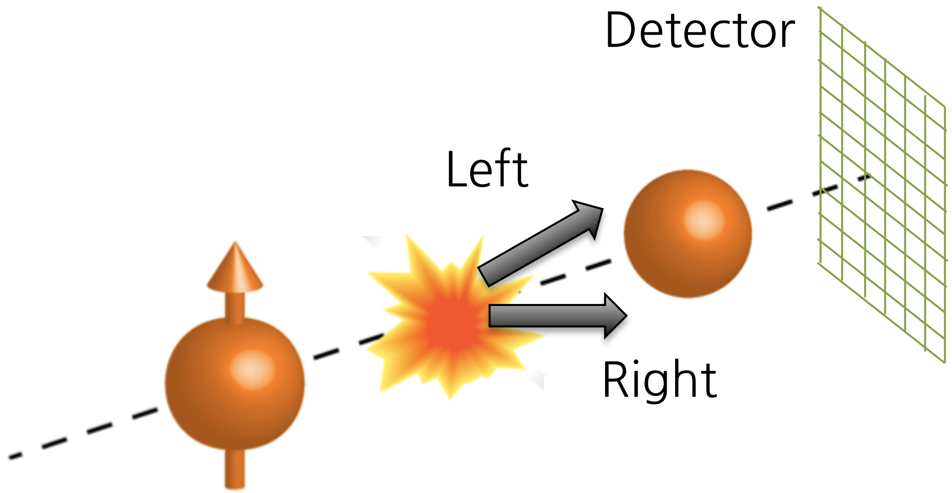
Transverse single-spin asymmetry for very forward π^0 production in $p^{\uparrow} + p$ collisions at $\sqrt{s} = 510$ GeV

Minho Kim (Korea Univ./ RIKEN)
on behalf of the RHICf collaboration

22 Oct. RHIC & AGS User's Meeting 2020

Transverse single spin asymmetry (A_N)

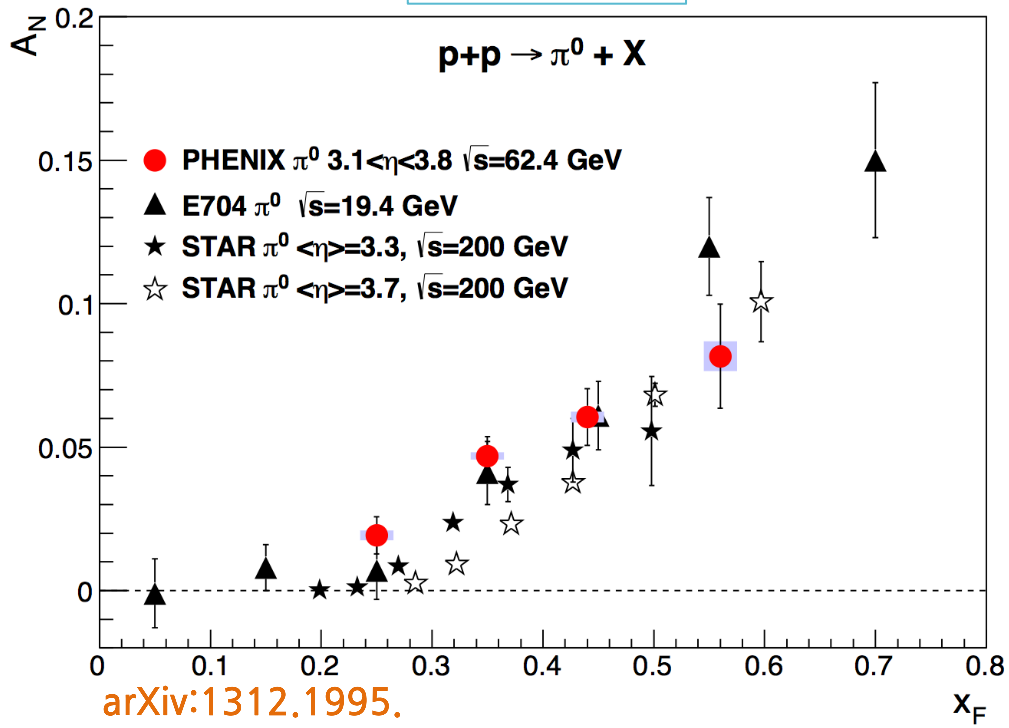


$$A_N = \frac{\sigma_L^\uparrow - \sigma_R^\uparrow}{\sigma_L^\uparrow + \sigma_R^\uparrow} = \frac{\sigma_L^\uparrow - \sigma_L^\downarrow}{\sigma_L^\uparrow + \sigma_L^\downarrow}$$

- In polarized p + p collision, A_N is defined as a left-right cross section asymmetry of a specific particle.
- Though the non-zero A_N of π^0 has been intensively studied for longer than 30 years, the origin of it is still open question.

A_N in forward π^0 production

$3 < \eta < 4$



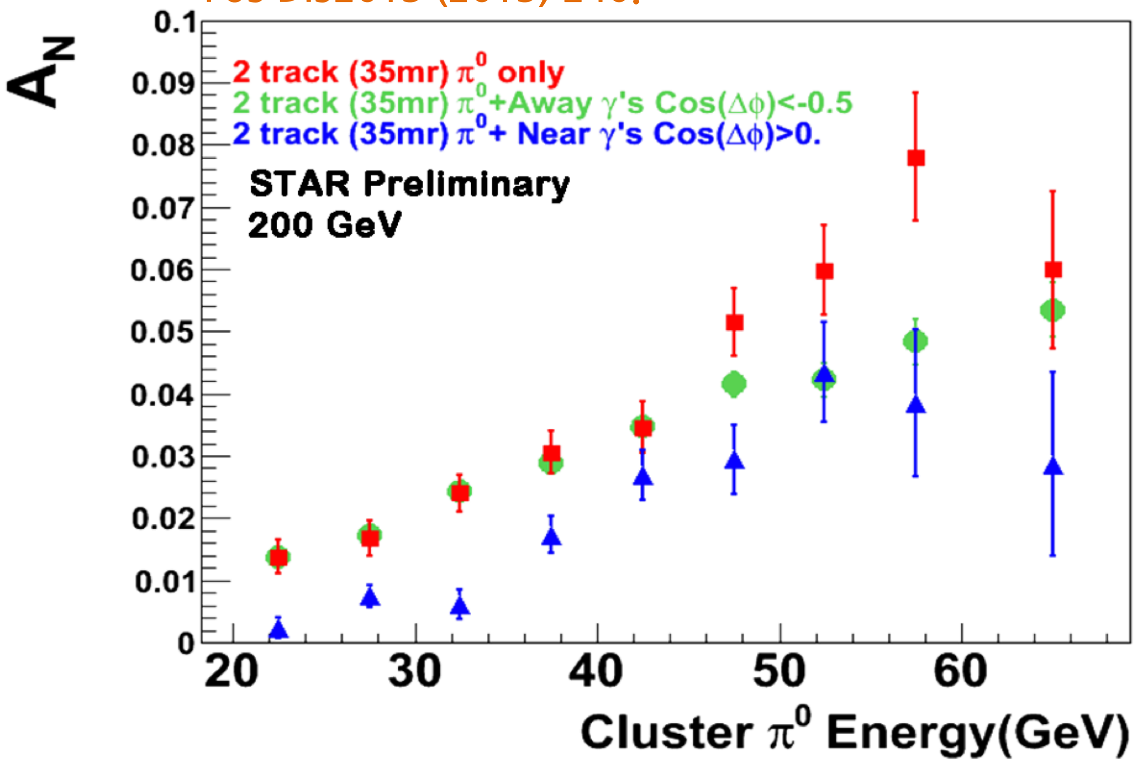
arXiv:1312.1995.

- Observed non-zero A_N of π^0 ever has been interpreted based on only perturbative picture theoretically.

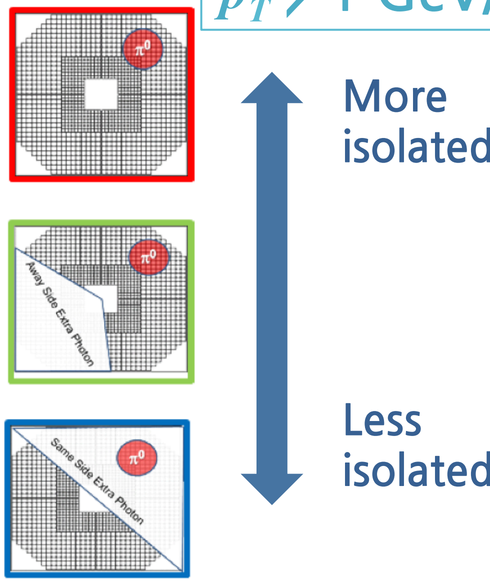
- Non-zero A_N comes from an asymmetry of the partonic-level fragmentation process or spin-dependent quark-gluon correlations in the proton.

New question to the A_N of forward π^0

PoS DIS2013 (2013) 240.

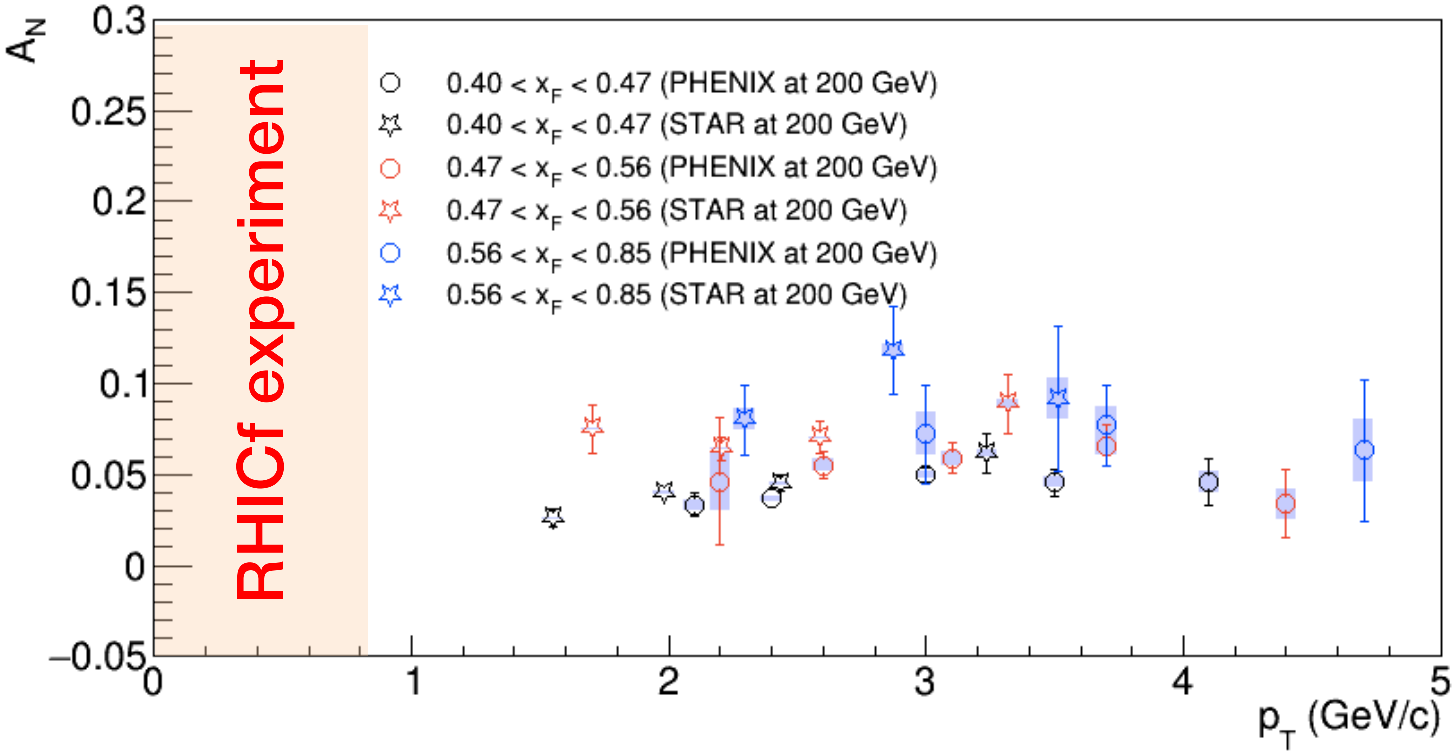


$2.6 < \eta < 4$
$p_T > 1$ GeV/c



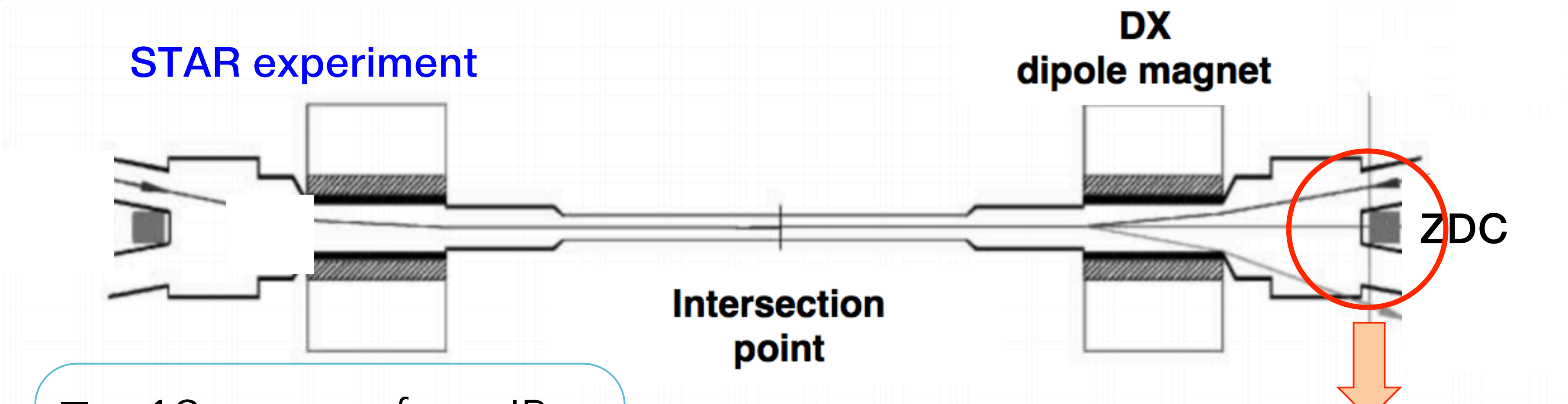
- Larger A_N was observed by more isolated π^0 than less isolated one.
- Non-perturbative process may have a finite contribution to the π^0 A_N as well as perturbative one.

A_N in very forward π^0 production

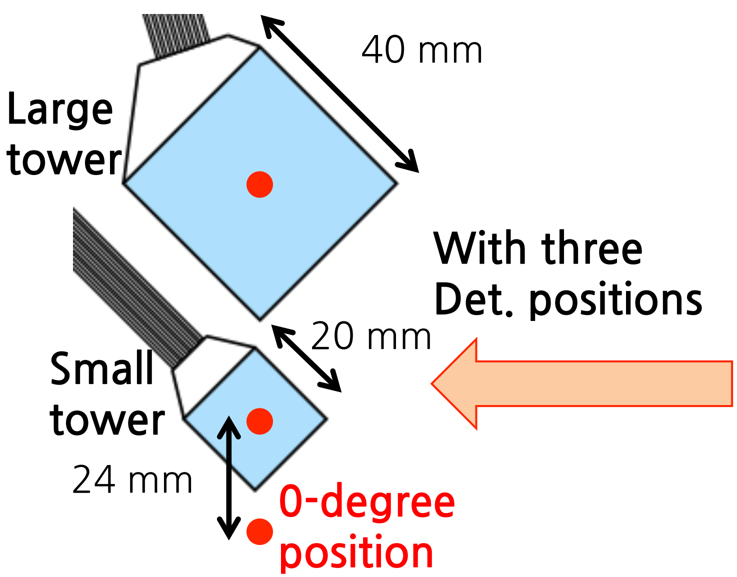


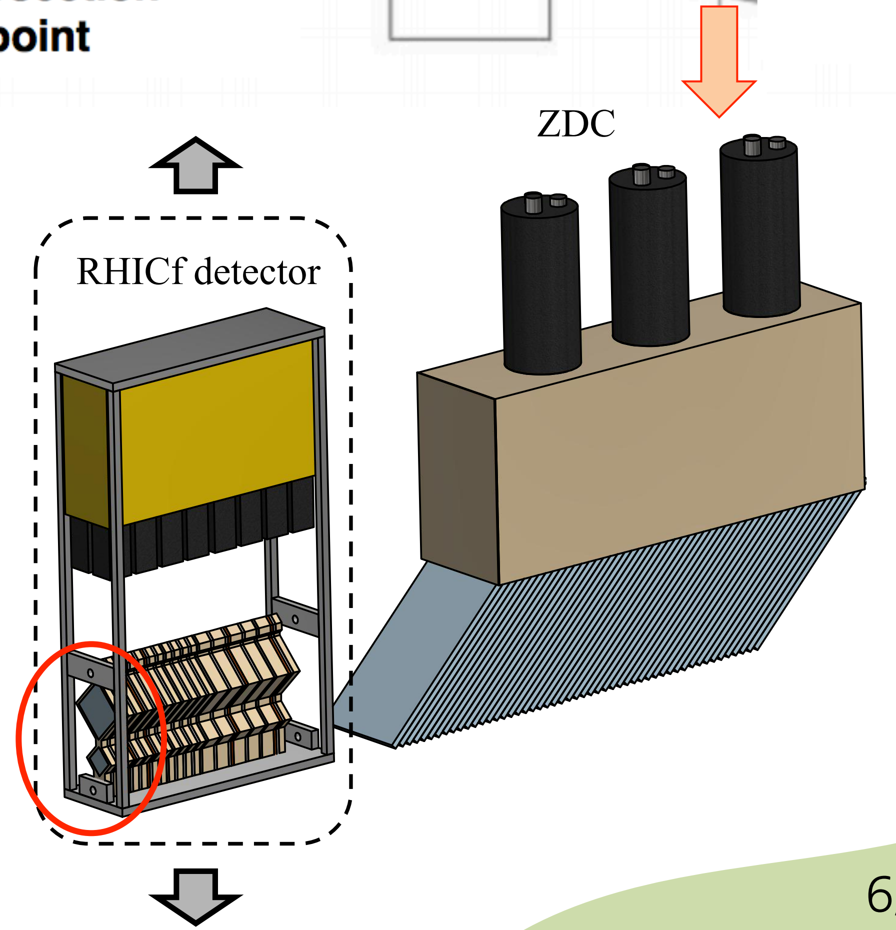
- No detailed measurement ever for the p_T range below 1 GeV/c.
- In June, 2017, RHICf experiment measured the A_N of very forward π^0 ($6 < \eta$ and $p_T < 1$ GeV/c) where the non-perturbative process is expected to be dominant.

RHIC forward (RHICf) experiment

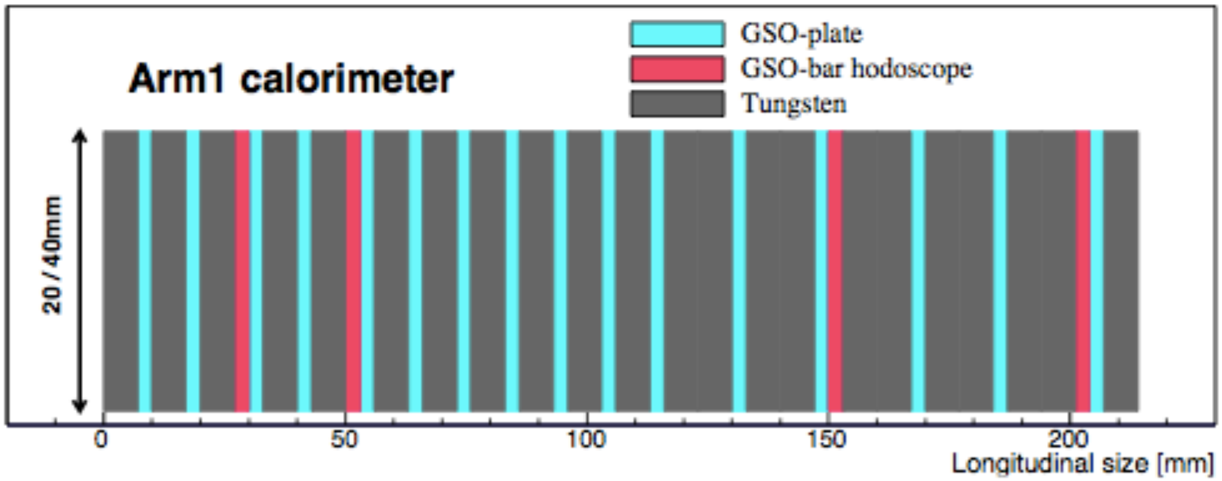


- 18 m away from IP.
- $0.2 < x_F < 1.0$.
  $0.0 < p_T < 1.0$ GeV/c.





RHICf detector & π^0 measurement

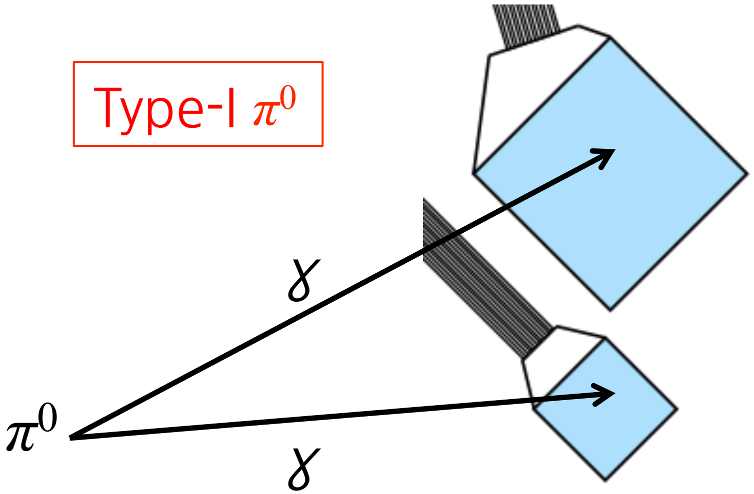


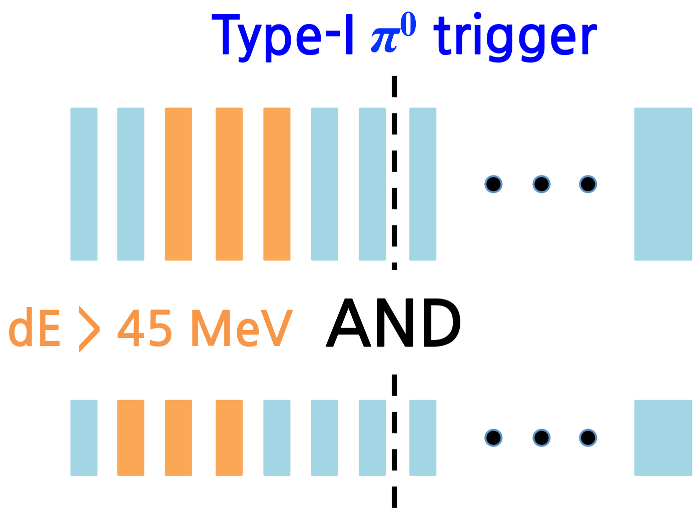
Small tower: 20/20 mm
Large tower: 40/40 mm

17 tungsten absorbers ($44\ X_0$, $1.6\ \lambda_{int}$)

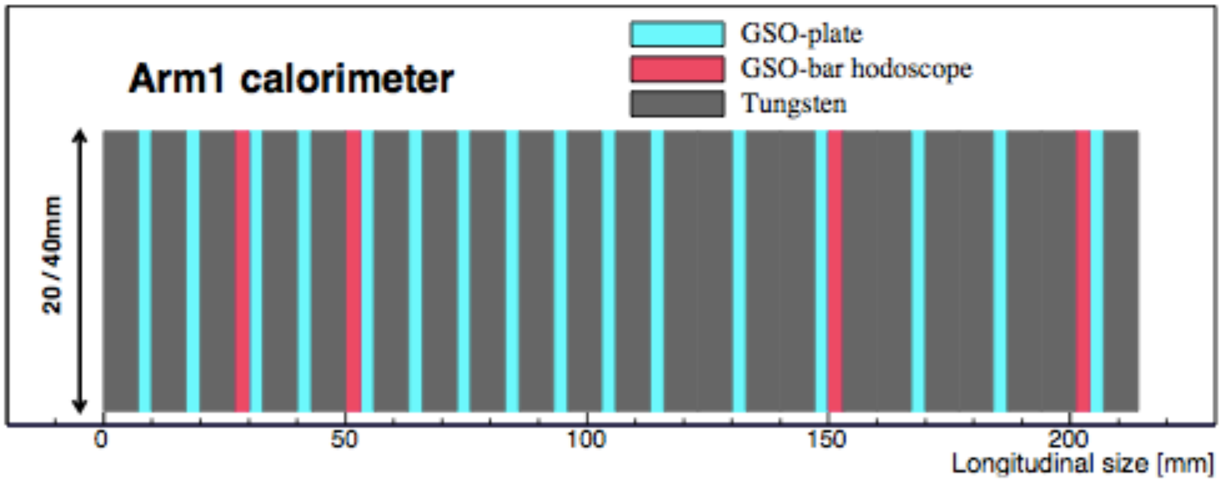
16 GSO plates for energy measurement

4 GSO bar layers for position measurement





RHICf detector & π^0 measurement



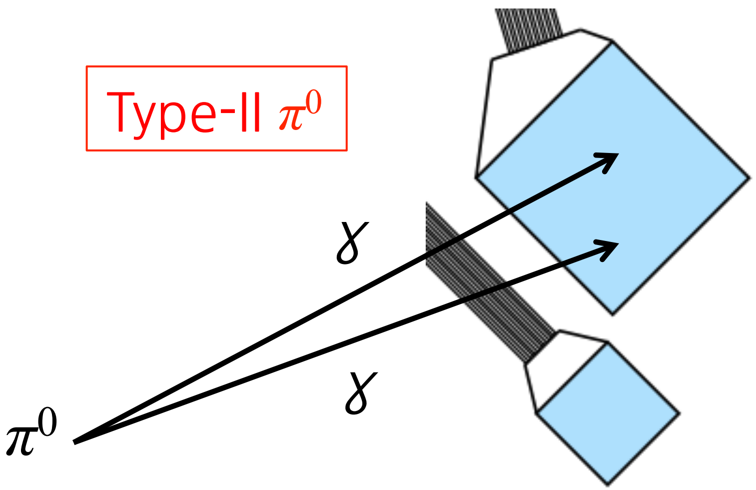
Small tower: 20/20 mm
Large tower: 40/40 mm

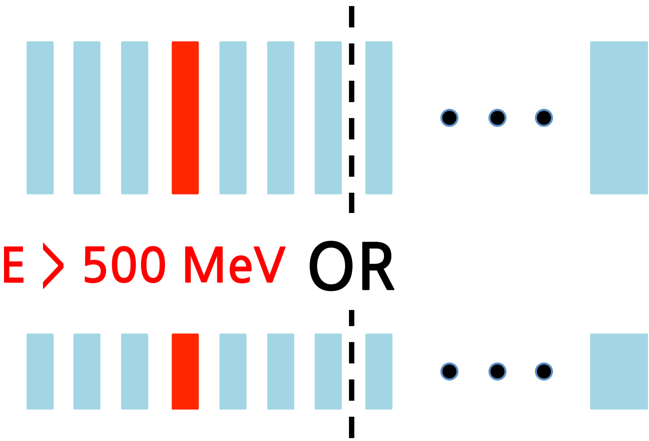
17 tungsten absorbers ($44\ X_0$, $1.6\ \lambda_{int}$)

16 GSO plates for energy measurement

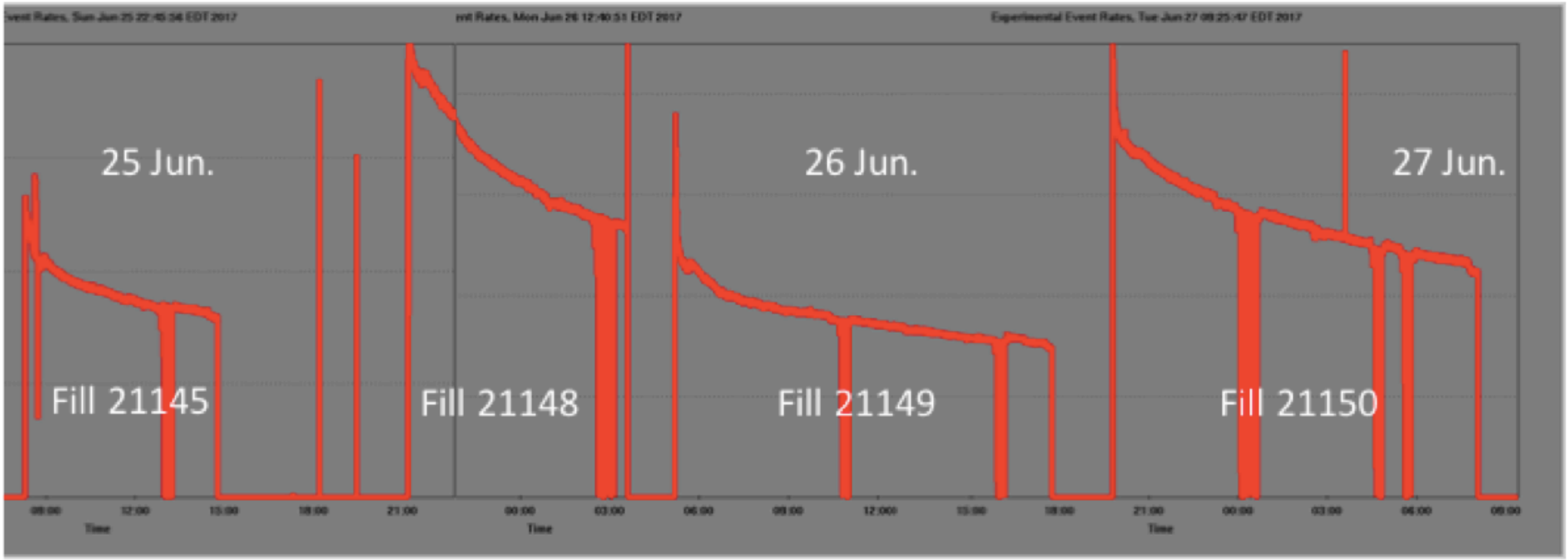
4 GSO bar layers for position measurement

Type-II π^0

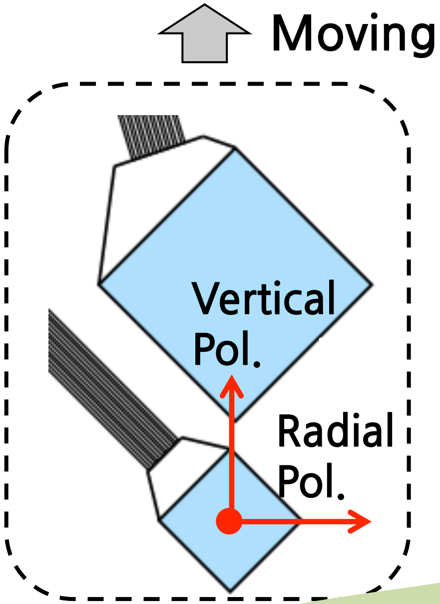




Operation summary

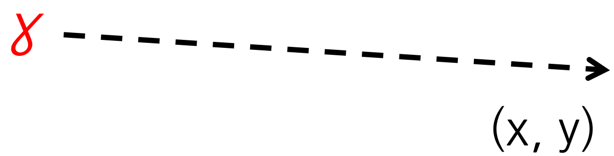


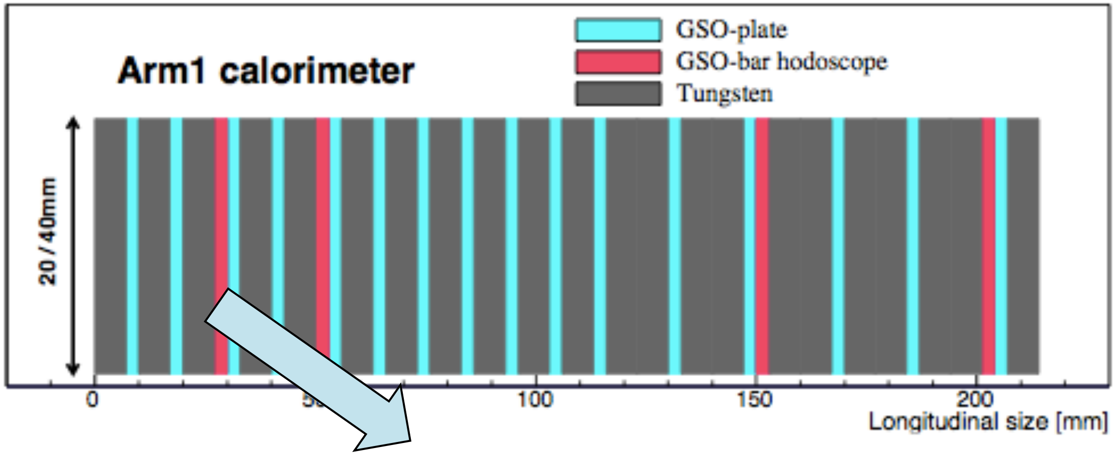
- Total 110 M events were accumulated for neutral particles (neutron, π^0, and single photon) during 4 fills (28 hours).
- 90°-rotated radial polarization.
- Higher β^* = 8 m and lower luminosity = 10^{31} $cm^{-2}s^{-1}$ than usual.

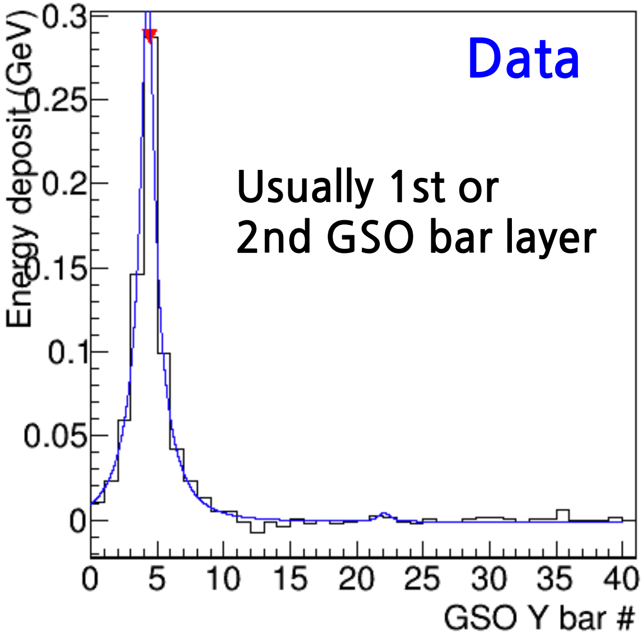


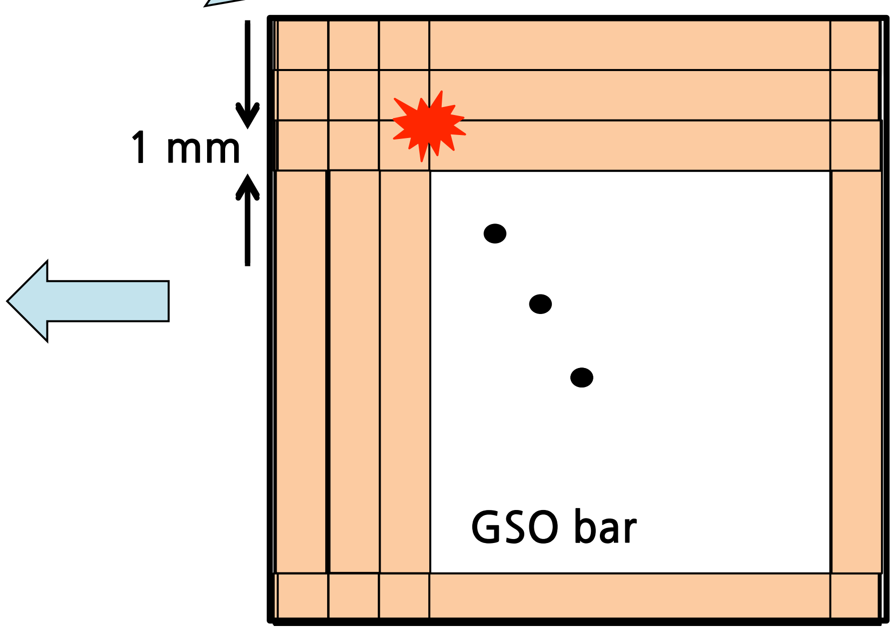
Position reconstruction of photon

- If a photon hit a tower,







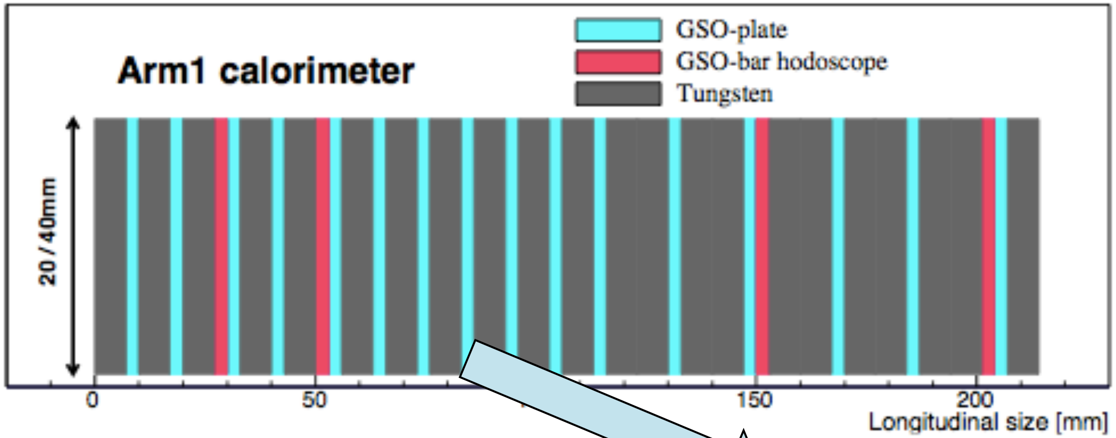


- Positions of decayed photons are measured by 1 mm dimension GSO bars.

Energy reconstruction of photon

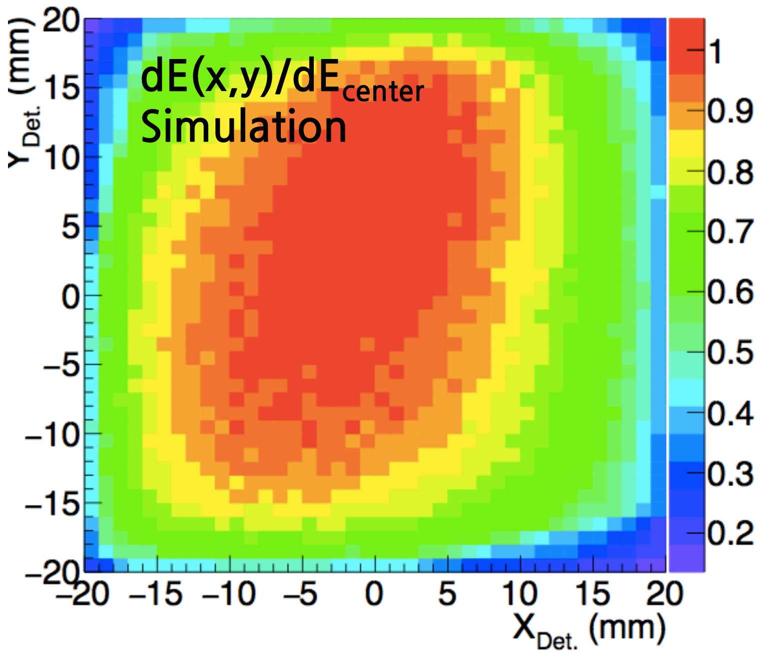
- If a photon hit a tower,

γ (x, y)

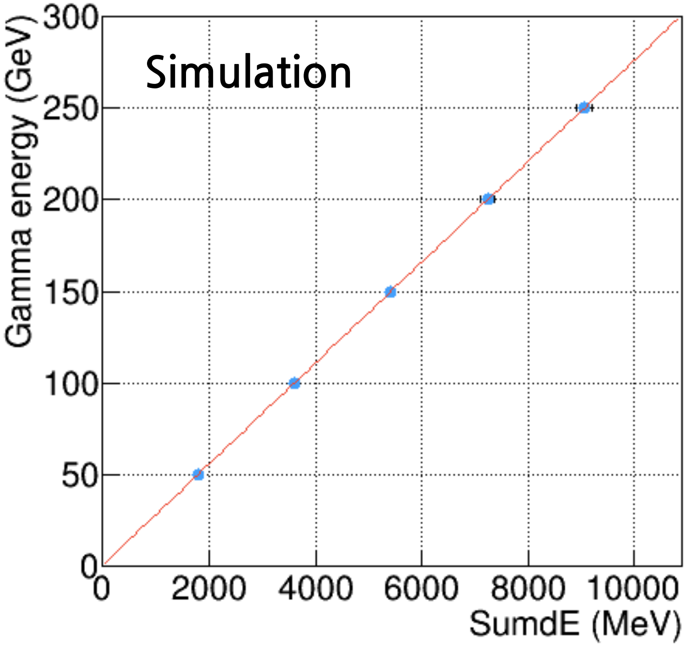


$dE(x, y)$ → Cor.1 → dE_{center} → $SumdE$ → Cor.2 → E_{gamma}

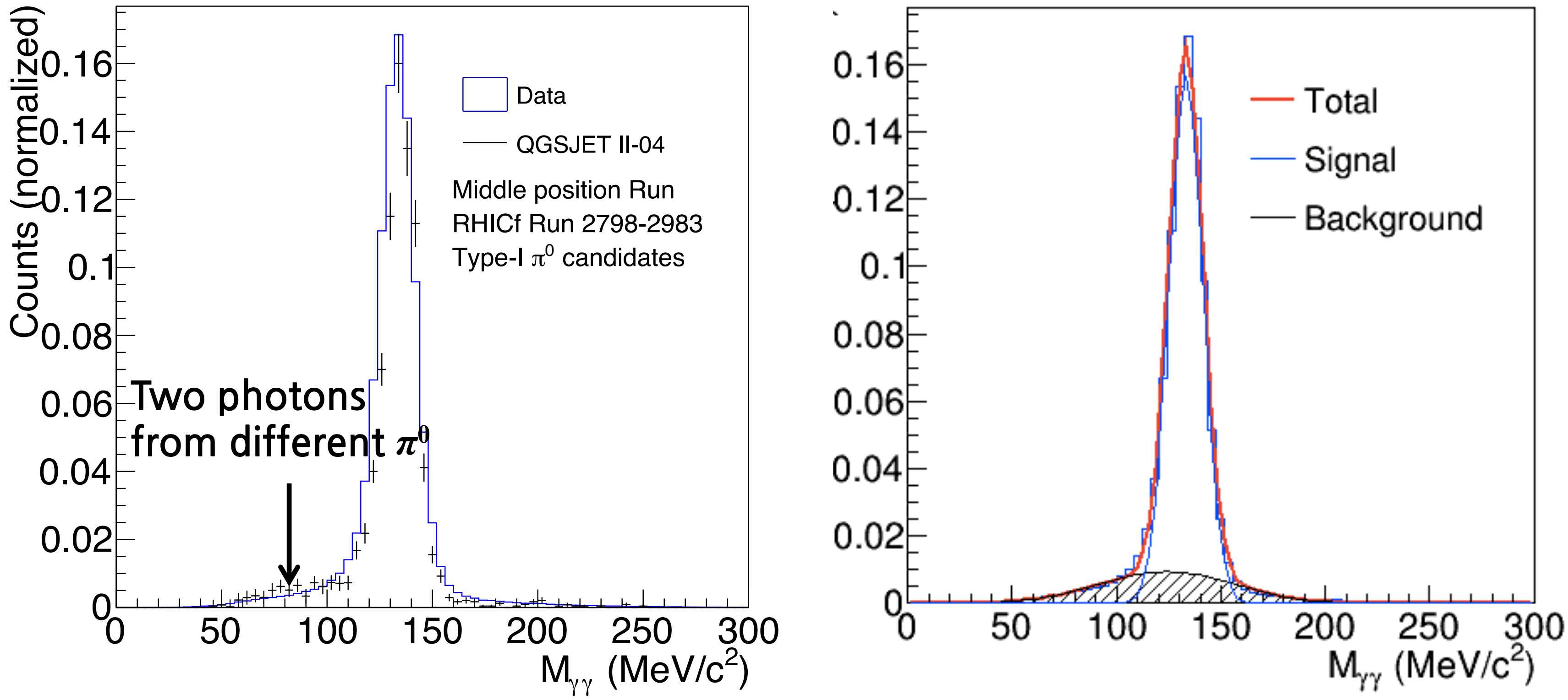
Cor.1



Cor.2

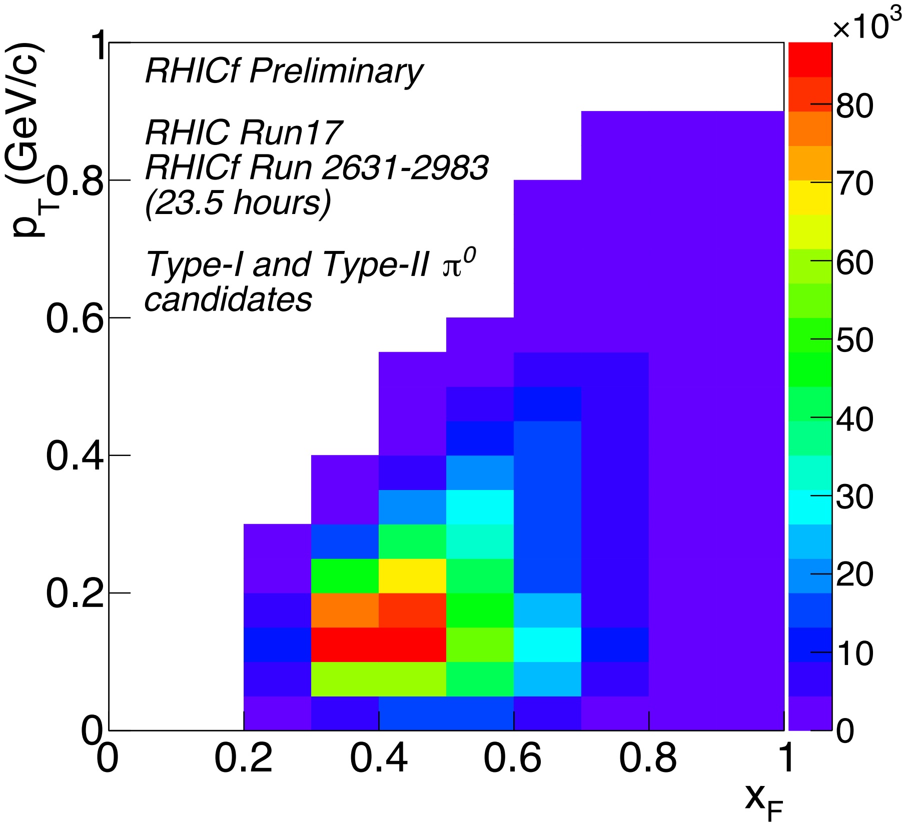


Invariant mass of two photons



- Data is well matched with simulation showing clear π^0 peak around 135 MeV/c^2 with ~8 MeV/c^2 peak width.
- Invariant mass was fitted by polynomial function for background and Gaussian one for π^0.

π^0 kinematics & A_N calculation



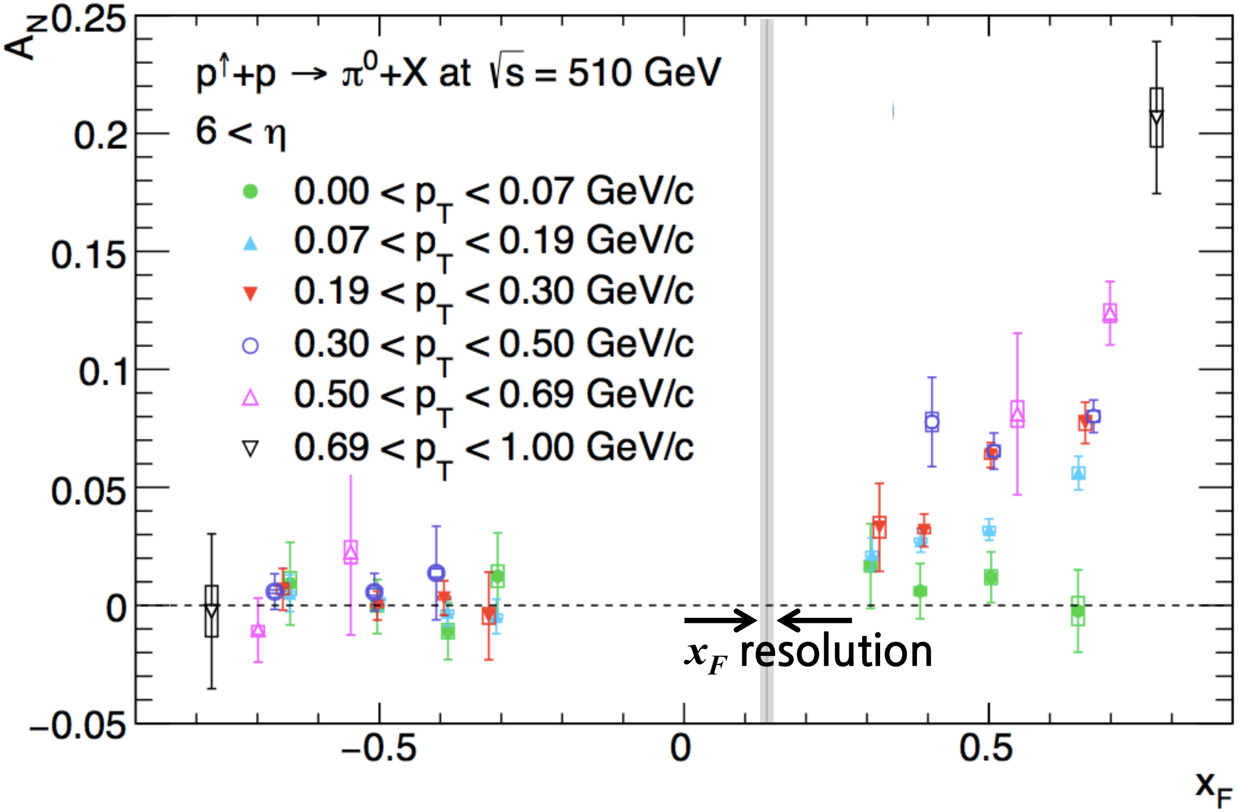
$$A_N = \frac{1}{P}\frac{1}{D_\phi}\left(\frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}\right)$$

P : Polarization
D_ϕ: Dilution factor
R : Relative luminosity

- Very forward π^0 over the x_F range of $0.2 < x_F < 1.0$ and p_T range of $0.0 < p_T < 1.0$ GeV/c was measured.
- Systematic uncertainties by polarization, background A_N subtraction, and beam center were included.

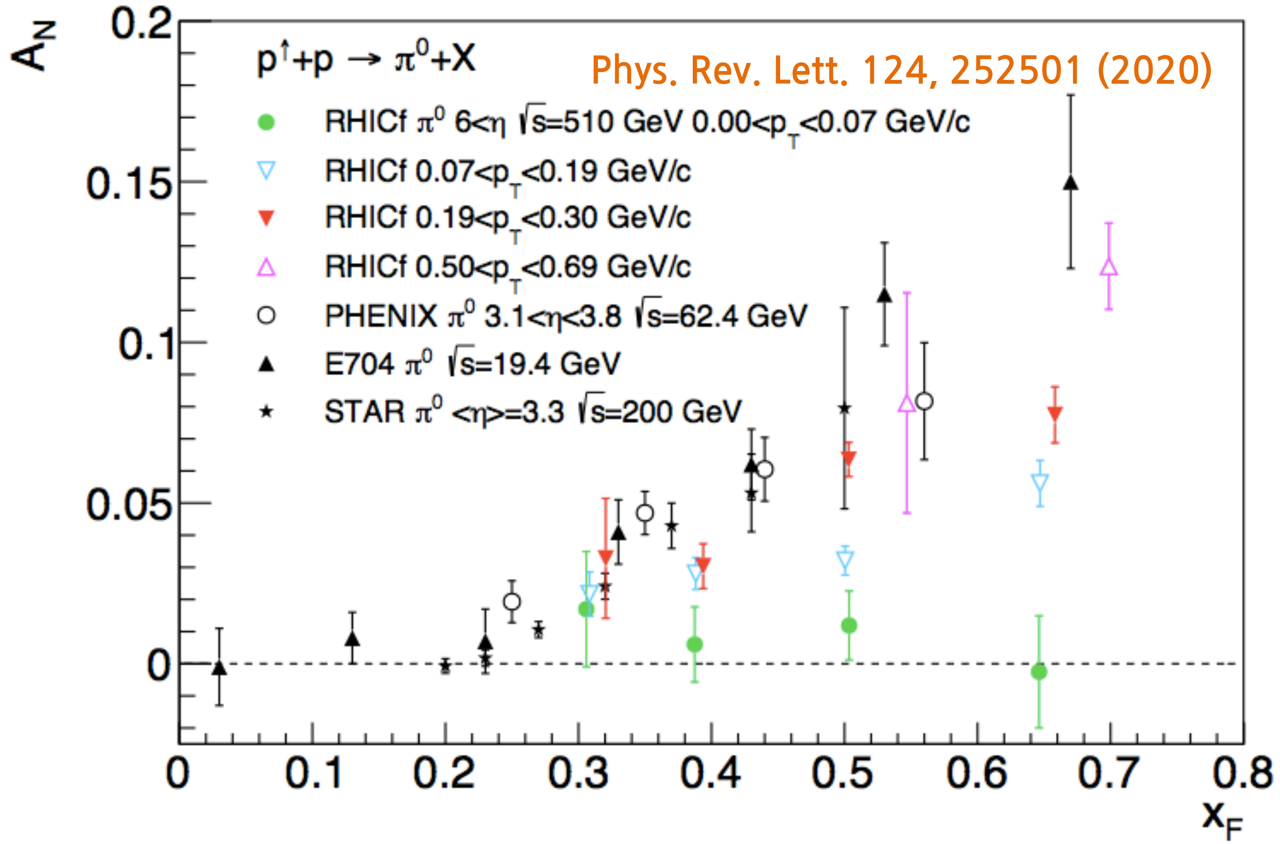
Very forward π^0 A_N as a function of x_F

Phys. Rev. Lett. 124, 252501 (2020)



- The higher p_T range the A_N is measured in, the more clearly it increases as a function of x_F.
- Note that x_F resolutions of the RHICf detector are much finer than x_F binning.

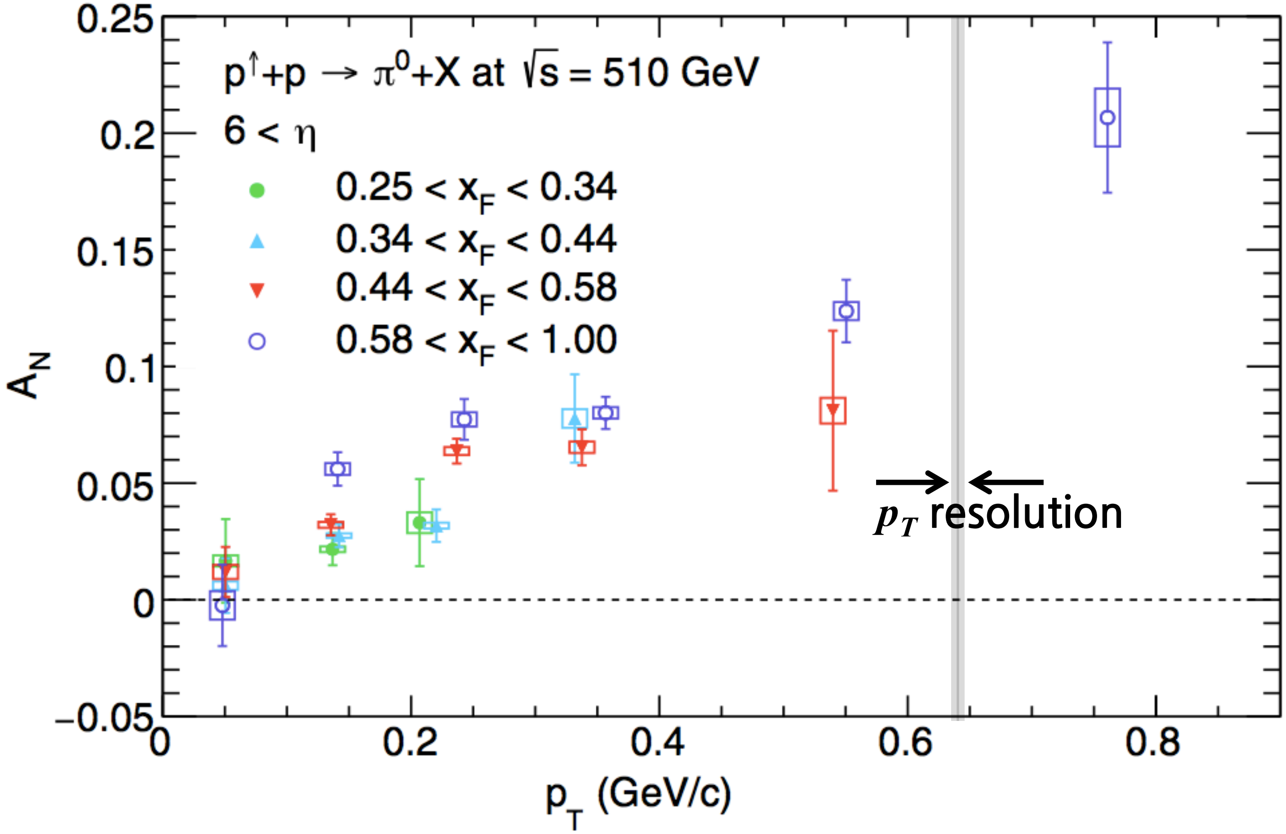
Comparison with previous measurements



- There can be perturbative contribution even in lower p_T area?
- The origin of the x_F scaling is non-perturbative process?
- We need to explore what makes the non-zero A_N in more direct way.

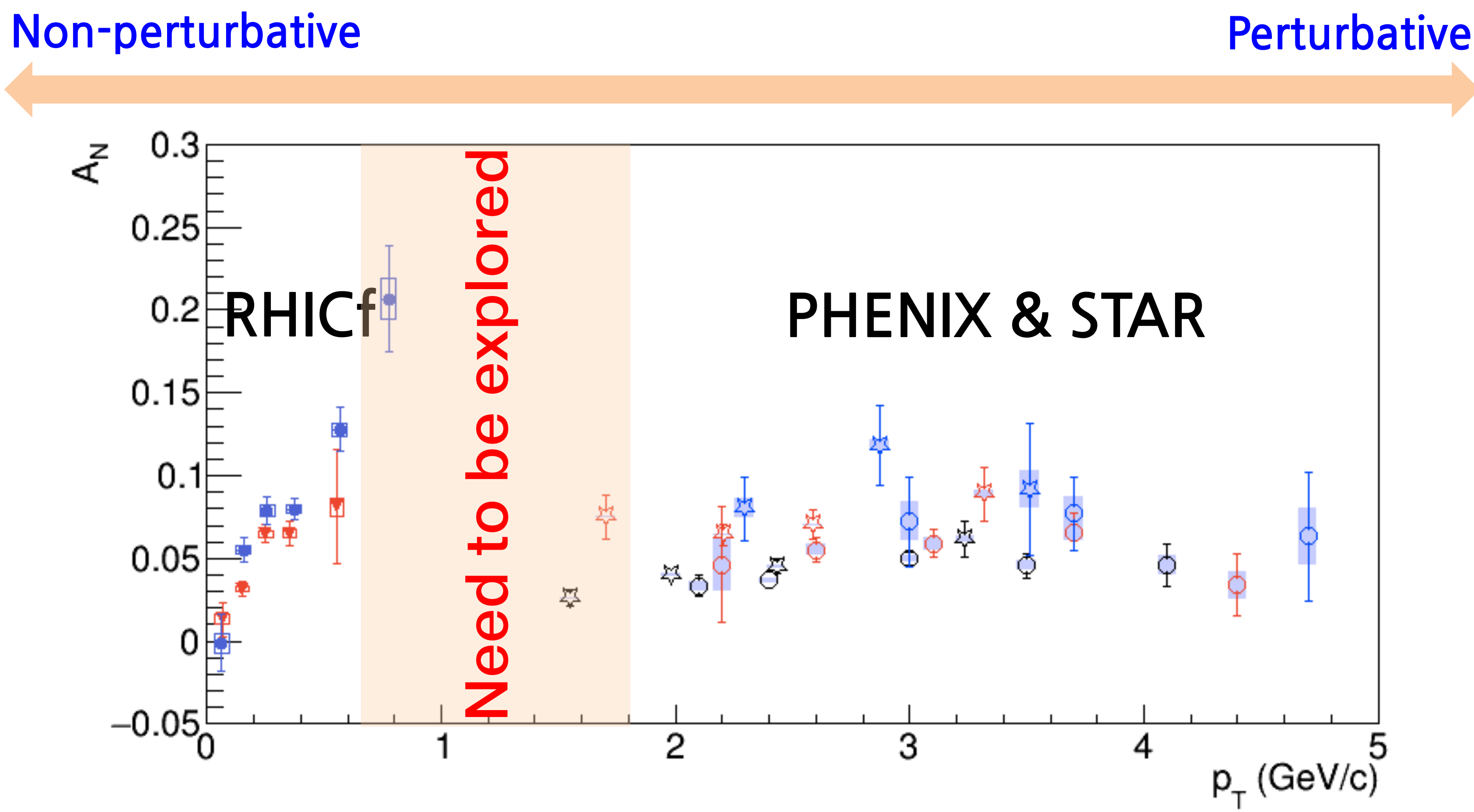
Very forward π^0 A_N as a function of p_T

Phys. Rev. Lett. 124, 252501 (2020)



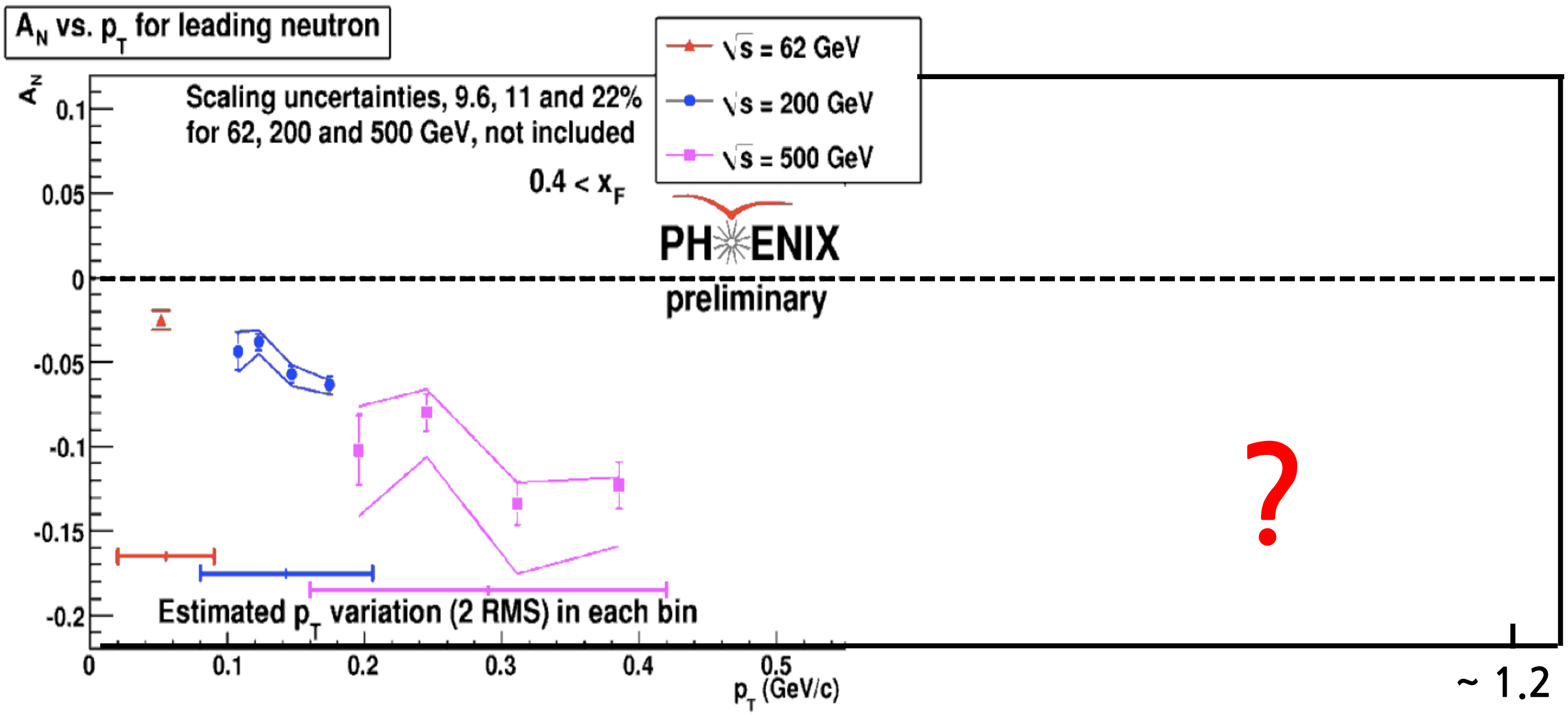
- Non-zero A_N was observed even in very forward π^0 showing clear increasing tendency as a function of p_T.
- Note that p_T resolutions of the RHICf detector are also much finer than the p_T binning.

Comparison with previous measurements



- What's the real origin of the non-zero A_N of π^0?
- How competitively each perturbative and non-perturbative process contribute to the π^0 A_N will be answered by combined analysis with STAR and follow-up experiments in near future.

Status of the neutron analysis



- The very forward neutron A_N is also being analyzed.
- The ongoing analysis shows the data is well matched with the previous measurements → will be extended to the higher p_T.

Summary

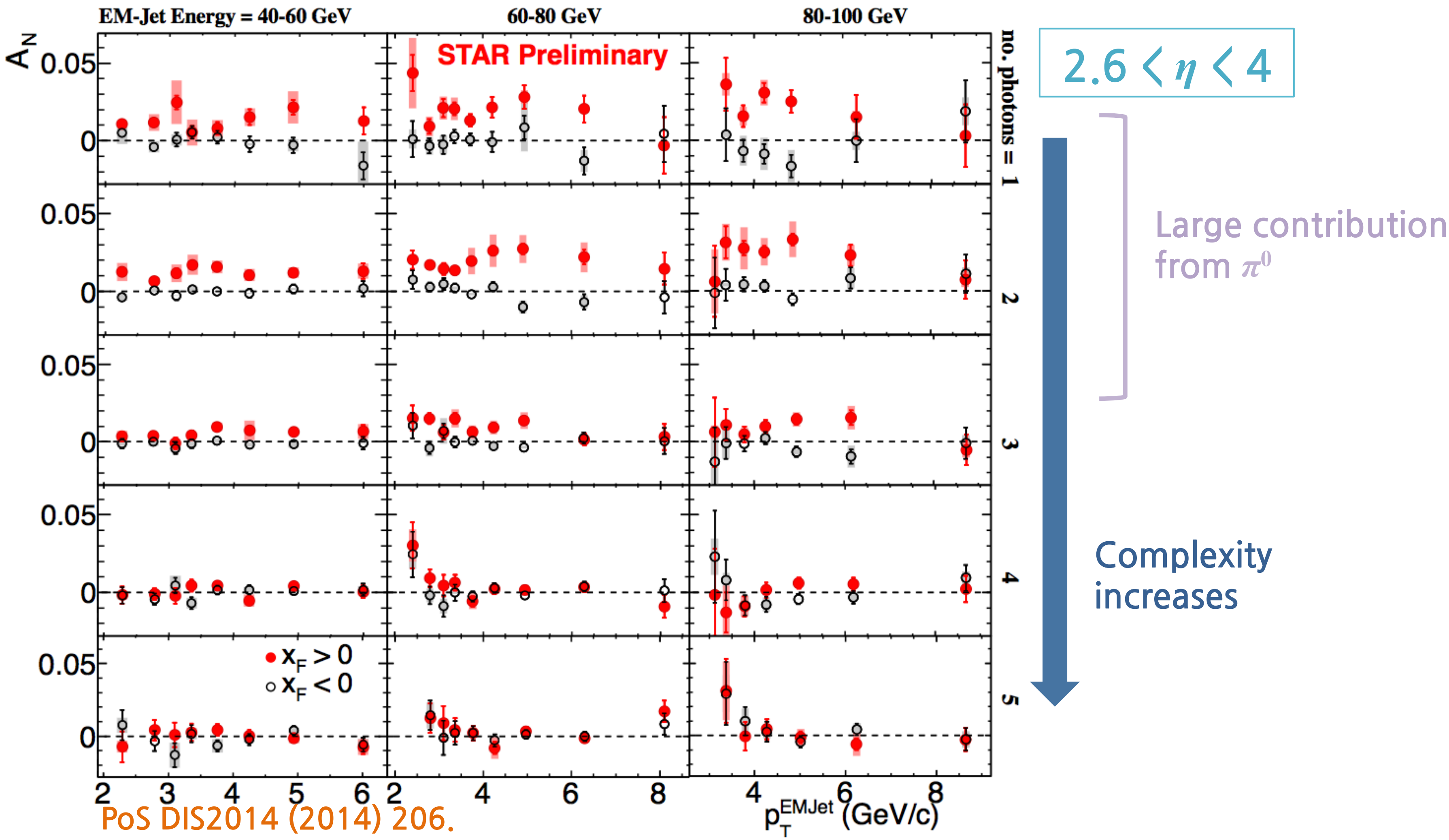
- RHICf experiment measured the A_N of very forward ($6 < \eta$) neutral particles (neutron, π^0, single γ).
- Large non-zero A_N was also observed in the kinematic range where the non-perturbative process is expected to be dominant.
- More detailed analysis with STAR detectors and follow-up experiment will provide a hint for the origin of the π^0 A_N.
- Result of the very forward neutron A_N will be also released soon.

Backup

Subject..

- Contents..
-

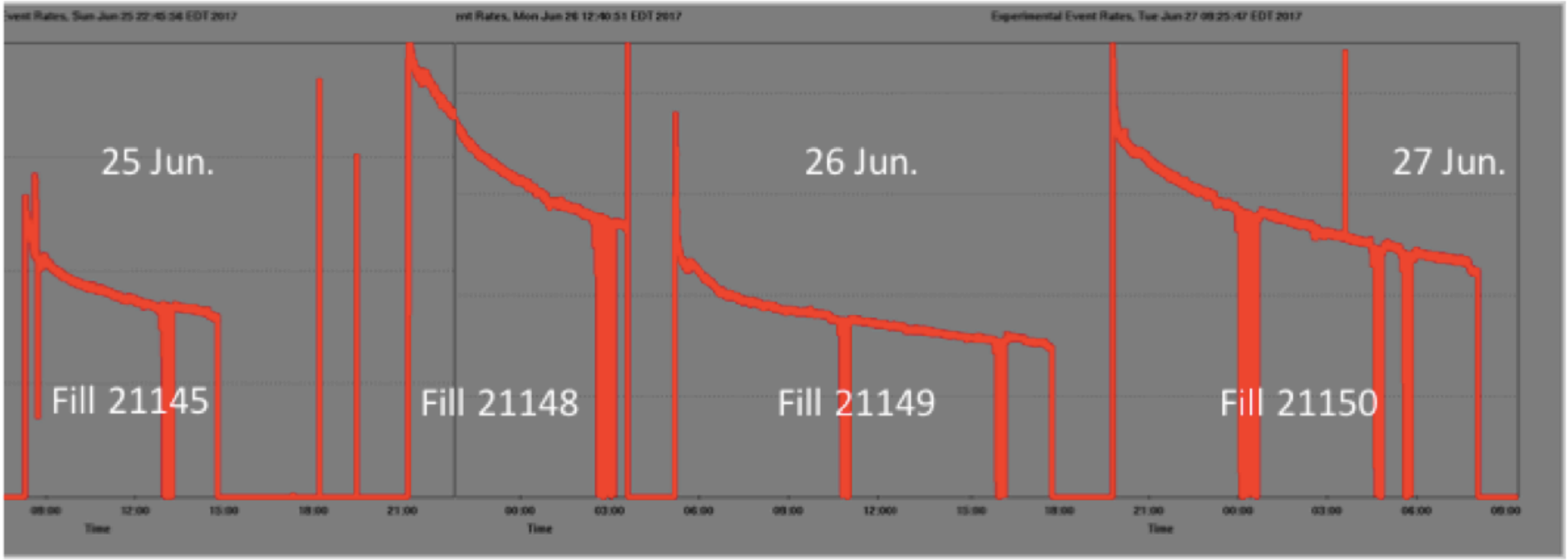
New question to the A_N of forward π^0



PoS DIS2014 (2014) 206.

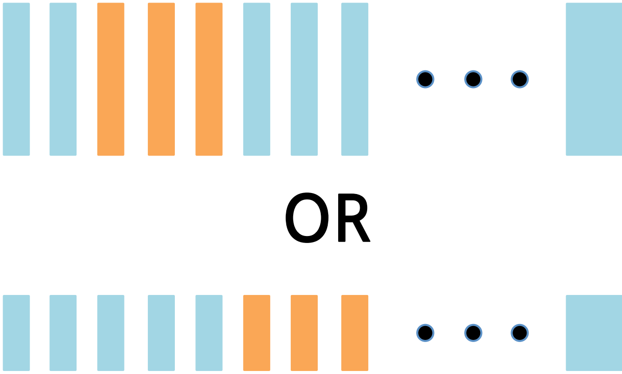
- Smaller A_N was observed with increasing multiplicity of photons (closer to hard scattering event topology).

Operation summary

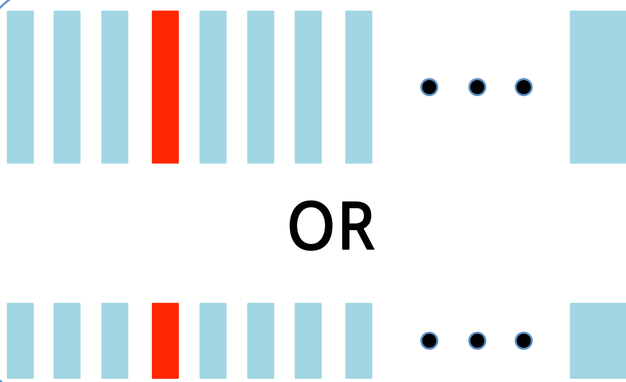


- RHICf experiment was successfully operated in June 2017.
- Total 110 M events were accumulated for neutral particles (neutron, π^0, and single photon) during 28 hours.
- Radial polarization.
- Higher β^*: 8 m and lower luminosity: 10^{31} $cm^{-2}s^{-1}$ than usual.

Triggers of RHICf detector



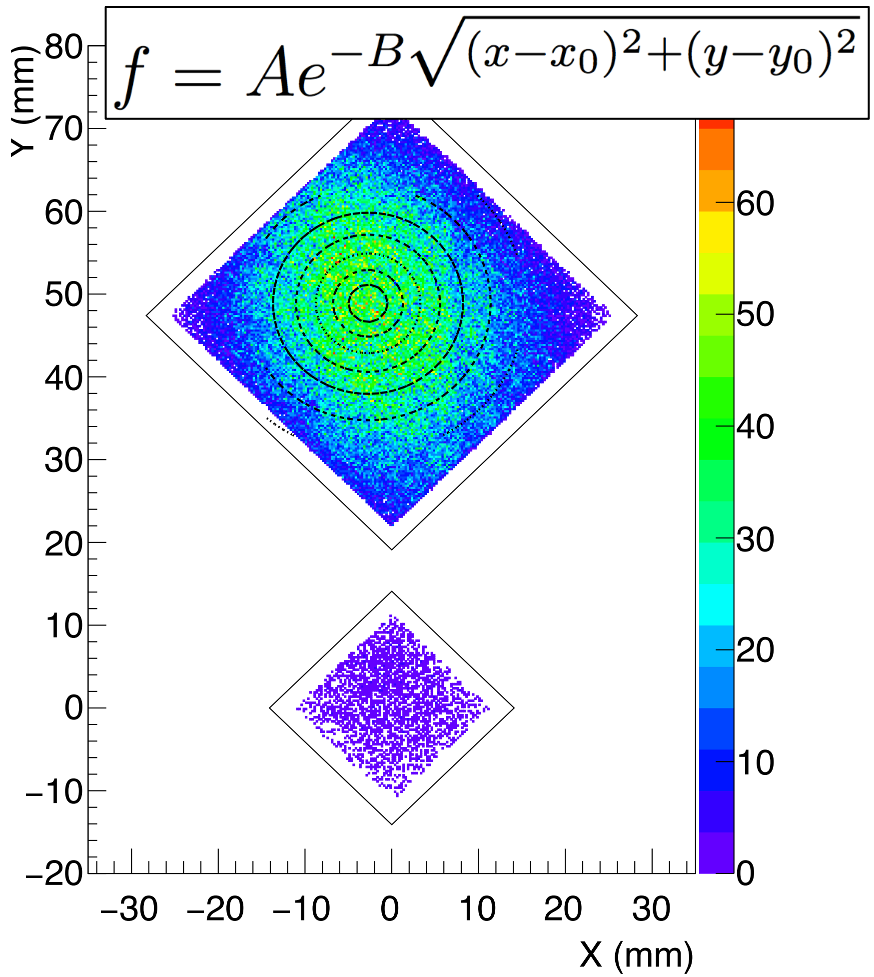
Shower trigger: Energy deposits of three successive layers at large or small tower are larger than 45 MeV.
(for neutron and single photon)

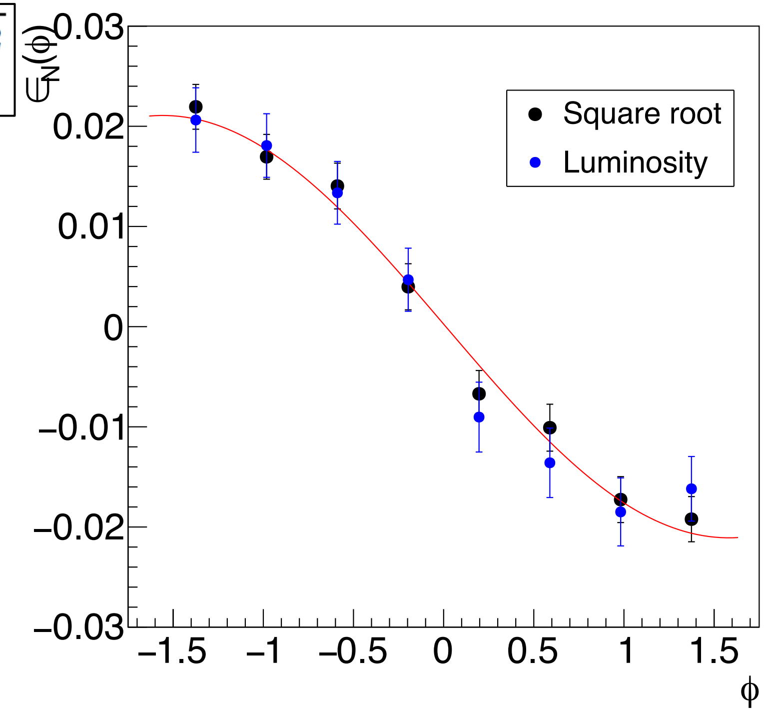


High EM trigger: Energy deposit of 4th layer at large or small tower is larger than 500 MeV.
(for high energy photon and Type-II π^0)

Type-I π^0 trigger: Energy deposits of three forward (up to 7th) successive layers at large and small tower are larger than 45 MeV.
(for Type-I π^0)

Beam center calculation (by neutron)

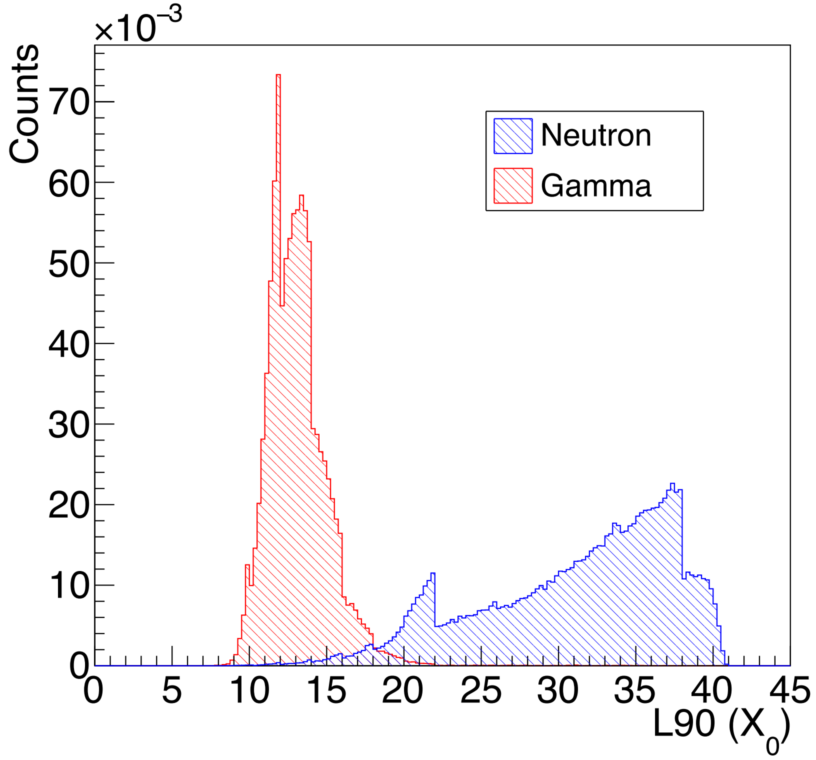




$$\frac{N_L^{\uparrow} - RN_R^{\uparrow}}{N_L^{\uparrow} + RN_R^{\uparrow}} = \frac{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} - \sqrt{N_R^{\uparrow}N_L^{\downarrow}}}{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} + \sqrt{N_R^{\uparrow}N_L^{\downarrow}}}$$

- Neutrons were used for beam center calculation.
- Square root formula shows good agreement with luminosity one.

Neutron and gamma PID



- L90 represents the longitudinal depth where the energy deposit reaches 90 % of total energy deposit.
- Gamma events can be distinguished from neutron ones using that EM shower develops more rapidly than hadronic one.

A_N calculation

Luminosity ratio between spin up and down

Number of π^0 in specific x_F and p_T range

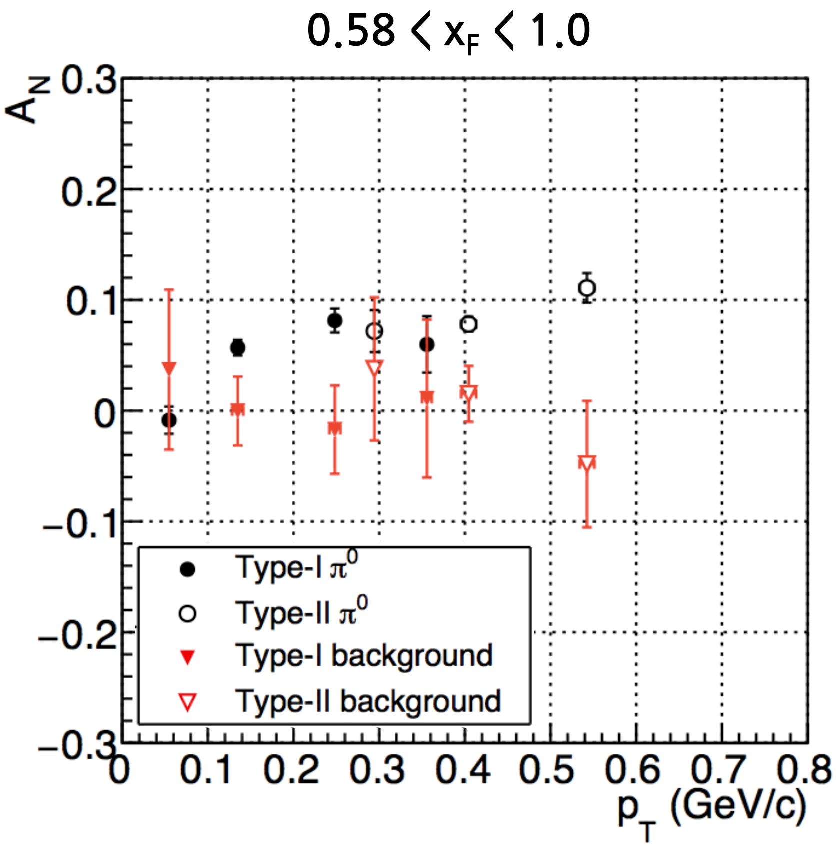
$$A_N = \frac{1}{P\epsilon}\frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}$$

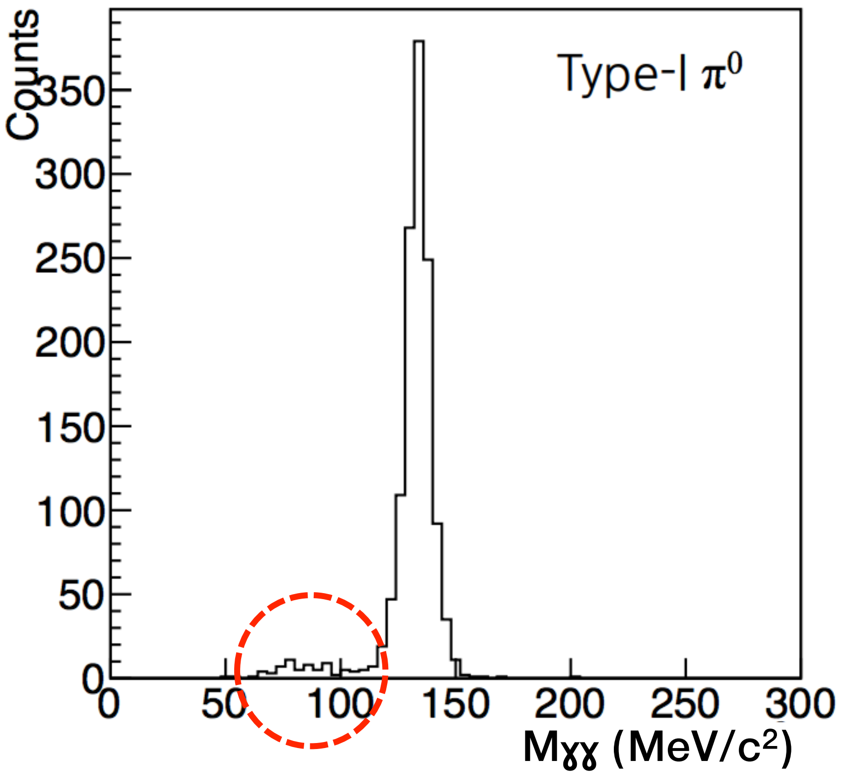
Beam polarization

Smearing by beam emittance, azimuthal angle distribution of π^0, and detector position resolution

- P (~ 0.55 ± 0.05) can be calculated by polarization monitor.
- R (~ 0.970 ± 0.02) is estimated by luminosity ratio of charged particles near IP.
- ϵ (~ 0.95 ± 0.05) can be studied by comparing actual and diluted A_N in simulation.

Background A_N subtraction





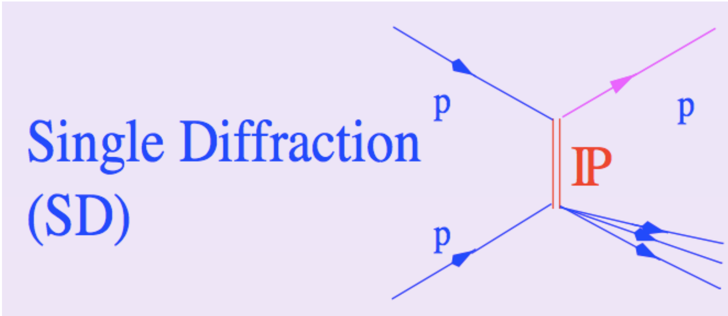
- Background A_Ns are all consistent with zero.

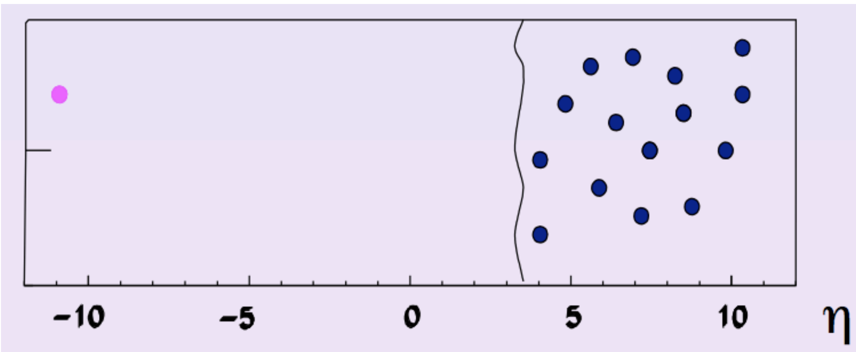
$$A_N^S = \left(1 + \frac{N_B}{N_S}\right) A_N^{S+B} - \left(\frac{N_B}{N_S}\right) A_N^B$$

- Difference between the A_N with and without the π^0 tail was considered as a systematic uncertainty.

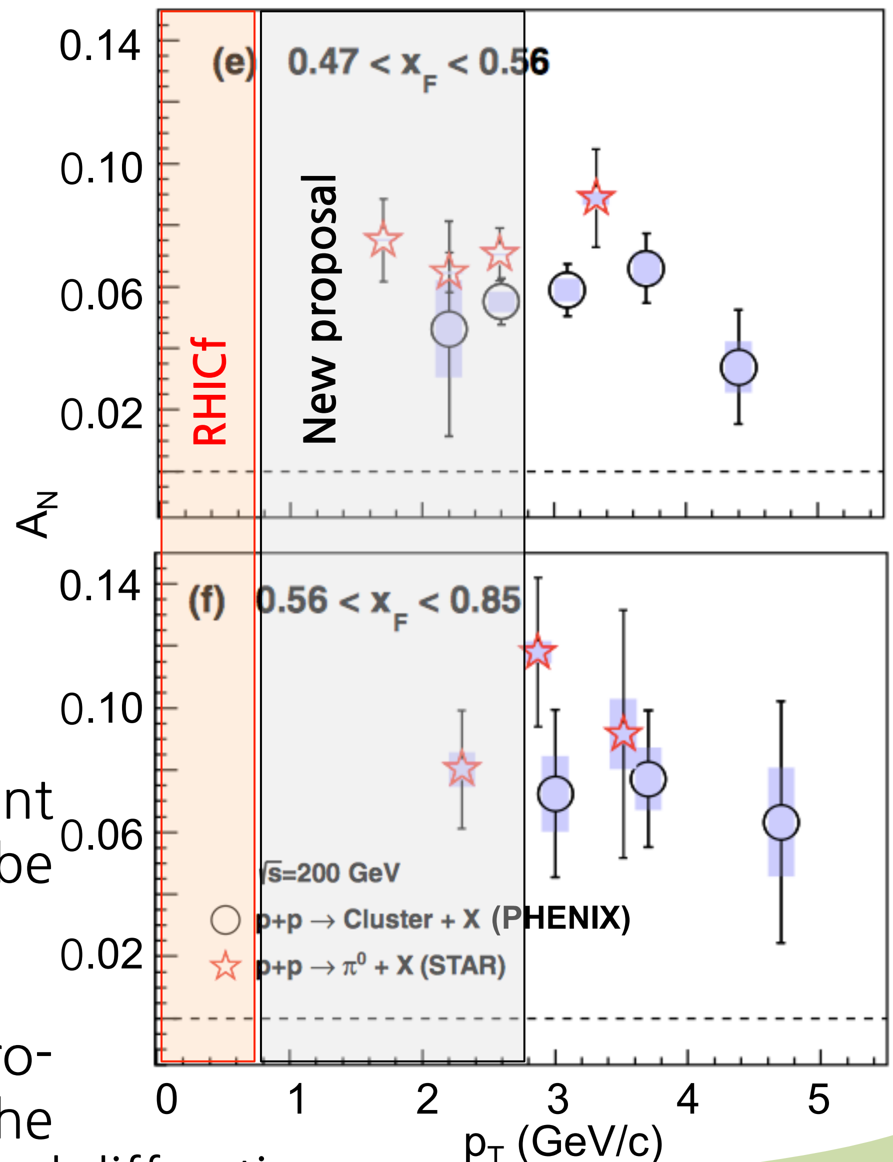
Should be overestimated due to the π^0 tail.

What's the next?





Phys. Rev. D90 (2014) 012006.



- Using other STAR detectors, event type dependence for the A_N can be studied.
- A follow-up experiment will be proposed to practically compare the each contribution from partnoic and diffractive process.