Detectors at the Large Hadron Collider

SLAC Summer Institute, 2006

Jos Engelen

CERN

with special thanks to Jim Virdee

The Detector Challenge of the LHC

Quote (mid 1980's): *' we think we know how to build a high energy, high luminosity hadron collider – **we don't have the technology to build a detector for it***

for a high energy, high luminosity electron-positron collider the situation is just the opposite '

The LHC detectors are radically different from their predecessors at the SppS collider, LEP, SLC, HERA, Tevatron, etc.

They are designed for a luminosity of 10^{34} $cm^{-2}s^{-1}$ for pp collisions at an energy of 14 TeV

Detectors need to be fast, radiation hard (also the electronics) and big

Large Hadron Collider

pp collisions at 7+7 TeV

Luminosity L:
collision rate normalized to cross section 10^{34} $cm^{-2}s^{-1}$

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$k_b f$ = 40 MHz: bunch crossing frequency,
i.e. 25 ns between bunches

PbPb collisions at 82x7 + 82x7 TeV (208 + 208 nucleons)

The Large Hadron Collider - experiments

Two 'general purpose' 4π detectors are in preparation

$$\int_0^{2\pi} d\phi \int_{-1}^{1} d\cos\theta = 4\pi$$

pp collisions at high L; some capabilities for PbPb
ATLAS and CMS

One dedicated PbPb detector with some capabilities for pp
ALICE

One dedicated detector for studying B mesons (CP violation; rare decays), prolifically produced in the forward (backward) hemisphere
LHCb

$$\sigma_{b\bar{b}} \approx 500\,\mu b$$

$$gg \to b\bar{b}$$

Furthermore:

precision (1%) measurement of total cross section (and more)
TOTEM (σ_{tot}~100 mb)

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{(dN/dt)|_{t=0}}{N_{el} + N_{inel}}$$

study of forward production of π^0 s
LHCf (LHC energy equivalent to 10^{17} eV beam on fixed target – cf cosmic rays)

search for magnetic monopoles
Moedal

Experimental Challenge

High Interaction Rate: $N = L\sigma = 10^{34} \times 100 \times 10^{-27}$

pp interaction rate 10^9 interactions/s

data for only ~100 out of the 40 million crossings can be recorded per sec

Level-1 trigger decision will take ~2-3 μs

⇨ electronics need to store data locally (pipelining)

Large Particle Multiplicity

~ <20> superposed events in each crossing

~ 1000 tracks stream into the detector every 25 ns

need highly granular detectors with good time resolution for low occupancy

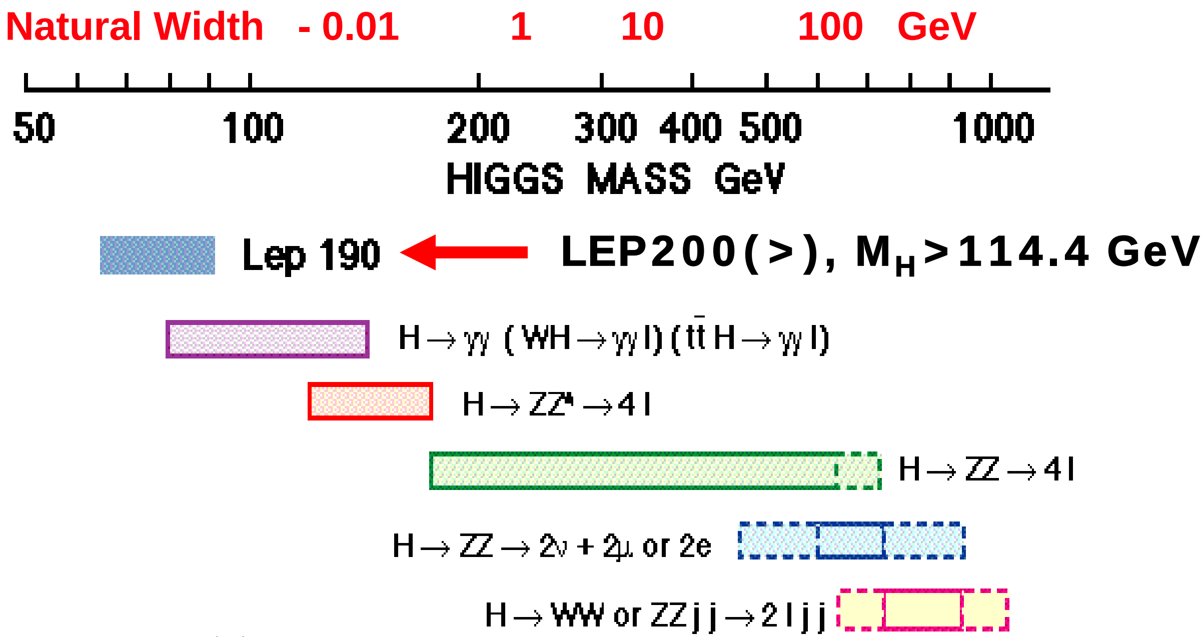
⇨ large number of channels

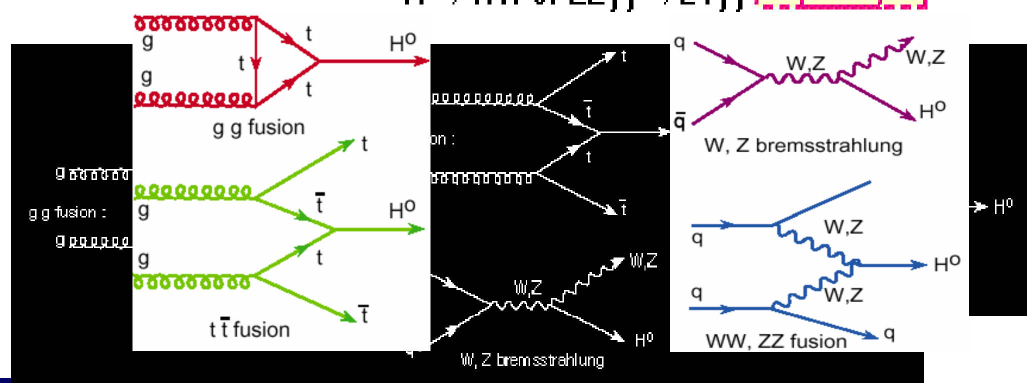
High Radiation Levels

⇨ radiation hard (tolerant) detectors and electronics

Physics Requirements

At the LHC the SM Higgs provides a good benchmark to test the performance of a detector





Very good muon identification and momentum measurement

trigger efficiently and measure sign of a few TeV muons

High energy resolution electromagnetic calorimertry

~ 0.5% @ E_T~50 GeV

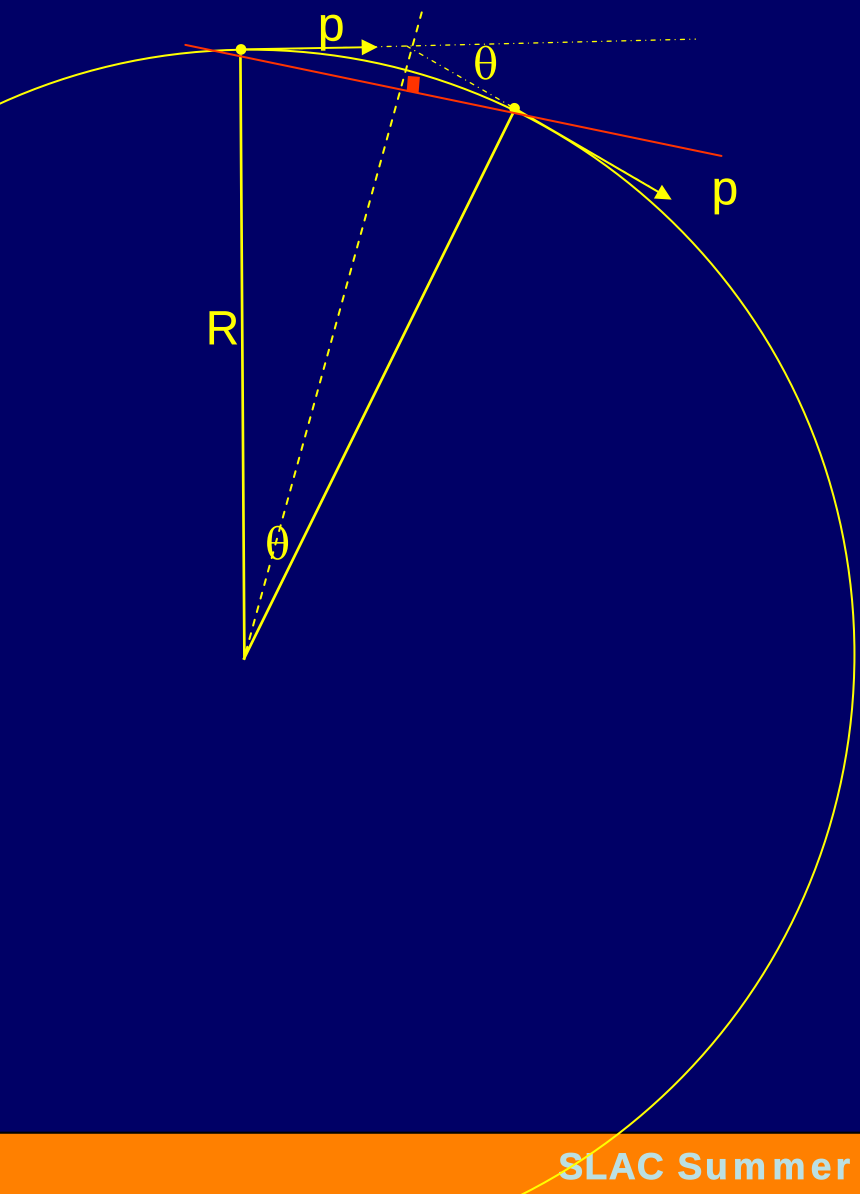
Powerful inner tracking systems

factor 10 better momentum resolution than at LEP

Hermetic calorimetry

good missing E_T resolution

(Affordable detector)



- Sagitta s

$$s = R - R\cos\frac{\theta}{2} \approx R\theta^2/8$$

$$p = 0.3BR$$

$$L = R\theta$$

$$s = \frac{0.3BL^2}{8p}$$

Units: Tesla, meter, GeV

Charged particle moving in magnetic field B

Resolution on *s* determines resolution on *p*

$$dp/p = (p/F)ds$$

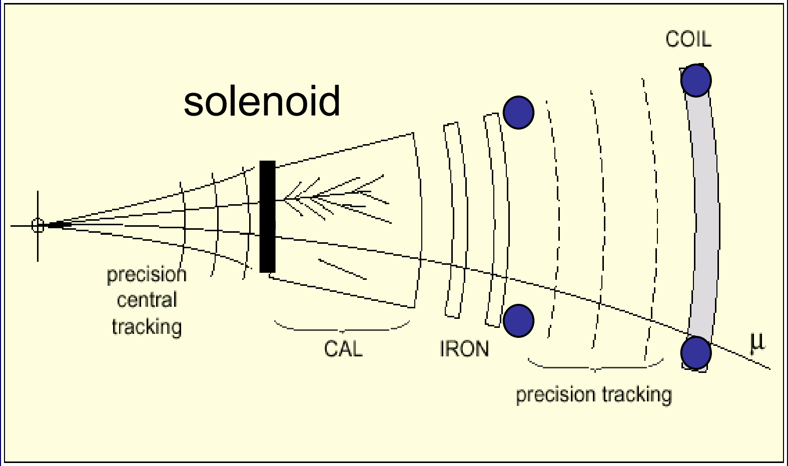
$$F = 0.3BL^2/8$$

ds depends on resolution tracking devices (technology!)
10 μ (Si) – 100 μ (Drift)

F is also determined by state of the art technology:
large magnets with high fields (superconducting)
1 – 4 Tesla

Large *L* better than high *B*, but the volume of the detector grows as L^3
1 – few Meters

Complementary Conception

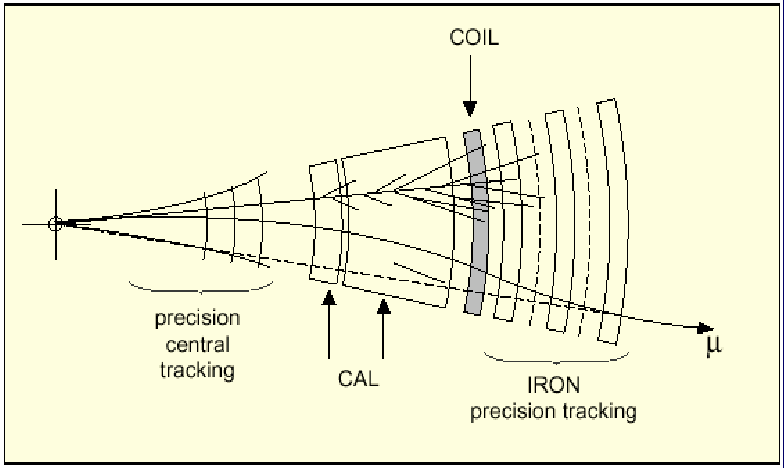


ATLAS

Standalone μ momentum measurement; safe for high multiplicities;

Air-core toroid

Property: σ_p flat with η



CMS

Measurement of momentum in tracker and B return flux;

Solenoid with Fe flux return

Property: muon tracks point back to vertex (not as in drawing)

(Pseudo)rapidity

Convenient variable: 'one particle phase space is uniform in rapidity'

inelastic particle production shows a 'rapidity plateau' (from ~-3 to +3 at LHC)

rapidity has a geometrical interpretation → detector 'granularity' corresponding to fixed rapidity intervals (and similarly for ϕ, azimuthal angle, intervals) (cf. calorimeter cell size)

$$\mathrm{d}^4 P\,\delta(E^2 - P^2 - m^2) = \mathrm{d}\vec{P}/E = P_T\,\mathrm{d}P_T\,\mathrm{d}\phi\,\mathrm{d}y$$

$$\mathrm{d}y = \mathrm{d}P_{//}/E$$

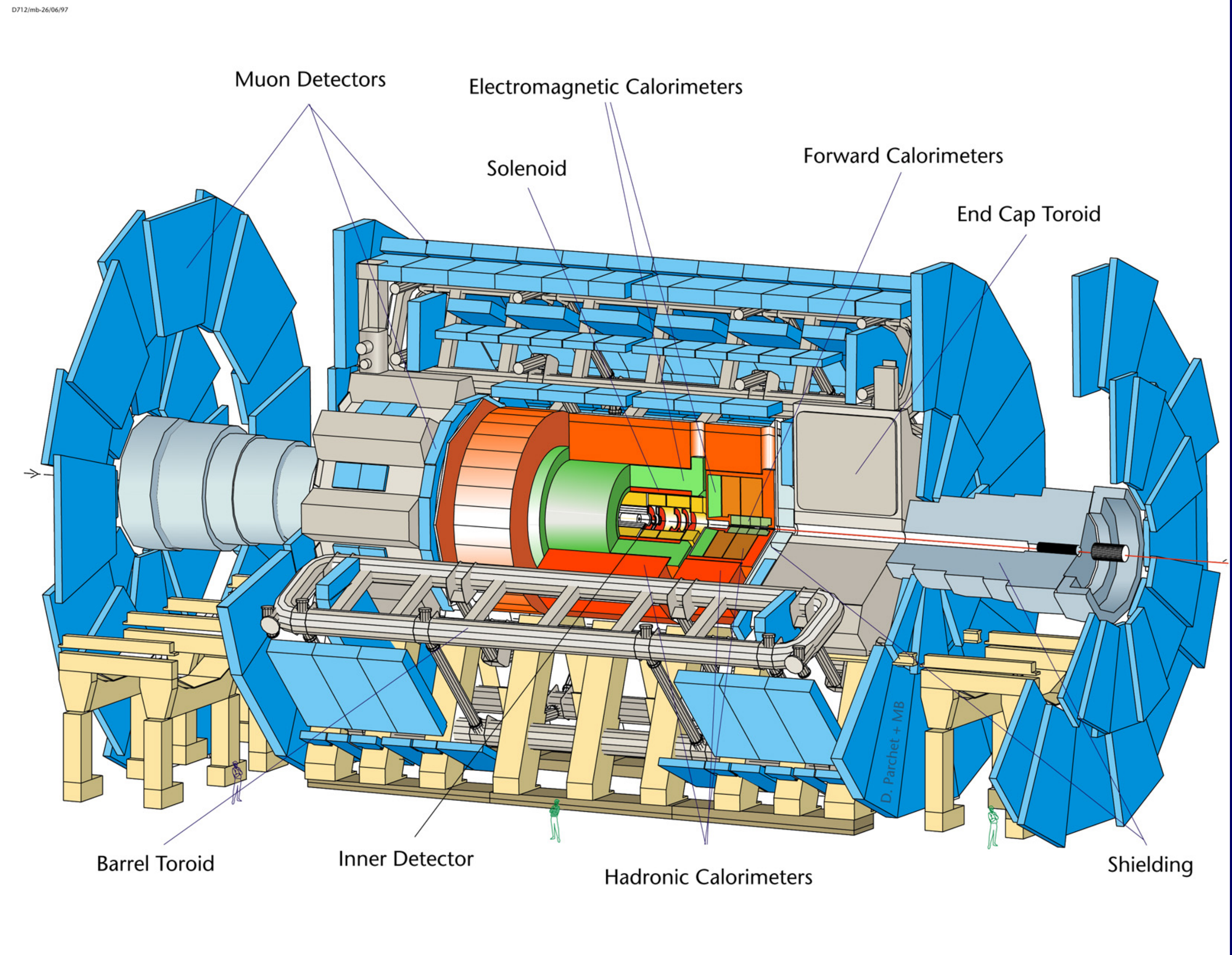
→

$$y = \frac{1}{2}\ln\frac{E + p_{//}}{E - p_{//}}$$

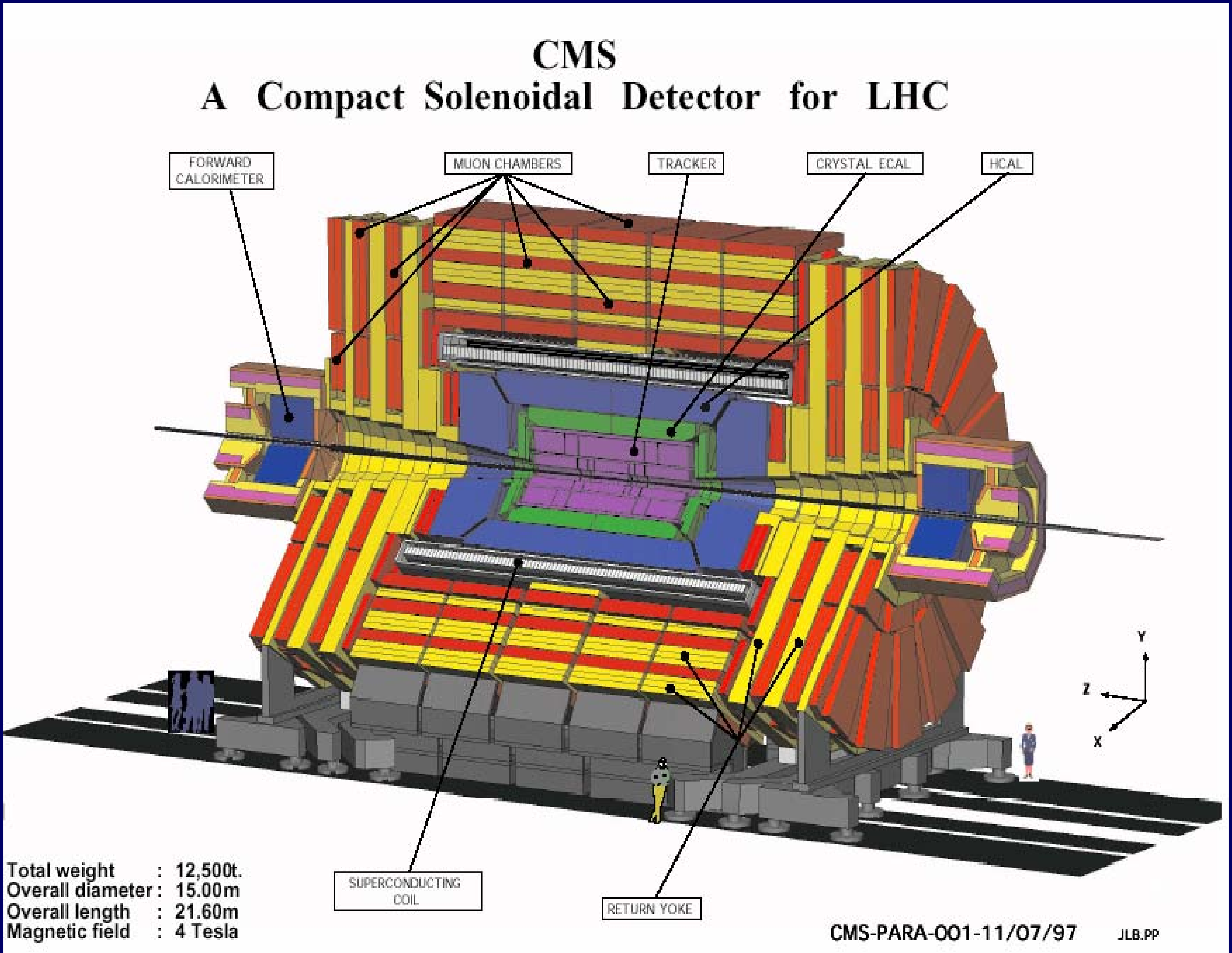
For *E>>m* : $y \approx \eta = -\ln\tan\theta/2$

The ATLAS Detector

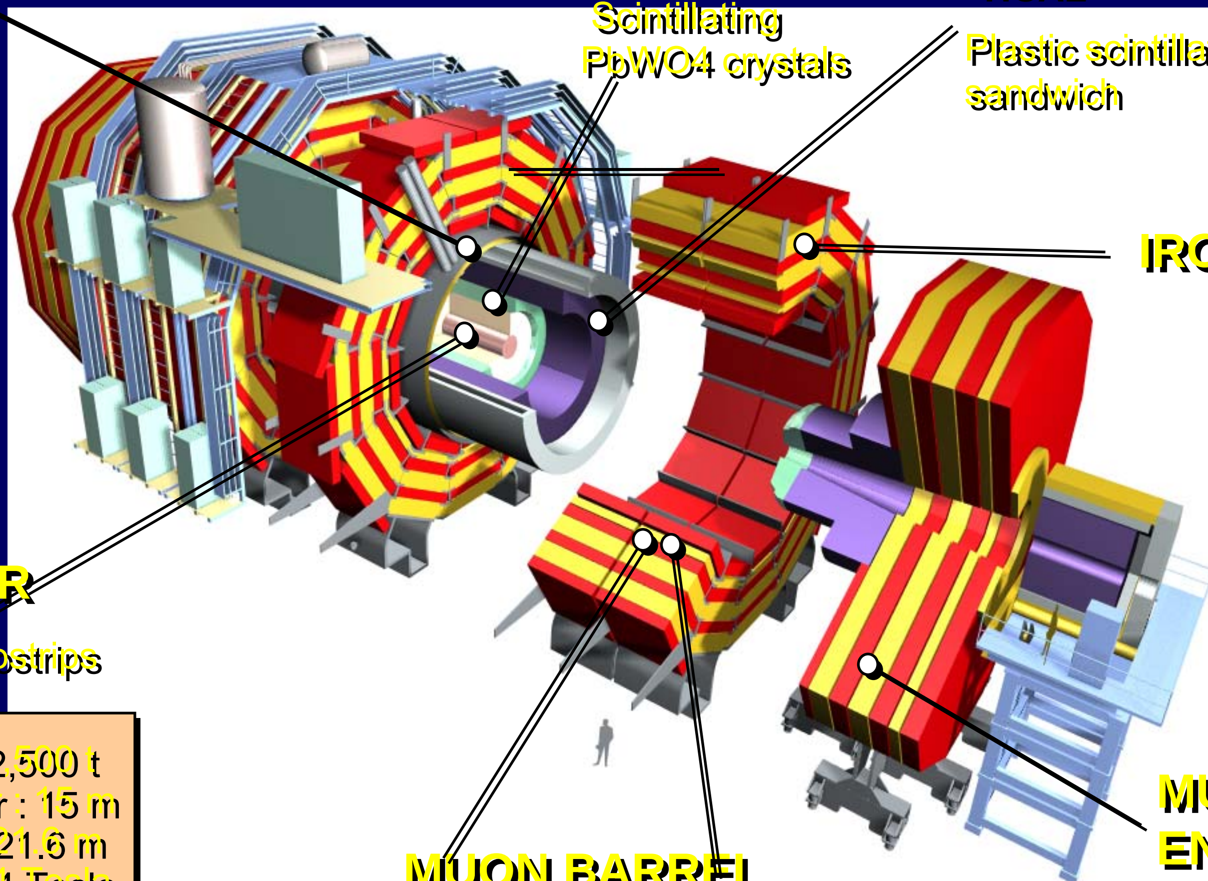
A Toroidal LHC ApparatuS



Compact Muon Solenoid



The CMS Detector



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

Choice of the Magnets

Design goal: measure 1 TeV muons with 10% resolution

ATLAS: <B>~0.6T over 4.5 m $\rightarrow$ s=0.5mm $\rightarrow$ need σ_s=50μm

- $B \sim \mu_0 nI \rightarrow nI = 2x10^7$ At
- With 8 coils, 2x2x30 turns: I=20kA (superC)
- Challenges: mechanics, 1.5GJ if quench, spatial & alignment precision over large surface area

CMS: B=4T (E=2.7 GJ) R=3 m but tracking only

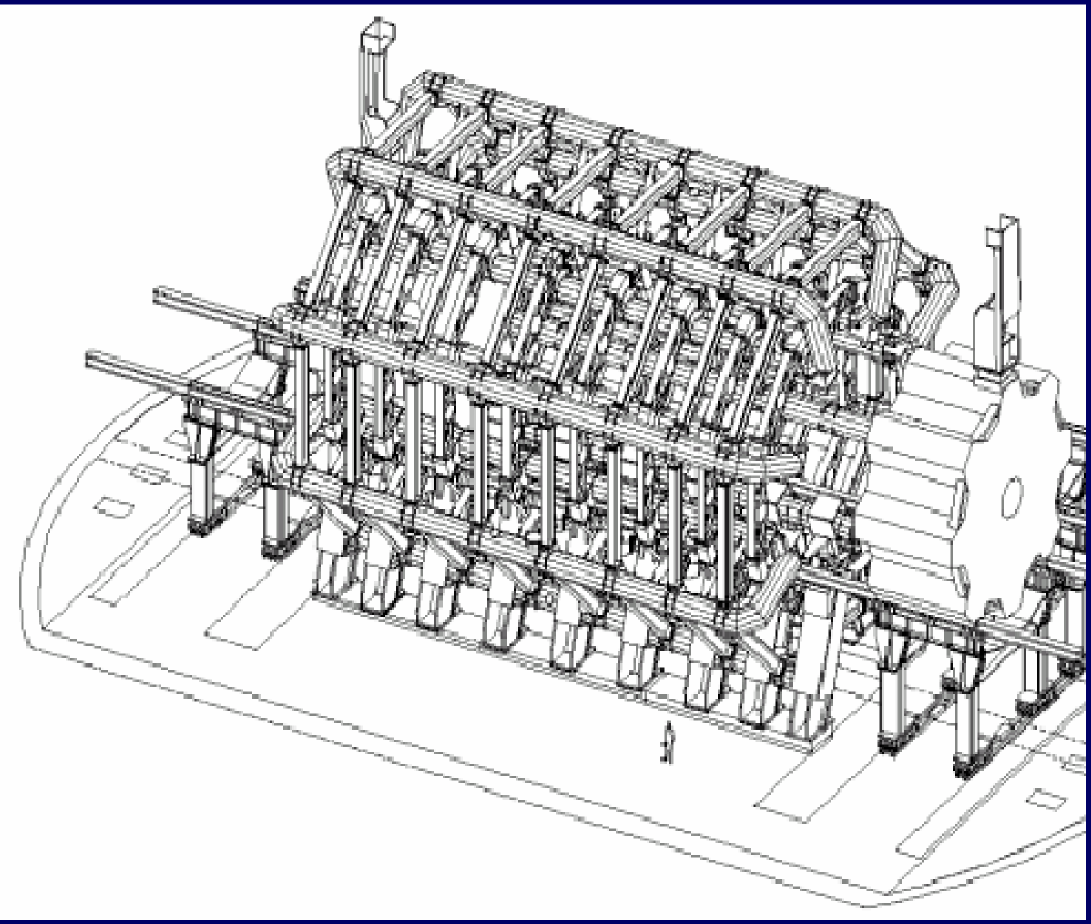
over 1.2 m

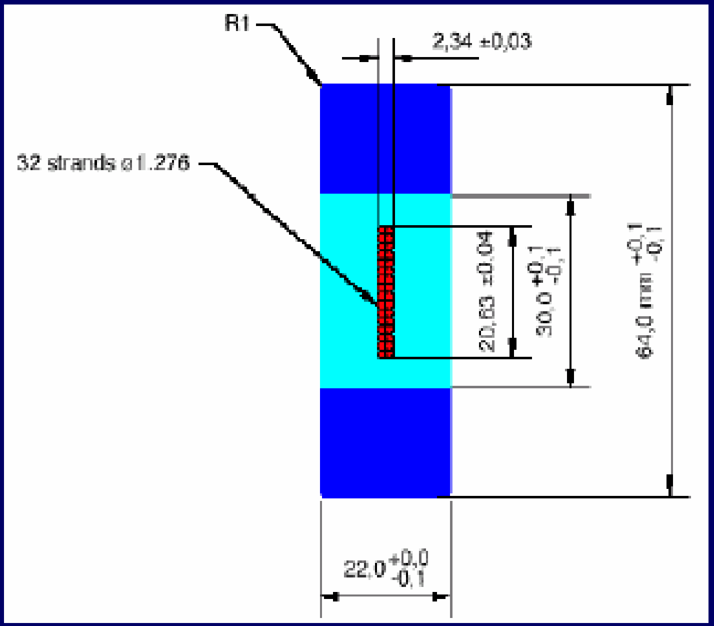
s=0.22 mm

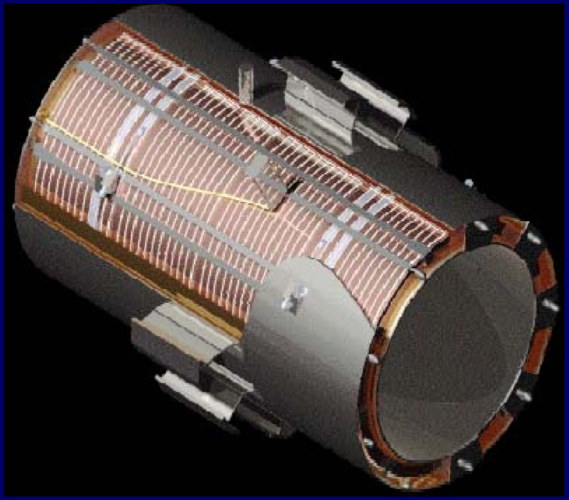
Si tracking

- $B = \mu_0 nI$; @2168 turns/m$\rightarrow$ I=20kA (SuperC)
- Challenges: 4-layer winding to carry enough I, design of reinforced superC cable

ATLAS




R1
2,34 ±0,03
32 strands ø1.276
20,63 ±0,04
30,0 +0,1 -0,1
64,0 mm +0,1 -0,1
22,0 +0,0 -0,1

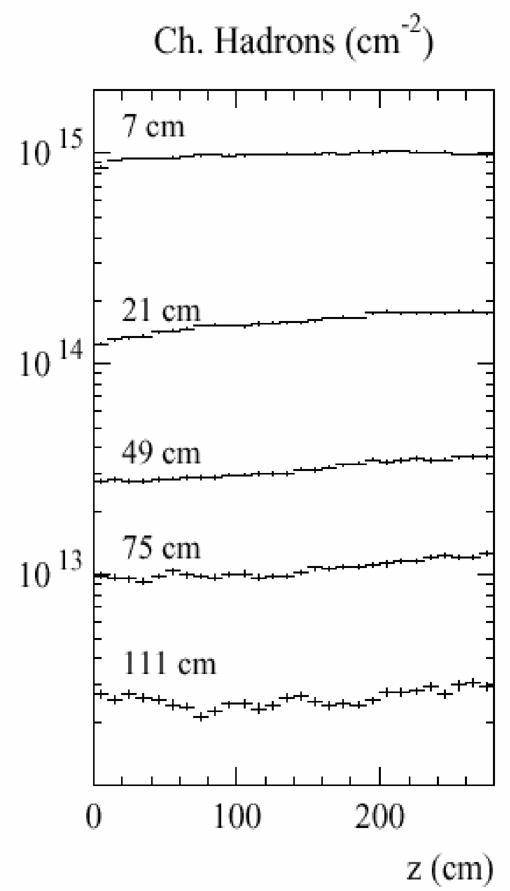


CMS

Factors that determine performance

Track finding efficiency – occupancy
Momentum resolution
Secondary vertex reconstruction

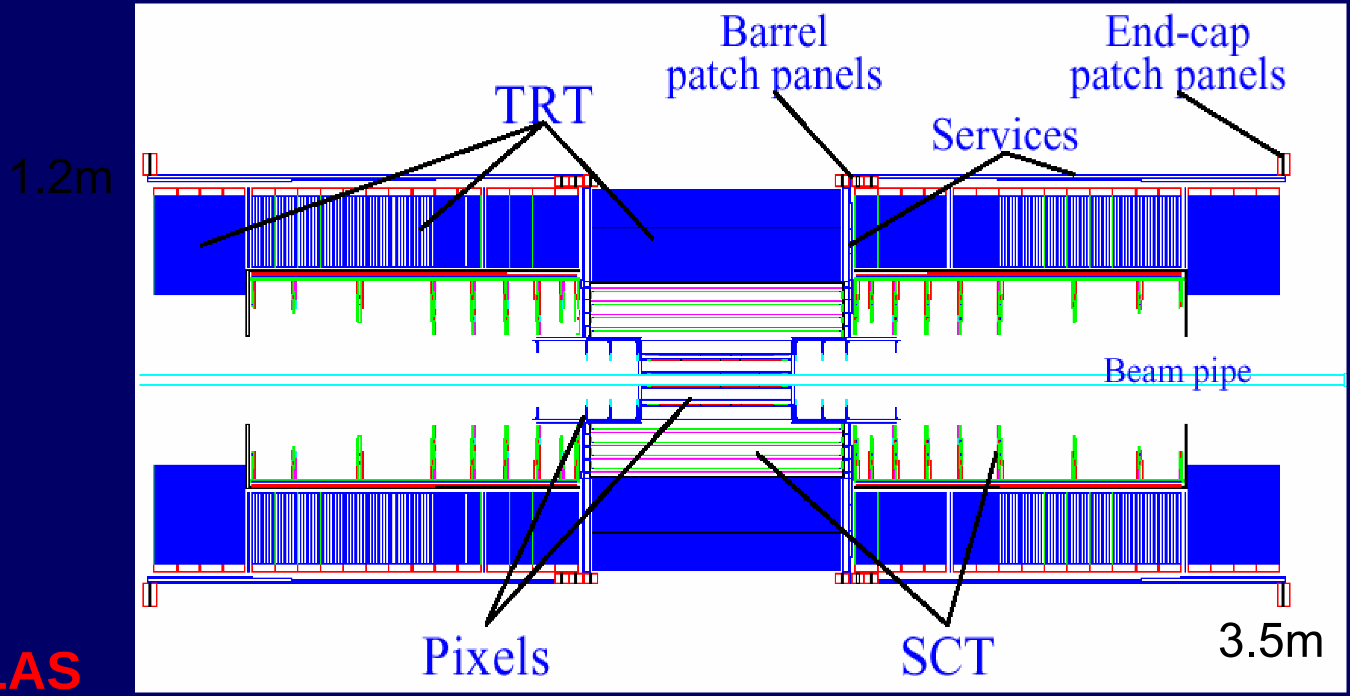
Fluence over 10 years



$\leq$ 4.10^{7} h$^{\pm}$/cm^{2}/s
pixels ($\approx$10^{4} μm^{2})
occupancy $\approx$ 10^{-4}

$\leq$ 4.10^{6} h$^{\pm}$/cm^{2}/s
Si μ-strip det.
($\approx$10 mm^{2})
occupancy $\approx$ 1%

$\leq$ 4.10^{5} h$^{\pm}$/cm^{2}/s
Si or Gas detectors.
($\approx$1 cm^{2})
occupancy $\approx$ 1%



ATLAS

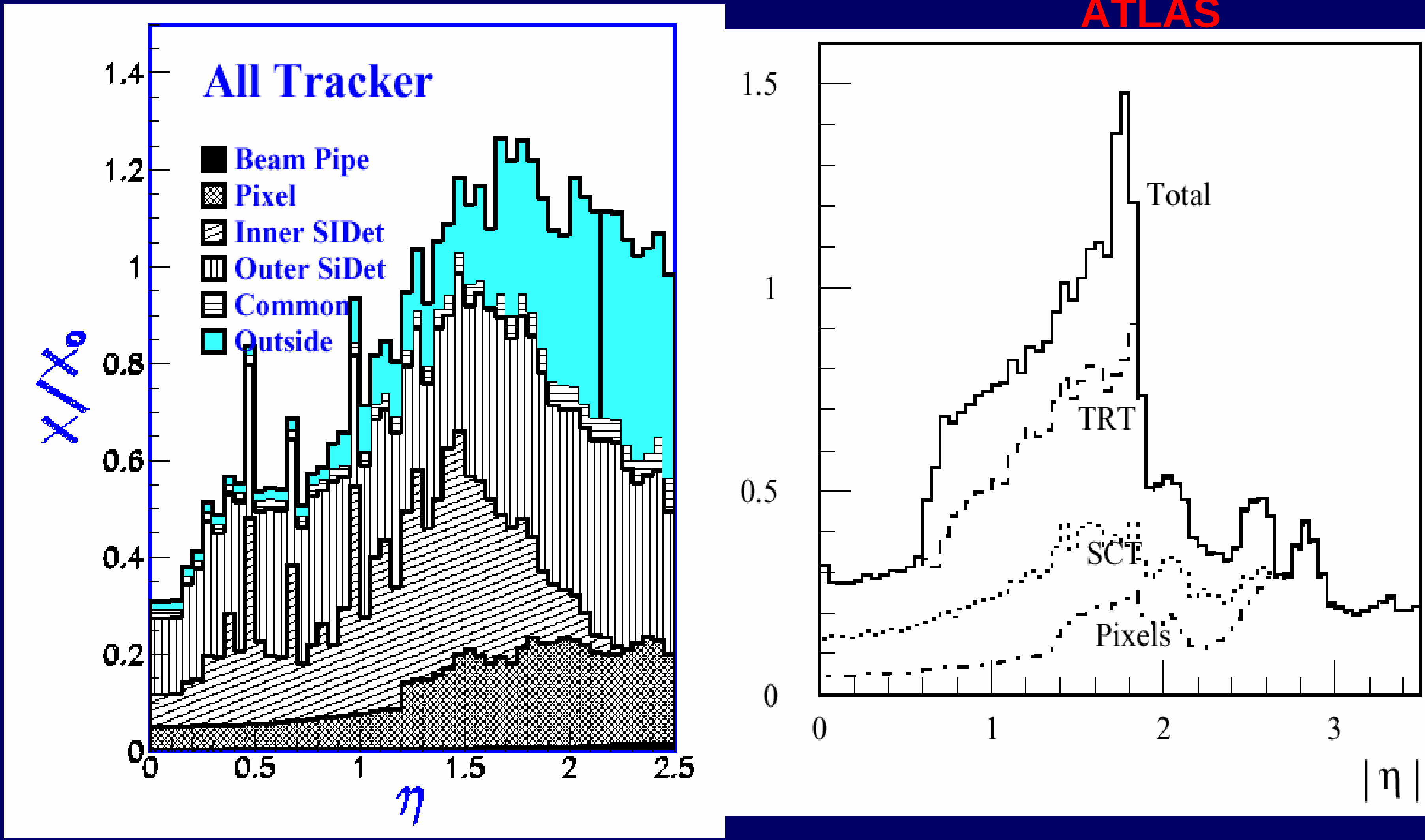
Pixels: ~ 2.3 m^2 of silicon sensors, 140 M pixels, 50x300 μm^2, r = 4, 10, 13 cm
Si μ-strips : 60 m^2 of silicon sensors, 6 M strips, 4 pts, r = 30 - 50 cm
Straws TRT: 36 straws/track, Xe-CO_2-CF_4 ϕ=4mm, r = 56 - 107 cm

CMS: Si pixels surrounded by silicon strip detectors
Pixels: ~ 1 m^2 of silicon sensors, 40 M pixels, 150x150 μm^2 , r = 4, 7, 11 cm
Si μ-strips : 223 m^2 of silicon sensors, 10 M strips, 12 pts, r = 20 – 120 cm

Material in Trackers

CMS

ATLAS



Calorimetry

Energy and position measurement of

- photons, electrons, positrons – electromagnetic calorimetry
  e.m. showers thru Bremsstrahlung, pair creation, etc.
  Energy E ~ N charged 'ionizing' (or generating scintillation, Cerenkov) light.

$$\Delta E / E = k / \sqrt{E} \oplus \ldots$$

k smaller for more samplings
(cf. homogeneous calorimeters)

Calorimeter depth determined by radiation length. Approximately:

$$X_0 = \frac{716.4A}{Z(Z+1)\ln(287/\sqrt{Z})}$$ [g cm^{-2}]

Granularity determined by Molière radius (lateral shower size)

$$\rho_M = 21.2 X_0 / \varepsilon_c$$

Calorimetry

- hadrons

Energy resolution scales as for e.m. calorimetry but with *k* typically larger

Calorimeter depth determined by interaction length $\lambda_{\text{int}} \propto 1/\sigma$

Courser granularity than e.m.

- jets

Some examples of materials:

	X_0 [cm]	λ_{int} [cm]
Fe	1.76	16.8
Pb	0.56	17.0
$PbWO_4$	0.89	18.0

Electromagnetic Calorimetry at LHC

In several scenarios moderate mass narrow states decaying into photons or electrons are expected:

SM : intermediate mass H → γγ, H → Z Z* → 4e
MSSM: h → γγ, H → γγ, H → Z Z* → 4e

In all cases the observed width (cf. signal over background) will be determined by the instrumental mass resolution. Need :

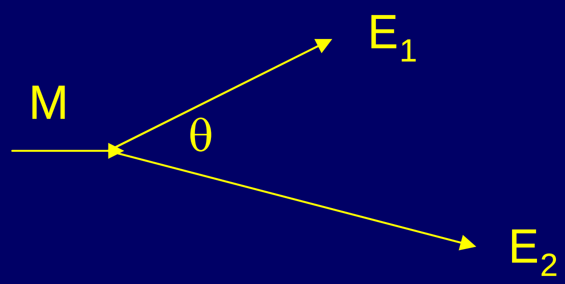
- good e.m. energy resolution
- good photon angular resolution
- good two-shower separation capability

$$M^2 = 2E_1E_2(1-\cos\theta)$$

$$dM/M \propto d\cos\theta/\cos\theta$$

$$dM/M \propto dE/E$$

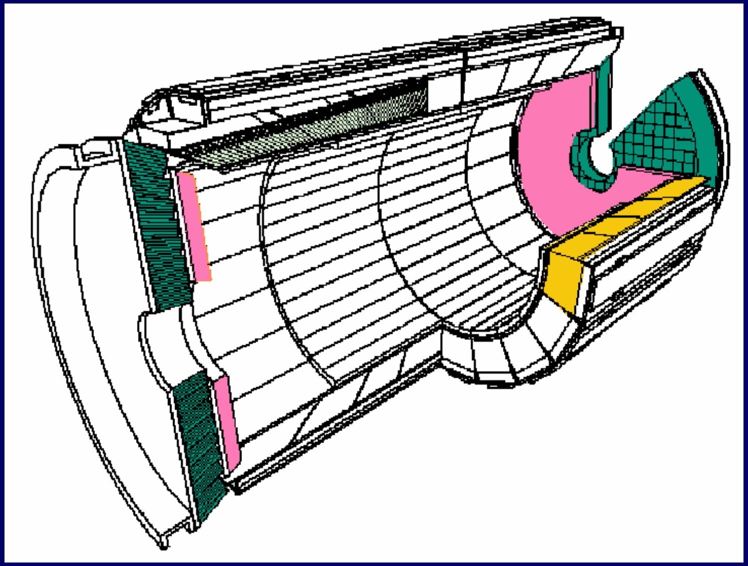
$$tg(\theta_{\min}/2) = M/2(E_1+E_2)$$



- **Jet energy resolution**
  - Limited by jet algorithm, fragmentation, magnetic field and energy pileup at high luminosity
  - Can use the width of jet-jet mass distribution as a figure of merit
    - Low p_t jets: W, Z → Jet-Jet, e.g. in top decays
    - High p_t jets: W', Z' → Jet-Jet
  - Fine lateral granularity (≤ 0.1) high p_t W's, Z's
- **Missing transverse energy resolution**
  - Gluino and squark production
    - Forward coverage up to $|\eta| = 5$
    - Hermeticity - minimize cracks and dead areas
    - Absence of tails in the energy distribution is more important than a low value for the stochastic term
  - Good forward coverage is also required to tag processes initiated vector boson fusion

CMS Calorimeters

ECAL: $PbWO_4$ crystals

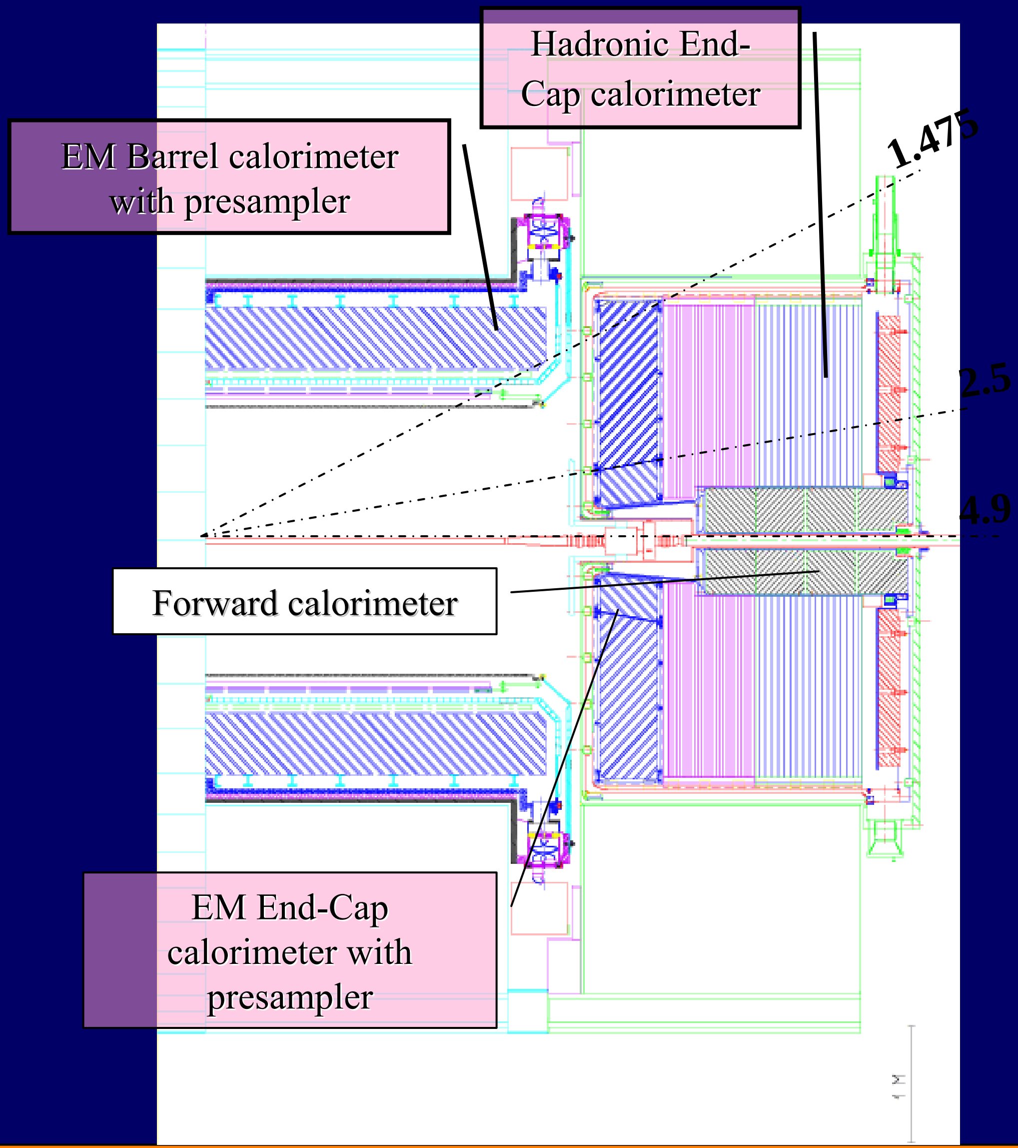


Parameter	Barrel	Endcap
η coverage	|η| < 1.48	1.48 < |η| < 3.0
Granularity (Δη×Δϕ)	0.0175×0.0175	varies in η
Crystal Dims. (cm³)	2.18×2.18×23	2.85×2.85×22
Depth in X_0	25.8	24.7 (+3X_0)
No. of crystals	61,200	14,950
Crystal Volume (m³)	8.14	3.04
Photodetector	APDs	VPTs
Modularity	36 supermodules	4 Dees

HCAL

Central Region (|η|<3) : Brass/Scintillator with WLS fibre readout, projective geometry, granularity ΔηxΔϕ = 0.0875x0.0875

Forward Region (3<|η|<5): Fe/Quartz Fibre, Cerenkov light



ECAL

Accordion Pb/LAr

$|\eta|<3.2$, 3 samplings

S1: $\Delta\eta \times \Delta\phi = 0.025 \times 0.1$

S2: $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$

S3: $\Delta\eta \times \Delta\phi = 0.05 \times 0.025$

HCAL

Barrel: Fe/Scintillator with WLS fibre readout

3 samplings - $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

Endcap: Fe/LAr

Forward: W/LAr

$3.1<|\eta|<4.9$

$\Delta\eta \times \Delta\phi = 0.2 \times 0.2$

Muon identification should be easy at L ~ 10^{34} cm^{-2} s^{-1}

Muons can be identified inside jets

b-tagging, control efficiency of isolation cuts

Factors that determine performance

Level-1 Trigger

rate from genuine muons (b,c → μX) is very high a must make a p_T cut with v. high efficiency – flexible threshold (p_T in the range 5 – 75 GeV)

Pattern Recognition

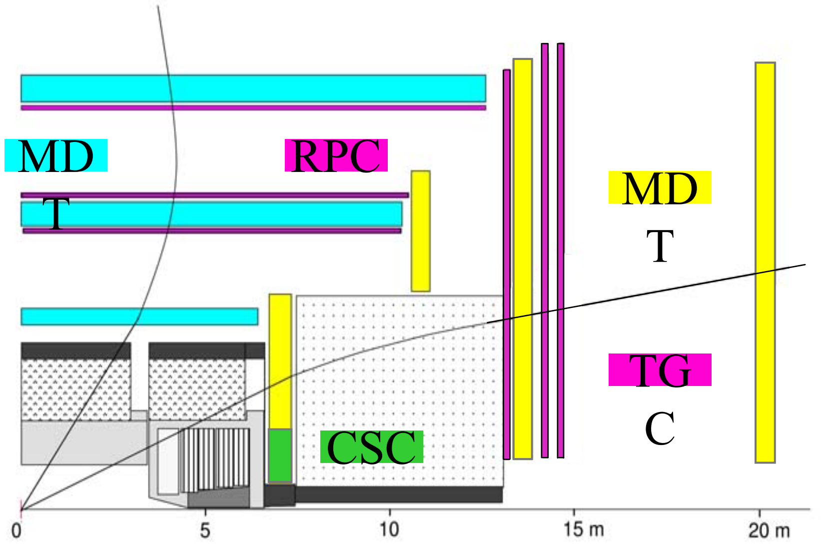
hits can be spoilt by correlated backgrounds (δ's, em showers, punchthrough) and uncorrelated ones (n's and associated photons)

Momentum Resolution

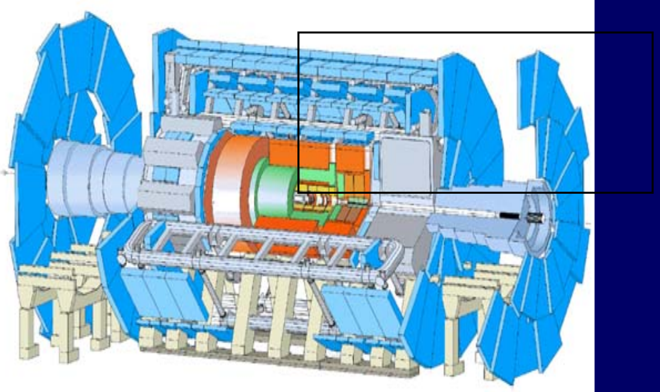
high momenta involved a high B.dl

good chamber resolution (~ 100 μm) and good alignment

for low momenta precision comes from inner tracking



Each detector has 3 stations.
Each station consists of 2-4 layers.



Precision chambers

Monitored **D**rift **T**ubes (|η| < 2)
with a single wire resolution of 80 μm
1194 chambers, 5500m^2

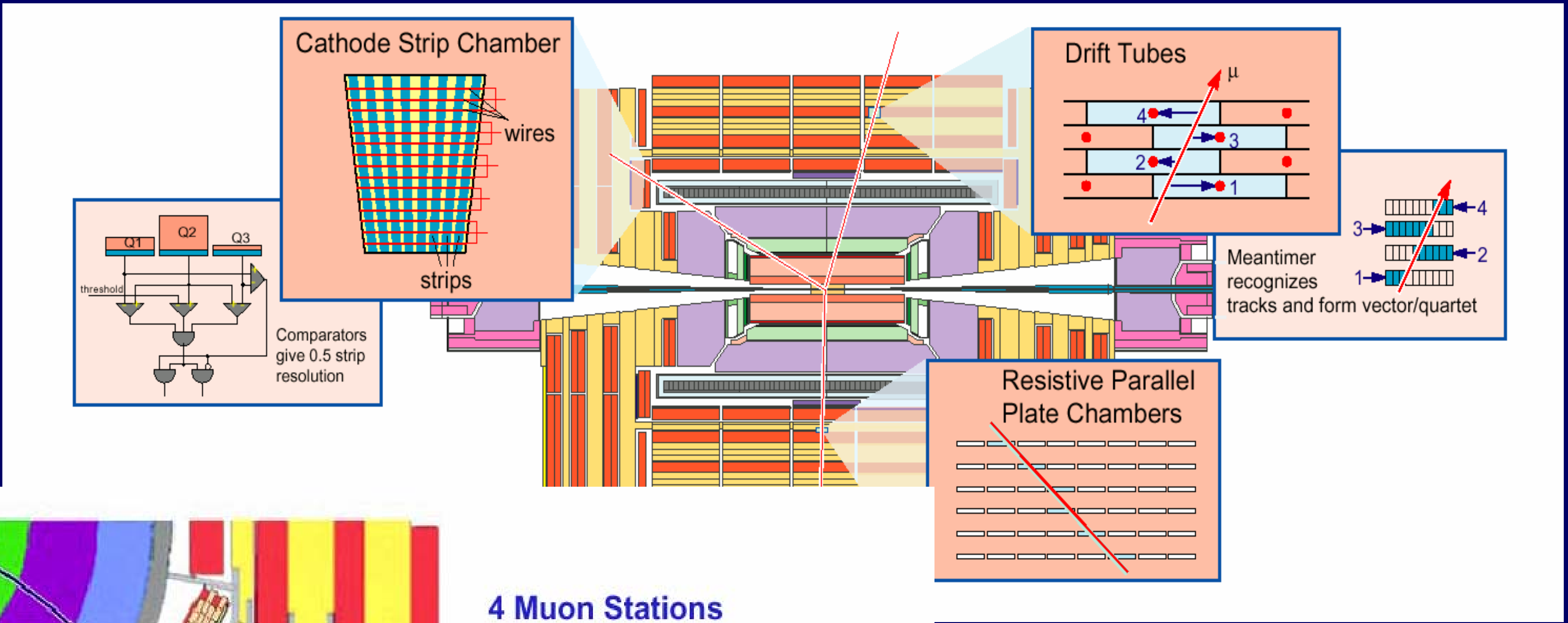
Cathode **S**trip **C**hambers (2 < |η| < 2.7)
at higher particle fluxes
32 chambers, 27 m^2

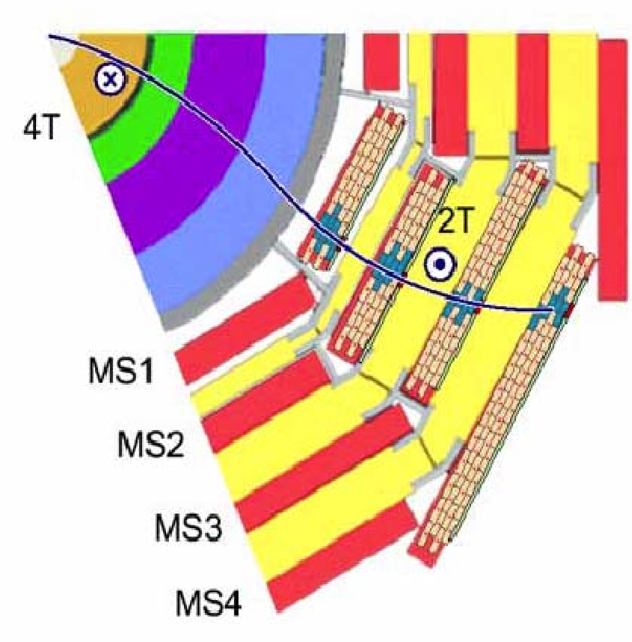
Trigger chambers

Resistive **P**late **C**hambers (|η| < 1.05)
with a good time resolution of 1 ns
1136 chambers, 3650 m^2

Thin **G**ap **C**hambers (1.05 < |η| < 2.4)
at higher particle fluxes
1584 chambers, 2900 m^2

CMS Muon Detectors





4 Muon Stations
- redundancy
- acceptance

Per Station
- barrel – 12 measuring planes
- endcap – 6 measuring planes

Measurement Accuracy
- position 70 – 100 μm /station
- direction ~ 1 mrad

ATLAS

Tracking ($|\eta|<2.5$, B=2T) :
- Si pixels and strips
- Transition Radiation Detector (e/π separation)

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

Muon Spectrometer ($|\eta|<2.7$) :
air-core toroids with muon chambers (standalone capabilities)

CMS

Tracking ($|\eta|<2.5$, B=4T) : Si pixels and strips

Calorimetry ($|\eta|<5$) :
- EM : PbWO4 crystals
- HAD: brass-scintillator (central+ end-cap), Fe-Quartz (fwd)

Muon Spectrometer ($|\eta|<2.5$) : return yoke of solenoid instrumented with muon chambers

	ATLAS	CMS
MAGNET (S)	Air-core toroids + solenoid in inner part Calorimeters outside field 4 magnets	Solenoid Calorimeters inside field 1 magnet
TRACKER	Si pixels+ strips TRD → particle identification B=2T $\sigma/p_T \sim 5\times10^{-4}\, p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
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 segmentation
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Brass-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → σ/p_T < 10 % at 1 TeV standalone; larger acceptance	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker

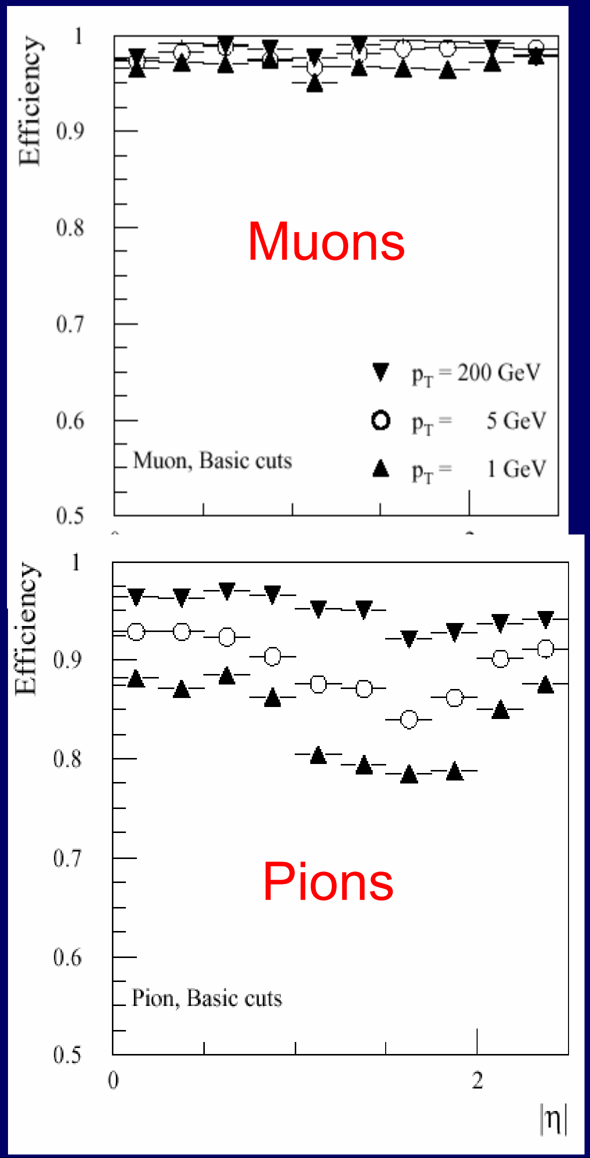
Performance

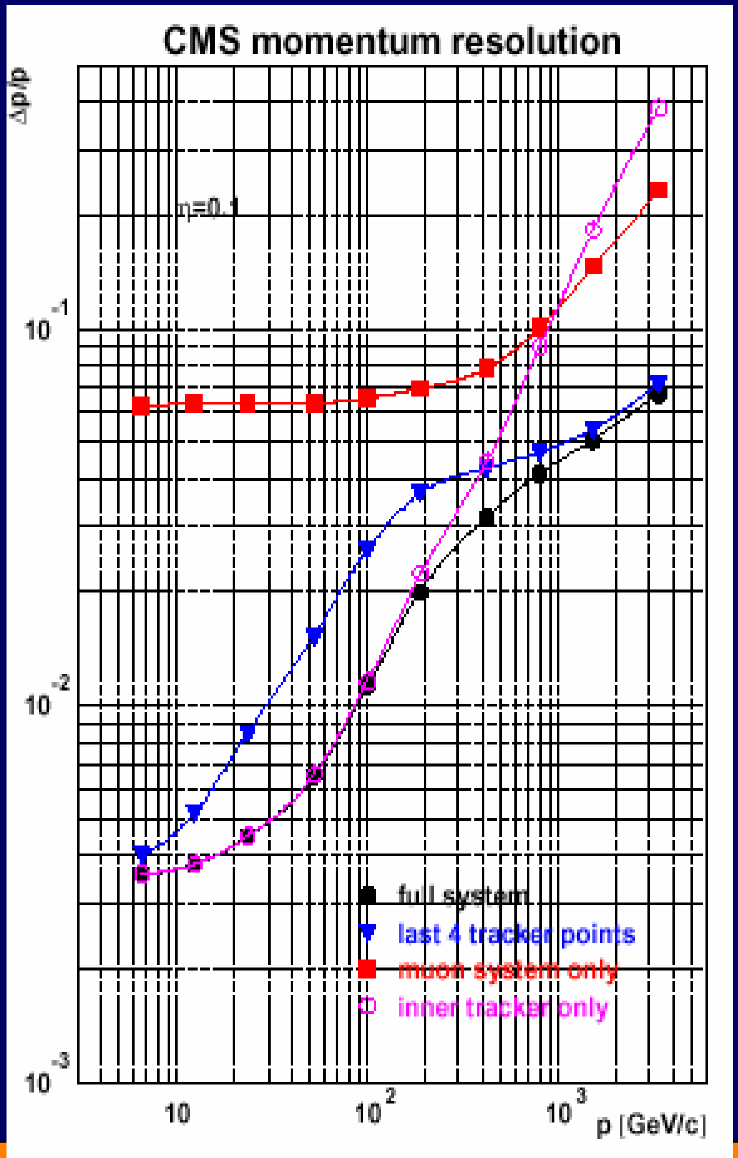
Extensive and in several cases very detailed studies exist

The general conclusion is that the detectors will allow the physics studies they were designed for (and even those they were not designed for)

Charged Track Reconstruction

ATLAS
Pattern
Recognition
>9 precision
hits
+ 2 pixel hits
+ s_d < 1mm





Multiple Scattering

Multiple Coulomb scattering adds an apparent deflection angle, i.e. apparent sagitta

$$\theta_{mlt} = \frac{13.6[\mathrm{MeV}]}{\beta pc} Z \sqrt{\frac{L}{X_0}}$$

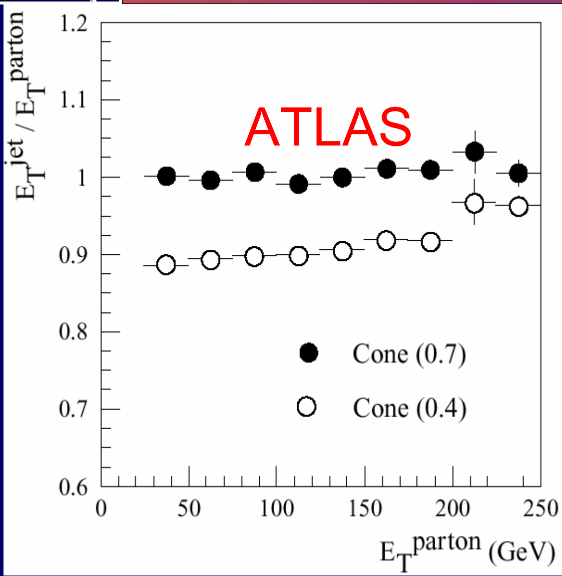
$$\left(\frac{dp}{p}\right)_{mlt} \approx 0.05 \frac{1}{B\sqrt{LX_0}}$$

Use light material in trackers

cf also CMS muon spectrometer ‘stand alone’

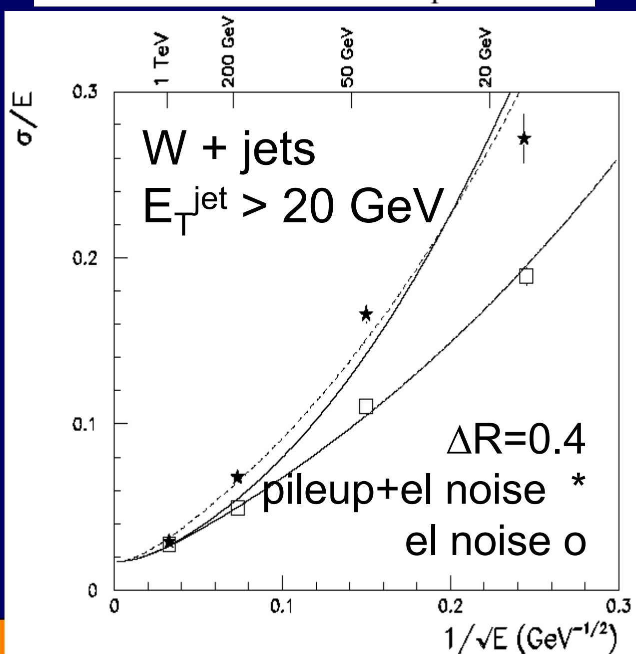
Classical 'cone' algorithm - jet built around a seed

- parameters: E_T^{seed} cut, cone opening radius DR

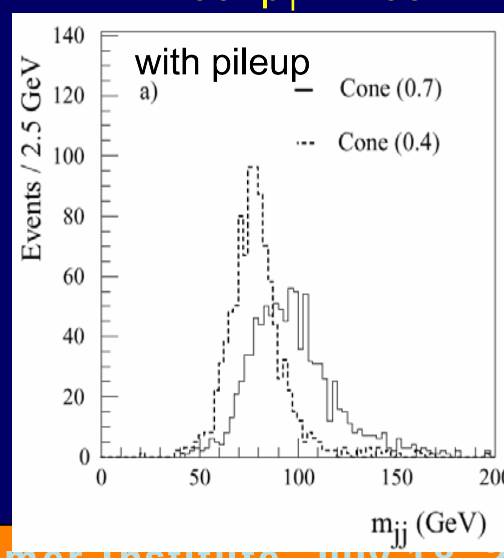


ATLAS: W → jet-jet mass resolution

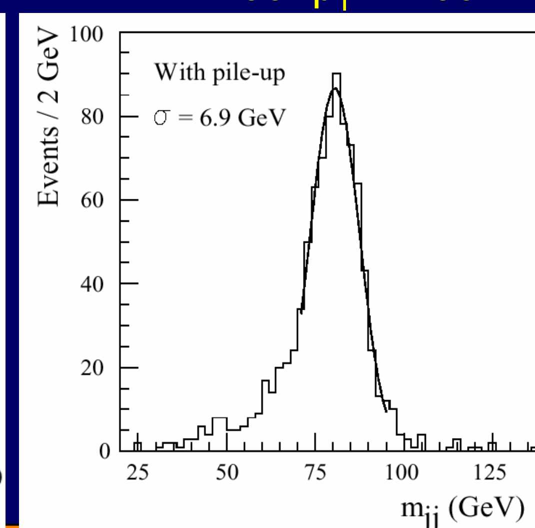
p_T^W(GeV)	ΔR	σ_{LoL}	σ_{HiL} (GeV)
p_T<50	0.4	9.5	13.8
100<p_T<200	0.4	7.7	12.9
200<p_T<700	0.3	5.0	6.9



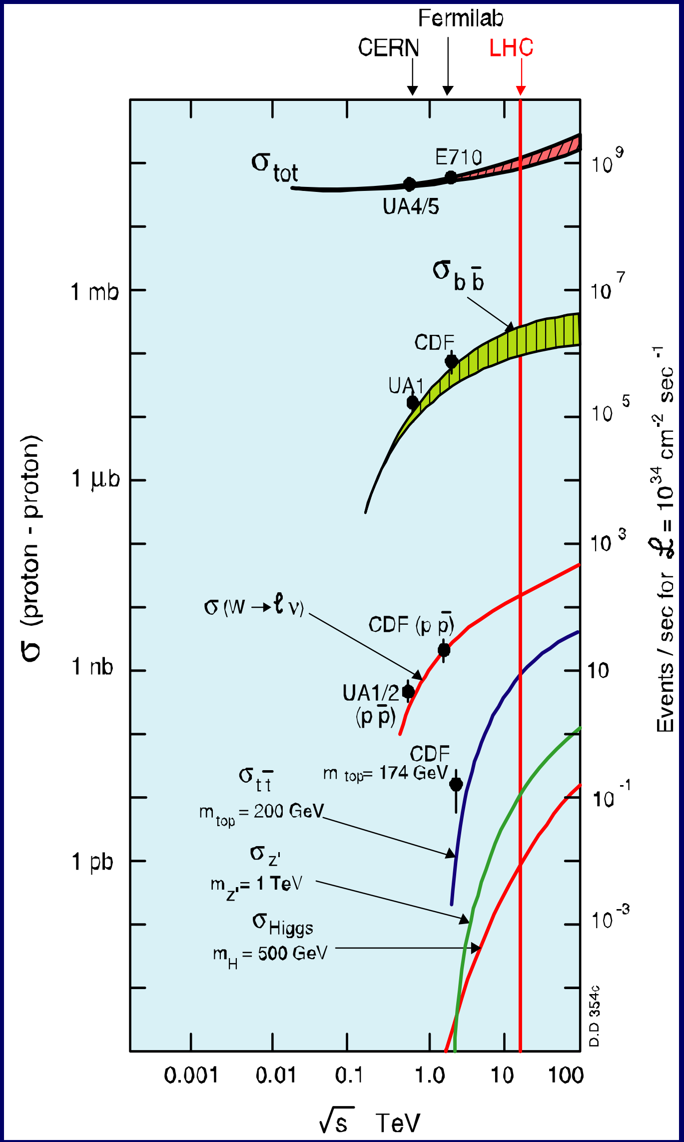
100<p_T^W<200



200<p_T^W<700



Production Cross-sections



At sqrt(s)=14 TeV

σ_{tot}	~ 105 mb
$\sigma_{elastic}$	~ 28 mb
$\sigma_{diffractive}$	~ 12 mb
σ_{inel}	~ 65 mb

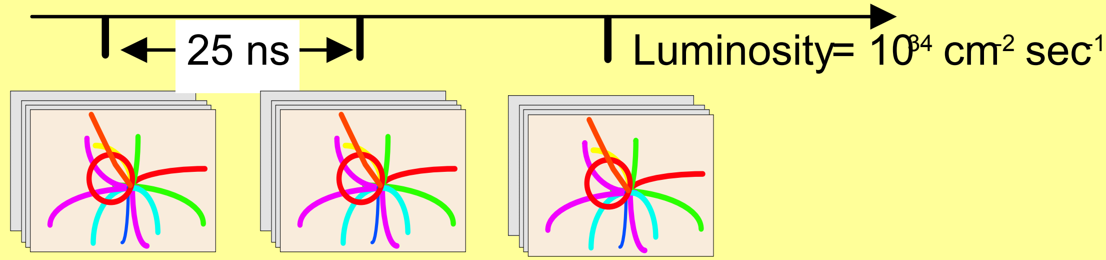
Evt rate $= L.\sigma = 10^{34} \times 65\ 10^{-27}$ /s
$= 6.5\times10^{8}$ /s

Operating Conditions

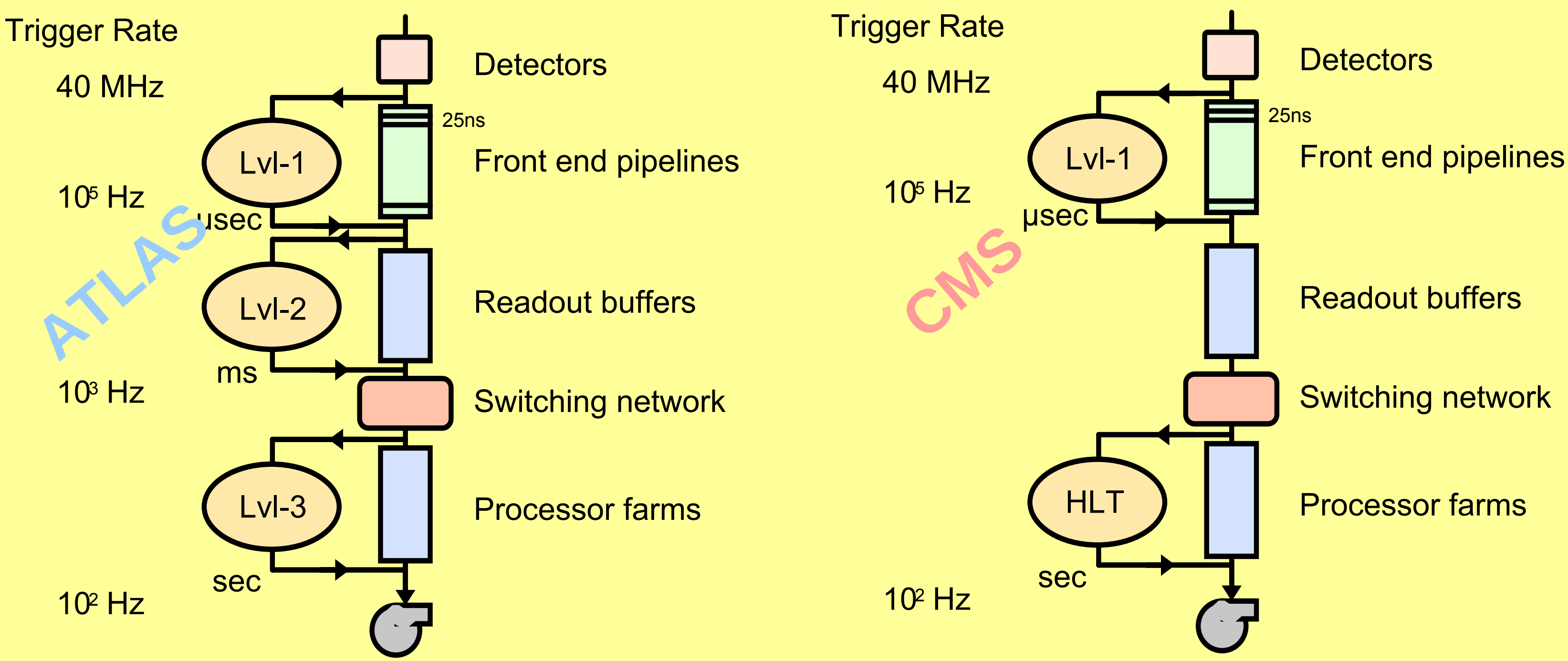
For every ‘good’ event containing a Higgs decay
there are ~ 20 extra ‘bad’ minimum bias interactions superposed

- 30 Collisions/25ns
(10^{9} event/sec)

10^{7} channels
(10^{16} bit/sec)



Multilevel trigger and readout systems



Data Acquisition

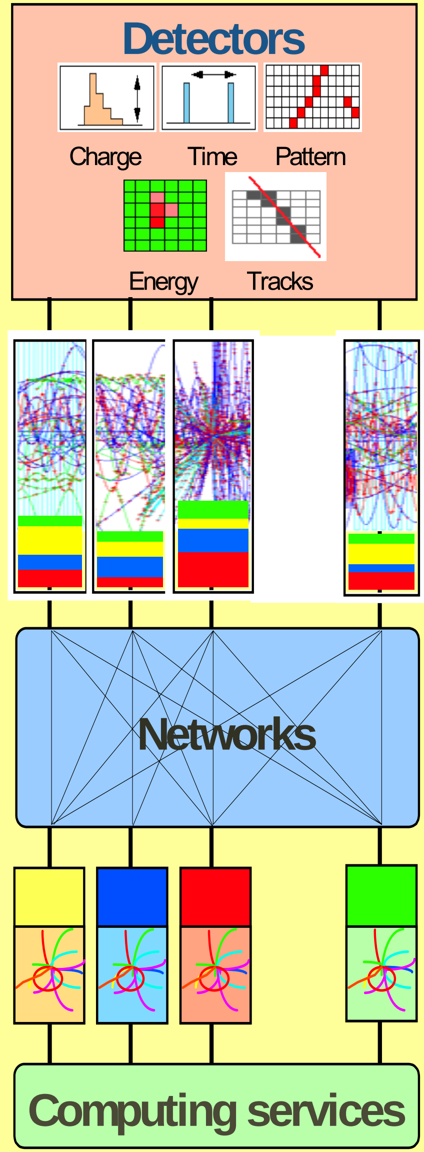
40 MHz COLLISION RATE

100 kHz LEVEL-1 TRIGGER

1 Terabit/s (50000 DATA CHANNELS)

500 Gigabit/s

Gigabit/s SERVICE LAN



16 Million channels

3 Gigacell buffers

1 Megabyte EVENT DATA

200 Gigabyte BUFFERS

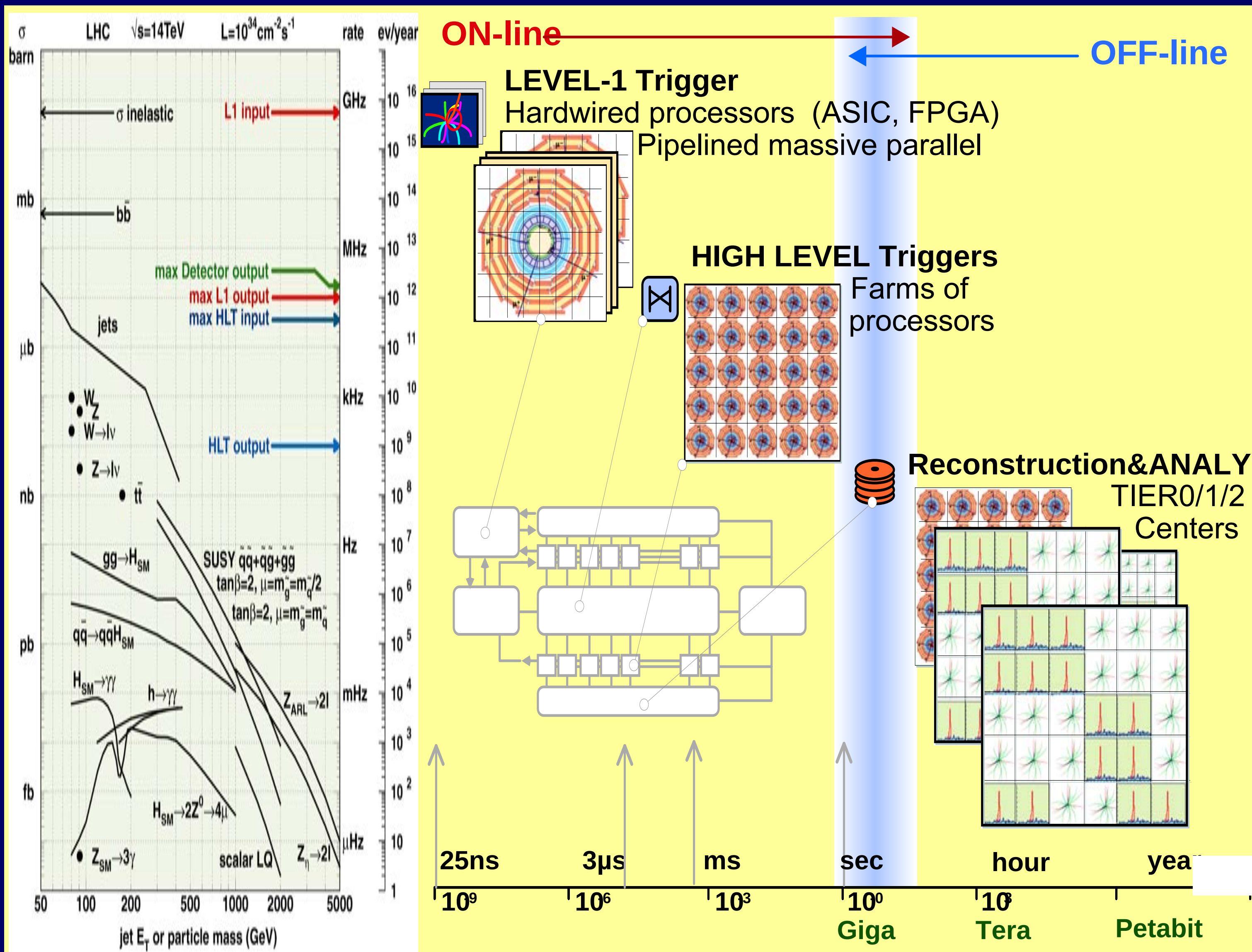
500 Readout memories

EVENT BUILDER. A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and distributes event building commands (read/clear) to RDPMs

5 TeraIPS

EVENT FILTER. It consists of a set of high performance commercial processors organized into many farms convenient for on-line and off-line applications. The farm architecture is such that a single CPU processes one event

Petabyte ARCHIVE


σ barn
LHC √s=14TeV L=10^34 cm^-2 s^-1
rate ev/year
σ inelastic
L1 input
bb̄
max Detector output
max L1 output
max HLT input
jets
W
Z
W→lν
Z→lν
tt̄
HLT output
gg→H_SM
SUSY q̃q̃+q̃g̃+g̃g̃
qq→qqH_SM
H_SM→γγ
h→γγ
Z_ARL→2l
H_SM→2Z^0→4μ
Z_SM→3γ
scalar LQ
jet E_T or particle mass (GeV)
GHz
MHz
kHz
Hz
mHz
μHz
ON-line
OFF-line
LEVEL-1 Trigger
Hardwired processors (ASIC, FPGA)
Pipelined massive parallel
HIGH LEVEL Triggers
Farms of
processors
Reconstruction&ANALYS
TIER0/1/2
Centers
25ns
3μs
ms
sec
hour
yea
10^9
10^6
10^3
10^0
10^3
Giga
Tera
Petabit

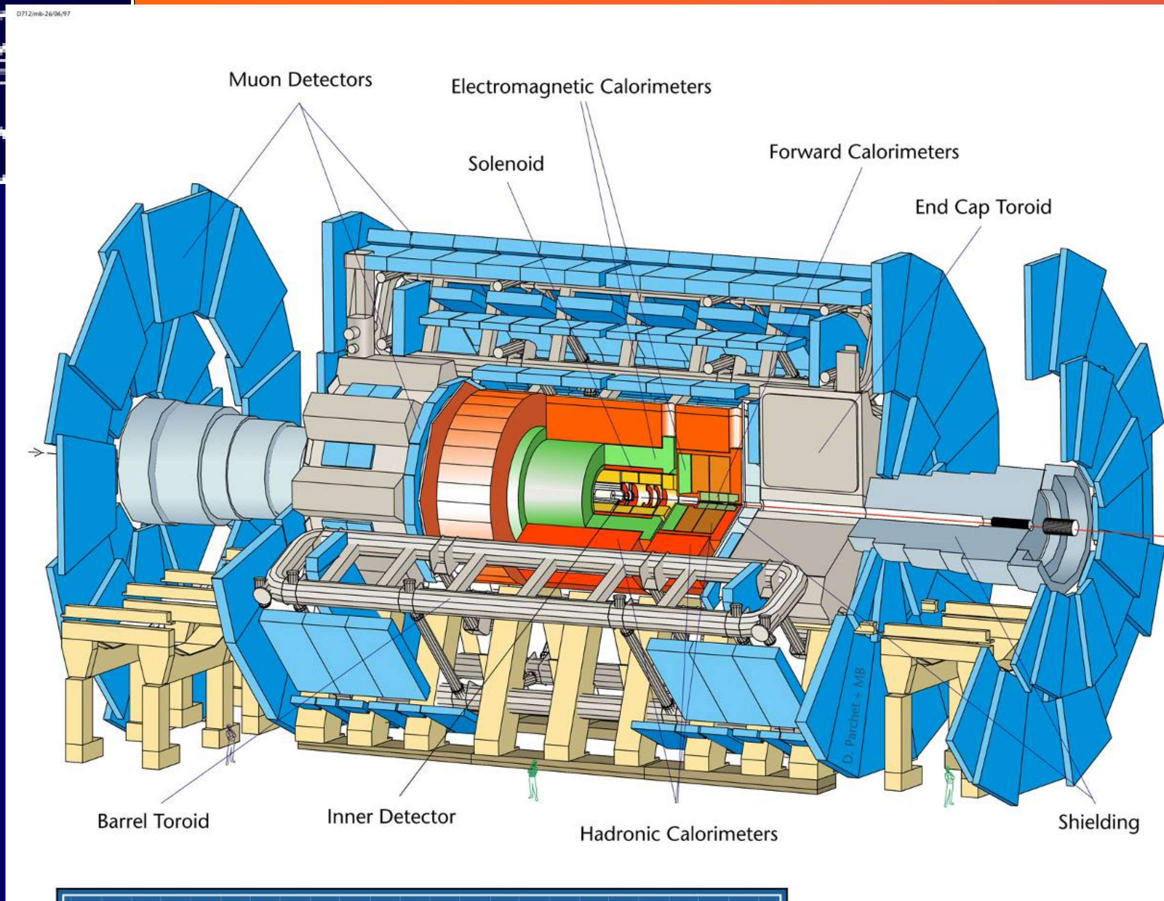
Status of the experiments – July 2006

A few pictures and some text to illustrate the status of the LHC experiments

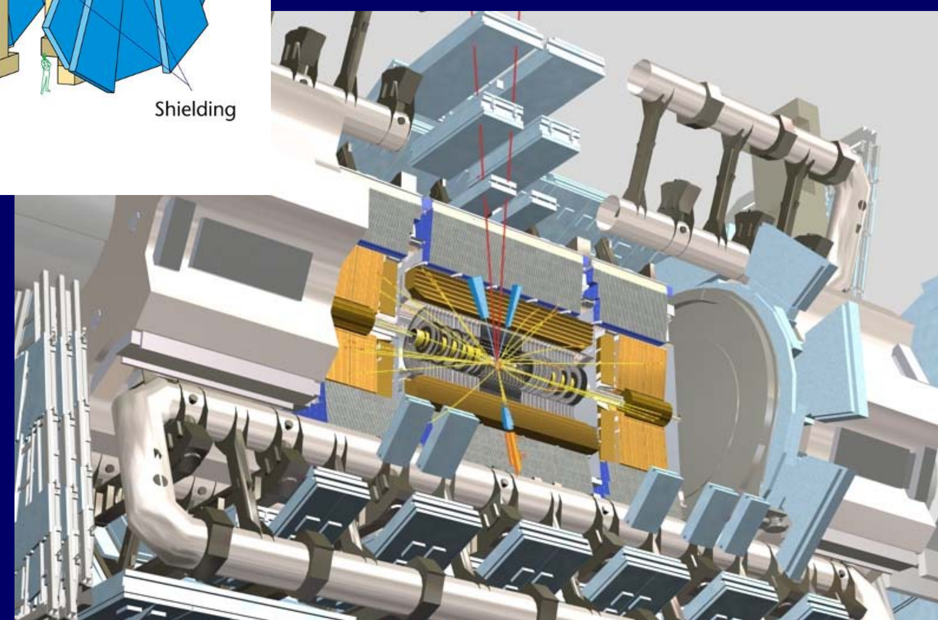
Detectors are ready or close to completion

Largest activity right now: Integration & Installation

ATLAS



Construction status: on track for collisions towards the end of 2007

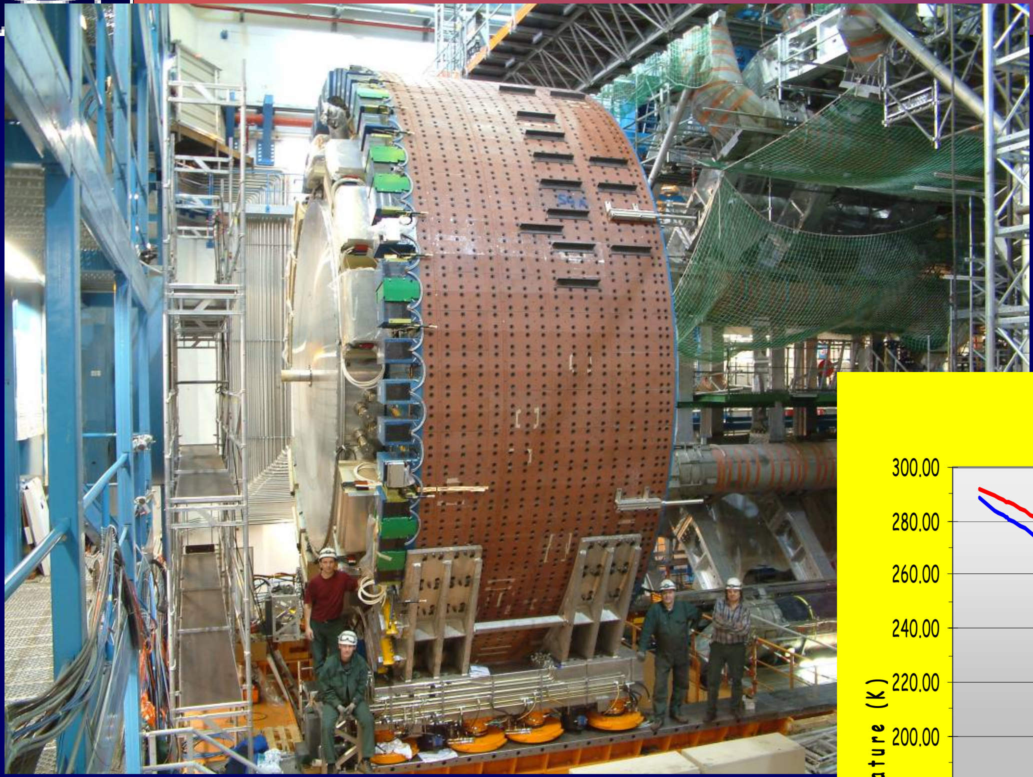


Simulation of a $H \to \mu\mu$ ee event in ATLAS

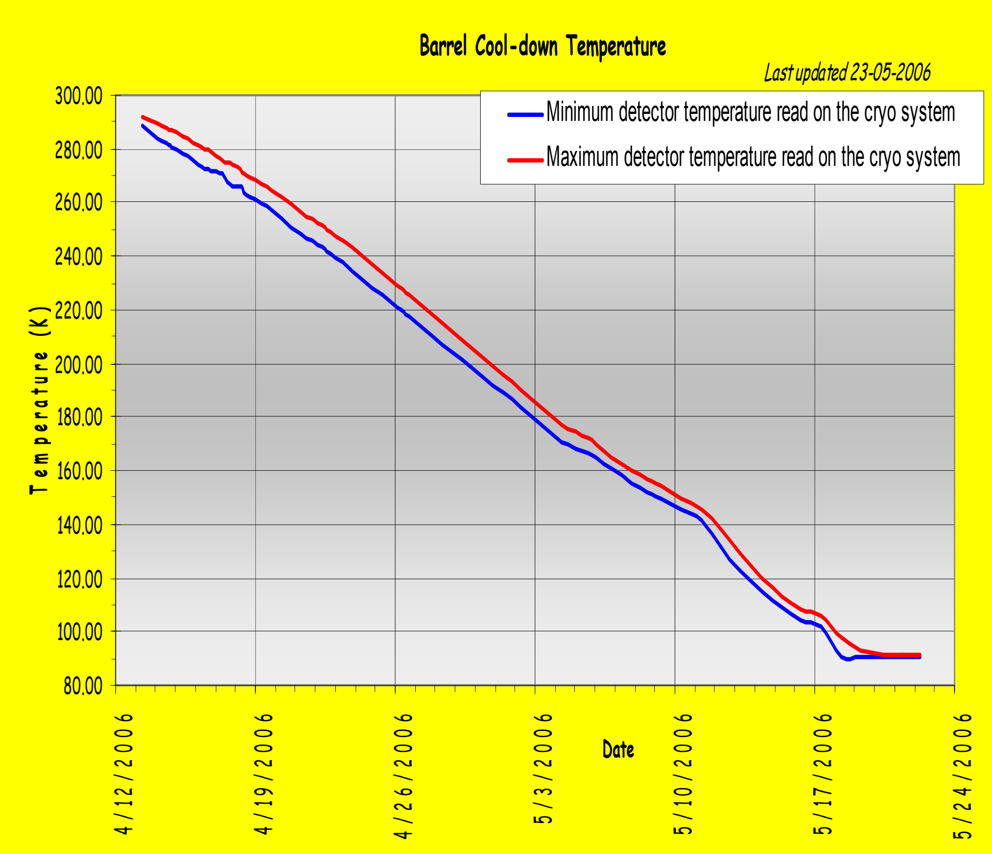
Calorimeters

All three calorimeter cylinders are installed in the underground cavern, and the gradual commissioning of them has started

→ The full calorimeter system is to be operational spring 07



Complete end-cap calorimeter cylinder (LAr and Tiles) just before insertion into the barrel toroid region



Cool-down history of barrel LAr EM calorimeter *in situ* at the centre of the ATLAS detector, having reached LAr temperature end of May 06

Inner Detector

Pixel detector: recovery from cooling pipe leaks in the barrel proceeding according to schedule

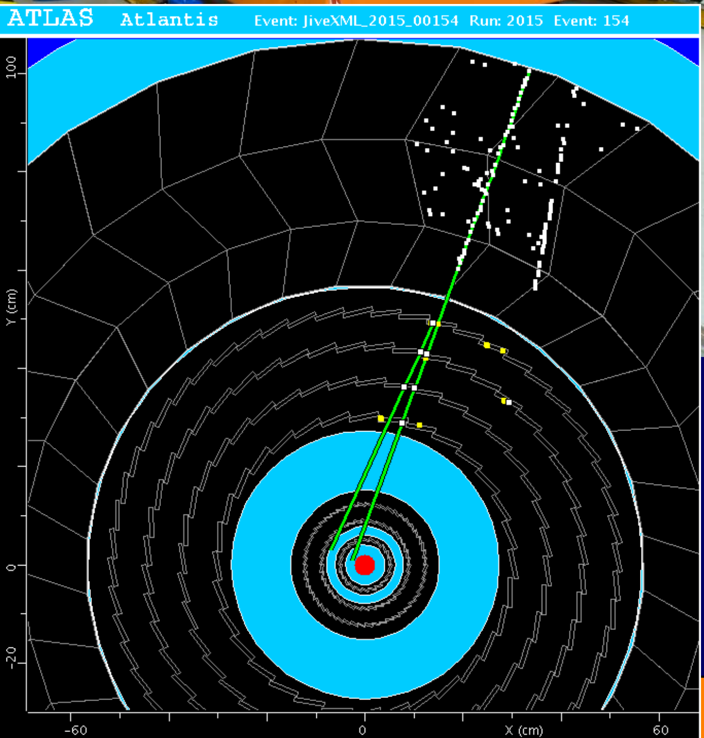
Silicon tracker (SCT): full system preassembled

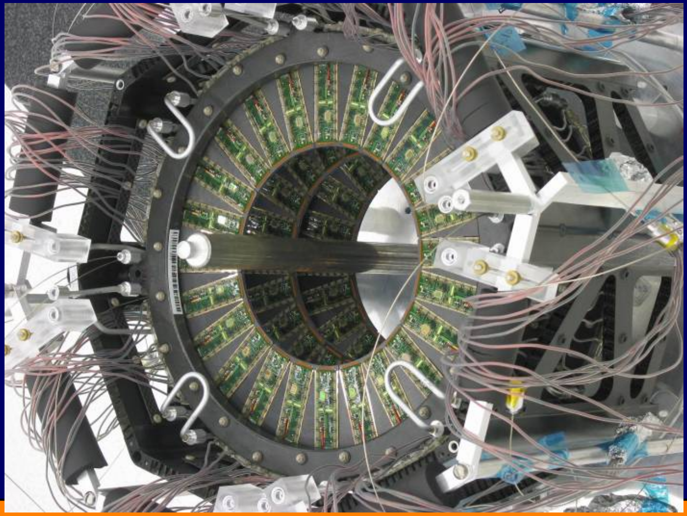
Transition Radiation Tracker (TRT): services Integration on fully preassembled system is being finalized

→ Installation of the complete system on time for June 07

Completely assembled barrel TRT and SCT

Completely integrated Pixel end-cap with 6.6 M channels at CERN





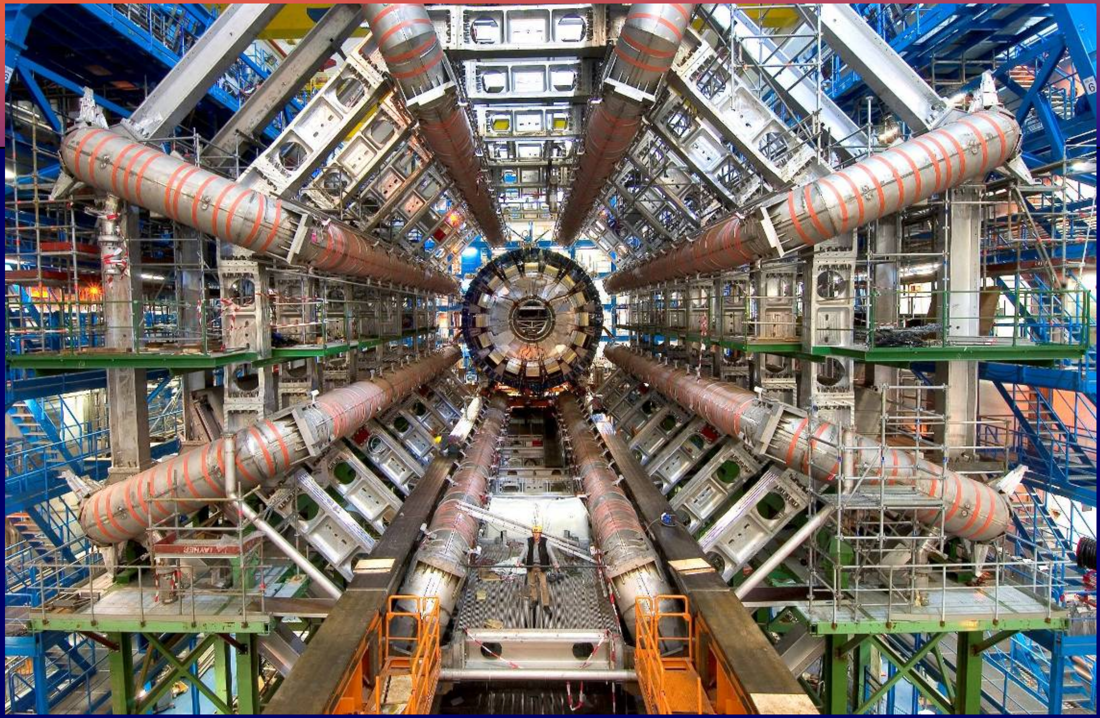
Cosmic rays recorded in barrel TRT and SCT in the surface building clean room SR1

Magnet System

The Barrel Toroid is installed, and is being pumped down, followed by full excitation tests in July/Aug 06

The End-Cap Toroids are in the final integration phase, on time for the cavern (end of 2006)

The solenoid has been tested already *in situ* at reduced current, awaiting the closure of the calo end-caps



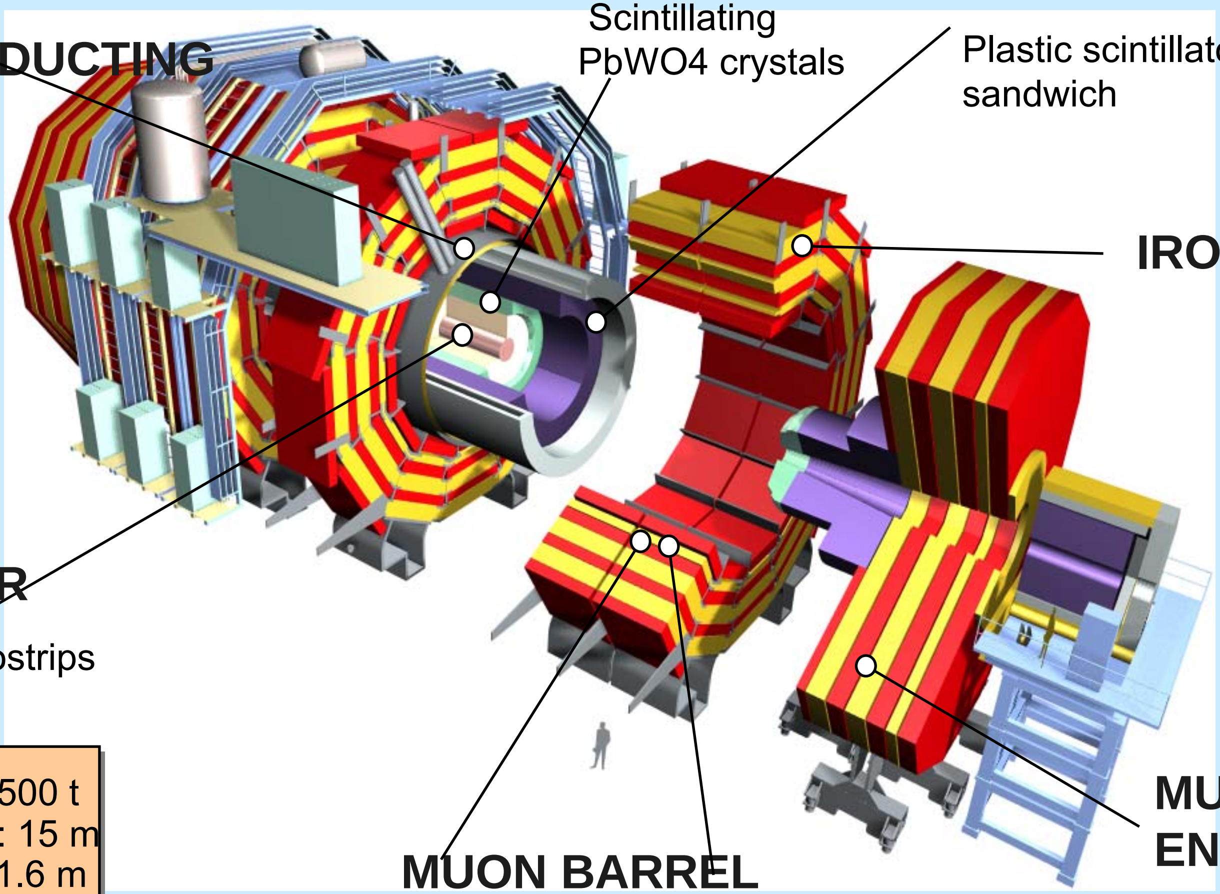
Barrel Toroid before insertion of the barrel calorimeter on 4th November 2005

Muon Chambers

All chambers are built, installation in the barrel region is in full swing (complete before end 2006), and end-cap sectors are being pre-assembled in Hall 180 (on the critical path for installation by summer 2007)

Installation of barrel muon chambers

The CMS Detector



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

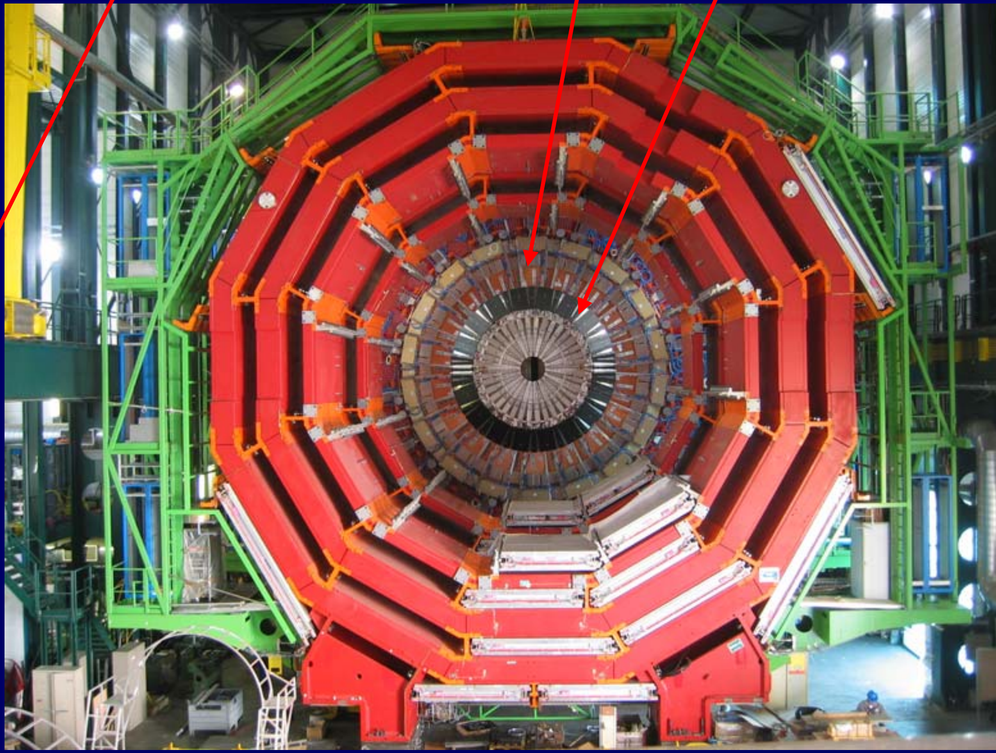
3 g/cm^3

CMS Assembly at Point 5 for Slice Test

Magnet Test and Detector Test - Jul-Aug06

Solenoid is cold
HB inserted in coil
2 ECAL SM
Tracker Components
DT + RPCs

HCAL Endcap
CSCs



CMS Construction Progress

The 4 Tesla s.c. coil is now cold, at liquid He temperature 4.5K.

Tracker assembly progressing well. All parts (~220 m^2 of Si sensors) expected to be installed in Support Tube (by end06) for final commissioning and then transport to Point 5.

80% of barrel crystals delivered. 27/36 bare Supermodules (1700 xtals) assembled. 16 out of 36 SM integrated so far. Install 30 SM into HB before lowering. Endcap ECAL will be installed for 2008 physics run.

HCAL source calibration complete. HCAL pre-calibrated to ~ 4%

Over 3 out of 5 wheels worth of DT/RPC packages installed. > 90% of CSCs installed on endcap disks. Half of endcap RPCs installed.

Commissioning with cosmics of large sub-parts (systems tests) has started. Cosmics have been recorded for all sub-detectors: TK, ECAL, HCAL and Muon system. Test a full slice of CMS in July-Sep 06.

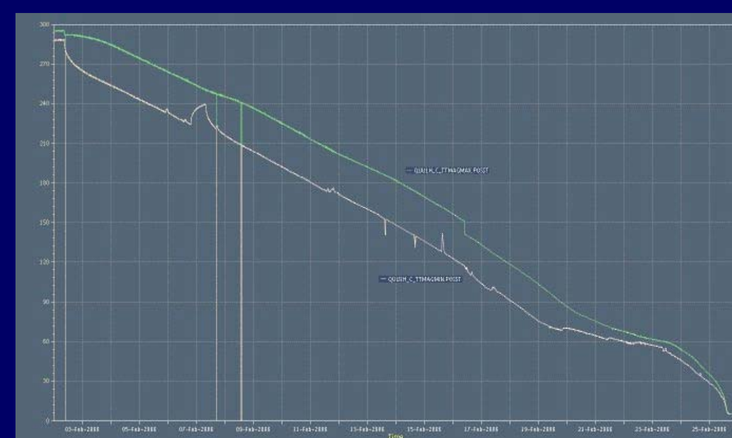
Start lowering disks and wheels in Oct06.

CMS will be ready for first collisions in pilot physics run of 2007.

CMS Solenoid

Vacuum Tank welded (Nov-Jan)

Coil Cooled to 4.5K in 25 days (Feb).
Test on Surface (Jun-Aug)



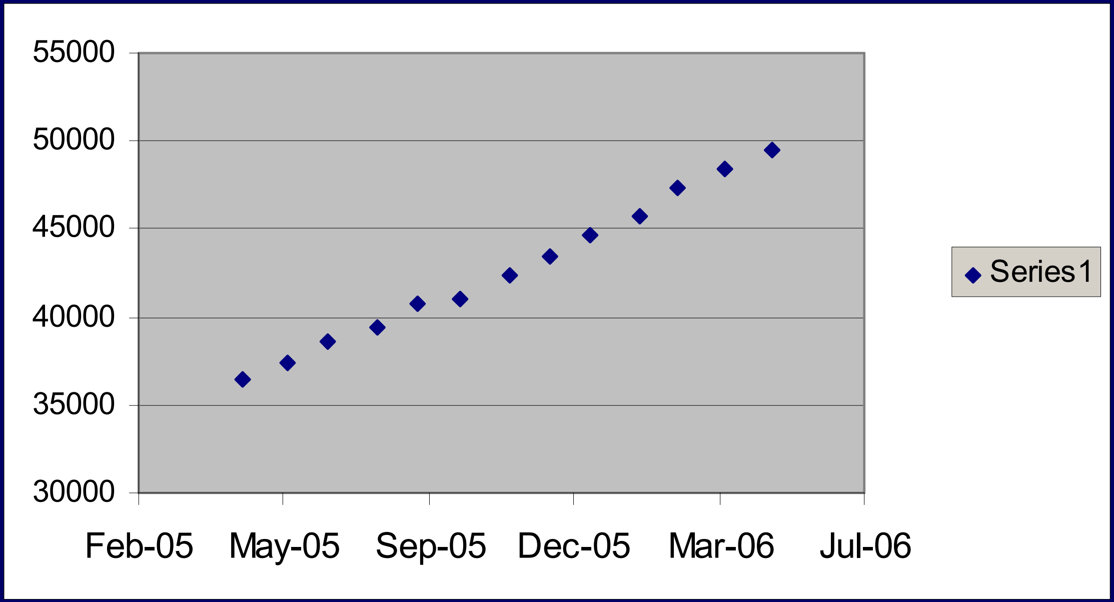
Crystals Production and ECAL Schedule

Crystals delivery determines ECAL Critical Path.

Last ECAL Barrel crystal delivered February 2007.

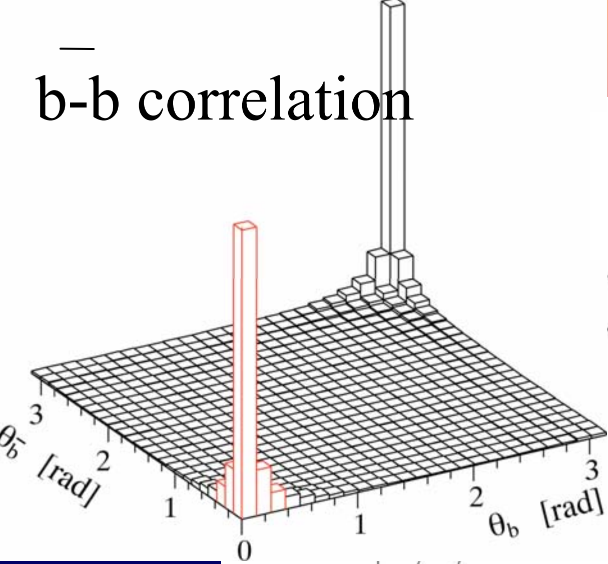
Last ECAL Endcap crystal delivered January 2008.

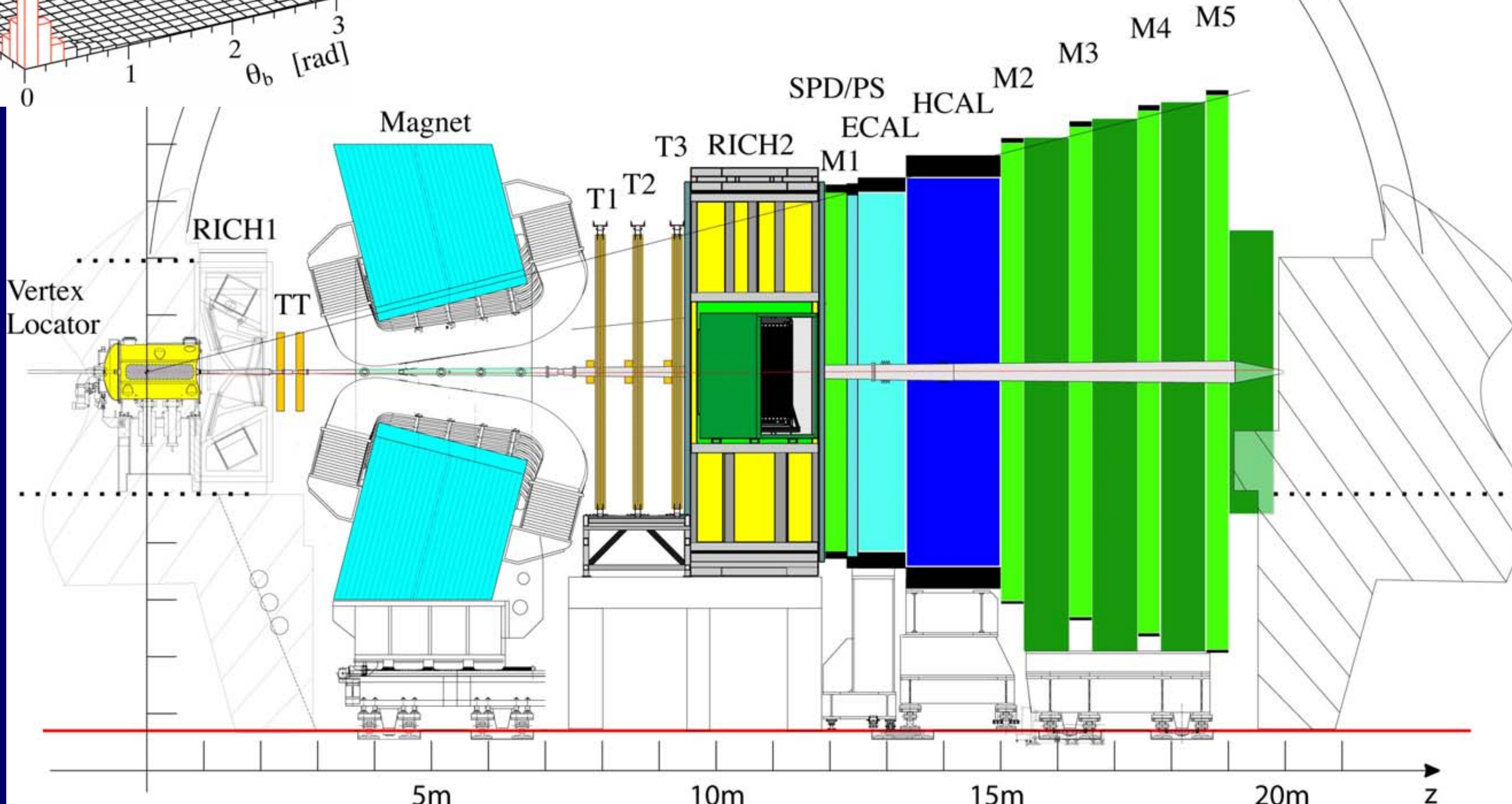
Plan is to have ECAL BARREL completed for the pilot run in 2007 and to install ECAL ENDCAP and pre-shower for the first physics run in 2008.



EB Crystal Production in Russia: > 50,000 usable crystals (80%).

LHCb detector at IP8





LHCb pit

Magnet: commissioned, B field measurement completed

VELO: Vertex Locator

vacuum tank installed, sensor module production started

Outer Tracker:

module construction completed, support structure being installed

Silicon Tracker: Inner Tracker and Trigger Tracker

Si ladder production and support structure construction in progress

RICH: RICH2 mechanics installed, RICH1 shielding box installed

Calorimeters:

Ecal and Hcal modules installed, Preshower ready for installation

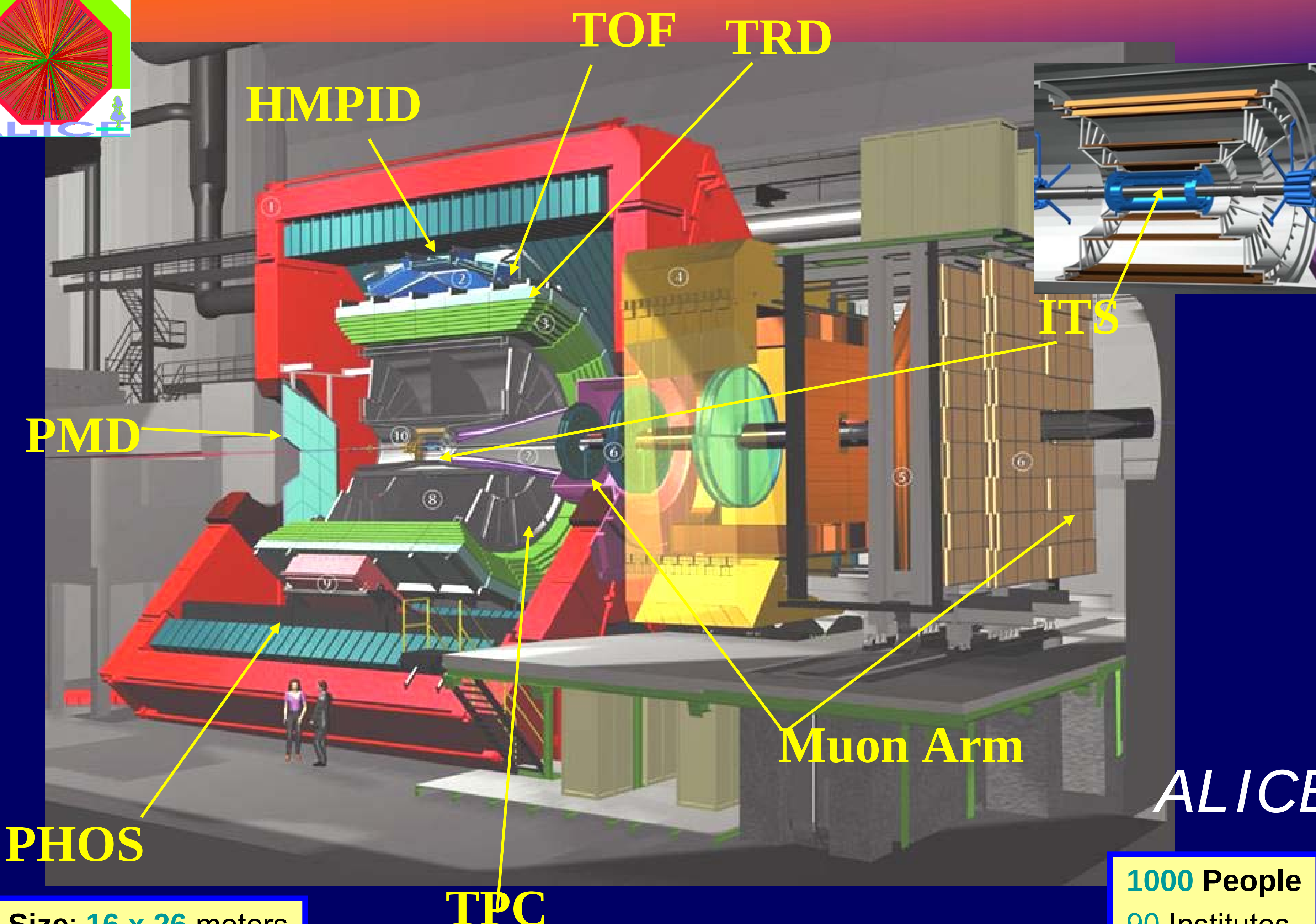
Muon:

chamber production progressing, infrastructure in preparation

Trigger:

Level-0 electronics production about to start

Planned to be ready for the first beam collisions



Size: 16 x 26 meters
Weight: 10,000 tons

1000 People
90 Institutes
30 Countries

Infrastructure (large structures, μ-absorbers, magnets,..)

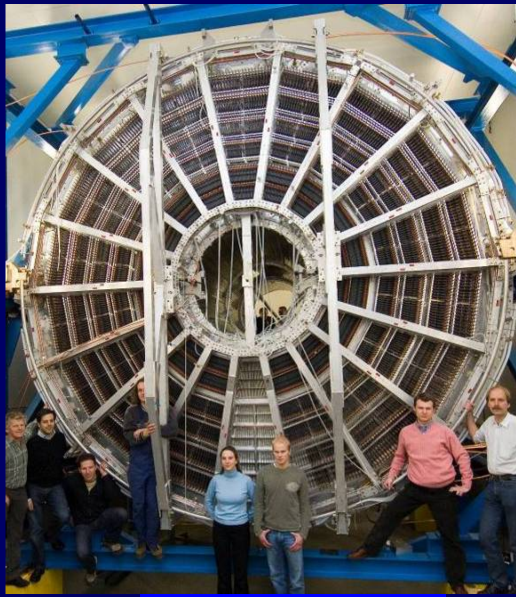
- installed and commissioned

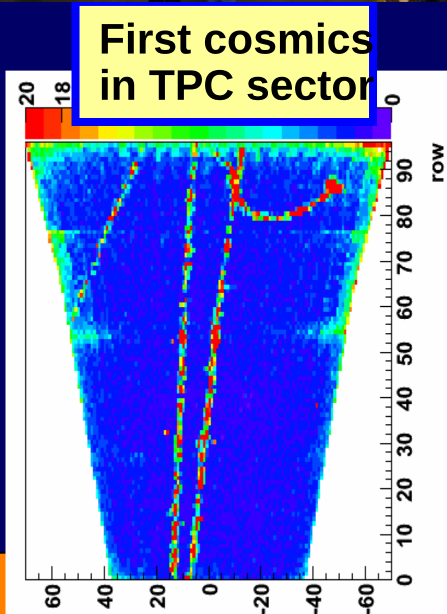
Detector Construction

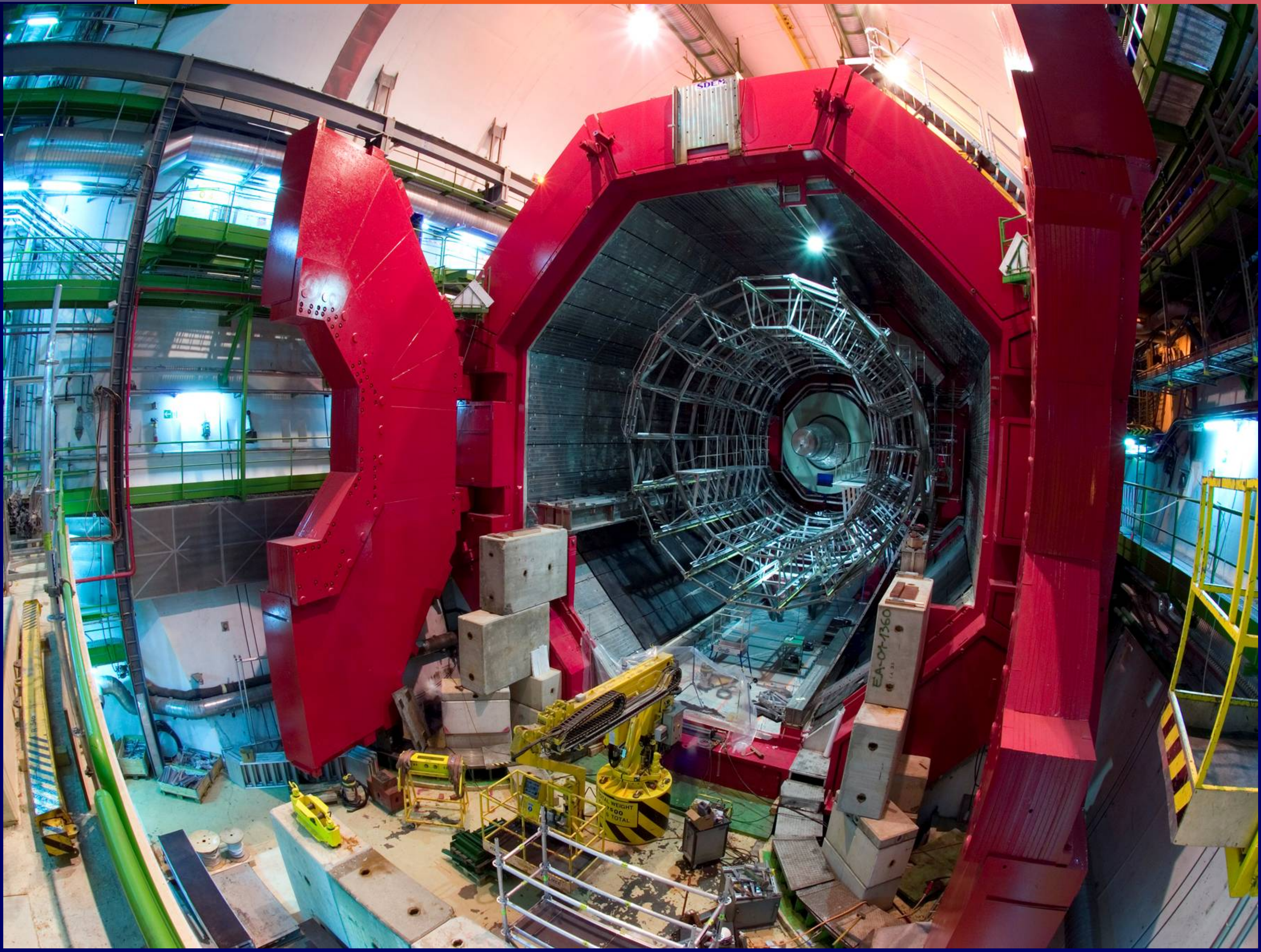
- **completed:** TPC, HMPID, PHOS, ZDC, Muon trigger, cosmic trigger array
- **nearing completion:** Muon tracking, TOF, TRD, ITS, forward (V0, T0, PMD, FMD)
  - **critical path: Silicon Vertex Detector (ITS)**

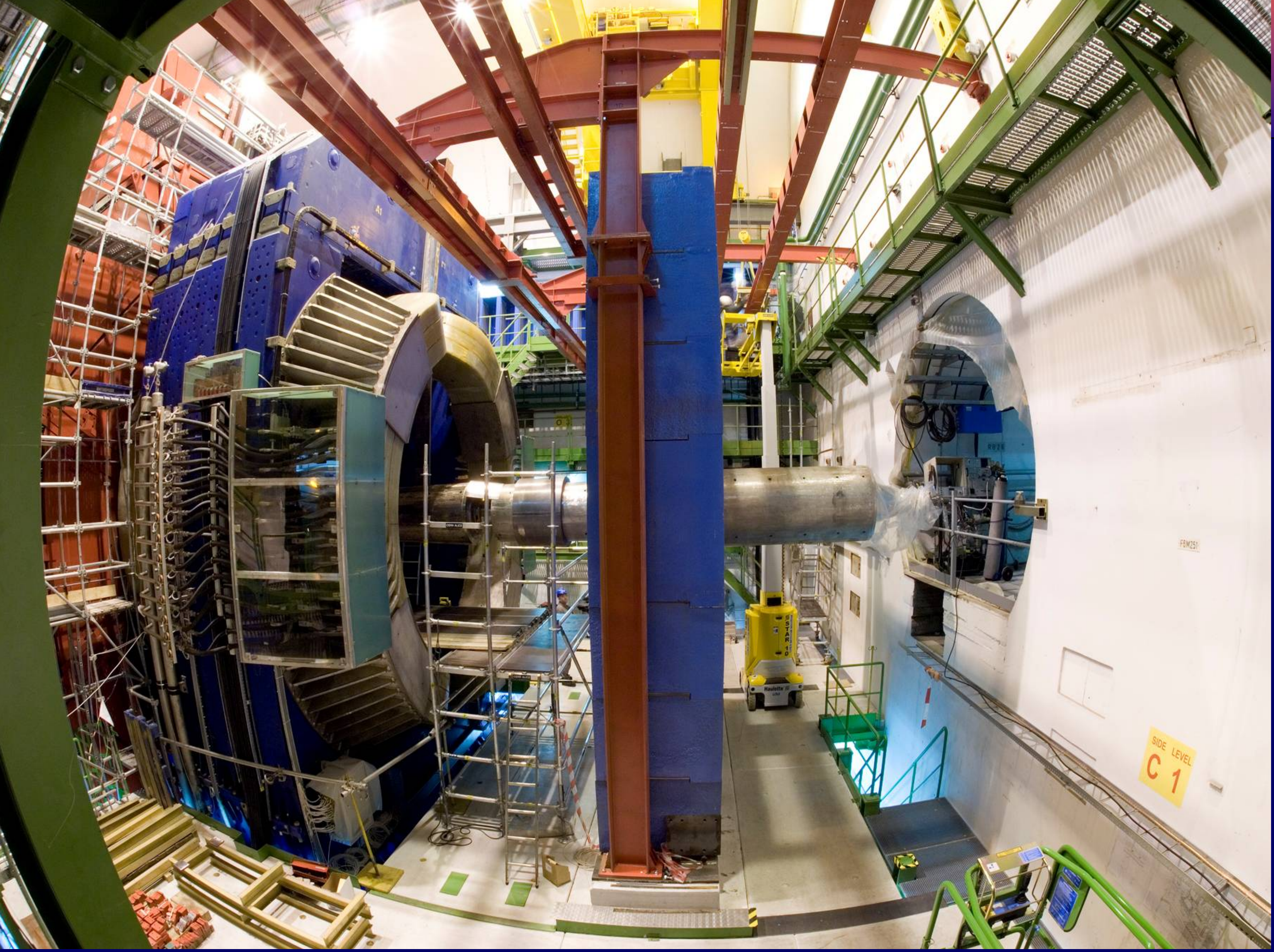
Detector Installation

- **precomissioning** of all detectors **on surface,** started
- **Installation:**
  - **Muon Spectrometer:** June 06 to March 07
  - **Central Barrel:** Sept. 06 to April 07
- **Installation after summer 2007**: parts of TRD, TOF, PHOS






SDEM
EA-04-1360
TOTAL WEIGHT

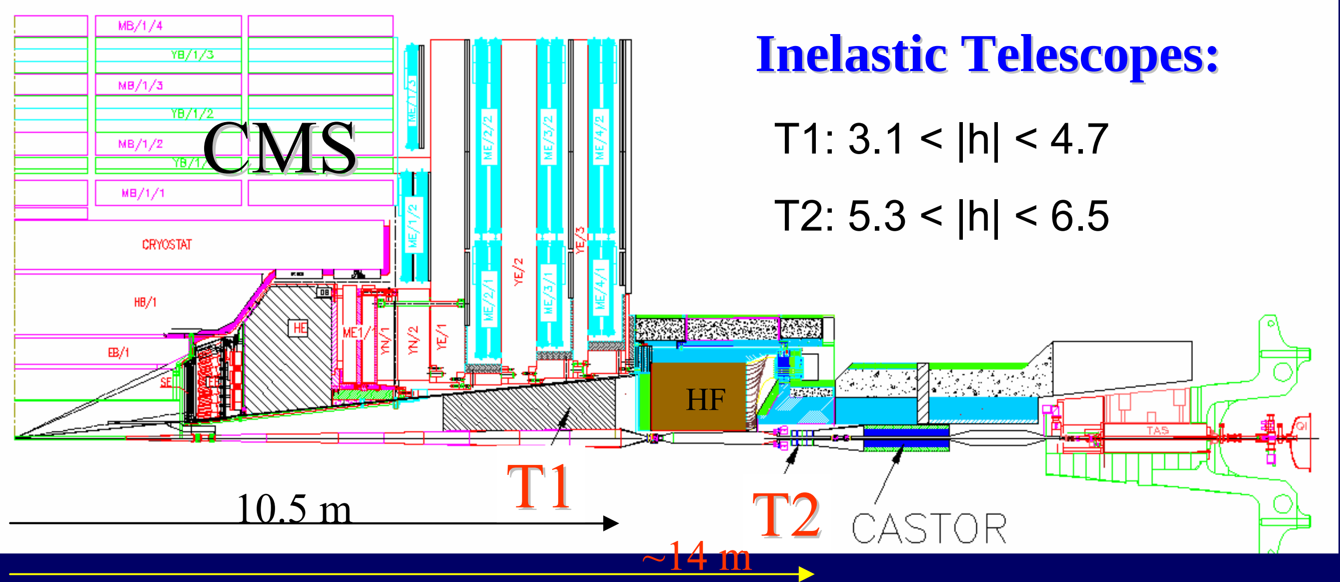

SIDE LEVEL
C 1

TOTEM Detectors

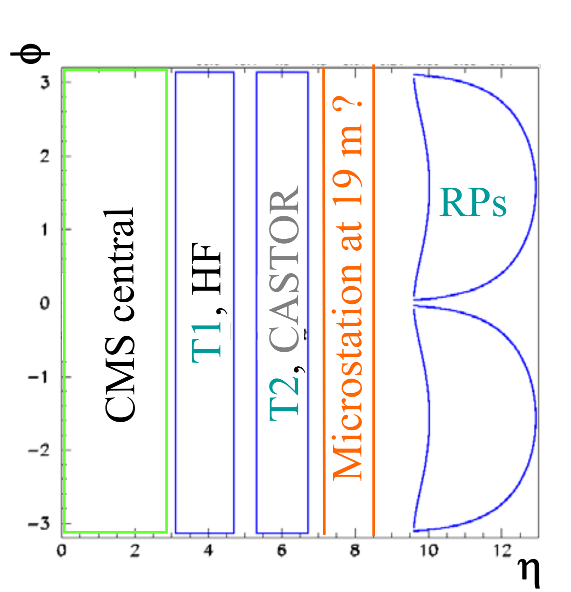
Inelastic Telescopes:

T1: 3.1 < |h| < 4.7

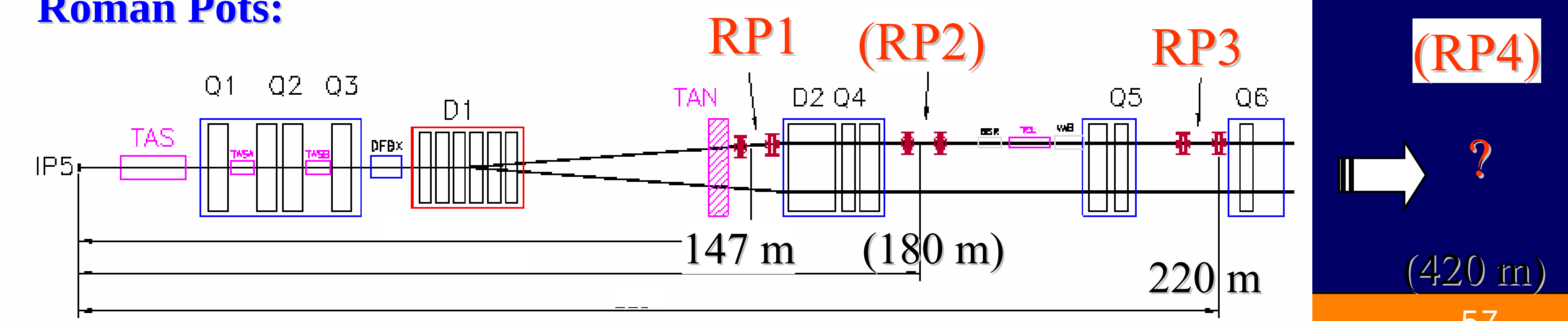
T2: 5.3 < |h| < 6.5



Acceptance:



Roman Pots:



Physics

Which physics the first year(s) ?

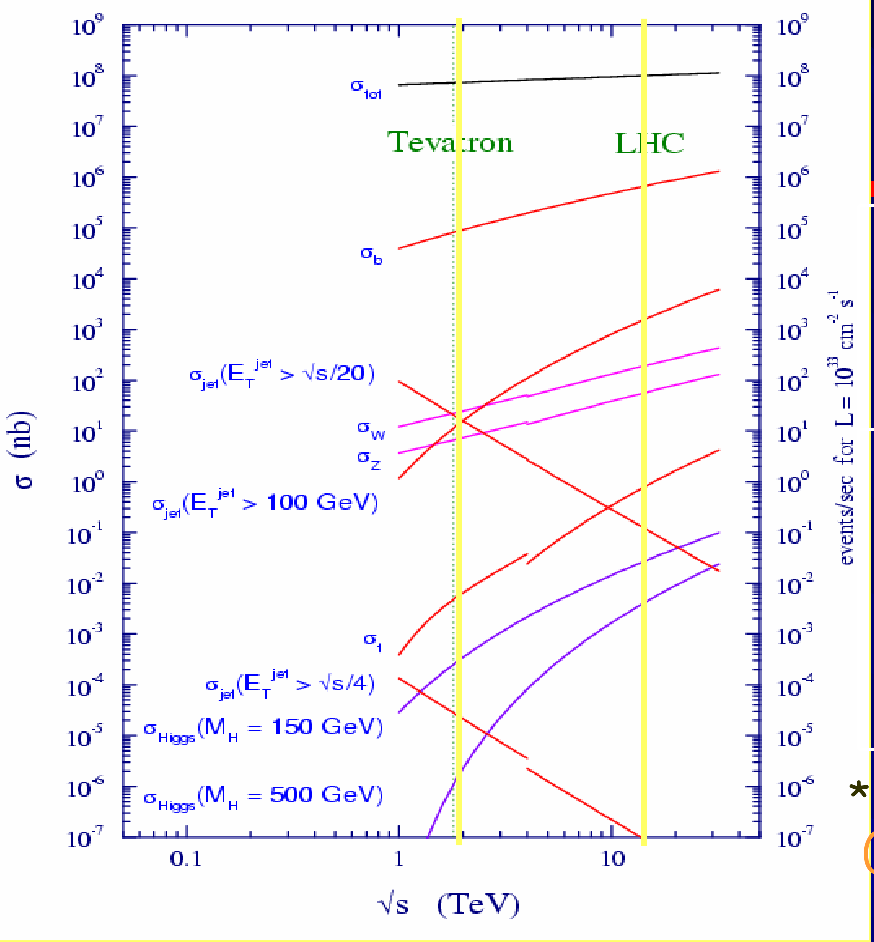
Expected event rates at production in ATLAS or CMS at $L = 10^{33}\ cm^{-2}\ s^{-1}$

Process	Events/s	Events for 10 fb^{-1}	Total statistics collected at previous machines by 2007
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tevatron
$Z \to ee$	1.5	10^7	10^7 LEP
t tbar	1	10^7	10^4 Tevatron
b bbar	10^6	10^{12} - 10^{13}	10^9 Belle/BaBar
H m=130 GeV	0.02	10^5	?
gluino gluino m= 1 TeV	0.001	10^4	---
Black holes m > 3 TeV (M_D=3 TeV, n=4)	0.0001	10^3	---

Already in first year, large statistics expected from:

-- known SM processes $\to$ understand detector and physics at $\sqrt{s}$ = 14 TeV

-- several New Physics scenarios



Implications for light Higgs

(assuming the same luminosity/detector/analysis)

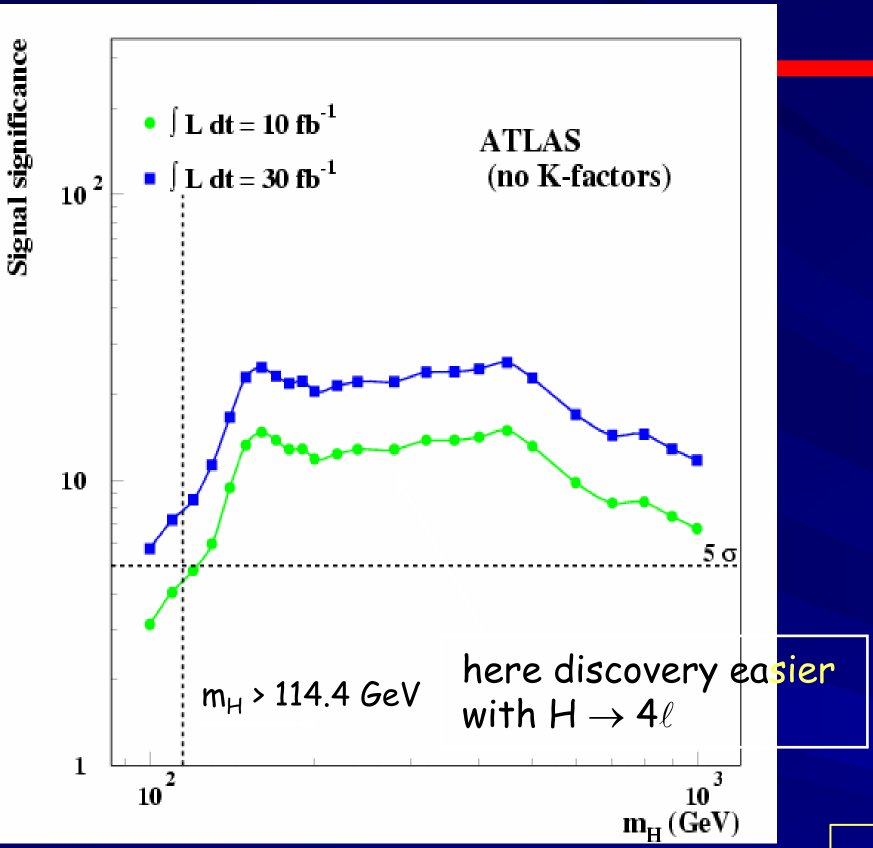
	$qq \rightarrow WH \rightarrow \ell\nu\, bb$ $qq \rightarrow ZH \rightarrow \ell\ell\, bb$ m_H=120 GeV	$gg \rightarrow H \rightarrow WW \rightarrow \ell\nu\, \ell\nu$ m_H=160 GeV
S(14)/S(2)	≈ 5*	≈ 30
B(14)/B(2)	≈ 25	≈ 6
S/B(14)/S/B(2)	≈ 0.2	≈ 3
S/√B(14)/ S/√B(2)	≈ 1	≈ 7

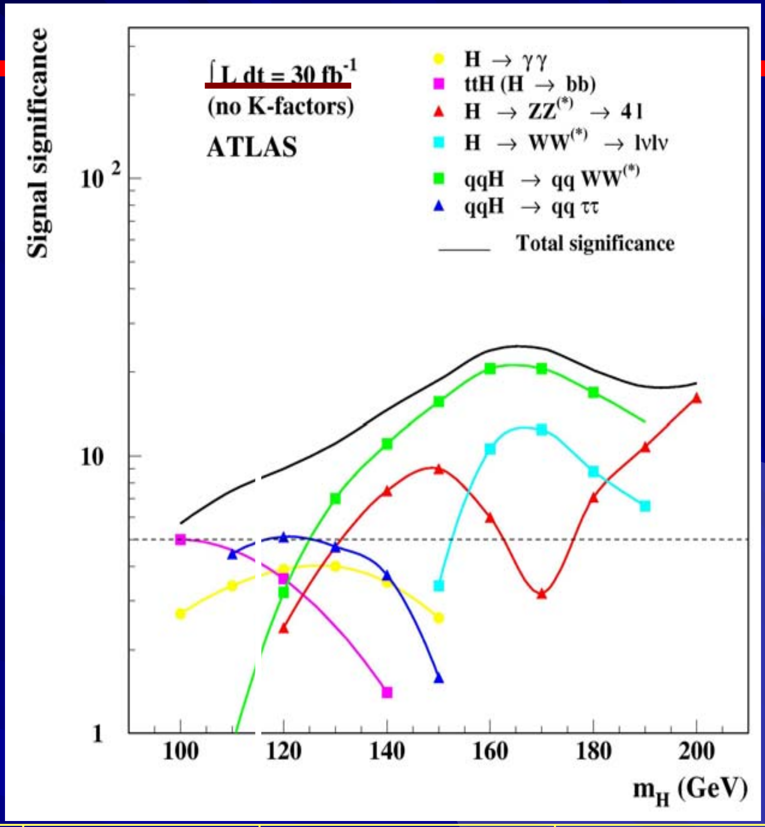
*Acceptance ~ 2 times larger at Tevatron (physics is more central, less initial-state g radiation)

EW cross-sections (e.g. $qq \rightarrow$ W, Z, WH) :
LHC/Tevatron ~ 10
QCD cross-sections (e.g. tt, $gg \rightarrow$ H) :
LHC/Tevatron ≥ 100 (because of gluon PDF) → cf HERA results

e/jet ~ 10^{-3} $\sqrt{s}$ = 2 TeV
e/jet ~ 10^{-5} $\sqrt{s}$ = 14 TeV
} p_T > 20 GeV

Standard Model Higgs





$m_H \sim 115$ GeV $\quad 10\ fb^{-1}$

total $S/\sqrt{B} \approx 4^{+2.2}_{-1.3}$

ATLAS	$H \to \gamma\gamma$	$ttH \to ttbb$	$qqH \to qq\tau\tau$ ($\ell\ell$ + ℓ-had)
S B	130 4300	15 45	~ 10 ~ 10
$S/\sqrt{B}$	2.0	2.2	~ 2.7

$K-\text{factor} \equiv \frac{\sigma_{NLO}}{\sigma_{LO}} \approx 2$ not included

Full GEANT simulation, simple cut-based analyses

Conclusions

The LHC detectors are almost ready to meet the challenge they were designed to meet

LHC represents the ‘next step’ in high energy physics, a crucial step

The coming years will be very exciting!