HEP Annual Meeting

Weak Mixing Angle Determination and VELO Upgrade Commissioning

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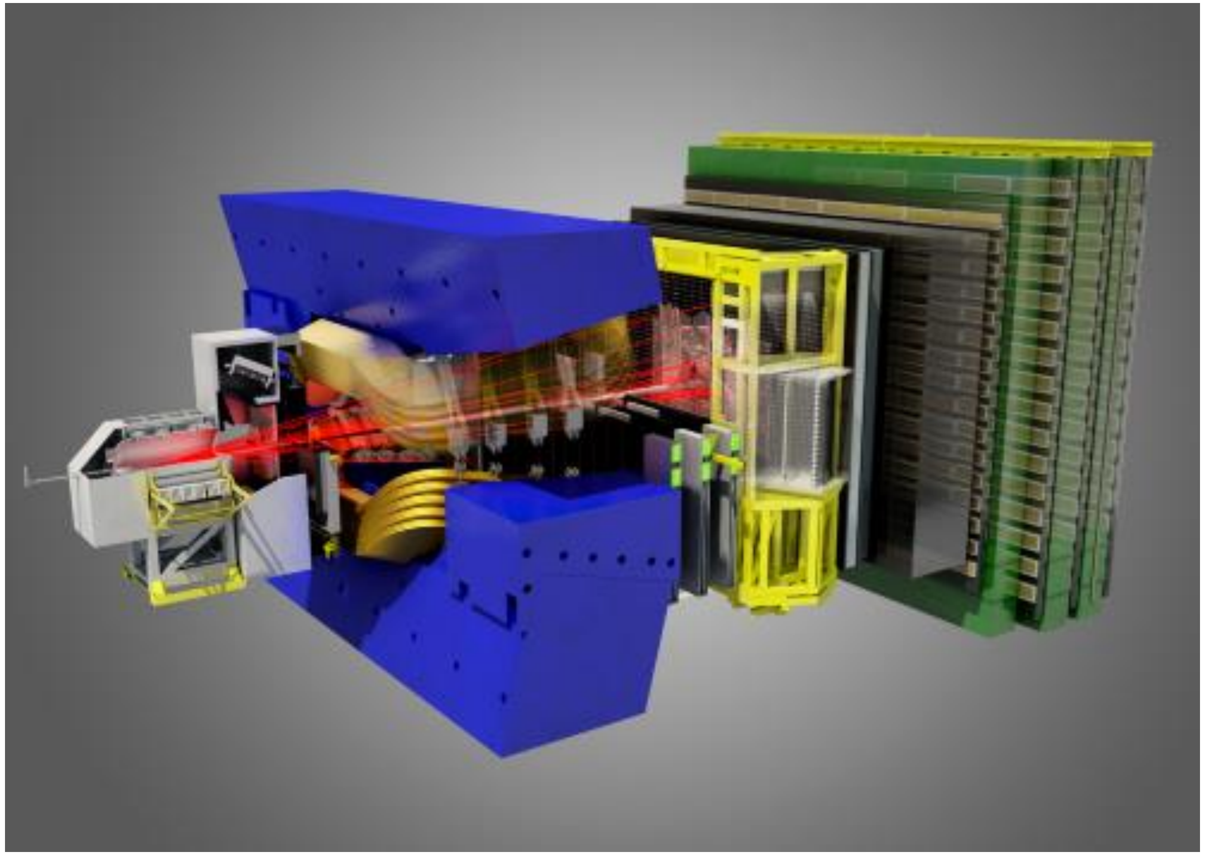
My Research Areas

Weak Mixing Angle

- LHCb pseudorapidity range $2 < \eta < 5$
- he weak mixing angle, $Sin^2\theta_W$, is a fundamental standard model parameter that relates the W and Z boson masses
- All parameters need to be very well characterised with high precision

- Run 2 data, $6fb^{-1}$ via the forward backward asymmetry, A_{FB} in $Z/\gamma^* \rightarrow \mu^+ \mu^-$
- Previous LHCb result used 7 TeV and 8 TeV with 1 fb^{-1} and 2 fb^{-1} of data respectively

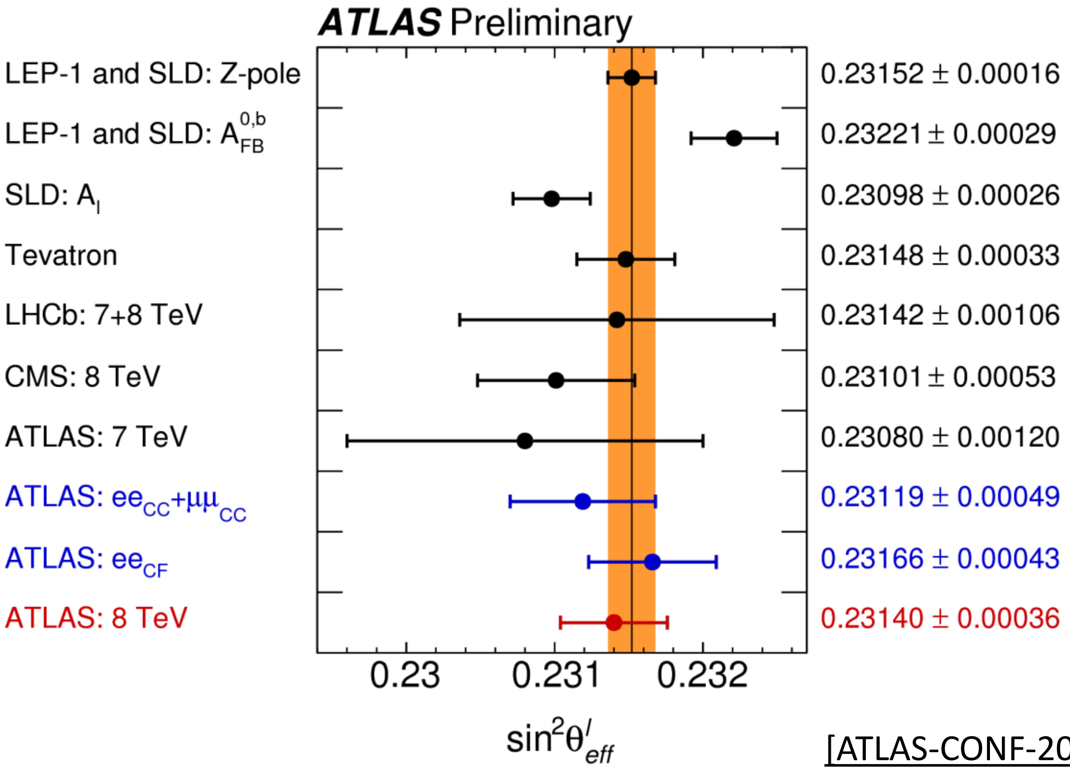


[LHCb - CERN]

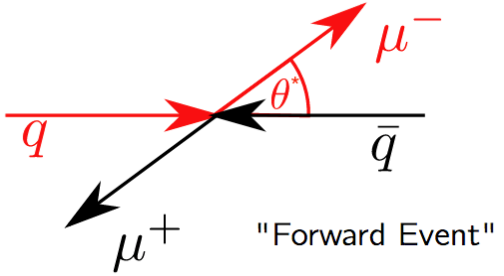
$$Sin^2\theta_w^{eff} = 0.23142 \pm 0.00073\ (stat.) \pm 0.00052\ (sys.) \pm 0.00056\ (theory)$$ *[2015]*

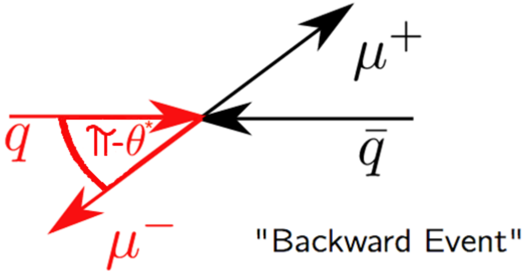
Weak Mixing Angle $\sin^2\theta_W$

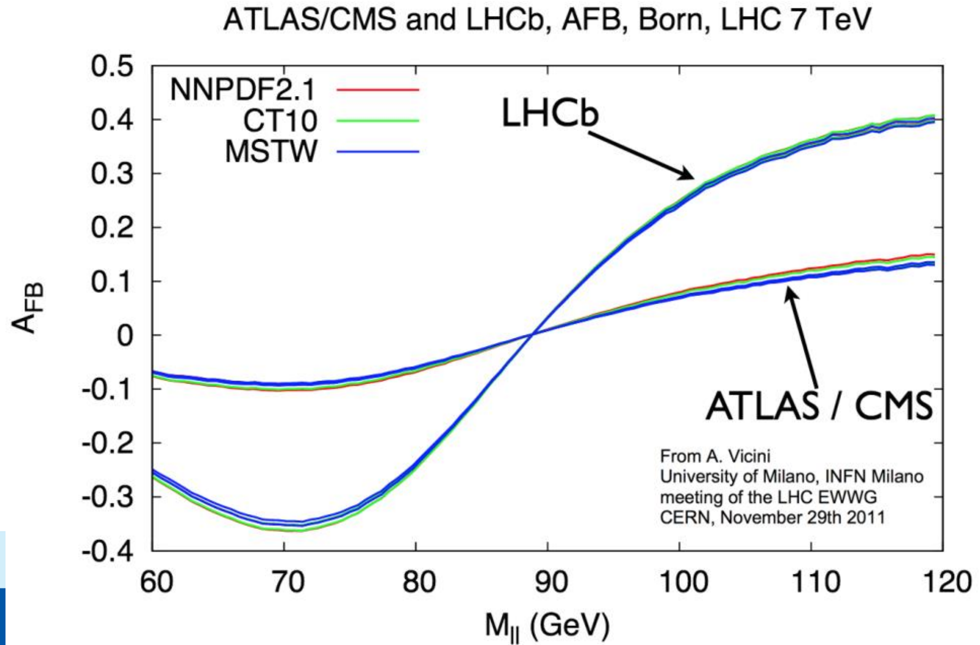
- LEP and SLD are the most precise measurements
- 3.2σ variation between those two
- Weak mixing angle cannot be measured directly, it is extracted from the measurement of variables sensitive to it (eg A_{FB})



[ATLAS-CONF-2018-037]







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

number of backward events

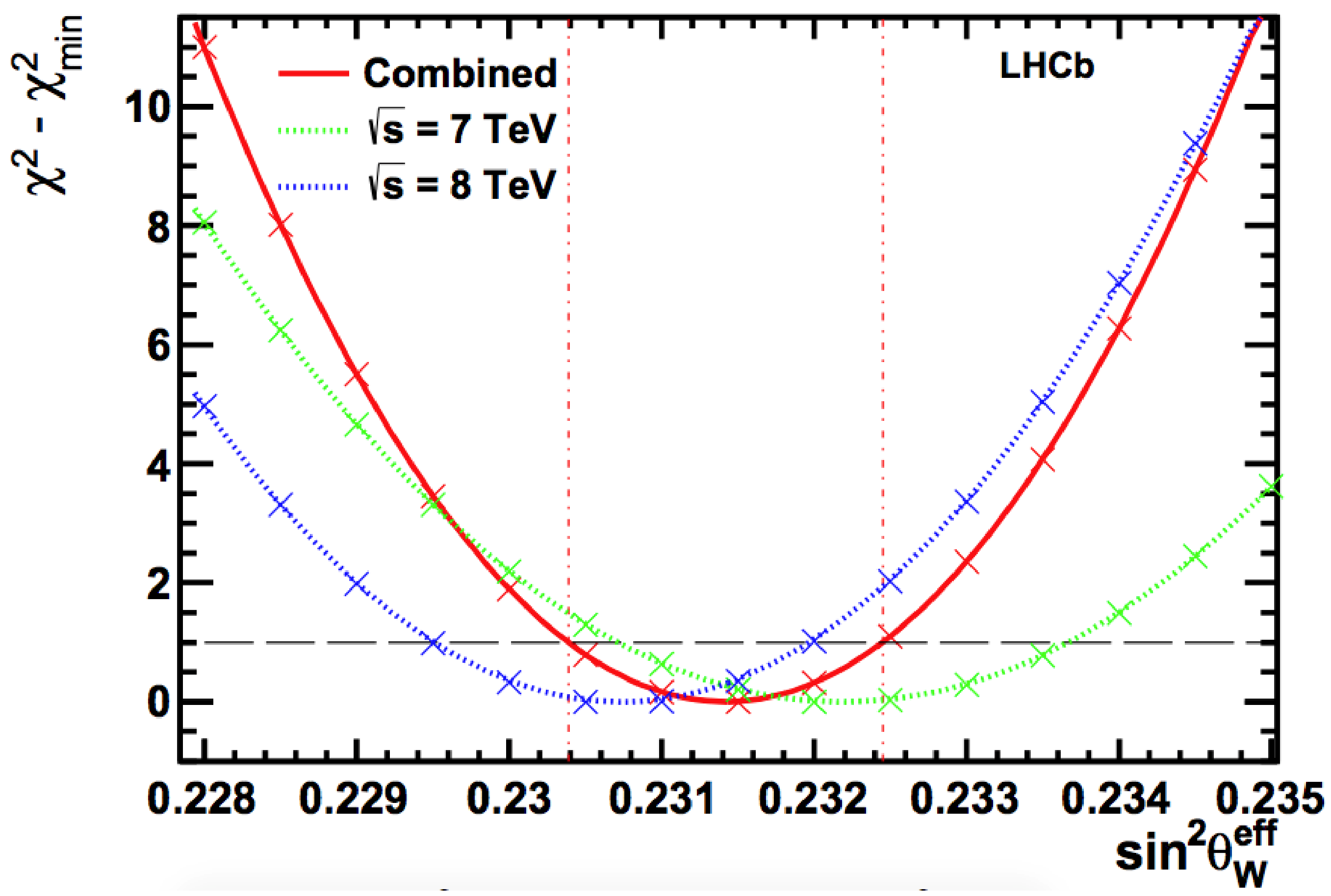
number of forward events

[Hang Yin, LHC EW precision meeting 2018]

$\text{Sin}^2\theta_W$ 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 $sin^2(\theta_W^{eff})$

From the 2015 3fb^{-1} measurement



[LHCb, 1509.07645]

Unfolding Study

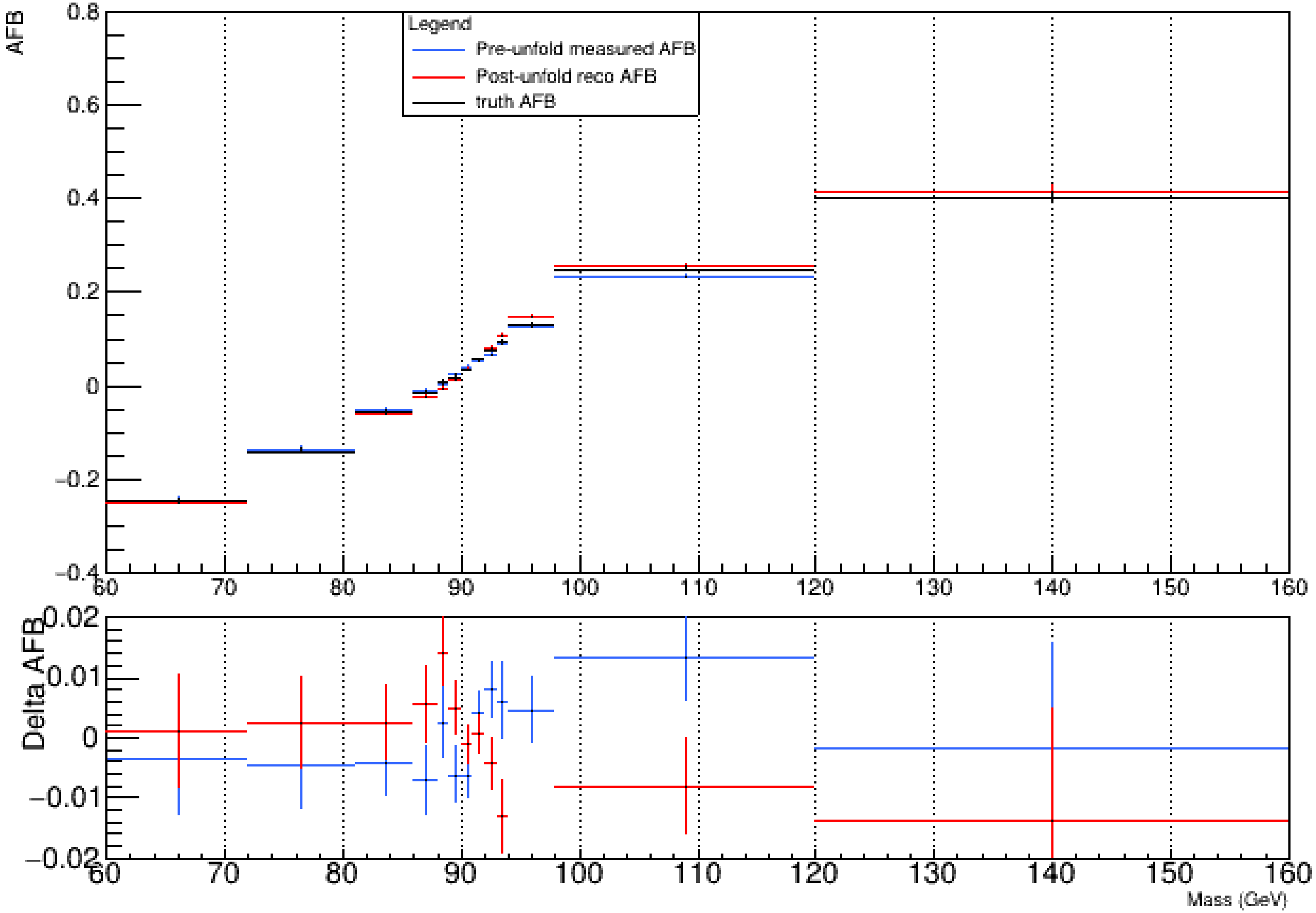
Many steps to get the weak mixing angle measurement including:

- Unfolding

  Unfolding removes the effect of measurement resolution, systematic biases and detector efficiency to give true AFB values

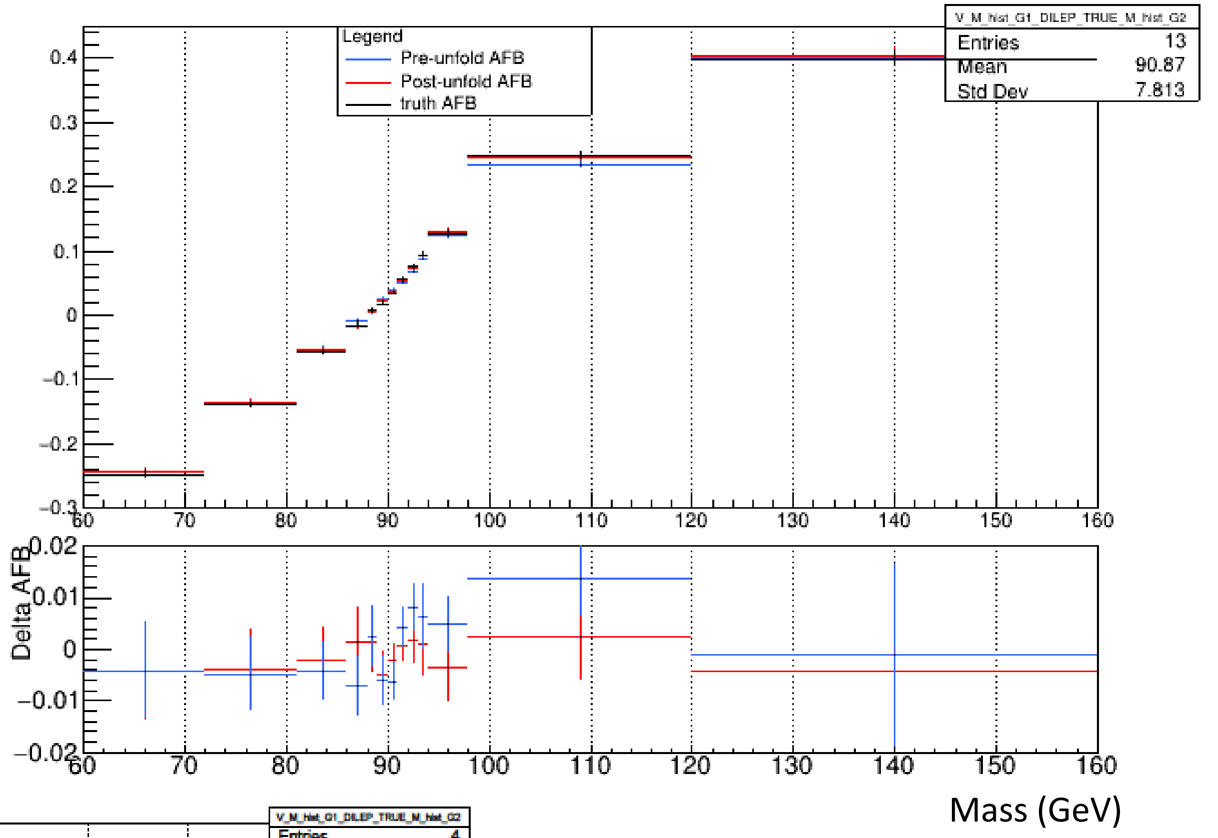
- Backgrounds
- Extract results
- Systematic errors

Simulation to test unfolding – comparison of pre and post unfolding

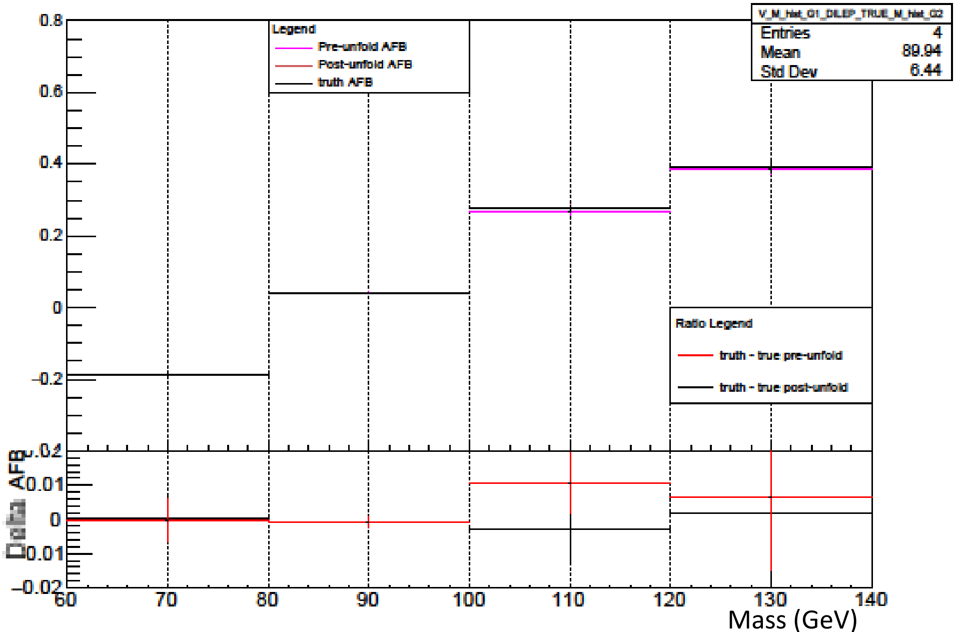


1D unfolding in Z mass

Unfolding Study Conclusion



- Using split forward and backward unfolding matrices removes most of the step in the unfolded data around 90GeV
- A variety of binning schemes trialled
- When a course binning scheme is used for unfolding it shows a good agreement
- AFB is still sensitive to $Sin^2\theta_W$ even with fewer bins



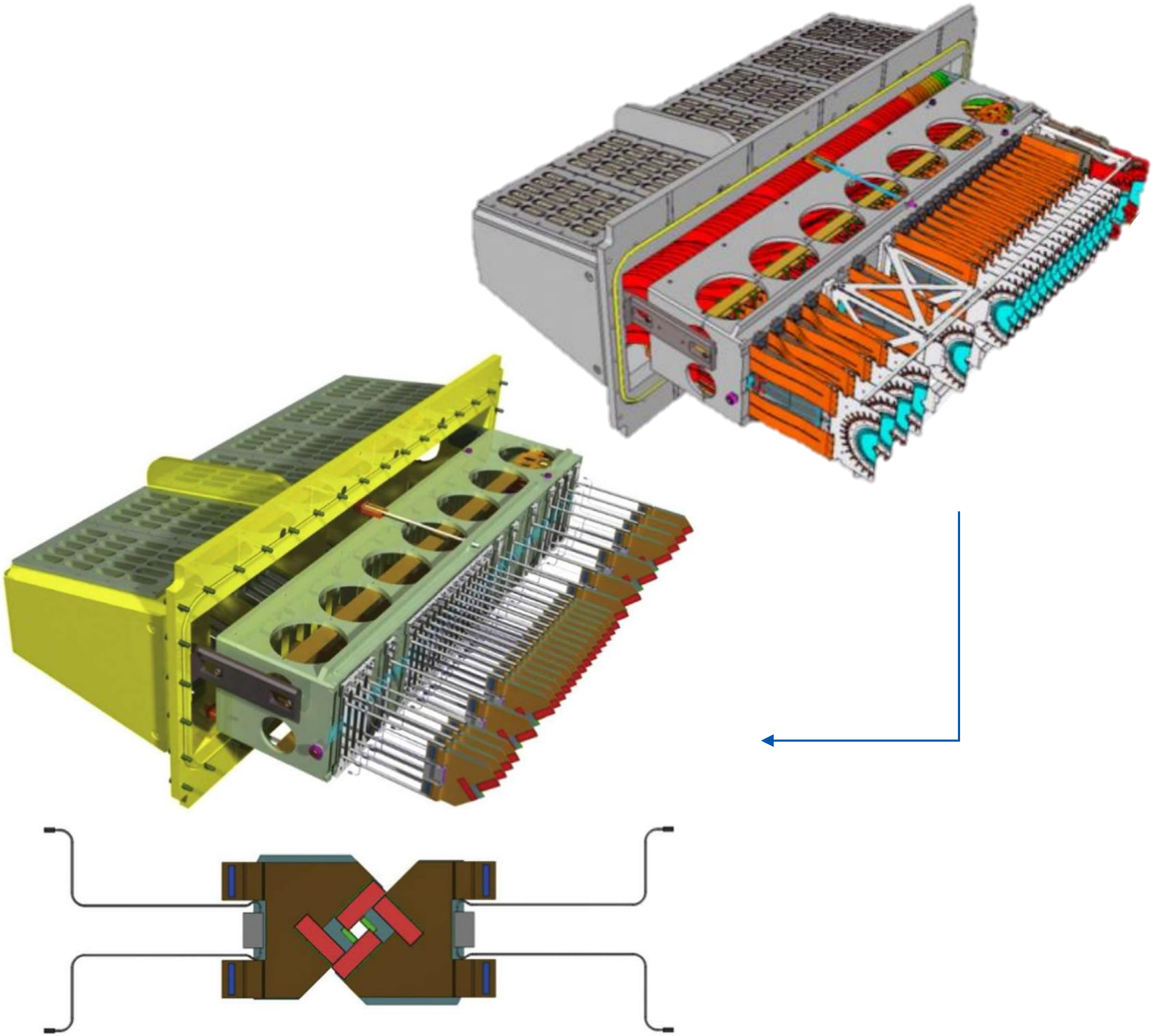
1D unfolding in Z mass with separate forward and backward unfolding matrices

My Research Areas

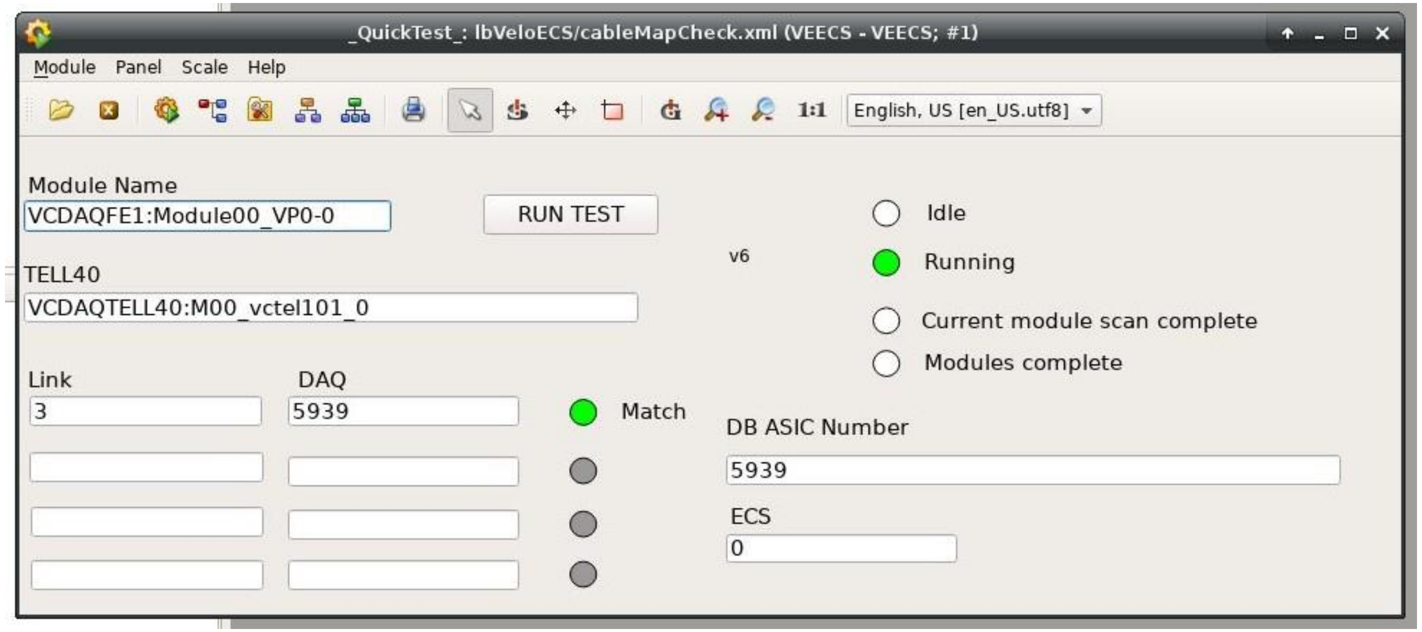
VELO Upgrade Commissioning

- VELO is the inner tracking system of LHCb
- Upgraded VELO:
    - 52 hybrid pixel modules
    - 4 sensors per double sided module
    - Each sensor bonded to three VeloPix ASICs

    - 5.1mm away from beam in closed position
    - 40MHz readout



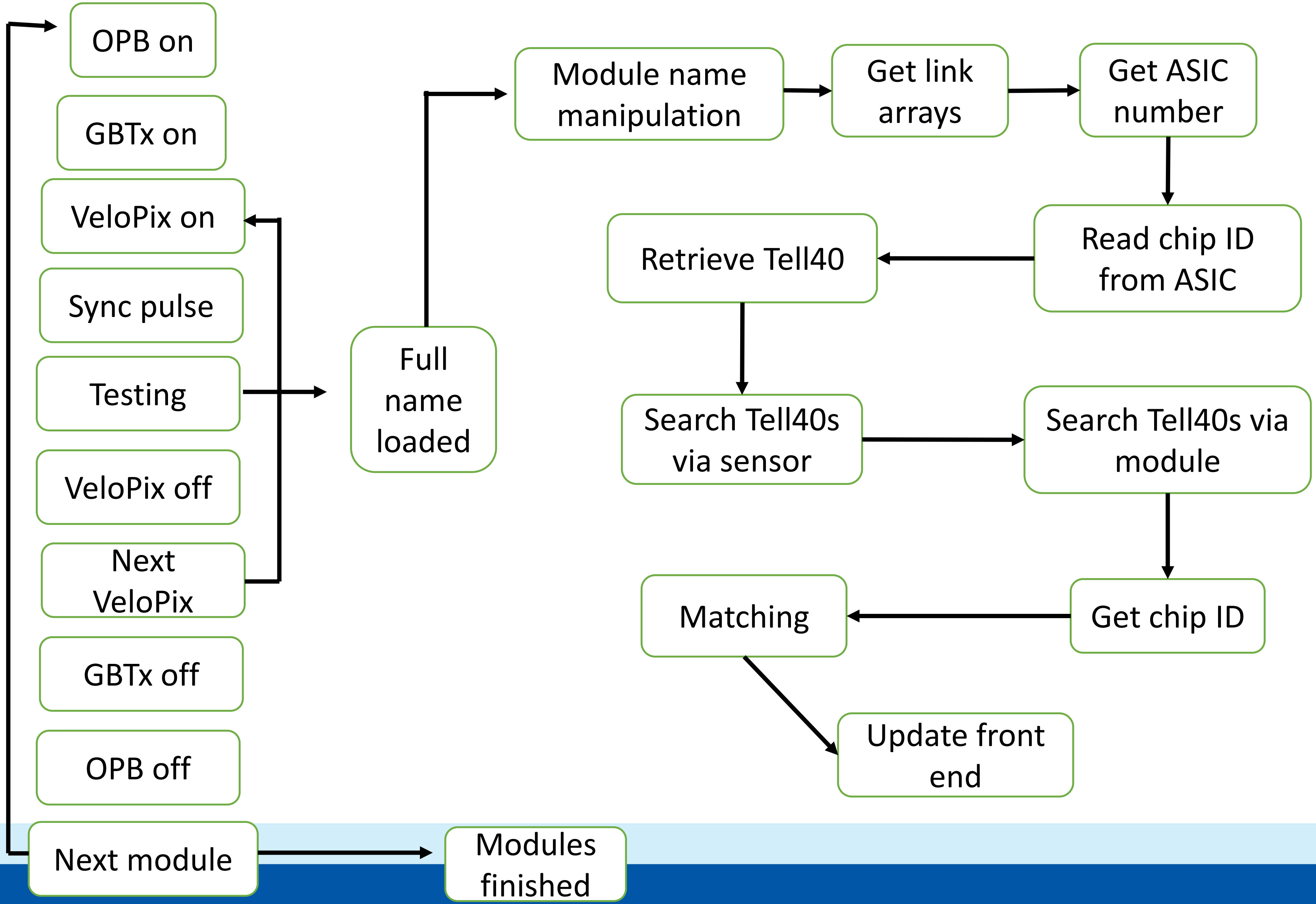
VELO Upgrade Commissioning



- WinCC OA
- Cable mapping panel

- Create mappings of crucial elements of VELO
- Check these elements against what is to be expected
- Panels that will be run as part of the testing and running of VELO

VELO Upgrade Commissioning



- Configure the each front-end ASIC using the control path.
- We do this for 624 chips
- We will do the whole system when the A-side is commissioned

Next Steps

Weak Mixing Angle Analysis

- The next step of the analysis is to complete all background studies
  - Semi-leptonic heavy flavour decays
  - Hadron misidentification
  - Electroweak and top production
- Systematics will then be started

VELO Upgrade Commissioning

- Testing on the full system once A side is commissioned
- Panel then ready for use during runs
- Noise scan panel

Also:

- Outreach
  - Co-ran a year 12 particle summer school online in August 2021
  - Helping to organise the 2022 school
  - Interviewed for The Institute for Research in Schools (IRIS)

- Applied for the Bell Burnell Graduate Scholarship Fund to extend my funding

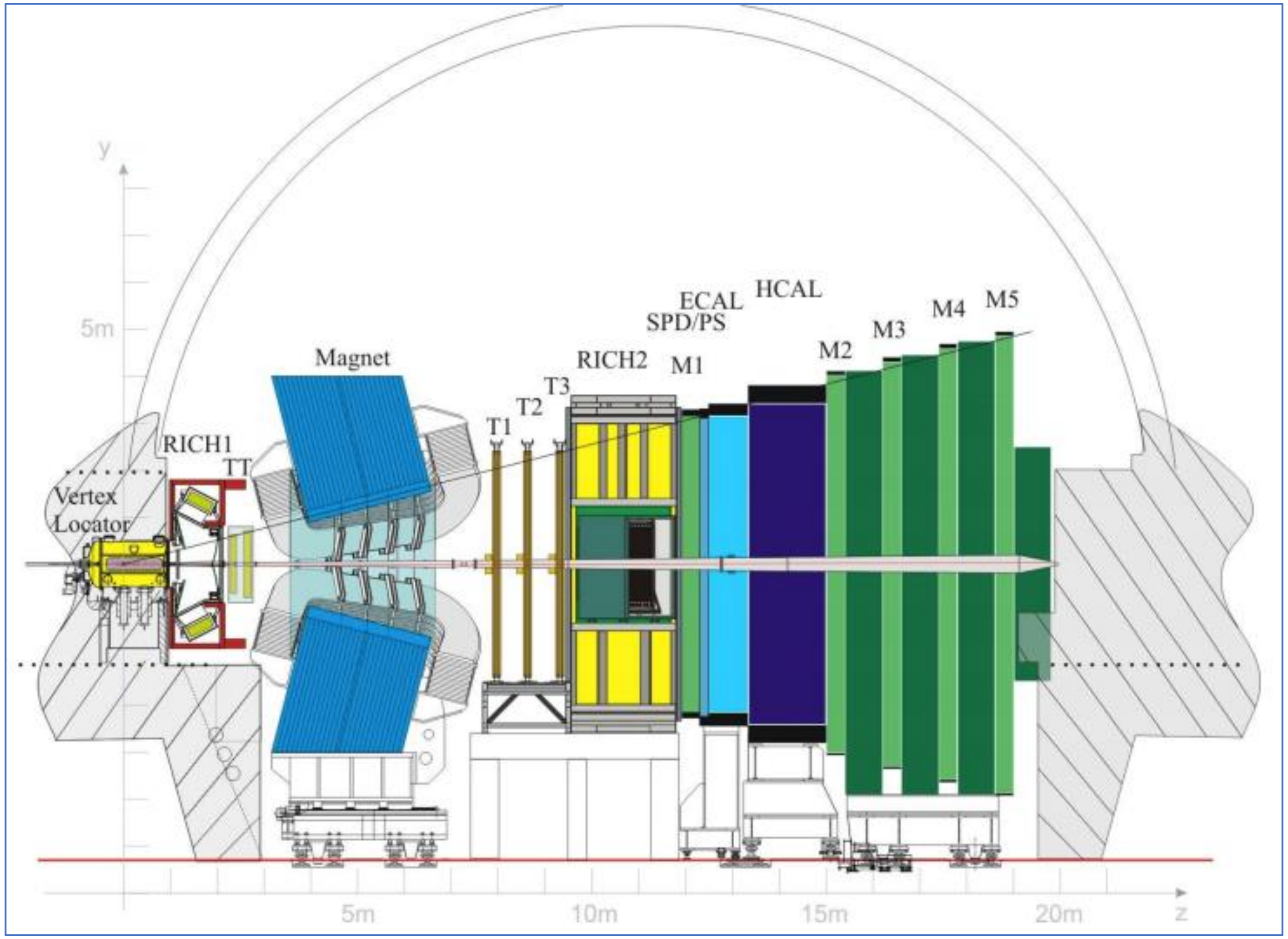
- Currently on LTA at CERN until October 2022

- Thesis writing has begun!

Backup Slides

The LHCb Experiment

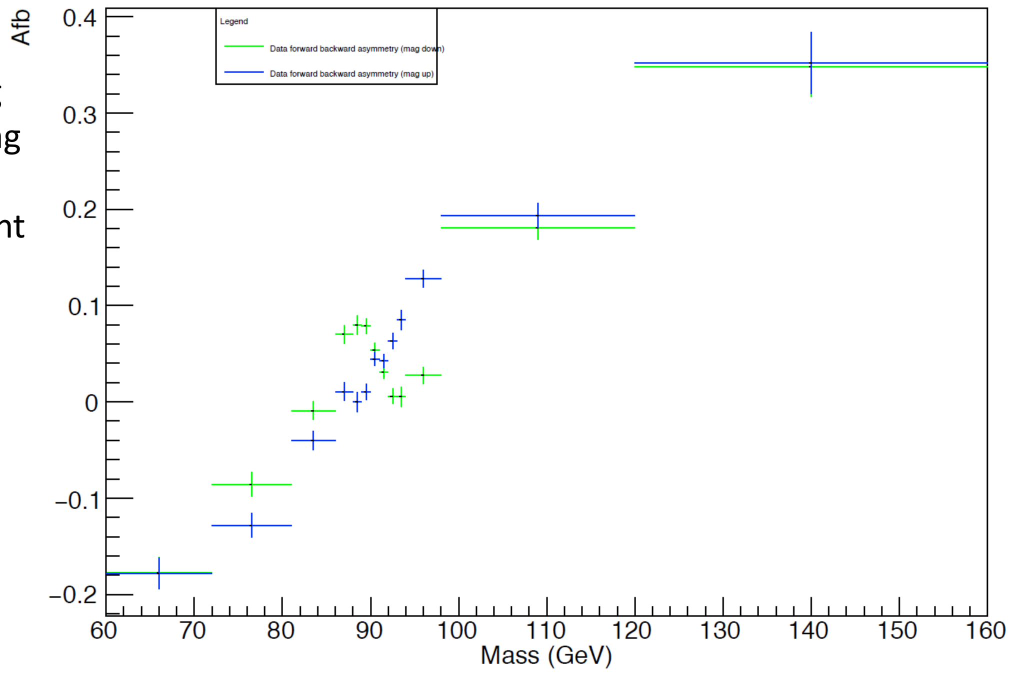
- Single-arm forward detector which has forward angular coverage of 15-300 mrad (bending plane/horizontal plane) and 15-250 mrad (non-bending plane/vertical plane) [1]
- At high energies $b\bar{b}$ pairs are produced with a strong boost along the beam line
- During run I (2010-2012) and run II (2015-2018)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



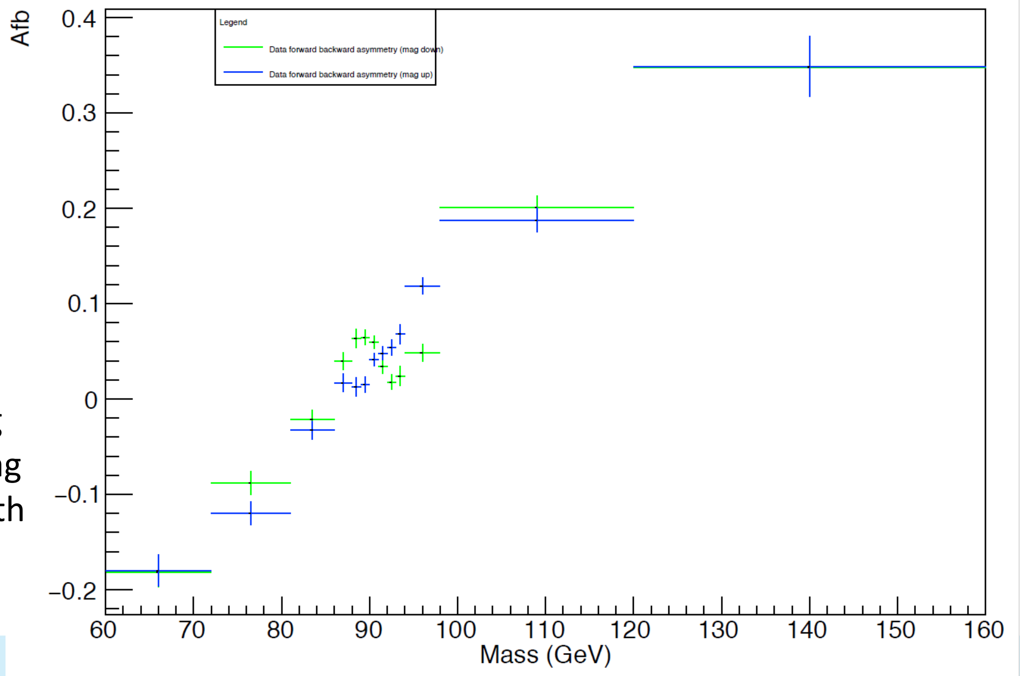
Alignment Study

- There is a bump 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
- The residual that is left can be corrected for within the unfolding

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

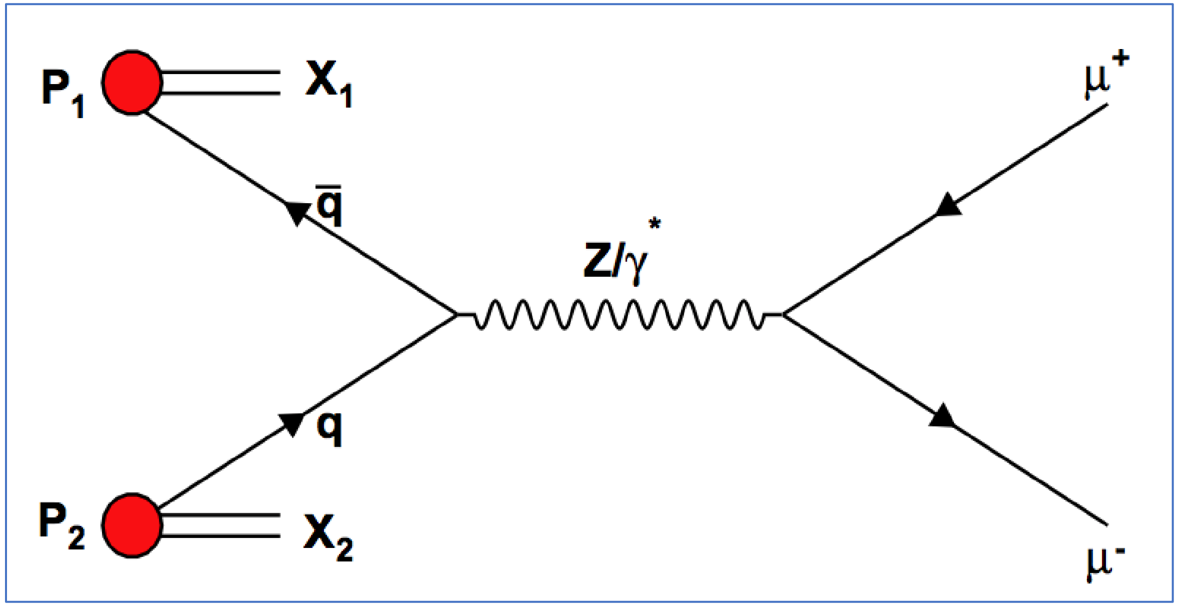


AFB split via mag up (blue) and mag down (green) with alignment

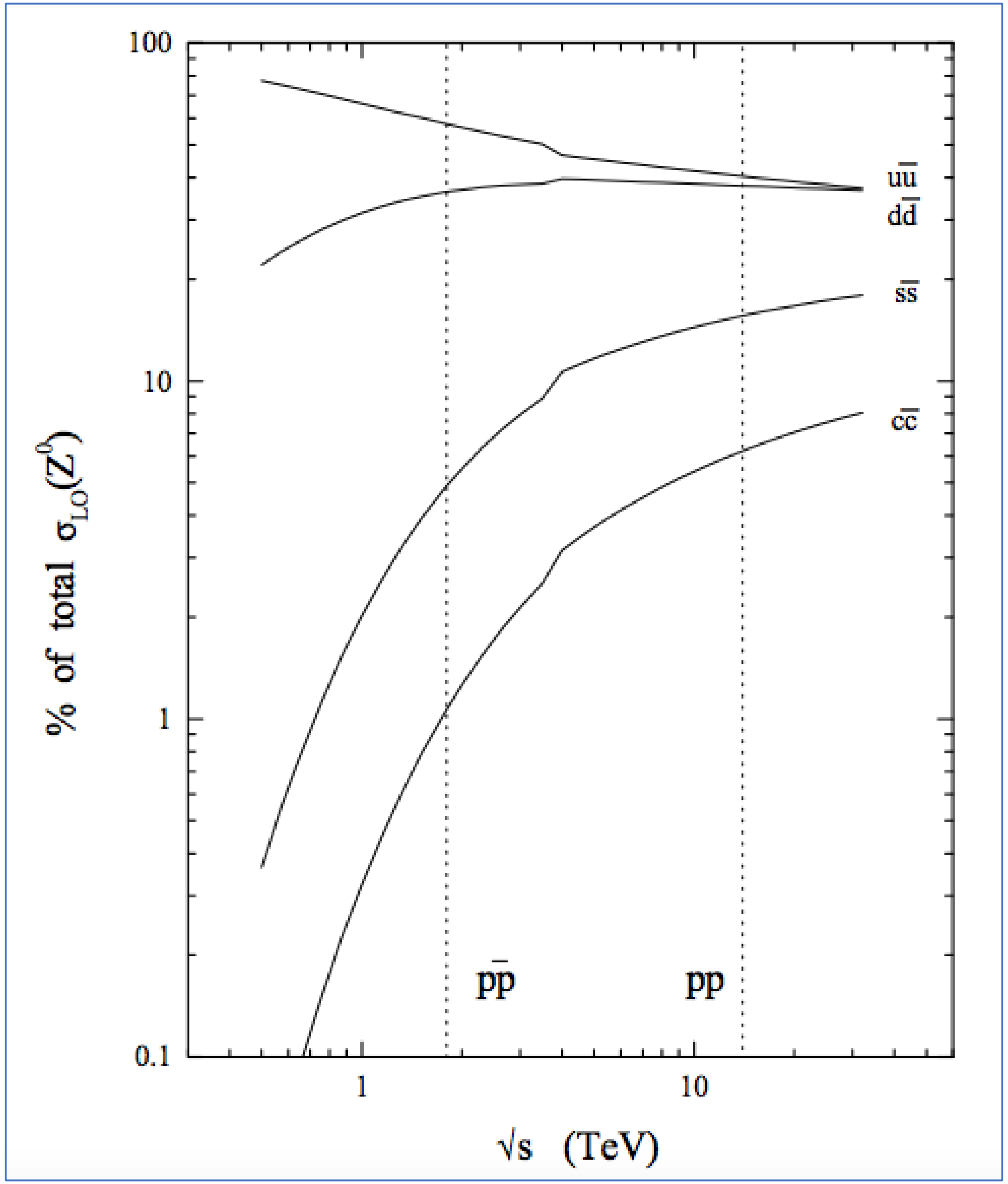


Z Production at the LHC: Drell-Yan Process

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



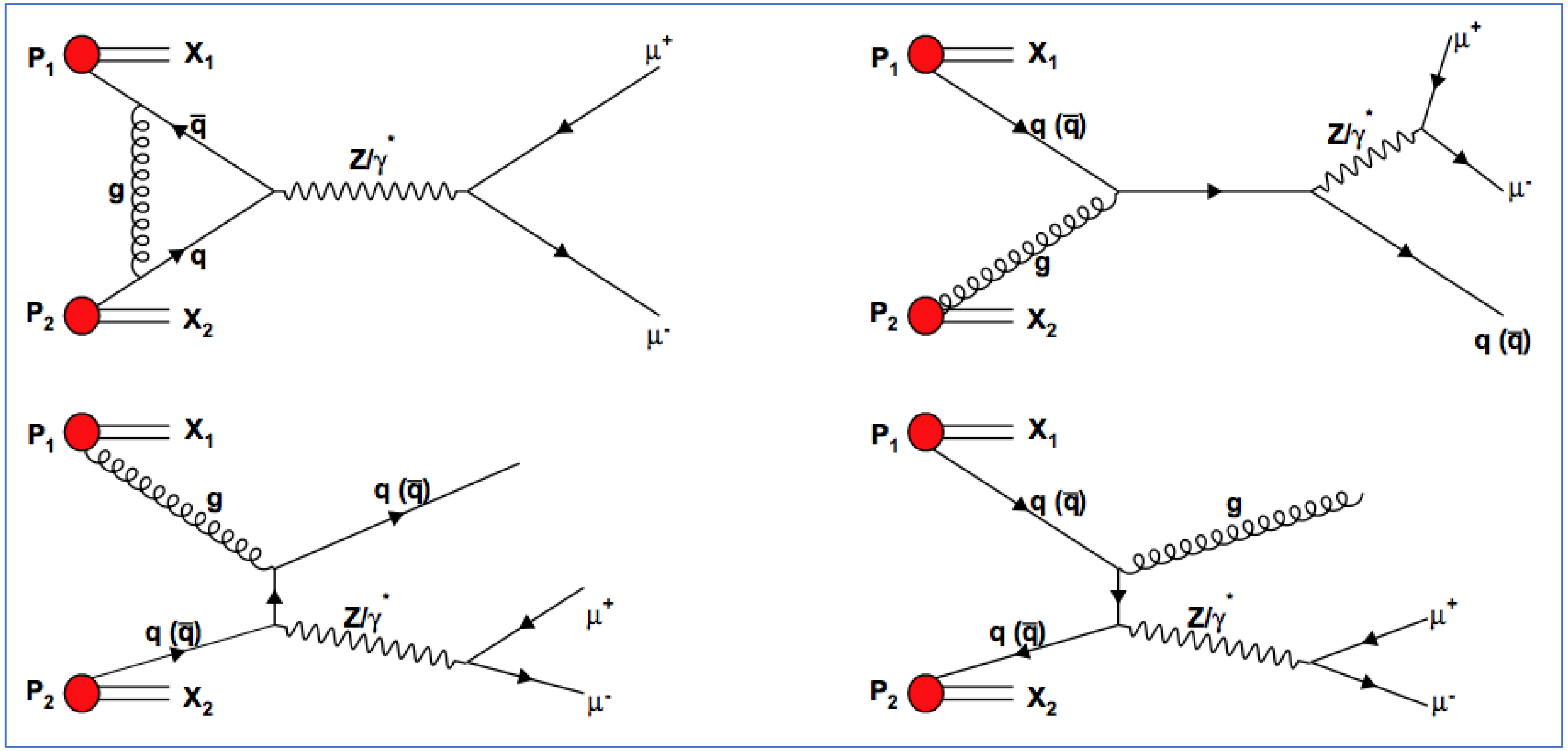
[CERN-THESIS-2011-202]



[Phys. J. C, 14:133– 145, 2000]

Drell-Yan Process

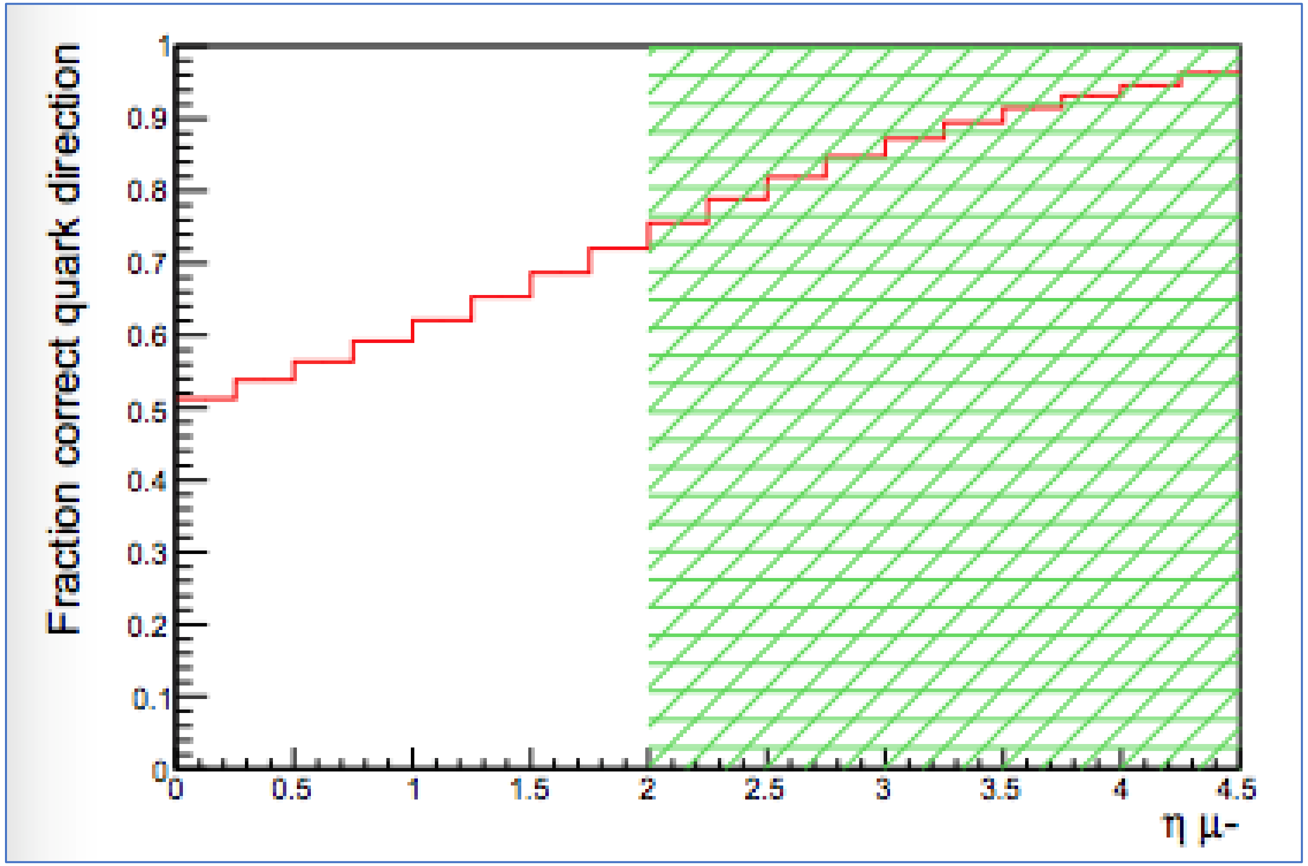
- A quark can be either valence or a sea quark, an antiquark can only be a sea quark (pp collisions)
- Higher order Feynman diagrams for the Drell-Yan process on the right
- Z and γ mixing produces a differential cross section that is a combination of three contributions: Z, γ and another dependant on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

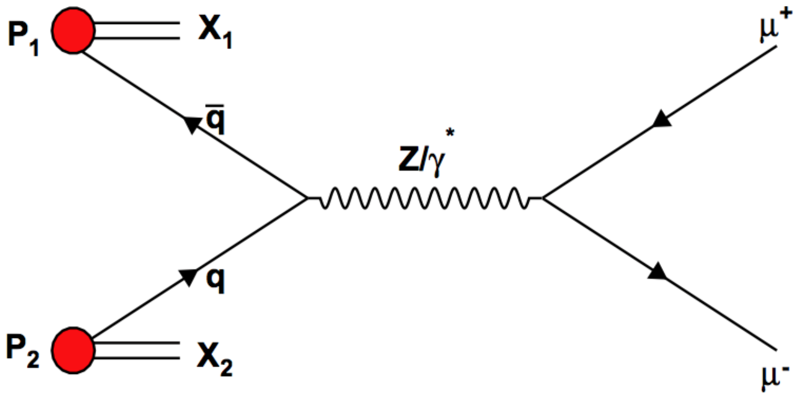
Forward Backward Asymmetry, A_{FB}

- 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]