Determination of the effective weak mixing angle via the forward-backward asymmetry in $Z/\gamma^* \rightarrow \mu^+ \mu^-$ decays

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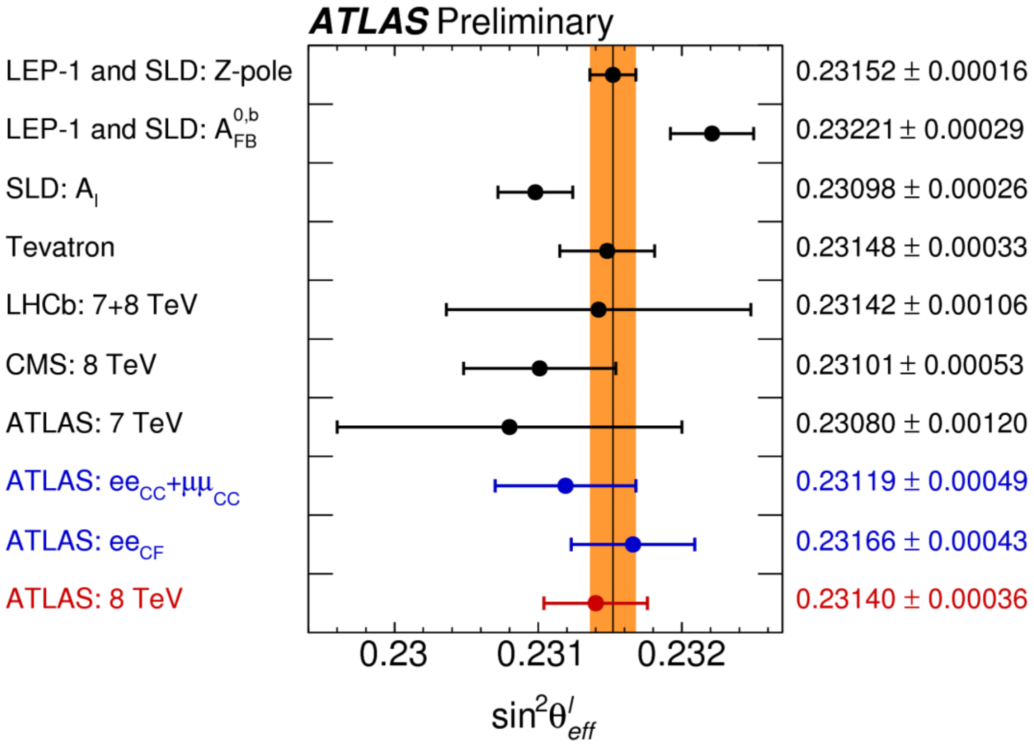
Weak Mixing Angle $\sin^2\theta_W$

- To test the SM, electroweak parameters need to be very well characterised with high precision.
- The weak mixing angle, $\sin^2\theta_W$, is a fundamental SM parameter that relates the W and Z boson masses
- Weak mixing angle cannot be measured directly, it is extracted from the measurement of variables sensitive to it (eg A_{FB})
- LEP + SLD is most precise measurement ever taken
- 3.2σ variation between two most precise measurements
- I am updating LHCb's result using full Run 2 data, 6fb^{-1} via A_{FB}

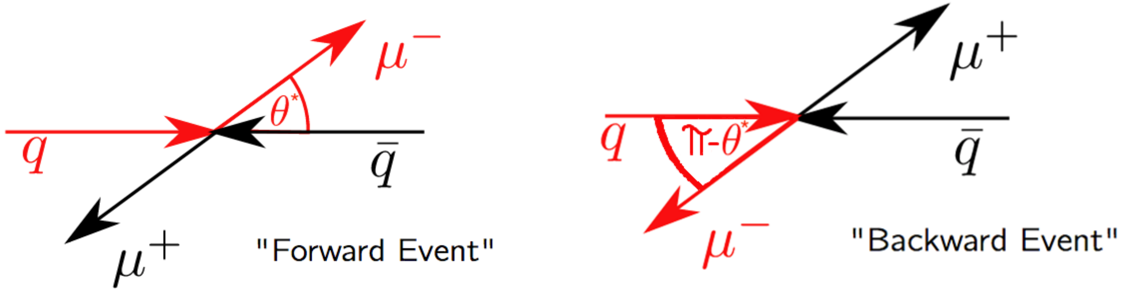


[ATLAS-CONF-2018-037]

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

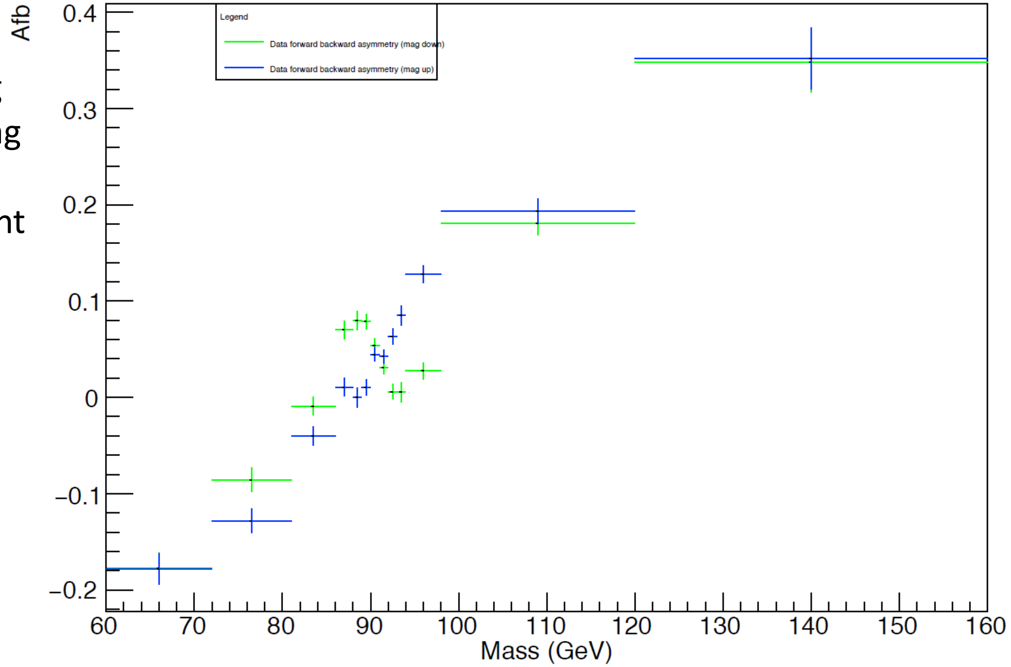
number of backward events

number of forward events



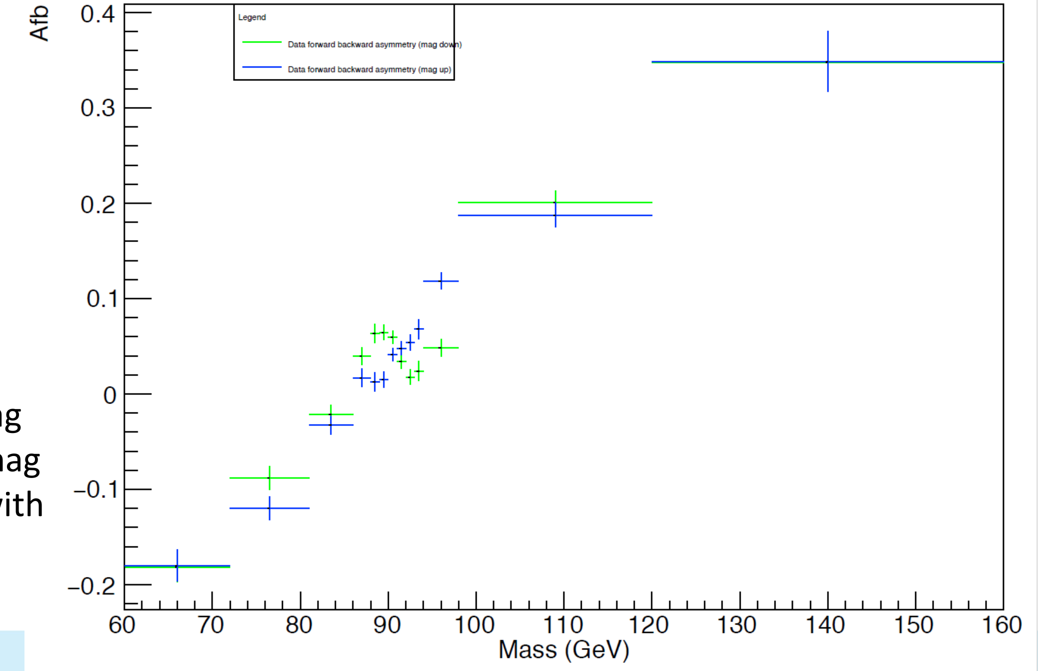
Alignment Study

AFB split via mag up (blue) and mag down (green) without alignment



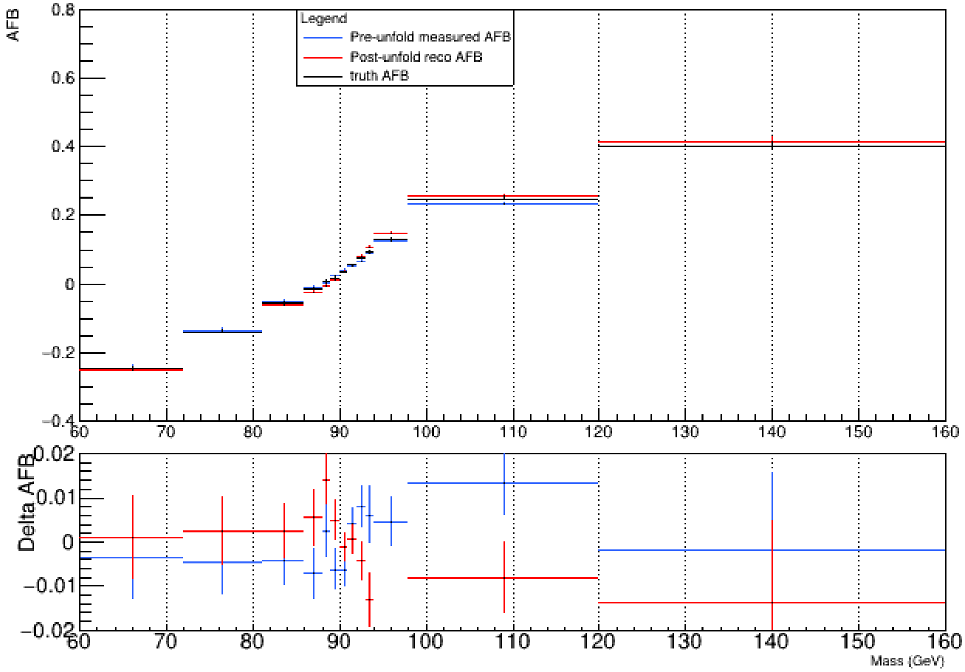
- There is a bump in data (2016, 1.9fb^{-1}) around the Z mass region which does not match MC
- This was investigated and the issue arose when splitting by polarity
- To correct for changes in the detector's ability to measure charge and momentum of particles according to polarity, an alignment can implemented - in this case offline.
- A_{FB} is sensitive to imperfections in the alignment so even though an improvement can be seen, it is not absolute
- Further studies are on going to remove the remaining effects

AFB split via mag up (blue) and mag down (green) with alignment

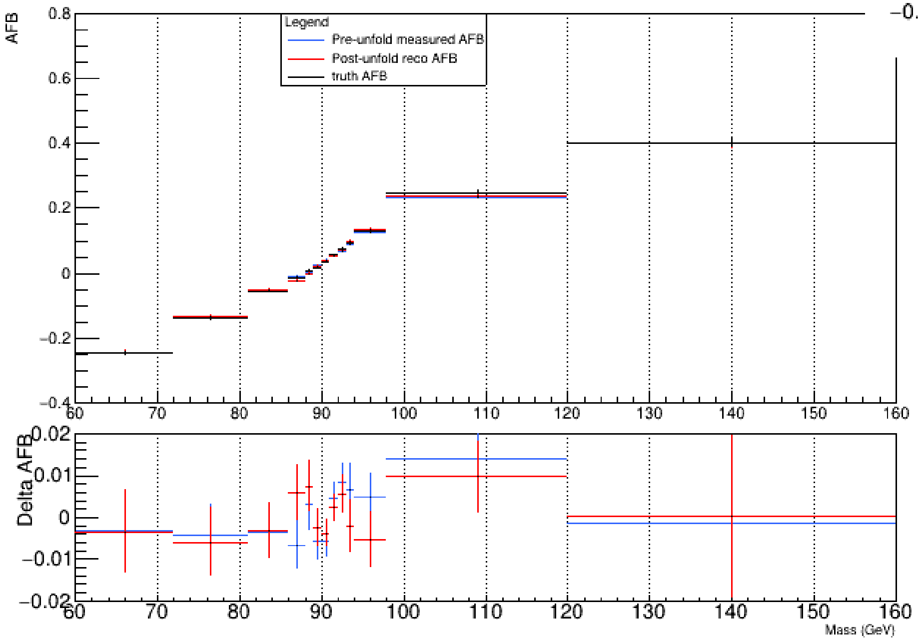


Unfolding Study

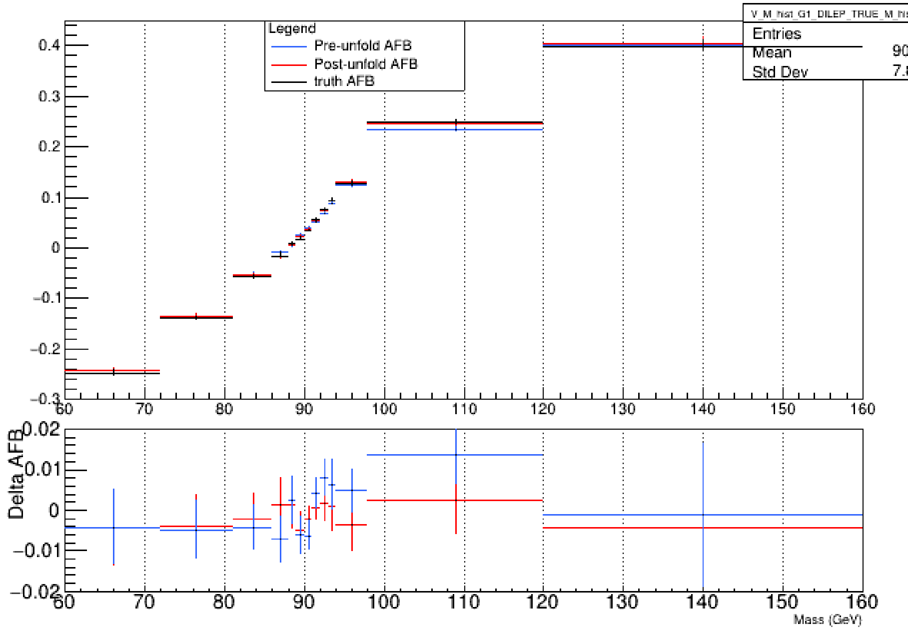
- Z -> MuMu
- Aim to find the optimum binning for AFB analysis when being unfolded
- Balance sensitivity to AFB while minimising the need for further correction after unfolding
- Unfolding removes the effect of measurement resolution, systematic biases and detector efficiency to give true AFB values
- Utilise methods of unfolding within RooUnfold



1D unfolding in Z mass



3D unfolding in bins of Z mass and muon pseudorapidities



1D unfolding in Z mass with two unfolding matrices

Future Work

Short term

- 15 month LTA at CERN
- Finish preparing the analysis running script to produce all required prefit plots
- Begin working on the fitter
- Work on putting together the timetable for the week long Y12 particle summer school being held online in August

Long term

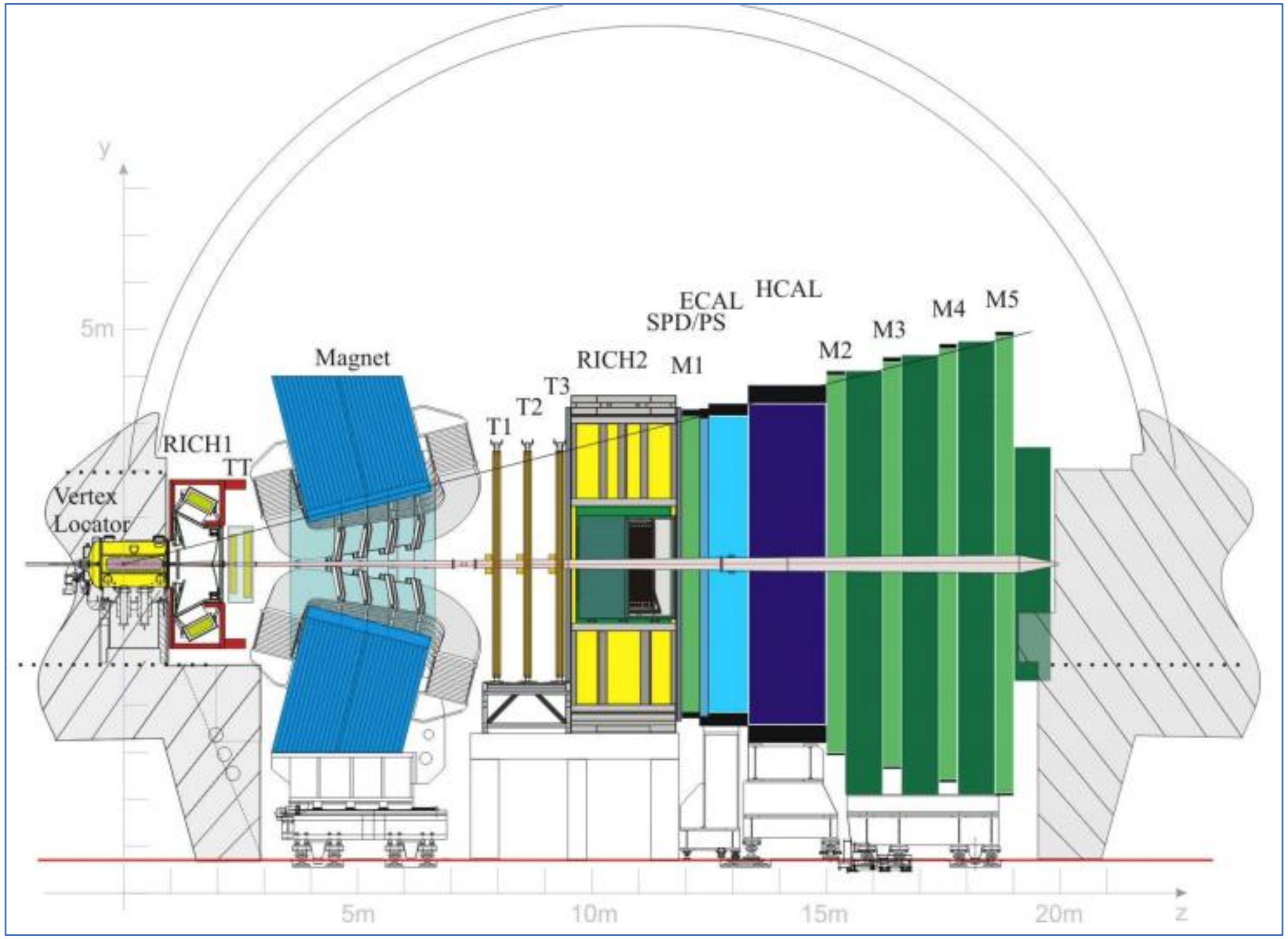
- Publish A_{FB} and $Sin^2\theta_W$ findings
- Start my LTA work based on aspects of the Upgraded VELO commissioning. This will include writing parts of monitoring code, testing, taking part in dry runs of the detector and analysing results

Thank you!

Backup Slides

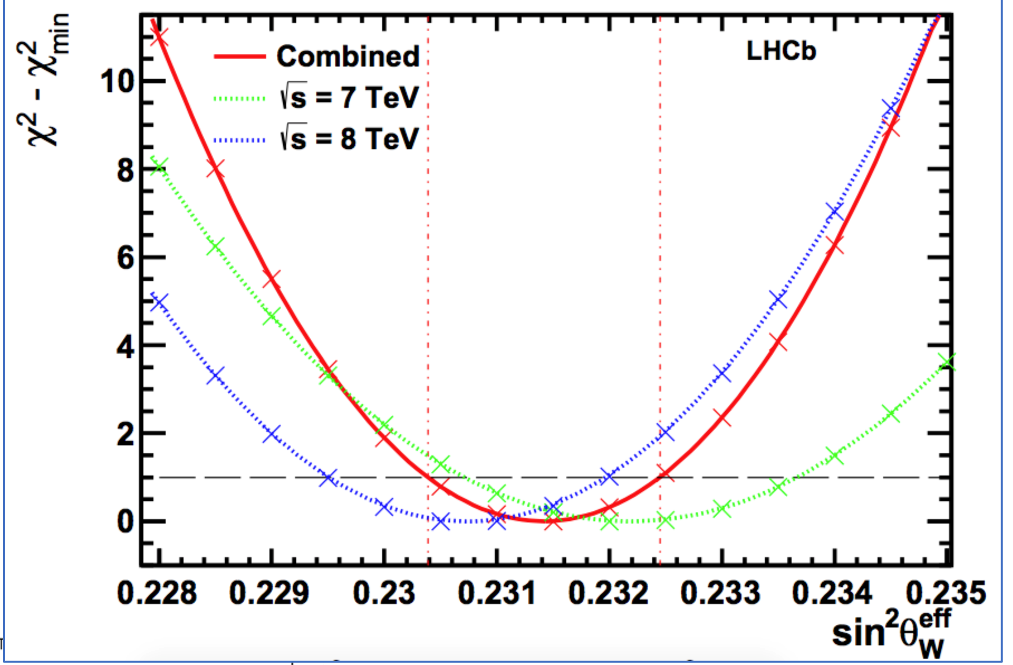
The LHCb Experiment

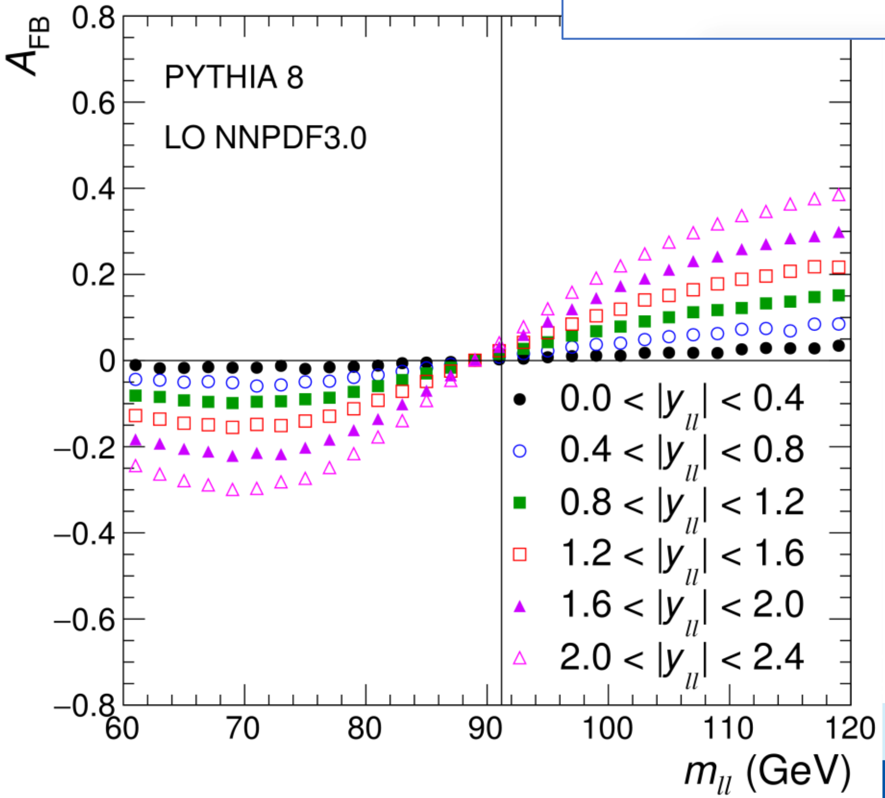
- Single-arm forward detector which has forward angular coverage of 15-300 mrad (bending plane/horizontal plane) and 15-250 mrad (non-bending plane/vertical plane) [1]
- At high energies $b\bar{b}$ pairs are produced with a strong boost along the beam line
- During run I (2010-2012) and run II (2015-2018) took 9 fb^{-1} worth of data (3-6 split)
- Instantaneous luminosity of $4 \times 10^{32}\ cm^{-2}s^{-1}$



$Sin^2\theta_W$ Calculation at LHCb

- Values for A_{FB}^{pred} are found via MC using a range of values for $sin^2(\theta_W^{eff})$
- χ^2 is calculated by comparing A_{FB}^{pred} to data values of A_{FB}
- Quadratic functions are fitted to the distributions
- The difference between χ^2 values and the minimum χ^2 value is plotted as a function of the $sin^2(\theta_W^{eff})$ values used in MC
- The minimum of the plotted χ^2 distribution is the final value of $sin^2(\theta_W^{eff})$

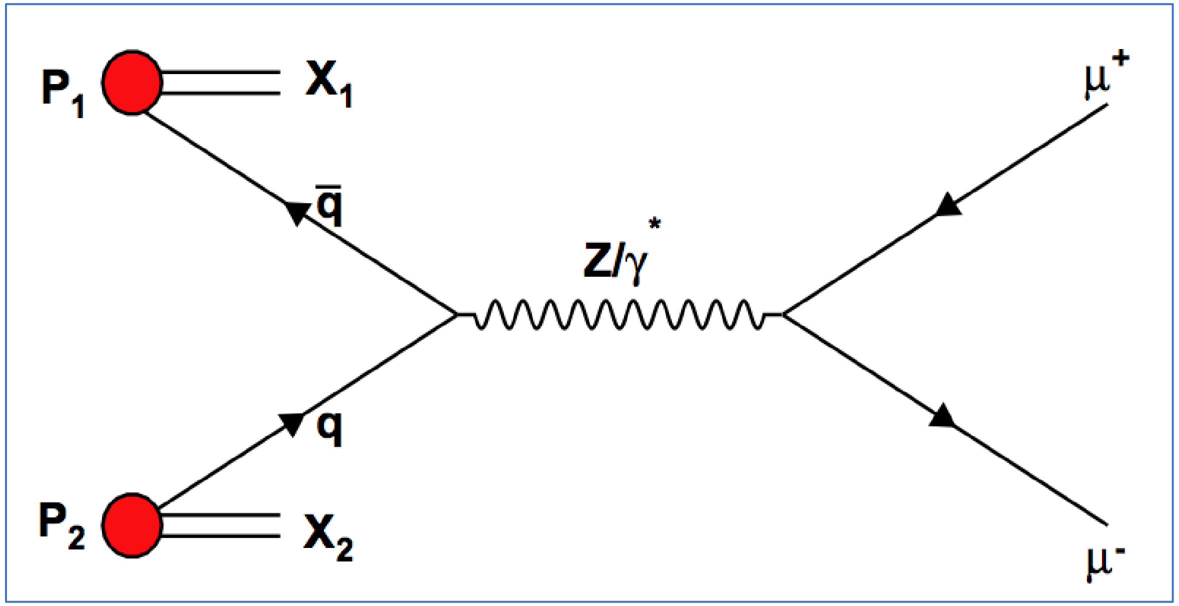




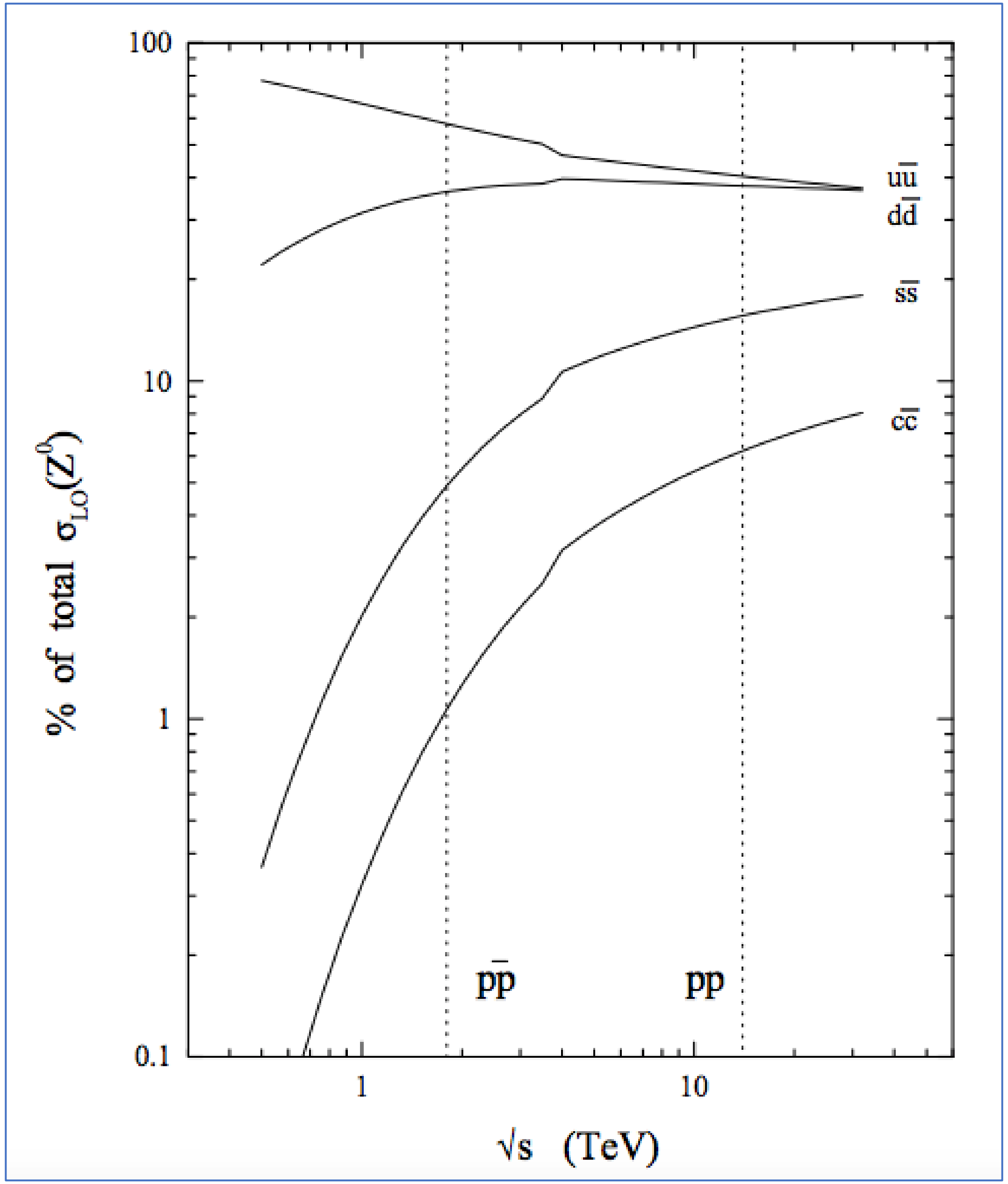
[CMS, 1806.00863]

Z Production at the LHC: Drell-Yan Process

- Quark-antiquark (same flavour) annihilation to produce a virtual photon γ*/Z boson
- Decays into a lepton pair



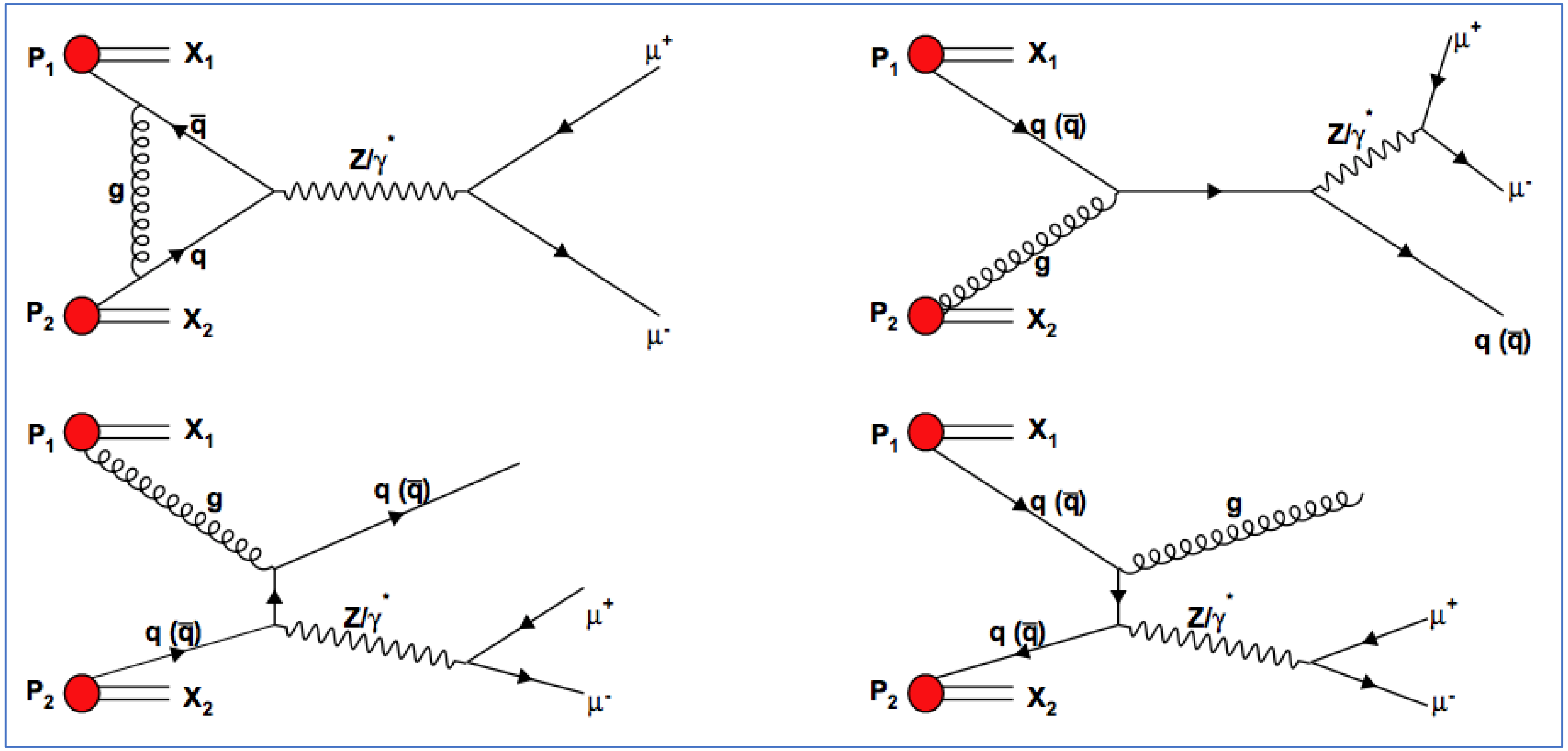
[CERN-THESIS-2011-202]



[Phys. J. C, 14:133– 145, 2000]

Drell-Yan Process

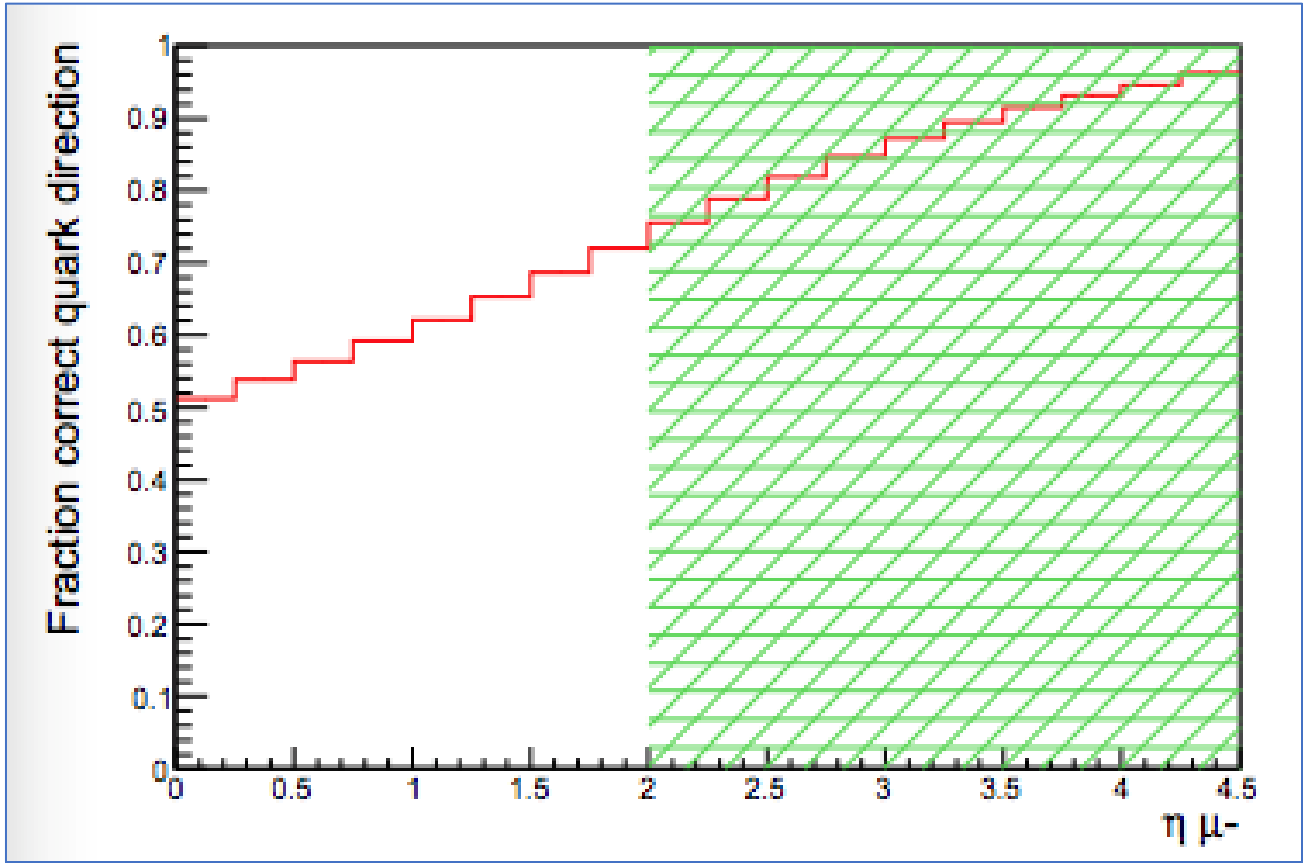
- A quark can be either valence or a sea quark, an antiquark can only be a sea quark (pp collisions)
- Higher order Feynman diagrams for the Drell-Yan process on the right
- Z and γ mixing produces a differential cross section that is a combination of three contributions: Z, γ and another dependant on both
- There is a cosθ dependence within a term which produces an asymmetry



[CERN-THESIS-2011-202]

LHCb and Weak Mixing Angle $Sin^2\theta_W$

- LHCb focuses on higher rapidity range, $2 < \eta < 5$, which has high sensitivity to A_{FB} and therefore $Sin^2\theta_W^{eff}$
- Asymmetry most pronounced when the Z boson direction is correctly known
- The further forward the more likely that the Z boson follows the direction of the quark
- LHCb focuses on the forward region and the further forward in rapidity, the more likely the Z forward direction is determined correctly



[LHCb-ANA-2015-002 28/09/2015]

Unfolding

- Response matrix is filled by looping over a training sample containing known measured and truth data
- Response matrix gives the fraction of events from the true distribution that are ultimately within corresponding the measured distribution bin
- This is then used via RooUnfold implementation on measured data of choice to find unknown truth

- There are many unfolding algorithms within RooUnfold:
  - Bayesian unfolding currently used

- 1D, 2D and 3D unfolding possible

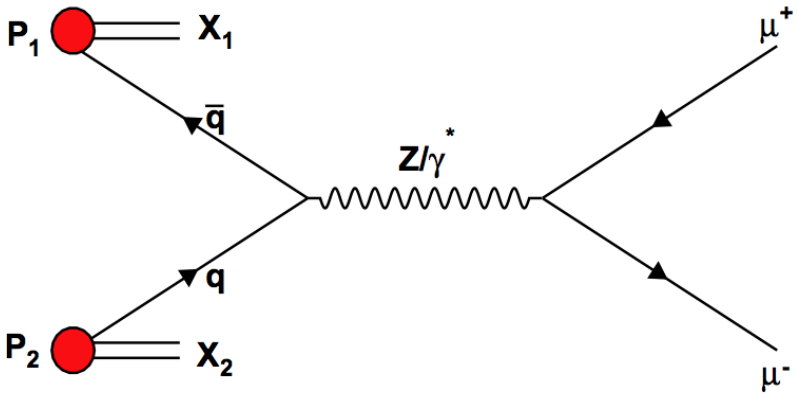
Forward Backward Asymmetry, A_{FB}

- A_{FB} can be found by splitting forward and backward events by their cosθ* value where θ* is the polar angle in Collins-Soper frame (θ_{CS})

number of backward events

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

number of forward events



[CERN-THESIS-2011-202]