Experimental systematic errors

for high Q^2 LHC Physics
Can one guess them today?

Michael Dittmar (ETH-Zürich/CMS)

- Introduction
- some assumptions
- LHC final states
- learning from previous experiments
- guessing the systematic errors

Introduction

- all cross section measurements
  (even at the LHC) will have systematic errors!

- experimental and theoretical limitations "should" match
  if one does not want to waste time and effort!

- estimates of statistical errors are straight forward
  (and "known" in most cases) ($\Delta(stat) = 1/\sqrt{N}$)

- sources of systematic errors:

  – how well do we know efficiencies

  – how well do we know backgrounds

  – reduce errors by "relative (ratio)" measurements

Experimental Event Counting

$$N_{\text{signal}} = N_{\text{observed}} - N_{\text{background}}$$

$$N_{\text{corrected}} = N_{\text{signal}} / \ \textbf{efficiency}$$

Experiment = Theory Prediction?

$$N_{\text{expected}} = \sigma_{\text{theory}} \times \ \textbf{L (luminosity)}$$

from protons to partons

$$N_{\text{expected}} = \sigma_{q,g \to X} \times \text{PDF}(x_1, x_2, Q^2) \times L_{pp}$$

Assumptions

1. ATLAS/CMS can be realized according to their design for most cases: they should function "better" than CDF/D0! (this is not the case for b-tagging!)

2. LHC experimentation more difficult than Tevatron/LEP measurements!

3. LEP (II) systematic errors can be used to guess limitations for LHC experiments! (like detector stability)

   + efficiency uncertainties for isolated leptons, photons, jets and missing E_T.

   ++ difficulties of counting jets

- modelling of Standard Model backgrounds
  $\rightarrow$ uncertainties must be larger at the LHC!

Experimental requirements for LHC precision reactions:

- counting statistics $\pm 1\%$ $\rightarrow$ with only 10^4 events ($\Delta N/N = 1/\sqrt{N}$)

- backgrounds: (reduced/controlled by cuts)

- efficiency and geometrical acceptance (as high as possible!)

some optimization between:
$\sqrt{N}$, signal/background and efficiency
(use reaction ratios to reduce systematics!)

CMS/ATLAS potential (my guess)

“Isolated” electrons, photons: $\Delta E/E_{e,\gamma} =$ few % $/\sqrt{E}$ + 0.5%(goal)
excellent angular resolution, “high” efficiency and “small/negligible” backgrounds
for $p_t \geq 10$ GeV (?) and $|\eta| \leq 2.5$(?)

“Isolated” (100 GeV?) muons: $\Delta p_t/p_t \approx 2 - 5\%$
excellent angular resolution “high” efficiency and “small/negligible” backgrounds
for $p_t \geq 10$ GeV (?) and $|\eta| \leq 2.5$(?)

“Isolated(??)” jets: $\Delta E_t/E_t \approx 100 - 200\%/\sqrt{E}$ + 5% (??)
good angular resolution and efficiency, but “difficult” systematics (nonlinearity)
for $p_t \geq 30$ GeV (??) and $|\eta| \leq 4.5$(??)

Missing transverse momentum: depends on final state!
in general a mixture between lepton and jet accuracies

Leptonic (plus γ) final states

- resonance production of W and Z, the normalization process:
  ($q\bar{q} \to Z \to \ell\ell$ and $q\bar{q} \to W \to \ell\nu$)

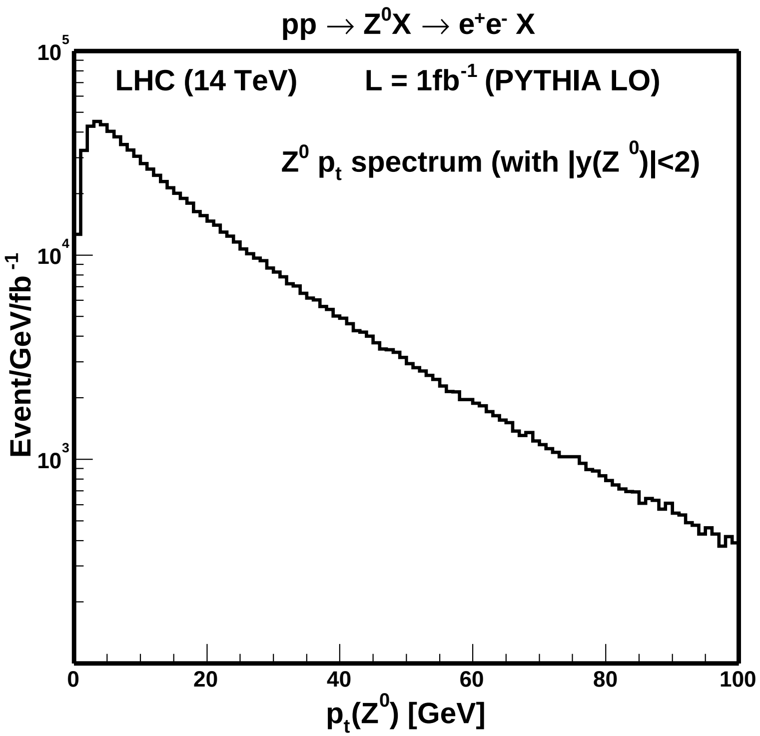
- high mass Drell–Yan lepton pairs
  $q\bar{q} \to (\gamma, Z)^* \to \ell\ell$ and
  $q\bar{q} \to W^* \to \ell\nu$

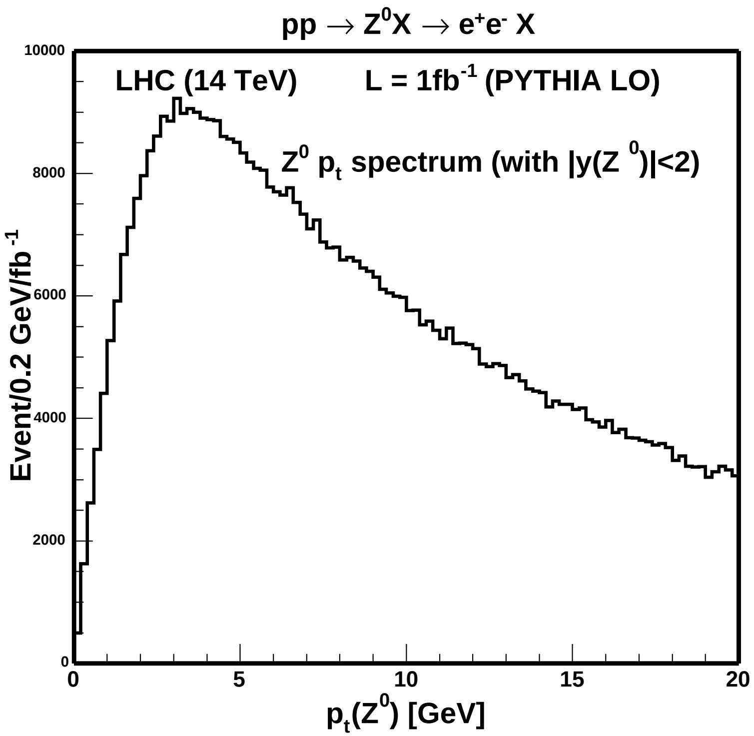
- boson pair physics (WW, WZ, ZZ, Wγ etc)
  $q\bar{q} \to WW(WZ, ZZ, W\gamma)$
  with $W, Z \to$ leptons
  ($ZZ \to \ell\ell\ell\ell$ has small cross section)

expect clean event samples, but diboson mass (Q^2)
sometimes not well measured($W \to \ell\nu$)
to be compensated with accurate Monte Carlo!

the most precise (QCD?) test at the LHC: the p_t spectrum of the Z boson!

Huge cross section, "no" background and precision measurement $pp \to ZX \to e{+}e^- X$





who will predict p_t spectrum in all its beauty?

including (multi)jet activity and rapidity distribution!

use result to invent (iterative?) a method to predict p_t spectrum for other final states!

Testing "initial state" QCD predictions

Measure/predict cross section ratios (including experimental cuts)
Electroweak leptonic "final" states like:

$pp \rightarrow \gamma Z * / pp \rightarrow Z^0$ and $pp \rightarrow WW / pp \rightarrow Z^0$

similar for other cross section ratios!

Some recent Tevatron Results

$\sigma\times$ Br(W) and $\sigma\times$ Br(Z) (CDF HEP-EX 0406078)

- measurements with electrons and muons (similar errors!)

- $\approx \pm$ 2% systematic error!
  systematics for cross section Ratio (W/Z) = $\pm$ 1.4%

- D0 measurement has factor 1.5-2 larger systematic errors, but ratio systematics similar to CDF!

Some recent Tevatron Results

σ Zγ(γ) (D0 18.2.05 hep-ex/0502036)

- 138 $ee\gamma$ and 152 $\mu\mu\gamma$ events selected

- roughly 10% background events (with systematic uncertainty $\approx \pm$ 10-15% from γ - jet misidentification)

- efficiency uncertainties $\approx$ 5% (from "data" using large Z sample)

- PDF choice (for SM comparison) adds another 3.3% error.

Some recent Tevatron Results

CDF top cross section measurement (197 pb^{-1}) (CDF Dec. 2004)

- $\sigma = 7.0 + 2.4(-2.1)(stat.) + 1.6(-1.1)(\approx 20\%)(syst.) \pm 0.4$ (lumi)
- expect that systematic error (with 2 fb^{-1} will drop to $\pm$ 10%!
- σ(theory) = $\pm$ 15%

CDF SUSY search with b-tagging (prelim. CDF Dec. 2004)

- expected background single b-tag: 16.4 $\pm$ 3.7 events (dominated by systematics 3.15 events)
- expected background double b-tag: 2.6 $\pm$ 0.7 events (dominated by systematics 0.66 events)

Some recent LEP II Results

ALEPH BR $(W \to q\bar{q}) = 67.13 \pm 0.37(stat) \pm 0.15(syst)$ %

OPAL: R_b relativ to SM $= 1.055 \pm 0.031(stat) \pm 0.037(syst)$ %

ALEPH/DELPHI $ee \to \gamma\gamma$

- ALEPH's combined systematic error = 2.2% (1.2 % from efficiency, 0.8% from background)

- DELPHI's combined systematic error = 1.1% (0.95% from efficiency).

Guessing (optimistic) experimental systematic limits for the LHC

$\Delta\epsilon/\epsilon \geq 1$**% for isolated leptons and photons(?)** $p_t \geq 20$ **GeV.**

$\Delta\epsilon(b)/\epsilon(b) \geq 5$**% for "isolated" b-flavoured jets** $p_t \geq 20$ **GeV.**

Jet Veto $\Delta\epsilon/\epsilon \geq$ **few % (larger errors if one does jet "counting"!**

Ratio measurements W^+/W^-**,** W/Z **etc.. relative errors of 0.5-1% not impossible!**

$t\bar{t}$ **cross section relative to W and Z difficult to imagine errors smaller than 5-10%!**

background uncertainties (from theory and cut efficiencies):
$\Delta B/B =$ **5-10%???**
thus signal/background ratios larger than 0.25-0.5 required for "discovery channels"!