Status Report of Angular Coefficients

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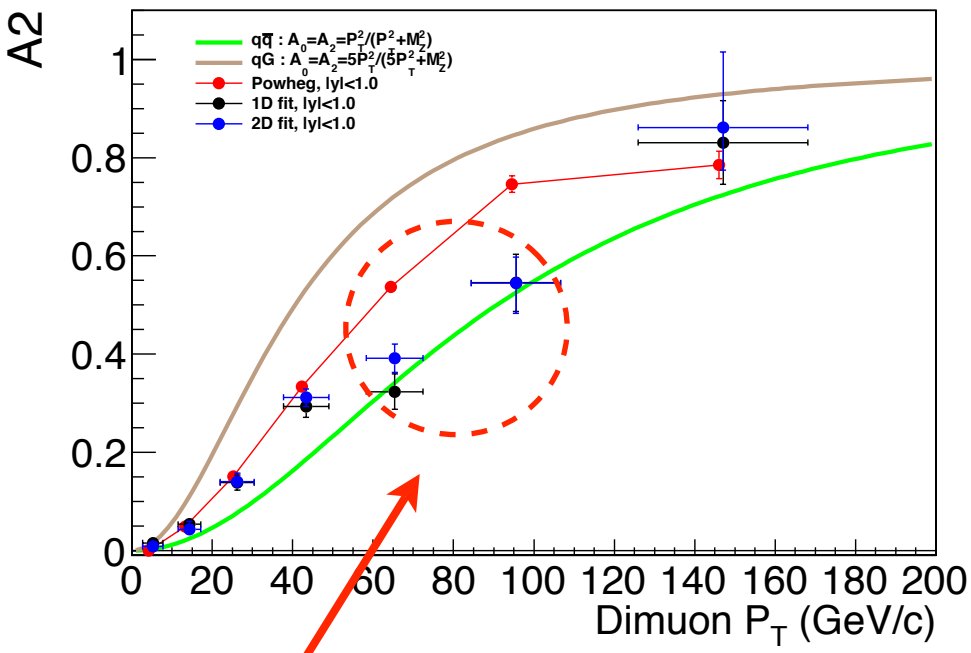
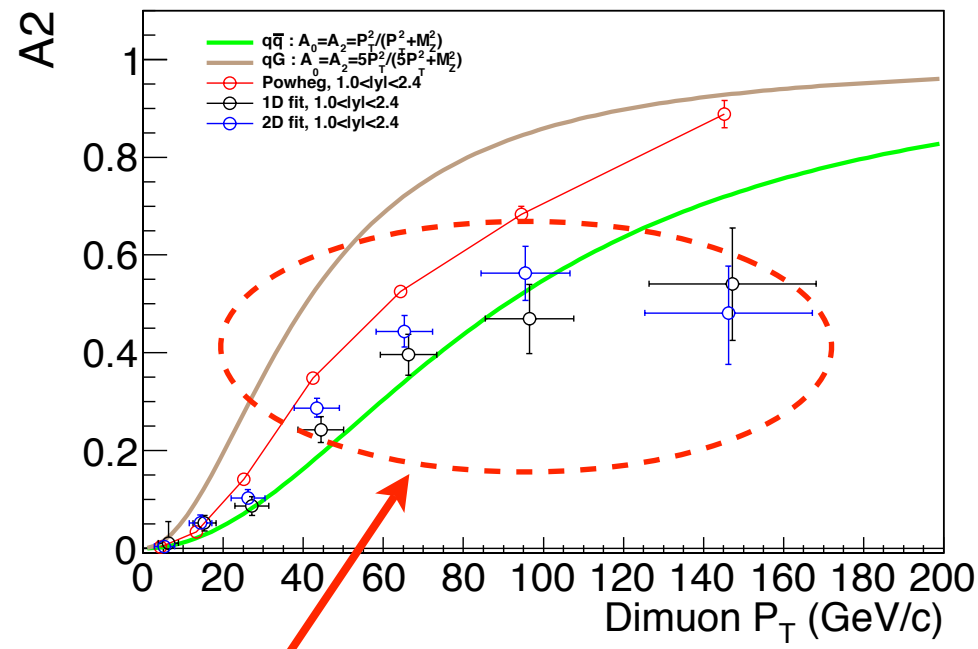
Status of analysis (I)

- Angular coefficients measurement in 7 TeV data
  - Analysis note : AN-2013/180,183 and SMP-13-010
  - Analysis status
    - A2 in high P_T needs to be understood → investigating
      - A2 shows unexpected result in high P_T region



A2 in |y|<1.0 drops in these two bins



A2 in 1.0<|y|<2.4 is systematically lower in most of P_T bins

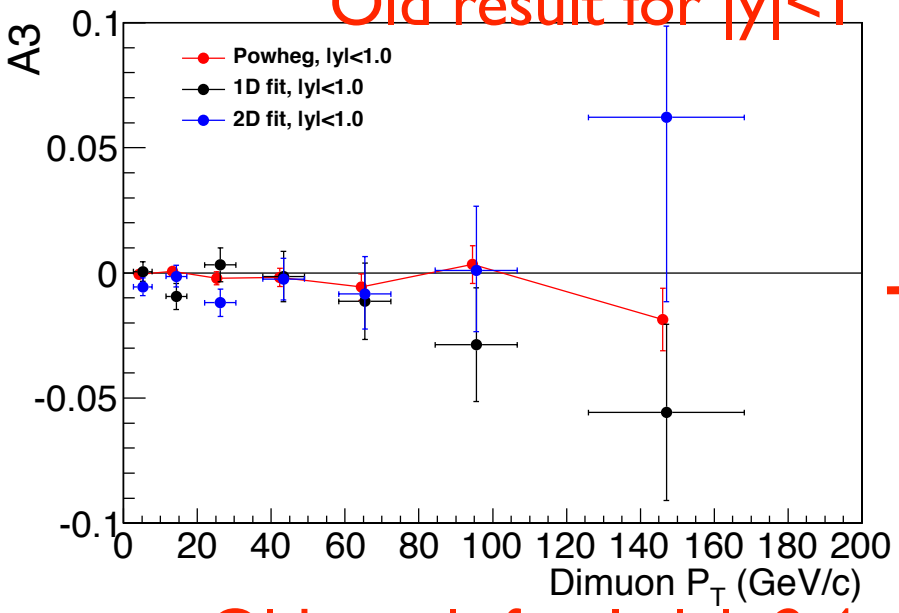
Status of analysis (II)

- 1D vs. 2D fitting result
  - Some bins in A0 and A3 result shows difference b/w 1D vs. 2D
  - Found a bug in ϕ(CS) calculation (sign assignment when y<0)
    - It only affects in 1D result
- Cross-check of the systematic uncertainty
  - Efficiency systematics
    - (η,ϕ) dependence considered for the central value
    - (η,p_T) dependence is applied to consider systematics
  - PU correction systematics
    - 2D fitting method had asymmetric error → found a bug
    - Systematic error is updated fixing a bug

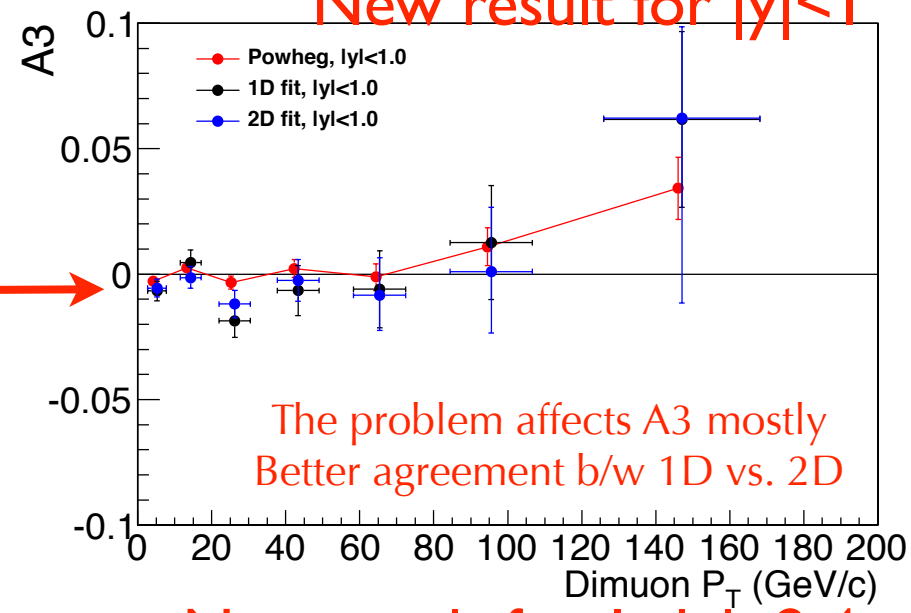
1D vs. 2D result

- ϕ(CS) calculation in 1D package had a problem with sign assignment
- Update 1D fitting result fixing the problem : Only A3 changes

Old result for |y|<1

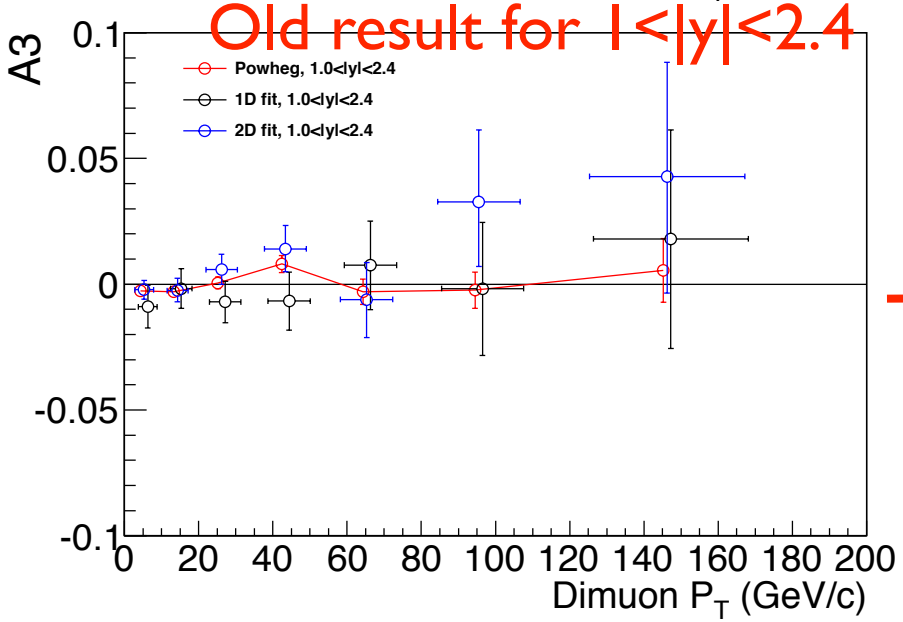


New result for |y|<1

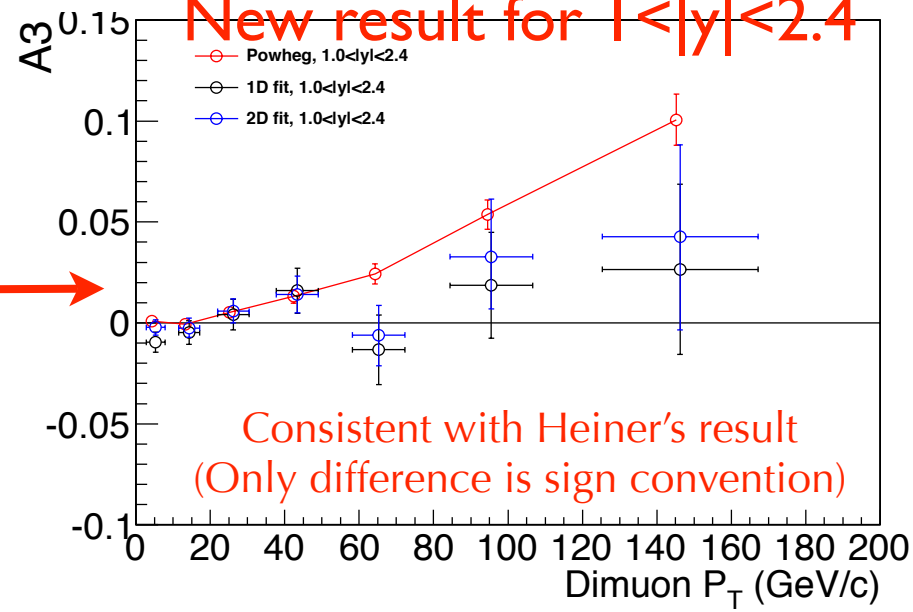


The problem affects A3 mostly
Better agreement b/w 1D vs. 2D

Old result for 1<|y|<2.4



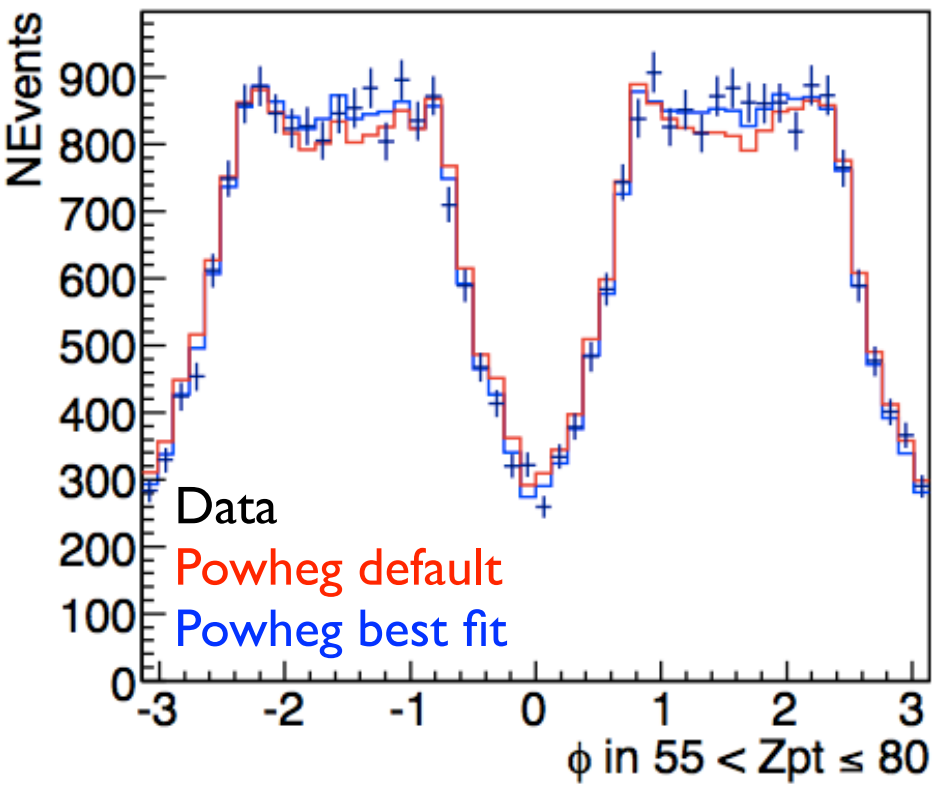
New result for 1<|y|<2.4



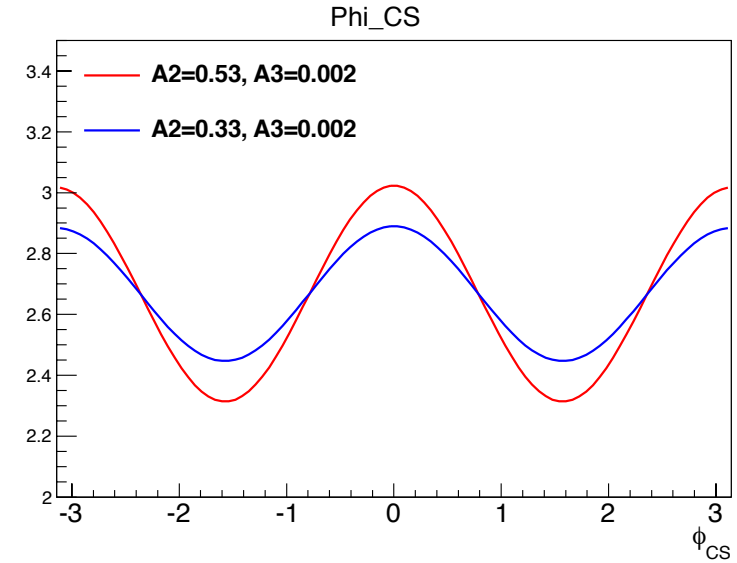
Consistent with Heiner's result
(Only difference is sign convention)

A2 in high P_T

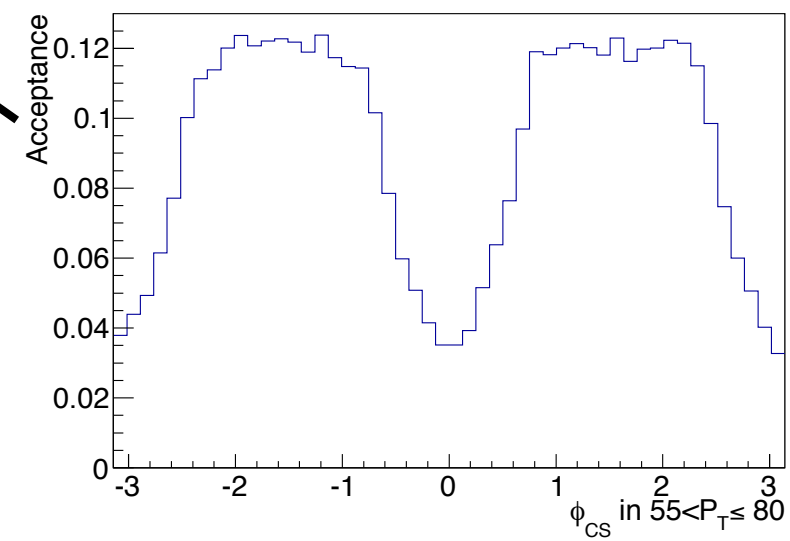
- ϕ_{CS} distribution looks more complicated in high P_T due to acceptance



ϕ_{CS} shape



A×ε



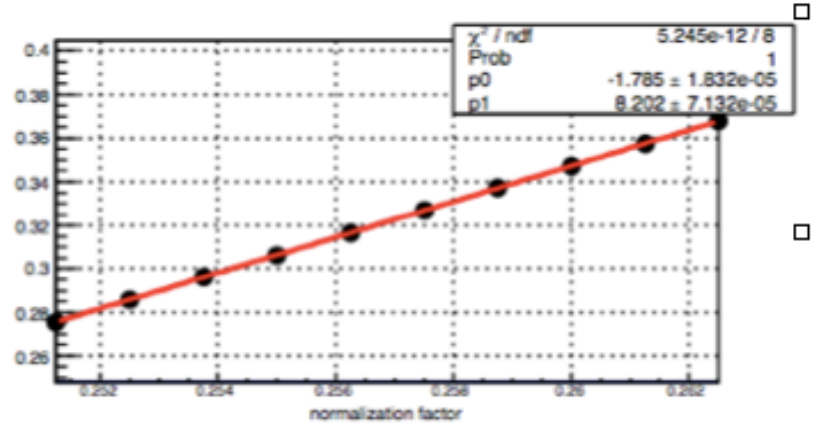
Found the shape difference b/w data and MC from binning

muon p_T acceptance in P_T is important to understand shape

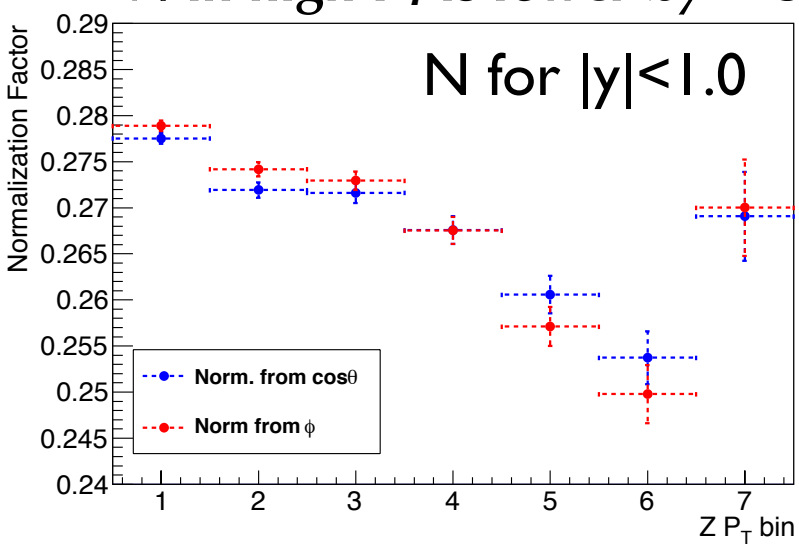
A2 vs. normalization

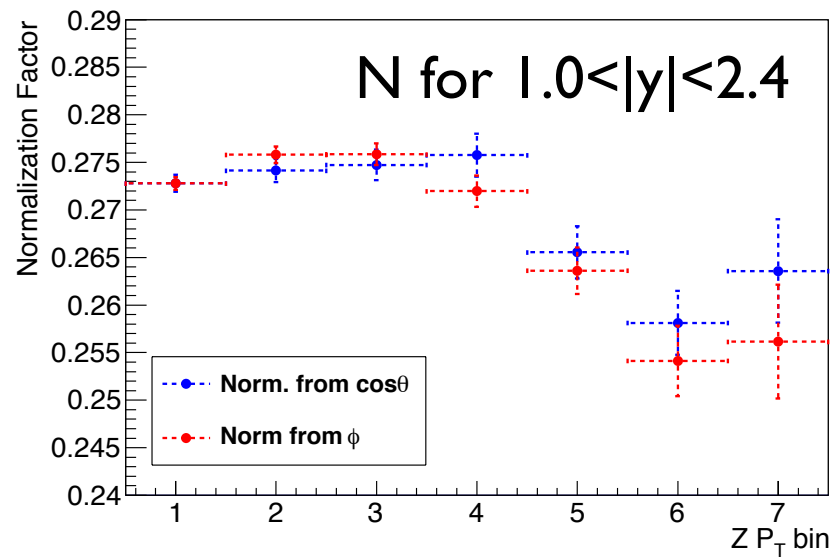
- Normalization (N) is determined by fitter
  - If Z P_T shape in MC describes data well, N should be flat in P_T
  - Z P_T correction derived for Rochester correction is applied
    - The correction was measured using 2011A data only
- Found that A2 in high PT has a correlation with the normalization

A2 vs. N in $55<P_T<80$
Slope = 8.20
(A0 has less correlation with N)



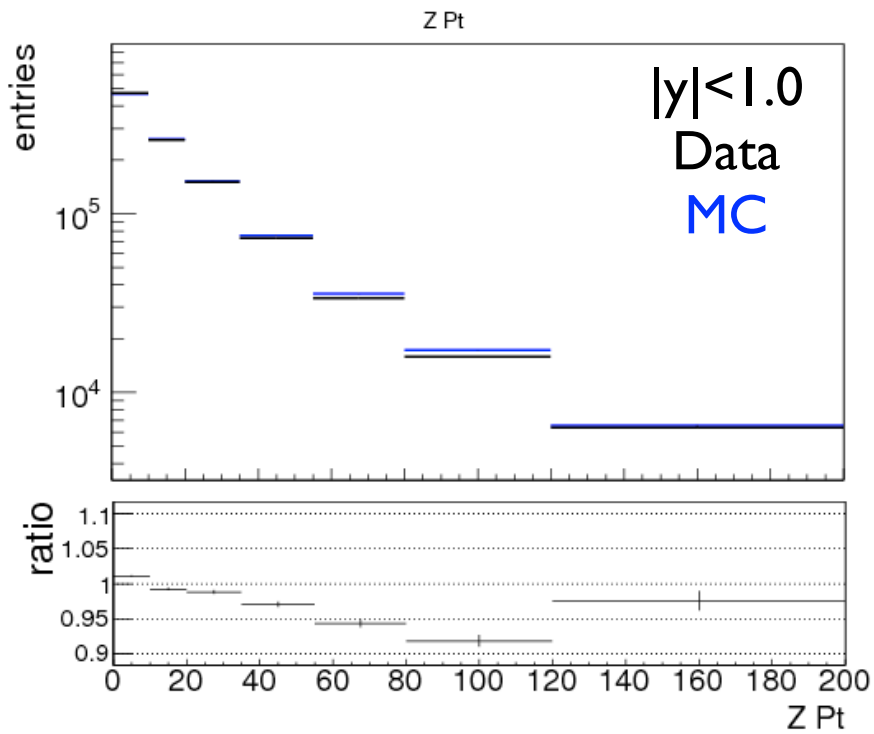
N in high P_T is lower by ~ 8 %

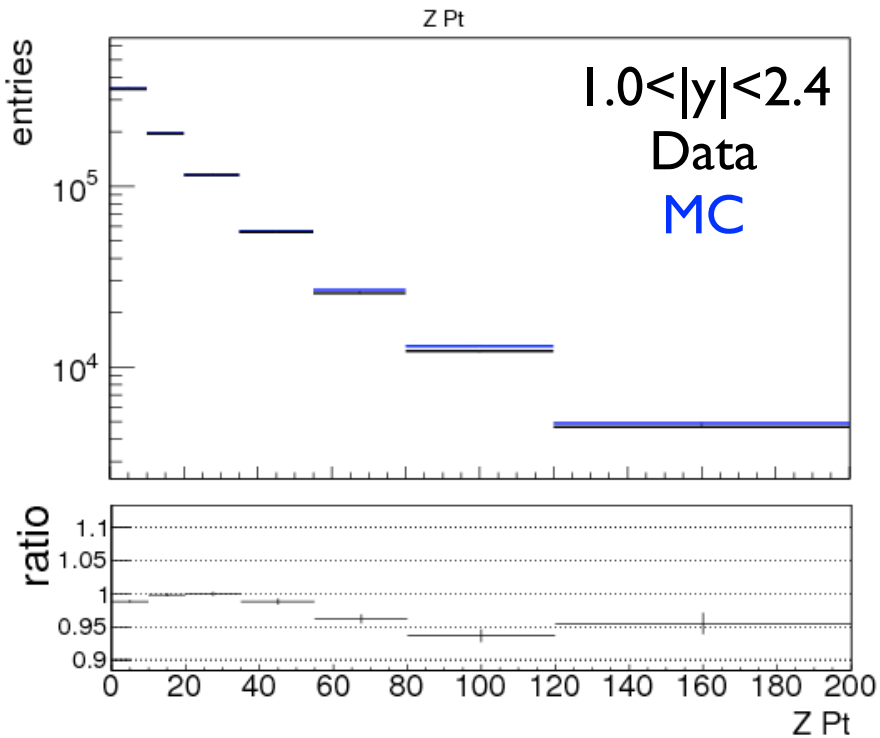




Z P_T correction

- Z P_T correction in Rochester correction package is applied
  - The correction was estimated using 2011A data (fine Z P_T bins)
- Checked Z P_T ratio (A+B) with 7 P_T bins used for angular coefficients

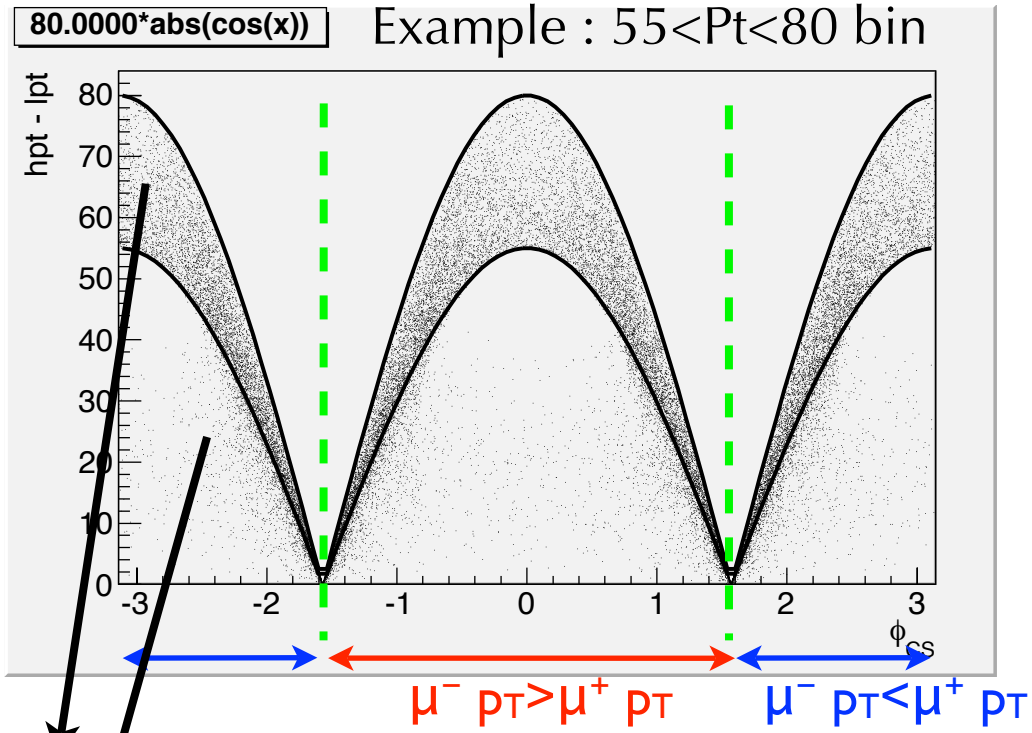


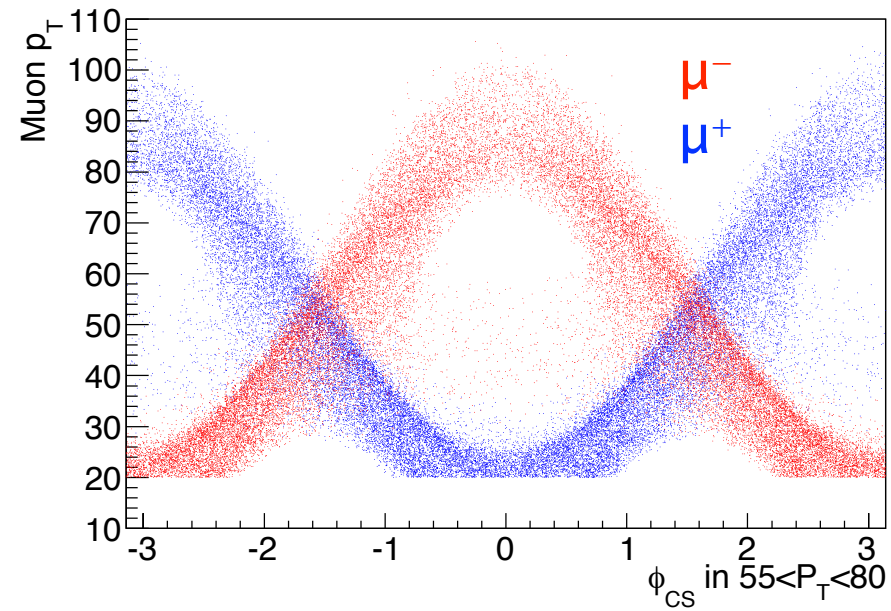


- High Z PT region has the difference up to ~ 8 % for both y region
- This ratio in P_T and y is applied into MC for better agreement

muon p_T vs. ϕ_{CS}

- Z PT limit in PT bin constrains muon p_T in ϕ_{CS}



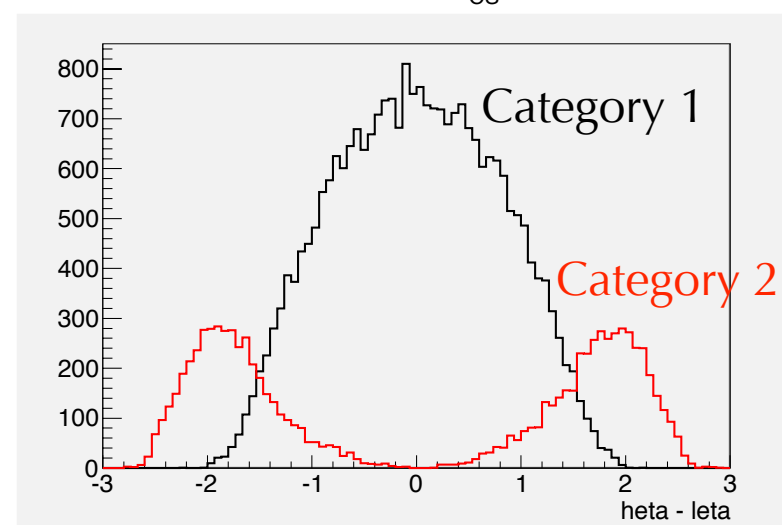


Category 1 : $55\times|\cos(\phi_{CS})|<(\text{hpt-lpt})<80\times|\cos(\phi_{CS})|$

Back-to-back in η

Category 2 : $(\text{hpt-lpt}) < 55\times|\cos(\phi_{CS})|$

It has opening angle ($\Delta\eta \sim 2.0$) in η



Category 1 has more restriction from Z P_T and p_T acceptance

Any small bias for μ^+ vs. μ^- p_T affects ϕ_{CS} distribution

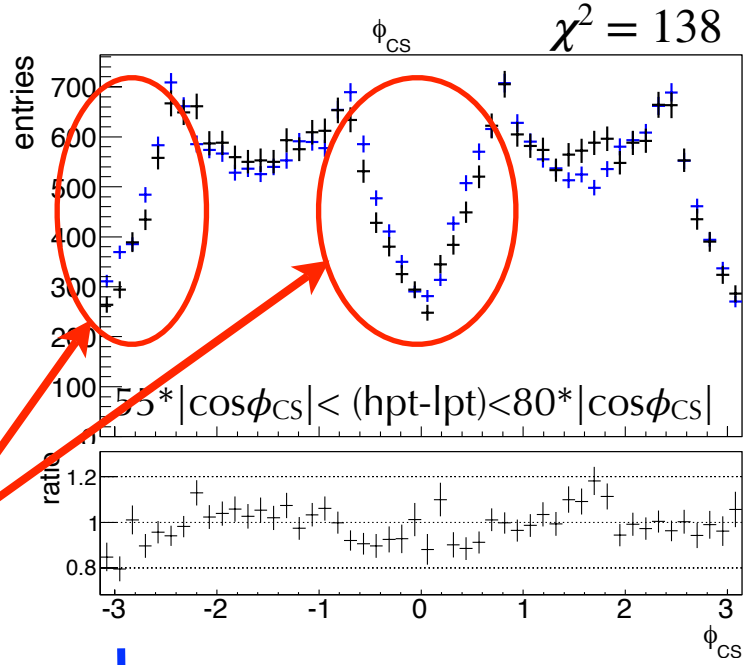
ϕ_{CS} in category 1 vs. 2

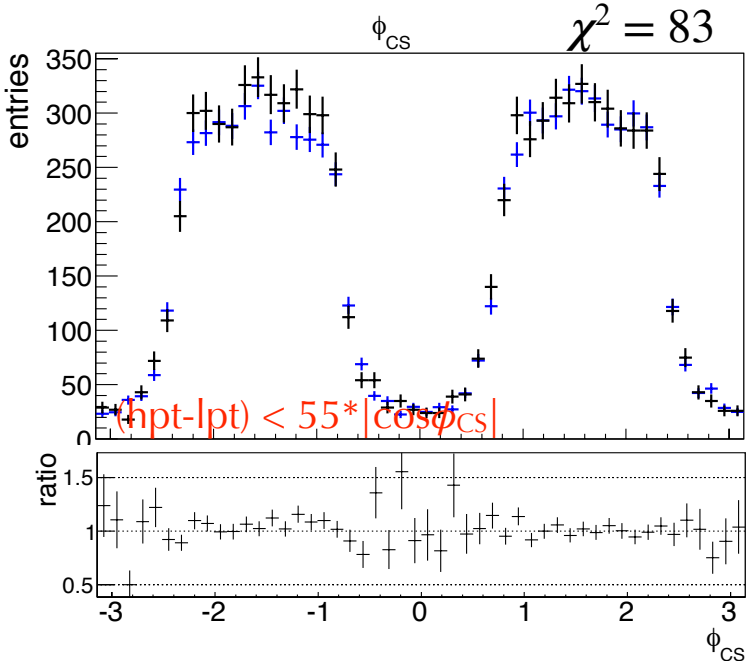
- Compare ϕ_{CS} in each category events in P_T (***data vs. MC***)

55<P_T<80
in |y|<1.0

*** Normalization is the total number of events in (y, pt) bin to compare the shape

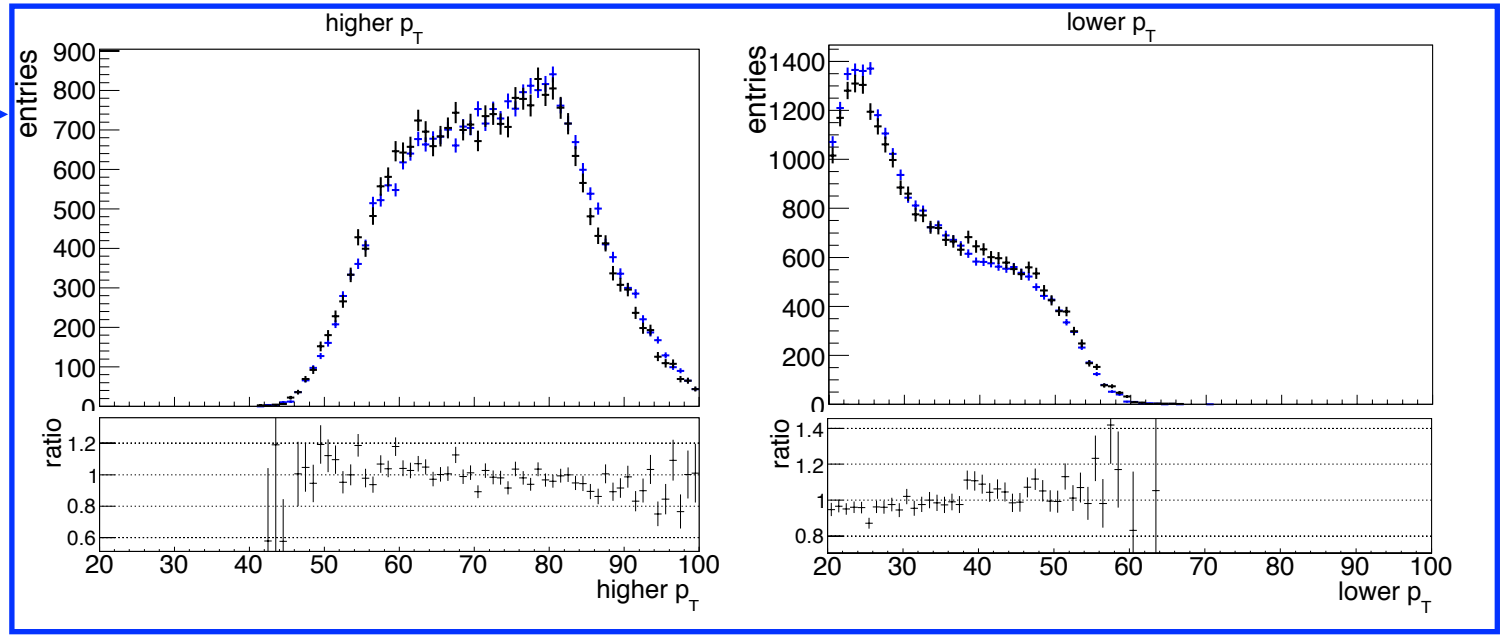
Sensitive to p_T acceptance





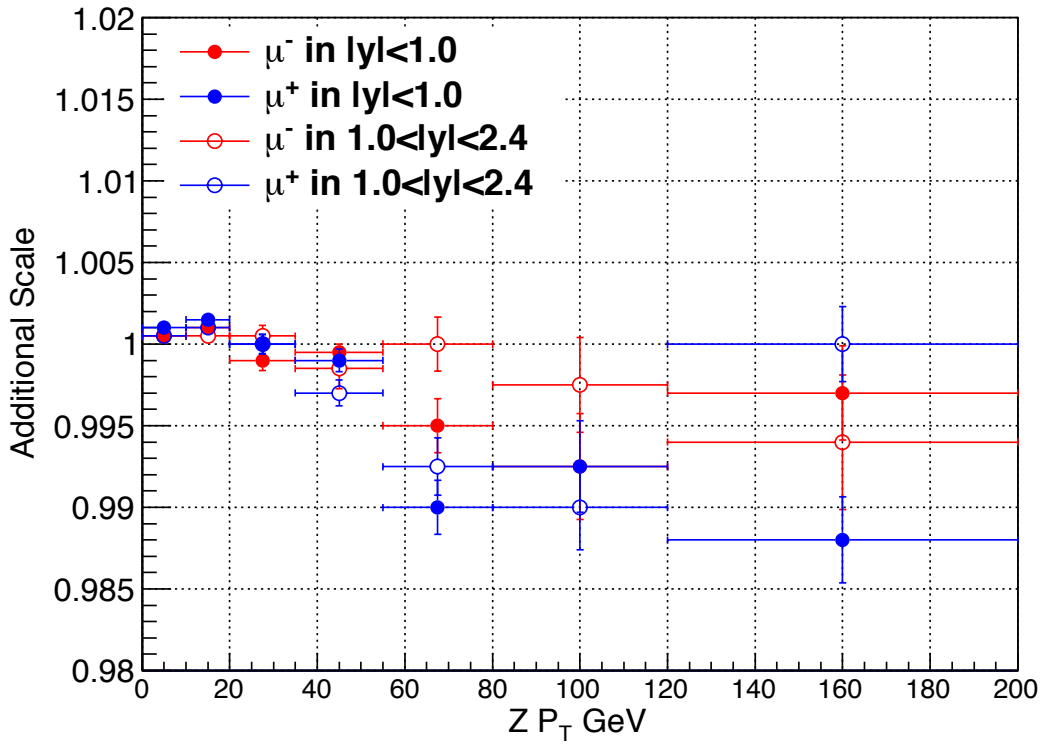
higher and lower muon pT for category 1

Ratio plot indicates the shape difference (bkg. is not subtracted yet)



Muon p_T corr. in Z P_T and y

- Estimate the muon momentum correction in Z P_T and y for μ^+ vs. μ^-
  - Rochester correction is applied to remove muon p_T bias
  - It might not be sufficient enough for this precision measurement
  - Find the minimum χ^2 of muon p_T distribution b/w data and MC
  - Background is not subtracted yet in muon p_T → need to update



High PT region needs up to ~ 1% additional correction and the correction has charge dependence

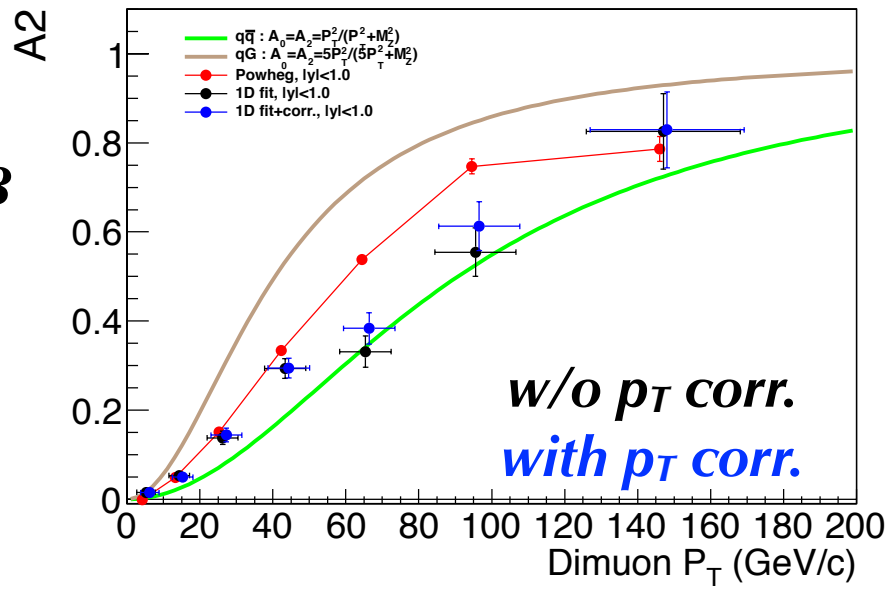
χ^2 of ϕ_{CS} distribution is improved after the additional correction

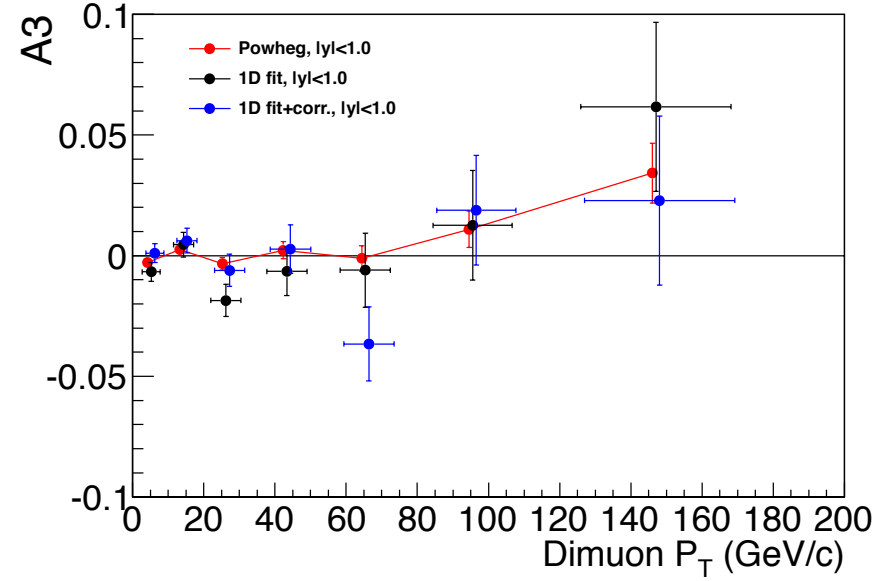
χ^2 of ϕ_{CS} in (55<PT<80, |y|<1.0) :
χ^2 in category 1 : 138 → 92
χ^2 in category 2 : 83 → 72

A2 and A3 after muon p_T corr.

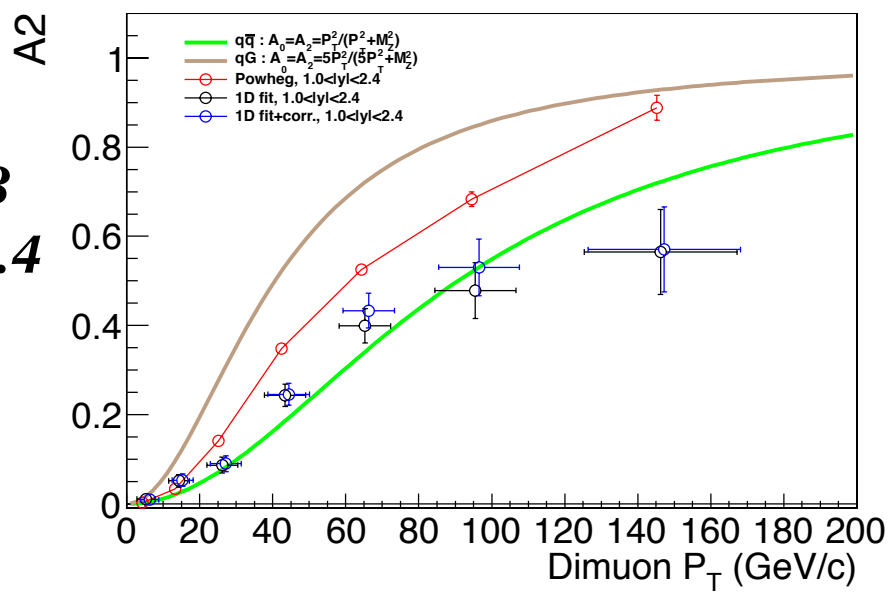
- Refit angular coefficients after applying muon p_T correction in (P_T, y)
  - The change in A0 and A4 is negligible

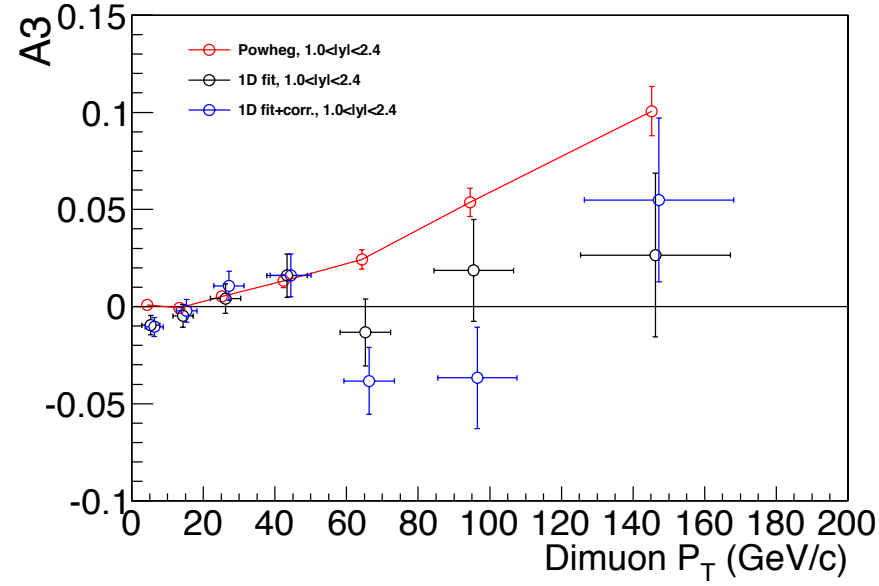
A2 and A3 for |y|<1





A2 and A3 for 1<|y|<2.4





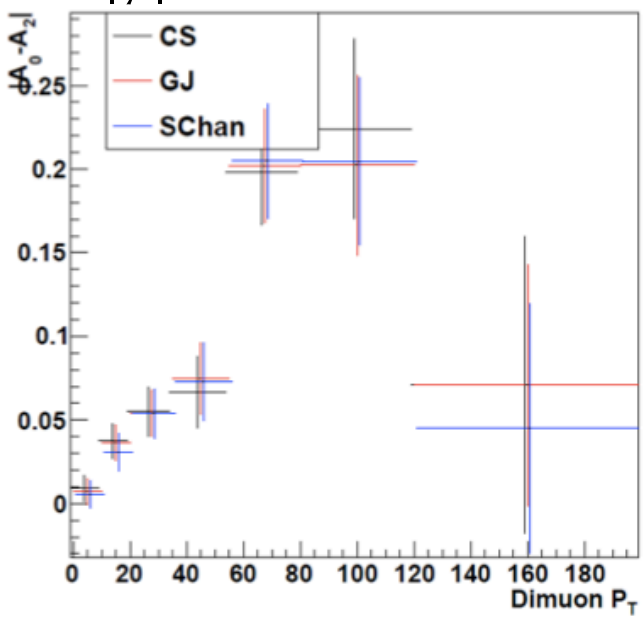
Other items for A2 issue (I)

- We also performed various approaches to understand A2 in high P_T
- The effect from the items listed here was negligible
  - FSR (QED) effect :
    - Tried to refit with tight mass window (80<M<100)
    - David estimated the migration before vs. after FSR in different frame in bins (https://indico.cern.ch/getFile.py/access?contribId=2&resId=0&materialId=slides&confId=256881)
    - At the end, the change in A0 and A2 are negligible
  - Efficiency in (η, ϕ) vs. (η, p_T) dependence
    - A0, A1 change from (η, p_T) dependence is large (~ stat. error)
    - A2, A3, and A4 change is small compared to stat. error
      - Still, need to include as the systematic error of efficiencies
      - More details later in systematic section
  - Test Lam-Tung relation (A0-A2) in different frame
    - Lam-Tung relation doesn't have any frame dependence
    - If there is no bug in CS frame, A0-A2 should be same in all frame
    - See next slide for the plot

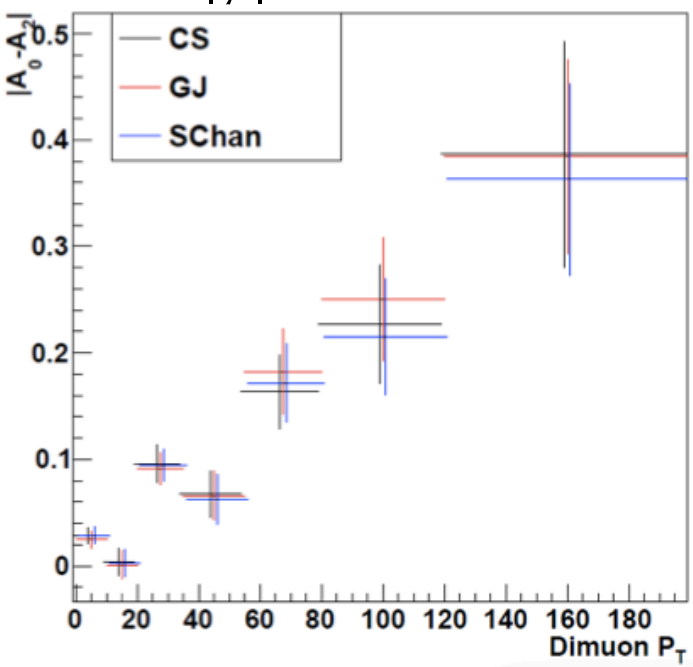
Other items for A2 issue (II)

- |A0-A2| in Gottfried-Jackson(GJ) and s-channel helicity(Schan) frame

|y|<1.0



1.0<|y|<2.4



- All frames have the similar result → No frame bias shown in CS frame

- It seems that the additional muon p_T tuning is the most promissing item
  - The background level increases in Z P_T
  - Refit the correction with the background subtraction and check the result

Systematic uncertainty check

- 2D fitting result had asymmetric PU systematic error
  - A bug found to generate the PU systematic error
  - Fixed a bug and now PU systematic error is symmetric
- Efficiency systematic uncertainty
  - We only consider the systematic error from background estimation and method (fitting vs. event counting)
  - Add the systematics between (η,ϕ) vs. (η, p_T) dependence
  - A0 and A1 in low P_T region changes bigger than stat. error
  - Other angular coefficients change much smaller than stat. error, but still larger than the systematic error considered before
  - Now, we add (η, p_T) dependence systematic error for the efficiency
    - The updated table for syst. error in 2D fitting is listed next slide

• A0 and A1 result and systematic error in |y|<1.0

Table 1: Central value of A0 for $|\gamma^*/Z\ Y| < 1.0$, with statistical and systematics uncertainties. With 7 TeV data we are statistics limited.

γ^*/ZP_T; $\|Y\| < 1.0$	0–10	10–20	20–35	35–55	55–80	80–120	120–200
A0 Central Value	0.0158	0.0808	0.1944	0.3828	0.5880	0.7637	0.9139
Stat. Uncert.	0.0049	0.0065	0.0100	0.0133	0.0160	0.0227	0.0350
PU Syst.	$\pm^{-0.0005}_{0.0006}$	$\pm^{-0.0004}_{0.0002}$	$\pm^{0.0005}_{-0.0007}$	$\pm^{0.0002}_{-0.0004}$	$\pm^{-0.0006}_{0.0008}$	$\pm^{0.0031}_{-0.0036}$	$\pm^{0.0018}_{-0.0018}$
Mom. Corr. Syst	0.0006	0.0011	0.0011	0.0006	0.0007	0.0027	0.0044
TnP Syst	0.0019	0.0019	0.0019	0.0017	0.0014	0.0037	0.0043
ZP_T Syst	−0.0018	0.0004	−0.0017	−0.0004	0.0002	−0.0009	0.0008
Finite MC	0.0016	0.0007	0.0007	0.0006	0.0005	0.0005	0.0005
MSTW PDF Syst	$\pm^{0.0000}_{0.0036}$	$\pm^{0.0027}_{0.0000}$	$\pm^{0.0014}_{0.0007}$	$\pm^{0.0013}_{0.0000}$	$\pm^{0.0081}_{0.0000}$	$\pm^{0.0030}_{0.0002}$	$\pm^{0.0038}_{0.0001}$
nnpdf PDF Syst	$\pm^{0.0002}_{0.0000}$	$\pm^{0.0001}_{0.0000}$	$\pm^{0.0000}_{0.0002}$	$\pm^{0.0000}_{0.0001}$	$\pm^{0.0003}_{0.0000}$	$\pm^{0.0001}_{0.0000}$	$\pm^{0.0000}_{0.0002}$
Bkgd Syst	$\pm^{0.0009}_{0.0009}$	$\pm^{0.0010}_{0.0010}$	$\pm^{0.0008}_{0.0007}$	$\pm^{0.0007}_{0.0007}$	$\pm^{0.0016}_{0.0016}$	$\pm^{0.0016}_{0.0016}$	$\pm^{0.0000}_{0.0001}$
FSR Syst	−0.0001	−0.0010	−0.0014	−0.0004	0.0002	0.0001	0.0000
(Eta,Phi/Pt) Syst	0.0106	0.0097	0.0100	0.0112	0.0100	0.0045	−0.0028

Table 2: Central value of A1 for $\gamma^*/Z\ |Y| < 1.0$, with statistical and systematics uncertainties.

γ^*/ZP_T; $\|Y\| < 1.0$	0–10	10–20	20–35	35–55	55–80	80–120	120–200
A1 Central Value	0.0077	−0.0016	0.0223	0.0278	0.0199	−0.0078	0.0629
Stat. Uncert.	0.0036	0.0050	0.0071	0.0116	0.0194	0.0264	0.0359
PU Syst.	$\pm^{-0.0001}_{0.0000}$	$\pm^{0.0003}_{-0.0004}$	$\pm^{-0.0001}_{-0.0001}$	$\pm^{-0.0006}_{0.0005}$	$\pm^{-0.0014}_{0.0009}$	$\pm^{0.0023}_{-0.0020}$	$\pm^{-0.0023}_{0.0017}$
Mom. Corr. Syst	0.0016	0.0013	0.0012	0.0015	0.0020	0.0024	0.0033
TnP Syst	0.0004	0.0005	0.0008	0.0015	0.0014	0.0032	0.0028
ZP_T Syst	0.0001	−0.0001	−0.0000	−0.0000	−0.0005	0.0005	0.0015
Finite MC	0.0011	0.0005	0.0005	0.0005	0.0006	0.0007	0.0004
MSTW PDF Syst	$\pm^{0.0007}_{0.0000}$	$\pm^{0.0000}_{0.0019}$	$\pm^{0.0003}_{0.0002}$	$\pm^{0.0008}_{0.0003}$	$\pm^{0.0000}_{0.0060}$	$\pm^{0.0026}_{0.0000}$	$\pm^{0.0000}_{0.0062}$
nnpdf PDF Syst	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0001}_{0.0000}$	$\pm^{0.0000}_{0.0001}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0001}_{0.0000}$
Bkgd Syst	$\pm^{0.0001}_{0.0001}$	$\pm^{0.0001}_{0.0001}$	$\pm^{0.0001}_{0.0001}$	$\pm^{0.0002}_{0.0002}$	$\pm^{0.0001}_{0.0000}$	$\pm^{0.0003}_{0.0002}$	$\pm^{0.0003}_{0.0001}$
FSR Syst	0.0000	−0.0000	−0.0000	−0.0000	−0.0001	−0.0001	−0.0001
(Eta,Phi/Pt) Syst	0.0018	0.0045	0.0070	0.0086	0.0067	0.0001	−0.0076

*** Other tables are in back-up slide

Summary

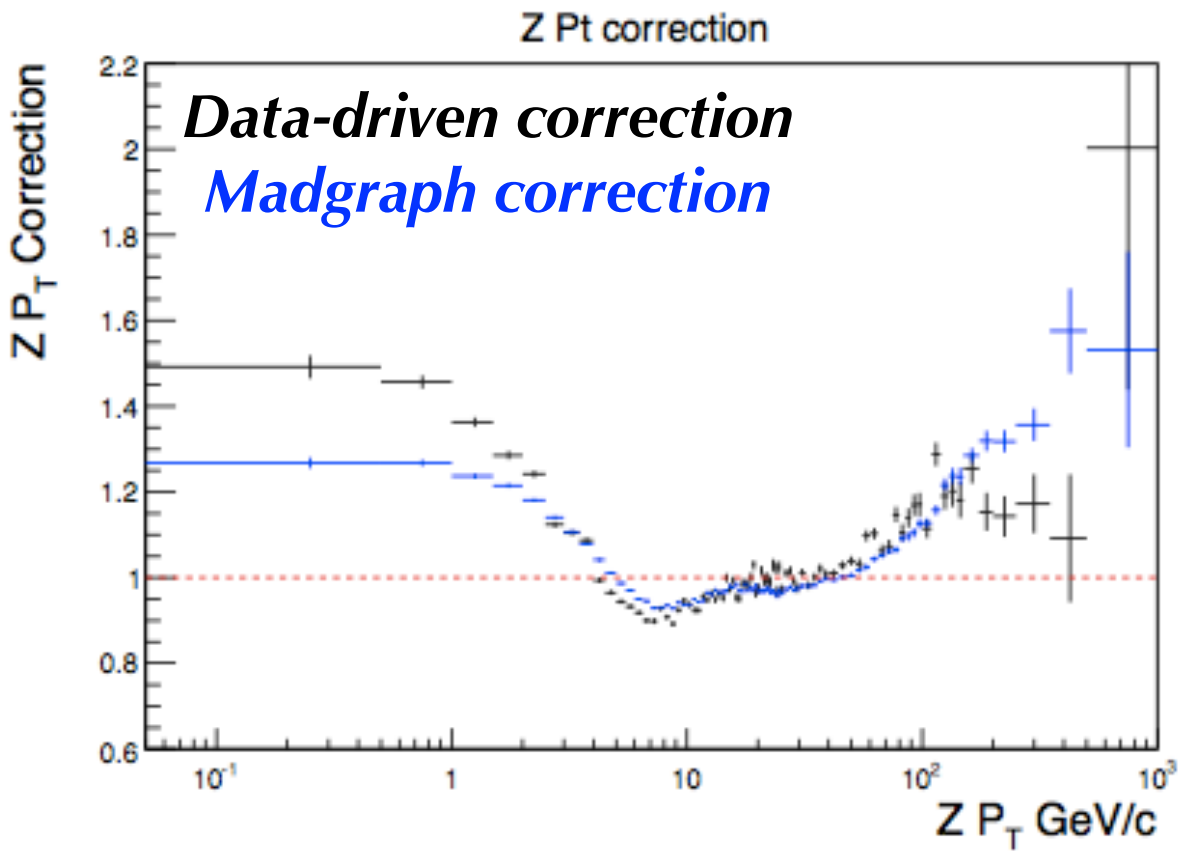
- Investigating A2 in high P_T region → the most priority in this stage
  - Tried many approaches to undestand A2 in high P_T region
  - The most promissing approach seems to understand muon p_T better
    - muon pT acceptance in Z P_T, y, and ϕ_{CS}
    - Fine tuning of muon p_T for each charge (μ^+ vs. μ^-)
    - Will try the fine muon p_T tuning with background subtraction
- Cross check of systematic uncertainty
  - Compare the systematic error b/w 1D and 2D package
  - Try to understand any difference
  - Confirm the procedure of the systematic erorr propagation

- Try to address the question/comment list from conveners

back-up slides

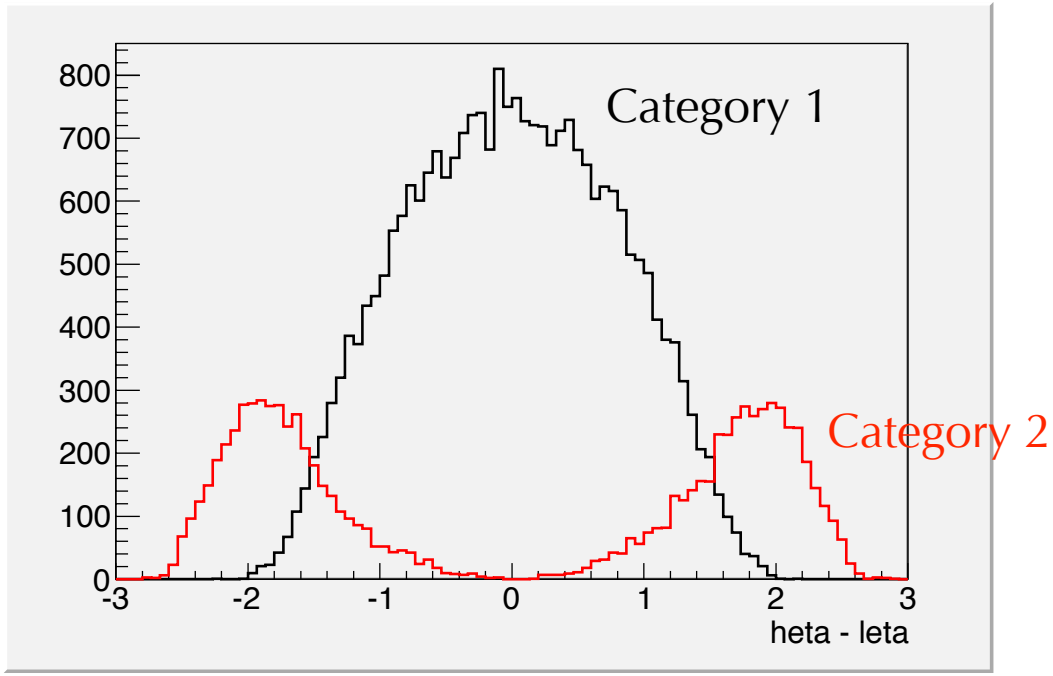
Z P_T correction

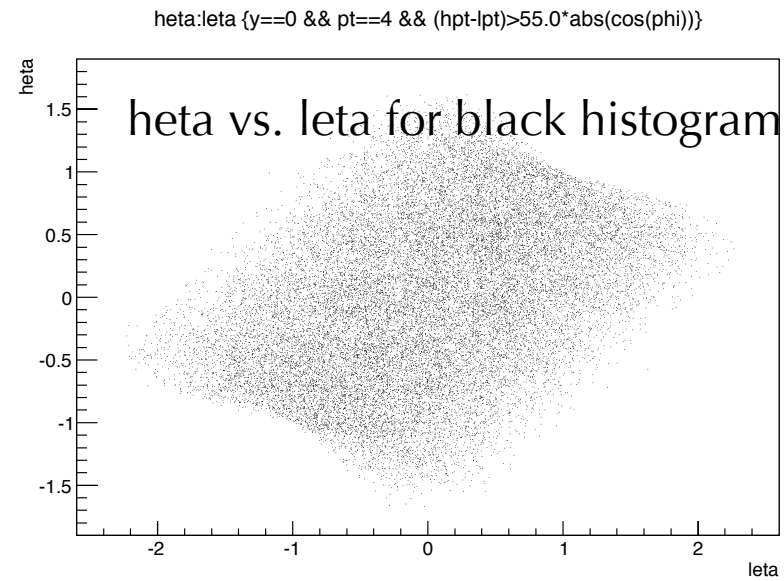
- Z P_T correction in Rochester correction package : 2011A data used

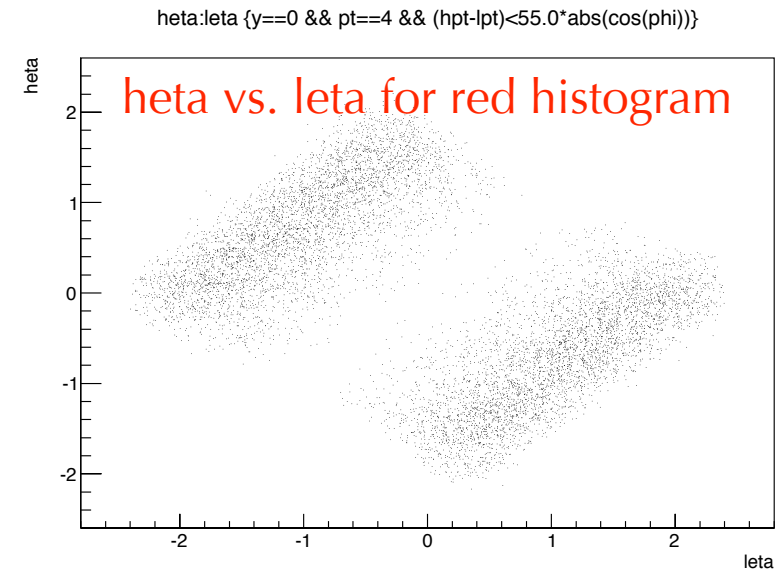


Event topology

- Events constrained to the kinematic range, opening angle







Black : $55*|\cos\phi_{CS}| < (hpt-lpt) < 80*|\cos\phi_{CS}|$

Red : $(hpt-lpt) < 55*|\cos\phi_{CS}|$
(opening angle in η is larger)

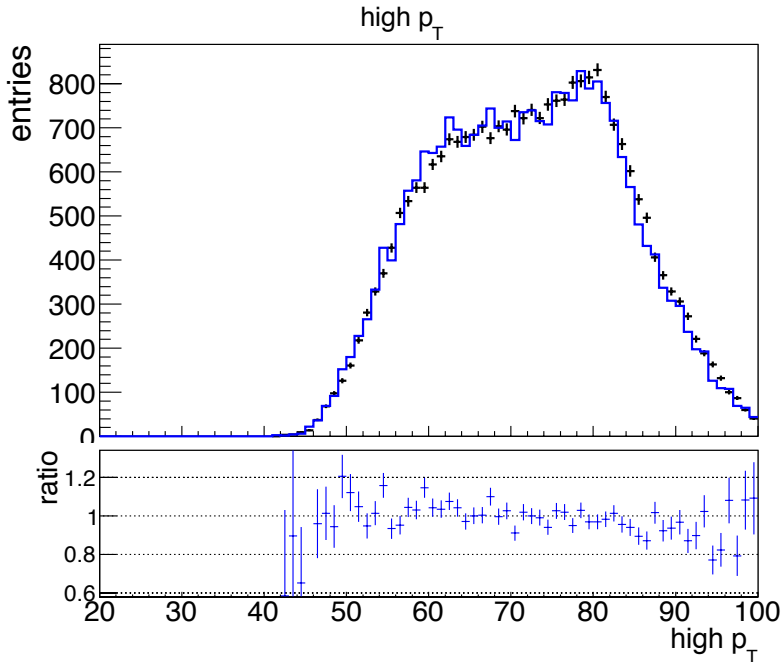
These two categories have different ϕ_{CS} distribution in P_T

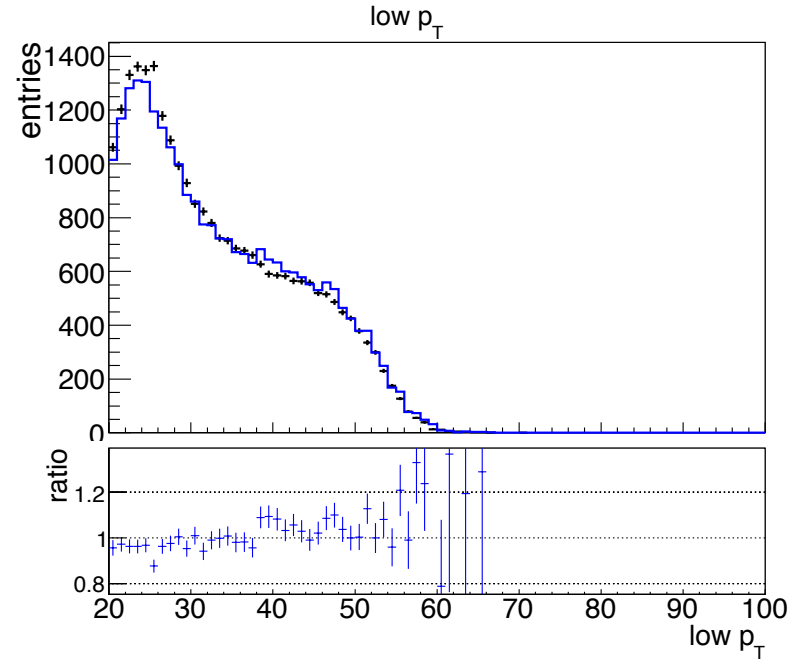
Check muon p_T spectrum

- p_T distribution comparison b/w data(blue) and MC(black)

55<P_T<80
in |y|<1.0

Category 1
high vs. low p_T

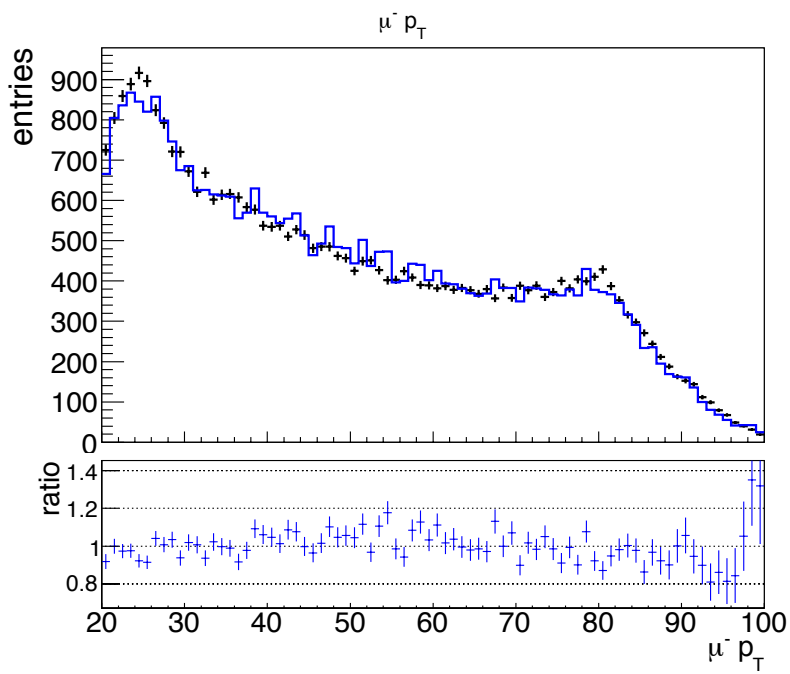




55<P_T<80
in |y|<1.0

All events
μ^- vs. μ^+ p_T

Low p_T region shows discrepancy



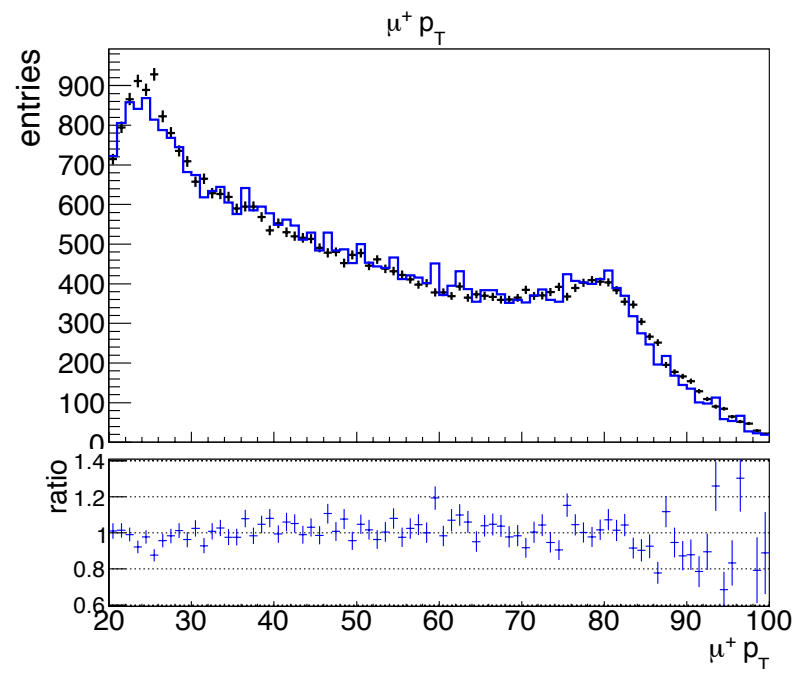


Table for 2D fitting result (I)

Table 3: Central value of A2 for γ^*/Z $|Y| < 1.0$, with statistical and systematics uncertainties.

$\gamma^*/Z P_T$; $\lvert Y\rvert < 1.0$	0–10	10–20	20–35	35–55	55–80	80–120	120–200
A2 Central Value	0.0068	0.0435	0.1393	0.3164	0.3897	0.5396	0.8430
Stat. Uncert.	0.0063	0.0084	0.0111	0.0168	0.0273	0.0489	0.0814
PU Syst.	$\pm^{-0.0004}_{0.0004}$	$\pm^{0.0003}_{-0.0001}$	$\pm^{0.0006}_{-0.0006}$	$\pm^{-0.0007}_{0.0008}$	$\pm^{-0.0019}_{0.0022}$	$\pm^{0.0046}_{-0.0067}$	$\pm^{0.0066}_{-0.0102}$
Mom. Corr. Syst	0.0005	0.0005	0.0009	0.0008	0.0023	0.0042	0.0073
TnP Syst	0.0006	0.0007	0.0008	0.0009	0.0012	0.0056	0.0102
$Z P_T$ Syst	0.0121	−0.0028	−0.0034	−0.0007	−0.0013	−0.0002	0.0009
Finite MC	0.0019	0.0008	0.0007	0.0007	0.0009	0.0011	0.0011
MSTW PDF Syst	$\pm^{0.0033}_{0.0000}$	$\pm^{0.0087}_{0.0000}$	$\pm^{0.0066}_{0.0000}$	$\pm^{0.0006}_{0.0018}$	$\pm^{0.0031}_{0.0001}$	$\pm^{0.0000}_{0.0156}$	$\pm^{0.0034}_{0.0071}$
nnpdf PDF Syst	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0001}_{0.0000}$	$\pm^{0.0001}_{0.0000}$	$\pm^{0.0001}_{0.0000}$	$\pm^{0.0000}_{0.0005}$	$\pm^{0.0003}_{0.0000}$	$\pm^{0.0000}_{0.0003}$
Bkgd Syst	$\pm^{0.0003}_{0.0002}$	$\pm^{0.0013}_{0.0013}$	$\pm^{0.0003}_{0.0003}$	$\pm^{0.0012}_{0.0012}$	$\pm^{0.0016}_{0.0016}$	$\pm^{0.0017}_{0.0020}$	$\pm^{0.0054}_{0.0053}$
FSR Syst	−0.0005	−0.0016	−0.0012	0.0002	0.0008	0.0008	−0.0002
(Eta,Phi/Pt) Syst	0.0001	0.0010	0.0014	0.0040	0.0031	−0.0040	−0.0196

Table 4: Central value of A3 for γ^*/Z $|Y| < 1.0$, with statistical and systematics uncertainties.

$\gamma^*/Z P_T$; $\lvert Y\rvert < 1.0$	0–10	10–20	20–35	35–55	55–80	80–120	120–200
A3 Central Value	−0.0061	−0.0010	−0.0124	−0.0033	−0.0085	0.0026	0.0825
Stat. Uncert.	0.0028	0.0038	0.0052	0.0082	0.0137	0.0229	0.0359
PU Syst.	$\pm^{0.0001}_{-0.0001}$	$\pm^{-0.0003}_{0.0003}$	$\pm^{-0.0005}_{0.0006}$	$\pm^{0.0002}_{-0.0001}$	$\pm^{-0.0004}_{0.0005}$	$\pm^{0.0014}_{-0.0014}$	$\pm^{0.0008}_{-0.0015}$
Mom. Corr. Syst	0.0020	0.0015	0.0012	0.0014	0.0013	0.0030	0.0031
TnP Syst	0.0003	0.0003	0.0003	0.0011	0.0003	0.0019	0.0017
$Z P_T$ Syst	0.0001	0.0000	0.0000	−0.0000	−0.0000	0.0005	−0.0013
Finite MC	0.0009	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005
MSTW PDF Syst	$\pm^{0.0004}_{0.0000}$	$\pm^{0.0008}_{0.0000}$	$\pm^{0.0007}_{0.0000}$	$\pm^{0.0006}_{0.0003}$	$\pm^{0.0011}_{0.0003}$	$\pm^{0.0070}_{0.0000}$	$\pm^{0.0000}_{0.0093}$
nnpdf PDF Syst	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0002}_{0.0000}$	$\pm^{0.0001}_{0.0000}$
Bkgd Syst	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0001}_{0.0001}$	$\pm^{0.0002}_{0.0002}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0008}_{0.0008}$
FSR Syst	−0.0000	0.0000	0.0000	0.0000	−0.0000	−0.0000	−0.0002
(Eta,Phi/Pt) Syst	−0.0000	−0.0000	0.0000	−0.0001	−0.0001	−0.0005	0.0008

Table for 2D fitting result (II)

γ^*/ZP_T; $\lvert Y\rvert < 1.0$	0–10	10–20	20–35	35–55	55–80	80–120	120–200
A4 Central Value	0.0165	0.0046	0.0150	0.0324	0.0018	−0.0075	−0.0011
Stat. Uncert.	0.0039	0.0054	0.0072	0.0102	0.0137	0.0178	0.0253
PU Syst.	$\pm^{-0.0002}_{0.0002}$	$\pm^{0.0003}_{-0.0003}$	$\pm^{-0.0002}_{0.0001}$	$\pm^{0.0009}_{-0.0008}$	$\pm^{-0.0002}_{0.0000}$	$\pm^{0.0002}_{0.0000}$	$\pm^{0.0006}_{-0.0006}$
Mom. Corr. Syst	0.0002	0.0003	0.0006	0.0009	0.0008	0.0015	0.0030
TnP Syst	0.0001	0.0002	0.0007	0.0011	0.0005	0.0016	0.0032
ZP_T Syst	−0.0000	0.0000	−0.0000	0.0000	−0.0002	−0.0002	0.0006
Finite MC	0.0011	0.0005	0.0005	0.0004	0.0004	0.0004	0.0003
MSTW PDF Syst	$\pm^{0.0006}_{0.0003}$	$\pm^{0.0001}_{0.0014}$	$\pm^{0.0013}_{0.0001}$	$\pm^{0.0000}_{0.0025}$	$\pm^{0.0000}_{0.0029}$	$\pm^{0.0000}_{0.0046}$	$\pm^{0.0007}_{0.0015}$
nnpdf PDF Syst	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0000}_{0.0002}$	$\pm^{0.0000}_{0.0004}$	$\pm^{0.0000}_{0.0000}$
Bkgd Syst	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0001}_{0.0001}$	$\pm^{0.0000}_{0.0000}$	$\pm^{0.0001}_{0.0001}$	$\pm^{0.0001}_{0.0002}$	$\pm^{0.0000}_{0.0001}$	$\pm^{0.0001}_{0.0001}$
FSR Syst	−0.0000	−0.0000	−0.0000	0.0001	−0.0000	0.0000	−0.0000
(Eta,Phi/Pt) Syst	0.0000	0.0000	−0.0000	0.0001	0.0000	0.0002	0.0004

Table 5: Central value of A4 for γ^*/Z $\lvert Y\rvert < 1.0$, with statistical and systematics uncertainties.