STAR Forward Upgrade

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University of Illinois at Chicago

Supported in part by:
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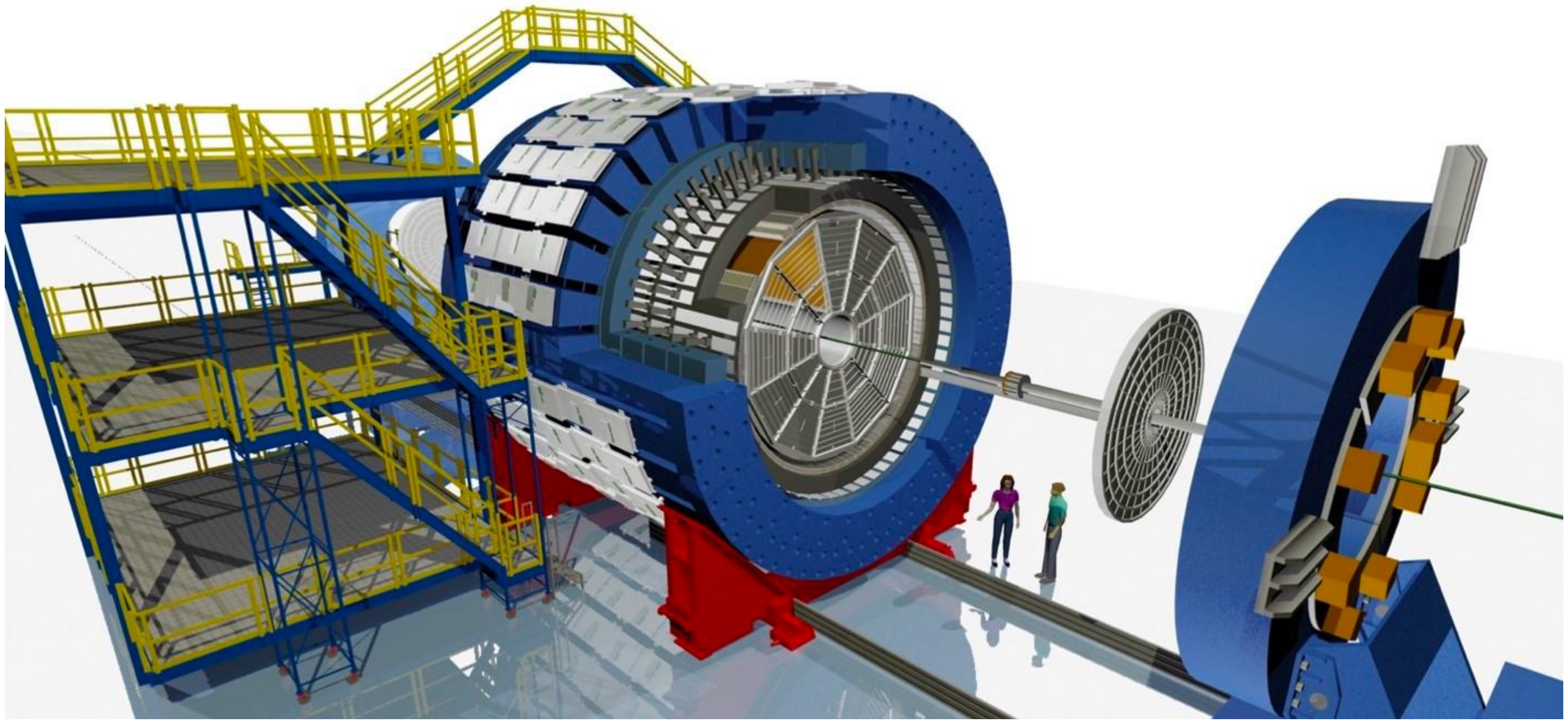
UIC The University of Illinois at Chicago

STAR

STAR Experiment with Mid-rapidity Detectors



pol. p+p @ $\sqrt{s}$ = 200/510 GeV
- proton spin structure
- perturbative QCD

p(d)+A @ $\sqrt{s_{NN}}$ = 200 GeV
- gluon saturation
- initial conditions
- diffractive interactions

A+A @ $\sqrt{s_{NN}}$ = 200 GeV
- QGP medium properties
- QCD in hot and dense medium

A+A @ $\sqrt{s_{NN}}$ = 3-62 GeV
- search for the critical point
- chiral symmetry restoration

- **Tracking, Calorimetry, PID**
  Solenoidal magnet: B_z=0.5 T
  TPC: $|\eta| < 1.5$
  TOF: $-1.5 < \eta < 0.9$
  EMC: $-1 < \eta < 2$
  MTD: $|\eta| < 0.5$

- **MB trigger, luminosity**
  BBC: $3.3 < |\eta| < 5$
  VPD: $4.2 < |\eta| < 5$
  ZDC: $6.5 < |\eta|$

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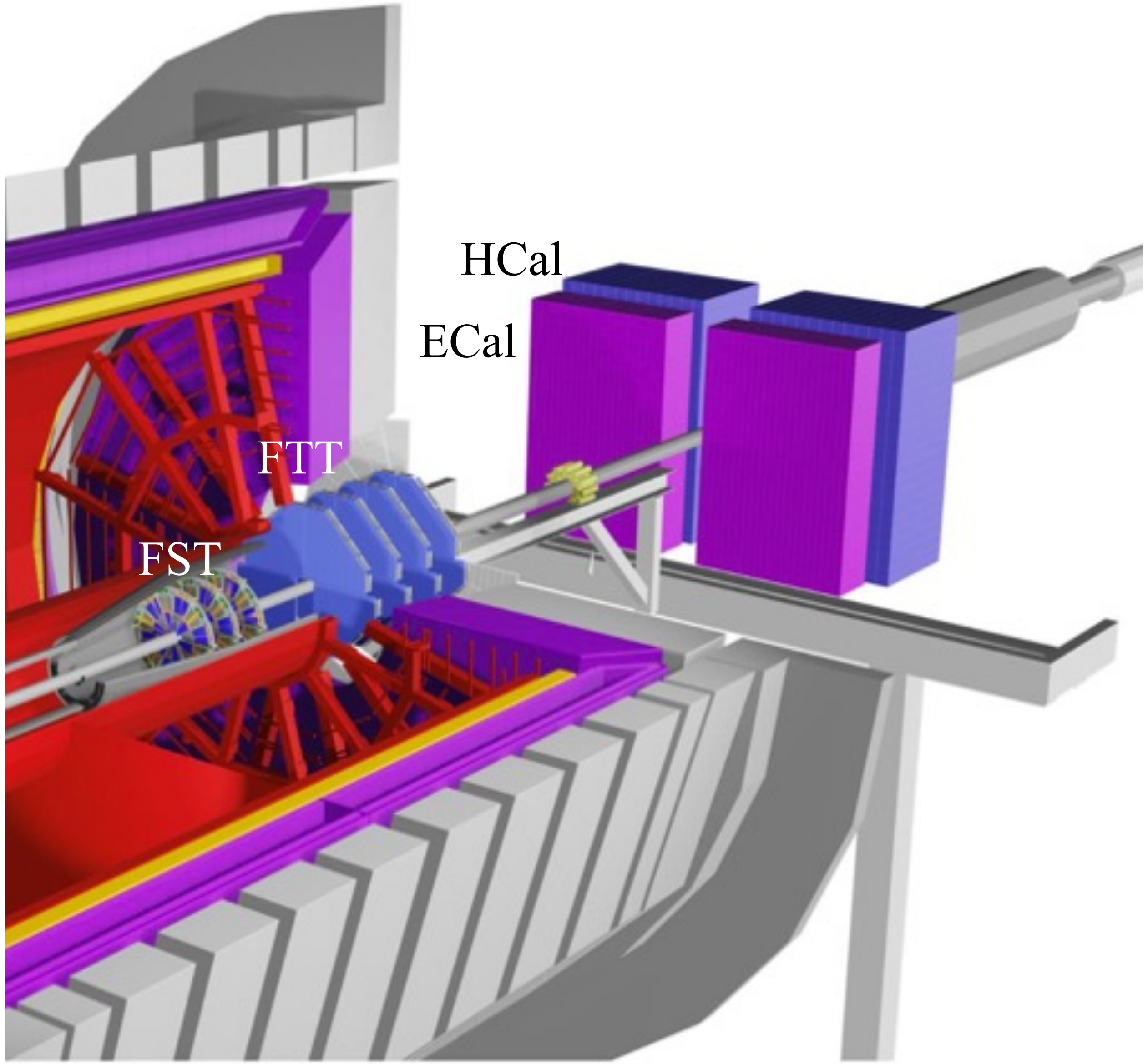

Rapidity coverage:

$2.5 < \eta < 4$ (similar to EIC hadron endcap)

Goal:

Charge separation; e, γ and π^0 identification

Components:

Forward Silicon Tracker (**FST**)
Forward sTGC Tracker (**FTT**)
EM Calorimeter (**ECal**)
Hadronic Calorimeter (**HCal**)

Requirements:

Detector	pp and pA	AA
ECal	$\sim 10\%/\sqrt{E}$	$\sim 20\%/\sqrt{E}$
HCal	$\sim 50\%/\sqrt{E} + 10\%$	-
Tracking	charge separation, photon suppression	$\delta p_T/p_T \sim 20-30\%$ for $0.2<p_T<2$ GeV/c

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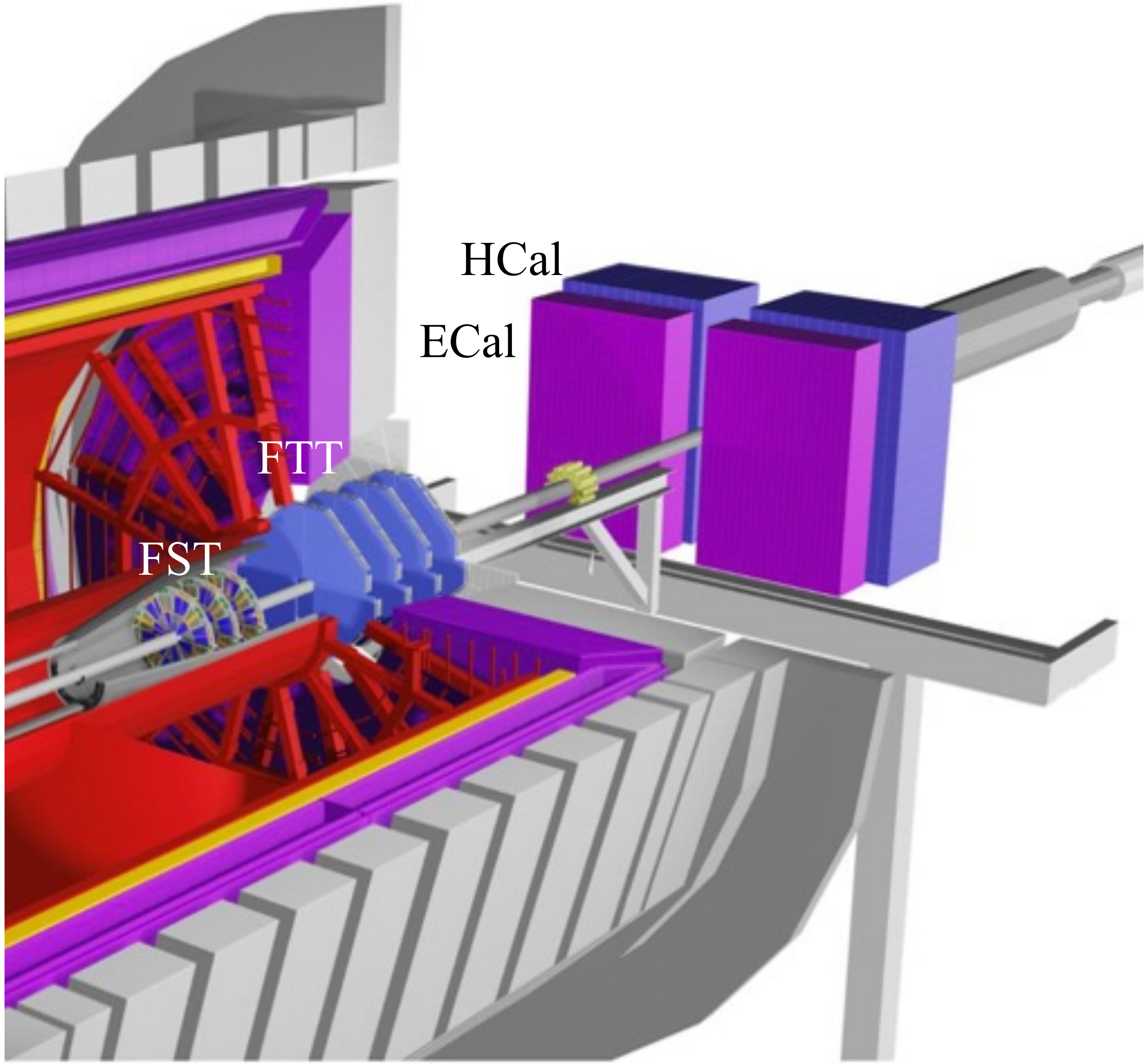


p+p@510 GeV (2022), p+p/Au @200 GeV (2024)

- Sivers asymmetries for hadrons, (tagged) jets
- Gluon PDFs in nuclei: R_{pA} for direct photon and DY
- Gluon saturation: di-hadron, γ+jets, …

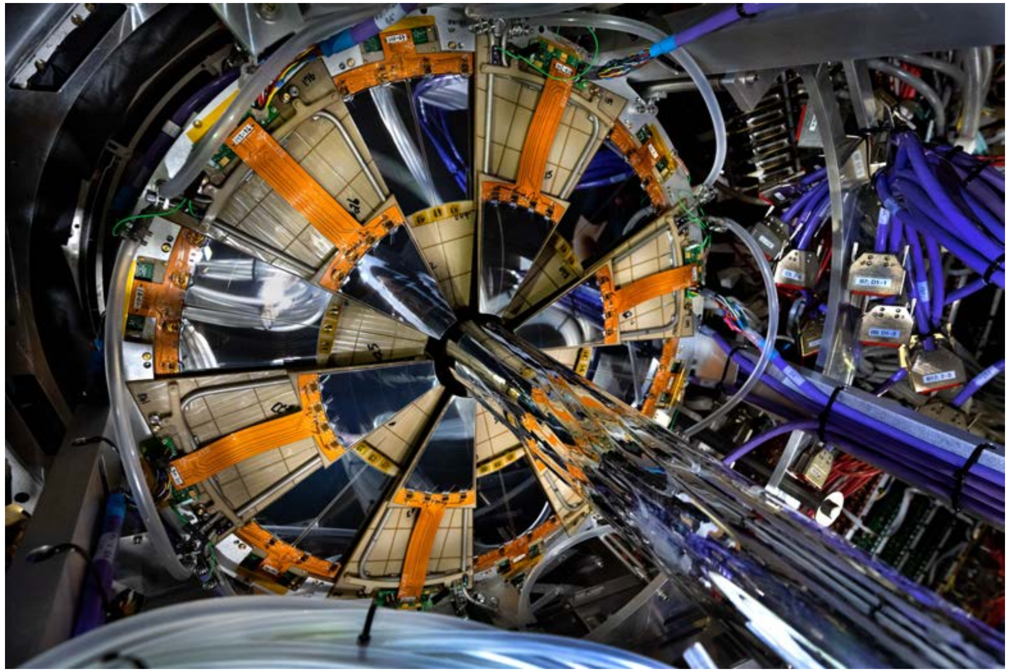
Au+Au@200 GeV (2023/2025)

- Temperature dependence of viscosity through flow harmonics up to η~4
- Initial conditions through longitudinal decorrelation
- Global Λ polarization rapidity dependence

Observables:

- Charged and neutral hadrons
- Electrons and photons
- Λ hyperons
- Inclusive jets and di-jets
- Mid-forward and forward-forward rapidity correlations
- …

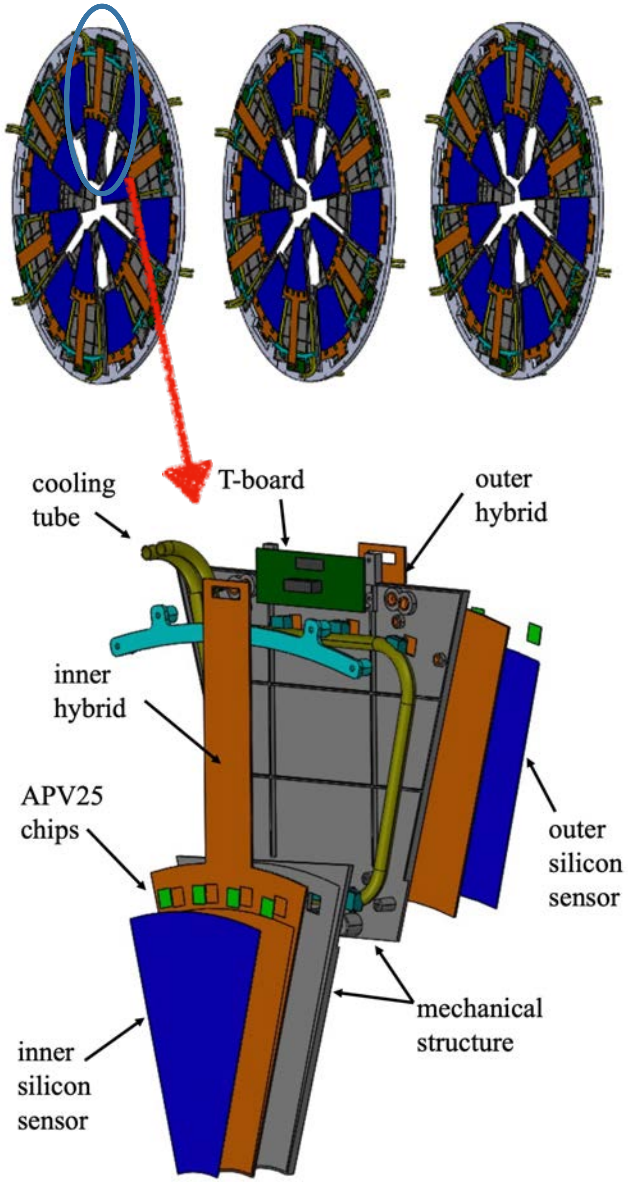
STAR Forward Silicon Tracker (FST)



3 Silicon disks: at 152, 165, and 179 cm from IP

$\Rightarrow$ Built on successful experience with STAR Intermediate Silicon Tracker (IST), reuse IST DAQ and cooling system

- Locate inside STAR TPC cone
- Single-sided double-metal mini-strip sensors
  Granularity: fine in ϕ and coarse in R
  Si sensors from Hamamatsu
- Frontend readout: APV25
- Material budget: ~1% per disk



Each module splits into two regions

- Inner-radius region: 5<R<16.5 cm
  - 1 Kapton flexible hybrid
  - 1 Si sensor: 128 × 4 (ϕ×R) strips
  - 4 APV chips
- Outer-radius region: 16.5<R<28 cm
  - 1 Kapton flexible hybrid
  - 2 Si sensors: 128 × 4 (ϕ×R) strips
  - 4 APV chips

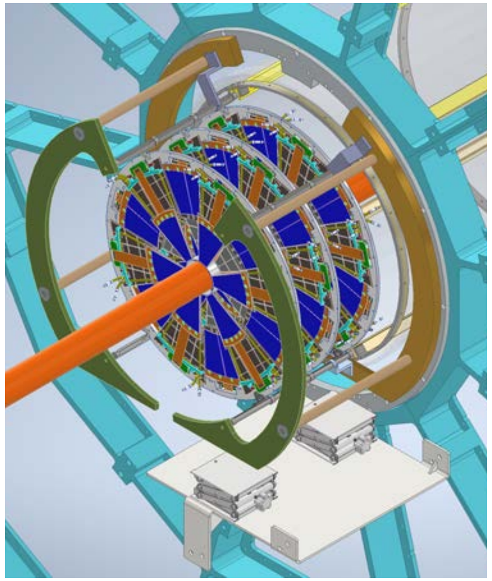
Mechanical structure is made of

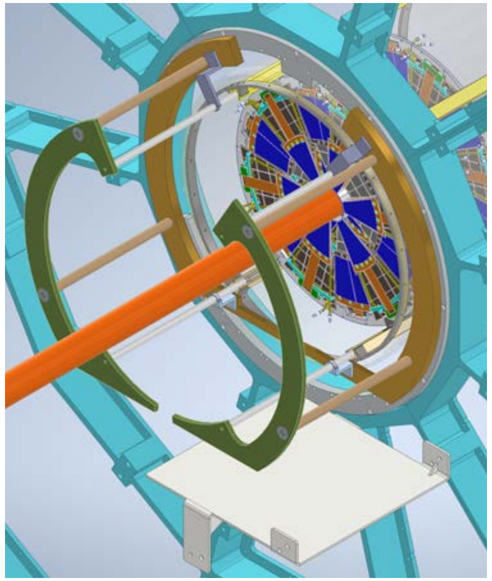
- PEEK (main structure, tube holder)
- Stainless steel (cooling tube)
- Aluminum (heat sinks)

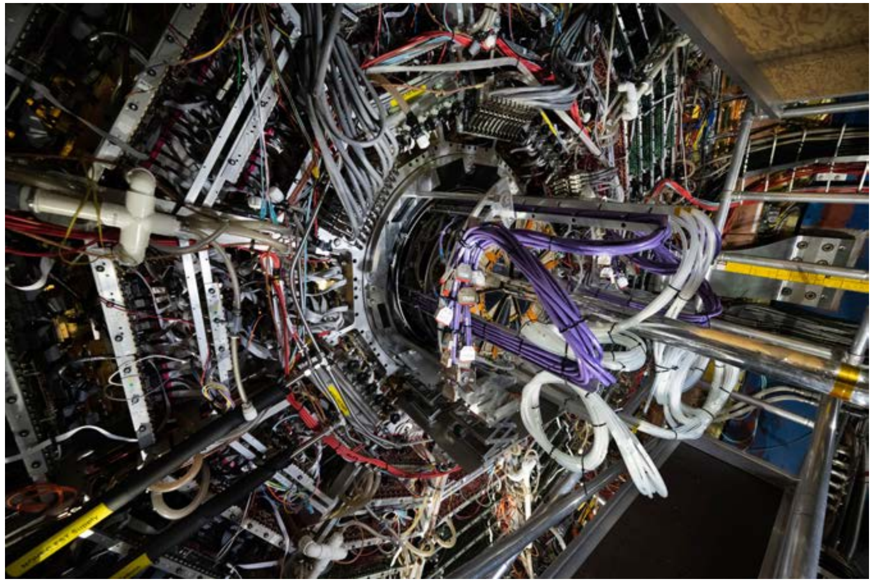
Module assembly is done in two steps

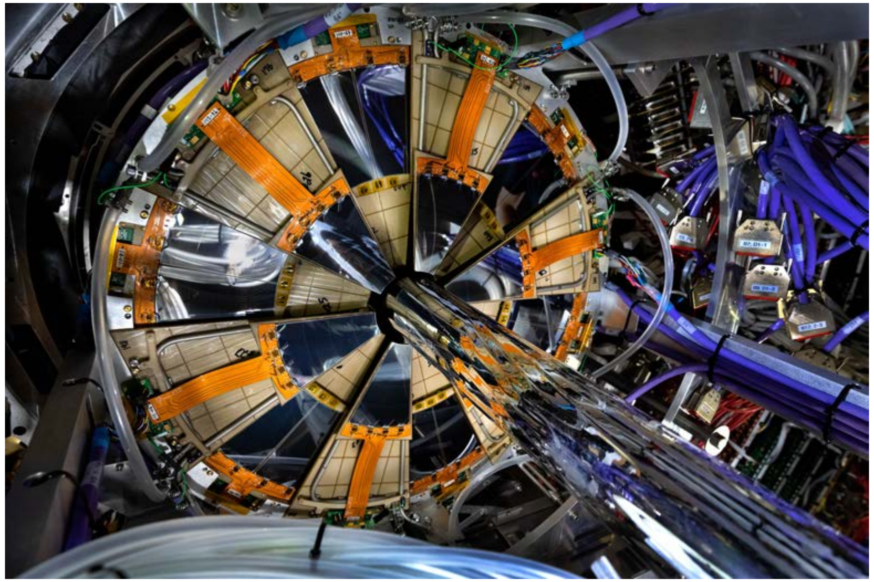
- Gluing inner/outer hybrids and mechanical structures together
- Mount/wire-bond APVs and Silicon sensors on hybrids

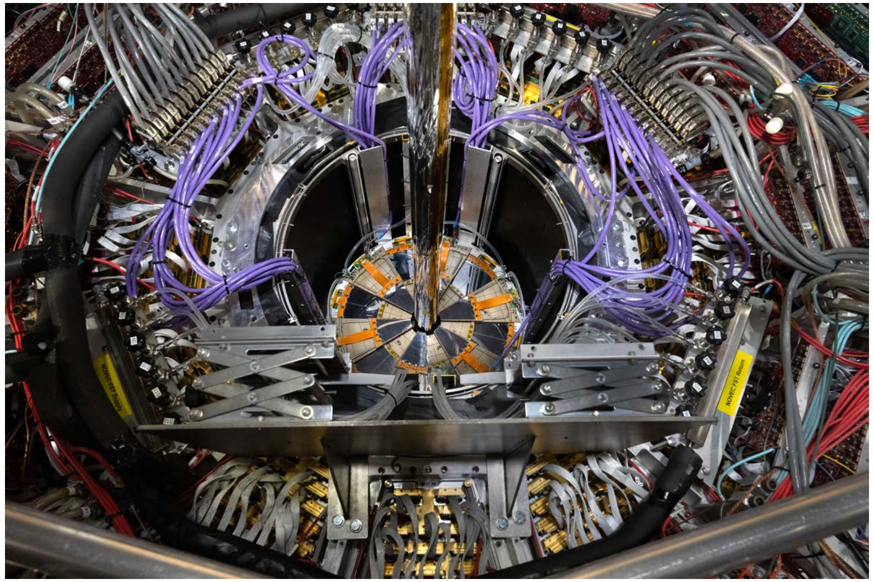
STAR FST Installation

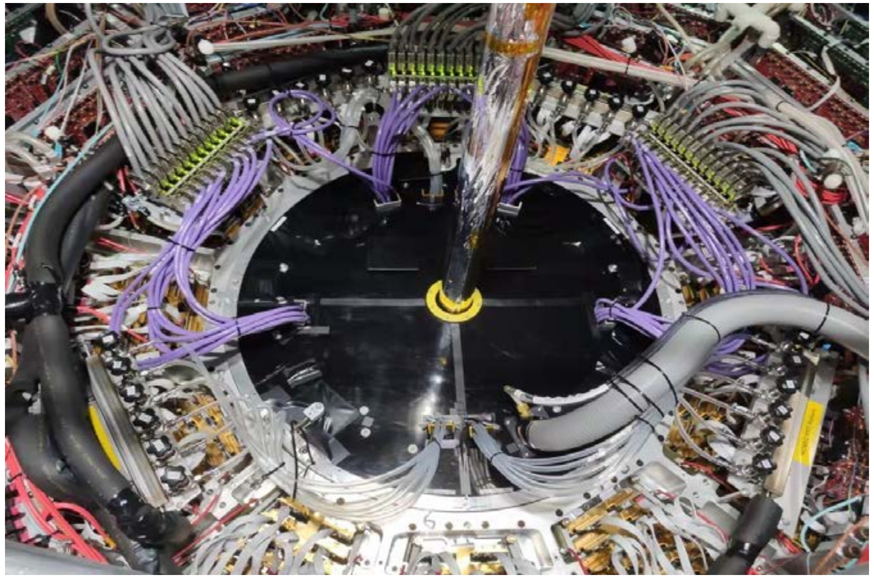






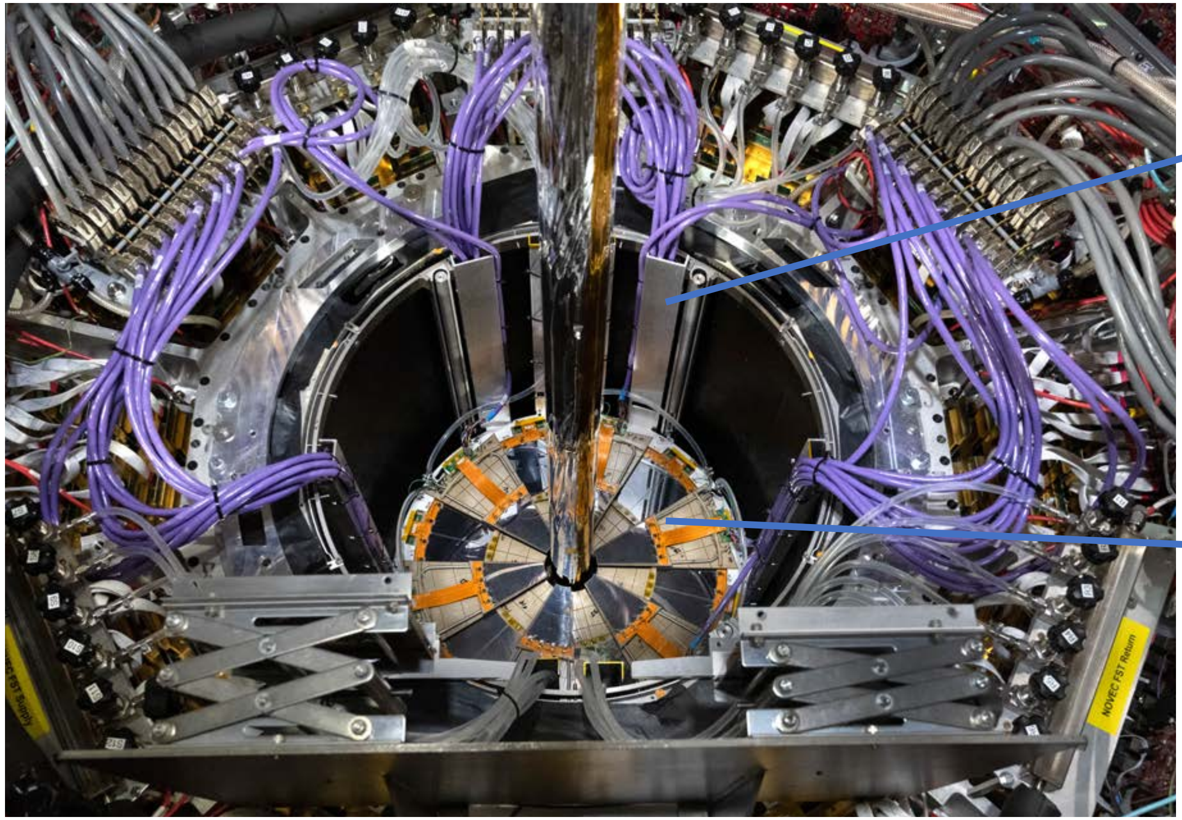




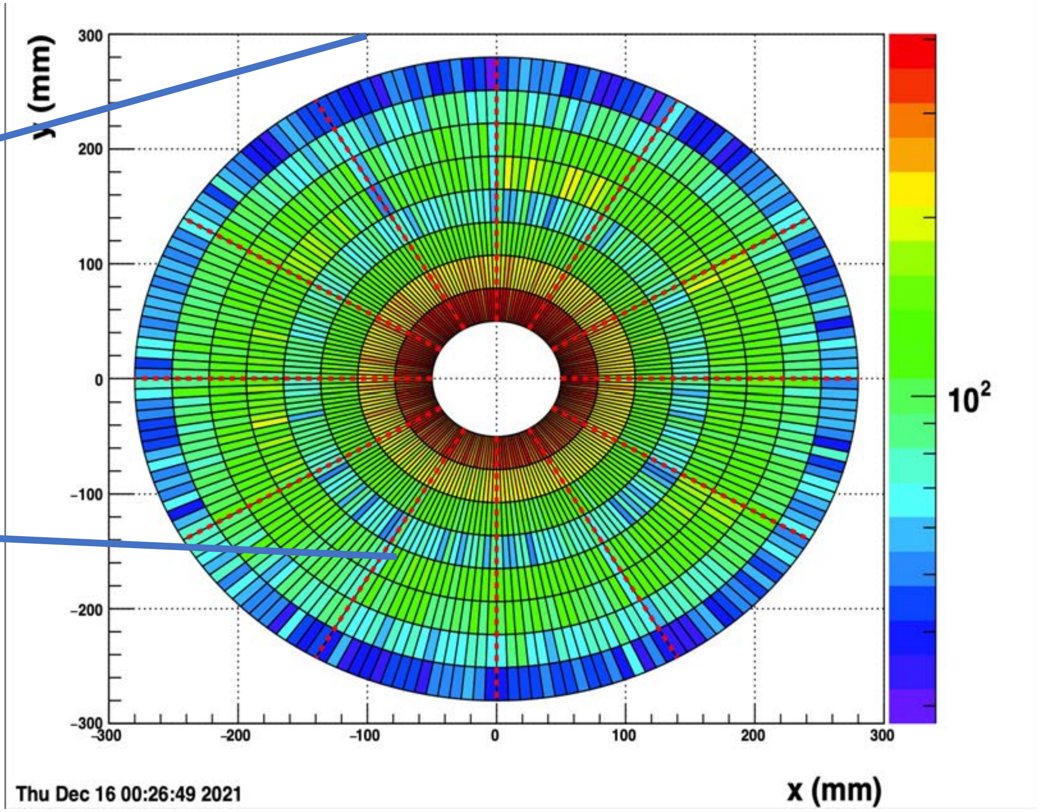


FST Installation completed on 08/13/2021

STAR FST Operations in Run22

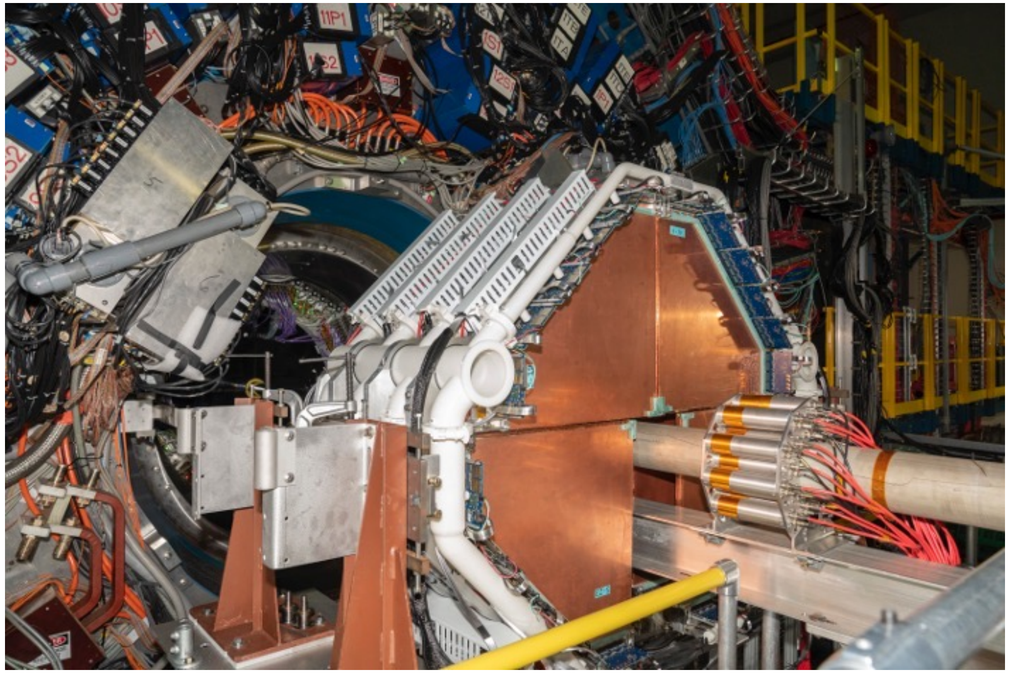


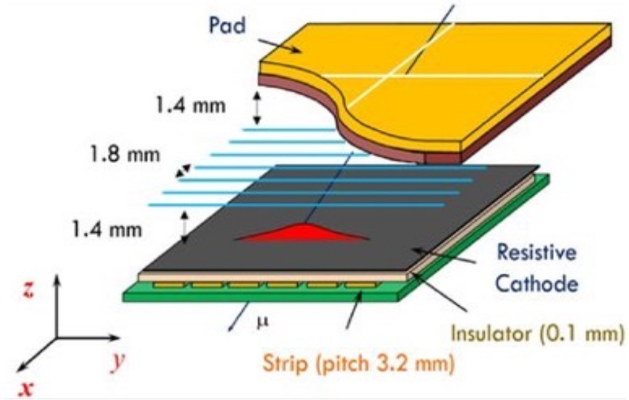
FST event display in run22 p+p 510GeV

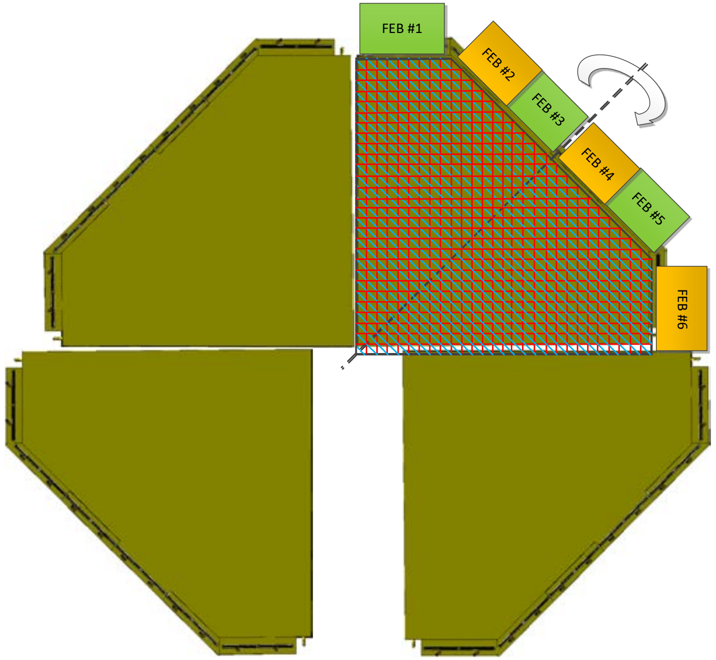


Operation HV: 140V for inner sensor and 160V for outer sensors
Cooling system refilled every ~4 weeks

STAR Forward sTGC Tracker (FTT)





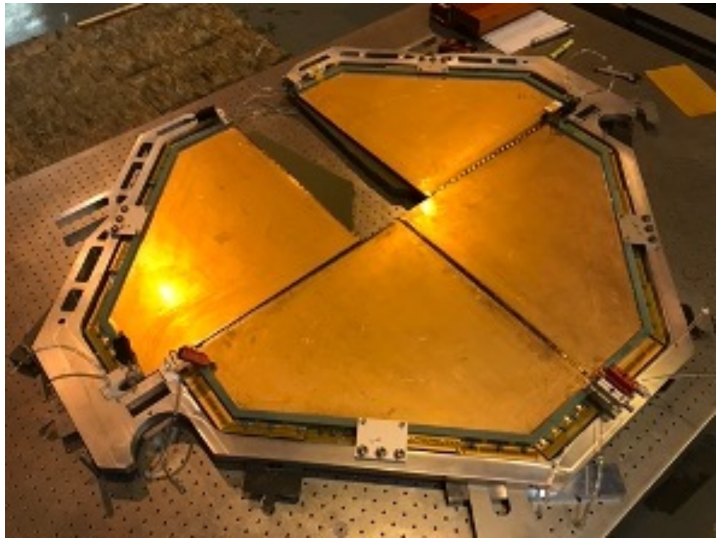
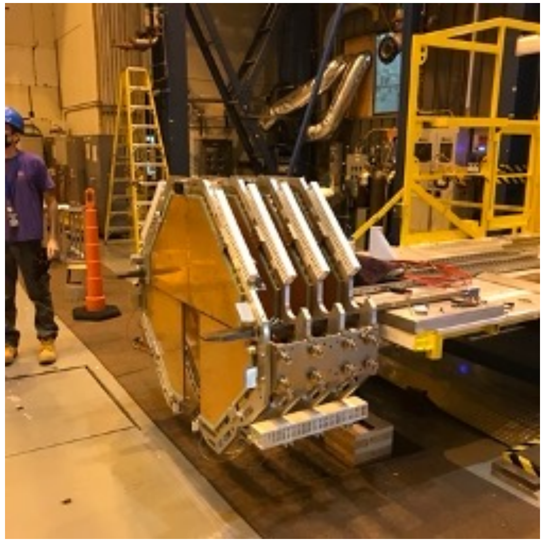
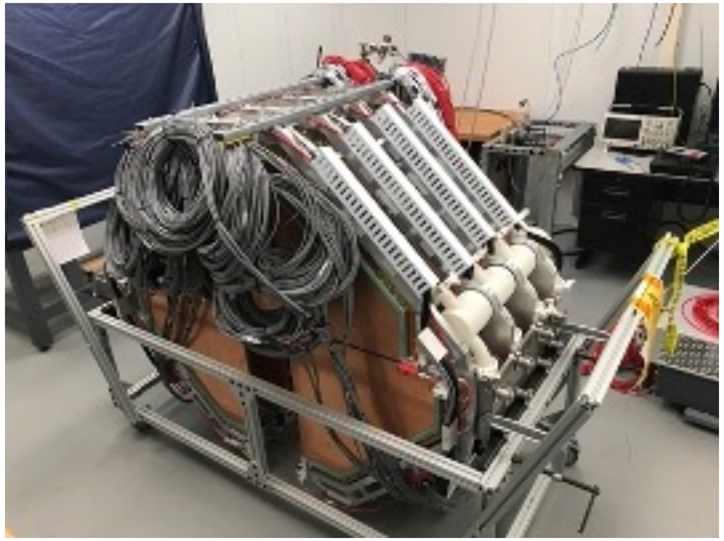
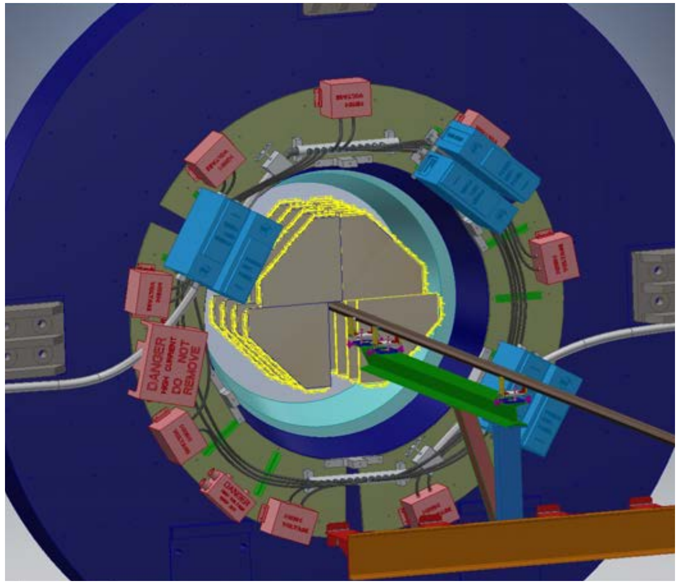
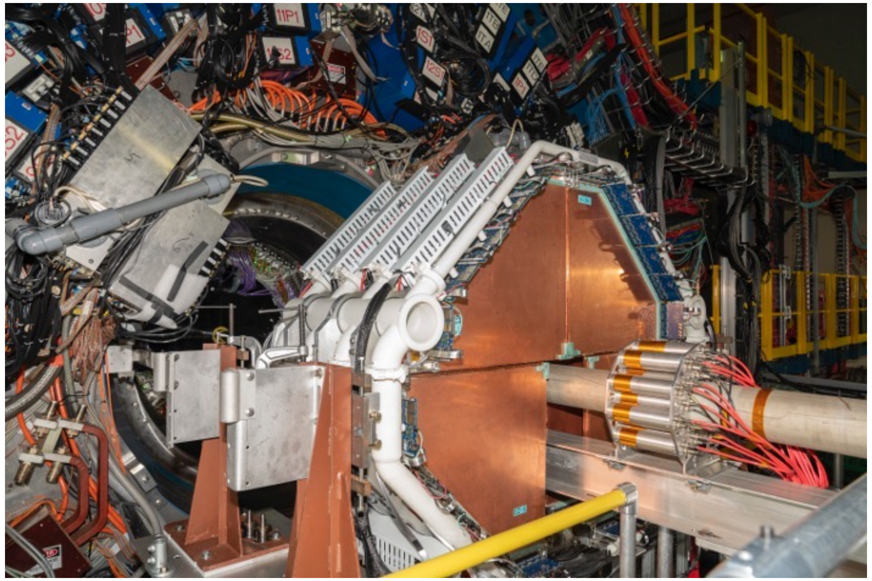
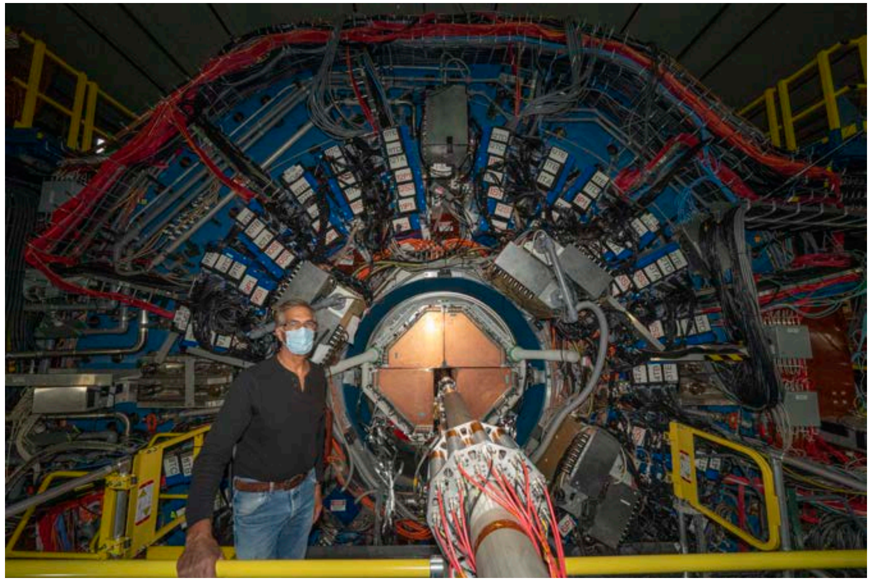


4 sTGC stations: at 307, 325, 343 and 361 cm from IP
=> Following ATLAS design

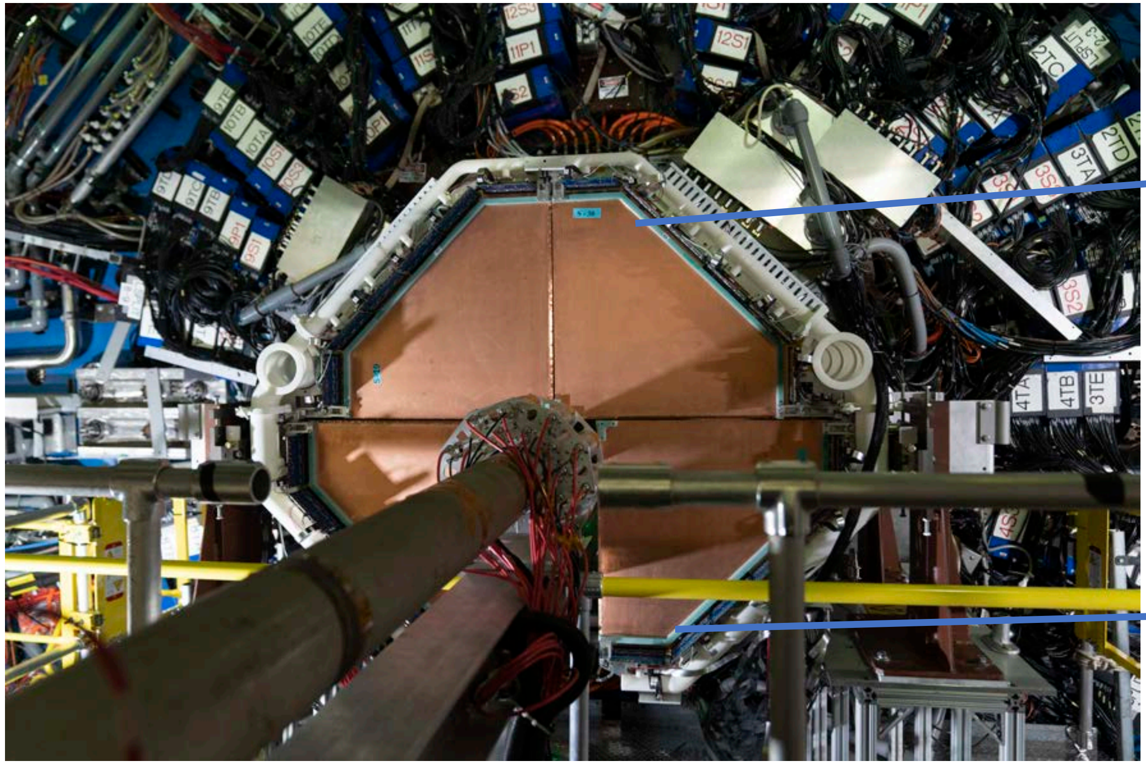
- Locate inside STAR magnet pole tip opening
  - Inhomogeneous magnetic field
- 4 quadrants double sided sTGC => 1 layer
  - Diagonal strips to suppress ghost hits
- Position resolution: ~100 μm
- Frontend readout: VMM-chips
- Material budget: ~0.5% per layer

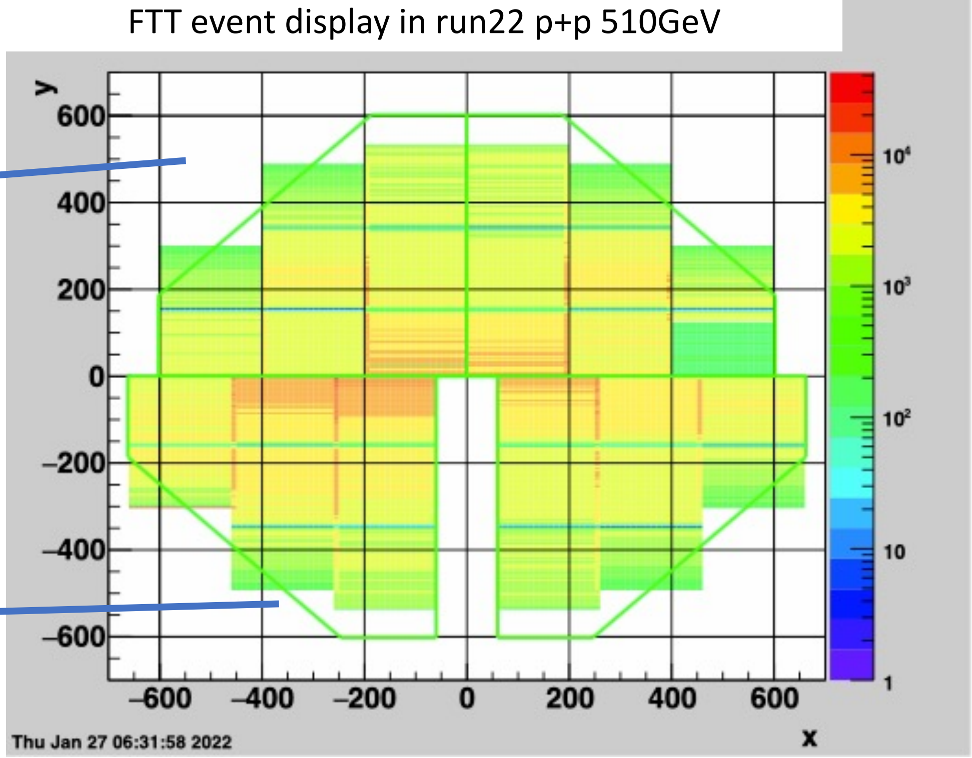
- Anode (HV): 50 µm gold-plated tungsten wires held at a potential of ~2900 V
- Cathode (Ground): graphite-epoxy mixture with a typical surface resistivity of 100 to 200 kΩ sprayed on G-10
- Readout: Small copper strips, perpendicular to anode wires, behind the cathode
- Working gas: n-Pentane+CO_2 = 45:55% by volume
  - Extreme care needed for the highly flammable n-pentane (C_5H_{12})
  - Flash point -49^{0}C; explosive limits 1.5–7.8%.
  - Boiling point of 36.1^{0}C further complicates things

STAR FTT Installation

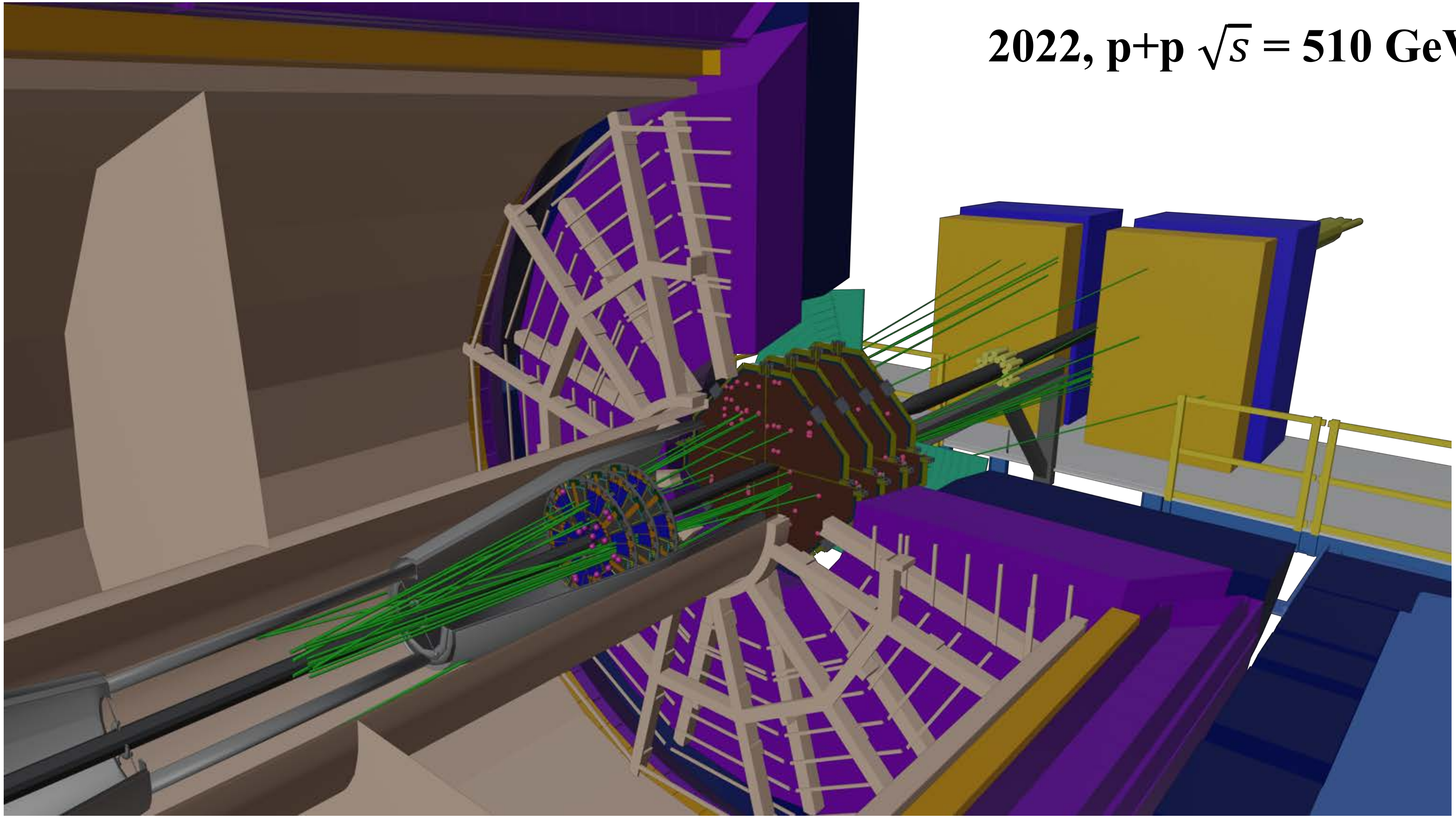
STAR FTT Operations in Run22





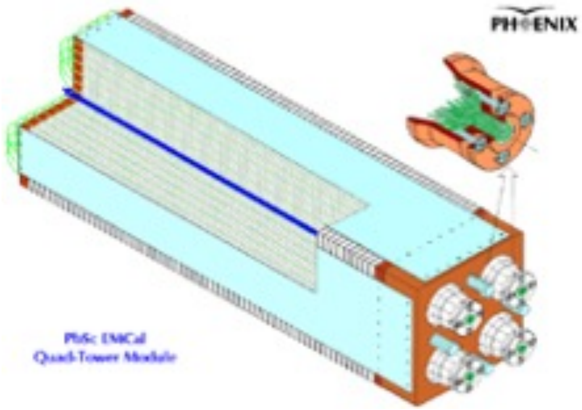
- Operation HV: 1500 V for standby and 3000 V for data taking
- Safety and gas mixing is automated through interlock logic
- Refill pentane, every three weeks by experts
- CO_2 change every two months by experts
  - Backed up by reserve tank online—no run out

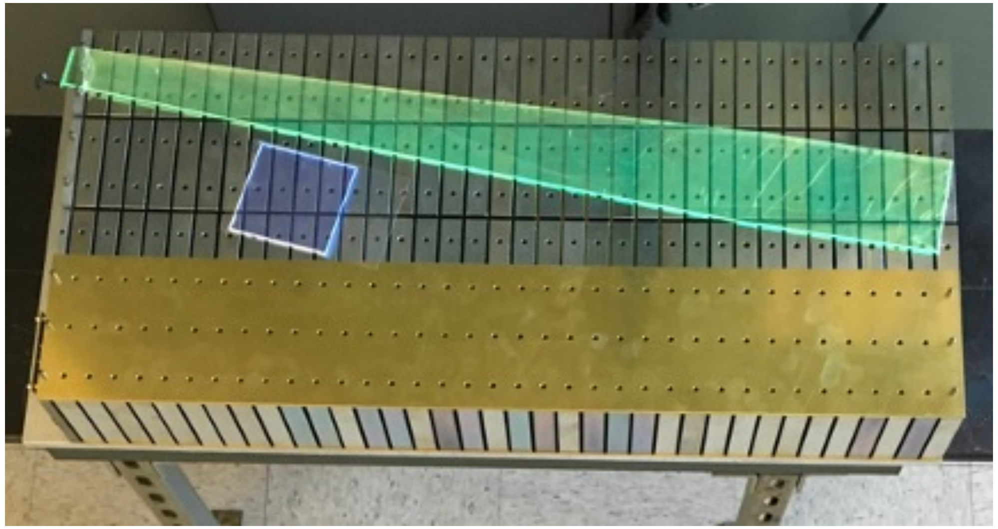
STAR Forward Tracking System in Run22



Both FST and FTT were successfully commissioned and took data in Run22 (12/2021-4/2022). Preliminary tracking from FTT is promising

STAR Forward Calorimeter System





Entire FCS (ECal + HCal + Electronics) was installed in 2020 and commissioned in Run21

- Extensive running with Au+Au at $\sqrt{s_{NN}} = 7.7$ GeV
- Brief runs with O+O and d+Au at $\sqrt{s_{NN}} = 200$ GeV

Location: 7 m from the IP on the "FMS platform"

Readout: SiPMs

- Used in Trigger
- Split in 2 movable halves inside and outside of ring
- Slightly projective

ECal: reuse PHENIX PbSC calorimeter

1496 channels: 5.52 x 5.52 x 33 cm^3
66 sampling cells with 1.5 mm Pb/4 mm Sc
36 wavelength shifting fibers per cell
18 X_0; 0.85 λ
replaced PMTs with SiPM readout

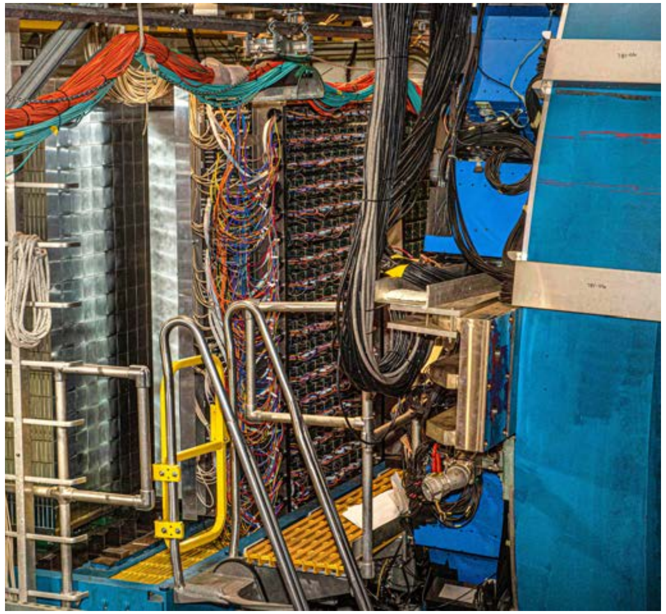
HCal: new Fe/Sc (20mm/3 mm) sandwich

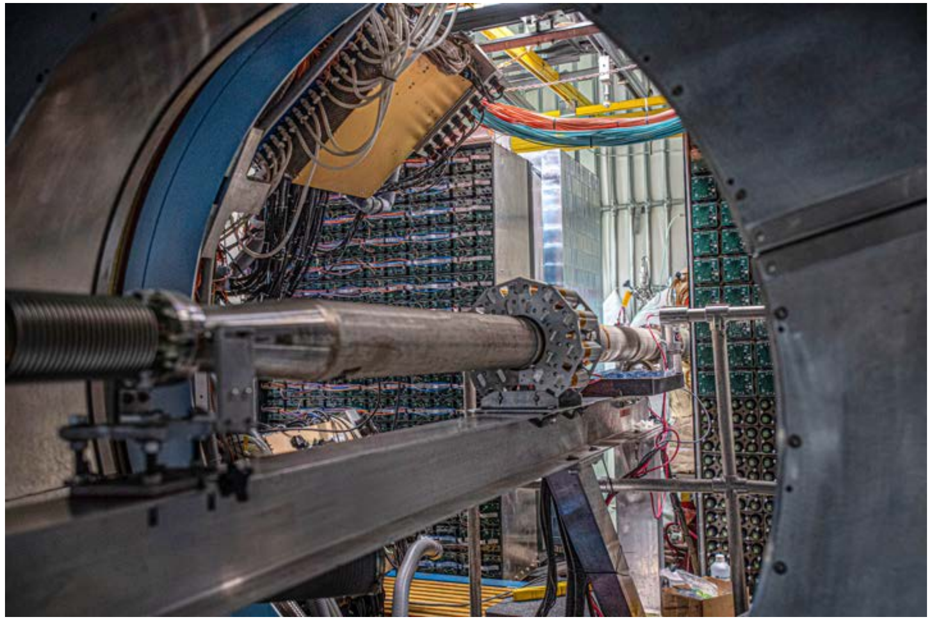
520 readout channels: 10 x 10 x 84 cm^3
~ 4.5 λ
Uses same SiPM readout as Ecal
In close collaboration with EIC R&D

Preshower: use STAR EPD

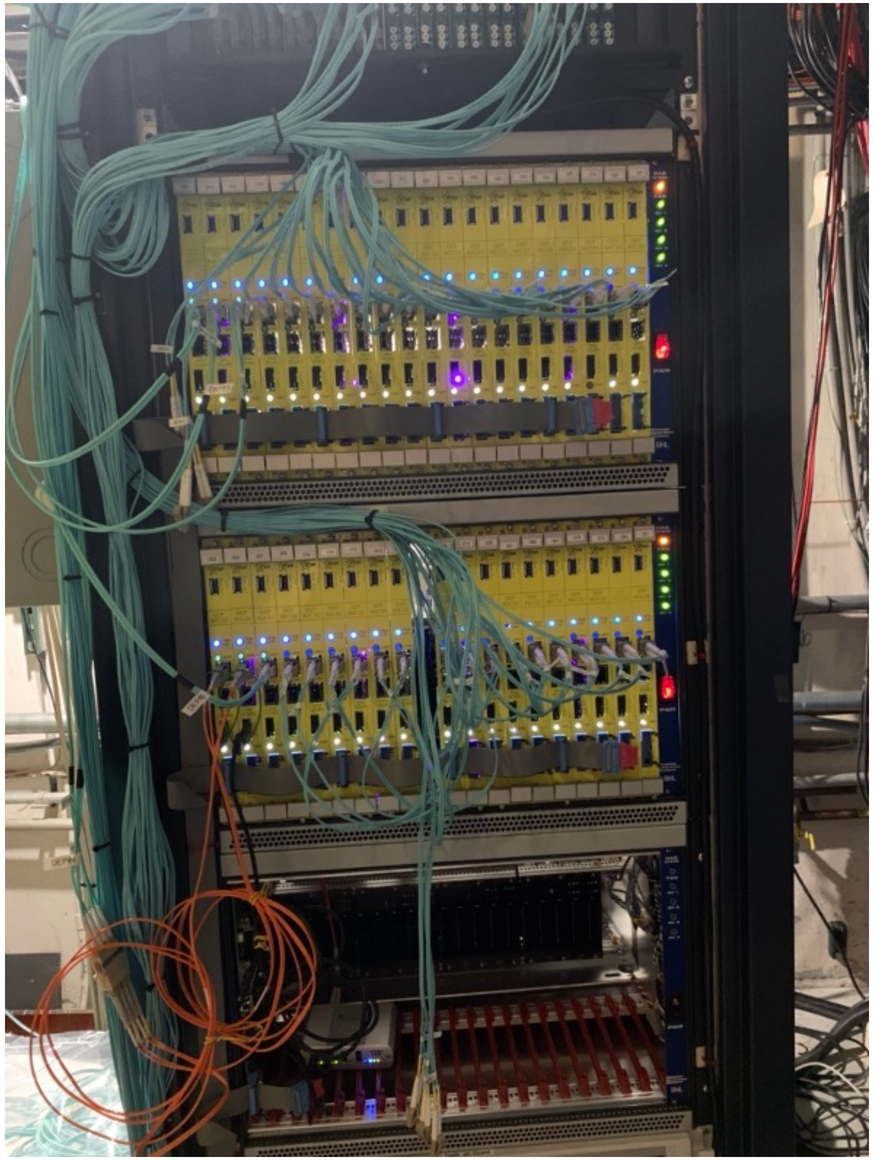
Split signals, using FCS readout & trigger boards

STAR FCS Assembly





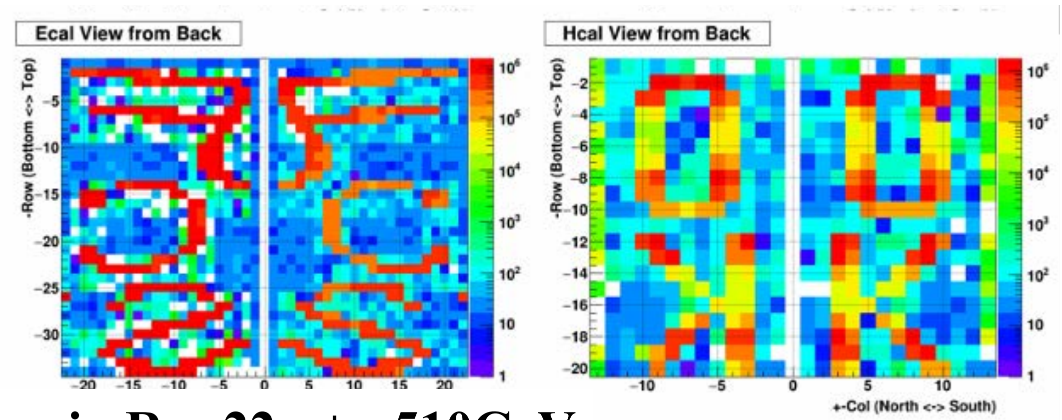
STAR FCS Commission in Run21



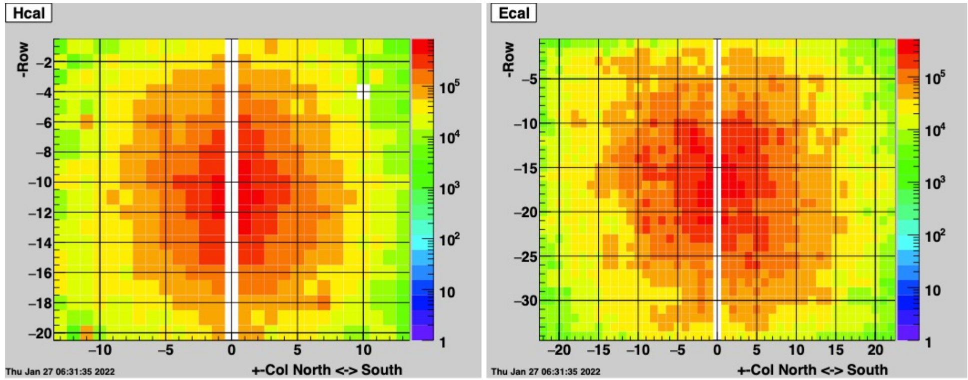
During Run21:

- Exercised the on-line data quality monitoring, and slow controls
- Off-line software and Monte Carlo also in place
- Trigger system fully commissioned
- System fully ready on Day-1 of Run 22

FCS LED Test

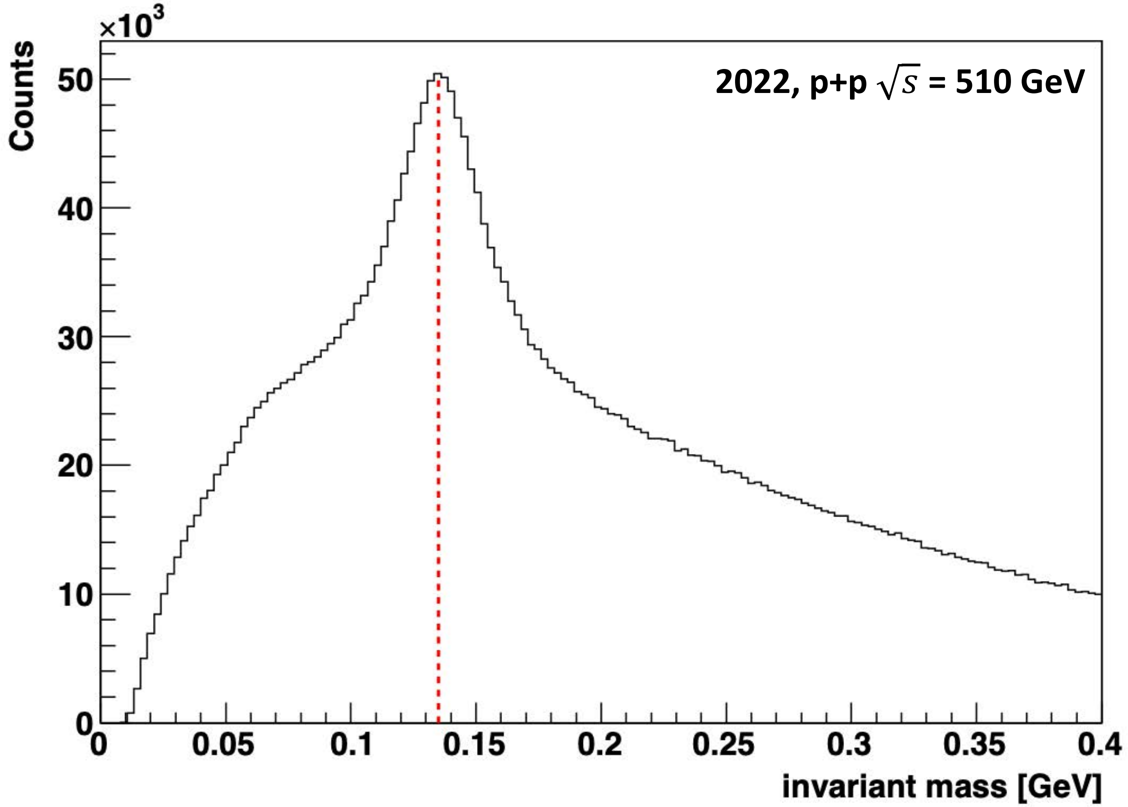


FCS event display in Run22 p+p 510GeV

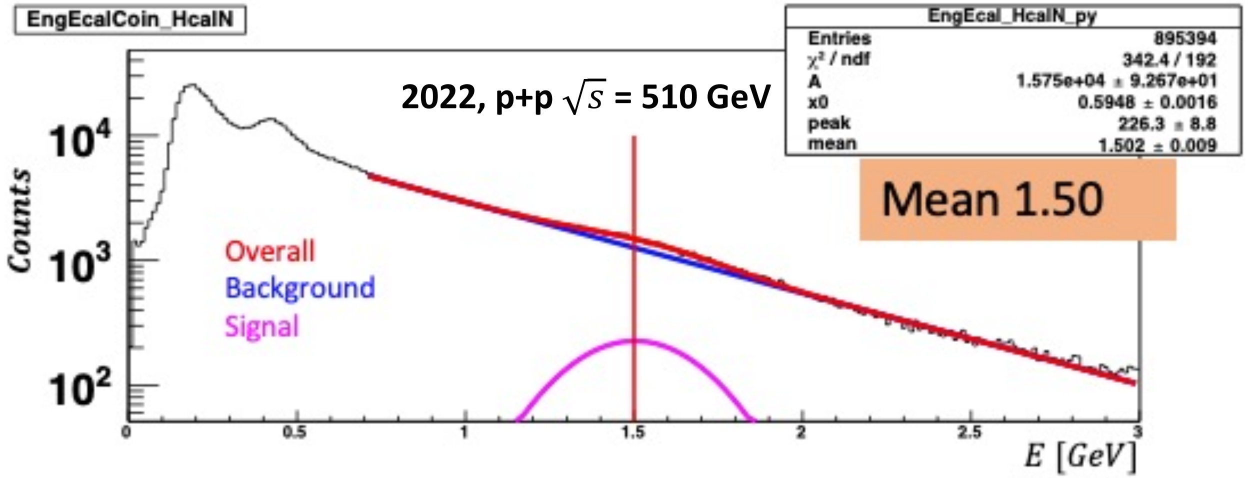


STAR FCS Performance in Run22

π^0 reconstructed by Di-photon from ECal



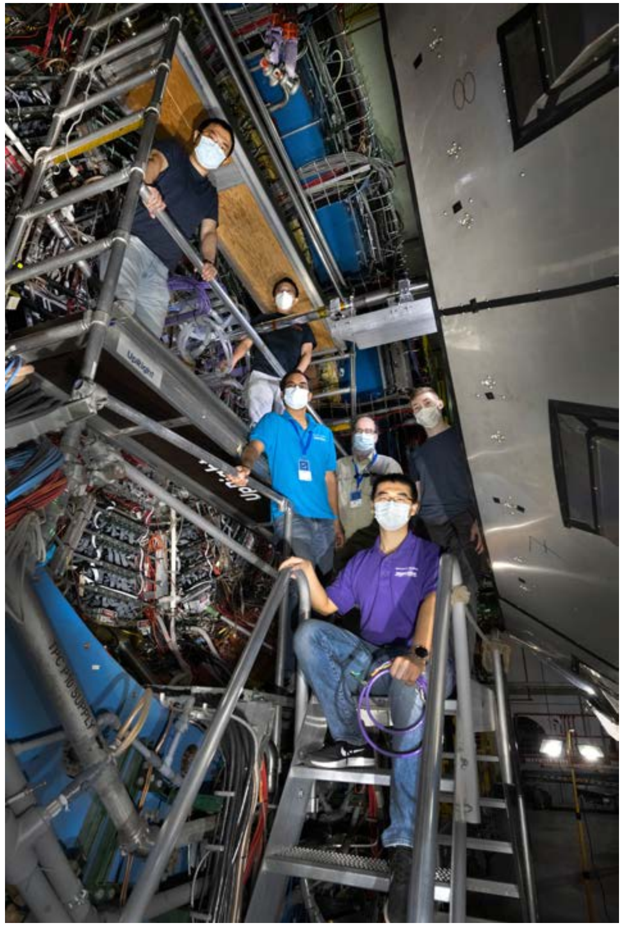
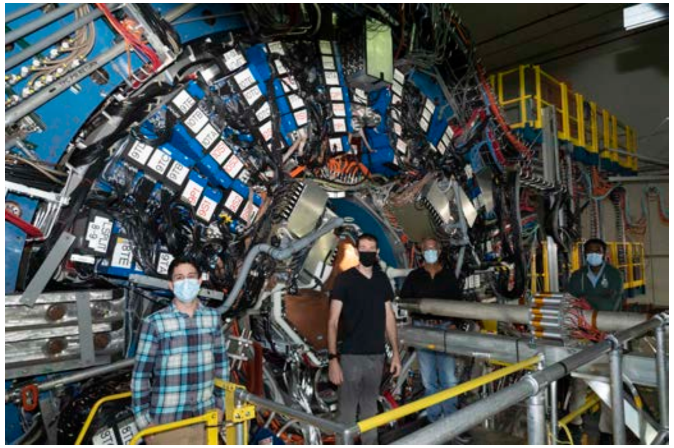
MIP peak from HCal (Matched with ECal MIP)

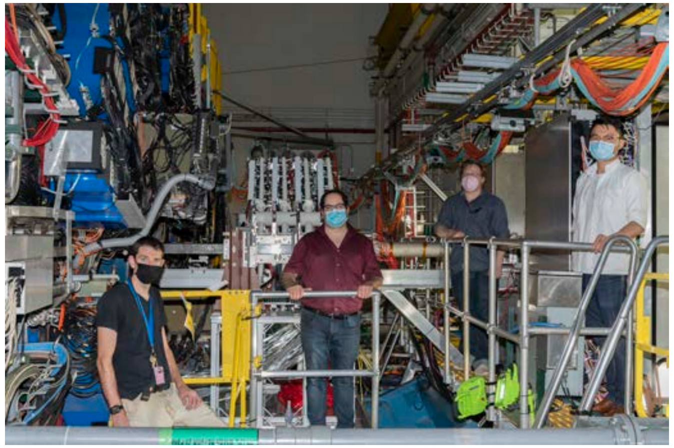


FCS was successfully commissioned in Run21 and took data in Run22
FCS performance is as expected

Summary and Outlook

- Despite of COVID, all the new STAR forward detectors were installed and commissioned on time and taking data in p+p collisions at 510 GeV in 2022. Thanks to all that are involved.
- Explore new territories of cold and hot QCD physics with STAR forward detectors in Au+Au (2023&25) and p+p & p+Au (2024) collisions at 200 GeV.




STAR Forward Upgrade Institutions

Dedicated personnel for each subsystem

sTGC
- BROOKHAVEN NATIONAL LABORATORY
- 山东大学 SHANDONG UNIVERSITY

Silicon
- UIC UNIVERSITY OF ILLINOIS AT CHICAGO
- BROOKHAVEN NATIONAL LABORATORY
- NATIONAL CHENG KUNG UNIVERSITY 1931
- 山东大学 SHANDONG UNIVERSITY
- INDIANA UNIVERSITY
- IISER TIRUPATI

ECal
- KENTUCKY
- VALPARAISO UNIVERSITY
- ABILENE CHRISTIAN UNIVERSITY

HCal
- UCLA
- TEXAS A&M UNIVERSITY
- INDIANA UNIVERSITY
- RUTGERS
- ABILENE CHRISTIAN UNIVERSITY
- OHIO STATE

Calorimeter Funded by NSF

NSF

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
- UC RIVERSIDE
- TEMPLE UNIVERSITY

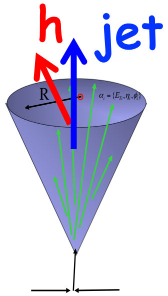
Slow Controls
- VALPARAISO UNIVERSITY
- ABILENE CHRISTIAN UNIVERSITY
- Creighton UNIVERSITY

and the STAR collaboration, which stands enthusiastically behind the upgrade

Constrain Transversity with Forward Upgrade

Collins asymmetry in pp collisions

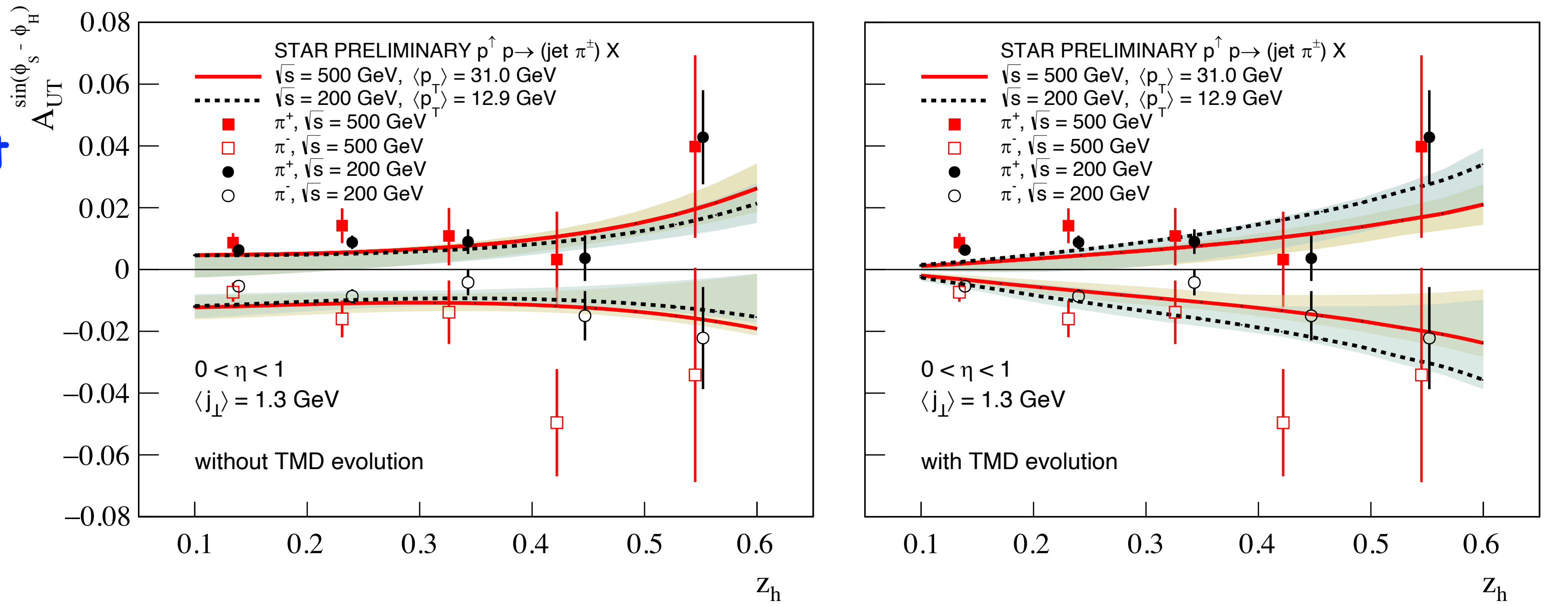
$$A_{UT}^{\pi^\pm} \approx \frac{\overbrace{\boxed{h_1^{q_1}(x_1,k_T)}}^{\text{transversity}} f_{q_2}(x_2,k_T)\,\hat{\sigma}_{UT}(\hat{s},\hat{t},\hat{u}) \overbrace{\boxed{\Delta D_{q_1}^{\pi^\pm}(z,j_T)}}^{\text{Collins FF}}}{f_{q_1}(x_1,k_T)\,f_{q_2}(x_2,k_T)\,\hat{\sigma}_{UU} D_{q_1}^{\pi^\pm}(z,j_T)}$$



STAR PLB 773 (2017) 300

PRD 97 (2018) 032004

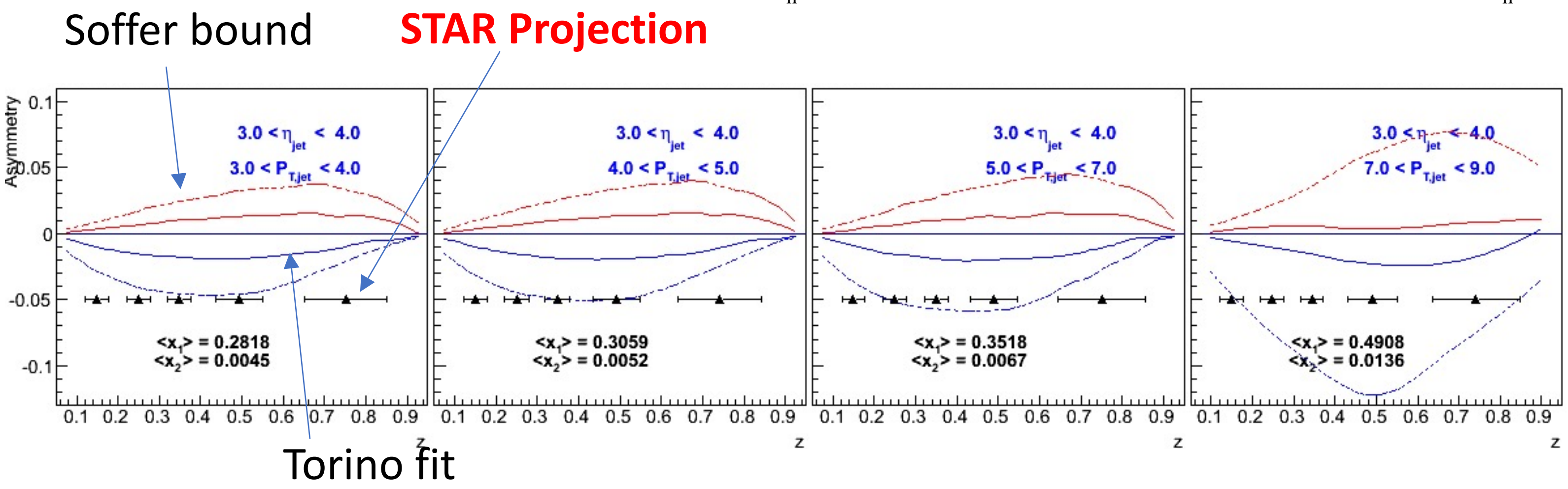
- 1^{st} observation at low x and high Q^2
- test of factorization & universality
  → compare with transversity from IFF
  → compare with SIDIS and e+e-
- TMD evolution: 200 GeV vs 500 GeV differ by a factor 3 in Q



Proton tensor charge

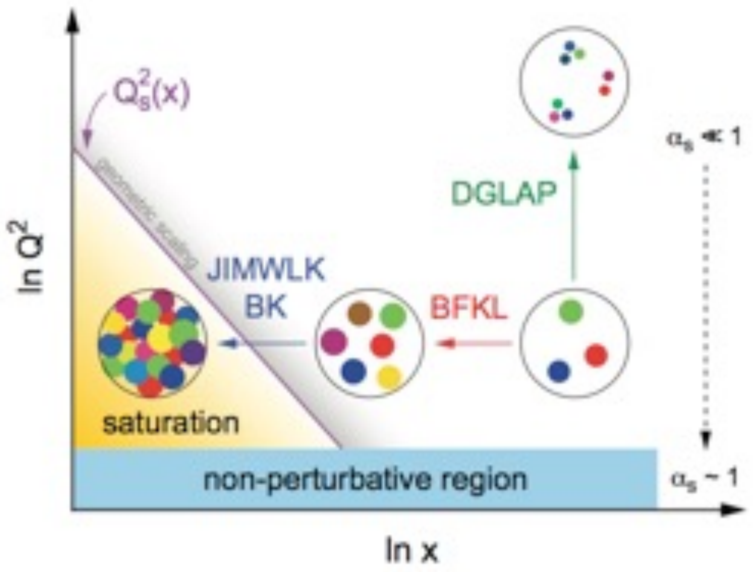
$$\delta q = \int_0^1 \left(h_1^q(x) - h_1^{\bar{q}}(x) \right) dx$$

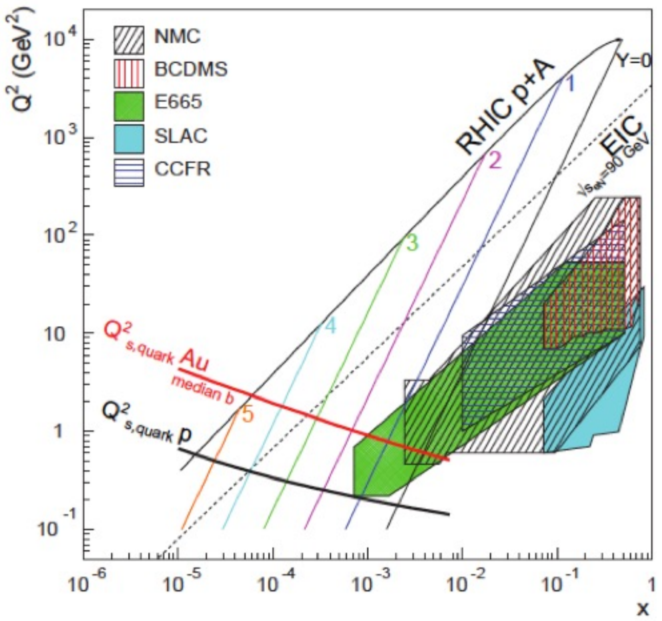
- needed for low-energy BSM search
- precision is currently limited



Transversity at small and large x and the tensor charge better constrained with forward upgrade

Study Gluon Saturation with Forward Upgrade



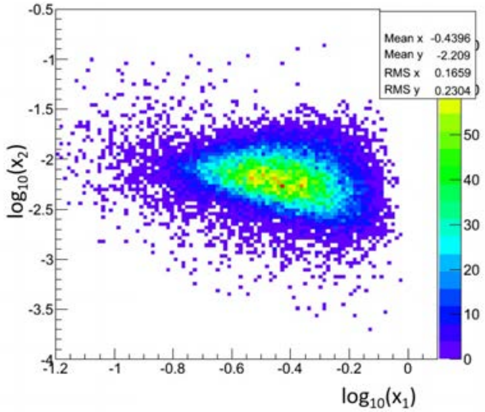


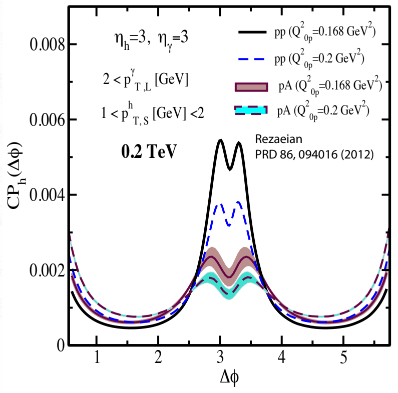
	DIS and DY	SIDIS	hadron in pA	photon-jet in pA	Dijet in DIS	Dijet in pA
$G^{(1)}$ (WW)	×	×	×	×	√	√
$G^{(2)}$ (dipole)	√	√	√	√	×	√

pp and pA collisions

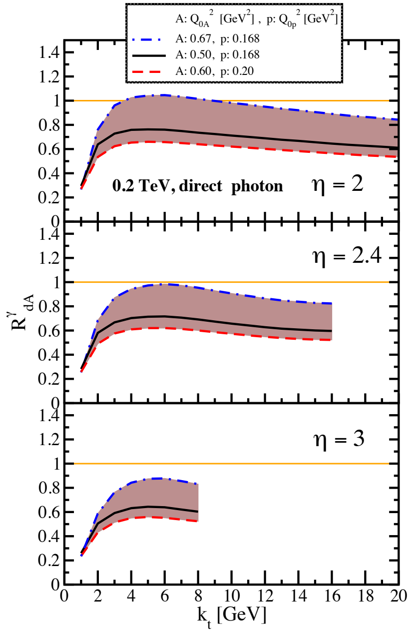
- different gluon distributions
- rigorous test of theory predictions
- universality for different probes
- evolution of Q_s^2 with A and x

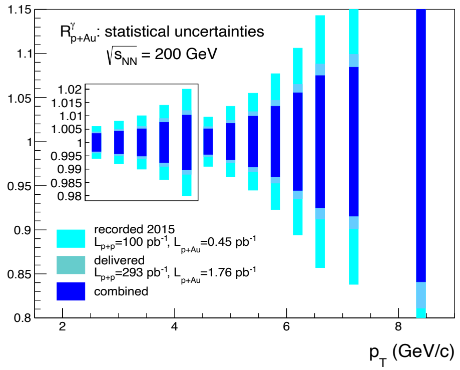
jet-hadron / jet-photon correlations





→ 1M events with forward upgrade in 2023 pAu and pAl

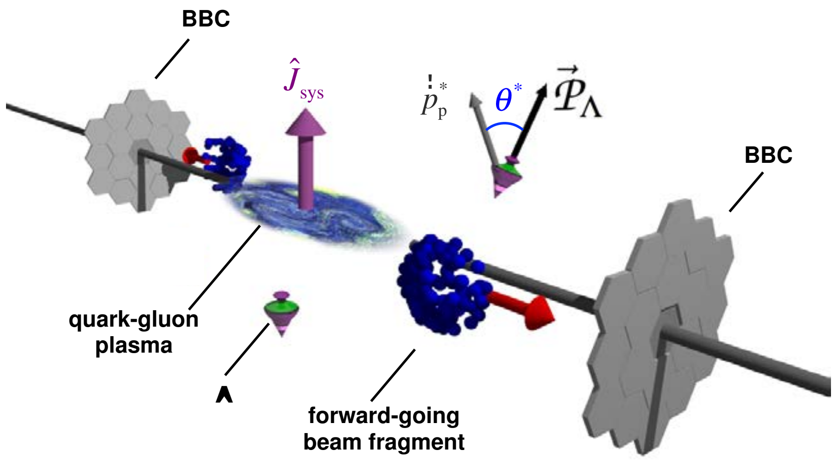


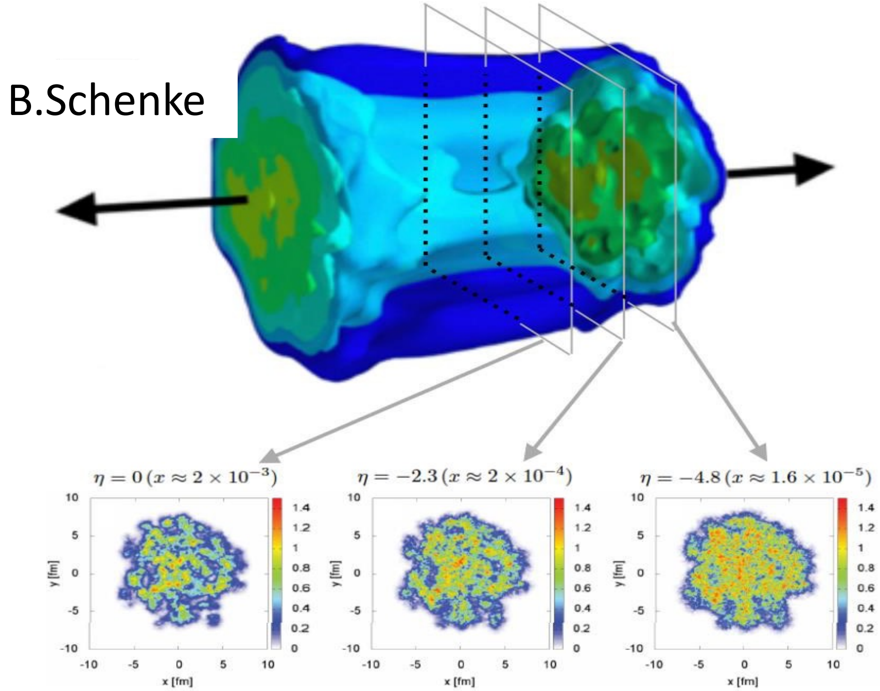


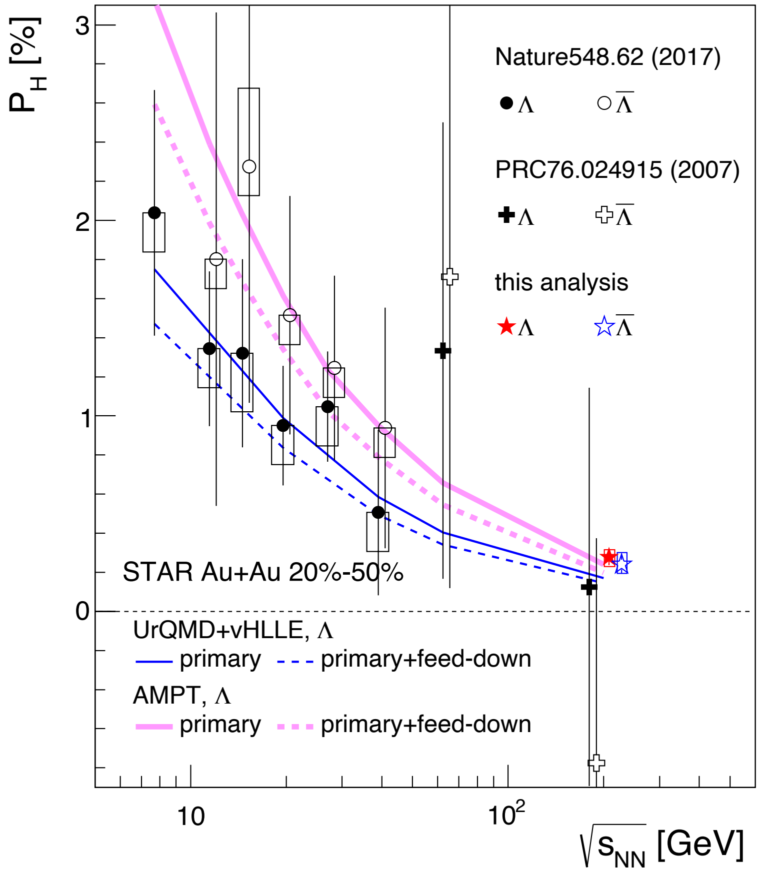
CGC prediction for direct photon R_{pA}

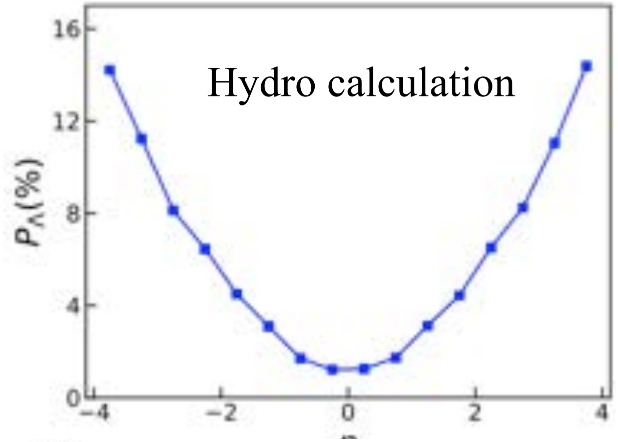
Study QGP in Au+Au Collisions with Forward Upgrade

STAR: Nature 548.62 (2017)









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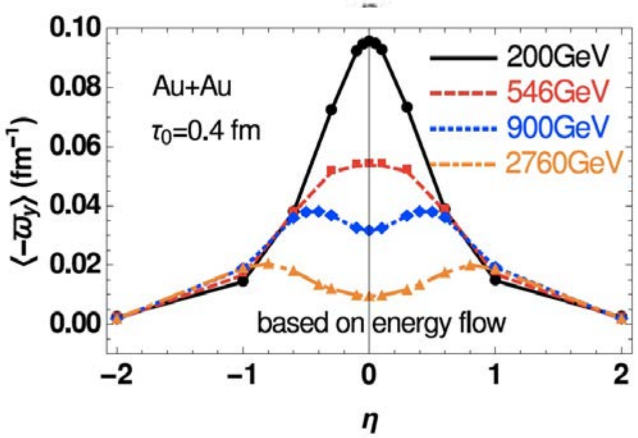

PRC 93 (2016) 064907

- Discern different scenarios of vorticity by Λ global polarization vs rapidity
- Constrain the longitudinal structure of initial conditions through correlations vs rapidity