Searching for new particles with Z’s and jets

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Oct. 10, 2007

Outline:
- Motivation
- CDF
- CMS

Photo of completed CMS Tracker Outer Barrel with cosmic hits and tracks overlaid.
Theoretical motivation
Theoretical motivation

Questions:

What is the origin of mass?
Why three generations?
Why the observed mass (or Yukawa coupling) hierarchy?
What is dark matter, and can we study it in the lab?
Are there additional symmetries or dimensions?
Theoretical motivation

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Models:

New Symmetries (SUSY)
New Forces (Z’)
New Dimensions (Large)
New Dimensions (Warped)
...

Theoretical motivation
for avoiding a specific theoretical motivation

Any one model point is most likely not correct.

So, look for anything new using what we already know.

Particularly at the LHC:

The large increase in energy will make some things striking in early data if kinematically clean signatures.
Search for high mass di-leptons

Dielectron Mass (GeV/c^2)
Search for high mass di-leptons
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Cousins et al.
CMS Physics TDR, Vol II
Search for high mass di-leptons

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Search for high mass particles decaying to a $Z + \text{jets}$

We are searching for new particles in $Z + \text{multi-jets}$ with large total energy.

The approach is to use simple kinematics.

Recently been completed at CDF.

We are preparing a similar one for CMS.
Search for high mass particles decaying to a $Z + \text{jets}$
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Standard Model backgrounds to Z+jets

Difficult to calculate NNLO QCD
Hard part is the soft QCD
  in jet counting due to fragmentation.
Convolved with PDFs
What $Q^2$?
Z+jets is easy to get wrong

E.g. Pythia $Z \rightarrow \nu\nu + \text{jets}$ prediction makes it look like that background is negligible: $S/B \sim 10/1$. 
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E.g. Pythia $Z \rightarrow \nu \nu + \text{jets}$ prediction makes it look like that background is negligible. S/B $\sim 10/1$.

A better MC (ALPGEN) gives S/B $\sim 1/1$. 
Z+jets is hard to model correctly

ALPGEN+MLM matching is an attempt to get it right (or at least less wrong).

Higher order matrix elements calculated explicitly.

Careful generator level matching of jets and partons removes effects from soft QCD (fragmentation) pushing events between $Z+n$ and $Z+n+1$ jets.
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Has been partially validated (and tuned) at the Tevatron.

Will need to be validated with LHC data.

Our approach is to use the data directly to predict the background.
Data-based Z+jets predictions

Searching for events with many jets and large energy.

\[ N_J \geq 3 \]

\[ J_T = \text{Sum of jet energies} > M_X. \]

Need to predict the number of jets and their energy.
Data-based Z+jets predictions

Could predict the high jet multiplicity events from a fit to the low. $N_J$ spectrum is approximately an exponential due to $\alpha_S$.

Not very robust.
Use lower-level kinematics…
Data-based $Z+\text{jets}$ predictions

Predict $N_{j}\geq3$ jet events from the ET spectrum of 2 jet events.

$$f \left( E_T \right) = N \: \frac{e^{-E_T/p_1}}{(E_T)^{p_2}}$$

![Graph showing the distribution of $3^{rd}$ highest jet $E_T$ (GeV) with $N_{j} = 2$ and $N_{j} \geq 3$.](image-url)
Data-based Z+jets predictions

Predict $J_T$ spectrum of $\geq 3$ jet events.

The jet $E_T$ shape changes with $N_J$ bin; it hardens, increasing $p_1$.

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Fit for this change in $N_J=1$ and 2.

Extrapolate.
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Predict $J_T$ spectrum of $\geq 3$ jet events.

Fit $N_J$ distribution
(now only mildly important)

Sample jet $E_T$ shapes
to obtain a total jet energy, $J_T$ distribution.
Data-based $Z + \text{jets}$ predictions

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Uncertainties from fit
(statistical and systematics).
How well does it work?

Check the method for self-consistency in MC.
How well does it work?

Check the method in data.

Can’t use Z+jet data--signal bias. So use X+jet, where X shouldn’t matter to the jets. Use X = fake Z made from 2 jets.
How well does it work?

Check the method in data.

Can’t use $Z$+jet data--signal bias. So use $X$+jet, where $X$ shouldn’t matter to the jets. Use $X = \text{fake } Z \text{ made from 2 jets.}$
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Can’t use Z+jet data--signal bias. So use X+jet, where X = fake Z made from 2 fake leptons.
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Can’t use Z+jet data—signal bias. So use X+jet, where X = fake Z made from 2 fake leptons.

Fake lepton sample large enough to allow pseudo-experiments to check uncertainties.

Systematic uncertainties appear a bit over-estimated.
How well does it work?

Can we find a signal?

Instead of Z+jet data, we look at W+jet data to search for decay of a heavy object (top).
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\[
g \geq 3 \text{ jet excess of } 323 \pm 29 \text{ evts.} \\
\sigma = 9 \pm 1 \text{ pb (stat only)}
\]
How well does it work?

Can we find a signal?

Instead of Z+jet data, we look at W+jet data to search for decay of a heavy object.

$J_T$ distribution well matched to top
Look in Z+jets data
Look in $Z+jets$ data
Searched was constructed to be model-independent. To quantify the null-result, we set limits on one model, a 4th generation quark.

hep-ex/07063264
Z+jets search at CMS

Aim to similarly predict Z+jets background from data.
Z+jets search at CMS

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Leptons:
\( p_T > 20 \)
\( |\eta| < 2.5 \)

Jets:
\( p_T > 60 \)
\( |\eta| < 3 \)
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Aim to similarly predict Z+jets background from data.

Jet $E_T$ extrapolation is long, and sensitive to jet energy scale.
Want a simple kinematic measure that is robust against a dirty accelerator background.
Want a simple kinematic measure that is robust against a dirty accelerator background and a messy detector.
Z+jets search at CMS

The kinematics of the Z are well measured; it is fully reconstructed.
The kinematics of the Z are well known; it is fully reconstructed. And, the kinematics are simple. The rapidity is $\approx$ flat.
Z+jets search at CMS

The kinematics of the Z are well known; it is fully reconstructed. And, the kinematics are simple. The rapidity is $\approx$ flat. *Signal* is central.
Z+jets search at CMS

Limited lepton coverage limits Z rapidity.
But same story: The rapidity is $\approx$ flat. **Signal** is central.
Z+jets search at CMS

Measure background with forward Z+jet events and look for an excess of central Z+jet events.
Z+jets search at CMS

Simple to say:

Measure the higher order QCD in bkgd dominated data.

Complications:

Lepton acceptance will vary with \( \eta \). Measurable in 0 jet.

Jet acceptance will vary with \( \eta \). Measurable in Z-jet balance.

Kinematics vary with \( \eta \) and \( N_J \). Measurable?
Measure central/forward $N_J$ ratio at low $N_J$ and extrapolate. 0-jet is special due to jet’s $p_T$ bias and $t$-channel diagrams.
Z+jets search at CMS

FWD prediction.
Central Zs.
≈ 10 /fb

750 GeV Gluino
Z+jets search at CMS

Obtain a reasonable prediction just from normalization scaling.
Z+jets search at CMS

Events / (50 GeV)

$N_{\text{j}} \geq 4$

Central S+Bkgd

750 GeV Gluino

Bkgd Prediction
Z+jets search at CMS

Events / (50 GeV)

$N_j \geq 5$

Central S+Bkgd

750 GeV Gluino

Bkgd Prediction

$J_T$ (GeV)
Z+jets search at CMS

![Graph with data points and labels: N_j ≥ 6, 750 GeV Gluino, Central S+Bkgd, Bkgd Prediction.]
Robustness checks

ALPGEN modeling is not perfect. Test robustness by making it more worse. Remove events with an odd number of partons. Only Z+0,2,4 partons. Distributions wrong(er)--but data-based prediction is self consistent.
ALPGEN modeling is not perfect. Test robustness by making it more worse. Remove events with an even number of partons. Only $Z+1, 3, 5$ partons. Distributions wrong--but data-based prediction is self consistent.
Detector modeling is not perfect. (Actually all done at generator level). Test robustness by randomly throwing out 20% of jets. Distributions wrong--but data-based prediction is self consistent.
Future work

• Simulation effects (and how well they can be measured)

• Jet $E_T$ dependence
  • Sensitivity vs $E_T$ threshold
  • Low $E_T$, high $N_J$ is a control sample

• Other samples, e.g., $\gamma +$ jets.
Summary

• Searched, and searching, for Z+jets

• Aim to minimize model dependence

• Aim to minimize modeling dependence
Additional slides
Search for high mass di-bosons
Search for high mass particles decaying to a $Z + \text{jets}$
Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla
Exponential parameter extrapolation in data
SM Alpgen MC: Z + 3 Jets