Controlling Backgrounds in New Physics Searches

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Outline

Backgrounds are important 4BSM

Prefer data-driven methods

Role of QCD theory and need for precision

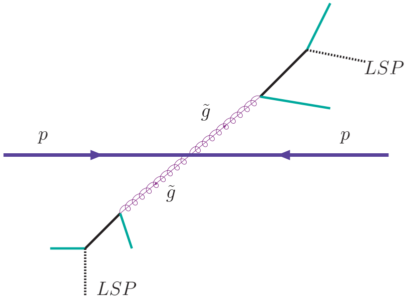
Distributing NLO results

Summary

New Physics Searches

- focus has been on MET
- e.g. gluino/squark pair production
- generic signature is MET + jets

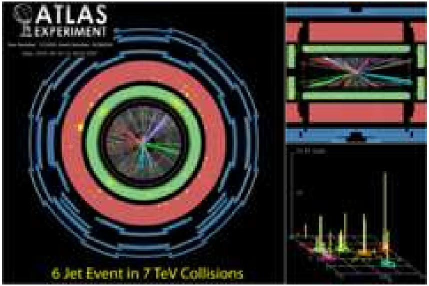
Typical SUSY event:

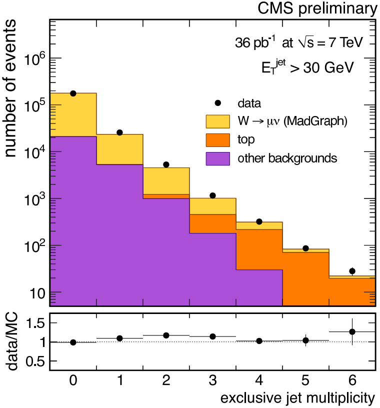


- How can SM mimic this?
  - $W \rightarrow l^{\pm}\nu$ with undetected lepton
  - QCD with mismeasured jet
  - $Z \rightarrow \nu\overline{\nu}$ Irreducible background - see later in this talk!

Hard Jets at the LHC

Multi-jet events are important at the LHC





- High energy → large phase space → many jets
- Important to confront this theoretically and experimentally

Large uncertainties at leading order

- LO predictions suffer from a large theoretical uncertainty
- coupling and PDFs depend on μ

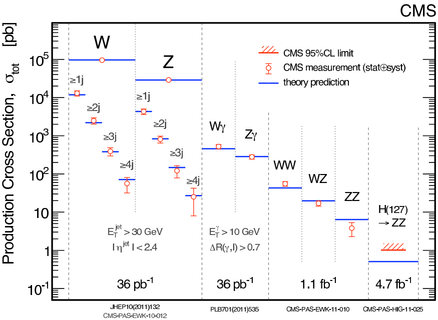
$$\alpha_S(\mu^2), \qquad f(x, \mu^2)$$

- we estimate uncertainty by varying μ
- each jet brings a power of $\alpha_S(\mu^2)$
  $\rightarrow$ multi-jet cross sections most in need of NLO correction
- higher precision knowledge of SM backgrounds increases discovery potential - see later

A few words on QCD Predictions

[see Stefan Hoeche's talk]

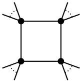
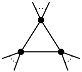
- LHC workhorses for full event simulation: Herwig, Sherpa, Pythia
- ME+PS matching important when there are many hard jets
  $\rightarrow$ gets shape right
- But need NLO to get normalization correct. This meant sacrificing shower + hadronization, but...



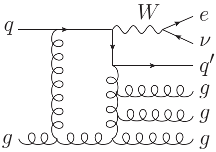
- ...recent exciting progress in matching NLO/PS:
  MC@NLO [Frixione, Webber; SHERPA]
  POWHEG [Nason; Frixione, Nason, Oleari]
- these tools still require the one-loop amplitude as input
  [BlackHat, GoSam, MCFM, Rocket ...]

BlackHat

- Efficient evaluation of 1-loop QCD amplitudes
  $\rightarrow$ component of NLO calculation (generally the hardest part)
- Implementation of modern generalised unitarity cut method
- Evaluates coefficients of integrals:

$$A = \quad R + \sum_i d_i$$  $$+ \sum_i c_i$$  $$+ \sum_i b_i$$ 

- Opens the door to precision for high-mulitiplicity observables
- Speed critical - require fast trees Berends Giele, BCFW, analytic
  $\rightarrow$ 90-95% of computing time spent on trees
- Extremely powerful: e.g.
  Z + 4 jets
  `[BlackHat 1108.2229]`
  W + 5 jets
  `[forthcoming]`



Case Study:

controlling MET+jets background with NLO precision

Data Driven Background Estimation

- CMS uses observed photons to estimate unobserved Z bosons

  [CMS PAS SUS-08-002]

  [1106.4503]

theory input

$$\sigma(pp \to Z(\to \nu\overline{\nu})) = \sigma(pp \to \gamma) \times R_{Z/\gamma}$$

background to NP

measure this

- similar approaches possible, benefit of above is statistics (no branching ratio!)
- so what is the conversion factor *R*? (and its uncertainty)

$\longrightarrow$ let's *calculate* this at NLO in QCD

Setup

- We calculate the ratio Z/γ in association with 3 jets, following the CMS cuts ("classical" MET + jets analysis)
- Use `BlackHat` for virtual part, `SHERPA` for real emission, integration and process management

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

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

- look at various regions in this space:
  1. $H_T > 300$, $|\overrightarrow{\text{MET}}| > 250$ high MET
  2. $H_T > 500$, $|\overrightarrow{\text{MET}}| > 150$ high H_T
  3. $H_T > 300$, $|\overrightarrow{\text{MET}}| > 150$ "baseline"
  4. ...

Estimating theoretical uncertainty

process	LO	ME+PS	NLO
$Z + 2j$	$0.521^{+0.180}_{-0.124}$	0.416	$0.560^{+0.012}_{-0.043}$
$\gamma + 2j$	$2.087^{+0.716}_{-0.494}$	1.943	$2.448^{+0.142}_{-0.225}$
ratio	0.250	0.214	0.229

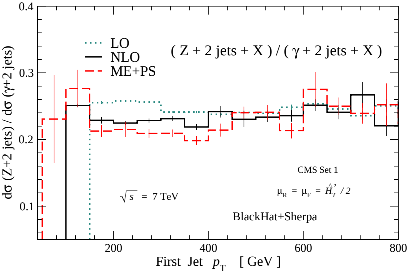
- Matrix Element + Parton Shower (ME+PS) as implemented in Sherpa. Parton shower matched to exact LO MEs.
- Usual prescription for theoretical uncertainty - scale variation
- For ratios this is problematic, as variation mostly cancels
- We estimate the uncertainty as difference between NLO and ME+PS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

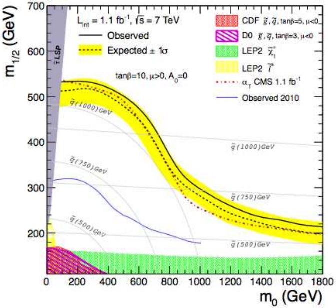
Outcome

- we worked closely with groups from CMS
- fruitful cross-talk between theory and expt
- this search was very constraining...

Good example of utility of high-precision theory (ratio = input into data driven method)

See 1111.4193 and [forthcoming] for many plots and numbers

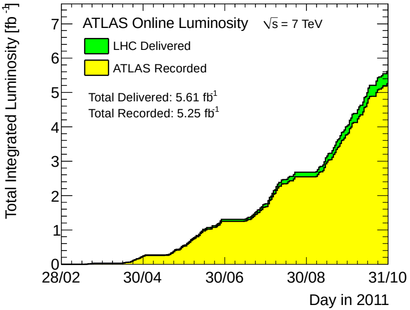




Outlook

- roughly $5\mathrm{fb}^{-1}$ taken in 2011
- With more data, we can cut more
- Higher H_T and MET [CMS PAS SUS-11-004]
- Potential large logs, e.g.:

$$\ln \frac{H_T}{p_T^Z}$$



Questions:

- how are theory predictions doing out on the tails?
- do electroweak corrections become important?
- Full event simulation? ✓

  [Ask, Parker, Sandoval, Shea, Stirling]
- Impact of tagging b-quarks ? [1106.3272, CMS-PAS-SUS-11-006]

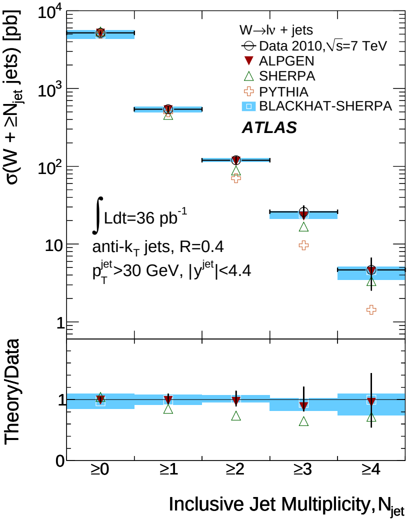
Analysis Tools

- NLO calculations often very computationally intensive
  $\rightarrow$ don't want to run again and again for different setups
- 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

Ntuples in Action - ATLAS $W + \text{jets}$ [1201.1276]



- ntuples generated with BLACKHAT+SHERPA [1009.2338]
- experimenters perform their own analysis of the NLO results
- see also Z+4-jets [ATLAS 1111.2690] and pure QCD 4-jet [forthcoming]
- we are moving towards public release of ROOT ntuples, including software for their analysis

Summary

- multi-jets crucial at LHC

- example: Z/γ ratio needed for NP search in Jets+MET channel
  $\rightarrow$ I presented a detailed study of higher order QCD corrections

- Our results used by CMS to estimate theoretical uncertainty
  $\rightarrow$ feeds directly into exclusion limits (and discovery potential. . .)

- ROOT ntuple format as a way to distribute NLO event samples
  $\rightarrow$ already in use by ATLAS, excellent agreement of NLO $V + 4$-jet with data