Forward-Backward asymmetry measurement in $pp \rightarrow Z/\gamma^* + X \rightarrow \mu^+\mu^- + X$ events with 236 pb^{-1}

V ATLAS-Italia Physics Workshop

Napoli, 18 – 19 Maggio 2011

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$Z \rightarrow \mu\mu$ forward-backward asymmetry

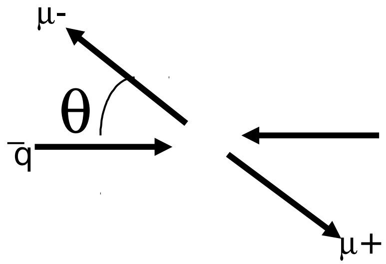
- The presence of both vector and axial-vector coupling of the quarks and leptons to the γ^*/Z boson gives rise to an asymmetry in the polar emission of muons.
  - Allow measurement of the effective weak mixing angle
- The F/B asymmetry measurement can be extended to higher invariant masses in Drell-Yan spectrum
  - Possible observation of new physics scenarios: extra dimensions, new gauge bosons, etc.

- Definition of forward-backward asymmetry:
  - **A_{FB} = (F-B)/(F+B)**

    F = number of events with $\cos(\theta*)>0$

    B = number of events with $\cos(\theta*)<0$
    - θ^* defined in Collins-Soper reference frame
- θ dependence of the x-section
  - angle between incoming particle (quark) and outgoing particle (lepton)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \frac{3}{8}N_c[1 + \frac{4}{3}A_{FB}\cos\theta + \cos^2\theta]$$



$Z \rightarrow \mu\mu$ candidate event selection

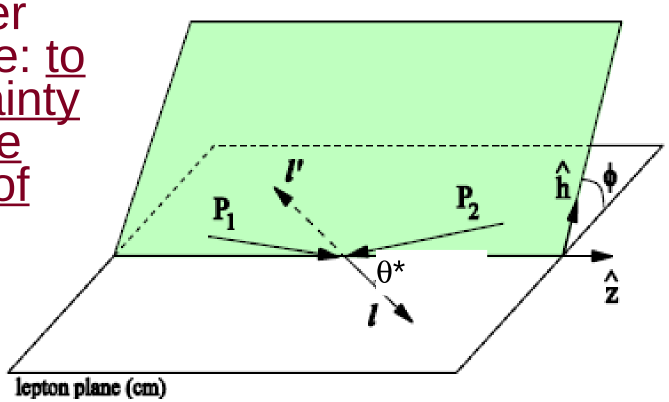
- Event selection (2011 data):
  - GRL + bcid
  - **Trigger: EF_mu20**
  - $N_{VTX} > 1$ and $N_{tracks} >= 3$ and $|Z_{VTX}| < 200$ mm
  - At least 2 combined muons with
    - **$p_T > 25$ GeV**
    - $|\eta| < 2.4$
    - $|z_0| < 10$ mm for both tracks (wrt to same "good" vertex)
  - Muon quality as Muon Combined Performance Group recommendations
  - Isolation: $\Sigma p_T/p_T < 0.2$ for both muon tracks
  - Charge: $c_1 * c_2 < 0$
  - Mass window: $66 < M_{\mu\mu} < 116$ GeV

- Data sample luminosity
  - **~ 236 pb^{-1} (actual 2011 available statistics!!)**
- Monte Carlo sample (Pythia MC10a, signal only)
  - mc10_7TeV.106047.PythiaZmumu_no_filter.merge.NTUP_SMWZ.e574_s933_s946_r2215_r2260_p545
- MC corrections (up to now...)
  - Primary vertex (re)weigthing (PileupReweighting tool 2011)
  - MCP p_T smearing 2011

“Raw” $A_{F/B}$ measurement

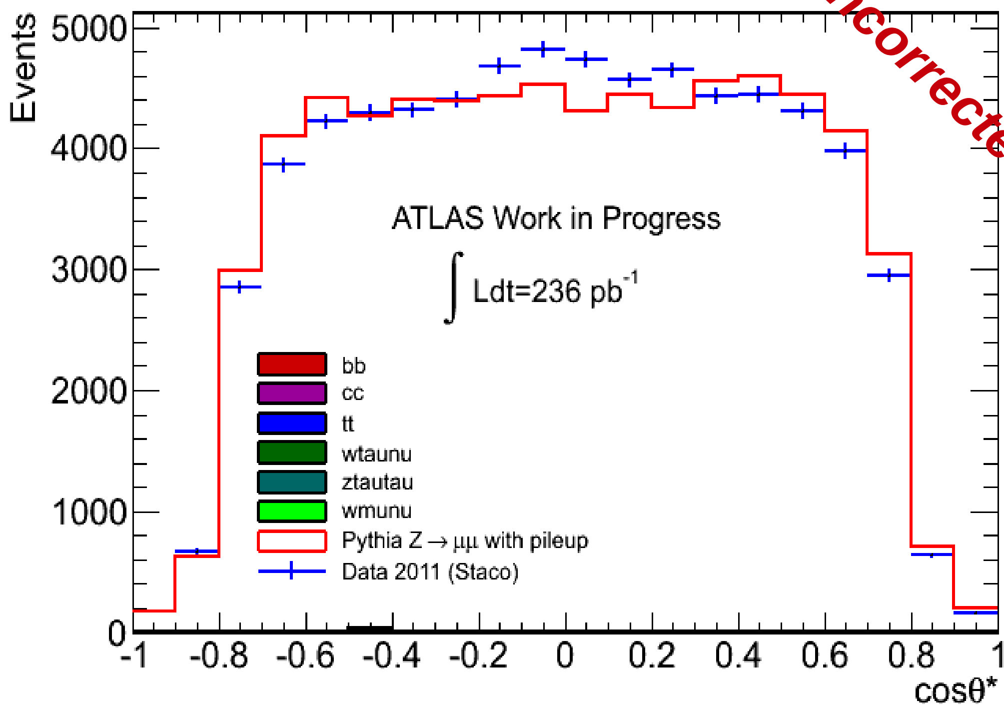
- Asymmetry evaluated with counting method:
  - $A_{FB}=(F-B)/(F+B)$
    F = number of events with cos(θ*)>0
    B = number of events with cos(θ*)<0
- Only statistical error

Collins-Soper reference frame: <u>to reduce uncertainty of transverse momentum of quarks</u>



cos(θ*) distribution

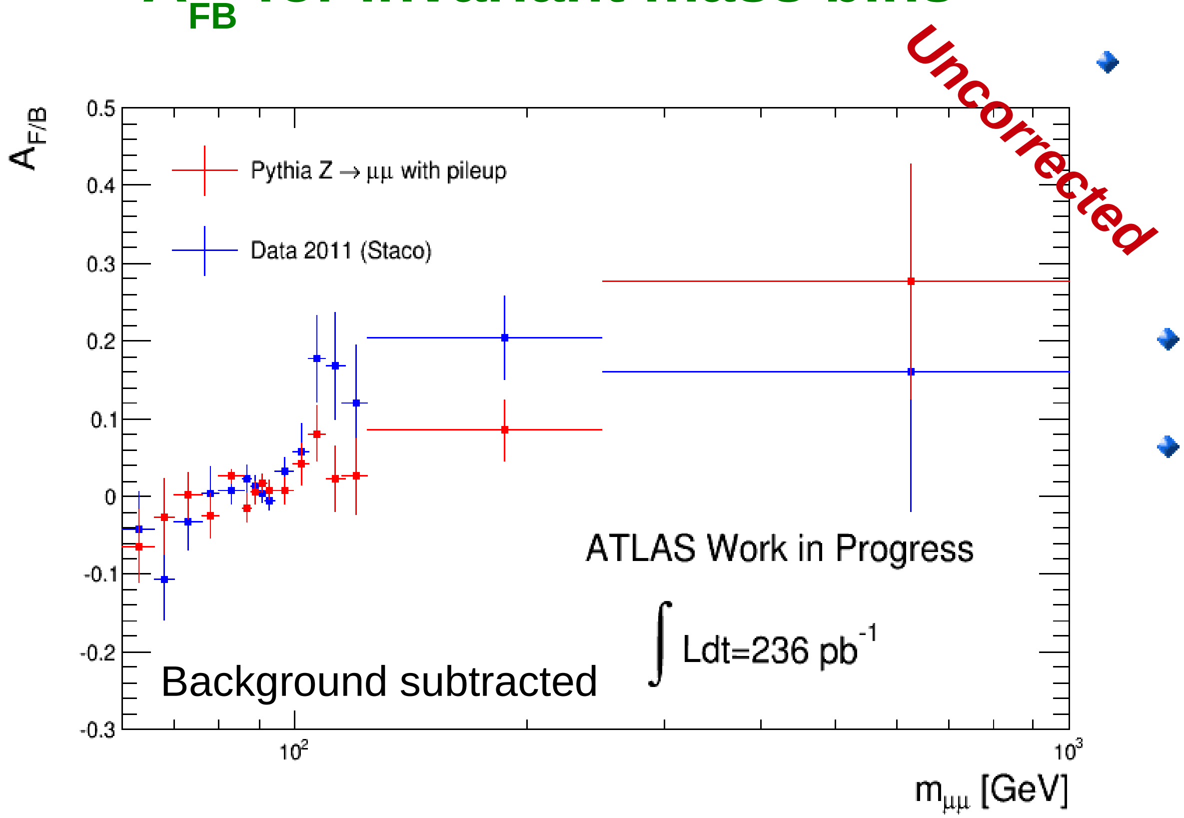
Uncorrected



Raw $A_{F/B}$(%)	
MC (Pythia)	1.1 ± 0.3 (stat)
Data 2011	0.9 ± 0.4 (stat)

$A_{F/B}$ vs di-muon invariant mass

A_{FB} for invariant mass bins

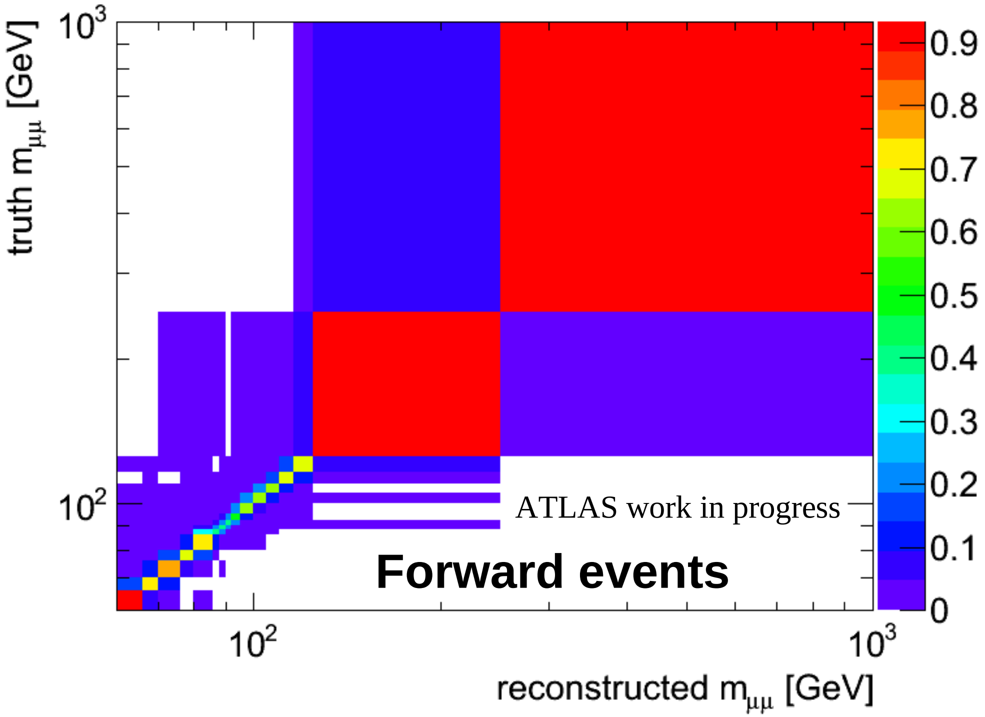


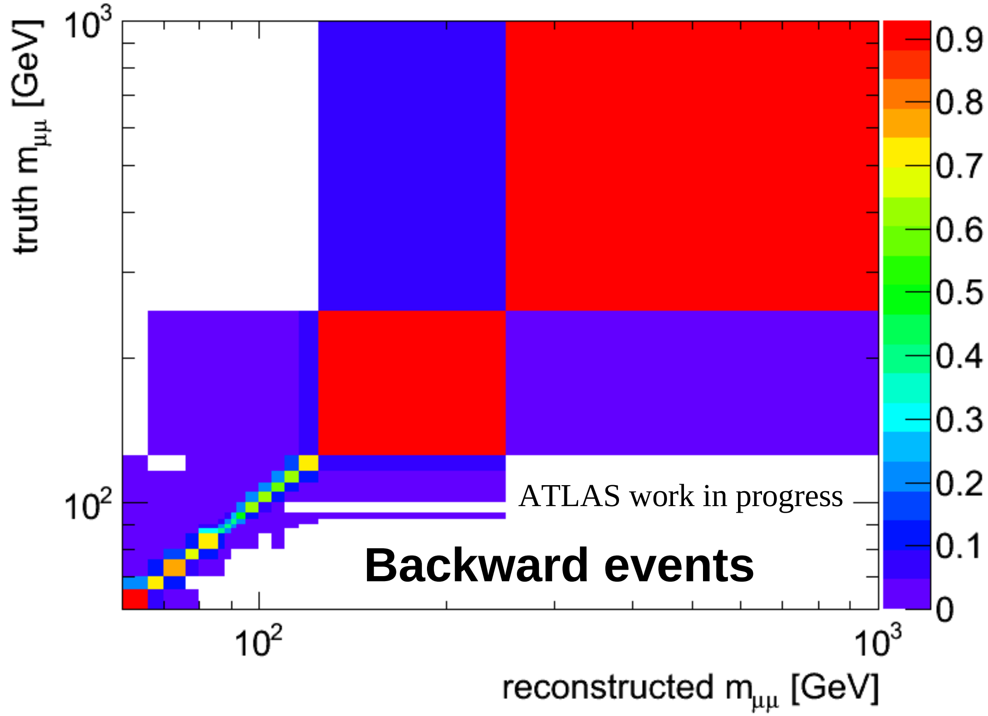
- "Raw" distributions should be corrected using MC based response matrices to take into account for:
  - detector resolution and FSR (mass bin migration correction)
  - incorrect quark direction: the direction of the quark and anti-quark is not known in proton-proton experiments and leads to a dilution in the asymmetry

Mass bin migration correction

- Reconstructed invariant mass is not equal to truth mass
  - Need to correct for invariant mass migration
- Calculate the probability of a reconstructed mass to be a different mass

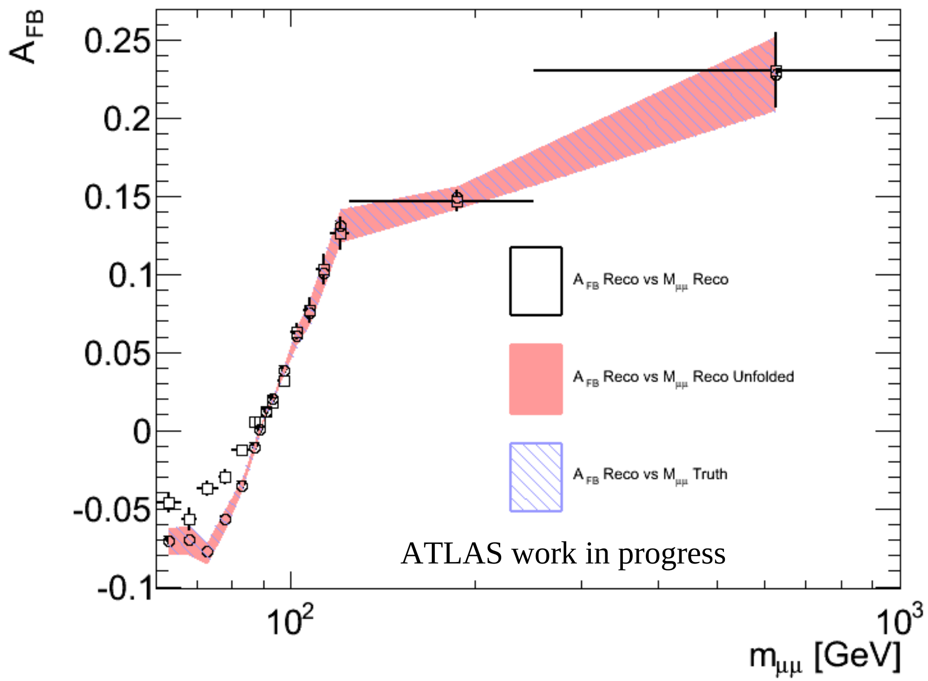
Mass Migration response matrices





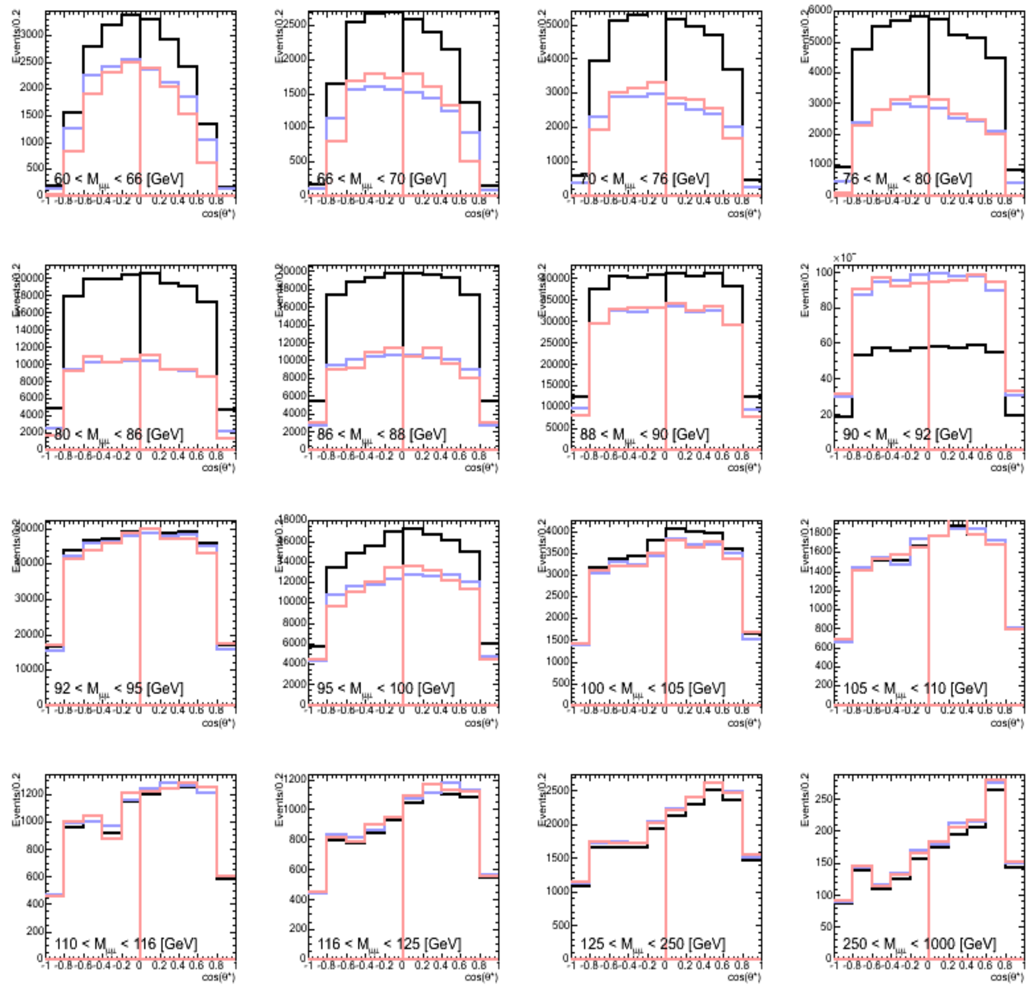
Mass migration closure test on MC

- Closure test on MC
- Compare:
  - **Reco asymmetry vs uncorrected mass**
  - **Reco asymmetry vs corrected mass**
  - **Reco asymmetry vs true mass**
- Correction brings back the mass distribution to its true value, up to the point that the two curves are indistinguishable



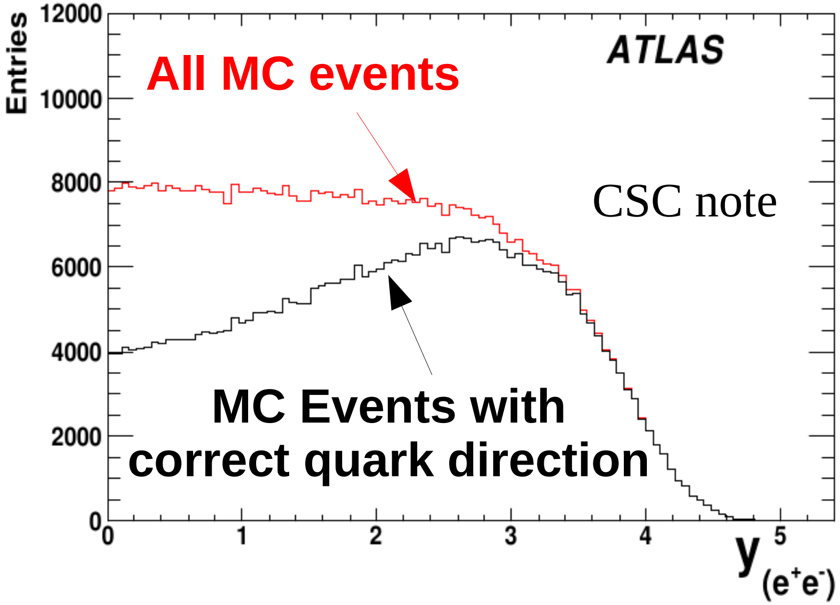
Showing the effect of mass bin correction on cos(θ*) distribution

ATLAS work in progress

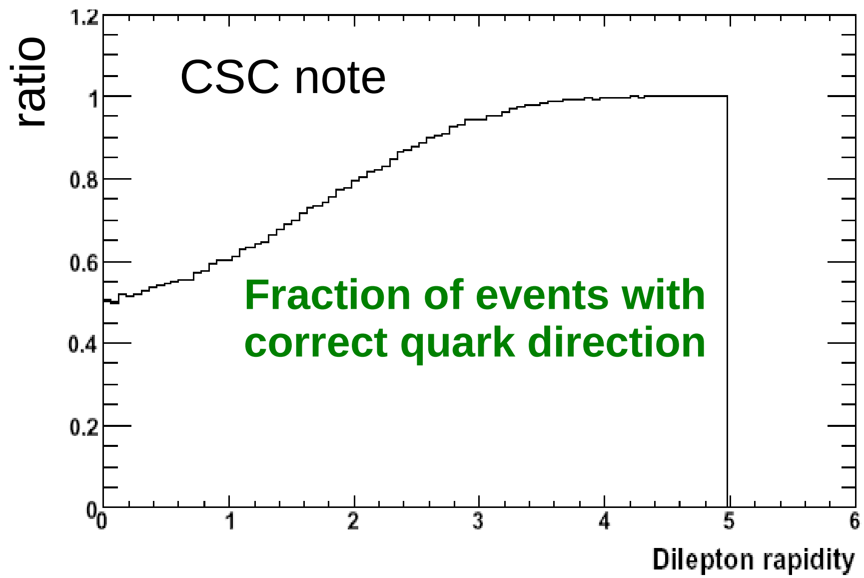


Quark direction: dilution

- At central di-lepton rapidity the probability that the valence quark direction and the di-lepton boost coincide is lower due the smallness of the valence quark distribution
  - This reduces the forward-backward asymmetry: **dilution**

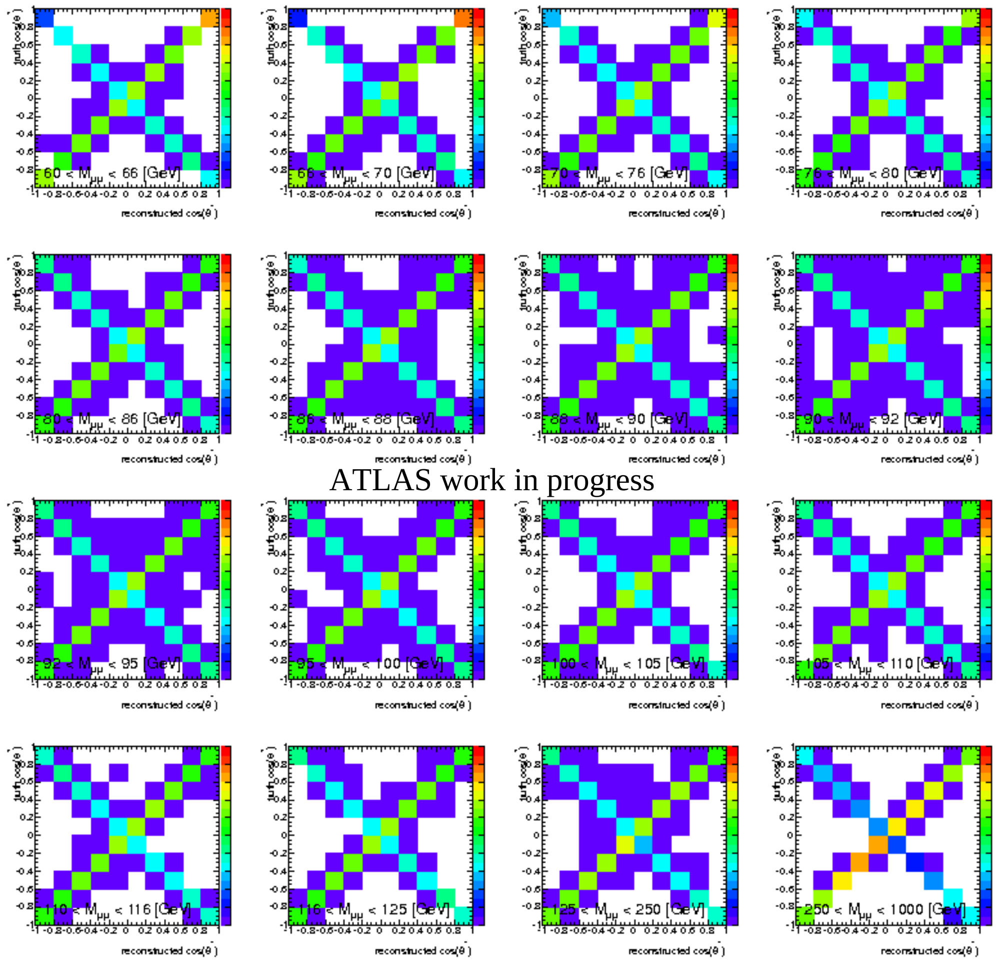


Less than 60% of events with correct quark direction at |Y| < 1



Dilution unfolding correction

- Same approach as for mass bin migration correction
  - A response matrix for each true mass bin
  - True vs Reconstructed cos(θ*)



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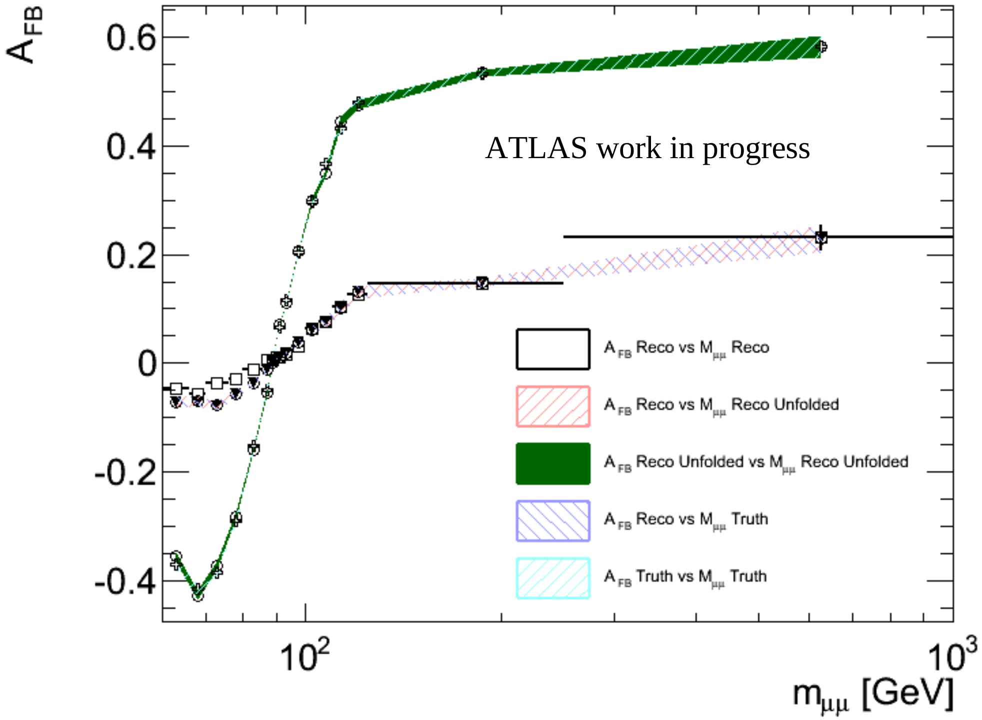
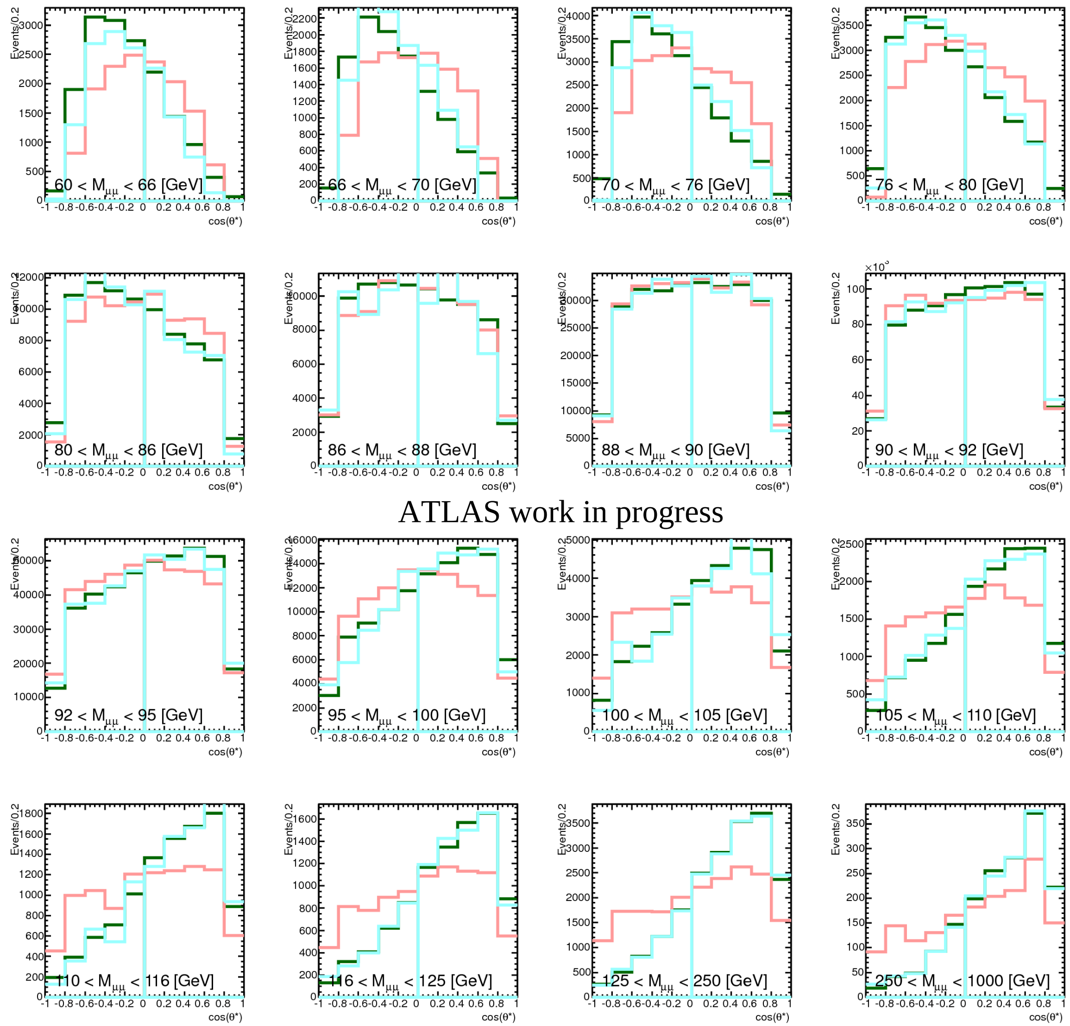
Unfolding closure test on MC

True and Unfolded A_{FB} are perfectly superimposed!!



Showing the effect of mass bin correction on cos(θ*) distribution



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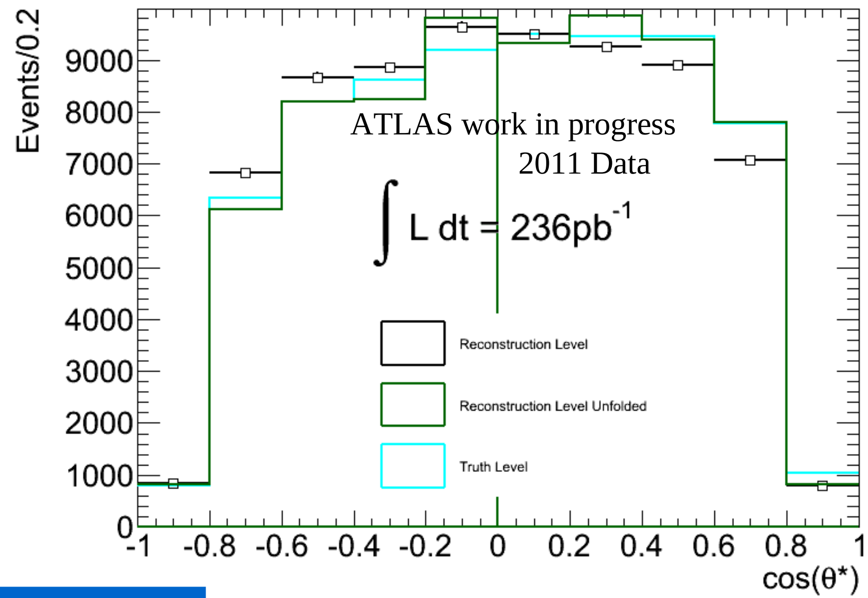
$A_{F/B}$ measurement with 2011 data

- MC based corrections applied to 2011 data
  - "Raw" distribution unfolded for incorrect quark direction
- To reduce impact of low statistics
  - No binning in $m_{\mu\mu}$ and $y_{\mu\mu}$
  - Average over all masses in range $66 < M_{\mu\mu} < 116$ GeV

cos(θ*) distribution



Dilution Unfolding

	$A_{F/B}$ (%)
Data 2011 "Raw"	0.9 ± 0.4 (stat)
Data 2011 Unfolded	5.7 ± 0.4 (stat)
MC Truth Level	5.9 ± 0.07 (stat)

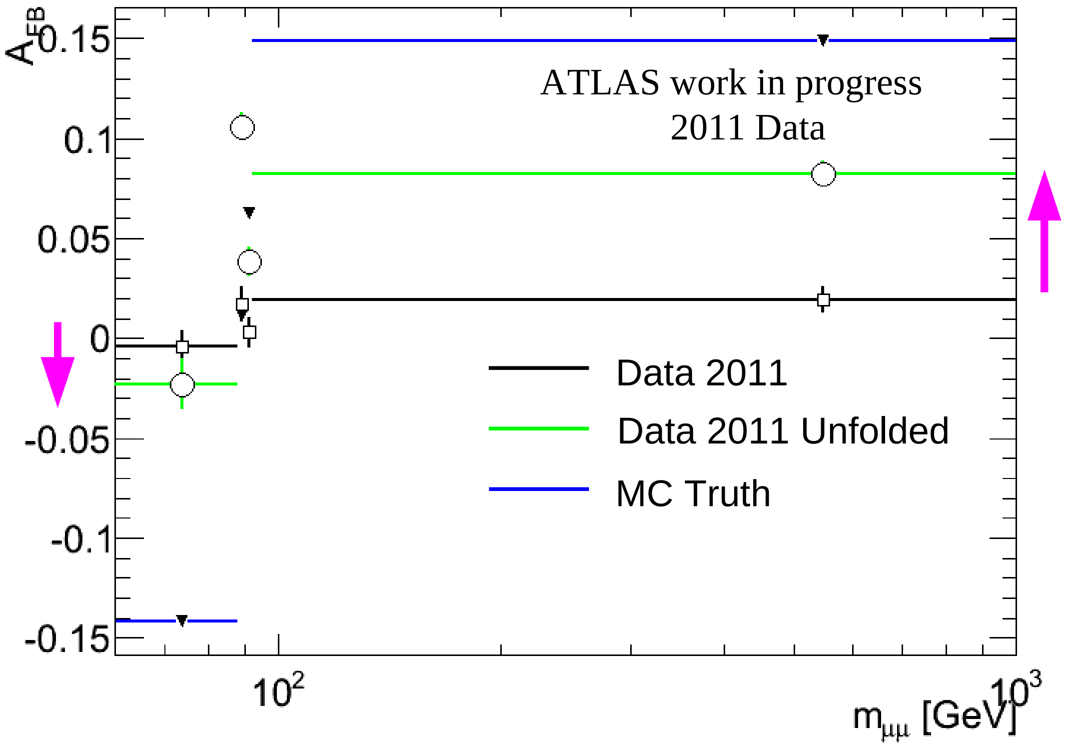
Perfect agreement in final $A_{F/B}$ result between 2011 data and MC!!

$A_{F/B}$ vs di-muon invariant mass

- All corrections applied
  - mass migration and dilution unfolding
- Corrections go in the ***right direction***
  - however, agreement less good wrt one-bin case
  - lower data statistics in each mass bin
- If MC sample used as input with **similar statistics** as data: **closure test fails!**

more statistics needed for $A_{F/B}$ binned in $M_{\mu\mu}/Y_{\mu\mu}$!

A_{FB} for invariant mass bins



Preliminary $\sin^2\theta_W$ extraction

Results from Giulio C. Grossi

At $\sqrt{s} = m_Z$ a direct relation between $A_{F/B}$ and $\sin^2\theta_W$ exists

$$AFB = \frac{3}{4} A_q A_\mu$$

$$AFB = \frac{3}{4}\left(\frac{2\frac{g_v}{g_a}}{1+\left(\frac{g_v}{g_a}\right)^2}\right)\frac{2(1-4\sin^2\theta_W^{eff})}{1+\left(1-4\sin^2\theta_W^{eff}\right)^2}$$

$$q\bar{q} \longrightarrow Z/\gamma^* \longrightarrow \mu\,\mu$$

Initial state

$$g_v^u = 0.29 \quad g_v^d = -0.33$$
$$g_a^u = 0.50 \quad g_a^d = -0.524$$

assumption: $(g_v/g_a)^u \sim (g_v/g_a)^d$

$$A_q = \frac{2\frac{g_v}{g_a}}{1+\left(\frac{g_v}{g_a}\right)^2}$$

Final state

$$A_\mu = \frac{2(1-4\sin^2\theta_W^{eff})}{1+\left(1-4\sin^2\theta_W^{eff}\right)^2}$$

Test method on **raw** 2011 asymmetry

Mass Bin (GeV)	$\sin^2\theta_W$
88 - 89	0.237 ± 0.007 (stat)
89 - 90	0.248 ± 0.006 (stat)
90 - 91	0.244 ± 0.006 (stat)

Actual PDG value:
0.23120 ± 0.00015

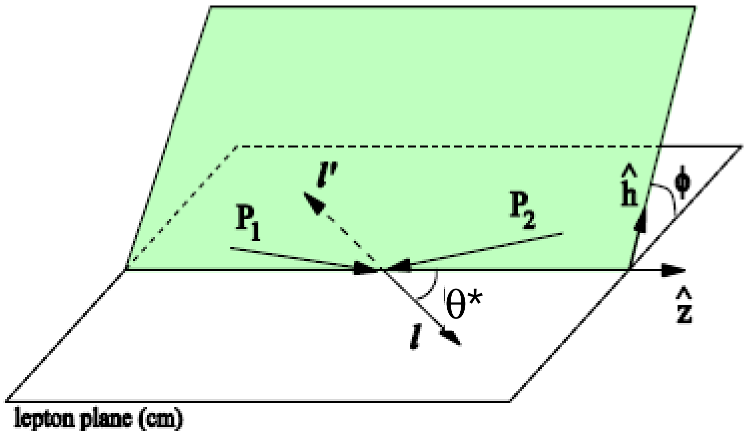
Summary and outlook

- A first measurement of the forward-backward asymmetry in $pp \rightarrow Z/\gamma^* + X \rightarrow \mu^+\mu^- + X$ with ~236 pb^{-1} has been presented
- MC based corrections for mass migration and dilution studied
  - Closure test on MC passed
  - Very good data/MC agreement for mass-averaged asymmetry value
  - Statistics still too small for $A_{F/B}$ binned in $M_{\mu\mu}/Y_{\mu\mu}$
- CONF note in preparation for EPS conference with muon (Roma2, Bonn) and electron (Mainz) results
- Work on $\sin^2\theta_W$ is ongoing

Backup slides

Collins-Soper reference frame

- Incoming quark direction not known at LHC
  - usually a valence quark annihilates with a sea anti-quark
  - in average the valence quark has more momentum than sea anti-quark
    - boosted system, quark same direction as Z/γ^*
- Collins-Soper frame reduces uncertainty of transverse momentum of quarks



- Polar axis is defined as the bisector of the two proton beams
- θ^* angle between polar axis and lepton

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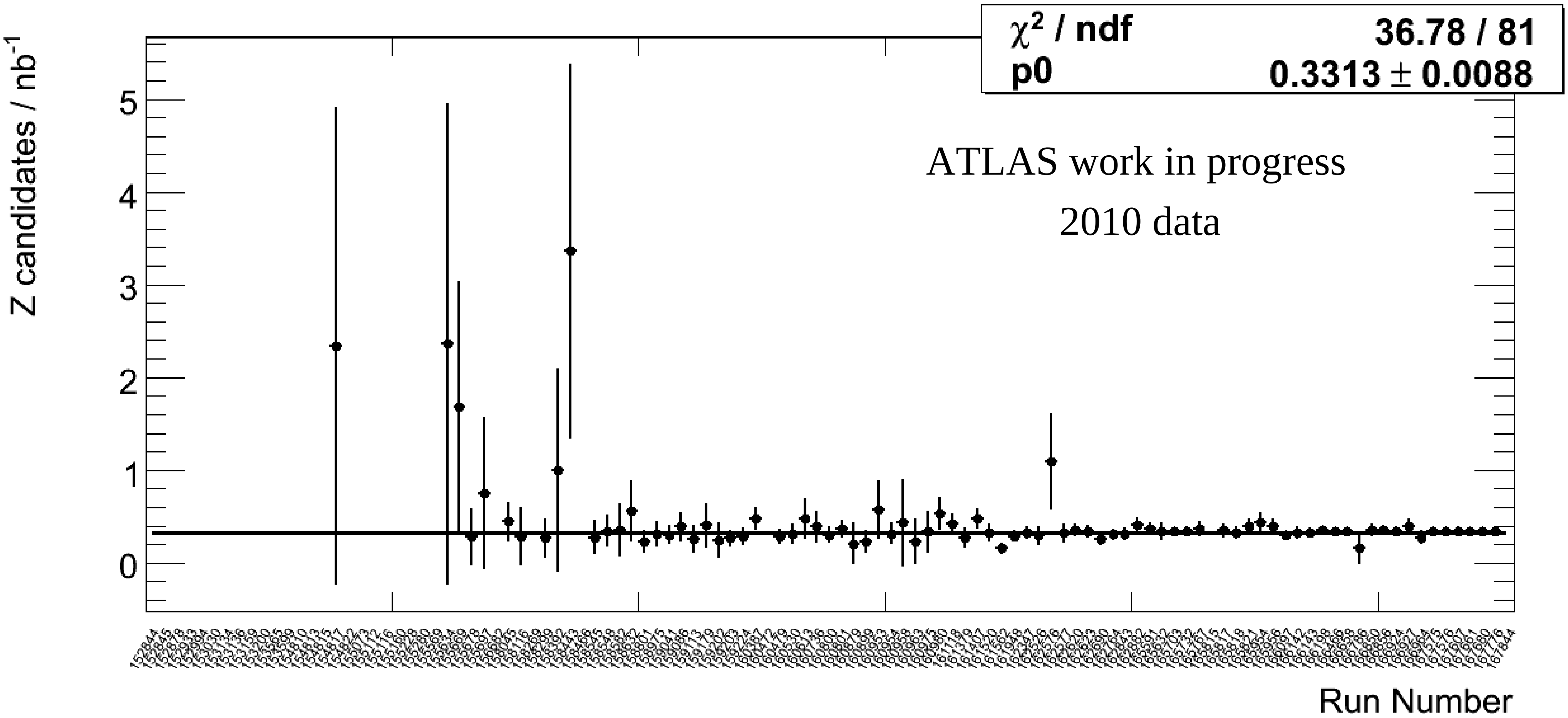
Stability studies of Z → μμ candidates

- Yield per nb^{-1}



More on mass correction and dilution

- Study effect of limited MC statistics (~ 2M reconstructed Z $\rightarrow \mu\mu$) on response matrices
- ToyMC:
  - Fluctuate matrix bins within statistical errors
  - For each matrix, calculate corrected mass[cos(θ*)] distributions, calculate asymmetry value
  - Next slide show the distribution of the asymmetry values in the various mass bins
    - Black line is value obtained with “nominal” (=non fluctuated) matrix
    - Dashed blue line: gaussian fit $\rightarrow$ mean and σ
    - As expected, bins where correction is larger have larger dependence on statistical precision of matrix (see also previous slides)

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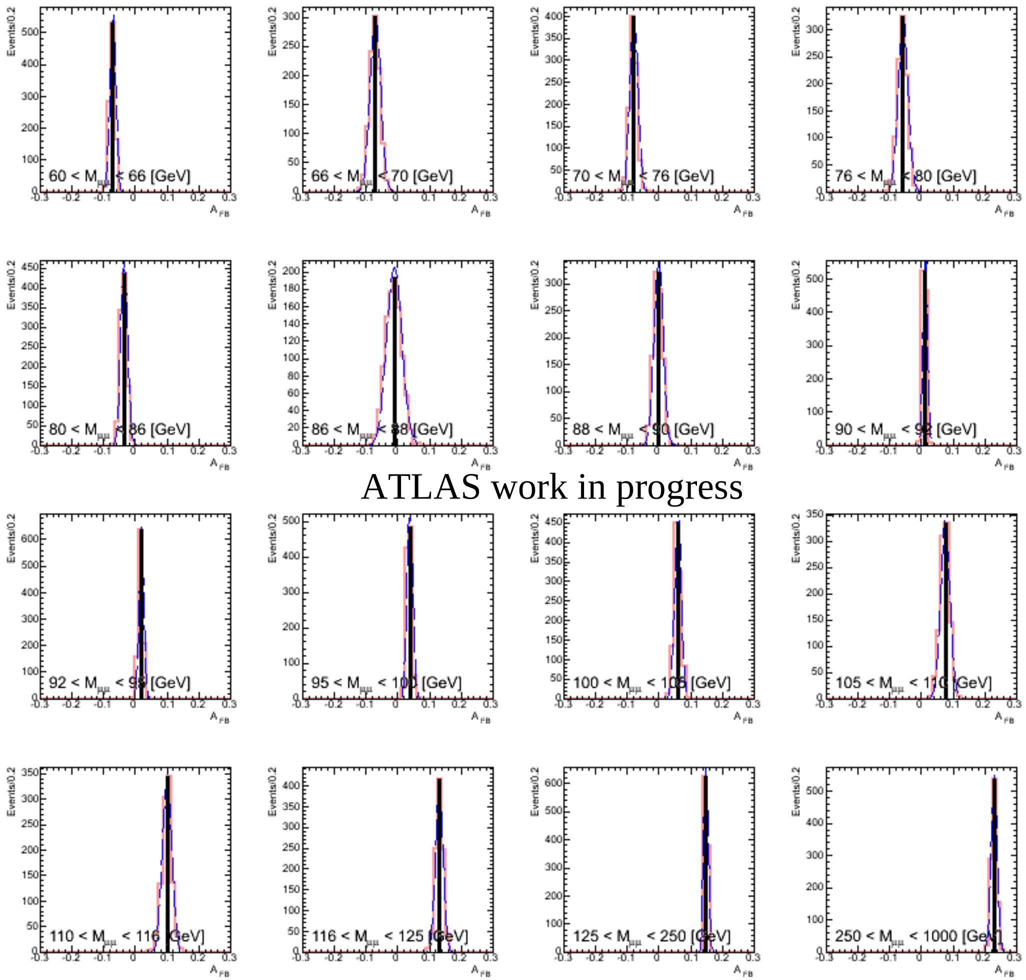
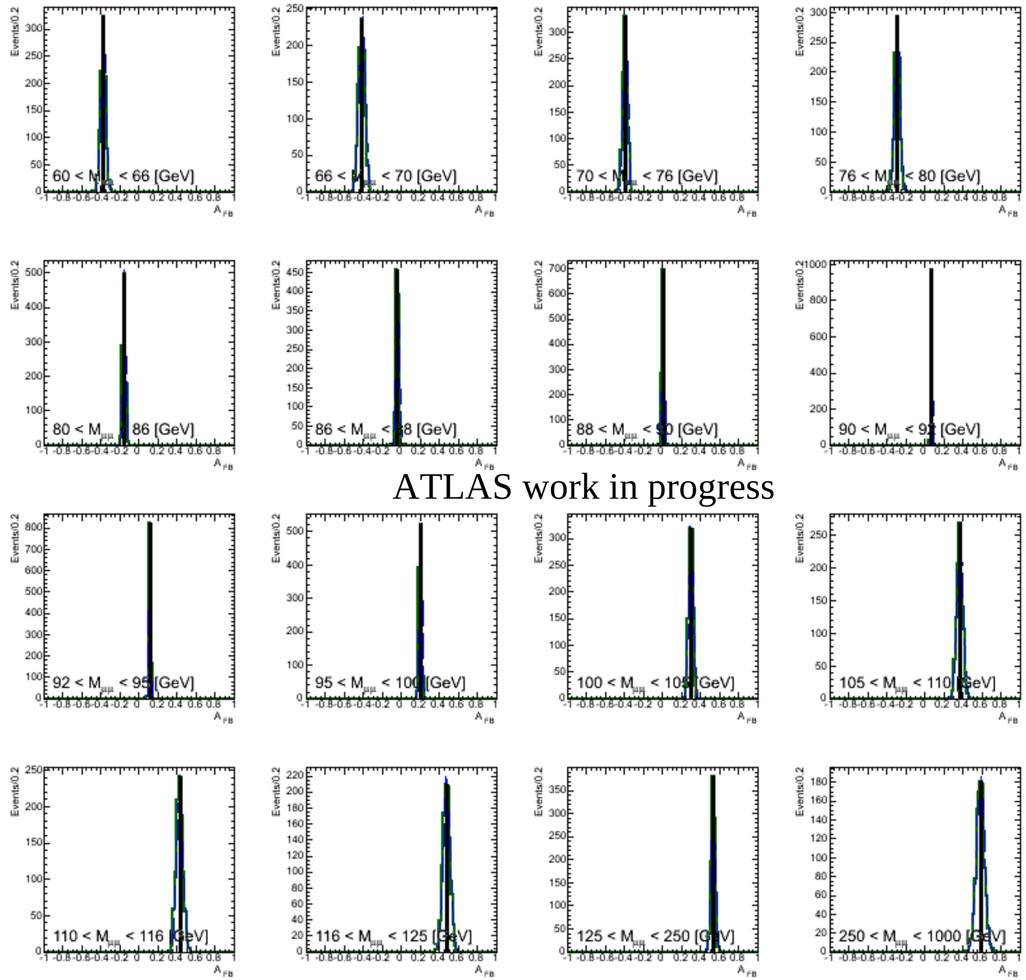
A_{FB} vs mass bin

Mass bin migration



Dilution



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