Progress towards measurement of A_{FB} and extraction of $\sin^2\theta_W$ in the process $q\bar{q} \to Z/\gamma^* \to \mu^+\mu^-$ at LHCb

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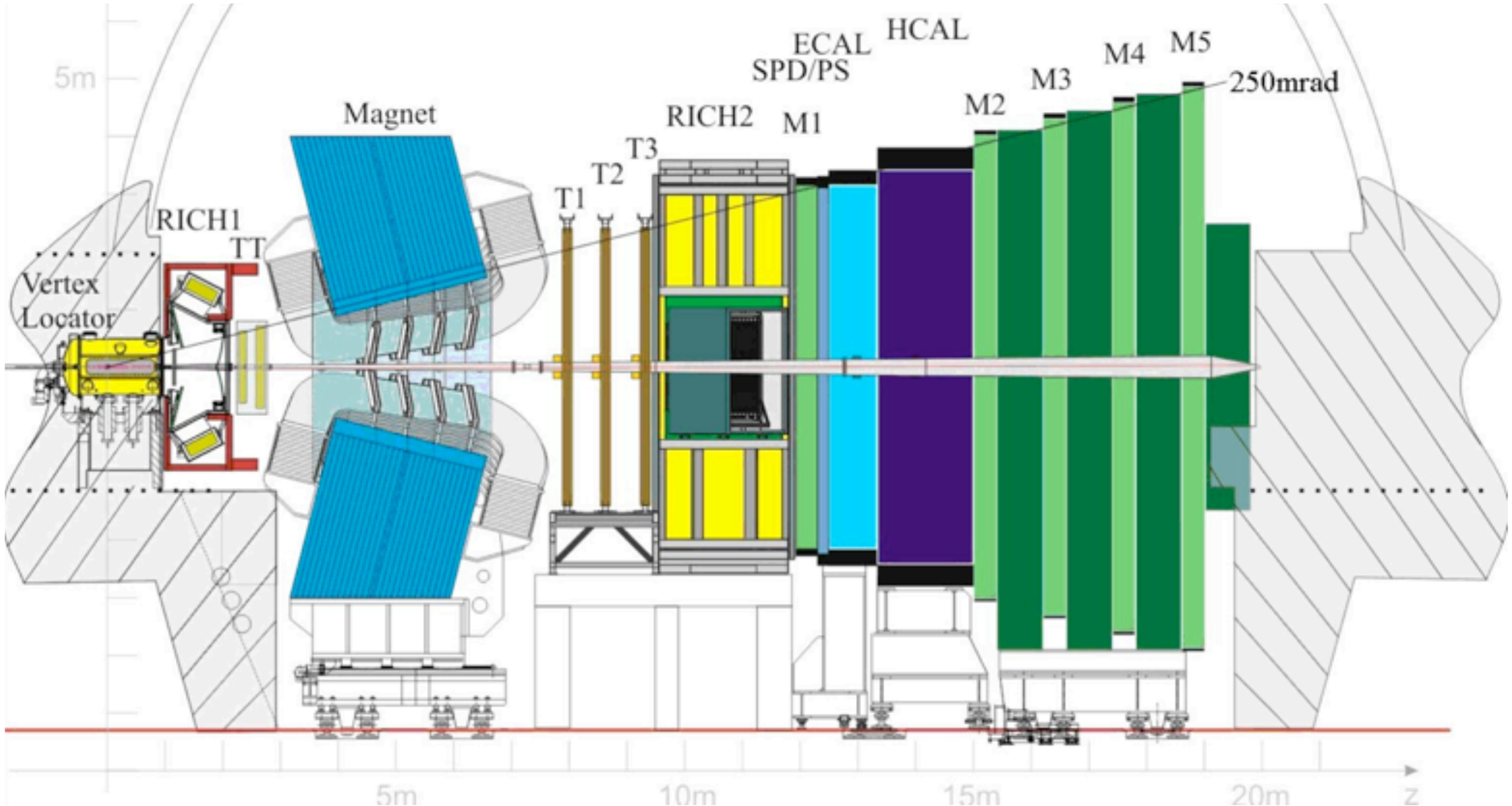
on behalf of the LHCb collaboration

IOP Joint HEPP and APP Annual Meeting
8th-10th April 2013
Liverpool

UNIVERSITY OF LIVERPOOL

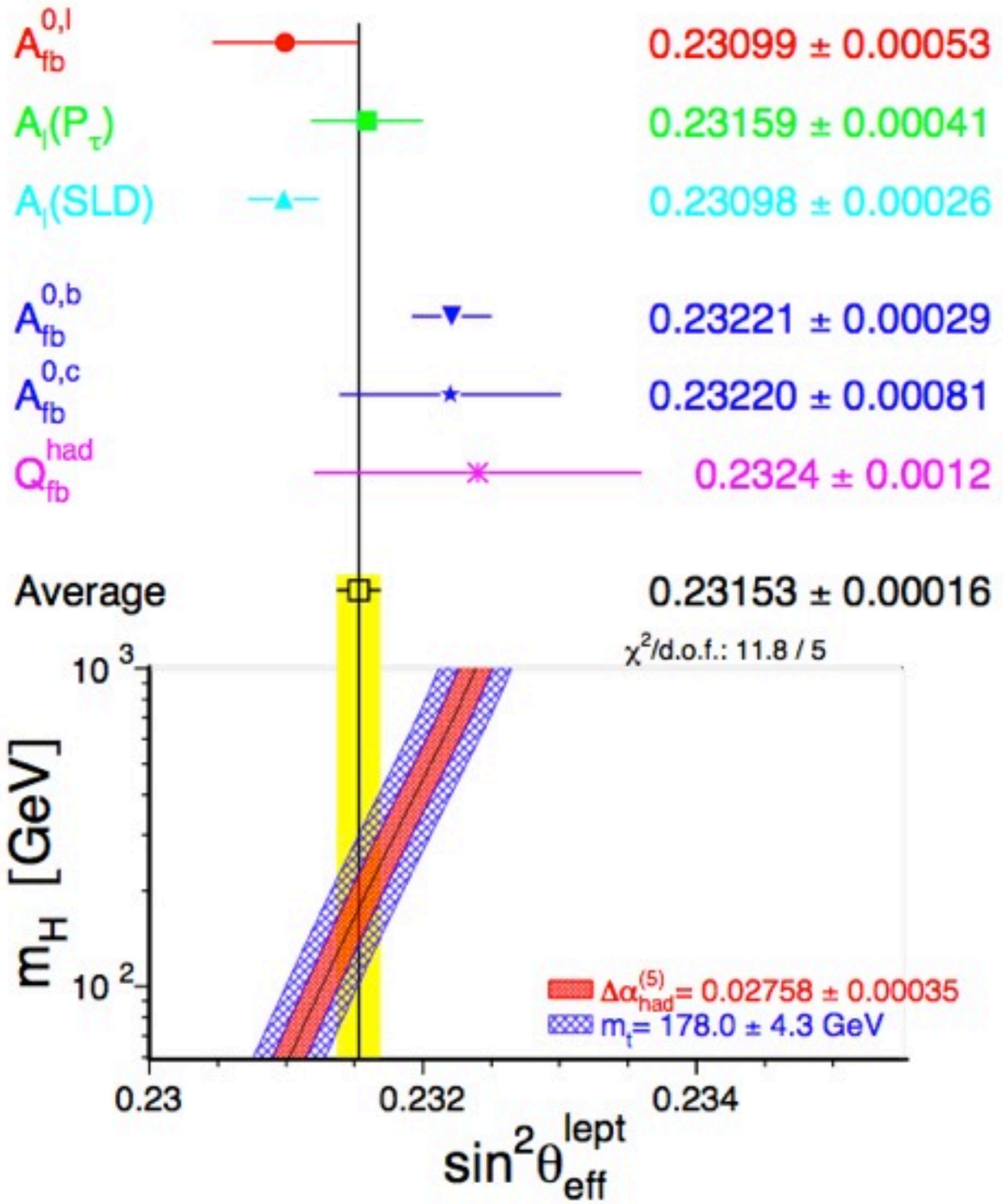
The LHCb Detector



Single arm spectrometer
Unique acceptance $1.9<\eta<4.9$
2011 $\int L = 1.10 fb^{-1}$ at 7TeV
2012 $\int L = 2.08 fb^{-1}$ at 8TeV

Motivation

- **2.9σ between two best constrained measurements**
- **Test Standard Model:**
  - Measure A_{FB}
  - Measure $\sin^2\theta_W$
    - Measure couplings of Z to quarks
    - New Physics: Z', little Higgs
- **LHCb the only LHC experiment that could reach world average of $\sin^2\theta_W$ without limitation from PDF uncertainty - A. Vicini, LHC EWWG Meeting 29/11/2011**



LHCEWWG CERN-PH-EP/2005-041 and hep-ex/0509008

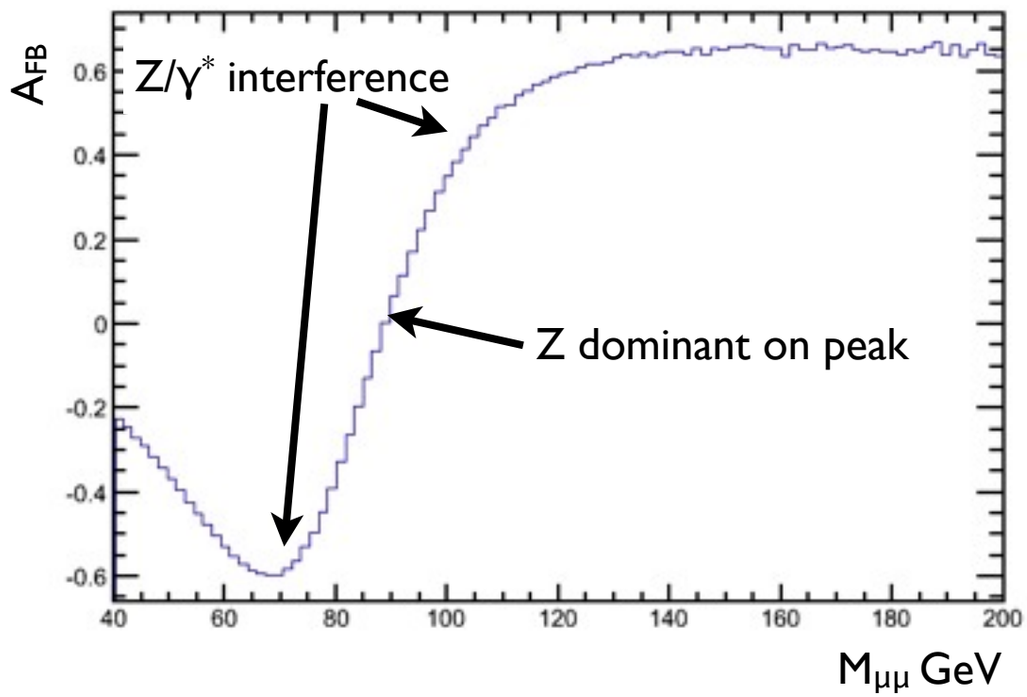
A_{FB} Introduction

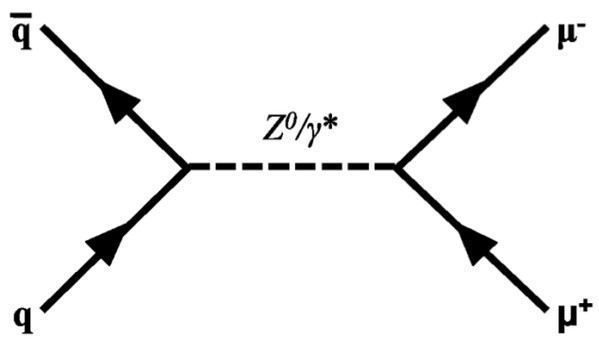
- Drell-Yan production
- Interference of vector and axial-vector couplings of Z and γ* to fermions leads to asymmetry

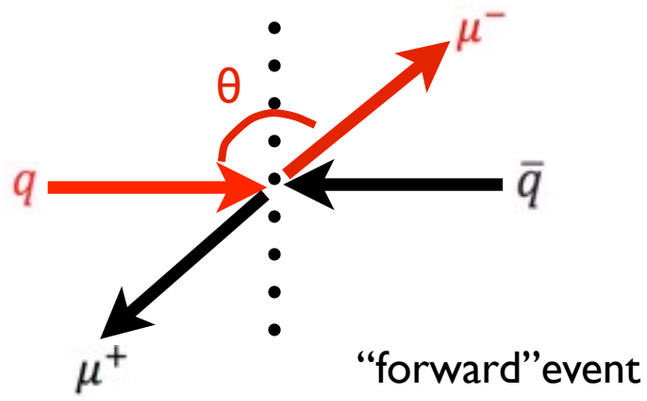
$$A_{FB} \propto \frac{2\, g_{Vf}/g_{Af}}{1 + g_{Vf}^2/g_{Af}^2}$$

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

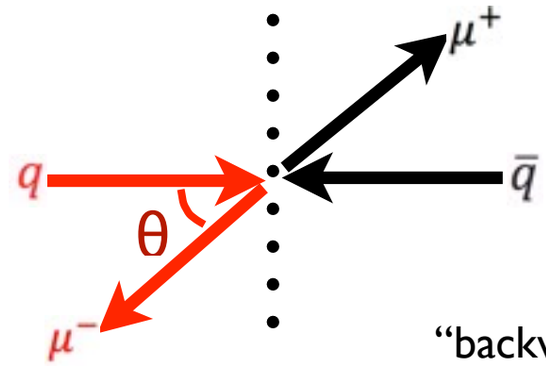
The shape of A_{FB}







"forward"event



"backward"event

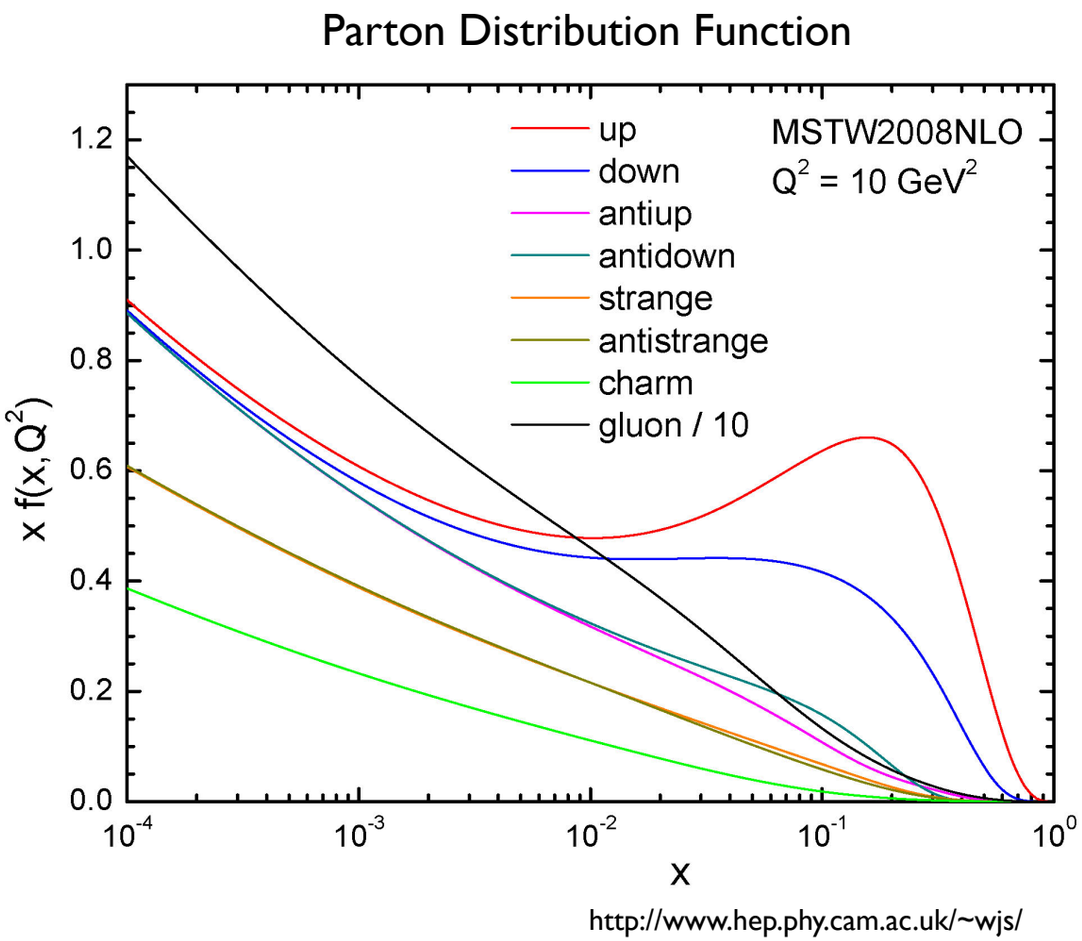
A_{FB} at the LHC

At LHC have PP collisions…

P → ← P

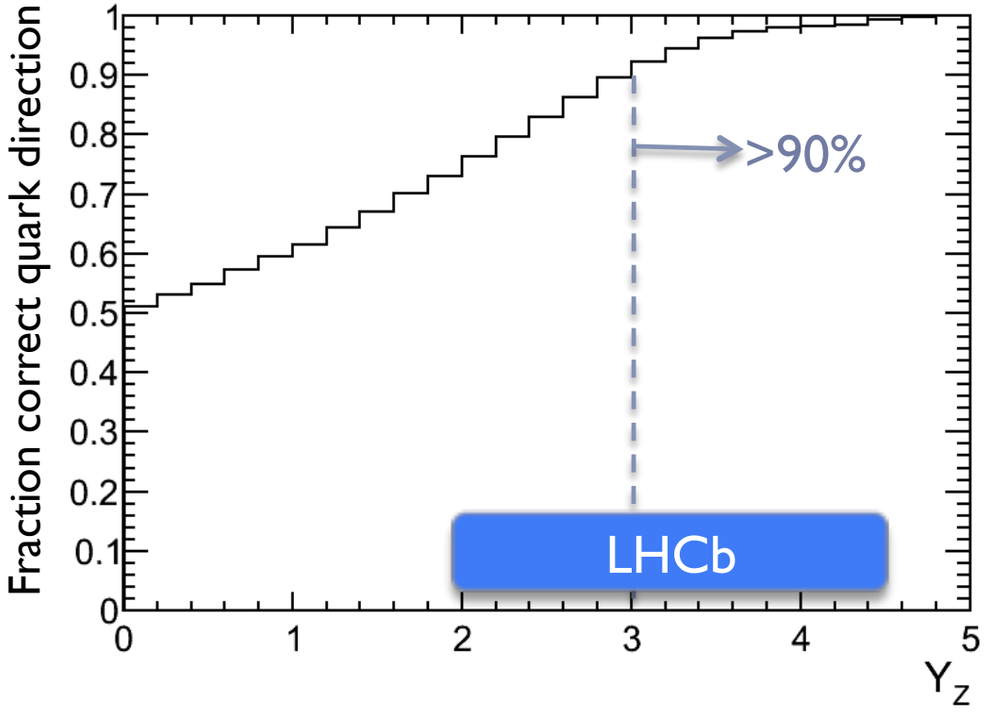
So which is the quark direction?

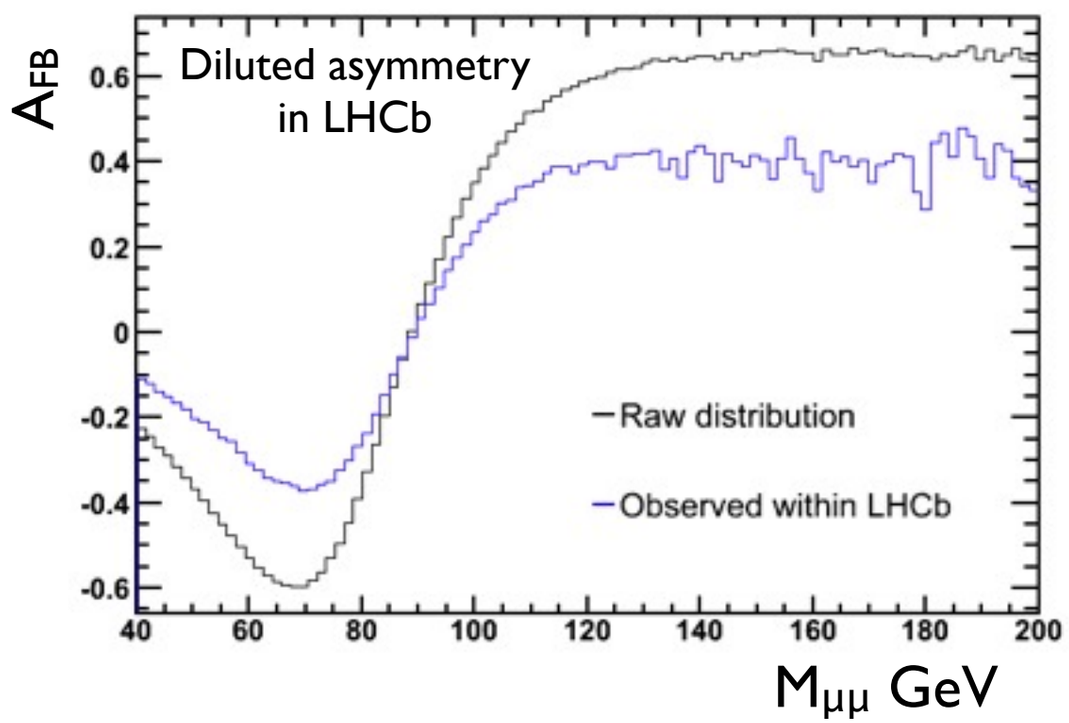
- Interactions are $q\bar{q}$ hence either sea-sea or valence-sea collisions
- PDF for valence quark predicts higher average momentum than sea quark
- Hence we assume Z boosted in direction of valence (matter) quark
- Can use this to approximate quark direction



A_{FB} diluted at the LHC

- Run Pythia simulation to check percentage of events where the boost of the Z is correctly aligned to the matter quark
- Using boost of Z to define matter quark direction - correct >75% over the LHCb acceptance
- Very diluted in ATLAS/CMS without harsh rapidity cuts
- Less dilution seen in LHCb





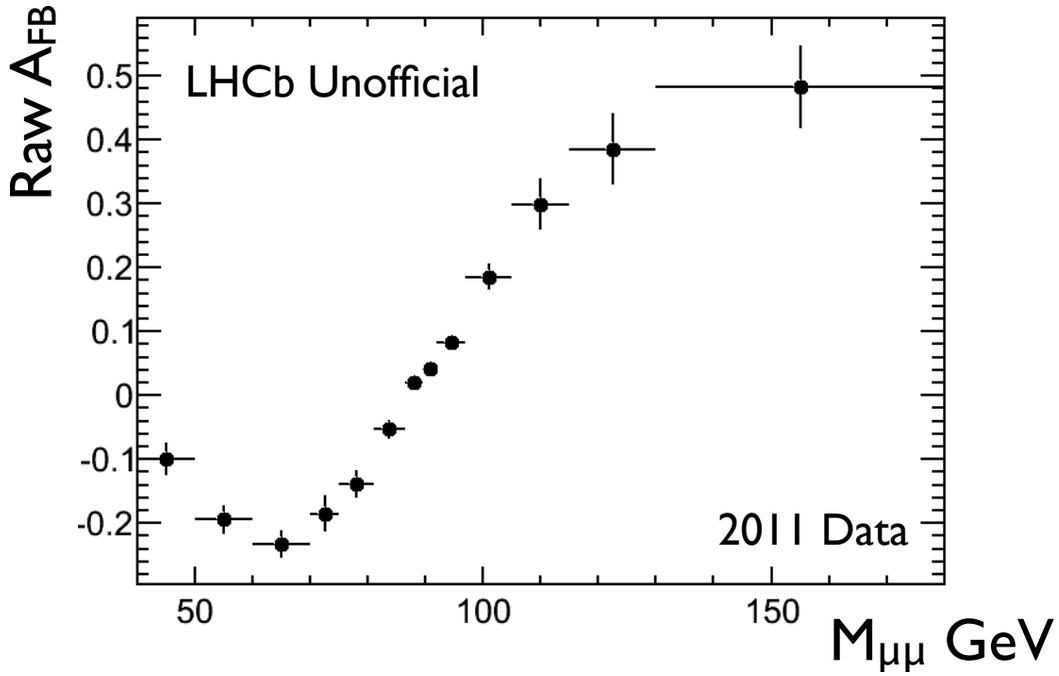
A_{FB} Strategy

- Standard Z selection at LHCb: J. High Energy Phys. 06 (2012) 058

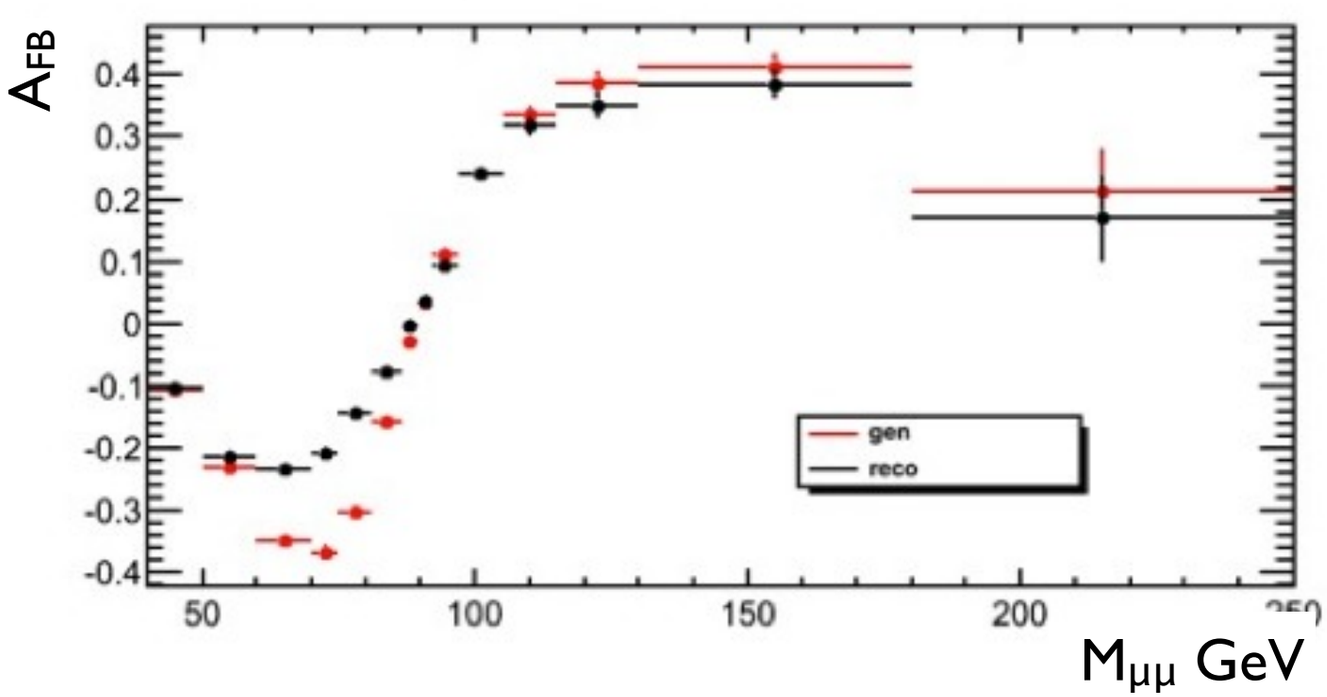
$$\sigma(Z \to \mu\mu : 2 < \eta_\mu < 4.5, P_{T\mu} > 20GeV, 60 < M_{\mu\mu} < 120GeV)$$

- Unfold the Data A_{FB} distribution to correct for detector effects, using high stats fully reconstructed LHCb MC and correct for the diluting effect of unknown quark direction

- Calculate systematics

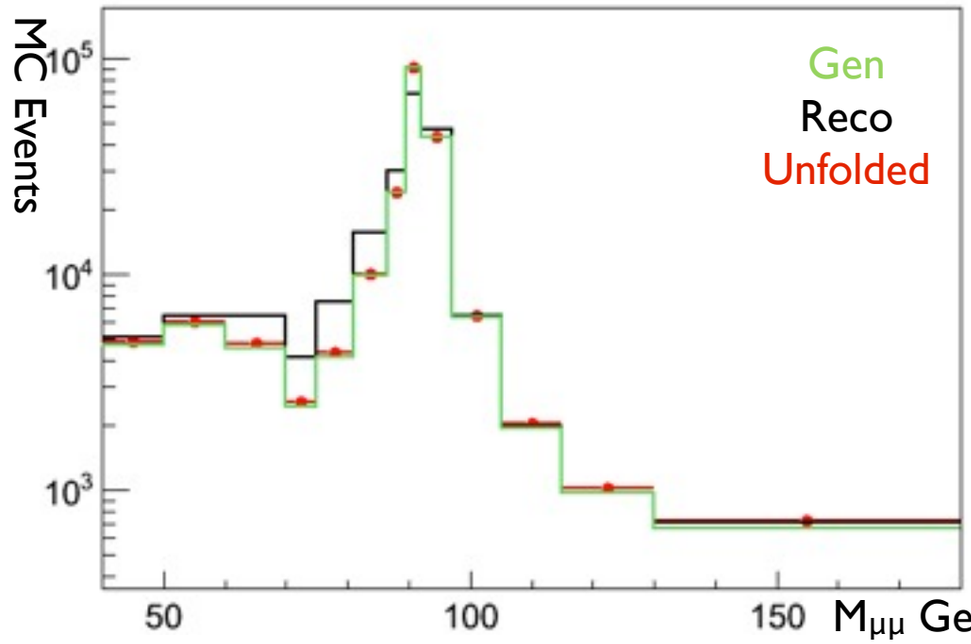


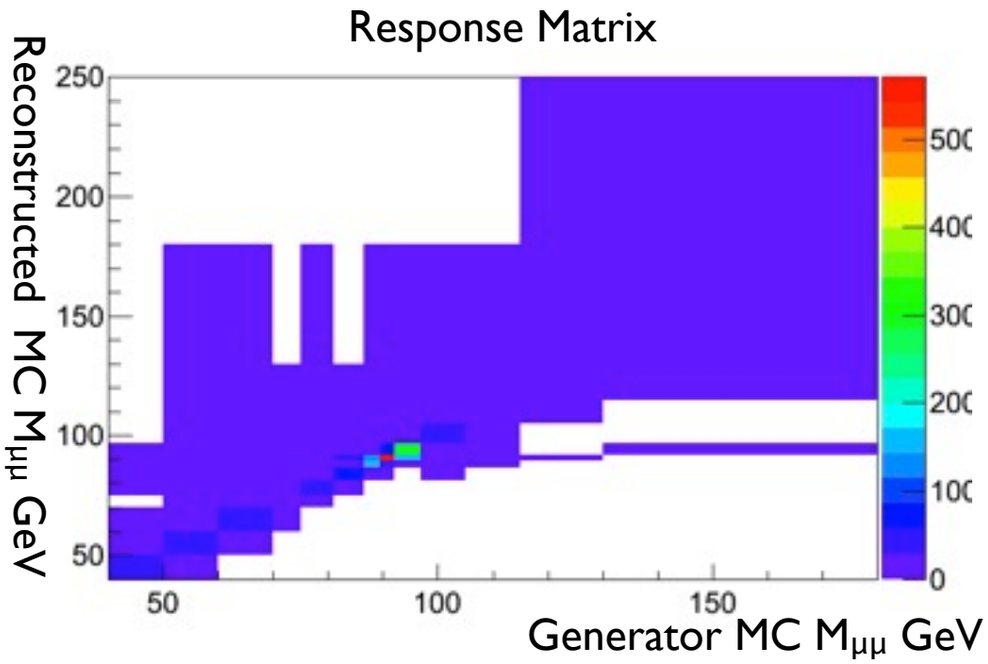
MC generator level and reconstructed



A_{FB} measurement - unfolding

- To make a true measurement of A_{FB} must correct for detector effects, final state radiation, the diluting effect of the unknown quark direction.
- Iterative Bayesian unfolding - D'Agostini method to unfold the detector and radiation effects arxiv:1010.0632
- Dilution will be treated separately as it requires the rapidity distribution

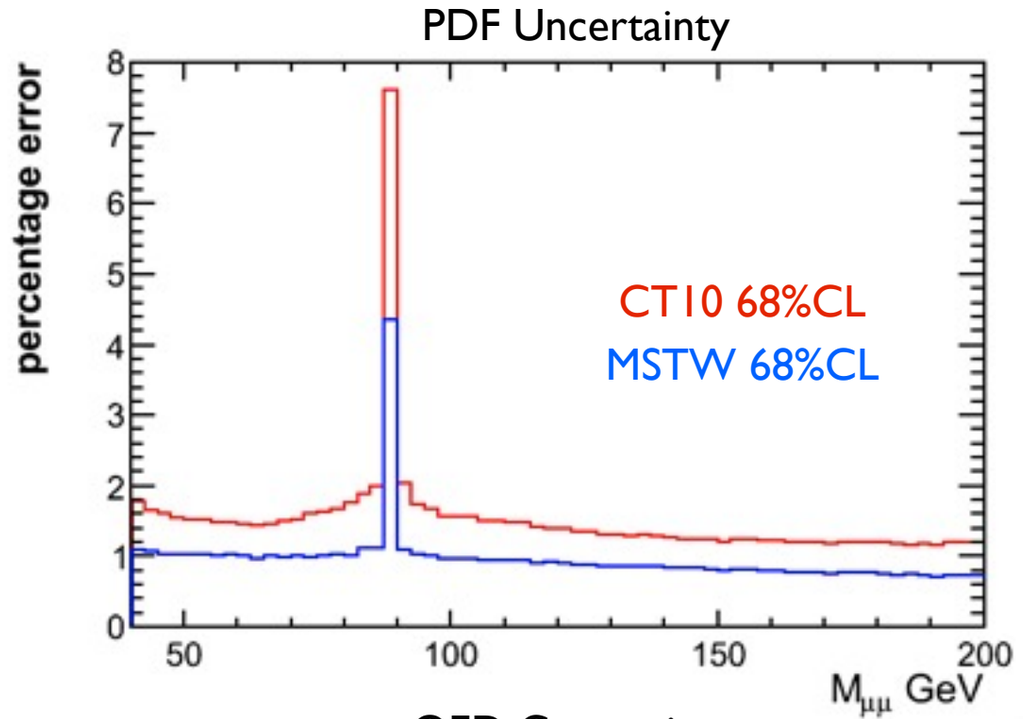




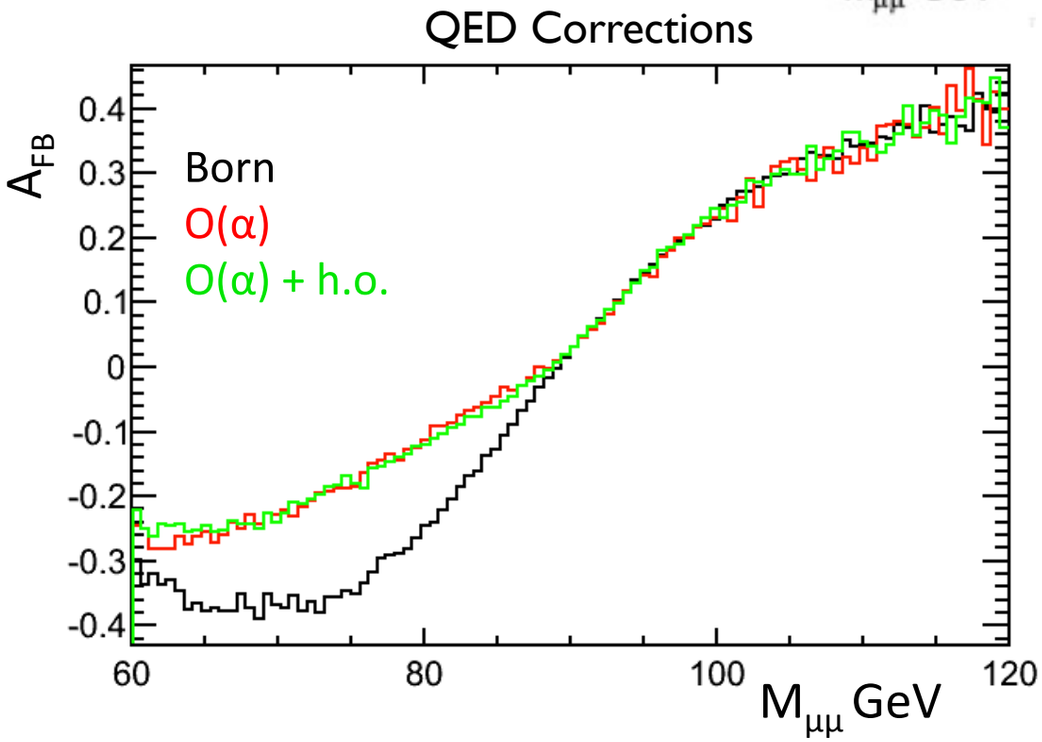
Systematics A_{FB}

Considered systematics for A_{FB}:

- **PDF uncertainty**
  - Using MCFM for NLO predictions
  - Relatively flat distribution in $M_{\mu\mu}$ for percentage uncertainty
  - Variations between PDF sets and eigenvectors for each set



- **Final State Radiation and Higher order QED effects**
  - FSR has a large effect on A_{FB} on and below Z peak, not well modelled in Pythia
  - Used Horace NLO QED generator to study
  - Pythia with native radiation over-estimates FSR for the muons
  - Now using PHOTOS integrated with Pythia for better modelling



Systematics A_{FB}

- **Backgrounds** - have very clean Z signal, <0.25% background in standard Z selection.
- **LO modelling in MC** - vary factorisation scale and renormalisation scale in PDFs
- **Choice of $\sin^2\theta$ in unfolding** - Bias from A_{FB} distribution used as prior in unfolding. Limited by extracting $\sin^2\theta_W$ then running the unfolding with this value as prior.
- **Momentum scale and resolution**
- **Correction for dilution of A_{FB}**

Extraction of $\sin^2\theta_W$

- Currently working on A_{FB} but extraction of $\sin^2\theta_W$ also planned
- The A_{FB} distribution is sensitive to $\sin^2\theta_W$ through the couplings

$$g_L = T_3 - Q\sin^2\theta_W \qquad g_R = -Q\sin^2\theta_W$$

$$g_V = g_L + g_R \qquad g_A = g_L - g_R$$

$$A_{FB}^0 = \frac{3}{4}A_f(uA_u + dA_d + sA_s)$$

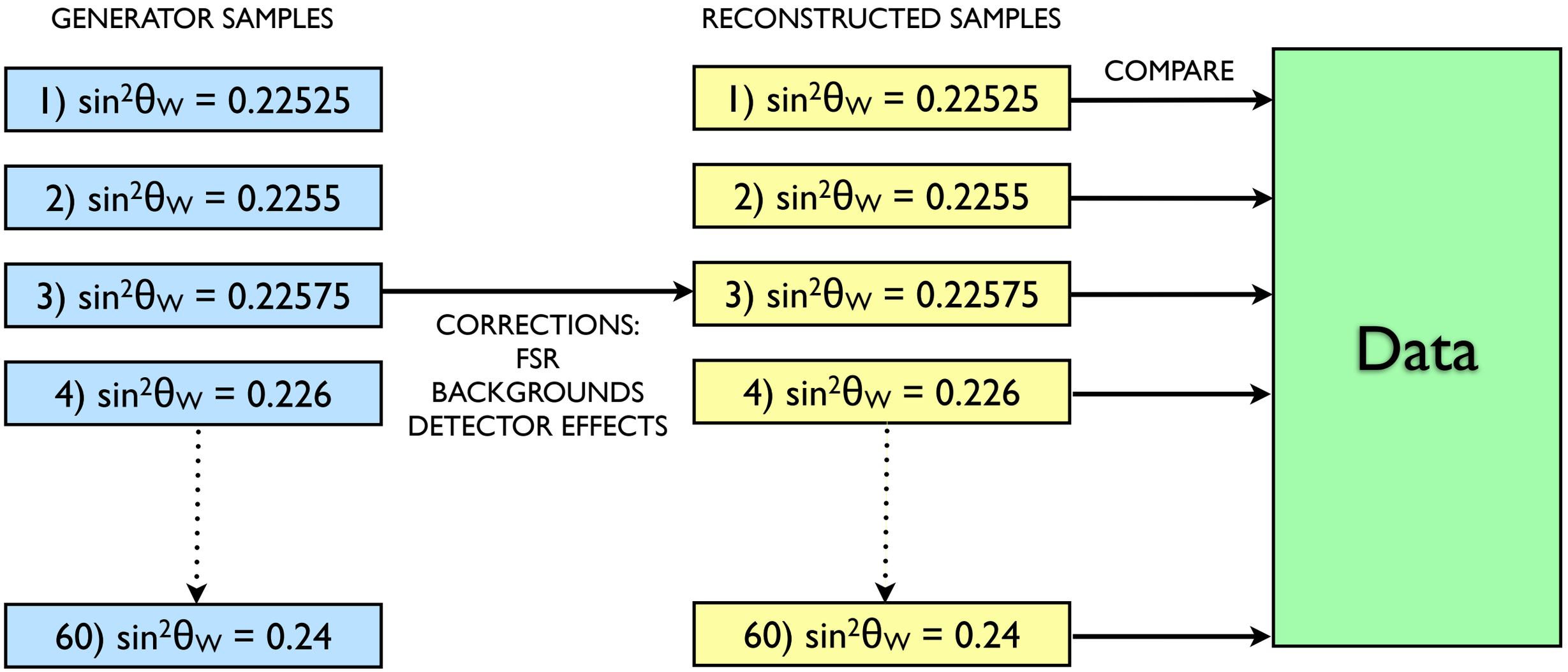
$$A_f = \frac{2g_{Vf}/g_{Af}}{1 + g_{Vf}^2/g_{Af}^2}$$

$$g_{Vf}/g_{Af} \propto \sin^2\theta_W$$

- The distribution changes if the value of $\sin^2\theta_W$
- To measure $\sin^2\theta_W$ compare uncorrected data A_{FB} distribution to MC templates

Fitting for $\sin^2\theta_W$

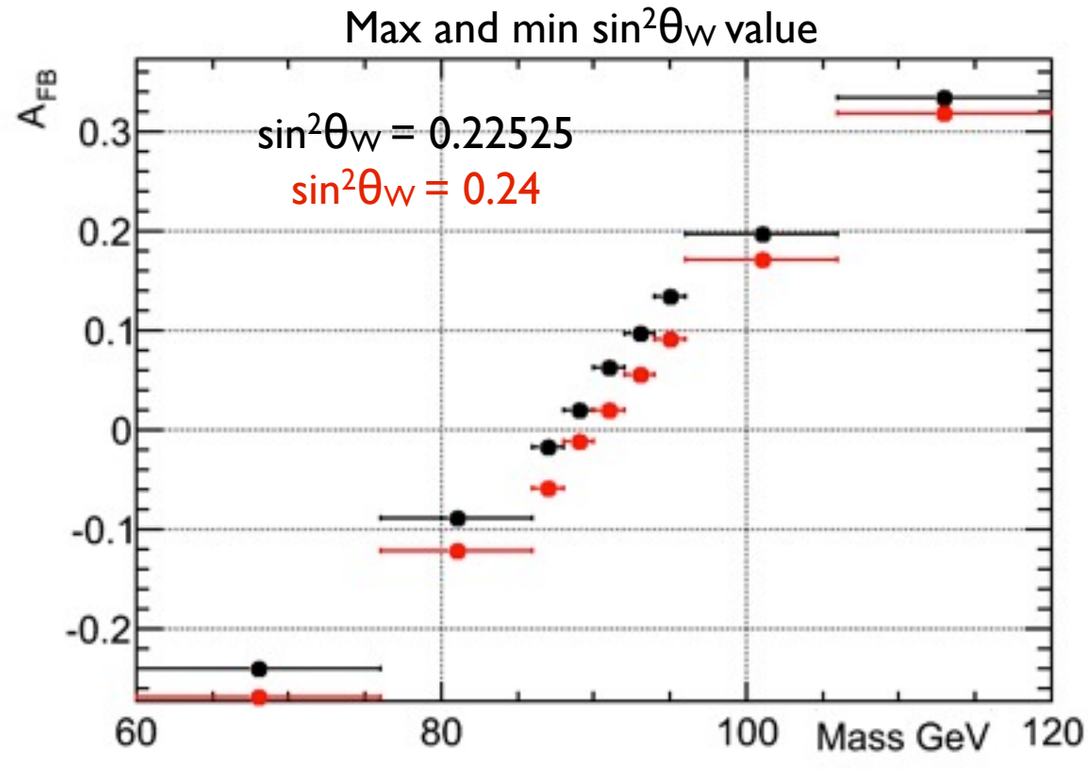
- Method for extracting $\sin^2\theta_W$ template fit with raw data A_{FB}
- 60 MC samples used for χ^2 comparison

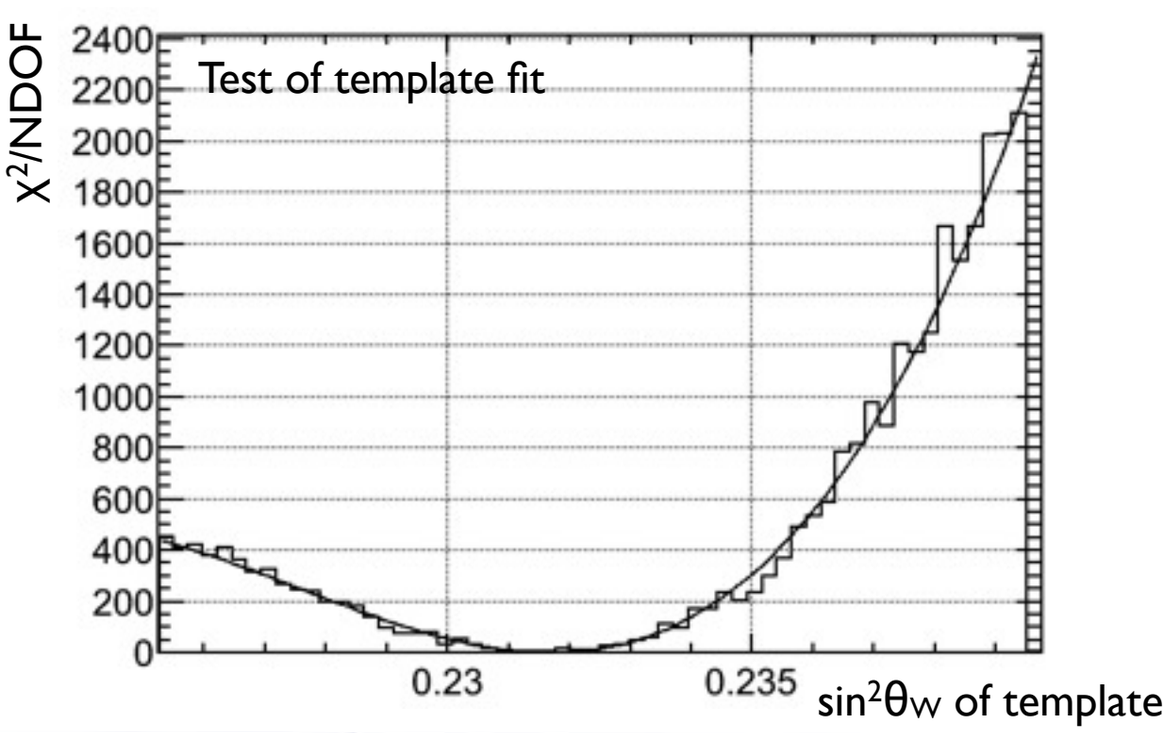


* range of $\sin^2\theta_W$ defined by allowed values in pythia MC generator

Proof of Method

- 60 values of $\sin^2\theta_W$ around world average
- perform χ^2 test of data to each template
- Plot the χ^2 value for each $\sin^2\theta_W$
- Fit a polynomial to the χ^2 values and take the minimum of the fit
- Evolving the extraction to a multivariate fit to make the most of all available statistics
  - should greatly improve statistical error





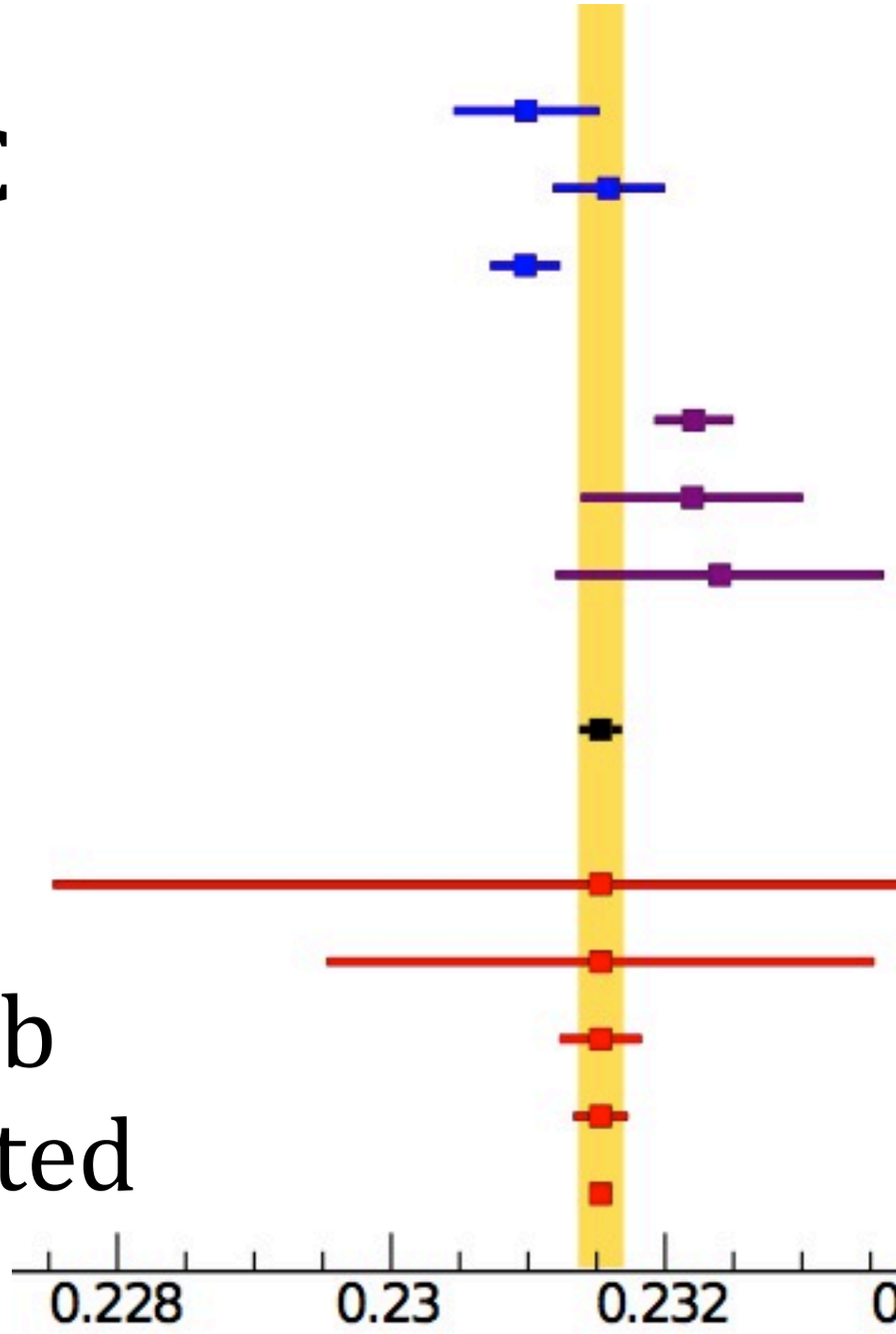
Systematics $\sin^2\theta_W$

- **PDF** - uncertainty from pdf error sets and difference between sets
- **Extraction method** - uncertainty from fitting method
- **Backgrounds** - cause minor dilution
- **Efficiency differences** - any differences between μ^+ and μ^- efficiencies

Future Potential

SLAC

LEP



LHCb expected

$A_{fb}^{0,l}$ 0.23099±0.00053

$A_l(P_\tau)$ 0.23159±0.00041

A_l(SLD) 0.23098±0.00026

$A_{fb}^{0,b}$ 0.23221±0.00029

$A_{fb}^{0,c}$ 0.23220±0.00081

Q_{fb}^{had} 0.2324±0.0012

World average 0.23153±0.00016

2011 $1fb^{-1}$ 0.2303±0.004

2012 $3fb^{-1}$ 0.2303±0.002

Upgrade $50fb^{-1}$ basic template fit 0.2303±0.0003 14TeV

Upgrade $50fb^{-1}$ with MVA 0.2303±0.0002 14TeV

A.Vicini $100fb^{-1}$ 0.2303±0.00011 7TeV*

*SLAC and LEP numbers from D0 paper http://prl.aps.org/abstract/PRL/v101/i19/e191801 $100fb^{-1}$ prediction from A.Vincini https://indico.cern.ch/conferenceDisplay.py?confId=145744

Summary

- Measurement of A_{FB} and the extraction of $\sin^2\theta_W$ ongoing at LHCb

- **In progress:**
  - Measurement of A_{FB} and the extraction of $\sin^2\theta_W$ ongoing at LHCb
  - Template extraction for $\sin^2\theta_W$ ready
  - Finalising systematics for A_{FB}
  - Systematics for $\sin^2\theta_W$ in progress
  - Measurement of A_{FB} and $\sin^2\theta_W$

- **The future:**
  - Change to MVA extraction of $\sin^2\theta_W$ to make best use of statistics
  - Measurement of quark couplings