Non-zero transverse single spin asymmetry of very forward π^0 in polarized $p+p$ collisions at $\sqrt{s} = 510$ GeV

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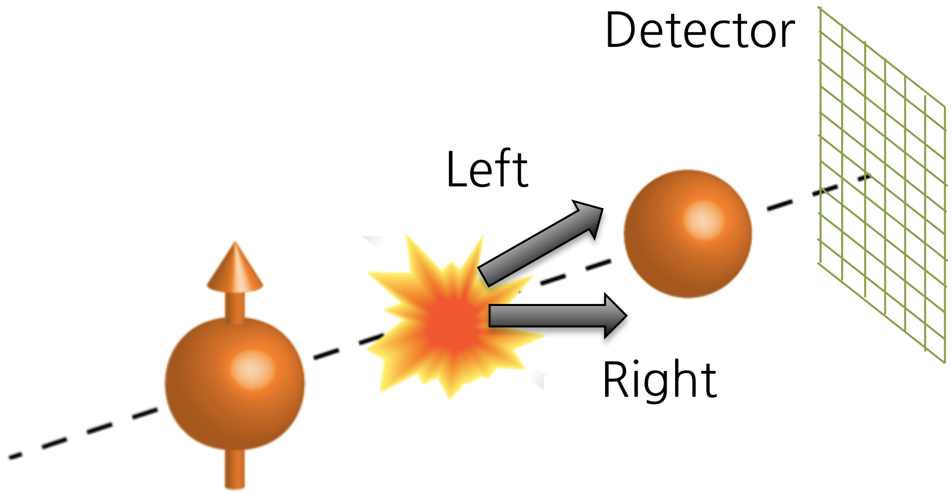
on behalf of the RHICf collaboration

Programs for Junior Scientists

14 April 28th Deep-Inelastic Scattering 2021

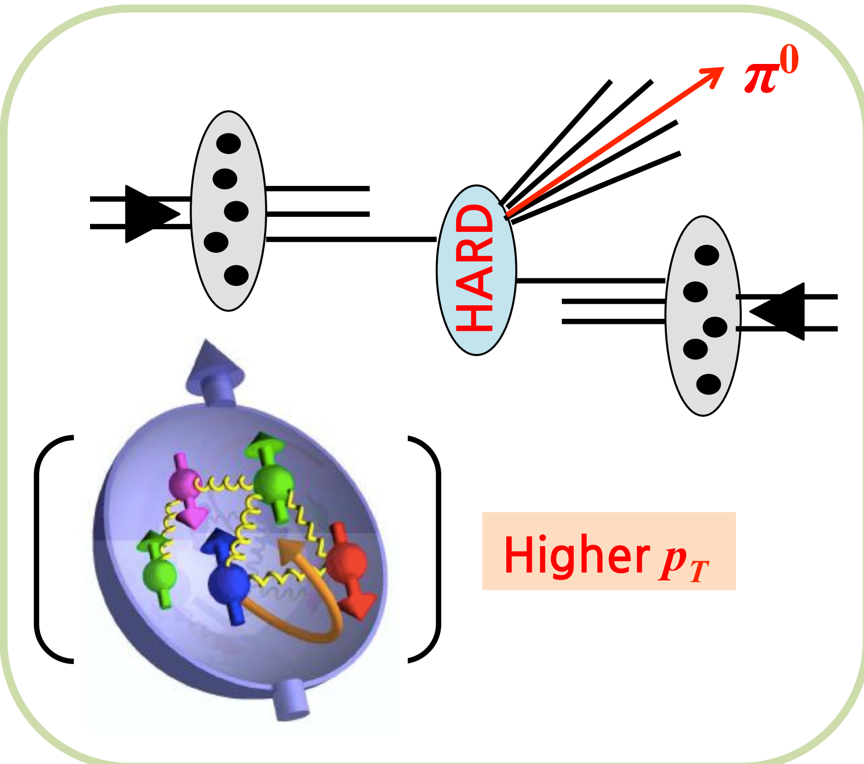
Transverse single-spin asymmetry (A_N)

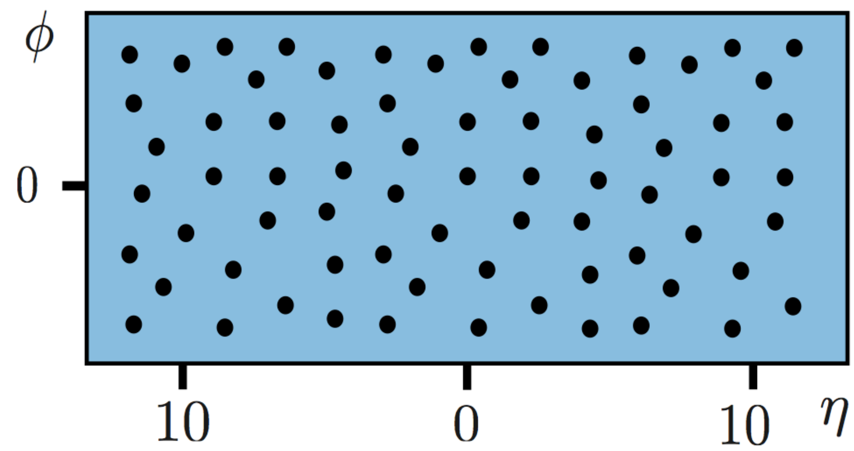


$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}} = \frac{\sigma_L^{\uparrow} - \sigma_L^{\downarrow}}{\sigma_L^{\uparrow} + \sigma_L^{\downarrow}}$$

- In polarized p + p collision, A_N is defined as a left-right cross section asymmetry of a specific particle or event.
- Though the non-zero A_N of π^0 has been intensively studied for longer than 30 years, its relation to the proton spin is not completely understood yet.

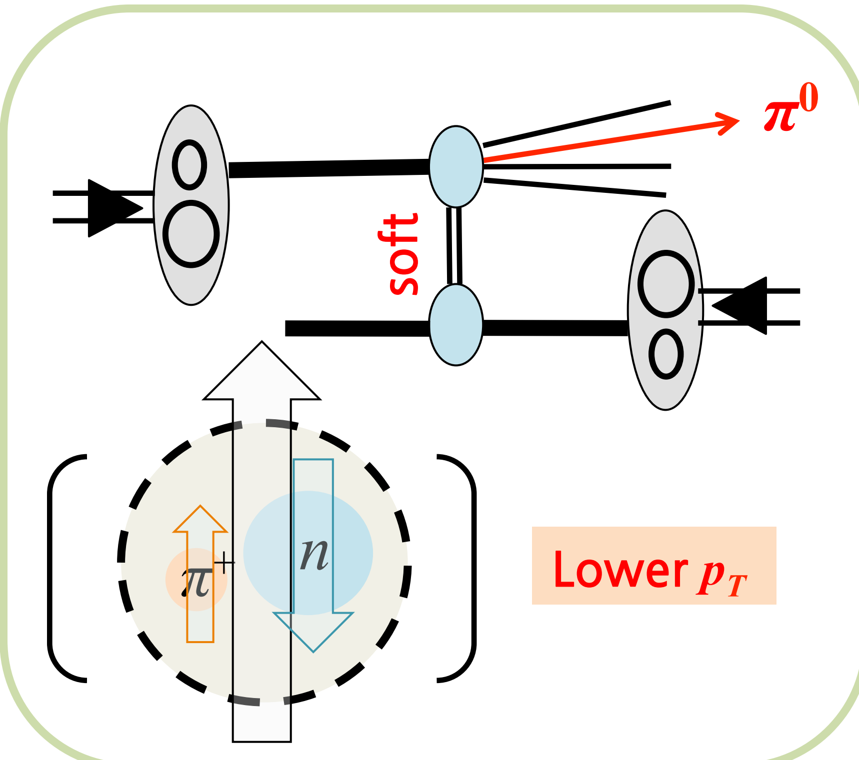
Non-diffractive (partonic) process

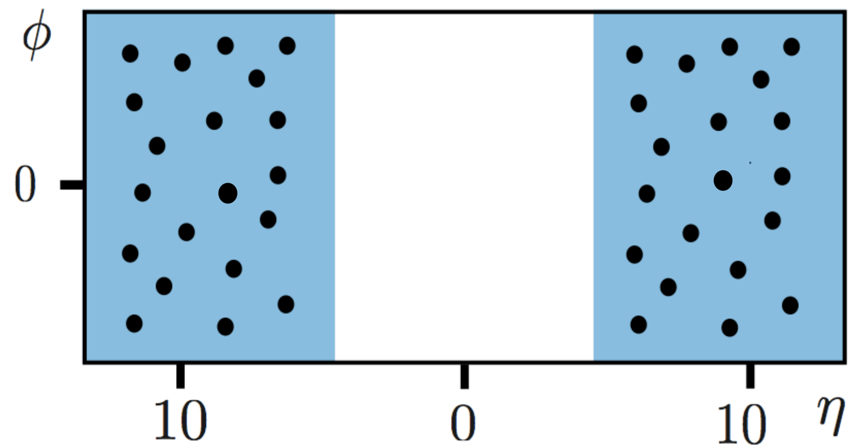




- Non-diffractive process usually describes the p + p collision as “hard” scattering between quarks and gluons.
- ~75% of inelastic collision at RHIC energy.
- Higher $p_T > 1$ GeV/c with many particles around.

Diffractive (hadronic) process

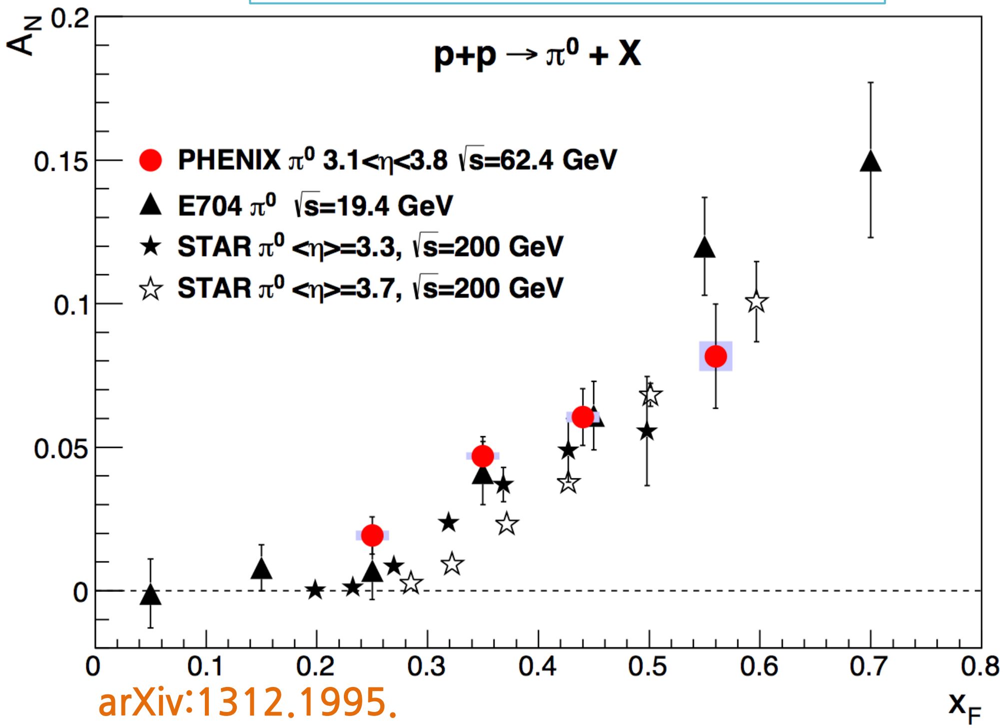




- Diffractive process usually describes the p + p collision as "soft" scattering in the mesonic degree of freedom.
- Lower p_T < 1 GeV/c with less particles around (isolated).
- ~25% of inelastic collision at RHIC energy.

A_N of forward π^0

$2 < \eta < 4, p_T > 1$ GeV/c



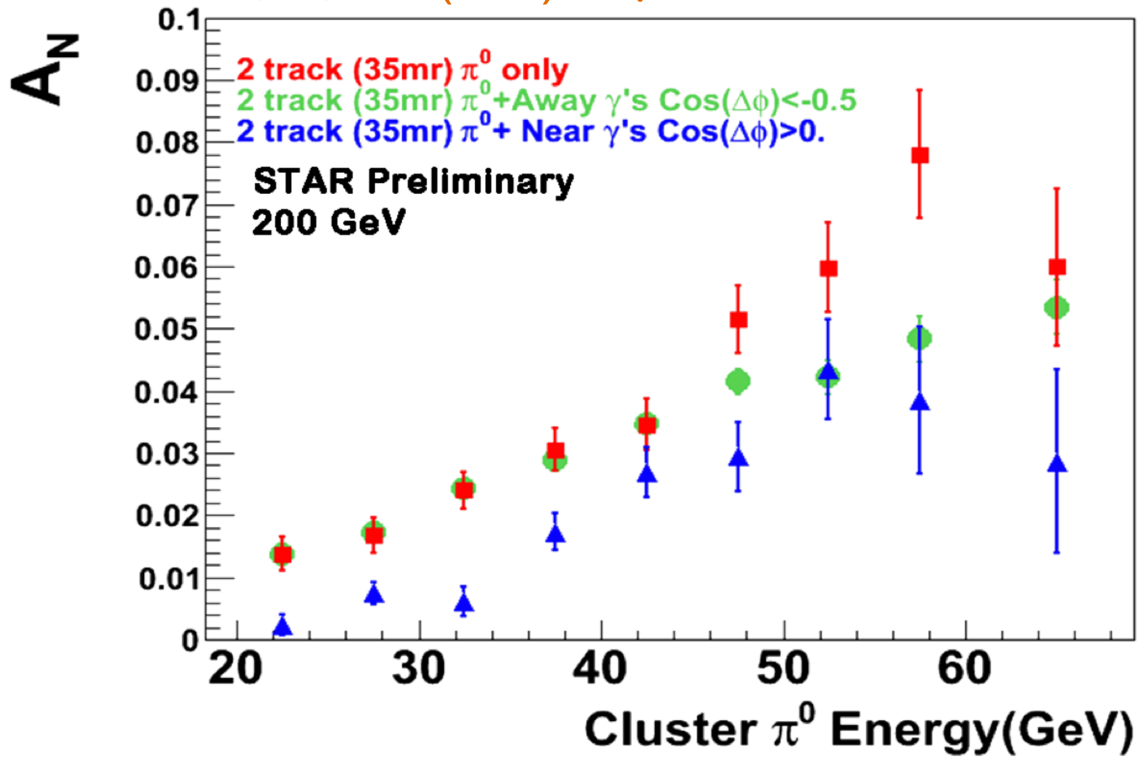
arXiv:1312.1995.

- So far, the non-zero A_N has been observed by only the "forward" π^0 production.
- It has been interpreted based only on the quarks and gluons' degrees of freedom theoretically.

A_N of isolated π^0

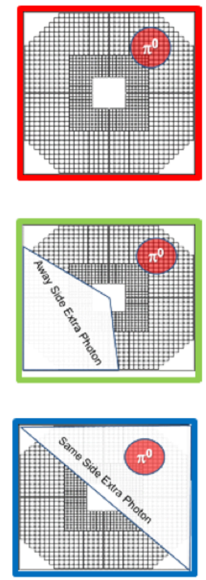
See arxiv:2012.11428 for recent result

PoS DIS2013 (2013) 240.



$2.6 < \eta < 4$

$p_T > 1$ GeV/c

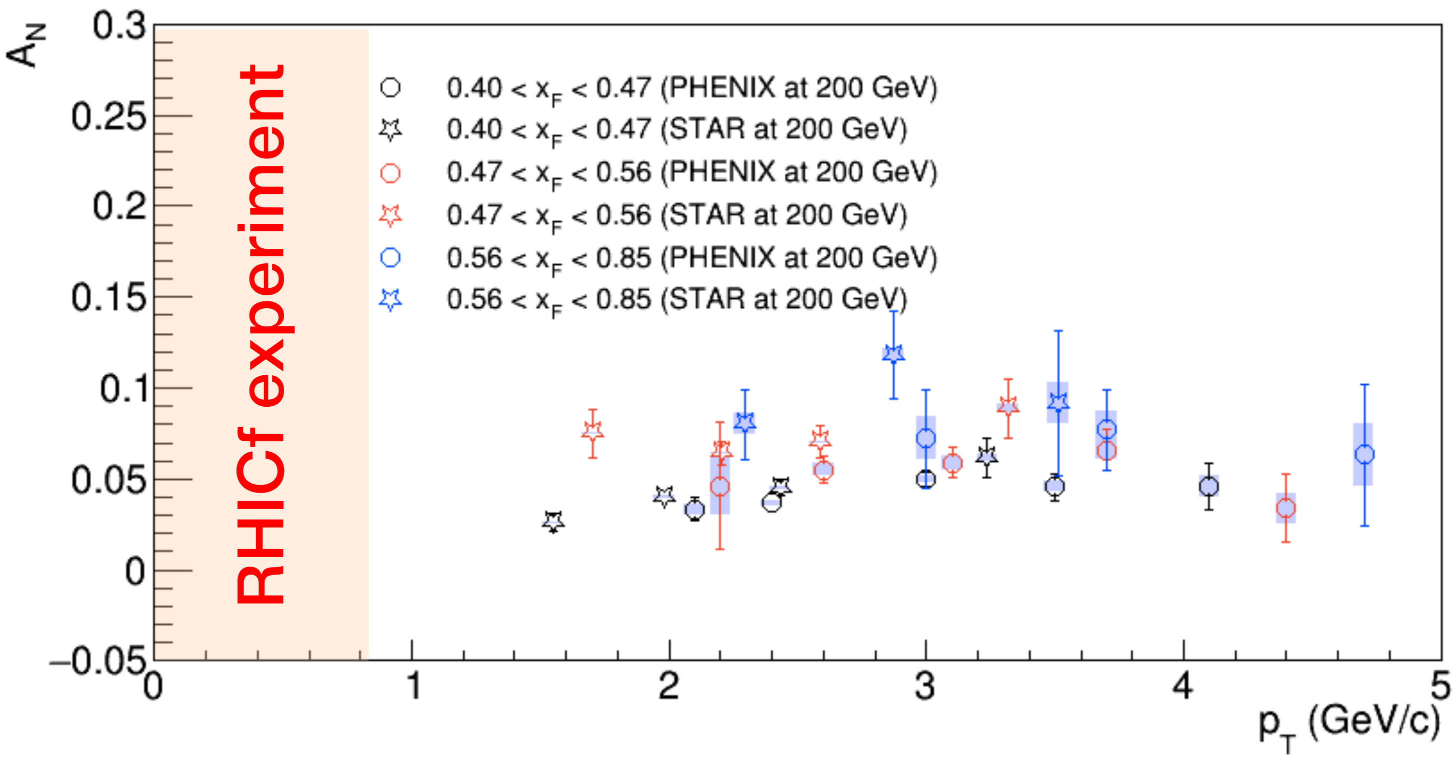


More isolated

Less isolated

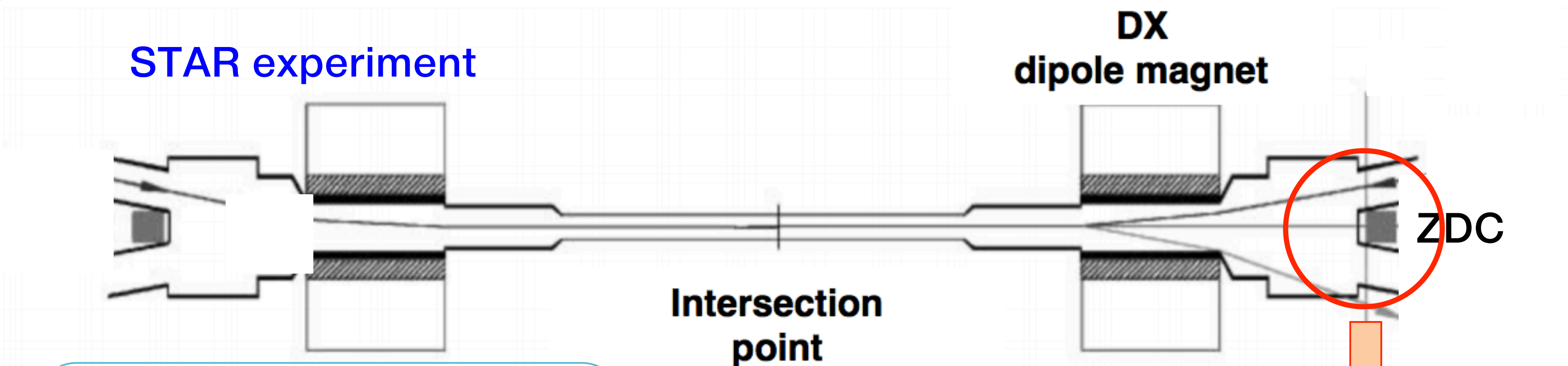
- Larger A_N was observed by more isolated π^0 than less isolated one.
- In this analysis, **isolated** = energy fraction close to 1.
- Diffractive process may have a finite contribution to the π^0 A_N as well as non-diffractive one.

A_N of very forward π^0

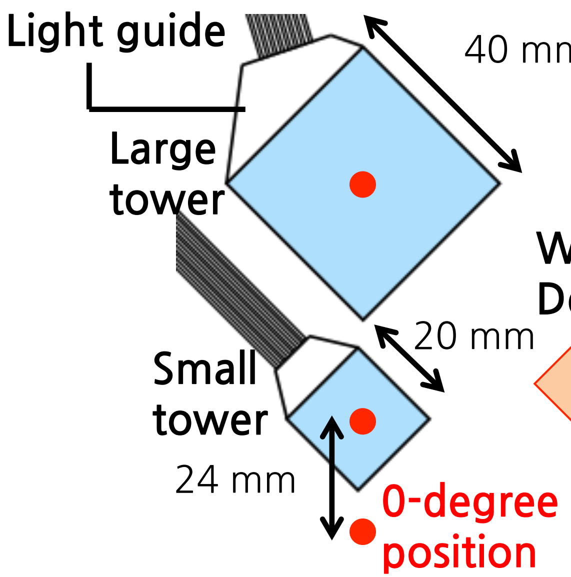


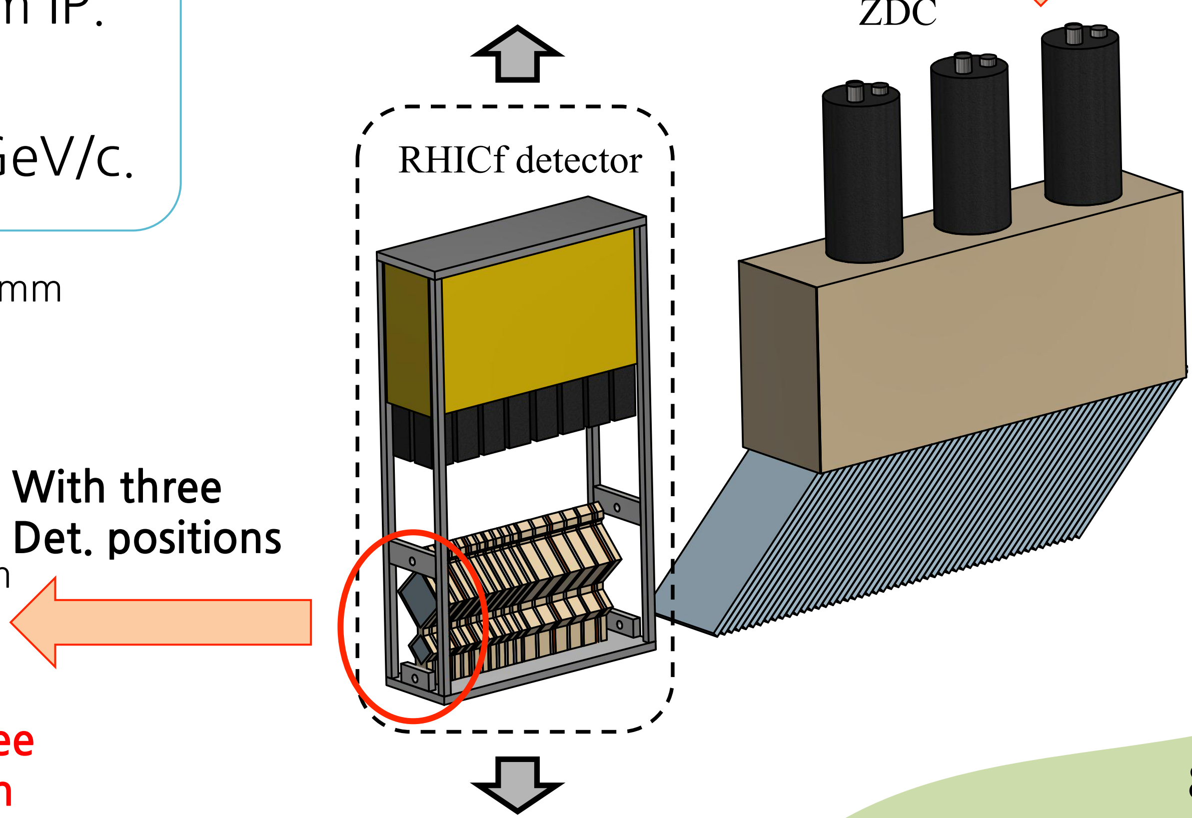
- No detailed measurement ever for the $p_T < 1$ GeV/c.
- In June, 2017, the RHICf experiment firstly measured the A_N of **very forward** π^0 ($6 < \eta$) at STAR to study the role of the diffractive process to the π^0 A_N.

RHIC forward (RHICf) experiment

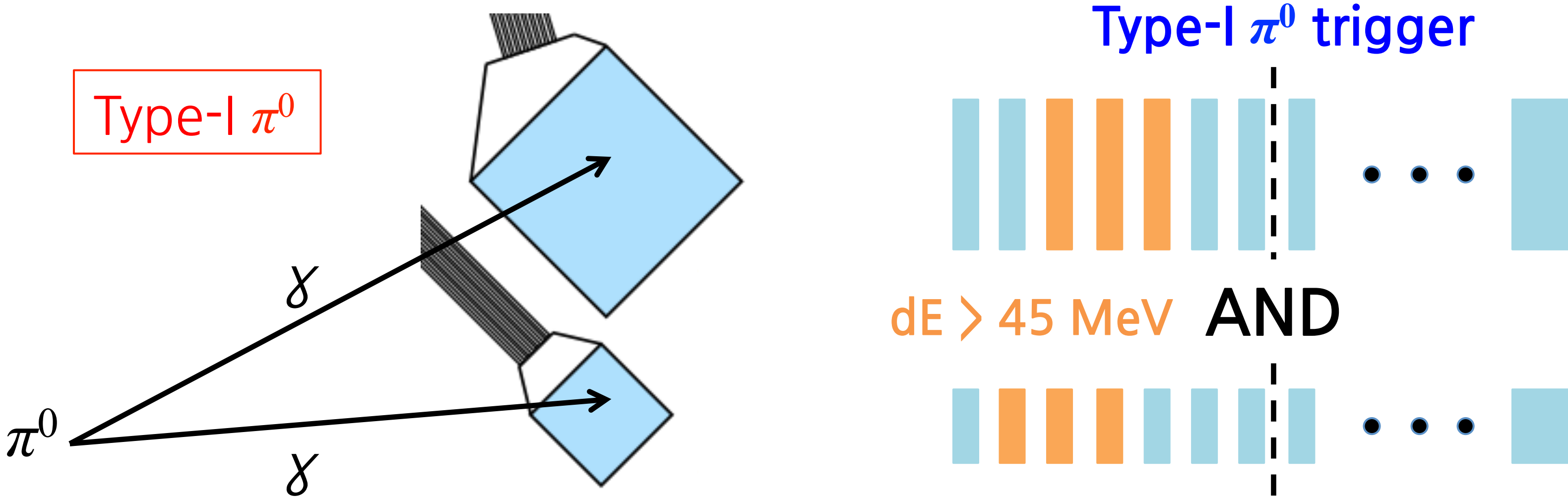


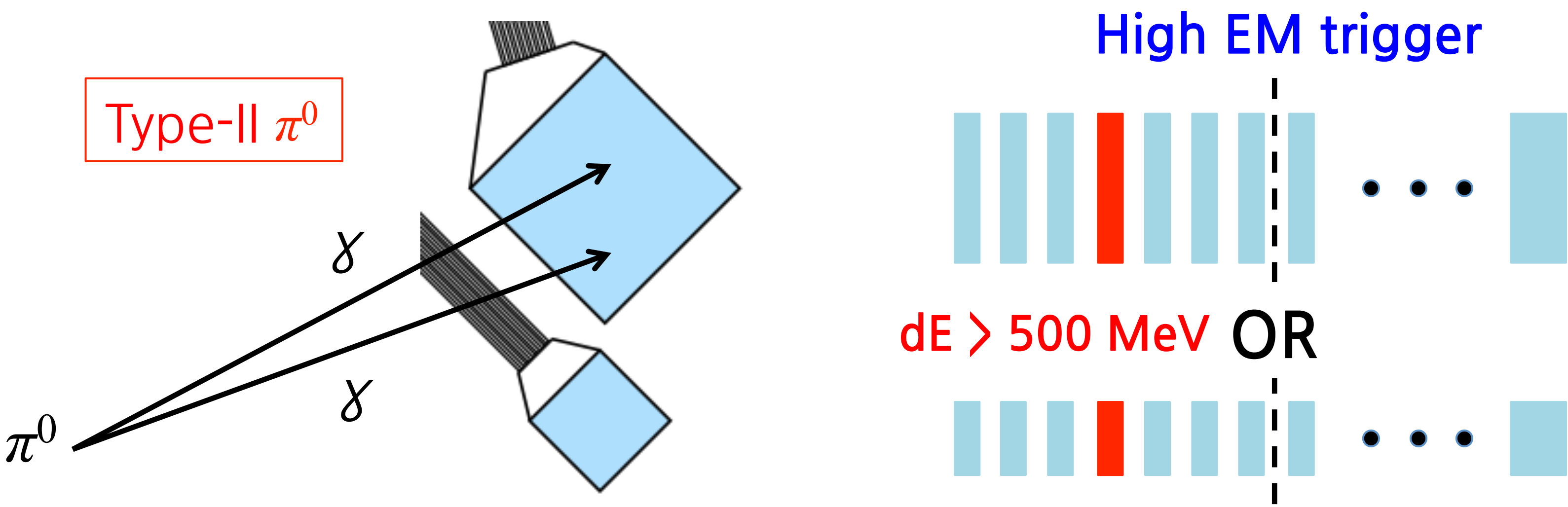
- 18 m away from IP.
- $0.2 < x_F < 1.0.$
  $0.0 < p_T < 1.0$ GeV/c.



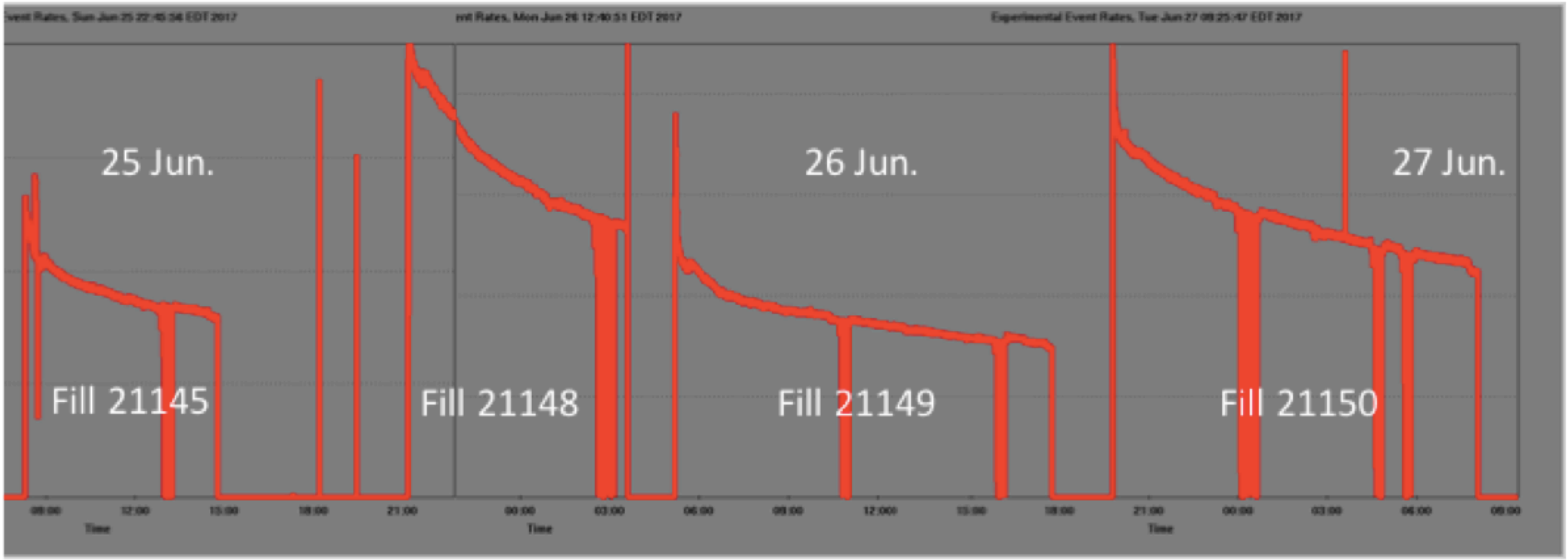


π^0 measurement

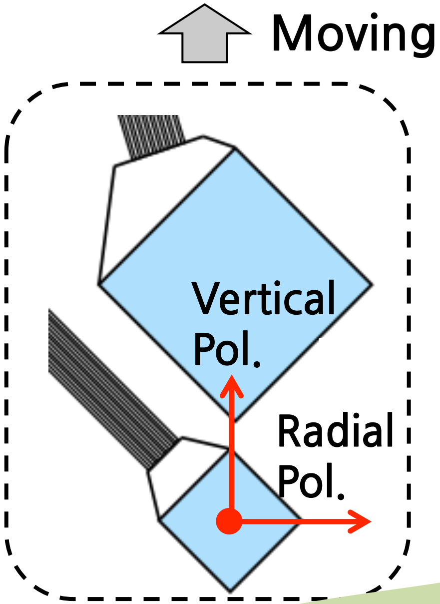




Operation summary

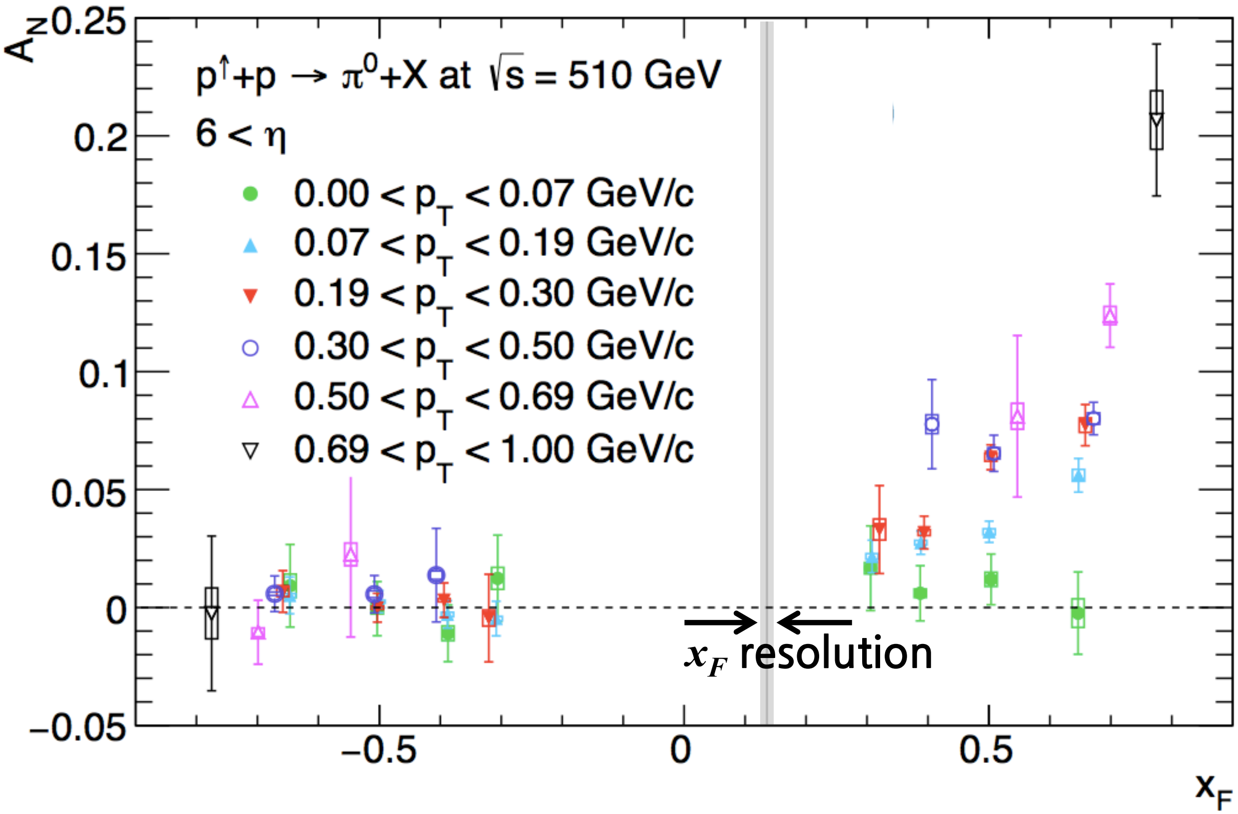


- Data was taken during 4 fills (28 hours).
- 90°-rotated radial polarization.
- Higher β* = 8 m and
  lower luminosity = 10^{31} $cm^{-2}s^{-1}$ than usual.



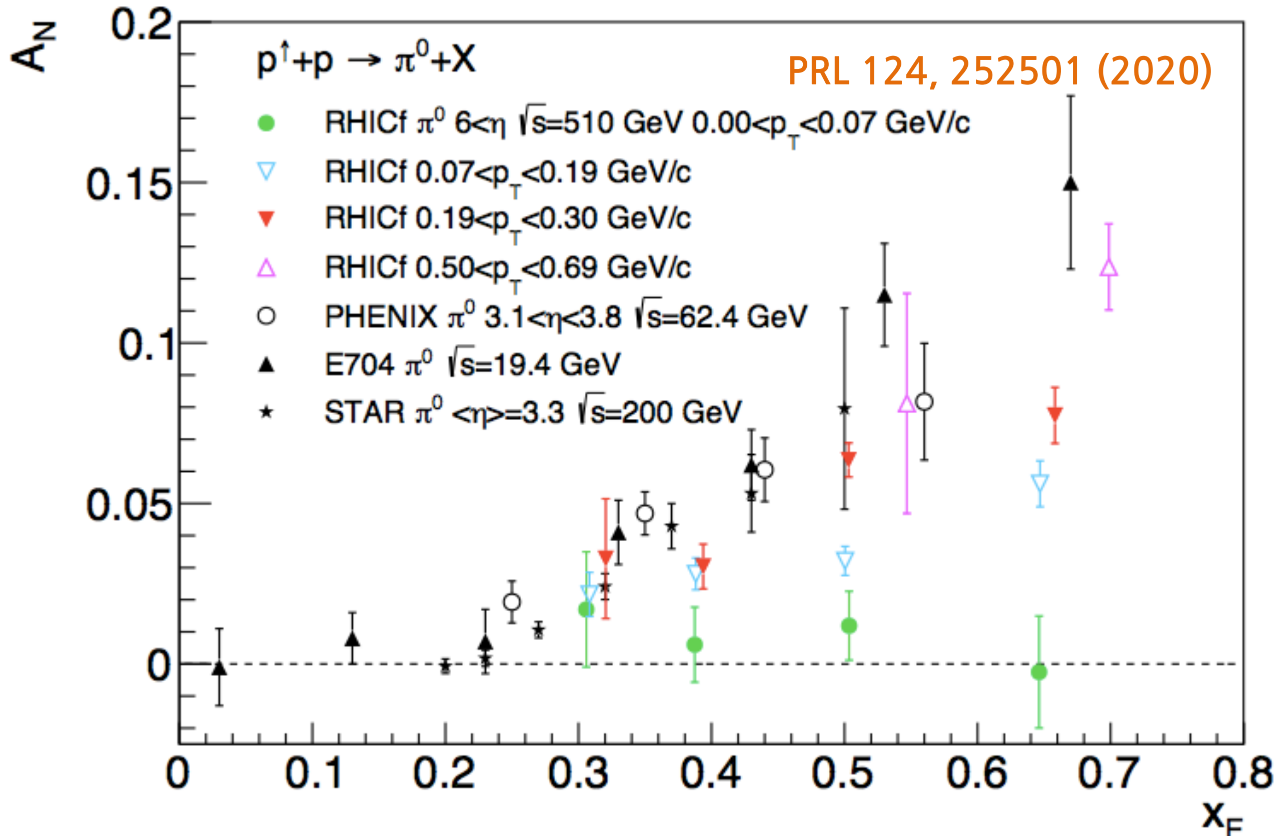
Very forward π^0 A_N as a function of x_F

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.

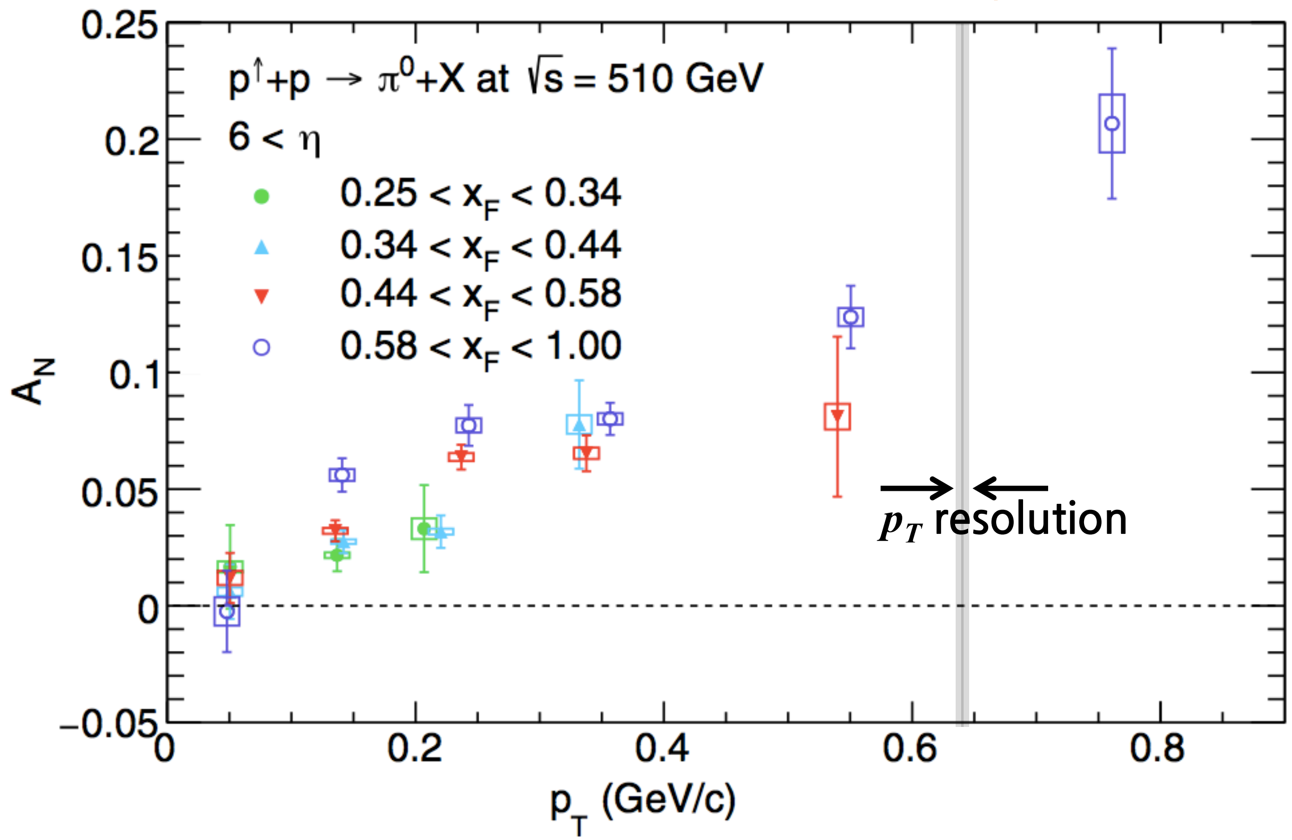
Comparison with previous measurements



- The very forward π^0 A_N seems to be comparable with the forward one even at low $p_T < 1$ GeV/c.
- Non-zero A_N of π^0 may come from not only the non-diffractive process but also the diffractive one.
- The forward and very forward π^0 A_N may share a common underlying production mechanism.

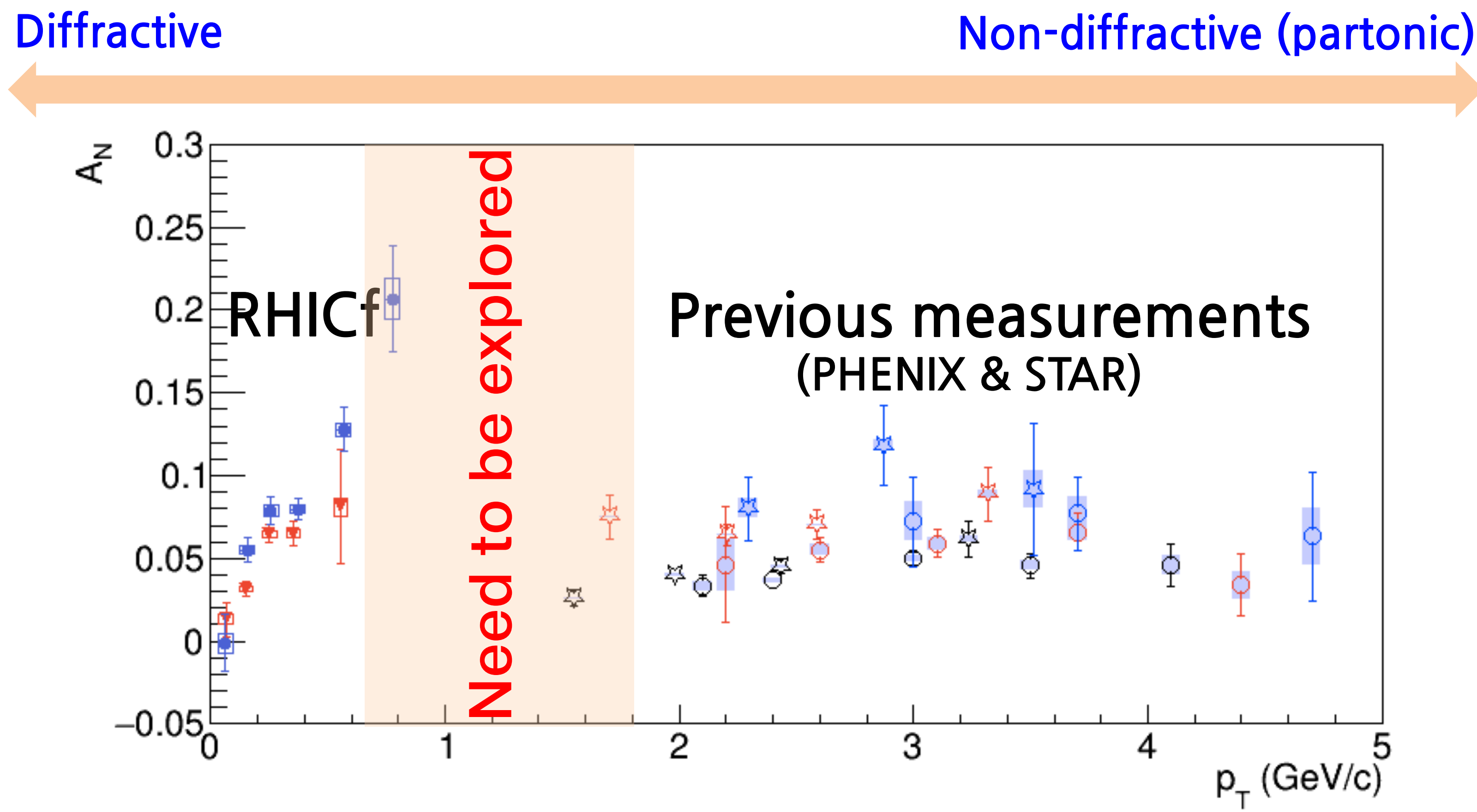
Very forward π^0 A_N as a function of p_T

PRL 124, 252501 (2020)



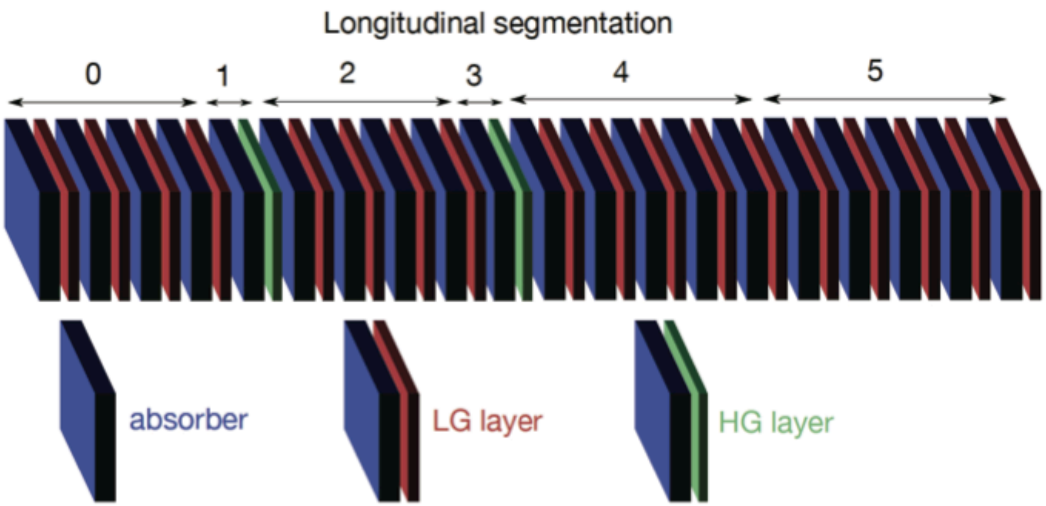
- The very forward π^0 A_N clearly increases as a function of p_T.
- Note that the resolution of the RHICf detector is much finer than the binning.

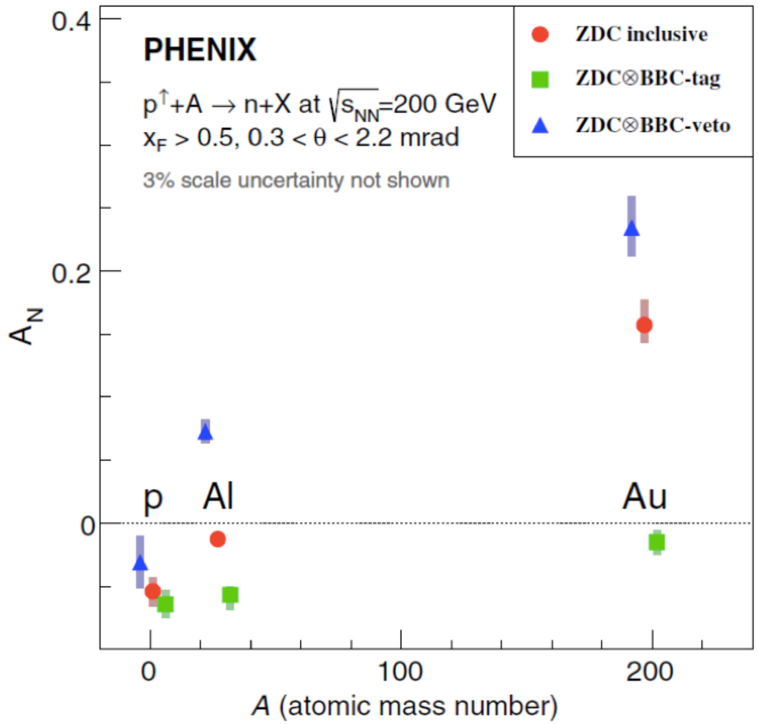
Comparison with previous measurements



- The gap between two data sets will be the connection from the diffractive to non-diffractive process.
- How competitively each process contribute to the non-zero A_N for π^0 production can be studied.

RHICf-II experiment

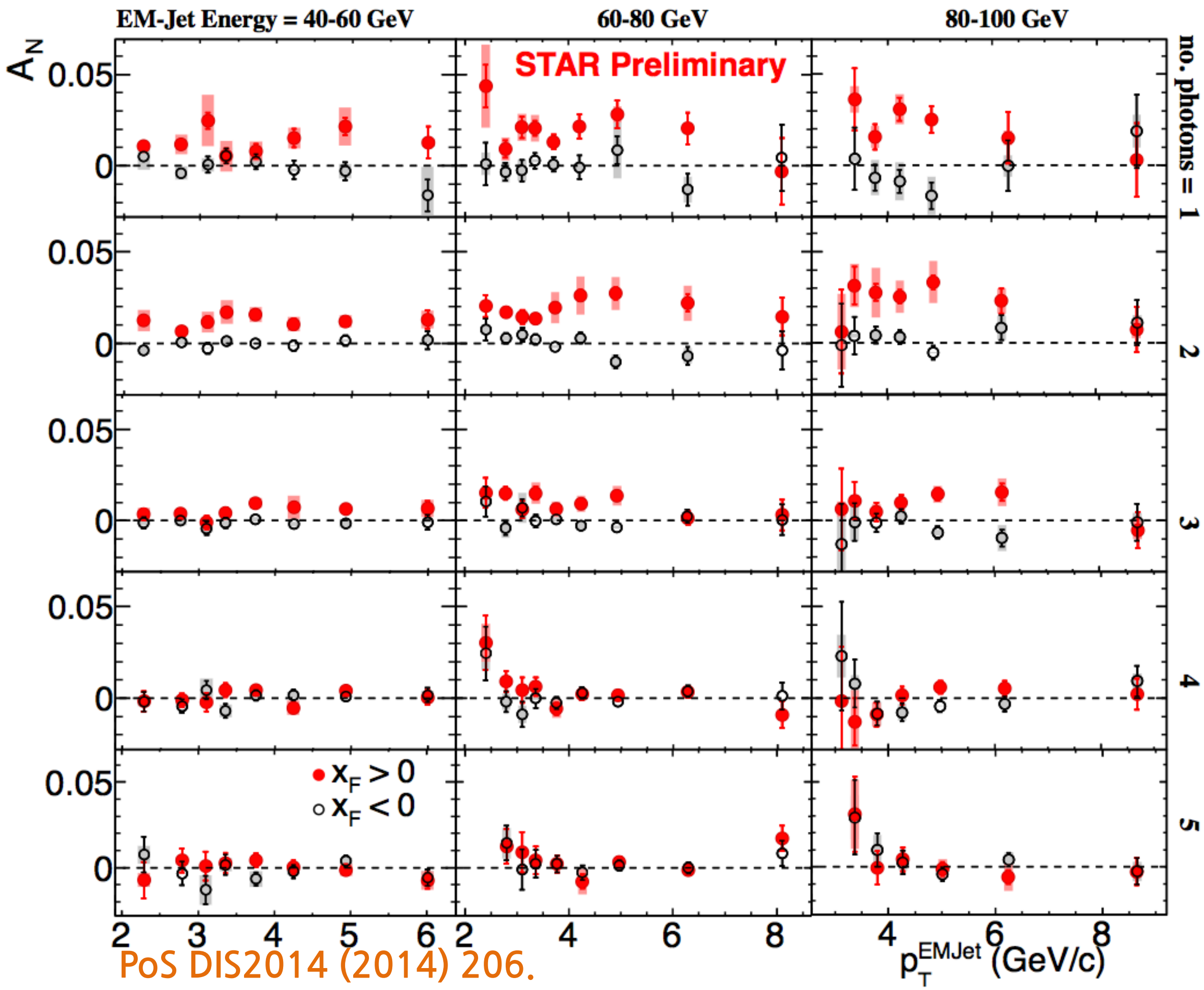




- For a new detector development, technology of the ALICE FoCal will be referred to.
- Very forward π^0 A_Ns with different $\sqrt{s}$, lambda A_N, neutron A_N in p + A, and so on.
- The first target is Run24.

Backup

New question to the A_N of forward π^0



PoS DIS2014 (2014) 206.

$2.6 < \eta < 4$

Large contribution from π^0

Complexity increases

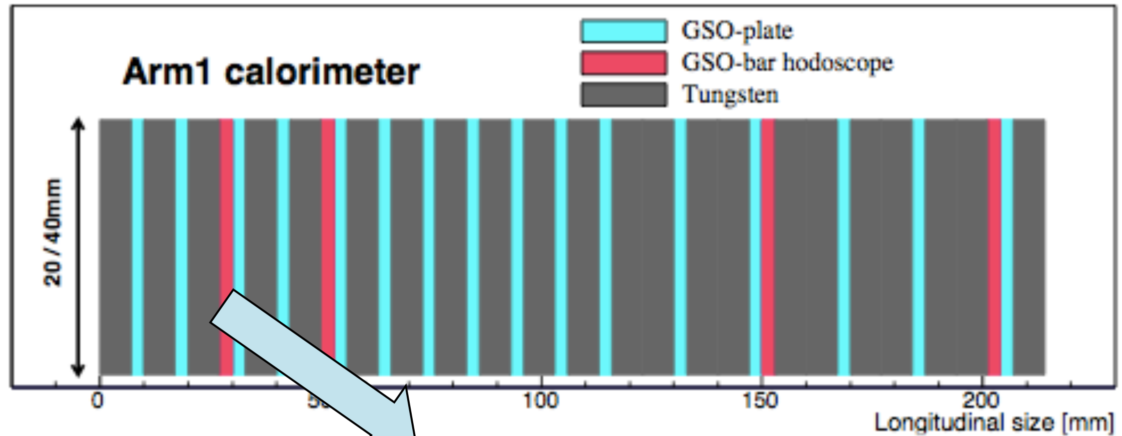
- Smaller A_N was observed with increasing multiplicity of photons (closer to hard scattering event topology).

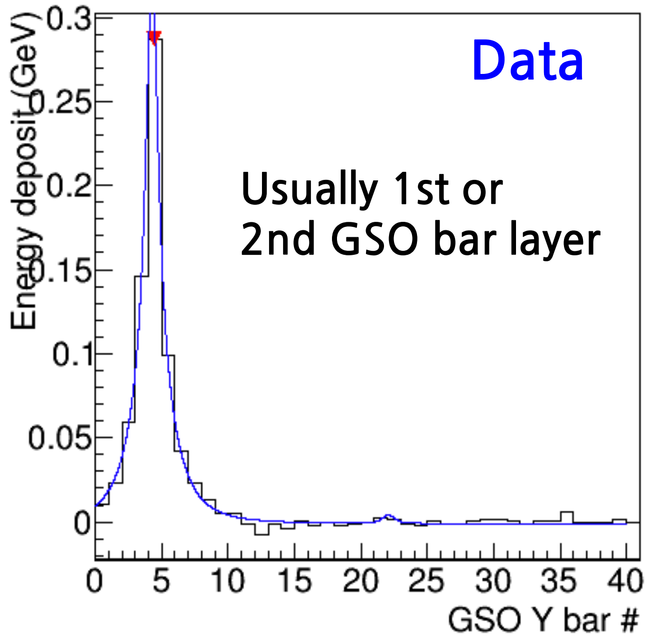
Position reconstruction of photon

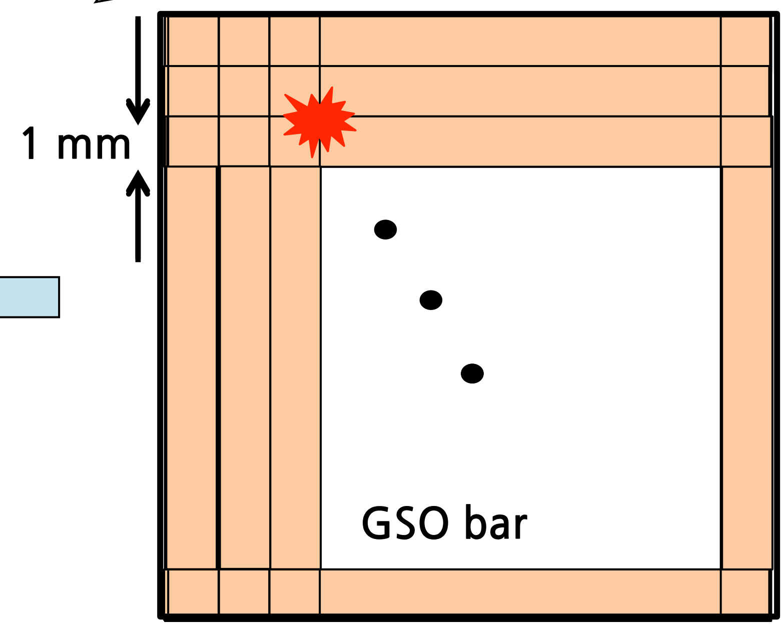
- If a photon hit a tower,

γ

(x, y)



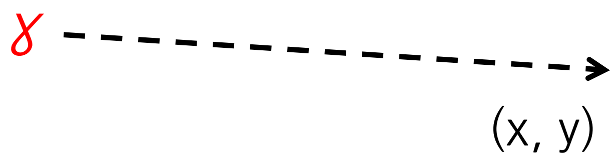


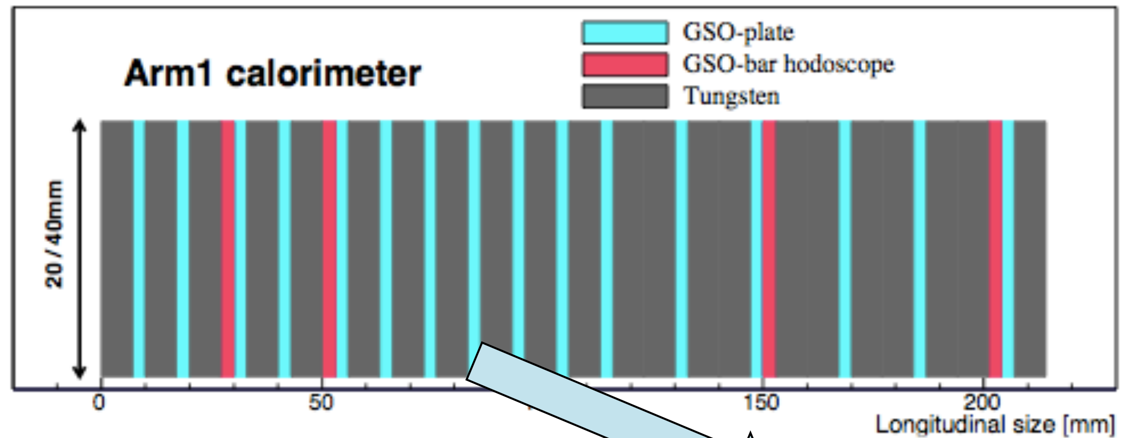


- Positions of decayed photons are measured by 1 mm dimension GSO bars.

Energy reconstruction of photon

- If a photon hit a tower,





$dE(x, y)$

↓ Cor.1

dE_{center}

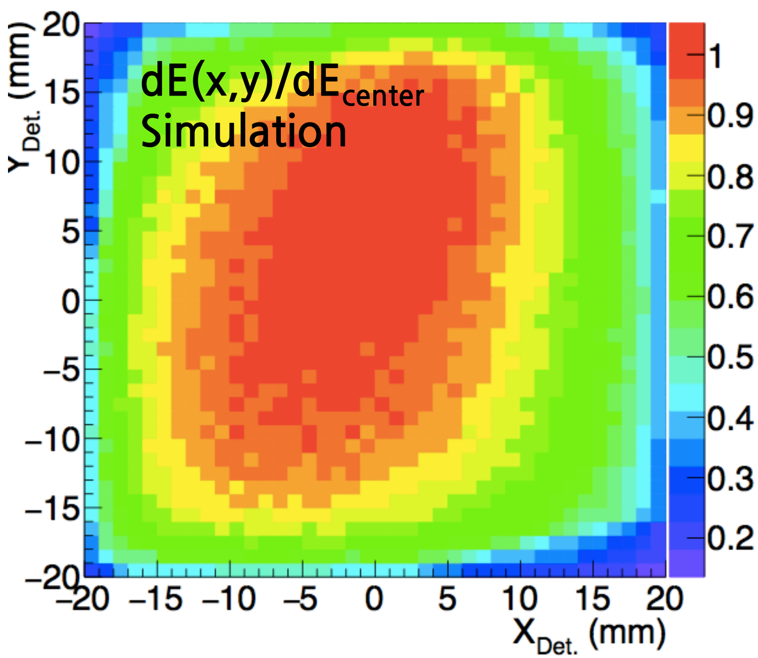
↓

SumdE

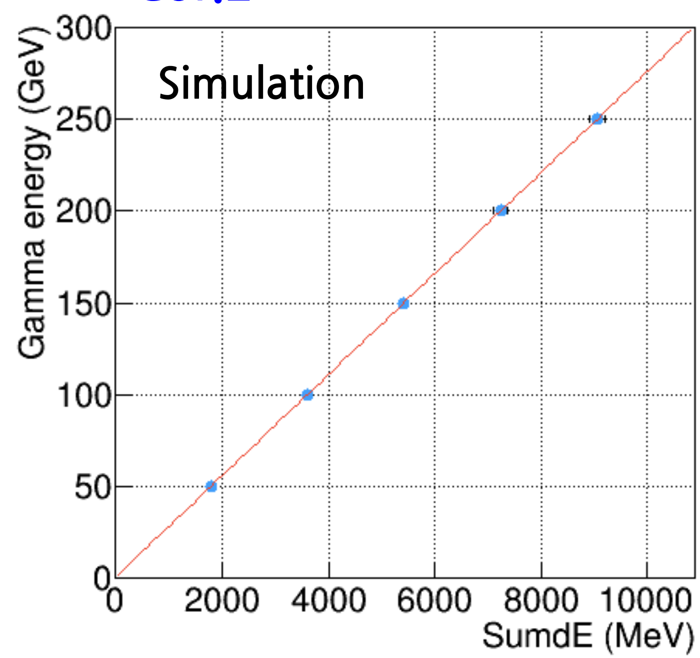
↓ Cor.2

E_{gamma}

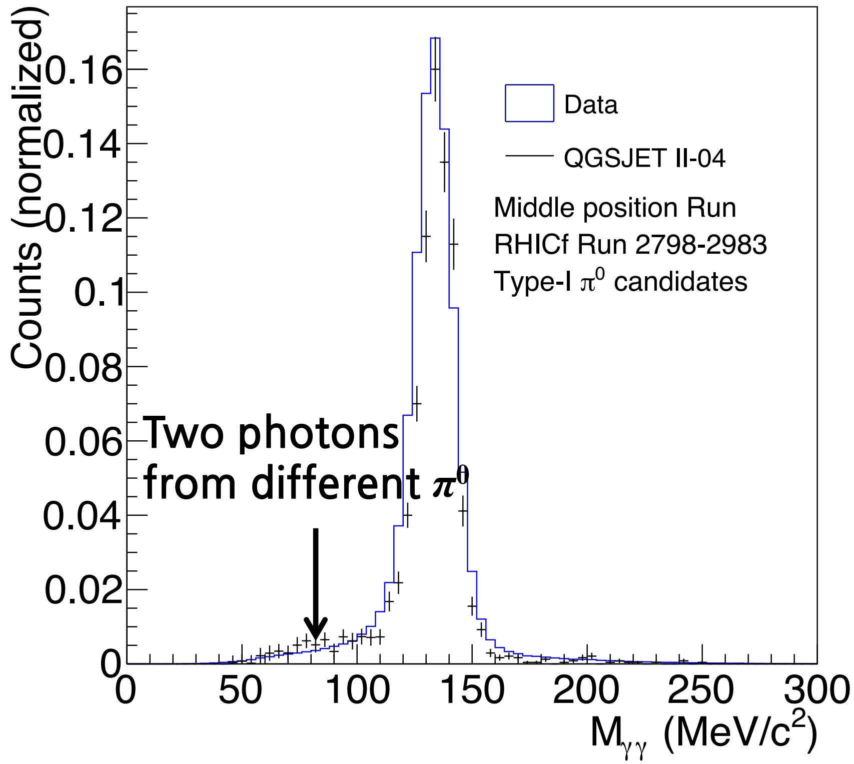
Cor.1

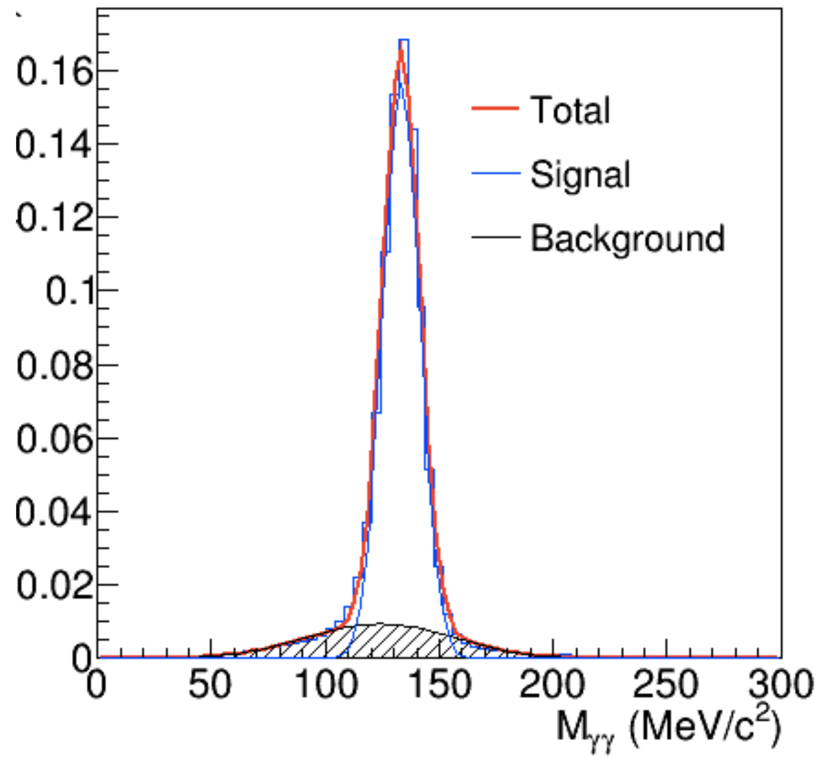


Cor.2



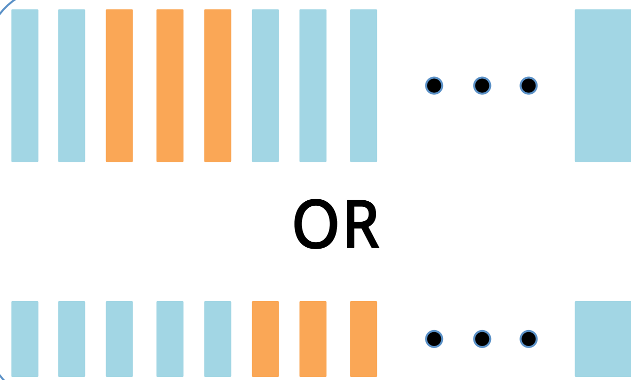
Invariant mass of two photons



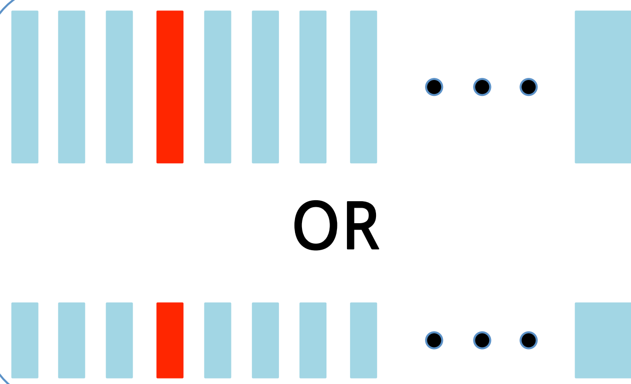


- Data is well matched with simulation showing clear π^0 peak around 135 MeV/c^2.
- Invariant mass was fitted by polynomial function for background and Gaussian one for π^0.

Triggers of RHICf detector



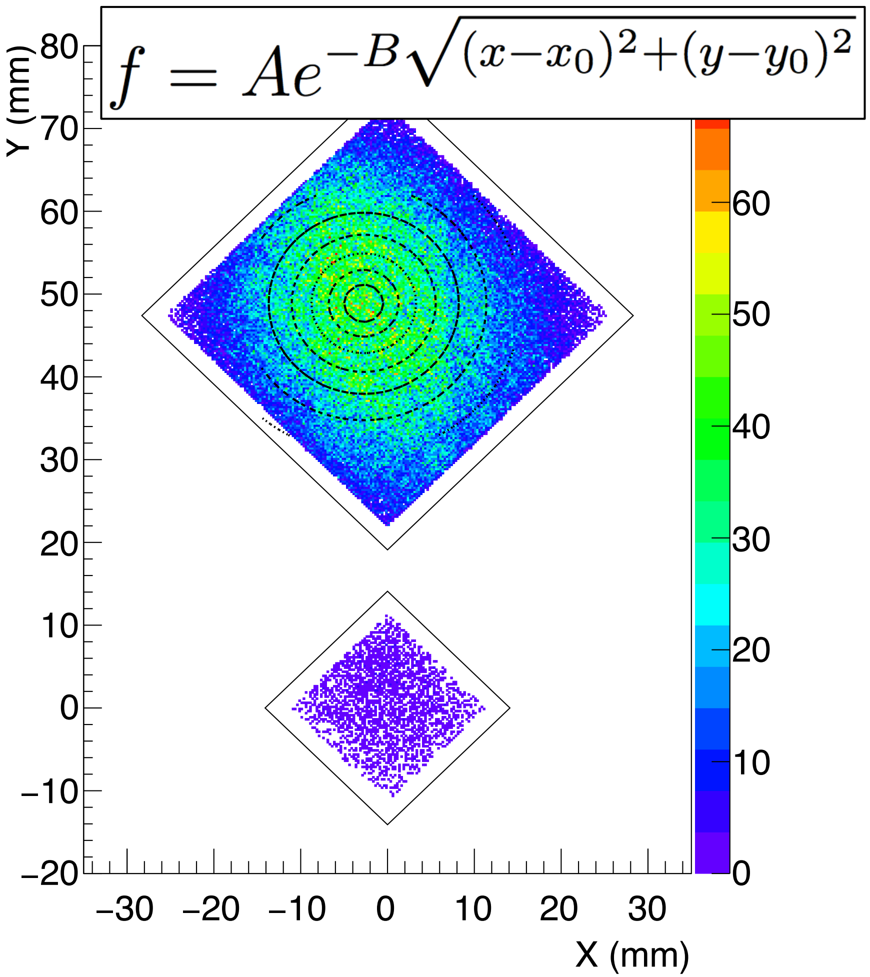
Shower trigger: Energy deposits of three successive layers at large or small tower are larger than 45 MeV.
(for neutron and single photon)

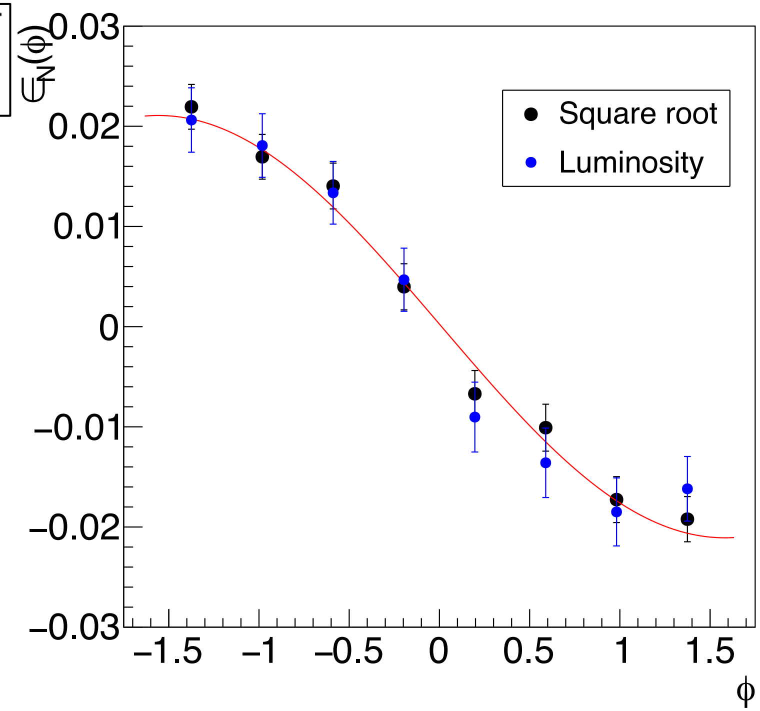


High EM trigger: Energy deposit of 4th layer at large or small tower is larger than 500 MeV.
(for high energy photon and Type-II π^0)

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)

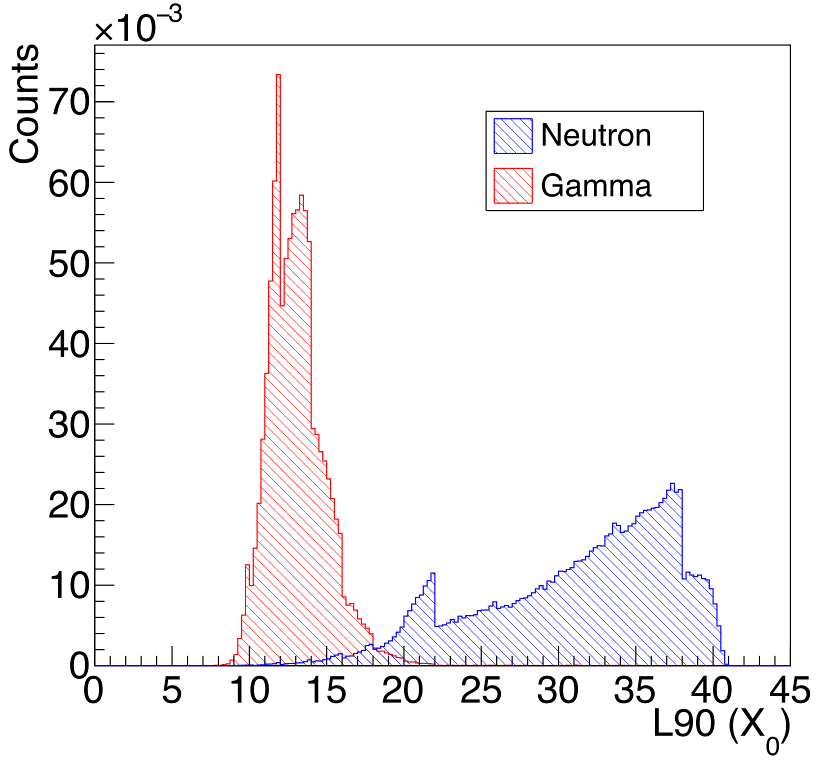




$$\frac{N_L^{\uparrow} - RN_R^{\uparrow}}{N_L^{\uparrow} + RN_R^{\uparrow}} = \frac{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} - \sqrt{N_R^{\uparrow}N_L^{\downarrow}}}{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} + \sqrt{N_R^{\uparrow}N_L^{\downarrow}}}$$

- 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

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

Luminosity ratio between spin up and down

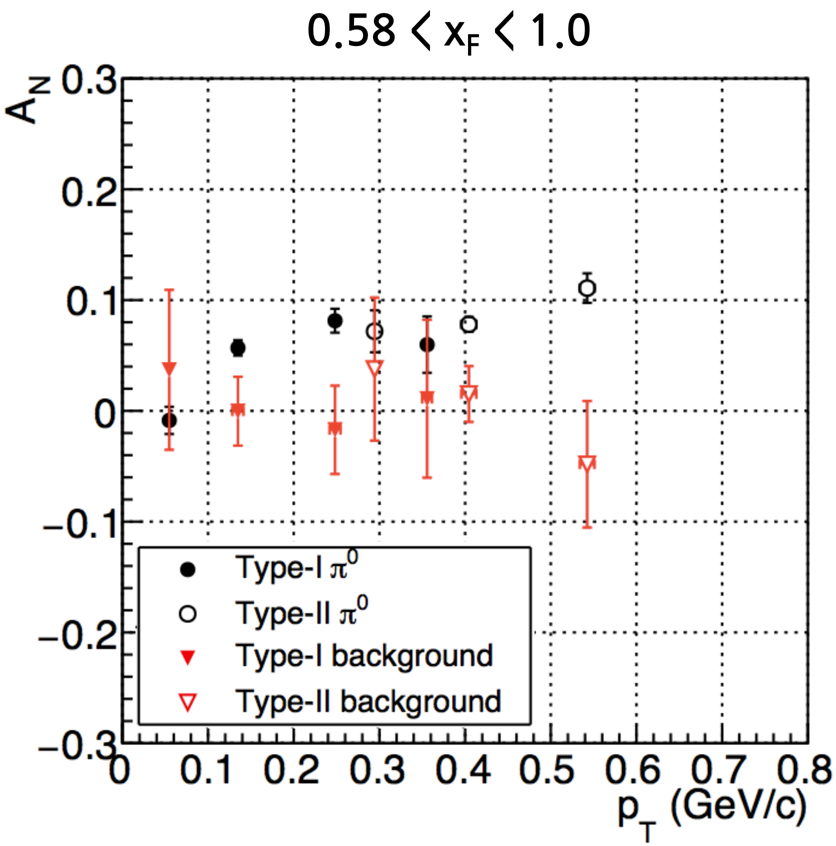
Number of π^0 in specific x_F and p_T range

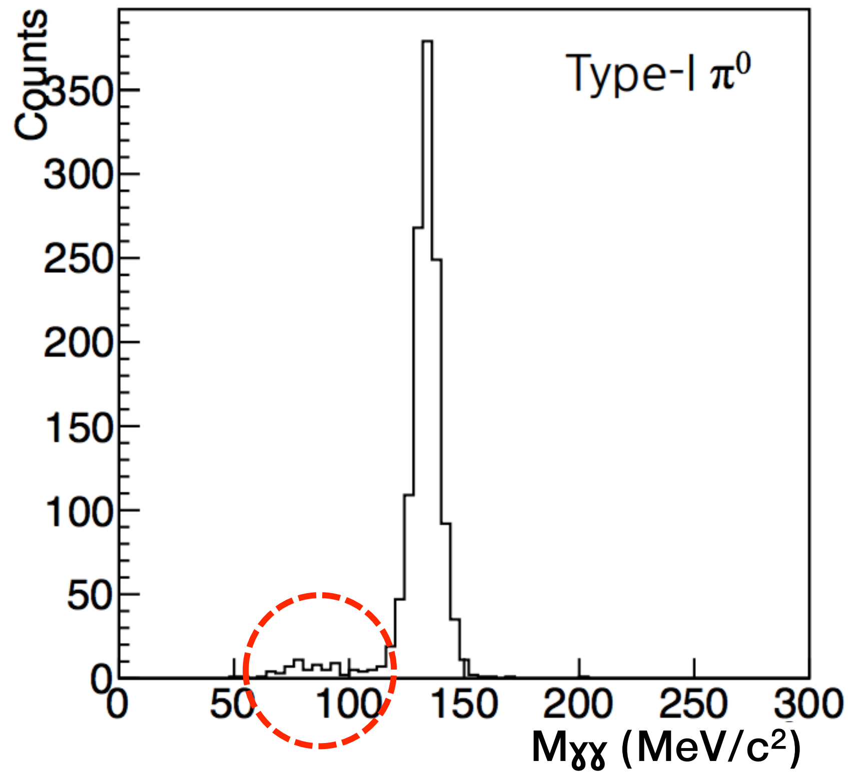
Beam polarization

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





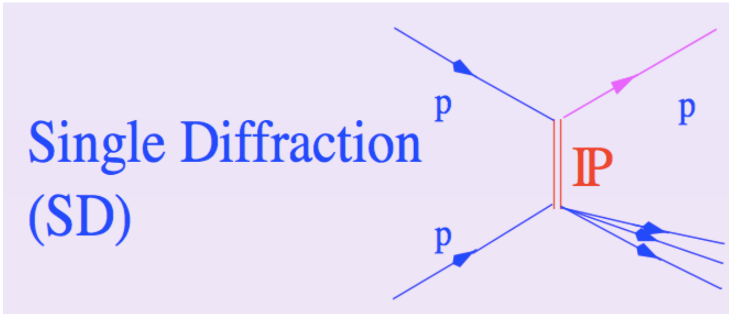
- Background A_Ns are all consistent with zero.

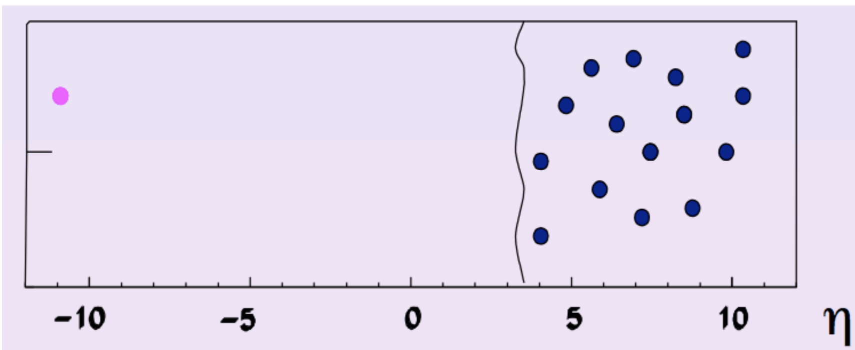
$$A_N^S = \left(1 + \boxed{\frac{N_B}{N_S}}\right) A_N^{S+B} - \left(\boxed{\frac{N_B}{N_S}}\right) A_N^B$$

Should be overestimated due to the π^0 tail.

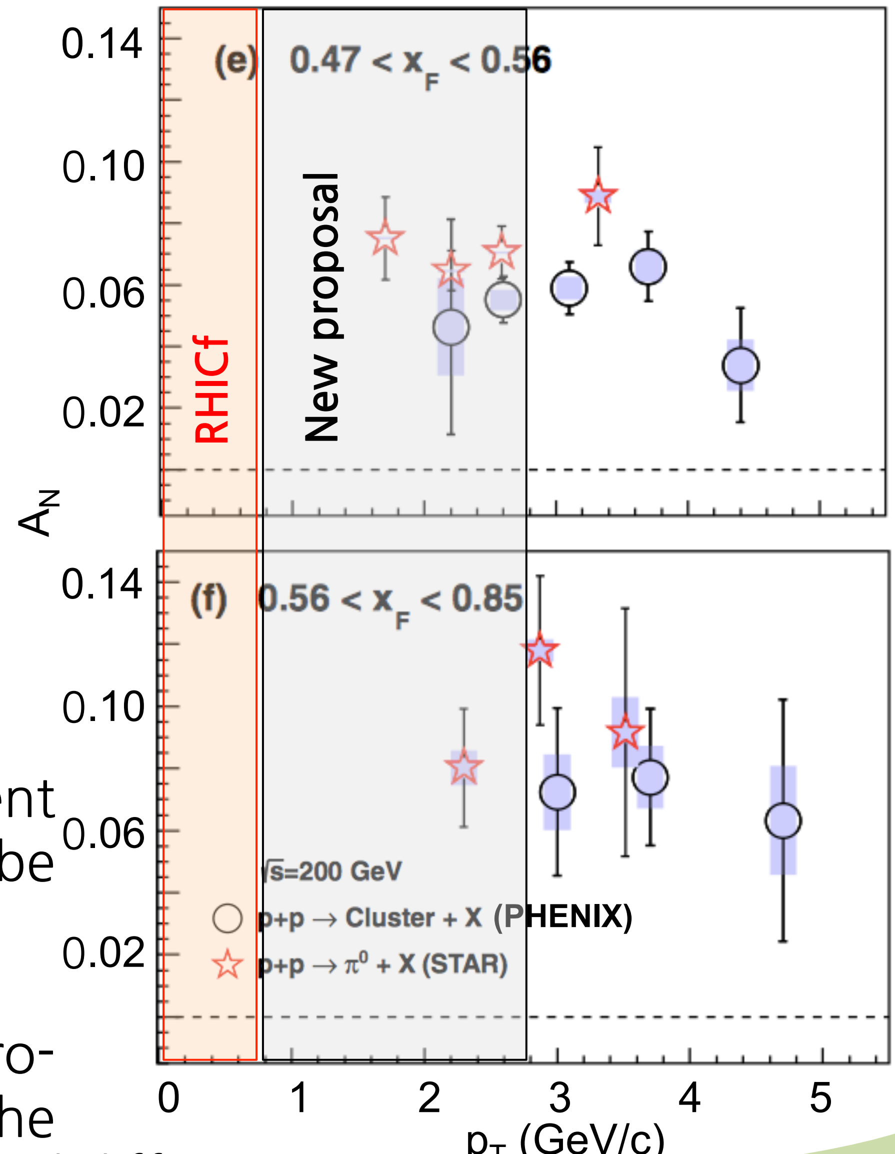
- Difference between the A_N with and without the π^0 tail was considered as a systematic uncertainty.

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.