Letter of Intent
RHICf-II experiment in Run 24

BNL NPP 2020 PAC Meeting

September 10th, 2020

Yuji Goto (RIKEN)

For the RHICf-II Collaboration

Introduction

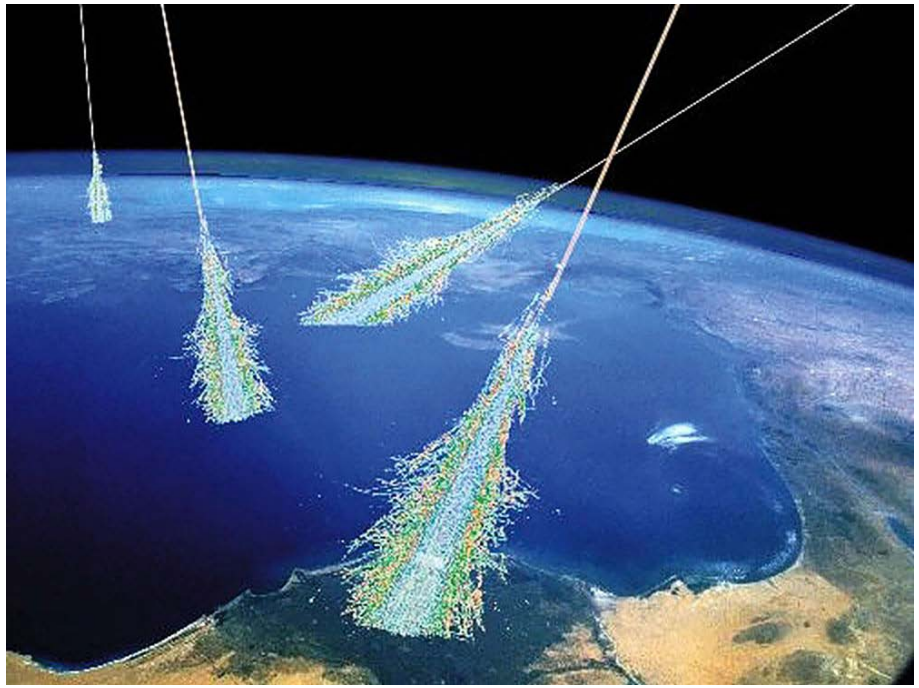
- In this LoI, we propose a second run for RHICf in 2024 (RHICf-II).
  - PAC recommendation in 2019
  - The prospects for taking additional RHICf data in future pp, pA, and AA runs should also be explored.
- We may need a request of dedicated beam time with special β^* and polarization direction similarly to our run in 2017, and special p + A collisions.
- It will have a large impact on the central detector BUR.

RHICf-II Collaboration

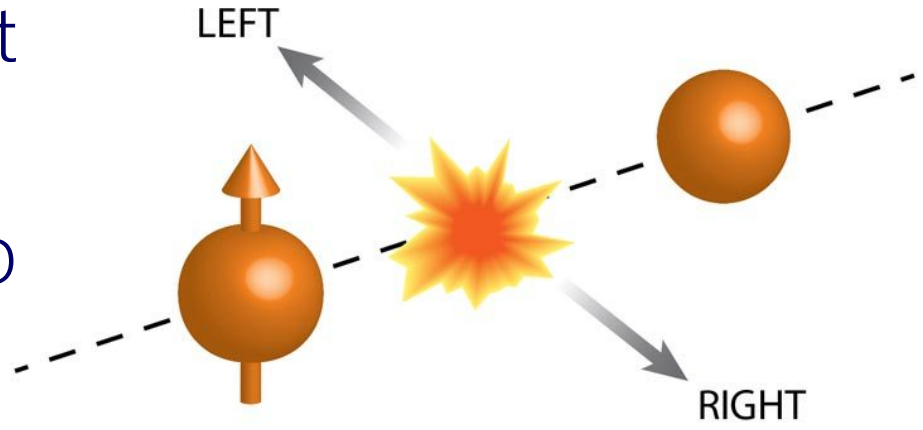
- Y. Goto, I. Nakagawa, R. Seidl (RIKEN)
- B. Hong, M.H. Kim (Korea Univ.)
- K. Tanida (JAEA)
- T. Chujo (Tsukuba Univ.) ← New
- Y. Itow, H. Menjo (Nagoya Univ.)
- T. Sako (ICRR, Univ. of Tokyo)
- K. Kasahara (Shibaura Tech.)
- O. Adriani, L. Bonechi, R. D'Alessandro (INFN Firenze)
- A. Tricomi (INFN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

Physics motivation

- Cosmic-ray study
  - Cross section measurement to understand ultra-high energy cosmic rays

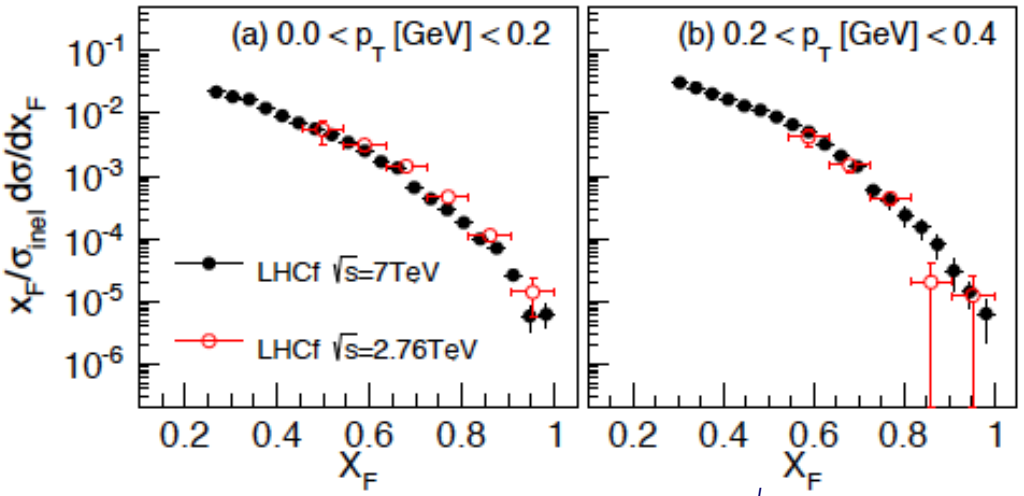


- Asymmetry measurement
  - To understand the hadronic collision mechanism based on QCD



Cross section measurement

- Majority of energy flow from hadronic collisions concentrated in the very forward region, but reaction mechanism insufficiently understood there
  - Uncertainty to understand air-shower from ultra-high energy cosmic rays
  - Improvement of high-energy collision models based on measurement essential
- Feynman scaling
  - Energy-independent x_F & p_T distribution of the cross section of very forward particle production
  - Wider p_T coverage at RHIC energy (limited at LHC low energy collision)



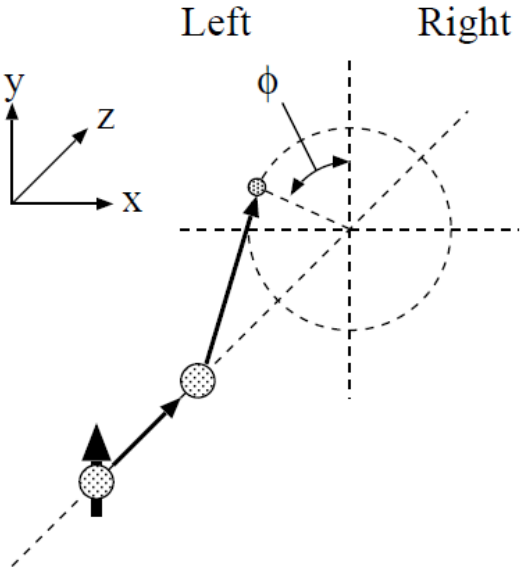
LHCf results of π^0 production cross section at $\sqrt{s}$=7TeV and 2.76TeV
Phys.Rev.D94 (2016) 032007

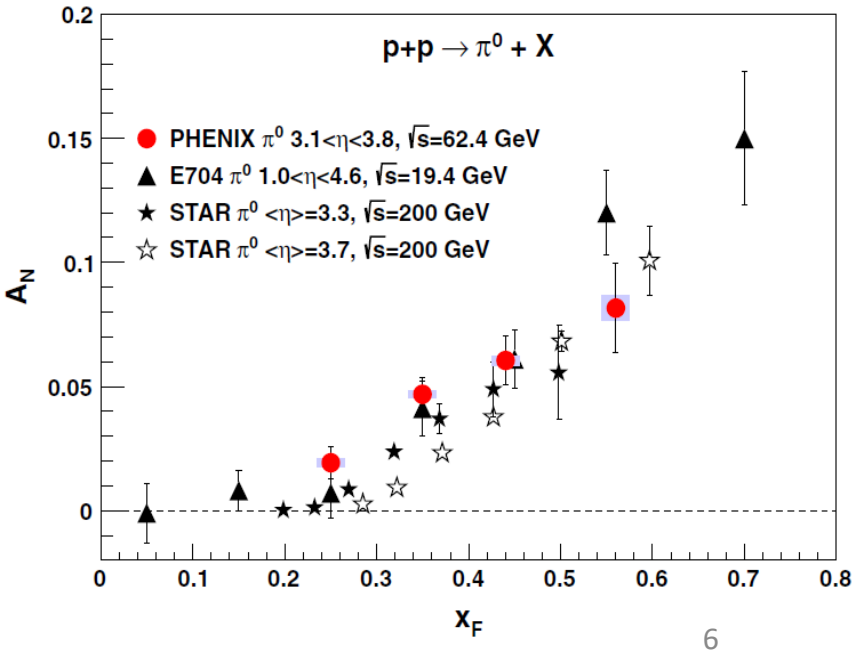
Transverse asymmetry measurement

- A_N (transverse single-spin asymmetry) measurement

$$A_N = \frac{d\sigma_{Left} - d\sigma_{Right}}{d\sigma_{Left} + d\sigma_{Right}}$$

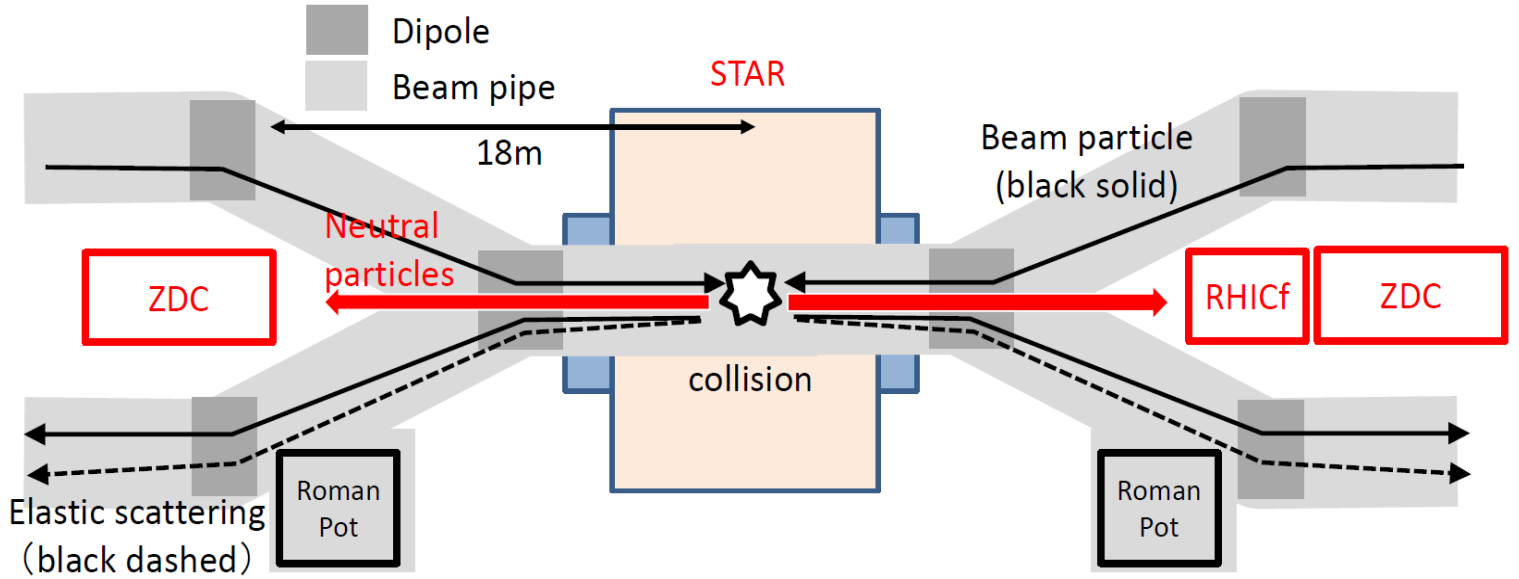
  - Azimuthal angle modulation
- Large A_N for forward hadron production
  - $1 < \eta < 4$, similar results in wide $\sqrt{s}$
- TMD (Transverse Momentum Dependent) function and higher twist function in pQCD regime
  - Initial-state effect or "Sivers" effe
  - Final-state effect or "Collins" effe
- Hard scattering and/or non-perturbative effect?



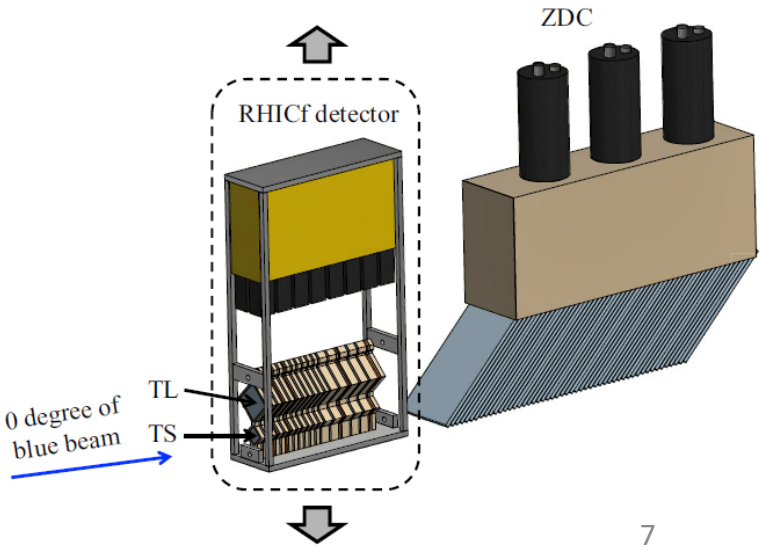


Run 17 operation

- EM calorimeter (RHICf detector) installed in front of the ZDC+SMD of the STAR experiment

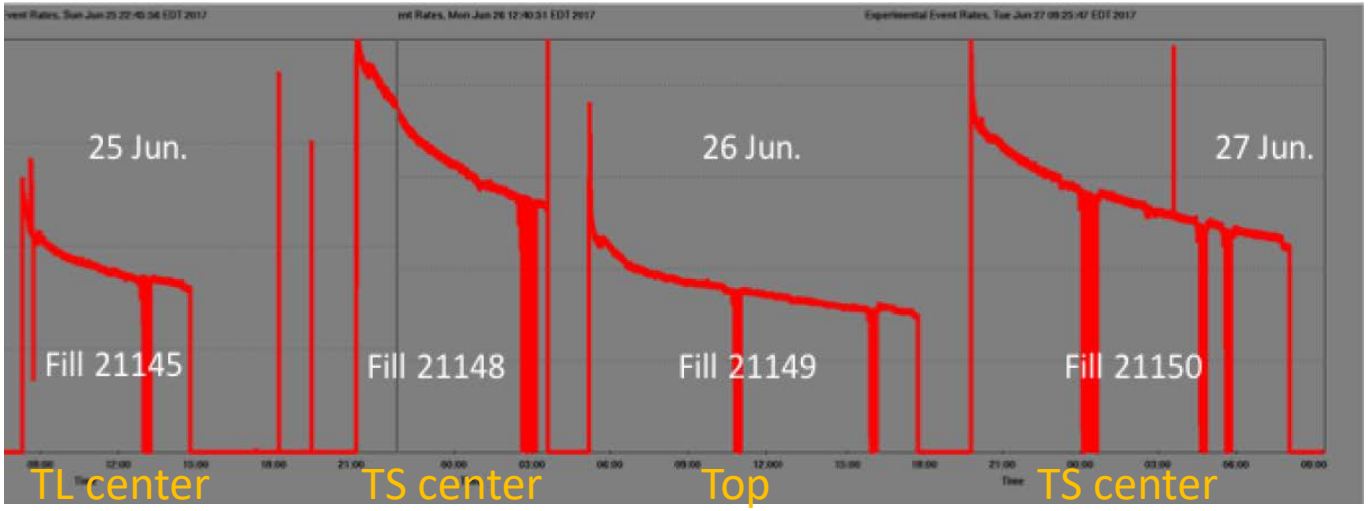


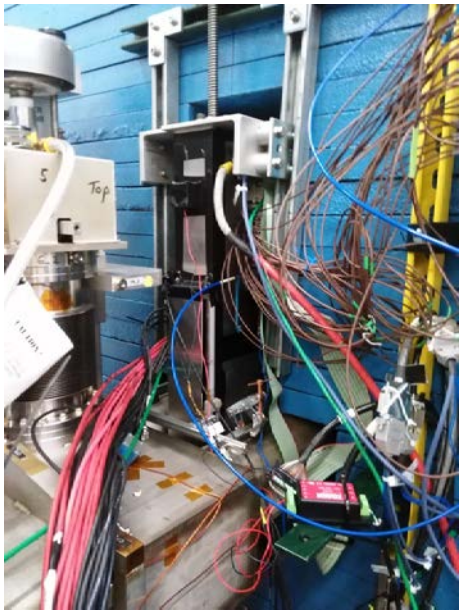
- Two position-sensitive sampling calorimeters
  - TS (small tower): 20mm x 20mm
  - TL (large tower): 40mm x 40mm
  - Tungsten absorber (44 X_0, 1.6 λ_{int})
  - 16 GSO sampling layers
  - 4 XY pairs of GSO-bar position layers

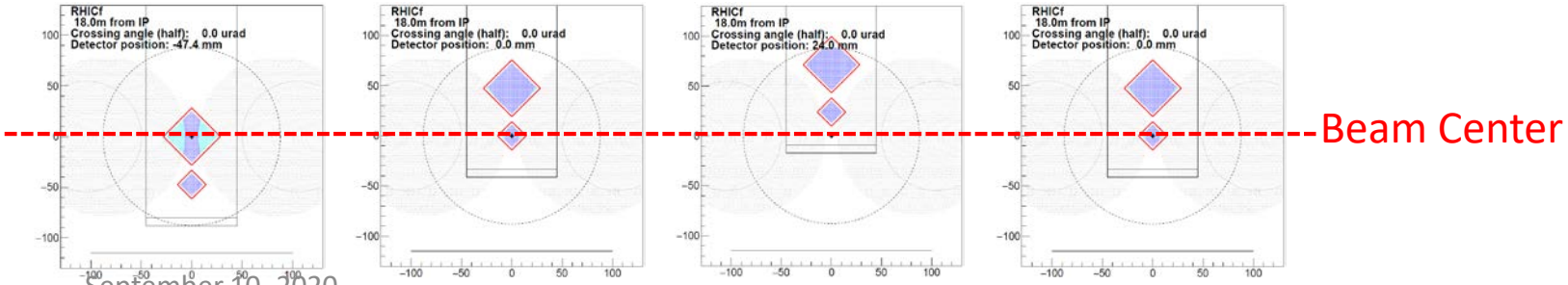


Run 17 operation

- June 24 – 27 physics data acquisition
  - $\beta^* = 8$m, radial polarization
  - 27.7 hours, ~110M events, ~700 nb^{-1}
- 3 detector positions: TL center / TS center / Top position

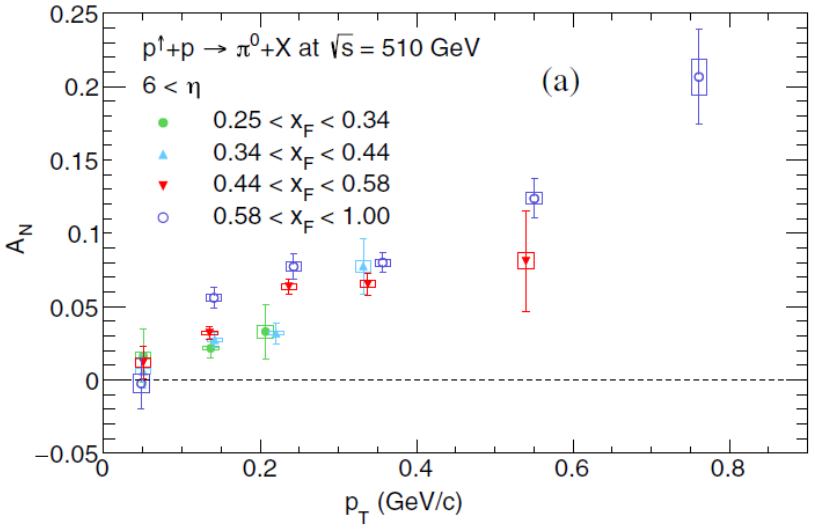


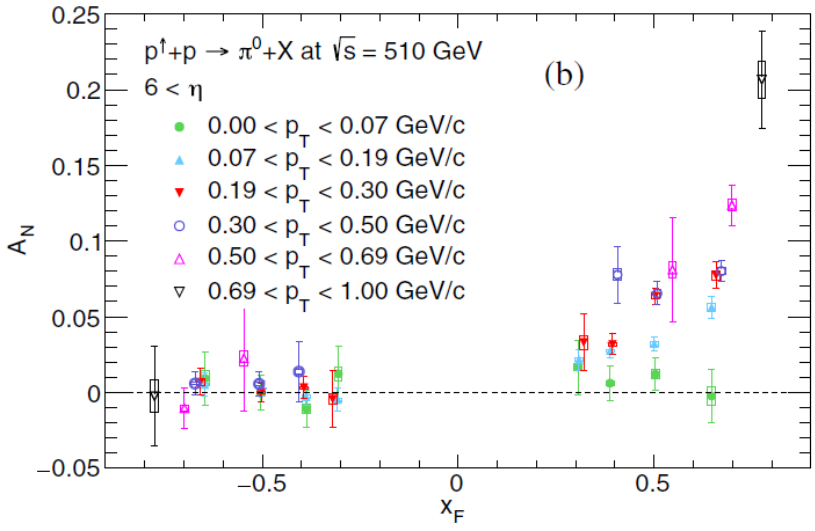




Run 17 results

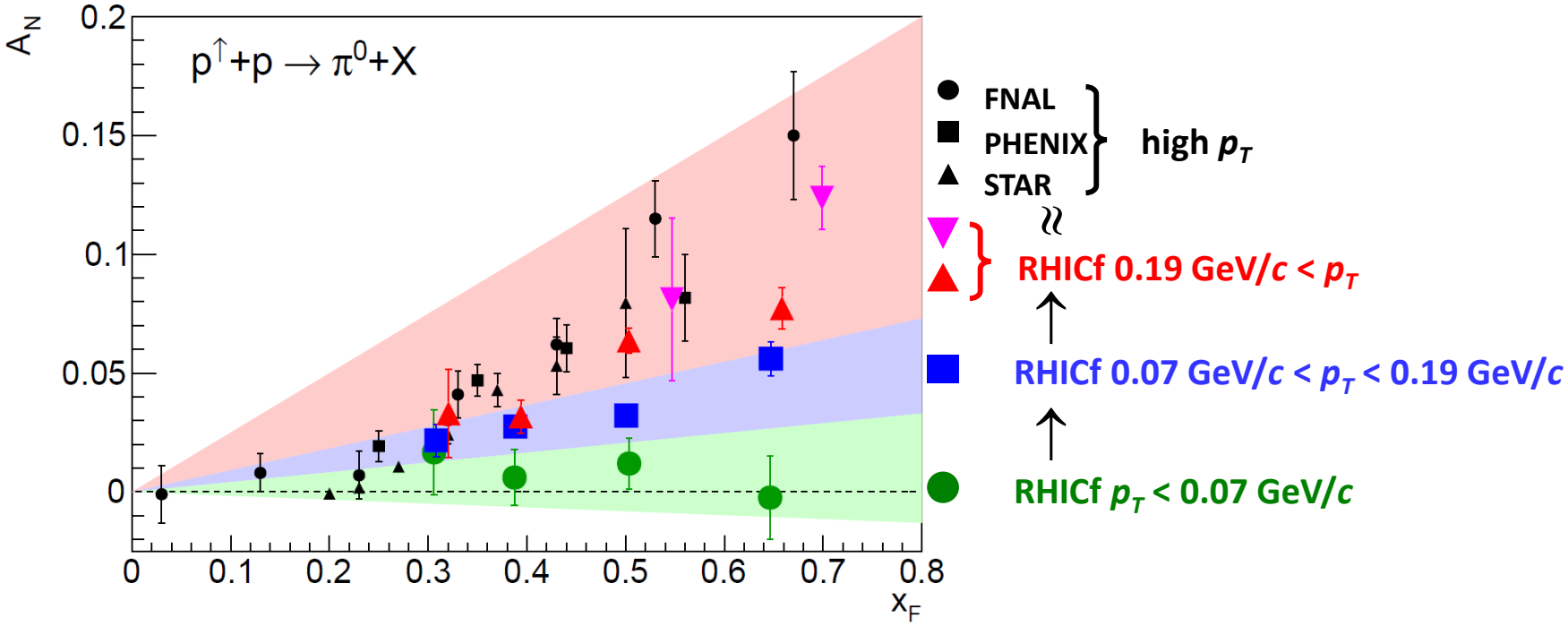
- π^0 asymmetry
  - Transverse single-spin asymmetry for very forward neutral pion production in polarized p+p collisions at $\sqrt{s}$ = 510 GeV
  - Phys. Rev. Lett. 124, 252501 (2020)
  - Research News
    - https://www.riken.jp/en/news_pubs/research_news/pr/2020/20200623_1/index.html (RIKEN)
    - https://www.bnl.gov/newsroom/news.php?a=117099 (BNL)
  - Asymmetry ~ 0 backward & forward $p_T < 0.07$ GeV/c





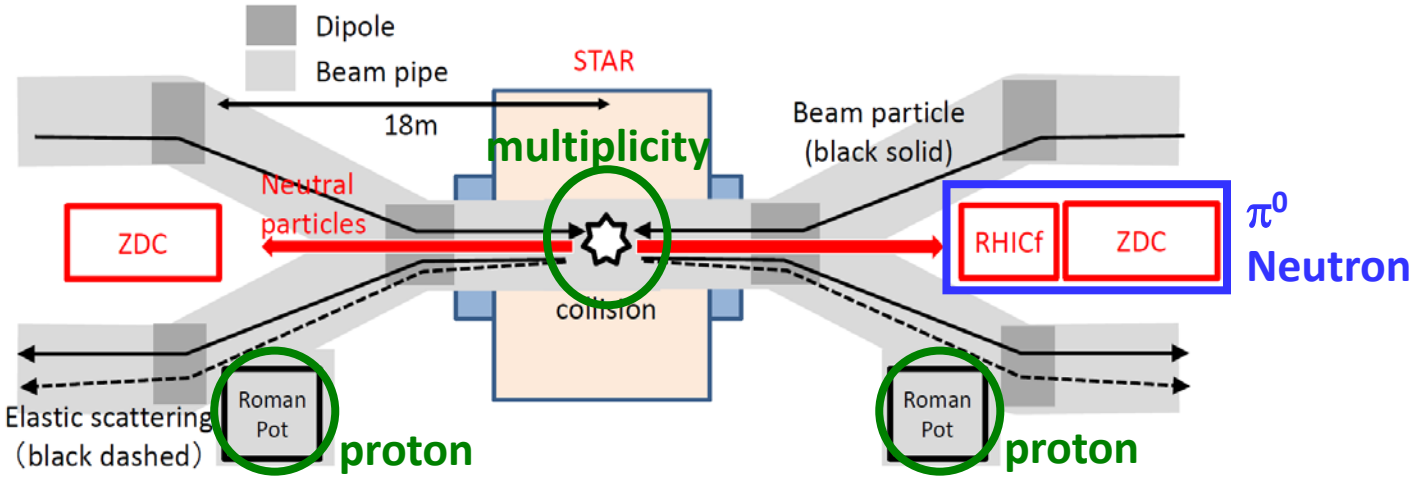
Run 17 results

- π^0 asymmetry
  - 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



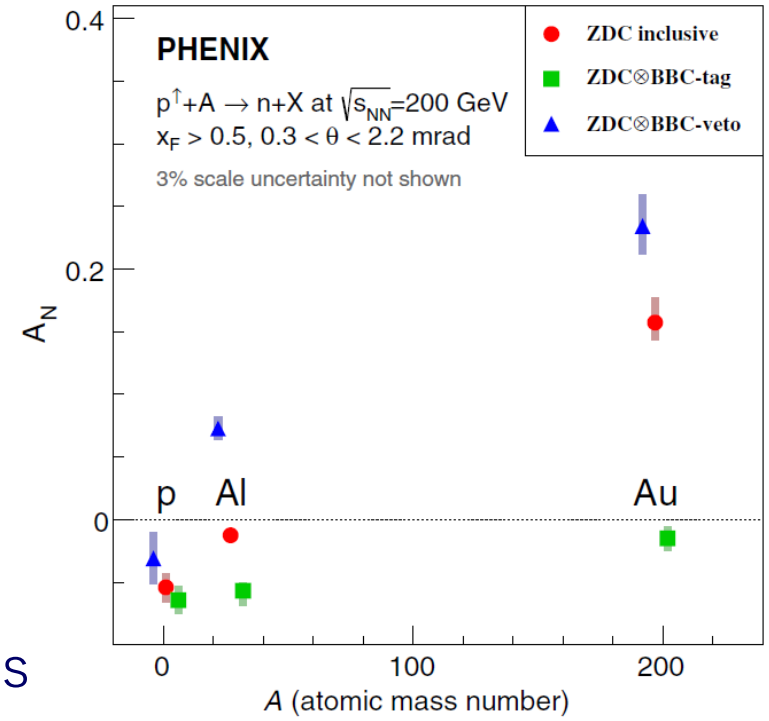
Run 17 results

- 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



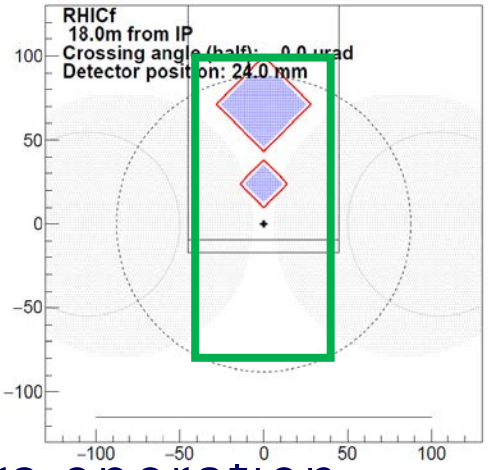
New topics at RHICf-II

- p + A collisions
  - Measurement of nuclear effect (p+A / p+p)
- Strong A-dependence of the neutron asymmetry
  - Measured at PHENIX in Run 15
  - Phys. Rev. Lett. 120, 022001 (2018)
  - UPC vs hadronic component
- A-dependence of the π^0 asymmetry
  - Correlation between asymmetries of forward neutron and π^0
- p + Oxygen collision
  - Ideal condition for cosmic-ray interaction studies measuring π^0, neutron, photon, K^0_S

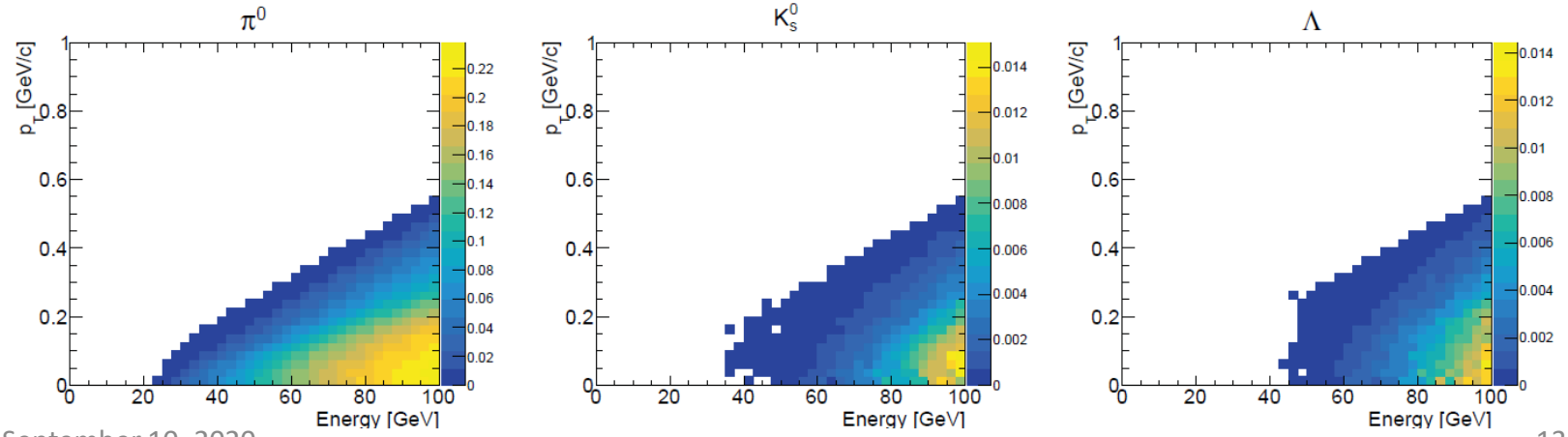


New topics at RHICf-II

- Large acceptance detector
  - 8cm x 18cm
  - For more particles: K^0_S and Λ

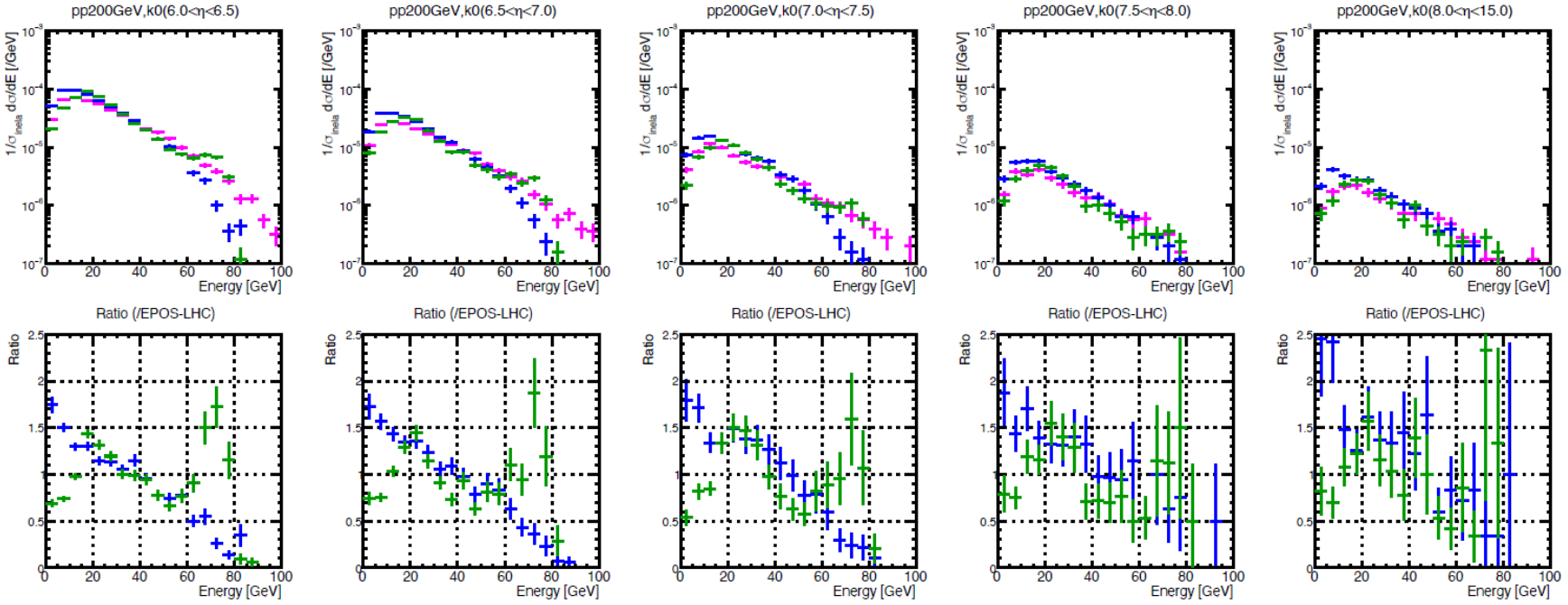


- $K^0_S \rightarrow 2\pi^0 \rightarrow 4\gamma$ (B.R. 30.7%)
  - 0.2 K^0_S /sec = 10^4 K^0_Ss in 14 hours operation
- $\Lambda \rightarrow n + \pi^0 \rightarrow n + 2\gamma$ (B.R. 35.9%)
  - 12 Λ /sec = 10^5 Λs in 2.5 hours operation
- Geometric acceptance of π^0, K^0_S and Λ



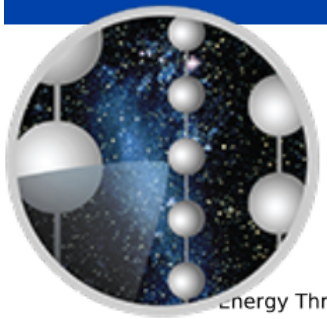
New topics at RHICf-II

- K^0_S for studying impact on the high-energy atmospheric neutrino flux
  - Differences in p+p collisions at 200 GeV between models: EPOSLHC (magenta), QGSJET II-4 (blue), SIBYLL 2.3 (green)



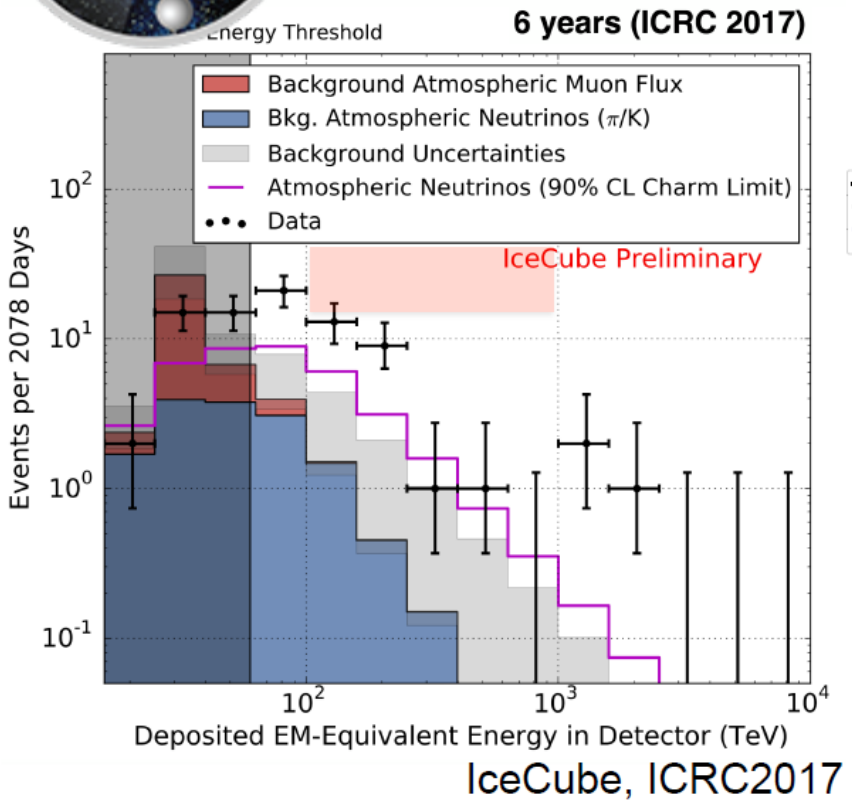
New topics at RHICf-II

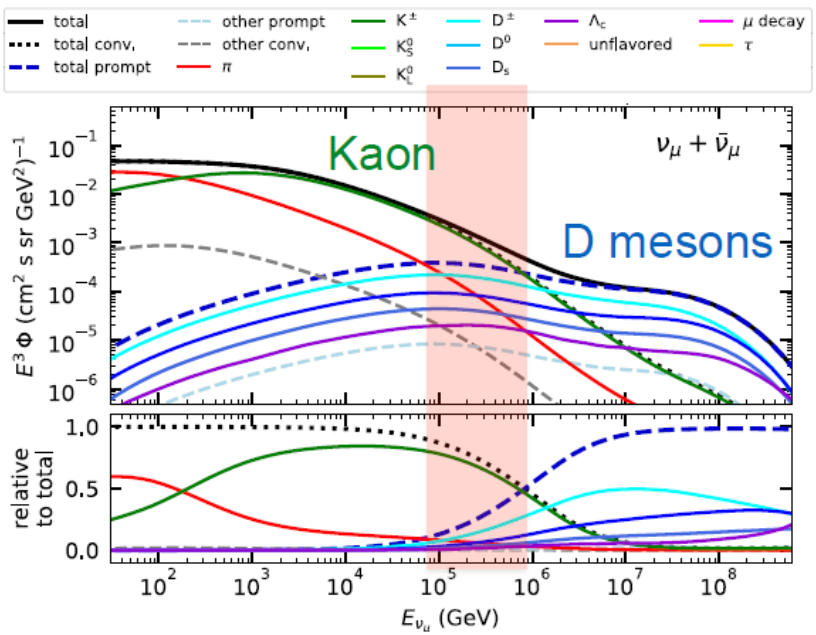
Kaons in atm. ν productions



IceCube detected astronomical neutrinos.
Better understanding of background
(Atmospheric neutrinos) is required.

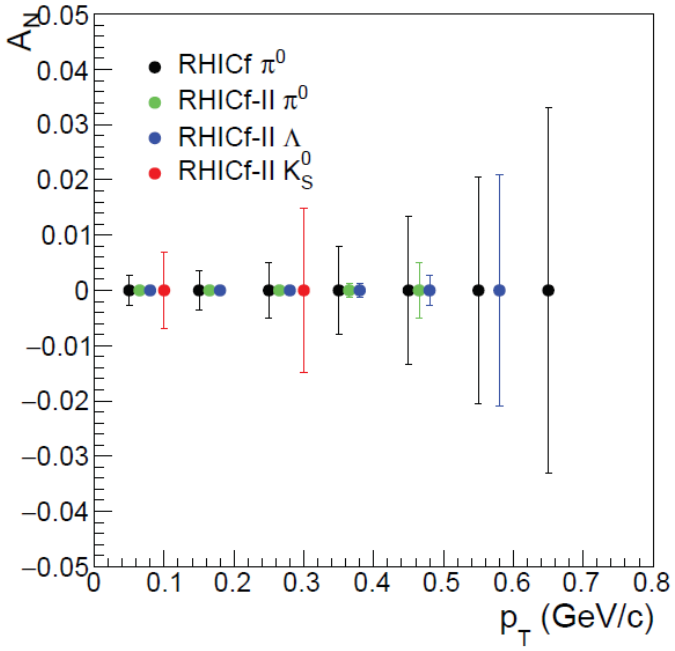
Slide by
H. Menjo

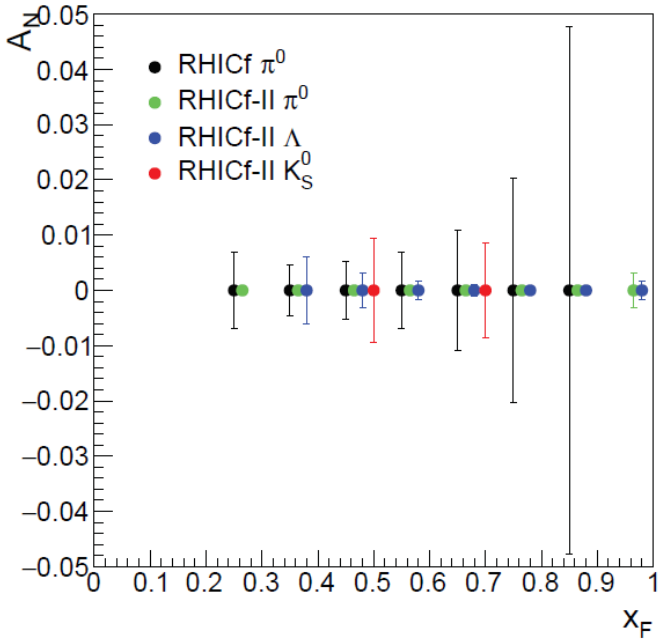




New topics at RHICf-II

- Asymmetry measurement of K^0_S and Λ
  - Expected statistical uncertainty of asymmetry measurements for π^0, K^0_S, and Λ compared to the RHICf (Run 17) π^0
  - Assuming the similar luminosity



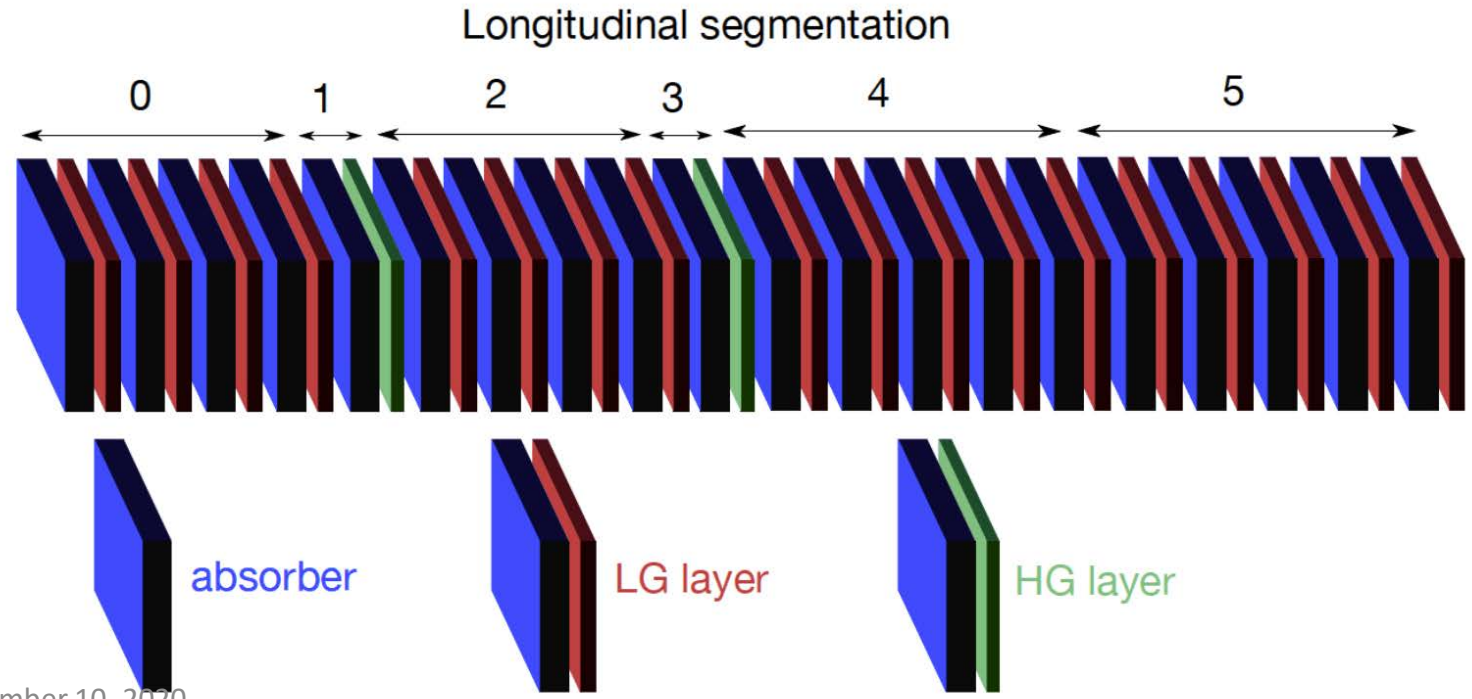


Large acceptance calorimeter

- We'll transfer ALICE FoCal-E technology for building an approx. 8cm x 18cm detector to be used at RHIC in 2024
  - Finalize the design of the detector in 2021
  - Construction in 2022-2023 by RIKEN budget + external fund in Japan
- The detector may have enough radiation hardness to work for a small β* and normal luminosity
  - pad sensor to be tested in this winter with a small neutron source facility in RIKEN

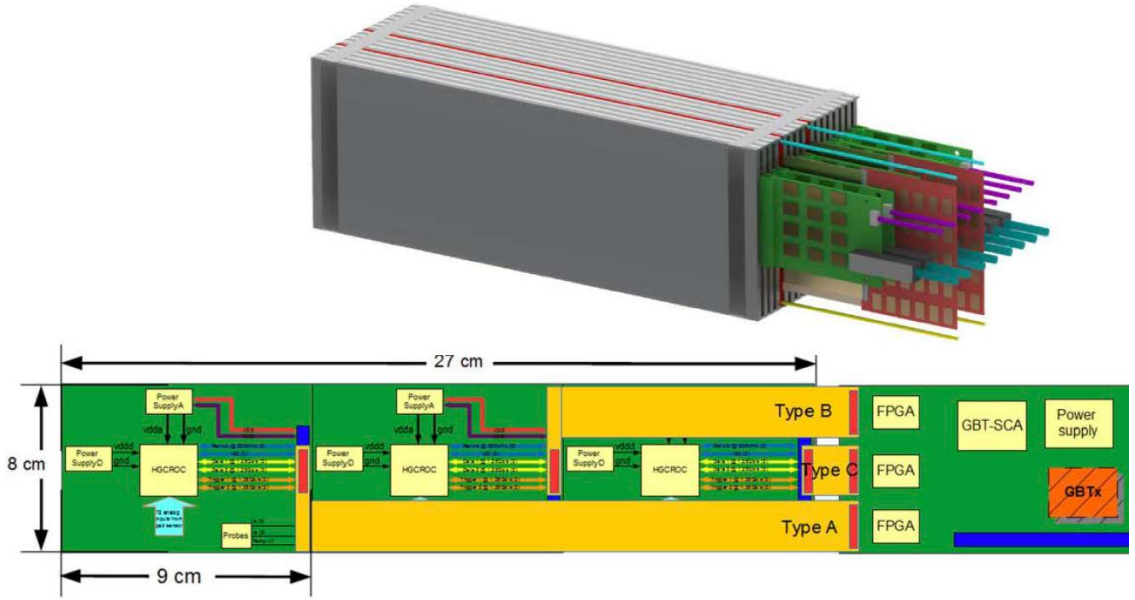
ALICE FoCal-E

- 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

- Space restriction at RHICf
- Readout electronics based on HGCROC ASIC (CMS)
  - Readout electronics & DAQ integration to the central detector system
  - Working with Grenoble group who is a leader of the HGCROC ASIC development



RHICf-II request

- 2022 at STAR not available
  - ALICE FoCal not available yet
  - LHCf detector not available due to conflict with LHC Run 3 in 2023
  - p+p 510 GeV
- 2024 at sPHENIX or STAR
- Dedicated beam use – 2 weeks
  - Large β^* and radial polarization
  - 1 week for pol-p + A at 200 GeV
    - A = O, Al, Au, ⋯
  - 1 week for pol-p + pol-p at 200 GeV
    - Comparison with p+A for A dependence
    - Comparison with 510 GeV (2017 run) for $\sqrt{s}$ dependence
    - K^0_S and Λ
- Or parasitic beam use
  - The detector may have enough radiation hardness to work for a small β^* and normal luminosity
  - We also need sufficient DAQ and trigger capability for high luminosity operation

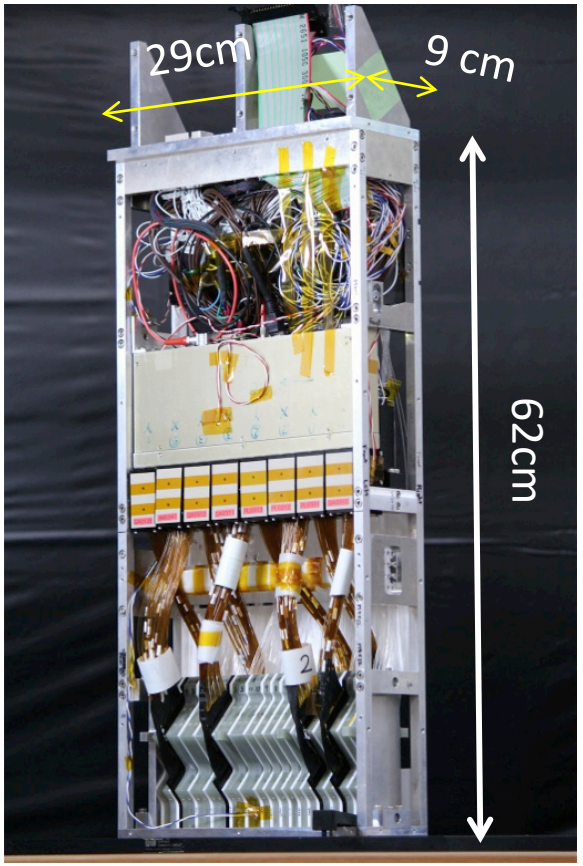
Summary

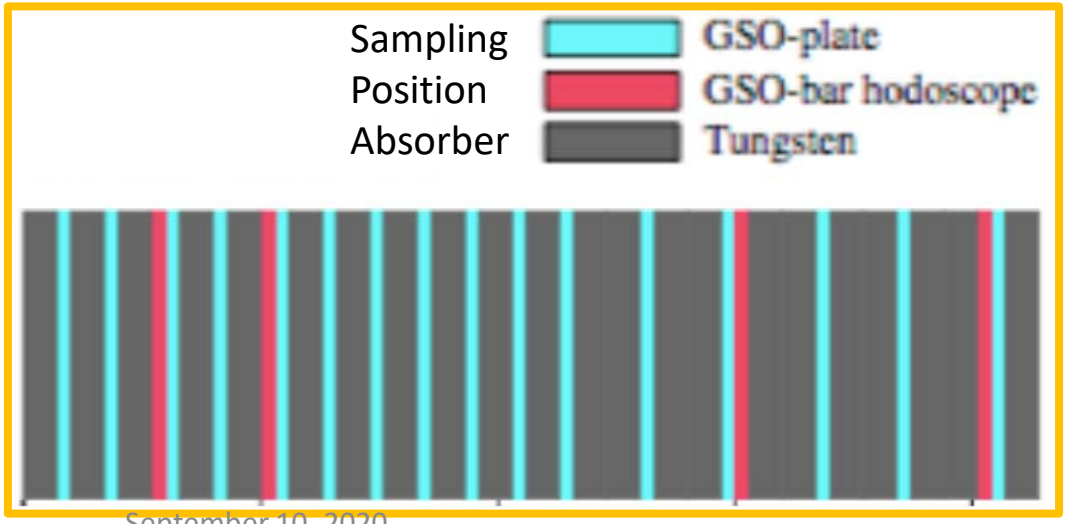
- In this LoI, we propose a second run for RHICf in 2024 (RHICf-II).
- We may need a request of dedicated beam time with special β^* and polarization direction similarly to our run in 2017, and special p + A collisions.
- It will have a large impact on the central detector BUR.
- We are still considering whether we need dedicated beam use or we can run parasitically.
- We will discuss collaboration with sPHENIX and STAR to locate our detector.

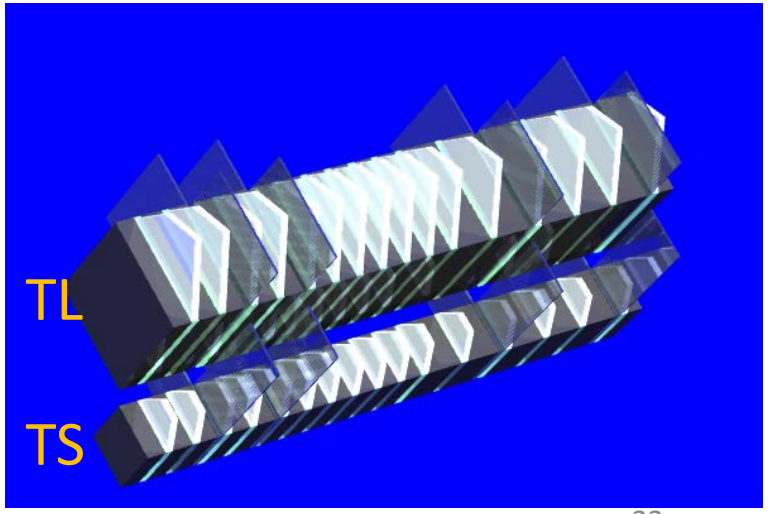
Backup Slides

RHICf detector

- 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 (MAPMT readout)

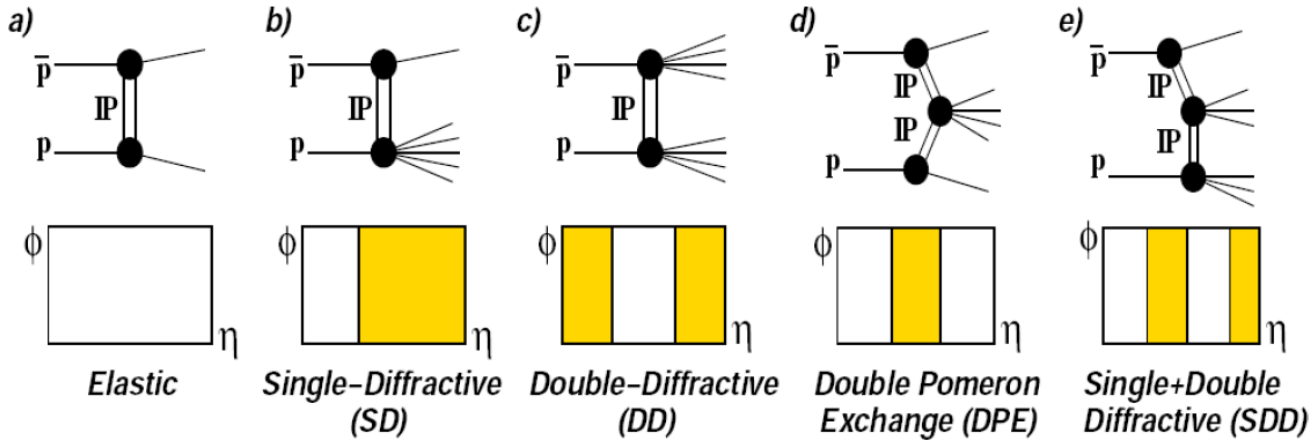




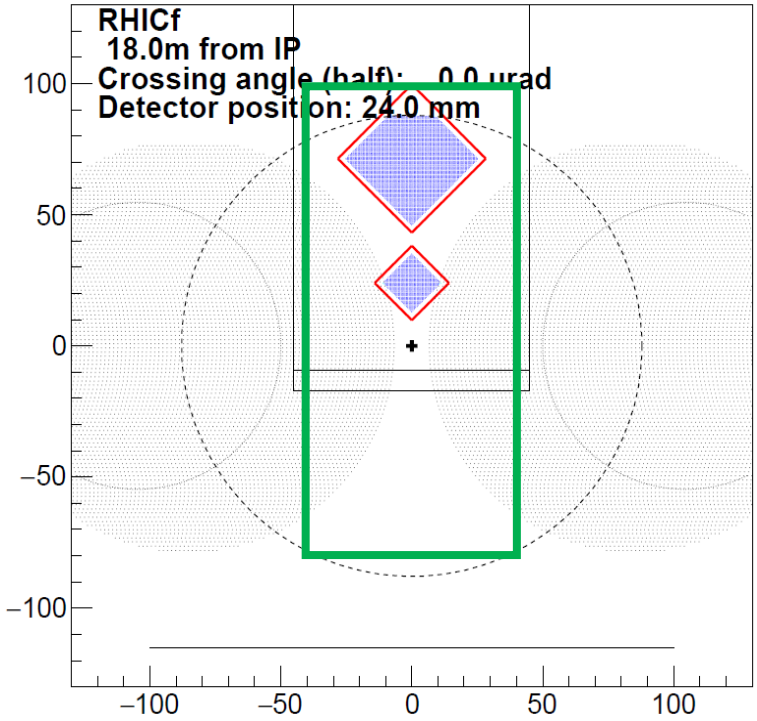


To do

- Event type categorization



- Diffraction + resonance tagging with STAR + RHICf combined data analysis
  - Resonance with STAR Roman Pot
  - Diffraction with STAR forward detectors (FMS, BBC, VPD)
  - Or no activity
- Event type, multiplicity (FMS) dependence of cross section & asymmetry to be obtained
  - For more information to study production mechanism


RHICf
18.0m from IP
Crossing angle (half): 0.0 urad
Detector position: 24.0 mm
100
50
0
−50
−100
−100
−50
0
50
100