The STAR iTPC Upgrade

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For the STAR Collaboration

BES Phase II – Physics Cases for iTPC

Beam Energy Scan – Phase I Results:

- Seen the turn-off of QGP signatures.
- Seen suggestions of the first order phase transition.
- Not seen conclusive evidence of a critical point.

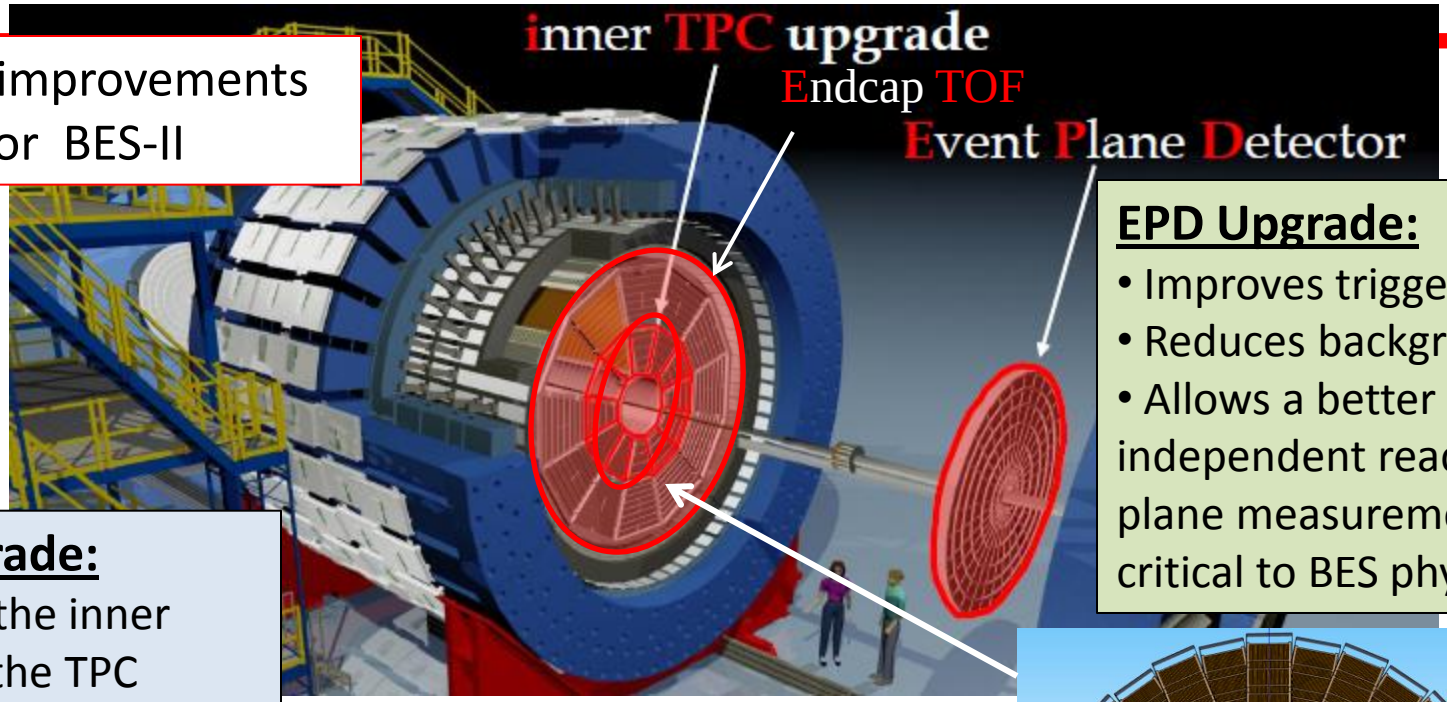
The most promising region for refining the search is in the lower energies➔ 19.6, 15, 11.5, 7.7, and lower.

The iTPC Upgrades strengthen the BES II physics program, and enables new key measurements:

- Rapidity dependence of proton kurtosis
- Dilepton program (sys. errors and intermediate mass region)
- Enables the internal fixed target program to cover 7.7 to 3.0 GeV

The STAR Upgrades and BES Phase II

Major improvements for BES-II



EPD Upgrade:

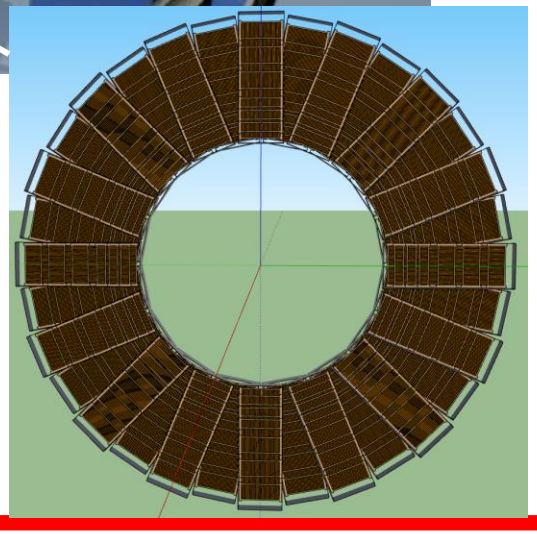
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

iTPC Upgrade:

- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

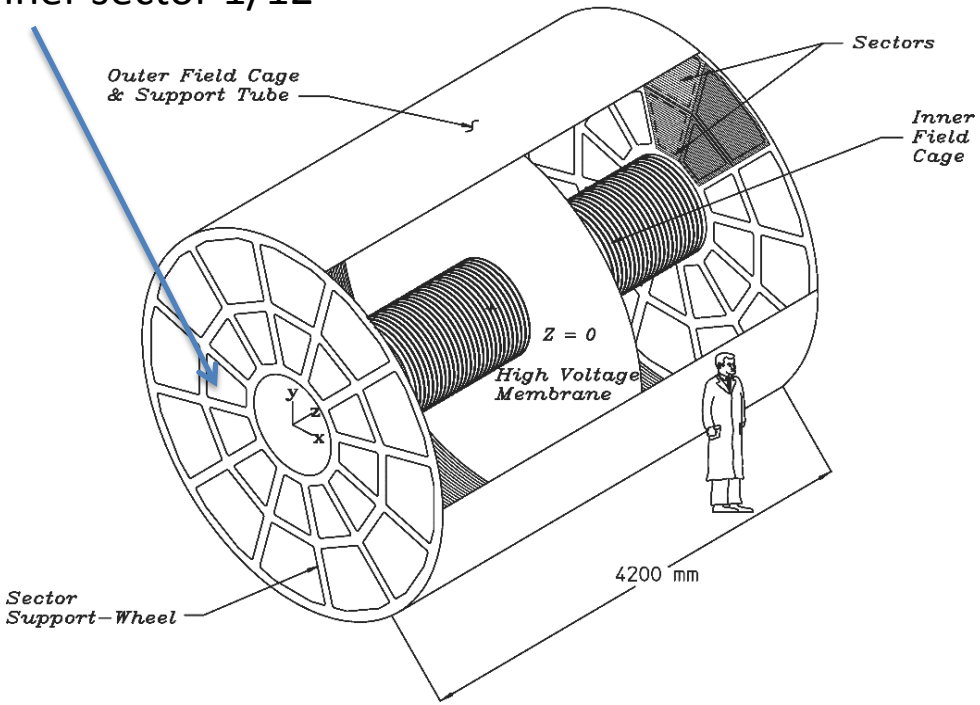
EndCap TOF Upgrade:

- Rapidity coverage is critical
- PID at η = 0.9 to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR



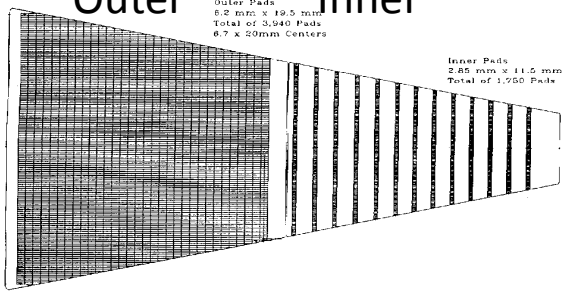
What is the Current TPC?

Inner sector 1/12



- 24 sectors
- 12 on each side
- Large pads for good dE/dx resolution in the Outer sector
- Small pads for good two track resolution in the inner sector

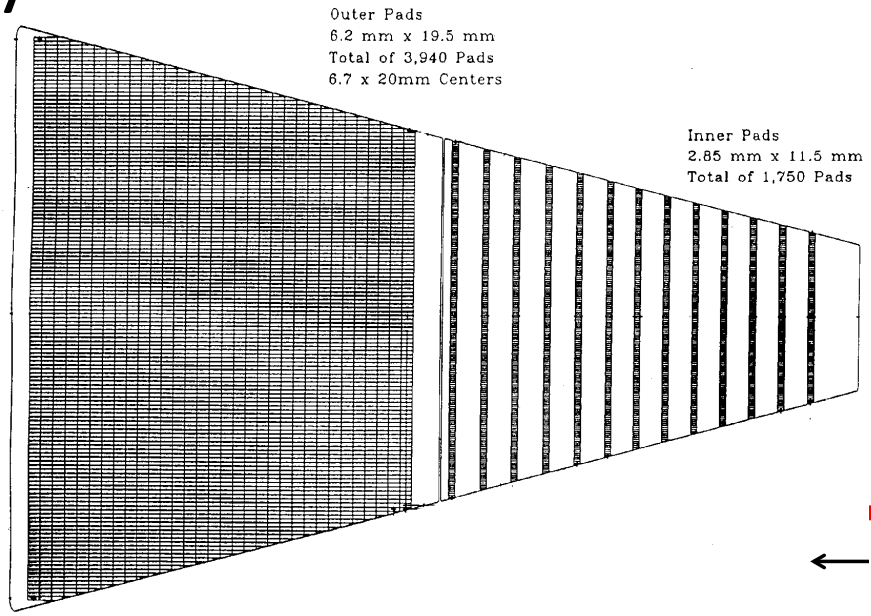
Outer Inner



32 Rows	13 Rows
6.2 X 19.5 mm	2.85 X 11.5 mm
3940 pads	1750 pads

Current Inner Sector Limitations

- Staggered readout
  - Only 13 maximum possible points
    - Issues in Tracking: recognition and resolution
  - Only reads ~20% of possible gas path length
    - Inner sectors essentially not used in dE/dx
- Essentially limits TPC effective acceptance to $|\eta|<1$



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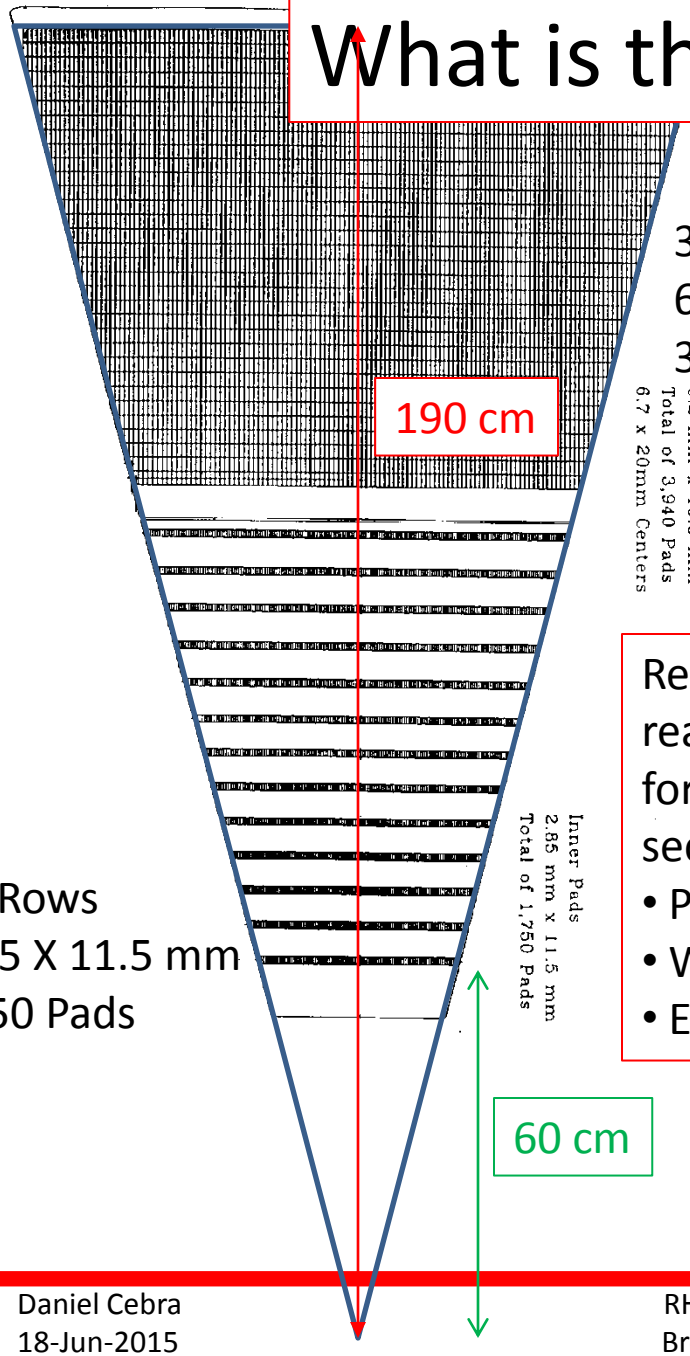
What is the iTPC Upgrade?



190 cm

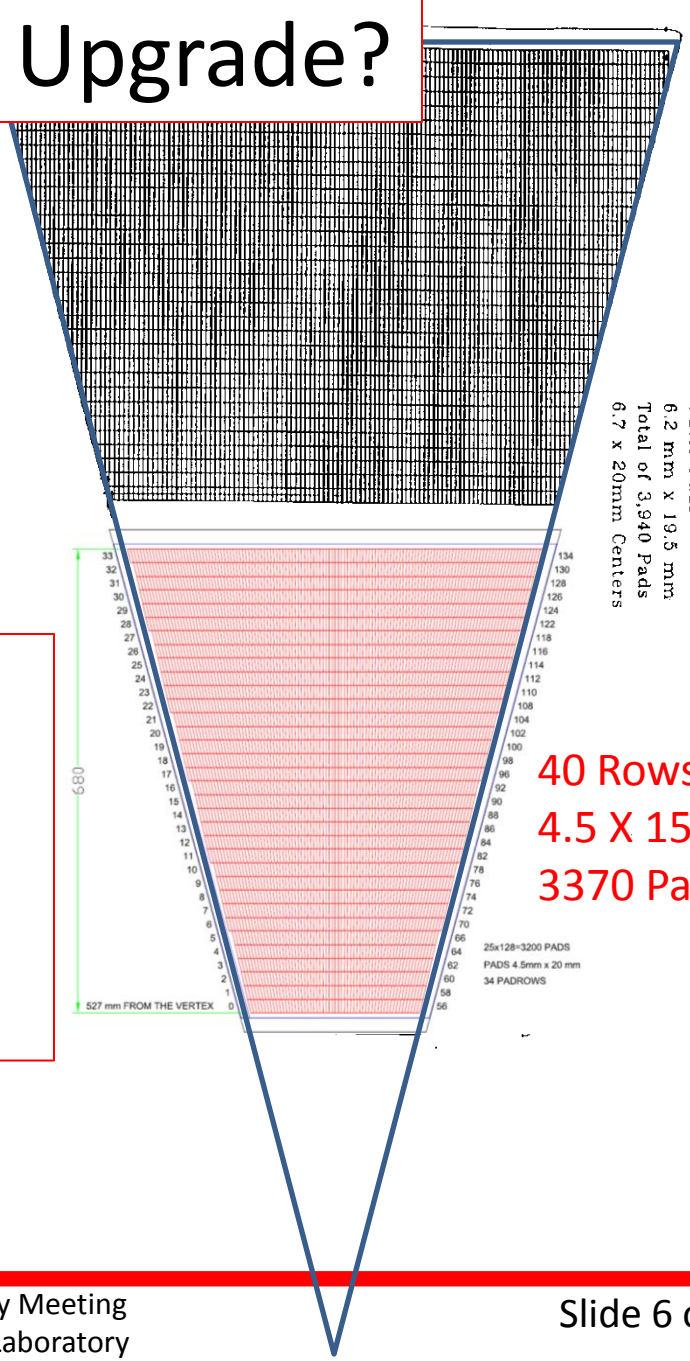
60 cm

32 Rows
6.2 X 19.5 mm
3940 Pads

13 Rows
2.85 X 11.5 mm
1750 Pads

Rebuild the readout regions for the inner sectors:

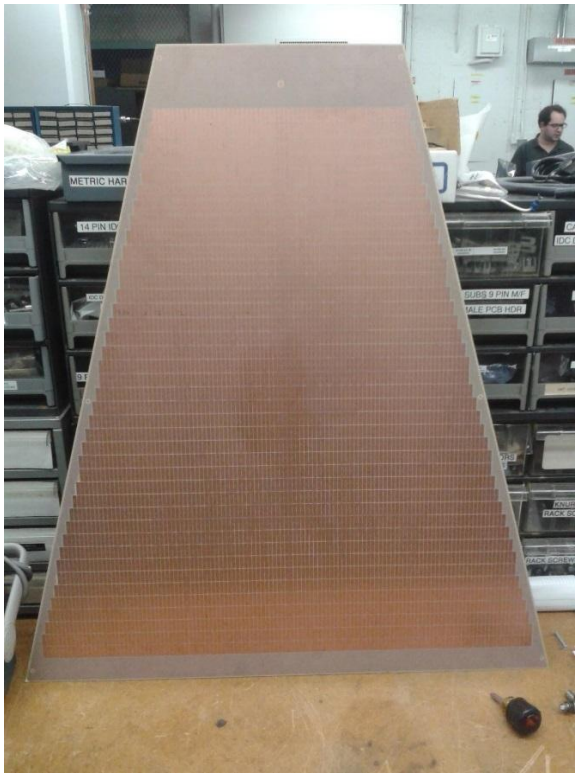
- Pad Planes
- Wire Planes
- Electronics

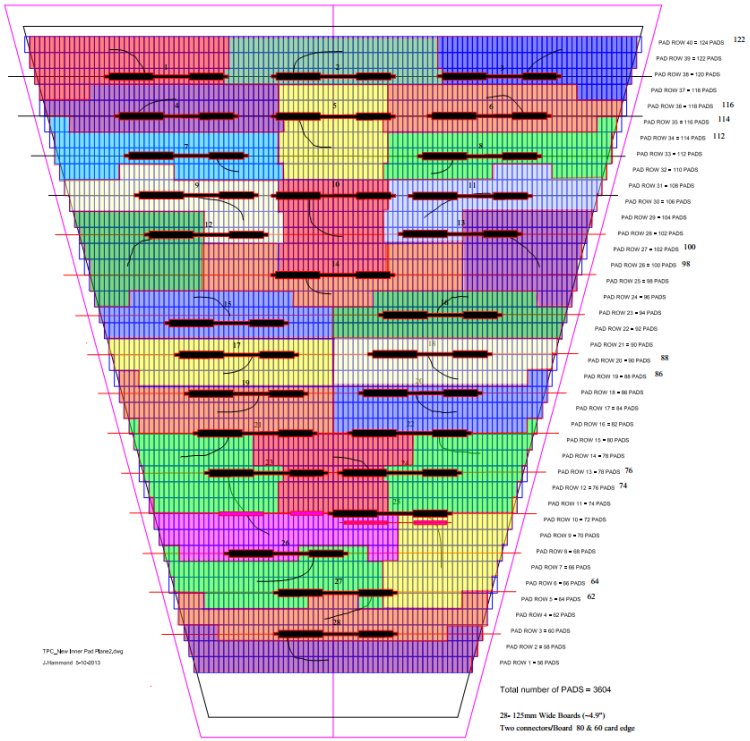


40 Rows
4.5 X 15.5 mm
3370 Pads

Pad plane

- Increase coverage. Higher density FEE
- Prototype has been produced and tested





BES Phase II – Relationship to TPC Upgrade

Basic performance improvements

The TPC inner sector upgrade is important for three reasons:

1) It extends the accessible rapidity range

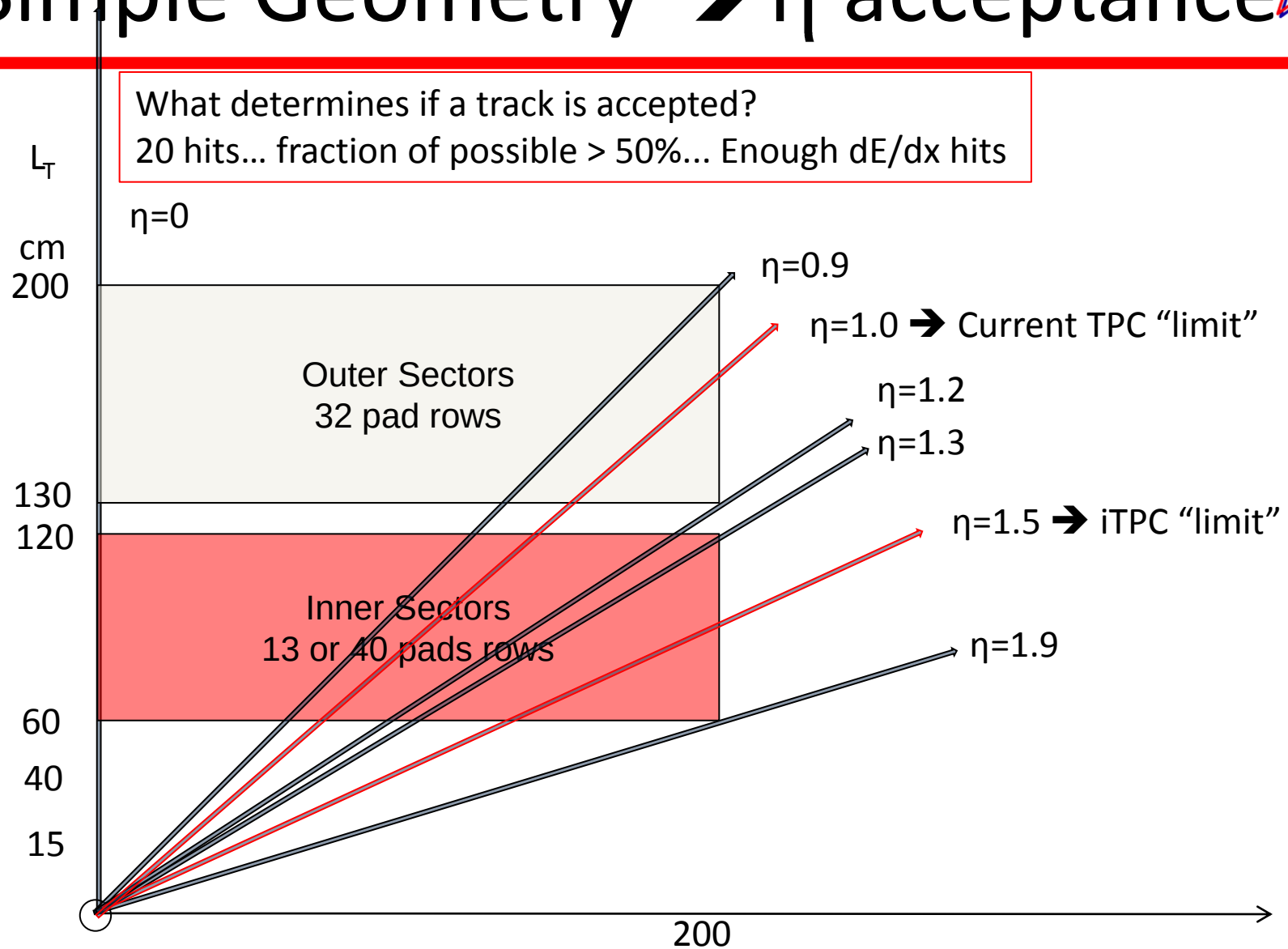
2) It reduces the low p_t cut-in threshold

3) Improves dE/dx resolution

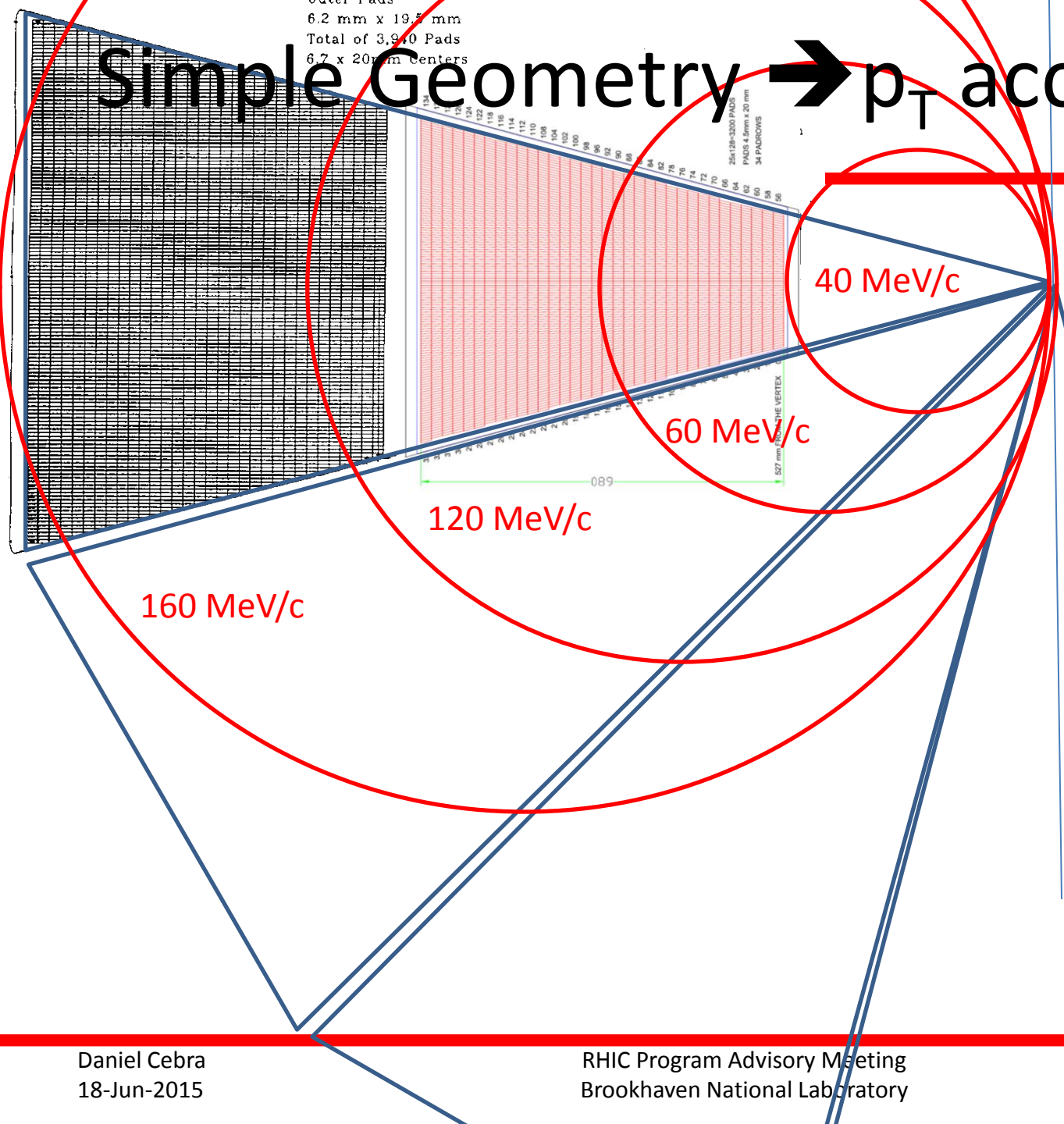
4) Also Improves the momentum resolution

Simple Geometry ➔ η acceptance

What determines if a track is accepted?
20 hits… fraction of possible > 50%... Enough dE/dx hits



Simple Geometry ➔ p_T acceptance



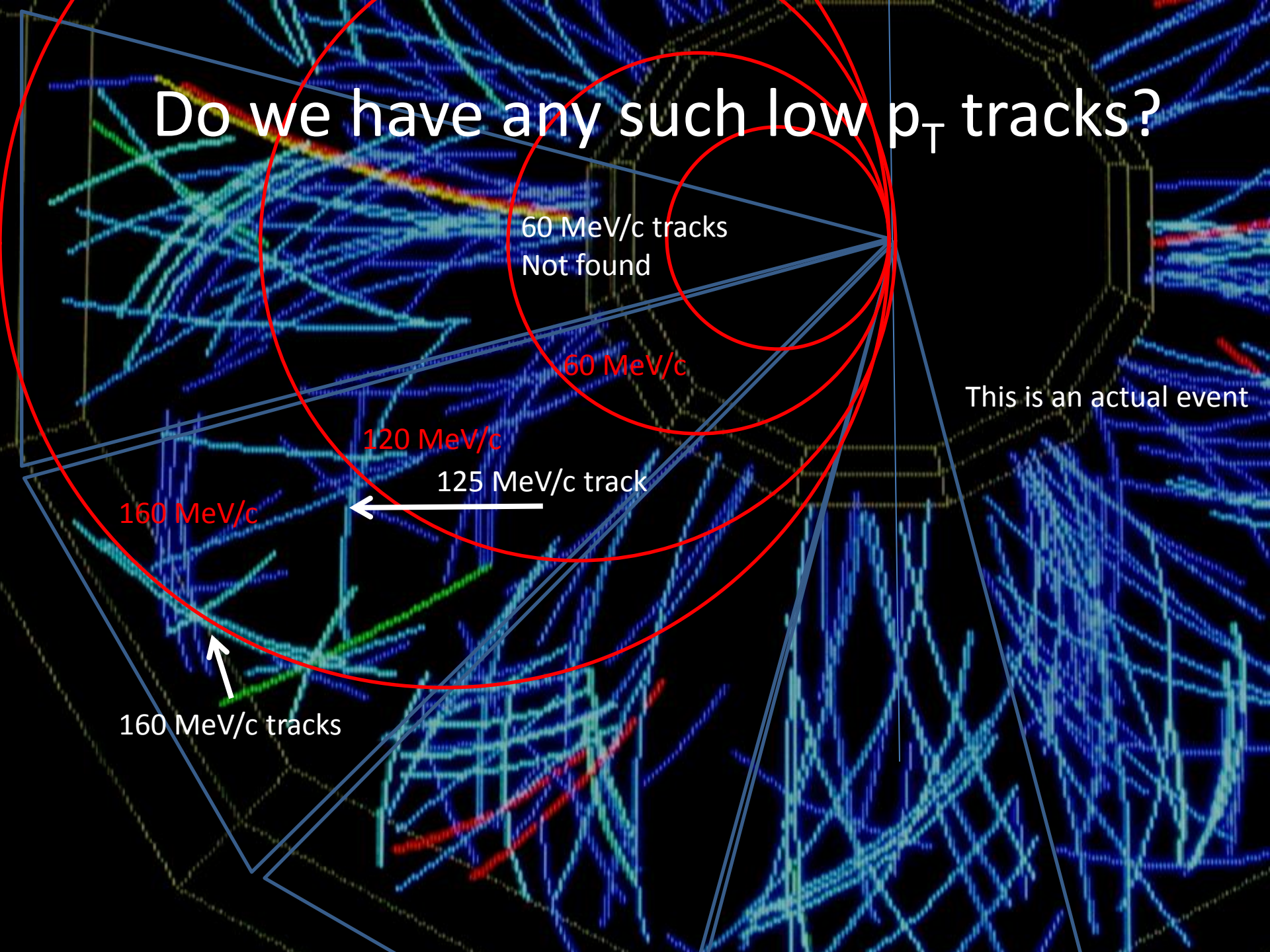
STAR Low p_T acceptance is dependent on the track quality cuts.

Quality tracks require at least 20 hits.

Current TPC low p_T limit is 125 MeV/c

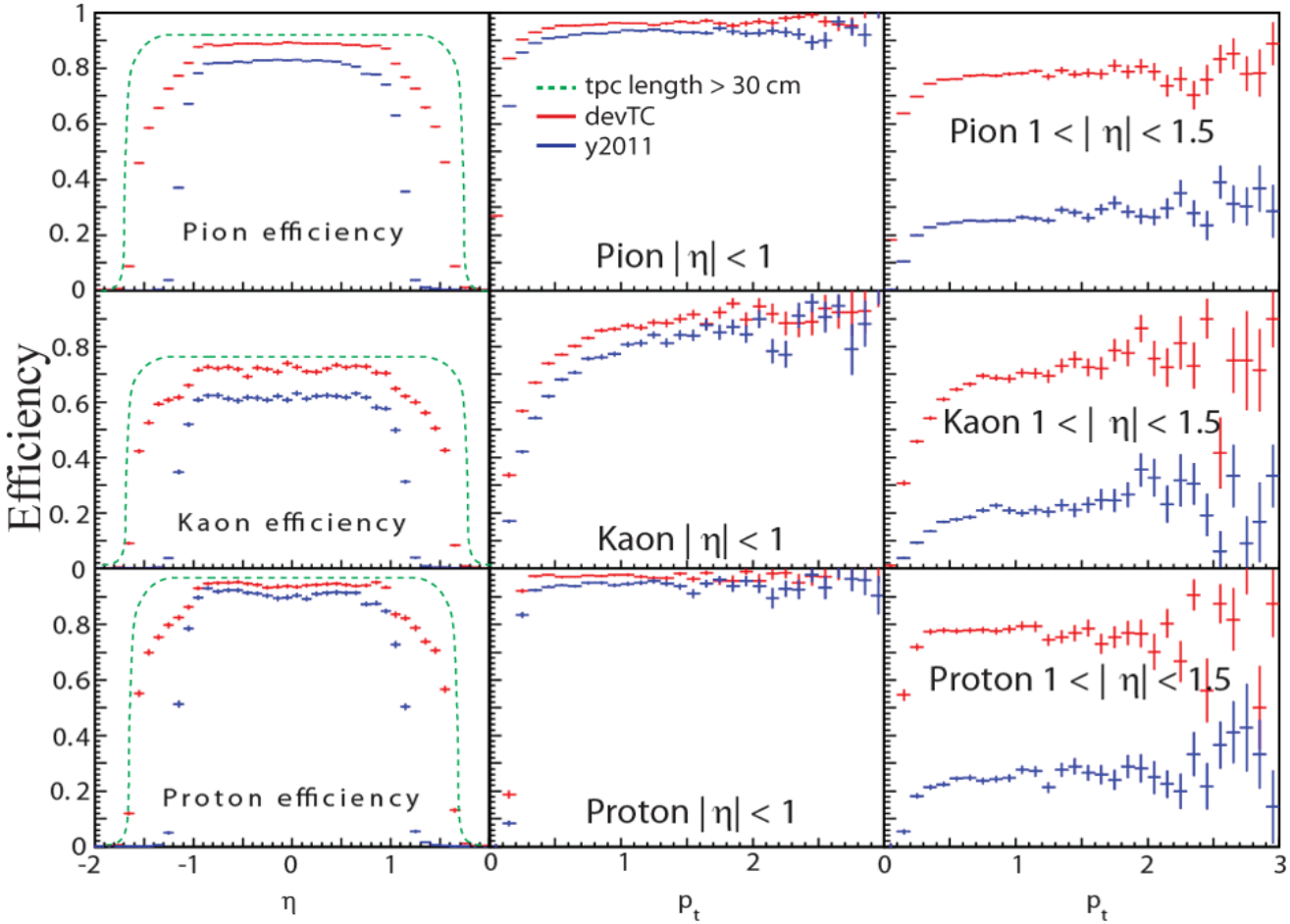
iTPC low p_T limit is 60 MeV/c

Do we have any such low p_T tracks?



Increased rapidity coverage

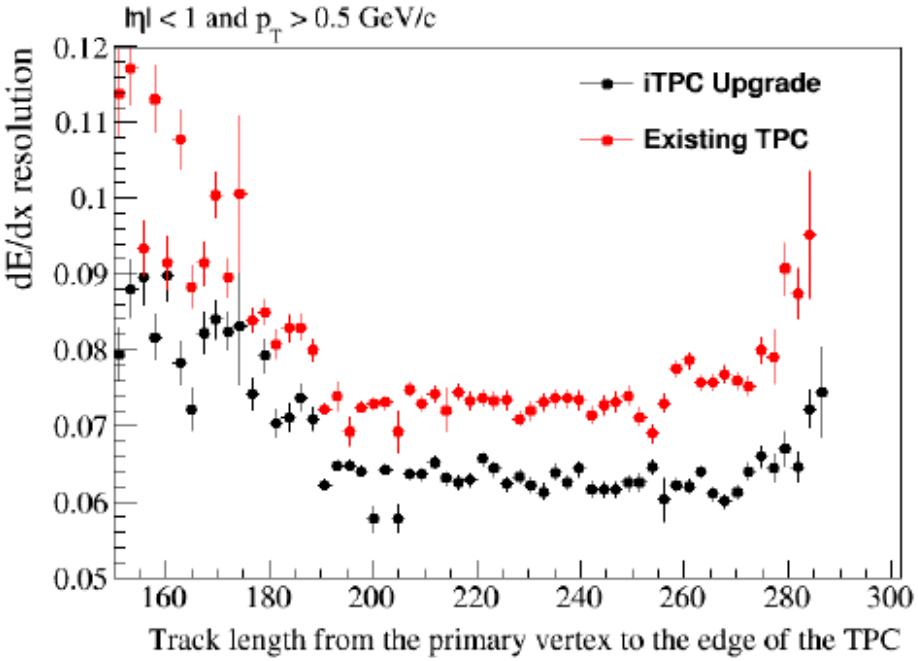
Increased efficiency for $|\eta| < 1$ mostly due to lower p_T cut-in values
Increased efficiency for $|\eta| < 1.5$ mostly due to tracks exiting the end cap

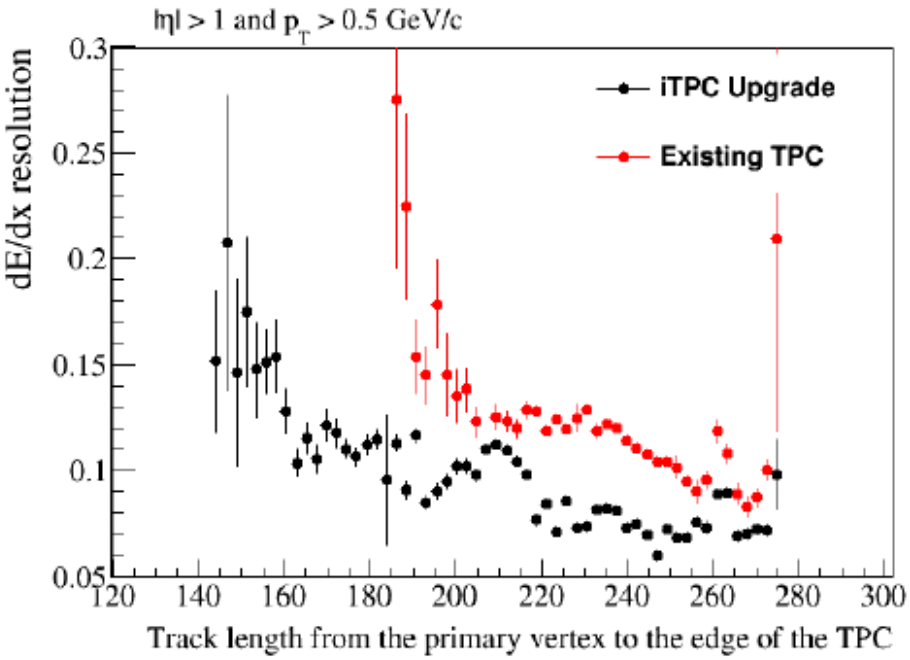


Additional Tracks Available for Physics

11.5 GeV		Total	Standard TPC	Inner Upgrade	p_T < 60 MeV/c
	Pions	234	152	+17%	18%
$\|\eta\|<0.5$	Kaons	25.3	12.4	+30%	4%
	Protons	34	26	+10%	6%
	Pions	435	283	+21%	
$\|\eta\|<1.0$	Kaons	47	22.9	+35%	
	Protons	66	50	+13%	
	Pions		<20%	90%	
$1.0<\|\eta\|<1.5$	Kaons		<20%	80%	
	Protons		<20%	90%	

Improvements to dE/dx

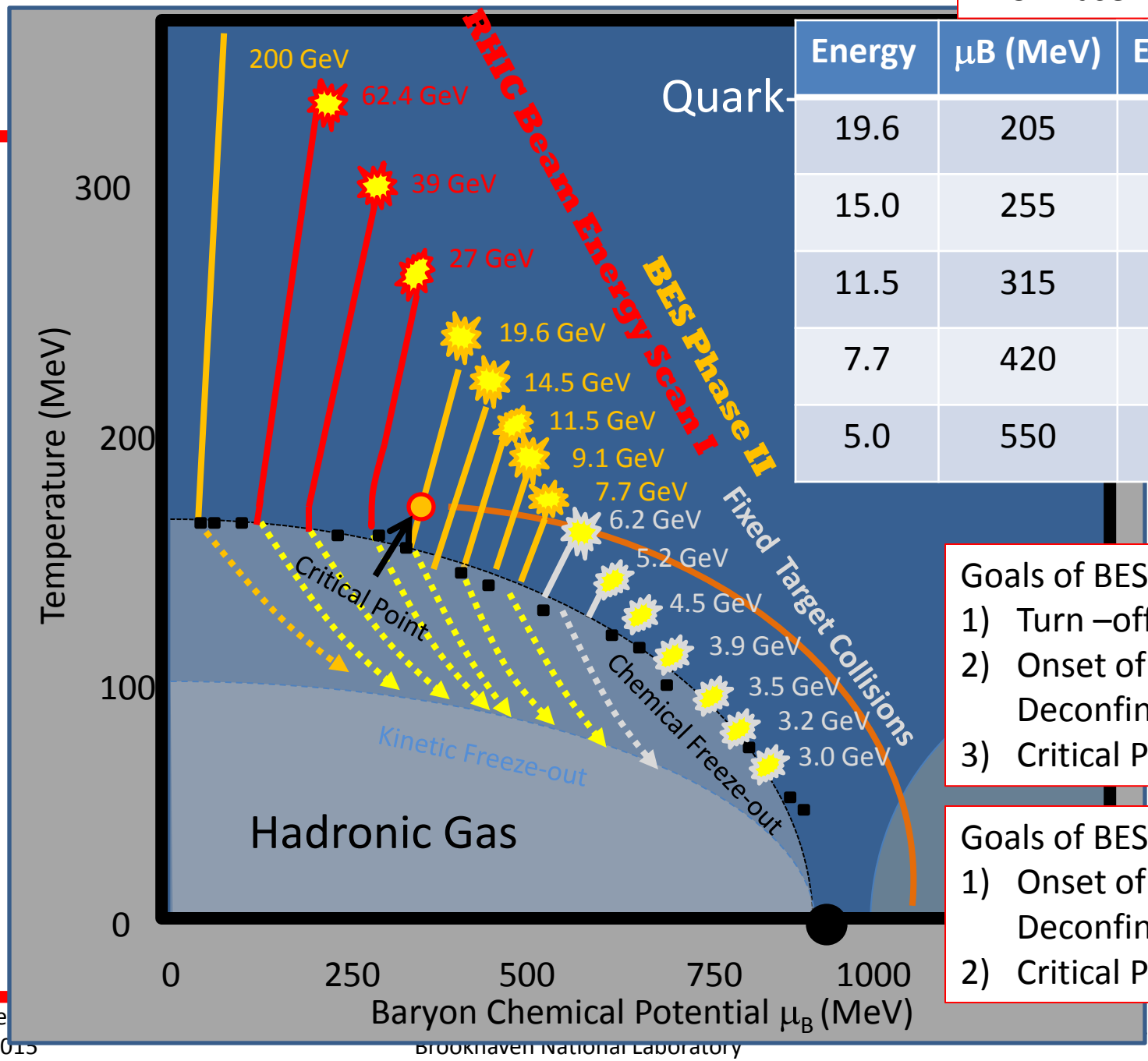




iTPC Physics

BES Phase II

Energy	μB (MeV)	Events (M)
19.6	205	150
15.0	255	150
11.5	315	50
7.7	420	70
5.0	550	TBD



Goals of BES I:
1) Turn –off of QGP
2) Onset of Deconfinement
3) Critical Point

Goals of BES II:
1) Onset of Deconfinement
2) Critical Point

Statistics Needed in BES phase II

Collision Energies (GeV):	**7.7**	**9.1**	**11.5**	**14.5**	**19.6**
Chemical Potential (MeV):	**420**	**370**	**315**	**260**	**205**
Observables	Millions of Events Needed				
R_{CP} up to p_T 4.5 GeV	NA	NA	160	92	22
Elliptic Flow of ϕ meson (v_2)	100	150	200	300	400
Local Parity Violation (CME)	50	50	50	50	50
Directed Flow studies (v_1)	50	75	100	100	200
asHBT (proton-proton)	35	40	50	65	80
net-proton kurtosis ($\kappa\sigma^2$)	80	100	120	200	400
Dileptons	100	160	230	300	400
Proposed Number of Events:	**100**	**160**	**230**	**300**	**400**

QGP

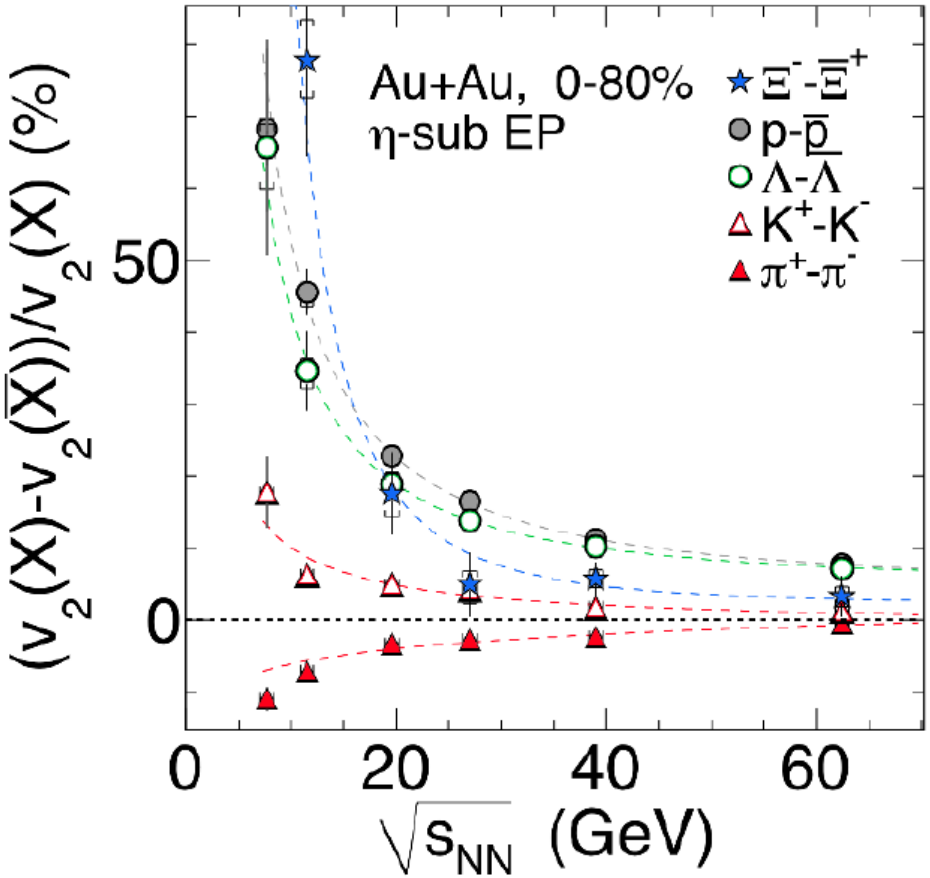
1st P.T.

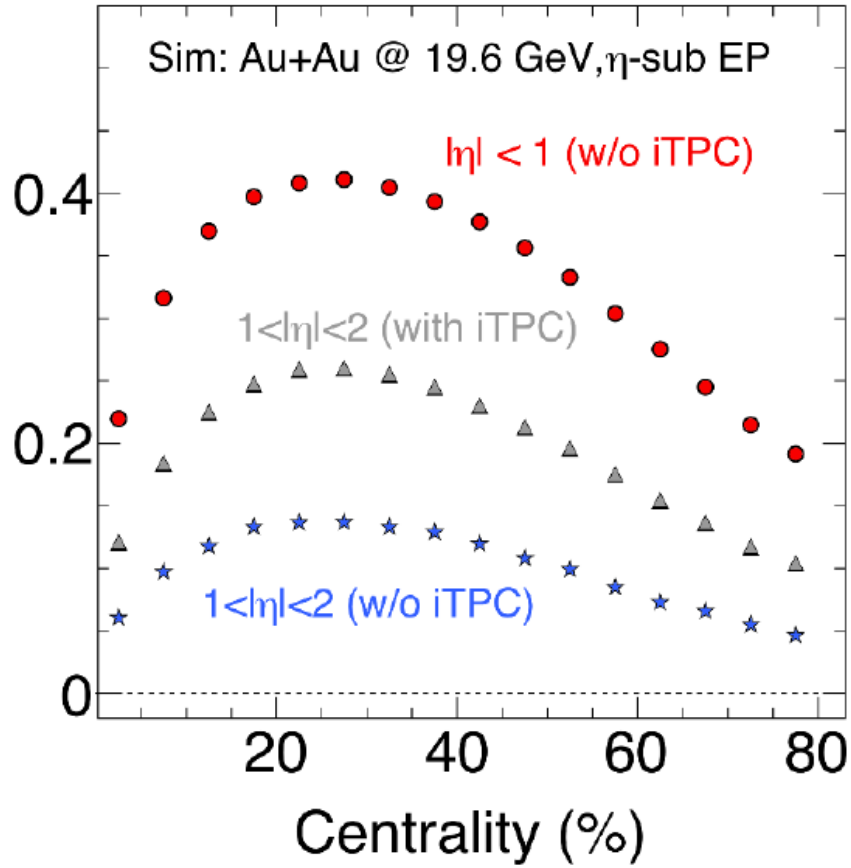
C.P.

EM Probes

Elliptic Flow

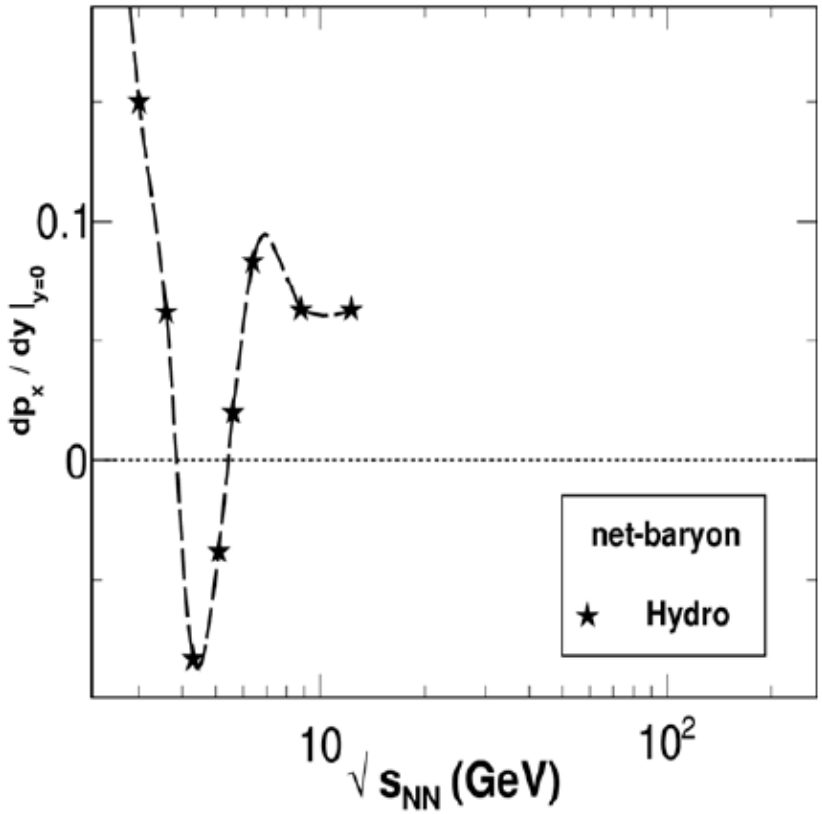
Elliptic flow results are improved

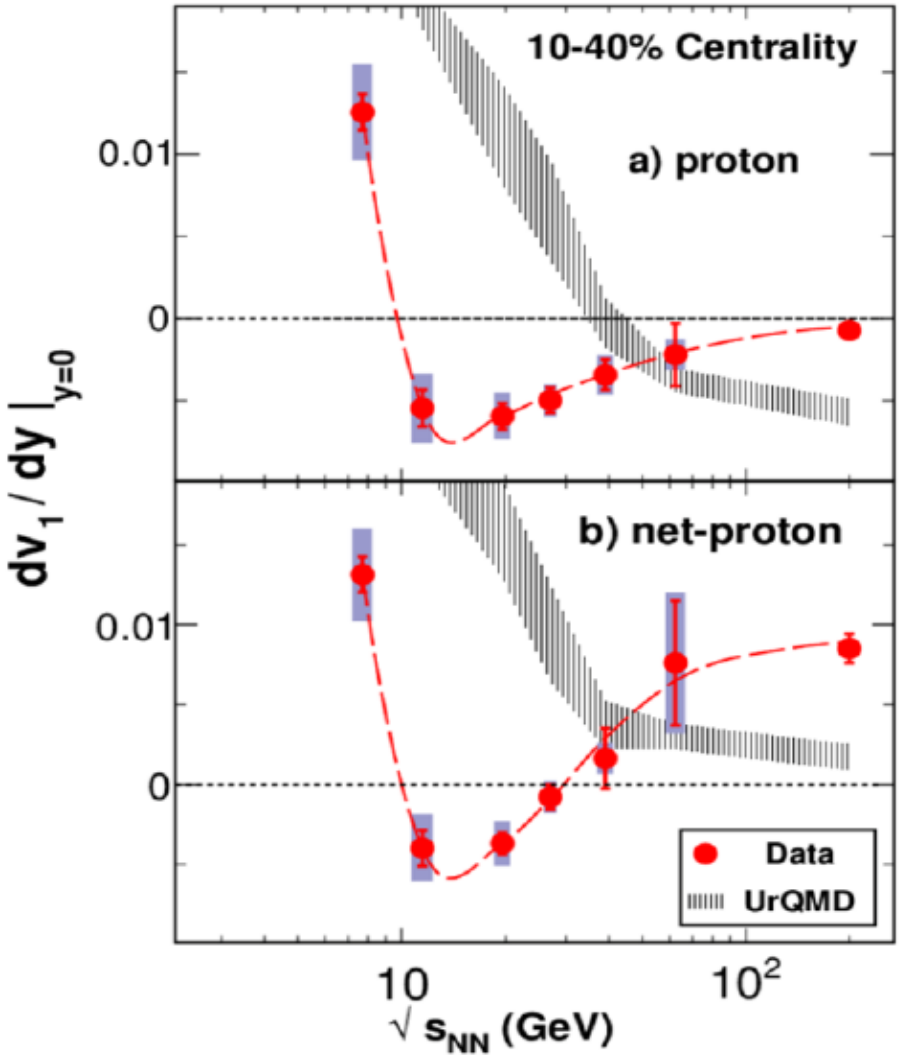




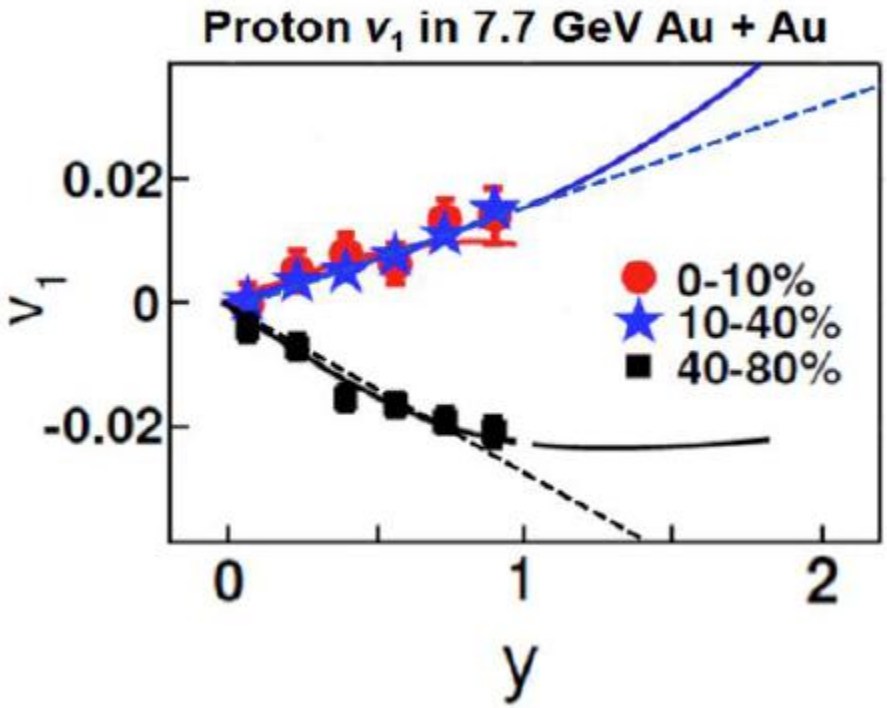
Directed Flow

Directed flow of net protons is one of the key BES-I results

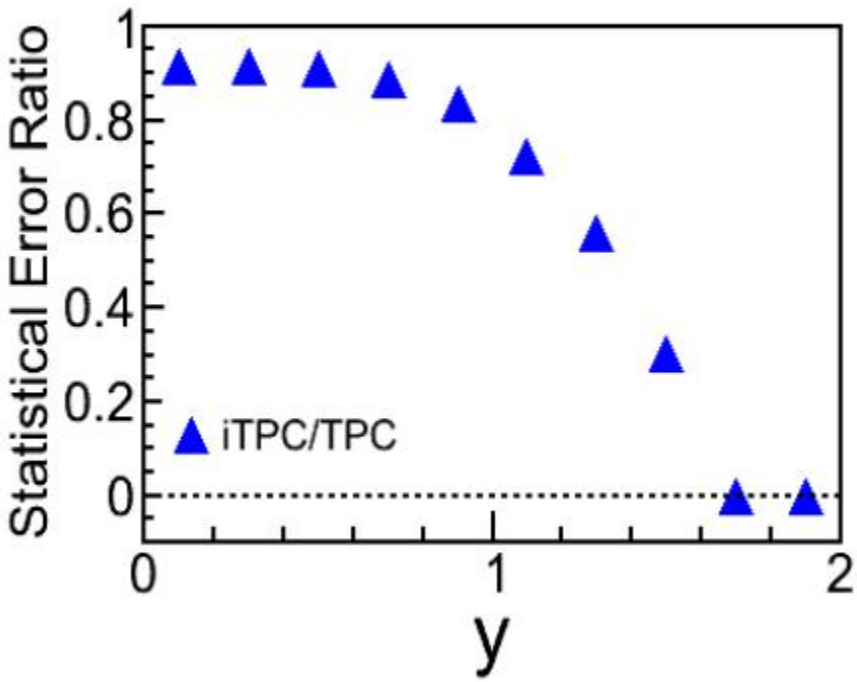




Directed Flow



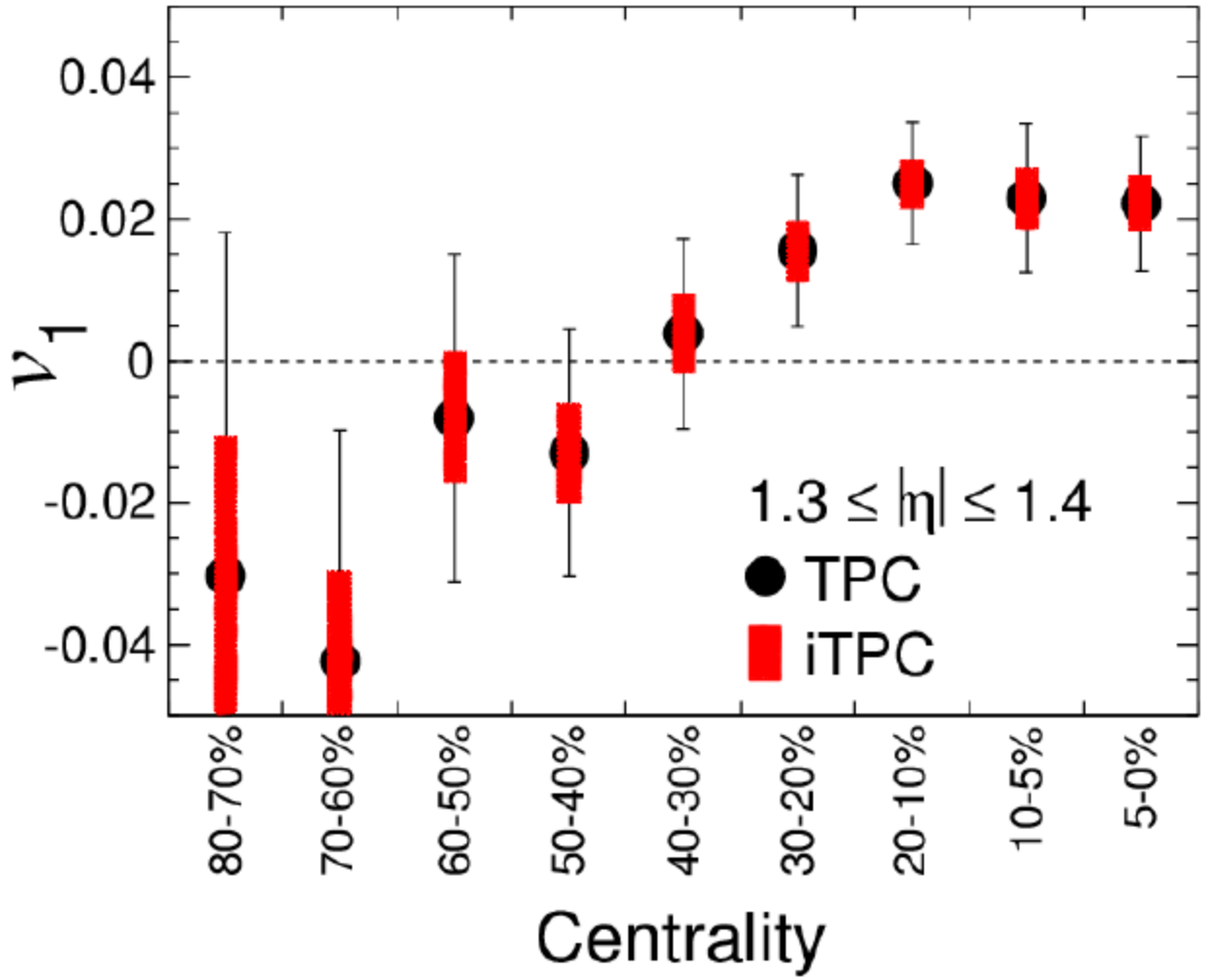
Open questions remain about the rapidity dependence of the directed flow



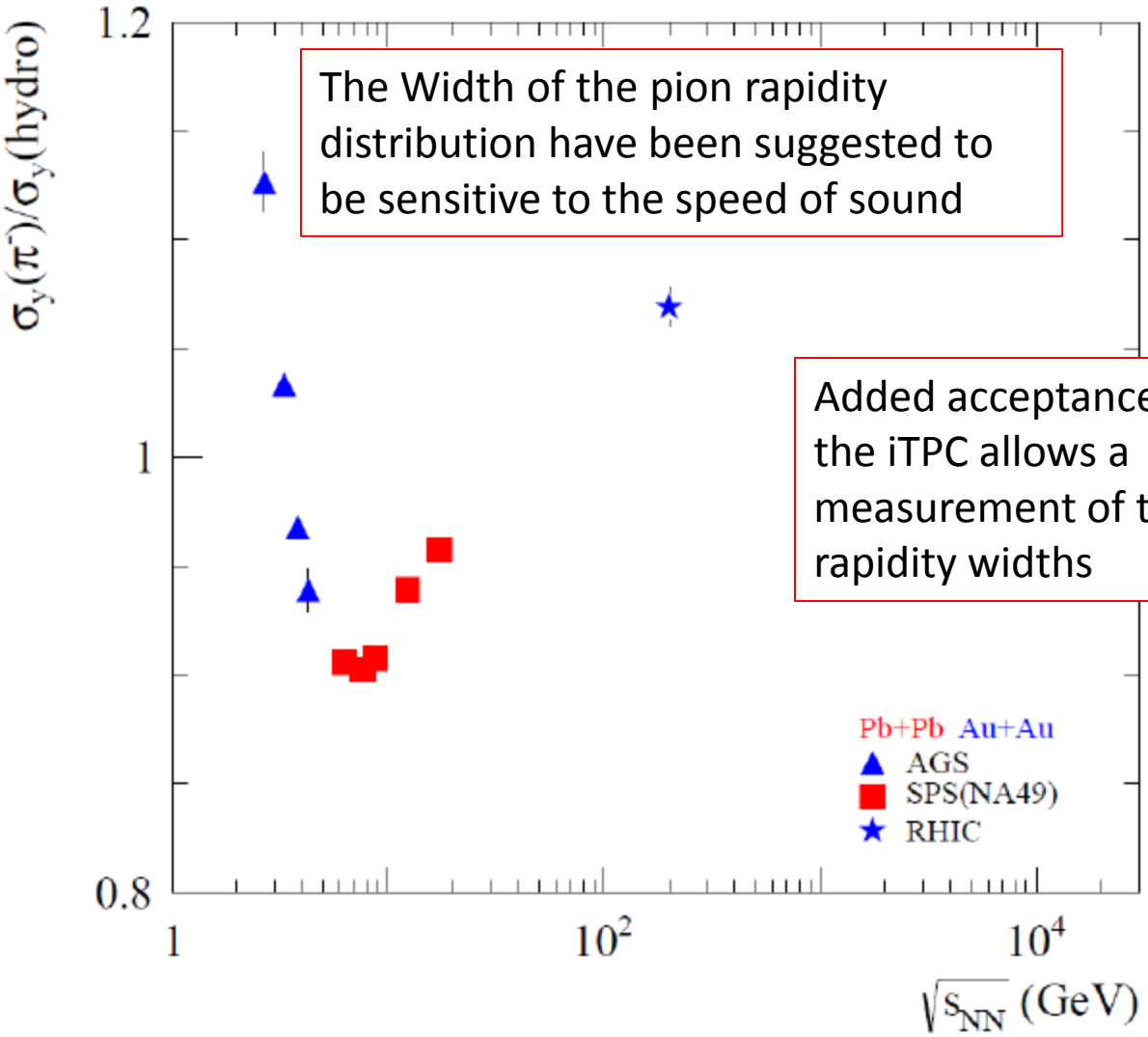
iTPC dramatically improves the results above y = 1.0

Directed Flow

The added reach of the iTPC allows a significant measurement of v1 for most centralities

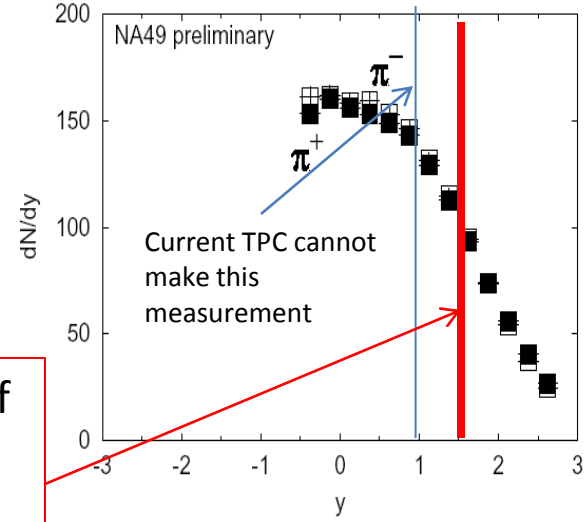


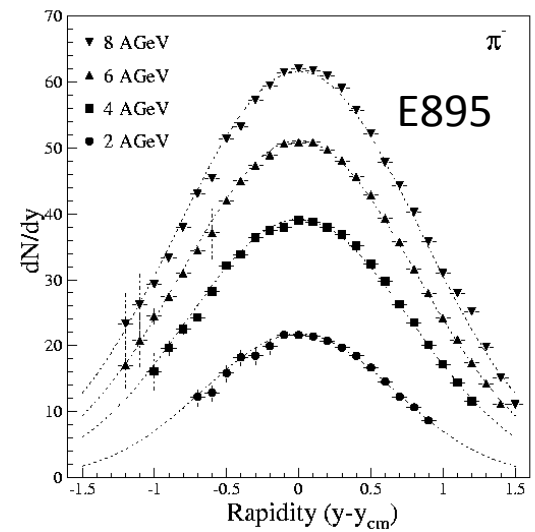
Rapidity Density Widths



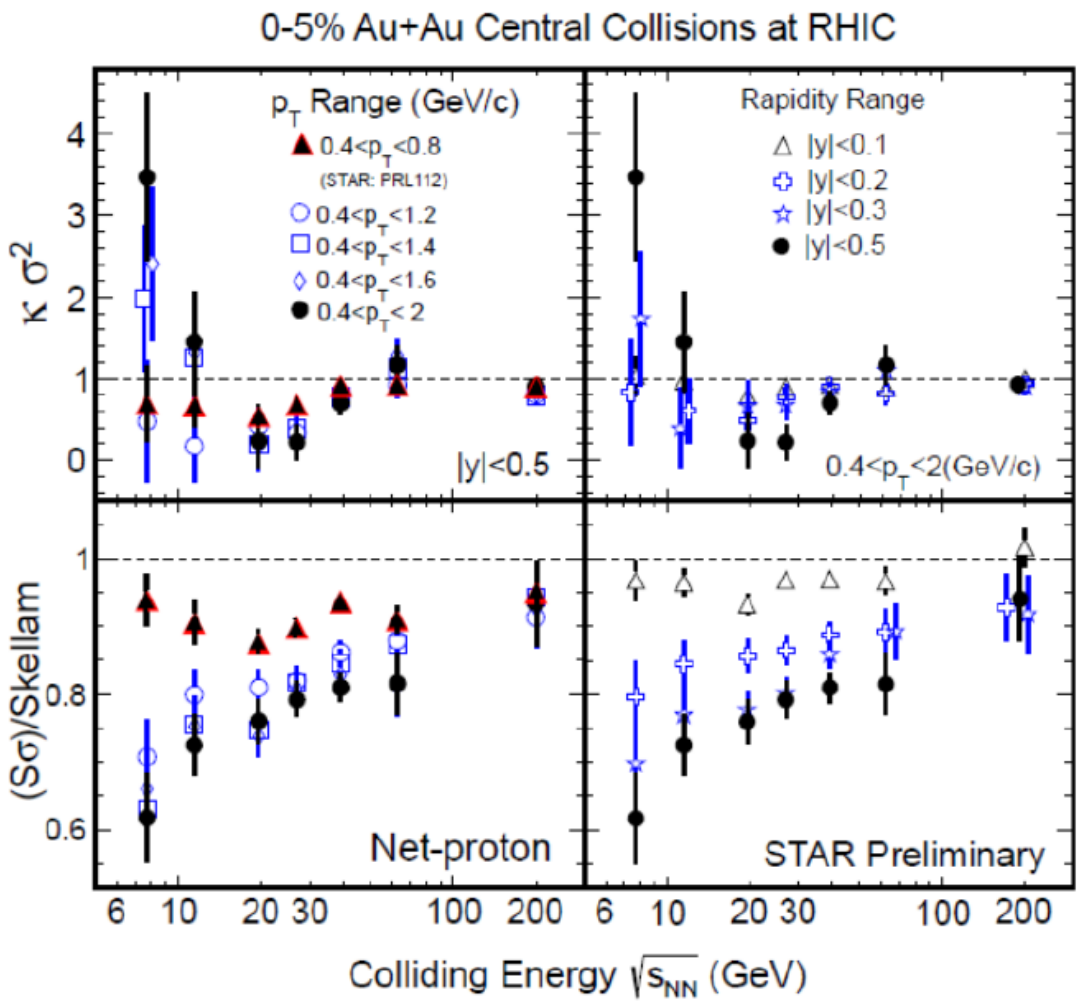
The Width of the pion rapidity distribution have been suggested to be sensitive to the speed of sound

Added acceptance of the iTPC allows a measurement of the rapidity widths



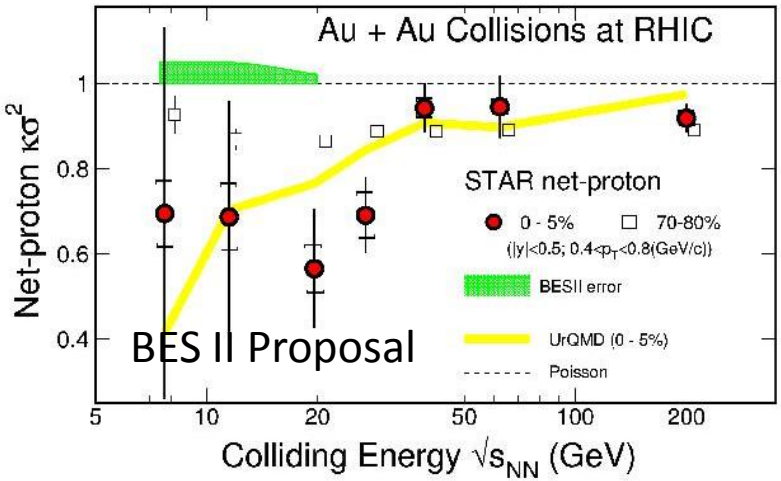


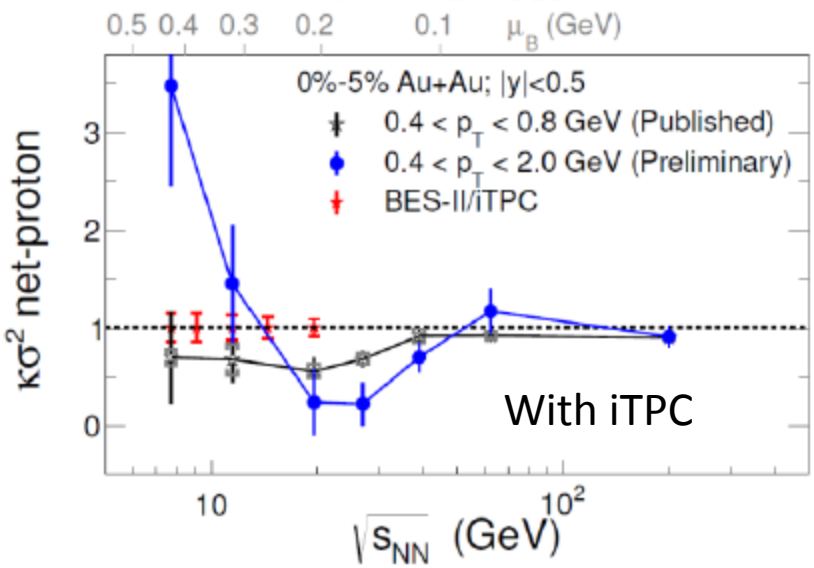
Fluctuation Analysis



Published STAR results for beam energy dependence of $\kappa\sigma^2$ (top panels) and Sσ/Skellam (lower panels for net protons in Au+Au collisions. The left panel illustrate the effect of p_T selections while the right panels indicate the effects of rapidity selections

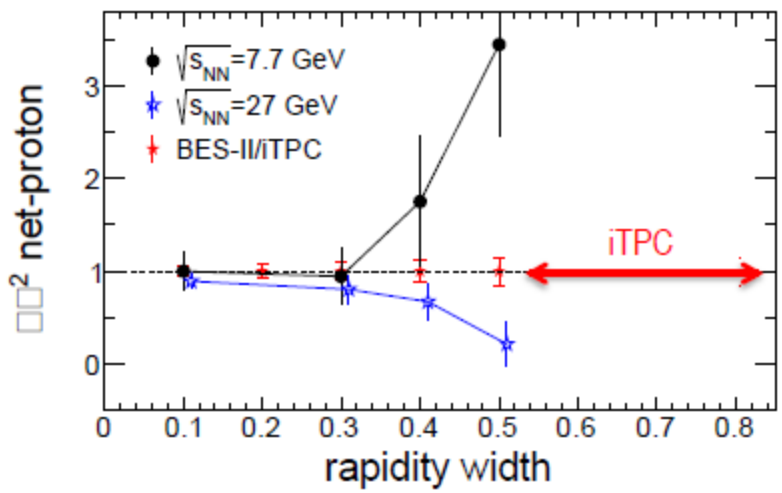
Fluctuation Analysis





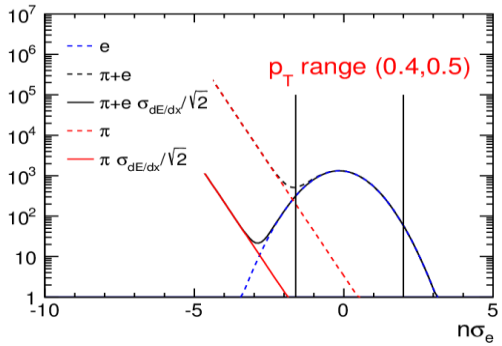
The iTPC brings significant new physics with the rapidity dependence of the net-proton kurtosis

This panel shows the effects of *rapidity* selections on the ks² signal and the projected errors for BESII

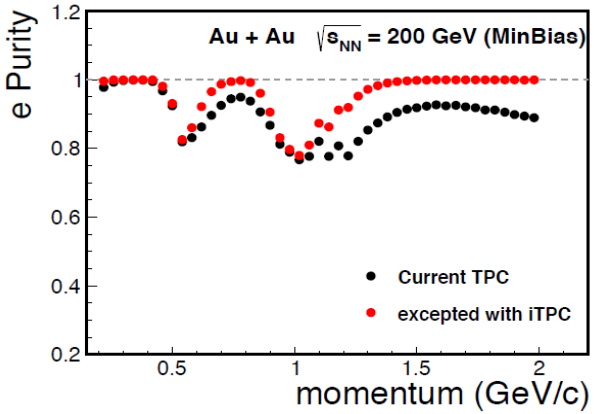


Di-lepton program

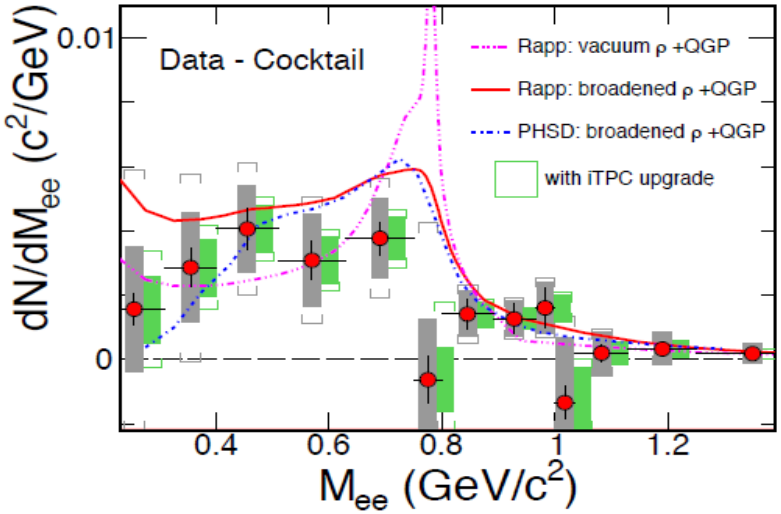
- The dominate systematic error on the di-electon experiment is the purity of electrons. The added pad-rows will **improve dE/dx**



The expected purity for electrons as a function of transverse momentum.



Di-electron program in the Intermediate mass region is now possible with the iTPC



The expected systematic uncertainty of dielectron excess mass spectrum with the iTPC upgrade compared to the current TPC case

Fixed Target Program

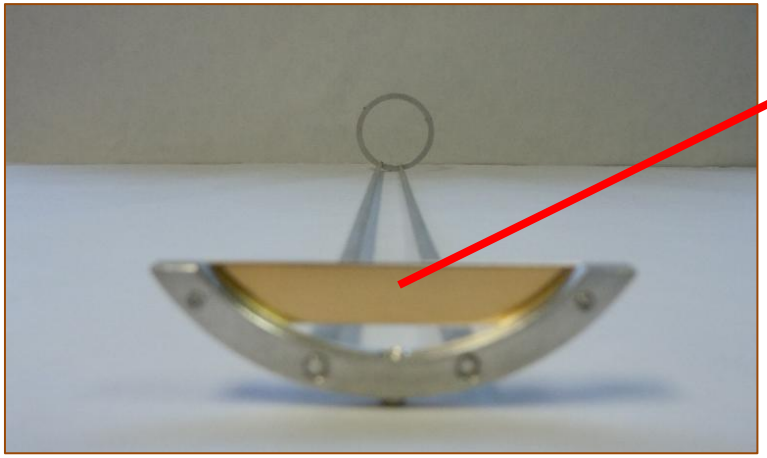
Collider Energy (GeV)	Fixed-Target Energy	Center-of-mass Rapidity
62.4	7.7	2.10
39	6.2	1.87
27	5.2	1.68
19.6	4.5	1.52
14.5	3.9	1.37
11.5	3.5	1.25
9.1	3.2	1.13
7.7	3.0	1.05

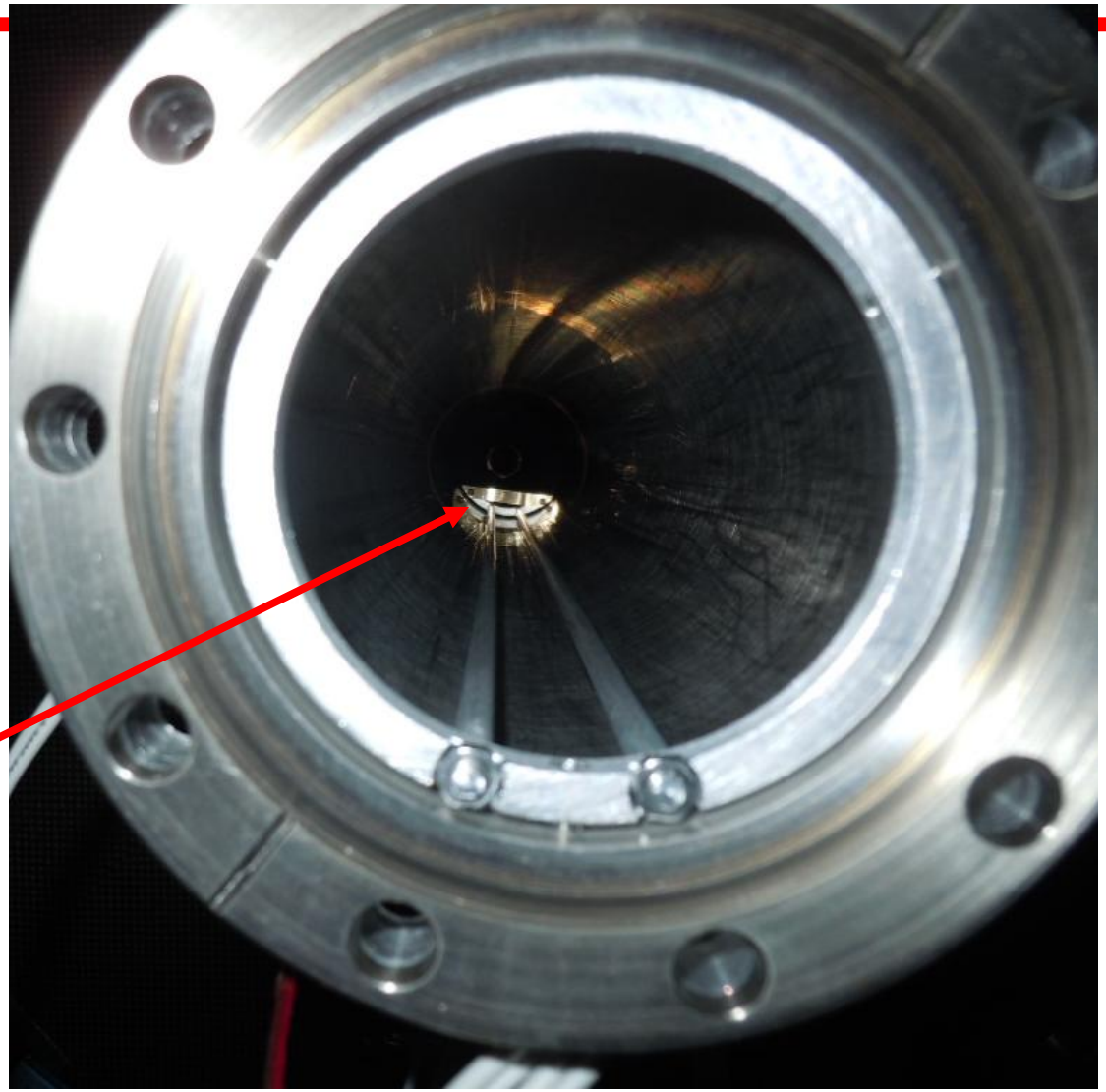
Target Design 2014 and 2015

Target design:

Gold foil
1 mm Thick
~1 cm High
~4 cm Wide
210 cm from IR

2014: Passive tests
2015: Beams steered to target

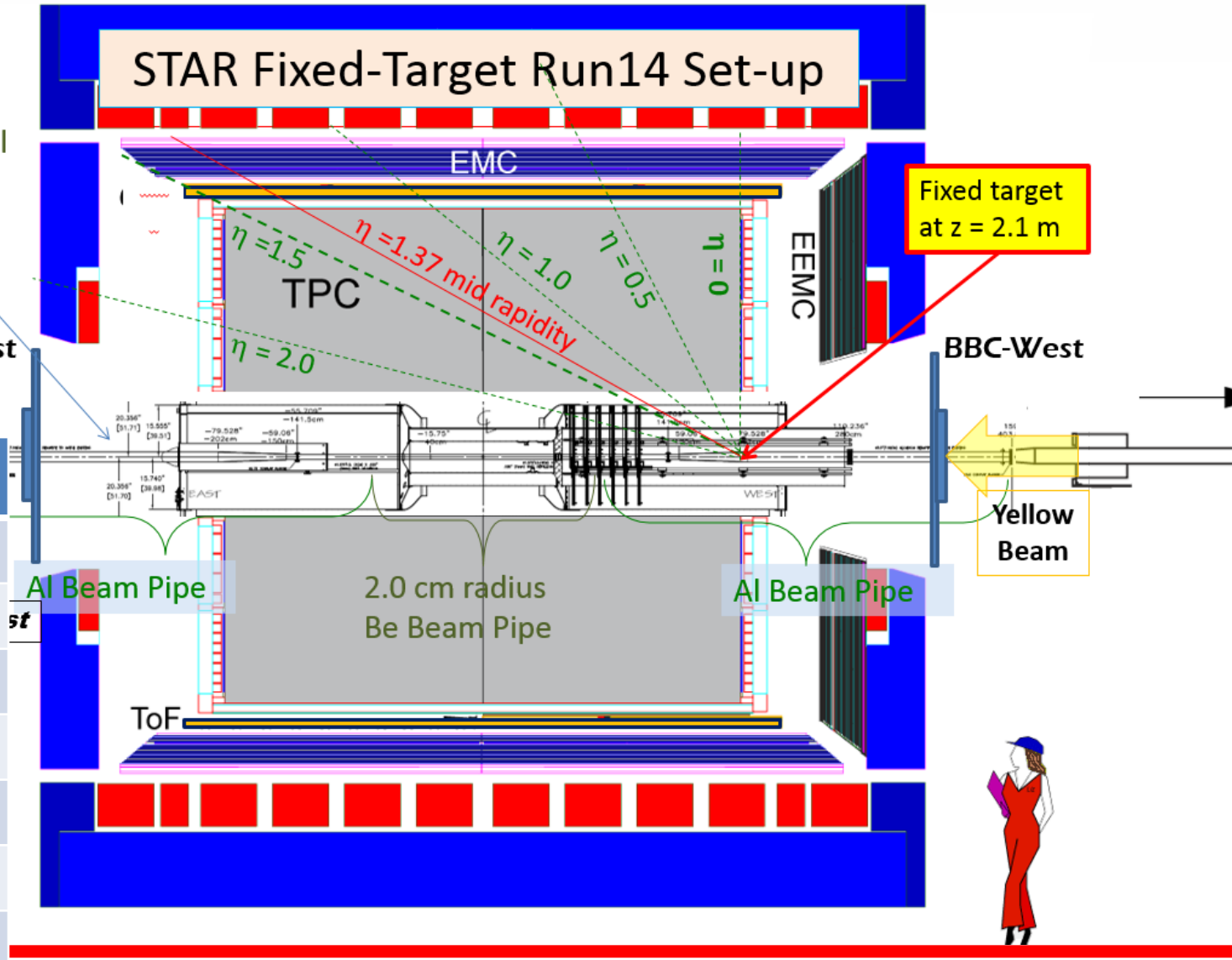




Run 14 and 15 Setup

iTPC allows FXT at 7.7, 6.2, and 5.2

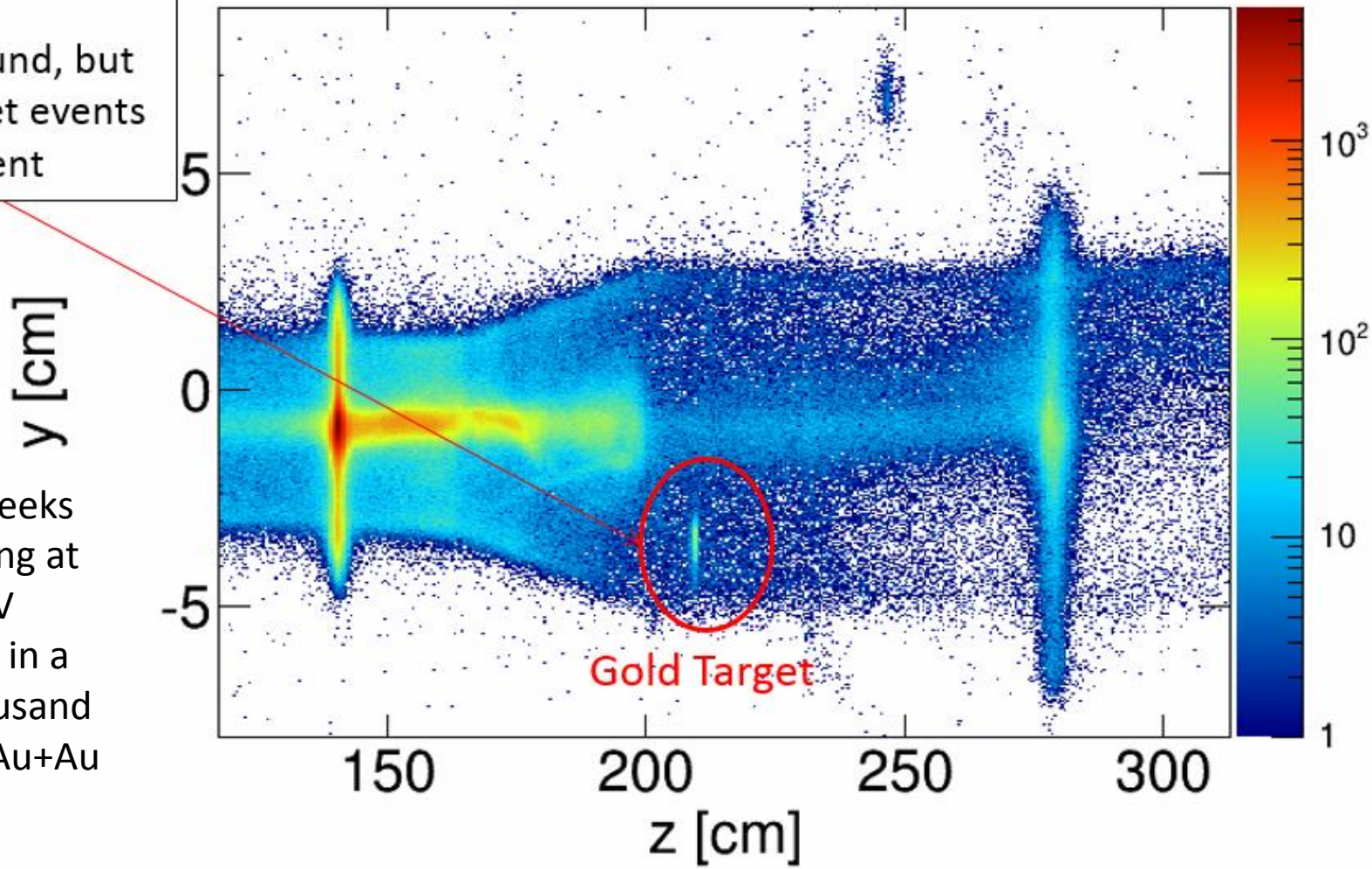
Fixed-Target Energy	Center-of-mass Rapidity
7.7	2.10
6.2	1.87
5.2	1.68
4.5	1.52
3.9	1.37
3.5	1.25
3.2	1.13
3.0	1.05



Identifying Target Events

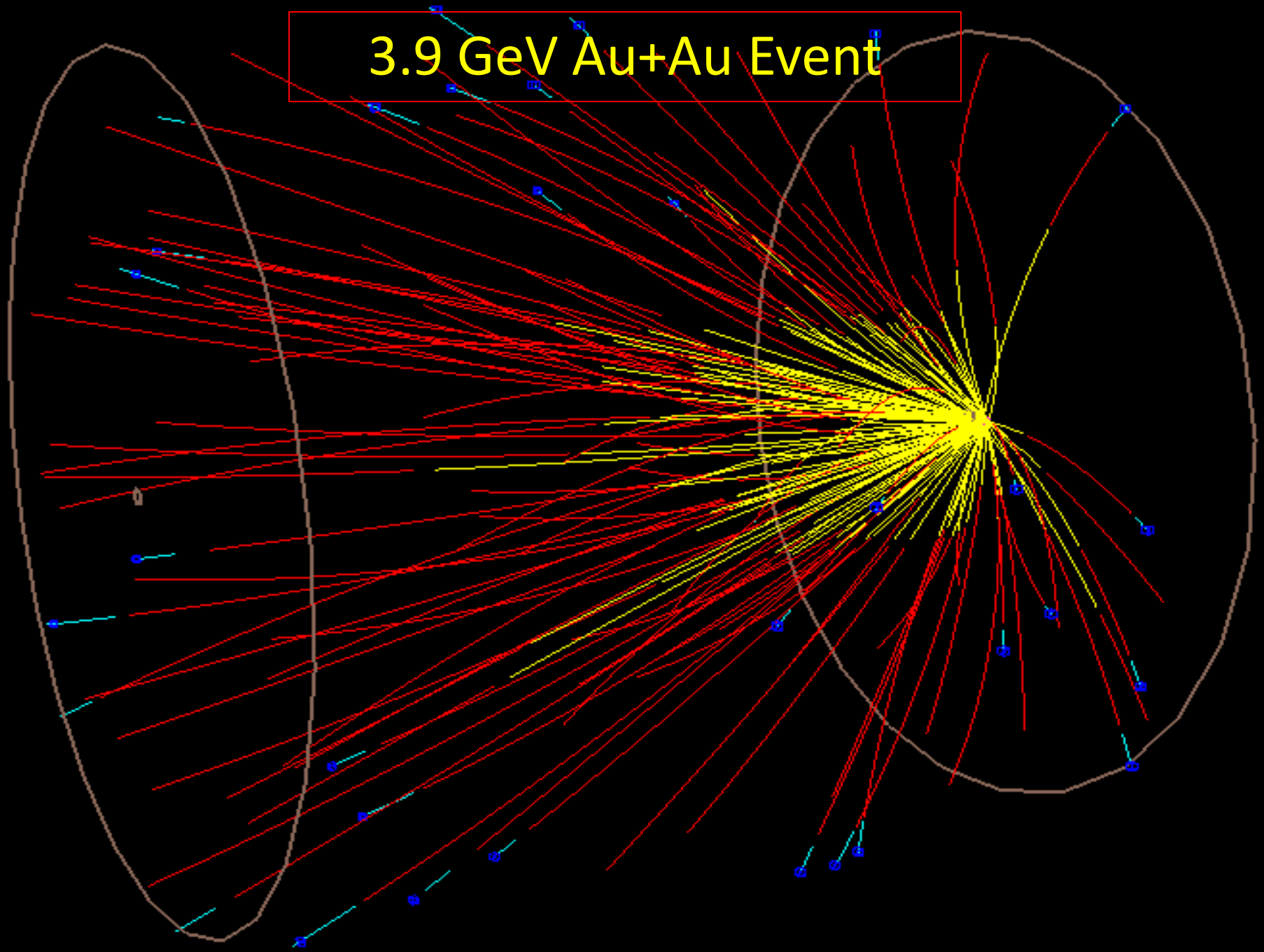
Lots of background, but the target events are evident

2014 Passive tests using the beam halo



Three weeks of running at 14.5 GeV resulted in a few thousand central Au+Au events

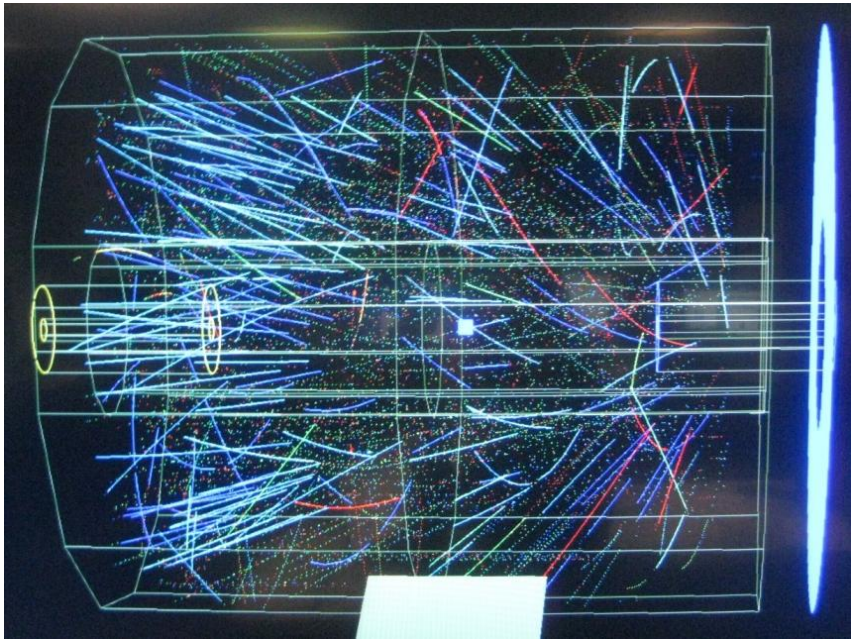
3.9 GeV Au+Au Event

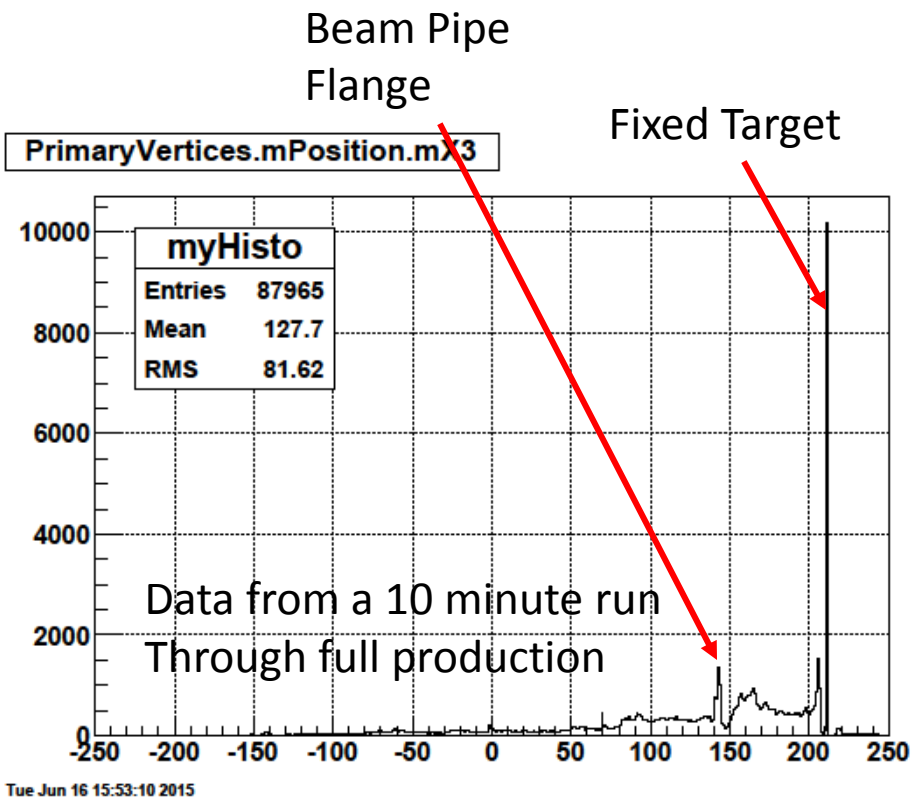


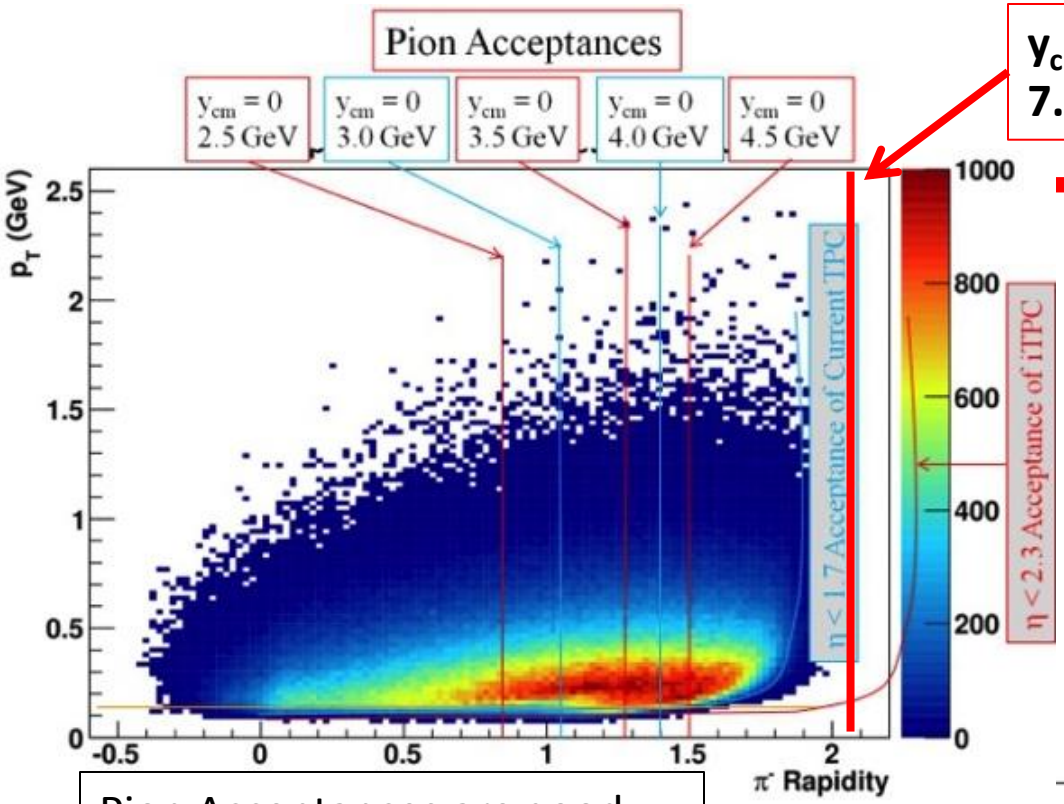
Au + Au Fixed Target 4.5 GeV

- May 20th 2015 – Test run with lowered beam
- 1.25 millions triggers, ~100k central events

Online Event Display





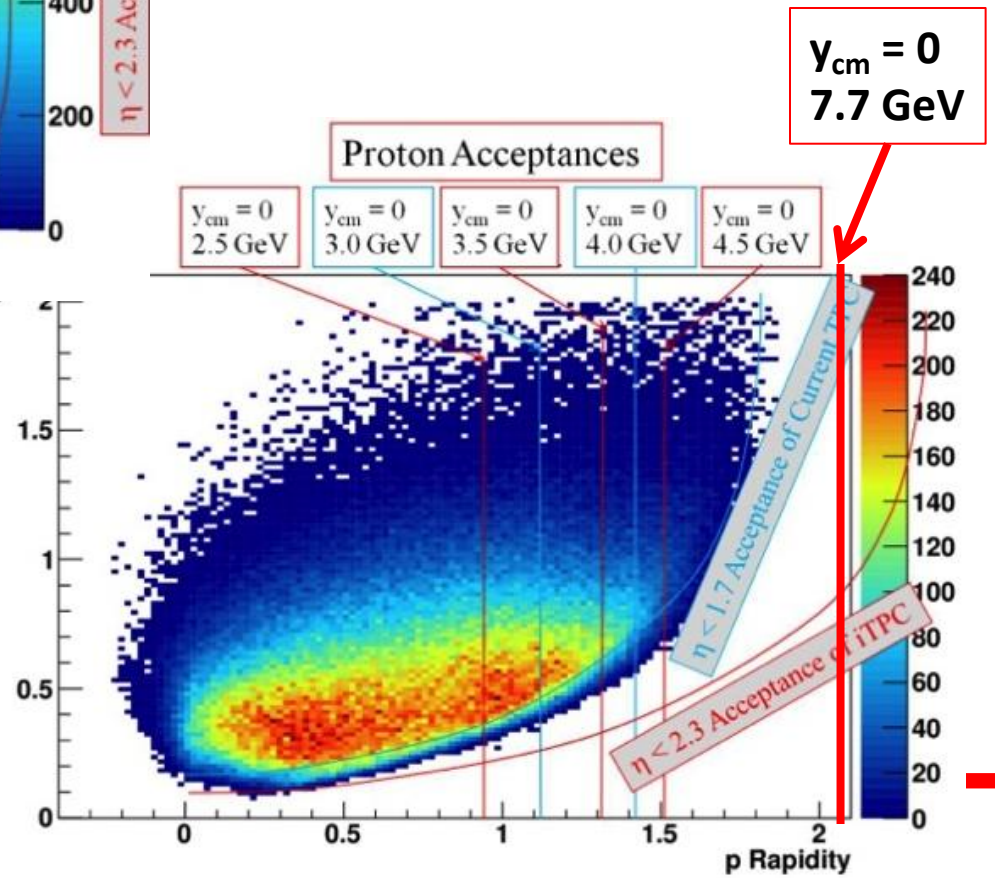


$y_{cm} = 0$
7.7 GeV

iTPC allows a physics program from 7.7 to 3.0 GeV in the Fixed target mode.

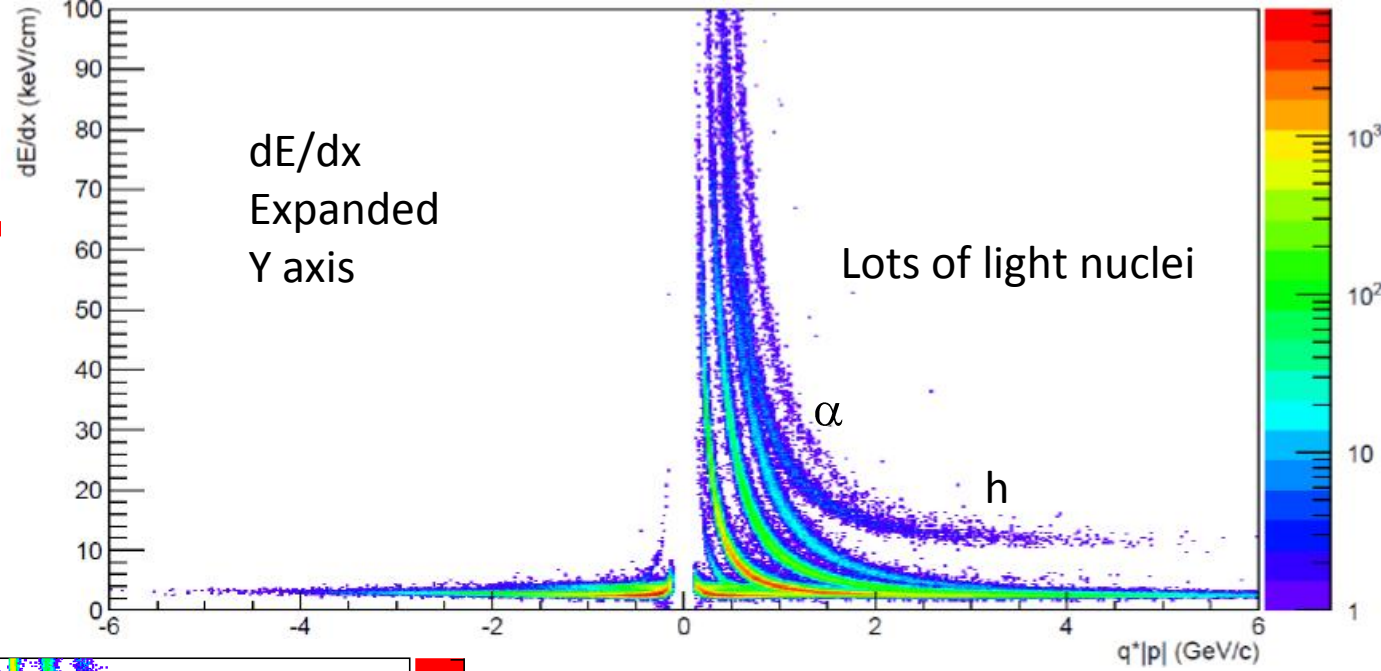
Pion Acceptances are good from target to mid-rapidity for all BES II energies

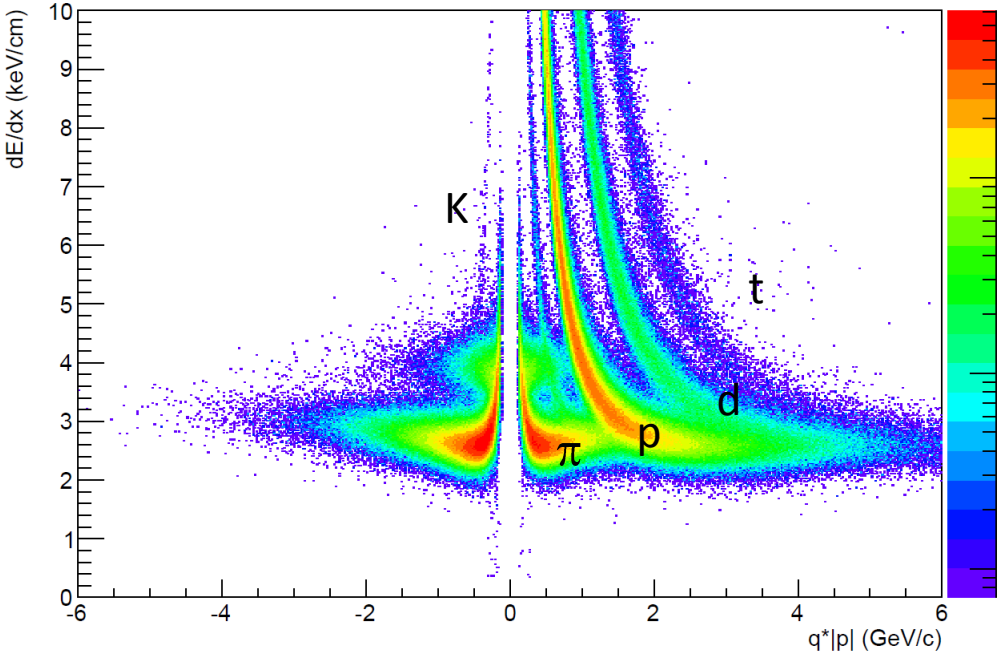
Proton Acceptances have low p_T acceptance threshold. An iTPC would greatly improve the acceptance reach here.

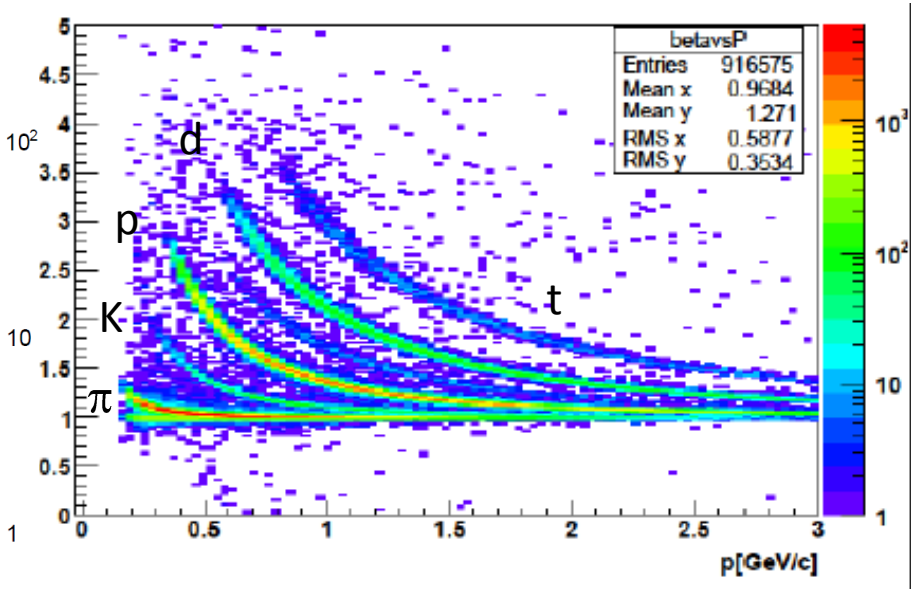


$y_{cm} = 0$
7.7 GeV

Particle Identification using dE/dx and TOF







iTPC Pictures

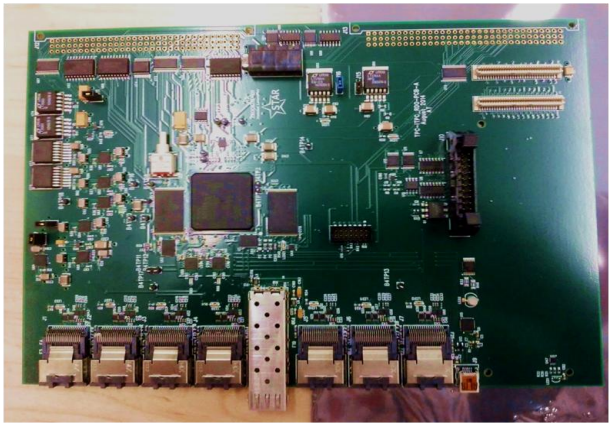
Strong back

Prototype – original drawings

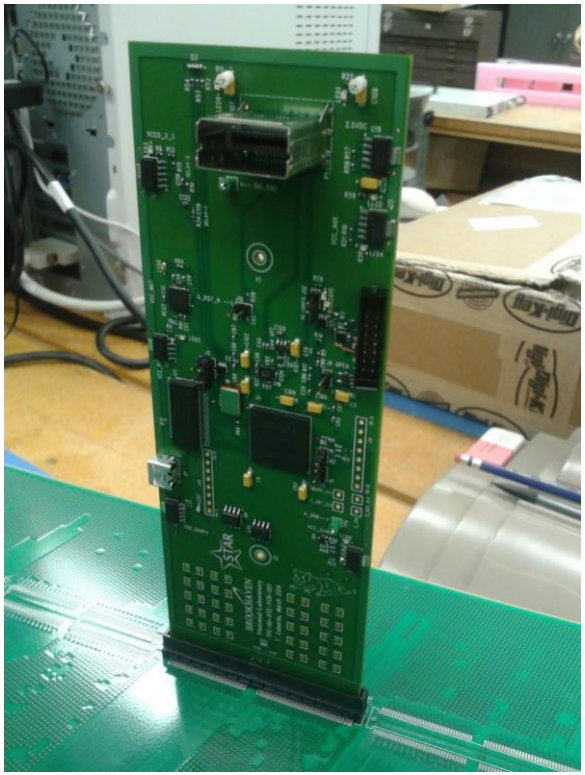
Only modify position of FEE openings.
No reduction in thickness
Pure construction project, no engineering and design
- but lots of retrieving old knowledge.

Electronics

- FEE based on current FEE, but using ALICE SAMPA chip
- Twice channels per FEE
- RDO similar to existing
- Developments over several years by BNL electronics group



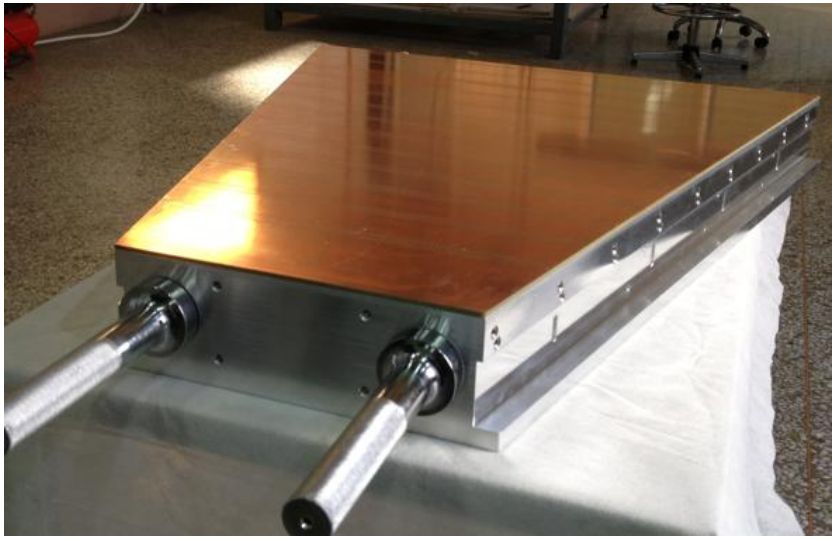
RDO prototype

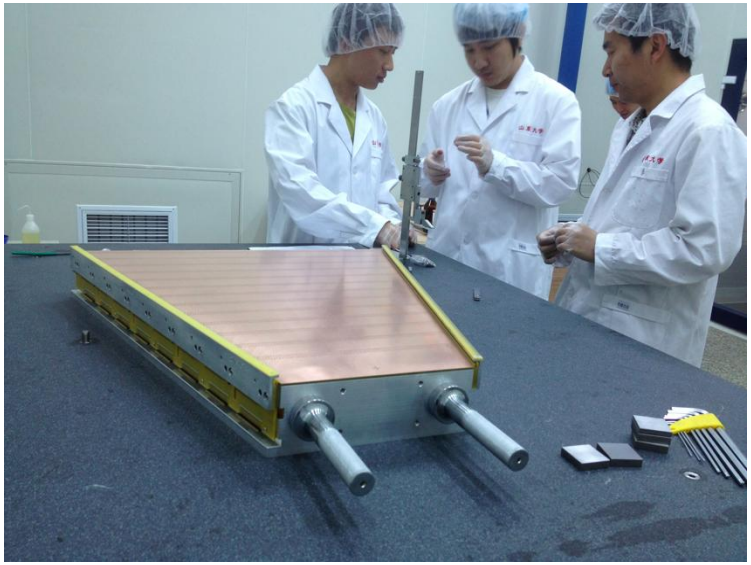


Pre-prototye iFEE (ppFEE) electronic card shown plugged into the padplane

Work in Shandong

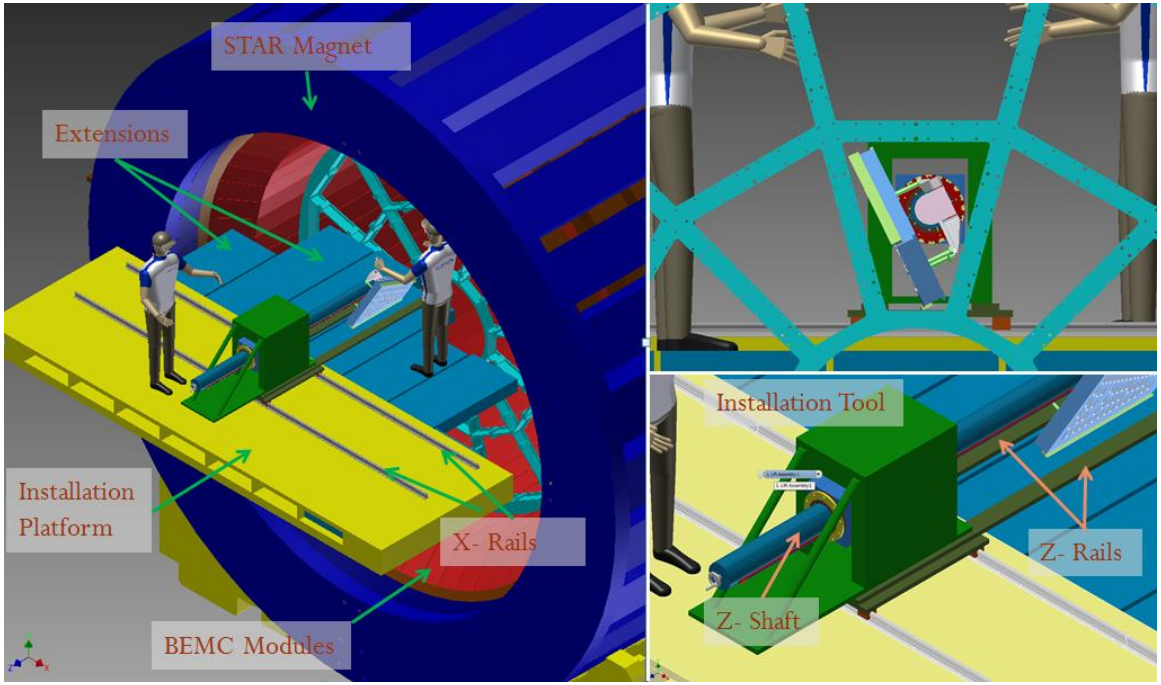
- Prototype work ; going through all the steps of assembly, winding, gluing and testing





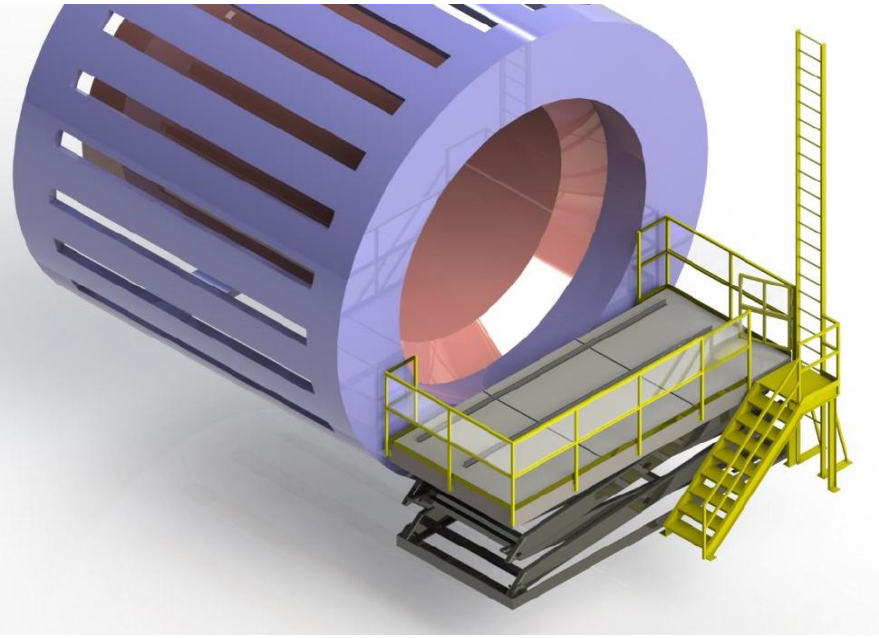
Sector Insertion Tooling

- Concept based on ALICE design
- Cartesian coordinates



Sector Insertion Tooling

- Sector Installation Platform – It is a platform that consists of extension slides that brings the sector manipulation tool into the position for the sector to be installed in the end-wheel.



Conclusions

- iTPC improves the reach of all BES II observables
- iPTC brings significant new physics
  - Radipity dependence of net-proton kurtosis
  - Di-electron program in the Intermediate mass region
  - Internal fixed target program covering 7.7 to 3.0 GeV
- The prospect of getting E-TOF for BESII will also be a boost for the physics.
- The project has made significant progress and has a dedicated team – for both and data analysis

Backup Slides

Simplified Production Plan

- Pad planes at BNL
- Strong backs at UT and/or commercial
- Joining of strong back and pad planes at LBNL
- Wire-winding, mounting at Shandong
- Insertion tooling at BNL
- FEE and RDO,DAQ at BNL

Path forward

- Proposal has been updated since submitted in Feb. New version is now available
- It was realized that project cannot be done for below 2M, and that the insertion tooling is a critical item and should be included
- Review BNL – DOE summer fall 2015
- Most production in FY17,18 – important procurements in FY16

Planned Cost to DOE

WBS		FY15	FY16	FY17	FY18	Conting	Total
1	**Mgt**	92.0	180.5	185.9	125.9	111.5	695.7
2	**Electronics**	53.3	602.8	38.9	727.8	268.3	1,691.1
3	**Mechanics**	70.4	423.4	381.4	4.9	173.6	1,053.6
4	**Insertion tooling**	58.0	406.2	82.8	0.0	106.1	653.1
5	**Installation**	0.0	0.0	0.0	0.0	0.0	0.0
	Total DOE	**273.7**	**1,612.8**	**688.9**	**858.6**	**659.4**	**4,093.5**

Wire arrangement

- A sub group has studied wire arrangements to optimize pad layout and looked at ways to reduced grid leak

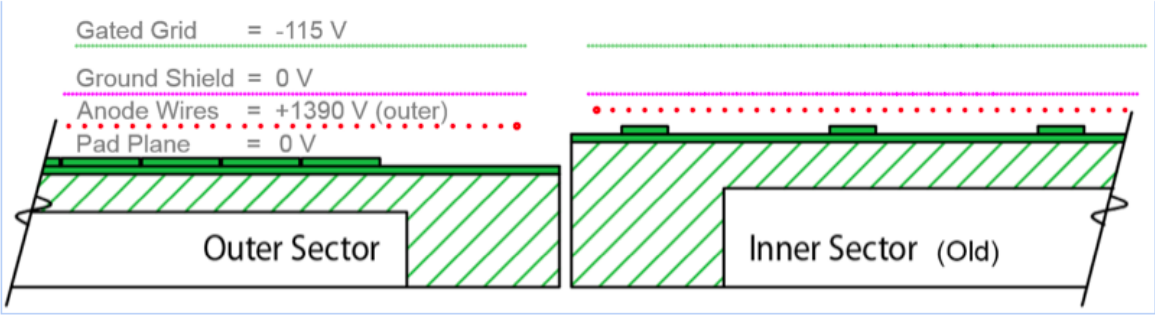


Figure 36: The original STAR pad plane geometry (side view). The outer sector pad rows covered the entire pad plane but the inner sector pad rows were widely spaced (> 5 cm).

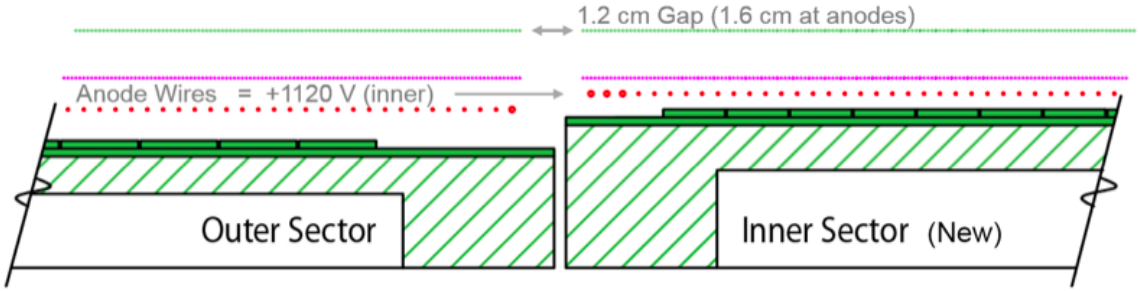
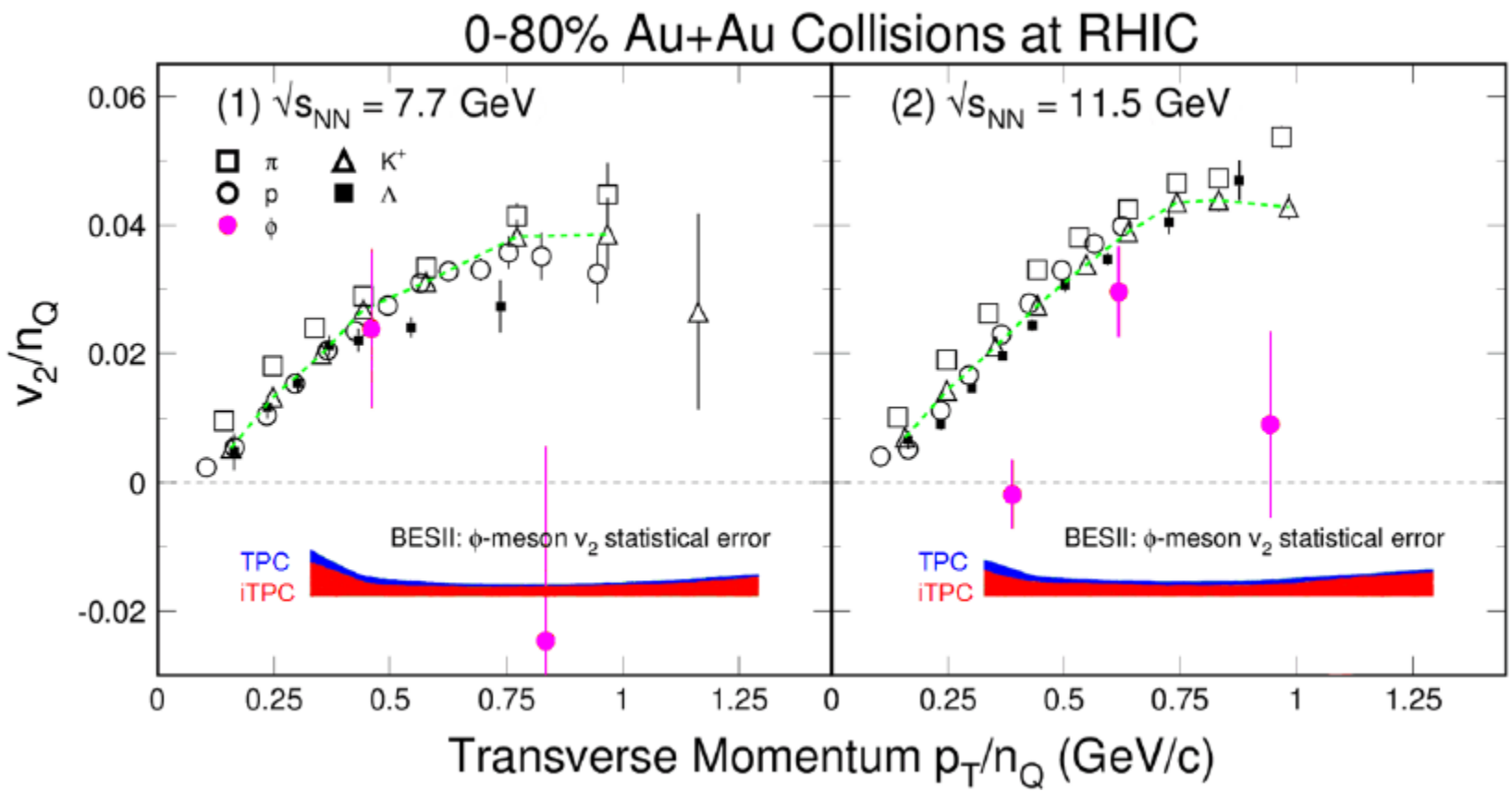
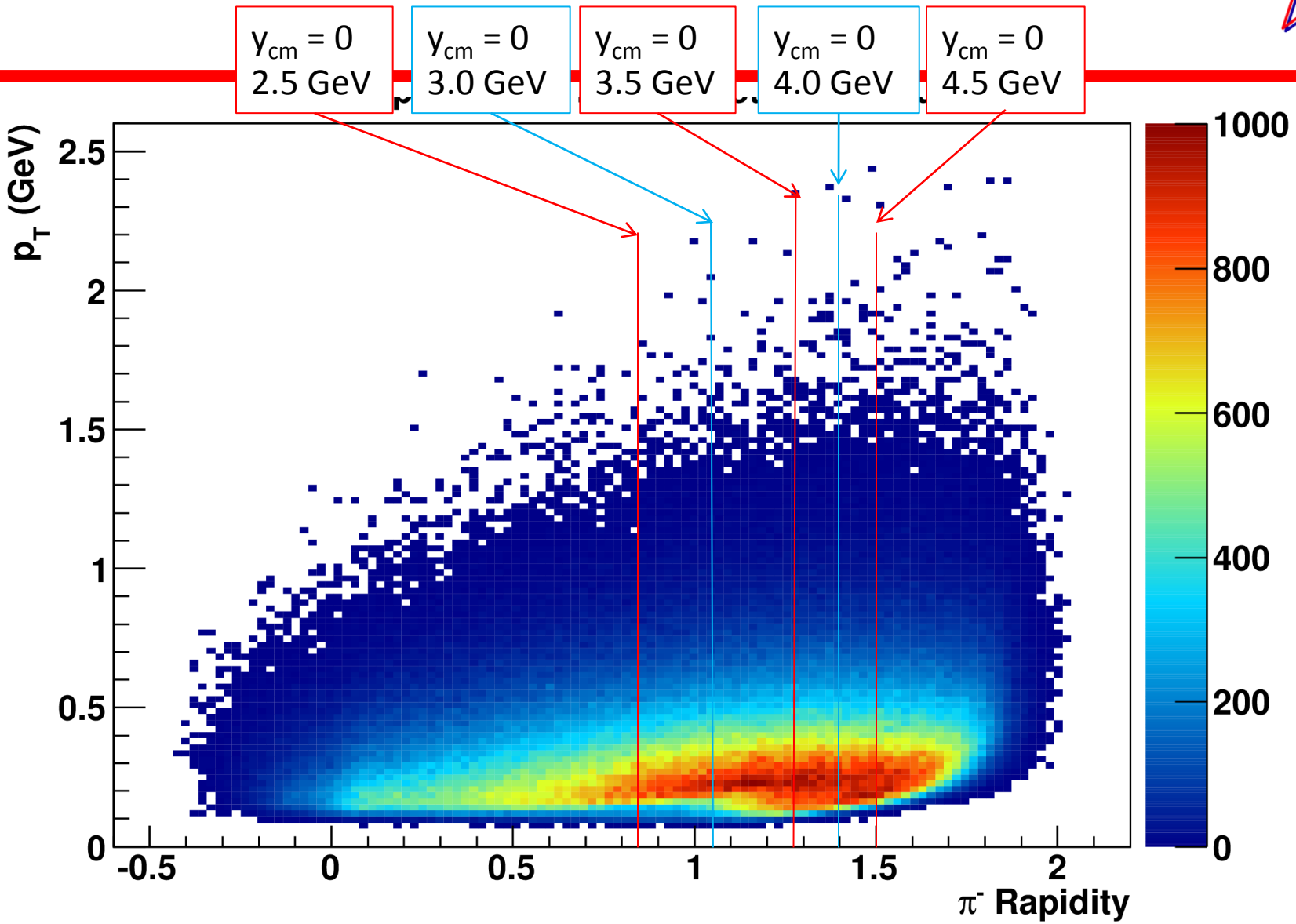


Figure 37: The new STAR pad plane geometry. The outer sector configuration remains the same, but the inner sector has more pad rows and there aren't any gaps between the pad rows.

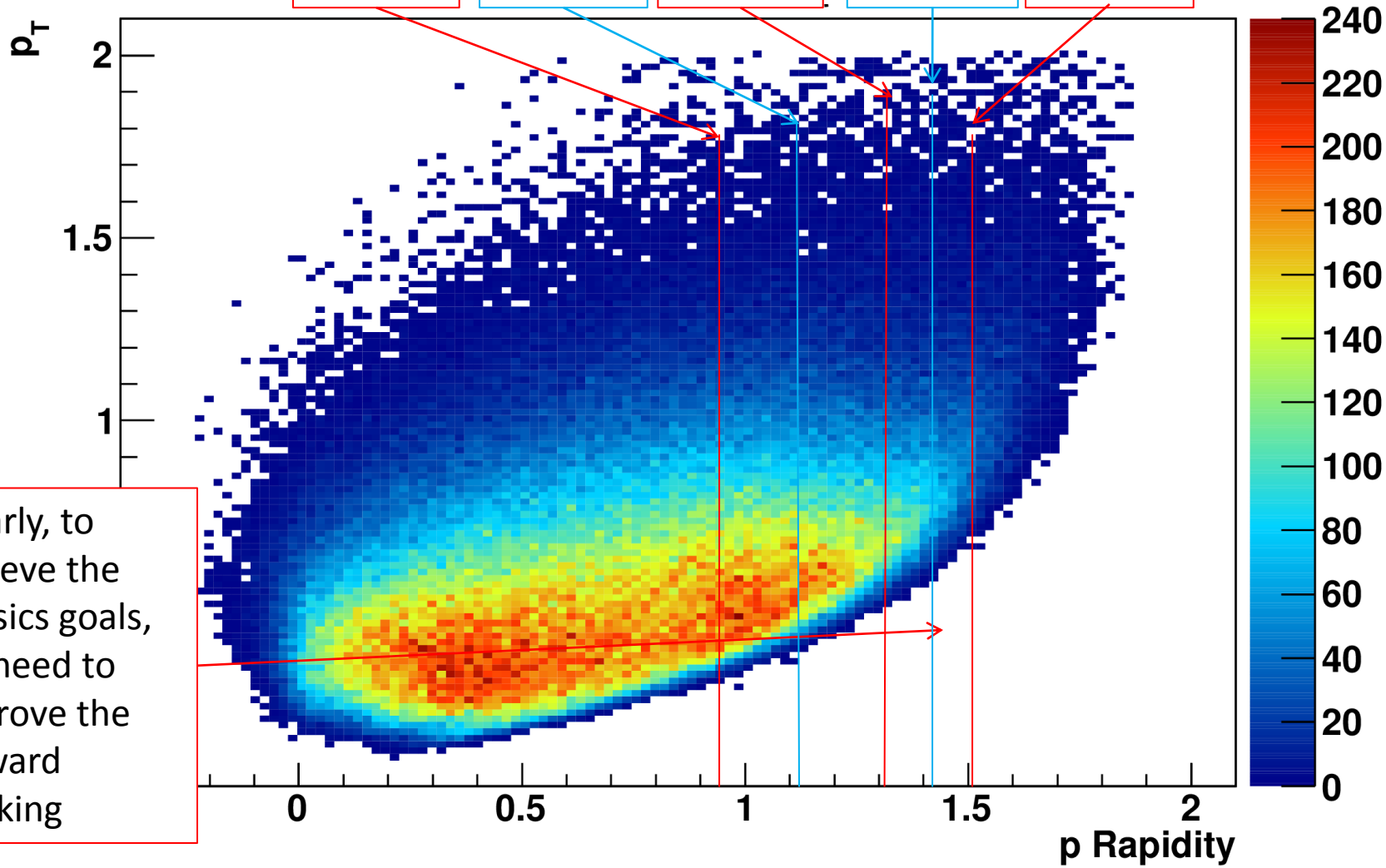
Elliptic Flow of the phi meson



Pion Acceptances



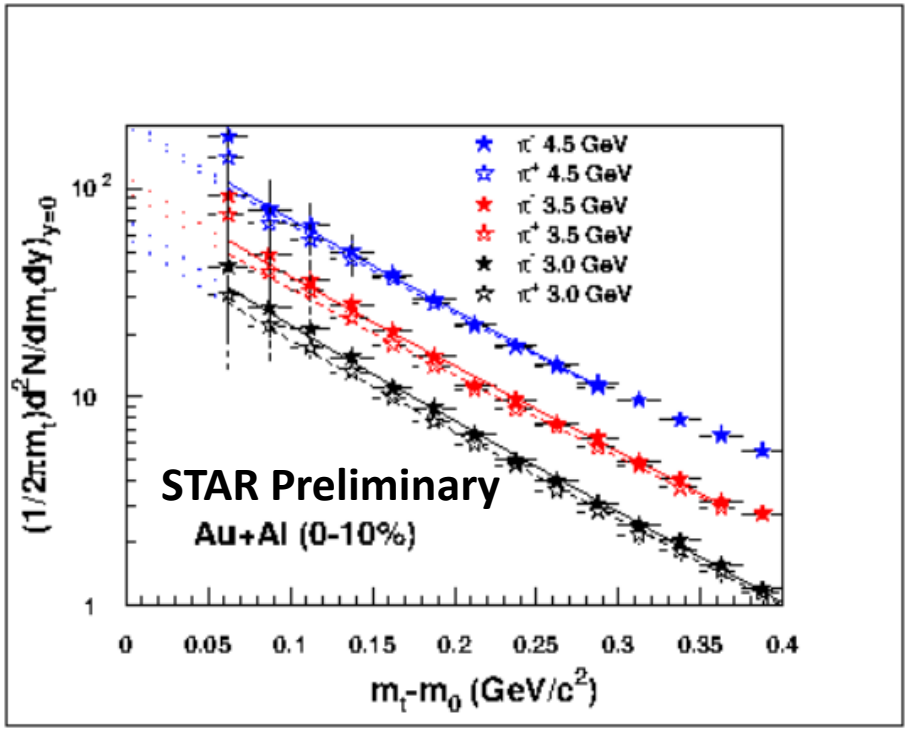
Proton Acceptances

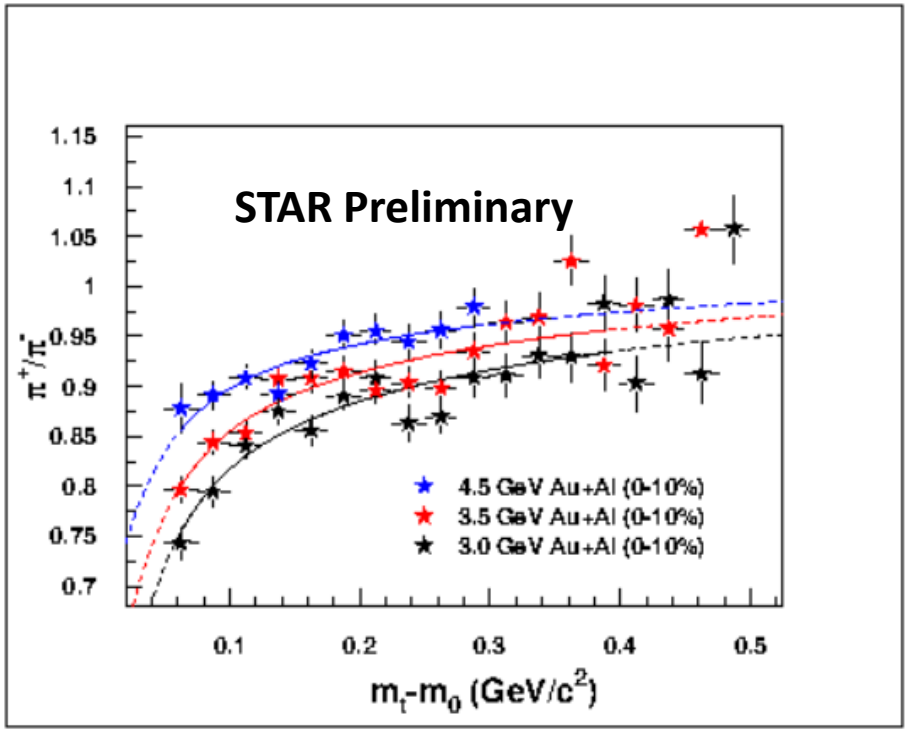


Clearly, to achieve the physics goals, we need to improve the forward tracking

Au + Al Results: Spectra and ratios

Paper has been signed off by the working group. Ready for God Parent Committee

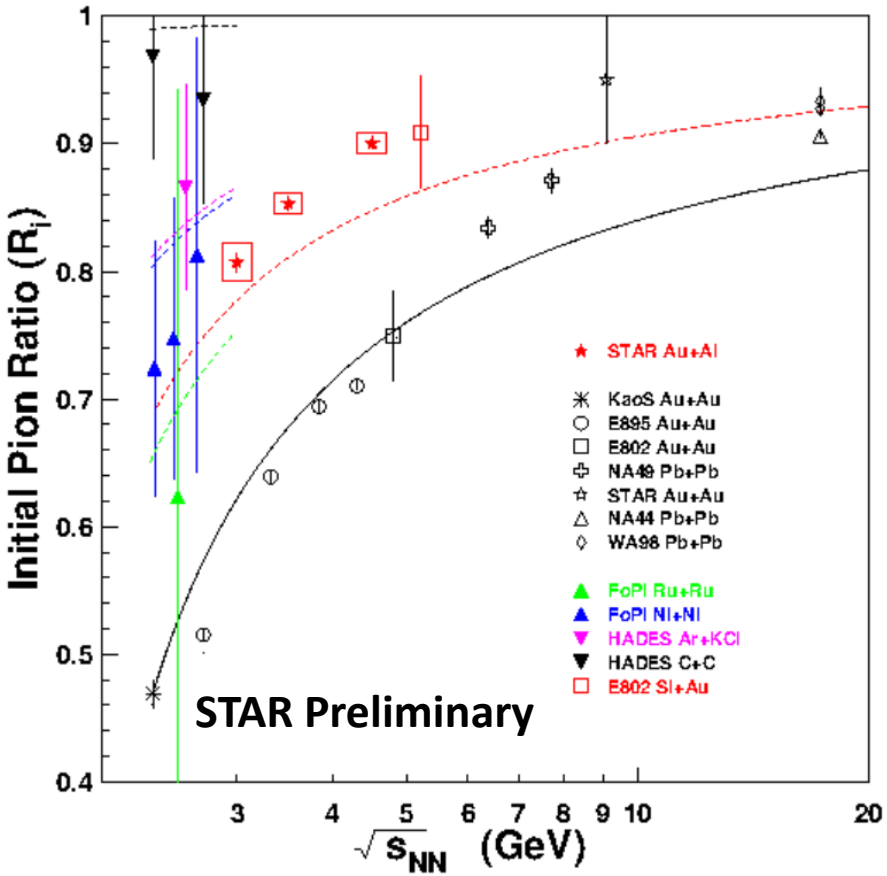


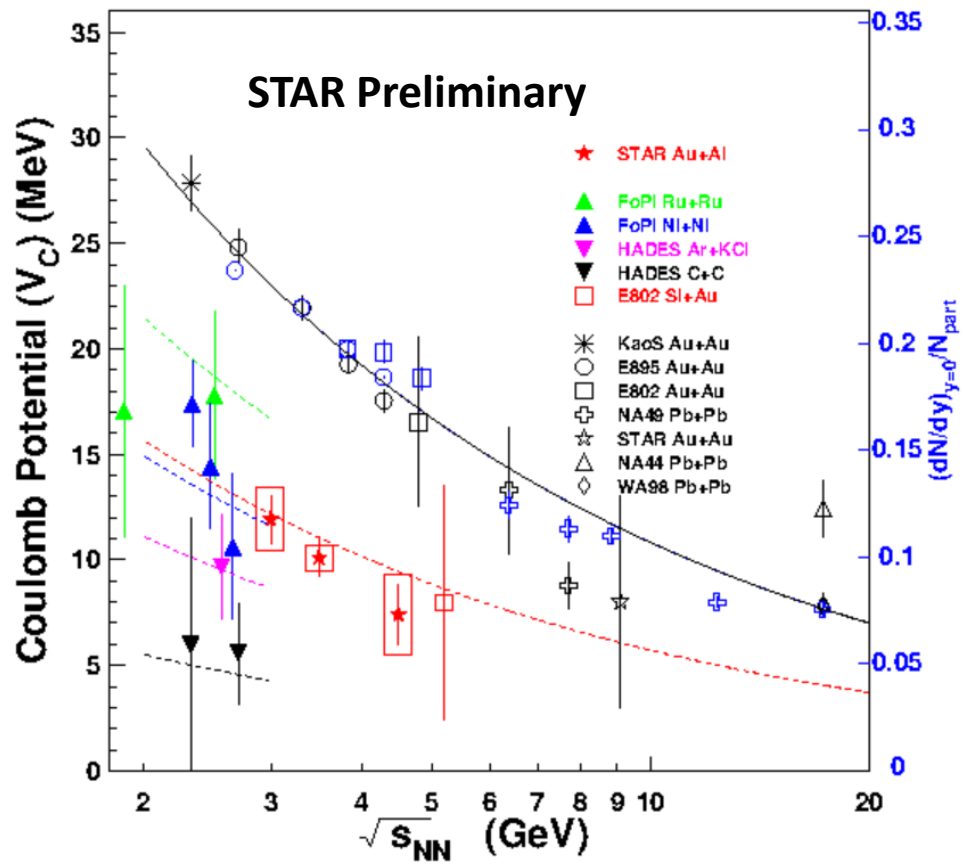


Spectra fit with Bose-Einstein Functions

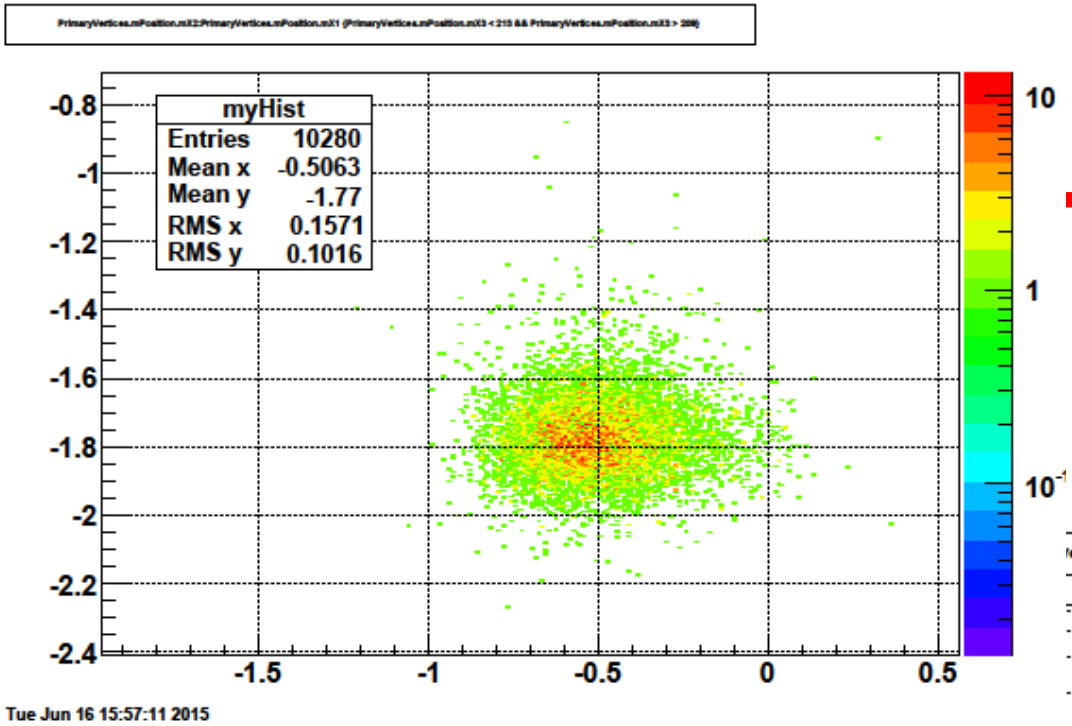
Ratios fit with Coulomb Functions

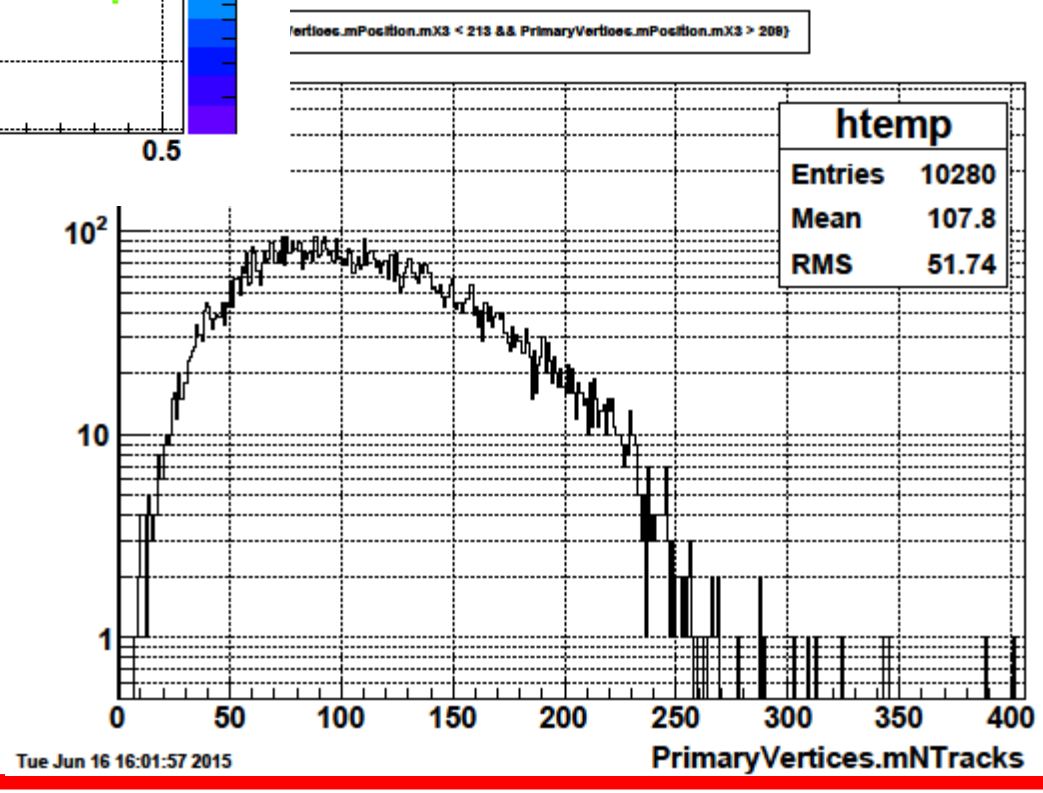
Pion Ratio and Coulomb Potential Comparison





Paper has been signed off by the working group. Ready for God Parent Committee

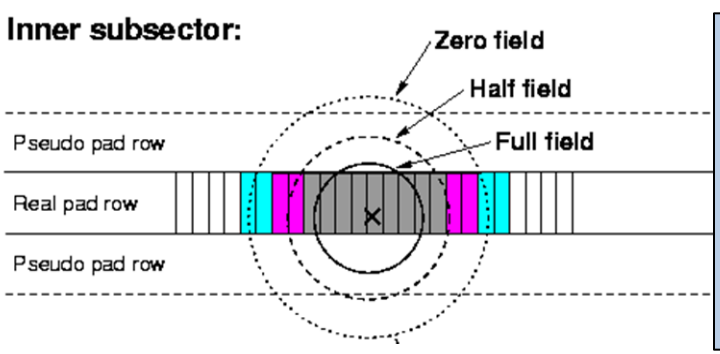




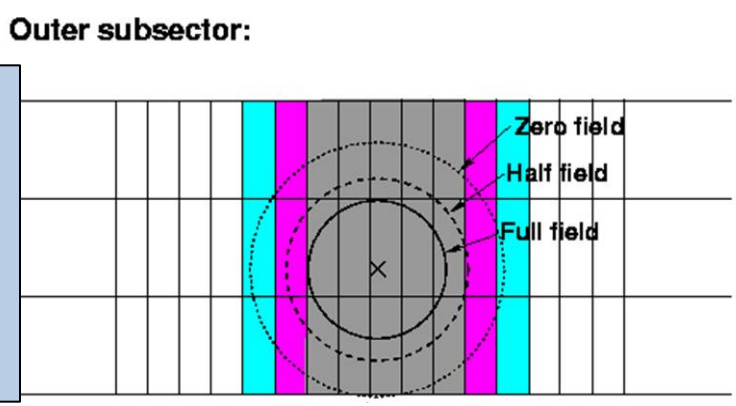
Fixed Target Tests
May 2015

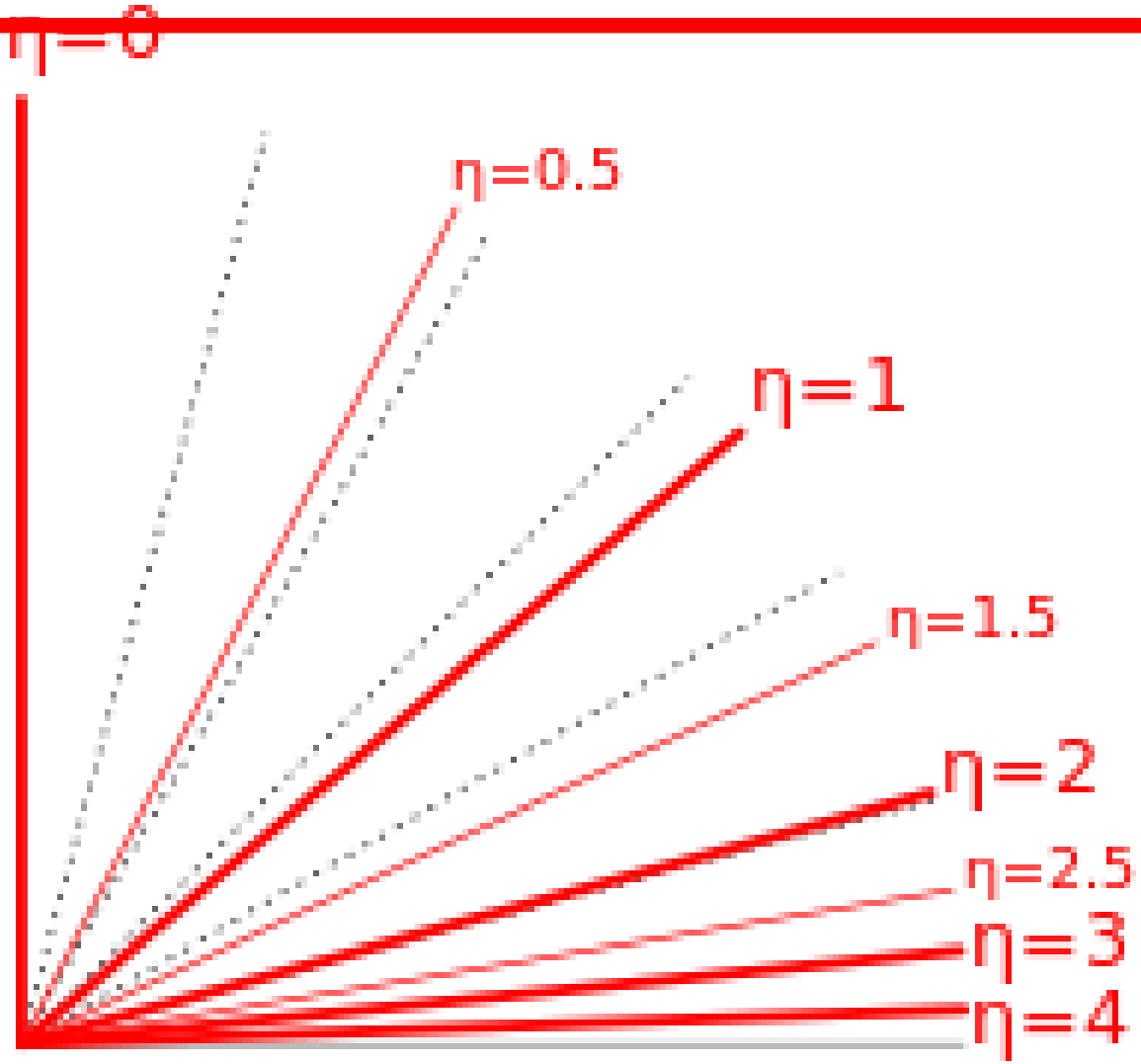
The Inner Sector Pads are too small

- The <u>outer</u> sector pad size was chosen to match the diffusion limit of P10
  - Width (pitch) in the outer sector is 6.7 mm
  - Tonko has measured an average of 3 pads hit per cosmic ray track
- The inner sector pads were deliberately made smaller (for no good reason except that people expected it, HW)
  - Width (pitch) in the inner sector is 3.35 mm
    - note different pad plane to anode wire spacing & gain (2 mm vs 4 mm)
  - Tonko has measured an average of 4 pads hit per cosmic ray track
- It seems quite reasonable to increase the size of the inner sector pads so that an average of 3 pads are hit per cosmic ray track
  - Note, this does not mean 6.7 mm pitch is best … due to different gain and wire geometries in the inner and outer sectors
  - Real simulations are required … but

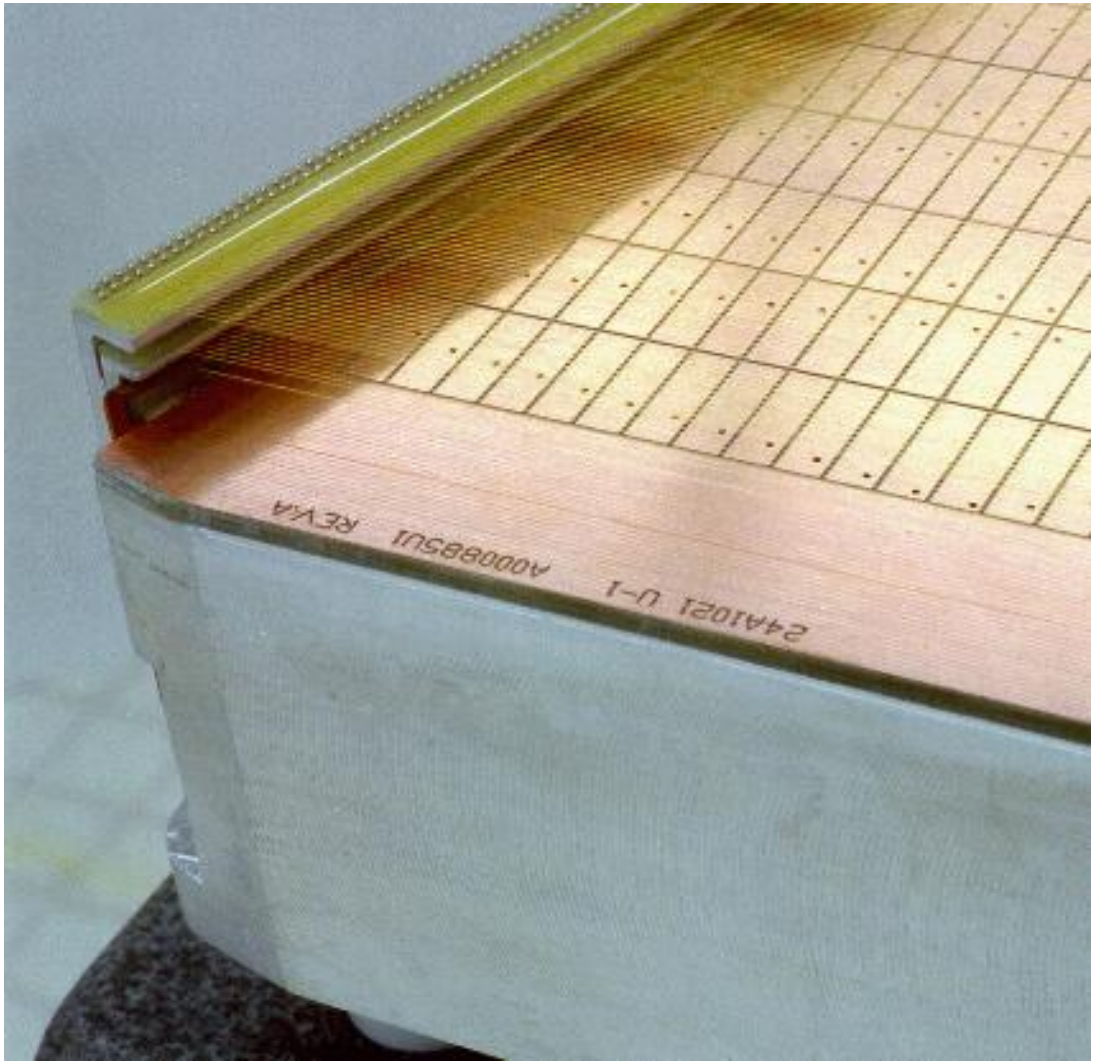


Roy Bossingham's simulations of the old pad geometry (3σ) agree with Tonko (~2σ)




η=0
η=0.5
η=1
η=1.5
η=2
η=2.5
η=3
η=4

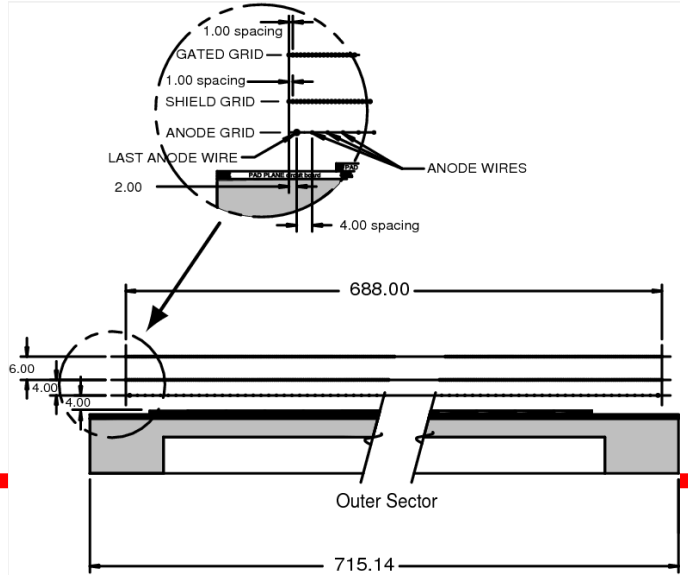
TPC Sector Detail – Aging of the Anode Wires



- Gating Grid
- Ground Shield
- Anode
  - 4 mm pitch, no field wires
  - Spacing: inner ≠ outer
- Pad Plane

Sector Operation for 20:1 signal to noise

Sector	anode voltage	gas gain
inner	1170	3770 ± 10%
outer	1390	1230 ± 10%



Pad Size: Constraints & possibilities … (numbers, not science)

- The outer sectors are 6.7 mm x 20 mm (pitch)
- The inner sectors are 3.35 mm x 12 mm (pitch)
- The full range of possibilities for the new inner pad plane
  - Height from 12 mm to 20 mm (nb: 0.5 mm gap on all edges)
    - Note: only 12, 16 and 20 mm match anode wire spacing (3x, 4x, 5x)
  - Width from 3.35 to 6.7 mm

Limited choices in the vertical dimension

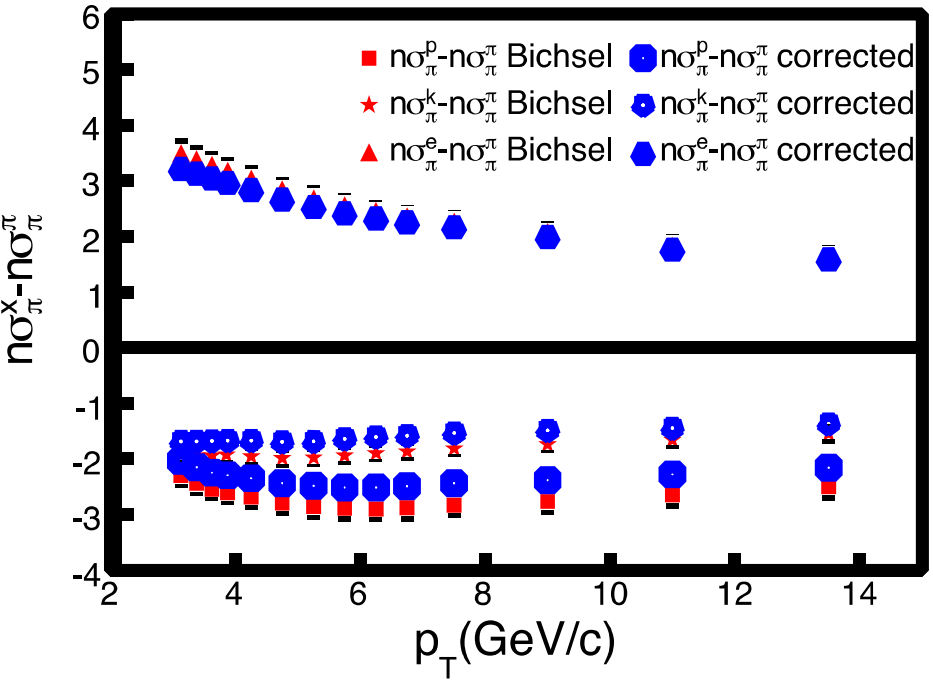
- Translate to number of electronic channels
  - 6,650 channels if 3.35 by 12 mm (50 rows)
  - 2,000 channels if 6.7 by 20 mm (30 rows)
    - Currently 1750 channels in 13 rows (widely spaced at ~5 cm)
  - Range is from 1 to 4x number of channels (for hermetic coverage)
    - 1x would accommodate 6.7 x 20 pad pitch (87% coverage, 30 rows)
    - 2x would accommodate 4.8 x 16 pad pitch (100% coverage, 40 rows)
    - 3x would accommodate 4.2 x 12 pad pitch (100% coverage, 50 rows)
    - (For reference, ALICE uses 4x7 pads, but note that Neon-CO2 has better diffusion characteristics so we expect smaller pads in their case)

Horizontal dimension will be determined by physics and engineering

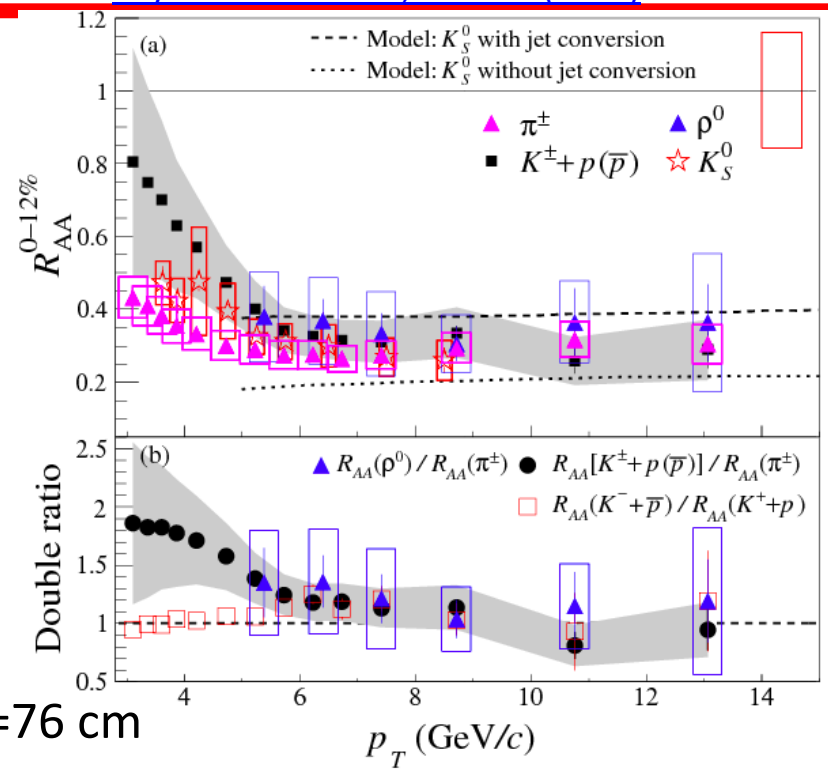
Optimize this number for performance cost and engineering factors

Implications for dE/dx

arXiv:0807.4303



Phys. Rev. Lett. **108**, 072302 (2012).



- This one shows $\sigma_{dE/dx}/(dE/dx)$=8% at L=76 cm
  - ~1.5σ K-π, 2.5σ p-π: 1σ K-p for p>5 GeV/c
  - Has gotten better since then: now more like 6%
  - Need TOF for K-p in the region 2-4 GeV
- Scales as 1/√L: with 130-180 cm, more like <5.5% everywhere
  - Something like 1.5σ K-p