Forward Rapidity Upgrade

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for the STAR Collaboration

5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan

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U.S. DEPARTMENT OF ENERGY | Office of Science

BROOKHAVEN NATIONAL LABORATORY

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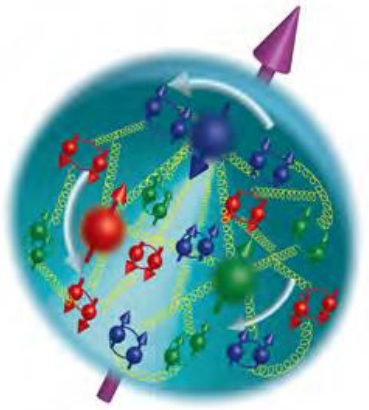
Context

1 Emerging Nucleons

How are gluons, sea quarks, and their intrinsic spins distributed in space and momentum in the nucleon?

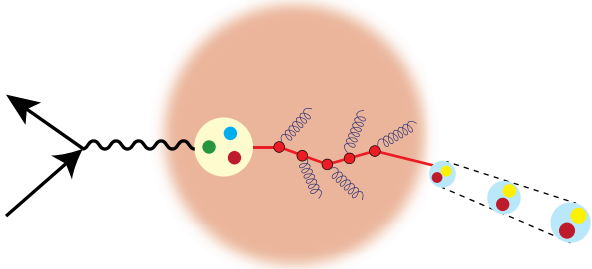


2 Nuclear Medium

How do colored quarks and gluons and colorless jets interact with the nuclear medium?

How does the nuclear environment affect quark and gluon distributions?

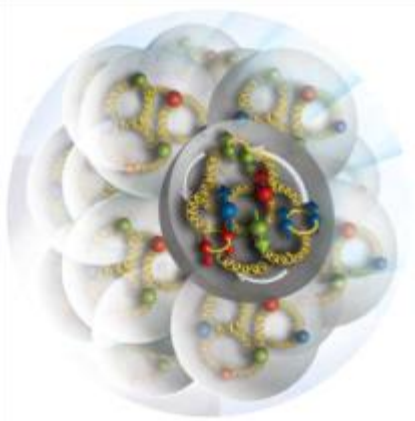
Are abundant low-momentum gluons confined within nucleons?



3 Gluon Saturation

What happens to the gluon density at high energy?

Are the properties of a saturated gluonic state universal among all nuclei?

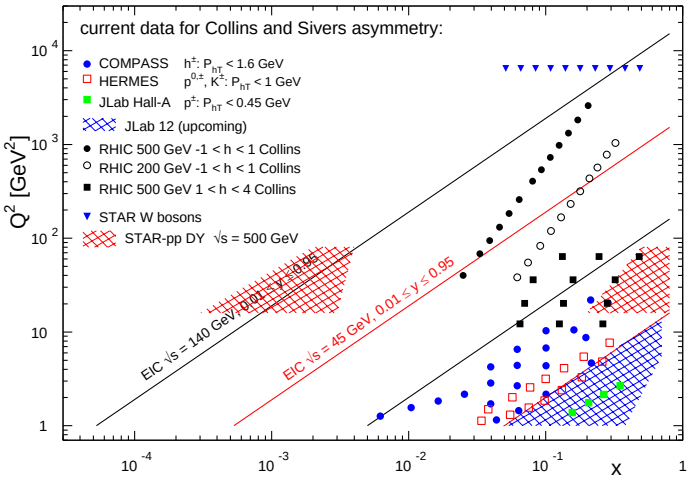


Transverse Spin Effects

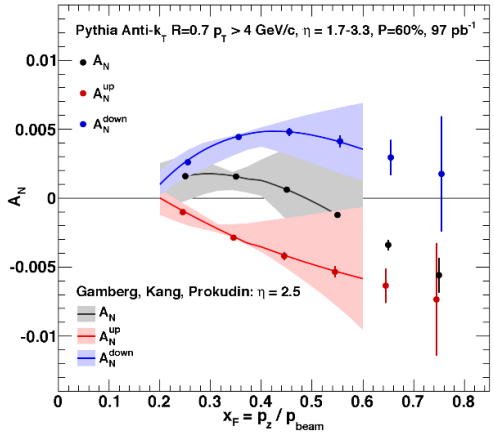
- Origin of large transverse asymmetries at high x_F

$$A_{UT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

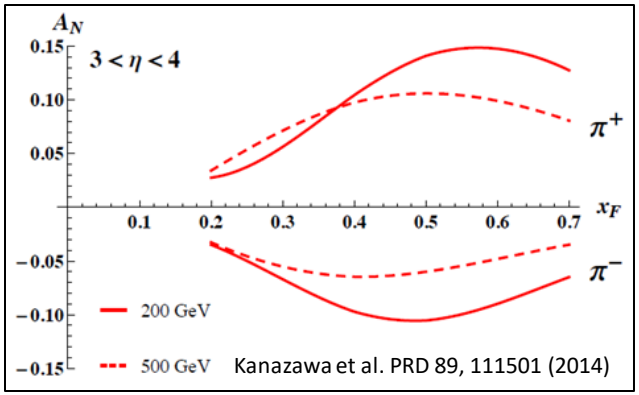
- Disentangle initial and final state effects
  - Transversity distribution
  - Spin-orbit correlations, fragmentation functions
  - Transverse momentum dependent vs. higher twist



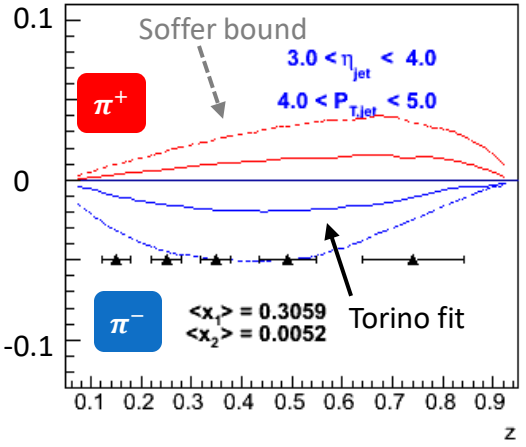
Tagged jets



Charged pions



Pions in jets



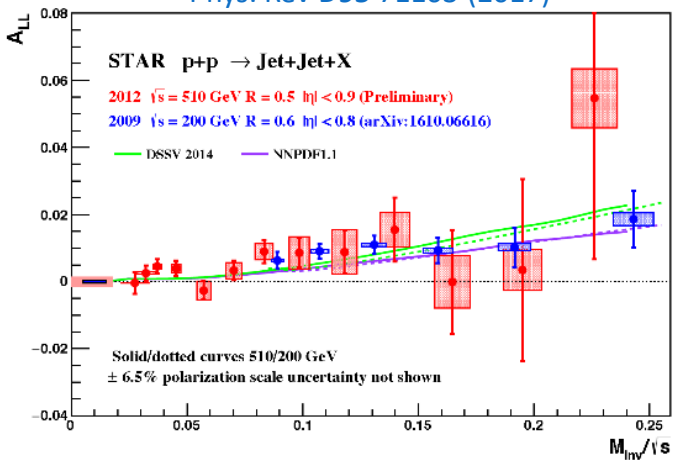
Helicity Asymmetries

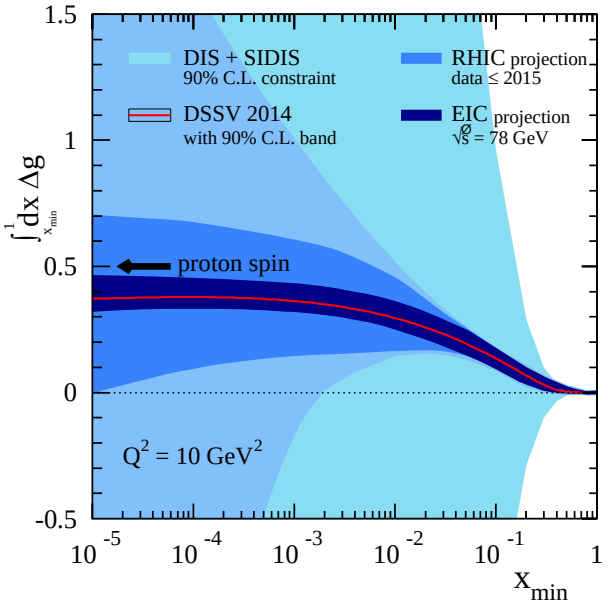
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$\int_{0.05}^{1} \Delta g(x, Q^2) dx = 0.2^{+0.06}_{-0.07}$$

Phys. Rev. Lett. 113, 012001 (2014)

Phys. Rev D**95** 71103 (2017)





Projections:

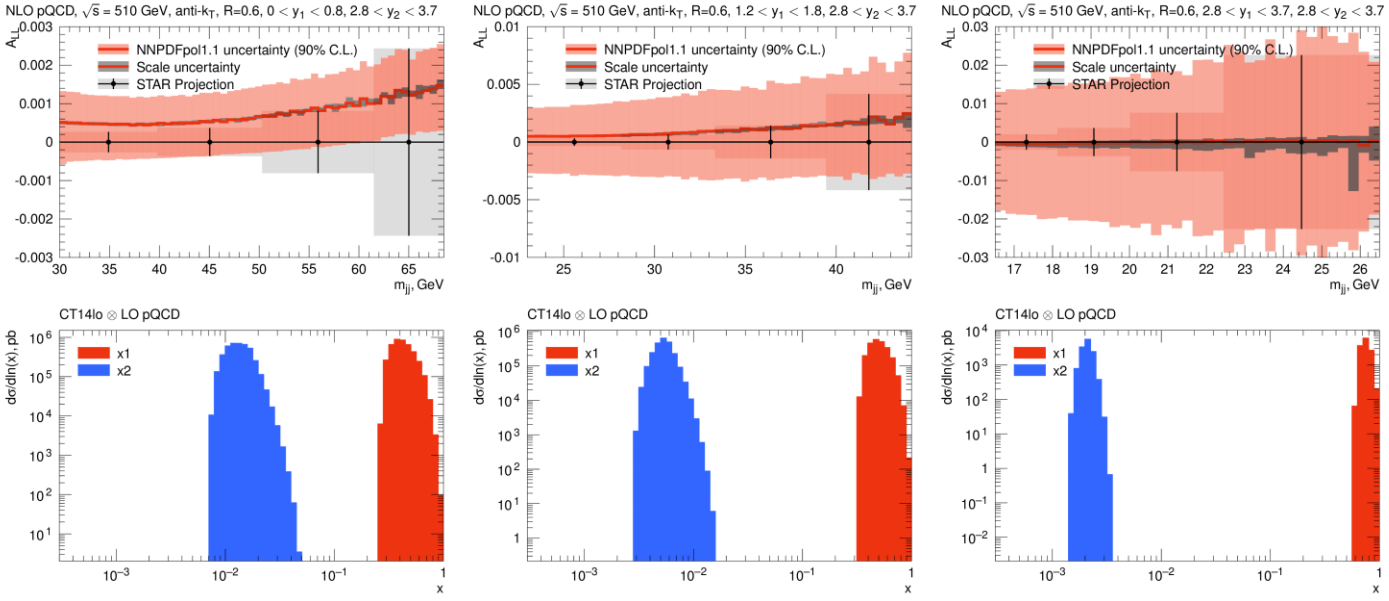
$\sqrt{s} = 510$ GeV

anti-k_T, $R = 0.6$

$E_{T3} > 5$ GeV

$E_{T4} > 8$ GeV

$\sqrt{x_1} \cdot \sqrt{x_2} = m_{jj}/\sqrt{s}$



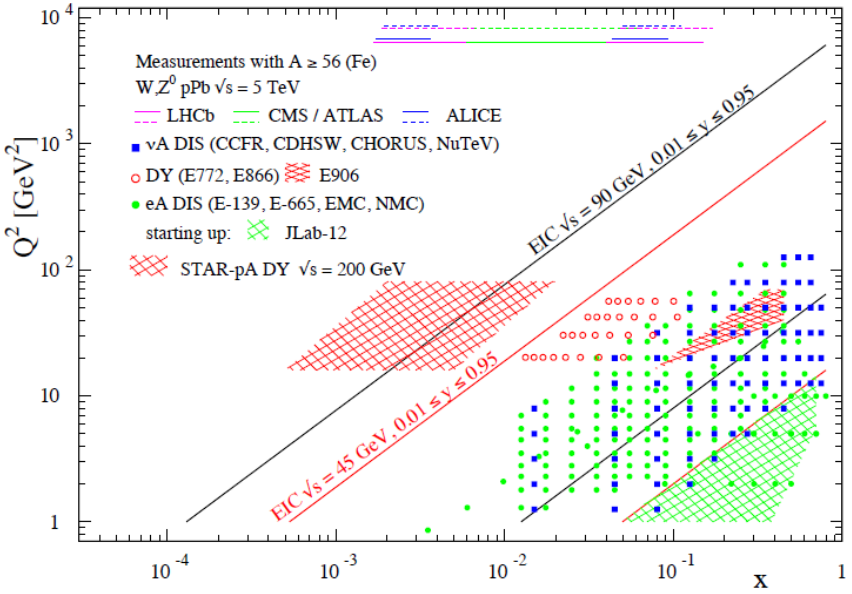
Nuclear Distribution Functions

- Poorly constrained, esp. towards low x
- LHC data at very high Q^2

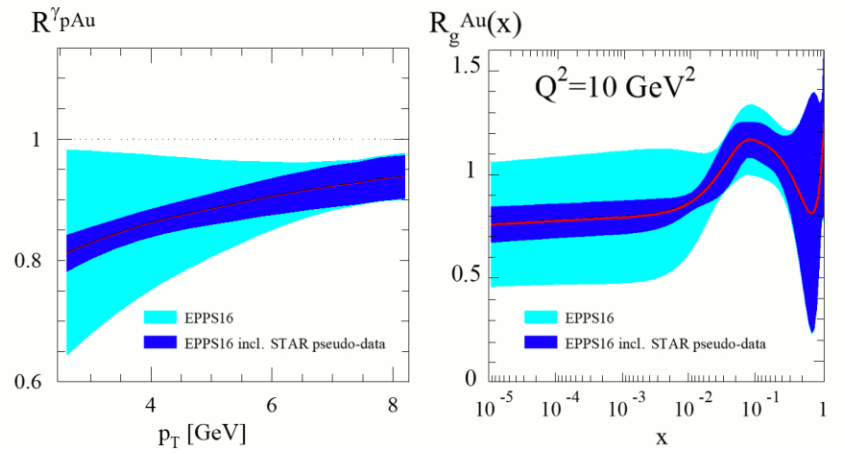
$$R_{pA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{pA}}{dN^{pp}}$$

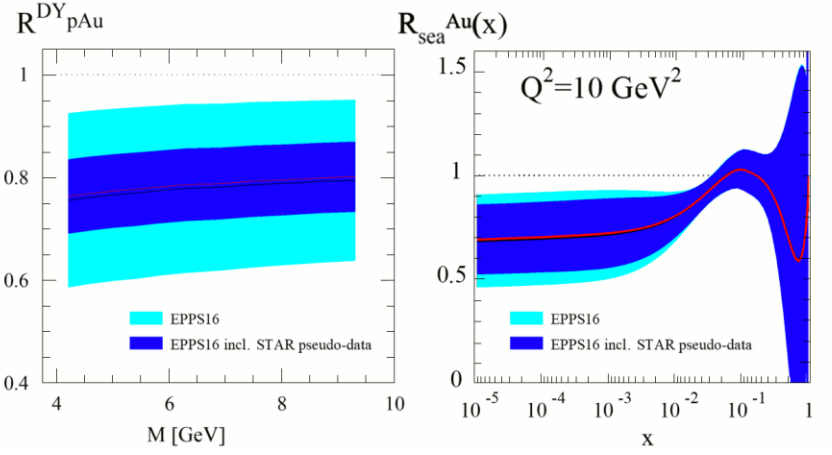
- Direct photons → gluon PDF
- Drell-Yan production → sea quarks

$$2.5 < \eta < 4.5$$



Projections:



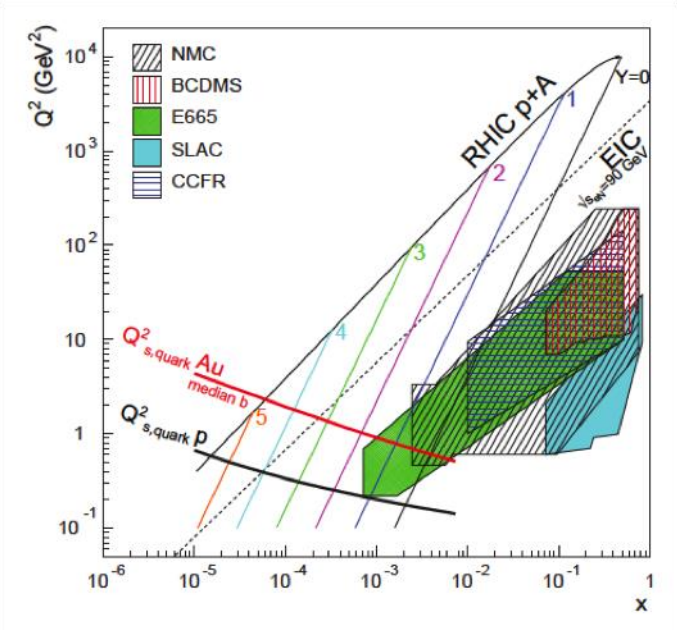


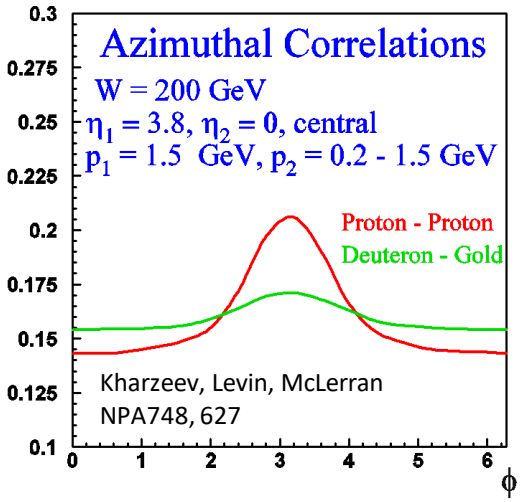
Gluon Saturation

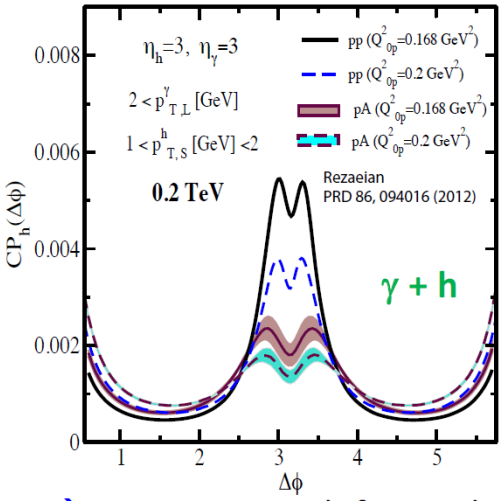
- Saturation scale

$$Q_A^2(x) \approx A^{1/3} Q_s^2(x)$$

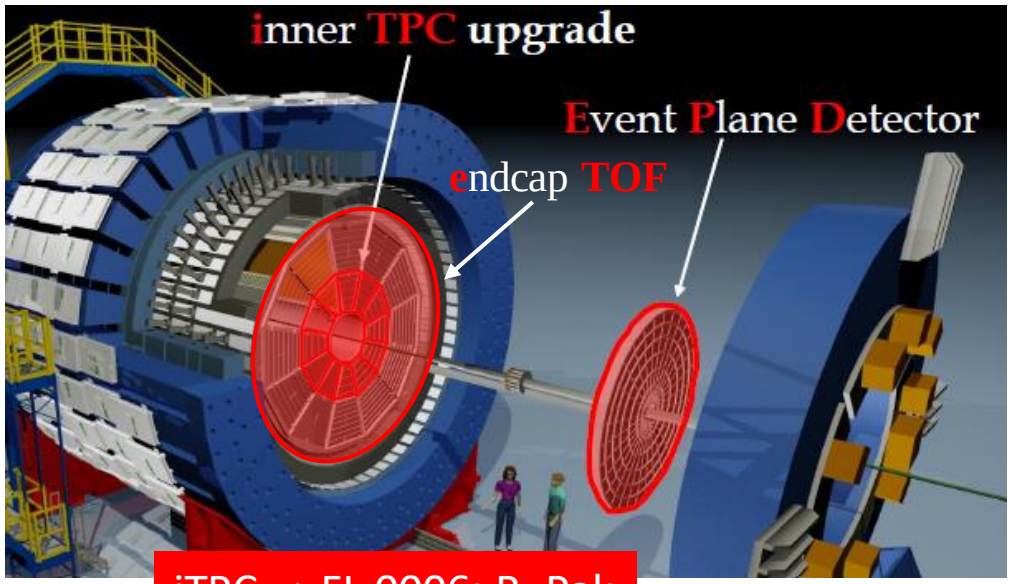
- Scan kinematic range: x & Q^2
  - Trigger p_T
  - Associated p_T
- Test A-dependence
  - $p + Al, p + Au$
- Other probes (forward)
  - γ-hadron correlation
  - γ –jet correlation

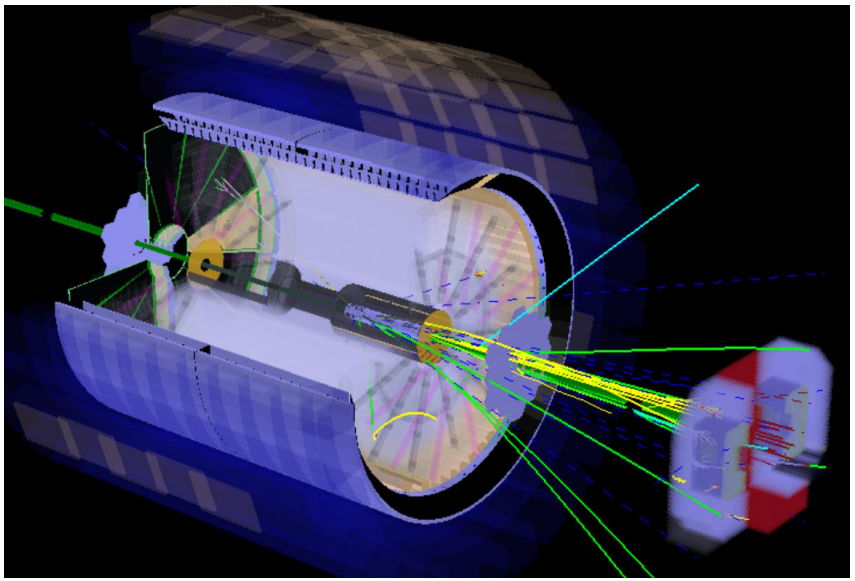






RHIC after Beam Energy Scan II





iTPC → FL.0006: R. Pak

The STAR Forward Calorimeter System and Forward Tracking System

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

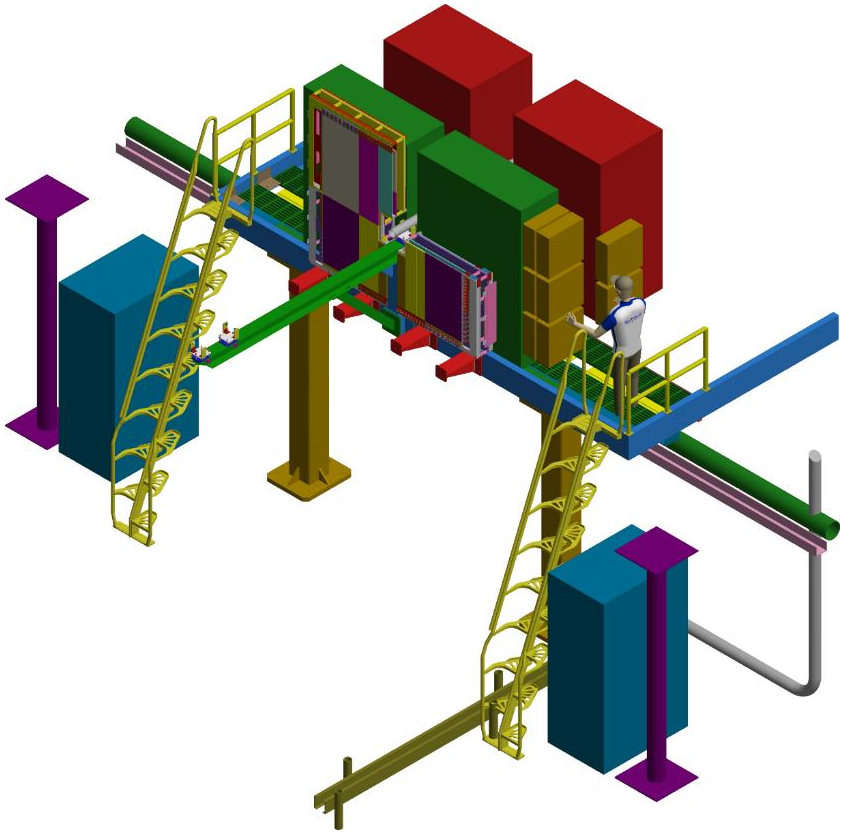
Highlights of the STAR midrapidity Physics Program after 2020

- https://drupal.star.bnl.gov/STAR/starnotes/public/sn0669

New detector upgrades for potential polarized $p + p$ collisions at $\sqrt{s} = 510$ GeV

Forward Calorimeter System

	p+p / p+A	A+A
ECAL	$\approx 10\%/\sqrt{E}$	$\approx 20\%/\sqrt{E}$
HCAL	$\approx 60\%/\sqrt{E}$	n/a



Preshower detector

EM calorimeter

- PHENIX PbSc
- New readout SiPM/APD
- Not compensating

Hadronic calorimeter

- $L = 4 \cdot \lambda_I$
- Sampling iron-scintillator
- Same readout

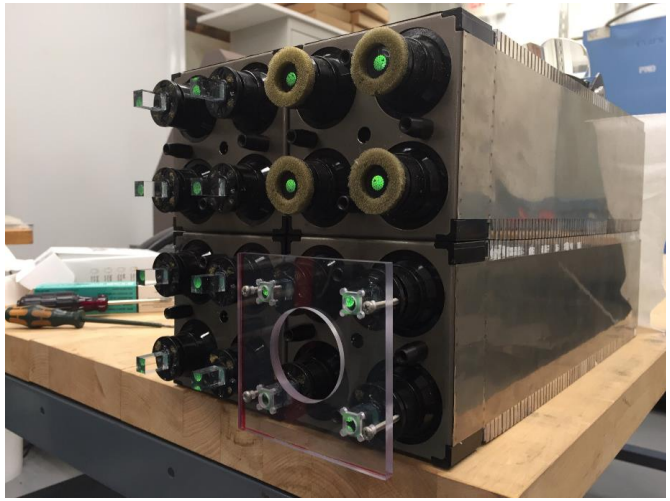
Calorimeter R&D as part of EIC studies, beam test, and in situ setup at STAR

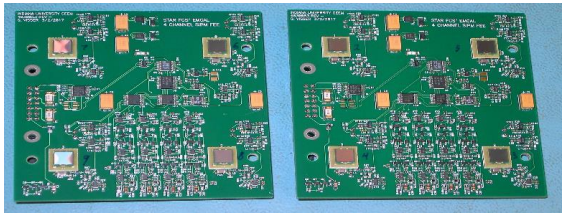
Balance of cost and performance

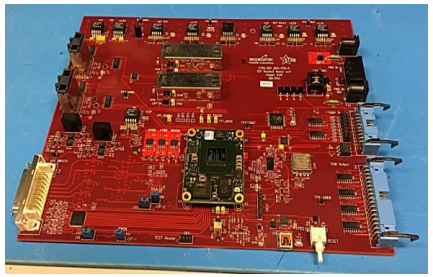
Cost ≈ $ 2.0 M

FCS – Research & Development

- Efforts for ECAL and HCAL as part of EIC R&D
- ECAL test in 2017
  - Hamamatsu SiPM $6 \times 6\ \mathrm{mm}^2$
  - FEE boards and digitizers
  - Integrated into STAR (DAQ, trigger)
- FCS test in 2018
  - Large scale ECAL prototype with HCAL towers

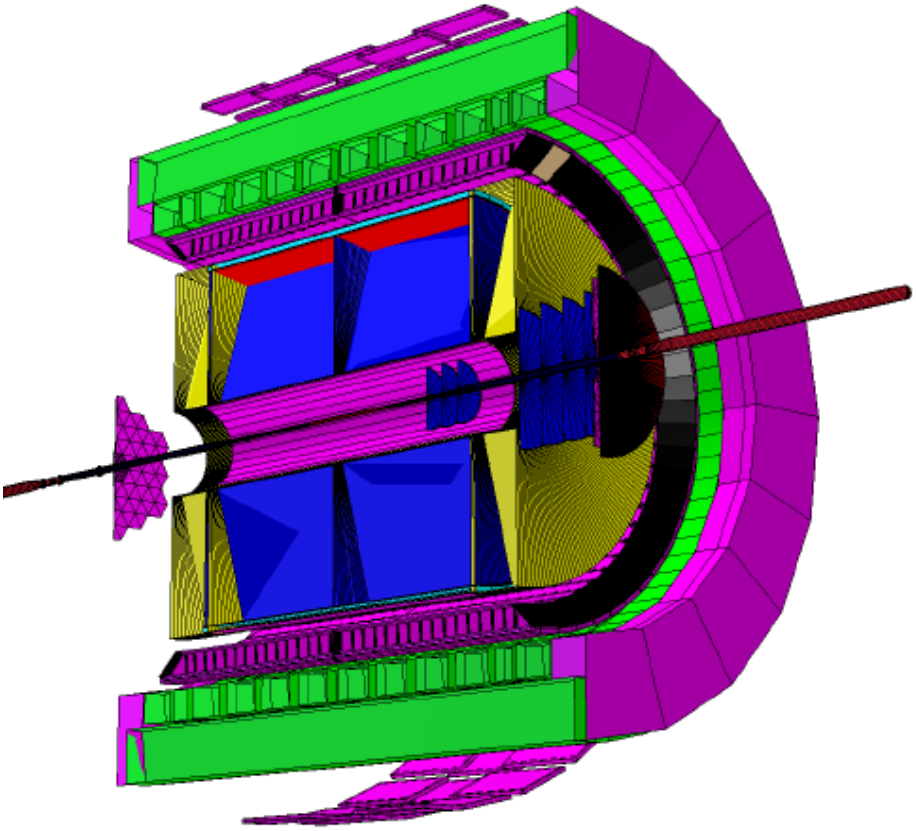






Forward Tracking System

	p+p / p+A	A+A
Tracking	charge separation photon suppression	$\frac{\delta p}{p} \approx 20 - 30\%$ at $0.2 < p_T < 2.0$ GeV/c



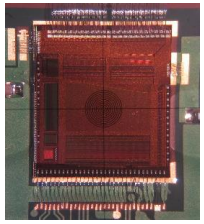
- 3 layers of silicon mini-strip disk
  - $z = 90, 140, 187$ cm
  - Builds on experience of STAR IST (Intermediate Silicon Tracker)
- 4 layers of small-strip Thin Gap Chambers
  - $z = 270, 300, 330, 360$ cm
  - Use of STAR TPC electronics for readout
  - Significant reduction of the project cost

Cost ≈ $ 3.3 M, mostly from Chinese consortium (with UIC and BNL)

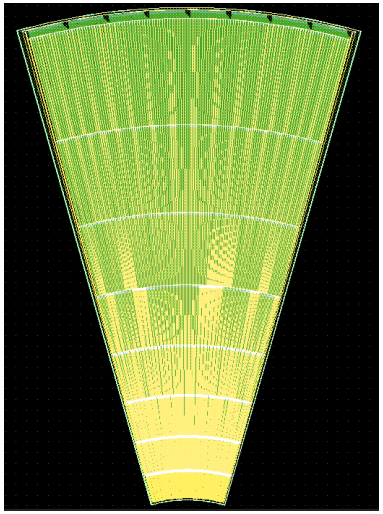
FTS – Research & Development

3 Silicon disks:

- 12 wedges, each with 128 azimuthal & 8 radial strips
- Single-sided double-metal Silicon Mini-strip sensors
  - under development @UIC
- Several different frontend chips, APV25-S1 chip (IST)
  - DAQ system for FTS same as IST
  - Replicating the IST cooling system

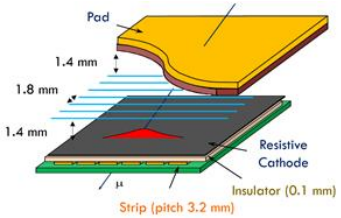


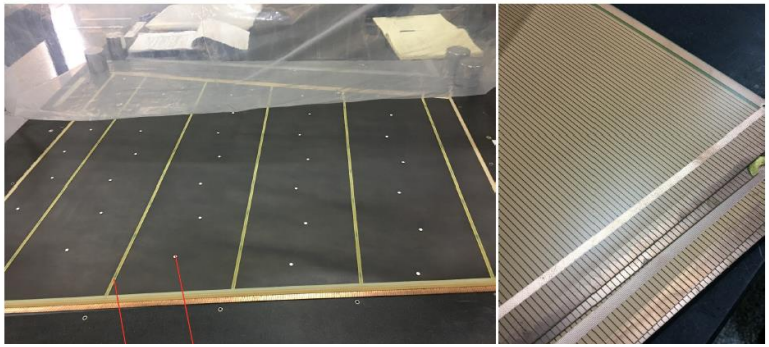
APV25-S1



4 sTGC disks:

- Based on ATLAS R&D from SDU
  - $\approx 0.5\% \, X_0$ per layer
  - Position resolution ~ 100 µm in x & y direction
- Read out with existing TPC electronics
- Prototype in preparation at SDU
  - ¼ length of ATLAS module
  - 30 cm x 30 cm module with 2 layers

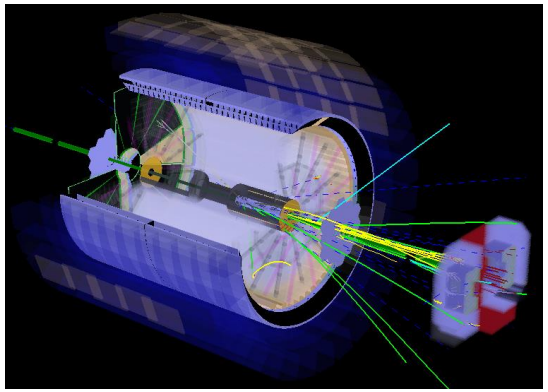




Summary / Outlook

- The STAR collaboration has proposed a forward detector upgrade that combines tracking and calorimetry at $2.5 < \eta < 4$.
- Hadron structure measurements are highly relevant for the physics of a future electron-ion collider.
- Further tests are planned during 2019 RHIC operations for a full installation and readiness after the beam energy scan (phase II).

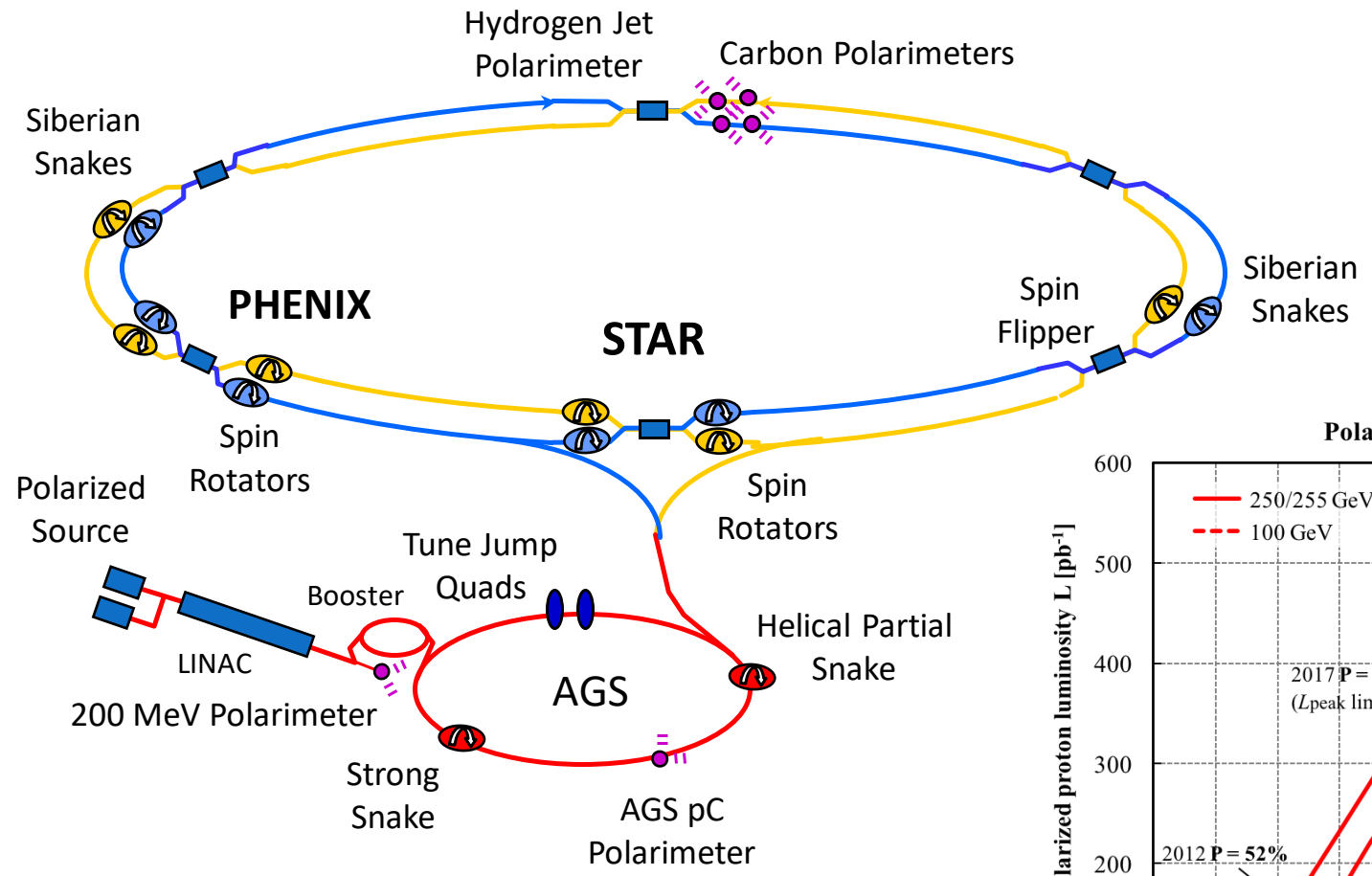
arxiv:1602.03922

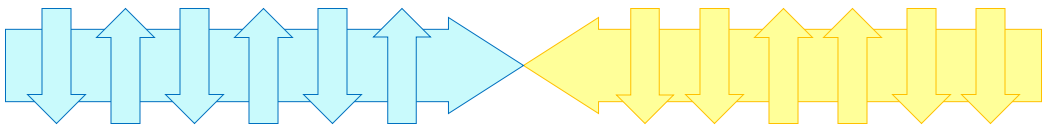


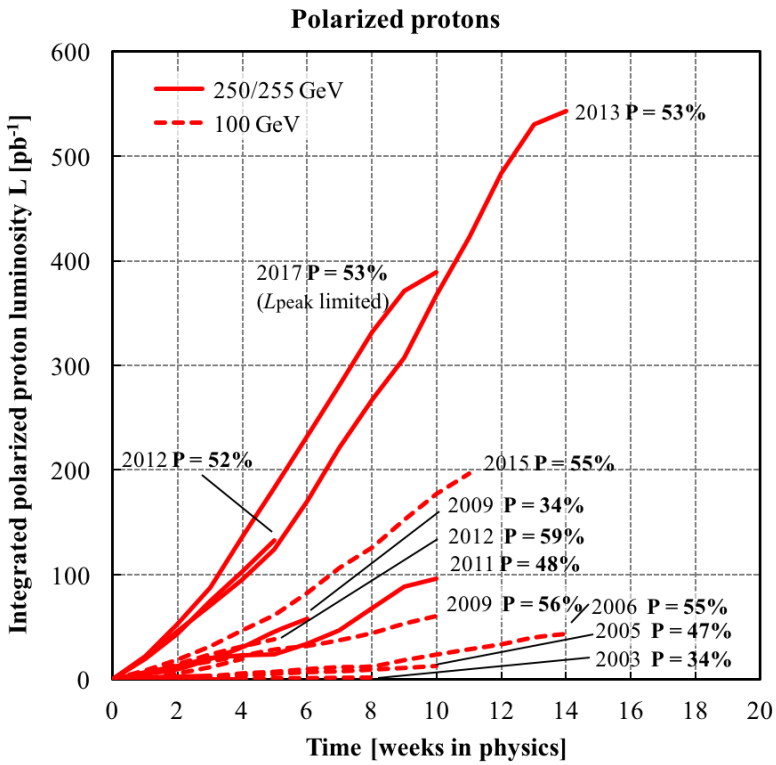
STAR

backup...

RHIC as a Polarized Proton Collider

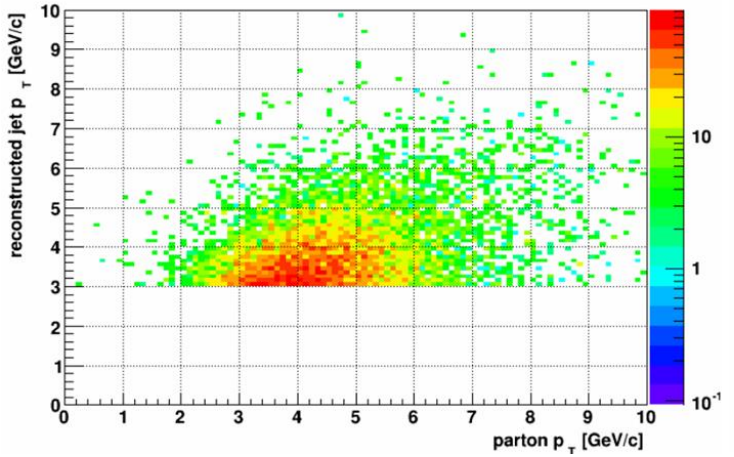


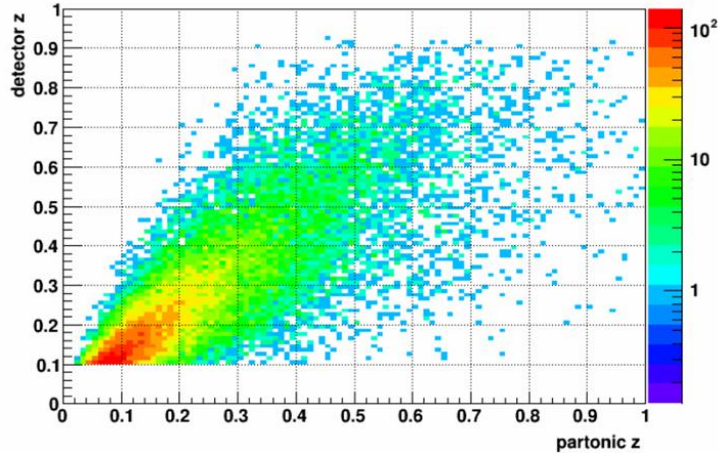




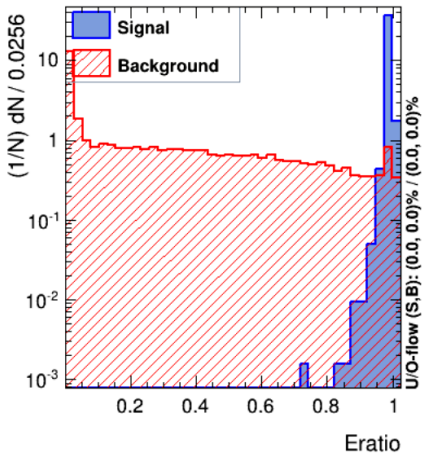
Physics Performance

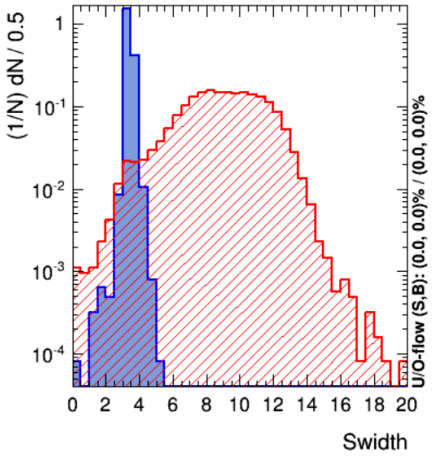
Matching jet reconstruction and partonic kinematics (3<η<4)

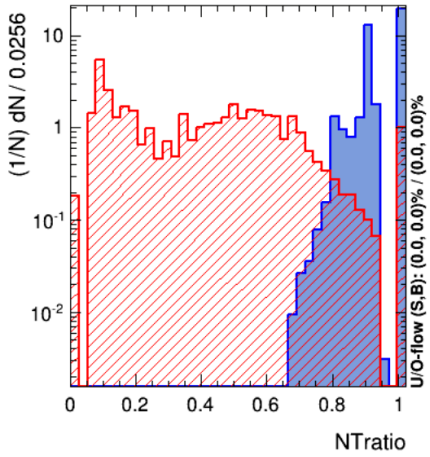




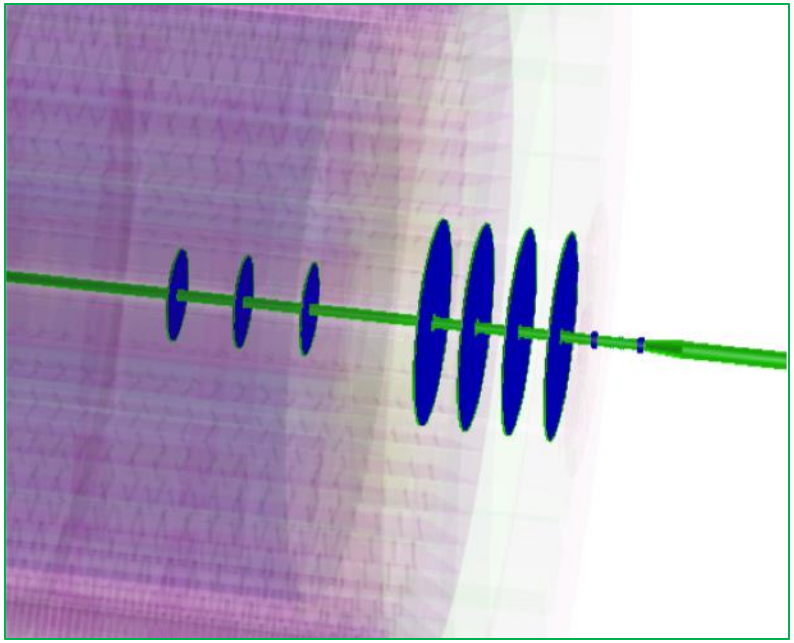
Drell-Yan identification (boosted decision trees)







FTS – Efficiencies & Resolution



Full detector simulation

$\delta p_T/p_T \approx 25 - 50\%$

$3^o < \theta < 8^o$

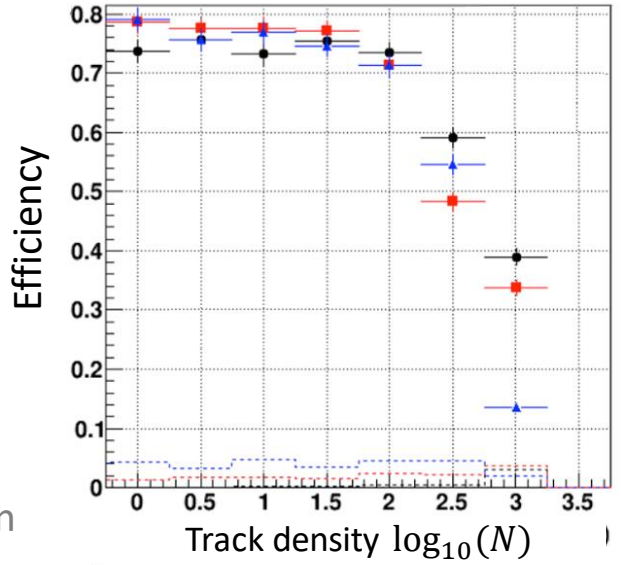
Pions

$p_T = 0.2$ GeV/c

$p_T = 1.0$ GeV/c

$p_T = 2.0$ GeV/c

dashed: wrong sign



Muons

$p_T = 0.2$ GeV/c

$p_T = 1.0$ GeV/c

$p_T = 2.0$ GeV/c