STAR Forward Rapidity Upgrade

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→ for the **STAR Collaboration**

Hard & Electromagnetic Probes

June 4, 2020

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Talk Outline

- STAR Forward Physics Program
  - Cold QCD Program
  - Opportunities in A+A collisions
- STAR Forward Rapidity Upgrade
  - Forward Tracking System
    - Silicon Tracker
    - Small-Strip Thin Gap Chambers (sTGCs)
  - Forward Calorimetry System
    - Electromagnetic Calorimeter
    - Hadronic Calorimeter
- Summary & Outlook

STAR Forward Rapidity Physics Program

Measurements planned for 2021+ with the STAR forward upgrade

→Address important topics in hot & cold QCD

Forward-rapidity 2.5<η<4

pp, pA

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 Drell-Yan
- $\Delta g(x, Q^2)$ at low x through Di-jets
- Gluon PDFs for nuclei
  - ➢ R_{pA} for direct photons & DY
- Test of Saturation predictions through di-hadrons, g-Jets

Au+Au

Beam:

200 GeV: Au+Au

Physics Topics:

- Temperature dependence of viscosity through flow harmonics up to h~4
- Longitudinal decorrelation up to h~4
- Global Lambda polarization

→ Test for strong rapidity dependence

Observables:

- Inclusive jets and di-jets
- Hadrons in jets
- Direct photons
- Drell-Yan e^+e^-
- Lambda polarization
- Mid-forward & forward-forward rapidity correlations

Requirements:

- Good e/h separation
- Hadrons, photons, π^0 identification

2021/22: 500 GeV polarized pp run

Additional pp, pA, and A+A data taking in parallel to the sPHENIX campaign

Cold QCD Physics Program @ RHIC

Unique program addressing several fundamental questions in QCD:

- 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	$\sqrt{s}$ (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
2021/22	$p^{\uparrow}p$ @ 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
2021/22	$\vec{p}\vec{p}$@ 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
	$p^{\uparrow}p$ @ 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_{pAu}: direct photons and DY Dihadrons, γ-jet, h-jet, diffraction	Forward instrum. ECal+HCal+Tracking

STAR Only Running

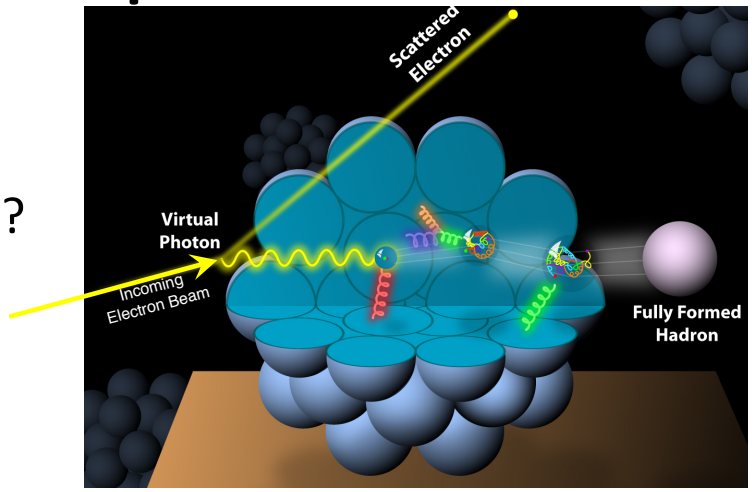
In parallel with sPHENIX running

Essential to RHIC hot & cold QCD physics mission

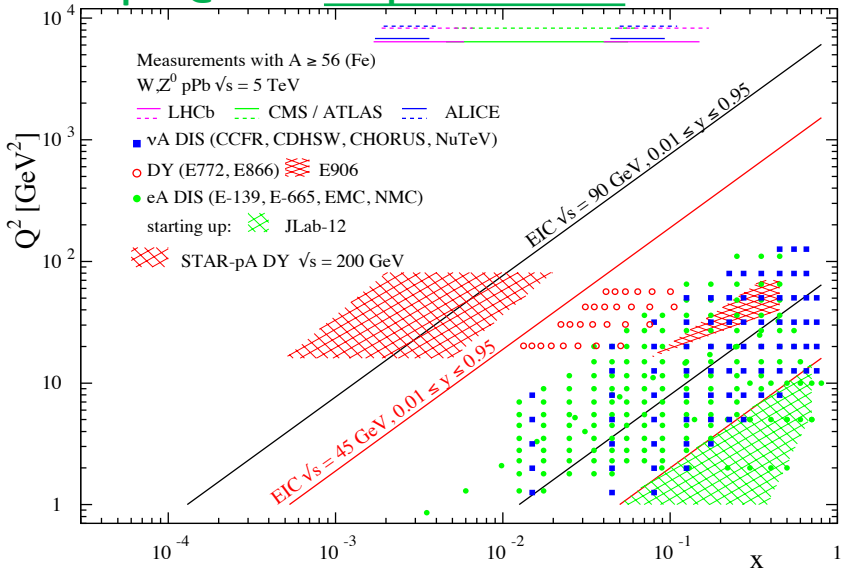
Probing the Initial State in p+A collisions

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



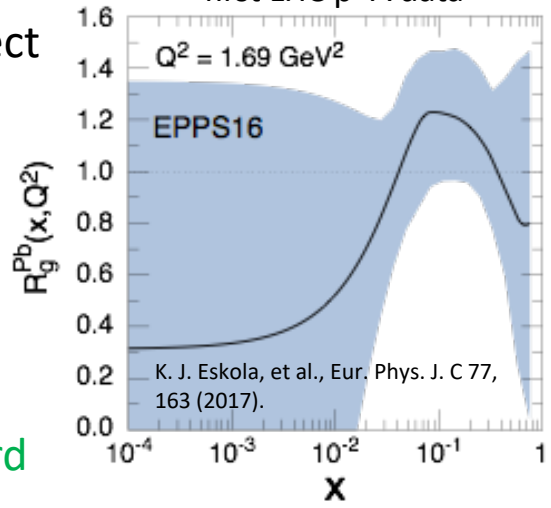
Observables free of final state effects:

- Gluons: R_{pA} for direct photons
- Sea-quarks: R_{pA} for Drell-Yan

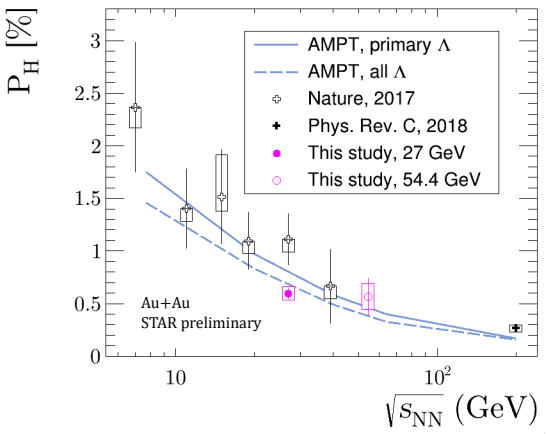
➢ Scan A-dependence prediction by saturation models

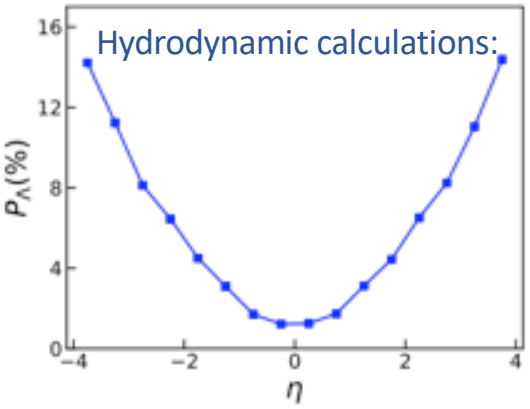
➢ Accessible at forward rapidity

Current knowledge including first LHC p+A data

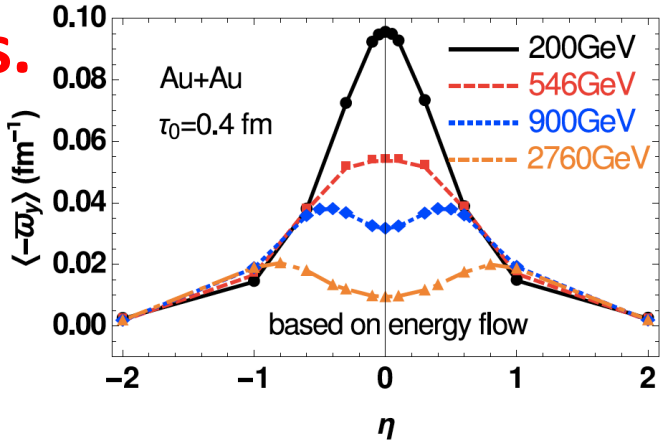


Global Hyperon Polarization in A+A



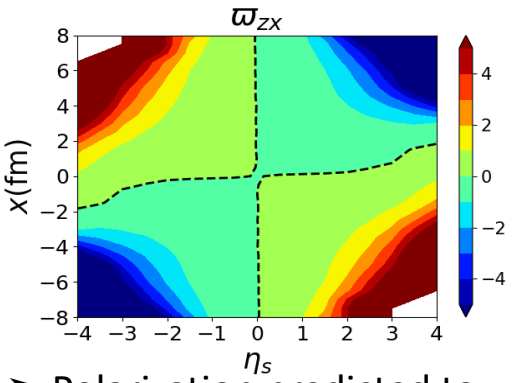


vs.



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

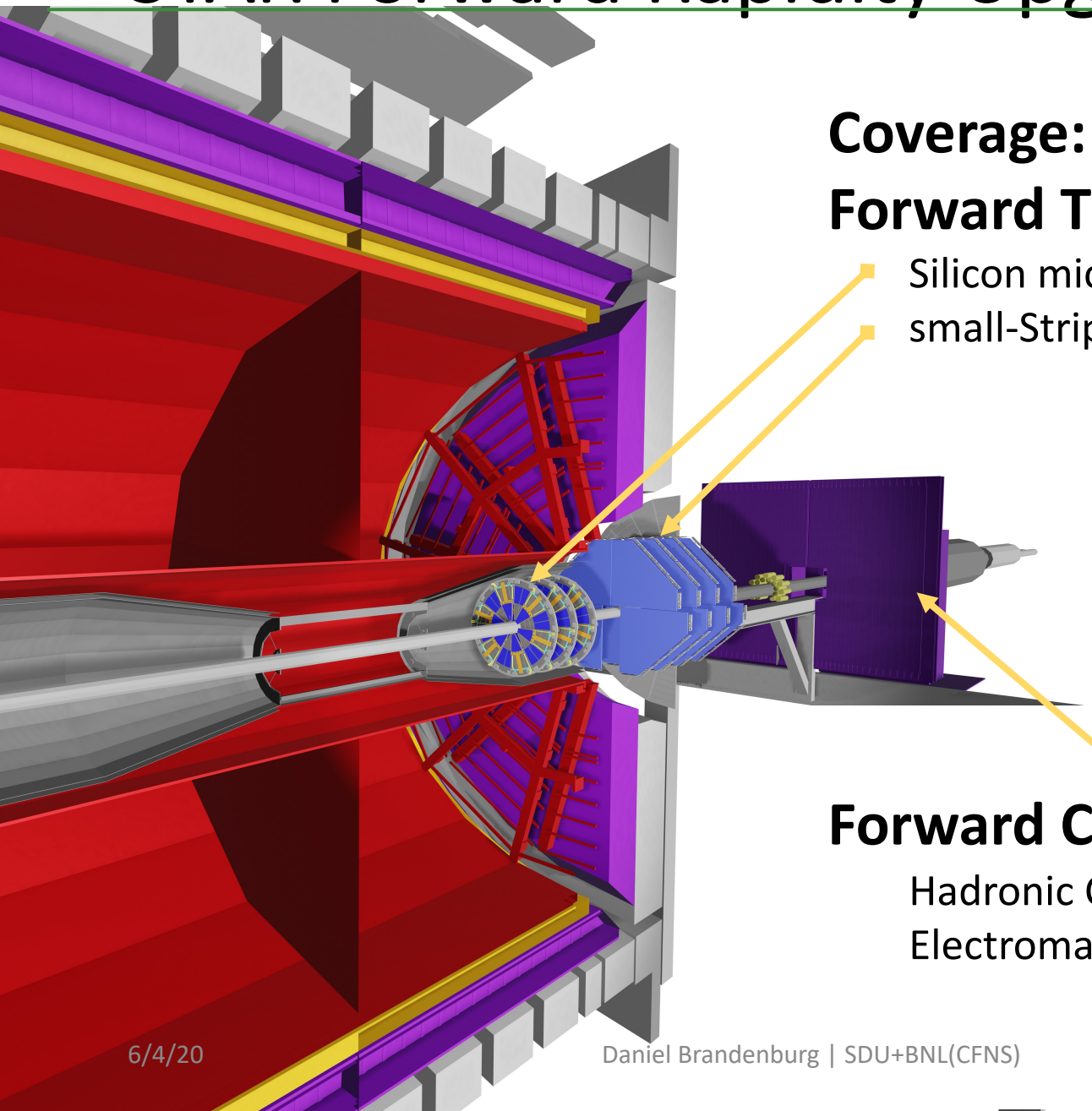


- Detailed STAR measurements of global hyperon polarization at mid rapidity to probe energy dependence
- Sensitive to <u>thermalization</u> and <u>viscosity</u>
- Polarization predicted to increase with viscosity

Models predict opposite polarization trend with rapidity

→ Measurements at forward rapidity are key

STAR Forward Rapidity Upgrade



Coverage: $2.5 < \eta < 4.0$

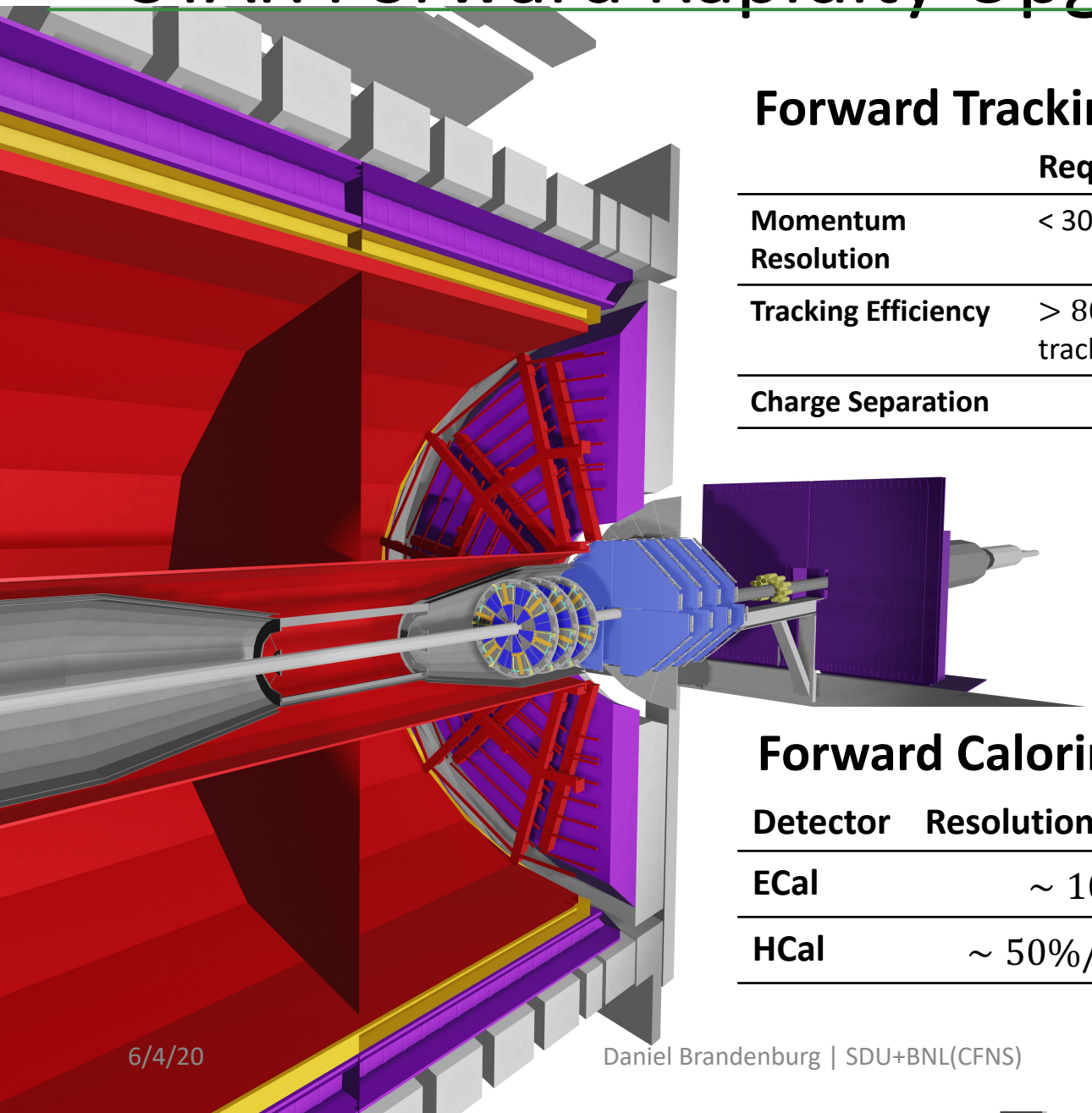
Forward Tracking System

- Silicon microstrip sensors
- small-Strip Thin Gap Chambers

Forward Calorimetry System

- Hadronic Calorimeter
- Electromagnetic Calorimeter

STAR Forward Rapidity Upgrade



Forward Tracking System

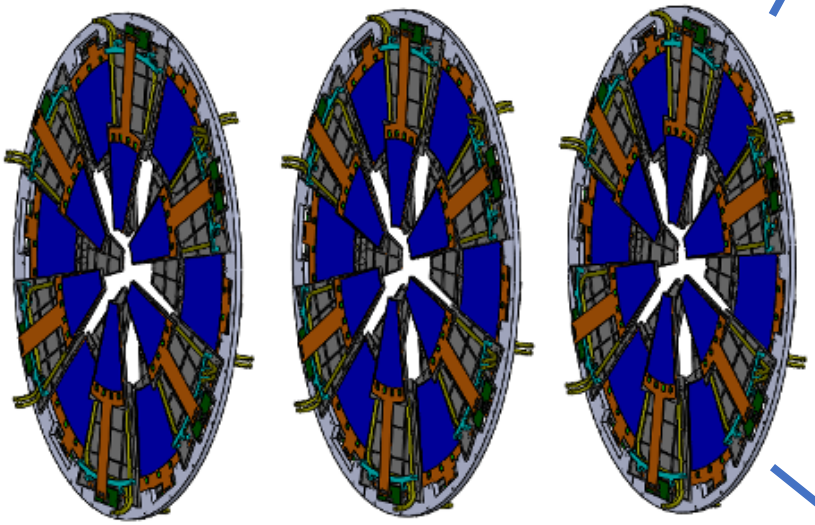
	Requirement	Motivation
Momentum Resolution	< 30%	A+A goals
Tracking Efficiency	$> 80\%$ @ 100 tracks / event	A+A goals
Charge Separation	–	p+p / p+A goals

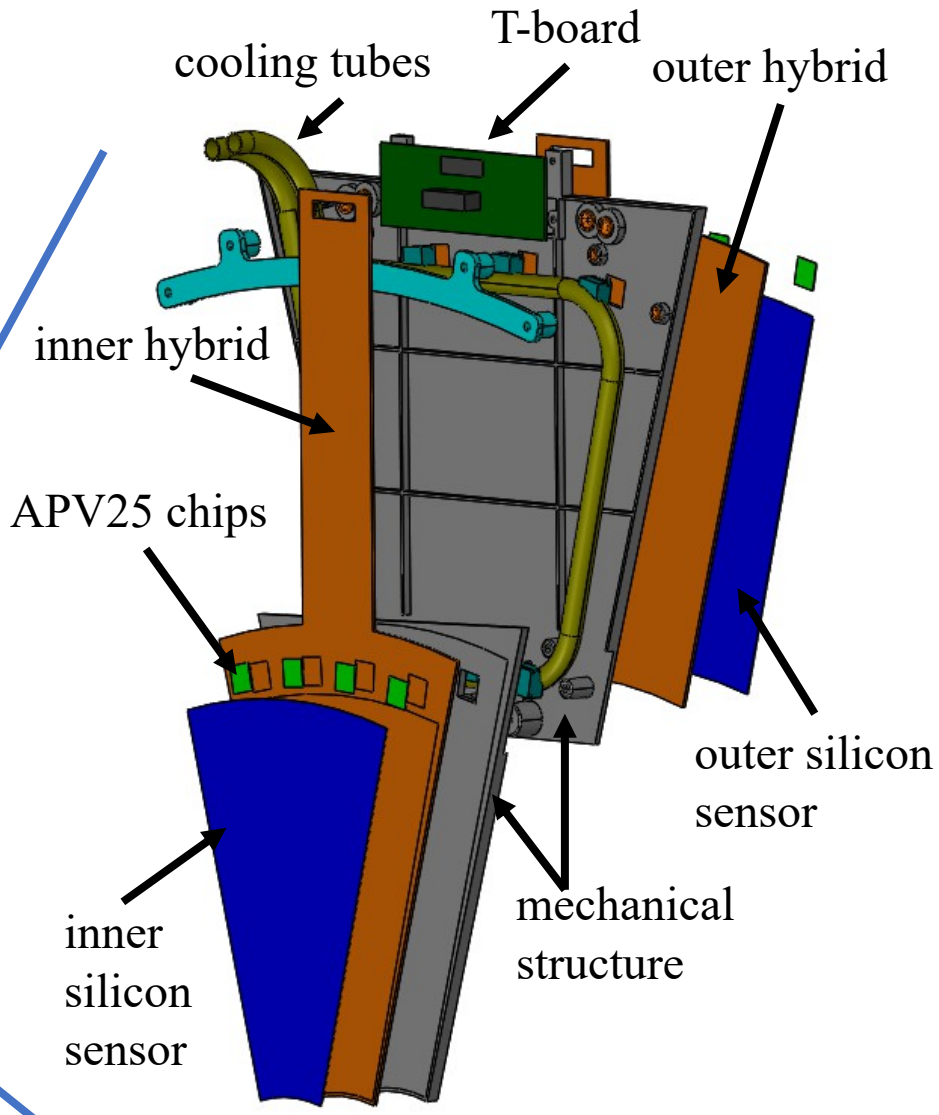
Forward Calorimeter System

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

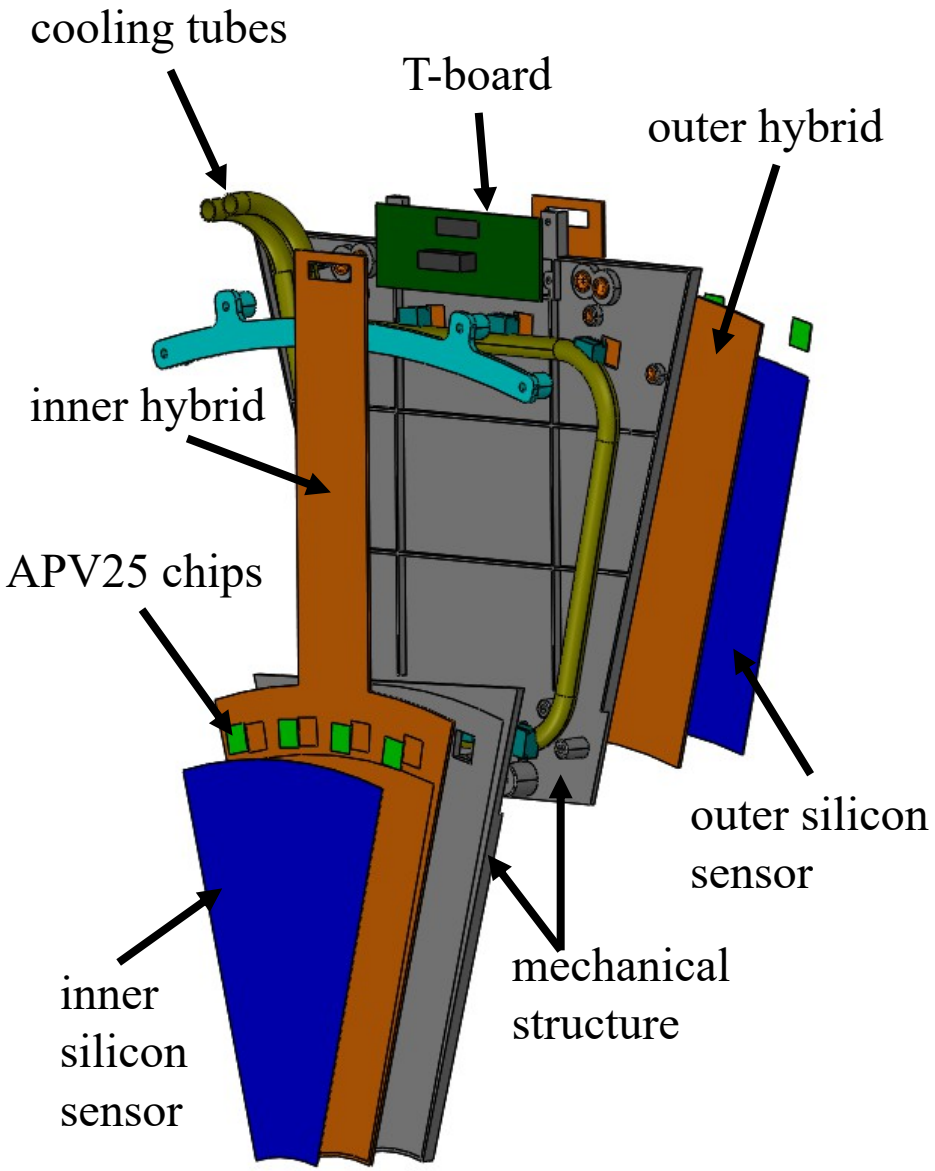
STAR Forward Silicon Tracker

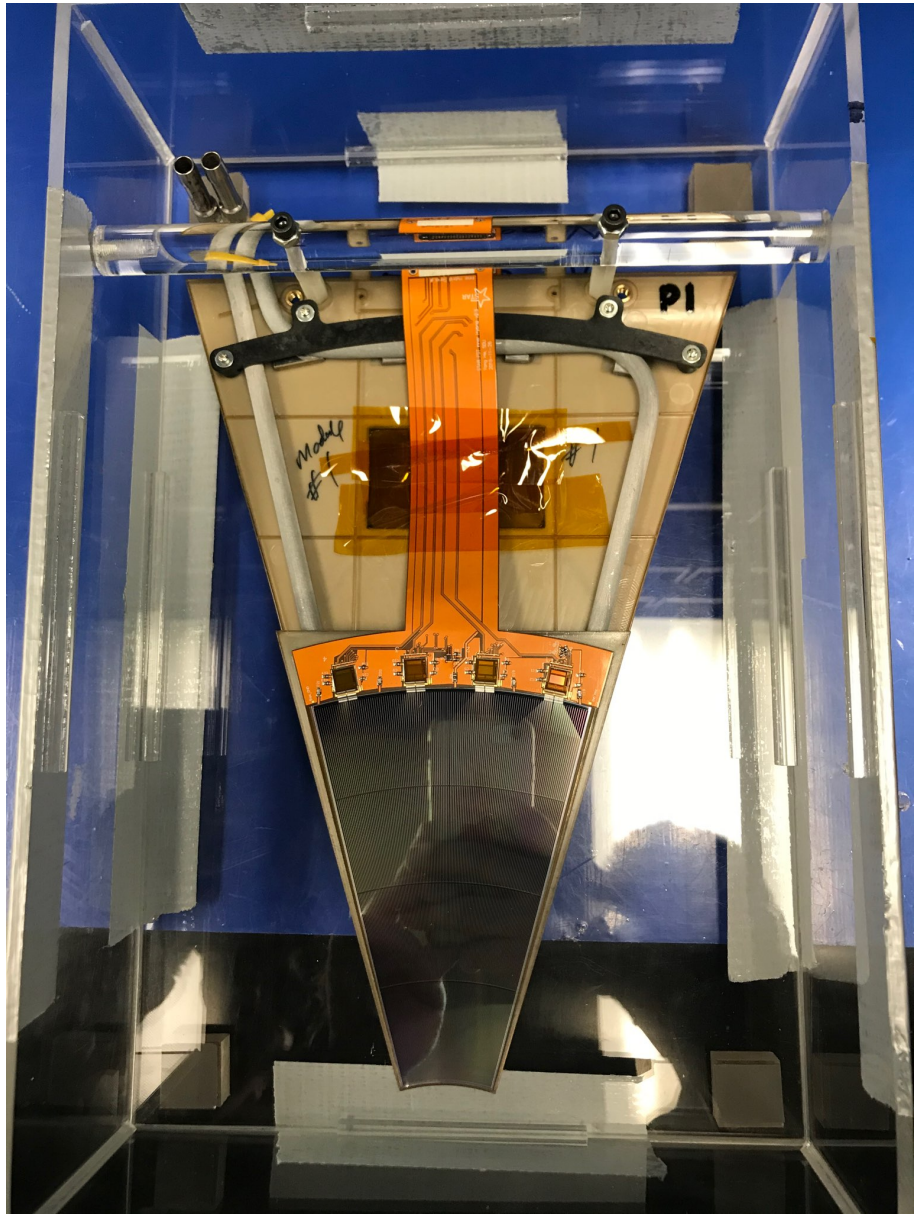
- Full installation: 3 identical disks
  - Acceptance:
  - $0 < \phi < 2\pi, \quad 2.5 < \eta < 4.0$
- 12 wedge modules / disk
- APV25 frontend readout chips
- Flexible hybrid





STAR Forward Silicon Tracker - Prototype Module

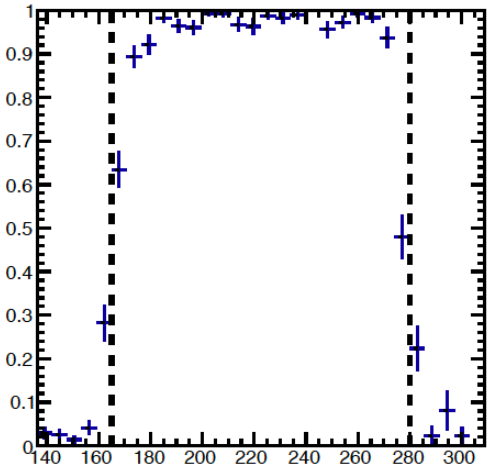




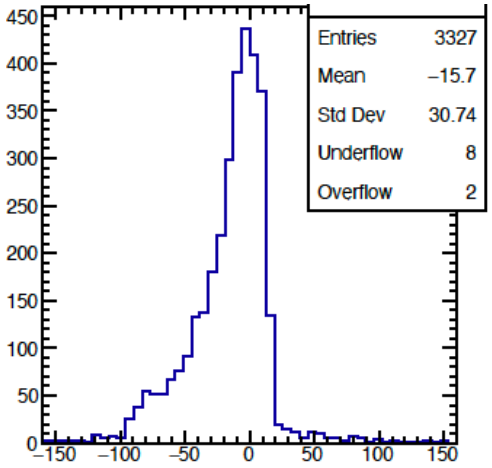
Prototype Testing & Integration Plans

✓Ongoing cosmic ray test of prototype outer sensor

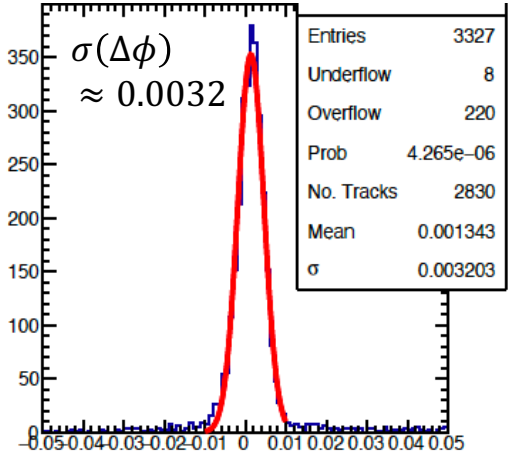
Hit Efficiency



Residual in R

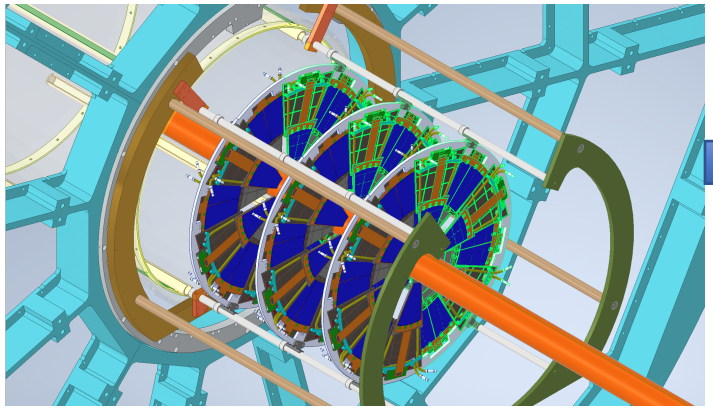


Residual in ϕ

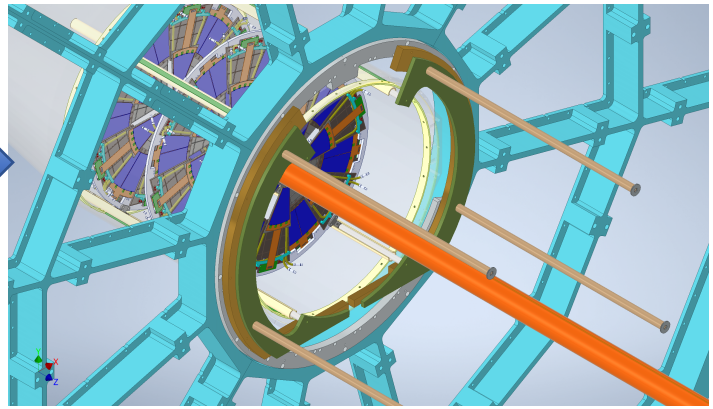


✓Special tool being designed for precision insertion into STAR

Before Insertion



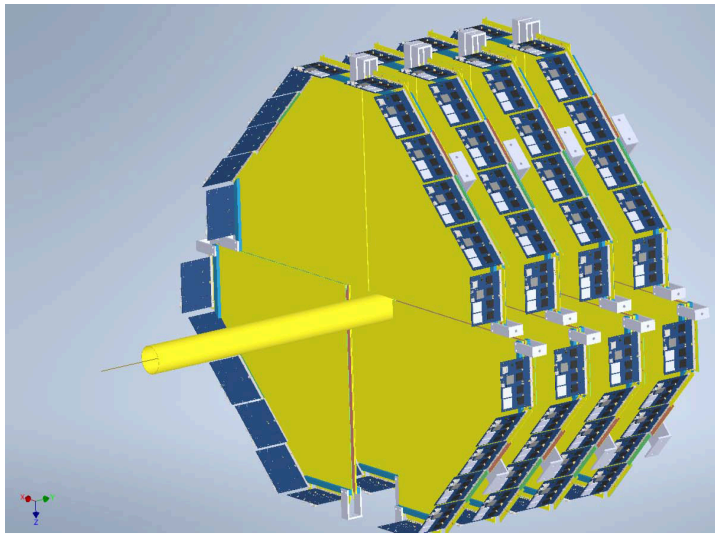
After Insertion

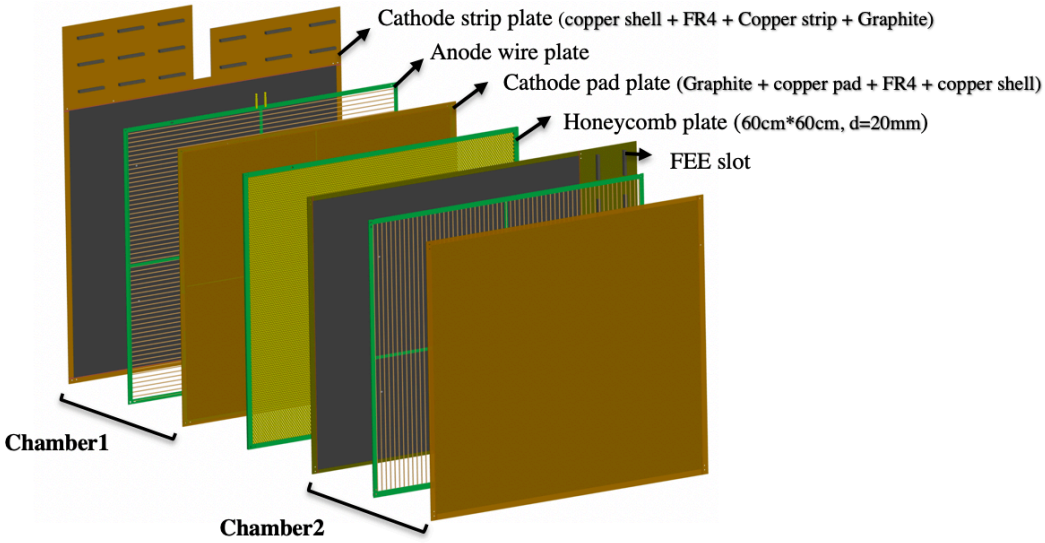


Small-Strip Thin Gap Chambers (sTGC)

Detector:

- Based on ATLAS sTGC design
- 4 layers in total
  - 4 modules/layer
  - 2 chambers/module
- Pentagon shape formed from identical modules
- Shandong University : sTGC R&D and production
- Position resolution: ~100 μm



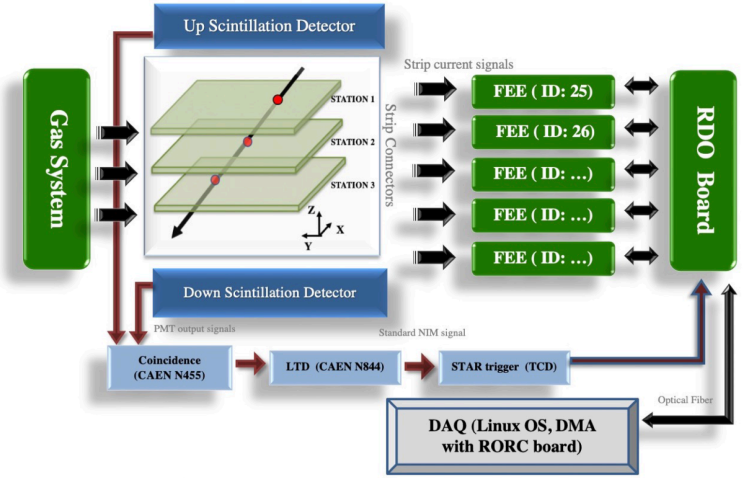


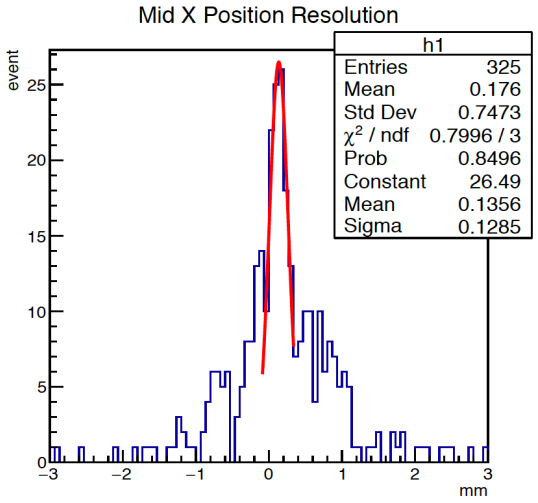
Wire: Au-plated tungsten wire
⌀ 50μm, 1.8mm pitch
Copper strip: 3.2mm pitch
Height of one layer: 5.8mm
Gas: 55% n-pentane+45%CO2
HV: 2900V

Requires dedicated gas system

R&D + Production at Shandong University

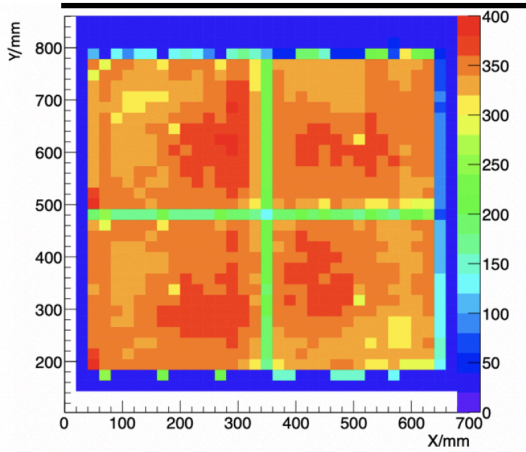
Performance tests using cosmic ray stand

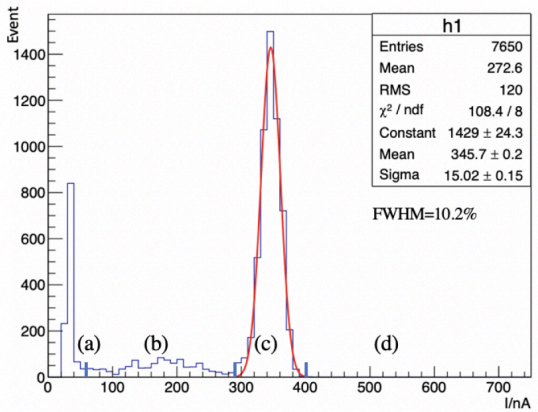




✓ **Position Resolution**
Performance meets expectation

Module flatness and quality control





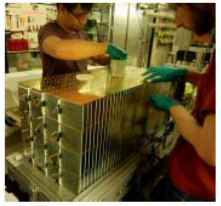
✓ 60cm x 60cm prototype
Finished in Jan 2020, will be delivered to BNL
✓Planned: in-beam testing at BNL

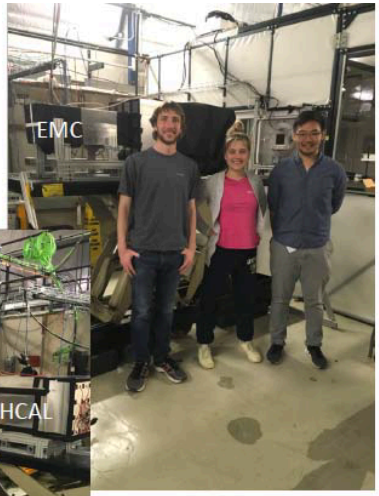
Forward Electromagnetic Calorimeter

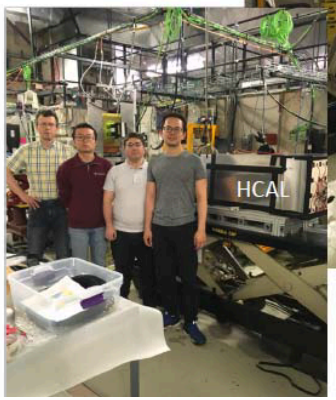
- Reuse PHENIX lead-scintillator calorimeter with new SiPM based readout
- 12 sectors, each has 6 × 6 EM modules
- EM module:
  - Each module has 4 independent towers
  - Penetrating WLS fibers for light collection

FCS, April 2019
FNAL Test Beam
4x4 Ecal, 4x4 HCal

A.Kiselev (BNL)
T. Lin (TAMU)
D. Kapukchyan (UCR)
D. Chen (UCR)
G. Visser (IUCF)
O. Tsai (UCLA)







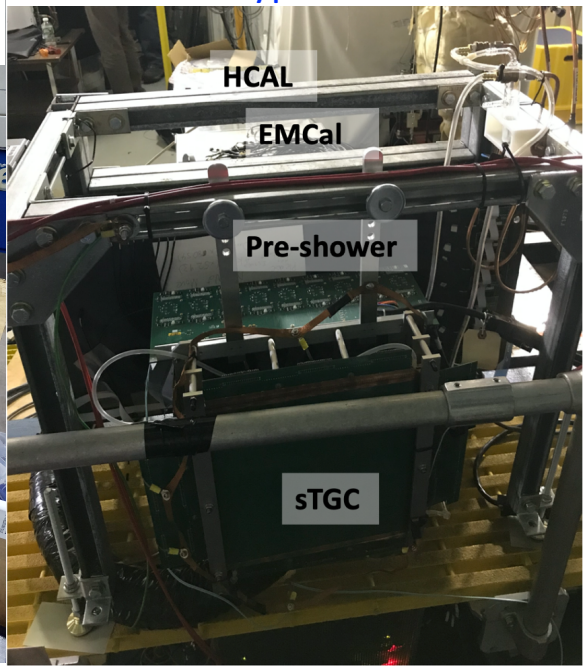
D. Neff (UCLA)
M.Sergeeva (UCLA)
B. Chan (UCLA)

Forward Hadronic Calorimeter

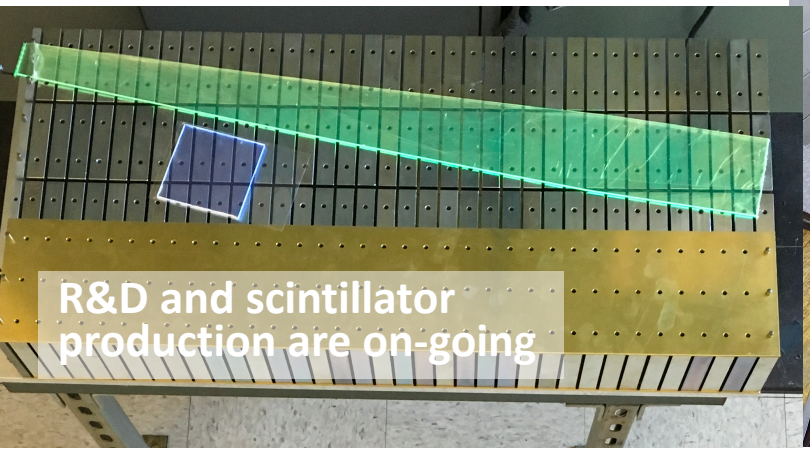
- **First use** of hadronic calorimeter @ STAR
- Fe/Sc sandwich sampling calorimeter
- Uses the same SiPM-based readout electronics as ECAL
- Ongoing production:
  - Scintillator tiles, absorber blocks
  - Wavelength shifting plates
  - Front-end electronics


Sc tiles preparations at BNL summer 2019

Prototype in Run 19



Absorber production at Chapman Lakes (Indiana) Feb. 2020


R&D and scintillator production are on-going

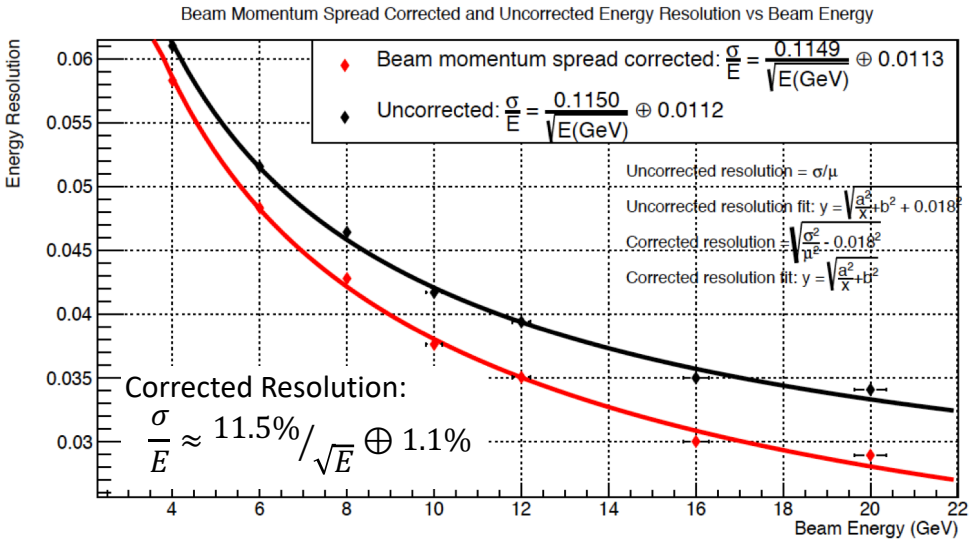
Performance of ECAL & HCAL @ FNAL

- Intensive test beam for Forward Calorimeter at Fermi National Accelerator Laboratory in 2019
- Performances of ECAL and HCAL prototype are near the requirements

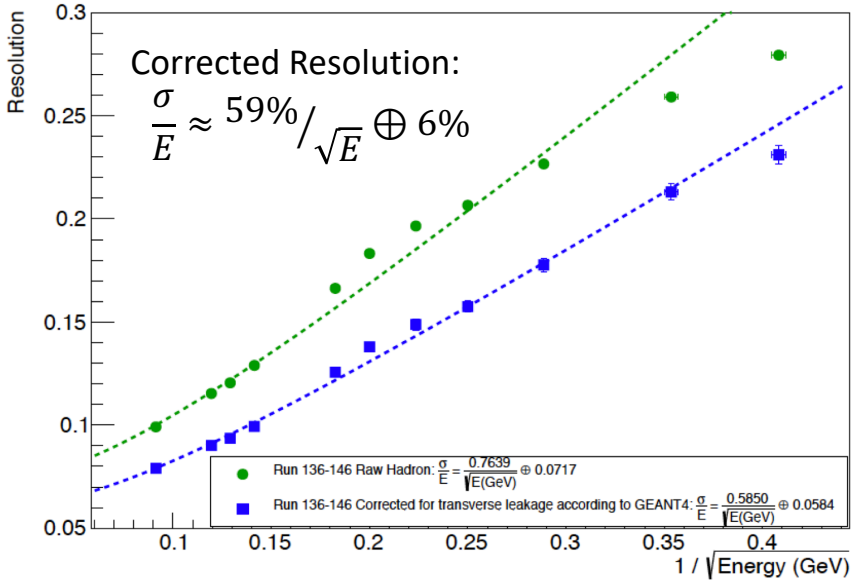
Detector	Goal for p+p & p+A	Goal for A+A	Achieved Resolution (FNAL Tests)
ECal	$\sim 10\%/\sqrt{E}$	$\sim 20\%/\sqrt{E}$	$11.5\%/\sqrt{E} \oplus 1.1\%$
HCal	$\sim 50\%/\sqrt{E} + 10\%$	–	$59\% /\sqrt{E} \oplus 6\%^{*}$

* with GEANT4-based transverse leakage correction

Electromagnetic Calorimeter

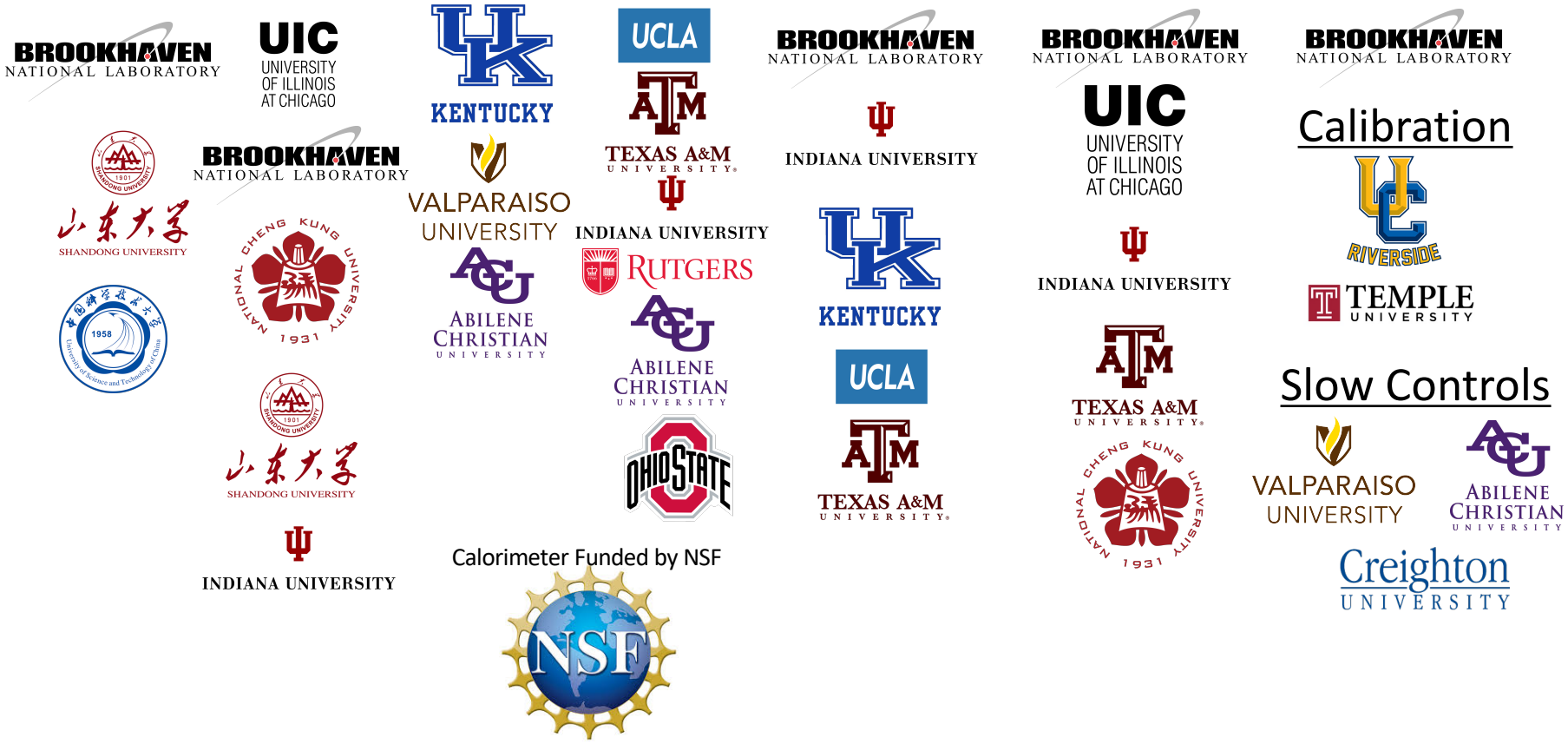


Hadronic Calorimeter



STAR Forward Upgrade Institutions

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



And support from the entire STAR Collaboration

Summary and Outlook

- The STAR forward upgrade consists of:
  - Tracking (silicon + sTGCs)
  - Calorimetry (ECAL + HCAL)
  - Coverage of $2.5 < \eta < 4.0$
- The forward upgrade is on track for data taking in 2021 and beyond

STAR forward rapidity physics program:

- Unique program addressing several fundamental questions in QCD
- Essential to RHIC hot & cold QCD physics mission
- Contributes to the success of the future EIC both scientifically and through detector development

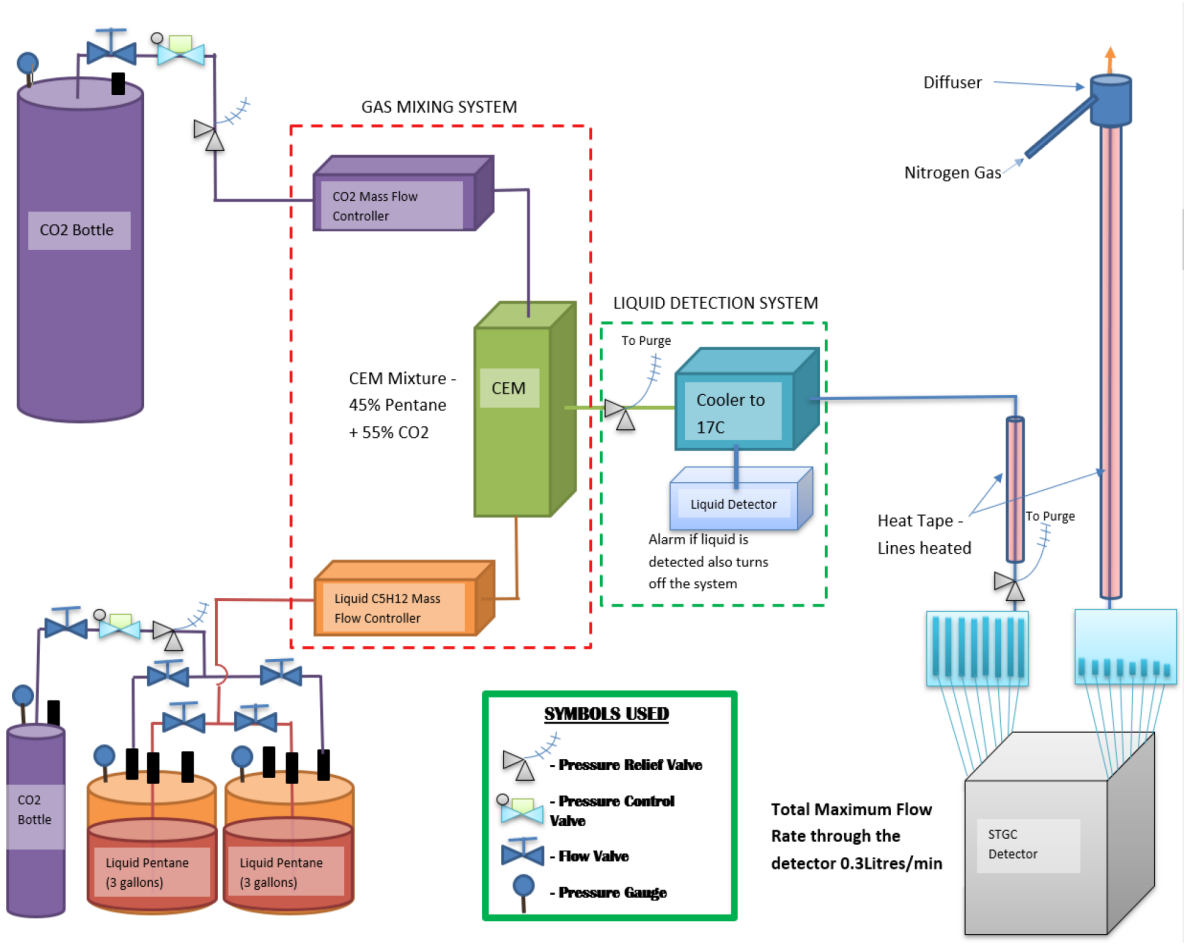
sTGC Gas System for n-pentane+CO2

Gas system for :
55% n-pentane+45%CO2

Uses controlled evaporative mixing (CEM)

Prototype gas system designed and built at Shandon University for testing prototype modules

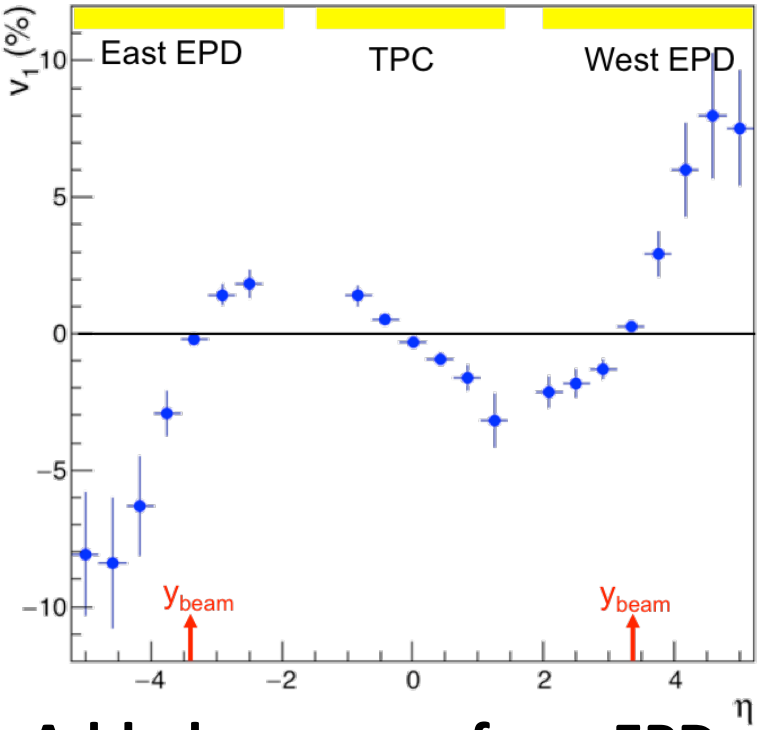
Integration at BNL is underway



Event Plane Detector

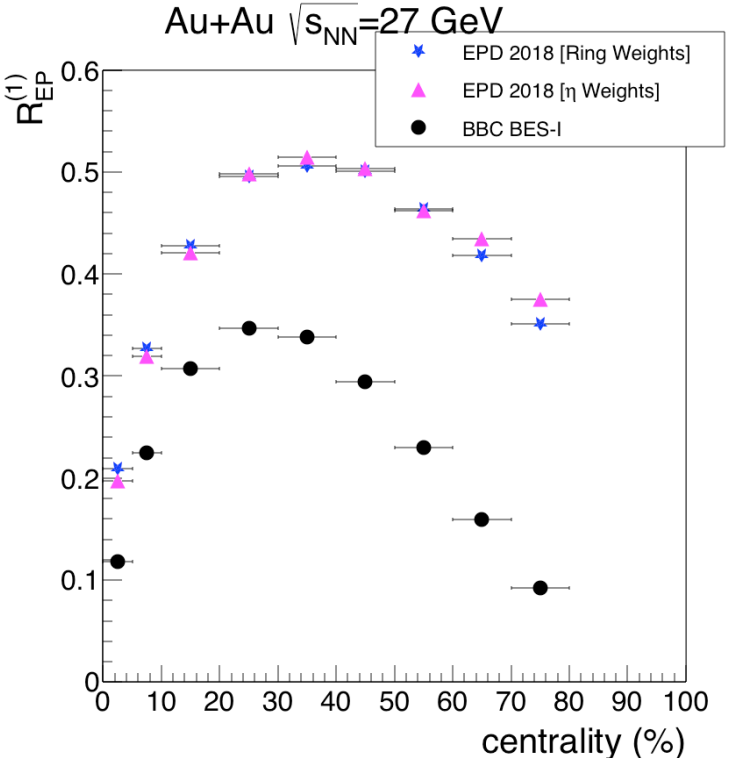
STARNote 666 https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666

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