Z Boson Production and Properties at LHC

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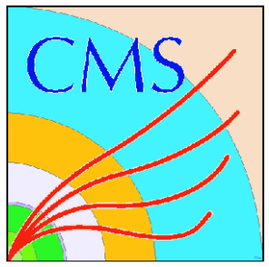
on behalf of the

ATLAS and CMS Collaborations



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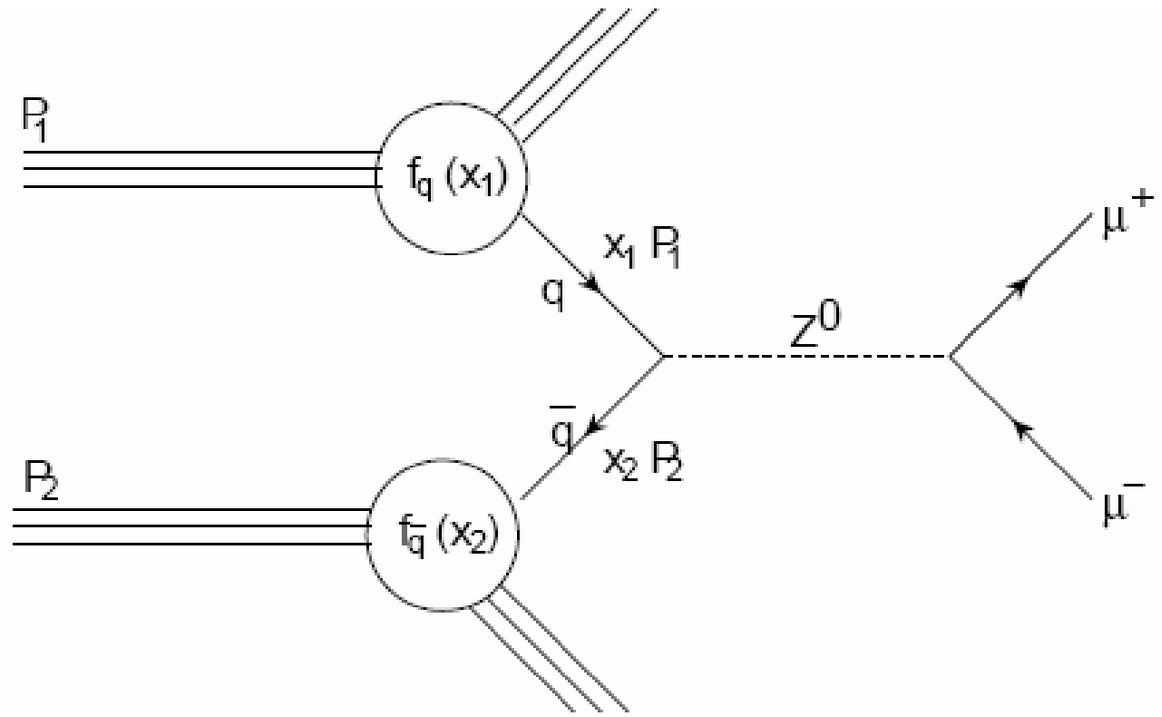
Z Boson Production at the LHC

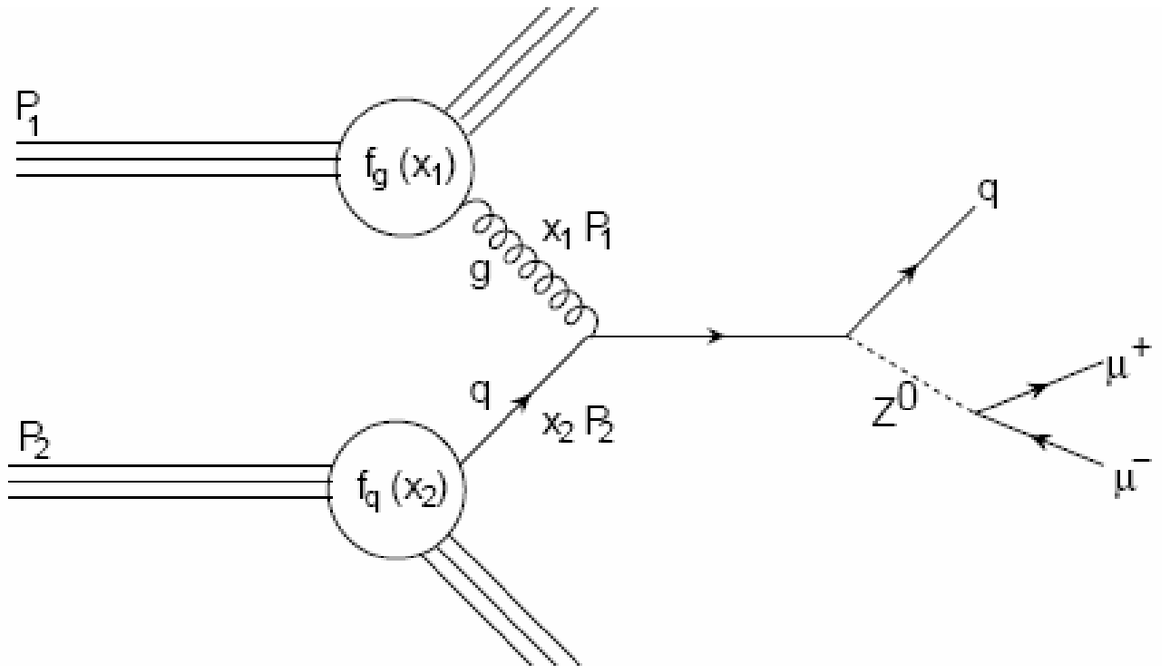
- Large Hadron Collider
  - Proton Proton Collisions
  - $\sqrt{s}$ = 14 TeV
  - Low Luminosity Phase:
    $L = 10^{33}\ cm^{-2}s^{-1}$
- Z boson production via Drell-Yan process



- Theoretical cross-section calculation available for NNLO

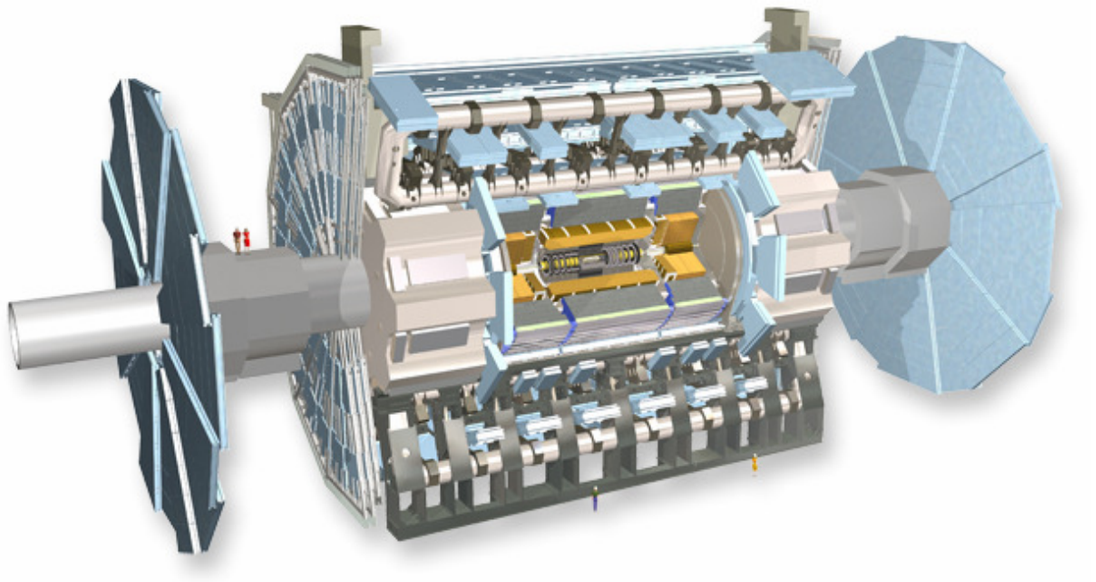
$$\sigma(pp \to Z/\gamma^* \to \mu\mu) = 1.972 \pm 0.019 nb$$

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

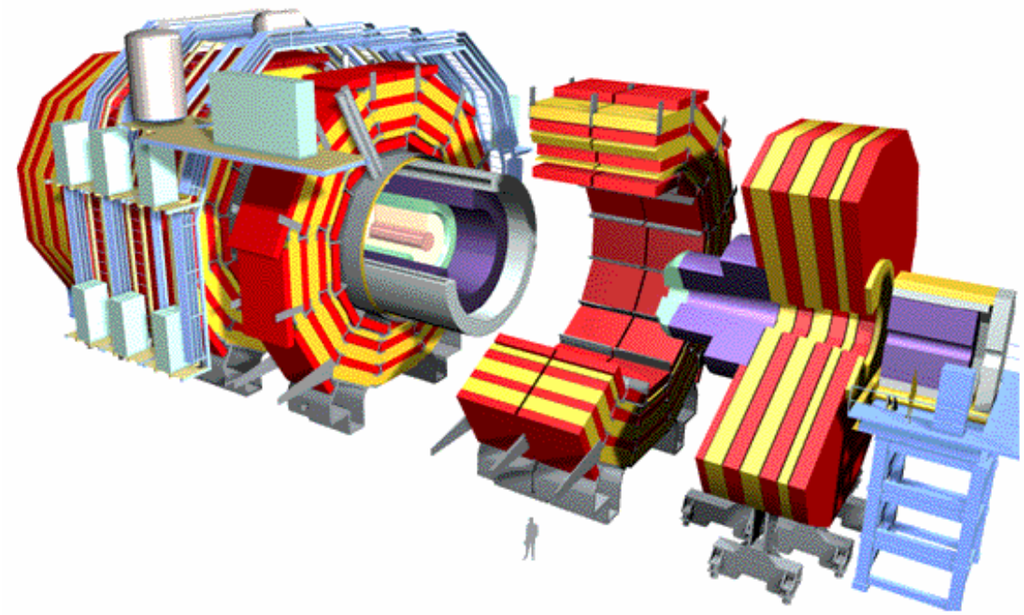


ATLAS and CMS Detector

- ATLAS Detector



- CMS Detector



	ATLAS Detector	CMS Detector
Tracker	*|η|<2.5 coverage* $\sigma / p_T \approx 5 \cdot 10^{-5} p_T \oplus 0.01\,[\mathrm{GeV}]$	*|η|<2.6 coverage* $\sigma / p_T \approx 1.5 \cdot 10^{-5} p_T \oplus 0.005$
EM Calorimeter	*|η|<4.9 coverage* $\sigma / E \approx 10\% / \sqrt{E}\,[\mathrm{GeV}]$	*|η|<4.9 coverage* $\sigma / E \approx 2-5\% / \sqrt{E}$
HAD Calorimeter	*|η|<4.9 coverage* $\sigma / E \approx 50\% / \sqrt{E} \oplus 0.03\,[\mathrm{GeV}]$	*|η|<4.9 coverage* $\sigma / E \approx 100\% / \sqrt{E} \oplus 0.05$
Muon Spectrometer	*|η|<2.7 coverage, 1TeV muons:* $\sigma / p_T \approx 0.07$ *(standalone)*	*|η|<2.6 coverage, 1TeV muon:* $\sigma / p_T \approx 0.10$ *(standalone)*

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

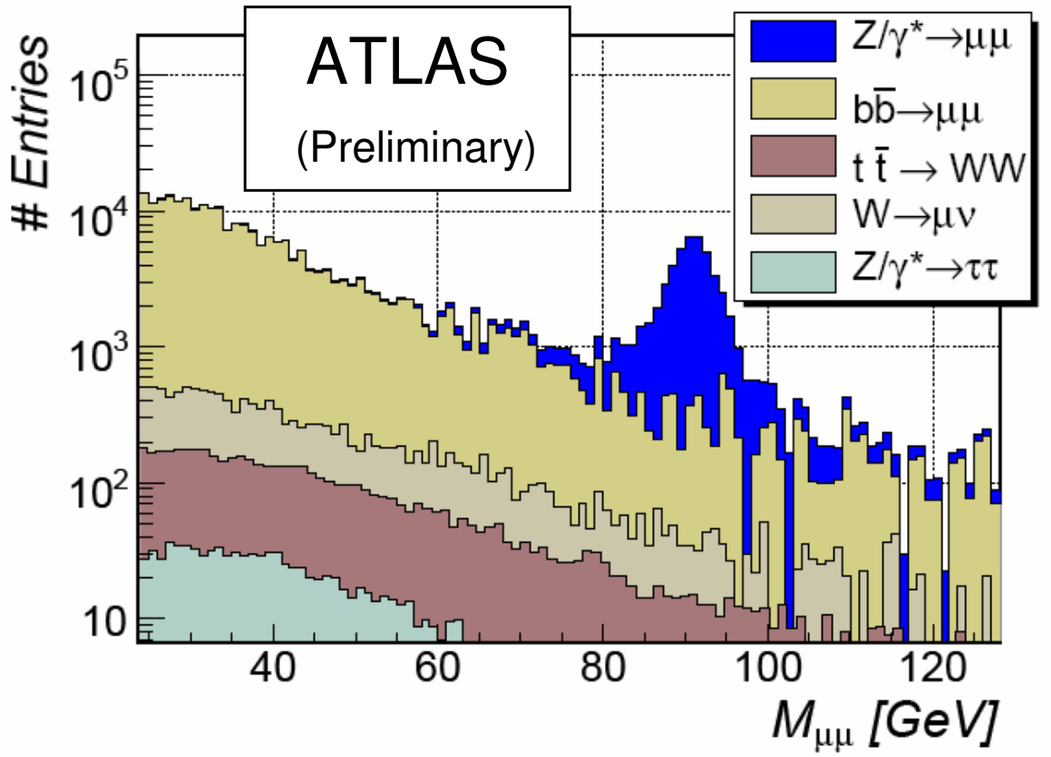
- In this talk:
  - Cross Section Measurement in the muon decay channel for the initial phase

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

  - Forward Backward Asymmetries in the electron decay channel

Signal Selection

- Background Processes
  - QCD Processes $b\bar{b} \to \mu\mu + X$
  - $W + jets \to \mu\upsilon + jets$
  - $Z \to \tau\tau \to \mu\upsilon + \mu\upsilon$
  - $t\bar{t} \to Wb + Wb \to \mu\upsilon + jet + \mu\upsilon + jet$
  - Background Uncertainty < 0.02



ATLAS Selection

- Two reconstructed muon tracks
- Opposite Charge
- $|91.2\ GeV - M_{\mu\mu}| < 30\ GeV$
- $p_T^1 > 15\ GeV$, $p_T^2 > 25\ GeV$
- Muon isolation requirements
- $|\eta| < 2.5$

CMS Selection

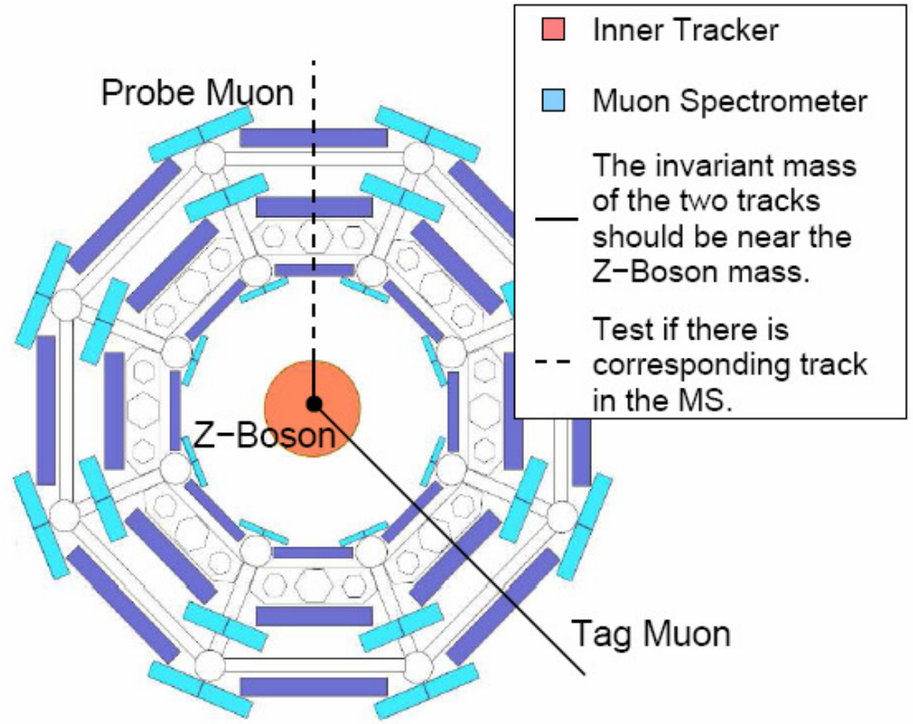
- One reconstructed muon track in the muon system + one opposite charged inner track
- $|91.2\ GeV - M_{\mu\mu}| < 7.5\ GeV$
- $p_T^{1,2} > 20\ GeV$
- Muon isolation requirements
- $|\eta| < 2.0$

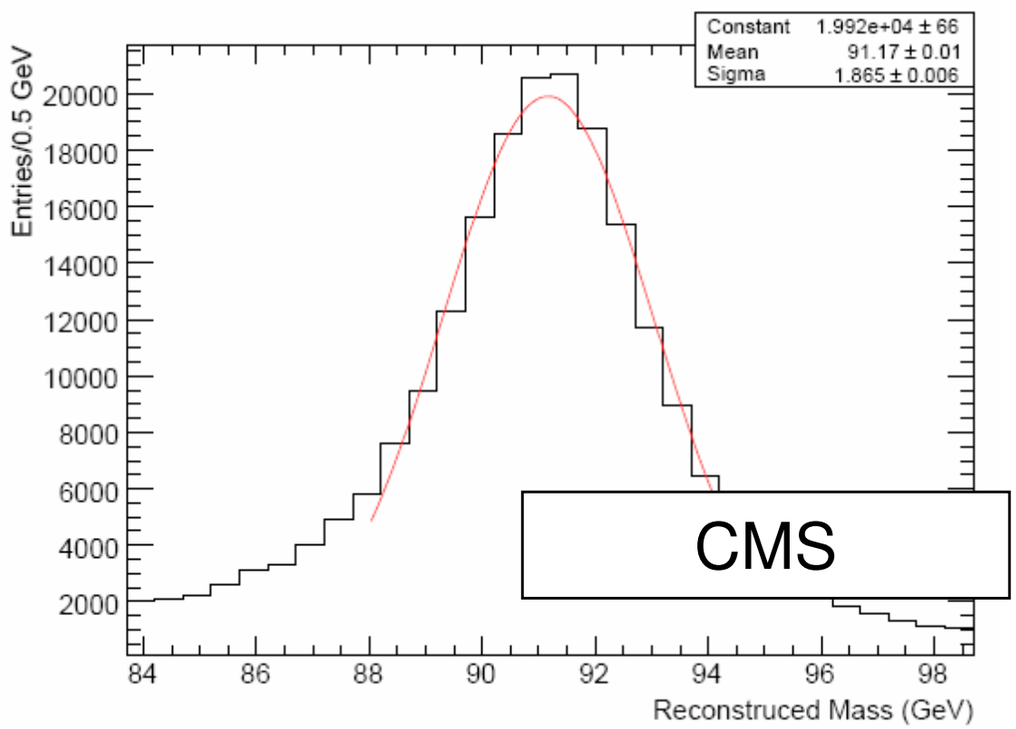
In Situ Determination of Detector Response

- 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

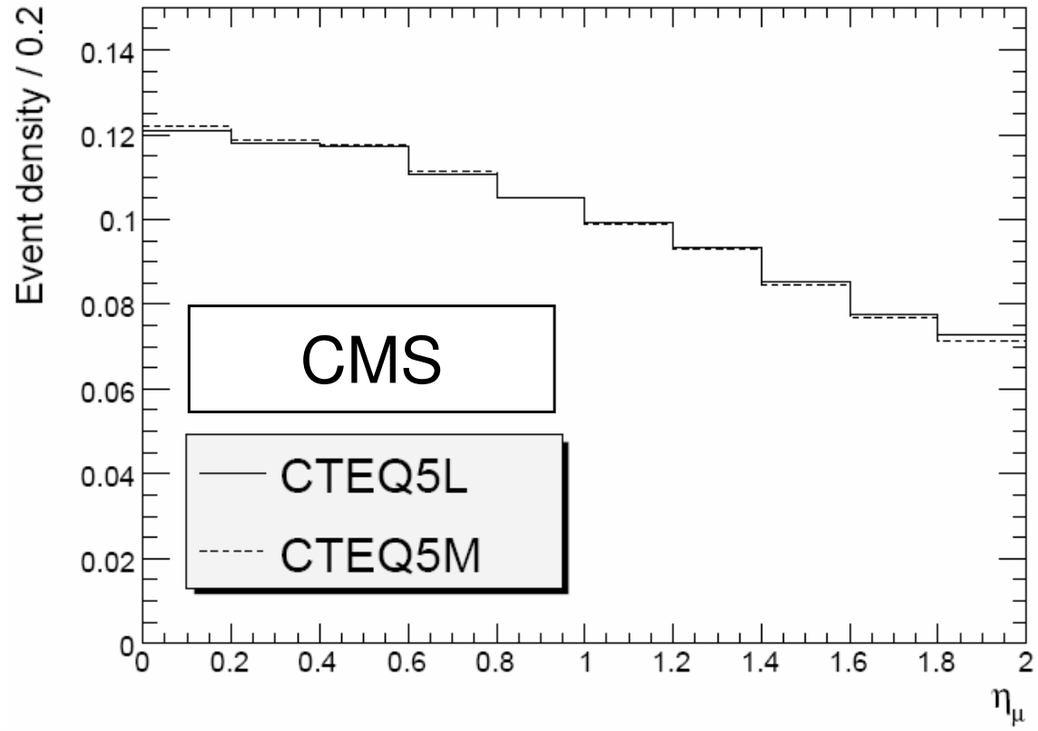
- $\Delta\varepsilon_{Tracking} \approx 0.2\text{-}0.5\%$
- $\Delta\varepsilon_{Trigger} \approx 0.2\%$
- momentum scale to few per mille
- …

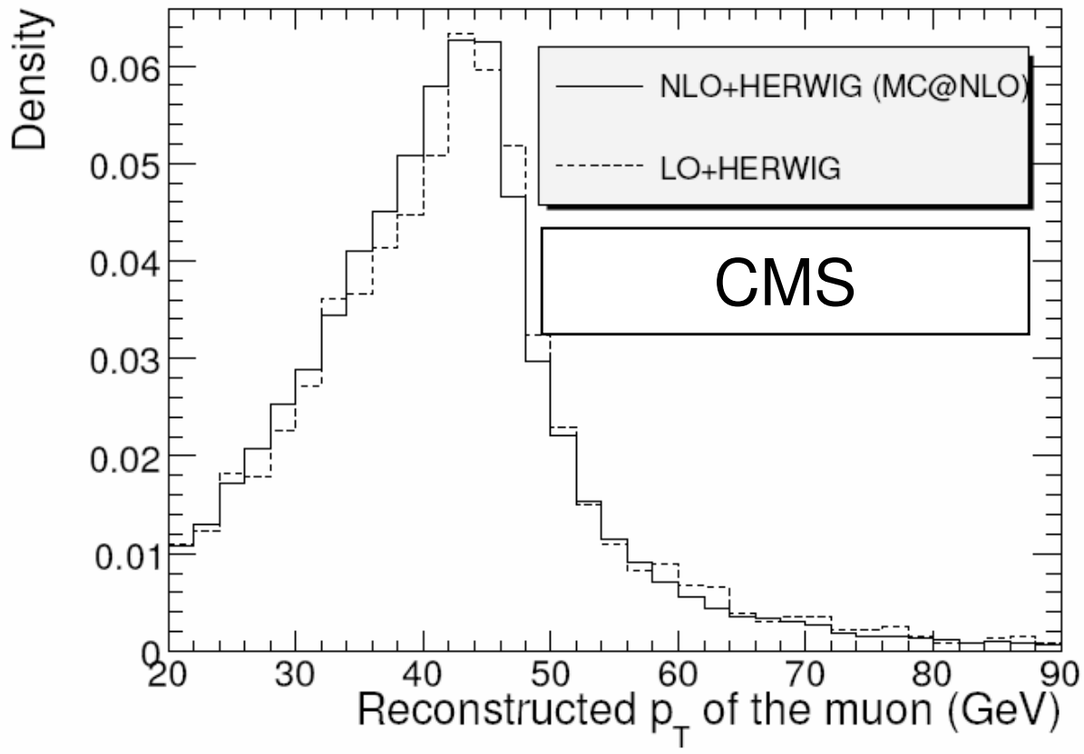




Further Systematic Uncertainties

- 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% for both detectors**
- Theoretical Systematic Uncertainties
  - PDF choice: **≈ 0.9%**
  - Initial state radiation: **≈ 0.2%**
  - p_T effects (LO to NLO): **≈ 1.8%**





Summary of Uncertainties

ATLAS (Preliminary)

- $\Delta\varepsilon_{\text{Reconstruction}} \approx 0.6\%$
  (Uncertainty of muon rec. eff.)
- $\Delta\varepsilon_{\text{Kinematic}} \approx 0.3\%$
  (Uncertainty of kinematic cuts)
- $\Delta\varepsilon_{\text{Trigger}} \approx 0.2\%$
  (Trigger uncertainty)
- $\Delta\varepsilon_{\text{Isolation}} \approx 0.2\%$
  (Uncertainty of muon isolation)

CMS

- $\Delta\varepsilon_{\text{Tracking}} \approx 1.0\%$
  (Uncertainty due to muon tracking)
- $\Delta\varepsilon_{\text{Trigger}} \approx 0.2\%$
  (Trigger uncertainty)
- $\Delta\varepsilon_{\text{Isolation}} \approx 0.2\%$
  (Uncertainty of muon isolation)

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

$$\frac{\Delta\sigma}{\sigma}(pp \to Z/\gamma^* + X \to \mu\mu) = 0.004\,(\text{stat}) \pm 0.011\,(\text{ex.sys}) \pm 0.02\,(\text{th.sys}) \pm 0.1\,(\text{lumi})$$

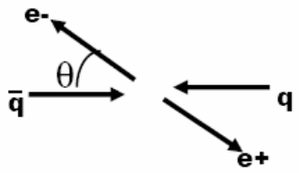
- ATLAS: Expected Precision for $\int Ldt = 100 pb^{-1}$ (preliminary)

$$\frac{\Delta\sigma}{\sigma}(pp \to Z/\gamma^* + X \to \mu\mu) = 0.004\,(\text{stat}) \pm 0.008\,(\text{ex.sys}) \pm 0.02(\text{th.sys}) \pm 0.1(\text{lumi})$$

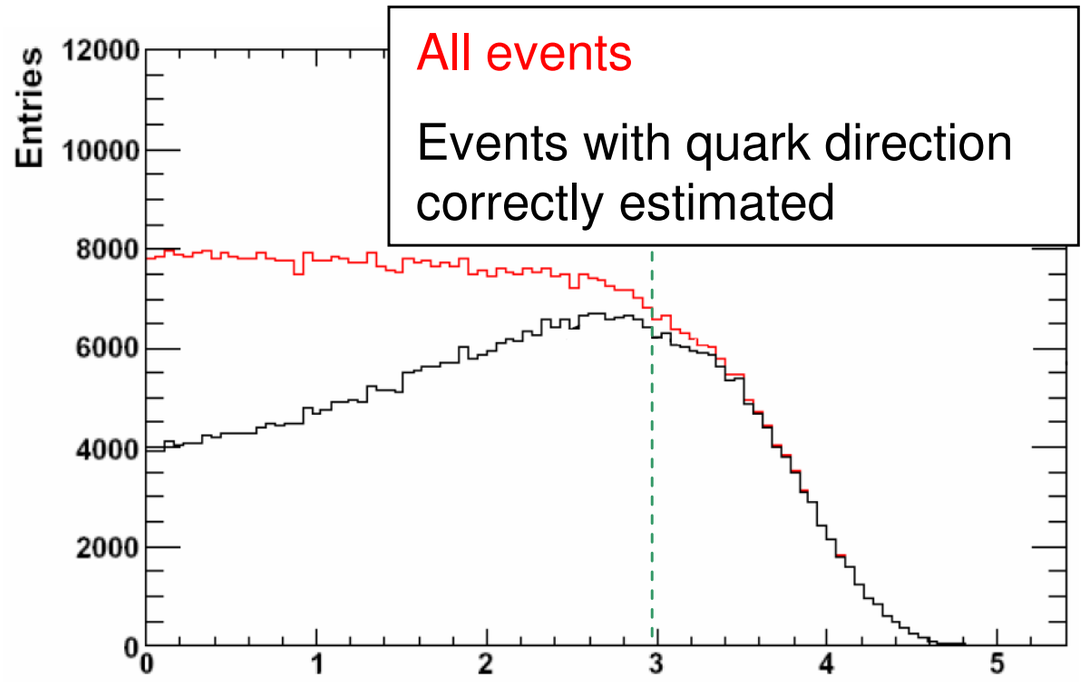
Forward and Backward Asymmetries at the Z Pole

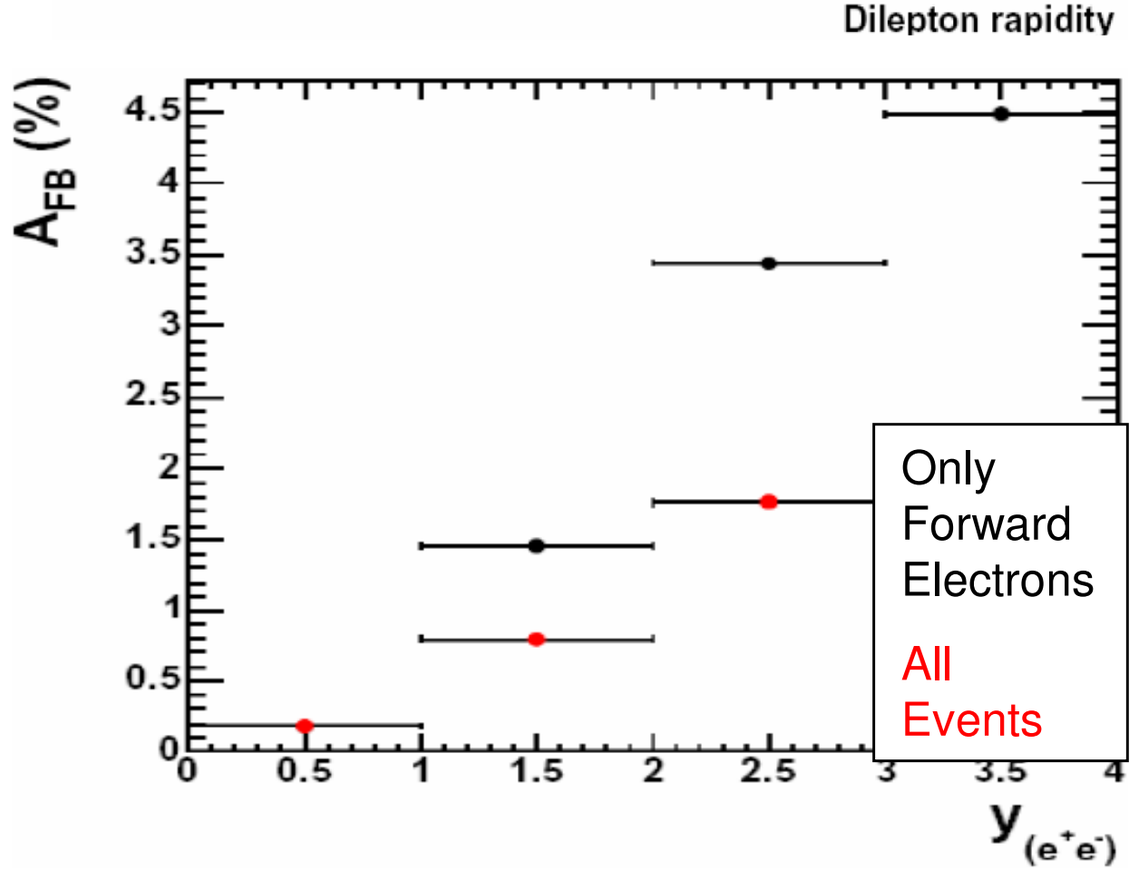
- Θ-dependence of cross-section

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



- Assumption for pp-collisions: the quark direction is the same as the boost of the Z
  - Correct for large di-lepton rapidities
  - Only EM calorimenters provide the required large η-coverage
- Determination of A_{FB} is a 'simple' counting problem
  - A statistical precision of the Weinberg angle of 10^{-4} at $\int Ldt = 100 fb^{-1}$ reachable.
  - Dominating systematic: PDF Uncertainties → **Use A_{FB} to constrain PDFs**





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

- **2008:** Let's hope to publish first results with real data to demonstrate the power of the ATLAS and CMS detectors

References

- **CMS**
  - CMS Physics Technical Design Report, Volume II
  - CMS Note: Measurement of Z→μμ and W→μν in CMS
  - Further contact persons: J. Alcaraz, M.Spiropulu, R. Tenchini, M. Thomas

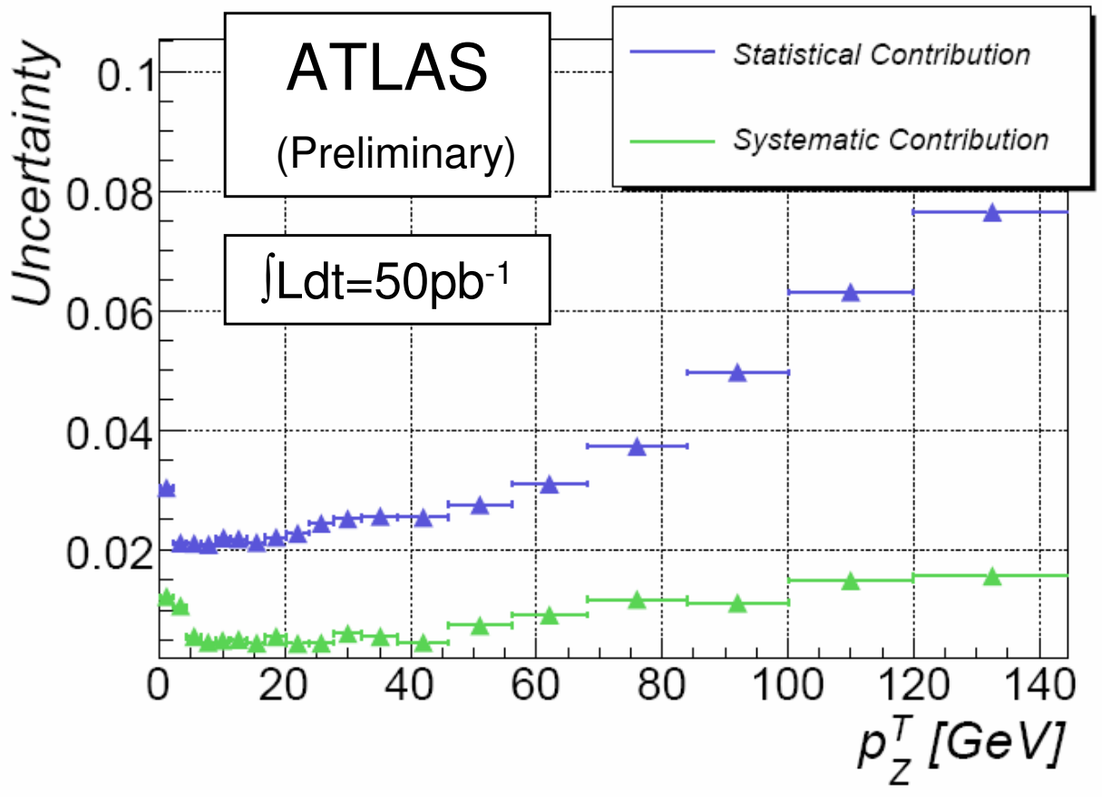
- **ATLAS**
  - CSC-Note: Measurement of the W/Z (to be published August 2008)
  - ATLAS-Note: Forward-Backward Charge Asymmetry in Z production at the LHC
  - Further contact persons: M. Aharrouche, M. Boonecamp, I Boyko, L. Di Ciaccio, T. LeCompte

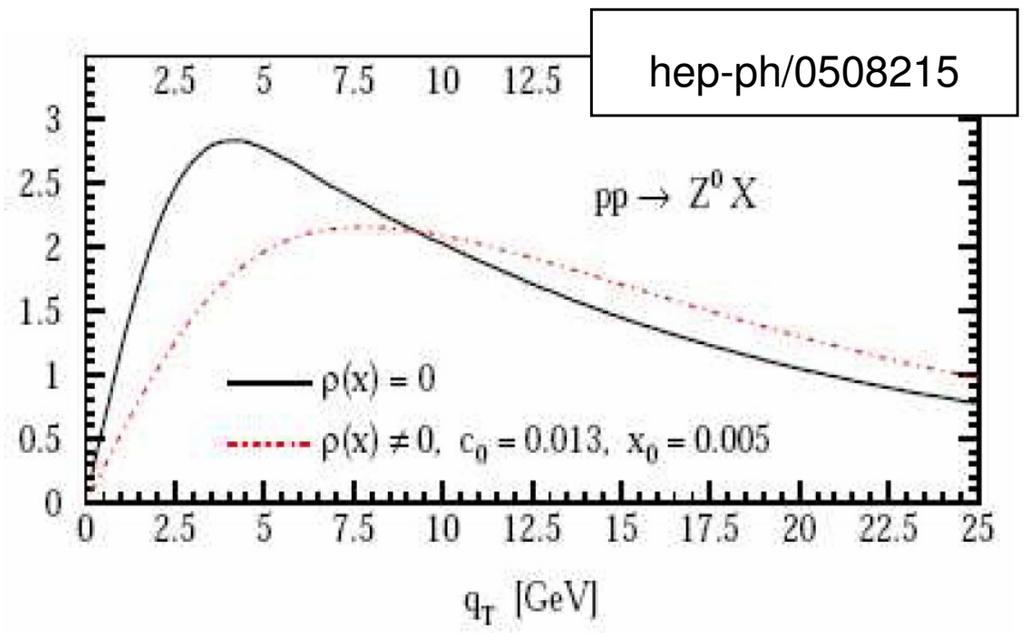
Backup Slides

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 $\int Ldt=100pb^{-1}$
  - Acceptance uncertainties are expected to be very small
  - Statistical uncertainties are expected to dominate during initial phase
  - Possibility to study dynamics of QCD and PDFs
    - E.g.: A possible first observation of x-broadening effect in hadron collisions



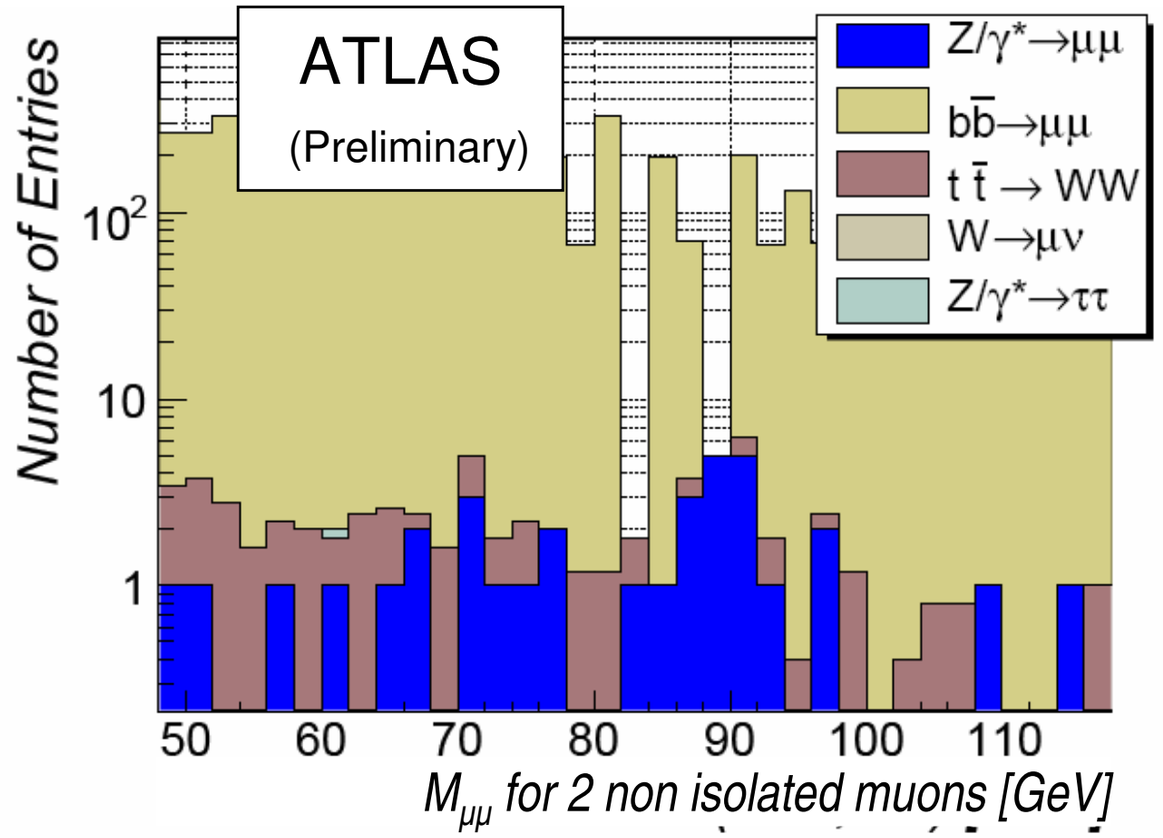


Background Estimation from Data

- Estimation of W background
  - Assumption

    $P_{3\mu}(Z\rightarrow\mu\mu) \approx P_{2\mu}(W\rightarrow\mu\nu)$

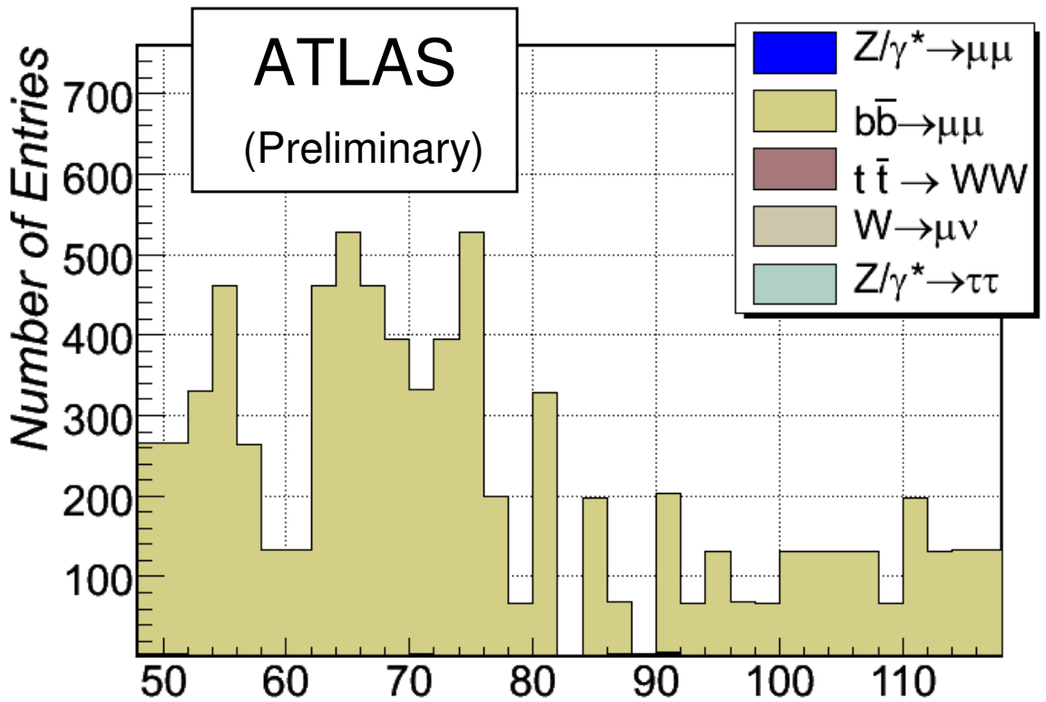
  - $P_{3\mu}(Z\rightarrow\mu\mu)$: Probability for 3 candidate muons passing the selection cuts in $Z\rightarrow\mu\mu$.
- Estimation of QCD background
  - Select sub-sample in data which is dominated by QCD-events, e.g. 2 non-isolated muons
  - Use this sub-sample to estimate the QCD background with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



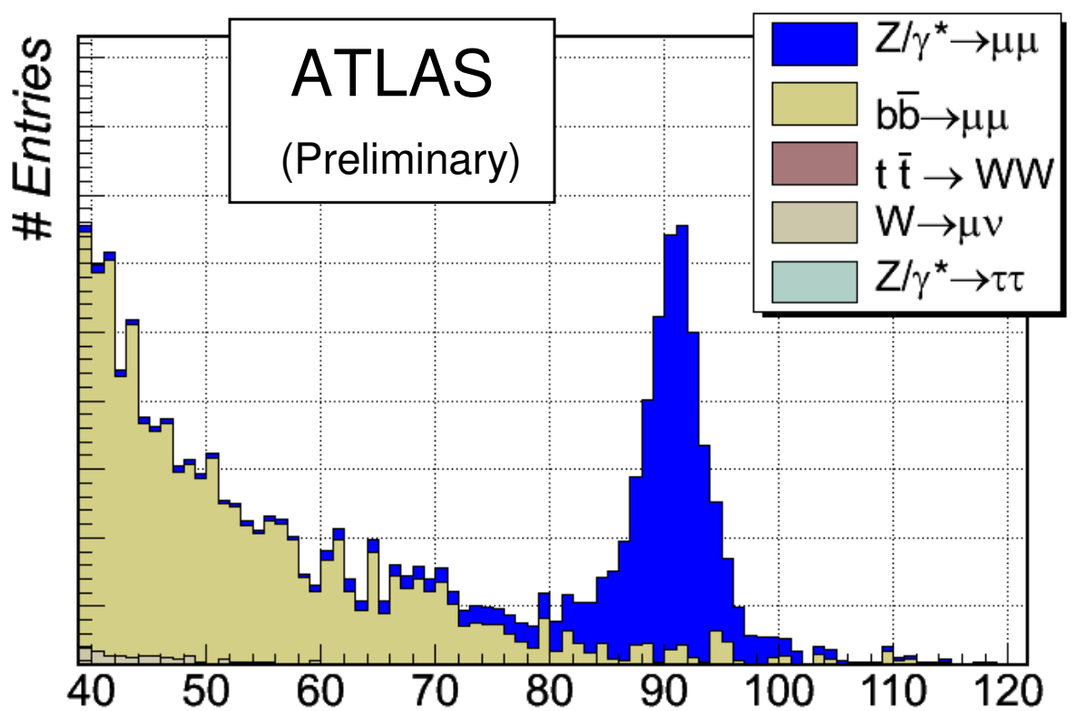
Background contribution (ATLAS)

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

Backup Slides



$M_{\mu\mu}$ *for 2 non isolated muons [GeV]*



$M_{\mu\mu}$ *[GeV]*