RHICf-STAR Combined analysis

Japan-Korea RHICf meeting

2024/04/30

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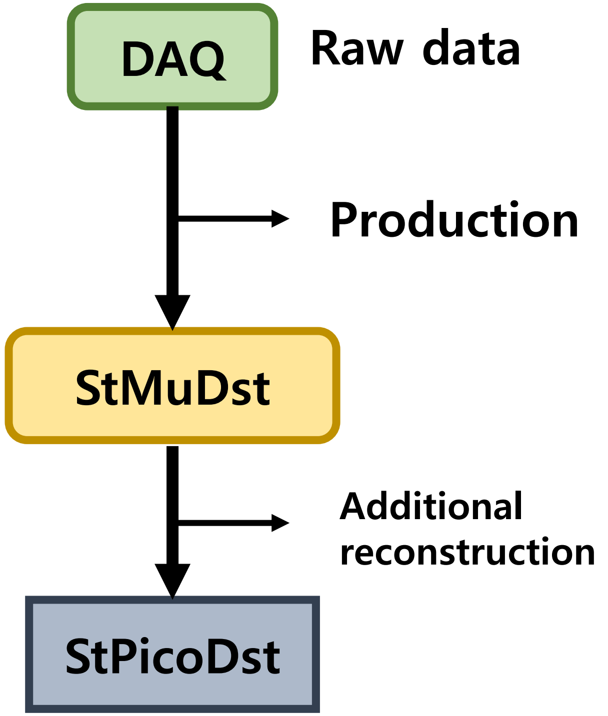
Outline

1. RHICf-STAR framework
2. Introduction
3. Diffractive Like Event
4. PYTHIA study
5. Neutral pion TSSA
6. Neutron TSSA
7. Further study

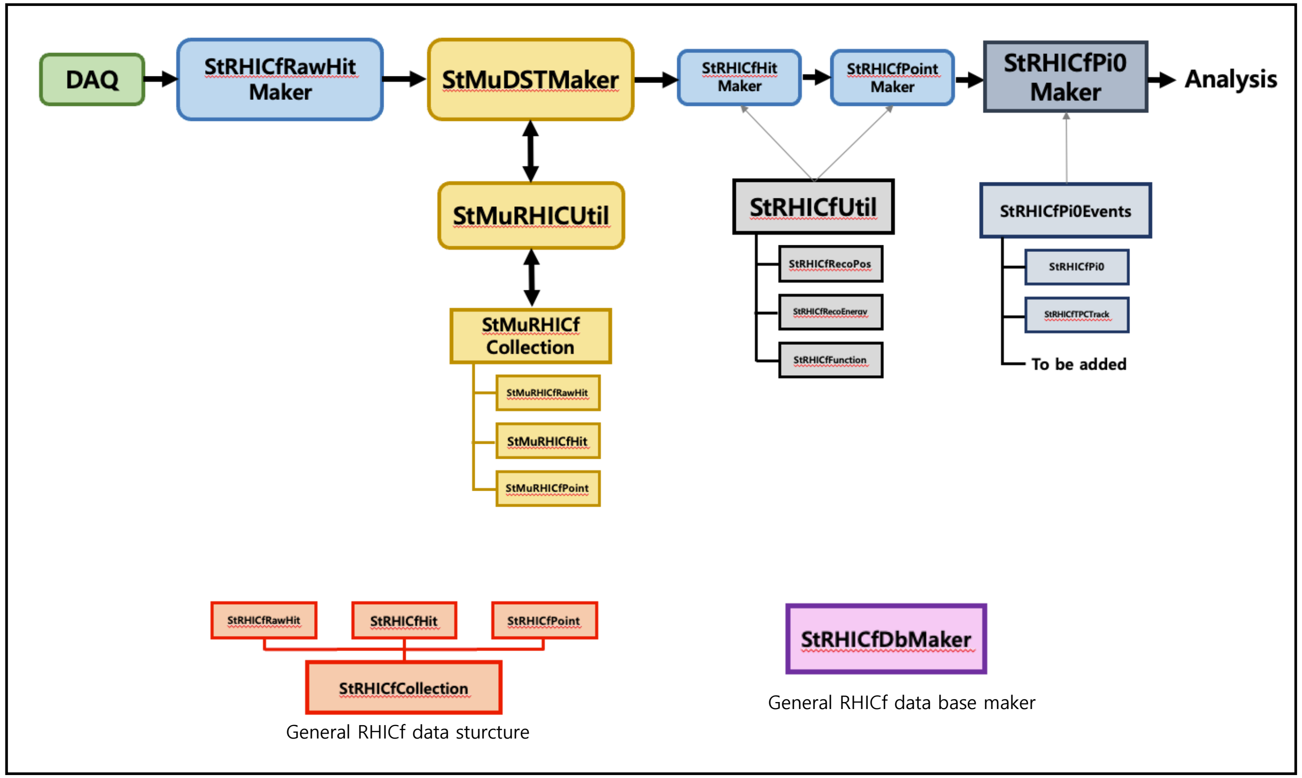
RHICf-STAR software framework

RHICf analysis library

- RHICf tool was made by LHCf and RHICf collaborations originally in a standalone manner.
- Recently we embedded it into the STAR library (2022 ~ 2023)



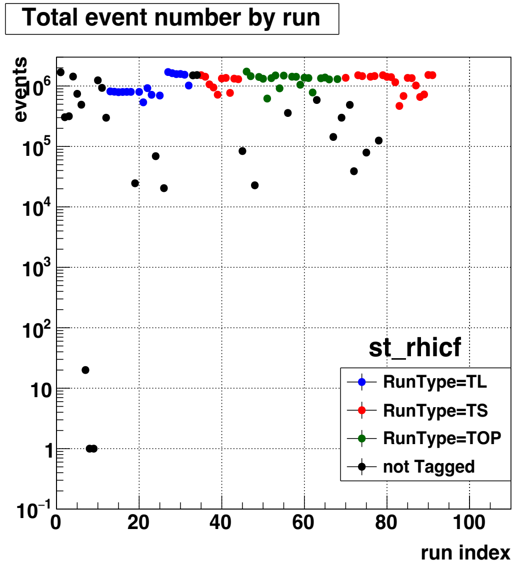
General STAR library flow

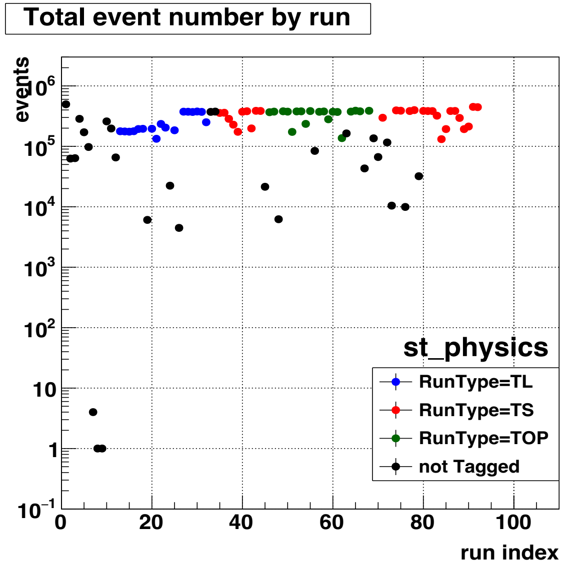


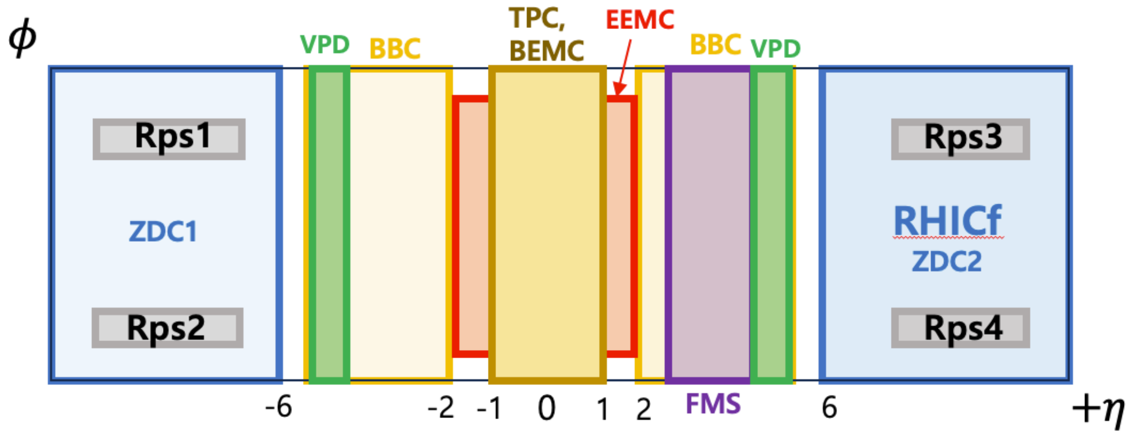
RHICf library flow in STAR library

RHICf-STAR software framework

Data production in 2023







RHICf-STAR detector acceptance diagram

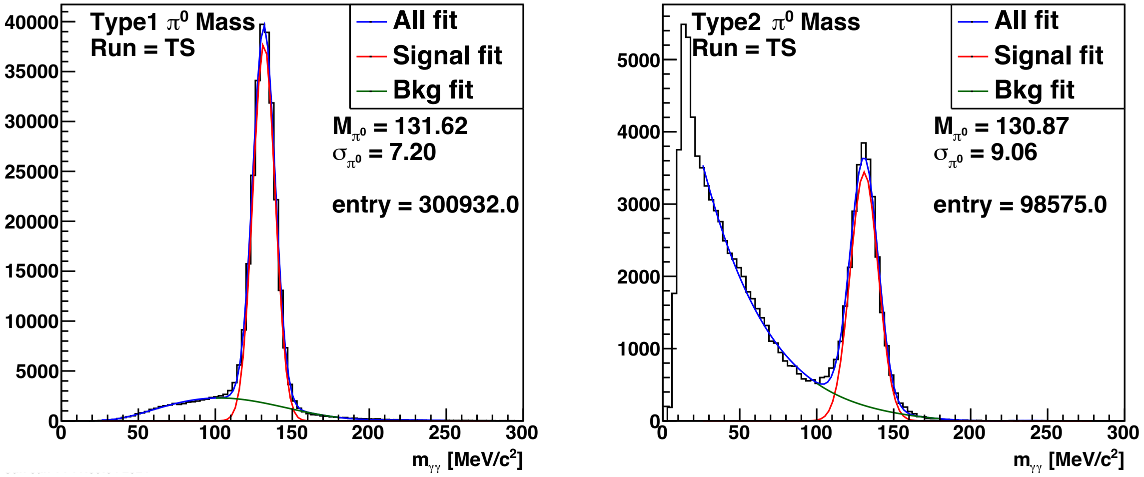
Detector list in data:

1. RHICf
2. TPC (for Tracks)
3. E,B-EMC: (for Energy)
3. BBC (for Trig.)
4. VPD (for Trig. and Vertex)
5. FMS (for Forward meson)
6. ZDC (for Trig.)
7. ToF (for Trig.)
8. Roman-Pot (for proton)

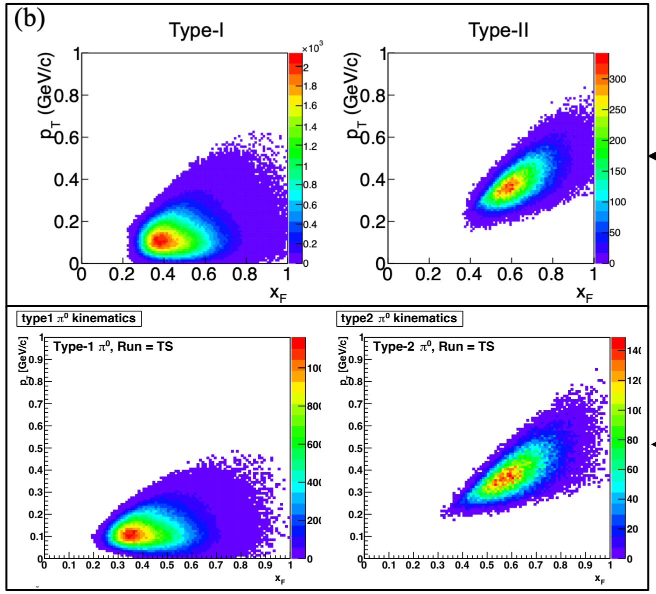
- We confirmed all of data produced well

Cross-checking

π^0 Invariant mass for this analysis



π^0 kinematics



previous result

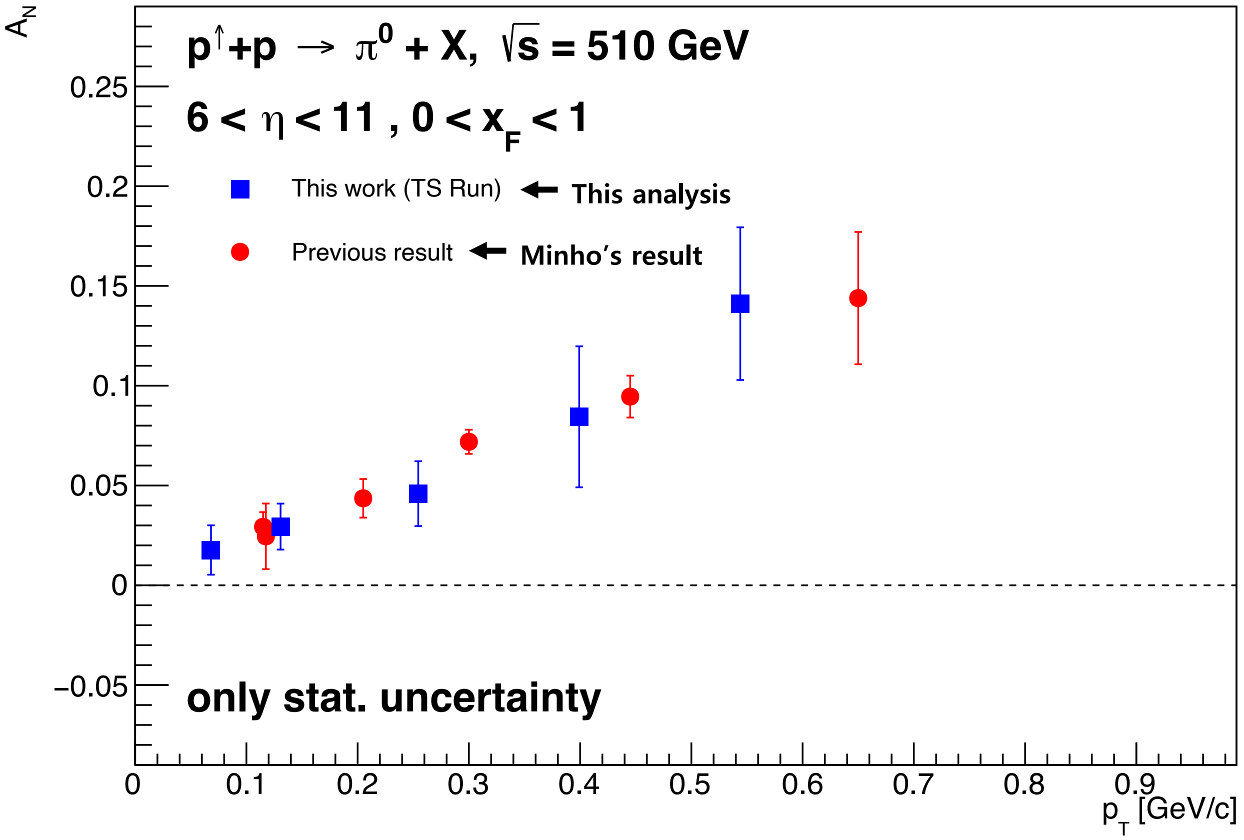
This analysis

- To validate the combined dataset,

  we reproduce the A_N, kinematics, and mass of π^0 and cross-check with M.H Kim's result.

- We also validated the event-by-event data between RHICf-STAR and RHICf standalone library.

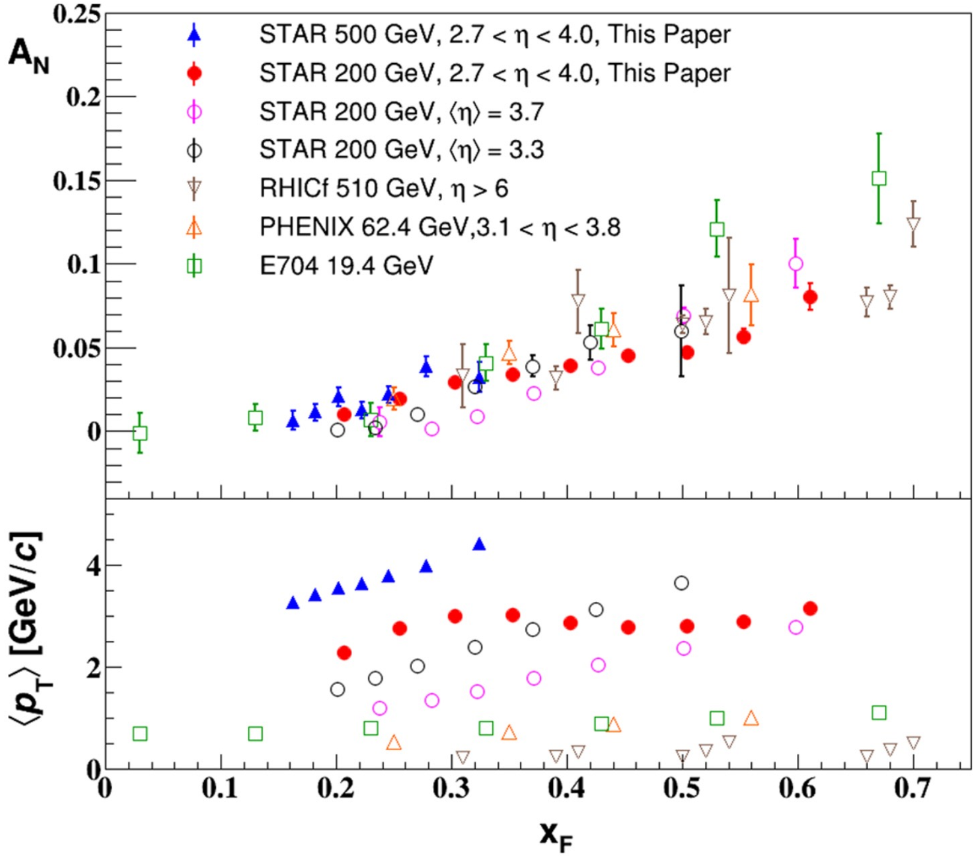
Cross-checking



- The tendency of A_N of π^0 as a function of p_T seems consistent with Minho's results

Introduction

π^0 TSSA

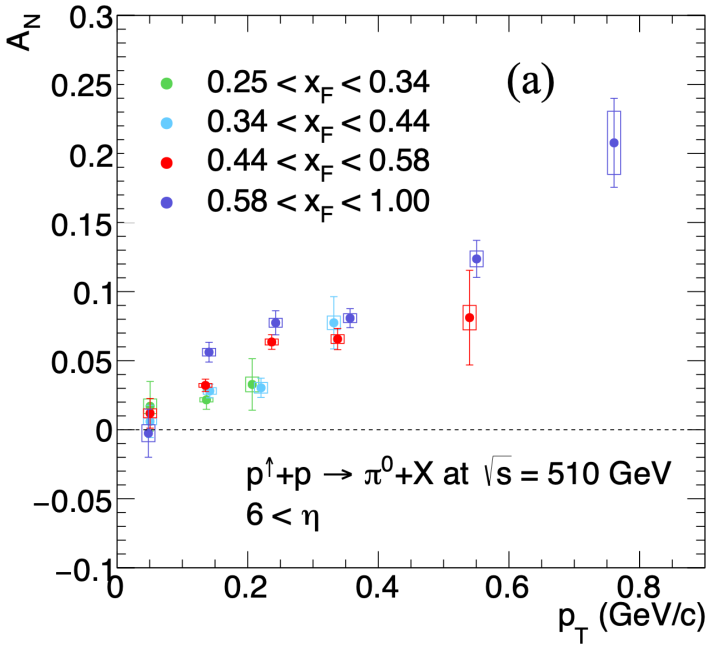


J. ADAM et al., PHYS. REV. D 103, 092009 (2021)

- Transverse Single-Spin Asymmetry for Neutral pion in forward region behavior non-zero
- RHICf π^0 can estimate to dominate the diffractive processes in RHICf region ($6 < \eta < 11$)

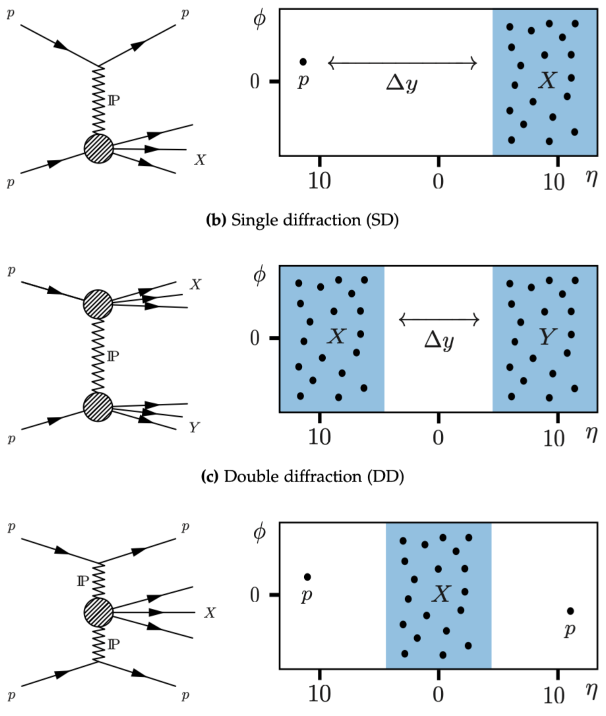
Introduction

RHICf π^0 TSSA



Minho Kim et al.: Phys. Rev. Lett. 124, 252501 (2020).

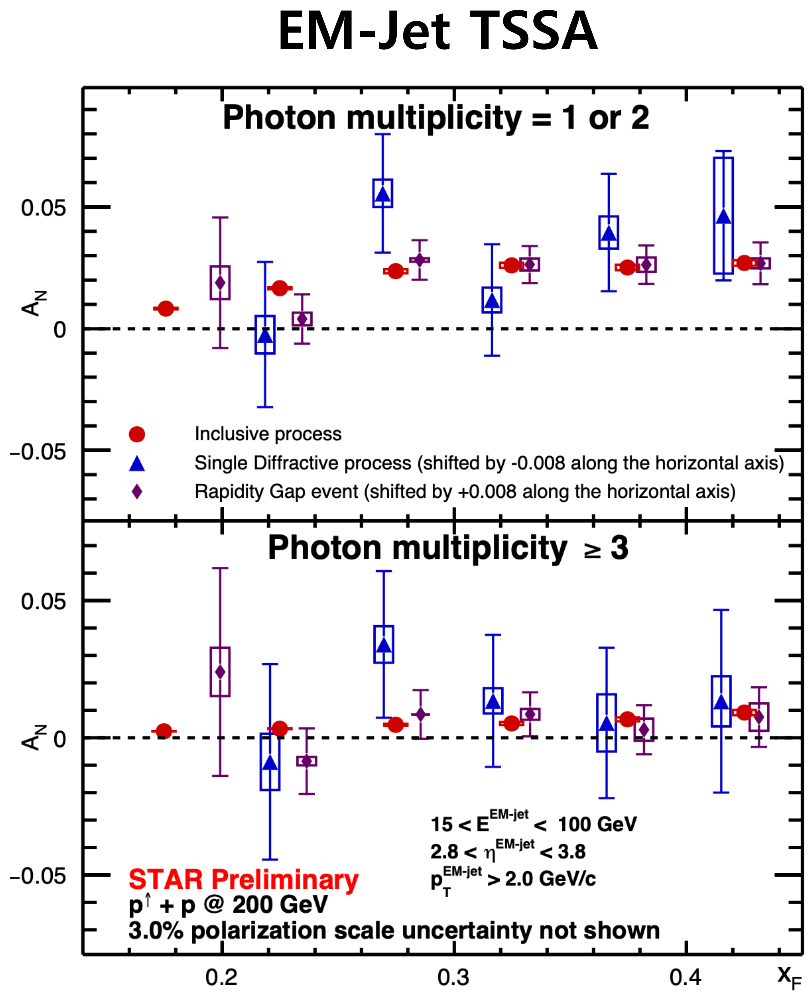
Diffractive processes



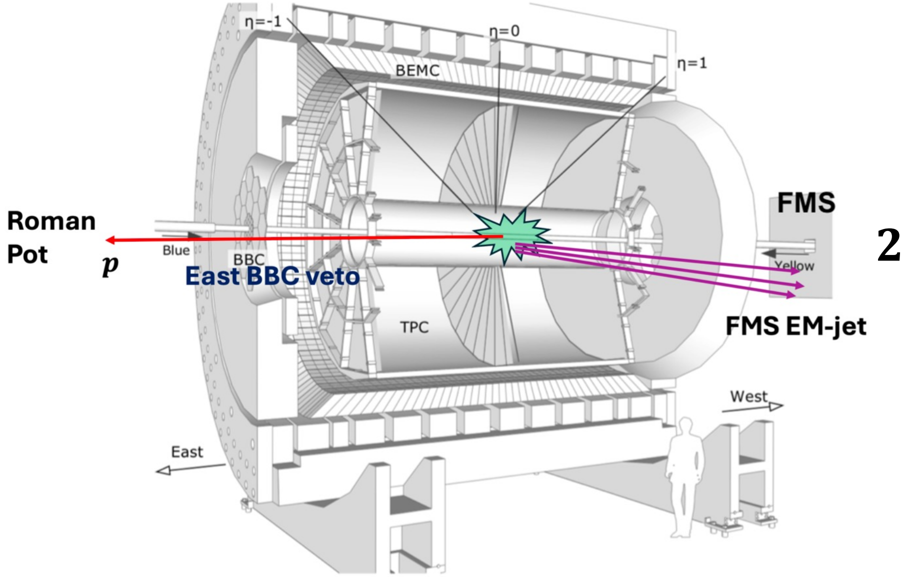
Analysis goal:

- Measure the RHICf π^0 TSSA depend on diffractive processes
- Find the origin of TSSA for each process.

Introduction: Diffractive EM-Jet TSSA



Xilin Liang, DIS2024



$2.8 < \eta^{EM-Jet} < 3.8$

1. **Single-Diffractive process :** tagged Proton with **Roman-Pot**
2. **Rapidity Gap Event :** with **BBC** veto signal

- **EM-Jet TSSA for SD event slightly different**

  (for Photon Mult. = 1 or 2)

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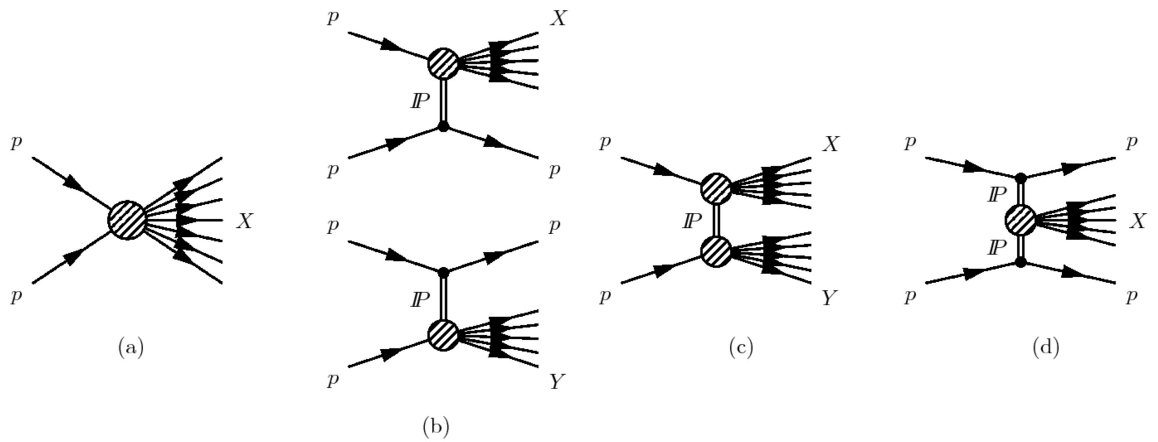
Diffractive Like Event

◆Diffractive processes



- **Diffractive event characteristics :**

1.Final state proton (tagging with Roman pot)

2.Large rapidity gap

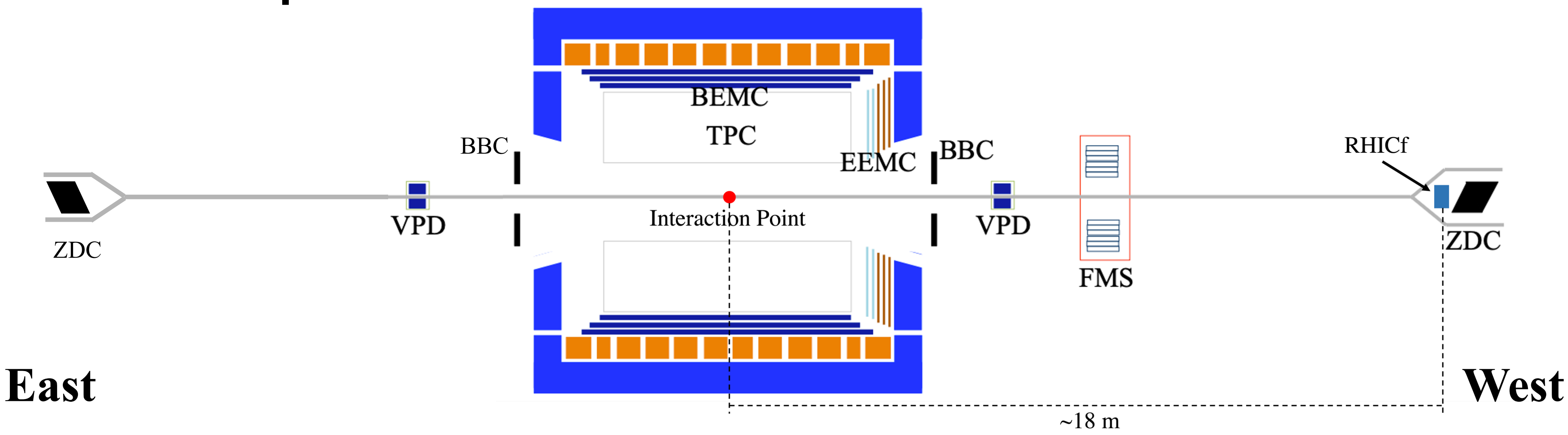
- Although the diffractive process is dominant,

  we cannot rule out the possibility that they originate from non-diffractive processes

- We focus on the large rapidity gap ($\Delta\eta$) to separate processes

Diffractive Like Event

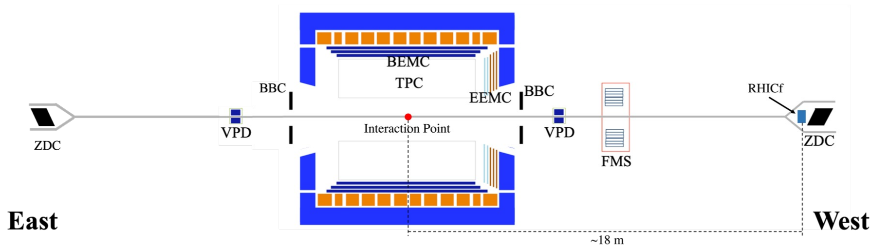
◆Detector setup

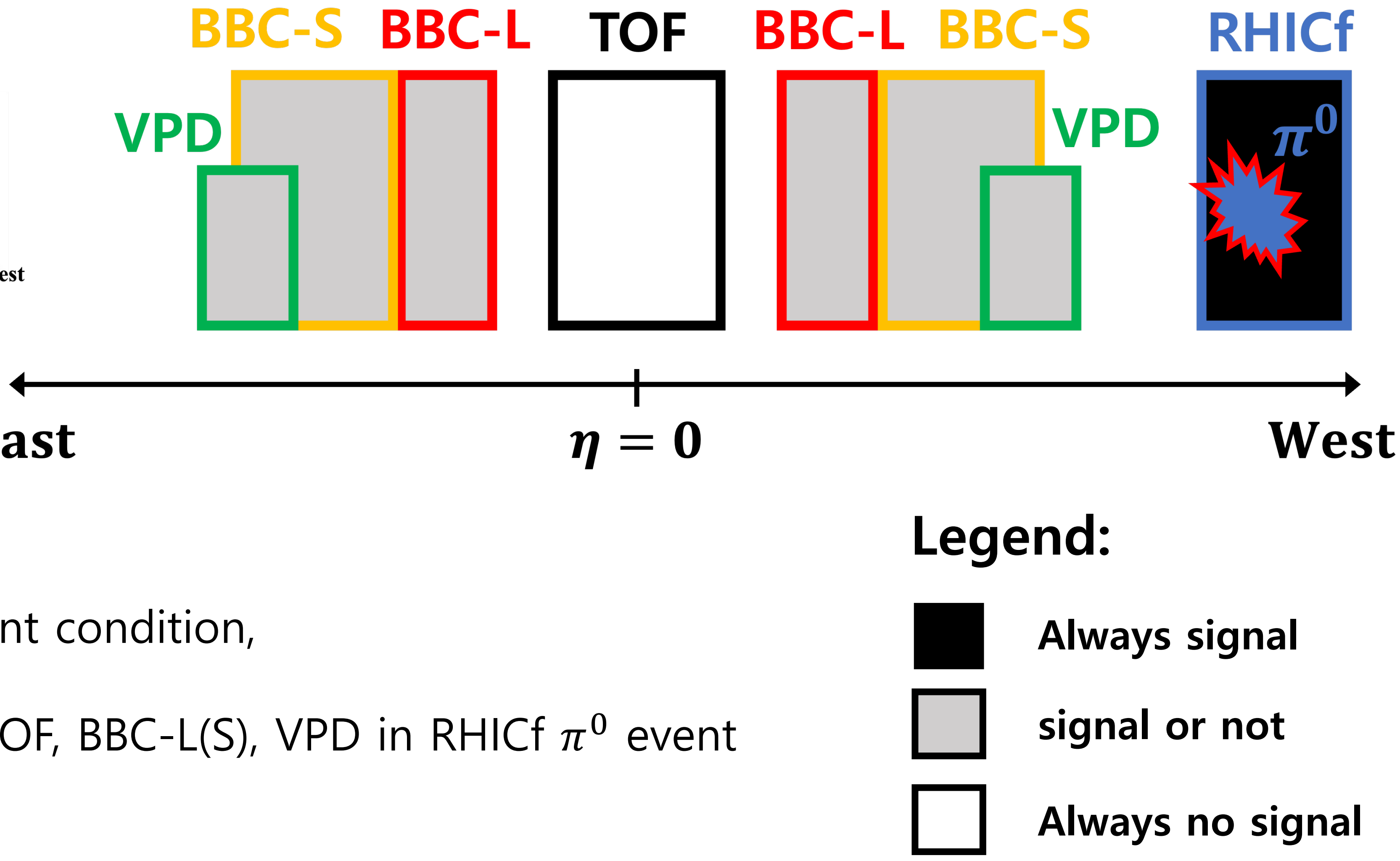


- B-TOF ($|\eta| < 1.0$)
- BBC-Large ($2.2 < |\eta| < 3.4$)
- BBC-Small ($3.4 < |\eta| < 5.0$)
- VPD ($4.24 < |\eta| < 5.1$)
- RHICf ($6 < \eta < 11$)

Diffractive Like Event

◆Condition definition





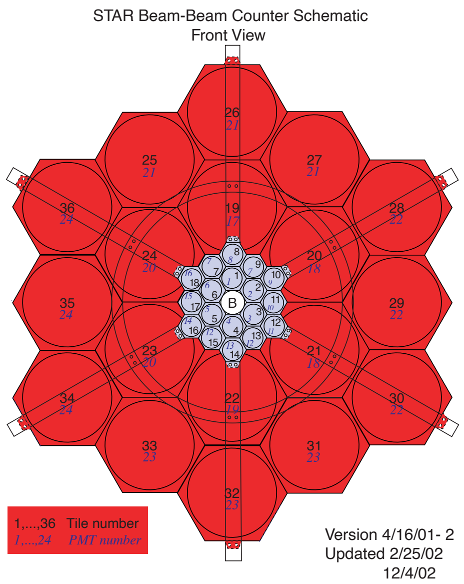
- To classify the diffractive event condition,

  we use the detector signal, TOF, BBC-L(S), VPD in RHICf π^0 event

Diffractive Like Event

◆Condition definition

STAR BBC (Beam-Beam Counter)



BBC-Large ($2.2 < |\eta| < 3.4$)

BBC-Small ($3.4 < |\eta| < 5.0$)

- BBC Large #Channel : 8
- BBC Small #Channel : 16

STAR VPD (Vertex Position Detector)

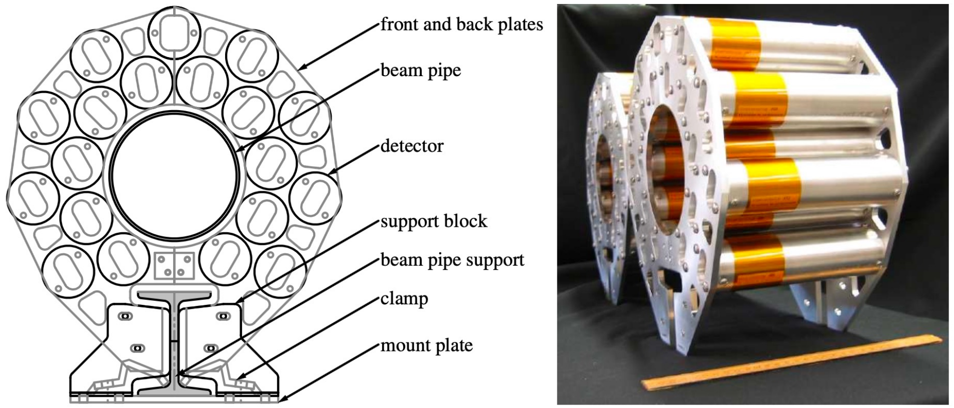


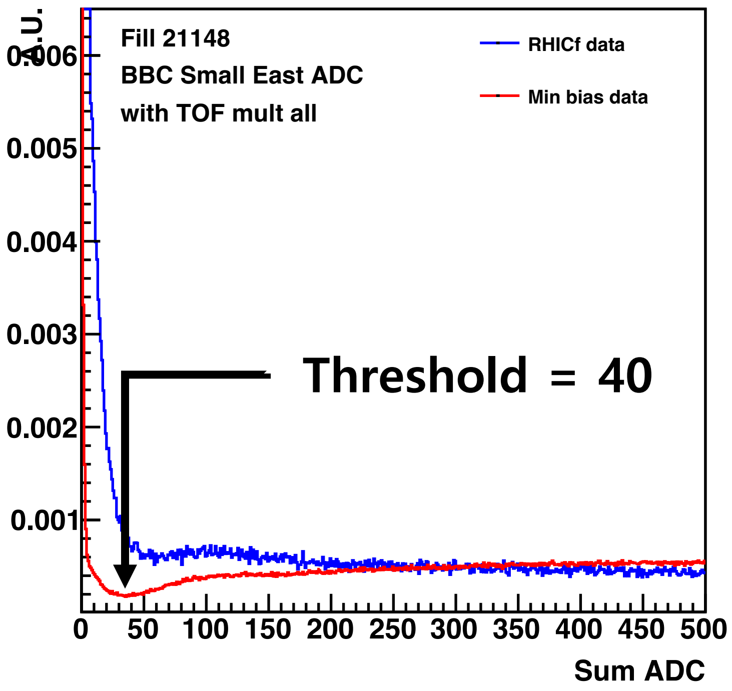
Figure 2: On the left is a schematic front view of a VPD assembly, and on the right is a photograph of the two VPD assemblies. A one foot long ruler is shown for scale on the right.

$4.24 < |\eta| < 5.1$

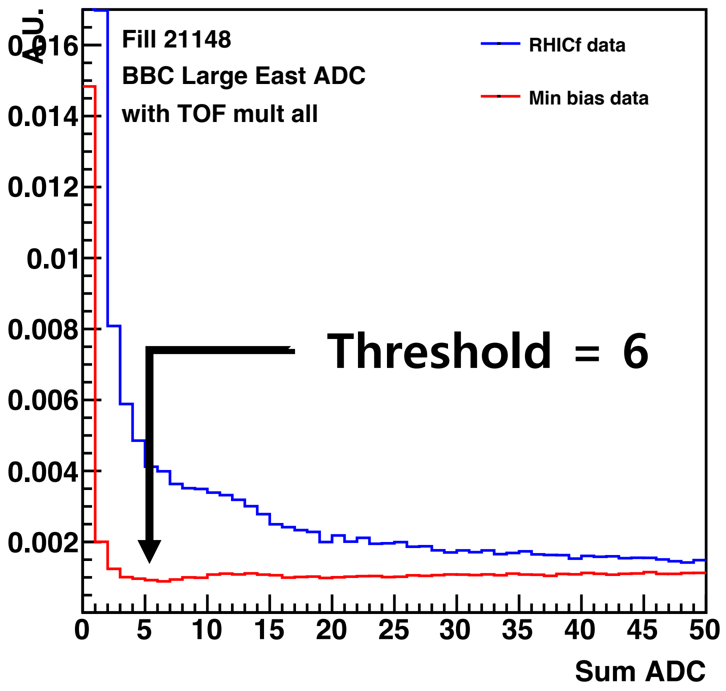
- VPD #Channel : 19

Sum ADC Threshold

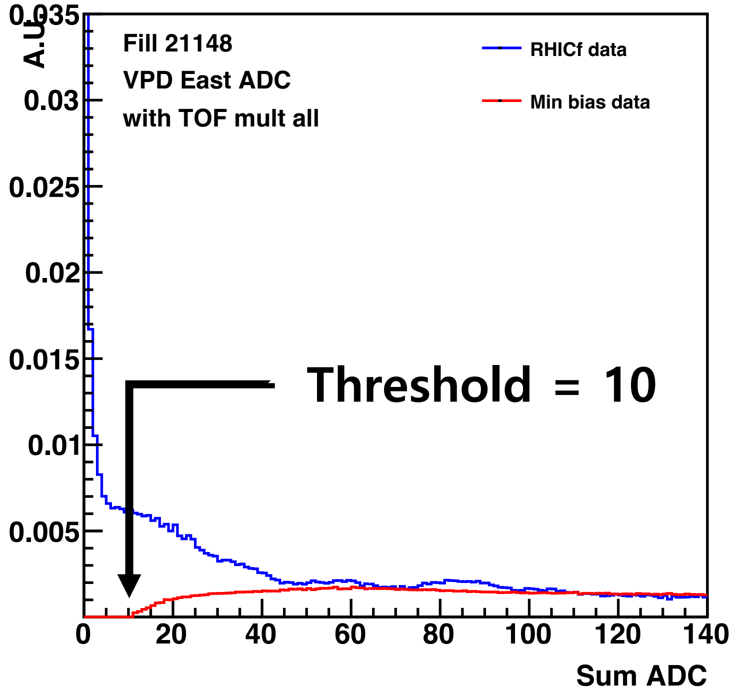
BBC Small East



BBC Large East



VPD East



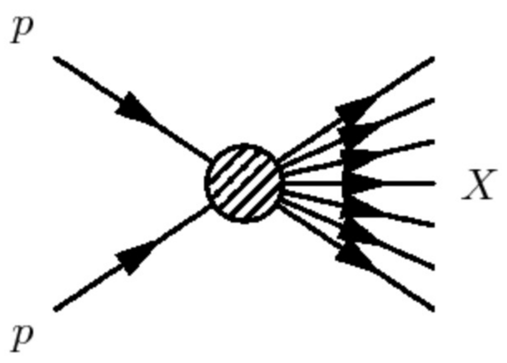
- **All detector's ADC Threshold determined by Sum ADC bump in Min-Bias data**
- **When detector sum of ADC is over specific threshold, charged particles suppose to hit in detector**

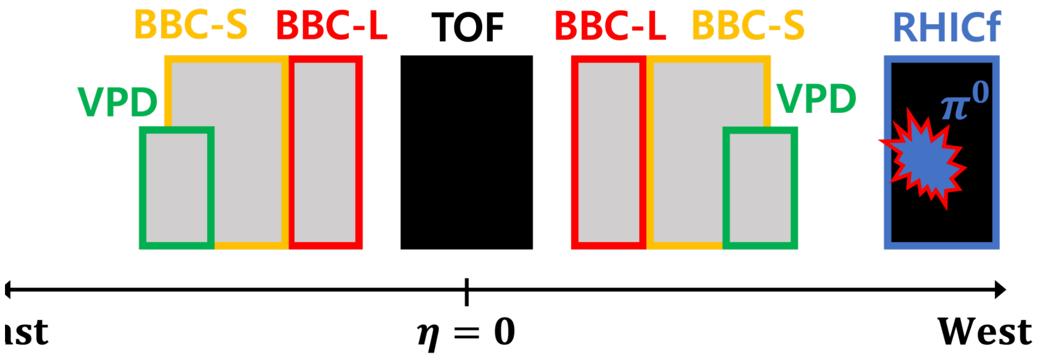
Sum ADC > Threshold : signal
Sum ADC < Threshold : no signal

Diffractive Like Event

◆Condition definition

1) NDLE (Non-Diffractive Like Event)





TOF Mult. > 0,

East-side : signal or not

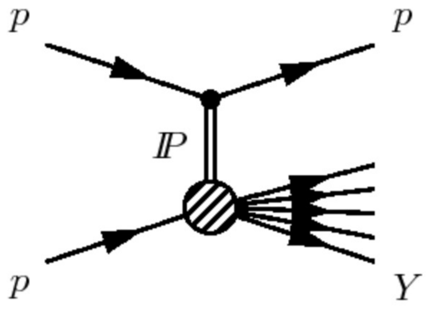
West-side : signal or not

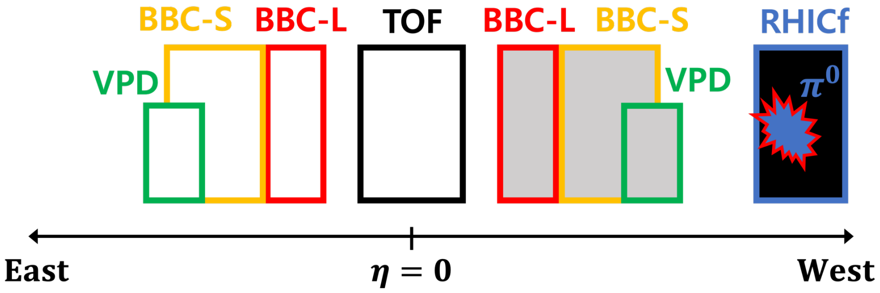
- TOF ($|\eta|$ < 1.0) multiplicity can classify non-diffractive or diffractive like event
- NDLE condition define there is always have a **non-zero TOF multiplicity**

Diffractive Like Event

◆Condition definition

2) SDLE (Single-Diffractive Like Event)



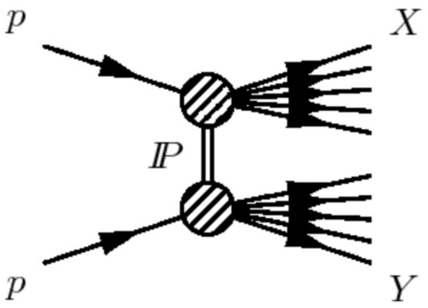


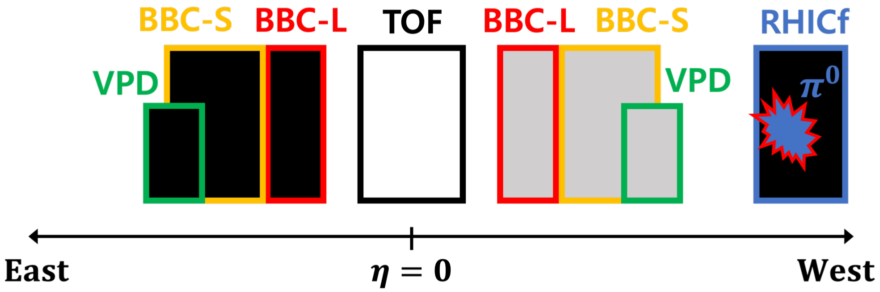
TOF Mult. = 0,

East-side : no signal

West-side : signal or not

3) DDLE (Double-Diffractive Like Event)





TOF Mult. = 0,

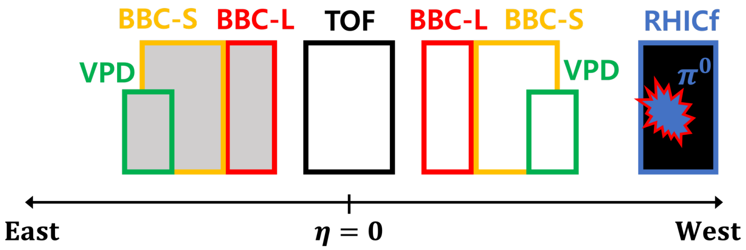
East-side : Always signal

West-side : signal or not

Diffractive Like Event

◆Condition definition

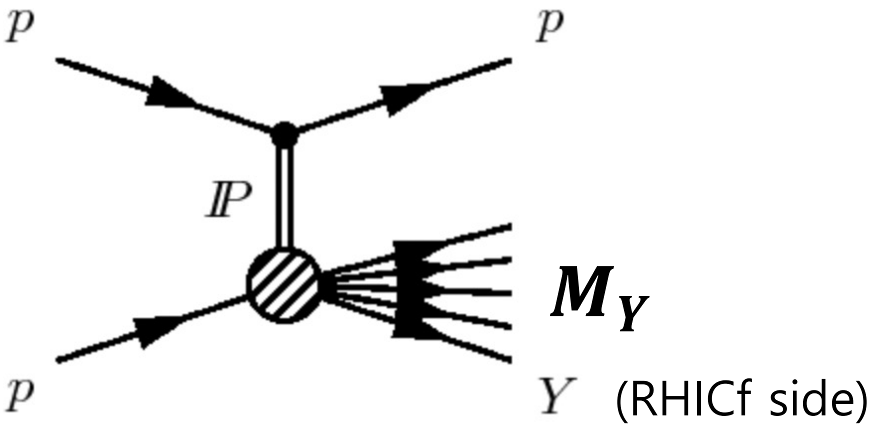
4) LMLE (Low-Mass diffractive Like Event)



TOF Mult. = 0,

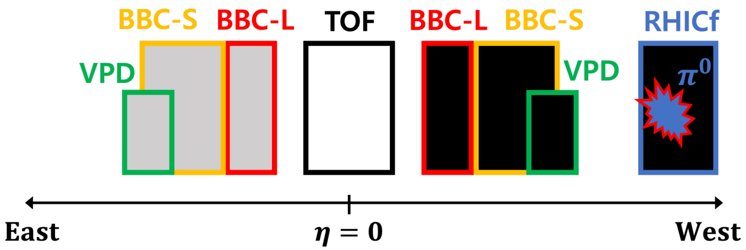
East-side : signal or not

West-side : no signal



5) HMLE (High-Mass diffractive Like Event)

$$\xi_Y = M_Y^2/s \;@\; \sqrt{s} = 510\ \text{GeV}$$



TOF Mult. = 0,

East-side : signal or not

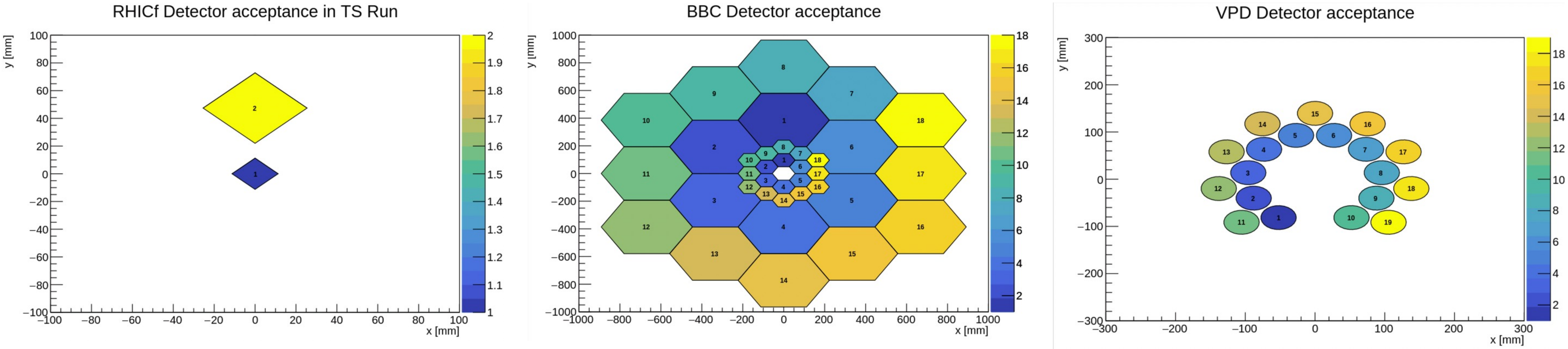
West-side : Always signal

low-mass diffraction = $\xi_Y < A$

high-mass diffraction = $\xi_Y > A$

(A : arbitrary value)

PYTHIA study



(TOF Acceptance : $-1 < \eta < 1$**)**

- BBC, VPD, and RHICf detectors acceptance applied in PYTHIA
- But **Not applied** a detector response.

PYTHIA study

- **Data sets**

  Applied Diffractive cross-section

  Event Selection : Only RHICf π^0 event

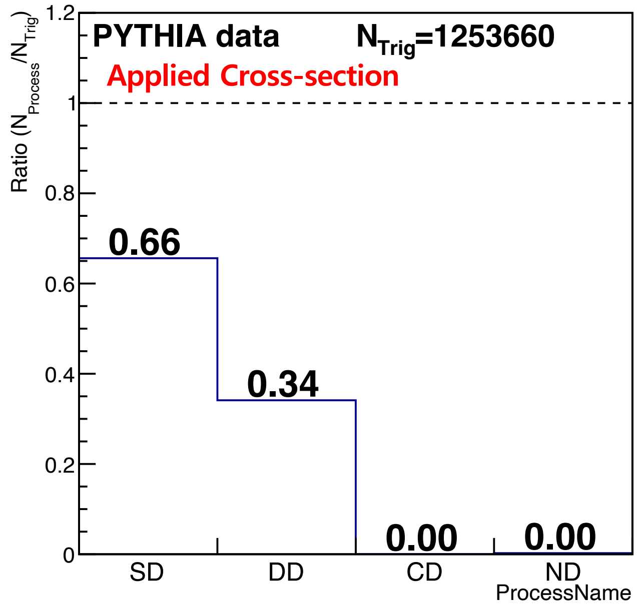
- **Ratio definition**

$$Ratio = \frac{N_{process}}{N_{Trig}}$$

$N_{process}$ = number of each **truth** process events in selected events

N_{Trig} = number of selected events according to conditions

Example for SDLE1

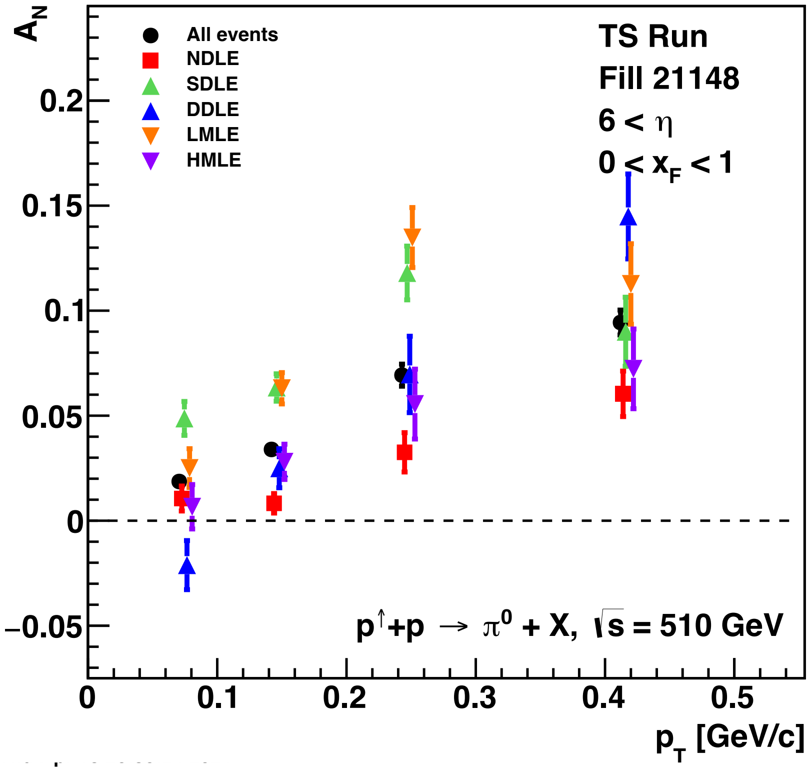


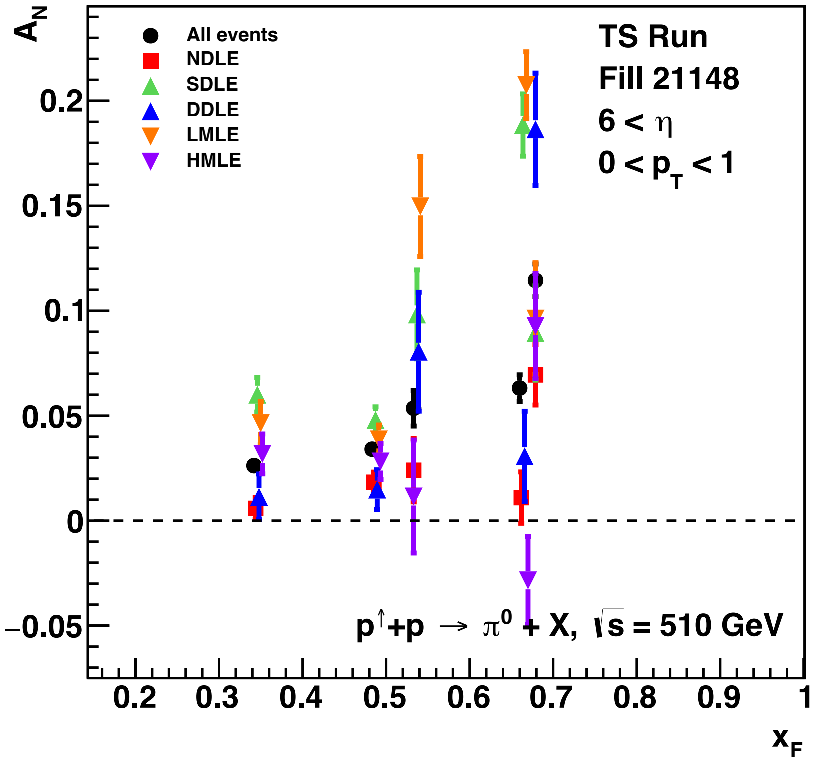
- **Condition definition in PYTHIA**

If the charged particle or photon hit in detector acceptance, detector determine to have multiplicity

- This data set also designed for checking the ratio of processes in each condition events

Neutral pion TSSA

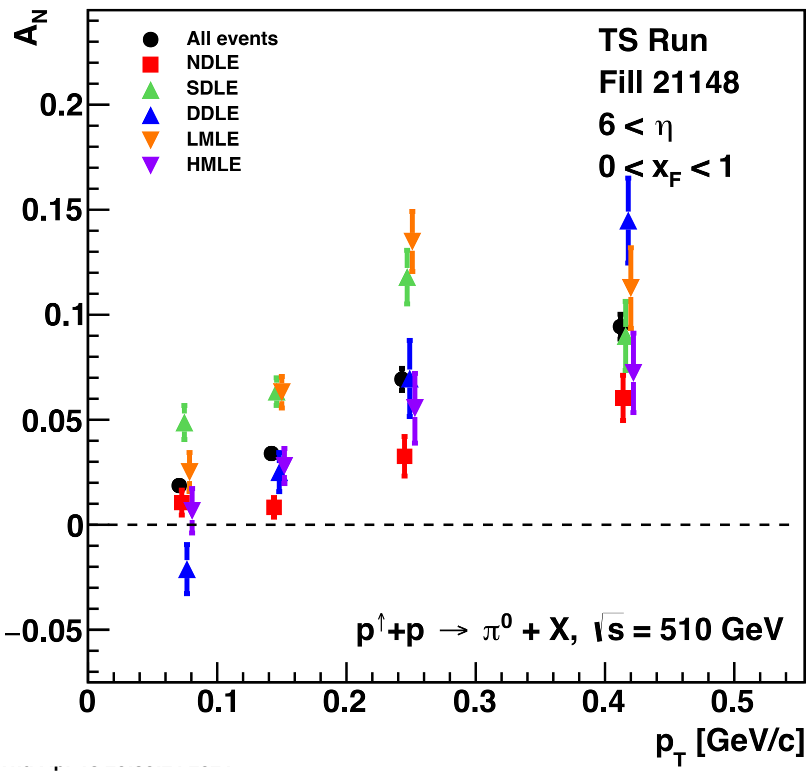


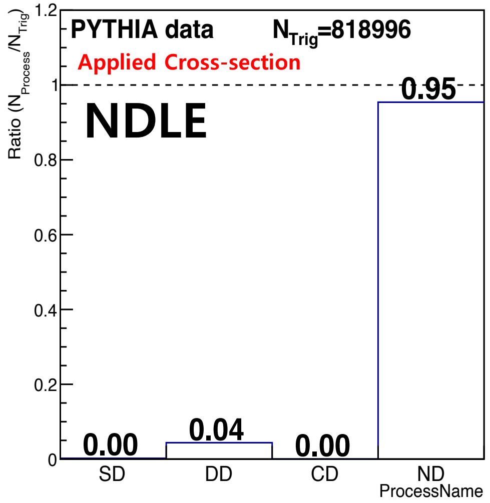


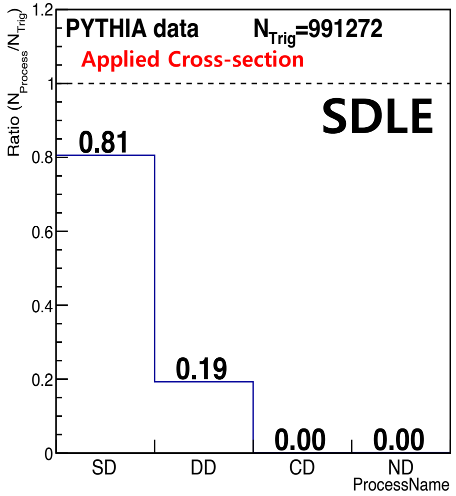
- **Each Diffractive condition was chosen to have reasonable statistics**

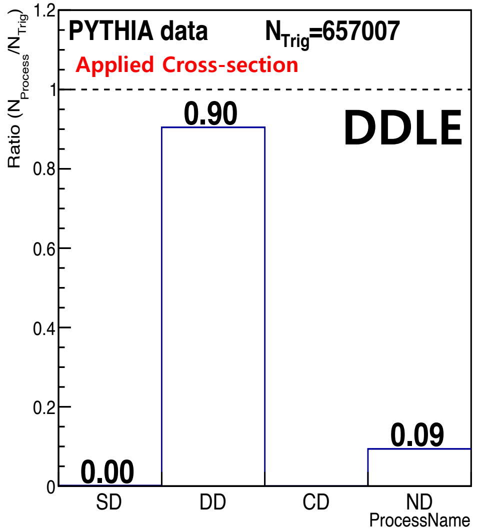
(ex, NDLE -> NDLE3Thr, SDLE -> SDLE2Thr)

Neutral pion TSSA



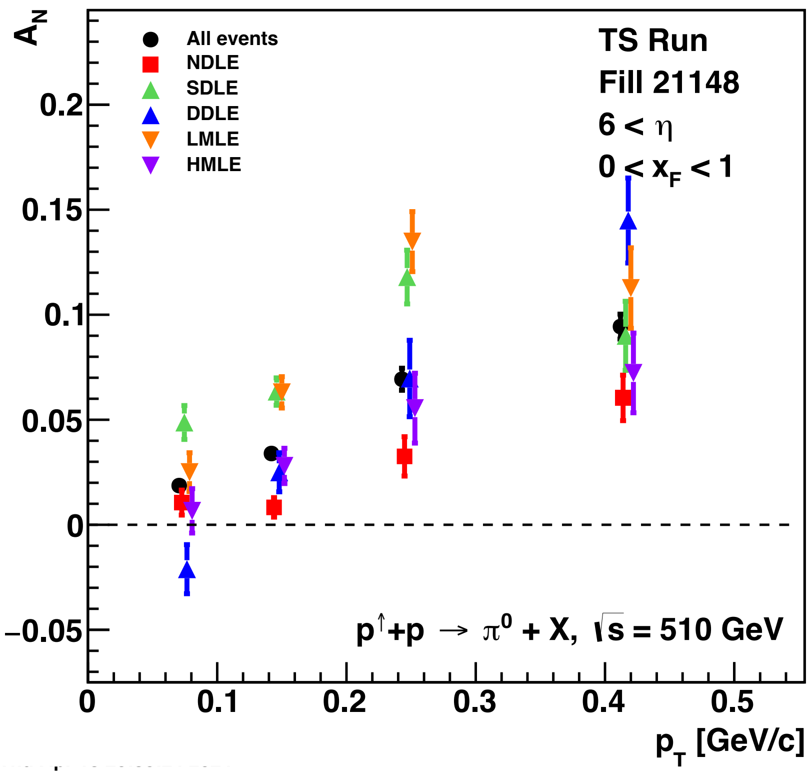


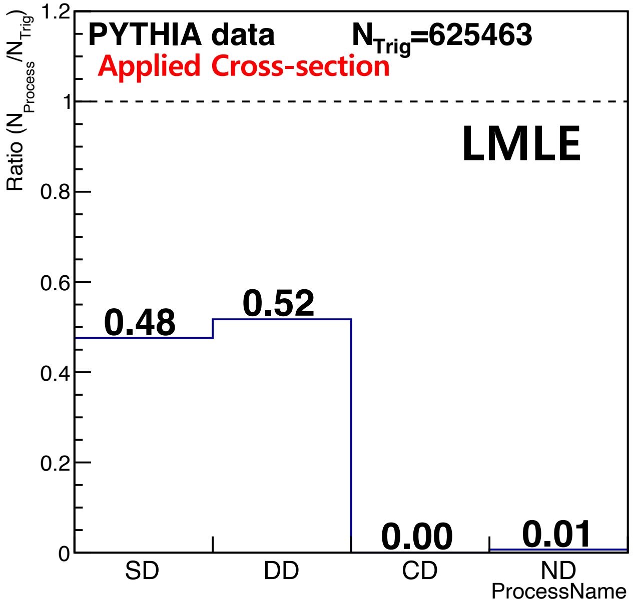


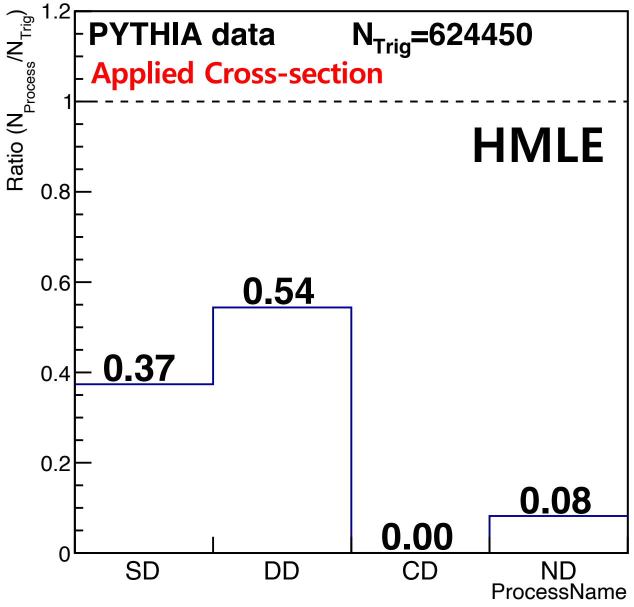


- **DLE ratio for each conditions are high compared to other processes**

Neutral pion TSSA

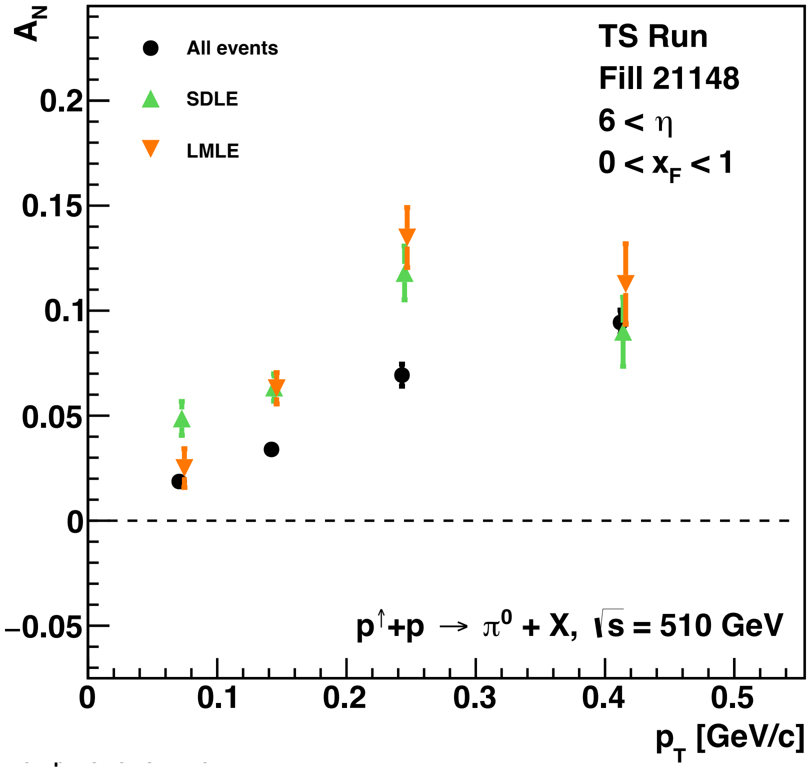


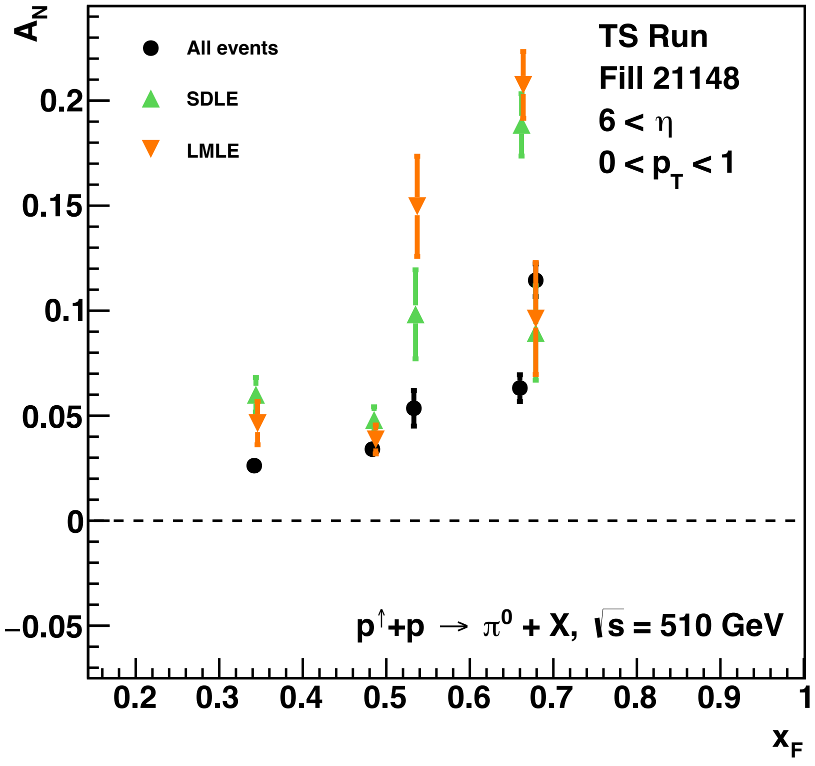




- DLE ratio for Low(High)-mass DLE might be mixed SD and DD

Neutral pion TSSA



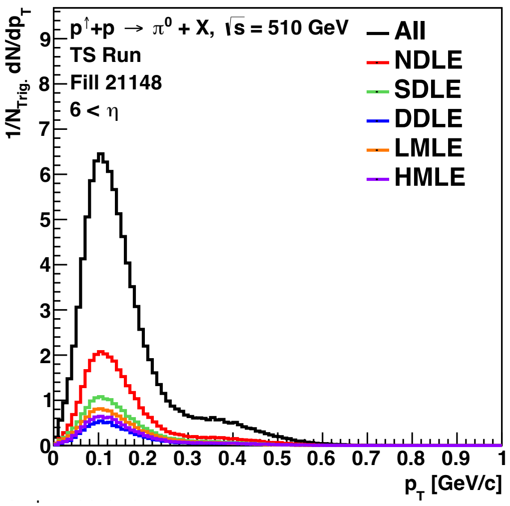


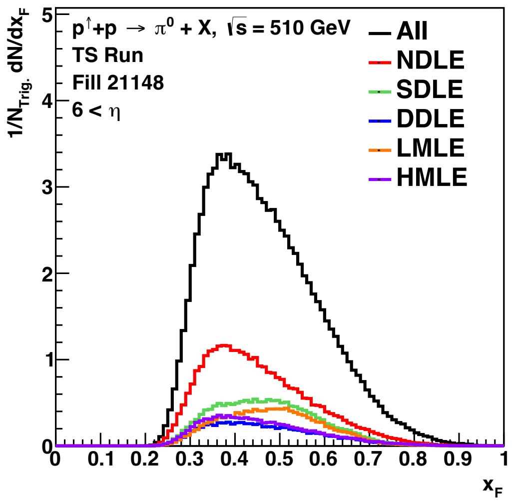
- **High A_N for SDLE and LMLE might be from Δ or *N* resonance decay**

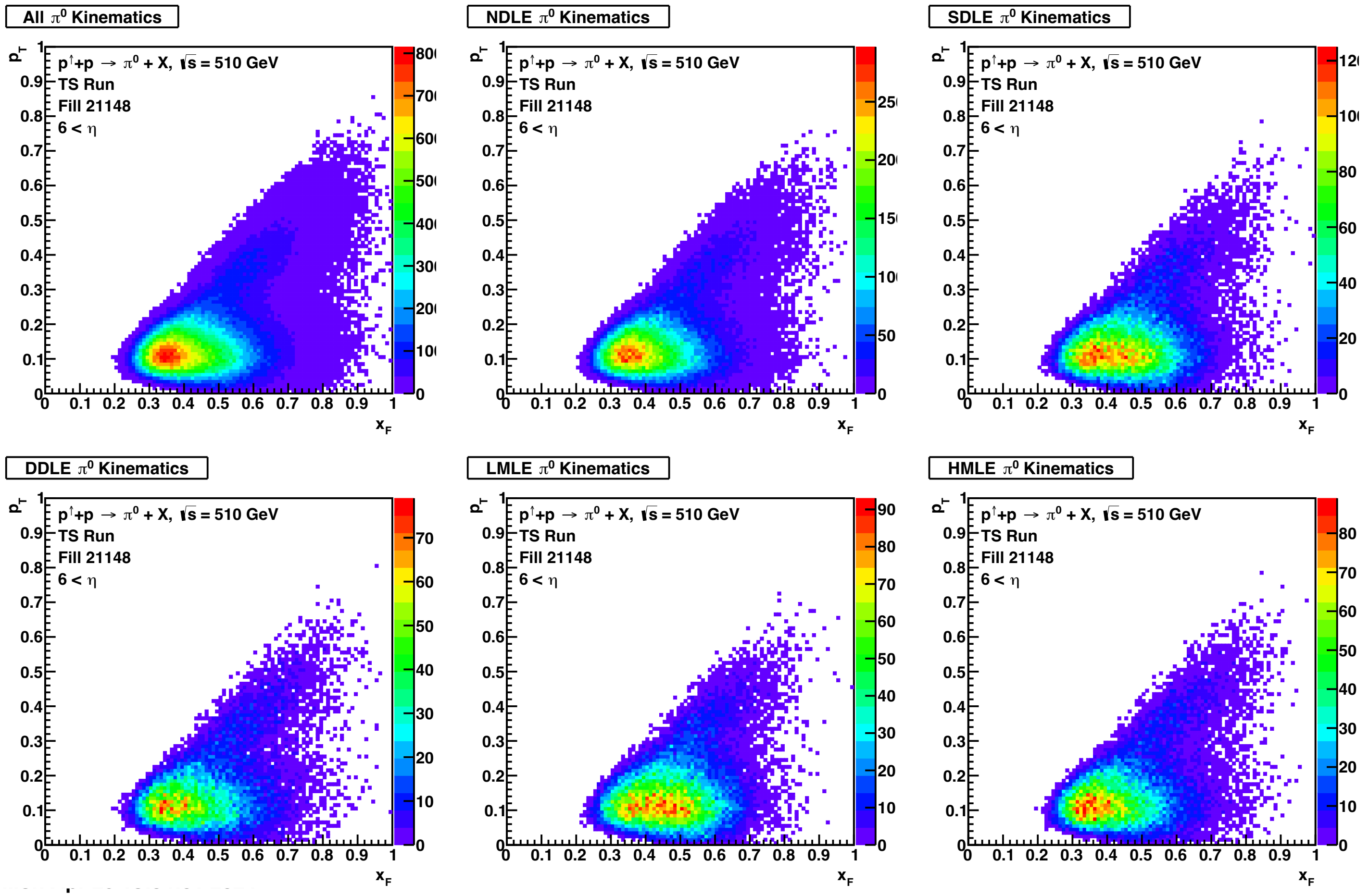
  (Menjo-san comments)

Neutral pion TSSA

π^0 kinematics by DLE events

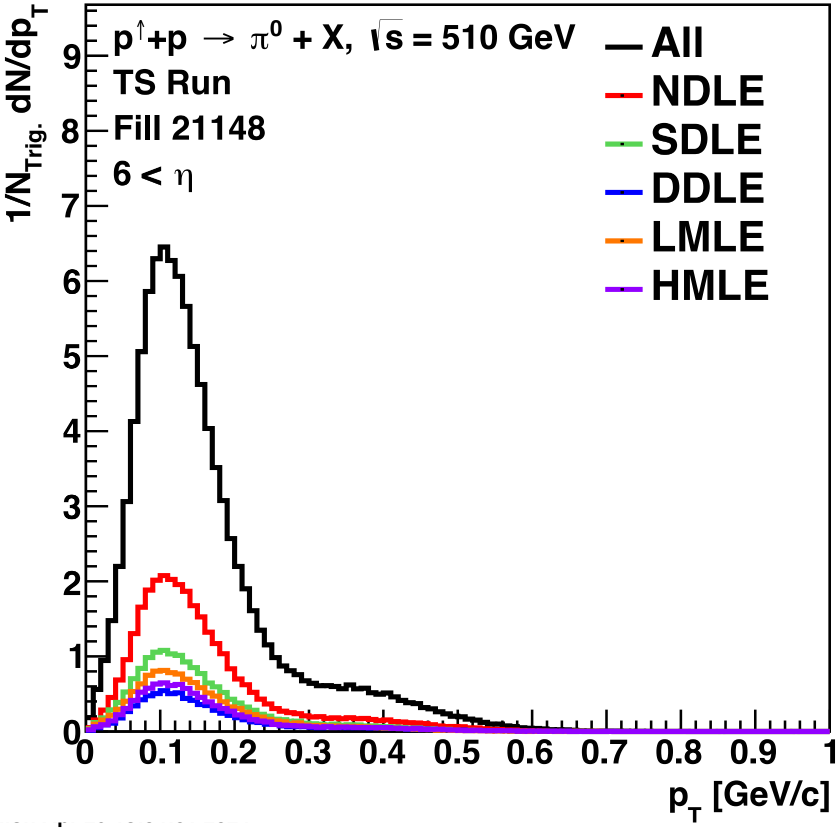


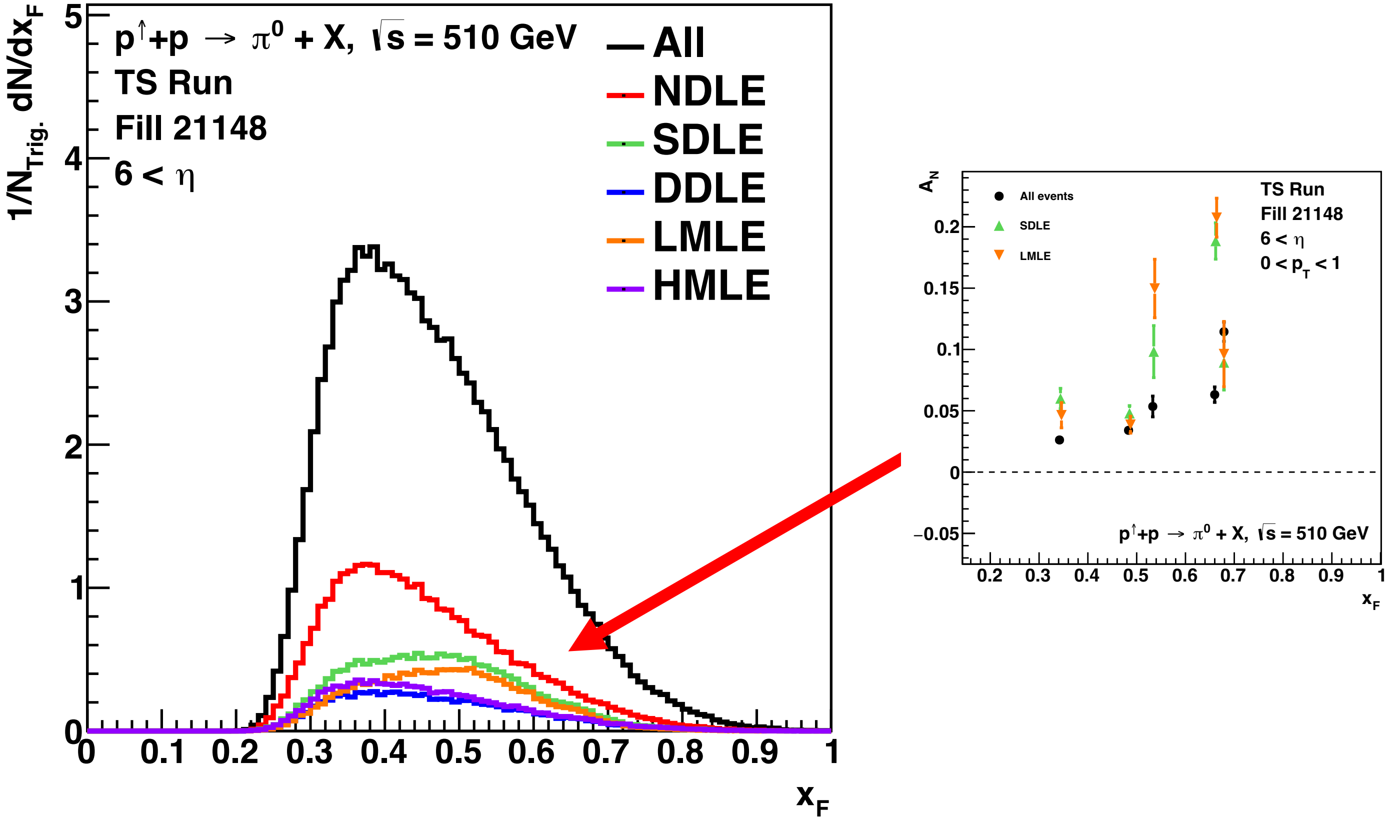




RHICf Data

Neutral pion TSSA





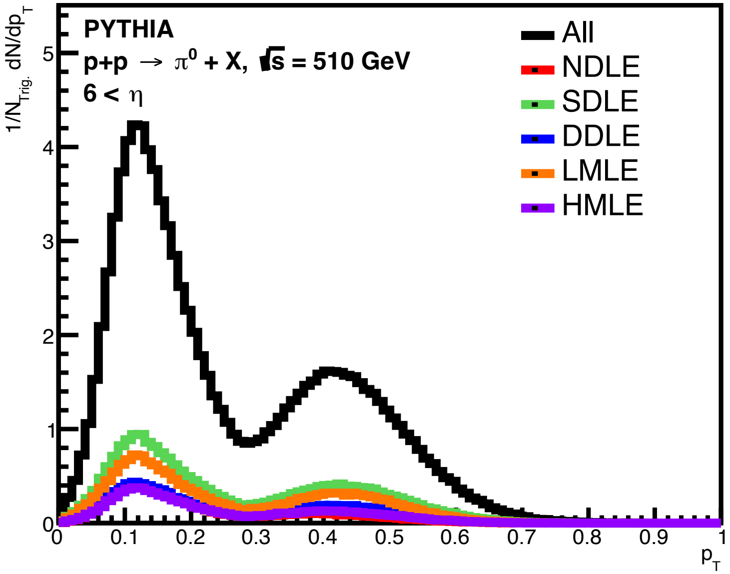
RHICf Data

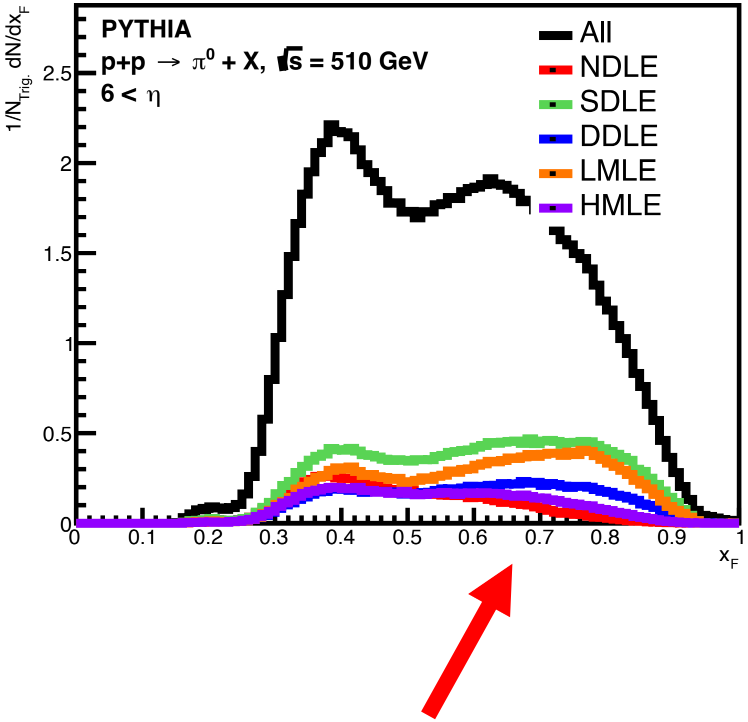
- $0.5 < x_F < 0.7$ for SDLE and LMLE are slightly different
- it can be originated from resonance particles

Neutral pion TSSA

◆ **Example: Δ resonance contributions**

PYTHIA Data



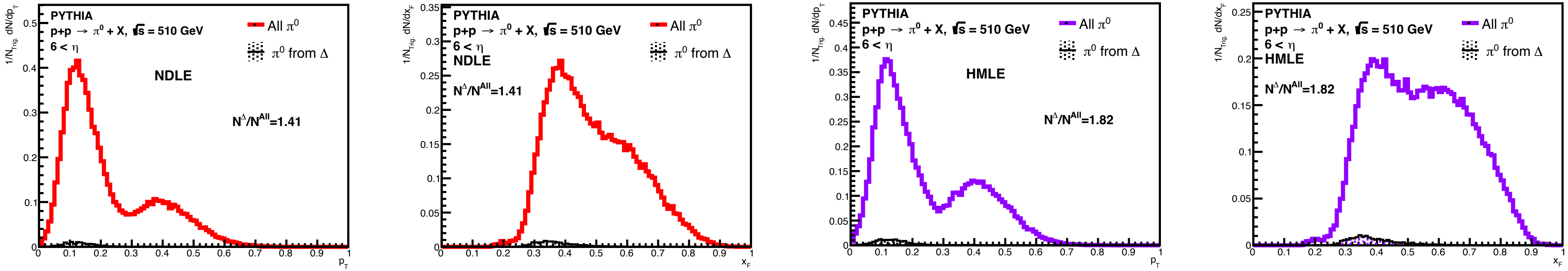


- **π^0 x_F regions for SDLE and LMLE also slightly differ than other processes in PYTHIA**

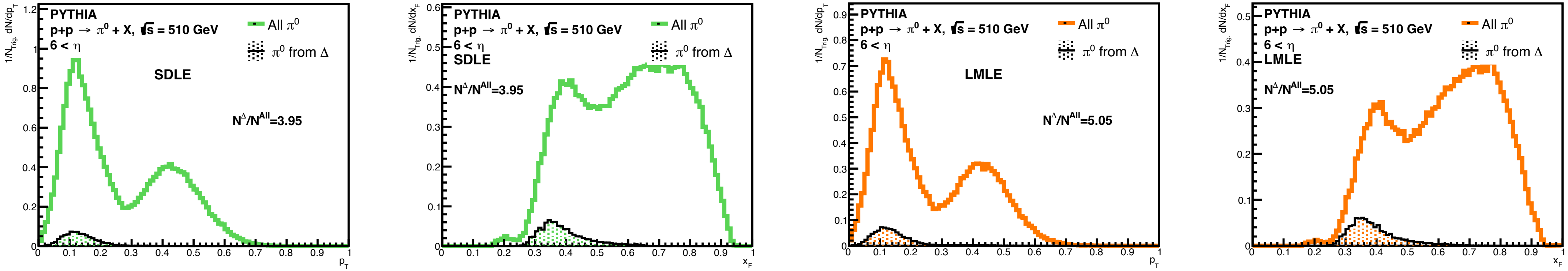
(Type-1, 2 π^0 reconstruction efficiency is not applied)

Neutral pion TSSA

◆ Example: Δ resonance contributions



PYTHIA Data



- While we cannot be certain that Δ resonance are abundant in this region, it is possible that other resonance particles are in this region.

Neutron TSSA

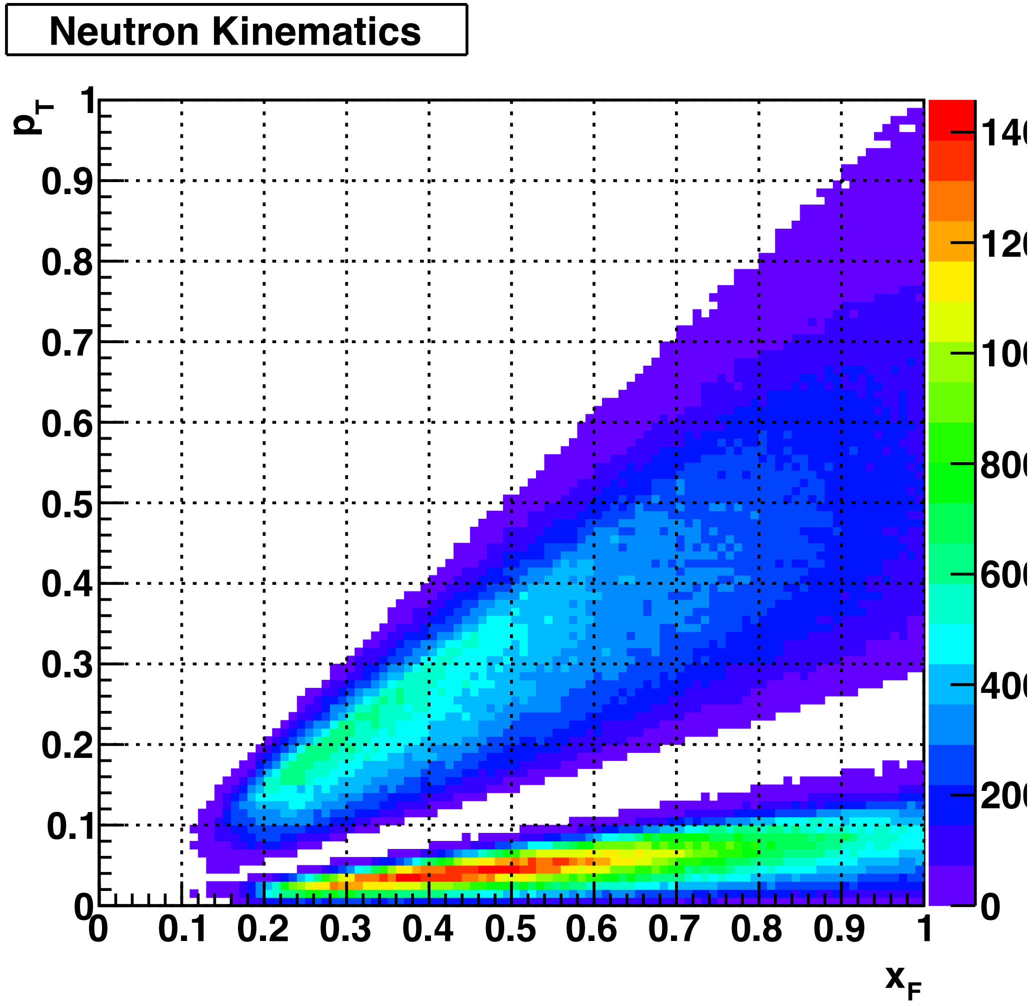
Semi-reconstruction condition for Neutron:

- L90 > 20
- Hadron Energy > 20 GeV

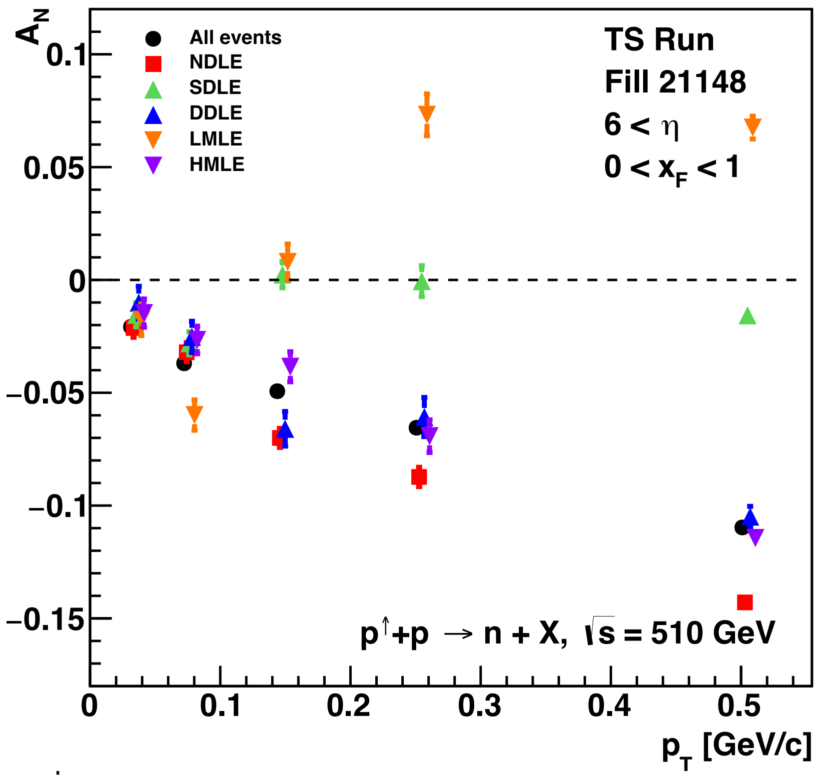
$$A_N = \frac{1}{PD_\phi}\left(\frac{N_L - RN_R}{N_L + RN_R}\right)$$

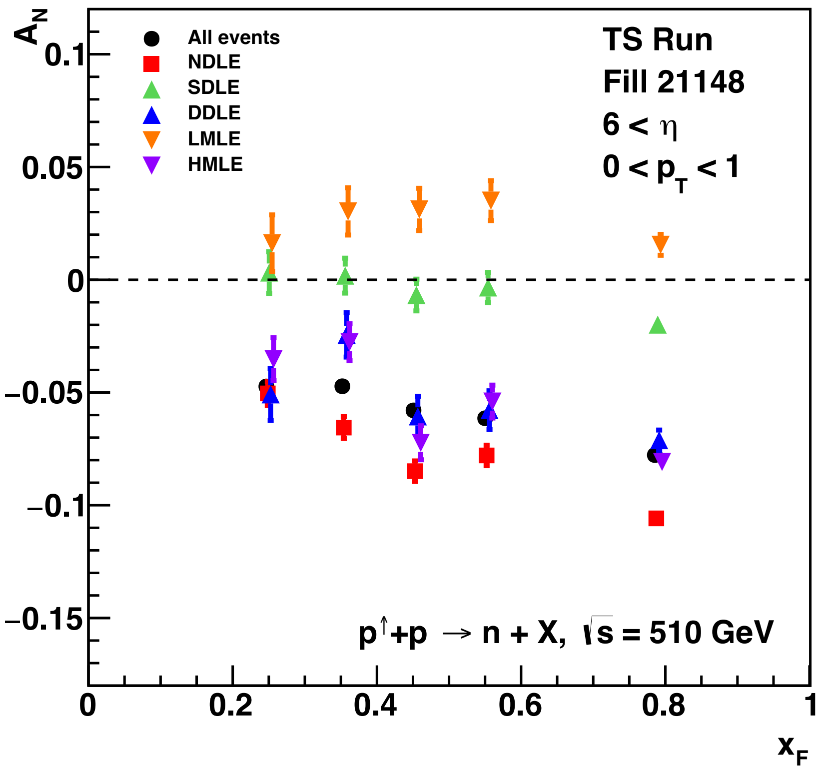
- $D_\phi = 0.977$ (dilution factor)
- P and R is the same as π^0 asymmetry

- All Diffractive condition is the same as π^0 asymmetry



Neutron TSSA





- LMLE is not negative value
- Neutron A_N needs to be studied more closely and carefully

Further study

- STAR detector simulation must be needs for this study

- Determine the reasonable DLE condition

- Find the origin of the π^0 TSSA,
  whether it is a contribution from a resonance particle or something else.

Further study

- **Determine the reasonable DLE condition**
  - **Detector level multiplicity needs to convert to physics level multiplicity**

$$N_{Det} \rightarrow N_{Ch}$$

Track N_{Ch} (Trk = 0)

By analogy, the unfolded photon spectrum for events with at least one charged particle with $p_T >$ 100 MeV and $|\eta| < 2.5$ is calculated as

$$N_\gamma^{N_{ch}\geq 1} = C_{track}\, C_\gamma^{N_{track}\geq 1}\, N^{N_{track}\geq 1}\,(1 - R_{bkg2})\,, \quad (2)$$

where $C_{track}(E_\gamma^i)$ are the correction factors for the inefficiency of the track detection in ATLAS, and $C_\gamma^{N_{track}\geq 1}(E_\gamma^i)$, $N^{N_{track}\geq 1}(E_\gamma^i)$ and R_{bkg2} are defined in a similar way as parameters from Eq. 1, except the extra $N_{track} \geq 1$ requirement.

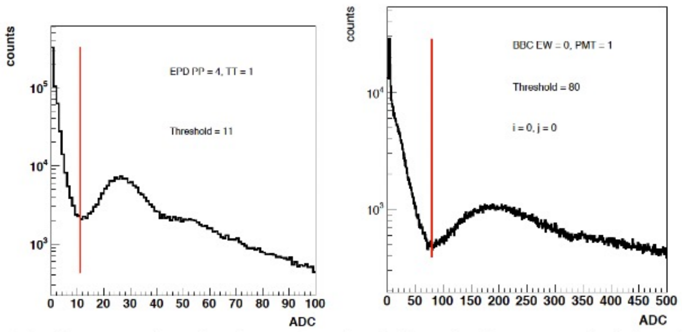
The photon energy spectrum corresponding to events with no charged particles in the fiducial region, $N_\gamma^{N_{ch}=0}(E_\gamma^i)$, is obtained by subtracting the photon energy spectrum for events having at least one charged particle from the inclusive-photon spectrum:

$$N_\gamma^{N_{ch}=0} = N_\gamma^{all} - N_\gamma^{N_{ch}\geq 1}\,. \quad (3)$$

Measurement of contributions of diffractive processes to forward photon spectra in *pp* collisions at $\sqrt{s}$ = 13 TeV

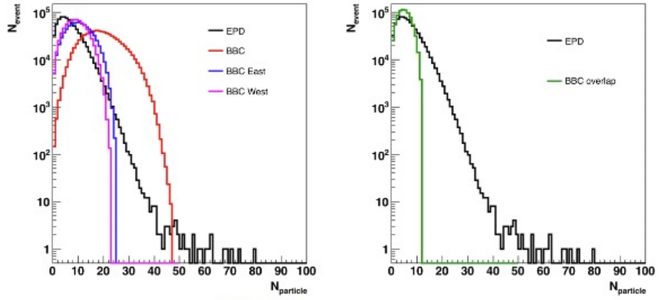
STAR detectors (BBC, VPD, …) multiplicity

An example for each is:



On the left is an EPD tile, on the right is a BBC PMT (small tile). In the pdf one can see why the large tiles weren't really u

I used these thresholds to look at multiplicity (assuming tiles were only 0 or 1):

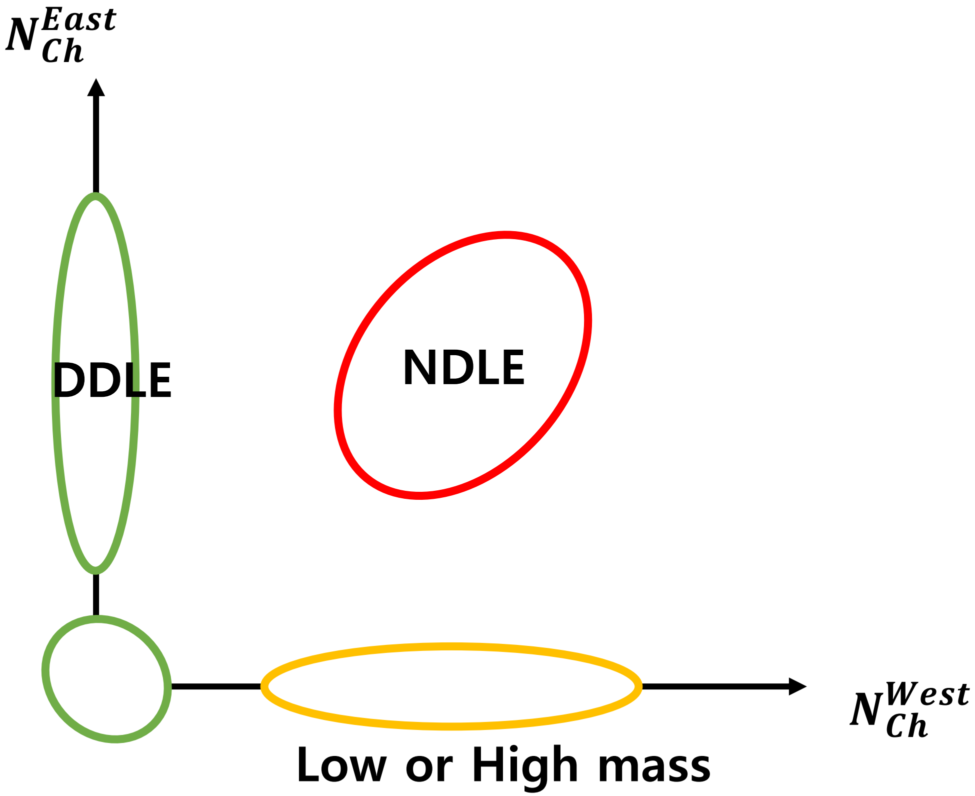


These are 1D plots showing the multiplicity distributions for the EPD and BBC using the thresholds I determined earlier.

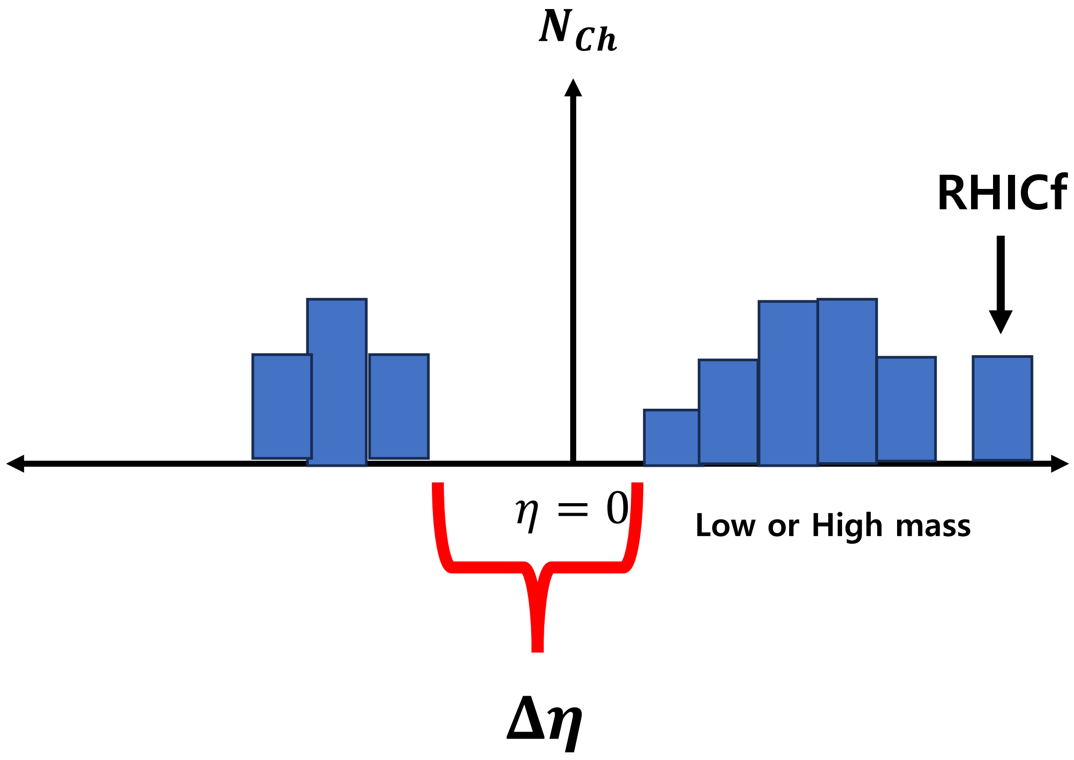
Further study

- Determine the reasonable DLE condition

1. Use the East-West N_{ch} correlation methode

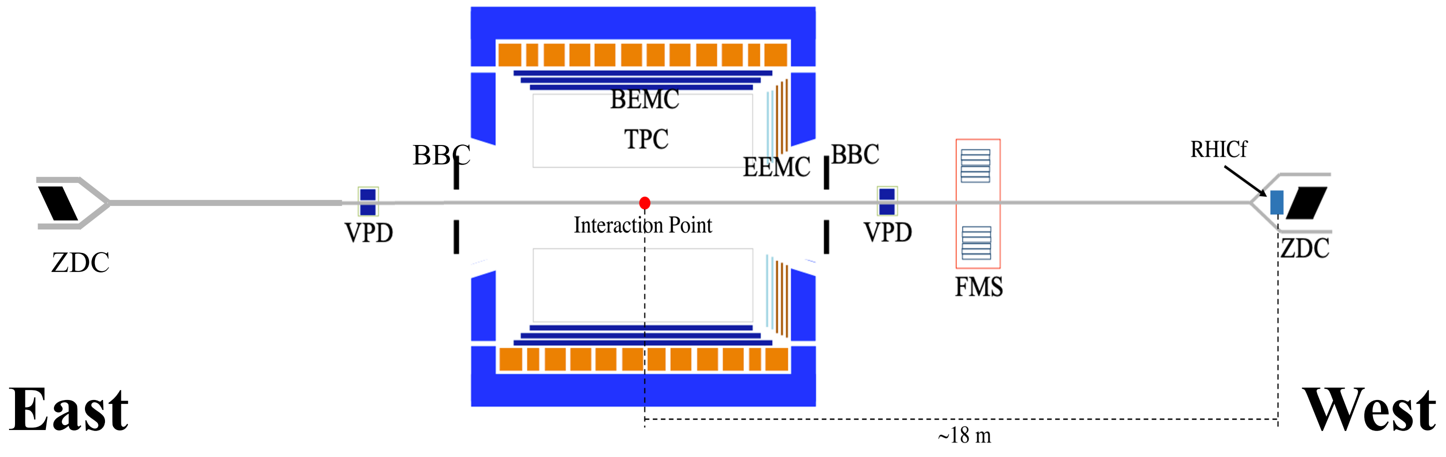


2. Use η distribution (detector eta boundary)



Further study

- Determine the reasonable DLE condition



Avaliable detectors in data :

TOF
TPC
B-EEMC
BBC
VPD
FMS
ZDC

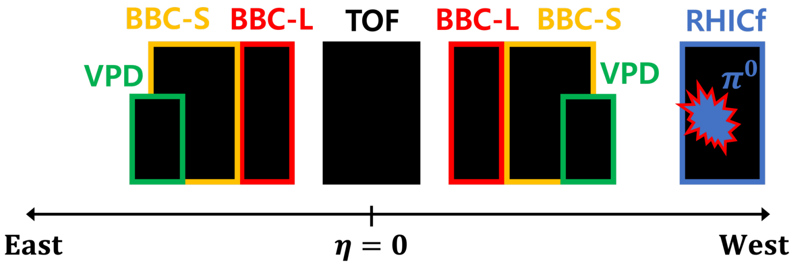
- Currently, BBC and VPD have a few channels,

  We can increase the number of channel if we use the EEMC and FMS

Backup

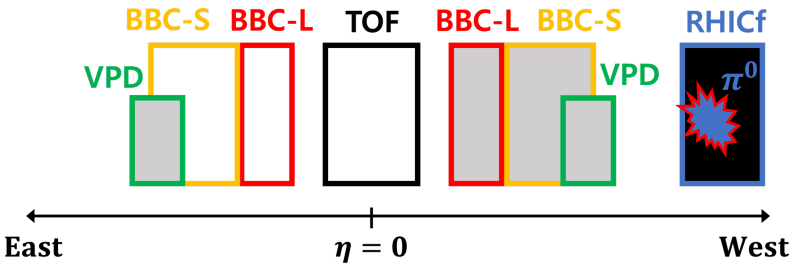
Used conditions

NDLE



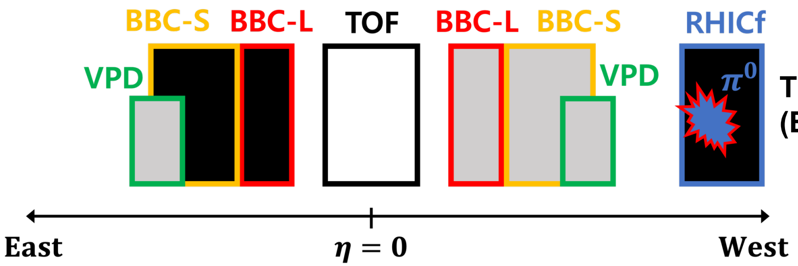
TOF > 0 &&
(BBCSE > Thr && BBCLE > Thr) &&
(BBCSW > Thr && BBCLW > Thr) &&
(VPDW > THr && VPDW > Thr)

SDLE



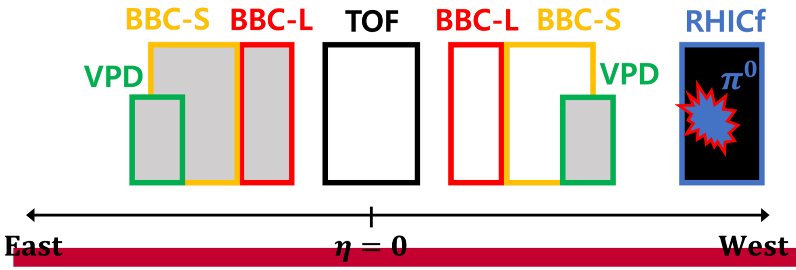
TOF == 0 &&
(BBCSE < Thr && BBCLE < Thr)

DDLE



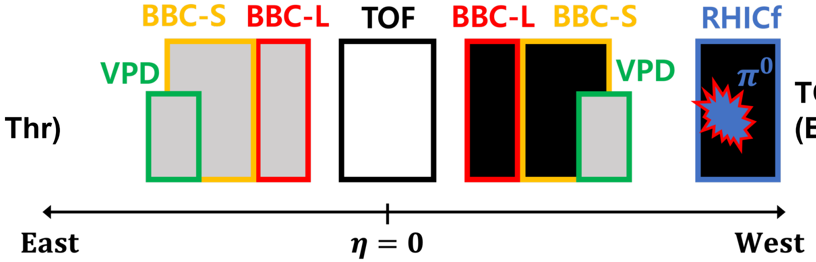
TOF == 0 &&
(BBCSE > Thr && BBCLE > Thr)

LMLE



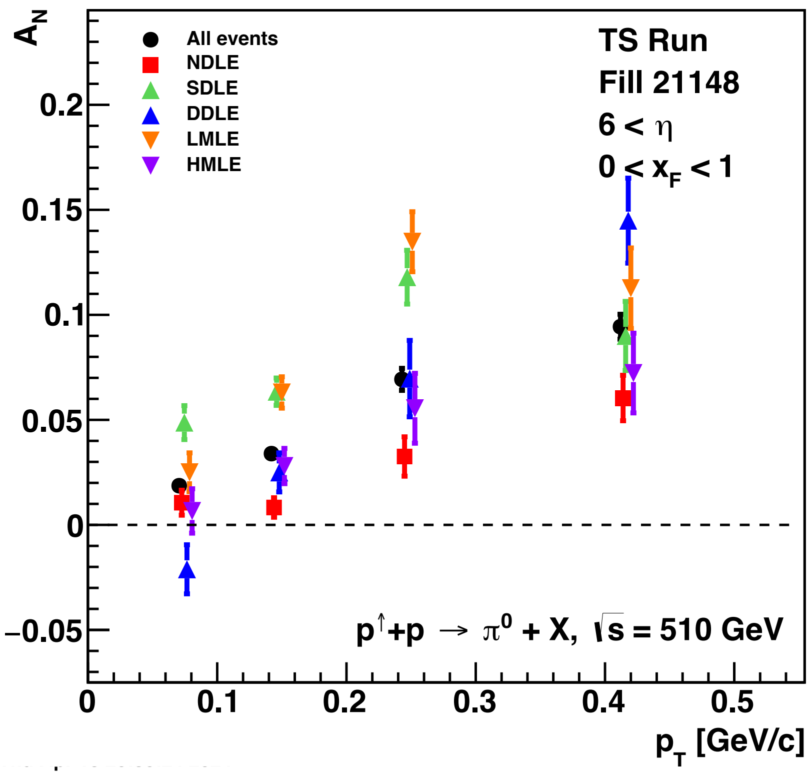
TOF == 0 &&
(BBCSW < Thr && BBCLW < Thr)

HMLE



TOF == 0 &&
(BBCSW > Thr && BBCLW > Thr)

Neutral pion TSSA event ratio



- Event Ratio = $\frac{N_{DLE}}{N_{\pi^0}}$

1. NDLE = 32.2 %
2. SDLE = 16.7 %
3. DDLE = 8.3 %
4. LMLE = 12.2 %
5. HMLE = 10.5 %

N_{π^0} = 423,054

N_{NDLE} = 136,273

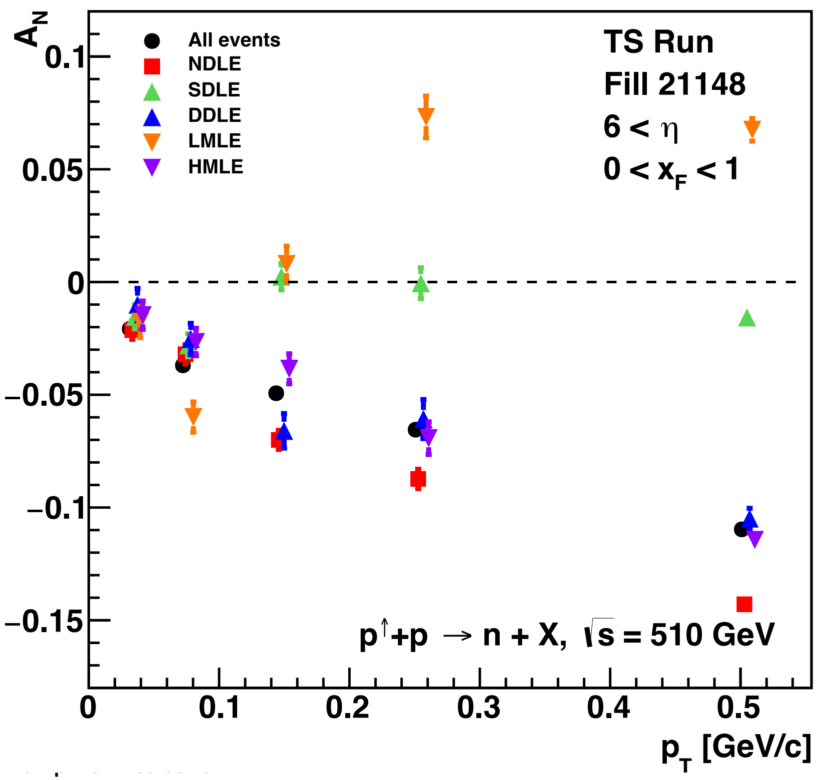
N_{SDLE} = 70,635

N_{DDLE} = 34,934

N_{LMLE} = 51,446

N_{HMLE} = 44,321

Neutral TSSA event ratio



- Event Ratio = $\frac{N_{DLE}}{N_n}$

1. NDLE = 27.8 %
2. SDLE = 14.2 %
3. DDLE = 8.7 %
4. LMLE = 7.9 %
5. HMLE = 11.6 %

N_n = 1,396,917

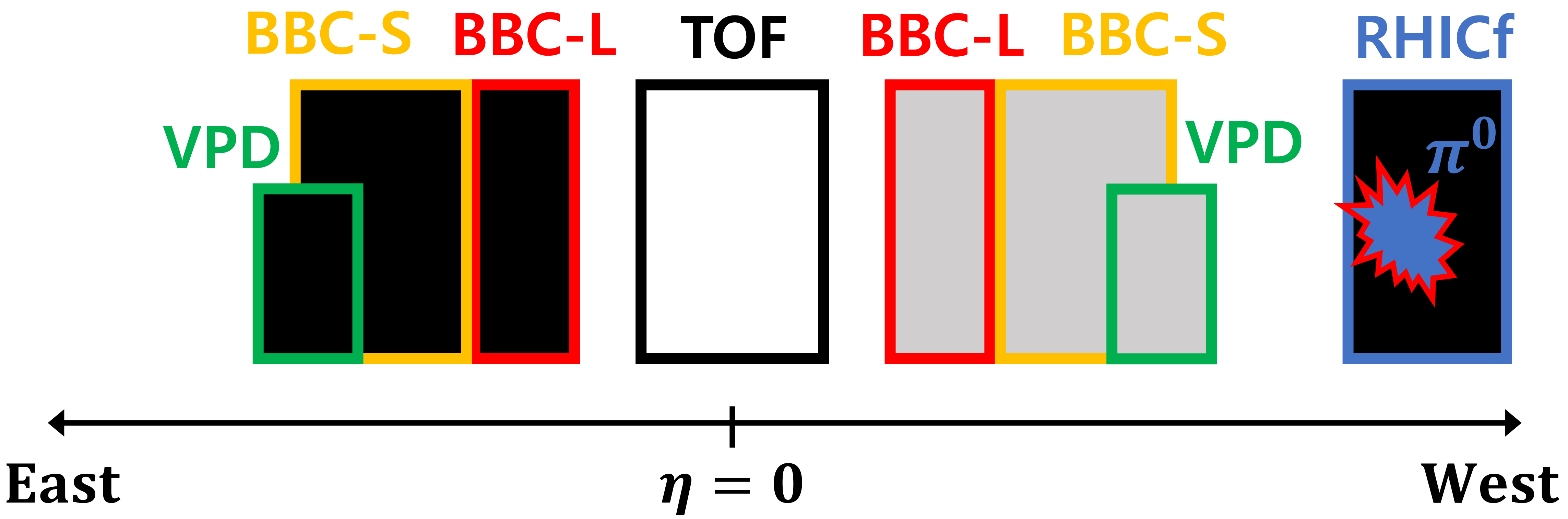
N_{NDLE} = 384,888

N_{SDLE} =197,090

N_{DDLE} = 119,990

N_{LMLE} =109,957

N_{HMLE} =160,455



BBC-S
BBC-L
TOF
BBC-L
BBC-S
RHICf
VPD
VPD
π^0
East
$\eta = 0$
West