Highlights and future plan of RHICf

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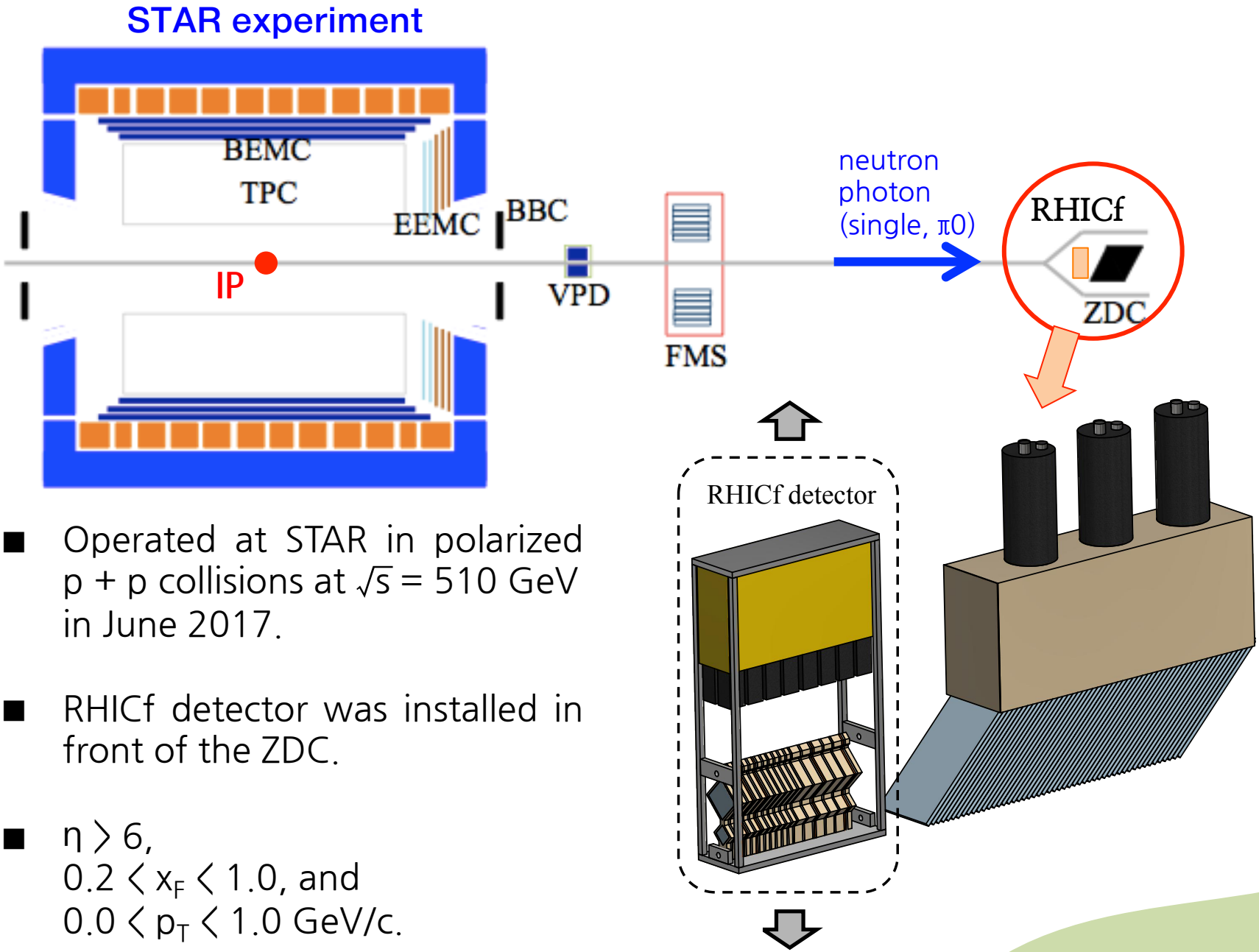
on behalf of the RHICf collaboration

8th June 2022 / RHICf & AGS Annual Users' Meeting

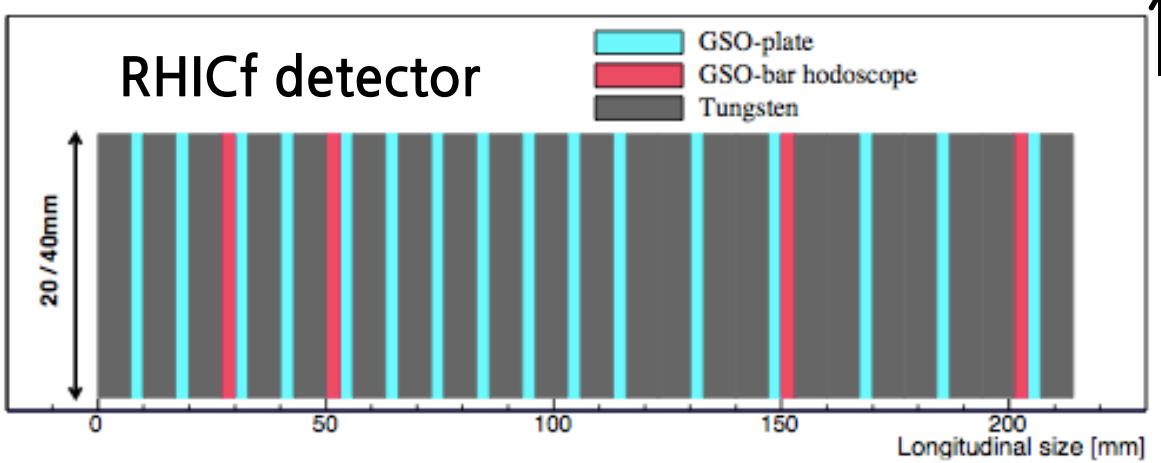
RHIC forward (RHICf) experiment

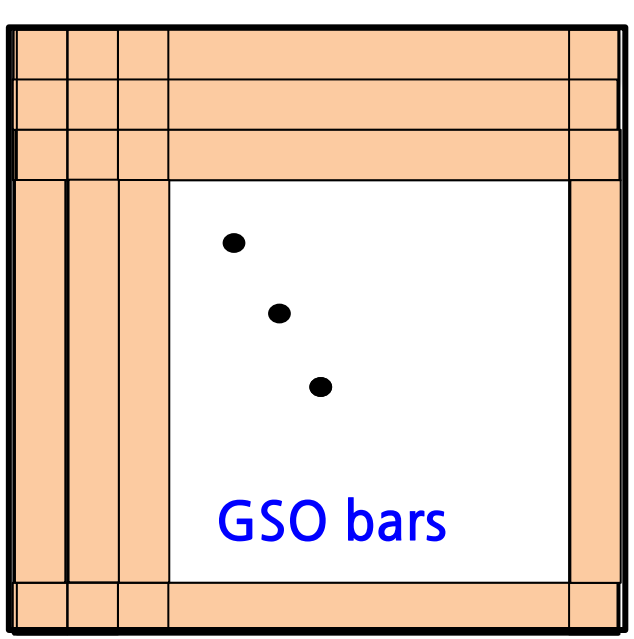


- Operated at STAR in polarized p + p collisions at $\sqrt{s}$ = 510 GeV in June 2017.
- RHICf detector was installed in front of the ZDC.
- $\eta > 6$,
  $0.2 < x_F < 1.0$, and
  $0.0 < p_T < 1.0$ GeV/c.

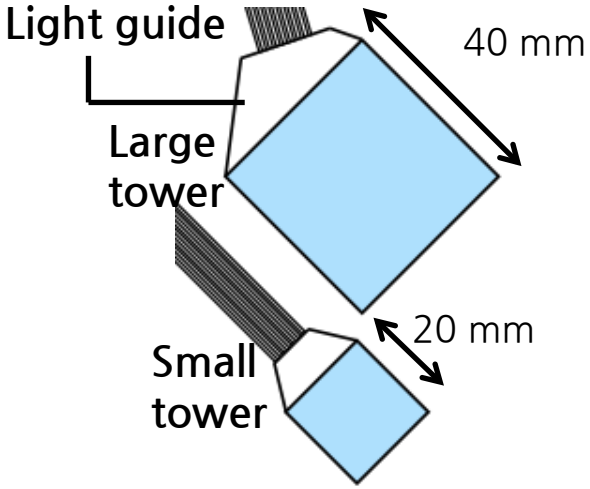
RHICf detector

Side view



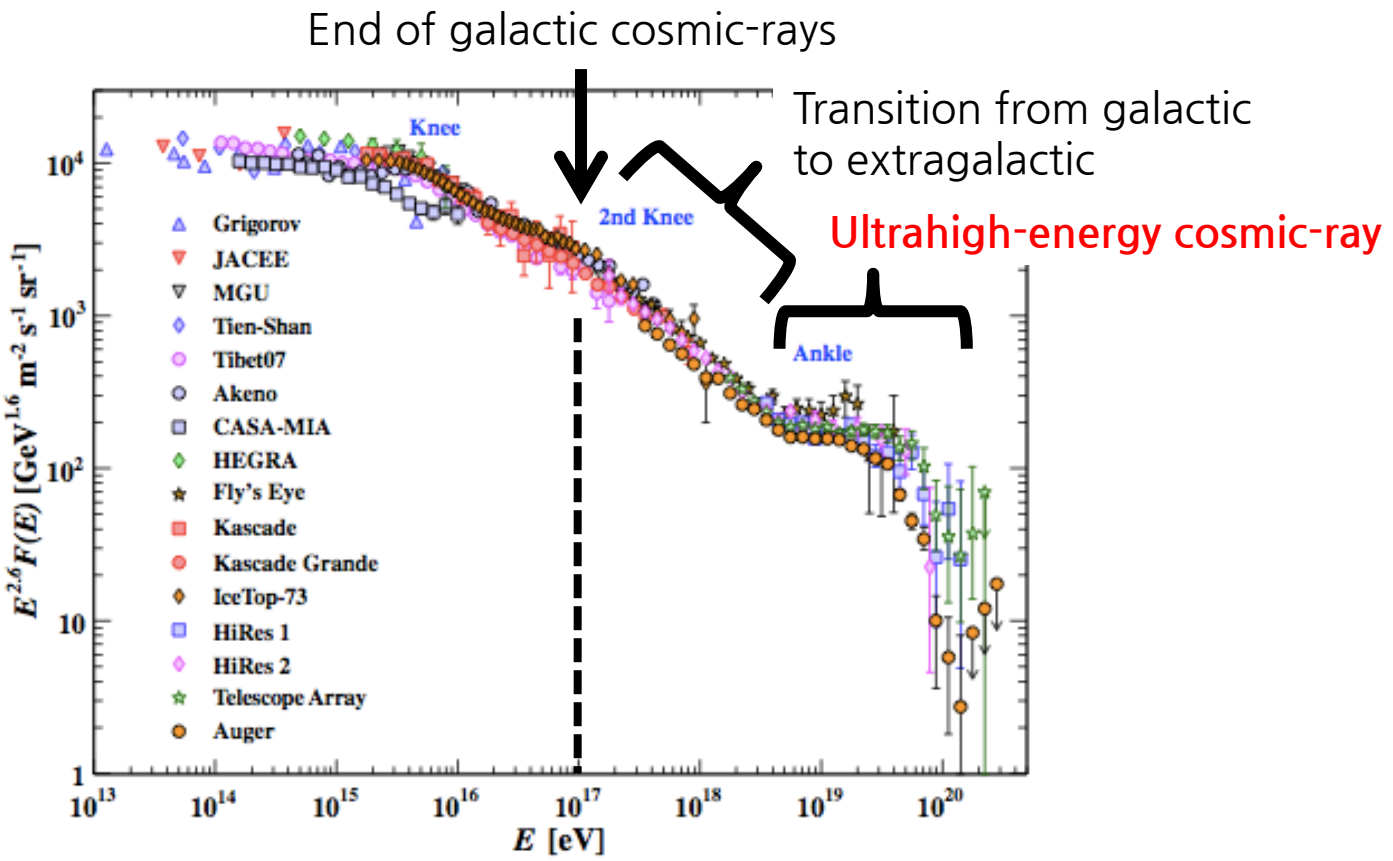


Front view



- 17 tungsten absorbers (44 X_0, 1.6 λ_{int}), 16 GSO plates, and 4 layers of GSO bars.
- σ_x ~ 0.1 mm, σ_E ~ 2% for 250 GeV photon.
  σ_x ~ 1.0 mm, σ_E ~ 35% for 250 GeV neutron.
- Shower is triggered using energy deposits in three successive layers.

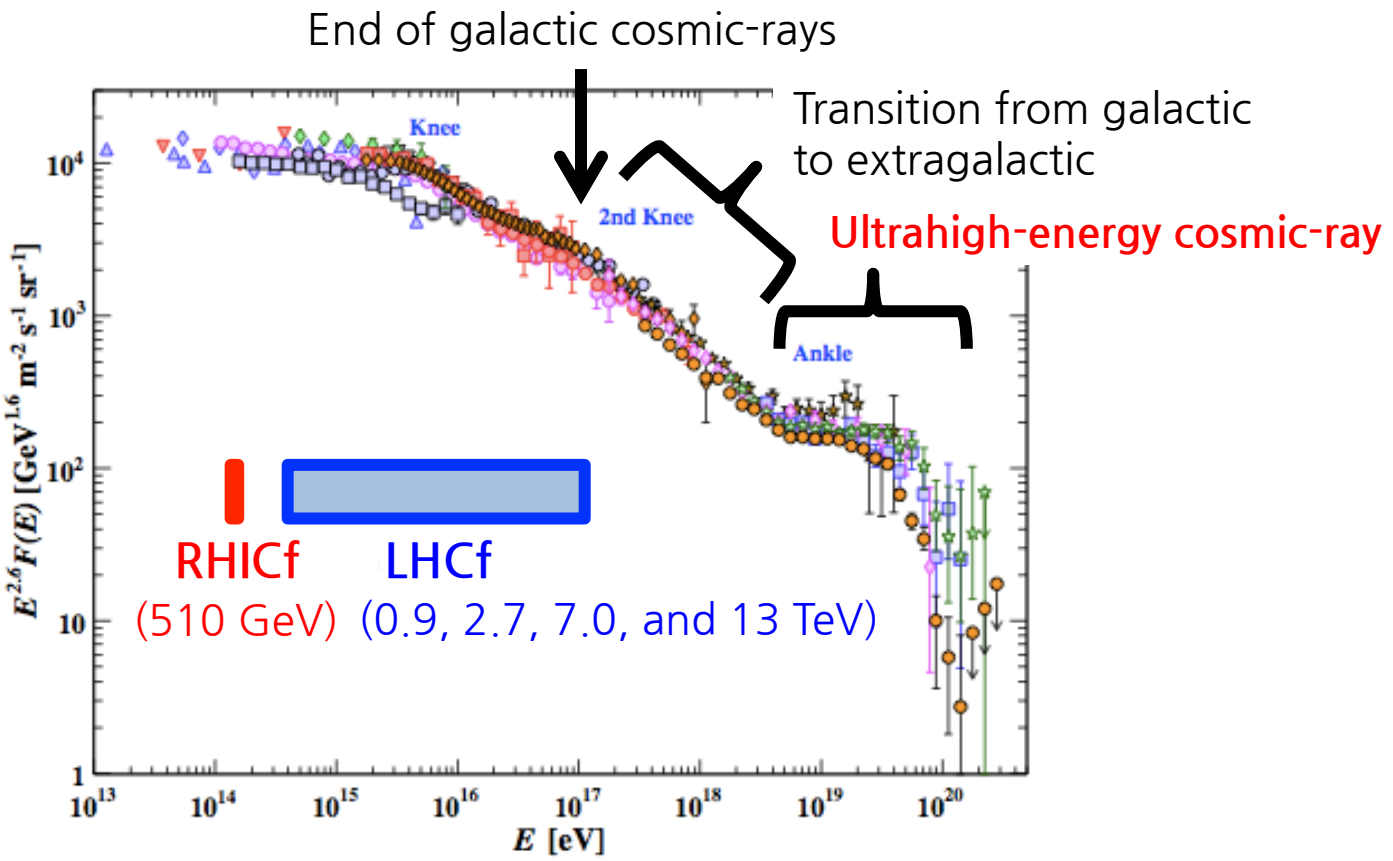
1. Cross section measurement



- Cosmic-ray above 10^{18} eV is called ultrahigh-energy cosmic ray (UHECR).
- Different interaction model predicts different acceleration mechanism for the origin of the UHECRs.

  → Cross section data can constrain and tune the existing models.

1. Cross section measurement

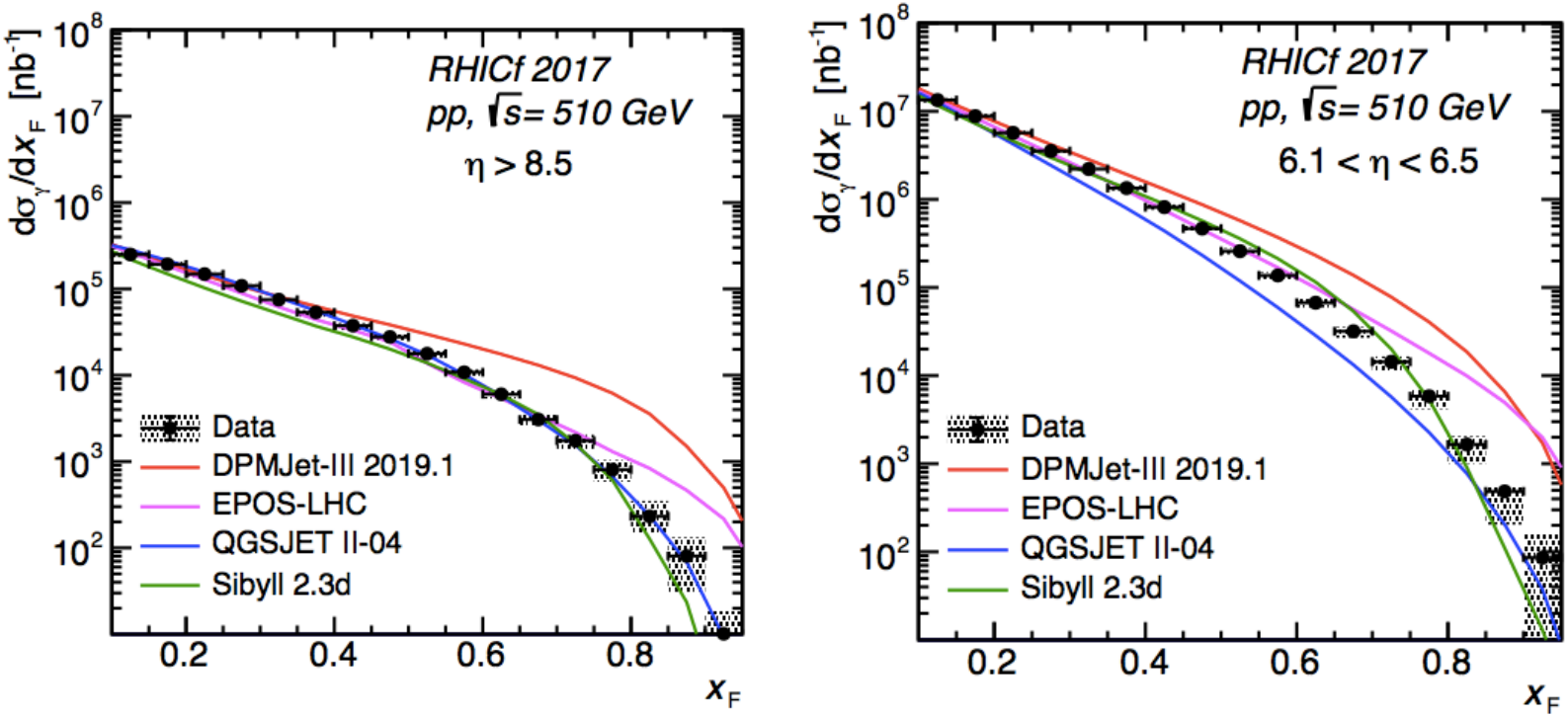


- Cross sections of neutron, photon, and π^0 have been measured by the LHCf experiment up to $\sqrt{s}$ = 13 TeV.
- $\sqrt{s}$ dependence of the forward particle production will be tested in a wide energy range by comparing the RHICf with LHCf data.

New result!

Photon cross section

arXiv:2203.15416

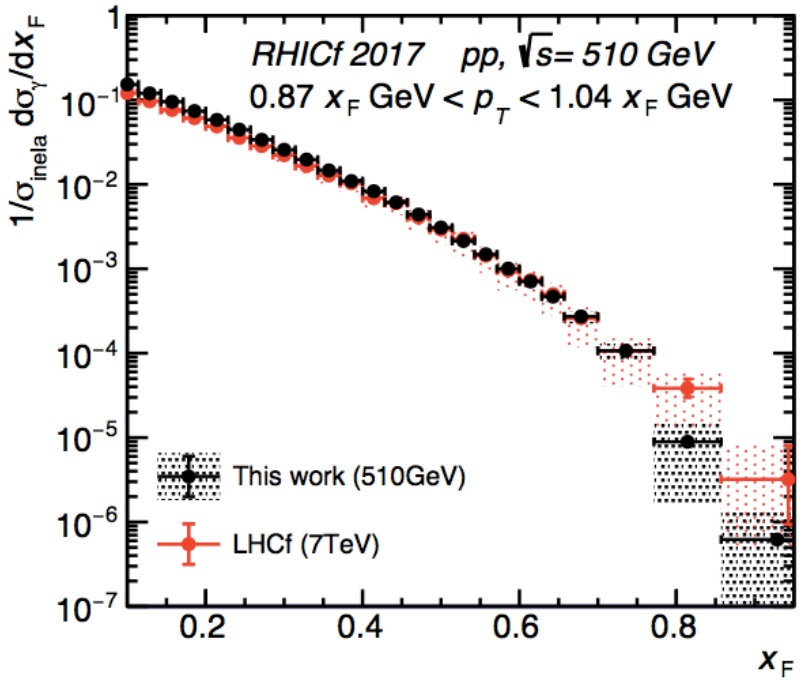


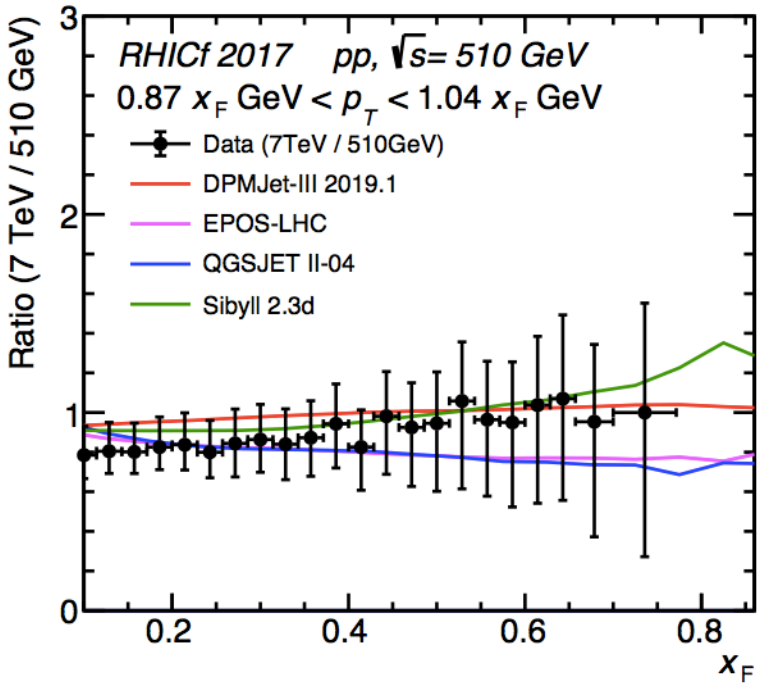
- DPMJet-III 2019.1 and EPOS-LHC well reproduce the data in the lower x_F region, but predict larger flux in the higher x_F.
- QGSJET-II 04 and Sibyll 2.3d show good agreement with data in the higher η, but show softer and harder slope in the lower η.

New result!

Photon cross section

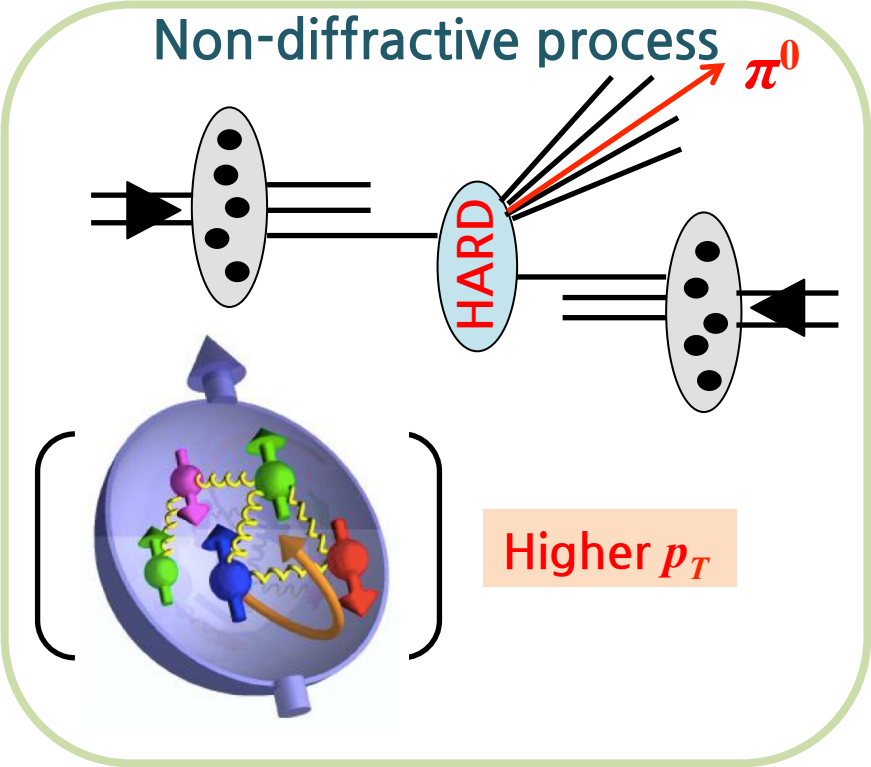
arXiv:2203.15416

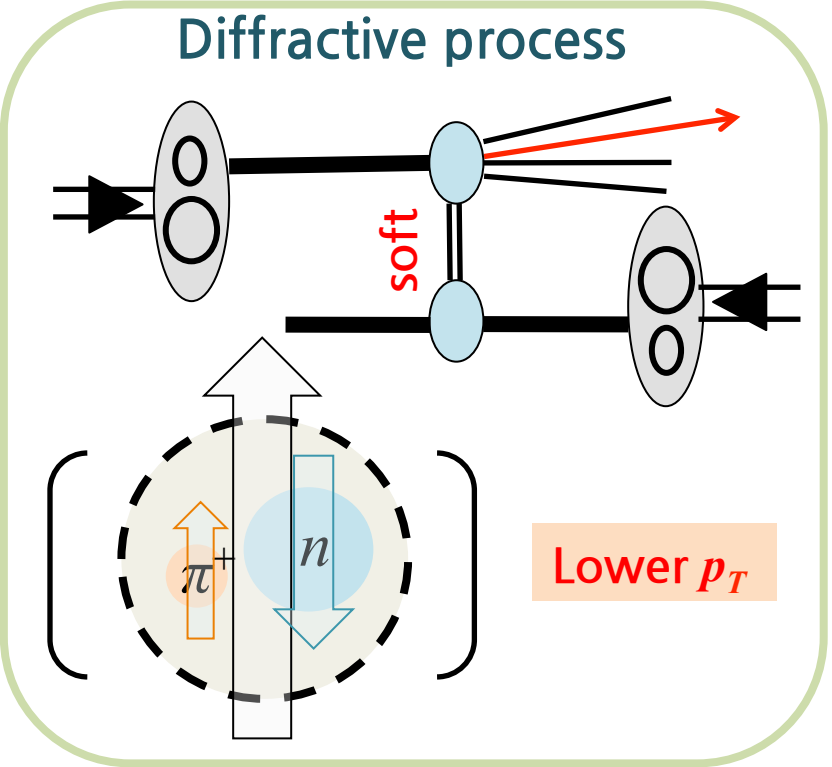




- RHICf result is consistent with LHCf result within the uncertainty.
- However, if the x_F scaling raw works or there is still a weak x_F dependence is not clear due to the uncertainty. → Will be more clear in the future publications.
- Comparison for neutron will also be studied soon.

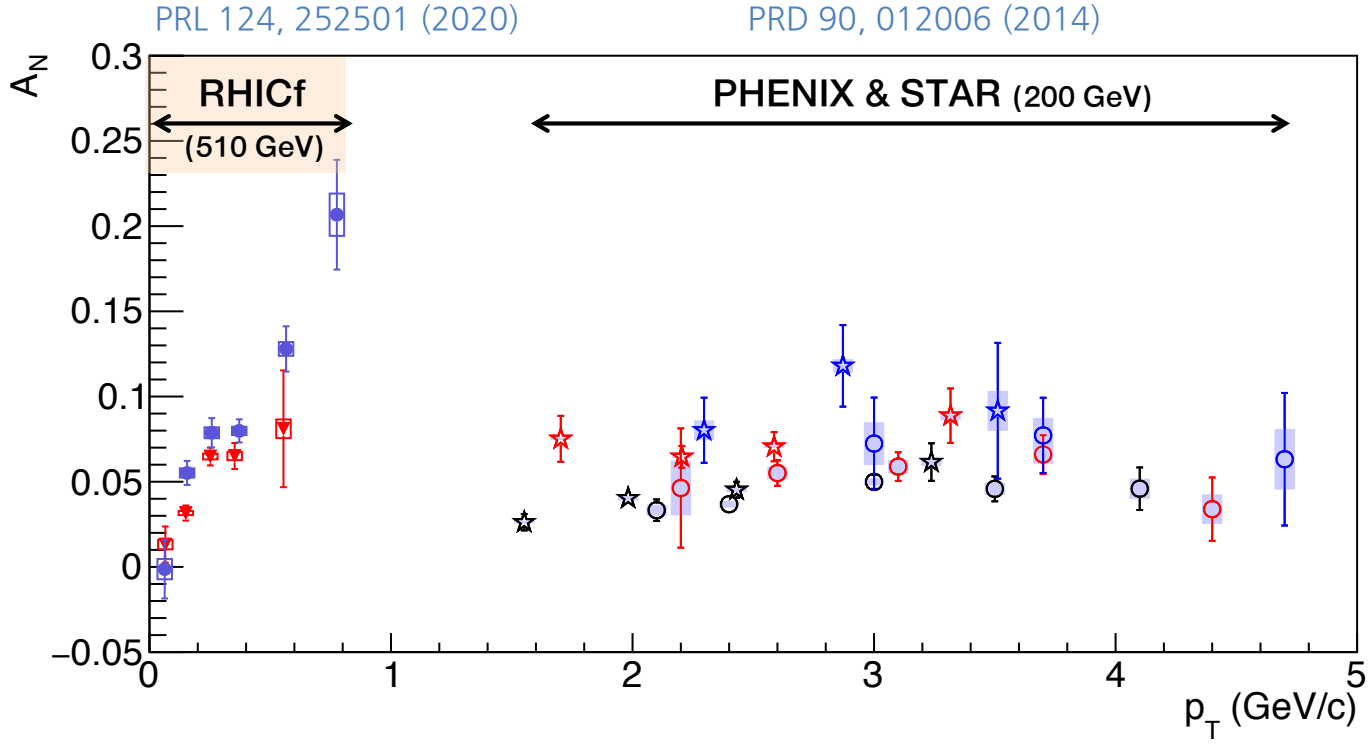
2. A_N measurement (neutral pion)





- The π^0 asymmetry has been measured and studied only in the quarks and gluons' degrees of freedom.
- In order to study a possible diffractive contribution to the π^0 asymmetry, the RHICf experiment measured the A_N for very forward π^0 production.

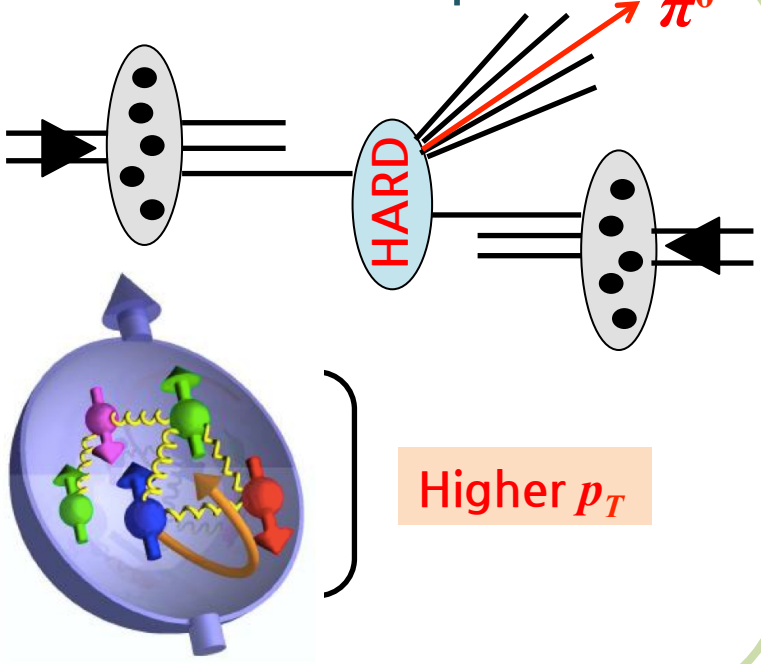
2. A_N measurement (neutral pion)



- Very forward ($\eta > 6$) neutral particle A_N is an important observable to study the spin-involved diffractive particle production mechanism.
- RHICf data showed a possible diffractive contribution to the finite π^0 A_N.
- Multi-dimensional analysis will be started using STAR detectors.

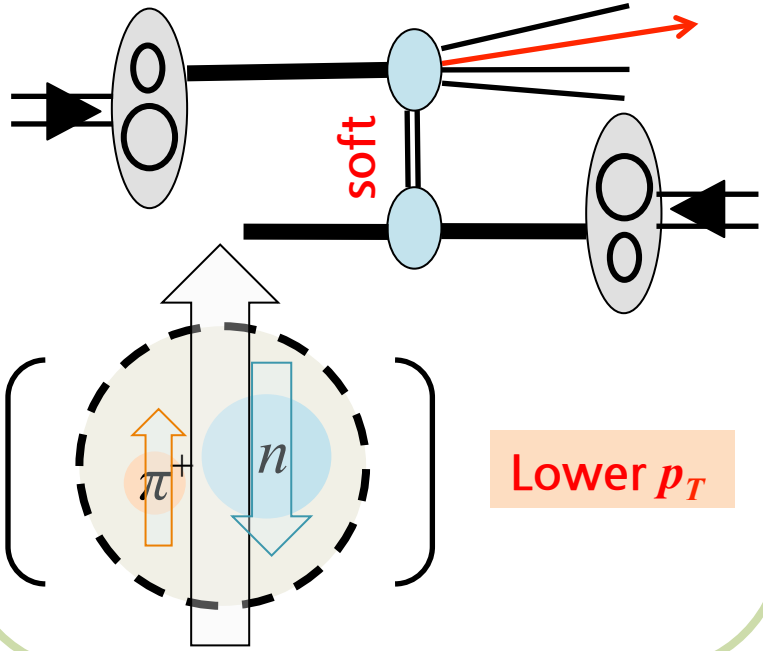
2. A_N measurement (neutral pion)

Non-diffractive process

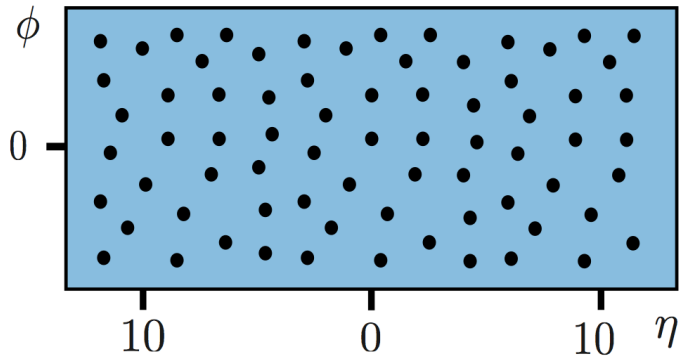


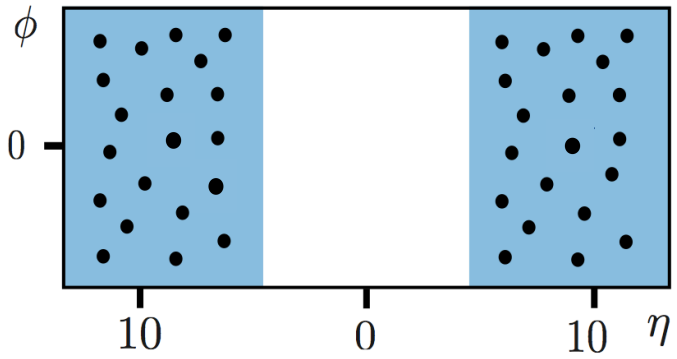
Higher p_T

Diffractive process

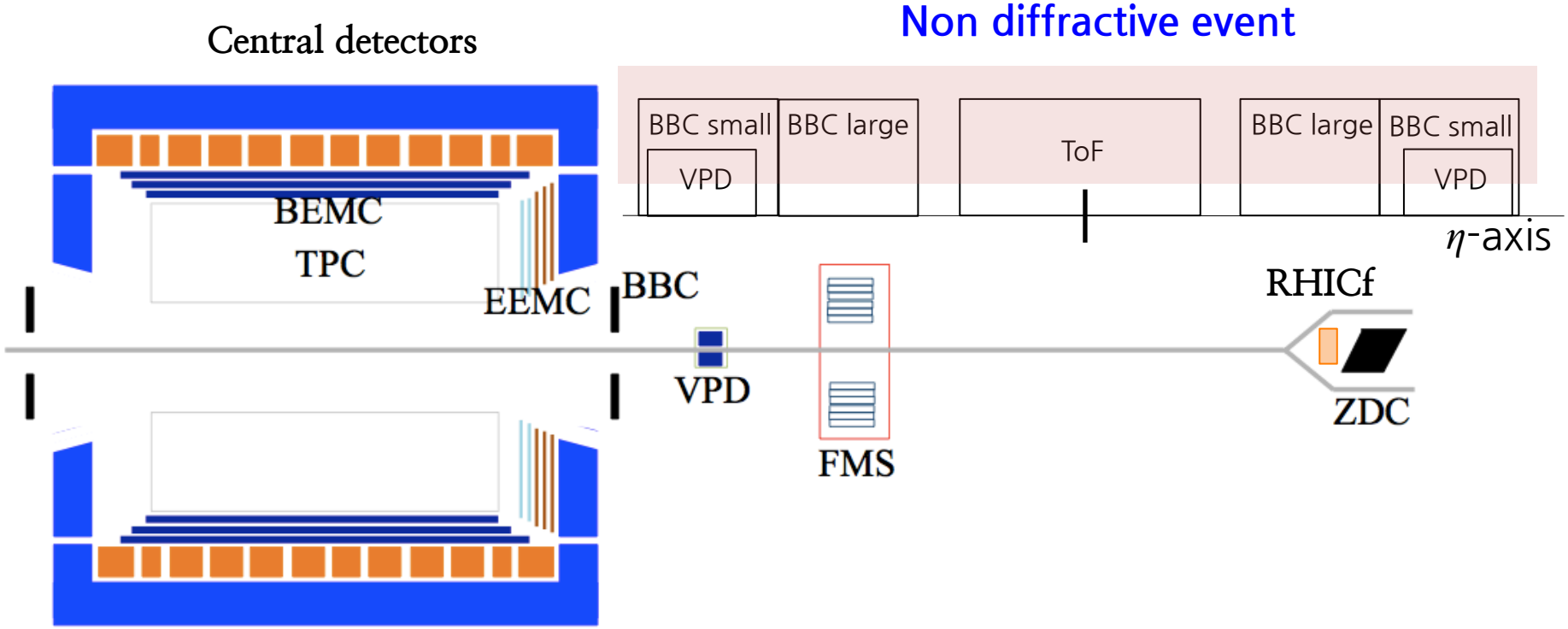


Lower p_T



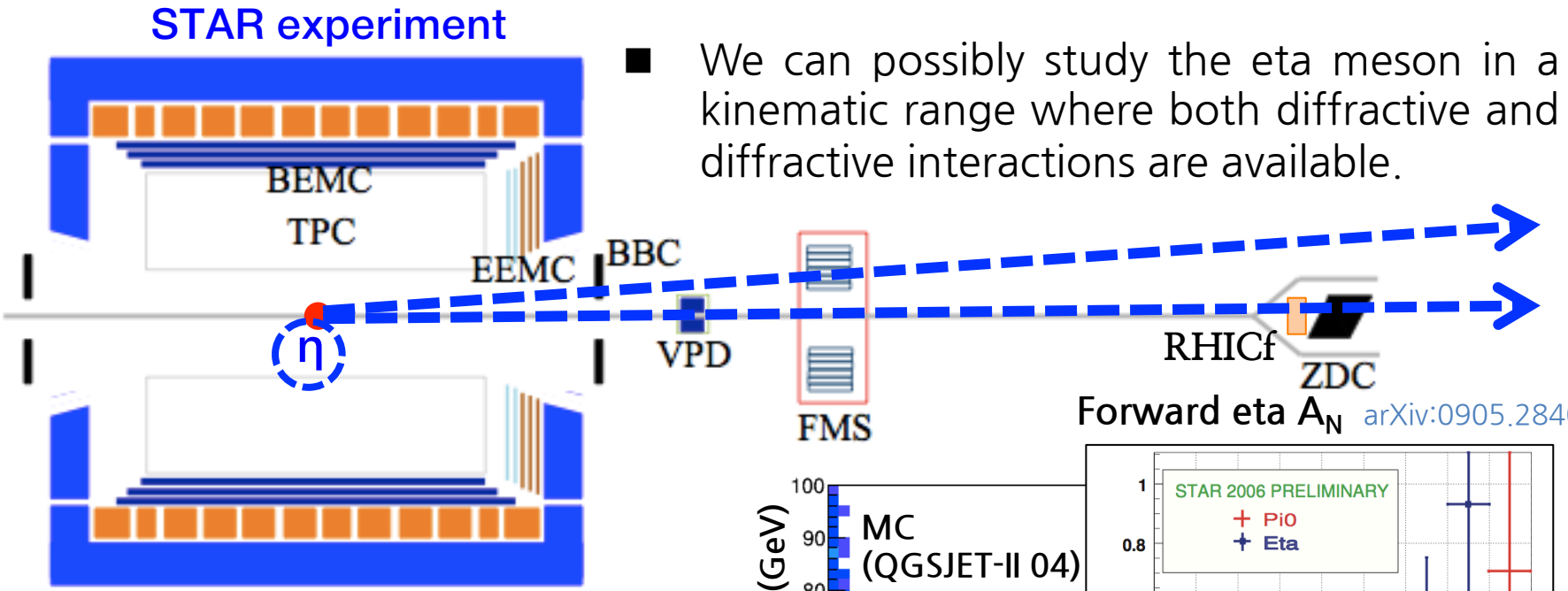


RHICf-STAR combined analysis



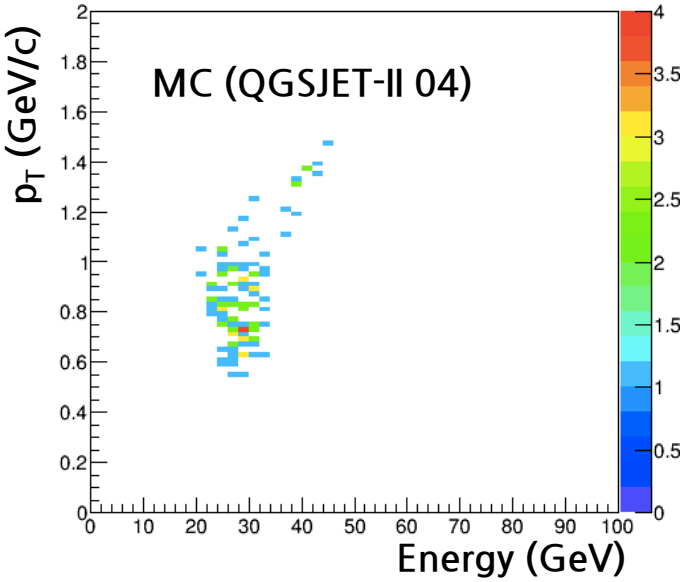
- Using STAR ToF, BBC, and VPD, we can study the detector correlation or event type dependence for the very forward π^0 A_N.
- For example, there should be signals in the TOF, BBC, and VPD if a π^0 comes non-diffractive event.
- Roman pot is also crucial for studying the event type dependence.

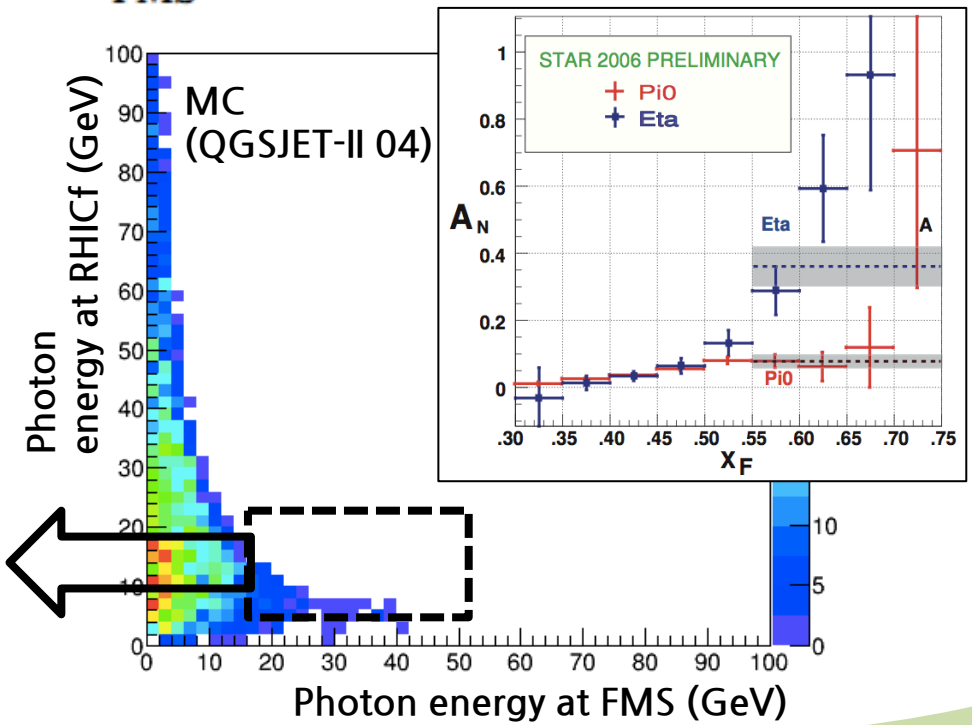
RHICf-STAR combined analysis



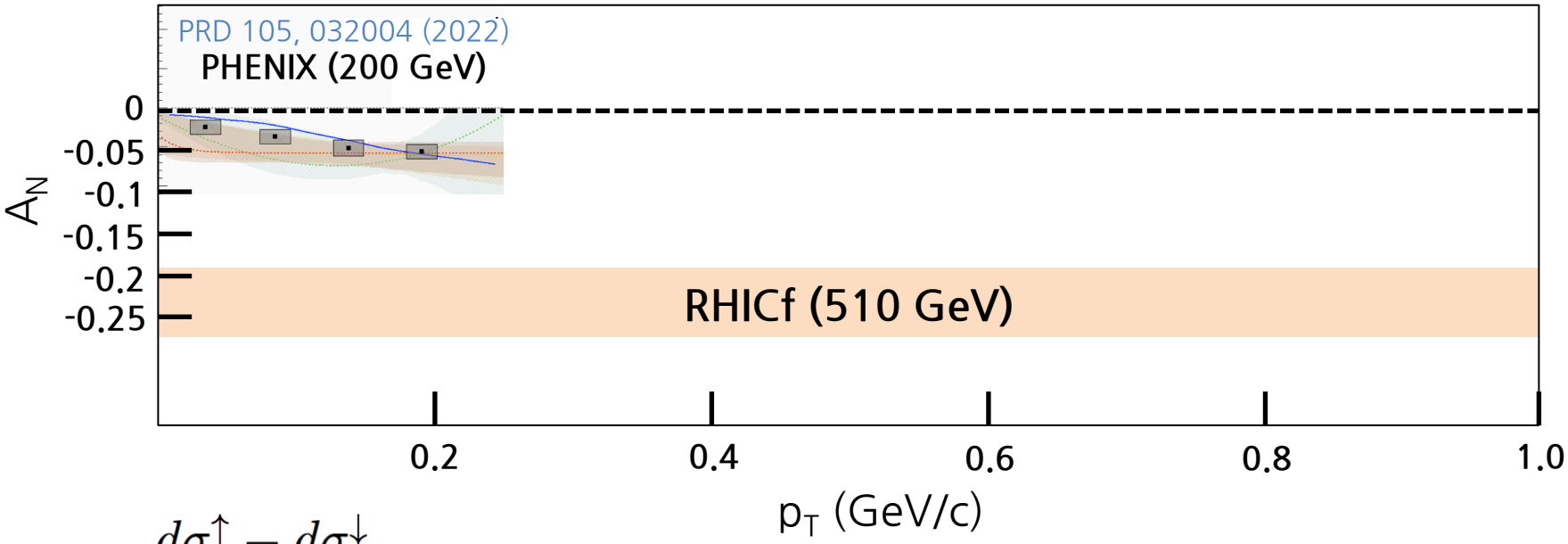
- We can possibly study the eta meson in a kinematic range where both diffractive and diffractive interactions are available.

Forward eta A_N arXiv:0905.2840v1





2. A_N measurement (neutron)



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

$$= \frac{\sum_X |\langle cX|T|\uparrow\rangle|^2 - \sum_X |\langle cX|T|\downarrow\rangle|^2}{\sum_X |\langle cX|T|\uparrow\rangle|^2 + \sum_X |\langle cX|T|\downarrow\rangle|^2}$$

$$= \frac{-2\mathrm{Im}\sum_X \langle cX|T|-\rangle\langle +|T^{\dagger}|cX\rangle}{\sum_X |\langle cX|T|+\rangle|^2 + \sum_X |\langle cX|T|-\rangle|^2}$$

- Neutron A_N can be explained by an interference between spin flip and non-flip amplitudes.
- RHICf data can test the π and a_1 exchange framework in a wide p_T region.

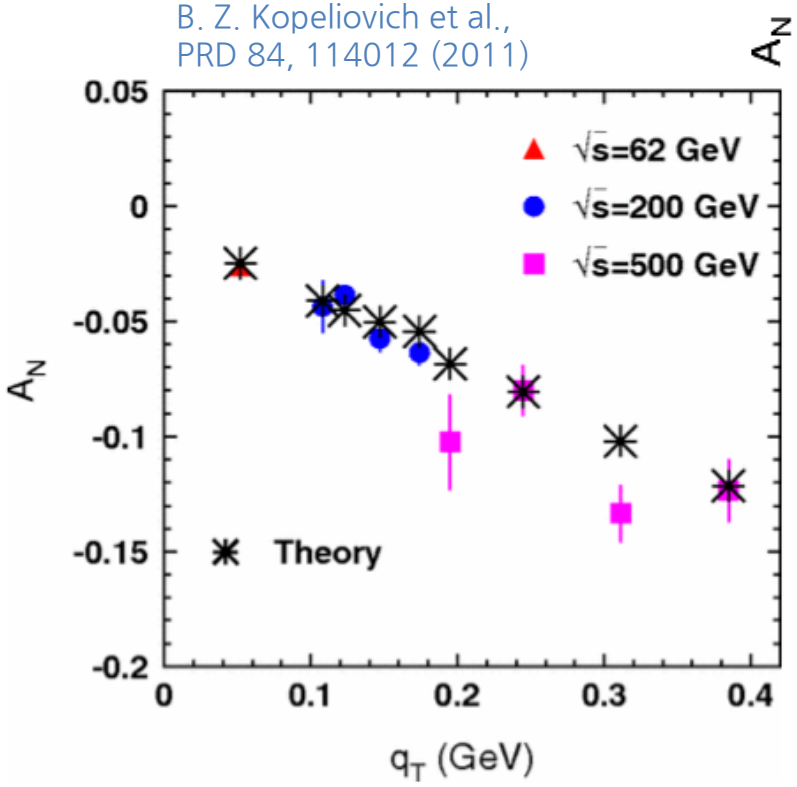
π exchange: spin flip

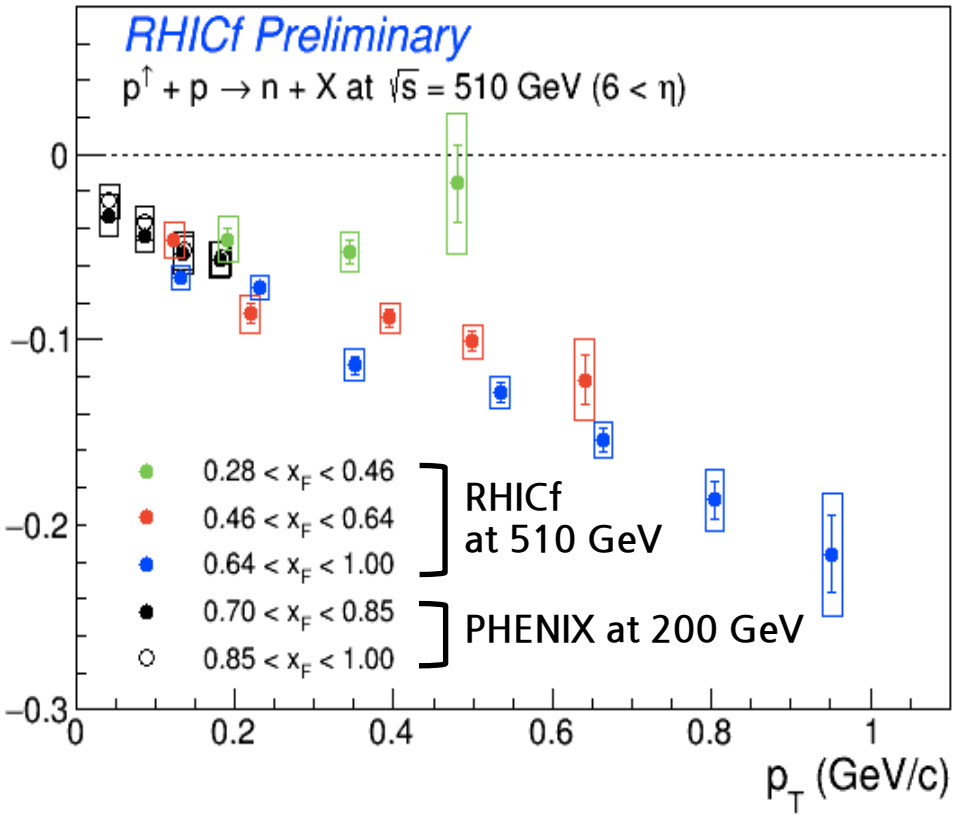
a_1 exchange: spin non-flip

New preliminary result!

Neutron A_N

B. Z. Kopeliovich et al.,
PRD 84, 114012 (2011)

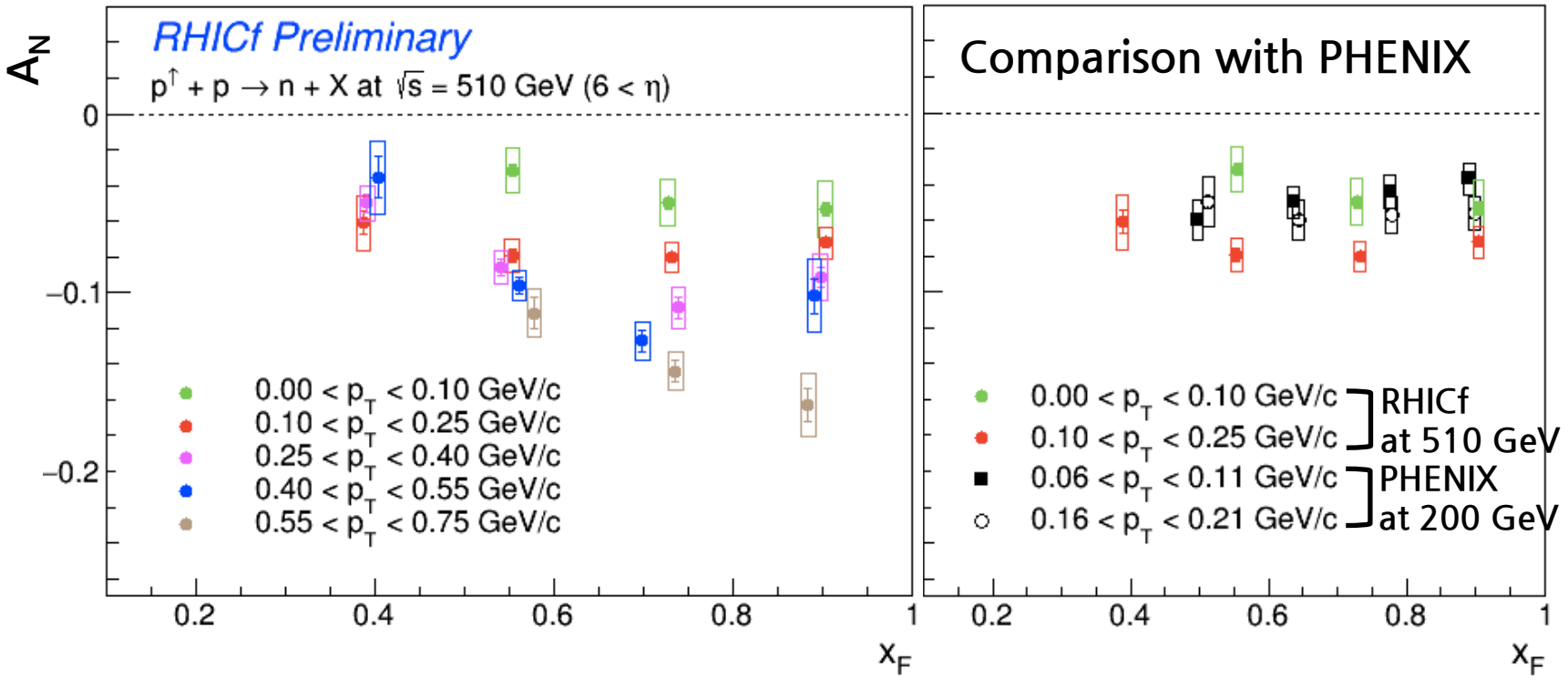




- π and a_1 exchange model predicts that the A_N increases in magnitude with p_T without x_F dependence.
- In higher x_F, the A_N increases in magnitude with p_T up to 1 GeV/c.
- There seems a x_F dependence especially in the higher p_T region.

New preliminary result!

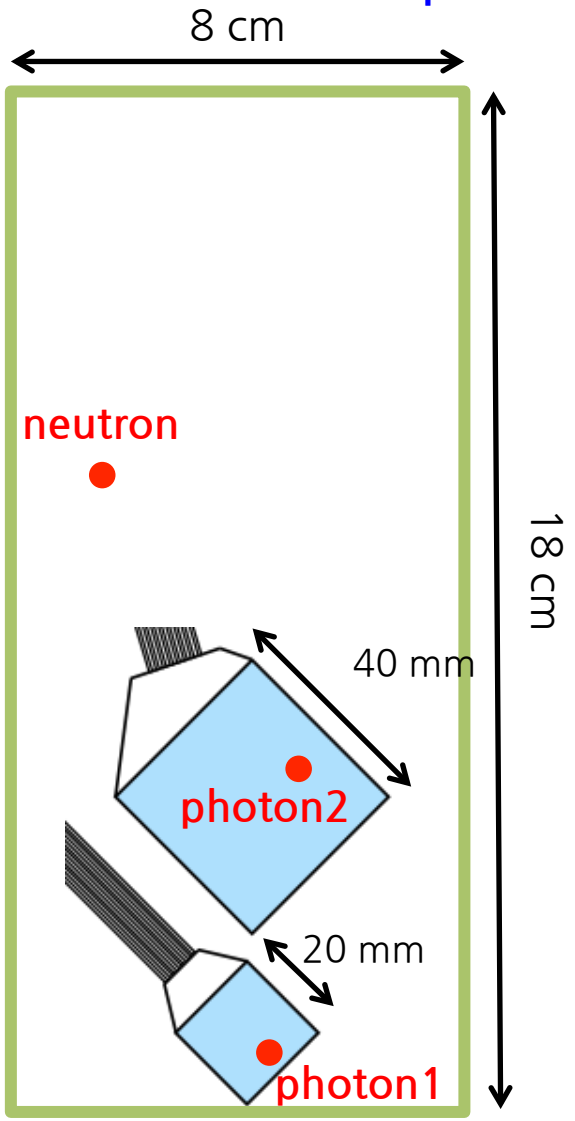
Neutron A_N



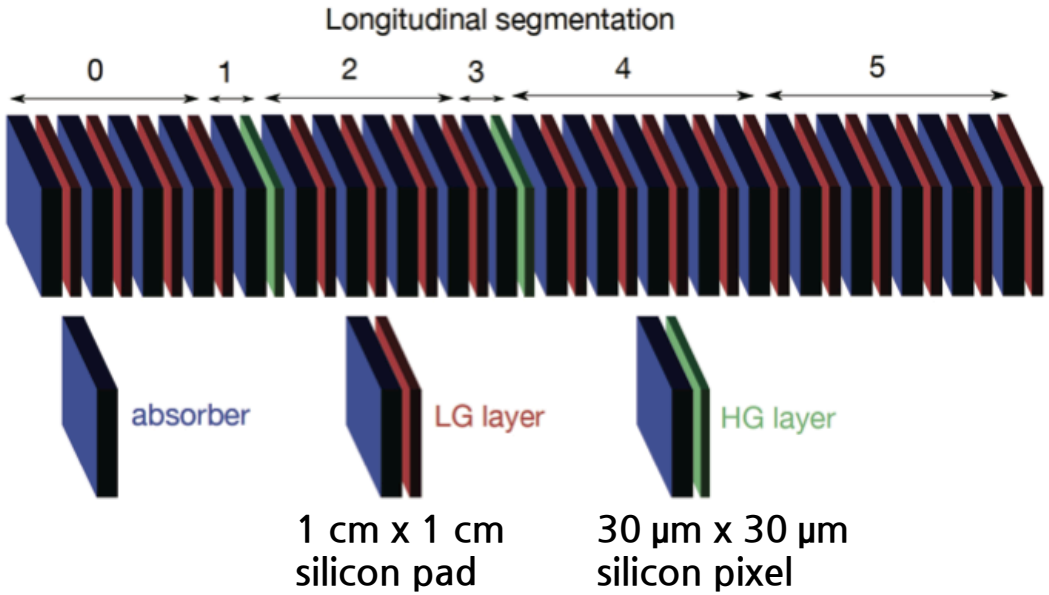
- In the lower p_T region, the A_Ns are flat showing no x_F dependence.
- In the higher p_T region, it seems that there is a x_F dependence.
- Whether the x_F dependence is true or not will become clear with more precise background estimation.

RHICf-II experiment

RHICf-II detector acceptance

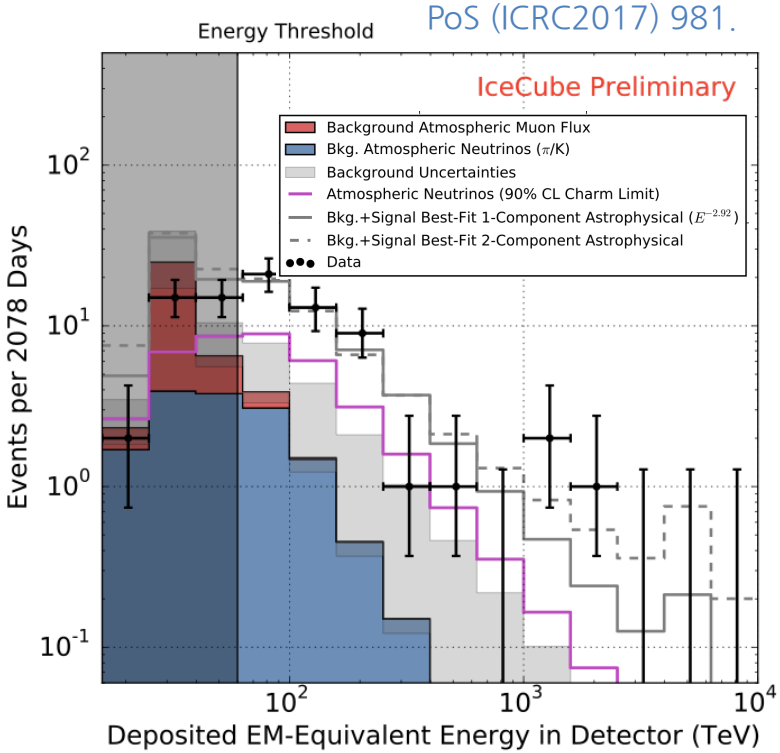


ALICE FoCal-E

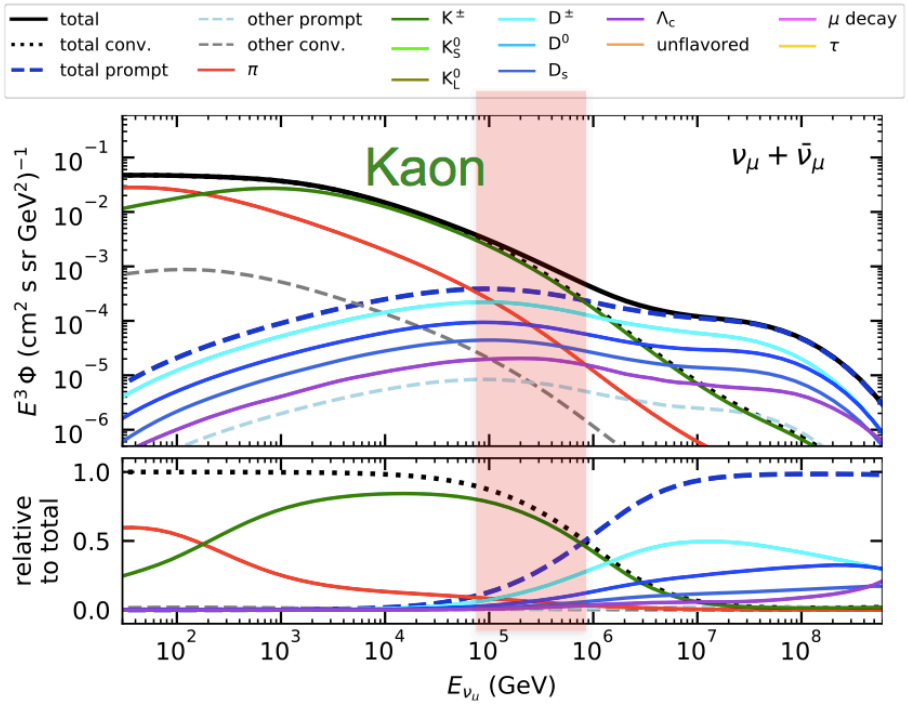


- RHICf-II experiment is to measure more various particles with larger detector.
- Technology of the ALICE FoCal-E is transferred to the RHICf-II detector.
- Unfortunately, a possible RHICf-II operation schedule at STAR was canceled due to lack of human resources.

Kaon study at RHICf-II



PoS (ICRC2017) 981.

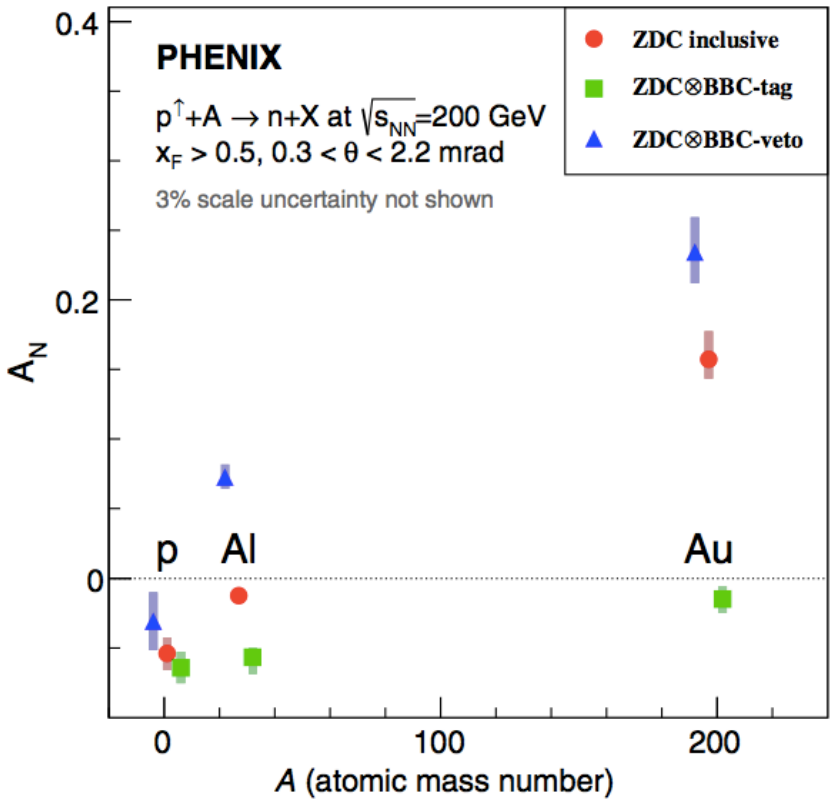


- Astrophysical neutrinos can enable us to understand the acceleration mechanism and source of the UHECRs.
- Atmospheric neutrino study is important to determine the background for the astrophysical neutrino search.
- One of the main sources for the atmospheric neutrino flux is kaon.

A_N study at RHICf-II

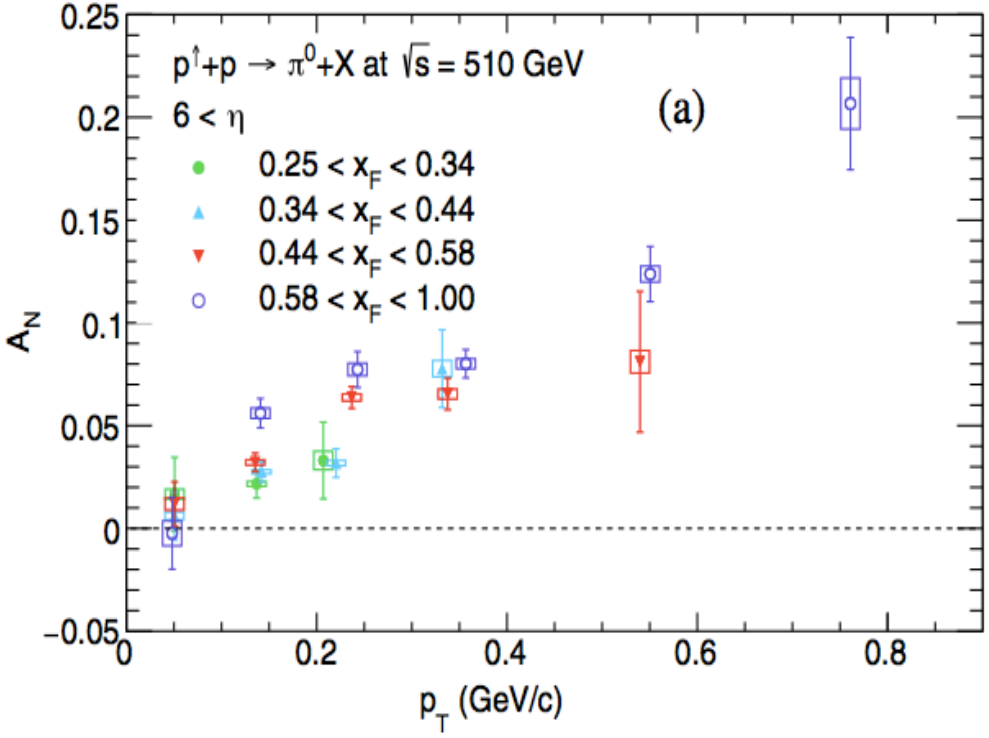
Neutron A_N

PRL 120, 022001 (2018)



π^0 A_N

PRL 124, 252501 (2020)



- With pA collisions, we can study the A dependence of the neutron A_N in more detail and also measure that of π^0.
- A_N of Λ and K^0_S can be measured to broaden our knowledge for the particle production mechanism and a possible origin of the RHICf π^0 result.

Summary

- In June 2017, the RHICf experiment measured the cross section and the A_N for very forward particles.
- Within the uncertainties, the RHICf photon cross section at $\sqrt{s}$ = 510 GeV showed a x_F scaling with that of LHCf at $\sqrt{s}$ = 7 TeV.
- There seems to be a x_F dependence in the neutron A_N especially in the higher p_T region.
- RHICf-STAR detector correlation will be studied to better understand the A_N for very forward π^0 (and neutron) production.
- A possible RHICf-II schedule was canceled by the lack of human resources.