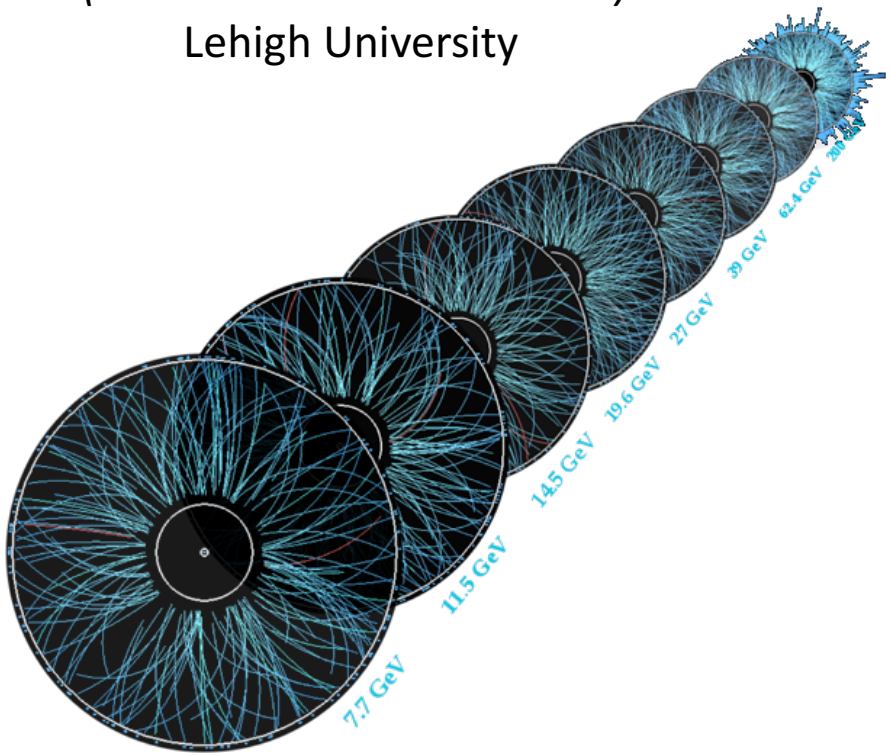
RHIC & AGS
Annual Users' Meeting
From Protons to Heavy Ions, and Back Again
Hosted By Brookhaven National Laboratory

STAR Detector Upgrades

Prashanth Shanmuganathan
(For the STAR Collaboration)
Lehigh University



Talk Outline

- **Beam Energy Scan I highlights**
- **STAR's Beam Energy Scan II Program**
- **Detector Upgrades for BES-II**
  - **i**nner **T**ime **P**rojection **C**hamber
  - **E**vent **P**lane **D**etector
  - **e**ndcap **T**ime **O**f **F**light
- **Forward Upgrade for Cold QCD**
  - **F**orward **C**alorimeter **S**ystem
  - **F**orward **T**racking **S**ystem

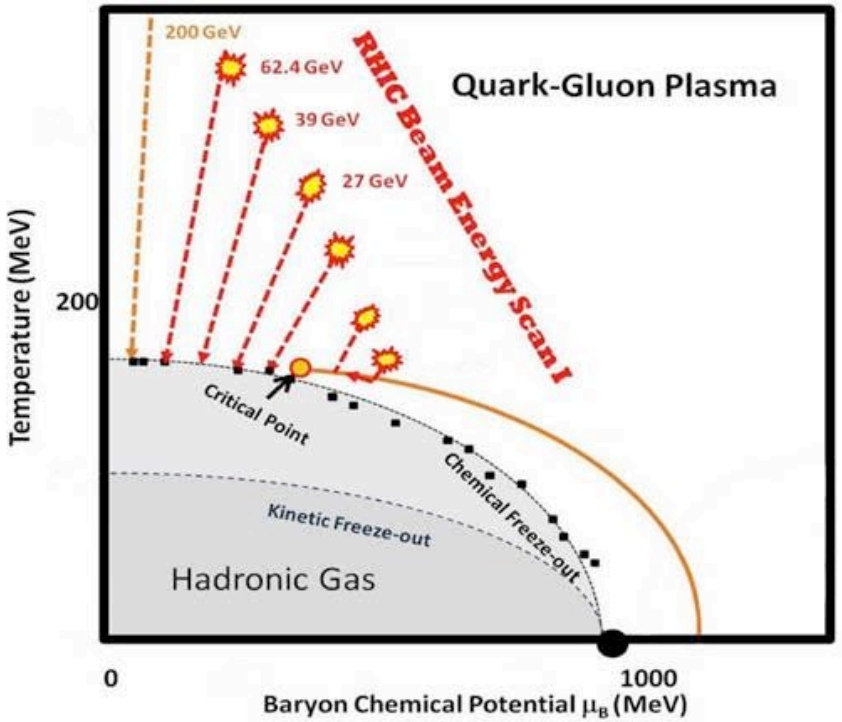
LEHIGH UNIVERSITY

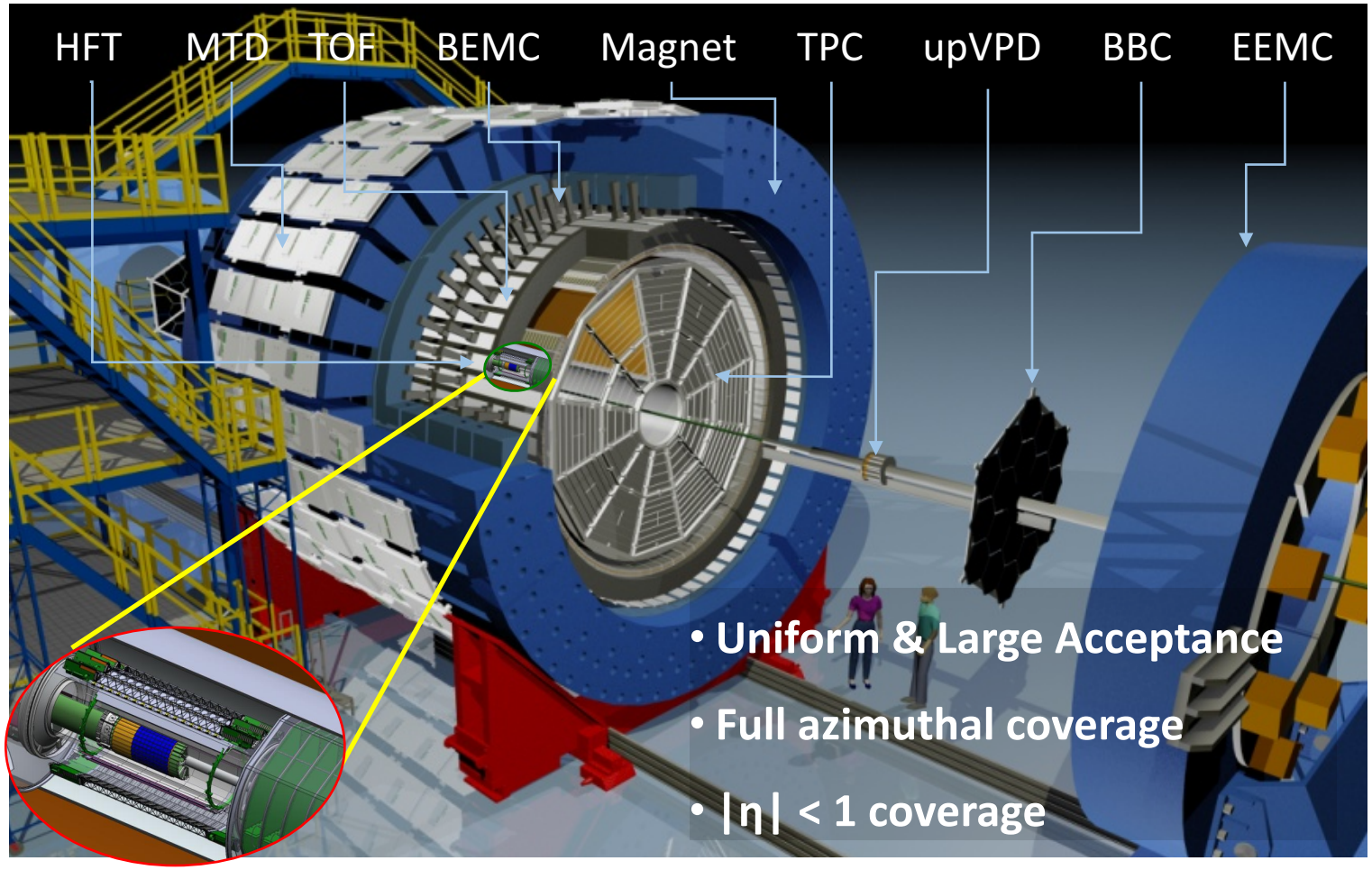
STAR

U.S. DEPARTMENT OF ENERGY | Office of Science

NSF

BES Program at STAR





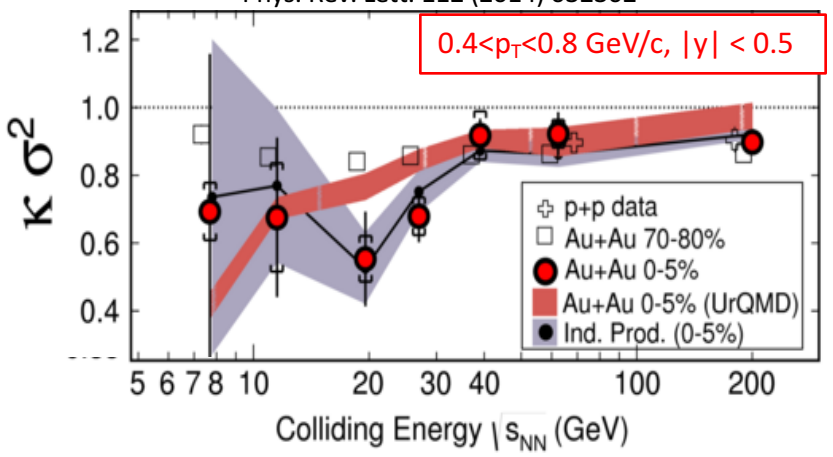
Goals of BES :

Explore QCD phase diagram

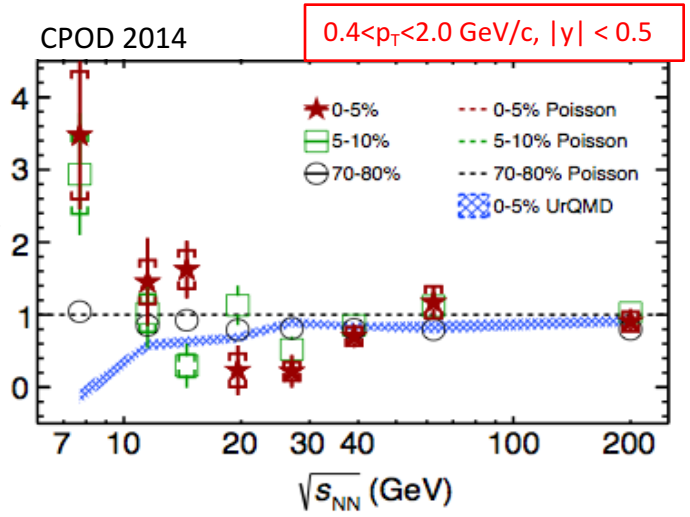
- **Search for a Critical Point**
- **Signatures of Phase Transition**
- **Map turn-off of QGP signatures**

BES I Physics Highlights – Search for Critical Point

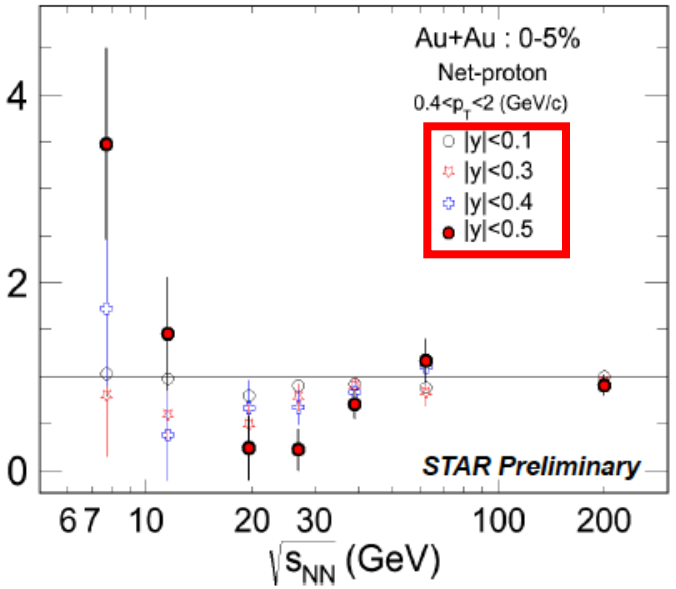
Phys. Rev. Lett. 112 (2014) 032302



CPOD 2014



QM2015



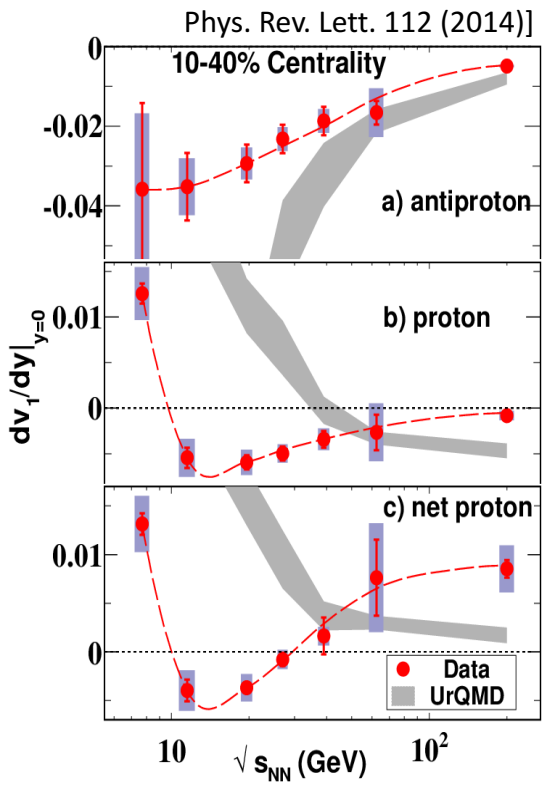
- Near CP ratios of cumulants ($\kappa\sigma^2$ or $S\sigma$) of the net-particle multiplicity distributions should diverge

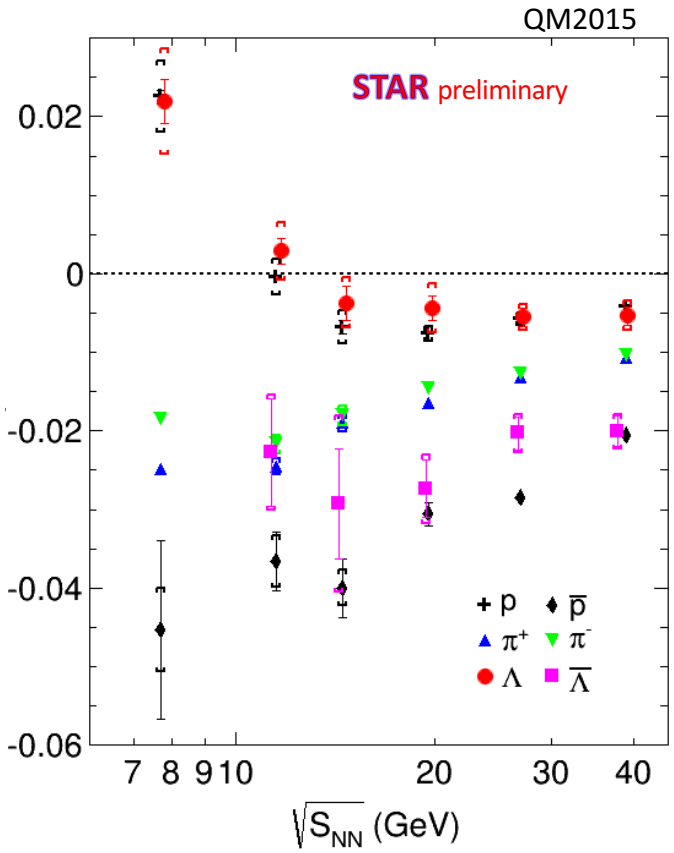
  =>2-3σ deviation from Poisson distribution seen

Limitation in Analysis

- Large uncertainty (Limited statistics)
- Need wider p_T acceptance
- Need wider y acceptance
- Centrality determined within mid-rapidity, using uncorrelated particles

BES I Physics Highlights –Signatures of Phase Transition





- Hydro calculations suggests minimum in baryon dv_1/dy vs. beam energy is softening of EOS
- Softening of EOS can be interpreted as 1st order phase transition
  - Proton dv_1/dy shows a minimum
  - Λ – baryons dv_1/dy shows similar trend

Limitation in analysis

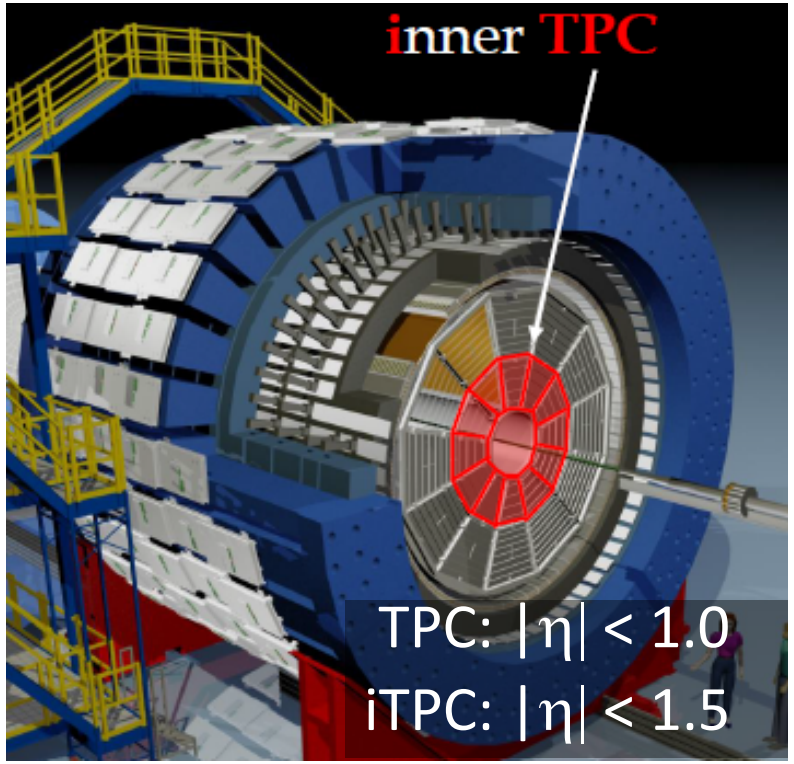
- Large uncertainty (Limited statistics)
- Poor reaction plane resolution

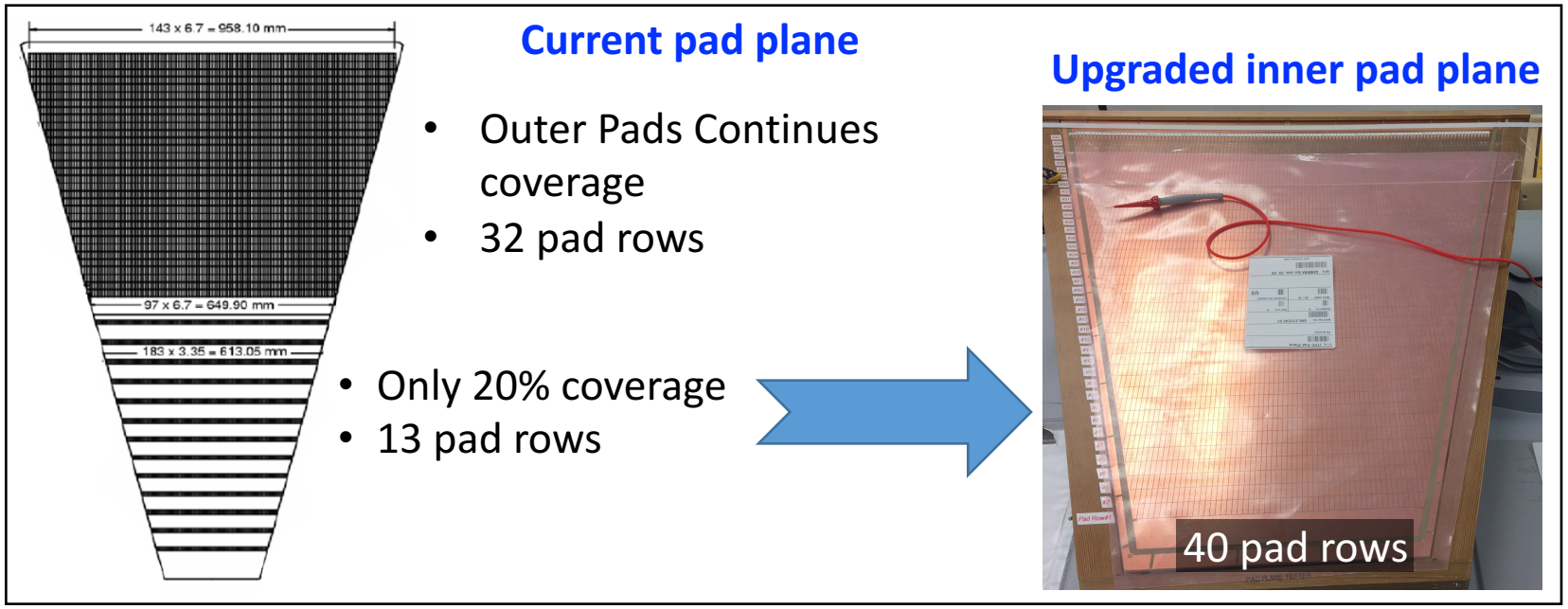
- Systematic analysis of centrality dependence
- v_1 is small near mid-y, structure develops at large y
- Improve particle identification
- Large μ_B gap between 7.7 and 11.5 GeV (~100 MeV)

Detector Upgrades for BES II

eTOF EPD iTPC	• Larger Acceptance
EPD	• Independent Centrality definition & better Event plane resolution
iTPC eTOF	• Improved PID capabilities
EPD LEReC	• Higher Statistics (CAD) & Improved Trigger

inner Time Projection Chamber Upgrade (iTPC)





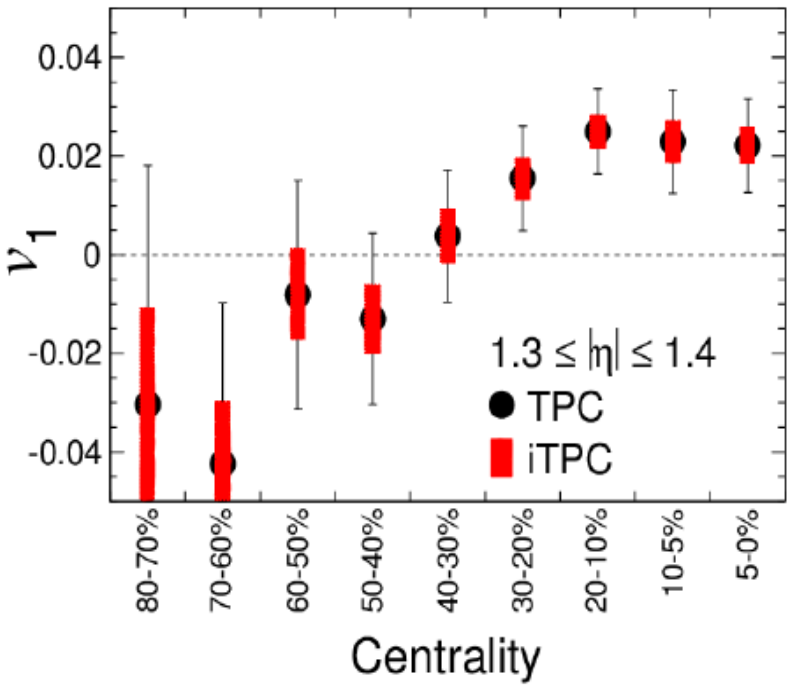
- Endcaps are Multi-Wire Proportional Chambers (MWPC)
- Each endcap has of 12 inner and outer sectors
- An important part of the endcap MWPCs is the read-out pad plane

Improvements

- Improves dE/dx (15-30%)
- Extends η coverage from 1.0 to 1.5 (50% increase)
- Better momentum resolution
- Lowers the minimum reconstructed track p_T cut from 125 MeV/c to **60 MeV/c**

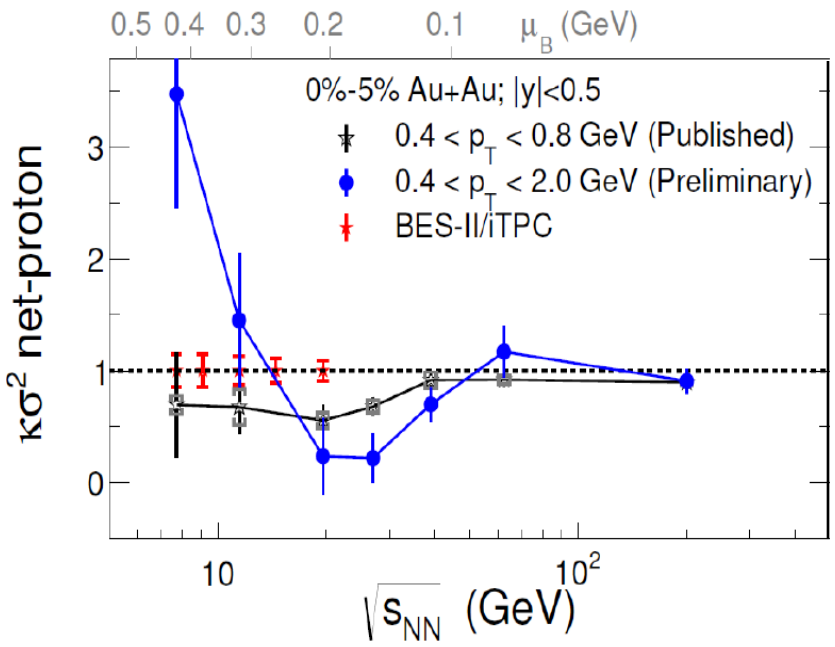
iTPC Physics Improvements

Directed Flow



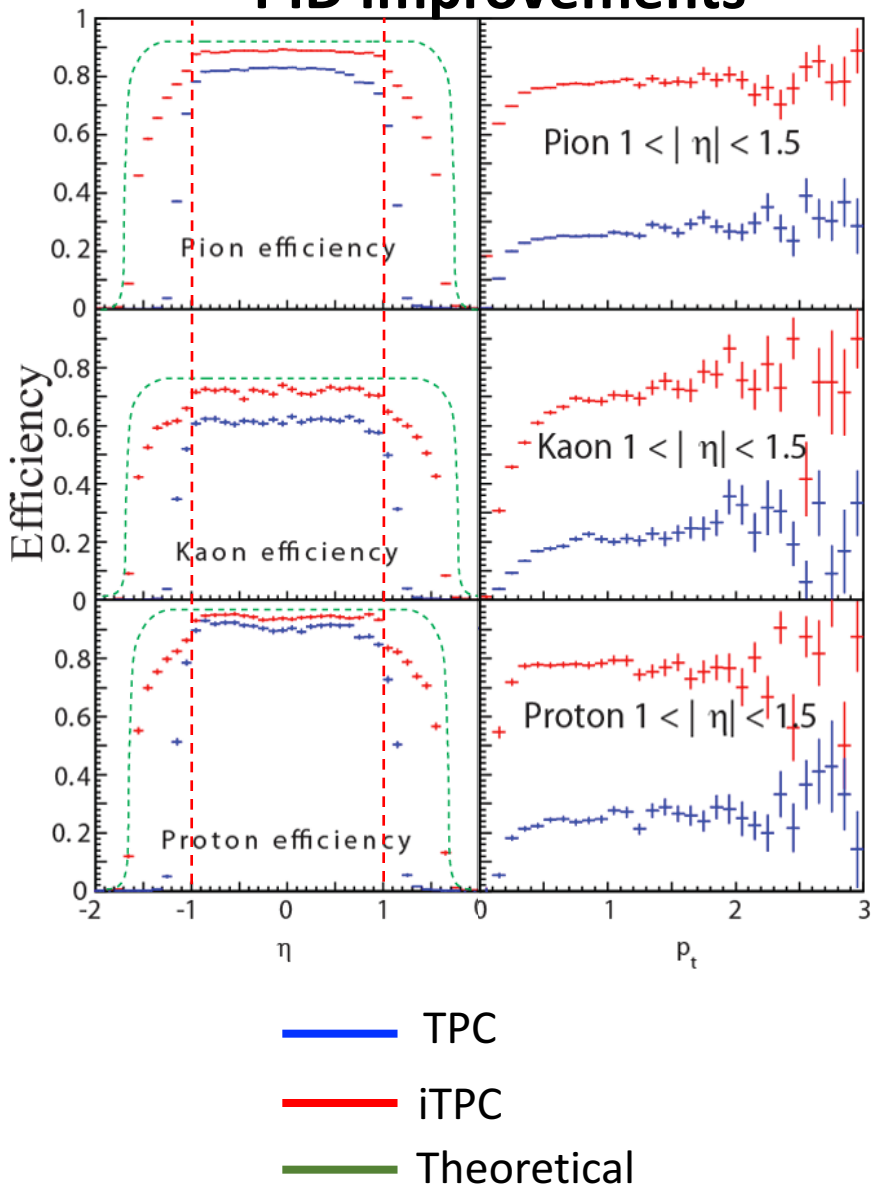
- Forward v_1 measurement as a function of centrality
- UrQMD Charged particles from 19.6 GeV Au+Au

Fluctuation Measurements



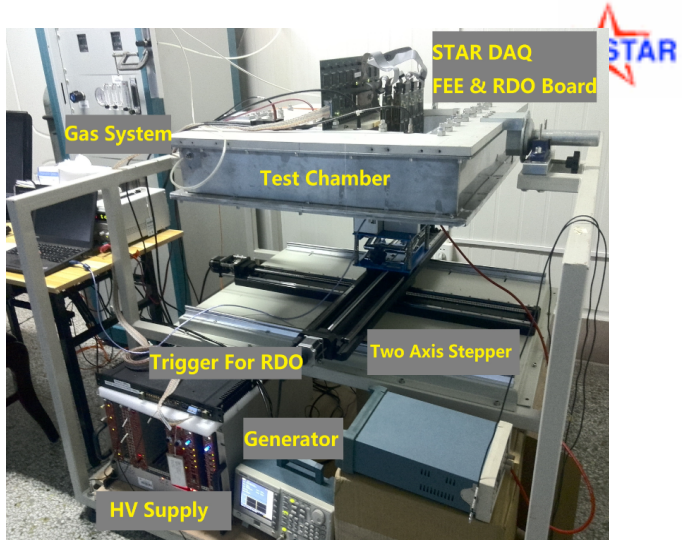
- Statistical errors for energies in the BES II program with the impact of the iTPC taken into account
- iTPC allows to explore finite volume scaling effects

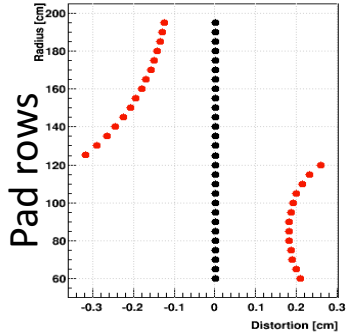
PID Improvements



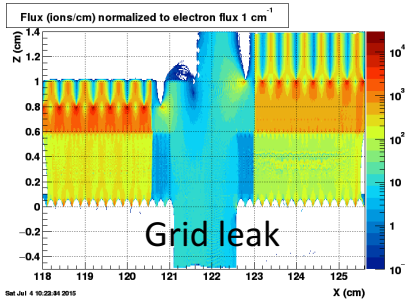
iTPC Project Scope

- **Inner Sectors**
  - Pad planes tested and ready by December
  - Bonding of pad planes/side mounts – LBL
  - Wire winding for MWPC at SDU
  - **Solved Grid Leak** issue
- **Electronics**
  - New FEEs are based on current FEE layout, but using ALICE SAMPA chip
  - Satisfied with the SAMPA performance during prototype run 17
- **Installation**
  - Special tool to remove and insert inner sectors
- **Full installation after Run 18**
  - Single sector for testing in Run 18

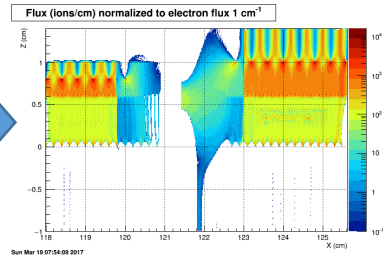




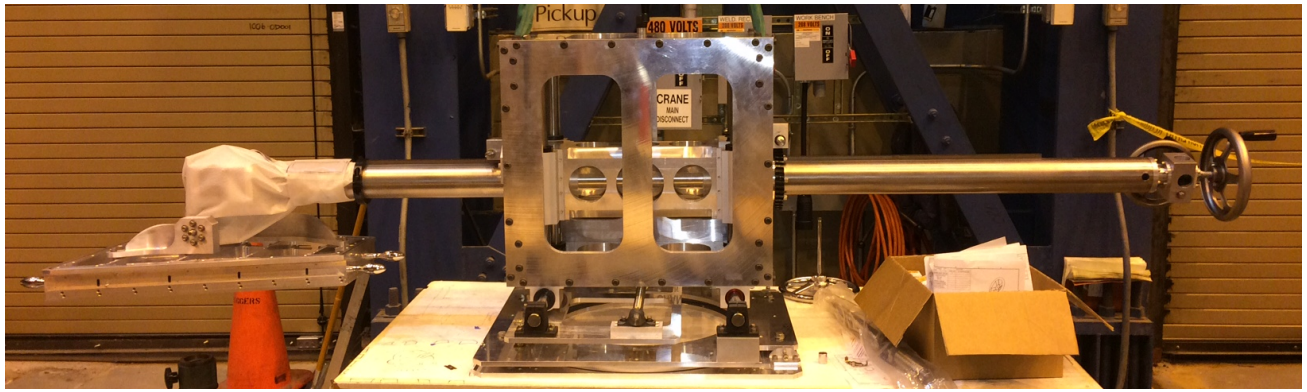
Observed hit pattern
Expected hit pattern



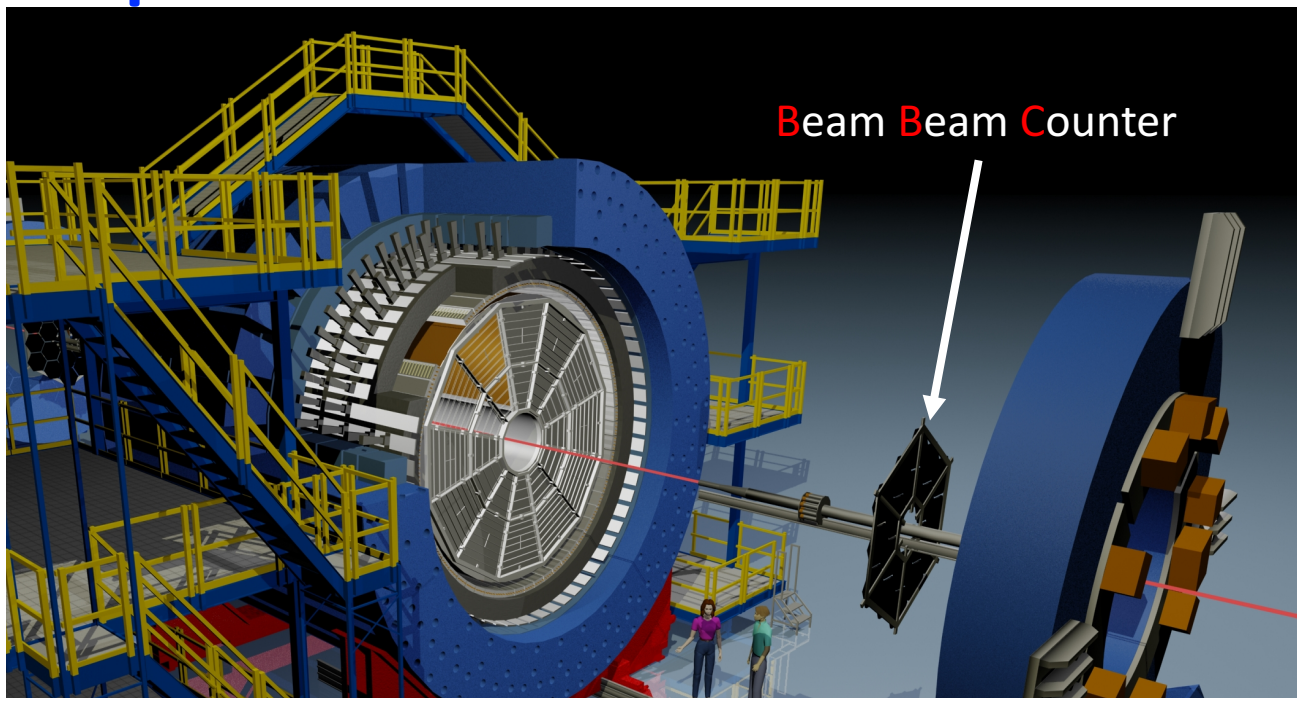
TPC



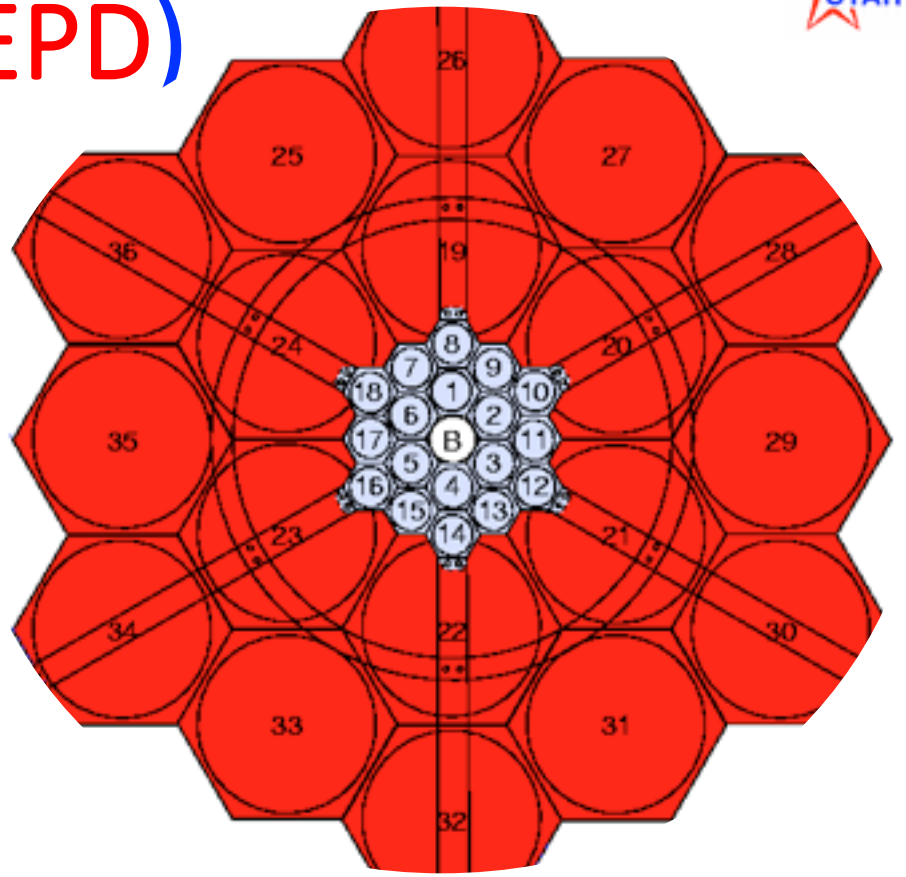
iTPC



Improved Event Plane Detector (EPD)



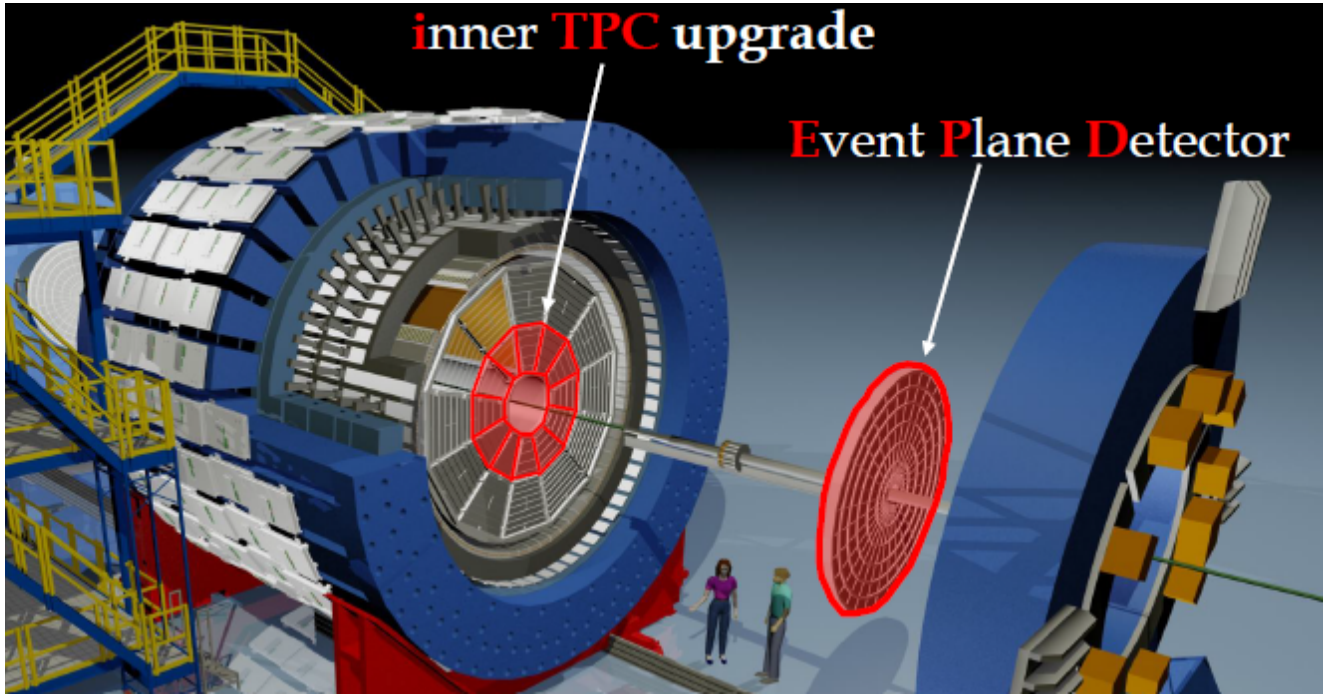
$3.3 < |\eta| < 5.0$

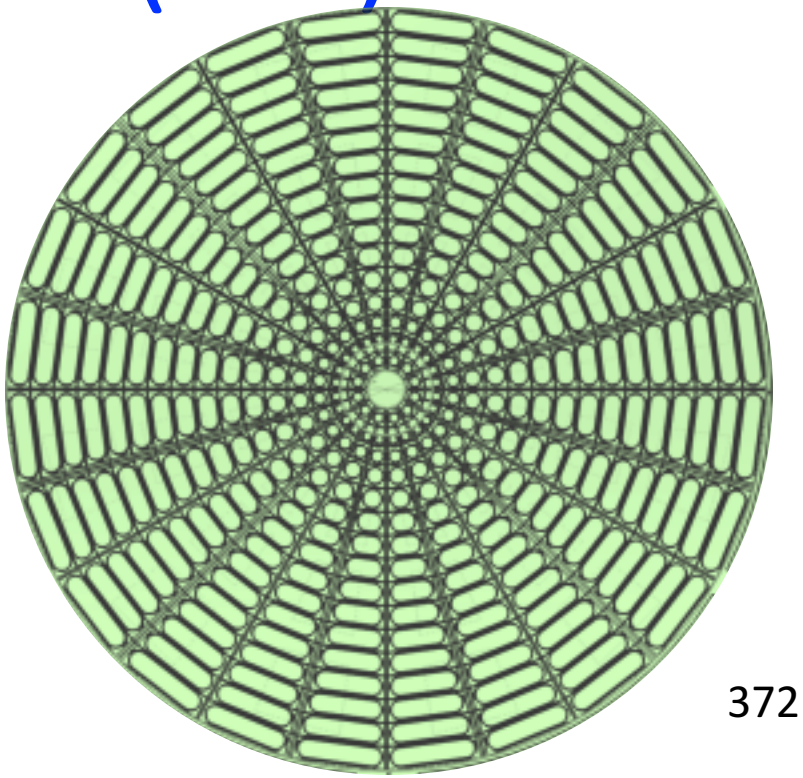


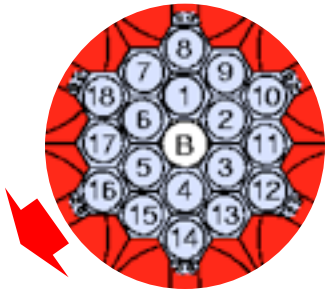
Beam Beam Counter (BBC)

- Existing detector used for:
  - (1st order)event plane
  - Triggering
- Mostly inner tiles are used
  - $3.3 < |\eta| < 5.0$
- 18 Tiles/ 16 channels

Improved Event Plane Detector (EPD)





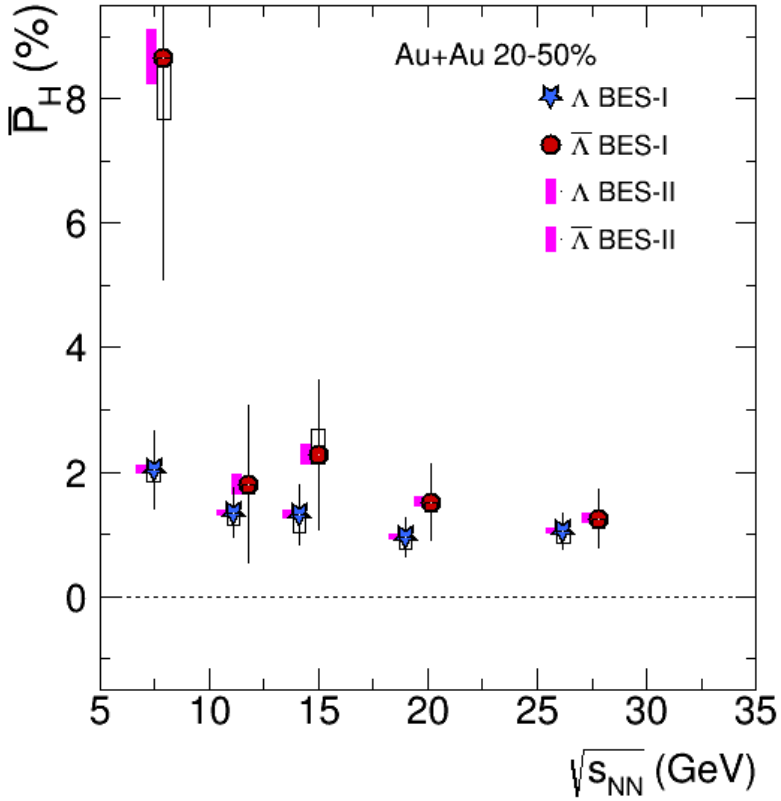


16 channels

372 channels

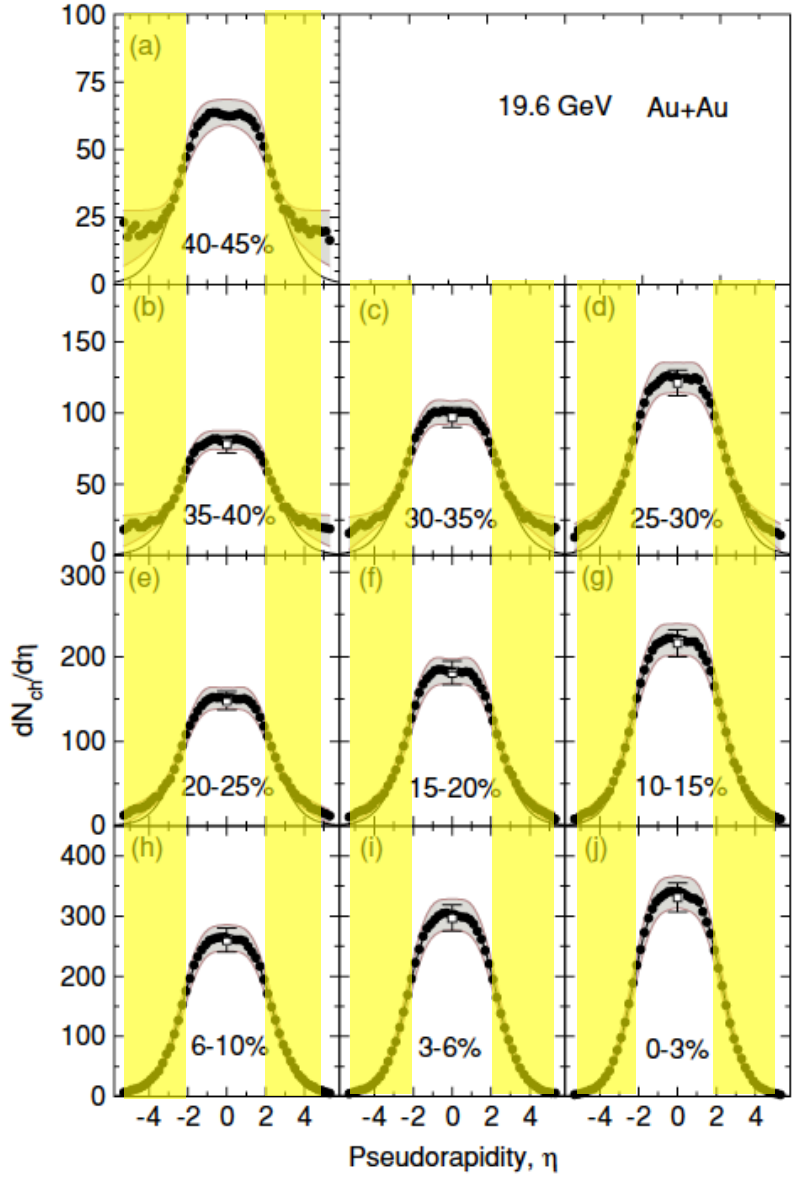
- Significant azimuthal & radial segmentation (372 x 2 channels)
- $3.3 < |\eta| < 5.0$ ➜ **$2.1 < |\eta| < 5.1$**
- 16 channels ➜ 372 channels
- Measure the Centrality and Event Plane at Forward rapidity

EPD Physics Improvements



- Global polarization of Λ and anti-Λ from Au+Au collisions
- Enhanced precision using 1B MB events and EPD

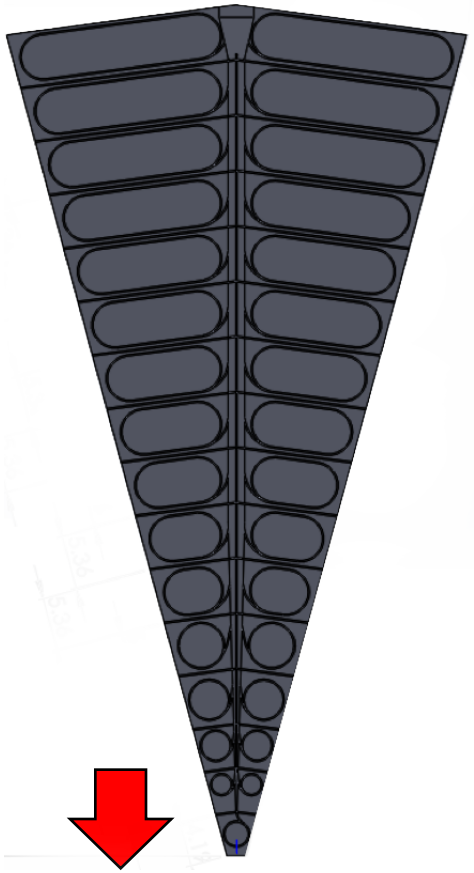
dN/dη

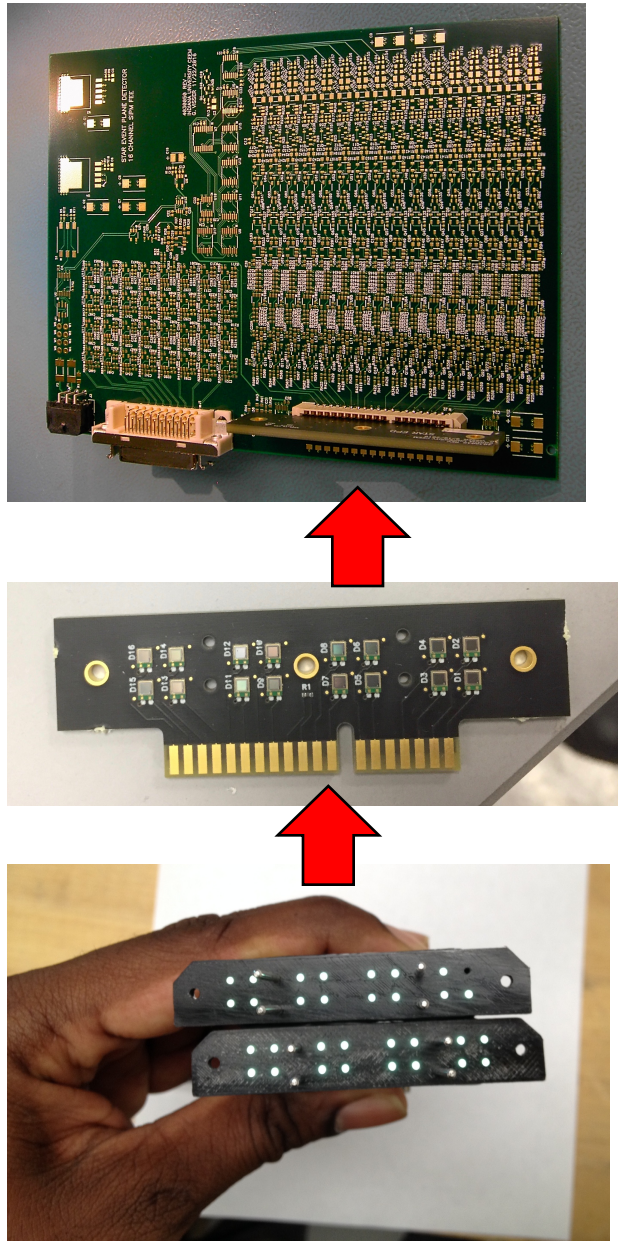


PHOBOS PRC 83, 024913

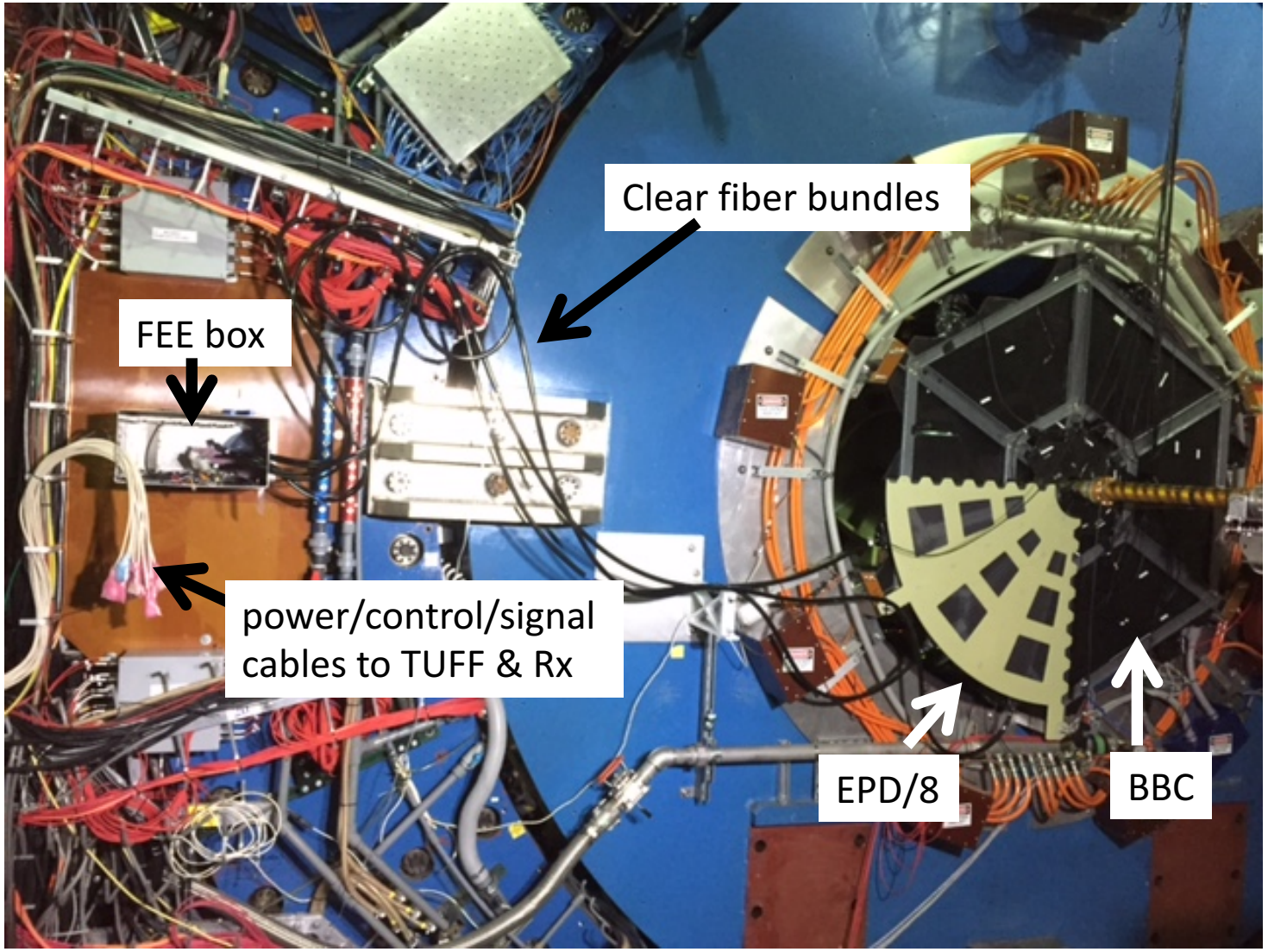
EPD Project Scope

- Super Sectors (1/12th of a wheel)
  - Scintillator wedges, milled to form 31 tiles
  - Optically separated by epoxy
- Coupling to electronics
  - Optical fiber
- Electronics
  - ~50 photoelectrons per MIP
- Engineering Run 17
  - 1/8th of the detector installed
- **EPD will be ready for Run 18**





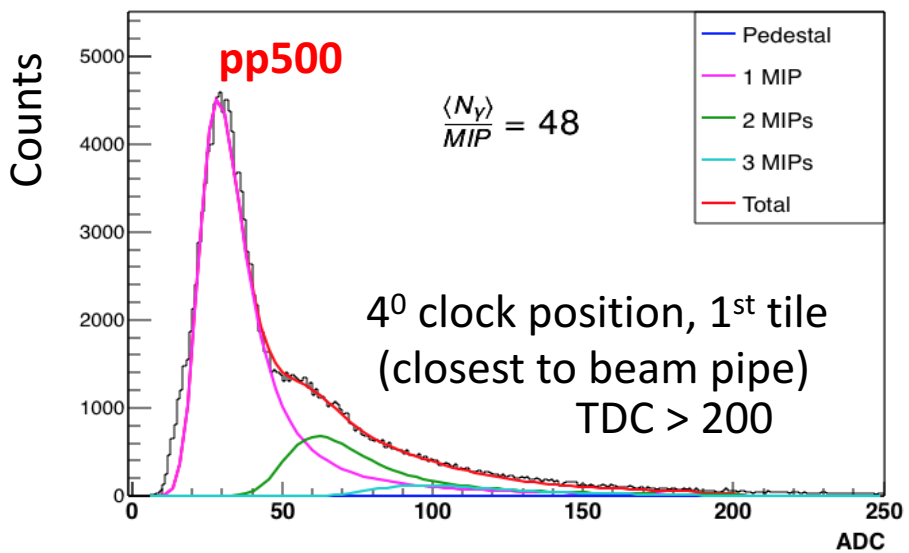
EPD- Run 17 Operation

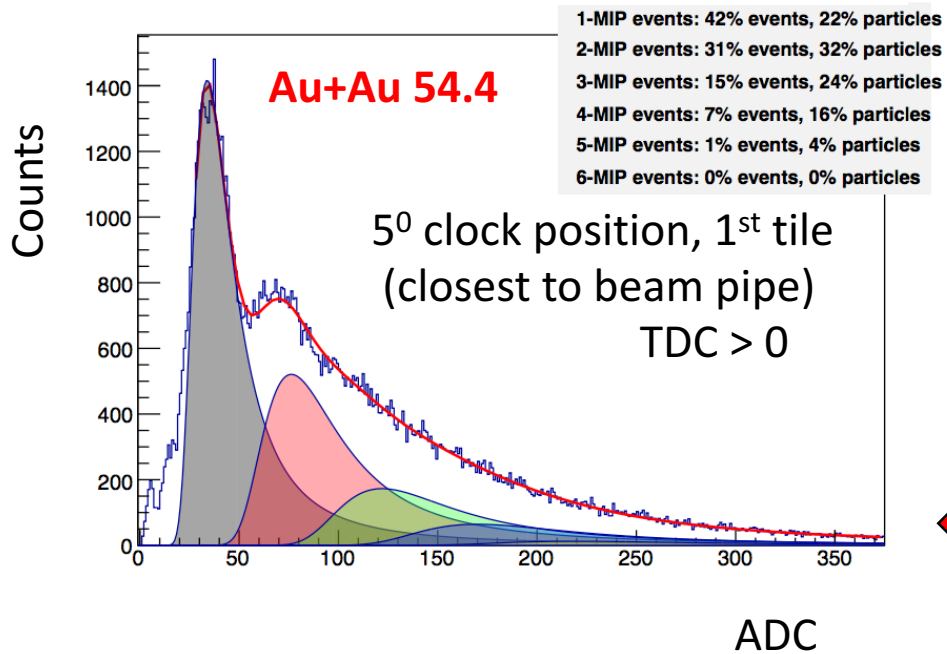


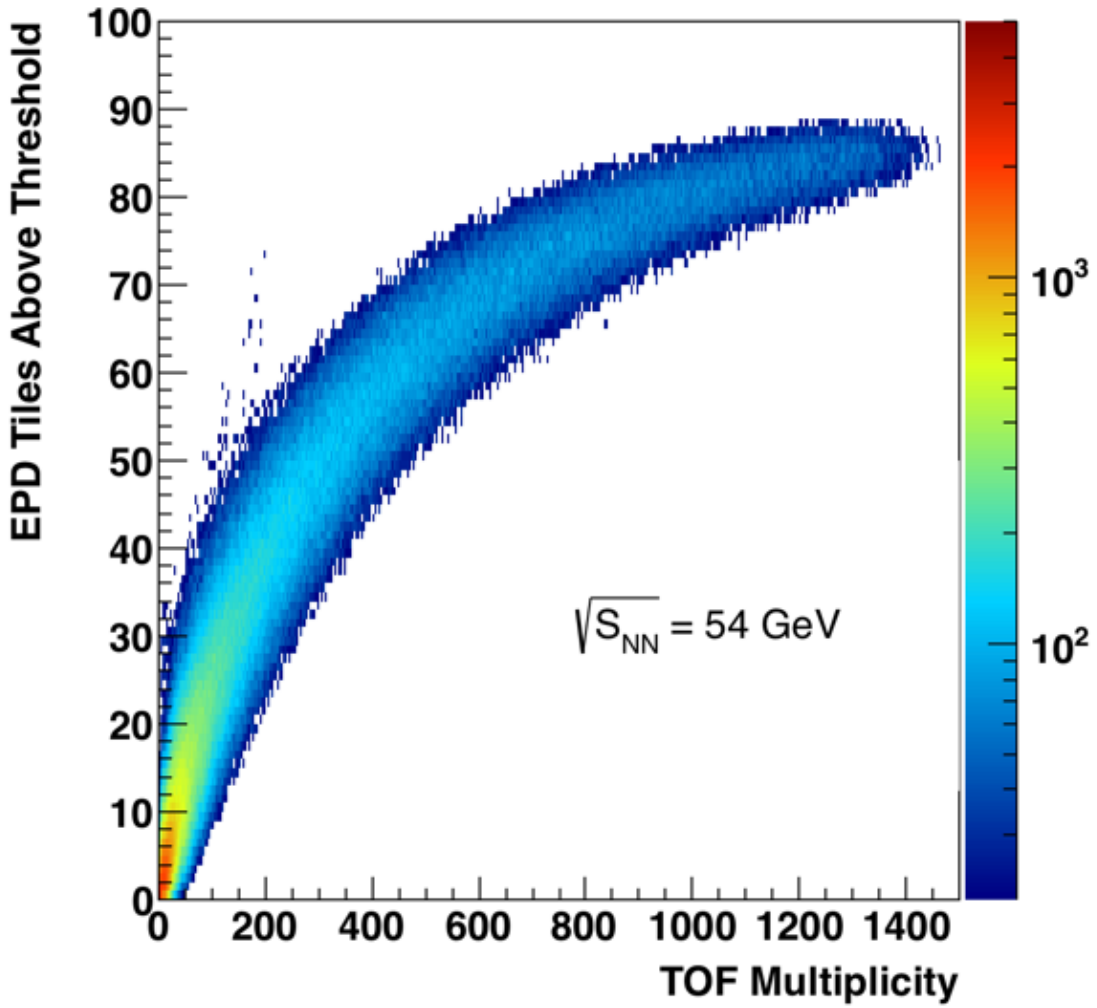
- ¼ of the wheel (1/8 of the detector) installed on the east side of STAR
- Timed in during pp500 running
- Clear MIP peaks seen in all tiles
- Uniform response from the detector
- Fully functional for Au+Au 54.4 GeV running → Taking data

EPD- Run 17 Performance

ADC Distribution

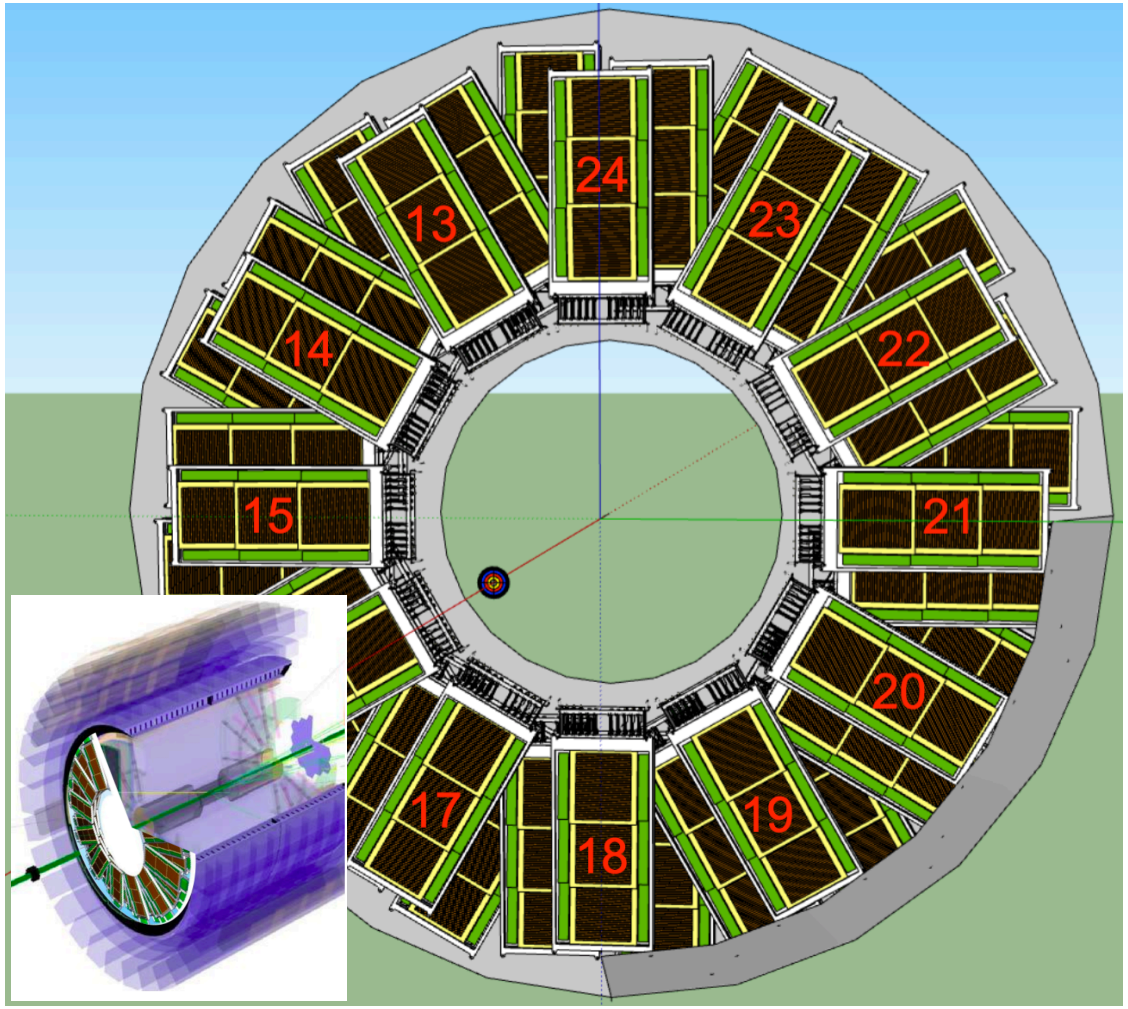






- ADC distribution fitted for multiple hits
- About 50 photoelectrons per MIP

endcap Time Of Flight detector(eTOF)



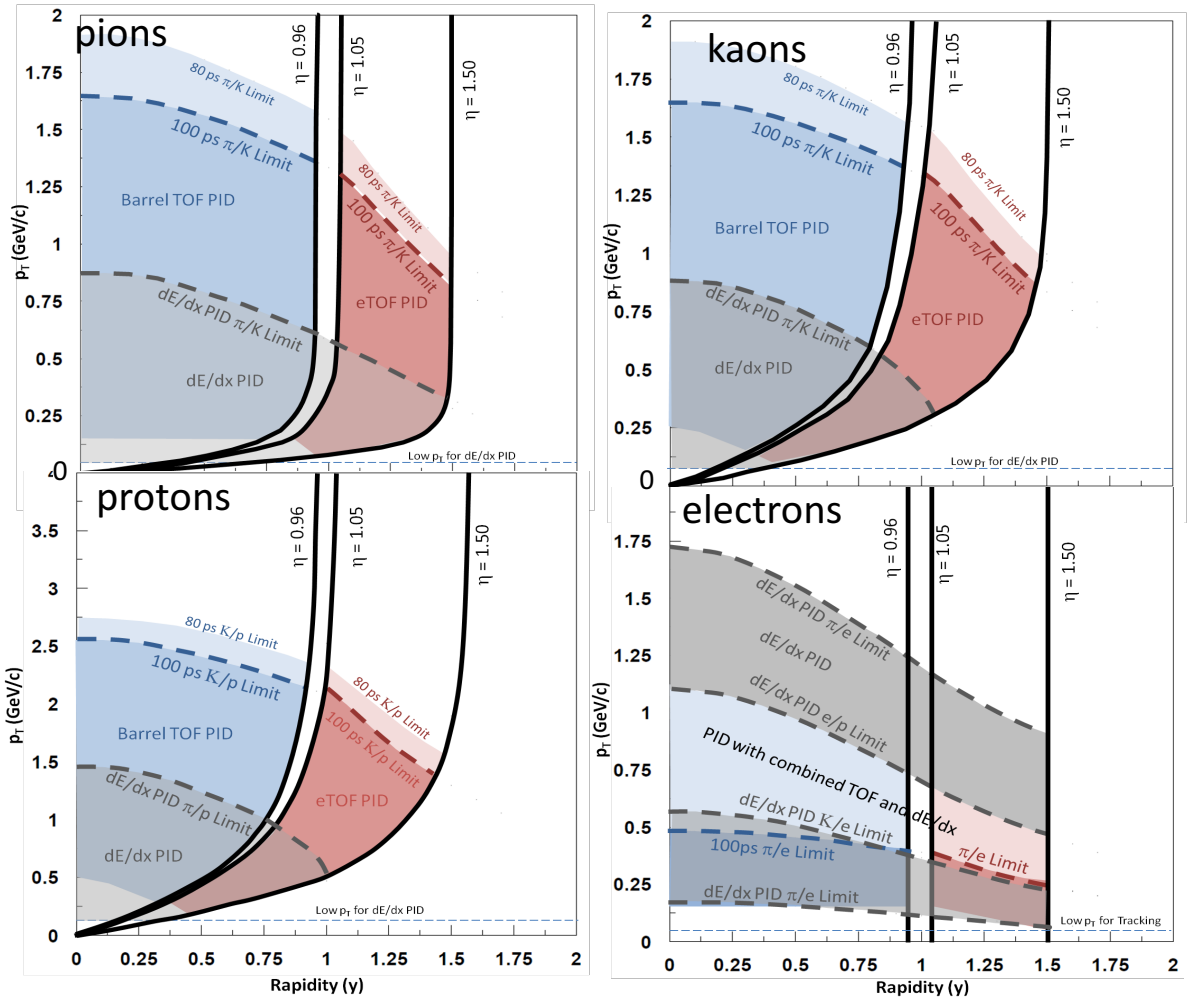
PID bTOF η : –0.9 to 0.9
eTOF η : –1.5 to –1.1

- FAIR Phase 0
  - Joint project between STAR and CBM
- Provides STAR with an endcap TOF for BES-II
  - Extend STAR's particle ID capabilities for π, K, p
- Improves the fixed target program
  - Extending the energy scan below 7.7 Gev with an internal fixed-target
  - Essential for mid-rapidity PID in Fixed-Target mode

eTOF PID Improvements

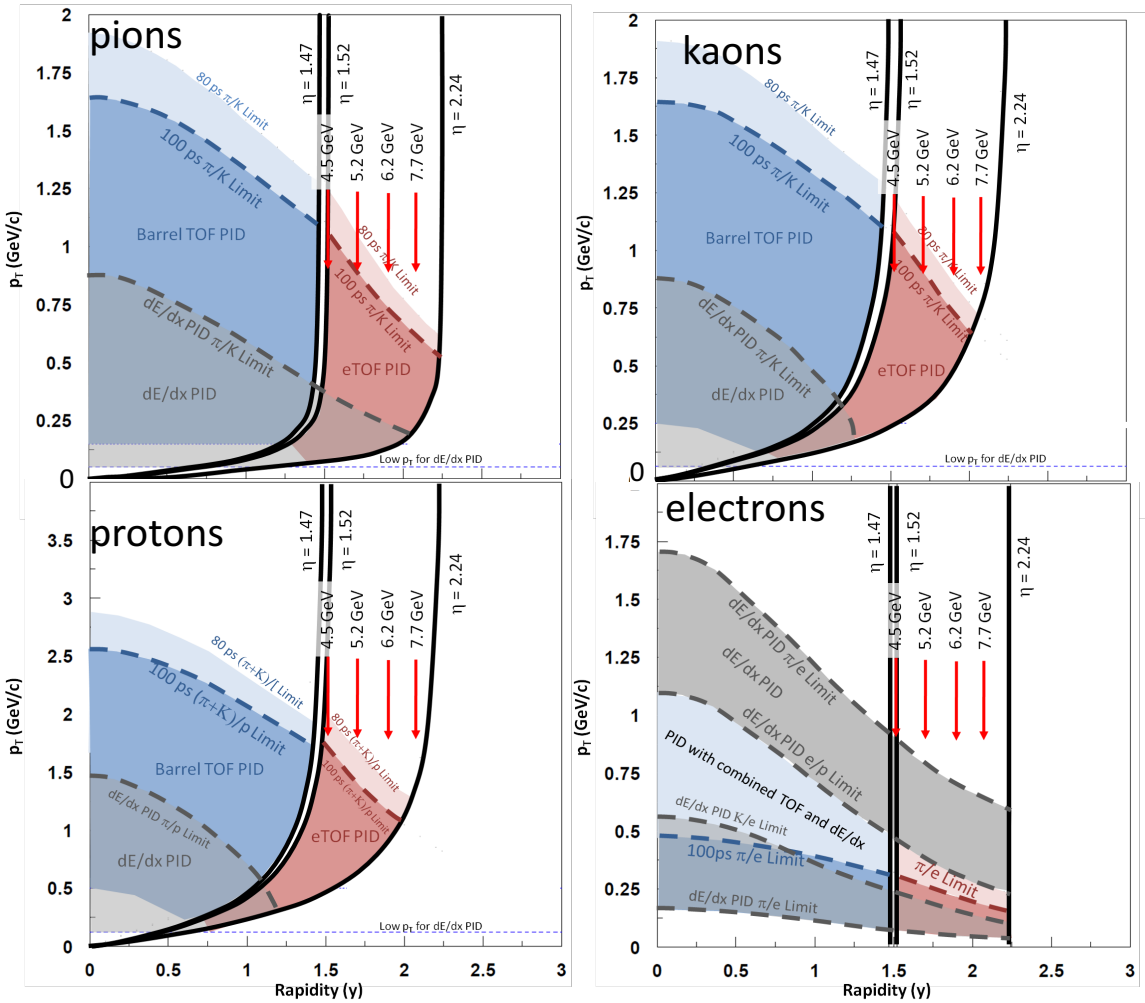
BTOF + eTOF acceptance

Collider Mode



Below 7.7 GeV

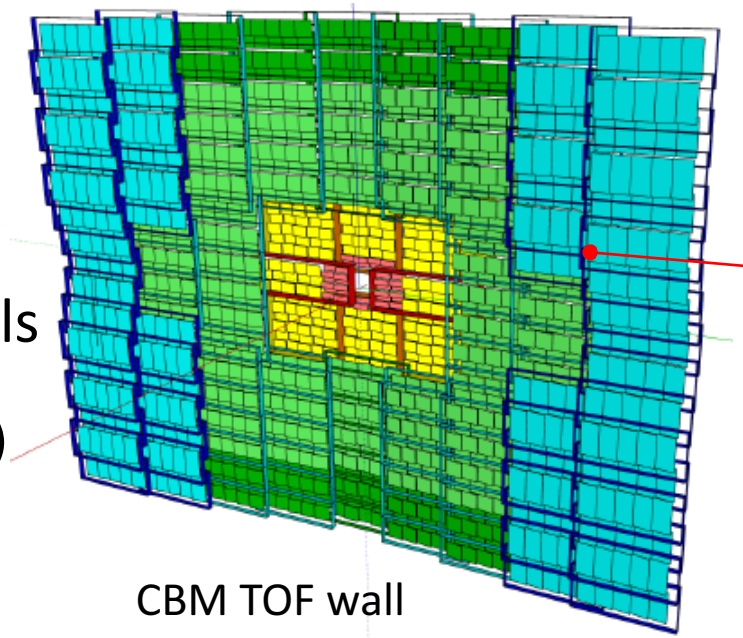
Fixed Target Mode

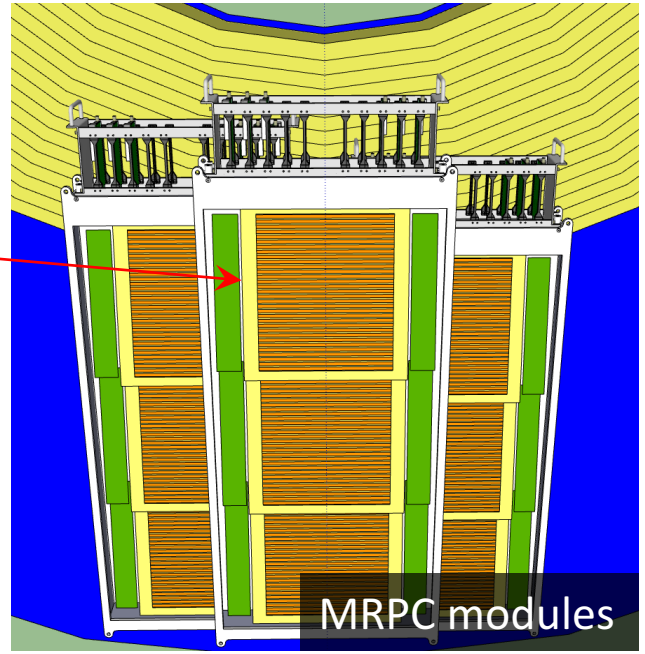


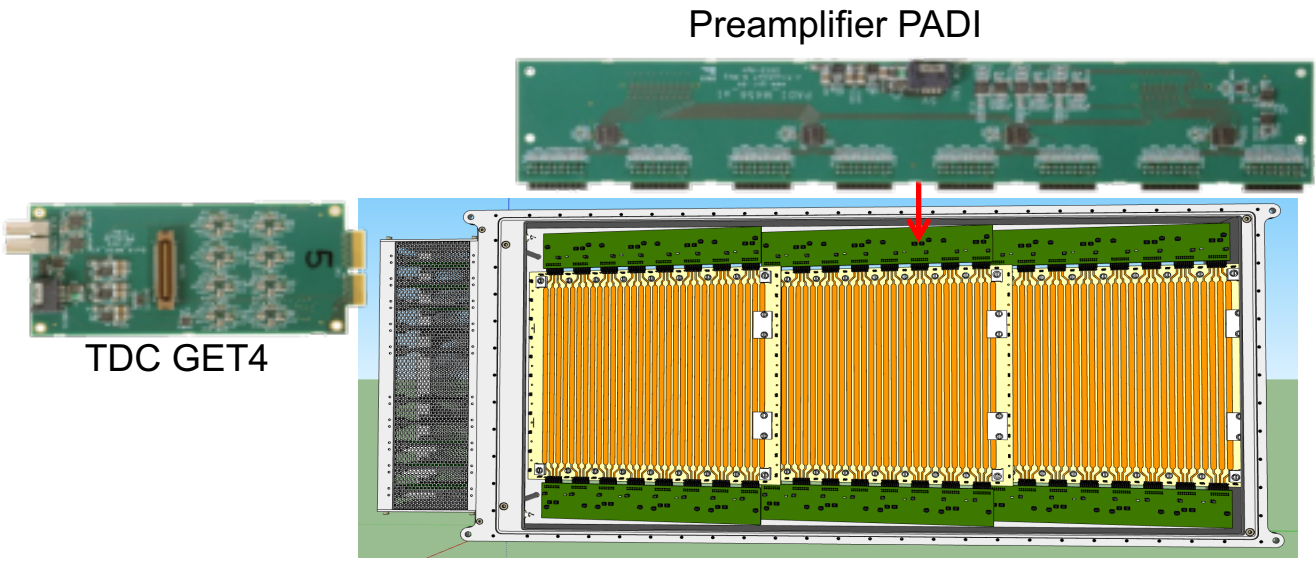
- Scan phase diagram below RHIC collision energy 7.7 GeV
- Equivalence of CM energy 3.0 to 7.7 GeV

eTOF Project Scope

- CBM TOF MRPC modules
  - 36 MRPC modules x 192 channels
  - Modified to fit STAR (shorten)
- Electronics
  - Pre-amp
  - RDO
  - Common readout board
- Complete installation in November 2018
- Decommission in July 2021



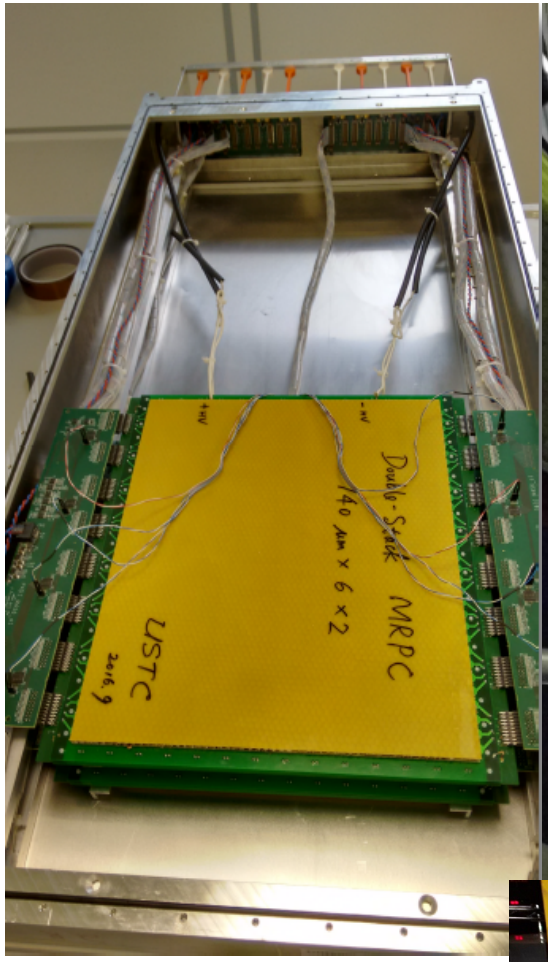




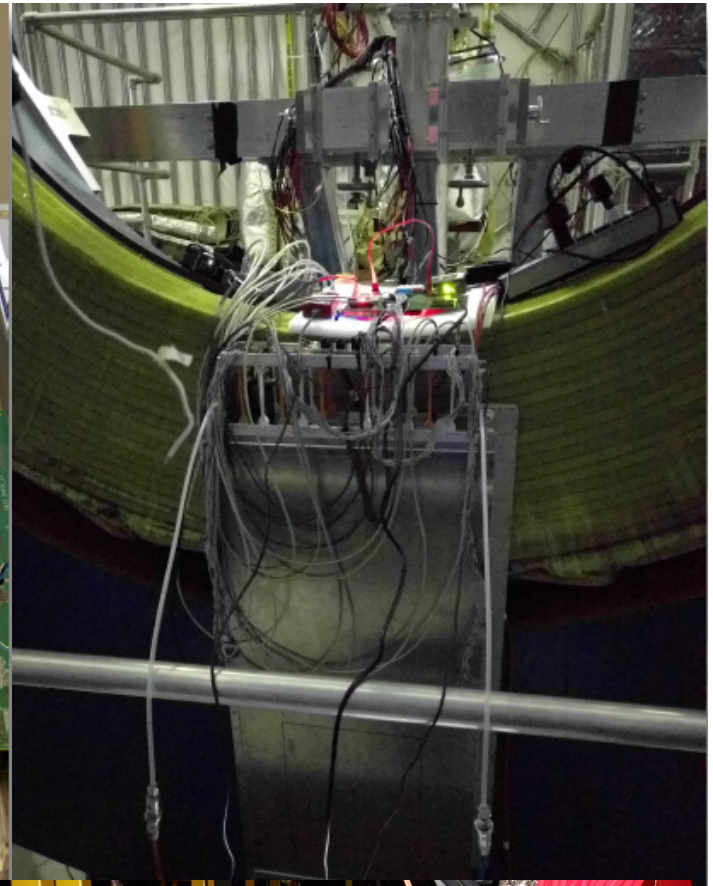
eTOF Run17 Operation

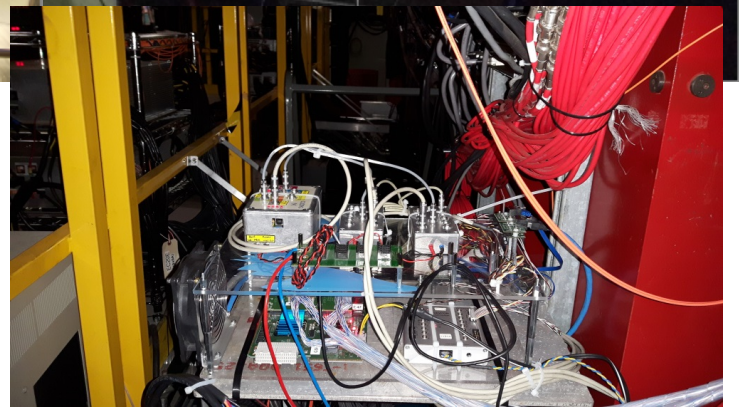
- successfully commissioned
  - Interface to STAR event builder
  - Interface to barrel TOF is stable
- Collected ~64M events with eTOF
- Run 17 engineering goals were met

Double Stack prototype

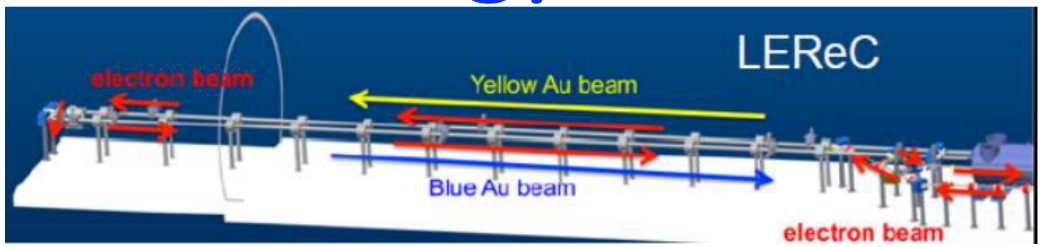


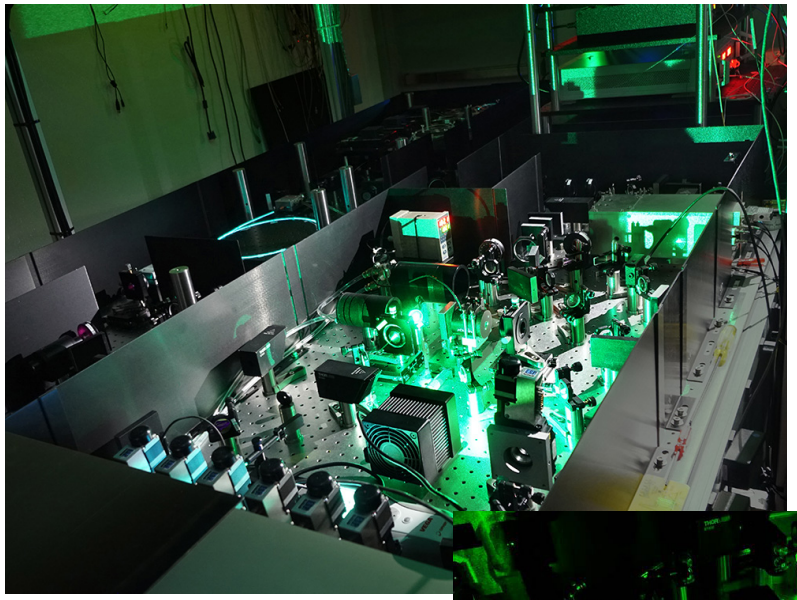
Module fixed at the pole-tip

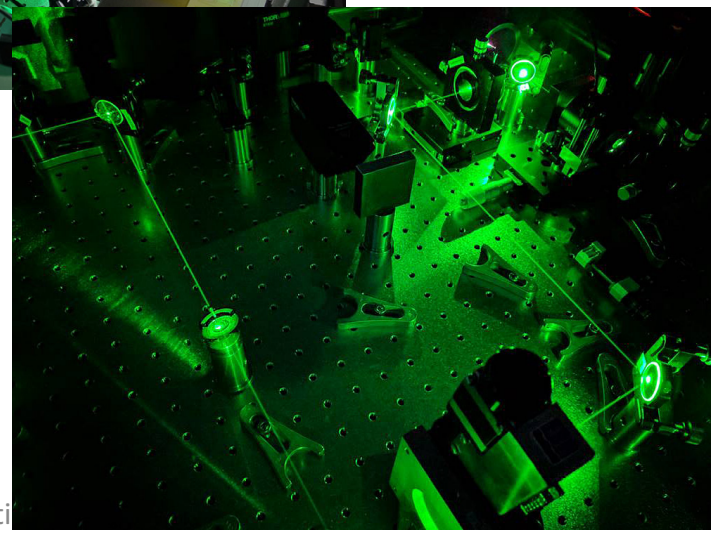




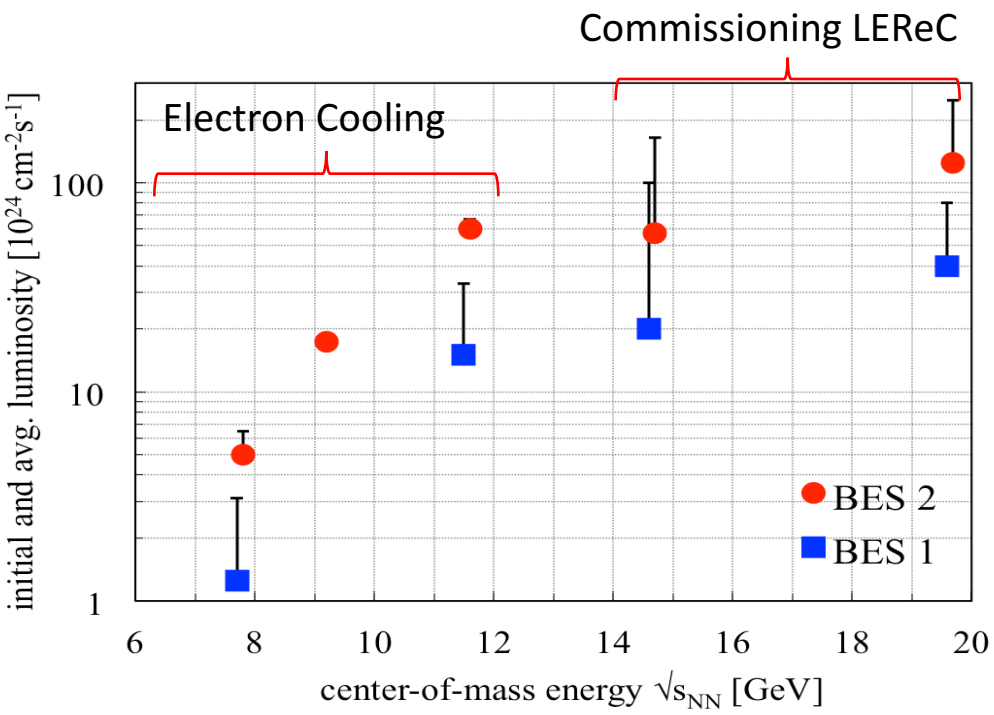
Low Energy RHIC electron Cooling (LEReC)

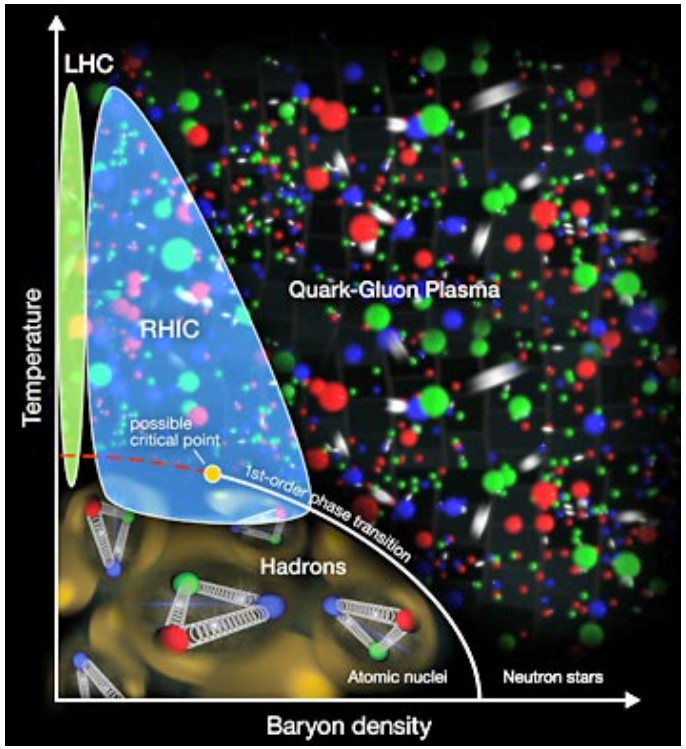




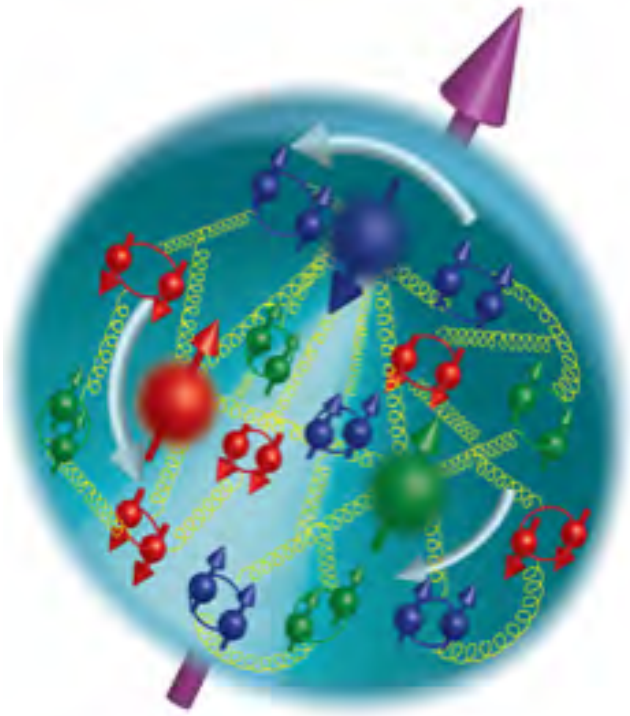


- Many results are statistics limited
- Take advantage of CAD experience gained in BES-I
- LEReC ➜ Improve event statistics




LHC
Temperature
RHIC
Quark-Gluon Plasma
possible
critical point
1st-order phase transition
Hadrons
Atomic nuclei
Neutron stars
Baryon density

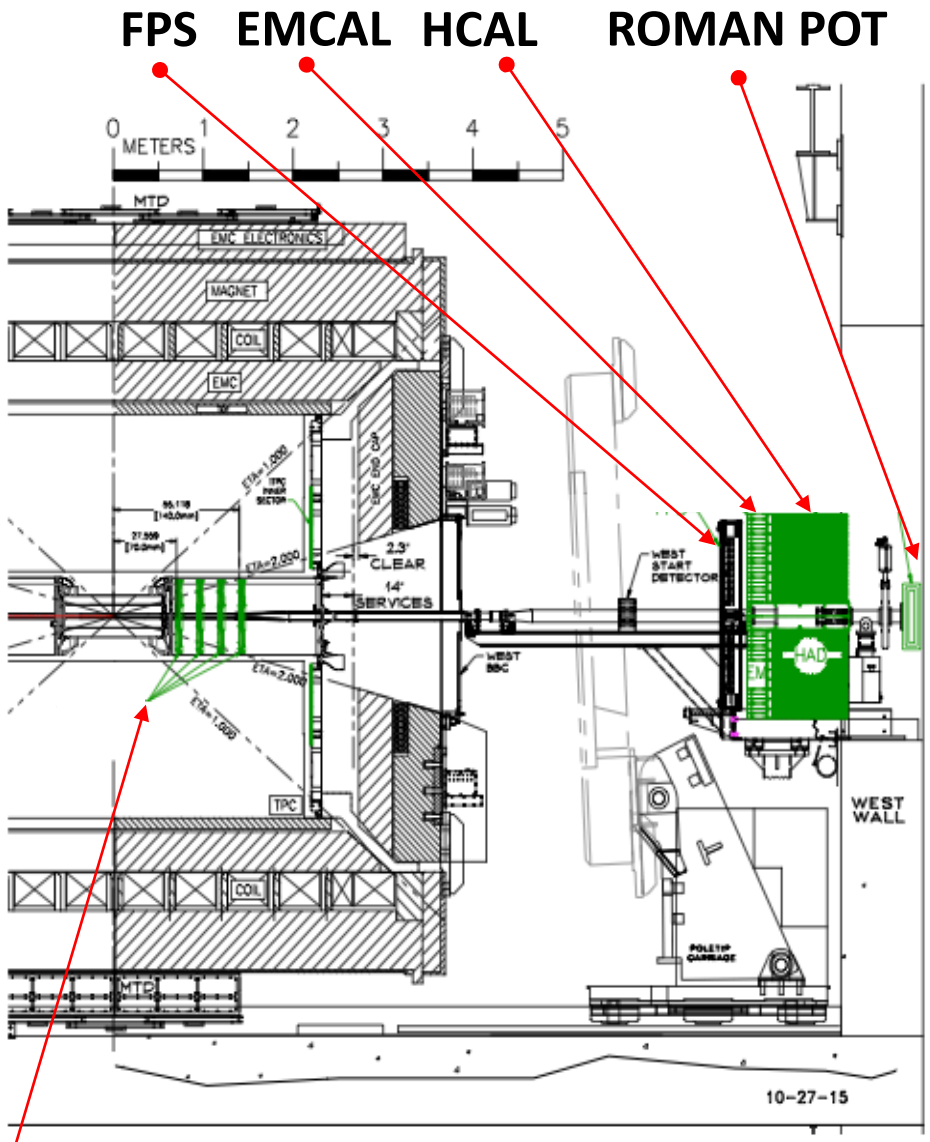
BES ➛ Cold QCD



STAR-Cold QCD Detector Upgrades

$\sqrt{s}$ (GeV)	Scientific Goals	Observable	Required Upgrade
$p^{\uparrow}p$ @ 200	Subprocess driving the large A_N at high x_F and η	A_N for charged hadrons and flavor enhanced jets	Forward instrum. ECal+HCal+Tracking
$p^{\uparrow}Au$ @ 200	What is the nature of the initial state and hadronization in nuclear collisions Clear signatures for Saturation	R_{pAu} direct photons and DY Dihadrons, γ-jet, h-jet, diffraction	Forward instrum. ECal+Hcal+Tracking
$p^{\uparrow}Al$ @ 200	A-dependence of nPDF, A-dependence for Saturation	R_{pAl}: direct photons and DY Dihadrons, γ-jet, h-jet, diffraction	Forward instrum. ECal+HCal+Tracking
$p^{\uparrow}p$ @ 510	TMDs at low and high x	A_{UT} for Collins observables, i.e. hadron in jet modulations at $\eta > 1$	Forward instrum. ECal+HCal+Tracking
$\vec{p}\vec{p}$@ 510	$\Delta g(x)$ at small x	A_{LL} for jets, di-jets, h/γ-jets at $\eta > 1$	Forward instrum. ECal+HCal

arXiv:1602.03922



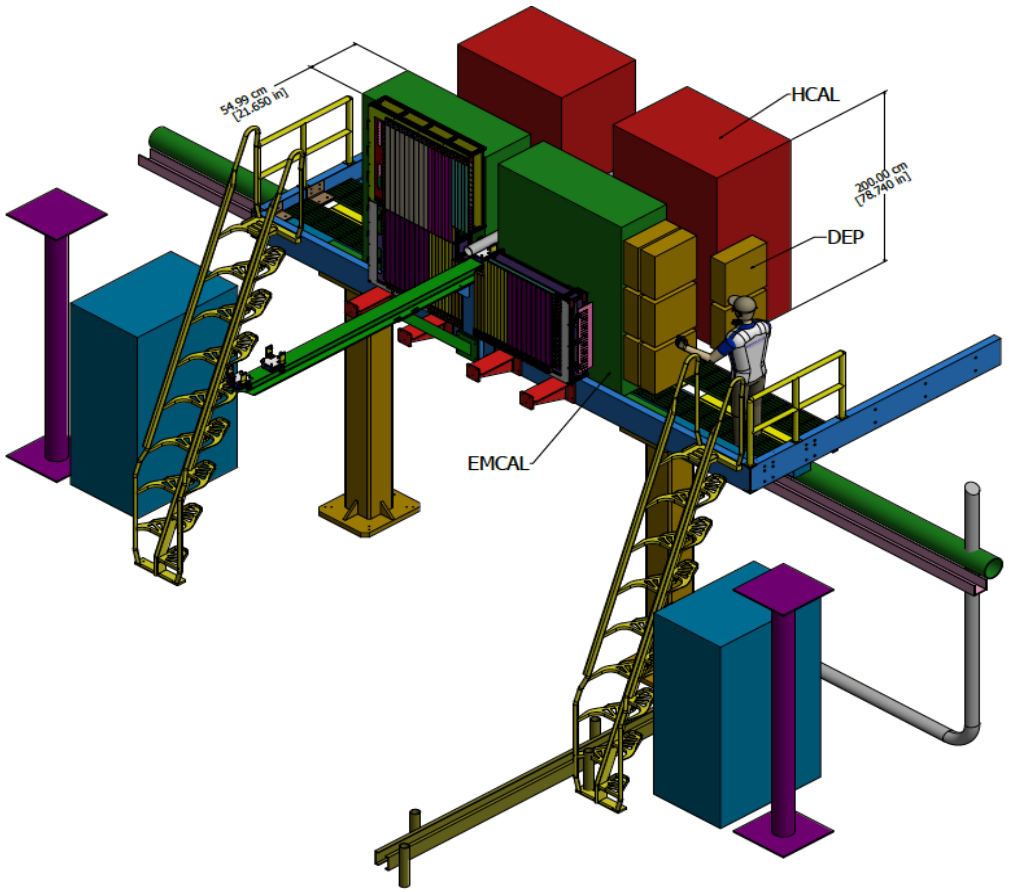
Forward Tracking System

Forward Calorimeter System (FCS)

- Part of STAR and EIC Detector R&D
- Add to STAR at rapidity $2.5 < \eta < 4.2$
  - **EM calorimeter**

    Reuse PHENIX PbSC Ecal
  - **Hadronic calorimeter**

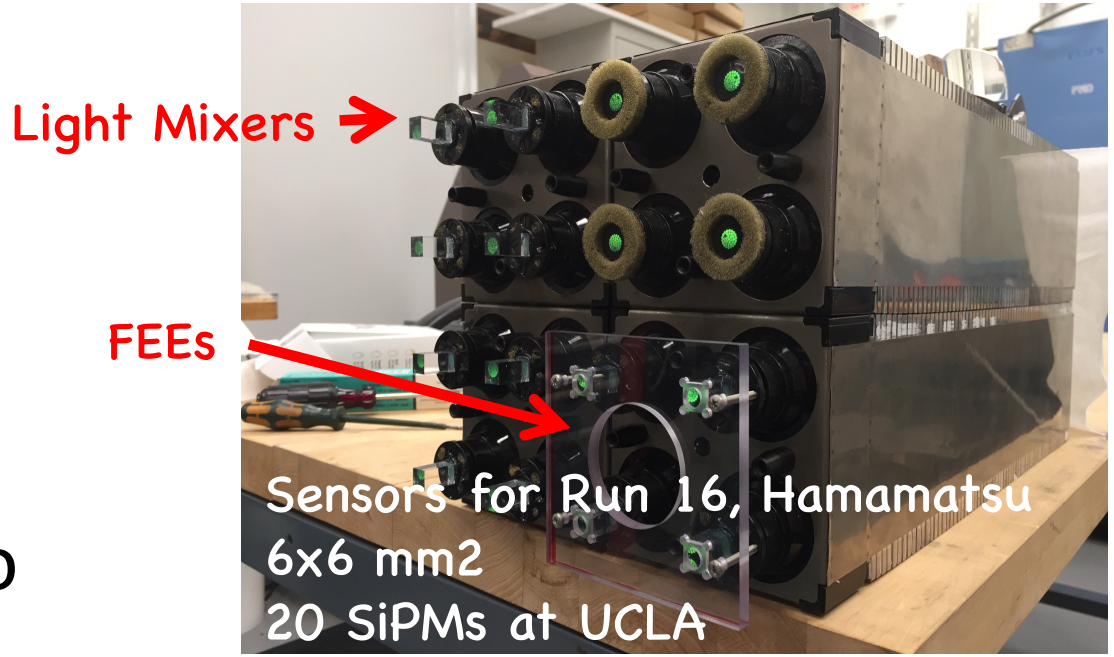
    Iron-scintillator plate sampling
  - Same readout for both



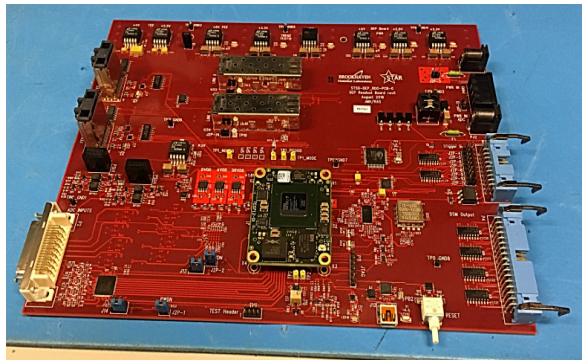
Detector	pp and pA	AA
ECal	~10%/√E	~20%/√E
HCal	~60%/√E	---

FCS' EmCal in STAR Run 17

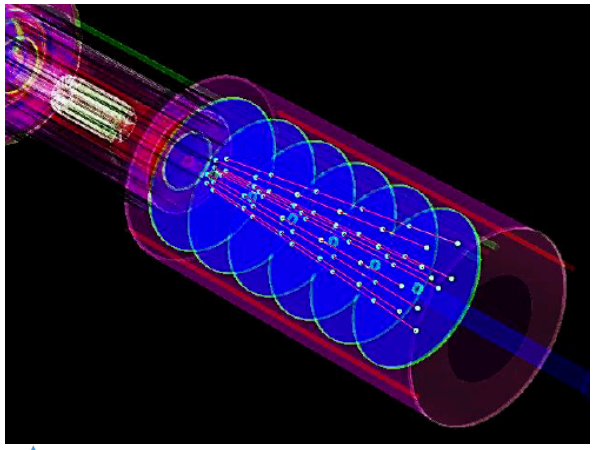
- Tested four components:
  1. Sampling Calorimeter
  2. FEEs
  3. Sensors (with help from EIC R&D)
  4. Digitizers
- FEEs and DEP was fully integrated to STAR
- For Run18
  - Large scale EMcal prototype
  - 2nd iteration of FEEs and DEP
  - HCAL towers

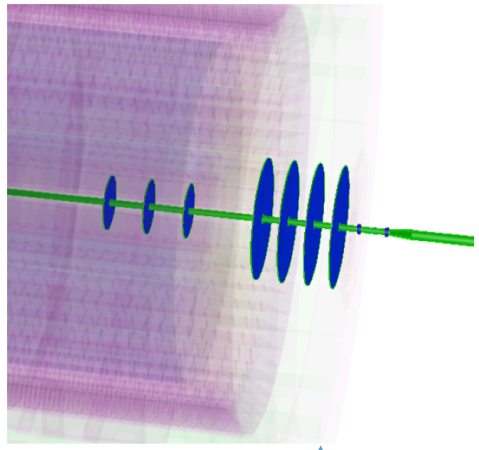


DEP:
Detector Electronics Platform



Forward Tracking System (FTS)





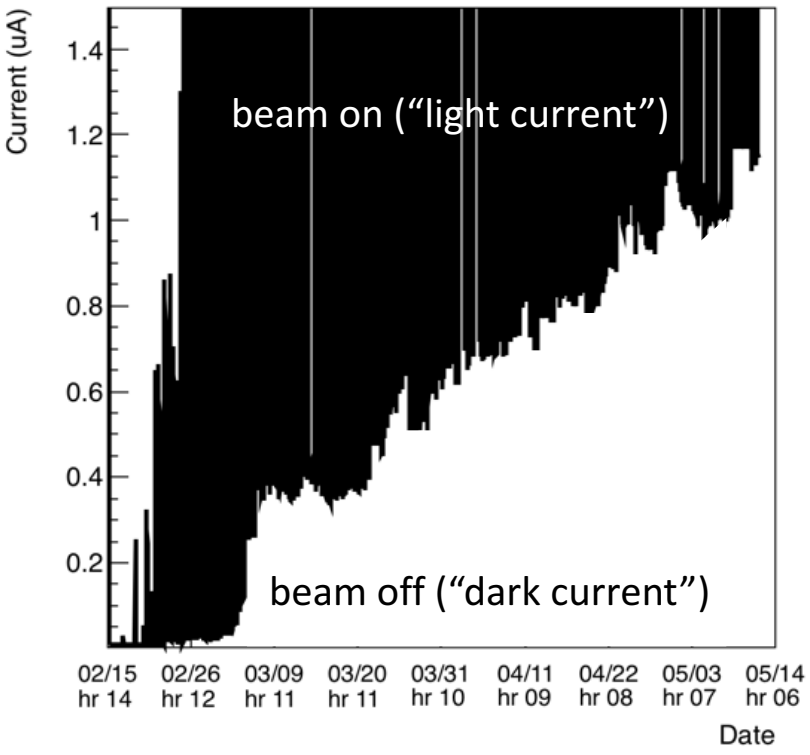
- Two Configurations:
  - Silicon mini-Strip Detectors

  or
  - Si + Small-strip Thin Gap Chambers
- Low material budget in detector acceptance

- **Forward transverse spin asymmetry measurements** for p+p and p+A **requires distinguishing h^+/h^- for p upto 80 GeV/c**
- Forward Drell-Yan measurements require excellent eID/γID to suppress hadron background
- **Improves eID** by comparing charged particles from FCS
- **Improves γID** by identifying hits from charged particles

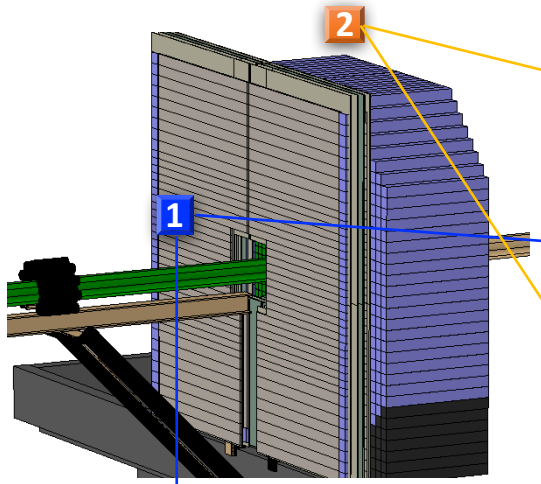
SiPM Performance in STAR Upgrades

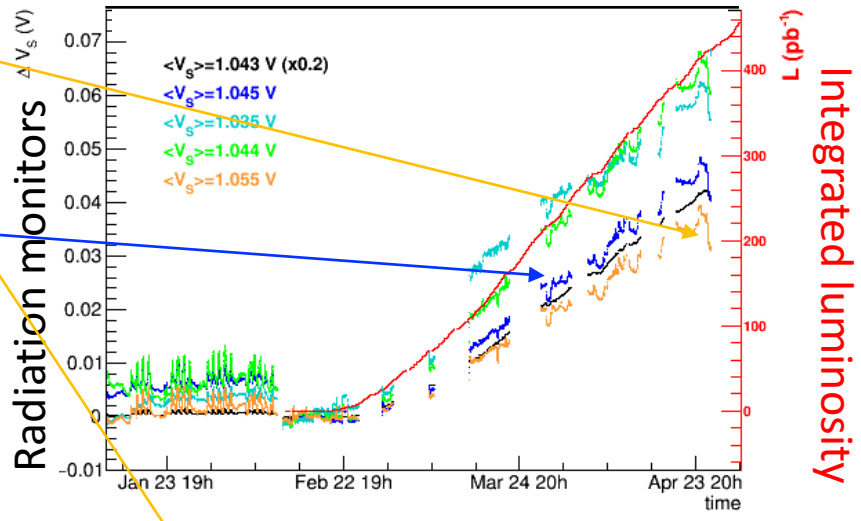
EPD SiPM Dark Current

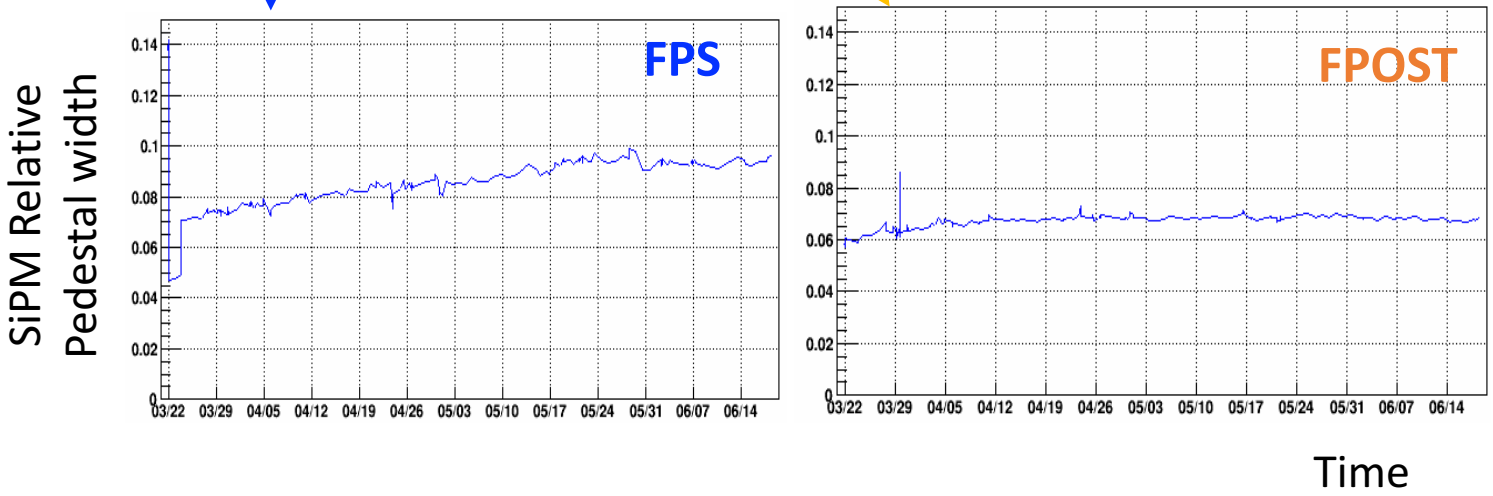


- Present dark current ~1 µA
- SiPMs are good for ~15 µA
- Much smaller radiation damage in Au+Au

FPS/ FPOST Pedestals







Summary

- **iTPC**, **EPD** and **eTOF** upgrades significantly extends Rapidity and p_T coverage of STAR
- **eTOF** improves PID
- **EPD** provide excellent Event Plane Resolution and Centrality Estimation out side of mid rapidity
- **LEReC** together with STAR detector upgrades provide good control of statistical fluctuations and systematics

BES I ➸ BES II

Qualitative Statements

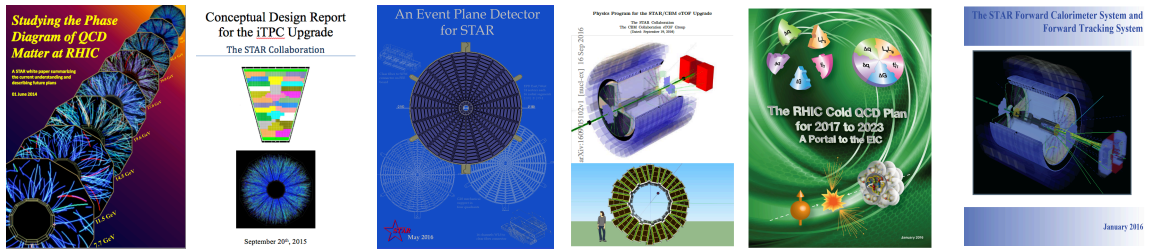
to

Quantitative Measurements

- Forward upgrades (FCS & FTS)

Probe

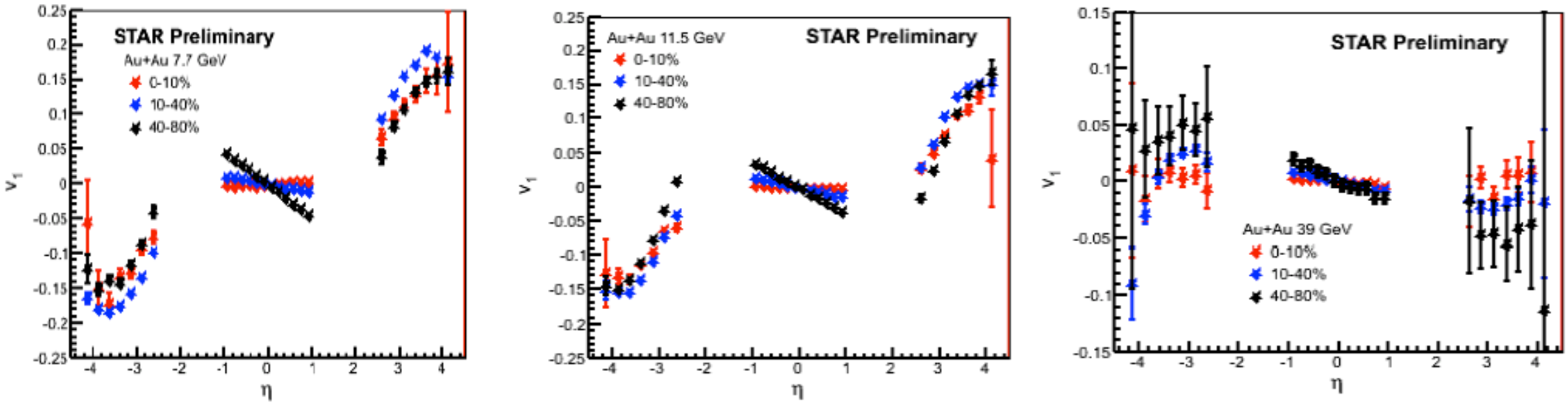
low-*x* region



Backup

Directed Flow of Charged Particles

Y. Pandit, SQM 2011



Forward TPC (FTPC) 2.5 < |eta| 4.0

eTOF Physics Improvements

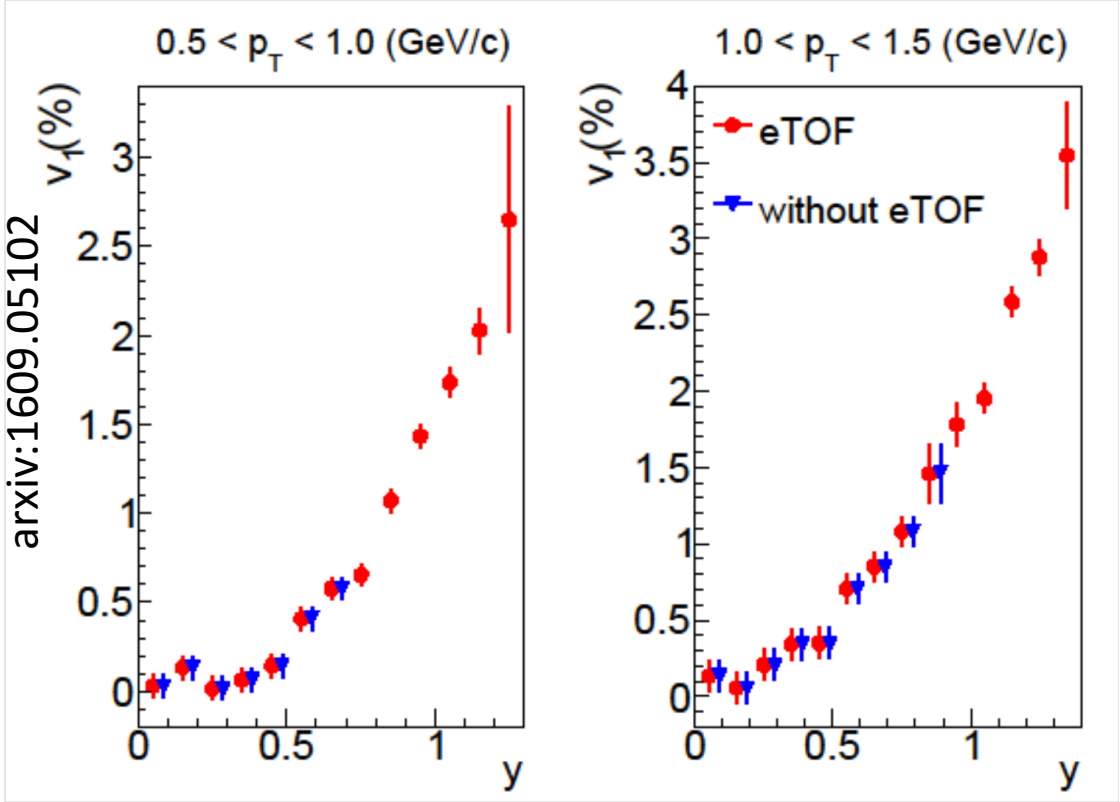
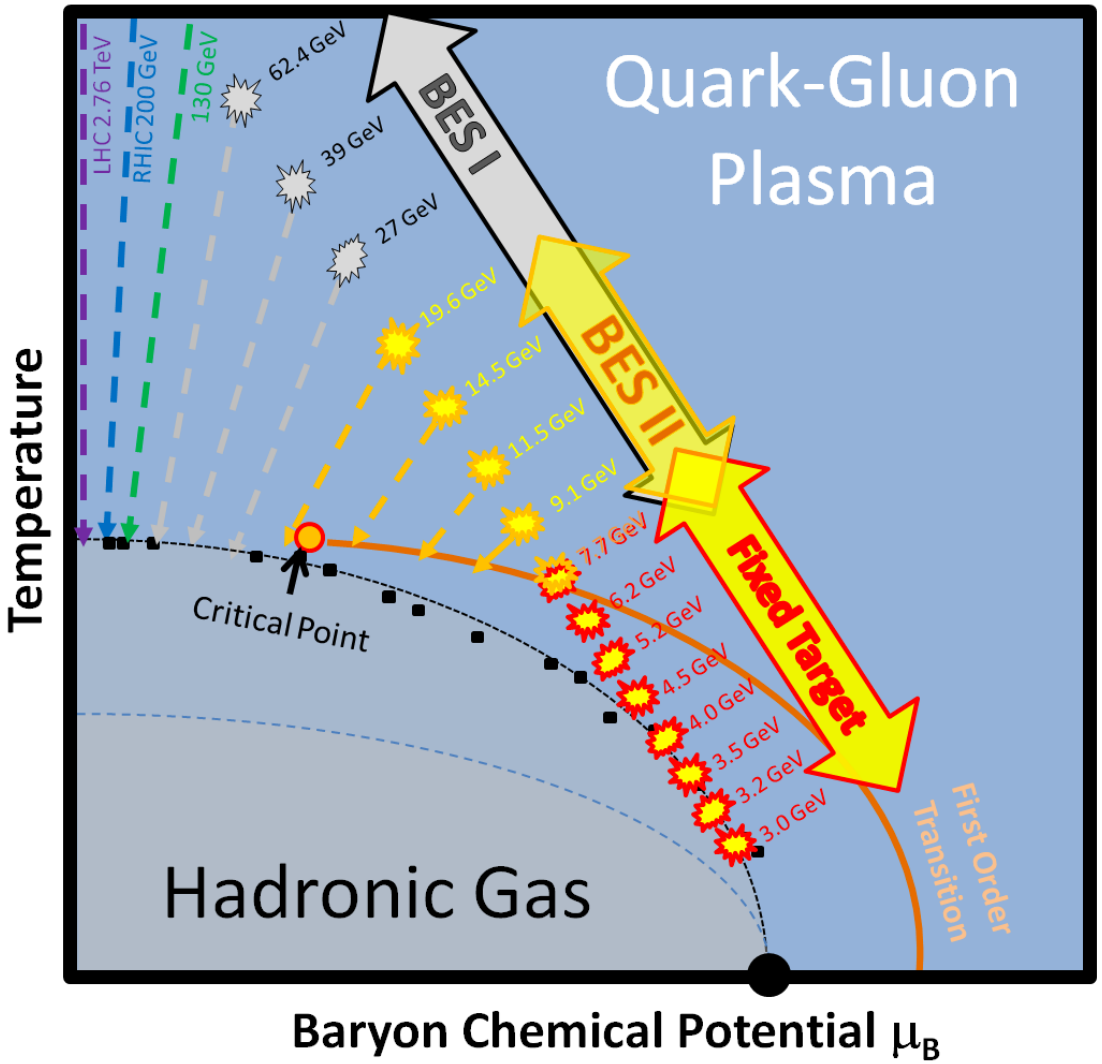


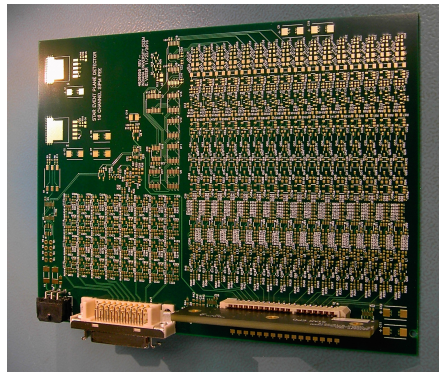
FIG. 8. Proton directed flow as a function of rapidity for minimum-bias Au + Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV, based on the UrQMD model. The simulated $v_1(y)$ in two intervals of p_T is compared between the acceptance of the STAR iTPC with the existing TOF barrel (blue triangles) and the upgraded acceptance after addition of the eTOF (red circles).

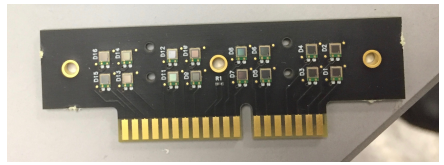
BES Collider and Fixed Target Energy(CM) range

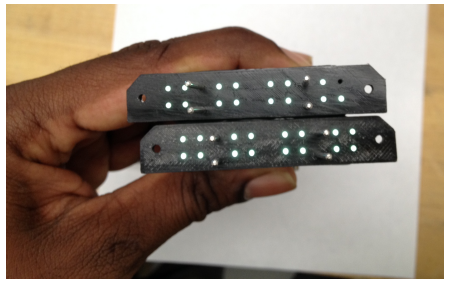


EPD Project Scope

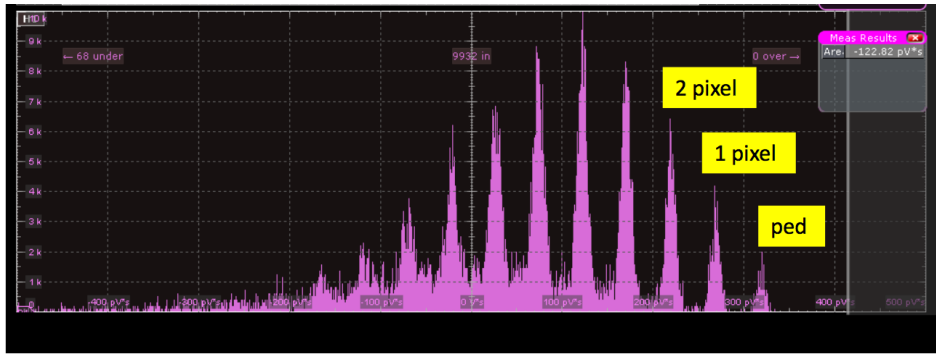
- Super Sectors (1/12th of a wheel)
  - 1.2 cm Eljen scintillator wedges, milled to form 31 tiles
  - optically separated by TiO_2-loaded epoxy
  - Construction is in progress at OSU
- Coupling to electronics
  - 5.5-m-long Clear fiber bundles
  - All connector components custom-designed and 3D printed
  - Construction is in progress at Lehigh University
- Electronics
  - Hamamatsu SiPMs
  - Excellent resolution, linearity
  - About 50 photoelectrons per MIP (MPV)
- Engineering Run 17
  - 1/8th of the detector installed
- **EPD will be ready for Run 18**



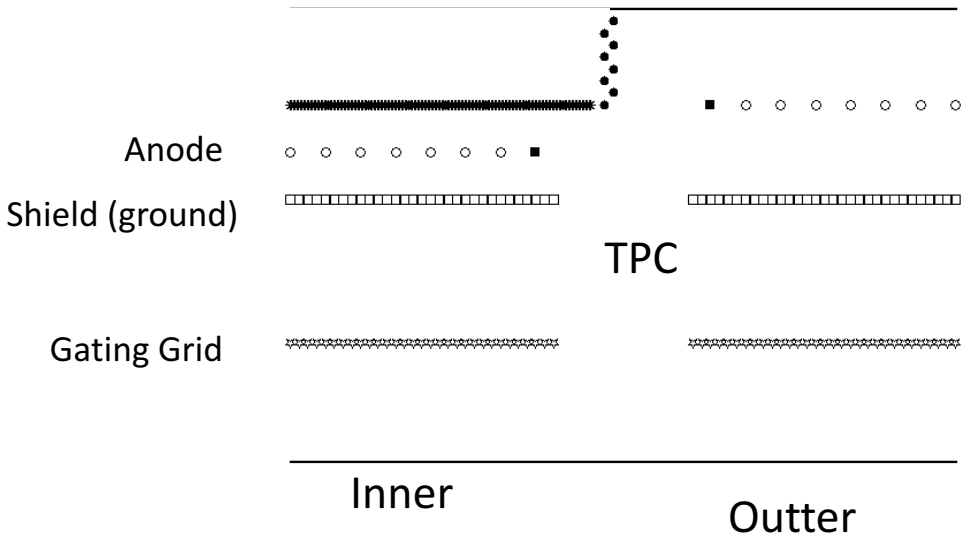


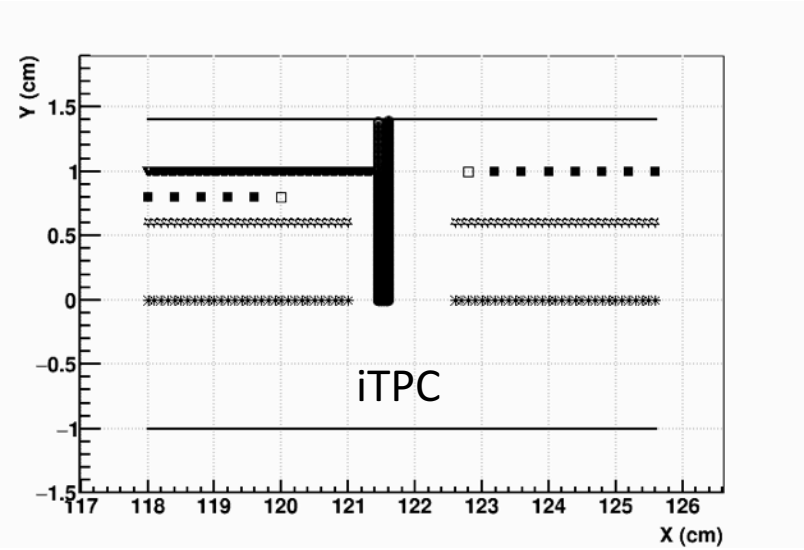


FEEs designed by G. Visser



iTPC





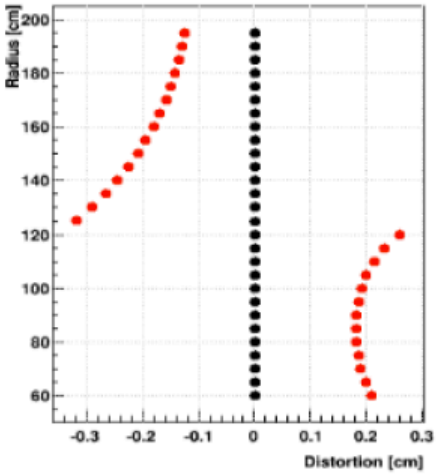
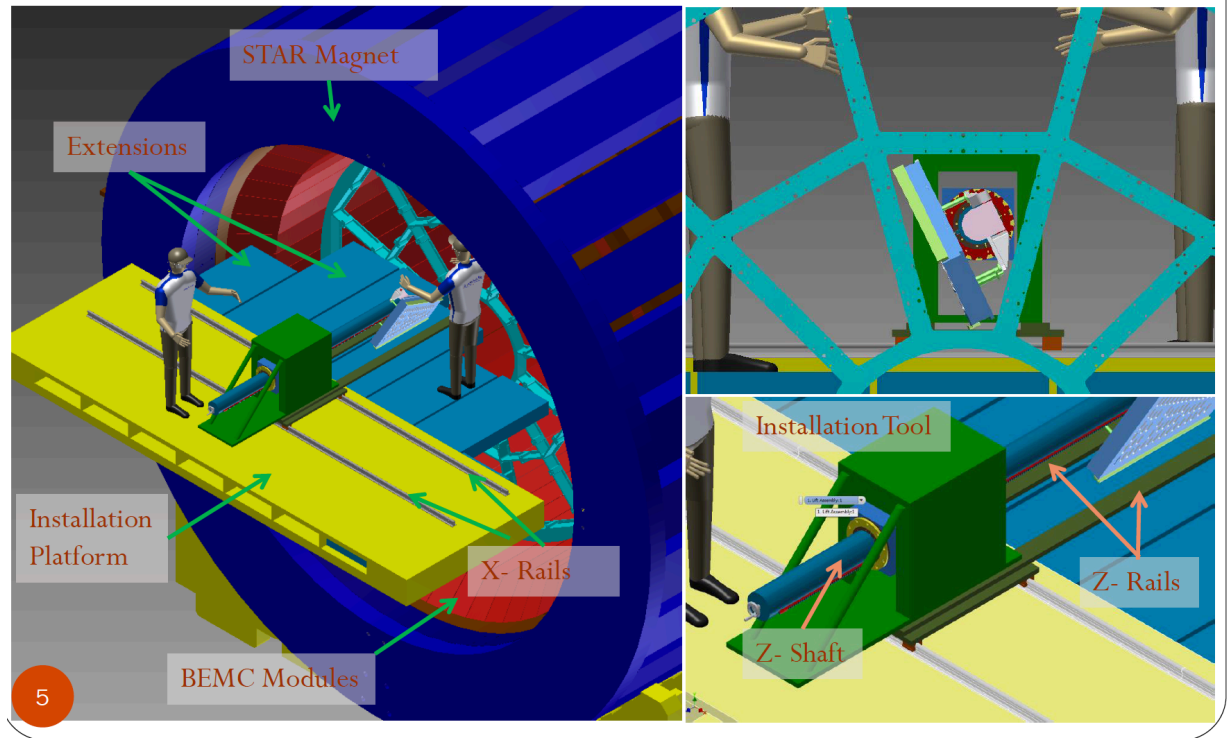
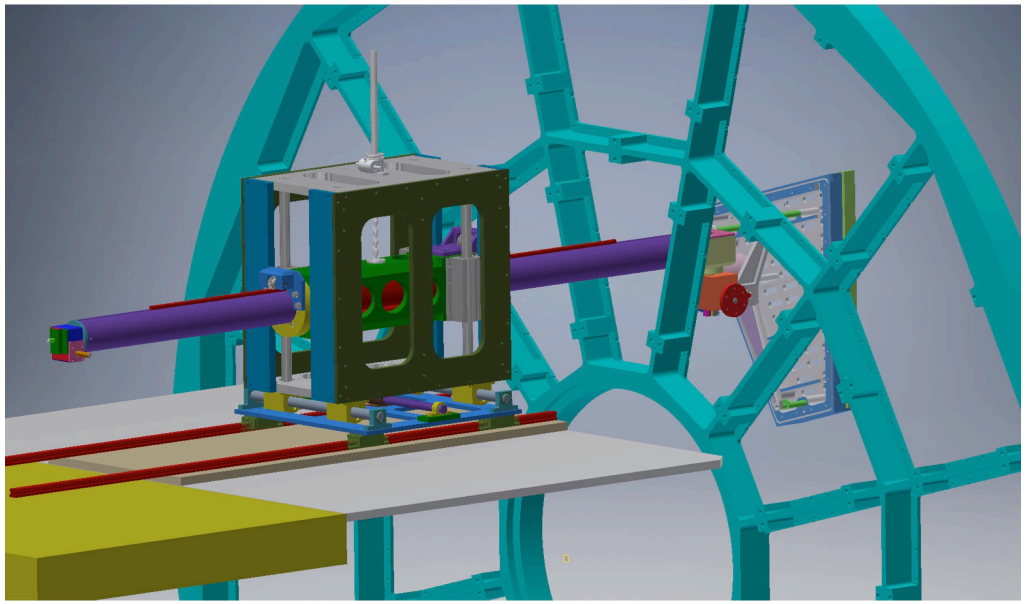


Figure 29: Distortions at the junction between the inner and outer gated grids. The vertical axis (cm) shows the position of a pad row (indicated by dots) in the radial direction. The horizontal axis is in millimeters. The black dots show the expected hit pattern for an infinite momentum track. The red dots show the observed hit pattern due to charge leaking out of the gap between the inner and outer gated grids.

iTPC

Cartesian Installation Tool Design





EPD

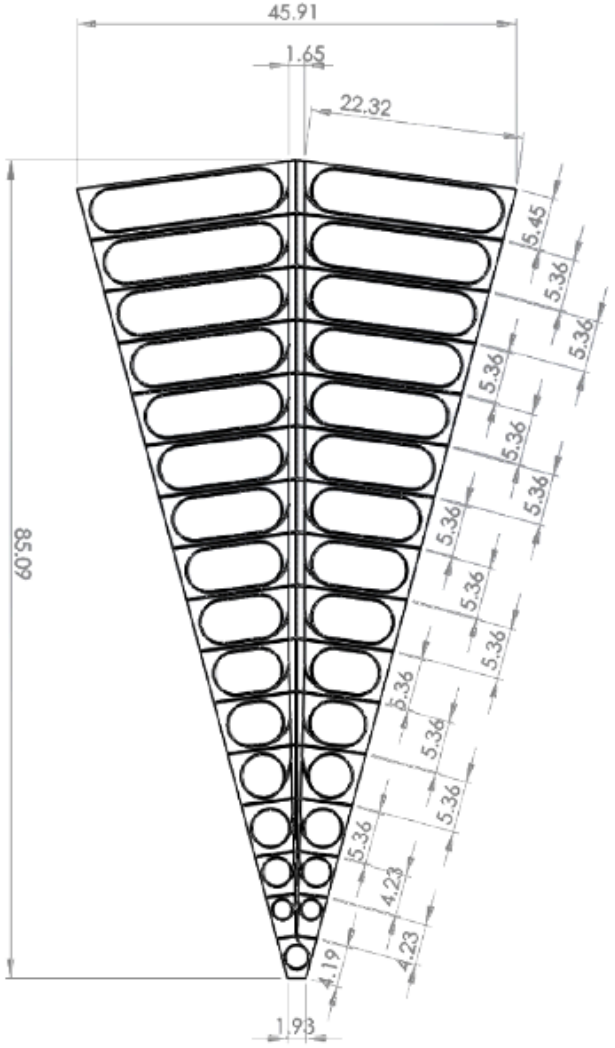
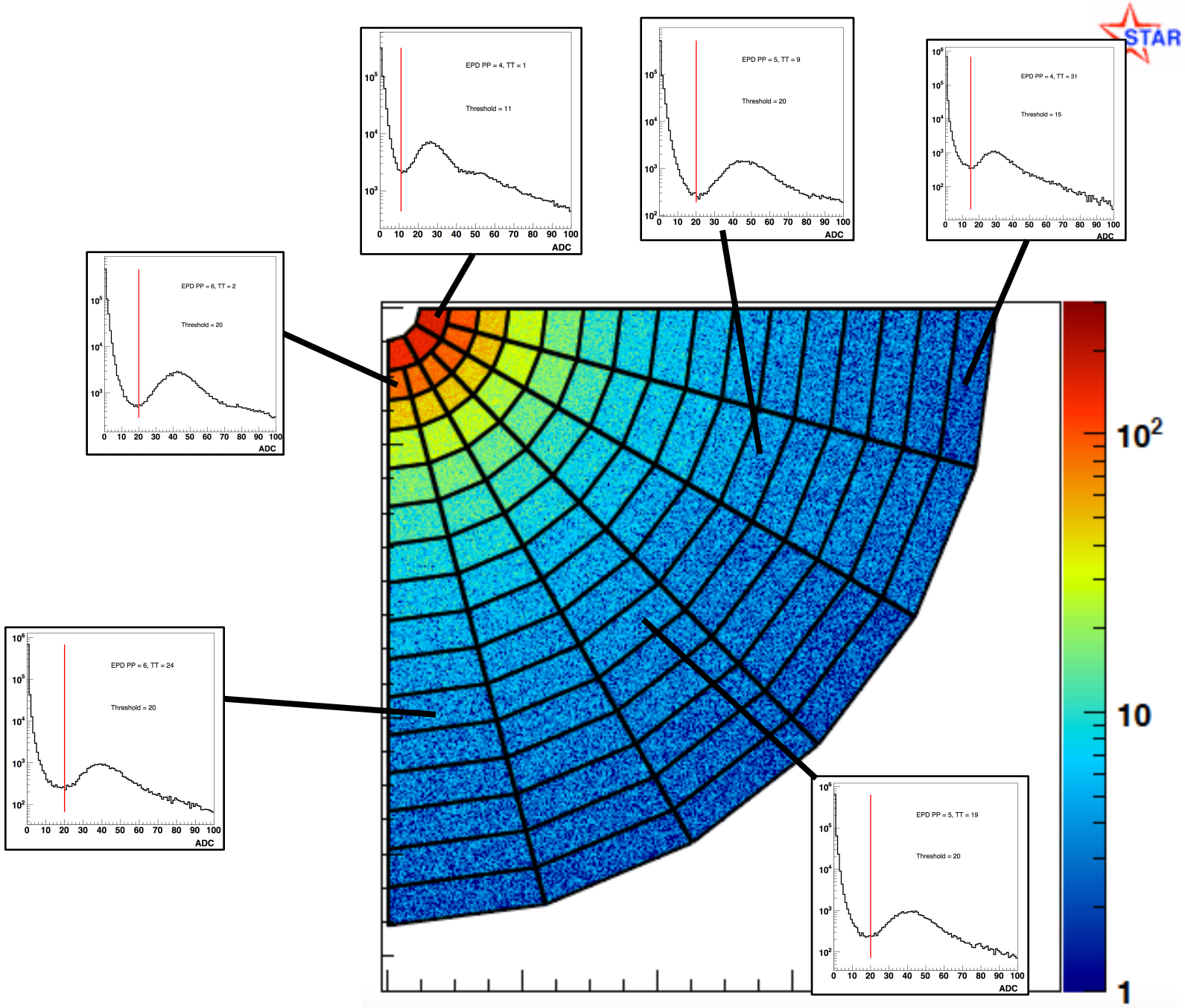



Figure 55: Schematic drawing of the super-sector with dimensions in cm.