High-p_T muon resolution measurement for 2022 and 2023

2024/06/03

Jan-Frederik Schulte, Yibo Zhong

Introduction and Method

- Measure 2022 and 2023 muon p_T resolution using spark_tnp.
  - Goal is to validate resolution modeling in MC
- Can't measure the resolution for single muons in collision data
  - -> Measure the dimuon resolution at the Z peak as function of leading muon p_T
- Muon selections: p_T>53 Gev, $|\eta|$<2.4 , relative momentum uncertainty< 0.3, high-pt ID, and one of the muons need to have fired the single muon trigger (HLT_CascadeMu100 or HLT_HighPtTkMu100 or HLT_Mu50_v)
  - Pair selection: require tag muon p_T > probe muon p_T , pair_tuneP_normalchi2 < 20 and cos_angle < pi -0.02

Introduction and Method

- Consider two categories: tag_abseta < 1.2 and 1.2 < tag_abseta < 2.4
- Pt bins: [52, 72, 100, 152, 200, 275, 452, 800] GeV
- Data: 2022 , 2022_EE, 2023, and 2023_BPix data taking periods
- MC: Inclusive Boosted DY, binned in Z p_T

Procedures:

1, Create the dimuon(Z) mass histograms as a function of leading muon pT

2, Fit the Histograms with 3 different functions : Crystal Ball, Cruijff, and Double-sided Crystal Ball

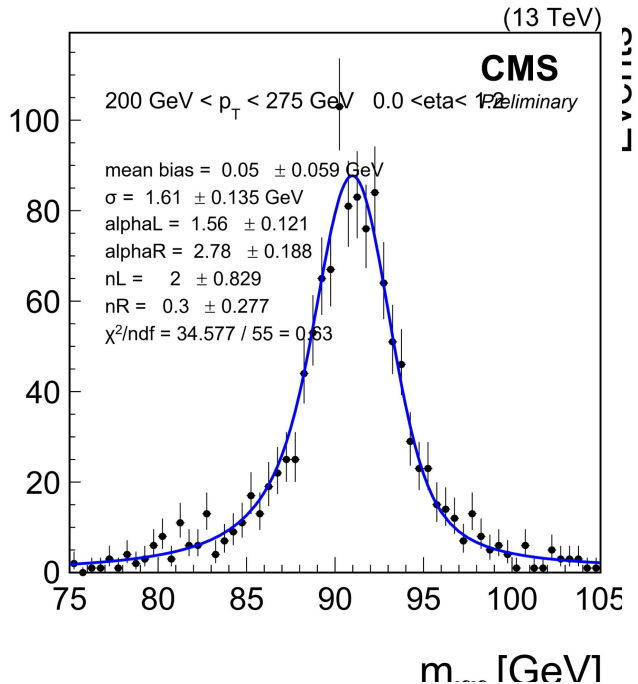
- We fit a convolution of the Breit-Wigner function with one of the three parametrizations of the resolution
- Double-sided Crystal Ball is default, Cruijff and Crystal Ball used for systematic varations

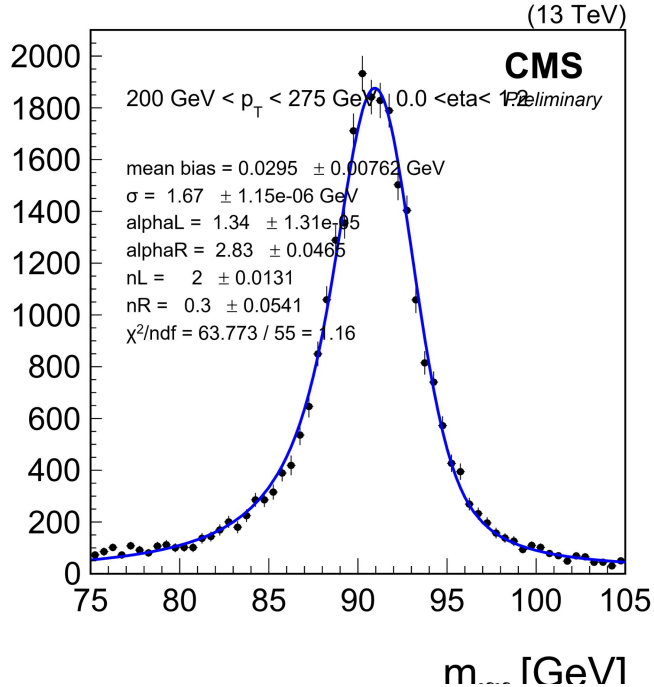
3, Extract the resolution values from the fits and calculate the systematic uncertainties.

4, If necessary, **smear the MC resolution to meet the Data resolution.**

- For simplicity, in the following plots of **comparison** between MC and Data, only the statistical error is shown.
- The impact of systematic uncertainties on the Data/MC comparison is evaluated separately.
- **Compared to the last update, we improved the fits and were able to improve the consistency of the results. A study of the systematic uncertainties was added**

Example fits





Data : 2022 Eta_[0,1.2]_Pt_[200,275]

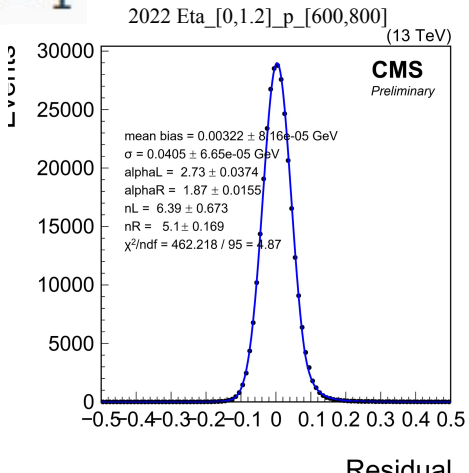
MC : 2022 Eta_[0,1.2]_Pt_[200, 275]

Resolution Smearing

- If Data and MC disagree, we need to smear of the momenta in MC
- New resolution given by $\sigma_{\text{smeared}} = \sqrt{\sigma^2_{\text{default}} + \sigma^2_{\text{extra}}}$, where $\sigma_{def\ ault}$ (p) is the resolution of the residual of MC : $\frac{1/p - 1/p^{\text{gen}}}{1/p^{\text{gen}}}$
- Written in terms of desired smearing: $x = \sqrt{\text{smearfac}^2 - 1}$

$$\text{smearfac} \cdot \sigma_{\text{default}} = \sqrt{\sigma^2_{\text{default}} + (x \cdot \sigma_{\text{default}})^2}$$

- For 10% smearing : smearfac= 1.1→ x=0.46
- For 5% smearing : smearfac=1.05→ x=0.32



Resolution Smearing

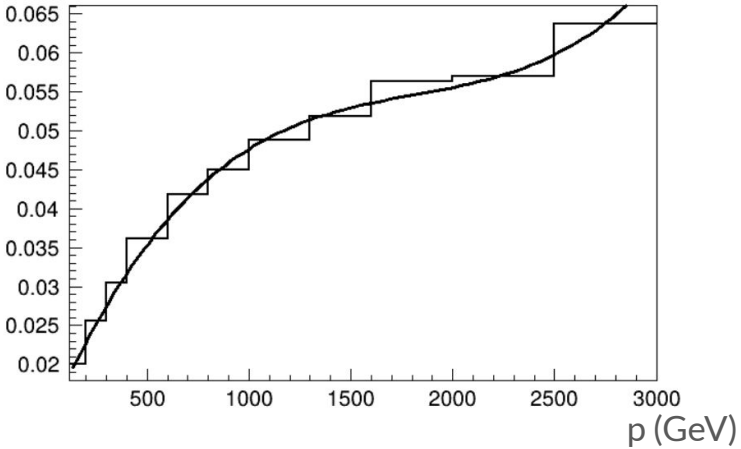
- Need to know: $\sigma_{default}$ as a function of p.

  In MC, fit the residual: $\frac{1/p - 1/p^{gen}}{1/p^{gen}}$ in bins of "p":

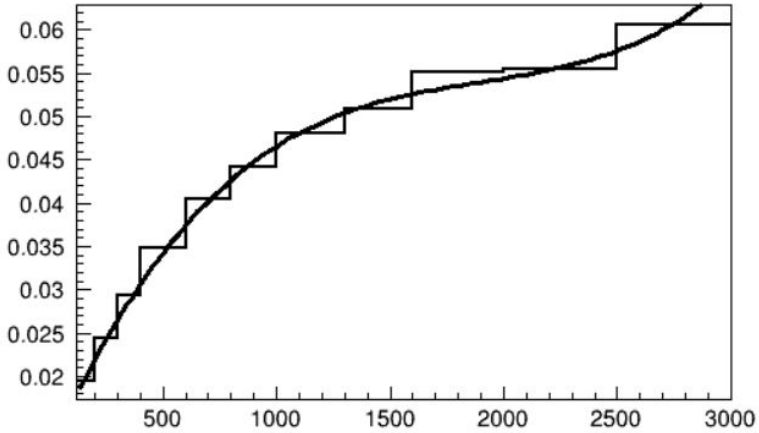
```
"p" :[120, 200, 300, 400, 600, 800, 1000, 1300, 1600, 2000, 2500, 3000],
```

  Fit the resolution of residual as a function of p with polynomial

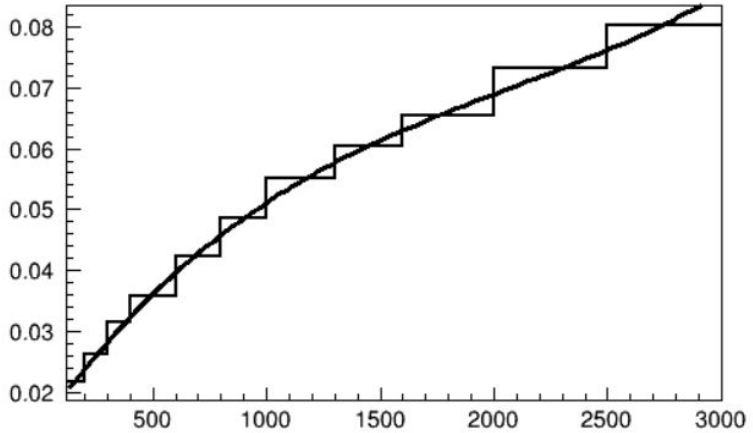
E.g. 2022 Eta_[0,1.2]



Era_2022



|Eta| ~ [0, 1.2] p (GeV)



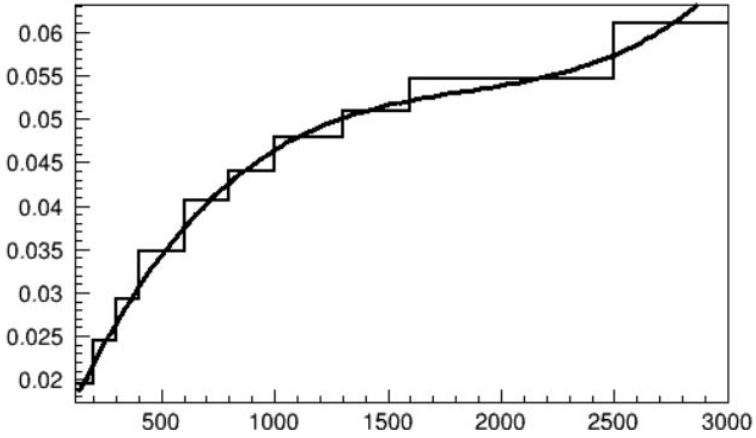
|Eta| ~ [1.2, 2.4] p (GeV)

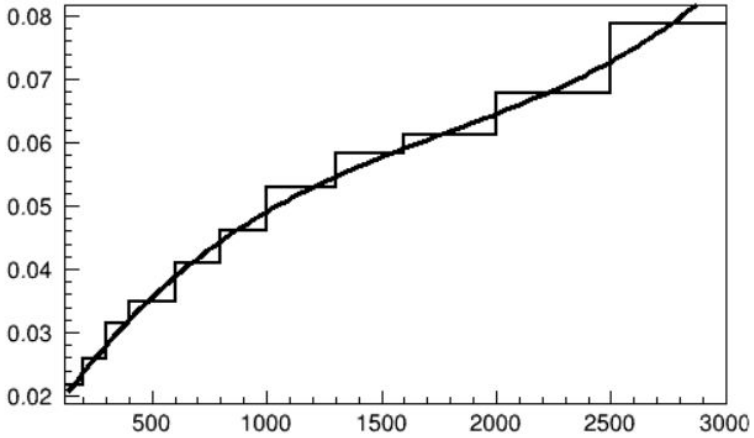
Paramaters for Eta_[0, 1.2] :

Eta_[1.2, 2.4] :

```
NO.   NAME      VALUE
 1  A              1.11520e-02
 2  B              5.94955e-05
 3  C             -2.92229e-08
 4  D              5.14353e-12
CN=8.16307e-05 FROM MINOS
                     EDM=1.167
EXT PARAMETER
NO.   NAME      VALUE
 1  A              1.40545e-02
 2  B              5.28169e-05
 3  C             -1.87005e-08
 4  D              3.00799e-12
```

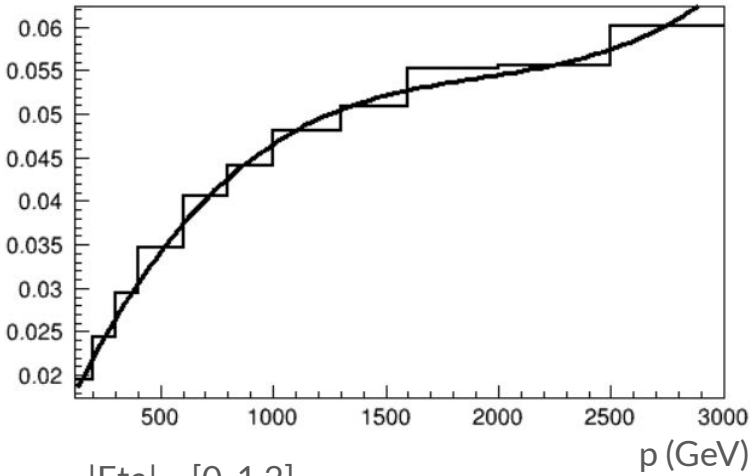
Era 2022 , Apply q/p modification



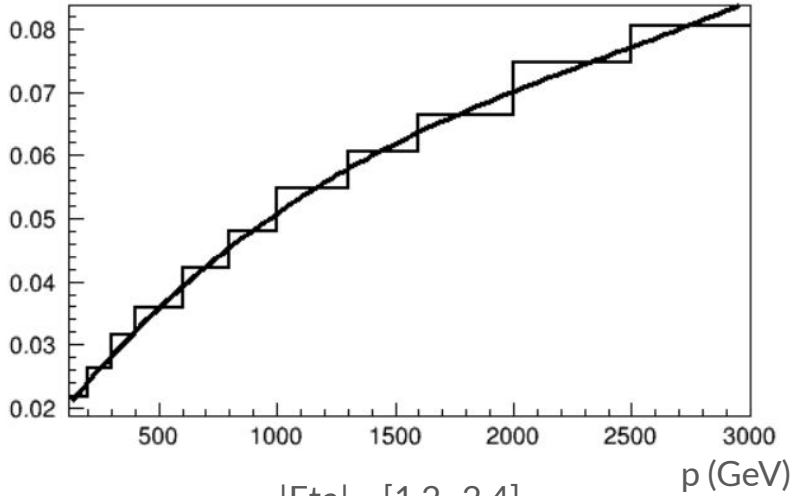



```
NO.   NAME       VALUE
 1  A           1.09739e-02
 2  B           6.06340e-05
 3  C          -3.06497e-08
 4  D           5.53341e-12
CN=0.000151367 FROM MINOS
                     EDM=5.470
EXT PARAMETER
NO.   NAME       VALUE
 1  A           1.39045e-02
 2  B           5.35022e-05
 3  C          -2.25294e-08
 4  D           4.22415e-12
```

Era 2022_EE



|Eta| ~ [0, 1.2]



|Eta| ~ [1.2, 2.4]

Paramaters for Eta_[0, 1.2] :

Eta_[1.2, 2.4] :

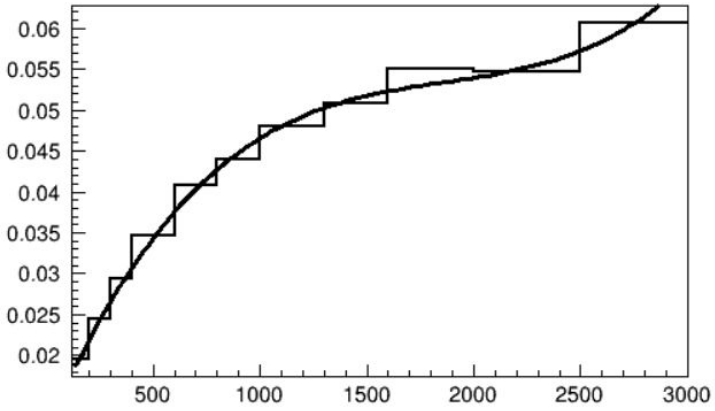
NO.	NAME	VALUE
1	A	1.12593e-02
2	B	5.88829e-05
3	C	-2.84651e-08
4	D	4.92264e-12

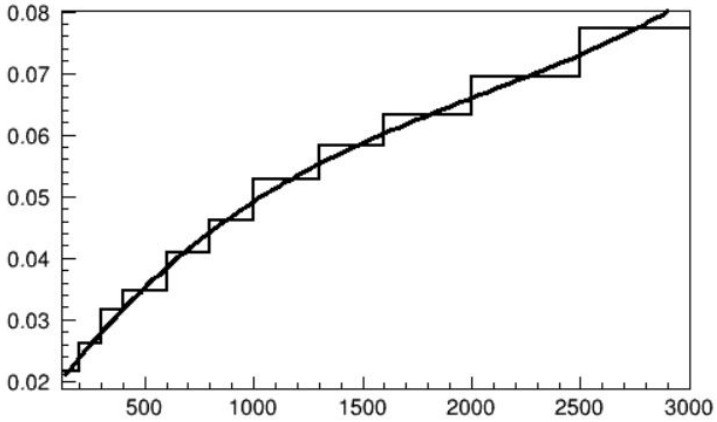
FCN=0.00011333 FROM MINOS EDM=7.2284

EXT PARAMETER

NO.	NAME	VALUE
1	A	1.50148e-02
2	B	4.81069e-05
3	C	-1.41678e-08
4	D	1.95231e-12

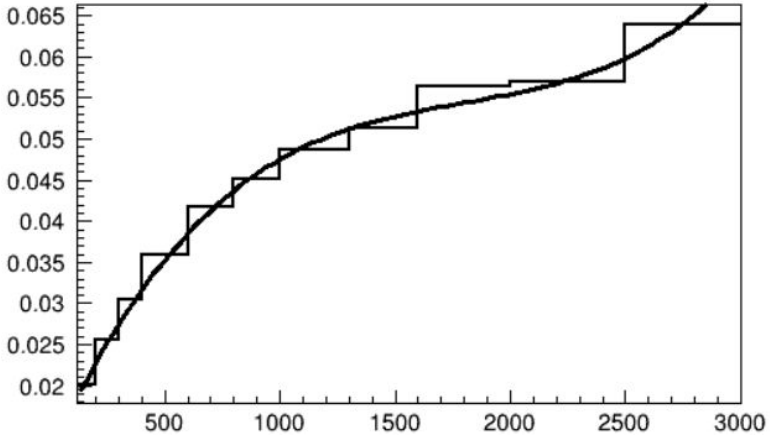
Era 22_EE , Apply q/p modification



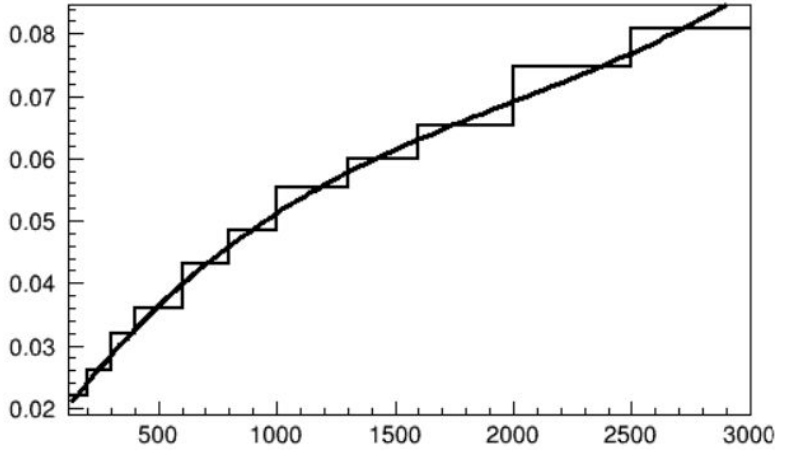



```
NO.   NAME      VALUE
 1  A           1.09851e-02
 2  B           6.05789e-05
 3  C          -3.04224e-08
 4  D           5.44030e-12
CN=0.000139119 FROM MINOS
                     EDM=6.767
EXT PARAMETER
NO.   NAME      VALUE
 1  A           1.47765e-02
 2  B           4.89326e-05
 3  C          -1.73438e-08
 4  D           2.84056e-12
```

Era_2023



|Eta| ~ [0, 1.2]



|Eta| ~ [1.2, 2.4]

Paramaters for Eta_[0, 1.2] :

NO.	NAME	VALUE
1	A	1.17191e-02
2	B	6.14187e-05
3	C	-3.14152e-08
4	D	5.81988e-12

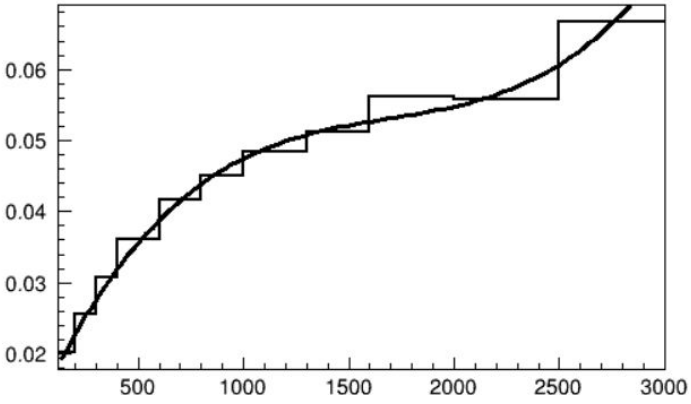
FCN=0.000144114 FROM MINOS EDM=2.877

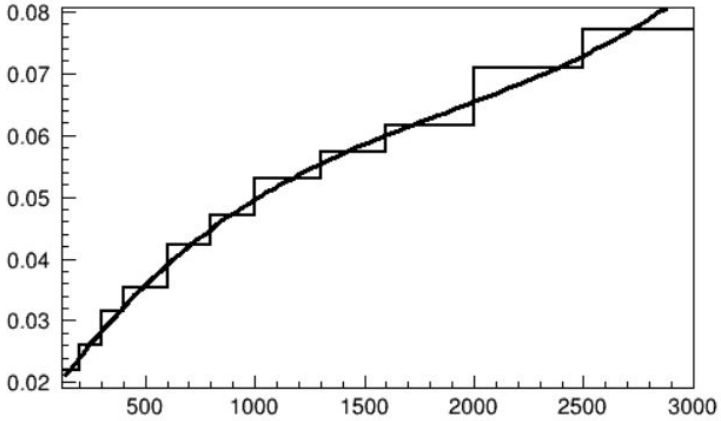
Eta_[1.2, 2.4] :

EXT PARAMETER

NO.	NAME	VALUE
1	A	1.42399e-02
2	B	5.30925e-05
3	C	-1.92247e-08
4	D	3.20733e-12

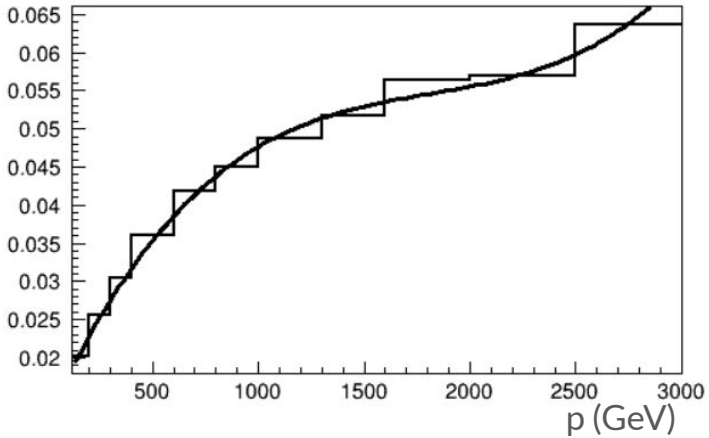
Era_2023, Apply q/p modification



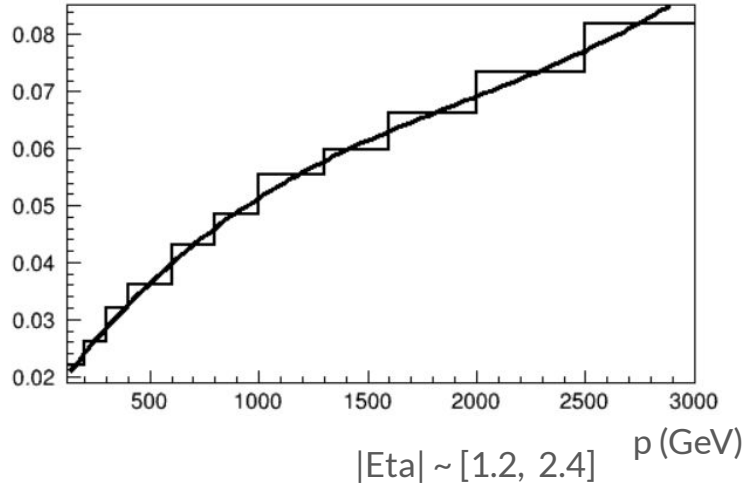



```
NO.   NAME       VALUE
 1  A           1.12477e-02
 2  B           6.46444e-05
 3  C          -3.53990e-08
 4  D           6.98089e-12
CN=0.000161953 FROM MINOS
                     EDM=1.173
EXT PARAMETER
NO.   NAME       VALUE
 1  A           1.43740e-02
 2  B           5.23100e-05
 3  C          -2.07144e-08
 4  D           3.66499e-12
```

Era_2023BPix



|Eta| ~ [0, 1.2]



|Eta| ~ [1.2, 2.4]

Paramaters for Eta_[0, 1.2] :

Eta_[1.2, 2.4] :

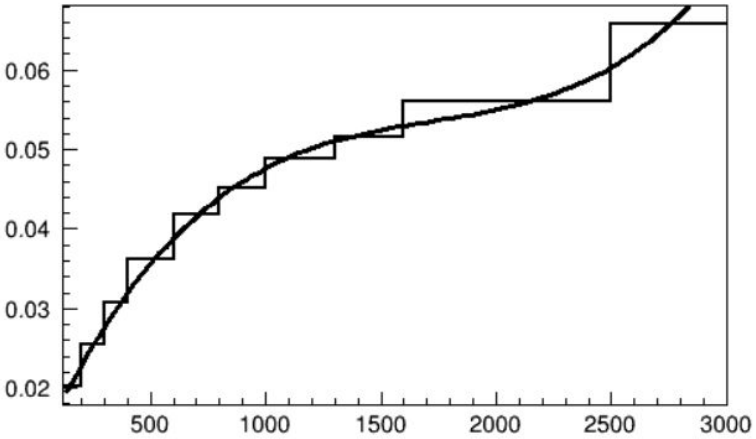
NAME	VALUE
A	1.17770e-02
B	6.13538e-05
C	-3.12168e-08
D	5.74134e-12

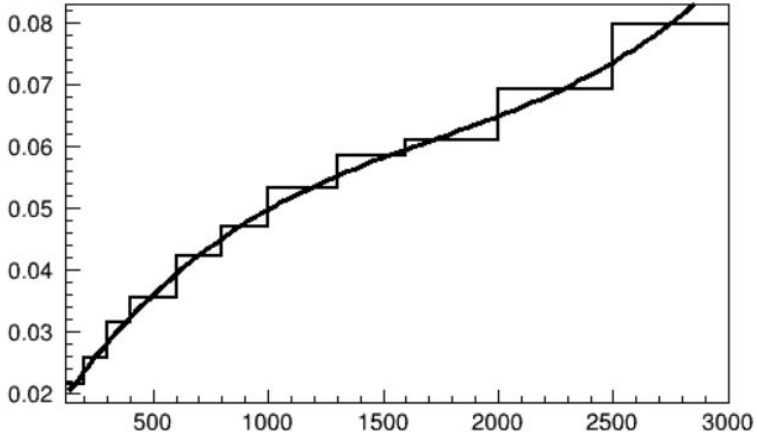
8.9033e-05 FROM MINOS
EDM=2.5150

PARAMETER

NAME	VALUE
A	1.40625e-02
B	5.38352e-05
C	-1.99658e-08
D	3.41569e-12

Era_2023BPix, Apply q/p modification





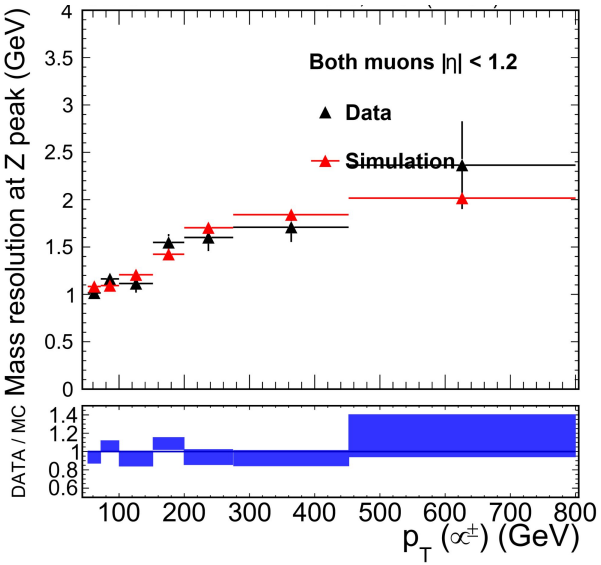
NO.	NAME	VALUE
1	A	1.13663e-02
2	B	6.41160e-05
3	C	-3.45094e-08
4	D	6.68243e-12

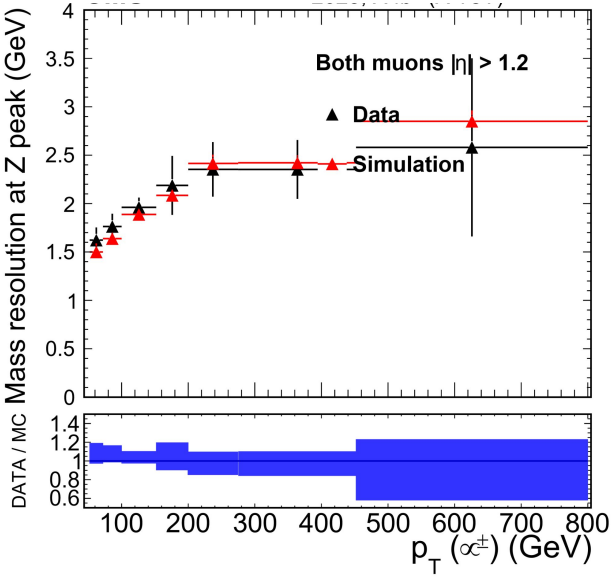
FCN=0.000120231 FROM MINOS EDM=4.618

EXT PARAMETER

NO.	NAME	VALUE
1	A	1.32530e-02
2	B	5.72957e-05
3	C	-2.56409e-08
4	D	4.95473e-12

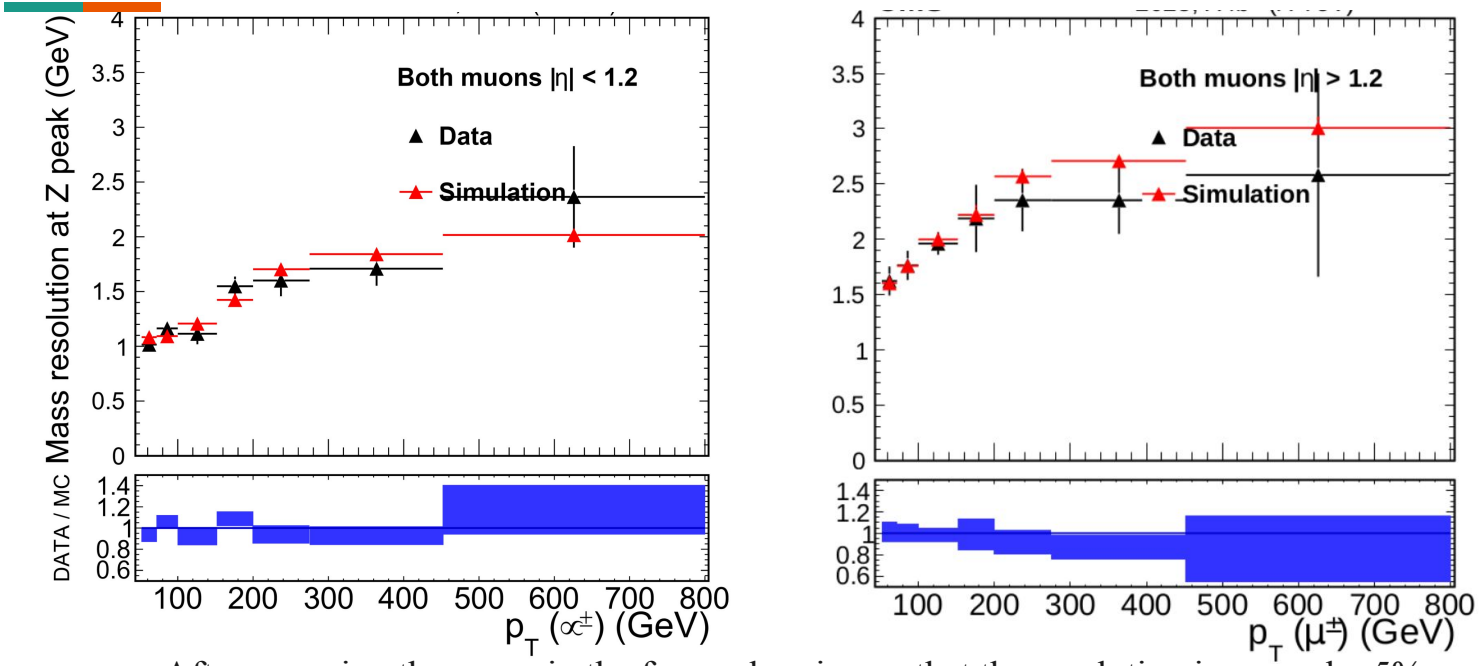
Era 2022





- Good agreement between Data and MC for central muons (|eta| < 1.2)
- Data resolution slightly worse than predicted by MC for forward muons (|eta| > 1.2)
- Will recommend a smearing of forward muons in MC

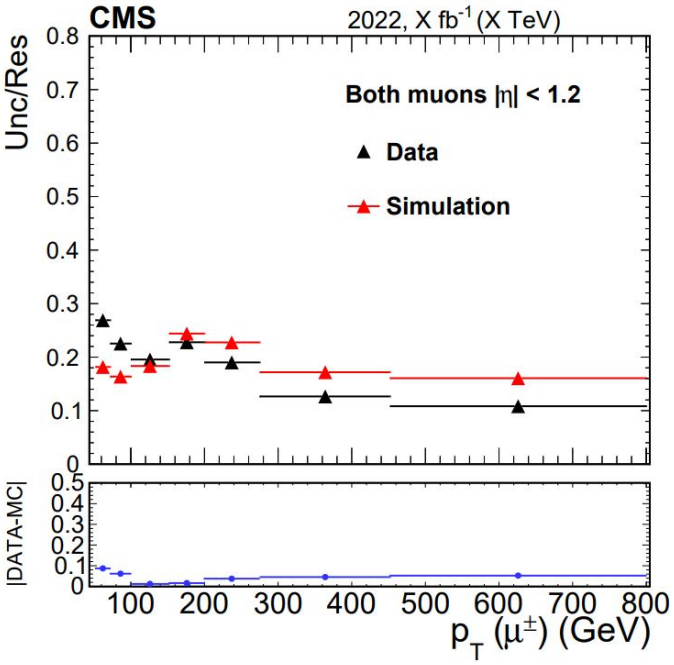
0 smearing in Barrel & 5% smear in Forward region.

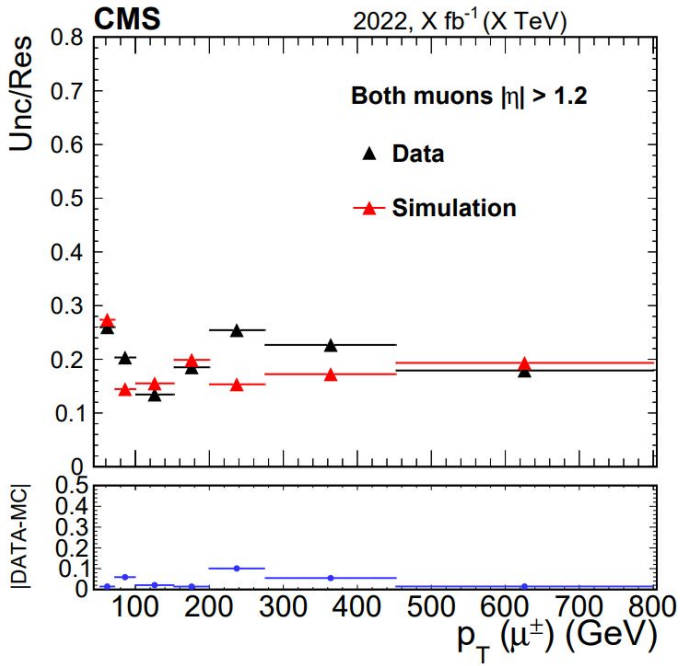


- After smearing the muon in the forward region so that the resolution is worse by 5%, very good agreement is observed for forward muons in the high statistics bins
- Average remaining Data/MC difference is ~10%
  - covered by systematic uncertainty

Relative Systematic Uncertainties - 2022

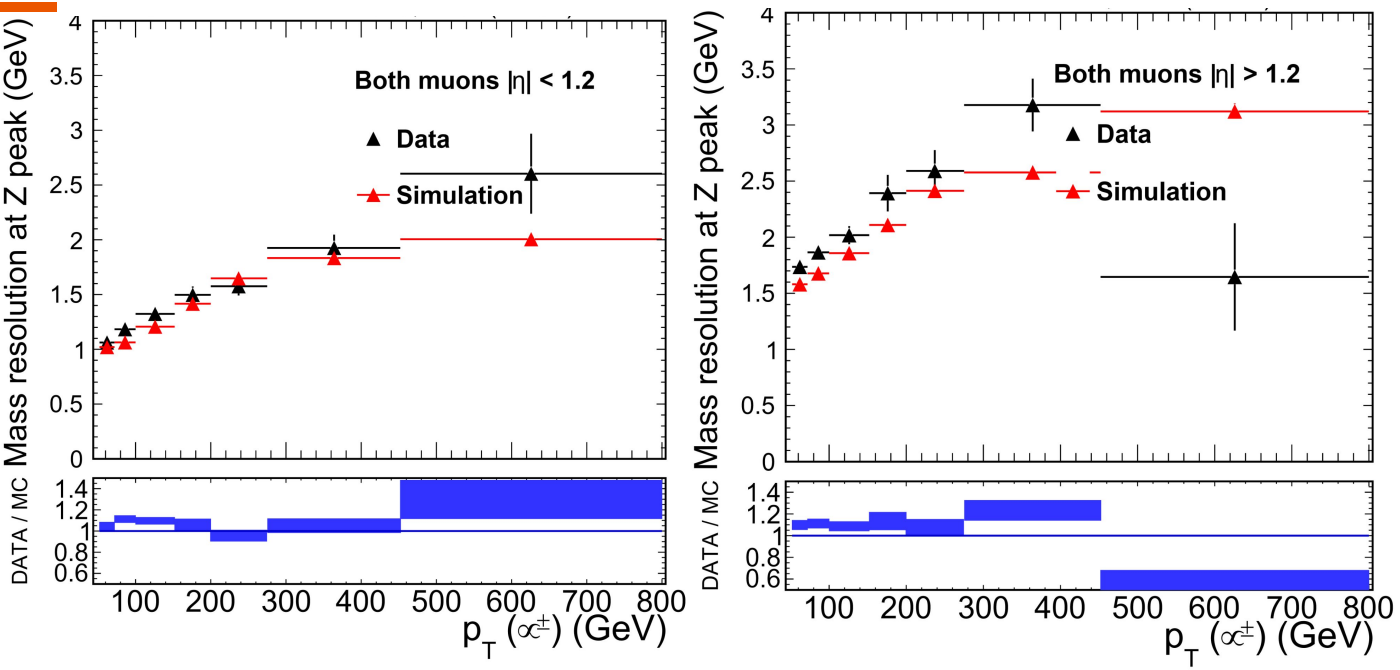
- Plot the total relative *sytemtic uncertainties (quadratic sum of impact of fit functions, binning, and fit range)* for both DATA and MC
- In this measurement, we care only about the agreement of DATA and MC
- We therefore look at the difference between the impact of the uncertainties in DATA and MC to assign a total systematic on the agreement





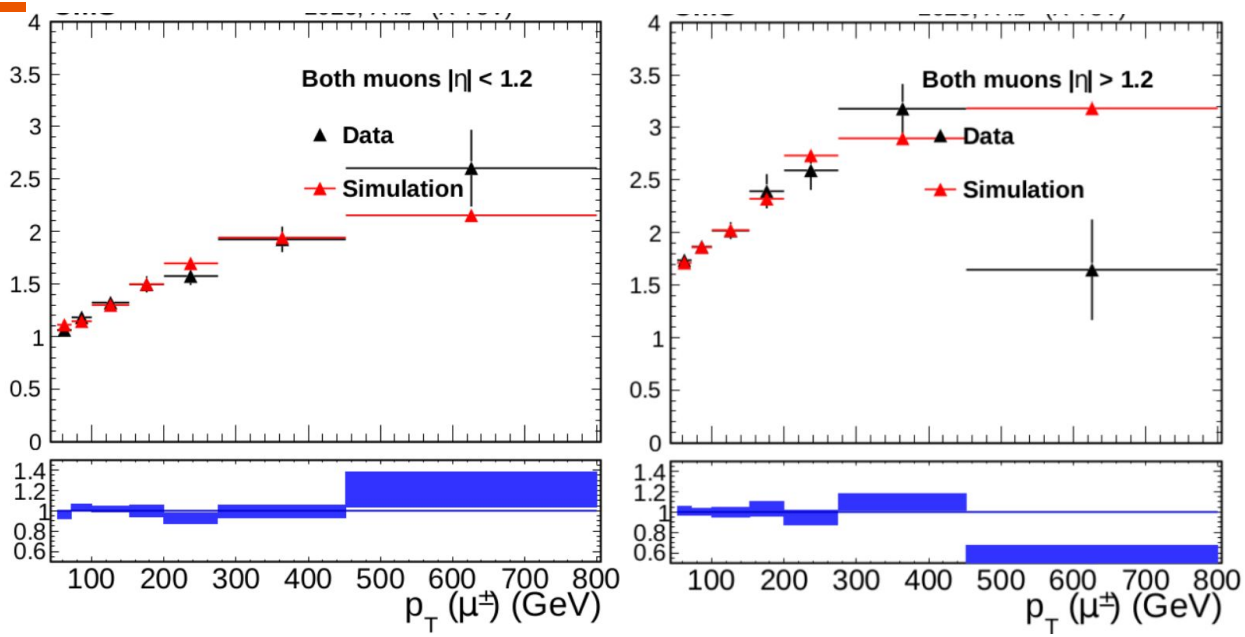
The systematic uncertainty is in general less than 10%, so we recommend a total 10% uncertainty in both Barrel and Forward region to covers the remaining differences after smearing and also covers this systematic uncertainty

Era 2022_EE comparision



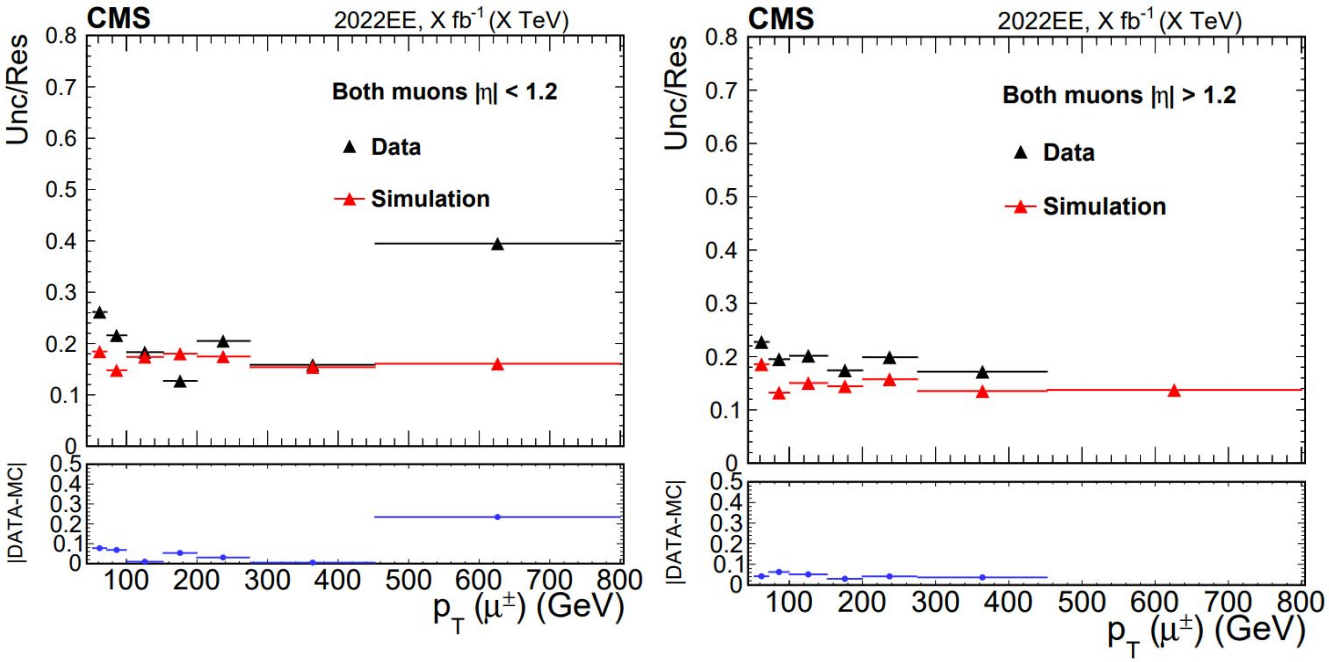
- Generally resolution in MC is better than in data -> need to recommend smearing the muon momenta in MC

5% on Barrel region & 10% on Forward region



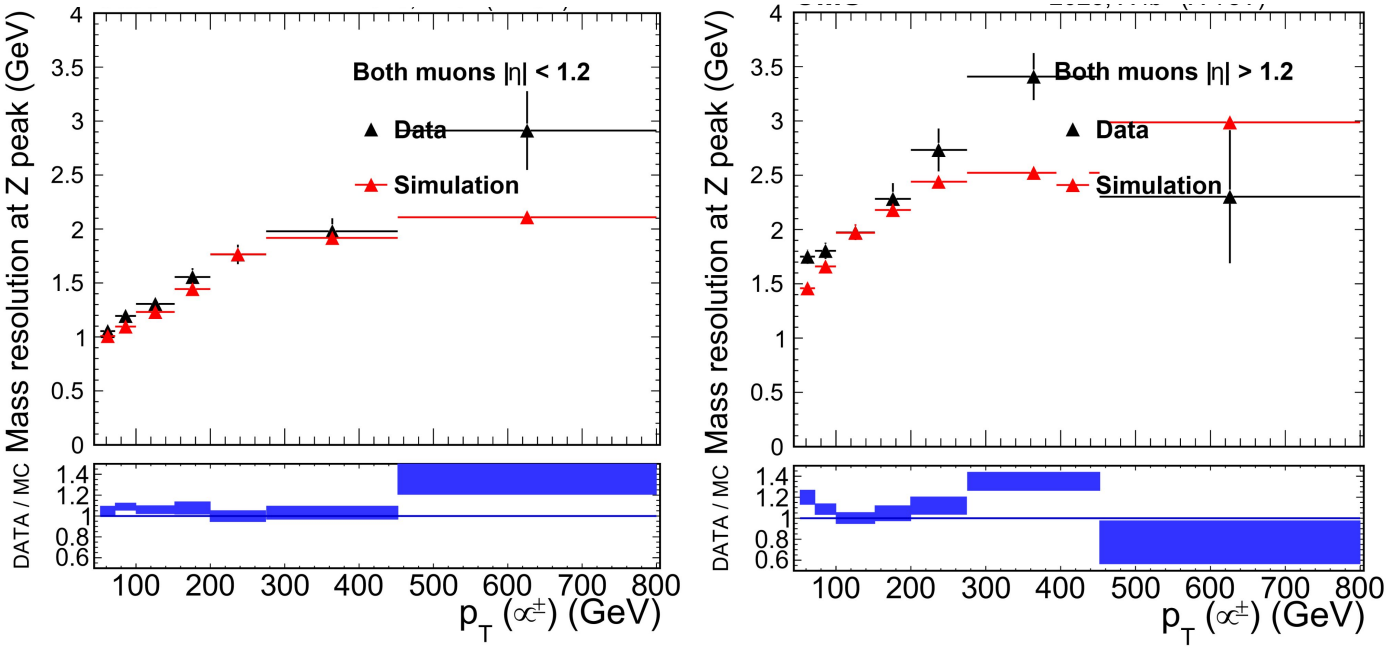
- Smearing momenta in MC by 5% in barrel and 10% in endcap results in very good Data/MC agreement subject to a limited (<5%) uncertainty.

Relative Syst Unc - 2022EE



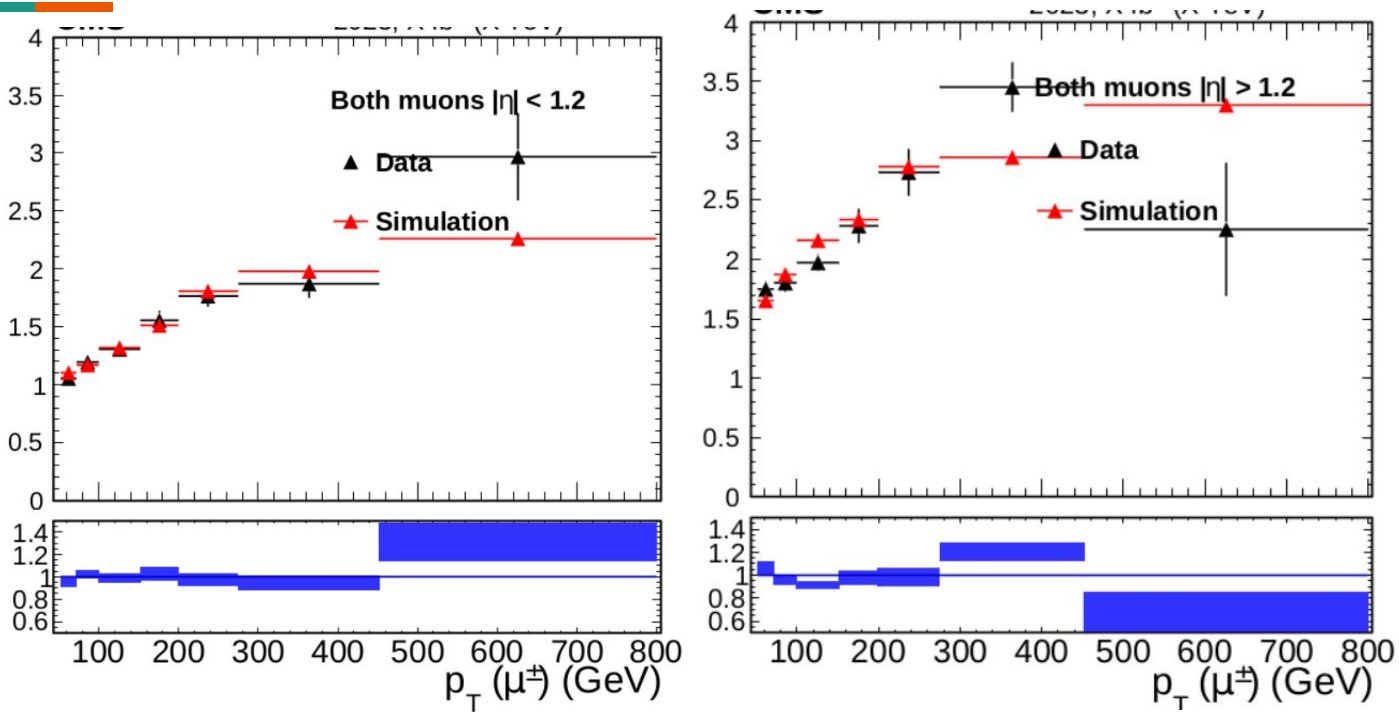
The systematic uncertainty is in general less than 10%, so we recommend a total 10% uncertainty in both Barrel and Forward region to covers the remaining differences after smearing and also covers this systematic uncertainty

Era 2023



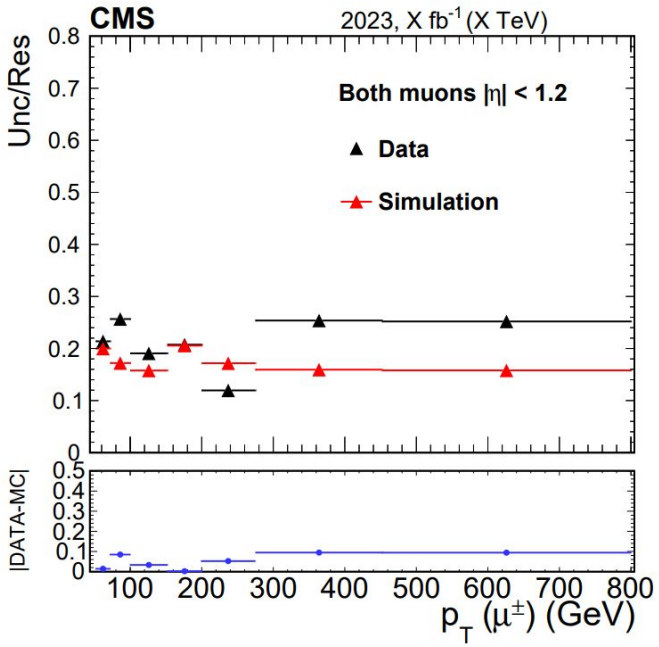
- Generally, resolution in MC is better than in data -> need to recommend smearing the muon momenta in MC

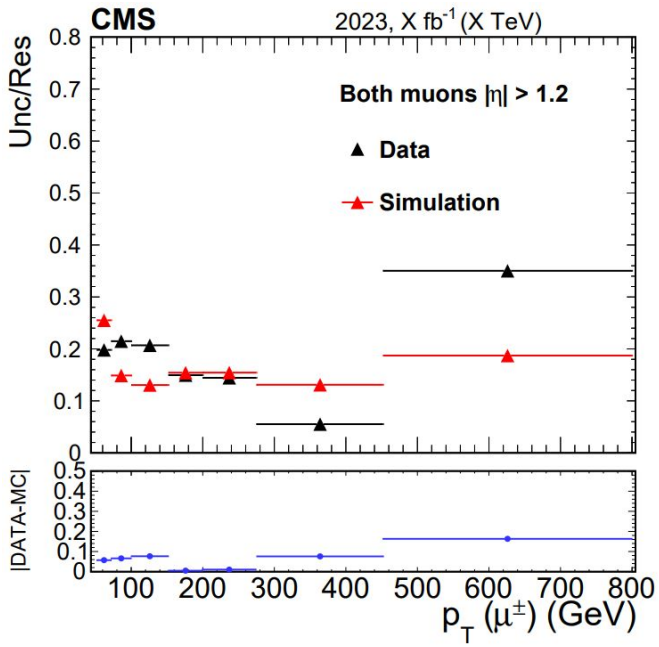
5% in Barrel region and 10% in forward region



- Data/MC agree well after smearing up to a <10% uncertainty if drop the high Pt bins.

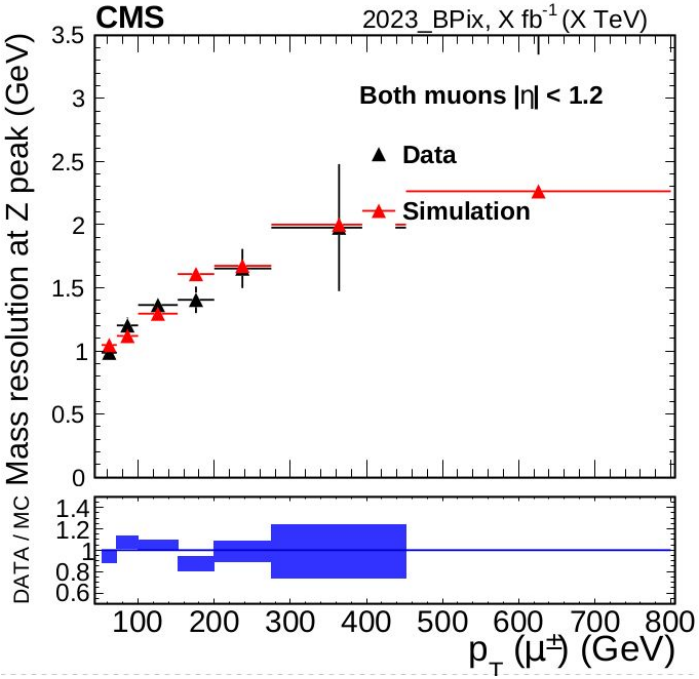
Relative Syst Unc - 2023

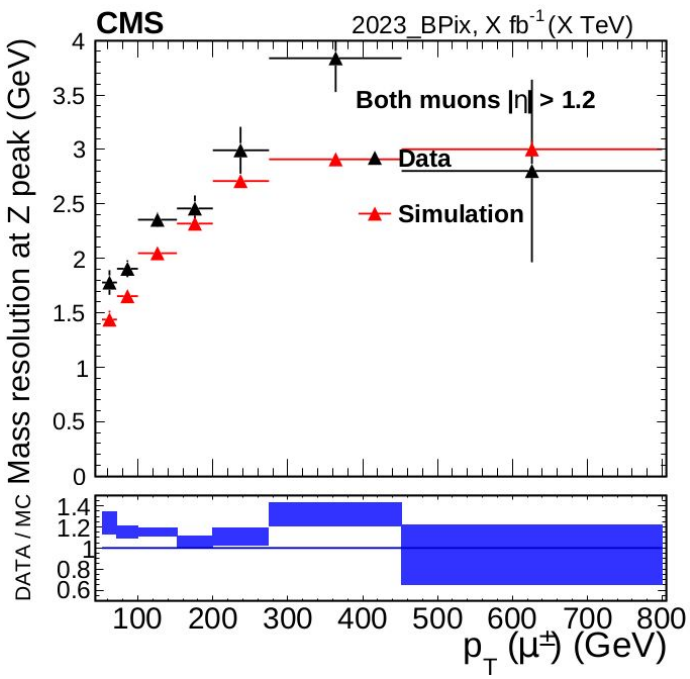




- The systematic uncertainty is in general less than 10%, so we recommend a total 10% uncertainty in both Barrel and Forward region to covers the remaining differences after smearing and also covers this systematic uncertainty

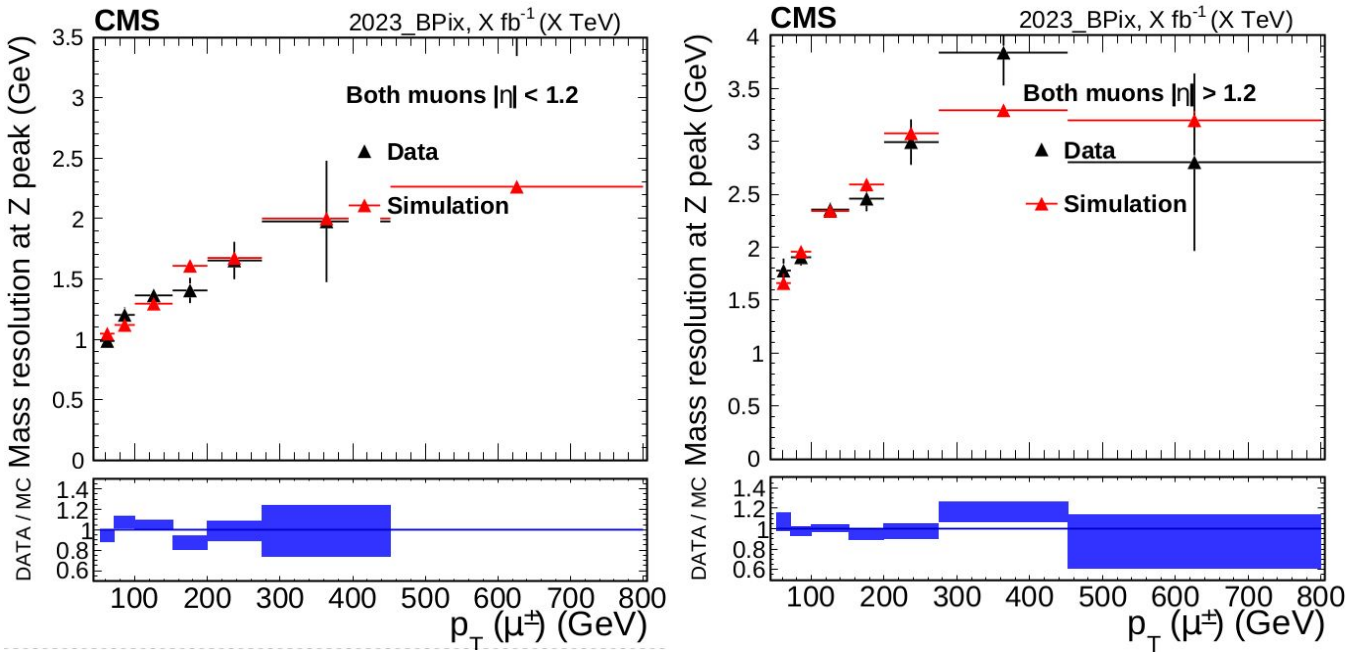
Era 2023_PBix comparision





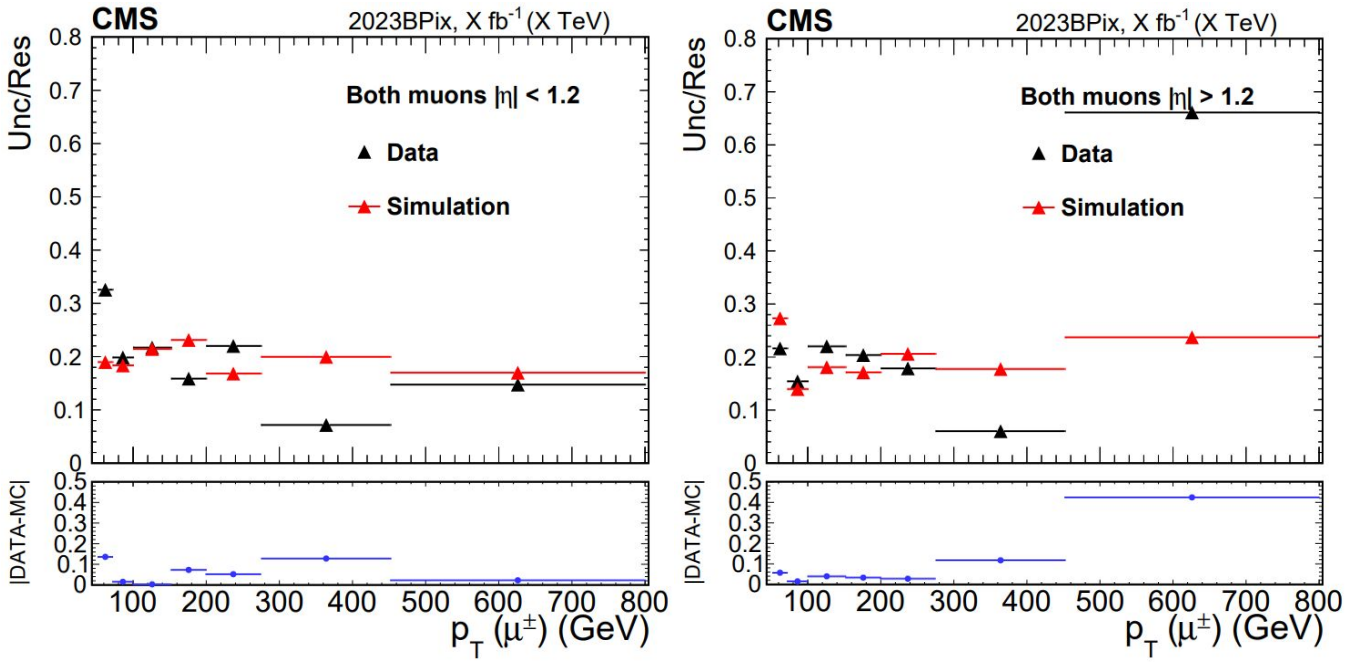
- Very good agreement in barrel region, about 15% better resolution in MC compared to data in endcap

0% on Barrel region & 15% on Forward region



- Good agreement in endcap restored after smearing up to a <10% uncertainty if drop the high Pt bins

Relative Syst Unc - 2023BPix

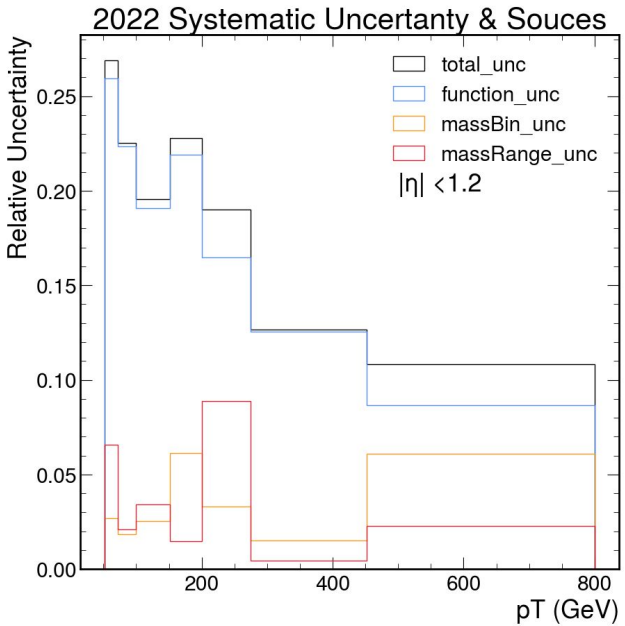


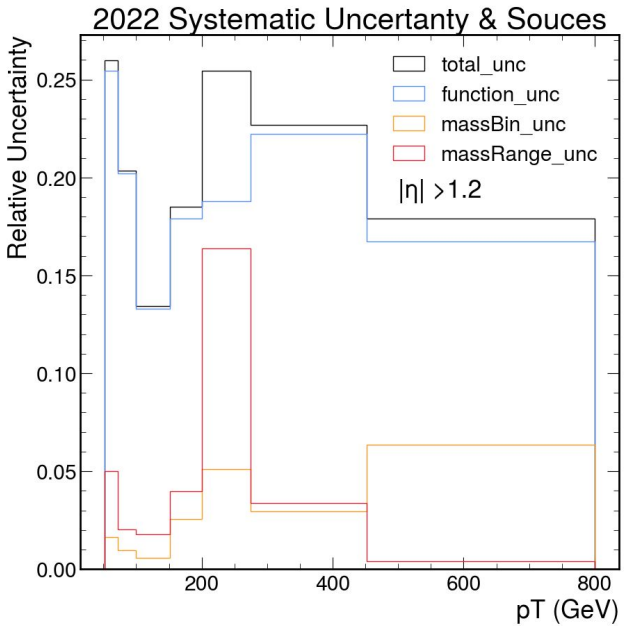
- The systematic uncertainty is in general less than 10%, so we recommend a total 10% uncertainty in both Barrel and Forward region to covers the remaining differences after smearing and also covers this systematic uncertainty
- This disregards the very first bin in the barrel region, but low p_T is less relevant for this recommendation

Calculation of Syst Uncertainty

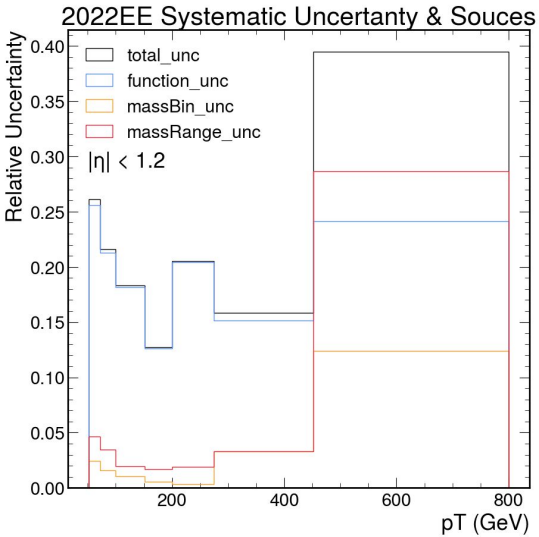
- There are 3 sources :
  S1. Fitting functions :
  max(Crystal-Ball_Unc, Cruijff_Unc) *(default: Double_Crystal-Ball)*
  S2. massRange shifts
  S3. massBin shifts
- Total_Syst_Unc = $\sqrt{S1^2 + S2^2 + S3^2}$

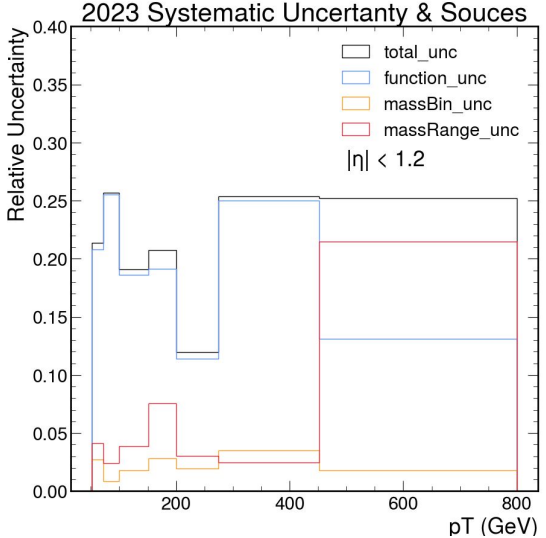
Sources of Systematic Uncertainty

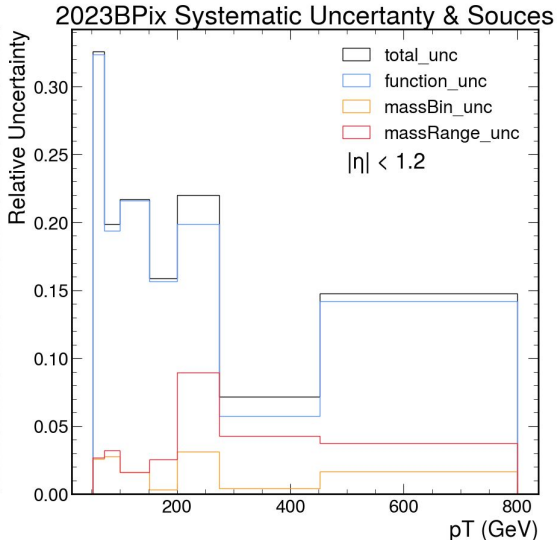


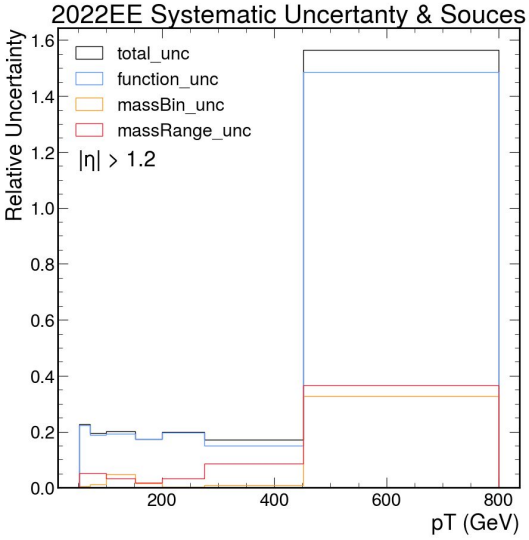


- Choice of fit function is by far the dominant source of uncertainty
- Binning and mass range for fits has mostly a quite small effect
- Consistent picture for all data taking periods, see next slides


2022EE Systematic Uncertanty & Souces
total_unc
function_unc
massBin_unc
massRange_unc
|η| < 1.2
Relative Uncertainty
pT (GeV)


2023 Systematic Uncertanty & Souces
total_unc
function_unc
massBin_unc
massRange_unc
|η| < 1.2
Relative Uncertainty
pT (GeV)


2023BPix Systematic Uncertanty & Souces
total_unc
function_unc
massBin_unc
massRange_unc
|η| < 1.2
Relative Uncertainty
pT (GeV)


2022EE Systematic Uncertanty & Souces
total_unc
function_unc
massBin_unc
massRange_unc
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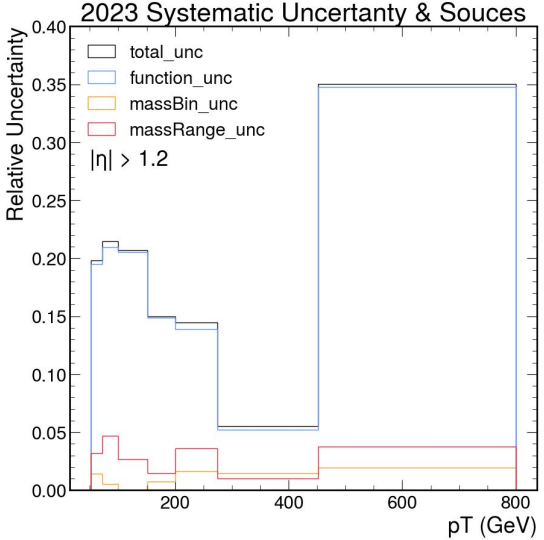
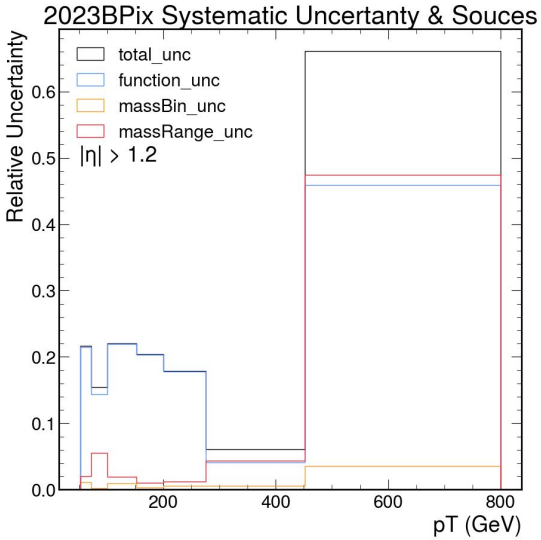
Relative Uncertainty
pT (GeV)


2023 Systematic Uncertanty & Souces
total_unc
function_unc
massBin_unc
massRange_unc
|η| > 1.2
Relative Uncertainty
pT (GeV)


2023BPix Systematic Uncertanty & Souces
total_unc
function_unc
massBin_unc
massRange_unc
|η| > 1.2
Relative Uncertainty
pT (GeV)

Conclusion

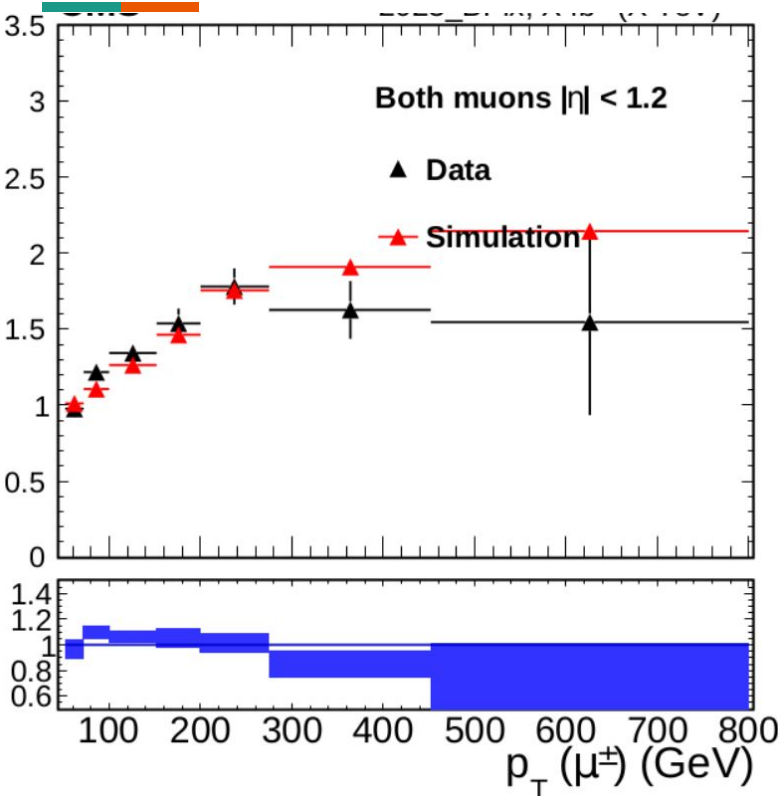
- Study of high-p_T muon momentum resolution is complete
- In general, we found good agreement between Data and MC
  - We will recommend that analyst apply additional smearing of the muon momenta in some cases, mostly for forward muons
- An overall systematic uncertainty of 10% will be assigned, that will be applied as additional smearing of the momenta as well
- All necessary information is available to add these recommendation to the Twiki pages
- If we are satisfied with the results, we can update the code in GitHub so it can be integrated in the central POG tool

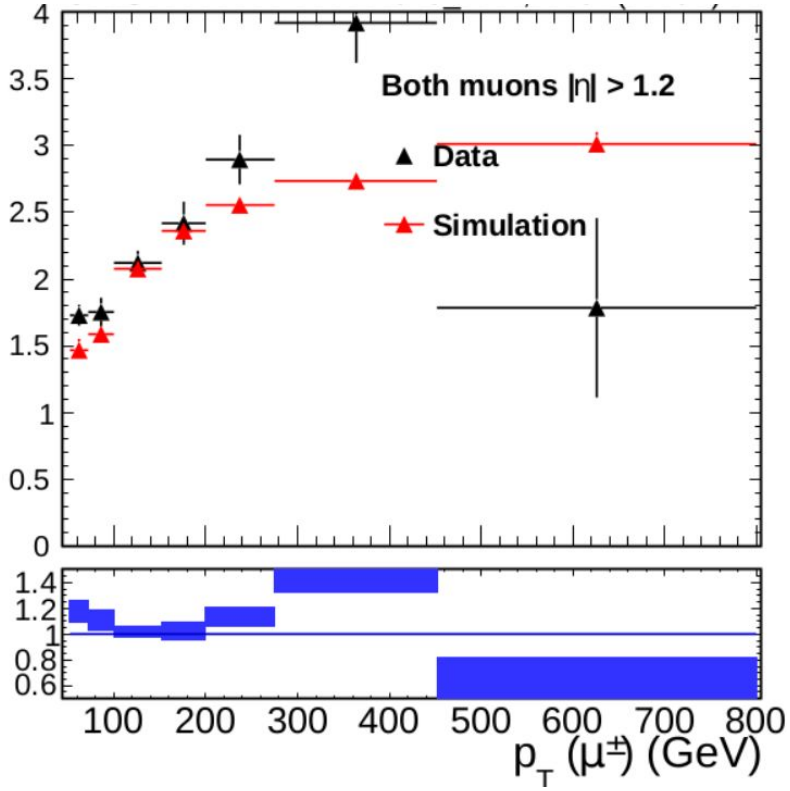
Back Up

Link to the config file:

https://gitlab.cern.ch/yibo/spark_tnp/-/blob/Run2022_EE/configs/mass_resolution.json?ref_type=heads

2023 tag_charge >0





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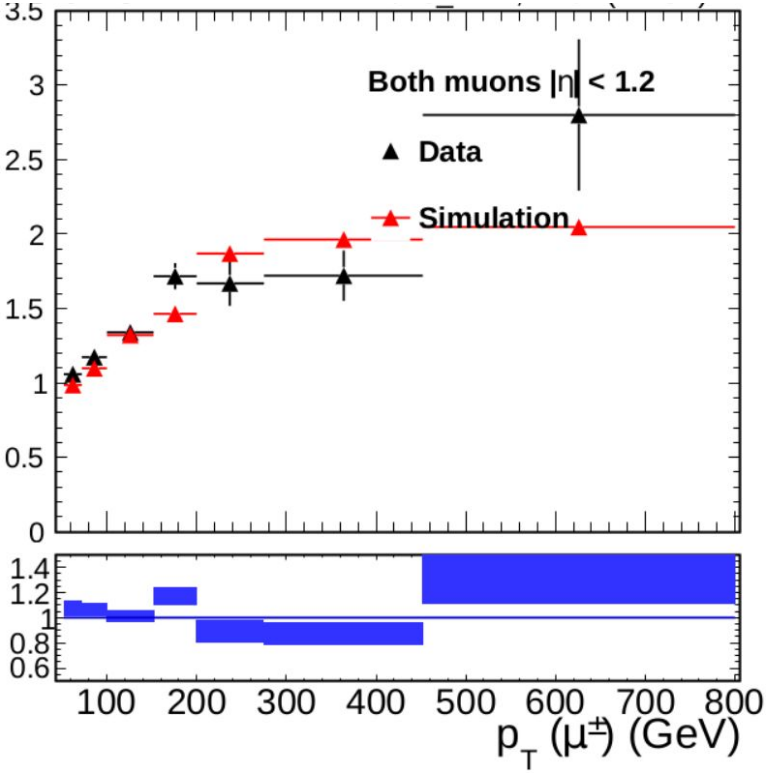
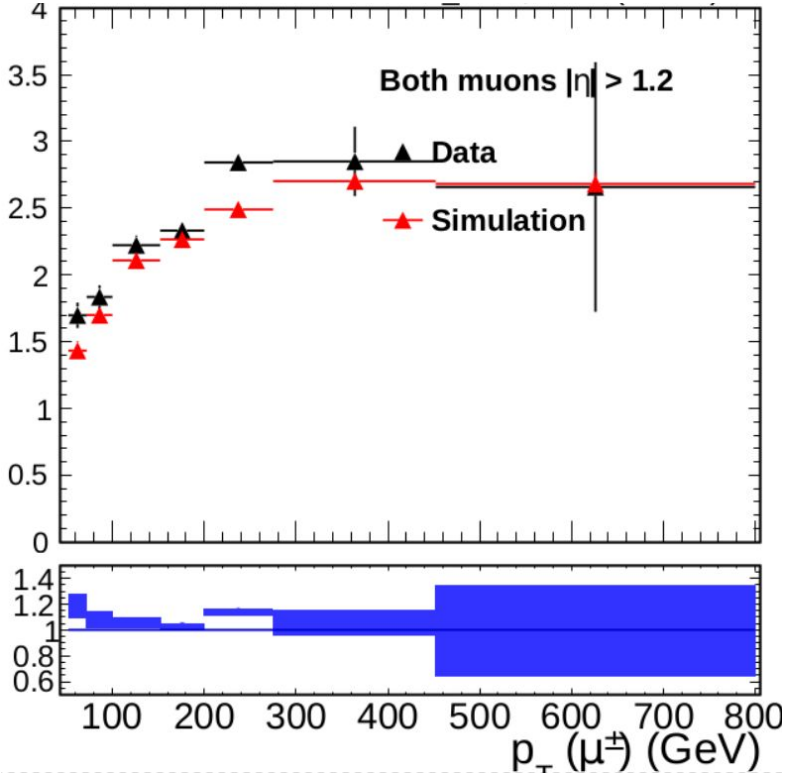


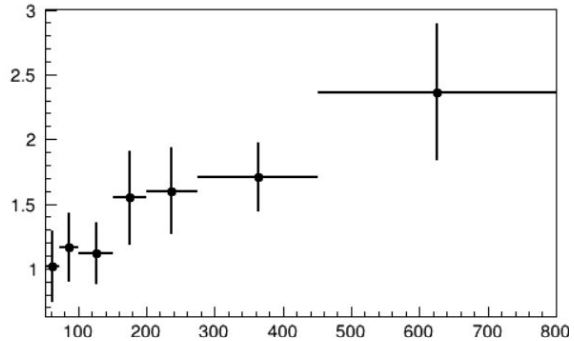


Smear the MC Resolution

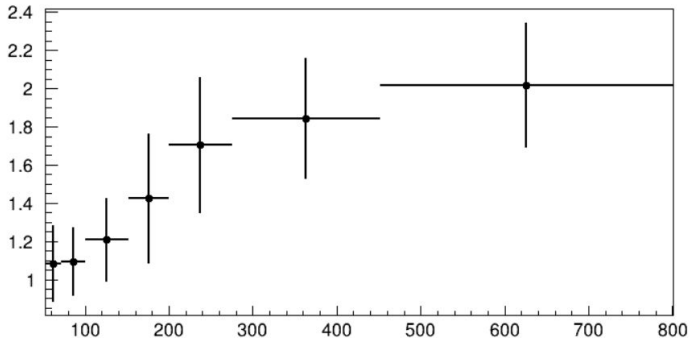
- Smear momentum: $p_{\text{smeared}} = p_{\text{default}} \cdot \text{Gaus}(1, \sigma_{\text{default}} \cdot \text{x})$
- Need to know: $\sigma_{\text{default}}(p)$
- In MC, fit the residual: $\frac{1/p - 1/p^{\text{gen}}}{1/p^{\text{gen}}}$
  in bins of `"p" :[120, 200, 300, 400, 600, 800, 1000, 1300, 1600, 2000, 2500, 3000],`
- Due to low stat of DY_Boost sample , we use DY_MassBinned for this.
- Fit the resolution of residual as a function of p with polynomial to calculate $\sigma_{\text{default}}(p)$

Full Errors : stat + systematic errors, Era 2022

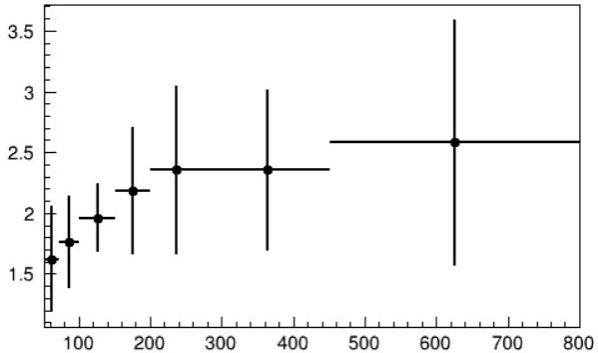
DATA Eta_[0, 1.2]



MC Eta_[0, 1.2]



DATA Eta_[1.2, 2.4]



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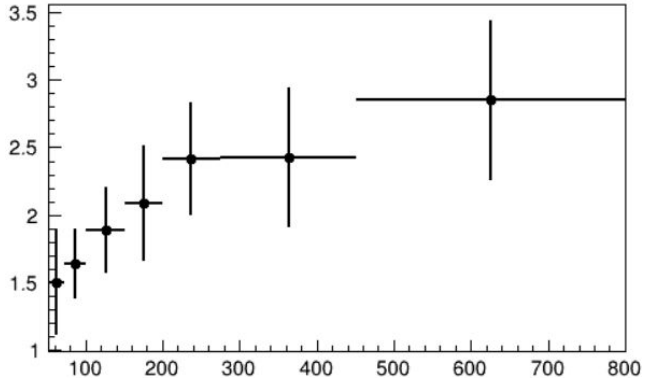

Full Errors : stat + systematic errors , Era 2022_EE

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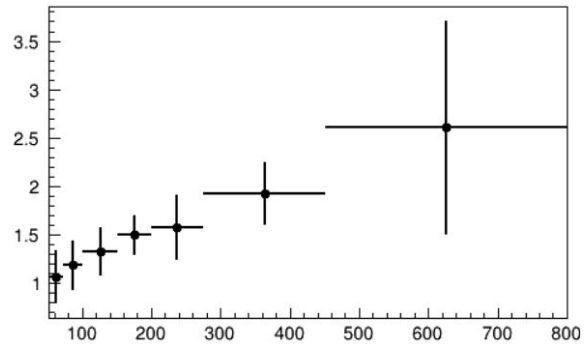

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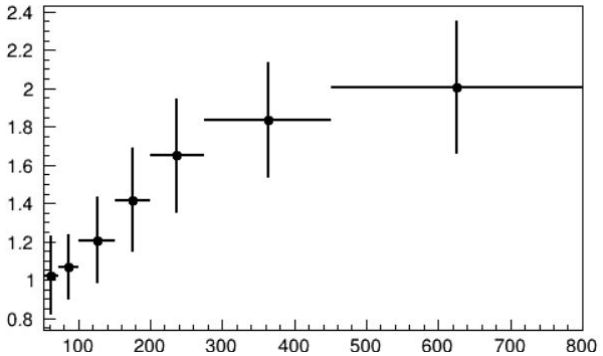

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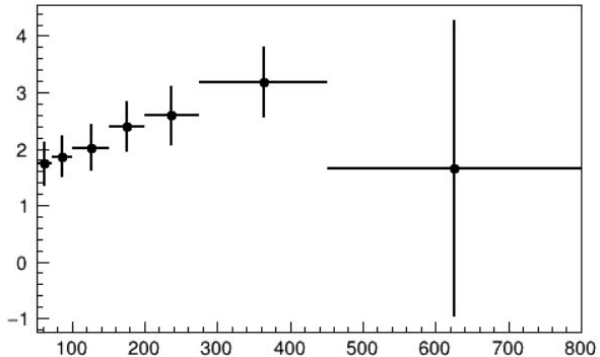

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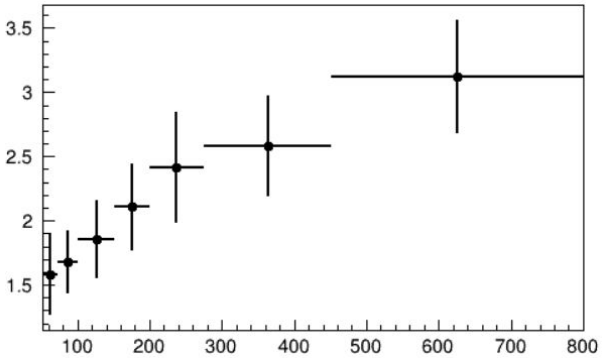

Full Errors : stat + systematic errors , Era 2023

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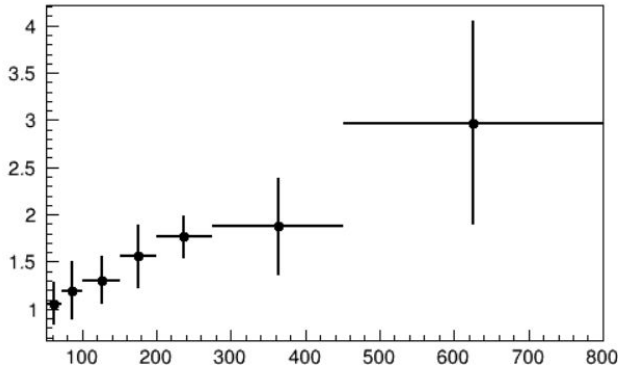

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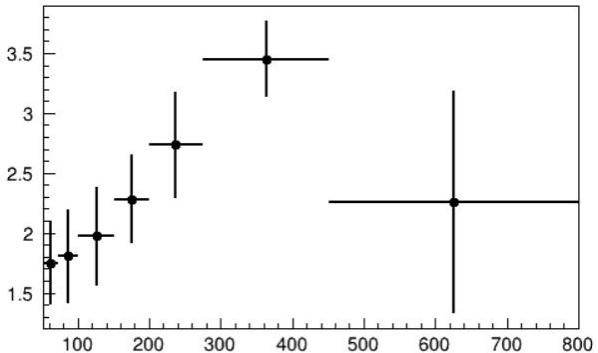

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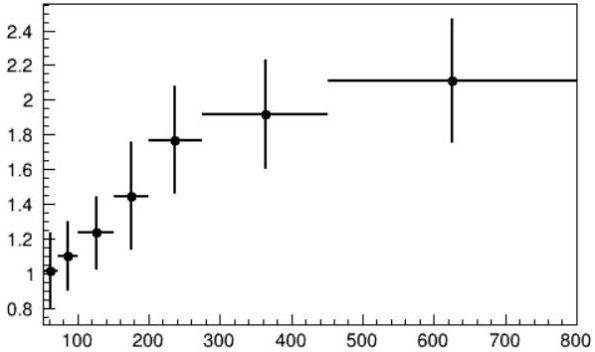

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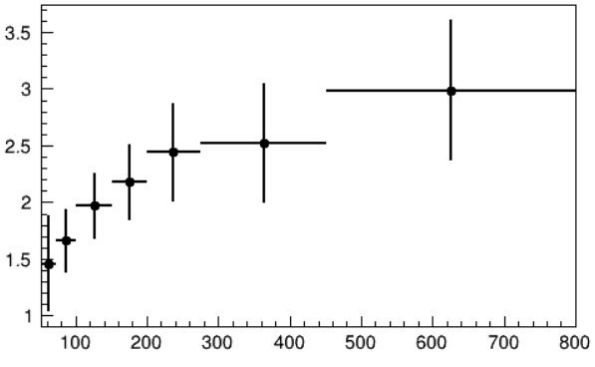

Full Errors : stat + systematic errors , Era 2023_BPix

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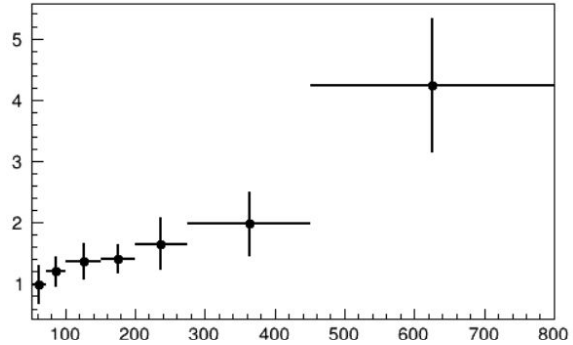

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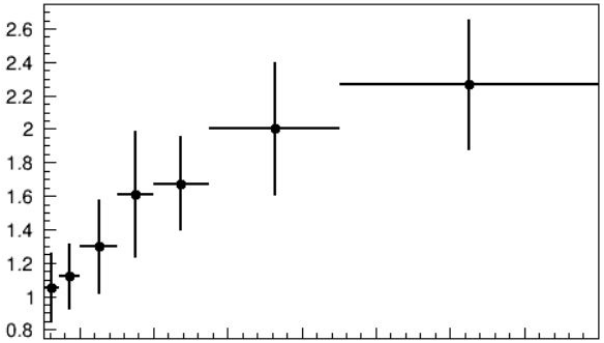

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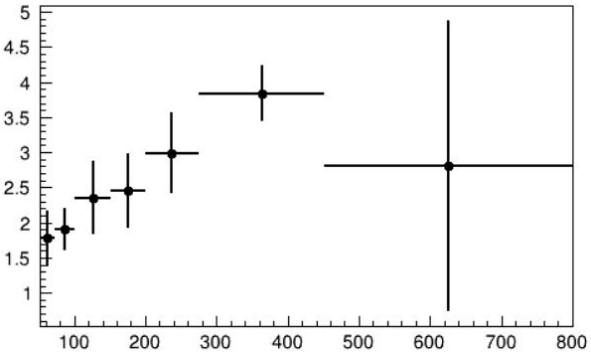

MC Eta_[1.2,2.4]