STAR upgrade plan

I. STAR Beam Energy Scan II Program (2019~2021)

II. Forward Upgrade & Opportunities at STAR (2021+)

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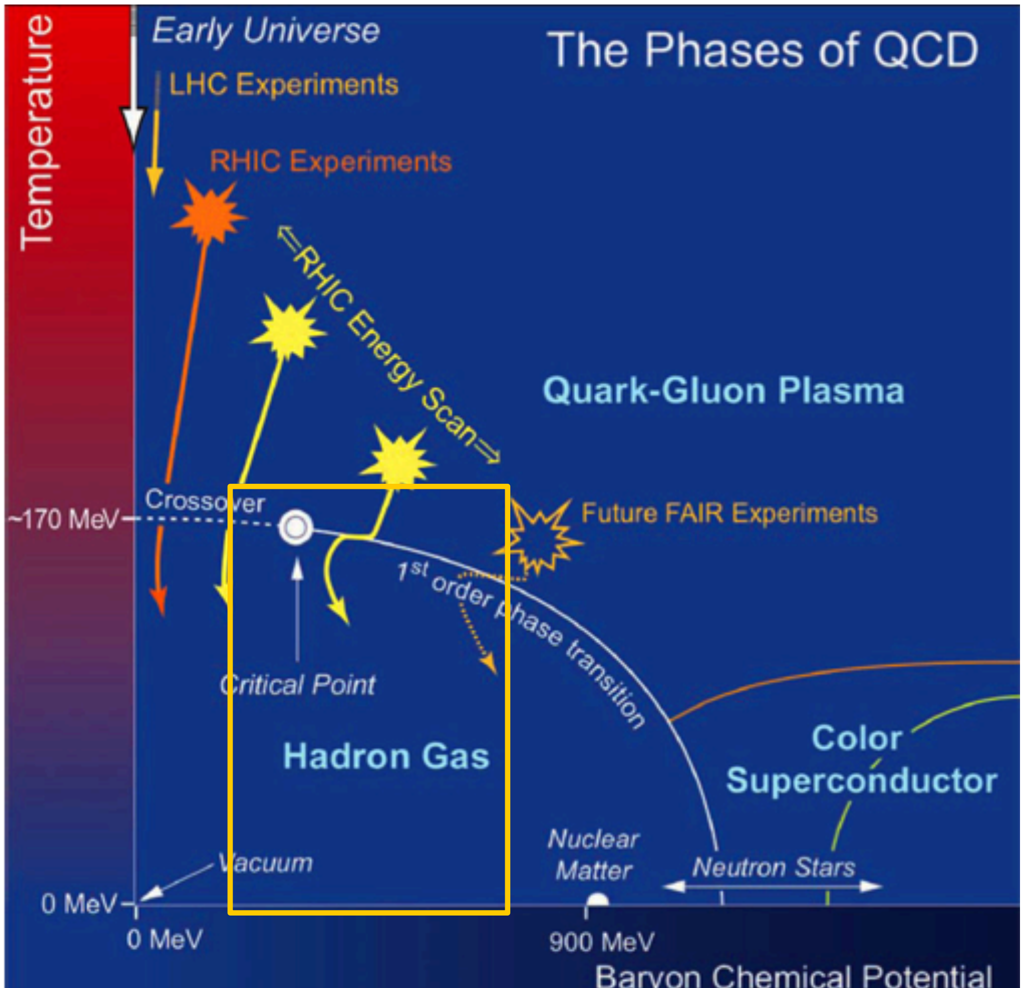
for the STAR Collaboration

RHIC-AGS user Meeting,
BNL, June, 2018

Beam Energy Scan Program at RHIC

- **Heavy ion collisions allow to explore the QCD phase structure by varying the collision energy.**



Goals of RHIC- BES program:

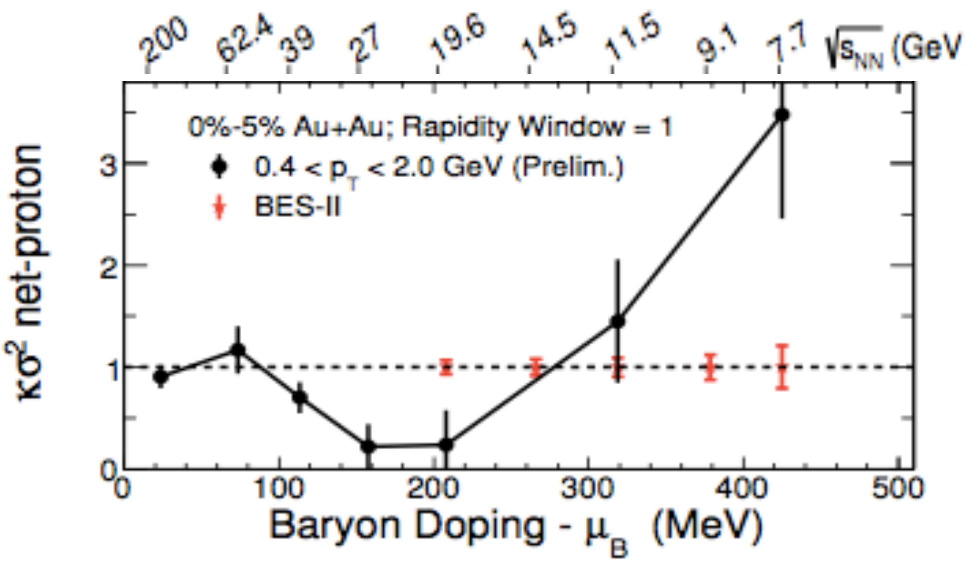
- ✓ Turn-off of QGP signatures
- ✓ Search critical point
- ✓ 1st order phase transition

$\sqrt{S_{NN}}$ (GeV)	Proposed Event Goals (M)	BES-I Event (M)
7.7	100	4
9.1	160	N/A
11.5	230	12
14.5	300	20
19.6	400	36
3.0 - 7.7*	100 per energy	N/A

*Fixed-target program

RHIC Beam Energy Scan II- Physics

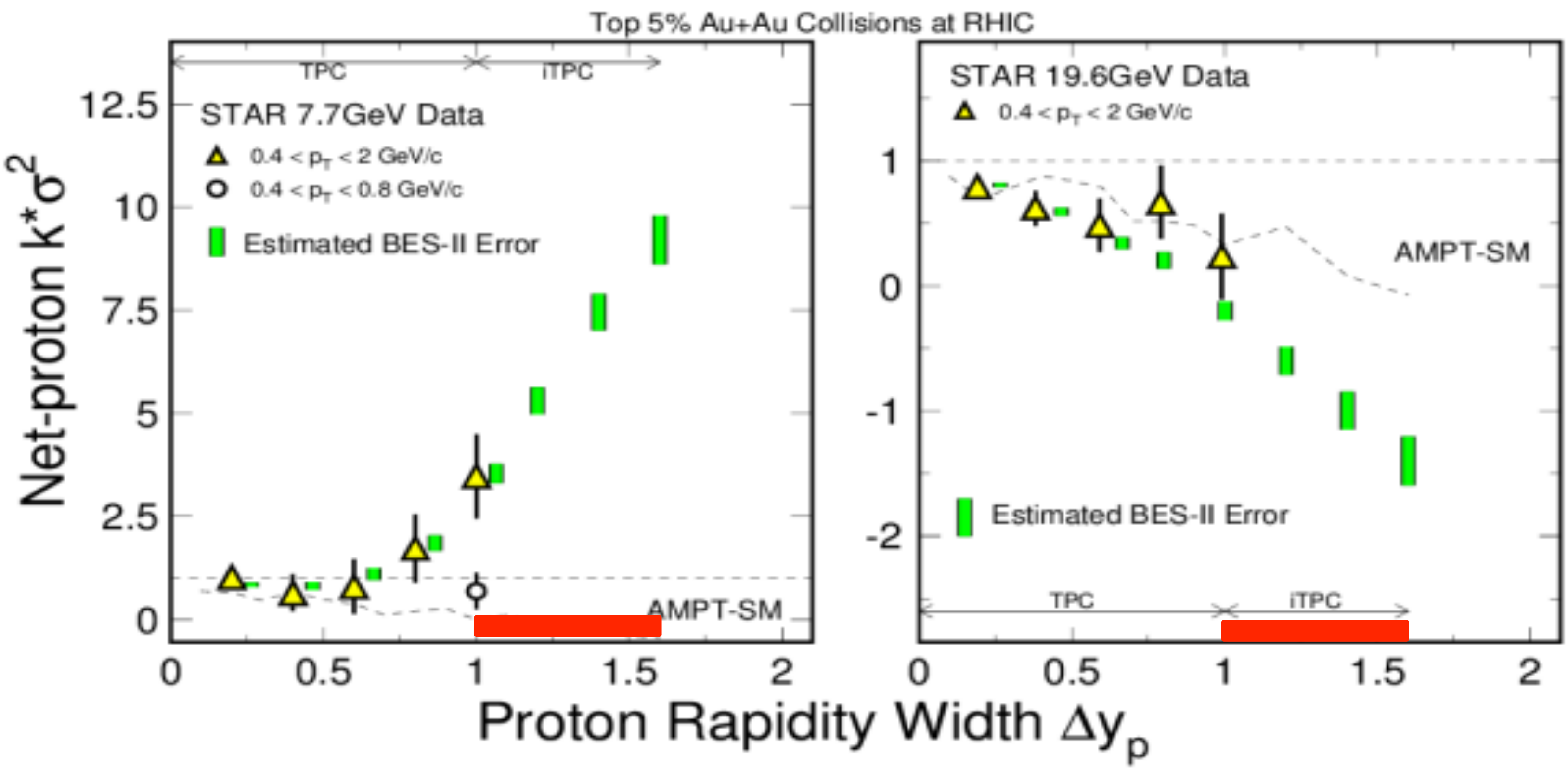
- **Beam Energy Scan – Phase I Results (2010-2014):**
  - ✓ **Seen the turn-off of QGP signatures.**
  - ✓ **Seen suggestions of the first order phase transition.**
  - ✓ **Seen indication of a critical point, but not conclusive.**
- **The most promising region for refining the search is in the energies -> 19.6, 15, 11.5, 7.7, and lower -> BES II (2019-2021)**



Kurtosis measurement with BES

Critical point search- Kurtosis measurement

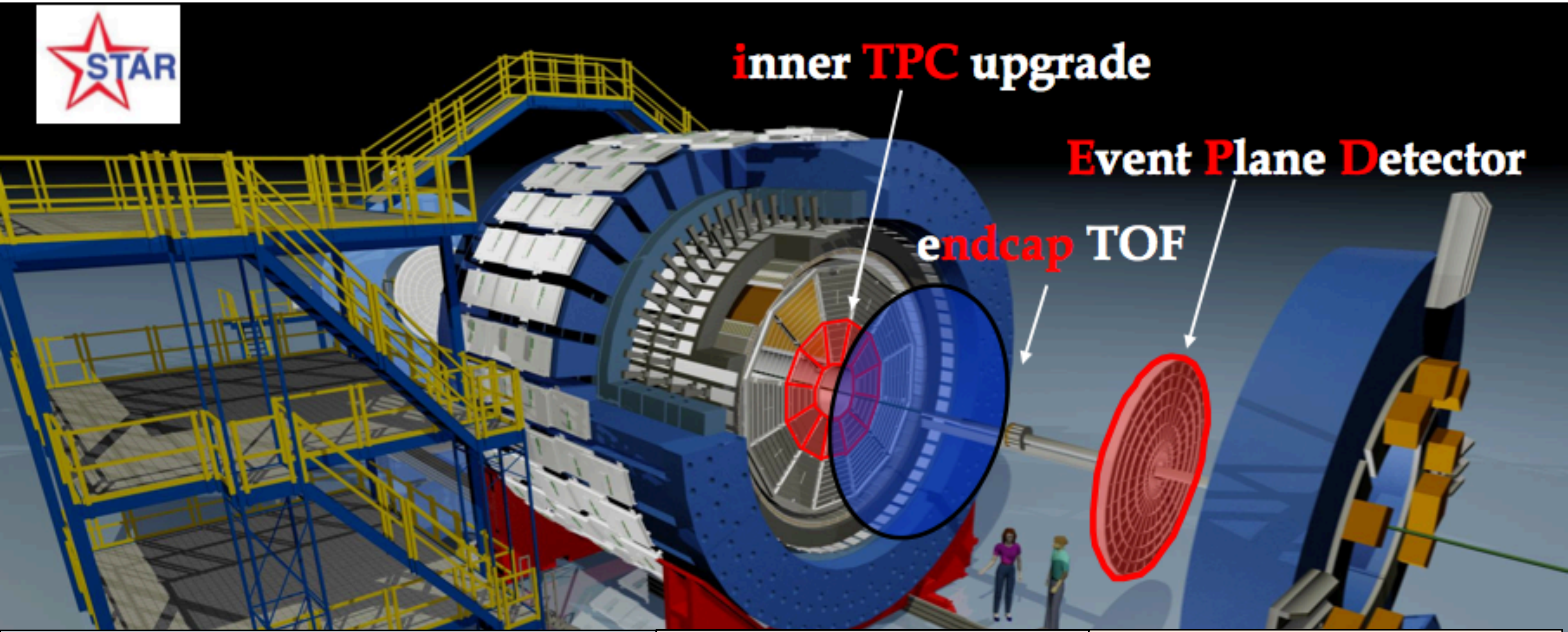
- **Extend the rapidity coverage to enhance the sensitivity with iTPC:**



✓ Non-trivial energy dependence from BES-I

✓ Rapidity length of correlation is important

Detector upgrades for BES II



<u>iTPC Upgrade:</u>

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

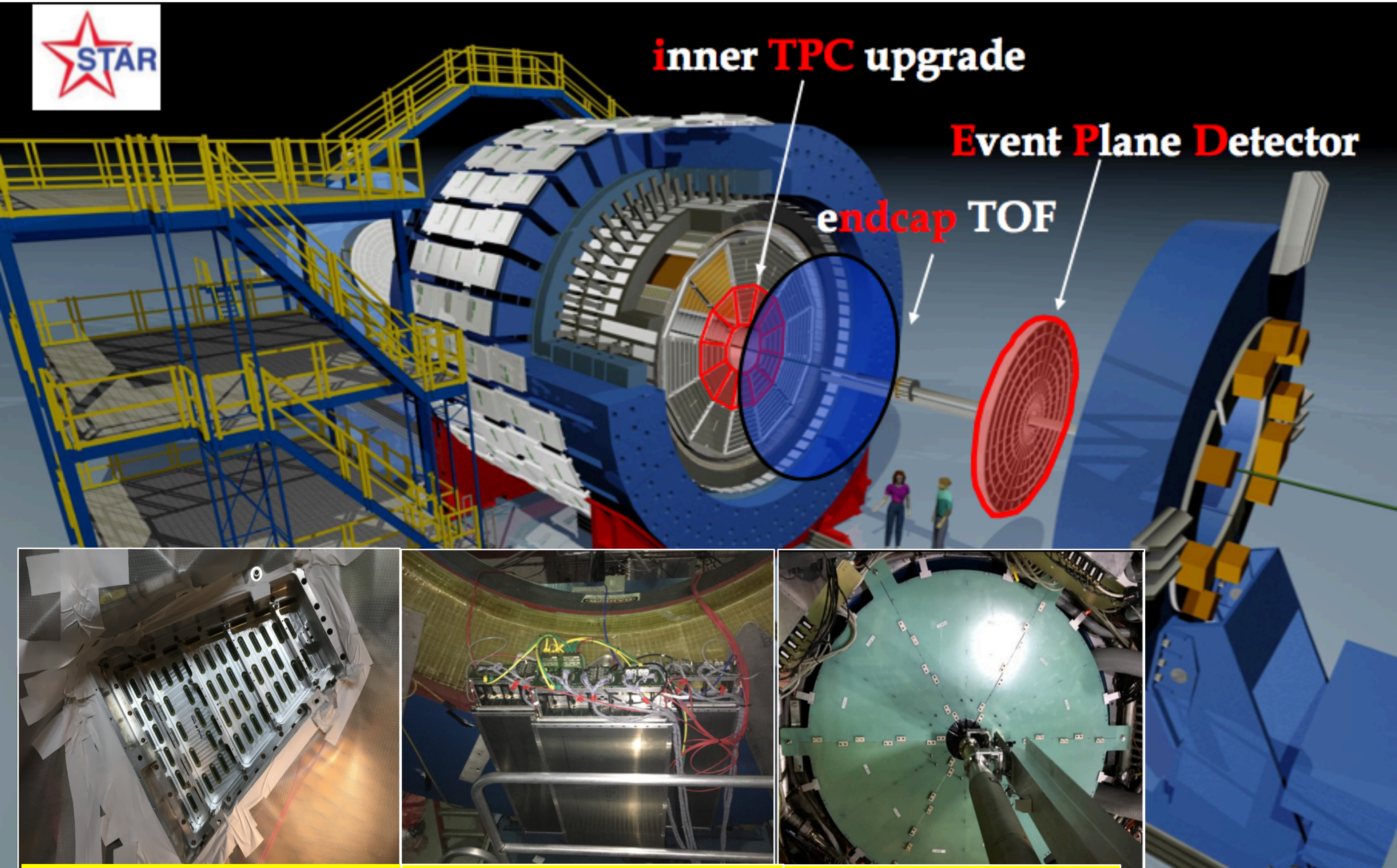
<u>EndCap TOF Upgrade:</u>

- PID at η = 0.9 to 1.5
- Allows higher energy range of Fixed-Target program
- Provided by CBM-FAIR

<u>EPD Upgrade:</u>

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

Detector upgrades for BES II



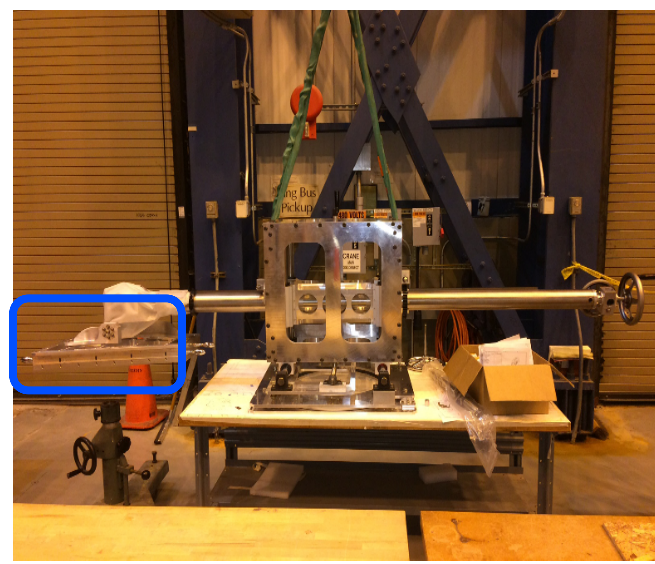
One iTPC sector has been installed

3 eTOF modules have been installed

Full EPD has been installed

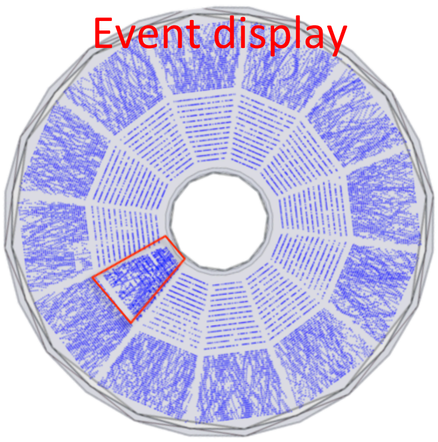
The inner TPC upgrade

- **Replace all 24 inner sectors**
  - ✓ New strongback & pad plane
  - ✓ Increase readout pad rows (13 to 40)
    -Coverage increased from 20% to ~100%
  - ✓ Renew all three wire grids
- **New electronics for inner sectors**
  - ✓ Doubled the readout channels， using ALICE SAMPA chip
- **New designed insertion tooling**
  - ✓ Removal and insertion of inner sectors
- **iTPC status**
  - ✓ One sector has been installed in Oct. 2017
  - ✓ 80% of MWPC sectors have been produced，12 sectors shipped to BNL.
  - ✓ Full installation in fall of 2018

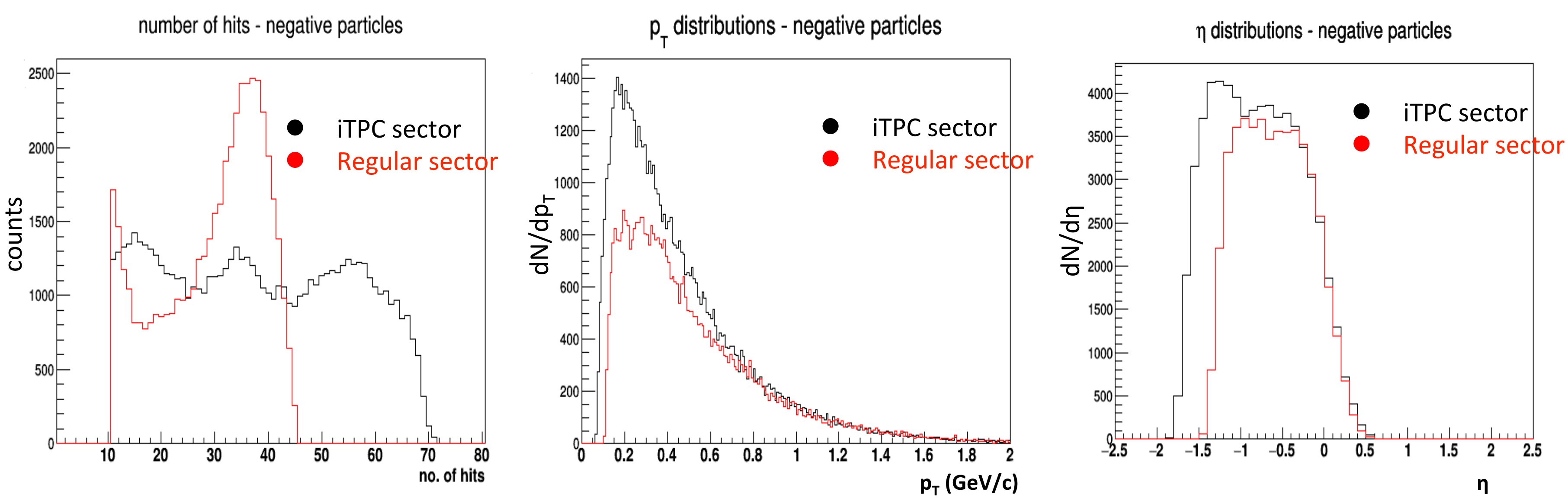


iTPC Performance

- **Excellent performance in bench test for MWPC**: [NIM A 896 (2018) 90]
  - ✓ Gas gain uniformity < 1.5% (RMS)
  - ✓ Energy resolution ~ 20% (FWHM)
  - ✓ Good stability under X-ray irradiation test

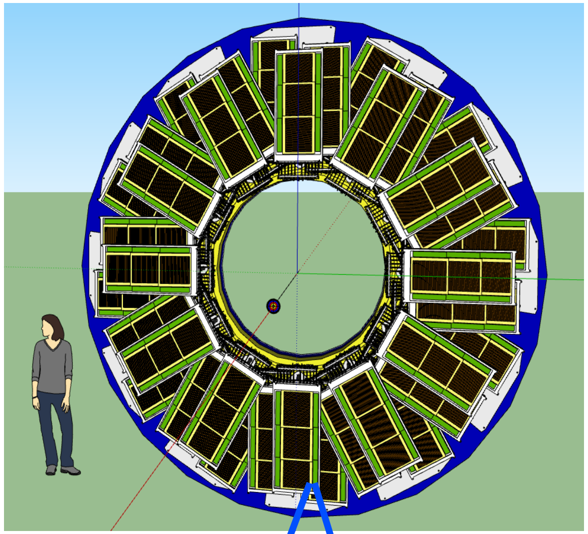


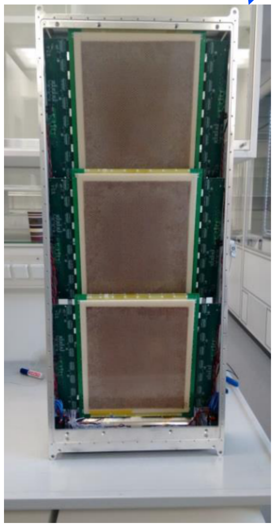
- **iTPC (one sector) performance in 2018 isobar collisions :**
  - ✓ Maximum hits number per track: 45 → 72
  - ✓ Lower transverse momentum threshold of 60 MeV/c
  - ✓ η coverage extended by 0.4 units.

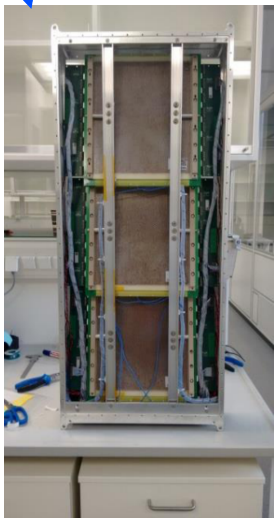


The endcap Time-Of-Flight

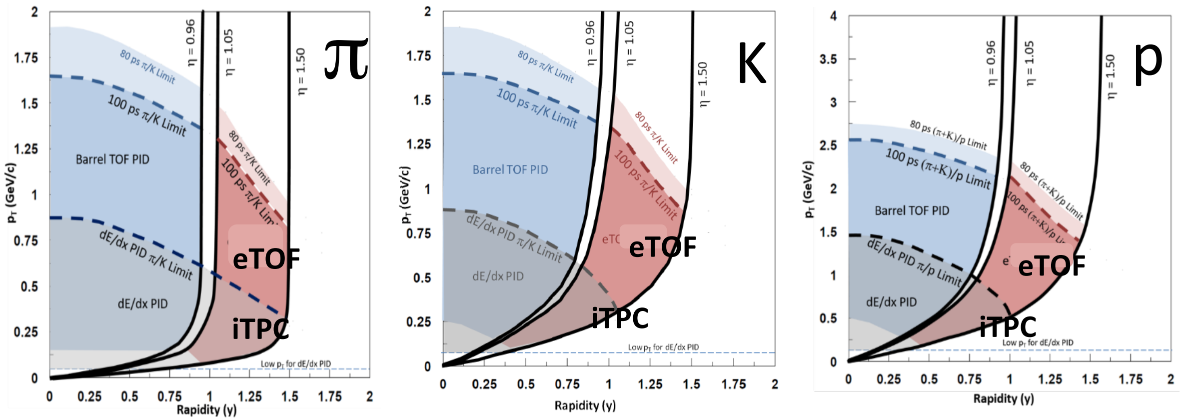
- Install, commission and use 10% of the CBM TOF modules at STAR.
- Design concept:
  - ✓ 3 layers, 12 sectors, 36 modules, 108 MRPCs
- Provides PID in the forward direction
  - ✓ Extended rapidity and yields
- **One sector with three modules has been installed for runs in 2018**
- **Full installation in November 2018**





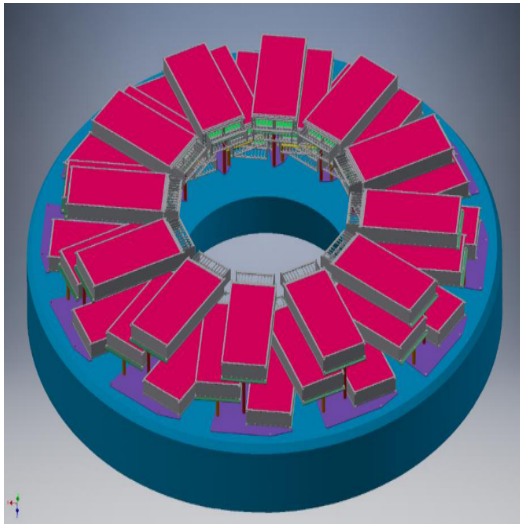


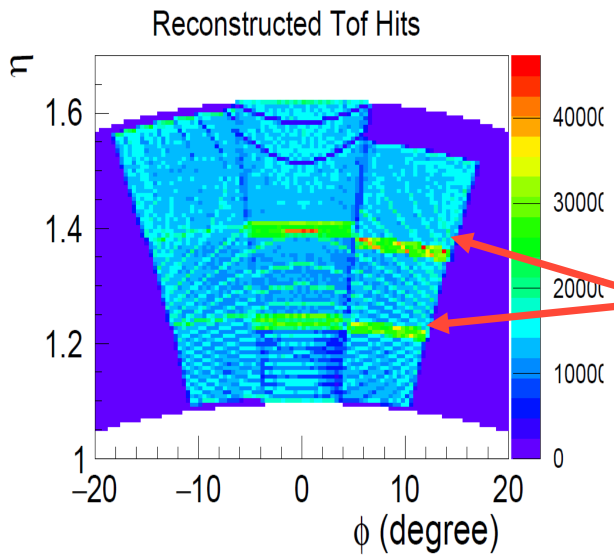
Collider mode



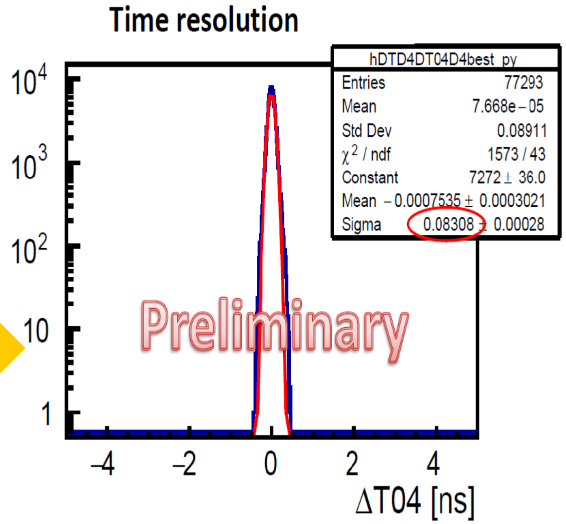
The endcap Time-Of-Flight

- Successfully commissioned in 2017 (one module)
  - ✓ Interface to STAR event builder & barrel TOF
- Engineering design for STAR module completed
  - ✓ Mounting scheme, HV distribution, gas system layout, etc.
- System integration successful → data taking in 2018
  - ✓ Reasonable η-ϕ hit distribution → eTOF working properly
  - ✓ Time resolution 59 ps





Overlap range of two MRPCs

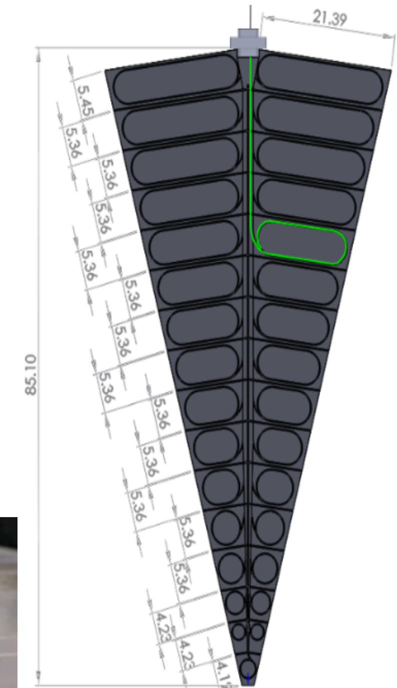


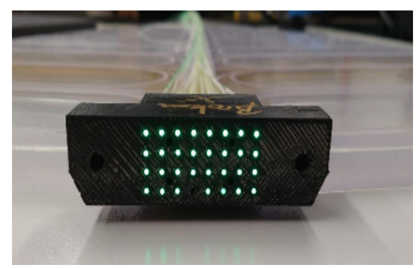
- ✓ System time resolution: 83 ps
- ✓ Counter time resolution: 59 ps

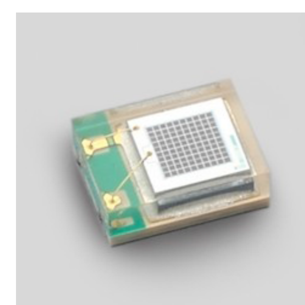
Event Plane Detector

EPD: **Scintillator + Wave Length Shifting fibers + Silicon Photon Multiplier**

- 2 Wheels
  - ✓ East and West EPD ($2.1 < |\eta| < 5.1$)
- 12 super sectors
  - ✓ Scintillator wedges, milled to form 31 tiles
  - ✓ Optically separated by epoxy
- Fiber Optics
  - ✓ Wavelength-shifting fibers
  - ✓ Grouped in 3D-printed connectors
- Sensors
  - ✓ Silicon Photon Multiplier (SiPM)

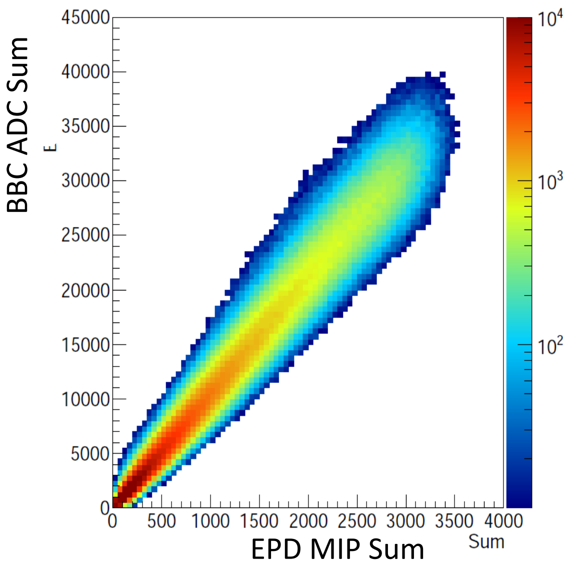


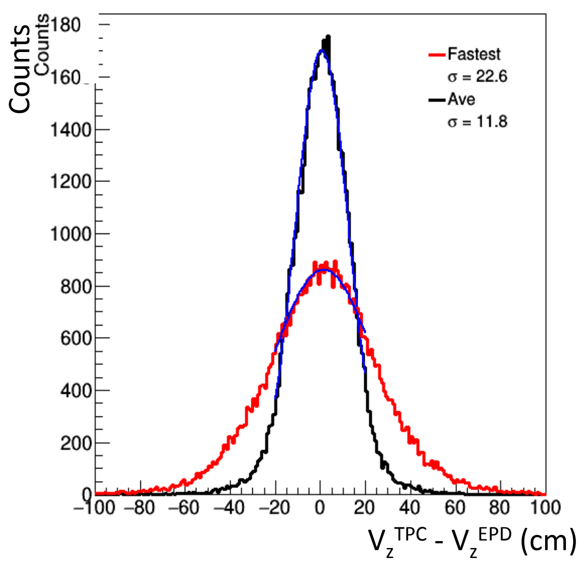


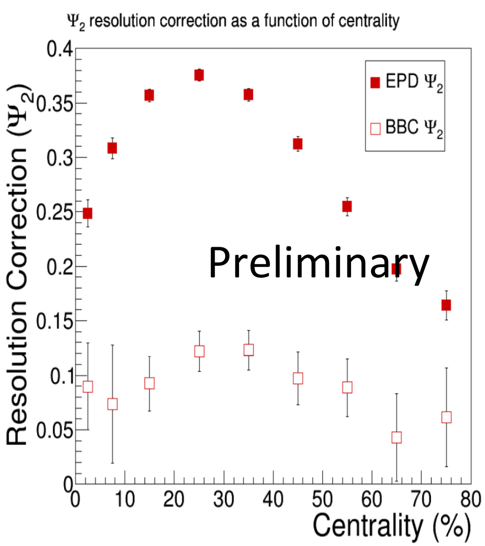


EPD Performance

- Measure current in SiPM using Strontium source
  - ✓ Tile uniformity within 2%, cross-talk less than 1%
- All 744 tiles are good
- Good correlation between BBC and EPD → correct timing
- Timing resolution is about 0.75 ns with fastest TAC method
  - ✓ 0.35 ns with average TAC method, raw slewing correction
- The second-order event plane resolution is 0.37 in 20-30% centrality in the run 18 isobar collisions, significantly improved compared using BBC.

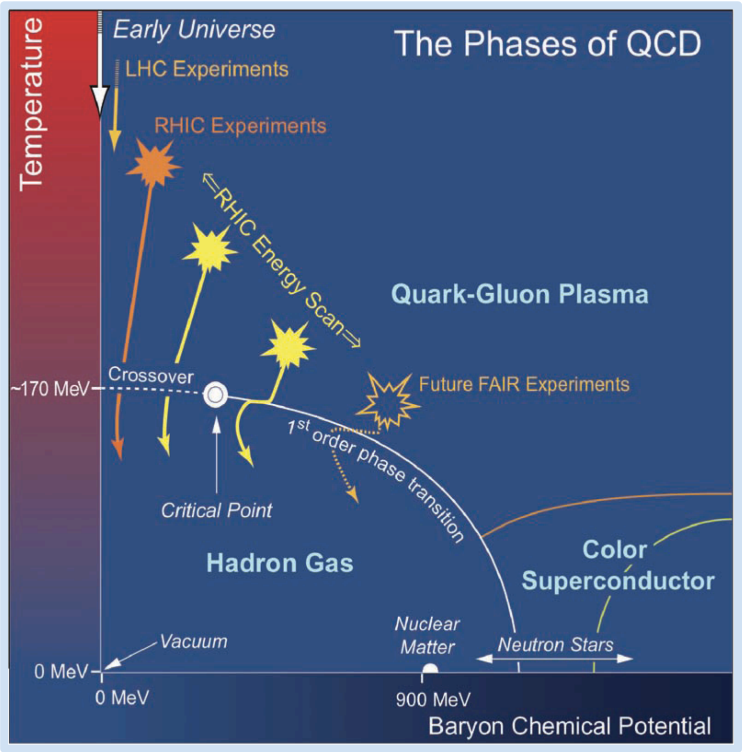






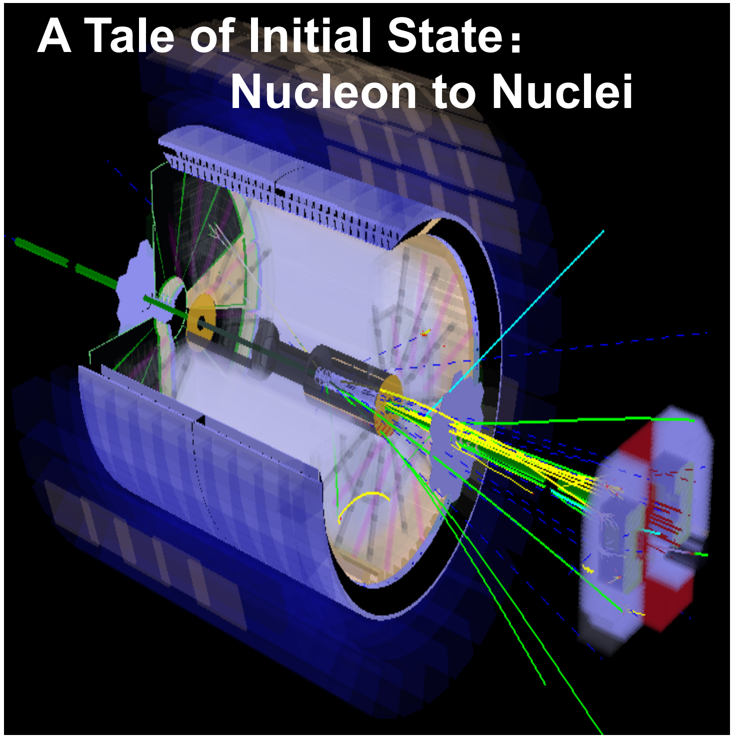
Looking Forward at STAR

Beam Energy Scan II
2019~2021



iTPC, eToF, EPD

Forward Physics
2021+



- ✓ Forward Tracking System
- ✓ Forward Calorimeter System

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0669

Physics motivation I- (un)polarized pp/pA

- Measurements planed in 2021+ with forward upgrade:

$\sqrt{s}$ (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
$p^{\uparrow}p$ @ 200	300 pb^{-1} 8 weeks	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	1.8 pb^{-1} 8 weeks	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	12.6 pb^{-1} 8 weeks	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	1.1 fb^{-1} 10 weeks	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	1.1 fb^{-1} 10 weeks	$\Delta g(x)$ at small x	A_{LL} for jets, di-jets, h/γ-jets at $\eta > 1$	Forward instrum. ECal+HCal

2 THE PHYSICS OF THE FORWARD UPGRADE

2.1 TRANSVERSE POLARIZATION EFFECTS IN THE PROTON: TWIST-3 AND TMDS

2.2 TRANSVERSITY, COLLINS AND INTERFERENCE FRAGMENTATION FUNCTIONS

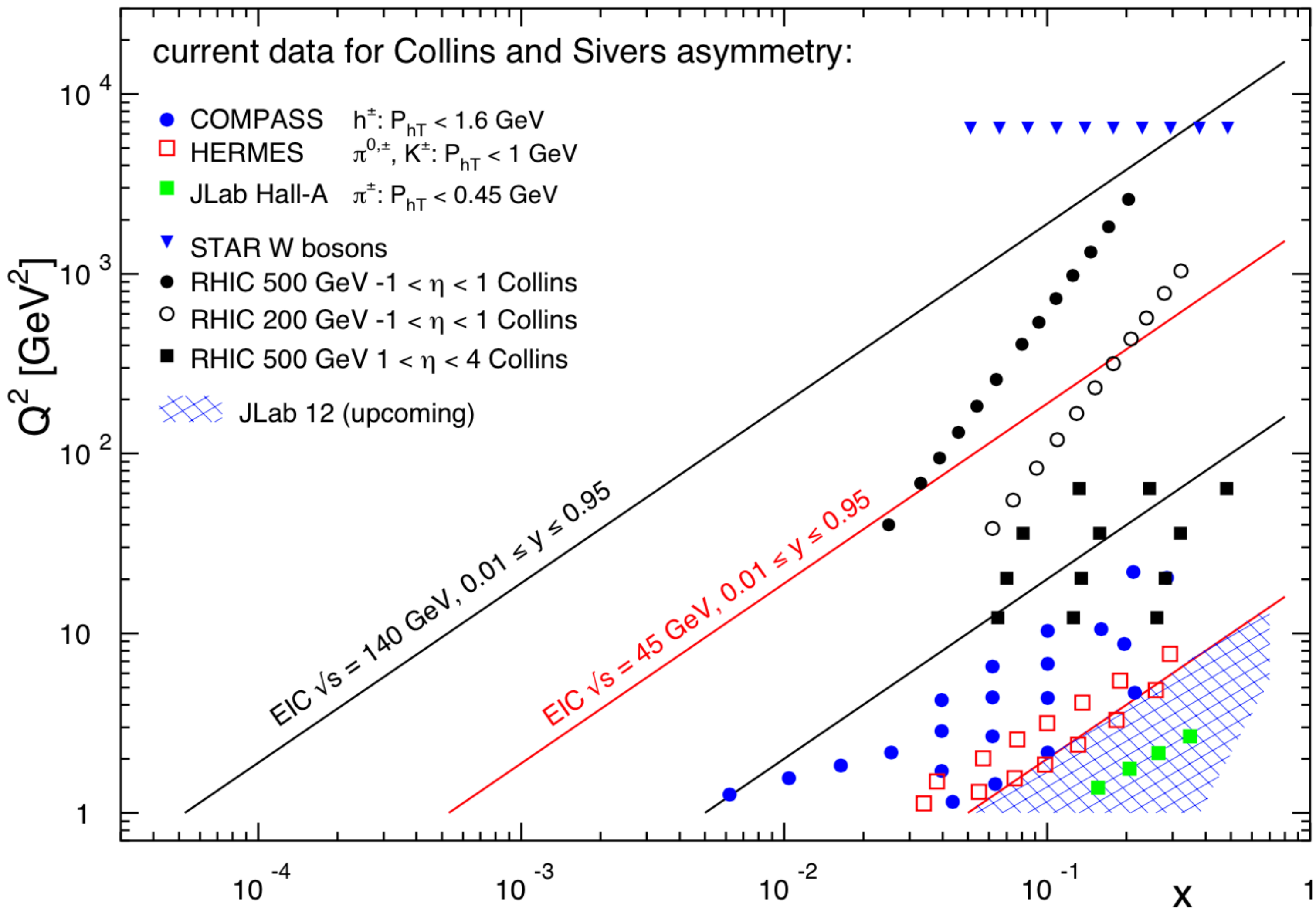
2.2.1 OPPORTUNITIES WITH A FUTURE RUN AT 500 GEV

2.3 USING DIJETS TO ACCESS ΔG AT $\sqrt{s}$ = 500 GEV

2.4 PHYSICS OPPORTUNITIES WITH (UN)POLARIZED PROTON-NUCLEUS COLLISIONS

Example: TMD-Collins and Sivers asymmetry

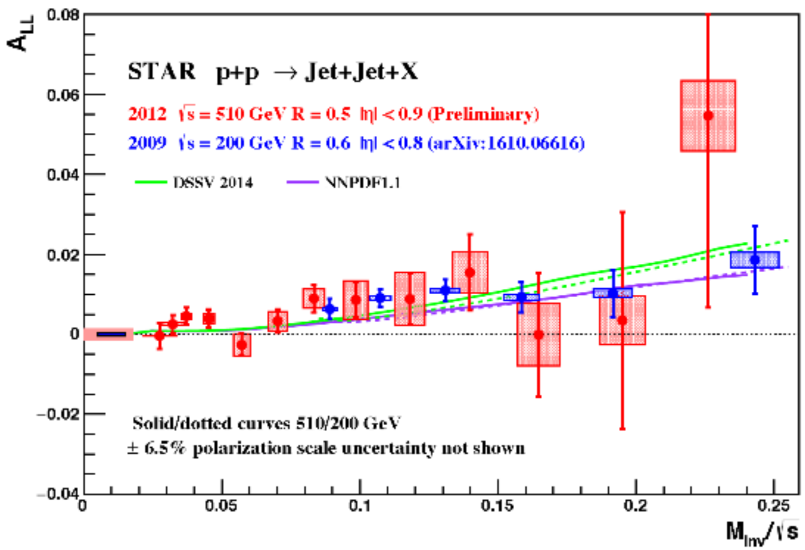
- STAR unique kinematics with polarized pp at RHIC: from high to low x at high Q^2



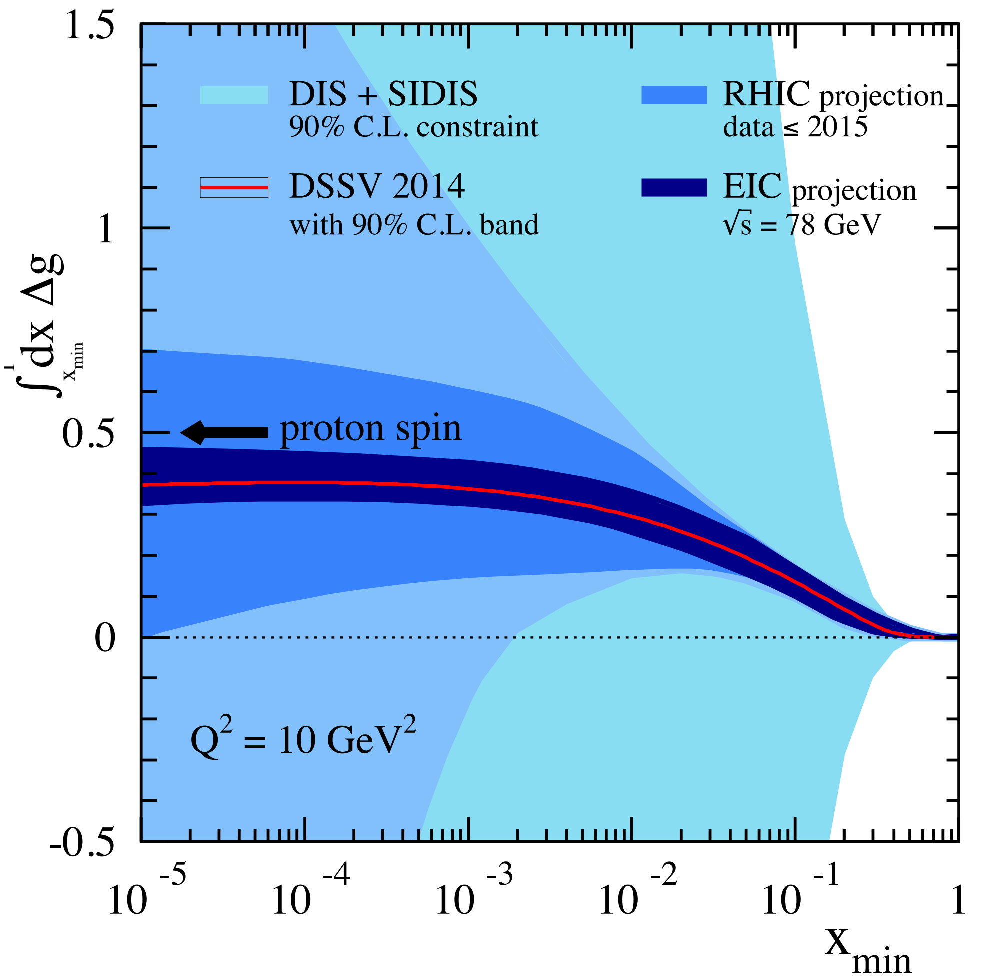
Example: forward jets to constrain Δg at small x

- Significant contribution from gluon spin to proton spin found at RHIC:

  ✓ Further constraint can be obtained with forward di-jet spin asymmetry measurements.

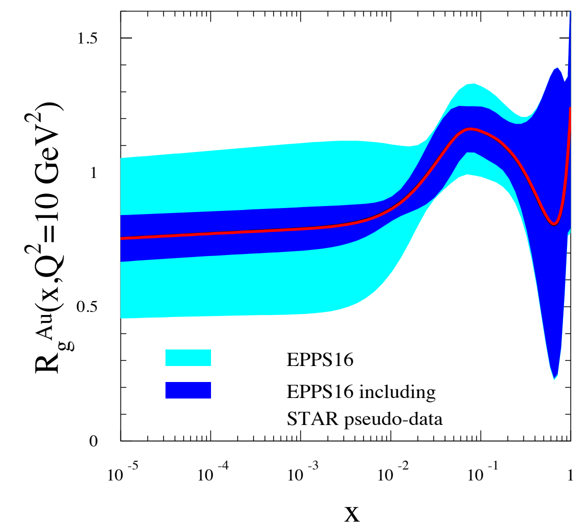


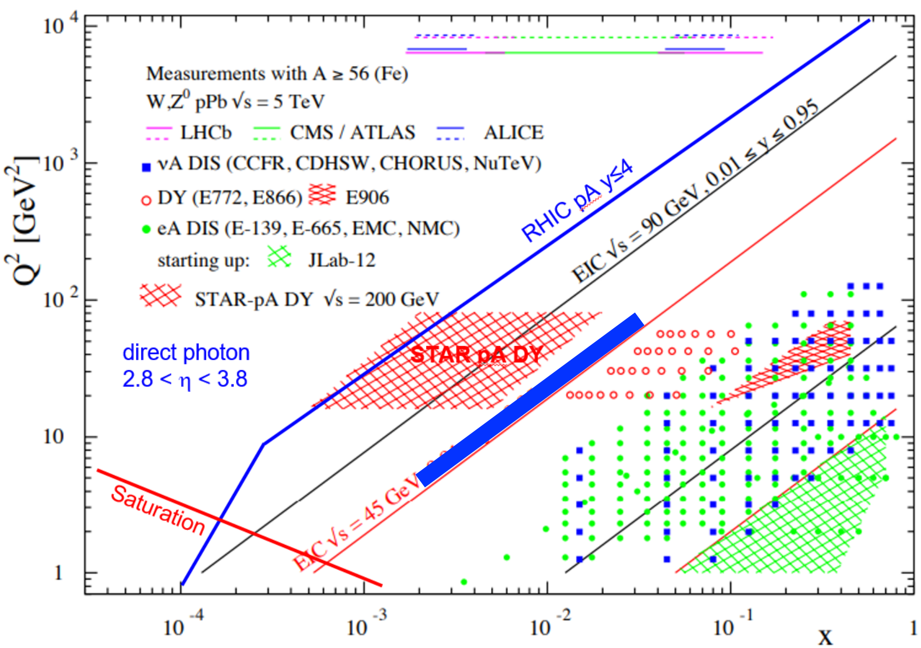
Phys. Rev D**95** 71103 (2017)



Example: initial state in heavy ion collisions

- pA at RHIC: unique kinematics coverage:
  - ✓ What are the nPDFs at low-x?
  - ✓ How saturated is the initial state of the nucleus?
  - ✓ What is the spatial transverse distribution of nucleons and gluons?





- ✓ Can measure nPDF in a x-Q^2 region where nuclear effects are large
- ✓ Observables free of final state effects
  - Gluons: R_{pA} for direct photons
  - Sea-quarks: R_{pA} for DY
- ✓ Scan A-dependence prediction by saturation models
- ✓ Access saturation regime at forward rapidity

Physics motivation II- AA

- Measurements planed in 2021+ with forward upgrade:

Physics Measurements		Longitudinal de-correlation $C_n(\Delta\eta)$ $r_n(\eta_a,\eta_b)$	η/s(T), ζ/s(T)	Mixed flow Harmonics $C_{m,n,m+n}$	Ridge	Event Shape and Jet-studies
Detectors	**Acceptance**					
Forward Calorimeter **(FCS)**	$-2.5 > \eta > -4.2$ E_T (photons, hadrons)	One of these detectors necessary		One of these detectors necessary	Good to have	One of these detectors needed
Forward Tracking System **(FTS)**	$-2.5 > \eta > -4.2$ (charged particles)		Important		Important	

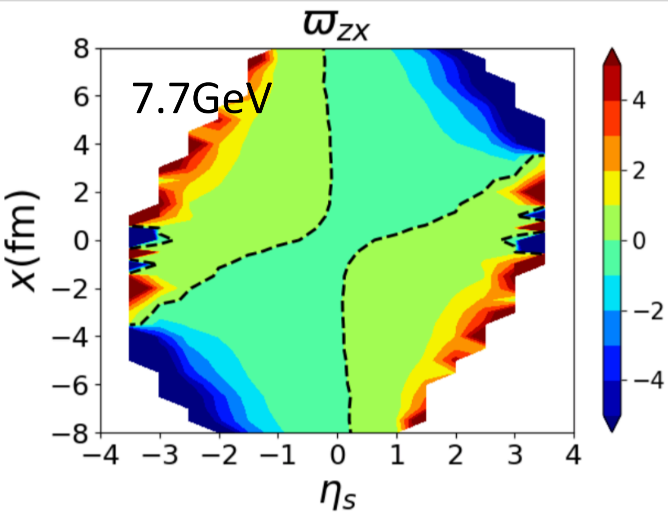
2.5 RIDGE IN P+P, P+A AND A+A

2.6 CORRELATION MEASUREMENTS TO CHARACTERIZE HOT AND DENSE NUCLEAR MATTER

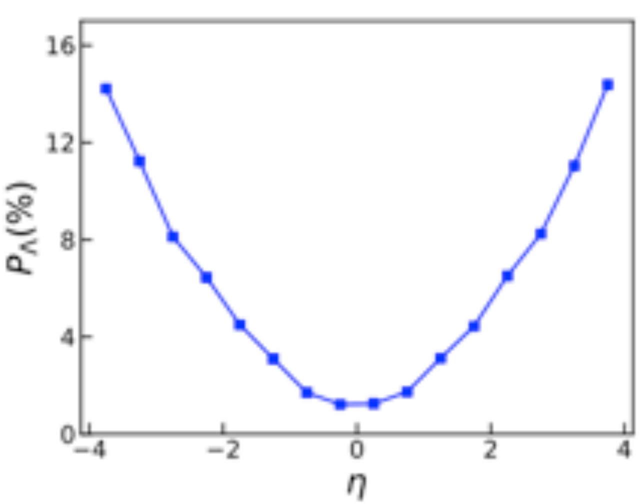
2.6.1 A MORE PRECISE ESTIMATION OF FLOW THROUGH MEASUREMENTS OF LONG-RANGE CORRELATIONS

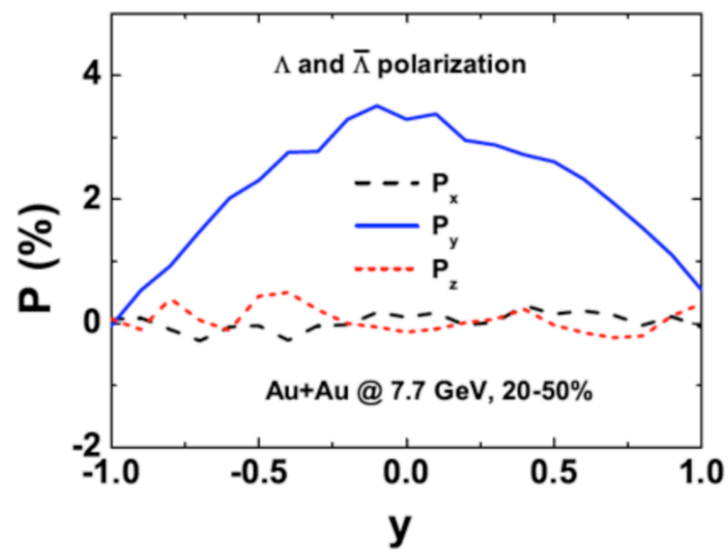
2.6.2 CONSTRAINING LONGITUDINAL STRUCTURE OF THE INITIAL STAGES OF HEAVY ION COLLISIONS

Global Polarization in the forward region



- ✓ Polarization increases with viscosity
- ✓ Rapidity dependence is key
- ✓ Different models predict opposite rapidity trend





Hydrodynamic calculations:
Li,Pang,Wang & Xia, PRC 96 (2017) 054908; (private comm.)
F. Beccattini et al. EPJC 75(2015)406;

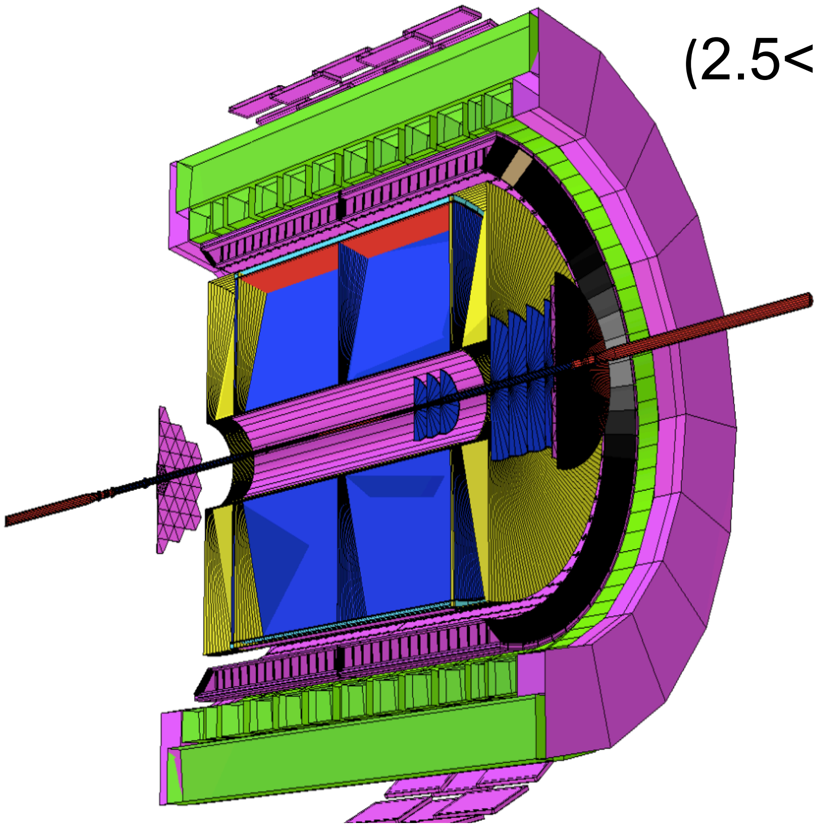
Y. Sun& C. M., Ko, PRC96, 024906 (2017)

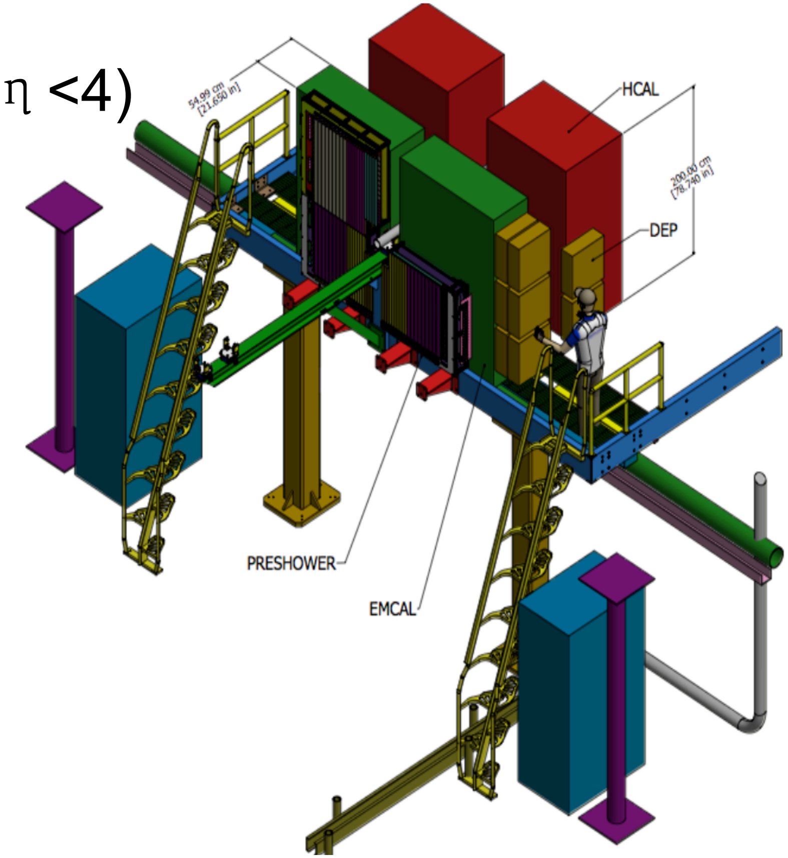
Forward upgrade: FTS+FCS

Forward Tracking System

Forward Calorimeter System

(2.5< η <4)





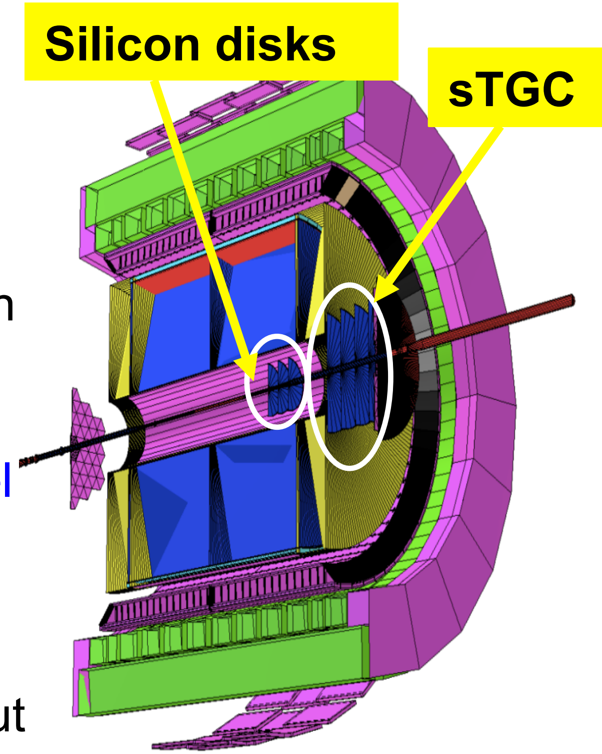
Silicon + sTGC

EM Cal + HCal

Forward Tracking System

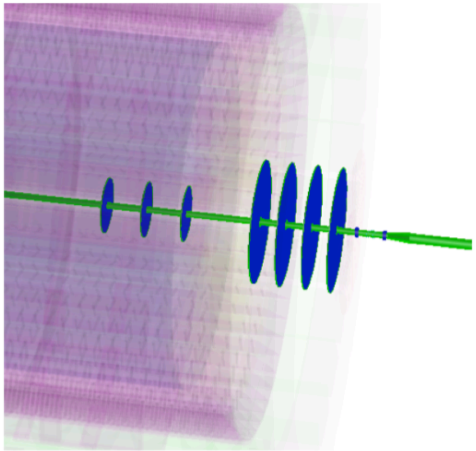
STAR Forward Tracking System (2.5 < η < 4.0)**:**

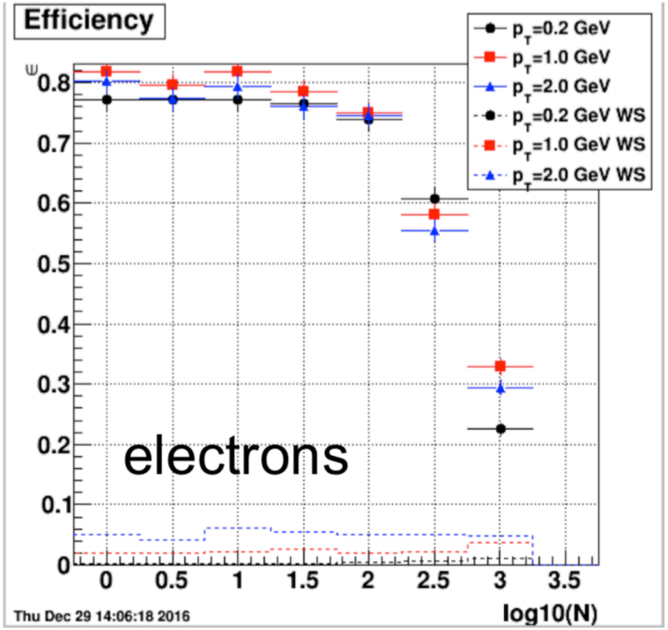
- 3 layers of silicon mini-strip disk
  - ✓ Location from IP: 90, 140, 187 cm
  - ✓ Successful experience of STAR Intermediate Silicon Tracker (IST) detector.
- 4 layers of Small-Strip Thin Gap Chamber (sTGC) wheel
  - ✓ Location from IP: 270, 300, 330, 360 cm
  - ✓ Significant reduction of the project cost
  - ✓ Possible reuse of STAR TPC electronics for readout
- Detector requirements
  - ✓ Momentum resolution: 20-30% for $0.2 < p_T < 2$ GeV/c (AA)
  - ✓ Tracking efficiency: 80% at 100 tracks per event (AA)
  - ✓ Charge separation (pp/pA)
- Cost: $3.3M – mostly will be covered by China consortium +UIC+ BNL

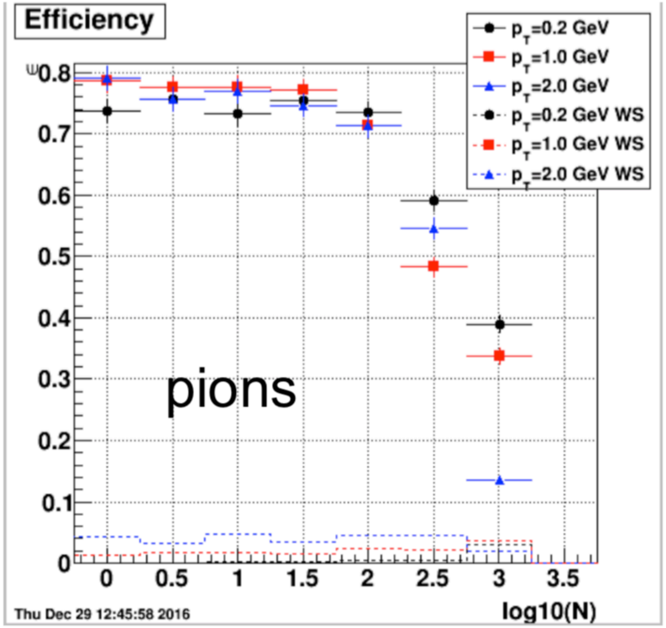


STAR FTS simulation

- FTS in STAR simulation framework
  - ✓ 3 silicon + 4 sTGC
  - ✓ Tracking efficiency 70%~80% for tracking number 10~100
  - ✓ Wrong charge sign: a few percent
  - ✓ Equivalent to 6 silicon disks option



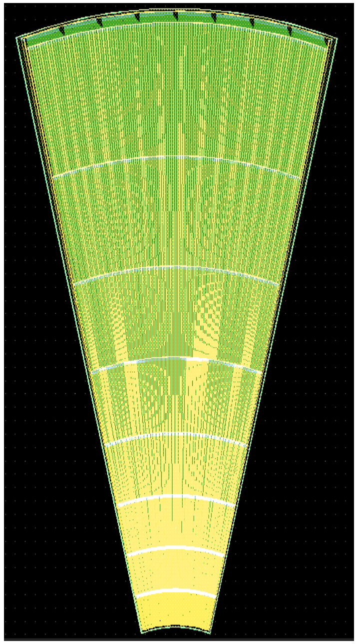


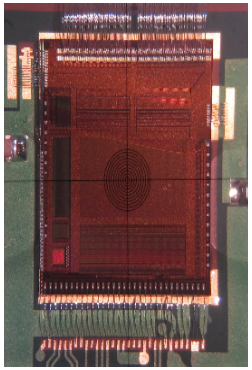


Forward Tracking System-Silicon

3 Silicon disks:

- 12 wedges, each with 128 strips in ϕ at fixed *r* and 8 strips in the *r* direction.
- Single-sided double-metal Silicon Mini-strip sensors
  - ✓ under development @UIC
- Several different frontend chips, APV25-S1 chip → IST
- IST DAQ system for FTS if using APV25-S1
- Replicating the STAR IST cooling system to cool the FTS
- Monte Carlo Simulation
  - ✓ Performance and layout optimization of Silicon sensors underway



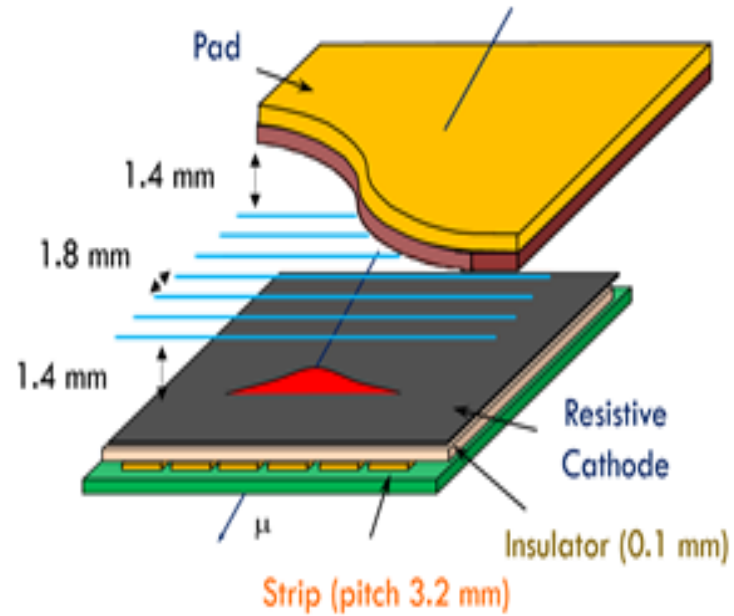


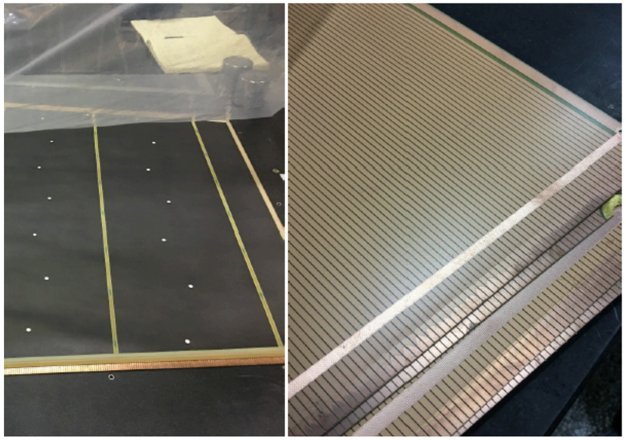
APV25-S1

Forward Tracking System-sTGC

4 sTGC disks:

- Use ATLAS technique at SDU
- Position resolution ~ 100 μm
- Two layers each disk (90^o angle), to provide x-y position.
- Signal seen by testing ATLAS module using STAR TPC electronics.
- Material budget: ~ 0.5% per layer.
- 1st sTGC prototype for STAR to be made at SDU in 2018
  - ✓ ¼ size of ATLAS sTGC in length
  - ✓ 30 cm x 30 cm module with 2 layers
  - ✓ Strip of 30 cm each

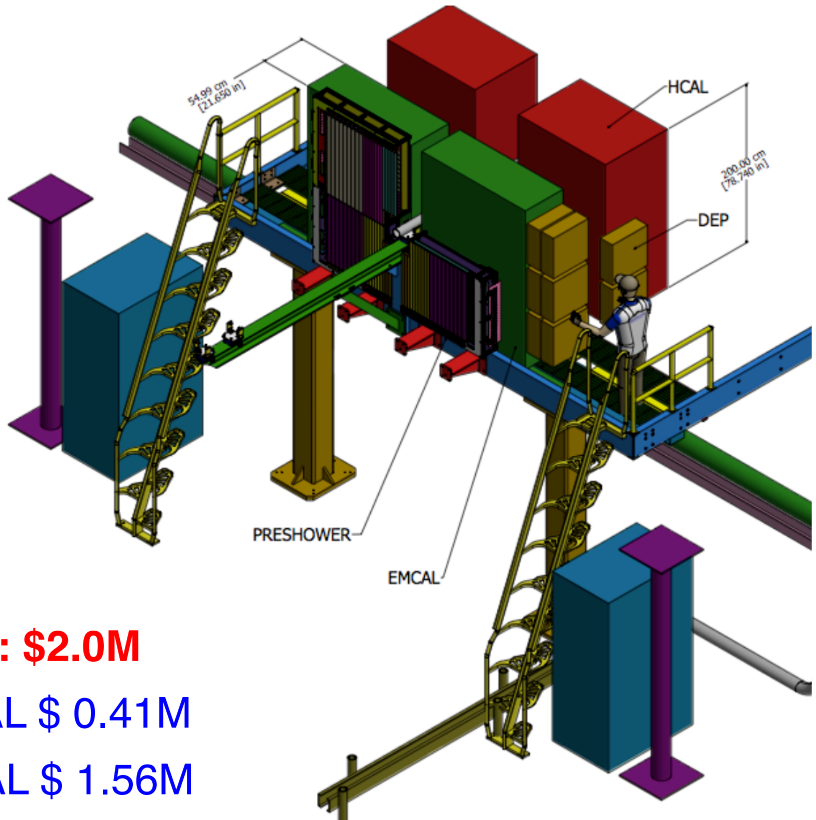




Forward Calorimeter System

- FCS Requirements for different physics:

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



Cost: $2.0M

-ECAL $ 0.41M

-HCAL $ 1.56M

-Preshower $ 0.06M

-Covered in the U.S.

Preshower detector

EM Calorimeter

- **PHENIX PbSc**
- **New readout SiPM/APD**
- **Not compensated**

Hadronic Calorimeter

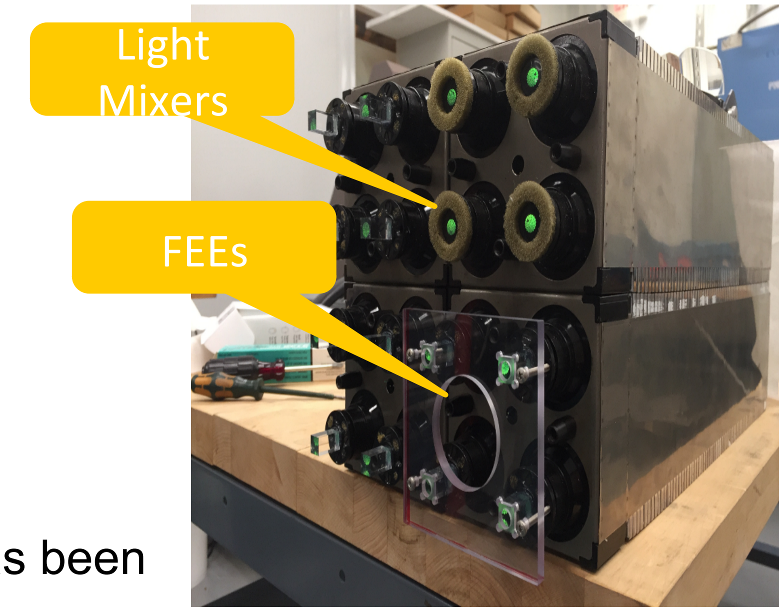
- **Sampling iron-scintillator**
- **Same readout as EMC**

✓ Calorimeter R&D as part of EIC study

✓ Balance of cost and performance

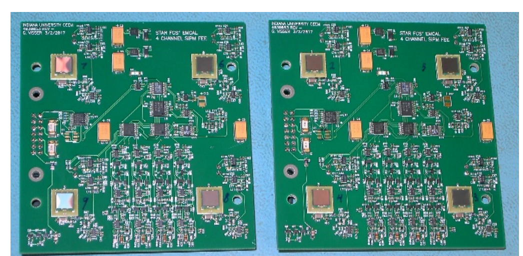
Forward Calorimeter System

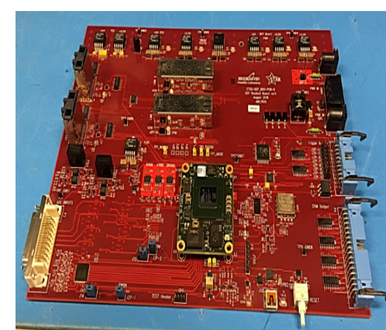
- Intensive R&D work on both ECal and HCal as part of STAR and EIC R&D
- Test FCS' ECal in STAR at 2017
  - ✓ Sampling Calorimeter
  - ✓ FEEs
  - ✓ Sensors with help from EIC R&D
    - ✓ SiPMs, Hammamastsu 6x6 mm^2
  - ✓ Digitizers
- FEEs and Detector Electronics Platform has been fully integrated to STAR
- In 2018
  - ✓ Large scale ECal prototype
  - ✓ 2^{nd} iteration of FEEs and DEP
  - ✓ HCal towers



Detector Electronics Platform (DEP)

FEEs





Summary

- **BES-II related detector upgrades show excellent progress:**
  - ✓ iTPC : one sector installed, good performance obtained. 80% sectors produced.
  - ✓ EPD : fully installed, good event plane resolution obtained.
  - ✓ eTOF : one sector installed, engineering design completed.
  - ✓ Full installation of iTPC and eTOF in fall of 2018 for the BES-II program (2019-2021).

- **STAR forward upgrade enables unique opportunities to cold QCD and HI physics in 2021+ during sPHENIX time:**
  - ✓ Forward Tracking System: Silicon + sTGC

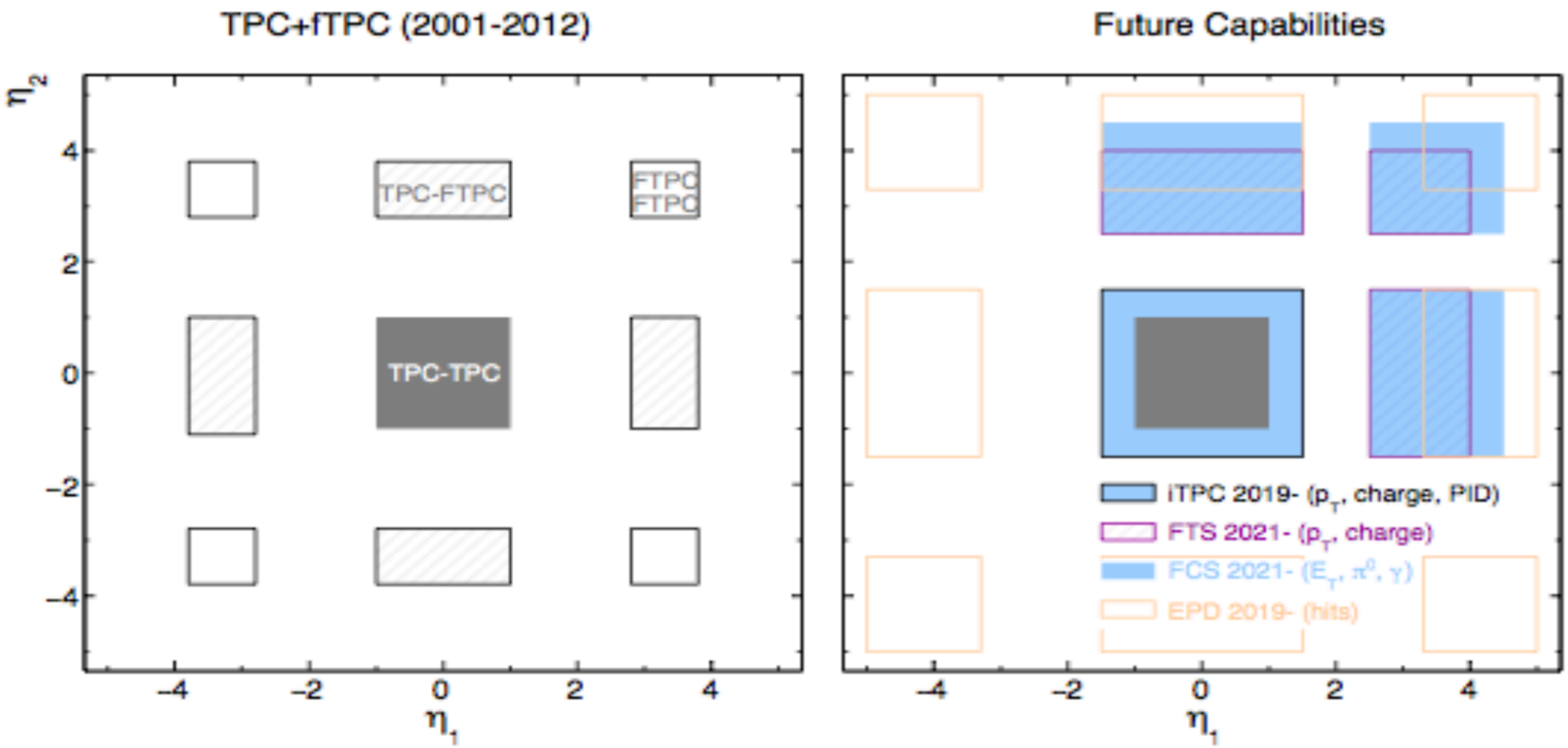
    - sTGC prototype to be made at SDU, planning test in 2019 at STAR.

    - Intensive R&D of Silicon sensors is ongoing at UIC&NCKU
  - ✓ Forward Calorimeter System: Ecal + Hcal

    - Large scale prototype calorimeter beam test planned early 2019 at Fermilab

Backup

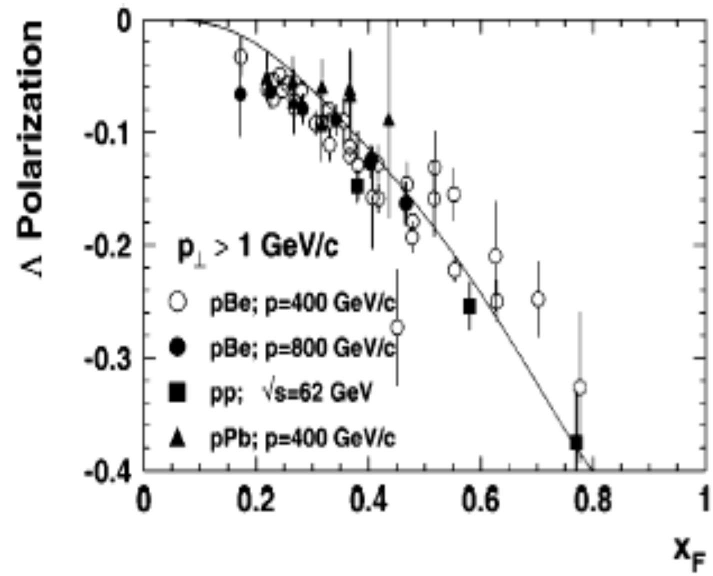
Example: Correlation Measurements to Characterize QGP



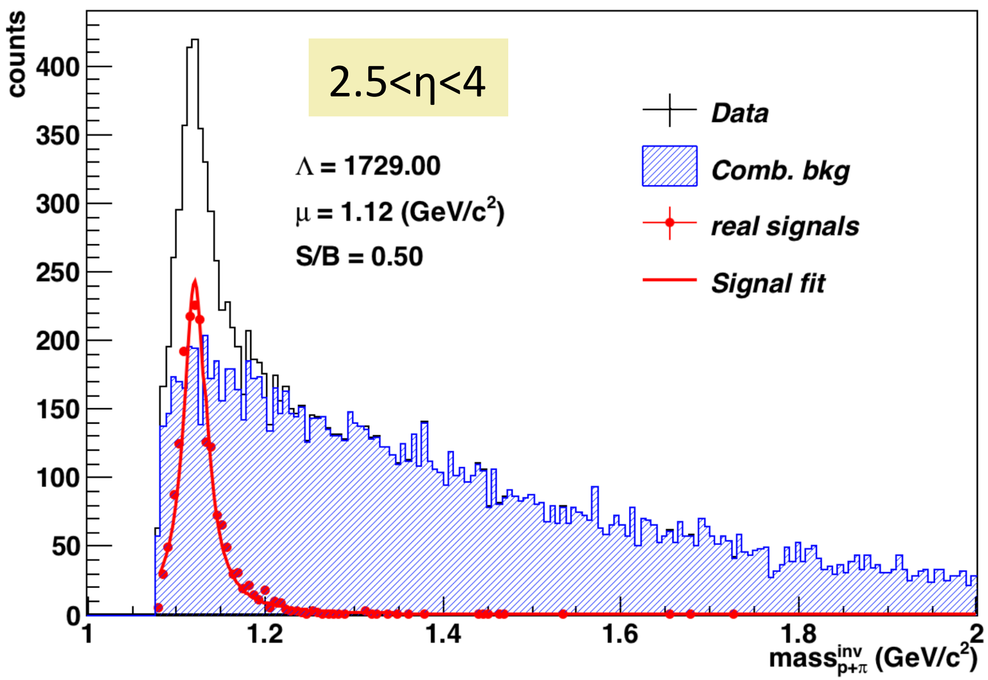
- ✓ The correlation at forward rapidity constrains the longitudinal structure of initial conditions
- ✓ Probe small x PDF with forward jets and forward-backward jet correlations
- ✓ Forward jet quenching and QGP tomography

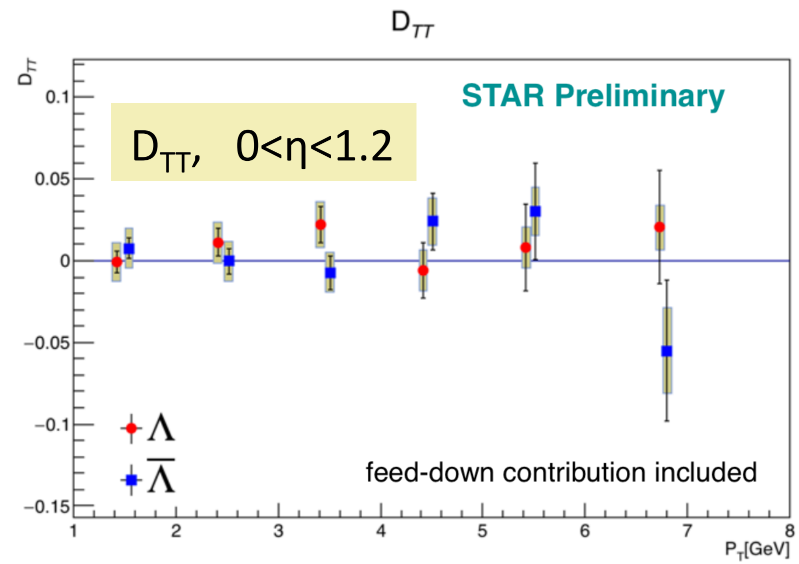
Example: forward hyperon polarization in pp

- Induced Λ polarization in unpolarized pp
- Spin transfer in both longitudinal and transverse polarized pp : D_{LL} & D_{TT}
  - -Sizable effects expected in forward region

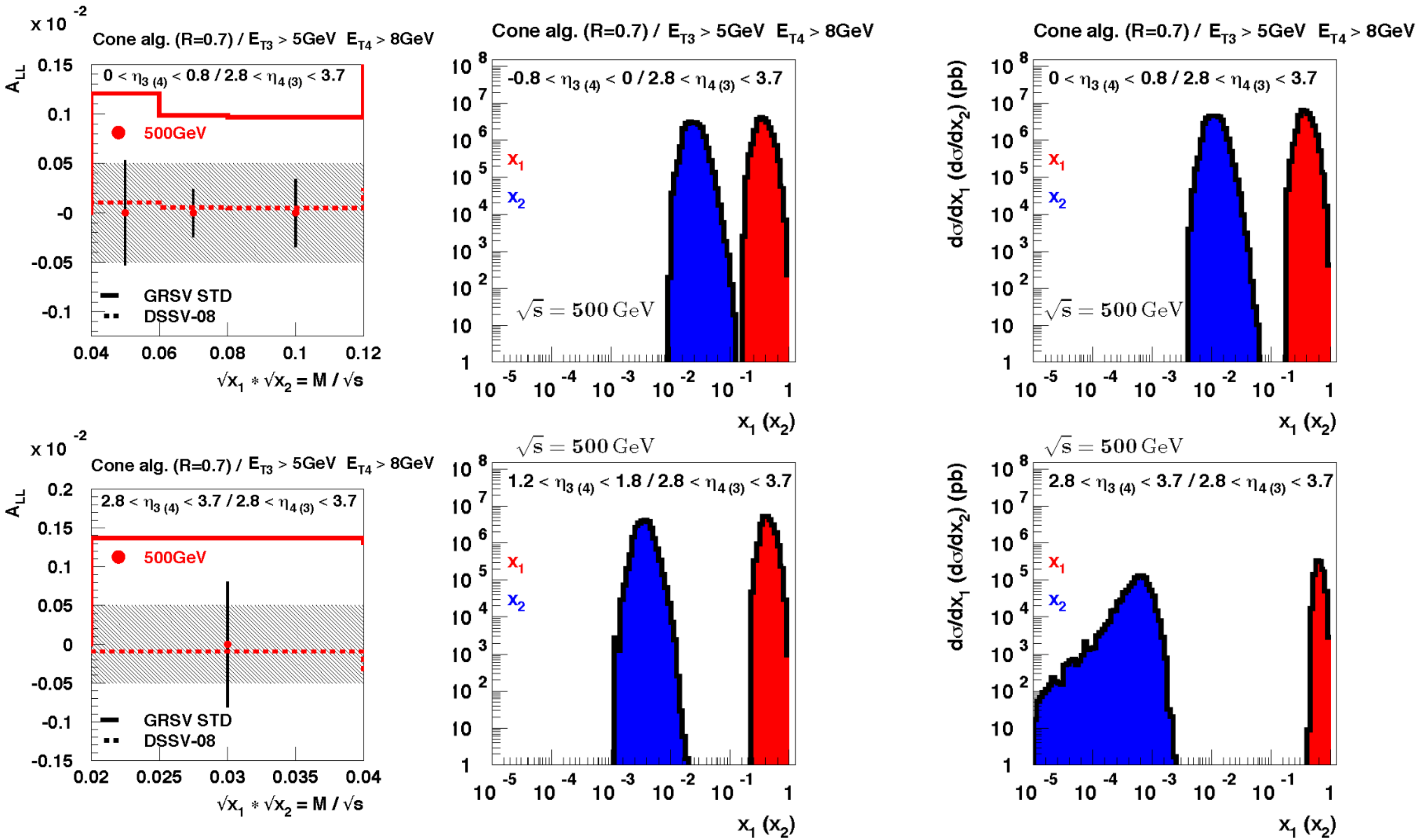


MC with FCS+FTS in pp:



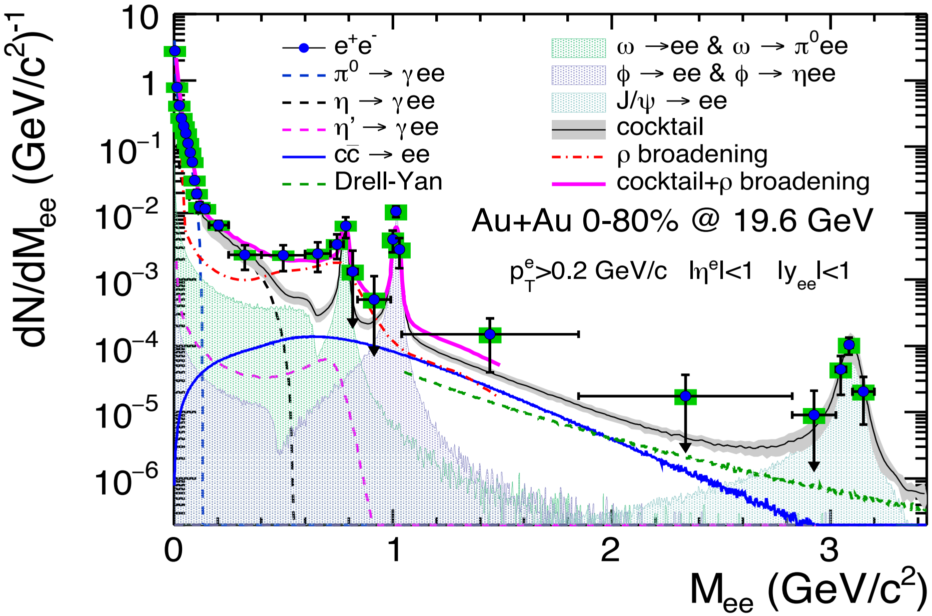


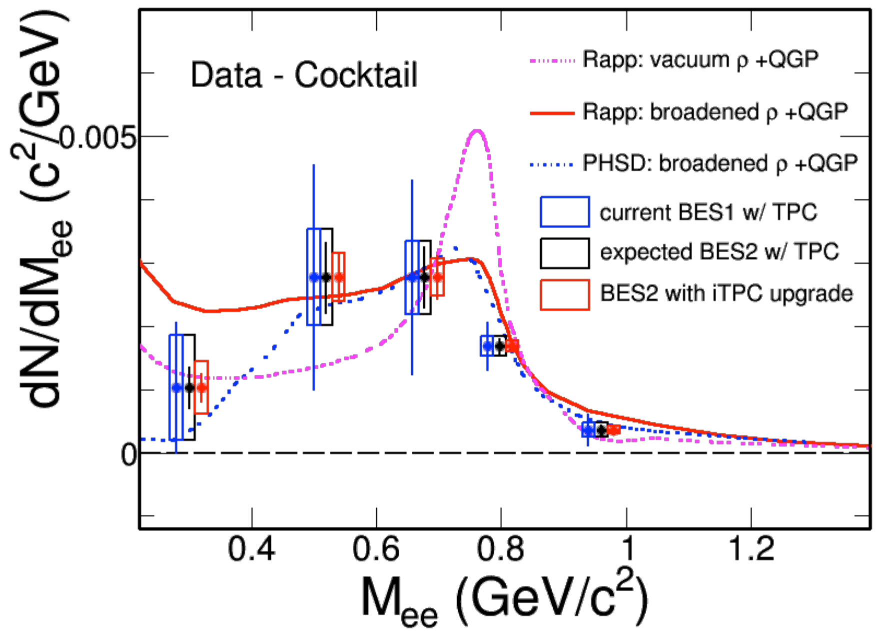
Example: forward jets to constrain Δg at small x



Di-lepton measurement- Chiral Symmetry Restoration

- **Reduce the systematic uncertainty for di-lepton:**





- ✓ **Systematically study di-electron continuum from $\sqrt{s_{NN}}$ = 7.7 -19.6 GeV**
- ✓ **Low invariant Mass Range (LMR) excess → chiral symmetry restoration**