The LHC

R.J.Cashmore
Director of Research
CERN
1999-2003

- **Motivations**
- **Machine**
- **Experiments**
- **Computing**
- **Future**

Motivation for the LHC

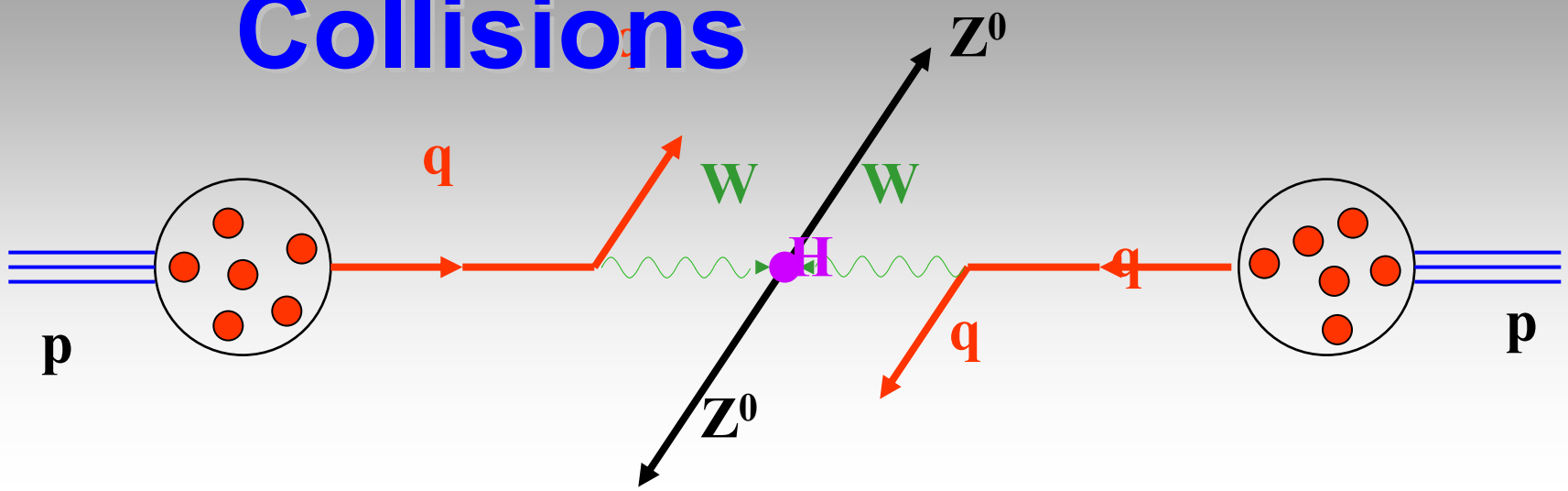
- Understand the origin of

  Mass or **Symmetry Breaking**

- Search for the **Higgs**

  M < 1 Tev

Higgs Production in pp Collisions



$M_H \sim 1000$ GeV

$E_W \geq 500$ GeV

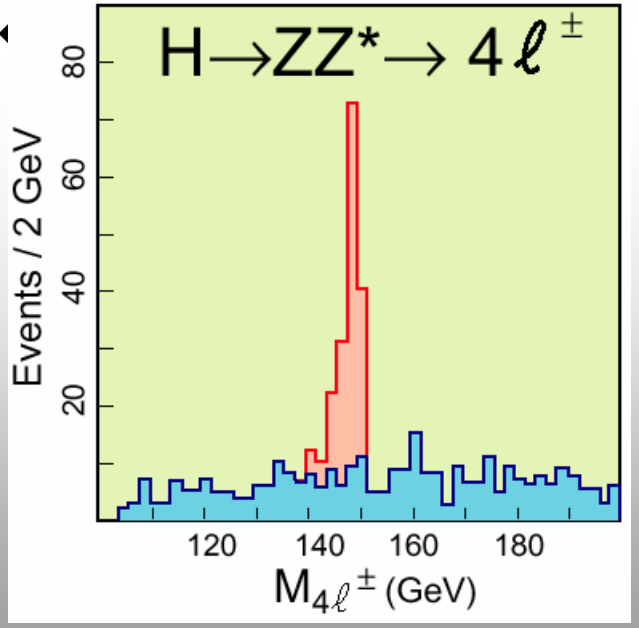
$E_q \geq 1000$ GeV (1 TeV)

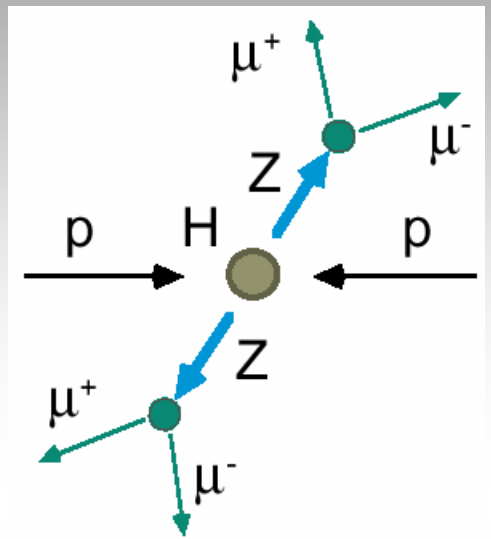
$E_p \geq 6000$ GeV (6 TeV)

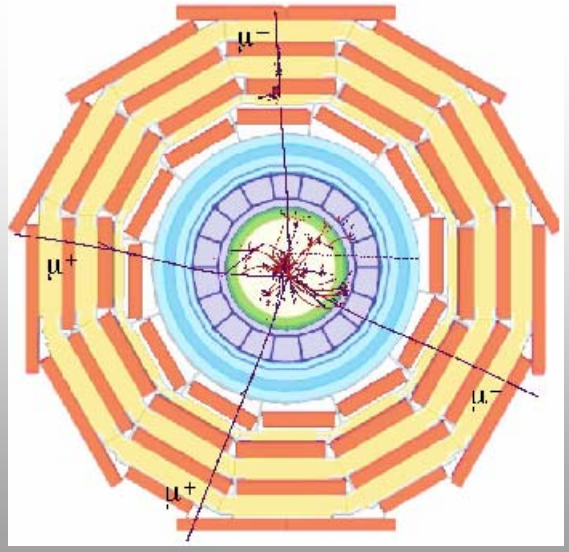
$\rightarrow$ Proton Proton Collider with $E_p \geq 7$ TeV

Intermediate mass Higgs

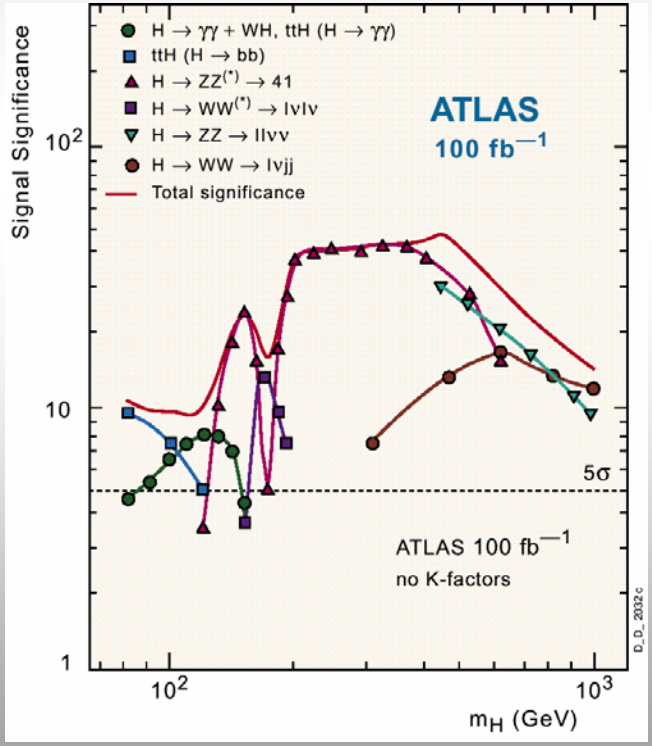
- $H \rightarrow ZZ \rightarrow \ell^+\ell^- \ell^+\ell^-$ (ℓ =e,μ)
  - Very clean
    - Resolution: better than 1 GeV (around 100 GeV mass)

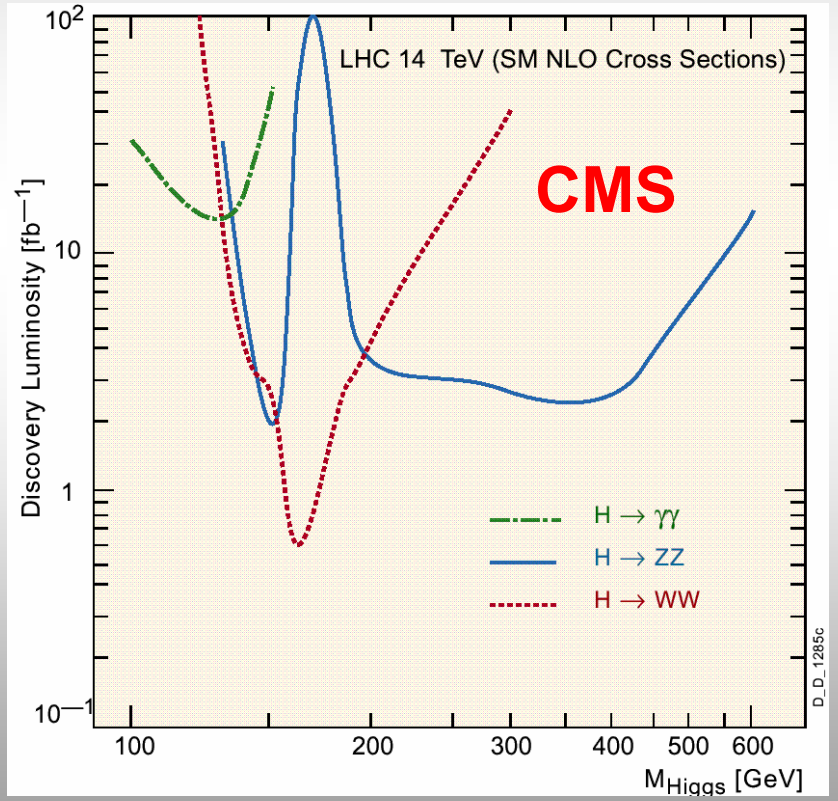




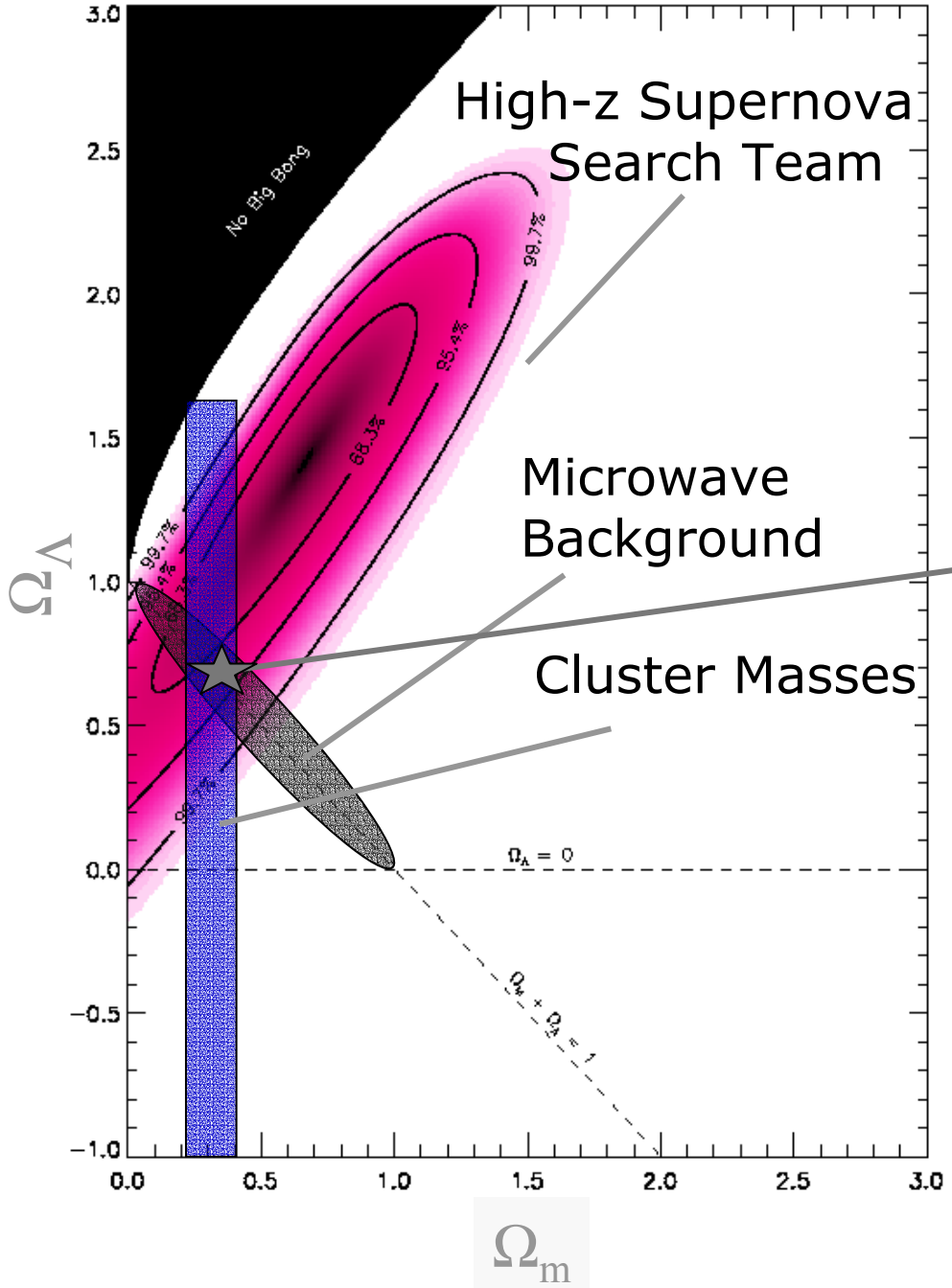


Higgs discovery prospects @ LHC





Dark Matter in the Universe



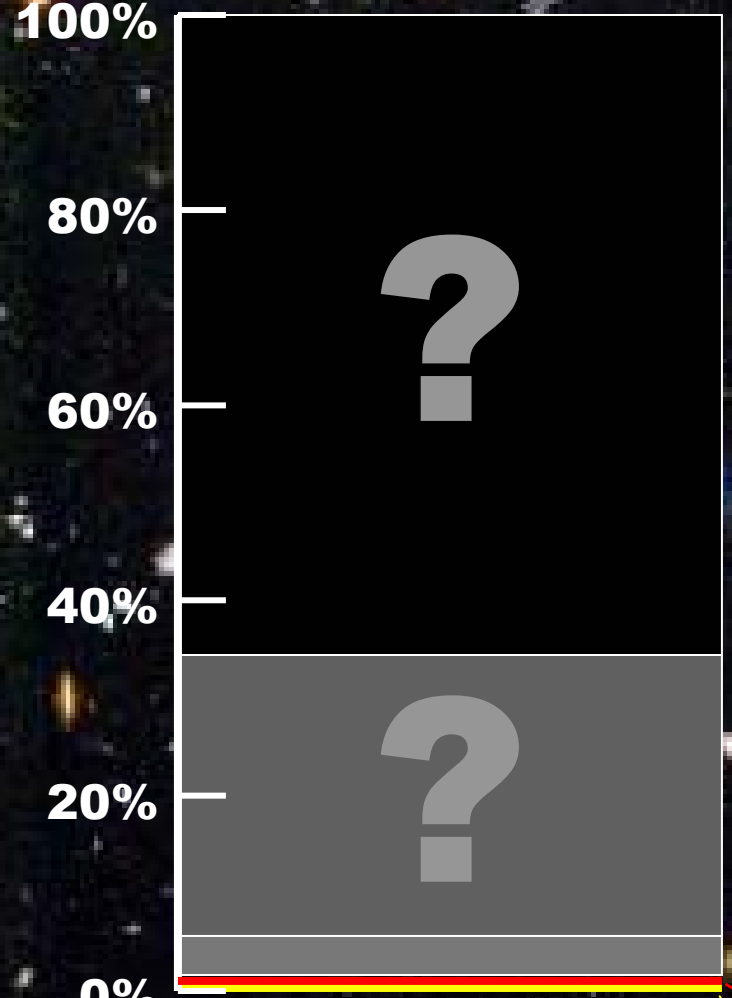
Best fit:

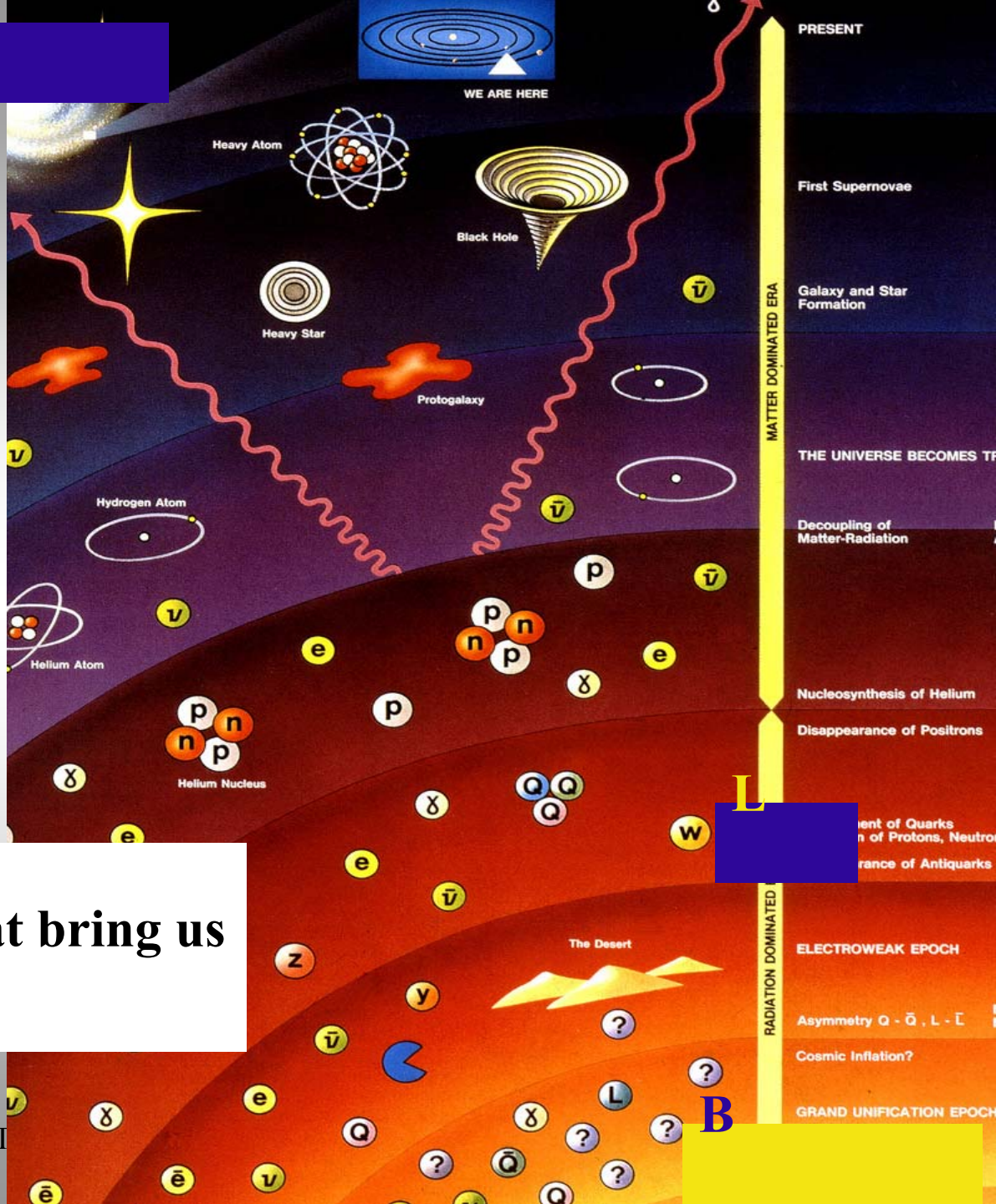
$\Omega_{mass} \sim 0.3$

$\Omega_\Lambda \sim 0.7$

Λ?

Our view of the Universe





T

T

L

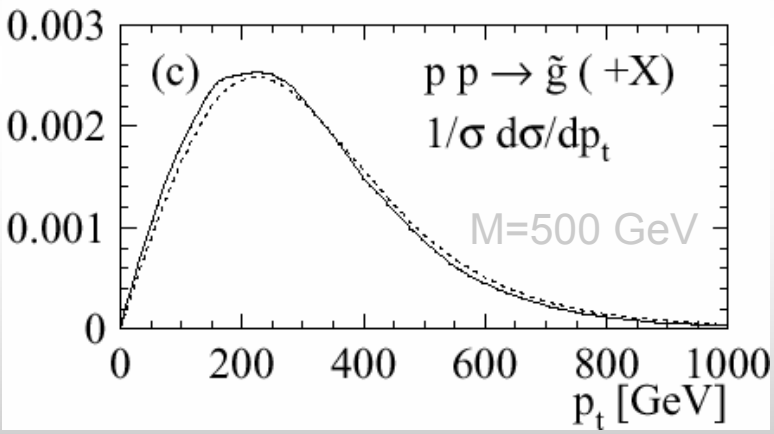
B

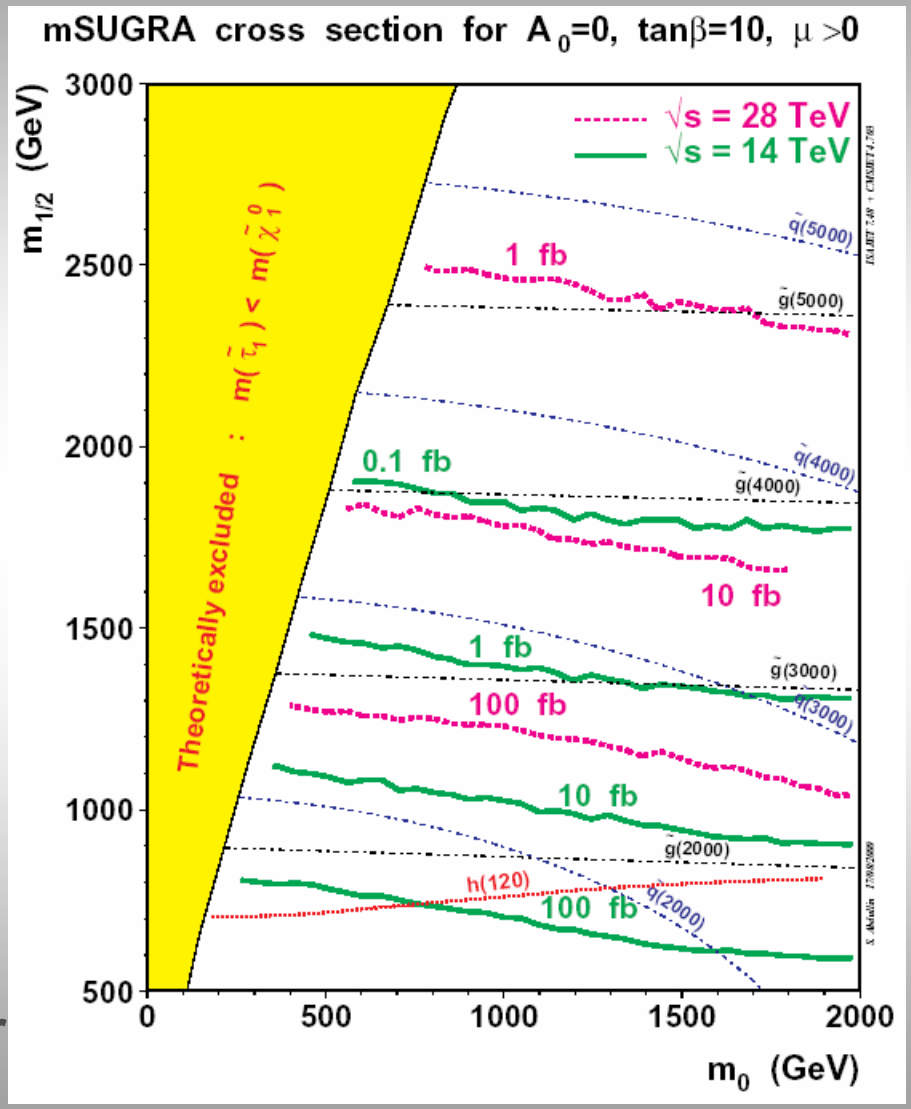
Particle Accelerators

are Time-Machines that bring us

SUSY @ LHC

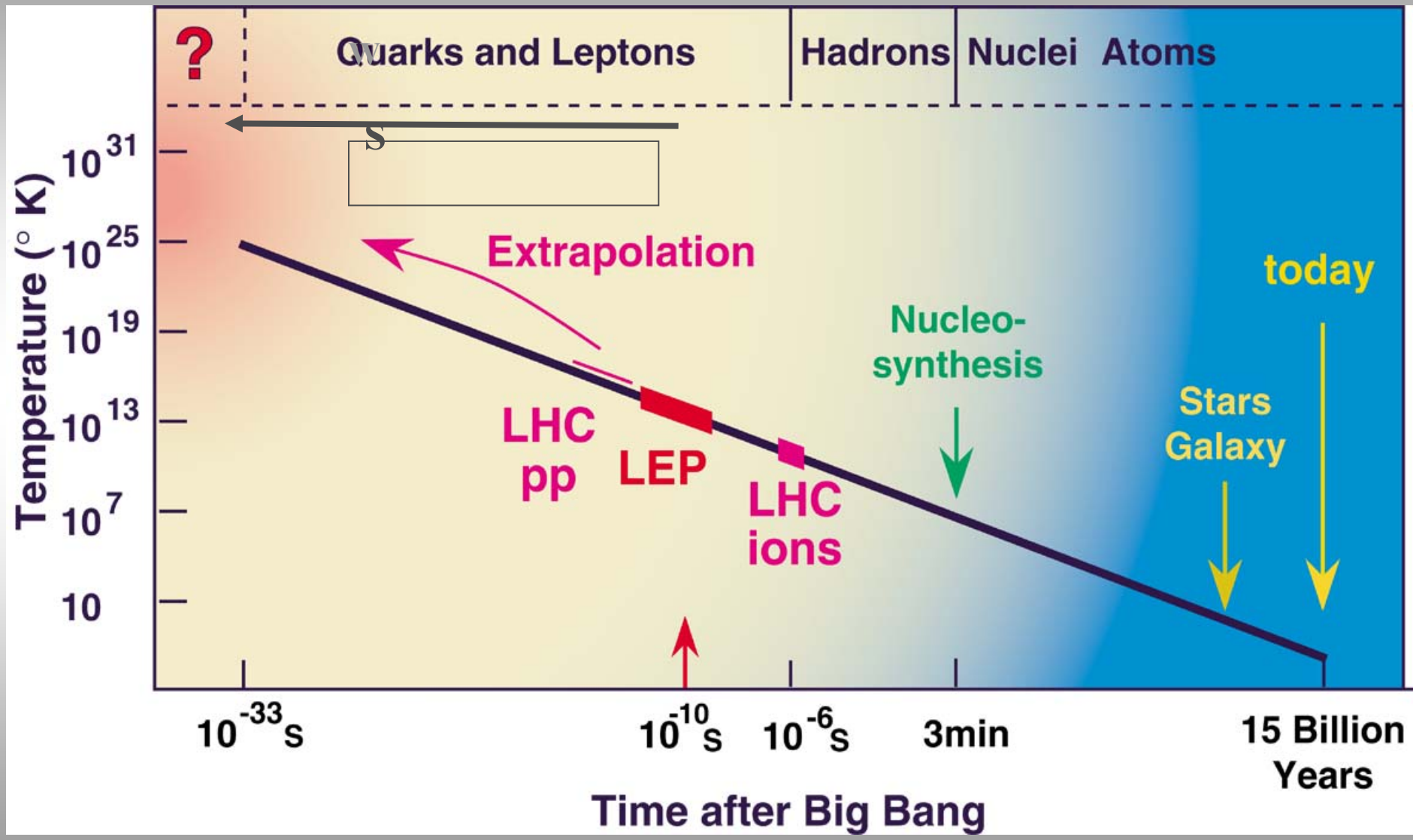
M_{sp}(GeV)	σ (pb)	Evts/yr
500	100	10^6-10^7
1000	1	10^4-10^5
2000	0.01	10^2-10^3





- Gauginos produced in their decay; example: $q_L \rightarrow \chi_2^0 q_L$

Towards the origin



The LHC

MUCH MORE than the HIGGS

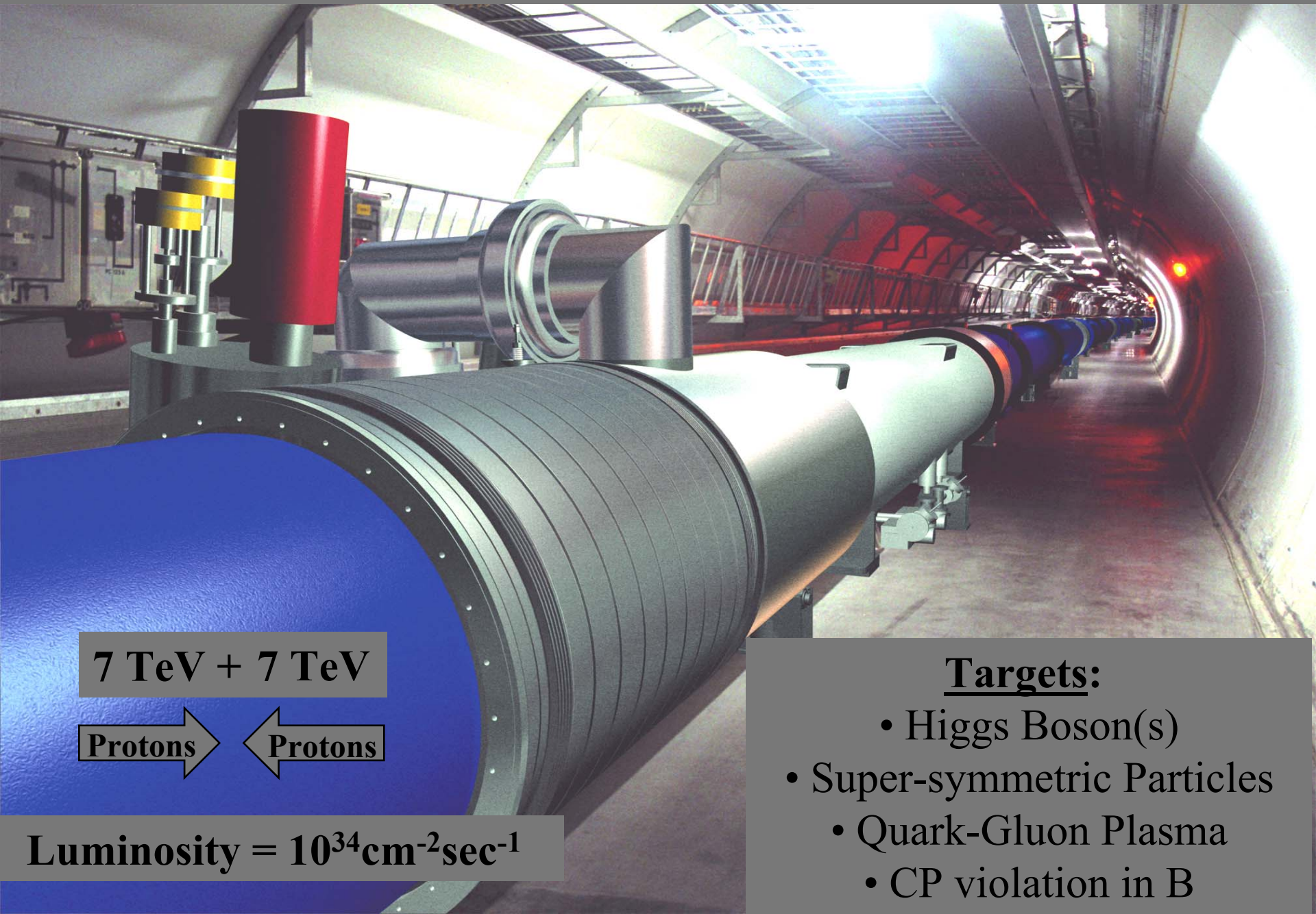
The LHC

- **pp collider**

but also

- **Pb Pb collider**

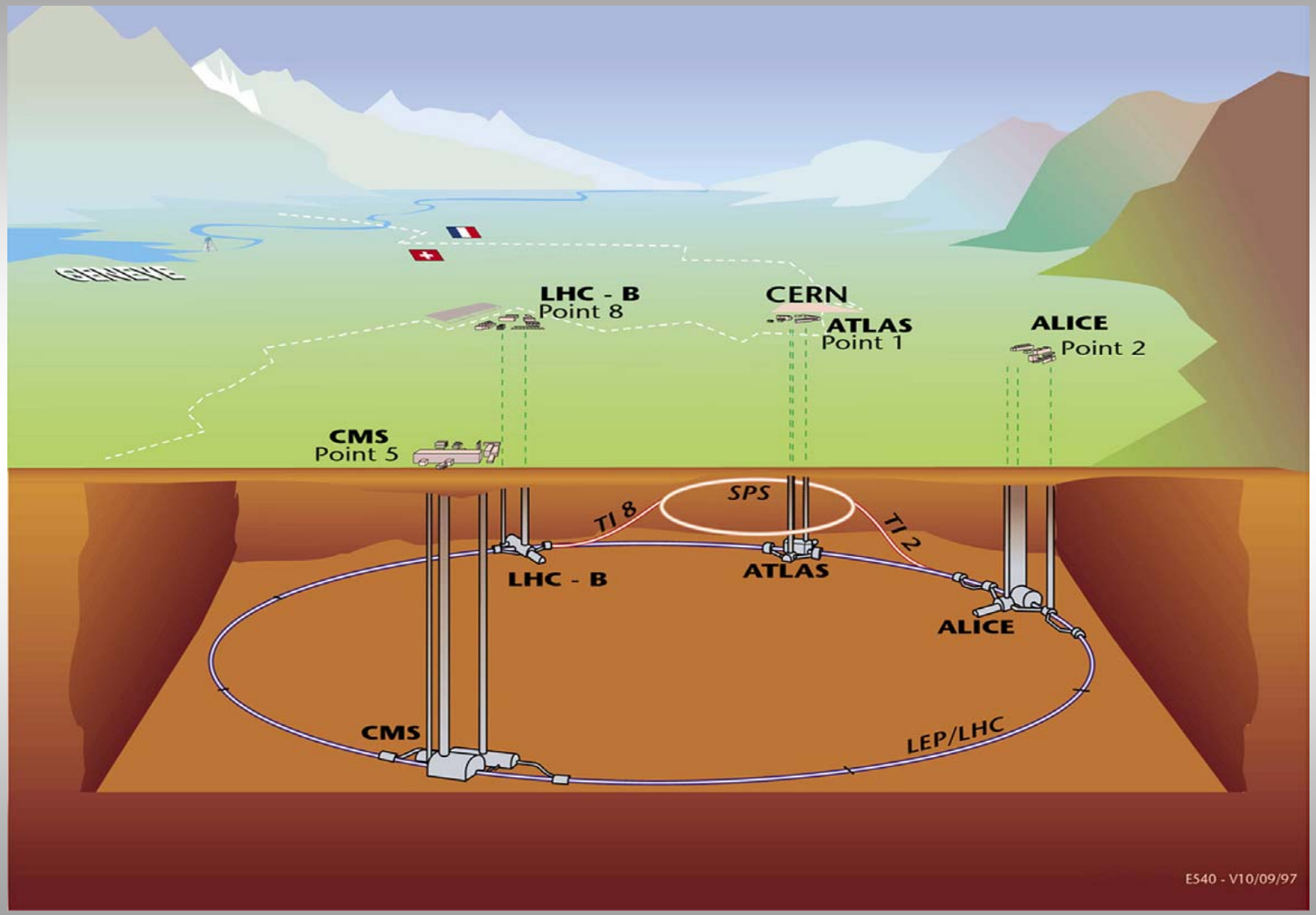
The Large Hadron Collider (LHC)



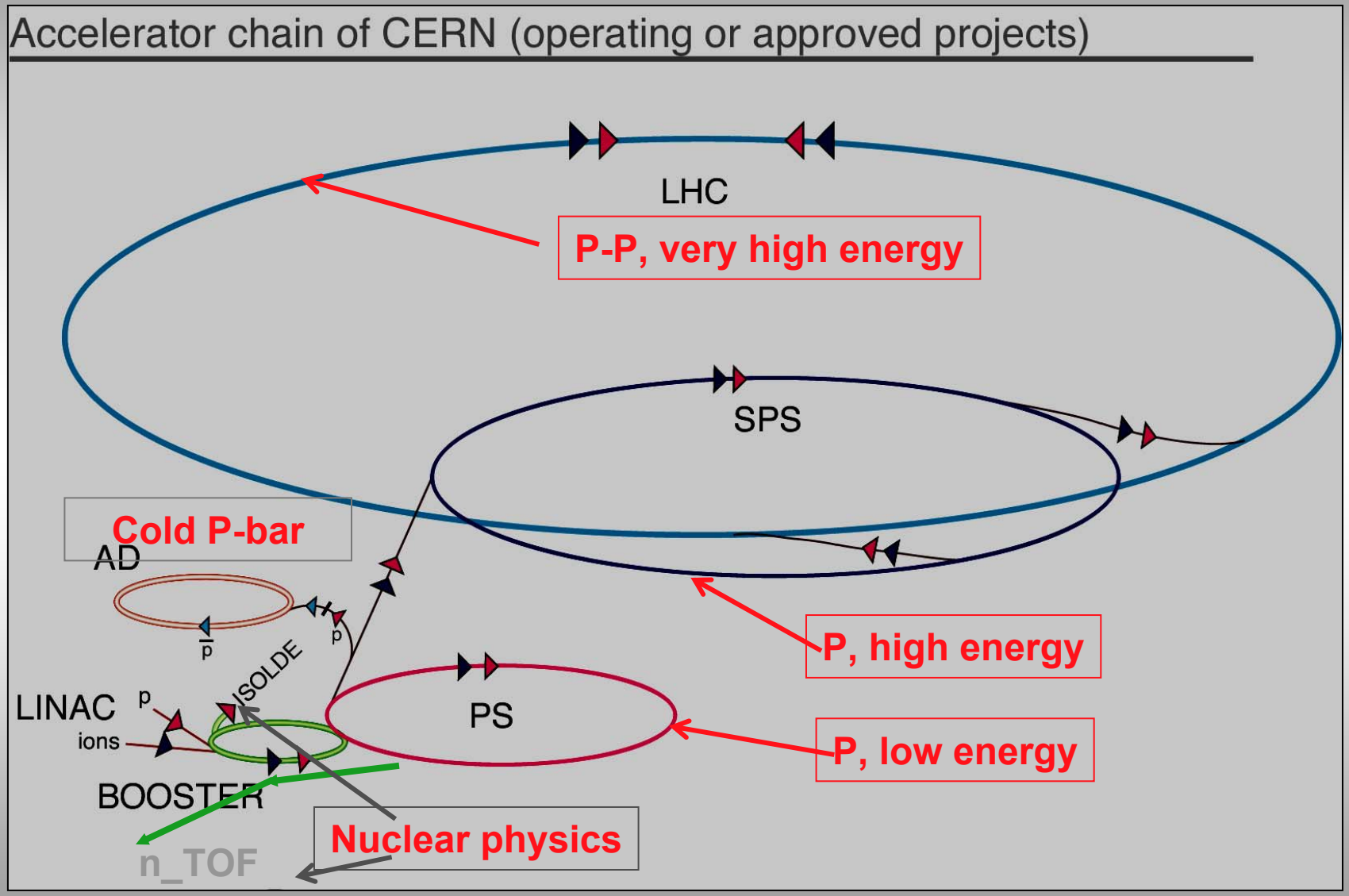
Targets:

- Higgs Boson(s)
- Super-symmetric Particles
- Quark-Gluon Plasma
- CP violation in B

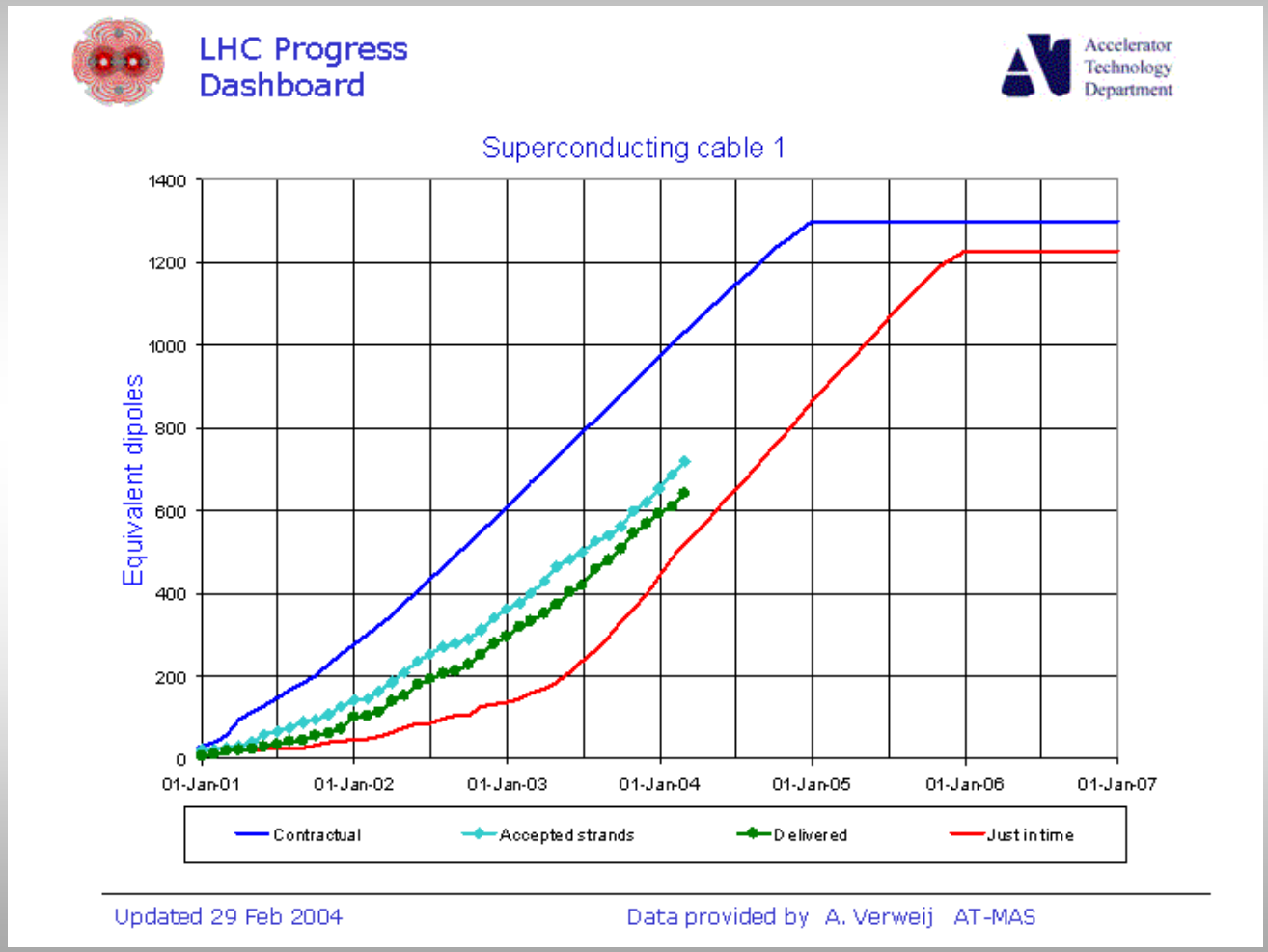
Overall View of the Large Hadron Collider (LHC)



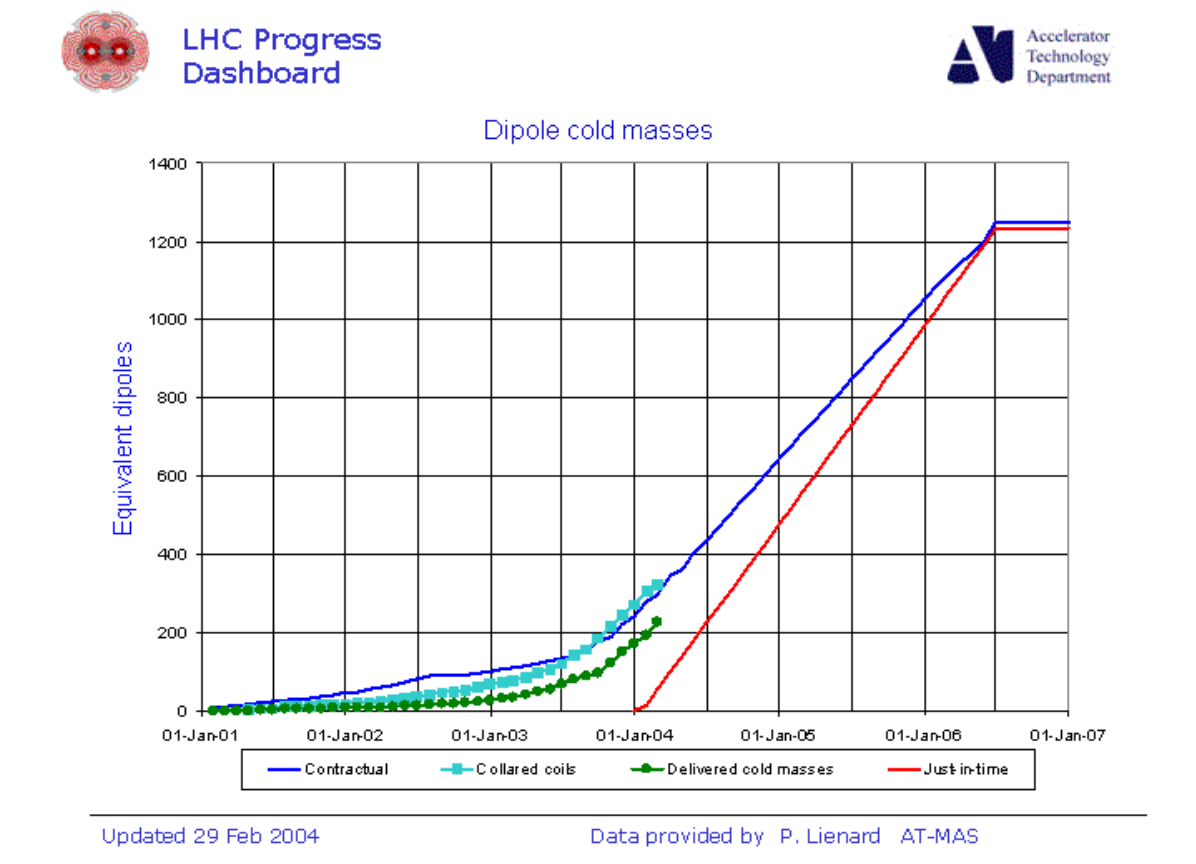
Accelerator chain of CERN



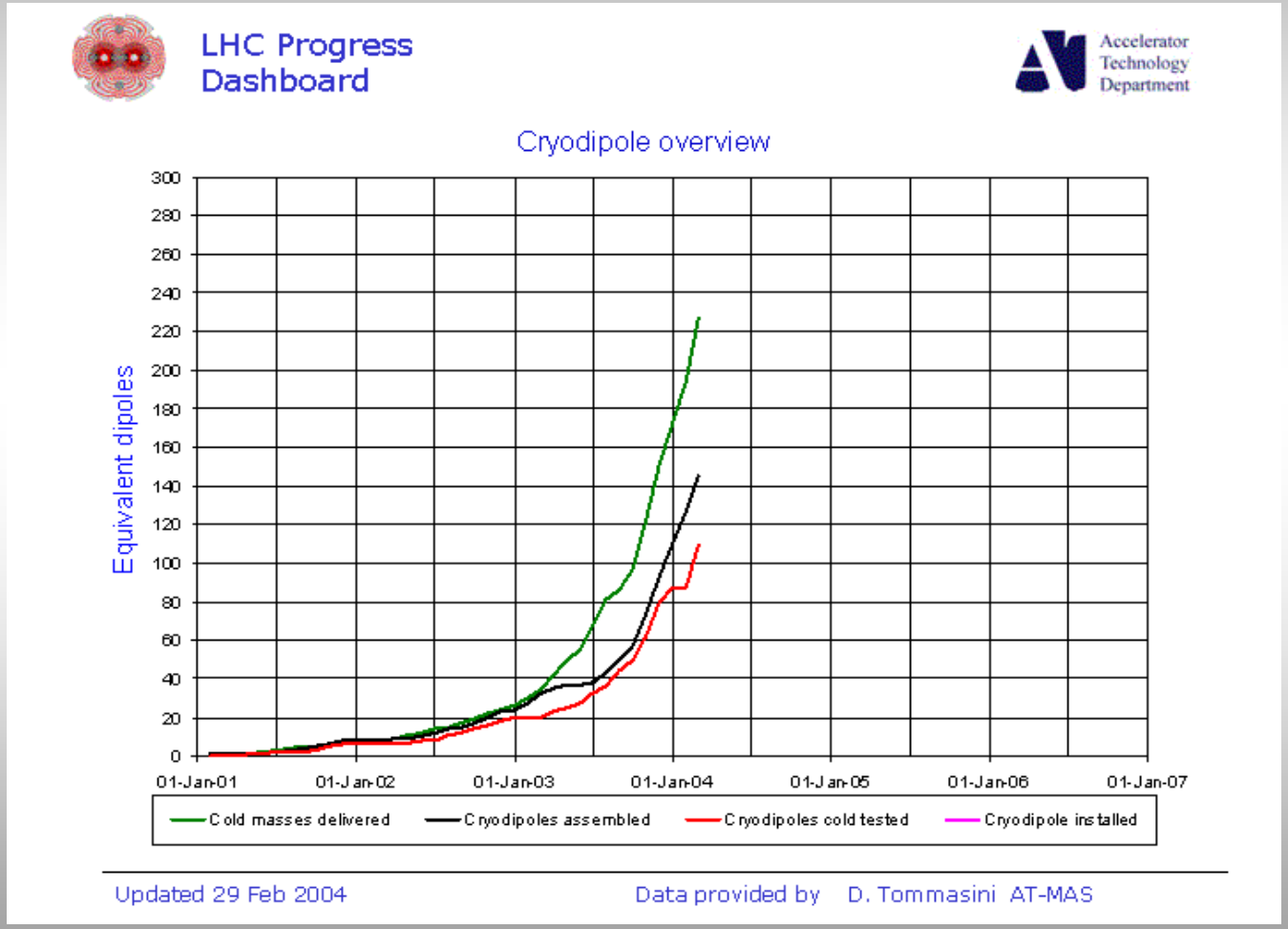
Cable 1


LHC Progress Dashboard
Accelerator Technology Department
Superconducting cable 1
Equivalent dipoles
1400
1200
1000
800
600
400
200
0
01-Jan-01
01-Jan-02
01-Jan-03
01-Jan-04
01-Jan-05
01-Jan-06
01-Jan-07
Contractual
Accepted strands
Delivered
Just in time
Updated 29 Feb 2004
Data provided by A. Verweij AT-MAS

Dipoles


LHC Progress Dashboard
Accelerator Technology Department
Dipole cold masses
Equivalent dipoles
1400
1200
1000
800
600
400
200
0
01-Jan-01
01-Jan-02
01-Jan-03
01-Jan-04
01-Jan-05
01-Jan-06
01-Jan-07
Contractual
Collared coils
Delivered cold masses
Just-in-time
Updated 29 Feb 2004
Data provided by P. Lienard AT-MAS

Cryodipoles



QRL Problems

- Conflicts between main contractor and installation subcontractor have caused many delays and finally CERN was informed of a change of subcontractor in January. Overall delay is now 8 months.
- The contractor has produced a new planning to recover the delays but this compresses the time for installation and testing.
- A new installation planning is being optimised to recover the delays. This is based on installation of 3 octants simultaneously.

Machine Summary

- **Schedule is very tight**
- **But …. The Schedule is VITAL**

Collisions in summer 2007

LHC Experiments

ATLAS, CMS:
- Higgs boson(s)
- SUSY particles
- ...??

ALICE:

Quark Gluon Plasma

LHC-B:

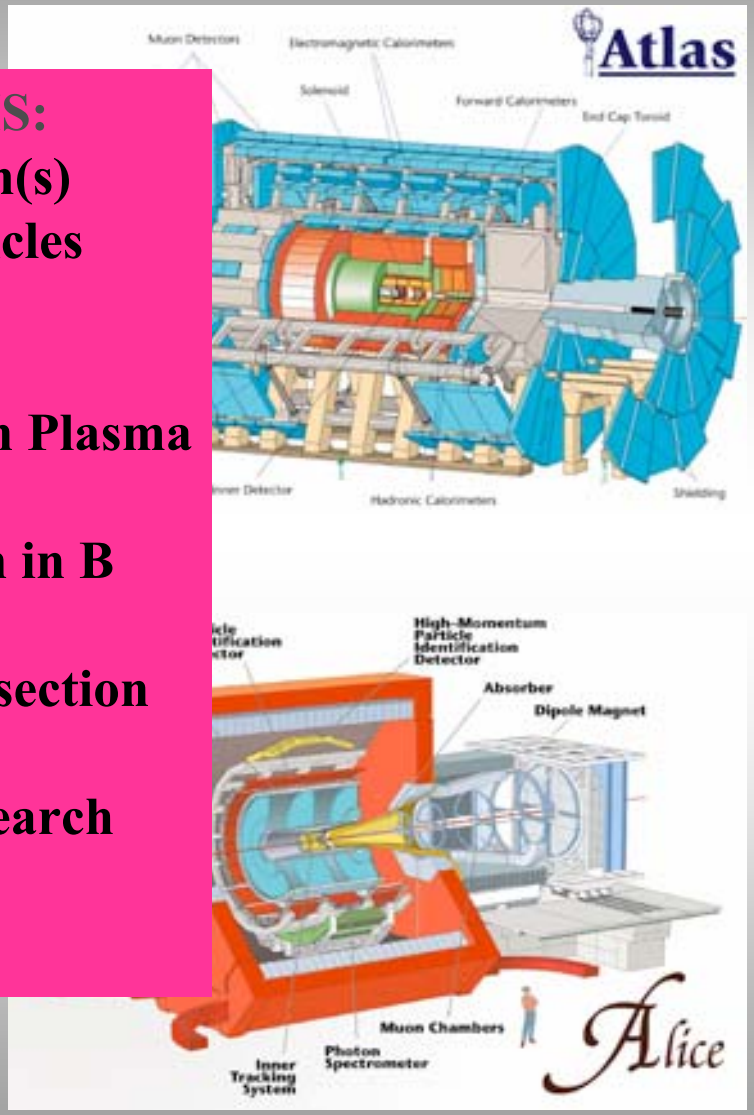
-CP violation in B

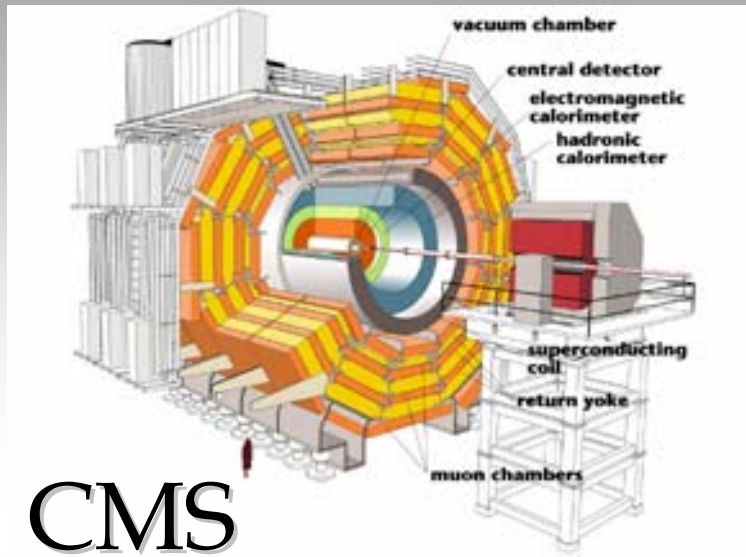
TOTEM:

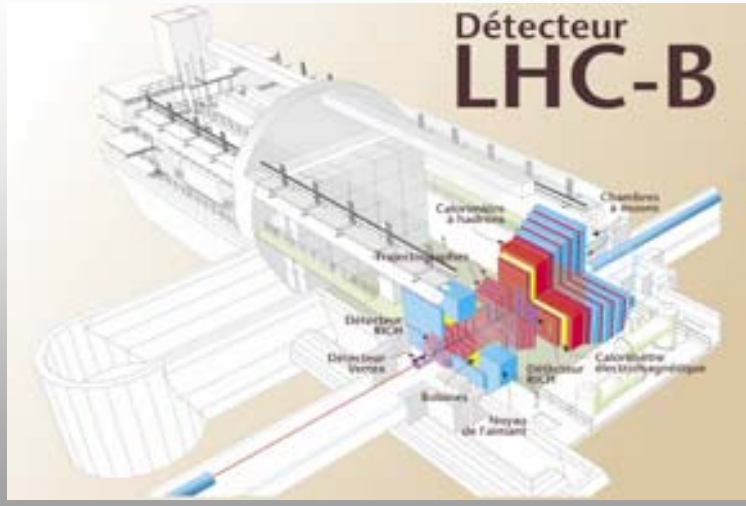
-Total cross-section

MOEDAL:

-Monopole search







LHC Experiments

ATLAS, CMS:

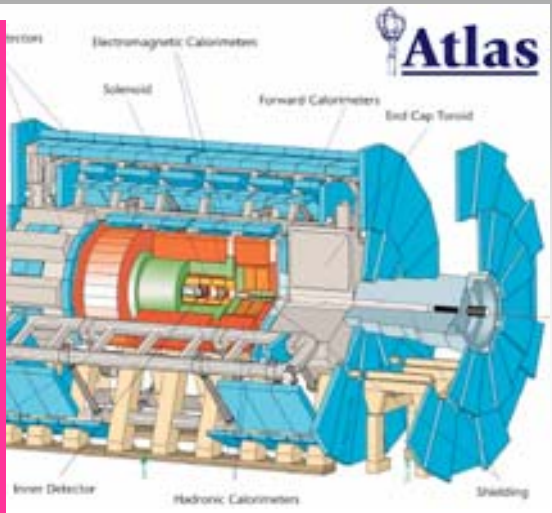
- **-Cost 1050 MCHF**
- **-Scientists 3720**
- **-Institutes 301**
- **-Countries ~50**

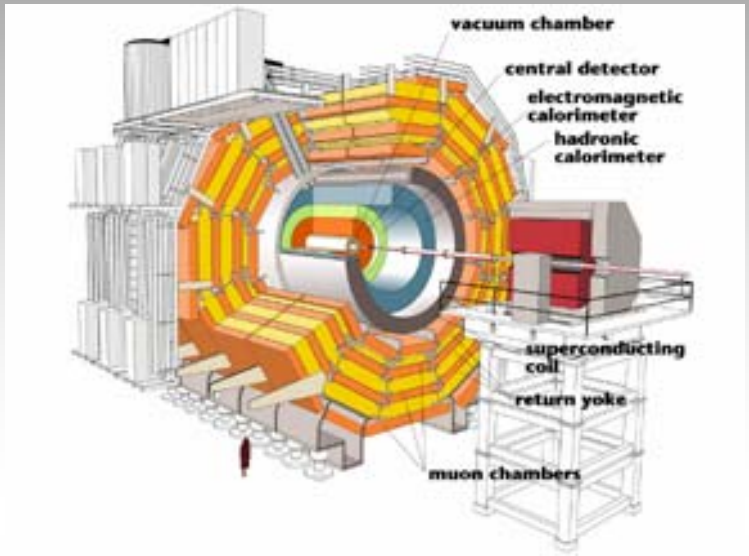
ALICE:

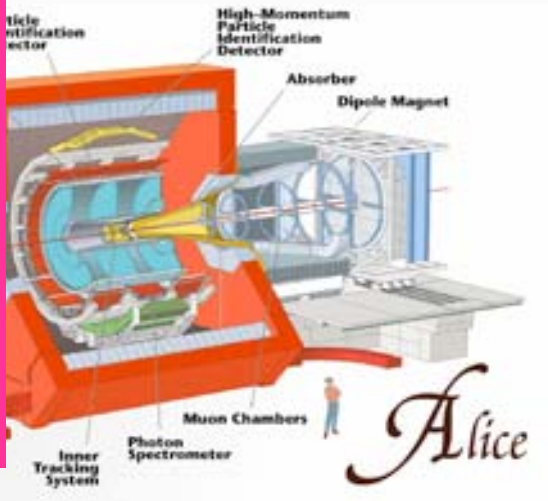
- **-Cost 125 MCHF**
- **-Scientists 1020**
- **-Institutes 80**
- **-Countries 28**

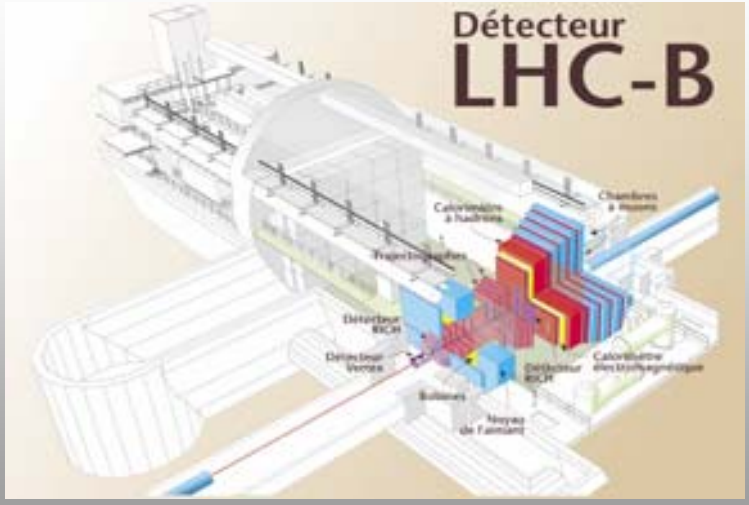
LHC-B:

- **-Cost 75 MCHF**
- **-Institutes 47**
- **-Scientists 501**
- **-Countries 13**



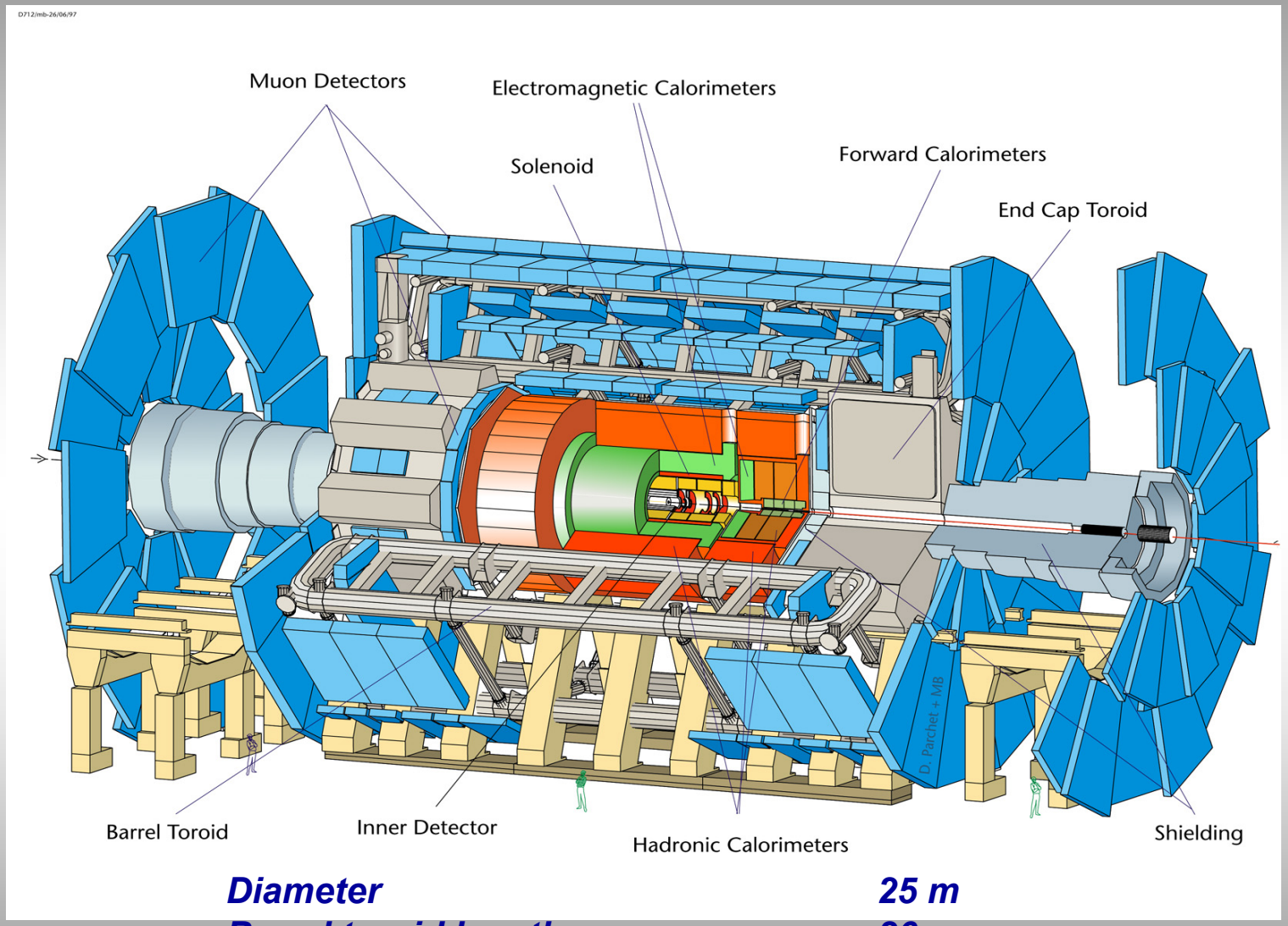






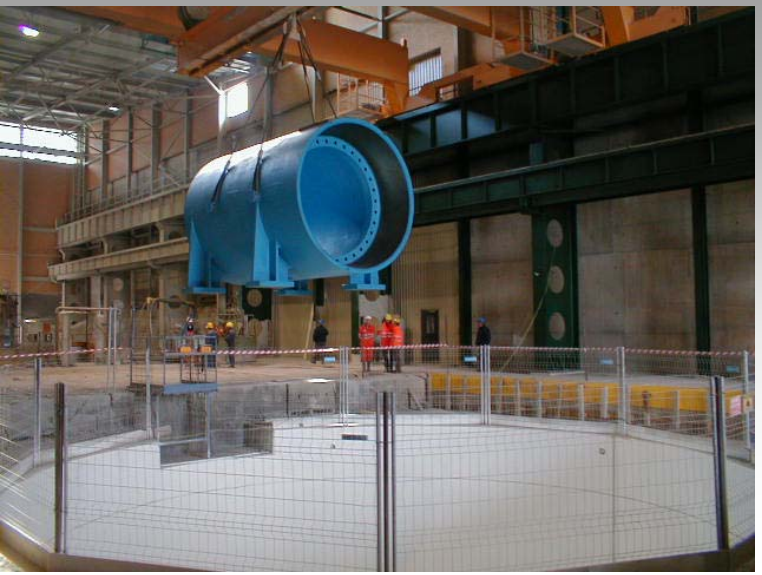
Transverse View

ATLAS



Diameter	***25 m***
Barrel toroid length	***26 m***
End-cap end-wall chamber span	***46 m***
Overall weight	***7000 Tons***

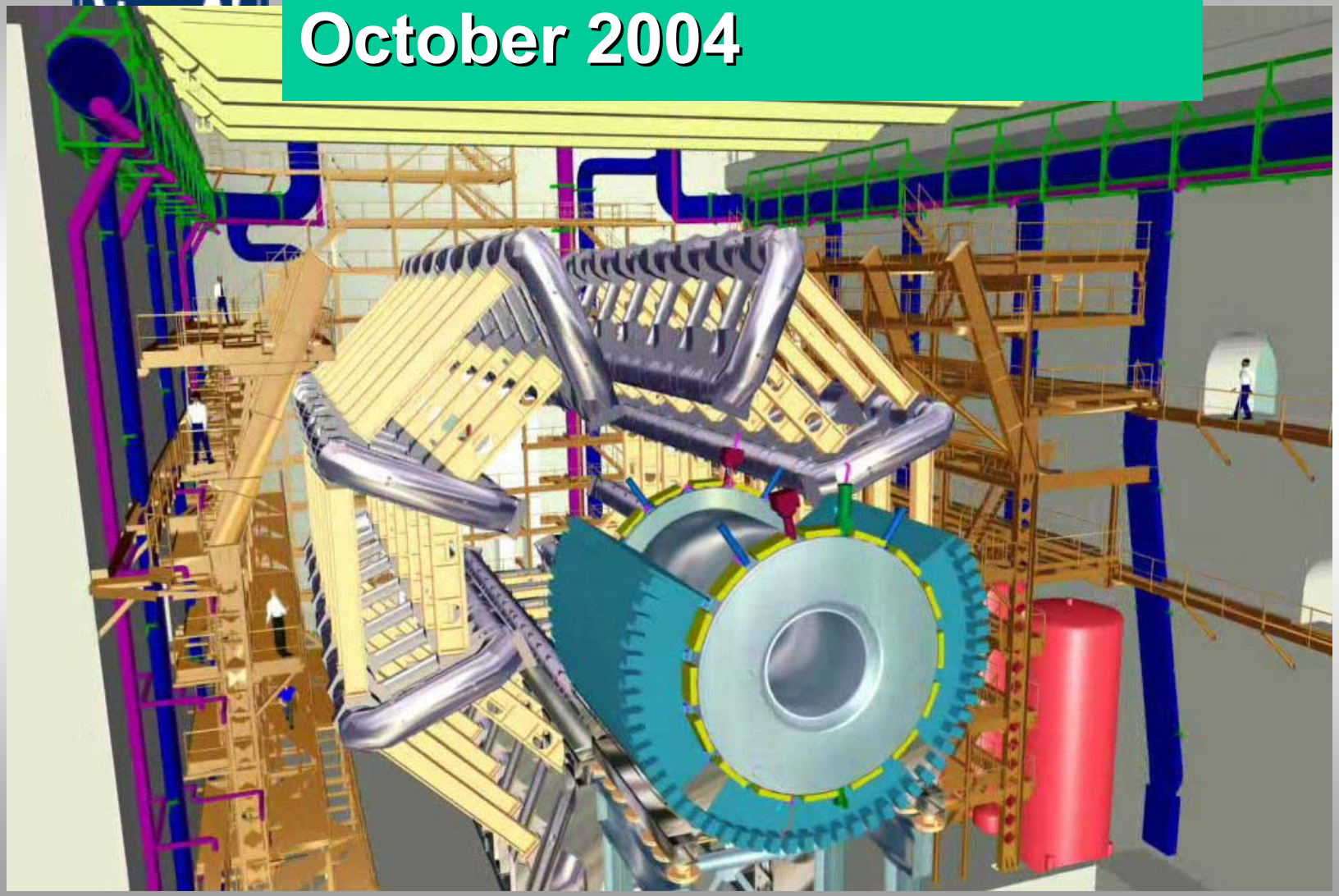
First detector elements installed TX1S shielding



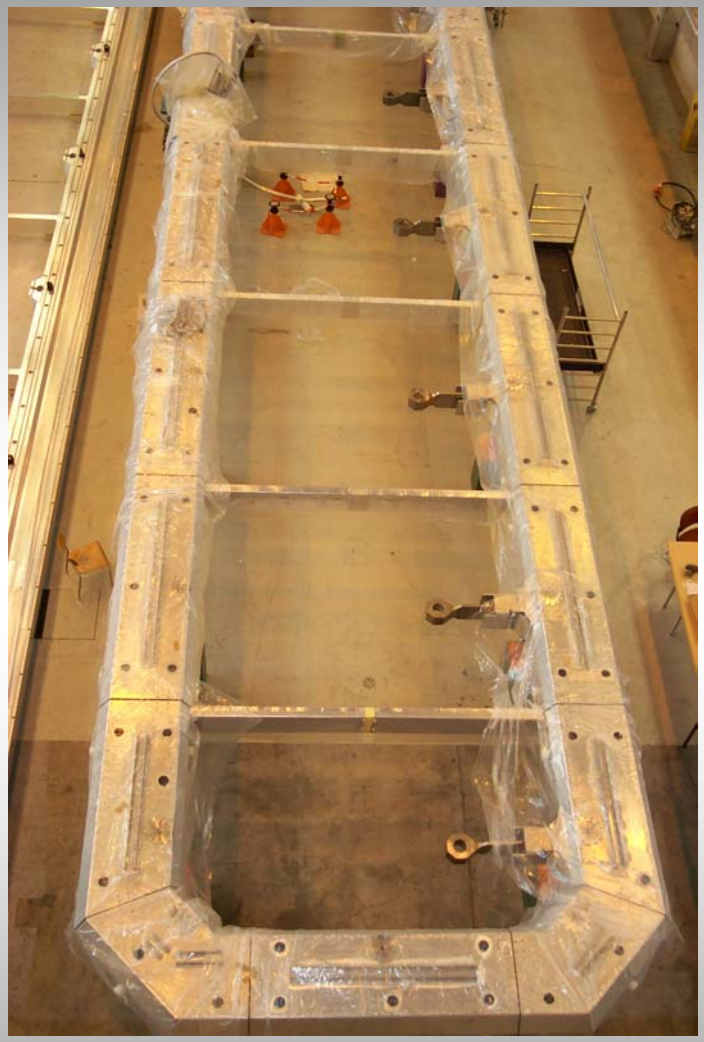
7 April 2003

Status of the ATLAS cavern on 25th February 2004 (just before the Tile Calorimeter installation)

ATLAS as planned for October 2004



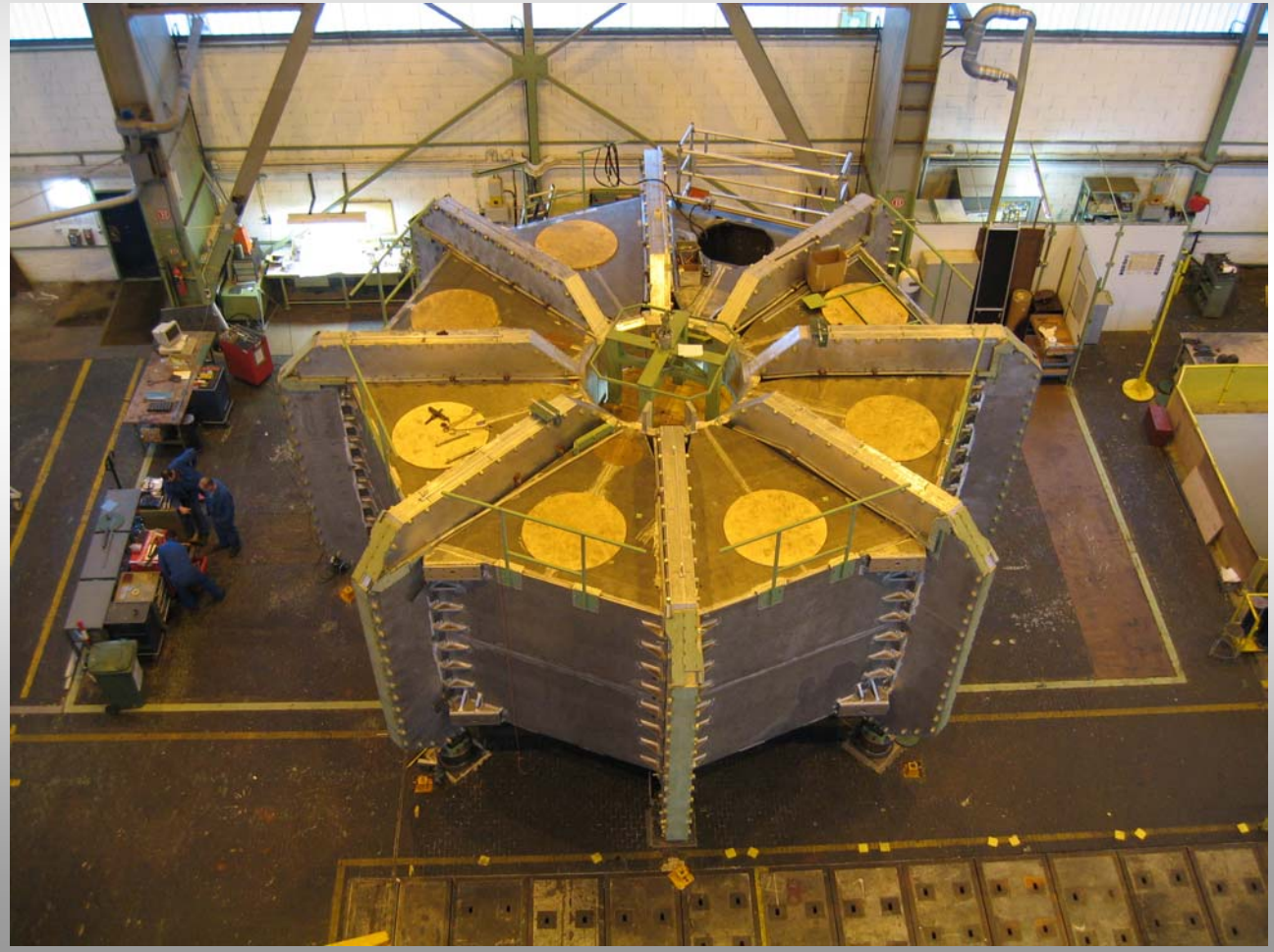
- A serious delay:
- First coil now ready for test by middle
- of May, and ready for installation end of
- July 2004 (5 months delay)
- Last coil in March 2005



The end-cap toroid assembly proceeds with the cold mass fabrication at the factory (all 16 coils are wound, and the first eight for ECT-1 are impregnated)

Final integration into the vacuum vessels (ready since some time) will start in May 2004 at CERN

The project has been reorganized with the cooling line welding being done at CERN during integration

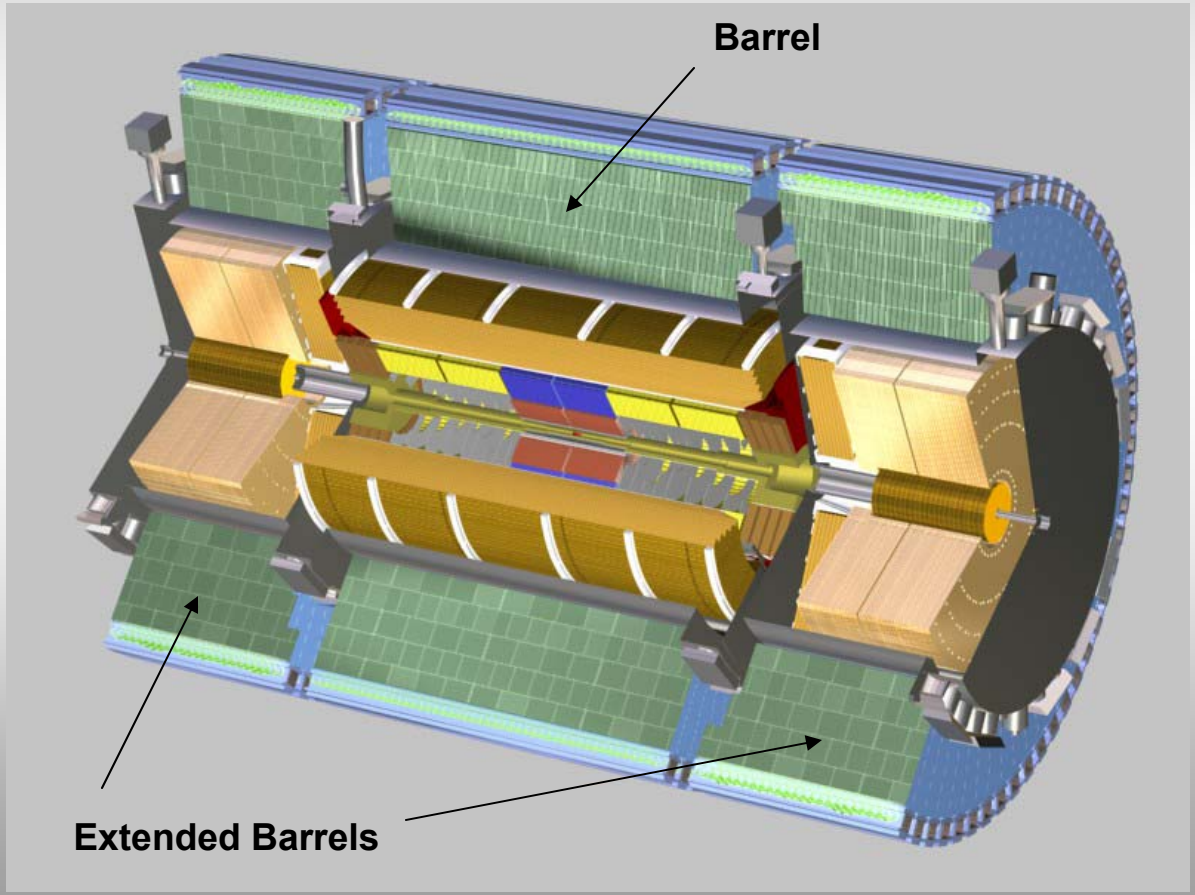


First of the two ECT cold masses pre-assembled

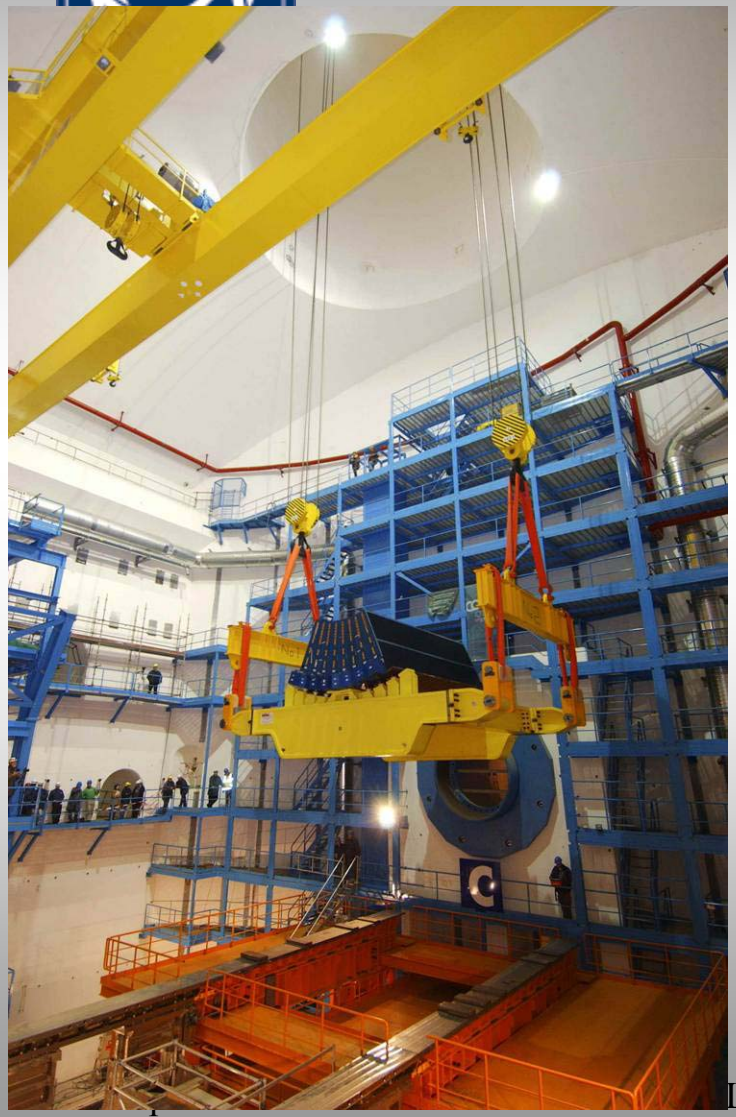
Tile Calorimeter

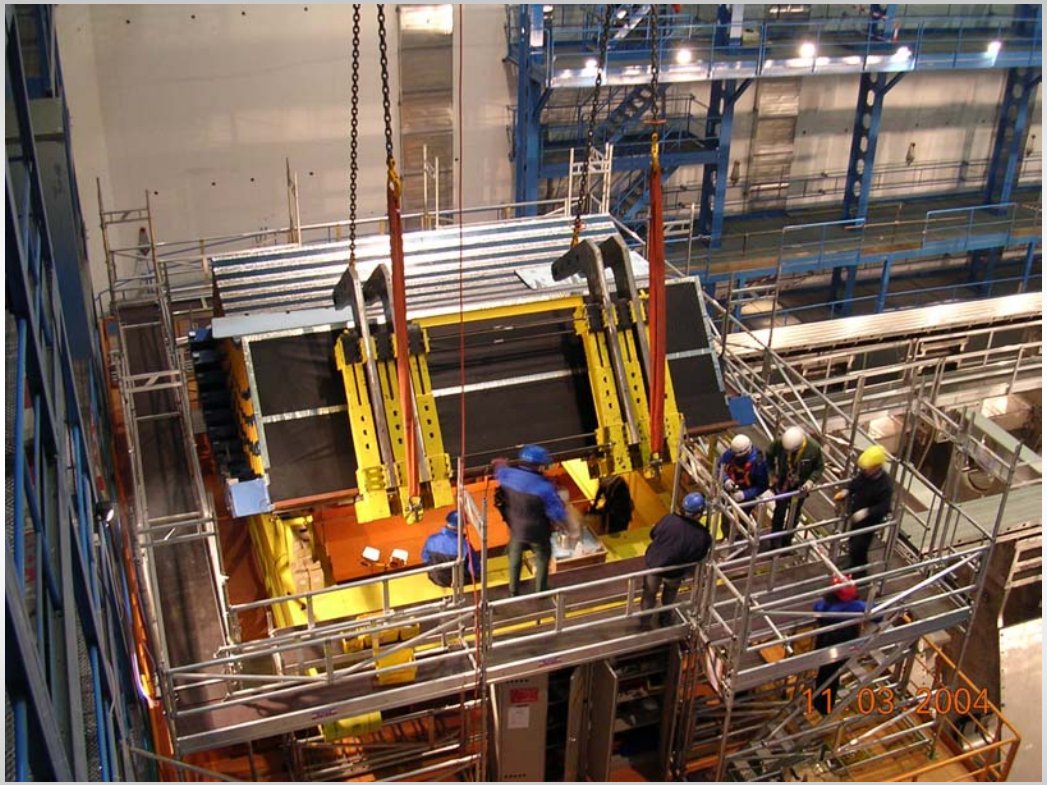
The module construction and instrumentation with their optical components (scintillators and fibres) is finished for all three cylinders

The next major step is the pre-assembly of the complete Tile Calorimeter cylinders, in order to gain time and experience for the installation (shimming)



The final barrel Tile Calorimeter assembly in the experimental cavern has started on March 1st 2004

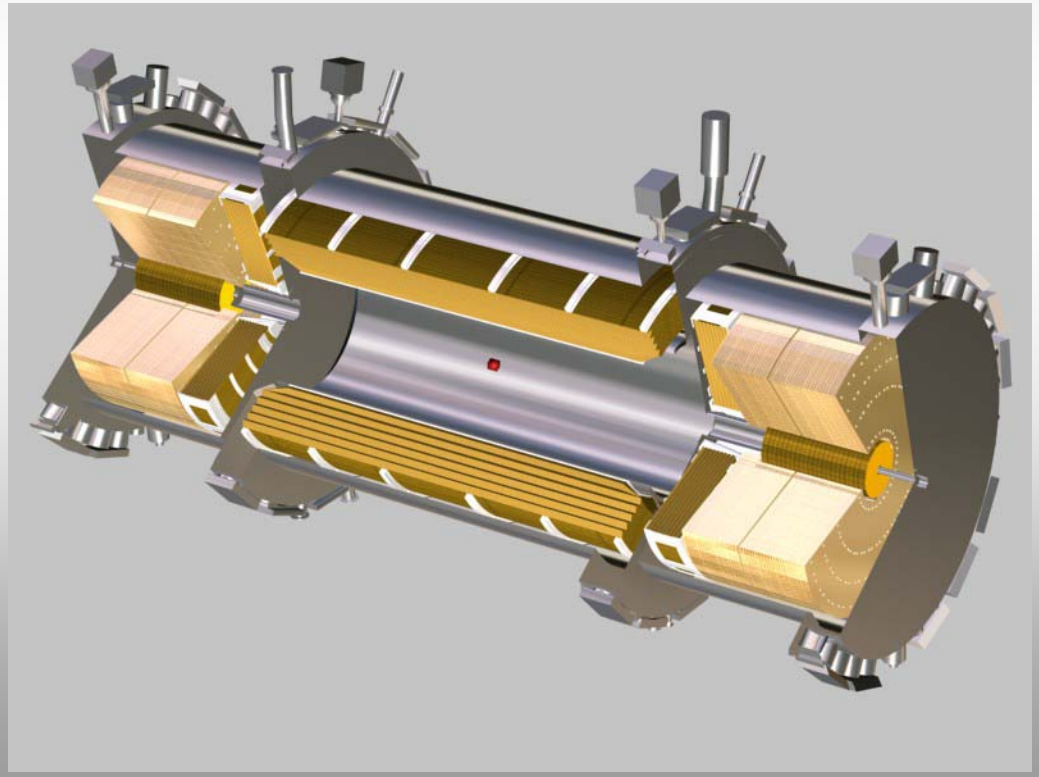


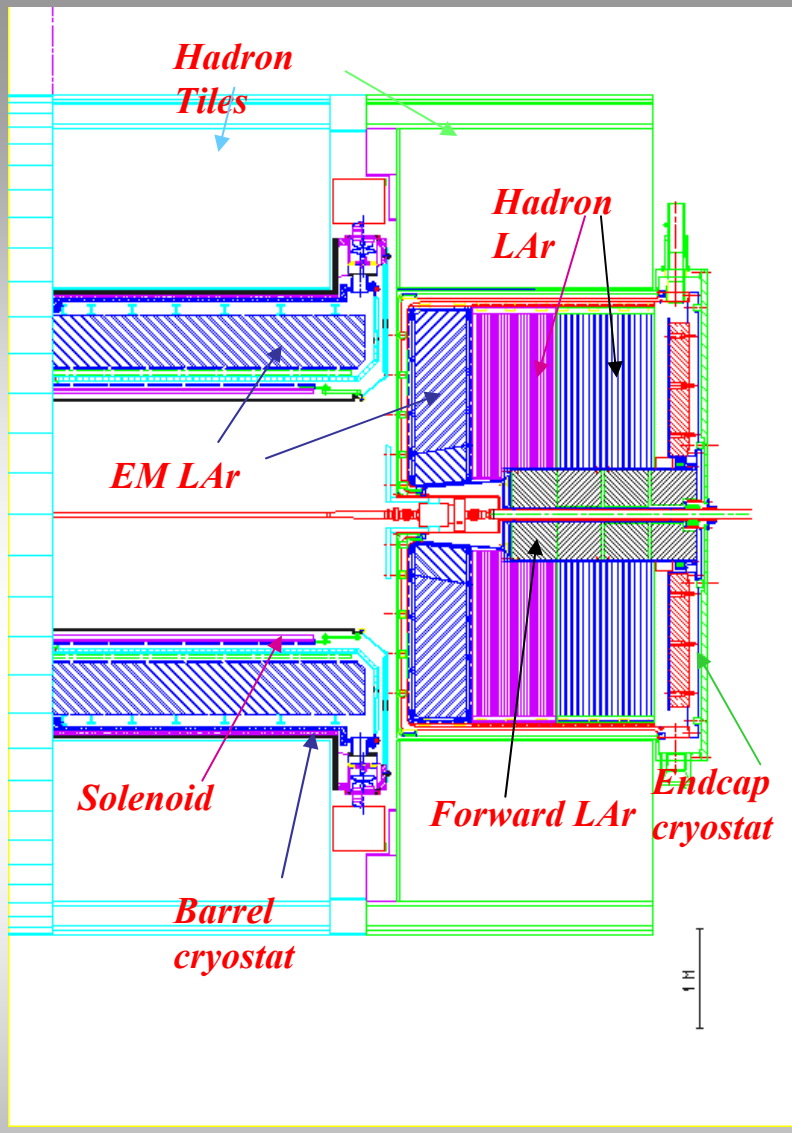


Status of the ATLAS cavern on 12th March 2004

LAr Calorimetry

The LAr calorimetry (pre-samplers, EM, hadronic end-caps, and forward calorimeters) has progressed well in its production phase





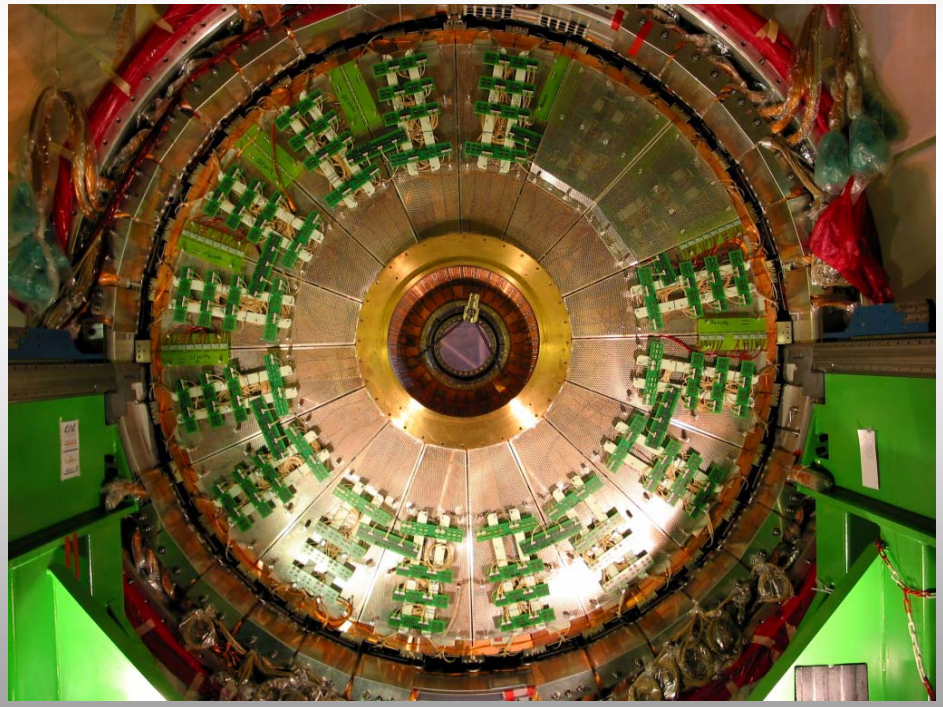
LAr Calorimetry

All modules have been stacked and cold tested

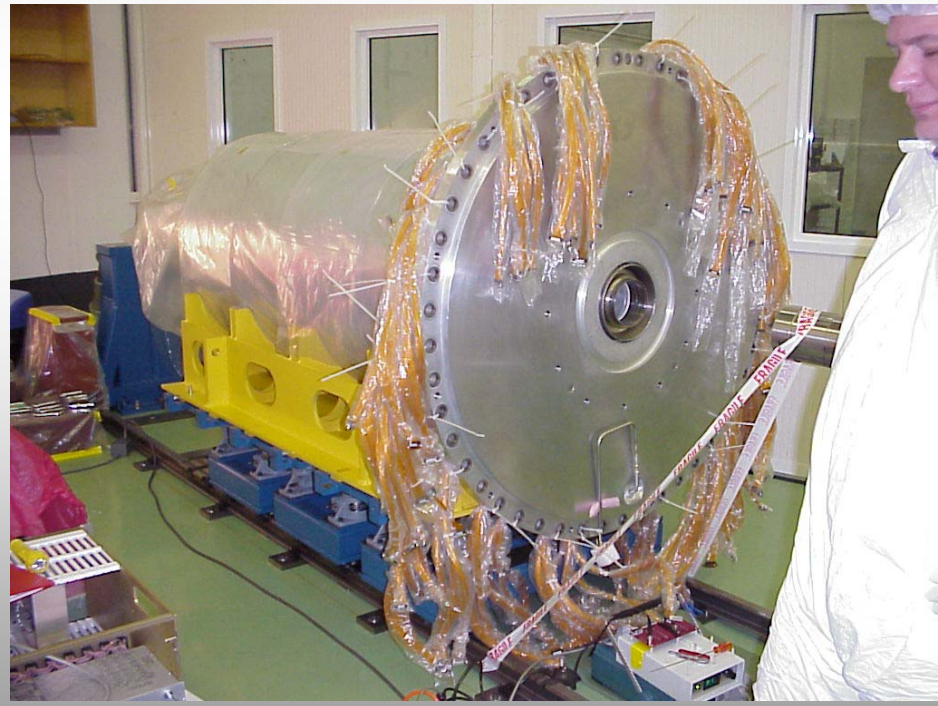
The barrel EM calorimeter is installed in the cryostat, the cold vessel has been closed and welded

The first of the two end-cap cryostats has the EM and the two hadronic wheels inserted, next will be the FCAL which is pre-assembled and ready

Cold tests of the barrel EM calorimeter and the solenoid will start in April 2004



End-cap cryostat with EM and hadronic wheels



FCAL ready for insertion

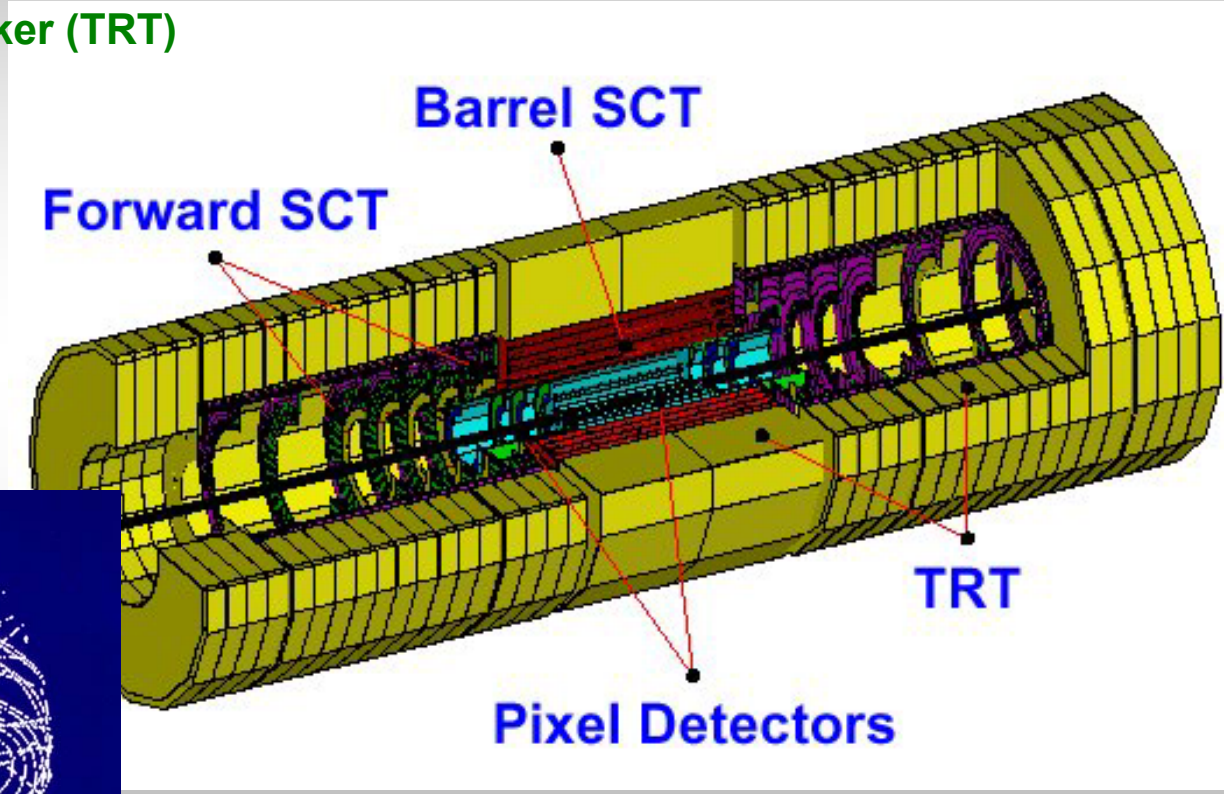
The solenoid was inserted into its final position in the LAr barrel cryostat on 27th February 2004

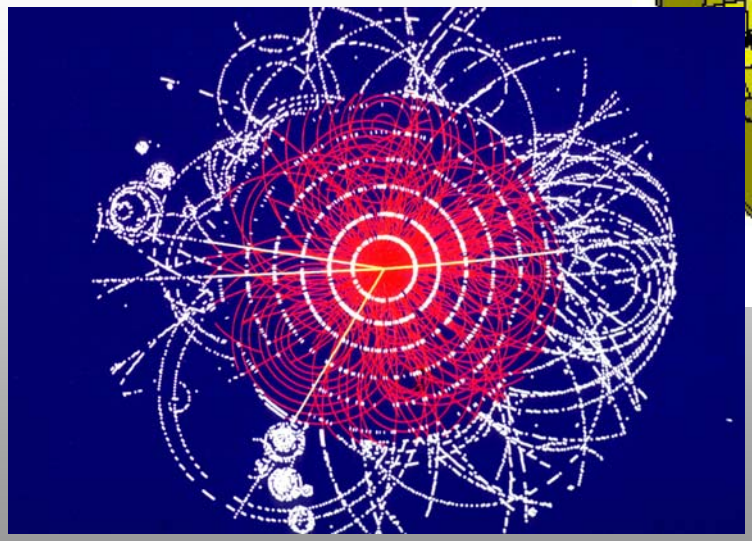
Next are cold tests for the LAr calorimeter and the solenoid, followed by the installation in the pit in October 2004

Inner Detector

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

- **Pixels**
- **Silicon Tracker (SCT)**
- **Transition Radiation Tracker (TRT)**
- **Common ID items**



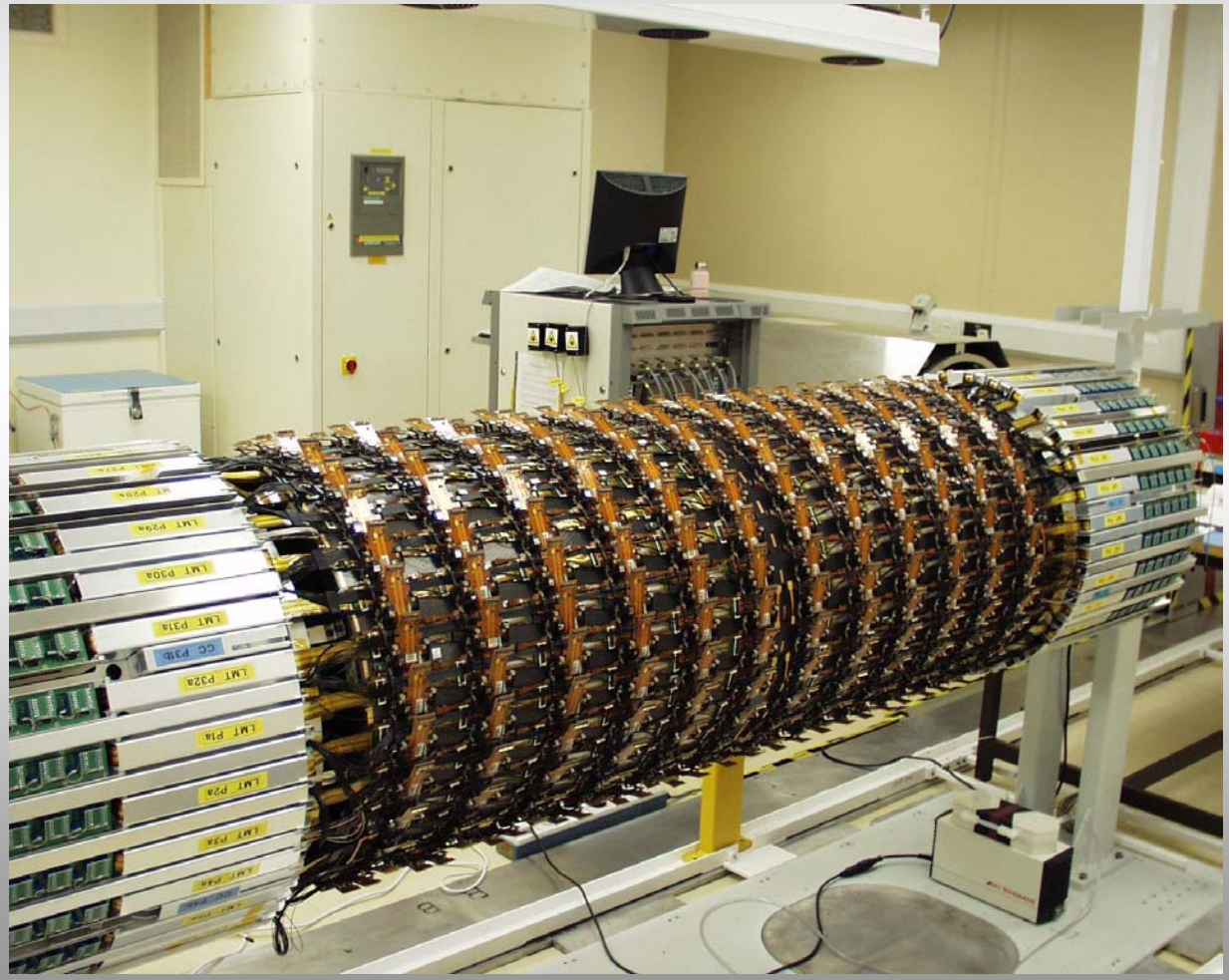


Barrel SCT

55% of the modules have been produced, completion scheduled for end August 2004

Barrel assembly started with services, first of the four cylinders is ready for module mounting

The pitch adaptor problem is now solved



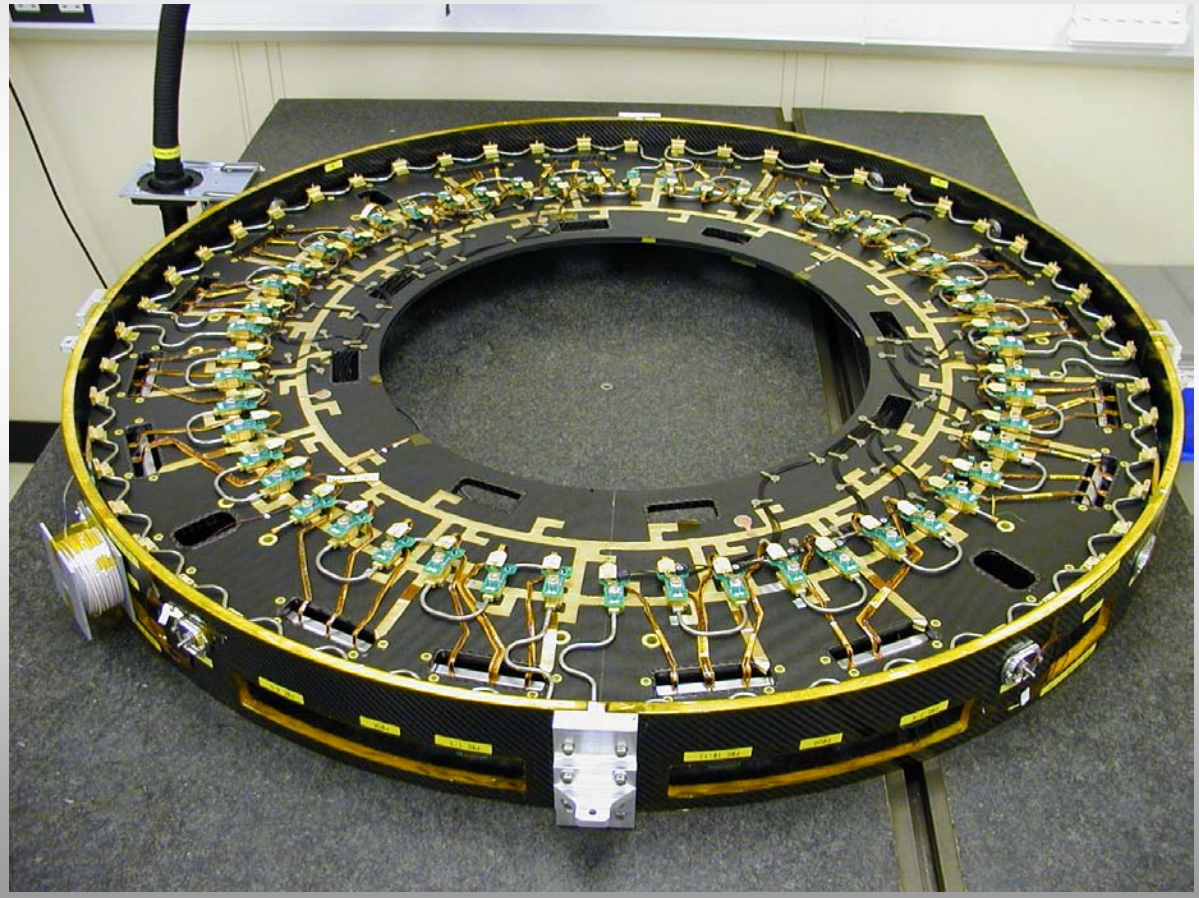
First barrel SCT cylinder equipped with all services

End-cap SCT

Module production has now started at several sites

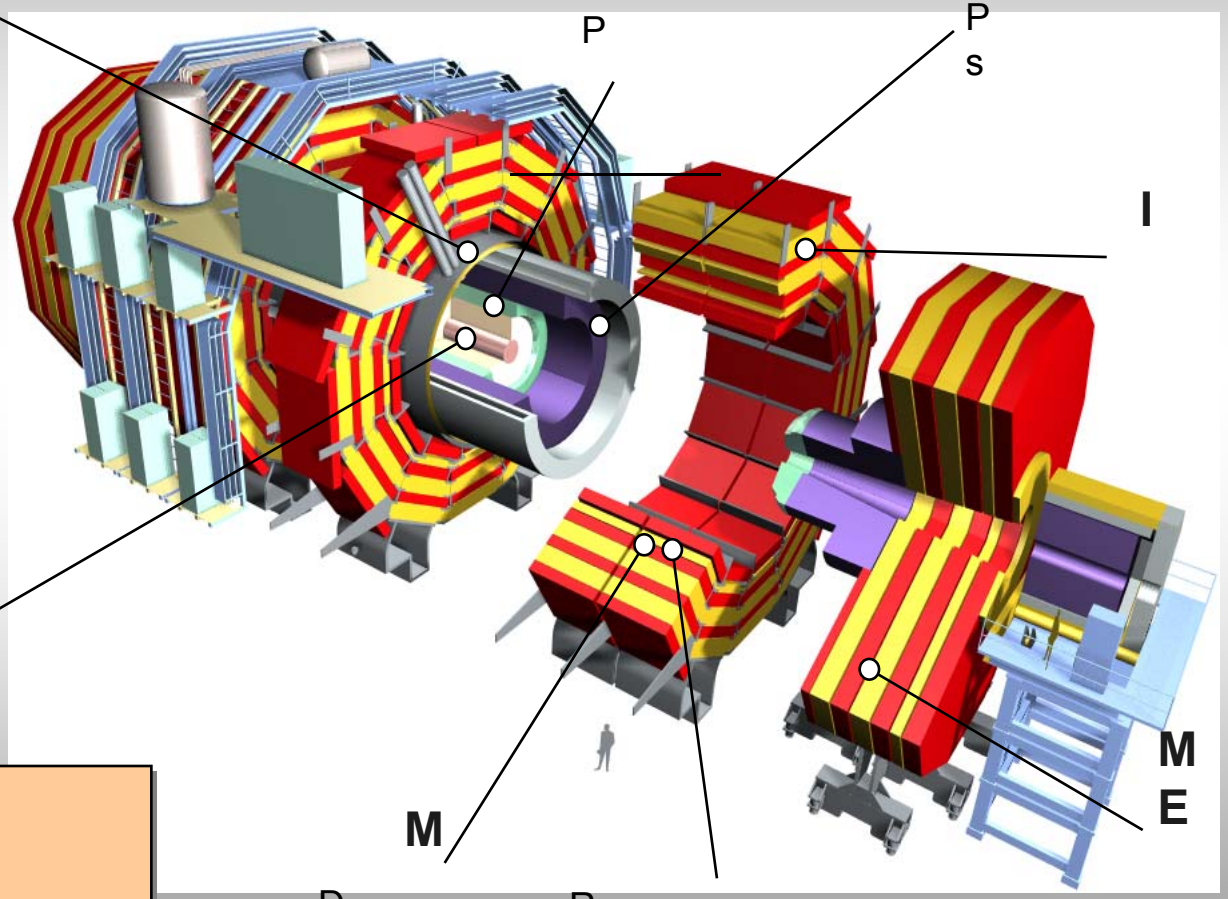
Support disk preparation is in full swing, and first module mounting is foreseen in April 2004

The hybrid problem for the modules is now solved, still critical is the delivery of thermo-conductor supports (‘spines’) within an ISTC contract



First end-cap SCT disk equipped with most of the services

The CMS Detector



UXC55 Cavern

LHC Point 5 - UXC55 Cavern - Crown Reinforcement fixing - 23-02-2004 - CERN TS/CE

LHC POINT 5 - UXC55 Cavern - Point 6 End Headwall Reinforcement Fixing - 23-02-2004 - CERN TS/CE

Civil Engineering Pt. 5

LHC Point 5 - SX5 Building extension - Bouchon Reinforcement Complete - 27-02-2004 - CERN TS/CE

MAGNET: Metallic Structures Completed

Coil: 1’st module

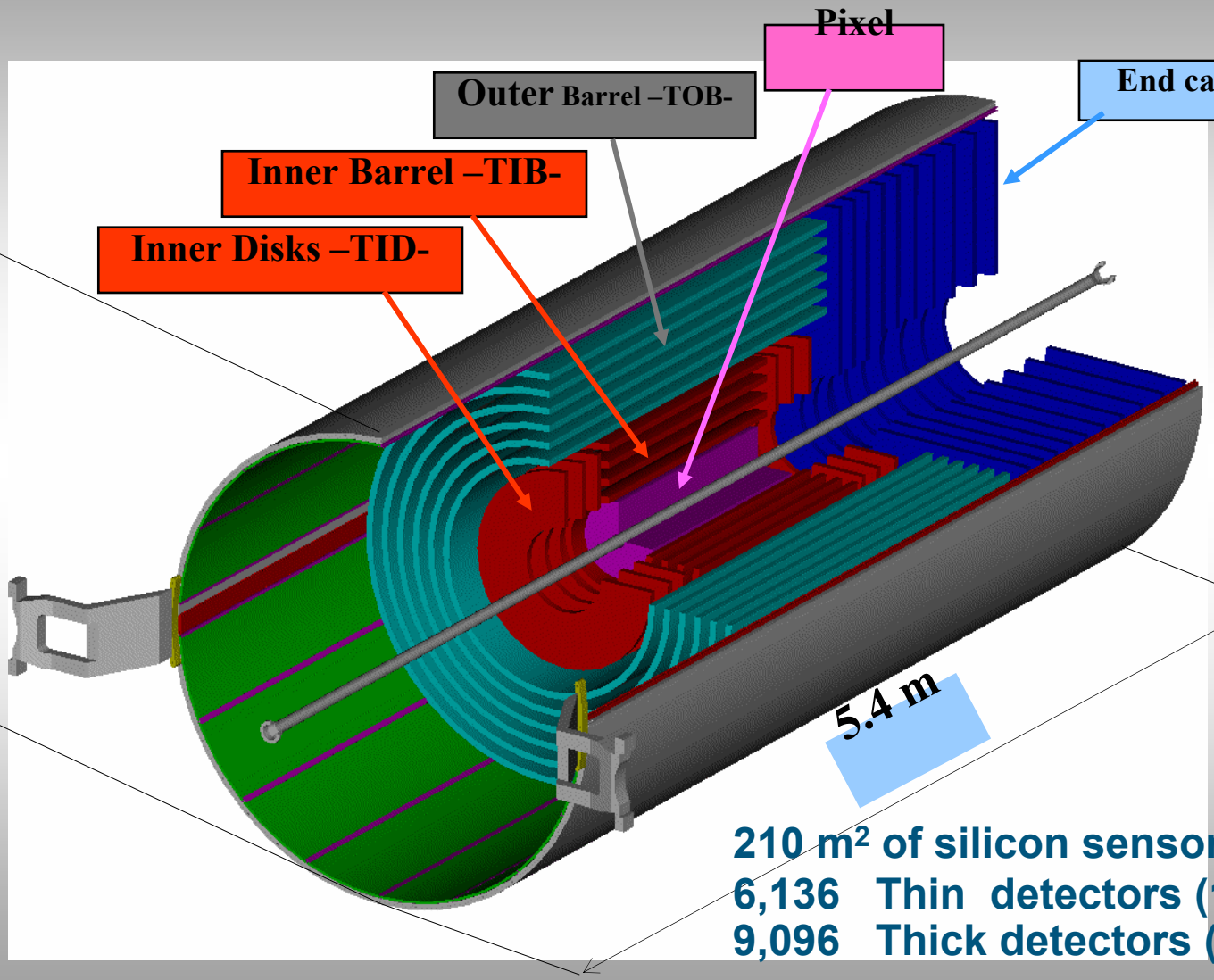
in transit

1st Coil Module at CERN-SX5 (mid-Feb)

Coil: 1’st module

at pt 5

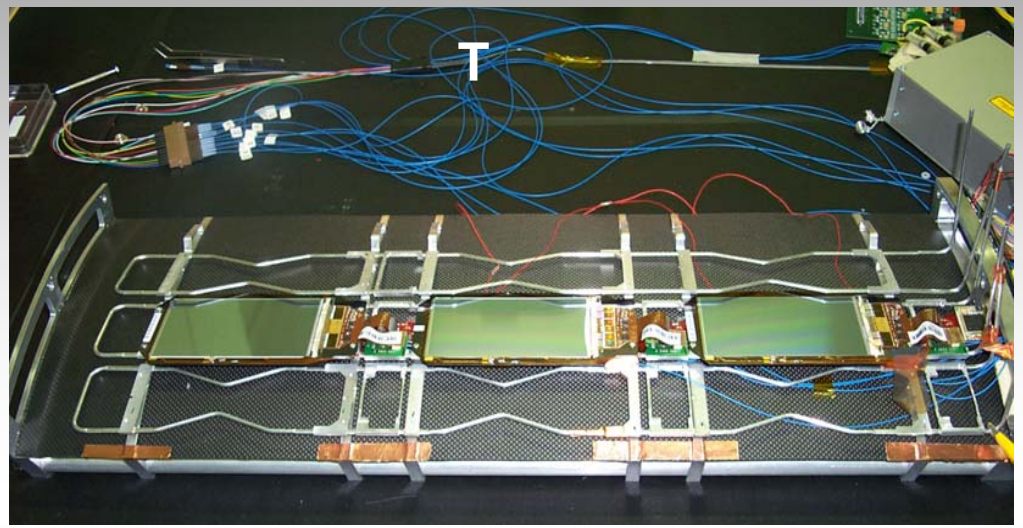
Inner Tracker



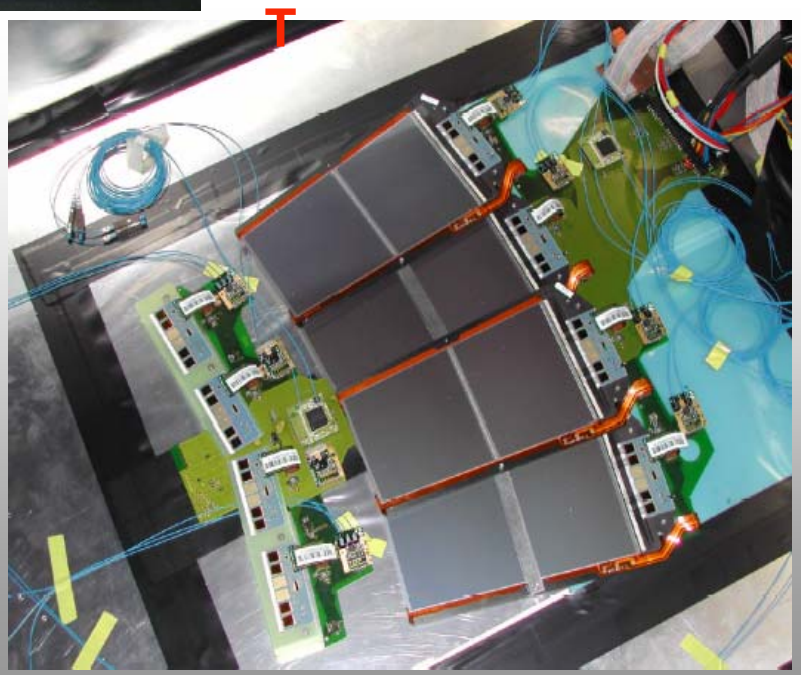
210 m² of silicon sensors
6,136 Thin detectors (1 sensor)
9,096 Thick detectors (2 sensors)

9,648,128 electronics channels

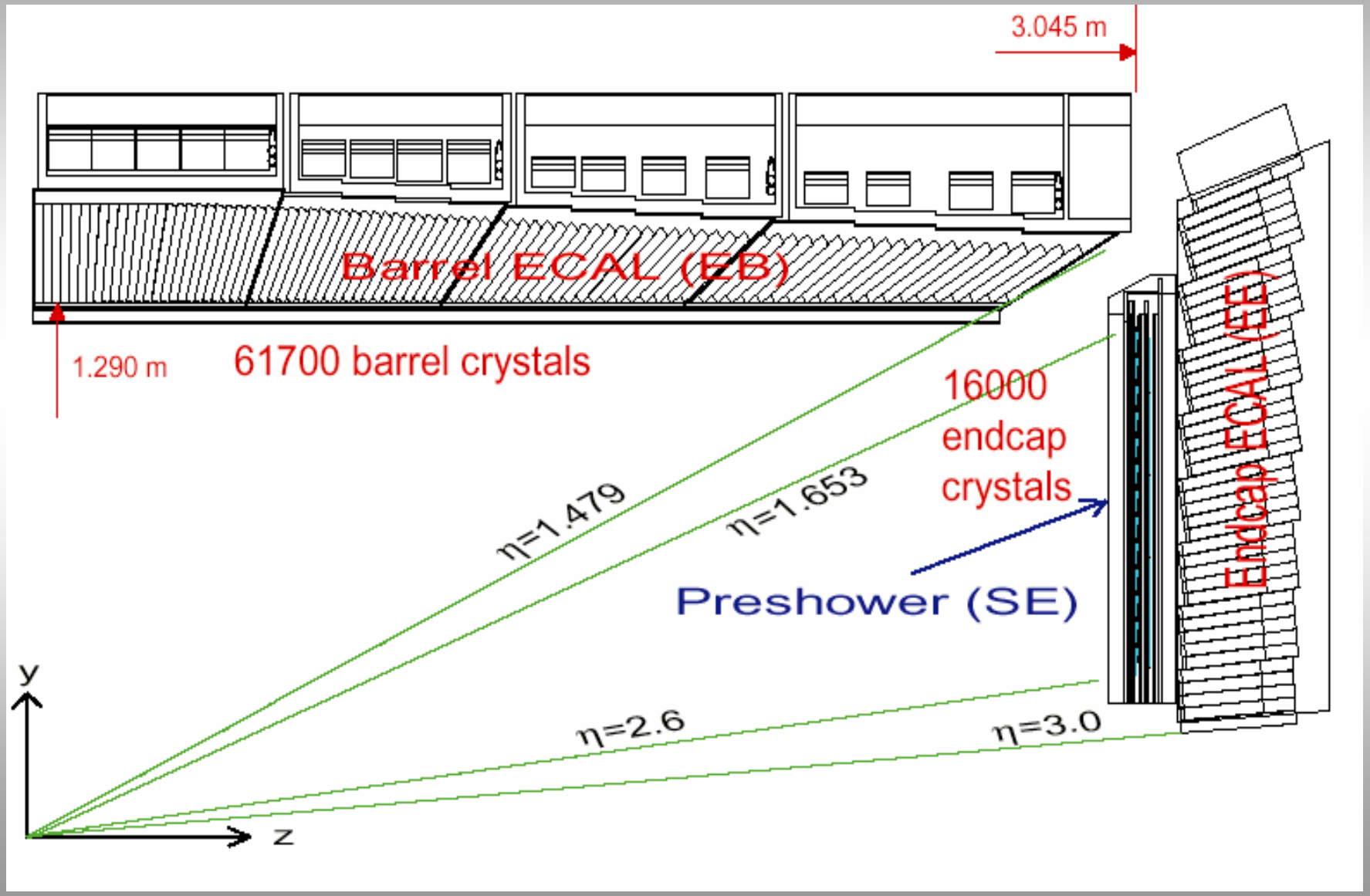
System Tests



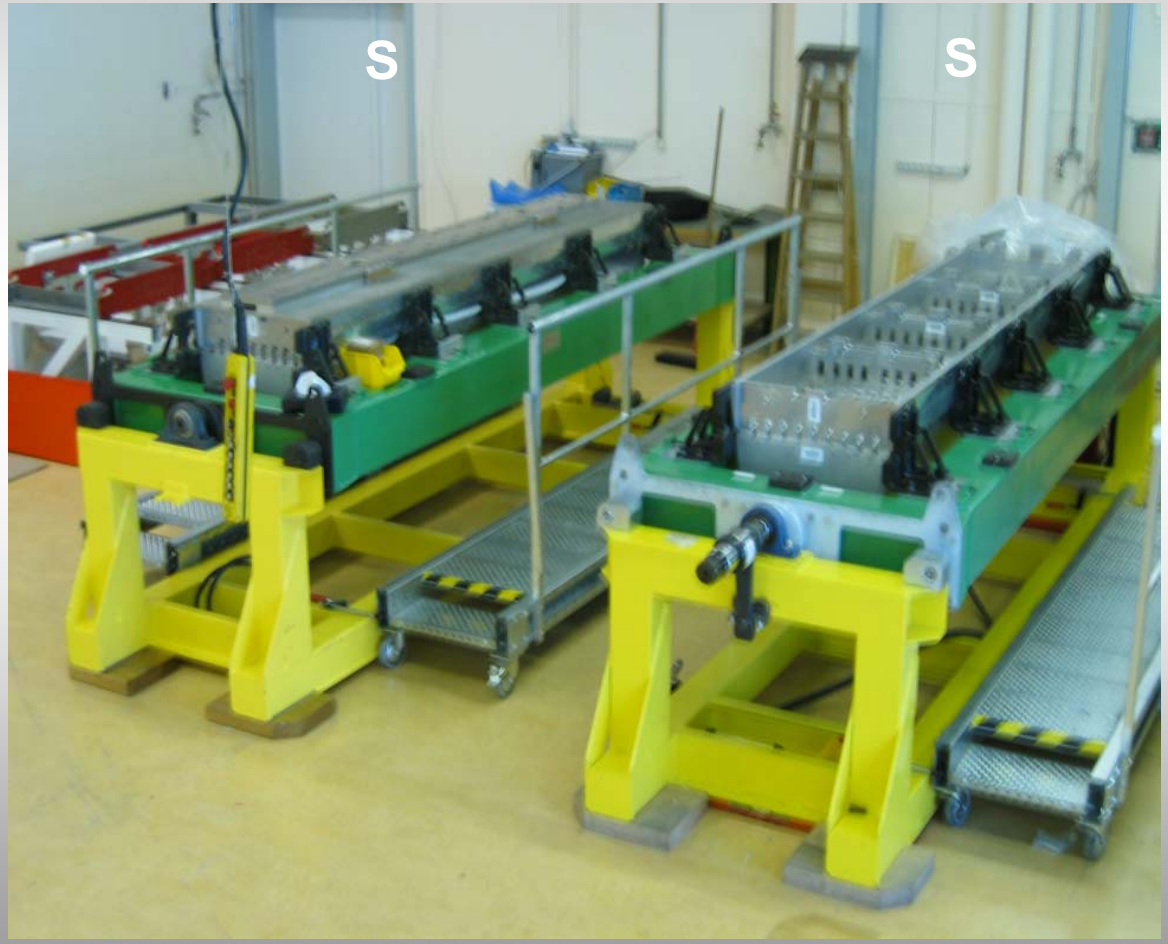
Clean signals
In tests of all 3

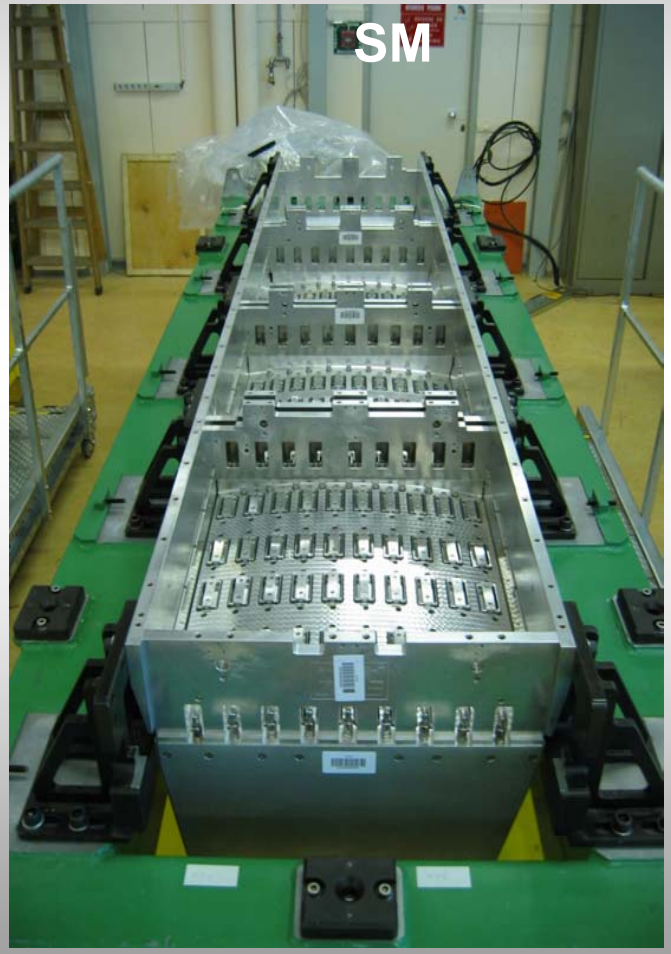


ECAL


3.045 m
Barrel ECAL (EB)
1.290 m
61700 barrel crystals
16000
endcap
crystals
Endcap ECAL (EE)
η=1.479
η=1.653
Preshower (SE)
η=2.6
η=3.0
y
z

Supermodule Assembly

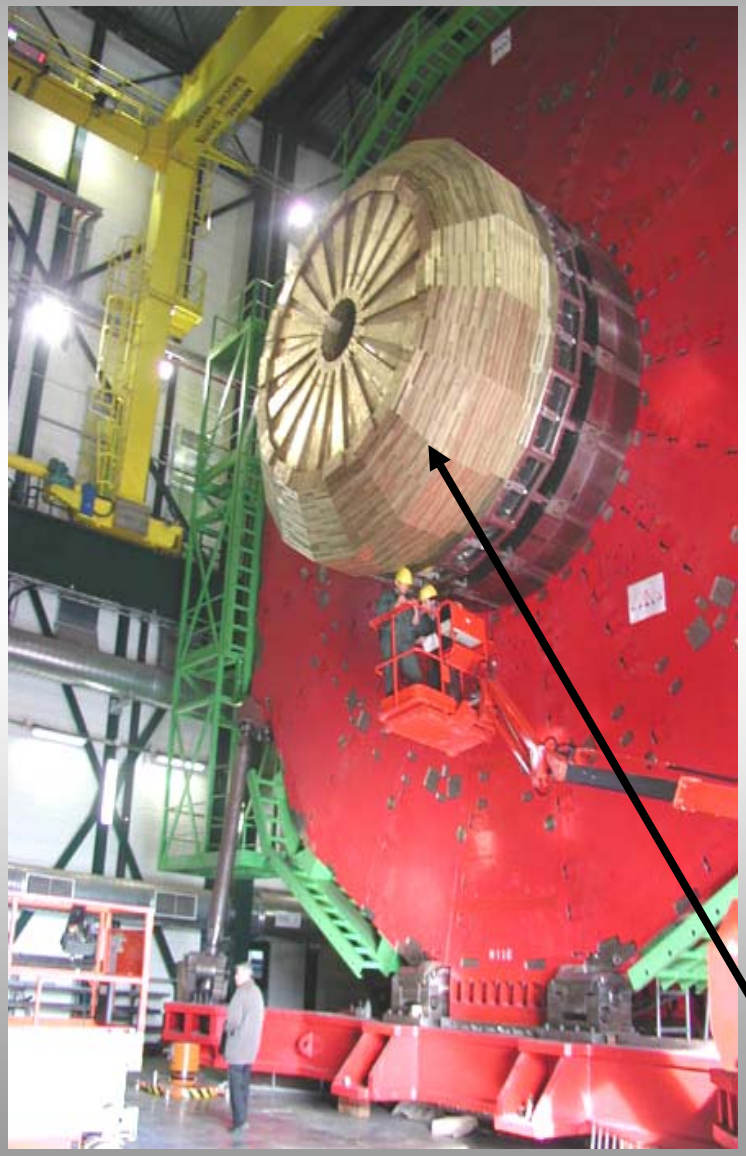




HCAL : HB and HE

HB complete,

install onboard electronics by Q2-04



HE-1 re-installed on YE-1 in Jan/Feb 2003.
Only 3mm droop.
Mount HE+1 by end of 2003,

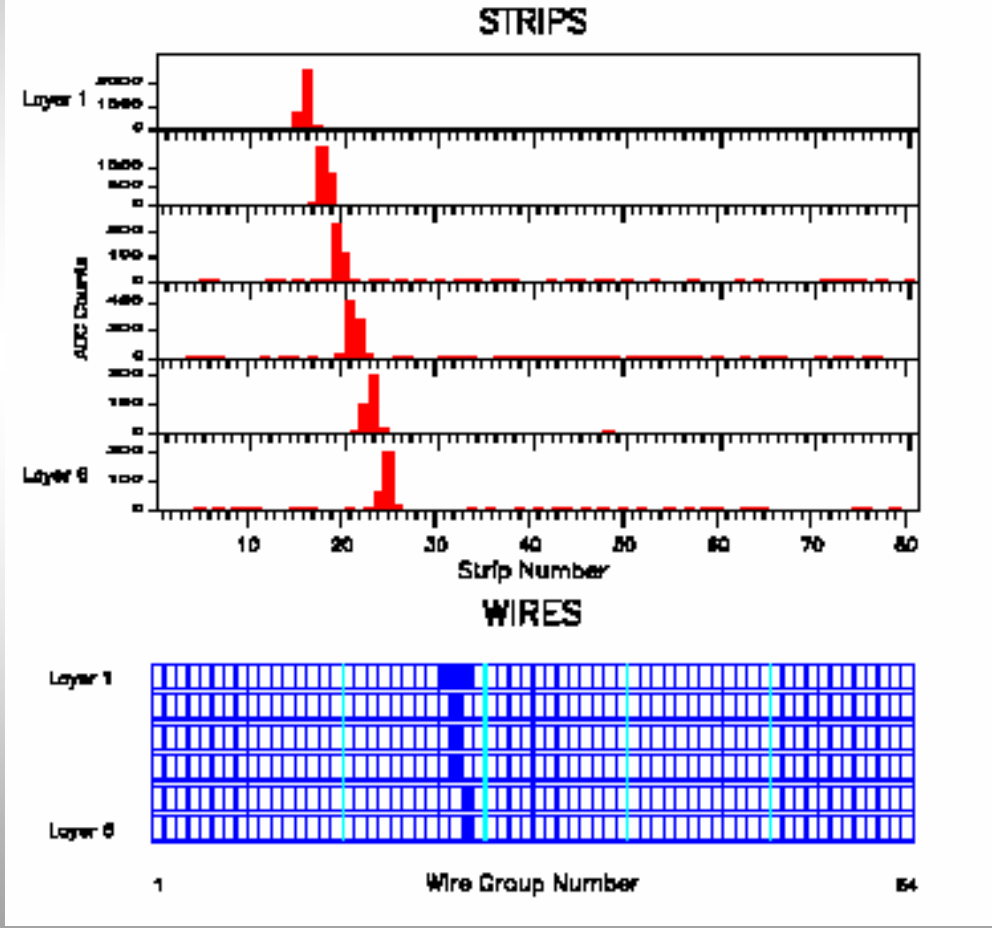
CMS Endcap: HCAL and Muon

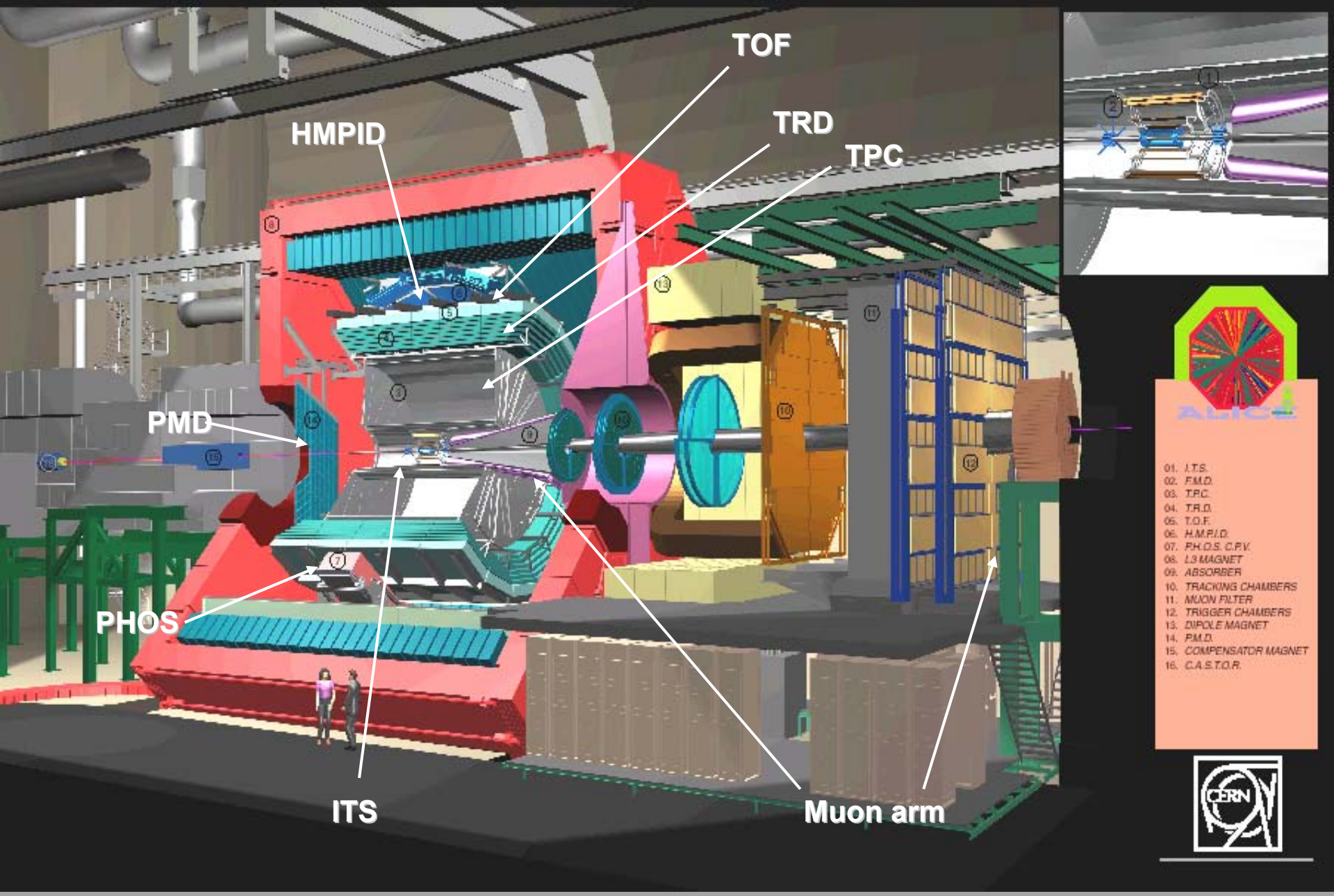
All optics (scintillators etc.)
Ready for installation of

95% of CSCs built
60% of CSCs tested a
23% of CSC installed and cabled in SX5

Off-chamber electronics in production
Chamber commissioning has begun at SX5
Some CSCs operational (gas, power,
Some CSCs taking cosmic ray data at

Cosmic ray seen by an installed CSC

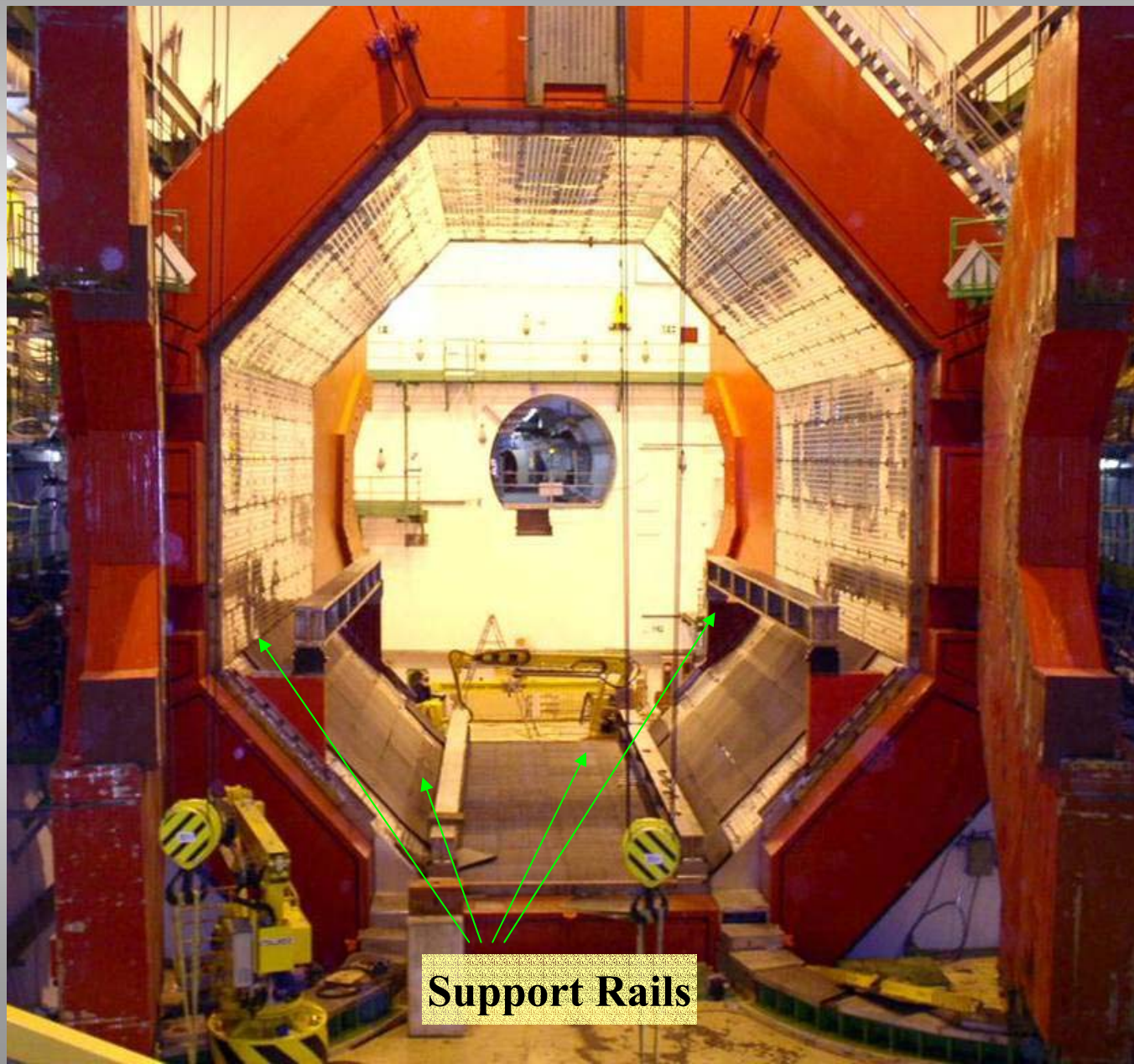


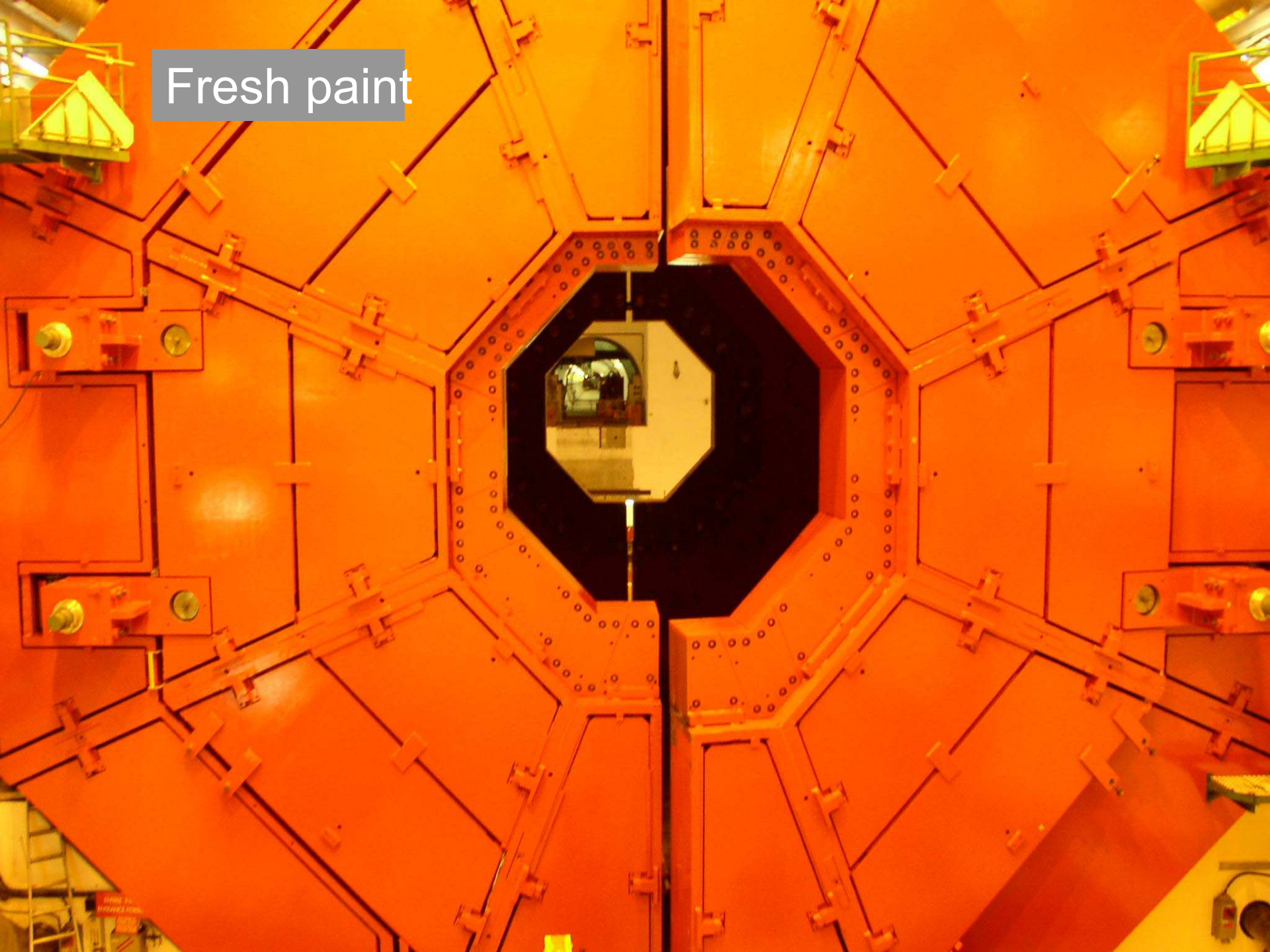


ALICE Detector

ALICE(L3) Magnet

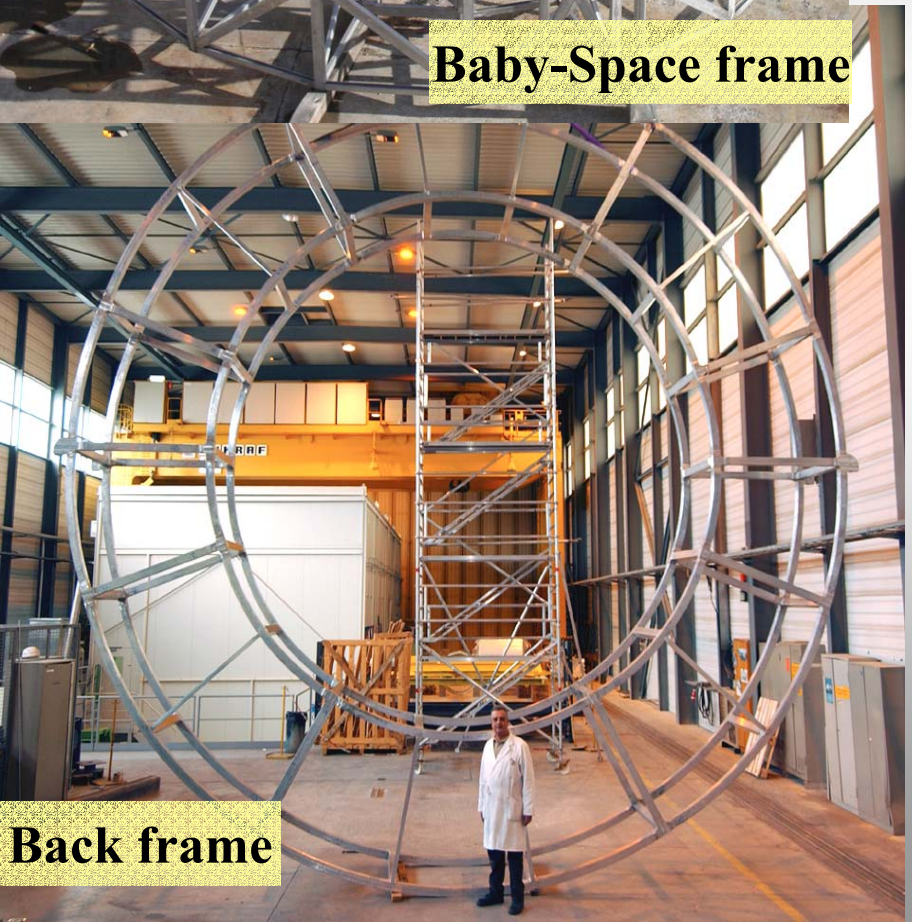
- power test
  - successful
  - first measurement of stray field
- Services
  - installation started
  - back door to be closed permanently in March 2004




Fresh paint

Support Structures

Baby-Space frame



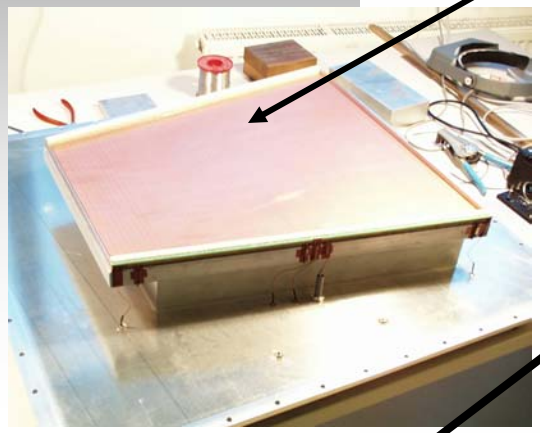
Back frame

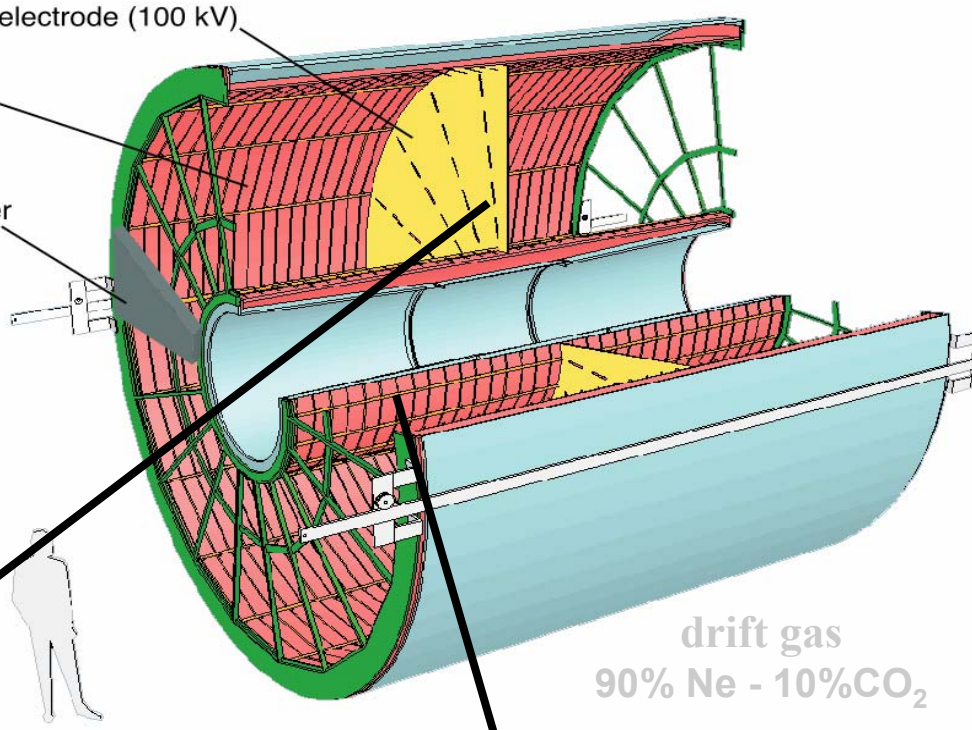
Space frame

Time Projection Chamber

for tracking and PID via dE/dx

- $0.9 < \eta < 0.9$



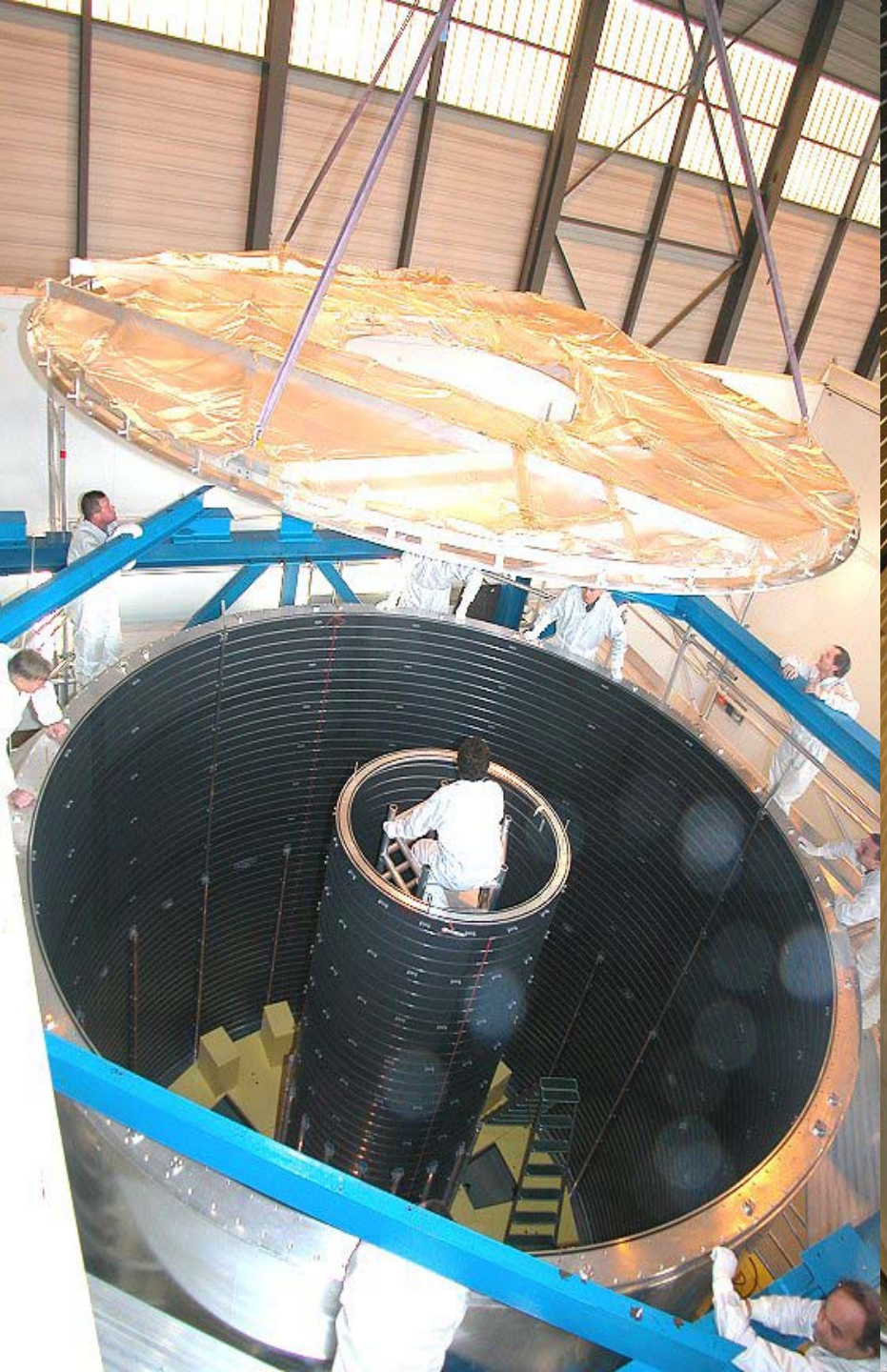


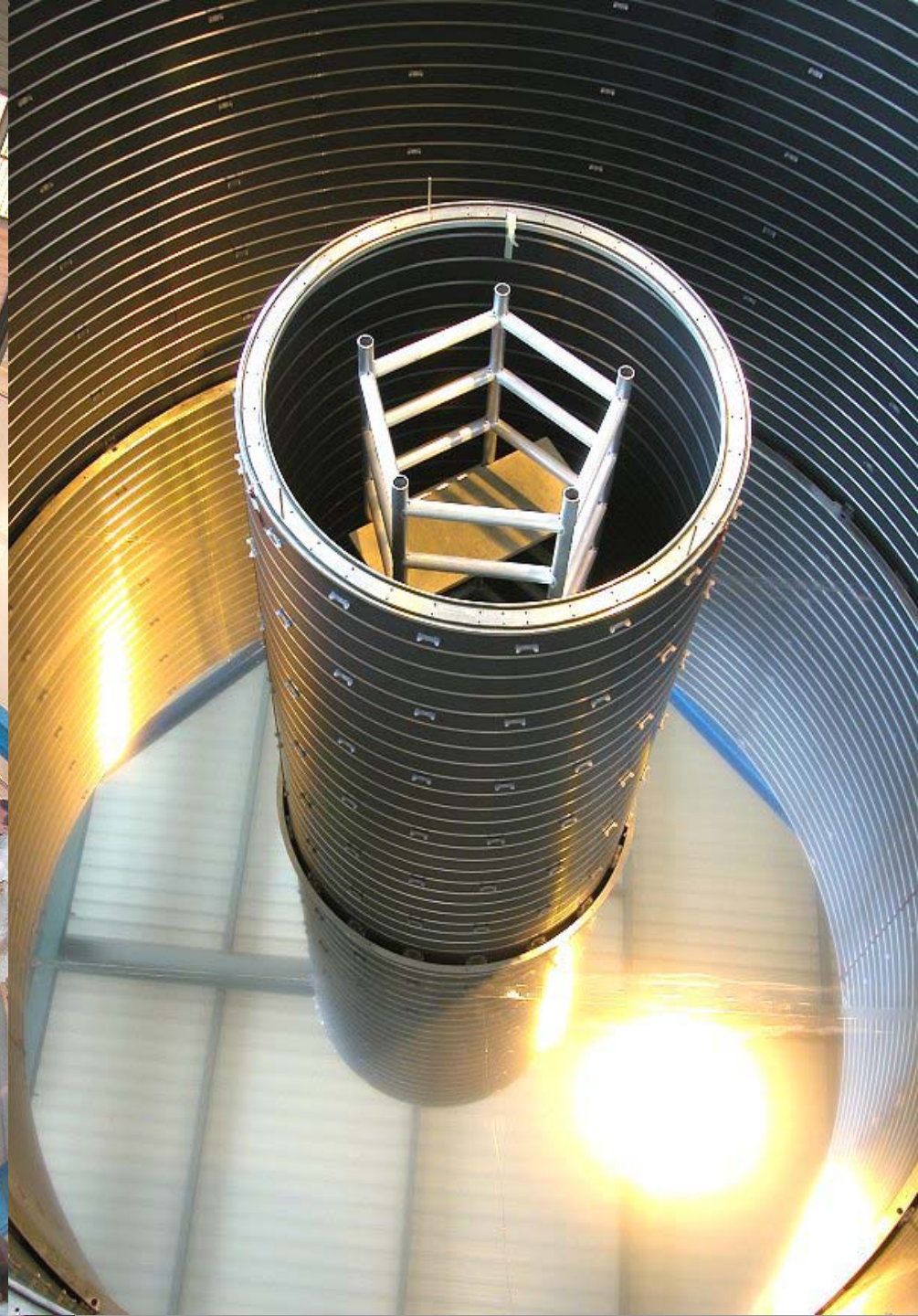
Central Electrode Prototype

25 µm aluminized Mylar on Al frame

~ 3 m diameter

Field Cage Inner Vessel





Muon Magnet

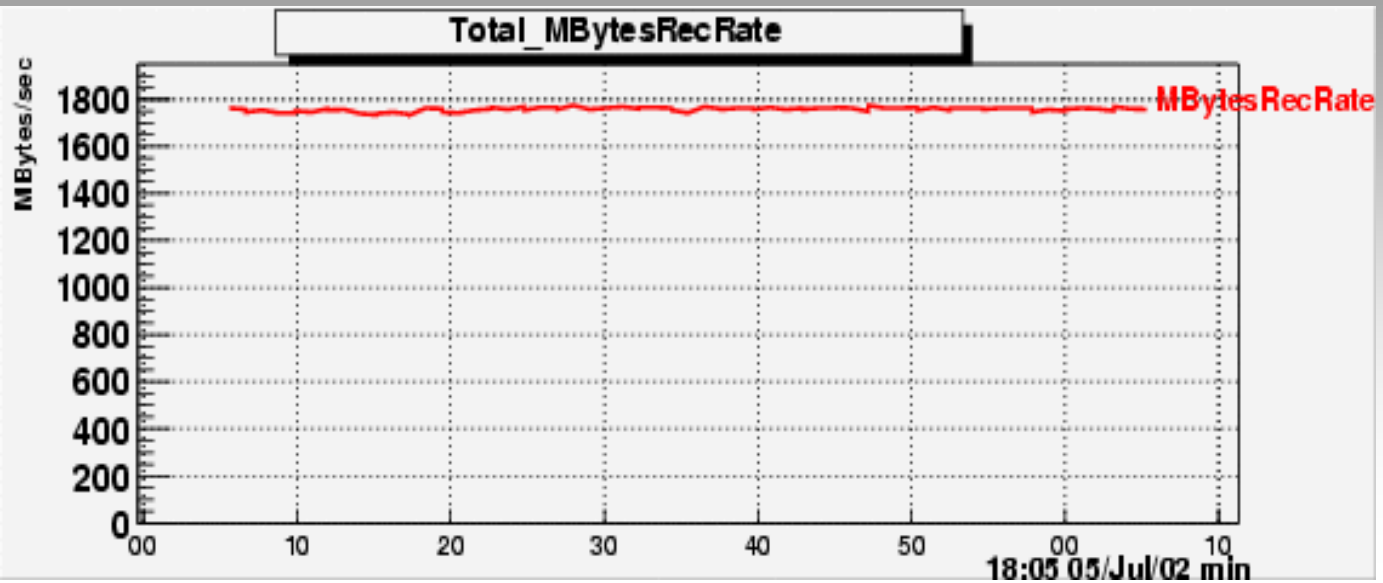
Iron Yoke finished at JINR Dec 02
(still) waiting for transport to CERN

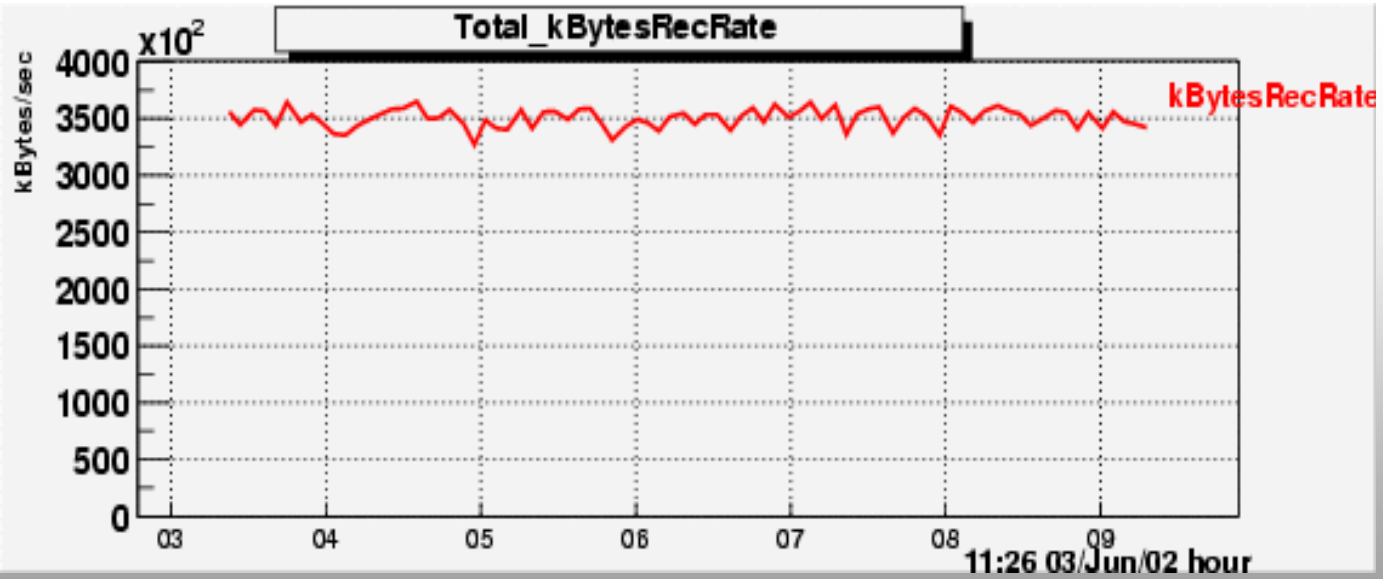
First sub coil (4 'pancakes') after bending
Production of coils finished Aug 03

- **Expect pre-assembly at CERN after summer 2003**

Muon Magnet

ADC IV performances





DATE event-building

1.8 Gbytes/s:

target 1 Gbyte/s

In stable operation

DATE event-building

RFIO

CASTOR

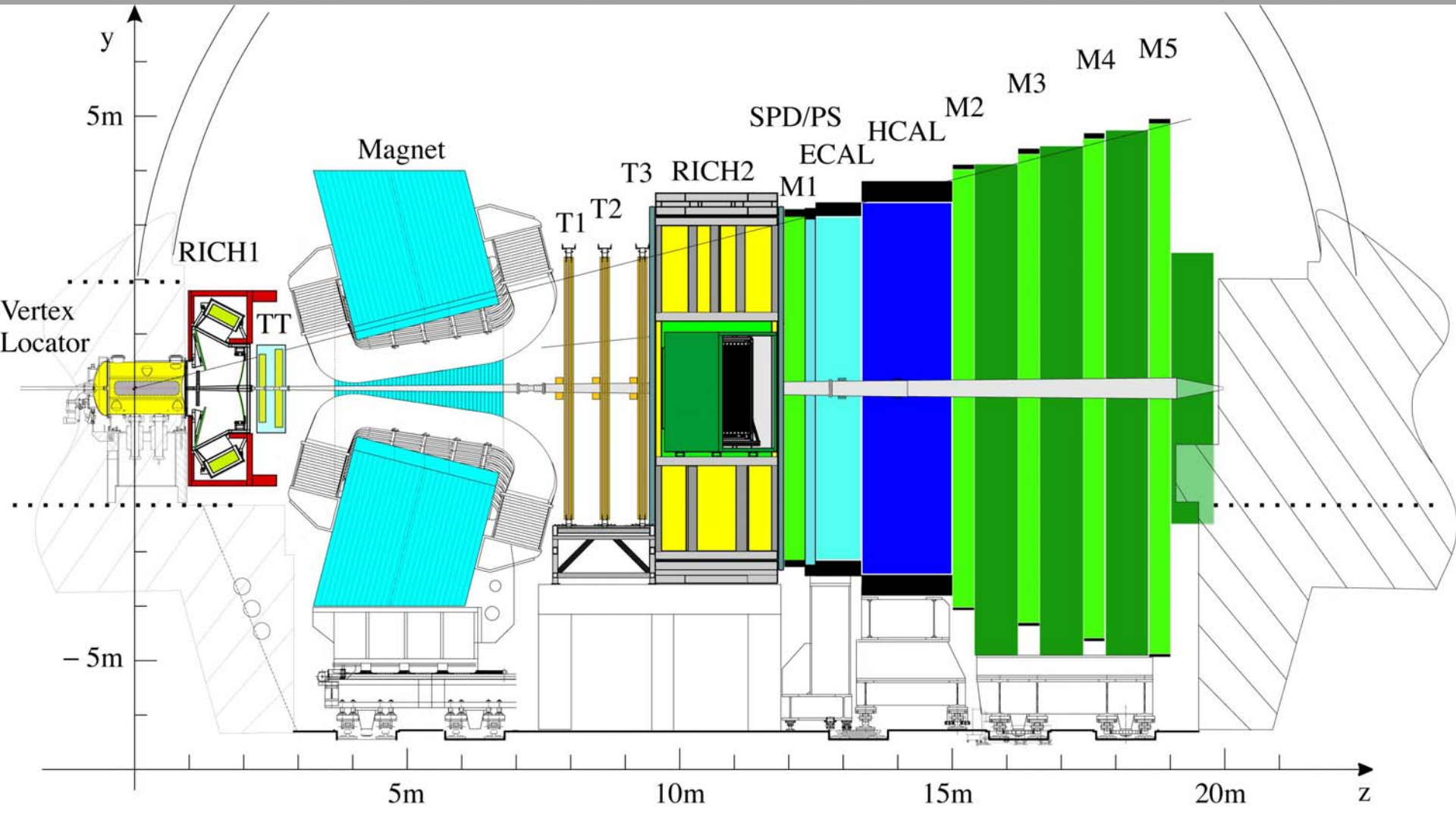
Data recording to disk

350 MBytes/s.

target 300 MBytes/s

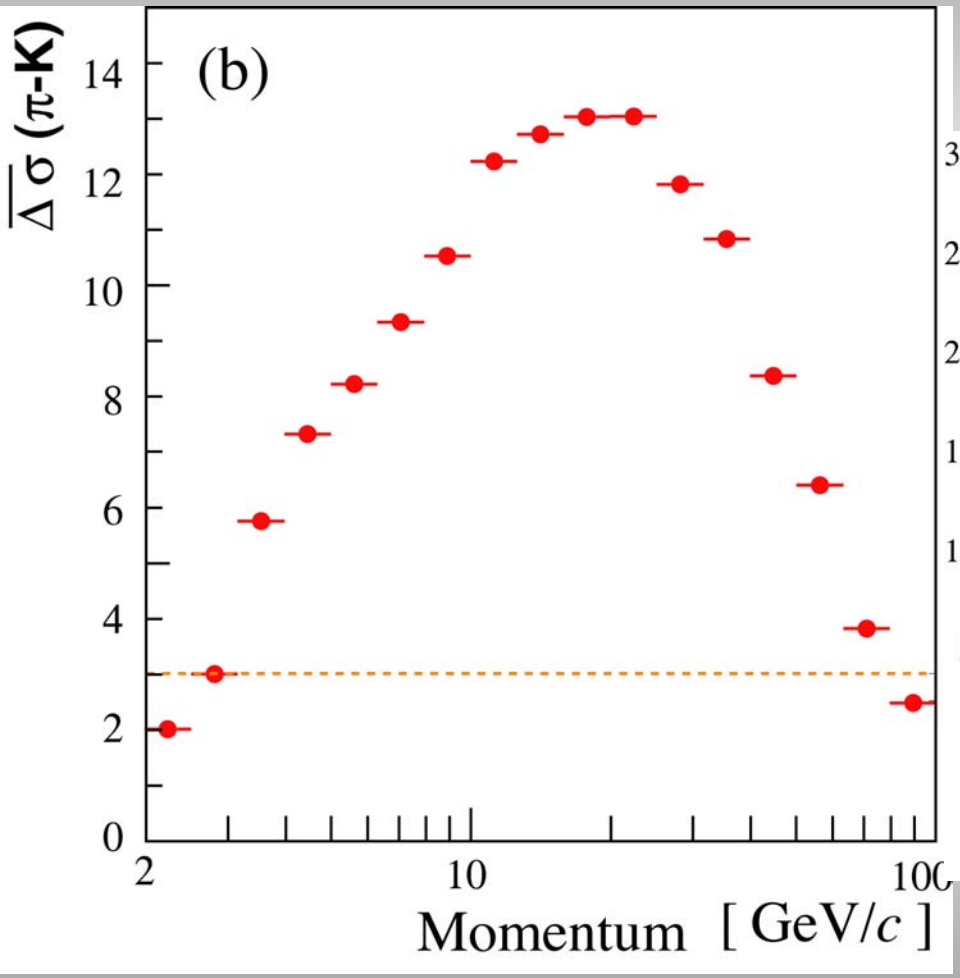
Outperforming the plan, with commodity hardware!

The LHCb detector

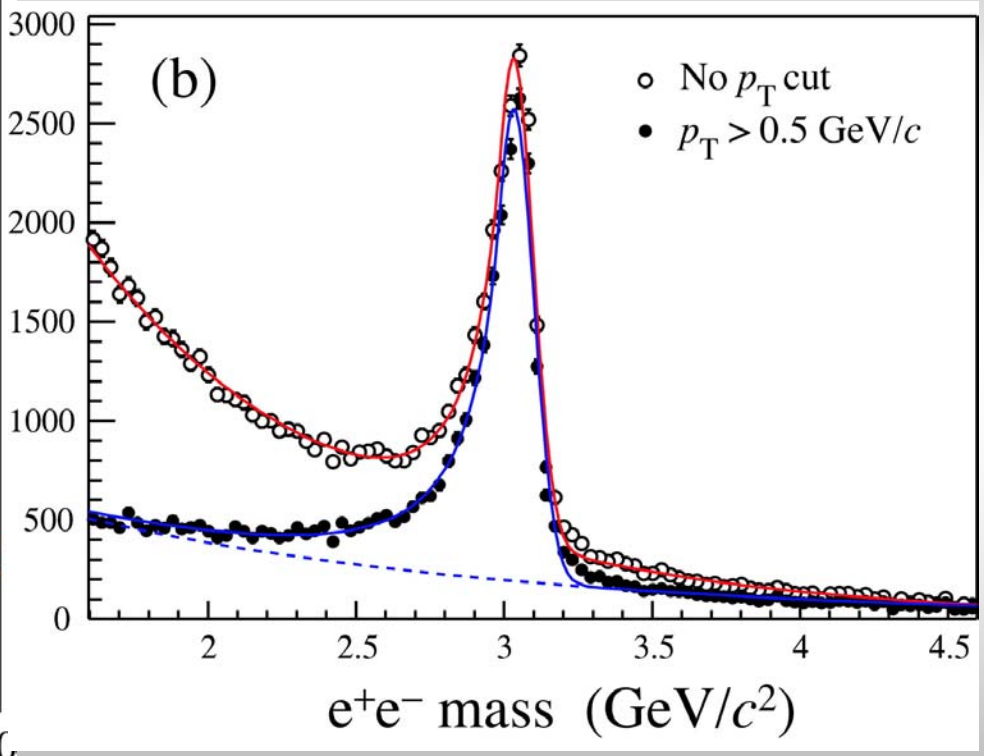


Brazil France Germany Italy Poland PRC Netherlands
Romania Russia Spain Switzerland UK Ukraine

K/π separation



J/ψ (e^+e^-) peak

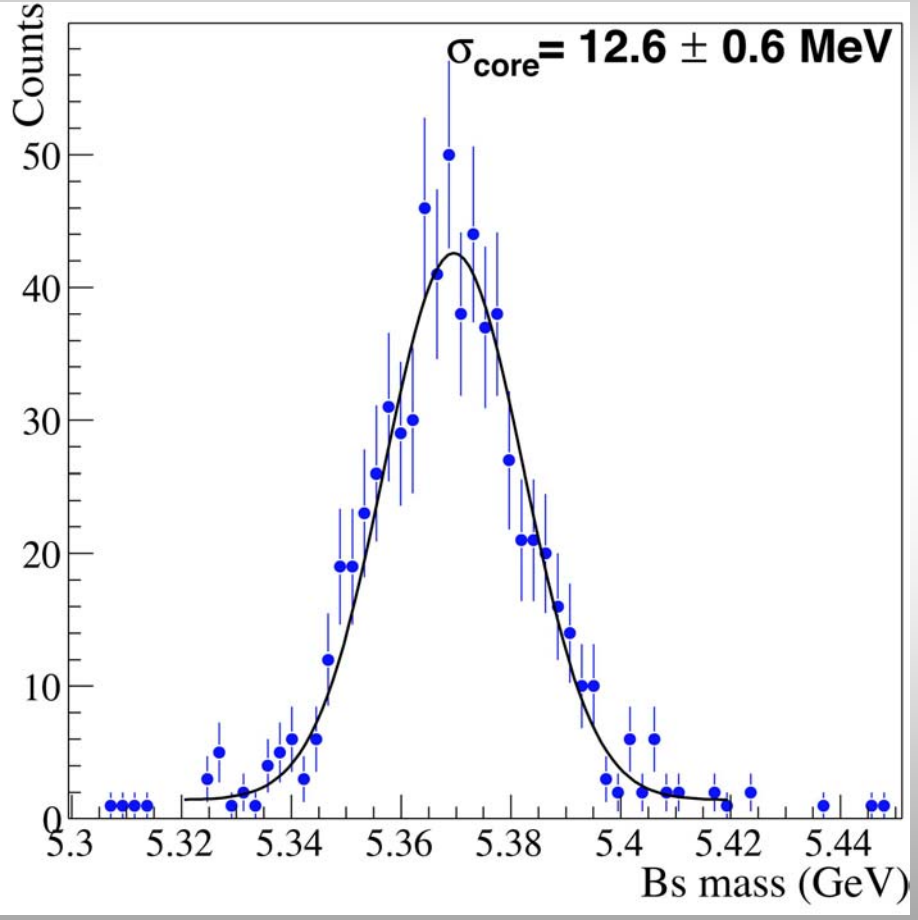


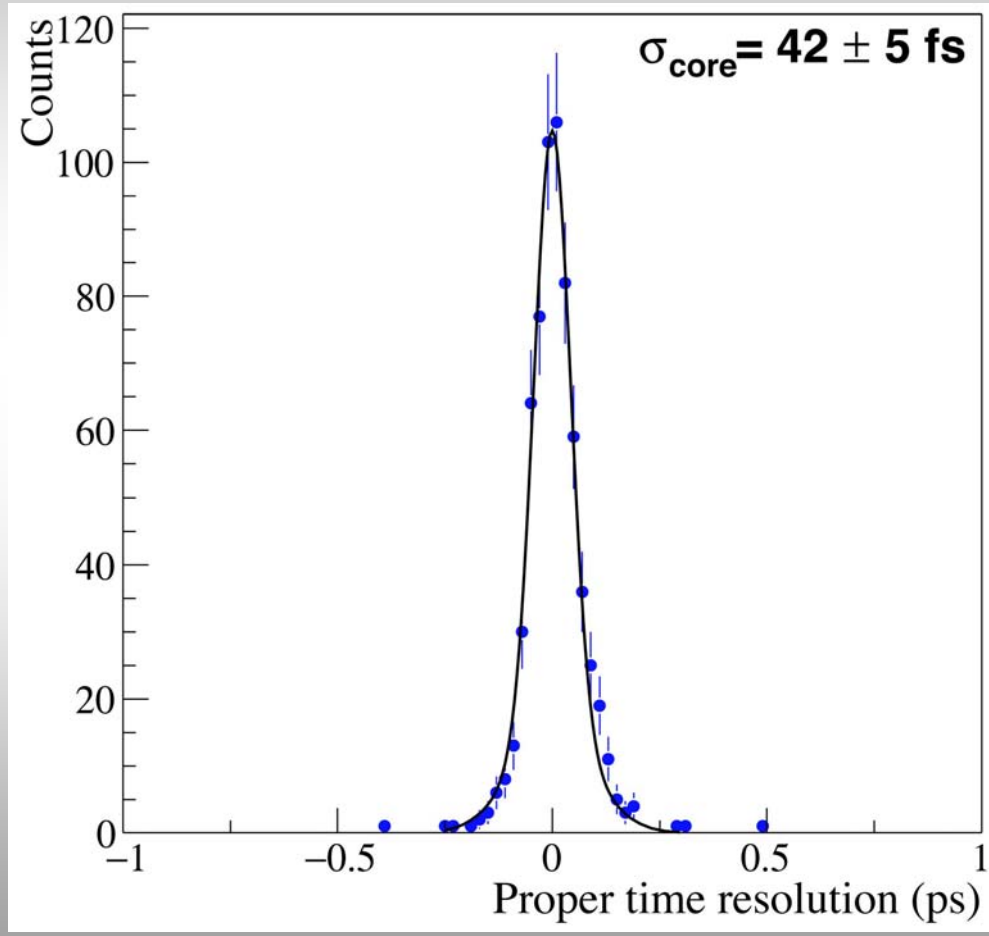
Particle ID performance good

electron reconstruction

Reconstruction qualities

$B_s \rightarrow D_s \pi$: mass and decay time resolutions





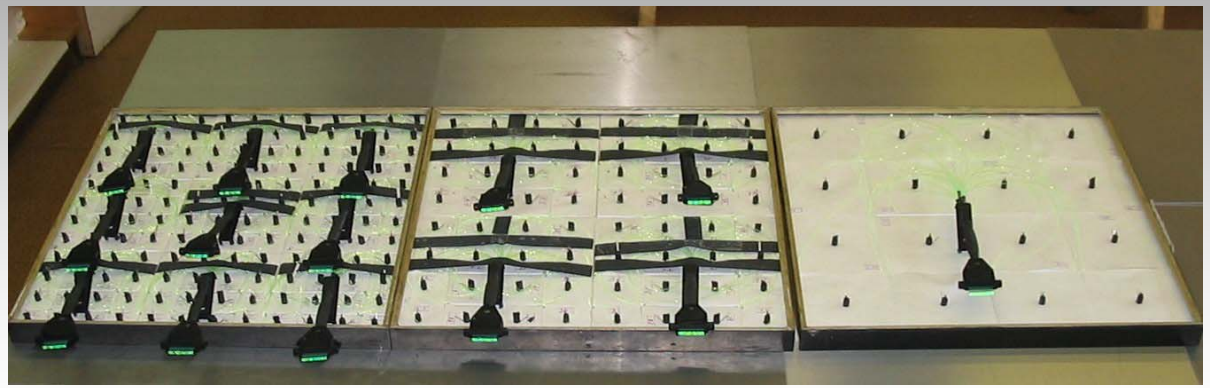
RICH2

RICH2 exit and entrance windows

RICH2 superstructure

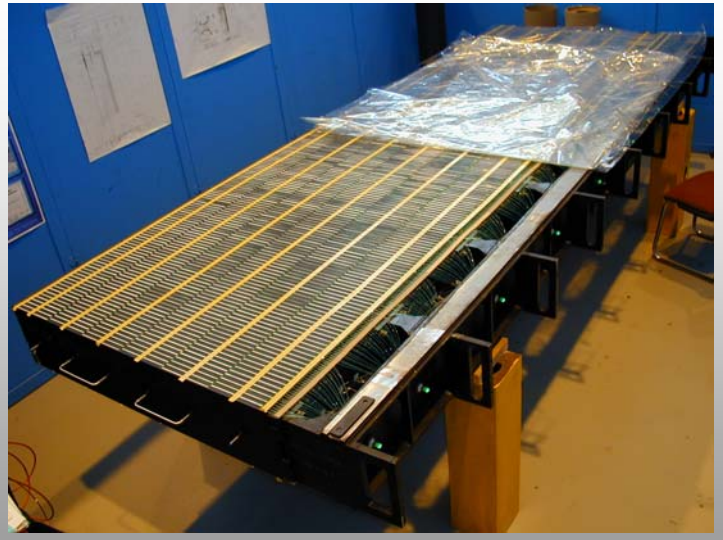
Calorimeter

SPD/Preshower production started



Ecal modules: 100% constructed

Hcal modules: 60% constructed



Concerns in the Experiments

- **ATLAS**
  - Barrel Toroid Completion
- **CMS**
  - ECAL production
  - Si tracker mass production

- **Tight Schedules and Resources**

On-line System

- Large variety of triggers and thresholds: select physics à la carte
- Multi-level trigger
- Filter out less interesting
- Online reduction 10^7
- Keep highly selected events

40 MHz (1000 TB/sec) equivalent)

Level 1 - Special Hardware

75 KHz (75 GB/sec)fully digitised

Level 2 - Embedded Processors/Farm

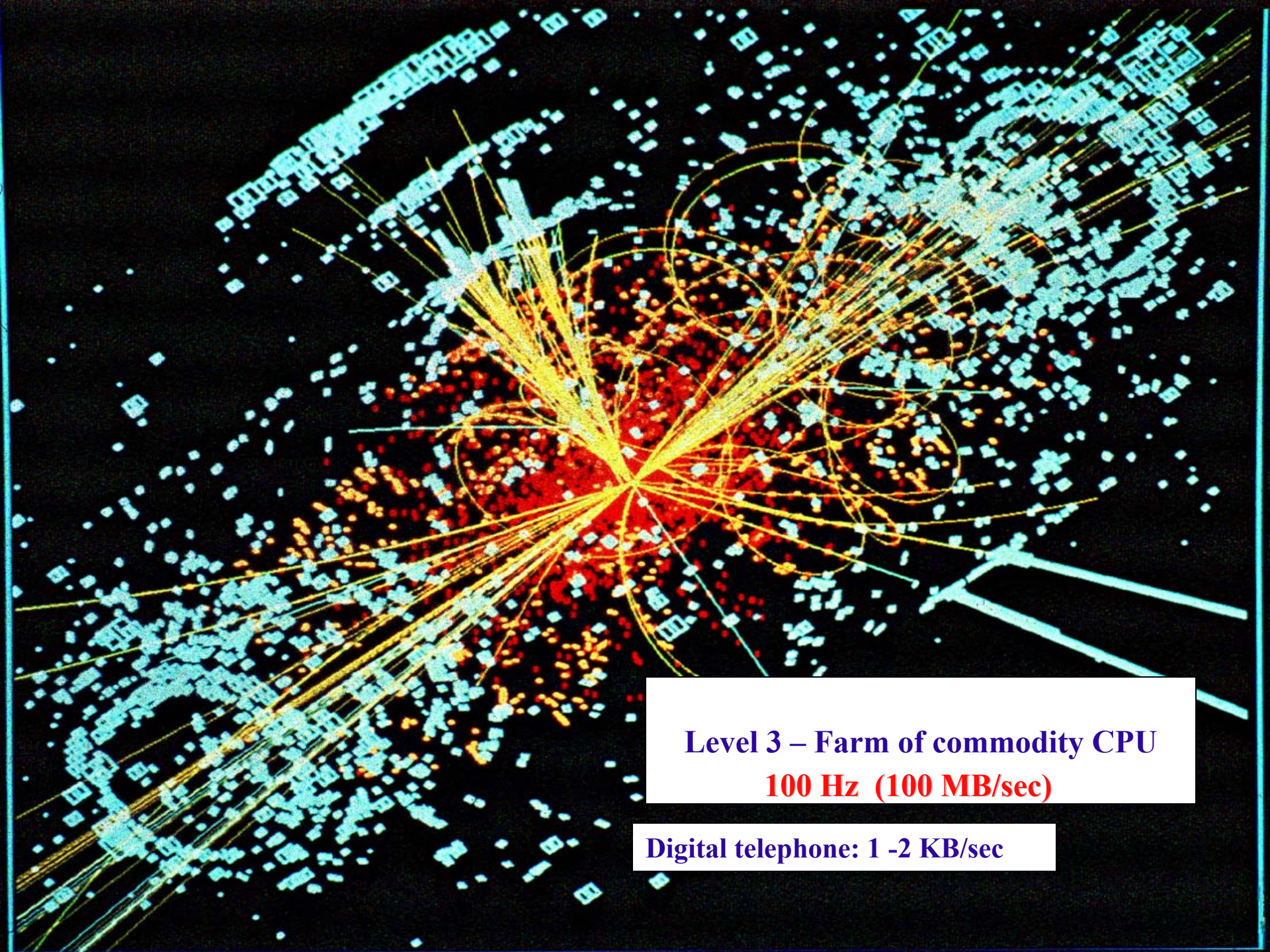
5 KHz (5 GB/sec)

Level 3 - Farm of commodity CPU

100 Hz (100 MB/sec)

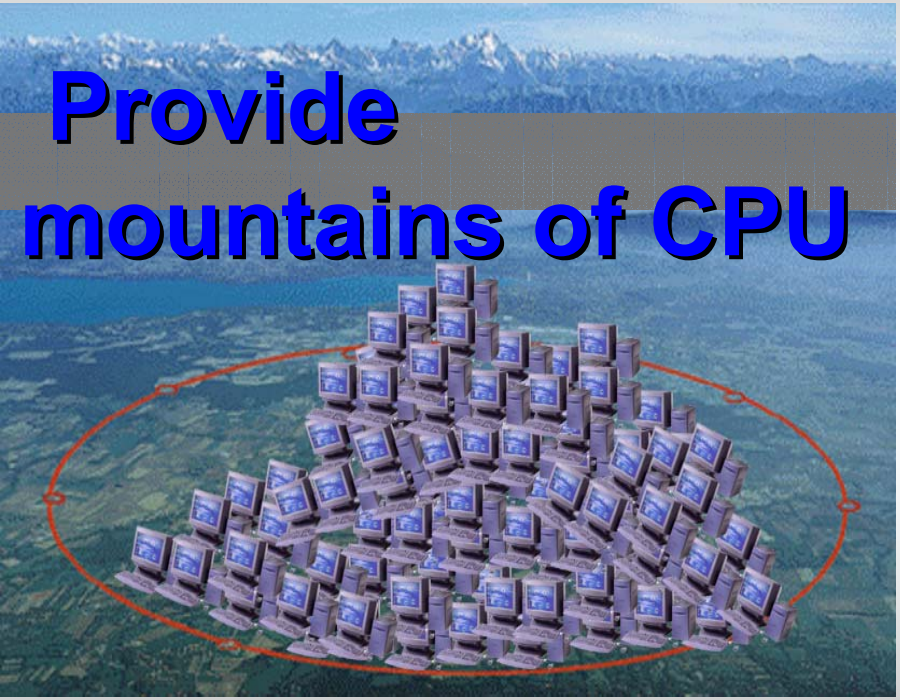
Data Recording & Offline Analysis

Digital telephone 1-2 KB/sec


Level 3 – Farm of commodity CPU
100 Hz (100 MB/sec)
Digital telephone: 1 -2 KB/sec

LHC: Compute Capacity-Data Volumes "to analyse all LHC data"

Calibration, Reconstruction, Simulation, Analysis

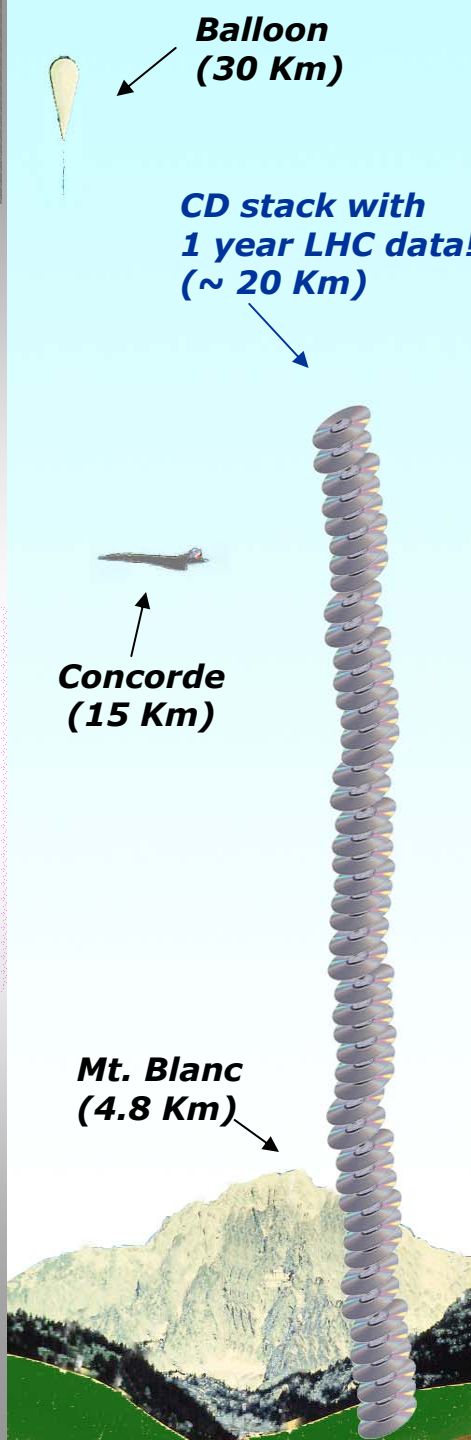


For LHC computing, some 100 Million SPECint2000 are needed!

a 3 GHz Pentium 4 has ~

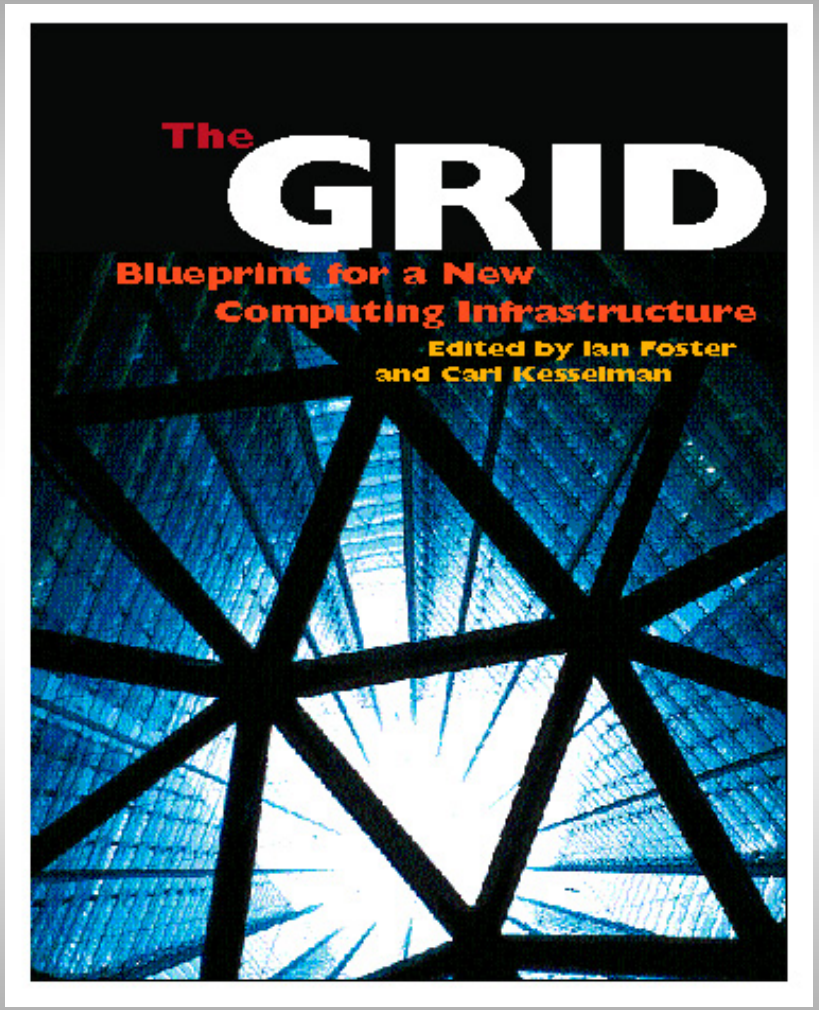
1000 SPECint2000 → 100K PCs

- Annual data storage:
- 12-14PetaBytes per year



Five Emerging Models of Networked Computing From *The Grid*

- Distributed Computing
  - || synchronous processing
- High-Throughput Computing
  - || asynchronous processing
- On-Demand Computing
  - || dynamic resources
- Data-Intensive Computing
  - || databases
- Collaborative Computing
  - || scientists



EGEE: Enabling Grids for E-science in Europe

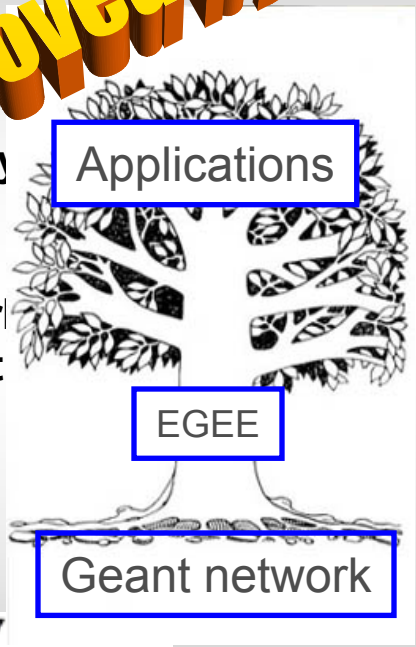
Goals

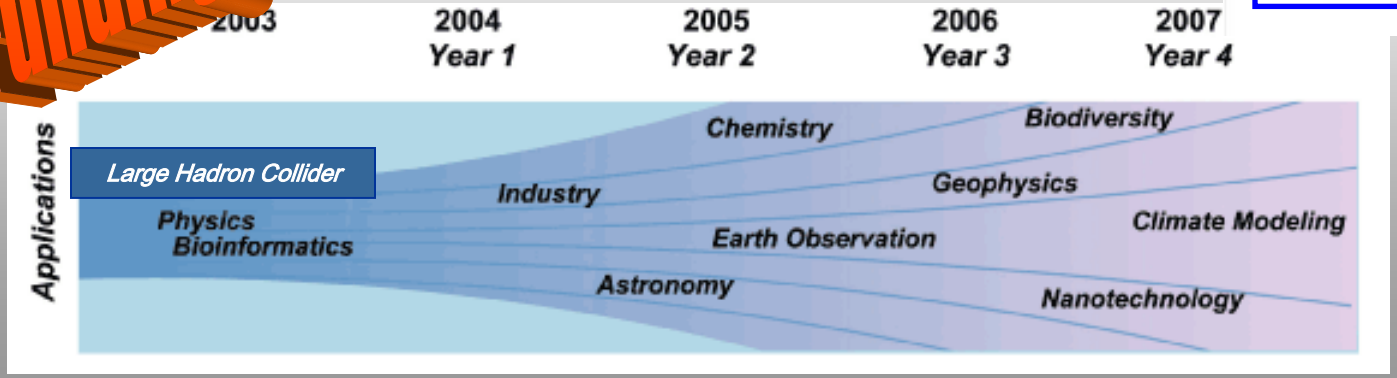
- Create a wide European Grid Infrastructure for the support of research in all scientific areas
- Establish the EU part of a world-wide Grid infrastructure for research

Strategy

- **Leverage national and regional Grid programmes (e.g. LCG)**
- **Build on EU and EU member states investments in Grid Technology**
- **Build on pioneering prototype results from previous projects**
- **Exploit International collaboration (US and Pacific)**
- **Work with industrial Grid developers and National Reseach Networks**
- **Become the natural EU counterpart to the US NSF Cyber-infrastructure**

Funding of ~32ME over two years approved by EU





LHC Grid Deployment – LCG-1

Significant use by CMS-Italy in last days of 2003 for production

Current major use by ALICE

LHC Grid for the 2004 Data Challenges

Upgraded version of the grid software (LCG-2)

- **Over 1,800 processors available now at core sites**
- **Data challenges have started in March – ALICE (PDC3), CMS (DC04)**
- **LHCb & ATLAS – start May**
- **Hewlett Packard to provide "Tier 2-like" services for LCG, initially in Puerto Ri**

Grid Operations Centre at RAL

CCLRC

User Support Centre at FZK

GridKa

Planning for a second operations & support centre in Taipei

ASCC
ACADEMIA Sinica Computing Centre
中央研究院計算中心

Upgrading the LHC … the SLHC

- Initial Studies
- Physics
- Detector R&D

References

+ Talks by F. Gianotti, D. Green and F. Ruggiero at the ICFA Seminar (Oct 2002)

Large Hadron Collider Project

LHC Project Report ??

LHC Luminosity and Energy Upgrade: A Feasibility Study

O. Brüning[§], R. Cappi[‡], R. Garoby[‡], O. Gröbner[‡], W. Herr[§], T. Linnecar[§], R. Ostojic[‡], K. Potter[*], L. Rossi[‡], F. Ruggiero[§] (editor), K. Schindl[‡], G. Stevenson[¶], L. Tavian[‡], T. Taylor[‡], E. Tsesmelis[*], E. Weisse[§], and F. Zimmermann[§]

CERN-TH/2002-078
hep-ph/0204087
April 1, 2002

PHYSICS POTENTIAL AND EXPERIMENTAL CHALLENGES OF THE LHC LUMINOSITY UPGRADE

Conveners: F. Gianotti [1], M.L. Mangano [2], T. Virdee [1,3]
Contributors: S. Abdullin [4], G. Azuelos [5], A. Ball [1], D. Barberis [6], A. Belyaev [7], P. Bloch [1], M. Bosman [8], L. Casagrande [1], D. Cavalli [9], P. Chumney [10], S. Cittolin [1], S.Dasu [10], A. De Roeck [1], N. Ellis [1], P. Farthouat [1], D. Fournier [11], J.-B. Hansen [1], I. Hinchliffe [12], M. Hohlfeld [13], M. Huhtinen [1], K. Jakobs [13], C. Joram [1], F. Mazzucato [14], G.Mikenberg [15], A. Miagkov[16], M. Moretti[17], S. Moretti [2,18], T. Niinikoski [1], A. Nikitenko[3,†], A. Nisati [19], F. Paige[20], S. Palestini [1], C.G. Papadopoulos[21], F. Piccinini[2,‡], R. Pittau[22], G. Polesello [23], E. Richter-Was[24], P. Sharp [1], S.R. Slabospitsky[16], W.H. Smith [10], S. Stapnes [25], G. Tonelli [26], E. Tsesmelis [1], Z. Usubov[27,28], L. Vacavant [12], J. van der Bij[29], A. Watson [30], M. Wielers [31]

Detectors: General Considerations

	LHC	SLHC
$\sqrt{s}$	14 TeV	14 TeV
L	10^{34}	10^{35}
Bunch spacing Δt	25 ns	12.5 ns *
σ_{pp} (inelastic)	~ 80 mb	~ 80 mb
N. interactions/x-ing ($N=L\,\sigma_{pp}\,\Delta t$)	~ 20	~ 100
$dN_{ch}/d\eta$ per x-ing	~ 150	~ 750
$\langle E_T \rangle$ charg. particles	~ 450 MeV	~ 450 MeV
Tracker occupancy	1	10
Pile-up noise in calo	1	~3
Dose central region	1	10

Normalised to LHC values

10^4 Gy/year R=25 cm

In a cone of radius = 0.5 there is E_T ~ 80GeV.
This will make low E_t jet triggering and reconstruction difficult.

Indicative Physics Reach

F

Units are TeV (except $W_L W_L$ reach)
Ldt correspond to 1 year of running at nominal luminosity for 1 experiment

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	LC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	7σ	18σ		90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
q*	6.5	7.5	9.5	13	75	0.8	5
Λ compositeness	30	40	40	50	100	100	400

† indirect reach
(from precision measurements)

Approximate mass reach of pp machines:

$\sqrt{s}$ = 14 TeV,	L=10^{34} (LHC)	: up to ≈ 6.5 TeV
$\sqrt{s}$ = 14 TeV,	L=10^{35} (SLHC)	: up to ≈ 8 TeV
$\sqrt{s}$ = 28 TeV,	L=10^{34}	: up to ≈ 10 TeV
$\sqrt{s}$ = 40 TeV,	L=10^{34}	: up to ≈ 13 TeV
$\sqrt{s}$ = 200 TeV,	L=10^{34} (VLHC)	: up to ≈ 75 TeV

Inner Tracking

The inner tracker will probably need to be changed as a whole

Preserve current pattern recognition, momentum resolution, b-tagging
⇨ cell sizes have to be decreased by a factor 10

Pixel:	4 cm layer:	Fast hadrons: Dose :	1.6×10^{16} cm^{-2} 4.2 MGy
	11 cm layer:	Fast hadrons: Dose :	2.3×10^{15} cm^{-2} 940 kGy
Tracker:	22 cm :	Fast Hadrons: Dose :	8×10^{14} cm^{-2} 350 kGy
	75 cm :	Fast Hadrons: Dose :	1.5×10^{14} cm^{-2} 35 kGy
	115 cm :	Fast Hadrons: Dose :	1×10^{14} cm^{-2} 9.3 kGy

C

Region 1 (r < 20 cm)

New approaches and concepts

Region 2 (20 < r < 60 cm)
Further developed hybrid pixel

Region 3 (r > 60 cm)
Detectors can be built by further

Summary

LHC luminosity upgrade can extend:

- physics reach of LHC at a moderate extra cost relative to initial LHC
- the LHC 'lifetime'

To realise this reach, the LHC detectors must preserve performance:
trackers must be rebuilt, and

calorimeters, muon systems, triggers and DAQ need development.
Upgrades programme, from launch to data taking will take 8-10 years

The time to start is now

CONCLUSIONS

- LHC Physics is as compelling as ever
- LHC machine
  - Components on schedule
  - Installation and commissioning will need continuous attention
- LHC experiments
  - Coming together well .. not without difficulties
- LHC computing
  - LCG-1 deployed and in use
- LHC upgrades
  - ATLAS and CMS have studies underway

Collisions …… Summer 2007