The Status of Angular Distribution of Unpolarized Drell-Yan Process Analysis

TQCD Meeting

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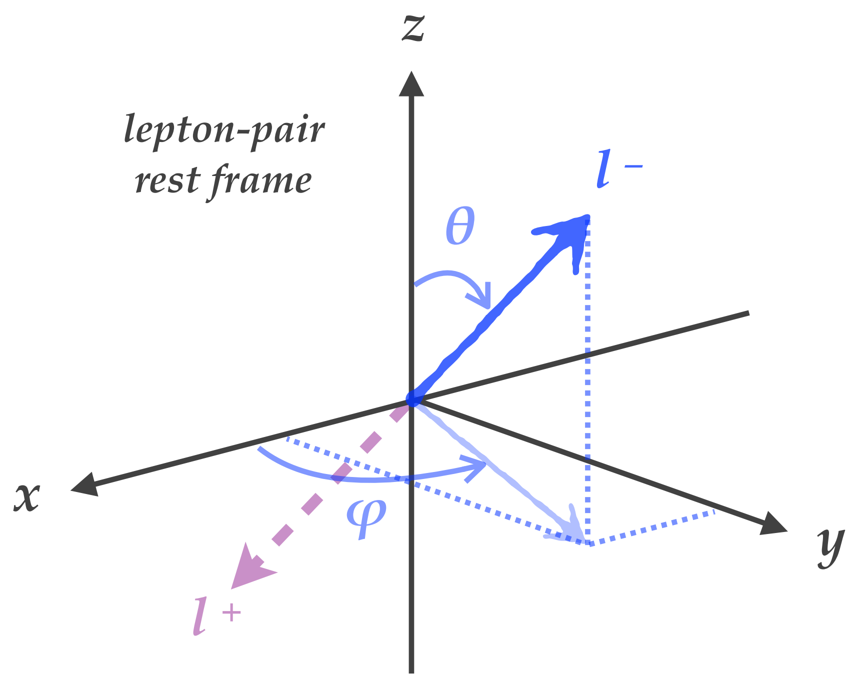
Angular Distributions

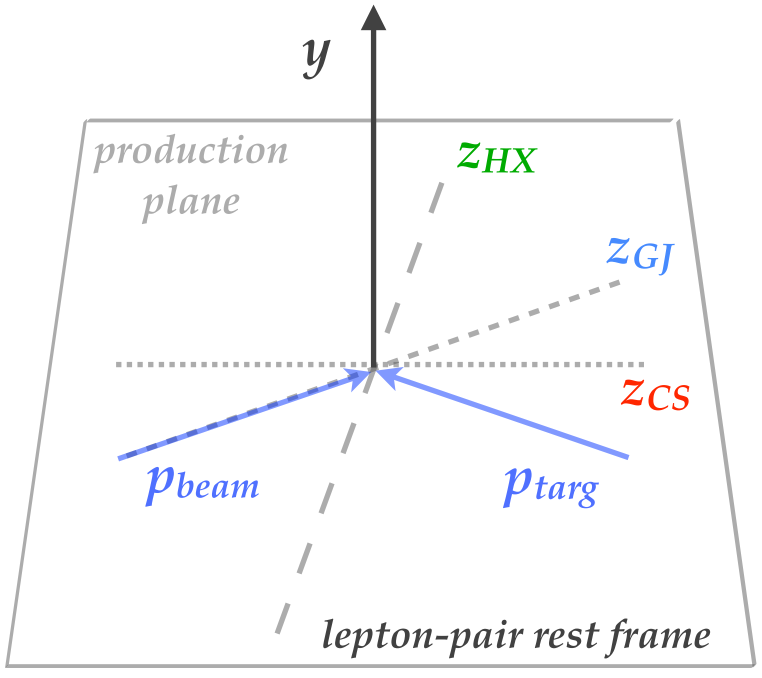
- The general expression for angular distribution of lepton-pair:

$$\frac{d\sigma}{d\Omega} \propto \frac{3}{4\pi}\frac{1}{\lambda+3}\left[1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\varphi+\frac{\nu}{2}\sin^2\theta\cos 2\varphi\right]$$

  - where θ and φ are the polar and azimuthal angles of the lepton$^-$ in the lepton-pair rest frame.

- The values of λ, μ and ν depends on the frame definition (e.g. **Helicity frame**, **Gottfried–Jackson frame**, **Collins–Soper frame** ···)

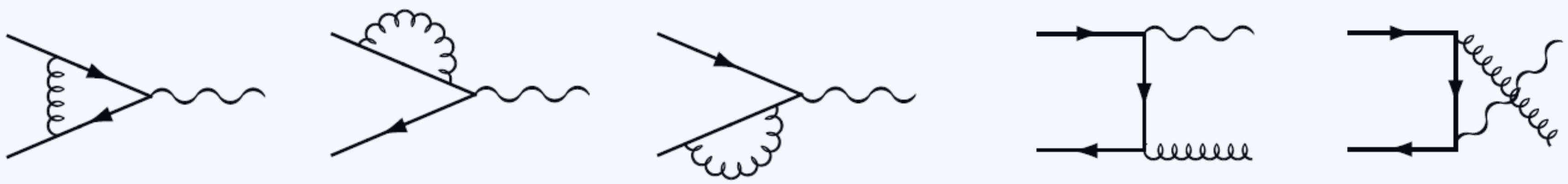




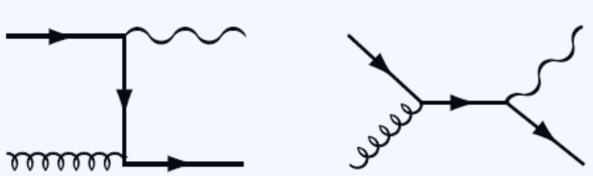
Unpolarized Azimuthal Asymmetries

$$\frac{d\sigma}{d\Omega} \propto \frac{3}{4\pi}\frac{1}{\lambda+3}\left[1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\varphi+\frac{\nu}{2}\sin^2\theta\cos 2\varphi\right]$$

- The amplitudes of the azimuthal modulations appearing in the cross section description are usually called **Unpolarized Azimuthal Asymmetries (UAs)**.
- In the naive Drell–Yan process, virtual photon is produced by the electromagnetic quark-antiquark annihilation. ($\lambda = 1, \mu = 0, \nu = 0$, because of $\vec{s}_{q,\bar{q}} = \frac{1}{2}$)
- The **Lam–Tung relation** ($1-\lambda = 2\nu$) [PRD 18(1978) 2447], valid for including leading-order(α_s) QCD corrections ➟ **non-zero of $\cos 2\varphi$ dependence**.



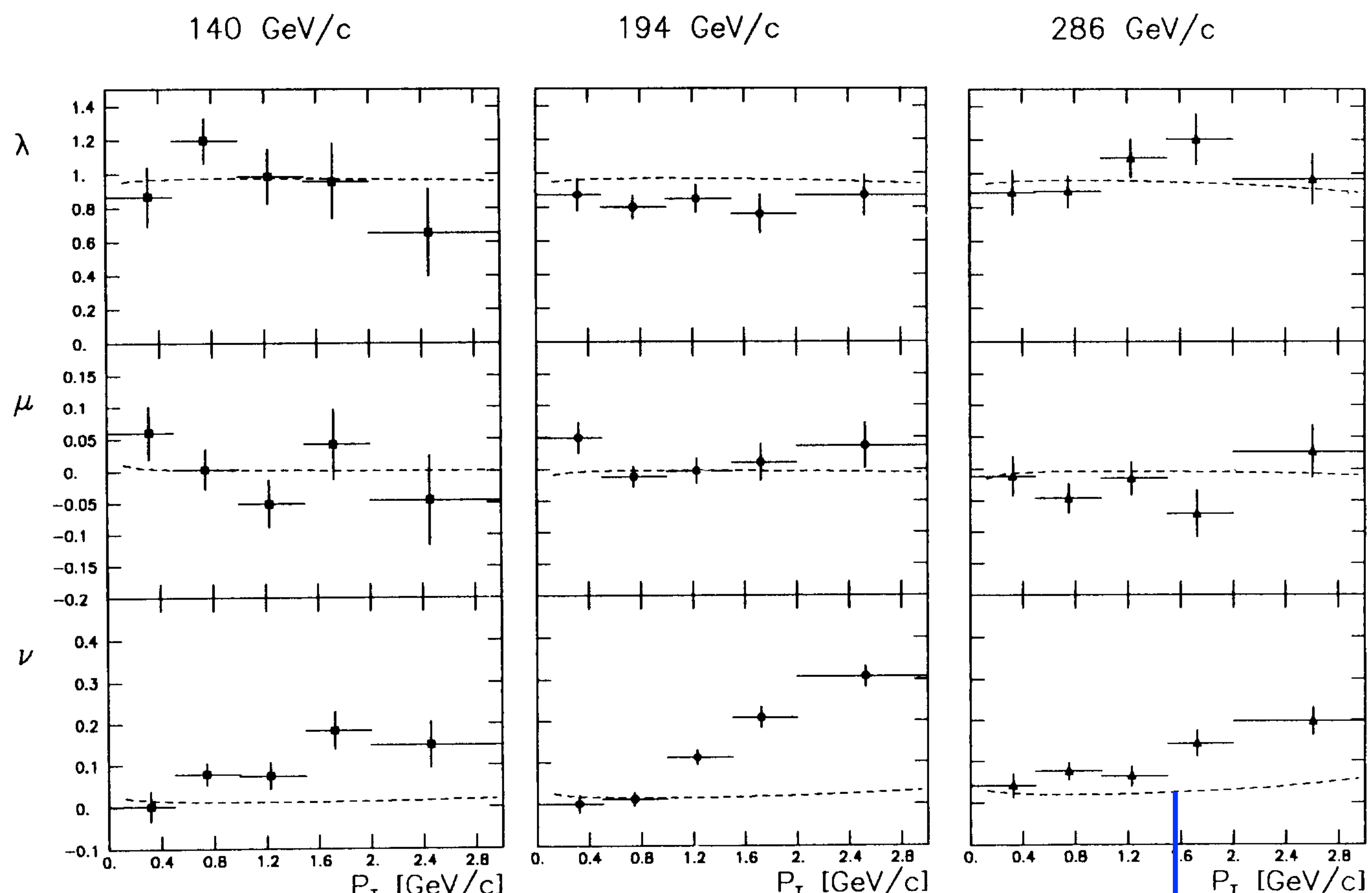
leading-order(α_s) annihilation diagram



leading-order(α_s) Compton diagram

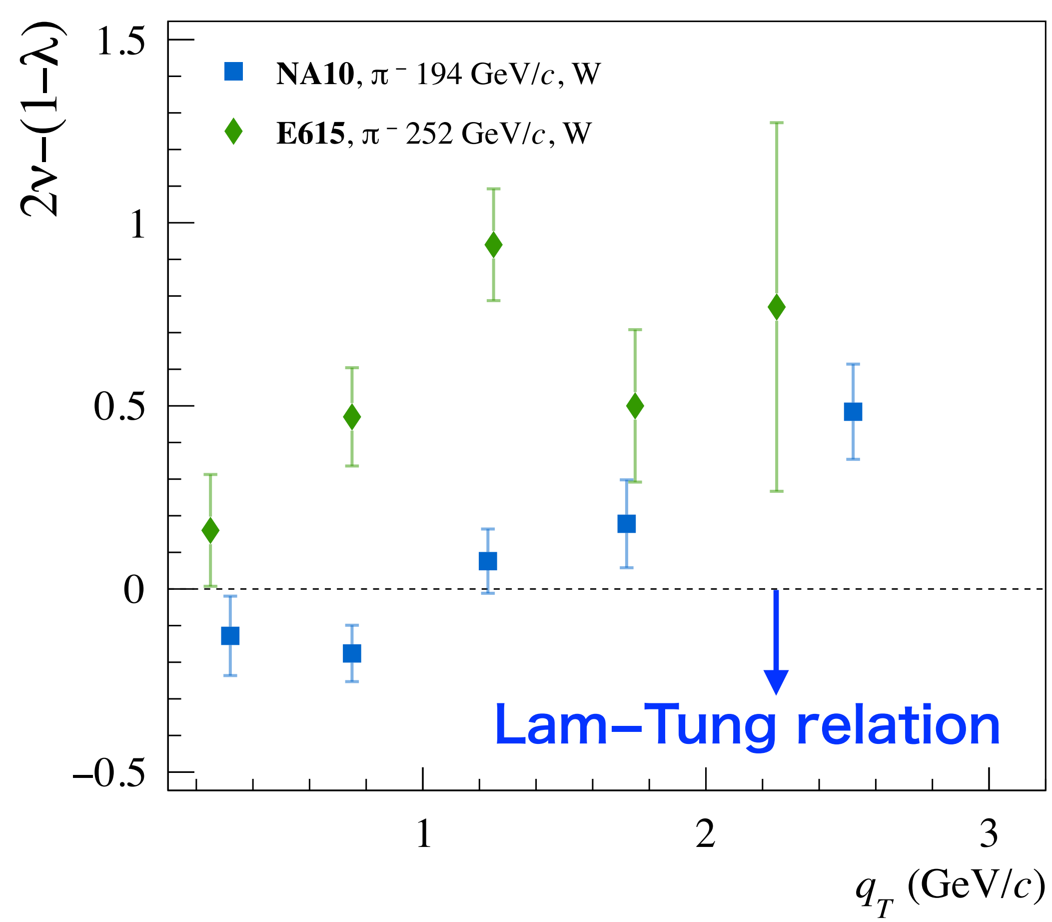
Violation of Lam–Tung Relation

- The Lam–Tung relation was found to be violated in past **pion-induced** DY experiments [NA10: ZPC 31, 513(1986)], [E615: PRD 39, 92(1989)].
- The significant inconsistency with **pQCD calculation** in the ν extraction as a function of transverse momentum of lepton-pair (q_T).



NA10

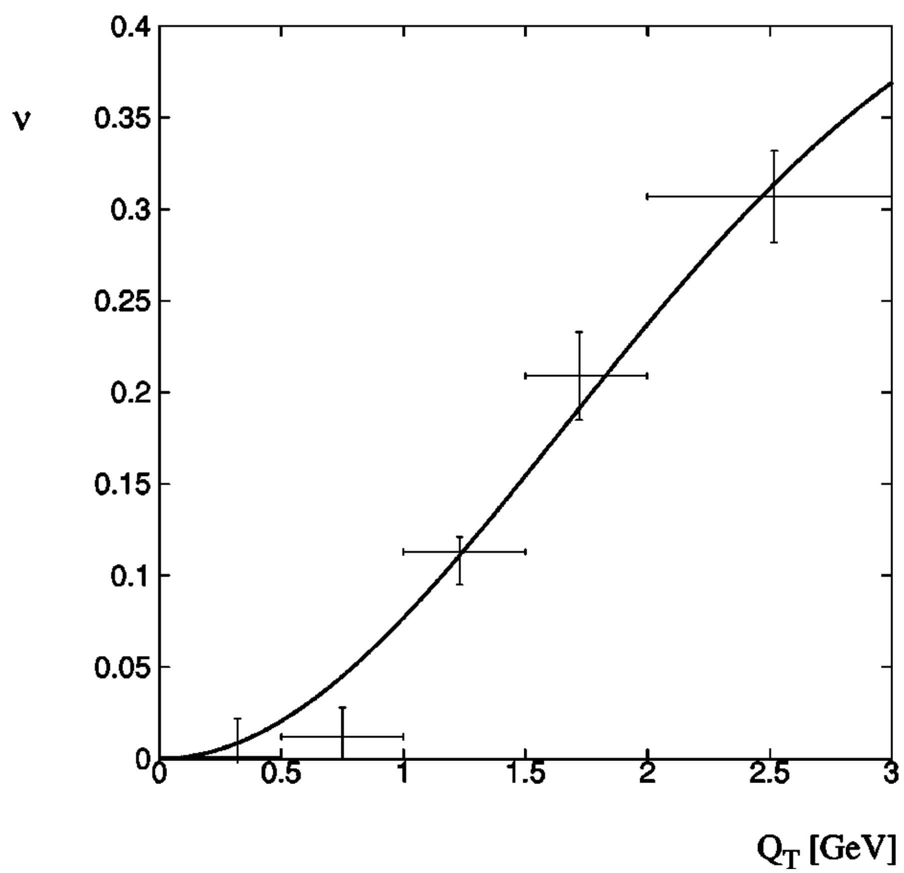
pQCD calculation

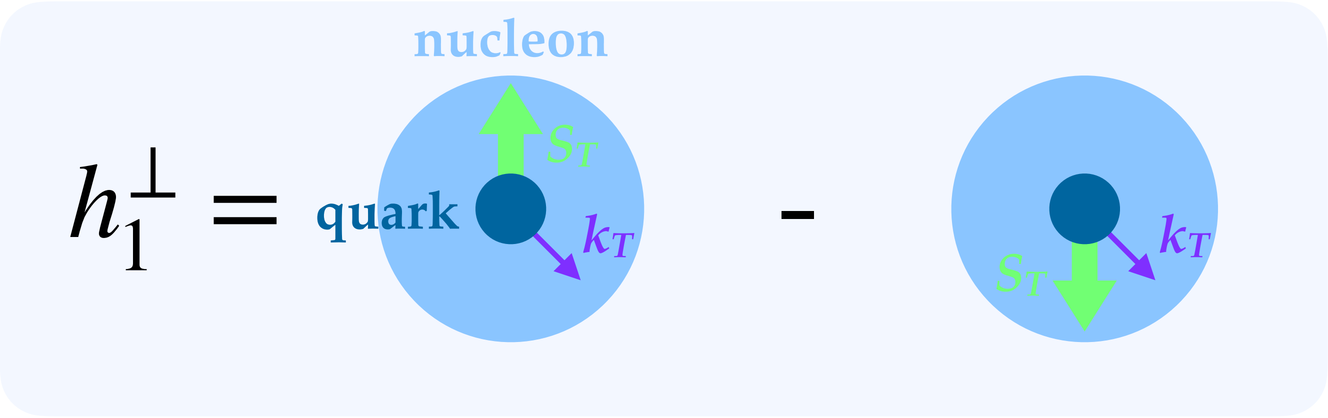


The Boer–Mulders Function

- An explanation to the $\cos 2\varphi$ dependence observed in the DY process was proposed, by introducing a non-perturbative transverse-momentum dependent (TMD) **Boer–Mulders function** [PRD 60 (1999) 014012].

- The Boer–Mulders function $h_1^\perp$ represents a correlation between quark's intrinsic transverse momentum k_T and transverse spin S_T (transversely polarized quark) in an unpolarized hadron.





$$\frac{\nu}{2} \propto h_1^\perp(N)\bar{h}_1^\perp(\pi)$$

Analysis Status — HMDY UAs

- **2015 HMDY unpolarized asymmetries analysis**:
  - Several systematic tests and cross-check have been performed.
  - **Showstopper**: the significant inconsistencies in λ extraction between NH_3 and W target. Puzzle have been identified ➠ trigger efficiencies and hodoscopes geometries which affect $\cos\theta_{CS}$ acceptance. (UAs analysis require a good description of acceptance)
  - First statistical uncertainties result have been released in November 2018.

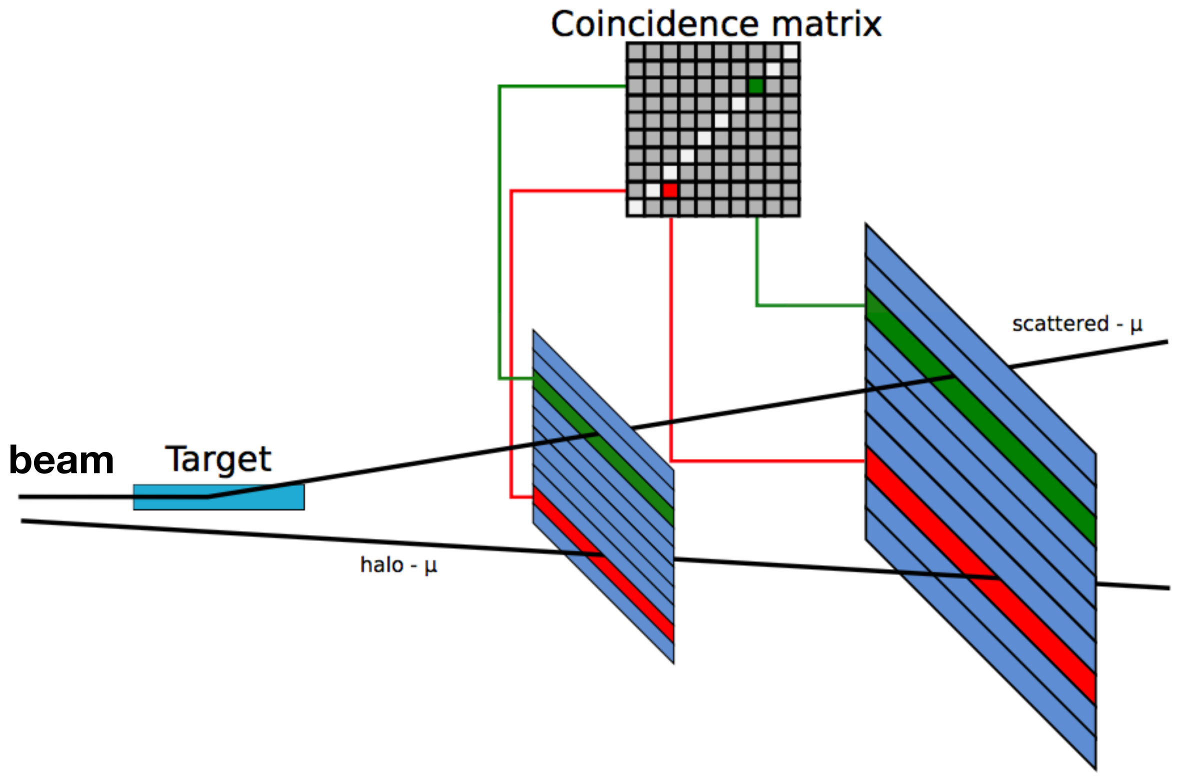
- **2018 HMDY unpolarized asymmetries analysis**:
  - Following the same analysis approach as 2015 data analysis, but more tests related to trigger have been studied.
  - The hodoscopes geometries have been corrected in 2018 MC.
  - The trigger efficiencies have been studied in details.

Data Analysis

HMDY UAs analysis	2015	2018 (exclude 3/9 periods)
Mass cut	[NH_3]: **4.3** < $M_{\mu\mu}$ < **8.5** [W(10cm)]: **4.7** < $M_{\mu\mu}$ < **8.5**	[NH_3]: **4.3** < $M_{\mu\mu}$ < **8.5** [W(20cm)]: **4.7** < $M_{\mu\mu}$ < **8.5**
Statistics	[NH_3]: **37,362** [W(10cm)]: **14,054**	[NH_3]: **28,226** [W(20cm)]: **18,036**
MC sample (Acceptance)	2015 HMDY MC (w/ Pythia 6)	2018 HMDY MC (w/ Pythia 8)
1D Kinematics Binning	**5** bins	[NH_3]: **5** bins [W(20cm)]: **3** bins

- In 2018 data analysis, the most significant improvement w.r.t 2015 is the MC sample (hodoscope geometries, trigger efficiencies, magnet scaling factor…).
- The three of periods (P00, P04, P07) have been excluded in 2018 data analysis for the moment, which were suggested by the other 2018 data analysis.

2015/2018 Trigger Hodoscopes



COMPASS Note—**Trigger Configuration Summary 2002 - 2012**,
J. Barth, J. Bernhard, E.M. Kabuß, N. du Fresne, B. Veit

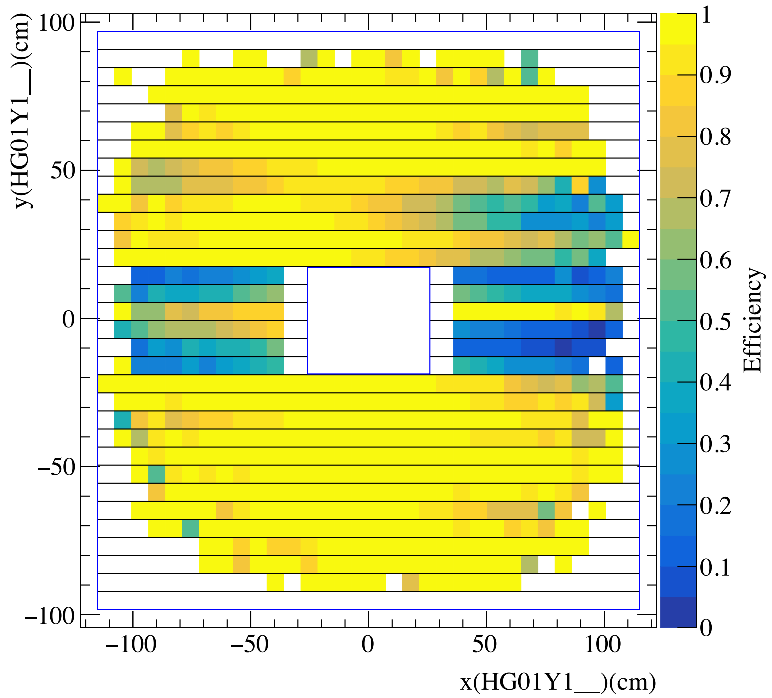
- Large-Angle Spectrometer region (**LAS**):
  - **LAS trigger (LAST)**: 1 upstream plane + 2 downstream planes
- Small-Angle Spectrometer region (**SAS**):
  - **Outer trigger (OT)**: 1 upstream plane + 2 downstream planes
  - **Middle trigger (MT)**: 2 upstream planes + 2 downstream planes

- In COMPASS trigger configuration, trigger coincided two hits from two hodoscopes (upstream and downstream) with the coincidence matrix in order to select a good muon track from the target.

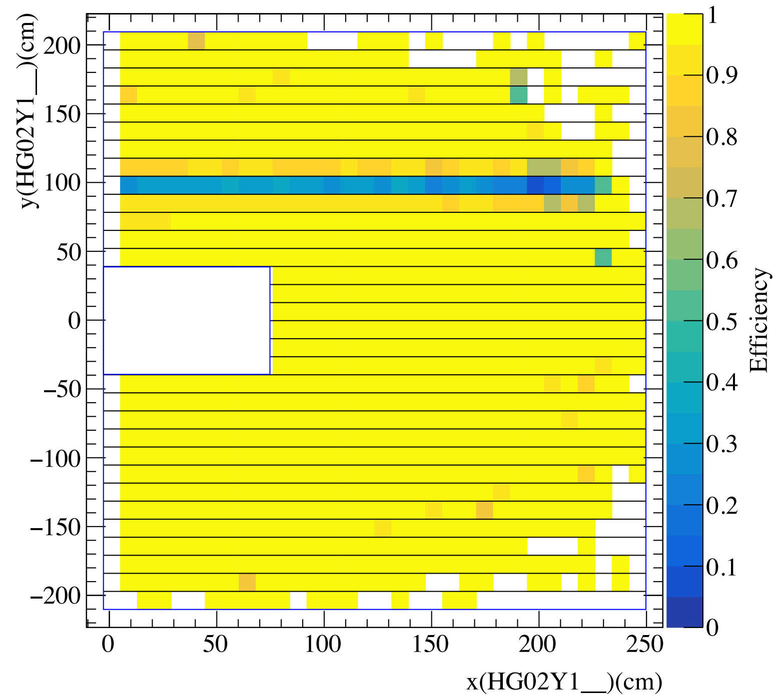
LAS Trigger in 2018 P02

Hodoscope Efficiency

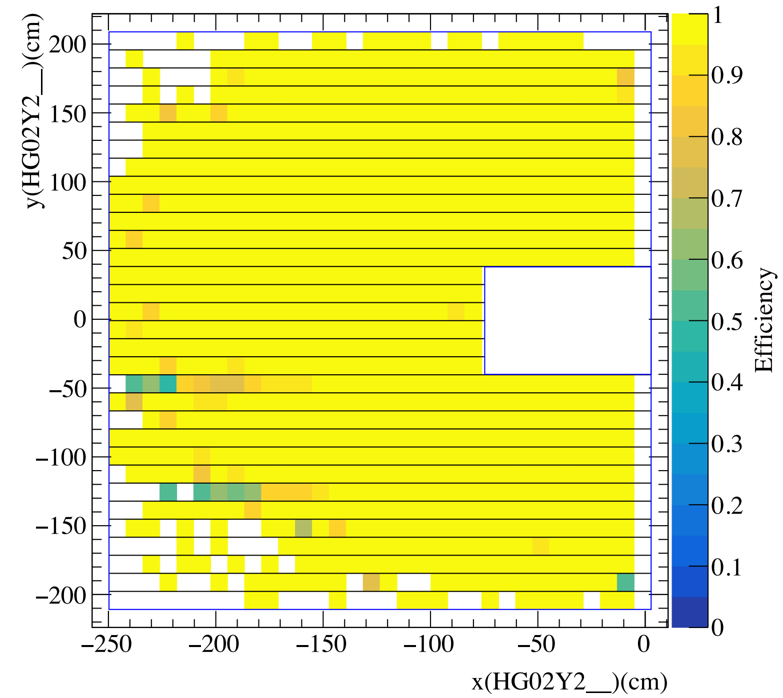
HG01Y1__



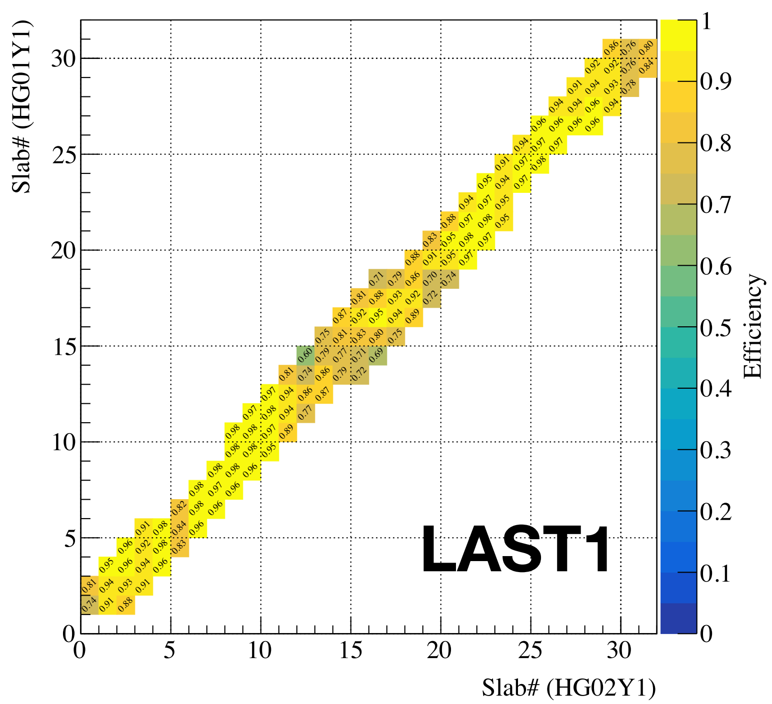
HG02Y1__

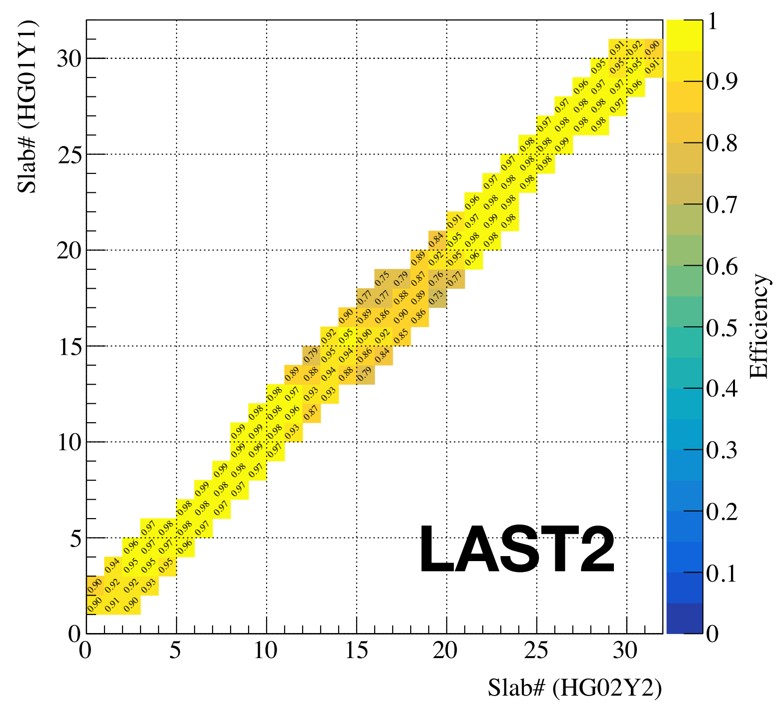


HG02Y2__



Matrix Efficiency



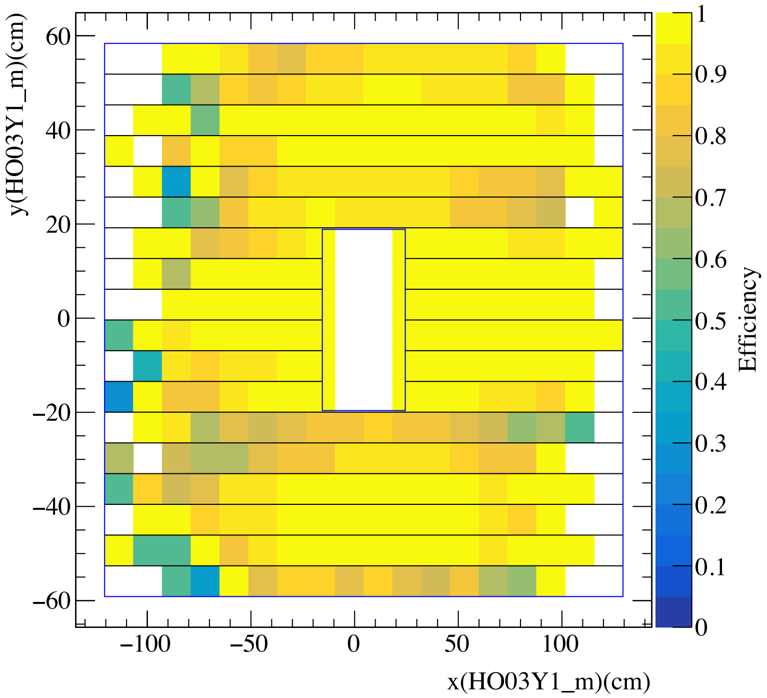


- The LAS trigger system are contributed by three hodoscopes and combined with two matrix pattern:
  - LAST1: HG01Y1⊗HG02Y1
  - LAST2: HG01Y1⊗HG02Y2

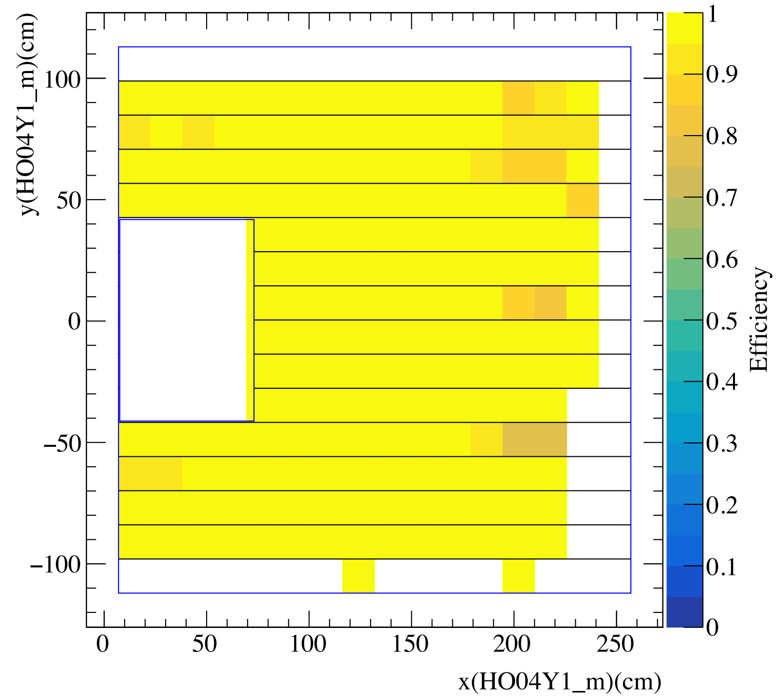
Outer Trigger in 2018 P02

Hodoscope Efficiency

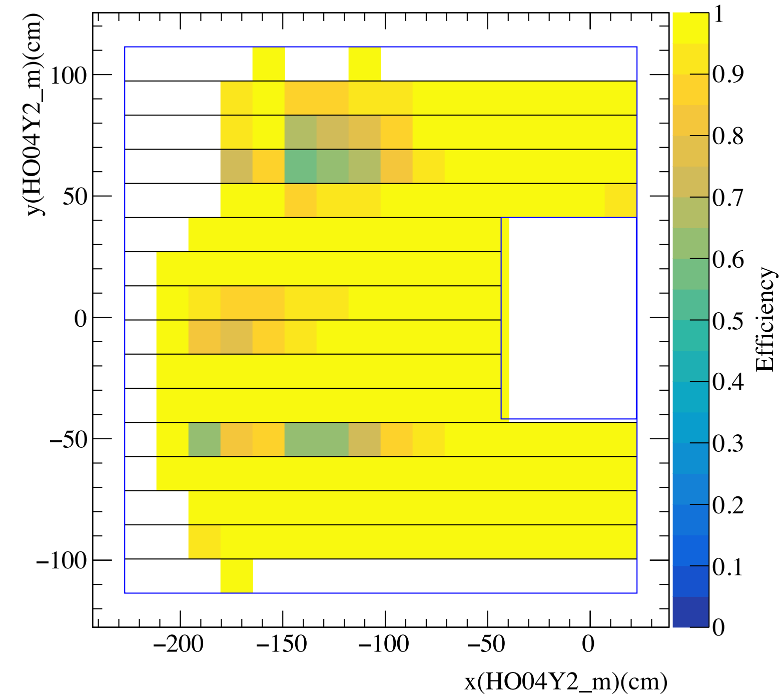
HO03Y1_m



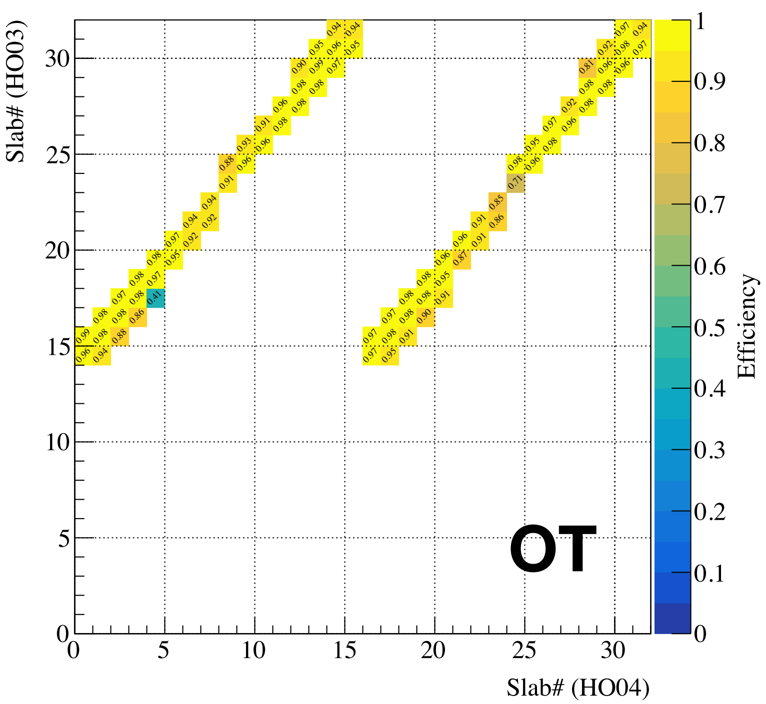
HO04Y1_m



HO04Y2_m



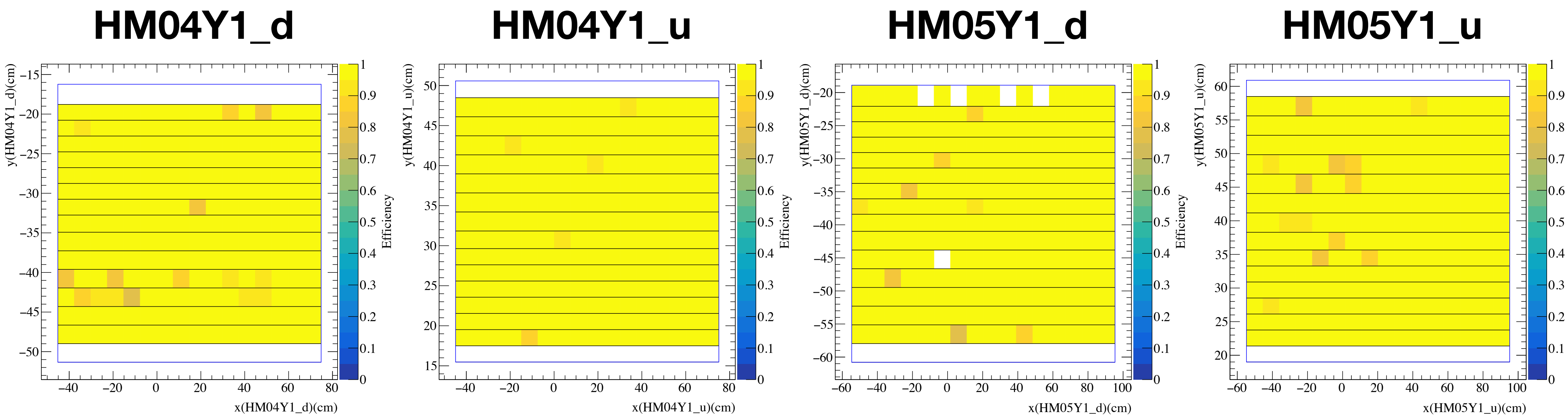
Matrix Efficiency



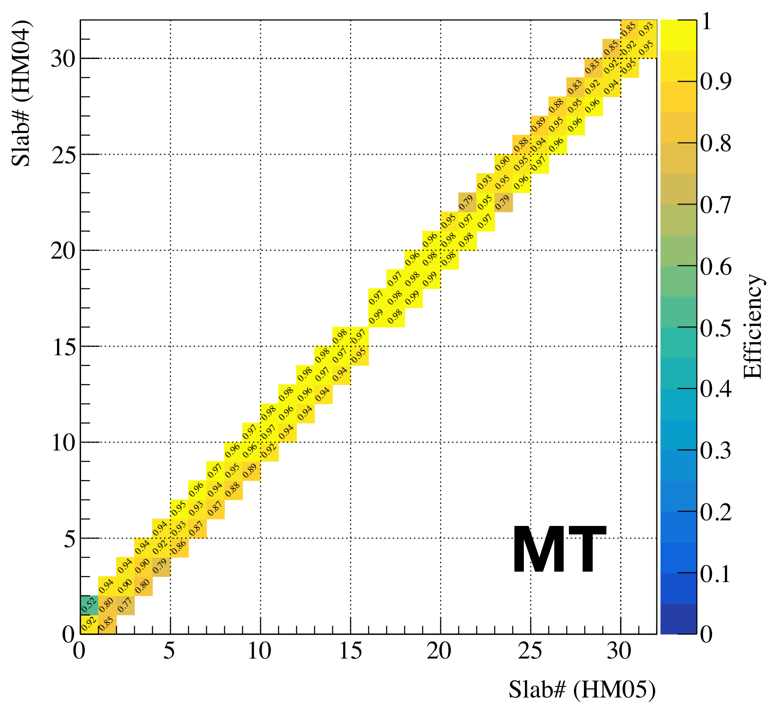
- The Outer trigger system are contributed by three hodoscopes and combined with one matrix pattern.
- The cause of inefficient spot on HO03 and HO04Y2 is still under investigation.

Middle Trigger in 2018 P02

Hodoscope Efficiency

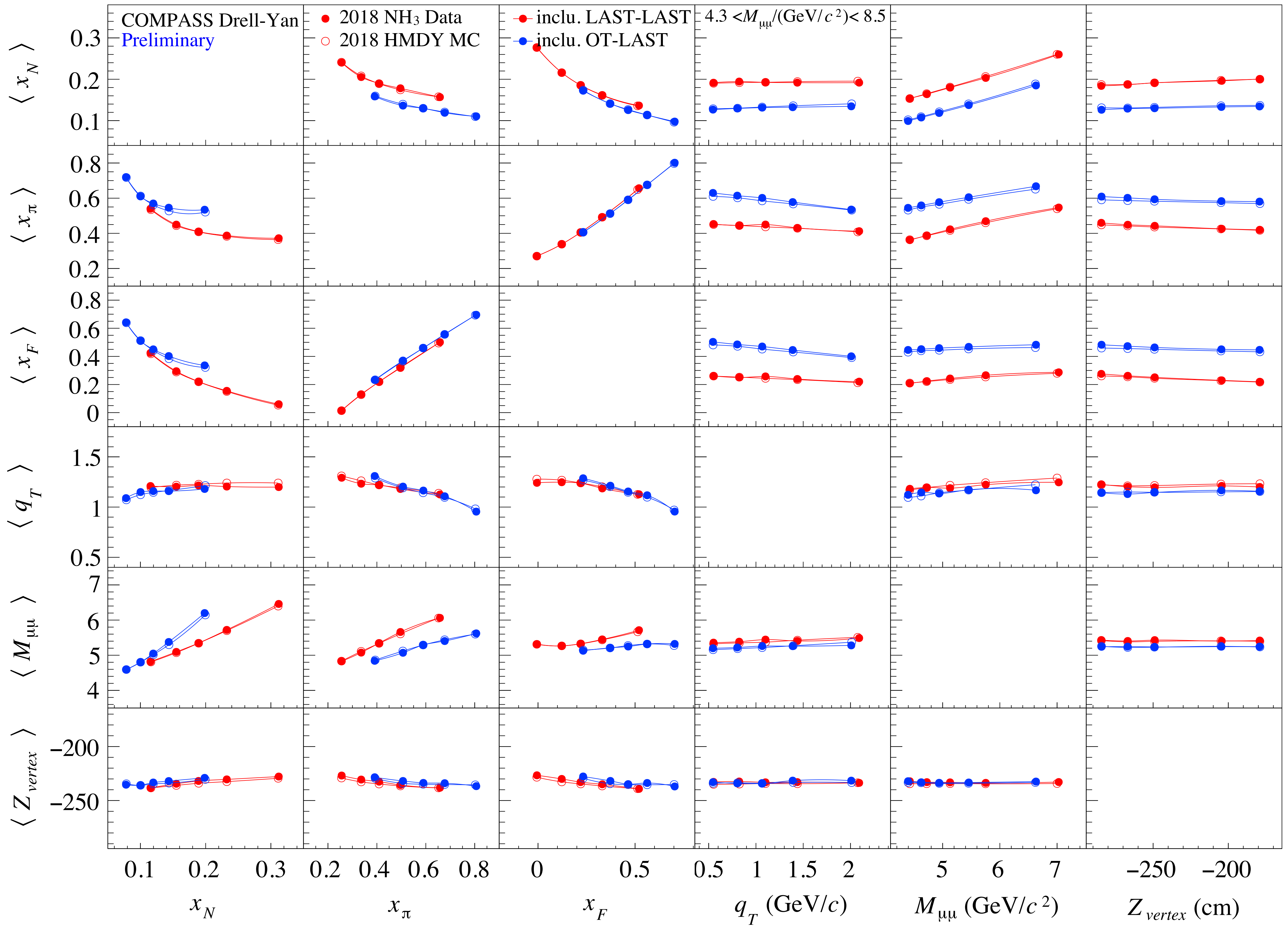


Matrix Efficiency

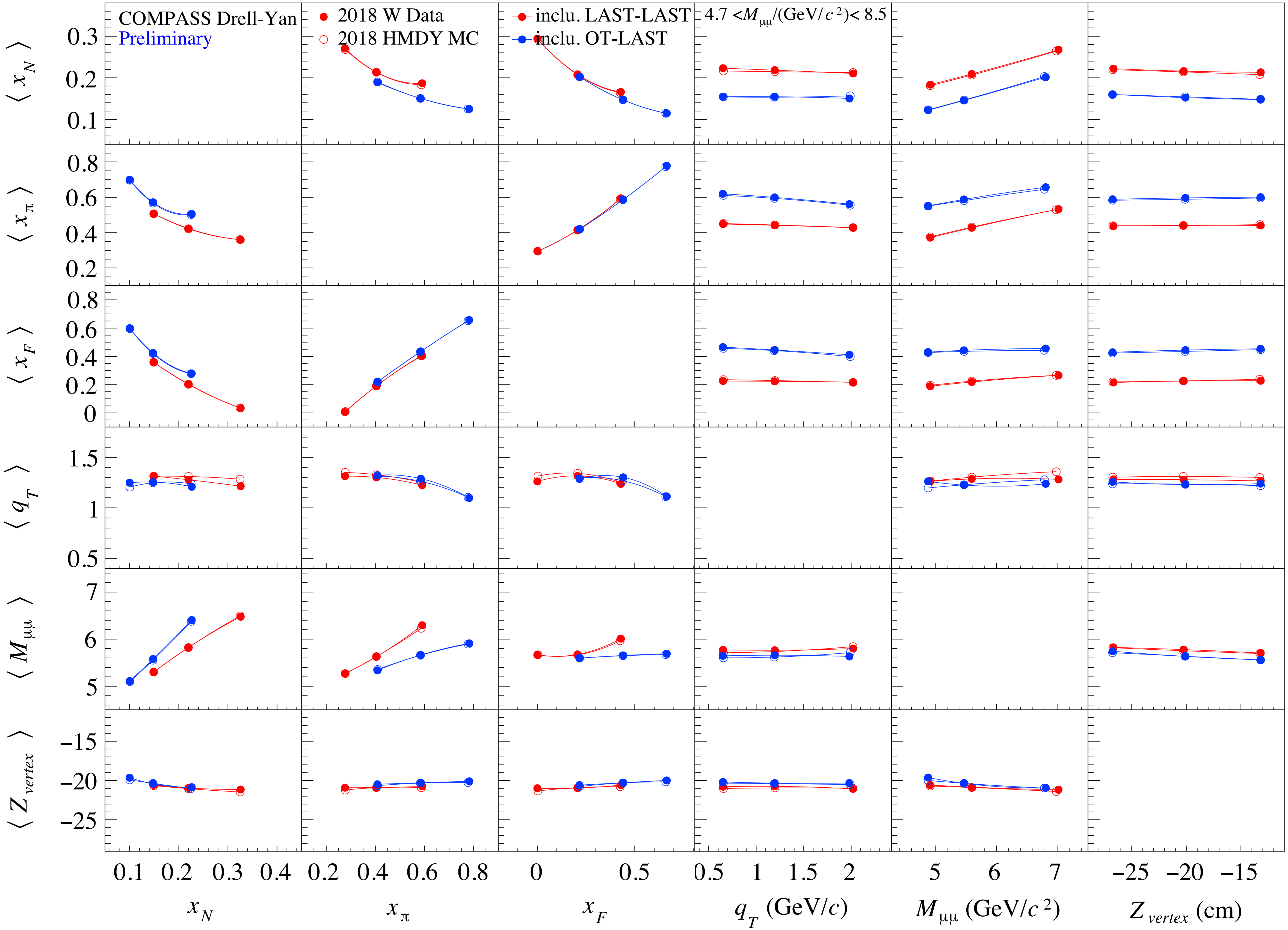


- The Middle trigger system are contributed by four hodoscopes and combined with one matrix pattern.
- The overall hodoscopes efficiencies in MT are higher and stable w.r.t. other hodoscopes (LAST, OT).

2018 HMDY Kinematics Map — NH_3

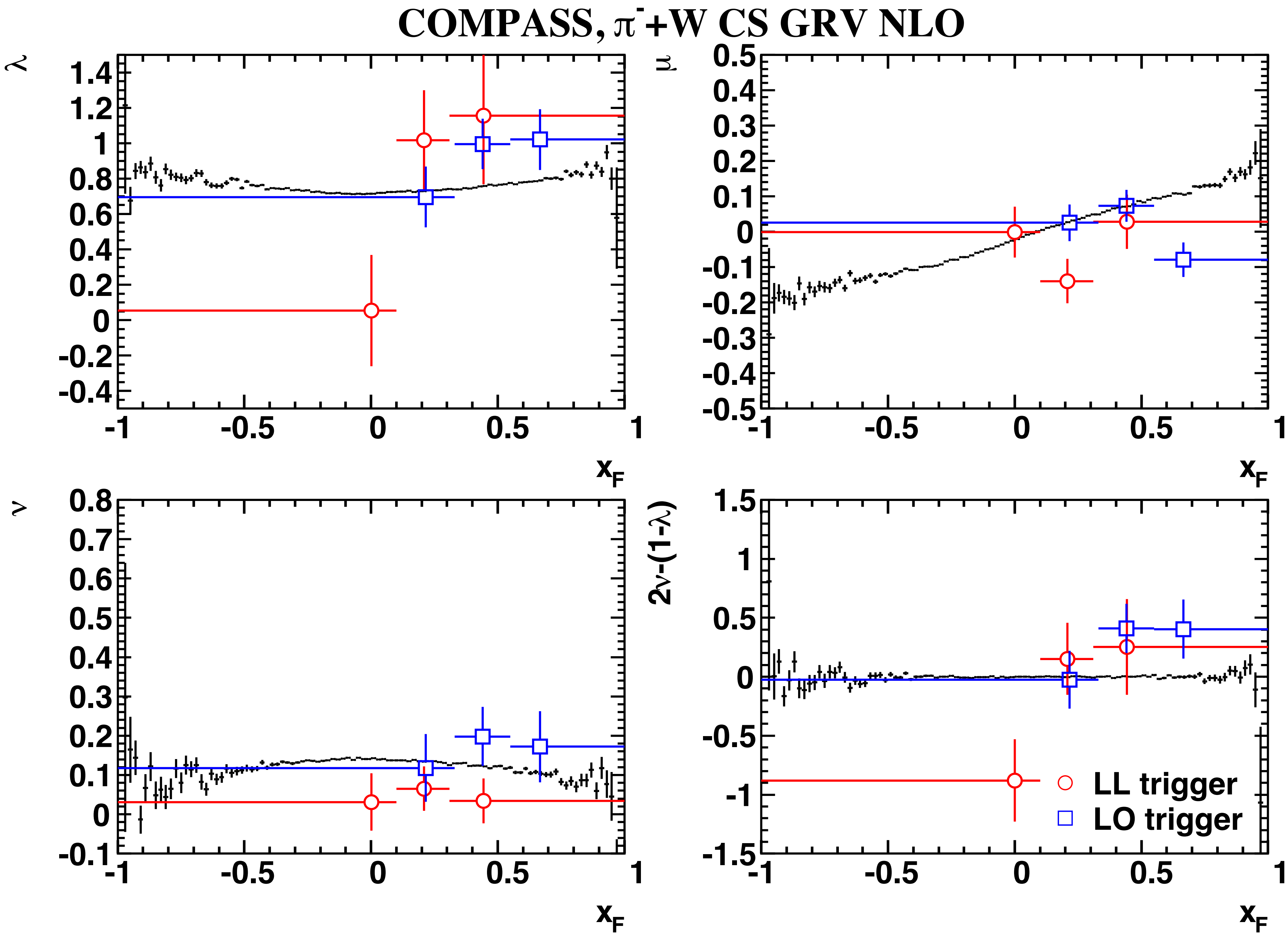


2018 HMDY Kinematics Map — W



Comparison w/ pQCD Calculation

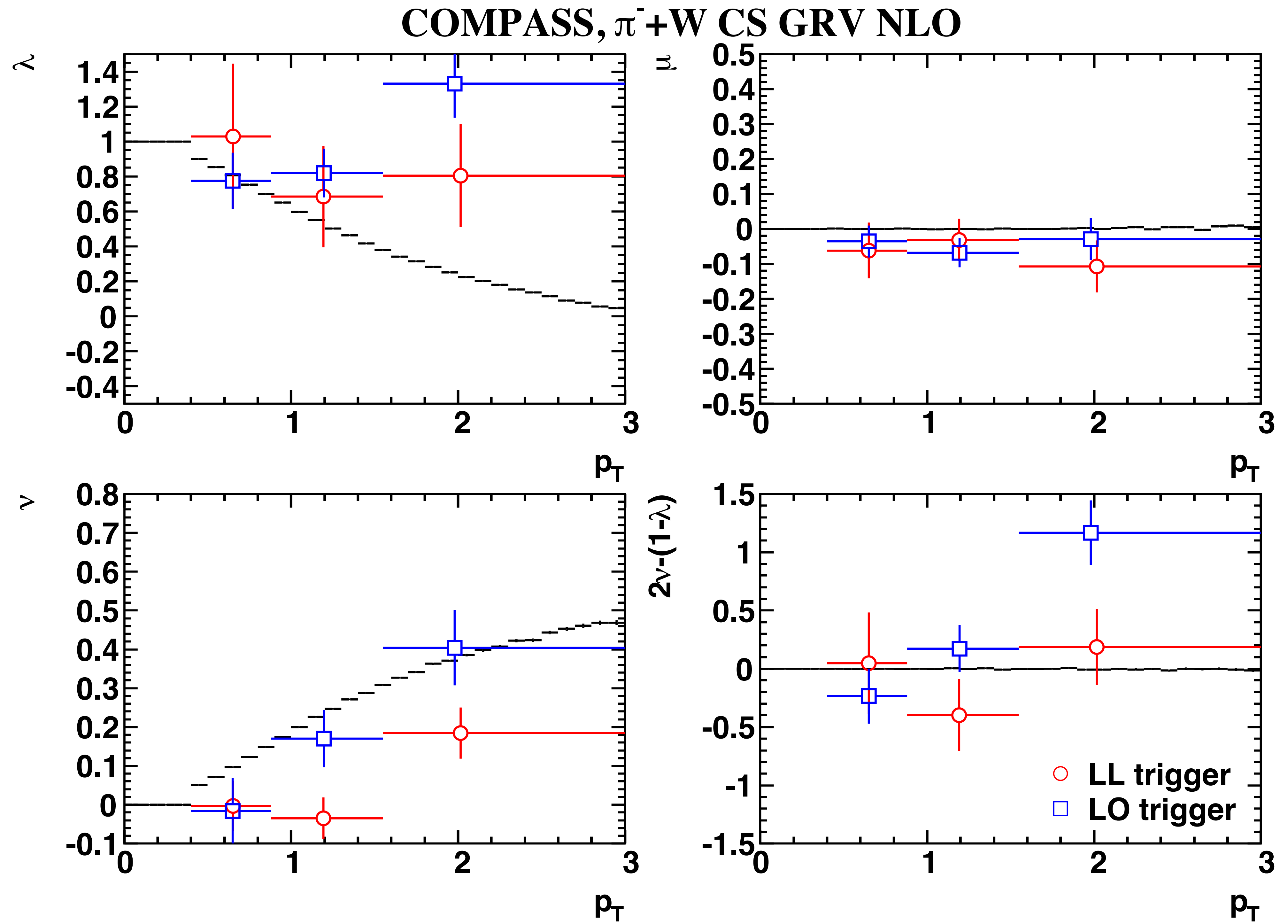
pQCD calculation: Prof. Chang Wen-Chen



- The preliminary COMPASS result are consistent w/ pQCD calculation at positive x_F region, also the result from two trigger region are consistent in overlap x_F region.

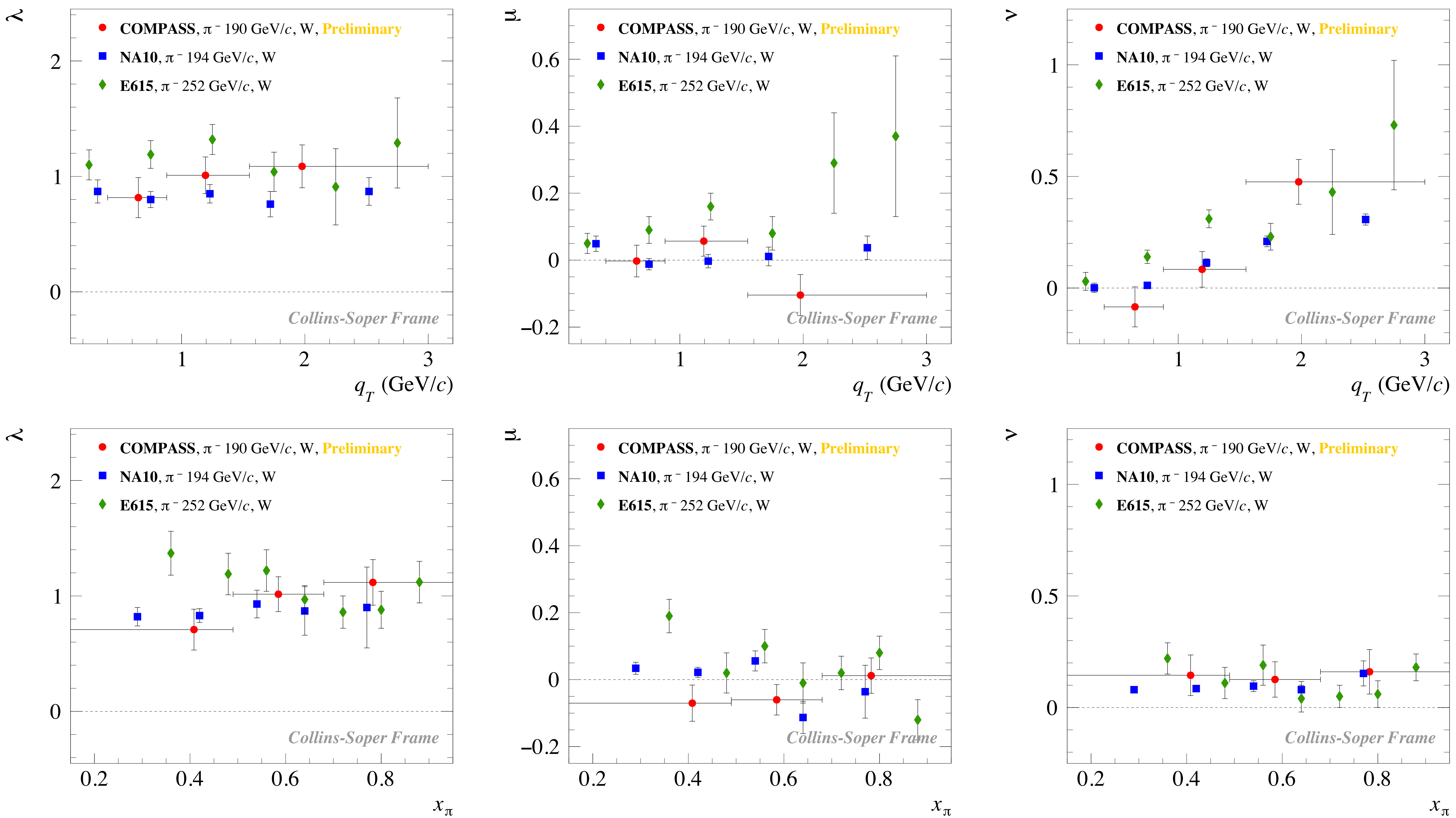
Comparison w/ pQCD Calculation

pQCD calculation: Prof. Chang Wen-Chen



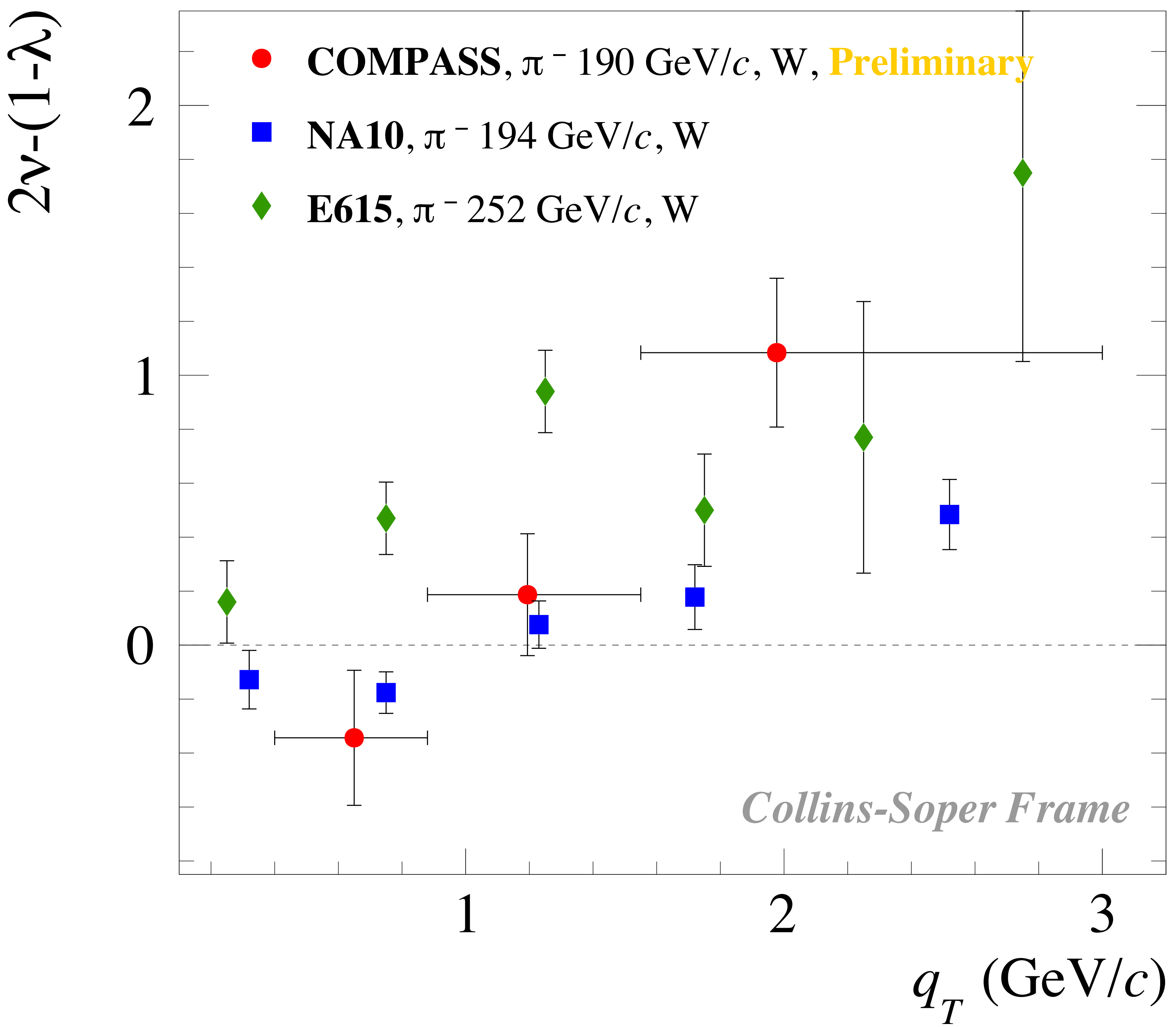
- The inconsistency result between two trigger region are expected because of different coverage of x_F region in different trigger.

Comparison w/ NA10, E615



- The advantage of COMPASS result w.r.t the other fixed target experiments is that we can determine the large x_F region.

Result of Lam-Tung Relation



- The preliminary HMDY UAs result in 2018 is also in favor of violation of Lam-Tung relation at large q_T region.

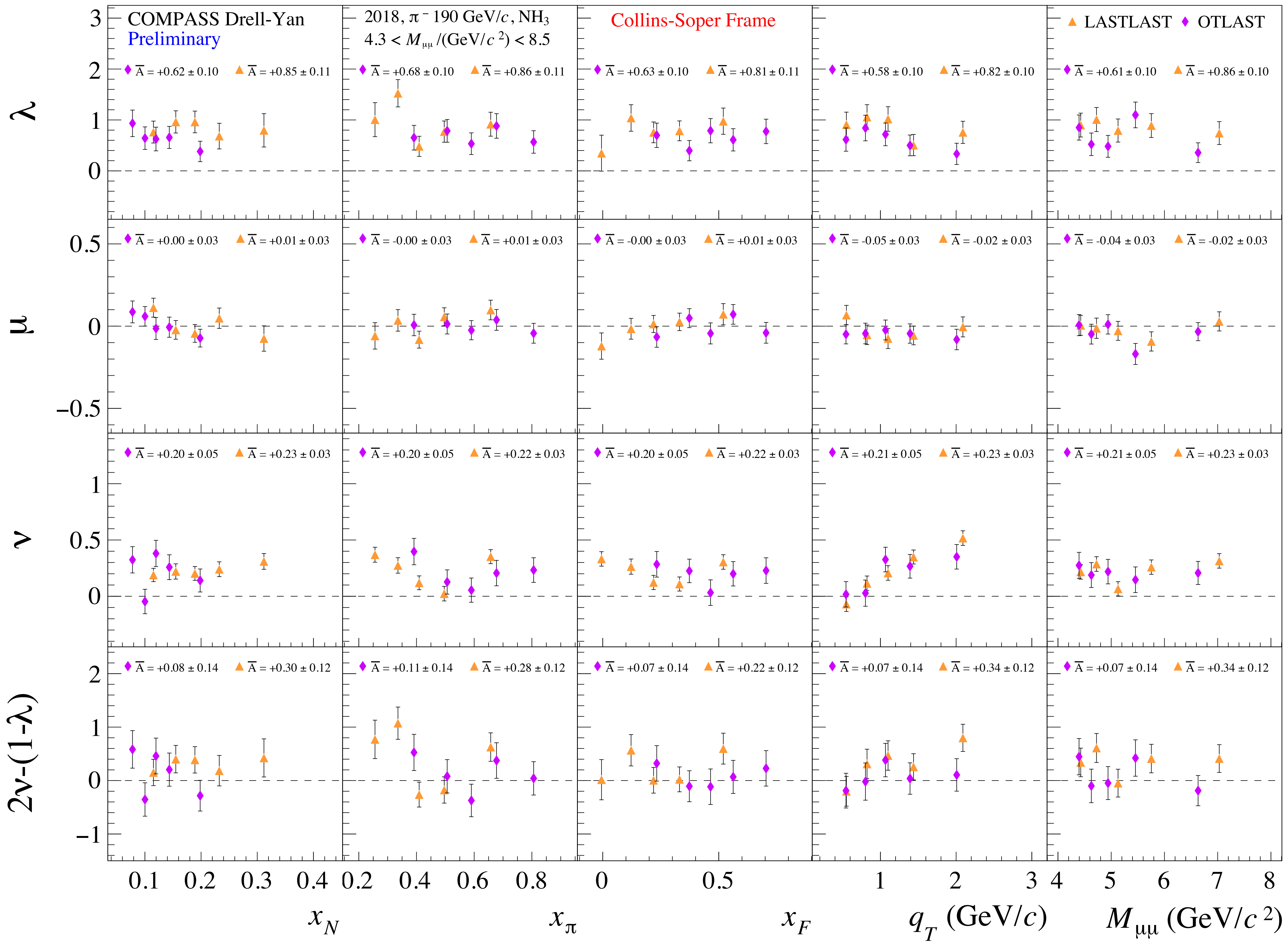
Summary and Outlook

- The RD/MC comparison has achieved nice agreement in both targets. Few minor remaining disagreement can be identified.
- The preliminary HMDY UAs result in 2018 is consistent between LAST-LAST and OT-LAST trigger.
- The preliminary HMDY UAs result in 2018 is consistent with NA10 and E615!

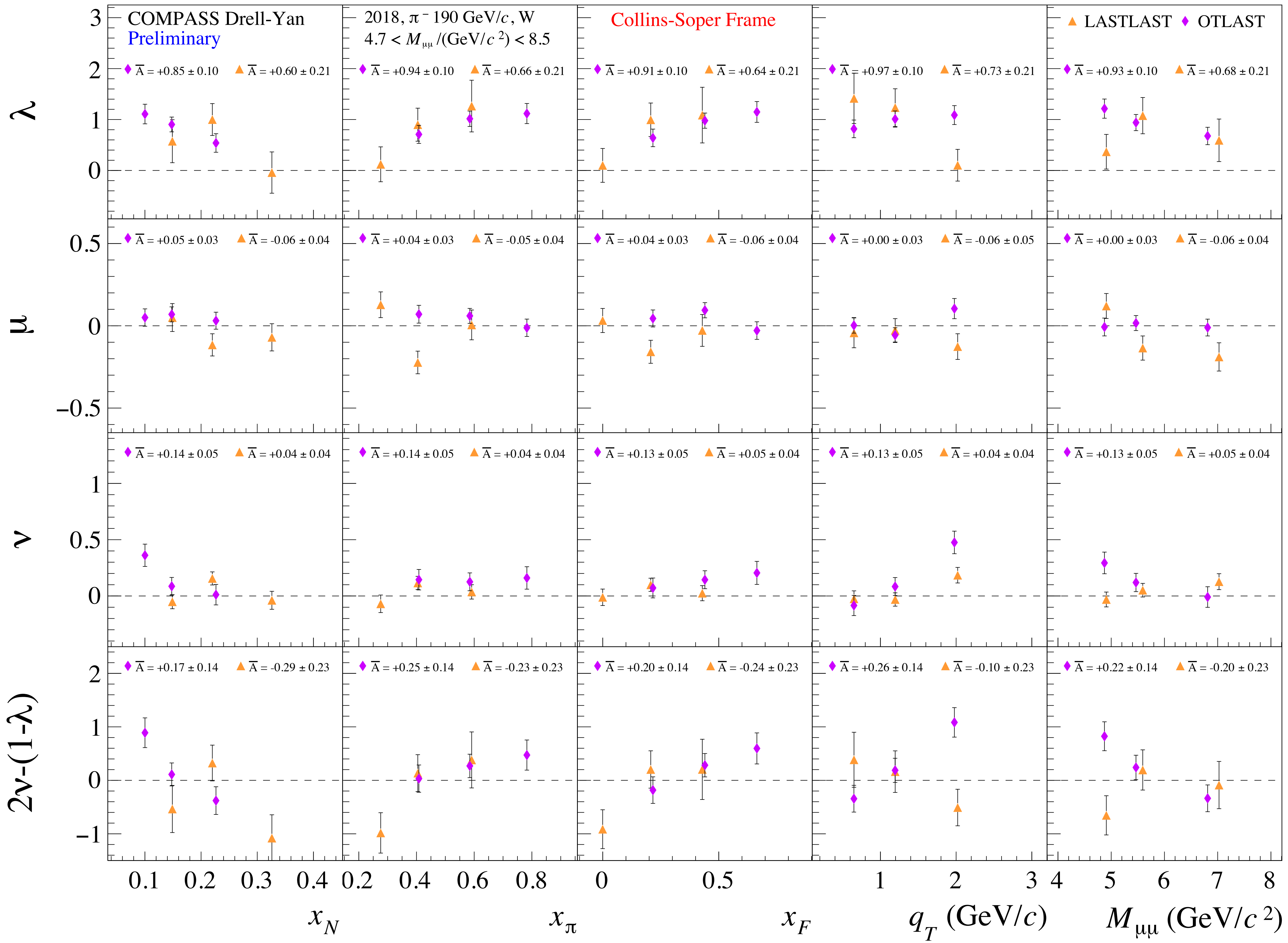
- **Outlook**:
  - Thanks to the dedicate trigger runs in 2018 data taking, the trigger efficiency can be extracted period by period, the final goal is to reconstruct 2018 MC period by period.
  - We plan to proceed systematic error study for HMDY UAs extraction in 2018 data (following the same study as in 2015 data analysis).
  - We plan to have 2018 data released in this year.

Back Up

2018 HMDY UAs — NH_3



2018 HMDY UAs — W



Extraction of Slab Efficiency in 2018t6

- Method:
  - Selecting muon tracks and requiring inclusive **CT** event.
  - Extrapolated tracks to each hodoscopes and requiring special hodoscopes cut (1)
  - Looping **hits from this events** and check corresponding hits was found in **this slab or neighboring slabs (slab#±1)**. (2)
  - Slab Efficiency = (2)/(1)

Selection criteria

Skip if there is no outgoing particle
Skip if there is no vertex
Skip if XX0 < 30
Skip if $\chi^2/ndf > 10$
Skip if $Z_{First} > 300$ cm

For LAS event:
- **skip if $p_\mu < 10$ GeV/c**
- **skip if #hits from muon wall A < 6**

For SAS event:
- skip if $Z_{Last} < 4200$ cm
- **skip if $p_\mu < 20$ GeV/c**
- **skip if #hits from muon wall B + MWPC < 6**

Cut on Hodoscopes

For all of hodoscopes:
- Shrink the edge by 2.5 cm in x and y
- Shrink the edge of slabs by **20% of slab size in y**

For HG01:
- Enlarge the dead zone by 2.5 cm in y
- Enlarge the dead zone by 10 cm in x

For HG02Y1 and HG02Y2:
- Shrink the edge by 10 cm in x (only on overlap region)

For HG02, HO03, HO04:
- Enlarge the dead zone by 2.5 cm in x and y

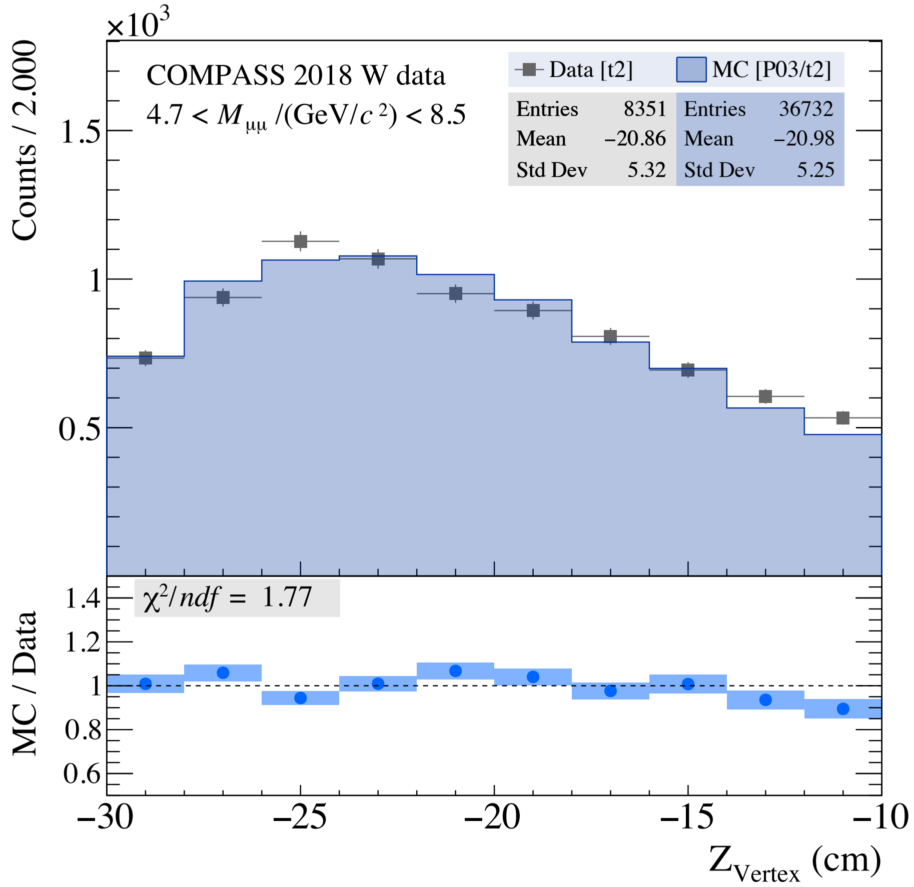
Extraction of Matrix Efficiency in 2018t6

- The previous extraction of 2018(**t2**) trigger efficiency have been presented in AM @ 08/08/2019.
- Analyze the selected runs in t6 production data which point out by Moritz.
- Method:
    - Selecting all of **hits** from each hodoscopes and requiring inclusive **CT** events.
    - Building the matrix pixel and requiring the trigger time window and matrix pattern. (1)
    - Requiring the corresponding single muon trigger flag. (2)
    - **Matrix Efficiency = (2)/(1)**

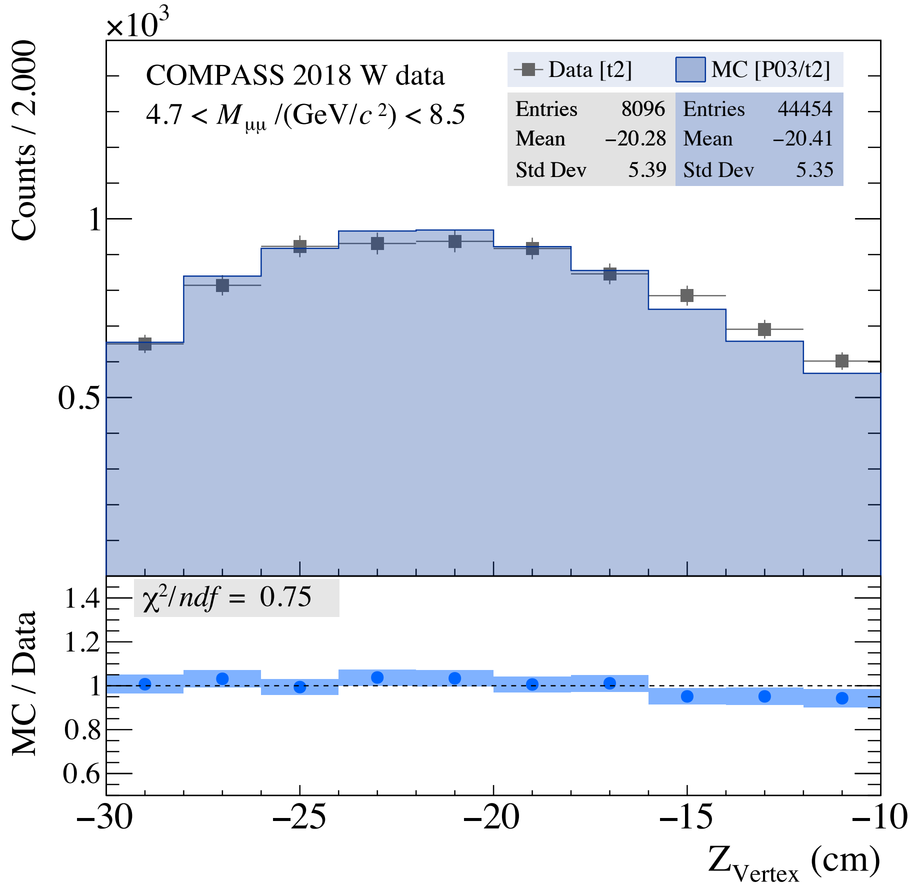
Selection criteria
Time gate cut for each hit: $|t| < 10$ ns
LAST trigger time window: $\Delta t < 10$ ns
OT trigger time window: $\Delta t < 6$ ns
MT trigger time window: $\Delta t < 4$ ns

Extension of W target region

Inclusive LASTLAST

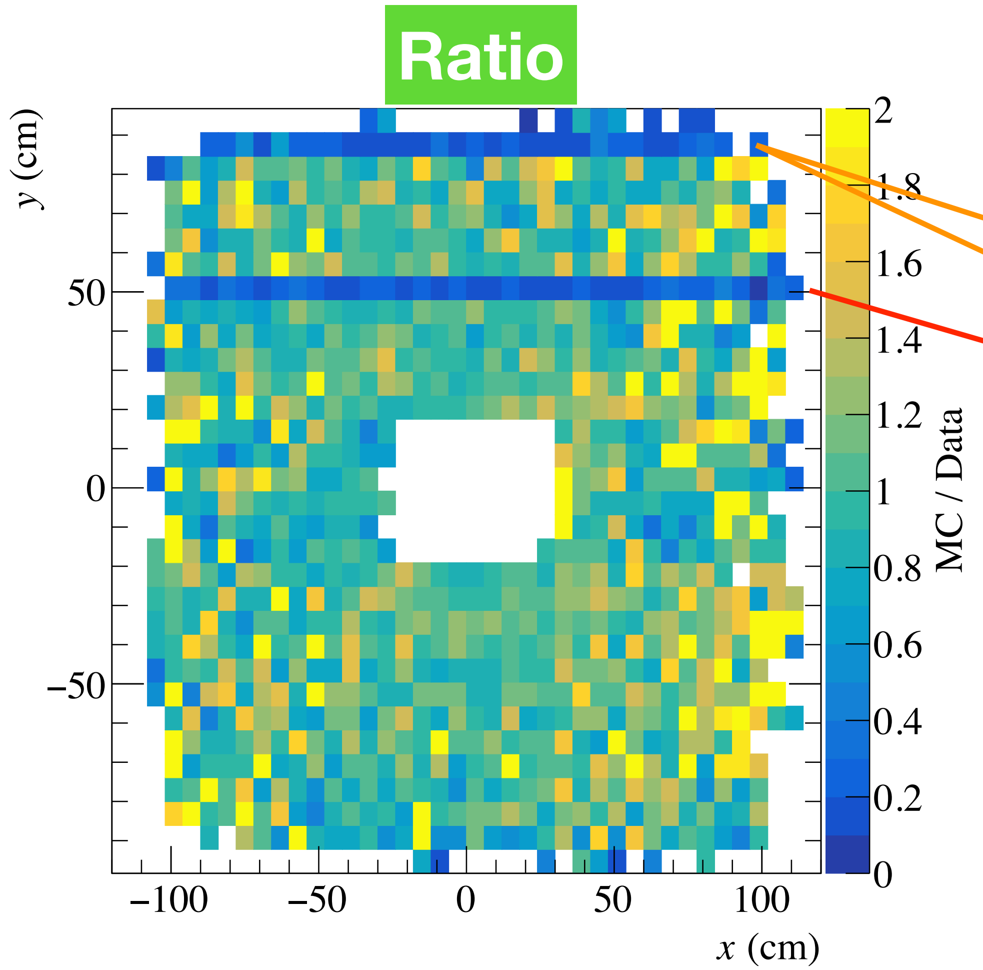


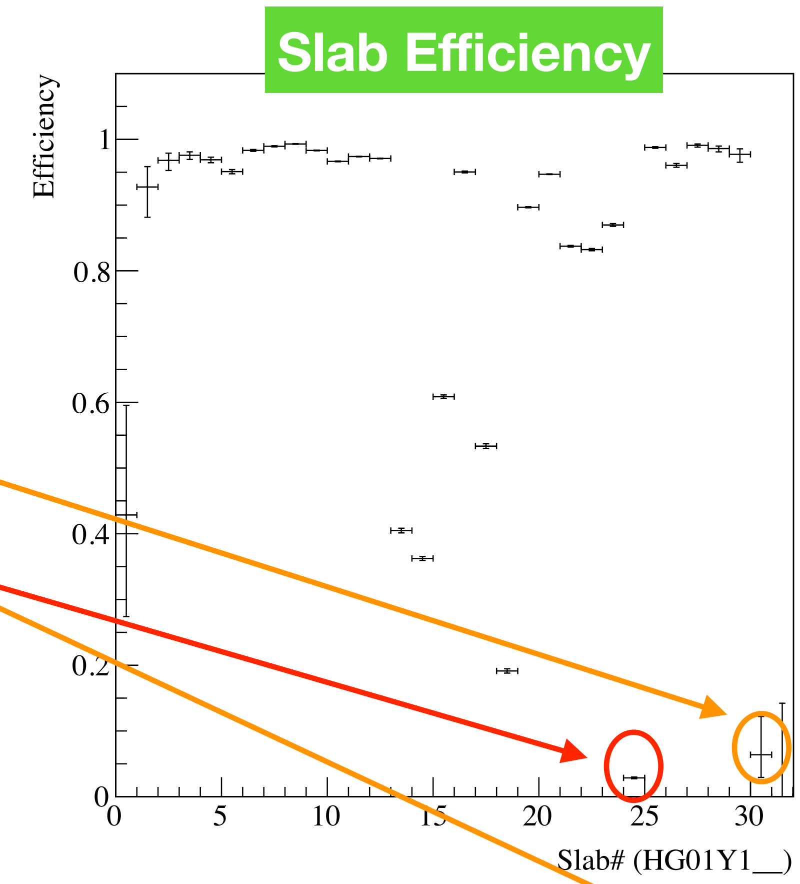
Inclusive OTLAST

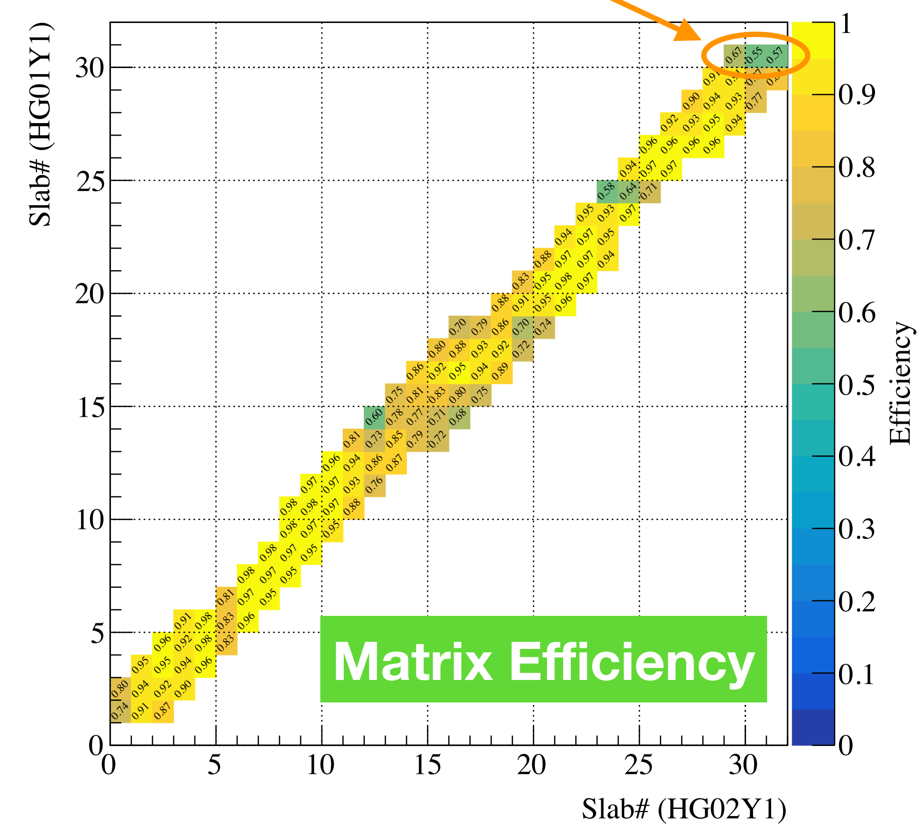


- The current statistics from W target in first 10 cm are too low to perform HMDY UAs analysis, it would be helpful if we extend the selected W target region.
- The RD/MC agreement from W in first 20 cm stay almost the same as first 10 cm, so it might be fine to use first 20 cm W target.

Additional HG01Y1 slab cut — I

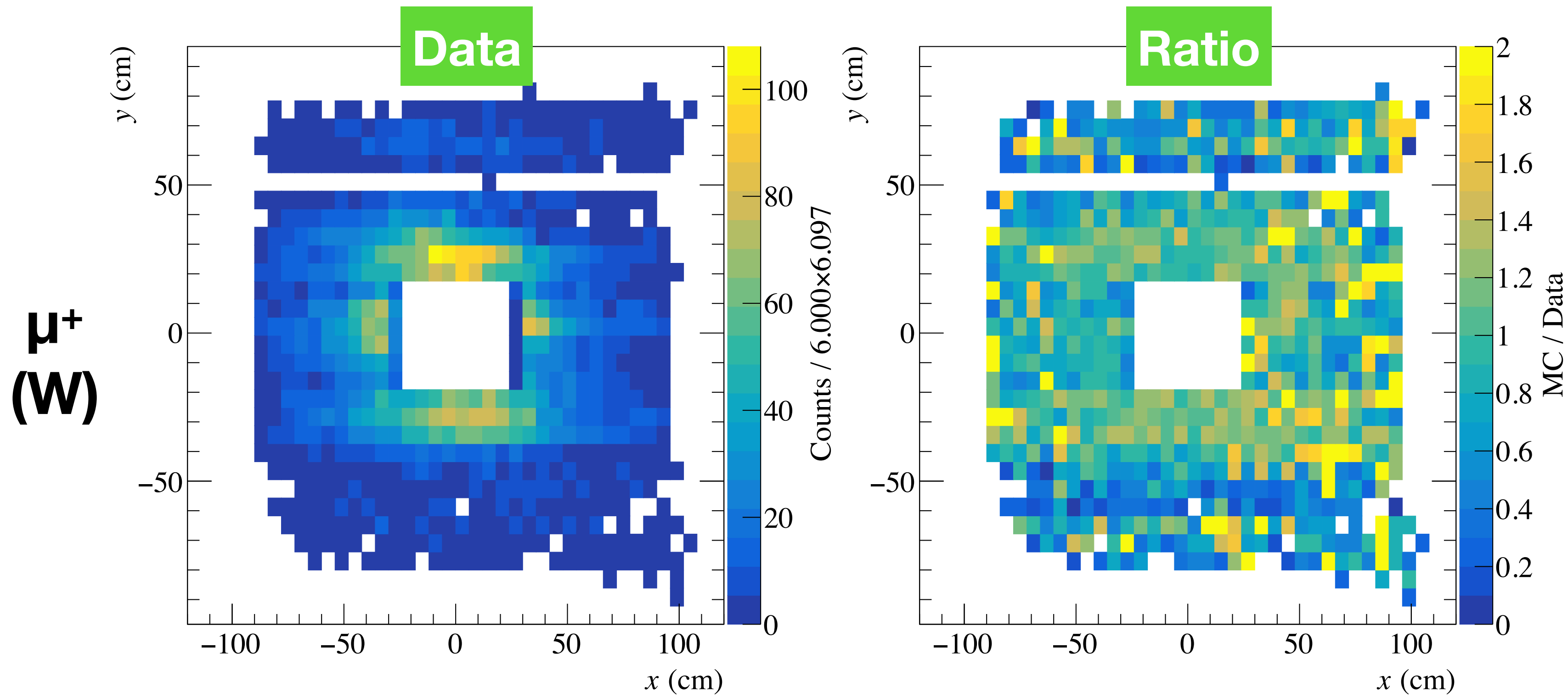




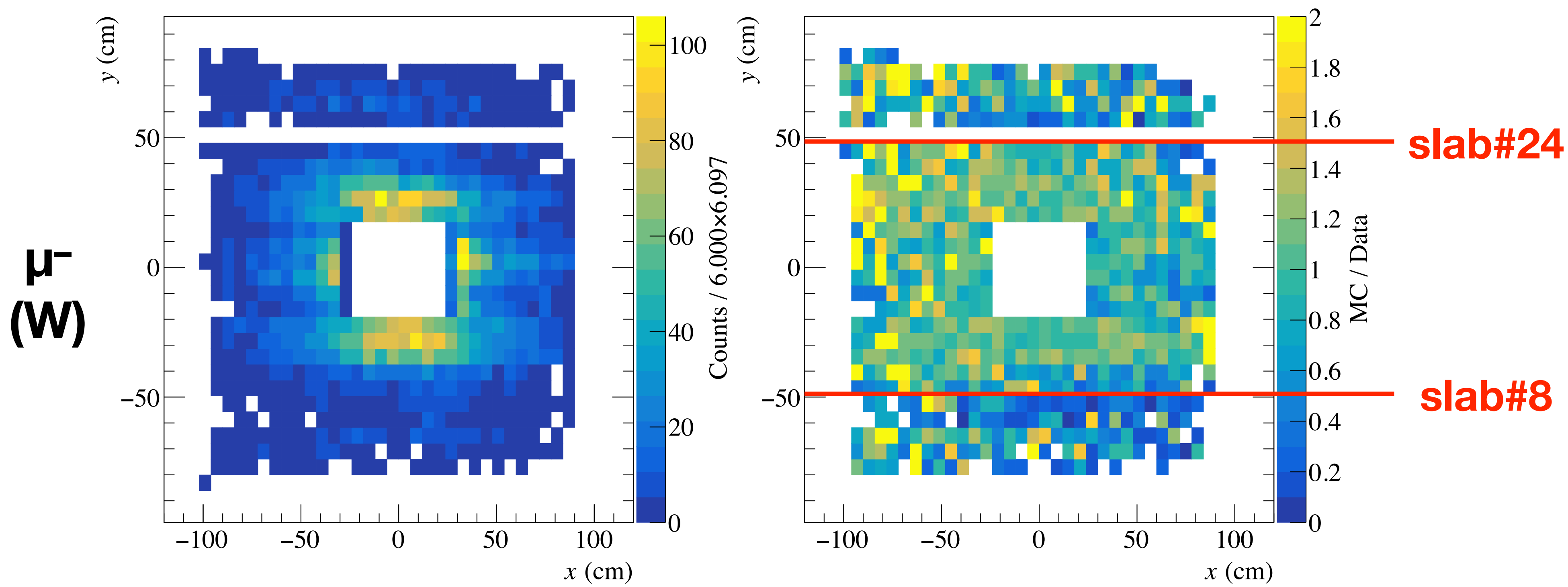


- The low slab efficiency in **slab#24, #30** are cause by the wrong mapping during the reconstruction (found by Vincent). The trigger efficiency extraction will be redone once the new production is ready.
- We then remove slab#24, 30 and 31 for all of data sample.

Additional HG01Y1 slab cut — II



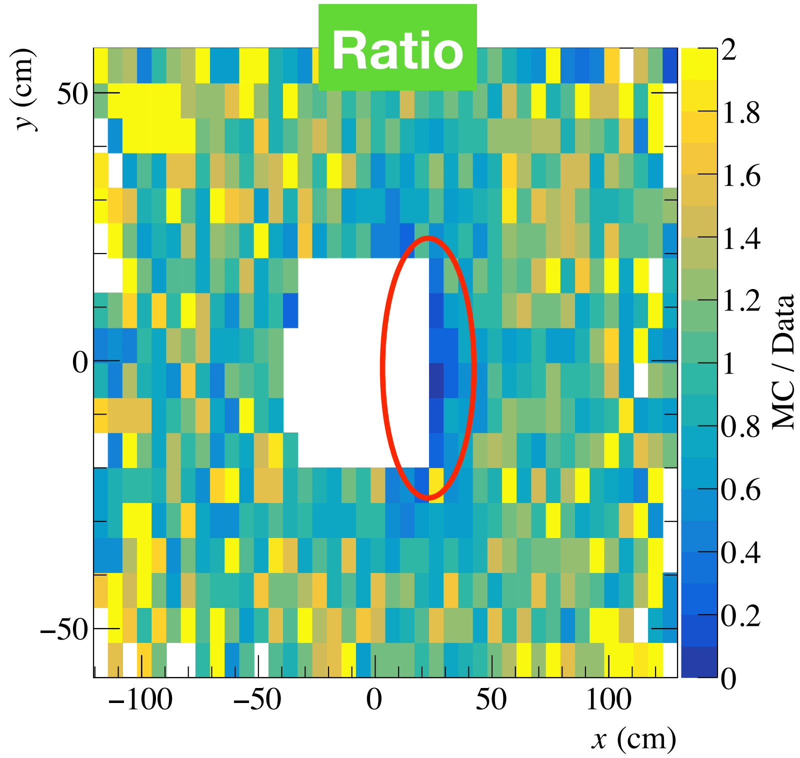
#paris (W)	LASTLAST	OTLAST
original	10523	9215
remove outer slabs	8351	8096
reduction rate	-20%	-12%

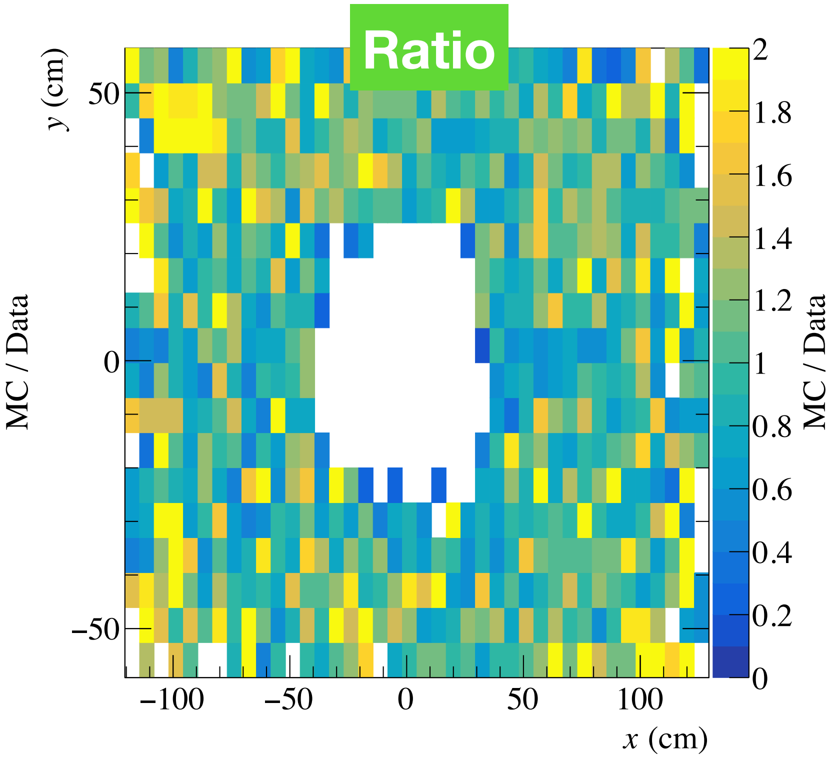


- Due to the RD/MC disagreement of track population on outer part of HG01Y1 from W target, we decided to remove them for the moment. (the large sensitivity on λ extraction which concluded from 2015 data analysis)

Theta cut and Momentum cut

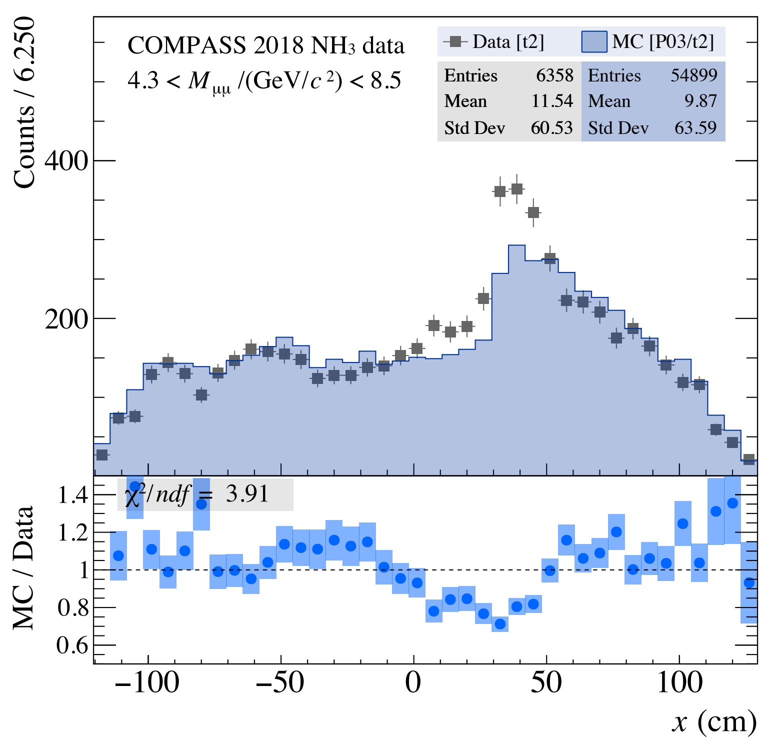
HO03Y1

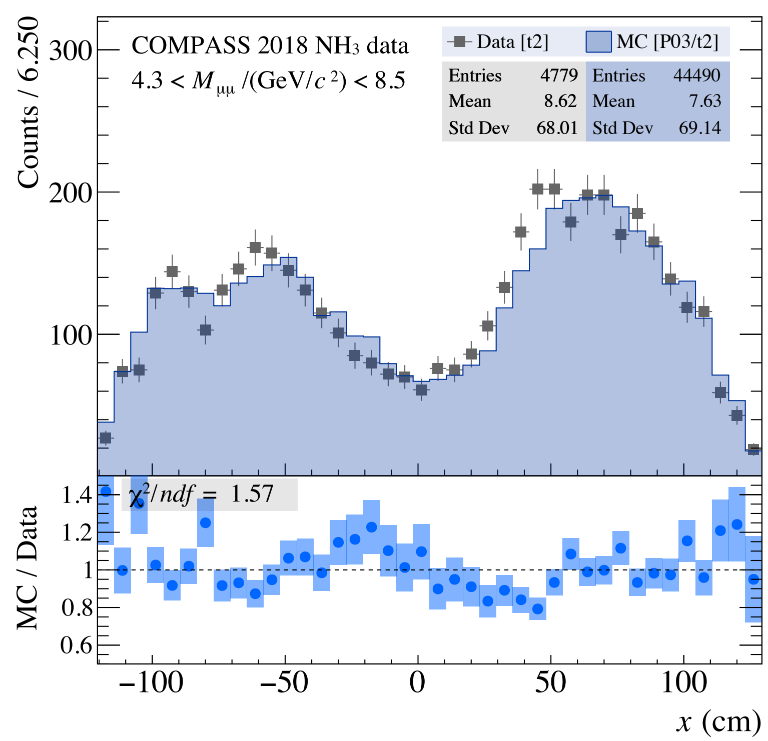




#paris (NH_3)	OTLAST
original	6358
Theta cut, momentum cut	4779
reduction rate	-25%

projection to x





Theta cut : $5.0 \cdot \theta_{\mu^+} > \theta_{\mu^-} > 0.2 \cdot \theta_{\mu^+}$

Momentum cut : $p_{\mu^\pm} > 7$ GeV/c, $|p_{\mu^+} - p_{\mu^-}| < 180$ GeV/c

- The RD/MC disagreement region on HO03Y1 can be removed by theta cut.
- This disagreement region only presented in NH_3 target, so we just applied this cut for NH_3 event.