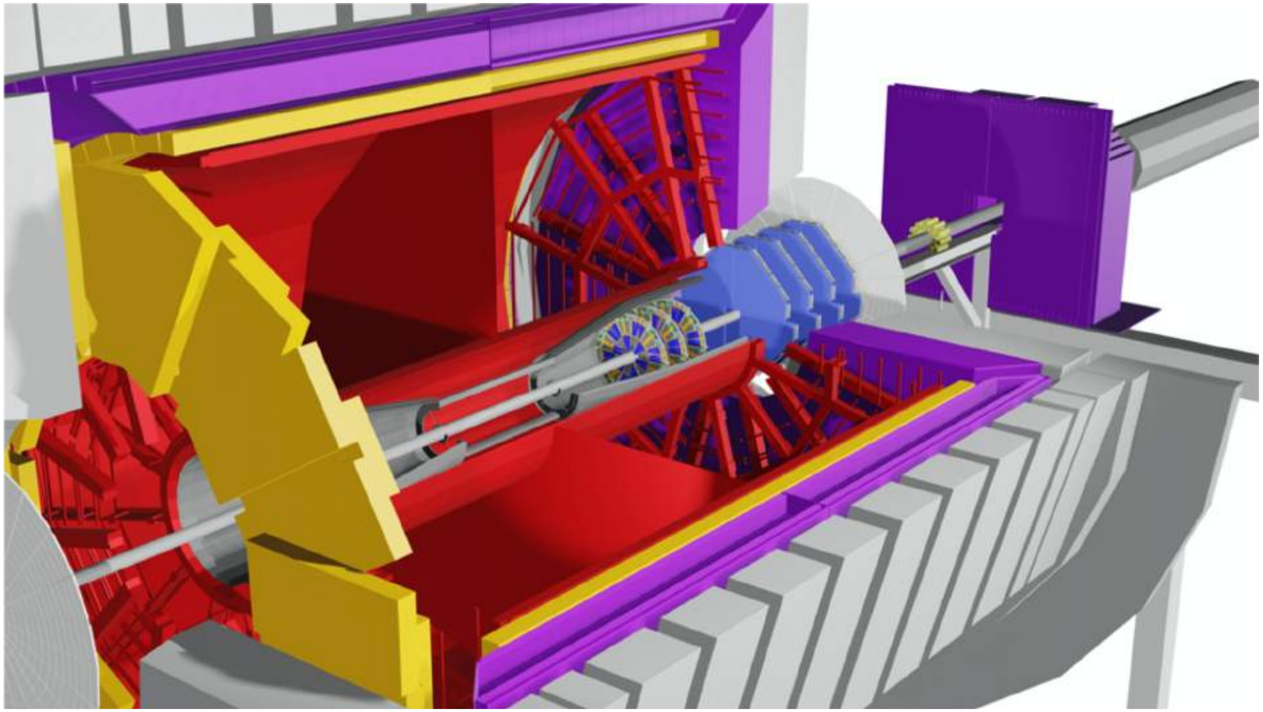
The STAR Forward Upgrade
An Overview



O.Tsai (UCLA)
(for the STAR Collaboration)

Supported by
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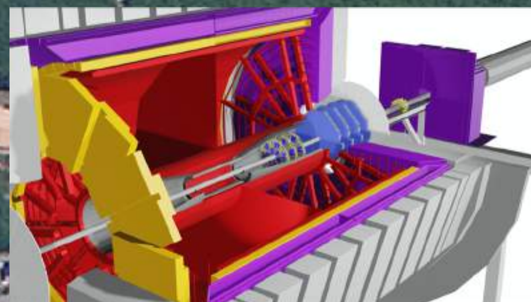
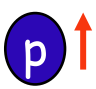
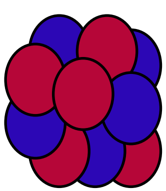
STAR



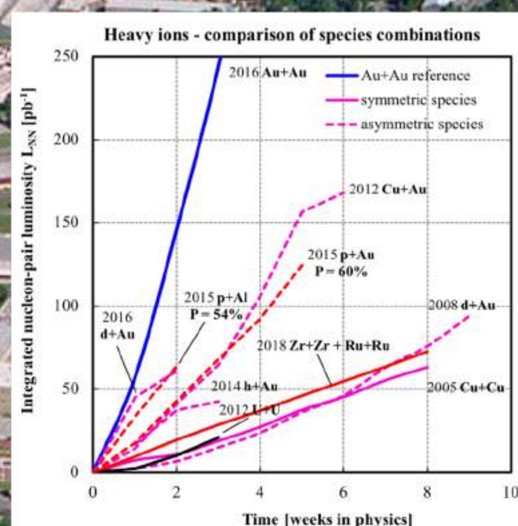
What do we collide ?

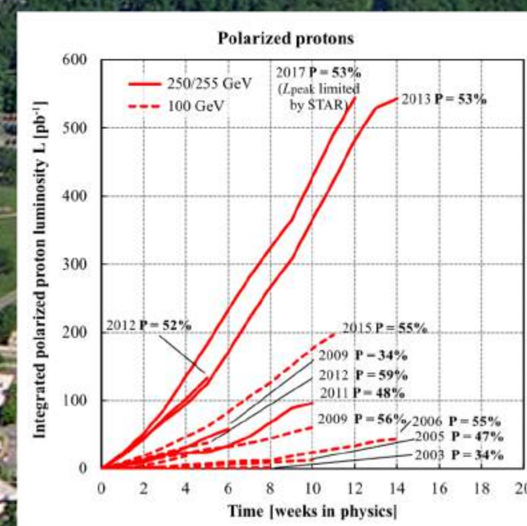


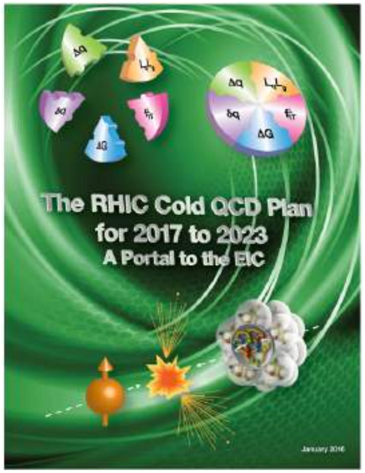
Polarized protons
24-255 GeV



Light ions (d,Si,Cu)
Heavy ions (Au,U)
5-100 GeV/u







arXiv:1602.03922

2016 RHIC Cold QCD plan identified measurements in p+p and p+A physics in years preceding the EIC focusing on:

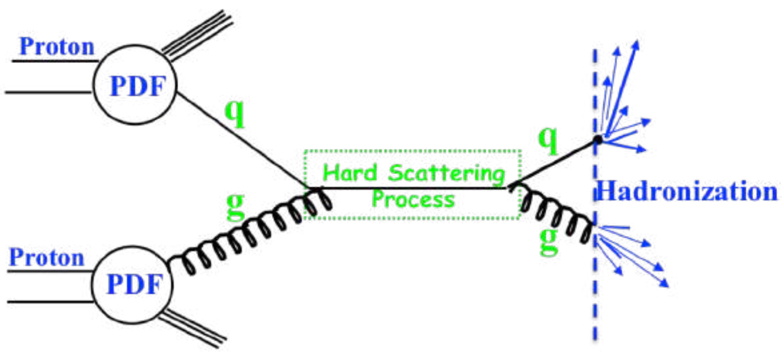
- Structure – description of QCD bound states in terms of quarks and gluons
- Hadronization – process by which quarks and gluons forms bound states
- Interactions involving hadrons – effects due to color flow in different scattering processes.

Runs 22, 23, 24 at RHIC (Last pp run was in 2017, EIC 2031).

Key words: QCD, Universality, Factorization and Evolution.

Instrumentation at forward region in addition to midrapidity capabilities.

Factorization



(un)polarized cross section ~

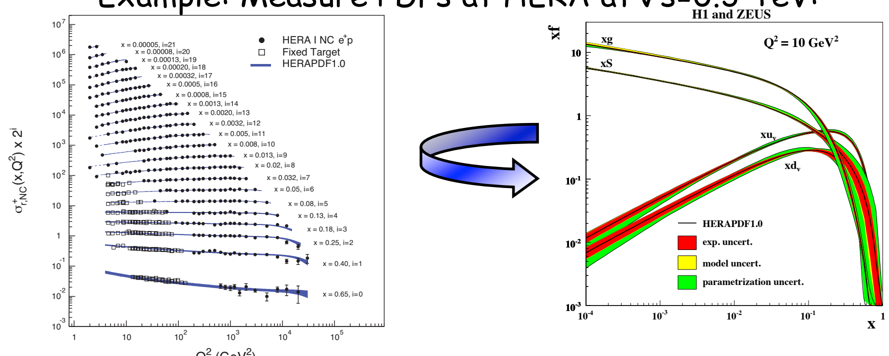
PDF ⊗ hard-scattering ⊗ Hadronization

hard-scattering : calculable in QCD

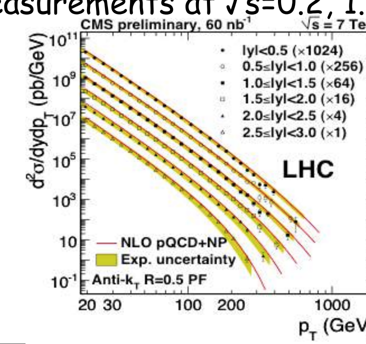
PDFs and Hadronization: need to be determined experimentaly

Universality

Example: Measure PDFs at HERA at √s=0.3 TeV:

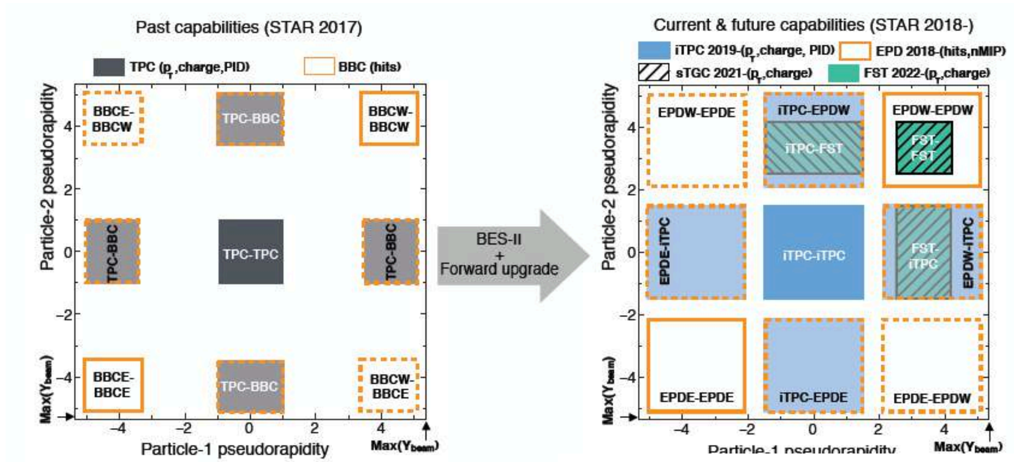


Predict pp measurements at √s=0.2, 1.96 & 7 TeV

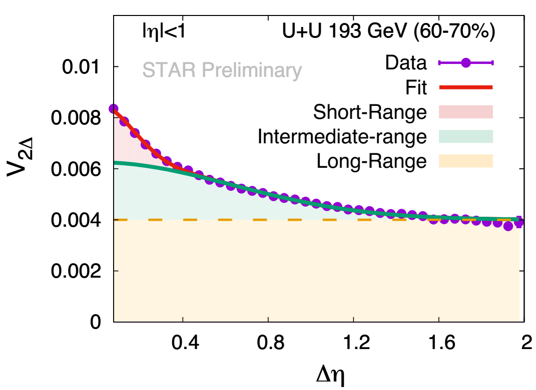


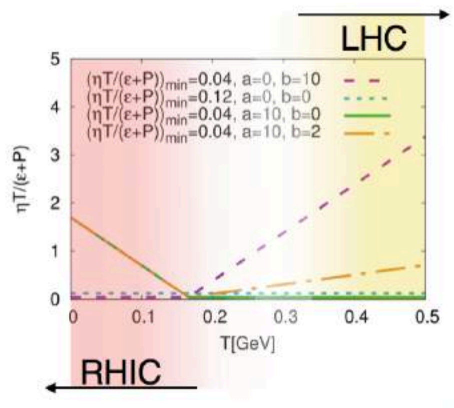
Hot QCD Topics

- Longitudinal structure of initial state in HIC <- luck of experimental constrains for modeling
- Temperature-dependent transport of the matter in HIC.
- Global Lambda Polarization.

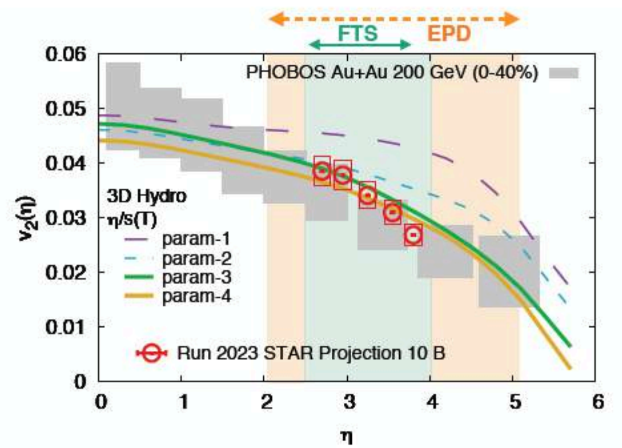


BES-II and STAR forward upgrades significantly improved detection capabilities to address these questions.





Phys.Rev C 86, 014909



Phys.Rev. Lett. 116, 212301

Forward-rapidity $2.8<\eta<4.2$

A+A

Beam:
Full Energy AuAu (2023/25)

Physics Topics:
- Temperature dependence of viscosity through flow harmonics up to $\eta\sim4$
- Longitudinal decorrelation up to $\eta\sim4$
- Global Lambda Polarization
  → strong rapidity dependence

$p^{\uparrow}+p^{\uparrow}$ & $p^{\uparrow}+A$

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

Physics Topics:

pp:
- TMD measurements at high x
  - o transversity → tensor charge
  - o Sivers through DY, direct γ and tagged jets

pA:
- Gluon PDFs for nuclei
- ➢ R_{pA} for direct photons & DY, and hadrons
- Test of Saturation predictions through di-hadrons, γ-Jets, di-jets

→ all measurement are critical to the scientific success of EIC to test universality and factorization

Observables:
- ❑ inclusive and di-jets
- ❑ hadrons in jets
- ❑ Lambda's
- ❑ correlations mid-forward & forward-forward rapidity

Requirements from Physics:
- ❑ good e/h separation
- ❑ hadrons, photon, π^0 identification

Detector	pp and pA	AA
ECal	~10%/√E	~20%/√E
HCal	~50%/√E+10%	---
Tracking	charge separation photon suppression	$0.2<p_T<2$ GeV/c with 20-30% $1/p_T$

FY2022: 500 GeV polarized pp run

All other data taking in parallel to sPHENIX data taking campaign: AA, pA, pp

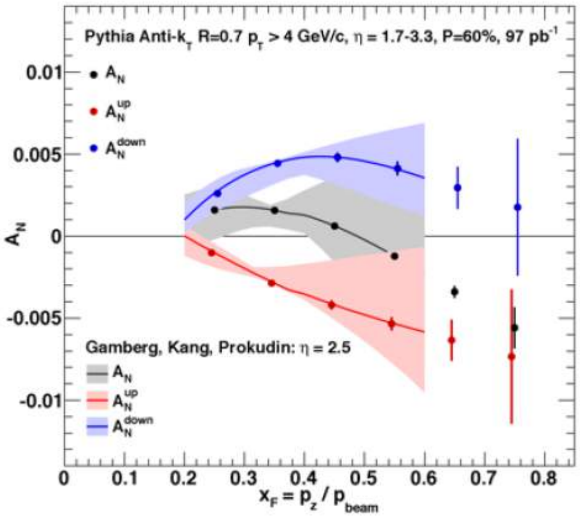
fSTAR and polarized $p^{\uparrow}p^{\uparrow}/p^{\uparrow}A$

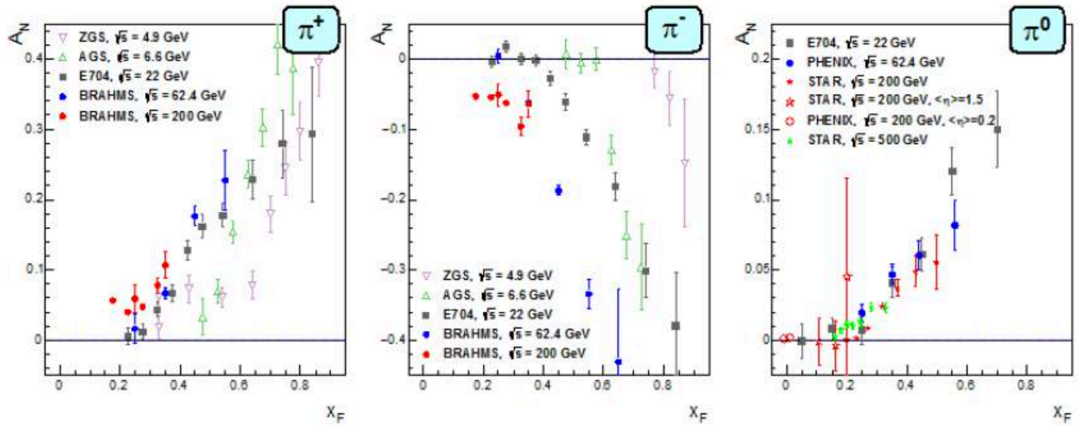
Understanding the proton in 3d: spatial and momentum critical to fully realize the scientific promise of the EIC

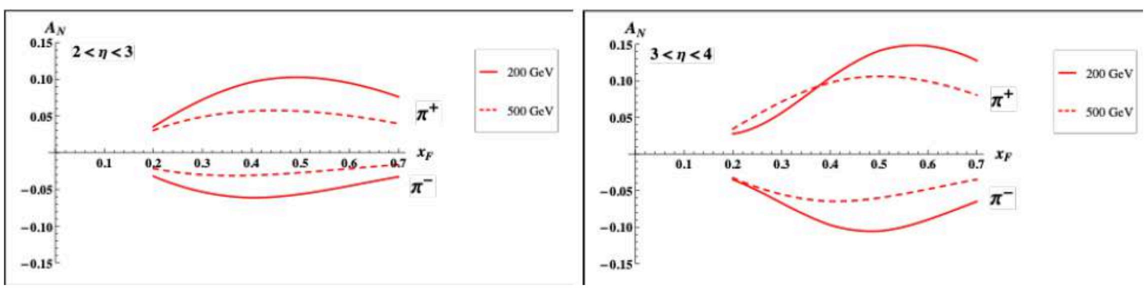
different complementary probes are critical to test universality

forward upgrade → access to low and high x

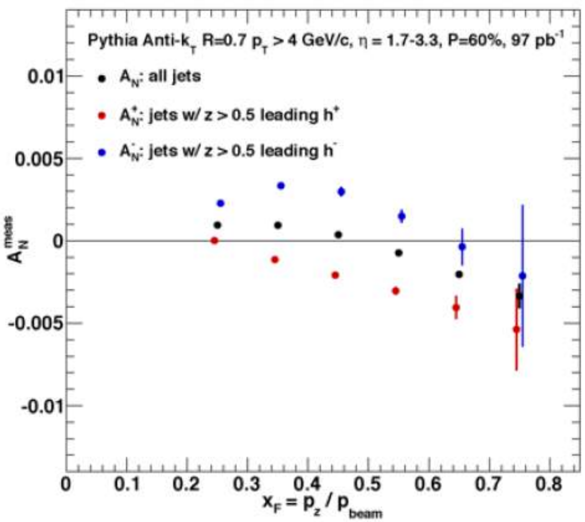
varying $\sqrt{s}$ → Test Evolution







Phys.Rev D 89, 111501



Sivers through tagged jets

Inclusive A_N at forward rapidities for: direct photons, neutral pions and charge hadrons

Understanding the proton in 3d: spatial and momentum critical to fully realize the scientific promise of the EIC

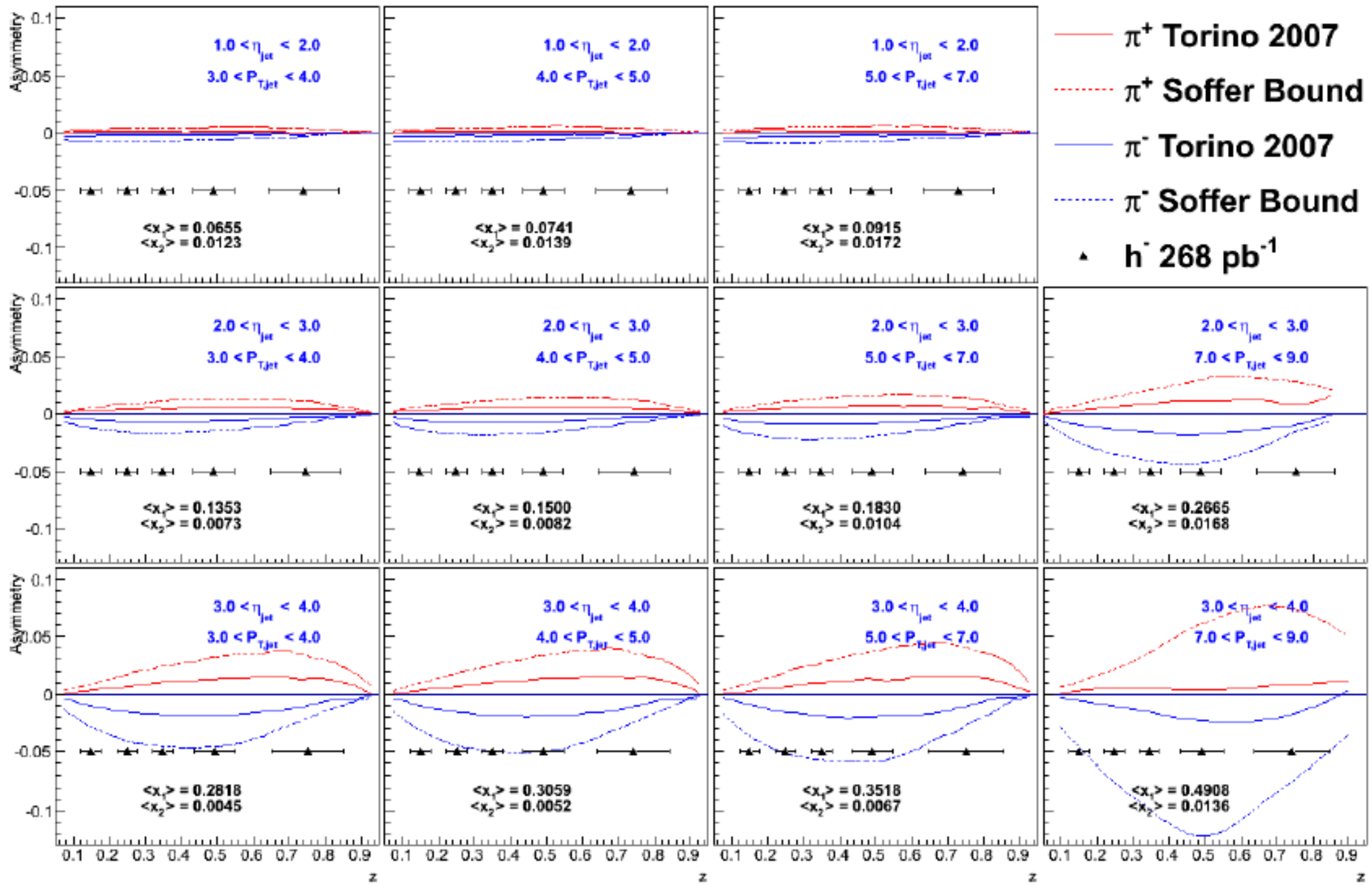
different complementary probes are critical to test universality

forward upgrade → access to low and high x

varying $\sqrt{s}$ → Test Evolution

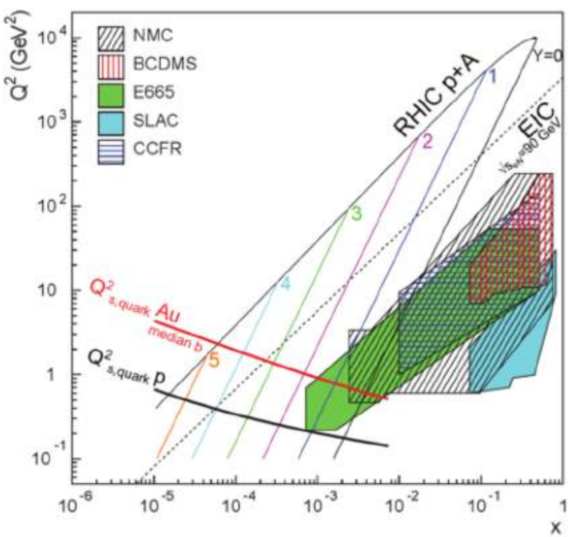
Transversity x Collins through hadron in jet

STAR will push sensitivity to higher (>0.3) and lower x ($\sim 10^{-3}$) at high Q^2 by reconstructing jets and charged hadrons (h+/h-) in the forward direction

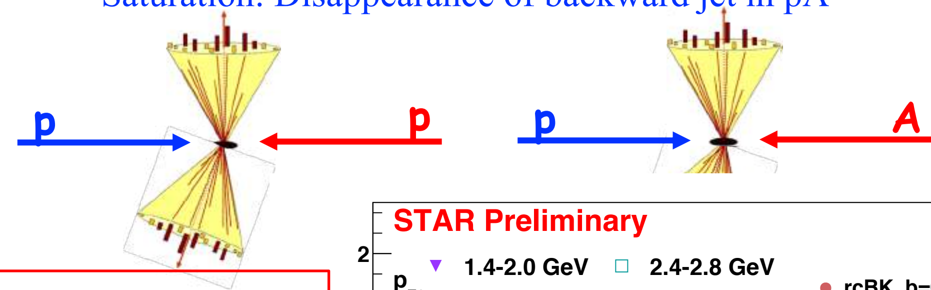


Probing Non-linear Effects in QCD

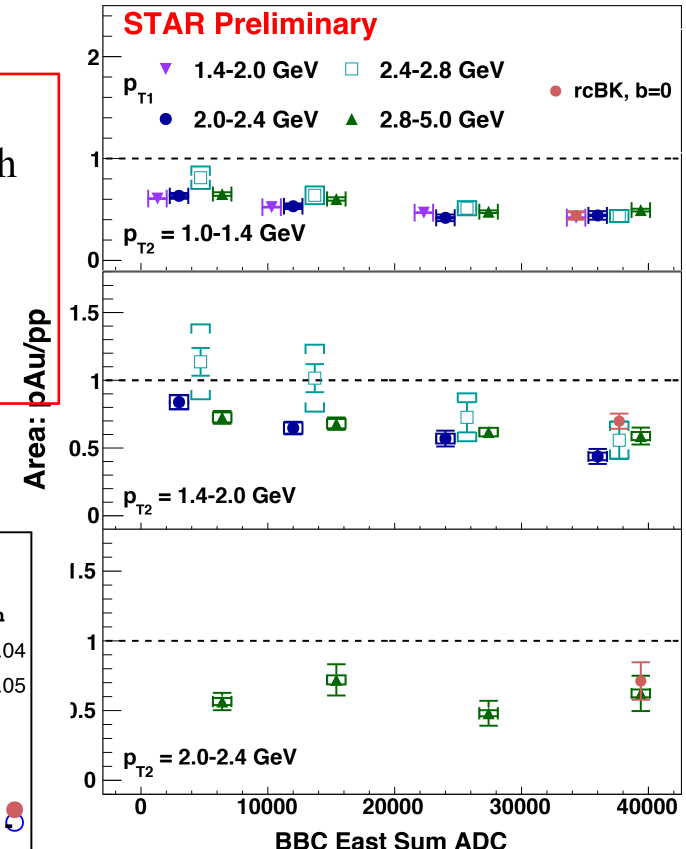
Forward rapidities at STAR provide an absolutely unique opportunity to have very high gluon densities
→ proton – Au collisions
combined with an unambiguous observable

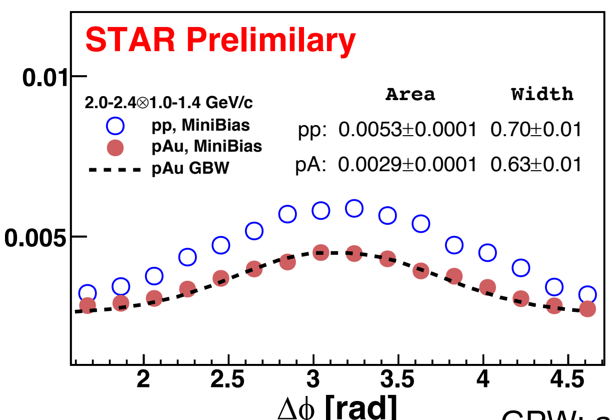


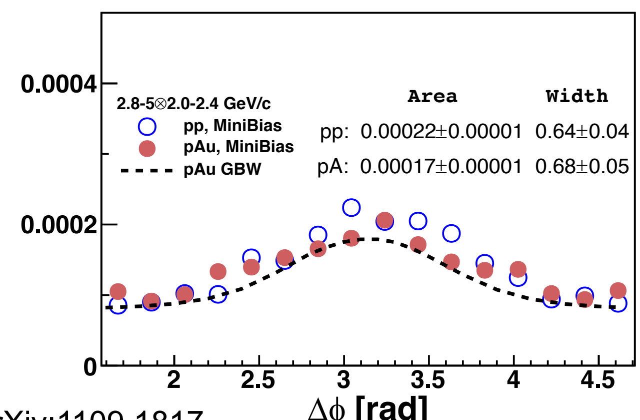
counting experiment of Di-jets in pp and pA
Saturation: Disappearance of backward jet in pA



STAR forward upgrade to characterize non-linear effects with charged di-hadrons, g-jet, di-jet
→ critical measurement to test universality → EIC



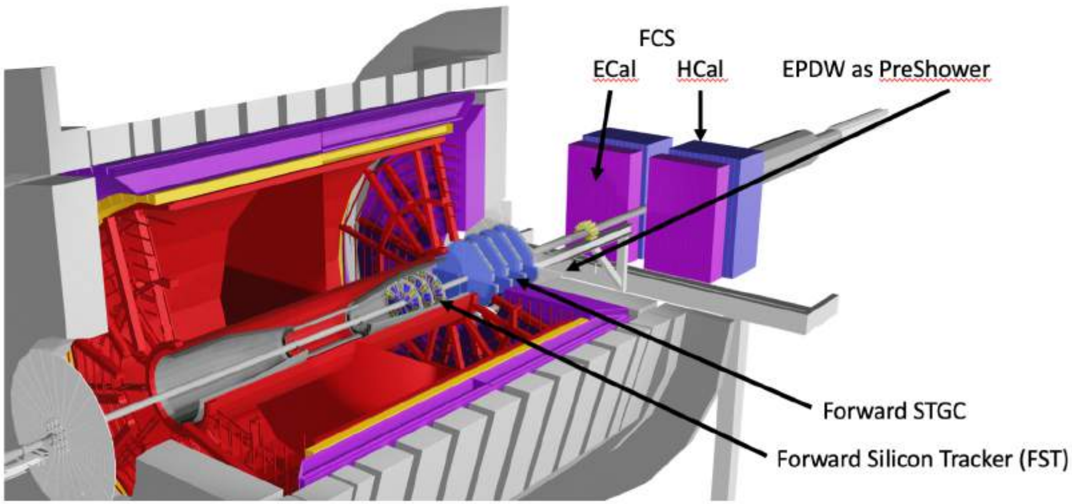




GPW: arXiv:1109.1817

rcBK: arXiv:1805.05711

fSTAR. New Detector Components.



FCS Location: 7 m from the IP.

ECal:
- ❑ Phenix SHASHLYK 1496 Ch.
- ❑ Lateral tower Size 5.5 x 5.5 cm2

HCal:
- ❑ Fe/Sc (20mm/3 mm) sandwich.
- ❑ 520 readout channels
- ❑ Lateral tower size 10 x 10 cm^2, ~ 4.5 l
  - ➢ in close collaboration with EIC R&D

Preshower
Existing EPD, with additional splitter

FST, 3 Silicon disks: at 146, 160, and 173 cm from IP
Built on successful experience with STAR IST
- Single-sided double-metal mini-strip sensors
  - ➢ Granularity: fine in f and coarse in R
  - ➢ Si from Hamamatsu
- Frontend chips: APV25-S1 → IST all in hand
- Material budget: ~1.5% per disk
- Reuse
  - ➢ IST DAQ system for FTS
  - ➢ IST cooling system

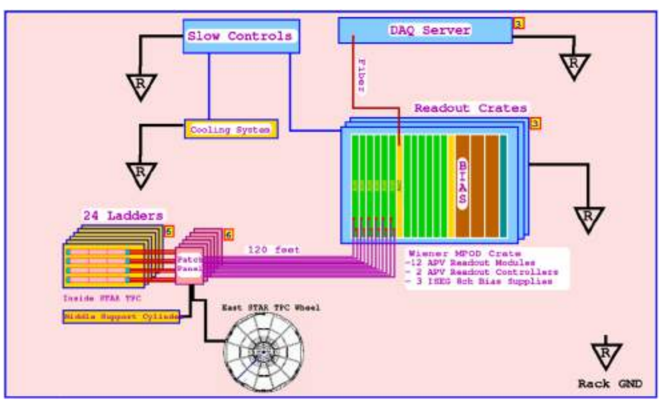
STGC, 4 sTGC disks: at 307, 325, 343 and 361 cm from IP
- location inside Magnet pole tip opening
  - ➢ inhomogeneous magnetic field
- 4 quadrants double sided sTGC → 1 layer
  - diagonal strips to break ambiguities in the sTGC
- Position resolution: ~200 mm
- Material budget: ~0.5% per layer,
- Readout: based on VMM-chips

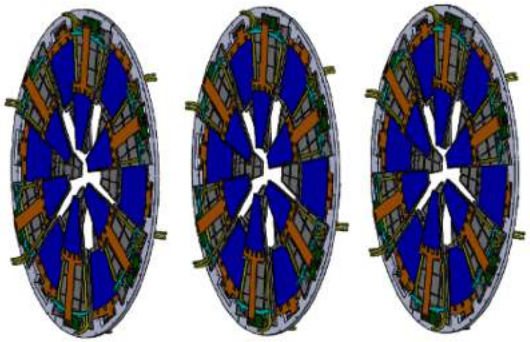
→ following ATLAS design

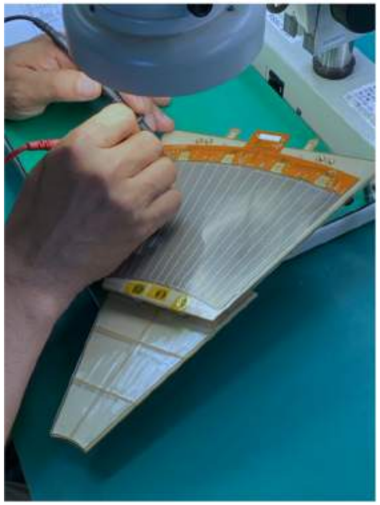
"Modest Upgrade": Minimize Technical, Cost and Schedule risks by using proven technologies and re-using STAR equipment. Extensive prototyping and testing started in 2017 during last RHIC 500 GeV pp run (synergy with EIC generic detector R&D)

FST, Status

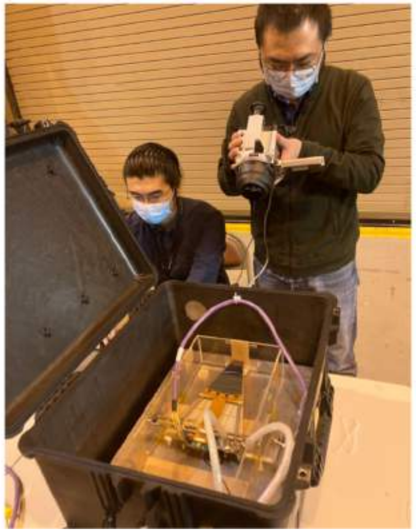
- **Detector Module Prototype** — **Completed / Projection**
  - Silicon sensor: **08/2019**
  - Flexible hybrid: **12/2019**
  - Inner signal cable: **02/2020**
  - Mechanical structure: **06/2020**
  - Detector module assembly: **07/2020**
  - Detector module testing: **08/2020**
- **Detector Module Production**
  - Flexible hybrid: **09/2020**
  - Silicon sensors: **02/2021**
  - Mechanical structure (delivered 30/48 as of 3/2/2021): **03/2021**
  - Detector module assembly (completed 8/48 as of 3/2/2021) **05/2021**
- **DAQ System**
  - T-boards and inner signal cables: **04/2021**
- **Mechanical Integration**
  - Cooling system: **12/2020**
  - Support structure design and fabrication **02/2021**
- **Installation**
  - Installed onto supporting structure: **07/2021**
  - Installed into STAR: **08/2021**





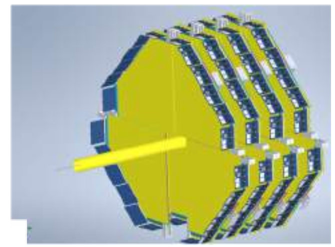


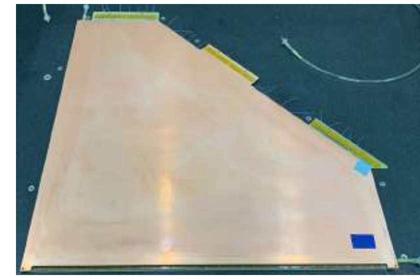
- Cooling test on FST-04 (Dec. 21, 2020@BNL)
  - Ambient T: 19.8 °C
  - Coolant T: 22.2 °C

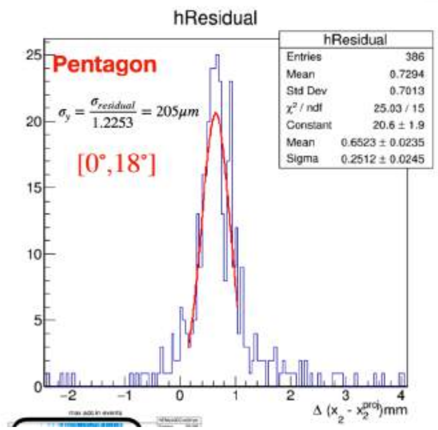


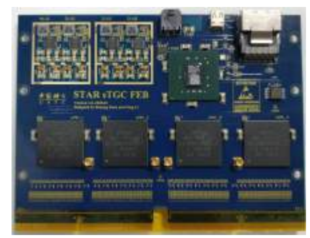
Forward sTGC Tracker, Details

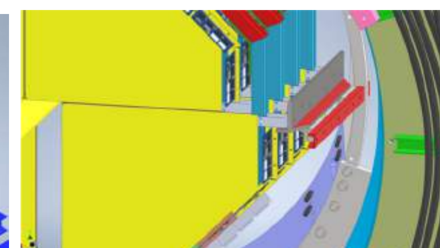
- **Four layers, 16 (+4) modules (SDU)**
  - Module R&D
  - Mass production
  - Quality and performance tests
- **96 (+12) FEB + 16 (+2) ROD (USTC)**
  - Electronics R&D
  - Mass production and test
- **DAQ system (BNL)**
  - Electronics Integration
- **Integrations (BNL)**
  - Support structure
  - Gas system
  - Installation, interlocks
- **Software (BNL+SDU)**
  - Simulator
  - Cluster finder

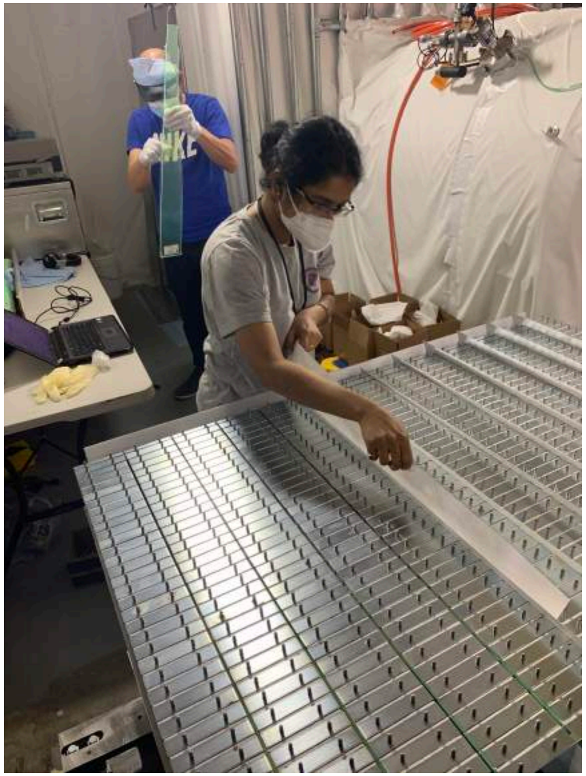












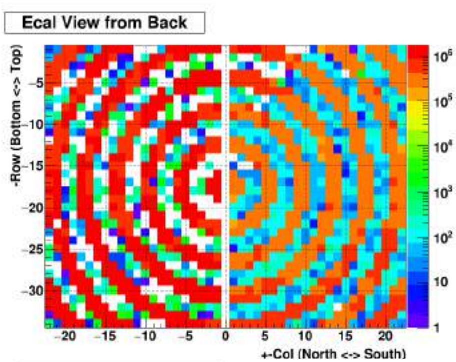
Forward Calorimeter System (FCS)
- ECal – 1496 channels ~ 8 tons
- HCal – 520 channels ~ 30 tons.
- SiPM Readout Bias ~ 67V
- New digitizers + Trigger FPGA = DEP boards

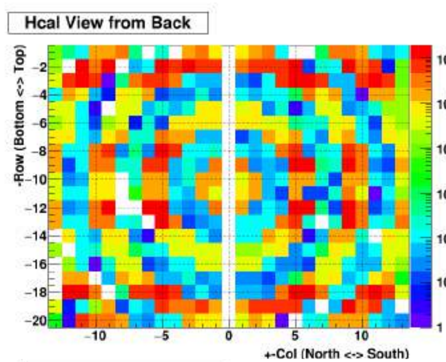
STAR Collaborators,
Members of UC EIC Consortia
Assembling FCS in Dec. 2020 at BNL

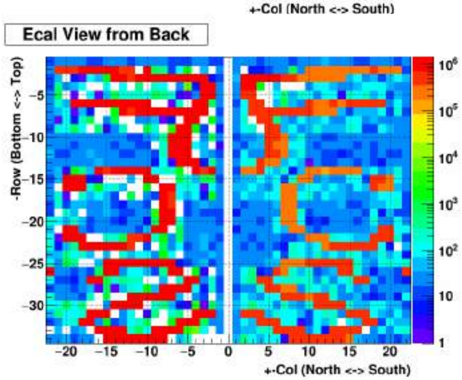
Large group of STAR collaborators actively engaged in all aspects of the project: ACU, BNL, UCLA, UCR, Indiana University CEEM, UKU, OSU, Rutgers U., Temple U., Texas A&M U., Valparaiso U.

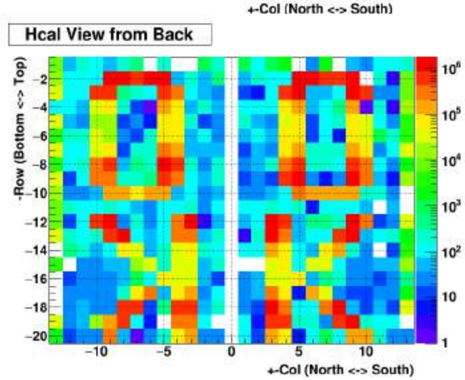
FCS Construction and Initial Commissioning Completed.

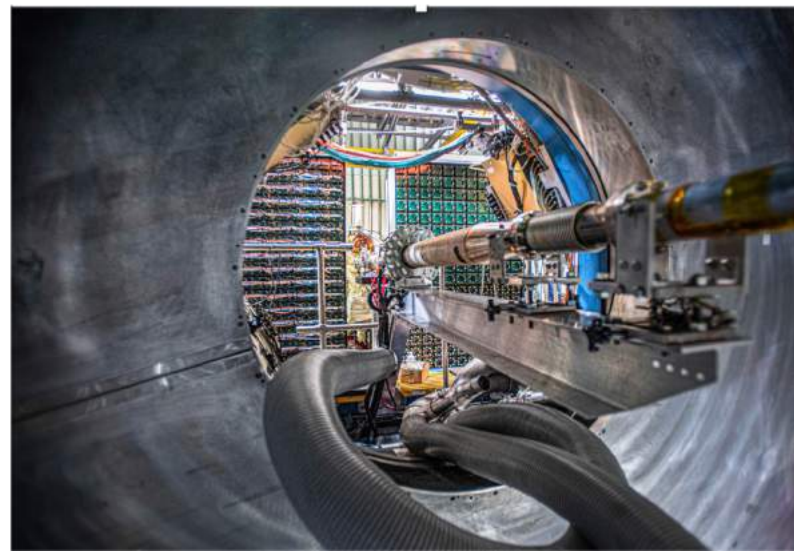
https://www.bnl.gov/newsroom/news.php?a=217681

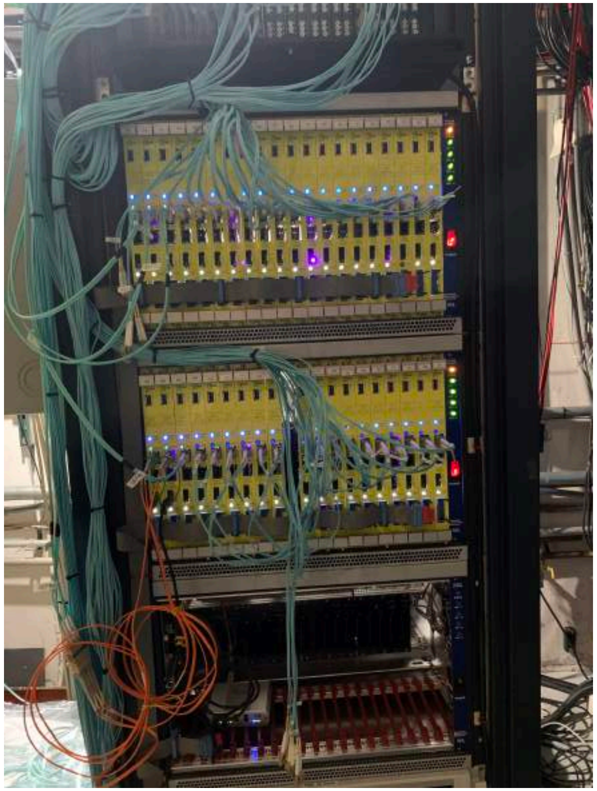






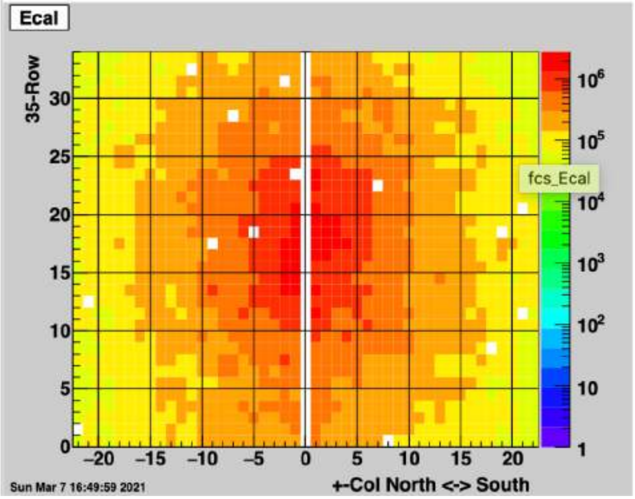


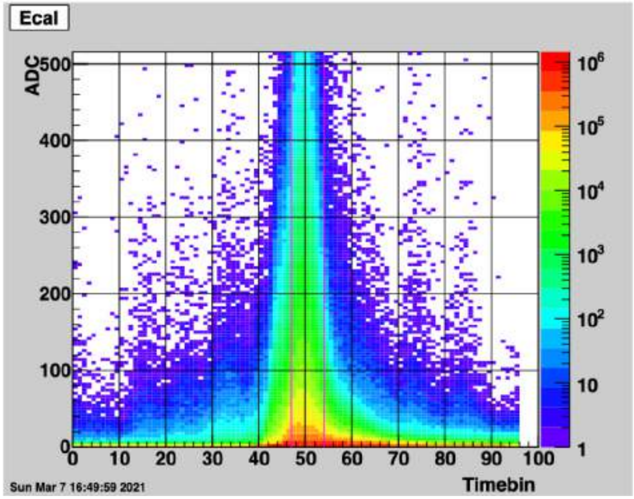




- 32ch 12bit ADC
- 8 time bins per RHIC clock (~13.5nsec/timebin)
- Each DEP is connected to a DAQ computer with a fiber
- FPGA for trigger logic - VHDL code under development at BNL
- Total of 48+18+12 = 78 DEP boards
- 3 DEP-IO boards for triggering
- Works great out of box! (First board were tested in 2017 ☺)

From jEVP @ STAR physics run (AuAu 7.7GeV)





Dedicated manpower with large expertise for each subsystem

sTGC
- Brookhaven National Laboratory
- Shandong University 山东大学
- University of Science and Technology of China

Silicon
- UIC University of Illinois at Chicago
- Shandong University 山东大学
- Indiana University
- Brookhaven National Laboratory
- National Cheng Kung University

ECal
- Kentucky
- Valparaiso University
- Abilene Christian University

HCal
- UCLA
- Texas A&M University
- Indiana University
- Rutgers
- Abilene Christian University
- Ohio State
- Valparaiso University

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

Integration
- Brookhaven National Laboratory

Calibration
- UC Riverside
- Temple University

Slow Controls
- Valparaiso University
- Abilene Christian University
- Creighton University

and the STAR collaboration, which stands enthusiastically behind the upgrade !

STAR forward upgrade: $2.5 < h < 4$

- rapidity coverage the same as EIC hadron Arm
  → high-x EIC physics

HCal +SiPM readout same as EIC-fHCAL (joint STAR EIC R&D)

- same rapidity as EIC
  - background

small-strip Thin Gap Chambers (sTGC)

→ sTGC alternative technology to EIC GEM Trackers

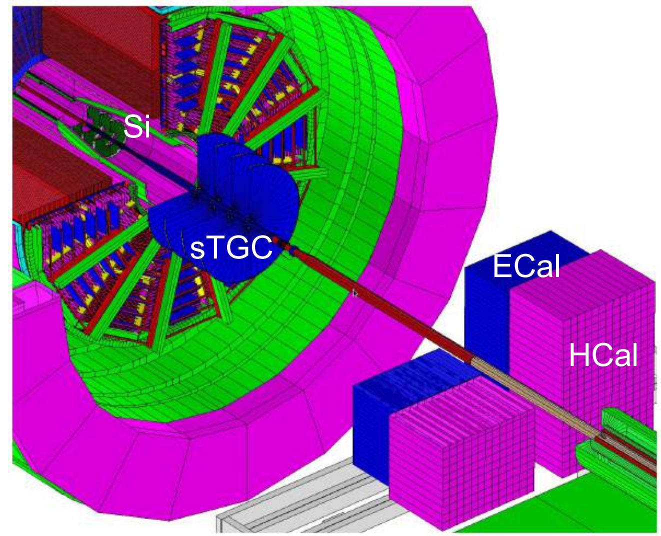
Analysis:
Learn how to reconstruct Jets close to beam rapidity

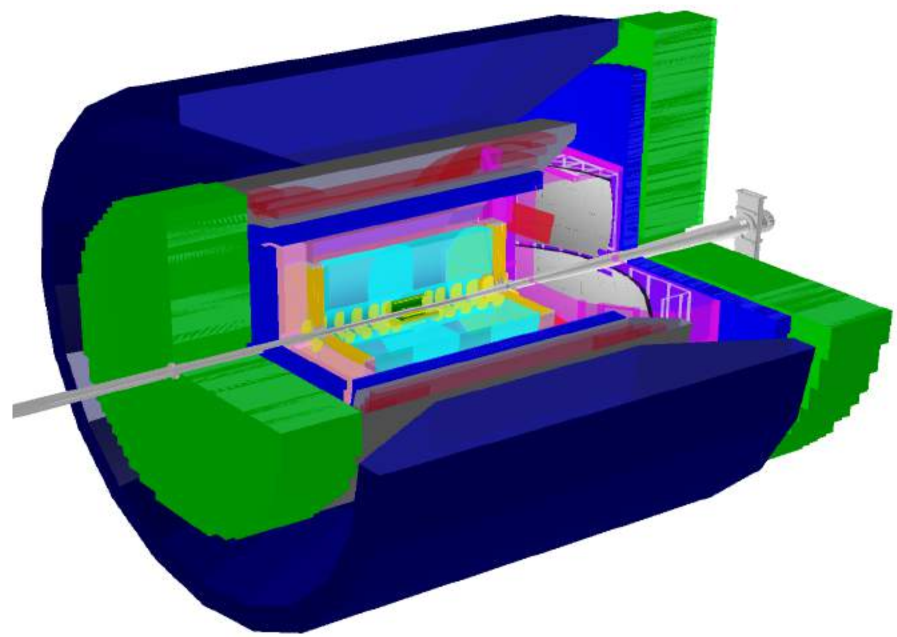
Jet solid angle ~ $R^2/\cosh^2(h)$.
so for fixed jet multiplicity, $dN/d\Omega$ grows like $\cosh^2(h)$

- 15 times larger at h=2, 100 times larger at h=3

→ what are the effects of underlying event ep & eA and $\sqrt{s}$

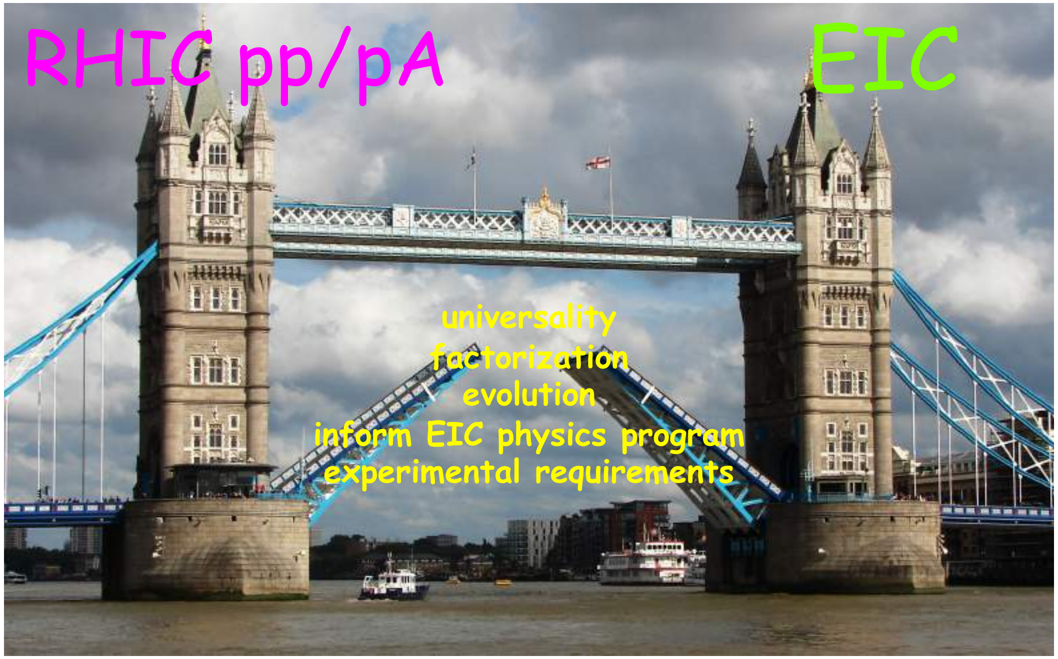
Training of young scientific generation:
20+ undergrads working > 2019/06





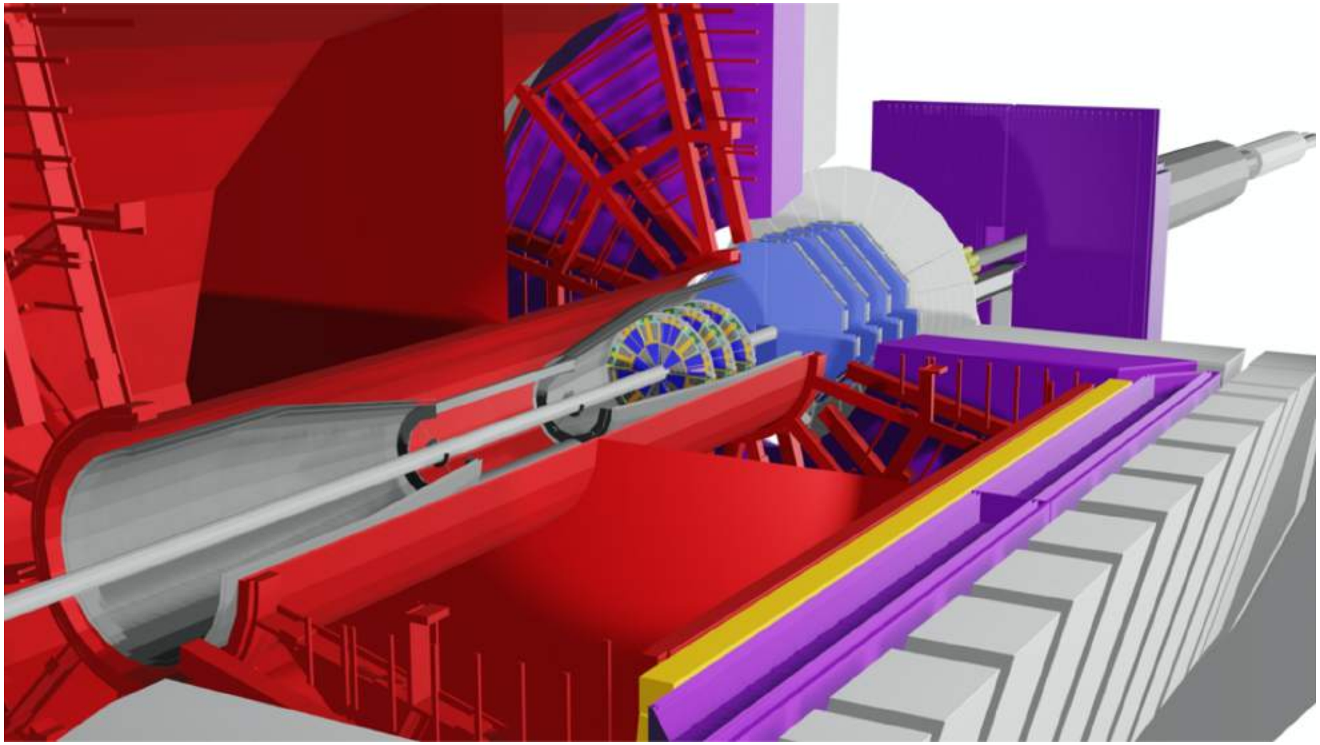
Unique RHIC forward and midrapidity pp/pA program addressing several fundamental questions in QCD

- essential to the mission of the RHIC physics program
- pp/pA program essential to fully realize the scientific promise of the EIC
  - inform the physics program
  - quantify experimental requirements
- Recent RHIC pp/pA result triggered a lot of new theory work
  - dedicated workshops on the RHIC pp/pA program



Beautiful STAR detector pretty soon will be even better!

- Enthusiastic STAR collaboration working hard to complete forward upgrade.
- FCS is already taking data/commissioning trigger at the moment.
- Silicon and sTGC installation and full system checks on schedule.



fSTAR will be important addition to realize RHIC Cold QCD and STAR Hot QCD plans with data taking during next four years.