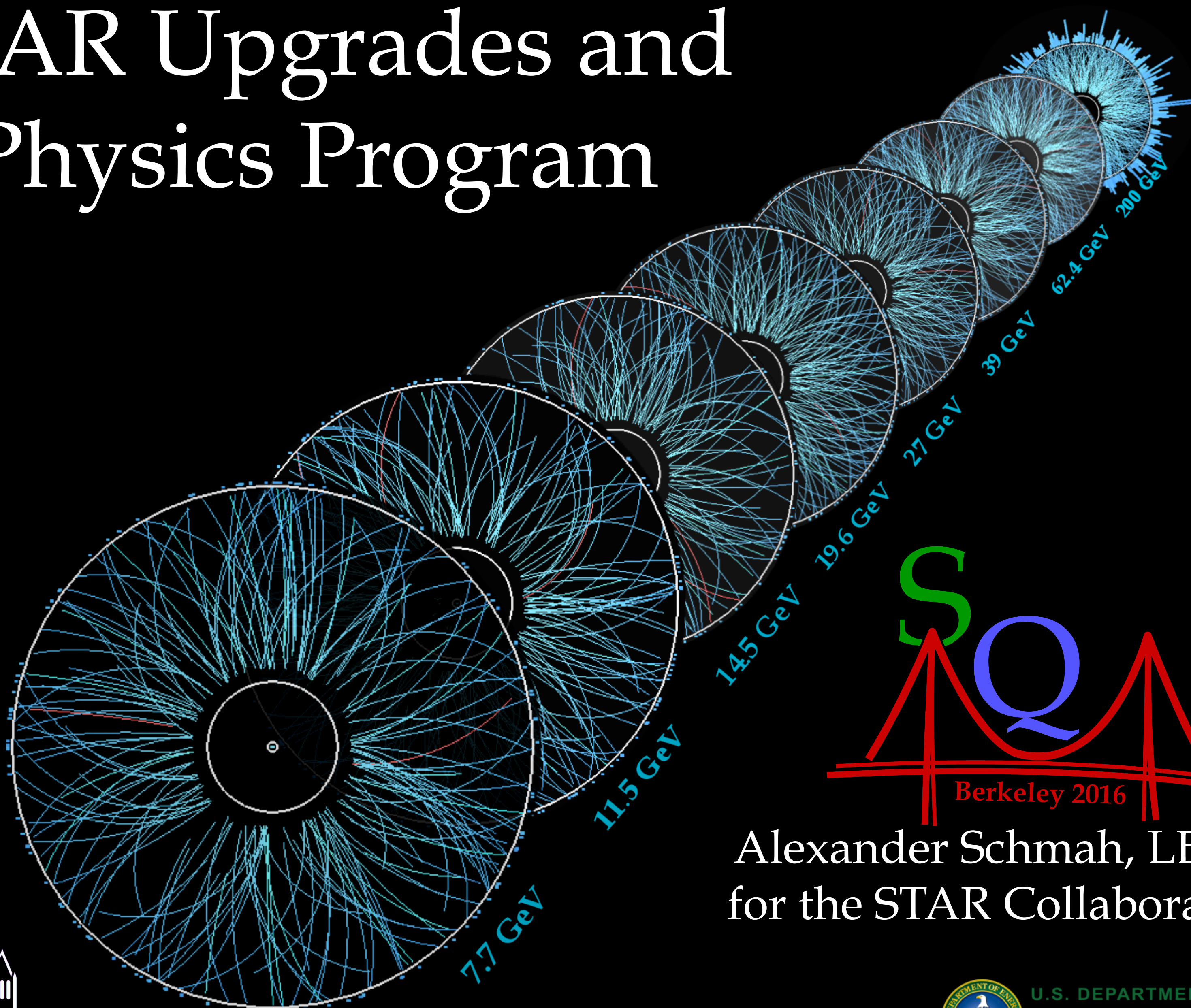
STAR Upgrades and Physics Program



SQM
Berkeley 2016

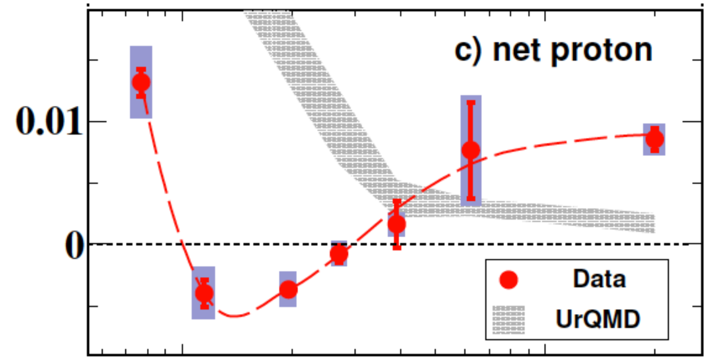
Alexander Schmah, LBNL,
for the STAR Collaboration

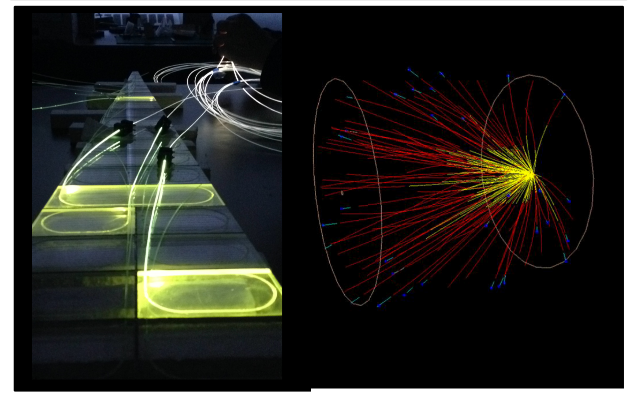
Berkeley Lab

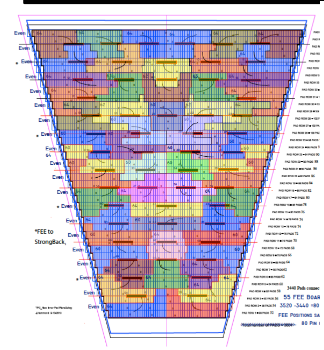
U.S. DEPARTMENT OF ENERGY

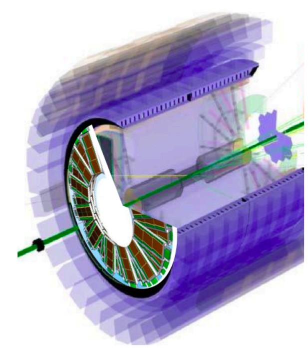
Outline

- Introduction to the Beam Energy Scan and future developments
- The **i**nner **TPC** upgrade
- The **e**ndcap **T**ime-**O**f-**F**light
- The **E**vent **P**lane **D**etector
- Upgrades for 2020+ and Physics Program







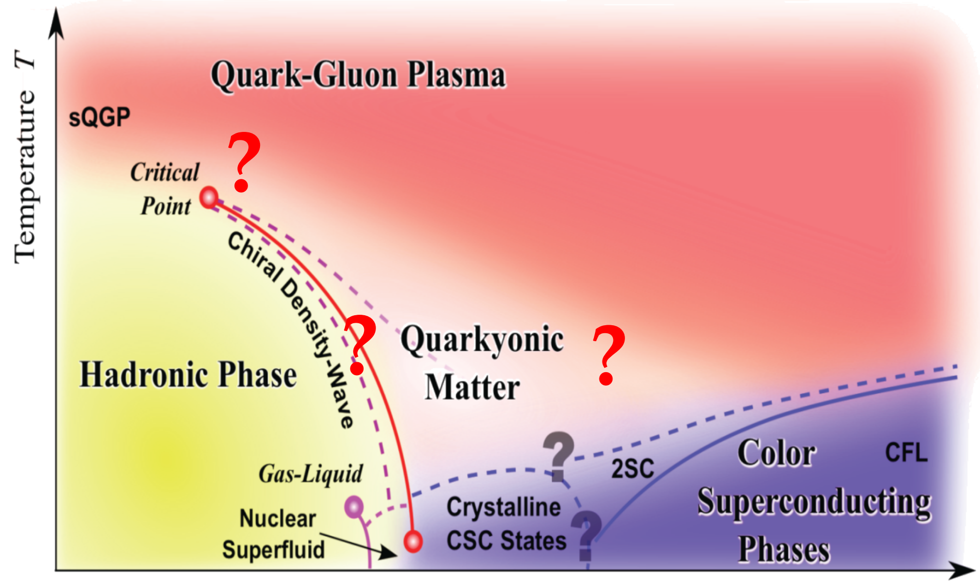


Why do a Beam Energy Scan?

Basic motivation: Exploration of the QCD phase diagram

- Hadron gas phase at low T and/or μ_B
- We expect from QCD lattice calculations a cross over at high energies
- QGP at high T and/or μ_B
  → R_{CP}, NCQ scaling of v_2,...
- Phase transition?
  → HBT, v_1 analyses
- Critical point?
  → Fluctuation analyses (net-protons)
- Chiral symmetry restoration?
  → Di-leptons

Rept.Prog.Phys. 74 (2011)



Courtesy of K. Fukushima & T. Hatsuda

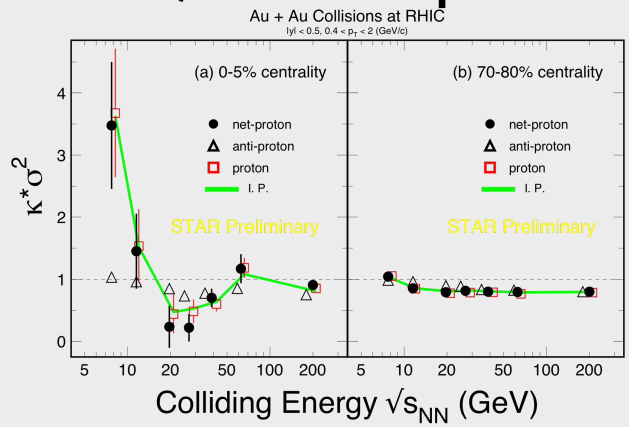
? QCD critical point

? QCD phase transition

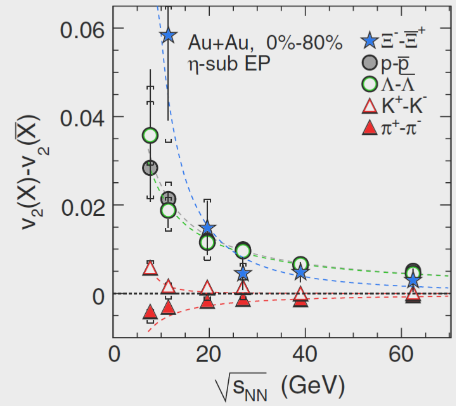
? Properties of QGP phase

Selected Results from BES-I

QCD critical point



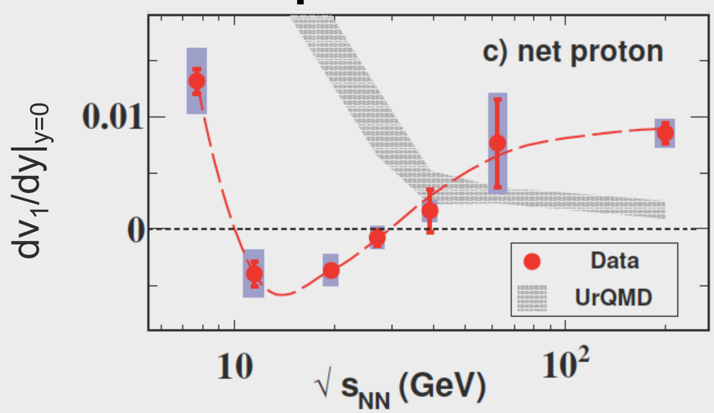
Bulk behavior



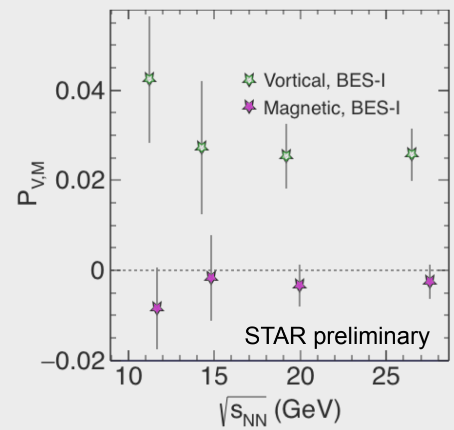
Phys. Rev. Lett. 110, 142301 (2013)

PRL, 112 (2014) 162301

QCD phase transition



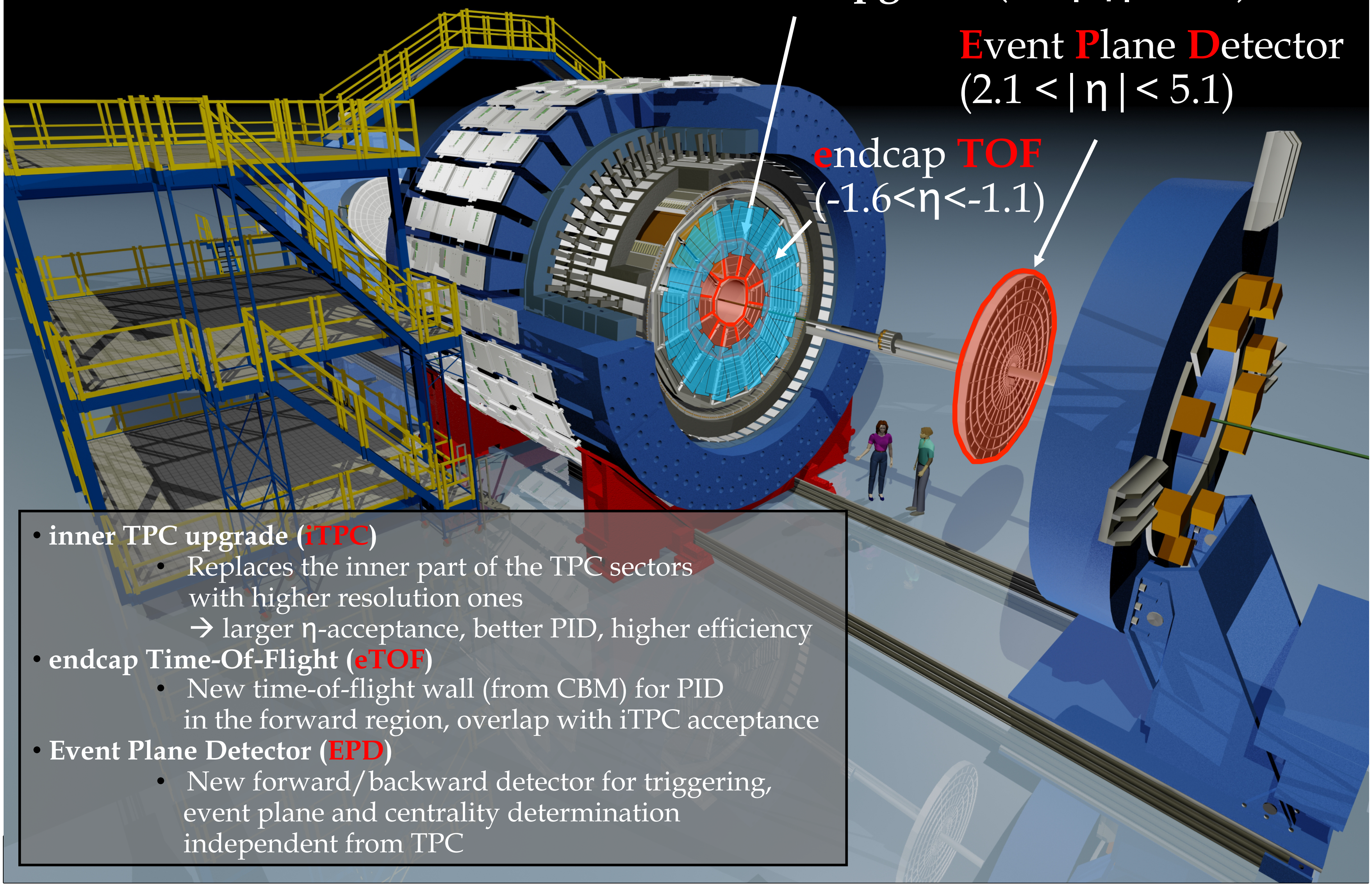
Chiral Vortical Effect



See talk by Mike Lisa

- Measurements are limited by statistics and systematics
  → BES-II with up to 10 times more statistic per energy and new detectors

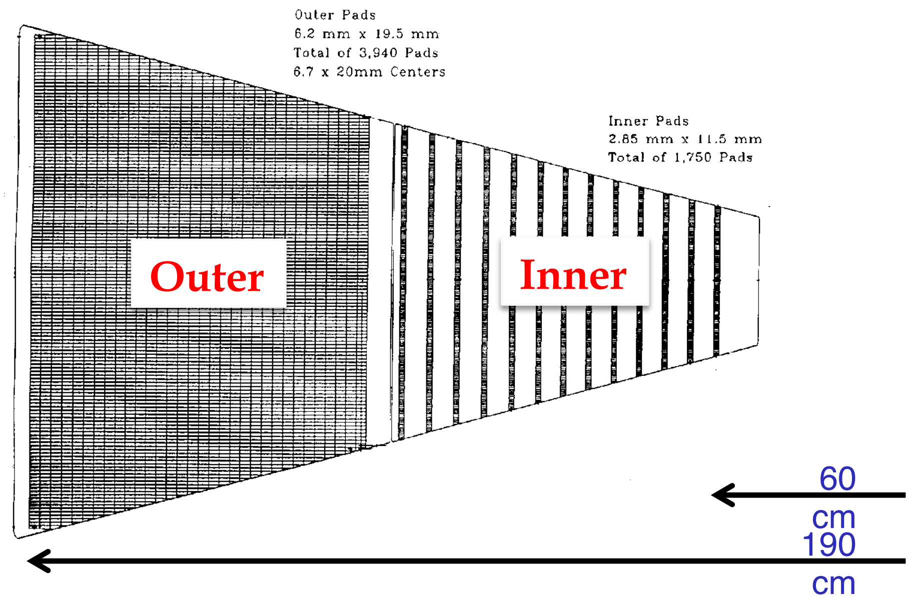
New Detectors for BES-II

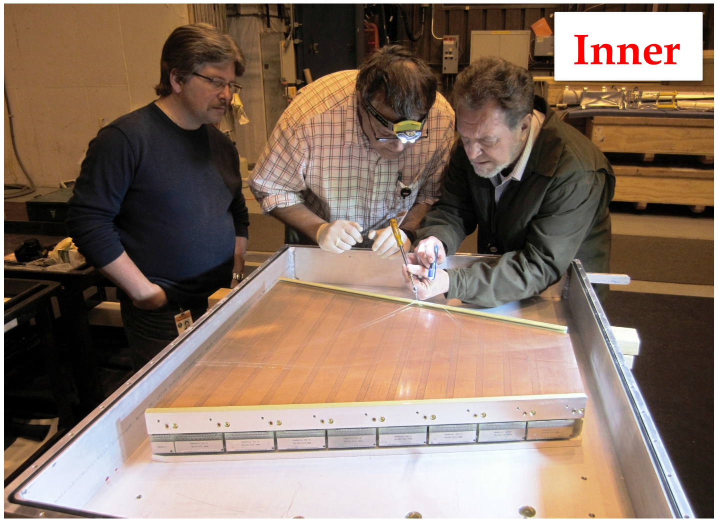


- **inner TPC upgrade (iTPC)**
  - Replaces the inner part of the TPC sectors with higher resolution ones
    → larger η-acceptance, better PID, higher efficiency
- **endcap Time-Of-Flight (eTOF)**
  - New time-of-flight wall (from CBM) for PID in the forward region, overlap with iTPC acceptance
- **Event Plane Detector (EPD)**
  - New forward/backward detector for triggering, event plane and centrality determination independent from TPC

The inner TPC Upgrade

More details: see talk by Yang Chi



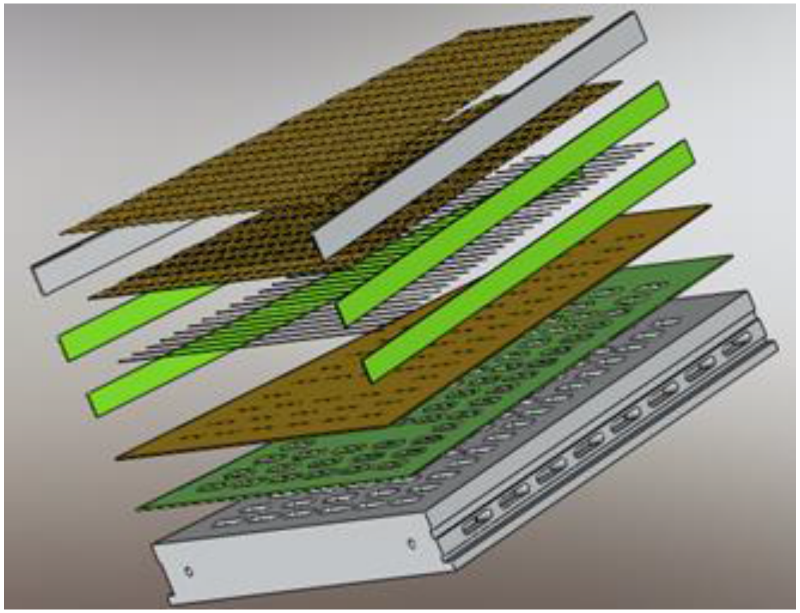


- Currently, the outer pad plane is hermetic while the inner pad plane is not
→ Goal: Add more pad rows on the inner sector, 2X total pad count
- Renew all wireframes (aged wires)

The upgrade will provide better momentum resolution, better dE/dx resolution, and improved acceptance at high η

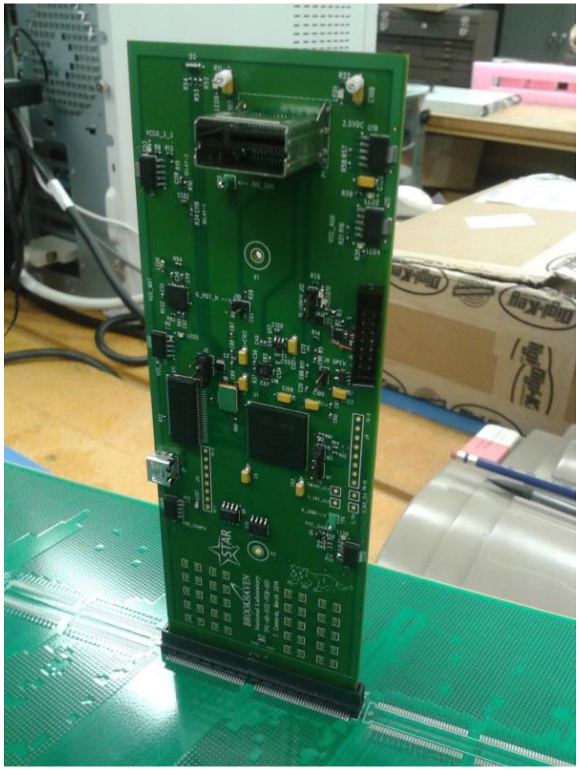
iTPC Strongback and Wireframe

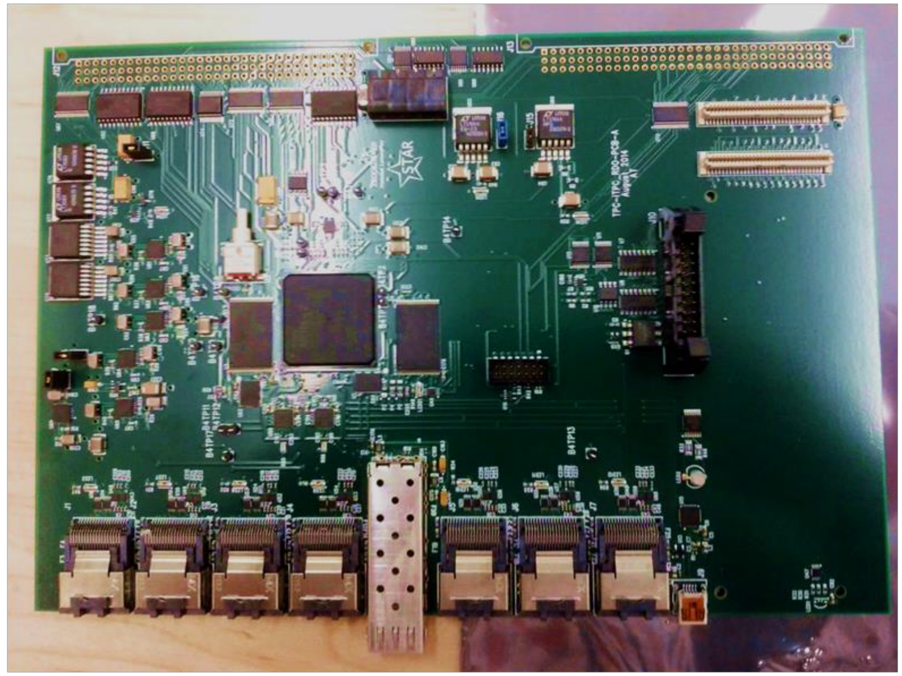
- New iTPC strongback
- Optimized slot positions for FEEs



- Three wireframes per sector
  → anode, ground, gate
- Precise wire tension, pitch and height
  → Gain uniformity, Active area

iTPC Electronics





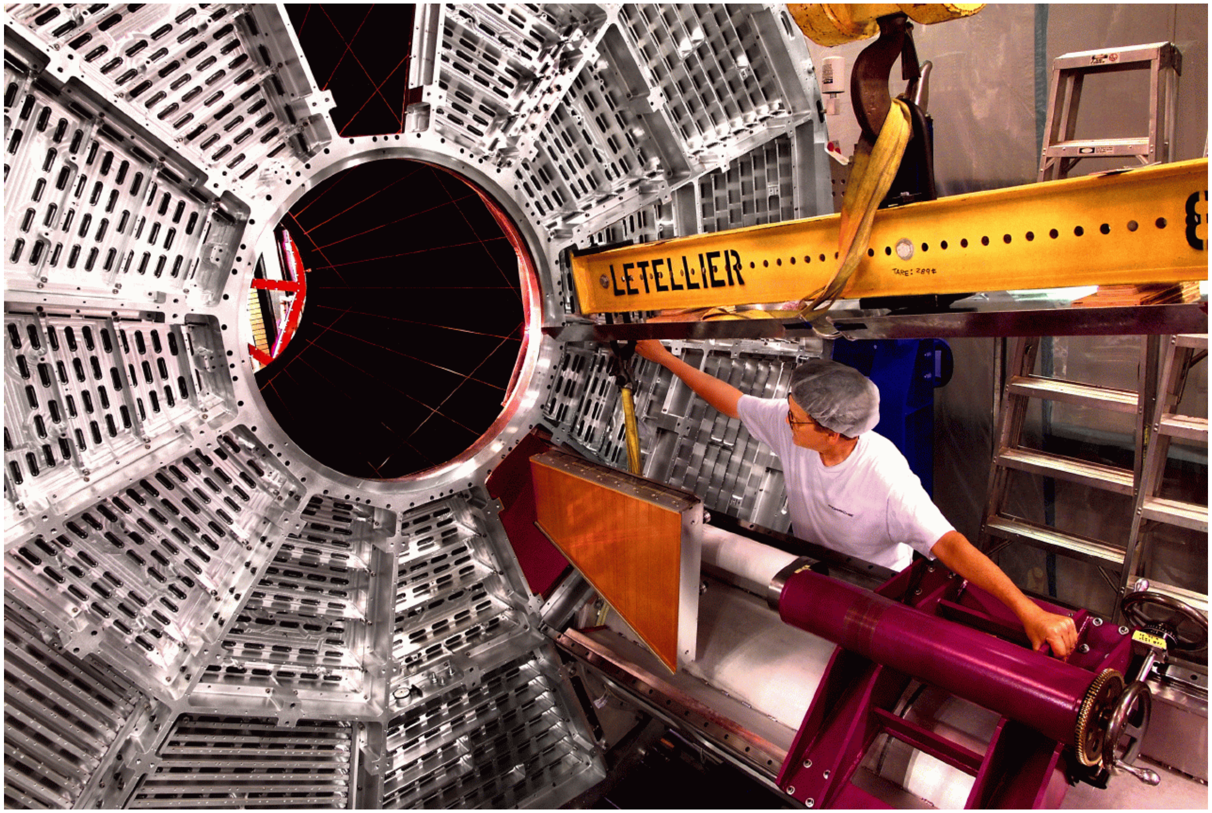
- Pre-prototye iFEE electronic card shown plugged into the padplane

- iFEE based on current FEE layout, with ALICE SAMPA chip

- Twice number of channels per FEE

- iRDO based upon a commercial daughtercard which houses the FPGA, PROM, SDRAM, clocks etc

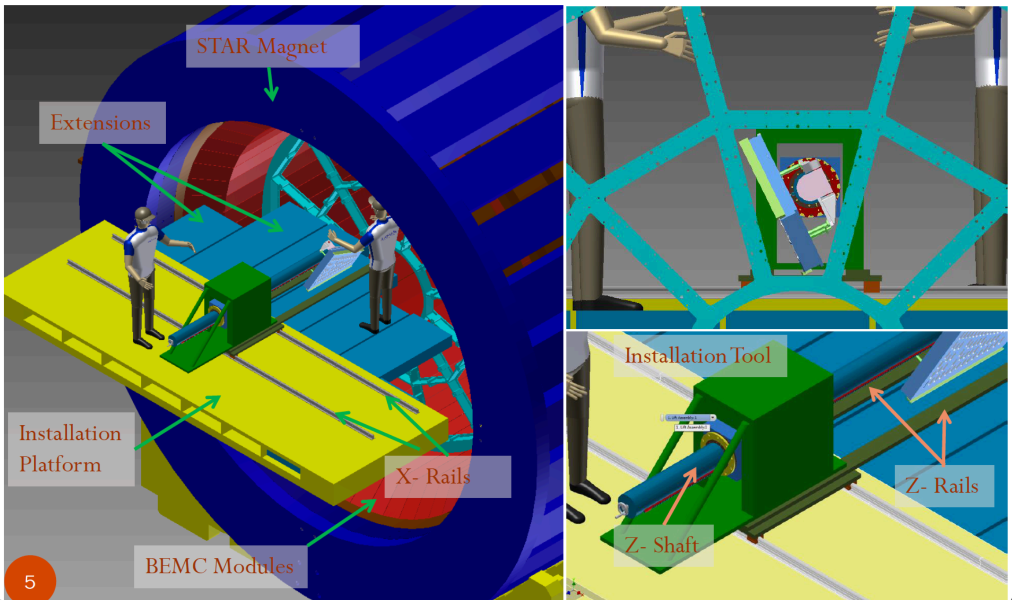
iTPC Old Insertion Tool



- TPC was outside magnet, clean environment
  → "relatively" simple installation

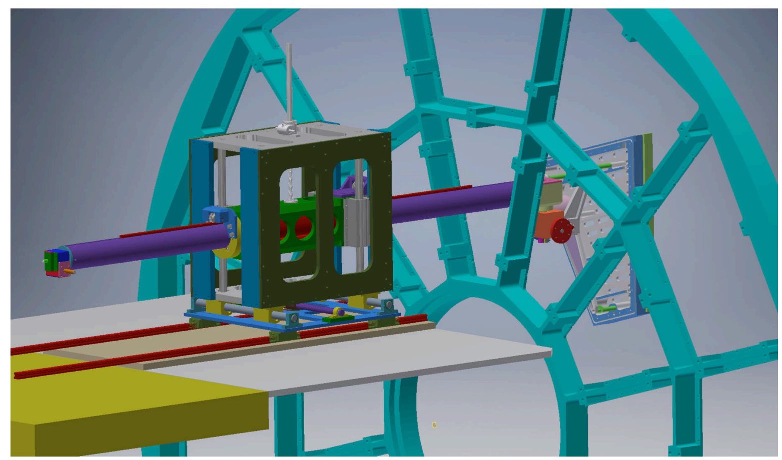
iTPC New Insertion Tool

Cartesian Installation Tool Design

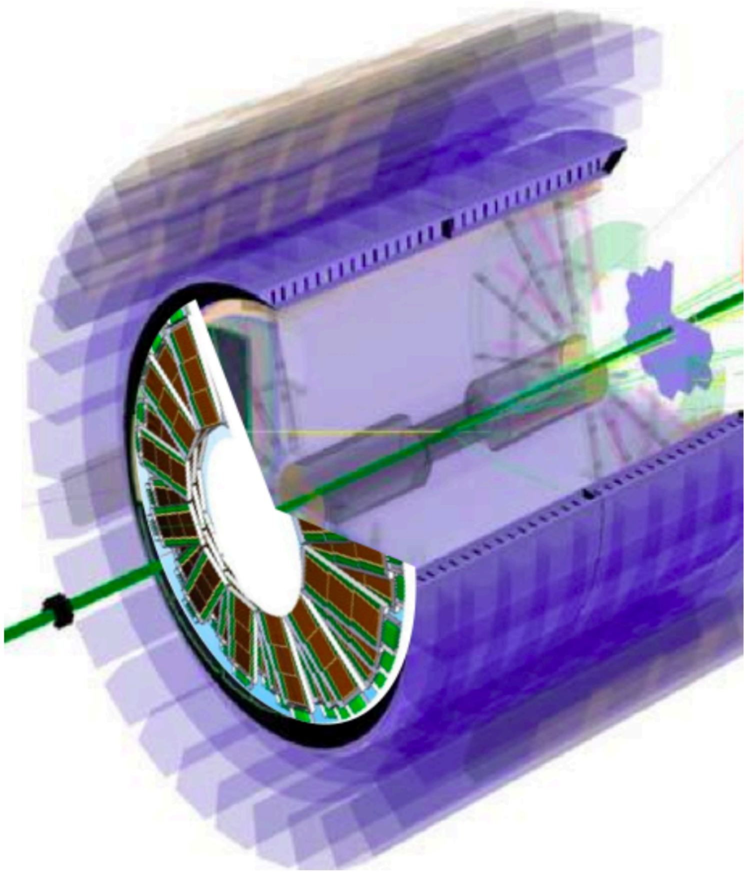


- TPC in magnet, surrounded by cables, electronic in the wide angle hall → need to make sure no dust is coming in!

- Insertion tooling needed for installation and for replacement of two outer bad sectors

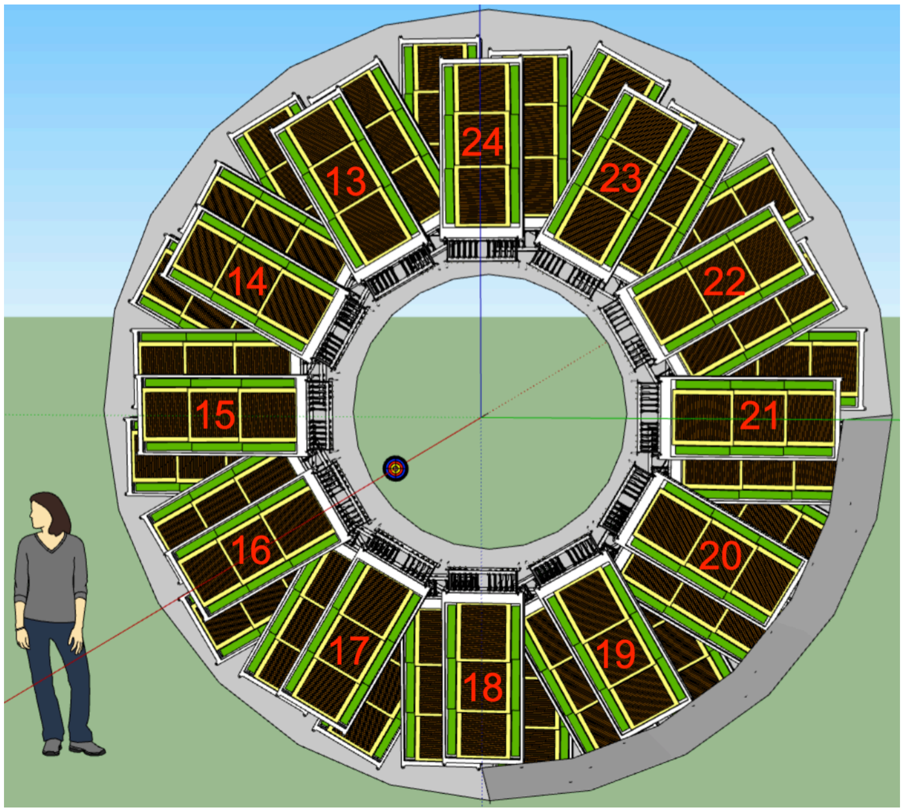


The endcap Time-Of-Flight



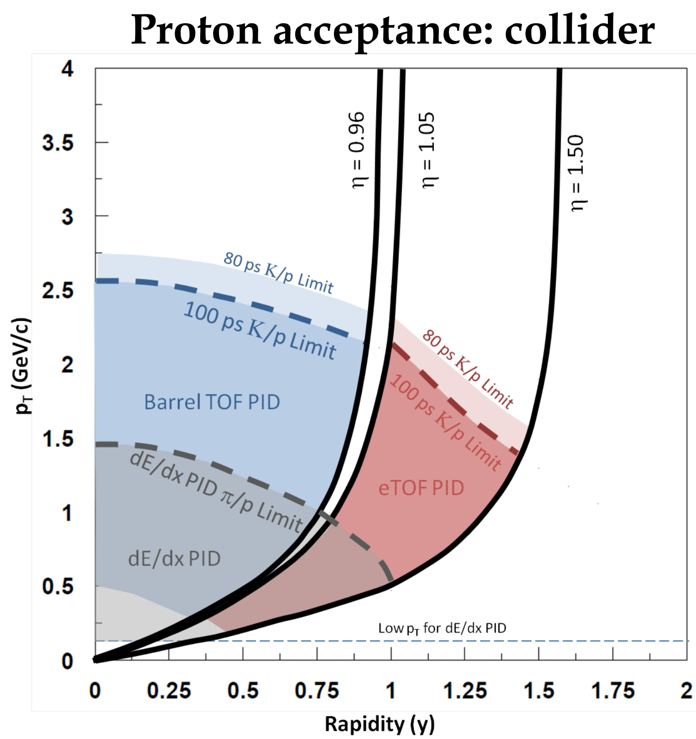
- Compressed Baryonic Matter Experiment (CBM) institutions proposed installing CBM TOF modules (10%) inside east pole-tip
- Acceptance: $-1.6 < \eta < -1.1$
- Provides STAR with an endcap TOF for BES-II
- Provides CBM a large-scale integration test of the CBM TOF system
- Adds the lower energy (fixed target) community to the RHIC/STAR program

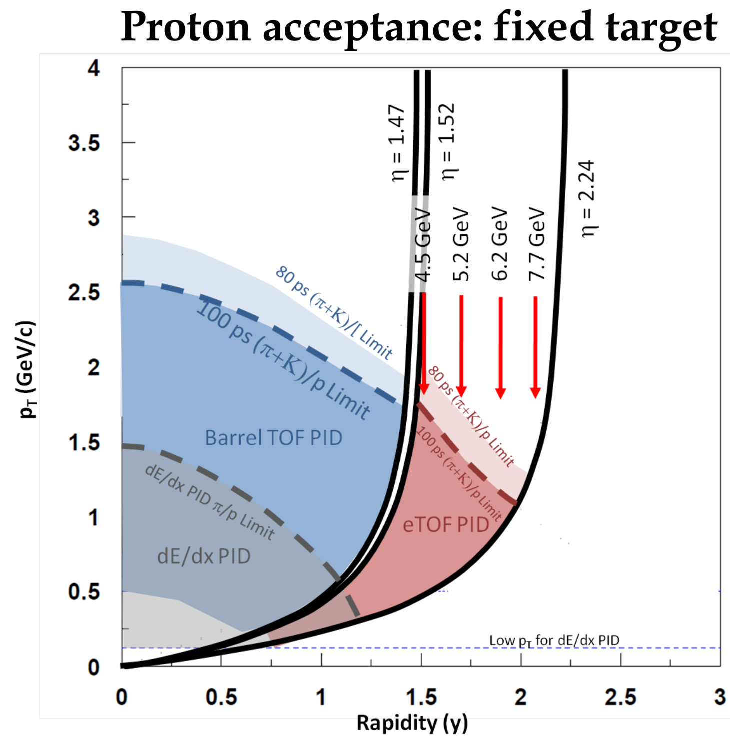
eTOF Setup



- 36 Modules in 3 layers, 6912 channels
- Modules arranged to match 12 TPC sectors
- Each module is long-strip MRPC read-out at both ends. Similar to existing STAR MTD.
- Prototypes installed during 2017 & 2018 RHIC runs.

eTOF: Acceptance Maps



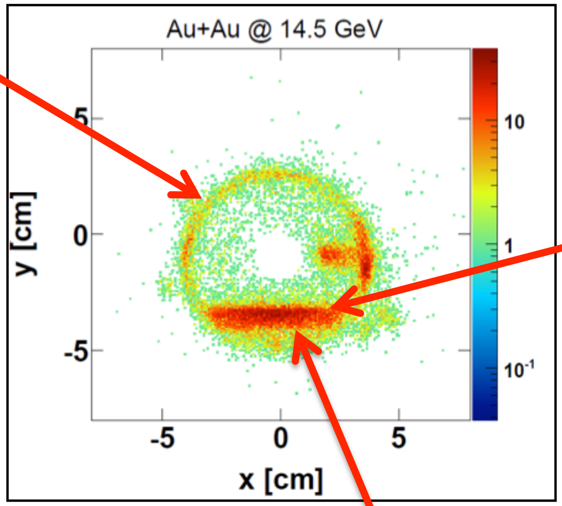


- eTOF is enabling PID of π/K/p for the whole iTPC acceptance in collider mode

- eTOF further adds PID to the fixed target program

eTOF and Fixed Target Program

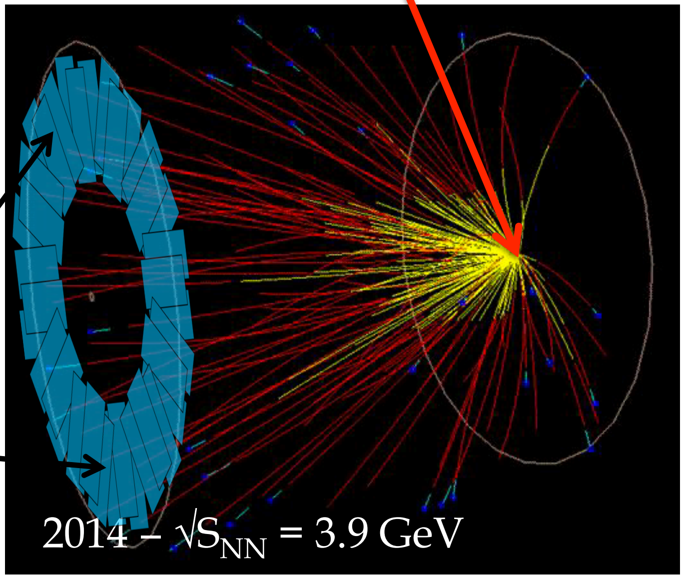
Beam pipe



Au-target

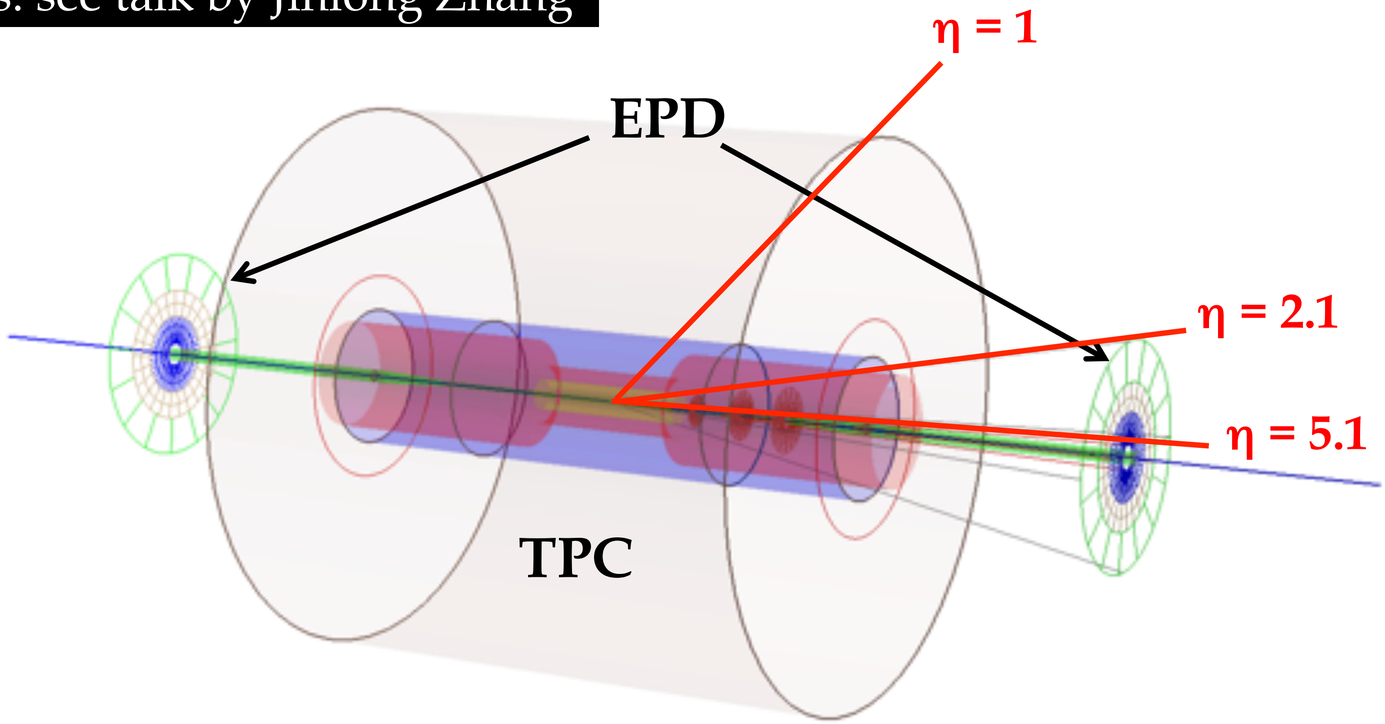
- Fixed target program at RHIC/BES-II extends the energy down to $\sqrt{s_{NN}}$ = 3.0 GeV
- Overlap with collider mode at $\sqrt{s_{NN}}$ = 7.7 GeV
- Results from successful tests in recent years: coulomb potentials, HBT radii
- Allows to push the μ_B to ~700 MeV

eTOF



The Event Plane Detector

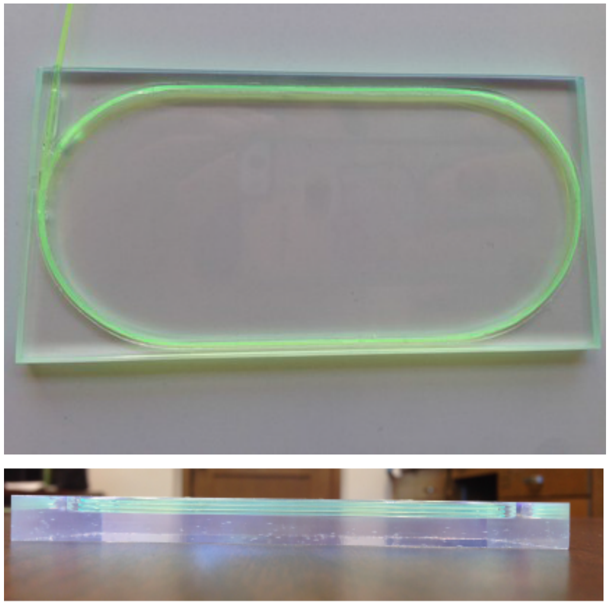
More details: see talk by Jinlong Zhang



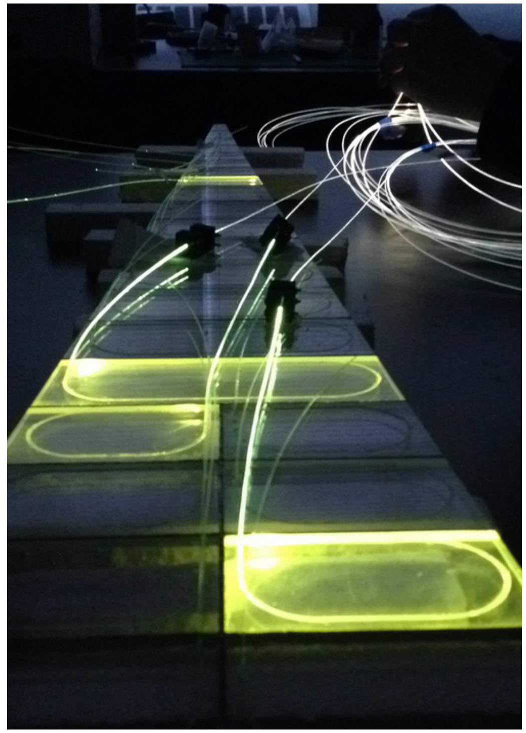
- Large eta coverage 2.1< |η|< 5.1 compared to TPC (|η|<1.0),
- Installed at z position +/- 375 cm
- High η (radial, 16) and azimuthal (24) segmentation
- Good timing resolution (~ 1 ns)

  → Adds mid-rapidity independent event plane and centrality determination. Also used as trigger detector for BES-II.

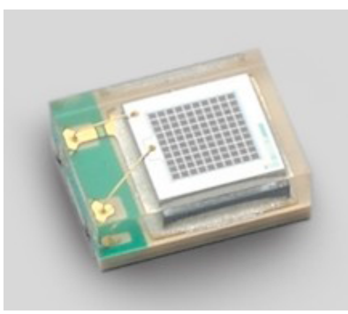
EPD Technology



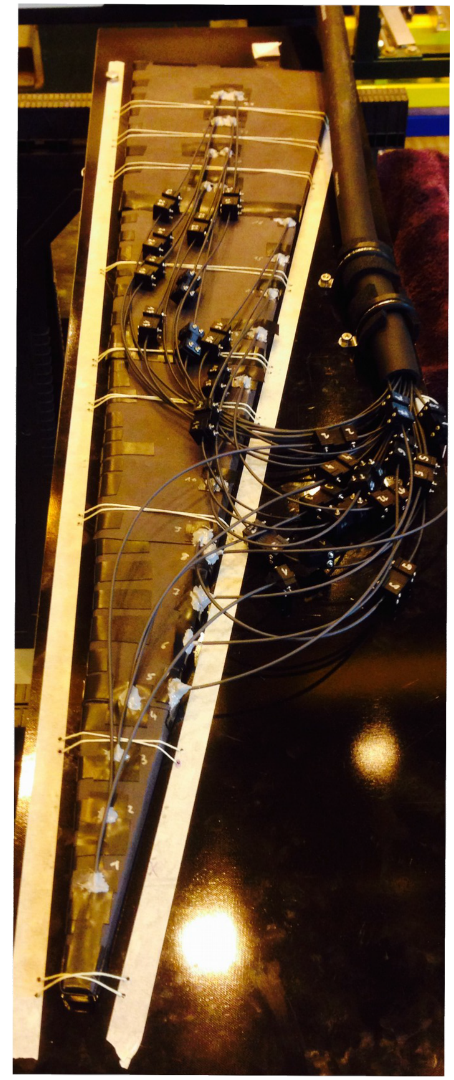
Triple layer WLS tile (EJ-200, Kuraray s-type, multi. clad.)



Light tests



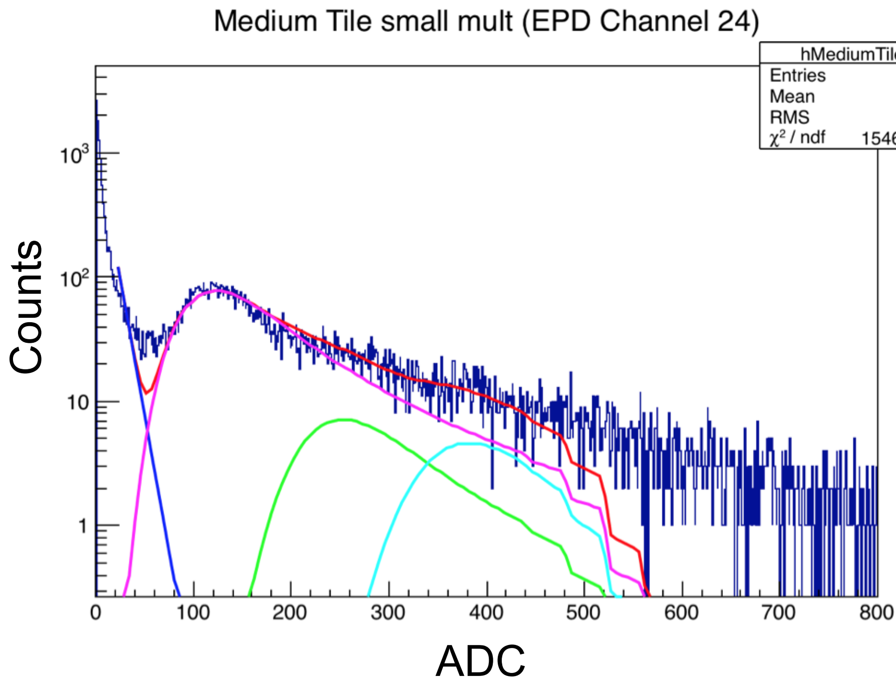
SiPM: S13360-1325PE



EPD prototype

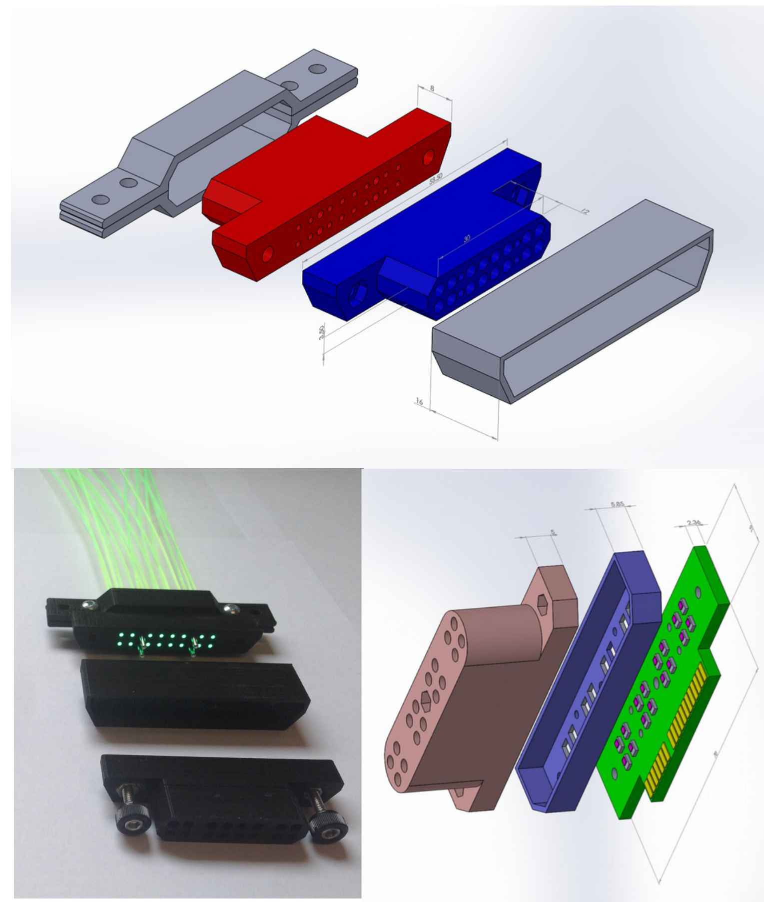
EPD Prototype Results and Connectors

Prototype ADC spectrum



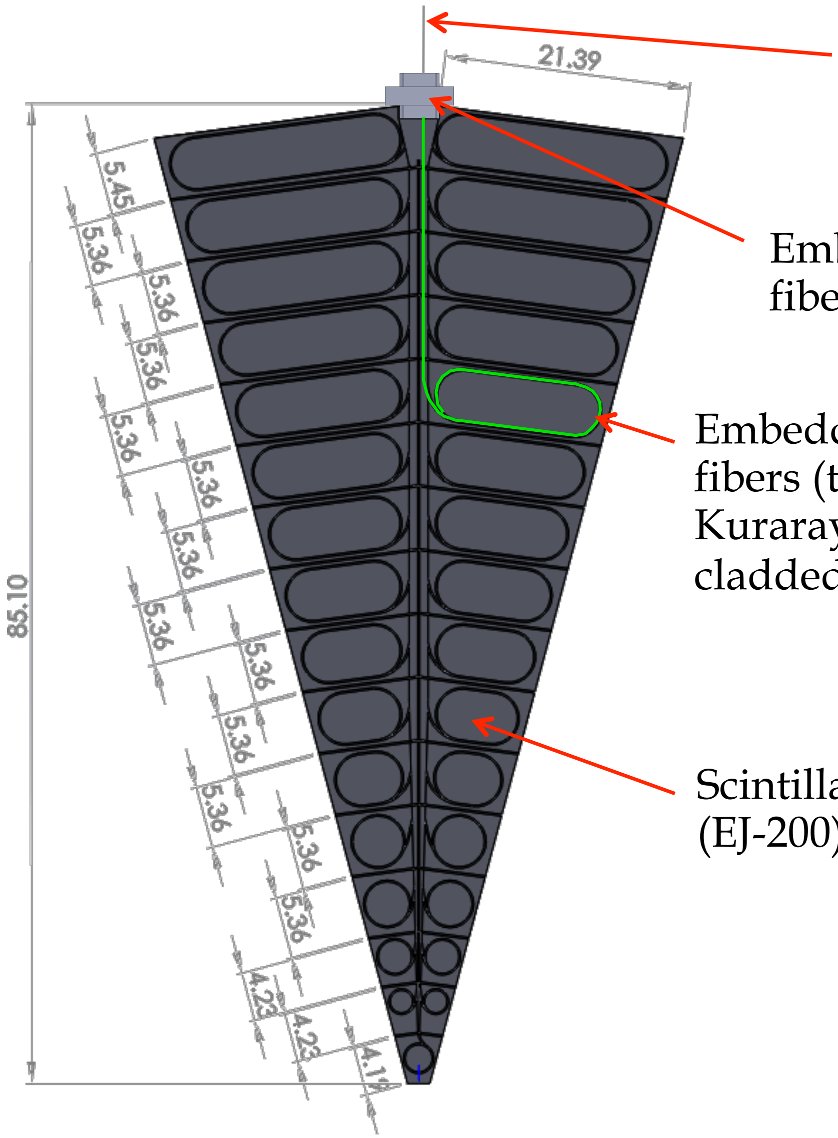
- Simultaneous fit for pedestal and several MIPs
  → results in 250 photoelectrons/MIP
  → in agreement with lab results

Fiber connectors



- Computer aided design + 3D printed

EPD Super-Sector Design



Clear fibers (Kuraray s-type multi-cladded, 1.15 mm)

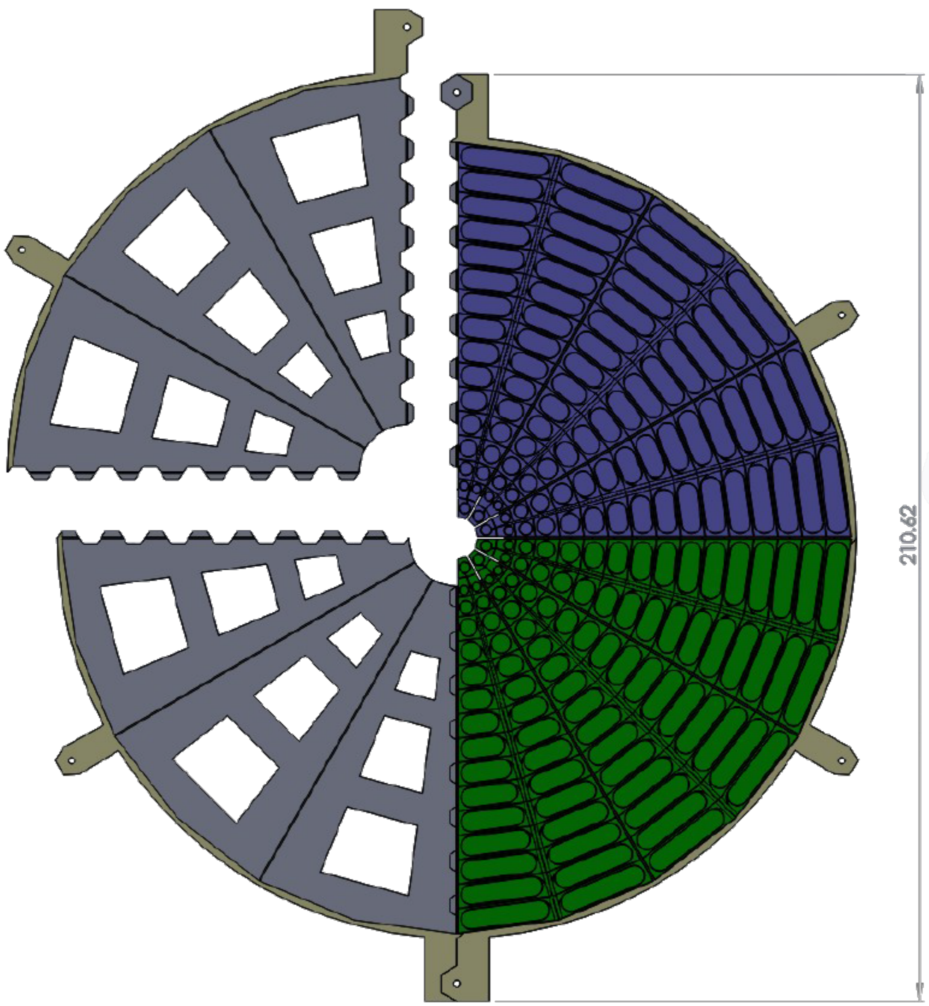
Embedded 32-channel fiber-to-fiber connector

Embedded WLS fibers (triple layer, Kuraray s-type multi-cladded, 1 mm)

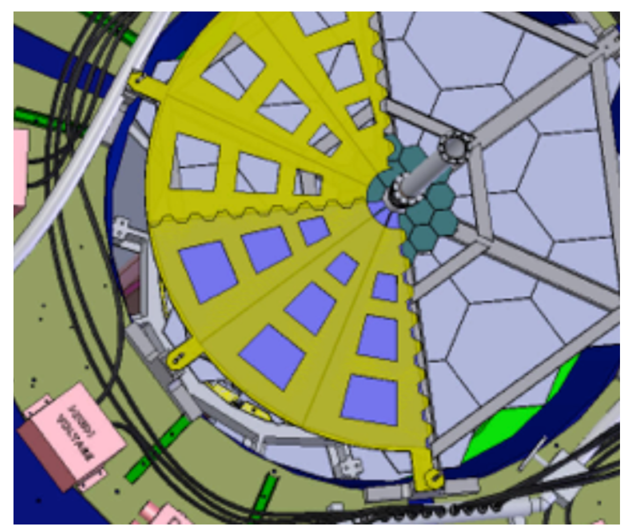
Scintillator (EJ-200)

- 24 azimuthal segments, 16 radial segments (~750 channels in total)
- Each supersector has 31 channels, 16 in radial direction
- Two azimuthal segments (sectors)
- Sigma-groves for WLS fibers, triple layer
- Smallest bending radius ~1 cm!

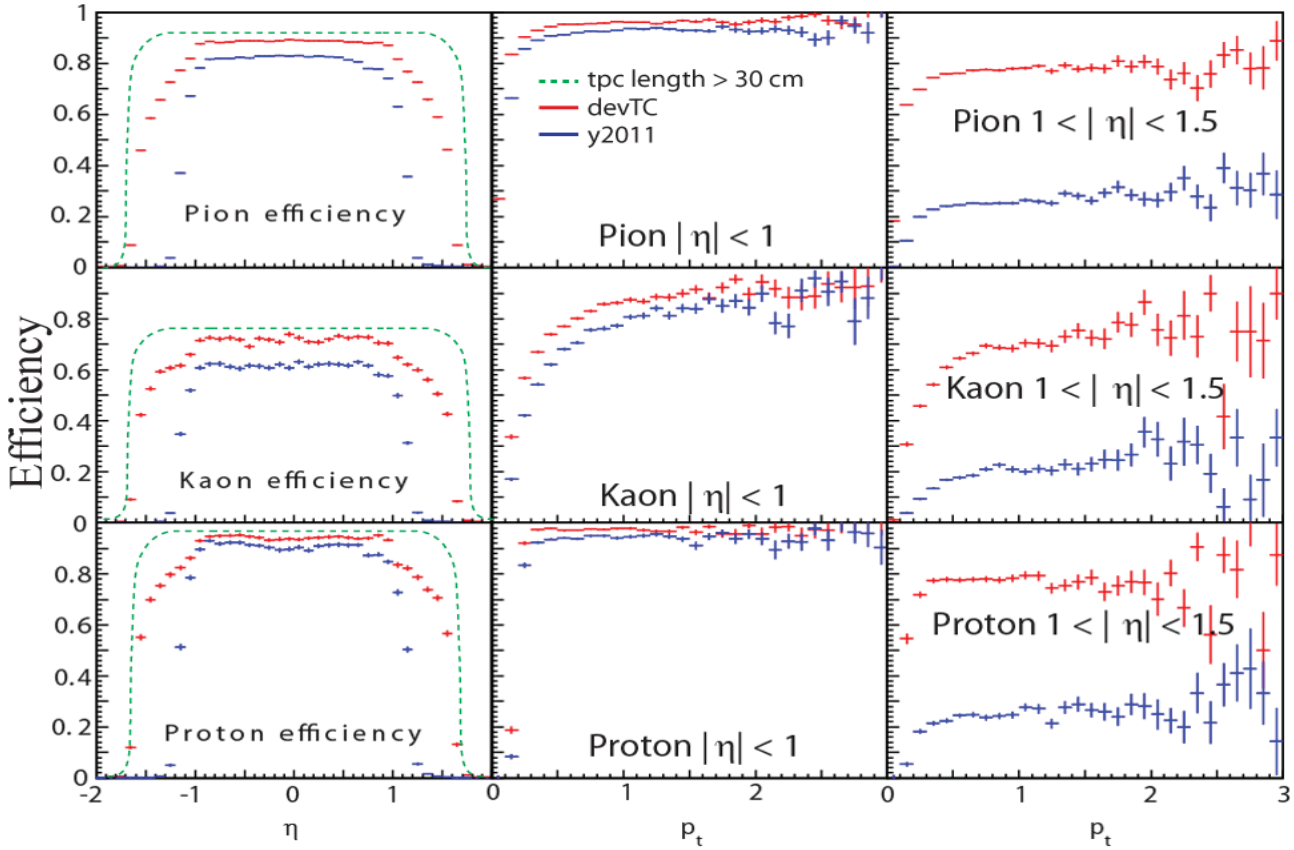
EPD Mounting and Integration



- The frame consist of four interlocking quadrants milled from 3/8 inch thick fiberglass-reinforced epoxy laminate sheets, FR-4.
- Stiff enough to support support three super sectors in each quadrant.
- Cutouts in frame to reduce weight
- $1/8^{th}$ of the detector will be installed in 2017

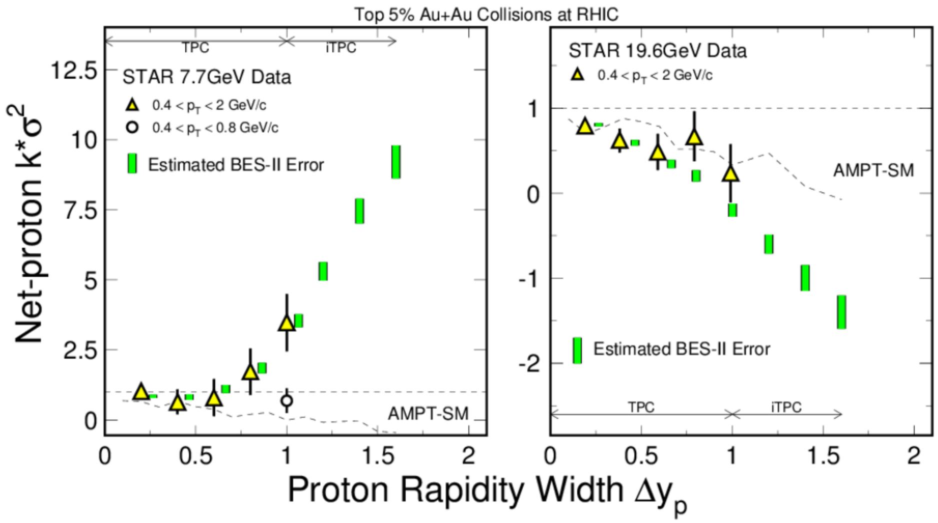


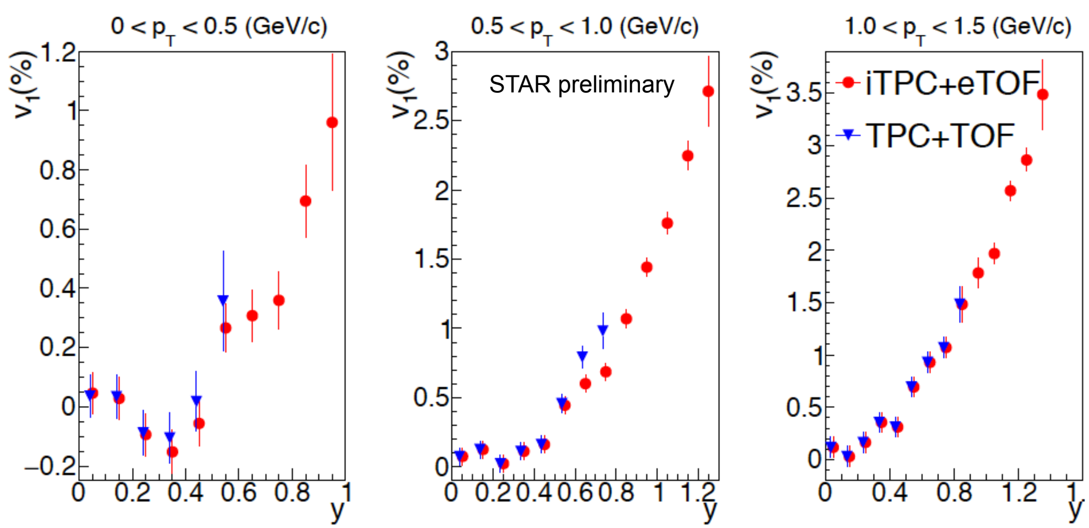
iTPC: Tracking Performance



- Acceptance increases from | η | < 1 to | η | < 1.5
- Transverse momentum acceptance increases from p_T>125 MeV to p_T>60 MeV/c
- dE/dx resolution improves from 7.5% to 6.2%

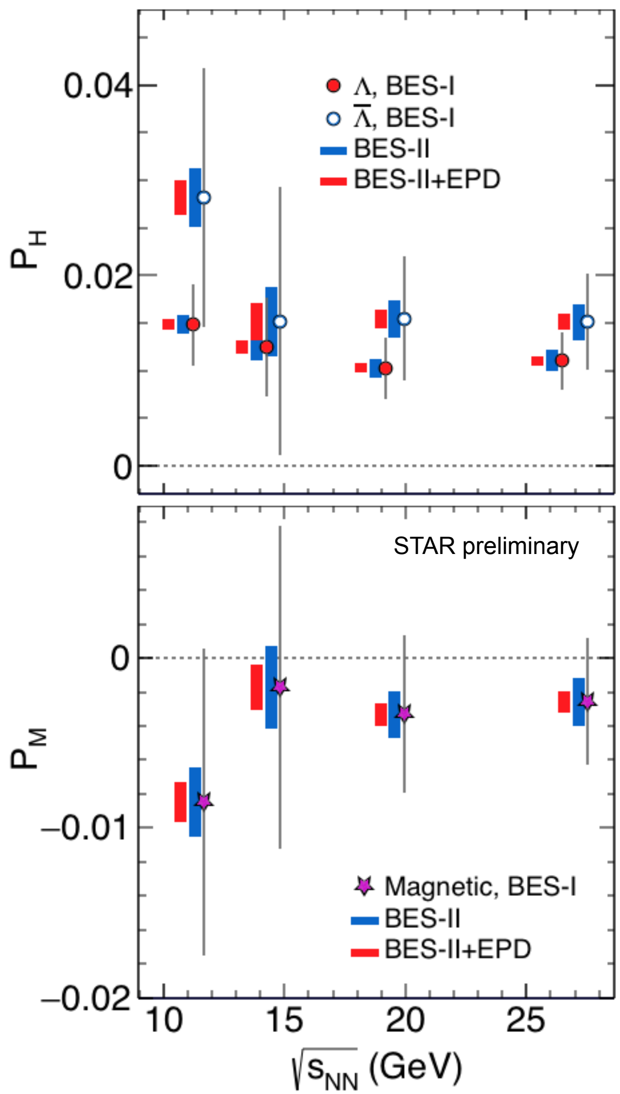
eTOF/iTPC: Impact on Physics Results

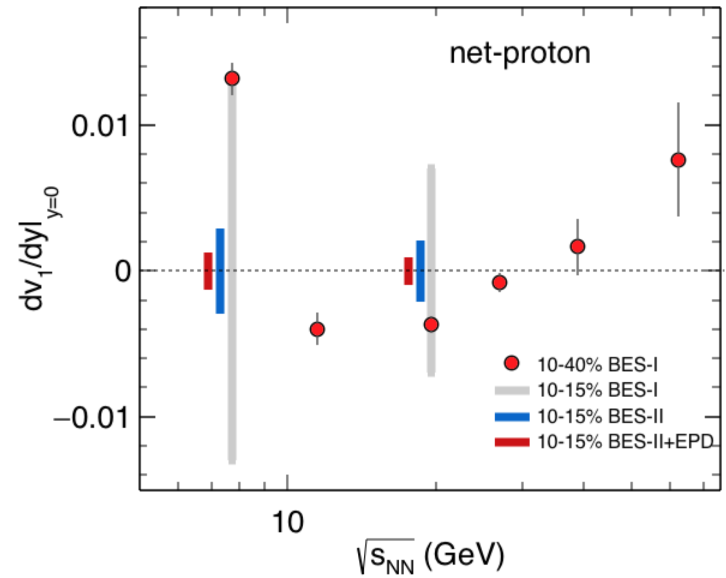




- Increased Δy coverage for net-proton studies
- Larger acceptance
  → larger proton+anti-proton multiplicity
- Larger coverage in rapidity for directed flow
- Large coverage for fixed target program
  → lower energies
- Also improvements on v_2, spectra,…

EPD Impact on Physics Results





- EPD is going to reduce the physics correlations to mid-rapidity measurements: net-protons, v2,…
- First harmonic event plane resolution at about 2-4 times larger at 7.7 GeV compared to existing BBC detector.
- The statistics (resolution) improvements are about 40% for mid-central collisions

→ e.g. needed to get a significant signal for P_M

Physics Opportunities for 2020+

STAR is after BES-II in perfect shape for future measurements!

Physics Goal	Measurements	Requirements							
			Base	fCal	fTS	RP	HFT+	BSMD	Streaming
Nuclear PDFs	DY, Direct photons +J/Psi R_{pA}	★■	✓	✓	Enh				
Nuclear FF	Hadron + Jet	★■	✓						Enh
Polarized Nuclear FF	Hadron + Jet	★	✓						
Odderon & Polarized Diffraction	A_{UT} of pion + forward proton	★		✓		✓			
Low-x ΔG	Di-jets	★	Enh	✓	✓				
High-x Transversity	Hadron+jet	★■		✓	✓				
Mapping the Initial State in 3-D: QGP Transport Properties	R. Plane Rapidity de-correlations	★	Needs iTPC						
	Ridge $\|\Delta\eta\|<3$	★	Needs iTPC						
	Ridge $\|\Delta\eta\|<6$	★	Needs iTPC		✓				
	Forward Energy Flow	★	Needs iTPC	✓					
Effects of Chiral Symmetry at $\mu_B=0$	Di-lepton spectra at $\mu_B=0$	★■	Needs iTPC				HFT out		Enh
	Extended LPV observables	★■	Needs iTPC						Enh
Internal Structure of the QGP and Color Response	Υ(1S,2S,3S)	○	✓						
	B R_{AA}	★■	✓				✓		
	B v_2	★■	✓				✓	✓	✓
	B-tagged Jets	○	✓				✓		
	Jets	○	✓						Enh
	γ –Jets	○	✓					✓	
Phase Diagram and Freeze-out	BES-II Observables at $\mu_B=0$	★	Needs iTPC						
	C6/C2, C4/C2	★	Needs iTPC						
The Strong Force	Exotics and Bound States (di-Baryons)	★	Needs iTPC						✓

- High statistics of hard probes
- Correlations and ridge with large rapidity coverage (initial conditions, baryon stopping, temperature dependence of η/s)
- Unique Cold QCD (DY): portal to EIC

✓ Measurement needs upgrade   Enh : Enhances measurement, but is not required

★ Unique to STAR ○ Complementary to sPHENIX ■ Complemented by LHC and/or JLab

Green highlighted rows require only continued running with STAR as instrumented for the BES-II

Base : STAR as instrumented for the BES-II
iTPC : Inner sector TPC upgrade extending coverage from $|\eta|<1$ to $|\eta|<1.5$
fTS : Forward Tracking System
fCal : Forward Electromagnetic and Hadronic Calorimeters
HFT+ : An extended faster heavy flavor tracker
Streaming : An electronics and DAQ upgrade allowing significant increase in minbias data rate
BSMD : Replacing the BSMD readout
HFT out: Di-lepton spectra at $\mu_B=0$ improved by running with less material

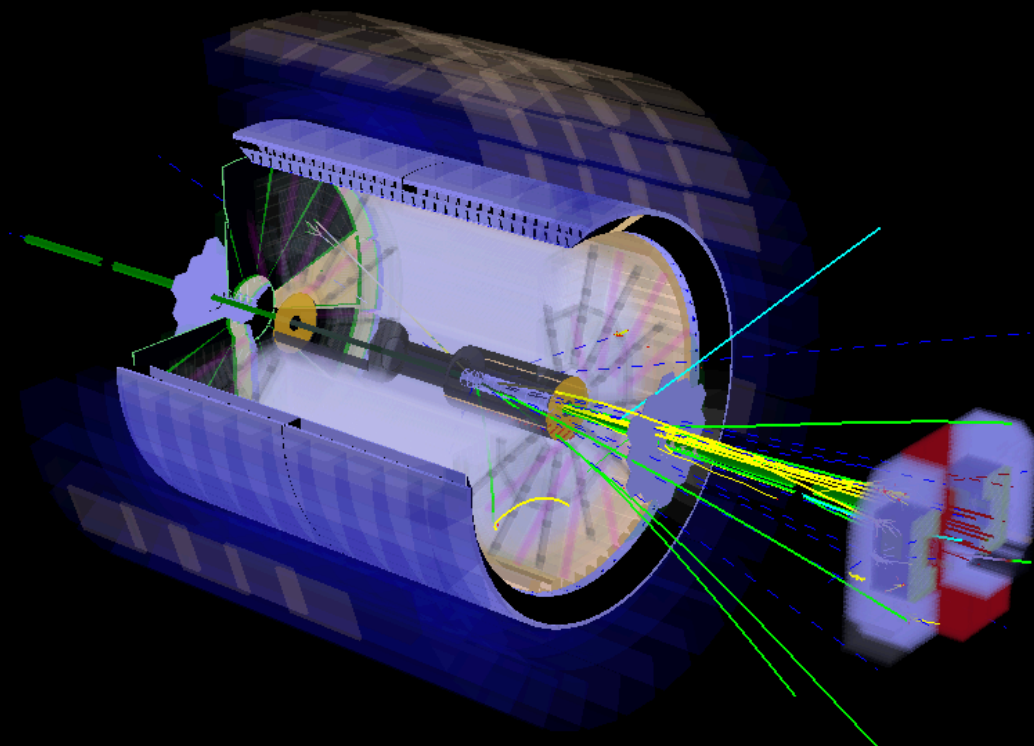
SN0640-Oct. 19, 2015 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0640

2020+: FCS and FTS

- Proposed FCS+FTS provide access to very small x
  - Facilitates investigations into the dynamics and nonlinear evolution effects in the regime of high gluon-density.

Forward
Calorimeter
System

Forward
Tracking
System



Physics Program

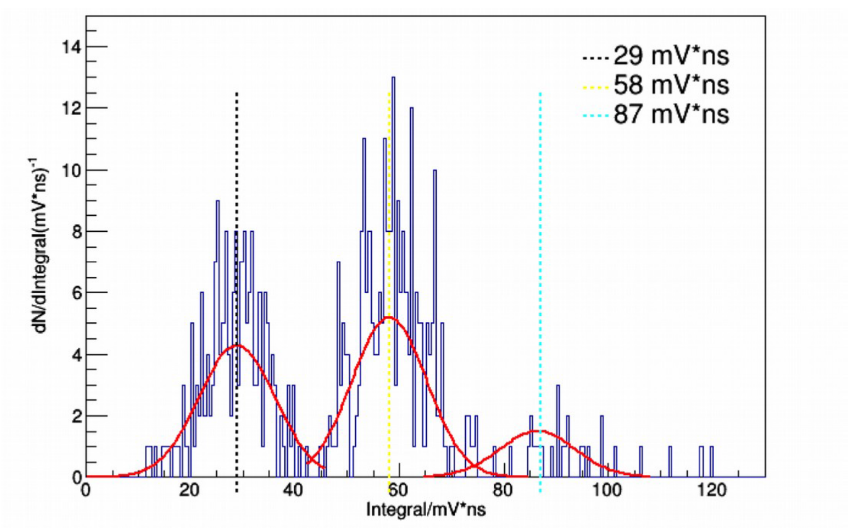
Year	System and Energy	Physics/Observables	Upgrade
2017	• p+p @ 500 GeV • Au+Au @ 62.4 GeV	• Spin sign change diffractive • Jets	FMS post-shower, EPD (1/8th), eTOF prototype
2018	• Zr+Zr, Ru+Ru @ 200 GeV • Au+Au @ 27 GeV	• CME, di-leptons • CVE	Full EPD? eTOF prototype
2019	Au+Au @ 14.5-20 GeV + fixed target	• QCD critical point • Phase transition • CME, CVE,…	Full iTPC, eTOF, and EPD
2020	Au+Au @ 7-11 GeV + fixed target	• QCD critical point • Phase transition • CME, CVE,…	
2020+	• Au+Au @ 200 GeV • p+A/p+p @ 200 GeV	• Unbiased jets, open beauty • PID FF, Drell-Yan, longitudinal correlations	• HFT+ • FCS, FTS


Thanks!

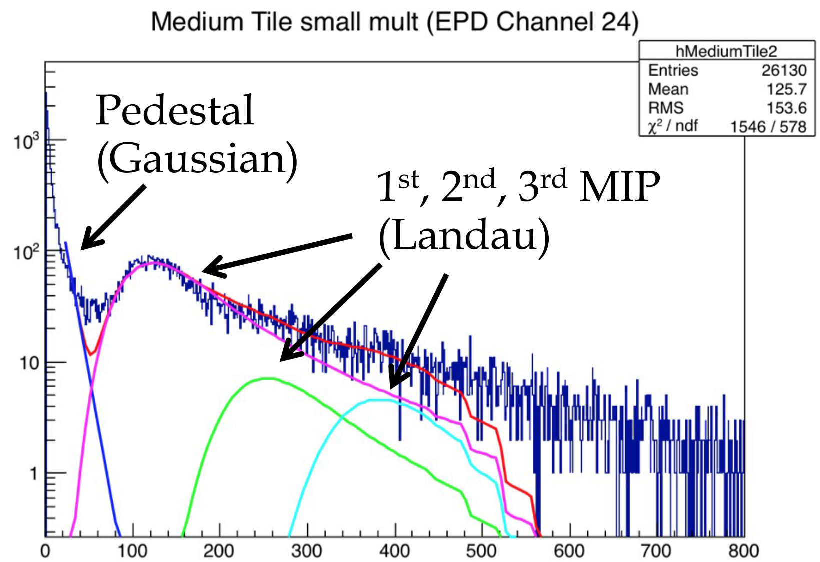
BACKUP

EPD Light Yield

Test bench setup



Prototype



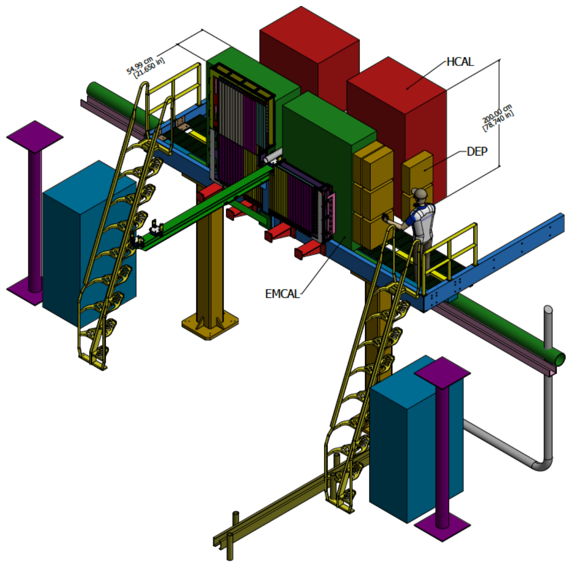
- SiPM dark noise for 1,2, and 3 pixels
- Triple WLS fiber setup, direct coupling:
- 250 photoelectrons/MIP

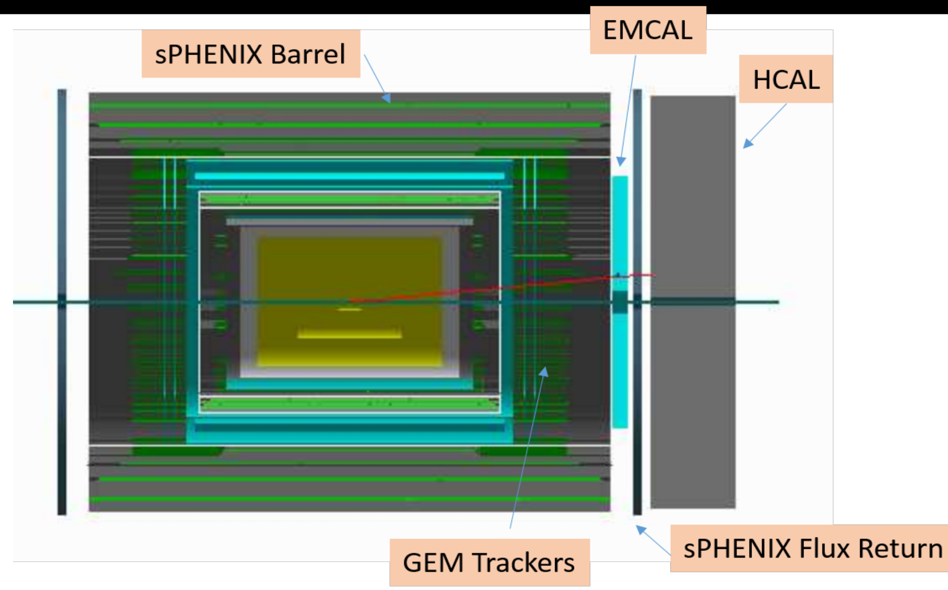
- Prototype ADC spectrum with "energy loss" fit
- Good description of ADC spectrum, results in ~42 photoelectrons/MIP
  → excellent agreement with test bench setup after correction for coupling losses, single WLS fiber loop ect.
  → 25 µm SiPM pitch needed to avoid saturation effects

iTPC Installation Schedule

- After Run-17 (6/2017)
  - 8 month installation period
  - Roll-in/out of STAR 3 mo.
  - Verify & test installation tooling
  - Exchange one outer sector, and possibly one new inner sector module with electronics (risk mitigation)
- After Run 18 (4/2018)
  - Long installation (shutdown) period needed
  - Aim for start of Run-19 in March 2019

RHIC Forward upgrade plans





Add to existing STAR at rapidity
2.5 < η < 4.5 (PID at mid-rapidity)

Forward Ecal:
reuse PHENIX Ecal

Forward Hcal:
STAR fHCal and EIC fHCal

Forward Tracking:
4-6 Si strip-disks

sPHENIX has a plan for a forward arm
1 < η < 4.5 (*needs mid-rapidity PID)

Forward Ecal:
reuse PHENIX Ecal

Forward Hcal:
Similar to STAR fHCal and EIC fHCal

Tracking:
3 stations of GEM Trackers