Z Boson Production and Properties at LHC

Matthias Schott*
on behalf of the
ATLAS Collaborations

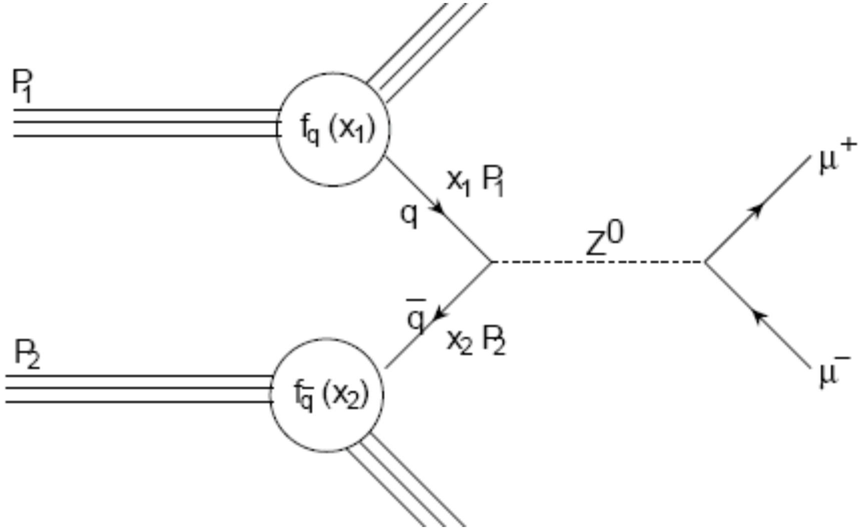
*Matthias.Schott@cern.ch
ATLAS Experiment
LMU Munich, Germany

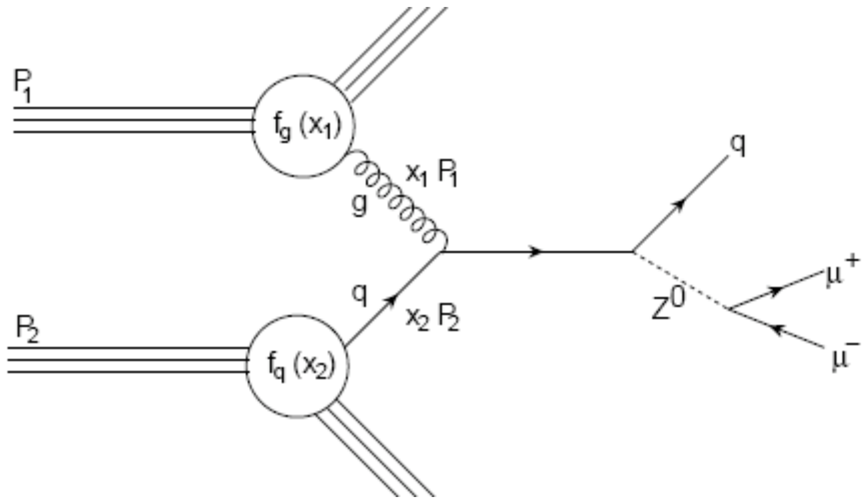
Z Boson Production at the LHC

- Large Hadron Collider
  - Proton Proton Collisions
  - $\sqrt{s} = 14$ TeV
  - Low Luminosity Phase:
    $L = 10^{33}\ cm^{-2}s^{-1}$
- Z boson production via Drell-Yan process
- Theoretical cross-section calculation available for NNLO

$$\sigma(pp \rightarrow Z/\gamma^{*} \rightarrow \mu\mu) = 1.972 \pm 0.019 nb$$

- Initial Phase of LHC:
  $\int Ldt = 100 pb^{-1}$ (≈ 100.000 $Z \rightarrow \mu\mu$)
- 200.000 $Z \rightarrow \mu\mu$ events are expected per day during low luminosity





Z Boson Production at the LHC

Physics Measurements

- Cross-Sections
- PDF Constraints
- Forward Backward Asymmetries
- Sensitivity to exotic physics processes

Detector Calibration

- Detector Efficiencies
  - Reconstruction
  - Trigger
- Resolution
- Alignment

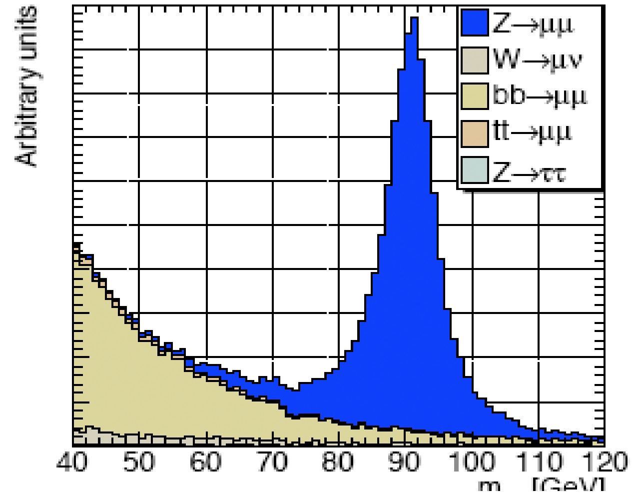
- In this talk:
  - Cross Section Measurement in the muon decay channel for the initial phase

$$\sigma(pp \to Z/\gamma^* + X \to \mu\mu) = \frac{\mathrm{N}_{\mathrm{Candidates}}(1 - \mathrm{f}_{\mathrm{Background}})}{\varepsilon_{\mathrm{total}} \int L dt}$$

  - Differential Cross-Section Measurement

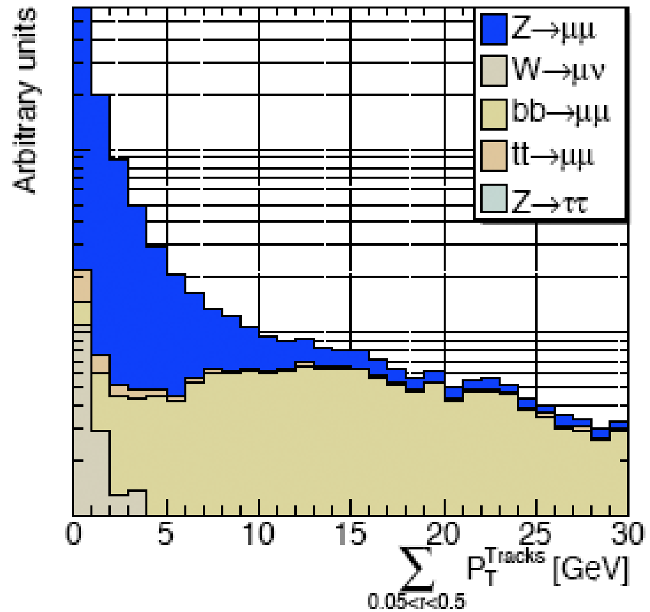
Signal Selection

- Background Processes
  - QCD Processes $b\bar{b} \rightarrow \mu\mu + X$
  - $W + jets \rightarrow \mu\upsilon + jets$
  - $Z \rightarrow \tau\tau \rightarrow \mu\upsilon + \mu\upsilon$
  - $t\bar{t} \rightarrow Wb + Wb \rightarrow \mu\upsilon + jet + \mu\upsilon + jet$
  - Background Uncertainty < 0.002



ATLAS Selection for first data

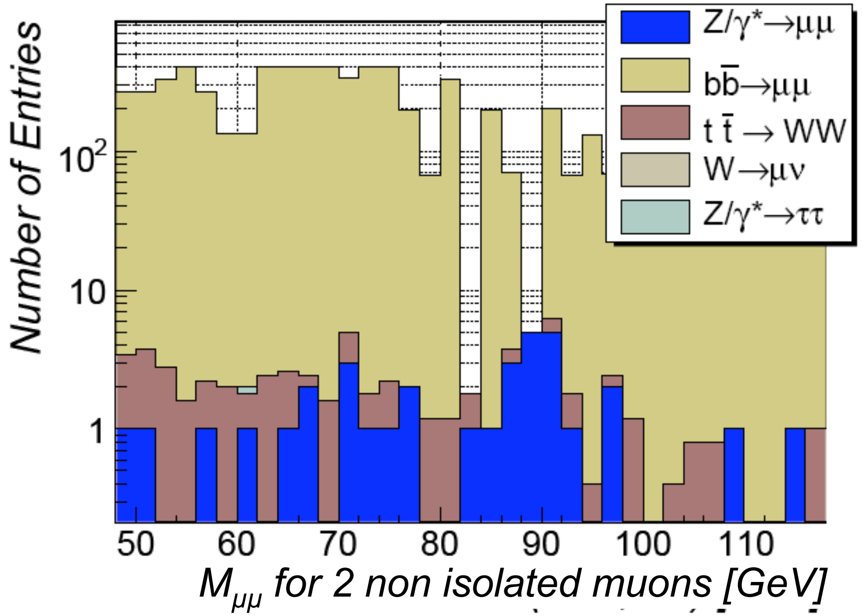
- Two reconstructed muon tracks
- Opposite Charge
- $|91.2\ \text{GeV} - M_{\mu\mu}| < 20\ \text{GeV}$
- $p_T^1 > 20$ GeV, $p_T^2 > 20$ GeV
- Muon isolation requirements
- $|\eta| < 2.5$



Background Estimation from Data

- Estimation of W background
  - Assumption

    $P_{3\mu}(Z\to\mu\mu) \approx P_{2\mu}(W\to\mu\nu)$
  - $P_{3\mu}(Z\to\mu\mu)$: Probability for 3 candidate muons passing the selection cuts in $Z\to\mu\mu$.
- Estimation of QCD background
  - Select sub-sample in data which is dominated by QCD-events, e.g. 2 non-isolated muons
  - Use this sub-sample to estimate the QCD background with full selection cuts
- Other background processes are well understood and can be estimated with Monte Carlo.

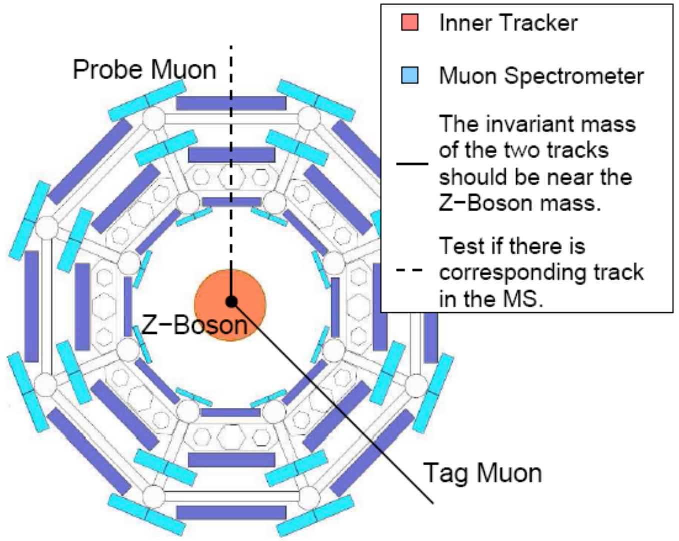


Background contribution (ATLAS)

- $f_{bb} \approx 0.002 \pm 0.002$ (sys)
- $f_{W} \approx 0.002 \pm 0.001$ (sys)
- $f_{tt} \approx 0.0043 \pm 0.001$ (sys)

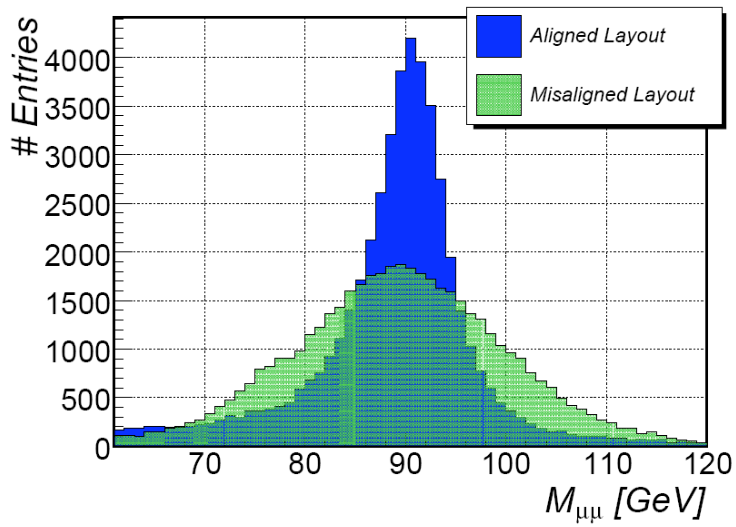
In Situ Determination of Detector Response

- Efficiency determination in data
  - 'Tag and Probe' method
  - Limitations: 'tag' and 'probe' correlations, background processes, Φ-symmetric inefficiencies
- Determination of detector resolutions
  - Folding the Monte Carlo predicted resolution by a smearing function to reproduce the measured Z boson resonance curve



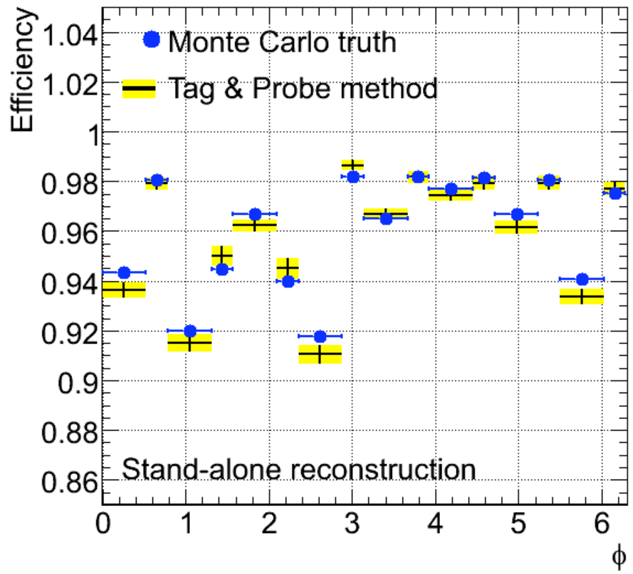
Expected precision

- $\Delta\varepsilon_{Tracking} \approx 0.2\text{-}0.5\%$
- $\Delta\varepsilon_{Trigger} \approx 0.2\%$
- momentum scale to few per mille
- …



Systematic Uncertainties

- Systematics due contribution of tag & probe
  - Dominating contribution
- Systematics due to determination of detector resolutions
- Further Experimental Systematic Uncertainties
  - Misalignment, magnetic field knowledge, collision point uncertainty, pile-up effects, underlying events
  - **An overall systematic uncertainty of less than 0.35%**
- Theoretical Systematic Uncertainties
  - PDF choice: **≈ 0.9%**
  - Initial state radiation: **≈ 0.2%**



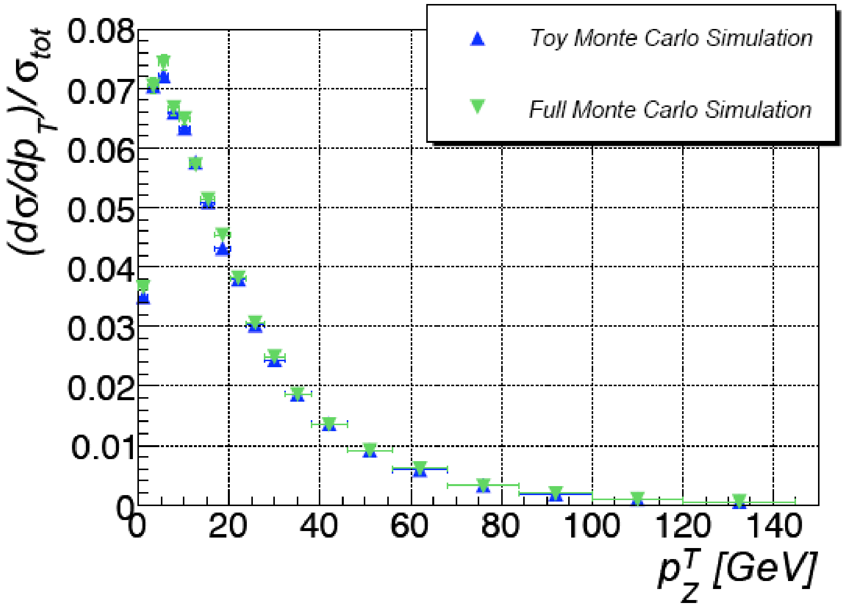
Expected Precision $\int Ldt = 100 pb^{-1}$

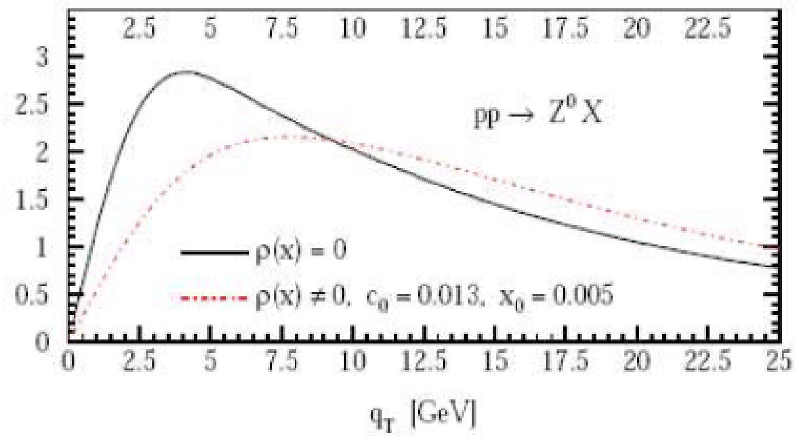
$$\frac{\Delta\sigma}{\sigma}(pp \to Z/\gamma^* + X \to \mu\mu) = 0.004\ (\text{stat}) \pm 0.01\ (\text{ex.sys}) \pm 0.01(\text{th.sys}) \pm 0.1(\text{lumi})$$

Differential Cross Section

- The PDF acceptance uncertainties on the total cross section measurement are an artefact of measuring the cross-section inclusively

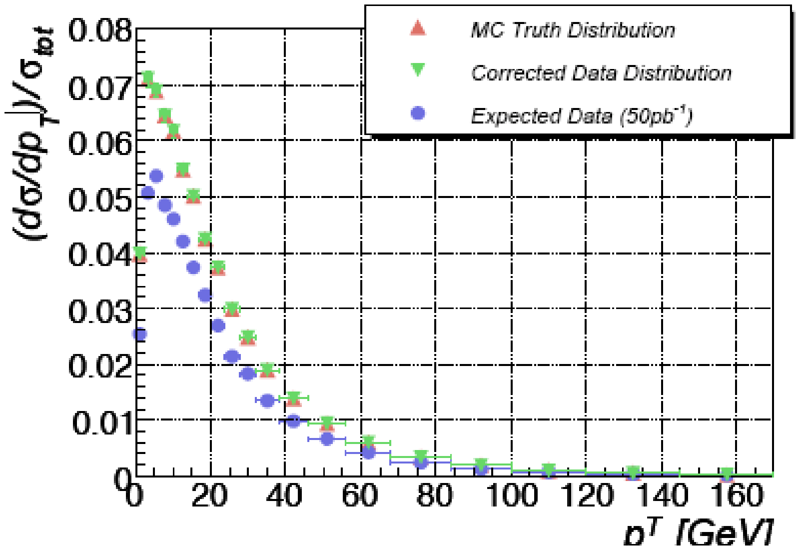
- Study also the differential cross section with ∫ Ldt=100pb^{-1}
  - Possibility to study dynamics of QCD and PDFs
  - E.g.: A possible first observation of x-broadening effect in hadron collisions.
    - Some theories (Phys.Rev. D72:033015) predict a broadening of the transverse momentum spectra of the Z boson at small x (inspired by HERA data)

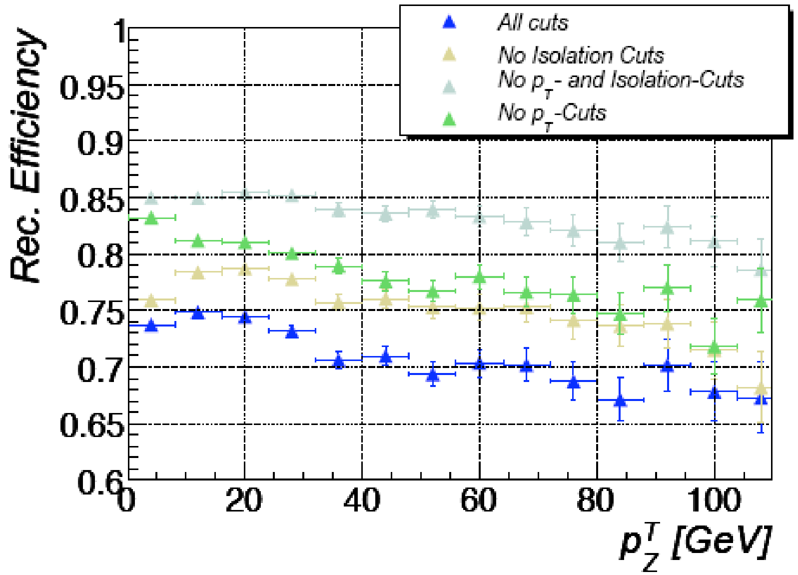




Iterative bin-by-bin correction

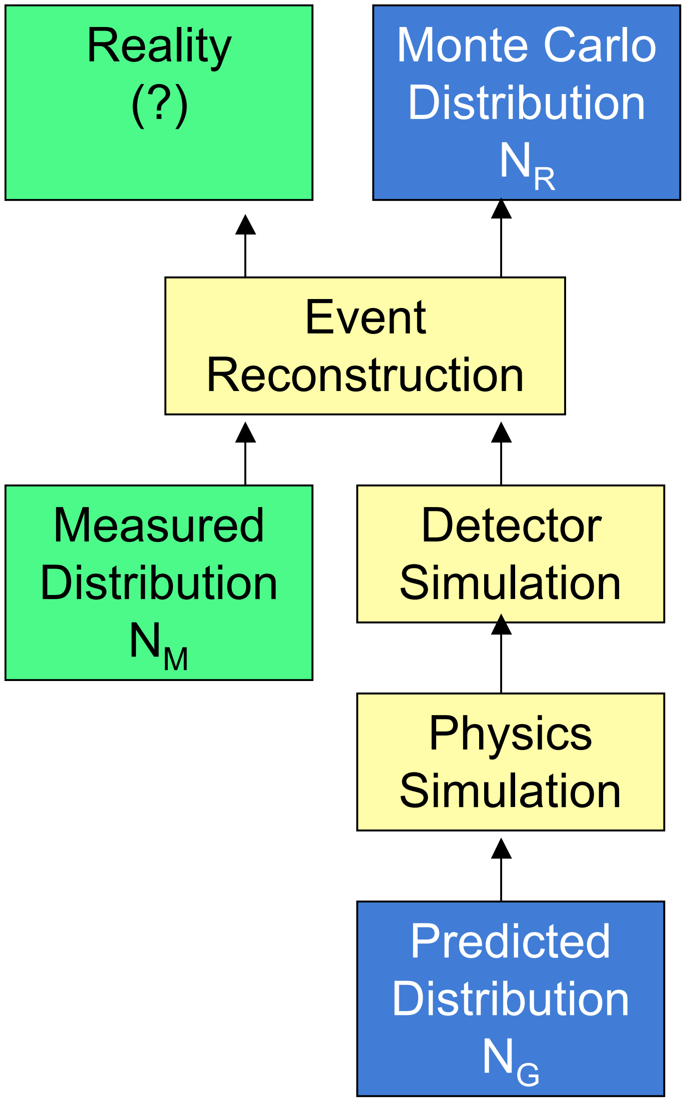
- What do we have so far:
  - Reconstructed momentum distribution of Z bosons (determined by the momenta of the two reconstructed muons)
  - **But:** The real distribution **differs significantly** from the measured distribution due to
    - **detector efficiencies:** not all muons are reconstructed
    - **detector resolution:** The measured momentum is not the true momentum
    - **signal selection**





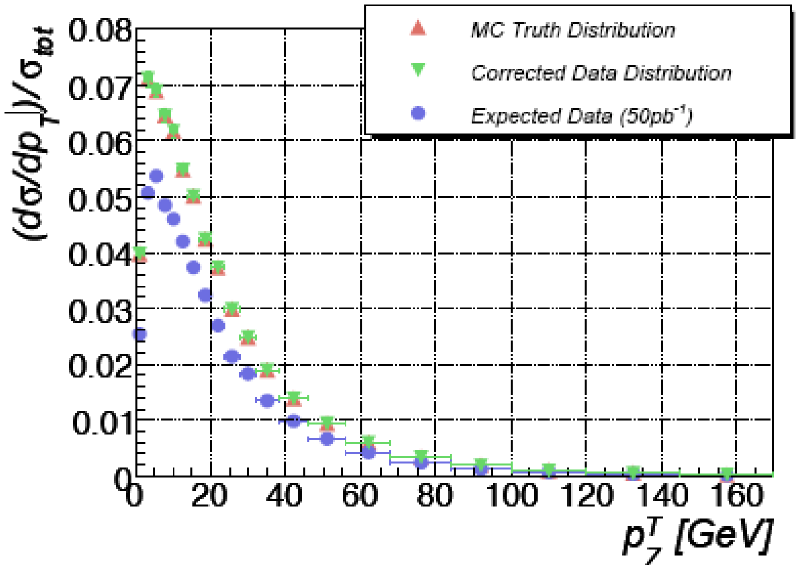
Iterative bin-by-bin correction

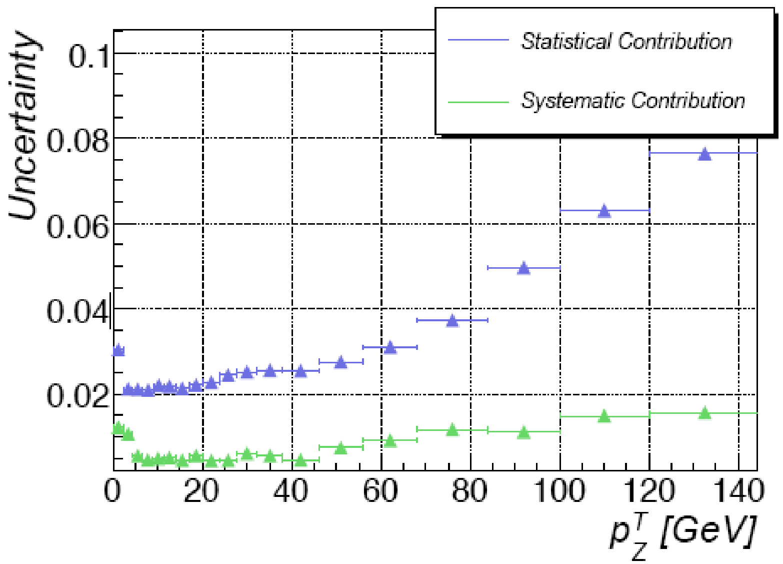
- **We assume for now:** We know our detector perfectly
- Determine the efficiency for each p_T-bin of the Z boson to correct the measured distribution, e.g. for 5GeV < p_T < 10GeV
  - N_G : Number of true Z bosons generated by Monte Carlo in this region
  - N_R : Number of reconstructed Z bosons in this region (again in Monte Carlo)
  - N_M : Number of measured Z bosons in this region (this time in data)
  - ➔ $N_M \times (N_G/N_R)$ is the number we want to know
- **Problem**: Even if we know all detector effects, we do not know the underlying real p_T distribution



Iterative bin-by-bin correction

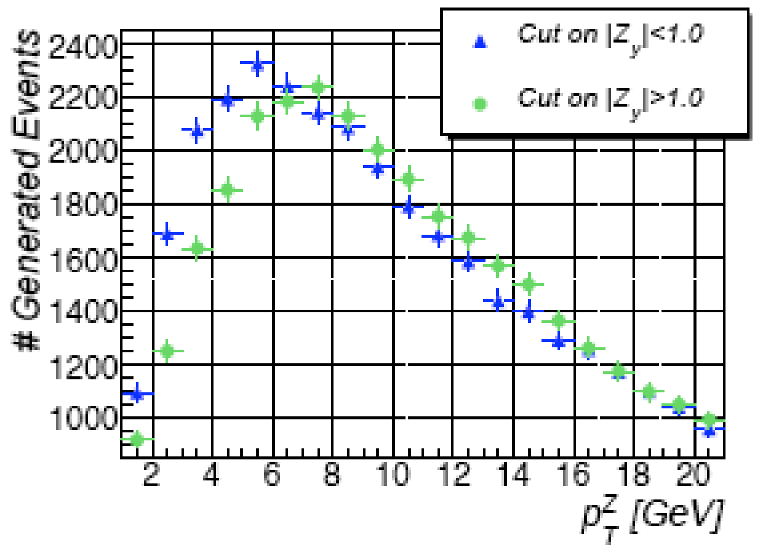
- If the predicted Monte Carlo distribution differs from measured distribution then this is due to a wrong assumption in the physics model (i.e. the assumed p_T distribution of the Z Boson)
  - **Assumption:** We know our detector perfectly ➔ the detector physics is simulated correctly
- **Idea:** Vary the assumed distribution until the measured and the Monte Carlo predicted distribution coincide
  - Done by an iterative procedure called bin-by-bin correction
- **➔ Now we have the determined the truth Z boson p_T distribution from data!**
- Statistical uncertainties are expected to dominate during initial phase

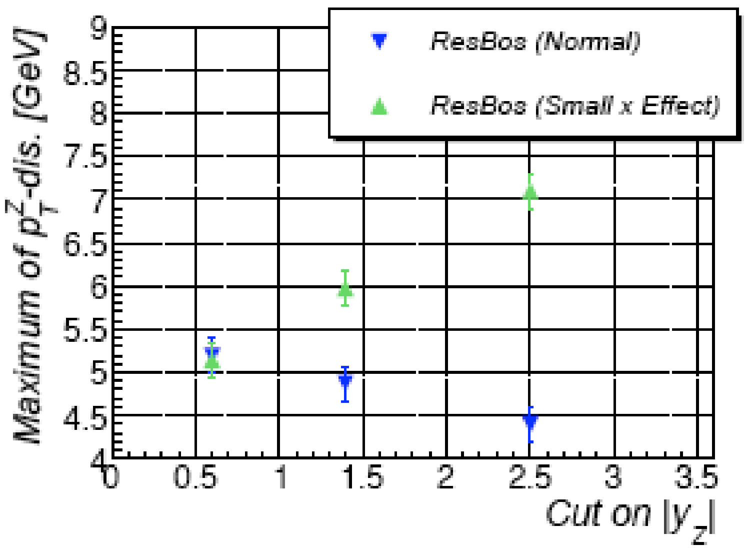




Measurement of the X-Broadening effect

- **Naive approach:** Just compare the predicted distribution of different models with the measurement
  - Problem: Many unknown unknowns, e.g. detector effects which have been forgotten
- **Developed approach** (little bit less naive)
  - The model introduces an x-dependence on the p_T distribution
  - The rapitity of the Z boson depends also on x
  - The rapitity can be determined by the angles of the reconstructed Z bosons
  - ➔ Measure the maximum-position of the Z Boson distribution for various rapidity ranges





Conclusion and Outlook

- The Z boson will be produced with extremely **high statistics**
  - Excellent (online) calibration channel for the muon systems and the electromagnetic calorimeters
  - The p_T and rapidity distribution of the Z boson will open new possibilities to constrain the PDF functions
  - Measurement of the forward backward asymmetry possible

- **Initial Phase of LHC**
  - Cross section measurement is expected to be already dominated by theoretical uncertainties
  - Independent CMS and ATLAS studies give similar expected precision
  - Possible cross-check of measured integrated luminosity
  - We might even have first constraints on PDF effects