CMS Overview

Robert Schöfbeck (HEPHY Vienna) on behalf of the CMS collaboration

ICNFP 2014 Greece
Total weight: 14000 t
Diameter: 15 m
Length: 28.7 m

ECAL: 76k scintillating PbWO₄ crystals
HCAL: Scintillator/brass
Interleaved ~7k ch

3.8T Solenoid

Iron Yoke

Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil

Pixels & Tracker
- Pixels (100x150 μm²)
  ~ 1 m² ~66M ch
- Si Strips (80-180 μm)
  ~200 m² ~9.6M ch

MUON BARREL
- 250 Drift Tubes (DT) and
  480 Resistive Plate Chambers (RPC)
- Preshower
  Si Strips ~16 m²
  ~137k ch
- Forward Cal
  Steel + quartz
  Fibers ~2k ch
CMS in reality
2010-12 LHC operation

- 7 TeV: ~5 fb\(^{-1}\) (2010), ~20 fb\(^{-1}\) (2012)
- 8 TeV: ~5 fb\(^{-1}\) (2011), ~160 \(\mu\)b\(^{-1}\) (Pb-Pb)
- 5 TeV (p-Pb): ~34 nb\(^{-1}\)

Fraction of LHC operations used for physics:

- 2010: 16.5%
- 2011: 23.7%
- 2012: 36.5%
CMS operation

avg. of ~ 20 collisions per BX

operational efficiency (Dec. 2012)

Excellent overall detector performance after 3 years:
≥96% of channels functional for each subdetector
publication statistics

323 submitted/published
1 paper / 4.4 days

Number of internal collaboration meetings:

CMS meetings
62,488 events

ATLAS Meetings
123,198 events

start of data taking spring 2010

last years science output: Let me discuss these papers one by one!
## other CMS talks

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Day</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Mohammadi</td>
<td>Thu.</td>
<td>Higgs @ CMS</td>
</tr>
<tr>
<td>G. Bruno</td>
<td>Thu.</td>
<td>HI Physics (all CERN achievements)</td>
</tr>
<tr>
<td>K. Theofilatos</td>
<td>Fri.</td>
<td>Search for an ‘edge’ (SUSY)</td>
</tr>
<tr>
<td>M. Takahashi</td>
<td>Fri.</td>
<td>Single and di-boson production</td>
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<td>A. Savin</td>
<td>Fri.</td>
<td>Higgs and SM measurements at HL-LHC</td>
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<tr>
<td>V. Gori</td>
<td>Sat.</td>
<td>Higgs in bosonic channels</td>
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<tr>
<td>R. Mankel</td>
<td>Sat.</td>
<td>Search for Higgs in BSM</td>
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<tr>
<td>A. Hinzemann</td>
<td>Sat.</td>
<td>Exotica</td>
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<tr>
<td>A. Garcia-Bellido</td>
<td>Sat.</td>
<td>SUSY</td>
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<tr>
<td>R. Venditti</td>
<td>Sat.</td>
<td>Identification of hadronic tau decays</td>
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<td>N. Parashar</td>
<td>Tue.</td>
<td>CMS Detector Performance</td>
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<tr>
<td>G. D’Imperio</td>
<td>Wed.</td>
<td>Jet and vector-bosons, $\alpha_S$ and PDFs</td>
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<tr>
<td>C. Beluffi</td>
<td>Wed.</td>
<td>Higgs in fermionic channels</td>
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<tr>
<td>S. Tosi</td>
<td>Wed.</td>
<td>Top Physics</td>
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<tr>
<td>K. Hoepfner</td>
<td>Wed.</td>
<td>Upgrades and future plans</td>
</tr>
<tr>
<td>C. Wulz</td>
<td>Wed.</td>
<td>B-Physics and Quarkonia</td>
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</table>

**disclaimer:** Will present a biased overview of the (to me) most interesting results

find all results under: [http://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults](http://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults)
two years anniversary of the Higgsdependence day on July 4th, 2012!

shift in scope from discovery mode to (precision) measurements: mass, BR/couplings, x-sec.

Coupling modifier fit

CMS PAS-HIG-14-009

125.03_{-0.27}^{+0.26} \text{ (stat.)}^{+0.13}_{-0.15} \text{ (syst.) GeV}
Particle-Flow algo links *tracks* to *calorimetry clusters* and identifies e, \( \mu \), \( \gamma \), charged & neutral hadrons. Those become *inputs* to jets, b-jets, taus, \( E_t^{\text{miss}} \) and isolation quantities. PF is a workhorse!
jets are clusters of reconstructed PF particles

energy scale uncertainty at ~ 1-2%, resolution generally below 10%

for 13 TeV: developed multi-variate techniques to
  discriminate quarks and gluons
  identify jets that do not originate from the primary collision vertex
  identify boosted W bosons or boosted top quarks using sub-jet techniques
**$E_T^{\text{miss}}$ performance**

- very good control of $E_T^{\text{miss}}$ observables
- 13 TeV run: expect on avg. ~50 events per bx.
- dedicated MVA tools to mitigate ‘PU’ effects.

$\sigma_{\text{PU}} = \sim 3.5, 2.0, \text{ and } 1.5 \text{ GeV per nvtx in quad.}$

- important if we have significant amount of data at 50ns at the beginning of Run-II

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CMS PAS-JME-13-003
muons/electrons

设计方案：
\[
\sigma(p_T)/p_T < 1\% \text{ for } 100 \text{ GeV} \\
\sigma(p_T)/p_T < 10\% \text{ for } 1 \text{ TeV}
\]

✧ 3 years of data-taking: Understand muons down to 3 GeV, \(\sigma(p_{T\mu}) \sim 1-4\%\), ~7% @ 350 < \(p_T\) < 2 TeV

✧ excellent e ID \(p_T > 10\) \(\sigma(p_{Te}) \sim 2-4\%\)

✧ exceeding spec, reproduced in Sim.
at % level.

Upsilon:
\[
\sigma(m_{\mu\mu}) \approx 70-95 \text{ MeV}
\]
recent results: Standard model
The ratio of the differential cross sections in 3- and 2-jet events is sensitive to the fundamental QCD coupling strength $\alpha_s$. The result is:

$$\alpha_s(M_Z) = 0.1148 \pm 0.0014 \text{ (exp.)}$$

$$\pm 0.0018 \text{ (PDF)} \pm 0.0050 \text{ (theory)}$$

World average:

$$\alpha_s(M_{Z}^2) = 0.1184 \pm 0.0007$$

$$R_{32} = \frac{d\sigma_{3+}/dp_T}{d\sigma_{2+}/dp_T} \propto \alpha_s(Q)$$

$$Q = \langle p_{T1,2} \rangle = \frac{p_{T1} + p_{T2}}{2}$$

arXiv:1304.7498
diamond SM gauge group + EWSB → production channels involving EWK and strong interactions → test ground for SM @ LHC
Z bosons produced by fusion of W bosons

- ‘VBF’ vector-boson fusion
- subject to large neg. interference
- require two jets with large rapidity gap
- MVA and cut-based analysis

\[ \sigma_{\text{EWK } l\ell jj} = 226 \pm 26_{\text{stat}} \pm 35_{\text{sys}} \text{ fb} \]
\[ \sigma_{\text{SM,NLO}} = 239 \text{ fb} \]

- 5.0 \( \sigma \) significance (expected: 5.9 \( \sigma \))
CMS has measured $m_t$ with unprecedented precision.

$\text{CMS PAS TOP-14-002 hadronc (new)}$

$m_t = 172.08 \pm 0.36\text{(stat.} + \text{JSF)} \pm 0.83\text{(syst.) GeV}$

- sys.: non-p. QCD, c.-reconnection, UE tune
- Measurements of $\sigma(\text{tt})$ and $\sigma(\text{single-t})$
**top physics**

- $tt+W$ x-sec. meas. with **same-sign di-leptons**
  
  $\sigma(ttW) = 170 +90-80 \text{ (stat.)} \pm 70 \text{ (sys.) \ fb}$

- $tt+Z$ x-sec. meas. with **3 and 4 leptons**

  $\sigma(ttZ) = 200 +80-70 \text{ (stat.)} \pm 40 \text{ (sys.) \ fb}$

- $ttW \sim 1.6\sigma$, $ttZ \sim 3.2\sigma$

- **combination** ($\sim 3.7\sigma$)

  $\sigma_{ttV} = 380^{+100}_{-90} \text{ (stat)} \pm 80_{-70} \text{ (syst) \ fb}$

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S. Tosi

**B physics**

- $B^0_{(s)} \rightarrow \mu^+\mu^-$ $\text{BR}_{\text{SM}} = (3.57\pm0.3)\times10^{-9}$ loop induced, helicity suppressed decay
- Very sensitive to flavour physics BSM

Measurement of CP weak phase $\phi_s$ and decay width difference $\Delta \Gamma_s$ in $B_s \rightarrow J/\psi (\mu \mu) \Phi (KK)$

$\phi_s = -0.03 \pm 0.11 \text{ (stat.)} \pm 0.03 \text{ (syst.) rad}$

$\Delta \Gamma_s = 0.096 \pm 0.014 \text{ (stat.)} \pm 0.007 \text{ (syst.) ps}^{-1}$

$\phi_s \sim -2\beta_s$

$\beta_s = \text{arg}\left(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*\right)$

$2\beta_s = 0.0363^{+0.0016}_{-0.0015}$

CMS PAS-BPH-13-007

LHCb 3fb$^{-1}$

CMS 25fb$^{-1}$

CMS+LHCb preliminary
recent results:
beyond the SM
limits on strong production of 3rd generation SUSY in (or close to) the TeV range
recent focus on compressed spectra
jets + $E_T^{\text{miss}}$ = SUSY

✧ special regions in phase space require careful analysis

✧ compressed spectra reduce visible energy → loss of acceptance

✧ requires dedicated low-threshold triggers and dedicated object reconstruction

✧ high $p_T$ initial-state-radiation (ISR) parton forms a jet, boosts heavy system → increase of acceptance
SUSY = 1 jet + $E_T^{miss}$

CMS Preliminary $\int L \, dt = 19.7 \text{ fb}^{-1}$, $\sqrt{s} = 8 \text{ TeV}$

CMS-PAS-SUS-13-009
Summary of CMS SUSY Results* in SMS framework

Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe "up to" the quoted mass limit

8 TeV/14 TeV

Mass scales [GeV]

σ (pb)

500 1000 1500 2000

SUS-13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
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more exotic searches

✧ rich program covering each corner (we could think of): excitations of SM particles, resonances, leptoquarks, W’/Z’, etc.

*arxiv:1406:5171*

excited quarks decaying via high $p_T$ photon ($\gamma + \text{jet channel}$)

*arxiv:1406:5171*

$W' \rightarrow tb$ resonance search in the 1l-channel
heavy ion physics
heavy ion physics

✧ collective phenomena in PbPb, pPb collisions (elliptic and triangular flow), ridge in pp in 2010

✧ energy loss in the medium: jets, b-jets, Jet fragmentation & shape, ...

✧ melting of Quarkonia (suppression of higher mass states)

✧ $J/\psi, \psi(2S), Y(1S), Y(2S), Y(3S)$

✧ electroweak probes

$Z/W$ bosons provide sensitivity to nuclear PDF

✧ new results from pPb run bridging pp and PbPb

HIN-14-002/006
HIN-14-008/012/013

HIN-12-003
HIN-14-010

HIN-13-003
HIN-12-007

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN
HI Physics: pPb run

- pPb LHC run (35nb$^{-1}$) in Jan.’13
- asymmetric system; study of EWK probes (Z/W) providing sensitivity to the nuclear PDF
- Z bosons: fwd./bkwd. ratio of diff. x-sec using 2183 candidates.

CMS PAS-HIN-13-007

CMS PAS-HIN-14-003

pp prediction

Different scaling of u/d in nPDF?

- W bosons: Charge asymmetry vs. $\eta_1$ in ~37k events with a $W \rightarrow l\nu$ decay
- isospin universality assumed in nPDF fits
- different nuclear modification of u/d?
CMS upgrade
CMS LS1 activities

- Silicon tracker sealed and cooled. Operation at -15°C to -20°C
- Channel count 96% → 99.2%
- Forward Calorimetry upgrade: multi-anode PMTs with thin windows (reject noise), new backend electronics
- New Muon station installed
- Improvements in efficiency and trigger rate
- Trigger system (L1): major upgrade, implemented in stages during Run II: better lepton isolation and PU subtraction algorithms
LHC operation schedule

**new Pixel detector:** 4 layers, 3 disks, boost in performance, avg. track-eff + 10%, b-tag eff + 10%

<table>
<thead>
<tr>
<th>Phase-1</th>
<th>Phase-2</th>
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<tr>
<td>$E_{CM}$ [TeV]</td>
<td>8</td>
</tr>
<tr>
<td>$L$ [cm$^{-2}$ s$^{-1}$]</td>
<td>$7 \times 10^{33}$</td>
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<tr>
<td>PU</td>
<td>$\sim 21$</td>
</tr>
<tr>
<td>$JL$dt [fb$^{-1}$]</td>
<td>$\sim 30$</td>
</tr>
<tr>
<td>...</td>
<td>2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025</td>
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<tr>
<td><strong>LS 1</strong></td>
<td><strong>LS 2</strong></td>
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</tbody>
</table>

**HCal Upgrade**
(PD, Electronics)
New L1 Trigger

**major redesign.** Replace endcaps, new tracker up to $|\eta| < 4$, new L1 Trigger
summary

- CMS has successfully completed the 7 and 8 TeV pp runs and the HI runs
- Physics output still accumulating, many more results in the pipeline
- We are on track for the 13 TeV run starting 2015
- What are the frontiers?
  - Close the case of low energy (natural) supersymmetry
  - Precision measurements in Higgs/top/EWK sectors
  - Keep looking in all corners of phase space
- Please enjoy many more details in the other CMS talks
BACKUP
Correlations Between Produced Particles

- Select high multiplicity events
- Study the correlation between two charged particles in the angles $\phi$ (transverse): $\Delta\phi$ and $\theta$ (longitudinal): $\Delta\theta$

$\eta = -\ln \tan \theta/2$

A new phenomenon in the ‘stronge force’?
- Multiple interactions?
- C-glass condensates?
- Hydrodynamic models?

Understanding the “Ridge” in pp collisions in MC? Need for new measurements?
jet performance

- Jets are clusters of reconstructed PF particles (AK5)
- JES uncertainty at ~ 1-2%, JER generally below 10%

q/g Disc., W/top tag, PU jet ID

p_T (GeV)

JEC Unc.

JME-13-002, JME-13-005, JME-13-006, JME-13-007
physics: jets

✧ measurement of differential inclusive and dijet jet x-sec

✧ excellent agreement with pred. from perturbative NLO QCD

✧ provide constraints for PDF fits
WV $\gamma$ and limits on aQGC

- search for WV $\gamma$ prod. in $W(l\nu)W/Z(jj)\gamma$ with $l=e,\mu$
- $\sigma(m_{jj})$ is around $\Delta m_{Z,W}$, can’t differentiate
- set limit on WV $\gamma$

$\sigma$(excl 95%) = 311 fb $\approx$ 3 $\sigma_{SM}$

- SM predicts WWWW, WWZZ, WWZ $\gamma$ and WW $\gamma\gamma$ providing a crucial test ground for EWK SB.
- deviations parametrized by dim. 6 and 8 operators

$p_T(\gamma)$ sensitive to aQGC!

arxiv:1404.4619
tt+W x-sec. meas. with same-sign di-leptons

\[ \sigma(ttW) = 170 \pm 70 \mathrm{fb} \]

tt+Z x-sec. meas. with 3 and 4 leptons

\[ \sigma(ttZ) = 200 \pm 40 \mathrm{fb} \]

extract \( \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)} \) from b-tag multiplicity fit in di-leptonic ttbar.

lower limit on \( |V_{tb}| > 0.975 \)

using t-channel x-sec, turn into an indirect measurement of the top total decay width

\[ \Gamma = 1.36 \pm 0.02 \mathrm{(stat.)} +0.14-0.12 \mathrm{(sys.)} \]
new 7 TeV measurement of $J/\psi$ and $\Psi (2S)$ diff. production x-sec:

Quarkonia polarization puzzle:

NRQCD prediction for quarkonia polarization does not reproduce measurement

arxiv:1307:6070
pPb: collective phenomena

- long-range 2-particle correlations probe collective flow phenomena in a ‘strongly interacting, expanding medium’. Here: \( K_0S, \Lambda/\bar{\Lambda} + h \) in pPb
- 1D \( \Delta \Phi \) correlation for \(|\Delta \eta| > 2\)
- elliptic and triangular flow harmonic \( v_{2,3} \): low \( p_T \) mass ordering expected from hyd. models

\[ \frac{v_2}{n_q} \text{ shapes as fkt. of } \frac{E_{\text{kin,} T}}{n_q} \text{ within } 10\% \]

collective flow in constituent quarks?
low-x physics: DPS

✧ double parton scattering in W+2 jet events
✧ probe $x \sim 10^{-3}$, 5$\text{fb}^{-1}$ at 7$\text{TeV}$

$$f_{\text{DPS}} = 0.055 \pm 0.002 \text{ (stat.)} \pm 0.014 \text{ (syst.)}$$
MC generation
summary on light top squark
### ATLAS SUSY Searches* - 95% CL Lower Limits

**Status:** Moriond 2014

\[ \sqrt{s} = 7, 8 \text{ TeV} \]

\[ \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>Jets</th>
<th>( \mathcal{L}^{-1} dt ) [fb(^{-1})]</th>
<th>Mass limit [GeV]</th>
<th>Reference</th>
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<td>GMSB, stable ( \tilde{t} \tilde{t} ) σ</td>
<td>1-2 µ</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
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<td>1-2 µ</td>
<td>-</td>
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<td></td>
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<tr>
<td>RPV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LFV, ( \mu \rightarrow e)</td>
<td>0</td>
<td>4 jets</td>
<td>Yes</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Binlinear RPV CMSM</td>
<td>1 e, µ, τ</td>
<td>7 jets</td>
<td>Yes</td>
<td></td>
</tr>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WIMP interaction</td>
<td>0</td>
<td>mono-jet</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1\(\sigma\) theoretical signal cross section uncertainty.

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\[ \sqrt{s} = 7 \text{ TeV} \]

\[ \sqrt{s} = 8 \text{ TeV} \]

\[ \sqrt{s} = 8 \text{ TeV} \]

\[ \sqrt{s} = 14 \text{ TeV} \]

Mass scale [TeV]

\[ \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1} \]

\[ \sqrt{s} = 7, 8 \text{ TeV} \]
CMS Preliminary

$\sqrt{s} = 8$ TeV, $L_{\text{int}} = 19.5$ fb$^{-1}$

$m_{\tilde{\chi}_0^0} - m_{\tilde{\chi}_1^-}$

$p p \rightarrow \tilde{\chi}_0^0 \tilde{\chi}_1^\pm$, (via $\tilde{l}_L/\tilde{\nu}$)

$p p \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^\pm$, (via $\tilde{l}_L/\tilde{\nu}$)

$p p \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$, (via $\tilde{l}_R$)

$p p \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$, (via $\tilde{\tau}_R$)

$p p \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow (Z \tilde{\chi}_1^0)(W \tilde{\chi}_1^0)$

$p p \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow (H \tilde{\chi}_1^0)(W \tilde{\chi}_1^0)$

$SUS-13-006$

$SUS-13-017$

$m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_0^0} + m_{Z}$

$m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^\pm} + m_{H}$
HAPPY HIGGS BOSON DAY
WITHOUT IT THERE'D BE NO MASS.

4. Juli 2012

C. Hagen
P. Higgs
F. Englert
G. Guralnik

Die Presse

Happy Higgs Day

Es geht darum, die Welt zu verstehen

EXPI, Aug. 2012