STAR Upgrades

Daniel Brandenburg (Shandong University / BNL-CFNS)

→ for the **STAR Collaboration**

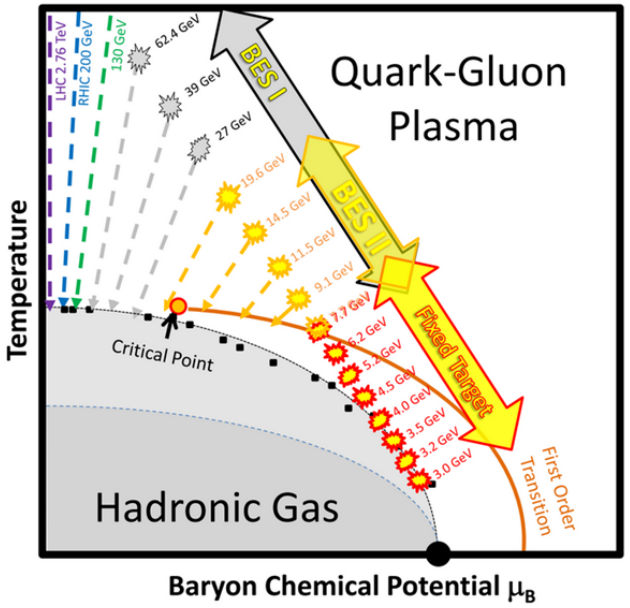
Initial Stages 2019

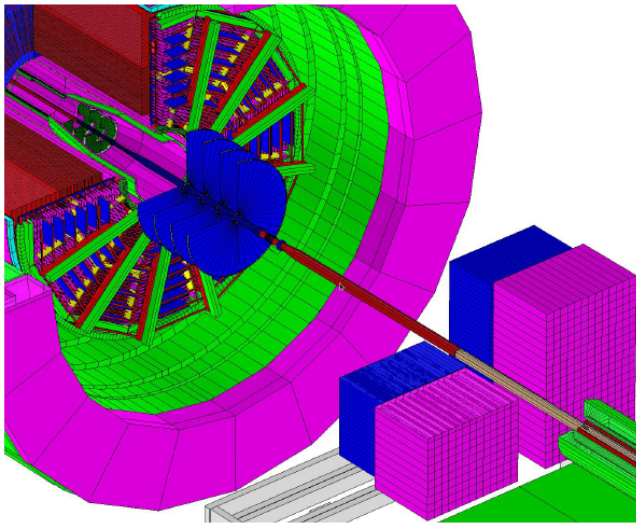
June 24-27, 2019

Columbia University, NY

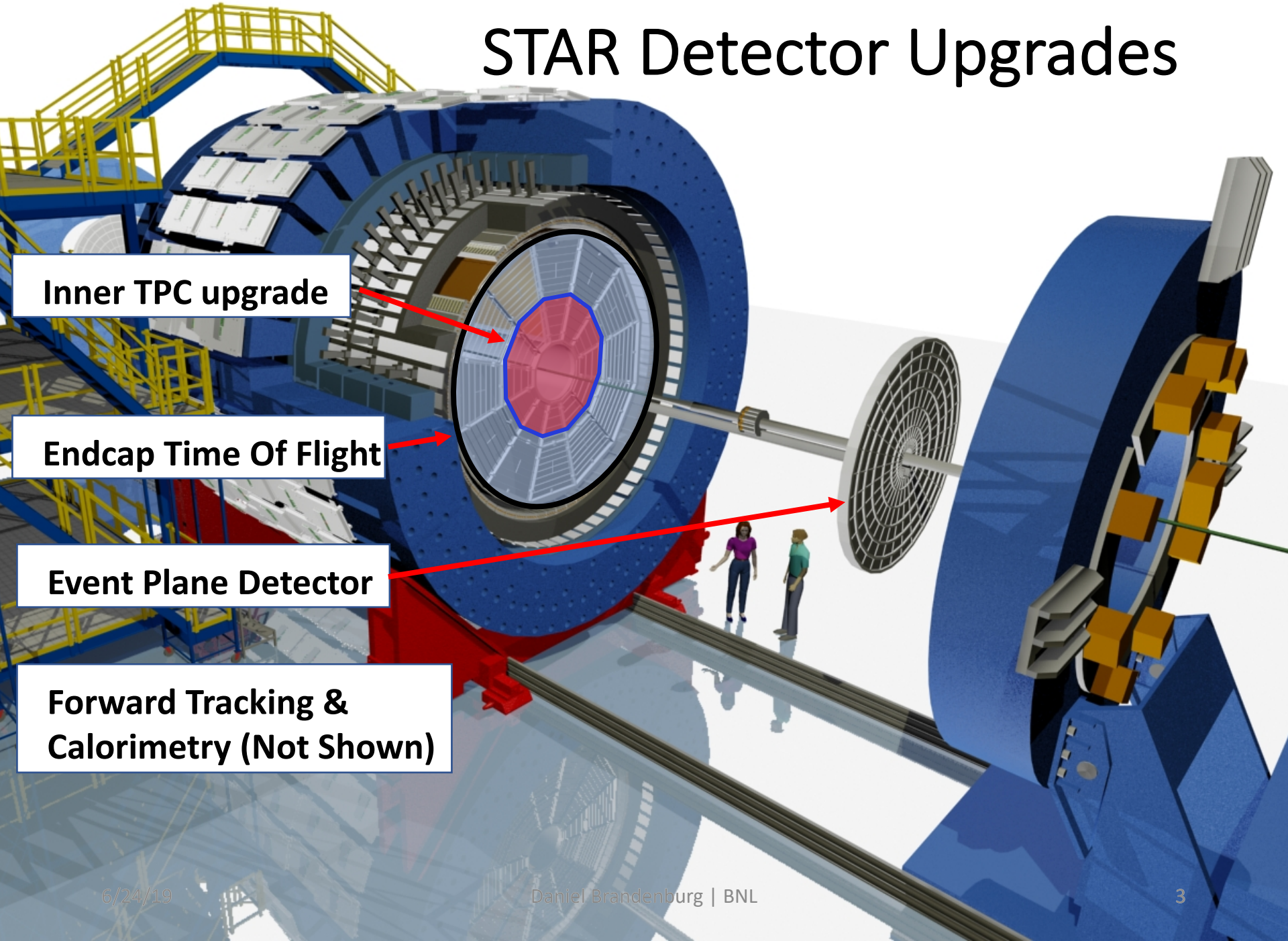
STAR Upgrades : Outline

- STAR Upgrades for BES II
  - Upgrade of the Inner TPC
  - Event Plane Detector
  - Endcap Time-of-Flight
- Forward Rapidity Physics
- The STAR Forward Upgrade
  - Tracking
  - Calorimetry
- Looking Forward
- Summary





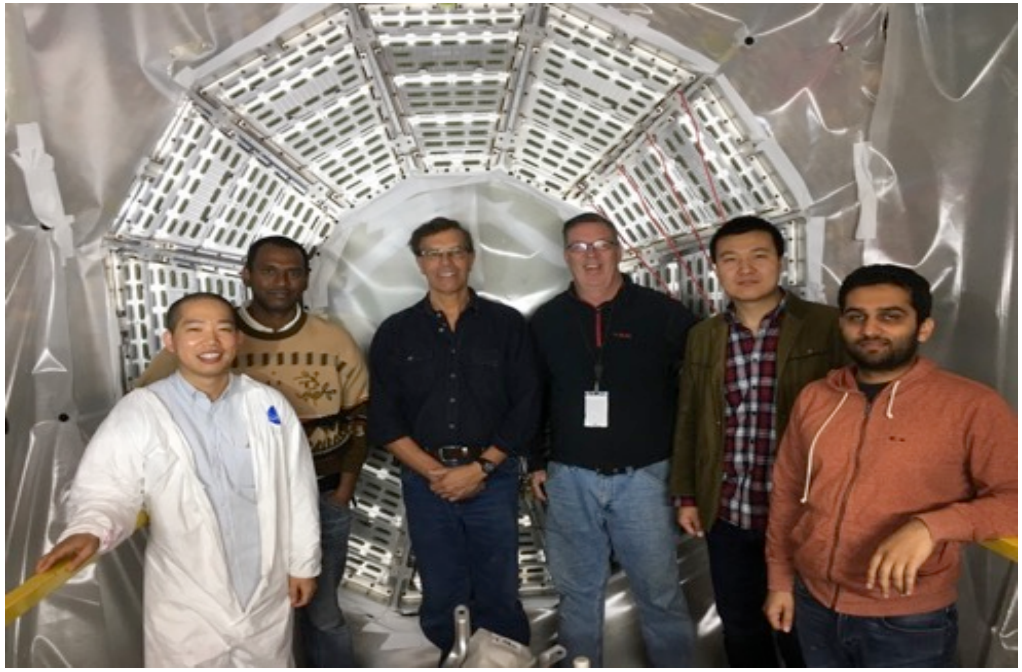
STAR Detector Upgrades



Inner TPC Installation

Installation

- East Side Sectors Complete 09/26/18
- West Side Sectors Complete 10/25/18



The testing and commissioning plan was developed~ 2 years ago, and updated following the fall DOE NP review - Includes hardware testing

Important components were:

- ✓Tests at SDU
- ✓Test at BNL pre-installation
- ✓Final inspection at installation time
- ✓Post Installation checkout
- ✓Cosmic data taking

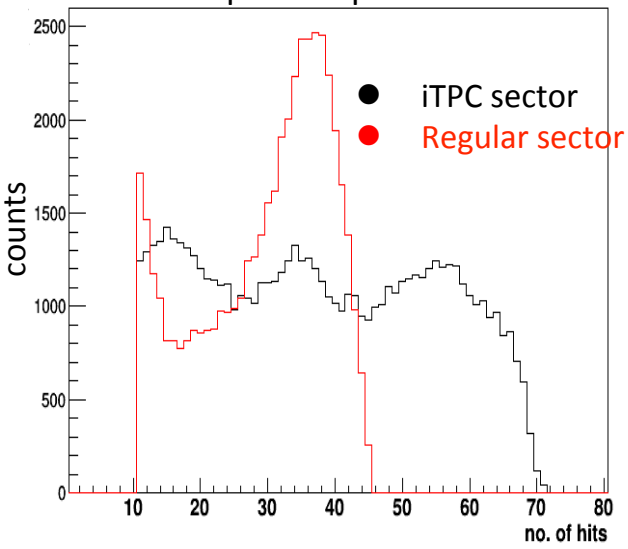
2019 Schedule followed:

- Jan 18 - Feb 4: Cosmic data with forward Full Field
- Feb 4: Change Magnet polarity
- Feb 4 - ~Feb 18 Cosmic data with reverse full field
- Feb. 11: cool down of 2nd half of blue ring begins
- Feb. 14: beam in blue ring starting with the day shift
- Feb. 19: cool down of 2nd half of yellow ring begins
- Feb. 20: beam in yellow ring starting with the day shift
- Feb. 20: 1st collisions in STAR overnight at injection energy
- Feb. 21-27: Physics setup

Inner TPC Upgrade

[NIM A 896 (2018) 90]

- **Replace all inner TPC sectors → continuous pad rows**
  - Doubled the readout channels. Using SAMPA chip developed for ALICE



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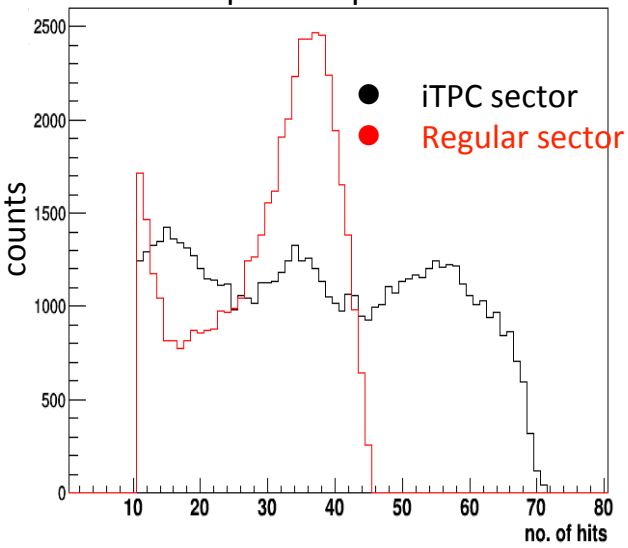
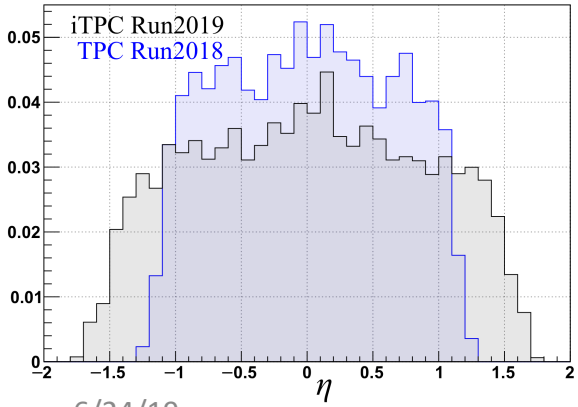


- **Increase mid-rapidity coverage from $|\eta| < 1.0$ to $|\eta| < 1.5$**



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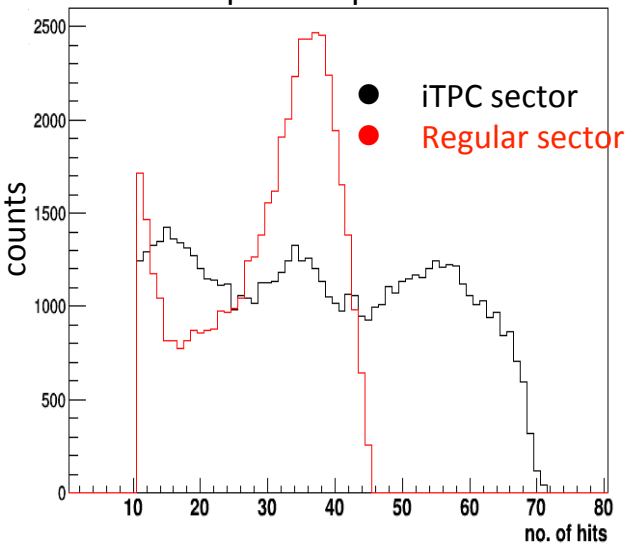

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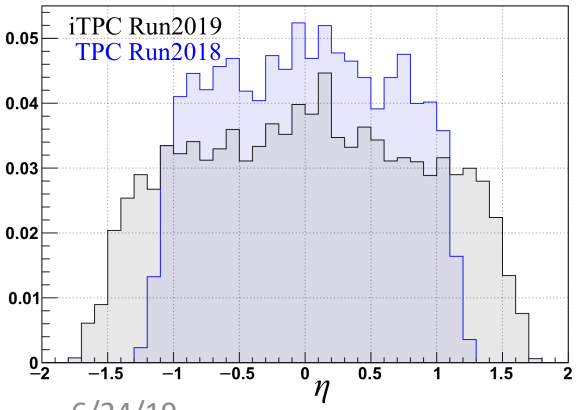
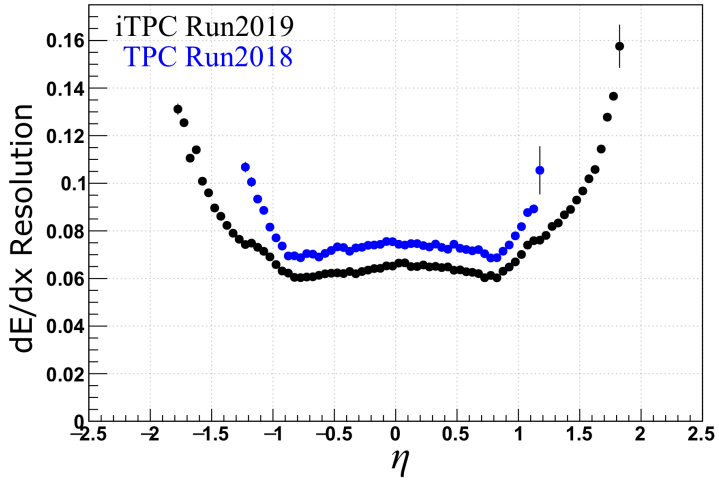


- **Improved dE/dx Resolution (15%-30%)**



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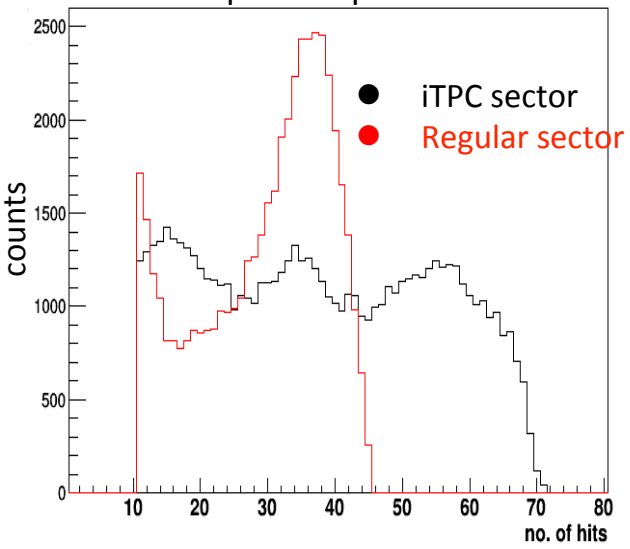

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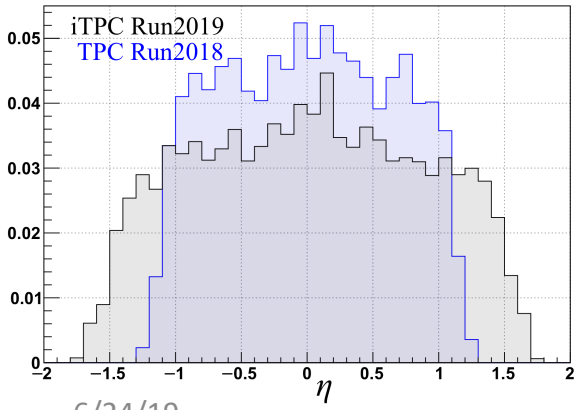

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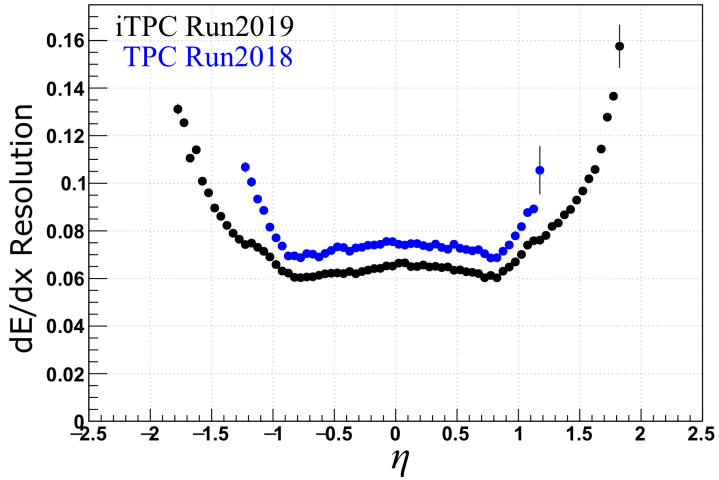
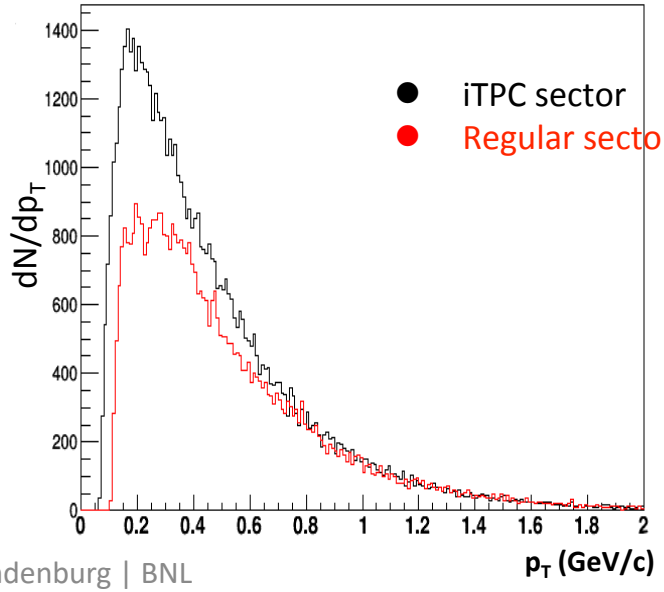
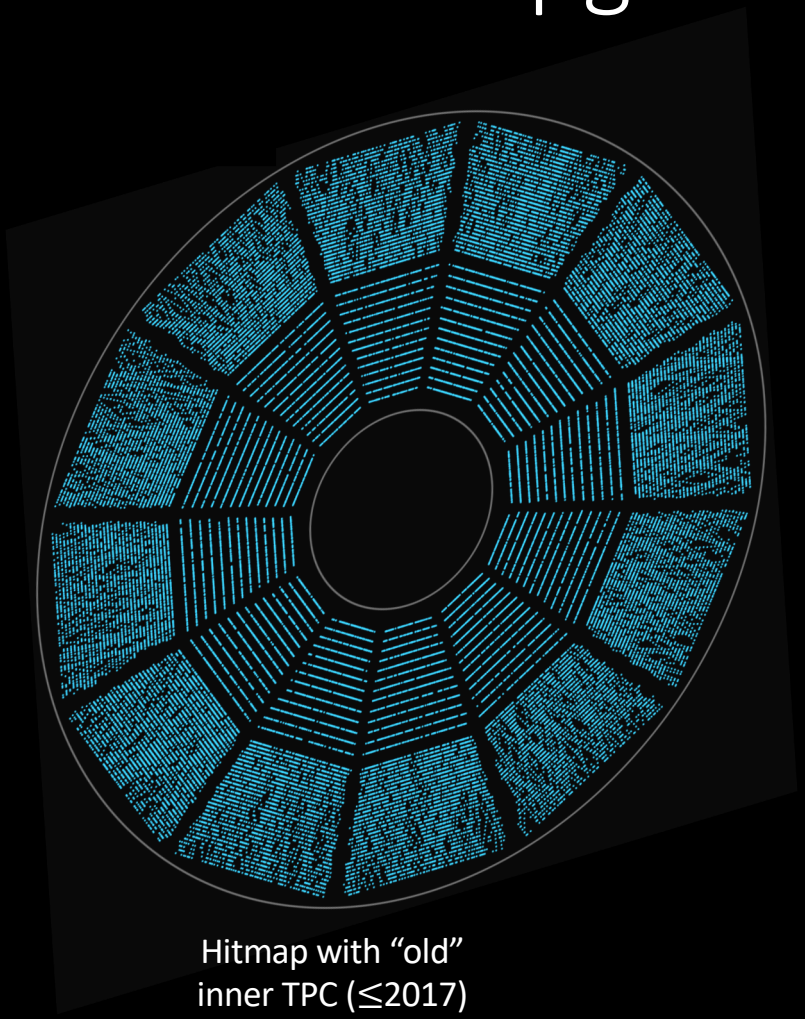


- Improved Momentum Resolution
- Decrease minimum p_T threshold from $p_T > 125\ MeV/c$ **to $p_T > 60\ MeV/c$**

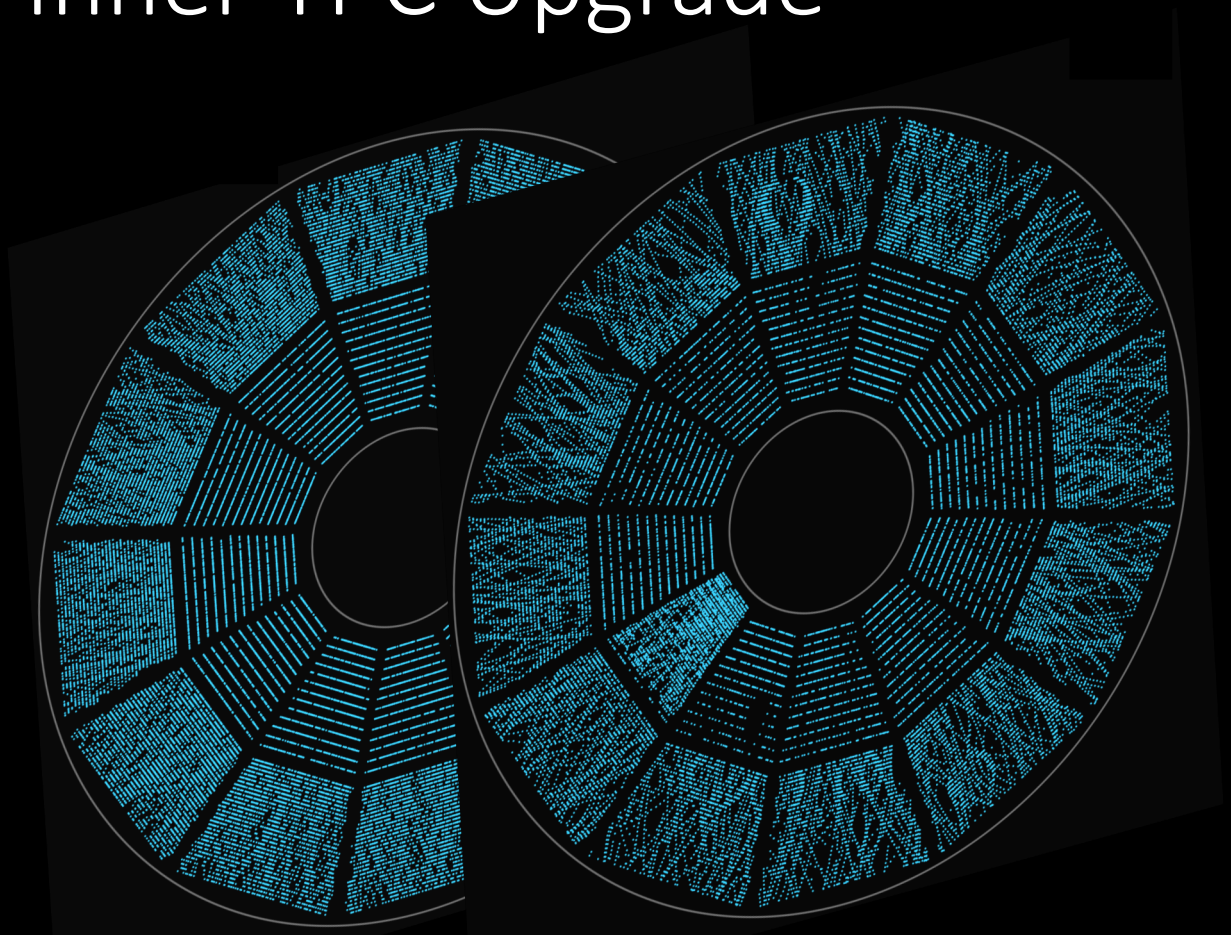


Inner TPC Upgrade



Hitmap with “old” inner TPC (≤2017)

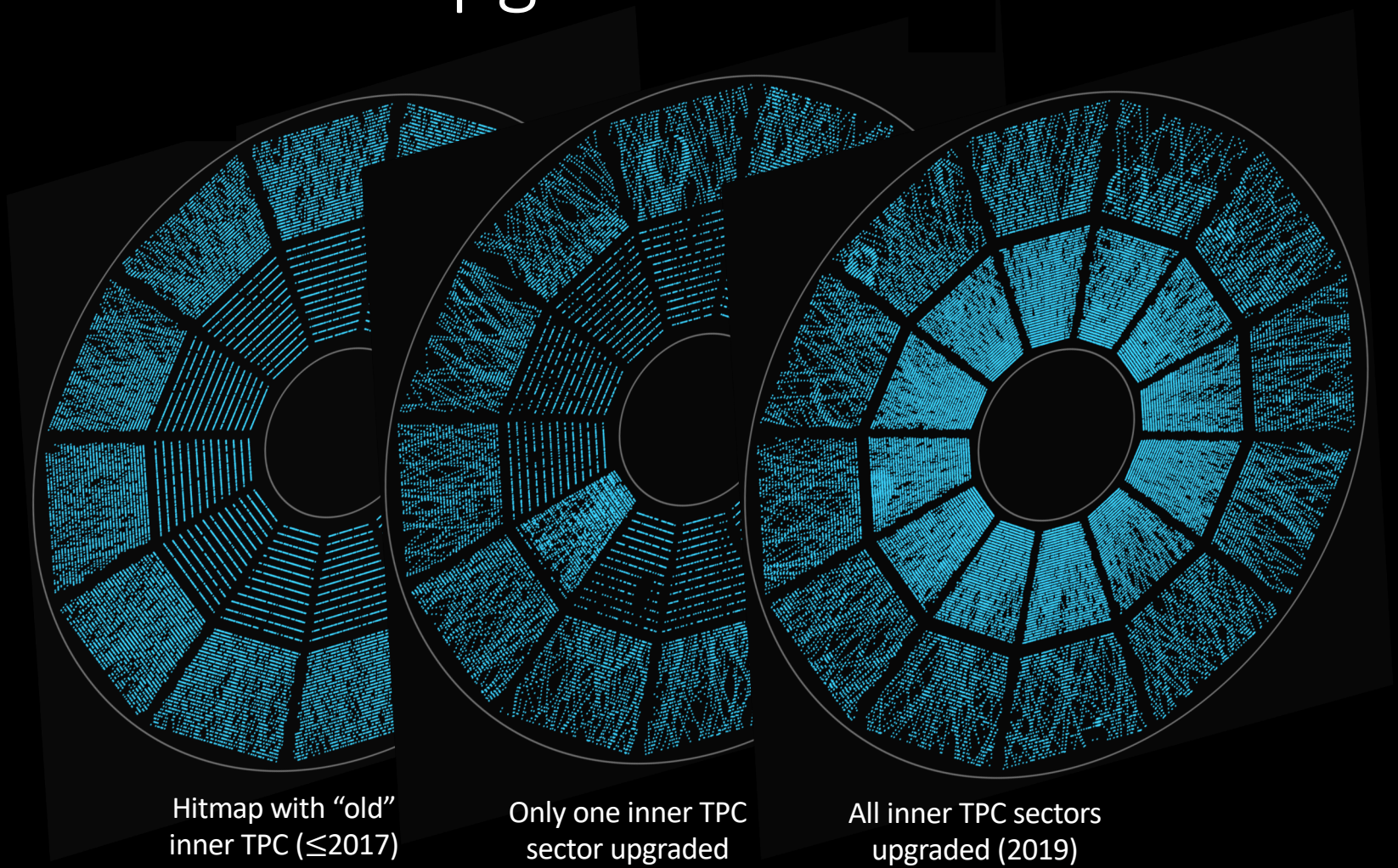
Inner TPC Upgrade



Hitmap with “old” inner TPC (≤2017)

Only one inner TPC sector upgraded (2018)

Inner TPC Upgrade



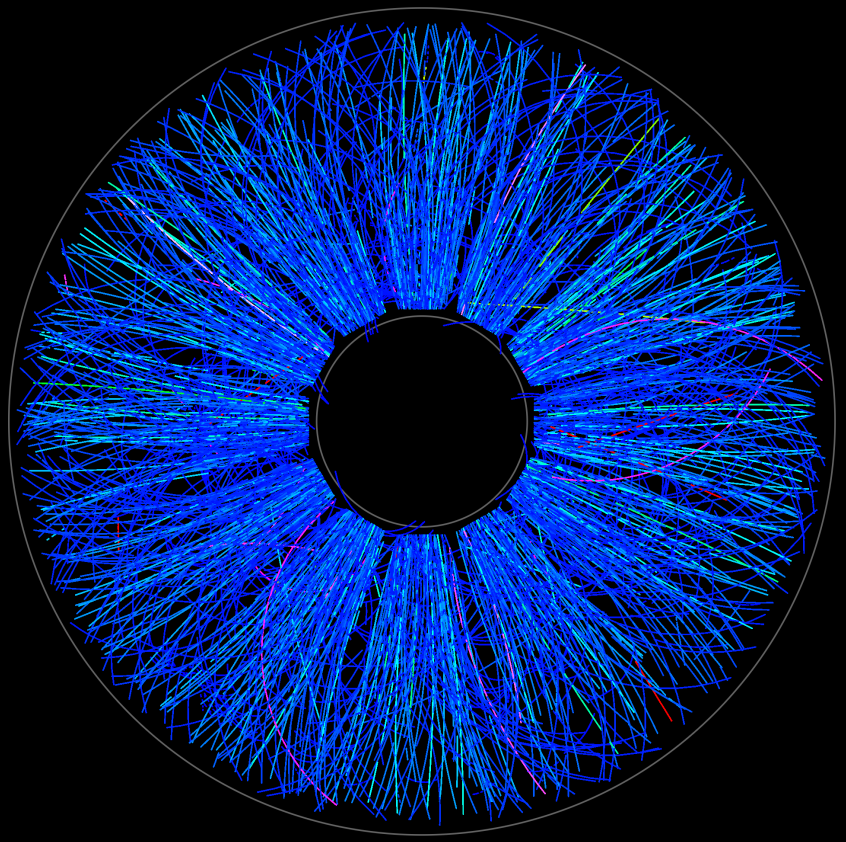
Hitmap with “old” inner TPC (≤2017)

Only one inner TPC sector upgraded (2018)

All inner TPC sectors upgraded (2019)

Inner TPC Upgrade

Successful, on-time & under budget completion of the iTPC upgrade

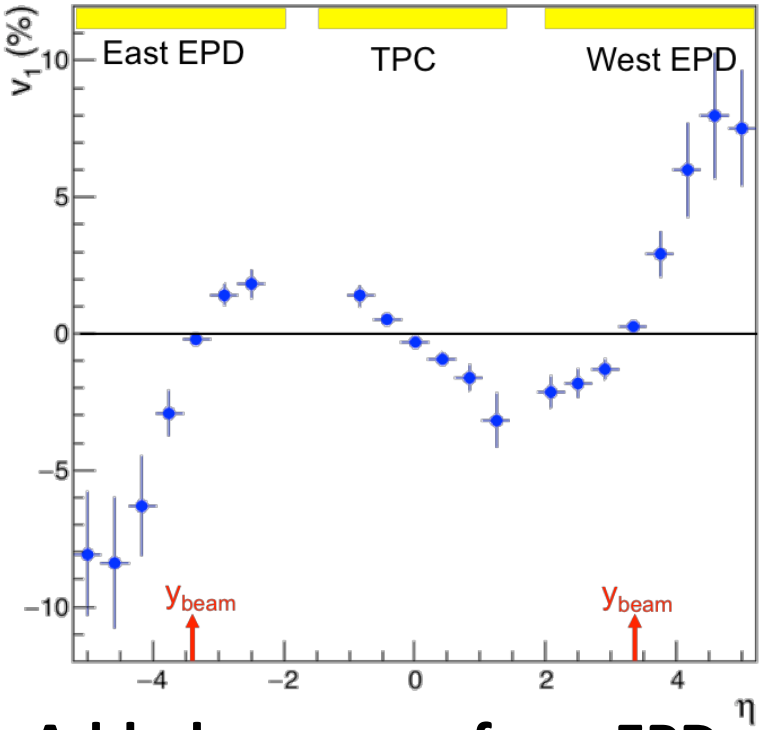


2019 Event Display : Au+Au 19.6 GeV
Full tracking with all iTPC sectors

Event Plane Detector

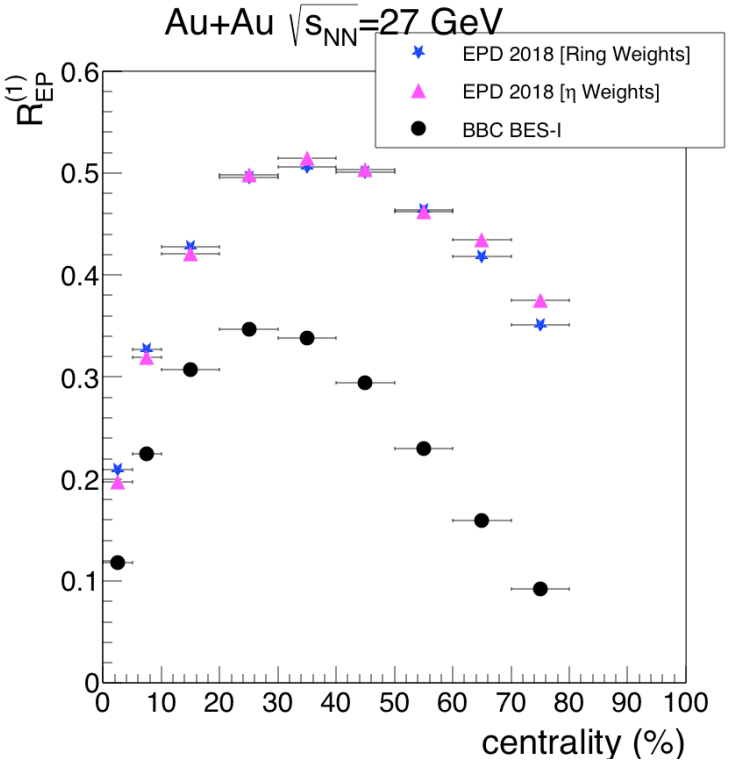
STARNote 666 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666

- Replaces Beam-Beam Counter (BBC)
  - Improved triggering capabilities
  - Extend η coverage
  - Improve event plane resolution
- Smooth installation
  - ✓ **Completed in 2018**
  - ✓ Already used in analysis of 2018 data



Added coverage from EPD

→ Allows measurement of v_1 over ~10 units of η!



1st order Event Plane Resolution

→ Significant improvement across all centrality

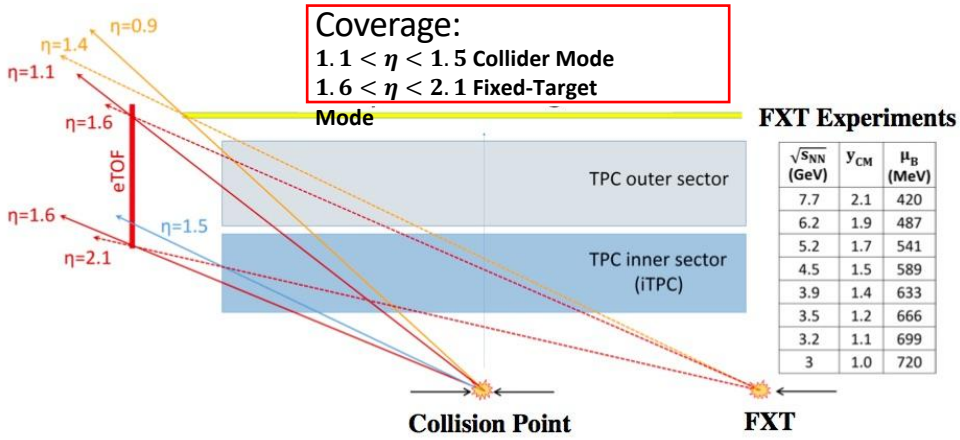
Motivation: Endcap Time-of-Flight Detector

- Extend STAR's particle ID capabilities (π, K, p)
  - **Complements the increased iTPC coverage $|\eta| < 1.5$**
  - **Essential for mid-rapidity particle ID in Fixed Target Program**

- Allows "gap-less" scan of phase diagram with collider + Fixed Target Energies
  - Rapidity dependence of key bulk observables
  - Particle ID – needed for fluctuation measurements in the Fixed Target Program

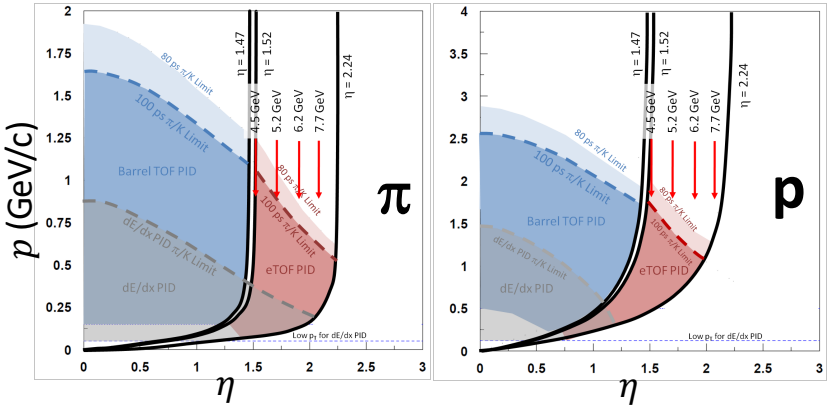
- First streaming DAQ system at RHIC – important step towards the future

- Collaboration with CBM Fair phase 0



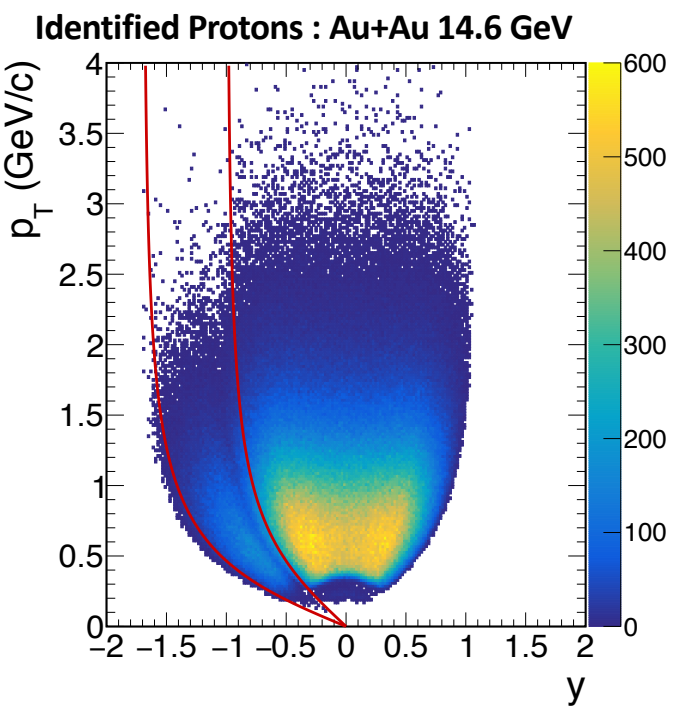
$\sqrt{s_{NN}}$ (GeV)	y_{CM}	μ_B (MeV)
7.7	2.1	420
6.2	1.9	487
5.2	1.7	541
4.5	1.5	589
3.9	1.4	633
3.5	1.2	666
3.2	1.1	699
3	1.0	720

Acceptance in Fixed Target Mode

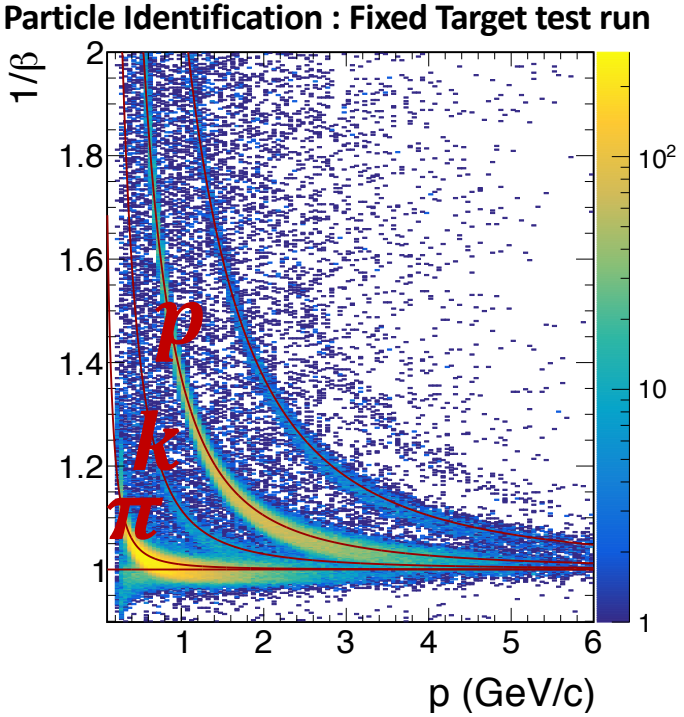


➢ Full eToF installation : **completed Nov 22, 2018**

ETOF Performance in 2019 Running



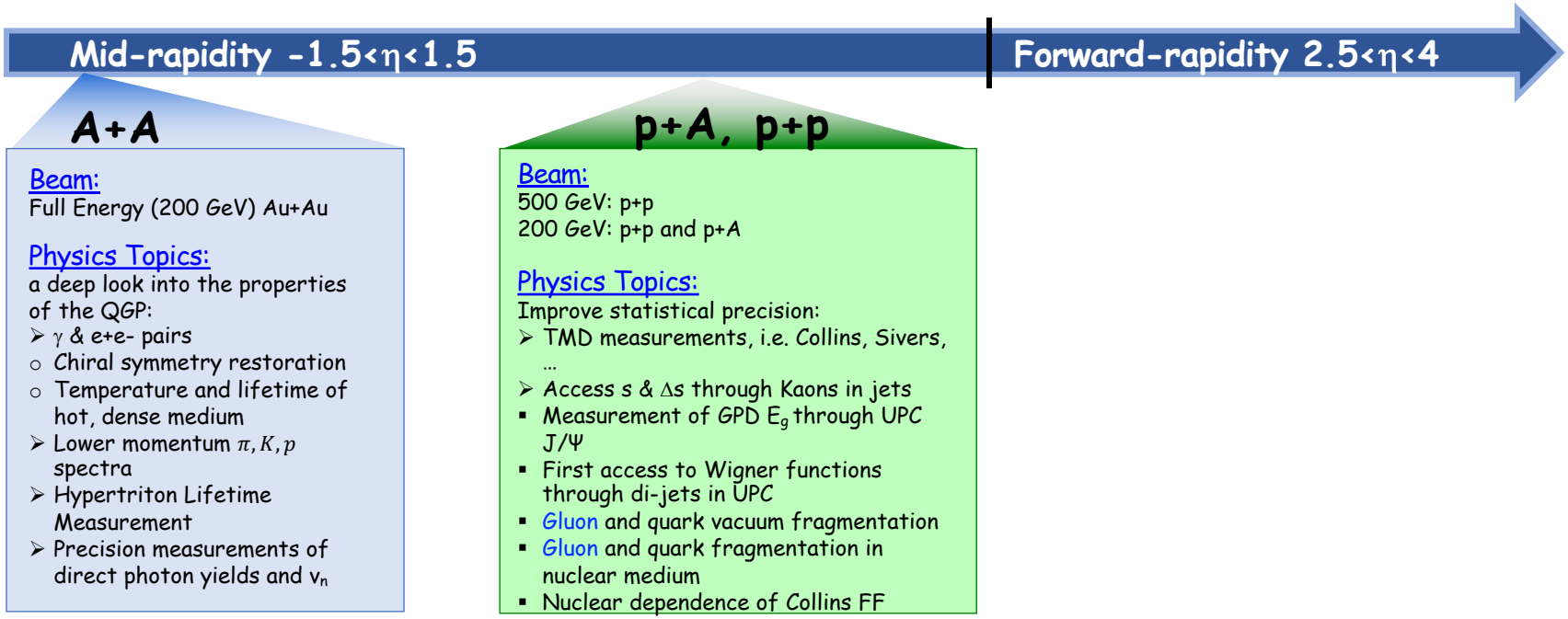
Region in red lines :
extended coverage added by eTOF
for identified protons



Particle bands are clearly distinguished over large momentum range.
Achieved target time resolution →
Calibrated time resolution ~85 ps

STAR Physics Program after BES II

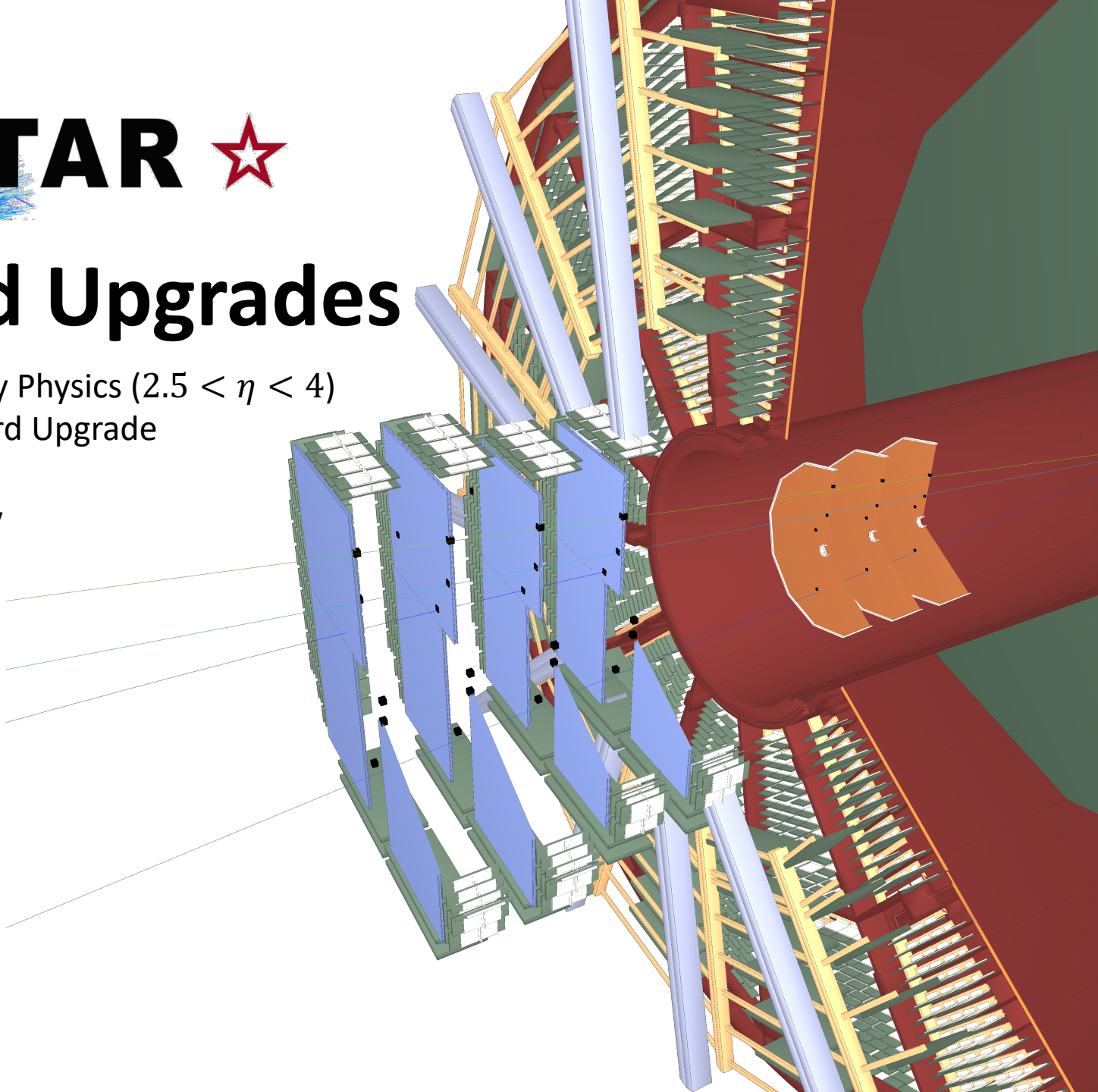
➢ **STAR Upgrades for BES II → provide unique opportunities at mid-rapidity in high energy A+A, p+A, and p+p**



The STAR midrapidity pp, pA, AA physics program beyond BES-II : https://drupal.star.bnl.gov/STAR/starnotes/public/sn0669

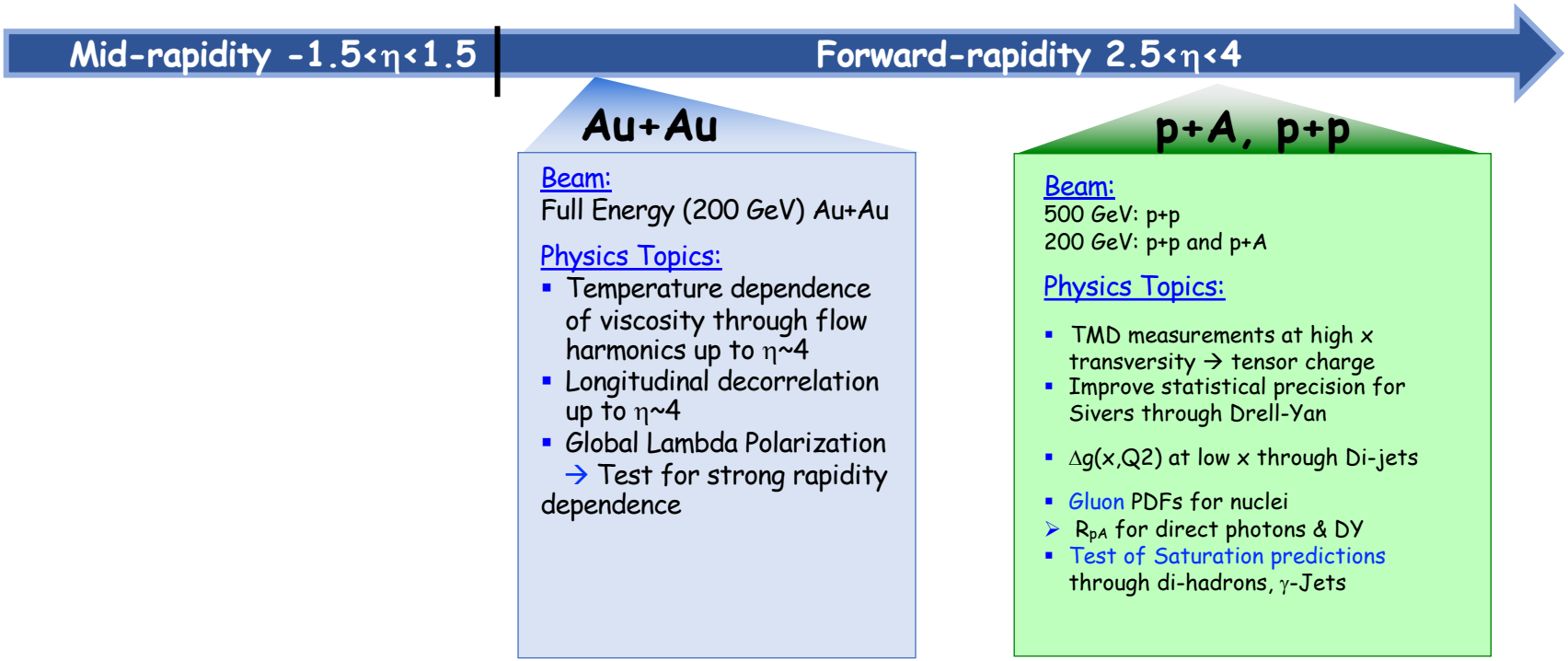
Forward Upgrades

- Forward Rapidity Physics ($2.5 < \eta < 4$)
- The STAR Forward Upgrade
  - Tracking
  - Calorimetry
- A Look Forward



Forward Rapidity Physics at STAR

- **Unique program addressing several fundamental questions in QCD**
- Essential to RHIC cold & hot QCD physics mission + fully realize scientific promise of future Electron Ion Collider



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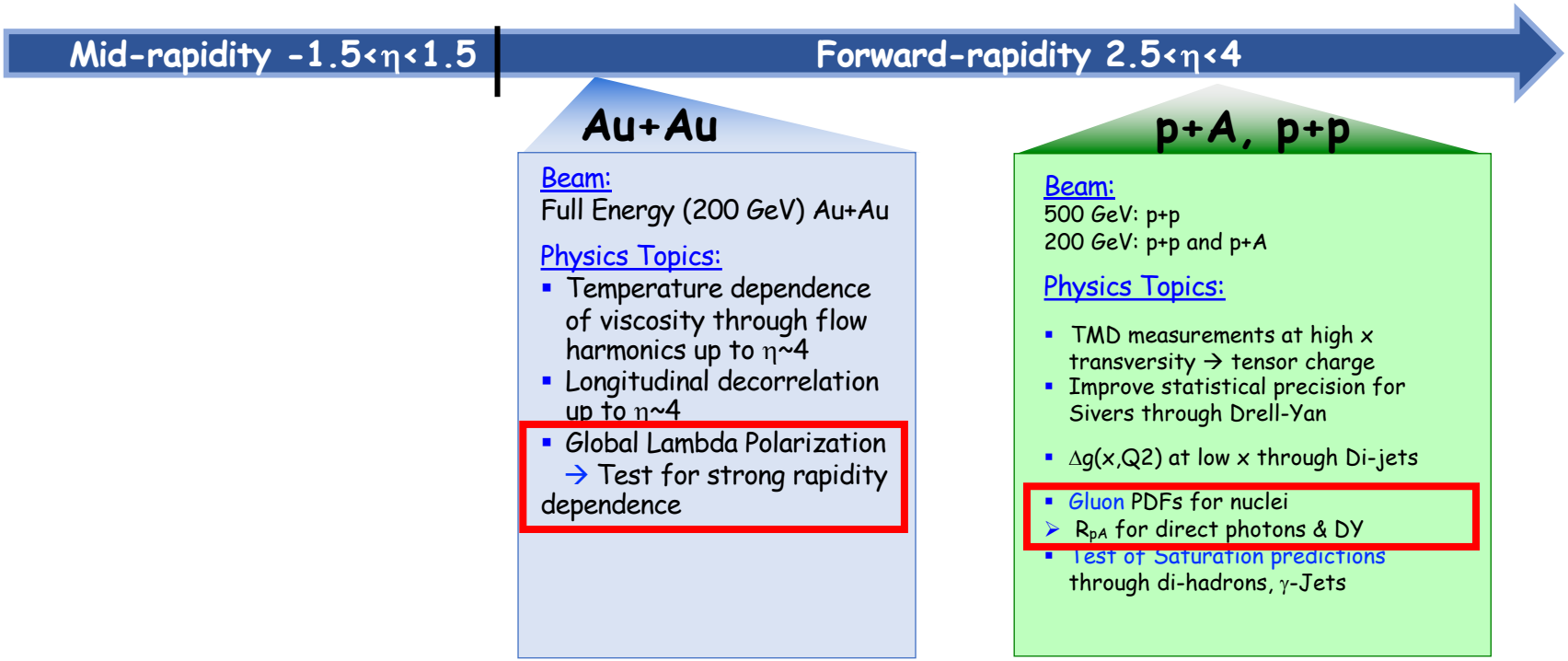
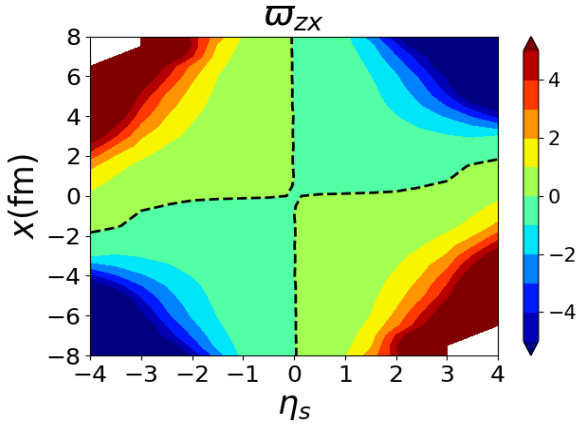
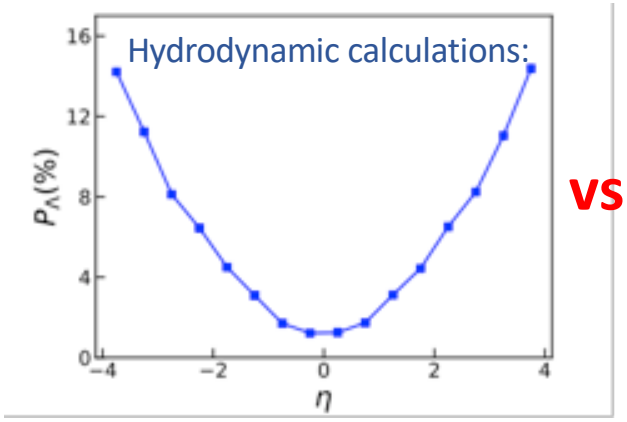


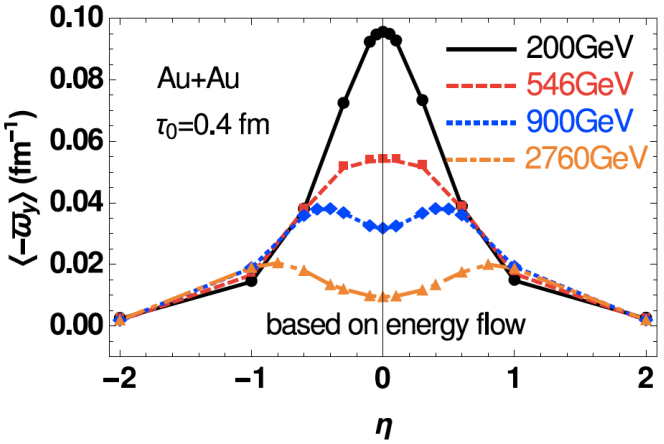
Global Hyperon Polarization

➢Sensitive to thermalization and viscosity





vs.



➢Polarization increases with viscosity

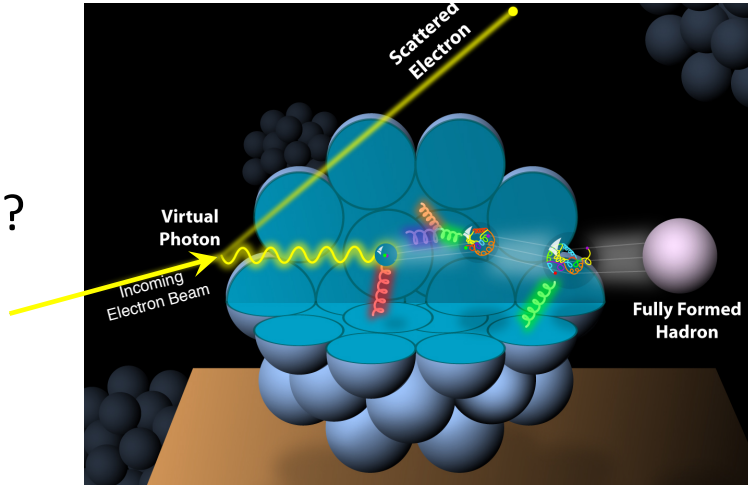
Hydrodynamic calculations:
Li,Pang,Wang & Xia, PRC 96 (2017) 054908; (private comm.)
F. Beccattini et al. EPJC 75(2015)406; arXiv:1501.04468

HIJING with energy flow:
Deng & Huang, PRC 93 (2016) 064907

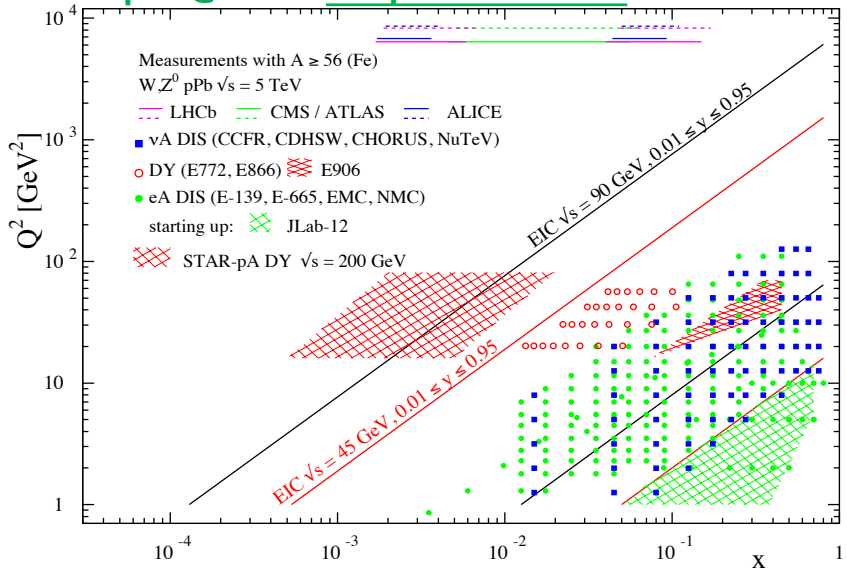
Model's predict opposite Polarization trend with rapidity
→ Measurements at forward rapidity are key

Probing the Initial State in A+A

➢3 important questions:
- What are the nPDFs at low-*x*?
- How saturated is the initial state of the nucleus?
- What is the spatial transverse distributions of nucleons and gluons?



p+A@RHIC: unique kinematics

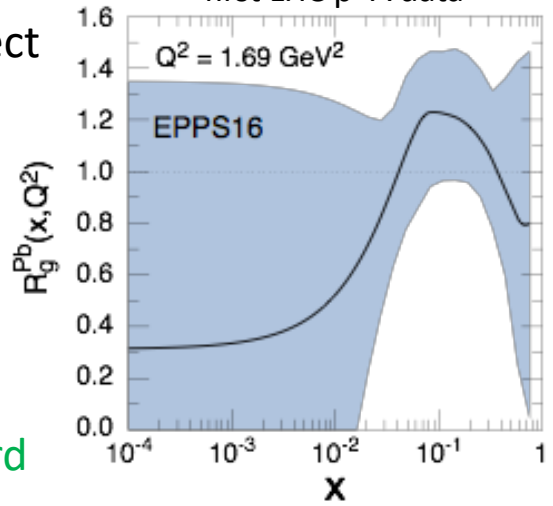


Observables free of final state effects:
- Gluons: R_{pA} for direct photons
- Sea-quarks: R_{pA} for Drell-Yan

➢ Scan A-dependence prediction by saturation models

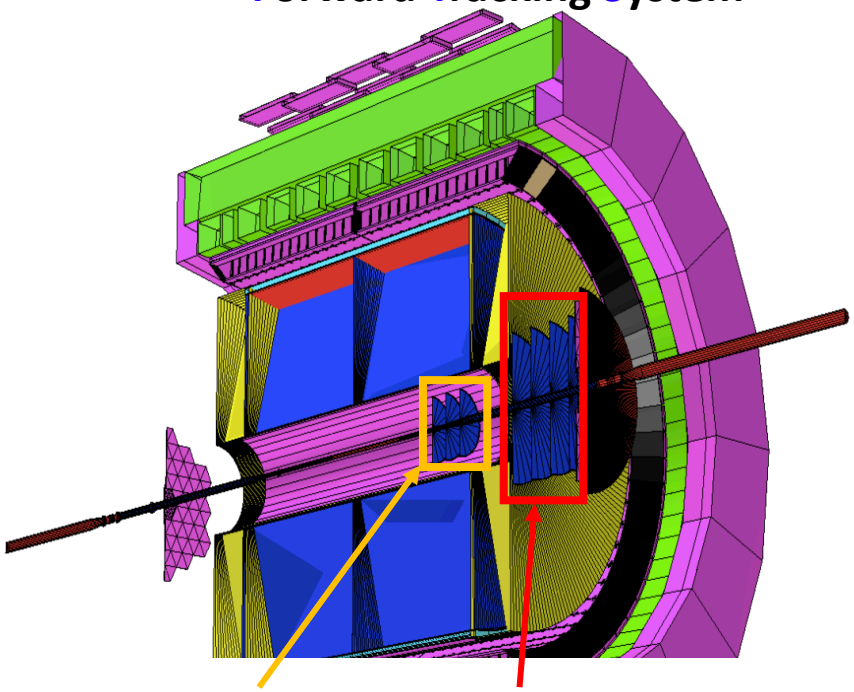
➢ Accessible at forward rapidity

Current knowledge including first LHC p+A data



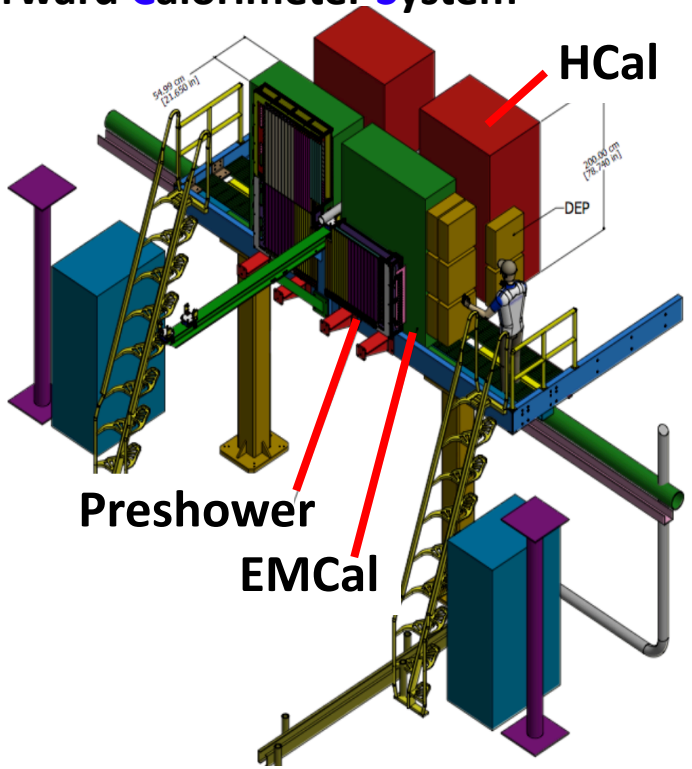
STAR Forward Detectors: FTS + FCS

Forward Tracking System



Silicon + small-Strip Thin Gap Chambers (sTGC)

Forward Calorimeter System

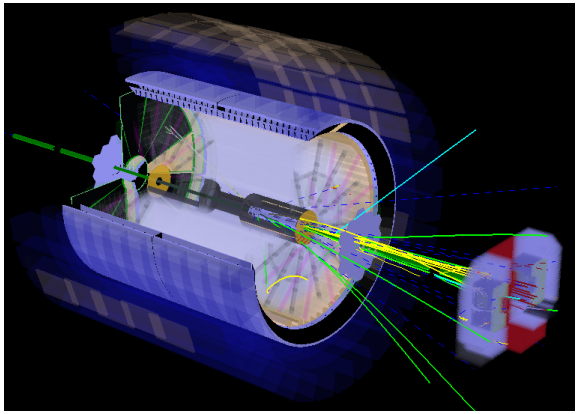


STAR Forward Upgrade Status

Associate Laboratory Director's Review

- Reviewed on 19th, November 2018 :
  - ✓ Physics requirements
  - ✓ Cost & Schedule for each subsystem
  - ✓ Readout & Triggering
  - ✓ Plan for integration and in-situ testing
- **Positive Feedback & Recommendations**
  - "Good progress has been made on an intriguing concept for a cold-QCD program to run in the near future in the forward direction at STAR"

The STAR Forward Calorimeter System and Forward Tracking System



NSF proposal submitted Jan 2019

- ➢ Funding for Forward Calorimeter systems
- ✓ **Received very positive feedback**
- ✓ **Awaiting final response from NSF Division of Grants and Agreements - expect to be funded**

Proposal November 2018

https://drupal.star.bnl.gov/STAR/system/files/ForwardUpgrade.Nov_.2018.Review_0.docx

Final Report ALD's review : https://drupal.star.bnl.gov/STAR/system/files/STAR%20forward%20upgrade%20review%20Final%20Report.pdf

STAR Forward Upgrade Institutions

Large project → **Dedicated manpower & expertise for each system**

Forward Tracking System

	Requirement	Motivation
Momentum Resolution	< 30%	A+A goals
Tracking Efficiency	$> 80\%$ @ 100 tracks / event	A+A goals
Charge Separation	–	p+p / p+A goals

Silicon mini-strip disks $\times 3$

- Location : z = 90, 140, 187 cm from interaction point
- **Build on and utilize STAR experience of successful Intermediate Silicon Tracker(IST) detector**
- minimal material (≤1% X0/layer) in the acceptance

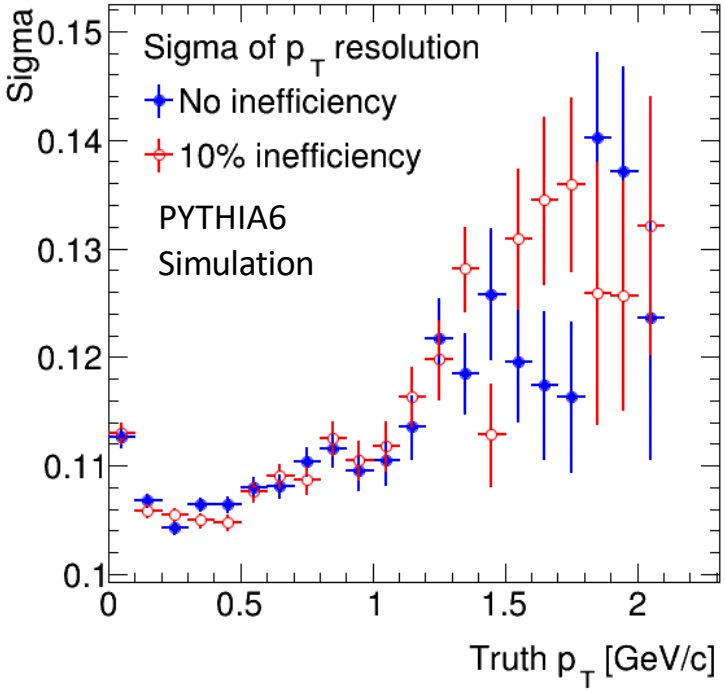
Small-Strip Thin Gap Chamber (sTGC) $\times 4$

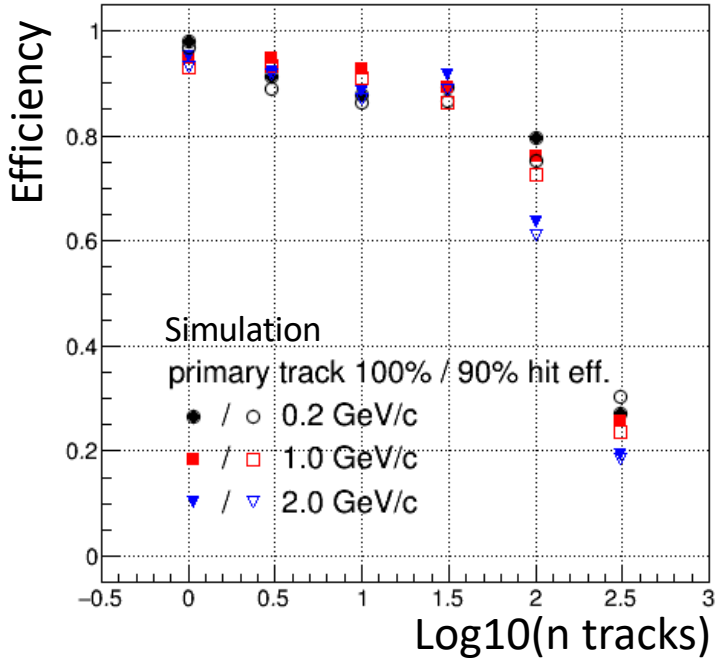
- Location : z = 270, 300, 330, 360 cm from interaction point
- **Significant reduction in cost (compared to all silicon)**
- Prototype at BNL, testing in STAR during 2019 run

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648

Forward Tracking System

	Requirement	Motivation
Momentum Resolution	< 30%	A+A goals
Tracking Efficiency	$> 80\%$ @ 100 tracks / event	A+A goals
Charge Separation	–	p+p / p+A goals





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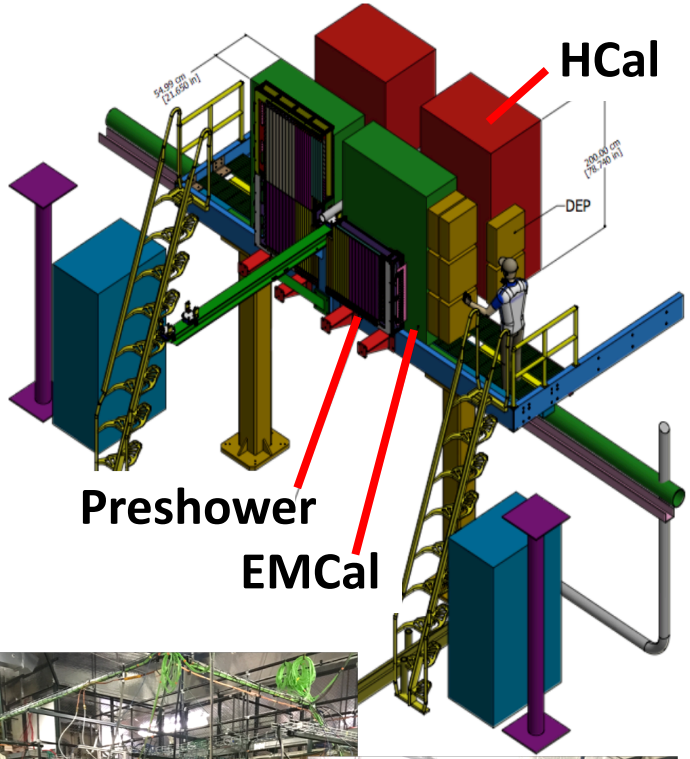
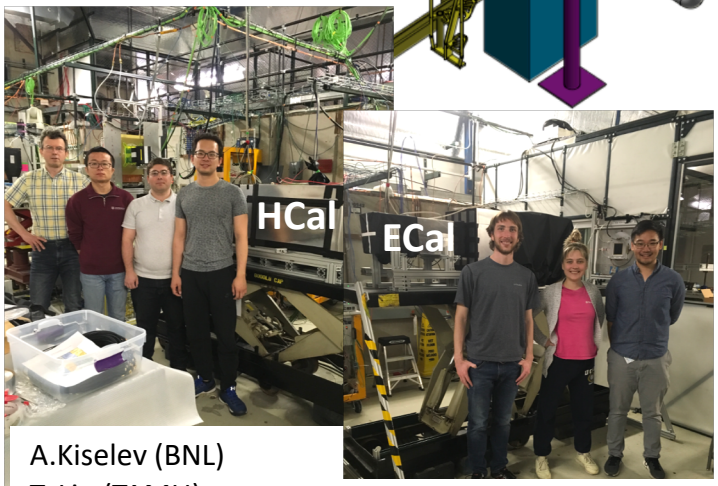
Forward Calorimeter System



Detector	Resolution p+p and p+A	Resolution A+A
ECal	$\sim 10\%/\sqrt{E}$	$\sim 20\%/\sqrt{E}$
HCal	$\sim 50\%/\sqrt{E} + 10\%$	–

Electromagnetic Calorimeter
- Reuse PHENIX PbSc
- New readout: SiPM

Hadronic Calorimeter
- Sampling iron-scintillator
- Uses same readout as ECal



A.Kiselev (BNL)
T. Lin (TAMU)
D. Kapukchyan (UCR)

D. Neff (UCLA)
M.Sergeeva (UCLA)
B. Chan (UCLA)

R&D in support of EIC

→ HCal development
→ All readout electronics
→ Balance Cost & performance

NSF grant expected to provide majority of funds

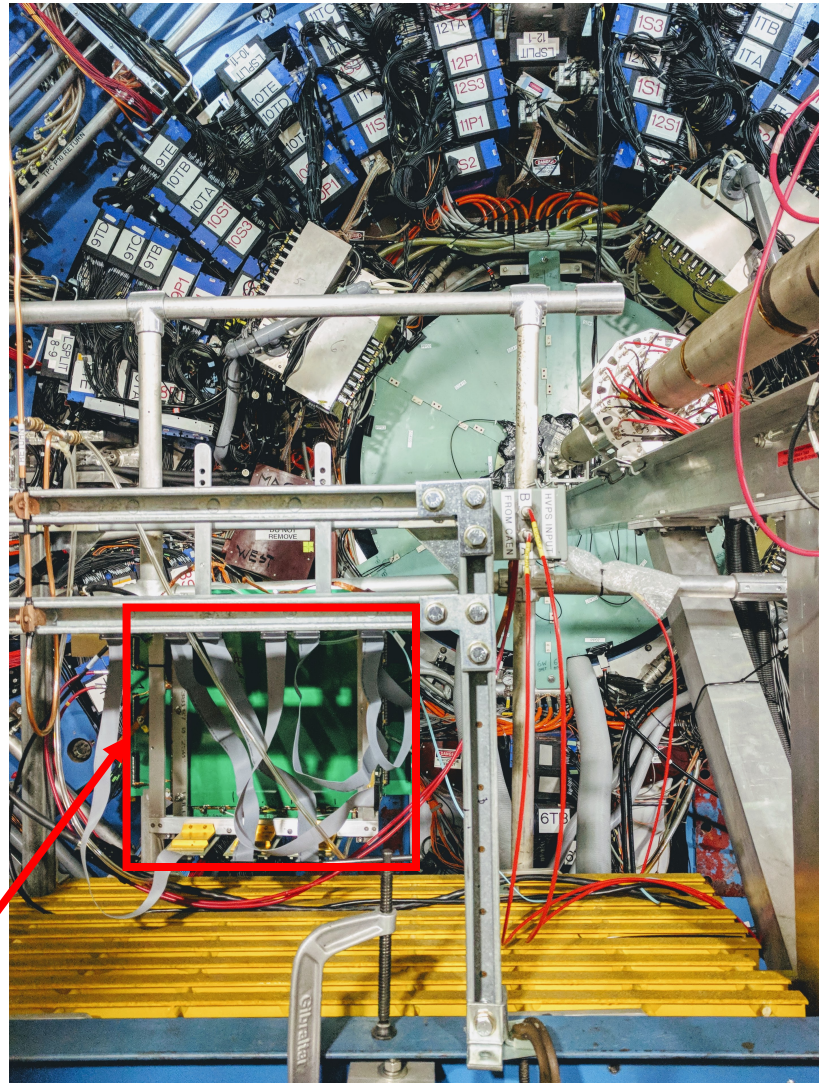
Plan/Goals for Run 19

Forward Calorimeter System

- ✓ Fermilab test beam results completed
- ✓ Measured ECAL energy resolution ~ 10% / $\sqrt{E}$
- ○ HCAL energy resolution measured ~ 75% / $\sqrt{E}$ + 7%
  - ➢ Work on modified light collection to improve resolution
- ➢ 10-20 hours of Au+Au 200 GeV collisions
  - ○ Test readout of calorimeters at ~ 10kHz rate
  - ○ Finish commissioning of DEP (digitizer/trigger) boards with this data
  - ○ Look at MIPS – use for calibration etc.

Forward Tracking System

- ➢ Silicon Detectors
  - ○ Complete the design of detector module in June 2019
  - ○ Build the first complete prototype module in Summer/Fall 2019
  - ○ Fully test the prototype module in Fall/Winter 2019
- ➢ sTGC Detectors
  - ✓ 30x30 cm prototype installed in STAR on June 5th, 2019
  - ✓ Test in STAR DAQ with C10 (90% argon + 10% CO2)
  - ○ Test performance with various gas mixtures at Shandong University in full size (60 x 60 cm) prototypes



Looking Forward

Measurements planned for 2021+ with the STAR forward upgrade

→Address important topics in hot & cold QCD

p+p and p+A

- Transverse polarization effects in the proton : Twist-3 and TMDs
- Transversity, Collins, and Interference fragmentation functions
- Access ΔG through dijets with p+p at $\sqrt{s}$ = 500 GeV
- Probe initial state with p+A collisions

A+A

- Correlation measurements in hot and dense nuclear matter
- Precision measurements of long range correlations
- Temperature dependence of the viscosity through flow measurements at $\eta \sim 4$

$\sqrt{s}$ (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

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648

Summary of STAR Upgrades

Crucial Upgrades for Beam Energy Scan II:

- Inner TPC : Successful, on-time & under budget completion, excellent performance
- Event Plane Detector : Excellent uniformity + delivered expected improvement in the event-plane resolution
- Endcap Time of Flight : Fully installed, commissioning and data taking are ongoing 2019

➢ **Upgrades provide unique opportunities at mid-rapidity in high energy A+A, p+A, and p+p**

STAR Forward Rapidity Upgrade:

➢ Essential to RHIC cold & hot QCD physics mission & to realize scientific promise of future Electron Ion Collider

➢ Forward Tracking System

- ➢ Silicon mini-strip detectors : build on STAR expertise from previous IST detector
- ➢ Small strip thin gap chambers : reduced cost, already testing prototypes in STAR now

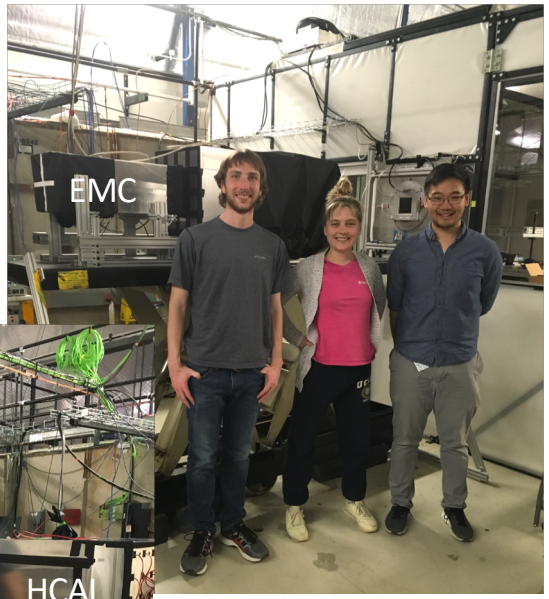
➢ Forward Calorimetry System : Preshower + ECal + Hcal

- ➢ In-situ testing at STAR now, received positive funding feedback from the NSF

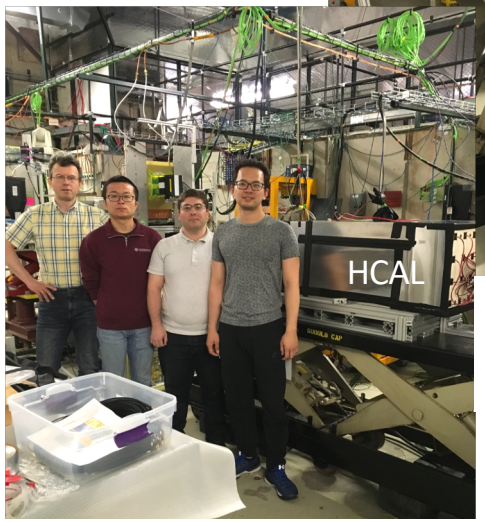
➢ **Unique program addressing several fundamental questions in QCD**

Calorimeter Current Status

- Fermilab test beam results
  - HCAL 16 channels, ECAL 16 channels
  - ECAL energy resolution measured ~ 10% / $\sqrt{E}$ - meets requirement
  - HCAL energy resolution measured ~ 75% / $\sqrt{E}$ + 7%
  - Work on modified light collection to improve resolution
    - Promising results - ongoing development, but does not effect design)
- Installation and in-situ testing at STAR
  - 64 (8x8) EMCAL installed
  - 16 (4x4) HCAL installed
  - 1 layer (9 slats) Pre-shower (former FMS Post-Shower detector)
  - New generation of digitizer/trigger boards for ECAL/HCAL/Preshower readout
- Currently commissioning in STAR with beam
  - Operating pedestal, LED, and physics runs
- Online + slow controls + offline software being developed



D. Neff (UCLA)
M.Sergeeva (UCLA)
B. Chan (UCLA)



A.Kiselev (BNL)
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D. Chen (UCR)
G. Visser (IUCF)
O. Tsai (UCLA)

Looking Forward

Future A+A Measurements with the STAR forward upgrade

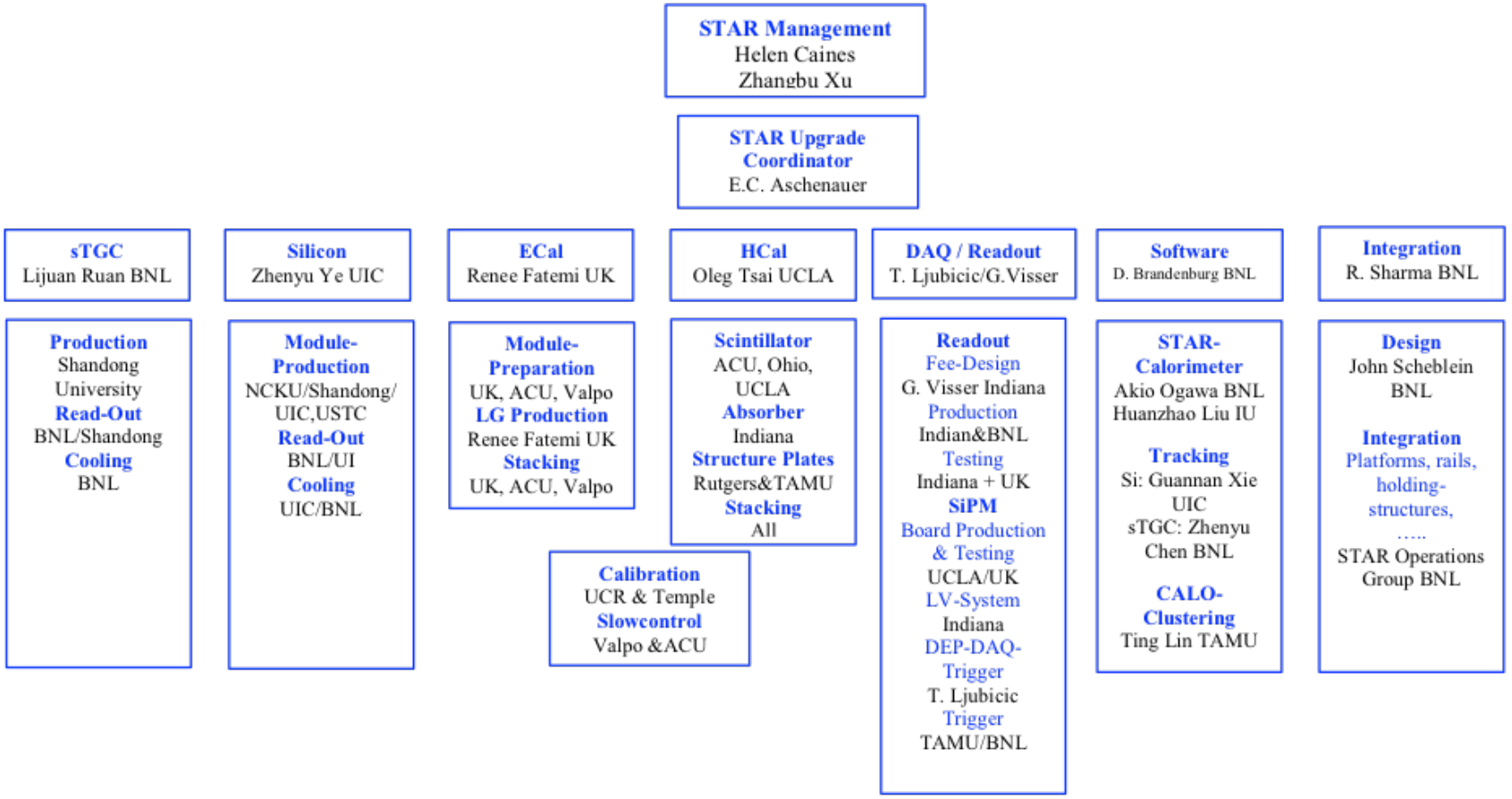
Physics Measurements		Longitudinal de-correlation $C_n(\Delta\eta)$ $r_n(\eta_a,\eta_b)$	η/s(T), ζ/s(T)	Mixed flow Harmonics $C_{m,n,m+n}$	Ridge	Event Shape and Jet-studies
Detectors	**Acceptance**					
Forward Calorimeter **(FCS)**	$2.5 < \eta < 4$ (photons, hadrons)	One of these detectors necessary		One of these detectors necessary	Good to have	One of these detectors needed
Forward Tracking System **(FTS)**	$2.5 < \eta < 4$ (charged particles)		Important		Important	

Addresses important topics in hot QCD:

- Ridge in p+p, p+A, and A+A
- Correlation measurements in hot and dense nuclear matter
- Precision measurements of long range correlations
- Temperature dependence of the viscosity through flow measurements at $\eta \sim 4$

Organizational Structure STAR Forward Upgrade

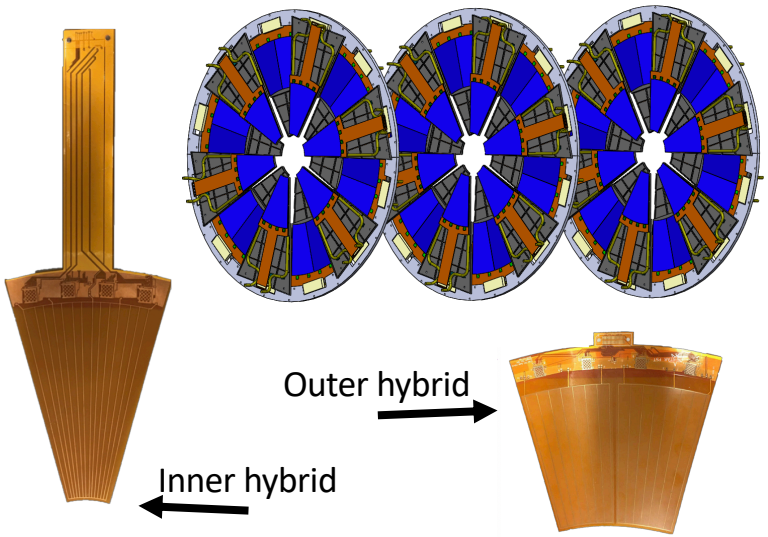
➢ Large project → Dedicated manpower & expertise for each system



Forward Tracking System Current Status

Silicon Detector

- Silicon strip sensors ordered from Hamamatsu
- Detector module design and prototyping in progress
- First complete prototype module for test in Fall/Winter 2019



sTGC Detector

- 30x30 cm prototype delivered to BNL in January 2019
- Module tested in test-stand using cosmic rays + scintillator pads for trigger
- Connected to STAR Data Acquisition system – first test data being analyzed now
- Installed in STAR on June 5, 2019
- Full-size 60x60 cm prototype being produced at Shandong University

Prototype in STAR Clean Room,

On the Mounting Structure