CMS Experiment Results and Future Plans for Upgrade

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On behalf of the CMS Collaboration

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Outline

- Standard Model Physics
- Higgs Physics
- Top
- Exotica
- SUSY
- Upgrade phase I
- Upgrade phase II
- Outlook
1700 physicists, 700 students, 950 engineers/technicians, 180 institutions from 43 countries
## peak luminosity

\[ L = \frac{kN_b^2 f \gamma}{4 \pi \beta^* \varepsilon_N} F \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>energy [TeV]</td>
<td>6.5</td>
</tr>
<tr>
<td>bunch spacing [ns]</td>
<td>25</td>
</tr>
<tr>
<td>$\beta^*$ [cm]</td>
<td>40</td>
</tr>
<tr>
<td>$\varepsilon_N$ [mm mrad] at start of fill</td>
<td>2</td>
</tr>
<tr>
<td>$N_b$, bunch population [10^{11} p/bunch]</td>
<td>1.12</td>
</tr>
<tr>
<td>k, max. number of bunches</td>
<td>2220</td>
</tr>
<tr>
<td>max. stored energy [MJ]</td>
<td>260</td>
</tr>
<tr>
<td>peak luminosity [10^{34} cm^{-2}s^{-1}] in IP1/5</td>
<td>~1.25</td>
</tr>
<tr>
<td>pile-up</td>
<td>41</td>
</tr>
</tbody>
</table>
Integrated Luminosity

CMS data collection efficiency = 92,0%
CMS data certification efficiency = 92,5%
Standard Model Physics
Cross-section Review

June 2016

Production Cross Section, σ [pb]

CMS Preliminary

- 7 TeV CMS measurement (L ≤ 5.0 fb⁻¹)
- 8 TeV CMS measurement (L ≤ 19.6 fb⁻¹)
- 13 TeV CMS measurement (L ≤ 2.7 fb⁻¹)
- Theory prediction
- CMS 95%CL limit

All results at: http://cern.ch/go/pNj7
2-3% system. Precision; compared NNLO predictions calculated with FEWZ and NLO predictions calculated with aMC@NLO [CMS-PAS-SMP-16-009]
\[ \sigma(ZZ) = (14.6 \pm 1.9 - 1.8(\text{stas}) + 0.5 - 0.3(\text{syst}) + /-0.2(\text{th}) + /-0.4(\text{lum})) \text{pb} \]

NNLO: (15.0 \pm 0.7 - 0.6 + /-0.2) \text{pb} \sim 14\% \text{ precision, limited by statistics} 

Double differential inclusive jet CS

Higgs Physics
Observation of the Higgs boson in the $\gamma\gamma$ channel alone with significance exceeding 6 sigma [CMS-PAS-HIG-16-020]
Observation of the Higgs boson in the ZZ* channel alone with significance exceeding 6 sigma [CMS-PAS-HIG-16-033]
The best fit value for the parameter $\mu$ from ATLAS and CMS data at $\sqrt{S}=7$ and 8 TeV.

[arXiv:1606.02266v2, JHEP08(2016)045]
TOP
Inclusive $\ttbar$ Cross-section measurement

..most recent:

**ATLAS**, 3.2$\text{fb}^{-1}$, 13TeV, Dilept., arXiv:1606.02699

**CMS**, 2.3$\text{fb}^{-1}$, 13TeV, $\ell+$jets
CMS-PAS-TOP-16-006

**CMS**, 2.53$\text{fb}^{-1}$, 13TeV, all jets
CMS-PAS-TOP-16-013

**CMS**, 26$\text{pb}^{-1}$, 5TeV, dilept.
CMS-PAS-TOP-16-015

Results consistent and in agreement with NNLO+NNLL over a large range of centre-of-mass energies
A moderate excess of events compatible with SM tZq production is observed. The measured CS is $\sigma(tZ\rightarrow lvbl+l-q)=(10+8-7)$ fb with a significance of 2.4 sigma. BR($t\rightarrow Zu)<0.022\%$, BR($t\rightarrow Zc)<0.049\%$ at 95 CL. No presence of FCNC production of $tZ(q)$ is observed.
Evidence for $tt$ production in association with a W or Z boson

$\sigma(ttZ) = (0.70 \pm 0.16 - 0.15(stas) + 0.14 - 0.12(syst)) \text{pb}$, $\sigma(ttW) = (0.98 + 0.23 - 0.22(stas) + 0.22 - 0.18(syst)) \text{pb}$. Expect.(obs.) signif. of 2.6(4.6) from the background-only hypothesis respectively. The measurement is in agreement with SM predictions.

[CMS-PAS-TOP-16-017]
EXOTICA
Search for resonances with dijets

7.7 TeV the highest dijet invariant mass [CMS-PAS-EXO-16-032]
Not excess of events observed in comparison with SM predictions [CMS-PAS-EXO-027]
Search for $Z'$ in $e-e^+$ and $\mu-\mu^+$ channels

Exclusion limits for: $Z'_{ssm}$ (3% width) > 4 TeV (95% CL) and $Z'_{\psi}$ (0.5% width) > 3.36 TeV (95% CL)  [CMS-PAS-EXO-16-031]
Dark matter

- Search in imbalance transverse spectrum in many topologies

<table>
<thead>
<tr>
<th>Mono-top(had, boosted)</th>
<th>Mono-V(had, boosted)</th>
<th>Mono-jet</th>
<th>MET+tt</th>
</tr>
</thead>
<tbody>
<tr>
<td>[CMS-PAS-EXO-16-040]</td>
<td>[CMS-PAS-EXO-16-037]</td>
<td>[CMS-PAS-EXO-16-037]</td>
<td>[CMS-PAS-EXO-16-037]</td>
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<tr>
<td>[CMS-PAS-HIG-16-005]</td>
<td>[CMS-PAS-HIG-16-039]</td>
<td>[CMS-PAS-HIG-16-038]</td>
<td>[CMS-PAS-HIG-16-012]</td>
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<tr>
<td>[CMS-PAS-HIG-16-011]</td>
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<td>[CMS-PAS-HIG-16-011]</td>
<td>[CMS-PAS-HIG-16-012]</td>
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Limits on Dark-Matter search

- No significant excess observed so far
- DM mass exclusion up to $\sim 550$ GeV
- Vector Mediator mass exclusion up to 1.95 TeV
SUSY
Gluino, stop and neutralino production

Constraints in the stop-neutralino plane obtained with fully-hadronic final states
[CMS-PAS-SUS-16-028]

Gluino decay to qq+LSP
Upgrade Phase I
Schedule for upgrades
Upgrade during the end of this year

Brand new pixel detector!
Upgrade Phase II
Upgrade to face high pile-up and high radiation

**Muon System**
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region $1.5 < \eta < 2.4$ (new GEM/RPC technology)
- Muon-tagging $2.4 < \eta < 3$

**Barrel EM calorimeter**
- Replace FE/BE electronics
- Lower operating temperature

**Replace endcap Calorimeters**
- Radiation tolerant - high granularity
- 3D capability

**Replace Tracker**
- Radiation tolerant - higher granularity - less material - better $p_T$ resolution
- Extended $\eta$ region up to $\eta \sim 3.8$
- Tracks trigger at L1

**Trigger/HLT/DAQ**
- Track information at L1
- L1-Trigger $\sim 750$ kHz
- HLT output $\sim 7.5$ kHz
Outlook

- LHC surpassing any expectation
- A lot of new impressive results in CMS
- Looking for more with full 2016 data set
- Upgrade Phase I well in advance
- Preparing for TDR phase II
Thank You for your Attention!!
Backup
Double-boson Cross section

July 2016

CMS measurements vs. NNLO (NLO) theory

γγ

Wγ, (NLO th.)

Zγ, (NLO th.)

WW+WZ

WW

WWW

WZ

WZ

WZ

ZZ

ZZ

ZZ

All results at:
http://cern.ch/go/pNj7

7 TeV CMS measurement (stat,stat+sys)

8 TeV CMS measurement (stat,stat+sys)

13 TeV CMS measurement (stat,stat+sys)

Production Cross Section Ratio: \( \frac{\sigma_{\text{exp}}}{\sigma_{\text{theo}}} \)
Upcoming ACTIVITIES for Upgrade I

- Install a new pixel detector
  - Four layers in the barrel (BPIX) rather than 3
  - Three disks in each endcap (FPIX) rather than 2
  - Better readout able to run up to $2 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ with almost no inefficiency (from hit loss on readout) or dead time

- Replace the sensors in the Hadron Calorimeter Endcap (HE) with Silicon Photomultipliers (SiPMs)
  - Improved light yield compensates for higher than expected radiation damage
  - More longitudinal segmentation

- Implement multianode feature of PMTS on Forward Haron Calorimeter (HF)
  - Reject spurious signals that produce false MET

- Several other improvements/Additions (GE1/1 demonstrator, luminosity monitor replacement)