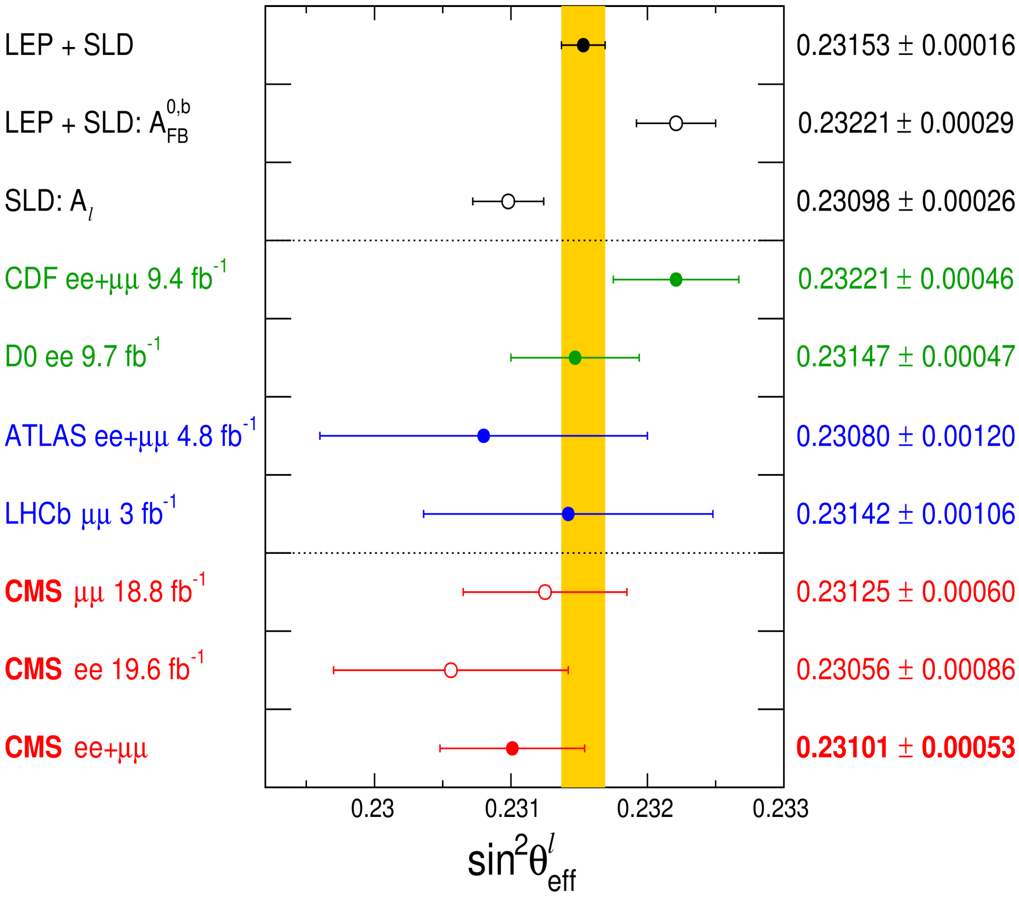
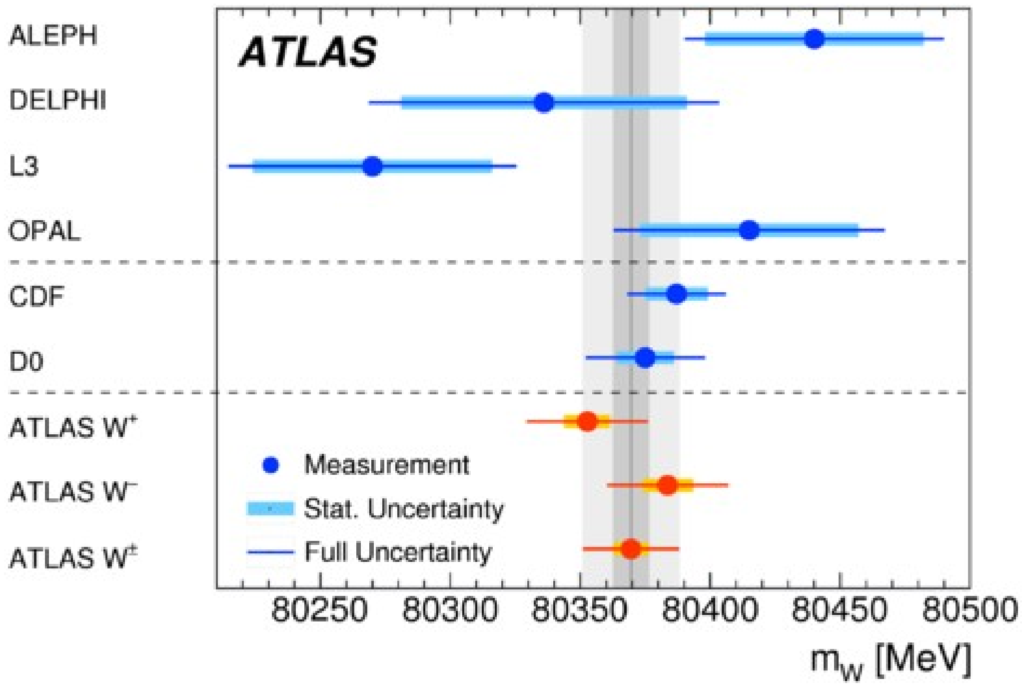
Towards Tevatron / LHC combinations

for m_W and $\sin^2\theta_{eff}$

A concrete issue





$\sin^2\theta_{eff}$: a variety of approaches

- Published
  - Fits to the detector-level forward-backard asymmetry
    - D0 electron channel arXiv:1408.5016
    - CDF muon channel arXiv:1402.2239
      electron channel arXiv:1605.02719
    - Tevatron combination arXiv:1801.06283
    - CMS ee, $\mu\mu$ CERN-EP-2018-126

- In preparation
  - Fits to unfolded cross sections
    - ATLAS “Z3D” : $d^3\sigma$ / dM dy dcosθ^* arXiv:1710.05167
  - Measurement of angular coefficients; A4 → $\sin^2\theta_{eff}$
    - ATLAS “A_i” arXiv:1606.00689

How to perform a consistent interpretation?

Status of discussions for $\sin^2\theta_{eff}$

- Focus on LHC experiments
- medium-term : global fit to A4/AFB values measured by ATLAS, CMS, and LHCb.
- longer term : combine many differential cross sections in a global QCD fit. Requires NNLO QCD over a wide range of bins in m_ll, y_ll and pT_ll, together with the EW corrections.
- Lepton fiducial requirements for ATLAS and CMS, and LHCb:
  - Lepton fiducial cuts
    - ATLAS and CMS: pT > 25 GeV and |eta| < 2.4.
    - LHCb: pT > 25 GeV and 2.0 < eta < 4.5
  - Binning
    - 12 bins of equal size for the dilepton mass between 60 and 120 GeV, and 9 rapidity bins of equal size for abs(y_ll) < 3.6.
    - the mass region near the pole mass is the most important one, so one could also consider single bins between 70 and 110 GeV or 80 and 100 GeV.
  - Remarks
    - This will also allow to use common benchmark predictions from the theory community.
    - Allows compatibility tests between between ATLAS and CMS at the experimental level; overlap insufficient between ATLAS/CMS and LHCb

Status of discussions for $\sin^2\theta_{eff}$

- First step : demonstrate the compatibility of unfolded measurements of the A4/AFB values in bins of rapidity and mass
  - A4 has to be defined based on Born leptons.
  - AFB values can be defined based on Born or dressed leptons (theoretical uncertainties in the extrapolations between Born and dressed leptons are very small)
  - Born lepton definition is the only one permitting direct comparisons between A4 measurements and AFB measurements extrapolated back to the full phase space of the decay leptons.
  - Given that unfolded AFB values are available from ATLAS and LHCb, it seems preferable to produce unfolded values from the most recent CMS measurement.

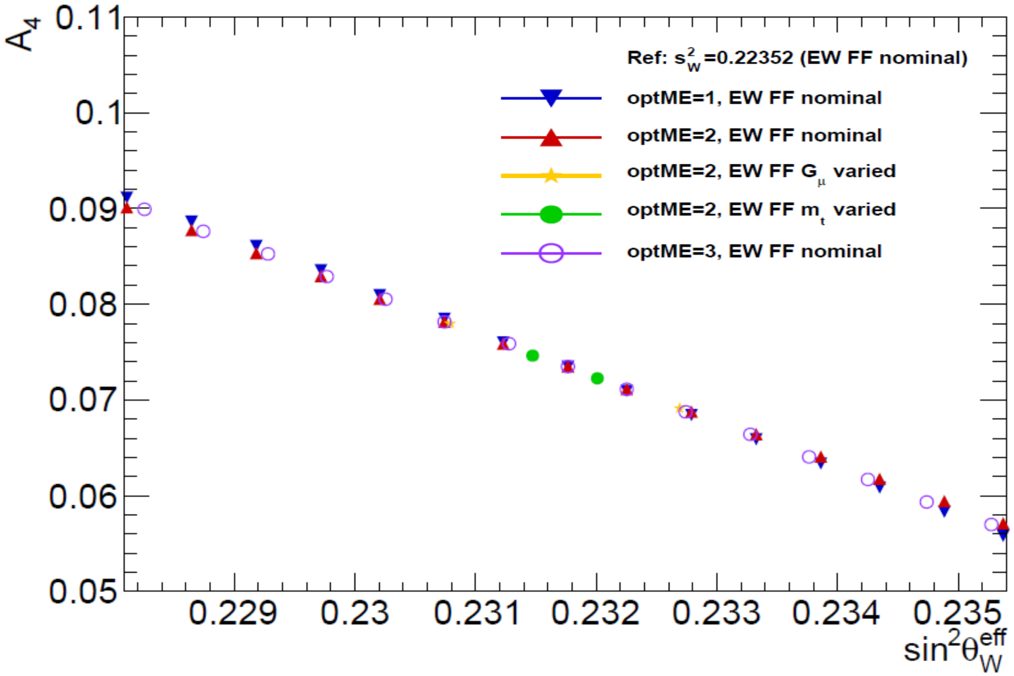
- Second step : interpret the unfolded measurement results in a global fit to $\sin^2\theta_{eff}$, with two alternatives
  - Single-parameter fit + PDF nuisance parameters
  - Simultaneous fit to PDFs + $\sin^2\theta_{eff}$

Interpretation framework for 1st iteration

- Baseline predictions : Z production at (N)NLO QCD + PS + QED FSR; weak corrections implemented using LEP-style form factors
  - Used in the past by Tevatron and CMS, and in forthcoming measurement by ATLAS

$$\sin^2\theta^{\rm f}_{\rm eff} \equiv \kappa_{\rm f}\sin^2\theta_{\rm W}$$
$$g_{\rm Vf} \equiv \sqrt{\rho_{\rm f}}\,(T_3^{\rm f} - 2Q_{\rm f}\sin^2\theta^{\rm f}_{\rm eff})$$
$$g_{\rm Af} \equiv \sqrt{\rho_{\rm f}}\,T_3^{\rm f}\,,$$

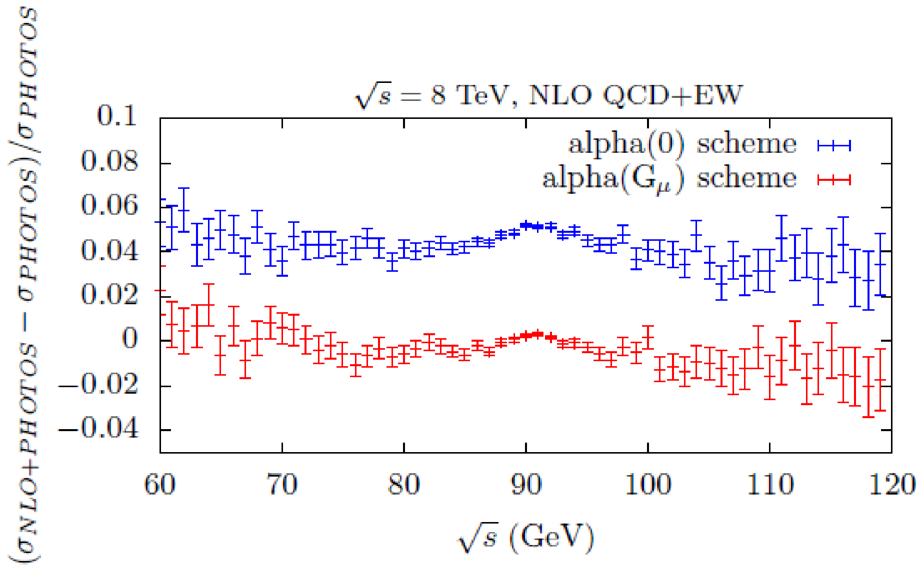
(κ, ρ are functions of s, t and flavour)



  - Allows incorporating EW effects in commonly-used MC generators
  - Used in the Tevatron/CMS publications and ongoing projects
  - not a full NLO EW calculation: lacks subleading ISR/IFI corrections present at O(α). Impact on $\sin^2\theta_W$ to be evaluated

(near) future developments

- NLO QCD + EW parton shower generators (Powheg EW, Sherpa, KKMC-hh…)
  - NLO QCD ⊕ NLO EW fixed order ($O(\alpha_S) \oplus O(\alpha)$ matrix elements)
  - NLOPS QCD ⊗ EW accuracy through matching with QCD/QED shower



(corrections to the μμ invariant mass distribution in Z → μμ events)

  - Scan in $\sin^2\theta_{eff}$ via variations of "free" input parameters (m_W, or G_μ, or m_{top}, or m_H, depending on the scheme) : Standard Model "closure" test
  - Possibly add dedicated form factors for a more model-independent measurement
  - Codes in final validation, and need to be adopted by the experiments

$\sin^2\theta_{eff}$: open questions

- Important issues to address

  - Benchmark EW corrections used for measurement and interpretation, e.g.
    - Comparison of available NLO QCD+EW predictions; focus on radiative effects and “pure weak” corrections (starting from arXiv:1606.02330)
    - effect of missing QED corrections (ISR, IFI) in form factor approach
    - Any bias from using Born leptons in interpretation?

  - PDF uncertainties : account for spread of fitted $\sin^2\theta_W$ values for different PDF sets?
    - Needs PDFs with a clean separation of data and theory uncertainties

      → request to PDF4LHC

  - Impact of missing higher-order QCD corrections (pT distribution, spin correlations)

Status for m_W

- Current most precise measurements:
  - CDF (2.2 fb-1) : 80387 ± 19 MeV
  - D0 (5.3 fb^{-1}) : 80376 ± 23 MeV
  - ATLAS (4.6 fb^{-1}): 80370 ± 19 MeV,
- Several statements on the combined uncertainty appearing in recent literature
  - PDG / Jens Erler : δm_W = 12 MeV "assuming 7 MeV of common uncertainty"
    - Moriond talk : https://indico.in2p3.fr/event/13763/contributions/15199
  - Gfitter : δm_W = 13 MeV, most frequent value obtained scanning over PDF correlations
    - http://inspirehep.net/record/1658767
  - HEPFit : δm_W = 12 MeV (http://inspirehep.net/record/1630895)
- All this is plausible, and on our side we find uncertainties ranging between 11 and 13 MeV for uncorrelated or fully correlated PDF uncertainties.

- We can not fully exclude anti-correlated uncertainties, though (cf. LHCb study)

PDF correlations : study by LHCb

Bozzi et al., EPJ. C75 12 601 2015

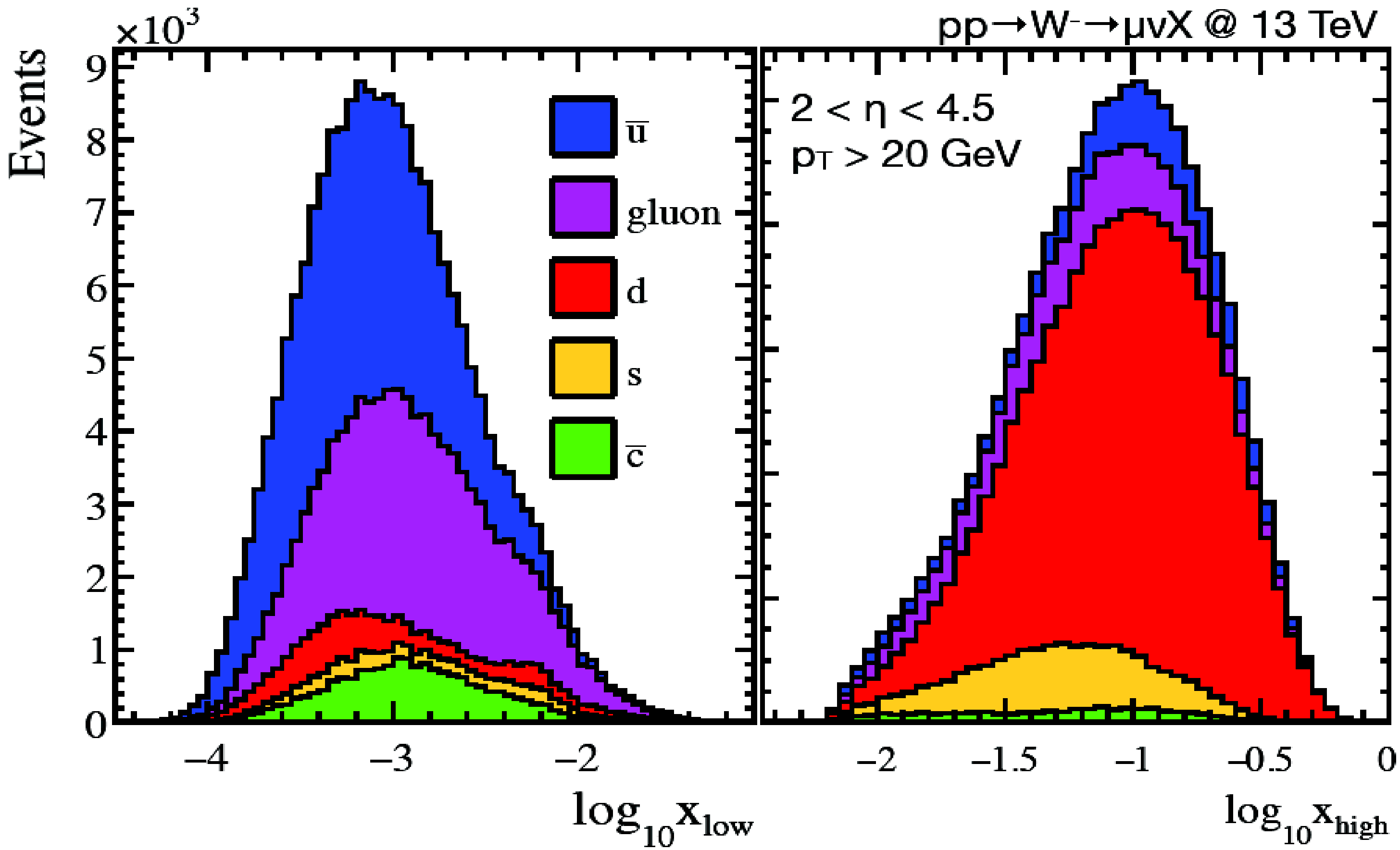
$$\delta_{\mathrm{PDF}} = \begin{pmatrix} \mathbf{G}^+ & 24.8 \\ \mathbf{G}^- & 13.2 \\ \mathbf{L}^+ & 27.0 \\ \mathbf{L}^- & 49.3 \end{pmatrix} \rho = \begin{pmatrix} & \mathbf{G}^+ & \mathbf{G}^- & \mathbf{L}^+ & \mathbf{L}^- \\ \mathbf{G}^+ & 1 & & & \\ \mathbf{G}^- & -0.22 & 1 & & \\ \mathbf{L}^+ & -0.63 & 0.11 & 1 & \\ \mathbf{L}^- & -0.02 & -0.30 & 0.21 & 1 \end{pmatrix}$$

Numbers correspond to $25 < p_T < 50$ GeV fit range, NNPDF2.3. Also assumed that the GPDs can perfectly reject events with W $p_T > 15$ GeV.

Negative correlation coefficients, between LHCb and GPD, are clearly beneficial in a LHC average. However, the standalone LHCb uncertainties are relatively large. Let's try to gain a deeper understanding of this…

PDF correlations : study by LHCb

Subprocess breakdown



Status for m_W : combining Tevatron and ATLAS results

- Common sources of uncertainty
  - PDFs
  - EWK / QED corrections
  - W width
- Uncertainties counted in the ATLAS measurement, and not explicitly covered by the Tevatron :
  - Z → W extrapolation uncertainty in the pT distribution
  - Spin correlations
- Correlation of PDF uncertainties?
  - ATLAS : used CT10 for central value + uncertainties; CT14, MMHT for checks
  - D0, CDF : CTEQ6.6 for central value + uncertainties; CTEQ6.1, MSTW2008 for checks
  - Can we evaluate correlation between existing measurements? Do they need to be repeated with common sets?
    - In all cases, needs mW shifts under PDF eigenset / replica variations

Possible approaches

- Key difference with $\sin^2\theta_W$: m_W has never been measured from unfolded distributions.
  - Very difficult for m_T; might be envisaged for p_T^l

- Global fits very difficult exercise (can only combine measurements after the fact).

  Not ideal!

Possible approaches

- Experiments re-run their measurements with a wider range of PDFs
  - Stick to PDFs used in the publications; find a way to estimate correlations starting from different PDF sets?
    - Profile PDF A into PDF B?
  - Stick to published central values, but evaluate uncertainty correlations for a (set of) common PDF sets?
    - Allows studying the model dependence of the correlations
    - How to remain consistent with the published individual uncertainties?
  - Update central values according to a common PDF set?
    - At the discussion in Orsay, A.Kotwal (CDF) and J.Stark (D0) agreed to rerun the existing measurements with a selection of updated PDF sets, and provide the corresponding shifts in mW.

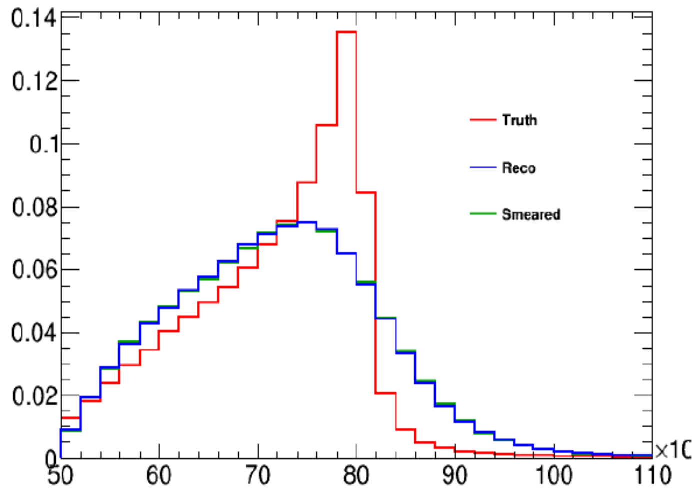
      CT10nnlo grids requested from ResBos authors; in progress
    - Complications : this will impact the complete measurement procedure (Z p_T tuning, control plots, ...)

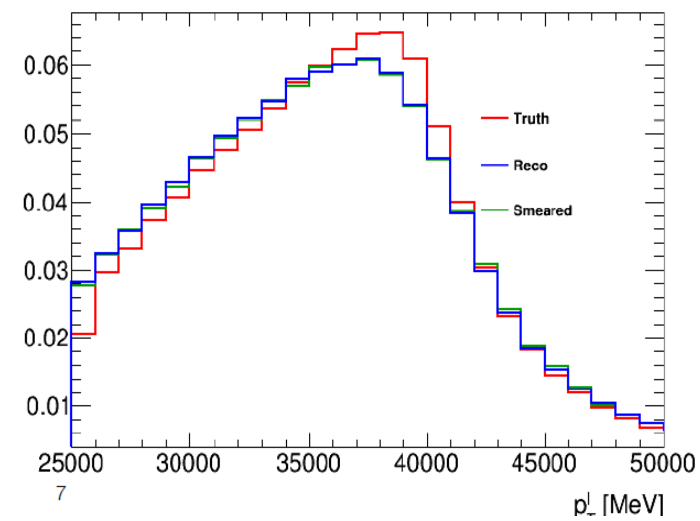
Most rigourous from the PDF uncertainty point of view; still different codes for the predictions (ResBos vs Powheg+Pythia+DYNNLO+DYRES+reweighting)

→ observed differences a combination of PDF and QCD effects

Possible approaches

- Emulate existing measurements using generator-level predictions + smearing
  - Needs simple parametrizations for the lepton and recoil resolutions, for the individual experiments.
    - ATLAS smearing shown below (μ=2). Use publications for Tevatron. CMS? LHCb?





  - Flexible : can be used for a variety of problems/questions
    - Tevatron / LHC, “GPD” / LHCb, energy dependence at the LHC...
  - Of course not adequate for a complete measurement, but enough to evaluate realistic PDF uncertainties

Use a single QCD/EW tool, cleanly isolating the effect of PDF uncertainties.

Next steps for m_W

- Agree on conventions :
  - Agree on a set of representative PDF sets
  - maintain or update published central values? PDF-dependent measurement result? evaluate the correlation of PDF uncertainties from above sets

- Pursue both approaches as much as possible :
  - Request CDF, D0, ATLAS to rerun the published measurements.
  - Smearing approach:
    - Collect simple parametrizations from the interested experiments. Could produce a standalone public tool applying these corrections
    - Can use consistent tools throughout. Common HepMC files with W+ & W- distributions at various roots, pp / ppbar etc.

- Provide shifts in mW for each set, with respect to a conventional baseline PDF; combine

- Timescale?

Timescales?

- Work essentially starting on most sides,
- Aim for at least preliminary results by December.