LHC

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Outline

- The Accelerator
- General purpose detectors: ATLAS, CMS
- Specialized detectors: ALICE, LHCb

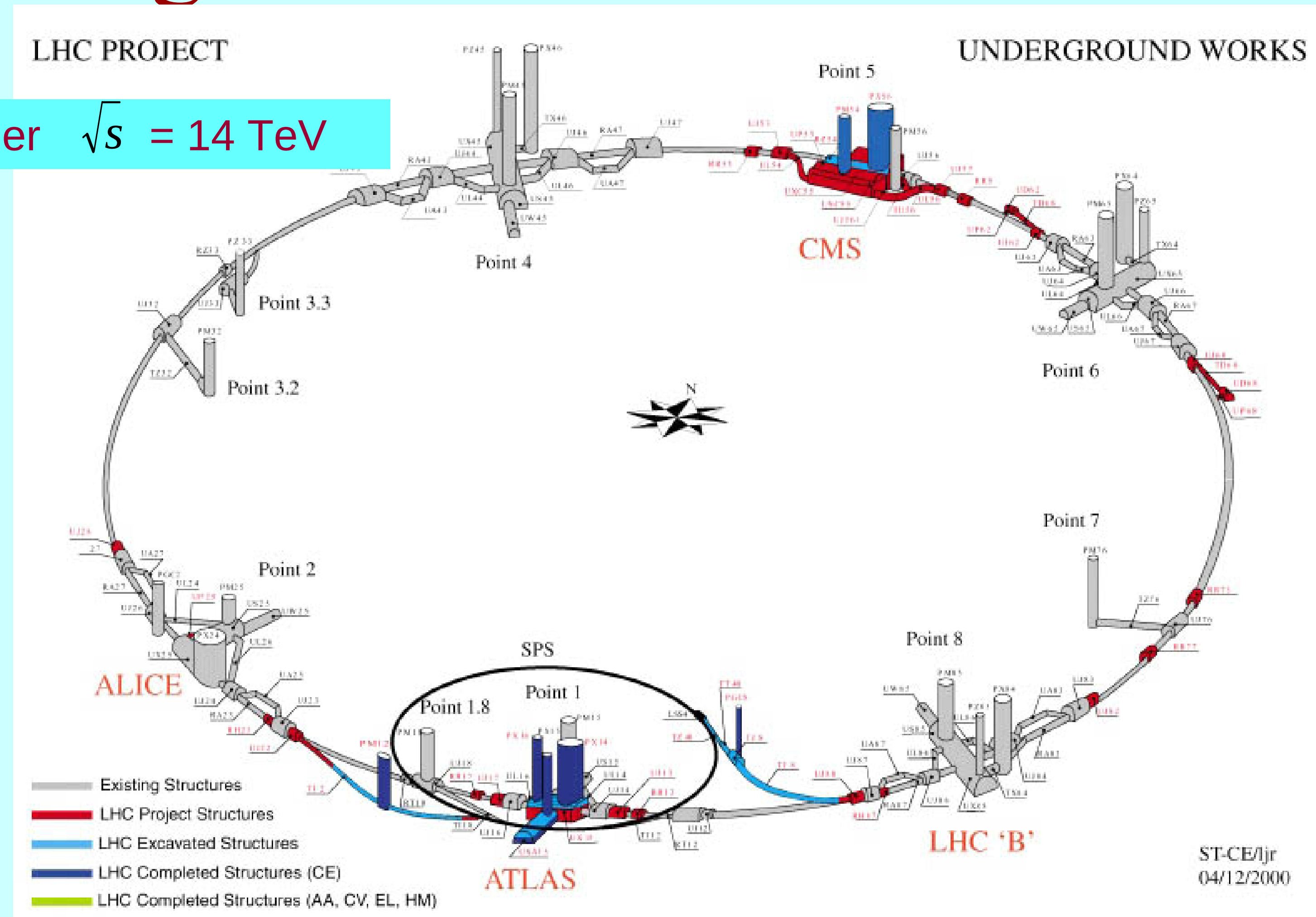
Physics Motivation

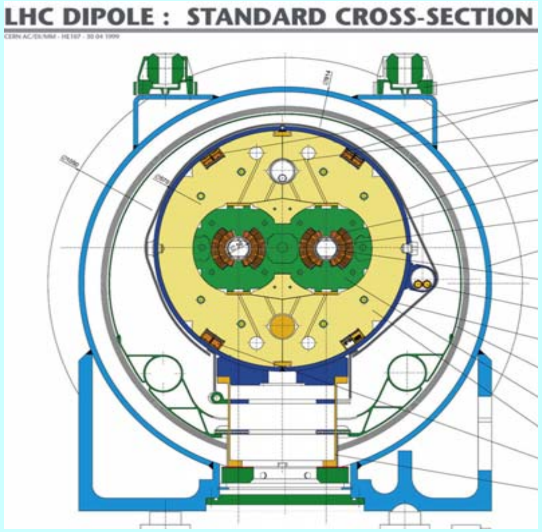
- Symmetry Breaking sector: Higgs, Technicolor – other
- Standard model tests: QCD, electroweak
- Exotic matter: extra dimensions, gauge bosons, Supersymmetry (dark matter?)
- CP violation in the B sector
- Quark-gluon Plasma

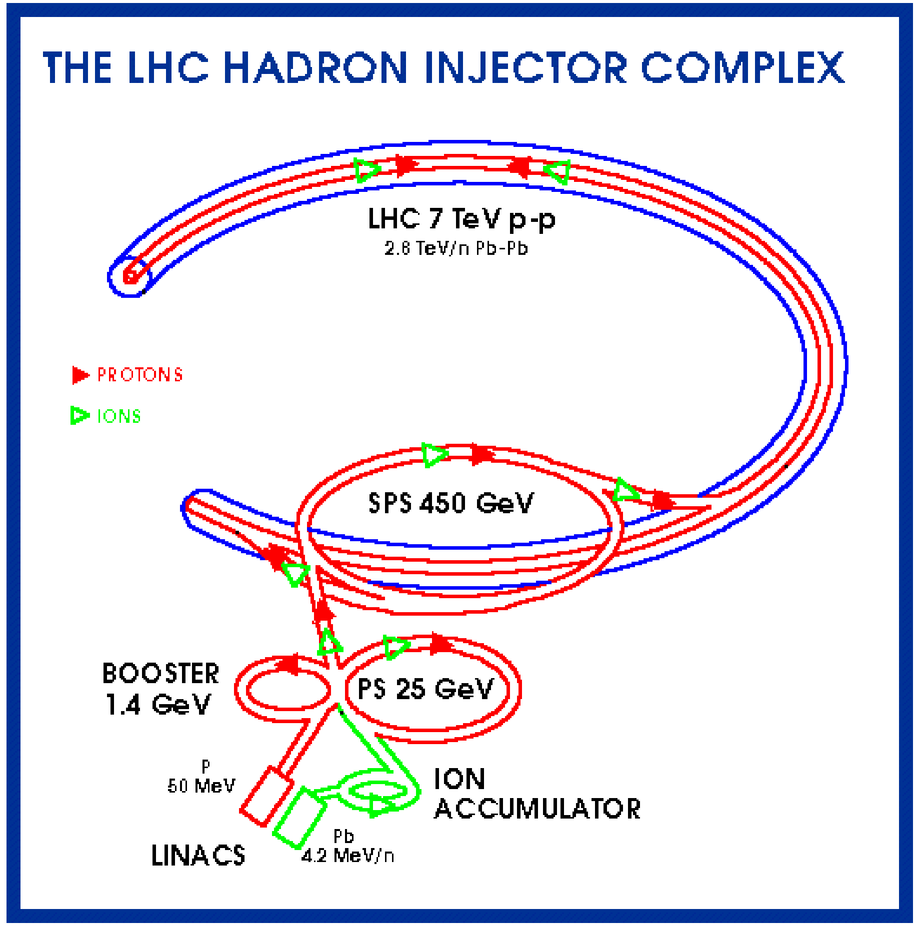
The Large Hadron Collider

Large Hadron Collider at CERN

pp collider $\sqrt{s}$ = 14 TeV







Dipole field: 8.33 T

P-P collisions $\sqrt{s} = 14 TeV$

Bunch spacing 25 nsec

Stored energy/beam 350 MJ

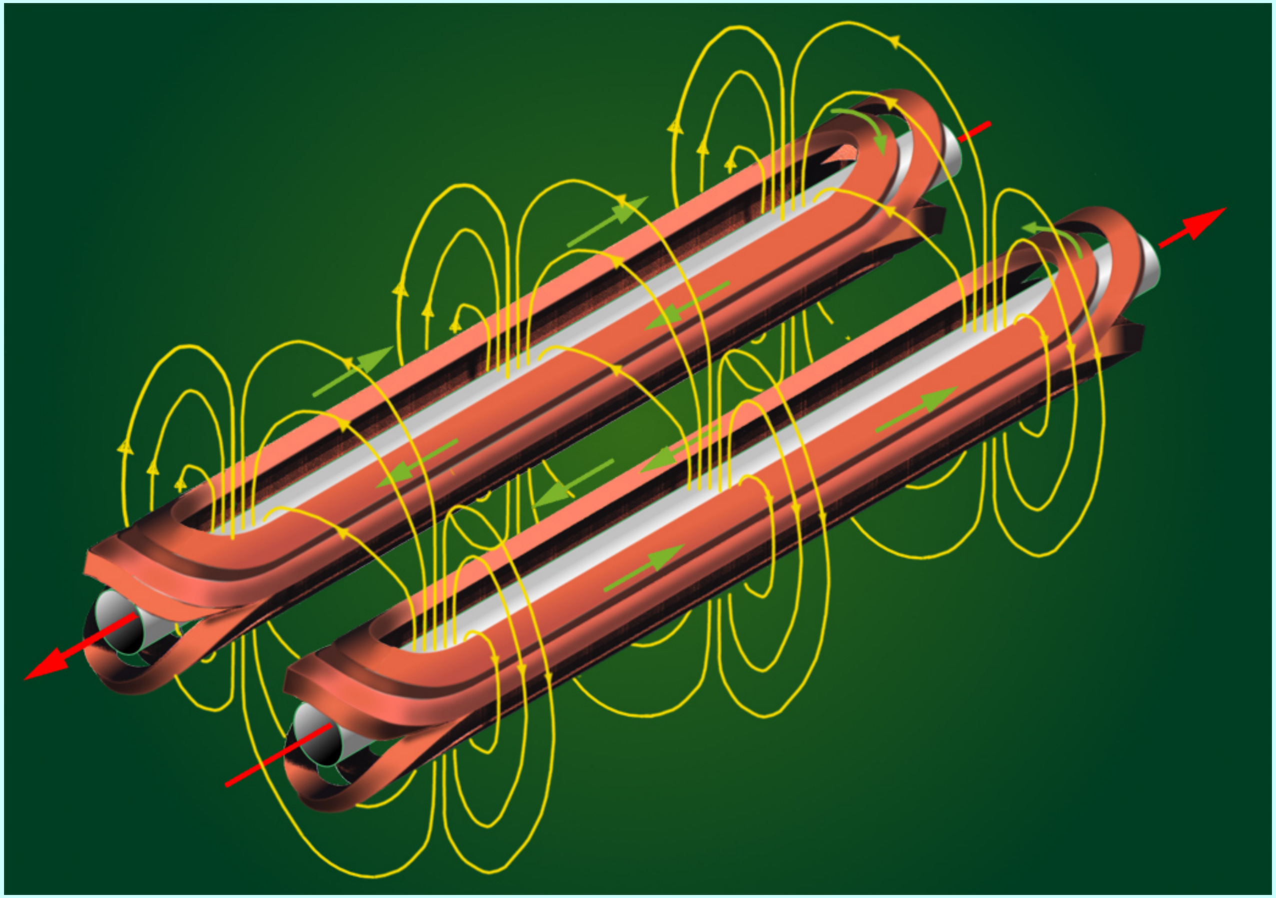
Initial Luminosity $10^{33}\ cm^{-2}\ \sec^{-1}$

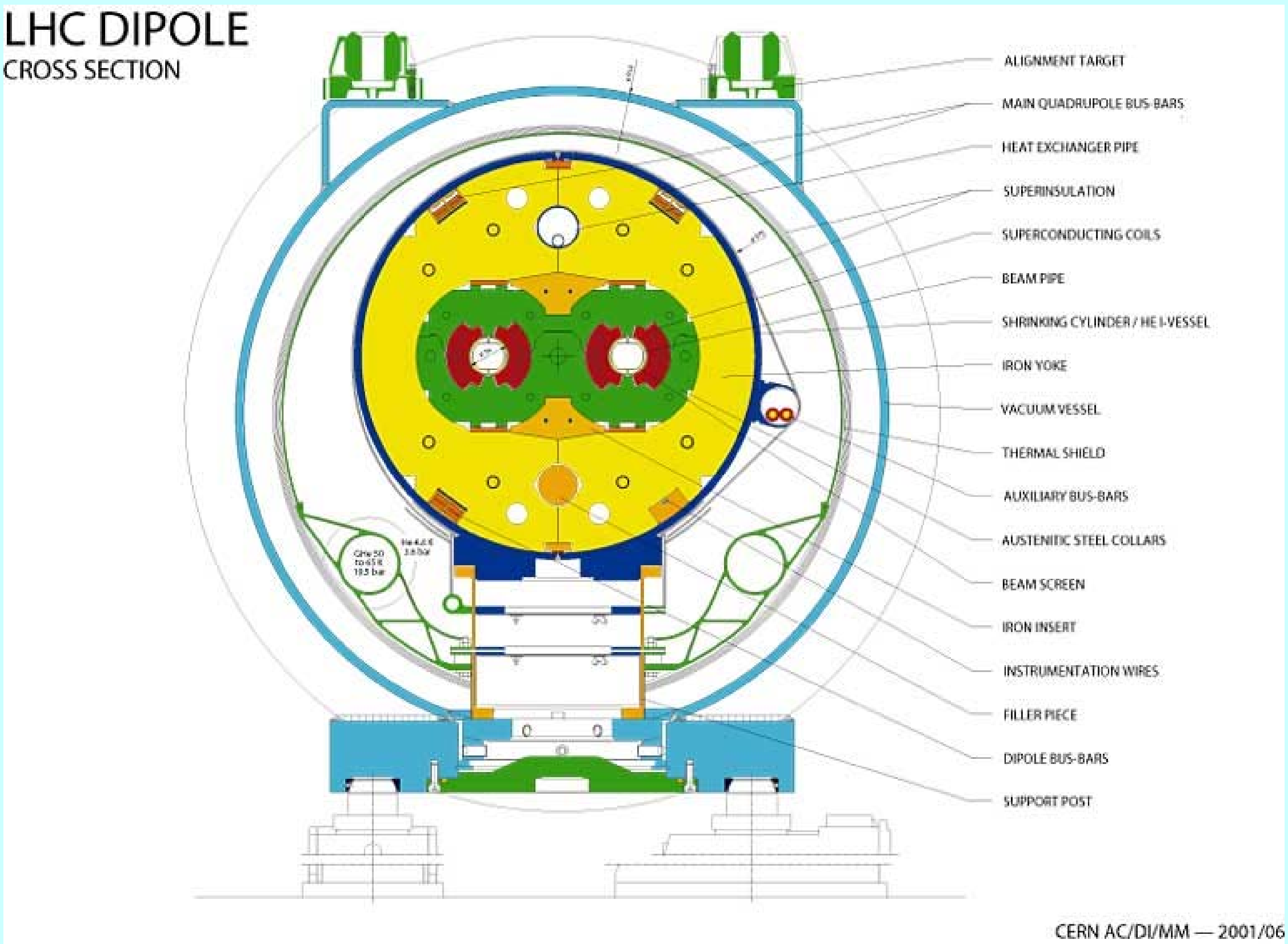
Ultimate Luminosity $10^{34}\ cm^{-2}\ \sec^{-1}$

Accelerator Challenges

- High luminosity
  - 2835 bunches, 10^{11} protons/bunch
- Beam-beam effects (limits bunch density)
- Collective instabilities (wake fields)
- Beam lifetime
- Quench protection (high stored energy)
- Synchrotron radiation (heat load on cryo)

Dipole Configuration

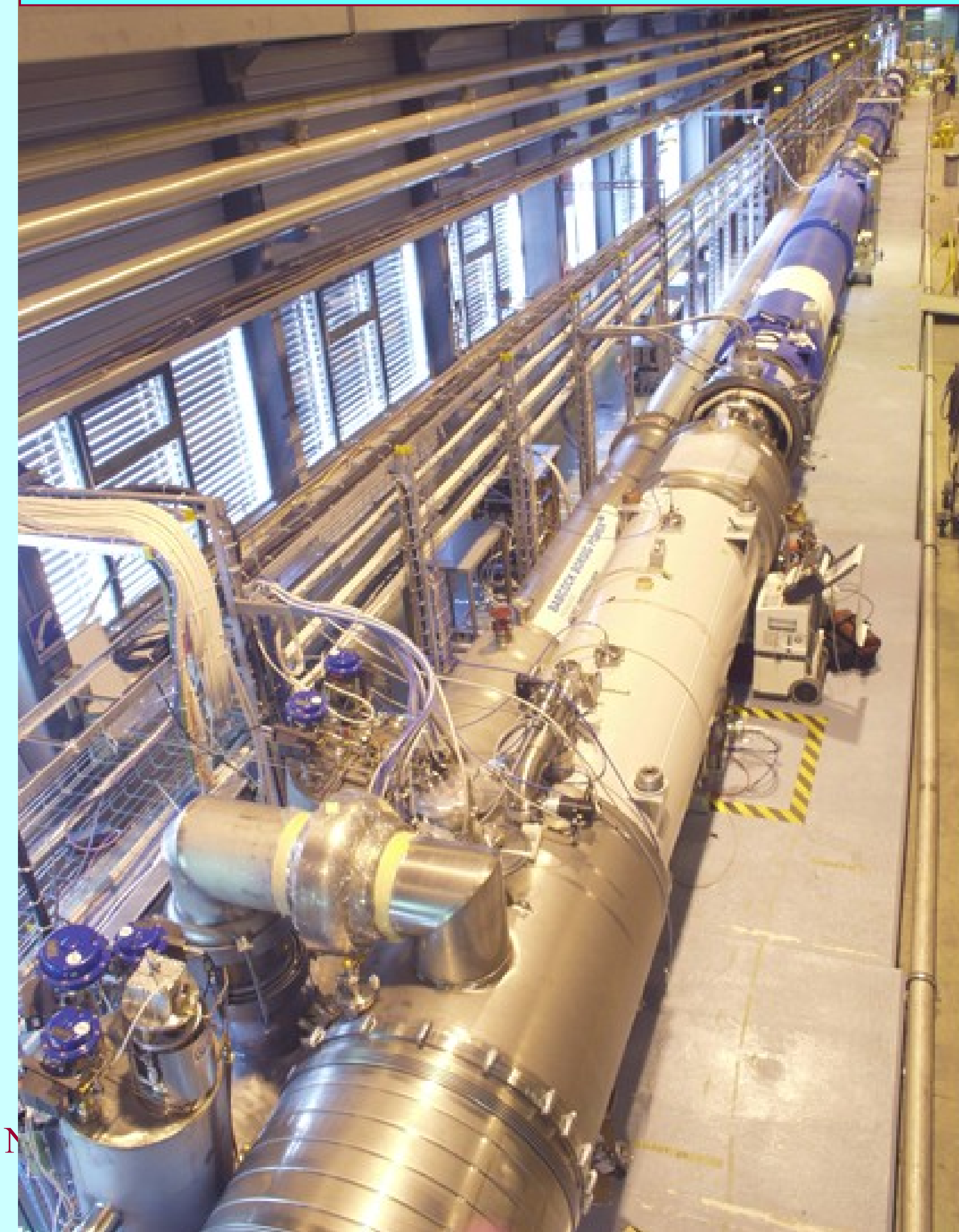



LHC DIPOLE
CROSS SECTION
ALIGNMENT TARGET
MAIN QUADRUPOLE BUS-BARS
HEAT EXCHANGER PIPE
SUPERINSULATION
SUPERCONDUCTING COILS
BEAM PIPE
SHRINKING CYLINDER / HE I-VESSEL
IRON YOKE
VACUUM VESSEL
THERMAL SHIELD
AUXILIARY BUS-BARS
AUSTENITIC STEEL COLLARS
BEAM SCREEN
IRON INSERT
INSTRUMENTATION WIRES
FILLER PIECE
DIPOLE BUS-BARS
SUPPORT POST
CERN AC/DI/MM — 2001/06

News from the LHC machine

8.4 Tesla

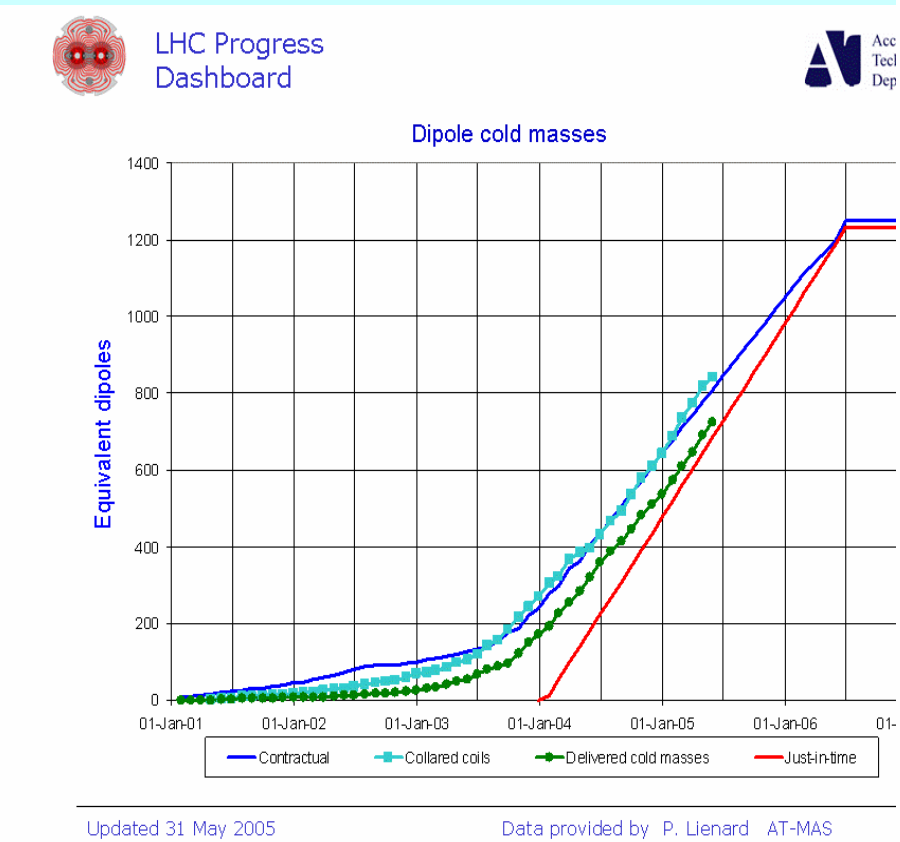
First full LHC cell (~ 120 m long) :
6 dipoles + 4 quadrupoles;
successful tests at nominal current (12 kA)

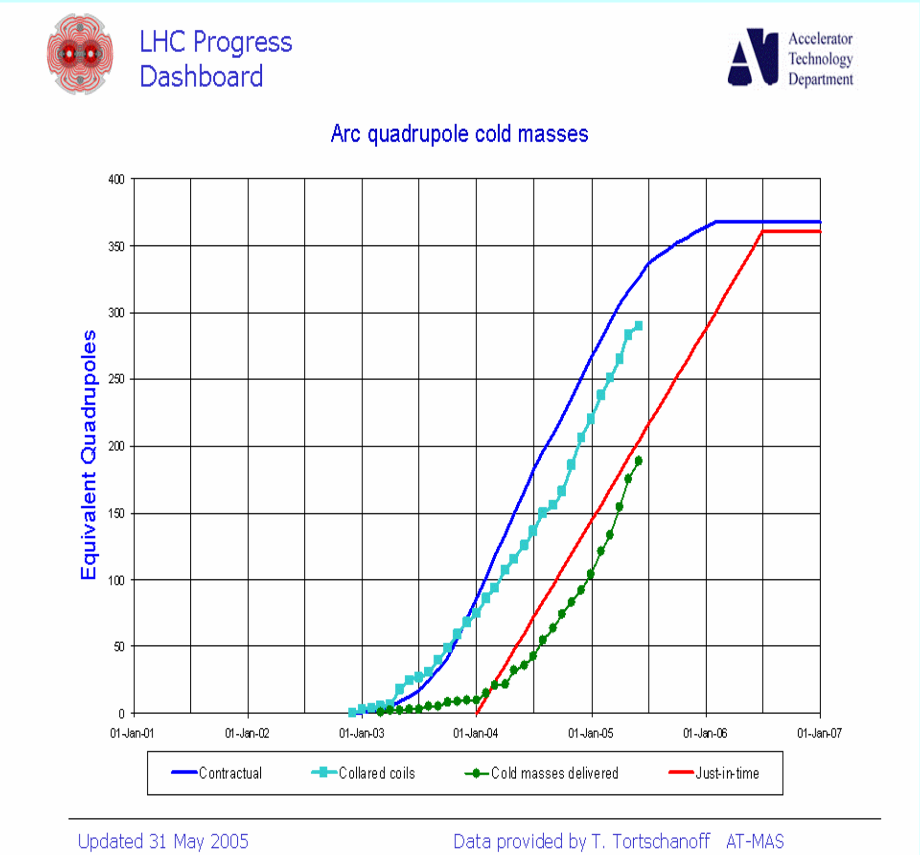


More than half of the 1232 dipoles are produced

Dipoles

Quadrupoles

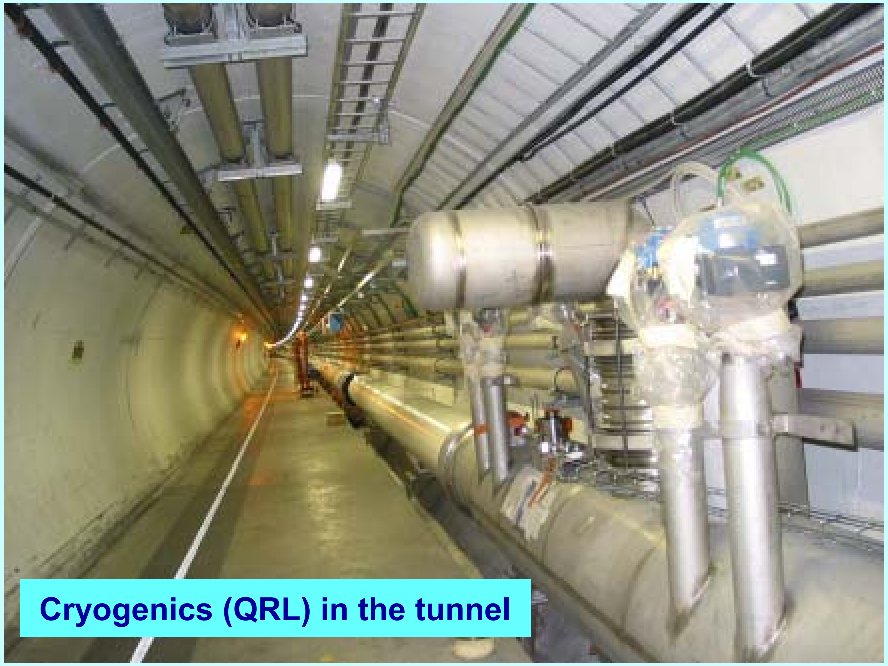




LHC construction and installation

Dipoles ready for installation

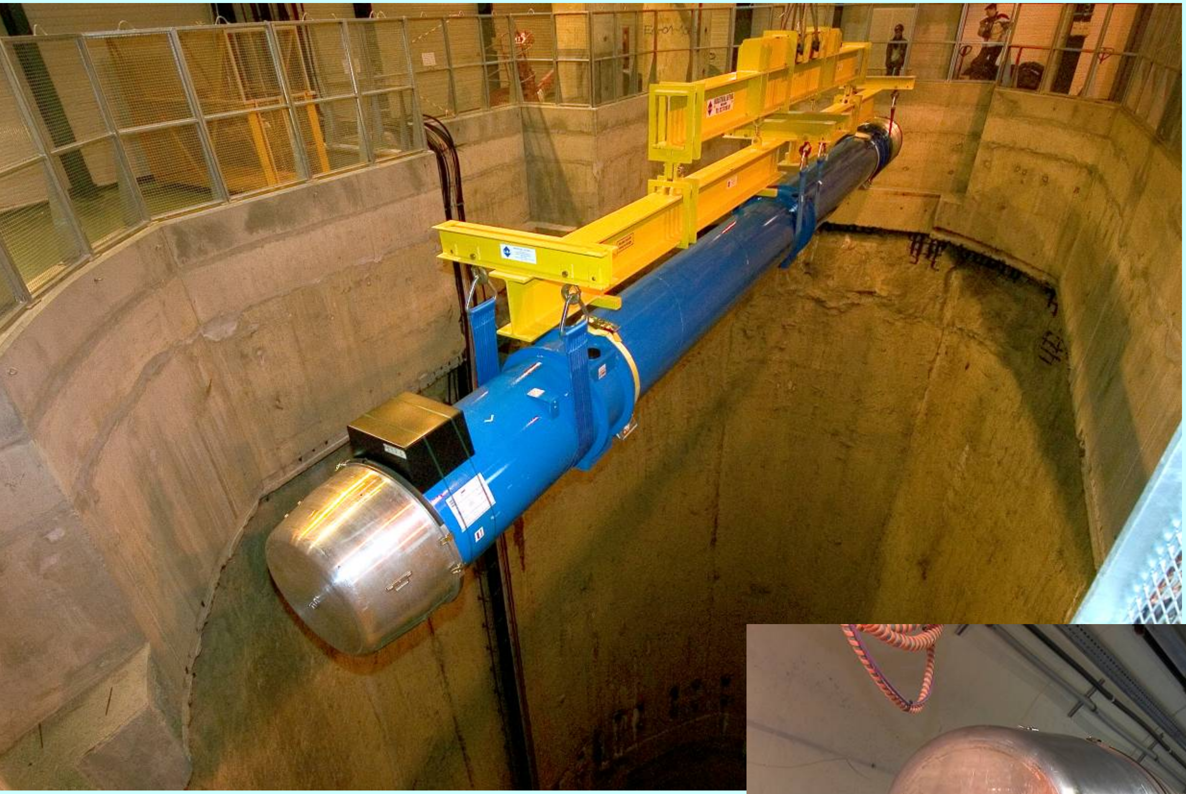
Dipole installation in the tunnel



Cryogenics (QRL) in the tunnel

The magnet production proceeds very well and is on schedule, also the quality of the magnets is very good

On the critical path for the first collisions in Summer 2007 is the installation of the LHC in the tunnel, in particular due to delays in the cryogenic services lines (QRL) which in 2004 had problems, and for which a recovery plan was implemented successfully

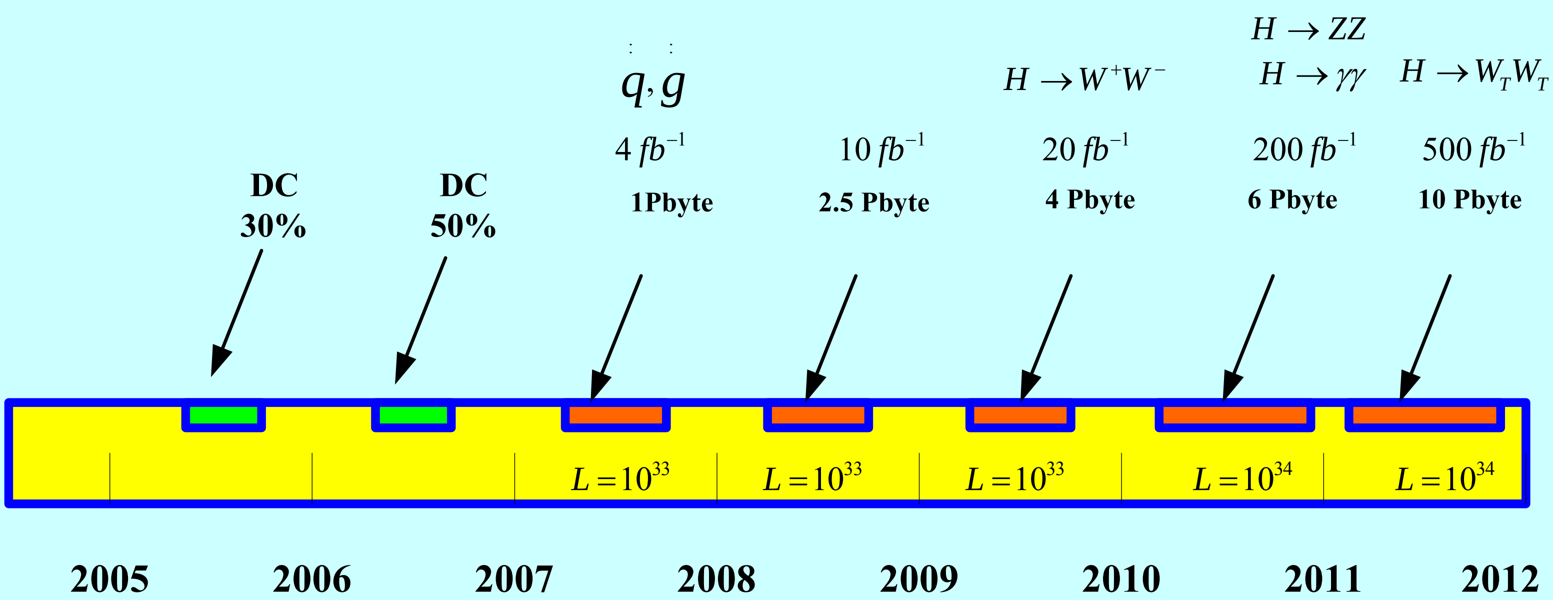


Lowering of the first dipole into the tunnel (March 2005)

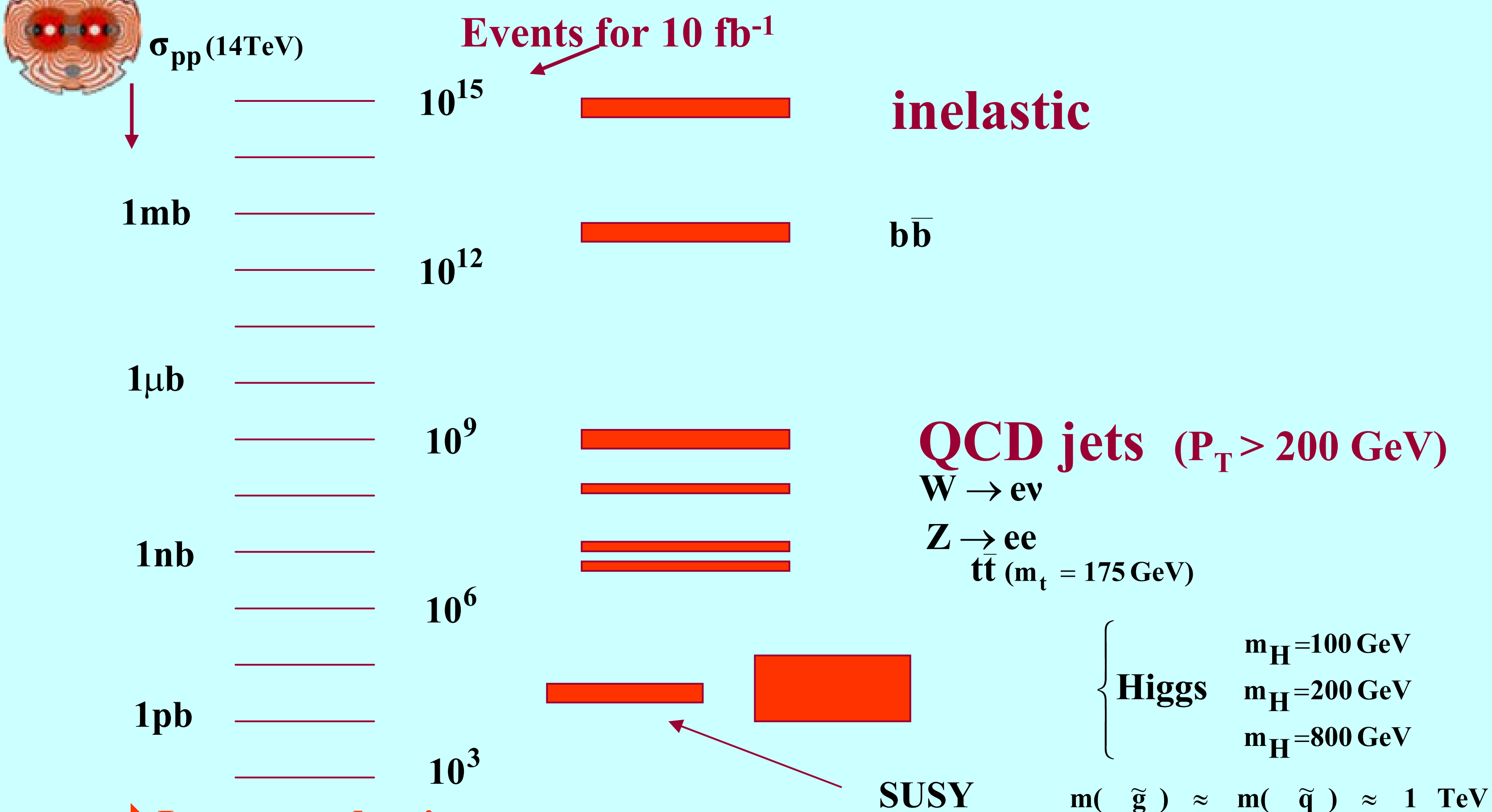
Installation of dipoles in the LHC ring has started

16, Aug, 05

Luminosity Evolution



Cross sections



- Large production rates
  - LHC is a top, b, W, Z factory
- Mass reach for new particles up to TeV range
- Precision measurements dominated by systematics

Major Higgs signals

$H \to \gamma\gamma$

$H \to b\bar{b}$

$H \to ZZ^{(*)} \to l^+l^-l^+l^-$

$H \to WW^* \to l^+\nu l^-\nu$

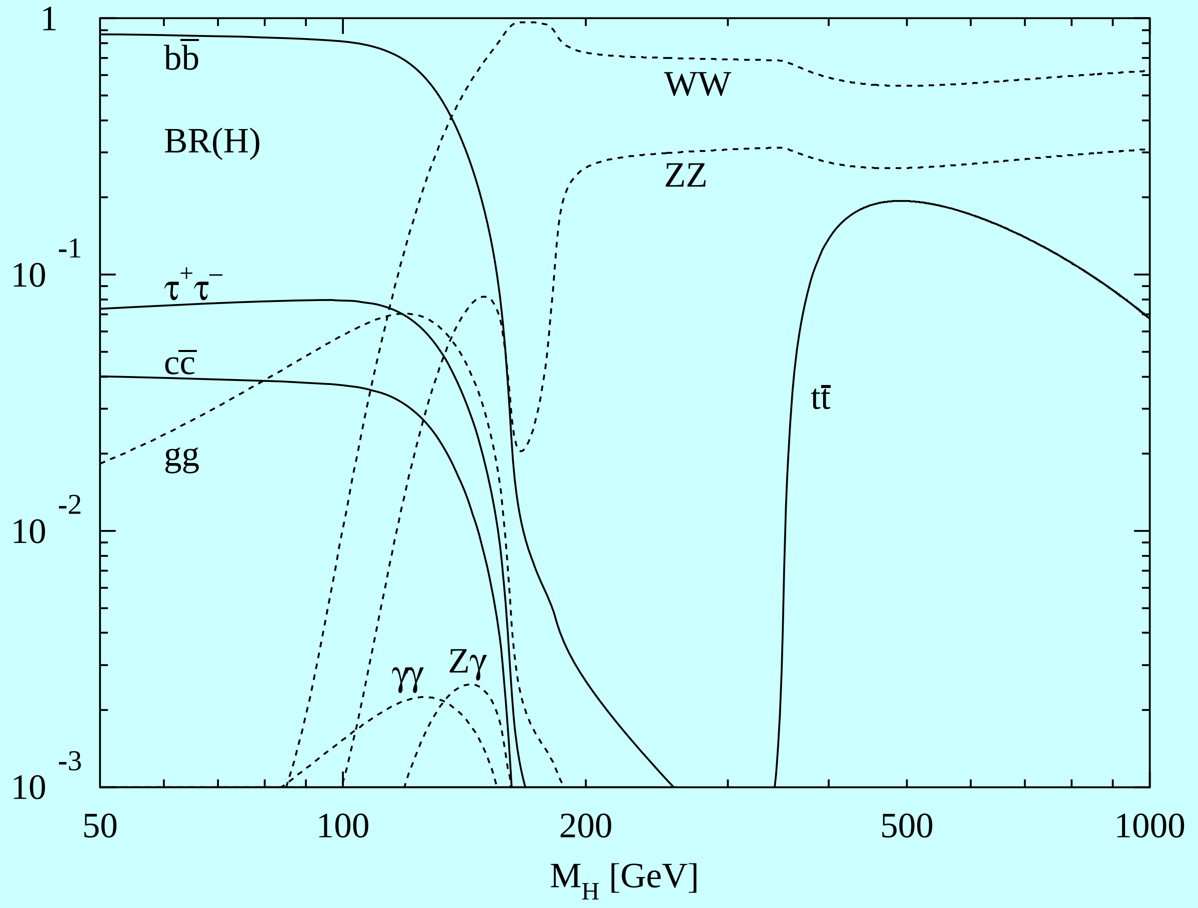
$H \to ZZ \to l^+l^-\nu\nu$

$H \to WW \to l\nu \text{ jet jet}$

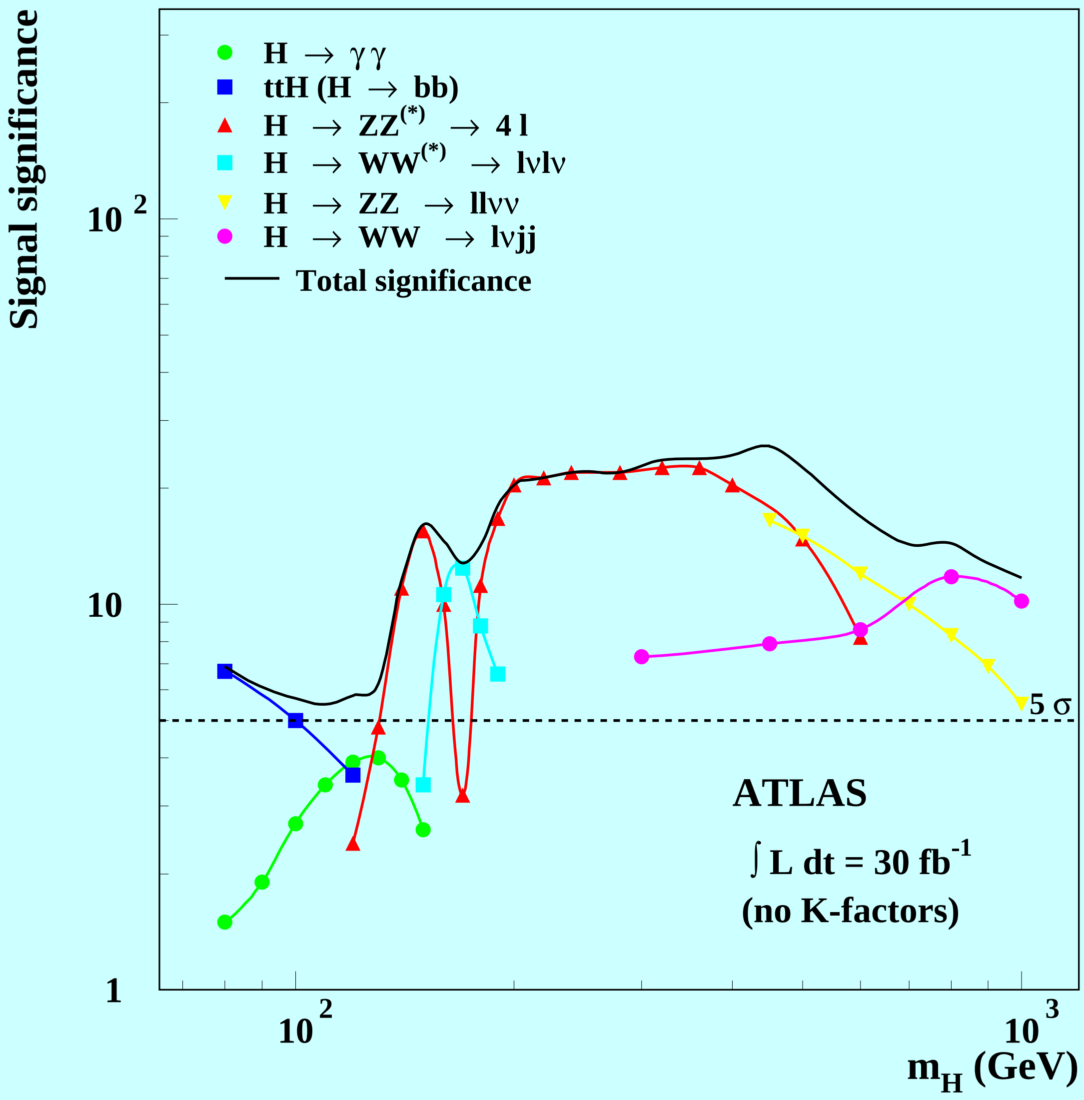
Standard model backgrounds are the largest issues

Detector requirements: B-tagging, lepton ID, photon ID
Jets, missing energy

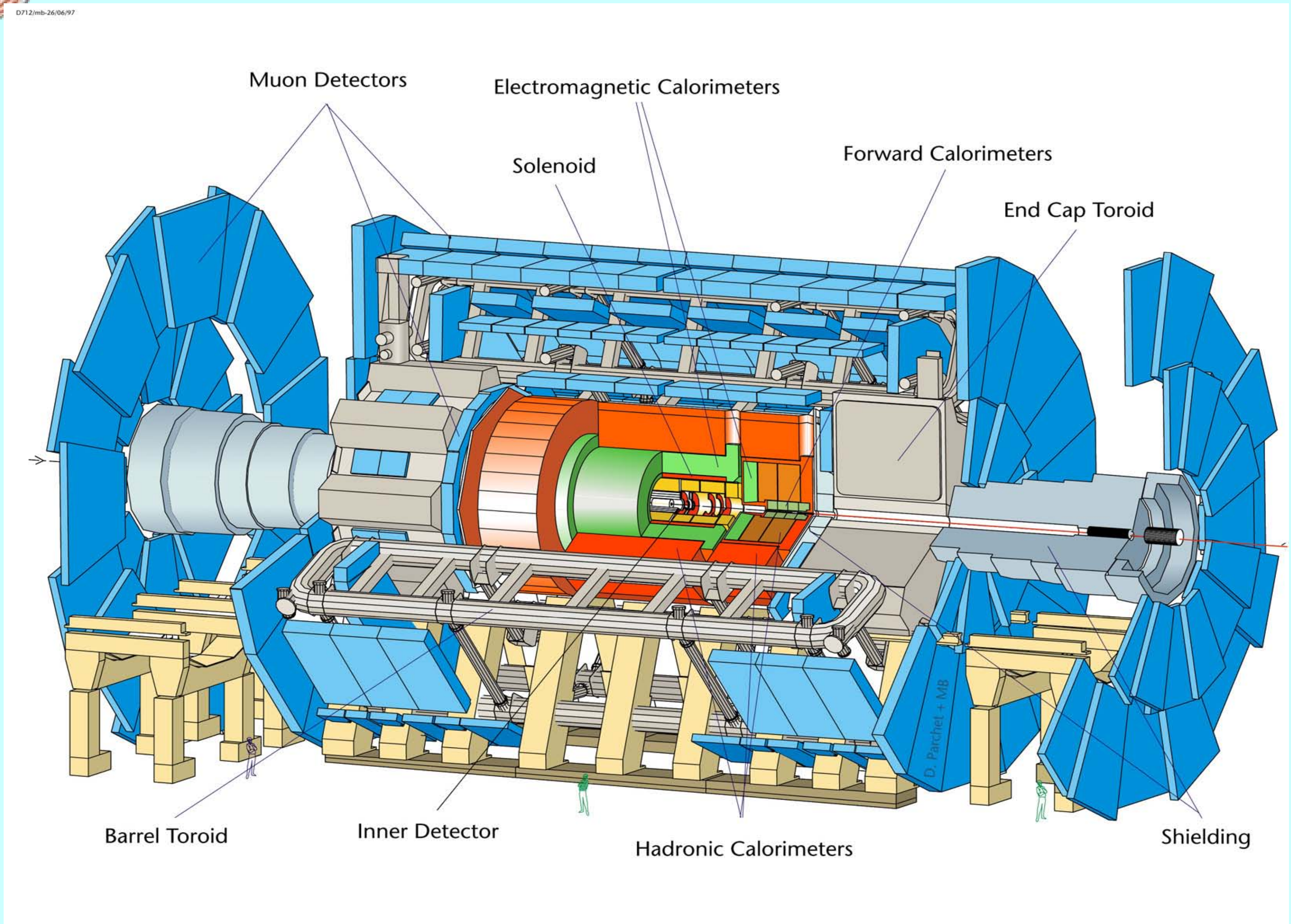
Higgs Decay Branching Fractions



Higgs Sensitivity

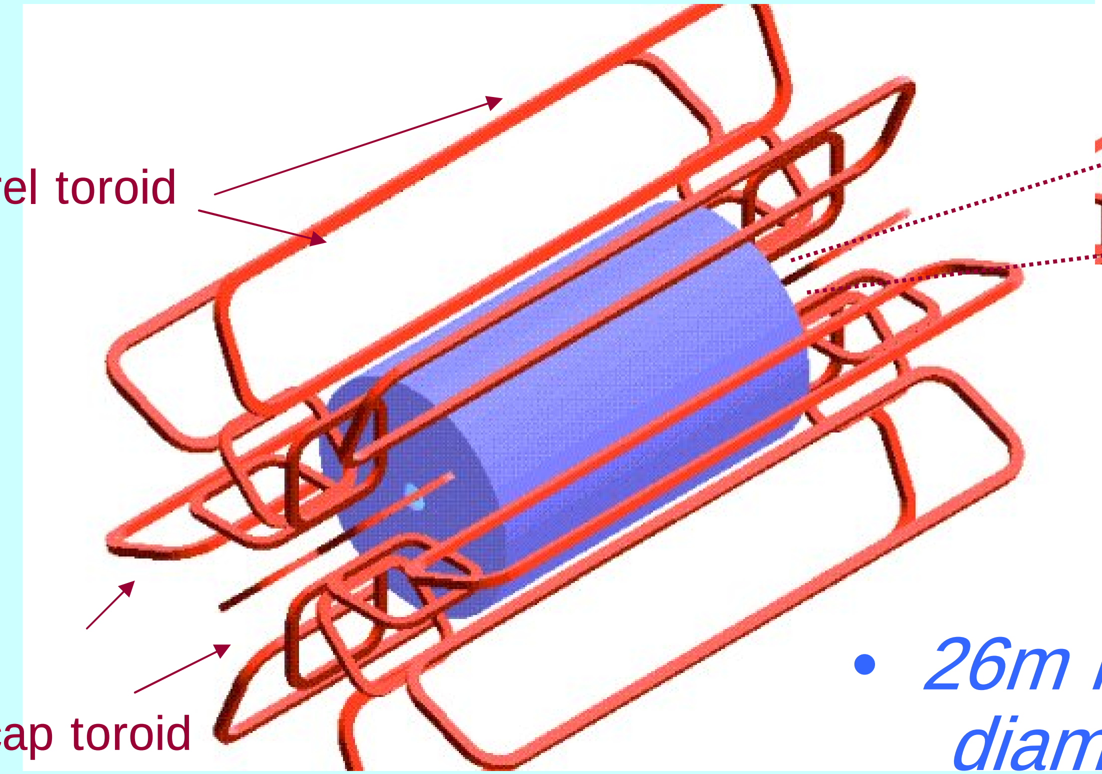


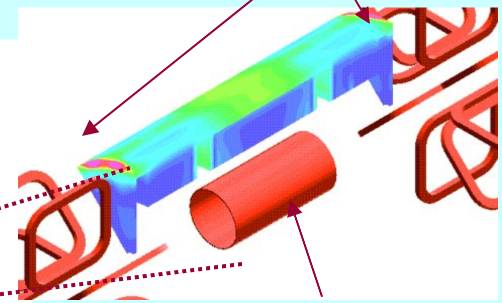
The ATLAS Detector



The ATLAS Magnet System

3 superconducting air core toroids





superconducting solenoid

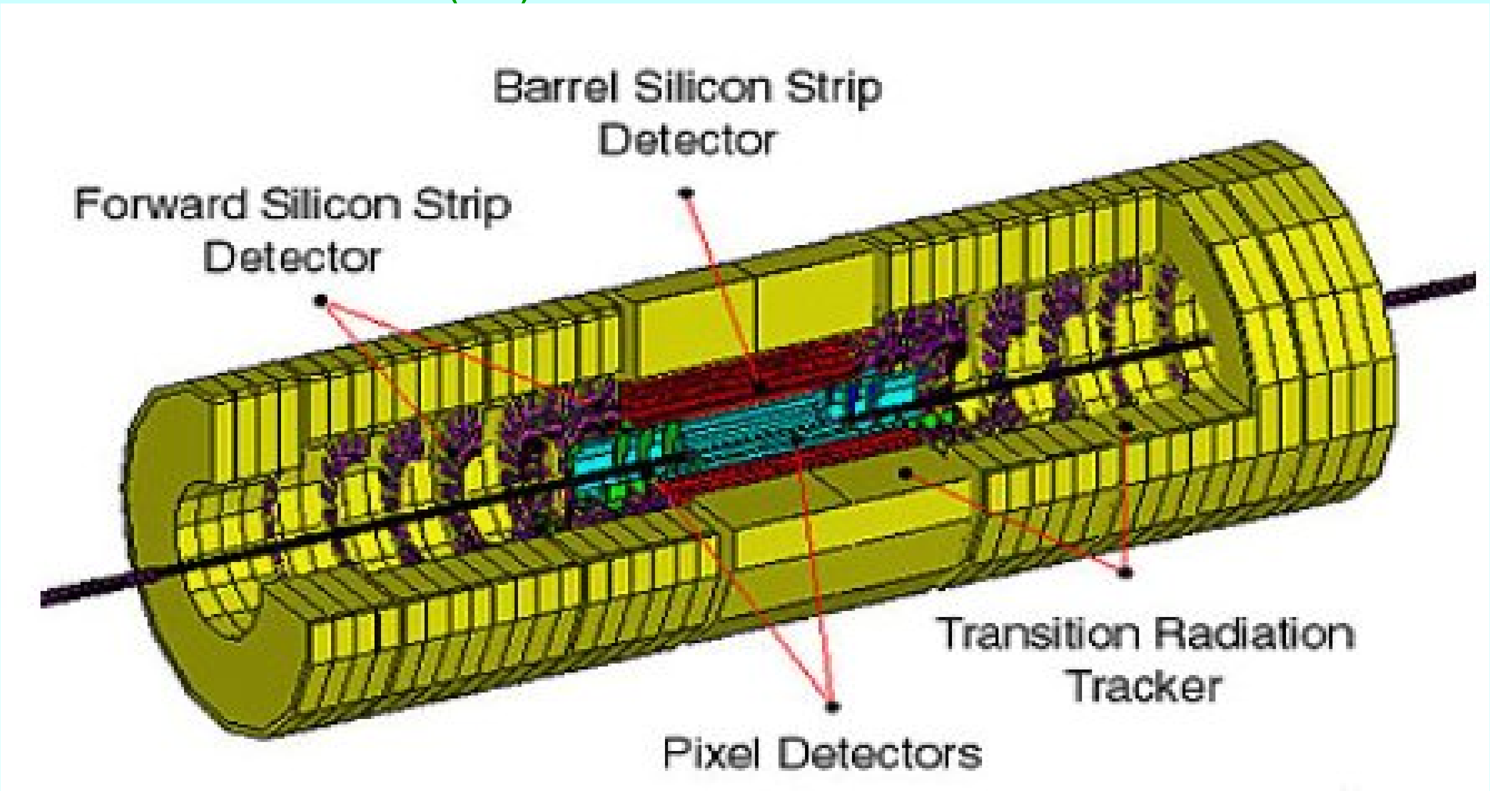
- *26m long, 20m outer diameter 1350 tons*

Barrel Toroid installation

ATLAS Inner Detector

The Inner Detector (ID) is organized into three sub-systems

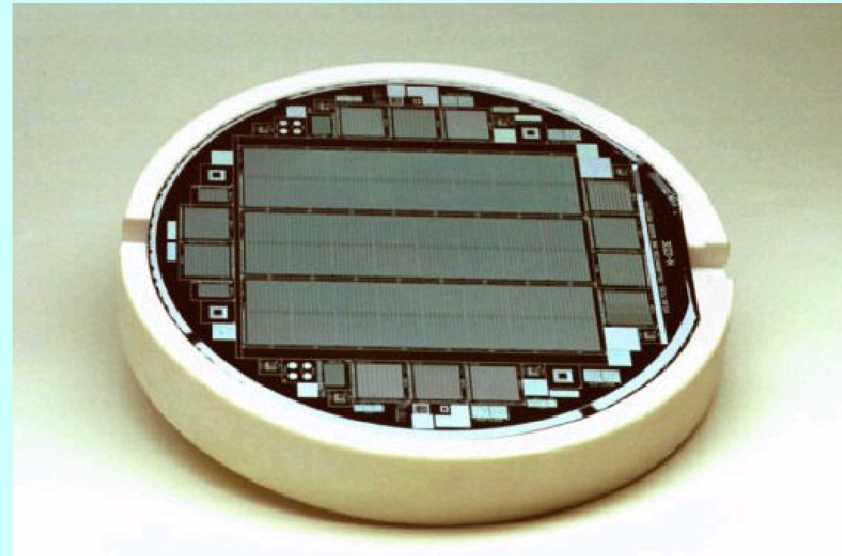
Pixels
Silicon Tracker (SCT)
Transition Radiation Tracker (TRT)



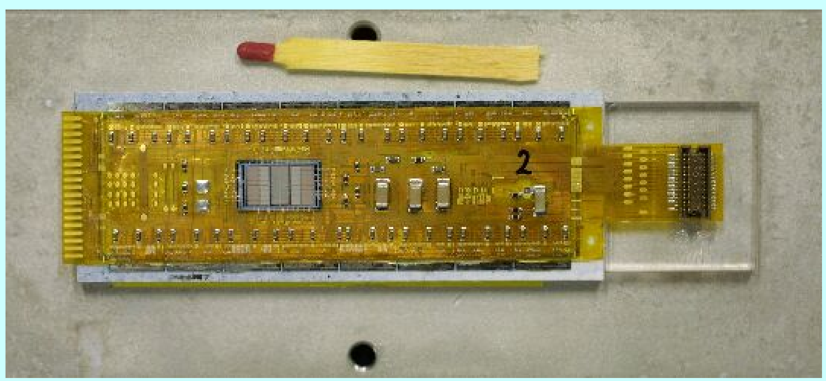
ATLAS ID Pixels

The Pixel sub-system is now designed as a fully independent and insertable detector which enables late installation and facilitates future upgrades

The plan is to start with 2 layers (out of 3) for the first physics run in 2006 which can be met within a tight schedule



Pre-production Pixel sensors

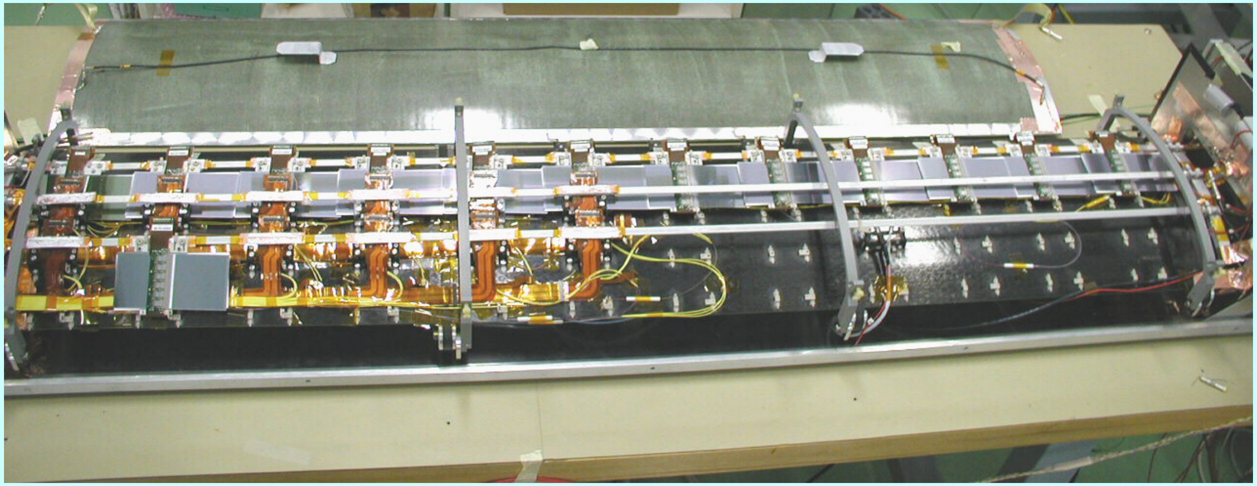


Pre-production Pixel module

ATLAS ID SCT

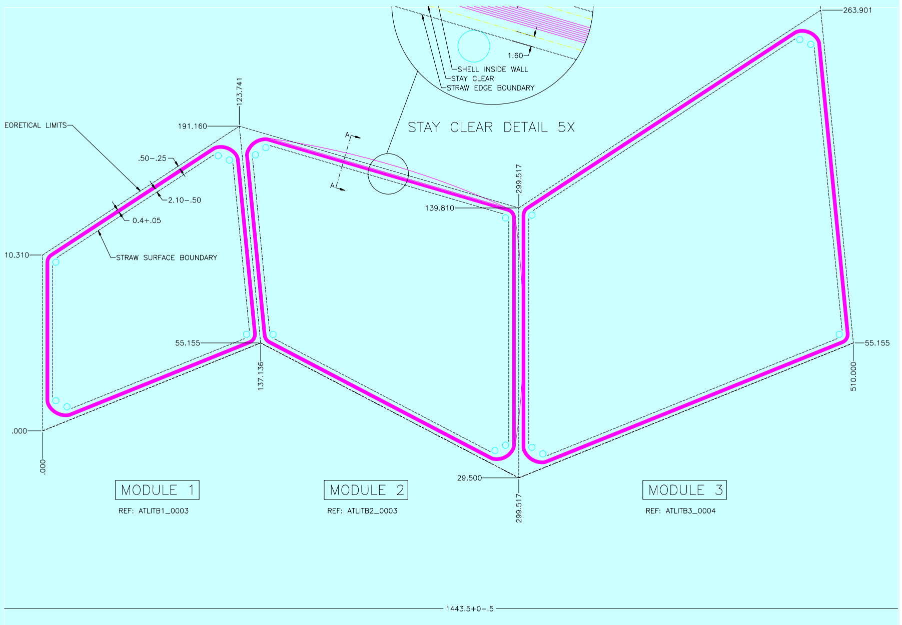
The silicon sensor production is running smoothly, about 20% have been delivered and accepted

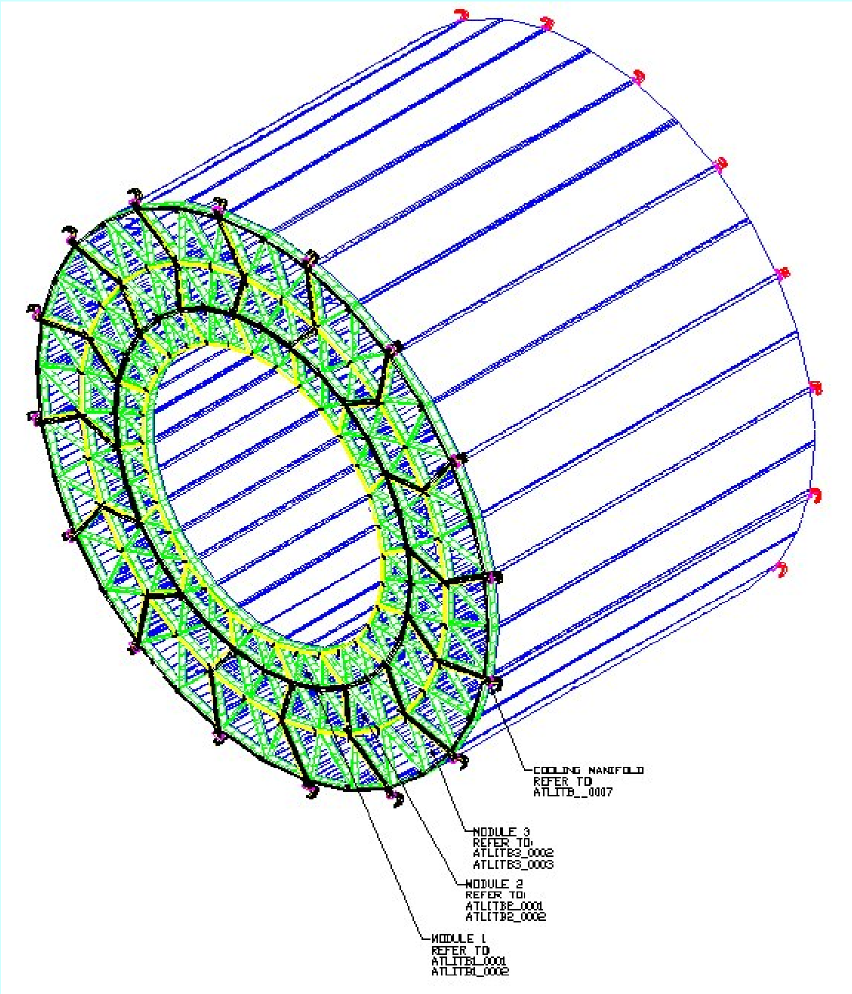
Substantial progress can be reported for the optical links, power supplies, and off-detector electronics

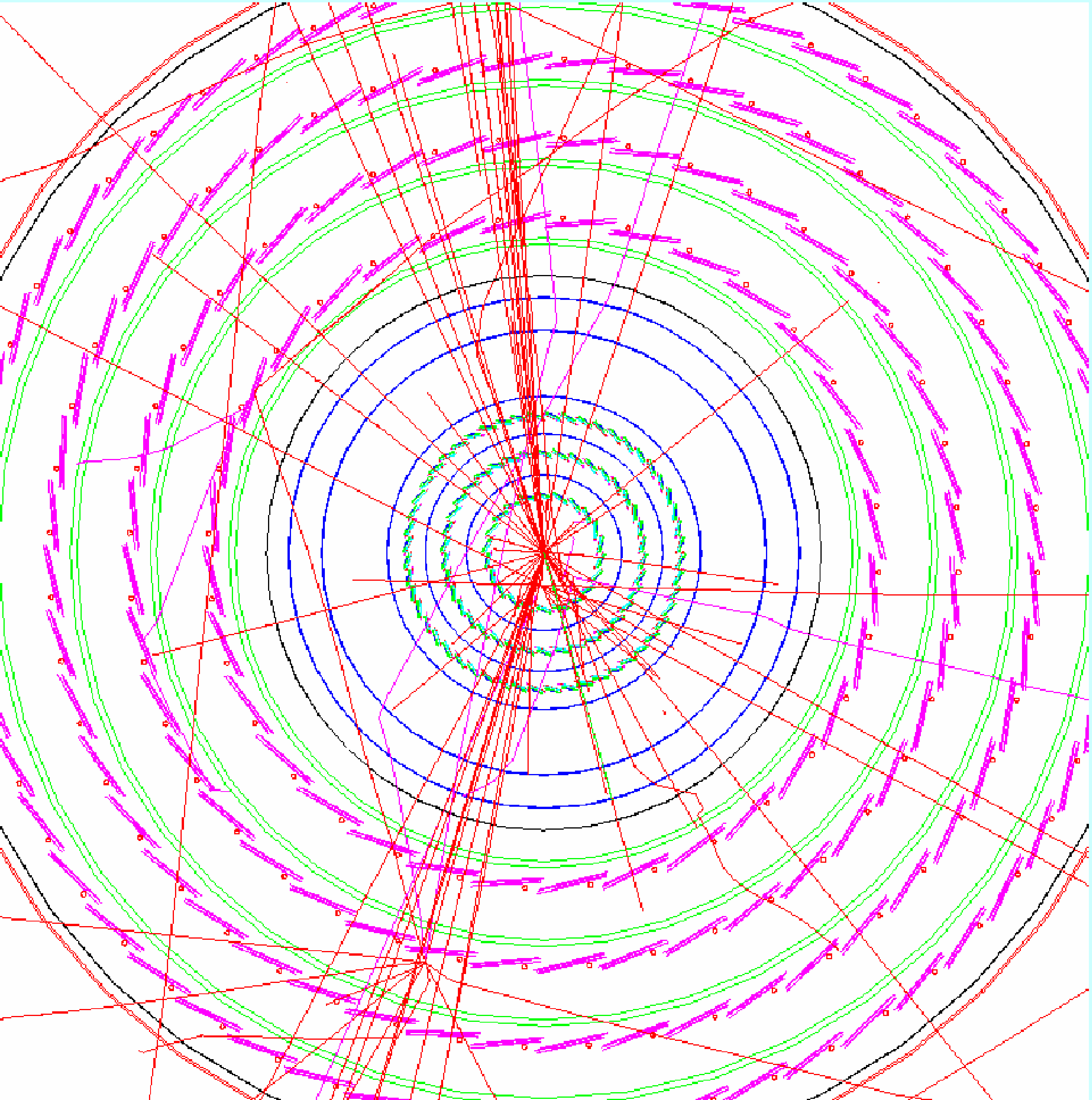


SCT barrel system test

Three Layers of TRT





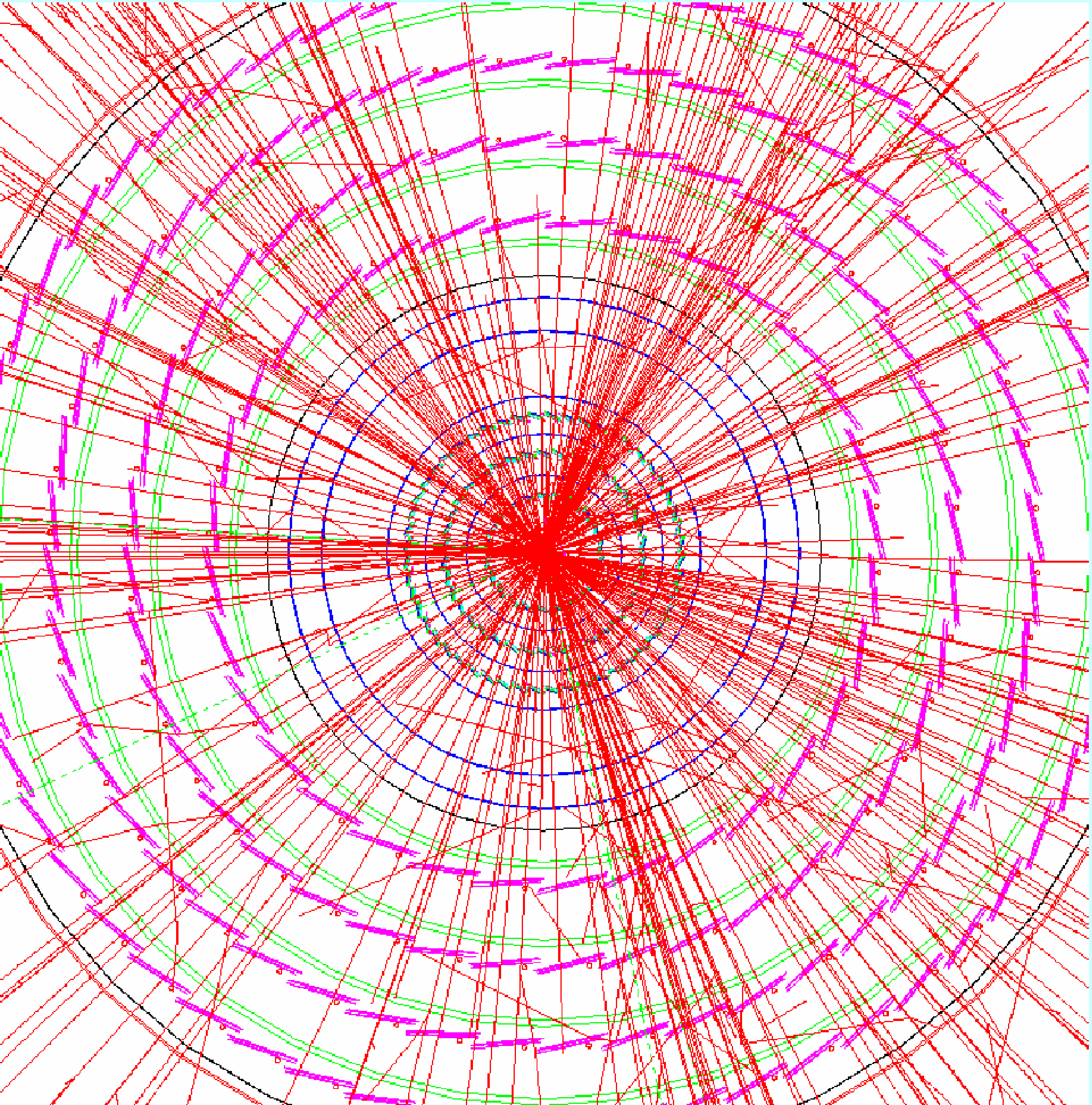


WH event

$H \to bb$

$W \to l\ \nu_l$

$M(H) = 120\ GeV/c^2$



ttH event

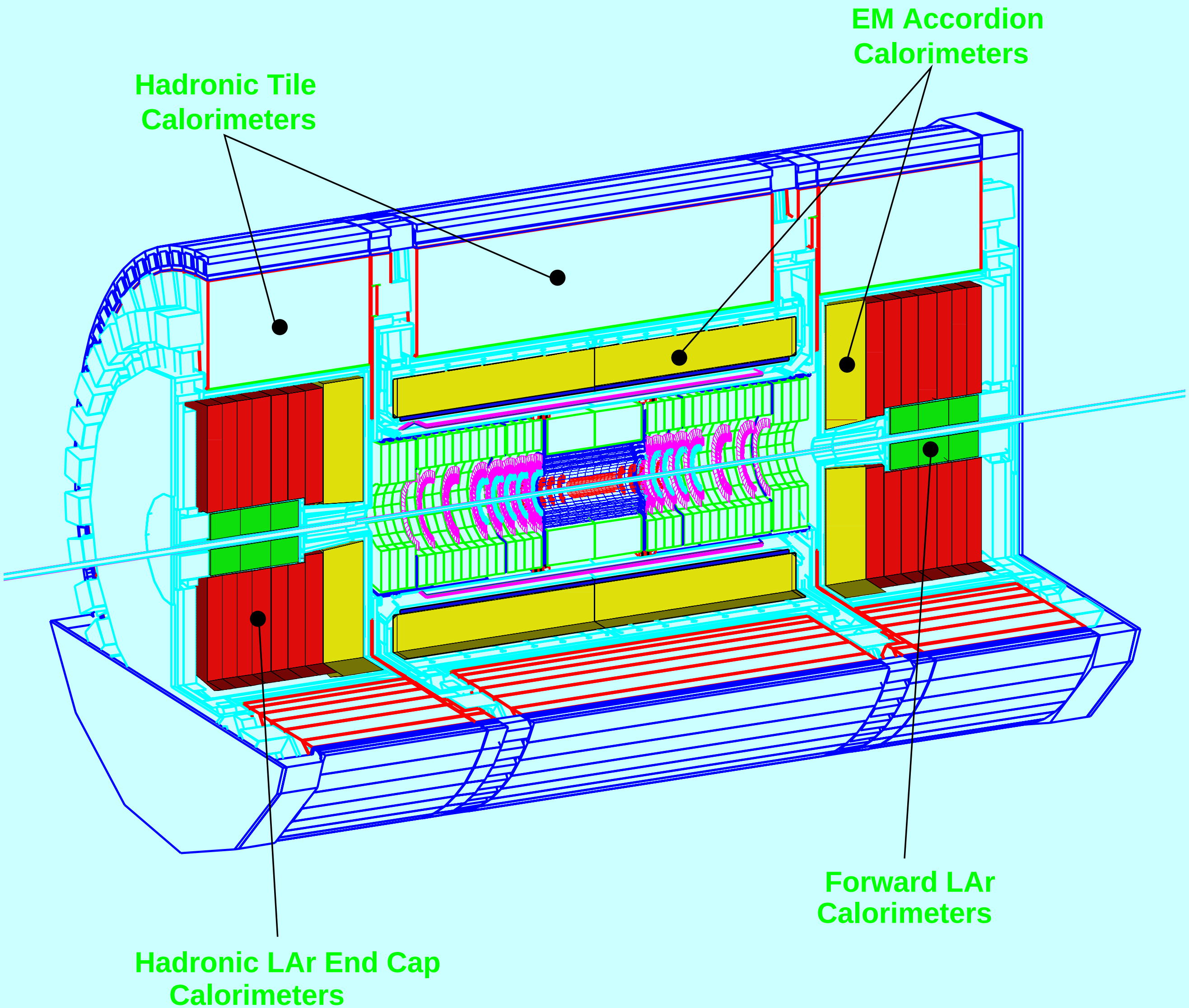
$H \rightarrow bb$

$tt \rightarrow$

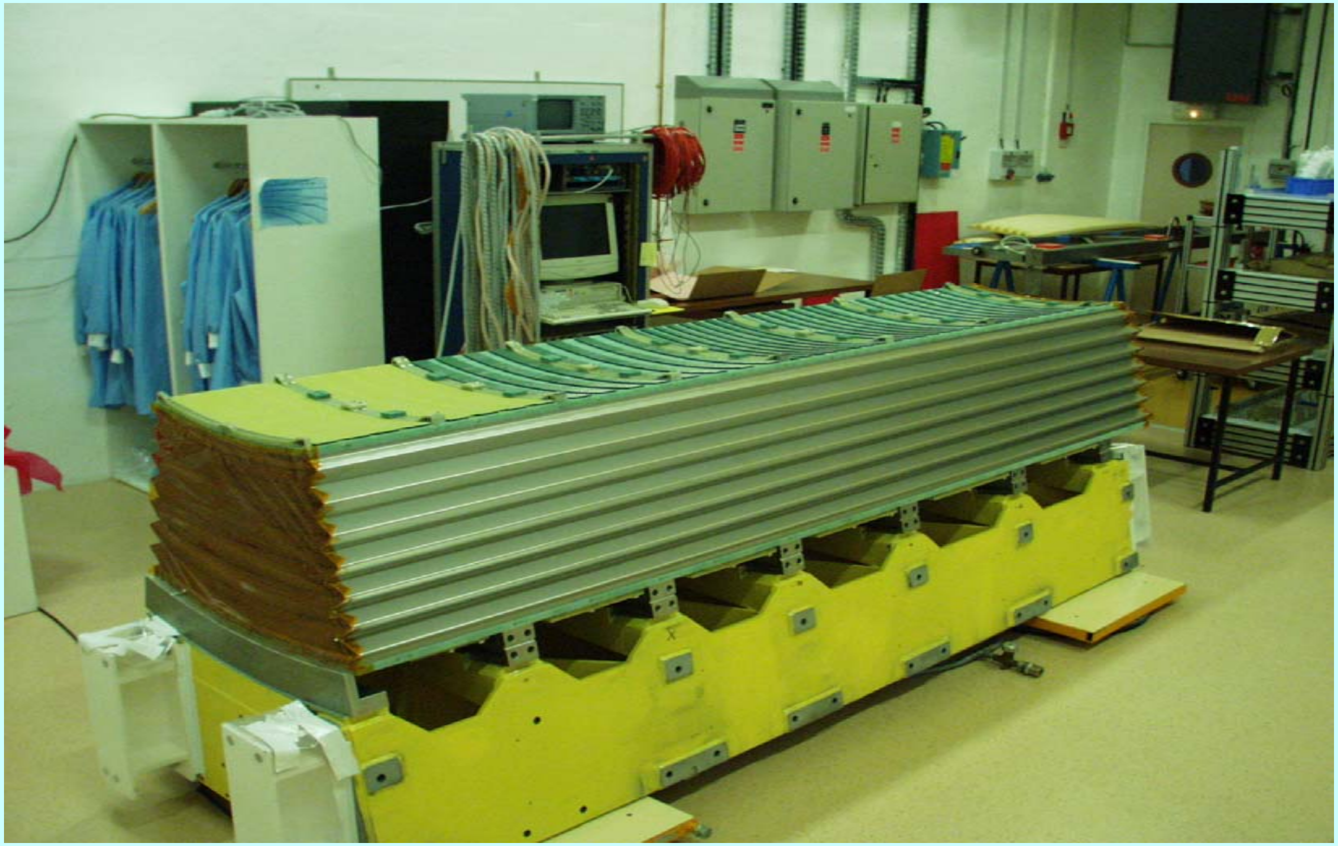
$W(l\ \nu_l)bW(qq)b$

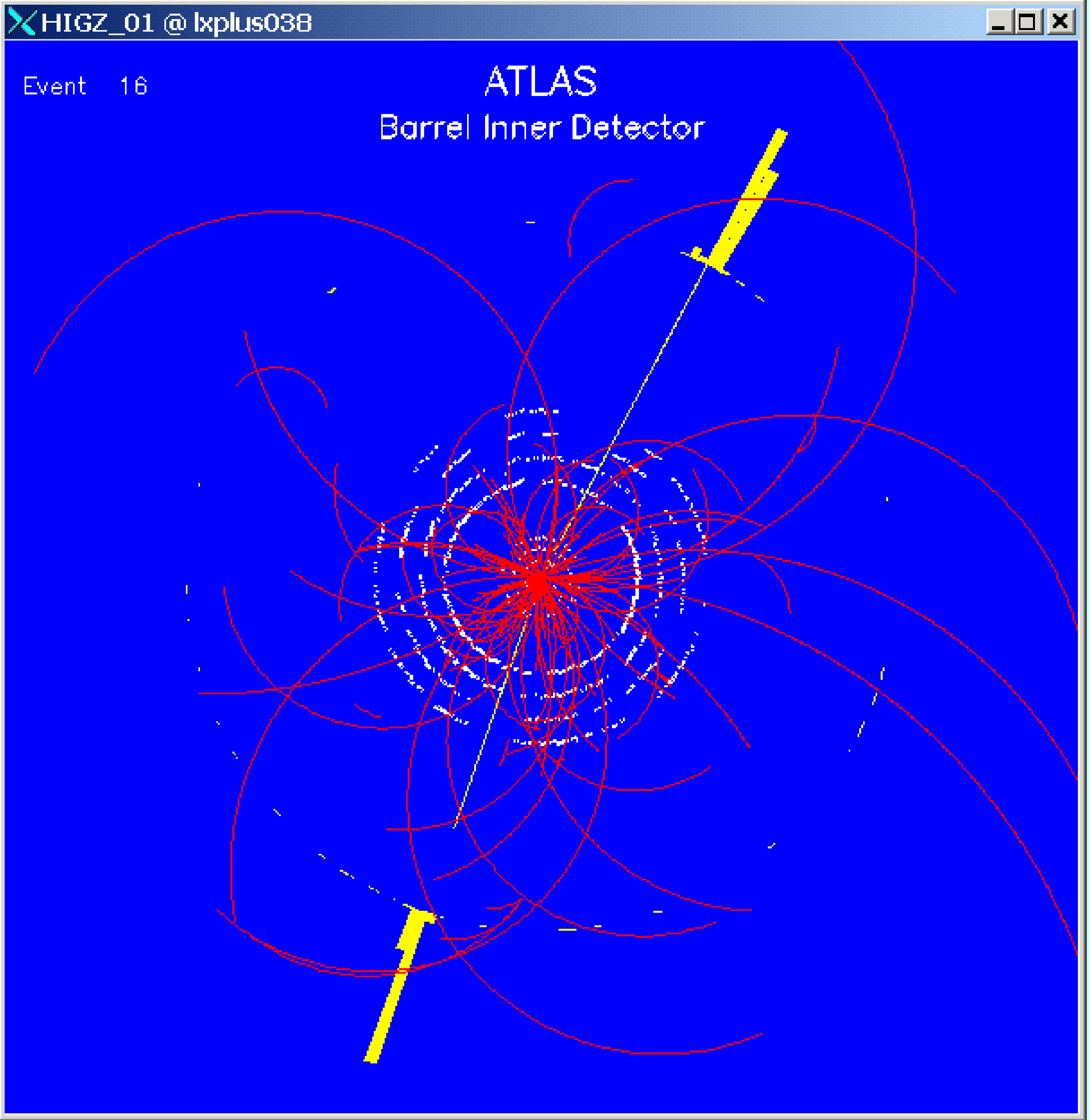
$M(H)=120\ GeV/c^2$

ATLAS Calorimetry (Geant)

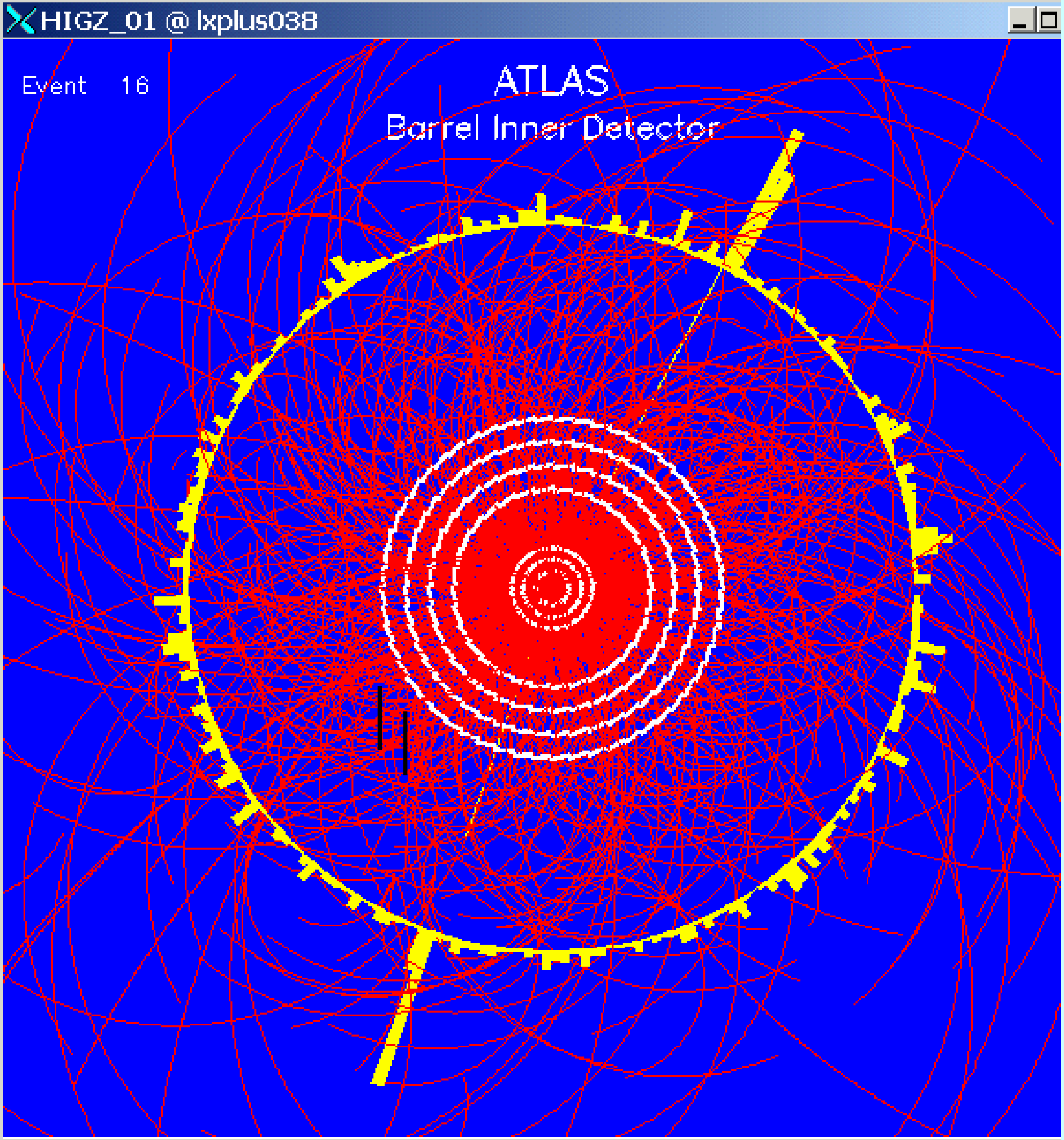


LAr EM barrel module at Saclay





H→γγ
no
pile-up



H→γγ

high luminosity (L=10^34)

23 interactions per bunch crossing

1000 charged tracks in tracker acceptance

$H \rightarrow \gamma\gamma$

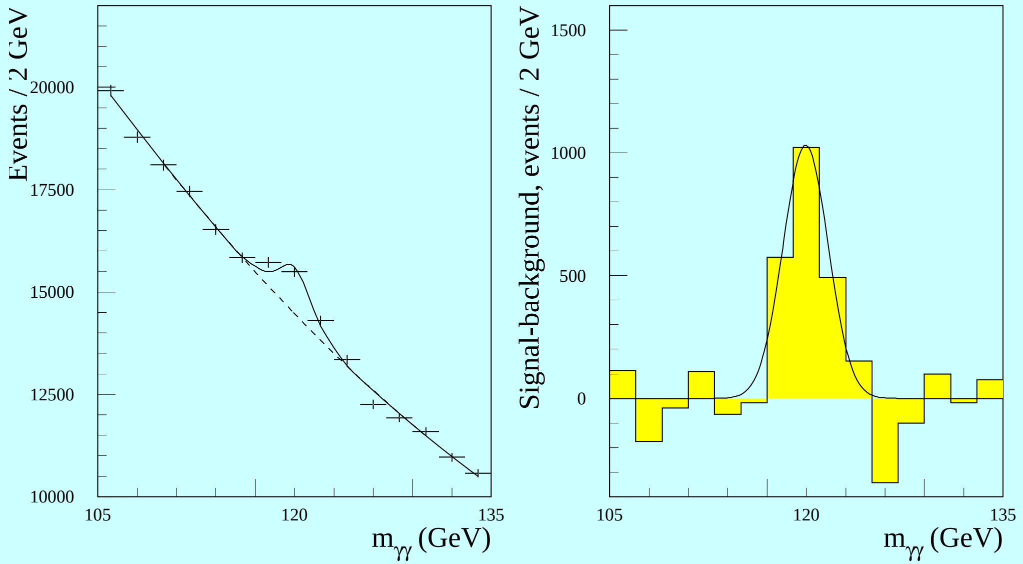
Signal $\sigma \times BR = 43\ \text{fb}\ (m_H = 100\ \text{GeV})$

$\gamma\gamma$ background (irreducible) $\frac{d\sigma}{dm_{\gamma\gamma}} \sim 1200\ \text{fb/GeV}\ (m_{\gamma\gamma} = 100\ \text{GeV})$

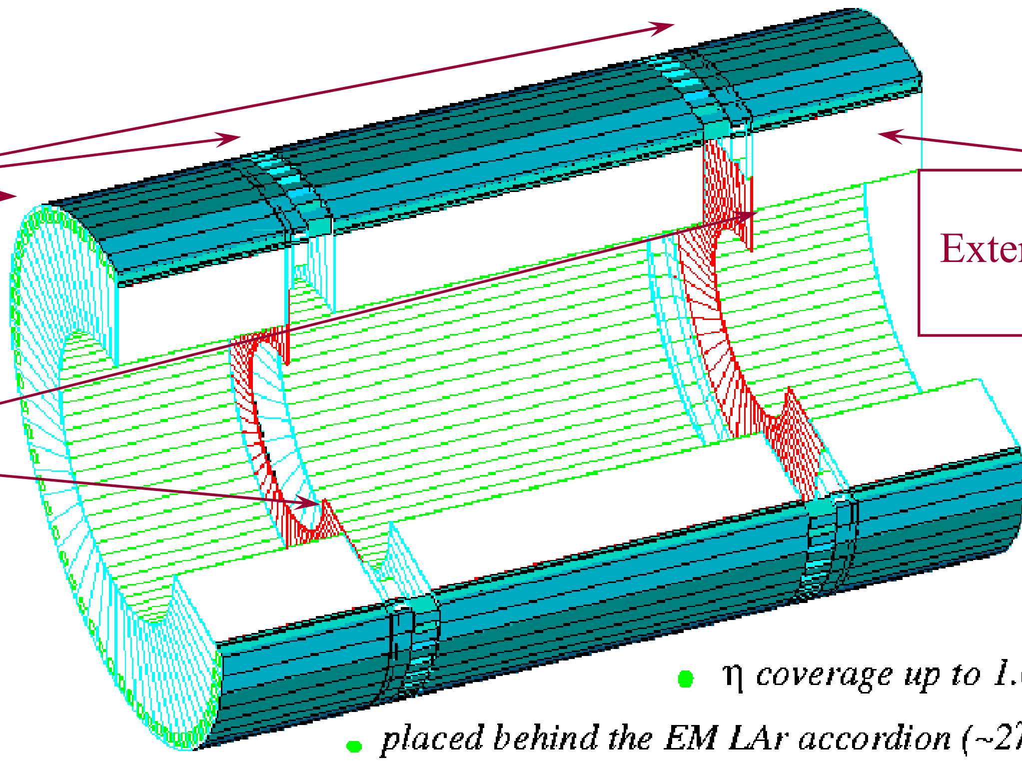
QCD jet background $\frac{\sigma_{\gamma,j}}{\sigma_{\gamma\gamma}} \sim 1000,\quad \frac{\sigma_{j,j}}{\sigma_{\gamma\gamma}} \sim 2\times10^6$ **(reducible)**

Must see bump above Two photon background.

Good photon ID reduces Jet background



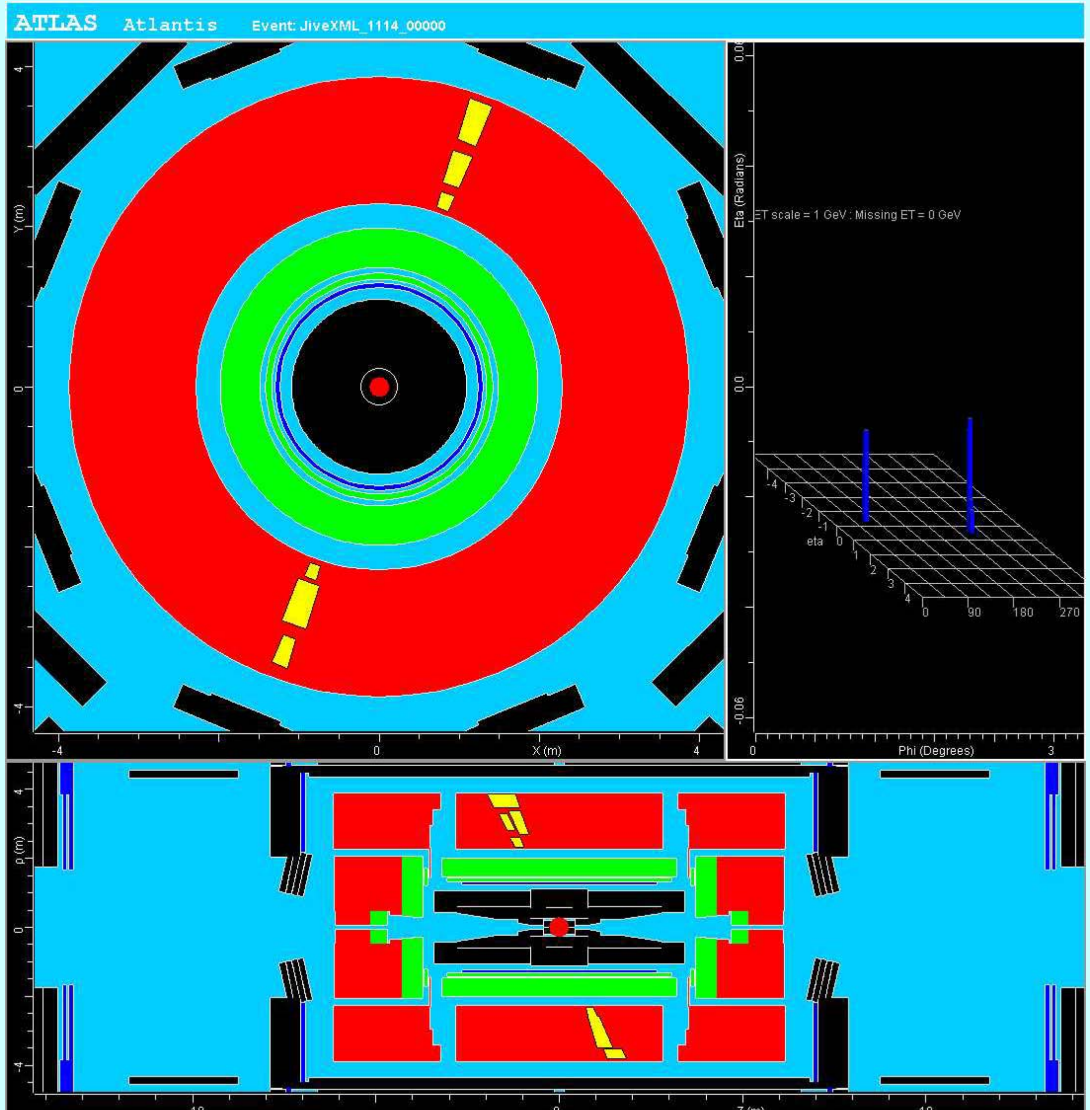
ATLAS Tile Calorimeter



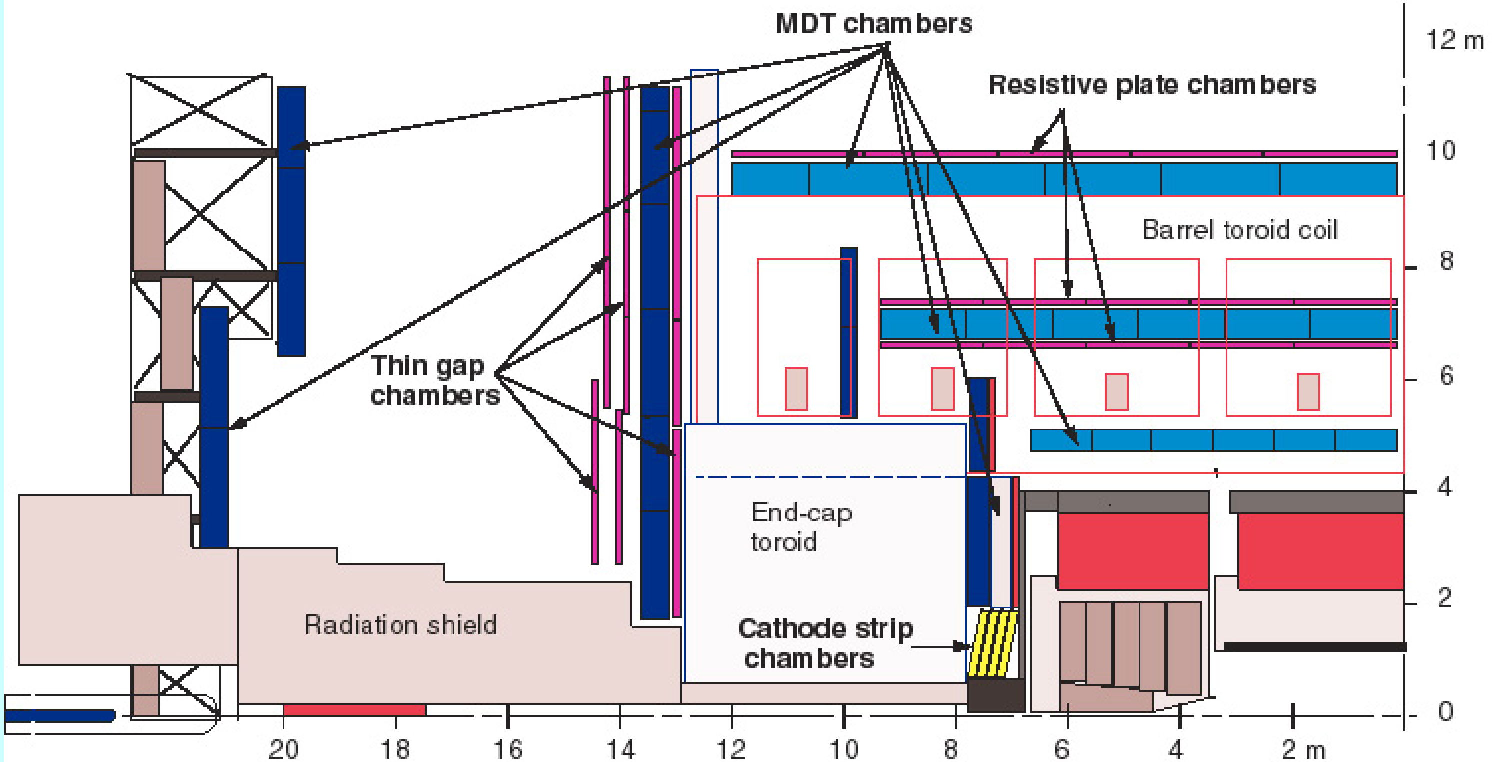
- *η coverage up to 1.6*
- *placed behind the EM LAr accordion (~2λ)*
- *outer diameter 8.5 m, 12.2 m long, 2900 tons, 64 wedges structure*
- *Fe-scintillator sampling calorimeter (ratio ~4:1), WLS fibres readout*
- *unconventional scintillator geometry, with tiles in the radial direction*
- *the calorimeter body and the massive iron outer support act as magnetic flux return for internal solenoid*

Hadronic Tile Cal – on track

First Events in the LHC!



ATLAS Muon System



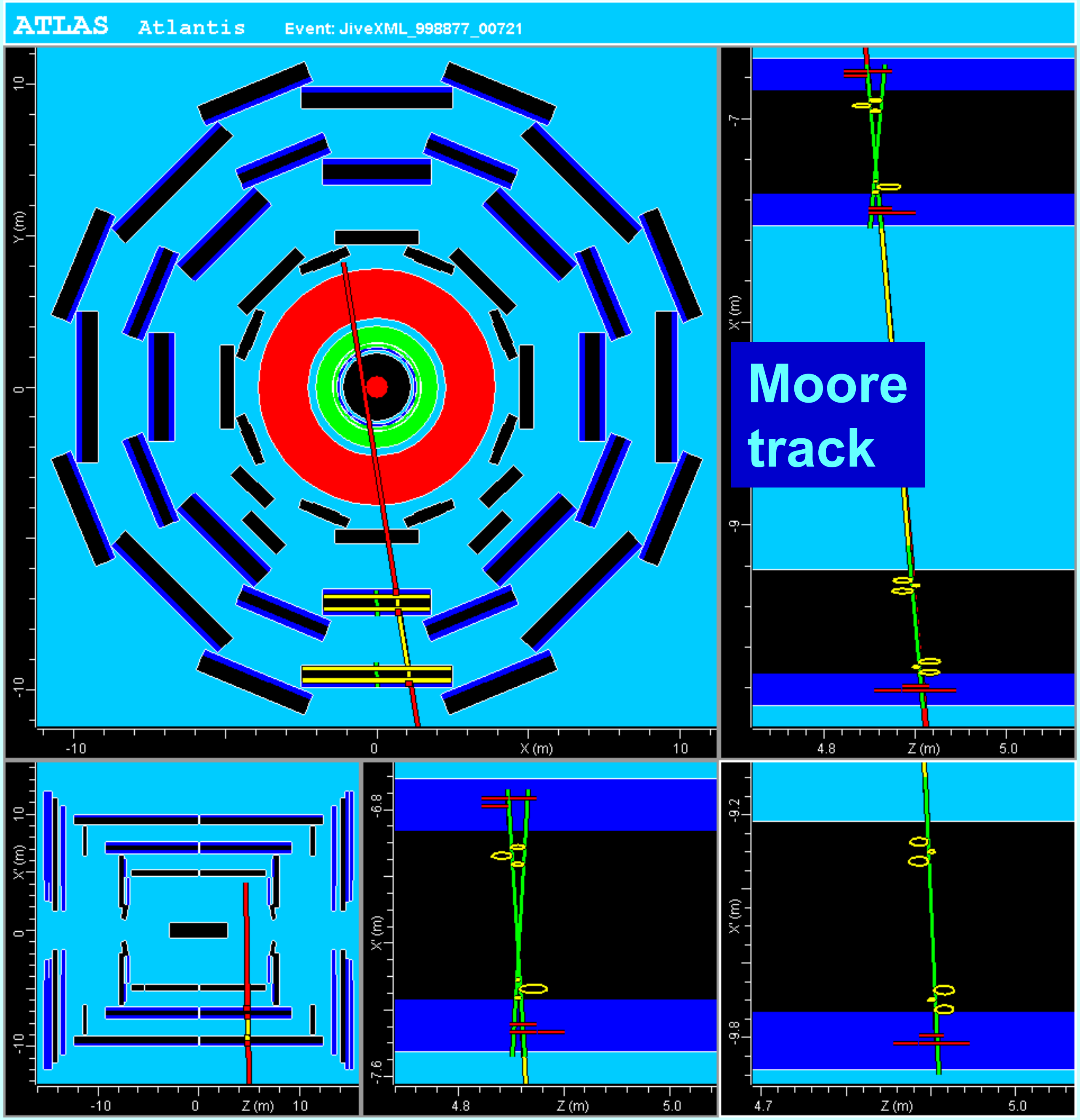
Typical MDT Chambers

EML2: 3-Layer Chamber
Tube length: 2 to 2.9 m
No. Tubes: 384
No. Endplugs: 768

Cosmics!

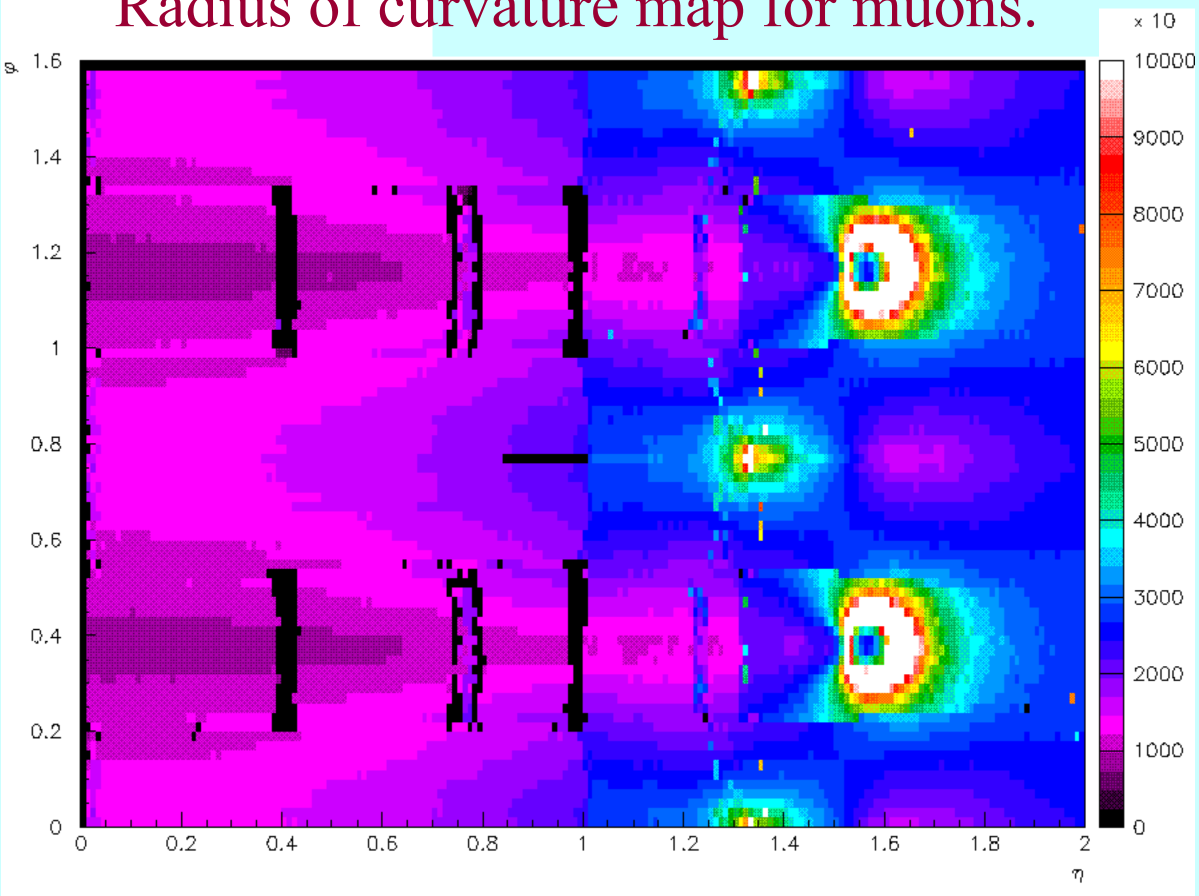
Moore and Muonboy able to reconstruct tracks

Plan to interface with dedicated pattern recogn. cosmics algorithm

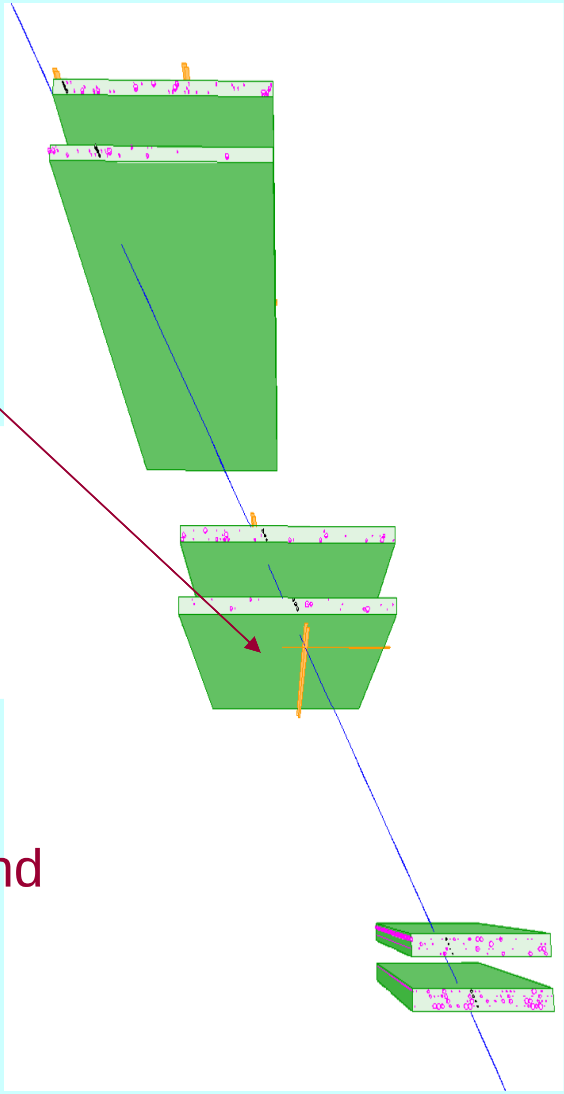


Muon Level 2 Trigger

Radius of curvature map for muons.

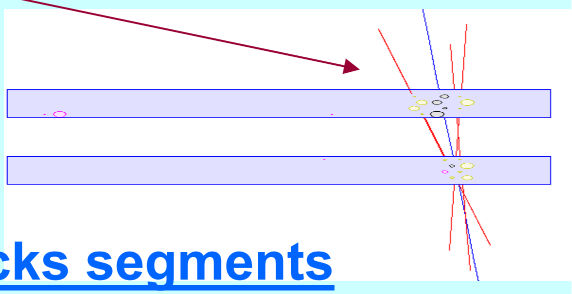


Muon reconstruction



1. **Identification of Region of Activity**

2. **Reconstruction of local straight track segments**



3. **Combination of three tracks segments**

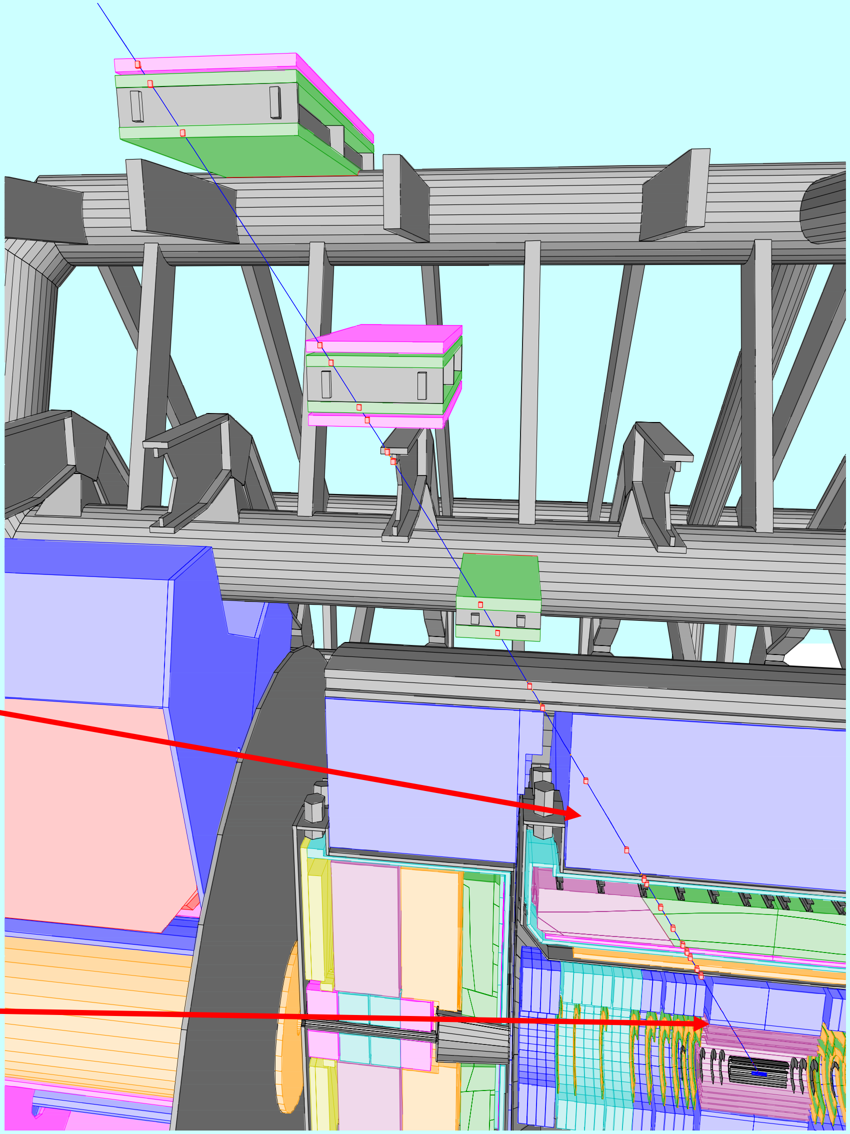
4. **Global fit** taking into account multiple scattering and energy loss

Muon backtracking

Backtracking from Muon System down to beam region through calorimeters taking into account E loss, multiple scattering and E loss fluctuations

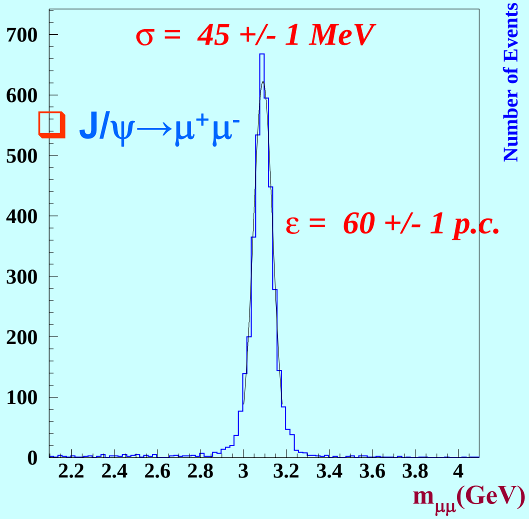
E loss from parametrization (from calo measurement possible but risk of pollution from nearby particle)

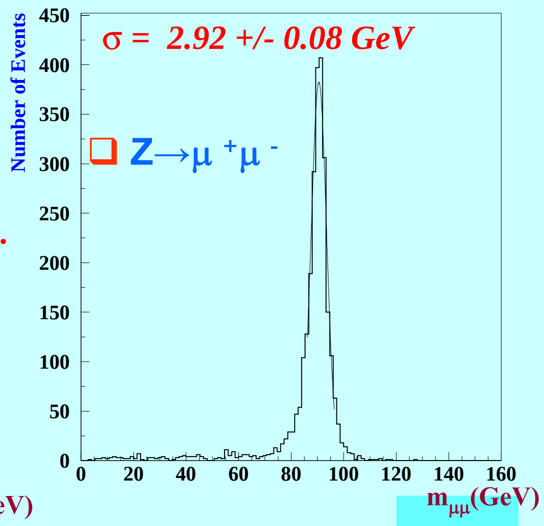
Combination with inner detector track

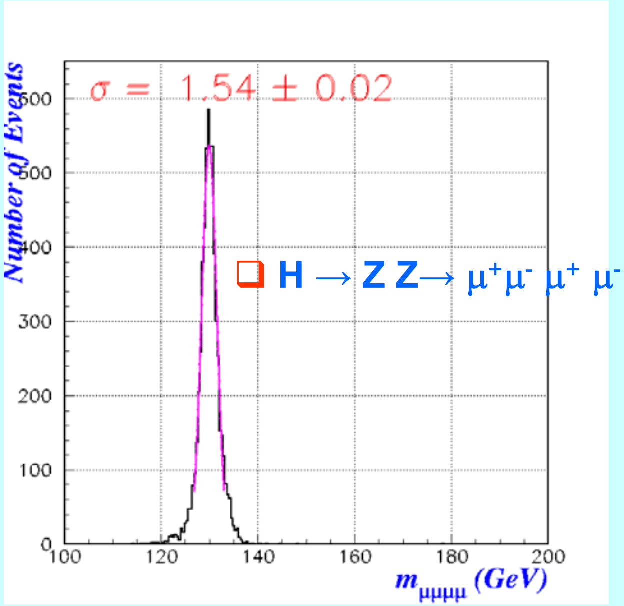


S.Hassani Athens 05/03 *A.Farilla Gallipoli 06/03*

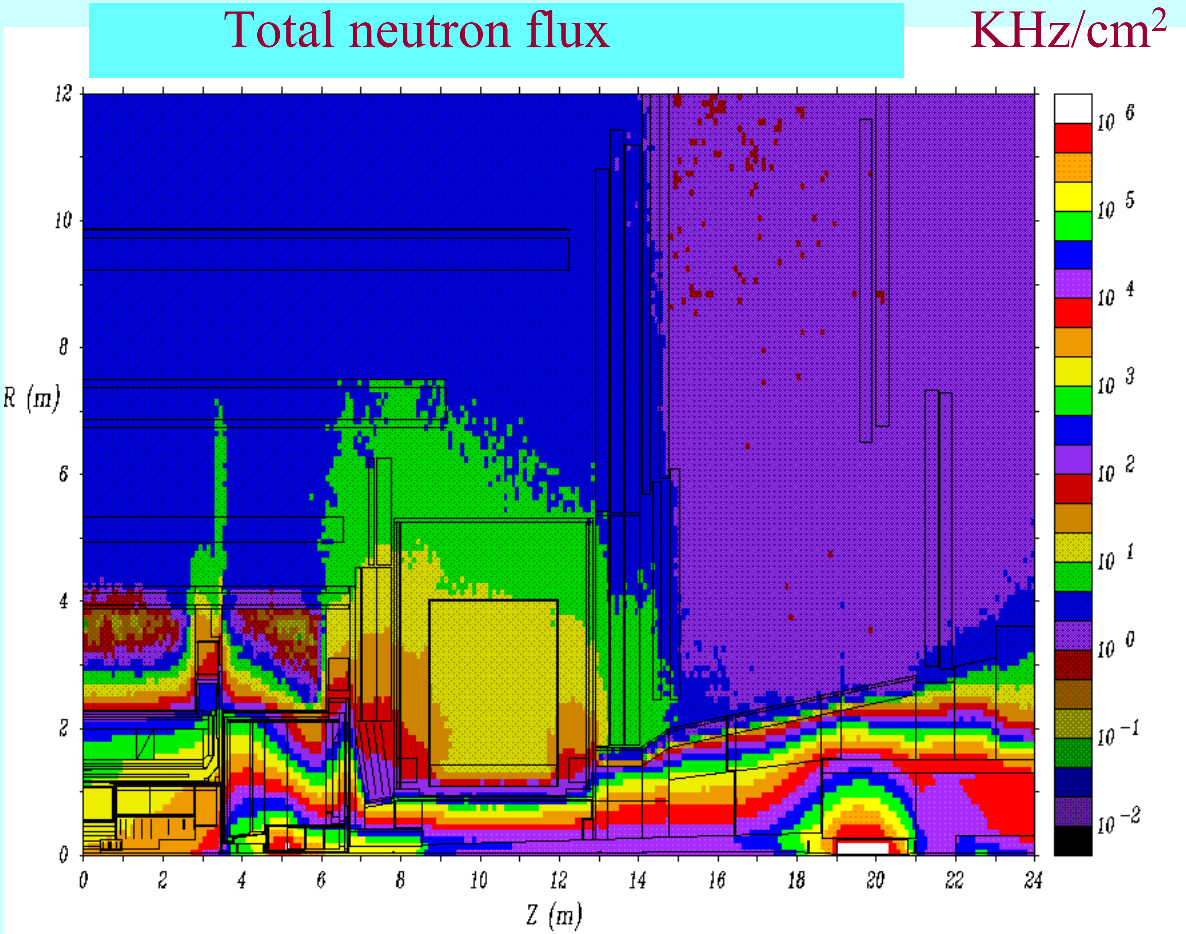
μ reconstruction Mass plots



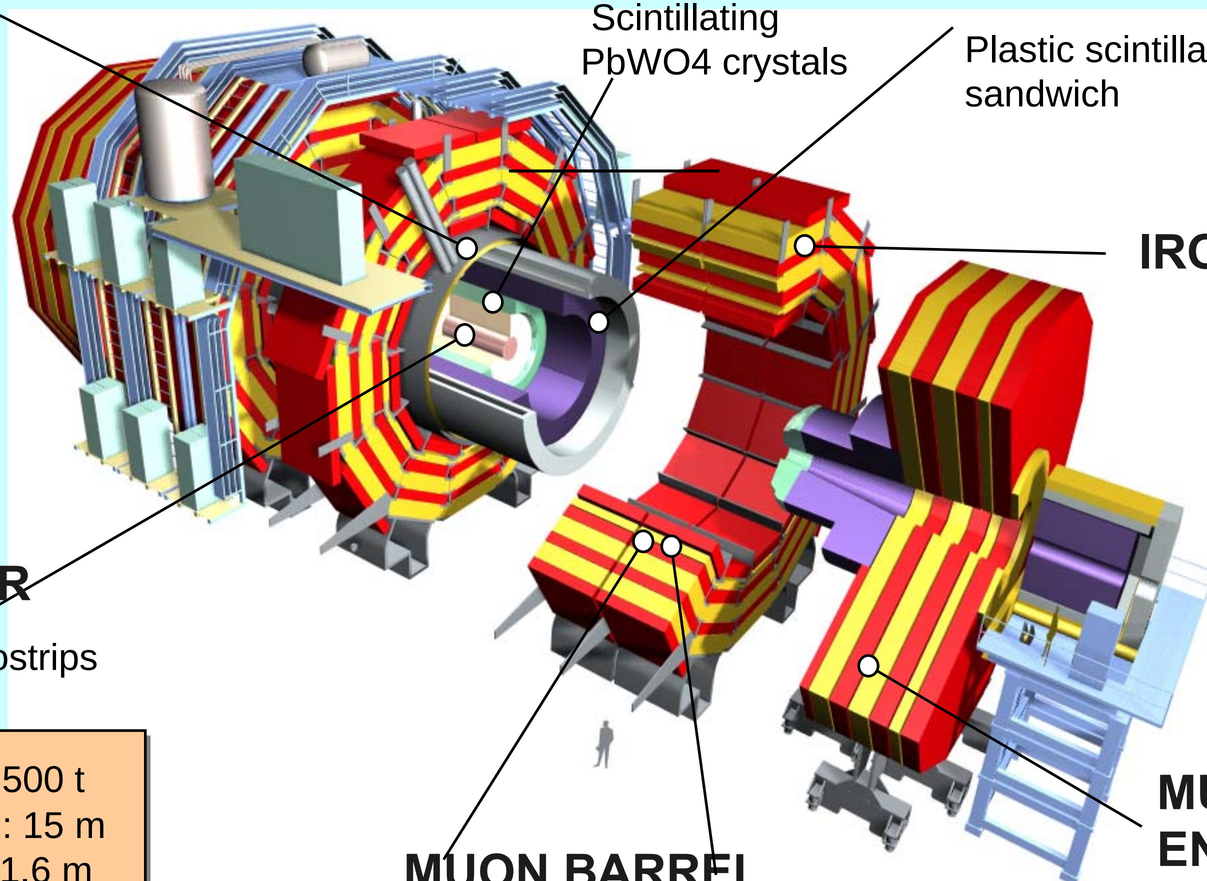




Neutron Background Studies



The CMS Detector

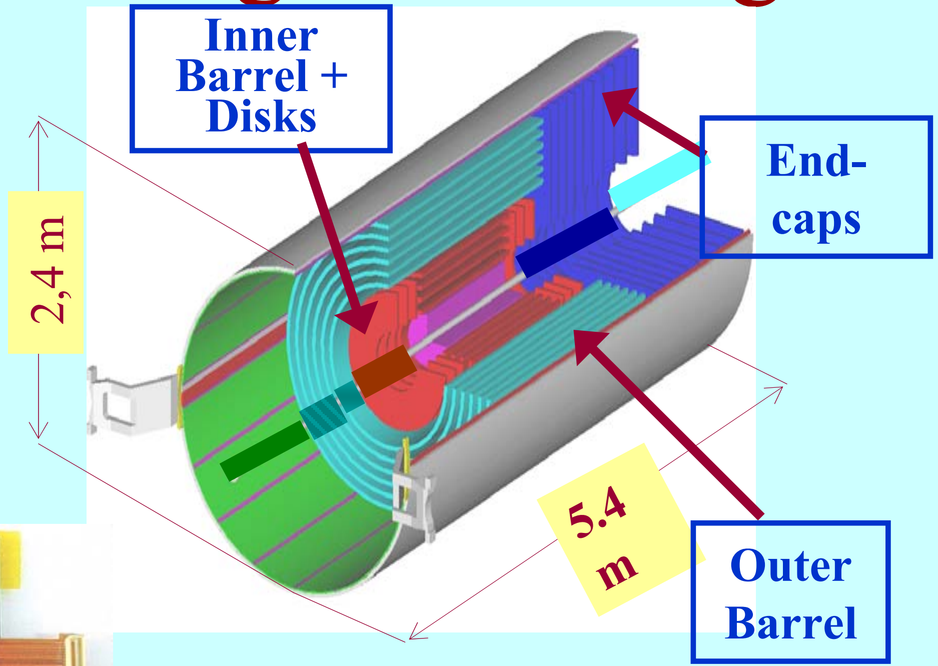


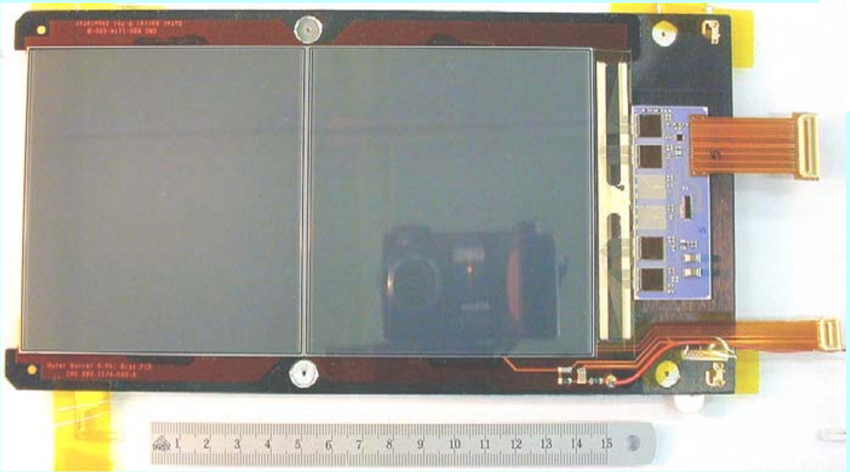
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

CMS Detector Design: Tracking

Tracker:

- Excellent momentum resolution:
  σ (Pt) / Pt ~ 0.15 (Pt / TeV)
  thanks to 4 Tesla solenoid.
- Coverage to | η | < 2.5 (i.e. $\theta > 9^0$).
- 10000 silicon strip modules.

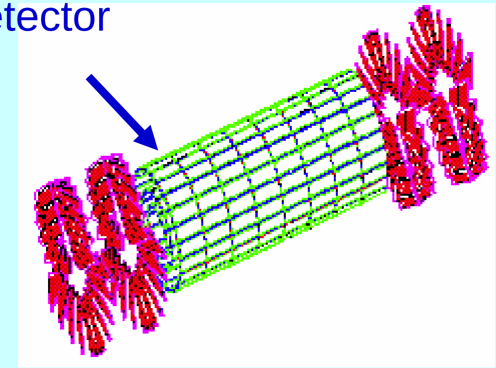


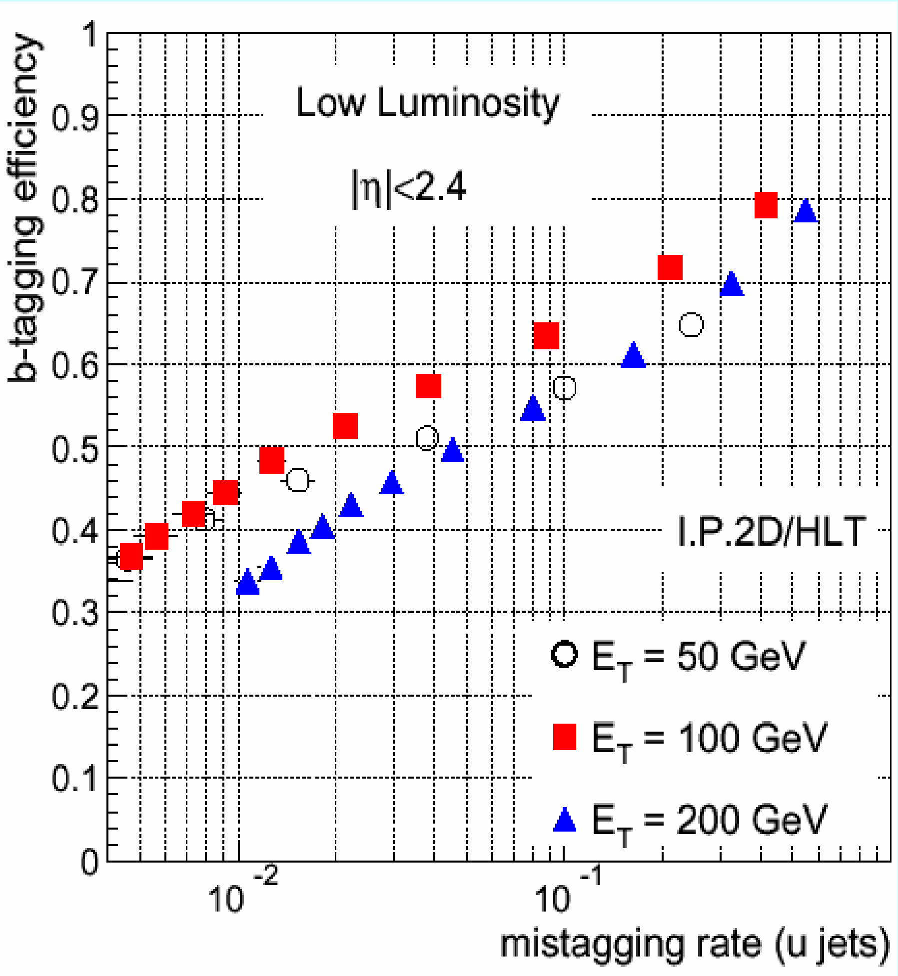


CMS Detector Design: Tracking

B tagging crucial to reject QCD backgrounds & identify signals (SUSY, Higgs …)

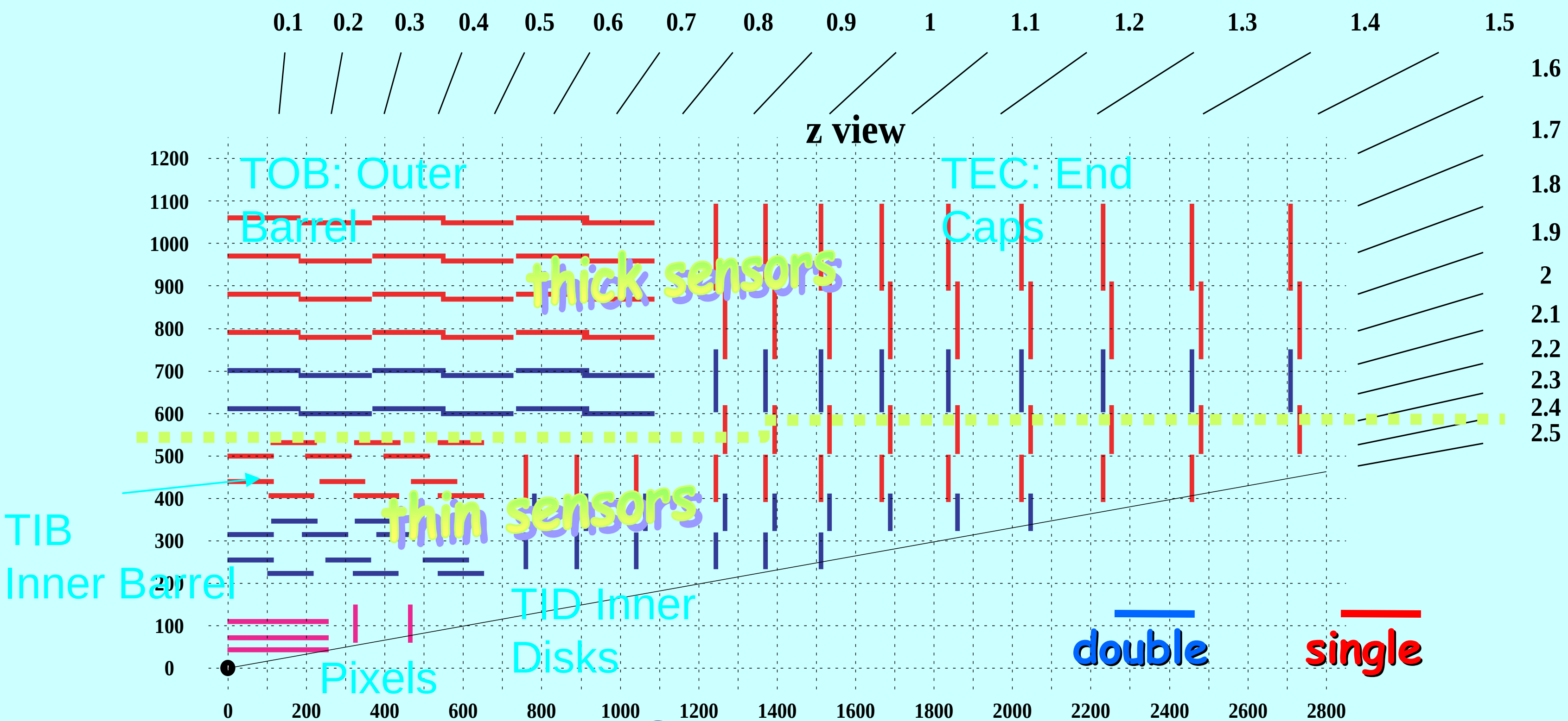
Relies on silicon pixel detector





- Inner layer only 4.4 cm from beam !
- Gives b-tag for | η | < 2.4.

CMS Tracker Layout

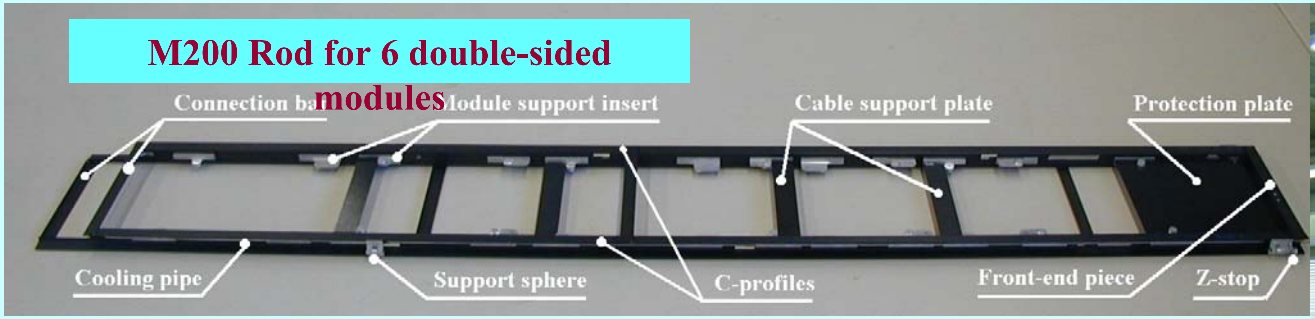


Some Numbers

6,136 Thin sensors - **3112 + 1512** Thin **modules** (ss +ds) **223 m² of silicon** 19,632 Thick sensors - **4776 + 2520** Thick **modules** (ss +ds) **sensors**

Tracker: Mechanics

M200 Rod for 6 double-sided modules

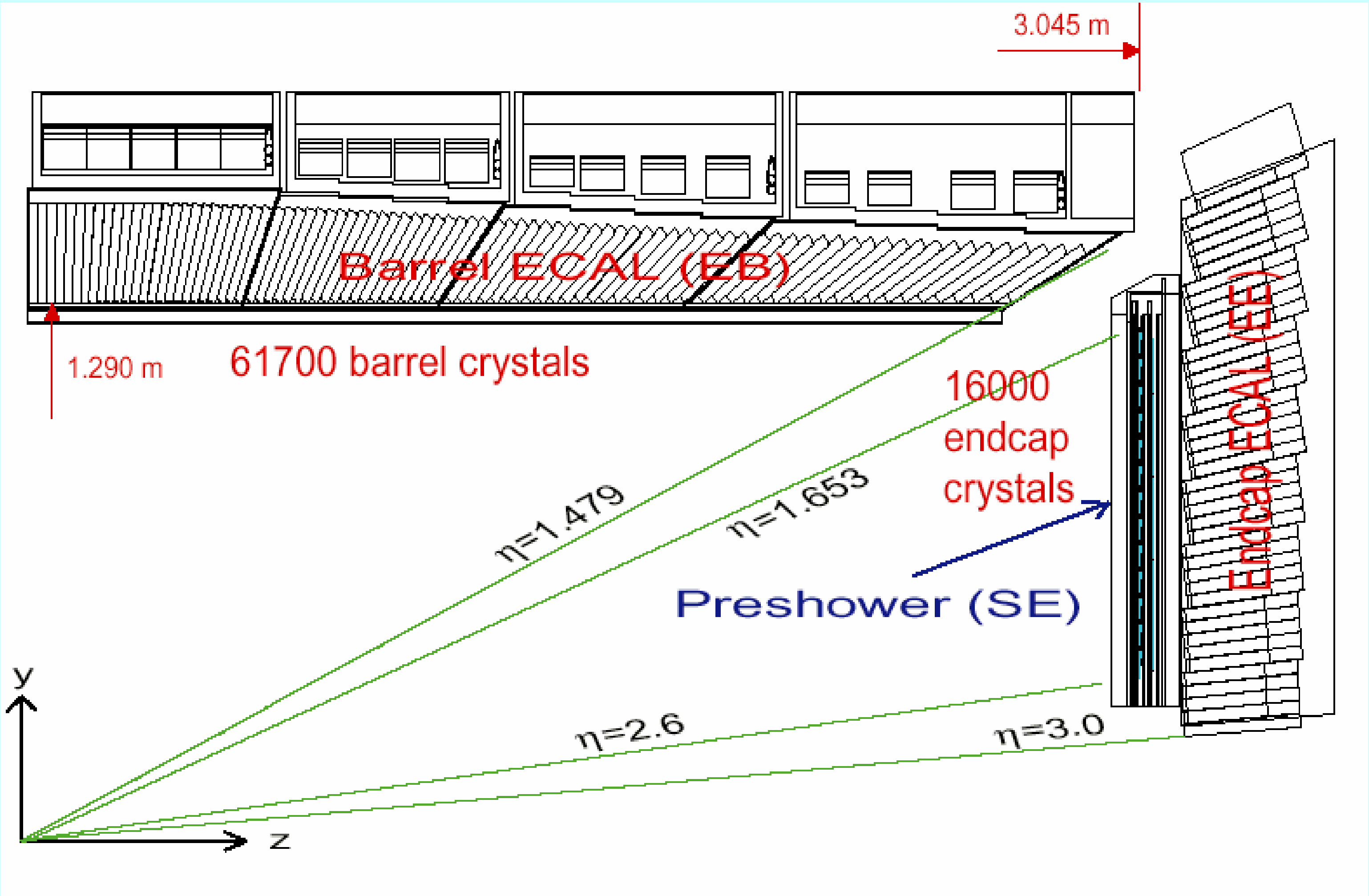


TOB

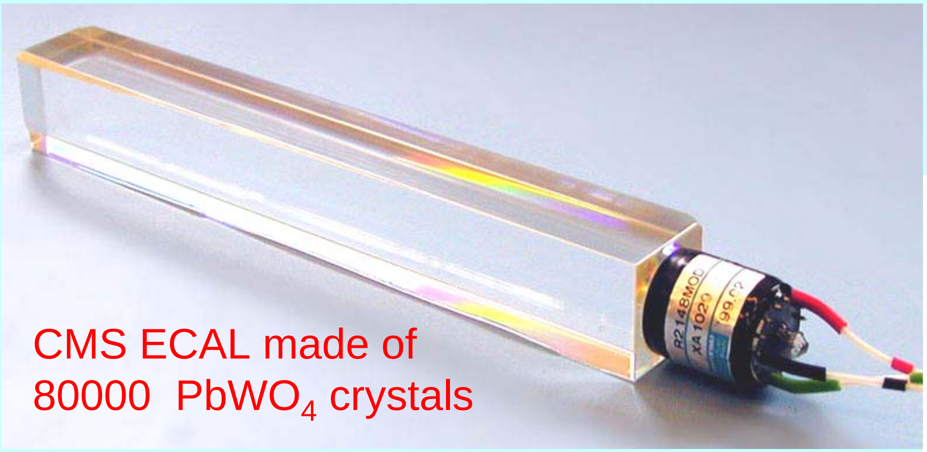
TEC

TIB: Upper cylinder mold

Electromagnetic Calorimeter:



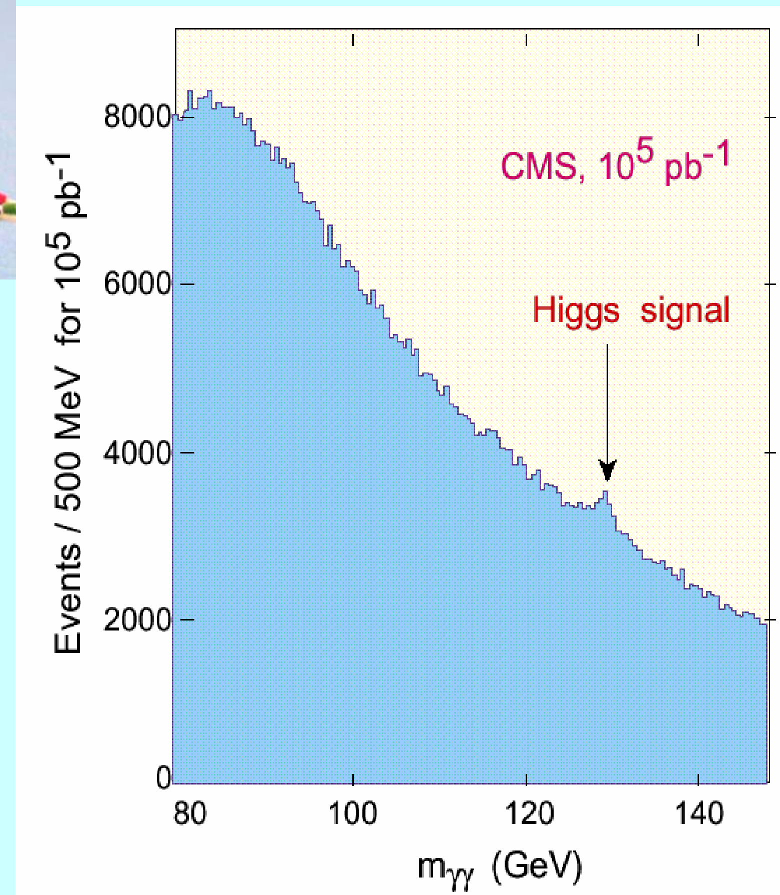
CMS Detector Design: ECAL



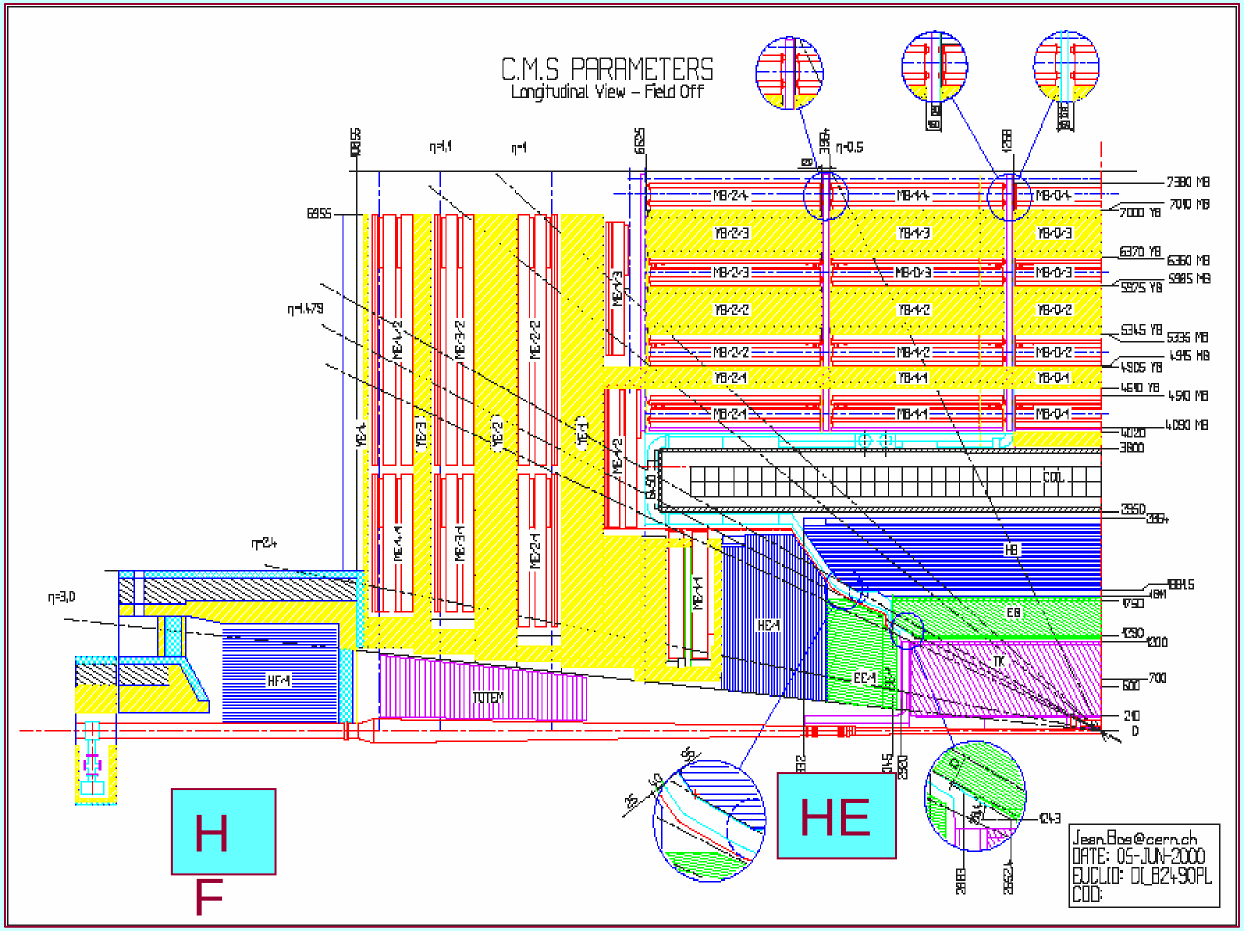
$H \rightarrow \gamma\gamma$ is main discovery channel for light Higgs (M < 150 GeV), but small branching ratio ⇒ difficult

ECAL gives ~0.7 GeV mass resolution & S/B ~ 1/20.

⇒ Discovery in ~1 year.



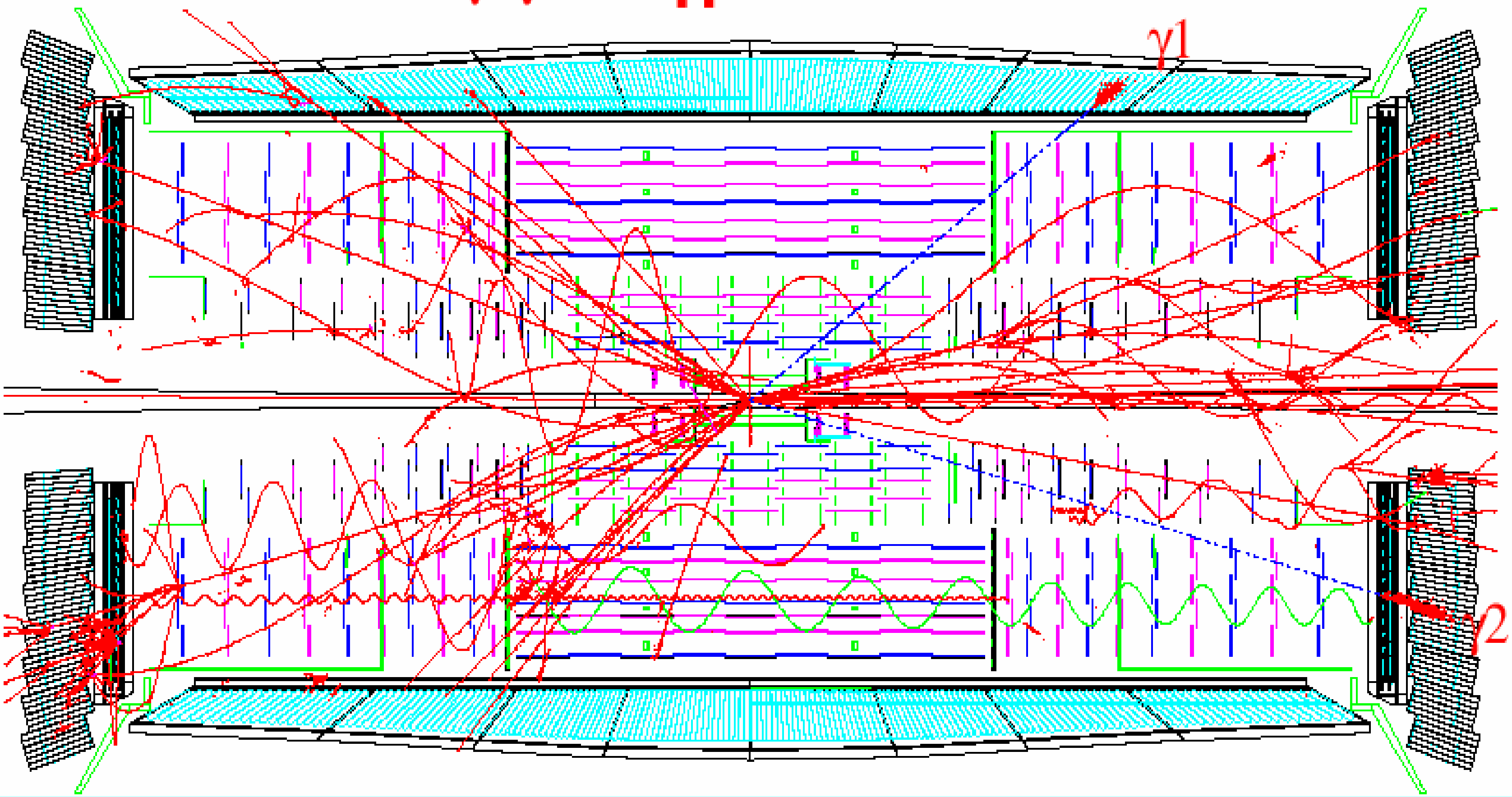
Hadronic Calorimeter: HCAL



HB

Higgs event into two Photons

H -> γγ , M_H = 100 GeV



CMS Detector Design: μ-chambers

3 different technologies:

- DT in barrel
- CST in end-cap (due to B-field)
- RPC mainly to help trigger (fast).

Vital for LHC physics:

$\chi_2^0 \rightarrow \chi_1^0$ **l+ l-**

t $\rightarrow$ b μ ν

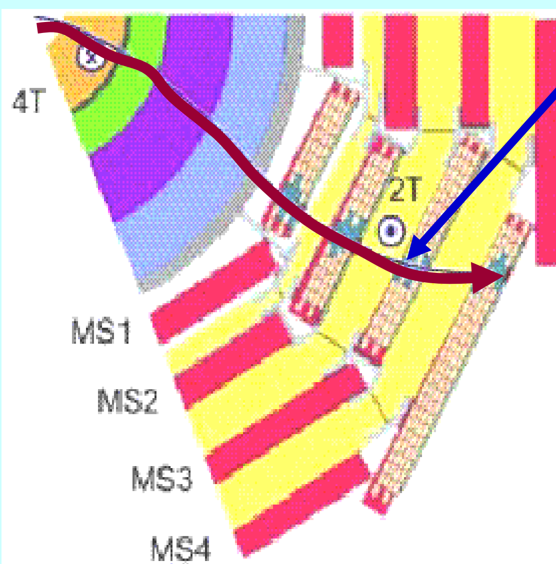
Z' $\rightarrow$ 2 μ **(TeV range)**

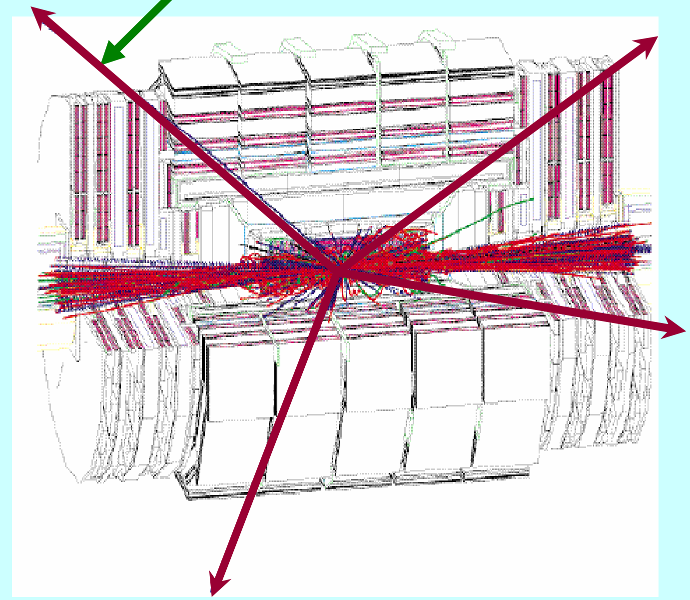
H $\rightarrow$ ZZ $\rightarrow$ 4 μ **(150-750 GeV)**

Excellent momentum resolution

σ (Pt) / Pt ~ 0.05 $\sqrt{}$ (Pt / TeV)

as measured in tracker + μ-chambers





ATLAS versus CMS ?

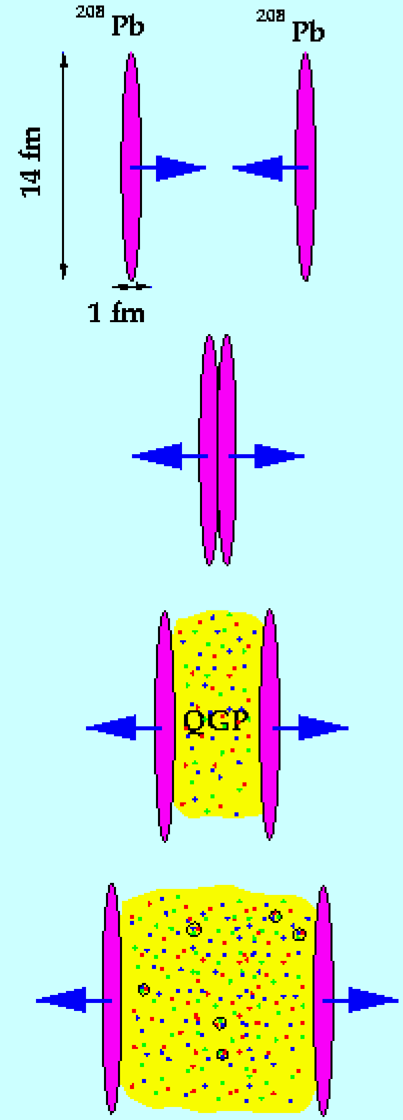
ATLAS & CMS have very similar performance.

But some differences …

- **ATLAS 2 X bigger !**
- **ATLAS μ resolution better in forward region (toroidal B-field).**
- **ATLAS ECAL worse and outside solenoid $\Rightarrow$** $H \rightarrow \gamma\gamma$ width doubles.
- ATLAS jet energy resolution 40% better (ECAL+HCAL combination better).
- ATLAS B-field only 2 Tesla $\Rightarrow$ **Pt resolution doubles.**
- **ATLAS Transition Radiation Tracker $\Rightarrow$ ~1σ π-K separation for $p < 20$ GeV.**

ALICE

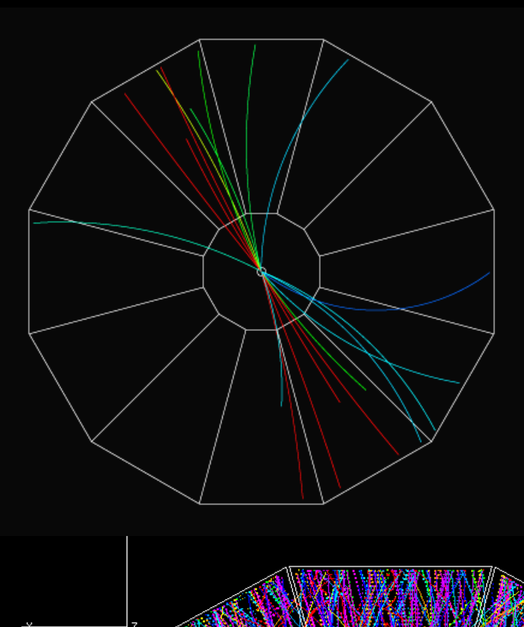
Heavy Ion experiment – explore Quark-Gluon plasma

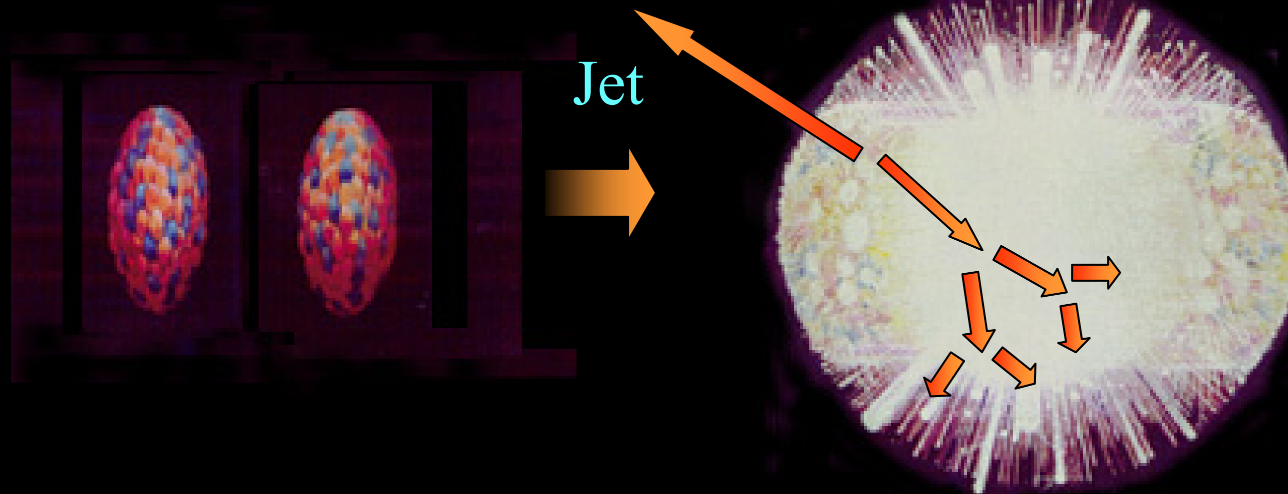


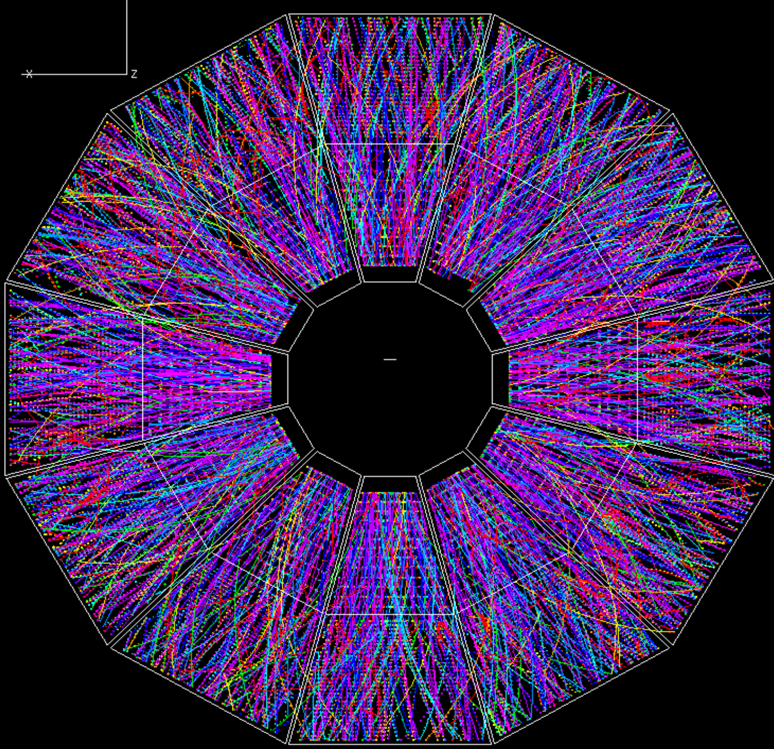
Recent results in jet quenching at RHIC – extensions at higher energy

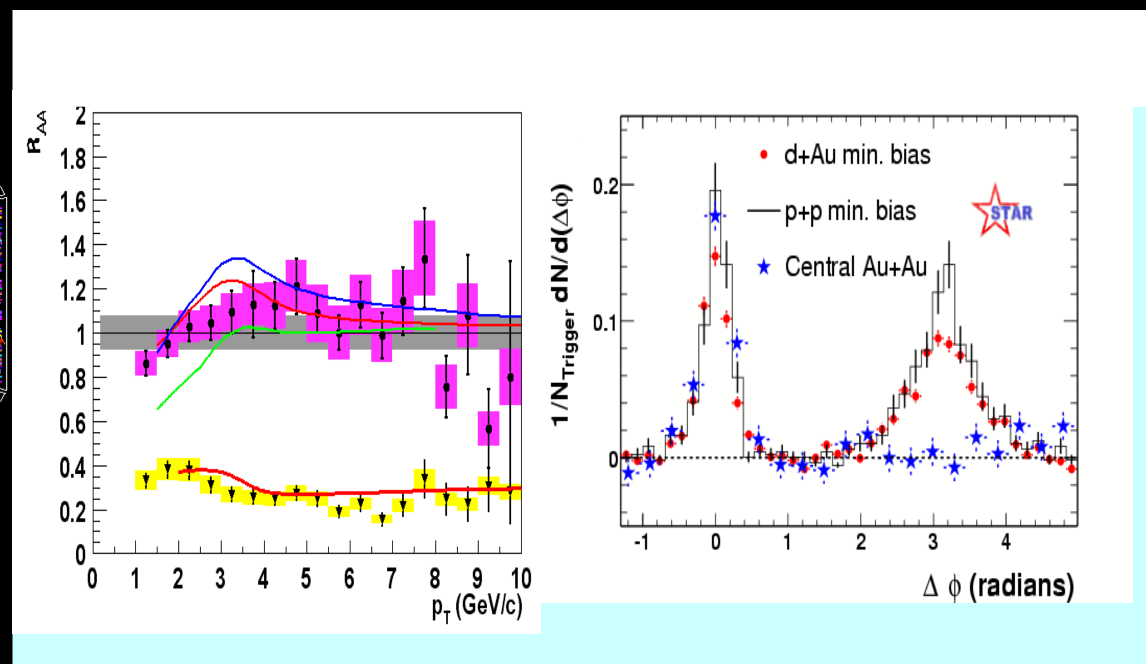
Running time limited by switchover For heavy-ions

Jet Quenching at RHIC

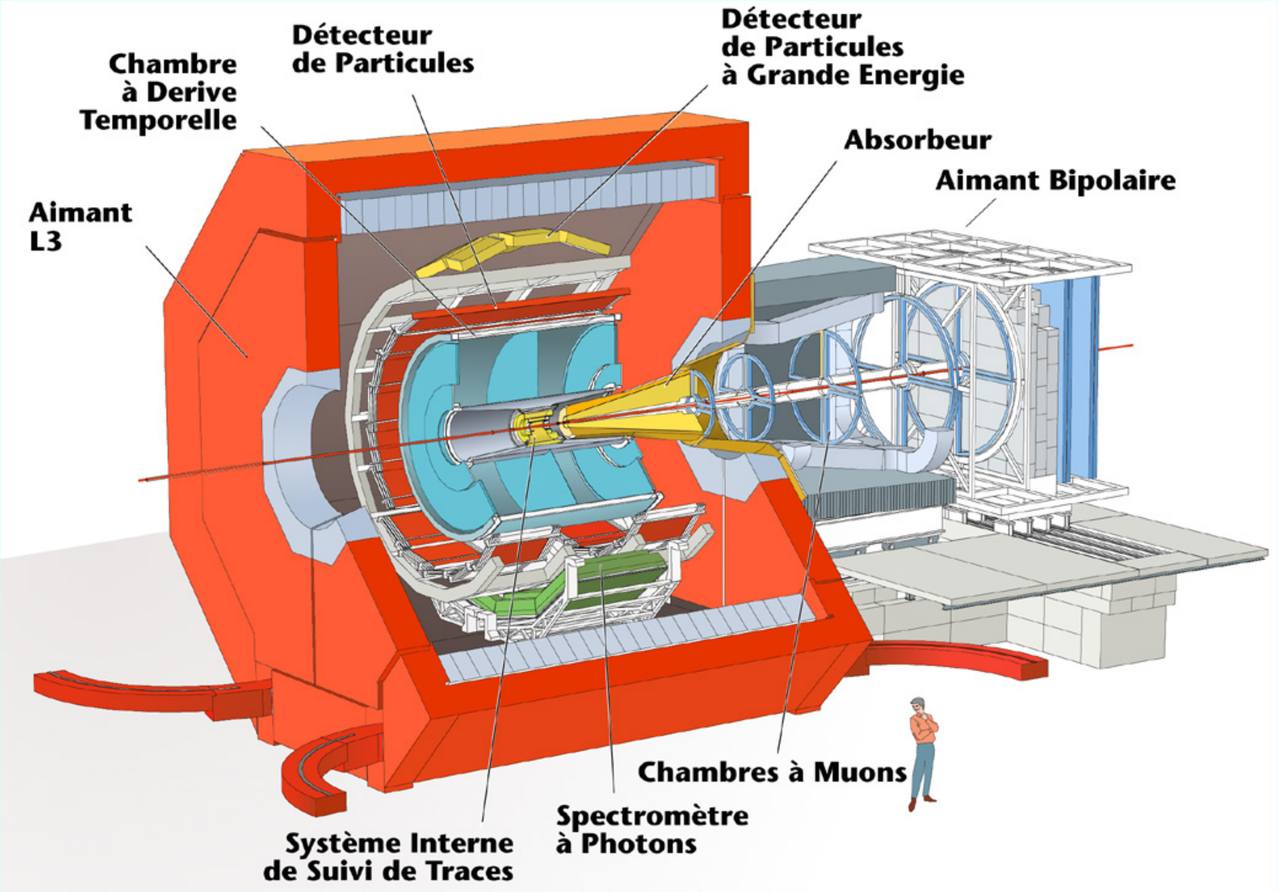




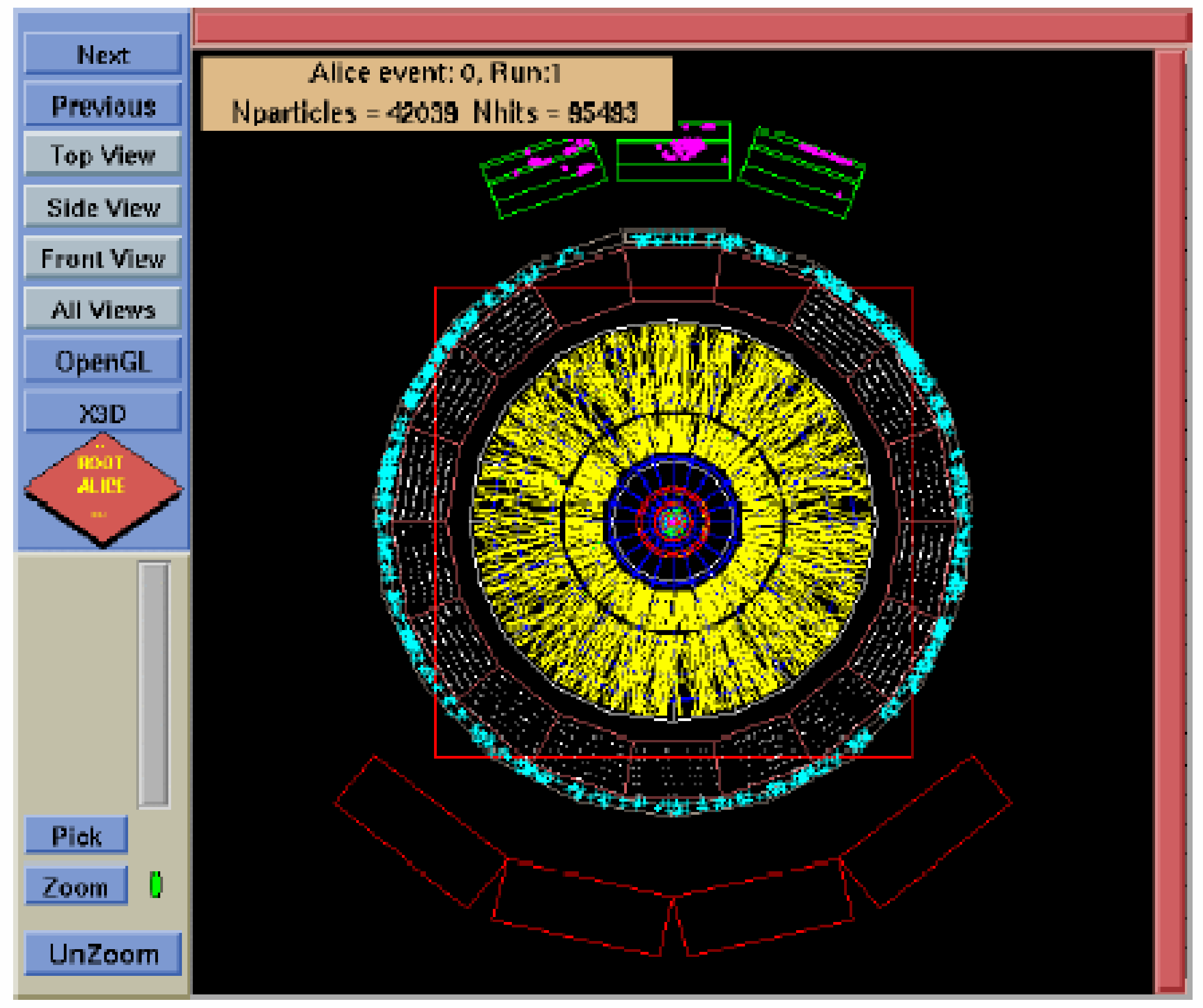




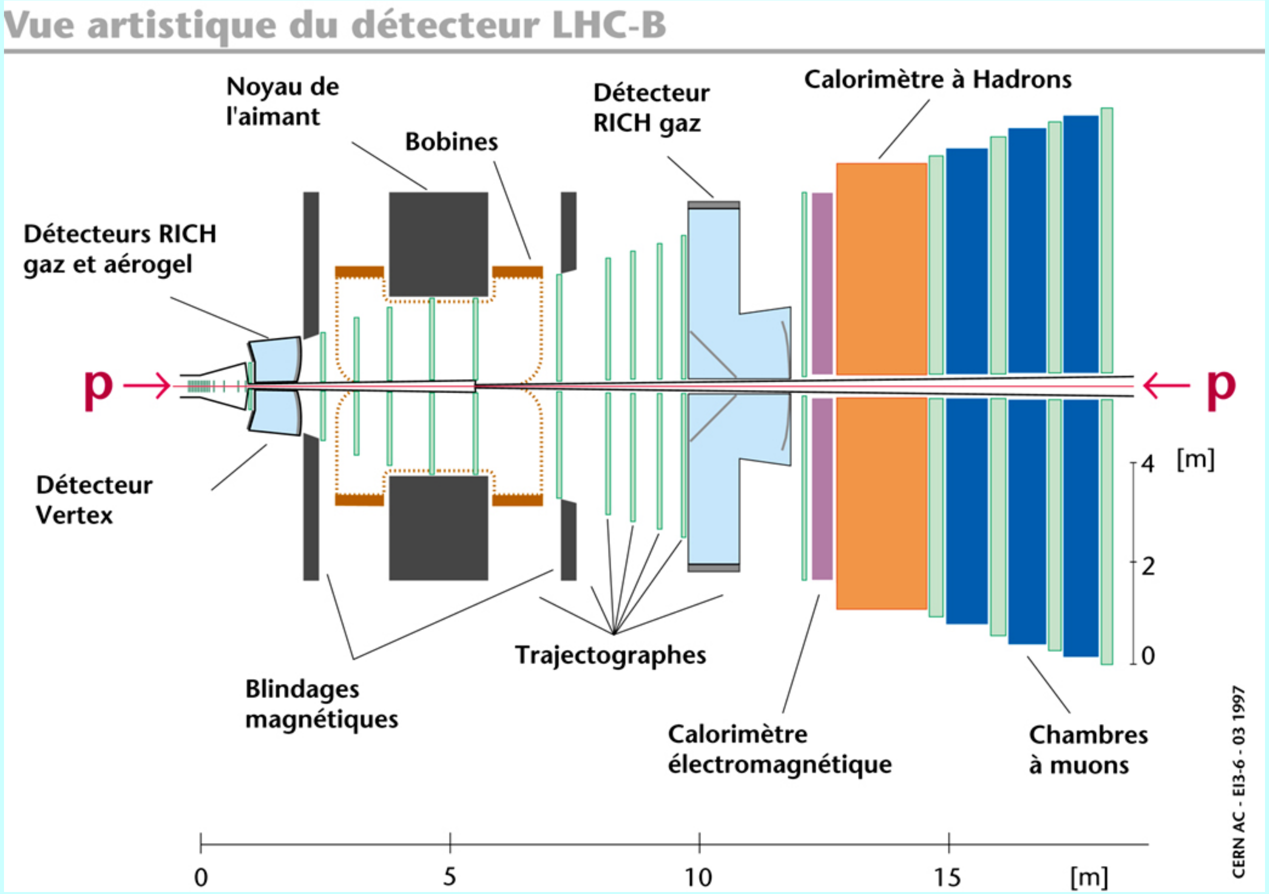
ALICE Detector



Typical ALICE Event



LHCb


Vue artistique du détecteur LHC-B
Noyau de l'aimant
Bobines
Détecteur RICH gaz
Calorimètre à Hadrons
Détecteurs RICH gaz et aérogel
p
p
Détecteur Vertex
4 [m]
2
0
Trajectographes
Blindages magnétiques
Calorimètre électromagnétique
Chambres à muons
CERN AC - EI3-6 - 03 1997
0
5
10
15
[m]

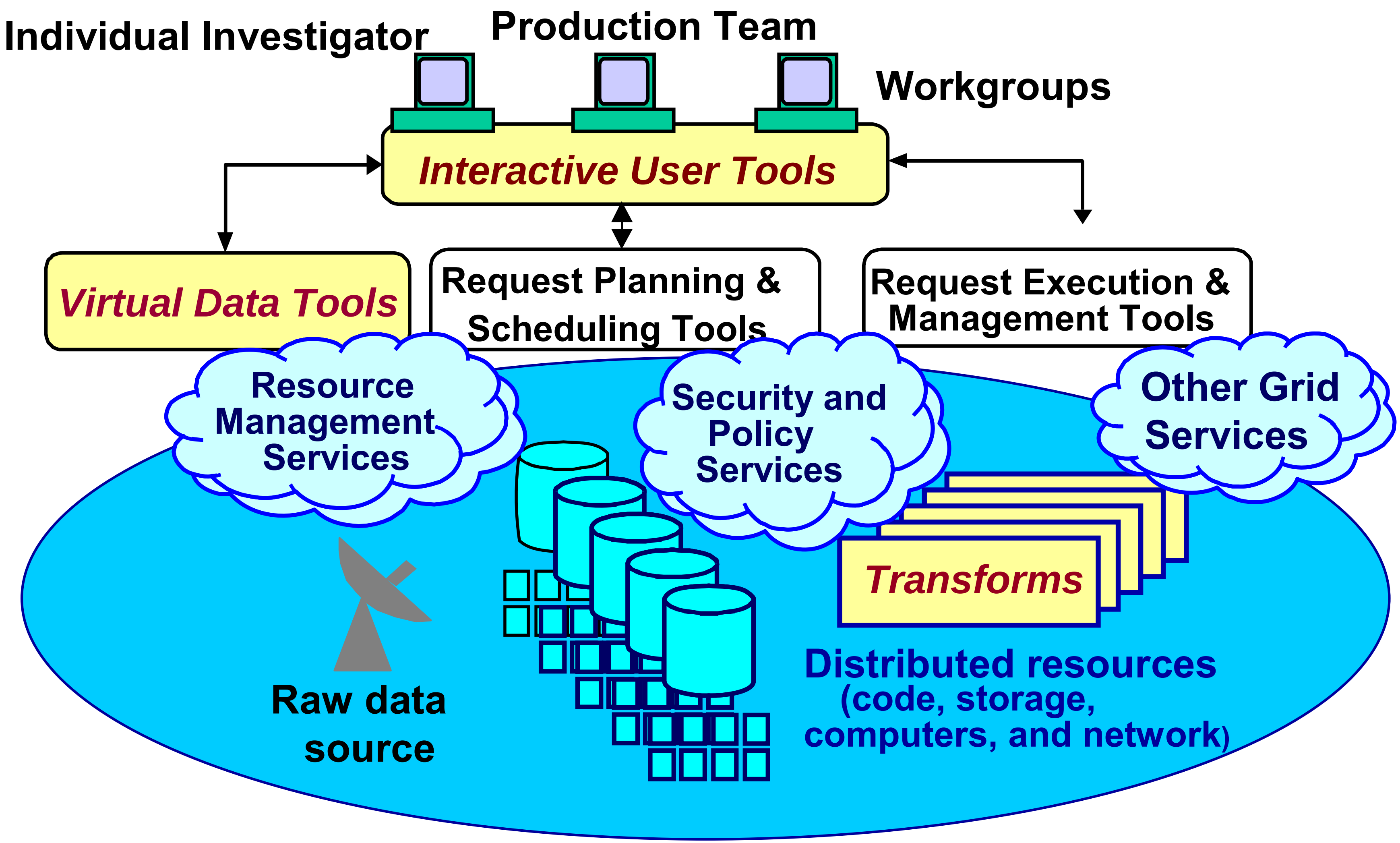
Computing at the LHC

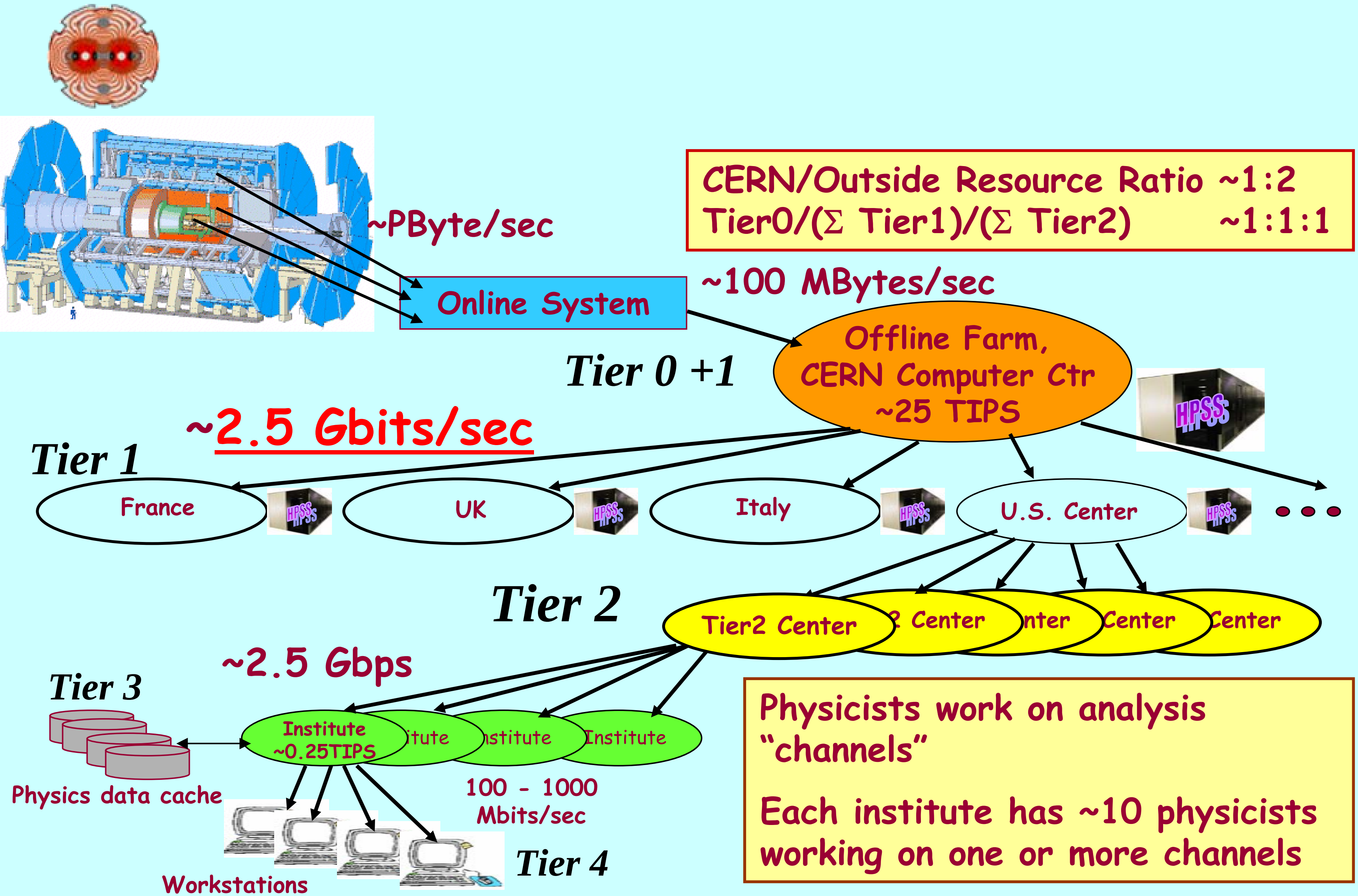
- Setting the scale: relative to Tevatron
  - Collaboration size: 5x (at turn-on)
  - Data volume: 10x (event size, output rate)
  - CPU requirements 100x (pattern recognition, complexity)
  - NB above numbers depend on factors such as trigger configuration, reconstruction algorithms etc.

Grid Computing

- Main issue: democracy of data access, locality of resources
- Design up-front the ability of collaborators to have seamless access to data, resources from home institutions
- Major elements:
  - Grid "middleware"
  - Hierarchy of computing centers

GriPhyN: PetaScale Virtual Data Grids




~PByte/sec
Online System
CERN/Outside Resource Ratio ~1:2
Tier0/(Σ Tier1)/(Σ Tier2) ~1:1:1
~100 MBytes/sec
Offline Farm,
CERN Computer Ctr
~25 TIPS
Tier 0 +1
HPSS
~2.5 Gbits/sec
Tier 1
France
UK
Italy
U.S. Center
• • •
Tier 2
Tier2 Center
~2.5 Gbps
Tier 3
Institute
~0.25TIPS
Physics data cache
100 - 1000
Mbits/sec
Physicists work on analysis "channels"
Each institute has ~10 physicists working on one or more channels
Workstations
Tier 4

CS-Physics Issues

- Resource requirement estimation from small set of parameters
- Interoperability in a heterogeneous environment
- Security, ease of use
- Virtual data: ability to make data "materialize" from an application signature

Summary Comments

- Physics at the LHC is exceedingly rich!
- We need experimental data for theories to advance
- Contact with symmetry breaking
- Accelerator, Detectors, Computing: All a challenge – complexity, backgrounds, energy