Getting ready for the LHC

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ETH Zürich

Planck’06
Paris
2.6.2006
Outline

- Introduction

- **Now**: Status of the
  - Machine
  - Detectors (ATLAS, CMS)

- **Pretty soon**: Commissioning and start-up scenarios of the
  - Machine
  - Detectors

- **Soon**
  - Pilot and first Physics run

- **Further aspects**
  - Learn amap from the data
  - Some comments
Our future playground

Introduction

Status of Machine Detectors

Startup of Machine Detectors

First Physics

Comments

LHC: 27 km long
100m underground

pp, B-Physics, CP Violation

General Purpose, pp, heavy ions

Heavy ions, pp

ATLAS

ALICE

CMS

+TOTEM

LHC
Now:
Status of the LHC and the Detectors

“The greater the obstacle, the more glory in overcoming it.” (Moliere)
The LHC: Basic parameters

Introduction

Status of Machine

Detectors

Startup of Machine

Detectors

First Physics

Phys. Reach

---

**10 GJ stored in magnets**

- 1232 superconducting dipoles
- 15 m long at 1.9 K, B=8.33 T
- Inner coil diameter = 56 mm
- Beam energy 7 TeV (7x TEVATRON)
- Luminosity 10^{34} cm^{-2} s^{-1} (>100x TEVATRON)
- Bunch spacing 24.95 ns
- Particles/bunch 1.1 \times 10^{11}
- Stored E/beam 350 MJ

---

Also: Lead Ions operation

- Energy/nucleon 2.76 TeV / u
- Total initial lumi 10^{27} cm^{-2} s^{-1} x 200
Lowering of the first dipole into the tunnel (March 2005).

By now there are > 500 dipoles

Schedule review in Spring 2006.
The LHC: Status report

Introduction
Status of Machine
Detectors
Startup of Machine
Detectors
First Physics
Comments


Updated 31 May 2006
Data provided by D. Tommasini AT-MAS, L. Bottura AT-MTM

G. Dissertori
**ATLAS**

**Introduction**

**Status of Machine**

**Detectors**

**Startup of Machine**

**Detectors**

**First Physics**

**Comments**

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**Muon Spectrometer** ( |\(\eta\)|<2.7 )
- air-core toroids with muon chambers

---

**Calorimetry** ( |\(\eta\)|<5 )
- EM : Pb-LAr
- HAD : Fe/scintillator (central), Cu/W-Lar (fwd)

---

**Tracking** ( |\(\eta\)|<2.5, B=2T )
- Si pixels and strips
- TRD (e/\(\pi\) separation)

---

<table>
<thead>
<tr>
<th>Diameter</th>
<th>25 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel toroid length</td>
<td>26 m</td>
</tr>
<tr>
<td>End-cap end-wall chamber span</td>
<td>46 m</td>
</tr>
<tr>
<td>Overall weight</td>
<td>7000 tons</td>
</tr>
</tbody>
</table>
Introduction

Status of Machine

Detectors

Startup of Machine

Detectors

First Physics Comments

Toroids:
8 out of 8 coils installed.
End of coil installation early Aug 05.
Introduction

Status of Machine

Detectors

Startup of Machine

Detectors

First Physics

Comments

Superconducting Coil, 4 Tesla

Tracker

Pixels
Silicon Microstrips
210 m² of silicon sensors
9.6M channels

MUON BARREL

Drift Tube Chambers (DT)

Resistive Plate Chambers (RPC)

CALORIMETERS

ECAL
76k scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich

IRON YOKE

Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m

Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m

MUON ENDCAPS

Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)
Magnet Insertion: Autumn 05 ; Cooled down early in 2006
CMS : Status report

Introduction

Status of Machine

Detector

CMS ECAL

Overview

DCS

Phys. Prep.

Outlook
CMS : lowering

Introduction

Status of Machine

Detectors

Startup of Machine

Detectors

First Physics

Comments
Pretty soon: Commissioning and start-up scenarios

“If we wait for the moment when everything, absolutely everything, is ready, we shall never begin.” (Ivan Turgenev)
LHC : Performance Limitations

- Two Examples: Magnet aperture, beam-beam, collimators

\[ \sigma = \sqrt{\beta(s)\epsilon} \quad \beta(s) = \beta^* + \frac{s^2}{\beta^*} \]

Badly conducting collimators: large wake fields: instability

Phase 1: graphite (robust), \( I < 0.3 \text{ A} \)
Phase 2: Cu (good conduct.), \( I < 0.85 \text{ A} \)

\[ \sigma^* = 16.6 \mu\text{m} \quad \sim 23\text{ m} \quad \sigma(\text{triplet}) = 1.54 \text{ mm} \]
Stage 1
Initial commissioning
43x43 to 156x156, N=3x10^{10}
Zero to partial squeeze
L=3x10^{28} - 2x10^{31}

Stage 2
75 ns operation
936x936, N=3-4x10^{10}
partial squeeze
L=10^{32} - 4x10^{32}

Stage 3
25 ns operation
2808x2808, N=3-5x10^{10}
partial to near full squeeze
L=7x10^{32} - 2x10^{33}

Stage 4
25 ns operation
Push to nominal per bunch
partial to full squeeze
L=10^{34}

- **Objective**: establish colliding beams as quickly as possible, safely, without compromising further progress
- Take two moderate intensity multi-bunch beams to high energy and collide them: minimize problems due to electron cloud, event pile-up, equipment restrictions, use phase 1 collimators.
Construction quality checks and beam tests of series detector modules show that the detectors as built should give a good starting-point performance.

However, a lot of data (and time …) will be needed at the beginning to:

- Commission the detector and trigger in situ
- Reach the performance needed to optimize the physics potential
- Understand “basic” physics at 14 TeV and normalize (tune) the MC generators
- Measure backgrounds to new physics and extract “early” convincing signals

Efficient/extensive/robust commissioning programme with physics data is therefore crucial to reach quickly the “discovery” mode.
Detectors : Commissioning

- **No Beam**:
  - Cosmic Muons
  - Initial alignment/detector calibration (barrel)
  - Debugging, dead-channels mapping
  - Rates:
    - $E_{\text{surface}} > 10 \text{ GeV}$: $\sim 1 - 5 \text{ kHz}$
    - Useful for calibration: $\sim 0.5 \text{ Hz}$

- **One Beam**:
  - Beam-Halo Muons
    - Alignment/calibration in end-caps
    - Rate for $E > 100 \text{ GeV}$: $\sim 1 \text{ kHz}$
  - Beam-Gas events
    - Resemble pp, with soft spectrum ($p_T < 2 \text{ GeV}$)
    - 25 Hz of reco. Tracks with $p_T > 1 \text{ GeV}$, $|z| < 20 \text{ cm}$
    - Eg. first alignment of inner trackers to about 100 $\mu\text{m}$ or better?
Soon: Pilot Run and First Physics

“The only place you’ll find SUCCESS before WORK is in the dictionary” (May B. Smith)
Pilot run : Luminosity

- 30 days maximum, probably less (?)
- 43x43 bunches, then 156x156 bunches

Lumi (cm$^{-2}$s$^{-1}$)

- $10^{31}$
- $10^{30}$
- $10^{29}$
- $10^{28}$

Pile-up

Int. Lumi (pb$^{-1}$)

- $10$
- $1$
- $0.1$

$\varepsilon_{LHC} = 20\%$ (optimistic!)

DAYS

- luminosity ($10^{30} \text{ cm}^2 \text{ sec}^{-1}$)
- integrated luminosity (pb$^{-1}$)
- events/crossing

Courtesy : G. Rolandi
Pilot Run : Number of events

**Assumed efficiencies:**

\[ \varepsilon(\text{jets}) = 100\% \]
\[ \varepsilon(W) = 20\% \]
\[ \varepsilon(Z) = 20\% \]
\[ \varepsilon(\text{ttbar}) = 1.5\% \]

Even within a few hours/days:

- **About 10 million minimum bias evts** (almost possible to trigger randomly)
- **A few million di-jet events with** \( E_T > 15 \text{ GeV} \)
- **Not much of anything else**
Pile-Up

- **Pile-up**: additional mostly soft-interactions per bunch crossing
- **Start-up Lumi**: $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \Rightarrow 4 \text{ events} / \text{bunch crossing}
- **High Lumi**: $10^{34} \text{ cm}^{-2}\text{s}^{-1} \Rightarrow 20 \text{ events} / \text{bunch crossing}

---

LHC event - no pile-up

LHC event - $10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Courtesy A. De Roeck
- ~12 particles/evt in the barrel (+12 forward)
- Half of them curl in the tracker, ~50% reach outermost tracker layer
Di-Jets

- Produced at high rate
- Use for jet calibration by balancing jet transverse momentum
  - analyse \( \Delta p_T / \text{di-jet } p_T \). Works well for low \( p_T \), but low stat. at high \( p_T \)
- Physics interest in the high mass tail

<table>
<thead>
<tr>
<th>Sensitivity to Dijet Resonances at CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross section * BR * Ac,* (pb)</td>
</tr>
<tr>
<td>Lum=1fb^-1</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Mass (TeV)</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>10^4</td>
</tr>
</tbody>
</table>

- QCD cross section between 1.9 - 2.1 TeV is 3.5 pb
- Excited quarks: 8 pb!
- CDF/D0 limits in the range 0.4 - 1 TeV
- With 15 pb^-1 at 14 TeV we could extend this
- Crucial: energy resolution in measuring jet energy (narrow resonances)

But … if we see a signal .. How can we be sure about the tails in the energy resolution?
First Physics runs (2008...)

- After first “good” 10 pb⁻¹
  - ~20000 W, decaying to lepton + neutrinos
  - ~2500 Z, decaying into two leptons
  - ~200 semi-leptonic top-pair events
    - Measure rates, align and calibrate better

- After first “good” 100 pb⁻¹
  - W(Z)+jets rates well measurable
    - Jet calibration, MET calibration (for SUSY)
  - Inclusive leptons, di-leptons, photons, di-photon triggers (for Higgs)

- From 100 pb⁻¹ to 1 fb⁻¹
  - Standard model candles
    - Top pair prod., W/Z cross sections, PDF studies, QCD studies, b-jet production
    - Do extensive MC tuning
  - Early Higgs boson search
    - H→γγ,WW,ZZ
  - Early SUSY-BSM searches
    - MET + anything, di-jet, di-leptons, di-photon, resonances...
The path to discovery

Introduction

Status of Machine

Detectors

Startup of Machine

Detectors

First Physics

Phys. Reach

<table>
<thead>
<tr>
<th>L [10^{30} \text{ cm}^{-2}\text{s}^{-1}]</th>
<th>weeks</th>
<th>e_{\text{LHC}} = 30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E+04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00E+03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00E+02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00E+01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00E-01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Re-discovery of the TOP
- Z' into muons
- SUSY - SUSY
- Higgs ???

1.9 fb^{-1}

LHC = 30\%

Courtesy G. Rolandi
Some comments

“Doing something ordinary is a waste of time” (Madonna)
## Event rates

Event production rates at $L=10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ and statistics to tape

<table>
<thead>
<tr>
<th>Process</th>
<th>Events/s</th>
<th>Evts on tape, $10^{10} \text{ fb}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow \text{en}$</td>
<td>15</td>
<td>$10^8$</td>
</tr>
<tr>
<td>$Z \rightarrow \text{ee}$</td>
<td>1</td>
<td>$10^7$</td>
</tr>
<tr>
<td>$t \bar{t}$</td>
<td>1</td>
<td>$10^6$</td>
</tr>
<tr>
<td>Minimum bias</td>
<td>$10^8$</td>
<td>$10^7$</td>
</tr>
<tr>
<td>QCD jets $p_T&gt;150 \text{ GeV/c}$</td>
<td>$10^2$</td>
<td>$10^7$</td>
</tr>
<tr>
<td>$b \bar{b} \rightarrow \text{mX}$</td>
<td>$10^3$</td>
<td>$10^7$</td>
</tr>
<tr>
<td>Gluinos, $m=1 \text{ TeV}$</td>
<td>0.001</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Higgs, $m=130 \text{ GeV}$</td>
<td>0.02</td>
<td>$10^4$</td>
</tr>
</tbody>
</table>

$10^7$ events to tape every 3 days, assuming 30% data taking efficiency, 1 PB/year/exp

- Statistical error negligible after few days (in most cases)!
- Dominated by systematic errors (detector understanding, luminosity, theory)
Early SUSY discovery?

- Large squark/gluino pair prod. cross sections, ~100 evts/day at $10^{33}$ for $m(\text{squarks, gluinos}) \sim 1\text{ TeV}$. Spectacular signatures

Use multi-jet, multi-leptons and $E_T^{\text{miss}}$ for discrimination.

eg. $M_{\text{eff}} = E_T^{\text{miss}} + \sum p_T(j)$

Beware ! : Good understanding of detector and SM bckgrds needed!

eg. parton shower not enough!

- Peak pos. related to $M_{\text{SUSY}}$
Warnings…

- Always try to be as independent from the Monte Carlo simulation as possible!
  - eg. find a “Standard Model candle” for calibration
  - Obtain backgrounds from the data whenever possible
    - Easy if we have mass peak (from sidebands)
    - More difficult in case of excess in high-energy tails, in particular in relation to MET or high-E_T jets

- But what to do?
  - Some examples in the following
  - Study carefully the validity of a Monte Carlo, and what it is exactly based on
    - eg. LO 2-to-2 process + parton shower, or 2-to-n + parton shower, or NLO+parton shower, or …

- Worry in particular about systematic errors in your search analysis when S/B << 1!!
  - be careful with calculation of significance
Getting things from data

- **Calibrations**
  - Electromagnetic calorimetry
    - $Z \rightarrow ee, W \rightarrow ev$, Minimum-bias
  - Hadronic calorimetry and jets
    - Di-jet balance, $Z \rightarrow ll + 1j$, $W \rightarrow jj$ in tt events, photon + jet
  - MET
    - $Z \rightarrow ll +$jets, then remove leptonic information
  - Tracker and Muon alignment:
    - $Z \rightarrow \mu\mu, W \rightarrow \mu\nu$
  - Lepton efficiencies, b-tagging
    - $Z \rightarrow ee, Z \rightarrow \mu\mu$
    - b-tag: use ttbar events to commission

- **Important kinematic properties**
  - $W + n$ jets, $p_t$ of $W$: take $Z \rightarrow ll + n$ jets
  - Use bbZ ($\rightarrow ll$) as benchmark for bbA

- **Backgrounds**
  - Sidebands, or
  - normalize background via background-enhancing selection, use theory to extrapolate to signal-enhancing selection
Summary

- We ARE getting ready for the LHC

- CERN is fully committed to the LHC project
  - Everybody (machine and detectors) is working like crazy to be in time

- Many efforts now concentrating on the very details of the start-up procedure
  - How to analyze the first data coming out

- Physics studies
  - be careful when using Monte Carlo programs for background (and signal) evaluation
  - The ingenuity of the experimenters really becomes visible when working on methods to get as much as possible from the data

“If we don’t succeed, we run the risk of failure” (B. Clinton)
Acknowledgements

- Many thanks to all these people:

- Thanks for the invitation!

- My hope for the LHC:
OF COURSE, IT'S STILL A COMPLETE MYSTERY AS TO HOW THE ANCIENTS EVEN MANAGED TO MOVE THESE MASSIVE STONES ....
Backups
## LHC: Performance Limitations

### Introduction

- **Status of Machine**
- **Detectors**
- **Startup of Machine**
- **Detectors**
- **First Physics**
- **Comments**

### Parameter/Effects

<table>
<thead>
<tr>
<th>Parameter/Effects</th>
<th>Limitations</th>
</tr>
</thead>
</table>

### Legend:

- $N$: particles/bunch
- $n$: nr. of bunches
- $I$: current / beam
- $\epsilon_n=\gamma\epsilon$, $\epsilon$: emittance
- $\beta^*$: $\beta$ at IP
- Beam size $\sigma^2=\beta\epsilon$
- $Q$: tune (number of trans. oscil./turn)
- Tune spread $\Delta Q \propto N / \epsilon_n$

### Formula

$$\mathcal{L} = \frac{N^2 n f_{rev}}{4\pi \epsilon_n \beta^*}$$
Pilot run

- The first time that we will see proton-proton collisions at 14 TeV!

- Pilot run is short (max 30 days) and data taking will happen only for a small fraction of time

- Important to use very efficiently this time optimizing between competing tasks
  - Changing conditions to commission the detector (e.g., synchronization)
  - Stable data taking for tracker alignment & measurement of minimum bias (can be done with coarse synchronization)
First Physics : Basic processes

\[ \frac{d\sigma}{dt} (h_1 h_2 \rightarrow c d) = \int_0^1 dx_1 dx_2 \sum_{a,b} f_{a/h_1}(x_1, \mu_F^2) f_{b/h_2}(x_2, \mu_F^2) d\sigma^{(a,b\rightarrow cd)}(Q^2, \mu_F^2) \]
LHC : Performance Limitations

- **Electron cloud**: heat load on the beam screen, larger for smaller bunch spacing

25 ns ok for well conditioned surfaces (⇒ 2808 bunches)

12.5 ns: at the limit!
Final conclusion only after LHC startup

- **Magnet aperture, beam-beam, collimators**

  $\sigma = \sqrt{\beta(s)\epsilon}$
  $\beta(s) = \beta^* + \frac{s^2}{\beta^*}$

  $\sigma^* = 16.6\mu m \overset{\sim}{\to} 1.54\text{ mm}$

Badly conducting collimators: large wake fields: instability

Phase 1: graphite (robust), $I < 0.3$ A
Phase 2: Cu (good conduct.) $I < 0.85$ A
The Underlying Event:

- beam-beam remnants
- initial-state radiation
- multiple-parton interactions

Issues:

- modeling (learn from min. bias)
- extrapolation to LHC energies
- impact on selection efficiencies?
  - isolation, trigger strategy
- have to tune MCs (e.g., Pythia) asap
Example : CMS preparations for Pilot Run

- Simulate 10 million min. bias evts and 1 million di-jets with $p_T^{\text{had}} > 10-15$ GeV, using pilot run geometry
  - No pixel det., no ECAL endcaps

- Reconstruct these evts with latest reconstruction software

- “collect” the events
  - Ie. determine with which rate these events can be handled by the initial DAQ config.
  - Determine a trigger strategy to saturate it
    - Random, ECAL low energy photons, HCAL low thresholds, muons
  - Study trigger conditions as function of increasing luminosity

see CMS Physics TDR due this year !!
**Issues:**

- **Backgrounds**: WW, tt (WbWb)
- Central jet veto (suppresses WbWb)
- Lepton isolation
- Different dynamics of signal and background, e.g., lepton angles
  → good MCs needed!
- Differential NNLO(+$\text{NNLL}$) Higgs cross section as function of Higgs $p_T$ is important
  - resummation, Grazzini, Catani et al
  - NNLO on its way, Babis et al.

**Recent full simul. CMS study**

- Best channel for $M_H\sim160-170$ GeV
- $5\sigma$ stat. significance for $\sim 1$ fb$^{-1}$
- Whole range $M_H\sim150-180$ GeV can be covered with $\sim 10$ fb$^{-1}$
CMS: Trigger/DAQ

Event rate

LEVEL-1 Trigger
Hardwired processors (ASIC, FPGA)
Pipelined massive parallel

HIGH LEVEL Triggers
Farms of processors

Reconstruction & ANALYSIS
TIER0/1/2 Centers

ON-line

OFF-line

Level-1

On tape

Event rate

Jet $E_T$ or particle mass (GeV)

25 ns

3 μs

ms

sec

hour

year

$10^{-3}$

$10^{4}$

$10^{-3}$

$10^{-6}$

Giga

Tera

Petabit

2.6.2006

G. Dissertori
These numbers from DAQ TDR.

\[ L = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \]

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Threshold (GeV or GeV/c)</th>
<th>Rate (Hz)</th>
<th>Cuml. rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusive electron</td>
<td>29</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Di-electron</td>
<td>17</td>
<td>1</td>
<td>34</td>
</tr>
<tr>
<td>Inclusive photon</td>
<td>80</td>
<td>4</td>
<td>38</td>
</tr>
<tr>
<td>Di-photon</td>
<td>40, 25</td>
<td>5</td>
<td>43</td>
</tr>
<tr>
<td>Inclusive muon</td>
<td>19</td>
<td>25</td>
<td>68</td>
</tr>
<tr>
<td>Di-muon</td>
<td>7</td>
<td>4</td>
<td>72</td>
</tr>
<tr>
<td>Inclusive tau-jet</td>
<td>86</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>Di-tau-jet</td>
<td>59</td>
<td>1</td>
<td>76</td>
</tr>
<tr>
<td>1-jet * ( E_{T}^{\text{miss}} )</td>
<td>180 * 123</td>
<td>5</td>
<td>81</td>
</tr>
<tr>
<td>1-jet OR 3-jet OR 4-jet</td>
<td>657, 247, 113</td>
<td>9</td>
<td>89</td>
</tr>
<tr>
<td>Electron * jet</td>
<td>19 * 45</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>Inclusive b-jet</td>
<td>237</td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>Calibration etc</td>
<td></td>
<td>10</td>
<td>105</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>105</strong></td>
</tr>
</tbody>
</table>

Computing TDR foresees some additional bandwidth (further SM rates, calibrations etc), so 150 Hz
### CMS L1 Trigger Table

**L = 2 x 10^{33} cm^{-2} s^{-1}**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Threshold (GeV or GeV/c)</th>
<th>Rate (kHz)</th>
<th>Cumulative Rate (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated e/g</td>
<td>29</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Di-e/g</td>
<td>17</td>
<td>1.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Isolated muon</td>
<td>14</td>
<td>2.7</td>
<td>7.0</td>
</tr>
<tr>
<td>Di-muon</td>
<td>3</td>
<td>0.9</td>
<td>7.9</td>
</tr>
<tr>
<td>Single tau-jet</td>
<td>86</td>
<td>2.2</td>
<td>10.1</td>
</tr>
<tr>
<td>Di-tau-jet</td>
<td>59</td>
<td>1.0</td>
<td>10.9</td>
</tr>
<tr>
<td>1-jet, 3-jet, 4-jet</td>
<td>177, 86, 70</td>
<td>3.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Jet*E_{T}^{miss}</td>
<td>88*46</td>
<td>2.3</td>
<td>14.3</td>
</tr>
<tr>
<td>Electron*jet</td>
<td>21*45</td>
<td>0.8</td>
<td>15.1</td>
</tr>
<tr>
<td>Min-bias</td>
<td>0.9</td>
<td></td>
<td>16.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>16.0</strong></td>
</tr>
</tbody>
</table>
CMS HLT efficiencies

With previous selection cuts

<table>
<thead>
<tr>
<th>Channel</th>
<th>Efficiency (for fiducial objects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H(115 \text{ GeV})\gamma\gamma$</td>
<td>77%</td>
</tr>
<tr>
<td>$H(160 \text{ GeV})\gamma WW^*\gamma 2m$</td>
<td>92%</td>
</tr>
<tr>
<td>$H(150 \text{ GeV})\gamma ZZ\gamma 4m$</td>
<td>98%</td>
</tr>
<tr>
<td>$A/H(200 \text{ GeV})\gamma 2t$</td>
<td>45%</td>
</tr>
<tr>
<td>SUSY (~0.5 TeV sparticles)</td>
<td>~60%</td>
</tr>
<tr>
<td>With $R_P$-violation</td>
<td>~20%</td>
</tr>
<tr>
<td>$W\gamma en$</td>
<td>67% (fid: 60%)</td>
</tr>
<tr>
<td>$W\gamma mn$</td>
<td>69% (fid: 50%)</td>
</tr>
<tr>
<td>Top$\gamma mX$</td>
<td>72%</td>
</tr>
</tbody>
</table>
## CMS Data Formats

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Size [Mb/evt]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAQ-RAW</td>
<td>Detector Data + L1 Trigger bits, input to online High Level Trigger (HLT)</td>
<td>1-1.5</td>
</tr>
<tr>
<td>RAW</td>
<td>Detector data after HLT + HLT trigger bits + objects created at HLT</td>
<td>1.5</td>
</tr>
<tr>
<td>RECO</td>
<td>Reconstructed Objects (Tracks, jets, electrons, muons, …) and reconstructed hits and clusters</td>
<td>0.25</td>
</tr>
<tr>
<td>AOD</td>
<td>Analysis Object Data : Reconstructed Objects + very localized hit information</td>
<td>0.05</td>
</tr>
<tr>
<td>TAG</td>
<td>Run/Event number, high-level physics objects, used to index events</td>
<td>0.01</td>
</tr>
<tr>
<td>FEVT</td>
<td>Term used to refer to RAW+RECO together (not a distinct format)</td>
<td>-</td>
</tr>
</tbody>
</table>
- **HLT output**: 150 Hz, \(10^7\) seconds running \(\Rightarrow\) \(1.5 \times 10^9\) evts/year

- **CMS-CAF**: at CERN, services similar to Tier-1 and Tier-2, size of \(~2\) Tier-2, login for every CMS user
Upgrade scenarios

- **SLHC**: *The upgrade of an upgrade*
  - **Phase 0**: Performance upgrade, without hardware modifications
  - **Phase 1**: Performance upgrade with IR modifications
  - **Phase 2**: Performance upgrade with major hardware modifications

### Parameter Value

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Phase 0</th>
<th>Phase 1</th>
</tr>
</thead>
<tbody>
<tr>
<td># bunches</td>
<td>2808</td>
<td>2808</td>
<td>5616</td>
</tr>
<tr>
<td>N / bunch</td>
<td>$1.15 \times 10^{11}$</td>
<td>$1.70 \times 10^{11}$</td>
<td>$1.70 \times 10^{11}$</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.55 m</td>
<td>0.5 m</td>
<td>0.25 m</td>
</tr>
<tr>
<td>$\varepsilon_n$</td>
<td>3.75 $\mu$m</td>
<td>3.75 $\mu$m</td>
<td>3.75 $\mu$m</td>
</tr>
<tr>
<td>$\sigma^*$</td>
<td>16.7 $\mu$m</td>
<td>16 $\mu$m</td>
<td>11.3 $\mu$m</td>
</tr>
<tr>
<td>$\sigma_L$</td>
<td>7.55 cm</td>
<td>7.55 cm</td>
<td>3.8 cm</td>
</tr>
<tr>
<td>Full crossing angle</td>
<td>285 $\mu$rad</td>
<td>315 $\mu$rad</td>
<td>445 $\mu$rad</td>
</tr>
<tr>
<td>Events per crossing</td>
<td>19.2</td>
<td>44.2</td>
<td>88.4</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>$1.0 \times 10^{34}$ cm$^2$ sec$^{-1}$</td>
<td>$2.4 \times 10^{34}$ cm$^2$ sec$^{-1}$</td>
<td>$9.6 \times 10^{34}$ cm$^2$ sec$^{-1}$</td>
</tr>
<tr>
<td>Luminosity lifetime</td>
<td>15 h</td>
<td>10 h</td>
<td>5 h (integrated)</td>
</tr>
<tr>
<td>E[TeV]</td>
<td>7</td>
<td>7 $\rightarrow$ 7.45</td>
<td>7 $\rightarrow$ 7.45</td>
</tr>
<tr>
<td>E[MJ]</td>
<td>366</td>
<td>541</td>
<td>1082</td>
</tr>
</tbody>
</table>

- **Detectors**:  
  - Radiation hardness, faster and more granular (increased pile-up noise)
  - Forward regions particular under “pressure” : improved shielding?  
  - Change L1 triggers if going to 12.5 ns bunch spacing
H → ZZ → 4ℓ (CMS)
## Detectors: Commissioning

### Expected performance day 1

<table>
<thead>
<tr>
<th>ECAL uniformity</th>
<th>~ 1% (ATLAS), 4% (CMS)</th>
<th>Physics samples to improve (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>e/γ scale</td>
<td>1-2% ?</td>
<td>Minimum-bias, Z → ee, W→eν</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z → ee</td>
</tr>
</tbody>
</table>

| HCAL uniformity | 2-3%                    | Single pions, QCD jets                 |
| Jet scale       | < 10%                   | Z (→ ll) +1j, W → jj in tt events      |

| Tracking alignment | 20-500 μm in Rφ ? | Generic tracks, isolated μ , Z → μμ |

### Using first collisions:

- **Trigger/DAQ:**
  - Timing-in, data coherence, sub-system synchronization, calibration, debug algorithms, …

- **Calorimeter calibrations (example CMS ECAL & HCAL):**
  - Crystal inter-calibration: phi-symmetry of energy deposition (min-bias, jets): ~2%
  - HCAL: cross check and complete source calibration: ~2%

- **Tracker and Muon alignment**

- **Ultimate statistical precision achievable after few days of operation in most cases. Then face systematics …**
  - e.g.: tracker alignment: 100 μm (1 month) → 20μm (4 months) → 5 μm (1 year)?
Searches : general remarks

as significance (number of ‘sigmas’) one usually sees the definition ( \( \sigma_{\text{stat}}(\text{background}) = \sqrt{n_b} \) for large enough statistics )

\[
\begin{align*}
n_\sigma = \frac{n_S}{\sqrt{n_b}}
\end{align*}
\]

Adding a relative systematic uncertainty \( f \),

\[
\sigma_{\text{syst}}(\text{background}) = f n_b ,
\]
in quadrature to the statistical uncertainty, this becomes:

\[
\tilde{n}_\sigma = \frac{n_S}{\sqrt{n_b + f^2 n_b^2}}
\]
this can be rewritten as

\[ \tilde{n}_\sigma = n_\sigma \cdot \left[ 1 + \left( \frac{f \cdot n_\sigma}{n_s/n_b} \right)^2 \right]^{\frac{1}{2}} \]

limiting cases:

\[ \frac{n_s}{n_b} \ll f \cdot n_\sigma \Rightarrow \tilde{n}_\sigma \approx \frac{n_s}{n_b} \]

dominated by systematics

\[ \frac{n_s}{n_b} \gg f \cdot n_\sigma \Rightarrow \tilde{n}_\sigma \approx n_\sigma \]

dominated by statistics
 Searches : general remarks...

- a concrete example (10% background uncertainty)

<table>
<thead>
<tr>
<th>$n_s$</th>
<th>$n_b$</th>
<th>$n_s / n_b$</th>
<th>$n_\sigma$</th>
<th>$\tilde{n}_\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>100</td>
<td>0.5</td>
<td>5</td>
<td>3.5</td>
</tr>
<tr>
<td>500</td>
<td>10000</td>
<td>0.05</td>
<td>5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- in the second case, more luminosity will not improve the significance! (unless more data help to better understand the background)
Background extrapolation

Backgrounds to $H \rightarrow WW \rightarrow \ell \ell \nu \nu$: $t\bar{t}$ for gluon fusion, $t\bar{t}j$ for qqH

Idea of extrapolation:
Cavelli, Kauer, Zeppenfeld

\[ \sigma_{bkg} \approx \left( \frac{\sigma_{bkg, \text{LO}}}{\sigma_{\text{ref}, \text{LO}}} \right) \cdot \sigma_{\text{ref}} \]

- $\sigma_{bkg}$: background with cuts optimized for finding signal
- $\sigma_{\text{ref}}$: background with cuts to enrich background (eg. revert the cuts above)

\( \sim 5\% \) background uncertainty

\( \sim 5\% \) scale uncertainty
Further Remarks

What are the important calculations needed, where is phenom. work wanted? Signal and Bkg:

- NLO wherever possible
- MC@NLO wherever possible!
- NNLO, fully differential
  - at least for the basic processes
- Backgrounds are important now, especially:
  - $t\bar{t}$, $t\bar{t}j$, $ttjj$, $W/Z+jets$
  - Investigate ratio method for more processes

Other interesting processes

- Jet + photon/Z : gluon pdf
- Excellent understanding of incl. jet and di-jet prod.
Preliminary results

For the first time, all ATLAS sub-detectors integrated and run together with common DAQ, “final” electronics, DCS, etc.

Gained lot of global operation experience during ~ 6 month run. Common ATLAS software used to analyze the data (4.5 TB).
CMS closed for Magnet test in the SX5 surface building (June/July 2006)

- Check functionality of all magnet systems
- Map the magnetic field
- Check installation & cabling of
  - ECAL/HCAL/Tracker inside coil
- Test combined sub-detectors in 20 degree slice(s) of CMS with Magnet. Try out operation procedures for CMS (24/7 running)
Our Master Equation

\[ \sigma_{\text{meas}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\varepsilon L} \]

Stat vs syst errors, backgrounds from data or MC? Signal Significance

Understand isolation, jet veto; \( p_T \) distributions at NLO; need calculations for detectable acceptance.

\[ \sigma_{\text{theo}} = \text{PDF}(x_1, x_2, Q^2) \otimes \tilde{\sigma}_{\text{hard}} \]

constrain, define uncertainties

HO calculations, implement in MC
Standard Model measurements

- **Drell-Yan (W, Z) production of lepton pairs**
  - best known cross section at LHC, at NNLO: scale uncert. ~ 1%!
  
  $$pp \rightarrow (Z, \gamma^*) + X$$

- **Top-Physics**
  - See the top immediately
  - simple selection: Missing $E_T$, 1 lepton, $\geq$4 jets, NO b-tag (!), cut on hadronic $W$ mass

  **Atlas FullSim Preliminary**
  
  $N_{\text{top}} = 580 \pm 48$
  $\sigma(m_{\text{top}}) = 15.4 \pm 1.2$

  Top pair events in 300 pb$^{-1}$

- **Study the top quark properties**
  - mass, charge, spin, couplings, production and decay, $\Delta M_{\text{top}} \sim 1$ GeV?

- **Constrain PDFs, determine Lumi.**

- **Similar** for $W^+/W^-$ (ratios are good!!)
  - NNLO scale uncertainty 0.5 - 0.7%

- **Important background for searches**

- **Jet energy scale** from $W \rightarrow$ jet jet, commission b-tagging