Effect of LHC Pile Up on Higgs searches

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• With current LHC conditions ~ **average 5 interactions per bunch crossing** (will increase in 2011)
• In high luminosity environment hadron collider it is crucial to address Pile Up (PU) issues
• Results in overall **higher activity** in the detector, and affects trigger rates, vertexing and tracking, **lepton isolation, missing energy and jet resolution**, b-tagging etc ...

Isolate low momentum minimum bias contribution from the hard scattering by:

• requiring **good vertexing** identification efficiency and matching of charged particles to the prompt vertex
• for neutral particles (no tracking info) calculate offset on an event-by-event basis
General Strategy:
- counting experiment
- divide in 4 subchannels: ee, μμ, μe, eμ final states
- cut-based or multivariate in 0/1/2 jet hypothesis

Signal: **2 well isolated and identified leptons plus high transverse missing energy (plus 0/1/2 jets)**

Main backgrounds
- WW (irreducible), W+jets, tt, Single Top, Drell-Yan

Main concerns for Pile-up are on:
- lepton isolation (against Wjets and QCD backgrounds)
- Missing \( E_T \) and jet resolution (against Drell Yann and Top)
• Good vertex identification is crucial for dealing with high pile-up conditions

• In CMS Deterministic Annealing (DA) algorithm was developed to deal with high pile-up

• Able to separate vertices in very close position

• DA allows to recover vertex reconstruction inefficiencies at high pile-up (linearity)

• In order to simulate the pile-up interactions in data, the hard process is superposed with minimum bias simulation and then reweighted in order to match the number of vertices distribution observed in data

Best vertex selection

• Vertex with highest momentum sum of tracks is chosen as the signal vertex

• Lepton tracks are required to be matched within \((d0,dZ)\), transv. and longitudinal distance with the best vertex
Method FastJet Area

Algorithm allows to measure the jet’s susceptibility to contamination from diffuse noise and a technique to measure the level $\rho$ of this diffuse noise (and the underlying event) in any given event.

“To define a sensible area one therefore adds additional, infinitely soft particles (ghosts) and identifies the region in $y$, $\phi$ where those ghosts are clustered with a given jet. The extent of this region gives a measure of the (dimensionless) jet area.”

After calculating the Area for each jet in the event, compute the median density:

$$\rho = \text{median} \left[ \frac{p_{Tj}}{A_j} \right]$$

Cacciari, Salam, Soyez

arXiv:0802.1188v2

arXiv:0707.1378v2
Lepton Isolation

• Isolation allows to **disentangle prompt electron and muons from fake jets reconstructed as leptons** (QCD, Wjets)

• Define a cone or size $\Delta R$ ($\eta, \phi$ plane) around the lepton and require the total momentum inside the cone (minus the lepton)

$$\Sigma p_T / p_T < \alpha(|\eta|)$$

• With high Pile-up, contributions from non-hard interaction add an offset to the $\Sigma p_T$ in the cone → spoils signal efficiency (especially at low Higgs mass)

  → don’t include every particle that lies in the cone in the sum but only the ones matched to the signal vertex

**Isolation Strategy**

Include in the sum particles satisfying:

• inside the cone of $\Delta R < 0.3$

• $|d_z \text{ (part.)} - d_z \text{ (lept.)}| < 0.1$ cm (if part is charged)

• $p_T > 1$ GeV if neutral hadron or $\gamma$
Missing $E_T$ (1)

- Missing transverse energy used to reject Drell Yan, and QCD backgrounds (fake missing $E_T$)
- Pile-Up introduces large tails in MET distribution
- Can increase resolution by defining:

$$\text{trk-MET} \equiv -\vec{p}_T(l_1) - \vec{p}_T(l_2) - \sum_i \vec{p}_T(i)$$

$pT(li) \rightarrow$ measured lepton momenta
$\Sigma p_T \rightarrow$ sum momenta of tracks matched with the signal vertex

- Then use projected $ME_T$ (projection on orthogonal direction of closest lepton, to help $Z \rightarrow \tau\tau$ rejection), gives flat response vs number of pile up interactions
• Use the **different correlation** between projected(trackMET) and projected(MET) in signal and background

\[
\text{min} \,(\text{MET}) \,=\, \text{min} \,(\text{projected(MET)}, \text{projected(trackMET)})
\]

• Cut on \( \text{min} \,(\text{MET}) \,>\, 40 \text{ GeV} \) for ee/\( \mu\mu \)
• \( \text{min} \,(\text{MET}) \,>\, 20 \text{ GeV} \) for e\( \mu \)/\( \mu e \)
• Analysis is subdivided in 0/1/2 jets.
  O jet = no jet with $p_T > 30$ GeV
  1 jet = 1 jet with $p_T > 30$ GeV ...
• Two ways Pile-Up can affect the jet energy:
  - presence of pure minimum bias jet $p_T > 30$ GeV (negligible in the current luminosity regime, will become more relevant later)
  - positively bias the jet momentum (therefore decreasing signal efficiency)

Jet Area Method
Calculate on an event-by-event basis a density of contamination in ($p_T/\text{Area}$)
Conclusions

Problems

Higher activity in the detector: trigger rates, vertexing and tracking, lepton isolation, missing energy and jet resolution, b-tagging etc ...

Methods

• When tracking info available, use vertex track association
• FastJet is able to estimate diffuse bias coming from additional min. bias interactions → In time Pile-Up issues are SOLVED

Next?

• Will be running soon at 2-5 $10^{33}$ cm$^{-2}$s$^{-1}$ → up to x4 more pile-up foreseen
• Bunch spacing smaller, out-of-time pile-up issues become important