The SLHC prospects at ATLAS and CMS

1) Introduction
2) Physics motivation
3) LHC machine upgrade
4) Experiment upgrades
5) New inner trackers for SLHC
6) Conclusions

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EPS 2007, Manchester
Introduction

  - Rich physics programme - Higgs, SUSY, etc.

- Extend the physics potential of the LHC with a luminosity upgrade around ~2016
- **Time scale of an LHC upgrade**

  ![Graph](image)

  - Radiation damage limit $\sim 700 \text{ fb}^{-1}$
  - Hypothetical luminosity scenario

- Life expectancy of LHC inner-triplet (focusing) magnets and experiment’s inner trackers $< 10$ years due to radiation damage.
- Statistical error halving time exceeds 5 years by 2011-2012. It is reasonable to plan a luminosity upgrade based on new inner-triplet focusing magnets around $\sim 2015/2016$
Physics motivation

- The physics potential of a luminosity upgrade will be better known with LHC data. In general:

1) Extend the mass reach by 0.5TeV→1Tev (increased statistics of high-x parton interactions)
   - Extra gauge bosons, heavy Higgs-bosons, resonances in extra-dimension models, SUSY particles (if relatively heavy).
   - For example, extra gauge bosons (W,Z like) appear in various extensions of the SM symmetry group.
2) Increased precision in Standard Model Physics
   - Triple and quartic gauge couplings
   - Rare FCNC top decays
   - Higgs couplings
   - Strongly coupled vector boson scattering (if no Higgs)

3) Physics beyond SM (if relatively light and discovered at LHC).
   For example - SUSY
   - Extend particle spectrum
   - Improve precision and access rare decay channels.

Number of multiple gauge boson events with leptonic final states - for a luminosity of 6000fb⁻¹.

<table>
<thead>
<tr>
<th>Process</th>
<th>www</th>
<th>wzw</th>
<th>zzw</th>
<th>zzz</th>
<th>wwww</th>
<th>wwwz</th>
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</thead>
<tbody>
<tr>
<td>N(m_H=120GeV)</td>
<td>2600</td>
<td>1100</td>
<td>36</td>
<td>7</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>N(m_H=200GeV)</td>
<td>7100</td>
<td>2000</td>
<td>130</td>
<td>33</td>
<td>20</td>
<td>1.6</td>
</tr>
</tbody>
</table>


Require two b-tagged jets and reconstruct peak from h → bb decay

Requires 5 years of SLHC

Measure coupling of neutralino to Higgs.

Plot assumes ε_b = 60% for light jet rejection of 100
LHC machine upgrade

- Big challenge to increase luminosity by factor of ten. Machine R&D already started - long lead times.
- Two scenarios currently being considered:

1. Improve beam focusing
   - Machine magnets inside experiments
   - 25ns or 50ns bunch crossing

2. Increase beam currents
   - More demanding on machine
   - 50ns bunch crossing

<table>
<thead>
<tr>
<th>parameter</th>
<th>symbol</th>
<th>25 ns, small $\beta^*$</th>
<th>50 ns, long</th>
</tr>
</thead>
<tbody>
<tr>
<td>protons per bunch</td>
<td>$N_b$</td>
<td>1.7</td>
<td>4.9</td>
</tr>
<tr>
<td>bunch spacing</td>
<td>$\Delta t$ [ns]</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>beam current</td>
<td>$I$ [A]</td>
<td>0.86</td>
<td>1.22</td>
</tr>
<tr>
<td>longitudinal profile</td>
<td></td>
<td>Gauss</td>
<td>Flat</td>
</tr>
<tr>
<td>rms bunch length</td>
<td>$\sigma_z$ [cm]</td>
<td>7.55</td>
<td>11.8</td>
</tr>
<tr>
<td>beta* at IP1&amp;5</td>
<td>$\beta^*$ [m]</td>
<td>0.08</td>
<td>0.25</td>
</tr>
<tr>
<td>full crossing angle</td>
<td>$\theta_c$ [$\mu$rad]</td>
<td>0</td>
<td>381</td>
</tr>
<tr>
<td>peak luminosity</td>
<td>$L$ [10^{34} cm^{-2}s^{-1}]</td>
<td>15.5</td>
<td>10.7</td>
</tr>
<tr>
<td>peak events per crossing</td>
<td></td>
<td>294</td>
<td>403</td>
</tr>
<tr>
<td>initial lumi lifetime</td>
<td>$\tau_L$ [h]</td>
<td>2.2</td>
<td>4.5</td>
</tr>
<tr>
<td>effective luminosity (T_{turnaround}=5h)</td>
<td>$L$ [10^{34} cm^{-2}s^{-1}]</td>
<td>3.6</td>
<td>3.5</td>
</tr>
</tbody>
</table>
- The 25ns scenario will require magnets inside the experiments!

- Peak luminosities may be too difficult for experiments to cope with - possibility of "luminosity levelling" being explored.

- Peak luminosities different for 25ns versus 50ns scenarios, but average luminosity similar.
Experiment upgrades

- From the LHC to the SLHC ...

- Both ATLAS and CMS in process of determining upgrade requirements.
Muon chambers

Forward calorimeters

- In general, most of calorimetry should be OK
- FCAL (|\eta|>3.1) particularly subject to beam radiation
  - Simulations show possible heating of LAr
  - Improve cooling? Or new "warm" FCAL?

- Background rates very uncertain (factor \(\sim 5x\))
  - Need LHC experience
  - Effect of slim quads?
- Use existing chambers as far as possible
- Beryllium beampipe will reduce by factor of 2.
**Level 1 trigger**

- There may not be enough rejection power using the muon and calorimeter triggers to handle the higher luminosity conditions at SLHC
  - Level 1 Muon Trigger has no discrimination for $p_T > 20$GeV/c, therefore problem to keep Level 1 at ~100kHz.
  - Adding tracking information at Level 1 gives the ability to adjust $P_T$ thresholds

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**Calorimeters**

- Electromagnetic calorimeters should be OK at SLHC.
- Hadronic calorimeter scintillator may suffer radiation damage for $\eta > 2$
  - R&D required
  - Impact on forward region not clear if machine magnet insertions?

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**Muon system**

- In general, expected to be quite robust, but some electronics “less” radiation hard and most likely need replacing.
- As with ATLAS, need experience with running at LHC.
New trackers for SLHC

- Both ATLAS and CMS need new inner trackers
- Started looking at new layouts.
  Simulations crucial to ascertain:
  - Occupancies
  - Material effects
  - Track reconstruction performance

- Silicon trackers at LHC use mainly p-in-n sensors - requires full depletion ⇒ high voltages already at LHC.
- Move over to n-in-p at SLHC - can operate underdepleted (lower costs than n-in-n).
For innermost layers - new technology required

3D silicon sensors?

Uses MEMS (Micro Electro Mechanical Systems) technology to engineer structures.

Both electrode types are processed inside the detector bulk instead of being implanted on the wafer's surface.

Electric field between electrodes - shorter signal collection distances compared with planar devices:
- Lower depletion voltage (and therefore power)
- Faster and more efficient charge collection.
- Large scale production? Timescale? Cost?

CVD Diamond?

Now well established with several applications (eg beam conditions monitoring)
- Large band gap and strong atomic bonds give excellent radiation hardness
- Low leakage current and capacitance = low noise
- Large band gap means ~2 less signal than Si for same X₀

Gas?

Eg GOSSIP (micromegas) low mass but gas issues such as sparking?

Planar silicon sensors?

- Use conventional planar silicon n-in-p or n-in-n should new technologies not be ready
Conclusions

- The implications of a major luminosity upgrade (SLHC) sometime around 2015-2016 are being studied by the LHC machine and experiments.
  - Significantly extend physics potential of LHC
  - Work started already - long lead times!
  - But the main priority is physics exploitation of the LHC.
- The baseline bunch crossing rate at the SLHC is 20MHz, with 40MHz as a backup.
  - The 80MHz option is no longer considered due to beam heating.
- ATLAS and CMS need new inner trackers
  - New technologies being investigated
- CMS will need to revise Level 1 trigger strategy.
- ATLAS forward calorimeter may need upgrading, as well as some of the muon system.
- A better understanding of upgrade requirements for ATLAS and CMS will be gained from running at LHC.
Backup slides
The European strategy for particle physics

“The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance. A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.”

(http://council-strategygroup.web.cern.ch/council-strategygroup/)
The relatively fast luminosity decay and high multiplicity call for Luminosity Leveling.

...but the issue is how to do it efficiently:

- **dynamic beta**: uses existing hardware; probably complex due to large number of side-effects in IR’s AND arcs.

- **dynamic bunch length**: needs new RF; possible side effects in whole machine related to modification of peak current.

- **dynamic crossing angle**: using the early separation hardware, no side effects identified. Even better: crabbing.
Possible sensor technology for the SLHC tracker

- Long strips (present p\textsuperscript{+}-n or n\textsuperscript{+}-p)
- Short strips (n\textsuperscript{+}-p)
- n\textsuperscript{+}-p pixels
- Pixel b-layer (3D? Diamond? thin-Si? Gas?)

The most challenging will be engineering work (cooling, cabling, shielding, other services)
Planar silicon n-in-p or n-in-n can still play a role for inner most layers should new technologies not be ready

- Tried and tested solution but high operating voltages unless thin?
Simulations for the inner tracker

- 1 MeV fluences obtained by convolving particle spectra predicted by FLUKA2006 with “displacement-damage” curves (RD48).

- av18 is current baseline geometry for upgrade studies
  - 5cm neutron moderator lining all the calorimeters
  - no tracker material

The beneficial moderating effect of the TRT is lost in an all silicon system. Can be recovered with 5cm of moderator lining barrel (as shown in Genova).
Parameterisation of 1MeV-neq fluences

- Several requests to parameterise inner tracker backgrounds.

\[ \Phi(r) = \frac{a_1}{r^2} + \frac{a_2}{r} + a_3 + a_4 \cdot r \]

- Parameterise also pion and neutron contributions separately.

- Use these types of plots for future investigations (Eg moderator design, impact of extra material etc.)