The LHC Upgrade

Daniela Bortoletto
Purdue University
FNAL PAC, 19 June, 2008

Outline
- The physics reach
- Machine upgrade scenarios
- The CMS detector upgrade plans
- The role of FNAL
- Conclusions
The Physics of the TeV scale

- Theoretical foundation of the SM established before 1973
- Three decades of wonderful measurements by machines and experiments that are leaving or have left great legacies
  - SPS and SP-PBAR-S
  - LEP and SLC
  - TEVATRON
  - CLEO, BELLE, Babar
  - HERA
- The opening of the TeV-energy scale initiates an era where experimental data might drive the theoretical roadmap
- LHC inverse problem: Reconstruct the Lagrangian of new physics from the LHC data.
The Physics case for a luminosity upgrade

- New physics expected in TeV energy range
  - There is a large selection of proposals for BSM physics
  - In each of these there are choices
- Initial LHC data should indicate what physics is present at this energy scale and what kind of detector capabilities can best study it
- More luminosity will:
  1) Improve the accuracy of SM parameters
  2) Improve measurement of new phenomena observed at the LHC
  3) Extend the sensitivity to rare processes
  4) Extend the discovery reach in the high-mass region

Physics Potential and Experimental challenges of the LHC Luminosity upgrade

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CERN has developed a plan to increase the machine luminosity, to strengthen the machine infrastructure and to optimize the LHC physics output.

- **PHASE 1** to start in 2013 with $L = 2-4 \times 10^{34}$ cm$^{-2}$ s$^{-1}$
- **PHASE 2** to be decided in 2011 with $L = 8 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ and to start in 2016

**Phase 1**

1. The interfaces between the LHC and the experiments remain unchanged at ± 19 m.
2. Beam crossing should remain 25 ns

**Phase 2**

1. Beam crossing might be 50ns or 25 ns
2. Pile-up can be up to 400 events per crossing
3. Very demanding to get the same performance of current detectors with so much pileup
4. Might require further focusing within the experimental envelop
Machine Phase I upgrade

- New interaction region
  - Enable focusing of the beams to $\beta^*=0.25$ m in IP1 and IP5
    - Conceptual Design Report mid 2008
    - Technical Design Report mid 2009
    - Model quadrupole end 2009
    - Pre-series quadrupole 2010
    - String test 2012
    - Installation shutdown 2013

- Reliable operation of the LHC at double the operating luminosity

- Stage 1: Linac4
  - Eliminates operation and maintenance problems with LINAC2
  - Space charge decreased by a factor of 2 in the PSB
    - potential to double the beam brightness
    - potential to double the intensity per pulse.
  - Provides beam for commissioning LPSPL + PS2 without disturbing physics

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Phase 2 machine upgrade

- Further machine upgrades will be decided by 2011
  - Stage 2: Low Power SPL + PS2
    - Eliminates operation and maintenance problems with PSB and PS
    - Provides higher performance:
      - Capability to deliver the ultimate beam for LHC to the SPS
      - Higher injection energy in the SPS + higher intensity and brightness
  - Both machines are entering the R&D phase
  - The construction can take place in parallel to operation of the LHC
  - Changeover foreseen in 2017 after an extended shut-down.
  - LPSPL is a first step towards the SPL
- Stage 2': SPL (multi-MW beam power at 2-5 GeV) which could allow neutrino factory and a future generation nuclear isotopes facility
Luminosity

- A realistic scenario


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Luminosity

- "Pessimistic" uses an effective year of $5 \times 10^6$ seconds.
- "Optimistic" is $7.5 \times 10^6$ seconds.
- Scheduled running time (15 x $10^6$ s).
Issues for the detector upgrades

• Components degrade because of:
  • Radiation damage
  • High occupancy that confuses pattern recognition, overflows buffers, link bandwidths ...
  • Trigger needs to achieve adequate rejection while maintaining efficiency

• Phase 1 plans are currently under development
  • How well do detector components handle the increasing luminosity? Consider instantaneous and integrated luminosity effects (Detector need to cope with 500 fb⁻¹)
  • R&D can only be very limited because of the 2013 goal

• Phase 2 very challenging. Need extensive R&D
  • Complete tracker replacement are expected for Phase 2.
    • Lengthy (18 months) shutdown requires coordination between machine, Atlas, and CMS
    • Current planning: ATLAS earliest date around 2015, CMS not earlier than 2017
**Performance**

The performance at $10^{34}$ should be taken as a minimal reference goal.

<table>
<thead>
<tr>
<th>Object</th>
<th>Performance benchmark</th>
<th>Detector issue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>b jets &amp; tau</strong></td>
<td>Higgs identification, BR measurements</td>
<td>Tagging efficiency vs purity (statistics and bg suppression)</td>
</tr>
<tr>
<td></td>
<td>Mass resolution in the ~1-few x 100 GeV region</td>
<td>Pileup</td>
</tr>
<tr>
<td><strong>b jets</strong></td>
<td>Higgs mass determination, bg suppression</td>
<td></td>
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<tr>
<td><strong>fwd jets</strong></td>
<td>Vector boson fusion:</td>
<td></td>
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<tr>
<td></td>
<td>- measure H couplings</td>
<td>- jet tagging efficiency/fake rate vs jet $E_T$</td>
</tr>
<tr>
<td></td>
<td>- if no H, search strong</td>
<td>- jet $E_T$ resolution</td>
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<tr>
<td></td>
<td>WW phenomena</td>
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<tr>
<td><strong>cen jets</strong></td>
<td>Jet vetoes for vector boson fusion</td>
<td>fake rate</td>
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<td>Mass spectroscopy</td>
<td>mass resolution</td>
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<tr>
<td><strong>electrons</strong></td>
<td>W/Z ID, SUSY decays, etc</td>
<td>ID efficiency vs fake rate</td>
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<tr>
<td></td>
<td>$W'/Z'$ properties</td>
<td></td>
</tr>
<tr>
<td><strong>muons</strong></td>
<td>W/Z ID, SUSY and H decays, $W'/Z'$ properties, etc.</td>
<td>Forward acceptance, fake rate</td>
</tr>
</tbody>
</table>

**Final focus magnets:**
- acceptance
- $bg$
- resolution

**Pileup**

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Experimental conditions

SLHC phase I: We expect \( \sim 40 - 50 \) pile-up events per bunch crossing for operation at \( 2 \times 10^{34} \text{cm}^{-2}\text{s}^{-1} \) and 25 nsec bunch separation.

SLHC phase II: We expect \( \sim 400 \) pile-ups in 50 nsec (at \( \sim 10^{35} \text{cm}^{-2}\text{s}^{-1} \))

\[ \frac{d\text{ch}}{d\eta} / \text{crossing} \approx 250 \text{ and } \approx 1250 \text{ tracks in tracker acceptance per crossing} \]

\[ H \rightarrow ZZ \rightarrow ee \mu \mu, \ m_H = 300 \text{ GeV}, \text{ in CMS} \]

Generated tracks, \( p_t > 1 \) GeV/c cut, i.e. all soft tracks removed!

If same granularity and integration time: tracker occupancy and radiation dose in central detectors increases by factor \( \sim 2 \), pile-up noise in calorimeters by \( \sim 1.4 \) for phase 1 (relative to \( 10^{34} \))

The tracker is the key detector which will require upgrading for SLHC Phase 2

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CMS

SUPERCONDUCTING COIL

CALORIMETERS

ECAL Scintillating PbWO₄ Crystals

HCAL Plastic scintillator copper sandwich

IRON YOKE

Total weight: 12,500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 Tesla

MUON ENDCAPS

Silicon Microstrips Pixels

Tracker

Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)

Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

Iron Yoke

Total weight: 12,500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 Tesla

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Upgrade Scope

**Phase 1**

- **System**: 
  - **Pixel**: New Pixel Detector (1 or 2 iterations?)
  - **Tracker**: FEDs?
  - **HCAL**: Electronics + PD replacement
  - **ECAL**: TP (Off Detector Electronics) ?
  - **Muons**: ME4/2, ME1/1, RPC endcap, Minicrate spares, some CSC Electronics
  - **Trigger**: HCAL/RCT/GCT to µTCA

**Phase 2**

- **System**: 
  - **Pixel**: New Tracking System (incl Pixel)
  - **Tracker**: HF/HE?
  - **HCAL**: EE?
  - **ECAL**: Electronics replacement
  - **Muons**: Complete replacement

---

J. Nash - CMS Ugrades

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Phase 1 Pixel upgrade

- Several options for pixel replacement are under discussion
  - In 2013 need to replace > 50% of the pixel modules due to radiation damage.
  - Sensors were built to a fluence limit of $6 \times 10^{14}$ cm$^{-2}$ (TDR)
- Plan to replace the full pixel system with 3 (possibly 4) barrel layers and 3 endcap disks (on each side)
- Pixel data loss due to data and time stamp buffer size

For Luminosity: $1 \times 10^{34}$ cm$^{-2}$sec$^{-1}$

Radii = 11 cm / 7 cm / 4 cm layer
Total data loss @ L1A =100kHz
  - 0.8%
  - 1.2%
  - 3.8%

- Present system: 12 timestamp buffers, 32 data buffers
  - $L < 2.5 \times 10^{34}$cm$^{-2}$s$^{-1}$ requires doubling the buffer size (24/64).
  - 250 nm CMOS still ok
- For SLHC $L=10 \times 10^{34}$ need 60 timestamp / 190 data buffers \(\rightarrow\) 130 nm CMOS!
Phase 1 pixel upgrade

- Reduce material budget by at least a factor of 3 in the barrel region and 2 in the forward region
- Current modules used high density kapton signal cables
- Substitute with $\mu$-twisted pairs 2x125$\mu$m of enameled Copper Cladded Aluminum (CCA) wires

1) Freedom in bending cables in all directions
2) Omit endflange print $\Rightarrow$ no soldering, simpler mechanics endflange, no PCB, no strong mechanics supports of PCB for plugging forces
3) Can move pxAOH-motherboard & pxDOH-motherboard with PLL, Delay25 etc further back (~50cm) to high $\eta$ - range and remove material budget from sensitive tracking region

- Use Bi-phase CO$_2$ cooling instead of C$_6$F$_{14}$
- CO$_2$ allows serialized pipes without pressure drop problems $\Rightarrow$ reduces resident cooling liquid by large factor.

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Current design has ~20 component layers for a blade. Allows for “standalone module” testing, but at a material price.

- Flip chip modules mounted directly on high heat transfer/stiff material (ex. pyrolytic graphite).
- Wirebond connections from ROCs to high density interconnect/flex readout cables through holes in rigid support/heat spreader.
Phase II: Tracker replacement

- We need a tracker with equal or better performance → More channels
- To do so, solve several very difficult problems
  - deliver power (probably greater currents)
  - develop sensors to tolerate radiation fluences \( \sim 10\times \) larger than LHC
  - construct readout systems to contribute to the L1 trigger using tracker data
  - reduce material in the tracker

Installation of services one of the most difficult jobs to finish CMS

- Tracker R&D focus
  - Performance
  - Detector layout
  - Sensor material optimization at various radii
  - Readout systems for inner and outer radii
  - Triggering
  - Manufacture and material budget
Phase II layout

Strawman A:
Similar to current tracking system
4 Inner pixel layers, 2 strixel + 2 short strip layers (TIB), 2-strixel + 4 short strip layers (TOB); strixel layers can be doublets

Strawman B:
Different from current tracking system
Super-layers, each with two doublet layers (integrated tracking/triggering layers); 3 inner Pixel layers; can use inner doublet for track seeding

Pixel Giga tracker
3.3 Billion channels

Layers simplified as rings for illustration!

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Phase 1 HCAL upgrade

- Change Hybrid Photo Detectors (HPD) to SiPm
- This will allow longitudinal segmentation
  - Radiation damage in the forward region $2.5<\eta<3$ of the HE, reduces the light from the inner layers.
  - The effect can be corrected by applying different weighting
- Longitudinal segmentation in HB and HE and add shaping (HB/HE) and timing circuitry (HB/HE/HF) to reduce out-of-time pileup.
Phase I HCAL upgrade

Charge-PedMean for all RM1 pixels

Pedestal

Ion Feedback

- run 1254
- run 1470

50 GeV Discharges

Charge-PedMean for all RM1 pixels

Entries 2.17601e+07
Mean 1.089 %
RMS 0.777
Underflow 0
Overflow 438

Entries 1.91570e+07
Mean 1.175
RMS 7.322
Underflow 0
Overflow 1008

First four events with MET > 100 GeV

Global Run Data

Asynchronous HPD Discharging can be identified in low occupancy events

Advantages of SiPm over HPD:
- x2 Higher Quantum Efficiency (~34%)
- x1000 Higher Gain (~10^6)
- x4 Higher Channel Density
- No Ion Feedback, No Discharging

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3 TeV

single HPD noise
Phase II HCAL upgrade

**HCAL**
- **HE**: Plastic scintillator tiles and wavelength shifting fiber is radiation hard up to 2.5 MRad while at SLHC we expect 25 MRad in HE.
- **HF**: Tower 1 loses 60% of light during LHC, down to 4% of original after SLHC. Tower 2 down to 23% light after SLHC.
- **HF**: May be blocked by potential changes to the interaction region
  - Direct impact on WW scattering

**ECAL**
- Barrel Crystal calorimeter electronics designed to operate in SLHC conditions
- Vacuum Photo Triodes in Endcap and Endcap crystals may darken at SLHC
  - Very difficult to replace
Phase 1 muon

- Build ME4/2 chambers (72) for high-luminosity triggering in $1.1 < |\eta| < 1.8$
- Replace ME1/1 cathode cards with Flash ADC version (DCFEB), restore trigger to $2.1 < |\eta| < 2.4$ and handle high rate.

- Target Rate 5 kHz

Rick Wilkinson, Ingo Bloch

- Trigger on 3/4 vs. 2/3 stations:
  - The high-luminosity L1 trigger threshold is reduced from $48 \rightarrow 18$ GeV/c

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Phase II Muon

- Barrel fairly robust even in Phase II
- Concerns for RPC at $\eta > 1.6$
  - Tested at neutron fluence $\sim 10^{12}\text{cm}^{-2}$ ($> 10$ years of LHC operation)
  - High rate → decrease the charge in the detector
    - Possible technologies for $\eta > 1.6$:
      - Evolution of RPC (thinner gap)
      - Thin gap chambers (ATLAS)
      - Gas Electron Multiplier (LHCb)

4 Stations in the barrel and each endcap

- The Clock and Control Board will need upgrading because of Timing Trigger Control (TTC) changes
- Redesign Muon Port Card (MPC) to increase throughput
- Upgrade of the trigger primitive generator cards (ALCT) for increased occupancy & asynchronous operation
- Upgrade CSC Track finder to achieve finer granularity in $\eta, \phi$ (L1 Track Trigger)
- Tests of high-bandwidth digital optical links operating at 10Gbps or greater, testing asynchronous data transmission and trigger logic

Might be needed already in Phase I
Phase 1 Trigger upgrade

- CMS trigger is designed to deliver the physics up to $L=10^{34}$.
  - The Level-1 trigger is a fairly complex processor with $\sim 10^2$ different components.
  - Uses data from the calorimeters and muon systems to derive the L1-Accept decision with a latency of 128 Bx (144 Bx at the moment).
  - The input rate is 40 MHz and the max. output rate is 100 KHz.

- Phase 1 upgrade
  - Need to investigate what is to be done to cope with $L=2-4\times10^{34}$ using almost the same detector but more clever electronics.

- Trigger related changes already foreseen for this phase.
  - HCAL Electronics upgrade.
  - Global Calorimeter Trigger (GCT) is moving to the uTCA (Telecom Computing Architecture) → Large increase in algo. capability
  - GCT-to-Global Trigger (GT) links become industry standard asynchronous optical links which will also increase the bandwidth.
  - Already in 2009 CMS plans to adopt industry standard with compatible optical interfaces for GCT and GT.
  - In 2010 we should be able to upgrade GCT into uTCA system.
**Proto. Generic Trigger System**

- **The Main Processing Card (MPC):**
  - Receives and transmits data via front panel optical links.
  - On board 72x72 Cross-Point Switch allows for dynamical routing of the data either to a V5 FPGA or directly to the uTCA backplane.
  - The MPC can exchange data with other MPCs either via the backplane or via the front panel optical links.

- **The Custom uTCA backplane:**
  - Instrumented with 2 more Cross-Point Switches for extra algorithm flexibility.
  - Allows dynamical or static routing of the data to different MPCs.
Phase II Trigger upgrade

- 50 ns beam crossing is the SLHC baseline
- 25 ns (current baseline) is a backup
  - Buffer sizes may need to be enlarged for more interactions distributed in half the number of crossings and larger event size.
  - Increase the Level 1 latency to 6.4 μsec
  - Leave present L1+ HLT structure intact (except latency)
  - Combine Level-1 Trigger data between tracking, calorimeter & muon at Regional Level at finer granularity

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Phase II LEVEL 1 Trigger

- Trigger
  - Adding tracking information at Level 1 gives the ability to adjust $P_T$ thresholds
- Might be important for:
  - Single muon trigger
  - Single electron trigger rate

  *Isolation criteria are insufficient to reduce rate at $L = 10^{35} \text{ cm}^{-2}\text{s}^{-1}$*
Phase II Trigger concepts

- Tracking could have a critical impact on L1 trigger
  - Number of hits in tracking devices on each trigger is enormous
  - Impossible to get all the data out in order to form a trigger inside

- Investigating:
  - “Stacked” layers which can measure locally the $p_T$ of track segments
    - Two layers about 1mm apart that could “communicate”
  - Cluster width may also be a handle

- Extensive R&D needed
CMS Upgrade Management

CMS Upgrade Project

Sub-Detector Upgrade Managers
- Tracker: G. Hall, D. Bortoletto, R. Horisberger
- ECAL: P. Busson
- HCAL: D. Baden
- TRIGGER: C. Foudes
- MUONS: P. Zotto (Barre), J. Hauser (Fwd)
- DAO: C. Schwick

Coordinator
- A. Tricomi

Upgrade Offline Coordinator
- A. Tricomi

Upgrade Physics Coordinator
- N.N.

Resources Manager
- A. Petrilli

Upgrade Peer Review Chair
- W. Smith

Ex Officio
- SP: T. Virdie
- DSP: G. Tonelli
- TC.: A. Ball

Upgrade Tech. Coord.
- W. Zeuner

Electronics
- M. Hansen

Advisers
- G. Faber
- E. Tsesmelis

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15 May 2008
Upgrade Budgets

PHASE 1
Based on current detector WBS.

<table>
<thead>
<tr>
<th>Sub-Detector</th>
<th>Estimated Cost in FY08$</th>
<th>Estimated US Share in FY08 $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel System</td>
<td>30.2M</td>
<td>9.0M</td>
</tr>
<tr>
<td>CSC Muon System</td>
<td>8.6M</td>
<td>7.0M</td>
</tr>
<tr>
<td>RPC Muon System(*)</td>
<td>16.1M</td>
<td>0.0M</td>
</tr>
<tr>
<td>DT mini crates (*)</td>
<td>0.8M</td>
<td>0.0M</td>
</tr>
<tr>
<td>HCAL</td>
<td>10.2M</td>
<td>7.0M</td>
</tr>
<tr>
<td>ECAL</td>
<td>2.2M</td>
<td>1.0M</td>
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<tr>
<td>Trigger</td>
<td>8.5M</td>
<td>5.0M</td>
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<tr>
<td>DAQ</td>
<td>3.4M</td>
<td>0.0M</td>
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<tr>
<td>Tracker TDR for Phase 2</td>
<td>6.0M</td>
<td>0.0M</td>
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<tr>
<td>Project Management</td>
<td>2.0M</td>
<td>1.0M</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>88.0M</strong></td>
<td><strong>30.0M</strong></td>
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</table>

PHASE 2
Extrapolated from current detector, adjusted for US costing, in FY08$, with 30% contingency. US share is 35%.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Escalation M$ FY'08</th>
<th>Contingency 30% M$ FY'08</th>
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<tbody>
<tr>
<td>Inner Tracker</td>
<td>60</td>
<td>78</td>
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<tr>
<td>Outer Tracker</td>
<td>180</td>
<td>234</td>
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<tr>
<td>Trigger</td>
<td>40</td>
<td>52</td>
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<tr>
<td>DAQ</td>
<td>20</td>
<td>26</td>
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<tr>
<td>Calorimeters and muons</td>
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<tr>
<td>Infrastructure</td>
<td>30</td>
<td>39</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>350</strong></td>
<td><strong>455</strong></td>
</tr>
<tr>
<td><strong>Total US</strong></td>
<td><strong>122</strong></td>
<td><strong>160</strong></td>
</tr>
</tbody>
</table>
Phase 2 Upgrades
Time Table for CMS

- CD0: mid 2008
- CD1: mid 2009
- CD2: Early 2010
- Concept: mid 2008
- LOI/TP: mid 2009
- TDR: Early 2010
- Strawman: Mid 2009
- TP/LOI: Mid 2010
- TDR: 2012

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## R&D PROGRAM FY08

**Total 1.353 M$**

### HCAL

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Trigger electronic</td>
<td></td>
</tr>
<tr>
<td>Scintillator rad hard</td>
<td>$140,000</td>
</tr>
<tr>
<td>Scintillator rad hard</td>
<td>$40,000</td>
</tr>
<tr>
<td>SIPM Radiation and B tests</td>
<td>$65,000</td>
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</table>

### ECAL

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger electronic</td>
<td>$35,000</td>
</tr>
<tr>
<td>Evaluate high speed link</td>
<td>$15,000</td>
</tr>
</tbody>
</table>

### TRAVEL

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMU Included EMU M&amp;O</td>
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<tr>
<td>DAQ and Trigger Included in DAQ/Trigger M&amp;O</td>
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</table>

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>FNAL</td>
<td>$50,000</td>
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### TRACKER

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost</th>
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<tbody>
<tr>
<td>strip sensors submission</td>
<td>UCSB $60,000</td>
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<tr>
<td>strip beam test</td>
<td>Rochester, FNAL, Brown $88,000</td>
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<tr>
<td>Stave Mechanics</td>
<td>UCSB $35,000</td>
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<tr>
<td>Pixel Design</td>
<td>FNAL, Purdue $20,000</td>
</tr>
<tr>
<td>Pixel submission</td>
<td>FNAL $100,000</td>
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<tr>
<td>Pixel bump bonding</td>
<td>FNAL $60,000</td>
</tr>
<tr>
<td>Pixel testing</td>
<td>Cornell Purdue $32,000</td>
</tr>
<tr>
<td>Pixel beam test and irradiation</td>
<td>FNAL and universities $40,000</td>
</tr>
<tr>
<td>Tracker ASIC</td>
<td>FNAL $190,000</td>
</tr>
<tr>
<td>Pixel Mechanical support</td>
<td>FNAL/Purdue $93,000</td>
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<tr>
<td>Tracking trigger</td>
<td>FNAL $150,000</td>
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### SIMULATION

<table>
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<tr>
<th>Project</th>
<th>Cost</th>
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<tbody>
<tr>
<td>FNAL/TAM</td>
<td>$100,000</td>
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Budget plan and FNAL role

<table>
<thead>
<tr>
<th>FY</th>
<th>Upg R&amp;D</th>
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<tbody>
<tr>
<td>08</td>
<td>1.35</td>
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<td>09</td>
<td>2.25</td>
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<tr>
<td>10</td>
<td>3.00</td>
</tr>
<tr>
<td>11</td>
<td>3.00</td>
</tr>
</tbody>
</table>

- FNAL is playing an important role in the R&D
  - Engineering
  - Unique ASIC capabilities
  - Coordinating submissions
- Unfortunately overhead is large for activities at FNAL

The current R&D budget profile was developed before the definition of Phase I and Phase II and therefore it should be refined.

<table>
<thead>
<tr>
<th></th>
<th>FY 08 Budget</th>
</tr>
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<tbody>
<tr>
<td>Fermlab - DOE</td>
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<tr>
<td>Personnel</td>
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<tr>
<td>FTE</td>
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<tr>
<td>M&amp;S</td>
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<tr>
<td>Purchases</td>
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<td>Travel</td>
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<tr>
<td>CERN (Cola)</td>
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<tr>
<td>Total</td>
<td>735,000</td>
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Conclusions

• The SLHC physics program requires detector upgrades able to maintain the performances expected at the standard $10^{34}$ cm$^{-2}$ s$^{-1}$ luminosity.
• The SLHC detector upgrades are very challenging and require significant detector R&D, especially for the inner tracking systems.
• FNAL can provide unique infrastructures/expertise to achieve the upgrade goals.

The program at the LHC and SLHC will dominate the exploration of the energy frontier for a long time.... We need success!!!!

Hopefully we will send many postcards about the discoveries from the Tera-energy scale.

PAC June 2008

Daniela Bortoletto, Purdue University
Backup
Higgs Decays

- **Rare decays:**
  - $H \to Z\gamma$ BR of $10^{-3}$ in the SM
  - $H \to \mu\mu$ BR of $10^{-4}$ in the SM

<table>
<thead>
<tr>
<th></th>
<th>300 fb$^{-1}$</th>
<th>3000 fb$^{-1}$</th>
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</thead>
<tbody>
<tr>
<td>$H \to Z\gamma$</td>
<td>$3.5 \sigma$</td>
<td>$11 \sigma$</td>
</tr>
<tr>
<td>$H \to \mu\mu$</td>
<td>$&lt;3.5 \sigma$</td>
<td>$7 \sigma$</td>
</tr>
</tbody>
</table>

**SLHC, 3000 fb$^{-1}$ per experiment**

- **Higgs couplings**
  \[ R(H \to ff) = \int L dt \cdot \sigma(pp \to H) \cdot \frac{\Gamma_f}{\Gamma} \]
  - Combining different production mechanisms and decay modes get ratios of Higgs couplings to bosons and fermions
  - Statistics limited at LHC

At phase 2 SLHC ($\sim1000$ fb$^{-1}$ per year) the ratios of Higgs couplings should be measurable with a $\sim 10\%$ precision

PAC, June 2008
Daniela Bortoletto, Purdue University
Higgs Pair Production & Self Coupling

Higgs pair production through two Higgs bosons radiated independently (from VB or top) & from trilinear self-coupling terms proportional to $\lambda_{HHH}^{SM}$.

• Very small cross sections, hopeless at LHC ($10^{34}$), some hope at SLHC
• Channel investigated, $170 < m_H < 200$ GeV (ATLAS):
• SLHC goal: Determine $\lambda$ to moderate precision; requires very large integrated luminosity and favorable Higgs mass.

Cross sections for Higgs boson pair production in various production mechanisms and sensitivity to $\lambda_{HHH}$ variations

arrows correspond to variations of $\lambda_{HHH}$ from 1/2 to 3/2 of its SM value
MSSM parameter space regions for > 5σ discovery for the various Higgs bosons, 300 fb⁻¹ (LHC), and expected improvement - at least two discoverable Higgs bosons - with 3000 fb⁻¹ (SLHC) per experiment, ATLAS & CMS combined.

Green area: region where only one (the h, ~ SM-like) among the 5 MSSM Higgs bosons can be found (assuming only SM decay modes)

LHC contour, 300 fb⁻¹/exp
SLHC contour, 3000 fb⁻¹/exp at least one heavy Higgs discoverable up to here
SLHC contour, 3000 fb⁻¹/exp at least one heavy Higgs Excludable (95% CL) up to here

Heavy Higgs observable region increased by ~ 100 GeV
• LHC reaches squarks, gluinos $\sim 2.5$ TeV
• SLHC Phase II could reach squarks, gluinos $\sim 3.0$ TeV

Maintain excellent MET resolution
Maintain excellent bb mass resolution
Maintain excellent lept ID
Maintain excellent b tagging eff

• Increased statistics (SLHC/I and II) yields increased sparticle spectrum reconstruction
• Requires excellent b-tagging

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Upgrade components

Proton flux / Beam power

Linac2
---
PSB
---
PS
---
SPS
---
SPS+
---
LHC / SLHC
---
DLHC

50 MeV
160 MeV

1.4 GeV
4 GeV

26 GeV
50 GeV

450 GeV
1 TeV

7 TeV
~ 14 TeV

LPSPL: Low Power Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to 1000 GeV)
SLHC: “Superluminosity” LHC (up to 10^{35} cm^{-2}s^{-1})
DLHC: “Double energy” LHC (1 to ~14 TeV)

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Lyn Evans
Phase 1 pixel upgrade

Pixel busy: 0.04% / 0.08% / 0.21%
Pixel insensitive until hit transferred to data buffer (column drain mechanism)

Double column busy: 0.004% / 0.02% / 0.25%
Column drain transfers hits from pixel to data buffer.
Maximum 3 pending column drains requests accepted

Datat Buffer full: 0.07% / 0.08% / 0.17%

For Luminosity: $1 \times 10^{34}$ cm$^{-2}$sec$^{-1}$

Radii = 11 cm / 7 cm / 4 cm layer

Total data loss @ L1A = 100kHz

- 0.8%
- 1.2%
- 3.8%

Timestamp Buffer full: 0 / 0.001% / 0.17%

Readout and double column reset:
0.7% / 1% / 3.0%
for 100kHz L1 trigger rate

SLHC rate data losses dominated by finite buffer sizes!

→ chip size!
periphery bigger

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Optimize layout

- Evaluate how well we can extract physics with 400 pile-up events per crossing
  - Study is technically difficult
  - Depends on geometry of a new tracking device
  - Long timescale for full answers

- Track density in heavy ions is very similar to 50ns running
  - $dnch/d\eta/crossing \approx 3000$
  - Tracker occupancy very high
  - Need more pixel layers/shorter strips

- Tracking possible when tracks are found they are well measured

Loss of efficiency due to 3 pixel points
Need more pixel layers!!
Phase II Radiation Damage

Fluence in $10^{14}$/cm$^2$

L=3000 fb$^{-1}$

- Develop sensors that can function at $10^{16}$/cm$^2$

Radiation Dose in Inner Detectors

M. Huhtinen  SLHC Electronics Workshop 26 February 2004
CMS

Much of CMS is well shielded and built to last through SLHC

These components will remain

Barrel HCAL calorimeters

Barrel EM calorimeters
Upgrade plans: Phase I

Goal of “Phase I” upgrade:
Enable focusing of the beams to $\beta^*=0.25$ m in IP1 and IP5, and reliable operation of the LHC at double the operating luminosity on the horizon of the physics run in 2013.

Scope of “Phase I” upgrade:

1. Upgrade of ATLAS and CMS experimental insertions. The interfaces between the LHC and the experiments remain unchanged at $\pm 19$ m.

2. Replace the present triplets with wide aperture quadrupoles based on the LHC dipole cables (Nb-Ti) cooled at 1.9 K.

3. Upgrade the D1 separation dipole, TAS and collimation system so as to be compatible with the inner triplet aperture.

4. The cooling capacity of the cryogenic system and other main infrastructure elements remain unchanged.

5. Modifications of other insertion magnets (e.g. D2-Q4) and introduction of other equipment in the insertions to the extent of available resources.
## FNAL personnel on Upgrade

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joe Howell</td>
<td>Mech Eng</td>
<td>0.05</td>
</tr>
<tr>
<td>Cm Lei</td>
<td>Mech Eng</td>
<td>0.15</td>
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<tr>
<td>Mech. Tech</td>
<td>Tech</td>
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<tr>
<td>Gregory Deputch</td>
<td>Elect. Eng.</td>
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<td>ASIC engineer</td>
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<tr>
<td>Gustavo Cancelo</td>
<td>Elect. Eng.</td>
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<tr>
<td>Alan Prosser</td>
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<tr>
<td>Marcos Turqueti</td>
<td>Elect. Eng.</td>
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</tr>
<tr>
<td>Jeff Andresen</td>
<td>Eng. Associate</td>
<td>0.15</td>
</tr>
<tr>
<td>John Chramowicz</td>
<td>Eng. Associate</td>
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</tr>
<tr>
<td>Elect. Tech</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
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<td><strong>1.75</strong></td>
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