Cross Section Measurement of $pp \to Z(e^+e^-) + X$ with First Data from the ATLAS Experiment

Motivation • Cross Section Determination • Prospects

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Physics on the TeV-scale at the Large Hadron Collider

FSP 101 ATLAS

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

Why studying the cross section for the Z?

Clean and fully reconstructed leptonic final states of the Z decay provides "standard candle" for detector calibration

From the physics point of view

- quite early sufficient statistics for $d\sigma/dp_T$ and $d\sigma/d\eta$ measurements
- $d\sigma/dp_T$ spectrum provides constraints on QCD, $d\sigma/d\eta$ is direct probe of the PDFs
- advantage of $Z \to ee$ over $Z \to \mu\mu$ is larger η acceptance

"Master formula" for calculation:

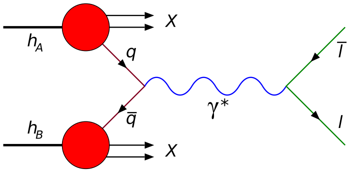
$$\boxed{\sigma = \frac{N-B}{\mathcal{A}\cdot\varepsilon\cdot\mathscr{L}}}$$

Ingredients:

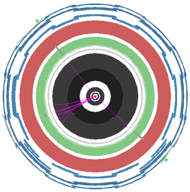
- N counted events
- B background events
- $\mathcal{A}$ acceptance
- $\mathscr{L}$ integrated luminosity
- $\varepsilon = \varepsilon_{\text{trigger}} \cdot \varepsilon_{\text{reco}} \cdot \varepsilon_{\text{ID}}$ efficiencies
  - $\varepsilon_{\text{trigger}}$ trigger efficiency
  - $\varepsilon_{\text{reco}}$ reconstruction
  - ε_{ID} identification

Simulations used for this Analysis

γ^*/Z production mechanism and decay into two leptons



ATLAS event display



- center-of-mass energy 14 TeV
- simulated with PYTHIA 6.411
- PDFs CTEQ6L

$Z \to e^+e^-$ signal simulation:

- limit on hard process $\sqrt{\hat{s}} > 60$ GeV
- $\sigma(pp \to Z/\gamma^*(e^+e^-) + X)$ 2.015 nb (NNLO)

background (QCD) samples:

- p_T^{jet} > 15 GeV
- $\sigma(pp \to \text{Dijet})$ $2.333 \cdot 10^6$ nb

- full detector simulation GEANT4

Presentation is based on an integrated luminosity of 50 pb^{-1}, if not stated otherwise.

How to find signal events

$$\sigma = \frac{N-B}{\mathcal{A}\cdot\varepsilon\cdot\mathscr{L}}$$

Event selection, $L = 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

1. trigger threshold

   $p_T > 10$ GeV

2. two electromagnetic clusters

   $E_T > 15$ GeV

   $|\eta| < 2.4$

   $80\ \text{GeV} < M_{\text{cl,cl}} < 100\ \text{GeV}$

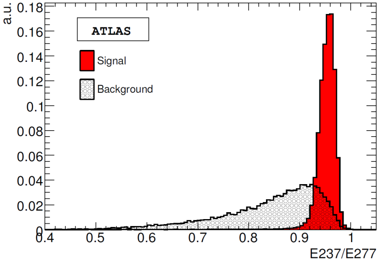
3. "loose" (i.e. calorimeter only) electron identification criteria

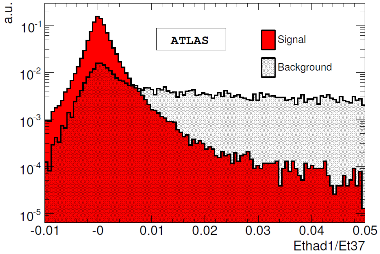
   hadronic leakage

   shower shapes

4. isolation in ΔR cone

   $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.45$





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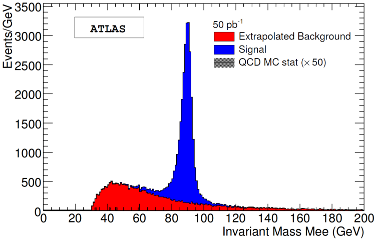
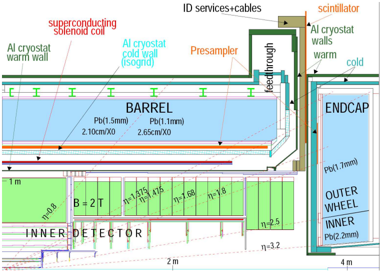


Expected number of $Z \to e^+e^-$-signal and background events ($\times 10^4$) for $\mathscr{L} = 50\ \mathrm{pb}^{-1}$ after the successive cuts

1	6.70 ± 0.01	3110 ± 40
2	2.76 ± 0.01	11.1 ± 0.8
3	2.64 ± 0.01	0.8 ± 0.2
4	2.48 ± 0.01	0.2 ± 0.1

Acceptance studies

$$\sigma = \frac{N-B}{\mathcal{A}\cdot\varepsilon\cdot\mathcal{L}}$$



The acceptance is defined as

- fraction of the signal that passes kinematic and geometric cuts

$$\mathcal{A} = \frac{N_{\text{after kinematical and geometrical cuts}}}{N_{\text{before cuts}}}$$

Uncertainties w.r.t. physics

- limited knowledge of underlying physics

non-pertubative mechanisms

PDFs

initial state radiation

intrinsic k_T of the incoming partons

Uncertainties $\delta\mathcal{A}$ were estimated by switching on and off the different effects, and a variety of generators have been used, namely

PYTHIA

Herwig

MC@NLO

- combined result: $\delta\mathcal{A}/\mathcal{A} = 2.3\%$

Intermezzo: The “tag and probe” method

$\sigma = \frac{N-B}{\mathcal{A}\cdot\varepsilon\cdot\mathscr{L}}$

Data-driven approach to get efficiencies

- motivation for data-driven technique is that one don’t want to rely on Monte Carlo for efficiency studies
- as real data won’t contain “true information”, methods need to be approved

Common use of the “tag and probe” method

- for $Z \to ee$, use hard cuts to find one “good” lepton as reference (“tag”)
- look for a cluster, such that

$$m_{\text{min}} < M_{\text{tag,cluster}} < m_{\text{max}}$$

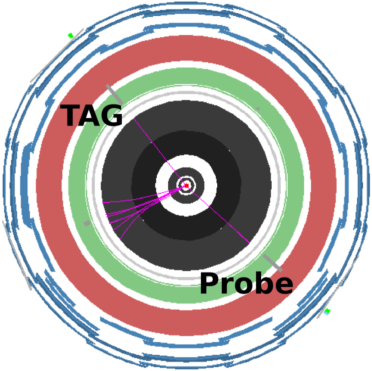
$$\Rightarrow N_1$$

- use this second cluster as “probe” to get a sub-sample when additional cuts are passed

$$\Rightarrow N_2$$

- “tag and probe” efficiency is then defined as

$$\varepsilon_{\text{tag and probe}} = \frac{N_2}{N_1}$$



Reconstruction and identification efficiencies

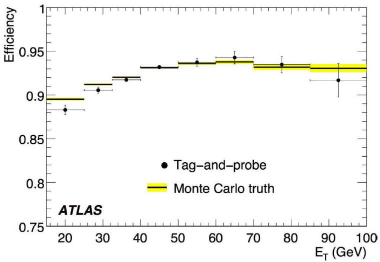
$$\sigma = \frac{N - B}{\mathcal{A} \cdot \varepsilon \cdot \mathscr{L}}$$

Technique for efficiency determination

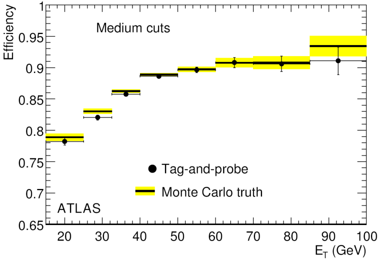
- based on seed-clusters in the EM calorimeter, matched to tracks
- conditions on the "tag"
  - reconstructed electron
  - "tight" isolation cuts
  - outside $1.37 < |\eta| < 1.52$
  - pass trigger threshold
  - $E_T > 15$ GeV
- conditions on the "probe"
  - $\Delta\Phi_{\text{tag, probe}} > 3/4\pi$
  - $E_T > 15$ GeV
  - $80\ \text{GeV} < M_{\text{tag, probe}} < 100\ \text{GeV}$

Tag and probe method shows good agreement with MC truth

reconstruction efficiency



identification efficiency



Trigger efficiencies

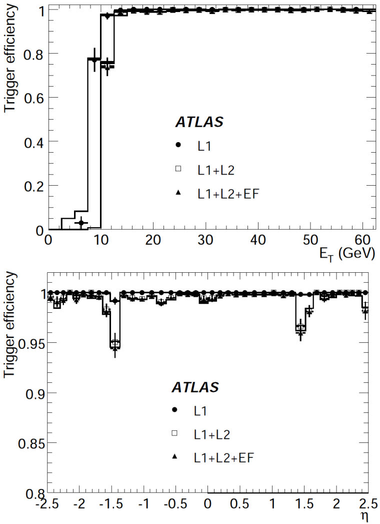
$$\sigma = \frac{N-B}{\mathcal{A}\cdot\varepsilon\cdot\mathcal{L}}$$

Early running at ATLAS

- vital for understanding of
  - detector performance
  - offline reconstruction
  - trigger performance
- low luminosity run allows
  - loose selections
  - low trigger thresholds

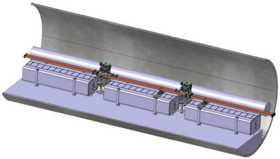
For early data, 10 **GeV trigger threshold**

- shown here: single electron trigger efficiency vs. E_T and $|\eta|$
- agreement better than 1% between tag and probe method and MC truth
- high efficiency



Luminosity measurement at ATLAS

$$\sigma = \frac{N-B}{\mathcal{A}\cdot\varepsilon\cdot\mathscr{L}}$$

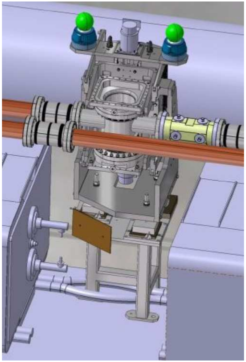


Luminosity parameters at LHC-startup

- instantaneous luminosity

$$L = 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1},\ \frac{\delta L}{L} \approx 10\%$$

- L "measurement" based on machine parameters



Measurement of the luminosity via "Roman pots"

- installed on both sides of the IP
- measuring elastic scattered protons
- $\mathcal{O}(1\ \mathrm{mm})$ distance from beam
- measurement done via dedicated runs, i.e. transfer to normal run conditions neccessary

Aim is to

- access "Coulomb Intereference Region"
- reach $\frac{\delta L}{L} \approx 2–3\%$

Results for the total cross section

$\sigma = \frac{N - B}{\mathcal{A} \cdot \varepsilon \cdot \mathscr{L}}$

With this toy-study for 50 pb^{-1} at a startup-luminosity of 10^{31} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, the following results were obtained:

- N $(2.71 \pm 0.02) \times 10^4$
- B $(0.23 \pm 0.04) \times 10^4$
- $\mathcal{A} \times \varepsilon$ 0.246
  - $\delta\mathcal{A}/\mathcal{A}$ 0.023
  - $\delta\varepsilon/\varepsilon$ 0.030

$\Rightarrow$ $\sigma = (2016 \pm 16_{\mathrm{stat}} \pm 83_{\mathrm{syst}})$ pb

Agreement with nominal total cross section ($\sigma = 2015$ pb), result is dominated by systematic uncertainties

Extrapolation to $\mathscr{L} \rightarrow \mathcal{O}(1\ \mathrm{fb}^{-1})$

- statistical uncertainty for N becomes negligible
- efficiency uncertainty decreases for part which is determined from measurement
- trigger threshold will be increased with "tight" selection criteria
- uncertainty on the acceptance will not scale with statistics and therefore will be dominating the result

$\Rightarrow$ $\sigma = (2016 \pm 4_{\mathrm{stat}} \pm 49_{\mathrm{syst}})$ pb

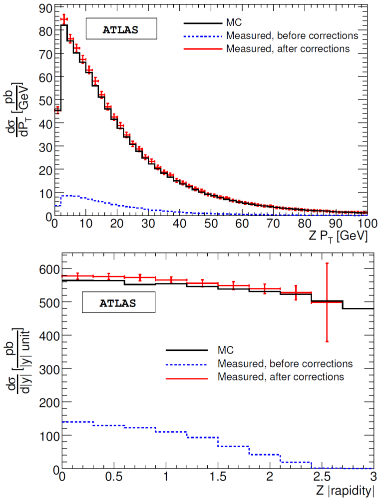
(Uncertainty on luminosity not included in these results!)

Differential Cross Section

$$\sigma_\alpha = \frac{S_\alpha}{\mathcal{L}} \frac{n_\alpha - b_\alpha}{\varepsilon_\alpha \cdot A_\alpha}$$

Differential cross sections useful to put constraints on uncertainties of the total cross section measurement, at the cost of higher statistics needed

- S_α in formula for σ_α represents the detector smearing correction
- signal selection
  - 12 GeV trigger threshold
  - $p_T > 20$ GeV
  - $|\eta| < 2.5$
- extraction of $d\sigma_Z/dp_T$ and $d\sigma_Z/dy$ in different regions α
  - 50 p_T bins
  - 9 y bins
- results show good agreement between reconstructed and true cross section



Summary and Outlook

Summary

- Motivation for this study was to test the tools for measuring the (differential) cross section and the expected uncertainty for this "standard candle"-process
- With the method presented, cross section measurement for $pp \to Z/\gamma^*(e^+e^-) + X$ possible with an uncertainty (including the one on luminosity) of
  - $\leq 10\%$ for the first $50\ \mathrm{pb}^{-1}$
  - $\leq 5\%$ extrapolated to $\mathscr{L} \approx 1\ \mathrm{fb}^{-1}$
- Measurement of the differential cross section also feasible within statistics intended for the first LHC-run

Outlook

- Ultimately, the uncertainty on this measurement is driven by strong interaction effects, affecting the y and p_T distributions of the W and the Z
- In the end, the lower bound is fixed by the precision of luminosity and acceptance
- Without further improvement of these two parameters, measurement of the total cross section will be limited to $\delta\sigma/\sigma \gtrapprox 2\%$

waiting for data