W/Z and direct photon production at the LHC

Massimo Casarsa

INFN, Trieste, Italy

on behalf of the ATLAS, CMS, and LHCb Collaborations
The study of the electroweak gauge bosons at LHC is producing a very rich harvest of results. This talk will show a selection of results focusing on the most recent ones on full datasets:

- overview and experimental apparatuses;
- inclusive W/Z production cross-sections and Z transverse momentum at 8 TeV;
- inclusive and differential W/Z production cross-sections at 7 TeV;
- lepton charge asymmetry in W production;
- prompt photon and diphoton production;
- summary.
Overview

- The direct production of electroweak gauge bosons in pp collisions provides a colorless probe of the hard scattering process.

  - Theory:
    - W/Z production known at NNLO in perturbative QCD.

  - Experiment:
    - at LHC among the most abundant processes;
    - leptonic decays provide clean signatures;
    - challenge: precision measurements dominated by systematics.

- Theory/experiment comparison allows to perform stringent pQCD tests, to constrain and explore the proton PDFs in previously not-accessible kinematic regions.

http://www.hep.phy.cam.ac.uk/~wjs/plots/plots.html
The experimental apparatuses

- General purpose detectors:
  - vertex detector and tracker,
  - electromagnetic and hadronic calorimetry,
  - muon detectors.
- ATLAS and CMS central detectors.
- LHCb instrumented within $2 < \eta < 5$. 
**W/Z inclusive production @ 8 TeV**

- Special 8 TeV low-pileup dataset (18.7 pb⁻¹);
- \( W \rightarrow \ell \nu \) and \( Z/\gamma^* \rightarrow \ell \ell \) channels:
  - electrons: \( E_T(e) > 25 \) GeV/c,
    \[ |\eta(e)| < 1.44 \text{ or } 1.57 < |\eta(e)| < 2.5; \]
  - muons: \( p_T(\mu) > 25 \) (20 for Z's) GeV/c,
    \[ |\eta(\mu)| < 2.1; \]
  - \( 60 < M_{\ell\ell} < 120 \) GeV/c².
Z boson transverse momentum @ 8 TeV

- Special 8 TeV low-pileup dataset (18.4 pb⁻¹);
- \( Z/\gamma^* \rightarrow \mu\mu \) channel with:
  - \( p_T(\mu) > 20 \text{ GeV/c} \) and \( |\eta(\mu)| < 2.1 \);
  - \( 60 < M_{\mu\mu} < 120 \text{ GeV/c}^2 \);
- low-\( q_T \) region tests non-perturbative soft gluon emission;
- high-\( q_T \) region probes pQCD hard gluon radiation in initial state.
Drell-Yan leptons $\phi^*$ distribution

- Full 7 TeV dataset (4.6 fb$^{-1}$);
- $Z/\gamma^* \rightarrow ee, \mu\mu$ channels:
  - $p_T(\ell) > 20$ GeV/c and $|\eta(\ell)| < 2.4$;
  - $66 < M_{\ell\ell} < 116$ GeV/c$^2$.

$$\phi^*_\eta = \frac{\tan[(\pi - \Delta \phi)/2]}{\cosh(\Delta \eta/2)} \approx \frac{p_T^Z}{M_{\ell\ell}}$$
High-mass DY differential cross-section

- Full 7 TeV dataset (4.9 fb⁻¹);
- \(Z/γ^* \rightarrow ee\) channel:
  - \(p_T(e) > 25\) GeV/c,
  - \(|\eta(e)| < 2.5\);
  - \(116 < M_{ee} < 1500\) GeV/c².
Drell-Yan differential cross-section

- Full 7 TeV dataset;
- $Z/\gamma^* \to \mu\mu$ channel (4.5 fb$^{-1}$):
  - $p_T(\mu_1) > 14$ GeV/c, $p_T(\mu_2) > 9$ GeV/c, $|\eta(\mu_{1,2})| < 2.4$;
  - $15 < M_{\mu\mu} < 1500$ GeV/c$^2$.
- $Z/\gamma^* \to ee$ channel (4.8 fb$^{-1}$):
  - $p_T(e_1) > 20$ GeV/c, $p_T(e_2) > 10$ GeV/c, $|\eta(e_{1,2})| < 2.5$;
  - $15 < M_{ee} < 1500$ GeV/c$^2$. 
Z differential production cross-section

- 7 TeV dataset (1 fb⁻¹);
- Z/γ* → μμ channel with:
  - $p_T(μ) > 20$ GeV/c,
  - $2 < \eta(μ) < 4.5$;
  - $60 < M_μμ < 120$ GeV/c².

$$\sigma_{pp→Z→\mu\mu} = 75.4 \pm 0.3_{\text{stat}} \pm 1.9_{\text{syst}} \pm 2.6_{\text{lumi}} \text{ pb}$$

$$\phi_\eta = \frac{\tan((\pi - \Delta \phi)/2)}{\cosh(\Delta \eta/2)} \approx \frac{P_T^2}{M_{ℓℓ}}$$
$Z/\gamma^* \rightarrow ee/\tau\tau$ inclusive production

- 7 TeV dataset;
- $Z/\gamma^* \rightarrow ee$ channel (0.94 fb$^{-1}$):
  - $p_T(e) > 20$ GeV/c,
  - $2 < \eta(e) < 4.5$;
  - $60 < M_{ee} < 120$ GeV/c$^2$.
- $Z/\gamma^* \rightarrow \tau\tau$ (1 fb$^{-1}$):
  - $p_T(\tau_1) > 20$ GeV/c, $p_T(\tau_2) > 5$ GeV/c,
  - $2 < \eta(e,\mu) < 4.5$, $2.25 < \eta(\tau_h) < 3.75$;
  - $60 < M_{\tau\tau} < 120$ GeV/c$^2$.

\[ \sigma_{pp \rightarrow Z \rightarrow ee} = 76.0 \pm 0.8 \text{ stat } \pm 2.0 \text{ syst } \pm 2.6 \text{ lumi} \text{ pb} \]
\[ \sigma_{pp \rightarrow Z \rightarrow \tau\tau} = 71.4 \pm 3.5 \text{ stat } \pm 2.8 \text{ syst } \pm 2.5 \text{ lumi} \text{ pb} \]
\( \mu^\pm \) charge asymmetry in W production

- 7 TeV dataset (4.7 fb\(^{-1}\));
- \( W \to \mu \nu \) channel:
  - \( p_T(\mu) > 25 \text{ GeV/c}, |\eta(\mu)| < 2.4; \)
- lepton charge asymmetry:
  \[
  A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \ell^+ \nu) - \frac{d\sigma}{d\eta}(W^- \to \ell^- \nu)}{\frac{d\sigma}{d\eta}(W^+ \to \ell^+ \nu) + \frac{d\sigma}{d\eta}(W^- \to \ell^- \nu)}
  \]

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\( \mu^\pm \) charge asymmetry in \( W \) production

- 7 TeV dataset (4.7 fb\(^{-1}\));
- \( W \rightarrow \mu\nu \) channel:
  - \( p_T(\mu) > 25 \text{ GeV/c}, |\eta(\mu)| < 2.4; \)
- lepton charge asymmetry:
  \[
  A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \rightarrow \ell^+ \nu) - \frac{d\sigma}{d\eta}(W^- \rightarrow \ell^- \nu)}{\frac{d\sigma}{d\eta}(W^+ \rightarrow \ell^+ \nu) + \frac{d\sigma}{d\eta}(W^- \rightarrow \ell^- \nu)}
  \]

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Isolated prompt photon production

- 7 TeV dataset (4.7 fb⁻¹);
- Prompt photons (direct and from fragmentation):
  - isolation: $E_T^{ISO} < 7$ GeV in isolation cone $R = \sqrt{\Delta \eta^2 + \Delta \phi^2} = 0.4$;
  - $100 \leq E_T(\gamma) \leq 1000$ GeV,
  - $|\eta(\gamma)| < 1.37$ or $1.52 < |\eta(\gamma)| < 2.37$.

\[ \int L \, d\sigma / dE_T^{\gamma} \left[ \text{[GeV]} \right] \]

\[ \sigma_{pp\rightarrow\gamma X} = 234 \pm 2^{+13}_{-9} \text{ stat} \pm 4 \text{ syst} \pm 4 \text{lumi } \text{pb} \]

\[ \sigma_{pp\rightarrow\gamma X} = 122 \pm 2^{+9}_{-7} \text{ stat} \pm 2 \text{ syst} \pm 2 \text{lumi } \text{pb} \]
Isolated photon pair production

- 7 TeV dataset (4.9 fb⁻¹);
- Photon selection: Isolation: $-4 < E_T^{\text{ISO}} < 4$ GeV in $R = \sqrt{\Delta \eta^2 + \Delta \varphi^2} = 0.4$;
  - $E_T(\gamma_1) > 25$ GeV, $E_T(\gamma_2) > 22$ GeV,
  - $|\eta(\gamma_1, \gamma_2)| < 1.37$ or $1.52 < |\eta(\gamma_1, \gamma_2)| < 2.37$.

\[ \sigma_{p p \rightarrow \gamma \gamma X} = 44.0^{+3.2}_{-4.2} \text{ pb} \]
Summary

- An overview of recent ATLAS, CMS, and LHCb results has been presented.

- The pQCD predictions on W, Z, and direct photon production have been extensively tested using the 7 TeV datasets and a special low-pileup dataset at 8 TeV.

- Over 20 fb\(^{-1}\) (2 fb\(^{-1}\)) of data, collected by ATLAS and CMS (LHCb) at 8 TeV, are available for more precise measurements.