The STAR Detector Upgrades for the BES-II and Beyond Physics Program

4-9 November 2019 @ Wuhan
Yi Yang
National Cheng Kung University
on behalf of the STAR collaboration

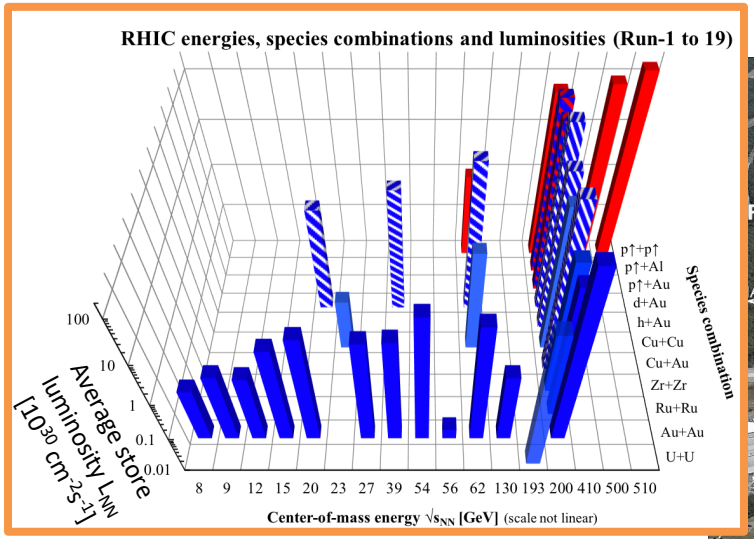
In part supported by

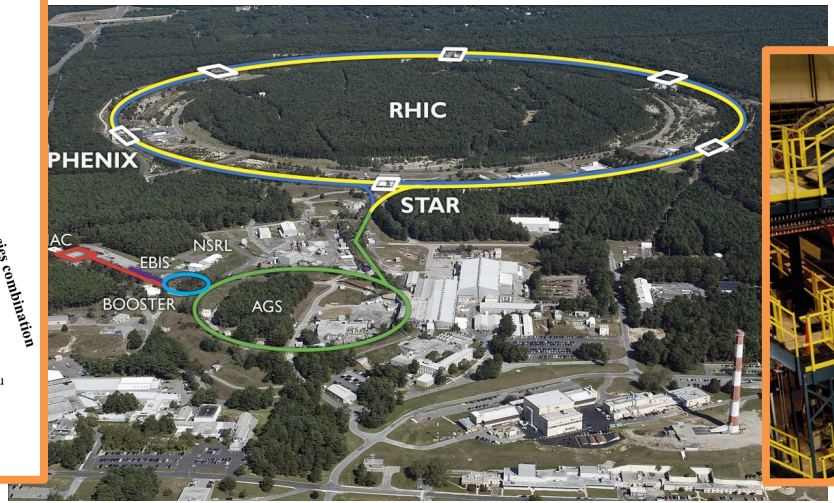
Relativistic Heavy Ion Collider (RHIC)

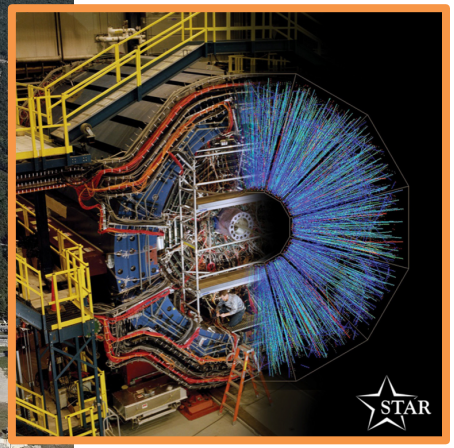
The most versatile particle collider

- The only **polarized proton** collider in the world
- Type of collisions: p+p, p+Au, Au+Au, d+Au, U+U, Zr+Zr, …
- Center-of-mass energy for Au+Au collisions: 3.0 - 7.7 - 200 GeV

Fixed-Target mode Collider mode

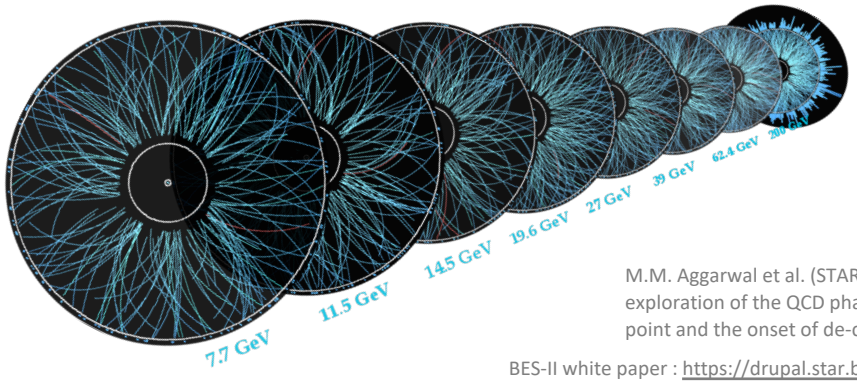




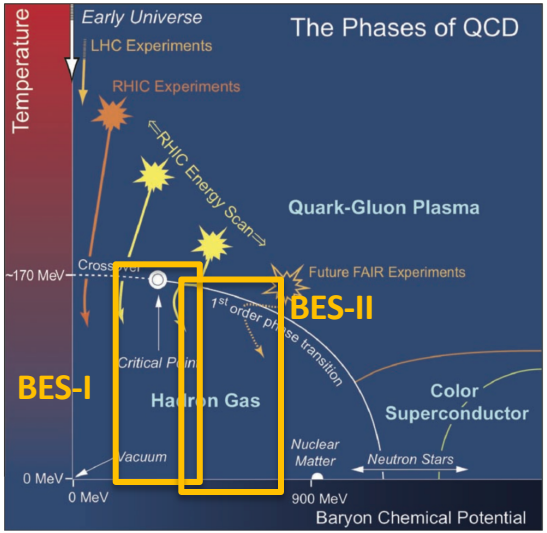


Beam Energy Scan (BES) Program @ RHIC

- RHIC provides a unique opportunity to explore the QCD phase diagram with different collision energies
  - ➔ Search for QCD critical point, 1st order phase transition, turn-off of QGP, etc.
- **BES-I** (2010 – 2011, 2014): $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 54.4, 62.4, 200 GeV
- **BES-II** (2019 – 2021):
  - Collider mode: $\sqrt{s_{NN}}$ = 7.7, 9.1, 11.5, 14.6, 16.7, 19.6 GeV
  - Fixed-Target mode: $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.7 GeV

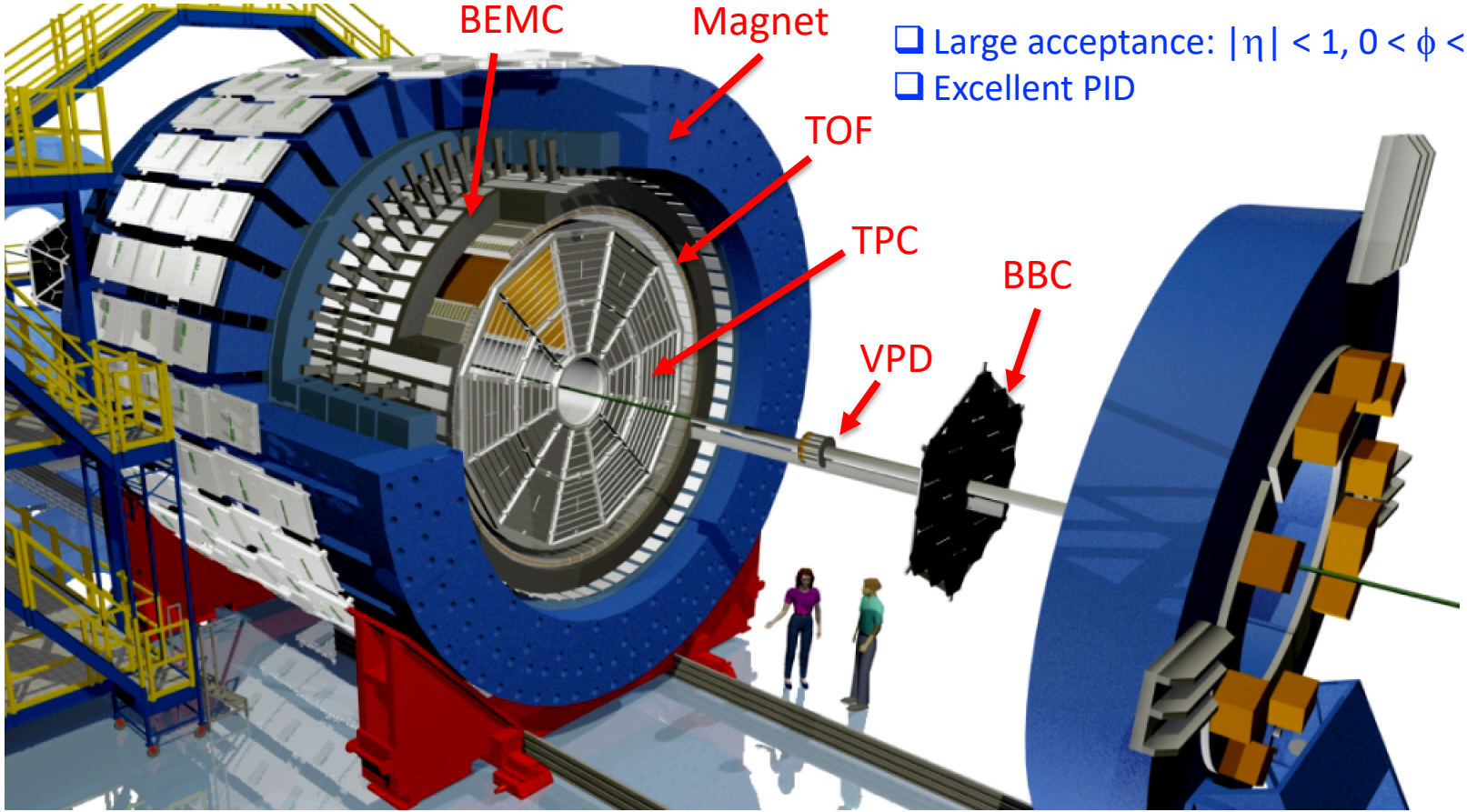


M.M. Aggarwal et al. (STAR Collaboration), An experimental exploration of the QCD phase diagram: the search for the critical point and the onset of de-confinement. arXiv: 1007.2613



BES-II white paper : https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

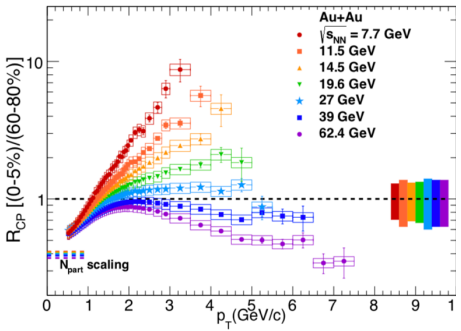
The STAR Detector for BES-I

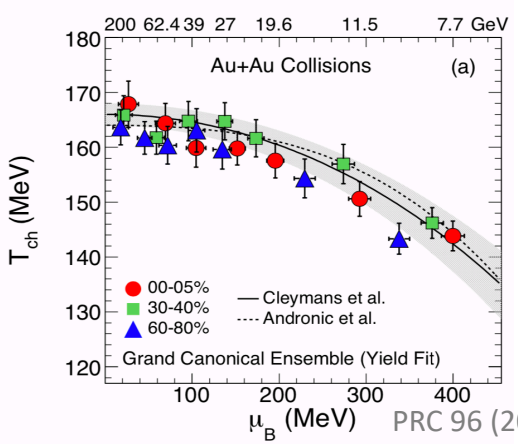


- Large acceptance: $|\eta| < 1$, $0 < \phi < 2\pi$
- Excellent PID

Selected Results from BES-I

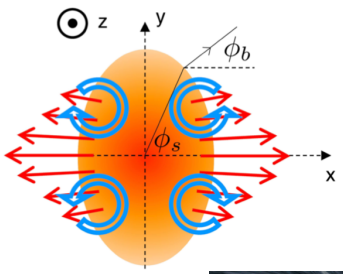
PRL 121, 032301 (2018)

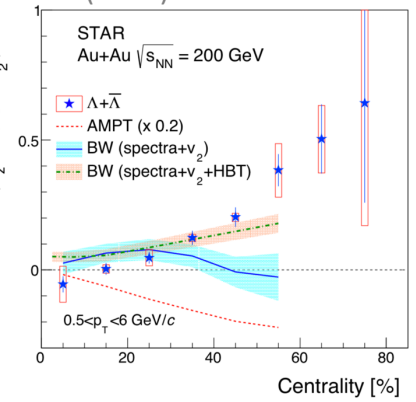


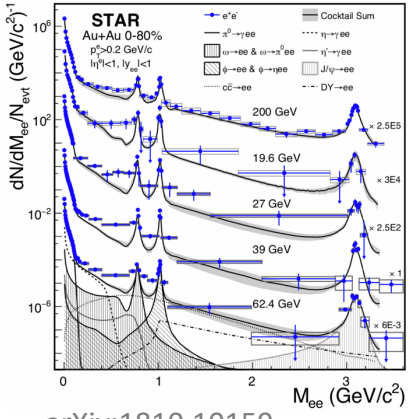


PRC 96 (2017) 44904

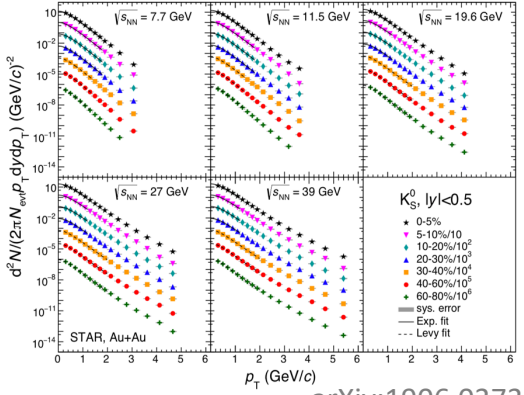
Phys. Rev. Lett. 123, 132301 (2019)



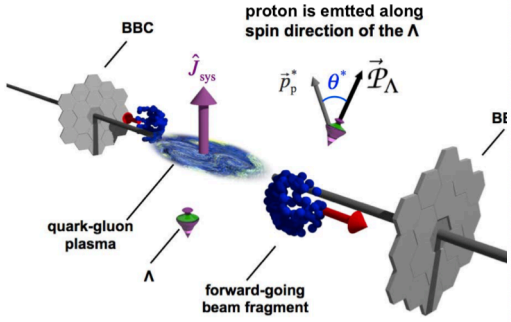




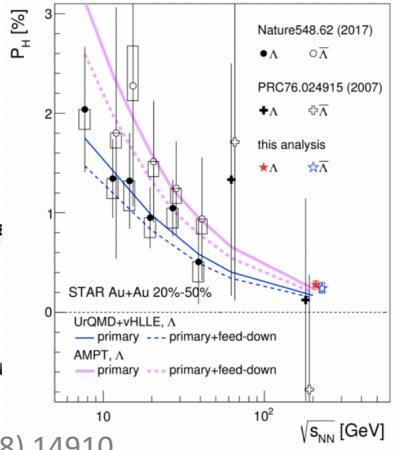
arXiv:1810.10159



arXiv:1906.03732

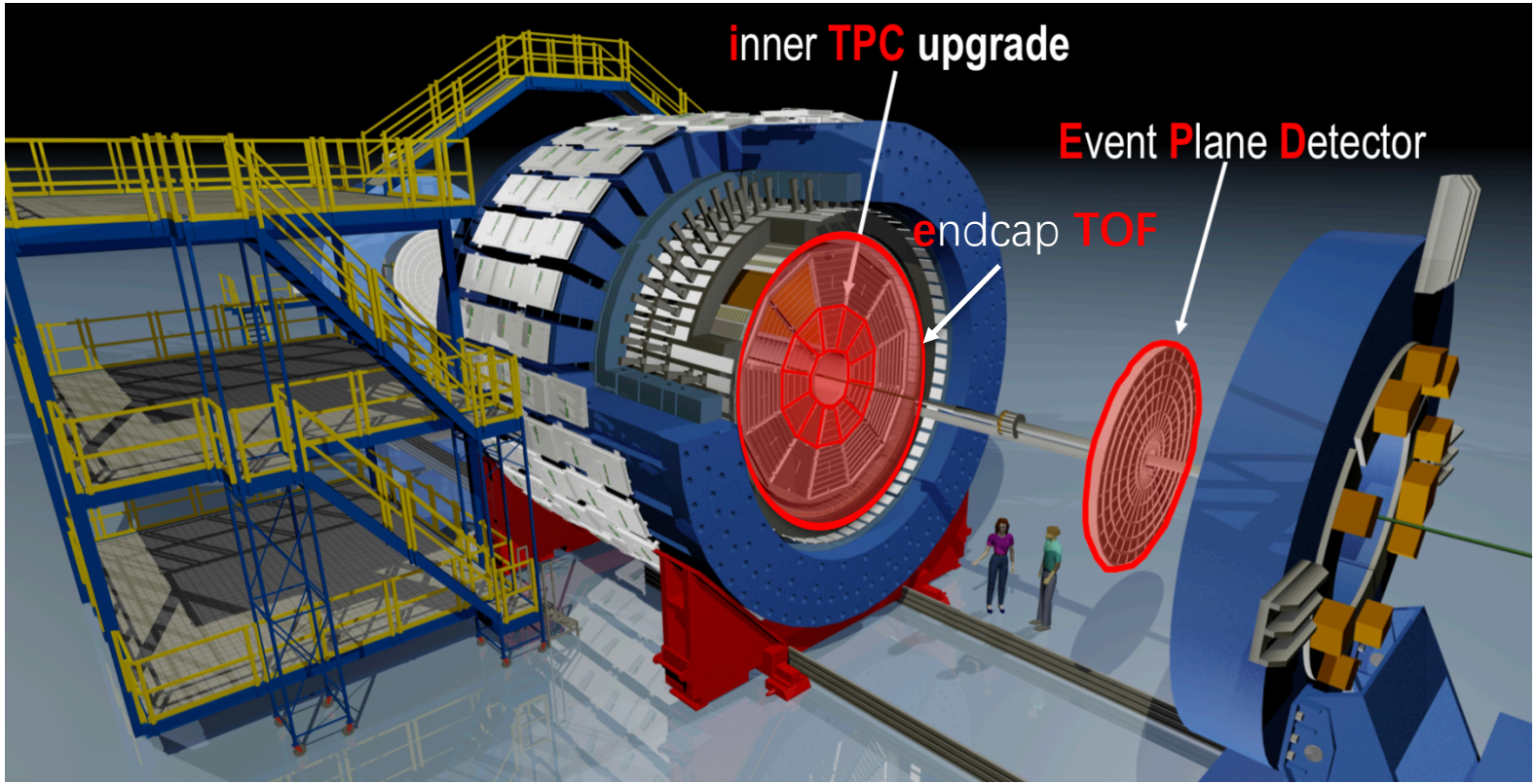


PRC 98 (2018) 14910



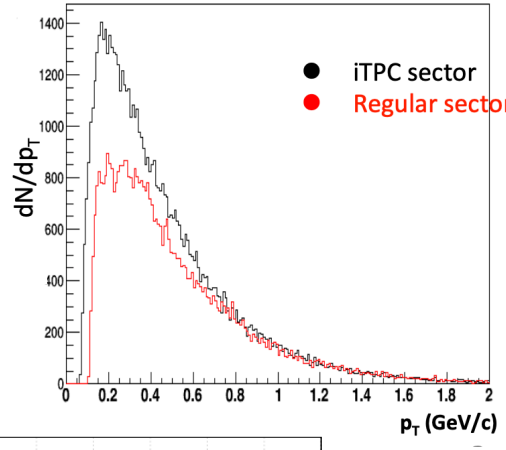
STAR Detector Upgrades for BES-II

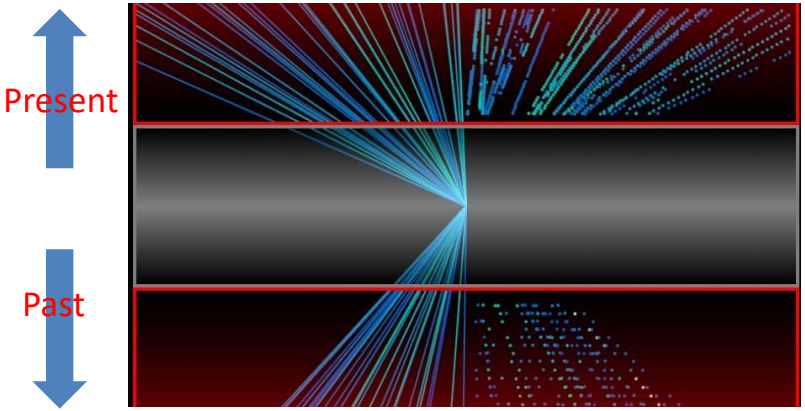
- RHIC: increase luminosity for low energy beams with ***e-cooling*** (LEReC)

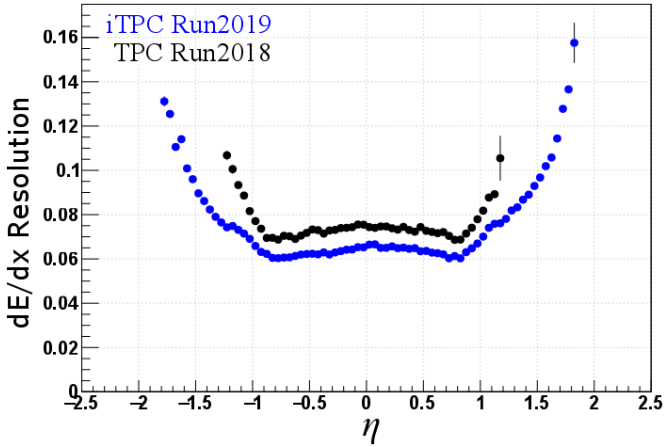


inner Time Projection Chamber (iTPC)

- Rebuild the inner sectors of the TPC to improve:
  - Continuous coverage
  - Better dE/dx and p_T resolution
  - Extend η acceptance from 1.0 to 1.5
  - Lower p_T cut from 125 MeV/c to 60 MeV/c
- Fully operational since 2019

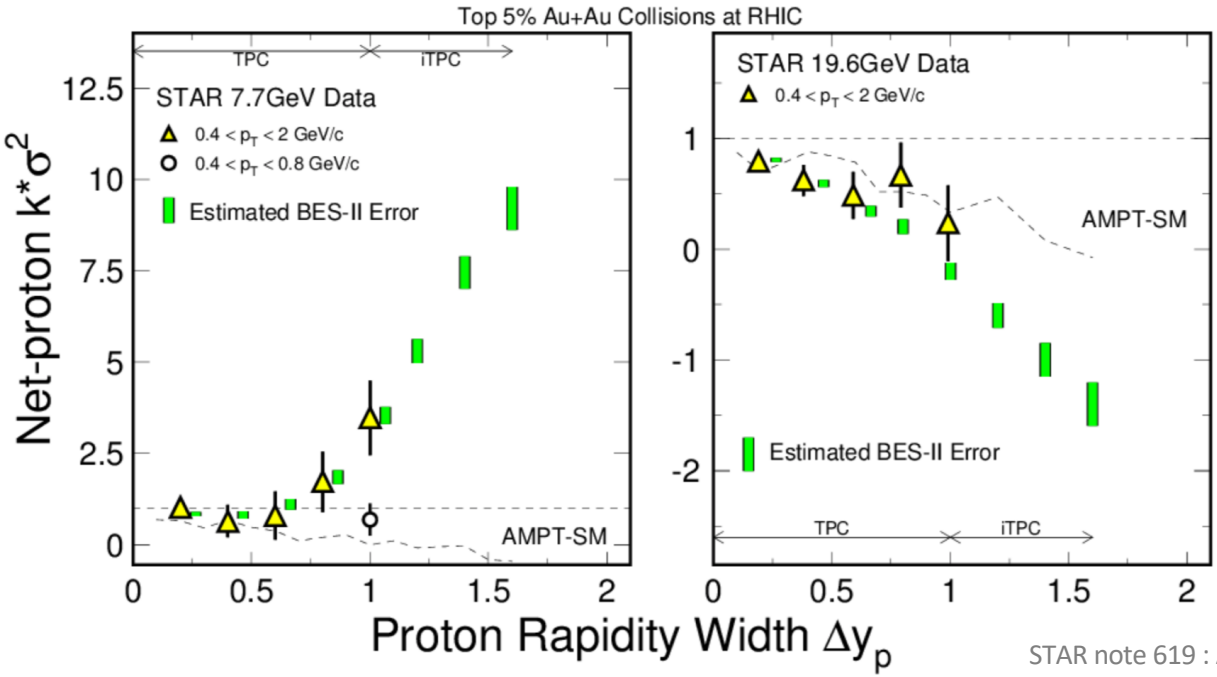






Expected Impact with iTPC in BES-II

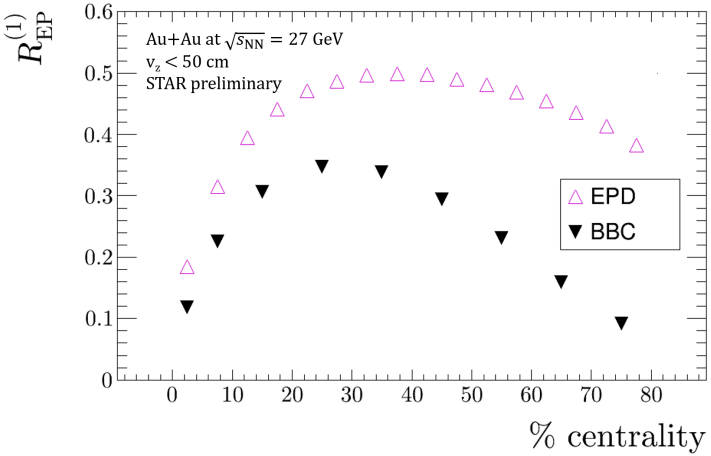
- Provides measurements of the net-proton Kurtosis to assess the sensitivity on the search of the QCD critical point

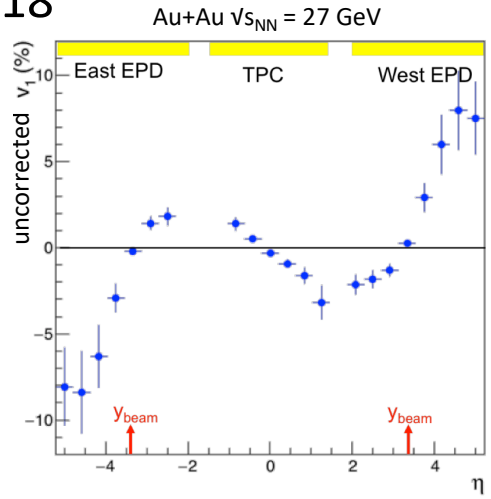


STAR note 619 : A proposal for iTPC upgrade

Event Plane Detector (EPD)

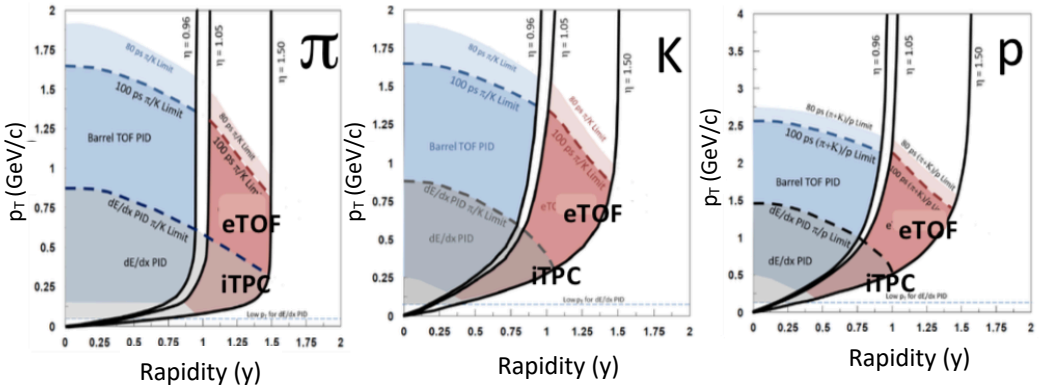
- Designed for event plane determination, centrality definition, and triggering
  - Scintillator based fast detector
  - Large η coverage: 2.1 <|η| < 5.1
  - Excellent timing resolution: ~ 1 ns
- Fully operational since 2018

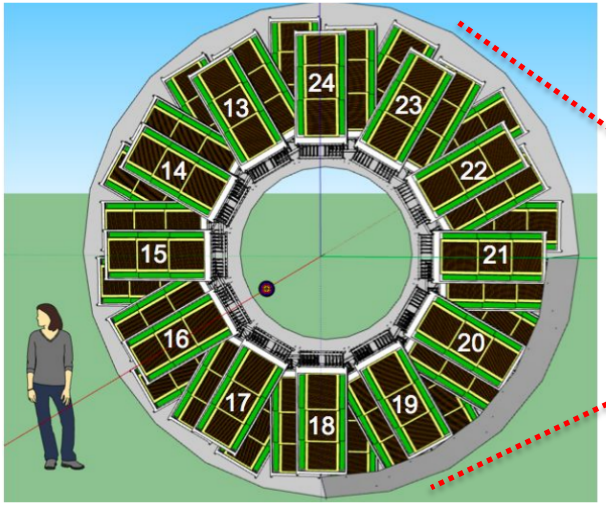


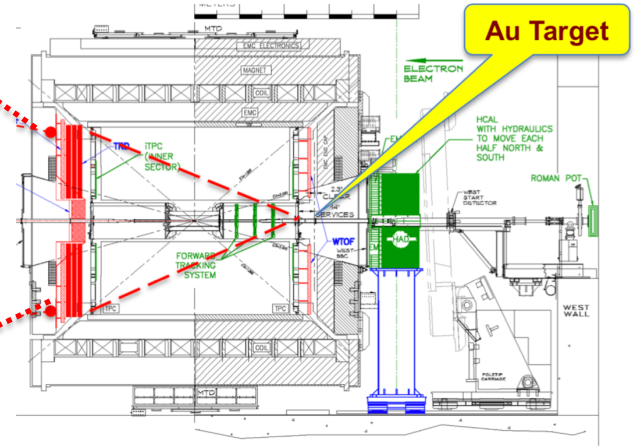


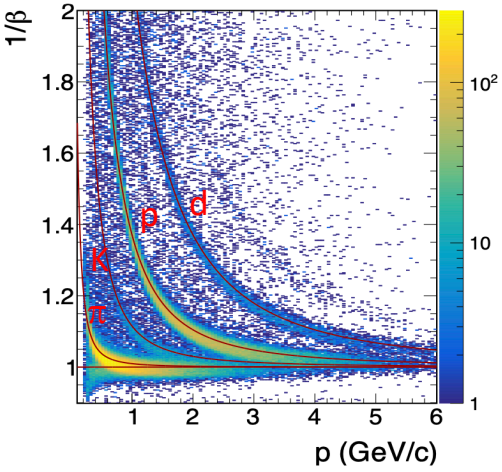
endcap Time-of-Flight (eTOF)

- Installed on one side of STAR (part of FAIR CBM Phase-0)
- Improve PID in $1.1 < \eta < 1.6$
- Multi-gap resistive plate chamber
- Fully installed for 2019

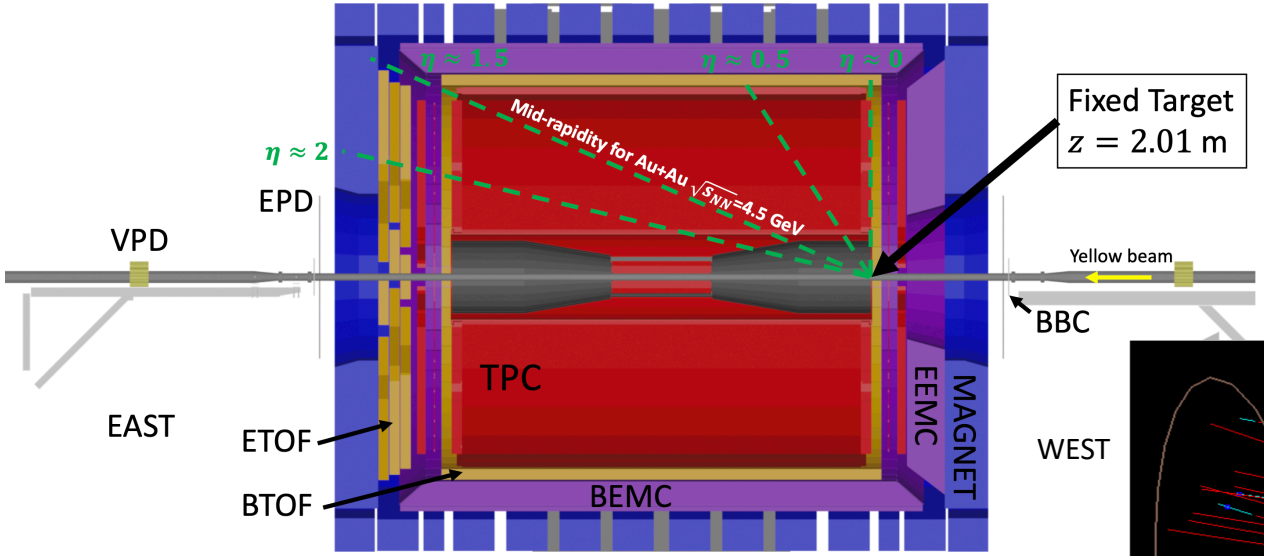


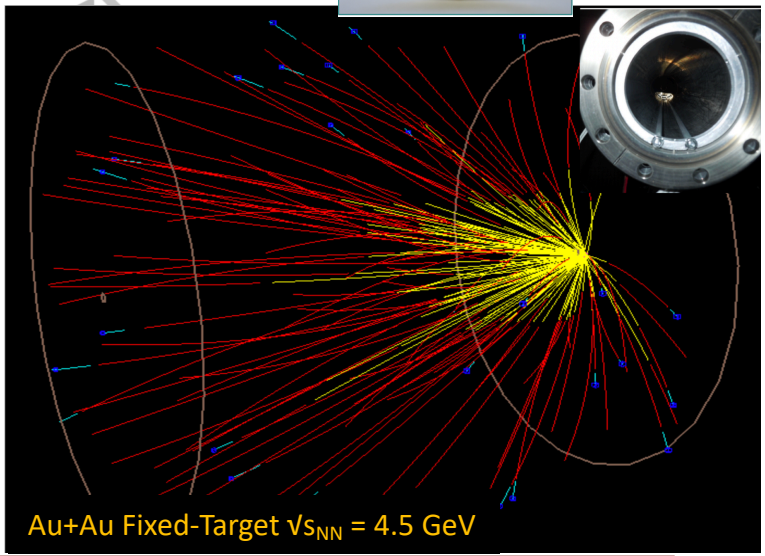






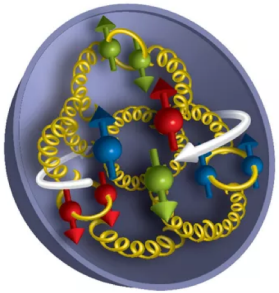
Fixed-Target Au+Au Collisions in STAR

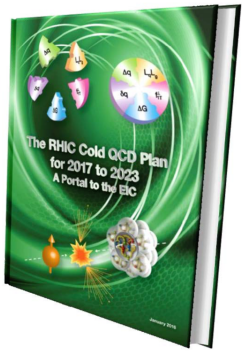




Cold QCD Program @ RHIC (Run2020+)

- RHIC provides unique opportunities to understand
  - How do sea quarks and gluons contribute to the nucleon spin?
  - How do the confined hadronic states emerge from quarks and gluons?
  - And more…





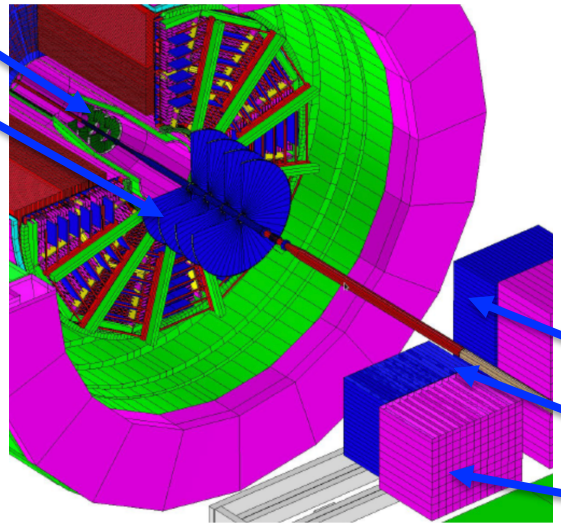
	Year	√s (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
STAR only running	2021/22	p↑p @ 510	1.1 fb^{-1} 10 weeks	TMDs at low and high x	A_{UT} for Collins observables, i.e. hadron in jet modulations at $\eta > 1$	ECal+HCal+Tracking
	2021/22	$\overrightarrow{p}\overrightarrow{p}$ @ 510	1.1 fb^{-1} 10 weeks	Δg(x) at small x	A_{LL} for jets, di-jets, h/g-jets at $\eta > 1$	ECal+HCal
In parallel with sPHENIX running		p↑p @ 200	300 pb^{-1} 8 weeks	Subprocess driving the large A_N at high x_F and h	A_N for charged hadrons and flavor enhanced jets	ECal+HCal+Tracking
		p↑Au @ 200	1.8 pb^{-1} 8 weeks	initial state and hadronization in nuclear collisions signatures for Saturation	R_{pAu} direct photons and DY Dihadron, g-jet, h-jet, diffraction	ECal+HCal+Tracking
		p↑Al @ 200	12.6 pb^{-1} 8 weeks	A-dependence of nPDF, A-dependence for Saturation	R_{pAl}: direct photons and DY Dihadrons, g-jet, h-jet, diffraction	ECal+HCal+Tracking

STAR Forward Physics Program

- The STAR forward upgrade includes **Calorimetry (ECAL & HCAL)** and **Tracking (silicon microstrip tracker & small-strip Thin Gap Chamber)** dedicated to study nuclear structure, the QGP, etc.

Detector	pp and pA	AA
ECAL	~10%/√E	~20%/√E
HCAL	~60%/√E	---
Tracking	Charge separation Photon suppression	$0.2 < p_T < 2$ GeV/c with 20 – 30% $1/p_T$

Forward Tracker
- 3 silicon disks
- 4 sTGC layers

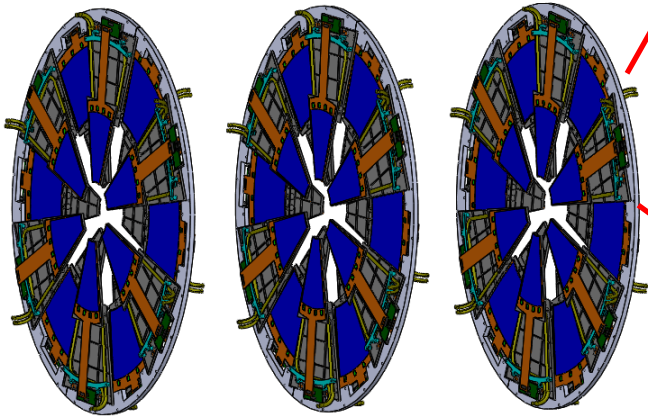


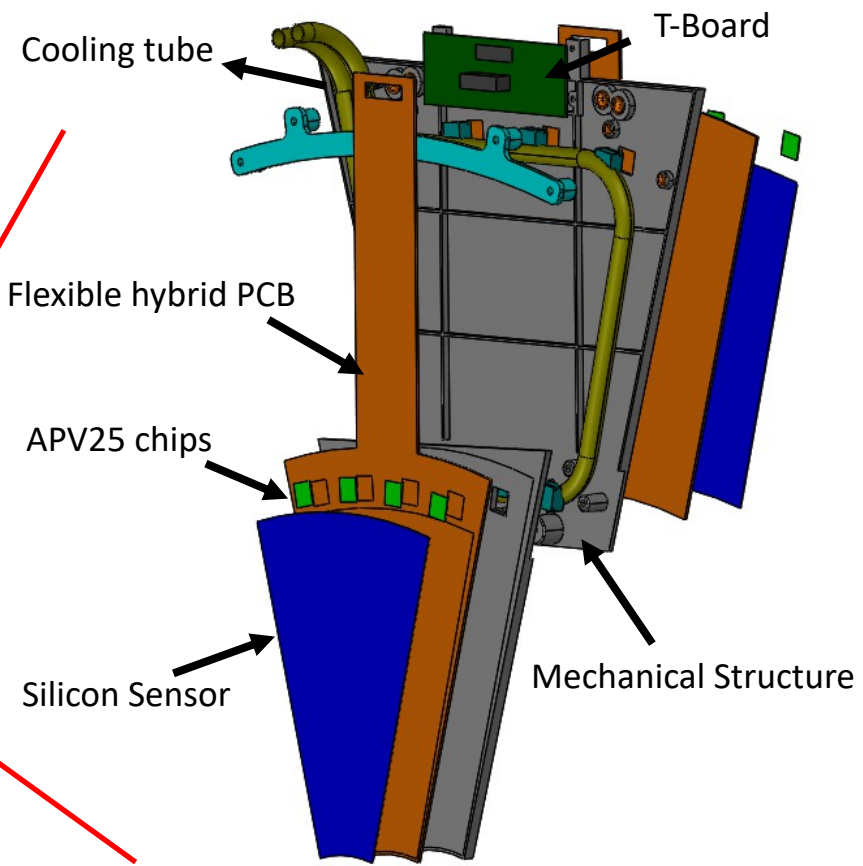
Forward Calorimeters
- Pre/post-shower: scintillator
- ECAL: PbSc towers (18 X_0)
- HCAL: FeSc plates (4.5 λ)

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

STAR Forward Tracker – Silicon Tracker

- 3 identical disks located at z = 140, 154, and 168 cm from IP
- Acceptance:
  - $0 < \phi < 2\pi$
  - $2.5 < \eta < 4.0$
- Each disk contains 12 modules

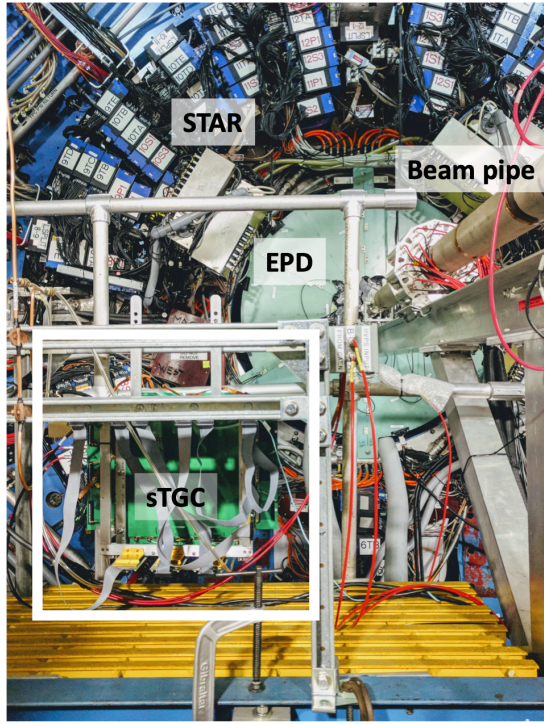


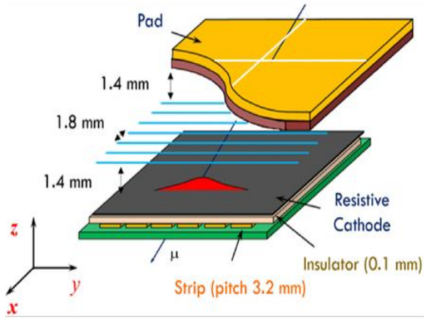


STAR Forward Tracker - sTGC

- A gaseous detector (developed by ATLAS)
- 4 sTGC layers located at 273, 303, 333 and 363 cm from IP
- Each layer is double-sided
  - ➔ Provide (diagonal) x-y coordinates
- Position resolution: ~100 μm
- Acceptance: $2.5 < \eta < 4.0$
- Efficiency greater than 98% achieved

Prototype in Run 19



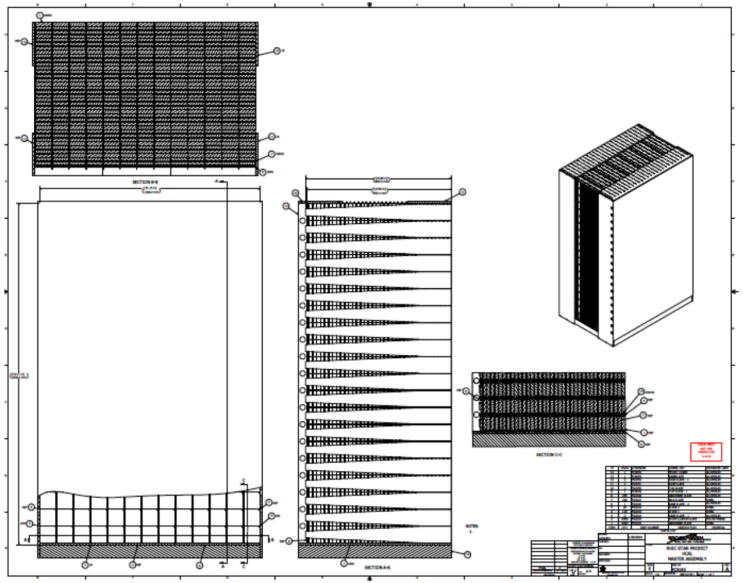


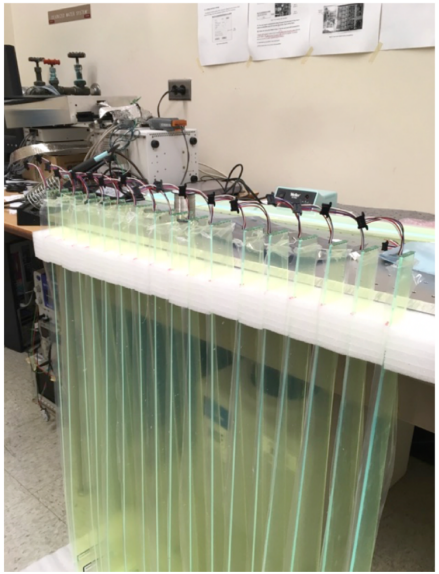
STAR Forward Calorimeters - ECAL

- Reuse PHENIX lead-scintillator calorimeter with new SiPM based readout
- Total 12 sectors
- Each sector has 6 × 6 EM modules
- EM Module:
  - Each module has 4 independent towers
  - Penetrating WLS fibers for light collection
- First forward upgrade detector installed in STAR (October 2019)

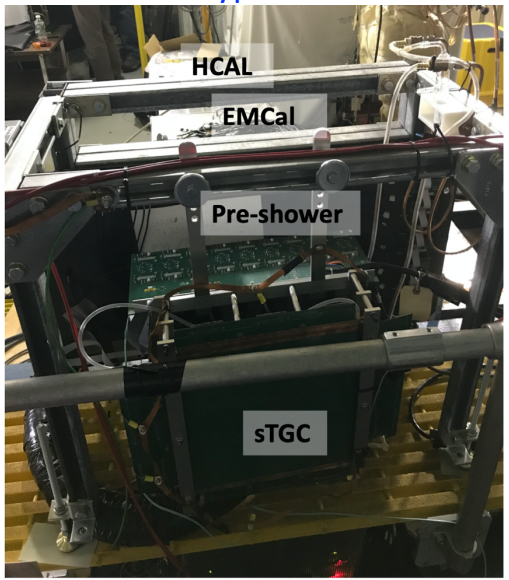
STAR Forward Calorimeters - HCAL

- First hadronic calorimeter in STAR
- Fe/Sc sandwich sampling calorimeter
- R&D and scintillator production are on-going





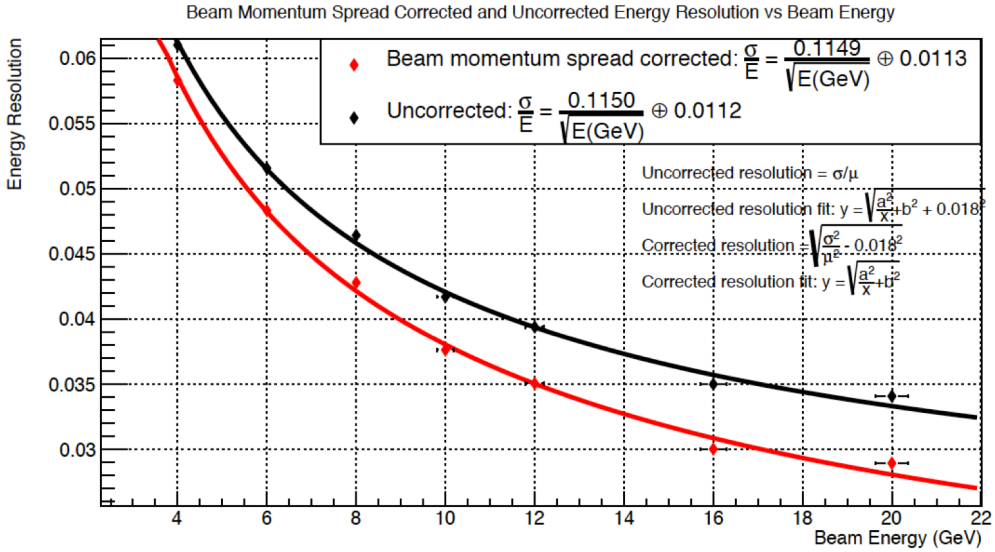
Prototype in Run 19



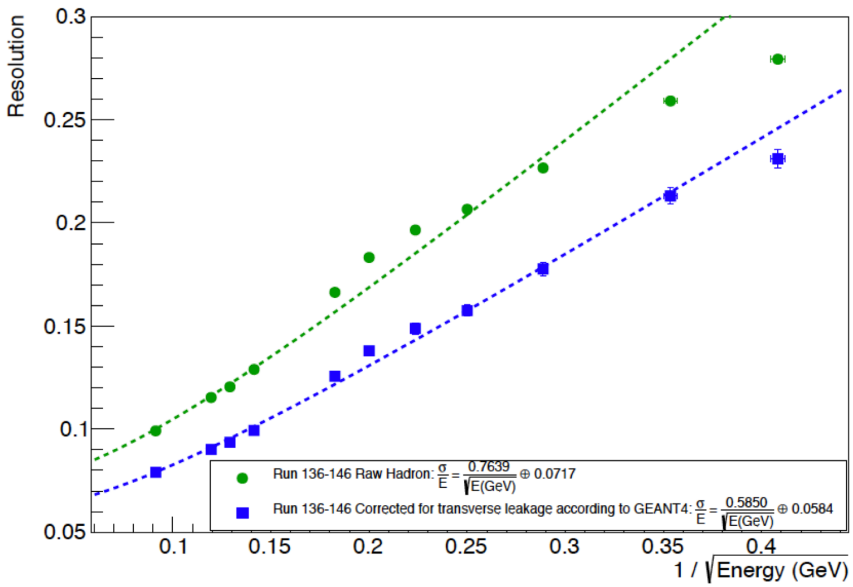
Performance of ECAL and HCAL

- Intensive test beam for Forward Calorimeter at FNAL in 2019
- Performances of ECAL and HCAL prototype are close to the requirements

ECAL



HCAL



Organizational Structure STAR Forward Upgrade

- Dedicated personnel with large expertise for each subsystem

sTGC

BROOKHAVEN NATIONAL LABORATORY

SHANDONG UNIVERSITY

Silicon

UIC UNIVERSITY OF ILLINOIS AT CHICAGO

INDIANA UNIVERSITY

BROOKHAVEN NATIONAL LABORATORY

SHANDONG UNIVERSITY

NATIONAL CHENG KUNG UNIVERSITY 1931

ECAL

KENTUCKY

VALPARAISO UNIVERSITY

ABILENE CHRISTIAN UNIVERSITY

HCAL

UCLA

TEXAS A&M UNIVERSITY

INDIANA UNIVERSITY

RUTGERS

ABILENE CHRISTIAN UNIVERSITY

OHIO STATE

DAQ/Readout

BROOKHAVEN NATIONAL LABORATORY

INDIANA UNIVERSITY

KENTUCKY

UCLA

TEXAS A&M UNIVERSITY

Software

BROOKHAVEN NATIONAL LABORATORY

UIC UNIVERSITY OF ILLINOIS AT CHICAGO

INDIANA UNIVERSITY

TEXAS A&M UNIVERSITY

NATIONAL CHENG KUNG UNIVERSITY 1931

Integration

BROOKHAVEN NATIONAL LABORATORY

Calibration

RIVERSIDE

TEMPLE UNIVERSITY

Slow Controls

VALPARAISO UNIVERSITY

ABILENE CHRISTIAN UNIVERSITY

Creighton UNIVERSITY

and the STAR collaboration, which stands enthusiastically behind the upgrade

Expected Results from STAR Forward Upgrade

Forward-rapidity 2.5 < η < 4.0

A+A

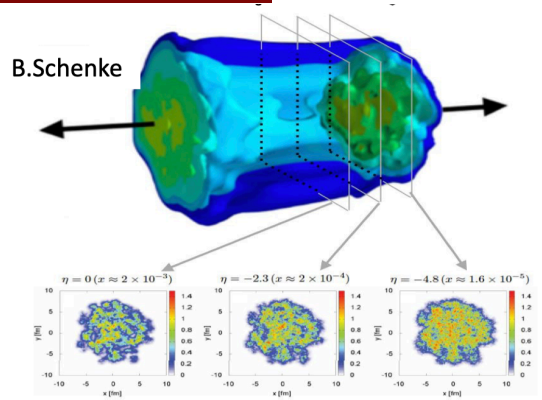
Beam:
Full Energy AuAu

Physics Topics:
- Temperature dependence of viscosity through flow harmonics up to η~4
- Longitudinal decorrelation up to η~4
- Global Lambda Polarization
  → strong rapidity dependence predicted

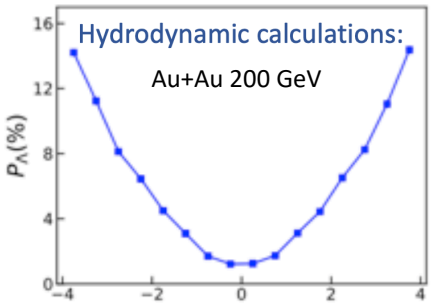
p+p & p+A

Beam:
500 GeV: p+p
200 GeV: p+p and p+A

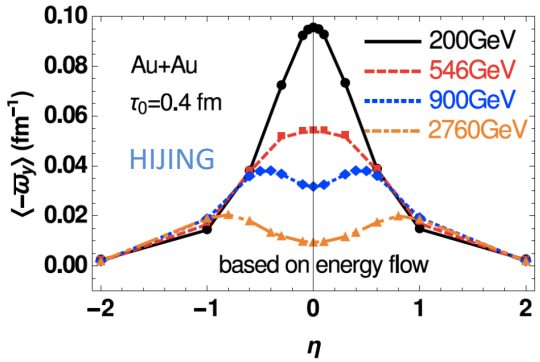
Physics Topics:
- TMD measurements at high x
  transversity → tensor charge
- Improve statistical precision for Sivers through DY
- $\Delta g(x,Q^2)$ at low x through Di-jets
- Gluon PDFs for nuclei
- ➢ R_{pA} for direct photons & DY
- Test of Saturation predictions through di-hadrons, γ-Jets



➔ Constrain the longitudinal structure of initial conditions through correlations vs rapidity



F. Beccattini et al. EPJC 75(2015)406
Li, Pang, Wang & Xia, PRC 96 (2017) 054908



Deng & Huang, PRC 93 (2016) 064907

➔ Measurements at forward region are the key to distinguish the model predictions for global hyperon polarization

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A+A

Beam:
Full Energy AuAu

Physics Topics:
- Temperature dependence of viscosity through flow harmonics up to η~4
- Longitudinal decorrelation up to η~4
- Global Lambda Polarization
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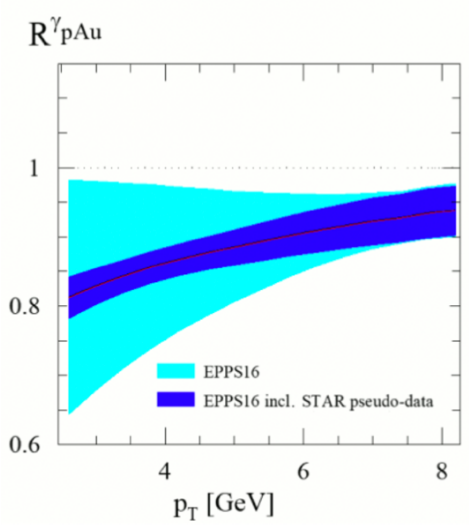
p+p & p+A

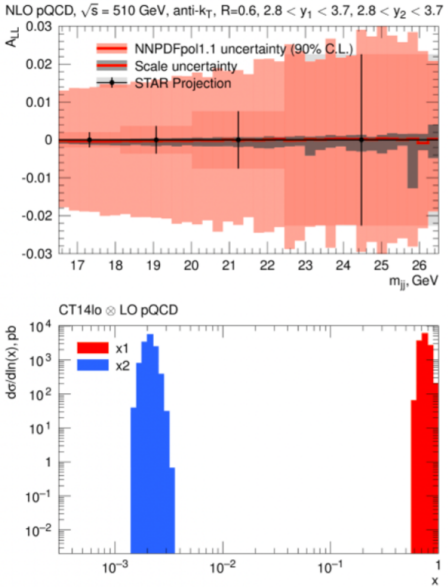
Beam:
500 GeV: p+p
200 GeV: p+p and p+A

Physics Topics:
- TMD measurements at high x
  transversity → tensor charge
- Improve statistical precision for Sivers through DY
- $\Delta g(x,Q^2)$ at low x through Di-jets
- Gluon PDFs for nuclei
- ➢ R_{pA} for direct photons & DY
- Test of Saturation predictions through di-hadrons, γ-Jets

Constrain Nuclear PDFs:
Unique kinematic coverage by STAR forward detectors
Direct photons → gluon PDF
Drell-Yan production → sea quarks



Constrain Gluon Helicity:
Di-jets A_{LL} at 510 GeV with STAR forward upgrade: constrain $\Delta g(x)$ at $x \sim 10^{-3}$



Summary

- STAR experiment plays a crucial role in understanding the QCD phase diagram and in expanding the frontiers of cold-QCD
- The STAR BES-II upgrades (iTPC, EPD, and eTOF) provide excellent PID with wider η coverage and better resolution in p_T and the event plane determination
- The STAR forward upgrade consists of tracking (silicon + sTGCs) + calorimetry (ECAL + HCAL) with a coverage of $2.5 < \eta < 4.0$
- The forward upgrade is on track for data taking in FY-22 and beyond