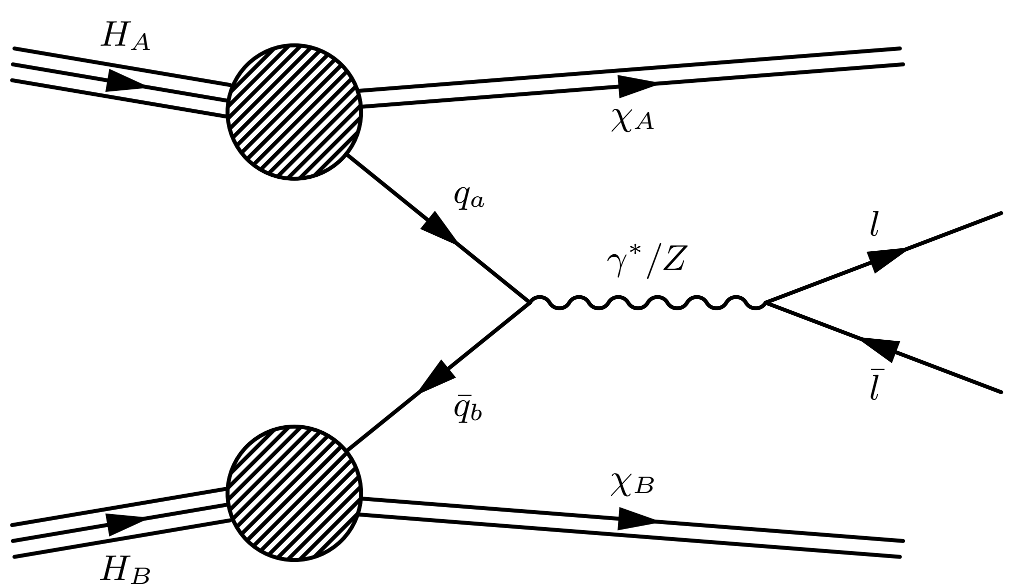
Drell-Yan Analysis in 3D (M, Y, Cosθ*)

IOP Presentation



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PDFs & The Drell-Yan Process

Knowing the structure of the proton is vital for hadron collider physics.

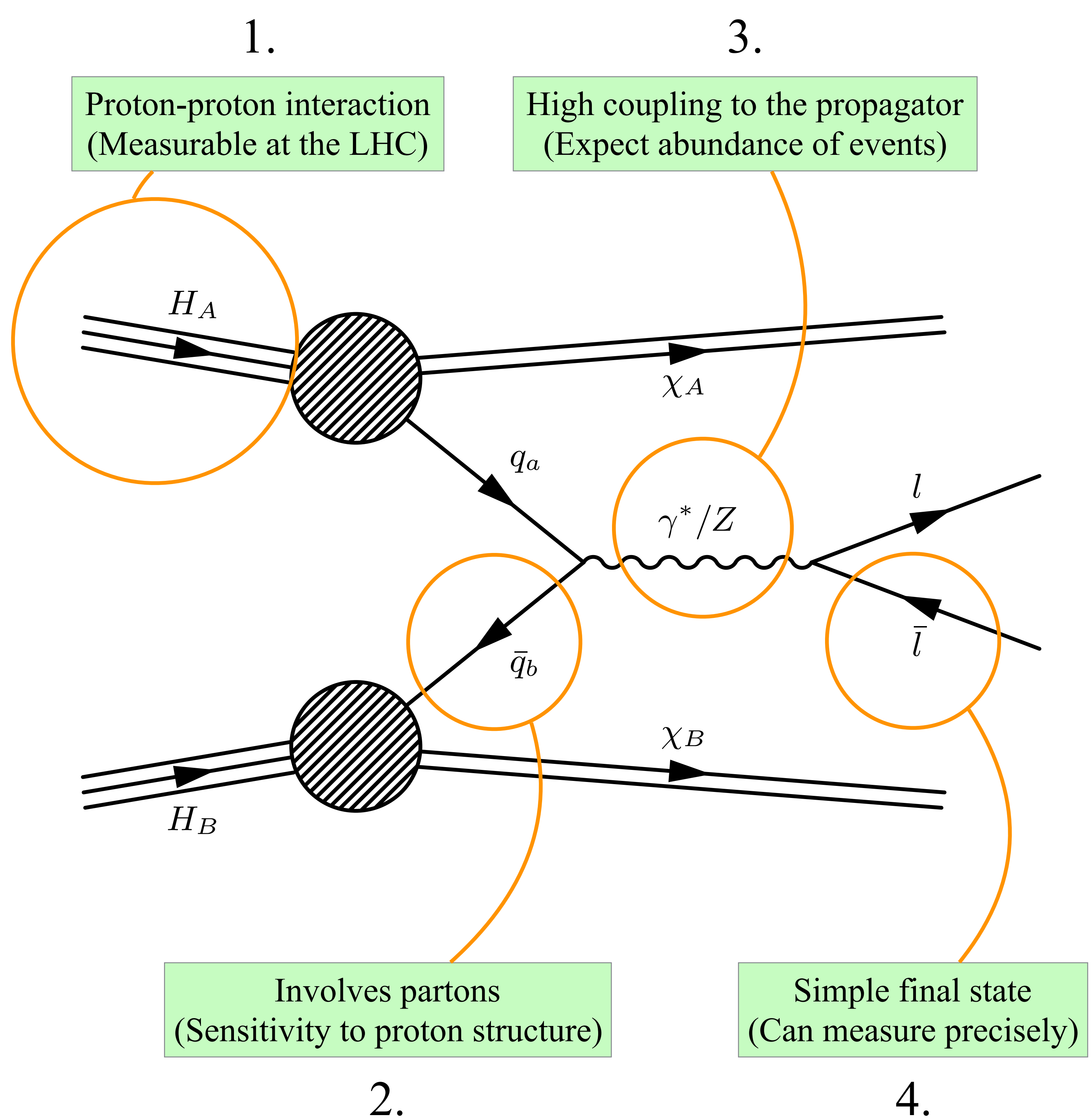
It is also a good test of our current theory where we can compare predictions against the data.

In high energy physics proton structure is typically measured in the form of parton distribution functions (PDFs).

PDFs tell us what the probability of encountering a particular proton constituent (parton) is.

The most precise PDF data we have currently comes from deep inelastic scattering (DIS) experiments.

Such experiments operate at lower energies than the LHC. New PDFs are being determined for the LHC era of energies…

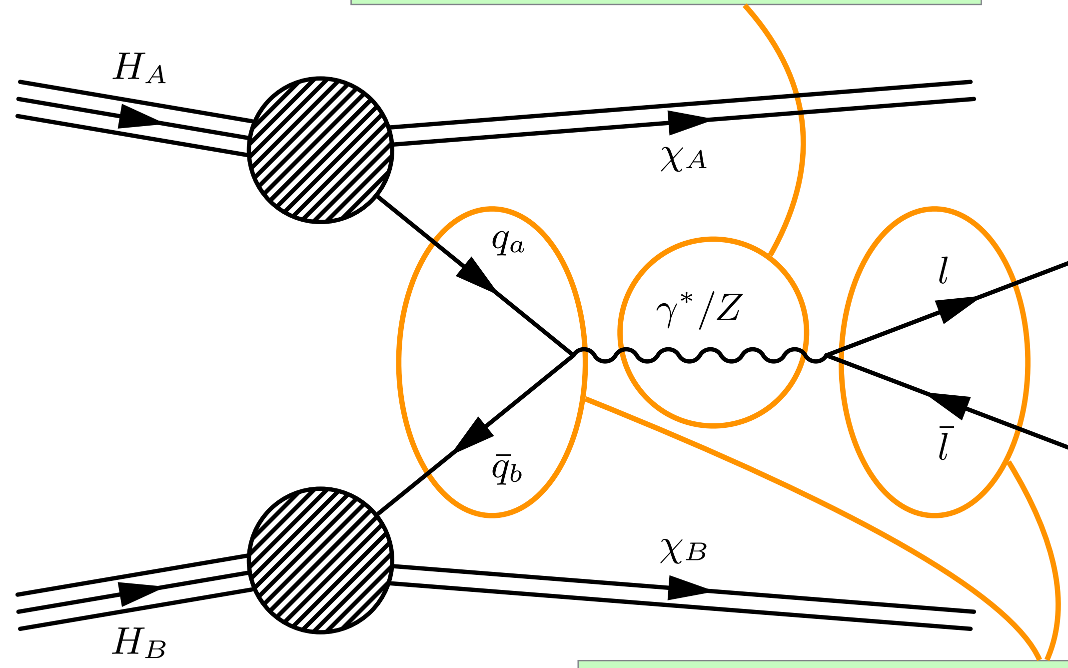


The Measurement

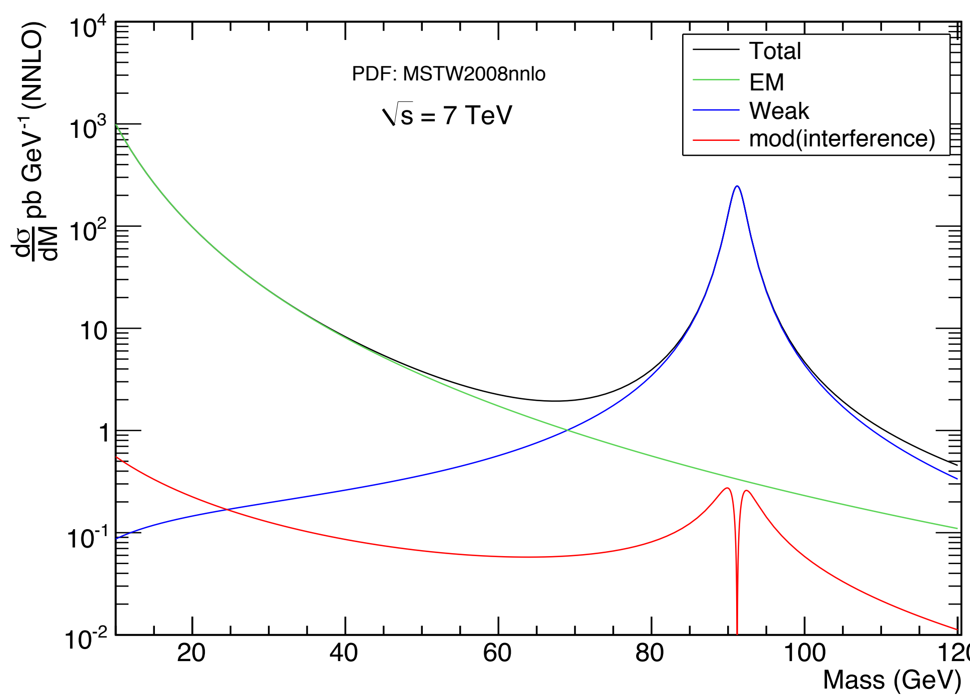
Due to the large size of the datasets we can afford to measure the Drell-Yan process simultaneously in three dimensions.

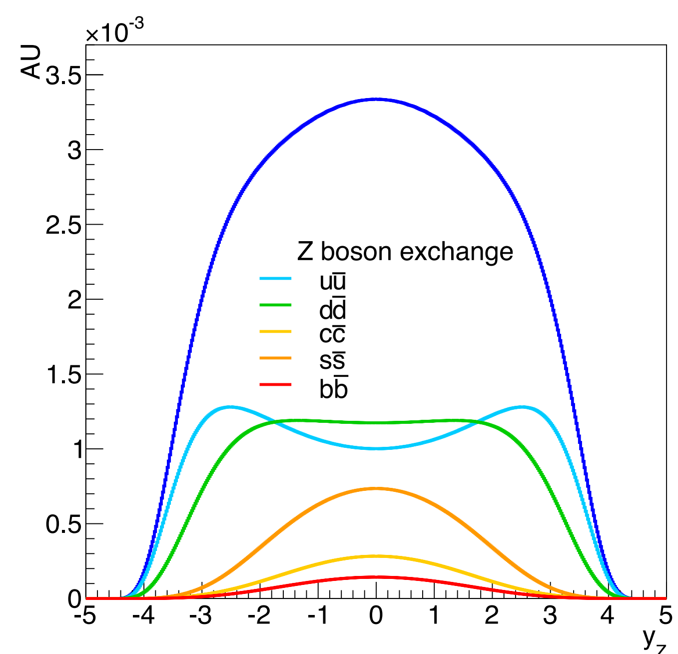
- Invariant mass is sensitive to the energy scale of the interaction.
- Rapidity it sensitive to the boost of the propagator.
- Lepton decay angle gives sensitivity to higher order processes and electroweak parameters.

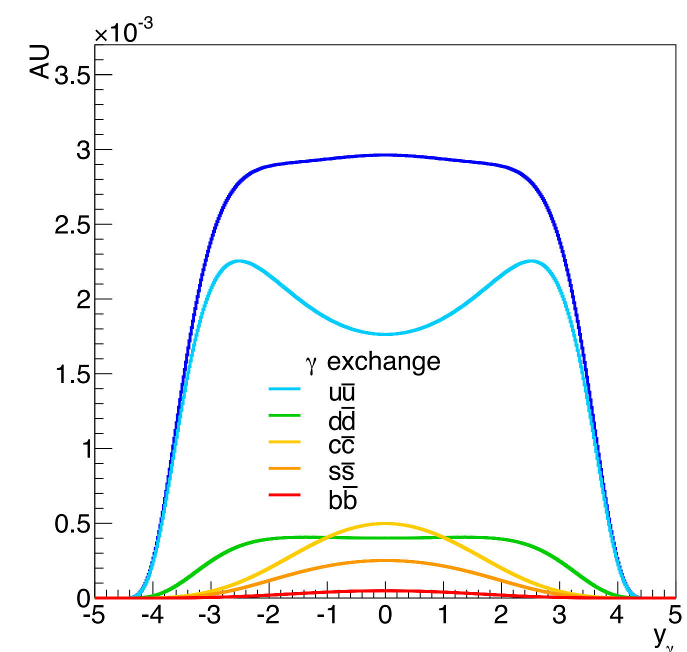
Invariant mass and rapidity are properties of the propagator



Di-lepton decay angle is a property of the leptons with respect to a frame of reference of the partons







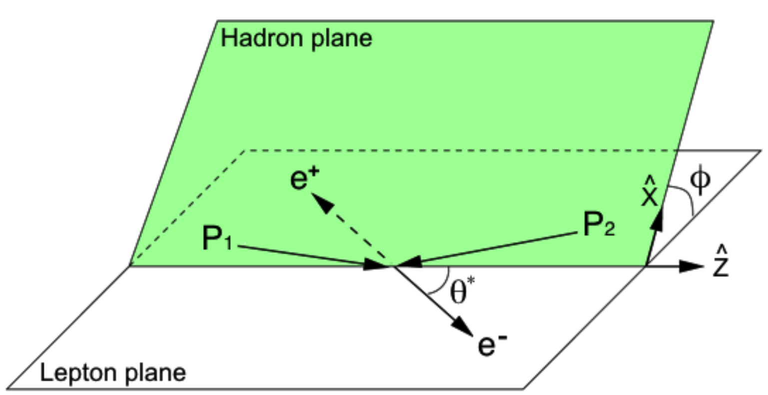
The Measurement

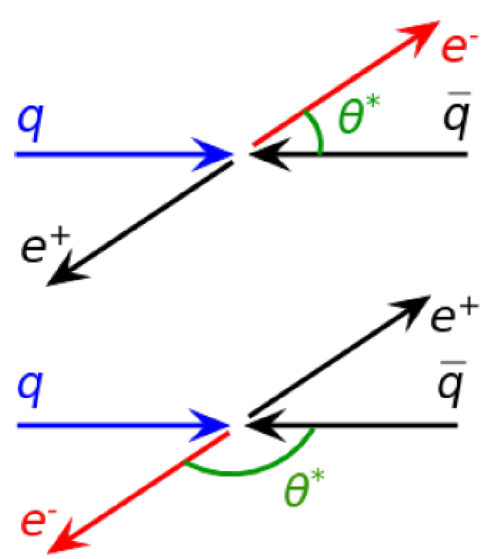
The di-lepton decay angle is defined in the Collins-Soper frame. This allows for the measurement of the forward-backward asymmetry.

Encoded in this asymmetry are important electroweak parameters, such as the weak mixing angle θ_W.

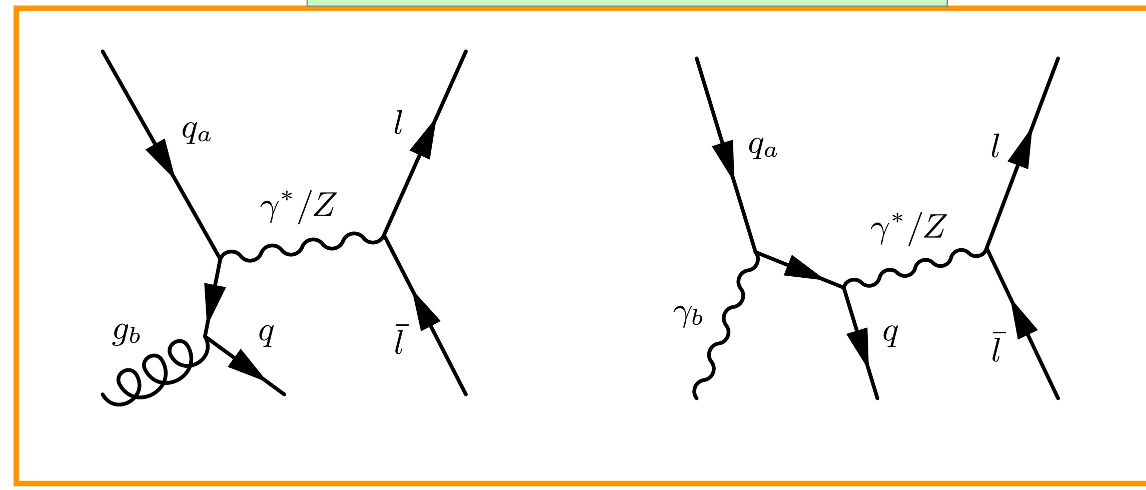
Therefore, in total we achieve:

- PDF sensitivity in 3D
- 3 analysis channels; muon, electron CC & CF
- Simultaneous extraction of θ_W and PDFs.

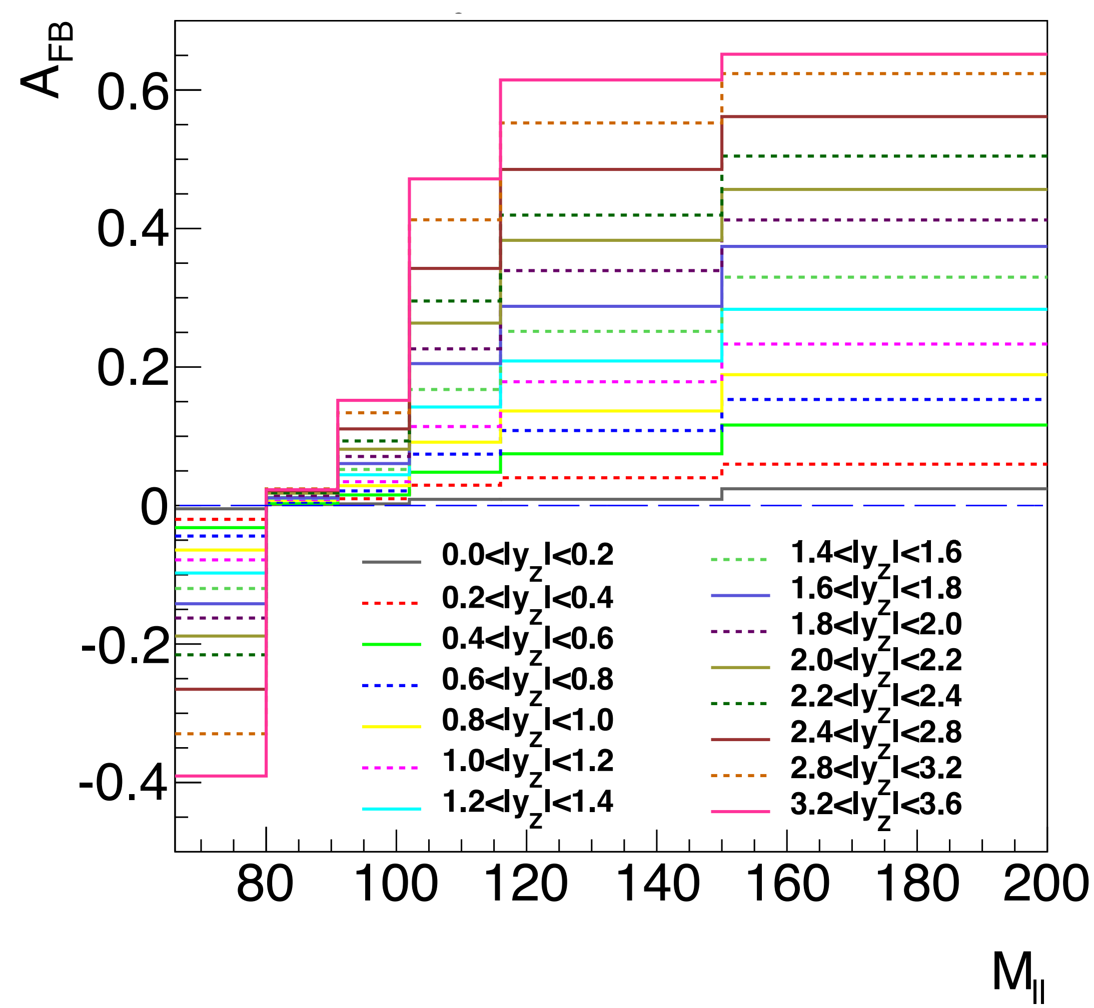




Example higher order processes



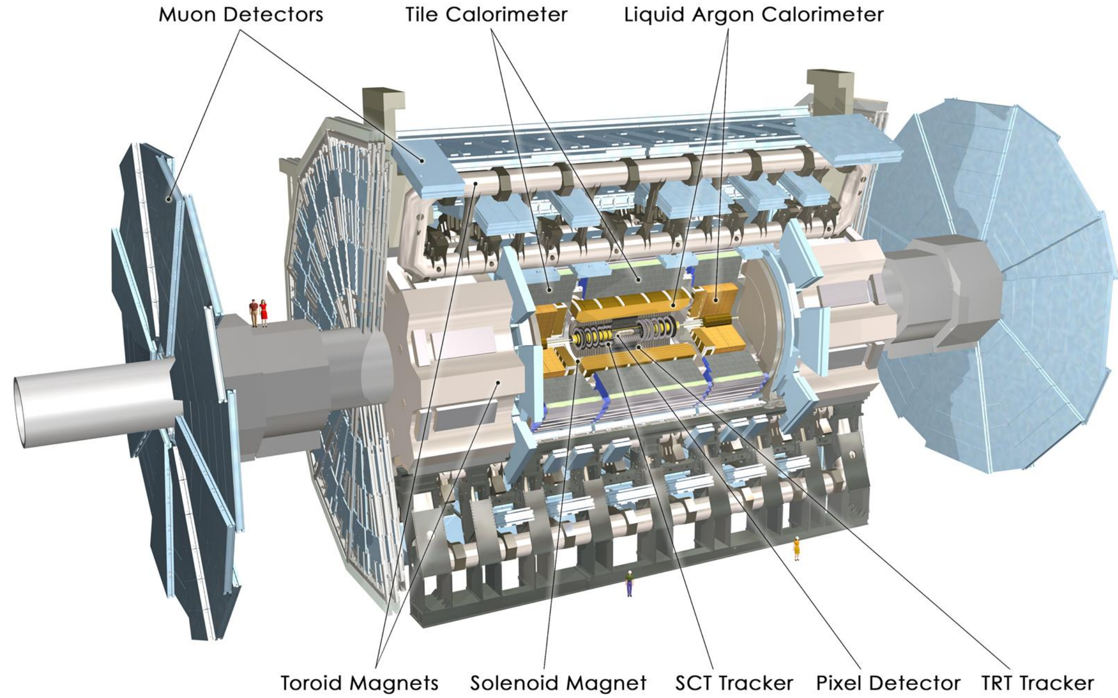
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B},$$

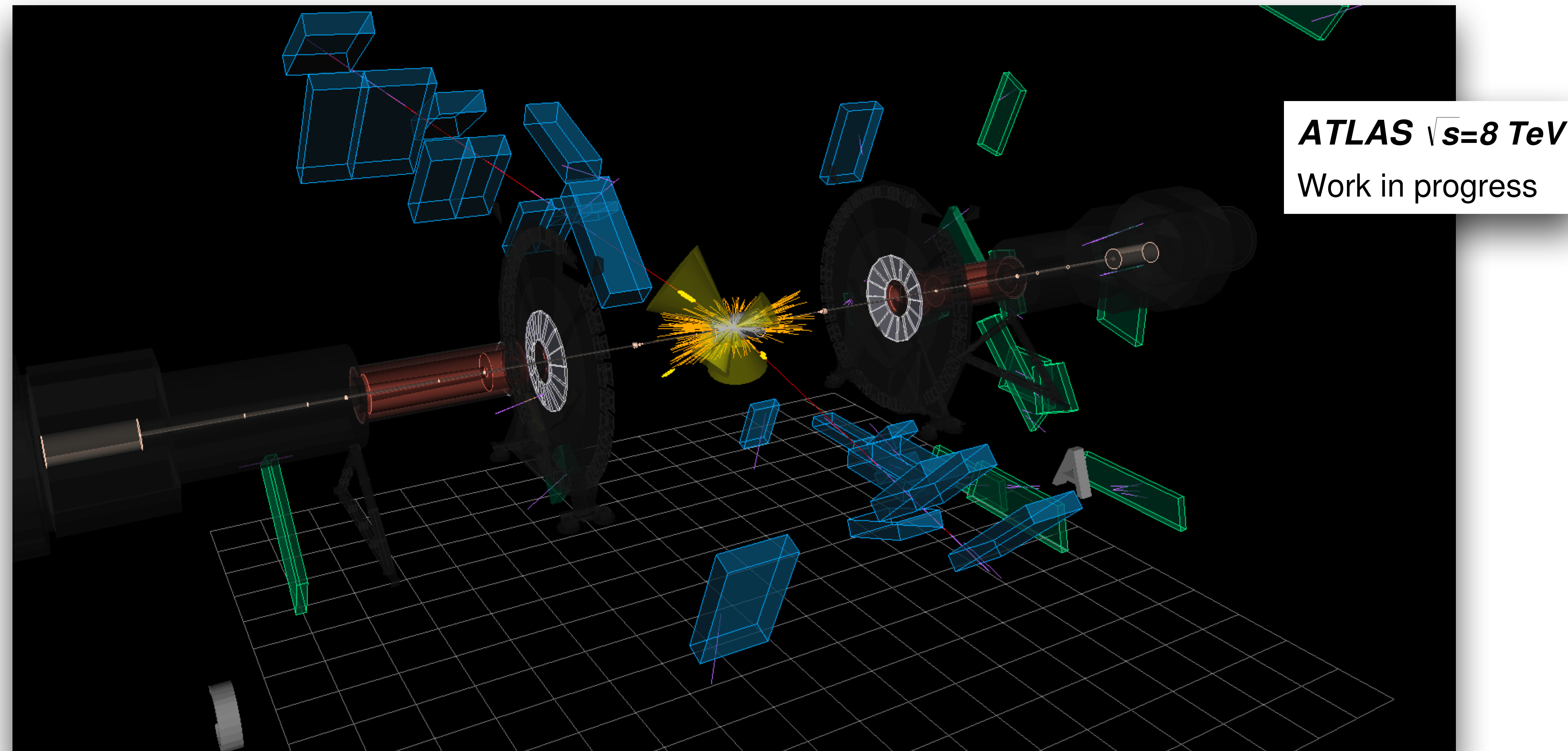


Events in ATLAS

We use the ATLAS detector at CERN to record interesting events for us to analyse.

An example di-muon candidate event is shown. (Visible: beam-pipe, inner detector tracks, muon tracks and excited muon chambers)



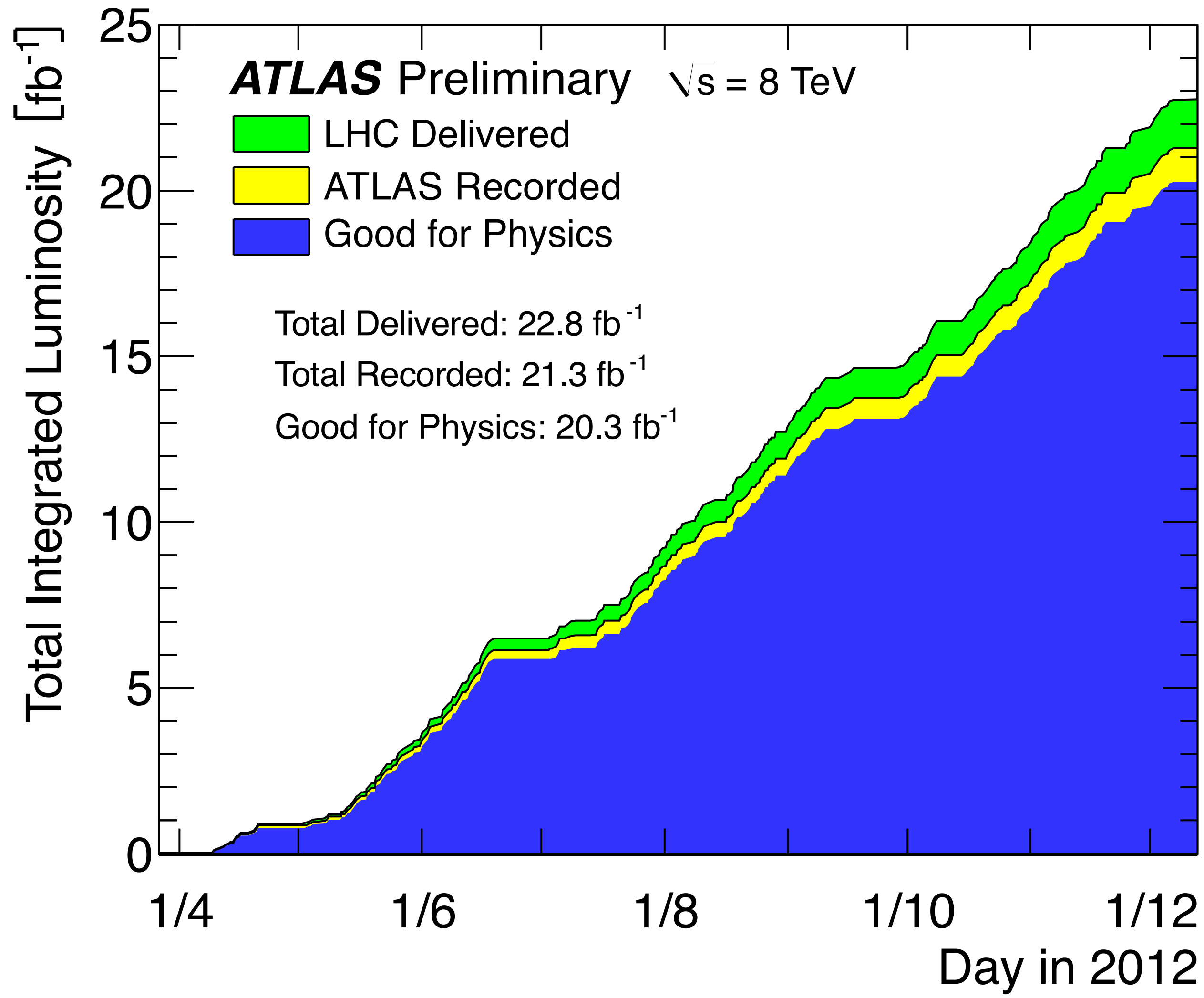


Zμμ Signal Selection

Selection:

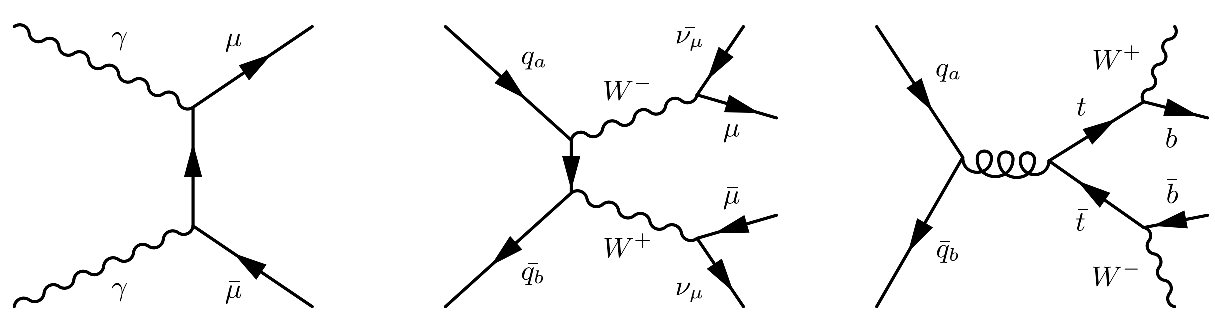
Each event we require:

- Good status of the detector
- Vertices ≥ 1
- Tracks to primary vertex ≥ 3
- No. reconstructed muons ≥ 2
- Events from the following triggers
  - 36GeV muon trigger
  - 24GeV isolated muon trigger
  - 18GeV di-muon trigger
- Good muon reconstruction quality
- Muon matched triggers
- Impact parameter cuts
- Pseudo-rapidity, |η| < 2.4
- Muon pT > 20GeV
- Isolation
- Third muon veto
- Mass > 46GeV



For this √s=8TeV analysis: Total integrated luminosity = 20.24fb^{-1} (± 1.9%)

Background Processes



Photon Induced | Diboson | ttbar

Other Backgrounds

- Single top
- DY -> tau,tau
- W -> mu,nu
- W -> tau,nu

The Fiducial Volume

Muon and CC-Electron channel

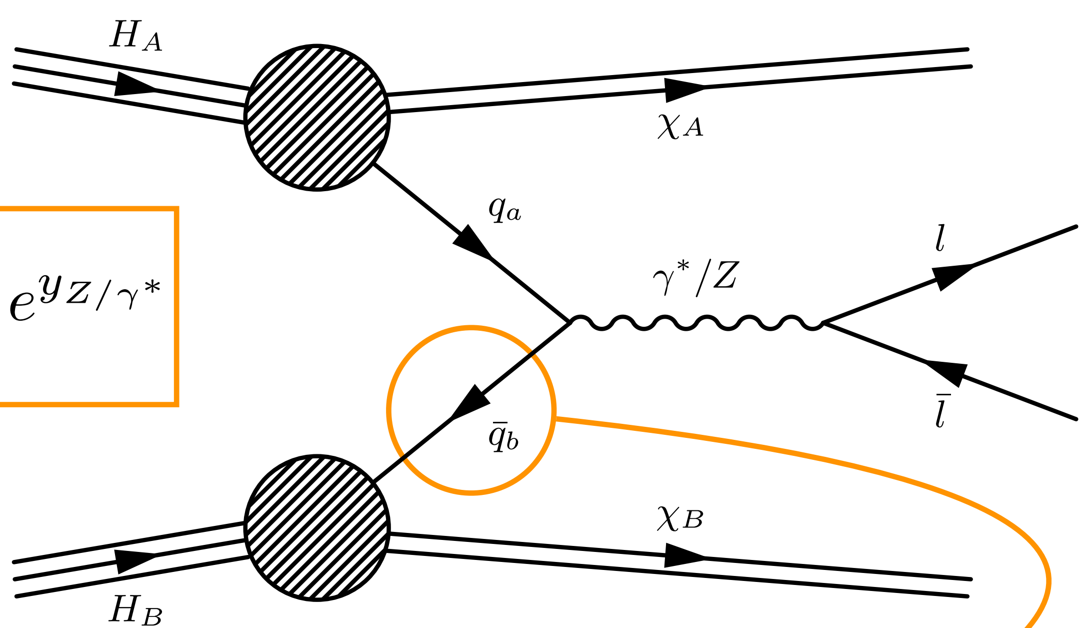
Binning
Invariant Mass:
7 bins from 46GeV to 200GeV

|Rapidity|:
12 bins from 0.0 to 2.4

Cosθ*:
6 bins from -1.0 to +1.0

→ 504 Analysis bins

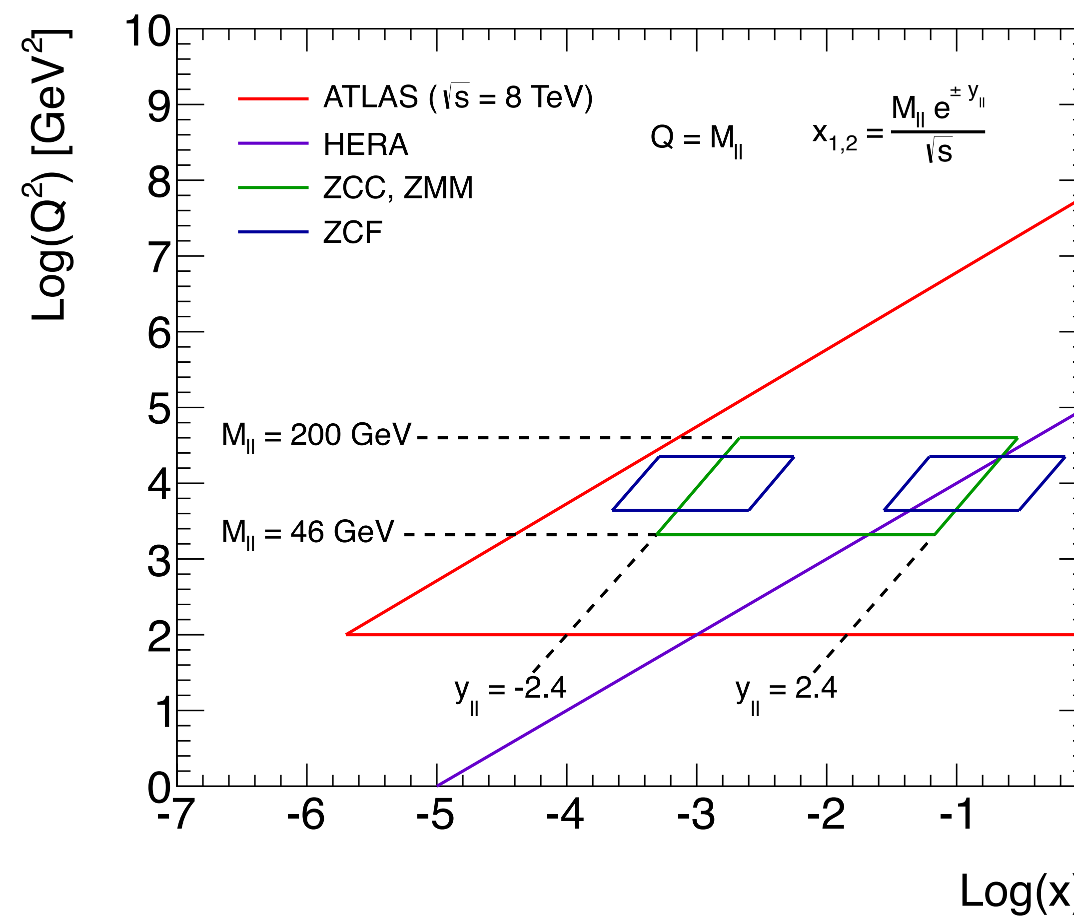
- Fine binning in rapidity to capture PDF / dilution variation.
- Relatively coarse bins in mass to mitigate migrations.
- Bin boundaries set for trivial extraction of asymmetry and reduction of E-resolution



$$x_{1,2} = \frac{M_{ll}}{\sqrt{s}} e^{y_{Z/\gamma^*}}$$

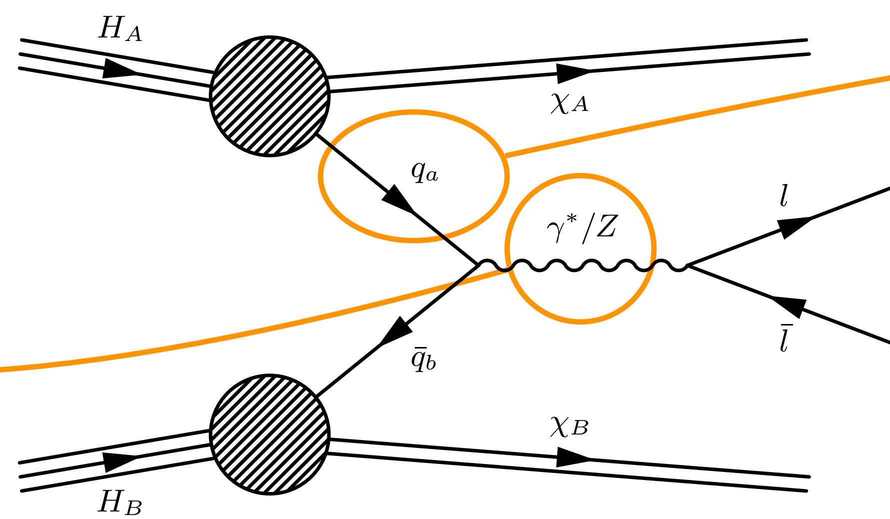
M = Invariant mass
y = Rapidity
√s = Collision energy

Each parton carries a fraction, x, of the incoming proton's momentum.

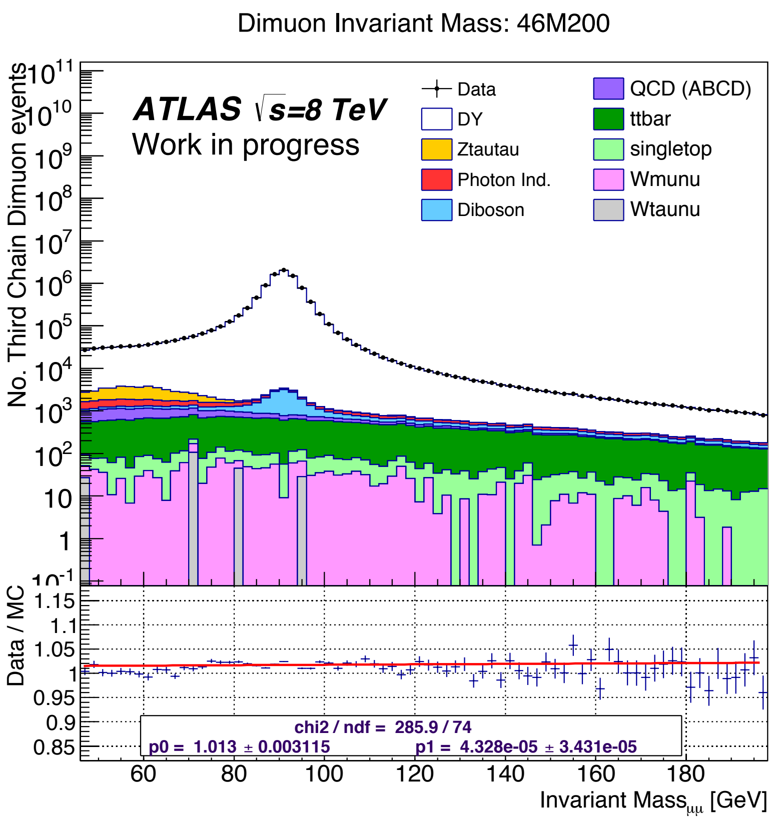


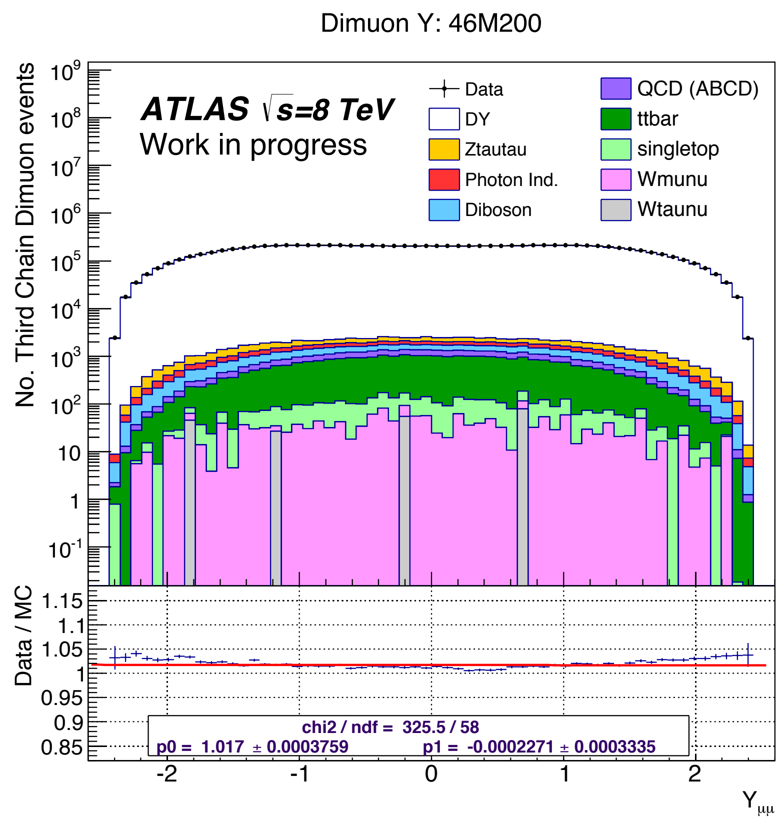
The plot above shows the coverage of the analysis phase-space in comparison to that achieved at HERA. (Q = invariant mass)

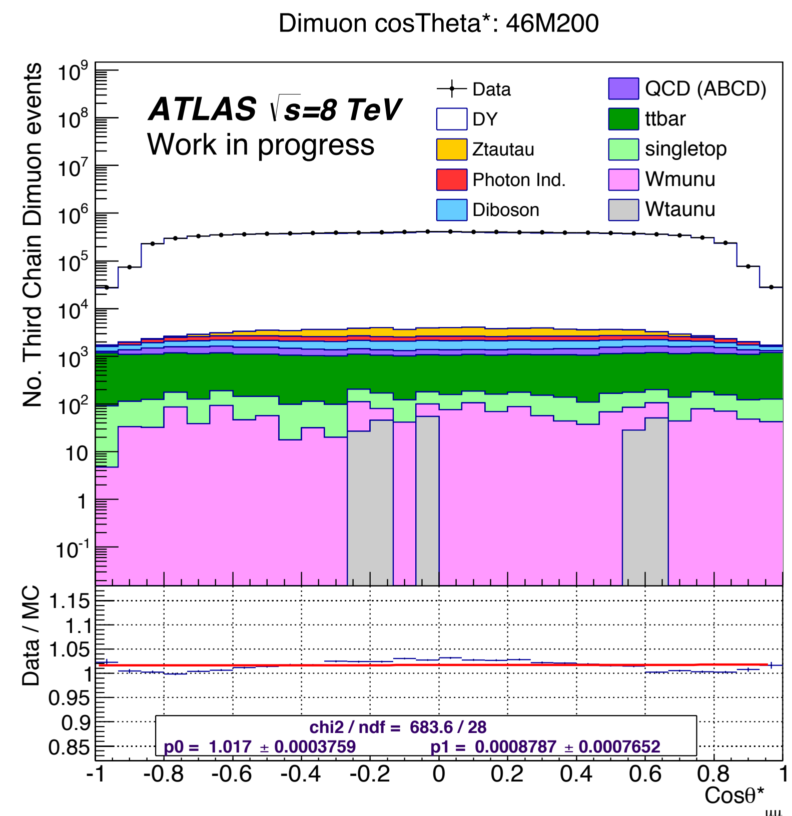
The Z-boson propagator provides the well known Z-peak



Parton interactions involving the quark sea populate the higher ranges of rapidity

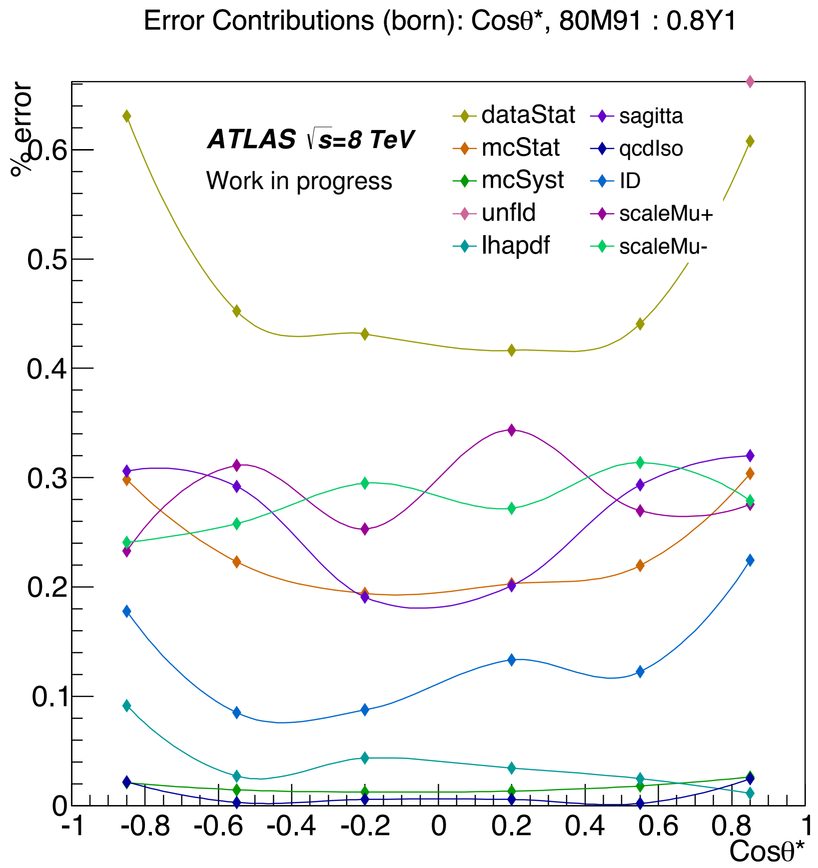


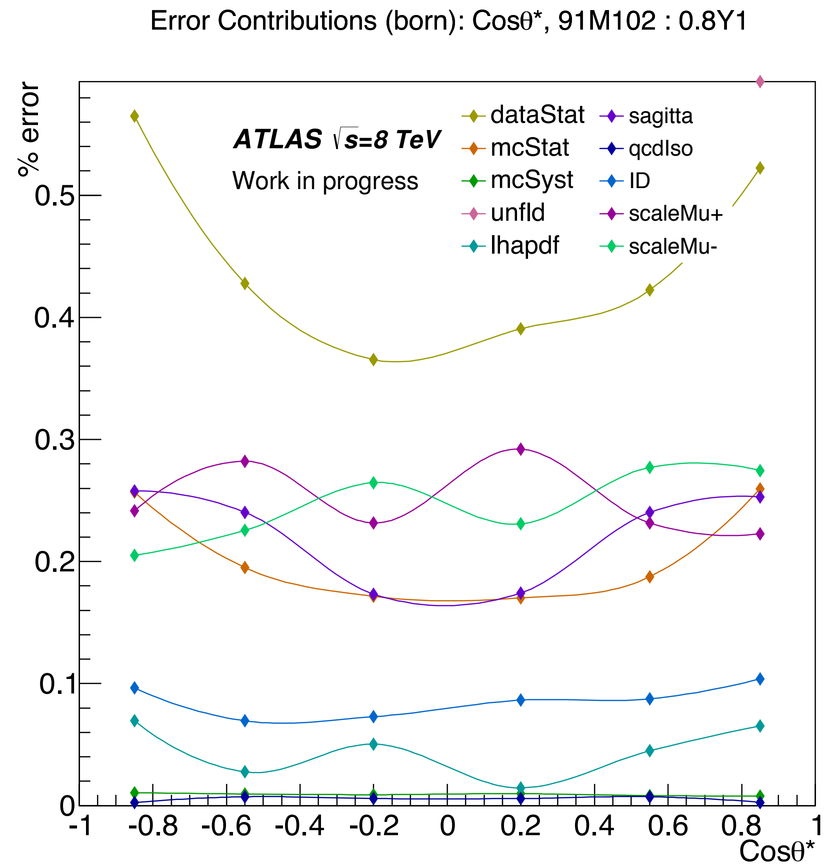


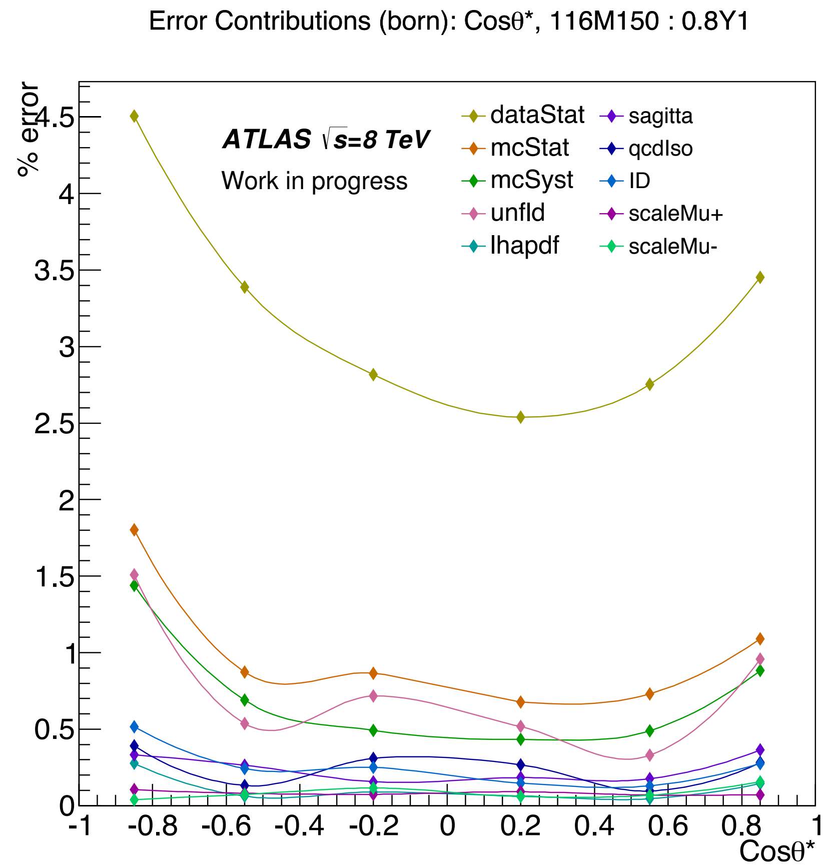


Control Plots: μ Channel

Good agreement between data and MC is observed.







Unfolded to born level

- In the muon channel all systematics are accounted for.
- These plots show that the measurement is statistics dominated at high mass, and systematics dominated on the Z-peak.
- The main systematic error sources are the muon scale and the unfolding.

Combination

The Z3D analysis uses the HERAverager tools

The electron CC and muon channels provide covariance matrices of error sources

A conversion of these matrices to nuisance parameter representation is required to interface with HERAverager

HERAverager provides the pulls and reductions of systematic sources after the combination along with the chi^2.

The full list of pulls and reductions of systematic uncertainties may be seen in the support note.

Covariance matrix representation data: μ_i, theory: m_i, Cov. matrix: C_{ij}

$$\chi^2 = \sum_{i,j} (m_i - \mu_i)(m_j - \mu_j) C_{ij}^{-1}$$

Nuisance parameter representation Nuis. param.: b_l, cross sec.: Γ_{li}

$$\chi^2 = \sum_i^{N_{data}} \left(\frac{m_i - \mu_i - \sum_l^{N_{\rm sus}} \Gamma_{li} b_l}{\delta_i} \right)^2 + \sum_l^{N_{\rm sys}} b_l^2$$

The two representations are equivalent, following:

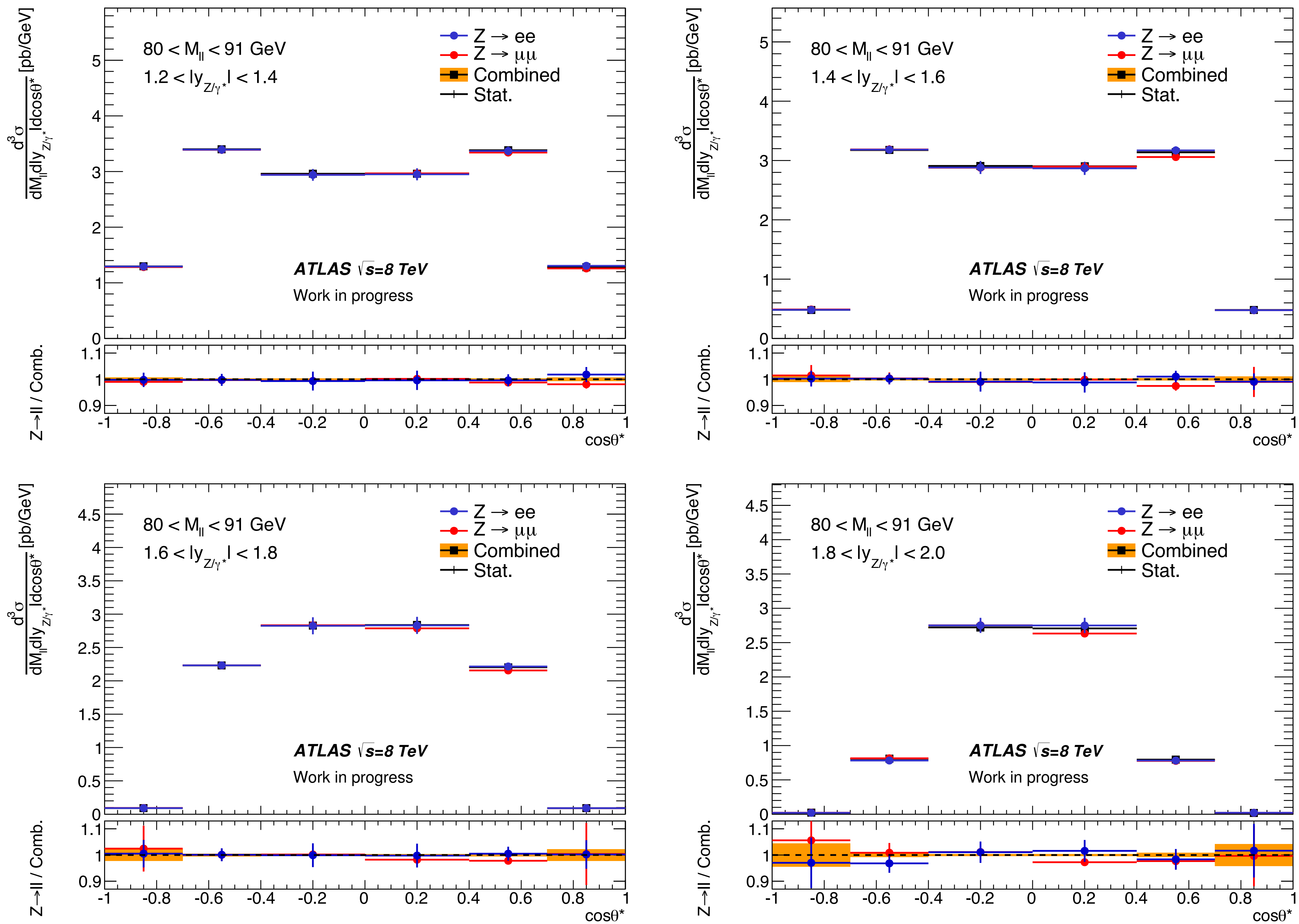
$$C_{ij} = \sum_l \Gamma_{li} \Gamma_{lj}$$

Sources of uncertainty	$f_{\rm eig}$ value	$N_{\rm NP}$
Muon reconstruction efficiency	0.8	5
Muon trigger efficiency	0.8	9
Muon sagitta correction	0.01	34
Electron reconstruction efficiency	0.002	28
Electron identification efficiency	0.002	11
Electron triggger efficiency	0.002	17

Combined Results:

80 more plots such as these due to having so many bins…

…Good agreement is observed across the measurement phase-space.

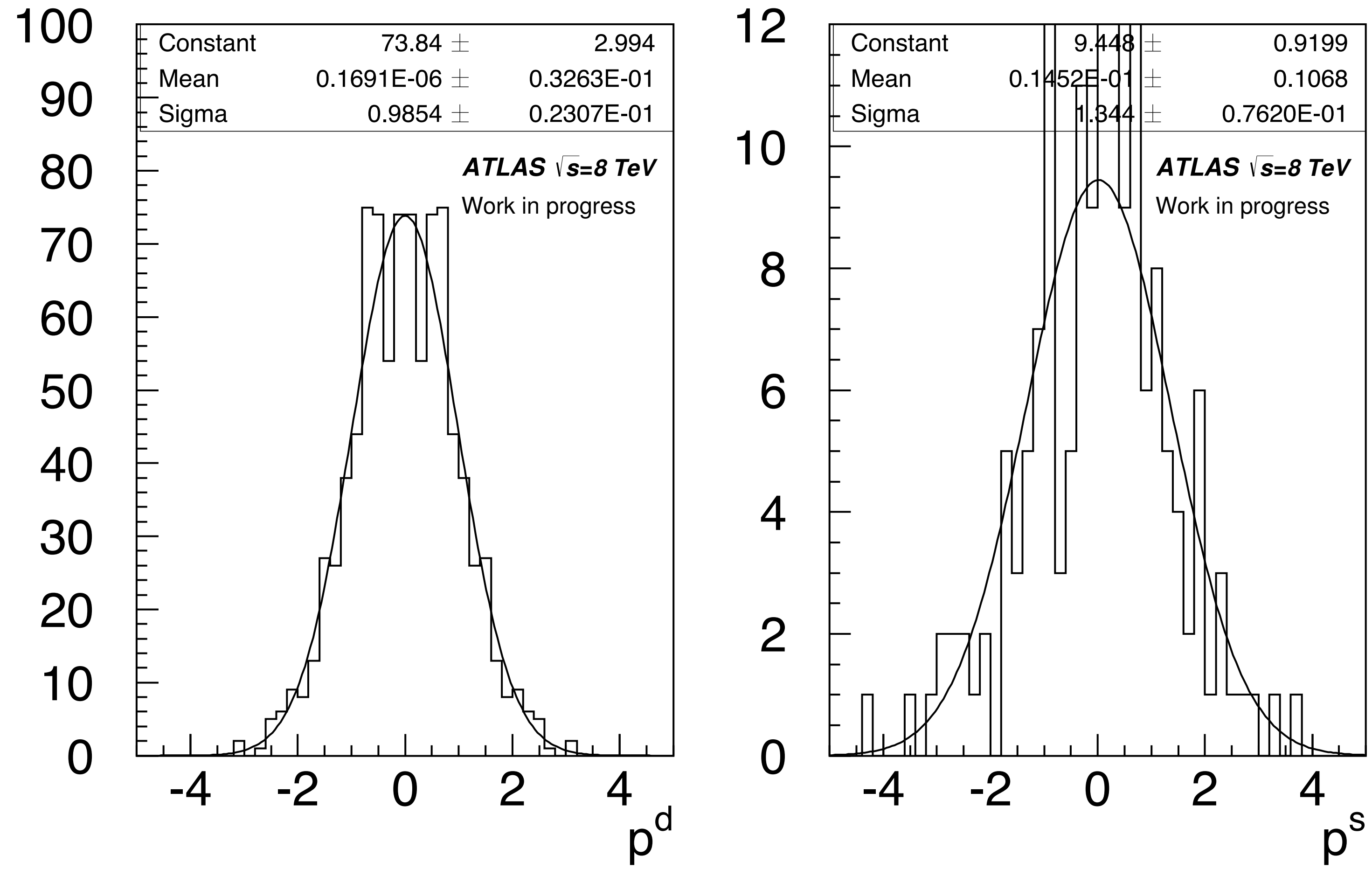


Conclusions

The experiment channels are ready to be compared to the theory predictions.
Due to the analysis parameters, predictions have been difficult to calculate so far - we remain patient.

However, the strong agreement between electrons and muons is a very promising sign.

We aim for publications of this work and the simultaneous PDF + θ_W extraction this year.



Distribution of pulls for cross-section measurements p^d (left) and systematic nuisance parameters p^s (right).

$$\chi^2/dof = 496.2/456$$

Backup