RHICf-II discussion with STAR Spin/Cold-QCD PWG

STAR Spin/Cold-QCD PWG Meeting

Jan. 26, 2022

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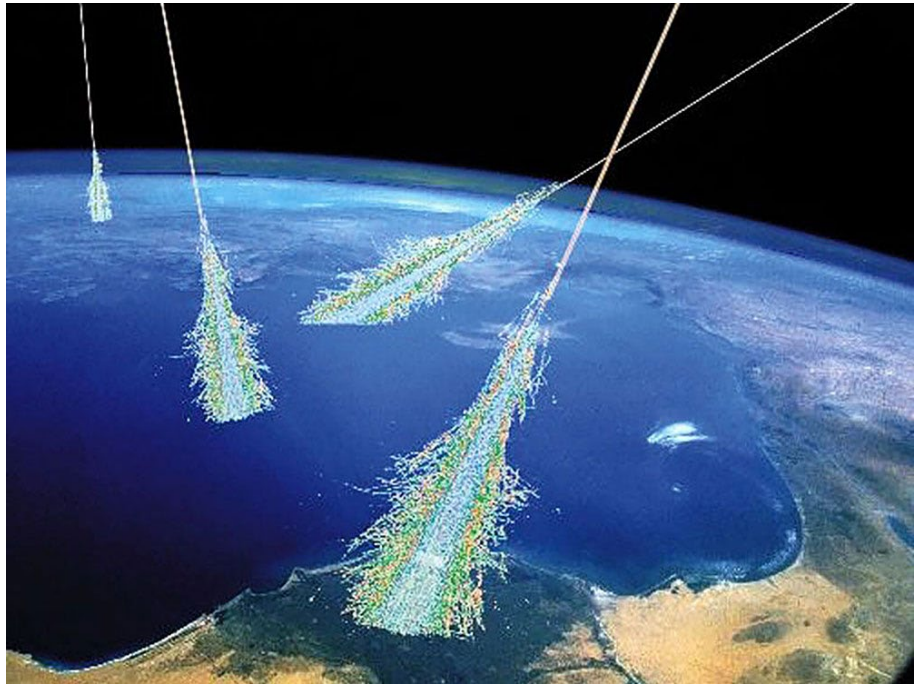
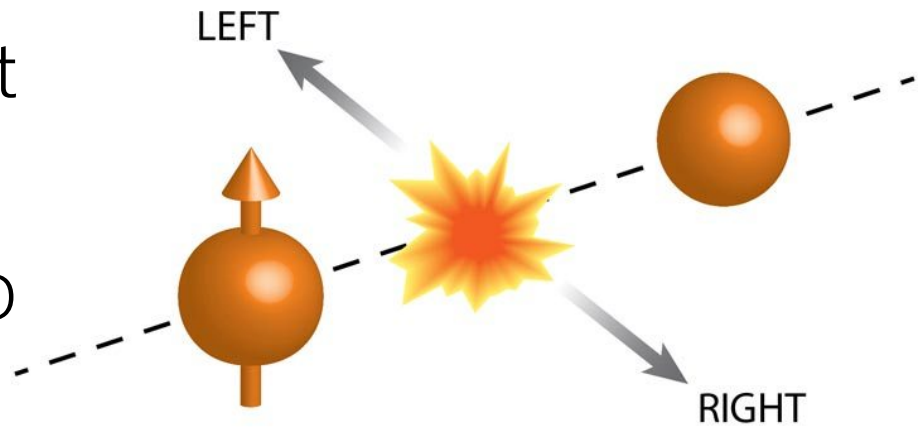
for the RHICf-II Collaboration

Physics at RHICf & RHICf-II

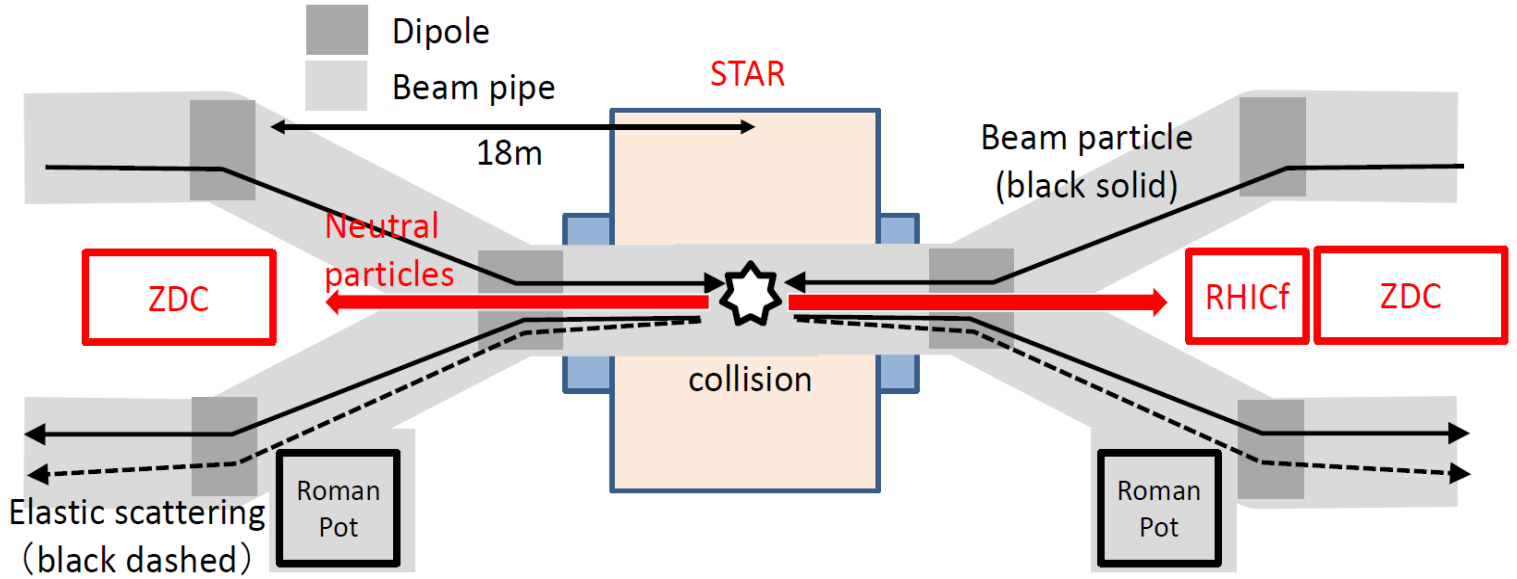
- Measurements of neutral particle production at zero degree with RHIC polarized proton collisions
- Cosmic-ray study
  - Cross section measurement to understand ultra-high energy cosmic rays
- Asymmetry measurement
  - To understand the hadronic collision mechanism based on QCD



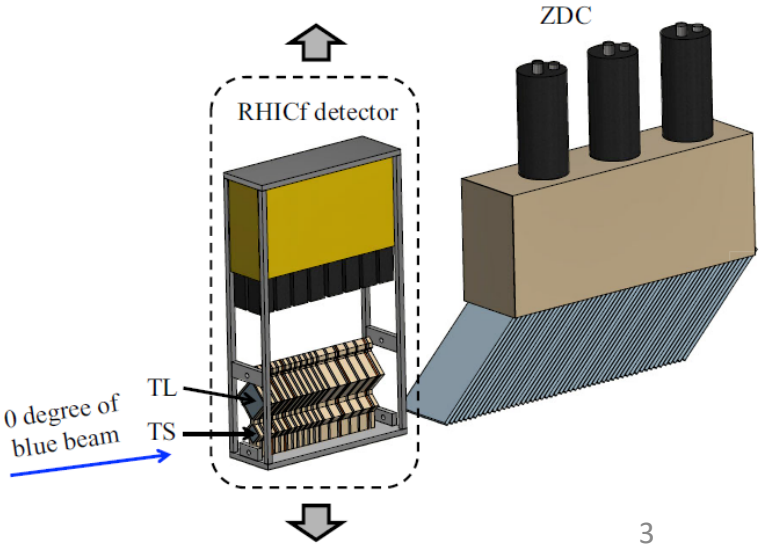


RHICf at STAR in 2017

- EM calorimeter (RHICf detector) installed in front of the Zero-Degree Calorimeter (ZDC) of the STAR experiment

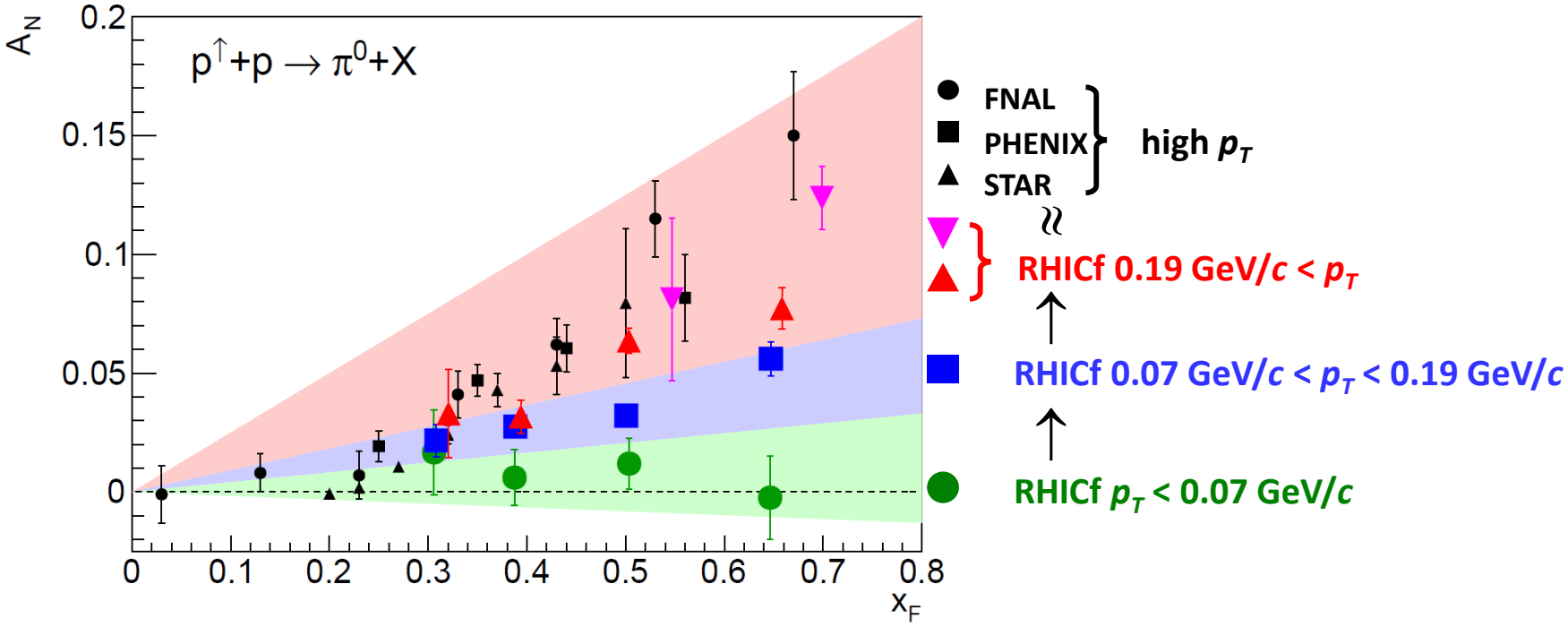


- Two position-sensitive sampling calorimeters
  - TS (small tower): 20mm x 20mm
  - TL (large tower): 40mm x 40mm
  - Tungsten absorber (44 X_0, 1.6 λ_{int})
  - 16 GSO sampling layers
  - 4 XY pairs of GSO-bar position layers



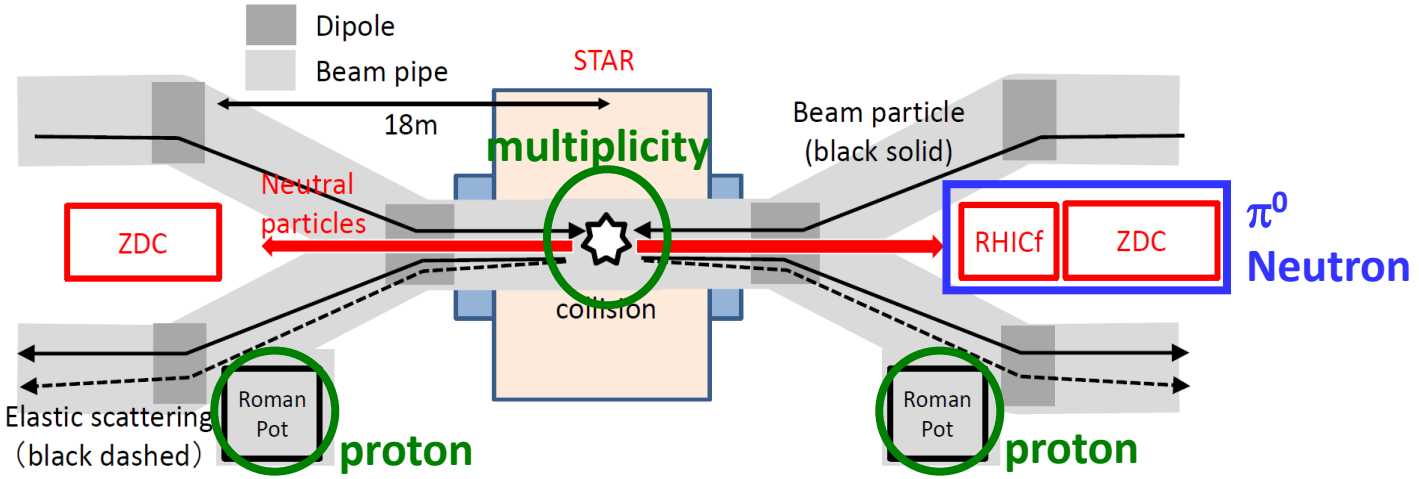
RHICf at STAR in 2017

- π^0 asymmetry
  - Phys. Rev. Lett. 124, 252501 (2020)
  - Comparison with high $p_T > 0.5$ GeV/c data of the past experiments
  - Nearly the same large asymmetry is reached at low $p_T < 0.2$ GeV/c
  - Contribution of other mechanisms, diffraction and resonance, may provide a hint to the mystery



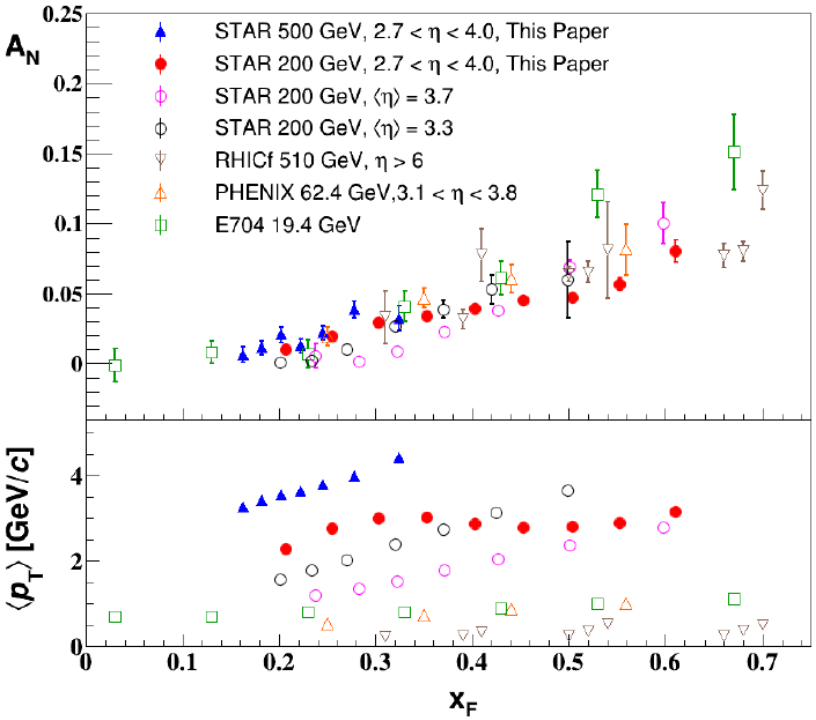
RHICf at STAR in 2017

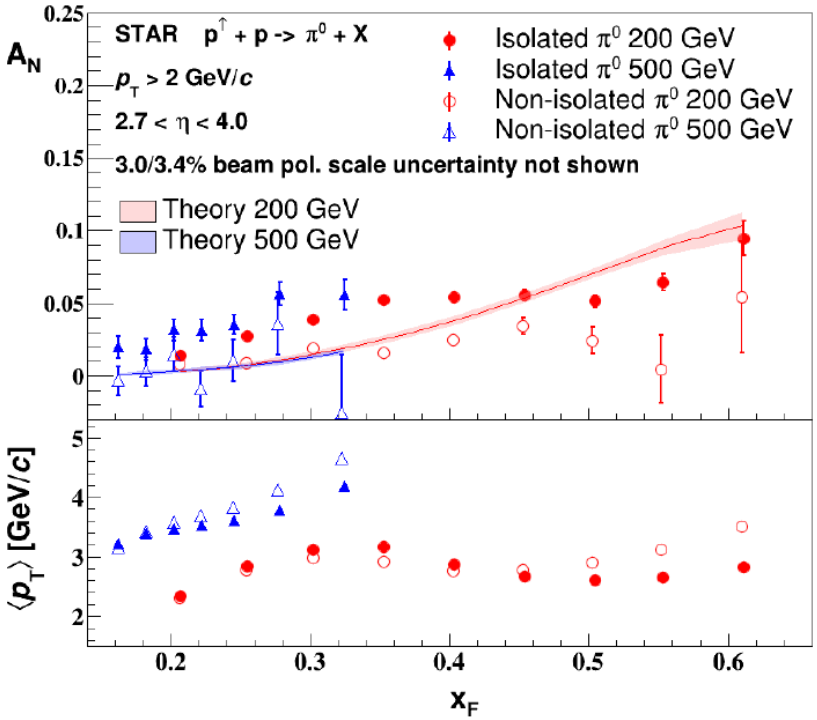
- Other analyses ongoing
  - π^0 & neutron cross section analysis
  - Neutron asymmetry (RHICf + ZDC)
  - Combined analysis with STAR detectors
    - Event type categorization
    - Diffraction + resonance tagging with STAR + RHICf combined data analysis
    - Event type, multiplicity (FMS) dependence of cross section & asymmetry to be obtained



New STAR results

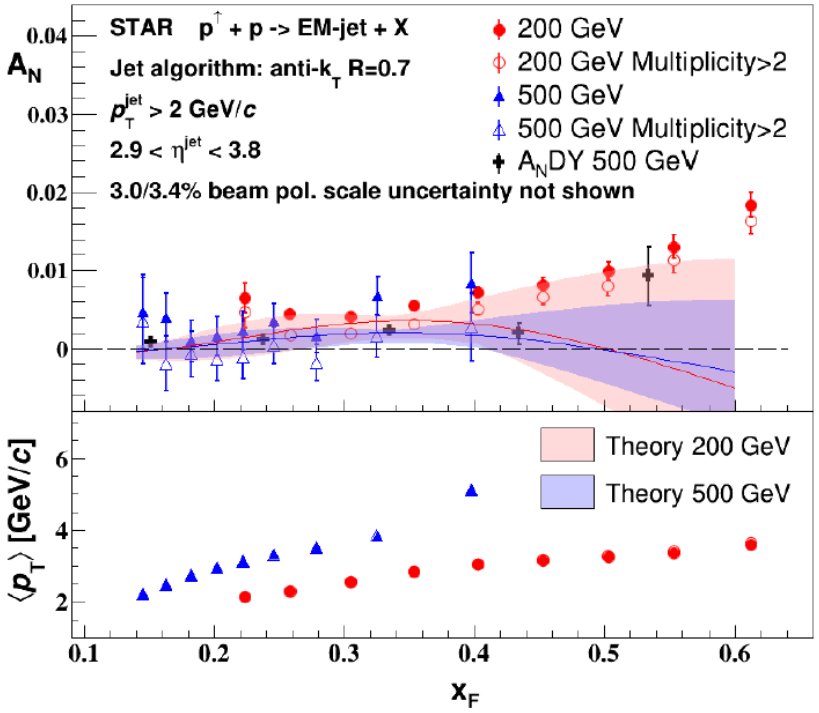
- Phys.Rev.D 103 (2021) 092009
  - $\sqrt{s}$ = 200 GeV & 500 GeV
  - Forward π^0, $2.7 < \eta < 4.0$
  - Asymmetries for the isolated π^0 are larger than these for the non-isolated π^0
  - Possible explanation is that a significant part of the isolated π^0 are from diffractive processes

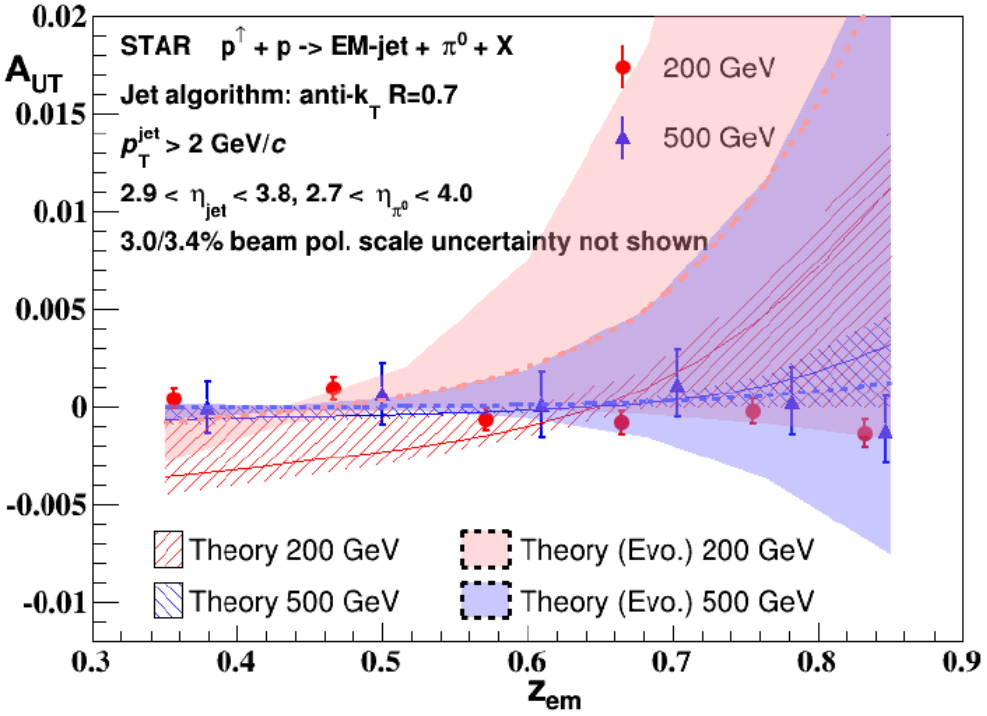




New STAR results

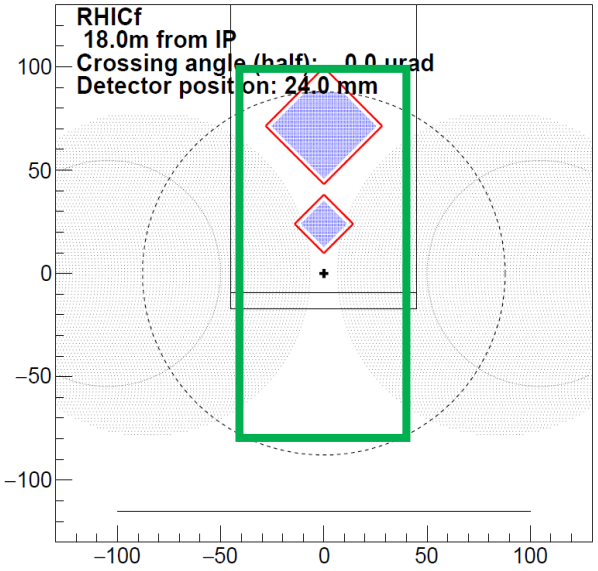
- Phys.Rev.D 103 (2021) 092009
  - Small EM-jet asymmetry, consistent with AnDY result
  - $z_{em} = E_{\pi 0} / E_{jet}$
  - Hadron in jet Collins asymmetries small
    - Cancellation of the Collins effect of the u/d quark?





RHICf-II proposal

- We have proposed a second run for RHICf in 2024 (RHICf-II)
- RHICf-II LoI was discussed by the PAC in 2020.9
  - Parasitic beam-time
- We're collaborating with ALICE-FoCal group to use the FoCal-E technology
  - 8cm x 18cm detector
  - Kakenhi-Kiban-A (2021-2024) + RIKEN budget
  - The detector have enough radiation hardness to work for a small β^* and normal luminosity



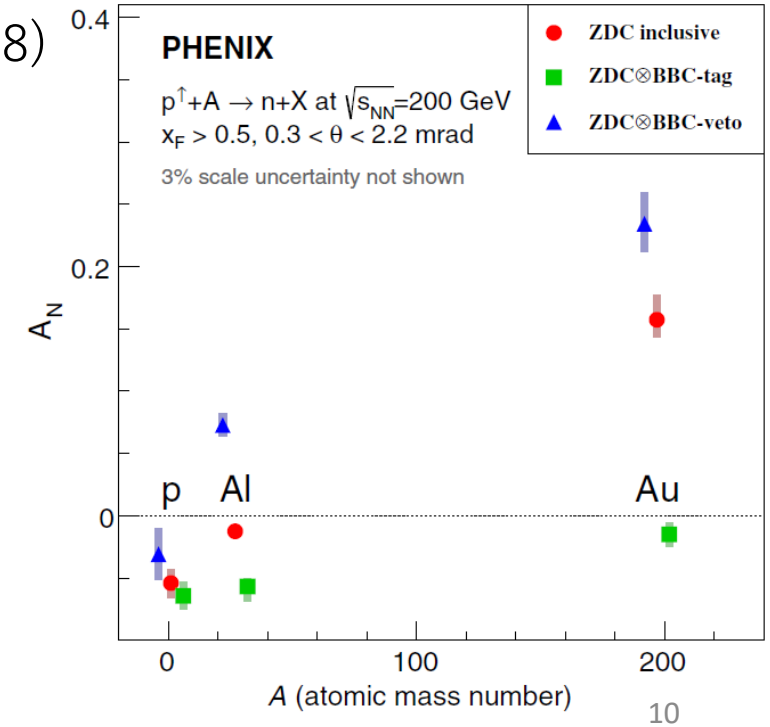
RHICf-II Collaboration

- Y. Goto, I. Nakagawa, R. Seidl (RIKEN)
- B. Hong, M.H. Kim (Korea Univ.)
- K. Tanida (JAEA)
- T. Chujo (Tsukuba Univ.) ← New
- Y. Itow, H. Menjo (Nagoya Univ.)
- T. Sako (ICRR, Univ. of Tokyo)
- K. Kasahara (Shibaura Tech.)
- O. Adriani, L. Bonechi, R. D'Alessandro (INFN Firenze)
- A. Tricomi (INFN Catania)

- New collaborators expected or under discussion from:
  - Sejong Univ.
  - Univ. of Kansas
  - Nara Women's Univ. and EIC Japan group
- Cooperation from FoCal collaboration
  - ORNL

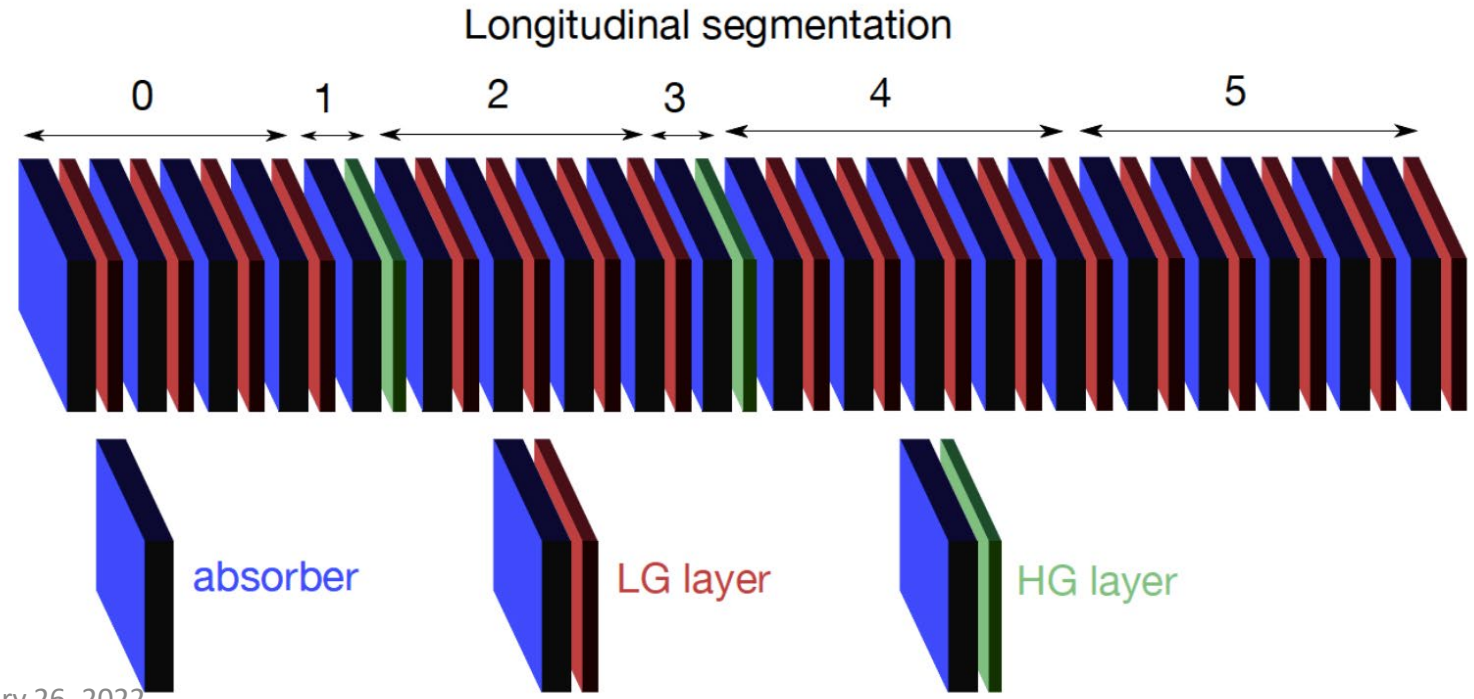
New topics at RHICf-II

- K^0_S and Λ measurement
  - Spectrum and cross section
  - Asymmetry
- A-dependence of the π^0 asymmetry
  - Correlation between asymmetries of forward neutron and π^0
  - Strong A-dependence of the neutron asymmetry measured at PHENIX in Run 15
    - Phys. Rev. Lett. 120, 022001 (2018)
    - UPC vs hadronic component



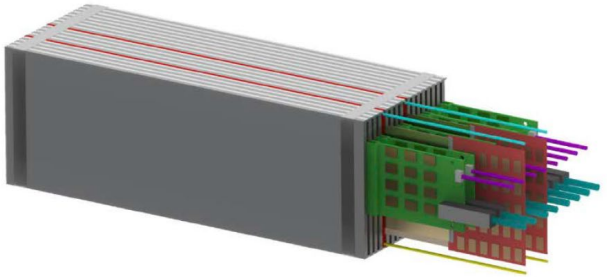
ALICE FoCal-E

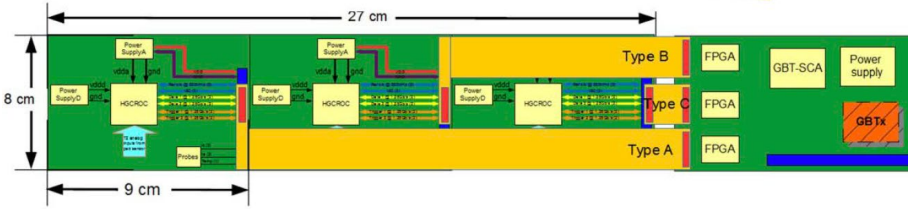
- Led by Tsukuba Univ. group
- Tungsten absorber
- Low granularity (LG) silicon pad for energy measurement
  - σ_E / E = 25% / √E (GeV) ⊕ 2% for photon energy resolution (simulation)
- High granularity (HG) silicon pixel (CMOS-MAPS) for accurate position measurement



ALICE FoCal-E for RHICf-II

- Space restriction at RHICf
- Pad layer
  - Lead by Tsukuba Univ. group
  - Readout electronics based on HGCROC ASIC (CMS) working with Grenoble group leading the development
- Pixel layer
  - Lead by European group
- Trigger
  - Rare trigger for asymmetry measurement
  - Shower trigger for cross section measurement
- DAQ
  - Standalone ALICE DAQ
  - Event correspondence with STAR DAQ



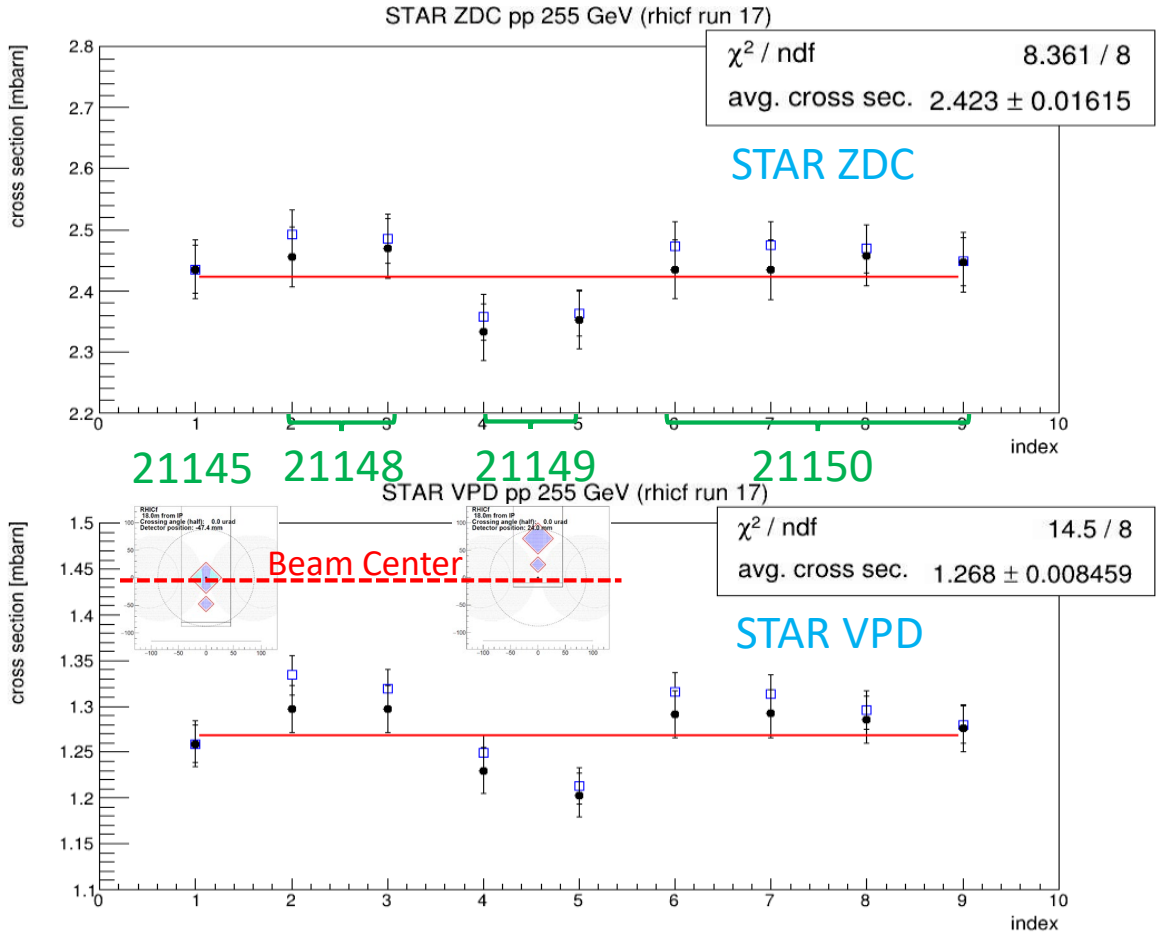


Q. 1

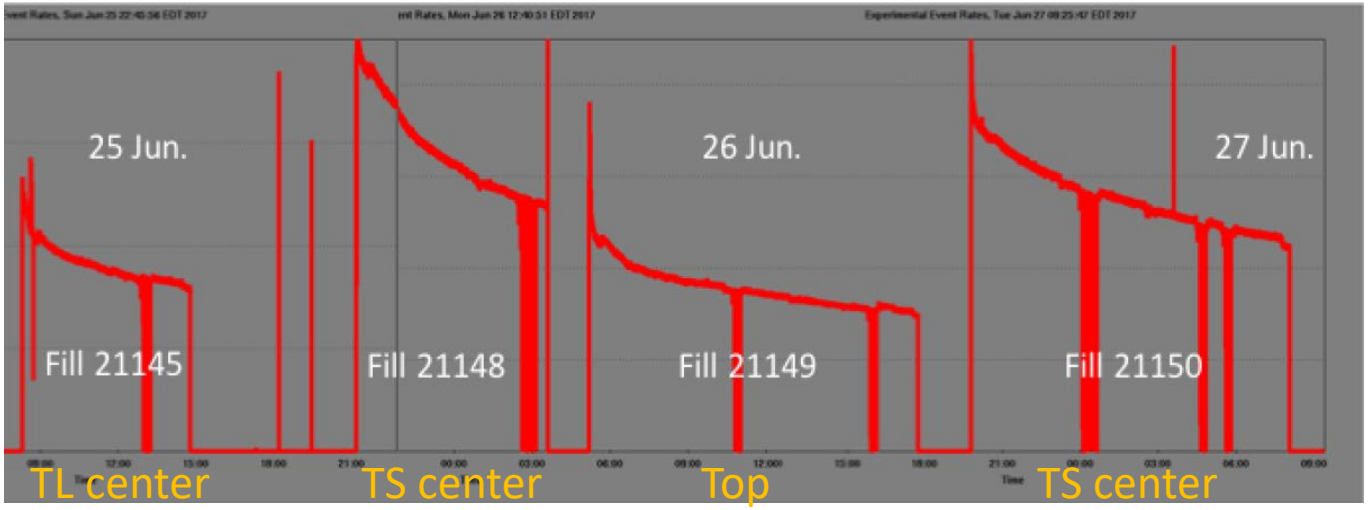
- Our first, and most critical question is what exact effect does the new calorimeter have on the ZDC performance?
  - No effect on luminosity and polarization direction measurements could be seen in the 2017 RHICf experiment.
  - We have been working with Angelika to study the issue.
  - Luminosity measurements were supported by the Vernier scans during data collection. A similar investigation will be conducted this time. If any effects are found, corrections can be made.
  - For neutron and photon (and π^0) measurements, the RHICf-II calorimeter will add better position (or p_T) resolution and energy resolution (especially for photon).

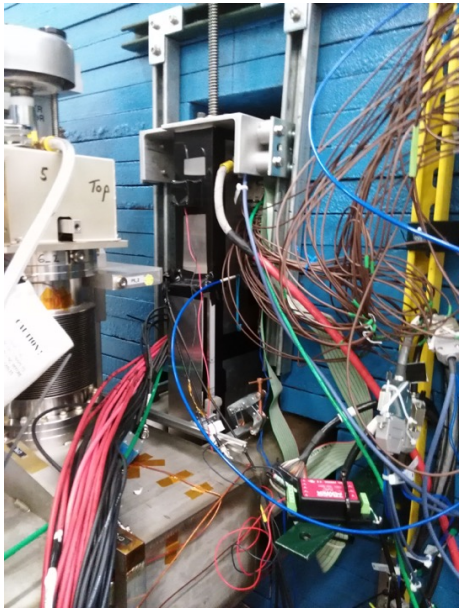
Q. 1

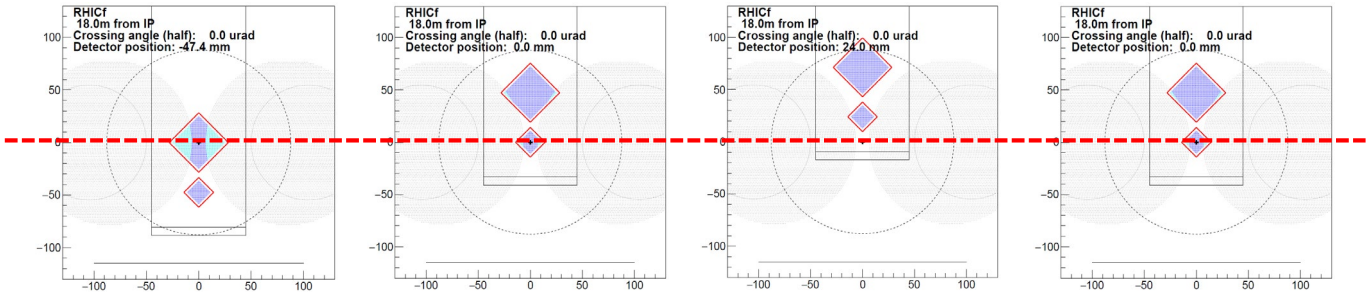
- No correlation between RHICf detector position and ZDC cross section measured by the Vernier scan
  - Opposite effect seen between fill 21145 and 21149
  - Correlation between ZDC and VPD
  - RHCf located between ZDC and VPD



Q. 1


25 Jun.
26 Jun.
27 Jun.
Fill 21145
Fill 21148
Fill 21149
Fill 21150
TL center
TS center
Top
TS center


S
Top

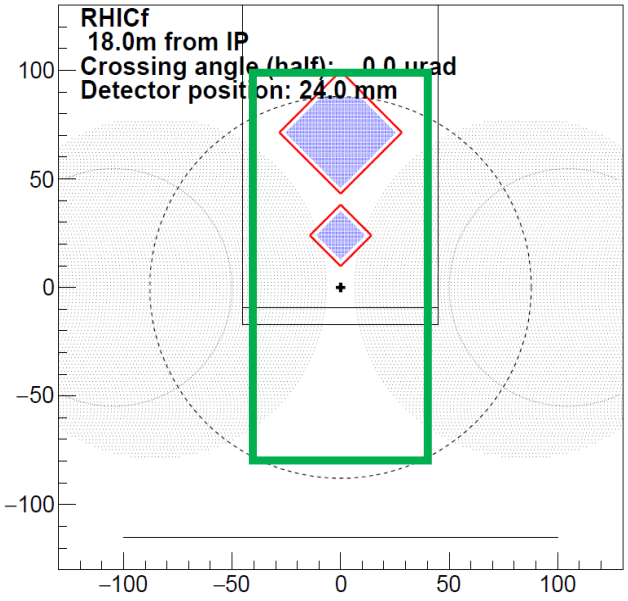

RHICf
18.0m from IP
Crossing angle (half): 0.0 urad
Detector position: -47.4 mm
RHICf
18.0m from IP
Crossing angle (half): 0.0 urad
Detector position: 0.0 mm
RHICf
18.0m from IP
Crossing angle (half): 0.0 urad
Detector position: 24.0 mm
RHICf
18.0m from IP
Crossing angle (half): 0.0 urad
Detector position: 0.0 mm
Beam Center

Qs. 2-5

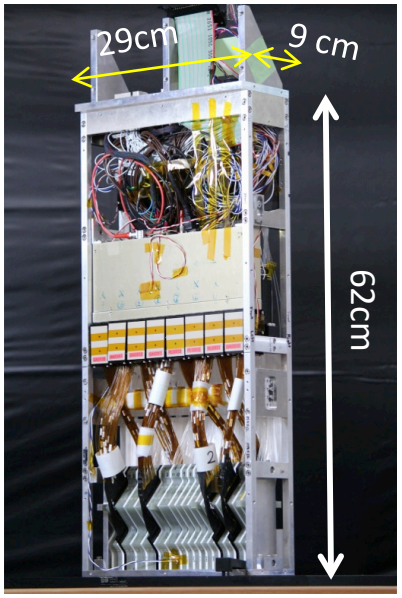
- 2. How are you planning on commissioning the detector? How much time do you need for the commissioning and how ZDC/STAR performance will be affected during the commissioning period?
- 3. Will the new calorimeter be able to physically fit in front of the ZDC? What is the size of the new calorimeter w.r.t. ZDC and old calorimeter.
- 4. How will the calorimeter be moved into and out of place? How difficult will it be to be moved?
- 5. How is the improved acceptance of the new calorimeter achieved?

Qs. 2-5

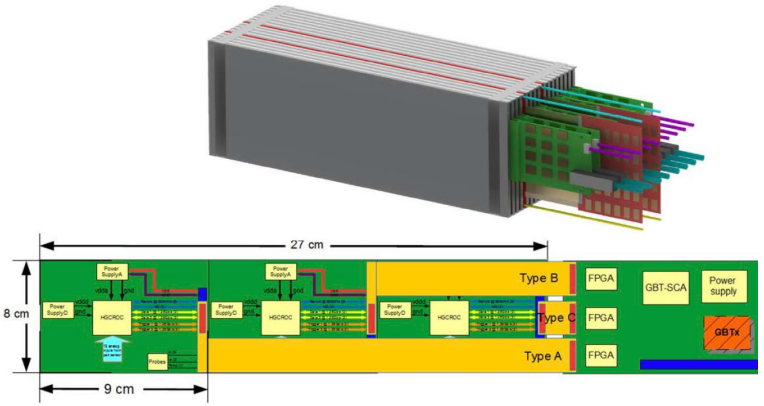
- The size of the main unit is 8cm x 18cm. The enclosure, including peripherals, will be designed to fit in front of the ZDC, between the beam pipes.
  - Old (RHCf): 2cm x 2cm + 4cm x 4cm
  - New (RHICf-II): 8cm x 18cm



RHICf module

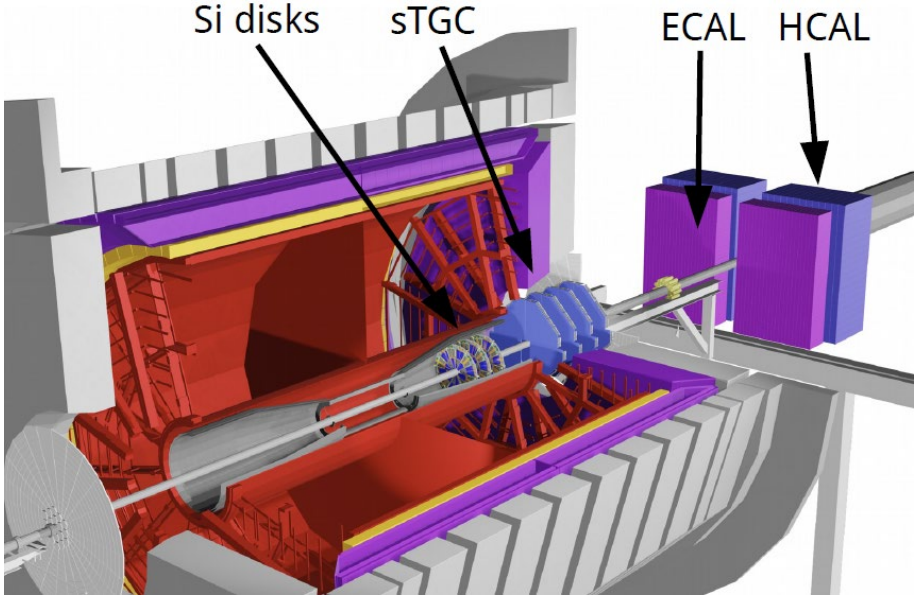


FoCal-E: 3 module design (8cm x 27cm)
(RHICf-II: 2 modules 8cm x 18cm)



Qs. 2-5

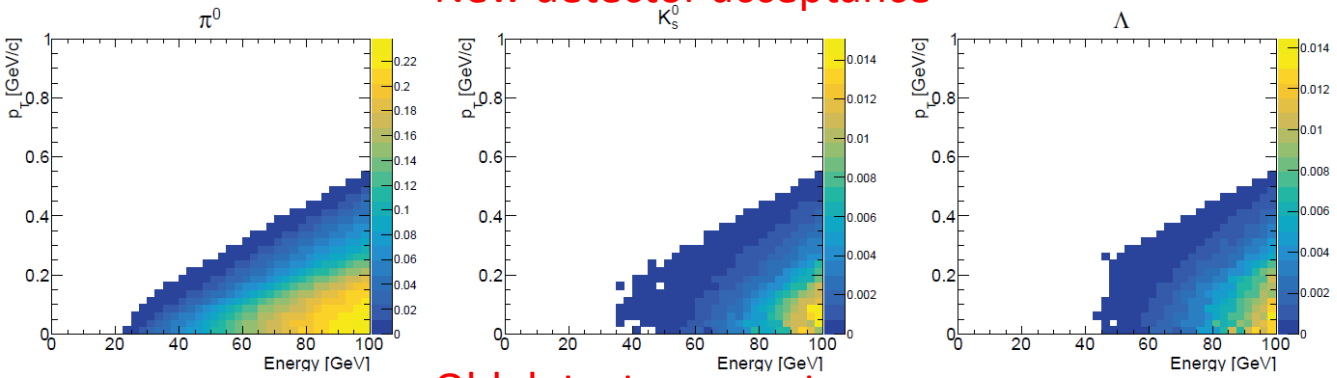
- We would like to place the detector somewhere in the STAR-IR in 2023 for commissioning, and confirm the coincidence with the STAR detector.
- Can we place it between the left and right FCSs on the west side, or somewhere on the east side, preferably near the beam pipe?
- If there are any effects, we will move it to an unaffected area.
- The manipulator will be manufactured in Japan that will allow us to move it upward remotely, for instance, in front of ZDC in 2024.
  - Careful manipulator design will be necessary for available space.
  - We will need cable rearrangement from 2023 to 2024.



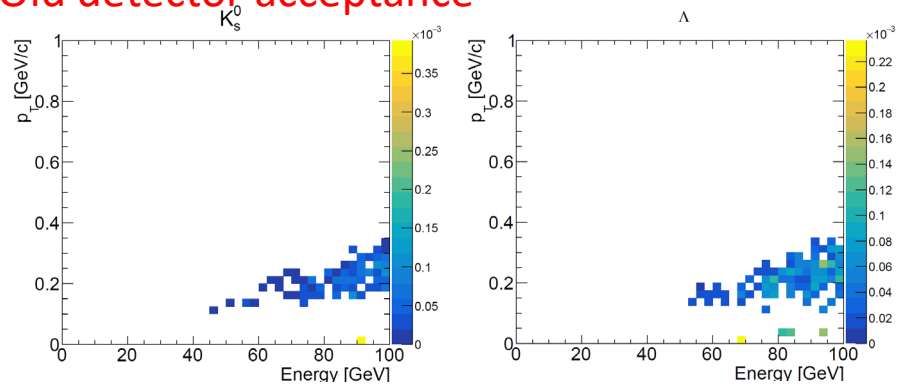
Q. 6

- You mention extending acceptance of the calorimeter to be able to measure, for example K^0_S and Λ, how is this achieved?
  - $K^0_S \rightarrow 4\gamma s$
  - $\Lambda \rightarrow$ neutron + $2\gamma s$

New detector acceptance



Old detector acceptance



Qs. 7-8

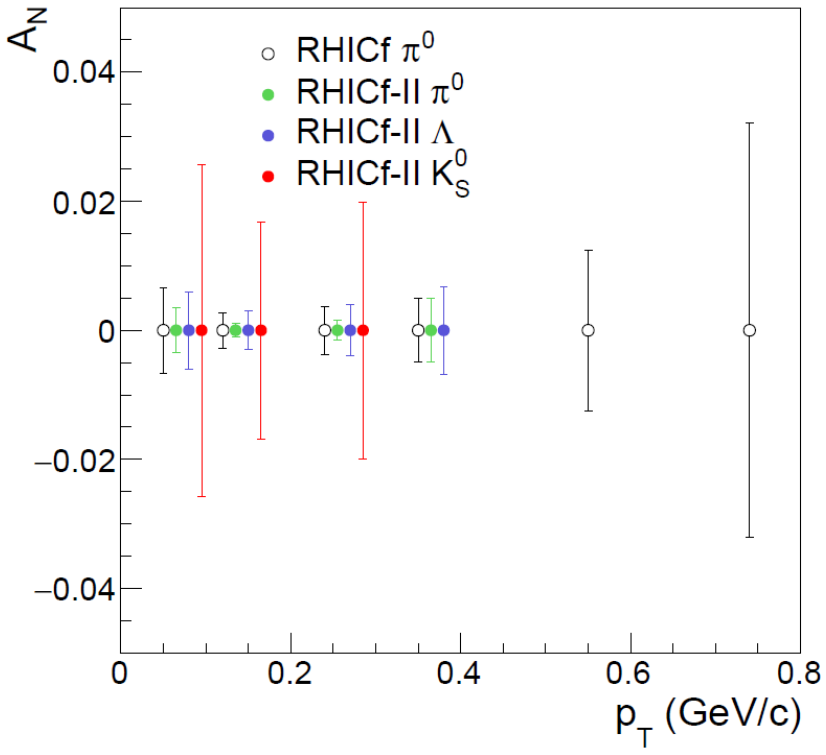
- 7. If running in an independent run, how much time would you need for your physics program.
- 8. It is mentioned that you would need several fills for your measurement, can you better quantify several fills?

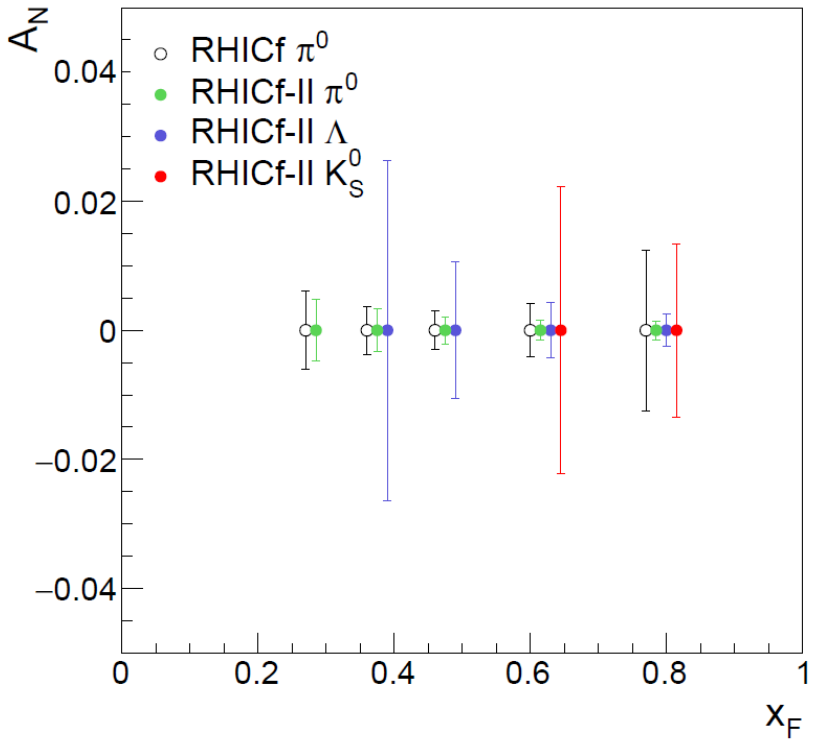
Qs. 7-8

- We want to collect at least as much data as the RHICf experiment in 2017; luminosity of 1 pb^{-1} for asymmetry measurement.
- Radial polarization is only needed for asymmetry measurements. It will be limited to the collection of rare events (high-p_T, K^0_S, Λ).
  - In 2017, we collected data at luminosity 10 times lower than normal luminosity for 4 fills and about 30 hours.
  - In 2024 with normal luminosity, it can be collected in a few hours at minimum (1 pb^{-1}). We aim to make high-efficiency triggers at around 200 Hz.
- Spectrum and cross-section measurements can be taken with vertical polarization. We want to collect 10^8 events with a simple shower trigger.
  - In 2017, it was collected in 4 fills with a bandwidth of 1 kHz in about 30 hours.
  - In 2024, the data is collected in about a week using a trigger rate of 200 Hz.

Qs. 7-8

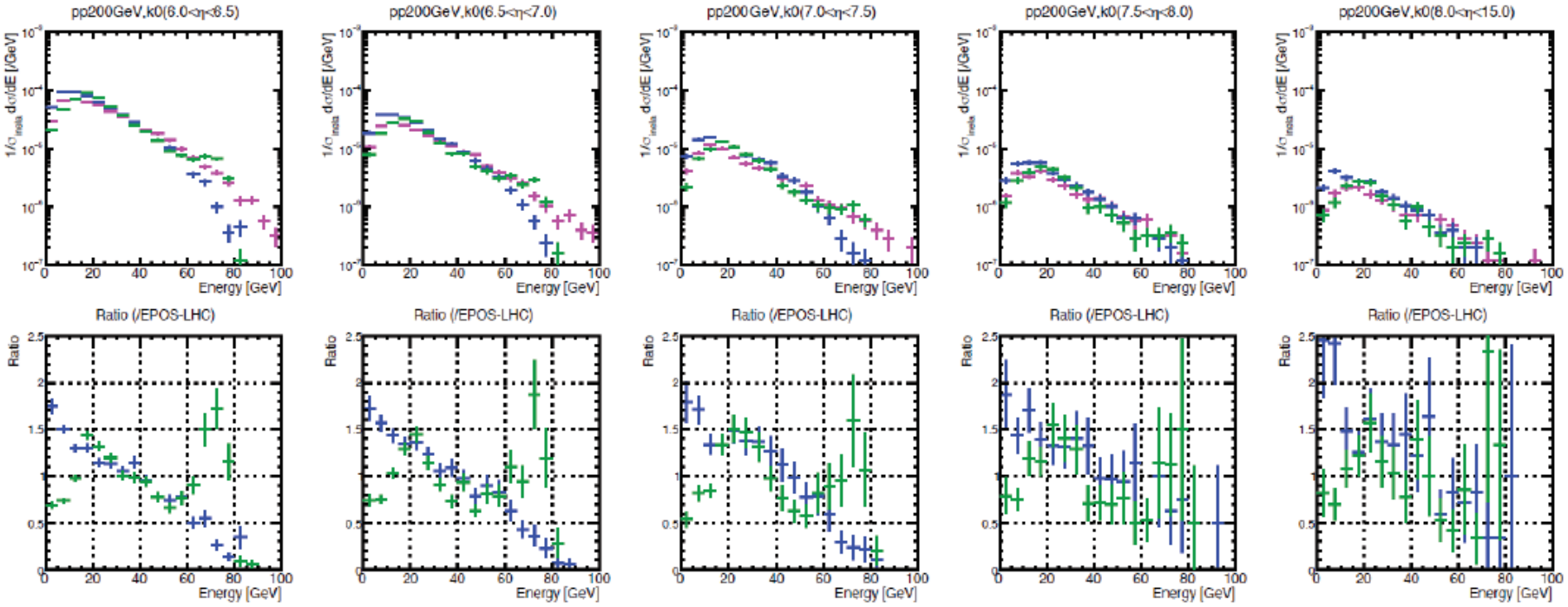
- Expected statistical uncertainty of asymmetry measurements for π^0, K^0_S and Λ with 1 pb^{-1} luminosity.





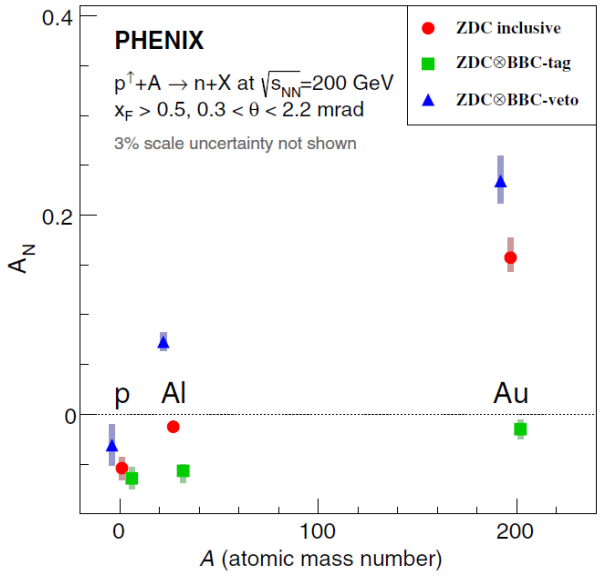
Qs. 7-8

- K^0_S spectra in p + p collisions at $\sqrt{s} = 200$ GeV; EPOSLHC (magenta), QGSJET II-4 (blue), and SIBYLL 2.3 (green).



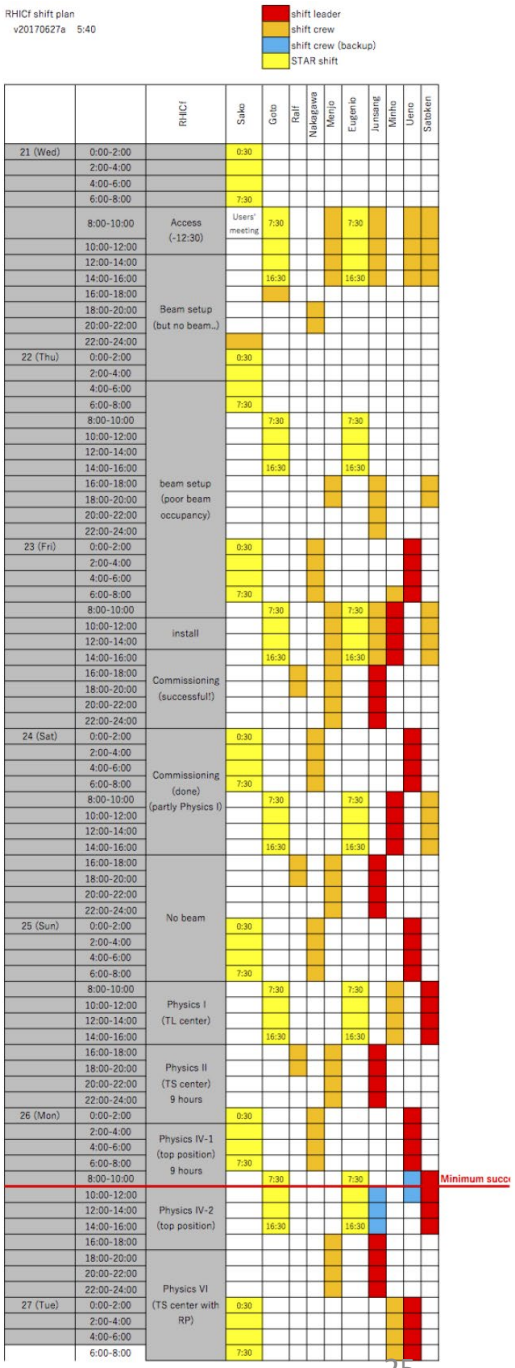
Q. 9

- How much time would you need for pp vs pA running?
  - We have not yet evaluated p+A, but we guess it is comparable to p+p.
  - We want to measure A-dependence of the forward π^0 asymmetry.
    - A-dependence of the forward neutron asymmetry measured at PHENIX in 2015.
    - We want correlation between asymmetries of forward neutron and π^0.



Q. 10

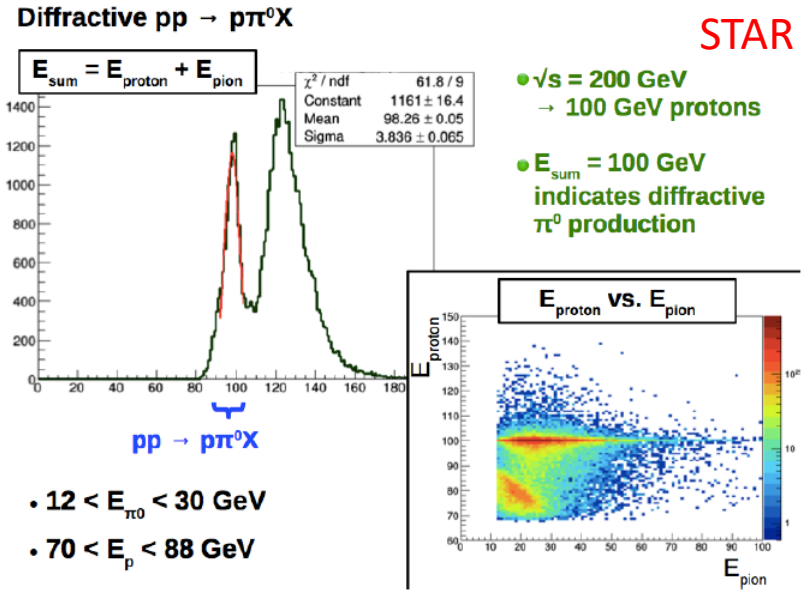
- During run 2024 we expect STAR to have very limited peoplepower for operations. How much FTE during and before running can you offer to support RHICf-II program?
  - In 2017, we took 3 STAR shifts per day for one week.
  - We consider taking more shifts as STAR members for a longer period during our stay.



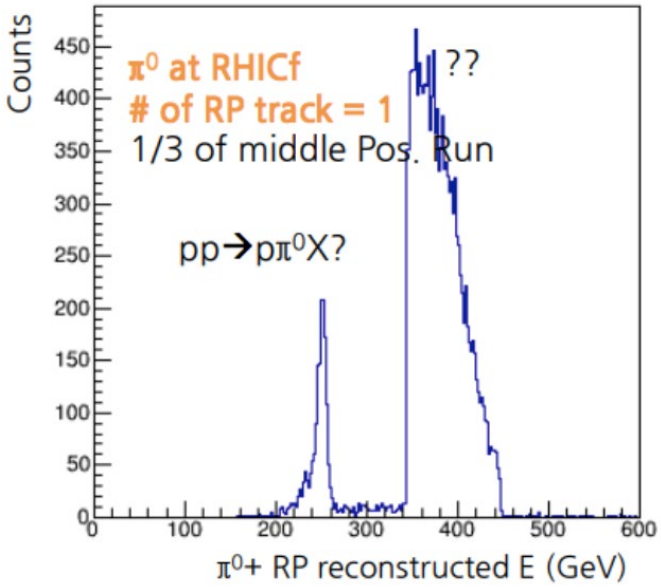
Q. 11

- Question to both STAR and RHICf: What can be gained by running STAR and RHICf in combination?
  - We classify the diffraction process and analyze the dependence of the measured quantities.
  - For instance, p + π^0 mass reconstruction with higher resolution.

STAR



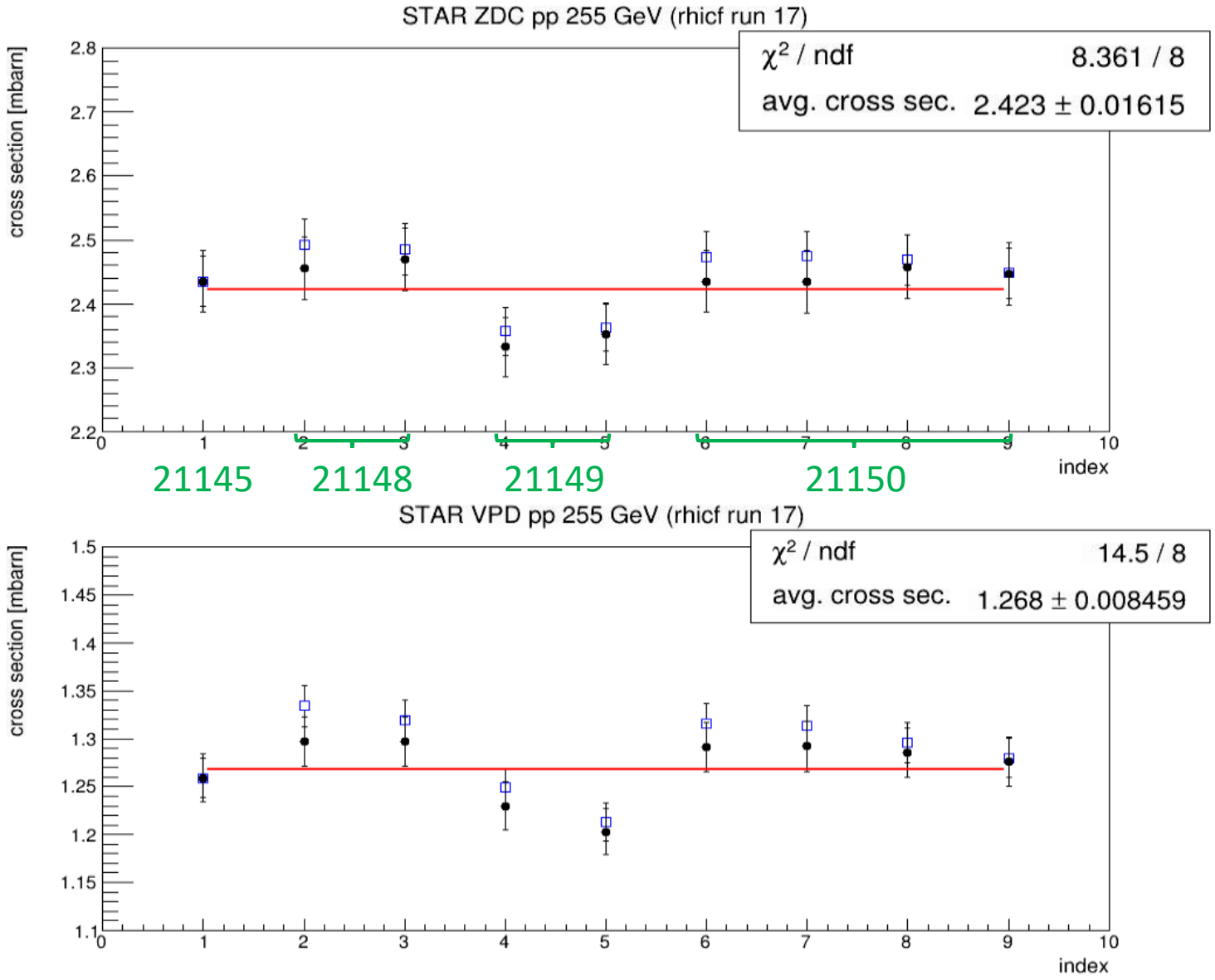
STAR + RHICf



Q. 12

- Would vertical beam polarization be useful with RHICf? How does that impact your physics goal in that case?
  - Data collection with radial polarization is performed using only K^0_S, Λ or high-p_T rare event triggers for short-term high luminosity data collection at a low rate with no prescale. We will perform asymmetry measurements.
  - In data collection with vertical polarization, a low-level trigger is prescaled for cross-section measurement, and it is performed at a low rate until the necessary events are collected.

Backup Slides

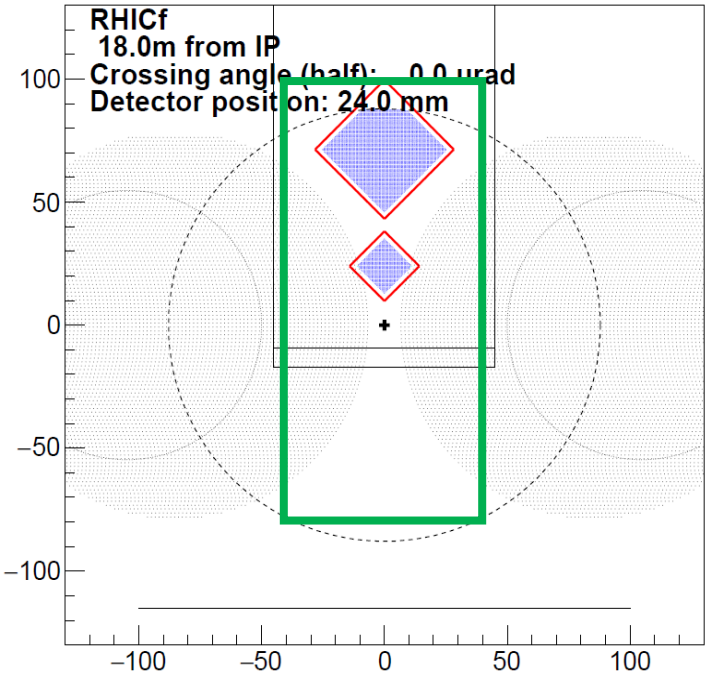

STAR ZDC pp 255 GeV (rhicf run 17)
χ² / ndf 8.361 / 8
avg. cross sec. 2.423 ± 0.01615
cross section [mbarn]
index
21145
21148
21149
21150
STAR VPD pp 255 GeV (rhicf run 17)
χ² / ndf 14.5 / 8
avg. cross sec. 1.268 ± 0.008459
cross section [mbarn]
index

Q. 2

- How are you planning on commissioning the detector? How much time do you need for the commissioning and how ZDC/STAR performance will be affected during the commissioning period?
  - We would like to place the detector somewhere in the STAR-IR in 2023 for commissioning, and confirm the coincidence with the STAR detector.
  - Can we place it between the left and right FCSs on the west side, or somewhere on the east side, preferably near the beam pipe?
  - If there are any effects, we will move it to an unaffected area.

Q. 3

- Will the new calorimeter be able to physically fit in front of the ZDC? What is the size of the new calorimeter w.r.t. ZDC and old calorimeter.
  - The size of the main unit is 8cm x 18cm. The enclosure, including peripherals, will be designed to fit in front of the ZDC, between the beam pipes.



Q. 4

- How will the calorimeter be moved into and out of place? How difficult will it be to be moved?
  - The manipulators will be manufactured in Japan that will allow us to move it upward remotely, for example.

Q. 5

- How is the improved acceptance of the new calorimeter achieved?
  - Old: 2cm x 2cm + 4cm x 4cm
  - New: 8cm x 18cm

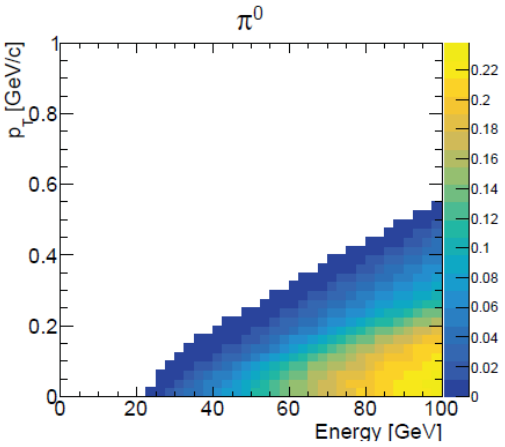
Q. 7

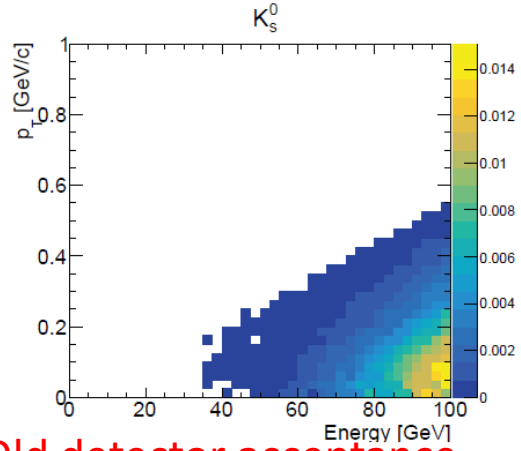
- If running in an independent run, how much time would you need for your physics program.
  - We want to collect at least as much data as the RHICf experiment in 2017; luminosity of 1 pb^{-1} for asymmetry measurement.
  - In 2017, we collected data at luminosity 10 times lower than normal luminosity for 4 fills and about 30 hours. In this case of normal luminosity, it can be collected in a few hours.
  - We want to collect 10^8 events for spectrum and cross section measurements. In the 2017 RHICf experiment, it was collected in 4 fills with a bandwidth of 1 kHz in about 30 hours.

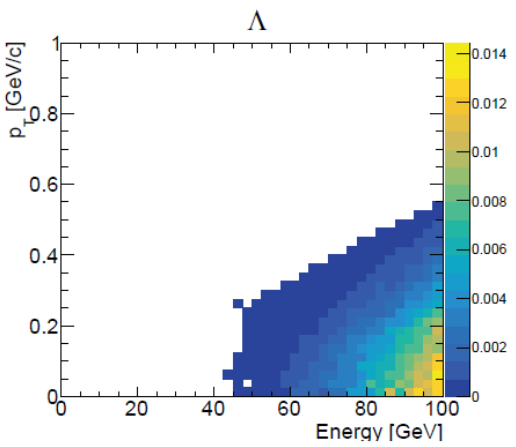
Q. 8

- It is mentioned that you would need several fills for your measurement, can you better quantify several fills?
  - If we can collect data along with STAR data at 1 kHz bandwidth, we need about 4 fills, 30 hours.
  - Radial polarization is only needed for asymmetry measurements. This data can be collected in a few hours at minimum (1 pb^{-1}). It will be limited to the collection of rare events (high-p_T, K^0_S, Λ), and we aim to make high-efficiency triggers at around 200 Hz.
  - Spectrum and cross-section measurements can be taken with vertical polarization. A simple shower trigger is used, and the data is collected in about a week using a trigger rate of 200 Hz.

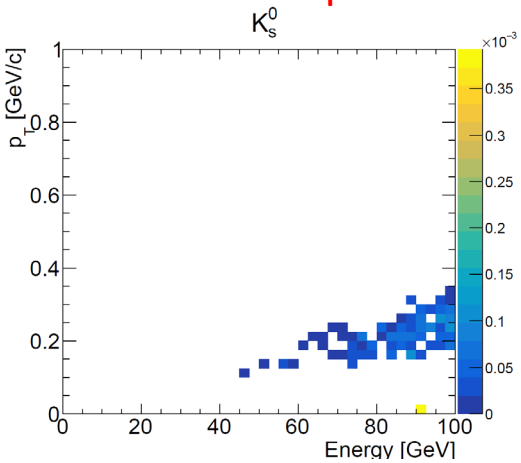
New detector acceptance

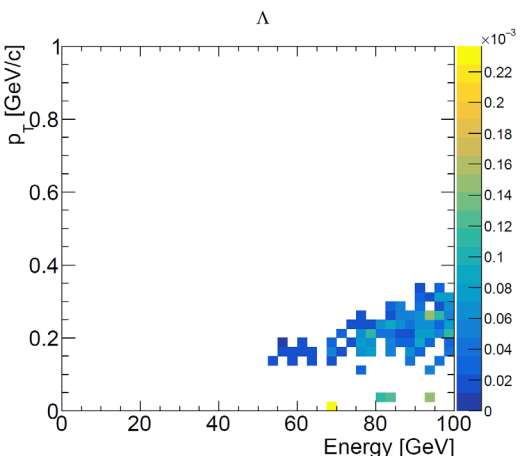


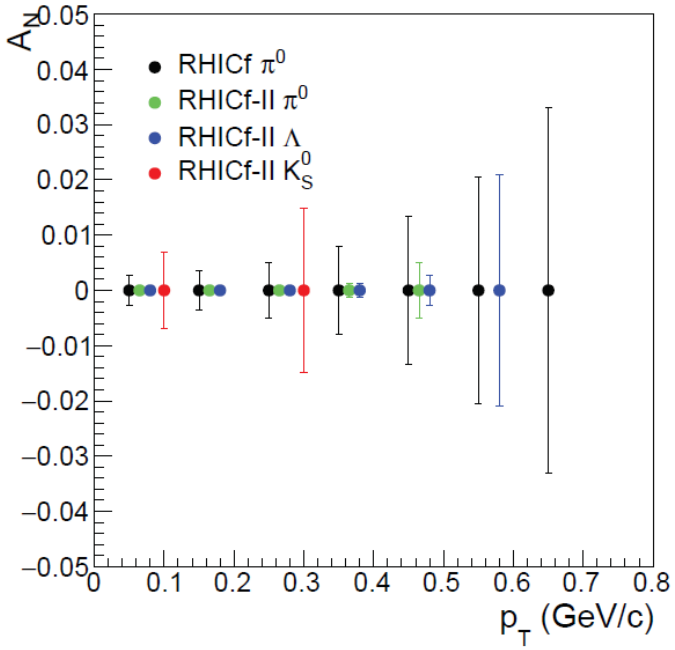


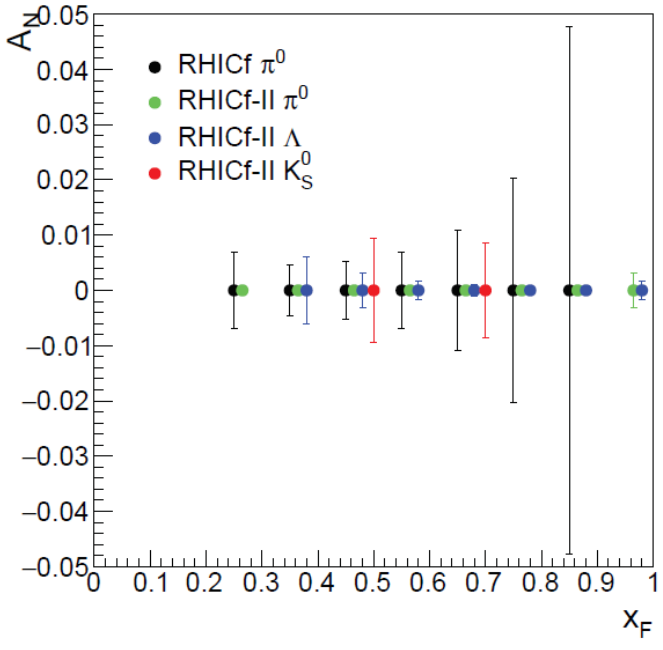


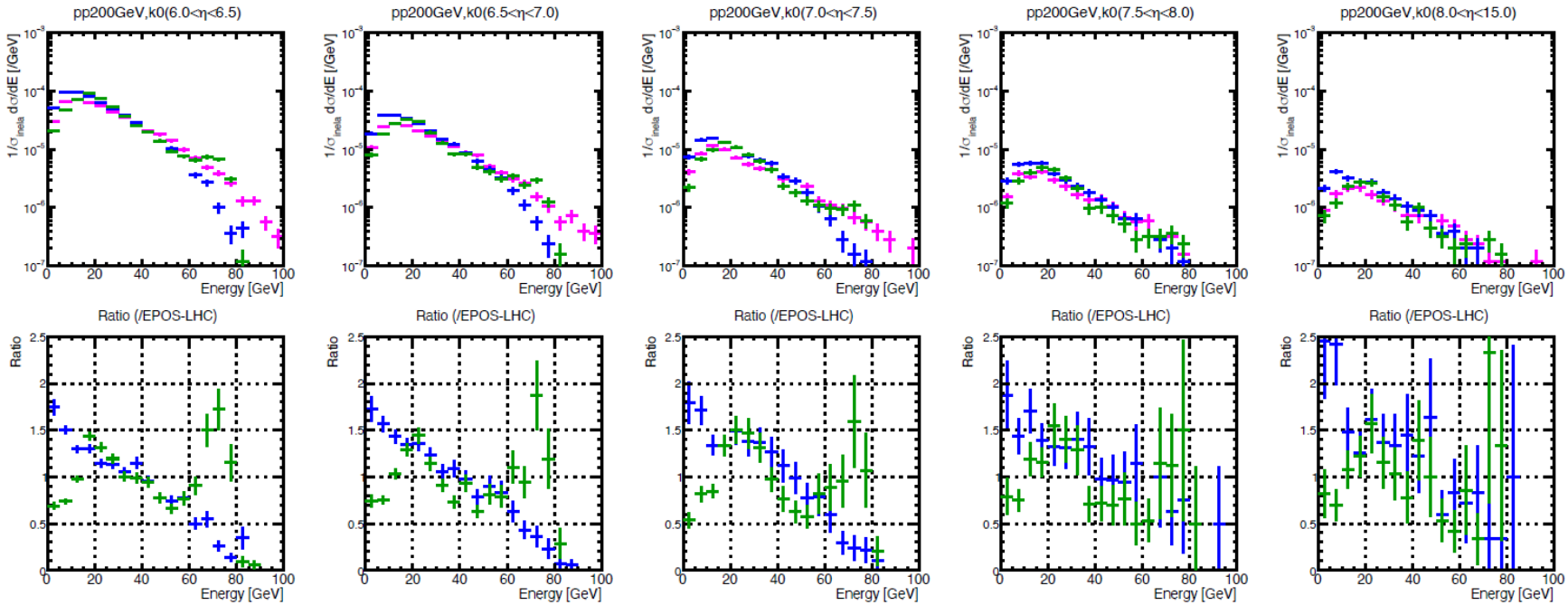
Old detector acceptance






A_N
RHICf π^0
RHICf-II π^0
RHICf-II Λ
RHICf-II K^0_S
p_T (GeV/c)


A_N
RHICf π^0
RHICf-II π^0
RHICf-II Λ
RHICf-II K^0_S
x_F


pp200GeV,k0(6.0<η<6.5)
pp200GeV,k0(6.5<η<7.0)
pp200GeV,k0(7.0<η<7.5)
pp200GeV,k0(7.5<η<8.0)
pp200GeV,k0(8.0<η<15.0)
Energy [GeV]
Ratio (/EPOS-LHC)
Ratio