Prospect of BSM/SUSY in CMS

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On behalf of the CMS Collaboration

LHC Days in Split, 29/09-04/10/2014
Outline

• Motivations

• Planning for the LHC Upgrade

• How projections are made

• Some results on Supersymmetry and vector like quark searches

• Conclusions
• Conclusions from Run1:
  – Discovery of the Higgs Boson
  – No evidence of new physics so far

• There should be something more
  – in order to cancel divergences appearing in the Higgs mass computation
  – also to explain the Dark Matter

• How to find this “something”?
  – increase the energy in the center of mass → look for higher mass particles
  – increase the luminosity → look for lower cross-section processes

  This is precisely what we can get with LHC upgrades!
Planning of the LHC Upgrade

New LHC / HL-LHC Plan

Phase 1:
- Pixel
- Hcal
- L1 trigger

Phase 2:
- Tracker replacement, $|\eta|<4$
- Forward calorimetry
- Muon $|\eta|<2.4$ to $3$
- Trigger upgrade

See talk of Yves Sirois

CMS:
- Detector Consolidation

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How projections for physics are made?

- First studies: extrapolation based on 8 TeV data with a scaling of the luminosity and the cross-sections
  - no re-optimization, assume no performance degradation
  - 2 different scenarios are considered for the systematics:
    - “A”: Conservative = same uncertainties as now
    - “B”: More optimistic = relative background uncertainty is reduced

Examples of 5σ discovery w/ 300fb⁻¹:
- Stop in t+LSP:
  - $M_{\text{stop}}$ of 750-950 GeV,
  - $M_{LSP}$ of 300-450 GeV
- Heavy gauge bosons in dileptons:
  - $M_{Z'}$ of 4.5-5 TeV depending of the models
  - (8 TeV : $M_{Z'} > 2.5$ TeV)

(CMS-PAS-FTR-13-013)
How projections for physics are made?

- First studies: extrapolation based on 8 TeV data with a scaling of the luminosity and the cross-sections

- Detailed studies: Prospects using the Delphes simulation, up to 3000 fb⁻¹, <PU>~140

Pile-up included in Delphes3
- If Δz(PV – V_{PU})<0.1: PU incorporate for the object reco
- Else: charged particle suppression inside tracker, & FastJet area method for neutral particles or charged outside tracker

The impact of the PU is studied on the discovery potential
How projections for physics are made?

- First studies: extrapolation based on 8 TeV data with a scaling of the luminosity and the cross-sections

- Detailed studies: Prospects using the Delphes simulation, up to 3000 fb⁻¹, using 2 configurations for the Phase 2 detector:
  - “Conf3”: new tracker with |η| < 2.5, muon system up to |η| = 2.4, EM endcap calo à la ”shashlik”, Had endcap calo with φ segmentation x4
  - “Conf4”: new tracker with |η| < 4, muon system up to |η| = 4, EM endcap calo à la ”shashlik”, new Had endcap calo

Impact of the |η| < 4 tracker
- Better background identification (Susy produced centrally, background also populating the forward direction) → gain in S/B
- Reconstruction of vertices and charged particle association to forward jets → PU suppression (particularly important for VBF)
How projections for physics are made?

- First studies: extrapolation based on 8 TeV data with a scaling of the luminosity and the cross-sections

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Remark: Full trigger is not available → assume triggers similar to 8 TeV data taking: not realistic but as most of the signal regions are in the tails, they should be triggered without problems.

→ Main topics of this talk

- Ongoing studies with latest performance estimates for the Upgrade detector

CMS-PAS-FTR-13-014
CMS-PAS-FTR-13-06
Search for SUSY with jets & missing hadronic energy

- Based on CMS-PAS-SUS-13-012 @ 8 TeV
- Topology: many jets, no leptons,
  Use of $H_T = \sum_{\text{jets}} p_T$ and $\not{H}_T = | - \sum_{\text{jets}} \vec{p}_T |$
- Event selection: 0 e/$\mu$, $\geq$ 3 jets, $H_T > 500$ GeV, $\not{H}_T > 200$ GeV, $|\Delta\phi(J, \not{H}_T)|$
- SM backgrounds: $Z(\nu\nu)$+jets, $W(l\nu)$+jets, (QCD multijets negligible at high $\not{H}_T$)

- Search regions for 3000 fb$^{-1}$: tighter cuts than for the 8 TeV analysis

<table>
<thead>
<tr>
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<th>High $M_{\text{gluino}}$</th>
<th>High $M_{\text{LSP}}$</th>
<th>Medium $M_{\text{gluino}}$ &amp; medium $M_{\text{LSP}}$</th>
<th>Low $M_{\text{gluino}}$ &amp; low $M_{\text{LSP}}$</th>
<th>Low $M_{\text{gluino}}$ &amp; high $M_{\text{LSP}}$</th>
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<td>$\not{H}_T$</td>
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• Study of the PU effect on $H_T$ and $\not{H}_T$: no major impact in the search regions

• 30% uncertainty on the background prediction.
• **5σ discovery reach@3000 fb⁻¹:**

Gluino masses up to ~ 2.2 TeV and LSP masses up to ~ 500 GeV.

For comparison: 95% exclusion limit with 8 TeV data: \( M_{\text{gluino}} \) up to 1.16 TeV are excluded for \( M_{\text{LSP}} < 100 \text{GeV} \)
• Based on CMS-PAS-SUS-13-007 @ 8 TeV
• Topology: 1 lepton, MET, jets (some being b-tagged)

• Event selection: 1 e/µ, ≥ 6 jets (≥ 1 b-tagged), 
  \( H_T > 500 \ \text{GeV}, \ S_T^{\text{lep}} > 250 \ \text{GeV}, \ \Delta \phi(W,l) > 1 \)
  with \( S_T^{\text{lep}} = \text{scalar } \Sigma \ \text{of } [\text{MET} + p_T(l)] \)

• SM backgrounds: ttbar+jets, V+jets, ttbar +V, single top.
• “Data-driven” background estimate with
  \[ N_{\text{SM}}^{\text{pred}}(\Delta \phi(W, \ell) > 1) = R_C S \cdot N_{\text{data}}(\Delta \phi(W, \ell) < 1) \]
  \[ R_C = \frac{N_{\text{signal}}}{N_{\text{control}}} = \frac{\text{Number of events with } \Delta \phi(W, \ell) > 1}{\text{Number of events with } \Delta \phi(W, \ell) < 1} \]

• Search regions:

<table>
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<tr>
<th>( S_T^{\text{lep}} )</th>
<th>[450,550], [550,650], [650,750], ≥750</th>
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<td>( N_b )</td>
<td>=3,</td>
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<td>≥4</td>
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Search for gluinos into tops & LSP

- **5σ discovery reach@3000 fb⁻¹:**
  
  Gluino masses up to ~ 2.2 TeV and LSP masses up to ~ 1.2 TeV.

  For comparison: 95% exclusion limit with 8 TeV data: $M_{\text{gluino}}$ up to 1.26 TeV.
  TeV are excluded for light $M_{\text{LSP}}$, and $M_{\text{LSP}}$ up to 580 GeV for $M_{\text{gluino}} = 1.1$ TeV.

CMS Simulation \( \sqrt{s} = 14 \text{ TeV} \)

The mass reach is mitigated due to pileup by about 100 GeV
EWKino search with 3 leptons and MET

- Based on CMS-PAS-SUS-13-006 @ 8 TeV
- Topology: 3 leptons, MET, low hadronic activity

- Event selection: 3 e/µ (with 1 OSSF pair → Z), no b-tagged jet
- SM backgrounds: WZ, ttbar, rare, single V
- Search regions: 15 SR with asymmetric binning in $M_T$ and MET
- Remark at large PU: worse MET resolution, higher fake rate → need optimization!
• 5σ discovery reach@3000 fb⁻¹:
  \( \chi_1^\pm \) and \( \chi_2^0 \) masses up to \(~ 700 \) GeV and LSP masses up to \(~ 200 \) GeV.

For comparison: 95% exclusion limit with 8 TeV data:
Dark matter in VBF

- $\chi_1^\pm$ and LSP: nearly mass-degenerate $\rightarrow$ both invisible
- Topology: 2 forward jets (large $M_{jj}$, opposite hemi), MET

- Event selection: 2 jets ($\eta_1-\eta_2>4.2$, $\eta_1^*\eta_2<0$, $M_{jj}>1500$ GeV) no 3rd jet in between, 0 b-tagged jets, 0 lepton, $H_T>200$ GeV
- SM backgrounds: V+jets, QCD, VBF production of V, ttbar

- Impact of the tracker $\eta$ extension:
  - Improve the lepton acceptance
  - $\rightarrow$ reduce W and ttbar (lepton veto)

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CMS-PAS-FTR-13-014
• Impact of the tracker $\eta$ extension:
  – Improve PU mitigation in forward region $\rightarrow$ improve the VBF tagging and MET resolution
Heavy vector-like charge 2/3 quarks

- Based on CMS-PAS-B2G-12-015 @ 8 TeV
- Vector-like quarks are non-SM 4th generation quarks, with only vector-coupling to $W \rightarrow$ mass term without the need of a Yukawa coupling to $H$. They can cancel divergences due to top loops in $H$ mass.
- Explore $tH$, $tZ$, $bW$ decay modes (in limit of large mass: BR= 25/25/50%)
  - topology: 2 to 4 $V$ and $\geq 2$ $b$-quarks.
- Event selection:
  - Single-lepton+jets: 1 e/μ, $\geq 3$ jets (leading $b$ pT$>150$ GeV), MET$>20$ GeV
  - Multi-leptons: $\geq 2$ leptons
    - Reconstruction of boosted hadronic $W/t$
- SM backgrounds: ttbar, V+jets, single top, DY, WW, WWW, ttbar+V
- Search regions: # & flavour of leptons, nJets, if boosted hadronic $W$/$t$

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Heavy vector-like charge $2/3$ quarks

- Systematics: 20% uncertainty on the background prediction, 5% for the signal selection efficiencies.

- **5σ discovery reach@3000 fb$^{-1}$:** mass up to 1.48 TeV for the combined multi-lepton & single-lepton+jets channels.

For comparison: 95% exclusion limit with 8 TeV data: $M_T > 696$ GeV

$\rightarrow$ Exclusion with HL-LHC : x2.6 larger
Conclusions

- CMS investigates the projection at $\sqrt{s} = 14$ TeV with up to $3000$ fb$^{-1}$ (HL-LHC) for several SUSY searches, interpreted within simplified models, and one benchmark of BSM scenario (VLQ).

- A huge improvement in term of sensitivity is expected, especially for low cross-section processes. A significant part of the interesting range of phase space will be accessible with HL-LHC. When searching for heavy particles, it becomes very interesting to use boosted reconstruction techniques.

- The big difficulty will come from a huge pile-up rate ($\sim 140$ in average). But the extension of the tracker up to $|\eta|=4$ will help a lot to cope with that. This extension is also important for the SM background reduction (reduce $W \rightarrow \mu\nu$ by a factor 3).
Expected increase of the different signals

ratios of LHC parton luminosities: 8 TeV / 7 TeV and 14 TeV / 7 TeV

Higgs

SUSY in 3rd Gen.

SUSY

Z' / W'

MSTW2008NLO

arXiv:1307.7135