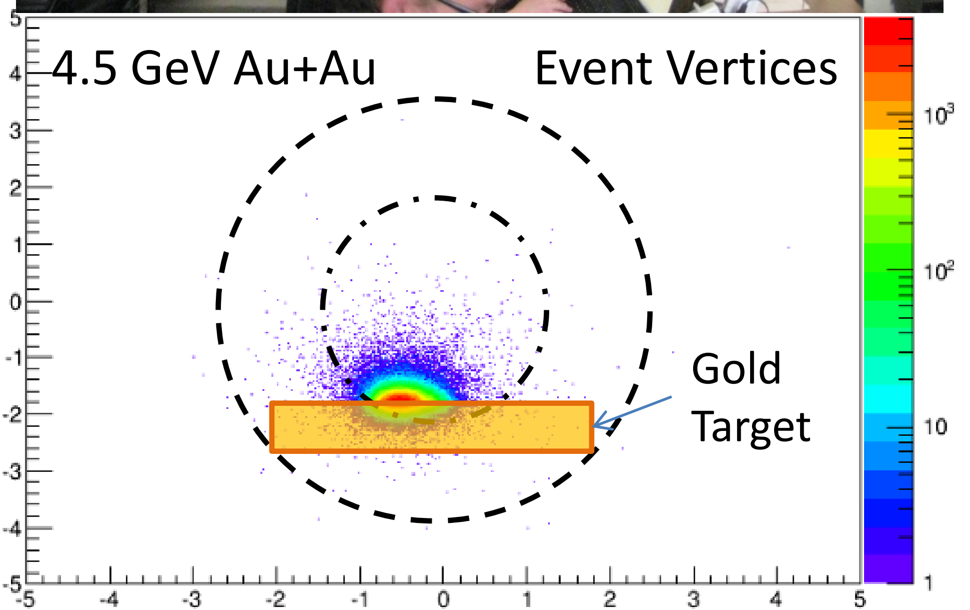
Goals:

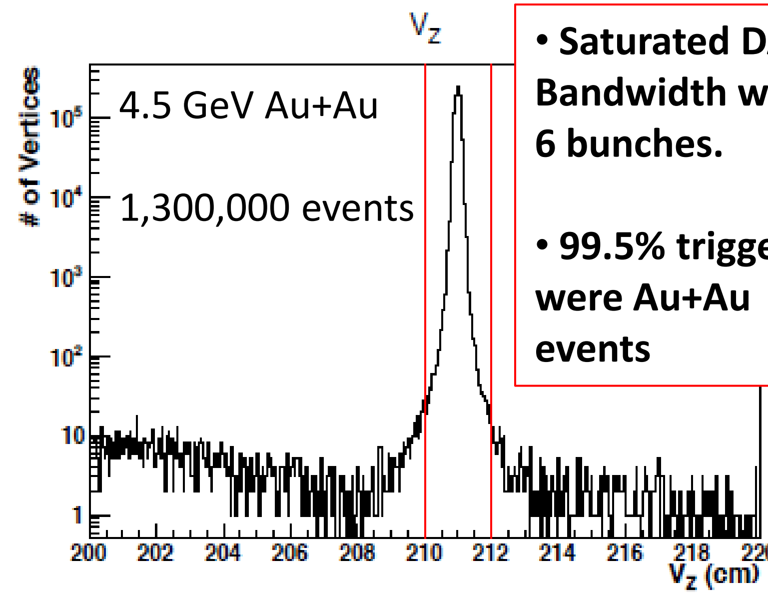
- Check the conclusion that there are gold ions in the halo
- Determine if the direct beam is a better conduct of operations
- Acquire enough data for significant feasibility studies
- Planned Analyses:
  - Reproduction of AGS results → paper draft by January
  - Particle ratio fluctuations → paper draft in working group review
  - Higher Moments analysis → expect first results by April 2017



May 20th, 2015

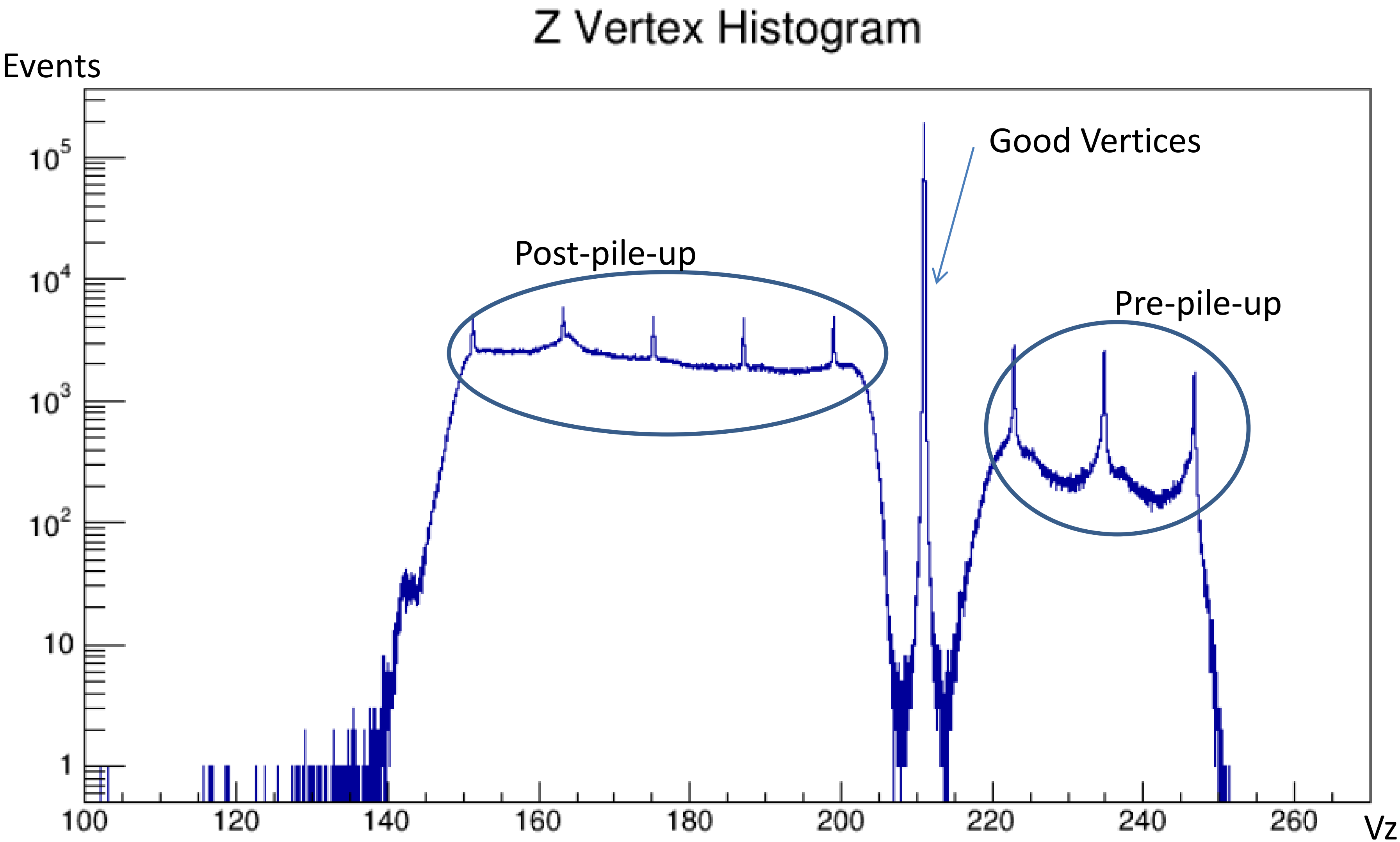




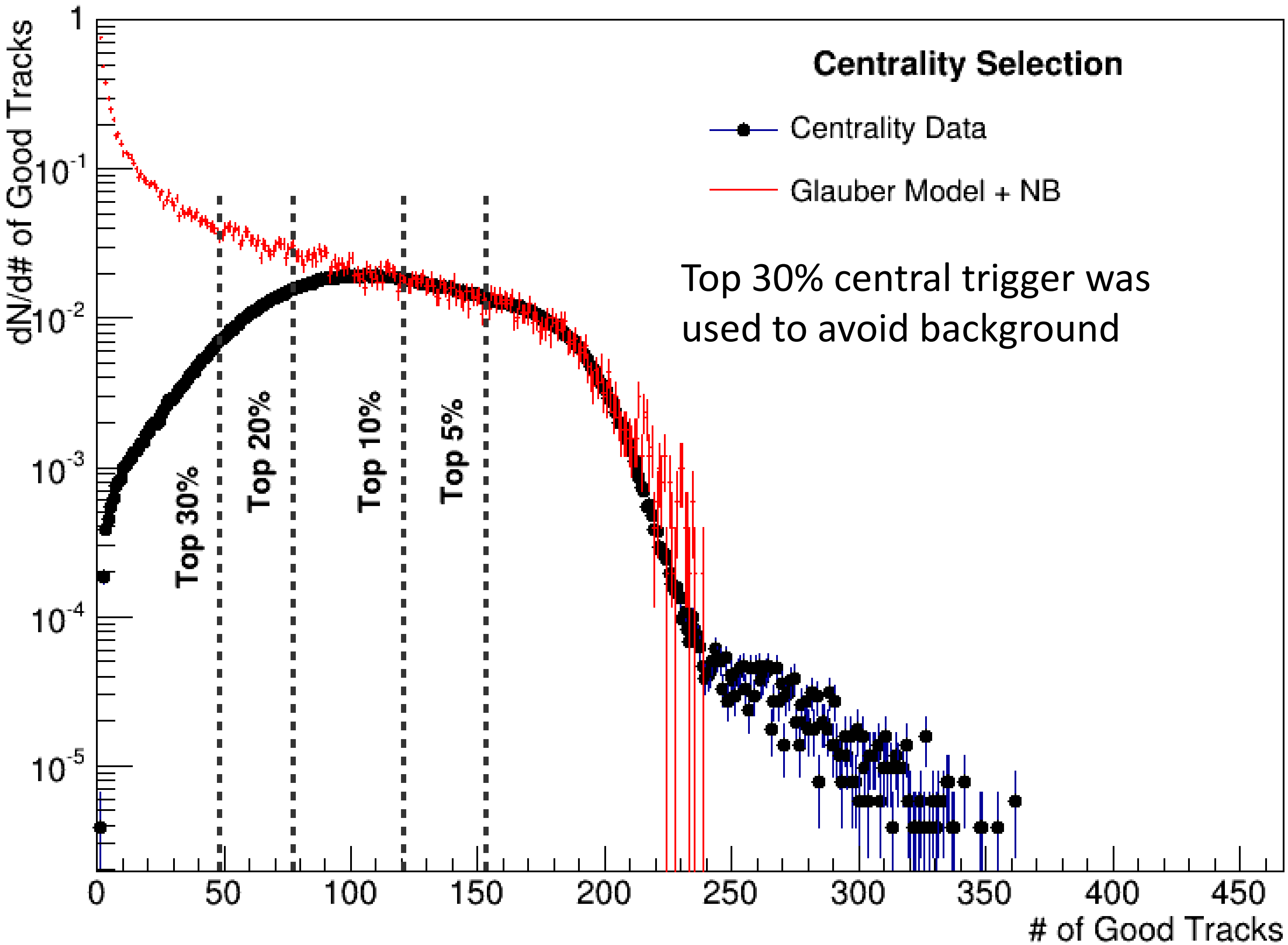


- **Saturated DAQ Bandwidth with 6 bunches.**
- **99.5% triggers were Au+Au events**

Out-of-time Pile-up

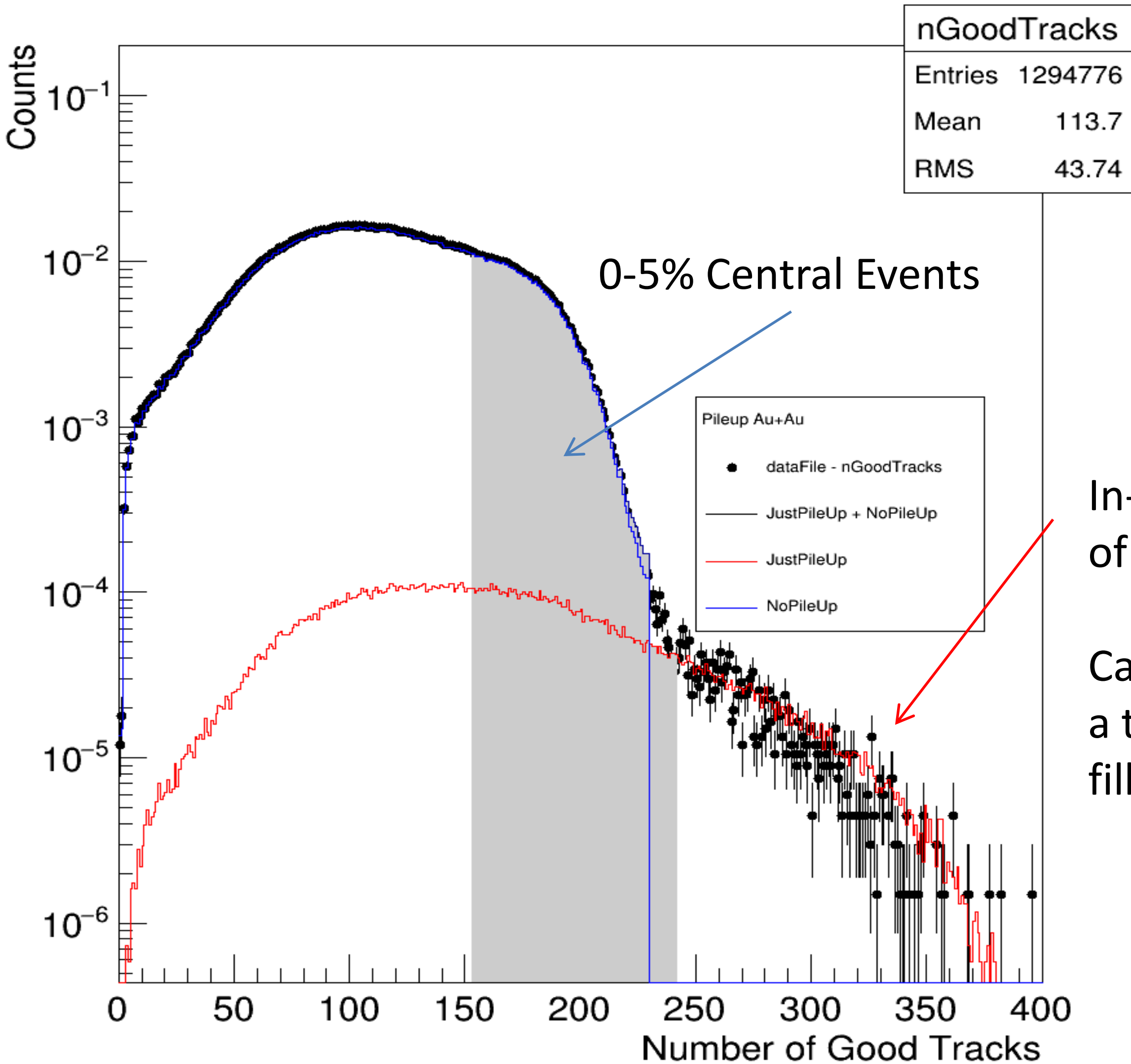


Centrality Determination



Top 30% central trigger was used to avoid background

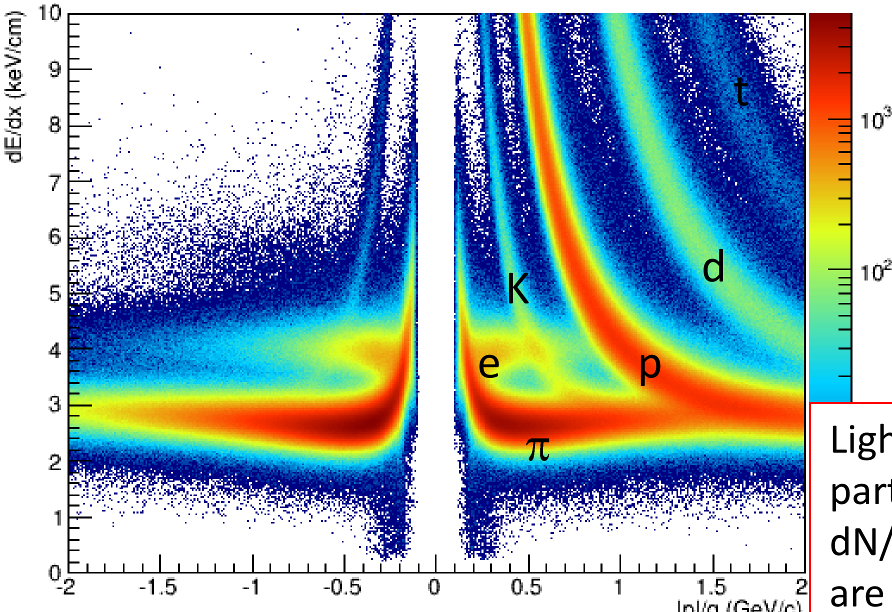
In-time Pile-up



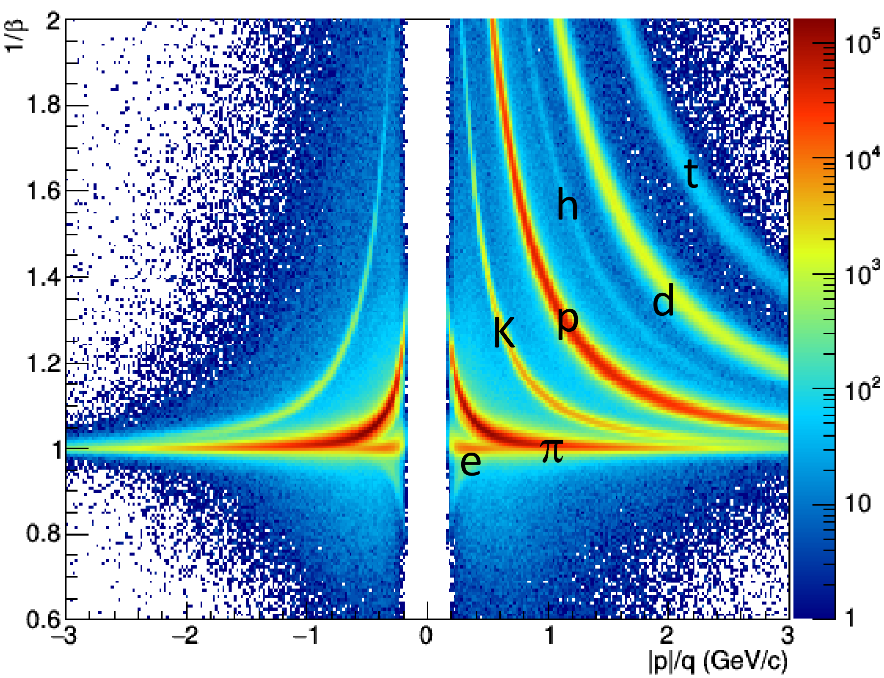
In-time pile-up in 0.8% of central events

Can be reduced by using a thinner target and filling more buckets

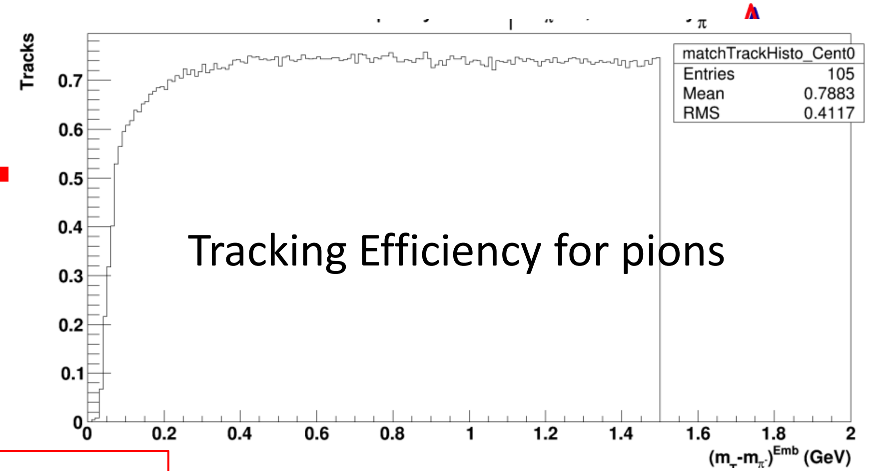
Energy Loss in TPC Zoomed In

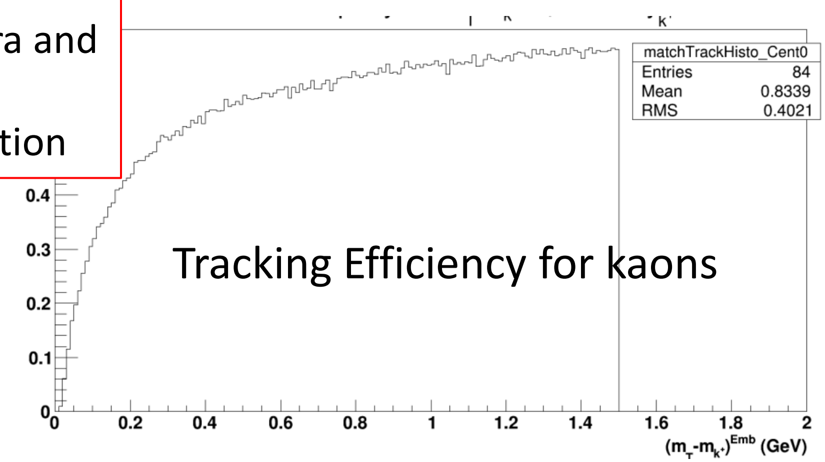


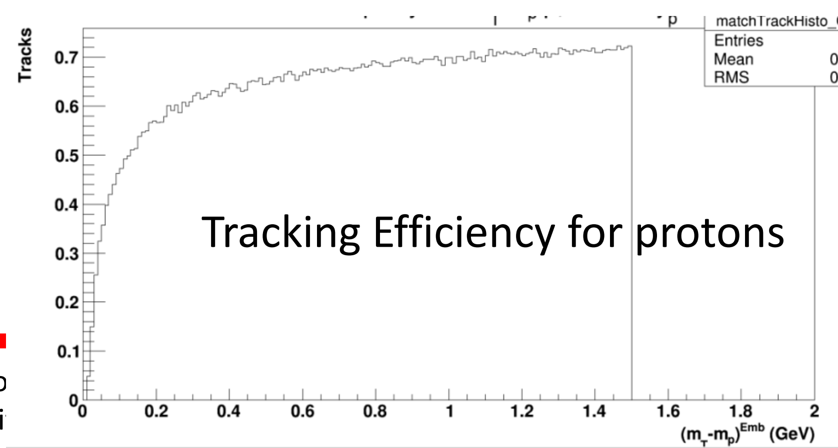
TOF 1/β



Light Charged particle spectra and dN/dy's are in preparation







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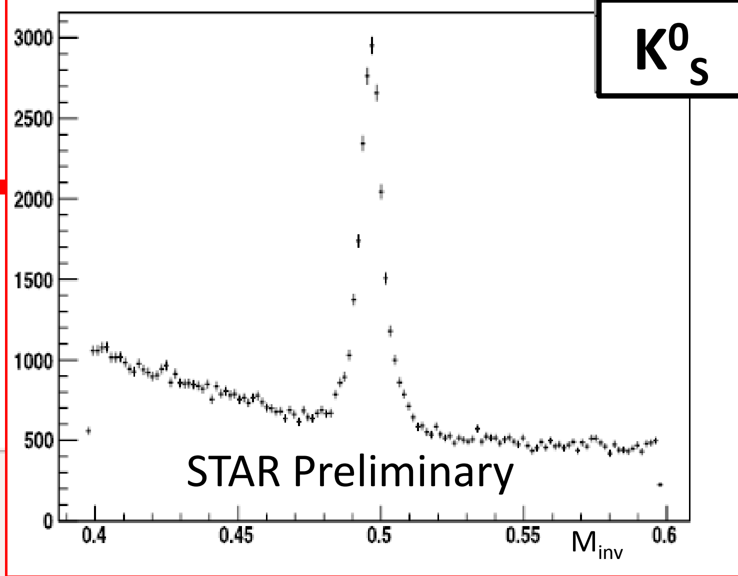
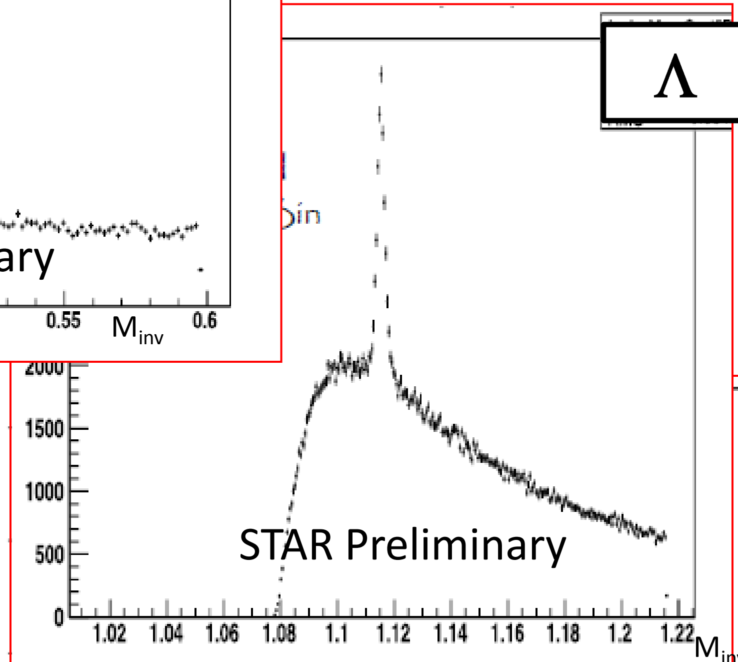
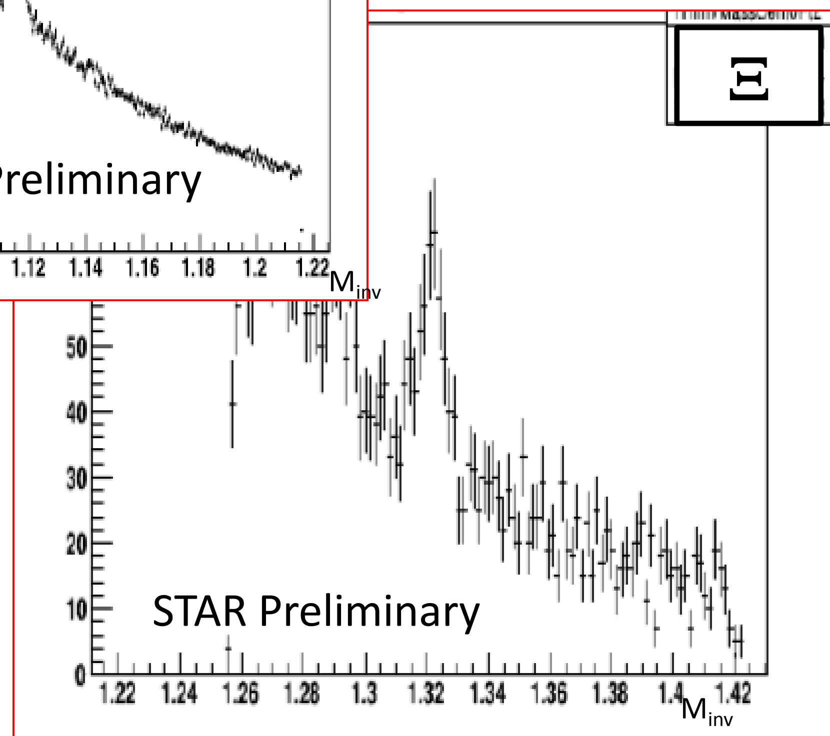
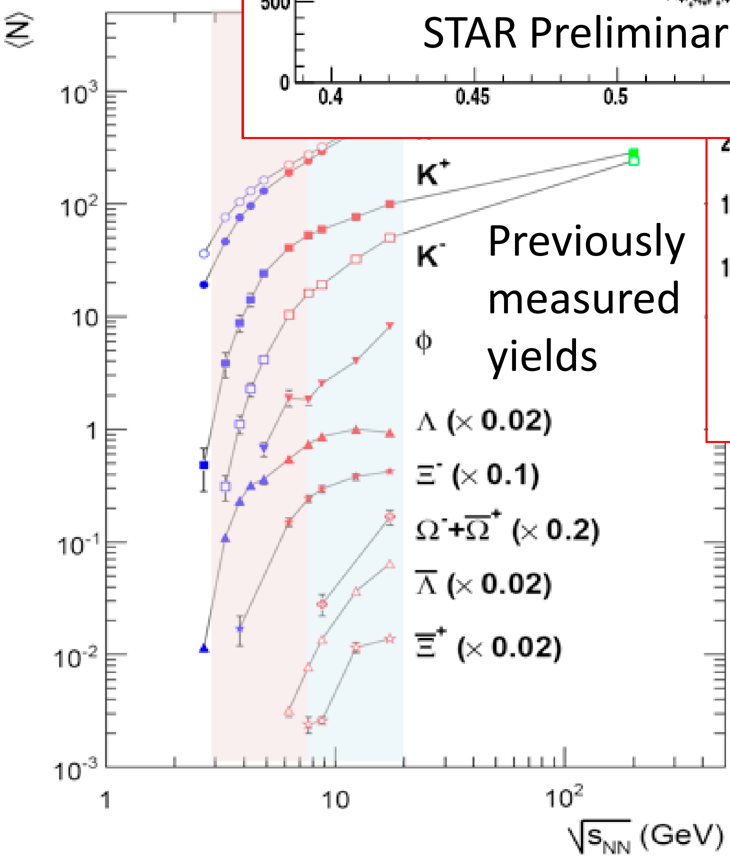
Strange Hadrons



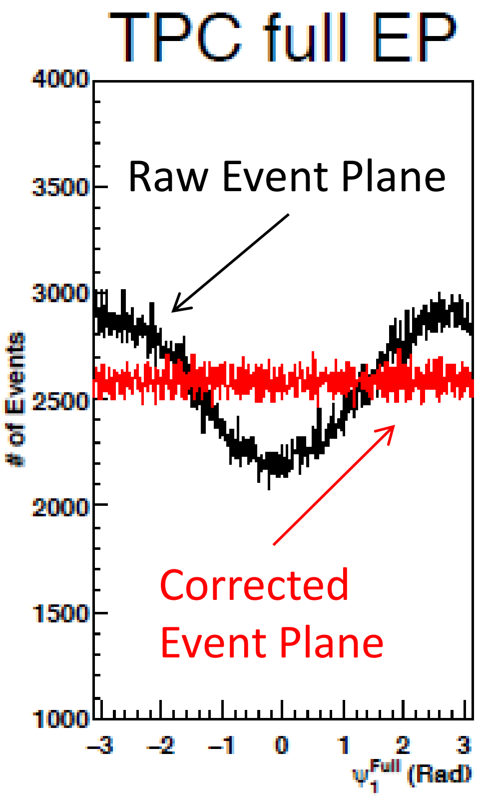


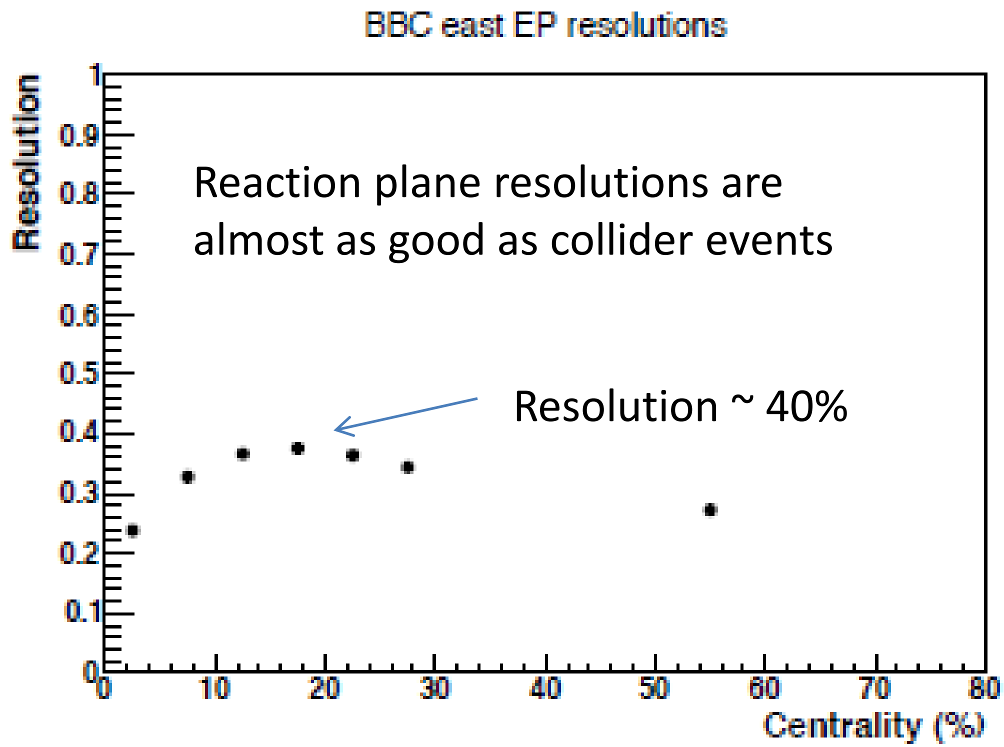


Strangeness spectra and dN/dy's ➔ In working group review



Directed and Elliptic Flow



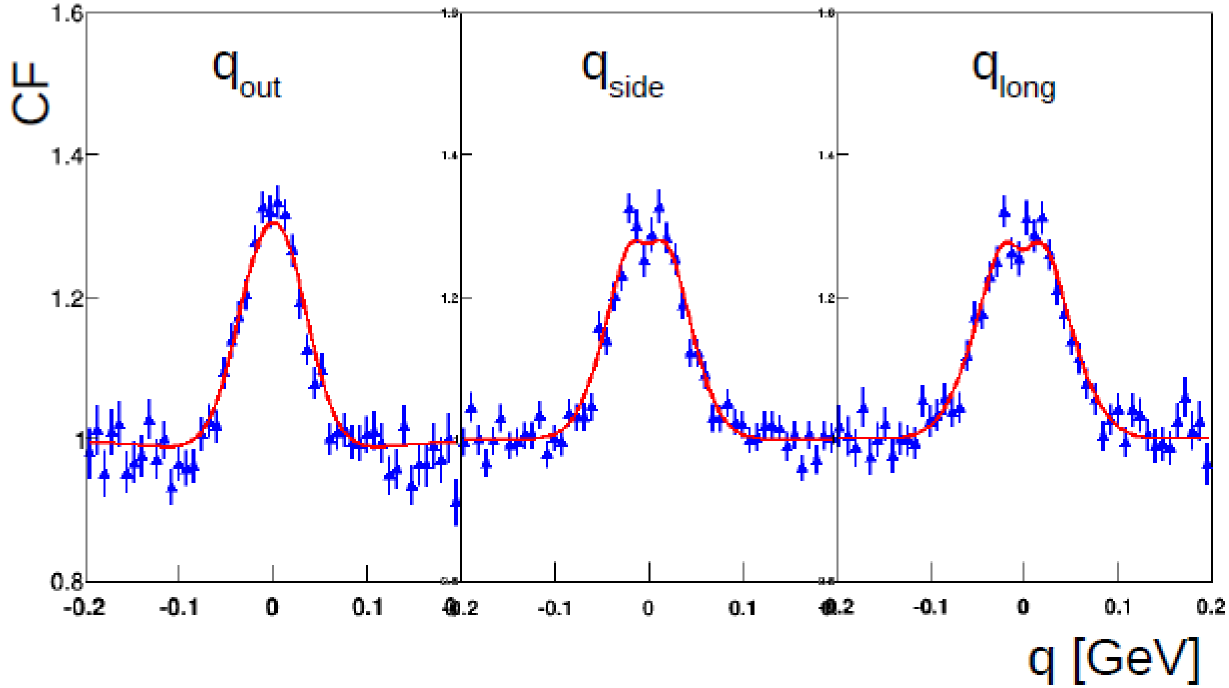


Flow results are in working group review:

➔Directed flow for: π, K, p, K^0_S, Λ

➔ Elliptic flow for: π, K, p

Femtoscopy



HBT results are in working group review:

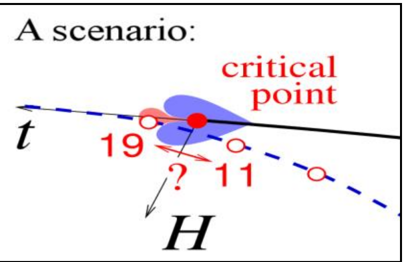
The radii are compared to the published data as a function of collision energy and k_T

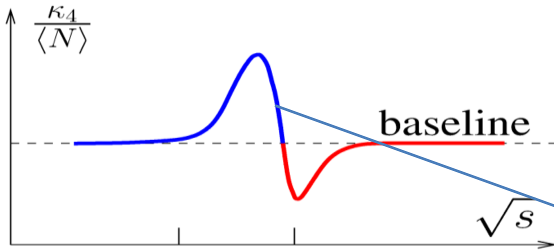
Particle Ratio Fluctuations

Draft of paper of Dynamical Fluctuations is in working group review

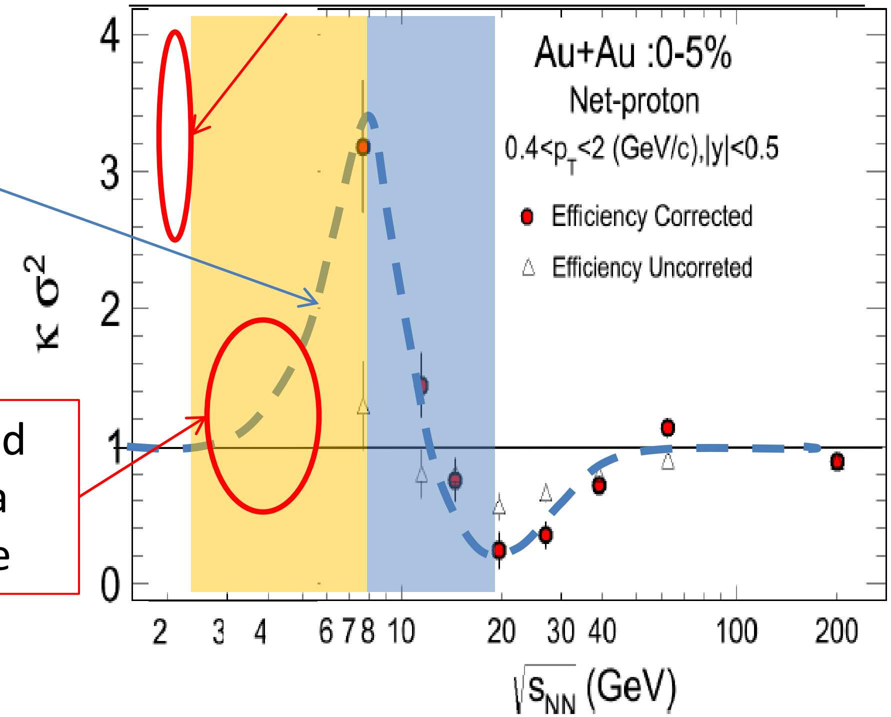

Dynamical Relative Charge Number Fluctuations Across Multiple Regimes of QCD Matter in Au_{lab}+Al, Al+Au, and Au+Au Collisions From $\sqrt{s_{NN}}$ = 3.0 - 200 GeV

Prospects for Higher Moments

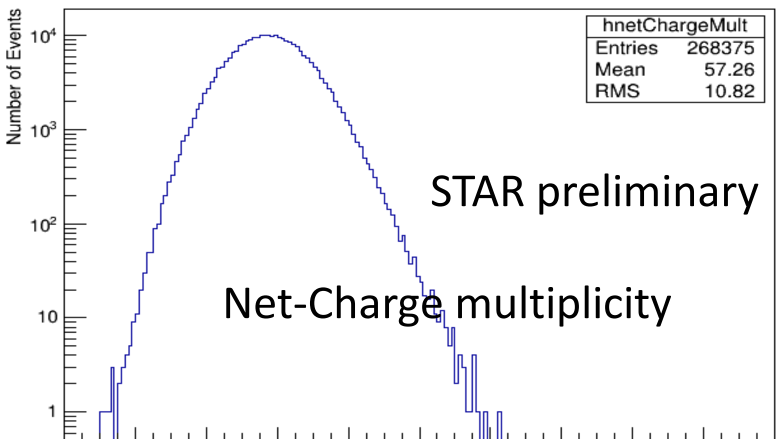


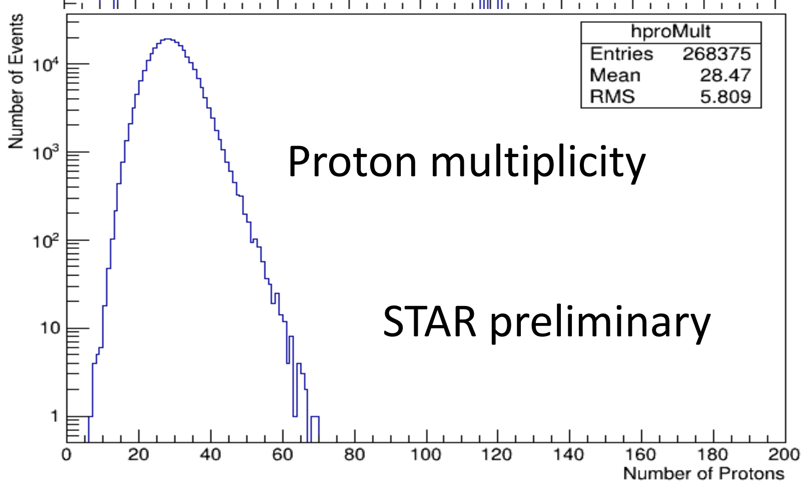


New HADES results



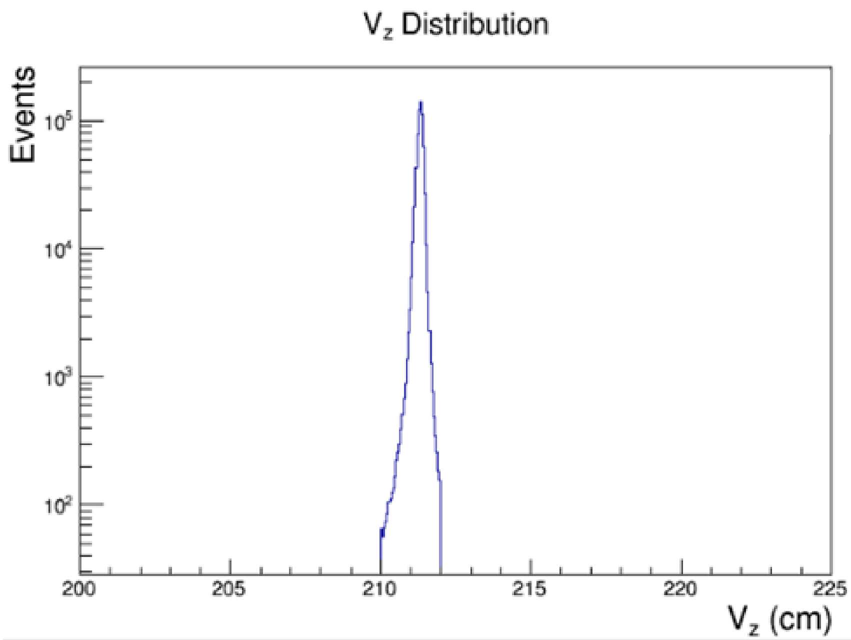
Need data here

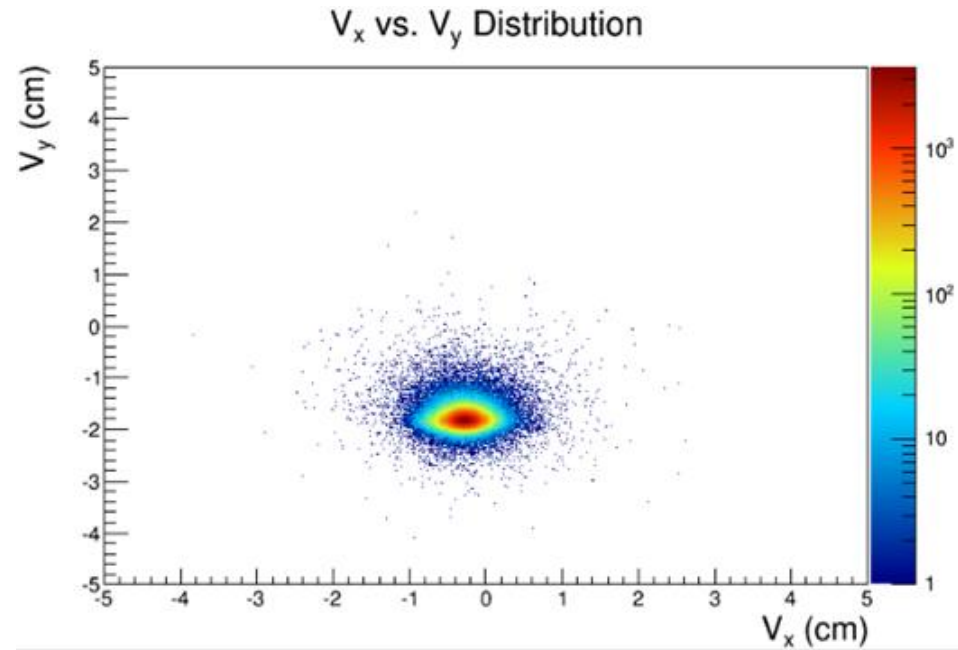




- Expect to have a sensitivity roughly comparable to the 7.7 GeV data point
- Analysis has not yet started
- Goal is to have preliminary result ready by April 2017 for use in the Beam Use Request

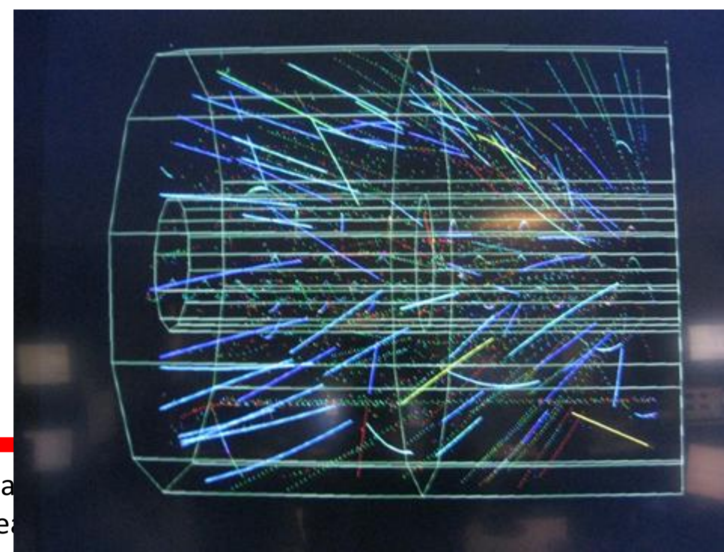
4.9 GeV Al + Au Test Run and Performance





3.3 Million Al+Au Events

- Will compare to AGS Si+Au results
- Expect preliminary results by September 2017



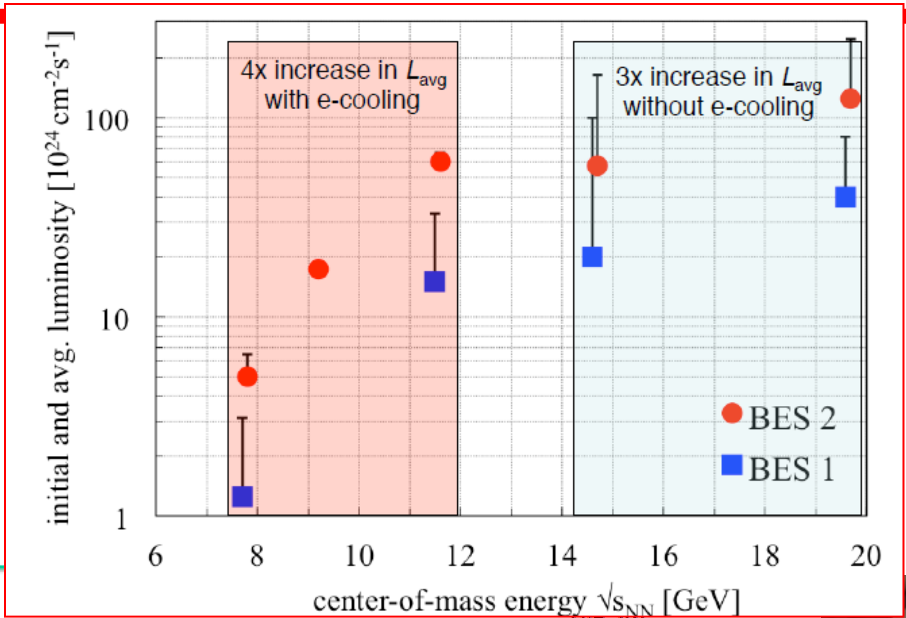
Plans for the Future 2018-2020

- Full FXT proposal will be inlcuded in the May 2017 Beam Use Request
- Will likely include a request for a single energy in 2018
- Will request an FXT energy scan to run during BES-II

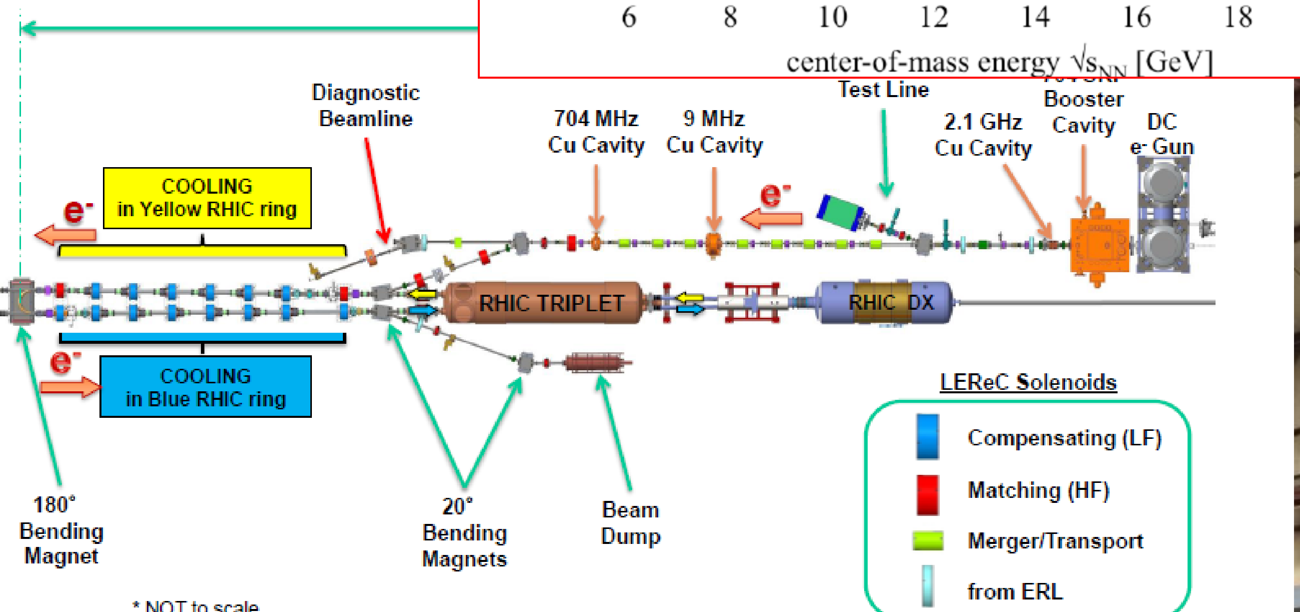
➔ Remember my early caveats….

Low Energy Electron Cooling at RHIC

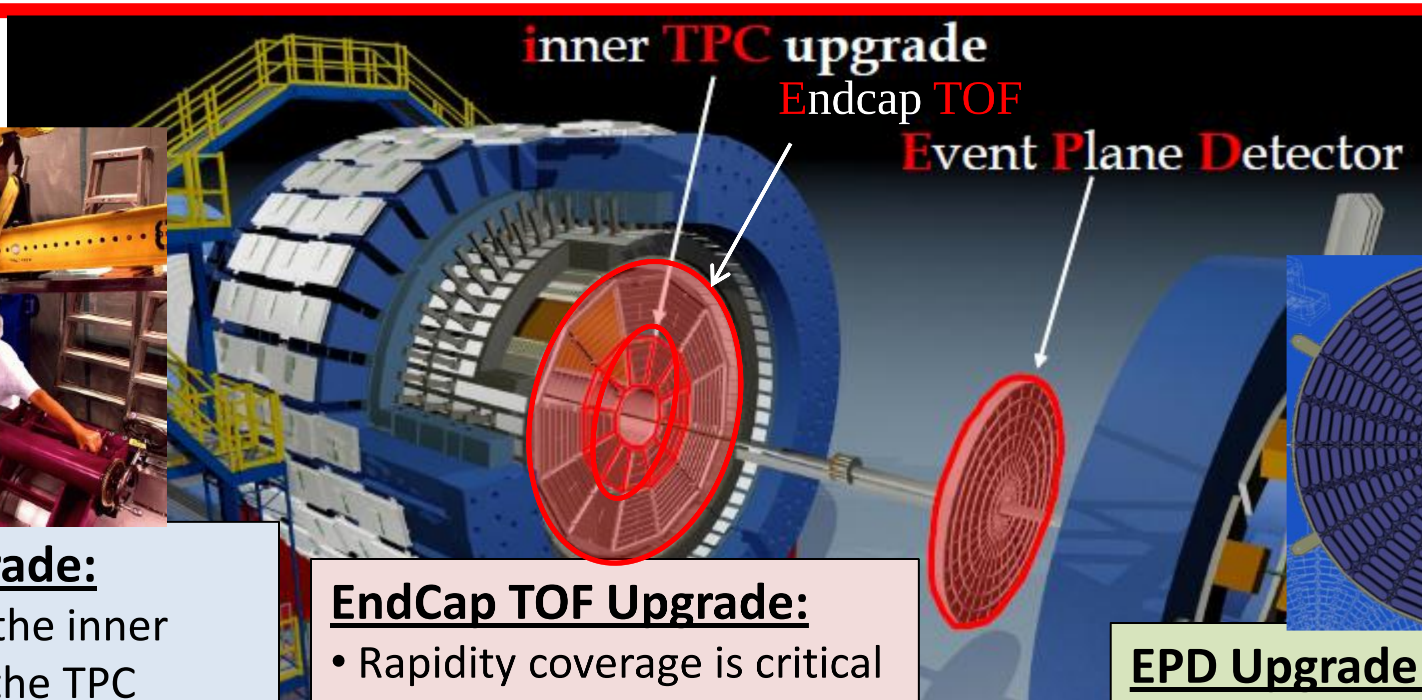
Improve luminosity for low energy beams with electron cooling

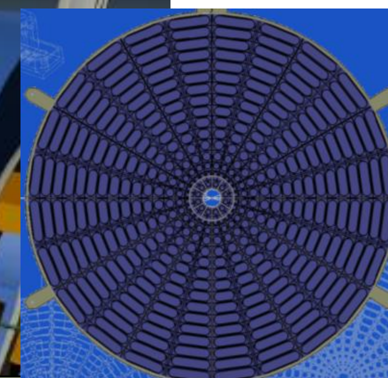


- Start with 14.5 and 19,6 3X improvement
- Following year, 7.7, 9.1, and 11.5, 4X improvement with eCooling
- Run 24 weeks



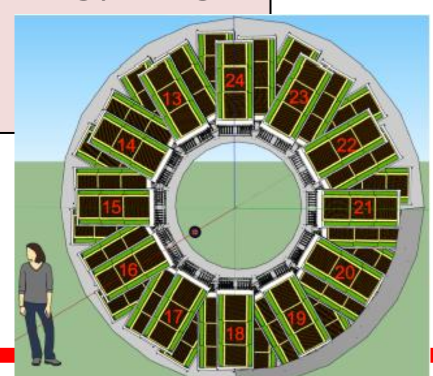
The STAR Upgrades and the FXT program





iTPC Upgrade:
- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.5 to 2.2
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c
- Ready in 2019

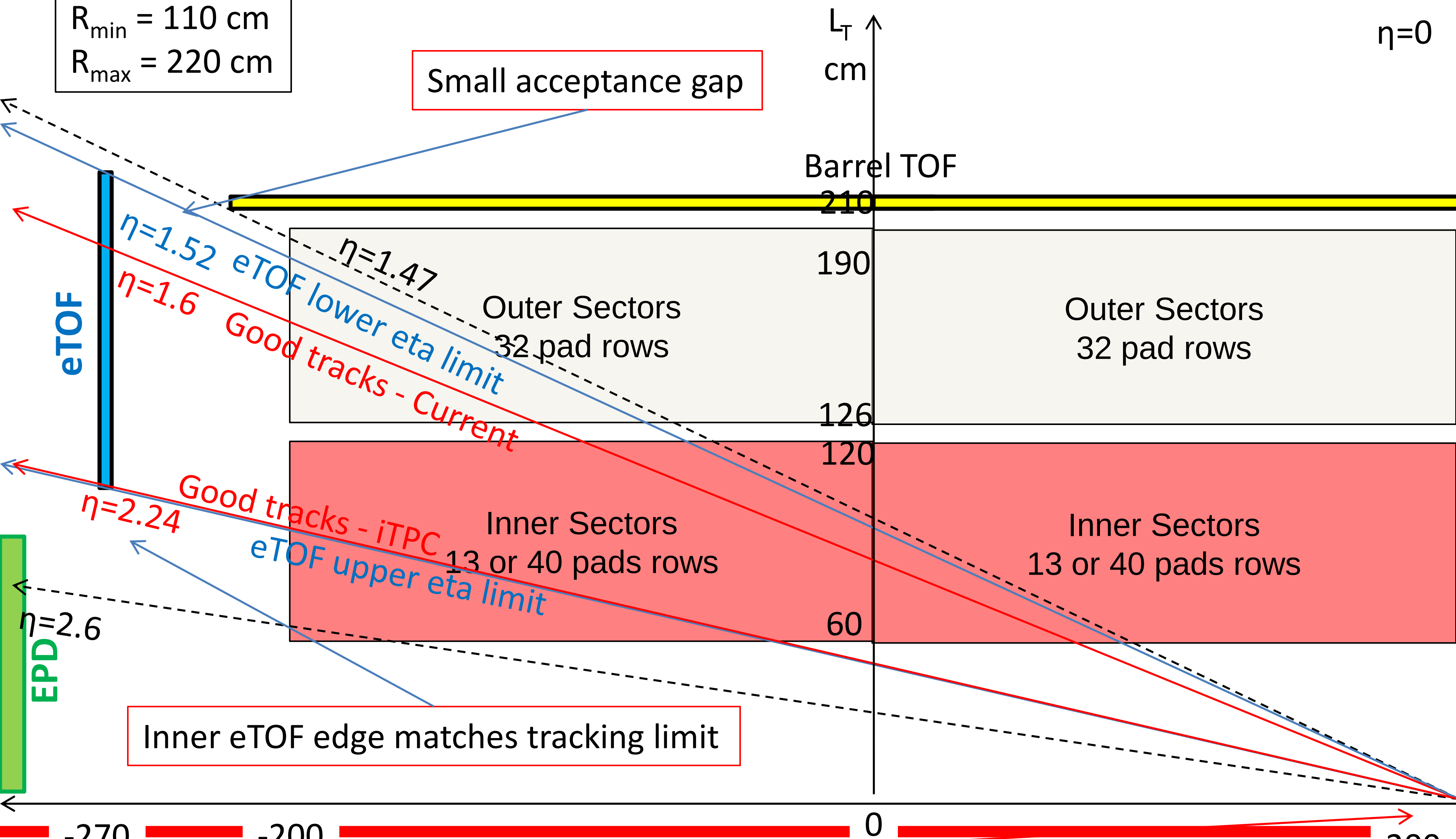
EndCap TOF Upgrade:
- Rapidity coverage is critical
- PID at forward rapidity
- Allows higher energy range of FXT program
- Ready 2019



EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics
- Ready 2018

Internal Fixed Target PseudoRapidity Considerations

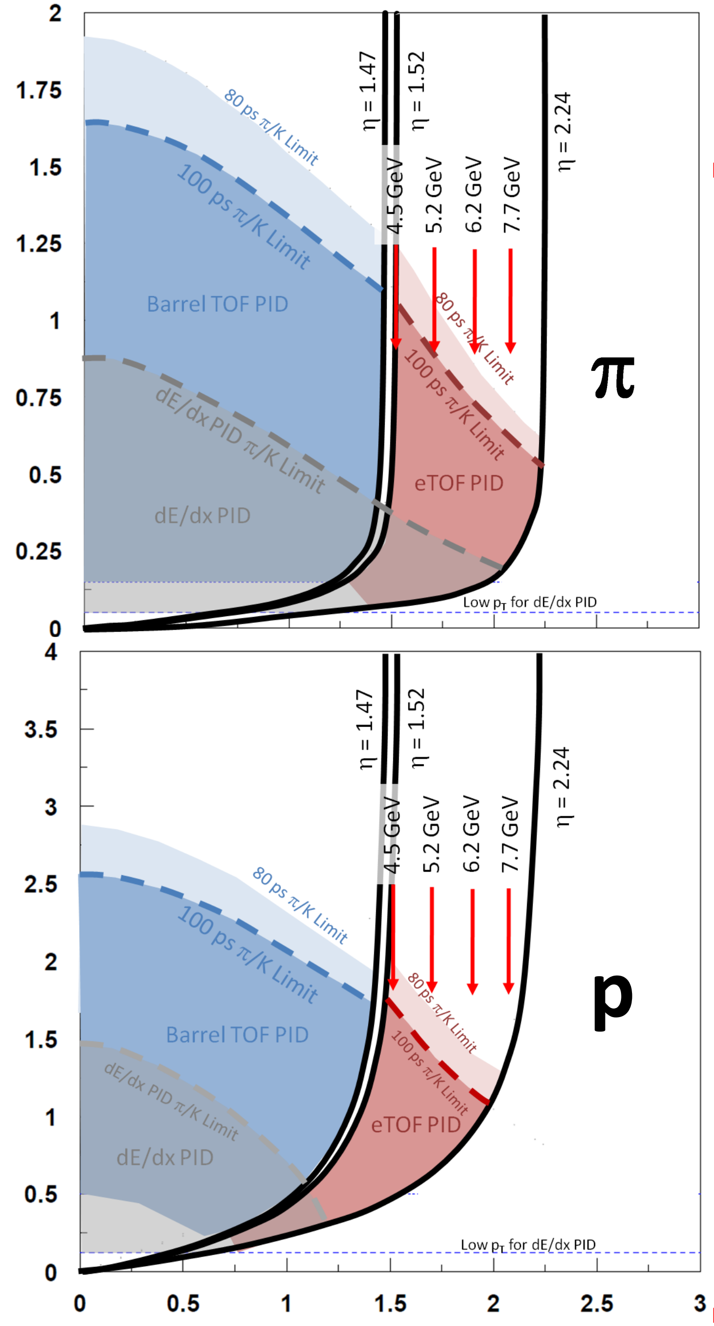
eTOF:
Z = -270 cm
ΔZ = 480 cm
R_{min} = 110 cm
R_{max} = 220 cm



FXT Program

Collider Energy	Fixed-Target Energy	Single beam AGeV	Center-of-mass Rapidity	μ_B (MeV)
62.4	7.7	30.3	2.10	420
39	6.2	18.6	1.87	487
27	5.2	12.6	1.68	541
19.6	4.5	8.9	1.52	589
14.5	3.9	6.3	1.37	633
11.5	3.5	4.8	1.25	666
9.1	3.2	3.6	1.13	699
7.7	3.0	2.9	1.05	721
5.0	2.5	1.6	0.82	774

- Data rate is DAQ limited
- Would need 100 Million Events at each energy to make the sensitivity of BES-II
- Roughly one to two days per energy



Comparison of Facilities

Facilty	**RHIC BESII**	**SPS**	**NICA**	**SIS-100** SIS-300	**J-PARC HI**
Exp.:	**STAR** +FXT	**NA61**	**MPD** + **BM@N**	**CBM**	**JHITS**
Start:	**2019-20** 2018	**2009**	**2020** 2017	**2022**	**2025**
Energy: $\sqrt{s_{NN}}$ (GeV)	**7.7– 19.6** 2.5-7.7	**4.9-17.3**	**2.7 - 11** 2.0-3.5	**2.7-8.2**	**2.0-6.2**
Rate: At 8 GeV	**100 HZ** 2000 Hz	**100 HZ**	**<10 kHz**	**<10 MHZ**	**100 MHZ**
Physics:	**CP&OD**	**CP&OD**	**OD&DHM**	**OD&DHM**	**OD&DHM**
	Collider Fixed Target	Fixed Target Lighter ion collisions	Collider Fixed Target	Fixed Target	Fixed Target

CP = Critical Point
OD = Onset of Deconfinement
DHM = Dense Hadronic Matter

Physics Goals of the FXT Program

STAR

The Onset of Deconfinement:

•High p_T suppression
•N_{CQ} scaling of Elliptic Flow
•LPV through three particle correlators (CME)
•Balance Functions
•Strangeness Enhancement

Compressibility → First Order Phase Transition

•Directed flow
•Tilt angle of the HBT source
•The Volume of the HBT source
•The width of the pion rapidity distributions (Dale)
•The zero crossing of the elliptic flow (~6 AGeV)
•Volume measures from Coulomb Potential

Criticality:

•Higher moments
•Particle Ratio Fluctuations

Chirality:

•Dilepton studies

No measurements in this energy range

Hypernuclei: → Lifetime of the hypertriton

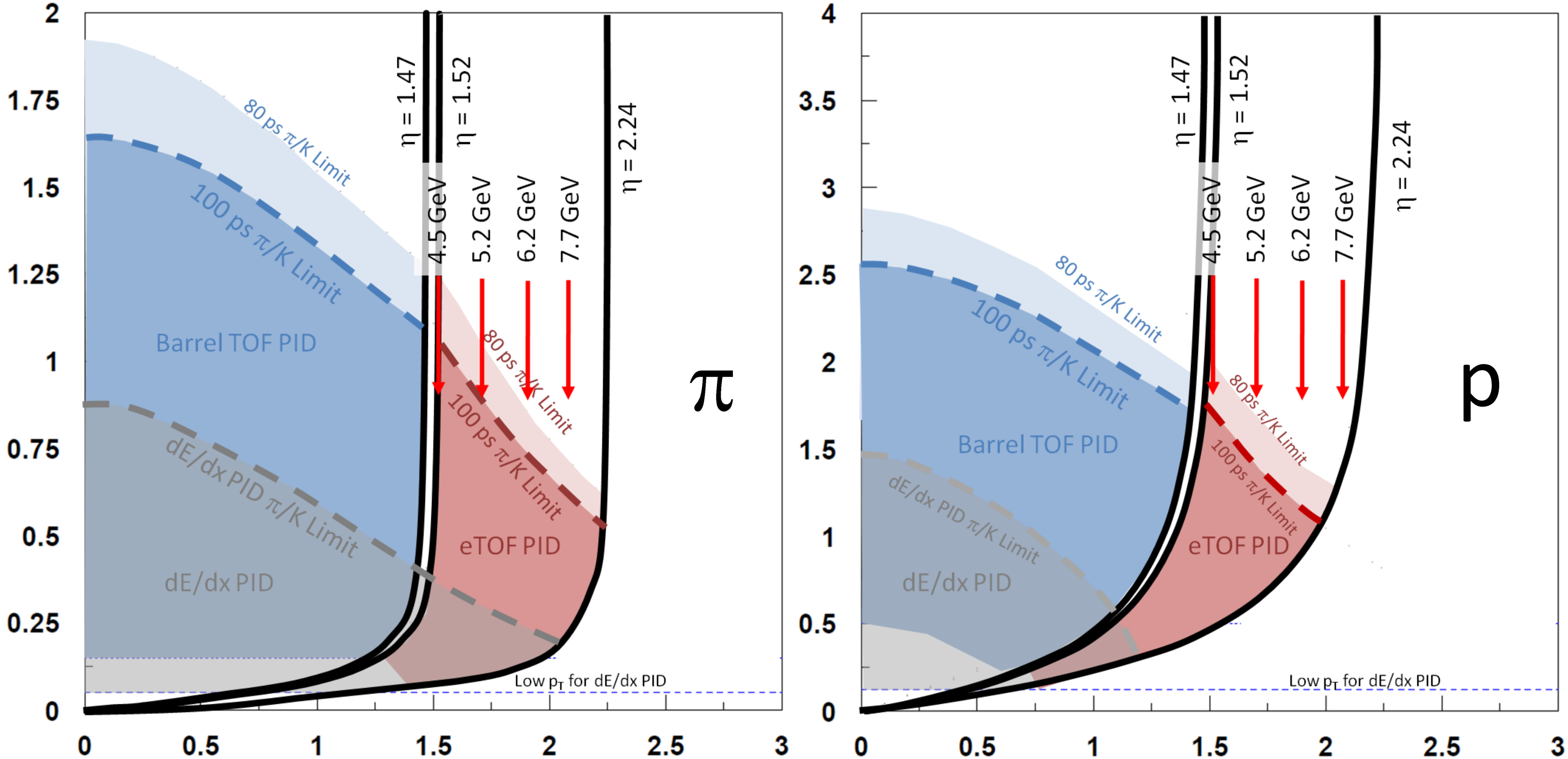
What a STAR FXT Program will not do:

- Omega's
- Charm
- Doublely Hyper nuclei
- p+p scan
- p+A scan
- peripheral collisions
- > 100 Million event per energy
- > two weeks of beam time

Conclusions

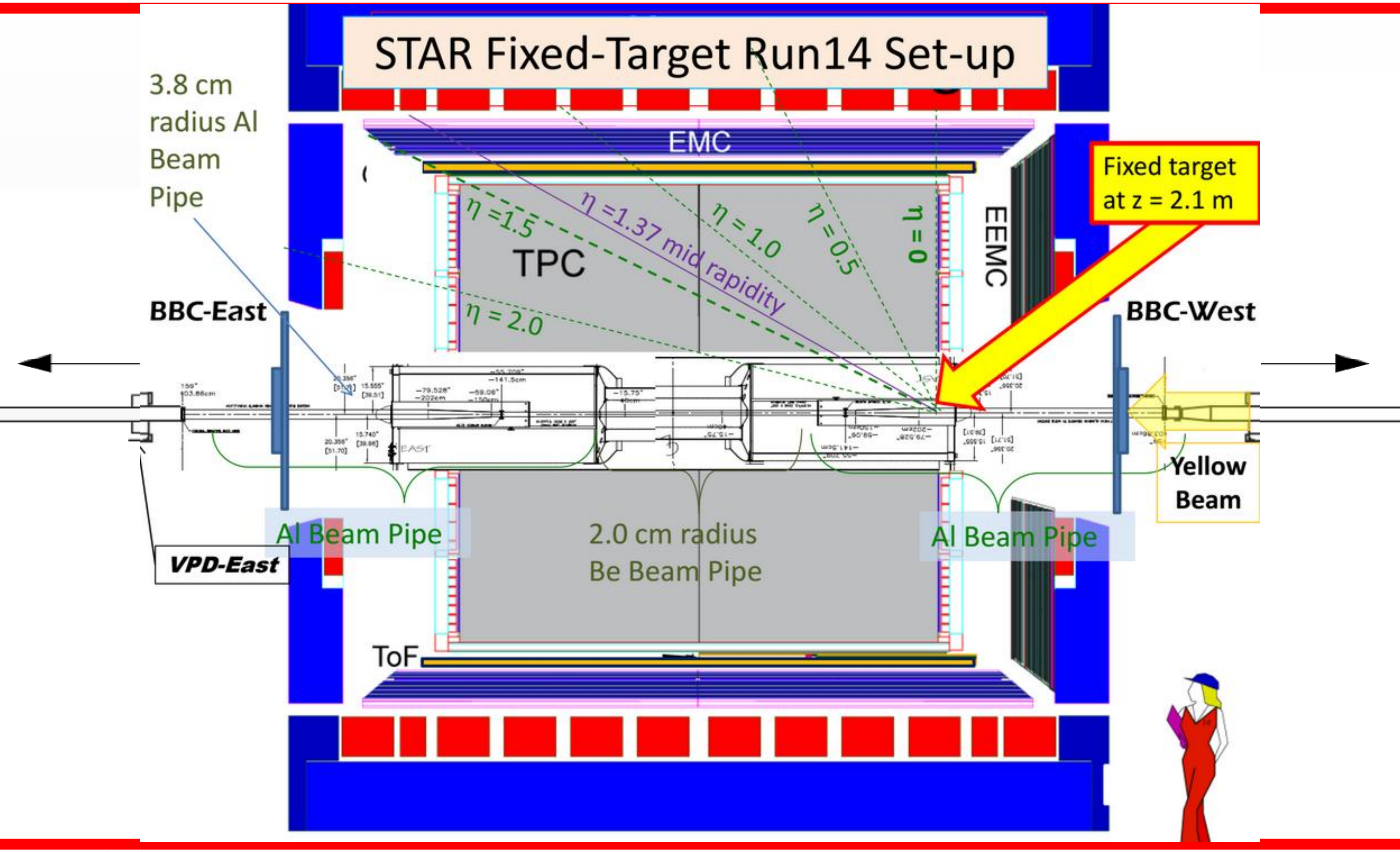
- STAR works well for Fixed-target events
- FXT program will allow for key measurements below 7.7 GeV
- Acceptance and physics have been demonstrated in test runs and other studies
- Will require a small amount of dedicated beam time
- Expect to include a full proposal in BUR18/19

Extras


80 ps π/K Limit
100 ps π/K Limit
Barrel TOF PID
dE/dx PID π/K Limit
dE/dx PID
η = 1.47
η = 1.52
η = 2.24
4.5 GeV
5.2 GeV
6.2 GeV
7.7 GeV
80 ps π/K Limit
100 ps π/K Limit
eTOF PID
Low p_T for dE/dx PID
π
p

Collision Energy (GeV)	Single Beam Energy	Fixed Target Root s	Single Beam Rapidity	Center of Mass Rapidity	Chemical Potential μ_B	Events (Millions)
200	100	13.713	5.369	2.685	0.276	NA
130	65	11.083	4.938	2.469	0.325	NA
62.4	31.2	7.737	4.204	2.102	0.420	100
39	19.5	6.170	3.734	1.867	0.487	100
27	13.5	5.185	3.366	1.683	0.541	100
19.6	9.8	4.468	3.042	1.521	0.589	100
14.5	7.25	3.904	2.741	1.370	0.633	100
11.5	5.75	3.528	2.507	1.253	0.666	100
9.1	4.55	3.196	2.269	1.134	0.699	100
7.7	3.85	2.985	2.097	1.049	0.721	100
5.0	2.50	2.320	1.644	0.822	0.774	100

Run 14 and 15 Setup



BES Phase II Proposal

BES Phase II is planned for two 24 cryo-week runs in 2019 and 2020

$\sqrt{S_{NN}}$ (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV)	420	370	315	250	205
BES I (MEvts)	4.3	---	11.7	24	36
Rate(MEvts/day)	0.25		1.7	2.4	4.5
BES I $\mathcal{L}$ ($1\times10^{25}/cm^2sec$)	0.13		1.5	2.1	4.0
BES II (MEvts)	100	160	230	300	400
Improvement (X)	4	4	4	3	3
Beam Time (weeks)	**12**	**9.5**	**5.0**	**5.5**	**4.5**

Revised estimates

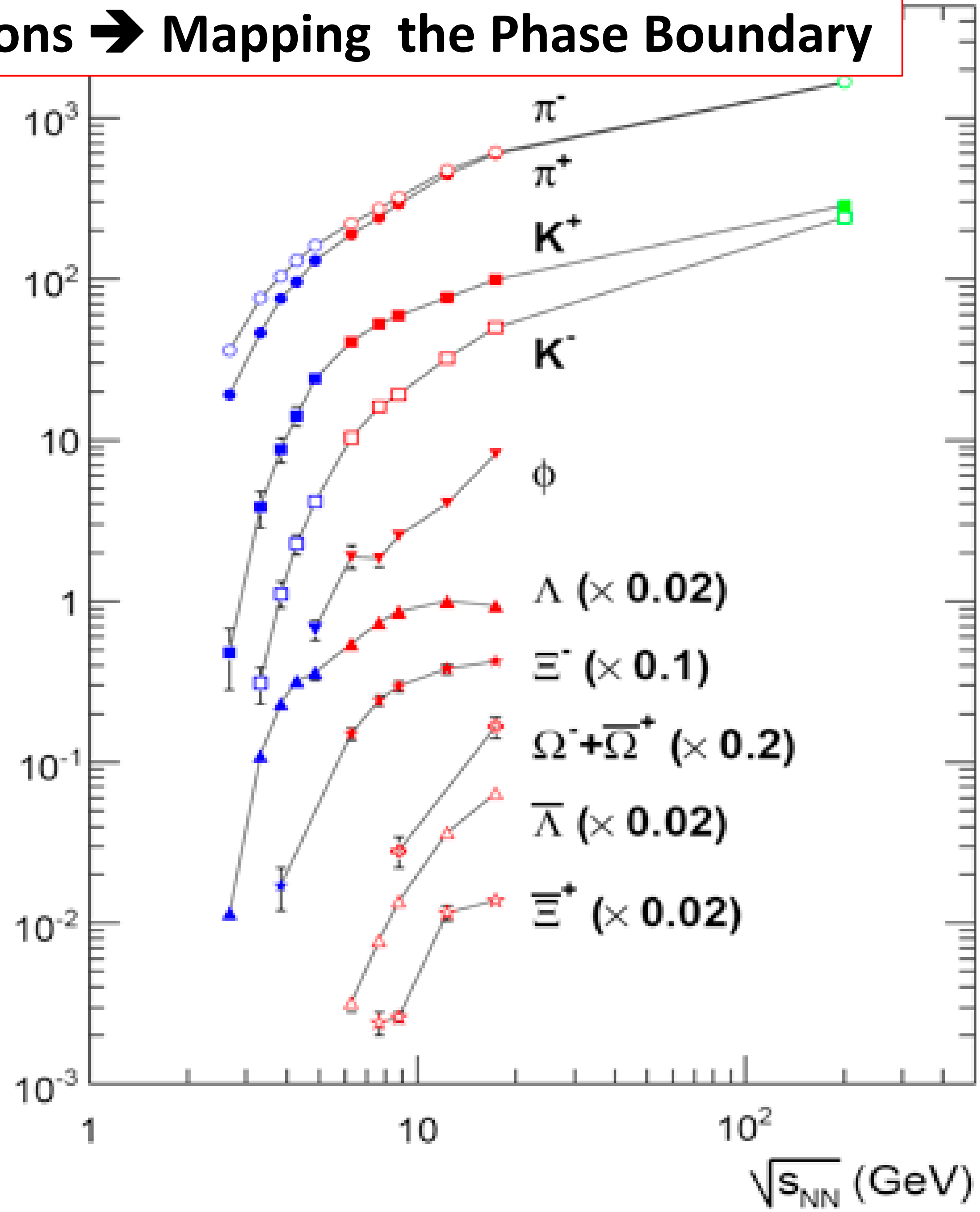
Yields of Hadrons → Mapping the Phase Boundary

Acceptance of π, K, p is good to midrapidity at all FXT energies. Acceptance for weak decay parents should be good as well.

Measurements can be extrapolated to 4π

Will be able to extend the low energy limits of measurements of most strange hadrons

4π strange hadron yields are needed for chemical equilibrium models to determine T and μ_B

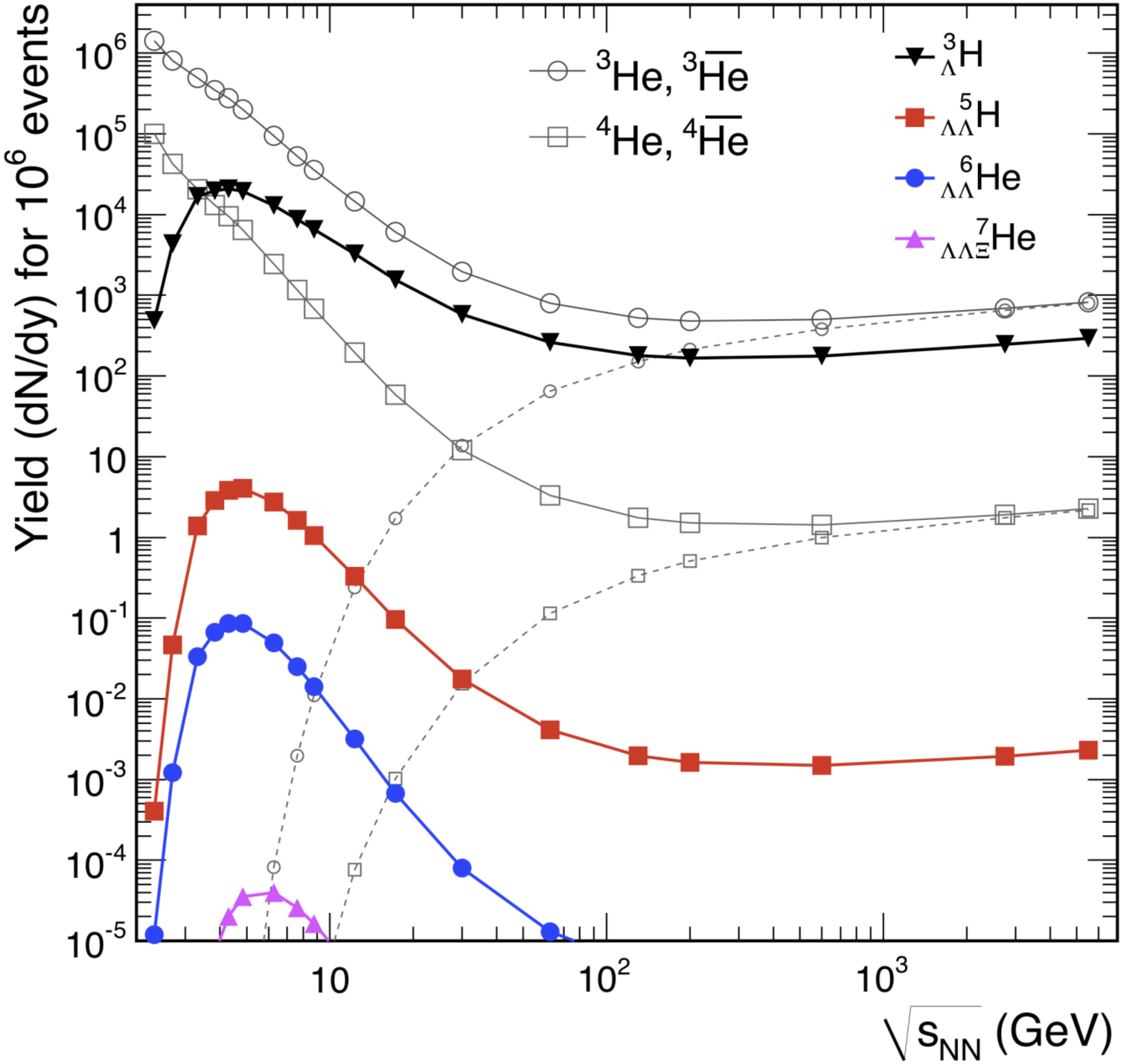


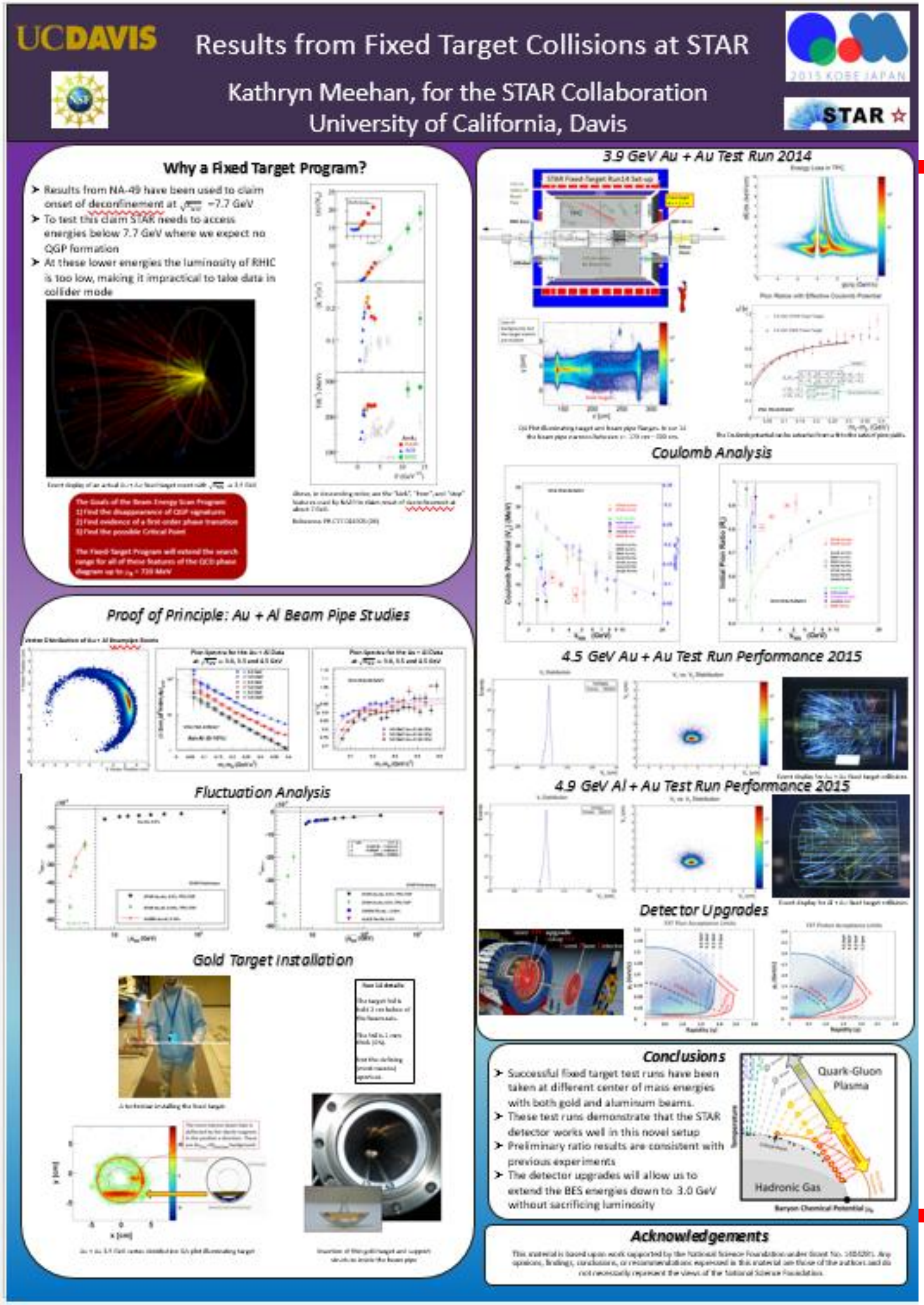
Hypernuclei

Perfect energy range to map out the production of $^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$

Previously only measured at two energies

Dynamic range will exclude searches for doubly strange hypernuclei




UCDAVIS
Results from Fixed Target Collisions at STAR
Kathryn Meehan, for the STAR Collaboration
University of California, Davis
STAR
Why a Fixed Target Program?
Results from NA-49 have been used to claim onset of deconfinement at $\sqrt{s_{NN}}$ ~7.7 GeV
To test this claim 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
3.9 GeV Au + Au Test Run 2014
Coulomb Analysis
Proof of Principle: Au + Al Beam Pipe Studies
4.5 GeV Au + Au Test Run Performance 2015
4.9 GeV Al + Au Test Run Performance 2015
Fluctuation Analysis
Detector Upgrades
Gold Target Installation
Conclusions
Successful fixed target test runs have been taken at different center of mass energies with both gold and aluminum beams.
These test runs demonstrate that the STAR detector works well in this novel setup
Preliminary ratio results are consistent with previous experiments
The detector upgrades will allow us to extend the BES energies down to 3.0 GeV without sacrificing luminosity
Quark-Gluon Plasma
Hadronic Gas
Acknowledgements