Update on ZZ->llnunu Analysis and Sensitivity to Anomalous Couplings

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Update on ZZ->llnunu analysis using CSC11 datasets (Tom Barber)

- V12 ZZ->llnunu with 1mm bug fixed is not yet available
- V12 sample with 1mm bug has shifted Z mass peak for electrons

Very preliminary investigation of limits on anomalous couplings from ZZ->llnunu

- Very large backgrounds from Z+jets and ttbar
- Sensitivity of limits to these backgrounds
Update on ZZ-\rightarrow ll
unu Event Selection

- Last meeting: cuts used in fast simulation study (S.Hassani ATL-PHYS-2003-022) applied to full simulation (csc11)
  - 2 leptons with pT>20GeV in |\eta|<2.5
  - |M(ll) – 91.2 GeV| < 10 GeV (opp charge)
  - MET_final_et > 50 GeV
  - No jet with pT>30 GeV in |\eta|<3
  - pT(ll) > 150 GeV
- Expected signal smaller than fast sim study, background very much higher (B/S ~ 15)
- Look for new cuts to remove background
pT Matching

- In signal events missing ET is balanced by pT of observed Z
- Jet veto, necessary to remove Z+jets background, removes signal events with hard gluon
- Require Z(II) transverse momentum to match the missing ET in magnitude and direction
  - $(\text{MET}-\text{Zpt})/\text{Zpt}$
  - $\phi(\text{MET}) - \phi(Z)$
- Magnitude of MET match discriminates against background
- Angle less powerful
pT Matching

- Apply pT matching cuts:
  \[ |\text{MET}-Zpt| / Zpt < 0.1 \]
  \[ 170 < \phi(\text{MET}) - \phi(Z) < 190 \text{ deg} \]
  (These rather tight – probably need loosening)
- Also veto events with 3\textsuperscript{rd} lepton (reduce WZ)
- Reduce pT(ll) cut from 150 GeV to 100 GeV
- Obtain signal/background ratio of 2.7
- Signal efficiency (for Z(ll) > 100 GeV, 2 leptons in |\eta| < 2.5 with pT > 20 GeV) \( \sim 23\% \)
- Largest remaining background is WZ
# Events Passing New Cuts

<table>
<thead>
<tr>
<th>Channel</th>
<th># selected</th>
<th># for 100 fb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZZ → ℓℓνννν</td>
<td>1192</td>
<td>649</td>
</tr>
<tr>
<td>ttbar</td>
<td>0</td>
<td>&lt; 439 (95%CL)</td>
</tr>
<tr>
<td>Z → ee, high p_T</td>
<td>0</td>
<td>&lt; 107 (95%CL)</td>
</tr>
<tr>
<td>Z → μμ, high p_T</td>
<td>0</td>
<td>&lt; 67 (95%CL)</td>
</tr>
<tr>
<td>W⁻Z → ℓ⁻νll</td>
<td>34</td>
<td>68</td>
</tr>
<tr>
<td>W⁺Z → ℓ⁺νll</td>
<td>97</td>
<td>140</td>
</tr>
</tbody>
</table>
Production of on-shell ZZ probes ZZZ and ZZg anomalous couplings: $f_4Z$, $f_5Z$, $f_4g$ $f_5g$ (all = 0 in SM)

- $f_4$ violate CP; helicity amplitudes do not interfere with SM; cross-sections depend on $f_4^{**2}$ and sign cannot be determined
- $f_5$ violate P; do interfere with SM

Forbidden in SM
Sensitivity to Anomalous Couplings

- Couplings depend on energy. Usual to introduce a form factor to avoid violation of unitarity:
  \[ f(s') = \frac{f_0}{(1 + s'/\Lambda^2)^n} \]
- Studies below use \( n=3 \), \( \Lambda = 2 \) TeV
- Also assume couplings are real and only one non-zero
- Study AC using LO Monte Carlo of Baur and Rainwater
- N.B. jet veto removes hard gluons, so LO not so bad
Comparison with Pythia

- Check BR MC: compare with Pythia for SM
Anomalous couplings produce increase in ZZ invariant mass, Z pT and lepton pT distributions.

For ZZ->llnunu can use high pT(Z) cross-section to obtain limit, or fit Z pT distribution.

e.g above for ZZ->eenunu with pT(e) > 15 GeV, |eta(e)| < 2.5
Limits from Cross-section Measurement

- First consider measurement of $ZZ \rightarrow ll\nu\nu$ cross-section for $p_T(l) > 20$ GeV, $|\eta(l)| < 2.5$, $Z(p_T) > 100$ GeV
- Calculate cross-section, hence expected events as function of $f_{4Z}$
- Use chi-squared comparison between expected and ‘observed’ (=SM) numbers of events to determine 95% c.l. on coupling
- Calculate limit as function of ratio of background to SM signal
- First assume statistical errors only, then consider effect of a systematic error on the background
Statistical errors only
Little dependence on background fraction
20% systematic error on background

Strong dependence on background: limits independent of luminosity for high background
Limits from Fits to pT Distribution

- Limits from a simple cross-section measurement depend on pT cut – harder pT cut can give better limit despite much lower statistics
- Therefore better to fit pT distribution
- Results below are for ZZ→llnunu with pT(l)>20 GeV, |eta(l)|<2.5
- Use BR program to generate pT distributions for several values of couplings (only one non-zero at a time)
- In each pT bin fit cross-section to quadratic in coupling to obtain distribution at arbitrary value
Cross-section v f4Z in pT bins

50 < pT(Z) < 100 GeV

100 < pT(Z) < 150 GeV

150 < pT(Z) < 200 GeV

200 < pT(Z) < 300 GeV

300 < pT(Z) < 500 GeV

500 < pT(Z) < 1000 GeV

4th June 2007

C.P. Ward
Create ‘fake data’ sample:
- Calculate expected SM events in each pT bin
- Add background – constant fraction of SM
- Apply Gaussian smearing

Construct error matrix
- Statistical errors plus systematic error on background assumed fully correlated

Fit fake data sample
- One parameter fit to f4Z**2 or f5Z
- 95% c.l. from $X^2 - X^2_{\text{min}} = 3.84$
Limits from Fits to pT Distribution

- Generate 1000 fake data samples for each value of background fraction and each value of background systematic
- Mean $X^2/dof = 1$
- Mean $f4^2 = 0$
  As expected
Results for 100 fb⁻¹, eff = 1.0 from Different Fit Ranges (statistical errors only)

- Lower pT cut has ~no effect on limits
- Important to go to as high pT as possible
Results for 100 fb-1, eff = 0.3 from Fit in Range
100 GeV < pT < 1000 GeV

With uniform background, systematic error has little effect
Effect of Different Background Assumptions

- Assuming 100 fb⁻¹, eff = 30%
  (systematic error 0 – 30%)

<table>
<thead>
<tr>
<th>Background Form</th>
<th>95% c.l. on f4Z</th>
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<tbody>
<tr>
<td>No background</td>
<td>0.0035</td>
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<tr>
<td>Uniform 30%</td>
<td>0.0037 – 0.0038</td>
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<tr>
<td>Rising from 30% to 80%</td>
<td>0.0040 – 0.0041</td>
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<td>25% + 0.1 event/GeV</td>
<td>0.0052 – 0.0059</td>
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Summary and Plans

• Cut on pT match gives good background rejection
  • Need to optimise cuts
  • Investigate remaining background – e.g. missing lepton in WZ?
  • Investigate estimation of background from data / Atlfast
  • Redo study with 12.0.6 when signal sample available

• First look at sensitivity to anomalous couplings:
  • Uniform background not a problem if it is well-known
  • More realistic background will give some degradation in limits
  • Optimal binning of pT distribution will depend on luminosity
  • Need to think how to predict expected pT distribution for serious analysis (reweighting, fast MC etc.)

• Finally: John Chapman has started feasibility study of ZZ->lltautau channel
Missing Pt Background

- Check correlations by making 2D histograms of angle and magnitude match for signal and background.
- Lines at:
  - $|\text{MET-Zpt}/Zpt| < 0.1$
  - $170 < \phi(\text{MET}) - \phi(Z) < 190$
  - Very effective at Z+jets removal.
  - WZ has peak in same region, but wider distribution.
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</table>

**Total:** 156

**S/B = 2.7, signal efficiency 2.45%**

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C.P. Ward