W, Z measurements from early data with CMS

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Workshop sui Monte Carlo, la Fisica, le Simulazioni

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Outline

- Introduction
- Inclusive cross section measurements (e, \( \mu \))
  - efficiency measurements
  - events selections and background estimation
  - acceptance studies
- Summary
Introduction

- **“early data”** → assume an integrated luminosity $\sim 10-100$ pb$^{-1}$
  - instantaneous luminosity $\sim 10^{32}$ cm$^{-2}$ s$^{-1}$

- W, Z (→ leptons) measurements with early data
  - large and high purity samples thanks to the high production cross section and clean experimental signature

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma \times \text{Br}$ [pb]</th>
<th>$\epsilon \times \mathcal{A}$ (estimate)</th>
<th>Events, 10 pb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z → ll</td>
<td>2000</td>
<td>25%</td>
<td>5000</td>
</tr>
<tr>
<td>W → lv</td>
<td>20000</td>
<td>35%</td>
<td>70000</td>
</tr>
<tr>
<td>ttbar → lv +X</td>
<td>370</td>
<td>1.5%</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Jet $E_T &gt; 25$ GeV</td>
<td>$3 \cdot 10^9$</td>
<td>100%</td>
<td>$3 \cdot 10^{10}$ x p.f.</td>
</tr>
<tr>
<td>Minimum bias</td>
<td>$10^{11}$</td>
<td>100%</td>
<td>$10^{12}$ x p.f.</td>
</tr>
</tbody>
</table>

- “Standard candles” for detector calibration/understanding and first physics measurements
  - inclusive cross sections measurements
  - monitor collider luminosity
  - constrain Parton Distribution Functions (looking at $\sigma_{TOT}$, W rapidity,...)
Inclusive cross section measurement

\[ \sigma_{W(Z)} \times BR(W(Z) \rightarrow \text{leptons}) = \frac{N^{obs}_{W(Z)} - N^{bkg}_{W(Z)}}{\epsilon_{W(Z)} A_{W(Z)} \int \mathcal{L} dt} \]

- compare the measure to theory or reverse the relation for:
  - luminosity measurement
  - constraining PDFs
- with large LHC datasets, main uncertainties are non-statistical:
  - luminosity (5-7%), systematics (2-3%)
    [see also D0 Note 4750; arXiv:hep-ex/0508029]

- Efforts to define methods to measure most of the parameters from the data themselves and to minimize the dependence on MC:
  - \( \epsilon \) = trigger and offline lepton efficiencies \( \Rightarrow \) from data
  - \( N^{bkg} \) = expected background \( \Rightarrow \) from data and MC
  - \( A \) = acceptance \( \Rightarrow \) from MC
Efficiency measurement from data

**The Tag&Probe method**

- Use $Z \rightarrow e e (\mu \mu)$ events to provide an unbiased, high purity electron (muon) sample to measure the efficiency of a particular selection.

**TAG**: electron (muon) selected with tight criteria

**PROBE**: electron (muon) candidate with loose selections depending on the efficiencies under study.

- tag-probe invariant mass within a narrow window around $M(Z)$ + possible requirement on $\Delta \Phi$ (tag-probe)

- tight tag selections + kinematic cuts to ensure a high purity sample

\[ \epsilon = \frac{\# \text{ probes passing the selection}}{\# \text{ all probes}} \]

- map efficiencies as a function of $p_T, \eta, \Phi$ for physics analysis

**Critical issues of the method**

- residual background contamination (QCD, W+jets) to be subtracted

- check of correlations and dependencies on the selections applied

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Muon efficiency with “Tag&Probe”

\[ \varepsilon = \varepsilon_{\text{reco}} \times \varepsilon_{\text{isolation}} \times \varepsilon_{\text{trigger}} \]

for muons: \[ \varepsilon_{\text{reco}} = \varepsilon_{\text{tracking}} \times \varepsilon_{\text{standalone}} \times \varepsilon_{\text{matching}} \]

- Example: measuring trigger efficiency
  - TAG: isolated global reconstructed muon, \( p_T > 20 \text{ GeV} \), passing HLT
  - PROBE: isolated global reco. muon
  - 83.7 GeV < \( M(\mu\mu) \) < 98.7 GeV
- overall precision on efficiency <1%

Global muon reconstruction efficiency

Isolation efficiency from \( Z \rightarrow \mu\mu \)

Trigger efficiency \( L1*L2*L3 \sim 90.5\% \)
Efficiency: Tag&Probe vs W→lν

- Apply efficiency measured with Z→lν to W→lν

- Efficiency mapped in $p_T, \eta$ bins to account for different kinematic distributions of leptons from Z and W

- Good agreement between “Tag&Probe” efficiency and MC truth in W→lν
  - From comparison between “Tag&Probe” efficiency and MC efficiency in W→lν performed as a function of $E_T$ and in $\eta$ slices

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Tag: HLT electron, $E_T>15$ GeV, track isolation
Probe: ECAL SC, $E_T>20$ GeV
85 GeV < M(tag-probe) < 95 GeV

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Events selection and backgrounds $Z\rightarrow ll$

- **Selections:**
  - two well reconstructed isolated leptons with opposite charge within detector acceptance ($|\eta|<2.4$)
    - lepton ID based on simple but robust cuts
  - high pt (well above trigger thresholds)
  - invariant mass ($70 \text{ GeV} < M < 110 \text{ GeV}$)

- **Main Backgrounds**
  - $Z\rightarrow \tau \tau$, ttbar, W+jets
  - true or misidentified leptons from di-jet events

- almost negligible background contamination ($\sim$ few $\%$) after all selections
Backgrounds from data in $Z \rightarrow ll$

- subtraction of residual background needed for a correct estimation of efficiencies with T&P and cross sections

**Different techniques under investigation**

(1) **“Charge Correlation” Method**
- look at “same-sign” (SS) and “opposite-sign” (OS) events
- $N(SS) = N(OS)$ under the assumption of no charge correlation in lepton pairs from hadronic events
- need to take into account charge mismeasurement probability in signal and possible non-negligible charge correlations

(2) **“Side Bands” Method**

(3) fit with background (or signal+bkg.) templates of a discriminating variable
- more sophisticated, may require higher luminosities (i.e. with enough data to model background shapes)

(1) and (2) are simple but robust methods:
- desirable for a start-up scenario
- adequate for the level of background expected in $\sim 10 \text{ pb}^{-1}$
Events selection and backgrounds $W \rightarrow l \nu$

**Selections**
- one well reconstructed lepton within detector acceptance and passing HLT requirements
- lepton isolation
- lepton $p_T > 20$ GeV
- transverse mass and/or MET cut + possible jet vetoes to reduce hadronic backgrounds

**Electroweak backgrounds**
- $W \rightarrow \tau l$, $Z/\gamma^* \rightarrow ll$, $Z \rightarrow \tau \tau$, $ttbar$ (~few %)
- $WW$, $WZ$, $ZZ$ (~negligible)
- can be reliably estimated from MC simulation

**Hadronic backgrounds**
- highest uncertainty
- can be estimated from data
Background estimation: “Matrix method”

General technique used by CDF and D0

- Consider two variables with signal/background discrimination power
  - Main assumption: the two variables are largely uncorrelated
  - E.g.: lepton isolation and MET($M^T$)
  - Look at Var1%Var2

- Simplest approach: assuming that $B_a$, $B_b$, $B_c$ are only QCD events, the number of bkg. events $B_d$ in the signal region is deduced by the ratio $R$

- “Non-QCD” contamination correction in regions a, b, c may be required

- Systematics dominated by the validity of the assumption $B_b/B_a=B_c/B_d$

$R = \frac{B_b}{B_a} = \frac{B_c}{B_d} \Rightarrow B_d = \frac{B_c}{B_a} \times B_d$

Results for QCD bkg estimation in $W \rightarrow \mu\nu$ shown for different control regions using 0.5 pb$^{-1}$
Background estimation from data (I)

MET distribution in QCD events is almost independent of whether the candidates pass or fail the isolation requirement.

It can then be modeled on ANTI-ISOLATED leptons.

\[ \sum_{\text{track}} \left( \frac{p_T^{\text{track}}}{p_T^{\text{lep}}} \right)^2 > 0.02 \]
Background estimation from data (II)

Possible systematic effects

- bias in modelling QCD and signal templates
- biases from W and EWK events in the non-isolated electron sample
- accuracy in the MC prediction of EWK backgrounds

QCD template from anti-isolated electrons

**W→ev MET template from Z→ee**
- ignore one lepton
- corrections for different W/Z kinematics

Other backgrounds: use full simulation

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Acceptance studies

- Comparisons between different generators and predictions (LO vs NLO)
- NLO QCD and EWK corrections
  - **MC@NLO+PHOTOS vs RESBOS-A**
  - **HORACE vs LO MC + PHOTOS**
  - using **MC@NLO+PHOTOS** ⇒ overall theoretical uncertainty on $Z \rightarrow ll$ acceptance at the percent level
- $W \rightarrow l\nu$
  - LO – NLO (MC@NLO) ~ 2% uncertainty on acceptance
uncertainty on acceptance in $Z \rightarrow \mu\mu$ events from PDFs at the 1% level
- evaluated with CTEQ6.5
- $\sim 1\%$ difference between CTEQ6.5 central value and other MRST PDF sets
Summary

- W,Z inclusive cross section measurements will be one of the first measurements with early data
- Efforts to investigate strategies to measure most of the parameters from data and to minimize the dependence on Monte Carlo
- Trigger and offline efficiencies can be measured from data exploiting Z \rightarrow ll events
- QCD background estimation (shape and normalization) from data using different methods
- Residual dependences on MC: acceptance determination, electroweak backgrounds
Backup slides
Trigger efficiency - electrons

Figure 3: L1+HLT efficiency versus supercluster $E_T$.

Figure 4: L1+HLT efficiency versus supercluster $\eta$. 

Electromagnetic calorimeter reconstruction efficiency as a function of probe track $p_T$: comparison between signal+background and after background subtraction

$L=10 \text{ pb}^{-1}$
Muon momentum scale from Z

- use $Z \rightarrow \mu\mu$ events to correct muon scale biases due to
  - effectiveness of the muon reconstruction procedure
  - imperfect knowledge of the detector conditions

- studied for $10 \text{ pb}^{-1}$ with different scenarios
  - normal detector conditions
  - tracker misalignment
  - muon system misalignment
  - modified B-field intensity

- correct $\mu$ scale as a function of muon kinematics: $p_T^\mu = k \times p_T$ with $k = F(p_T, \eta, \phi; \alpha...)$

- scale corrections improve also systematics on cross section measurements (acceptance uncertainties)