Driving Missing Data at the LHC

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on behalf of the BlackHat collaboration

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Outline

SUSY search at LHC, at 7 TeV

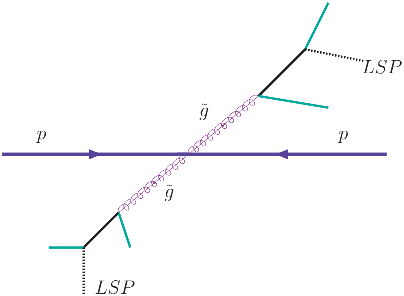
Estimating backgrounds

Role of QCD theory

SUSY searches

- Gluinos/squarks are pair produced
- Generic signature is MET + jets

Typical SUSY event:



- How can SM mimic this?
  - $W \rightarrow l^{\pm}\nu$ with undetected lepton
  - QCD with mismeasured jet
  - $Z \rightarrow \nu\overline{\nu}$ Irreducible background - subject of this talk

Data Driven Background Estimation

- CMS uses photons to estimate Z (Incandela's Group)

  [CMS PAS SUS-08-002]

  [CMS PAS SUS-10-005]

theory input

$$\underbrace{\sigma(pp \to Z(\to \nu\overline{\nu}))}_{\text{SM irr. BG}} = \underbrace{\sigma(pp \to \gamma)}_{\text{measure this}} \times \overbrace{R_{Z/\gamma}}^{\text{theory input}}$$

SM irr. BG

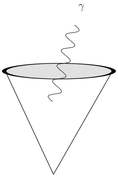
measure this

- Can also use $Z \to \mu\overline{\mu}$, but γ has better statistics
- So what is the conversion factor R? (and its error)

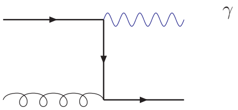
See later in this talk!

Photons at Colliders

- Two types of photon - prompt and fragmentation
- Z production related to first kind
- Require isolated photons to remove the fragmentation contribution



fragmentation



prompt

- No concrete distinction in pQCD
- We want to limit hadronic activity close to photon
- Two approaches:
  1. Use (non perturbative) fragmentation functions
  2. Define an observable for which frag. contribution is zero

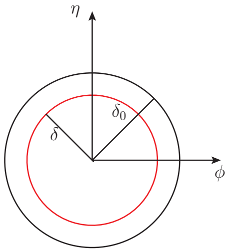
Photon Isolation a la Frixione [hep-ph/9801442]

[see Jaeger, Williams]

- In pQCD, have to be careful to preserve Infrared Safety
- Can't veto QCD radiation arbitrarily!
- Frixione: remove frag. photons in an IR safe way

$$\sum_i E_{iT}\,\theta(\delta - R_{i\gamma}) \leq H(\delta)$$

$$H(\delta) = E_T^{\gamma}\epsilon\left(\frac{1-\cos\delta}{1-\cos\delta_0}\right)^n$$



- Important: $H(\delta) \to 0$ as $\delta \to 0$: soft radiation allowed close to γ
- We choose $\epsilon = 0.025$, $\delta_0 = 0.3, n = 2$

QCD Predictions

Next-to-leading order predictions are needed to control uncertainties in LHC predictions

Need for NLO

- reduced scale uncertainties: $\mathcal{O}(50\%) \to \mathcal{O}(10\%)$
- can study appropriate scale to use
- beginnings of jet structure

But severe technical difficulty... need to automate!

- complicated IR structure of QCD
- traditional bottleneck: virtual corrections
- dramatic progress last $\sim$ 3 years
- BlackHat, CutTools, Madloop, Rocket, Samurai . . .

BlackHat

- Implementation of modern generalised unitarity cut method
- Evaluates coefficients of integrals:

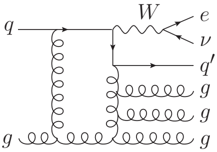
$$A = R + \sum_i d_i$$

$$+ \sum_i c_i$$

$$+ \sum_i b_i$$


- High-multiplicity one-loop QCD amplitudes
- Speed critical - require fast trees Berends Giele, BCFW, Grassmanian(new!)
  $\rightarrow$ 90-95% of computing time spent on trees

- Extremely powerful -
  e.g. W + 4 jet
  [BlackHat Collaboration 1009.2338]



Setup

- We calculate the ratio Z/γ in association with 2 jets, following the CMS cuts (3 jets coming soon)
- Use SHERPA for real emission, integration and process management

  [Gleisberg, Hoeche, Krauss, Schonherr, Schumann, Siegert, Winter]
- The critical variables are

$$H_T = \sum_{\text{jets}} E_T^{\text{jets}}, \qquad \overrightarrow{\mathrm{MET}} = -\sum_{\text{jet}} \vec{p}_{\text{jet},T}$$

- three sets of cuts:
  1. $H_T > 300$, $|\overrightarrow{\mathrm{MET}}| > 250$ high MET
  2. $H_T > 500$, $|\overrightarrow{\mathrm{MET}}| > 150$ high H_T
  3. $H_T > 300$, $|\overrightarrow{\mathrm{MET}}| > 150$ "baseline"
- impose

$$\Delta(\Phi)(\overrightarrow{\mathrm{MET}}, \text{jet}) > 0.5$$

  to suppress QCD multijet background

Analysis Tools

- NLO calculations often very computationally intensive
  $\rightarrow$ don't want to run again and again for different cuts
- solution: store events and apply analysis cuts later
- ROOT ntuple files are tailor made for this purpose. Store event momenta and weights:

$$M^{\mathrm{loop}} = A + B \ln \mu + C \ln^2 \mu$$

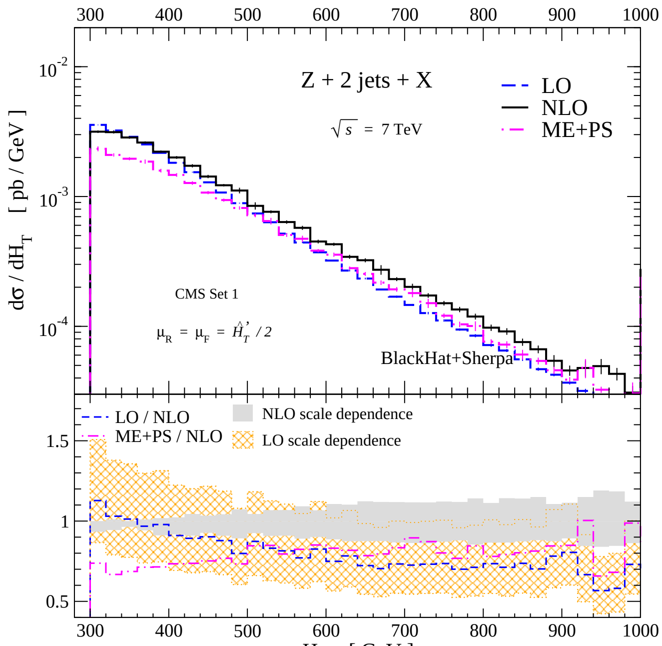
- Can change scales/pdfs/jet definitions after the run
- Experimentalists fluent in this framework
  $\rightarrow$ just give them the ntuples
- Health warning: you can tighten, but not loosen the cuts

Preliminary Results

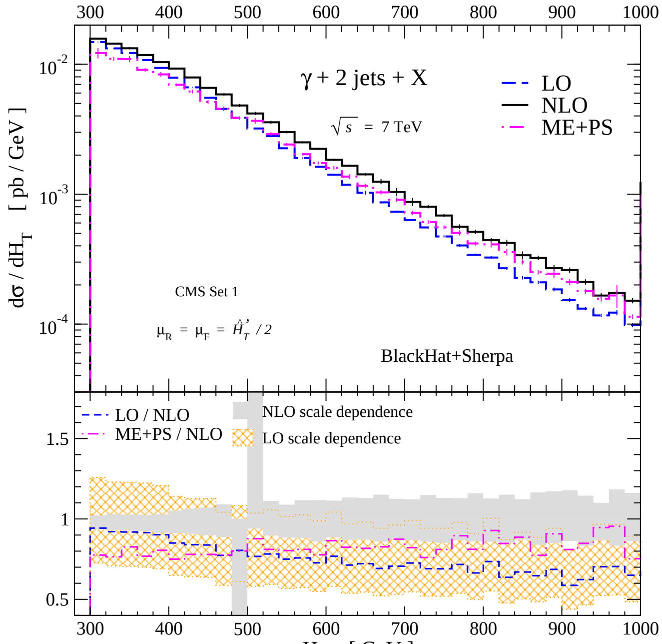
process	LO	ME+PS	NLO
$\gamma + 2j$	$2.220^{+0.762}_{-0.526}$	2.110	$2.609^{+0.159}_{-0.241}$
$Z + 2j$	$0.521^{+0.180}_{-0.124}$	0.478	$0.560^{+0.012}_{-0.043}$
ratio	0.235	0.226	0.214

- Matrix Element + Parton Shower (ME+PS) as implemented in Sherpa. Parton shower matched to exact LO MEs, using CKKW to avoid double counting.
- Usual prescription for theoretical uncertainty - scale variation
- For ratios this is problematic, as variation mostly cancels
- We estimate the error as difference between NLO and ME+PS results
  $\rightarrow 5 - 10\%$
- Encouraging agreement between very different calculation schemes

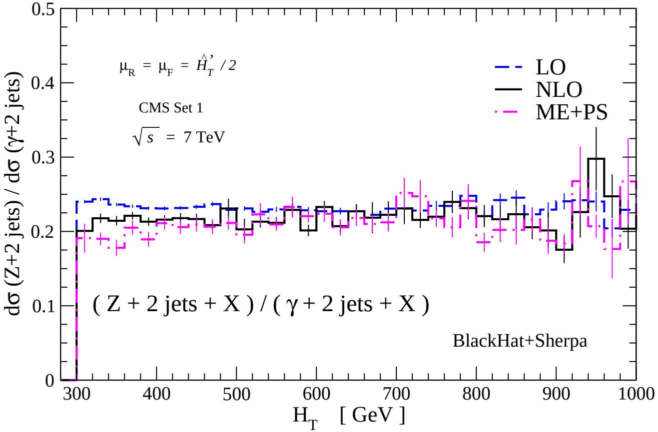
Preliminary Results



Preliminary Results



Preliminary Results



- Excellent agreement between different theoretical approaches

Summary

- CMS uses γ+jets measurement to predict Z+jets
- Important background to SUSY (MET+jets)
- Extrapolation calls for precise theory prediction
  $\rightarrow$ ratio is calculated in pQCD
- I presented a NLO+MEPS study using BlackHat+Sherpa
- Our results used directly for estimating error in γ/Z conversion in CMS analysis