On behalf of the CMS Collaboration
Beautiful physics results are the final chapter of a long journey!!

- Excellent accelerator, beautiful detector, efficient trigger and optimally calibrated, reconstructed and certified data & MonteCarlo
LHC has increased the luminosity by several orders of magnitude over the past 3 years... **Fabulous performance**.

Many thanks to LHC team!

Efficiency improving all the time but several ‘incidents’ cost ≥0.5 fb⁻¹
<table>
<thead>
<tr>
<th>CMS Subsystem</th>
<th>muon CSC</th>
<th>muon DT</th>
<th>muon RPC</th>
<th>HCAL Barrel</th>
<th>HCAL Endcap</th>
<th>HCAL Forward</th>
<th>HCAL Outer</th>
<th>ECAL Barrel</th>
<th>ECAL Endcap</th>
<th>Preshower</th>
<th>Strips</th>
<th>Pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Operational</td>
<td>97.6</td>
<td>98.6</td>
<td>97.7</td>
<td>99.4</td>
<td>99.96</td>
<td>99.9</td>
<td>96.9</td>
<td>99.11</td>
<td>98.4</td>
<td>96.8</td>
<td>97.5</td>
<td>95.9</td>
</tr>
</tbody>
</table>
Several changes/improvements in HLT menu to cope with higher luminosity
- Widespread usage of Particle Flow for Jets, HT, MET/MHT and Tau triggers
- Jet Energy Corrections and pileup mitigation tools for Calorimetric and PF jets
- Optimisation of lepton identification and isolation
- Weekly updates to ECAL transparency corrections
- Introduction of regional tracking for double tau triggers
  - improve the CPU time, only needed for luminosity above $7.7 \times 10^{33}$ (not used yet)

No effect on trigger turn-on for different pile-up scenarios when using PF algorithms!

Jet HLT Turn on for a PF Jet 320 GeV online cut

HLT Tracking: linearity versus Pile-up

No effect on trigger turn-on for different pile-up scenarios when using PF algorithms!
HLT Status

- CPU time linear with PU, no sign of runaway
- HLT is working fine, up to the recent record luminosity of 7.5nb⁻¹/s

Overall (Stream A=Physics) cross section is constant

Particle Flow Jet Energy corrections cured non-linearities of many paths!

- Limit current conf. ~7.7 E33
- L1 and HLT configurations ready for 8e33 cm⁻²s⁻¹ and higher luminosity
Data Parking and Data Scouting

- **Core Data (300-350 Hz)**
  - Produce the datasets we need for our main physics program

- **Parked Data (300-600 Hz)**
  - Triggers are either a looser version of the physics triggers or brand-new triggers with small overlap with the rest
  - They complement and greatly enhance the physics program to be processed during the 2013-2014 LHC shutdown
    - For example, special Higgs production, Supersymmetry channels and B Physics

- **Data Scouting**
  - Typical use case: recover sensitivity for new physics searches in hadronic final states at “low jet $P_T/H_T/…$”
  - Novel trigger and data acquisition strategy applied to physics analysis
    - Trigger: $H_T > 250$ GeV
    - High event rate (~$10^3$ Hz)
    - Reduced event content (i.e. store only calorimeter jets reconstructed during HLT, no raw data, no offline reconstruction possible)
    - Bandwidth (rate x size) under control

Scouting approach extended the di-jet search below 1 TeV

Test Feasibility of Data Scouting in 2011:
Dijet Resonance Search (0.13 fb⁻¹)
Prompt calibration workflows:

- conditions which need continuous updates:
  - beam-spot position → every lumi-section (235)
  - tracker problematic channels → follow HV trips/noise
  - ECAL laser corrections

- conditions which need monitoring
  - calorimeter problematic channels → mask hot channels
  - tracker alignment → monitor movements of large structures

Update strategy based on delay between express and prompt reconstruction:

- dedicated streams out of express
  - compute conditions in time for prompt-reconstruction → start 48h later

Reduce need for offline re-reconstruction:

- save disk space & CPU
- physics data ready soon after data-taking

E/p scale stable to ±0.2%

CMS-DP-2012-015
Physics Performance Validation

Workflows automation and physics validation procedures
Data Certification

2012 data certification
- Delivered 21.2 fb⁻¹
- Recorded 20.1 fb⁻¹ (94.8%)
- Certified (respect to delivered, recorded)
  - Golden 18.3 fb⁻¹ (86%, 91%)
  - Muon 19.4 fb⁻¹ (92%, 97%)

Exclusive Luminosity Losses
~260 pb⁻¹ recoverable with re-reco

2011 final numbers:
- Delivered 6.10 fb⁻¹
- Recorded 5.56 fb⁻¹ (91%)
- Certified (respect to delivered, recorded)
  - Golden 5.051 fb⁻¹ (83%, 91%)
  - Muon 5.28 fb⁻¹ (87%, 95%)

91 - 92 % of delivered luminosity is used for physics

Data certification workflow
Example: Looper reconstruction (up to 7 turns)
The power of our reconstruction is extraordinary!

Event with 78 reconstructed vertices and 2 muons...
Global Event Description (Pflow)

Made possible by CMS granularity and high magnetic field

- Optimal combination of information from all subdetectors
- Returns a list of reconstructed particles
  - $e, \mu, \gamma$, charged and neutral hadrons
    - Used in the analysis as if it came from a list of generated particles
    - Used as building blocks for jets, taus, missing transverse energy, isolation and PU particle identification
To find signal we look for isolated $e$, $\mu$, $\tau$ and $\gamma$

- Isolation means little energy deposited nearby as would be expected for jets
- Isolation is critical to separate signal from background
- Pileup can add energy all over and limit the effectiveness of isolation

Particle flow isolation is much less sensitive to pileup!!

- Higher efficiency with fewer fakes!

**Efficiency stable in high PU environment**

**CMS Preliminary**
\[ \sqrt{s} = 8 \text{ TeV}, \ L = 5.1 \text{ fb}^{-1} \]

- Detector Isolation
- Particle Flow Isolation

Endcaps
$p_T < 10 \text{ GeV}$

Detector vs Particle Flow
MonteCarlo Productions

Updated on December 3rd:

~ 4.5 B events

~ 4.0 B events

Efficiency to save resources

- Vastly improved speed of reconstruction allows huge production rates
- Reprocessed Monte Carlo to match data pile-up makes it possible to use 100% of the samples, as opposed to 30-40% before
  - All of this allows us to make more of our computing resources, saving money.

Huge thanks to LHC Grid computing!

Number of reconstructed pp collisions

Generation+ Simulation

Digitization+ Reconstruction
CMS Publications on LHC data

224 Published papers

- QCD
- Exotica Searches
- Supersymmetry
- B Physics
- Electroweak
- Top Physics
- Heavy Ion
- Higgs
- Forward Physics
- Standard Model
- Beyond the SM: B2G

Remaining (planned) publications with 2011 data ~ 15-20 mostly precision measurements

- 224 Published papers
- + 6 detector performance papers
- +19 CRAFT papers

Planned publications with 2012 data ~ 100-120

Since 111th LHCC
- 26 new submission for publication
- 25 new public Physics Analysis Summary

http://cmsdoc.cern.ch/~mccauley/cmsphysics/
Recent Results
To investigate the long-range, near-side correlations in finer detail, and to provide a quantification for high multiplicity events. Distributions showed similar features as those seen in Fig. 1, in particular the ridge-like correlations, which originate primarily from decays of $\Lambda$s as a cross-check, correlation functions were also generated for tracks paired with ECAL photons over a wide range of energies [3–10].

Similar to that seen in high-multiplicity pp collision data at $\sqrt{s} = 7$ TeV, a pronounced "ridge"-like peak has been truncated. High-multiplicity events ($N_{\text{trk}} > 110$) also show the same-side jet structure emerging at the correlation peak and back-to-back correlation structures. However, in addition, a pronounced "ridge"-like peak has been truncated.

Figure 1 compares 2-D two-particle correlation functions for events with low (a) and high (b) multiplicity, for pairs of charged particles with $0.5 < p_T < 2$ GeV.

Results

- See a near-side long-range ridge similar to pp and PbPb data, but much enhanced compared to pp.
- Very pronounced for particle pairs with $0.5 < p_T < 2$ GeV.

Preparation for Heavy Ion data taking in January on-going!!
B and Forward Physics Highlights

$\Lambda_b$ lifetime $1.503 \pm 0.052$ (stat.) $\pm 0.031$ (syst.) ps.

$\Lambda_b \to J/\psi \Lambda^0$

$B^+ \to J/\psi K^+$

Measurement of the electroweak production cross sections of the Z boson with two forward-backward jets

$brem$  
VBF  
multiperipheral

$M_1 = 4148.2 \pm 2.0$ (stat) $\pm 4.6$ (syst) MeV

$M_2 = 4316.7 \pm 3.0$ (stat) $\pm 7.3$ (syst) MeV

$\sigma_{\text{meas}} = 154 \pm 58$ fb

Agreement with theoretical expectation NLO QCD corrections
W, Z, WW, and ZZ cross sections at 8 TeV
(Special Low pile-up runs used for W,Z at 8 TeV)

\[ \sigma(pp \rightarrow Wx) \times Br(W \rightarrow l \nu) = 11.88 \pm 0.56 \text{ nb} \]
\[ \sigma(pp \rightarrow Zx) \times Br(Z \rightarrow l^+ l^-) = 1.12 \pm 0.05 \text{ nb} \]

Predicted increase of the cross sections with energy is confirmed by our measurements.

Excellent understanding of the Standard Model at 7,8 TeV...
Electroweak Highlights

• Standard for calibration of Higgs mass!
  • Use $Z \rightarrow 4\ell$ to understand the mass of 4 leptons for $H \rightarrow ZZ \rightarrow 4\ell$
  • Gives 10x more events
  • Current statistics already allow $\pm 0.5\%$ on $m_{4\ell}$ scale. This will improve and improve

7 TeV

Z → 4\ell decay
9.7σ observation

arXiv:1210.3844
SMP-12-009
$m_t = 173.36 \pm 0.38 \text{ (stat.)} \pm 0.91 \text{ (syst.) GeV}$

Table 3: Correlation coefficients between the input measurements.

<table>
<thead>
<tr>
<th></th>
<th>Di-lepton 2010</th>
<th>Di-lepton 2011</th>
<th>Lepton+jets 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di-lepton 2010</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Di-lepton 2011</td>
<td>0.35</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Lepton+jets 2011</td>
<td>0.26</td>
<td>0.64</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 4: The weight coefficients assigned to the input measurements.

<table>
<thead>
<tr>
<th></th>
<th>Di-lepton 2010</th>
<th>Di-lepton 2011</th>
<th>Lepton+jets 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight coefficient</td>
<td>-0.024</td>
<td>0.127</td>
<td>0.898</td>
</tr>
</tbody>
</table>

5.2 Combination of Published CMS results

For this combination, we only consider CMS published results \[4, 6, 7\]. The total correlation matrix for the measurements is shown below in Table 3.

The combined CMS top-quark mass measurement is:

$m_t = 173.32 \pm 0.27 \text{ (stat.)} \pm 1.02 \text{ (syst.) GeV}$

The total uncertainty is 1.05 GeV, corresponding to a relative precision on the top quark mass of 0.6%. The improvement with respect to the most accurate input measurement is 1.5%. The resulting total uncertainty is dominated by the factorization scale and the different components of JES uncertainty. The $\chi^2$ for the combination is 1.1 for two degrees of freedom, corresponding to a fit probability of 59%. Again, the combined value for the top mass is close to the 2011 lepton+jets input measurement \[7\], this time with a small improvement in accuracy as this measurement dominates the combination.

6 Summary

We present a preliminary combination of five CMS top-quark mass measurements using data collected from proton-proton collisions at a center-of-mass energy $p_s = 7 \text{ TeV}$ in 2010 and 2011, using up to 5.0 fb$^{-1}$ of integrated luminosity. Three published and two preliminary results are taken into account. The systematic uncertainties were classified into categories to include the correlations between measurements. To the extent possible, the categories have been kept similar to the ones used in Tevatron, so that future combinations with the ATLAS and Tevatron results can be facilitated. The resulting combination with statistical and systematic uncertainties is:

$m_t = 173.36 \pm 0.38 \text{ (stat.)} \pm 0.91 \text{ (syst.) GeV}$

This result agrees very well with the latest Tevatron top-quark mass measurement \[1\], both in central value and precision.
95% CL Exclusion Limits [TeV]

- Z' SSM II
- Z' SSM tau tau
- Z', ttbar, hadronic, width=1.2%
- Z', dijet
- Z', ttbar, lep+jet, width=1.2%
- Z' SSM II (tbb=0.2)
- G, dijet
- G, ttbar, hadronic
- G jet+MET k/M = 0.2
- G γγ k/M = 0.1
- G, ZllZ(qq), k/M=0.1
- W' lv
- W' dijet
- W' → td
- W' → WZ(lep-tonic)
- WR, MNR=MWR/2
- WKK μ = 10 TeV
- pTC, nTC > 700 GeV
- string Ball M, MD=2.1, Ms=1.7, gs=0.4
- String Resonances (qg)
- s8 Resonance (qg)
- s8 Resonance (gg/bb, fbb=1
- E6 diquarks (qg)
- Axigluon/Coloron (qbar)
- gluino, 3iet. RPV

Resonances

Compositeness

Exotica Highlights

- b' → tW, (3I, Z2) + b-jet
- q', b'/t' degenerate, Vtb=1
- b' → tW, +jets
- B' → bZ (100%)
- T' → tZ (100%)
- t' → bW (100%), +jets
- t' → bW (100%), ±l

4th Generation

7 TeV

Long Lived

No new results for HCP but ~20 new results expected for Moriond!

LeptoQuarks

- LQ1, β=0.5
- LQ1, β=1.0
- LQ2, β=0.5
- LQ2, β=1.0
- LQ3, (bunu) Br(LQ → bντ) = 1
- LQ3, (btau) β=1.0
- stop (btau)
Search for direct top squark pair production

Search for supersymmetry in final state with $E_T$ and $0, 1, 2, 3, \geq 4$ b jets

No excess in data observed above expected SM background.

Exclusion for pair-produced gluinos, each decaying to a bottom quark-antiquark pair and a neutralino LSP.
Search for $Z'\rightarrow t\bar{t}$ in dileptons + jets final states

No excess beyond SM observed. Leptophobic $Z'$ topcolor particle is excluded for $M_{Z'}<1.3$ TeV with $\Gamma_{Z'} = 0.012 M_{Z'}$, and for $M_{Z'}<1.9$ TeV with $\Gamma_{Z'} = 0.10 M_{Z'}$.

Search for heavy quarks decaying into a top quark and a $W$ or $Z$ boson using lepton+jets events

Quark masses below 675 (625) GeV decaying into $tW$ ($tZ$) are excluded at the 95% confidence level.
Performance increase
Sensitivity up from 5.8 to 7.8 σ
CMS $ZZ \rightarrow \mu\mu \mu\mu$ candidate
Yields for $m(4l) = 110..160$ GeV

<table>
<thead>
<tr>
<th>Channel</th>
<th>4e</th>
<th>4µ</th>
<th>2e2µ</th>
<th>4ℓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZZ background</td>
<td>4.7 ±0.6</td>
<td>9.6 ±1.0</td>
<td>12.5 ±1.4</td>
<td>26.8 ±1.8</td>
</tr>
<tr>
<td>Z+ X</td>
<td>3.4^{+3.0}_{-2.3}</td>
<td>1.6^{+1.2}_{-0.9}</td>
<td>5.6^{+5.4}_{-3.6}</td>
<td>10.6^{+5.3}_{-4.4}</td>
</tr>
<tr>
<td>All backgrounds</td>
<td>8.0^{+3.1}_{-2.3}</td>
<td>11.2^{+1.6}_{-1.4}</td>
<td>18.1^{+5.8}_{-3.8}</td>
<td>37.3^{+4.6}_{-4.7}</td>
</tr>
<tr>
<td>$m_H = 125$ GeV</td>
<td>2.4 ±0.4</td>
<td>4.6 ±0.5</td>
<td>5.9 ±0.7</td>
<td>12.9 ±0.9</td>
</tr>
<tr>
<td>$m_H = 126$ GeV</td>
<td>2.7 ±0.4</td>
<td>5.1 ±0.6</td>
<td>6.6 ±0.8</td>
<td>14.4 ±1.1</td>
</tr>
<tr>
<td>Observed</td>
<td>12</td>
<td>16</td>
<td>19</td>
<td>47</td>
</tr>
</tbody>
</table>

Significance now 4.6 standard deviations

Bosons

HIG-12-041
pseudomELA = \left[ 1 + \frac{\mathcal{P}_0^-(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^* \Phi_1 | m_{4\ell})}{\mathcal{P}_0^+(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^* \Phi_1 | m_{4\ell})} \right]^{-1}

7 TeV L=5.1 fb^{-1}, 8 TeV, L=12.2 fb^{-1}

Expected separation between 0^+ and 0^-: 2 std
Scalar (0^+): data consistent (0.5 std)
Pseudo-scalar (0^-): data different by 2.4 std

Significant excess
- Observed: 3.1 std and expected: 4.1 std
Mild excess of 2.2 std building up
- Coherent picture between the sub channels Z(ll)H(bb); Z(νν)H(bb); W(lν)H(bb) need more statistics

Very small contribution

Very mild excess is building up at 1.3 std
Combined results

By $\sqrt{s}$

HIG-12-045

Overall significance:
6.9σ observed versus 7.8σ expected
Signal strengths, mass and couplings

$\frac{\sigma}{\sigma_{SM}} = 0.88 \pm 0.21$

- **Compared to SM**
- Significant discrepancies could indicate new physics!

$2D$ scan in $3$ channels

$m = 125.8 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (syst)}$

**K$_V$ and K$_F$:**
- Couplings of Higgs to $W, Z, \gamma$ (bosons) and to quarks and leptons (fermions)
Upgrades
Pixel and HCAL Upgrades

- Upgraded Pixel Detector
  - Less material, better radial distribution
    - New readout chip & extra layer recovers tracking efficiency, reduces fakes

- Upgraded HCAL
  - Improve background rejection
  - Improve MET resolution
  - Improve Particle Flow
    - Via improved S/N photo-detectors
  - Identify depth of shower max
    - Via longitudinal segmentation, timing
Improved Tracking & Btagging

- CMS Full simulation \(tt\) comparisons vs PU
  - B-tag performance (Top-Right)
  - Tracking performance (Bottom)
    - Efficiency (Left) and Fake rate (Right)

- Very powerful even without optimization!
  - B tagging, tracking efficiency at 65-70 PU equal to current detector at 25 PU
    - Fakes not quite as big improvement but usually requires careful optimization
Upgrades: Impact on Higgs Physics

\( H \rightarrow ZZ \rightarrow 4l \)
- Sensitive to lepton efficiency
  - 50% improved

\( ZH \rightarrow \mu \mu bb \)
- Associated production
  - High muon ID efficiency
  - High b-tagging efficiency
  - Good dijet mass resolution
  - 65% improved

\( H \rightarrow \tau \tau \) (VBF)
- Improved
  - MET resolution
  - Forward jet tagging capability
  - Identification

Improved signal yield (relative to current detector): shaded regions indicate cuts with biggest gains expected

- Improved signal yield:
  - \( ZH \rightarrow \mu \mu bb \) +65%
  - \( H \rightarrow ZZ \rightarrow 4l \) +50%
  - \( H \rightarrow \tau \tau \) (VBF) +65%

- More good leptons
  - better tracking & isolation

- Improved \( m_{\tau \tau} \) resolution

- Sensitive to lepton efficiency
CMS performing extremely well
- In 3rd year of operation!

Major Discovery
- A new boson with mass of ~125 - 126 GeV. Particle behaves even more like Higgs compared to ICHEP.

A lot of publications on 2011 data, 2011+2012 data and many more to come!
- To study precision measurements of the new boson

Acquiring lots of new data
- Winter conferences will be almost 2x the statistics of HCP conference

Good progress preparing for the future
- LS1 planning & Upgrades
- Physics Studies for high luminosity and High Energy LHC
~ $1/8^{th}$ of the people who made CMS possible

41 Countries and 179 institutes ~3000 Authors including ~2200 PhD’s and ~800 PhD students
Thank you for your attention
Additional Information
μ rate cut 50% for few % loss in efficiency
- And re-scoped to |η| = 2.4

- e/γ Triggers in 2012
  - ECAL transparency corrections implemented → sharper turn-ons

- HLT μ efficiency increased in 2nd half of 2012 via introduction of pileup corrections for isolation

- Tau trigger: changed quality criteria on isolation tracks
  - 60% improvement in H → ττ efficiency
Level 1 (L1) and High Level Trigger (HLT) Rates

When rates rise like this it means we are getting a data sample that has more backgrounds.

- L1 Jets: Adjusting for high luminosity!

HLT: Particle Flow Energy corrections cure non-linearity of many triggers!

In high-PU test runs, the problem returns: We’ll need to do a lot more to run after LS1.
A challenge in 2012: Pile-up

- Design value: $(L=10^{34}, 25\text{ns})$

- Raw $\Sigma E < 2\text{ TeV}$
- 14 jets with $E_T > 40$
- Estimated PU $\sim 50$

- CMS Average Pileup, pp, 2012, $\sqrt{s} = 8\text{ TeV}$

- CMS Peak Luminosity Per Day, pp
  - Data included from 2010-03-30 11:21 to 2012-12-03 03:58 UTC

- 2010, 7 TeV, max. 203.8 Hz/mb
- 2011, 7 TeV, max. 4.0 Hz/mb
- 2012, 8 TeV, max. 7.7 Hz/mb
e/\gamma reconstruction and m(\gamma\gamma) resolution

Mass resolution continually improving with more data.

Even better performance

- **EPS – Jul 2011**: FWHM = 4.23 GeV
- **LP – Aug 2011**: 4.35 GeV
- **Moriond – Feb 2012**: 3.29 GeV
- **ICHEP – Jul 2012**: 3.18 GeV

- Cluster reconstruction in ECAL
- Dedicated track reconstruction for electrons
  - Gaussian Sum Filter allows for tracks w/large bremsstrahlung
- Photon identification specific to H \rightarrow \gamma\gamma
- Energy scale and resolution
  - Extensive control with Z and J/\Psi \rightarrow e e for both electrons and photons
Electron reconstruction and identification

- Multivariate e identification in 2012
  - 30% efficiency improvement in $H \rightarrow ZZ \rightarrow 4e$ wrt cut based ID
    - ECAL, tracker, ECAL-tracker-HCAL matching, impact parameter
    - MVA training against background in data

Isolation: Energy of particles in $\Delta R$ cone around the lepton
- Global event description eliminates double counting
Muons reconstruction and identification

- Start with particle flow muons
- $\epsilon > 96\%$ down to $p_T = 5$ GeV
- $\epsilon > 99\%$ for $p_T > 10$ GeV
- Measure using $J/\Psi$ and $Z$ peak

Pile-up contribution:
- Negligible for charged hadrons (vertexing)
- Neutrals corrected via global energy density ($\rho$) estimate

![Graph showing efficiency stable in high PU environment](image)
- **Tau identification:**
  - Reconstruct individual decay modes
  - Charged hadrons + electromagnetic obj
    - EM strips account for material effects
- **Tau isolation:**
  - Multivariate discriminator using sum of energy deposits in $\Delta R$ rings around the tau
Virtual particles contribute to the Higgs mass via “loop corrections” that are huge.

- $\Lambda$ could be $10^{19}$ times the mass of the proton (Planck scale)

This is a big problem

- A.K.A. The Hierarchy problem

Something is needed to cancel out these effects!
The cure comes from partner particles

- A much smaller term is all that’s left.
- It too becomes large if the new partners are very very heavy
- All indications are that they should be in range of the LHC but what are they?

$$m_h^2 = (m_h^2)_0 - \frac{1}{16\pi^2} \lambda^2 \Lambda^2 + \frac{1}{16\pi^2} \lambda^2 \Lambda^2 + \ldots$$

Cancellation
7 TeV searches excluded 1\textsuperscript{st} and 2\textsuperscript{nd} generation squarks and gluinos up to \sim 1 \text{ TeV}
Higher collision energy translates directly into higher mass scales: \( Z', W' \), Black holes, ...

No bumps yet!

\[ Z' \rightarrow \mu \mu \]

\( Z' \): \( M > 2.6 \) TeV  
\( W' \): \( M > 2.9 \) TeV  
\( BH \): \( M > 5-6 \) TeV  
\( q^* \): \( M > 3.2 \) TeV
Higgs production at LHC

Higgs production in proton-proton collisions

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

\[ \sigma_{pp \rightarrow H+X} \text{[pb]} \]

area of largest interest
Higgs production at LHC

Common: Leptons/Photons are essential for any search
5 channels are most promising: $H \rightarrow \gamma\gamma$; $H \rightarrow \tau\tau$; $H \rightarrow bb$; $H \rightarrow WW$; $H \rightarrow ZZ$
Signature and background

- two high momentum photons
- low mass Higgs narrow
- two photon resolution excellent
- Looking for narrow peak
- Large irreducible background from direct two photons
- Smaller fake photon background

Key analysis features:
- Energy resolution is almost everything: calibrate and optimize
- Rejection of fake photons and optimize use of kinematics

No update since ICHEP
- Sum of mass distributions for each event class, weighted by S/B
- B is integral of background model over a constant signal fraction interval

**Significant excess**
- **Observed ≥4.1 std**
Signature and background
- 4 isolated high pt leptons
- consistent with Z decays
- from same vertex
- fit mass peak with resolution : 2-4 GeV
- little background, non-resonant ZZ production
- also Zbb and top

Background removal
- Leptons from b-decays are non isolated and displaced

Analysis with minor modifications since ICHEP
Significance now 4.6 standard deviations
Expected separation between $\phi^+$ and $\phi^-$: 2 standard deviations
Scalar ($\phi^+$): data consistent (0.5 std)
Pseudo-scalar ($\phi^-$): data different by 2.4 std
Higgs: $WW \rightarrow 2\ell 2\nu$

- **Signature**
  - 2 opposite charged leptons ($e, \mu$)
  - 2 neutrinos $\Rightarrow$ missing transverse energy MET
  - no Higgs mass peak
  - basically a counting analysis

- **Analysis Challenges**
  - understand backgrounds
  - normalize to control regions
  - Backgrounds: WW, W+jets, top, DY

\[ \mu: 32 \text{ GeV} \]
\[ e: 34 \text{ GeV} \]
\[ \text{MET: 47 GeV} \]
\[ \text{Higgs is scalar} \]
\[ \text{leptons are close} \]
Higgs: $\tau\tau$

**$Z\rightarrow\tau\tau$:**
- Embedding: in $Z\rightarrow\mu\mu$, replace $\mu$ by sim. $\tau$ decay.
- Normalized from $Z\rightarrow\mu\mu$ events.

**QCD:**
- Normalization & shape taken from LS/OS or fakerate.

**ttbar:**
- From madgraph.
- Normalization from sideband.

**$Z\rightarrow ee (/\mu\mu)$:**
- From powheg.
- Corrected for jet$\rightarrow\tau$, e/$\mu\rightarrow\tau$ fakerate.

**Diboson/W+jets:**
- From madgraph.
- Normalization from sideband.

- Select isolated leptons.
- Restrict $E_T'_{\tau}$ (supp. W+jets, ttbar).
- Discriminate signal from background based on $m_{\tau\tau}$. 
Basic analysis idea
- by far largest number of Higgs decays
- but lots of background (jets)
- trigger based on leptons and missing $E_T$
- b-jets identified through displaced tracks
- go to high $p_T$ where Higgs is enhanced
- main background $W/Z+\text{jets}$ and top
Combined results

CMS Preliminary \( \sqrt{s} = 7 \text{ TeV}, L \leq 5.1 \text{ fb}^{-1} \) \( \sqrt{s} = 8 \text{ TeV}, L \leq 12.2 \text{ fb}^{-1} \)

By \( \sqrt{s} \)

By decay

Local p-value

Combined obs.
Exp. for SM H
\( \sqrt{s} = 7 \text{ TeV} \)
\( \sqrt{s} = 8 \text{ TeV} \)

HIG-12-045

0

1

2

3

4

5

6

7

8

10^{-13}

10^{-17}

10^{-17}

100

200

300

400

500

600

700

800

900

1000

m_H (GeV)

m_H (GeV)
A couple of puzzling features of the discovery dataset have been resolved

- The $M(Z_1)$ vs. $M(Z_2)$ distribution filled in and now shows a clear cluster at $M(Z_1) = 90$ GeV
- The $2\sigma$ deficit in $\tau\tau$ VBF category is gone
Some Projections

2011+2012 datasets
Matrix element (MELA)
- for hypothesis discrimination
- $3.1\sigma$ by the end of the run (expectation = $1.6\sigma$ for July 4th sample)
  - depends on assumed yield, $\sim4\sigma$ with mean SM expectation
  - SM expectation is higher than observed significance in this channel in CMS
- $H\rightarrow ZZ$ channel most promising for spin-0 parity determination
  - add $H\rightarrow WW$ and $\gamma\gamma$ for spin-2 analysis

$$\text{pseudo MELA} = \left[ 1 + \frac{P_{0-}(m_1, m_2, \theta_1, \theta_2, \Phi, \Phi^*, \Phi^1|m_{4\ell})}{P_{0+}(m_1, m_2, \theta_1, \theta_2, \Phi, \Phi^*, \Phi^1|m_{4\ell})} \right]^{-1}$$
Follow-up study

- S. Bolognesi et al., arXiv:1208.4018
- WW feature: angle between decay planes
- $\gamma\gamma$: production angle

<table>
<thead>
<tr>
<th>scenario</th>
<th>$X \rightarrow ZZ$</th>
<th>$X \rightarrow WW$</th>
<th>$X \rightarrow \gamma\gamma$</th>
<th>combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^+_m$ vs bkg</td>
<td>7.1</td>
<td>4.5</td>
<td>5.2</td>
<td>9.9</td>
</tr>
<tr>
<td>$0^+_m$ vs $0^-$</td>
<td>4.1</td>
<td>1.1</td>
<td>0.0</td>
<td>4.2</td>
</tr>
<tr>
<td>$0^+_m$ vs $2^+_m$</td>
<td>1.6</td>
<td>2.5</td>
<td>2.5</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Up to $4\sigma$ separation possible (certainly true for ATLAS+CMS)

- For both odd parity and spin-2
  - More scenarios are possible...
LS1 Projects: in production
• Completes muon coverage (ME4)
• Improve muon operation (ME1), DT electronics
• Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD → SiPM)

Phase 1 Upgrades (TDRs)
• New Pixels, HCAL electronics and L1-Trigger
• Preparatory work during LS1
  – New beam pipe
  – Install test slices
    – pixel, HCAL, L1-trigger
  – Install ECAL optical splitters
    – L1-trigger upgrade, transition to operations

Phase 2: Now being defined
• Tracker Replacement, Track Trigger
• Forward: Calorimetry and Muons and tracking
• Further Trigger upgrade
Next up: Phase 1 L1-Trigger upgrade

- New system allows low trigger thresholds
  - FPGAs and μTCa technology standard for
    - Higher calorimeter granularity, better muon reconstruction
    - Global trigger with more inputs and algorithms for correlated quantities
- To be ready after 2015-16 Year End Tech Stop (YETS)
  - Development/commissioning during operations
    - Requires splitter installation during LS1 for ECAL and CSC

Calorimeter Trigger board prototype and demonstrator
**Energy increase**
7 TeV $\rightarrow$ 13/14 TeV

**Injection upgrade**

**Interaction region upgrade**

---

**LHC - European Strategy Aug. 12**

**Phase 1:**
2x$10^{34}$ Hz/cm$^2$ 500 fb$^{-1}$

**Phase 2:**
HL-LHC
5 x $10^{34}$ Hz/cm$^2$
3000 fb$^{-1}$
Phase 2 HL-LHC Projects

- Study longevity of detectors through phase 1 and phase 2
- Study constraints at experimental area
- Develop scope for phase 2 detector:
  - Motivation and requirements on detector performance
  - Trigger Performance and Strategy
    - Develop requirements (rates) and architecture
  - Forward Detector
    - Develop detector concept including tracking, calorimetry and muons
  - Tracker project
    - Develop concept with hardware trigger capability
  - Simulation and reconstruction
    - Develop tools for new geometries and high pile-up
- Target R&D programs
Looking further ahead: Signal strengths, couplings: 300,3000 fb⁻¹

- **Signal Strengths**: ~10-15%
- Present (Green). Present systematics at 300 /fb 14 TeV (Red). Setting theoretical uncertainties to zero (Black).

<table>
<thead>
<tr>
<th>Coupling</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300 fb⁻¹</td>
</tr>
<tr>
<td>( \kappa_\gamma )</td>
<td>6.5</td>
</tr>
<tr>
<td>( \kappa_V )</td>
<td>5.7</td>
</tr>
<tr>
<td>( \kappa_g )</td>
<td>11</td>
</tr>
<tr>
<td>( \kappa_b )</td>
<td>15</td>
</tr>
<tr>
<td>( \kappa_t )</td>
<td>14</td>
</tr>
<tr>
<td>( \kappa_\tau )</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Simple scenarios for couplings
1. Systematics unchanged
2. Theory uncertainties reduced \( \frac{1}{2}, \) all other systematics \( \sim \frac{1}{\sqrt{\int L dt}} \)
The Tier-o today

Even with all the performance improvements that went into the Release at the beginning of the year, The reconstruction time is still non-linear with instantaneous luminosity

Data point measured from record

~33PU

Instantaneous Luminosity ($10^{30}$ cm$^2$ s$^{-1}$)

reco time per event (s)
Simulation performance measurements are always an underestimate.

What is still not clear is how much Reconstruction code can be optimized Without affecting physics performance.