Letter of Intent
RHICf-II experiment in Run 24

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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 $\beta^*$ 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

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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 $\pi^0$ production cross section at $\sqrt{s}=7\text{TeV}$ and $2.76\text{TeV}$

Transverse asymmetry measurement

- $A_N$ (transverse single-spin asymmetry) measurement
  
  \[
  A_N = \frac{d\sigma_{\text{Left}} - d\sigma_{\text{Right}}}{d\sigma_{\text{Left}} + d\sigma_{\text{Right}}}
  \]

  - 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” effect
  - Final-state effect or “Collins” effect

- 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 $\lambda_{\text{int}}$)
  - 16 GSO sampling layers
  - 4 XY pairs of GSO-bar position layers
Run 17 operation

- June 24 – 27 physics data acquisition
  - $\beta^* = 8m$, radial polarization
  - 27.7 hours, $\sim 110M$ events, $\sim 700$ nb$^{-1}$
- 3 detector positions: TL center / TS center / Top position
Run 17 results

• \( \pi^0 \) asymmetry
  • Transverse single-spin asymmetry for very forward neutral pion production in polarized p+p collisions at \( \sqrt{s} = 510 \) GeV
  • Research News
  • Asymmetry \( \sim 0 \) backward & forward \( p_T < 0.07 \) GeV/c
Run 17 results

- $\pi^0$ 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
  - $\pi^0$ & 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 π⁰ asymmetry
  • Correlation between asymmetries of forward neutron and π⁰
• p + Oxygen collision
  • Ideal condition for cosmic-ray interaction studies measuring π⁰, neutron, photon, K⁰_S
New topics at RHICf-II

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

- $K^0_S \rightarrow 2\pi^0 \rightarrow 4\gamma$ (B.R. 30.7%)
  - $0.2 \, K^0_S /\text{sec} = 10^4 \, K^0_S\text{s in 14 hours operation}$

- $\Lambda \rightarrow n + \pi^0 \rightarrow n + 2\gamma$ (B.R. 35.9%)
  - $12 \, \Lambda /\text{sec} = 10^5 \, \Lambda\text{s in 2.5 hours operation}$

- Geometric acceptance of $\pi^0$, $K^0_S$ and $\Lambda$
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: EPOS-LHC (magenta), QGSJET II-4 (blue), SIBYLL 2.3 (green)
New topics at RHICf-II

Kaons in atm. v productions

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

IceCube Preliminary

Atmospheric $\nu_\mu$ flux

Kaon

D mesons
New topics at RHICf-II

- Asymmetry measurement of $K^0_S$ and $\Lambda$
  - Expected statistical uncertainty of asymmetry measurements for $\pi^0$, $K^0_S$, and $\Lambda$ compared to the RHICf (Run 17) $\pi^0$
  - 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 $\beta^*$ 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
  - $\sigma_E / E = 25\% / \sqrt{E} \text{ (GeV)} \oplus 2\%$ 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 $\beta^*$ 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 $\Lambda$

- Or parasitic beam use
  - The detector may have enough radiation hardness to work for a small $\beta^*$ 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 $\beta^*$ 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 \((44 \, X_0, \, 1.6 \, \lambda_{\text{int}})\)
  - 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