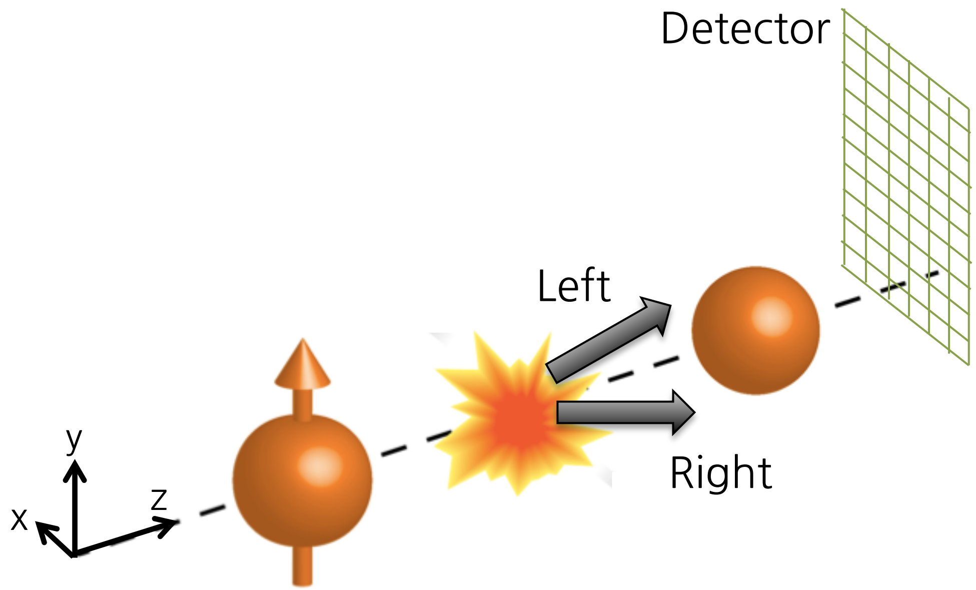
Transverse single-spin asymmetry measurement at the RHICf experiment

Minho Kim (RIKEN BNL Research Center)
on behalf of the RHICf collaboration

RIKEN's Programs for Junior Scientists

第18回高エネルギーQCD·核子構造勉強会

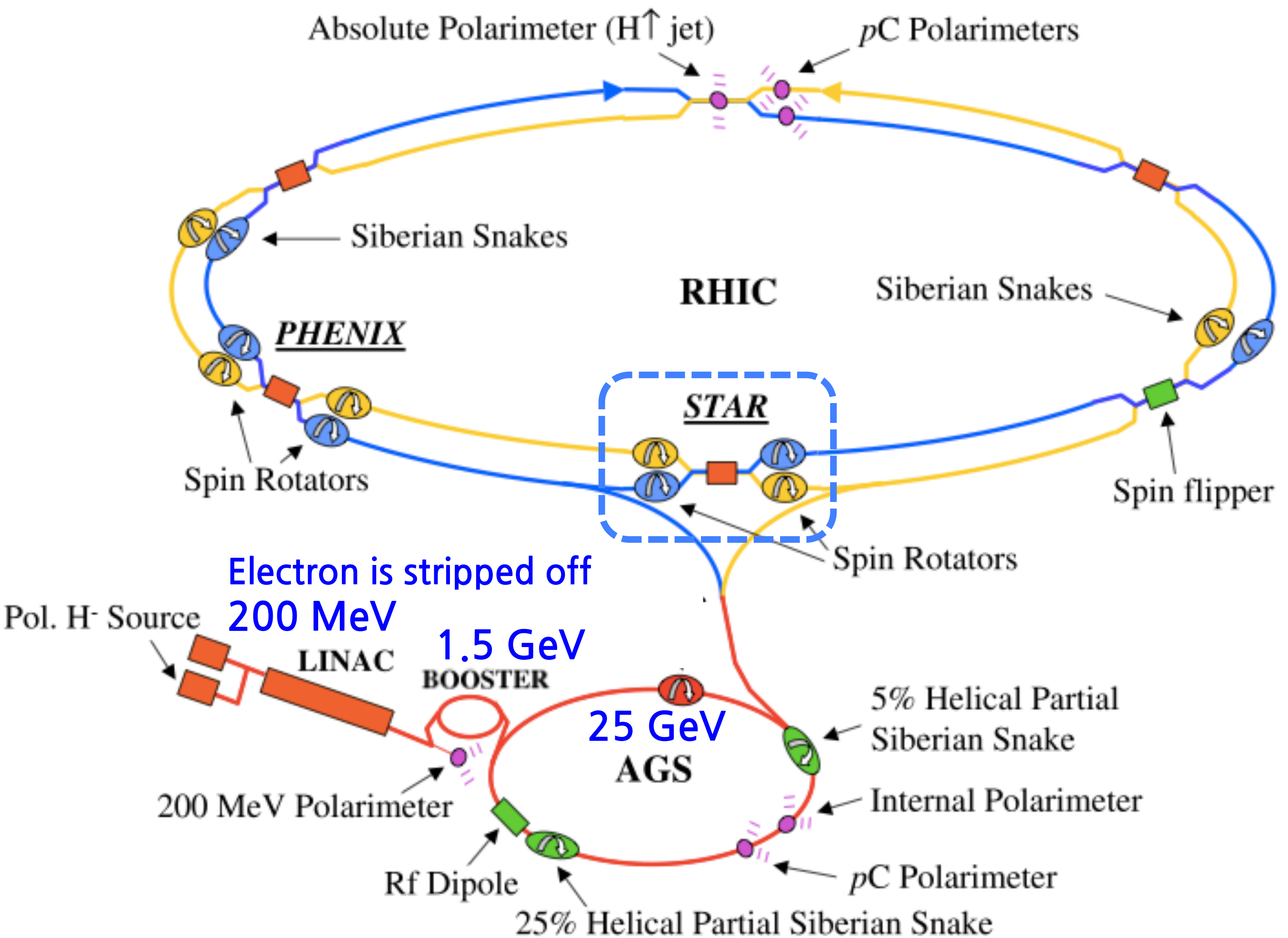
Transverse single-spin asymmetry (A_N)



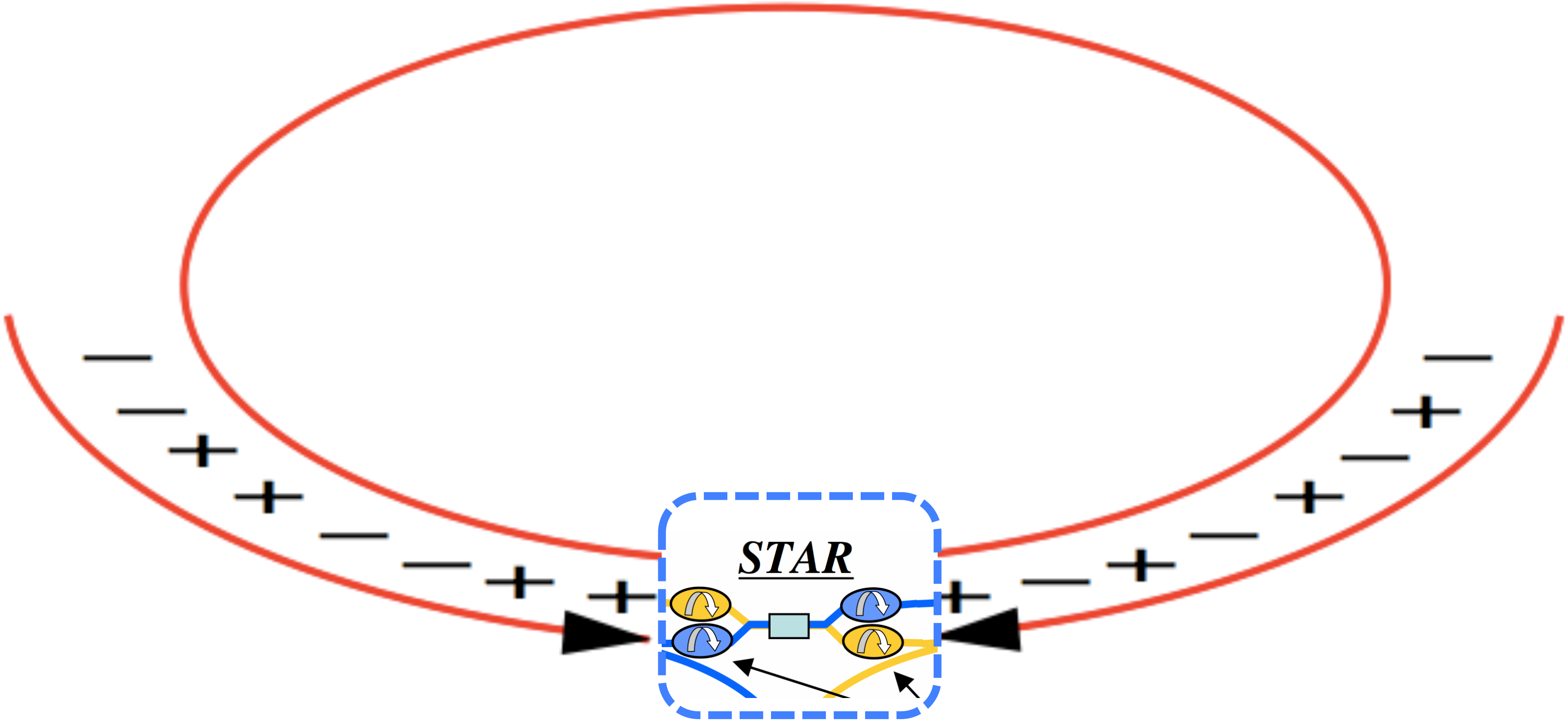
$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}} = \frac{\sigma_L^{\uparrow} - \sigma_L^{\downarrow}}{\sigma_L^{\uparrow} + \sigma_L^{\downarrow}}$$

- In polarized p + p collision, A_N is defined as a left-right cross section asymmetry of a specific particle.
- In the RHICf experiment, with the cross section we also measured the A_Ns for very forward neutron and π^0 productions.
  - Why do we measure the A_N for very forward neutron and π^0 production?
  - How do we measure and analyze it?

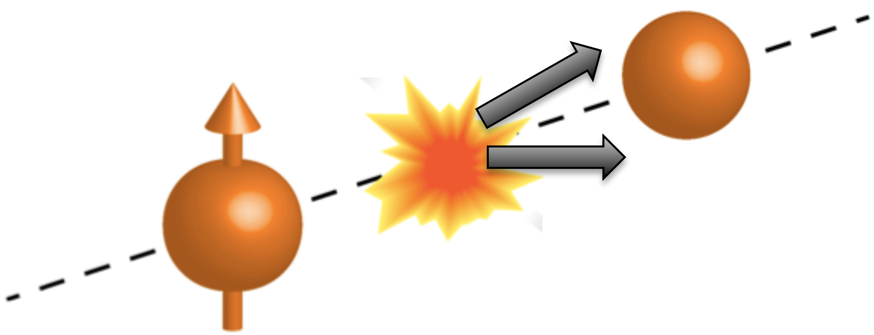
Relativistic Heavy Ion Collider (RHIC)



Polarized p + p collision

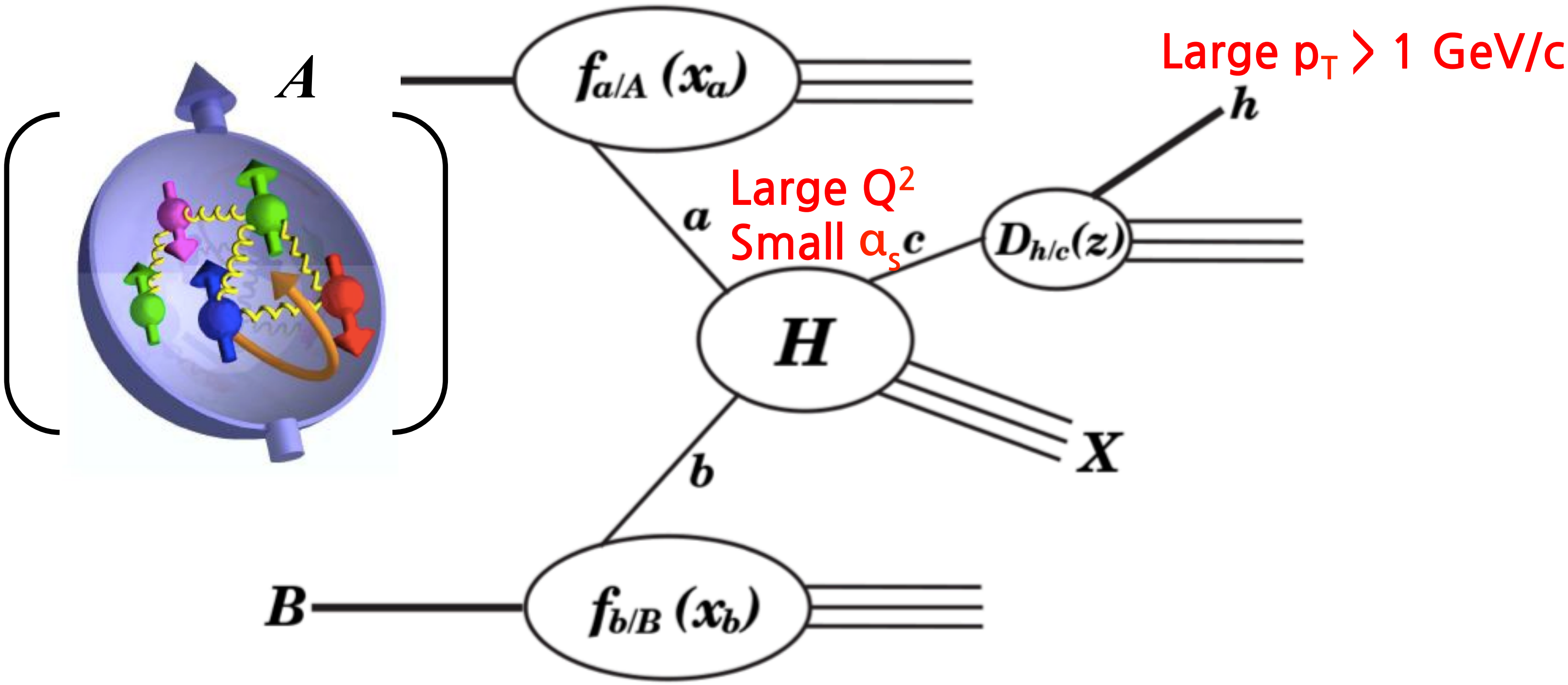


- To estimate the A_N, polarization of only one side proton beam is considered.



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

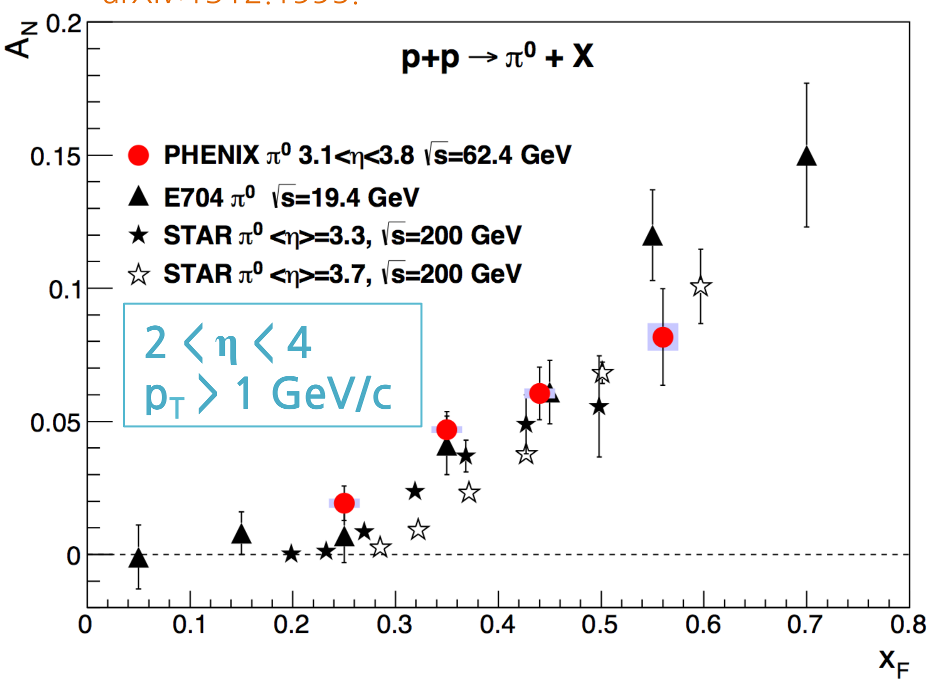
Non-diffractive process

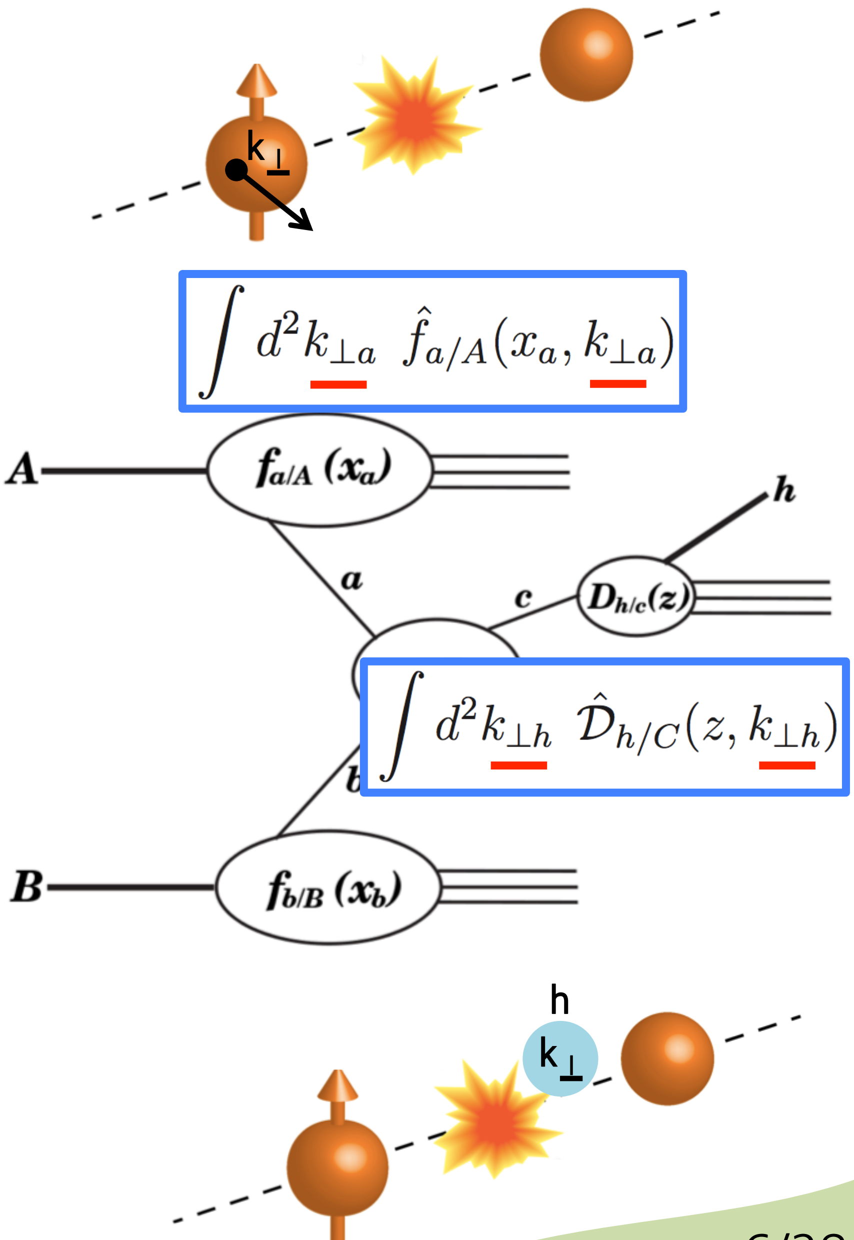


- Non-diffractive process is described by a hard scattering between quarks and gluons.
- By hard scattering, there is a large Q^2 and the large Q^2 makes the p_T of the fragmented hadron usually larger than 1 GeV/c.

A_N for forward π^0 production

arXiv:1312.1995.

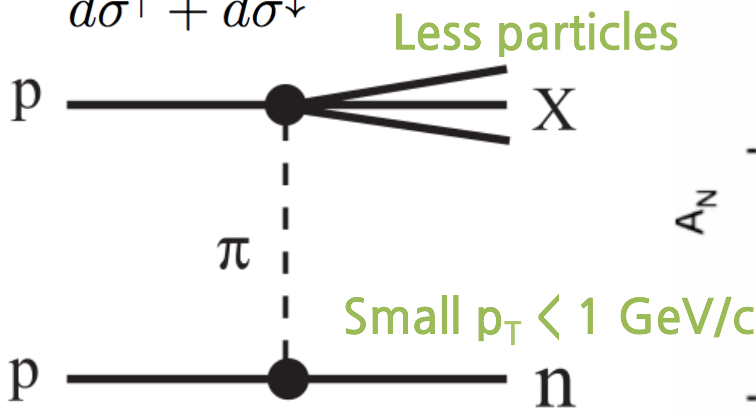




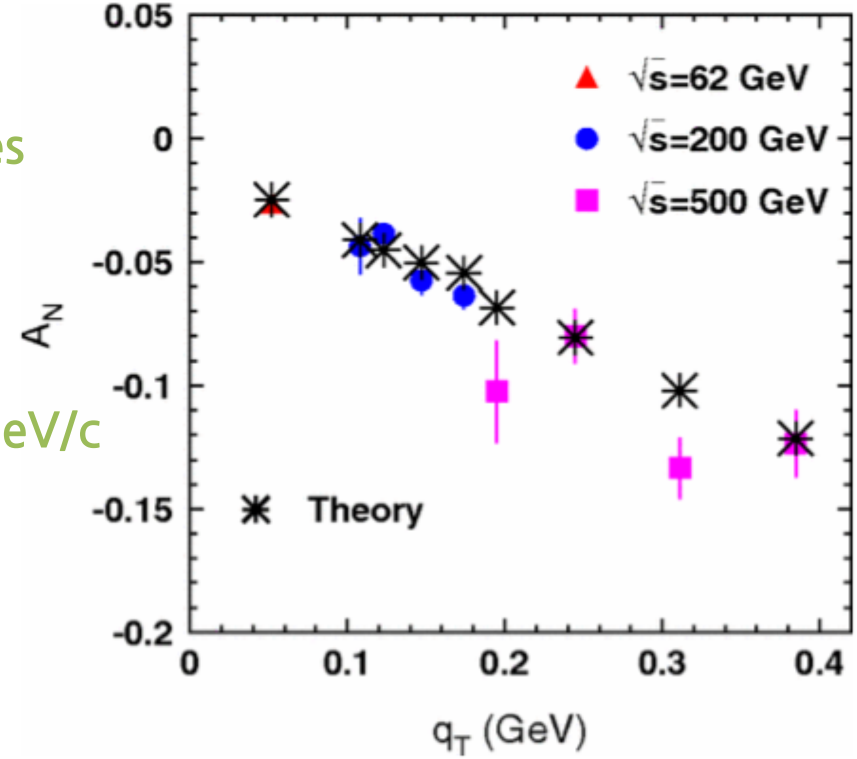
- A_N for forward π^0 production has been understood based on the non-diffractive process.
- An intrinsic transverse momentum can be assumed in the initial or final state.

Diffractive process

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



B. Z. Kopeliovich et al., PRD 84, 114012.



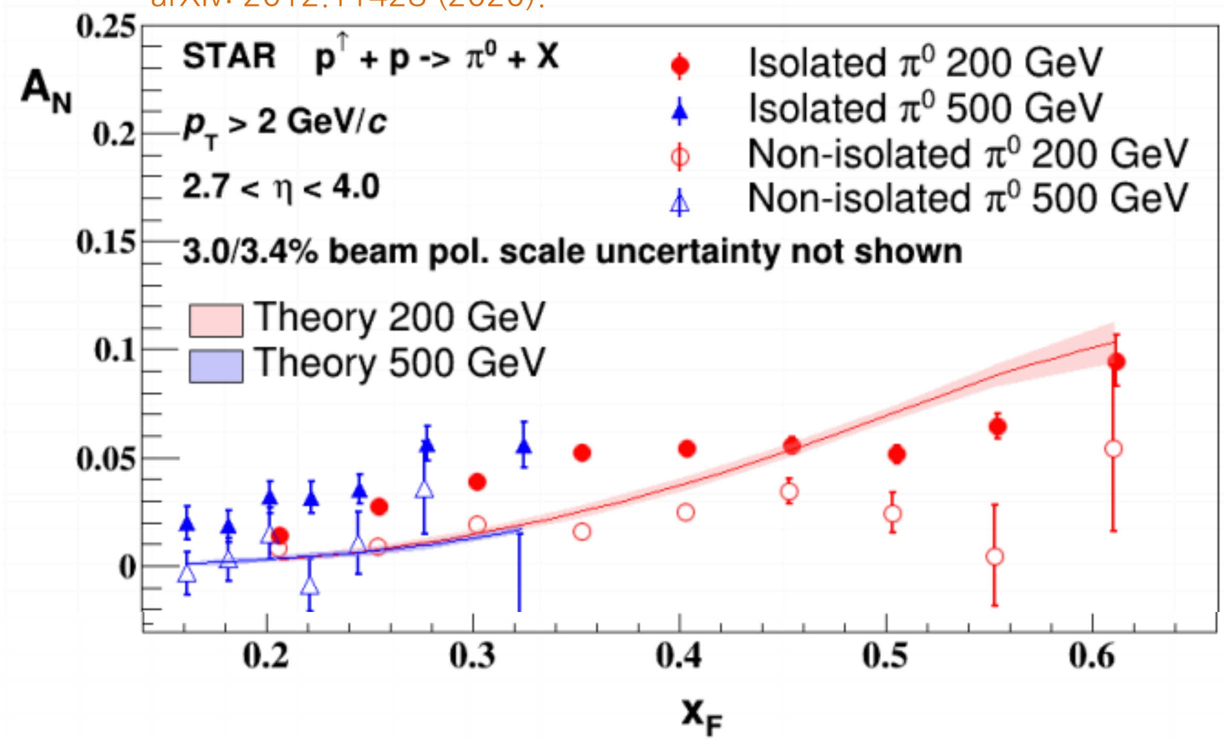
π exchange: spin flip

a_1 exchange: spin non-flip

- Diffractive process is described by a soft scattering in the mesonic degree of freedom.
- Very forward neutron A_N has been explained by an interference between spin flip (π exchange) and non-flip (a_1 exchange) amplitudes.

RHICf motivation for π^0

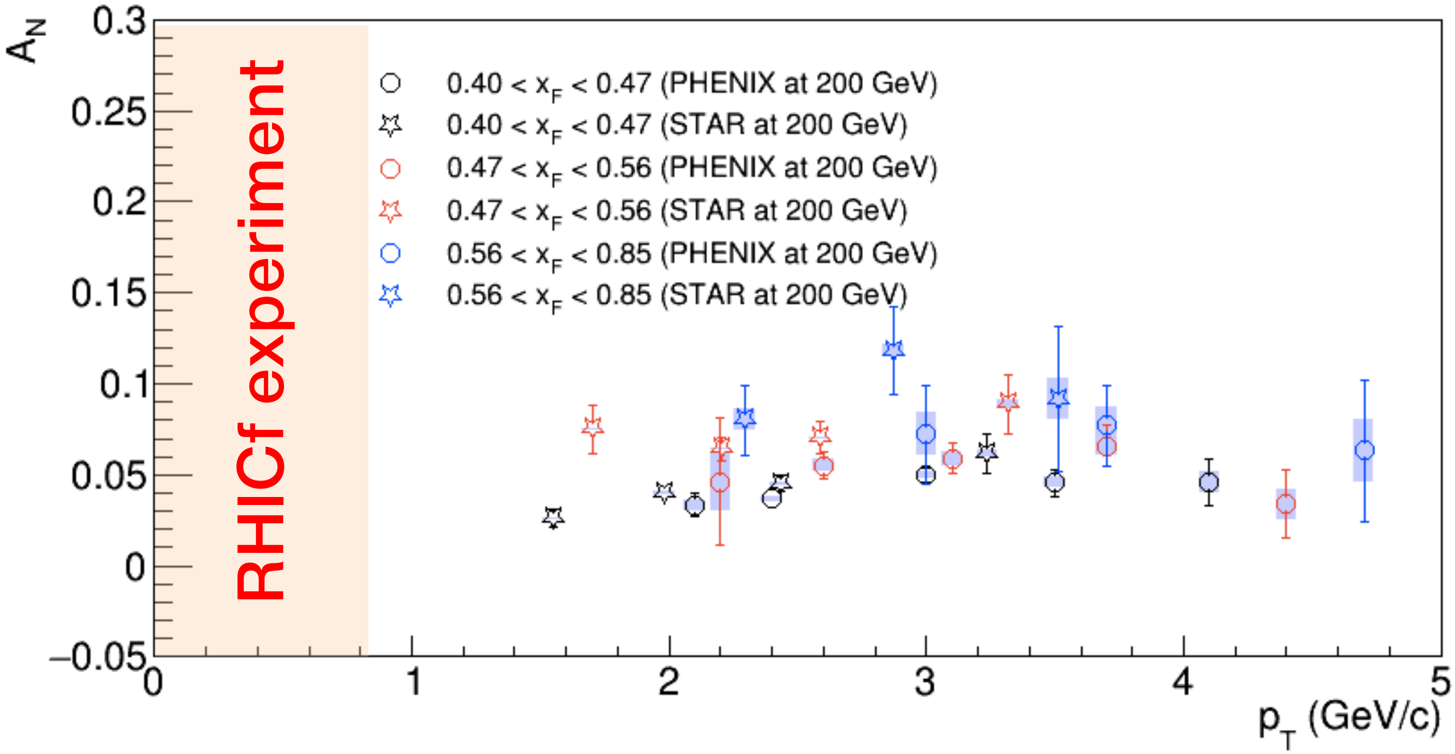
arXiv: 2012.11428 (2020).



$2.6 < \eta < 4$
$p_T > 1$ GeV/c

- A_N of isolated π^0 is larger than that of non-isolated π^0.
- The condition, isolated, corresponds to large z which can carry large fraction of the spin effect making larger A_N.
- On the other hand, the diffractive process may have a finite contribution to the π^0 A_N as well as the non-diffractive one.

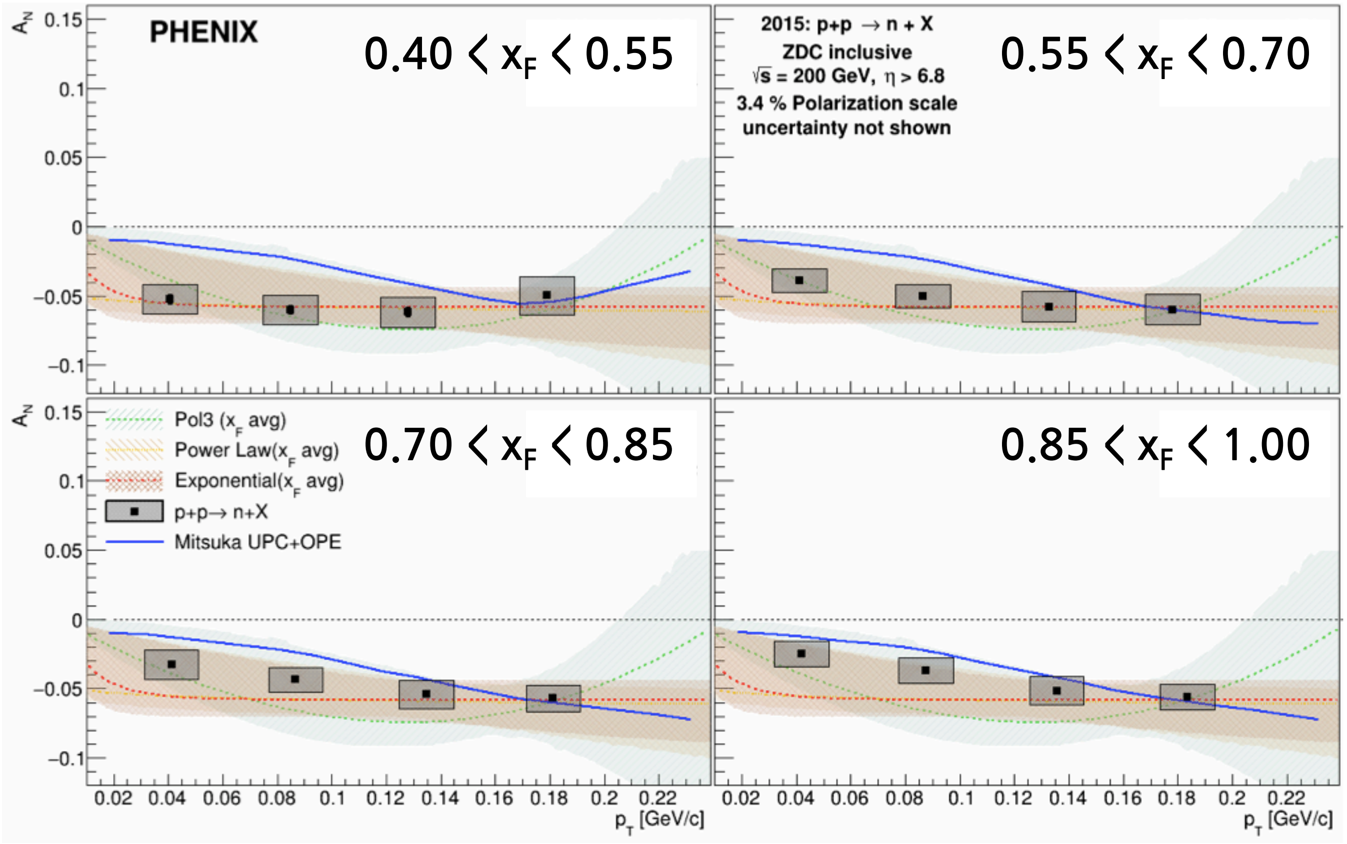
RHICf motivation for π^0



- No detailed measurement ever for the p_T < 1 GeV/c.
- RHICf experiment measured the A_N for very forward π^0 production to study a possible diffractive contribution.

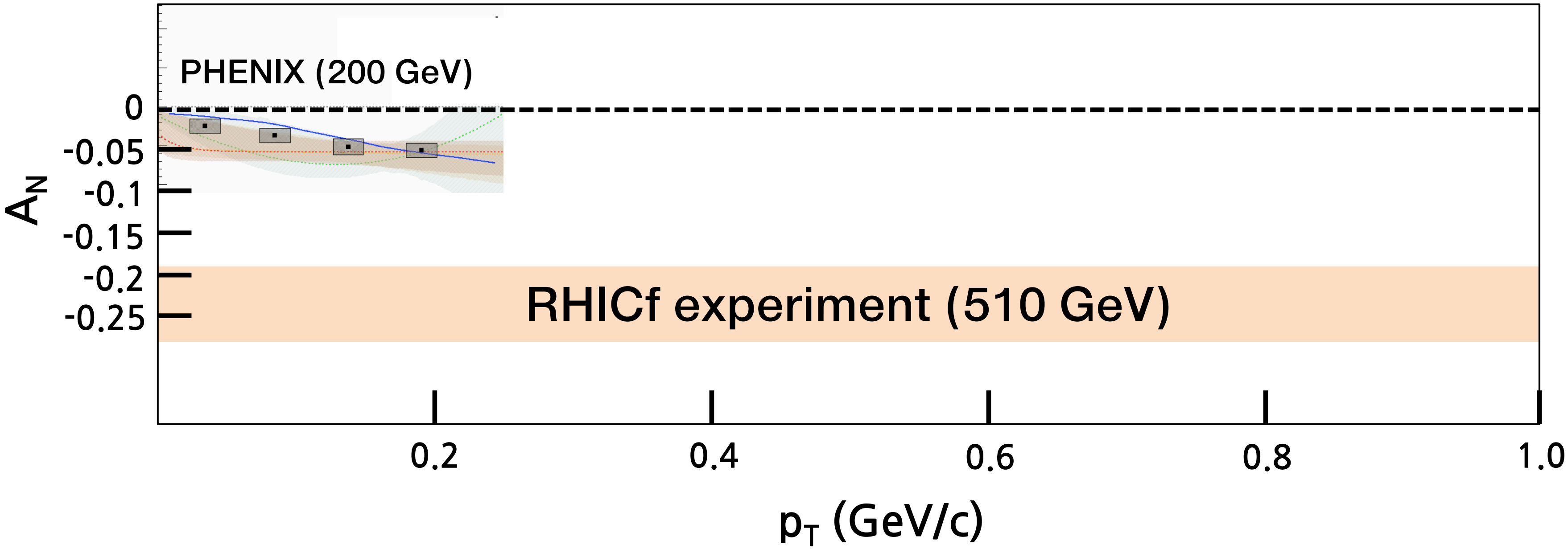
RHICf motivation for neutron

PRD 105, 032004.



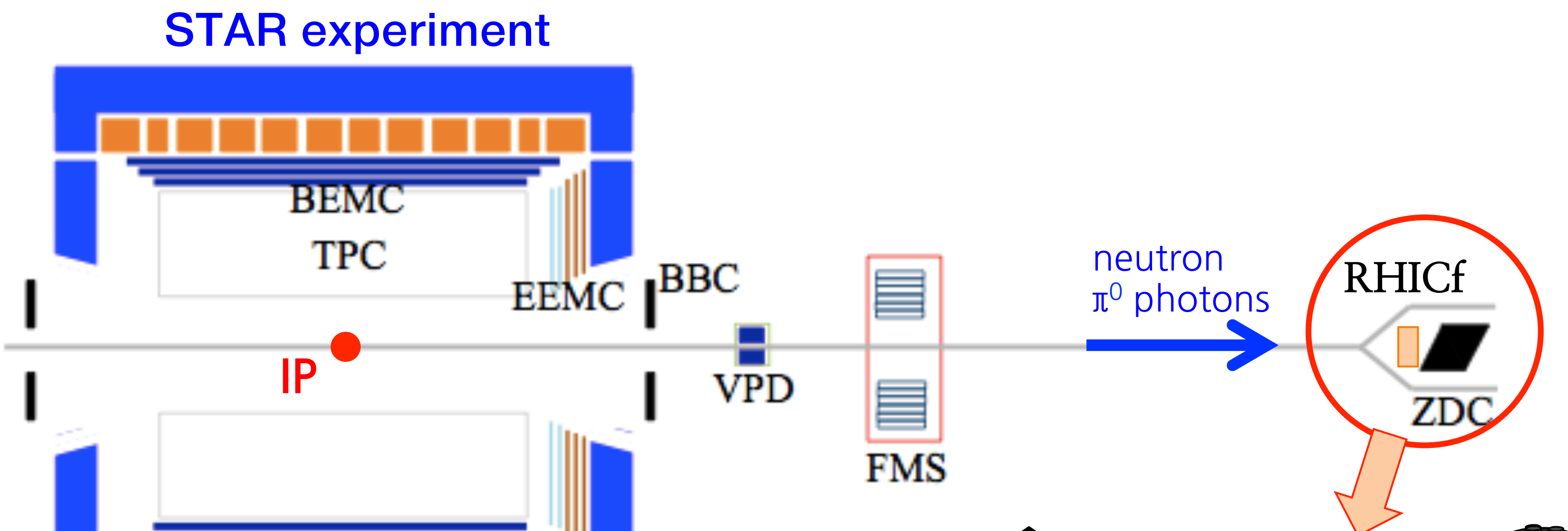
- The π and a_1 exchange model predicts that the A_N increases in magnitude with p_T without x_F dependence.
- Recently, unfolded A_N at PHENIX showed a consistent behavior with the model prediction.

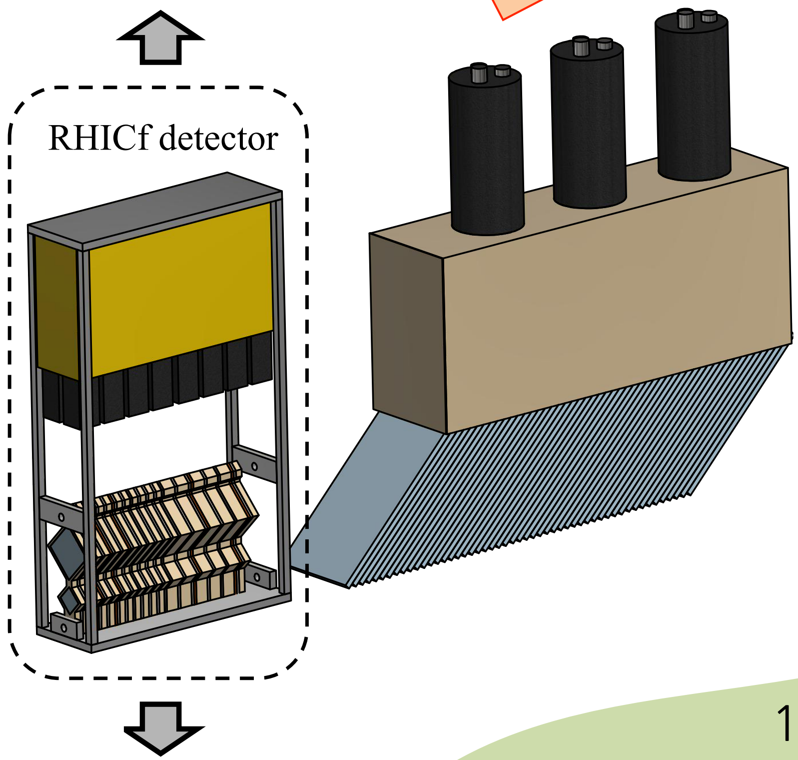
RHICf motivation for neutron



- RHICf experiment measured the neutron A_N up to the highest p_T region ever measured to test the π and a_1 exchange model in a wide p_T coverage.
- Comparison between RHICf and PHENIX data also should be done to make sure if there is collision energy dependence.

RHIC forward (RHICf) experiment

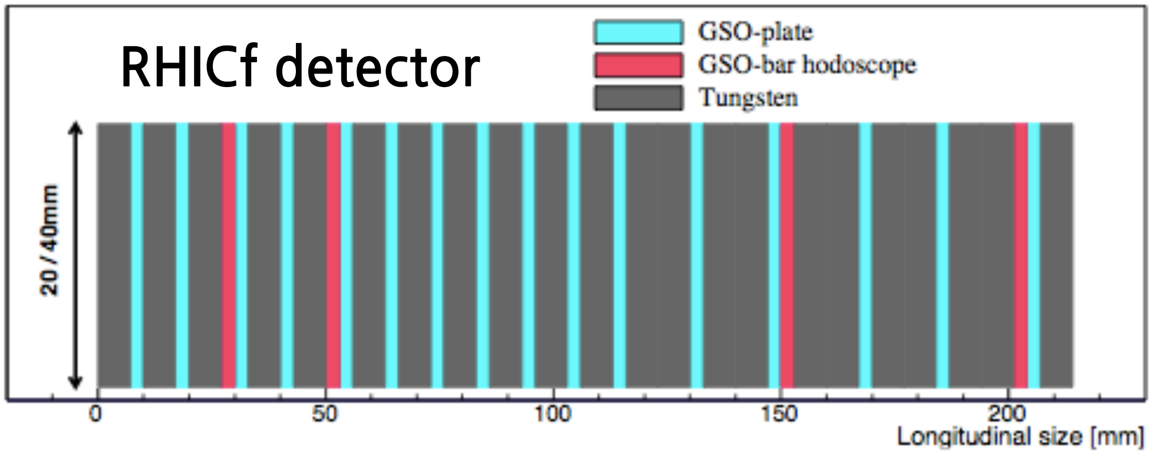




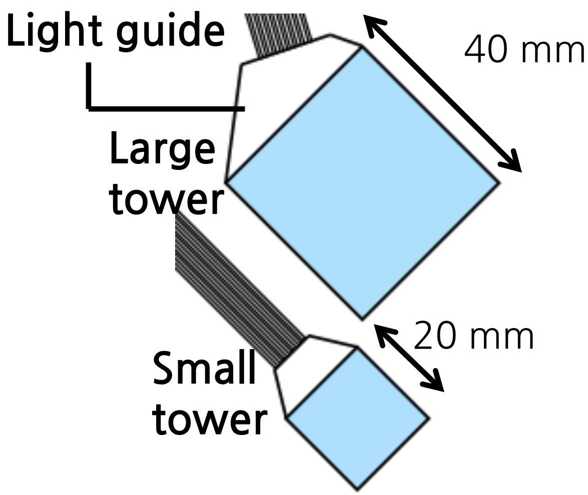
- Operated at STAR in polarized p + p collisions at $\sqrt{s}$ = 510 GeV in June 2017.
- RHICf detector was installed in front of the ZDC.
- $\eta > 6$,
  $0.2 < x_F < 1.0$, and
  $0.0 < p_T < 1.0$ GeV/c.

RHICf detector

Side view



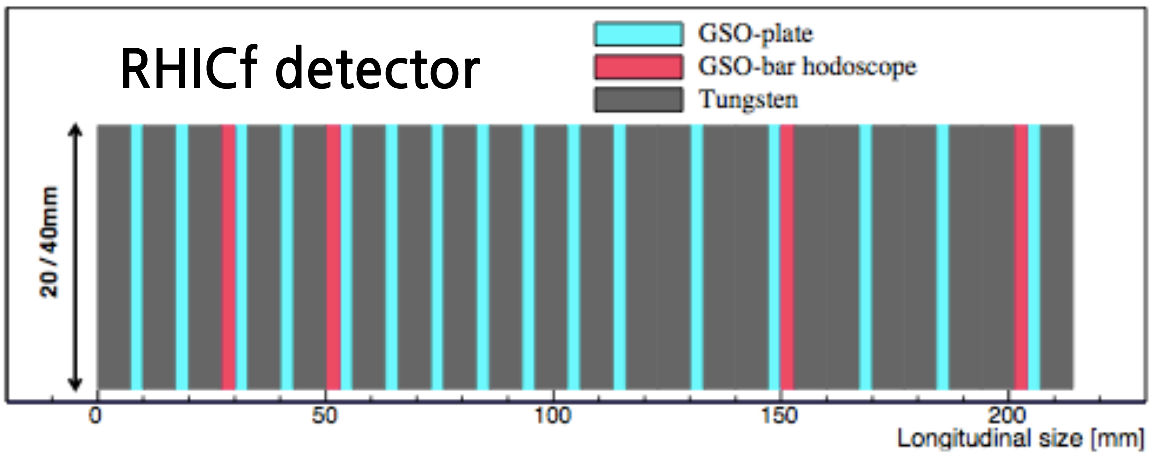
Front view



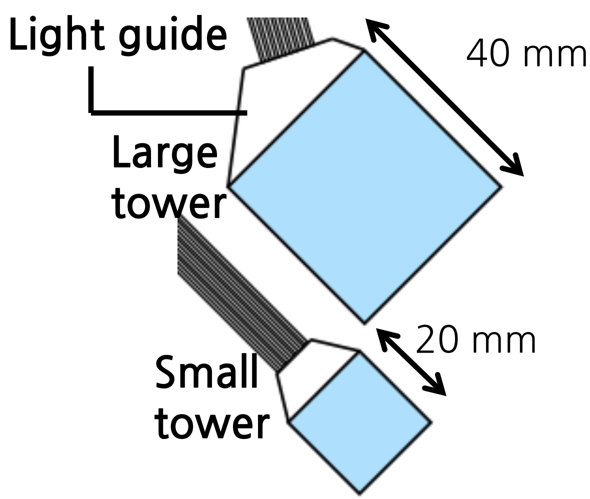
- RHICf detector consists of two sampling towers.
- 17 tungsten absorbers (44 X_0, 1.6 λ_{int}), 16 GSO plates, and 4 layers of GSO bars.
- Two diamond shape is for
  - Measurement of two π^0 photons.
  - Minimum shower leakage from one to the other tower.

Neutron measurement

Side view



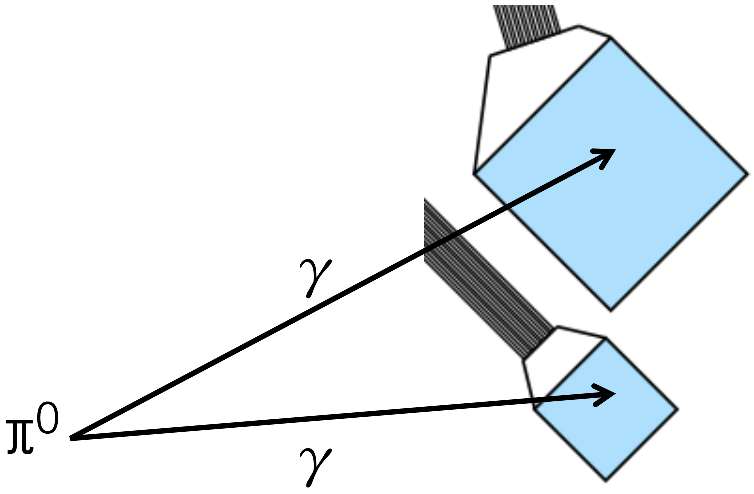
Front view

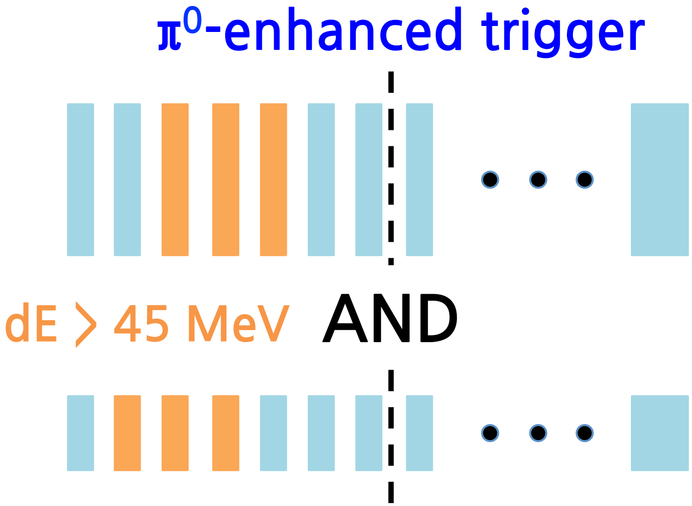


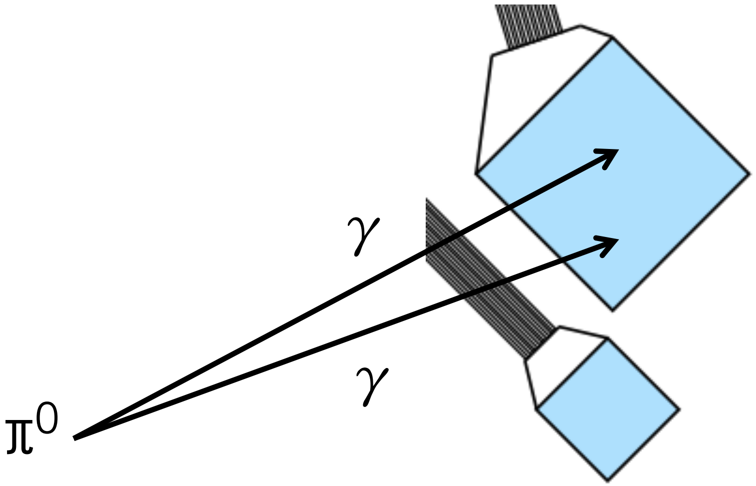
Shower trigger

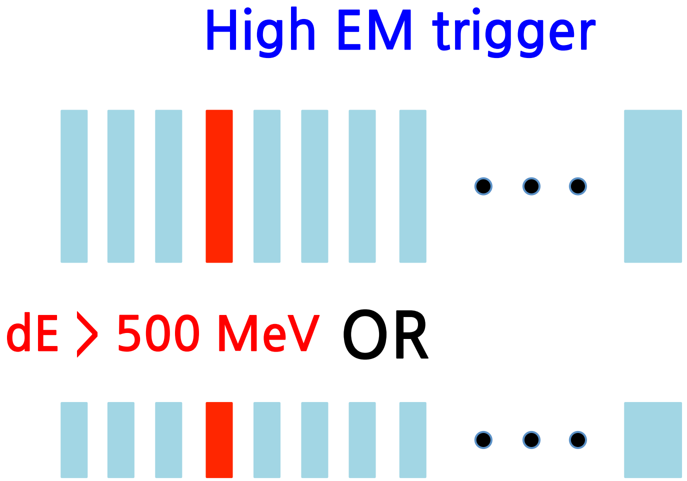
- Shower trigger is operated when the energy deposits of three successive layers are larger than 45 MeV.

π^0 measurement



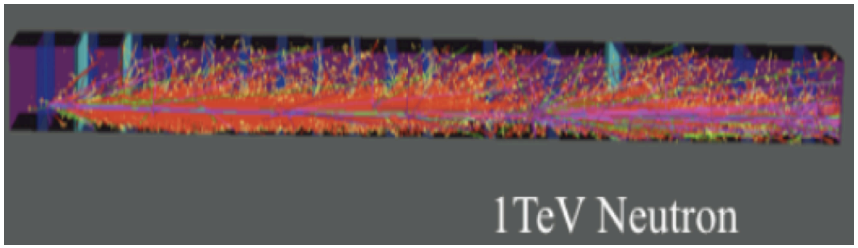


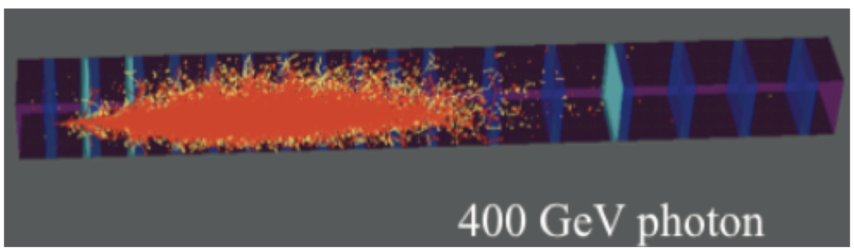


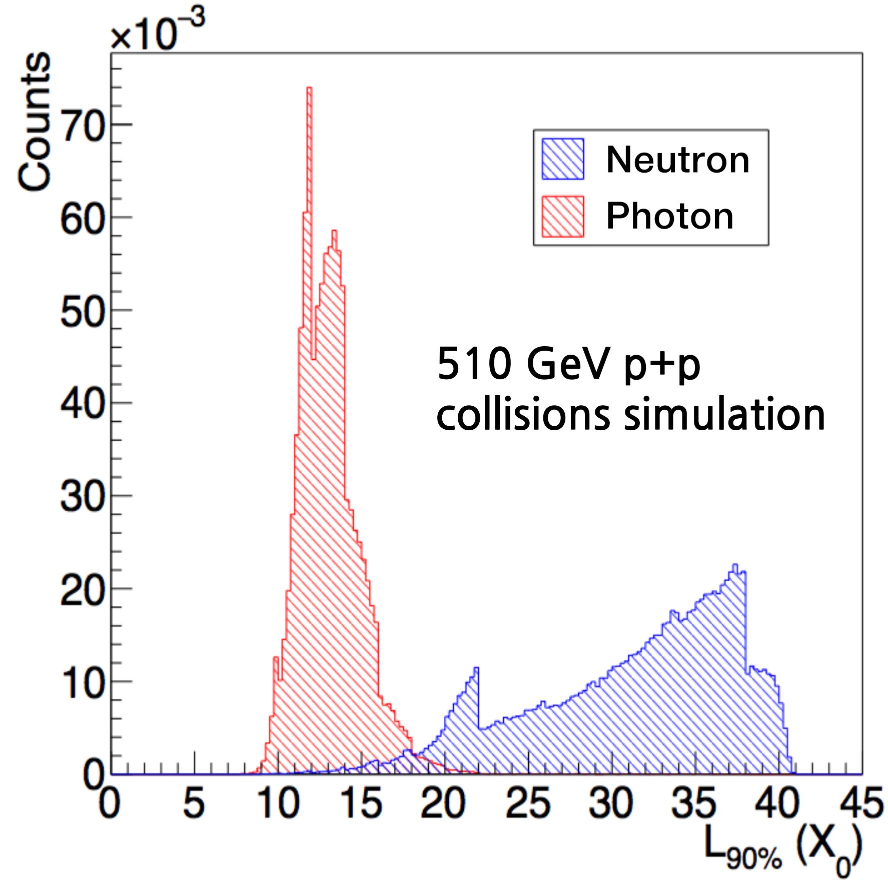


Neutron photon separation

Shower development (Sim.)







- $L_{90\%}$ is defined as the longitudinal depth in the detector where the accumulated energy deposit reaches 90% of total energy deposit.

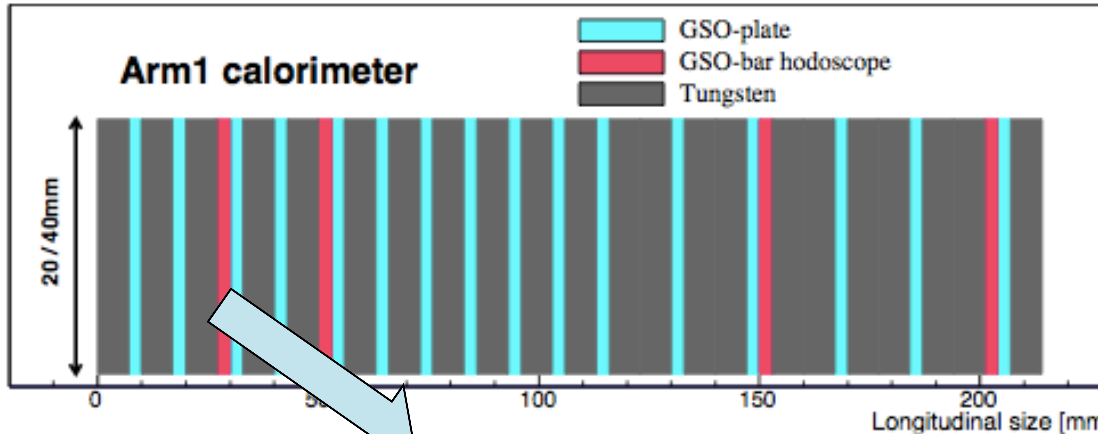
- Electromagnetic shower is developed in more forward area than hadronic one. → $L^{EM}_{90\%} < L^{Hadron}_{90\%}$

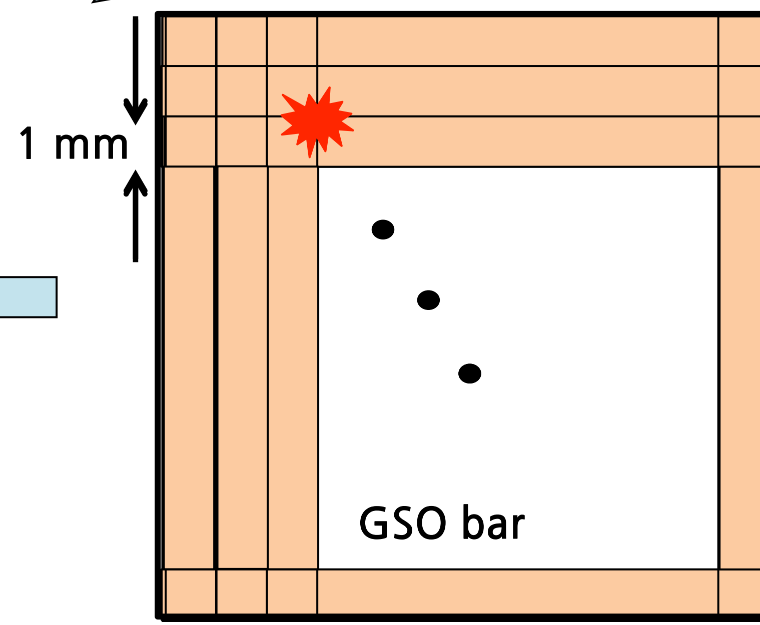
Position reconstruction

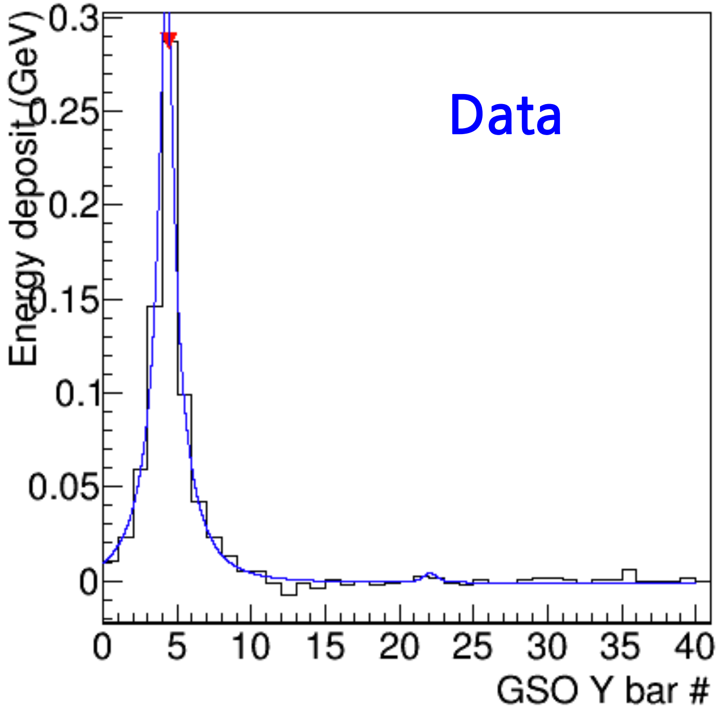
- If shower is developed by a particle,

photon
(neutron)

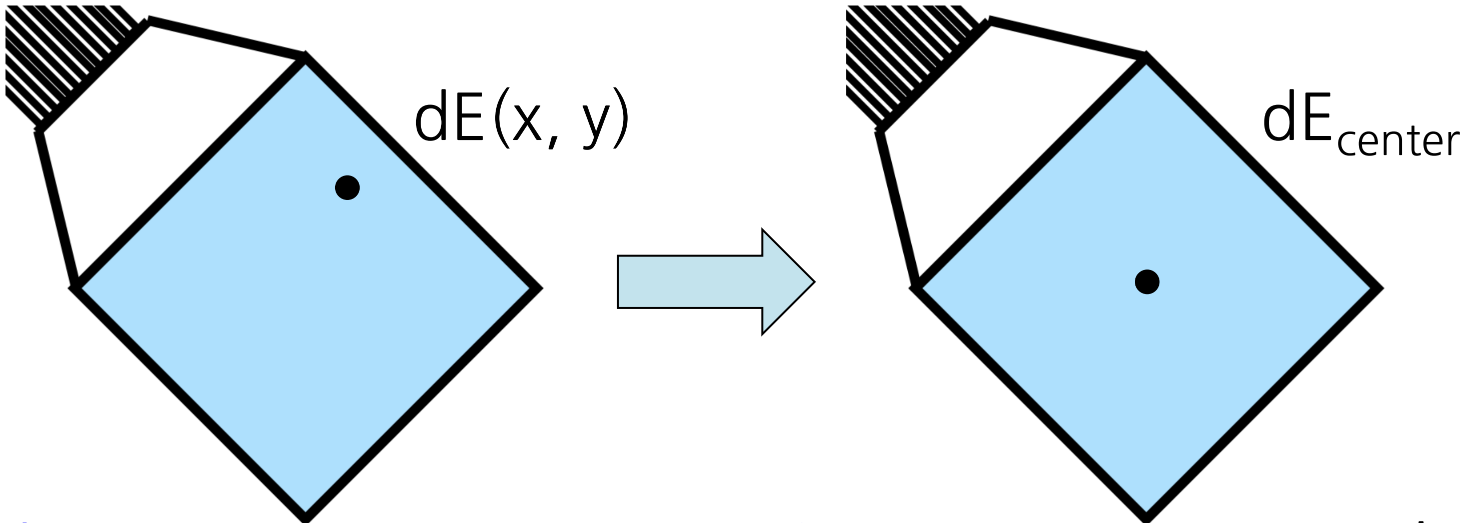
(x, y)

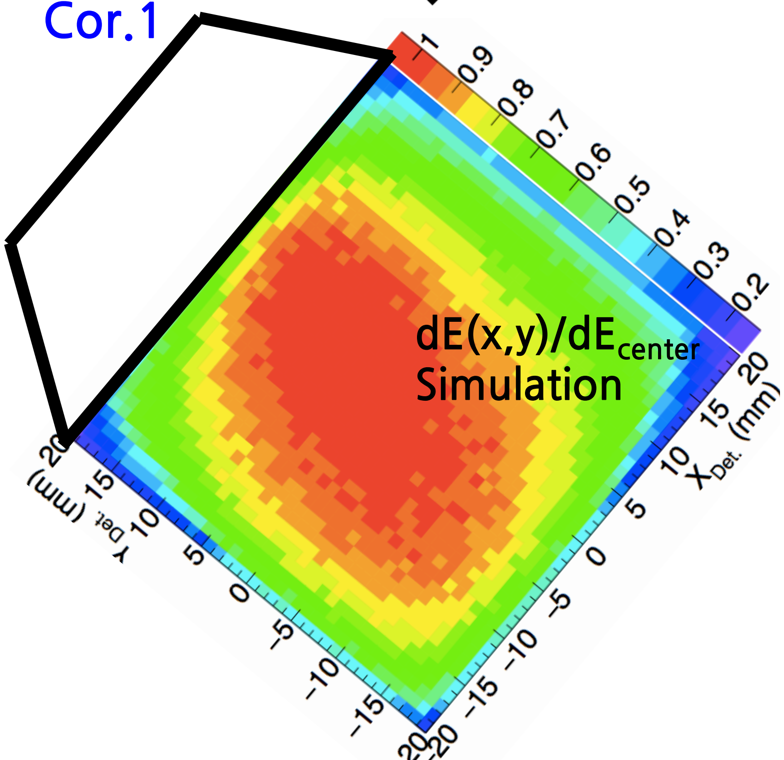


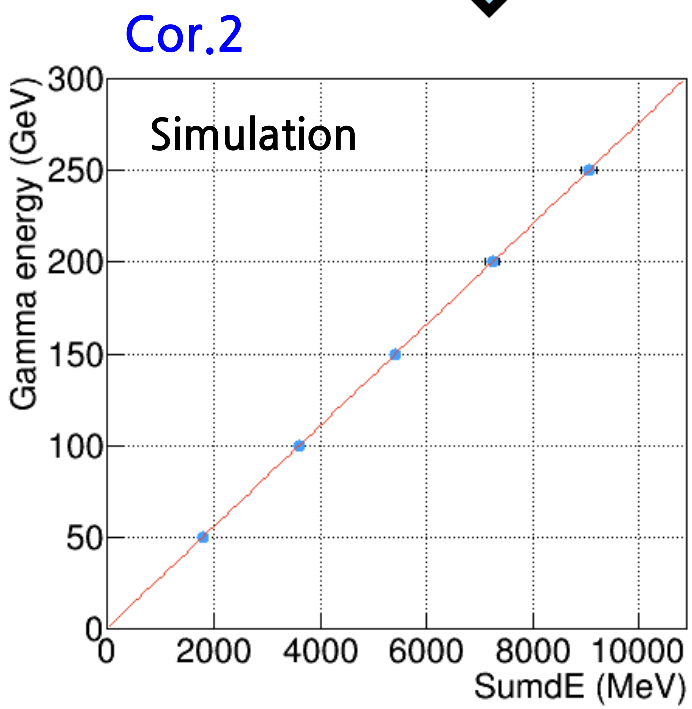




Energy reconstruction







dE(x, y)

↓ Cor.1

dE$_{center}$

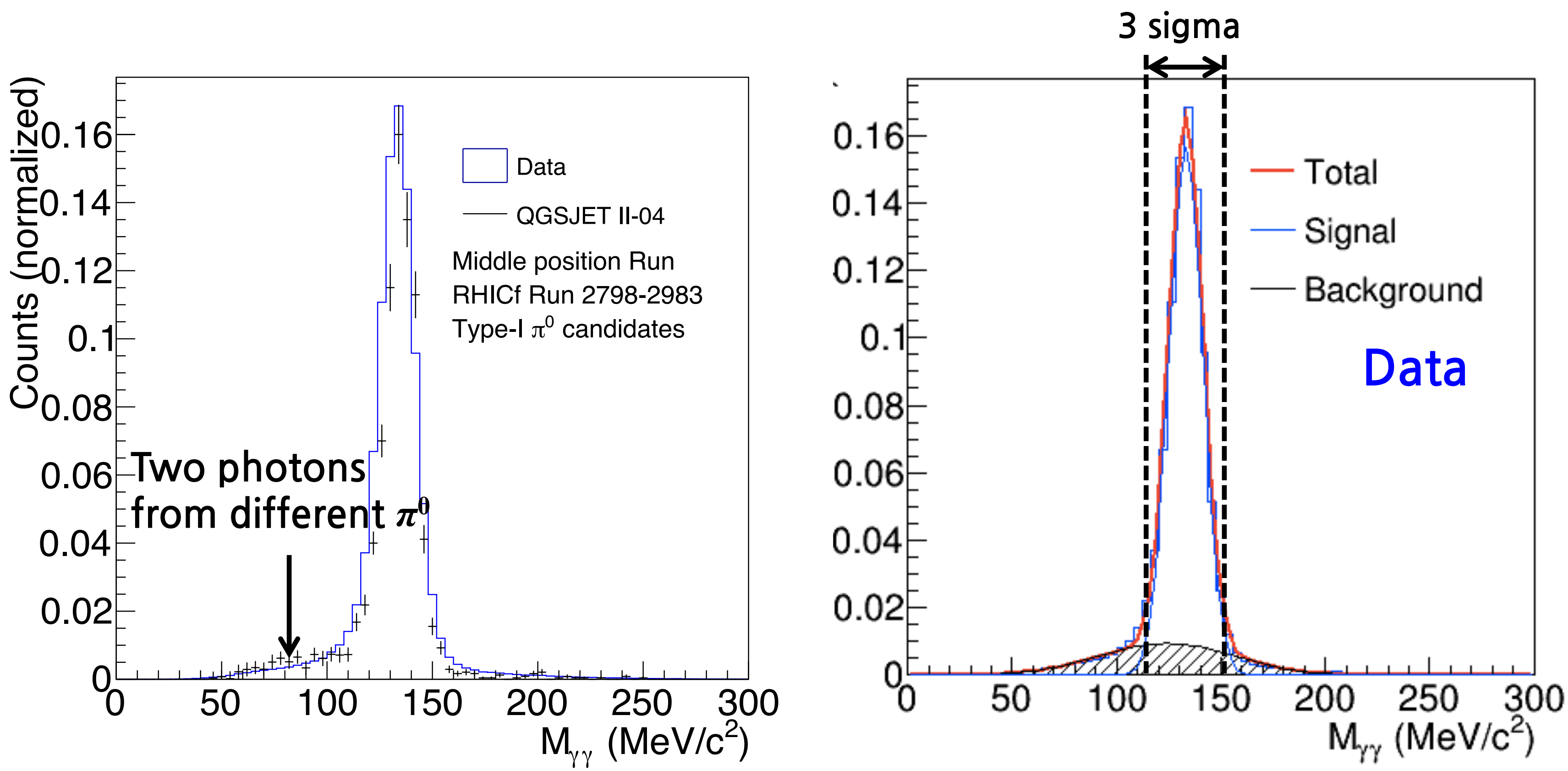
↓

SumdE

↓ Cor.2

E$_{photon}$

Invariant mass distribution



- Data is well matched with simulation showing clear π^0 peak around 135 MeV/c^2. → Calibration was done well.
- Invariant mass was fitted by polynomial function for background and Gaussian one for π^0.

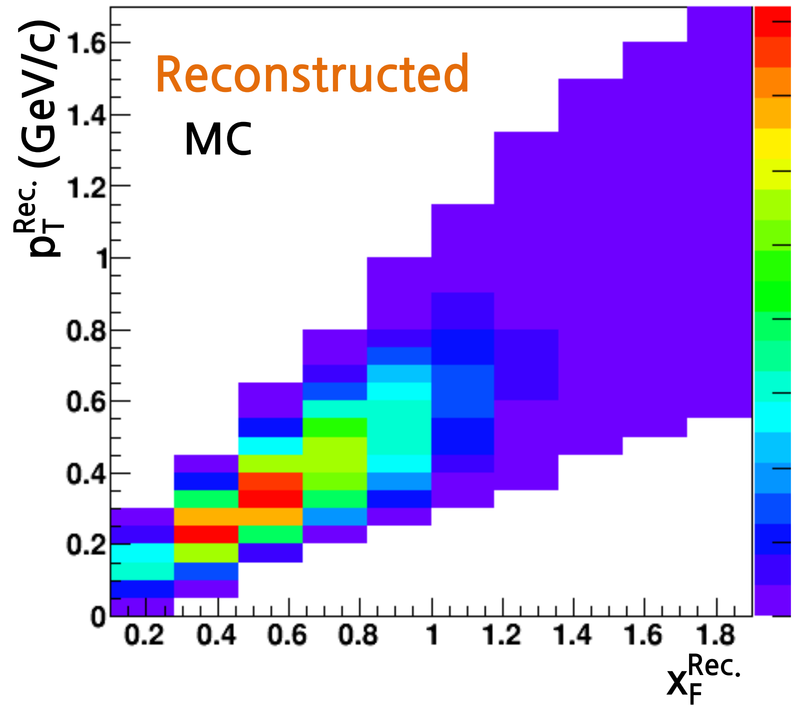
Background A_N subtraction

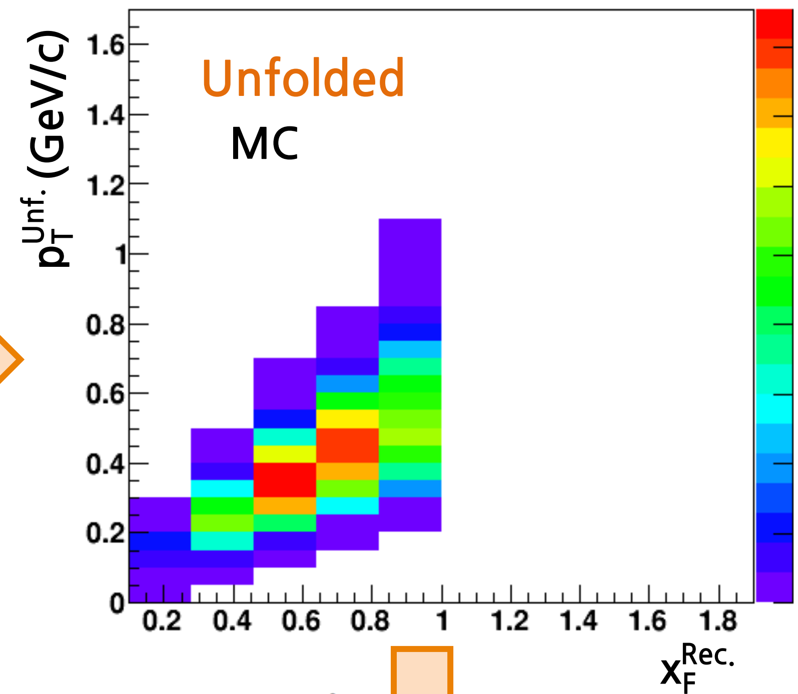
$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_L^{\downarrow}}{\sigma_L^{\uparrow} + \sigma_L^{\downarrow}} = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} = \frac{(N_S^{\uparrow} + N_B^{\uparrow}) - (N_S^{\downarrow} + N_B^{\downarrow})}{(N_S^{\uparrow} + N_B^{\uparrow}) + (N_S^{\downarrow} + N_B^{\downarrow})}$$

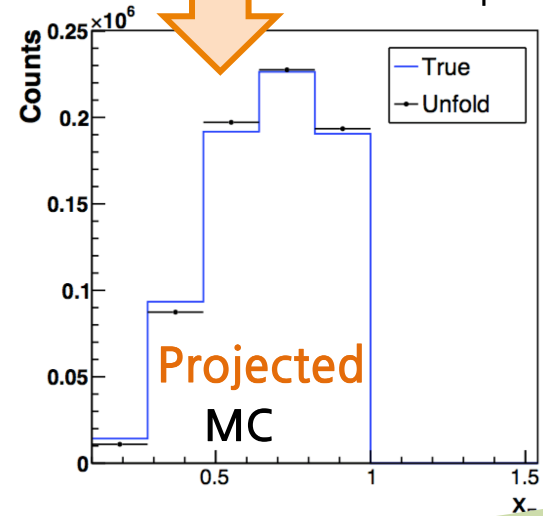
$$\Rightarrow \quad A_N^{S+B} = \left(\frac{N_S}{N_{S+B}}\right) A_N^S + \left(\frac{N_B}{N_{S+B}}\right) A_N^B$$

- Spin up-down cross section can be replaced by number of particles measured.
- Two ratios, N_S/N_{S+B} and N_B/N_{S+B}, can be estimated by fitting the invariant mass distribution.
- Background A_N is calculated by using the entries where the invariant mass is further than 5σ from the peak.

Neutron unfolding



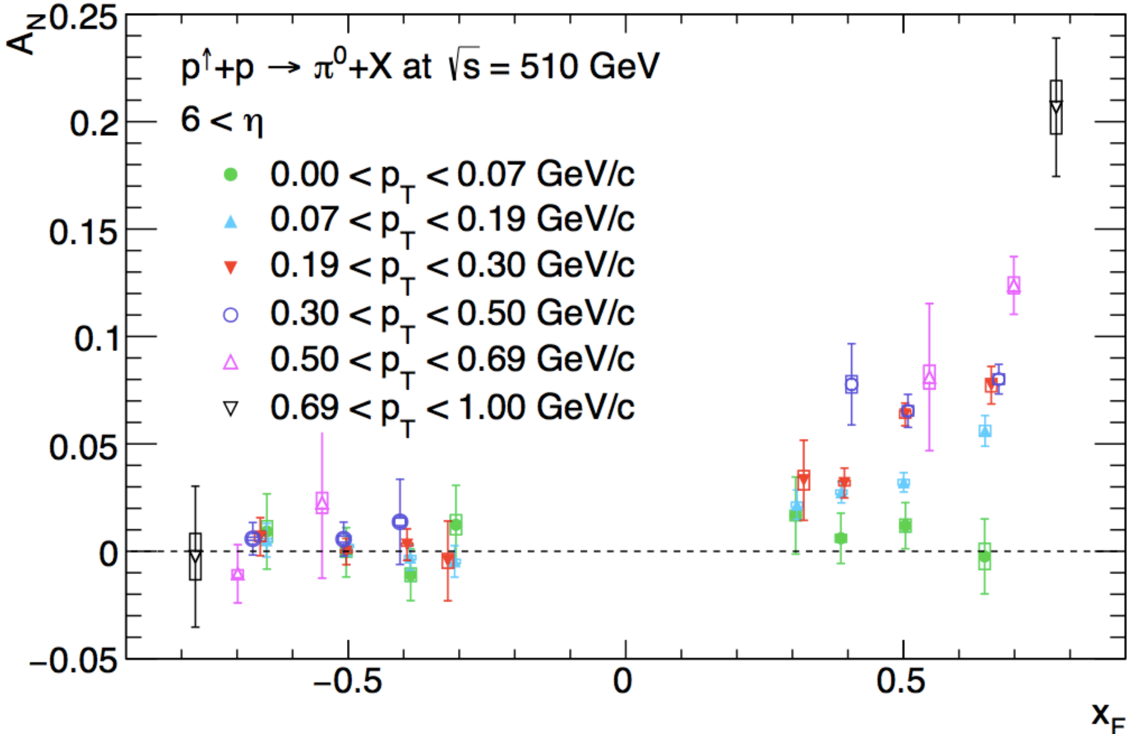




- RHICf detector has insufficient interaction length of 1.6 λ_{int}.
- To build the response matrix, neutron was uniformly generated to the detector.
- The neutron distribution was two-dimensionally unfolded to get the true distribution.

A_N for very forward π^0 production

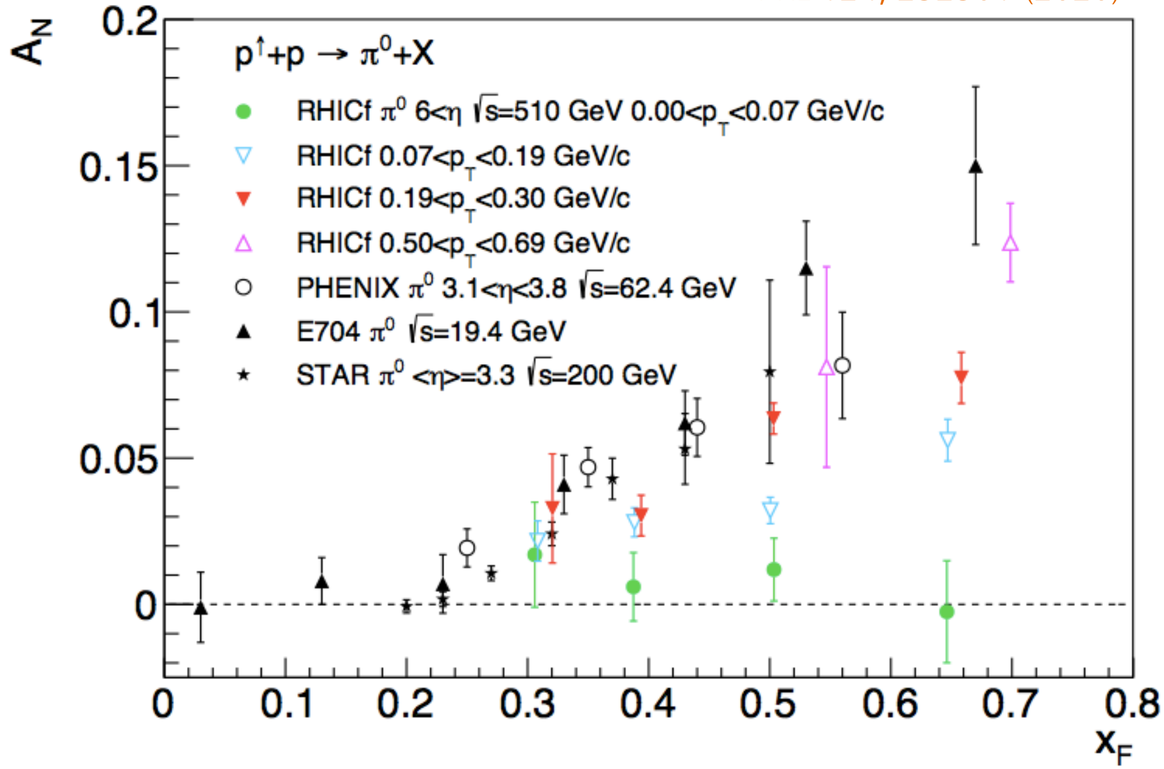
PRL 124, 252501 (2020)



- At very low p_T < 0.07 GeV/c, the A_N is consistent with zero.
- However, the higher p_T range the A_N is measured in, the more clearly it increases as a function of x_F.
- Non-zero A_N of π^0 may come from not only the non-diffractive process but also the diffractive one.

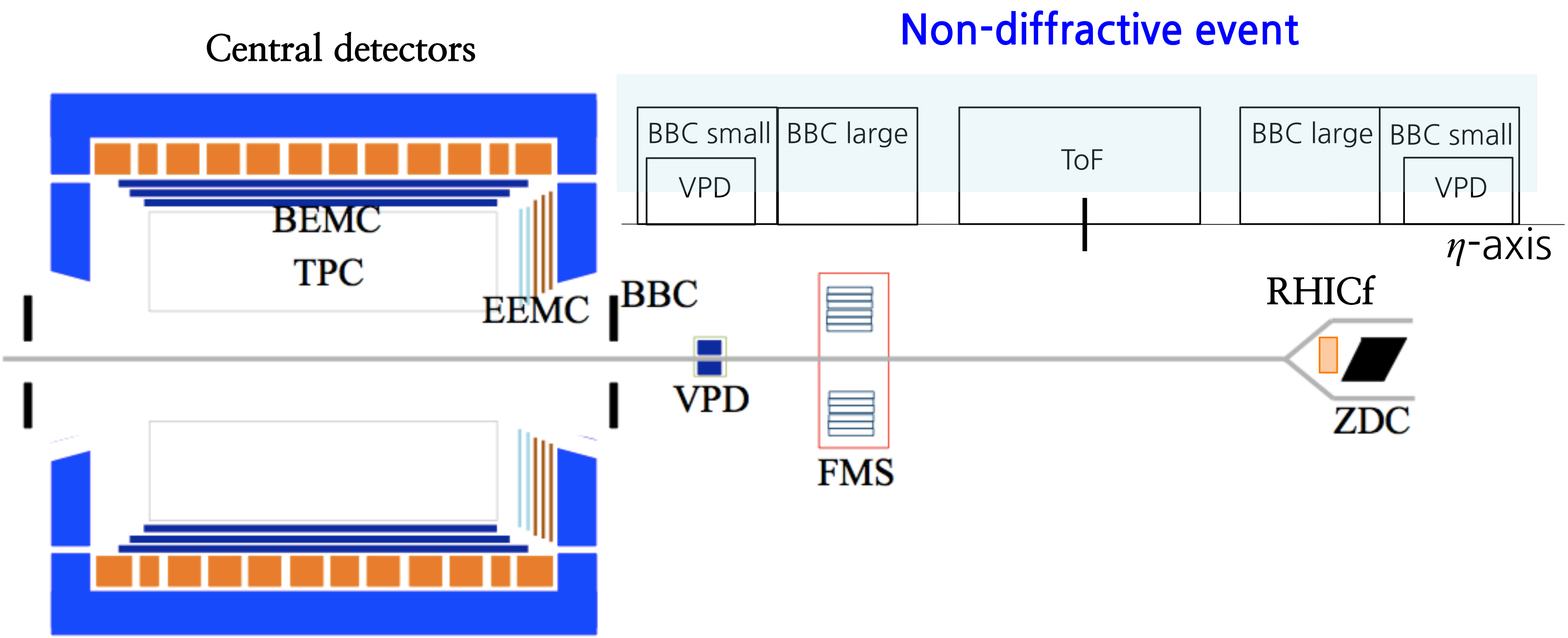
Comparison with forward π^0

PRL 124, 252501 (2020)



- The very forward π^0 A_N seems to be comparable with the forward one even at low p_T < 1 GeV/c.
- They may share a common underlying production mechanism or may have their own ones.

RHICf-STAR combined analysis

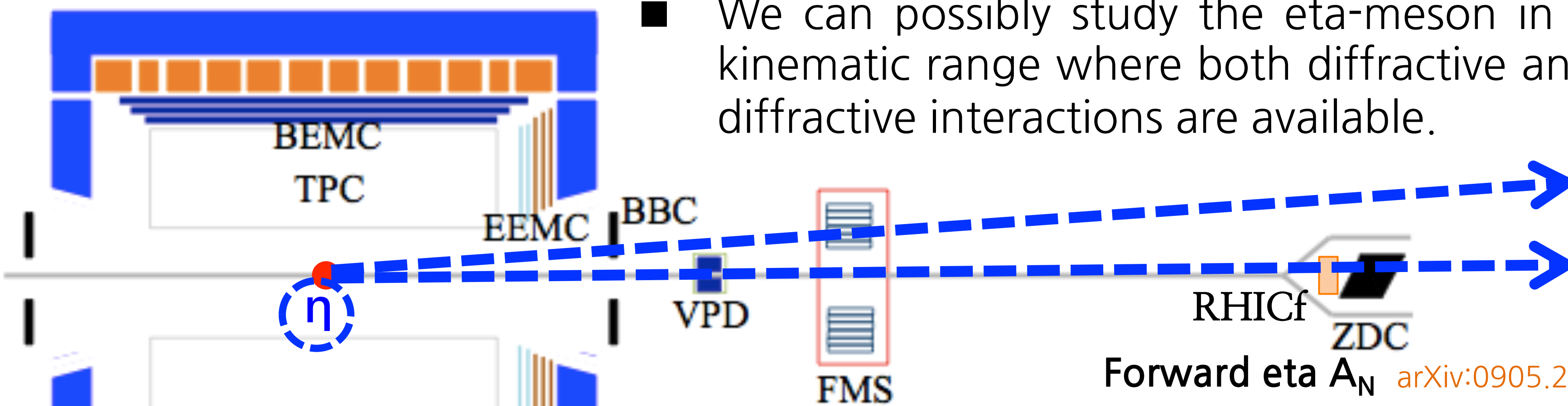


- Using STAR ToF, BBC, and VPD, we can study the detector correlation or event type dependence for the very forward π^0 A_N.
- For example, there should be signals in the TOF, BBC, and VPD if a π^0 comes non-diffractive event.

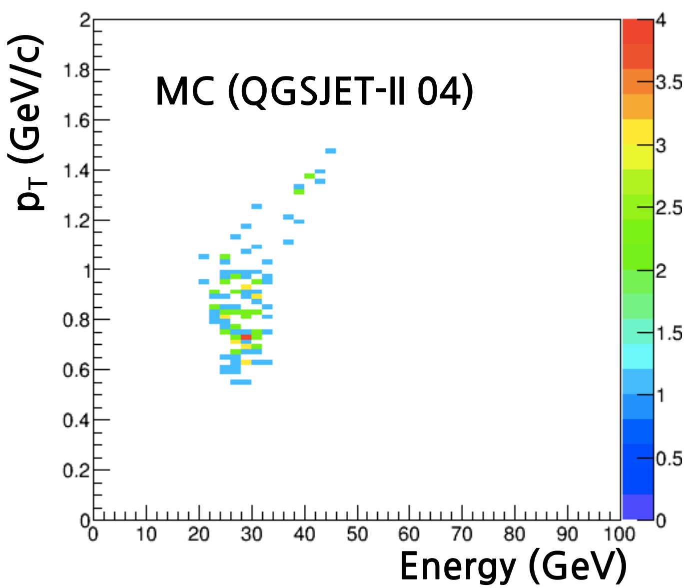
Eta-meson reconstruction

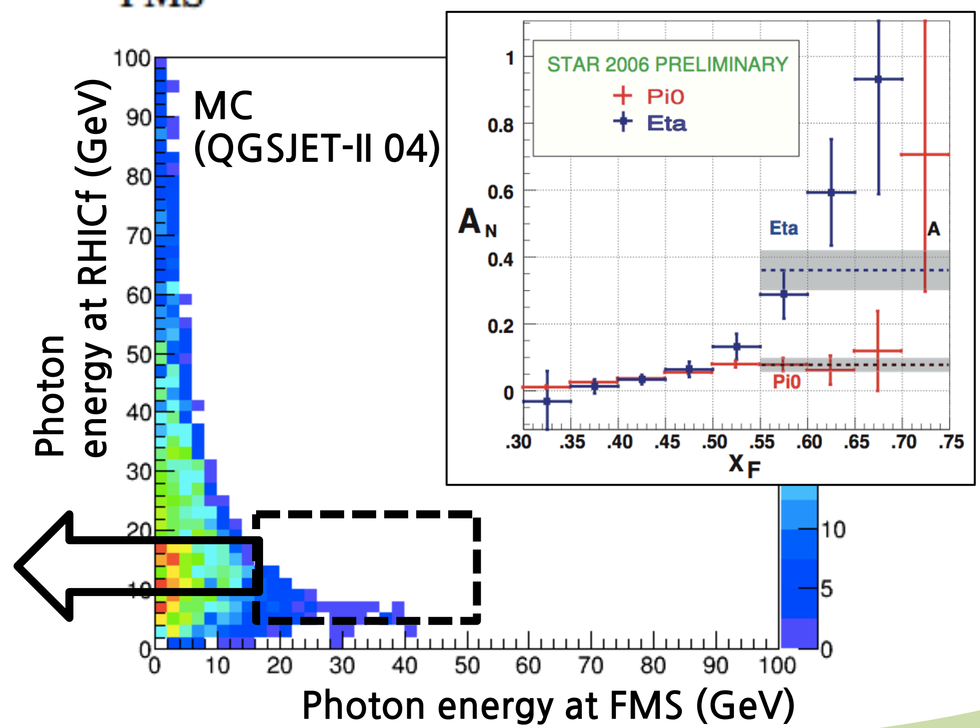
STAR experiment

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

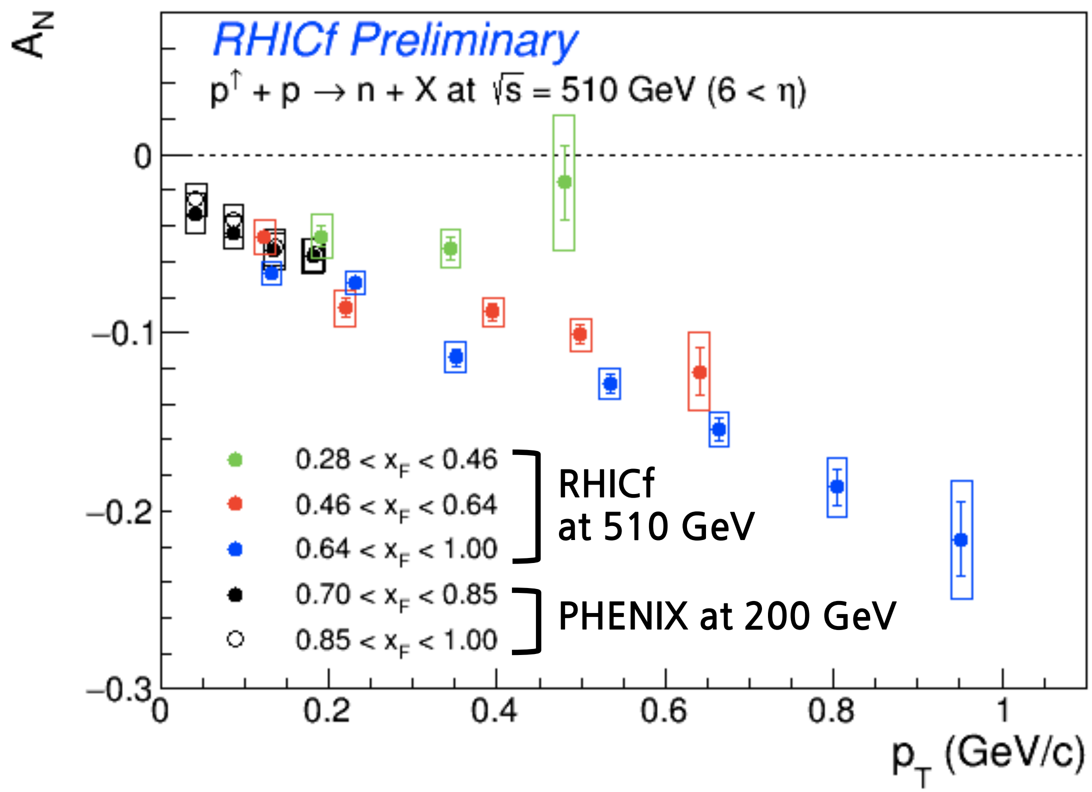


Forward eta A_N arXiv:0905.2840v1



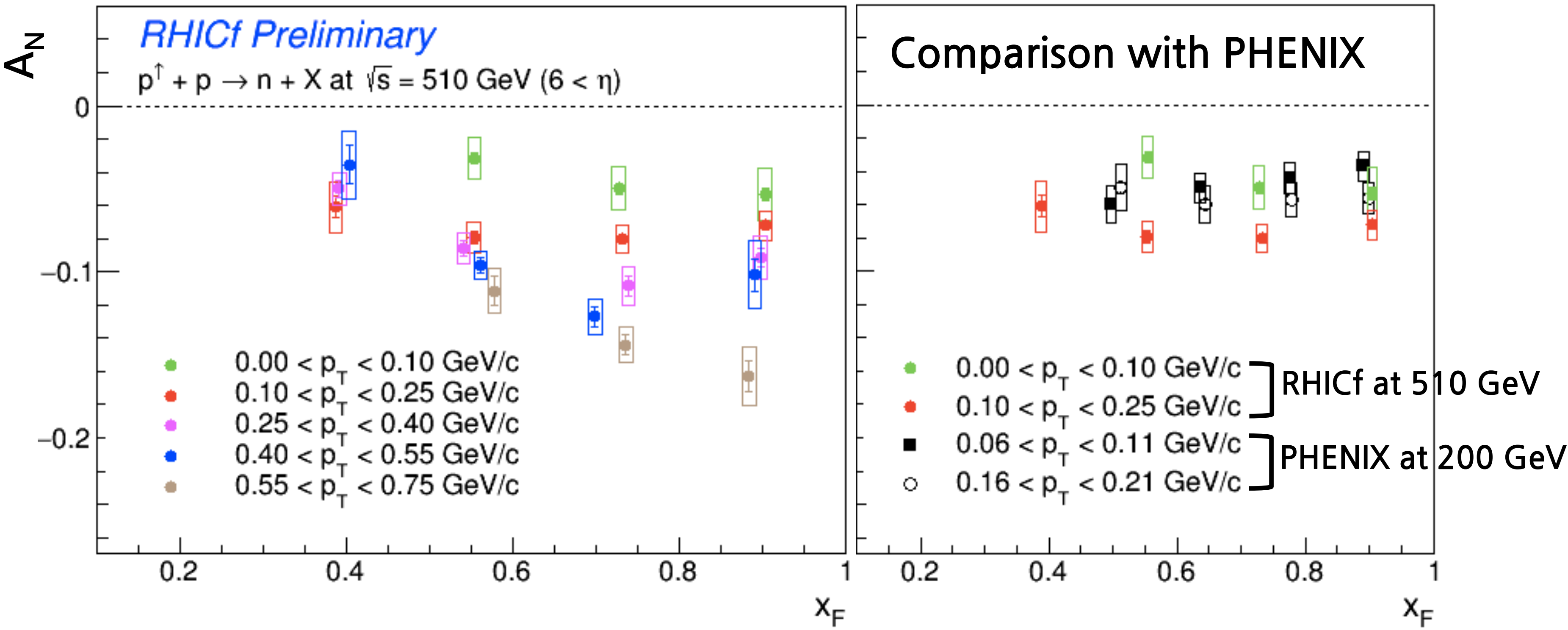


A_N for very forward neutron production



- In the higher x_F region, the A_N increases in magnitude with p_T.
- In the low p_T region, RHICf and PHENIX data are consistent with each other without x_F dependence as the model predicted.
- In the high p_T region, there seems a x_F dependence.

A_N for very forward neutron production



- In the low p_T region, the A_Ns are flat showing no x_F dependence.
- In the high p_T region, a clear x_F dependence is observed.
- The analysis will be complete soon with more precise background estimation.

Summary

- In June 2017, the RHICf experiment measured the A_Ns for very forward neutron and π^0 production.
- Non-zero A_N was observed even in the very forward π^0 production.
  - Will be studied in more detail by the RHICf-STAR combined analysis.
- A x_F dependence was observed in the very forward neutron A_N.
  - Analysis will be complete with more precise background estimation.
  - Could find a hint from the combined analysis.