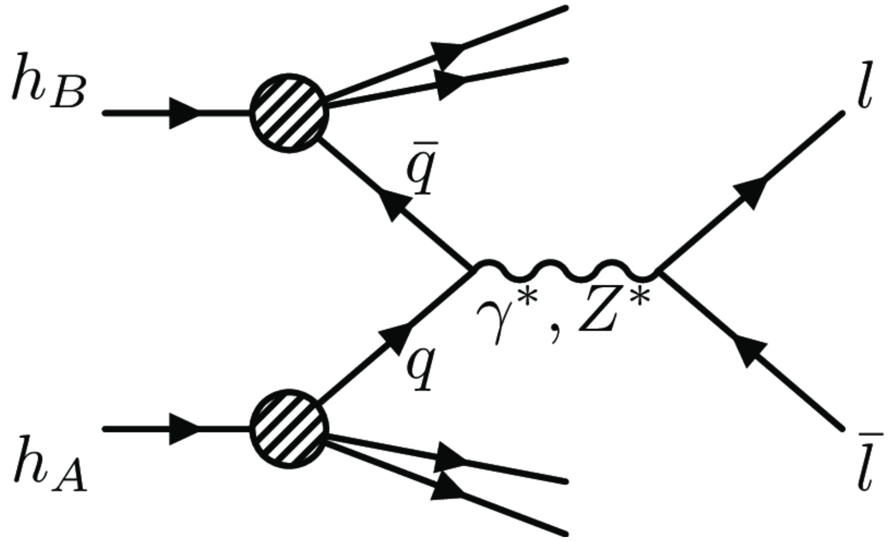
Low-Mass Drell-Yan at $\sqrt{s} = 13\text{TeV}$ with the ATLAS Detector

Alessandro Guida

21.04.21

The Drell-Yan Process



Vector Boson creation in high energy hadron collision

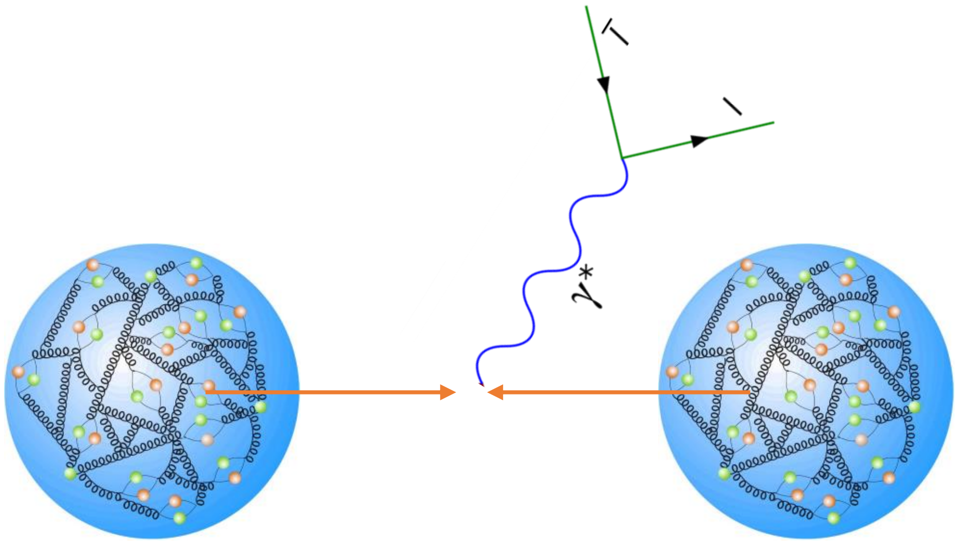
- A quark and an antiquark annihilate into a vector boson
- The boson then decay leptonically

Main Production mode for Z boson (m_Z = 91.2 GeV) at the LHC

Interesting for:

- Precision measurement and test of the Standard Model
  - QCD and EW measurement
  - Input for Parton Distribution Function (PDF) evaluation

Proton-Proton Collision at LHC



At the LHC proton are colliding

- At high energy their structure is broken
- We observe the product of their constituent interaction

An input for the calculation of all the process at the LHC

- Most of the PDF input come from **electron-proton scattering** data from the HERA experiment
- Represent the probability that a parton carries a fraction *x* of the proton momentum
- LHC PDF program complementary to HERA

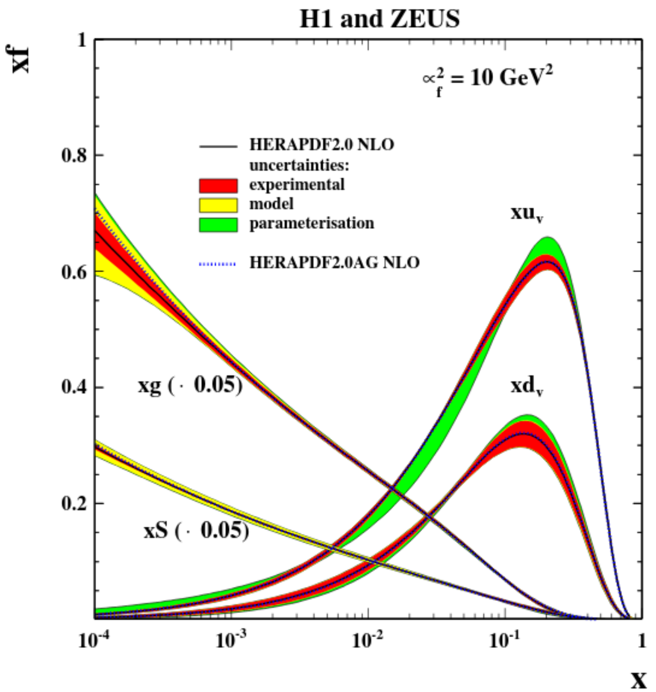


Image from 0911.0884

The Low Mass Drell-Yan

Measurement of the Drell-Yan process in the **dimuon** channel

- In proton-proton collision at $\sqrt{s} = 13$ TeV
- At **low invariant mass**, $m_{\mu\mu} = 7 - 60$ GeV (below the Z pole $m_Z \sim 91 GeV$)

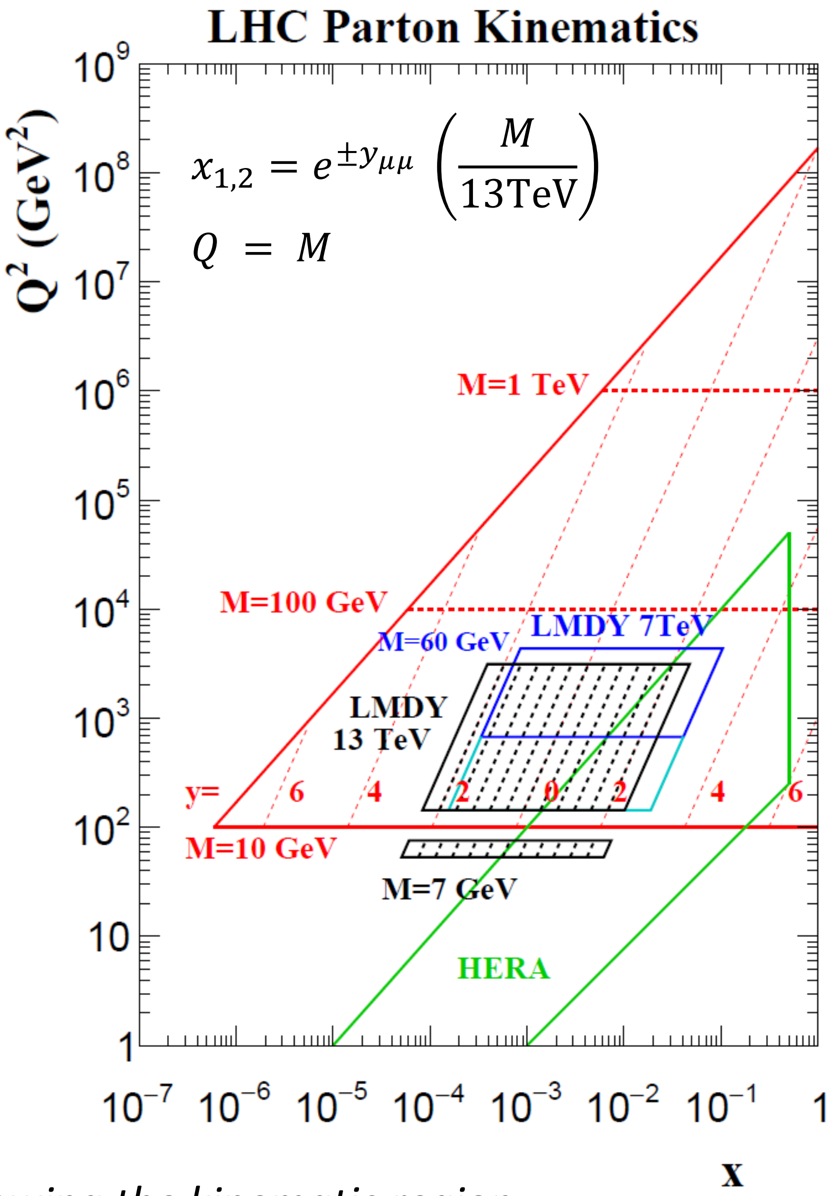
Measure Single and Double **differential cross section** in dimuon pair quantities

- $\frac{d\sigma}{dm_{\mu\mu}}$
- $\frac{d\sigma}{dm_{\mu\mu}\, d|y_{\mu\mu}|}$: rapidity more sensitive to x

The analysis **explores extreme region of the phase**

- With $m_{\mu\mu}$ ~8 GeV → $x\sim$ 4×10^{-5}
- Test low-x resummation prediction

[Prev. Analysis at 7TeV]



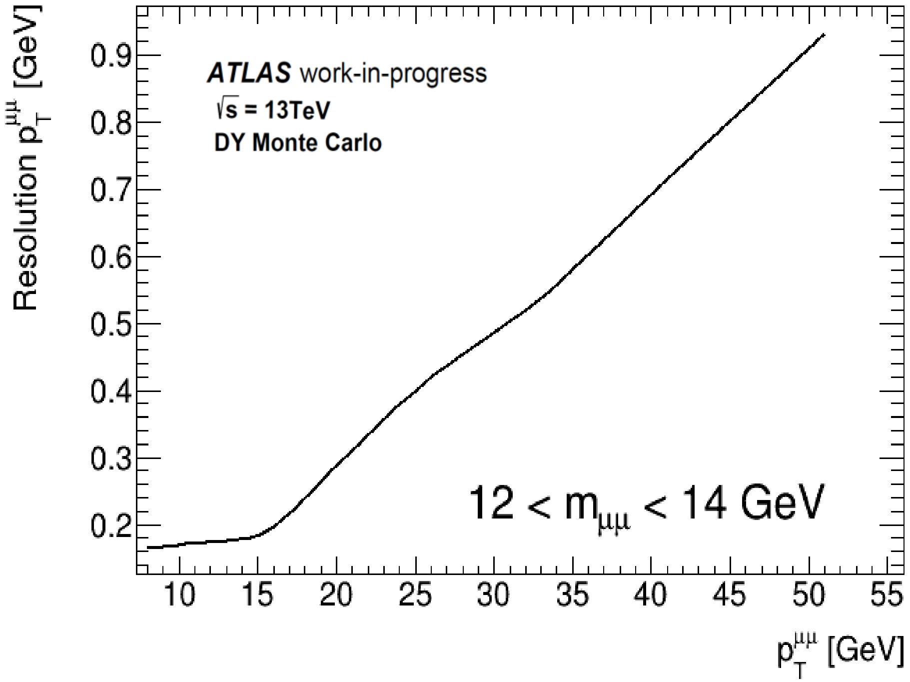
x-Q^2 plane showing the kinematic region accessed by the analysis, complementary region to one accessed by HERA

Image from http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html

The Low Mass Drell-Yan

Measurement of dimuon pair $\boldsymbol{p_T^{\mu\mu}}$ **spectrum** at low invariant mass

- $\frac{d\sigma}{dm_{\mu\mu}\, dp_T^{\mu\mu}}$
    - Exploit the good μ momentum resolution of the ATLAS detector at low mass
- Interesting test for QCD prediction
- Test the tuning of non perturbative parameters in the theoretical prediction
    - Useful for prediction of W p_T prediction and W mass measurement



***Resolution** of the momentum reconstruction as function of $p_T^{\mu\mu}$ at low mass*

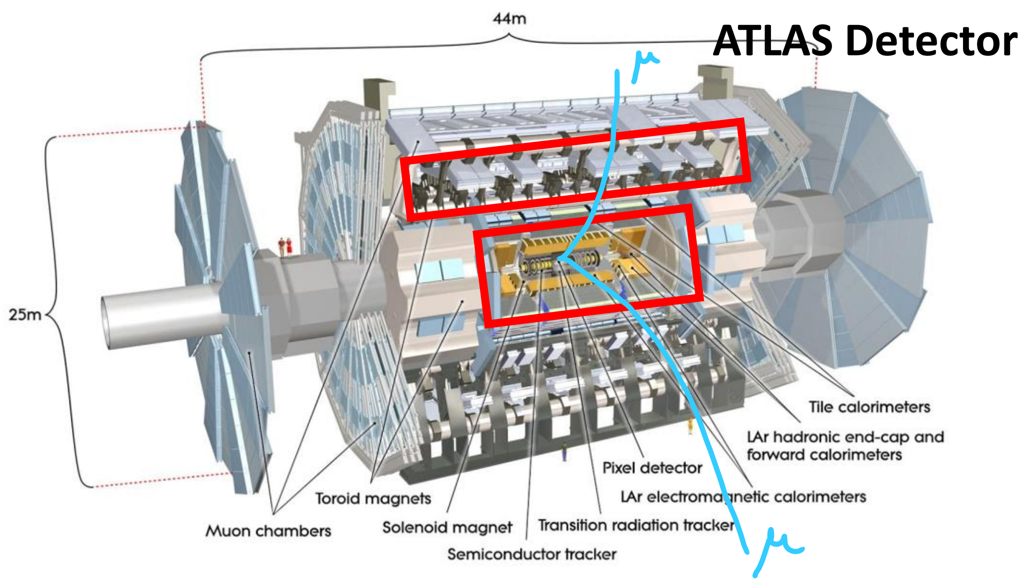
The Low Mass Drell-Yan

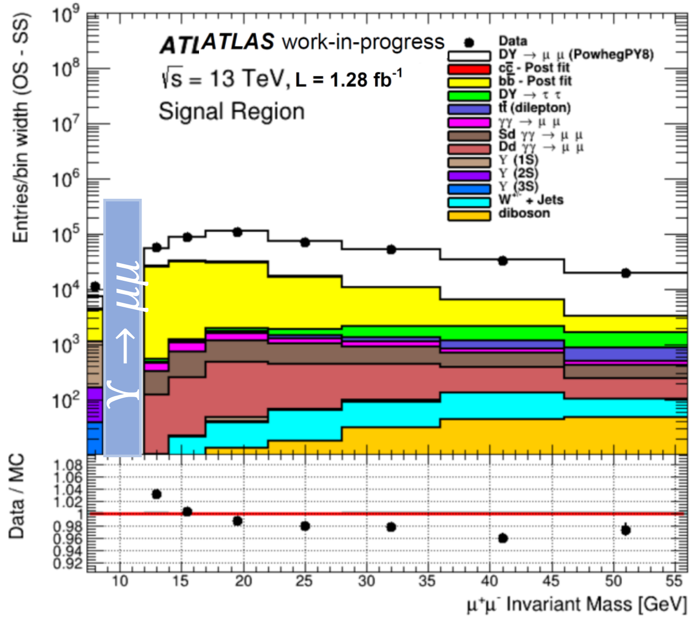
Drell-Yan process measurement in the dimuon channel in proton proton collision at $\sqrt{s} = 13$ TeV

Event Selection

- ATLAS 2015 dataset
  - 1.28 fb^{-1}
  - Need to use special low mass di-muon triggers
- Two muons required
- Low invariant mass selection
  - $m_{\mu\mu}$= (7.3, 8.7)+(12, 56) GeV
- Low Pt requirement
  - p_T^{μ}> 4.5 GeV

ATLAS Detector





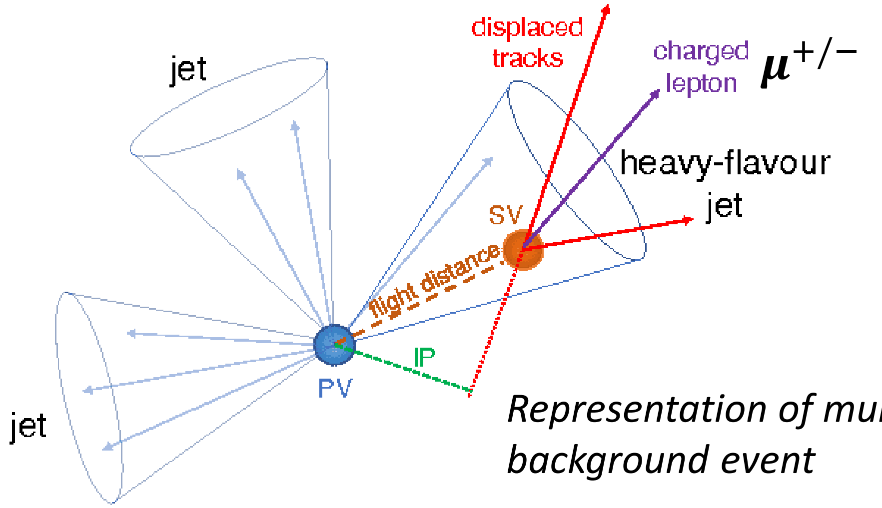
Mass Spectrum of the selected signal region

Background

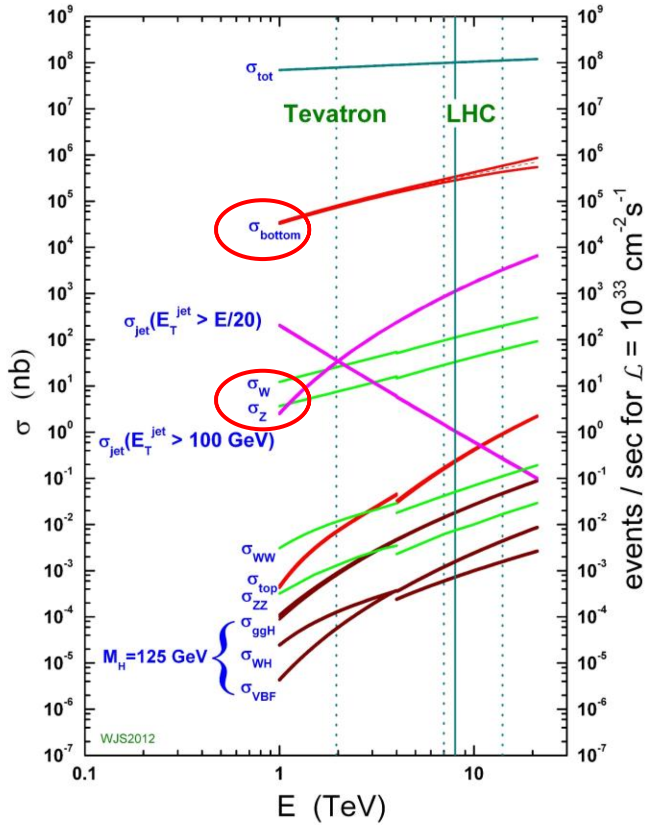
Perform the measurement – subtract the background

Fake Muons: $\pi^{\pm}$, K misidentified as muons
- Require high reconstruction quality muons
- Assumed to be symmetric in charge
- $N_{Fake}^{Opposite\ Charge} = N_{Fake}^{Same\ Charge}$
  - Reduced by plotting the distribution as opposite sign minus same sign subtraction

Biggest background components is given by muon generated in **Multijets events,** in particular $b\bar{b}$ / $c\bar{c}$ **jets events**
- Non prompt decay muons are misidentified as DY muons
- Excess in opposite sign muons
- Track isolation requirement greatly reduce this component…
  - …but still a large number of these events enter in the selection
- Poorly described in MC
  - Difficult to describe the rate of these events in the selection
  - Data-driven estimation approach



Representation of multijet background event



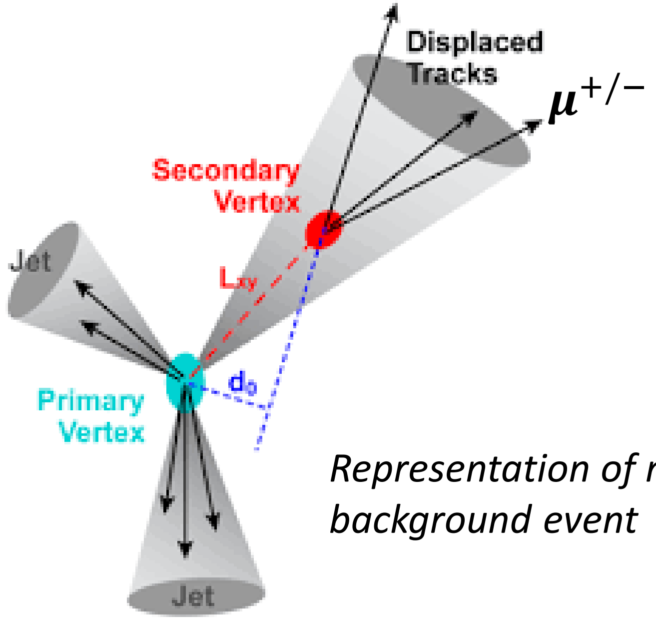
Analysis Strategy

Data-driven estimation of the Multijets + $b\bar{b}$ / $c\bar{c}$ jets background components

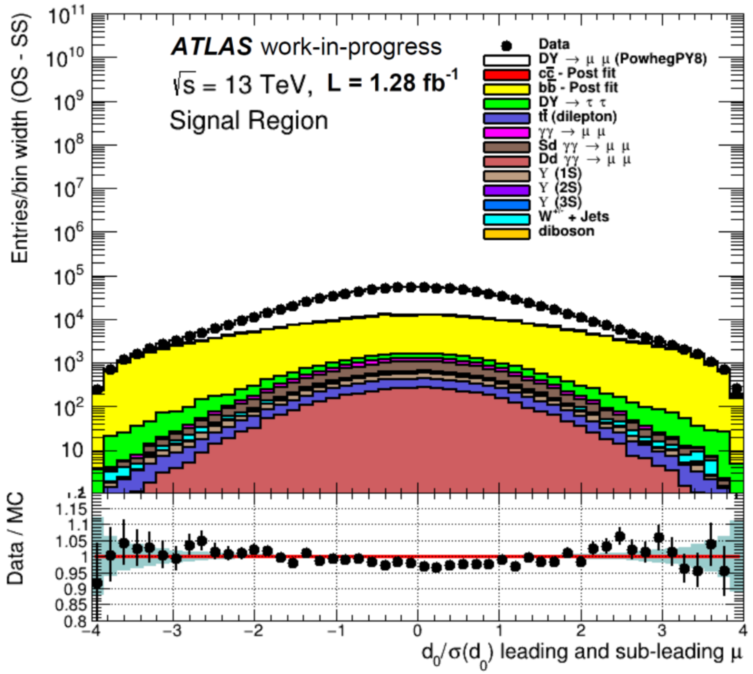
- This component is extracted by a **data-driven approach**
- **Use the impact parameters quantities to discriminate** between signal events and background events
  - Fit the quantity given by the squared sum of the d_0 and Δz_0 significance

$$\chi^2_{QCD} = \left(\frac{d_0(\mu_1)}{\sigma_{d0}(\mu_1)}\right)^2 + \left(\frac{d_0(\mu_2)}{\sigma_{d0}(\mu_2)}\right)^2 + \left(\frac{\Delta z_0(\mu_1,\mu_2)}{\sqrt{\sigma^2_{z_0}(\mu_1) + \sigma^2_{z_0}(\mu_2)}}\right)^2$$

- $\Delta z_0(\mu_1,\mu_2) = z_0(\mu_1) - z_0(\mu_2)$



Representation of multijet background event

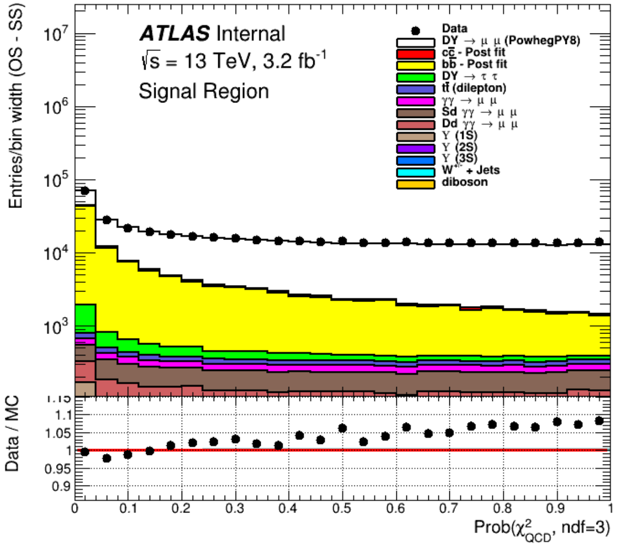


d_0 distribution in Data and MC

Analysis Strategy

The probability

$$Prob(\chi^2_{QCD}, ndf = 3)$$



Represents the probability that the 2 muons are coming from the same vertex

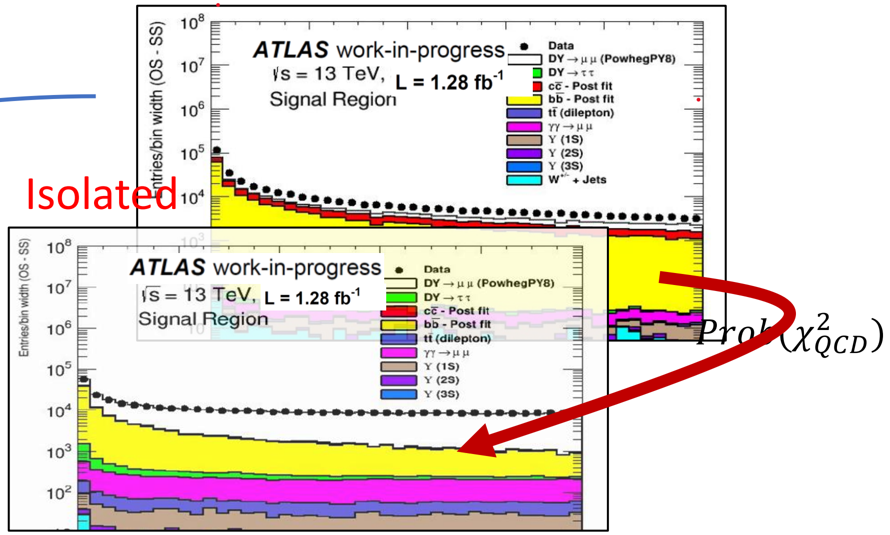
- Use **Control Region given by not isolated muons**
    - Gives template for Background from data
- Fit this quantity to the real data

$$Prob^{not-isolated}(\chi^2_{QCD}, ndf = 3) \sim BG_i$$

$$Prob^{isolated}(\chi^2_{QCD}, ndf = 3) \sim k \cdot DY^{iso-iso} + b^{iso-iso} BG_i$$

Not Isolated

Isolated



$Prob(\chi^2_{QCD})$

Blue component – from Monte Carlo

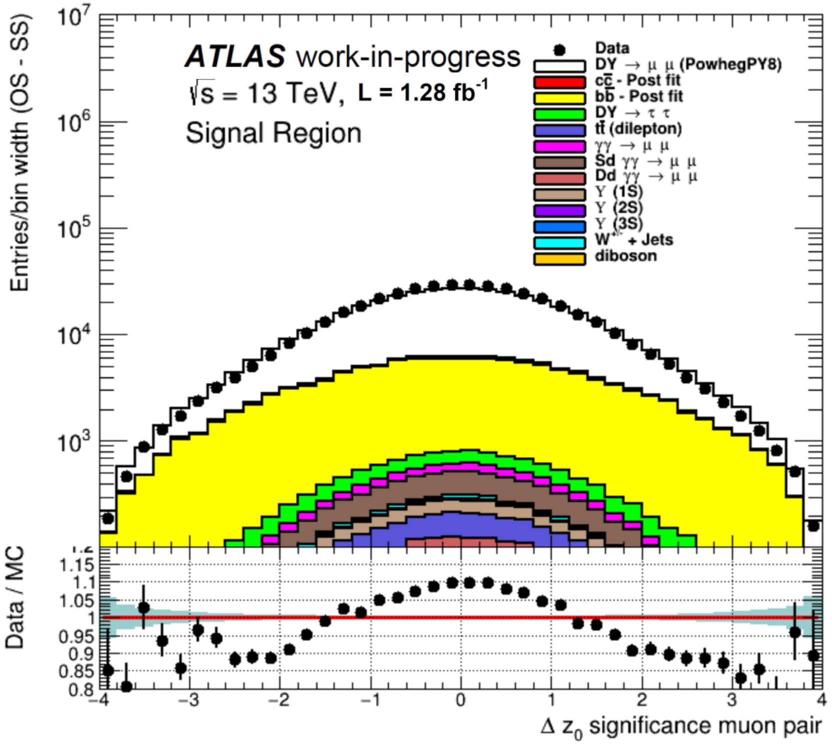
Red component – fitted to the data

$Prob(\chi^2_{QCD}, ndf = 3)$ distribution for isolated and not-isolated selection

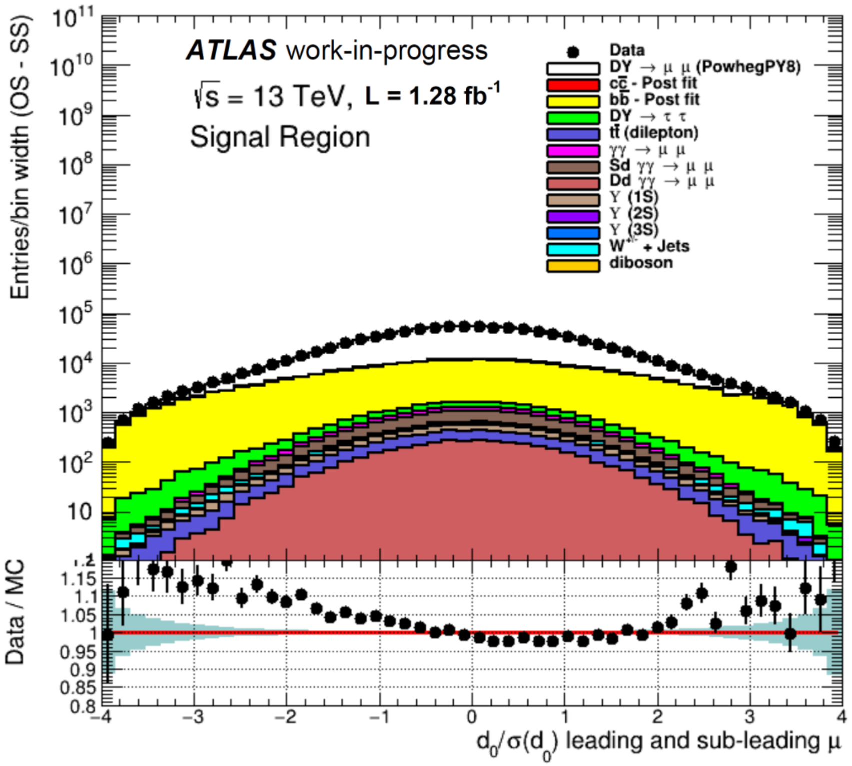
Modelling of the Impact Parameters

Check that the impact parameters are well described in Monte Carlo

- Distance of the track from the beam spot
- These quantities enter in the Background estimation



Δz0 significance distribution



d0 significance distribution

Evaluate a data driven correction to improve the Data/MC agreement

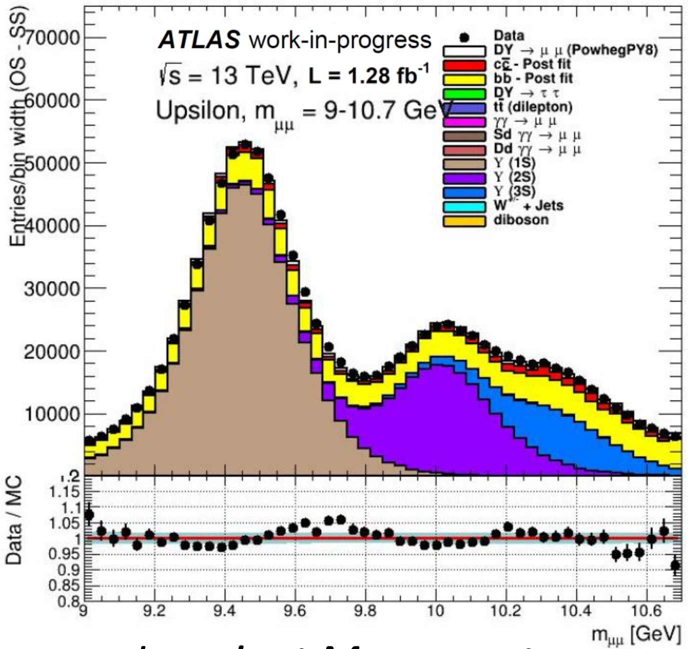
Modelling of the Impact Parameters

Extrapolate a data driven correction for the Impact Parameters distribution outside the Signal Region

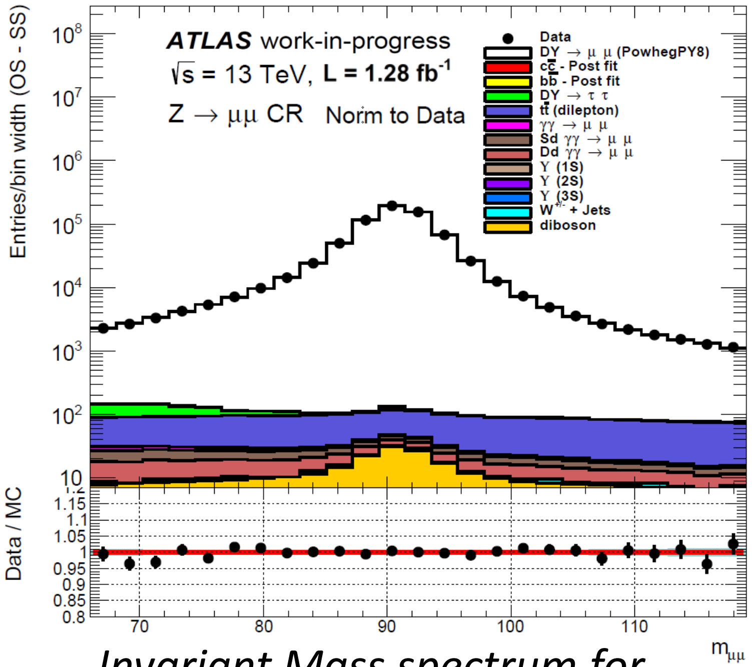
- Look at region excluded by the invariant mass selection
  - Υ → μμ Region ($Υ_{1S}$ = 9.46 GeV)
  - Z → μμ peak region (m_Z = 91.2 GeV)

Evaluate a correction

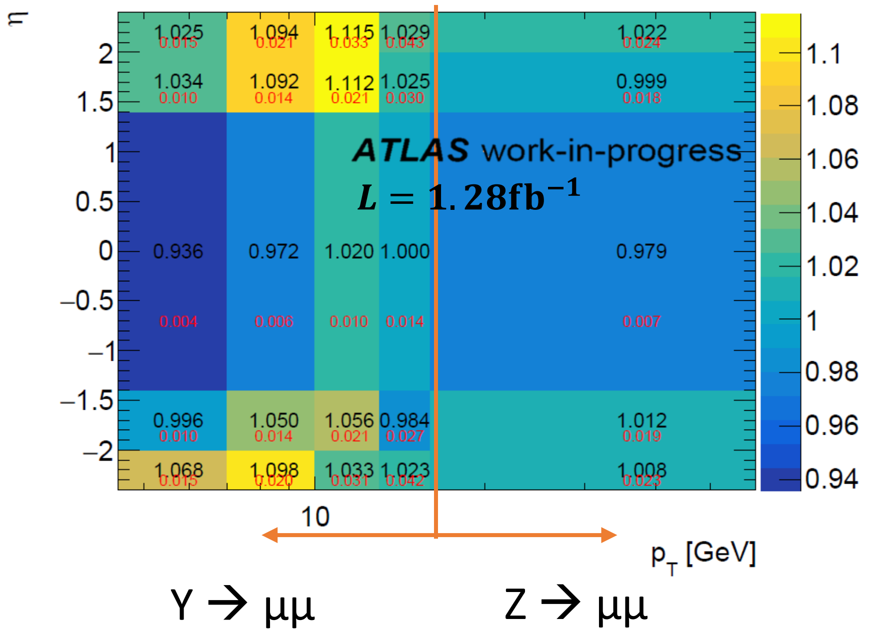
- That span a wide range in pT
- Depends on the detector coordinate



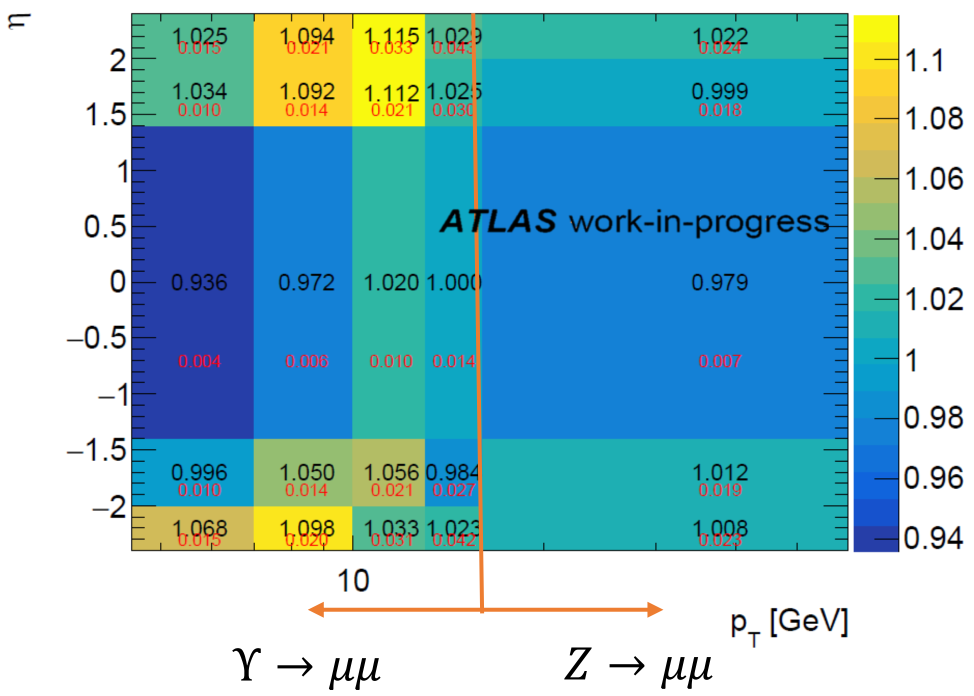
Invariant Mass spectrum for the Υ → μμ Region



Invariant Mass spectrum for the Z → μμ peak region

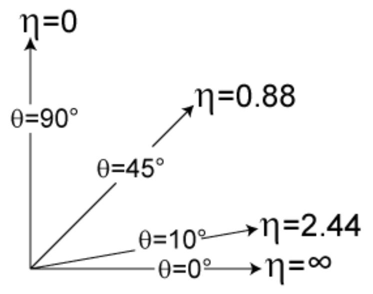


Impact Parameter Corrections

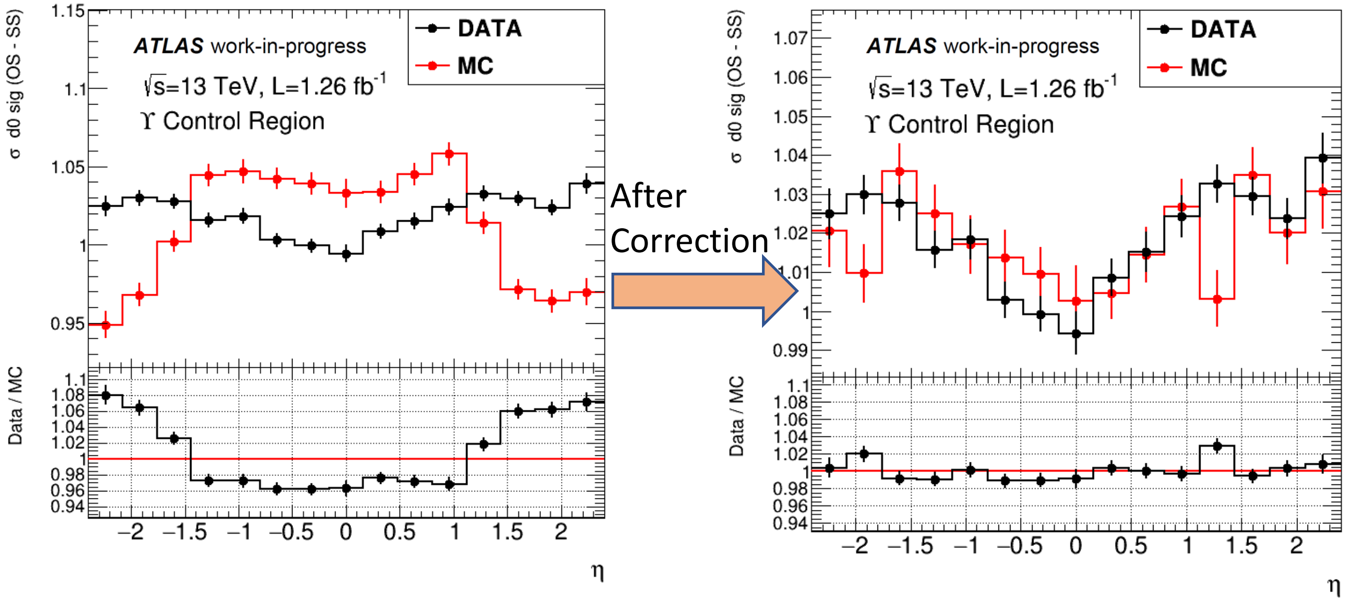


Evaluate a correction

- span a wide p_T^μ
- p_T^μ and η^μ dependent correction
- Rescale the Monte Carlo IP resolution to the Data one

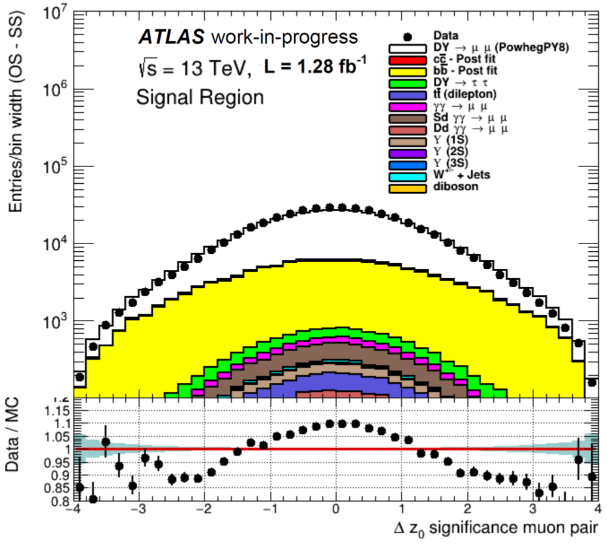


Pseudorapidity

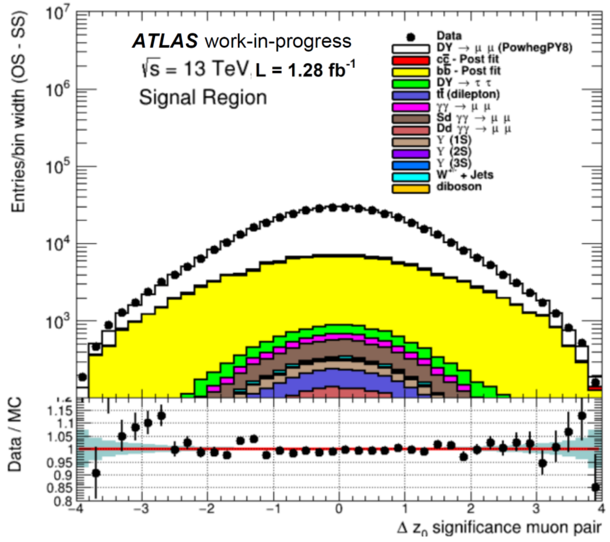


The agreement is restored as function of η and p_T^μ

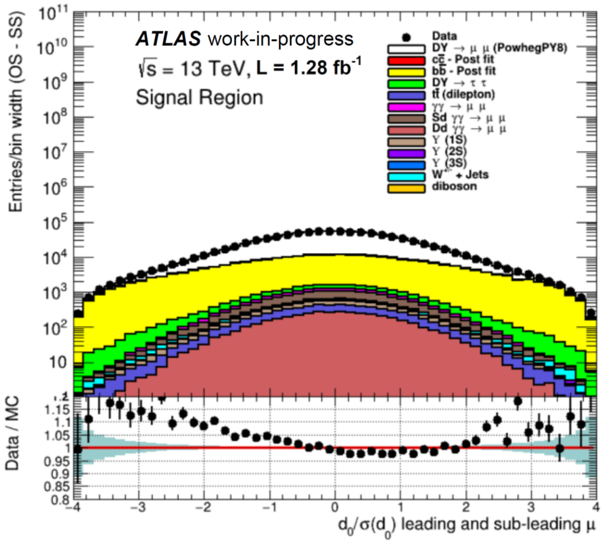
Modelling of the Impact Parameters



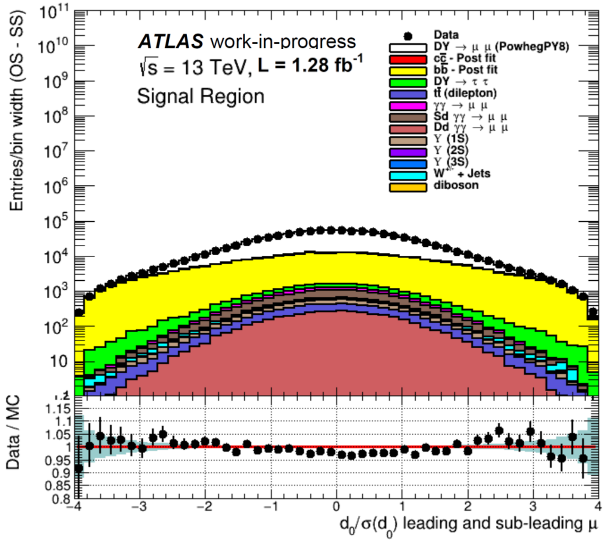
After Correction



Improvement of the Impact Parameter description after the applying the correction



After Correction

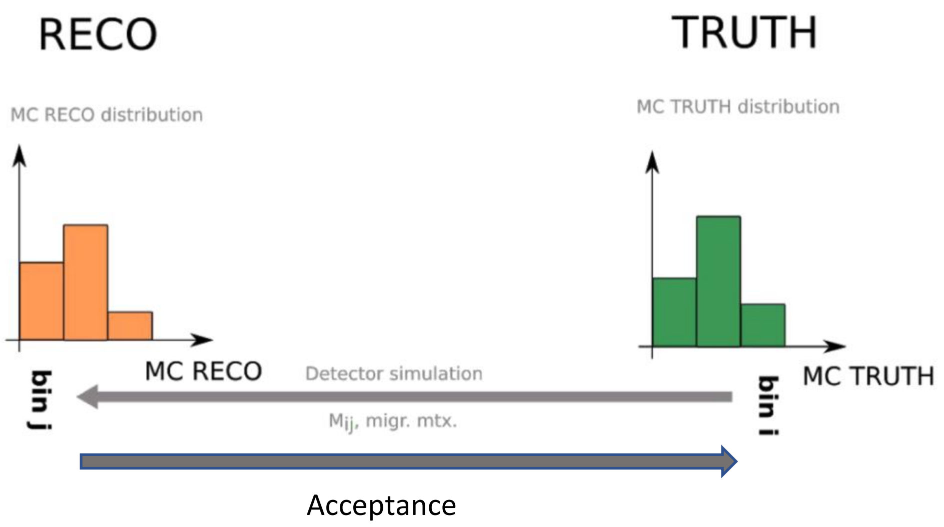


Δz0 and d0 significance inclusive distribution before and after applying the impact parameters correction

Cross-section Unfolding

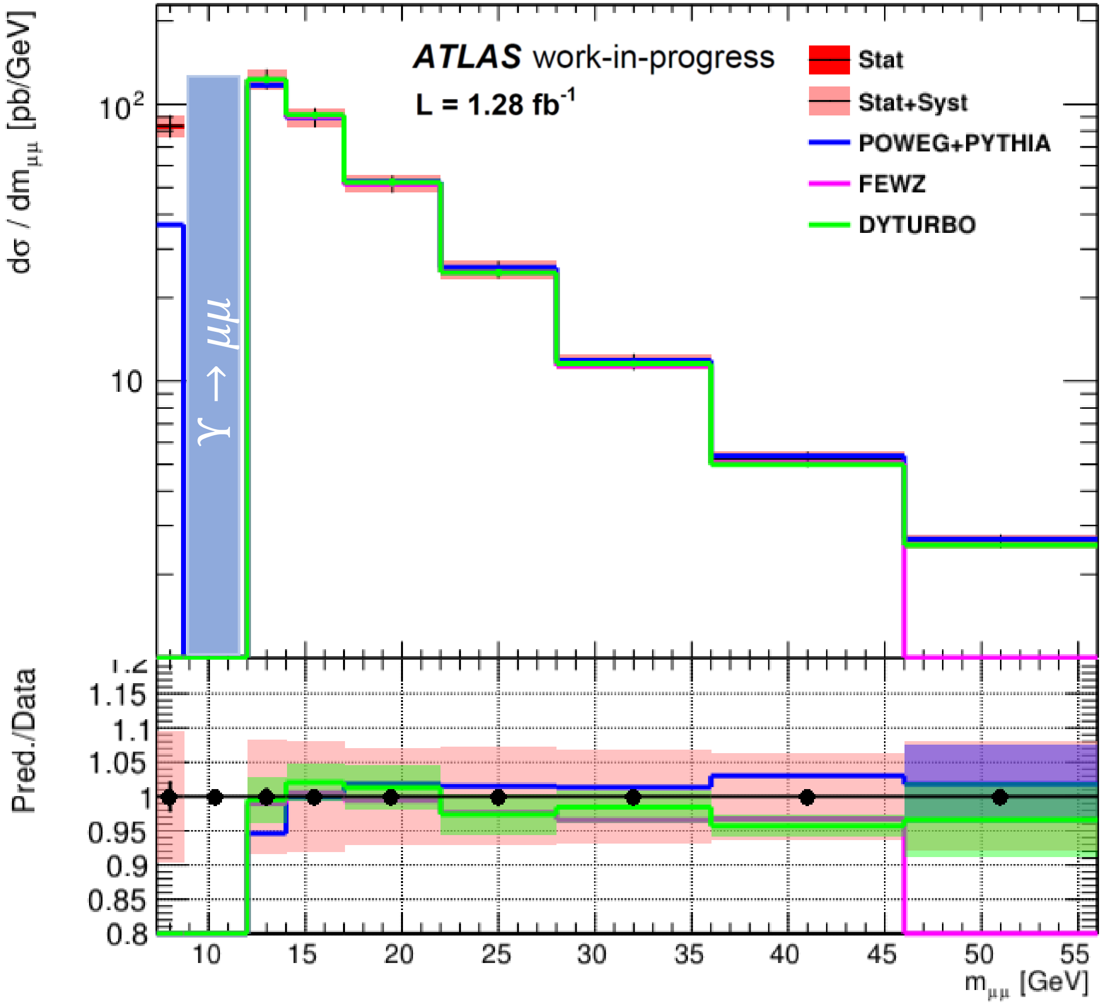
In the Next Slides studies on the systematic uncertainties affecting the analysis are presented
The studies show the effect of the uncertainties on the cross-section results

- The cross-section extrapolated with bin-by-bin unfolding
- $\left(\frac{d\sigma}{dm_{\mu\mu}}\right) = \frac{N_i^{DATA} - N_i^{BG}}{L \cdot C_{DY,i} \cdot \Gamma_i}$
  - C_{DY} = Acceptance = $N_{RECO}^{MC} / N_{GEN}^{MC}$
  - Γ_i = Bin size



Under Study: iterative unfolding method

Results – Single Differential Result



Data plotted with (first determination) of systematic and statistical uncertainty

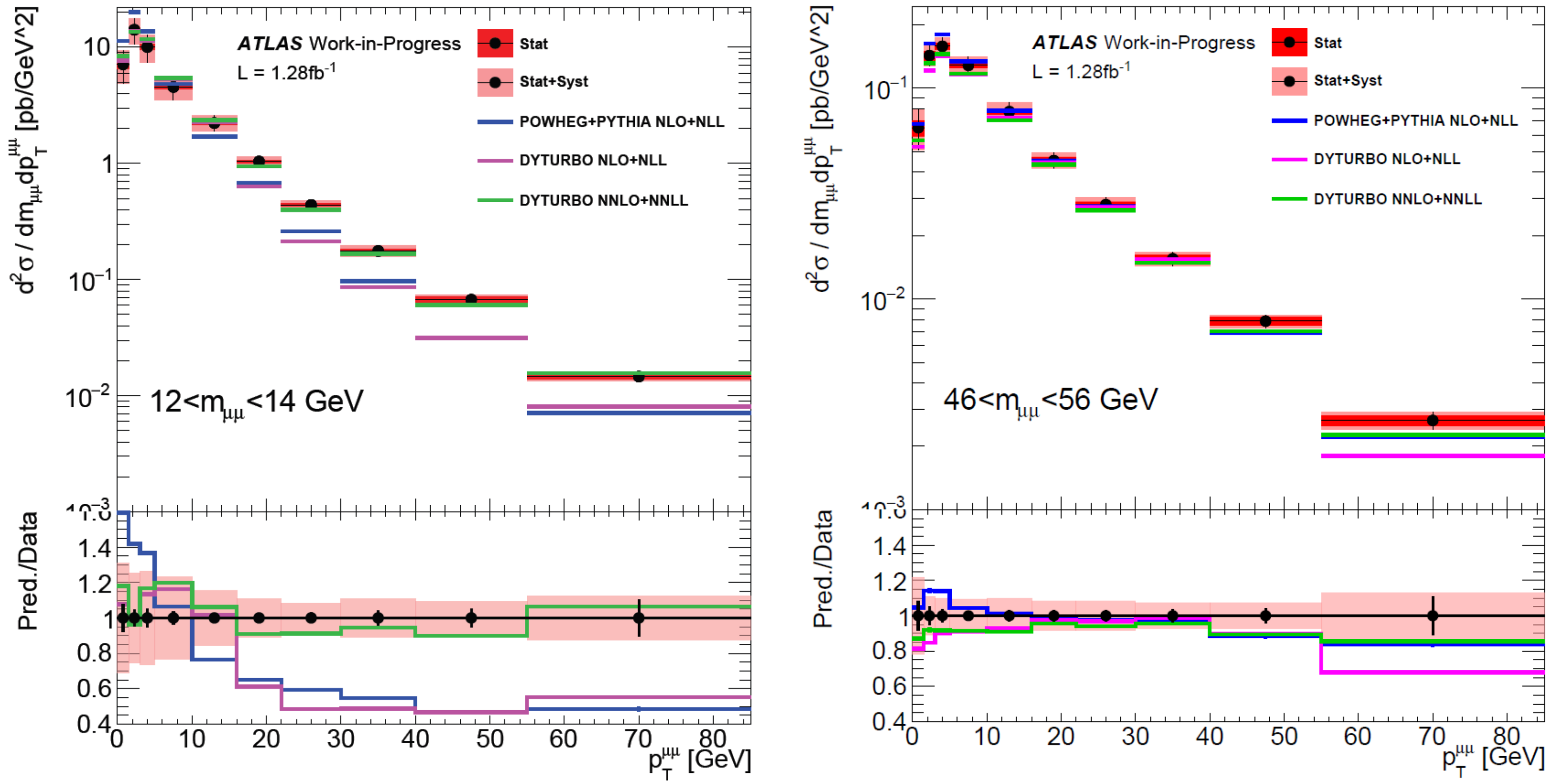
- Poweg+Pythia: NLO (+ LL Parton Shower)
  - NNLO QCD k_F
  - MC generator used in the analysis
- FEWZ → NNLO + NLO EW Correction
  - In the **first and last bin** FEWZ is set to Zero: the prediction are not ready yet
- DYTURBO → NNLO + NNLL + NLO EW Correction

Uncertainty studies not finalised

Systematic Uncertainty

- Isolation efficiency systematic
- Trigger efficiency systematic

Results – Double Differential Result

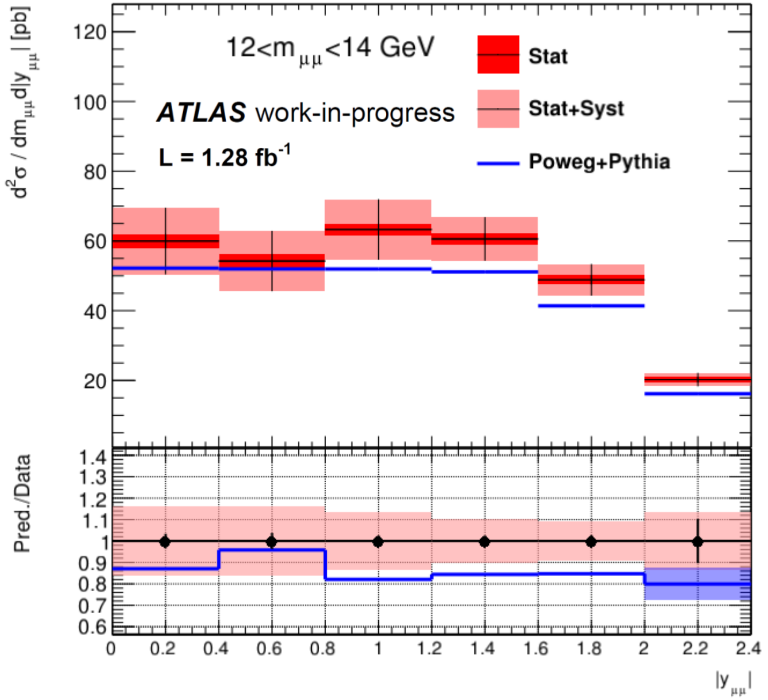


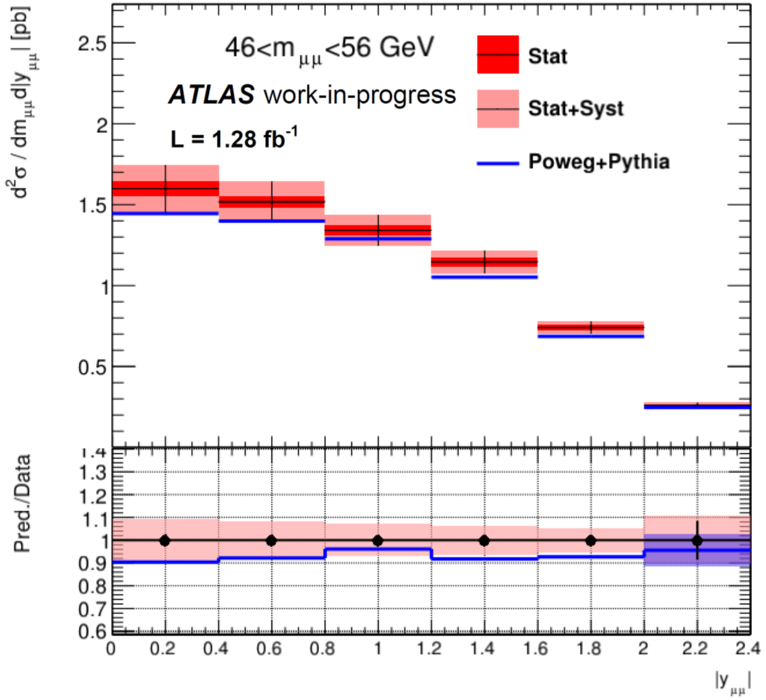
Cross-section results unfolded in $m_{\mu\mu}$ and $p_T^{\mu\mu}$

- Poweg+Pythia
  - NLO (+LL from Parton Shower)
- DYTURBO
  - NLO + NLL
  - NNLL + NNLO

Double differential cross-section result at low mass and high mass

Results – Double Differential Result





Cross-section results unfolded in $m_{\mu\mu}$ and $|y_{\mu\mu}|$

- Poweg+Pythia
  - NLO (+LL from Parton Shower)

Dominating Uncertainty
Systematic Uncertainty

- Isolation efficiency systematic
- Trigger efficiency systematic

Double differential cross-section result at low mass and high mass

Summary and Outlook

Low Mass Drell-Yan Analysis
- **Probe extreme region of the phase space**
- Test Low-x region
- Test low-$p_T^{\mu\mu}$ prediction in new phase space region

Main challenges in the analysis
- **Large Background component**
  - Data driven template method
- **Modelling of the Impact Parameters** quantities
  - Data driven correction evaluated from control region

Next Steps
- Finalize Uncertainties Evaluation
- Modelling of $p_T^{\mu\mu}$ for the $m_{\mu\mu} - |y_{\mu\mu}|$ measurement
- Finalize Unfolding Strategy

Thanks for the Attention!

BACKUP

Trigger Selection

Explore low invariant mass and low p_T^μ event selection

- Use of **special di-muon trigger**
  - Z and High Mass Drell-Yan typically use single muon trigger
  - Can't trigger at low mass on single muon event, too may events
- To keep the ATLAS trigger rate at $\sim 1\mathrm{kHz}$ **low mass trigger are prescaled** (rejection rate)
- Different pre-scale between the different trigger in the trigger chain that needed to be taken into account in MC

Trigger	Prescale	Luminosity
HLT $p_T^\mu > 4, GeV\ m_{\mu\mu} \in (7,\ 9)GeV$	4	$319.68\ \mathrm{pb}^{-1}$
HLT $p_T^\mu > 4, GeV\ m_{\mu\mu} \in (12, 60)GeV$	4	$319.68\ \mathrm{pb}^{-1}$
HLT $p_T^\mu > 6, GeV\ m_{\mu\mu} \in (12,\ 24)GeV$	1	$1280.28\ \mathrm{pb}^{-1}$
HLT $p_T^\mu > 6, GeV\ m_{\mu\mu} \in (24,\ 60)GeV$	1	$1280.28\ \mathrm{pb}^{-1}$