Asymmetry Measurement of Very Forward Neutral Particle Production in the RHICf Experiment

Diffraction and Low-x 2018

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RHICf collaboration

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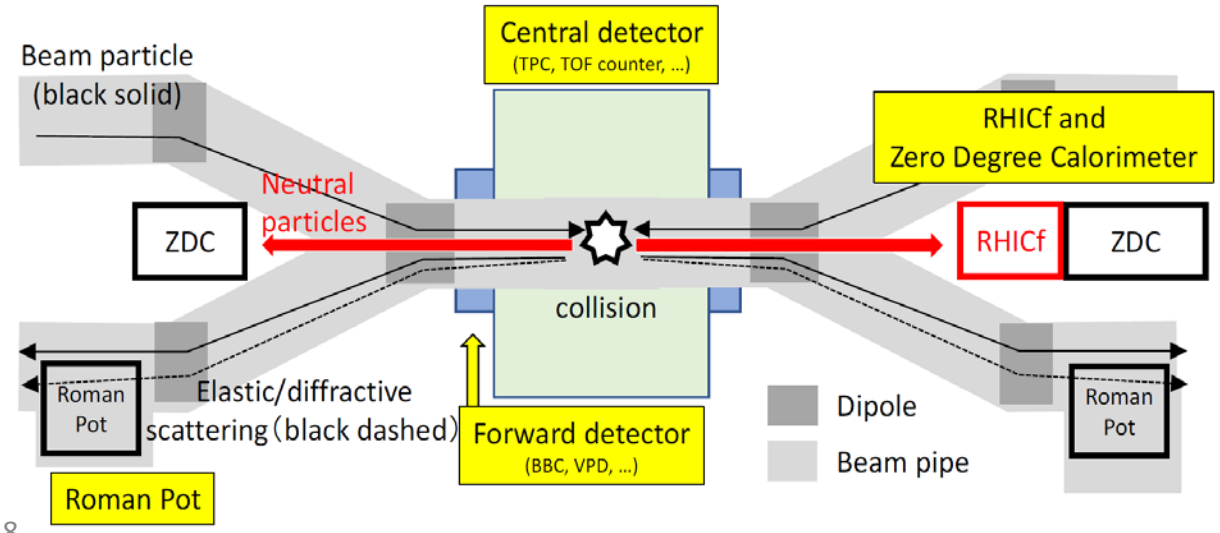
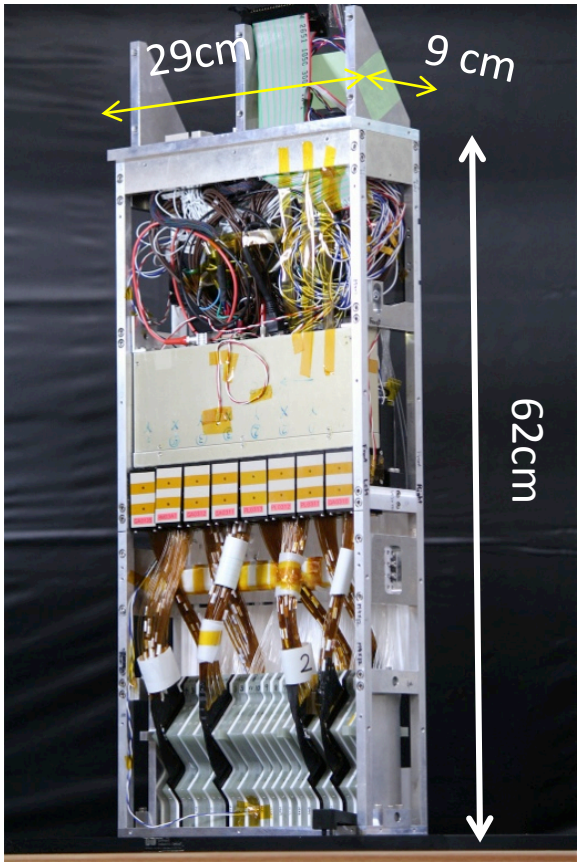
RHICf experiment

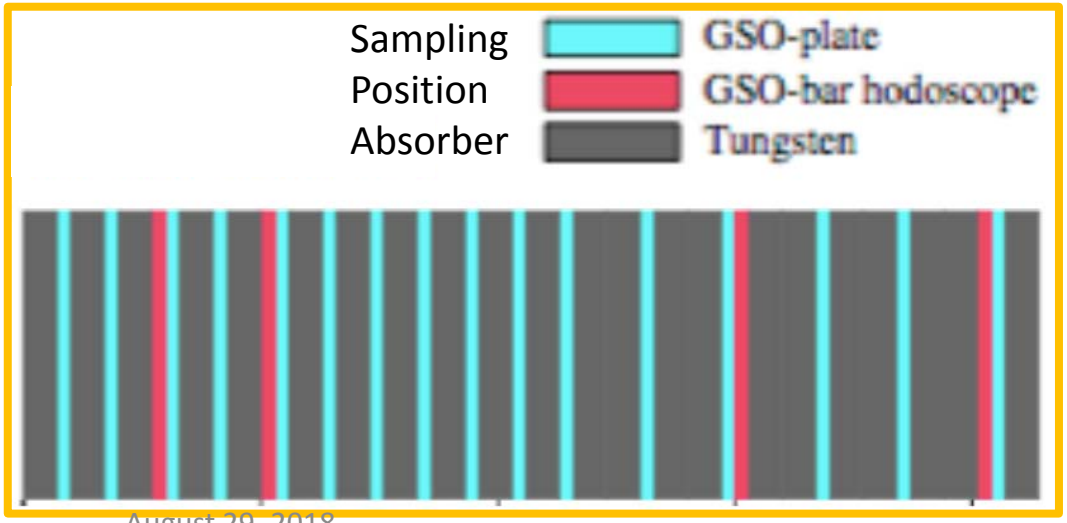
- EM calorimeter (RHICf detector) installed in front of the ZDC+SMD of the STAR experiment
  - Cross section and asymmetry measurement of neutral particle production (neutron, photon, π^0) with $\sqrt{s}$ = 510 GeV polarized proton collisions
  - Wide p_T region covered by changing the position of the RHICf detector vertically (up to 1.4 GeV/c)
  - Much higher position resolution than ZDC+SMD so that enable us higher resolution of p_T measurement

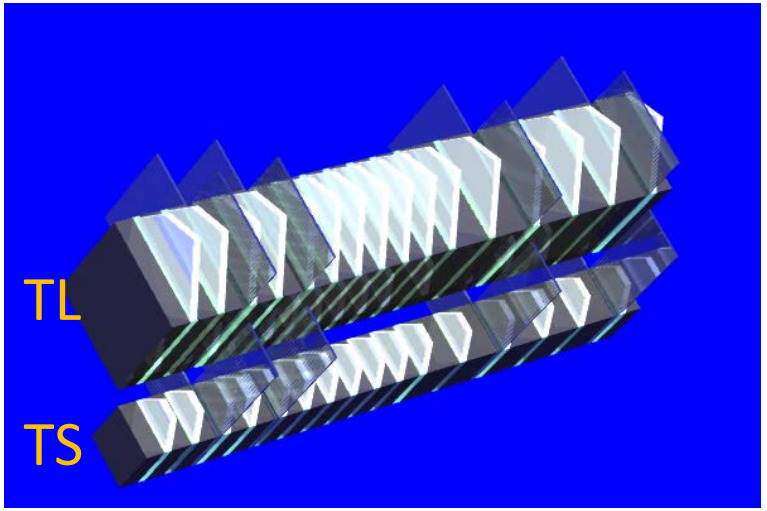


RHICf detector

- Two position-sensitive sampling calorimeters
  - TS (small tower): 20mm x 20mm
  - TL (large tower): 40mm x 40mm
  - Tungsten absorber (44 X_0, 1.6 λ_{int})
  - 16 GSO sampling layers
  - 4 XY pairs of GSO-bar position layers (MAPMT readout)

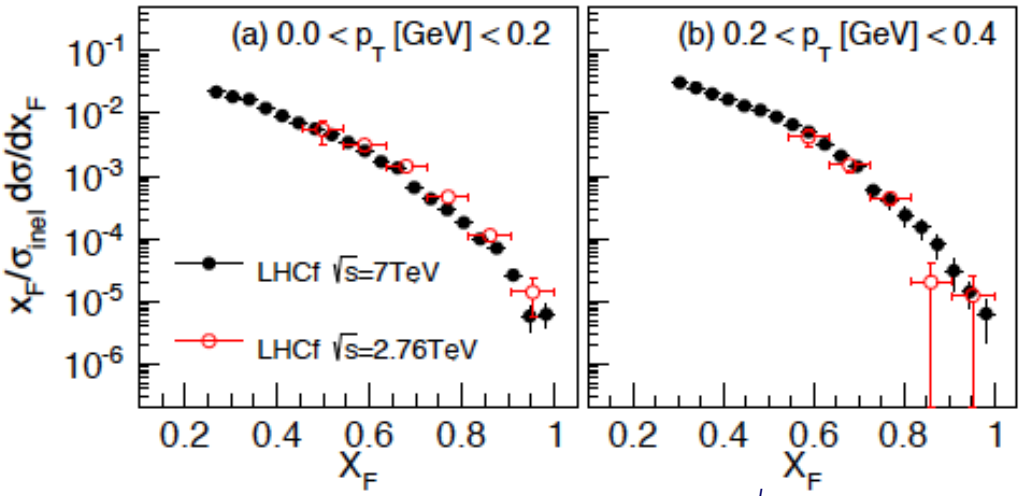






Cross section measurement

- 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)



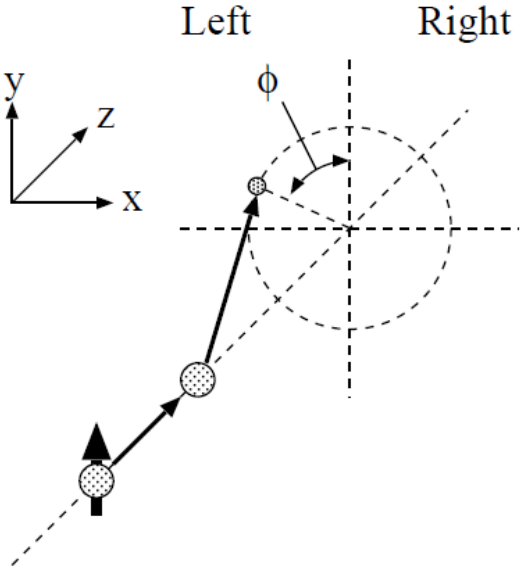
LHCf results of π^0 production cross section at $\sqrt{s}$=7TeV and 2.76TeV
Phys.Rev.D94 (2016) 032007

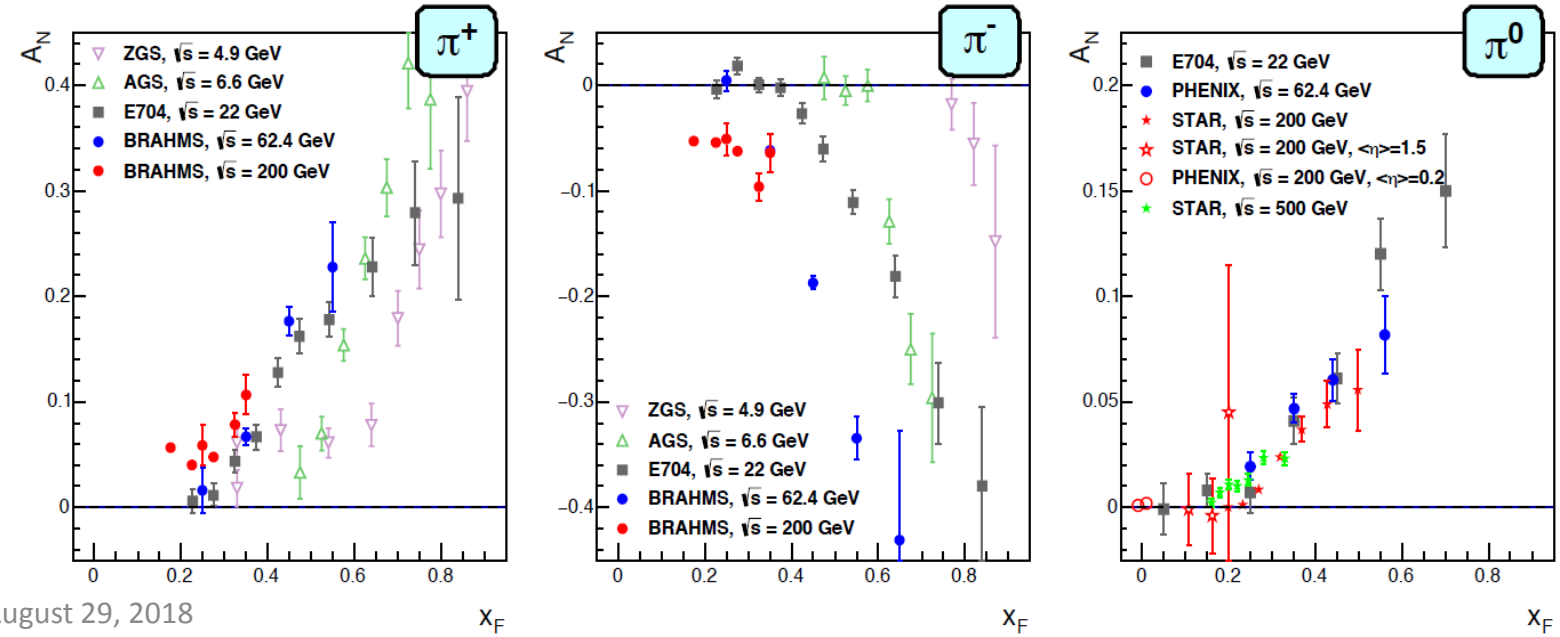
Transverse polarized proton collision

- A_N (transverse single-spin asymmetry) measurement

$$A_N = \frac{d\sigma_{Left} - d\sigma_{Right}}{d\sigma_{Left} + d\sigma_{Right}}$$

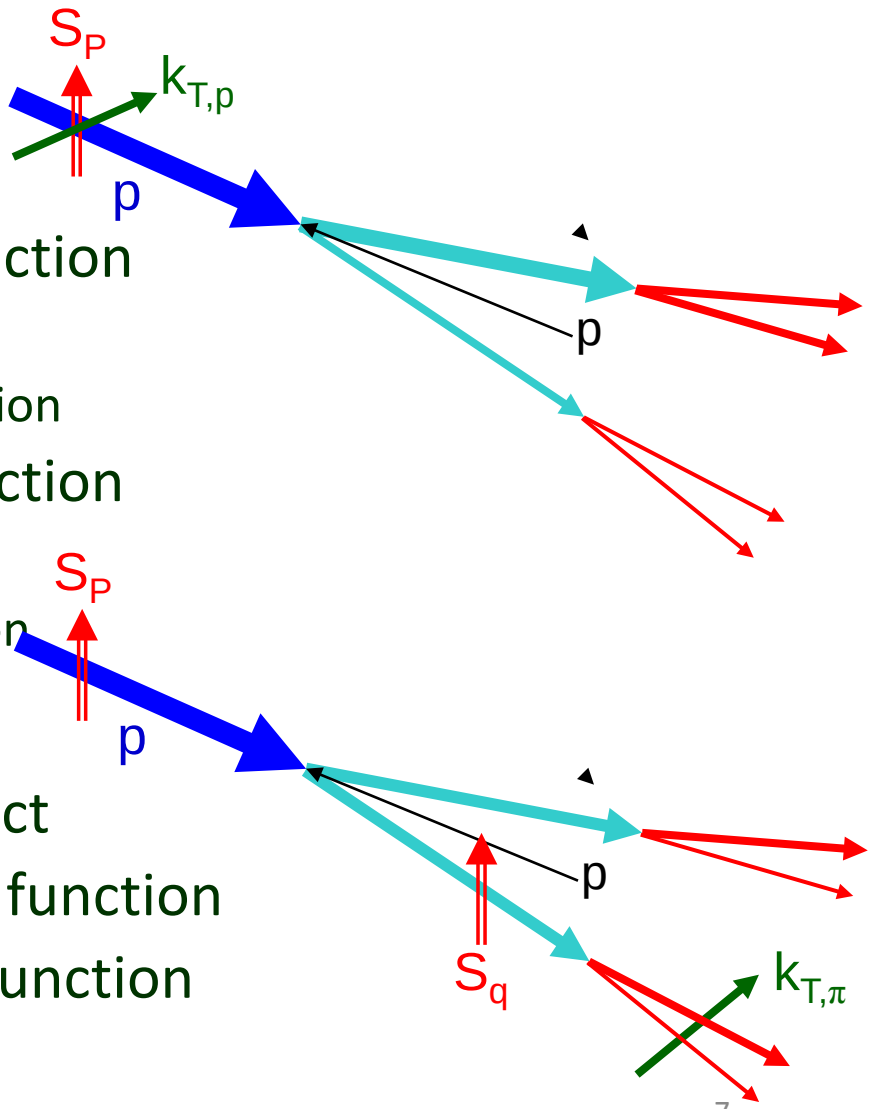
  - Azimuthal angle modulation (or dependence)
- Large A_N for forward hadron production
  - $1 < \eta < 4$, similar results in wide $\sqrt{s}$





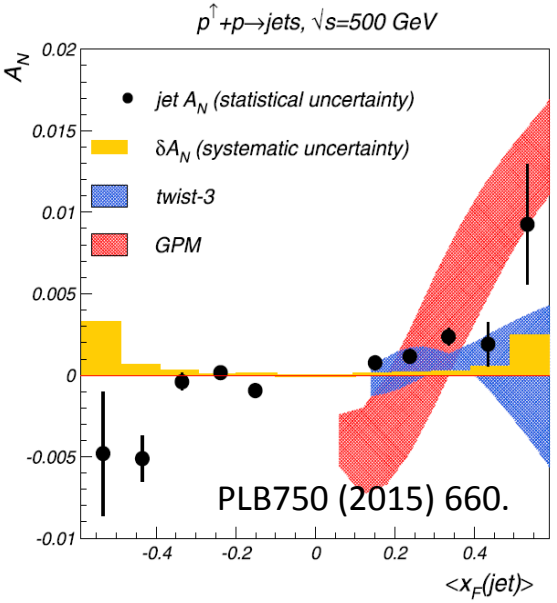
Transverse polarization phenomena

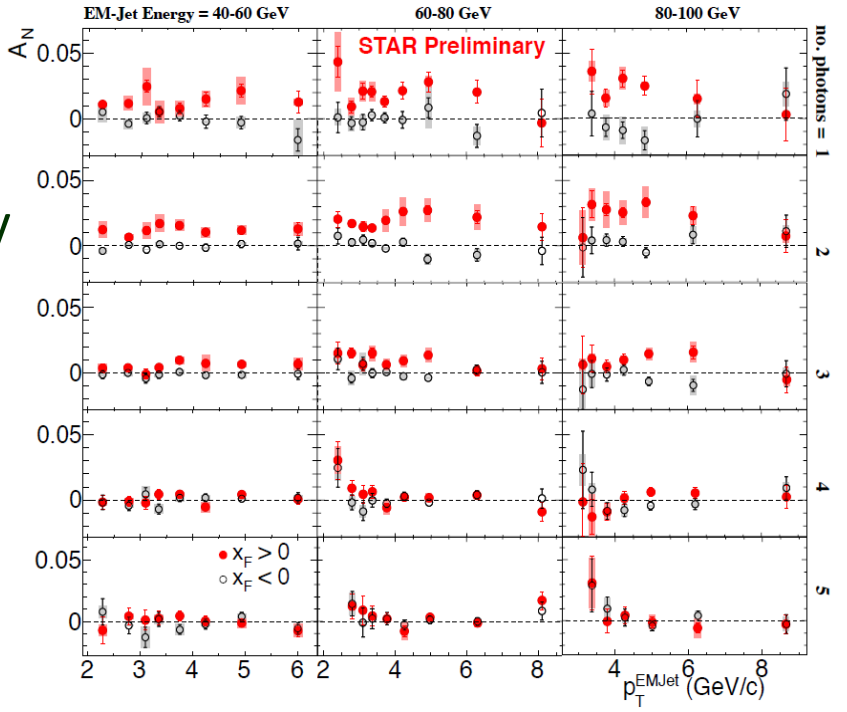
- TMD (Transverse Momentum Dependent) function and higher-twist function
- "Sivers" effect
  - Initial-state effect
  - TMD (Sivers) distribution function
    - Need 2 scales (p_T and Q^2)
    - Drell-Yan, W/Z boson production
  - Higher-twist distribution function
    - Need 1 scale (p_T)
    - Hadron, photon, jet production
- "Collins" effect
  - Transversity + final-state effect
  - TMD (Collins) fragmentation function
  - Higher-twist fragmentation function



New question

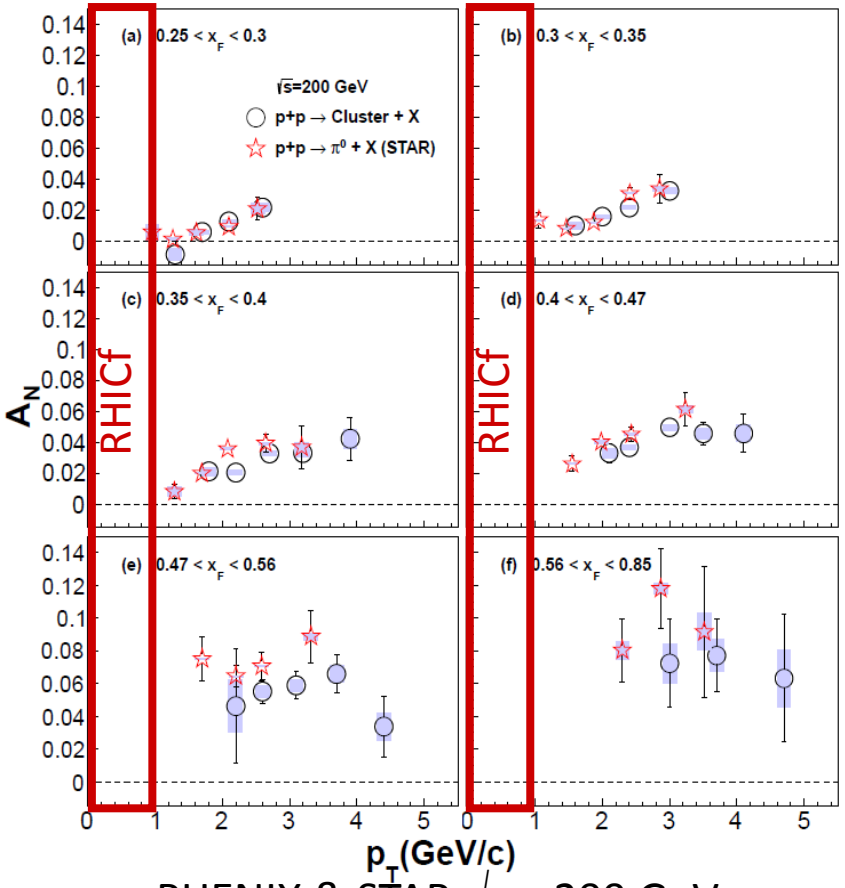
- Hard scattering and/or diffraction?
- A_NDY jet asymmetry
  - Small A_N of forward jet production comparing with that of forward hadron production
  - Mixture (cancellation) of u-quark jet and d-quark jet, or diffraction?
- STAR multiplicity dependence
  - A_N for different number of photons
  - A_N decreases as the event complexity increases (more jet-like)
  - How much of the large π^0 A_N comes from hard scattering or diffraction?
- π^0 asymmetry at RHICf?



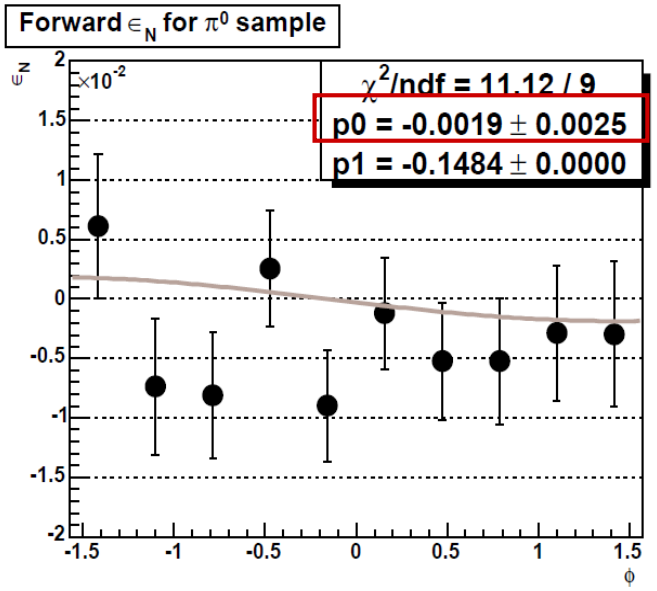


π^0 asymmetry at RHICf

- $p_T < 1$ GeV/c, $\eta > 6$
  - Limited by the shadow of the beam pipe
- Non-perturbative regime



PHENIX & STAR $\sqrt{s}$ = 200 GeV
Phys. Rev. D90 (2014) 012006.



RHIC-IP12 $\sqrt{s}$ = 200 GeV $p_T < 0.1$ GeV/c
Very forward π^0 raw asymmetry
M. Togawa, PhD thesis (2008).

Table 1
Asymmetries measured by the EMCal. The errors are statistical and systematic, respectively. There is an additional scale uncertainty, due to the beam polarization uncertainty, of $(1.0^{+0.47}_{-0.24})$

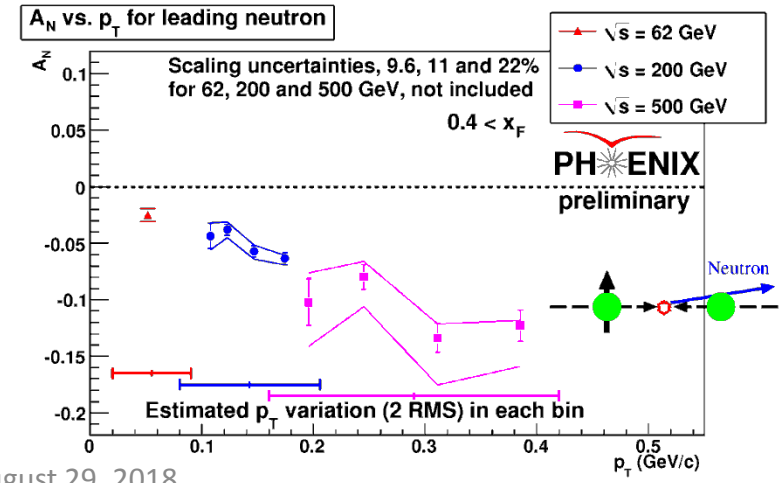
	Forward	Backward
Neutron	$-0.090 \pm 0.006 \pm 0.009$	$0.003 \pm 0.004 \pm 0.003$
Photon	$-0.009 \pm 0.015 \pm 0.007$	$-0.019 \pm 0.010 \pm 0.003$
π^0	$-0.022 \pm 0.030 \pm 0.002$	$0.007 \pm 0.021 \pm 0.001$

Phys. Lett. B650 (2007) 325.

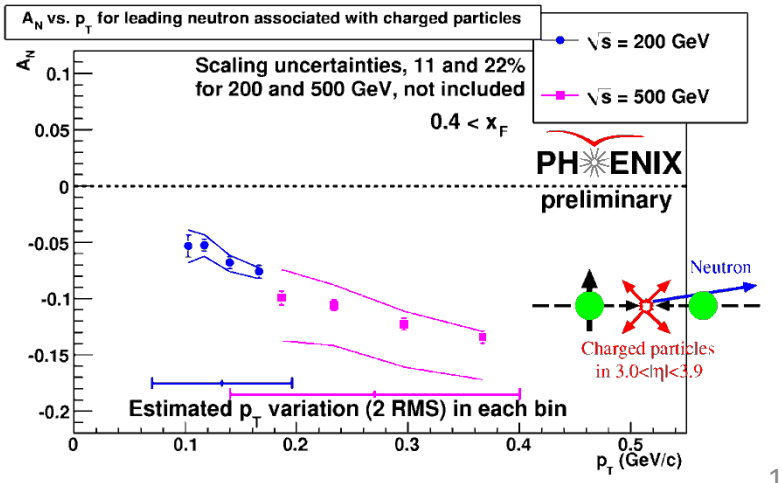
Neutron asymmetry

- Very large left-right asymmetry (A_N) of very forward neutron discovered at RHIC
  - A_N(62 GeV) < A_N(200 GeV) < A_N(500 GeV)
  - $\sqrt{s}$ dependence or p_T dependence?
- Interference of pion exchange and other Reggeon exchange?
  - Kopeliovich, Potashnikova, Schmidt, Soffer: PRD84, 114012 (2011)
- Improved p_T precision and wider p_T coverage (p_T < 1.2 GeV/c) at $\sqrt{s}$ = 510 GeV in the RHICf experiment

Inclusive neutron

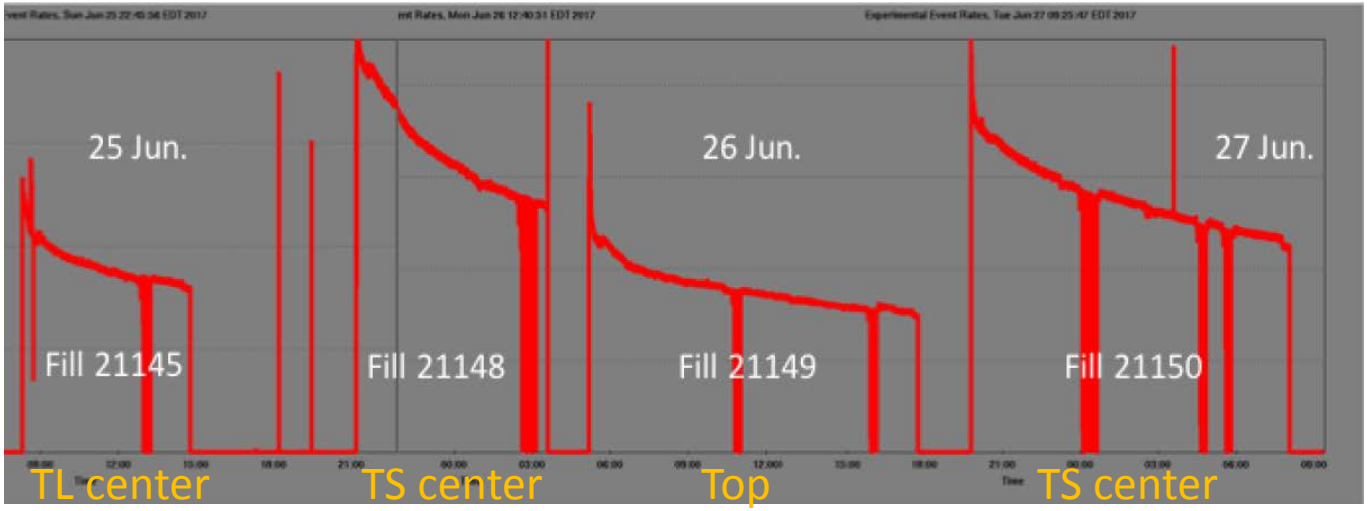


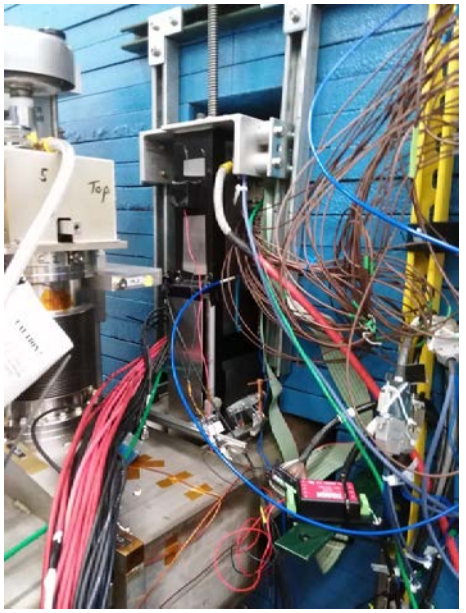
Neutron with charged particles

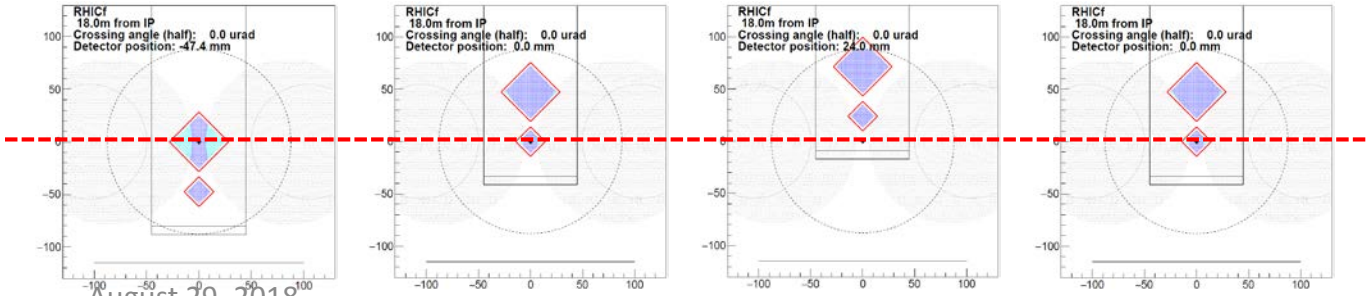


2017 operation

- June 23 commissioning of polarized proton collisions, detector installation at the final position, detector commissioning
  - β^* = 8m, radial polarization
- June 24 – 27 physics data acquisition
  - 27.7hours, ~110M events, ~700 nb^{-1}
- 3 detector positions
  - TL center / TS center / Top position

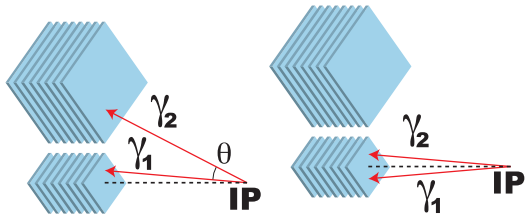






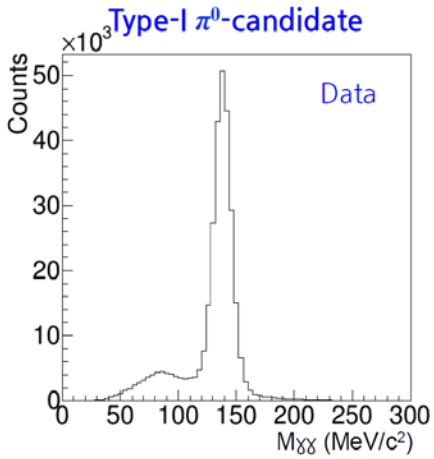
π^0 kinematics

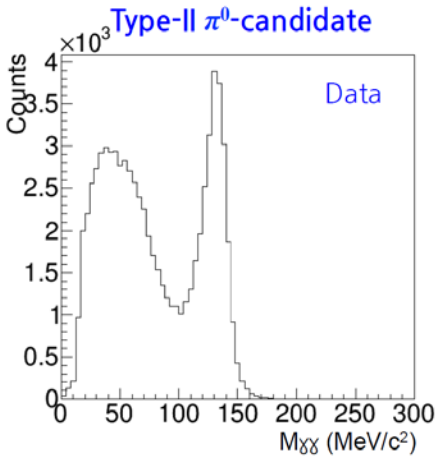
- π^0 peak with ~10 MeV/c^2 width
  - 3σ region selected as π^0 candidates
- $p_T < 1.0$ GeV/c
- $0.2 < x_F < 1.0$

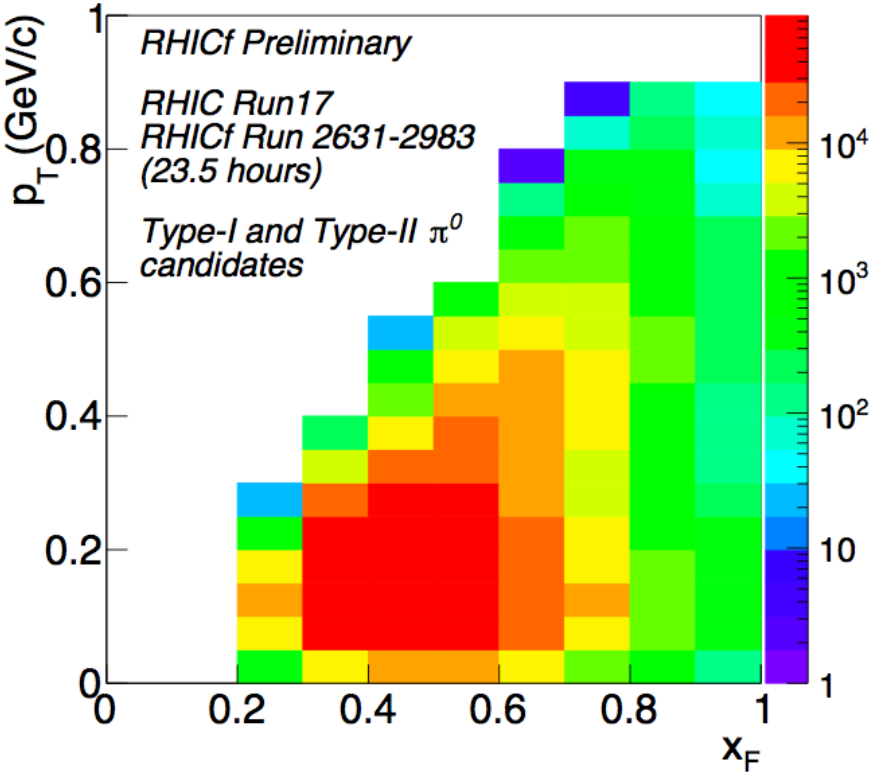


Type-I Type-II

(same as single high-E photon)

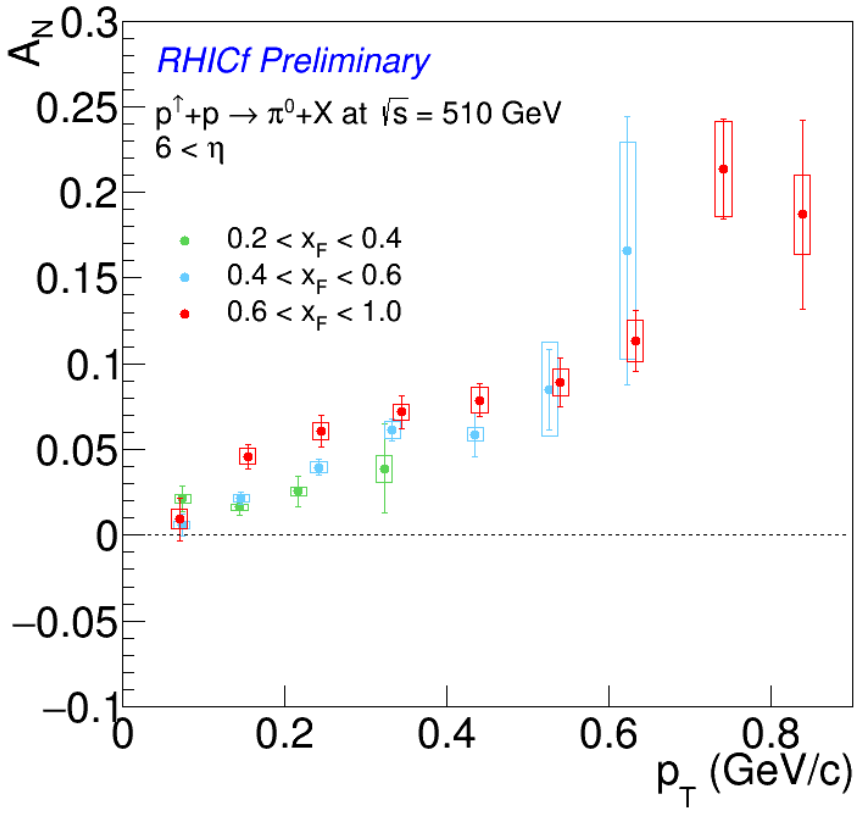






A_N of very forward π^0

- Large asymmetry (up to 0.1) even at low p_T (p_T < 0.6 GeV/c)
  - Production mechanism?
- Becoming larger (more than 0.1) at high p_T (0.6 GeV/c < p_T)
  - Contribution from hard scattering?



Data analysis has been performed by Minho Kim (Korea Univ.) who will present the results in the Spin 2018 symposium 2 weeks later

Background asymmetry (measured, zero consistent) subtracted

Bar: statistical error
Box: systematic uncertainties including beam center correction, acceptance correction, polarization, and background asymmetry subtraction

Summary & next plan

- Successful operation in 2017
  - Common data taking with STAR DAQ
- Preliminary A_N result of very forward π^0 obtained
  - Large asymmetry even at low p_T and larger at high p_T
  - Production mechanism, soft & hard component?
- STAR + RHICf combined analysis to be performed
  - Event type definition with forward detectors and Roman Pot
    - For more information to study production mechanism
  - Event type, multiplicity dependence of cross sections & asymmetries
  - Neutron analysis with RHICf + STAR ZDC
  - Asymmetry of STAR forward and midrapidity detectors with neutron/π^0 tag at RHICf