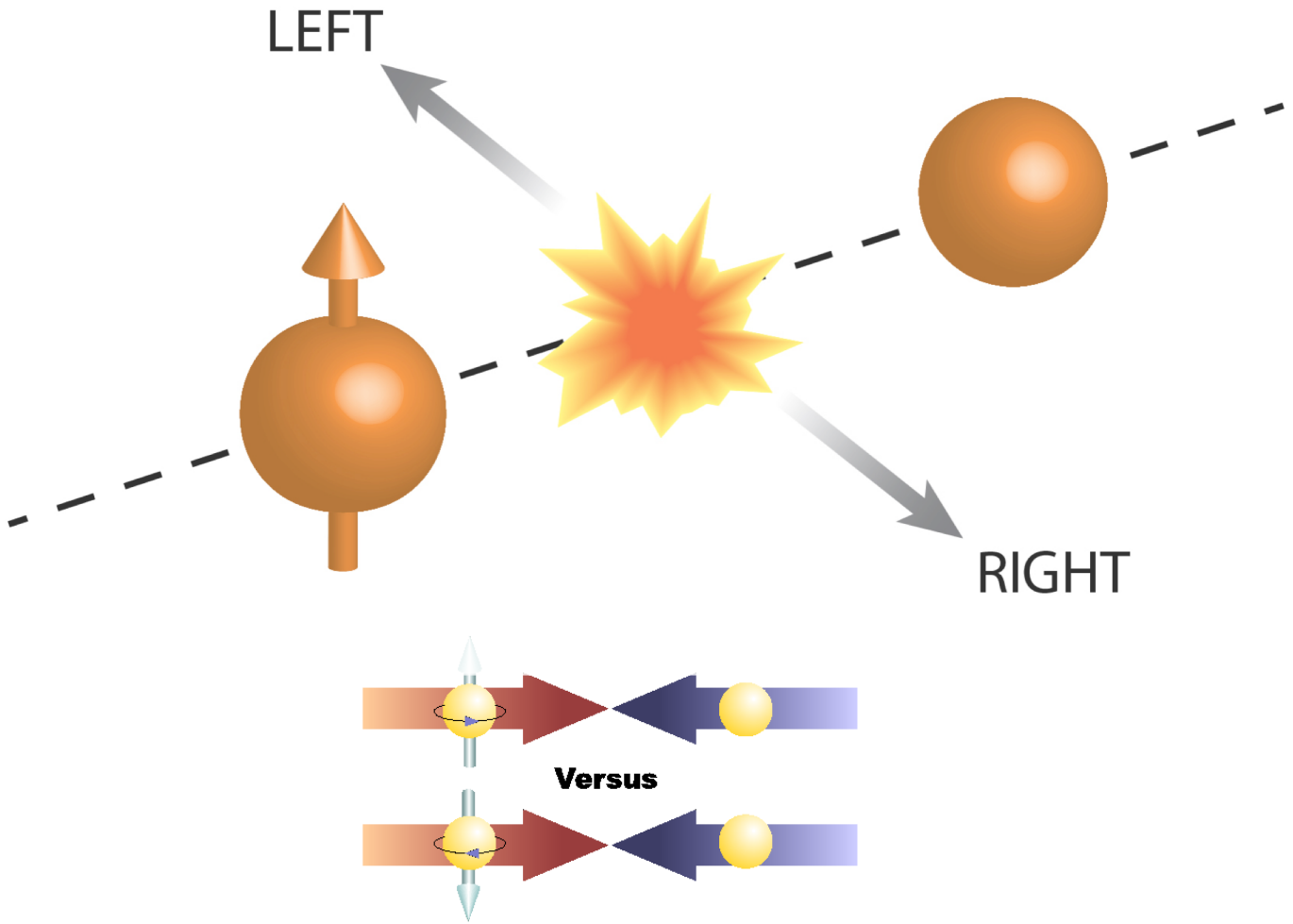
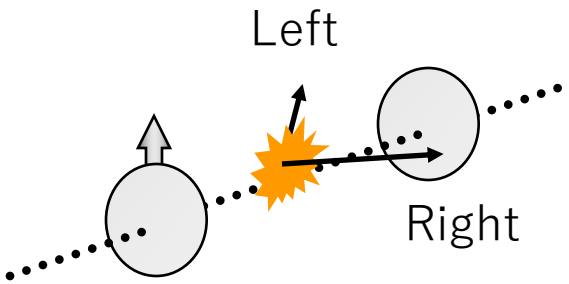
The role of diffractive process in the inclusive asymmetry at almost zero degree in transversely polarized proton + proton collision at RHIC

Itaru Nakagawa (RIKEN)
for the RHICf Collaboration

Transverse Single Spin Asymmetry



Pioneering Transverse Single Spin Assymmetry



$$A_N = \frac{1}{P}\frac{\sigma_L^\pi - \sigma_R^\pi}{\sigma_L^\pi + \sigma_R^\pi}$$

Naïve Theory Prediction:
Small in high energy
(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{\sqrt{s}}$$

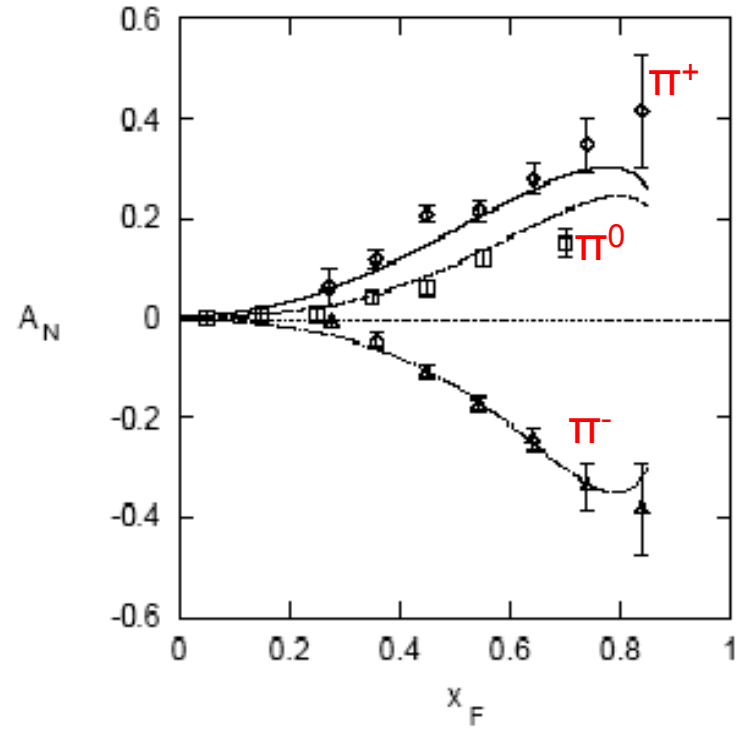
A_N O(10^{-4}) Theory

Experiment:
(E704, Fermi National Laboratory, 1991)

$$pp^{\uparrow} \rightarrow \pi + X$$
$$\sqrt{s} = 20\,\mathrm{GeV}$$

A_N O(10^{-1}) Measured

E704: pion single spin asymmetry A_N



$$x_F = \frac{2p_L}{\sqrt{s}}$$

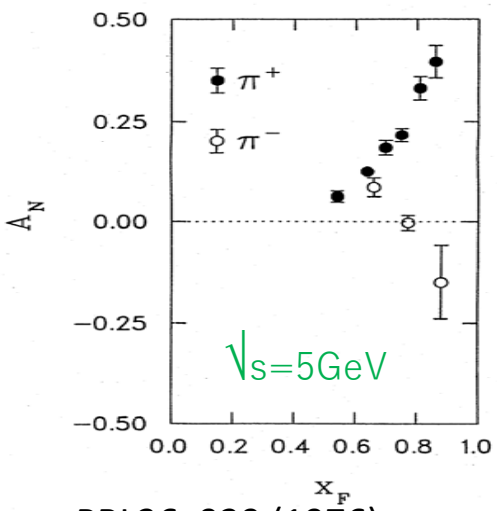
Energy Dependence of A_N

Naïve Theory Prediction:
Small in high energy
(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{\sqrt{s}}$$

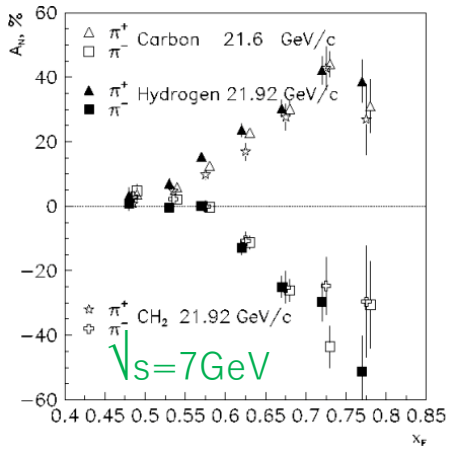
A_N O(10^{-4}) Theory

ZGS 12 GeV beam



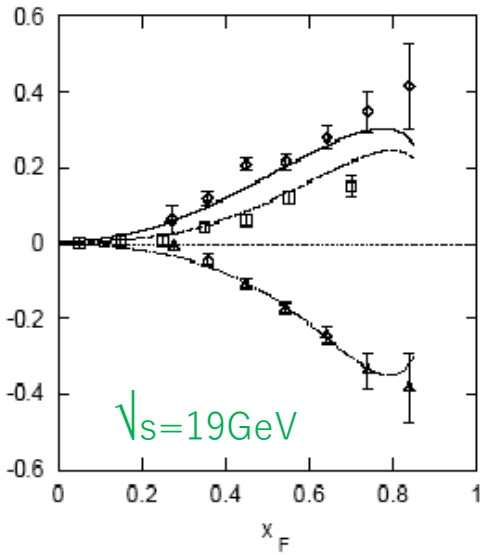
PRL36, 929 (1976)

AGS 22 GeV beam



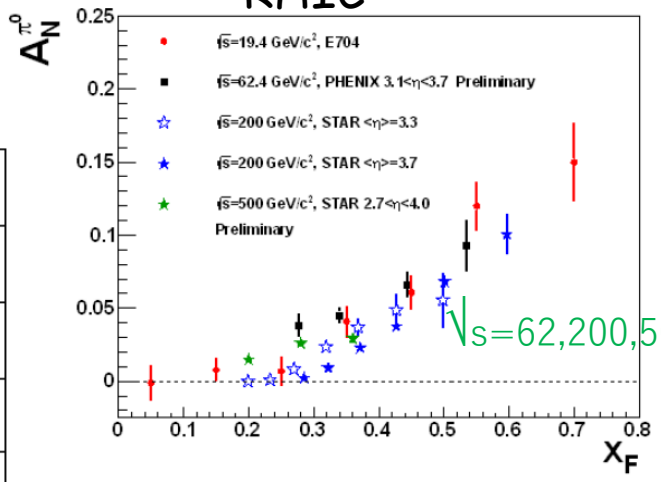
PRD65, 092008 (2002)

E704 200GeV beam



PLB261, 201 (1991)
PLB264, 462 (1991)

RHIC

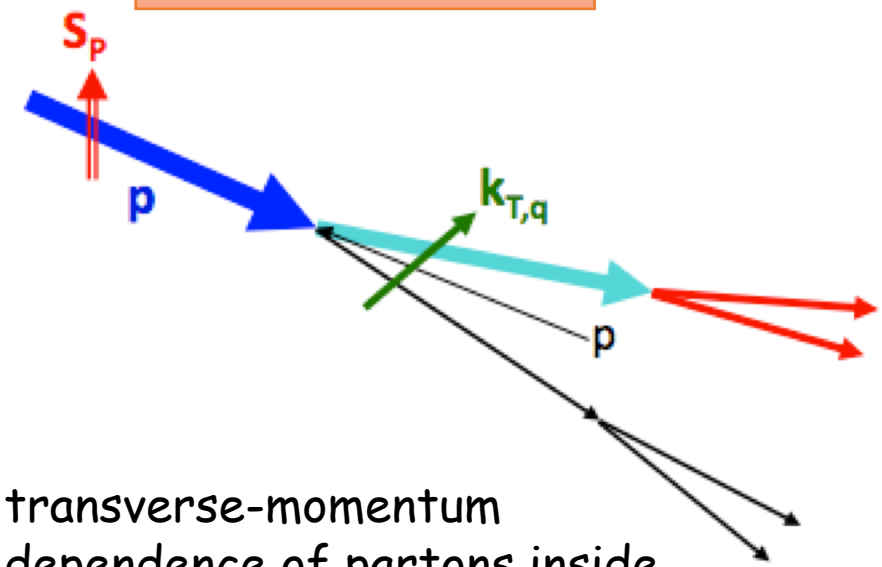


Asymmetry still persists even in high energy!

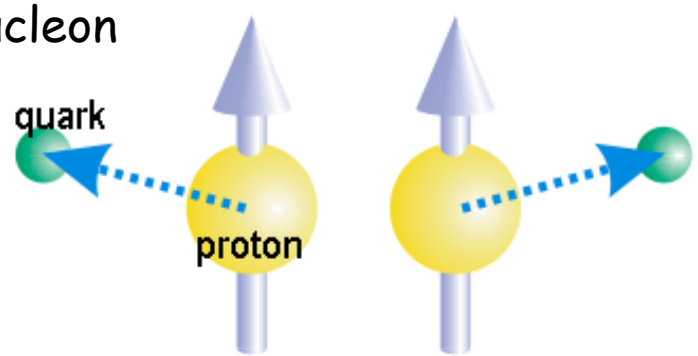
Non-perturbative ⟷ Perturbative

Initial State Effect

Sivers Mechanism

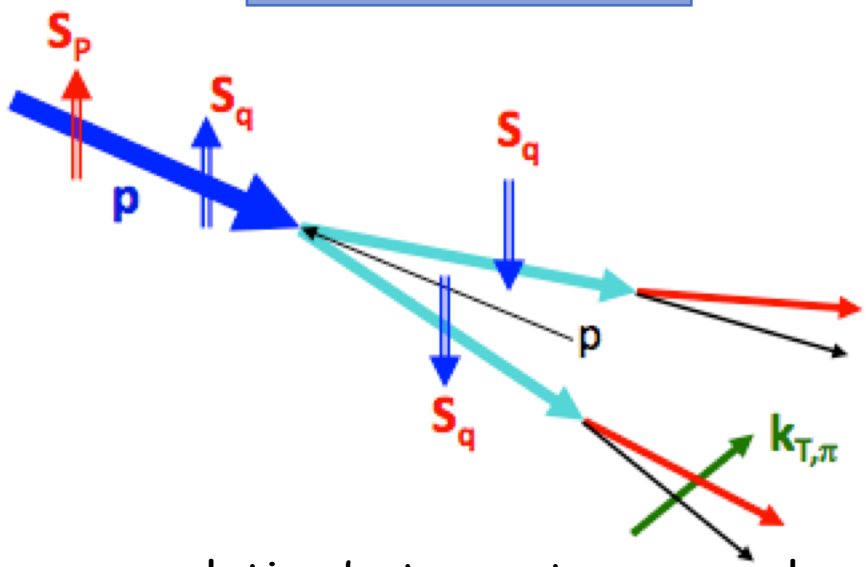


transverse-momentum dependence of partons inside the transversely-polarized nucleon

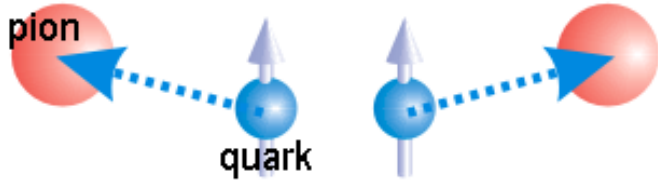


Final State Effect

Collins Mechanism



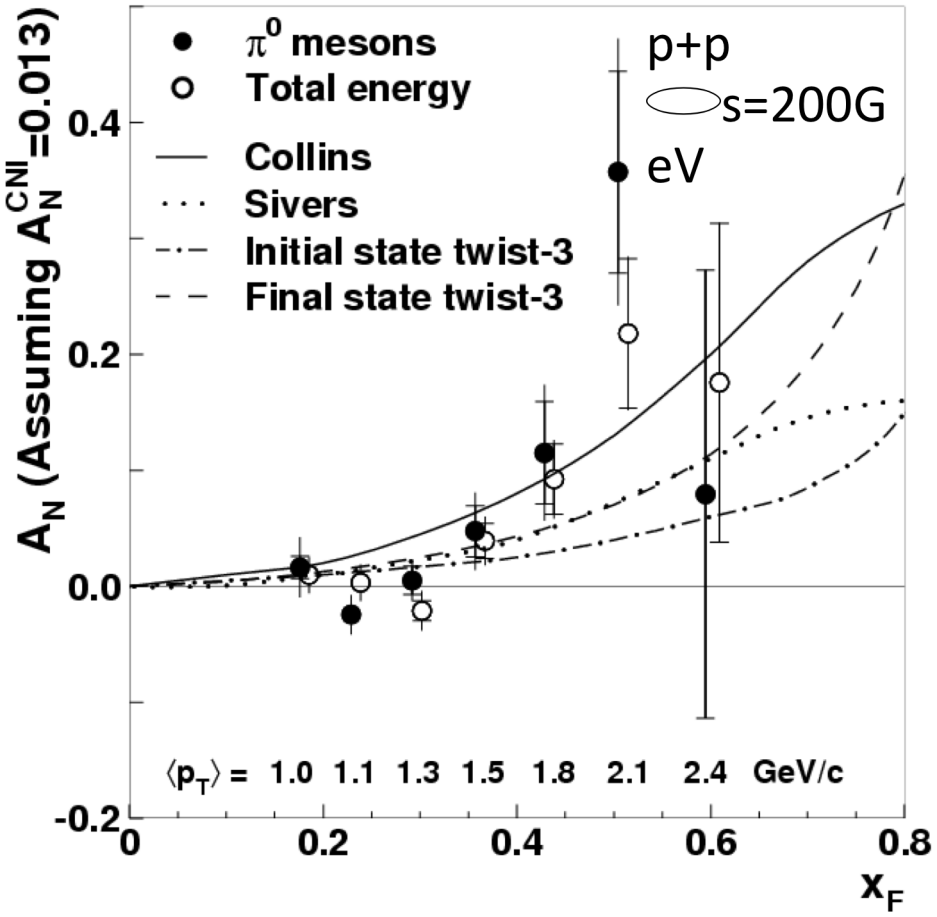
correlation between transversely-polarized nucleon and transversely polarized partons inside

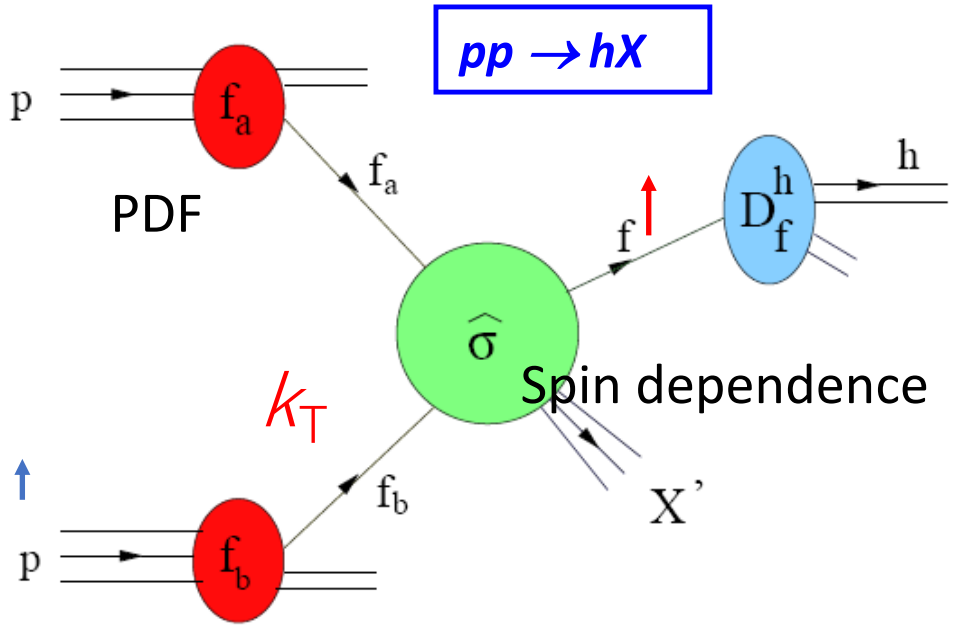


+ higher twist mechanism

pQCD interpretation

STAR PRL 92,171801, 2004

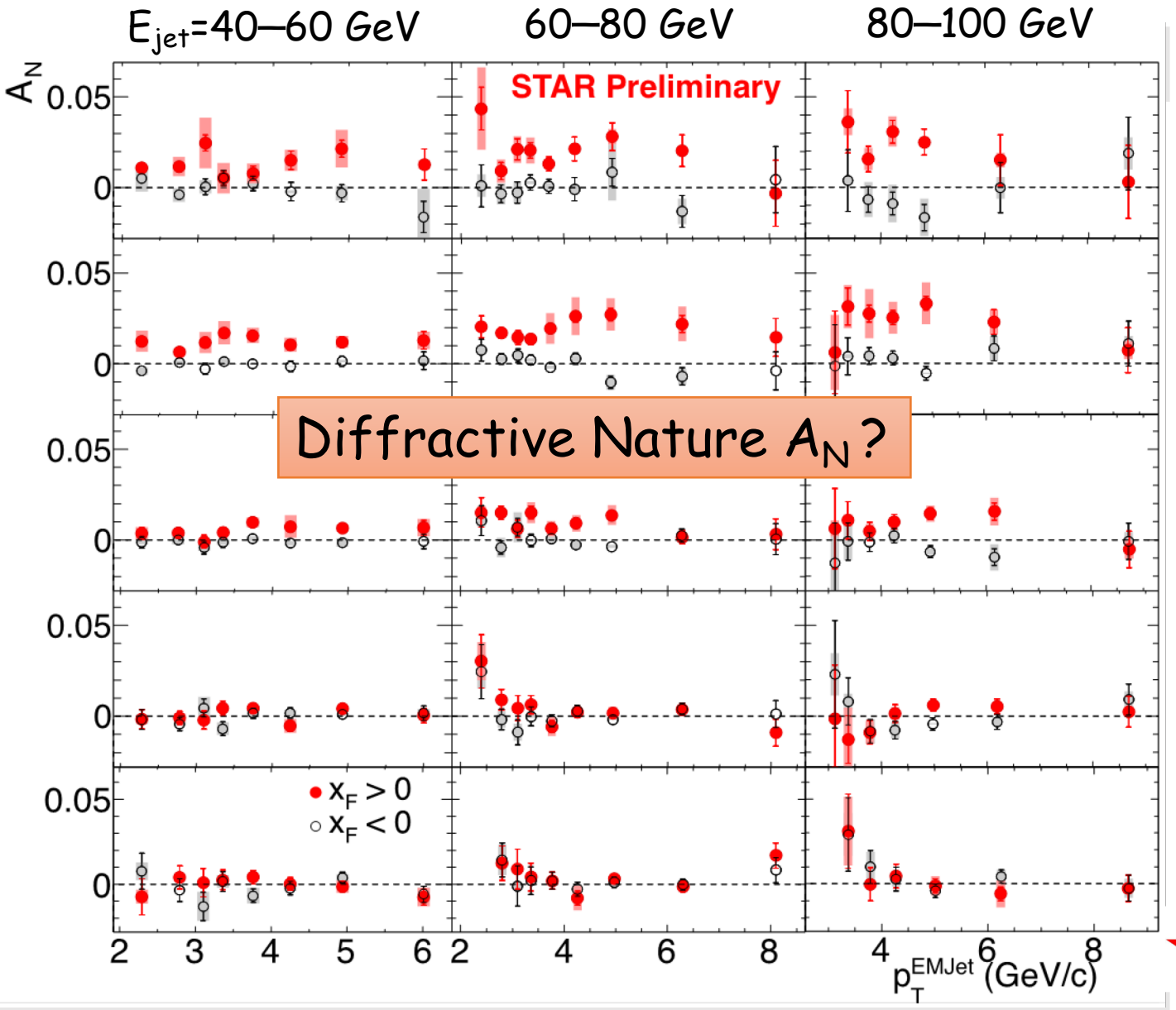


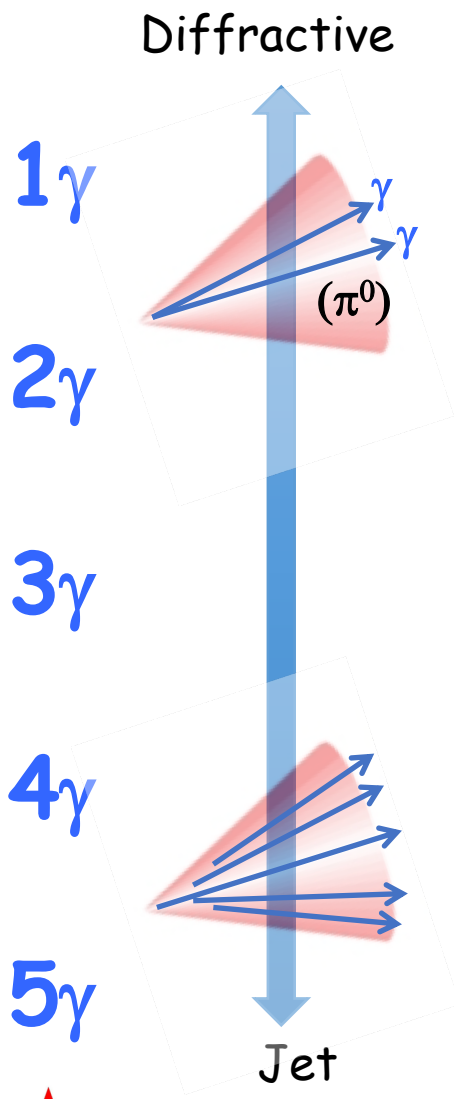


Initial State effect or Final State Effect?

Remain Unsolved

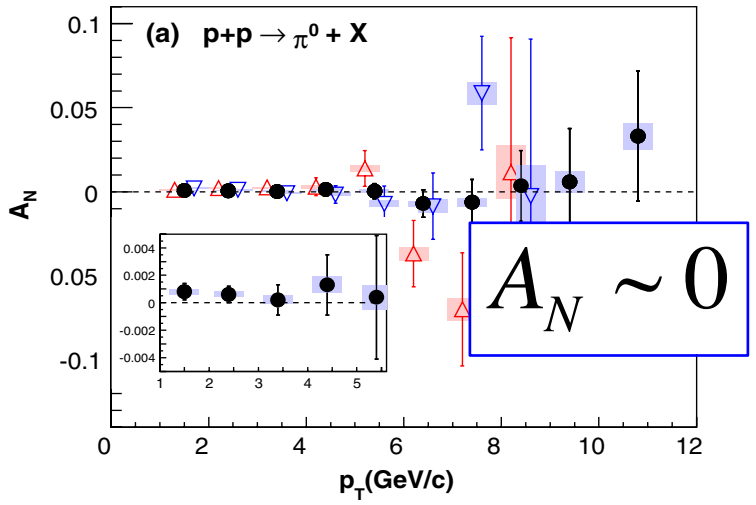
γ-multiplicity dependence of Forward ($2<\eta<4$) π^0 A_N





Rapidity Dependence of A_N

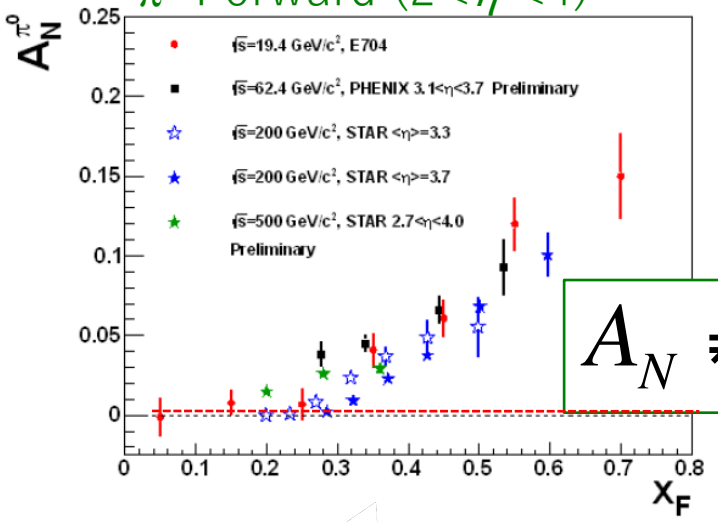
π^0 Central ($0.35>|\eta|$)



$A_N \sim 0$

PRD90,012006(2014)

π^0 Forward ($2<\eta<4$)

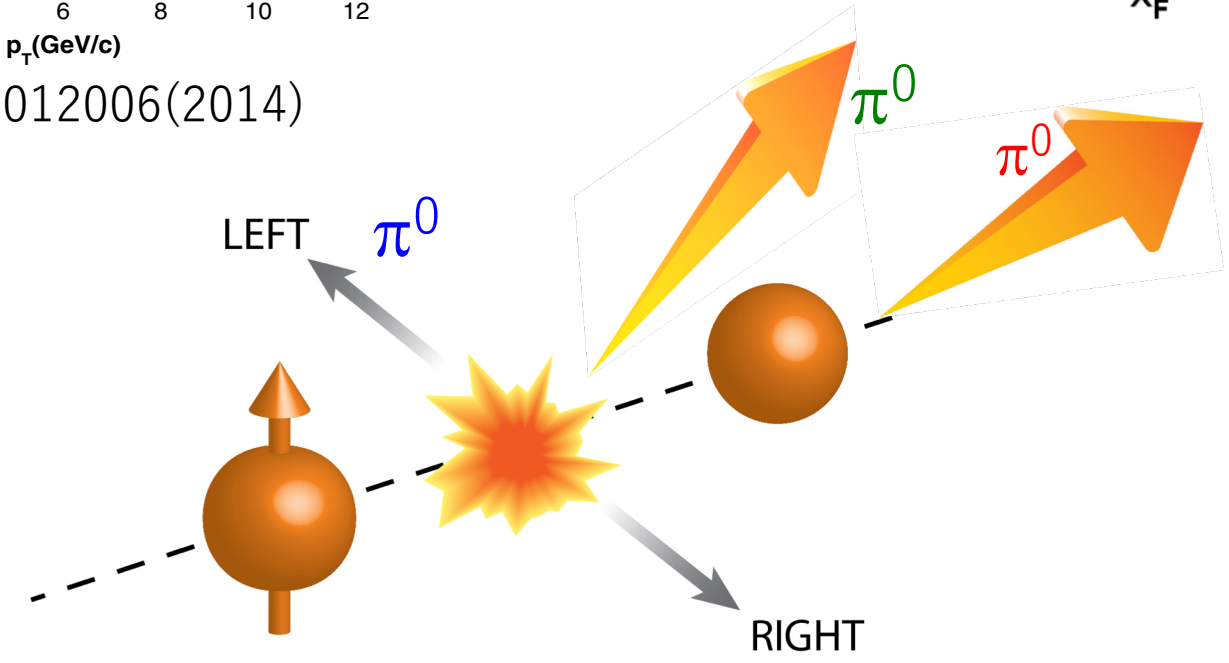


$A_N \neq 0$

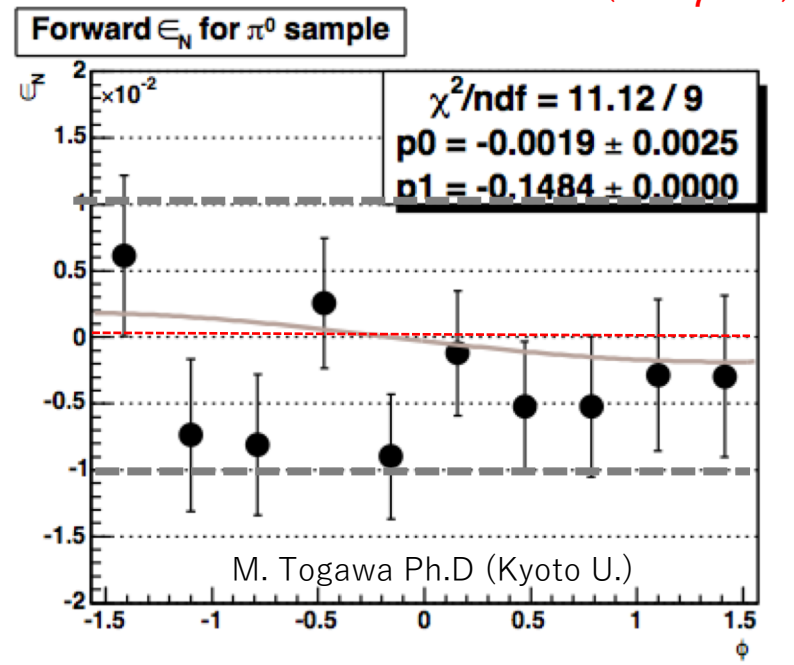
Phys. Lett. B650 (2007) 325.

	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	$-0.022 \pm 0.030 \pm 0.002$	$0.007 \pm 0.021 \pm 0.001$

TABLE I: 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 $(1.0^{+0.47}_{-0.24})$.

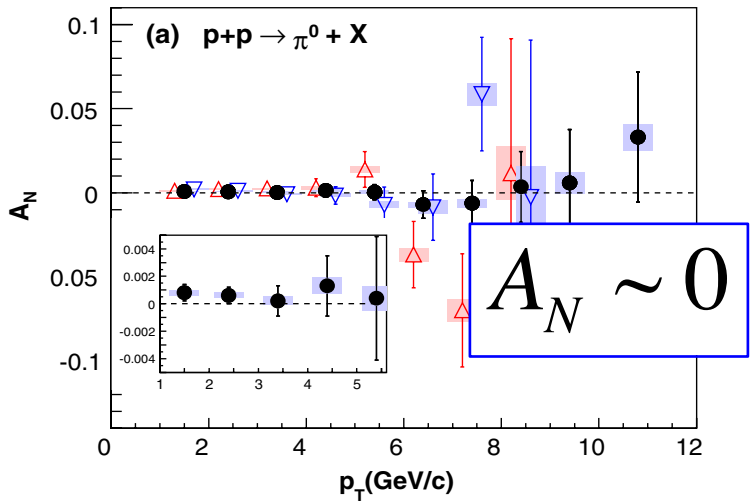


π^0 Forward ($6<\eta<8$)



Rapidity Dependence of A_N

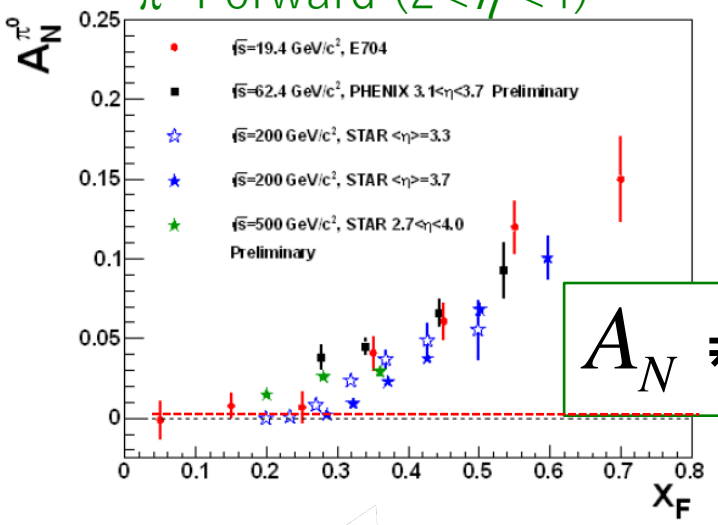
π^0 Central ($0.35>|\eta|$)



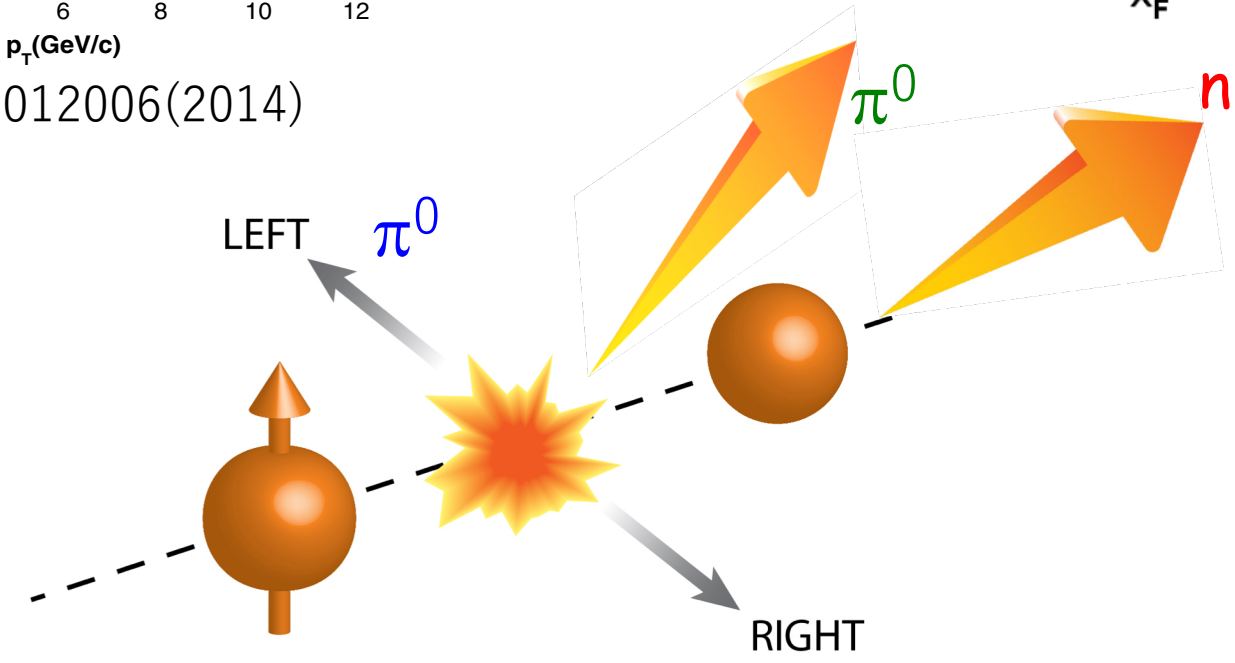
$A_N \sim 0$

PRD90,012006(2014)

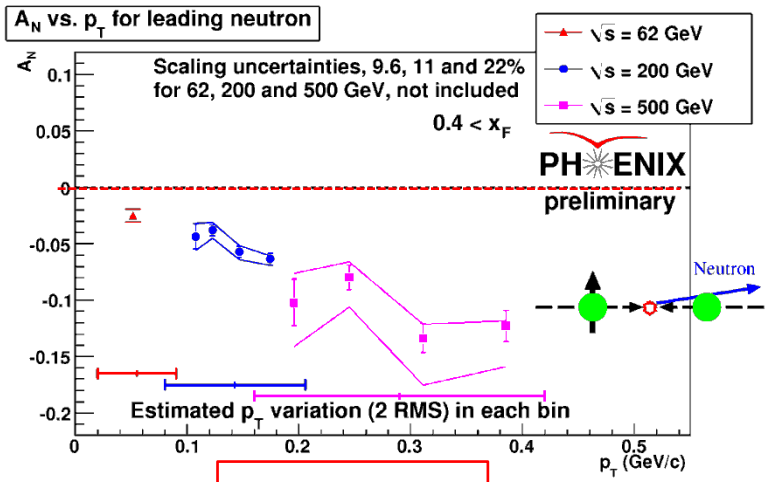
π^0 Forward ($2<\eta<4$)



$A_N \neq 0$

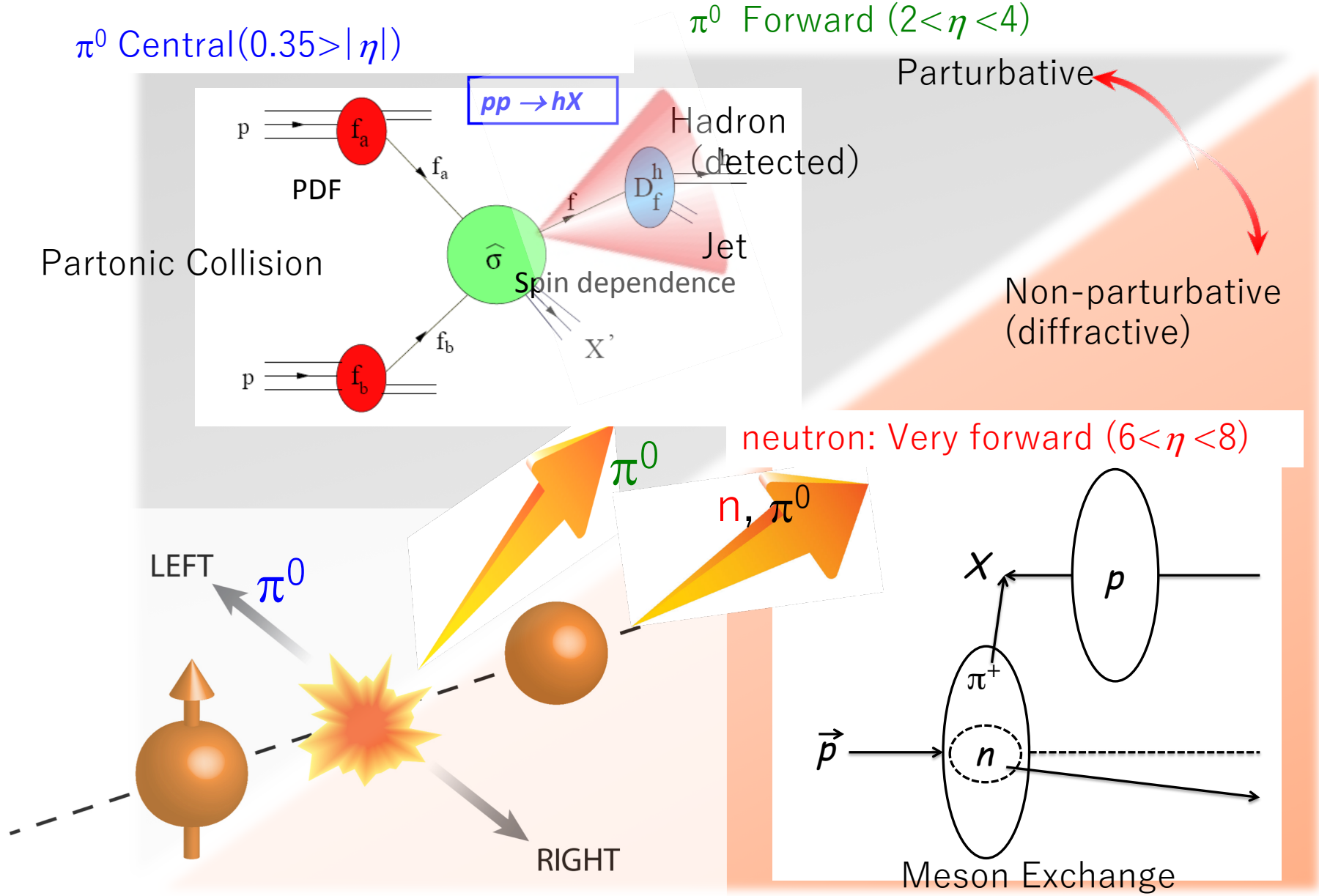


Neutron: Very Forward($6<\eta<8$)

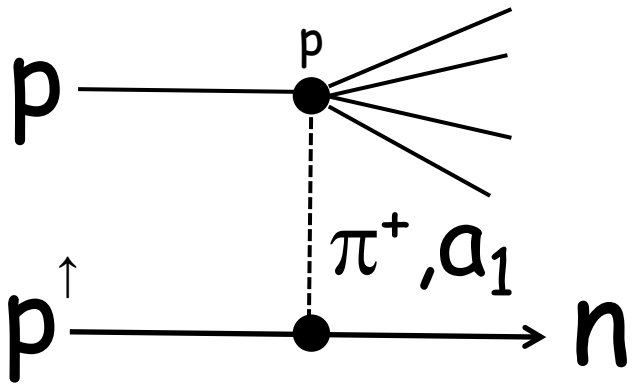


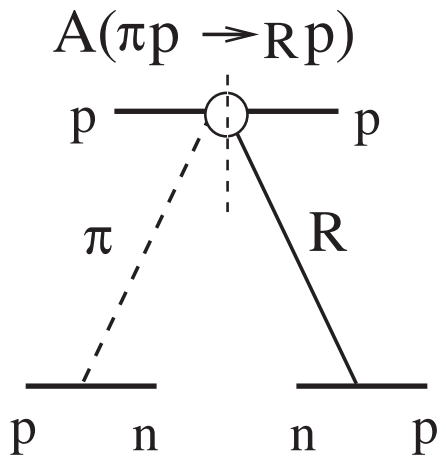
$A_N \neq 0$

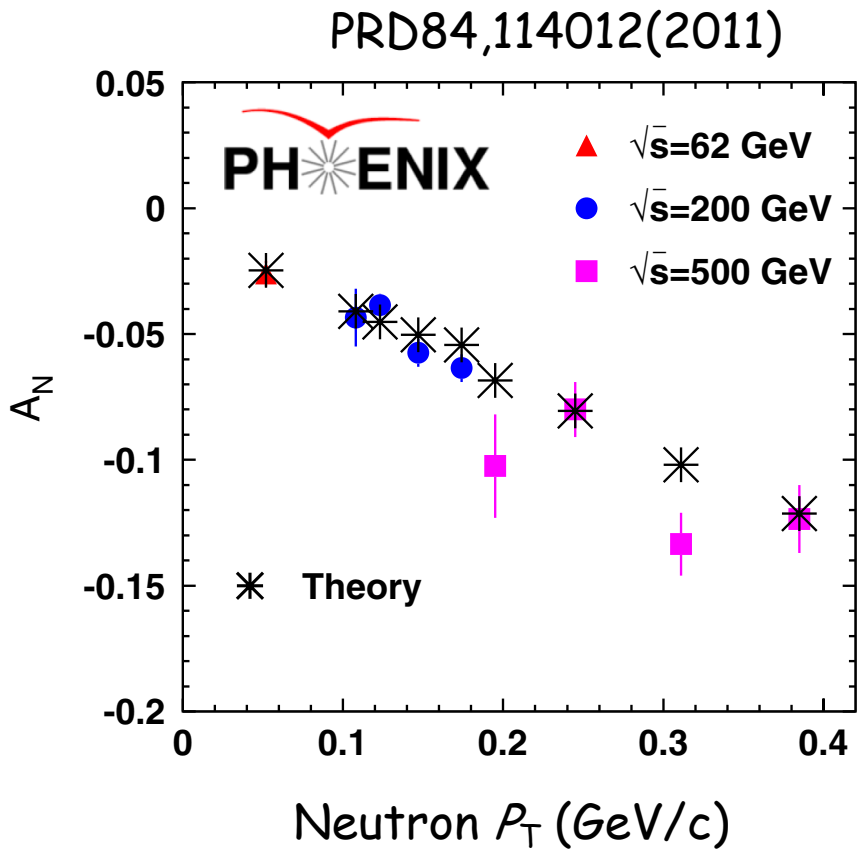
Hadron Production Mechanism



$p^{\uparrow}$+p Forward Neutron A_N

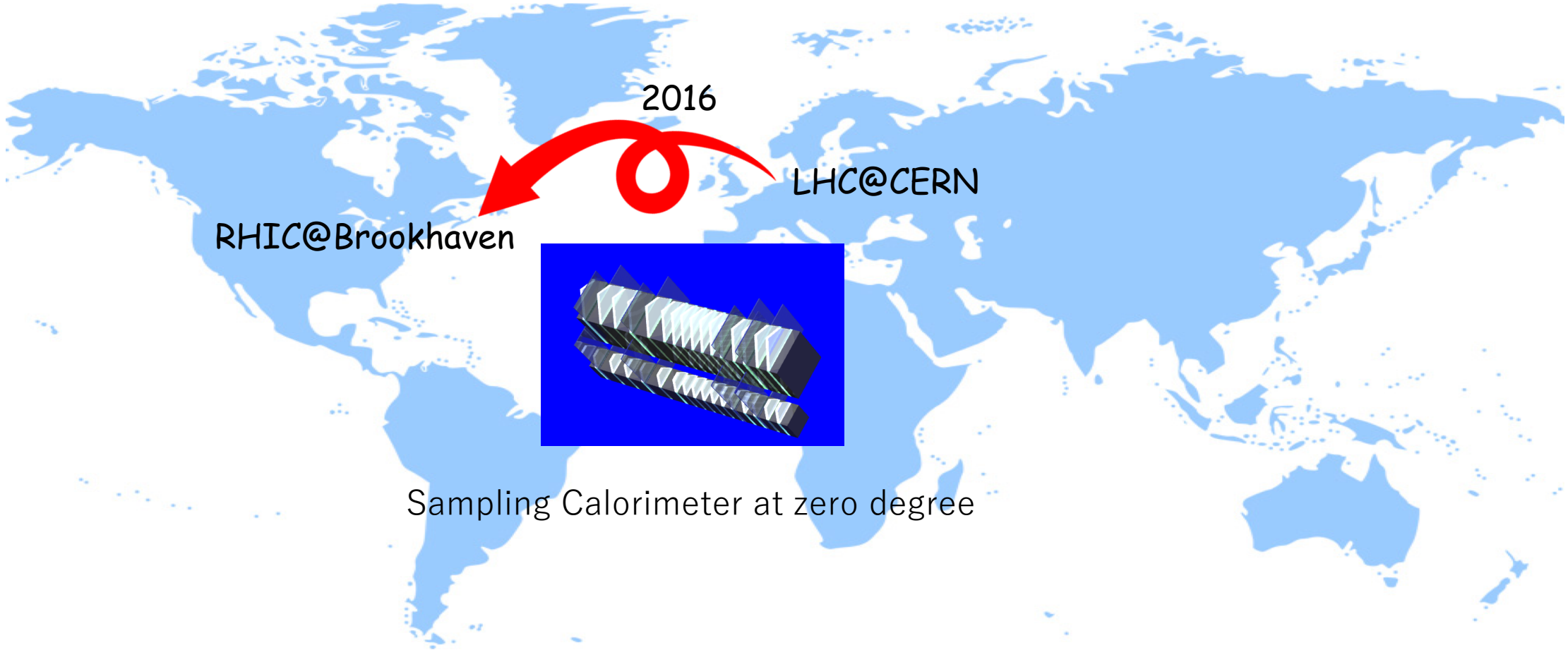




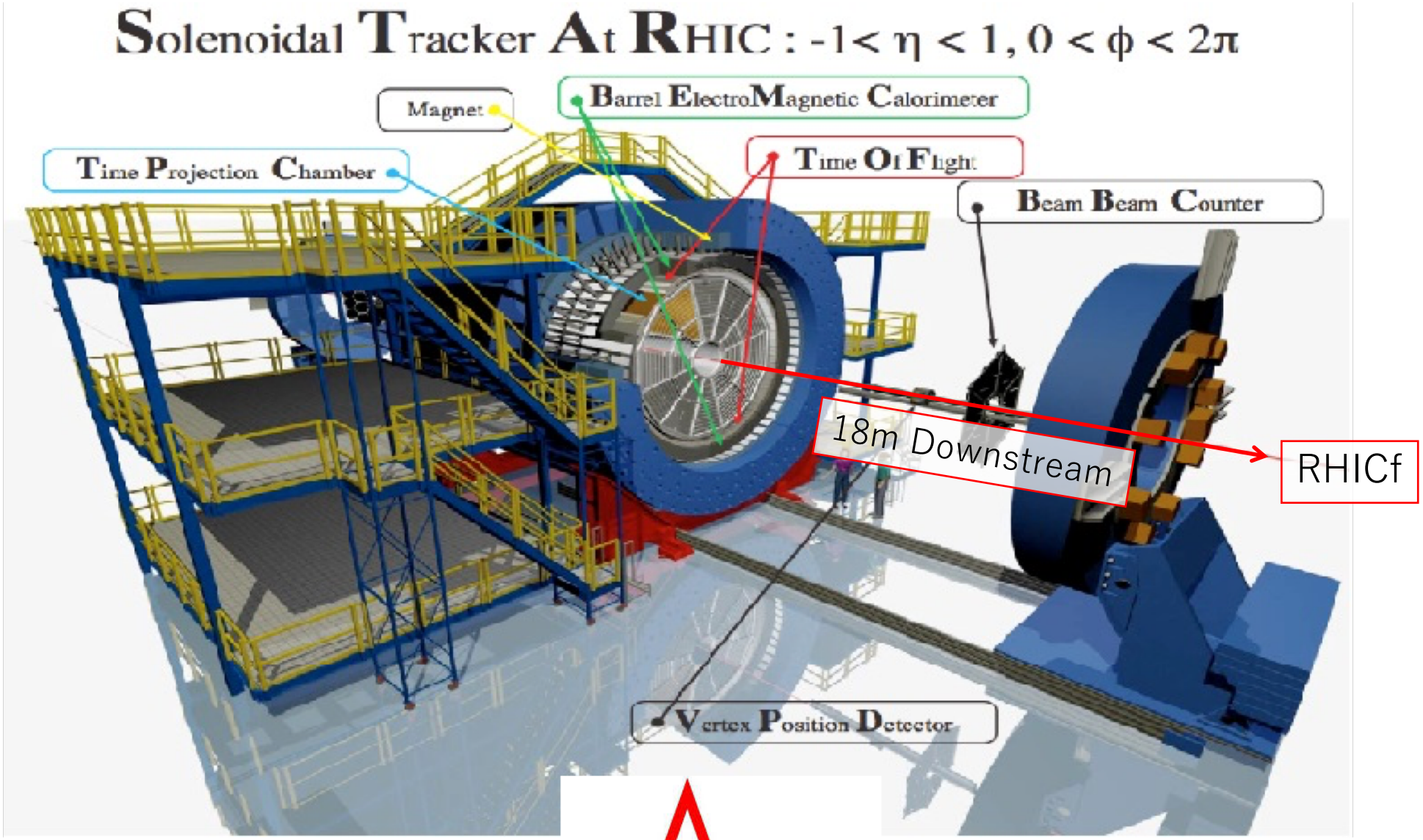


Data are well reproduced by the interference between π and a_1 Reggeon

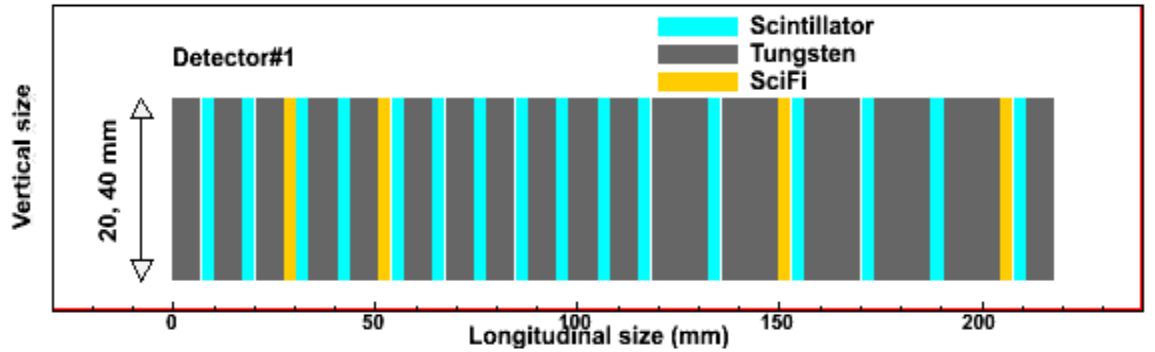
LHCf -> RHICf

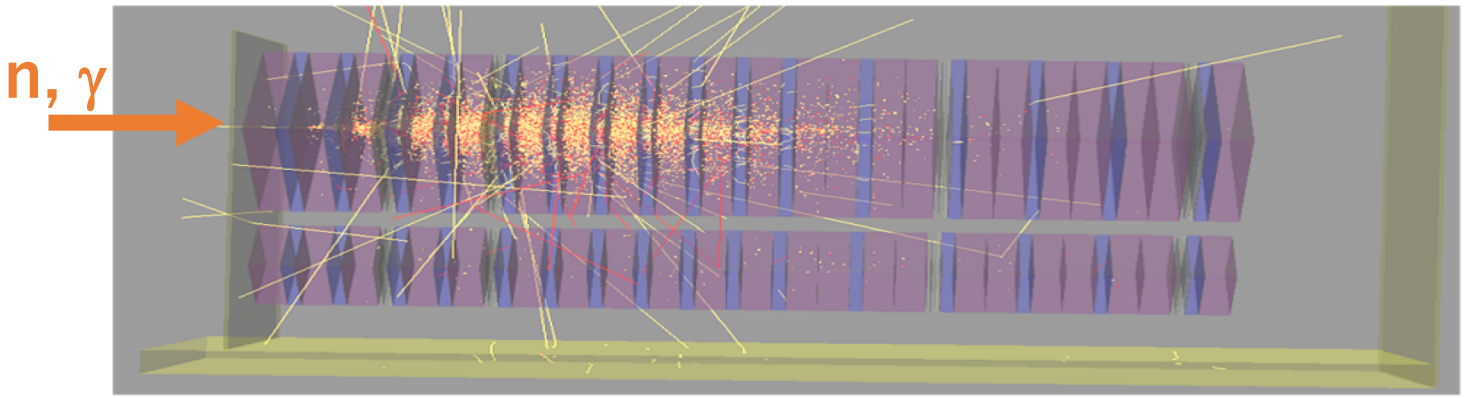


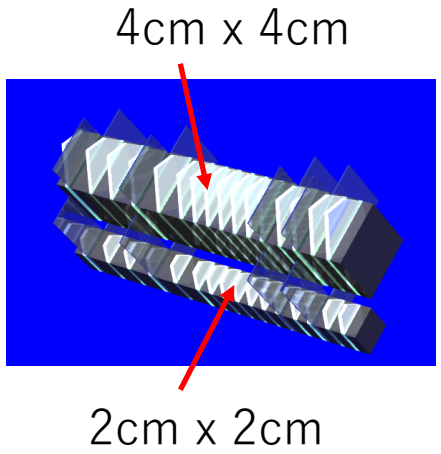
Sampling Calorimeter at zero degree


Solenoidal Tracker At RHIC : -1< η < 1, 0 < ϕ < 2π
Magnet
Barrel ElectroMagnetic Calorimeter
Time Projection Chamber
Time Of Flight
Beam Beam Counter
18m Downstream
RHICf
Vertex Position Detector
STAR


290mm
90mm

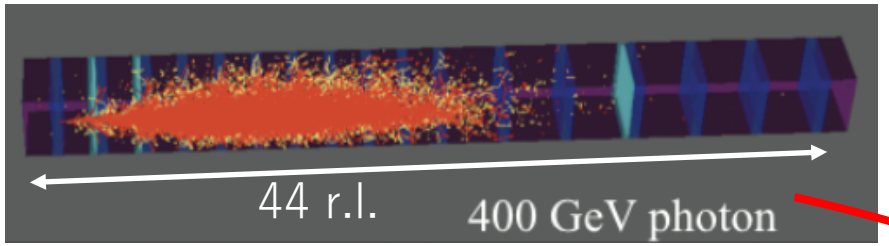

Detector#1
Scintillator
Tungsten
SciFi
Vertical size
20, 40 mm
0
50
100
150
200
Longitudinal size (mm)

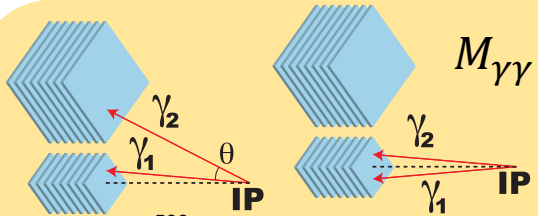

n, γ


4cm x 4cm
2cm x 2cm

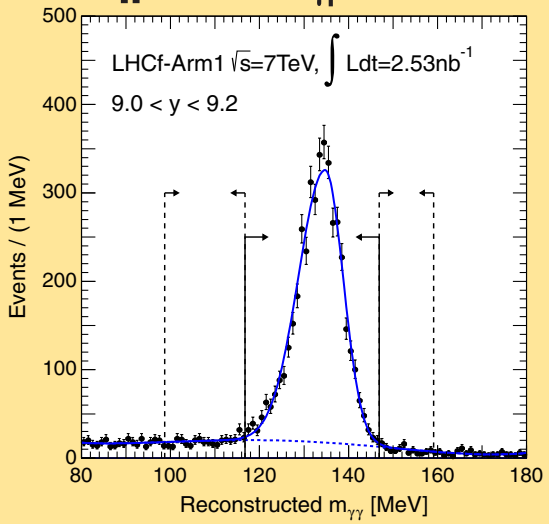
Particle ID (PID)

Photon event





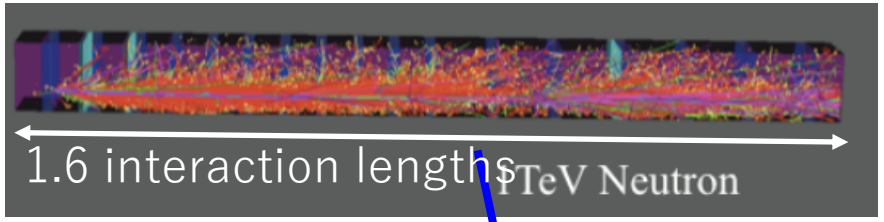
$$M_{\gamma\gamma} = \theta\sqrt{E_1 E_2}$$

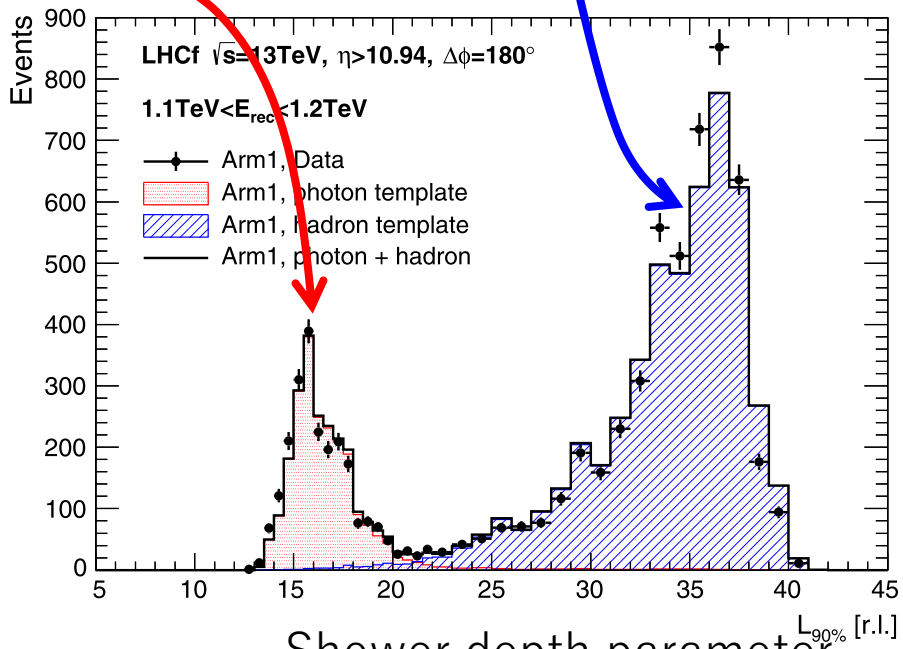


Invariant mass of photon pair
Peak @ 135MeV from π^0 decay events

(Adriani et al., PRD, 2012)

Neutron event

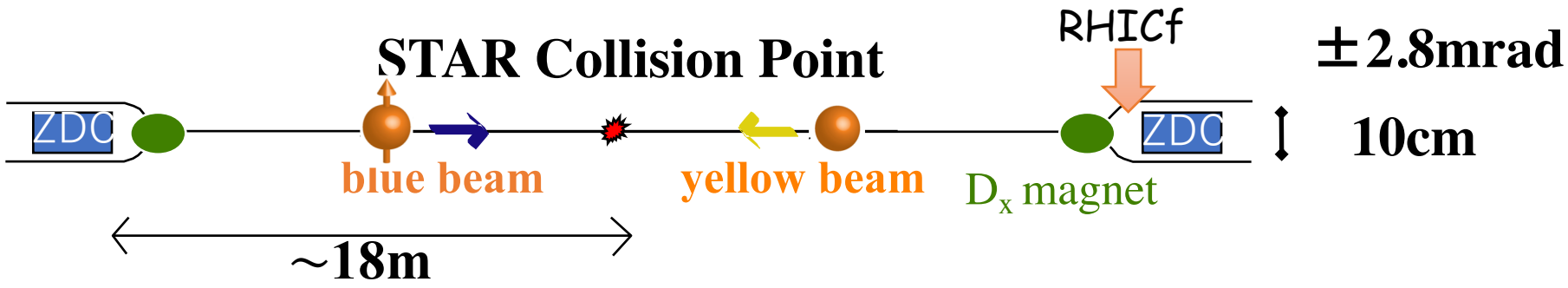




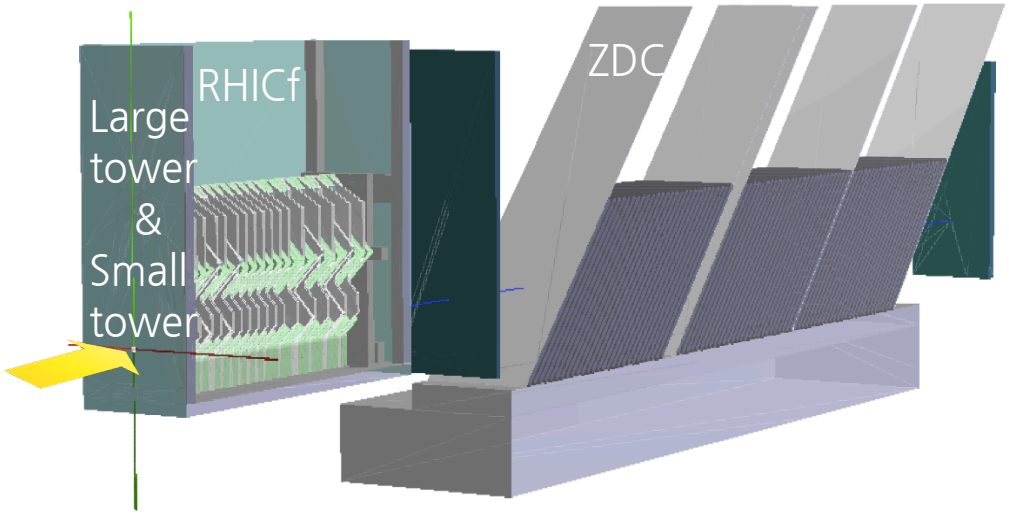
Shower depth parameter

(Adriani et al., PLB, 2018)

RHICf Experimental Setup

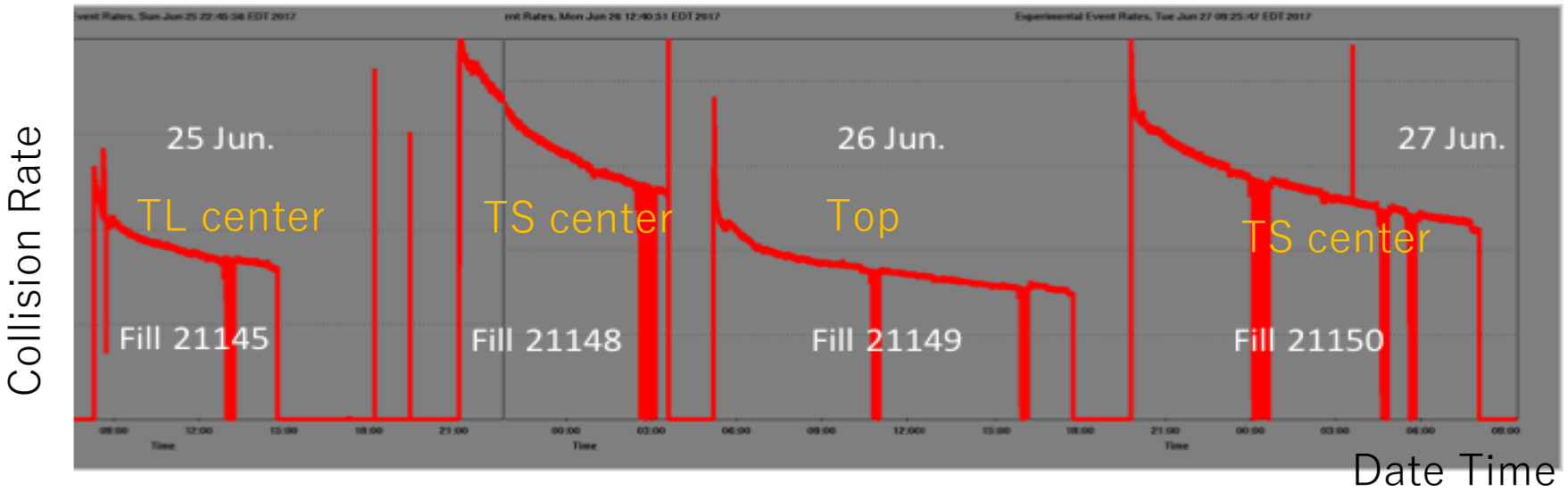


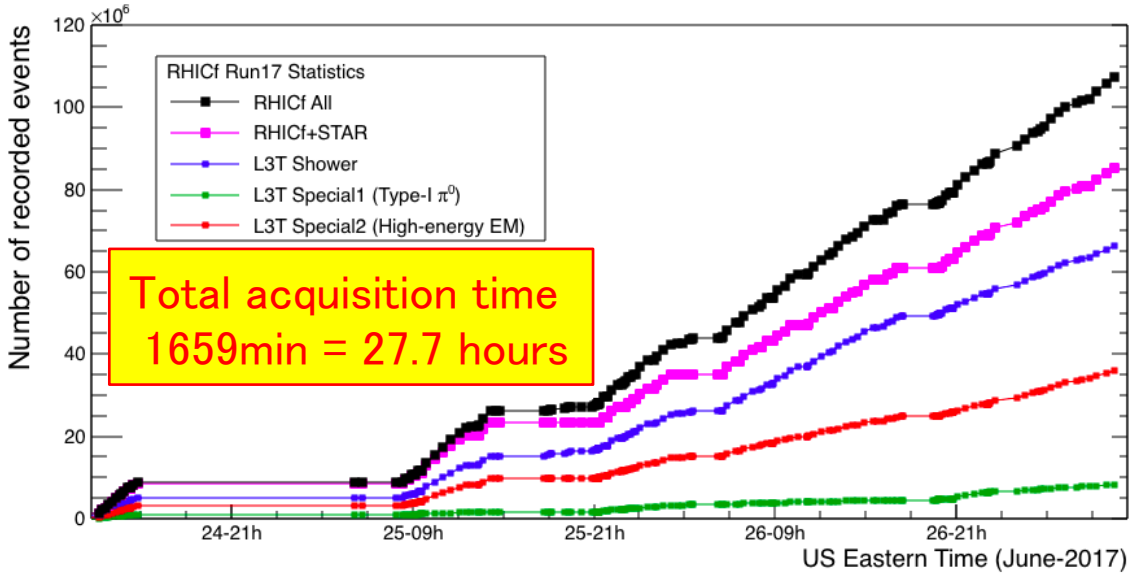
RHICf	ZDC+SMD
Sampling (λ_I=1.7)	Total Absorption (λ_I=5.1)
S=4cm × 4cm + 2cm × 2cm	S=10cm × 10cm
ΔE_n~35%	ΔE_n~18%
Δx_n~0.1cm	Δx_n~1cm



Installed new sampling calorimeter RHICf in front of existing neutron calorimeter, ZDC.

RHICf Experiment : June 2017





Total : 110M events

RHICf+STAR

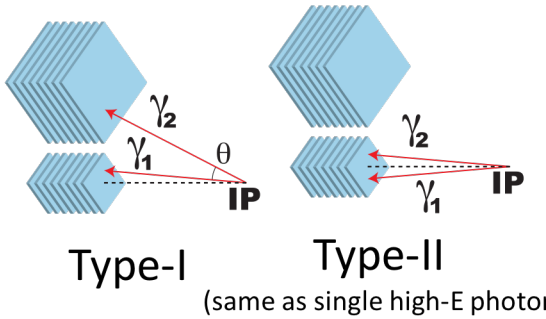
RHICf (shower event)

RHICf (High-energy EM trigger)

RHICf (Type-I π^0 trigger)

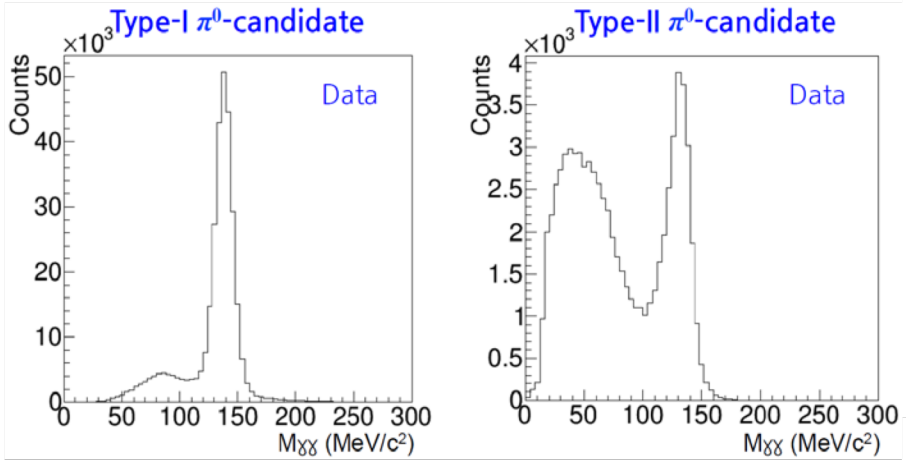
π^0 Performance

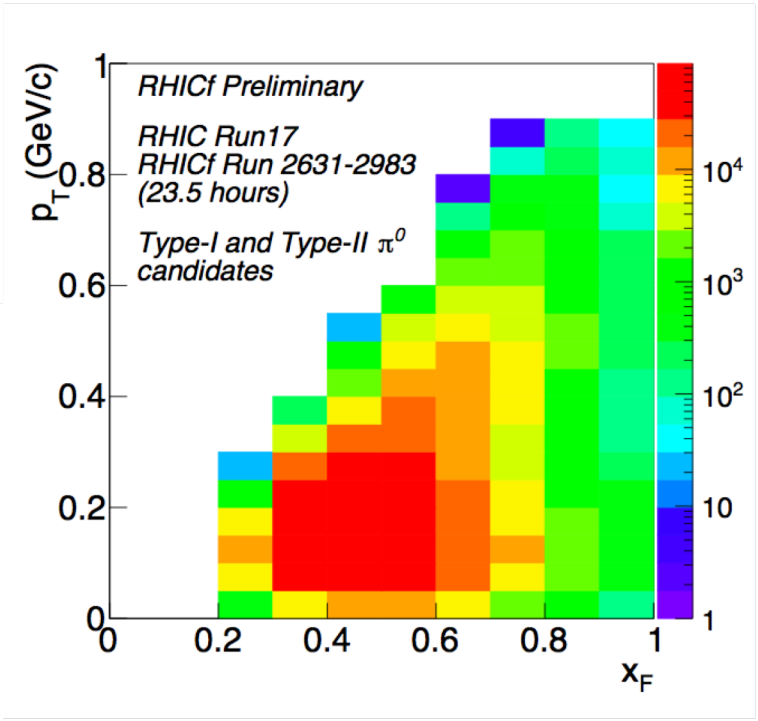
- π^0 peak with ~10 MeV/c^2 width
  - 3σ region selected as π^0 candidates
- p_T < 1.0 GeV/c
- 0.2 < x_F < 1.0



Type-I Type-II

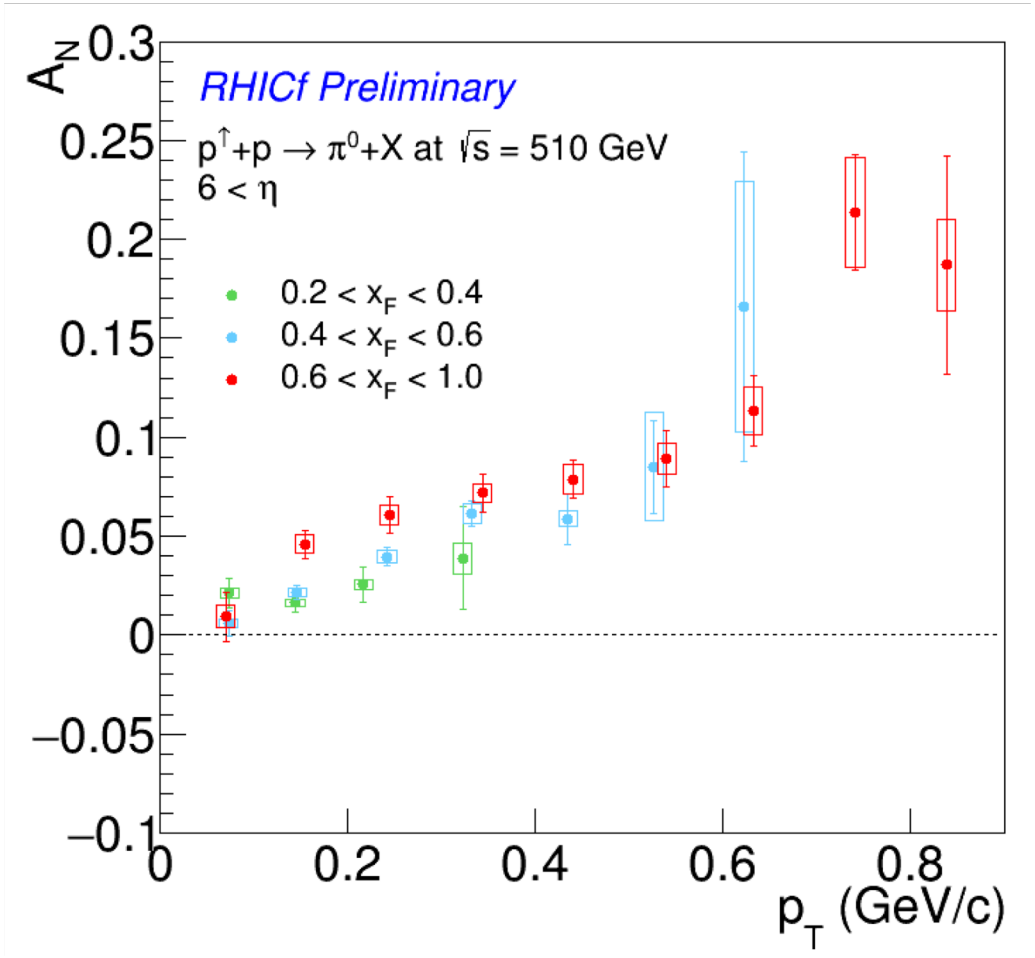
(same as single high-E photon)



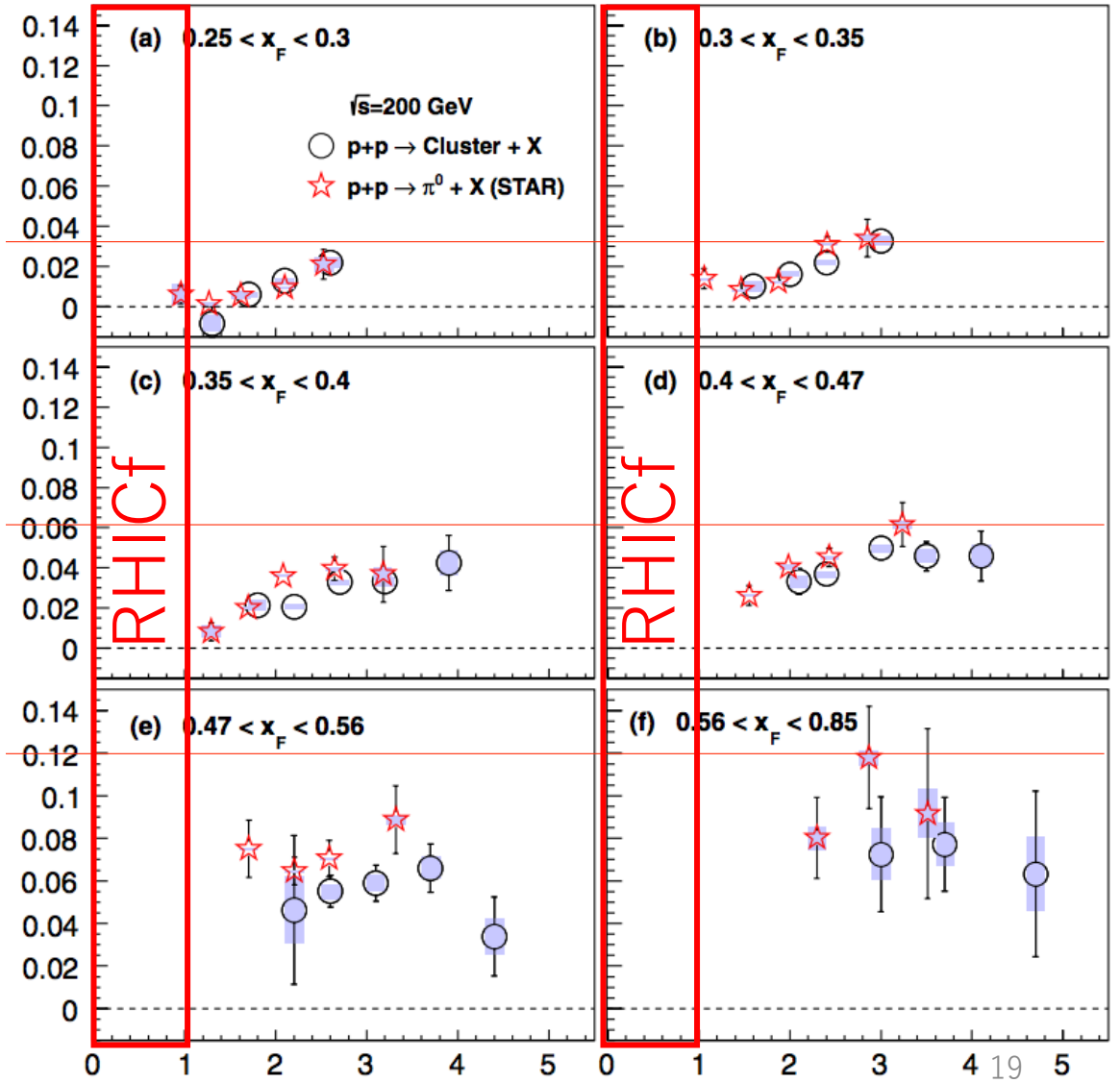


Data analysis by Minho Kim

π^0 Asymmetry Preliminary Results

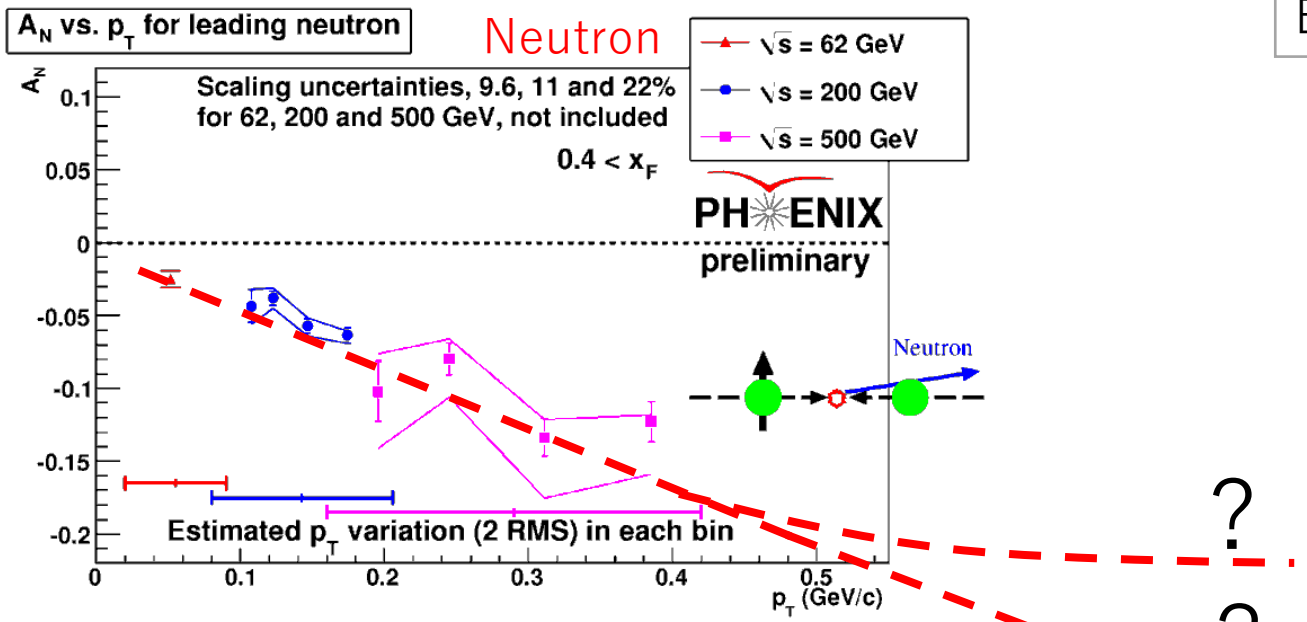


Large Asymmetry was observed p_T<1GeV.



Neutron p_T coverage extention

Explore the proton spin in diffractive and transition to pQCD regime.



Extend p_T region up to 1.2GeV

$p_T(GeV)$	N $(\times 10^3)$	δA
0.0–0.1	2,310	0.0013
0.1–0.2	2,570	0.0012
0.2–0.3	1,710	0.0015
0.3–0.4	2,190	0.0014
0.4–0.5	1,210	0.0018
0.5–0.6	1,130	0.0019
0.6–0.7	402	0.0032
0.7–0.8	260	0.0039
0.8–1.2	104	0.0062

?

?

diffractive ⟷ pQCD

Summary

- Forward transverse single spin asymmetry has been considered to be sensitive to the orbital angular momentum.
- Forward π A_N has been studied in pQCD framework, but recent data indicate possibility of soft process may be (partially) playing a role.
- New p0 results showed large asymmetry pT<1GeV where diffractive process expected to dominate.
- RHICf experiment is expected to interconnect asymmetries between hard (pQCD) and soft (diffractive) nature.

RHICf Collaboration

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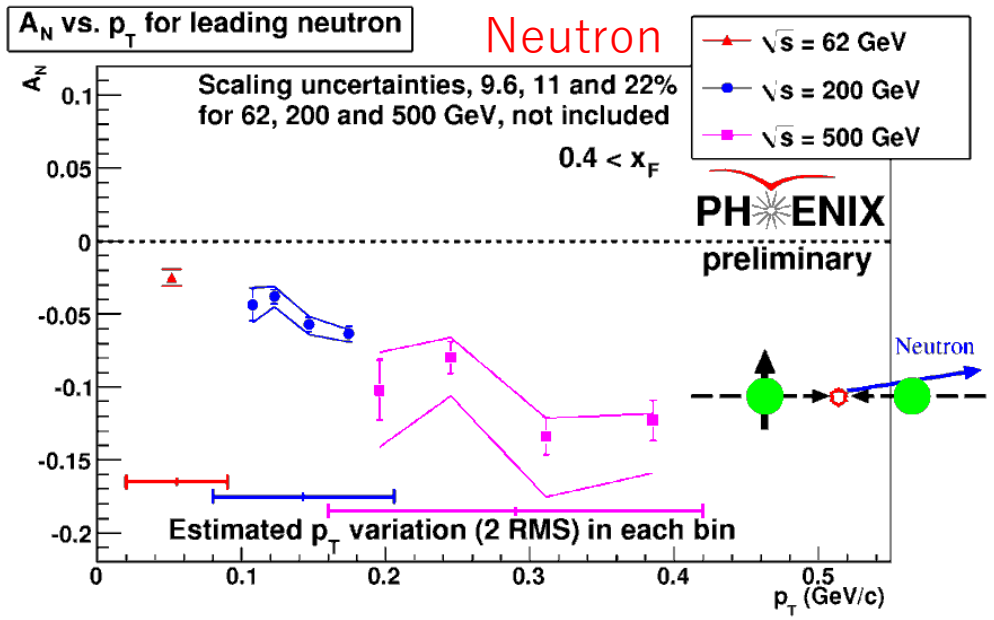
K. Kasahara, T. Suzuki, S. Torii (Waseda Univ.)
N. Sakurai (Tokushima Univ.)
O. Adriani, E. Berti, L. Bonechi,
R. D'Alessandro (INFN Firenze)
A. Tricomi (INFN Catania)

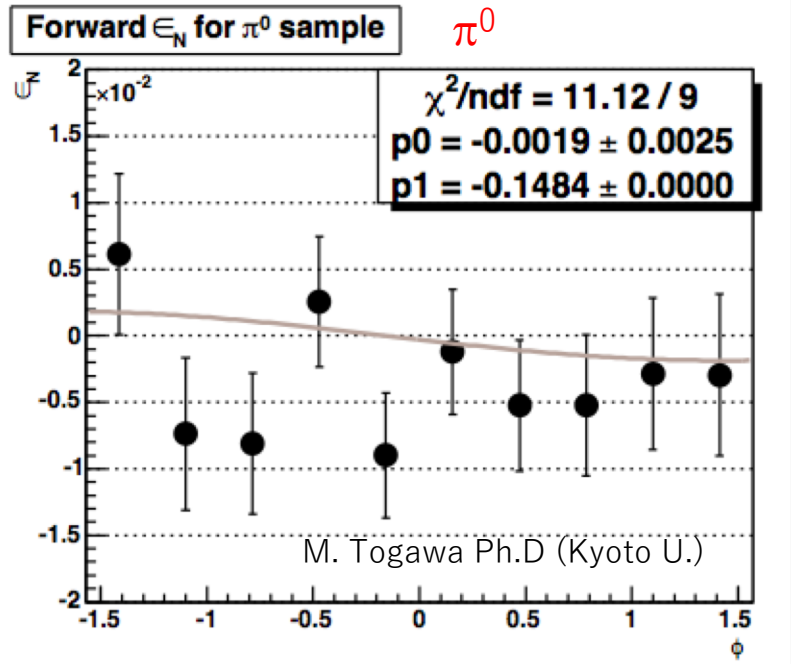
Backup slides

Goal of RHICf Spin

Measure transverse single spin asymmetry of π^0 and neutron at zero degree. Explore the proton spin in diffractive and transition to pQCD regime.



Observed asymmetry look scaling with p_T, but what about collision energy dependence?



The statistically insufficient existing data.

Goal of RHICf Spin

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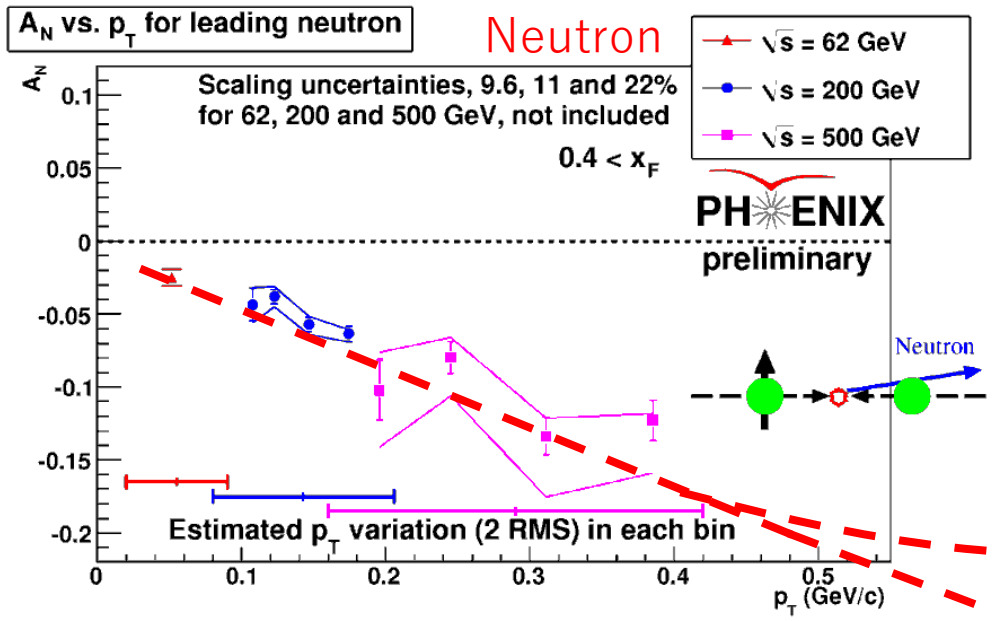


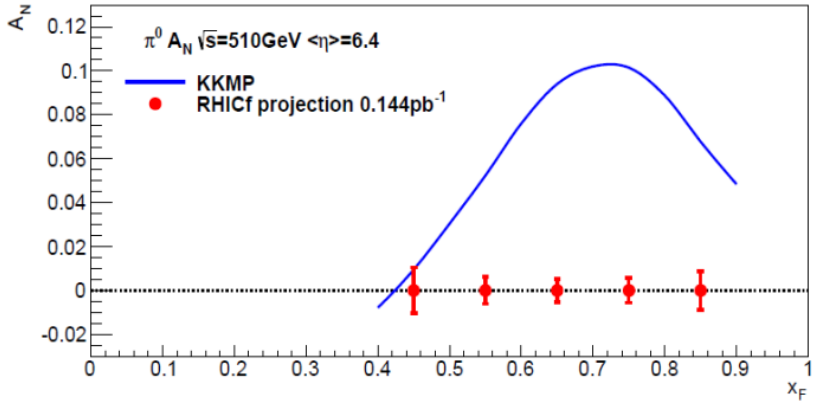
$p_T(GeV)$	N $(\times 10^3)$	δA
0.0–0.1	2,310	0.0013
0.1–0.2	2,570	0.0012
0.2–0.3	1,710	0.0015
0.3–0.4	2,190	0.0014
0.4–0.5	1,210	0.0018
0.5–0.6	1,130	0.0019
0.6–0.7	402	0.0032
0.7–0.8	260	0.0039
0.8–1.2	104	0.0062

Extend p_T region up to 1.2GeV

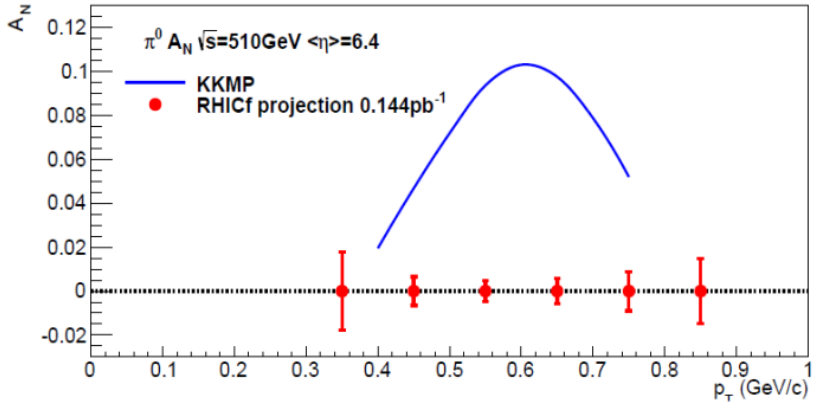
Improve p_T Resolution by an order of magnitude

Goal of RHICf Spin

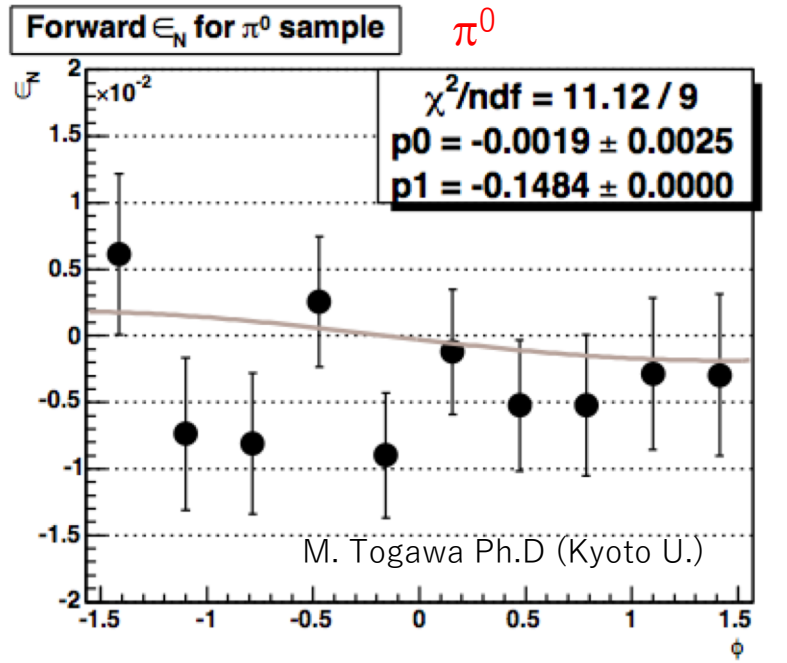
Measure transverse single spin asymmetry of π^0 and neutron at zero degree. Explore the proton spin in diffractive and transition to pQCD regime.



pQCD Calculation and Projected Error



π^0



← Challenge to understand with existing TSSA data ($2<\eta<4$) altogether.