CMS Status Report

Yves Sirois
Ecole Polytechnique, IN2P3/CNRS
110th LHCC

On behalf of the CMS experiment
$\mathcal{L} \sim 35 \text{ pb}^{-1} / \text{exp.}$

$\sqrt{s} = 7 \text{ TeV}$

$\sim 7.3 \mu\text{b}^{-1}/\text{exp.}$

$\sqrt{s_{\text{nn}}} = 2.76 \text{ TeV}$
Re-discovery of the Standard Model

CMS Preliminary

\[ \sqrt{s} = 7 \text{ TeV}, \quad L_{\text{int}} = 40 \text{ pb}^{-1} \]

1983

\[ 40 \text{ pb}^{-1} \text{ collected in 2010} \]
2011

pp
\[ \mathcal{L} \sim 5 \text{ fb}^{-1}/\text{exp.} \]
\[ \sqrt{s} = 7 \text{ TeV} \]

PbPb
\[ \sim 150 \mu\text{b}^{-1}/\text{exp.} \]
\[ \sqrt{s_{nn}} = 2.76 \text{ TeV} \]
Weak Boson Production

Production Cross Section, $\sigma_{\text{tot}}$ [pb]

- $W$ (CMS 95%CL limit)
  - CMS measurement (stat+syst)
  - theory prediction

- $Z$

- $W\gamma$
  - CMS 95%CL limit

- $Z\gamma$

- $WW$

- $WZ$

- $ZZ$

- $H(127)$

- $E_T^{\text{jet}} > 30$ GeV
- $|\eta^{\text{jet}}| < 2.4$
- $E_T^\gamma > 10$ GeV
- $\Delta R(\gamma,l) > 0.7$

- 36 pb$^{-1}$
- 36 pb$^{-1}$
- 1.1 fb$^{-1}$
- 4.7 fb$^{-1}$

References:
- JHEP10(2011)132
- CMS-PAS-EWK-10-012
- PLB701(2011)535
- CMS-PAS-EWK-11-010
- CMS-PAS-HIG-11-025
Jun 11, 2012,

Dear All,

We just crossed the 5/fb recorded.

We would like to invite you for a drink TODAY at 12:00 at P5 as an appreciation of the data taking so far and in anticipation of a whole lot more.

Maria / Greg/ Christophe
CMS Operational Status*

* As of April 15th 2012

- Pixels 97.1%
- Strips 97.75%
- Preshower 97.1%
- ECAL Endcap 99.2%
- ECAL Barrel 98.54%
- HCAL Barrel 99.9%
- HCAL Endcaps 99.96%
- HCAL Forw. 99.9%
- HCAL Outer 96.9%
- m DT 99.1%
- Muon CSC 97.7%
- Muon RPC 98.2%
2011 → 2012

7 TeV → 8 TeV
Increased production \( \sigma \) for new physics

- \( \beta^* \)
  - 1 m → 0.6 m
  - Increased \( d\mathcal{L}/dt \)
  - Increased PU

- 50 ns bunch spacing
  - max.: 1318 bunches

- \( d\mathcal{L}/dt \) (x \( 10^{33} \text{ cm}^2\text{s}^{-1} \))
  - 3.5 → 7.0 (goal)

CMS Daily Run Meeting Minutes - June 3rd 2012

- 1 fill in the past 24 hr (2692)
  + Total Delivered: 246.3 pb-1 (RECORD!)
  + Total Recorded: 238.9 pb-1 (RECORD!)
  + Total Efficiency: 97.0%
Living with High Pileup

Raw $\Sigma E_T \sim 2 \text{ TeV}$

14 jets with $E_T > 40$

Estimated PU $\sim 50$
New CMSSW software (5.X)
Gain of x 2.5 in speed (~15 s/evt)
Reduction of > 33% of memory
→ Avoids limitation our data-taking rate from Prompt Reco at Tier-0

Rates and CPU times on the HLT Farm:

- Peak rate: ~440 Hz @ 5x10^{33} cm^{-2}s^{-1}
- Average: ~350 Hz

Right on the target of <rate>
Now running the 7E33 menu with many improvements

~ 300 Hz of additional « parked » data collected

Physics performance unchanged!
(or even improved)

See J. Varela,
109th LHCC – 21 Mars 2012
MAX. INST. $\mathcal{L} = 6.64 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

$7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

L1 Trigger Menu V2 deployed

$5 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

L1 Trigger Menu V1 deployed
# HLT Trigger Menu for $6 \times 10^{33}$ cm$^{-2}$s$^{-1}$

## Highlights

<table>
<thead>
<tr>
<th>(Unprescaled) Object</th>
<th>Trigger Threshold (GeV) @ 6E33</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Muon</td>
<td>40</td>
</tr>
<tr>
<td>Single Isolated muon</td>
<td>24 (</td>
</tr>
<tr>
<td><strong>Double muon</strong></td>
<td>(17, 8) [13, 8 for parked data]</td>
</tr>
<tr>
<td>Single Electron</td>
<td>80</td>
</tr>
<tr>
<td>Single Isolated Electron</td>
<td>27</td>
</tr>
<tr>
<td><strong>Double Electron</strong></td>
<td>(17, 8)</td>
</tr>
<tr>
<td>Single Photon</td>
<td>150</td>
</tr>
<tr>
<td><strong>Double Photon</strong></td>
<td>(36, 22)</td>
</tr>
<tr>
<td><strong>Muon + Ele x-trigger</strong></td>
<td>(17, 8), (5, 5, 8), (8, 8, 8)</td>
</tr>
<tr>
<td>Single PFJet</td>
<td>320</td>
</tr>
<tr>
<td>QuadJet</td>
<td>80 [50 for parked data]</td>
</tr>
<tr>
<td>Six Jet</td>
<td>(6 × 45), (4 × 60, 2 × 20)</td>
</tr>
<tr>
<td>MET</td>
<td>120</td>
</tr>
<tr>
<td>HT</td>
<td>750</td>
</tr>
</tbody>
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$H \rightarrow \gamma\gamma$
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H $\rightarrow$ ZZ* $\rightarrow$ 4 $\ell$
Living with Pile-UP

• Increase of $\langle \text{PU} \rangle$ less important than for Chamonix estimations $\langle \text{PU} \rangle_{2012} \sim 13$ compare to $\langle \text{PU} \rangle_{2011B} \sim 9$ and $\langle \text{PU} \rangle_{2011A} \sim 5$

• Meanwhile: continue deployment of PU mitigation techniques for physics analysis and evolve to less sensitive observables
  → event-by-event corrections based on mean jet energy density and/or local track matching at primary vertex
  → rely on « Particle Flow » reconstruction techniques (jets, lepton isolation, etc ...) putting more emphasis on « good tracks » which are not affected
  → deployment of MVA techniques validated on SM candles and adjusted on PU-reweighted MC for photon and lepton ID, etc.
    (e.g. “BDT” now used for photons and electrons in Higgs analyses)

After all the hard work the mean pile-up effects on the physics relying on isolated $\ell$’s and $\gamma$’s [e.g. EWK and main Higgs boson decay channels] or high PT jets [e.g. Top physics and BSM at the TeV scale] is well under control (small effects on PU corrected observables or final sensitivity)
130 CMS Physics Papers Published
Expect ~100 more on full 2011 dataset
New Particle Discovery
garnered a lot of media attention

Candidate event display

\[ \Xi^0_b (5945 \text{ MEV}) \rightarrow \Xi_b^- \pi^+ \rightarrow \Xi^- J/\psi \pi^+ \rightarrow \Lambda \pi^- \mu^+ \mu^- \pi^+ \rightarrow p^+ \pi^- \mu^+ \mu^- \pi^+ \]

Likely the \( J^P = 3/2^+ \) companion of the \( \Xi_b \) baryon

\[ M(p^+\pi^-) = 1116.7 \text{ MeV} \]
\[ M(\Lambda^0\pi^-) = 1315.5 \text{ MeV} \]
\[ M(\mu^+\mu^-) = 3117.1 \text{ MeV} \]
\[ M(J/\psi\Xi^-) = 5787.8 \text{ MeV} \]
\[ Q(J/\psi\Xi^-\pi^+) = 15.7 \text{ MeV} \]
Measurement of Drell-Yan $d\sigma/dM$ and $d^2\sigma/dMdY$

The figure shows the distribution of dilepton invariant mass ($M(\ell\ell)$) in CMS data compared to the theoretical predictions for electron-electron ($\gamma^*/Z \to \ell\ell$) and muon-muon ($\gamma^*/Z \to \mu\mu$) channels. The data is compared to the NNLO, FEWZ+MSTW08 model predictions.

The results show a clear peak at the Z resonance region ($M(\ell\ell) = 91.2$ GeV) with a significance of $\sin^2 \theta_{\text{eff}} = 0.2287 \pm 0.0020$ (stat.) $\pm 0.0025$ (syst.).

**Figure**: Left diagram describing the SM process $\ell^+ \ell^- \to X \to \gamma^*/Z \to \ell^+ \ell^-$. The right diagram shows the definition of the $\theta^*$ angle.

**Figure 1**: Phenomenology of the Drell–Yan Process at the LHC. The method is applied to a sample of proton-proton collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV corresponding to an integrated luminosity of $4.5 \, fb^{-1}$.

**Equation**: $\sin^2 \theta_{\text{eff}} = 0.2287 \pm 0.0020$ (stat.) $\pm 0.0025$ (syst.)
Di-jet Invariant mass in W + jets events

- Important background for Higgs and BSM
- Extented phase space for hard recoiling jets
- Excess observed by CDF at the Tevatron (not confirmed by D0)

Look for a high $P_T\ell + E_T^{miss} + 2$ or $3$ jets

No evidence for a resonance enhancement around $M_{jj} \sim 150$ GeV

EWK-11-017
**Top quark Mass Measurements**

CMS Preliminary, \( \sqrt{s} = 7 \) TeV

<table>
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<th>Experiment</th>
<th>Mass (GeV)</th>
<th>Notes</th>
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<td>173.3 ± 1.2 ± 2.5</td>
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<td>173.1 ± 2.1 ± 2.7</td>
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- **Graph 1:**
  - CMS Preliminary, \( \sqrt{s} = 7 \) TeV
  - Mass measurements from top quark decays in both di-lepton and \( \ell+jets' \) channel are competitive with corresponding Tevatron measurements.
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- **Graph 2:**
  - Measured cross section for \( m_{\text{pole}} \) (Langenfeld et al.)
  - Cross section corrected for \( m_{\text{pole}} \) (Langenfeld et al.)
  - Measured cross section dependence on \( m_{\text{MC}} \)

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- **Langenfeld et al.:**
  - 170.3 ± 7.3
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Test CPT invariance in the top sector

\[ \Delta M_t = M_{\text{top}} - M_{\text{top}} \]

- Reconstruction of the hadronic side: compare \( \ell^+\)+jets and \( \ell^-\)+jets events
- Use kinematic fit, and event-per-event likelihood for \( \ell^-\) and \( \ell^+\) separately

\[ \Delta m_t = -0.44 \pm 0.46 \text{ (stat.)} \pm 0.27 \text{ (syst.) GeV} \]

Most systematic effects cancel out! → the measurement is stat. limited

World’s best so far

Consistent with SM,
Consistent between e and \( \mu \)

TOP-11-019
Top Charge Asymmetry Measurements

- Anomalous charge asymmetries observed at the Tevatron  
  CDF PRD83 (2011); D0 PRD84 (2011)

- Different definition possible a the LHC  
  (asymmetry partly diluted):

\[
A_C = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} \quad \Delta |y| = |y_t| - |y_{\bar{t}}|
\]

New CMS Measurement:  
\[A_C = 0.004 \pm 0.010 \text{ (stat.)} \pm 0.012 \text{ (syst.)}\]

Theory Prediction (SM):  
\[A_C = 0.0115 \pm 0.0006\]

- No dependence on phase space within uncertainties:
Top Decays: Search for $t \rightarrow H^+ b$

e.g. diagram

Improves by an previous Tevatron limits on $B \ (t \rightarrow H^+ b)$ by $\sim O(10)$

HIG-11-019
<table>
<thead>
<tr>
<th>CMS « <strong>Higgs</strong> » Papers</th>
<th>Full Datasets at $\sqrt{s} = 7$ TeV</th>
<th>$\mathcal{L} \sim 4.7 - 5$ fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \rightarrow ZZ \rightarrow 2\ell 2\tau$</td>
<td>HIG-11-028</td>
<td>JHEP arXiv:1202.3617v1</td>
</tr>
<tr>
<td>$H \rightarrow ZZ \rightarrow 2\ell 2\nu$</td>
<td>HIG-11-026</td>
<td>JHEP arXiv:1202.3478v1</td>
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<tr>
<td>$H \rightarrow ZZ \rightarrow 2\ell 2q$</td>
<td>HIG-11-027</td>
<td>JHEP arXiv:1202.1416v1</td>
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<tr>
<td>$H \rightarrow WW \rightarrow 2\ell 2\nu$</td>
<td>HIG-11-024</td>
<td>PLB arXiv:1202.1489v1</td>
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<tr>
<td>MSSM $H^\pm$</td>
<td>HIG-11-019*</td>
<td>JHEP arXiv:1205.5736v2</td>
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**CMS Physics Analysis Summaries (PAS)**

<table>
<thead>
<tr>
<th>$H \rightarrow 2\gamma$</th>
<th>HIG-12-001</th>
<th>Mar. 2012</th>
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<tbody>
<tr>
<td>H Fermiophobic</td>
<td>HIG-12-002</td>
<td>Mar. 2012</td>
</tr>
<tr>
<td>H Combination</td>
<td>HIG-12-008</td>
<td>Mar. 2012</td>
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<tr>
<td>$WH \rightarrow \ell \nu \tau_\tau h$</td>
<td>HIG-12-006</td>
<td>Mar. 2012</td>
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<tr>
<td>$H \rightarrow 2\tau_\mu$</td>
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<tr>
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<td>$H^{\pm\pm}$</td>
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* $\mathcal{L} \sim 2$ fb$^{-1}$
## SM Higgs Boson Searches in CMS

### Table: Higgs Channel Summary

<table>
<thead>
<tr>
<th>Channel</th>
<th>m_h Range</th>
<th>Lumi</th>
<th>Sub-Channels</th>
<th>m_h Resolution</th>
<th>Main Background</th>
<th>Expected sensitivity</th>
<th>Number of signal events after cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>H → γγ</td>
<td>110-150</td>
<td>4.8</td>
<td>5</td>
<td>1-3%</td>
<td>γγ γj jj</td>
<td>1.5-2</td>
<td>~70</td>
</tr>
<tr>
<td>H → ττ</td>
<td>110-145</td>
<td>4.6</td>
<td>9</td>
<td>20%</td>
<td>Z→ττ W+jet QCD</td>
<td>2-3</td>
<td>40-90</td>
</tr>
<tr>
<td>H → bb</td>
<td>110-135</td>
<td>4.7</td>
<td>5</td>
<td>10%</td>
<td>V+jet Vbb tt</td>
<td>3-6</td>
<td>0.5-2</td>
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<tr>
<td>H → WW → lνlν</td>
<td>110-600</td>
<td>4.6</td>
<td>5</td>
<td>20%</td>
<td>WW DY tt</td>
<td>0.7-7</td>
<td>25-180</td>
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<tr>
<td>H → ZZ → llll</td>
<td>110-600</td>
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<td>3</td>
<td>1-2%</td>
<td>ZZ Z+jets tt Zbb</td>
<td>0.5-10</td>
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<tr>
<td>H → ZZ → llττ</td>
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<td>4.7</td>
<td>8</td>
<td>10-15%</td>
<td>ZZ Z+jets tt</td>
<td>3-12</td>
<td>0.5-2</td>
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<tr>
<td>H → ZZ → llνν</td>
<td>250-600</td>
<td>4.6</td>
<td>2</td>
<td>7%</td>
<td>ZZ WZ Z+jets</td>
<td>0.6-2</td>
<td>3-20</td>
</tr>
<tr>
<td>H → ZZ → llqq</td>
<td>130-164</td>
<td>4.6</td>
<td>6</td>
<td>3%</td>
<td>Z+jets tt</td>
<td>5-15</td>
<td>~15</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1-5</td>
<td></td>
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</table>

*Background derived from Data*

### Notes:
- **Signal MC:** POWHEG, reweighted at NNLO
- **Background:** PYTHIA, MadGraph, etc reweighted at NLO
Exclusion Limits: Combined Results

CMS, \( \sqrt{s} = 7 \) TeV

\( L = 4.6-4.8 \) fb\(^{-1} \)

114.4 – 127.0 GeV/c\(^2\)

Allowed \( M_H \) range for the SM Higgs Boson
$H \rightarrow ZZ \rightarrow 4\ell$

**Low Masses**

**Baseline Selection**

- $50 < M_{Z1} < 120 \text{ GeV/c}^2$
- $12 < M_{Z2} < 120 \text{ GeV/c}^2$

$\varepsilon(M_{H\sim 120}) \sim 20\% (4e), \ 40\% (4\mu), \ 25\% (2e2\mu)$

$\varepsilon(M_{H\sim 160}) \sim 42\% (4e), \ 75\% (4\mu), \ 55\% (2e2\mu)$

**Event Yields:**

- **Final state:** $4e \ 4\mu \ 2e2\mu$
- **Obs. events:** $3 \ 5 \ 5$
- **Exp. events:** $1.7 \ 3.3 \ 4.5$

$100 < M_{4\ell} < 160 \text{ GeV/c}^2$  

**Observed:** 13  

**Expected:** $9.5 \pm 1.3$ events
Mass Measurement Uncertainties

CMS Preliminary 2011

L_{int} = 4.71 fb^{-1}

\Delta m_{4l} [GeV/c^2]

\Gamma_H

Experimental resolution dominates

Intrinsic width \Gamma_H dominates

m_{4l} [GeV/c^2]

4e final state
4\mu final state
2e2\mu final state
Event-by-event Mass Measurement Uncertainties

CMS Preliminary 2011

$L_{int} = 4.71 \text{ fb}^{-1}$

$m_{4\ell}$ [GeV/c$^2$]

$\Delta m_{4\ell}$ [GeV/c$^2$]

$<\Delta m_{4\mu}/m_{4\mu}> > <\Delta m_{2e2\mu}/m_{2e2\mu}> > <\Delta m_{4e}/m_{4e}>

\sim 1.1\% \sim 1.6\% \sim 2.1\%$
$H \rightarrow \gamma\gamma$

**Mass Spectra**

**All classes combined**

CMS $\sqrt{s} = 7$ TeV $L = 4.8$ fb$^{-1}$

- Data
- Bkg Model
- $\pm 1 \sigma$
- $\pm 2 \sigma$
- $2x$SM $m_{H}=120$ GeV

**Dijet-tagged class**

CMS $\sqrt{s} = 7$ TeV $L = 4.8$ fb$^{-1}$

- Data
- Bkg Model
- $\pm 1 \sigma$
- $\pm 2 \sigma$
- $2x$SM $m_{H}=120$ GeV
$H \rightarrow \gamma\gamma$ Candidate in Dijet-Tag Class
Low Mass Excess: Anatomy

Local Significance
\[ P_{\text{min}} = 0.001 \]
\[ Z_{\text{max}} = 3.1\sigma \]

Global Significance
- Full range: 110-600 GeV/c²
  \[ Z_{\text{max}} = 1.5\sigma \]
- Restricted range: 110-145 GeV/c²
  \[ Z_{\text{max}} = 2.1\sigma \]

Within 1\( \sigma \) of unity in the mass range 117-126 GeV!

Local p-value = probability of a background fluctuation resembling a signal-like excess for a given value of \( m_H \)

Broad excess at \( \sim 1\sigma \) level from \( H \to \text{bb} , \tau \tau , \text{ww} \) complemented by localized excesses from \( H \to 4l \) and \( H \to \gamma \gamma \)

CMS, \( \sqrt{s} = 7 \text{ TeV} \)
\[ L = 4.6-4.8 \text{ fb}^{-1} \]
Low Mass Excess: Anatomy

**Using new**

\( H \rightarrow \gamma \gamma \) < MVA >

**CMS Preliminary, \( \sqrt{s} = 7 \) TeV**

- Local p-value
  - Global significance
    - 0.8\( \sigma \) in range 110-600 GeV
    - 2.1\( \sigma \) in range 110-145 GeV

**Higgs boson mass (GeV)**
- 110
- 115
- 120
- 125
- 130
- 135
- 140
- 145

**L = 4.6-4.8 fb\(^{-1}\)**

**95% CL limit on \( \alpha SM \)**

**Combined obs.**

**Exp. for SM Higgs**

- **H \rightarrow bb** (4.7 fb\(^{-1}\))
- **H \rightarrow \tau \tau** (4.6 fb\(^{-1}\))
- **H \rightarrow \gamma \gamma** (4.8 fb\(^{-1}\))
- **H \rightarrow WW** (4.6 fb\(^{-1}\))
- **H \rightarrow ZZ** (4.7 fb\(^{-1}\))

**Higgs boson mass (GeV)**

- 110
- 115
- 120
- 125
- 130
- 135
- 140
- 145

**CMS PAS-HIG-12-001 + PAS-HIG-12-008**
Reminder: CMS Input for Chamonix

You are HERE?

Note: Very roughly, for $M_H \sim 125$ GeV, one expects 3 to 4 signal events per 5 fb$^{-1}$ in $H \rightarrow 4\ell$ for a S/B of $\sim 2$

⇒ Requires about 20 fb$^{-1}$ for 5$\sigma$ in stand-alone
⇒ We should see something starting to build-up already now
Standard Model or Fermiophobic?

\[ \sigma_{tot}^{(FP)} = \sigma_{VBF} + \sigma_{WH/ZH} \]

\( \sqrt{s} = 7 \text{ TeV} \)

Fermiophobic

For Higgs production cross sections, NNLO VBF, WH/ZH numbers can be used.

Assume Yukawa coupling off and SM like HVV coupling.

Higgses

Standard Model or are born – SM

H

t

W

Z

H

ttH

VH

(NLO)

Gluon

tt

V

q

q

q

q

\( q \rightarrow V \rightarrow H \)

\( q \rightarrow V \rightarrow H \)

\( q \rightarrow W, Z \)

\( q \rightarrow W, Z \)

\( q \rightarrow t \rightarrow H \)

\( q \rightarrow t \rightarrow H \)

\( \tau^+ \rightarrow \nu \tau \rightarrow t \rightarrow H \)

\( \tau^+ \rightarrow \nu \tau \rightarrow t \rightarrow H \)

\( \tau^- \rightarrow \nu \tau \rightarrow t \rightarrow H \)

\( \tau^- \rightarrow \nu \tau \rightarrow t \rightarrow H \)

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\( \tau^+ \rightarrow \nu \tau \rightarrow t \rightarrow H \)

\( \tau^- \rightarrow \nu \tau \rightarrow t \rightarrow H \)

\( \tau^+ \rightarrow \nu \tau \rightarrow t \rightarrow H \)

\( \tau^- \rightarrow \nu \tau \rightarrow t \rightarrow H \)

\( \tau^+ \rightarrow \nu \tau \rightarrow t \rightarrow H \)
Search for a Fermiophobic Higgs Boson

Figure: The measured signal cross section times the branching ratio to photon pairs excluded at 95% CL over expected by the FP model as a function of the Higgs boson mass for combination of inclusive and exclusive analyses. The green-yellow band corresponds to the expected exclusion in the case of 3-4 fluctuation of the background-only distribution of the test statistic. The Asymptotic CLs method was used. Individual contributions to the expected limit are shown for each of the channels (dotted lines).

CMS Preliminary
\( \sqrt{s} = 7 \text{ TeV}, L = 4.8 \text{ fb}^{-1} \)
ECAL Barrel:
crystals qualified for
<6% loss under 0.15 Gy/h

ECAL Endcap:
higher radiation level

- Damage and recovery
during LHC cycles
- Steady recovery during
Heavy Ion run (low
luminosity) and in periods
without beam

- Monitoring data: 1 point/channel/40 min
  - Corrections ready for reconstruction in less than 48 h!
  - A few iterations with data reprocessing required in 2011
- New diode pumped laser installed in 2012
  - Less maintenance intensive → reduced medium term instabilities

T. Tabarelli de Fatis, CALOR 2012
Stability of Response for Electrons: $W \rightarrow e \nu$

- Stable energy scale after monitoring corrections
  - Barrel:
    - $<\text{signal loss}> \sim 2.5\%$,
    - RMS stability $\sim 0.12\%$
  - Endcap:
    - $<\text{signal loss}> \sim 10\%$,
    - RMS stability $\sim 0.45\%$

- Corrections include:
  - Barrel: $\alpha = 1.52$
  - Endcap: $<\alpha> \sim 1.28$

- Further tuning of the corrections in progress:
  - Time-invariance of energy flow: signal loss vs transmission loss at the single crystal level
    - In situ measurement of $\alpha$

$$\frac{S}{S_0} = \left(\frac{R}{R_0}\right)^\alpha$$

$(S/S_0) =$ relative response to e’s
$(R/R_0) =$ relative resp. to laser light
Stability of the Energy Resolution: $Z \rightarrow e e$

- ECAL resolution (from $Z \rightarrow ee$ peak width) stability before and after the application of Laser Monitoring corrections (LM):
  - ECAL Barrel: resolution stable within errors
  - ECAL Endcap: resolution worsens by $\sim 1.5\%$ in quadrature

→ Requires further tuning of corrections and/or pile-up effects
  (e.g. $in situ$ measurement of the ‘effective $\alpha$’ at single crystal level)
Response dependence on Pile-up

Dependence $E_{\text{reco.}}$ on $N_{\text{vtx}}$

Data (open dots) and MC (full dots) are compared for the default reconstruction (red dots) and after MC-driven corrections to the energy based on a multivariate analysis of the energy response including pileup sensitive global event variables.

- Pileup-resilient clustering algorithms are under study

T. Tabarelli de Fatis, CALOR 2012
Progress in Understanding …

• July 2011 (EPS):
  – FWHM = 4.23 GeV

• March 2012 (Moriond):
  – FWHM = 3.29 GeV

• July 2012 (ICHEP)

Improved single crystal and cluster corrections
Search for SM Higgs: 2011+2012 Data

What do we see in the low mass range?

CMS is blinded

Analysis improvements:
use MC for optimisation +
use DATA only in background
and SM candles phase space

Both 2011 and 2012 data have been blinded for the analysis improvements
<table>
<thead>
<tr>
<th>CMS « SUSY » Papers</th>
<th>Full Datasets at $\sqrt{s} = 7$ TeV</th>
<th>$\mathcal{L} \sim 4.7 - 5$ fb$^{-1}$</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>CMS Physics Analysis Summaries (PAS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSSM $l + \text{jets} + E_T^{\text{miss}}$ (Templates)</td>
</tr>
<tr>
<td>CMSSM $l + \text{jets} + E_T^{\text{miss}}$</td>
</tr>
<tr>
<td>SUSY $l + \text{b-jets} + E_T^{\text{miss}}$</td>
</tr>
<tr>
<td>SUSY Fully hadronic states</td>
</tr>
<tr>
<td>Simplified Models</td>
</tr>
<tr>
<td>CMSSM $l + \text{jets} + E_T^{\text{miss}}$ (NN)</td>
</tr>
<tr>
<td>GMSB $\gamma$’s + $E_T^{\text{miss}}$</td>
</tr>
<tr>
<td>CMSSM « Razor inclusive »</td>
</tr>
<tr>
<td>$\ell^{\pm}\ell^{\pm}$ b-jets + $E_T^{\text{miss}}$</td>
</tr>
<tr>
<td>$\ell^{+}\ell^{-}$ jets + $E_T^{\text{miss}}$ (NN)</td>
</tr>
</tbody>
</table>

* $\mathcal{L} \sim 4.4$ fb$^{-1}$  * $\mathcal{L} \sim 2.2$ fb$^{-1}$
Supersymmetry: Constrained Models

Minimal Models (e.g. cMSSM) under pressure ...

Explore general mass spectra (e.g. « simplified models ») or exceptional (e.g. multileptons, mono-photons) topologies!

Limits > 1 TeV on squarks and gluinos

SUSY is not dead yet
115-130 GeV Higgs tailor made for SUSY

More complicated (and interesting) “natural” SUSY models still plentiful
that the gluino can undergo a direct three-body decay into jets and a chargino or a neutralino...

```

<table>
<thead>
<tr>
<th>Simplified Model Spectra</th>
<th>Mass scales [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^0_1$</td>
<td>1.1 fb$^{-1}$, gluino</td>
</tr>
<tr>
<td>T1tttt: $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}^0_1$</td>
<td>4.98 fb$^{-1}$, gluino</td>
</tr>
<tr>
<td>T2: $\tilde{q} \rightarrow q\tilde{\chi}^0_1$</td>
<td>1.1 fb$^{-1}$, squark</td>
</tr>
<tr>
<td>T3w: $\tilde{g} \rightarrow q(W)\tilde{\chi}^0_1$</td>
<td>4.98 fb$^{-1}$, gluino</td>
</tr>
<tr>
<td>T3Lh: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_2^0</td>
<td>\tilde{\chi}^0$</td>
</tr>
<tr>
<td>T5zz: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_2^0</td>
<td>\tilde{\chi}^0$</td>
</tr>
<tr>
<td>T5Lnu: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^\pm_1$</td>
<td>4.98 fb$^{-1}$, gluino</td>
</tr>
</tbody>
</table>

| TChiSlep: $\tilde{\chi}^0_2, \tilde{\chi}_1^\pm \rightarrow lll\tilde{\chi}^0_1$ | 4.98 fb$^{-1}$, neutralino/chargino |

CMS performed a comprehensive search with “Simplified Models”

CMS-SUS-11-021 + CMS-SUS-11-016
Search for Anomalous Production of Multilepton Events

- Search for anomalous production of events with 3 or 4 isolated leptons (e, mu, or tau)
- cMSSM with neutralino or gravitino LSP
- SUSY with R-parity violating couplings
- GMSB in the so-called "slepton co-NLSP" scenario

<table>
<thead>
<tr>
<th>Selection</th>
<th>N(τh)=0</th>
<th>N(τh)=1</th>
<th>N(τh)=2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>obs</td>
<td>expected</td>
<td>obs</td>
</tr>
<tr>
<td>4 Lepton results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4ℓ $E_T^{\text{miss}}$ &gt;50, $H_T$ &lt;200, no Z</td>
<td>1</td>
<td>0.20 ± 0.07</td>
<td>3</td>
</tr>
<tr>
<td>4ℓ $E_T^{\text{miss}}$ &gt;50, $H_T$ &lt;200, Z</td>
<td>1</td>
<td>0.79 ± 0.21</td>
<td>4</td>
</tr>
<tr>
<td>4ℓ $E_T^{\text{miss}}$ &lt;50, $H_T$ &lt;200, no Z</td>
<td>1</td>
<td>2.6 ± 1.1</td>
<td>5</td>
</tr>
<tr>
<td>4ℓ $E_T^{\text{miss}}$ &lt;50, $H_T$ &lt;200, Z</td>
<td>33</td>
<td>37 ± 15</td>
<td>20</td>
</tr>
<tr>
<td>CMS « <strong>Exotica</strong> » Papers</td>
<td>Full Datasets at $\sqrt{s} = 7$ TeV</td>
<td>$\mathcal{L} \sim 4.7 - 5$ fb$^{-1}$</td>
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<tr>
<td>-----------------------------</td>
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<td></td>
</tr>
<tr>
<td>Long lived $Q\pm$</td>
<td>EXO-11-022</td>
<td>PLB arXiv:1205.0272v1</td>
<td>May 2012</td>
</tr>
</tbody>
</table>

* $\mathcal{L} \sim 2$ fb$^{-1}$

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**CMS Physics Analysis Summaries (PAS)**

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<tr>
<td>X $\rightarrow$ t anti-$t$</td>
<td>EXO-11-093</td>
</tr>
<tr>
<td>X $\rightarrow$ Z Z $\rightarrow$ 4$\mu$</td>
<td>EXO-11-025</td>
</tr>
<tr>
<td>X $\rightarrow$ V Z</td>
<td>EXO-11-081</td>
</tr>
<tr>
<td>G* $\rightarrow$ ZZ $\rightarrow$ 2l2q</td>
<td>EXO-11-102</td>
</tr>
<tr>
<td>Contact Int.</td>
<td>EXO-11-009</td>
</tr>
</tbody>
</table>

**Most recent post-Moriond**

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<tr>
<td>W’ $\rightarrow$ t b</td>
<td>EXO-12-001</td>
</tr>
<tr>
<td>W’ $\rightarrow$ t d</td>
<td>EXO-11-056</td>
</tr>
</tbody>
</table>

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**Contact Int.**

| Contact Int.                        | EXO-11-009                           | May 2012 |
Search for Dark Matter

• Look for « nothing » + monophoton or monojet
• Probe the same effective operators as in direct detection
• High sensitivity to spin dependent couplings

Spin-independent couplings
Extend limits to low masses where nuclear recoil imposes a threshold for direct detection

EXO-11-096
Search for a Heavy Z’ Boson

Z’_{SSM} > 2330 GeV
Z’_{\psi} > 2000 GeV
G_{KK} > 2140 GeV (k/M_{Pl} = 0.1)
> 1810 GeV (k/M_{Pl} = 0.05)

Topcolor Z’
Mass range 1-1.6 TeV
excluded for \sigma_{Z’}/m_{Z’} = 3%

Most stringent constraints to date

EXO-11-019
Search for New Heavy Quarks

\[ b'^-b' \to tW^-\bar{t}W^+ \to bW^+W^-\bar{b}W^-W^+ \]

- \( b' \rightarrow tW^- \): \( b' \) with masses below 611 GeV/c^2 excluded at 95% CL
- \( t' \rightarrow W^+ b \): \( t' \) with masses below 557 GeV/c^2 excluded at 95% CL

SM-Higgs of the SM4 is excluded now by CMS in the range 120-600 GeV

Have to explore Heavy Q in the context of BSM Physics!

EXO-11-036 + arXiv:1203.5410
Heavy Ions and the QGP in CMS

15 published papers and a wealth of remarkable results!

quarkonia suppression, jet quenching, azimuthal and elliptic anisotropy

Recall (J. Varela, 99th LHCC):

Hadrons up to $p_T \sim 100$ GeV/c are suppressed ... $\gamma$'s up to $E_T$ 80 GeV are not

$$R_{AA} = \frac{\text{yield in PbPb}}{(N \text{ equivalent pp collisions} \times \text{yield in pp})}$$

$$R_{AA} < 1 \rightarrow \text{suppression}$$
Jet Quenching Using Isolated $\gamma + \text{jet}$

Very recent: use isolated $\gamma$ as a «tag» to probe high $p_T$ quark production and characterize its propagation in hot-dense medium

\[ \langle x_{J\gamma} \rangle_{0-10\%} = 0.73 \pm 0.02 \text{(stat.)} \pm 0.04 \text{(syst.)} \]

\[ x_{J\gamma} = \frac{p_T^{\text{Jet}}}{p_T^\gamma} \]

\[ R_{J\gamma} = 0.49 \pm 0.03 \text{ (stat.)} \pm 0.02 \text{ (syst.)} \]

= fraction of isolated photons that have an associated jet passing the analysis selection

HIN-11-010
Quarkonia Suppression

$\Upsilon$ excited states and $J/\psi$ are suppressed in PbPb relative to pp
A ‘thermometer’ of strongly interacting matter

CMS Preliminary, PbPb $\sqrt{s_{NN}} = 2.76$ TeV

- $\Upsilon(1S)$, $0 < p_T^{\Upsilon(1S)} < 50$ GeV/c
- $\Upsilon(2S)$, $0 < p_T^{\Upsilon(2S)} < 50$ GeV/c
- Prompt $J/\psi$, $6.5 < p_T^{J/\psi} < 30$ GeV/c

2011 Data

CMS Preliminary, PbPb $\sqrt{s_{NN}} = 2.76$ TeV

- $\Upsilon(1S)$, $0 < p_T^{\Upsilon(1S)} < 50$ GeV/c
- $\Upsilon(2S)$, $0 < p_T^{\Upsilon(2S)} < 50$ GeV/c
- Prompt $J/\psi$, $6.5 < p_T^{J/\psi} < 30$ GeV/c

Preliminary data

- PbPb fit
- pp shape

Cent. 0-100%, $|y| < 2.4$

L_{int} = 150 \mu$b$^{-1}$

$p_T^\mu > 4$ GeV/c

m_{\mu\mu} (GeV/c^2)

Events / (0.1 GeV/c^2)
Conclusions

• The CMS experiment is operating at full regime and very high efficiency to collect large amount of data at $\sqrt{s} = 8$ TeV $> 2 \times L_{2011}$ already collected!

• The discovery (or exclusion) of the SM Higgs boson is in sight ... the analysis have been improved and re-deployed under a strict blinding policy
  Opening of the « box » this week!

• High precision measurement of SM candles have been performed ... and stringent constraints on BSM models have been established
  BSM Physics remains out of reach for the moment!
  (better hopes for $\sqrt{s} = 13$ TeV ?)

And to conclude ...
Many thanks to the LHC accelerator teams, and the many other institutes and people who made this possible!
Search for $B_s^0 \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow \mu^+\mu^-$ decays

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B^0 \rightarrow \mu^+\mu^-$ Barrel</th>
<th>$B_s^0 \rightarrow \mu^+\mu^-$ Barrel</th>
<th>$B^0 \rightarrow \mu^+\mu^-$ Endcap</th>
<th>$B_s^0 \rightarrow \mu^+\mu^-$ Endcap</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_{\text{tot}}$</td>
<td>0.0029 ± 0.0002</td>
<td>0.0029 ± 0.0002</td>
<td>0.0016 ± 0.0002</td>
<td>0.0016 ± 0.0002</td>
</tr>
<tr>
<td>$N^\text{signal}_{\text{exp}}$</td>
<td>0.24 ± 0.02</td>
<td>2.70 ± 0.41</td>
<td>0.10 ± 0.01</td>
<td>1.23 ± 0.18</td>
</tr>
<tr>
<td>$N^\text{peak}_{\text{exp}}$</td>
<td>0.33 ± 0.07</td>
<td>0.18 ± 0.06</td>
<td>0.15 ± 0.03</td>
<td>0.08 ± 0.02</td>
</tr>
<tr>
<td>$N^\text{comb}_{\text{exp}}$</td>
<td>0.40 ± 0.34</td>
<td>0.59 ± 0.50</td>
<td>0.76 ± 0.35</td>
<td>1.14 ± 0.53</td>
</tr>
<tr>
<td>$N^\text{total}_{\text{exp}}$</td>
<td>0.97 ± 0.35</td>
<td>3.47 ± 0.65</td>
<td>1.01 ± 0.35</td>
<td>2.45 ± 0.56</td>
</tr>
<tr>
<td>$N_{\text{obs}}$</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>upper limit (95%CL)</th>
<th>observed</th>
<th>expected</th>
</tr>
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<tbody>
<tr>
<td>$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$</td>
<td>$7.7 \times 10^{-9}$</td>
<td>$8.4 \times 10^{-9}$</td>
</tr>
<tr>
<td>$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)$</td>
<td>$1.8 \times 10^{-9}$</td>
<td>$1.6 \times 10^{-9}$</td>
</tr>
</tbody>
</table>
Higgs Production and Decay at the LHC

Graph showing Higgs production cross-sections and decay branching ratios.

- Production cross-sections for $pp \rightarrow H + X$ for different processes.
- Decay branching ratios for Higgs bosons to various final states.

Final states:
- $b\bar{b}$: 5 exclusive final states
- $\tau\tau$: 9 exclusive final states
- $\gamma\gamma$: 4 exclusive final states
- $WW \rightarrow l\nu l\nu$: 5 exclusive final states
- $ZZ \rightarrow 4\ell$: 3 exclusive final states
- $ZZ \rightarrow 212\tau$: 8 exclusive final states
- $ZZ \rightarrow 212q$: 6 exclusive final states
- $ZZ \rightarrow 212\nu$: 2 exclusive final states

Graph includes:
- $\sqrt{s} = 7$ TeV
- $M_H$ vs. Higgs boson mass, GeV/c$^2$