Preparing for physics at the LHC

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- ☆ Machine status and schedule
- 🕒 Status of experiments and preparation for physics with test beams and cosmics runs
- 🕒 First physics with first data

LHC

- pp $\sqrt{s} = 14 \text{ TeV}$ $L_{\text{design}} = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (after 2009)
 $L_{\text{initial}} \leq \text{few} \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ (until 2009)
- Heavy ions (e.g. Pb-Pb at $\sqrt{s} \sim 1000 \text{ TeV}$)

TOTEM (integrated with CMS):
pp, cross-section, diffractive physics

ATLAS and CMS :
general purpose

27 km LEP ring
1232 superconducting
dipoles $B=8.3 \text{ T}$

Here:
ATLAS and CMS

ALICE :
ion-ion,
p-ion

- Existing Structures
- LHC Project Structures
- LHC Excavated Structures
- LHC Completed Structures (CE)
- LHC Completed Structures (CV, EL, HM, MA)

LHCb :
pp, B-physics, CP-violation

☆ Machine status

As of this morning:
- 1154 dipoles (out of 1232)
delivered at CERN
- 660 installed in the tunnel

Dipole interconnect work
proceeding in 2 octants in parallel

Not only dipoles

Main dipoles	1232
Quadrupoles	~ 400
Sextupoles	} ~ 6000
Octupoles/decapoles	
Other correctors	
Total	~ 8000

Straight section at IP 8

Straight section at IP 1

First 600 m of cryoline (QRL) successfully cooled down on 14/9/2005,
followed by cool-down of full cryoline sector 8-1 and pressure test of sector 4-5.

LHC Progress Dashboard

Accelerator
Technology
Department

Cryogenic distribution line

Updated 30 Jun 2006

Data provided by G. Riddone AT-ACR

(Revised) LHC schedule

as presented to CERN Council on 23 June 2006

- Last magnet installed : March 2007
Machine and experiments closed : 31 August 2007
- First collisions ($\sqrt{s} = 900 \text{ GeV}$, $L \sim 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$) : November 2007
Commissioning run at injection energy until end 2007, then shutdown (3 months ?)
- First collisions at $\sqrt{s}=14 \text{ TeV}$ (followed by first physics run): Spring 2008

Goal : deliver integrated luminosity of few fb^{-1} by end 2008

L. Evans,
CERN Council,
23/6/2006

- Sectors 7-8 and 8-1 will be fully commissioned up to 7 TeV in 2006-2007. If we continue to commission the other sectors up to 7 TeV, we will not get circulating beam in 2007.
- The other sectors will be commissioned up to the field needed for de-Gaussing.
- Initial operation will be at 900 GeV (CM) with a static machine (no ramp, no squeeze) to debug machine and detectors.
- Full commissioning up to 7 TeV will be done in the winter 2008 shutdown

Status of ATLAS and CMS:
a few examples ...

(ALICE and LHCb are also on track)

ATLAS

Length : ~45 m
 Radius : ~12 m
 Weight : ~ 7000 tons
 Electronic channels : ~ 10^8
 ~ 3000 km of cables

- **Tracking ($|\eta| < 2.5$, $B=2T$) :**
 - Si pixels and strips
 - Transition Radiation Detector (e/π separation)
- **Calorimetry ($|\eta| < 5$) :**
 - EM : Pb-LAr with Accordion shape
 - HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- **Muon Spectrometer ($|\eta| < 2.7$) :**
 - air-core toroids with muon chambers

Oct. 2005

Barrel toroid: cool down started (this morning $T \sim 120$ K), first tests of full field in Sept. End-cap toroids: will be installed in the pit end 2006-beg 2007

Barrel calorimeter (EM liquid-argon + HAD Fe/scintillator Tilecal) in final position at $Z=0$. Barrel cryostat cold and filled with Ar.

One end-cap calorimeter (LAr EM, LAr HAD, LAr Forward inside same cryostat, surrounded by HAD Fe/Scintillator Tilecal) being moved inside the barrel toroid

In February, barrel Si detector (SCT) was inserted into barrel TRT → ready for installation in the pit in August 2006

Three completed Pixel disks (one end-cap) with 6.6 M channels

Barrel pixel detector on critical path (problems with low-mass cables), but still scheduled for installation in the pit in April 2007

Cosmics DATA taken in barrel SCT+TRT : ~ 450k events

ATLAS
preliminary

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

SCT efficiency
per layer

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture

Cabling error in
two modules

Muon Spectrometer : measurement chambers MDT, CSC (innermost forward)
trigger chambers RPC (barrel), TGC (end-caps)

~50% of barrel stations installed
(mostly complete end of Summer '06)

First sectors of TGC end-cap
"big-wheels" installed

First cosmics have been registered in the underground cavern with barrel Muon chambers (MDT and RPC) and Level-1 μ trigger

Towards Physics (1) : the 2004 ATLAS combined test beam

Full "vertical slice" of ATLAS tested on CERN H8 beam line May-November 2004

ATLAS preliminary

ATLAS @ LHC:
 γ -conversion probability in tracker
 is $> 30\%$ $\rightarrow$ important to develop
 (and validate !) efficient
 reconstruction tools

Inner Detector tracks extrapolated
 to ECAL and compared to calo clusters

Length : ~22 m
Radius : ~7 m
Weight : ~ 12500 tons

Total weight : 12,500t.
Overall diameter : 15.00 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

CMS-PARA-001-11/07/97

JLB,PP

Compact and modular:
assembled at the surface
and lowered in the cavern
piece by piece

YBO lowering (2000t): Dec. 2006

- Tracking ($|\eta| < 2.5$, $B=4T$) : Si pixels and strips
- Calorimetry ($|\eta| < 5$) :
 - EM : PbWO_4 crystals
 - HAD: brass/scintillator (central+ end-cap), Fe/Quartz (fwd)
- Muon Spectrometer ($|\eta| < 2.5$) : return yoke of solenoid instrumented with muon chambers

At the surface, solenoid inserted on 14 Sept. 2005;
cooled down to 4.5 K in February 2006;
ramping up the current, now at 12.5 kA (2.5 T)
→ magnetic test/field map starting Aug./Sept. 2006 (MTCC)

Magnetic length	12.5 m
Diameter	6 m
Magnetic field	4 T
Nominal current	20 kA
Stored energy	2.7 GJ

Installation of Muon chambers : ~ 90% complete in end-cap (CSC+RPC), ~ 60% in barrel (DT+RPC)

Surface Hall
SX5

50% of RPCs installed
on YE disks.

3 out of
5 YB
wheels
done
(DTs,
RPCs)

Detailed commissioning studies with cosmic muons

Track reconstruction efficiency in MB2

are needed to see this picture.

Cosmic muon bending in the CMS return yoke, collected yesterday with 12.5kA in the solenoid ($B=2.5\text{T}$)

NEW !

Electromagnetic calorimeter

Barrel : 36 SuperModules (SM), 1700 crystals each
Total of ~ 61000 barrel crystals (85% delivered)
27 bare SM assembled, 22 equipped with electronics

2 barrel SM installed
inside HCAL for MTCC

Crystal delivery determines ECAL
schedule: last barrel (end-cap) crystal
delivered in Feb. 2007 (Jan. 2008).
Plan is to have barrel completed for
commissioning run in 2007 and end-caps
installed for 2008 physics run

Inner tracker:

~ 220 m² of Si sensors
10.6 million Si strips
65.9 million Pixels

- Assembly of all 16000 modules completed
- Integration progressing well
- Installation at Point 5 in April 2007

Towards Physics (2) : the CMS Magnet Test and Cosmic Challenge (MTCC)

Cosmics run of a ~full detector slice (few percent of CMS coverage) inside 4T field.
Magnet being energized, detector closed, data taking started ...

Test: detector installation and closing; magnet commissioning and field map;
combined operation of full chain detector-electronics-DAQ-trigger-DCS-software
identical to final experiment; timing, calibration, alignment procedures

CMS Physics Technical Design Reports

650 pages
308 figures
207 tables
1.50 Kg

<http://cmsdoc.cern.ch/cms/cpt/tdr/>

CERN/LHCC 2006-001

February 2006

CERN/LHCC 2006-021

June 2006

First physics with first data

- Understand detector and Standard Model physics
- Discoveries ?

Here only a few examples
(top, SUSY, Higgs ...)

What data samples in 2007 ?

ATLAS preliminary

$\sqrt{s} = 900 \text{ GeV}$, $L = 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$

30% data taking efficiency included (machine plus detector)
Trigger and analysis efficiencies included

Jets $p_T > 15 \text{ GeV}$

(b-jets: $\sim 1.5\%$)

Jets $p_T > 50 \text{ GeV}$

Jets $p_T > 70 \text{ GeV}$

$Y \rightarrow \mu\mu$

$J/\psi \rightarrow \mu\mu$

$W \rightarrow e\nu, \mu\nu$

$Z \rightarrow ee, \mu\mu$

+ 1 million minimum-bias/day

- Start to commission triggers and detectors with collision data (minimum bias, jets, ..) in real LHC environment
- Maybe first physics measurements (minimum-bias, underlying event, QCD jets, ...) ?
- Observe a few $W \rightarrow l\nu$, $Y \rightarrow \mu\mu$, $J/\psi \rightarrow \mu\mu$?

Example 1: CMS ECAL calibration

only ~ 6 SM will be tested with test beams → most/all SM will be calibrated with cosmic rays

SuperModule on the cosmic rays stand

Energy deposition of traversing cosmic rays vs eta

~ 1.5% calibration uniformity achievable in central barrel with 18 million minimum-bias (few days of data taking in 2007)

Further step toward the ~ 0.5% needed to observe a $H \rightarrow \gamma\gamma$ signal

Example 2: Measurement of the underlying event in di-jet production

Particle multiplicity of underlying event obtained from the region transverse to the leading jet.

Comparison of plateau's between LHC and Tevatron will tell if detector performance, reconstruction tools and physics are under control

Multiplicity of charged particles with $p_T > 0.5 \text{ GeV}$ and $|\eta| < 1$ in region transverse to leading jet

~ 15 days of data taking in 2007 enough to cover up to $p_{T \text{ (leading jet)}} \sim 40 \text{ GeV}$

With the first physics run in 2008 ($\sqrt{s} = 14 \text{ TeV}$)

1 fb⁻¹ (100 pb⁻¹) $\equiv$ 6 months (few days) at $L = 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
 with 50% data-taking efficiency
 → may collect a few fb⁻¹ per experiment by end 2008

Channels (examples ...)	Events to tape for 100 pb ⁻¹ (per expt: ATLAS, CMS)	Total statistics from some of previous Colliders
$W \rightarrow \mu \nu$ $\sim 10^4 \text{ LEP}, \sim 10^6 \text{ Tevatron}$ $Z \rightarrow \mu \mu$		$\sim 10^6$
$\tilde{g}\tilde{g}$	$\sim 10^5$	$\sim 10^6 \text{ LEP}, \sim 10^5 \text{ Tevatron}$
$t\bar{t} \rightarrow W b \ W \bar{b} \rightarrow \mu \nu + X$	$\sim 10^4$	$\sim 10^4 \text{ Tevatron}$
QCD jets $p_T > 1 \text{ TeV}$	$> 10^3$	---
<u>With these data:</u>	~ 50	---

- Understand and calibrate detectors in situ using well-known physics samples
 e.g. - $Z \rightarrow ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.
 - $t\bar{t} \rightarrow b\bar{\nu} bjj$ jet scale from $W \rightarrow jj$, b-tag performance, etc.
- Measure SM physics at $\sqrt{s} = 14 \text{ TeV}$: $W, Z, t\bar{t}, \text{QCD jets}$...
 (also because omnipresent backgrounds to New Physics)

→ prepare the road to discovery it will take time ...

Example of initial measurement: understanding detector and physics with top events

Can we observe an early top signal with limited detector performance ?
And use it to understand detector and physics ?

$$\sigma_{tt} \approx 250 \text{ pb for } tt \rightarrow bW \ bW \rightarrow b\bar{\nu} \ bjj$$

Top signal observable in early days with no b-tagging and simple analysis
(100 ± 20 evts for 50 pb^{-1}) $\rightarrow$ measure σ_{tt} to 20%, m to 10 GeV with $\sim 100 \text{ pb}^{-1}$?
In addition, excellent sample to:

- commission b-tagging, set jet E-scale using $W \rightarrow jj$ peak
- understand detector performance for e, μ , jets, b-jets, missing E_T , ...
- understand / constrain theory and MC generators using e.g. p_T spectra

Example of "early" discovery: Supersymmetry ?

If SUSY at TeV scale $\rightarrow$ could be found "quickly" thanks to:

- large $\tilde{q}, \tilde{g}$ cross-section $\rightarrow \approx 10$ events/day at 10^{32} for
- spectacular signatures (many jets, leptons, missing E_T)

$$m(\tilde{q}, \tilde{g}) \sim 1 \text{ TeV}$$

Our field, and planning for future facilities, will benefit a lot from quick determination of scale of New Physics. E.g. with 100 (good) pb^{-1} LHC could say if SUSY accessible to a ≤ 1 TeV ILC

BUT: understanding E_T^{miss} spectrum (and tails from instrumental effects) is one of the most crucial and difficult experimental issue for SUSY searches at hadron colliders.

E_T^{miss} spectrum contaminated by cosmics, beam-halo, machine/detector problems, etc.

Estimate physics backgrounds using data (control samples)

Needed $\int L dt$ (fb^{-1})
per experiment

What about the SM Higgs boson ?

here discovery easier with
gold-plated $H \rightarrow ZZ \rightarrow 4l$
 $\rightarrow$ **by end 2008 ?**

$H \rightarrow 4l$: narrow mass peak, small background
 $H \rightarrow WW \rightarrow l\nu l\nu$ (dominant at the Tevatron):
counting channel (no mass peak)

Light Higgs : more difficult

$$m_H \sim 115 \text{ GeV} \quad 10 \text{ fb}^{-1} : S/\sqrt{B} \approx 4 \quad \text{ATLAS}$$

K-factors $\equiv \sigma(\text{NLO})/\sigma(\text{LO}) \approx 2$
for $H \rightarrow \gamma\gamma$ NOT included (conservative)

3 (complementary) channels with similar (small) significances:

- different production and decay modes
- different backgrounds
- different detector/performance requirements:
 - ECAL crucial for $H \rightarrow \gamma\gamma$ (in particular response uniformity) : $\sigma/m \sim 1\%$ needed
 - b-tagging crucial for $t\bar{t}H$: 4 b-tagged jets needed to reduce combinatorics
 - efficient jet reconstruction over $|\eta| < 5$ crucial for $qqH \rightarrow qq\tau\tau$:
forward jet tag and central jet veto needed against background

All three channels require very good understanding of detector performance and background control to 1-10% $\rightarrow$ convincing evidence likely to come later than 2008 ...

Note: $WH \rightarrow l\nu b\bar{b}$ (dominant at the Tevatron) provides less sensitivity than $t\bar{t}H$ at LHC

Those of you who have bet for ATLAS can still hope to make money out of it....

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2004-09-03 17:00:00		

Selections will be settled on the basis of reports published in **New Scientist** magazine.

Conclusions

- Impressive achievements in the machine construction over last months:
>50% dipoles installed, problems with cryoline solved, better understanding of commissioning and operation, etc.
- New LHC schedule: -- machine and experiments closed 31 August 2007
-- commissioning run at $\sqrt{s}=900$ GeV end 2007
-- first physics run at 14 TeV starting in Spring 2008
- Experiments (huge progress as well !) on track to meet above schedule.
Test-beam and cosmics results indicate they work as expected.
- All efforts now to continue installation and commissioning of machine and detectors of unprecedented complexity, technology and performance

With the first collision data (1-100 pb⁻¹) at 14 TeV

Understand detector performance in situ in the LHC environment, and perform first physics measurements:

- Measure particle multiplicity in minimum bias (a few hours of data taking ...)
- Measure QCD jet cross-section to $\sim 30\%$?
(Expect $>10^3$ events with $E_T(j) > 1$ TeV with 100 pb⁻¹)
- Measure W, Z cross-sections to 10% with 100 pb⁻¹?
- Observe a top signal with ~ 30 pb⁻¹
- Measure tt cross-section to 20% and m(top) to 7-10 GeV with 100 pb⁻¹ ?
- Improve knowledge of PDF (low-x gluons !) with W/Z with O(100) pb⁻¹ ?
- First tuning of MC (minimum-bias, underlying event, tt, W/Z+jets, QCD jets,...)

And, more ambitiously:

- Discover SUSY up to gluino masses of ~ 1.3 TeV ?
- Discover a Z' up to masses of ~ 1.3 TeV ?
- Surprises ?

And, later on

The LHC will explore in detail the highly-motivated TeV-scale with a direct discovery potential up to $m \approx 5\text{-}6\text{ TeV}$

- if New Physics is there, the LHC will find it
- it will say the final word about the SM Higgs mechanism and many TeV-scale predictions
- it may add crucial pieces to our knowledge of fundamental physics → impact also on astroparticle physics and cosmology
- most importantly: it will likely tell us which are the right questions to ask, and how to go on

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Back-up slides

What about the comparison with the Tevatron ?

Today : $\sim 1.3 \text{ fb}^{-1} / \text{exp. on tape}$
 Projections for end 2009:
 4 fb^{-1} : present machine performance
 8 fb^{-1} : electron cooling of pbar and other improvements

With $4 (8) \text{ fb}^{-1}$:
 $\sim \text{no } 5\sigma \text{ sensitivity}$
 $3\sigma \text{ evidence up to } 120 (130) \text{ GeV}$
 $95\% \text{ C.L. exclusion up to } \sim 130 (180) \text{ GeV}$

competition between Tevatron and LHC
 in 2008-2009 if $m_H < 190 \text{ GeV}$?

Tevatron vs LHC after kin. cuts	$WH \rightarrow l\nu b\bar{b}$ ($m_H = 120 \text{ GeV}$)	$H \rightarrow WW(*)$ ($m_H = 160 \text{ GeV}$)
S (14 TeV/ 2 TeV)	≈ 5	≈ 17
B (14 TeV/ 2 TeV)	≈ 25	≈ 6
S/B (14 TeV/ 2 TeV)	≈ 0.2	≈ 3
$S/\sqrt{B}$ (14 TeV/ 2 TeV)	≈ 1	≈ 7

Assuming same integrated luminosity and same detector performance at Tevatron and LHC

LHC operation cycle

Ramp down	≈ 18 mins
Pre-injection plateau	15 mins
Injection	≈ 15 mins
Ramp	≈ 28 mins
Squeeze	< 5 mins
Prepare physics	≈ 10 mins
Physics	10-20 hours

Distribution Feed Box

Cryogenics overview

Cryogenics overview

Point 1.8 **Point 2** **Point 4** **Point 6** **Point 8**

Storage **Storage** **Storage** **Storage** **Storage**

QSCB **QSCC** **QSCA** **QSCC** **QSCC** **QSCA** **QSCB** **QSCC** **QSCC** **QSCA** **QSCC** **QSCC** **QSCA** **QSCB** **QSCC**

QSRB **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB** **QSRB**

QURA **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA** **QURA**

QUIB **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA** **QUIA**

QURC **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC** **QURC**

Sector 1-2 **Sector 2-3** **Sector 3-4** **Sector 4-5** **Sector 5-6** **Sector 6-7** **Sector 7-8** **Sector 8-1**

Legend

Cryogenic Distribution Line

Electrical Feed Box

Superconducting Link

Commissioned & accepted

Delivered / Under installation

Ordered (Contract placed)

Under commissioning

Under fabrication

Under definition

QSC_(A,B,C): Warm Compressor Station

QSR_(A,B): Surface 4.5 K Refrigerator Cold Box

QURA: Underground 4.5 K Refrigerator Cold Box

QURC: 1.8 K Refrigeration Unit Cold Box

QUI_(A,B,C): Cryogenic Interconnection Box

L. Tavian AT-ACR

Staged commissioning plan for protons

I. Pilot physics run

- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance (156 bunches, partial squeeze in 1 and 5, push intensity)
- Performance limit $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ (event pileup)

II. 75ns operation

- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ (event pileup)

III. 25ns operation I

- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit $2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

IV. 25ns operation II

- Push towards nominal performance

2008

2008-2009

~ few fb^{-1} end 2008,
 $O(10) \text{ fb}^{-1}$ end 2009 ?

≥ 2010

$O(100) \text{ fb}^{-1}$

Note: dates and integrated luminosities are MY interpretation

	ATLAS	CMS
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5 \times 10^{-4} p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5 \times 10^{-4} p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	PbWO ₄ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim 7\%$ at 1 TeV standalone	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker

CMS Magnet Test and Cosmic Challenge (MTCC)

Ramping up of the magnet to nominal field started. A combined test of a slice of CMS will then be performed with cosmics.

Commissioning ECAL with cosmics (first studies ...)

- check calorimeter timing to < 1 ns --> input to optimal filtering in electronics
- check calorimeter position in η / ϕ wrt other sub-detectors to < 1 mm
- check response uniformity vs η : $\approx 0.5\%$ precision could be achieved

Test-beam data

Commissioning ID with cosmics and beam gas (some ideas ..)

Cosmics : O (1Hz) tracks in Pixels+SCT+TRT

- useful statistics for debugging readout, maps of dead modules, etc.
- check relative position Pixels/SCT/TRT and of ID wrt ECAL and Muon Spectrometer
- first alignment: may achieve statistical precision of $\sim 10 \mu\text{m}$ in parts of Pixels/SCT, $50 \mu\text{m}$ in TRT
- first calibration of t_0 and R-t relation in straws

Beam-gas :

- $\sim 25 \text{ Hz}$ of reconstructed tracks with $p_T > 1 \text{ GeV}$ and $|z| < 20 \text{ cm}$
> 10^7 tracks (similar to LHC events) in 2 months
- enough statistics for alignment in "relaxed" environment --> exceed initial survey precision of $\sim 100 \mu\text{m}$

standard ATLAS patt. rec.
(no optimisation for cosmics ...)

Which detector performance on day one ?

A few examples and educated guesses based on detector construction quality, test-beam results, cosmics, and simulation studies

	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/ γ scale	$\sim 1\%$ (ATLAS), 3% (CMS) $\sim 2\%$	Minimum-bias, $Z \rightarrow ee$ $Z \rightarrow ee$
HCAL uniformity Jet scale	$\sim 3\%$ $< 10\%$	Single pions, QCD jets $Z (\rightarrow ll) + 1j$, $W \rightarrow jj$ in tt events
Tracking alignment	20-200 μm in $R\phi$?	Generic tracks, isolated μ , $Z \rightarrow \mu\mu$

Ultimate statistical precision achievable after few weeks of operation. Then face systematics..
E.g. : tracker alignment : 100 μm (1 month) $\rightarrow$ 10 μm (6 months) $\rightarrow$ 5 μm (1 year) ?

Huge (QCD) backgrounds (consequence of high energy ...)

- No hope to observe light objects (W, Z, H ?) in fully-hadronic final states $\rightarrow$ rely on l, γ
- Fully-hadronic final states (e.g. $q^* \rightarrow qg$) can be extracted from backgrounds only with hard $O(100 \text{ GeV})$ p_T cuts $\rightarrow$ works only for heavy objects
- Mass resolutions of $\sim 1\%$ (10%) needed for l, γ (jets) to extract tiny signals from backgrounds, and excellent particle identification (e.g. e/jet separation)
- S (EW) / B (QCD) larger at Tevatron than at LHC

How many events per experiment at the beginning ?

Knowledge of SM physics on day 1 ?

W, Z cross-sections: to 3-4%
(NNLO calculation → dominated by PDF)

tt cross-section to ~7% (NLO+PDF)

Lot of progress with NLO matrix element
MC interfaced to parton shower MC
(MC@NLO, AlpGen,...)

LHC ?

Candidate to very early measurement:

few 10^4 events enough to get $dN_{ch}/d\eta$, dN_{ch}/dp_T

→ tuning of MC models

→ understand basics of pp collisions,
occupancy, pile-up, ...

B-physics with 100pb-1 - statistics in dominant inclusive, exclusive channels

	10 pb-1	100 pb-1
$pp \rightarrow \mu 6 X$	$60 \cdot 10^6$	$600 \cdot 10^6$
$bb \rightarrow \mu 6 X$	$40 \cdot 10^6$	$400 \cdot 10^6$
$cc \rightarrow \mu 6 X$	$20 \cdot 10^6$	$200 \cdot 10^6$
$bb \rightarrow \mu 6 \mu 3 X$	$2 \cdot 10^6$	$20 \cdot 10^6$
$pp \rightarrow J/\psi(\mu 6 \mu 3)$	$2.8 \cdot 10^5$	$2.8 \cdot 10^6$
$\Upsilon(\mu 6 \mu 3)$	$0.9 \cdot 10^5$	$0.9 \cdot 10^6$
$B^+ \rightarrow J/\psi K^+$	1700	17 000
$B^0 \rightarrow J/\psi K^{0*}$	870	8700

B-physics with 100 pb-1 measurements in control channels at 14 TeV

Sensitive tests of understanding of detector properties with strong impact on selected B-physics measurements: masses, lifetimes

		Statistics 100 pb-1	Statistical error on Lifetime	World today (stat + syst)
B^+	$B^+ \rightarrow J/\psi K^+$	17000	1.5 %	0.4 %
B^0	$B^0 \rightarrow J/\psi K^{0*}$	8700	2.2 %	0.5 %
B_s	$B_s \rightarrow J/\psi \phi$	900	6 %	2 %
Λ_b	$\Lambda_b \rightarrow J/\psi \Lambda$	260	8 %	5%

ATLAS sensitivity in discovery channel
 $\text{Br}(B_s^0 \rightarrow \mu^+ \mu^-)$
sensitive to SUSY with 100 pb⁻¹ and later

Integral LHC Luminosity	Signal ev. after cuts	BG ev. after cuts	ATLAS upper limit at 90% CL	CDF&D0 upper limit at 90% CL
100 pb⁻¹	~ 0	~ 0.2	6.4×10^{-8}	8×10^{-8}
10 fb⁻¹	~ 7	~ 20	7.0×10^{-9}	
30 fb⁻¹	~ 21	~ 60	6.6×10^{-9}	

Constraining PDF with early ATLAS data using $W \rightarrow l\nu$ angular distributions

$$x_{1,2} = \frac{M}{\sqrt{s}} \exp(\pm y) \Rightarrow W \text{ production over } |y| < 2.5 \text{ at LHC}$$

involves $10^{-4} < x_{1,2} < 0.1$
 $\Rightarrow$ region dominated by $g \rightarrow q\bar{q}$

Tricoli et al., ATL-PHYS-CONF-2005-008

Uncertainties on present PDF: **4-8%**
 $\rightarrow$ ATLAS measurements of $e^\pm$ angular distributions provide discrimination between different PDF if experimental precision $\sim 3-5\%$

Effect of including ATLAS data on PDF fits

Sample of 10^6 $W \rightarrow e\nu$ generated with CTEQ6.1 and ATLAS fast simulation

Statistics corresponds to $\sim 100 \text{ pb}^{-1}$

4% systematic error included by hand (statistical error negligible)

Central value of ZEUS-PDF prediction shifts and **uncertainties is reduced**
Error on low- x gluon shape parameter λ ($xg(x) \sim x^{-\lambda}$) reduced by 35%

Systematics (e.g. $e^\pm$ acceptance vs η) can be controlled to few percent with $Z \rightarrow ee$
(~ 30000 events for 100 pb^{-1})

An "easy case" : Z' of mass ~ 1 TeV with SM-like couplings

$Z' \rightarrow ee$, SSM

Mass	Expected events for 1 fb^{-1} (after all cuts)	$\int L dt$ needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 160	$\sim 70 \text{ pb}^{-1}$
1.5 TeV	~ 30	$\sim 300 \text{ pb}^{-1}$
2 TeV	~ 7	$\sim 1.5 \text{ fb}^{-1}$

- large enough signal sample with $\int L dt \sim 100 \text{ pb}^{-1}$ up to $m \approx 1 \text{ TeV}$ if "reasonable" $Z'ee$ couplings
- dominant Drell-Yan background small
(< 0.2 events in the region $1400\text{--}1600 \text{ GeV}$, 100 pb^{-1})
- signal as mass peak on top of background

$Z \rightarrow ll + \text{jet}$ samples and DY needed for E-calibration and determination of lepton efficiency

ALPGEN

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

SUSY inclusive search

Effective mass

0-lepton mode, $L=1\text{fb}^{-1}$

Effective mass (after bkg. subtraction)

0-lepton mode, $L=1\text{fb}^{-1}$

Result with fast simulation.
only scale is changed (slope is same).

Important to understand background scale and slope.

LHC Kinematic regime

Kinematic regime for LHC much broader than currently explored

→ Test of QCD:

- ❑ Test DGLAP evolution at small x:
 - ❑ Is NLO DGLAP evolution sufficient at so small x ?
 - ❑ Are higher orders $\sim \alpha_s^n \log^m x$ important?
- ❑ Improve information of high x gluon distribution

At TeV scale New Physics cross section predictions are dominated by **high-x gluon** uncertainty (not sufficiently well constrained by PDF fits)

At the EW scale theoretical predictions for LHC are dominated by **low-x gluon** uncertainty (i.e. W and Z masses) => see later slides

$$x_{1,2} = \frac{M}{\sqrt{s}} \exp(\pm y) \quad Q = M \quad y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right)$$

How can we constrain PDF's at LHC?

PDF scenario at LHC start up (2007) might be different

- In most of the relevant x regions accessible at LHC
HERA data are most important source of information in PDF determinations (low- x sea and gluon PDFs)

HERA-II projection shows significant improvement to high- x PDF uncertainties

⇒ relevant for high-scale physics at the LHC

→ where we expect new physics !!

- significant improvement to valence-quark uncertainties over all- x
- significant improvement to sea and gluon uncertainties at mid-to-high- x
- little visible improvement to sea and gluon uncertainties at low- x

- HERA now in second stage of operation (HERA-II)
 - substantial increase in luminosity
 - possibilities for new measurements

Missing ET resolution can be studied in 2007
(plot made with 35k minimum-bias events)

- HLT/DAQ deferrals limit available networking and computing for HLT → limit LVL1 output rate
- Large uncertainties on LVL1 affordable rate vs money (component cost, software performance, etc.)

Selections (examples ...)	LVL1 rate (kHz) $L = 1 \times 10^{33}$ no deferrals	LVL1 rate (kHz) $L = 2 \times 10^{33}$ no deferrals	LVL1 rate (kHz) $L = 2 \times 10^{33}$ with deferrals An example for illustration...
MU6, <u>8</u> , <u>20</u>	23	→ 19	→ 0.8
2MU6	---	0.2	0.2
EM20i, <u>25</u> , <u>25</u>	11	→ 12	→ 12
2EM15i, <u>15</u> , <u>15</u>	2	4	4
J180, <u>200</u> , <u>200</u>	0.2	0.2	0.2
3J75, <u>90</u> , <u>90</u>	0.2	0.2	0.2
4J55, <u>65</u> , <u>65</u>	0.2	0.2	0.2
J50+xE50, <u>60</u> , <u>60</u>	0.4	0.4	0.4
TAU20, <u>25</u> , <u>25</u> +xE30	2	2	2
MU10+EM15i	---	0.1	0.1
Others (pre-scaled, etc.)	5	5	5
Total	~ 44	~ 43	~ 25

LVL1 designed for 75 kHz
→ room for factor ~ 2 safety

Likely max affordable rate,
no room for safety factor

③ Which data samples ?

Total trigger rate to storage at 2×10^{33}
reduced from ~ 540 Hz (HLT/DAQ TP, 2000)
to ~ 200 Hz (now)

High-Level-Trigger output

Selection (examples ...)	Rate to storage at 2×10^{33} (Hz)	Physics motivations (example)
$e25i, 2e15i$	~ 40 (55% $W/b/c \rightarrow eX$)	Low-mass Higgs ($ttH, H \rightarrow 4\ell, q\bar{q}$)
$\mu20i, 2\mu10$	~ 40 (85% $W/b/c \rightarrow \mu X$)	W, Z, top, New Physics ?
$\gamma60i, 2\gamma20i$	~ 40 (57% prompt γ)	$H \rightarrow \gamma\gamma$, New Physics (e.g. $X \rightarrow \gamma\gamma$ $m_X \sim 500$ GeV)
$j400, 3j165, 4j110$	~ 25	Overlap with Tevatron for new $X \rightarrow jj$ in danger ...
$j70 + xE70$	~ 20	SUSY : ~ 400 GeV squarks/gluinos
$\tau35 + xE45$	~ 5	MSSM Higgs, New Physics (3 rd family !)
$2\mu6 (+ m_B)$	~ 10	More difficult Rare decays $B \rightarrow \mu\mu X$
Others (pre-scaled, exclusive, ...)	~ 20	Only 10% of total !
Total	~ 200	No safety factor included. "Signal" (W, γ , etc.) : ~ 100 Hz

Best use of spare capacity when $L < 2 \times 10^{33}$ being investigated

ALICE Experimental Layout

MUON spectrometer set-up

Complex absorber/small angle shield system ($\sim 10 \lambda_I$) to minimize background (90 cm from vertex)

- 0.7 T, bending power 3 Tm
- 4 MW power, 800 tons
- World's largest warm dipole

b-b correlation

LHCb detector at IP8

Compact Muon Solenoid (CMS)

Strong Field 4T

Compact design

Solenoid for Muon P_t
trigger in transverse
plane

Redundancy: 4 muon
stations with 32 r-phi
measurements

$\Delta P_t/P_t \sim 5\%$ @1TeV for
reasonable space
resolution of muon
chambers (200 μ m)

CMS-TS-00079

Transverse View

Muon Reconstruction (Momentum Res.)

CMS

Muon System

ECAL: PbWO₄ Crystals

Material	PbWO ₄	Pb	Fe
Density (g/cm ³)	8.3	11.3	7.9
X ₀ (mm)	8.9	5.6	17.6

Radiation
Resistance: 10⁵ Gy
(10 Mrad)

Inner Tracker

Bpix: 3 layers
20 μ m

Fpix: 2 disks

Pixel size 150 μ m; Resol ~

TIB: 4 layers

TID: 3 disks

Pitch: 80 μ m to 200 μ m

TOB: 6 layers

TEC: 9 disks

Resol: 20 μ m to 50 μ m

Laser Alignment System

Laser profile in all 9 disks (laser at “full” gain to illuminate all disks)

Hadronic Calorimeter: HCAL

The low mass cable problem

- The barrel Al cables are made of 100 μm wire for signal and 300 μm for power (21 wires in a bundle), both wire-bonded on a small printed board + mini connector ($\sim 1\text{m}$, module $\rightarrow$ PP0).
- The initial interpretation was that the cable was stressed during manipulation and strain relief and better practice should solve the problem.
- Visual inspection and electrical tests after stress on all production started and found that $\sim 50\%$ of the 2000 cable produced are bad or likely to evolve bad.
- Indeed the insulation was found to have cracks and, being the insulator much stronger than a 100 μm Al wire, any stress would concentrate on the wire thus breaking it (sooner or later), this is not true for the thicker power wires.