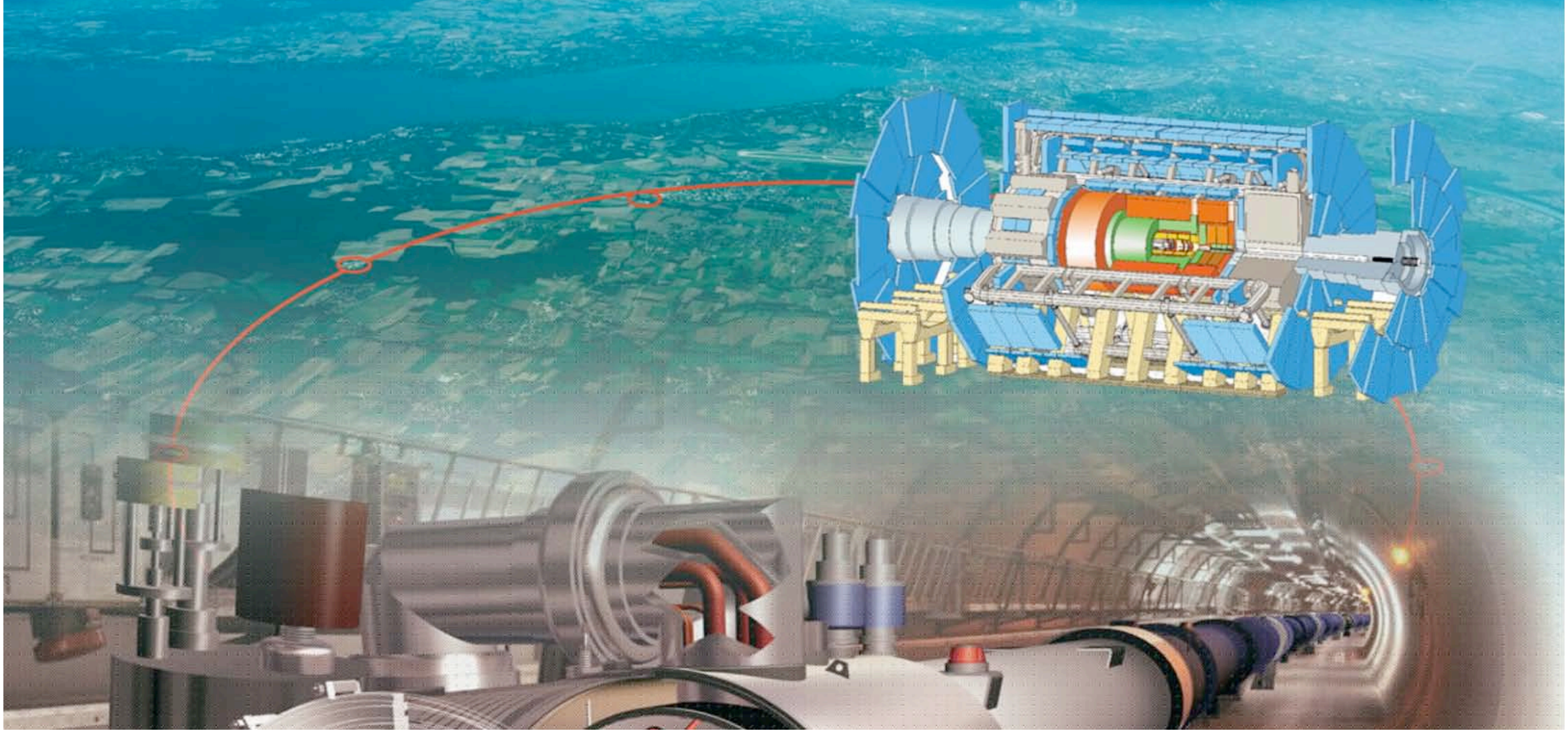
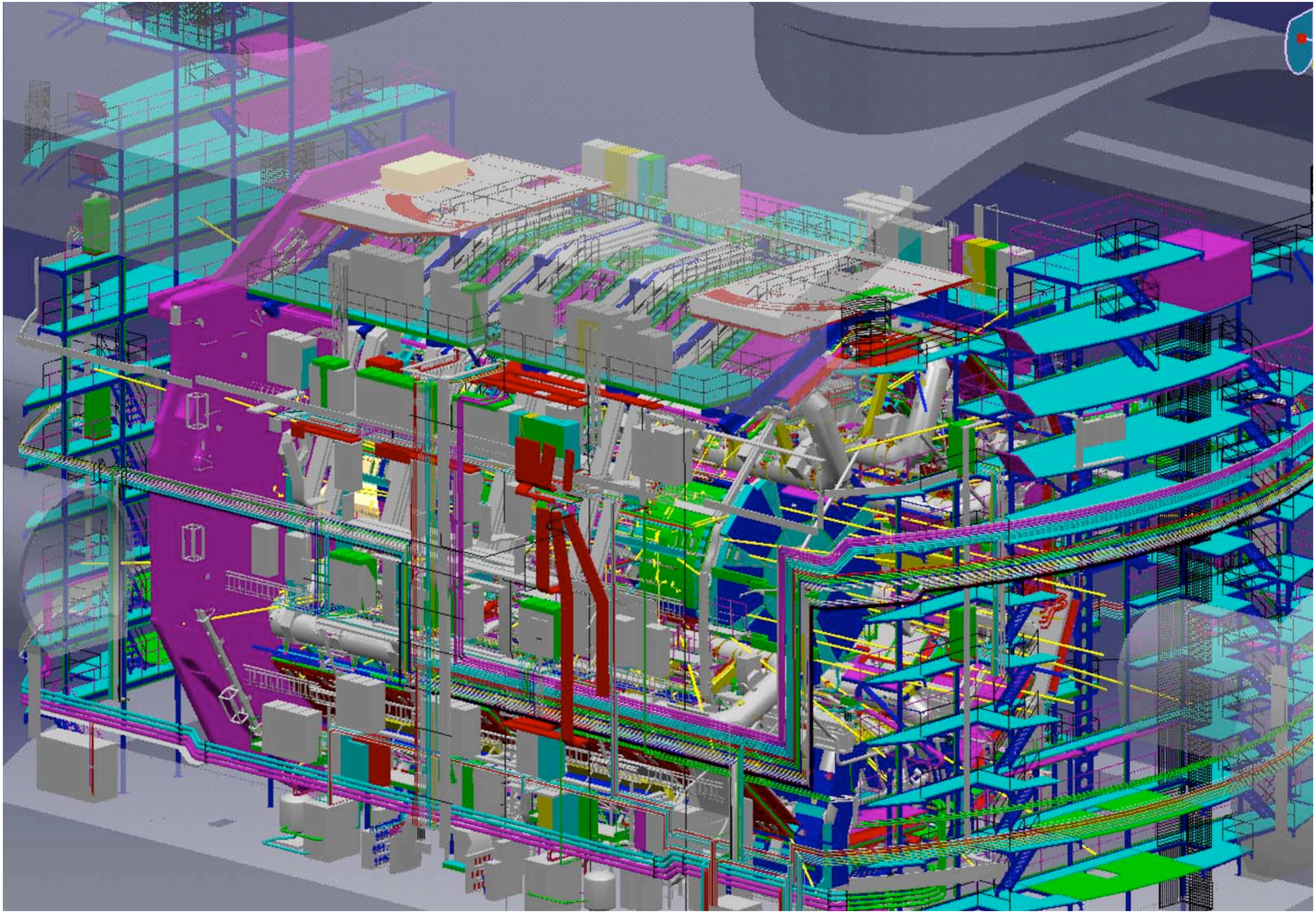
Getting ATLAS ready for Physics

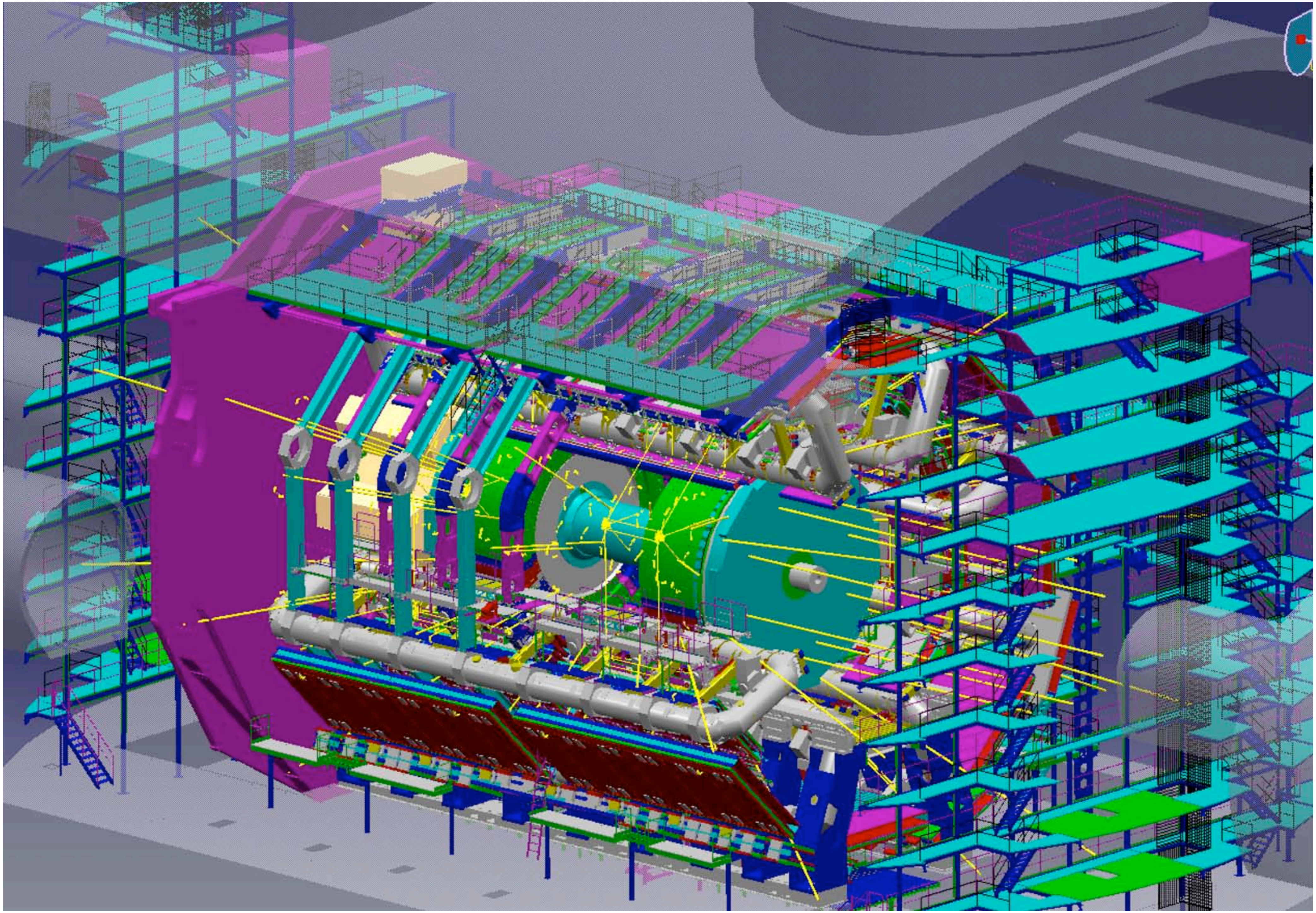
Marzio Nessi

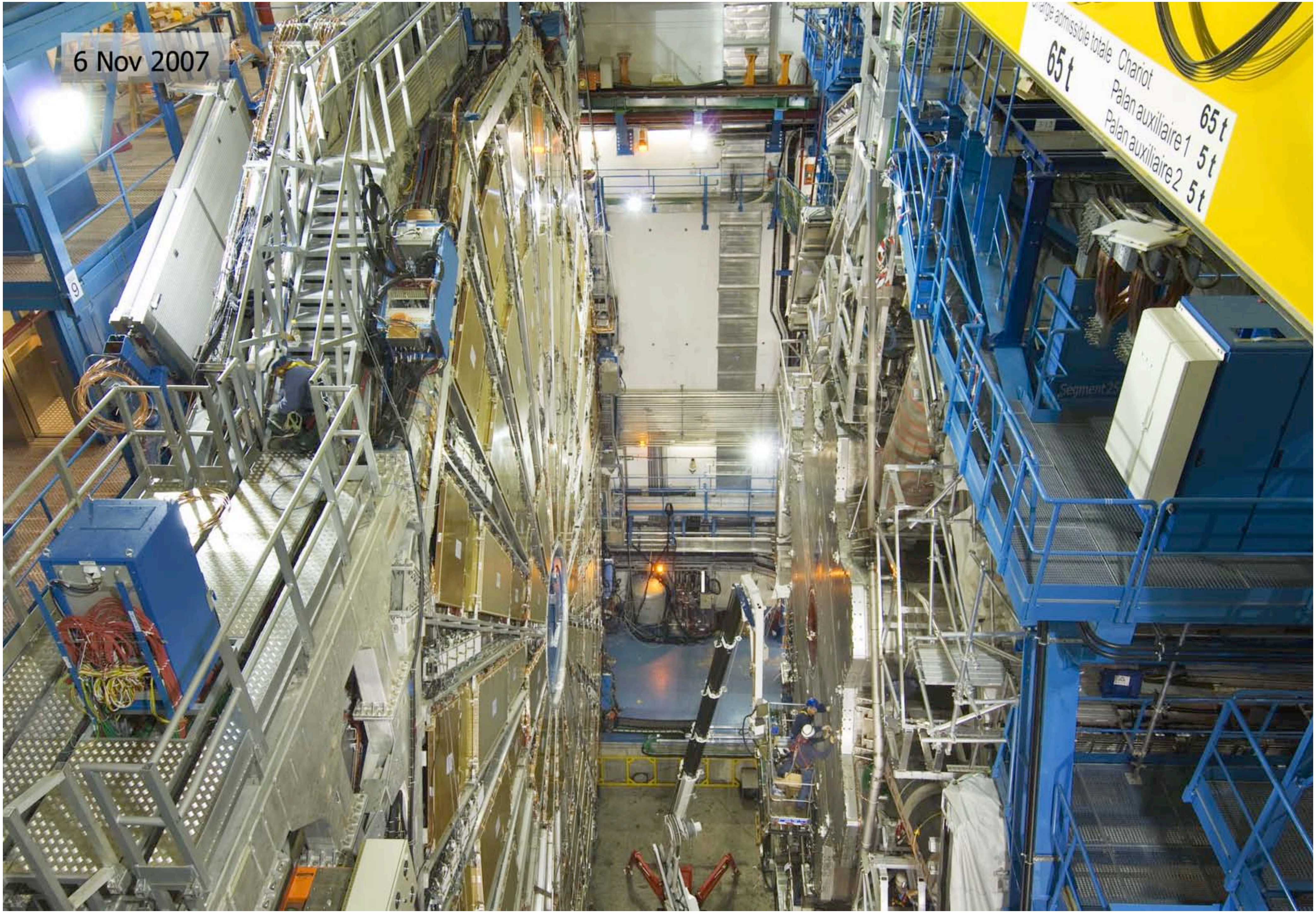
November 15th, 2007



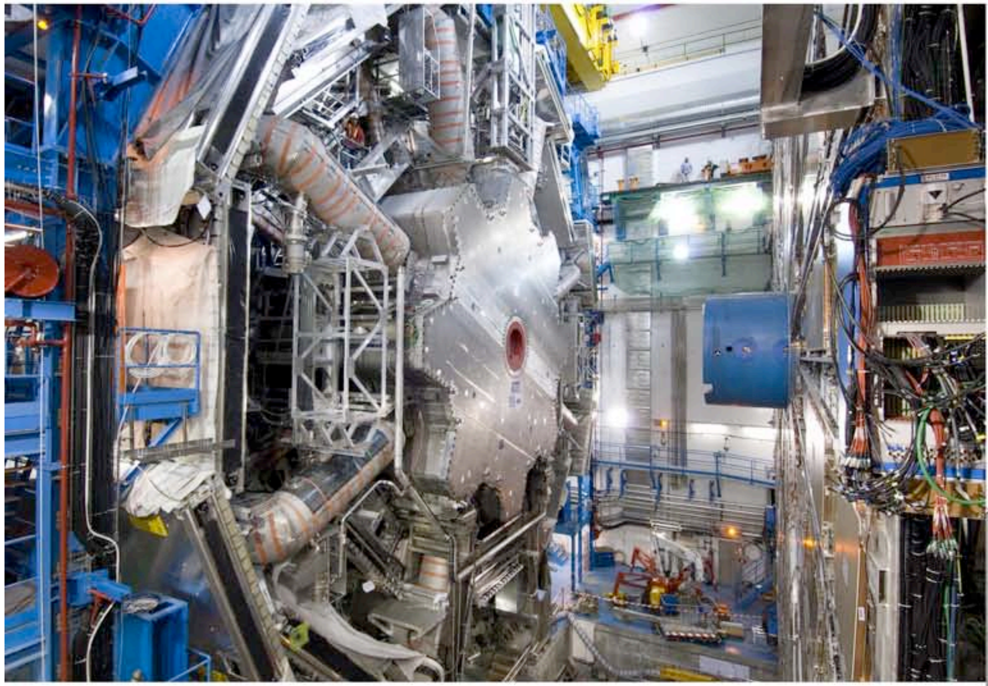
Taking a picture in 2003 was easy !





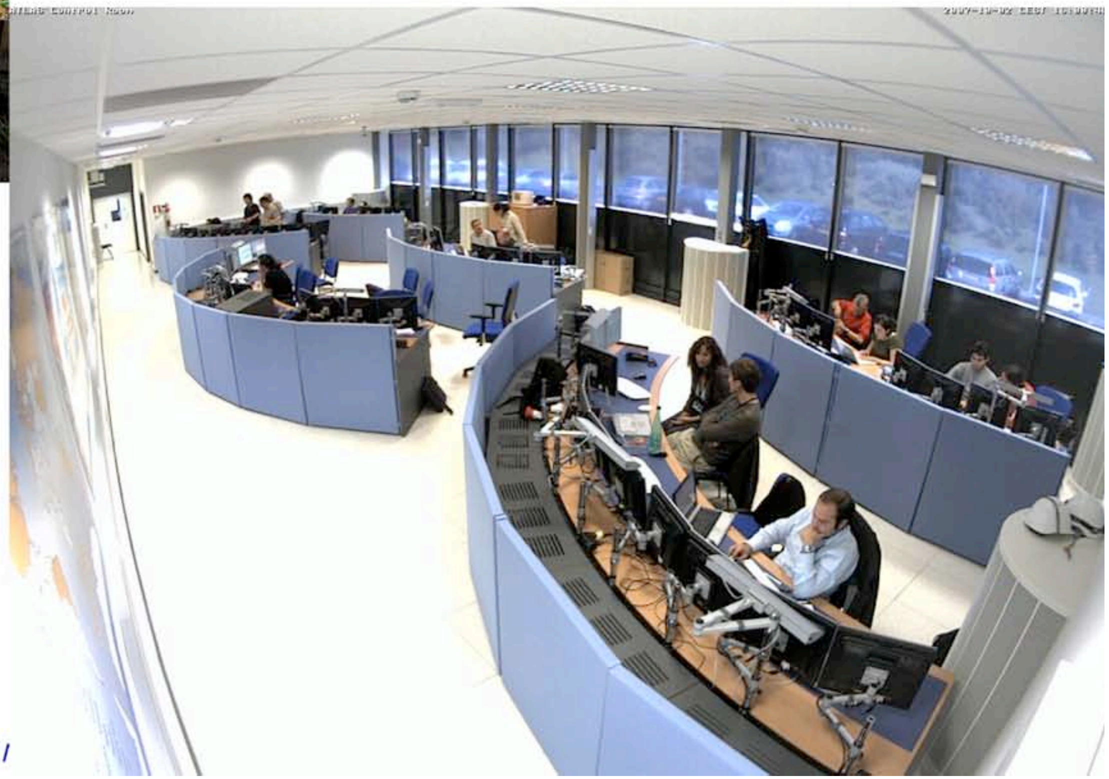

6 Nov 2007
65 t
Chariot 65 t
Palan auxiliaire 1 5 t
Palan auxiliaire 2 5 t

Today's activities



✓Completion of the detector installation and all related services (~6000/7000 tons installed) … part of the forward muon spectrometer and forward shieldings still on surface

✓Hardware commissioning of all electronics components, controls and safety systems

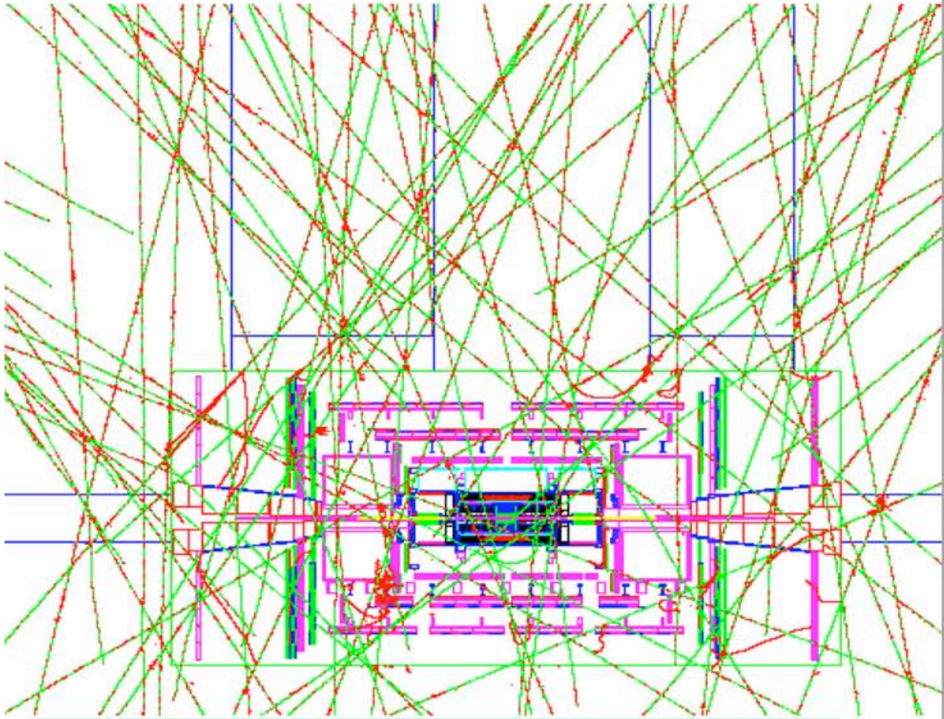


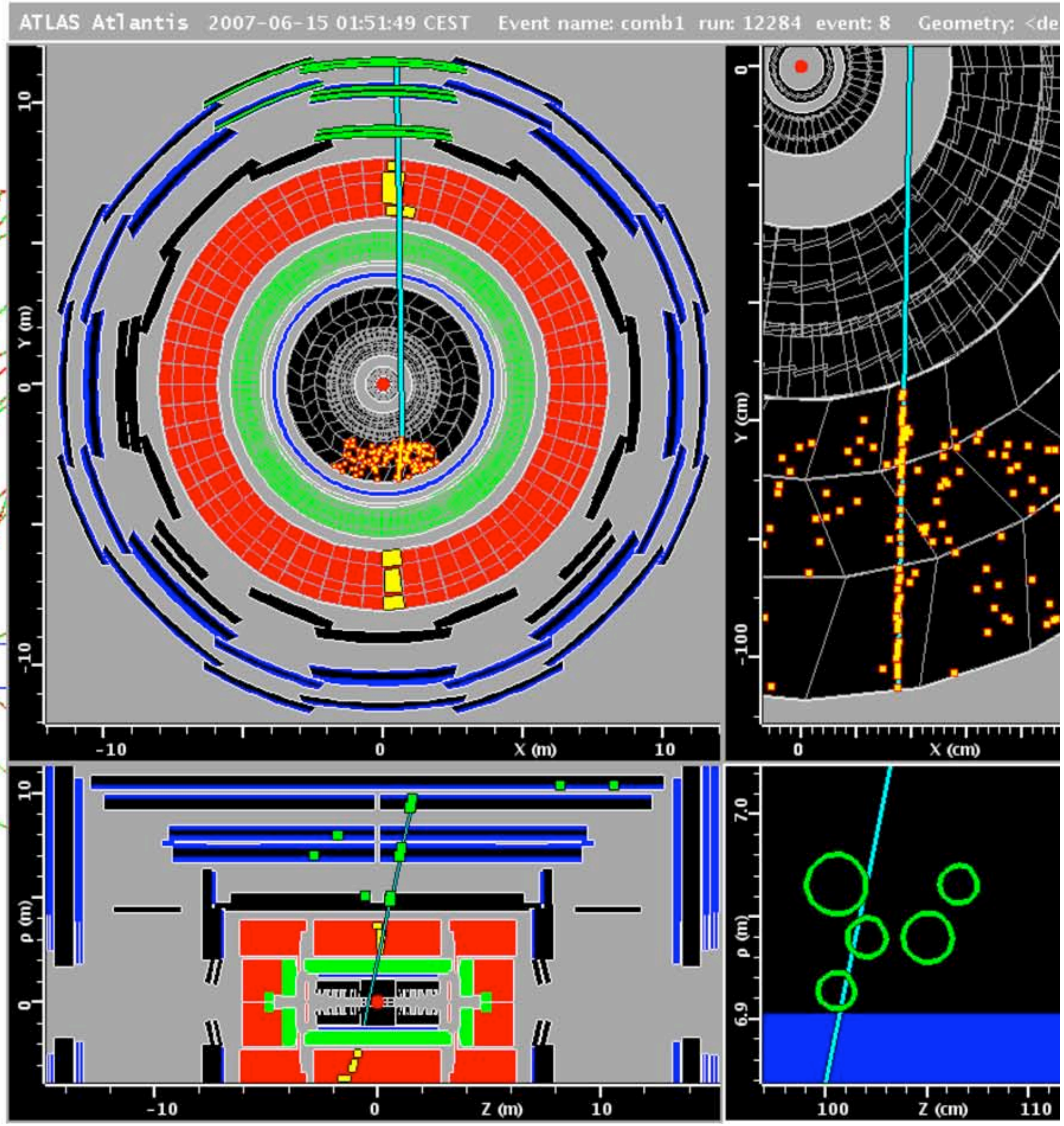
✓Integration and tuning of all controls

✓Full test of the data taking chain with calibration and cosmics events. Operation mode mimics and ATLAS runs

✓Test of all the online and offline software and computing infrastructure

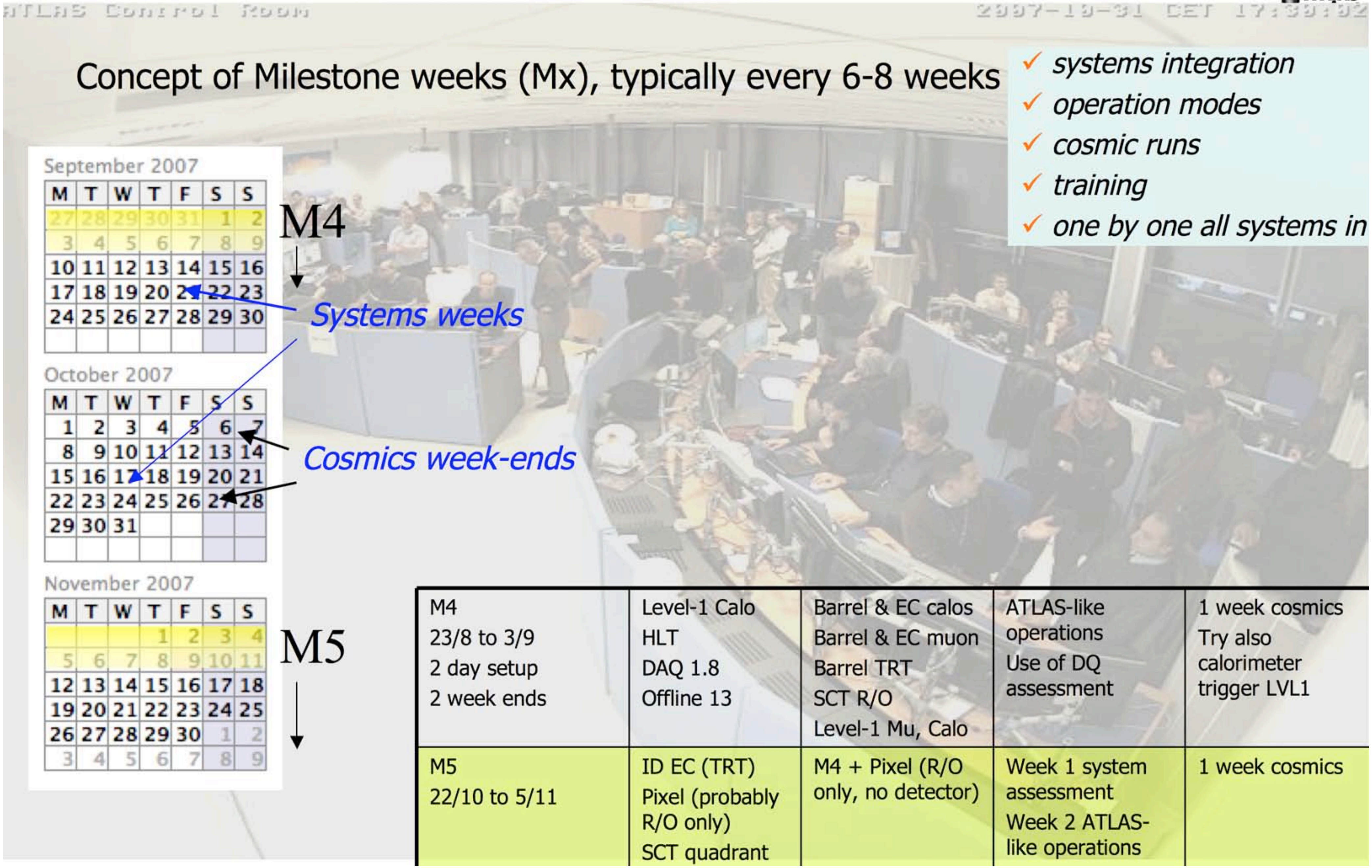
Thanks to cosmic rays … a nice help





10 ms of cosmics, trigger rate 1-200Hz depending on experimental cuts

Commissioning organization



Concept of Milestone weeks (Mx), typically every 6-8 weeks

- ✓ *systems integration*
- ✓ *operation modes*
- ✓ *cosmic runs*
- ✓ *training*
- ✓ *one by one all systems in*

September 2007

M	T	W	T	F	S	S
27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

October 2007

M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

November 2007

M	T	W	T	F	S	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	1	2
3	4	5	6	7	8	9

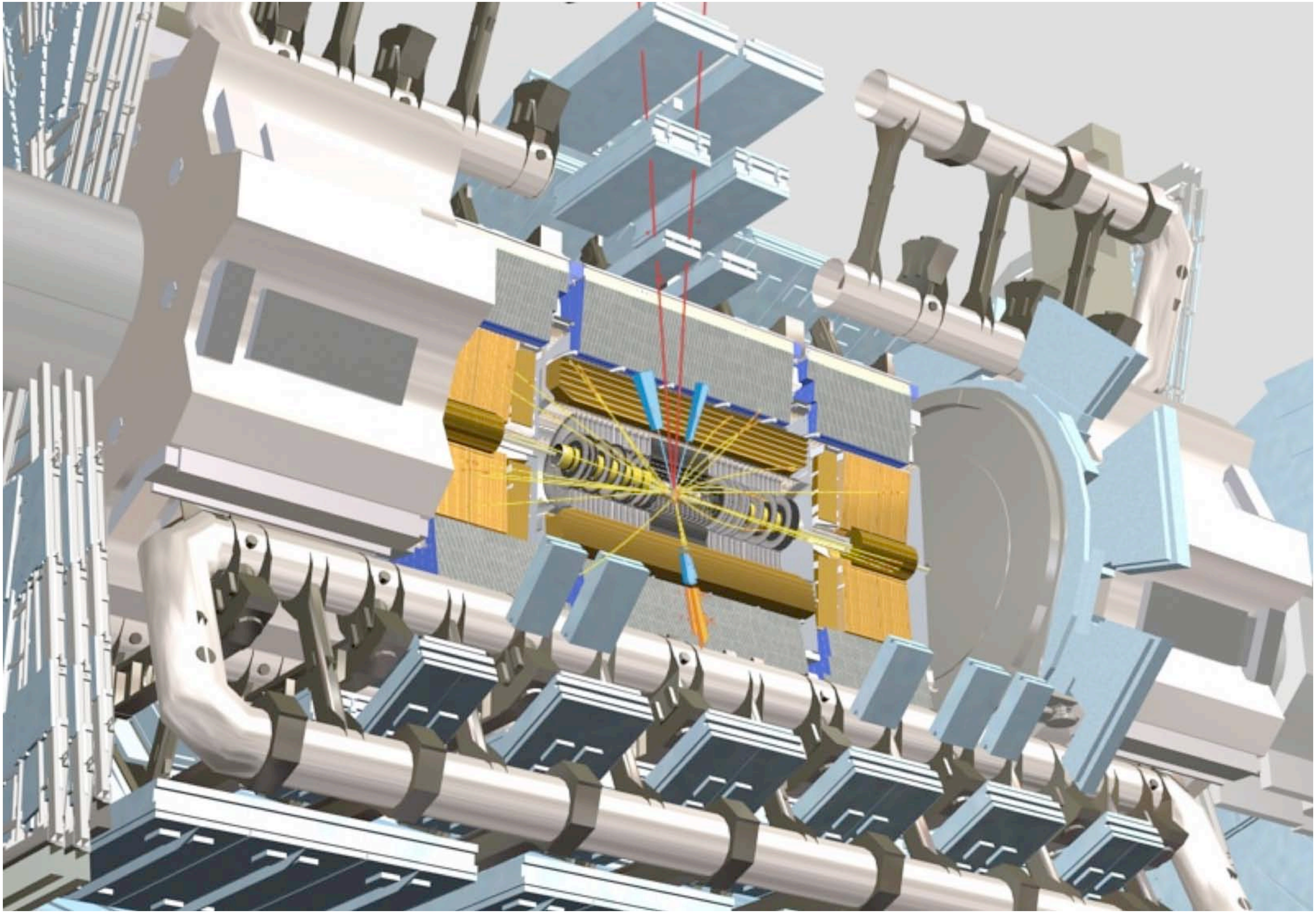
M4 ↓

Systems weeks

Cosmics week-ends

M5 ↓

M4 23/8 to 3/9 2 day setup 2 week ends	Level-1 Calo HLT DAQ 1.8 Offline 13	Barrel & EC calos Barrel & EC muon Barrel TRT SCT R/O Level-1 Mu, Calo	ATLAS-like operations Use of DQ assessment	1 week cosmics Try also calorimeter trigger LVL1
M5 22/10 to 5/11	ID EC (TRT) Pixel (probably R/O only) SCT quadrant	M4 + Pixel (R/O only, no detector)	Week 1 system assessment Week 2 ATLAS-like operations	1 week cosmics



Today the ATLAS detector is a combination of

- Active detectors
- Connectivity services (cables and pipes)
- Support and access structures
- Operation infrastructure (cryogenics, cooling units, gas distribution, power distribution, ventilation …)
- Controls and safety systems
- Front-end and back-end electronics
- Data flow hardware and software

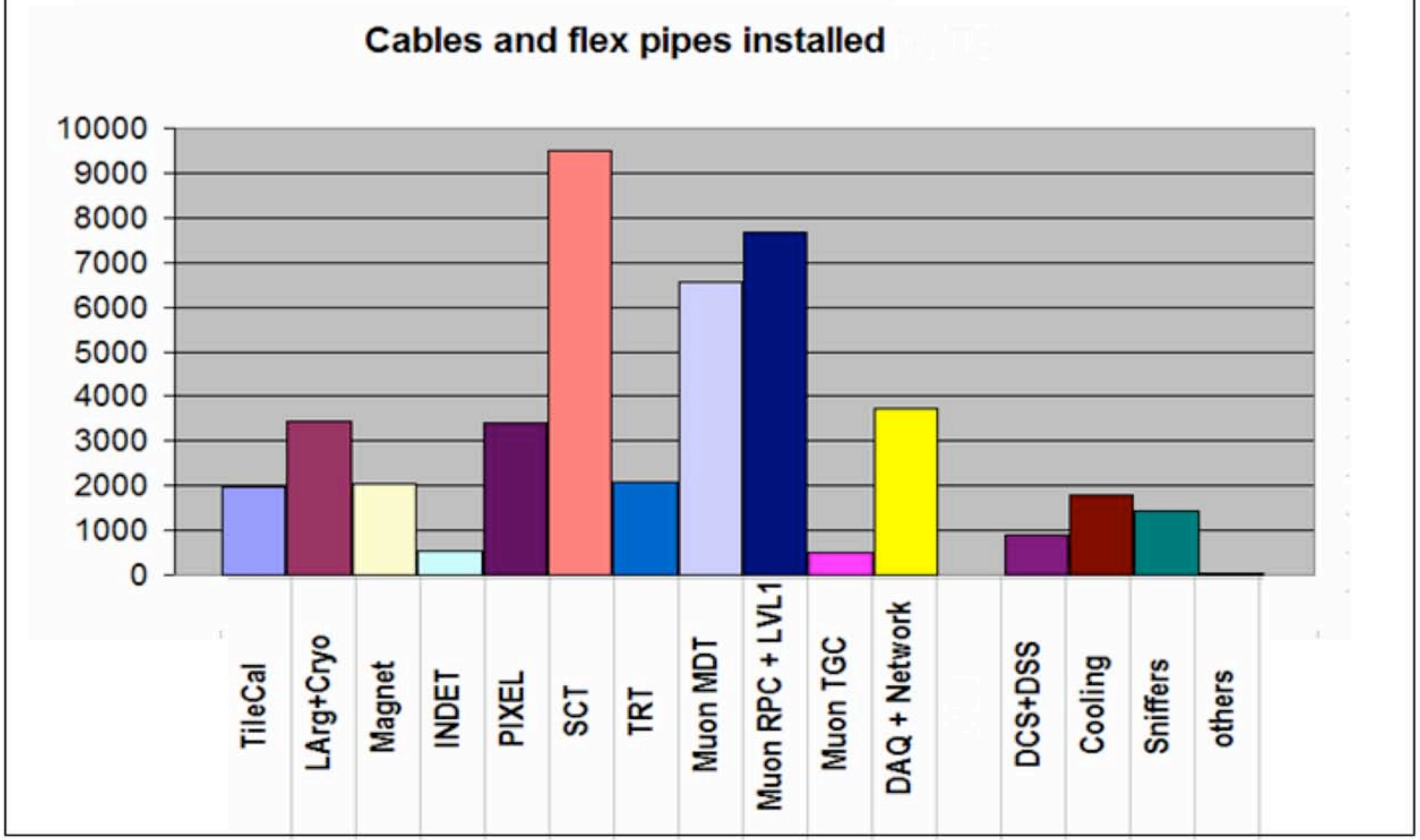
Today the ATLAS detector is a combination of

Sub-detector	*N. of channels*
Pixels	*80×10^6*
Silicon strip detector (SCT)	*6×10^6*
Transition Radiation Tracker (TRT)	*3.5×10^5*
Electromagnetic calorimeter	*1.7×10^5*
Fe/scintillator (Tilecal) calorimeter	*9800*
Hadronic end-cap LAr calorimeter	*5600*
Forward LAr calorimeter	*3500*
Barrel Muon Spectrometer	*7×10^5*
End-cap Muon Spectrometer (TGC)	*3.2×10^5*
Forward detectors	*1.2×10^4*

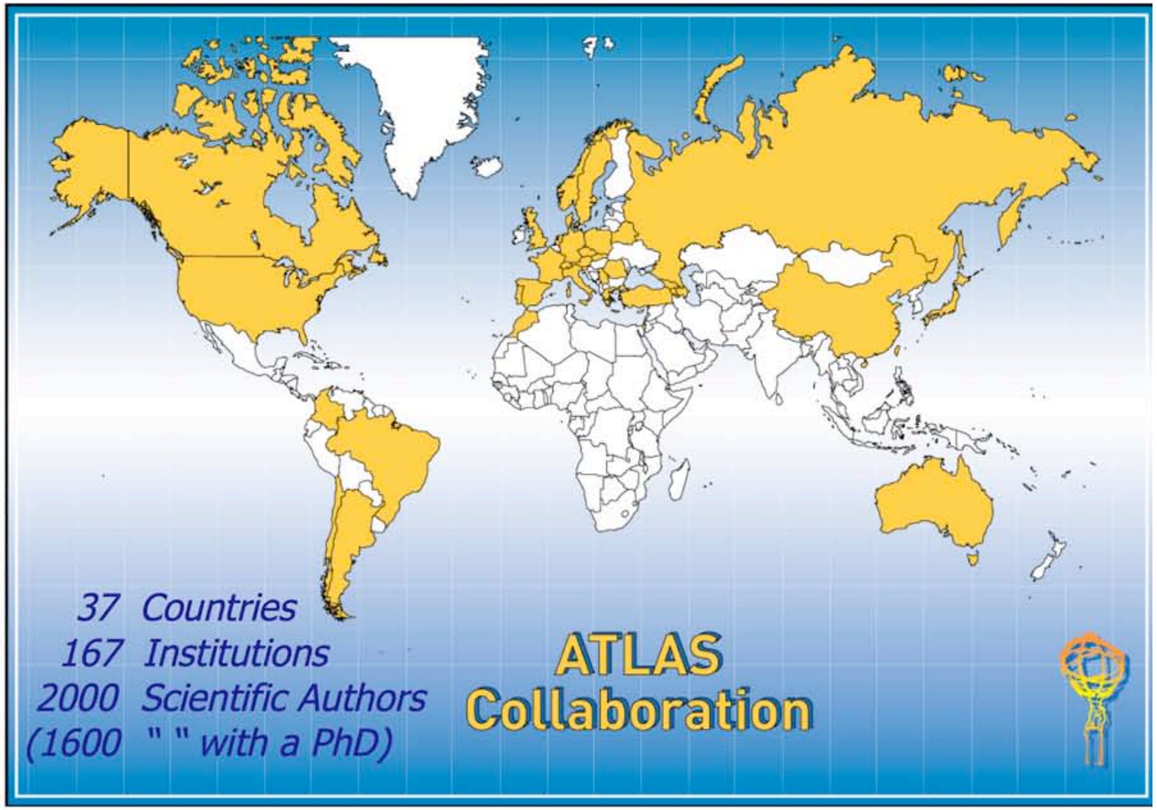
total ~ 87.6×10^6

Today the ATLAS detector is a combination of

> 55000 cables and pipes installed, > 3000 km

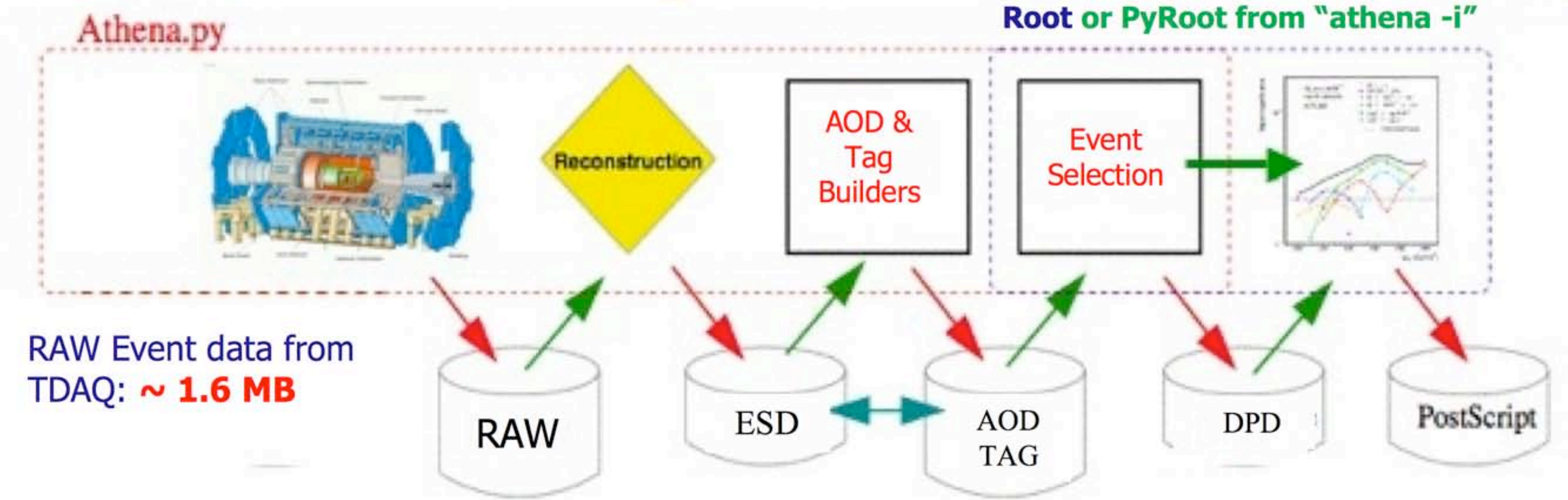


A thoroughly Collaborative Effort



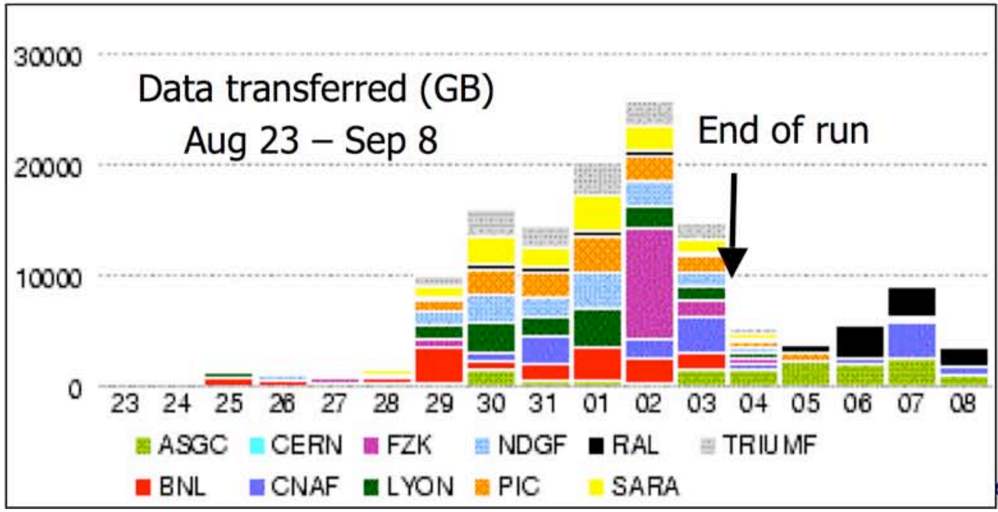
… which was there from the early '90 for design and tuning of technologies, then for construction, for writing software, setting up computing and now for debugging, operating and then analyzing the huge amount of data ATLAS will produce

The data chain



RAW Event data from
TDAQ: **~ 1.6 MB**

ESD	(Event Summary Data): output of reconstruction (calo cells, track hits, ..): **~ 1 MB**
AOD	(Analysis Object Data): physics objects for analysis (e,γ,m,jets, …): **~ 100 kB**
TAG	Reduced set of information for event selection: **~ 1 kB**
DPD	(Derived Physics Data): equivalent of old ntuples: **~ 10 kB**



essi

Data collected during the September global run processed at CERN (Tier0), distributed to Tier-1 and some Tier-2 centres, analyzed at Tier-2 level (following the Computing Model)

A trigger strategy (MHz → 200Hz)

Trigger menus strategies:

Item (examples)	Trigger output rate @10^{31} (not prescaled)
2e5	3 Hz
e15	20
2e15	1
γ20	6
μ10	10
2μ4	15
j100	9
4j23	17
τ20+xE30	10
τ20i+μ6	0.1

2e5: 2 $e^{\pm}$ p_T>5 GeV

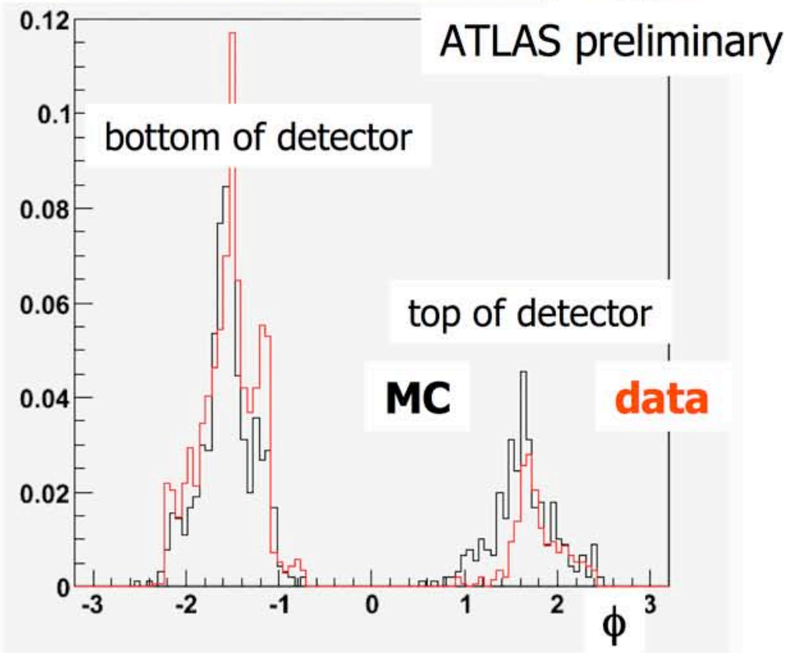
j100: 1 jet p_T>100 GeV

τ20+xE30: 1 τ p_T>20 GeV+ E_T^{miss}>30 GeV

Preliminary, for illustration

Continuous optimization and adaptation the current needs and present understanding of the detector and its response; extensive use of MC to tune and predict

From M4 cosmics run:
Muon tracks reconstructed by trigger

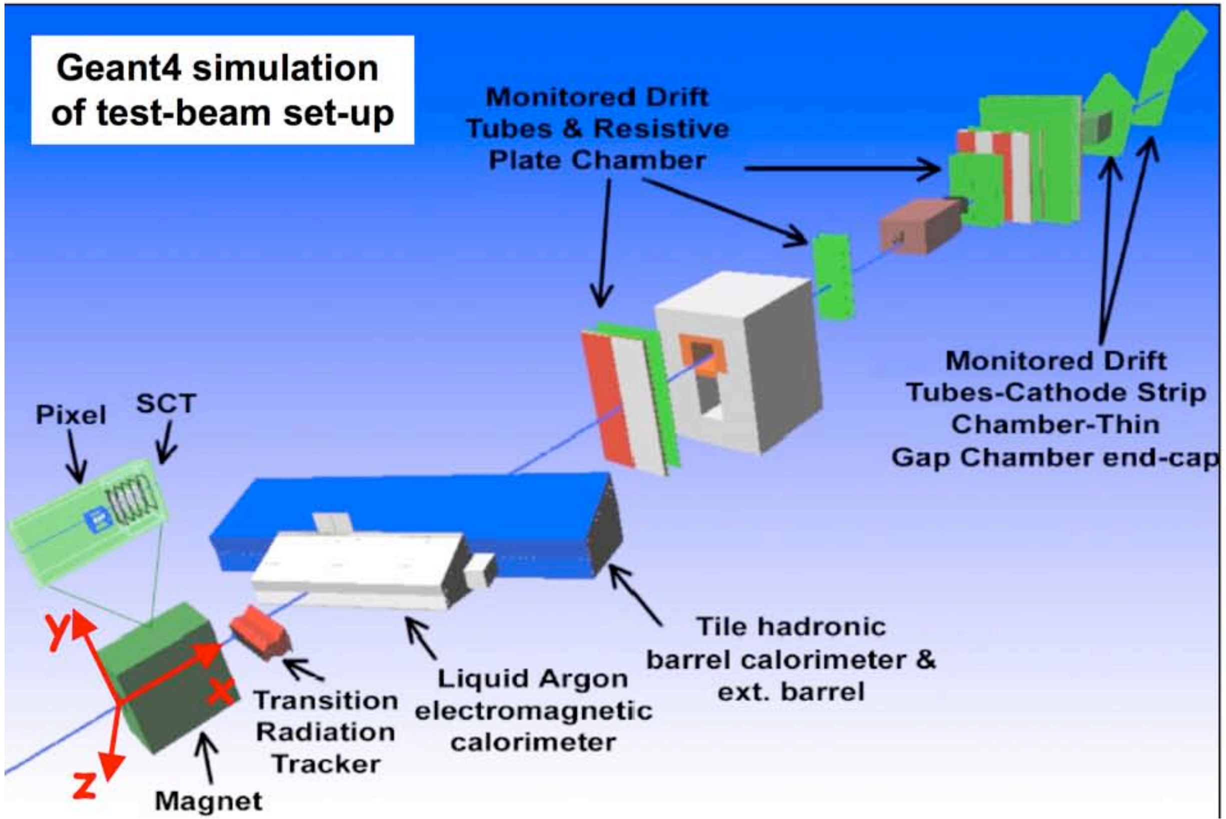


At low initial luminosity we can afford: low thresholds w/o prescaling, simple selections, redundant items, several triggers for calibration and sanity checks, run High-Level-Trigger in pass-through mode, etc.
An essential step to understand trigger and detector

A deep understanding of the hardware over the years using test beams

A major ingredient for the physics preparation is the understanding of the detector performance gained in many test beam campaigns, which culminated in the large 2004 Combined Test Beam efforts with large-scale set-ups for the barrel and end-cap regions in the SPS H8 and H6 beams

- All sub-detectors, LVL1 trigger integrated and running together with common DAQ
- Data analyzed with common ATLAS SW, DataBases



~ 90 million events collected

e±, p ±	1 -> 250 GeV
$\mu^{\pm}, \pi^{\pm}, \pi^0$	up to 350 GeV
γ	20-100 GeV
B-field = 0 -> 1.4 T	

Many configurations (e.g. additional material in ID, 25 ns runs, …)

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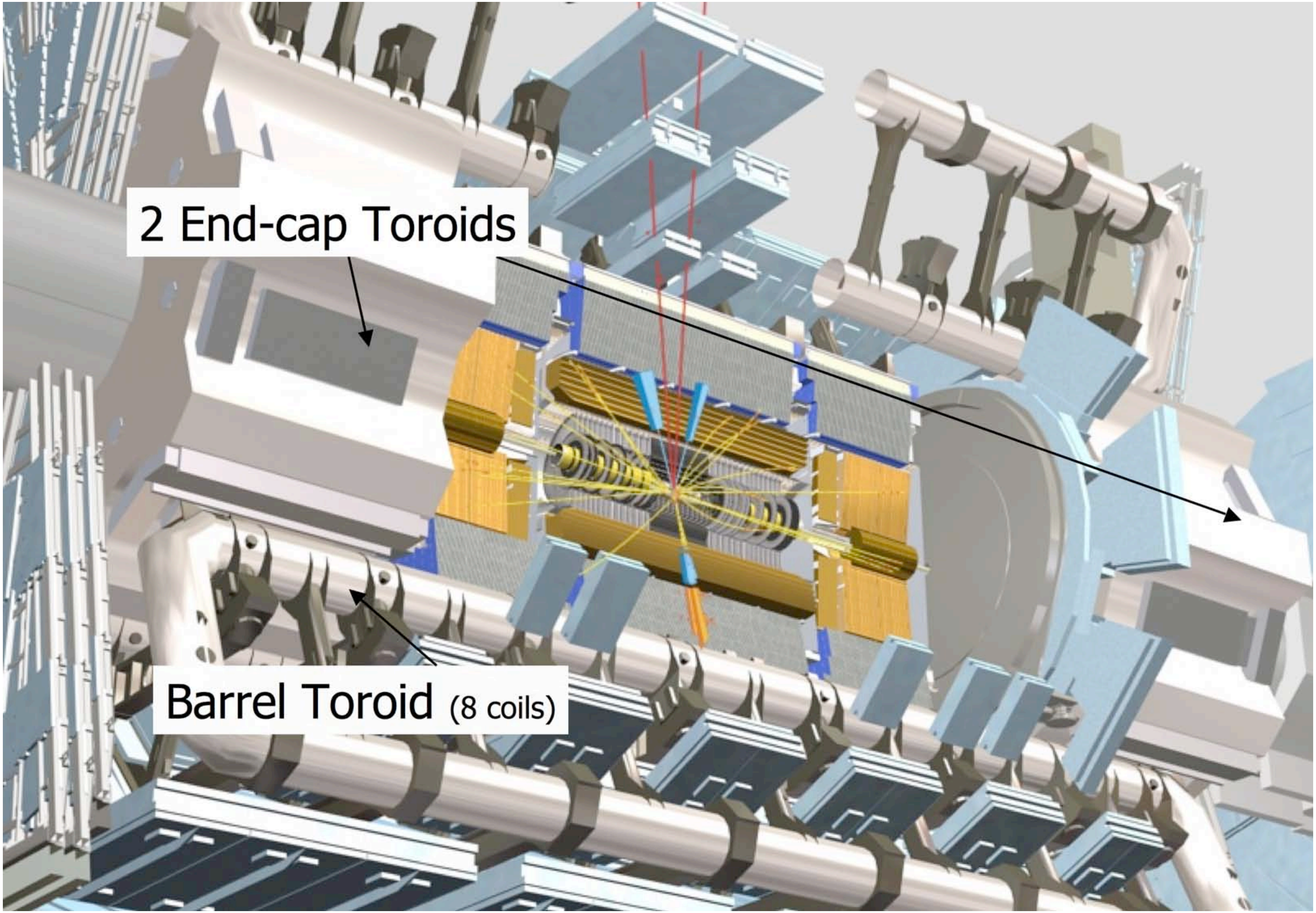
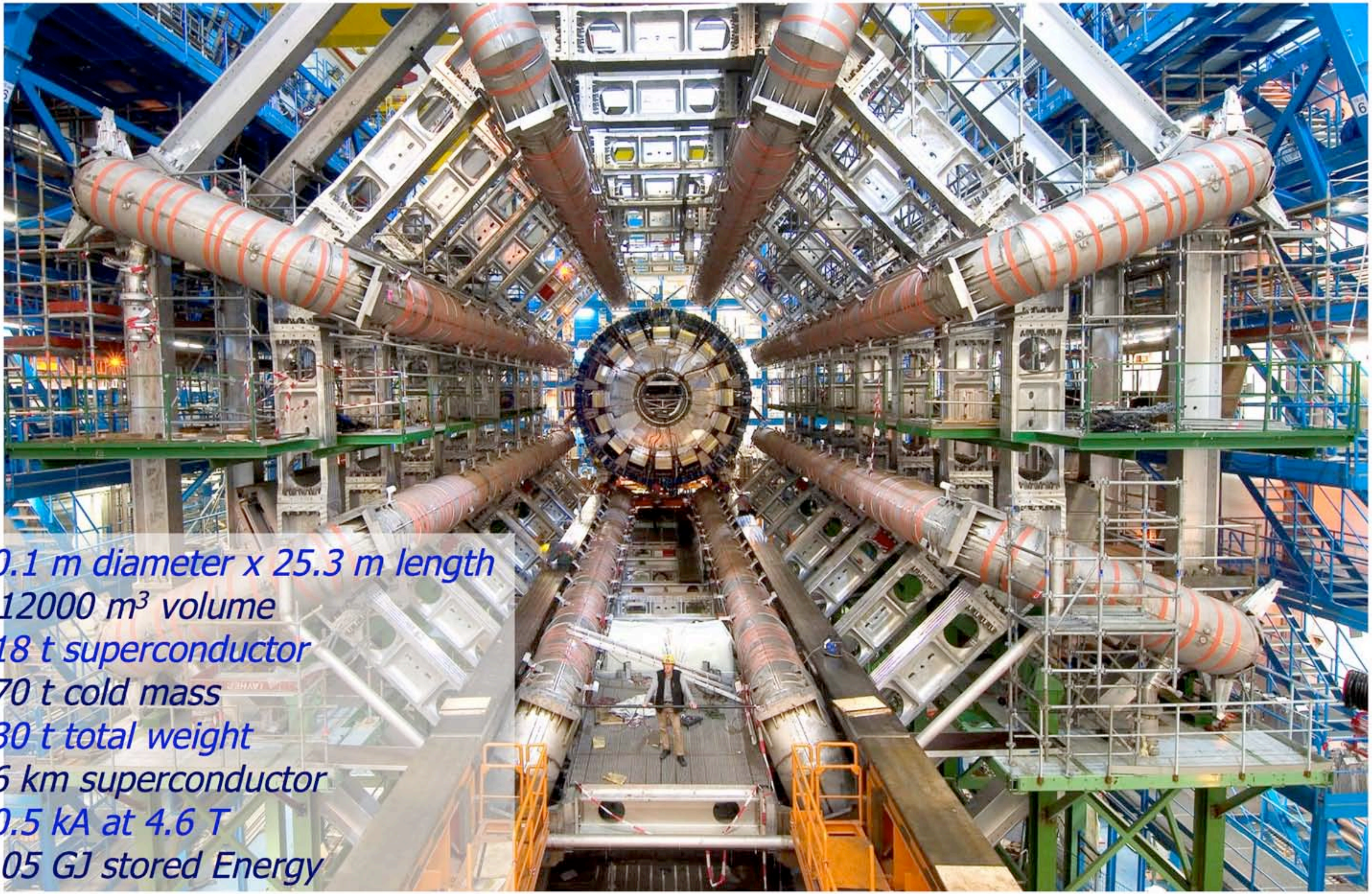


2 End-cap Toroids
Barrel Toroid (8 coils)

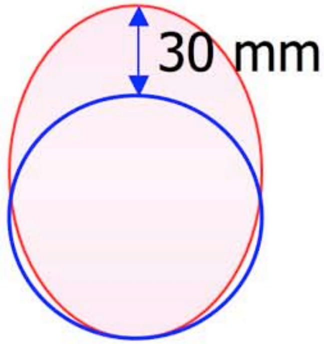
The ATLAS barrel Toroid



- *20.1 m diameter x 25.3 m length*
- *~12000 m³ volume*
- *118 t superconductor*
- *370 t cold mass*
- *830 t total weight*
- *56 km superconductor*
- *20.5 kA at 4.6 T*
- *1.05 GJ stored Energy*

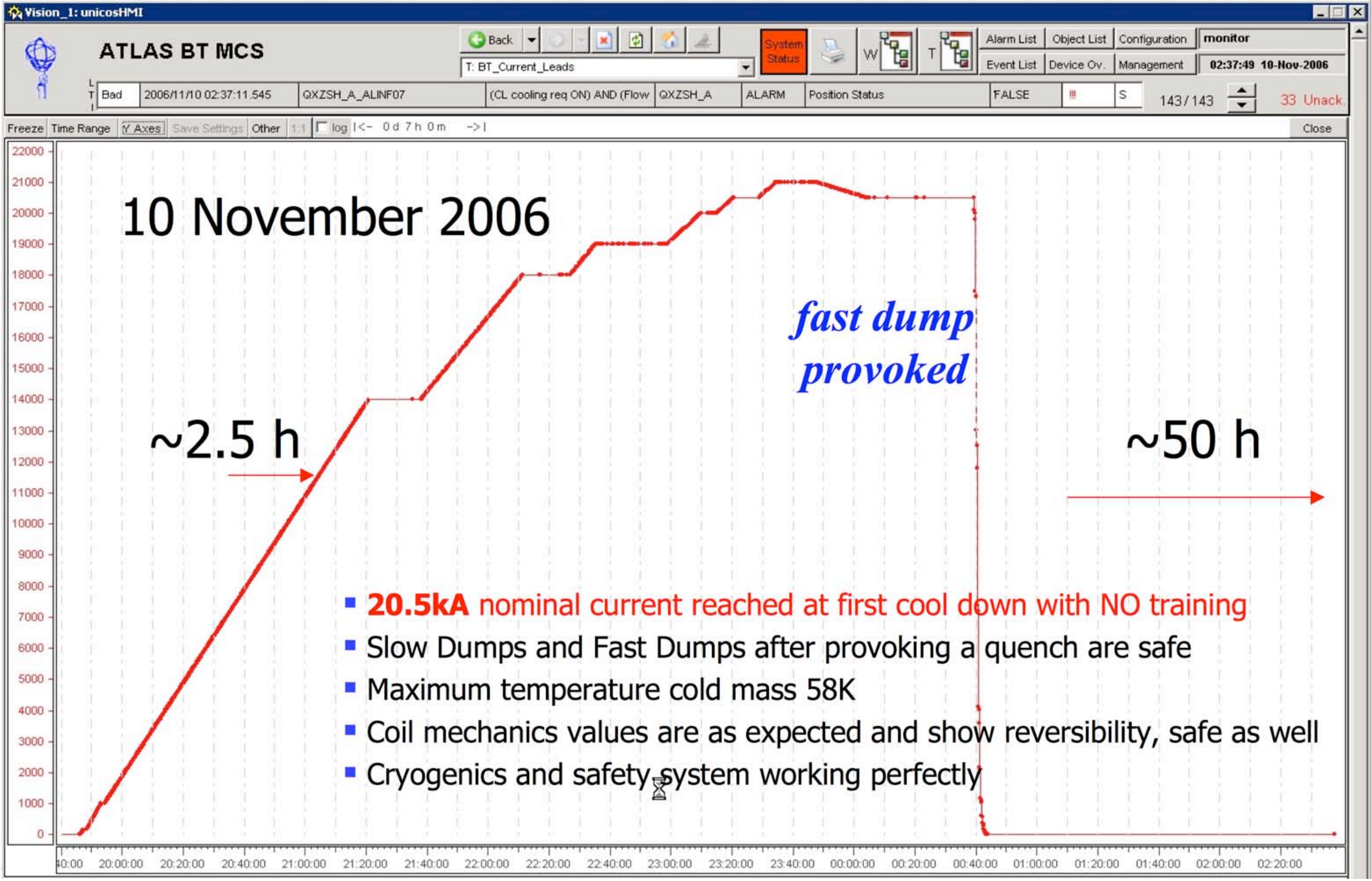
And this, after many months of hard work

More than 11 months of intensive and unconventional assembly work, no accidents



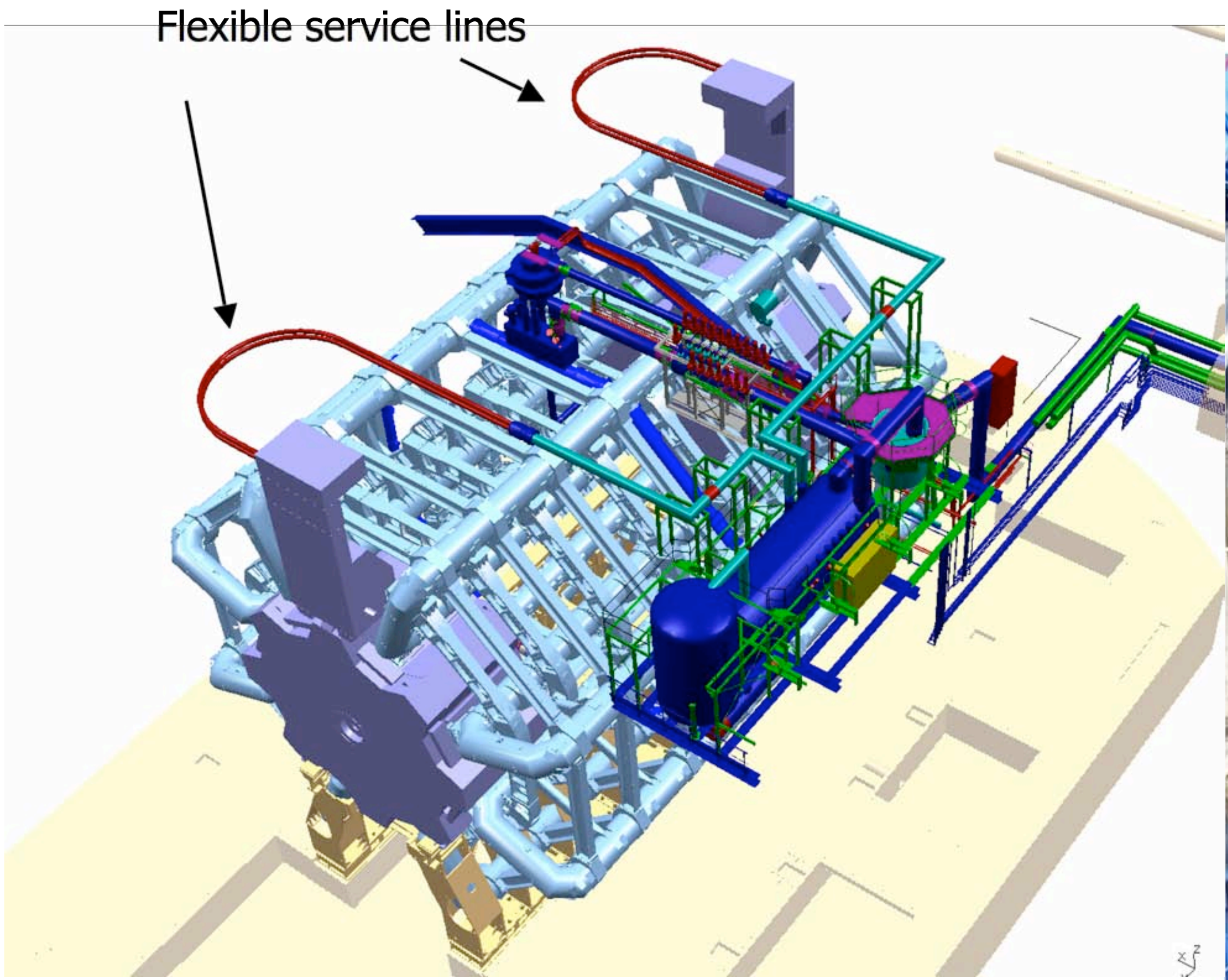
~27 mm measured

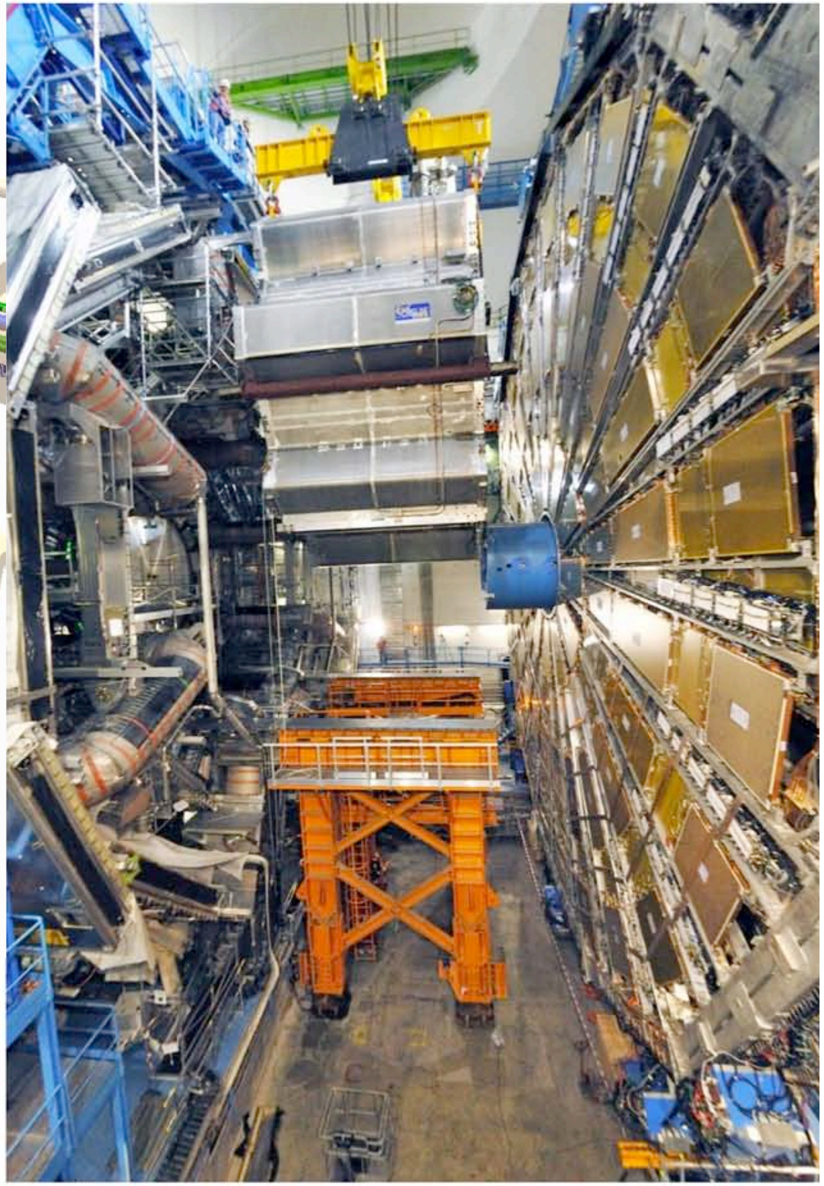
The Barrel Toroid at nominal current



- **20.5kA** nominal current reached at first cool down with NO training
- Slow Dumps and Fast Dumps after provoking a quench are safe
- Maximum temperature cold mass 58K
- Coil mechanics values are as expected and show reversibility, safe as well
- Cryogenics and safety system working perfectly

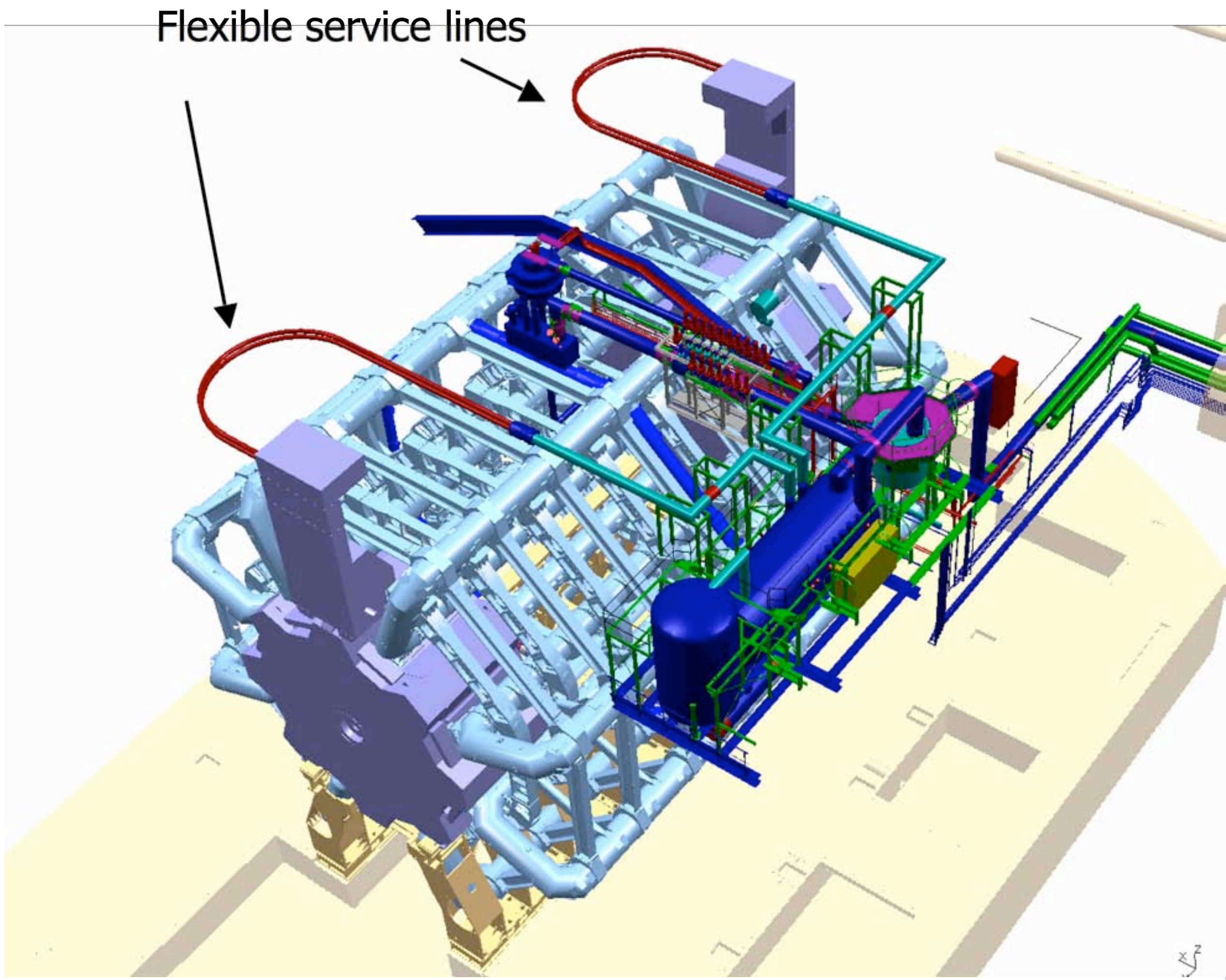
The End-Cap Toroids

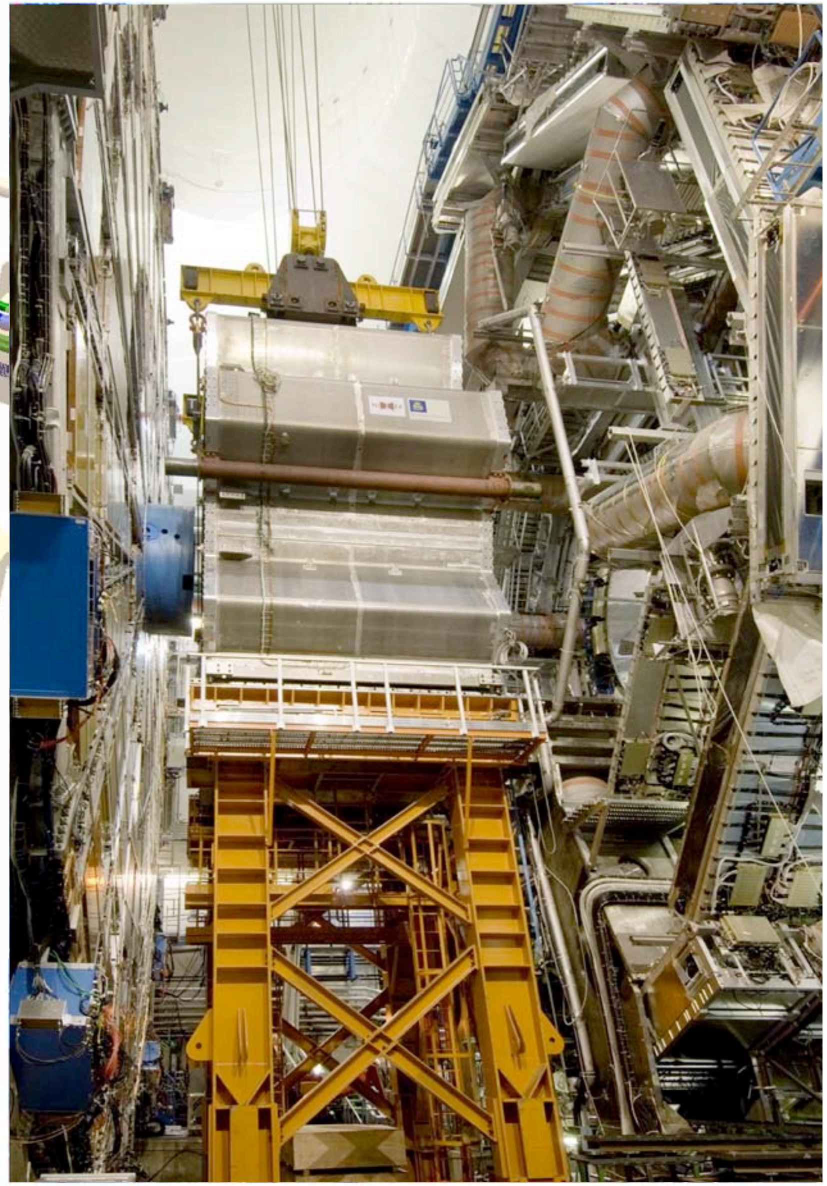




Last one smoothly inserted in the cavern
on 12 July 2007

The End-Cap Toroids





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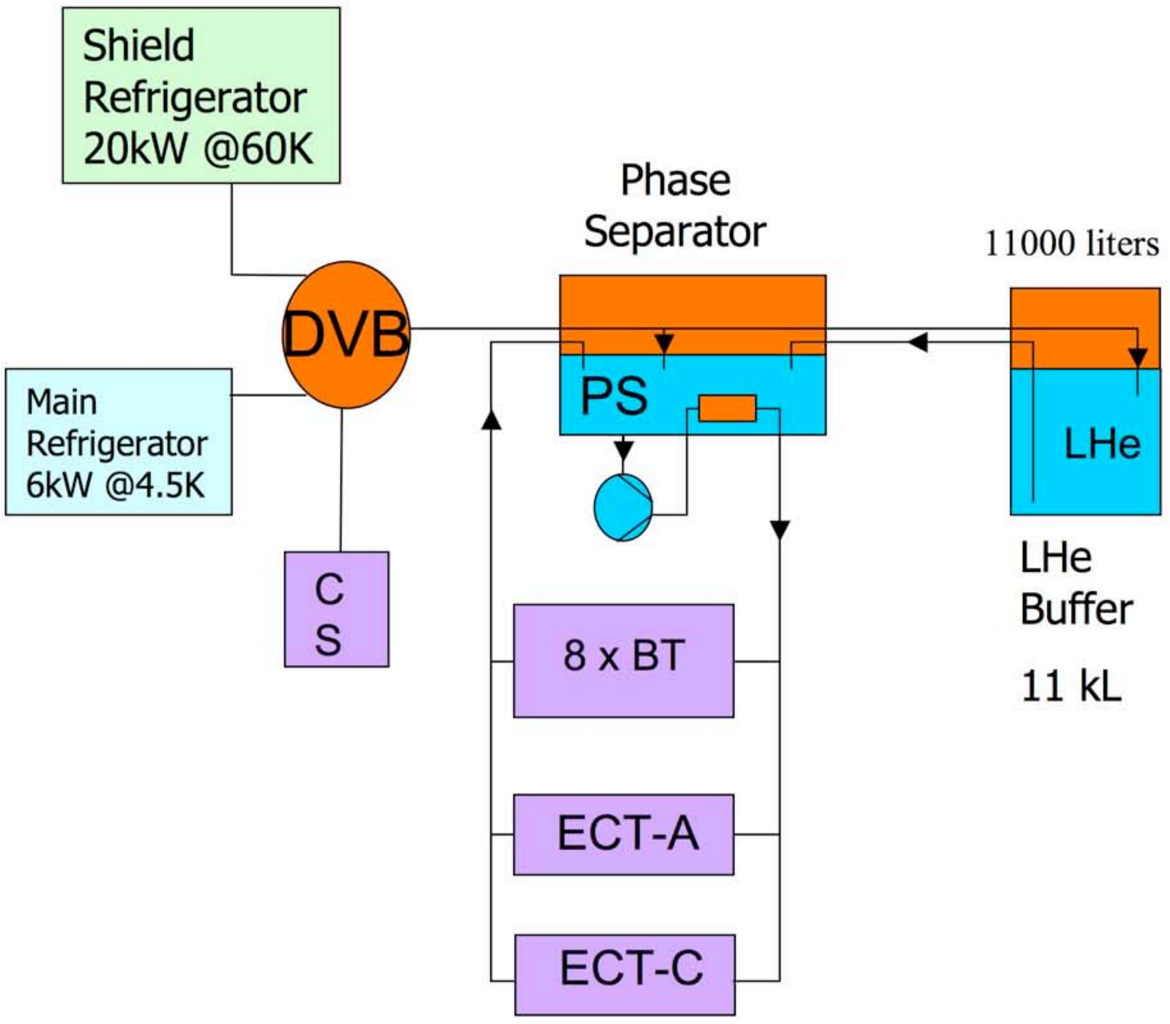
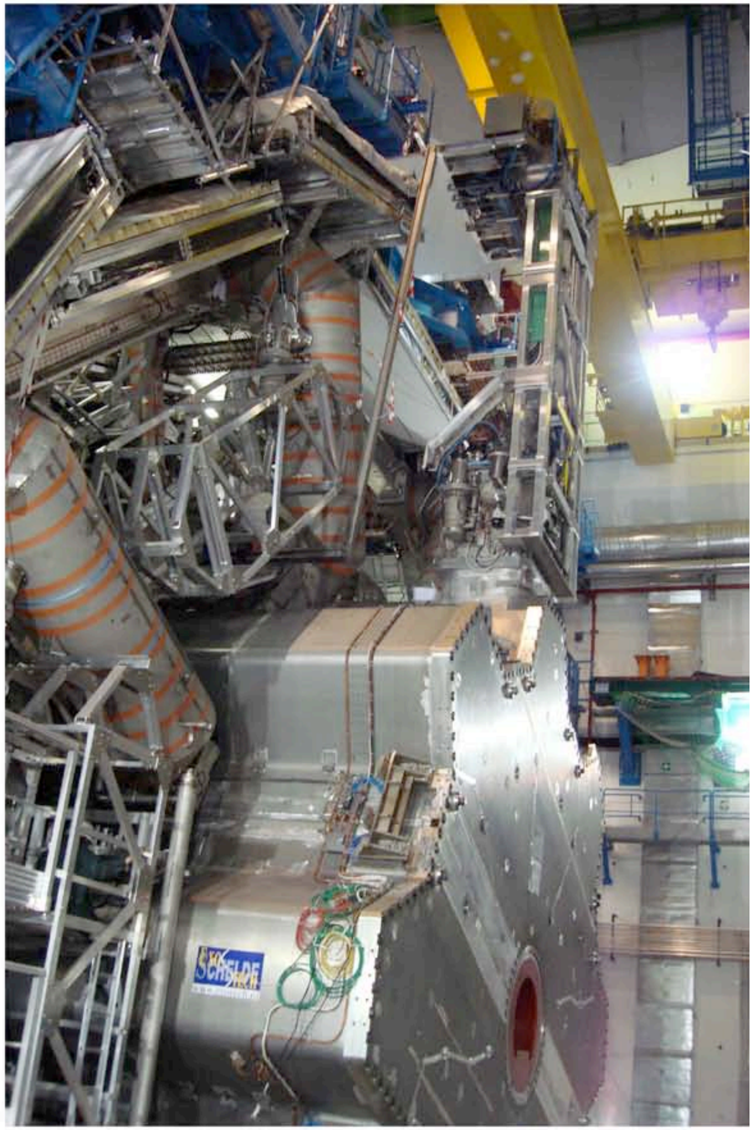
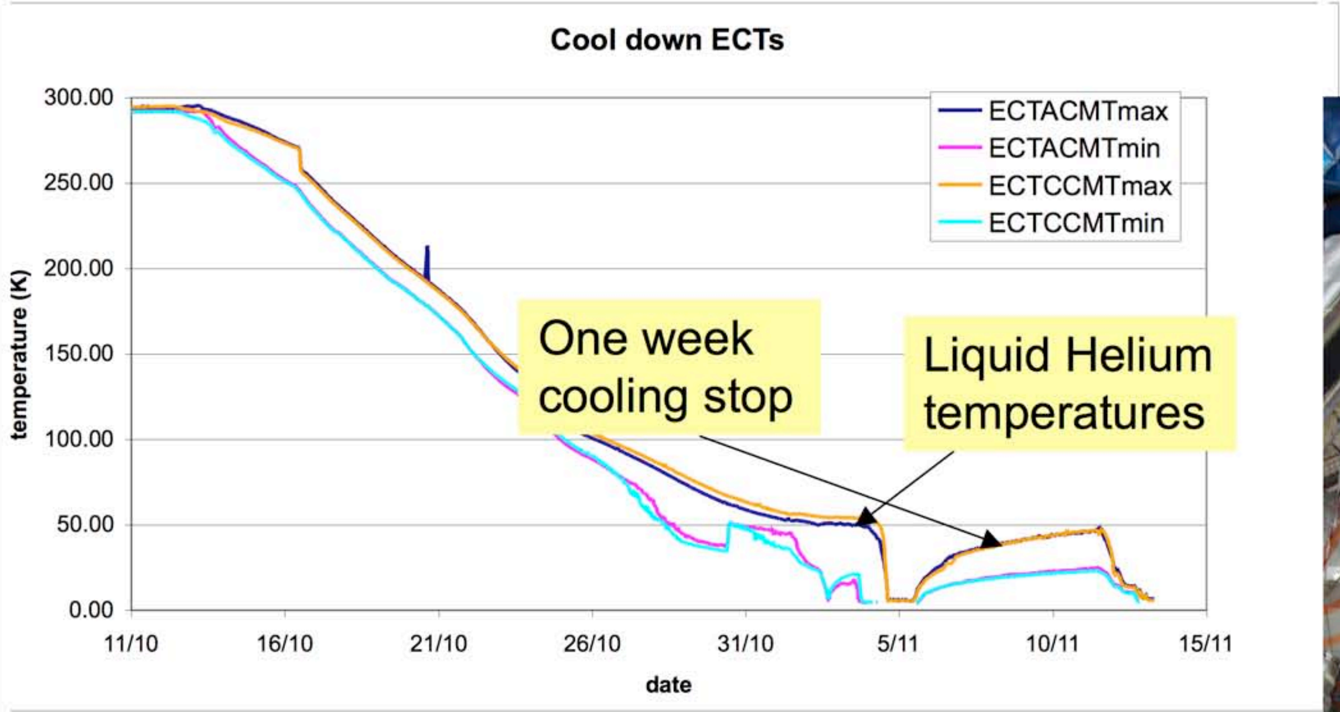
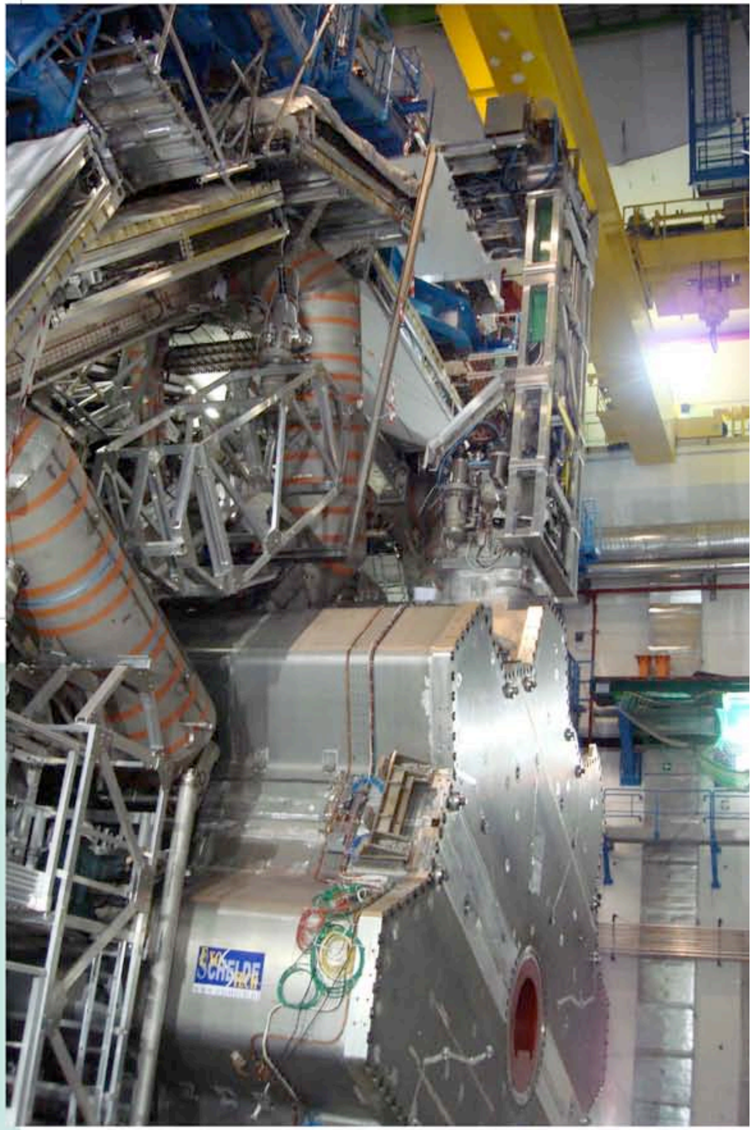




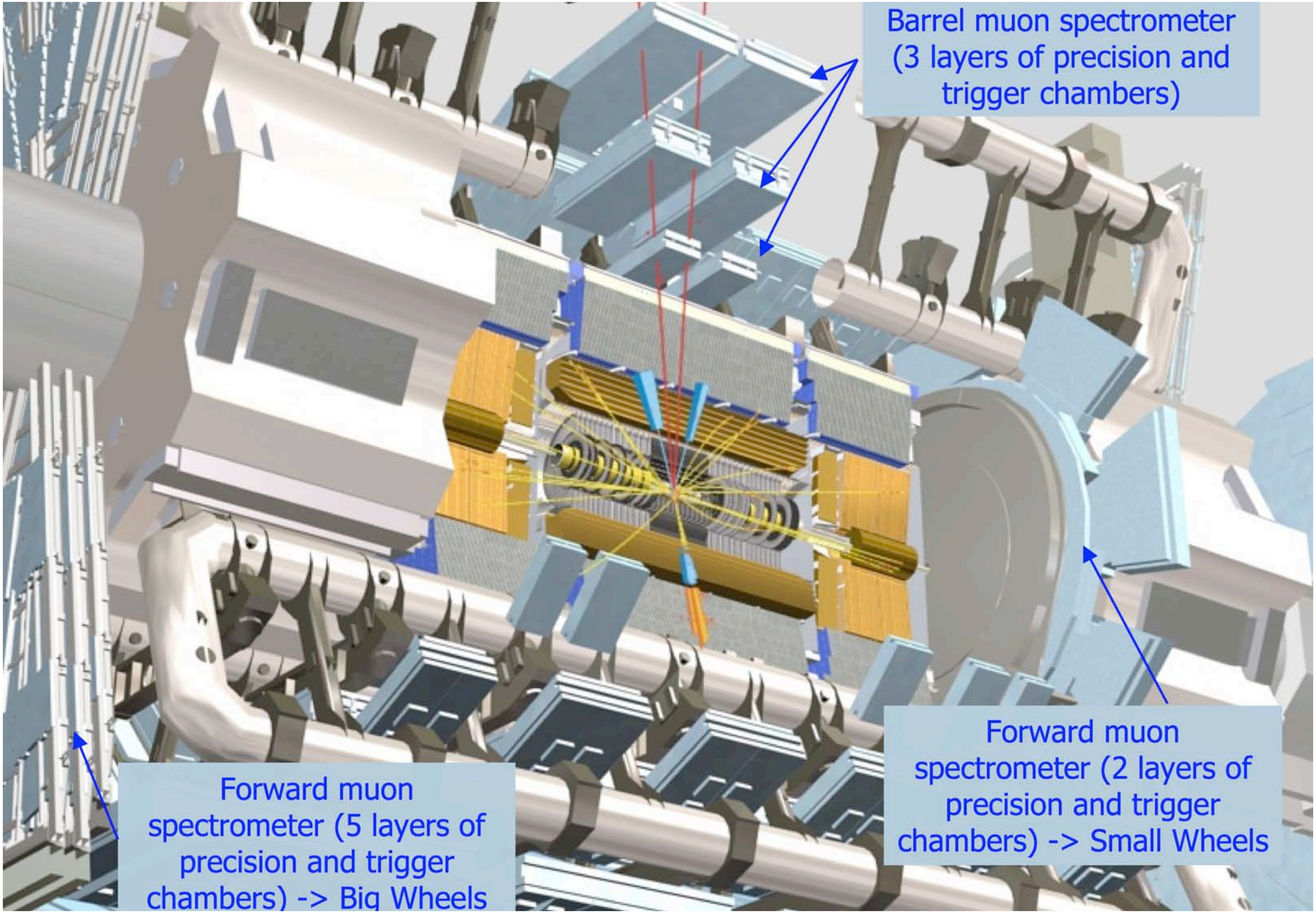
DVB: distribution valve box, PS=phase separator, CS= Central Solenoid

The End-Cap Toroids

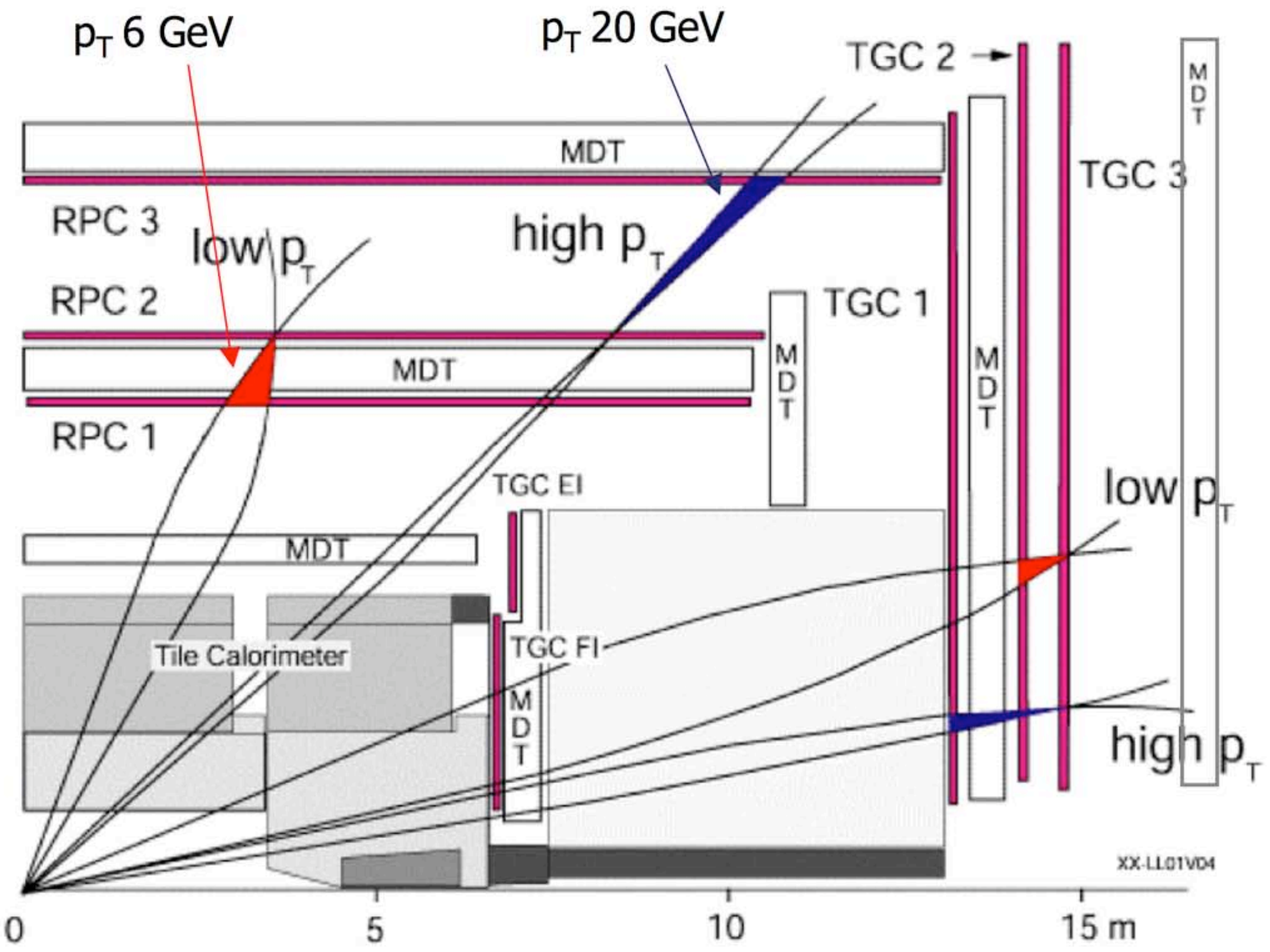




- Cooling down started week 41, it takes 4 weeks incl.some cryo problems; first current in 2nd week of Nov.
- Test ECT-A and ECT-C separately (250 MJ), like with BT
- Full magnet tests (with all 4 magnets) requires ATLAS closed and fully integrated (spring 2008)
- Operating these magnets systems over time is being set up, still not exercised yet on long time periods. Goal is to move to an automatic running mode


Barrel muon spectrometer (3 layers of precision and trigger chambers)
Forward muon spectrometer (2 layers of precision and trigger chambers) -> Small Wheels
Forward muon spectrometer (5 layers of precision and trigger chambers) -> Big Wheels

The Muon Spectrometer



Precision chambers :

MDT : monitored drift tubes

1108 chambers, 339 k channels

CSC : cathode strip chambers

32 chambers, 31 k channels

Trigger chambers (LVL1):

RPC : resistive plate chambers

560 chambers, 359 k channels

TGC : thin gap chambers

3588 chambers, 318 k channels

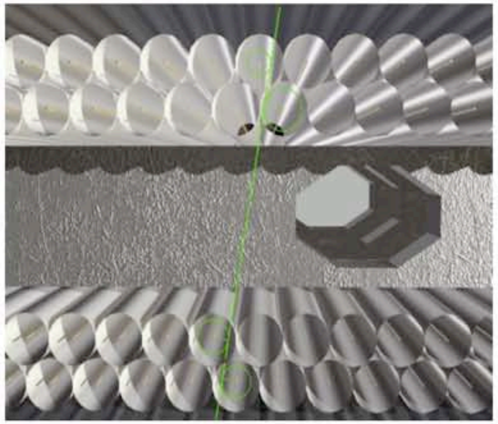
$\Delta p_T/p_T \sim 3\%$ for $p_T = 10–100$ GeV
in standalone mode

Total : ~12'000 m^2, ~ 1.1 M channels

Barrel Stations

Two MDT layers (2 x 3 planes)

Two (M-layer), One (O-layer) RPC chambers



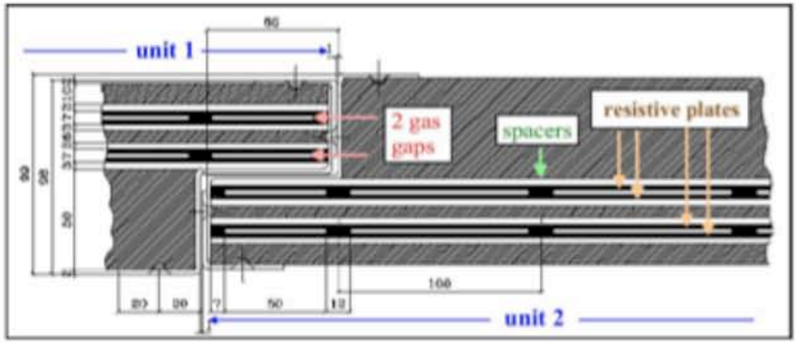
3 layers of tubes
(4 layers inner ch.)

3(4) layers of tubes (wire position 10μm)

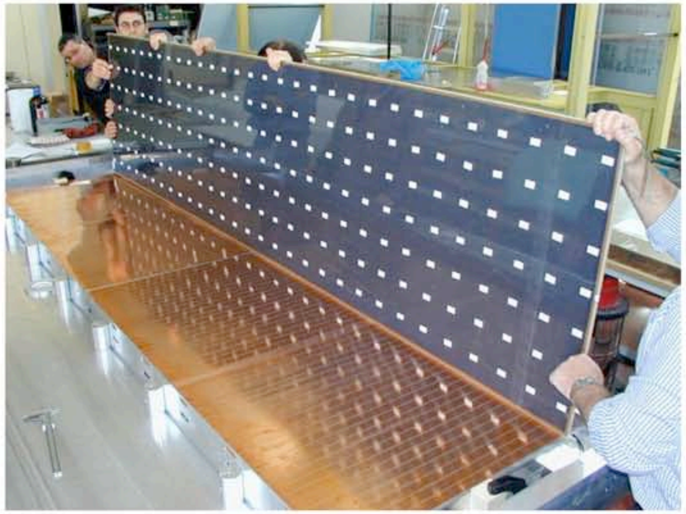
Average resolution / tube ~80 μm

Each RPC chamber consists of 2 times 2 gas volumes (units)

Each unit delivers 2 coordinates (η, ϕ)



Trigger chambers (RPC) rate capability ~ 1 kHz/cm^2



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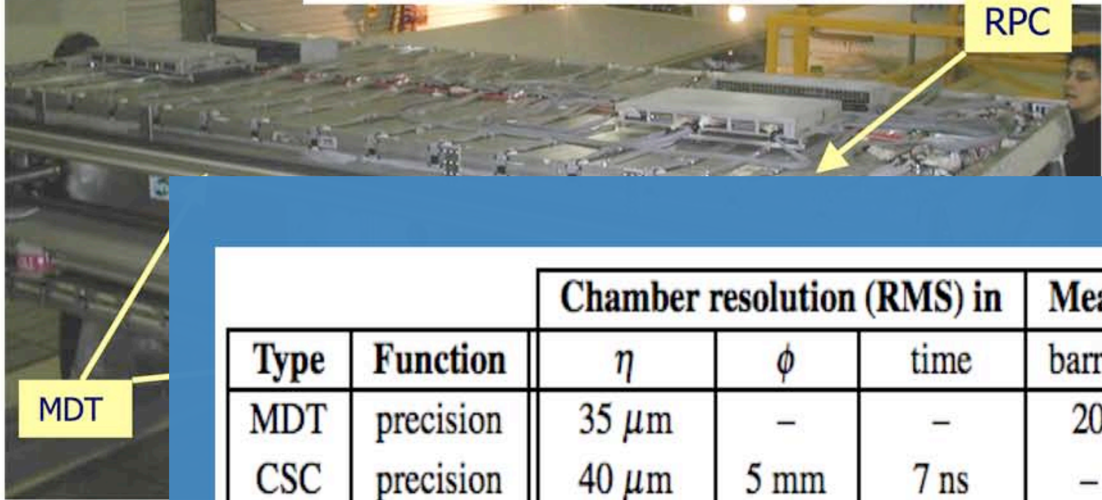
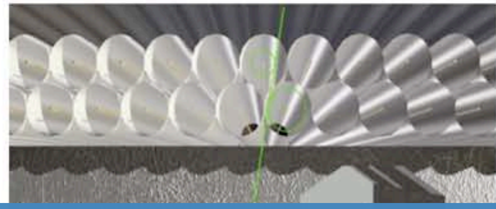


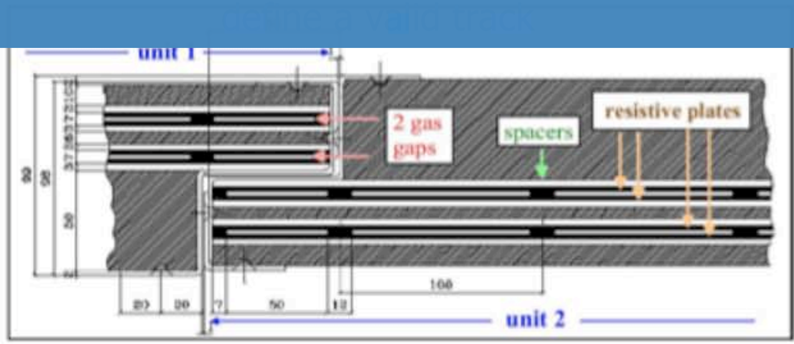


3 layers of tubes
(4 layers inner ch.)

		Chamber resolution (RMS) in			Measurements/track		Number of	
Type	Function	η	ϕ	time	barrel	end-cap	chambers	channels
MDT	precision	35 μm	–	–	20	20	1108 (1172)	339k (354k)
CSC	precision	40 μm	5 mm	7 ns	–	4	32	30.7k
RPC	trigger	10 mm	10 mm	1.5 ns	6	–	560 (622)	359k (373k)
TGC	trigger	3–12 mm	8 mm	4 ns	–	9	3588	318k

Each RPC chamber consists of 2 times 2 gas volumes (units)

Each unit delivers 2 coordinates (η, ϕ)



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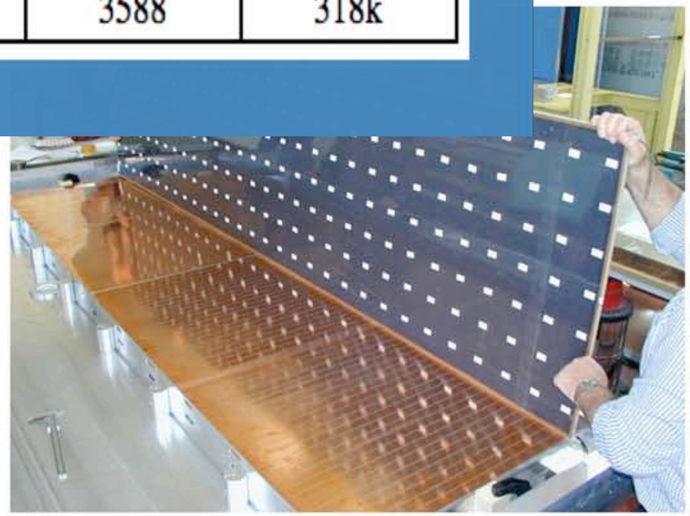
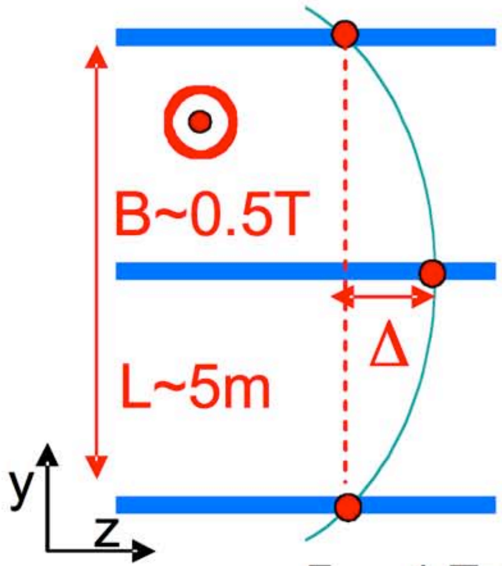


Muon Spectrometer Strategy

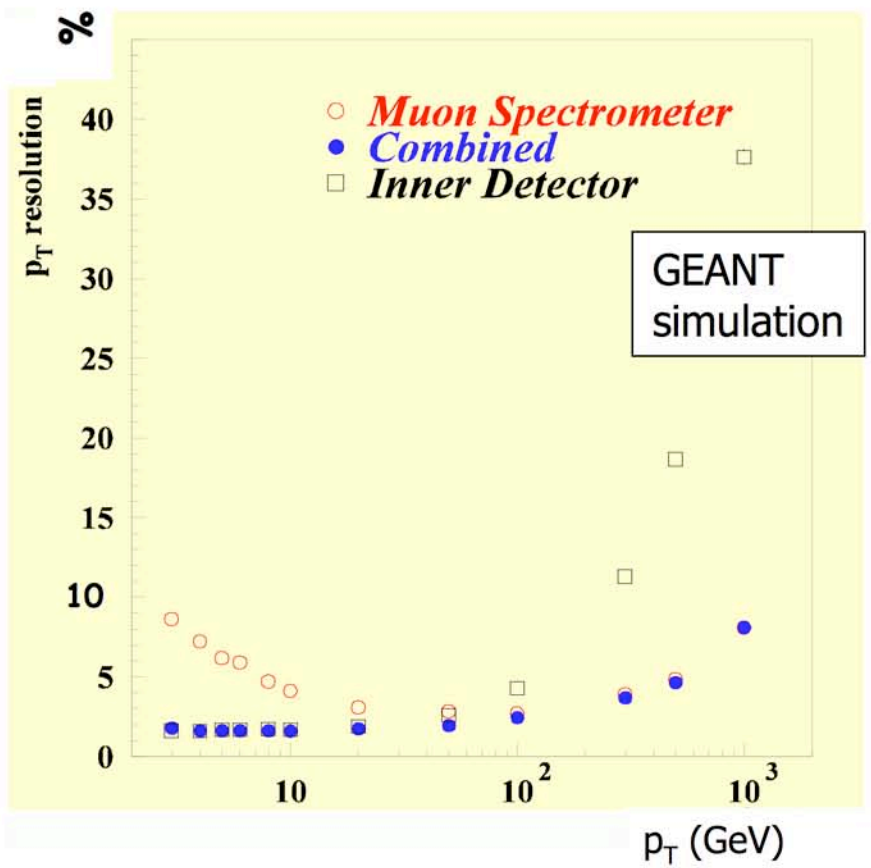
$\sigma/p < 10\%$ for $E_\mu \sim$ TeV needed to observe a possible new resonance $X \to \mu\mu$ as a "narrow" peak

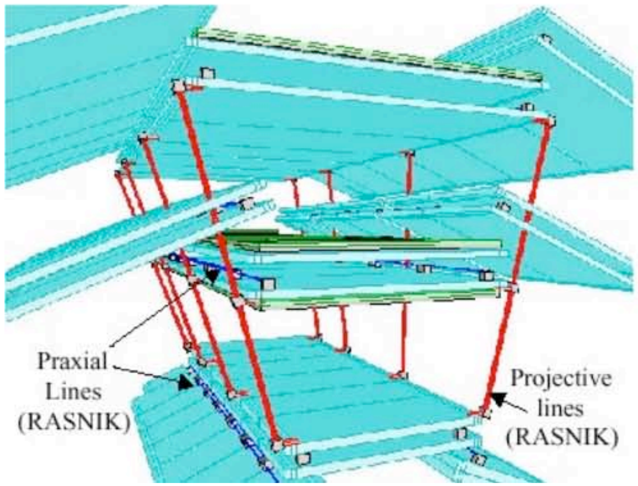


$E_\mu \sim 1$ TeV $\Rightarrow \Delta \sim 500\ \mu m$

$\sigma/p \sim 10\% \Rightarrow \delta\Delta \sim 50\ \mu m$

Muon momentum resolution





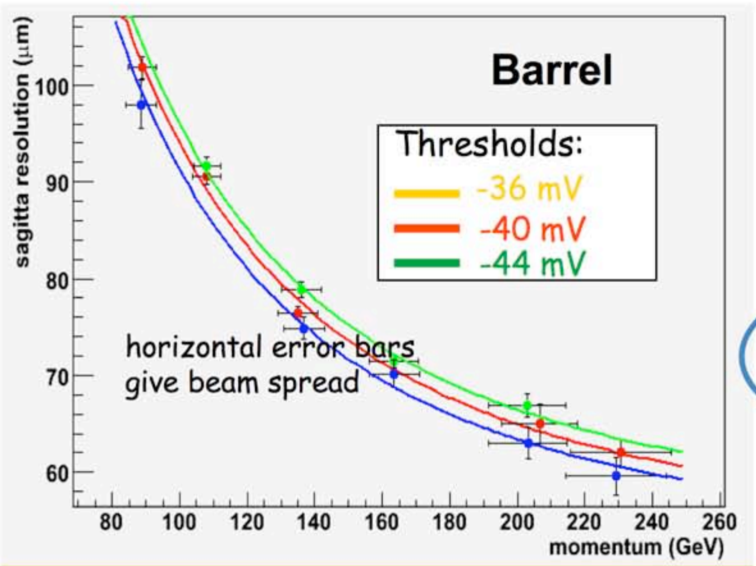
alignment accuracy to $\sim 30\ \mu m$

M.Nessi

Can we achieve such a precision ?

1) Showing that we master the intrinsic resolution of the MDT chambers (monitored drift tubes)

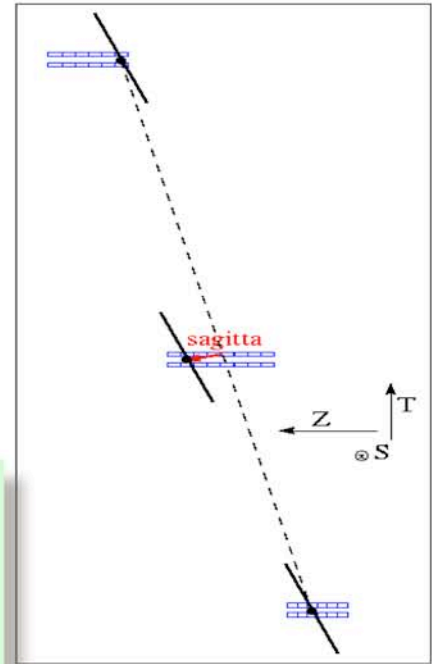
Sagitta resolution measured in the 2004 combined test beam



Data fitted with: $\sigma = \sqrt{K_1^2 + (K_2/p)^2}$

- p = muon momentum from beam magnet
- K_1 = intrinsic resolution
- K_2 = multiple scattering

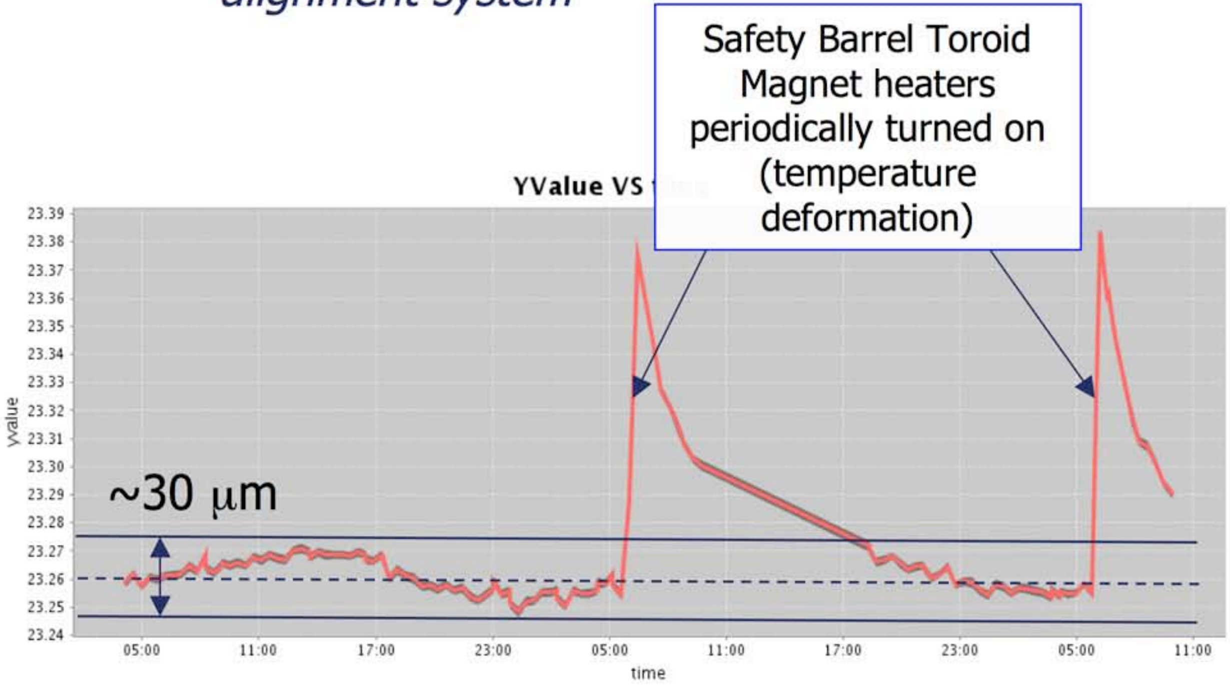
Data	Simulation
K_1 = 50.7±1.5 μm	K_1 = 40±3 μm
0.29±0.01 X_0	0.32 ±0.02 X_0



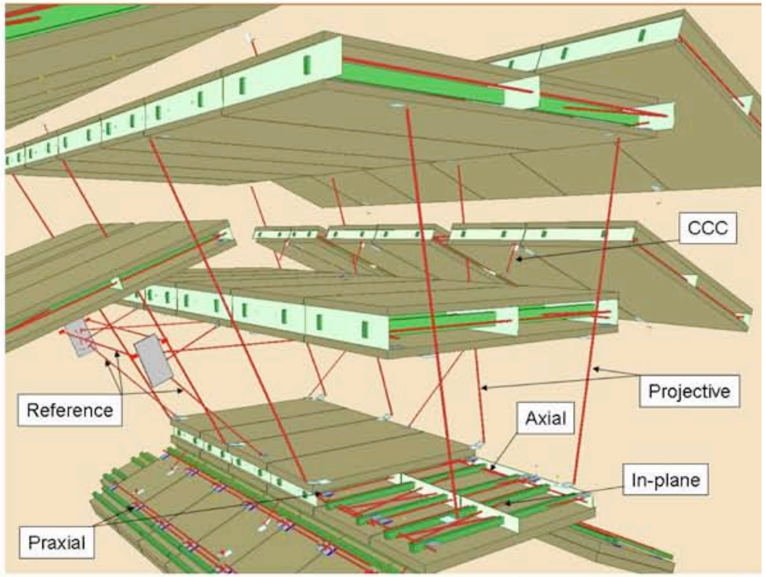
All this might sound obvious but it is not: think of wire positioning, tubes mechanical properties, straightness, gravitational sag, gaps between tubes, traceability, mass production in many different locations, …

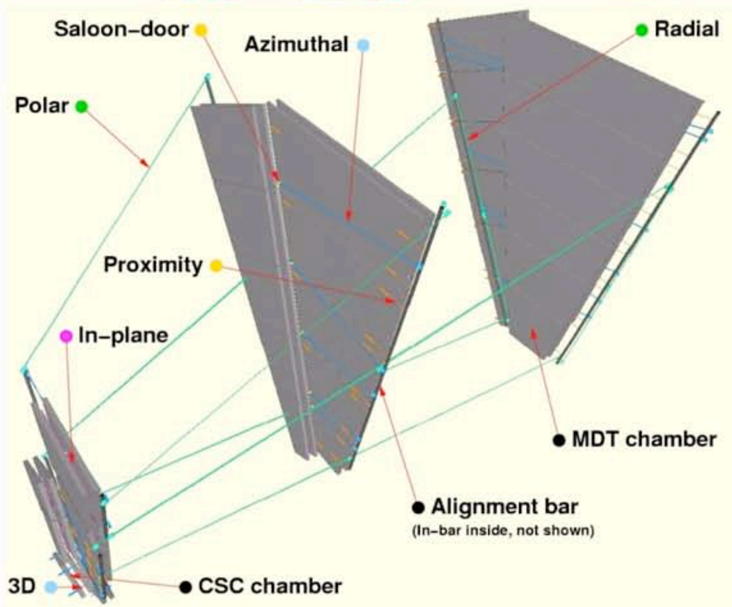
Can we achieve such a precision ?

2) Showing that we know the geometrical position of all chambers in time, using a sophisticated alignment system



Example of one projective line stability





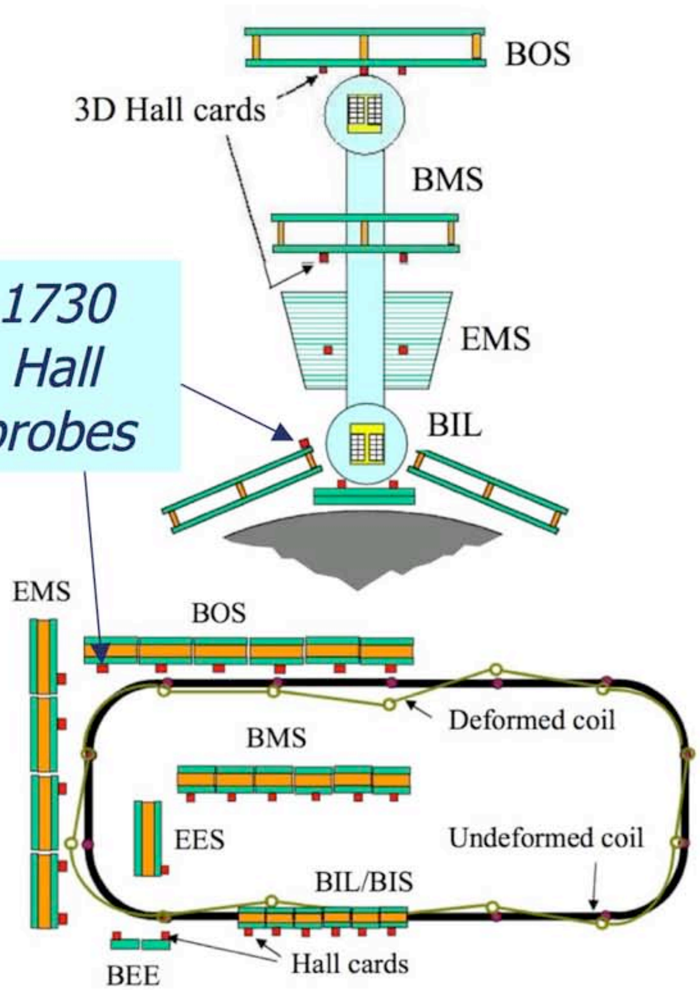
We demonstrated an alignment precision of ±20 μm with the test beam setup already

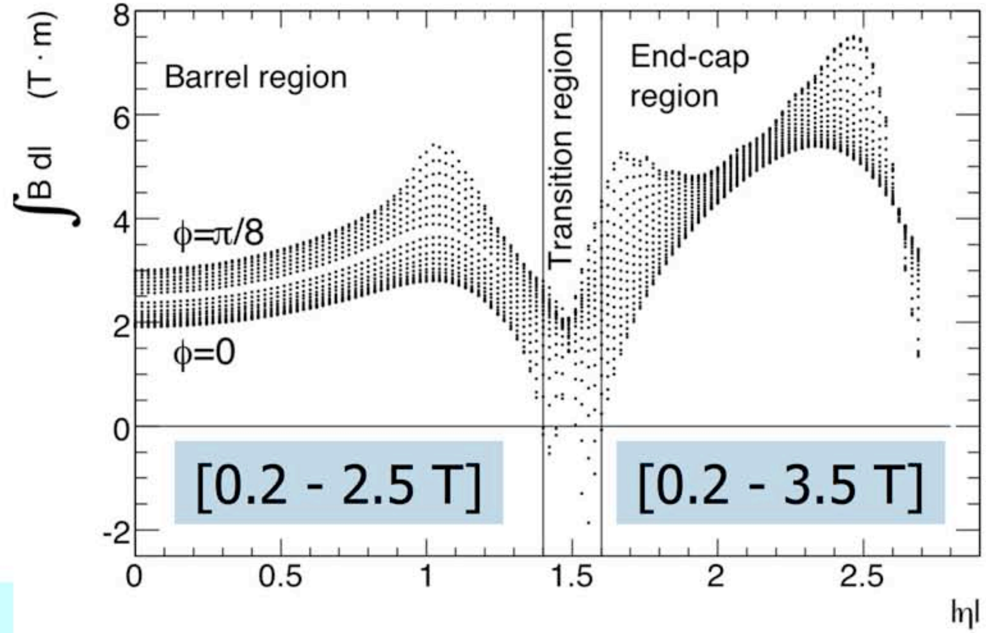
Can we achieve such a precision ?

3) By controlling and knowing the B-field properties of the spectrometer

Accuracy goal: | $\Delta \underline{B}$ | ~ 1-2 mT

1730 Hall probes

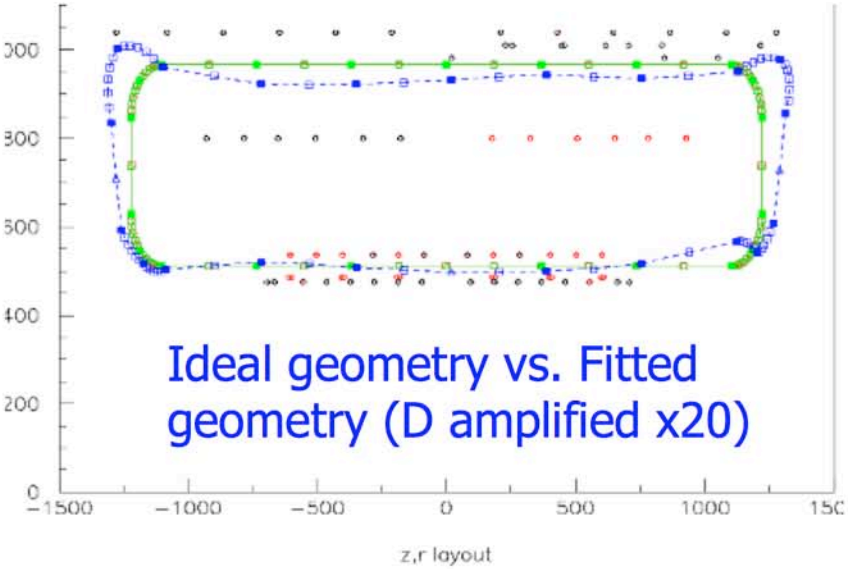




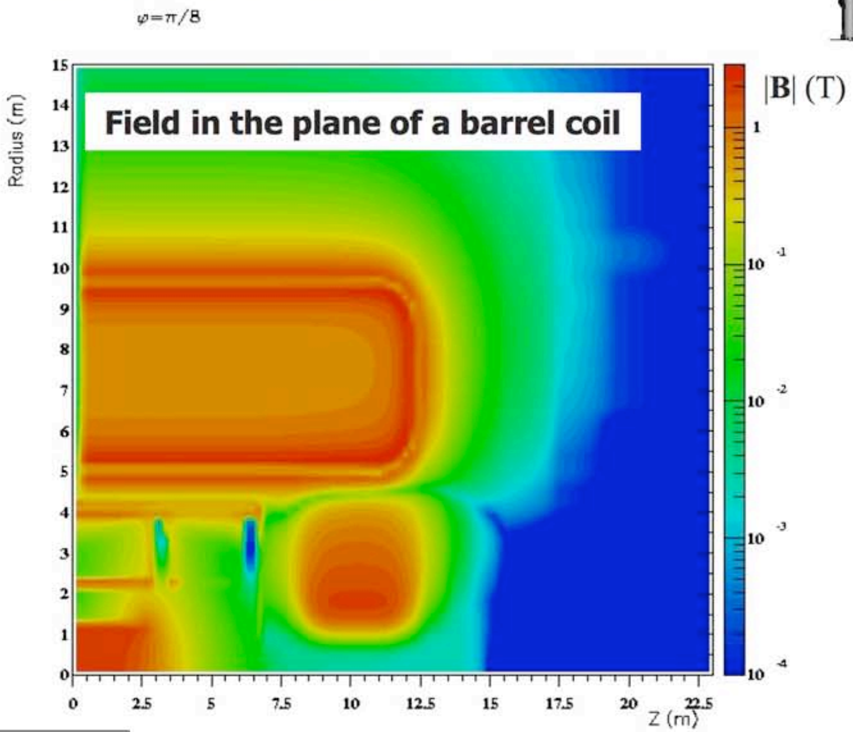
Strategy:

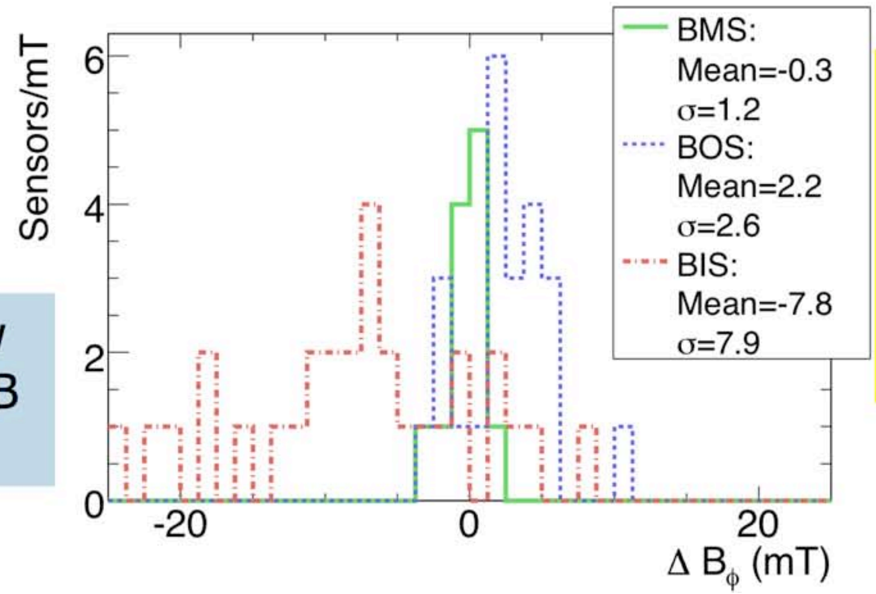
- Measure the B-field vector ($B_{x,y,z}$) to < 0.5 mT with ~ 1800 sensors (3-D Hall cards) positioned (2mm, 3 mrad) at places where the field gradient is large
- Use the B-sensor readings after correcting for the magnetic pollution predicted for known regions, to fit the position (and shape) of each toroid coil
- Once the geometry is known, compute B numerically everywhere

Can we achieve such a precision ?



Comparison of ***ideal*** *coil geometry, with that reconstructed from B-sensor data*



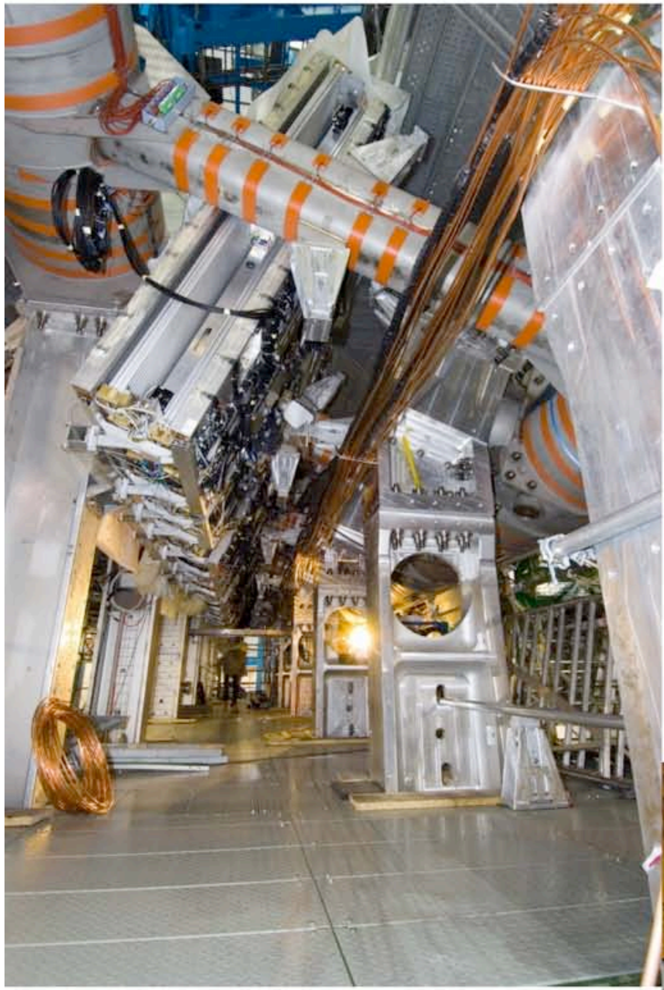


Field reconstruction residual ΔB_ϕ, in mT, for a middle (green, solid), outer (blue, dashed) and inner (red, dot-dashed) MDT layer.

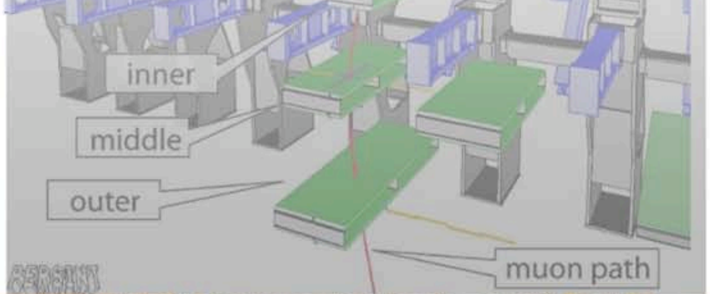
By comparison, the accuracy goal is $< \Delta B > = 0$, $\sigma (\Delta B) \sim 1\text{-}2$ mT

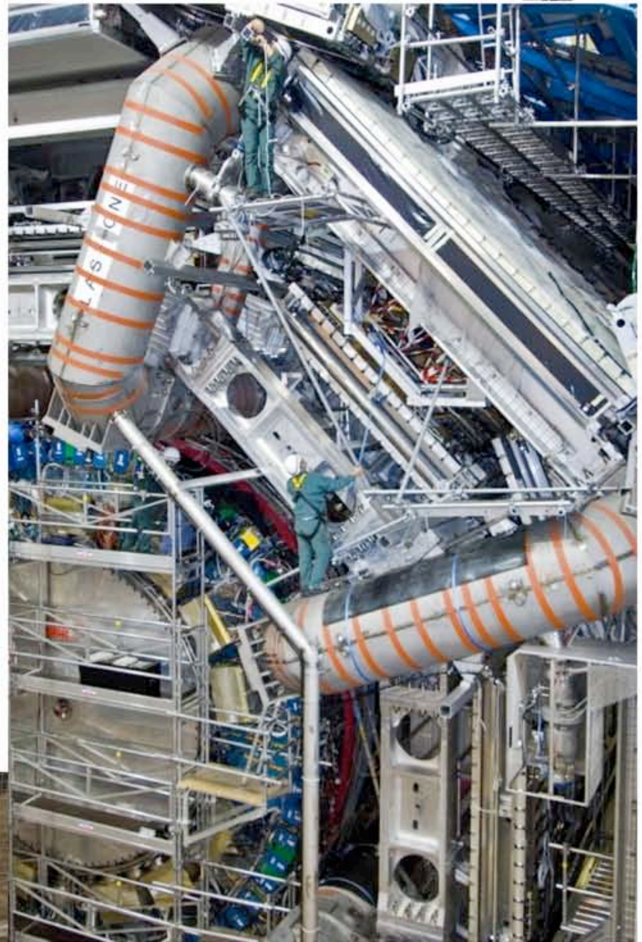
First results now waiting for final B test in 2008

99% of all barrel muon chambers installed



- ✓ 701/704 stations installed
- ✓ ~96% precisely positioned
- ✓ very acrobatic enterprise, no accidents, no damages
- ✓ all gas pipes and services distribution installed
- ✓ ~98% of all cables installed

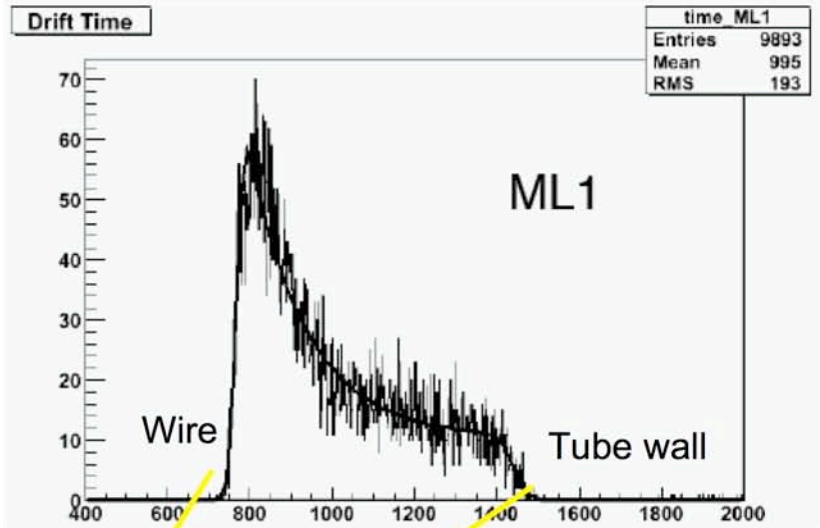




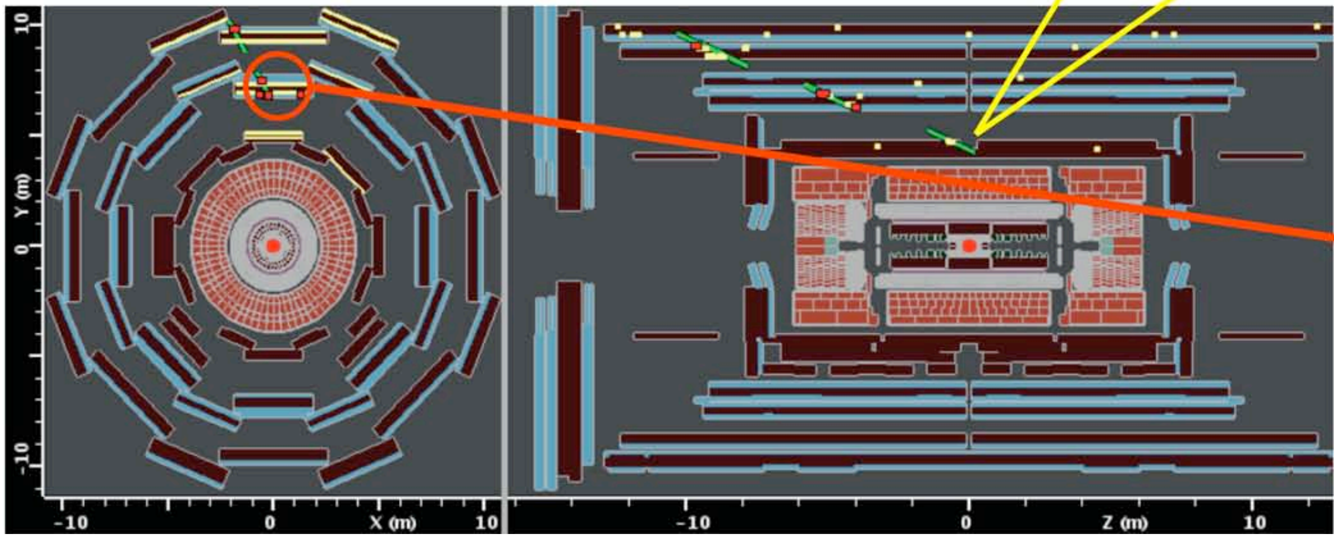
Barrel Muon Spectrometer

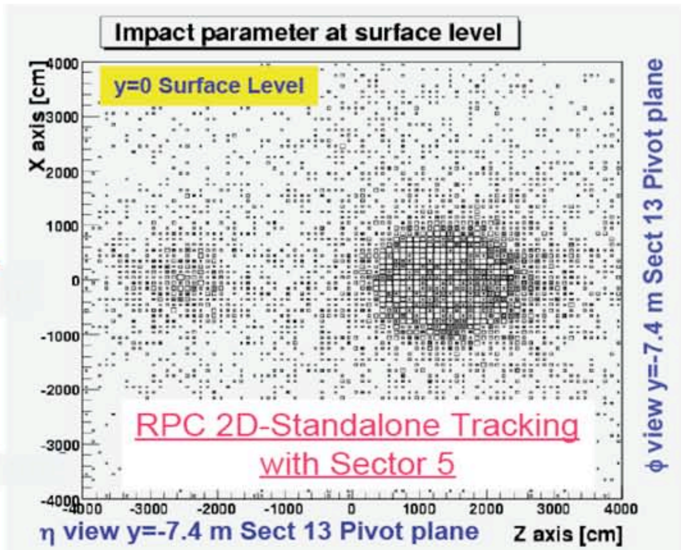
- ✓ Cosmic rays acquired for 25% of barrel precision chambers + noise analysis (30%)
  - ~210 MDT's → ~72000 channels
  - Dead and Noisy channels <0.5% level

- ✓ Trigger provided by RPC top sector
  - Trigger rate ~200Hz
  - Standalone RPC tracking reproduce shaft images



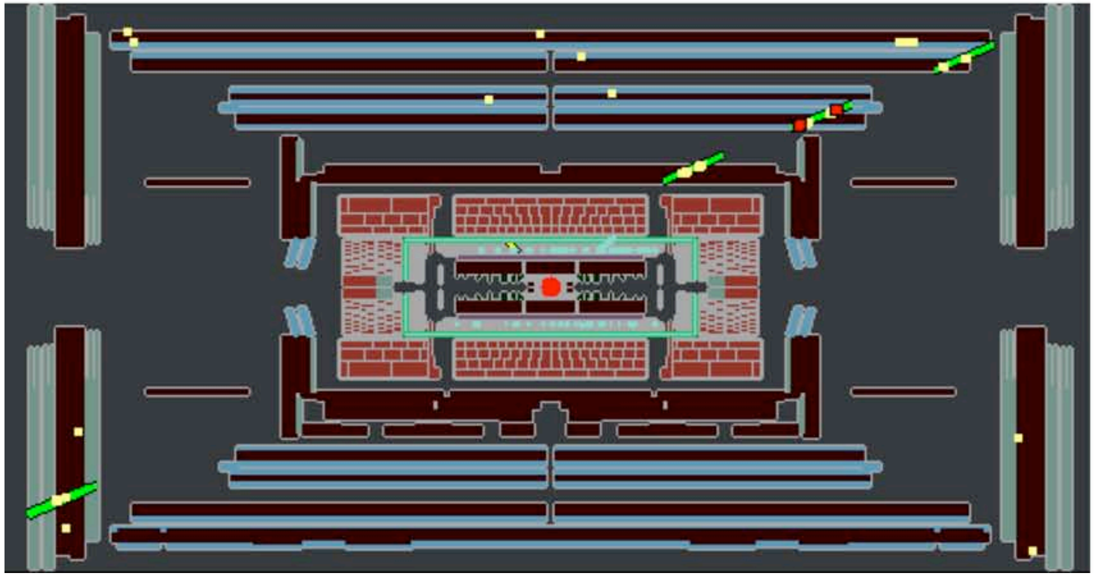
- Cosmic rays mainly from the shafts
- All open coincidence windows: 3/4 LowPt
- 3 clusters / track / view and chi2/dof<3



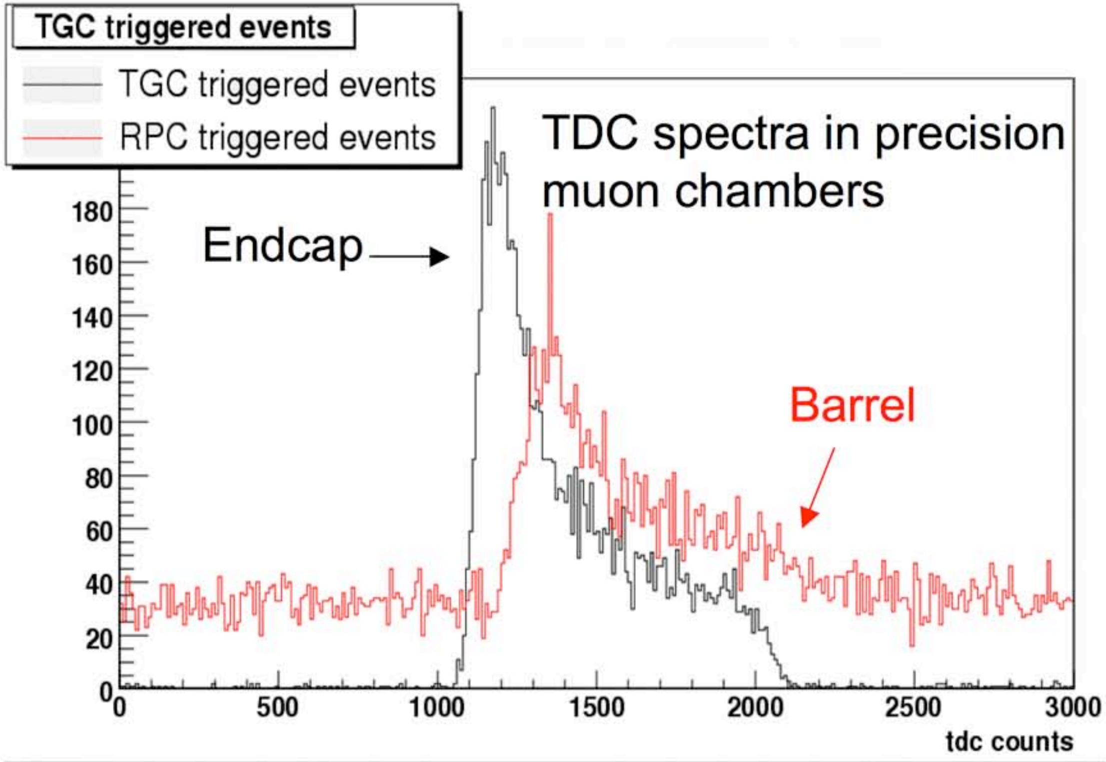


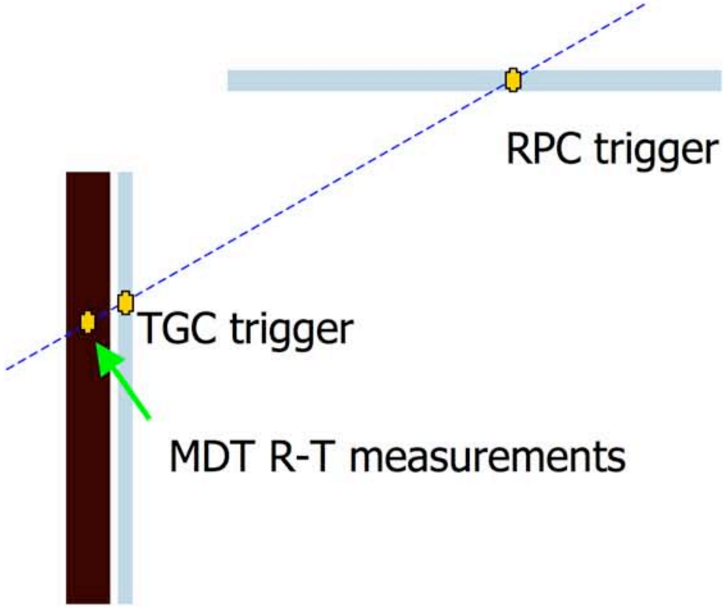
Forward Muon Spectrometer (Big Wheels)

- ✓ ~ 3 years of integration and assembly work on surface
- ✓ 13 months of transport and installation in situ
- ✓ wheels translation system operational
- ✓ all BW chambers have been positioned
- ✓ all alignment azimuthal lines operational
- ✓ cables and services connected, still working on the final gas connection to the cavern wall
- ✓ Both wheels already brought to operation



TGC (Thin Gas Chamber) triggers

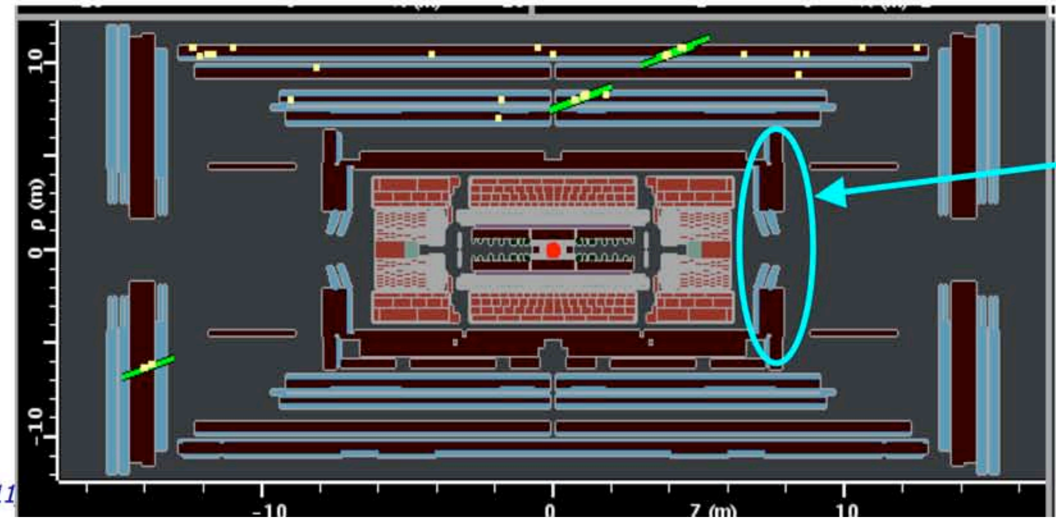


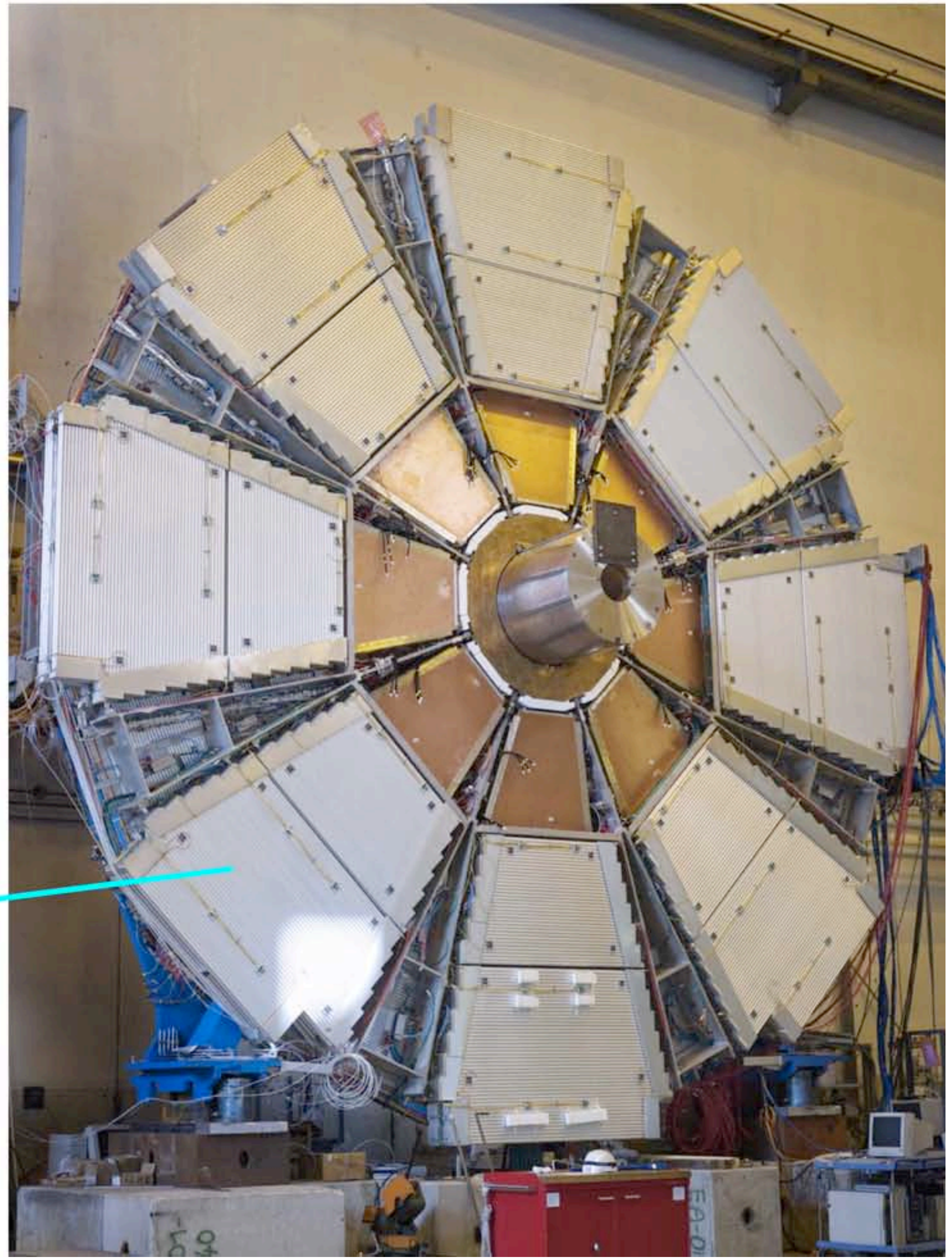


- ✓ Both, endcap- and barrel-triggered events have hits in the precision muon chambers with a characteristic muon TDC spectrum
- ✓ Trigger from barrel reaches the precision muon chamber front-end electronics 130 ns sooner than from endcap
- ✓ Measured TGC trigger latency: 1550 ns from chamber signal to output of the Central Trigger Processor, as expected

Forward Muon Spectrometer (Small Wheels)

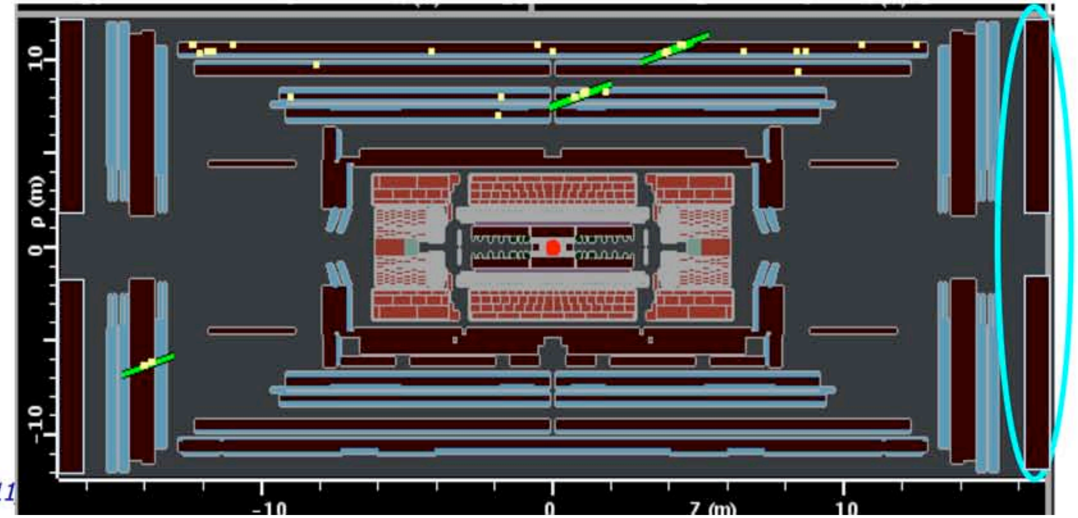
- ✓ Still on surface and being prepared for installation during December/January
- ✓ Once in position they will stop most of the access activities to the inside of the detector. Therefore they have been left as last element to be installed, just before closing
- ✓ Some of these chambers are designed for high rate and are the closest to the beam line (CSC)

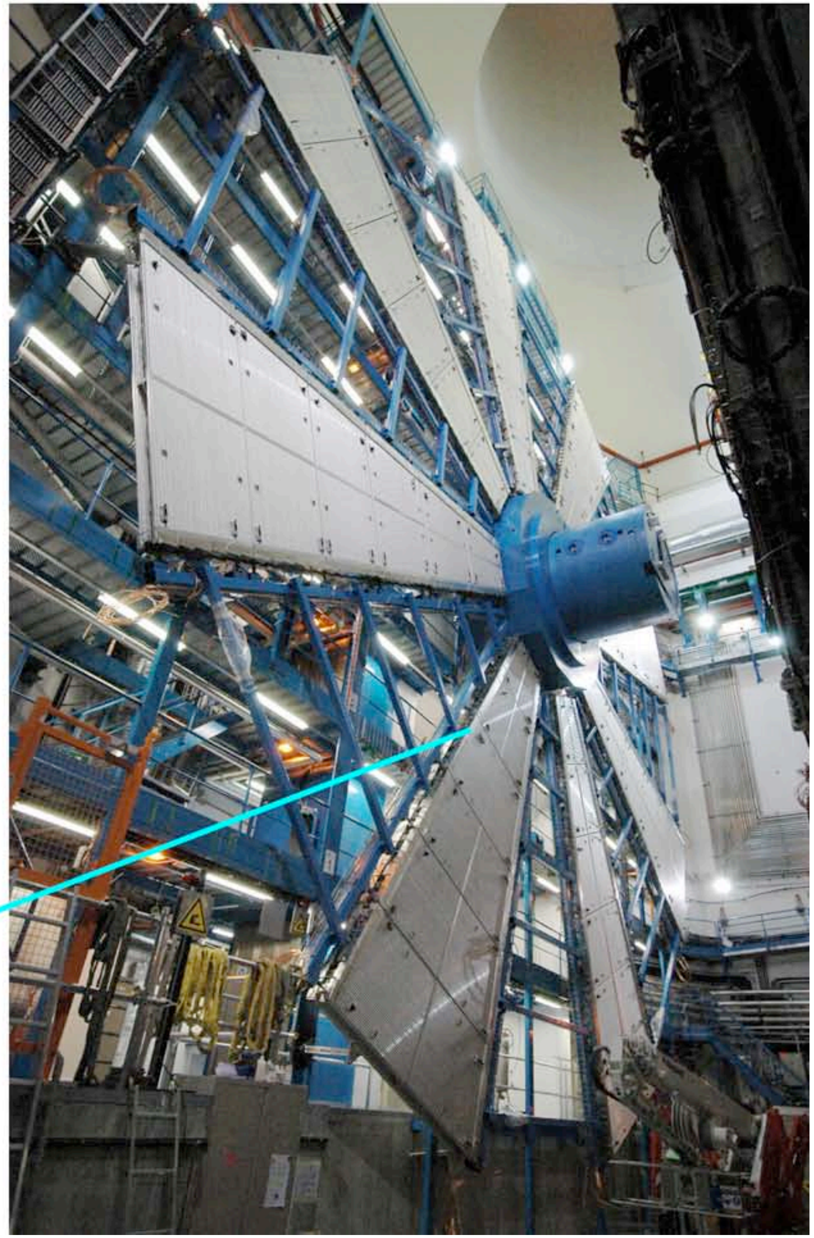




Forward Muon Spectrometer (EO Wheels)

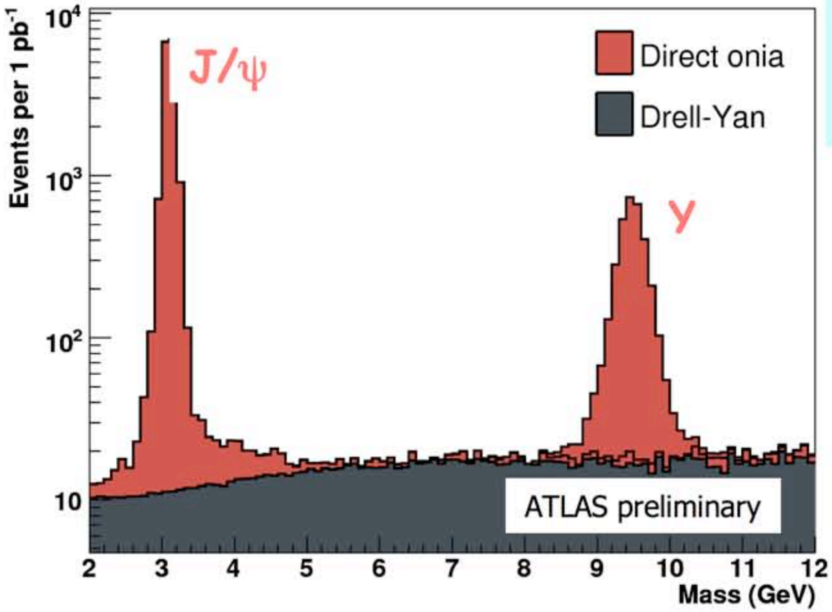
- ✓ Last large mechanical assembly we are installing
- ✓ It covers the end wall of the cavern with precision chambers (MDT), too big to be sectorized on surface. We are installing it in situ piece by piece
- ✓ It will close the alignment system with large bars that will link all projective rays.





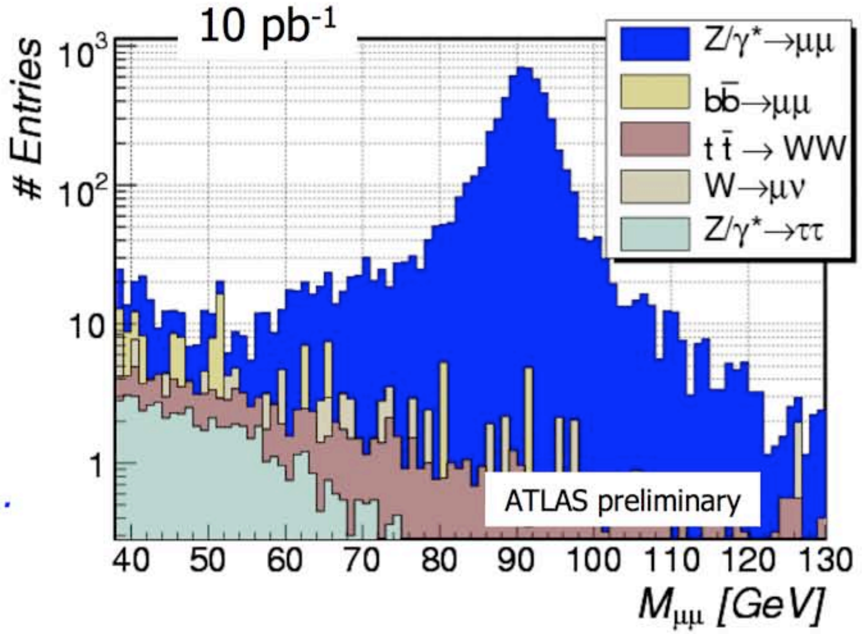
First peaks in the muon spectrometer

1 $pb^{-1} \equiv$ 3 days at 10^{31} at 30% efficiency



After all cuts:
~ 4200 (800) J/ψ (Υ) → μμ evts per day at L = 10^{31} cm^{-2} s^{-1}
(for 30% machine x detector data taking efficiency)

→ *tracker momentum scale, trigger performance, detector efficiency, sanity checks, …*

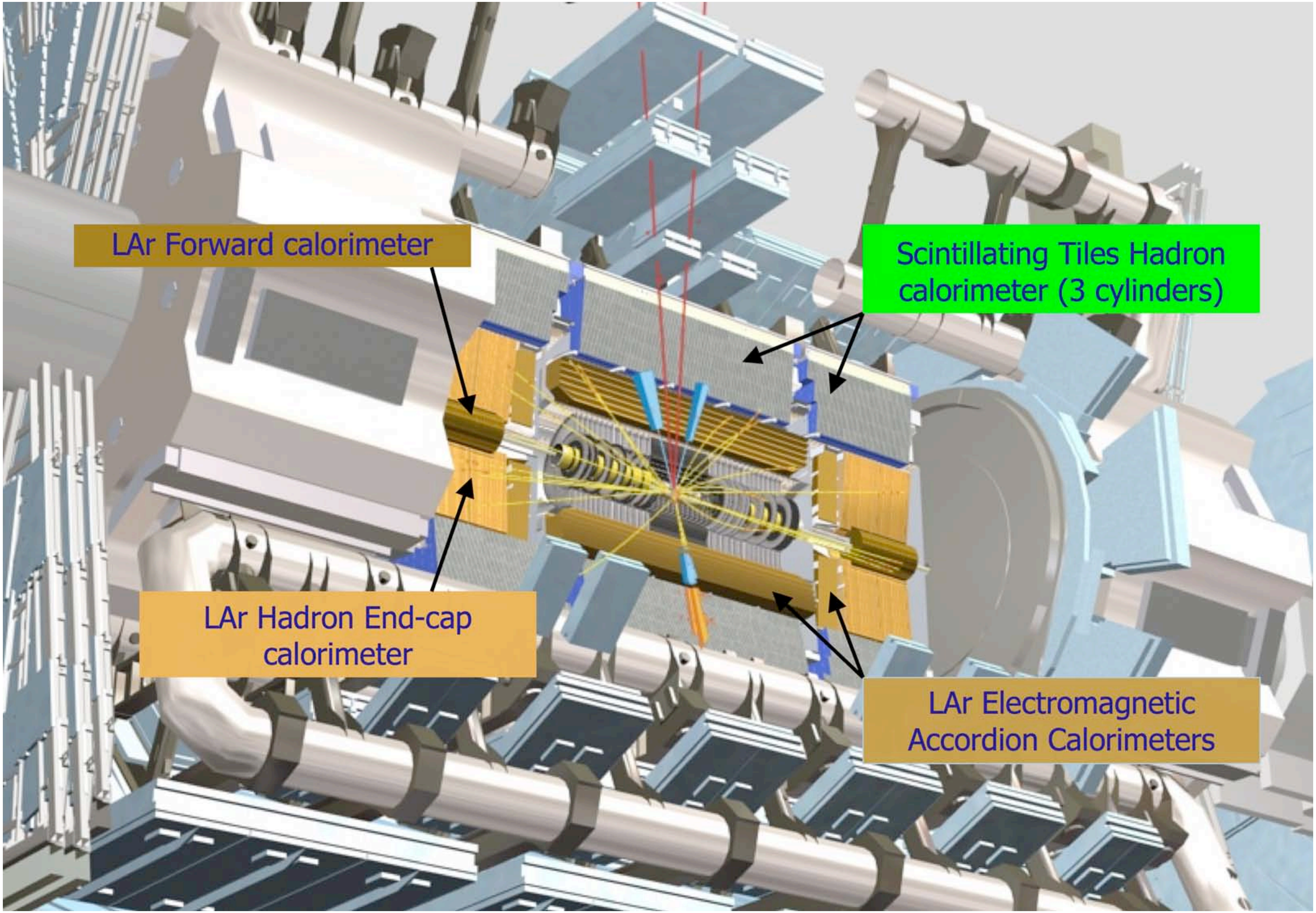


After all cuts:
~ 160 Z → μμ evts per day at L = 10^{31}

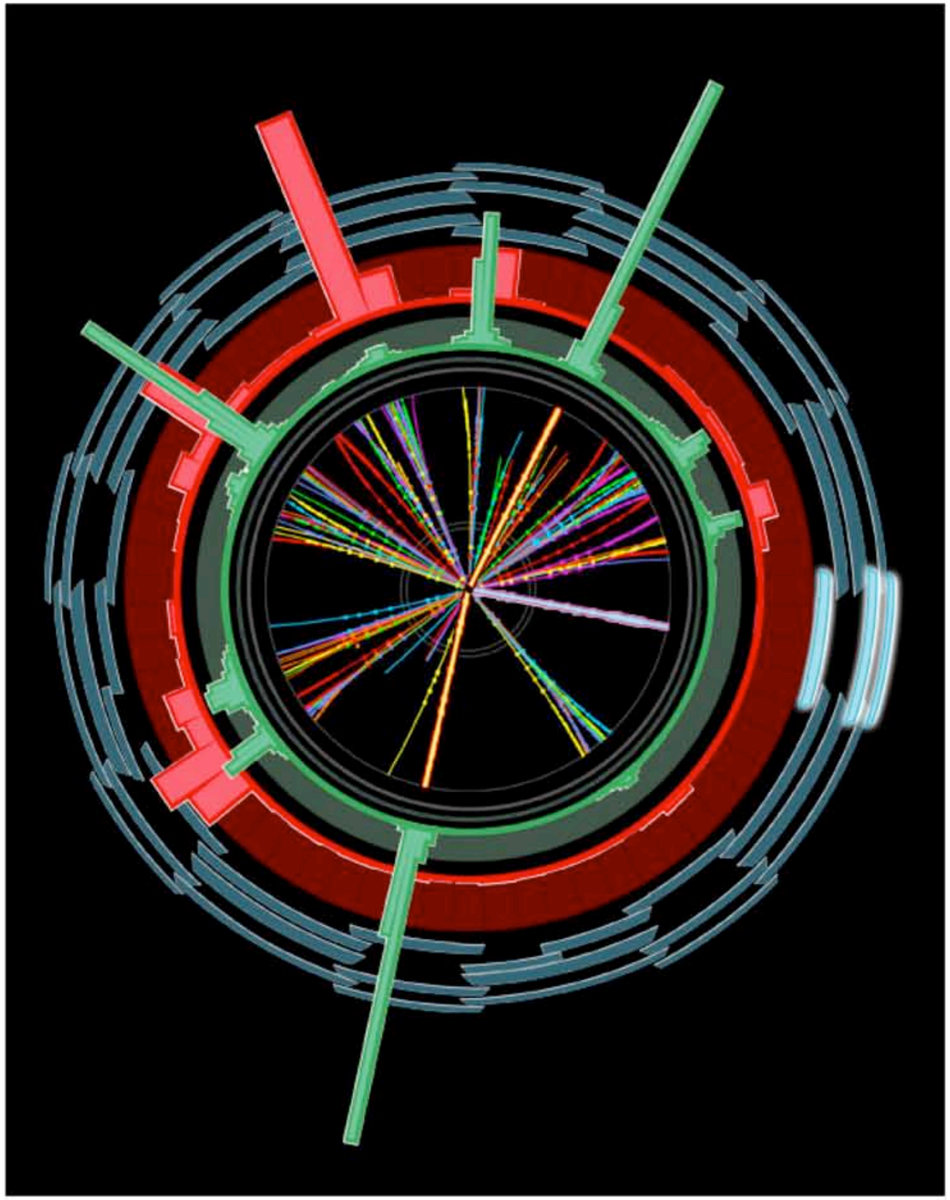
→ *Muon Spectrometer alignment, energy/momentum scale of full detector, lepton trigger and reconstruction efficiency, …*

Muon Spectrometer status

- ✓ All magnets hardware installed. Barrel toroid tested, End-caps being tested. We foresee a final combined magnet test just when ATLAS is fully closed in April 2008. Field quality definition progressing and will then be fully defined once we test all magnets together
- ✓ Most of the active detector components (muon chambers) are installed and are being tested and read out through the final data flow/trigger chain. We are still missing part of the back-end electronics to be able to read out all the detector at once. It will converge by Spring 2008
- ✓ The LVL1 muon trigger system is operational and we are gaining experience.
- ✓ The overall calibration/alignment of the spectrometer is pursued and exercised
- ✓ From what we know and learned from test beams and cosmics we will have a sound spectrometer already from the start, according to specifications and design performance. The noise level and the number of problematic channels are well under control


LAr Forward calorimeter
Scintillating Tiles Hadron calorimeter (3 cylinders)
LAr Hadron End-cap calorimeter
LAr Electromagnetic Accordion Calorimeters

Calorimeters Challenge



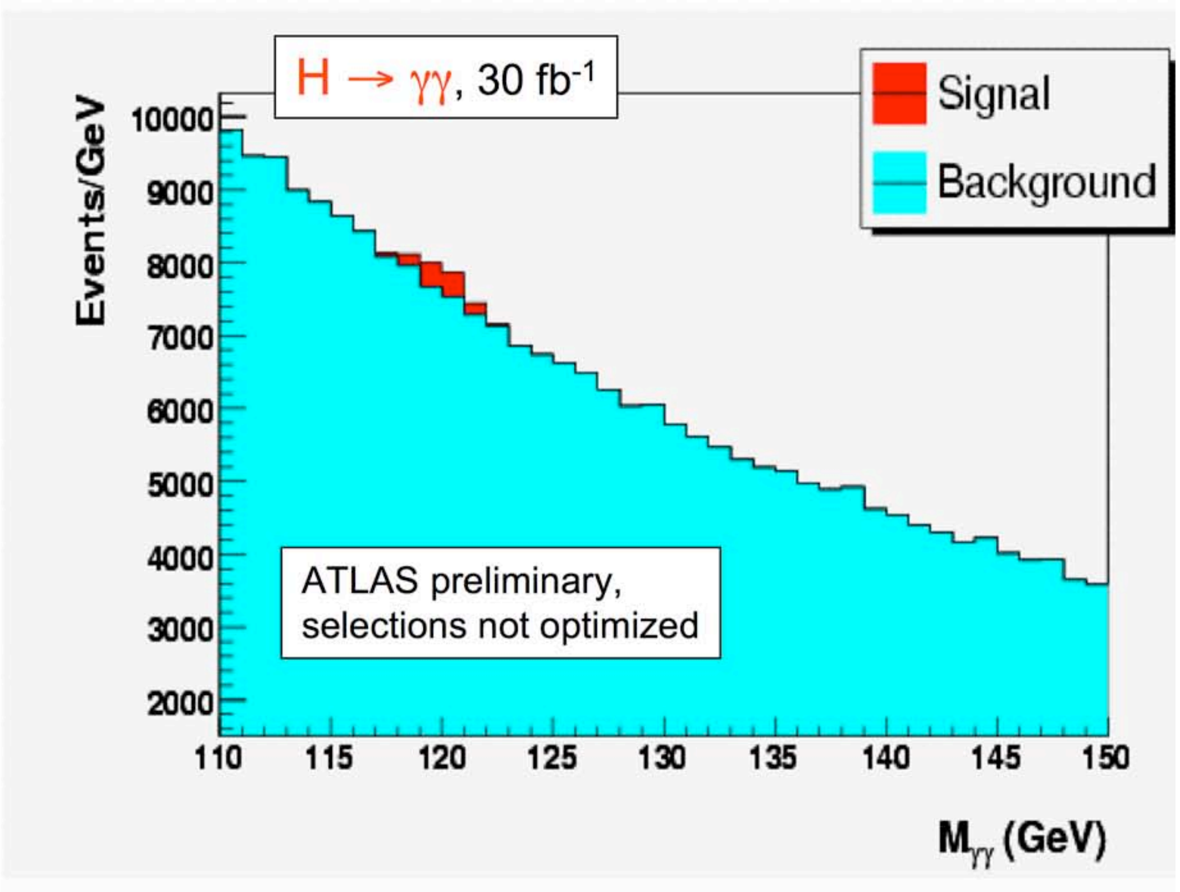
- ✓ Need to trigger and measure γ, e and hadron energies by total absorption in sampling mode.
- ✓ Need to operate in an integrated dose of γ and n, ranging up to a few Mrad.
- ✓ Need to maintain the energy scale precision at the 1% level.
- ✓ Need to allow particle identification (γ vrs. π^o, e, jets, γ conversion,..) --> longitudinal and transverse segmentation, presampler in the first radiation lengths.

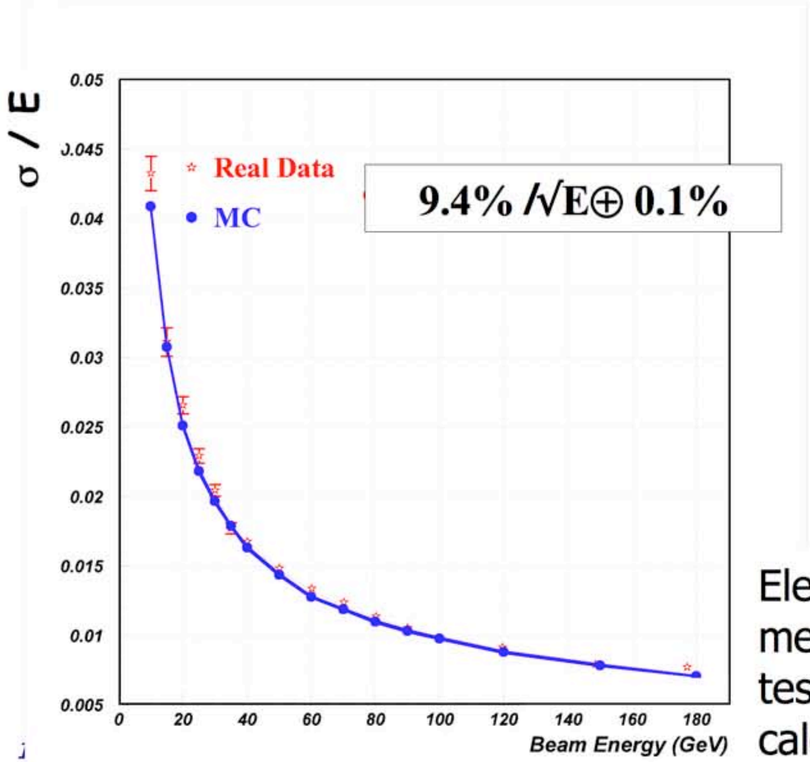
Electromagnetic Calorimeters

$H \to \gamma\gamma$: to observe a signal peak on top of a huge background need

- energy/mass resolution ~ 1%

- rejection of $\pi^0 \to \gamma\gamma$ faking single γ





Electron Energy resolution measured in beam tests of the ATLAS EM accordion calorimeter (Pb/LAr)

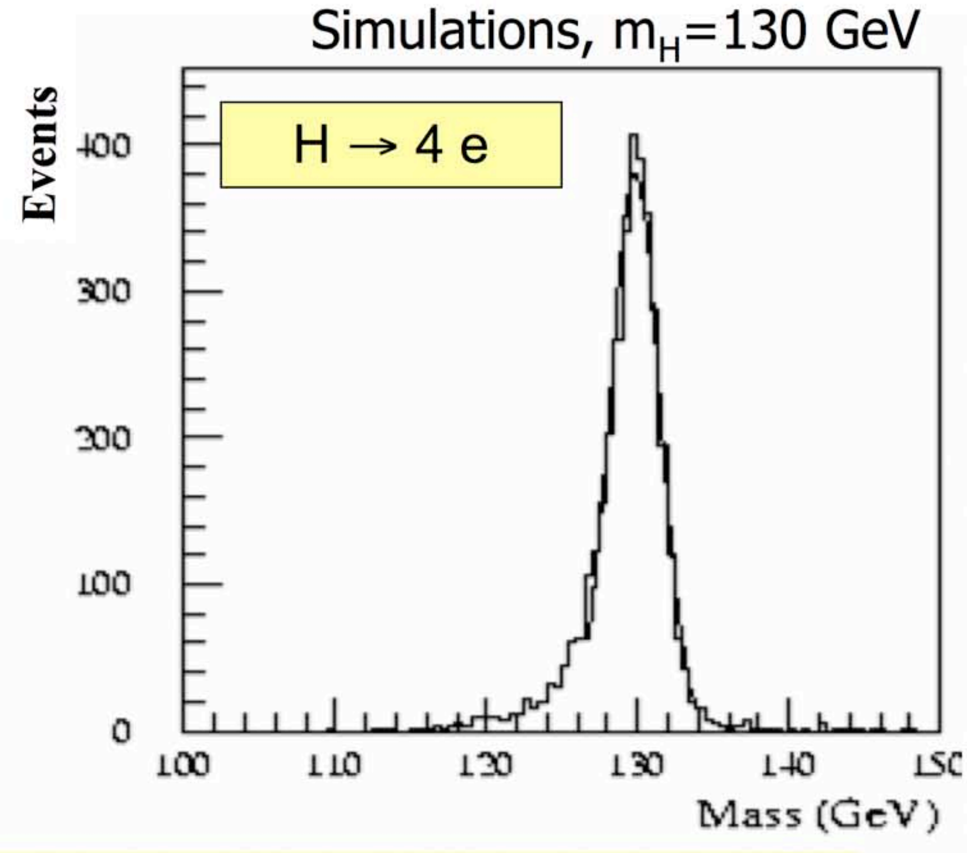
Electromagnetic Calorimeters

✓ $H \rightarrow \gamma\gamma$

Resolution: ~1%

✓ $H \rightarrow 4e$

Resolution: ~1.5%

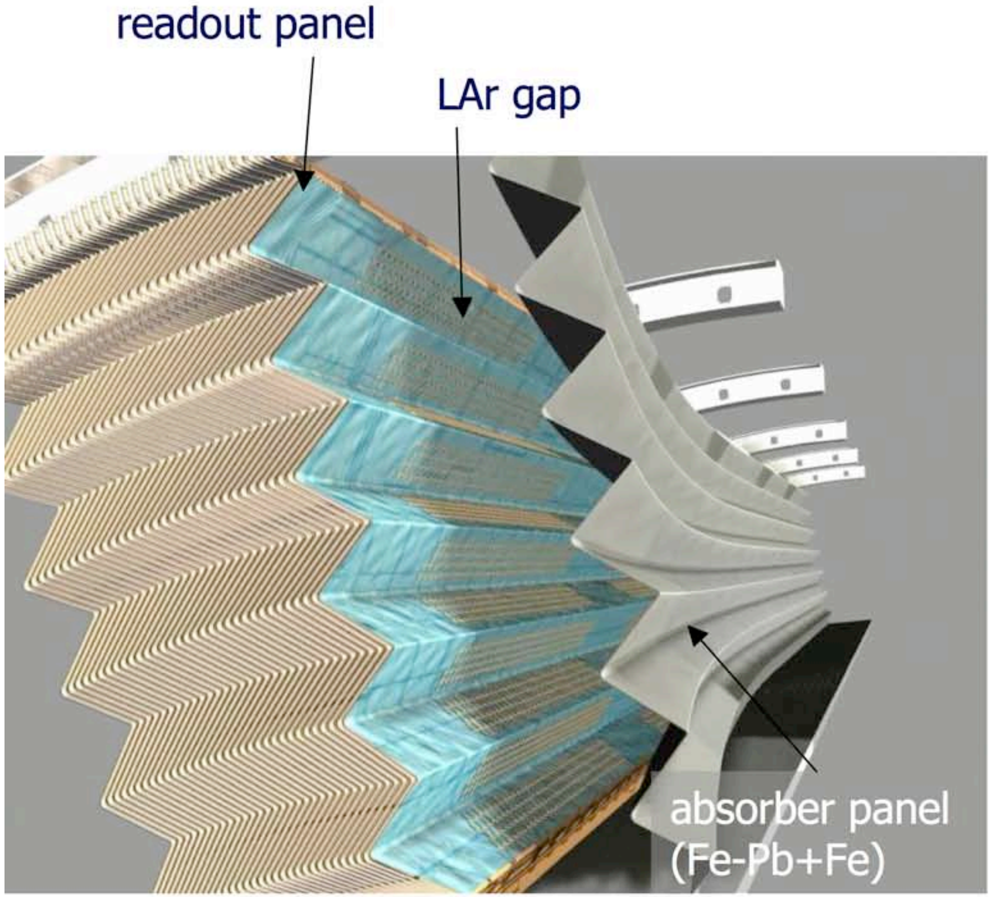


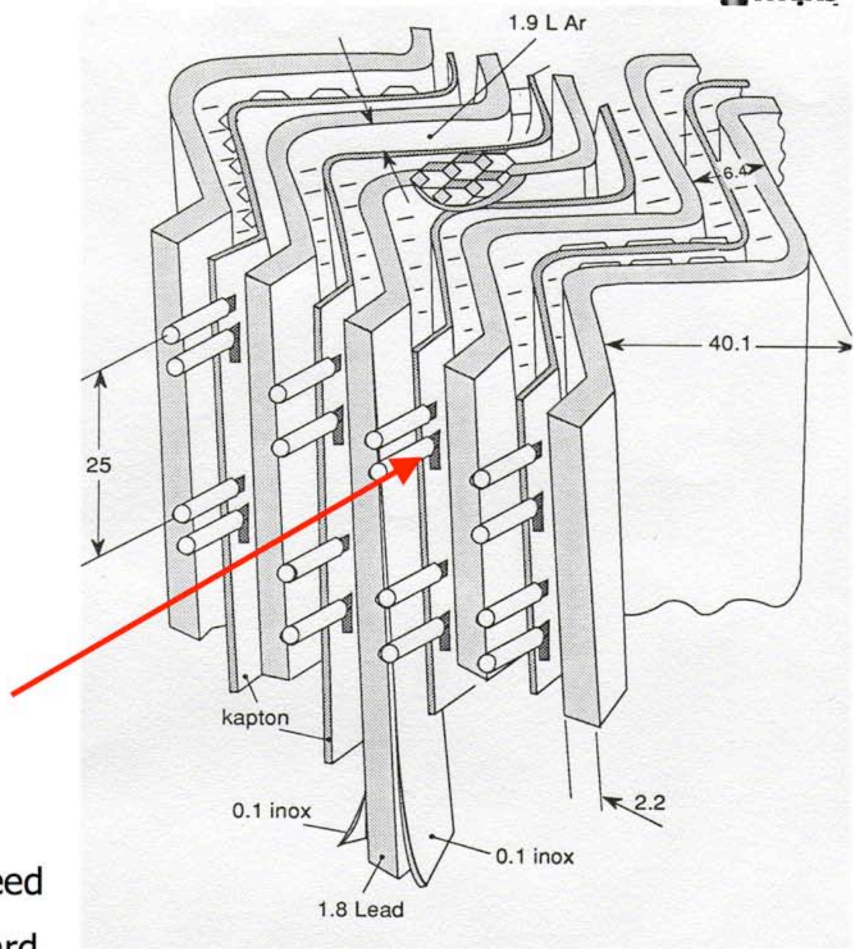
Assuming : local resolution of 9.4% /$\sqrt{E} \oplus$ 0.1%
overall response uniformity 0.7%
excellent position/angular resolution thanks to the lateral/longitudinal segmentation (vertex γ pointing)

Electromagnetic Calorimeters

LAr sampling calorimeter

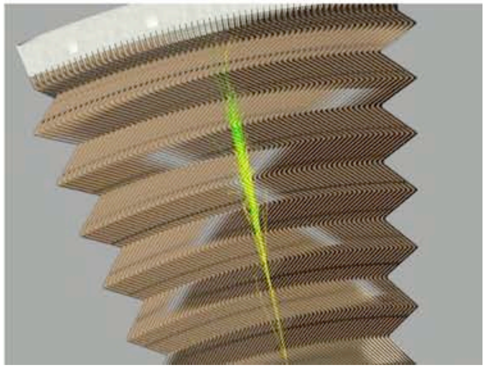
accordion geometry





Why ?

- readout speed
- radiation hard
- electronically inter-calibrated
- allows longitudinal segmentation
- hermetic in phi
- good energy, angular resolution



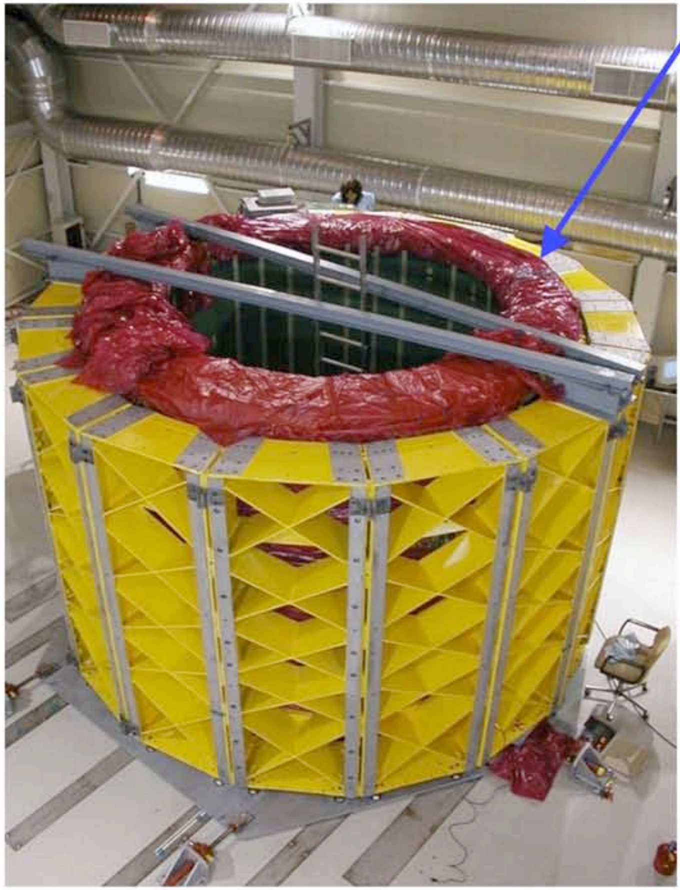
Electromagnetic Calorimeter

- 1024 accordion absorber plates
- 2x16 identical modules
- $\eta < 1.7$

- Inner +Outer wheel
- 768 (256) accordion absorbers/wheel
- 8 identical modules/wheel
- $1.375 < \eta < 3.2$

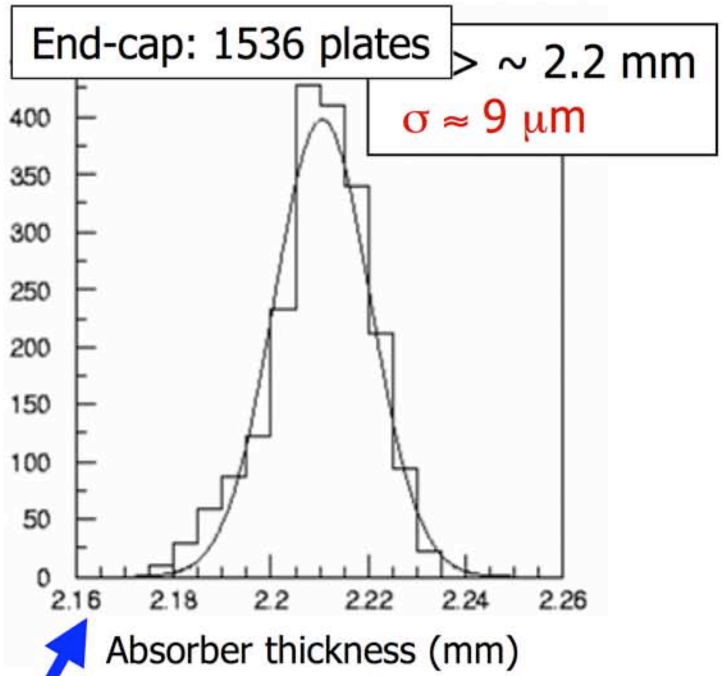
Electromagnetic Calorimeter

LAr EM barrel assembly in the vertical position



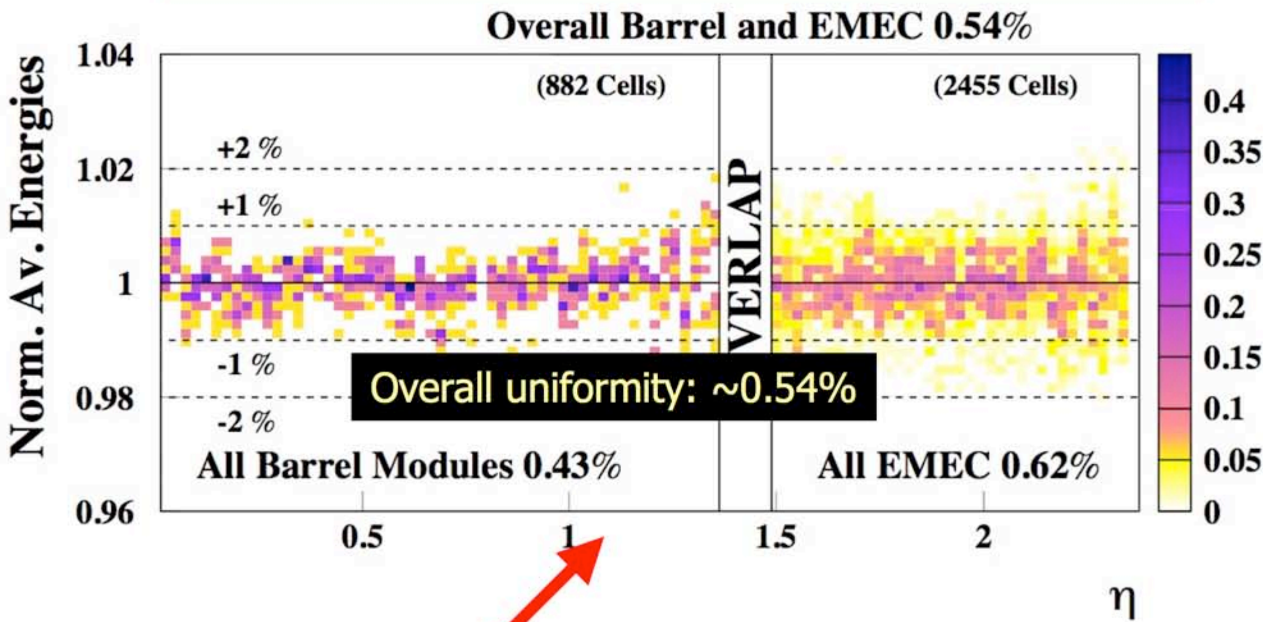
Then insertion inside the cryostat

Response uniformity (goal 0.7%)



Thickness of Pb plates must be uniform to 0.5% (~10 μm)

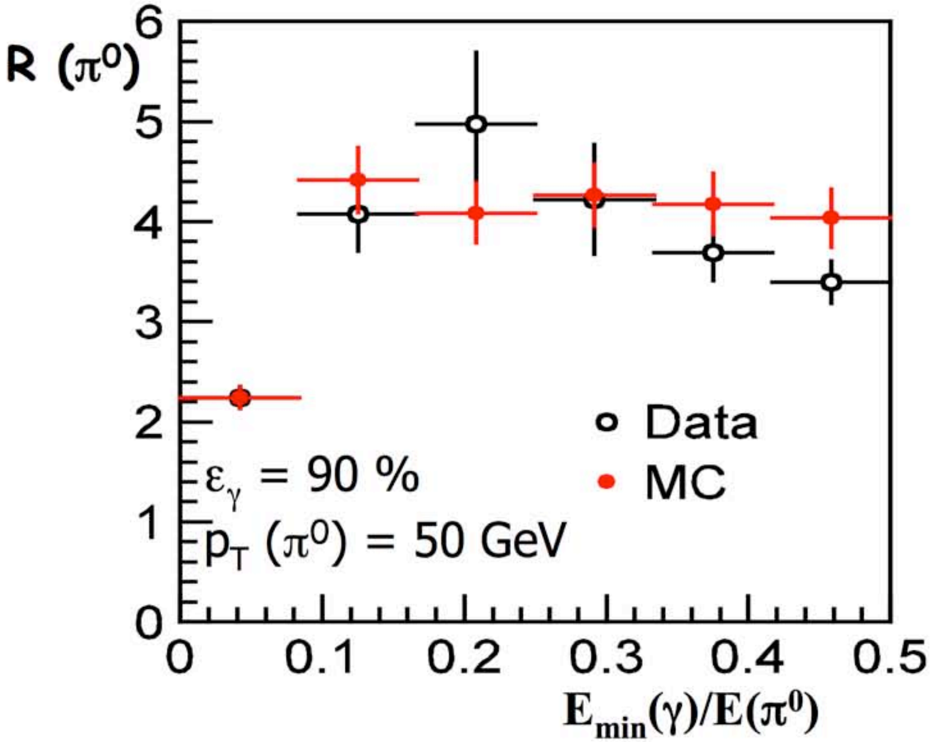
Scans with 120-245 GeV electrons (all 7 tested modules)

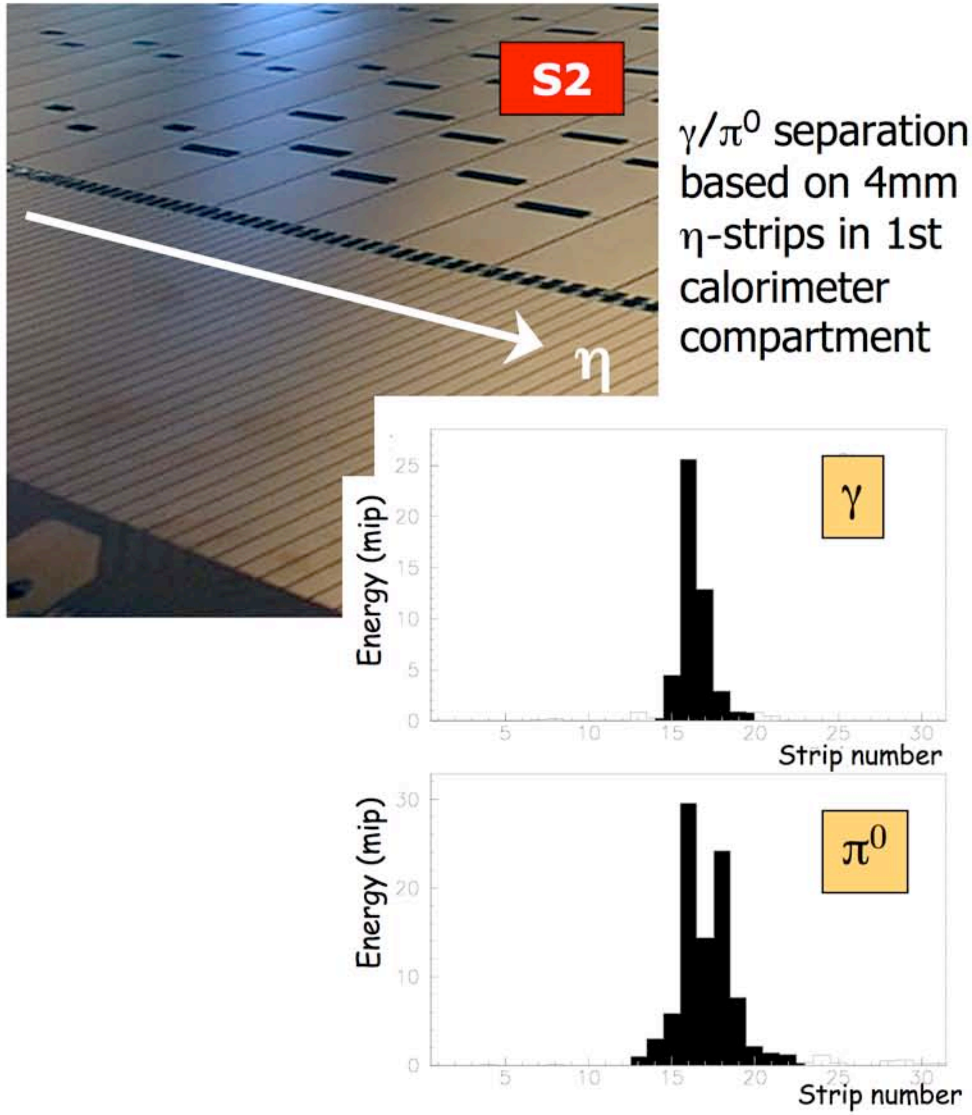


4 (out of 32) barrel modules and 3 (out of 16) end-cap (EMEC) modules tested with beams

π^o rejection performance

1999-2000 test-beam data
collected with special photon beam



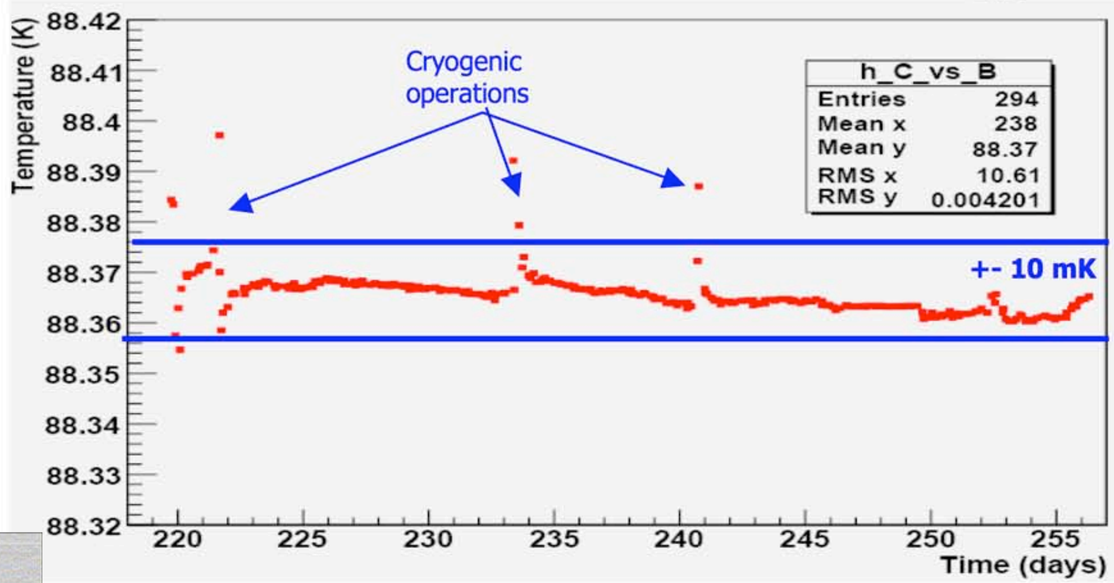


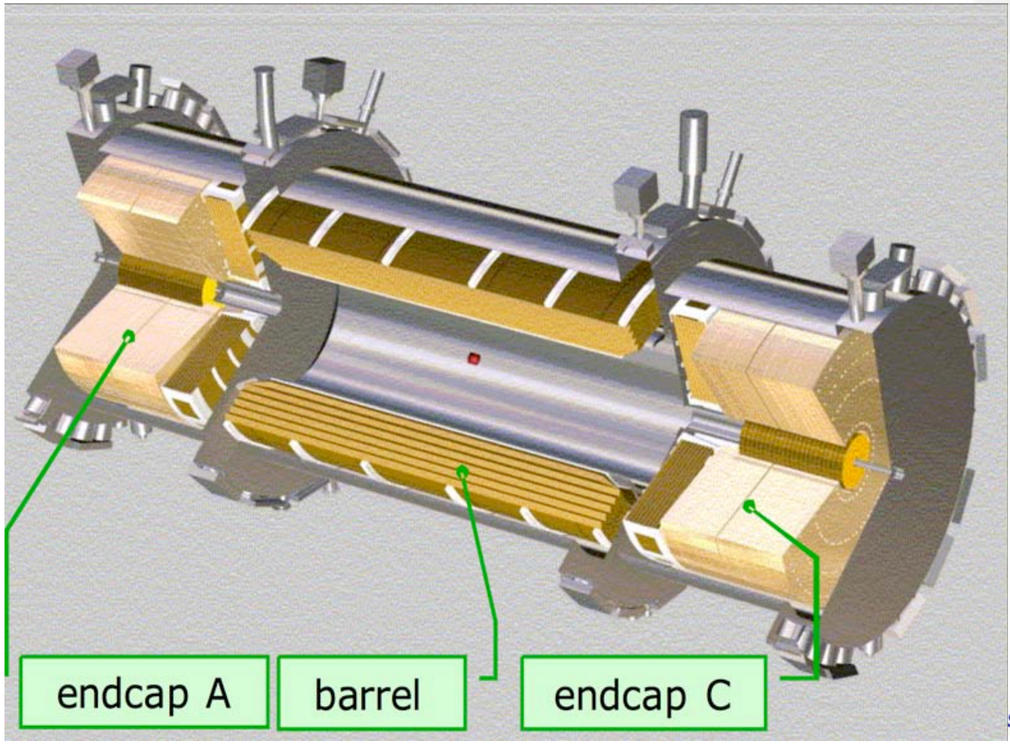
γ/π^0 separation based on 4mm η-strips in 1st calorimeter compartment

$R(\pi^0) \geq 3$ for $\varepsilon(\gamma)$~90% needed, to reject $\gamma j+jj$ background in $H \rightarrow \gamma\gamma$

The LAr Calorimeters

- ✓ All 3 cryostats cold, full of LAr and operational since several months
- ✓ Temperature very stable in time, average within 20 mK
- ✓ Liquid purity stable and well below 0.5 ppm (barrel <210 ppb, EC <150 ppb)
- ✓ Controls, safety system,… unproblematic





- ✓ *Barrel calorimeter + presampler operational with HV on continuously since March 2007*
- ✓ *Endcap-A started electronics commissioning with all services on in April 07, Endcap-C in May 07*
- ✓ *All low voltage power suppliers on the detector retrofitted in summer 07*
- ✓ *Retrofitting of all the Front-end electronics boards ongoing*

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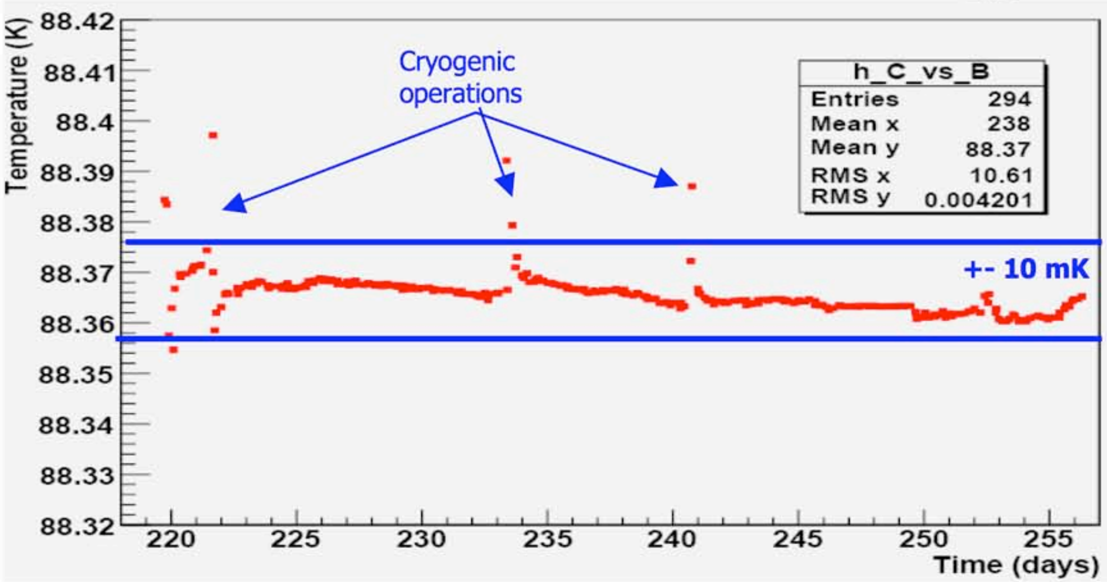

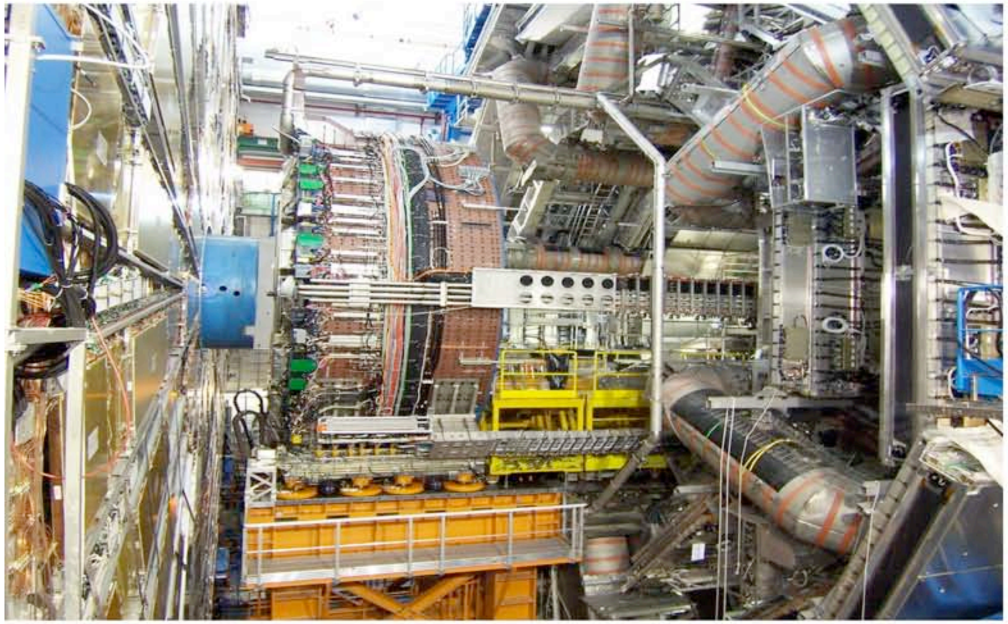

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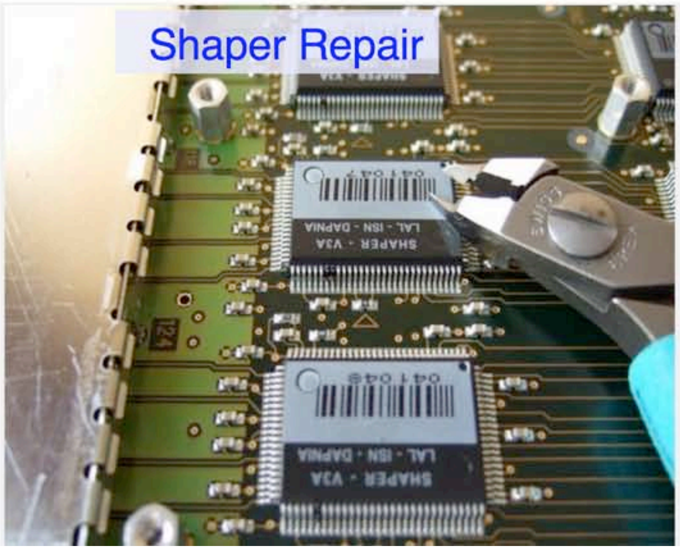
The LAr Calorimeters

✓ Mapping of all problematic channels (typically HV problems or connectivity errors) and fixing using various techniques

Barrel / ECA: all channels active, few at reduced HV

ECC: all but 2 channels active, few have shorts (mostly in the hadronic section) and need to be operated with higher current

✓ Detailed analysis of all sources of electronic noise. Try to itemize noise contributions to LVL1 from detector, FEC, pickup on trigger cables and receiver modules

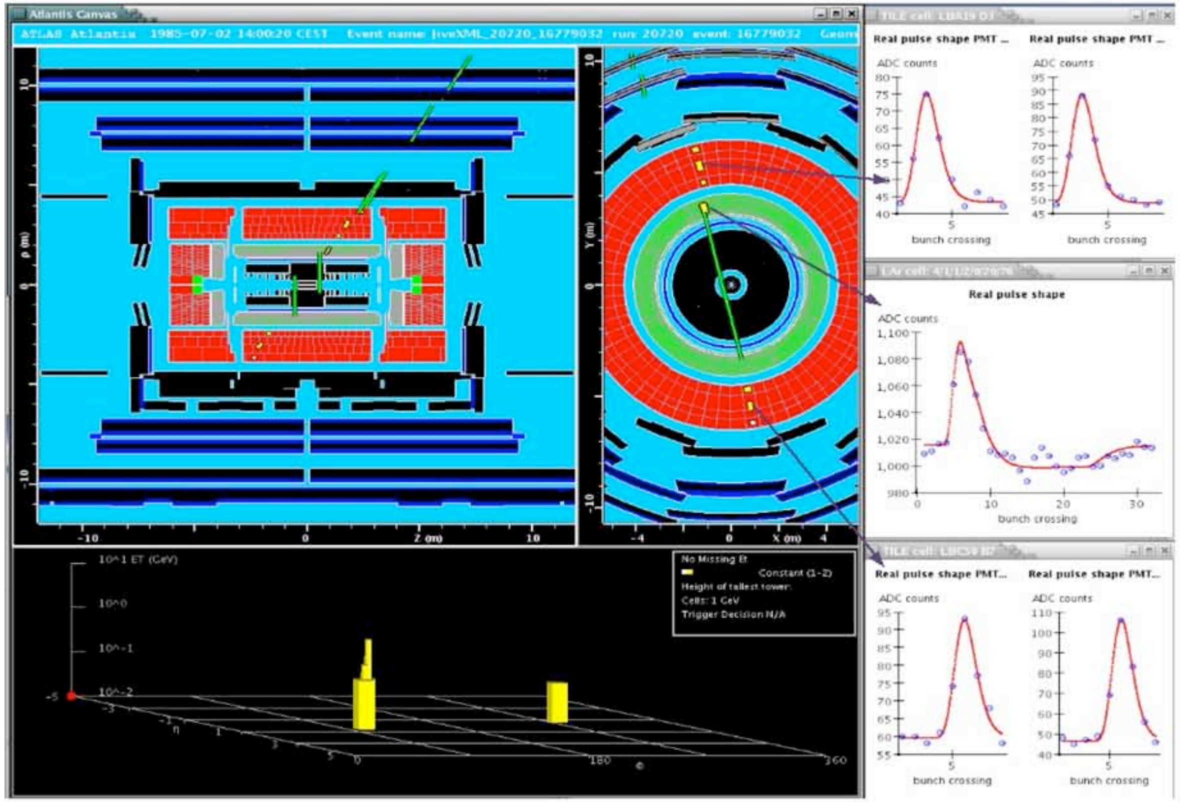


✓ In April 2007, two errors in the FEB schematics were discovered (boards on the detectors):

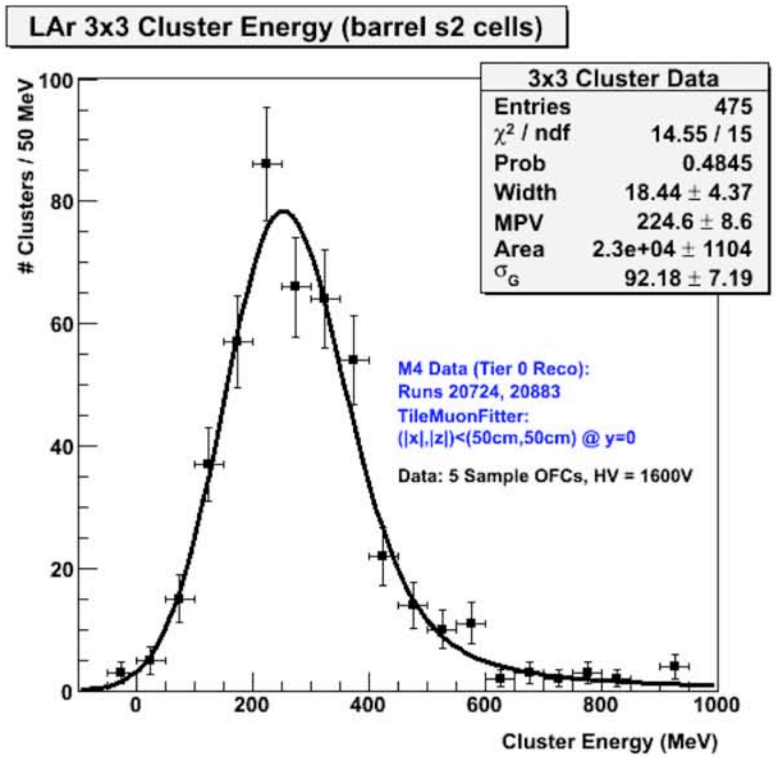
- *missing voltage-level adaptation between some DMILL and DSM components*
- *consequence is overstressing of components, reducing their lifetime*
- *no failures observed yet, but decided (as a precaution) to repair all ~1600 FEBs*

50% of the work is already done !

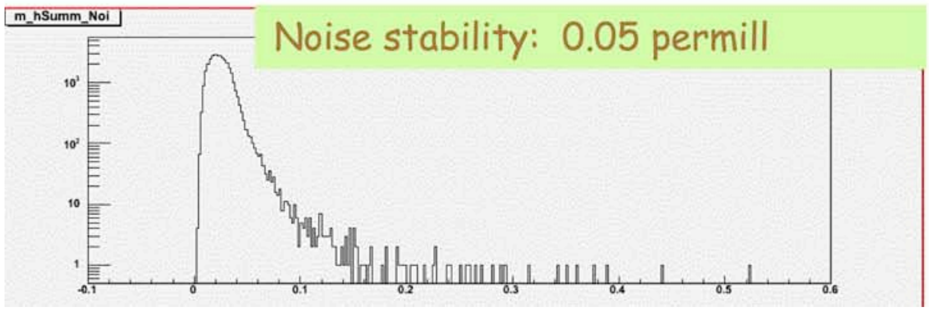
The LAr Calorimeters



- ✓ Currently take data every week end and during commissioning milestone weeks
- ✓ All Endcap and Barrel crates are now included in the readout
- ✓ A total of ~1000k cosmic events registered since August 2006, 100K fully analyzed
- ✓ Extensive use of monitoring to check rates, DCS, bad channels, trigger timing



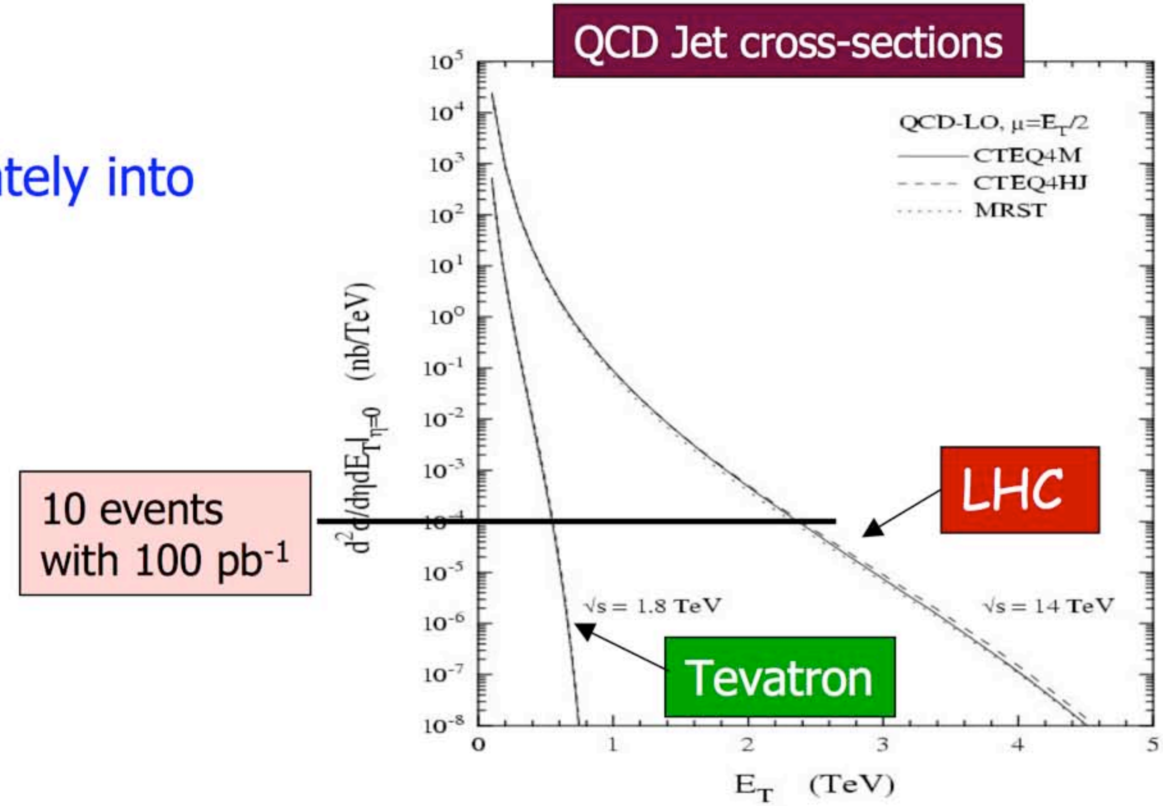
Noise variation over 4 months (11 runs)



M.Nessi

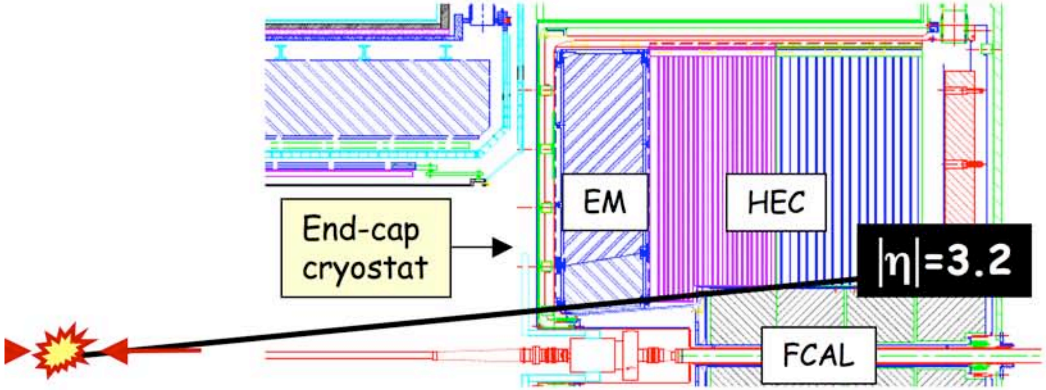
Hadron Calorimetry

… will jump immediately into a new territory



ATLAS has given great importance to a well performing hadron calorimeter system in term of resolution, segmentation and ETmiss properties

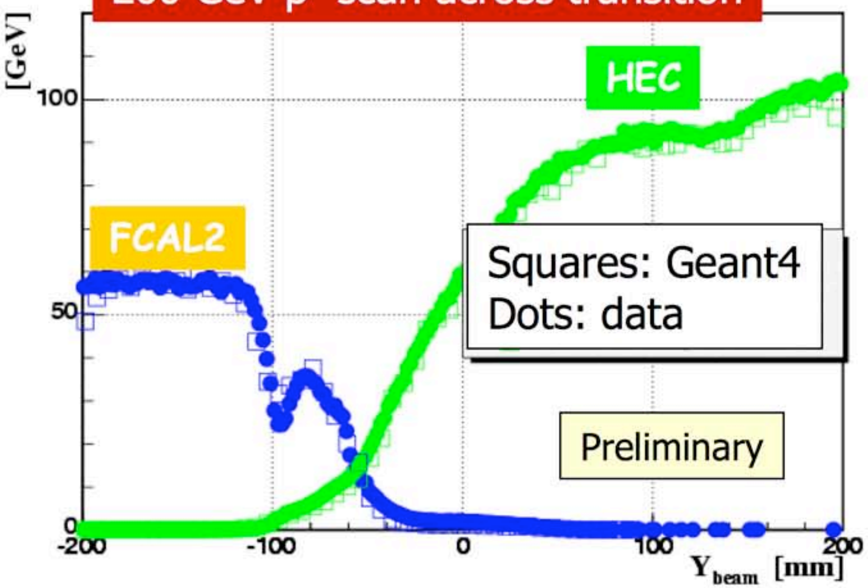
ET miss studies (tails)



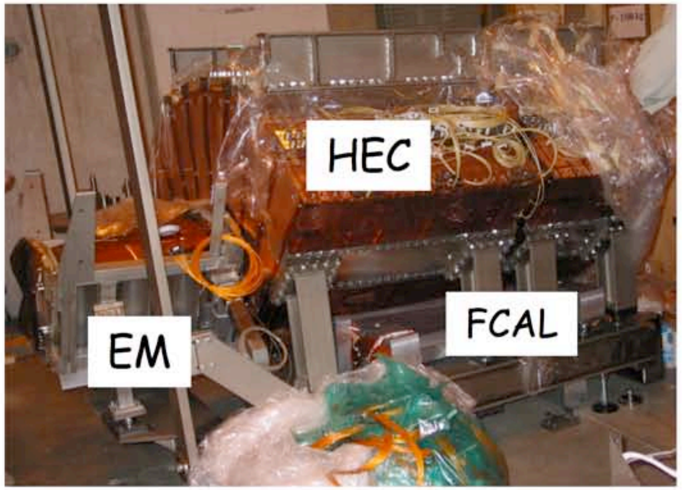
Transition between end-cap (EM, hadronic/HEC) and forward (FCAL) calorimeters at η=3.2 studied with dedicated combined test-beam in 2004

One of the backgrounds to SUSY discoveries comes from fake E_T^{miss} tails from instrumental effects (calorimeter non-linearities, resolution, cracks, …)

200 GeV p- scan across transition



M.Nessi

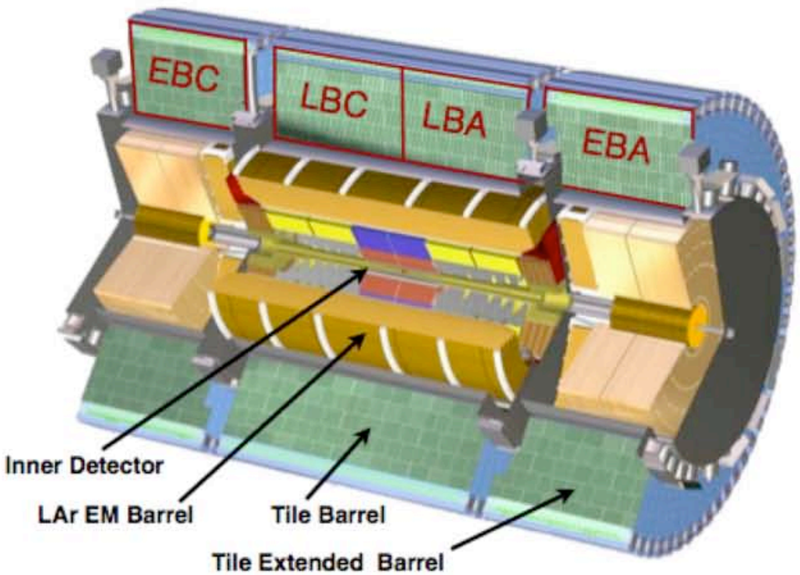


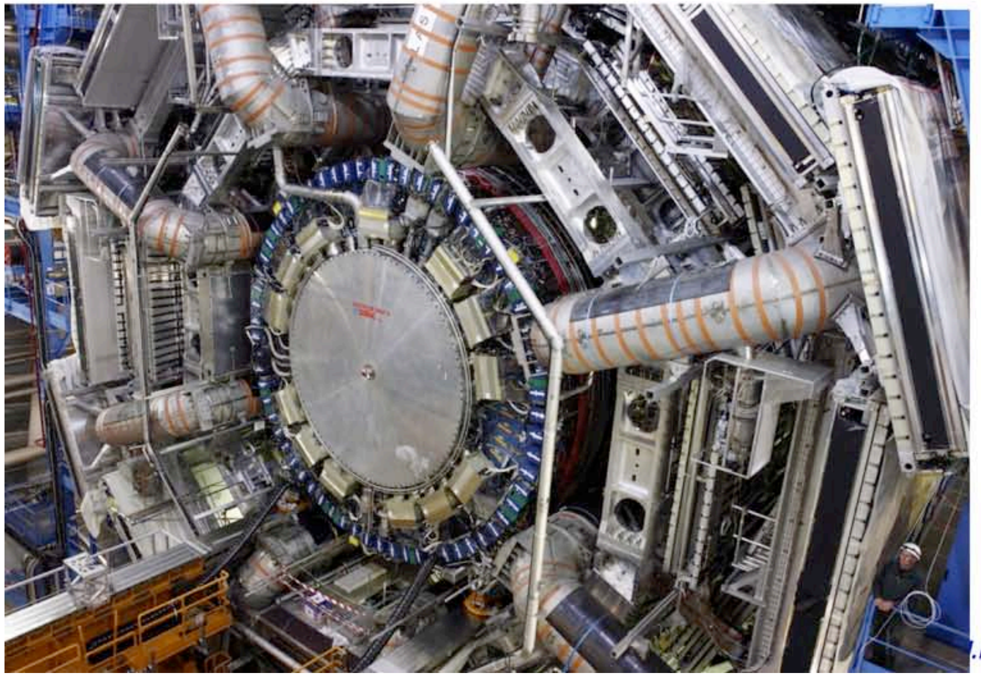
The Tile Hadron Calorimeter

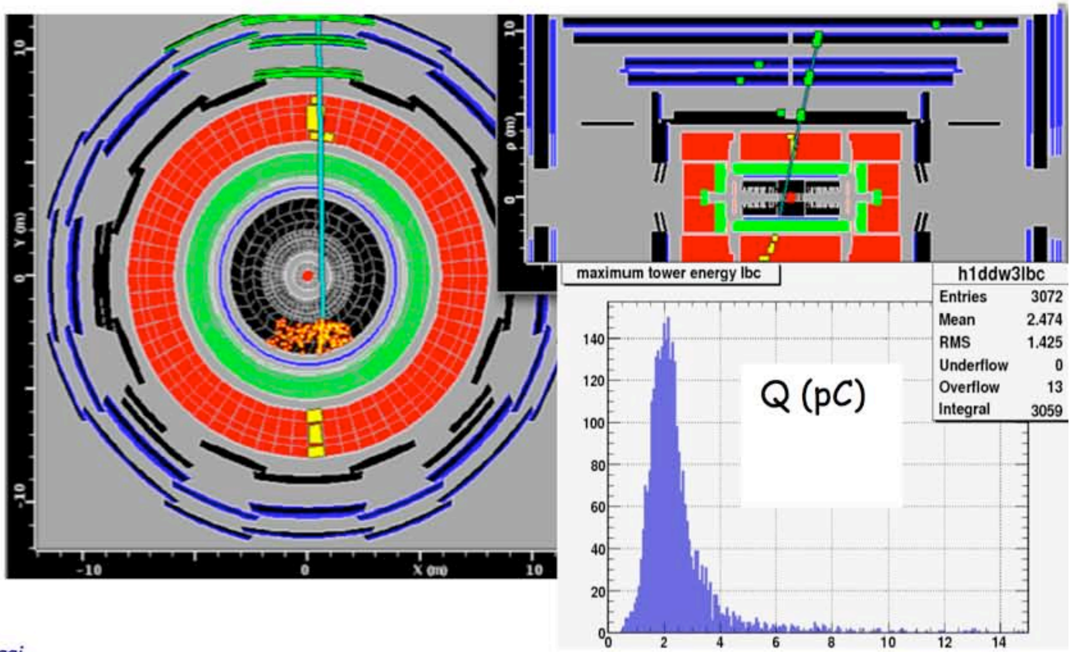
- ✓ Detector fully installed and operational since several months, including a set of dedicated minimum bias scintillators

- ✓ Low voltage power suppliers all refurbished and operational. Instabilities in the front-end electronics readout observed and due to various connectivity problems (aging of connectors,..) -> decision to refurbish all drawers: ~ 60% already done

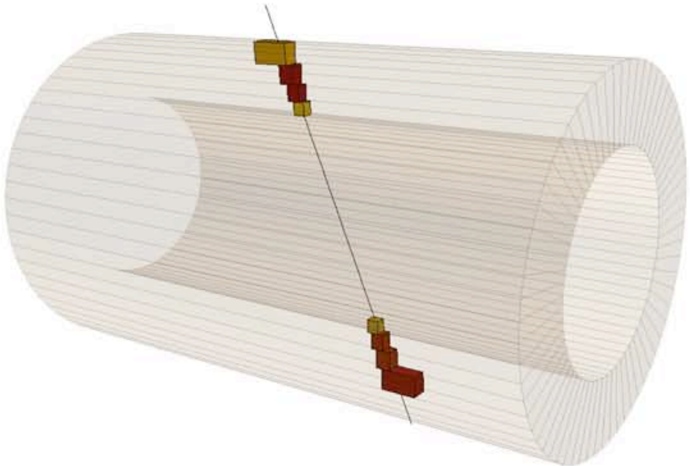
- ✓ Entering operation-like phase, i.e routinely data-taking of calibration runs (pedestals, charge injection, integrator calibrations, laser) during the week. Cosmics data-taking during the week-ends



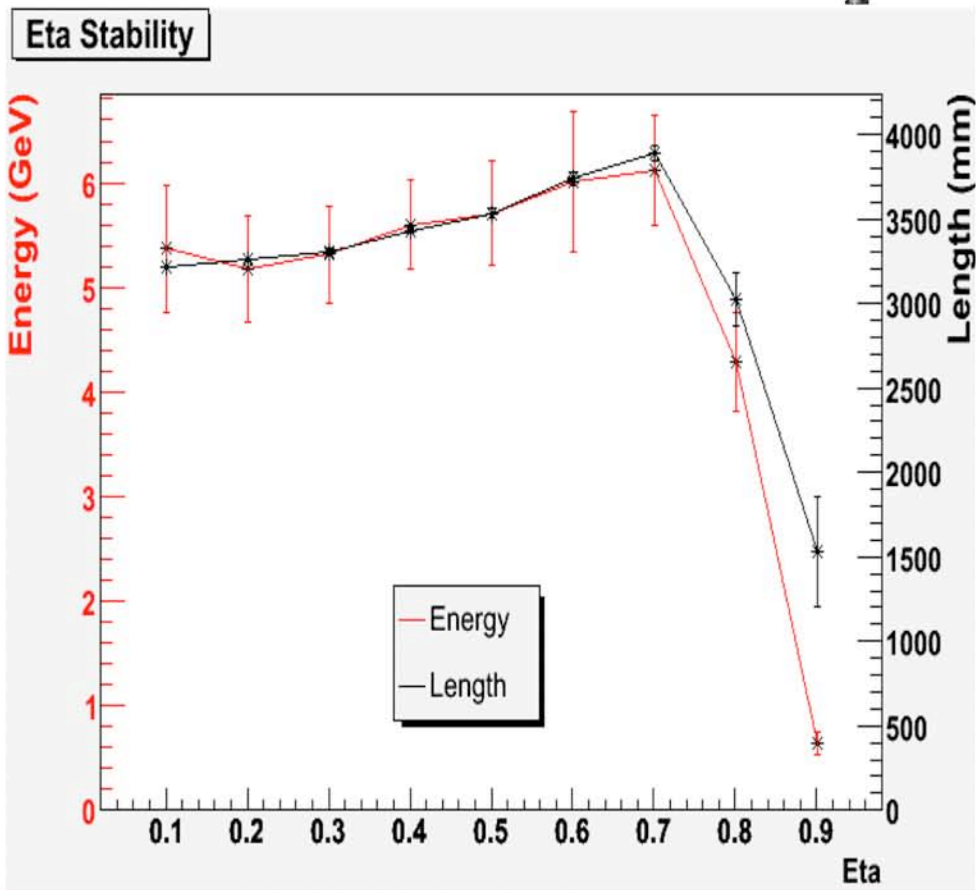




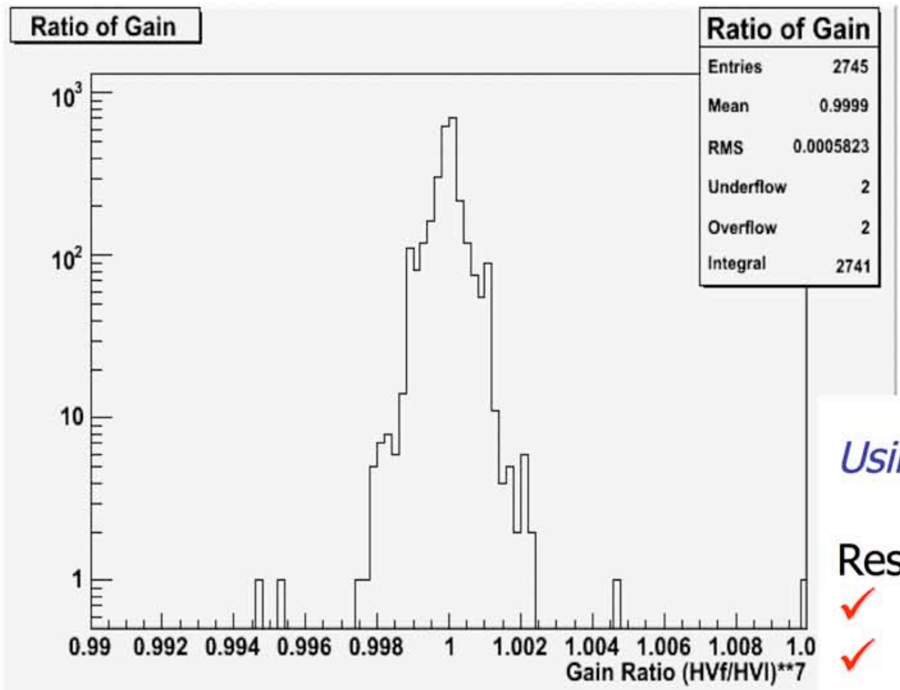
The Tile Hadron Calorimeter



Sum all cells with energy >120MeV (cosmics events)



Nice agreement with expected track length versus η



Using the laser to study HV stability :

Results in LBA, EBA :

- ✓ Gain ratio over few days, is stable at the level of 0.05%
- ✓ No hint for voltage fluctuations

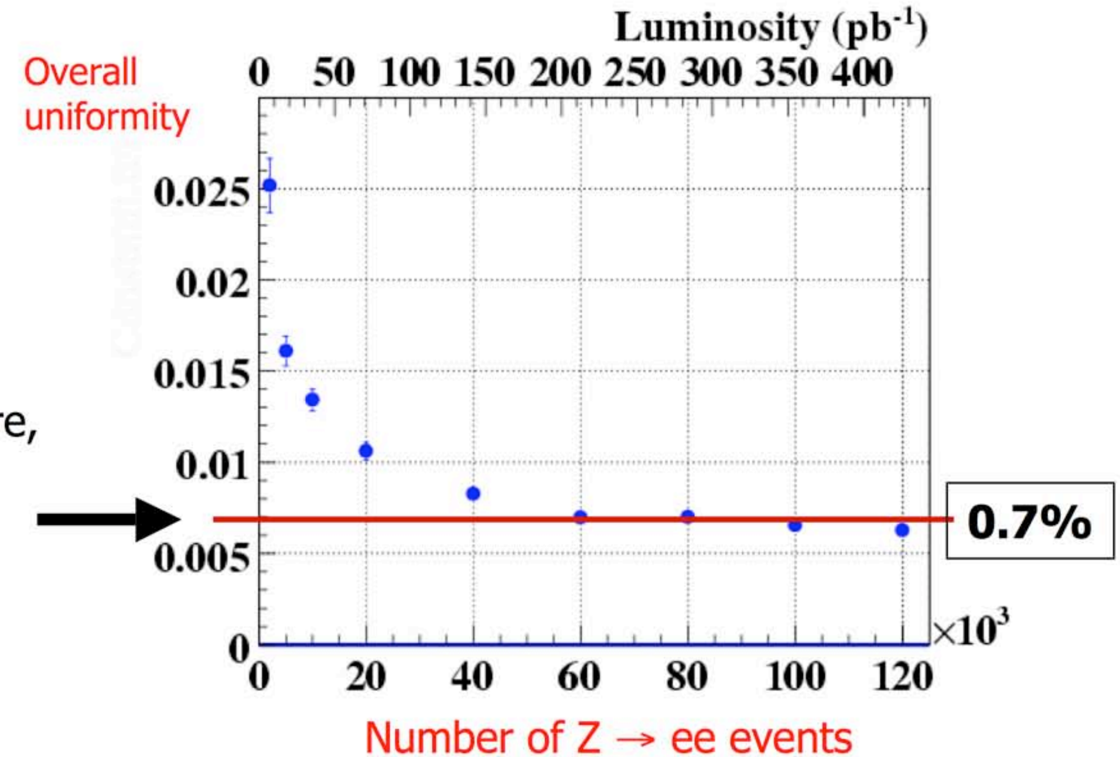
Expected calorimeter performance at day 0

	Expected performance day-0	Physics samples for improvement (examples)
ECAL uniformity	1-2% (~0.5% locally)	Isolated electrons, Z→ ee
e/γ E-scale	~ 2 %	Z → ee
HCAL uniformity	~ 3 %	Single pions, QCD jets
Jet E-scale	< 10%	γ/Z + 1j, W → jj in tt events

ECAL calibration:

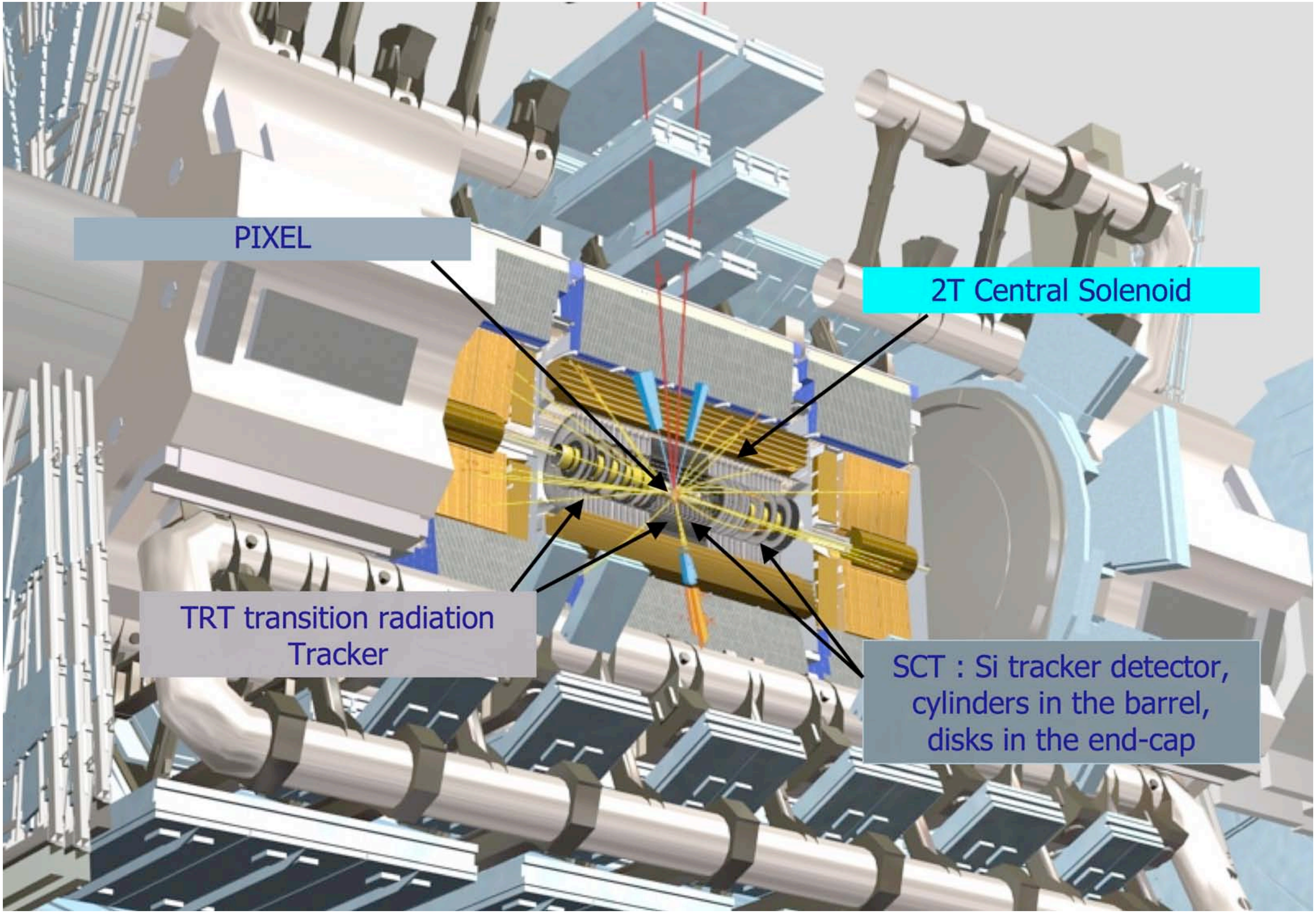
use Z-mass constraint to correct residual long-range non-uniformities (module-to-module variations, temperature, effect of upstream material, etc.)

~ 10^5 Z → ee events enough to achieve the goal response uniformity of ~ 0.7%



Calorimeters status

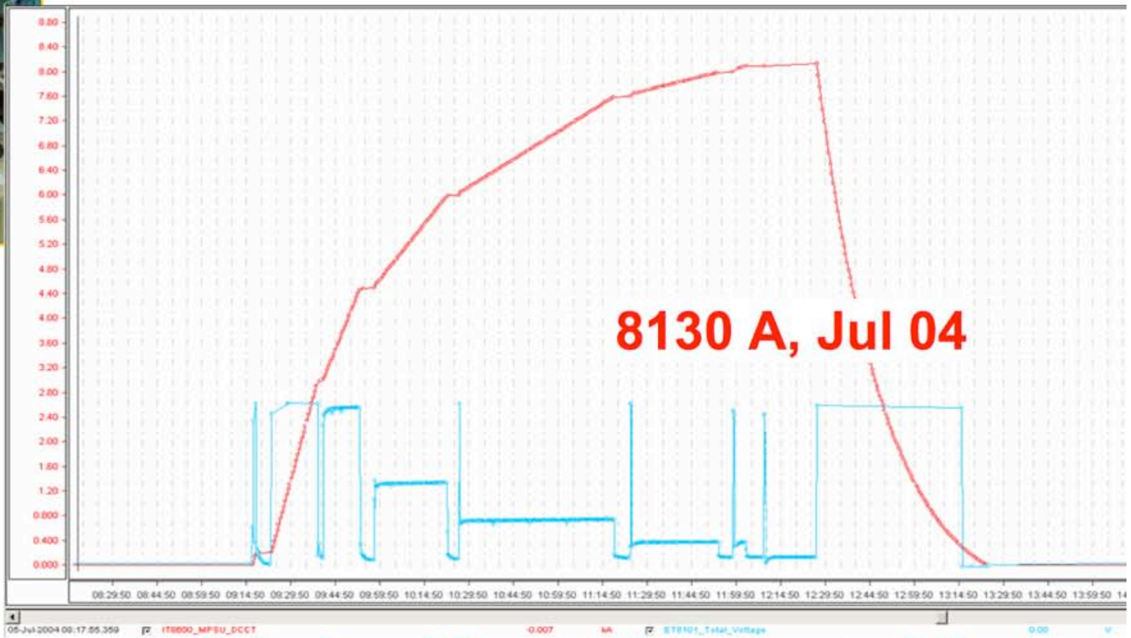
- ✓ All hardware installed and operational, all readout cells active (the 2 dead cells are in the overlap region barrel/end-cap)
- ✓ Thanks to a vigorous test beam program these devices are well understood and within the design specifications
- ✓ The entire calorimeter system is since months operational on cosmics, through the entire data flow up to the grid environment
- ✓ The overall energy calibration of the detector is at the moment based on the test beam calibration for part of it, plus all what can be cross-checked and transferred across modules with cosmics rays


PIXEL
2T Central Solenoid
TRT transition radiation
Tracker
SCT : Si tracker detector,
cylinders in the barrel,
disks in the end-cap

The inner 2T solenoid

During on-surface tests at CERN in July'04, after 2 training quenches at 7950A and 8110A (both beyond the nominal 7600 A current), the test maximum of 8130 A was achieved (6% safety margin). 0.66 X_0 (radiation lengths)

- Cooled down in May '04
- Surface test in June '04
- Test completed in July '04
- Installed into the cavern 28th Oct '04
- Fully connected and tested in situ in summer '06

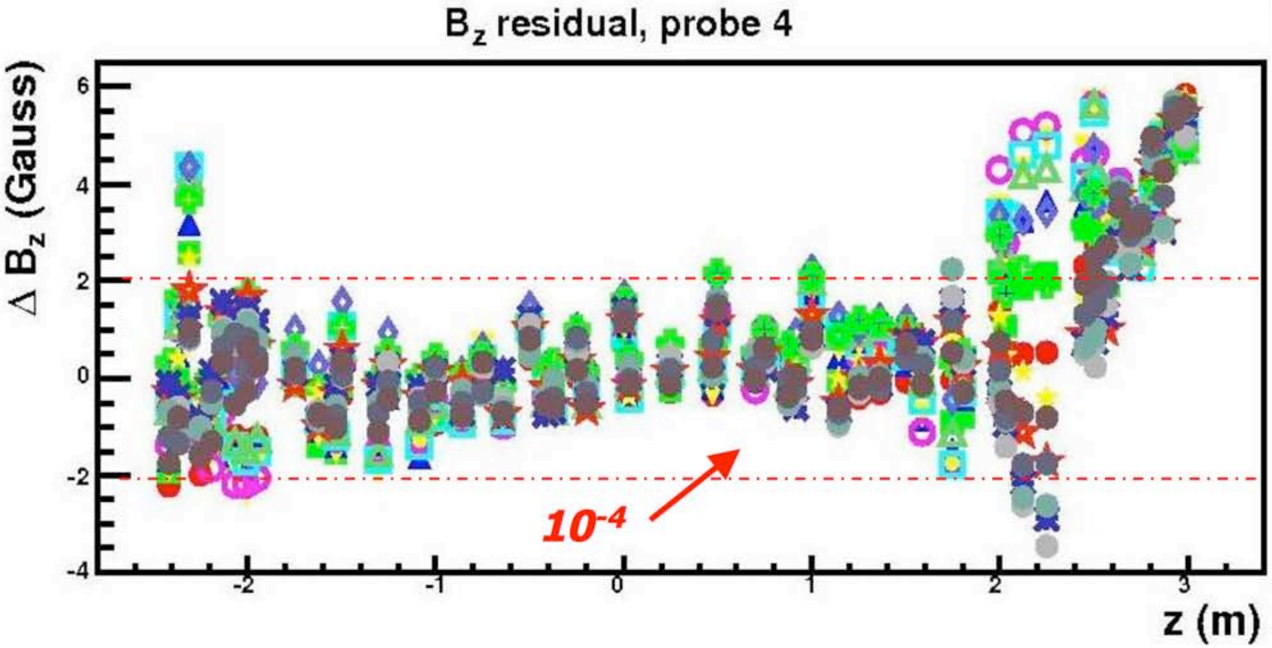


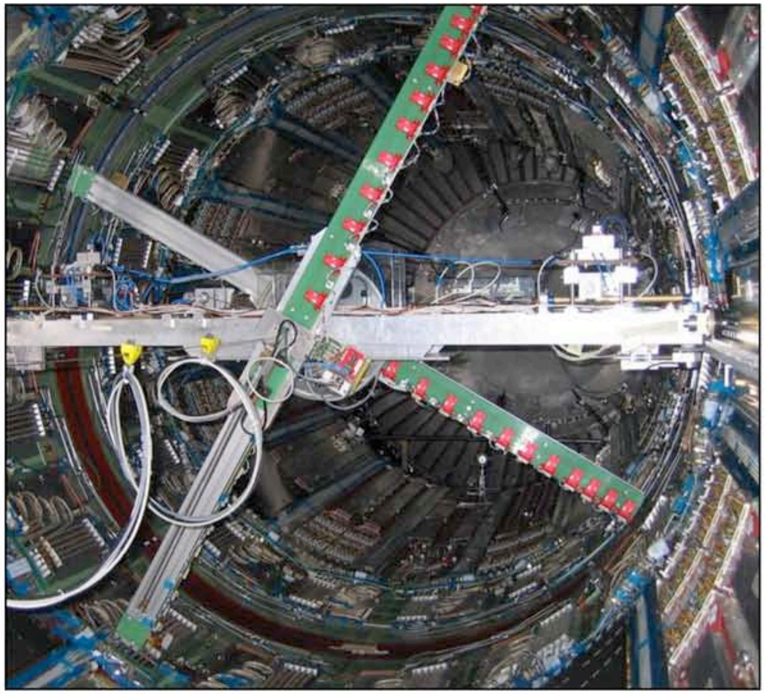
Coil is healthy and accepted for installation

Solenoid field map (Fall '06)

Full maps made at 7730 A (nominal 2 T at centre) + at various lower current values. Typical map contains 300 x 12 x 16 = 57600 data points. Three field components measured at each data point, < 1 Gauss reproducibility

Data corrections. Probe calibration accuracy 5G at 2T (2G up to 1.4T) Probe position accuracy 0.3 mm. Maxwell constraints allow correction of individual probe alignment (to ±0.2 mrad.)

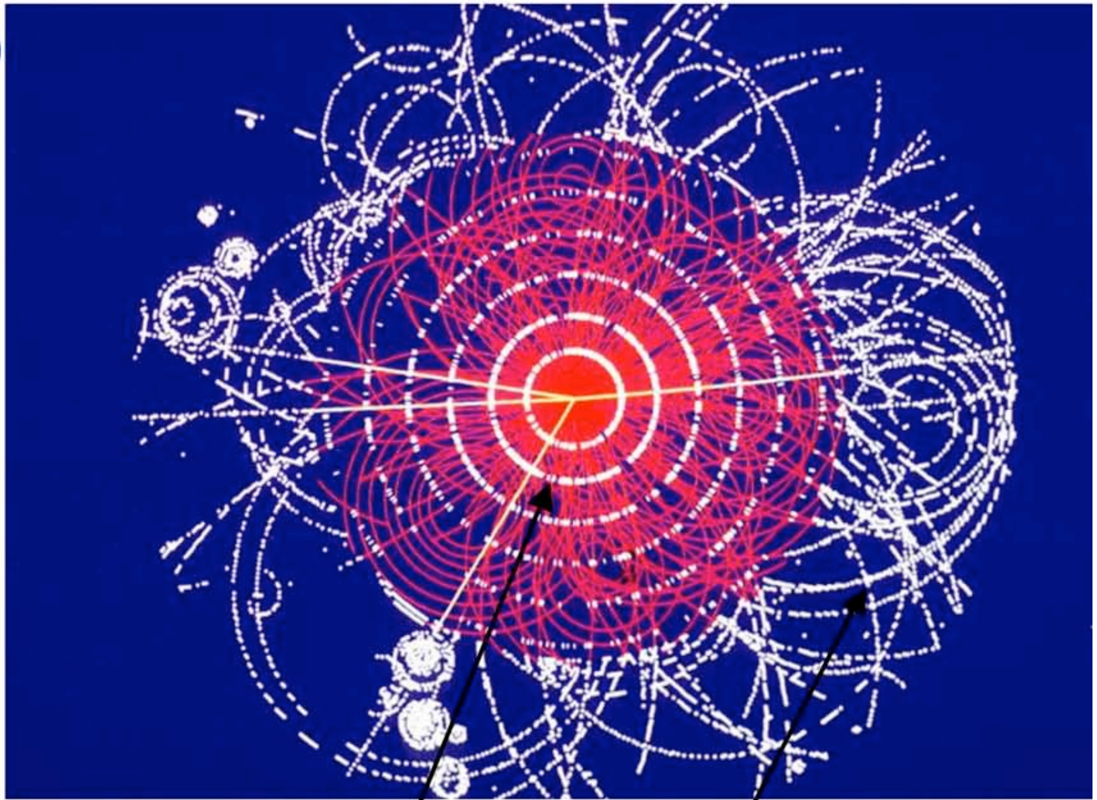




Still possible to improve fit quality at the coil extremes!

The Inner Detector (ID) challenge

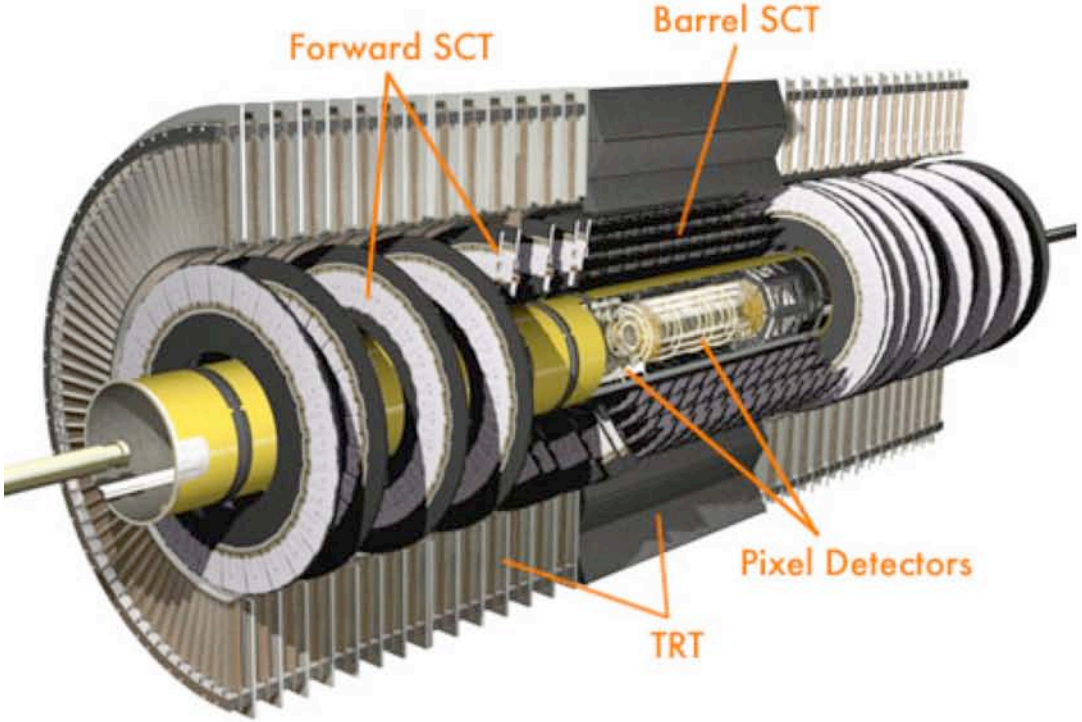
- *Patter recognition challenging: high track density*
  - ✓7 precision points/track (3 pixel+4 SCT)
  - ✓Each r-ϕ and z (40 mrad stereo in SCT)
  - ✓Up to 36 TRT straw hits
  - ✓Continuous tracking… optimised for tracking performance, not TR e-
  - ✓π rejection up to 100 for 80% e-efficiency
- Needs to operate up to an integrated dose between 10 and 60 Mrad
- Hermetic coverage up to $|\eta|$=2.5
- B-tagging capability

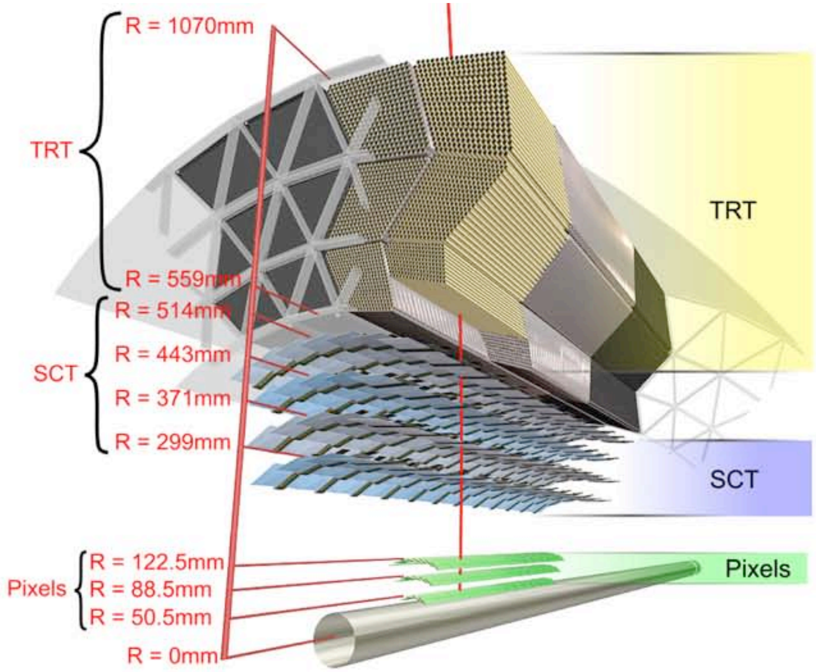


Pixel, SCT precision tracking

TRT continuous tracking

The Inner Detector





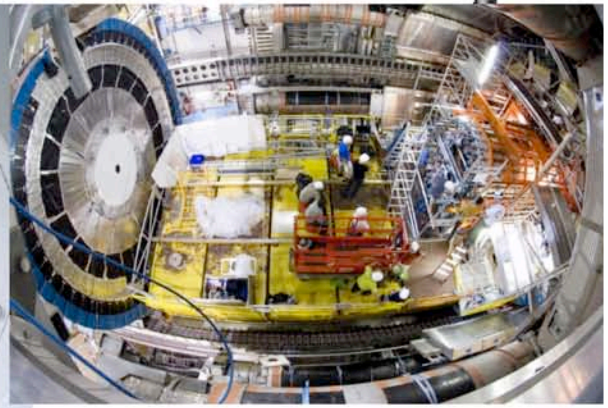
All detector components installed in 4 steps

- ✓ Barrel SCT + TRT
- ✓ 2 End-Caps SCT + TRT
- ✓ Full pixel detector + Be beam pipe

- ✓ All cables and pipes installed, SCT and TRT fully connected
- ✓ Pixel detector cables and pipes installed, pixel connection waiting for SCT sign off

Inner Detector installation

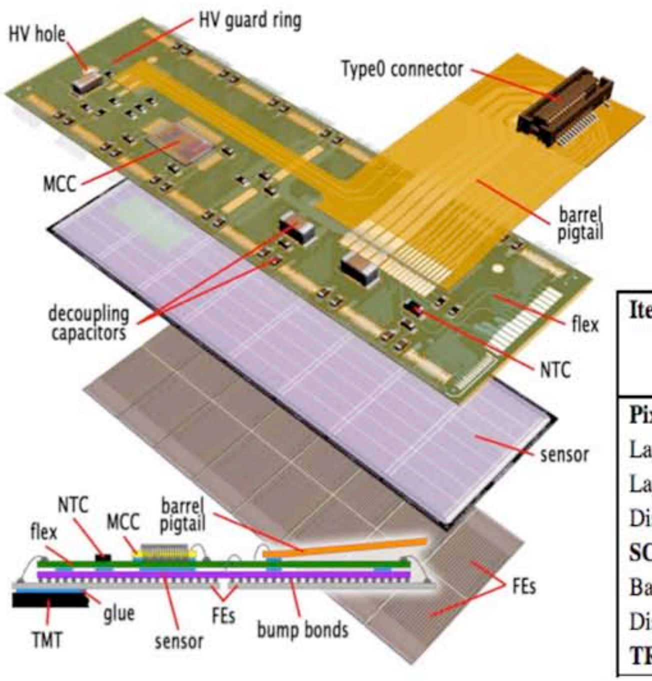


Task Name	Date
Lower ID EC-A	May 24
ID EC-A installed	May 29
Lower ID EC-C	June 18
ID EC-C installed	June 19
Lower Pixel	June 25
insertion LAr vacuum pipe	June 25
Pixel insertion	June 26
Pixel insertion completed	July 2
Be beam pipe aligned	Aug 9
Connection of all 3 central beam pipes	Aug 28

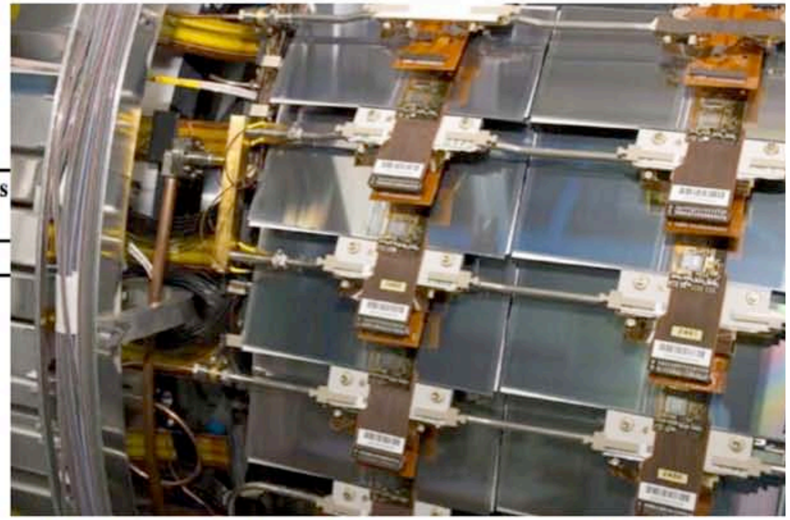


ID Si-sensors

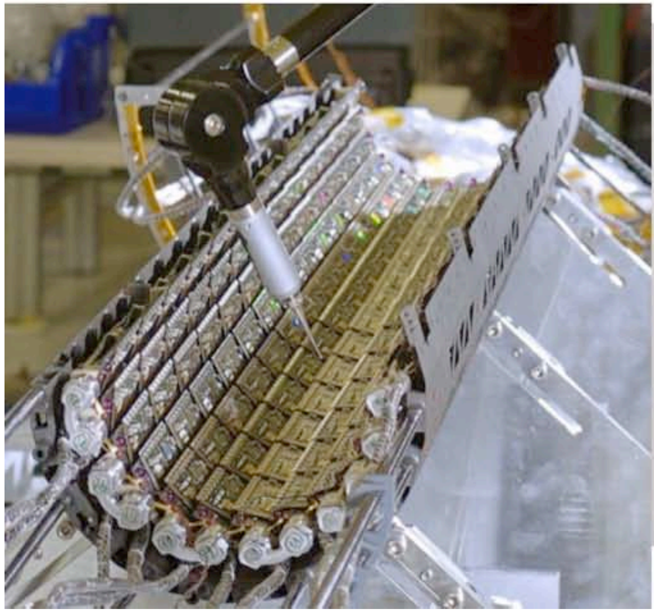


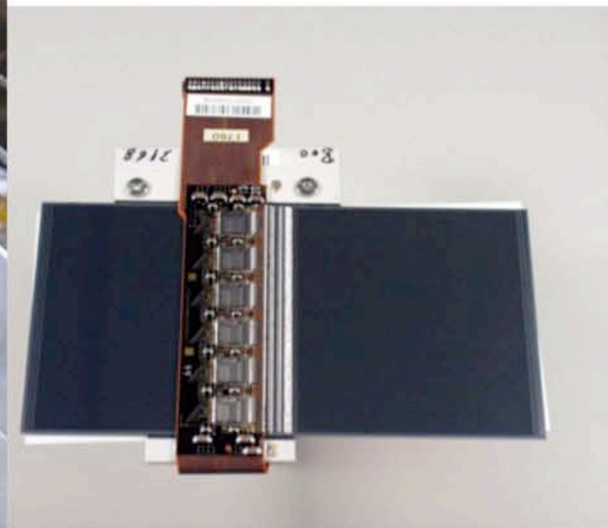
1744 modules, min 50x400 μm^2

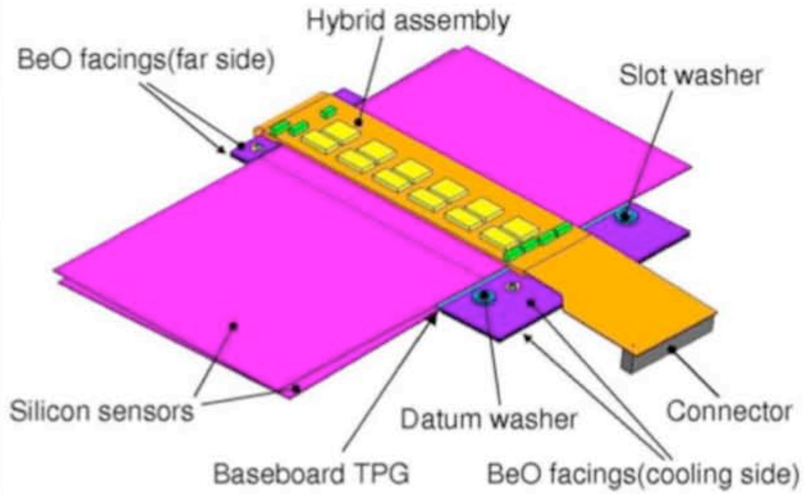
Item	Intrinsic accuracy (μm)	Alignment tolerances (μm)		
		Radial	Axial z	Azimuth Rϕ
Pixel				
Layer 0	10 ($R\phi$) 115 (z)	10	20	7
Layers 1 and 2	10 ($R\phi$) 115 (z)	20	20	7
Disks	10 ($R\phi$) 115 (R)	20	100	7
SCT				
Barrel	17 ($R\phi$) 580 (z)[1]	100	50	12
Disks	17 ($R\phi$) 580 (R)[1]	50	200	12
TRT	130 (drift time)			30[2]



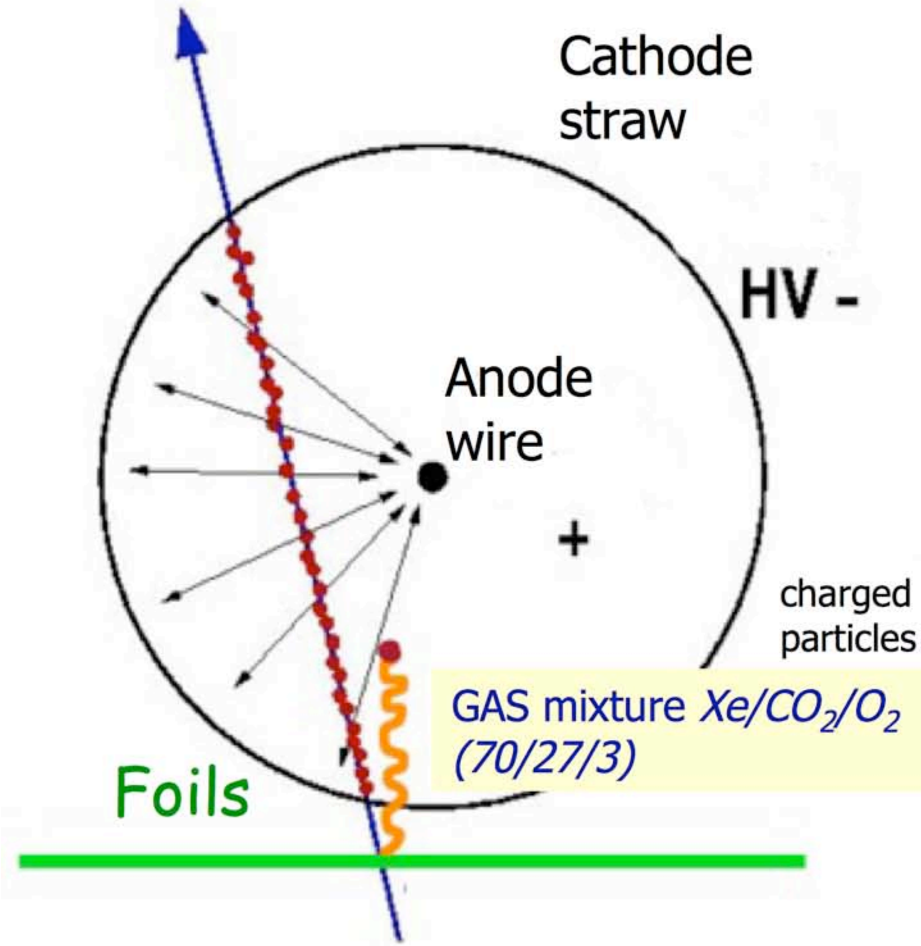
4088 modules, 80 μm micro-strips





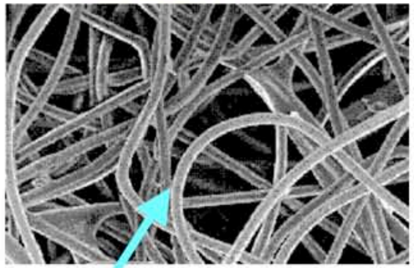


The TRT (Transition Radiation Tracker)

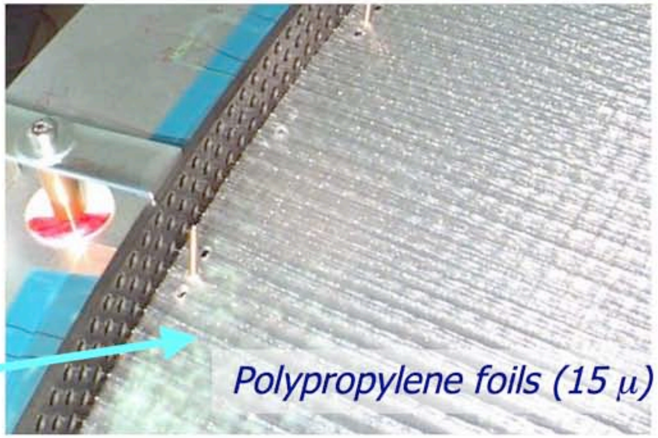


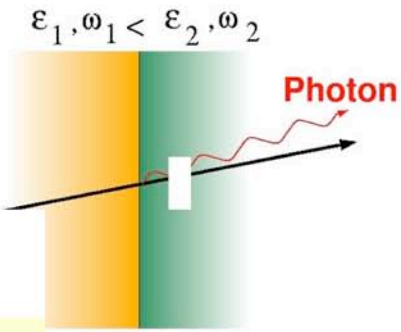
GAS mixture $Xe/CO_2/O_2$ (70/27/3)

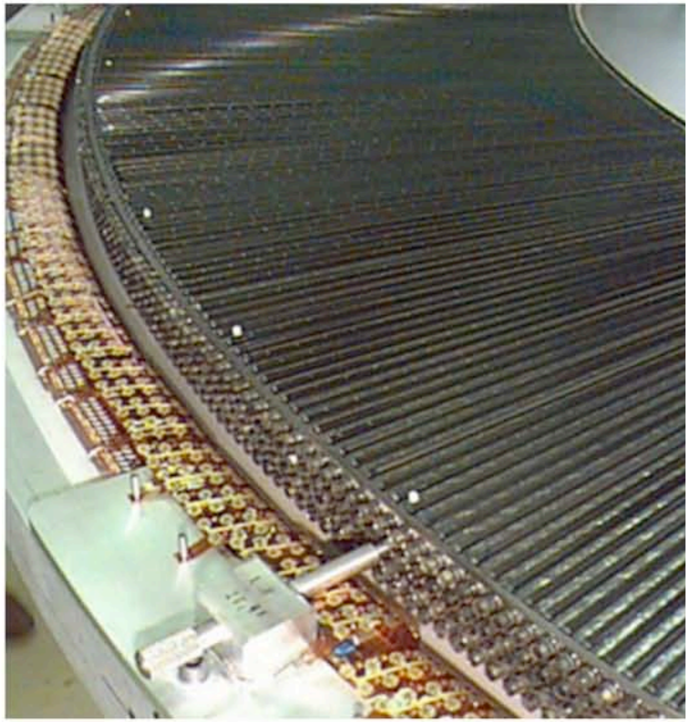
radiator



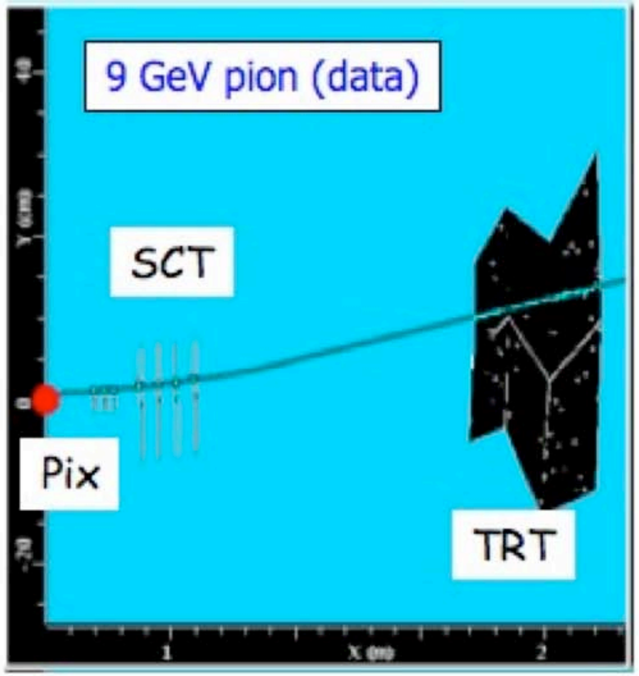
Barrel end-cap

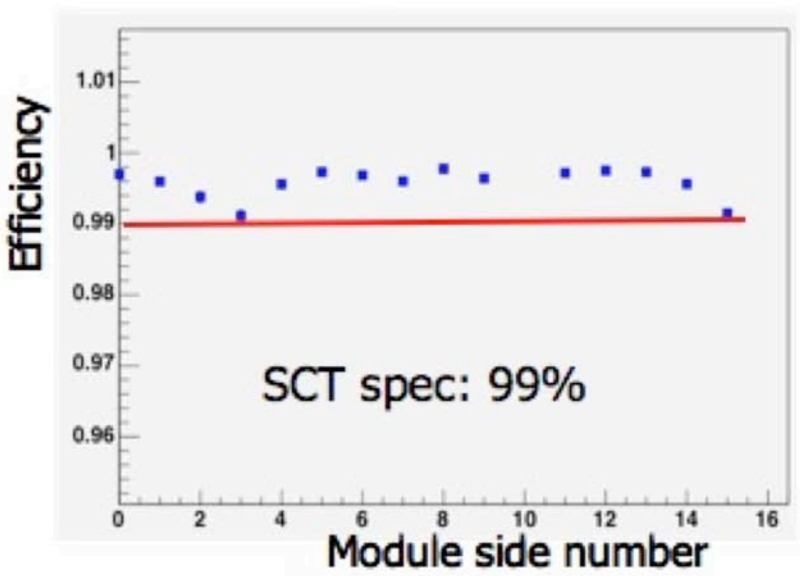






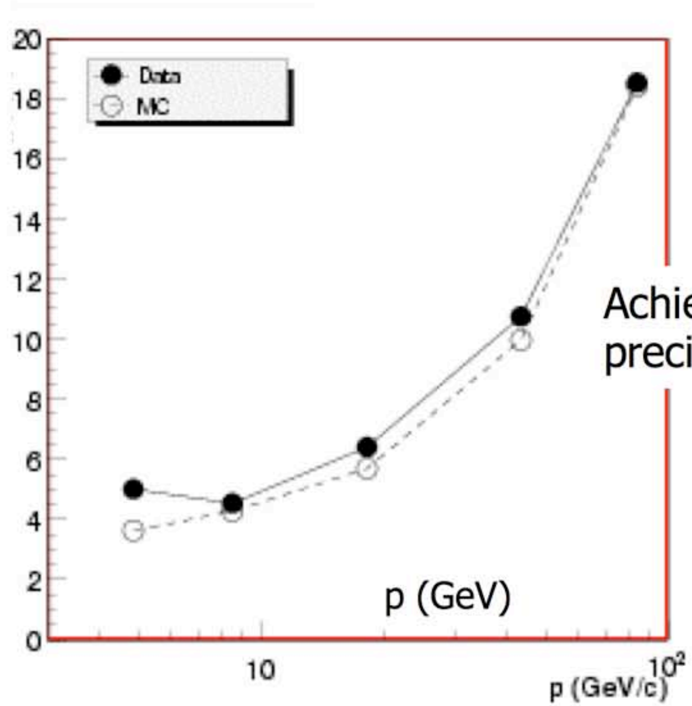
Test Beam data





Pion momentum resolution from 2004 combined test beam using just Pixels+SCT

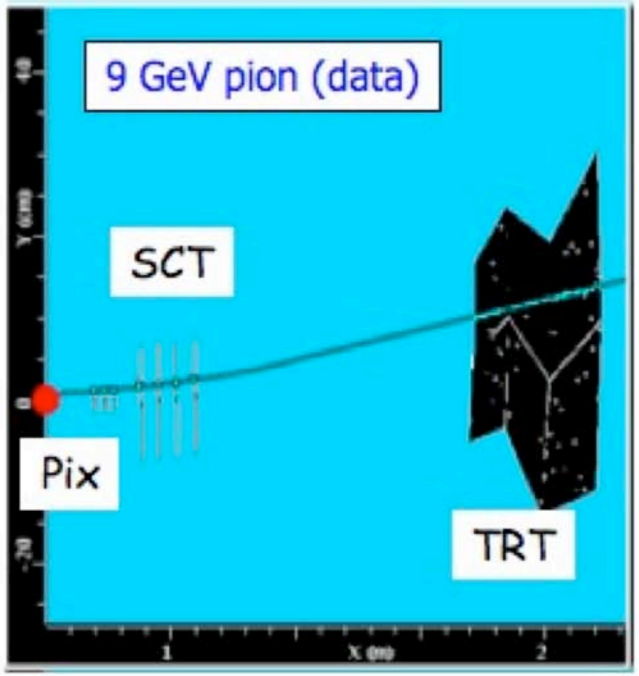
Note:
no TRT,
B=1.4 T

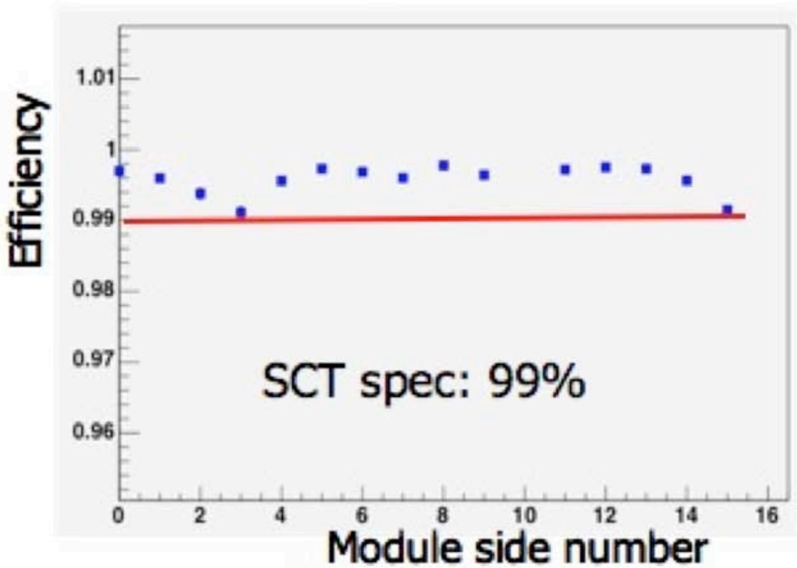


Achieved alignment precision: 5-10 μm

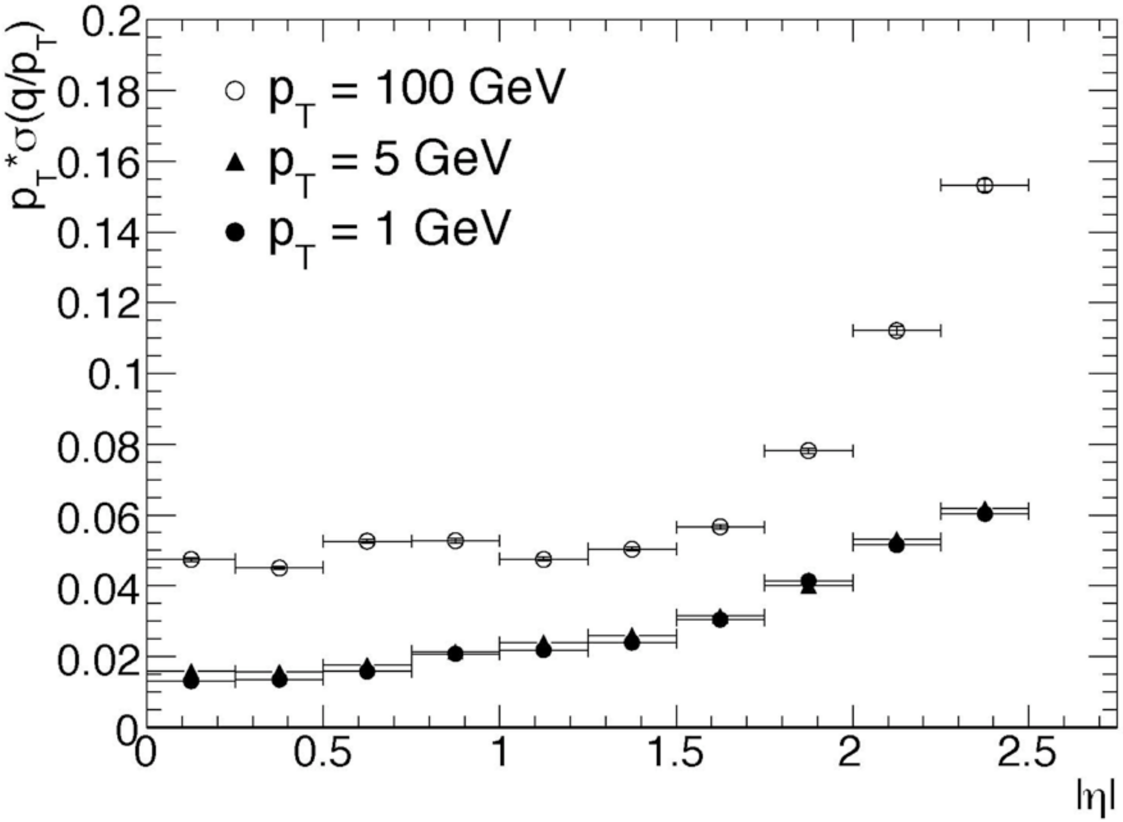
M.Nessi

Test Beam data



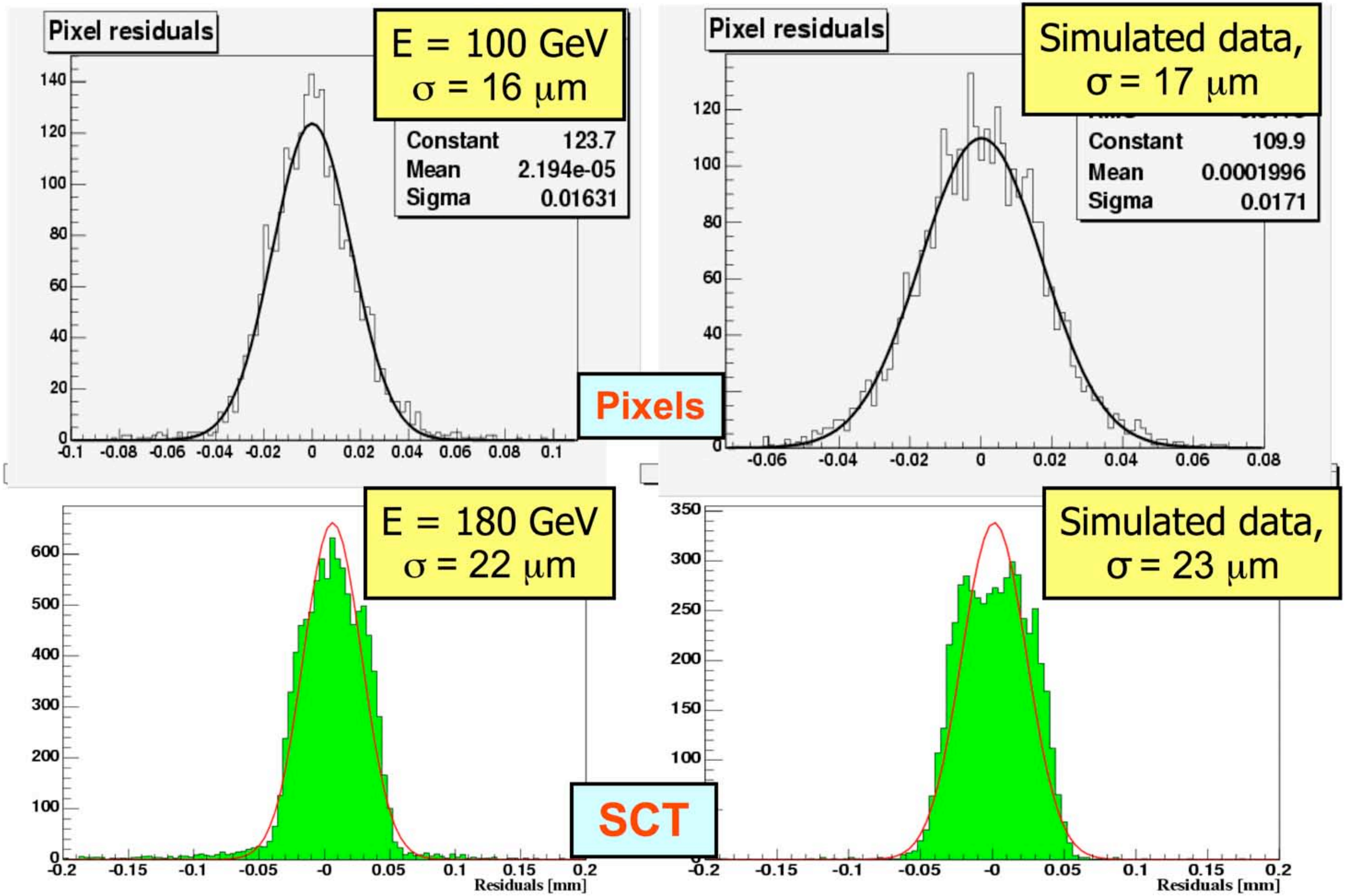


Pion momentum resolution from 2004 combined test beam using just Pixels+SCT

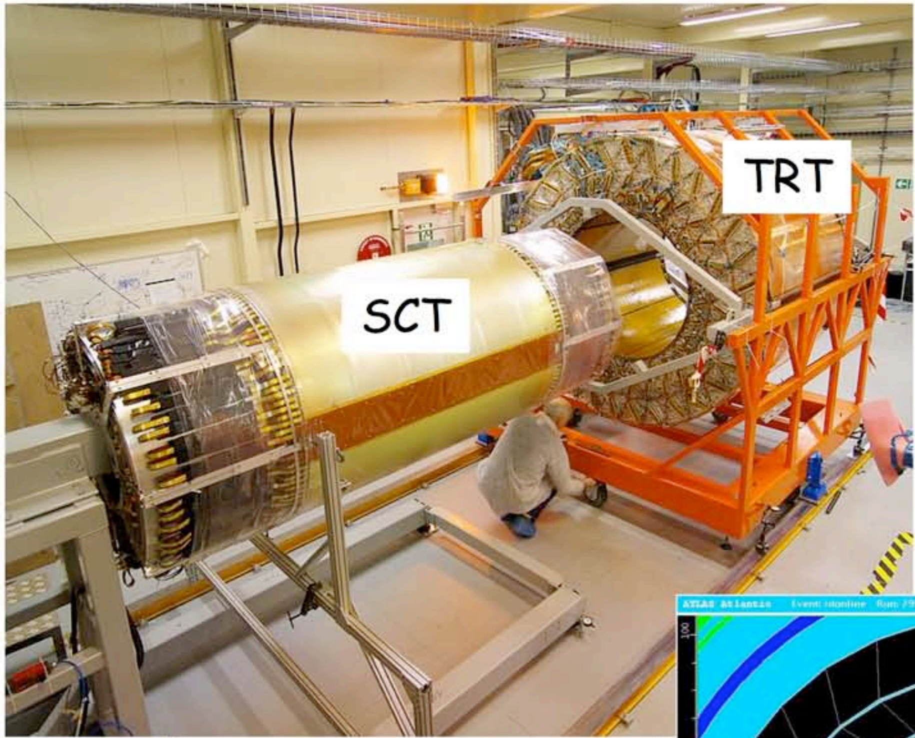


M.Nessi

Test Beam Data



Relative Alignment data

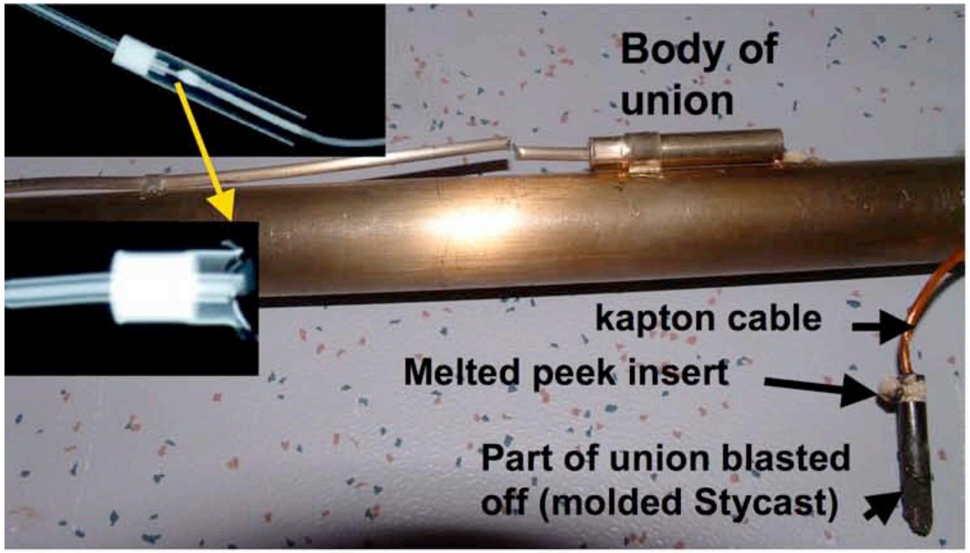


SCT-TRT integration in surface clean room in Feb 2006

Global SCT-TRT barrel misalignments from survey measurements compared to results from reconstructed cosmics tracks after alignment

Displacement	Survey	Cosmics
Δx (mm)	-0.300 ±.008	-0.290 ±.007
Δrot-y (mrad)	0.221 ±.042	0.285±.021

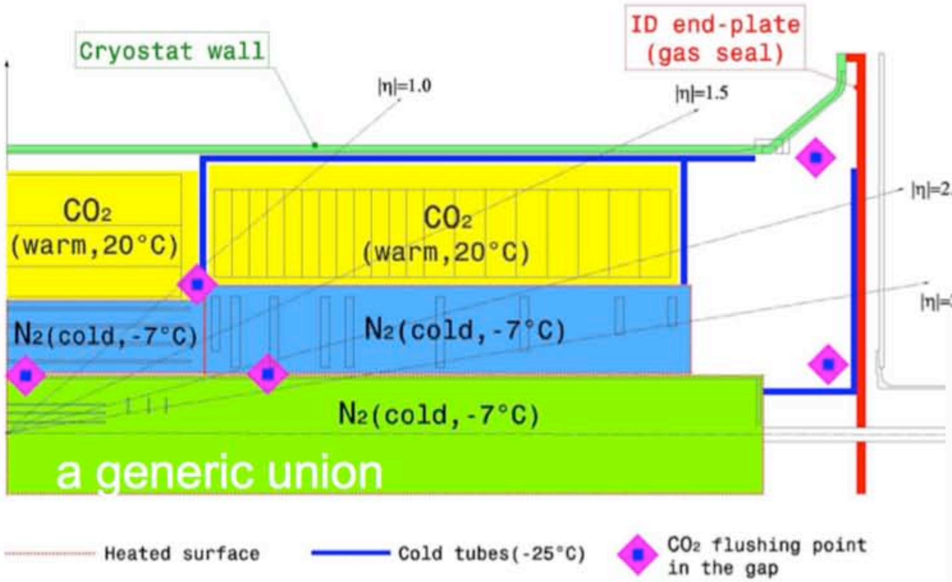
ID heater problem

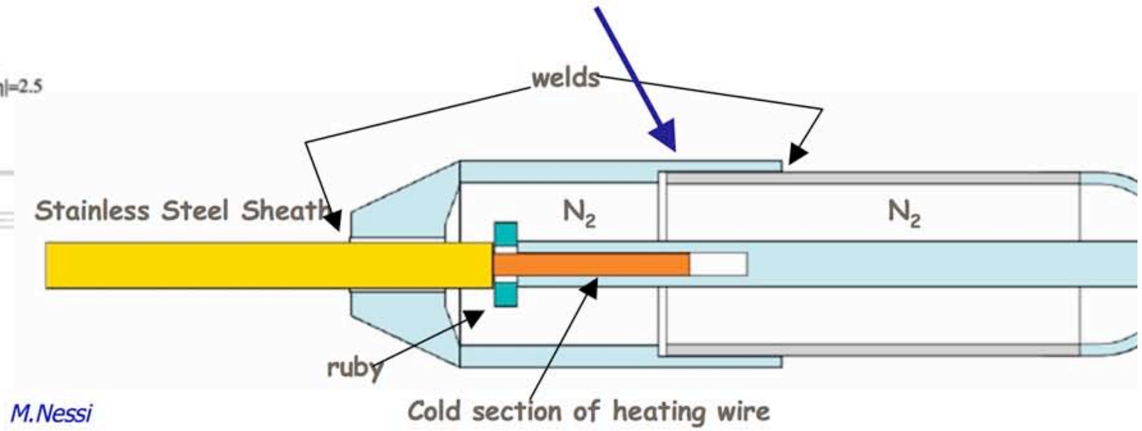


A catastrophic failure of the heater power connection was experience in February this year

Heaters had been placed just at the end of the cooling loop and their function is to vaporize the cooling liquid exiting the detector, in order to push it through the circuit loop

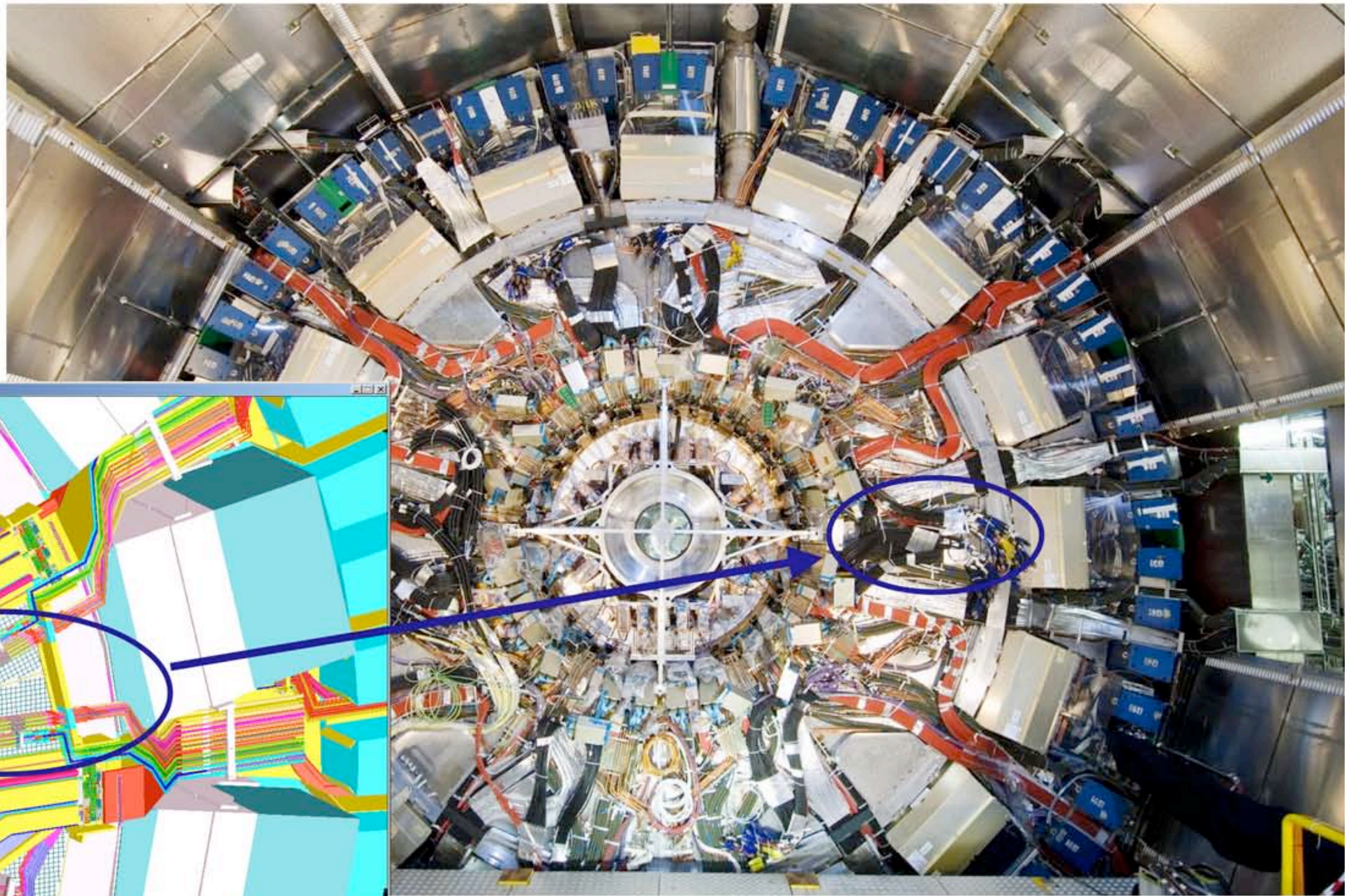
After a new failure in May, the decision was taken to bring the heaters outside the ID volume (far heaters solution). A new connector was developed with the producers with good results (air ceramic connector). Full delivery ongoing

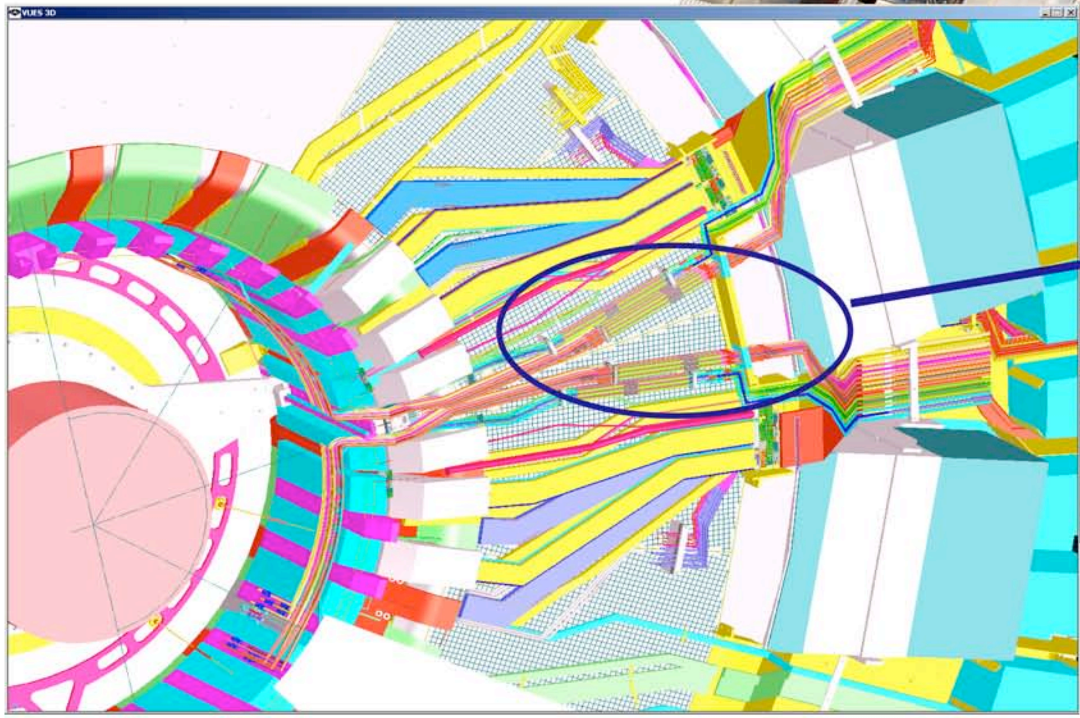




Far heaters solution

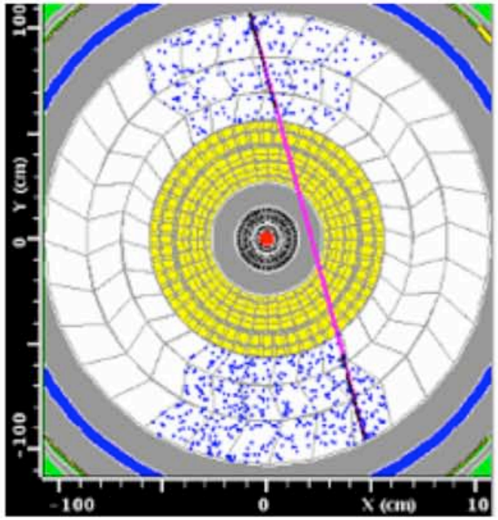
Decision taken a few months ago to place all SCT heaters outside the detector volume, on the calorimeter barrel flange





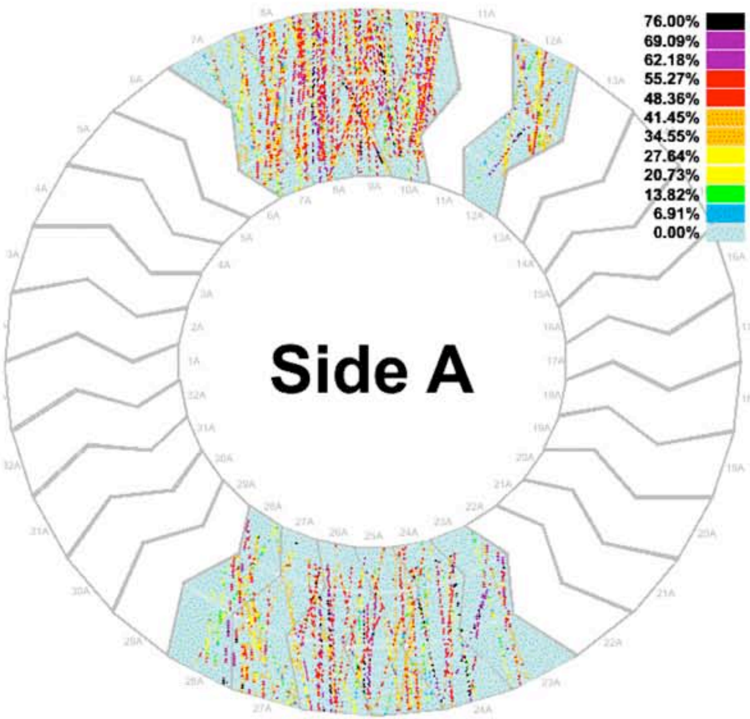
Most pipes rerouted inside and outside the detector. Some of the retrofitted units are installed and final qualification tests are ongoing. Final SCT sign off waiting for all this to be fully operational

SCT/TRT commissioning



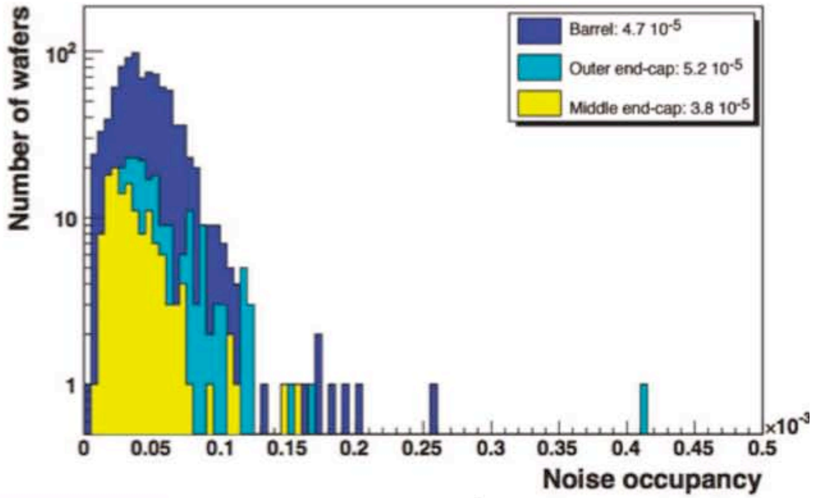
TRT part	Dead channels Mech.,Electr., HV	Gas Ar/CO2 since	HV
Barrel	1.8% (A) 2% (C)	March 2007	~5 months
EC-A	1.7%	August 2007	~ few weeks
EC-C	1.2%	Sept. 2007	~ few weeks

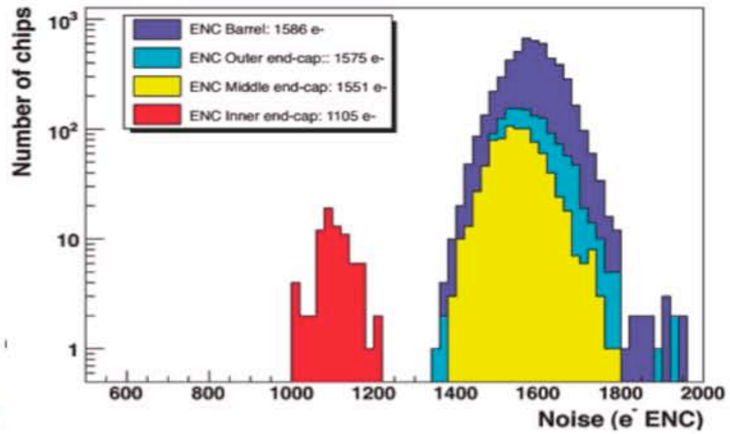
4 10^5 active channels



SCT: Noise + 60e as of lab tests, only 1 additional module lost during installation (HV connection)

overall ~0.25% problematic channels out of 6 10^6 channels





M.Nessi

Pixels performance

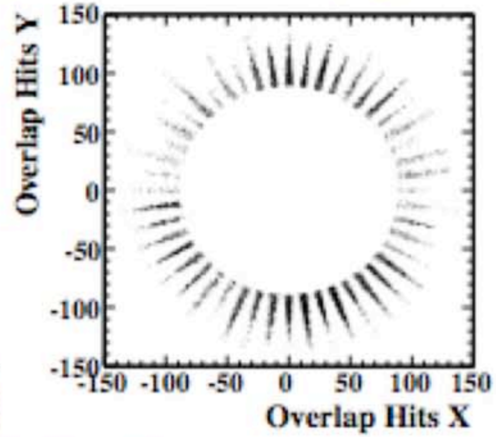
Electrical quality tested just before installation in situ (0.8 10^8 active channels):

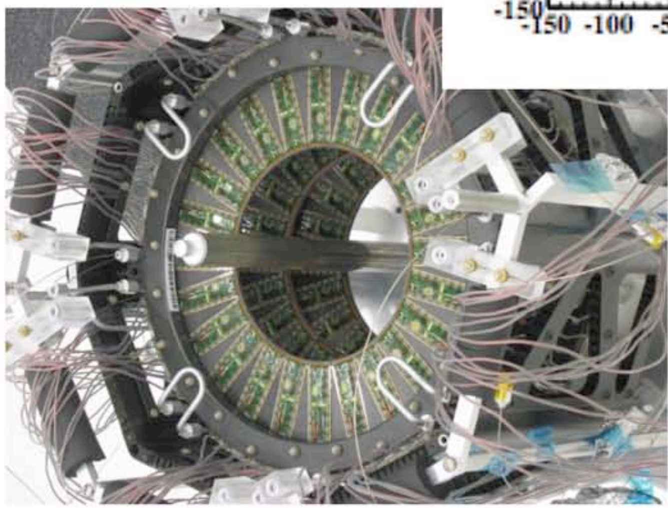
Defective channels (%)				
End-cap A	Disk 1A	Disk 2A	Disk 3A	Average defects (%)
	0.14	0.23	0.52	0.30
End-cap C	Disk 1C	Disk 2C	Disk 3C	
	0.12	2.19	0.31	0.87
Barrel	Layer-0	Layer-1	Layer-2	
	0.07	0.40	0.29	0.28
Pixel average				0.33

Excellent B-Layer

System test of Endcap A done on surface prior to installation:

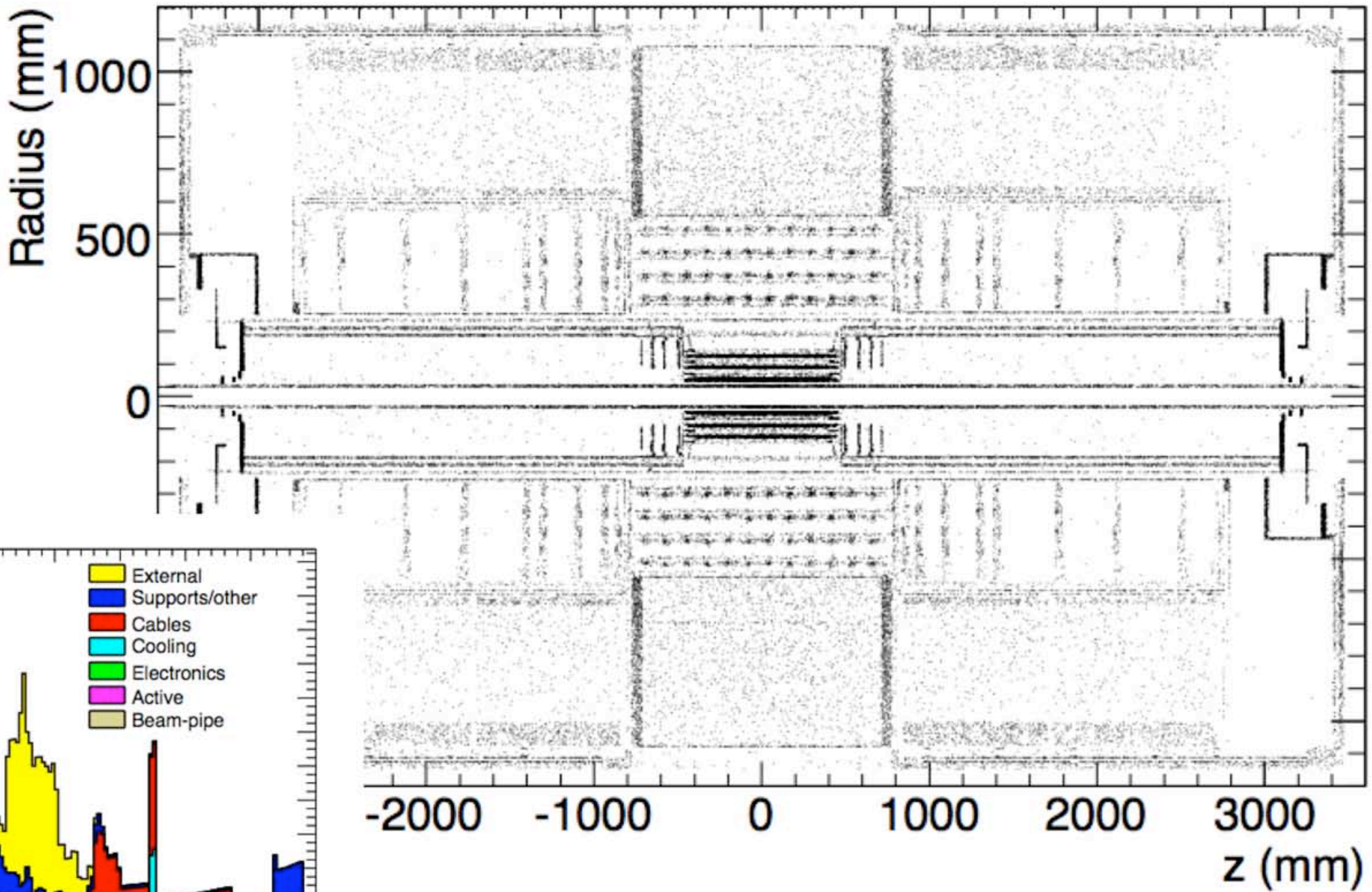
- 15K cosmic tracks reconstructed
- Achieved pixel noise occupancy below 10^{-9} per pixel/BCID. Very good!

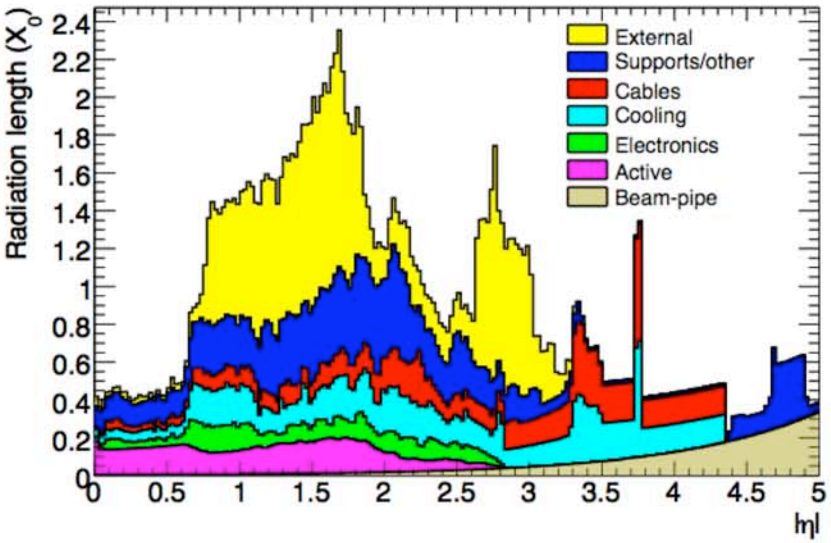




γ conversion challenge

~ 40% of all photons will convert to an e pair, before reaching the LAr cryostat



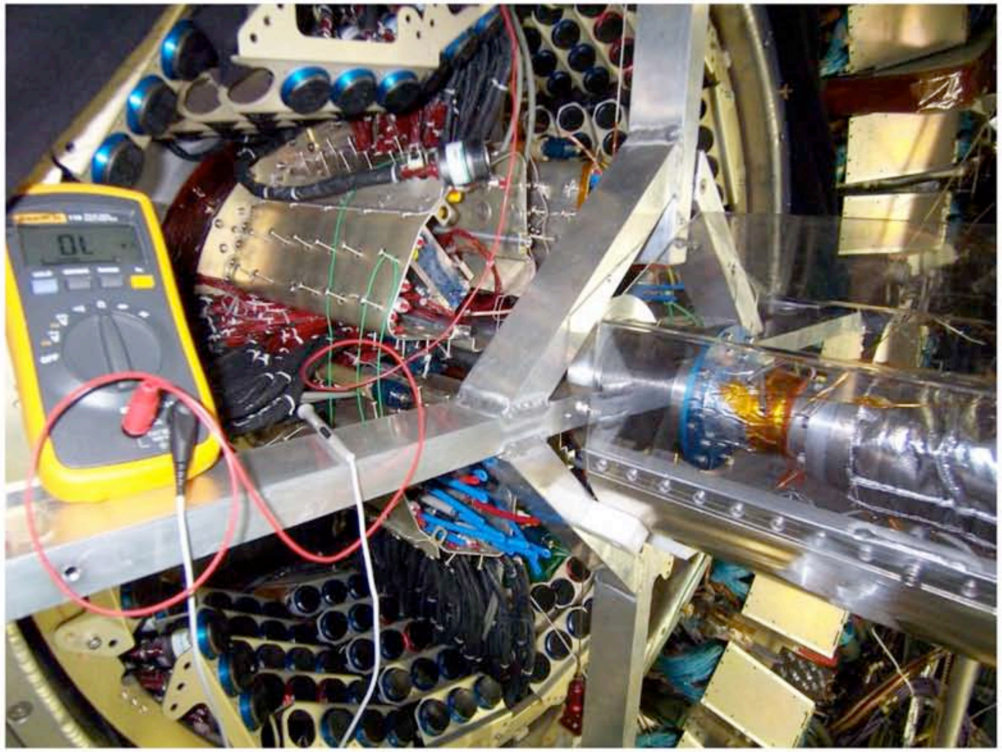


Mapping of photon conversion using π^o,η in 500000 minimum bias MC events

The beam vacuum pipe

The first three sections of the beam pipe have been installed and connected, and they passed the initial leak test

The two sections in the ECT bores are also installed, and the preparation of the other outer section is also well advanced



Installation of the ID beam pipe (with the Beryllium section) together with the Pixel package

Connection of the ID section to the LAr EC beam pipe section

Inner Detectors status

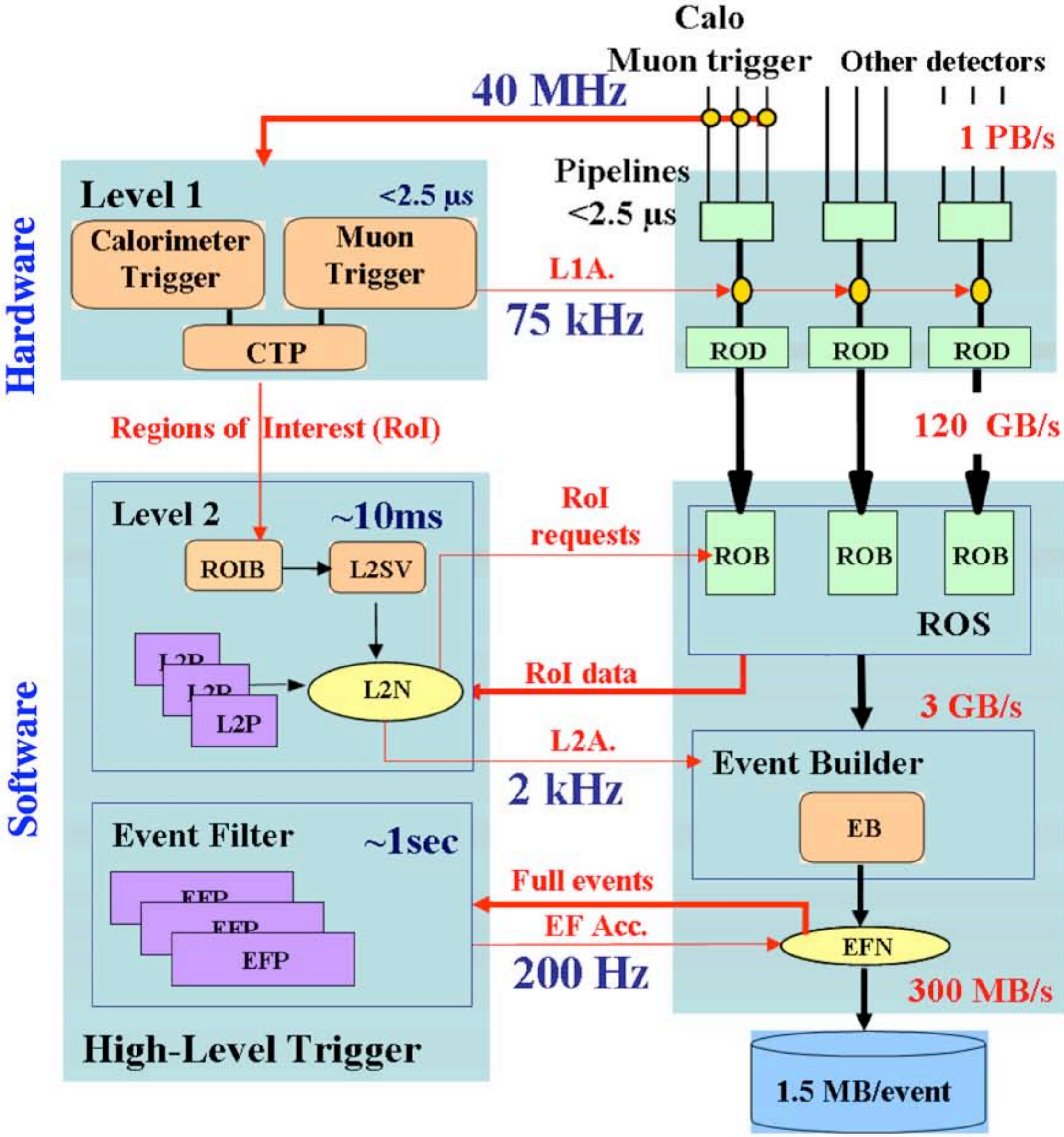
- ✓ The central Solenoid is operational, the B-field is mapped and the required precision demonstrated
- ✓ All hardware installed, including all services, the TRT is fully signed off, the SCT is connected but we are waiting for the final cold tests. The Pixel detector is waiting to be finally connected and then activated
- ✓ We still have a problem to solve, related to some repairs in the Si cooling system, which is holding up the final closure of the detector
- ✓ The performance of this detector have been demonstrated in test beams and in cosmic runs. The number of problematic channels is low and well within the design figures

Trigger and Data Acquisition

Level 1 decision based on data from calorimeters and muon trigger chambers; synchronous at 40 MHz

Level 2 uses Regions of Interest identified by Level-1 (< 10% of full evnt) with full granularity from all detectors

Event Filter has access to full event and can perform more refined event reconstruction



Reduce rate from 40 MHz to 200Hz while retaining the rare, interesting events

Trigger and Data Acquisition

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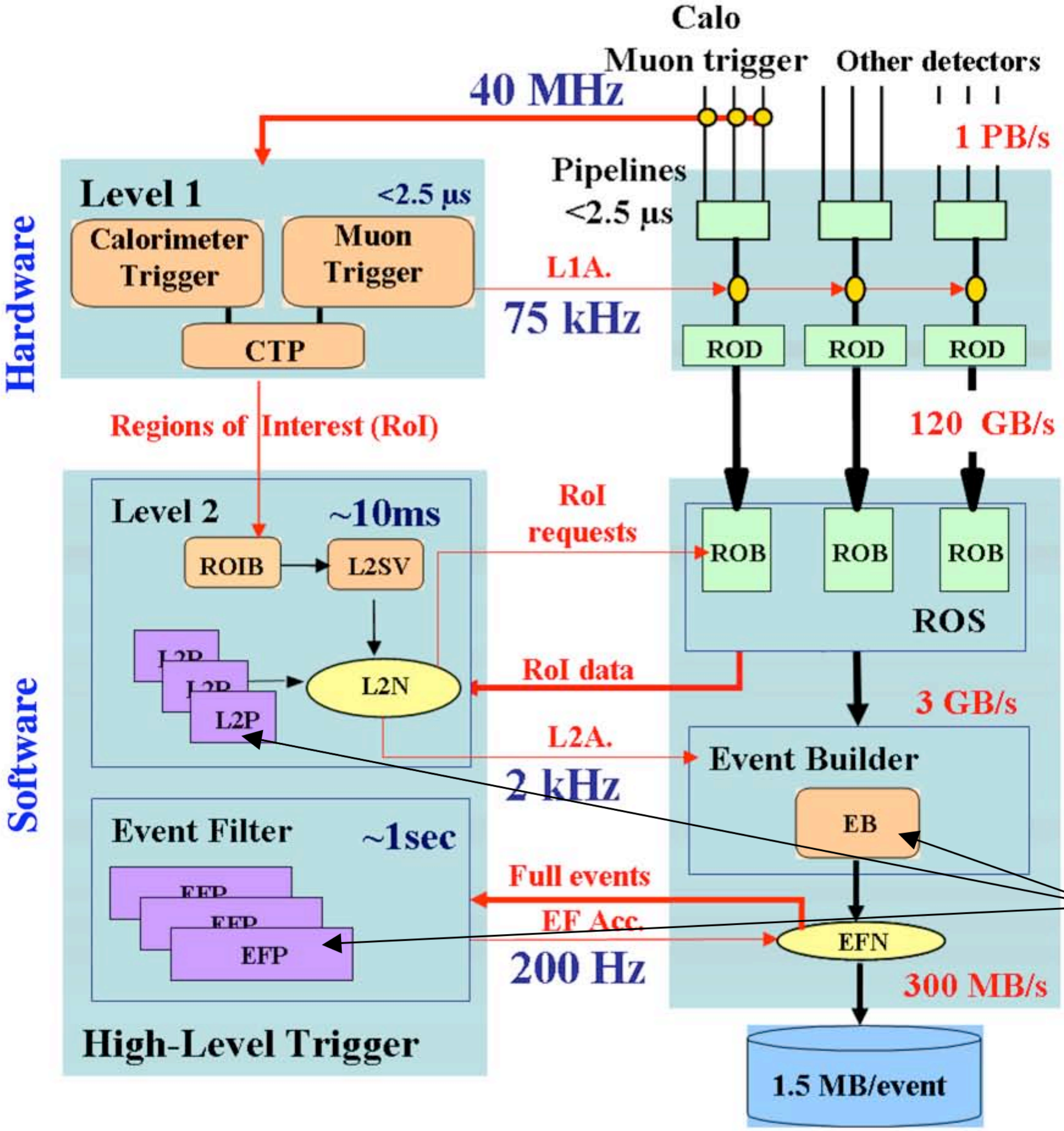


Reduce rate from 40 MHz to 200Hz while retaining the rare, interesting events

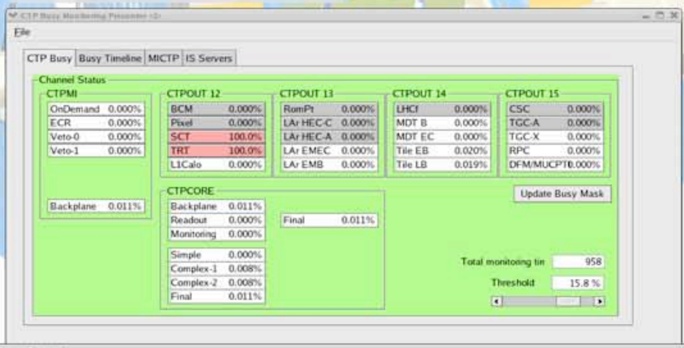
50% viable at LHC start-up for resource reasons

Run Control

ATLAS Control Room

Shifters and systems readiness

Trigger status



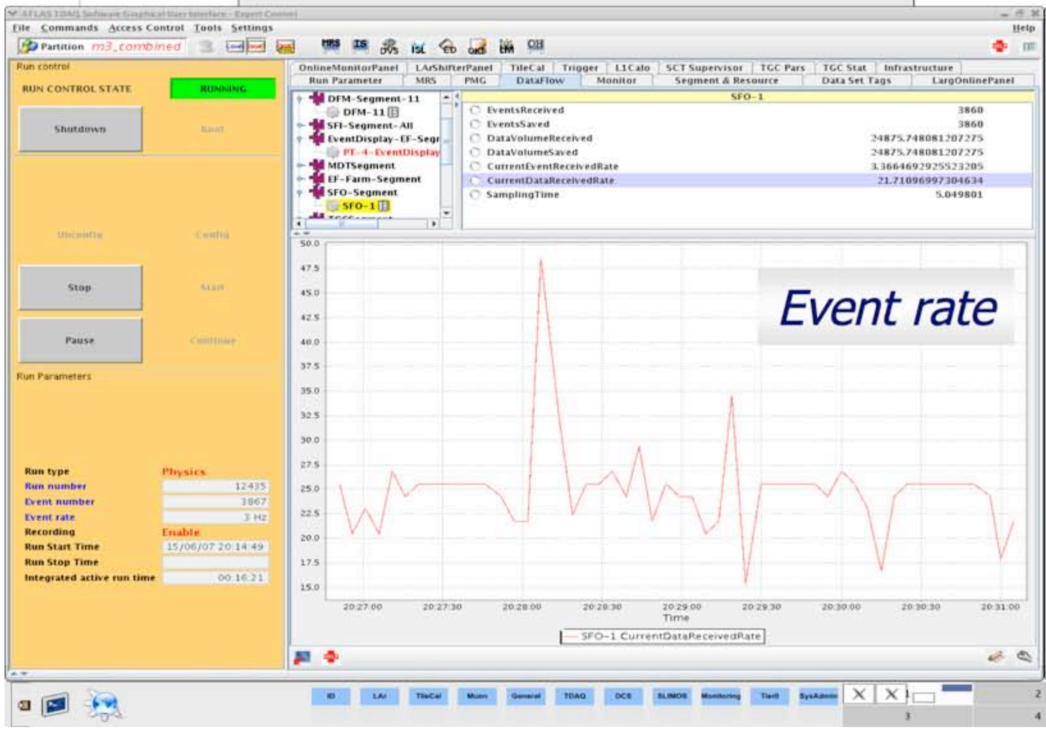
The M4 Commissioning Run (Aug 23 - Sep 03, 2007)

Essentially all detectors integrated

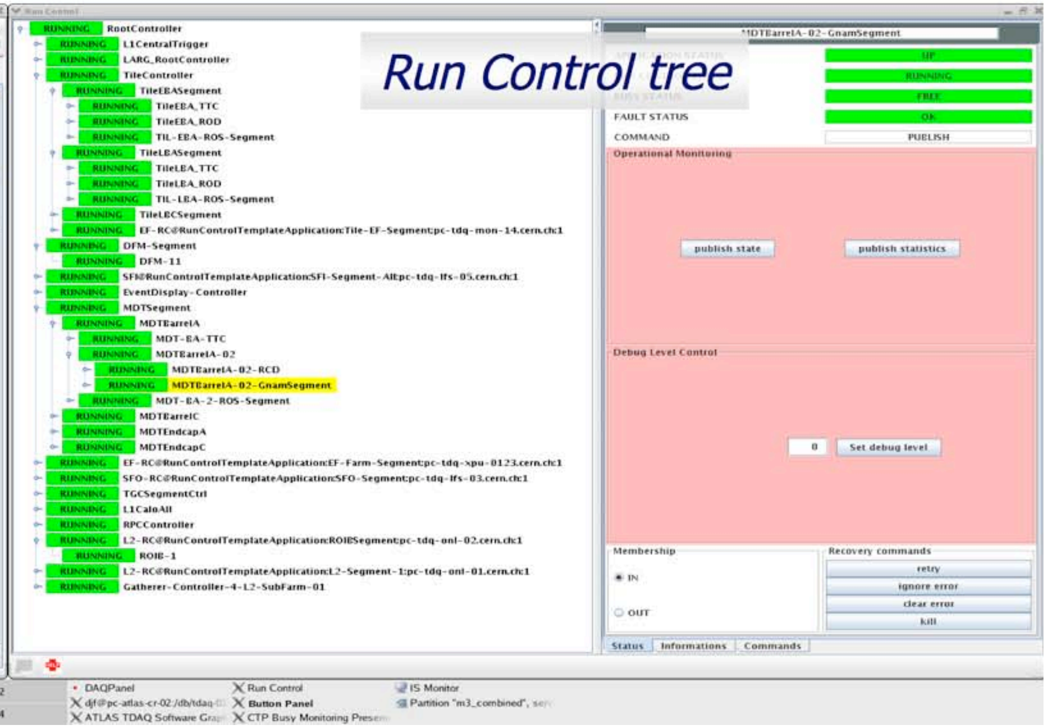
Full DAQ chain (up to Tier0)

Tile+RPC+TGC triggering on cosmics

Event rate



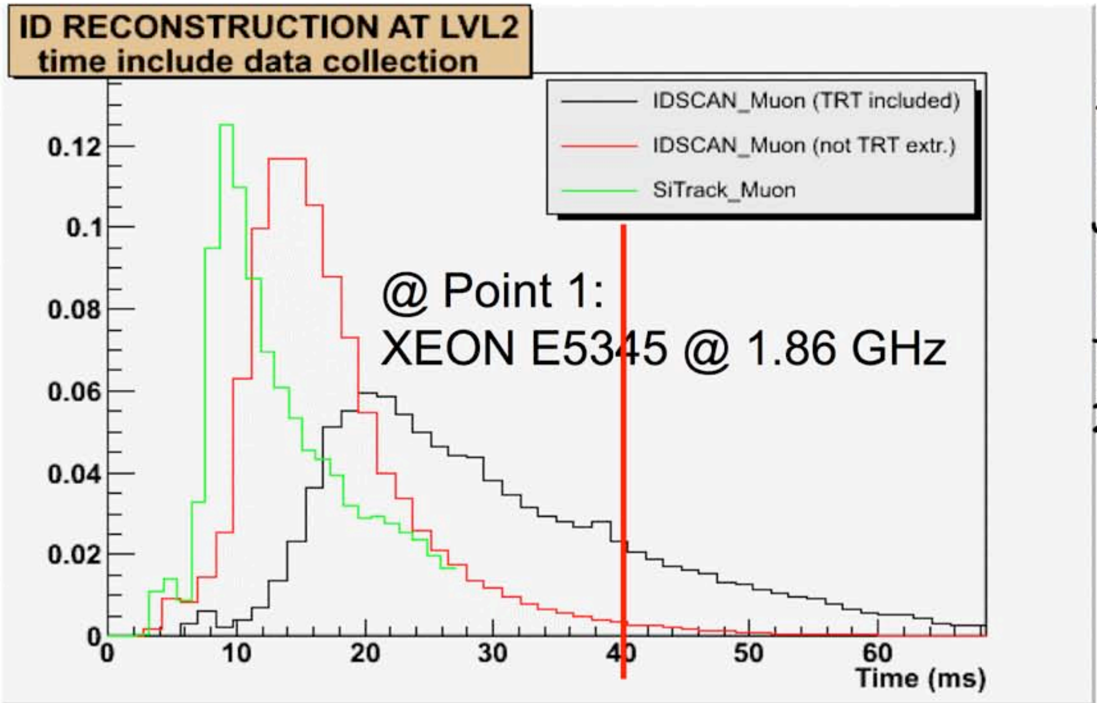
Run Control tree

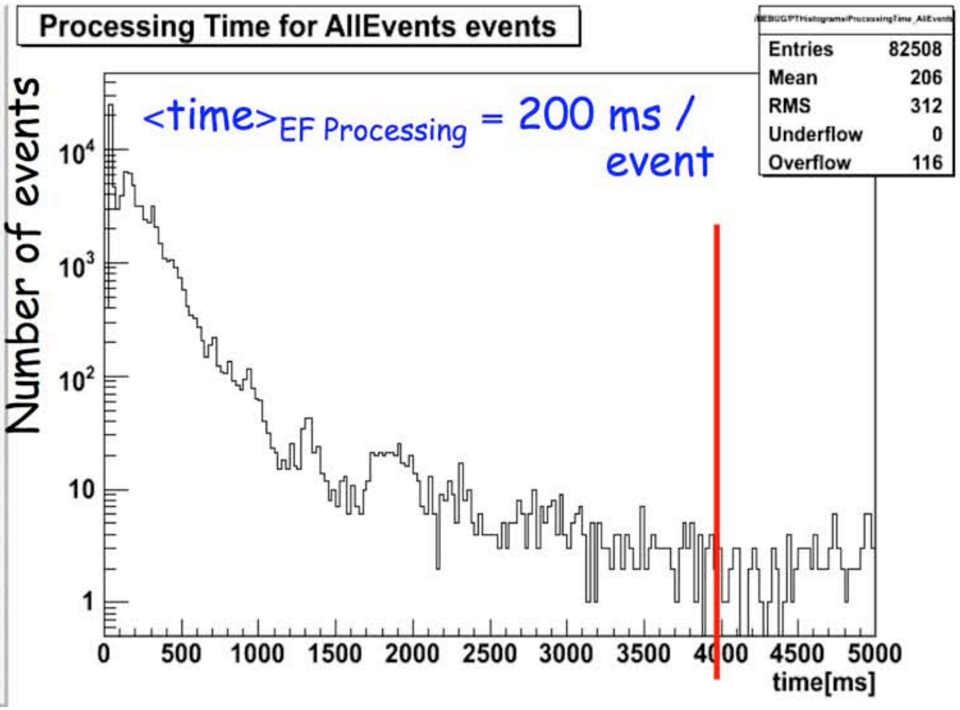


LVL2 & EB performance studies

- ✓ Trigger performance studies advancing well – main focus: signal efficiency, background rejection and algorithm execution time
- ✓ Algorithms from all slices are tested continuously online with cosmic ray events and by playing back pre-loaded simulated physics events
- ✓ Timing measurements are consistent with projections in the TDR (40ms/event LVL2, 4s/event EF on 2 GHz machines)

  -> Examples of algorithm timing for simulated tau and jet event samples





LHC delivery guess !!

Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μrad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ^* (μm, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	**6×10^{30}-10^{32}**	**10^{32}-10^{33}**	**$(1-2) \times 10^{33}$**	**10^{34}**

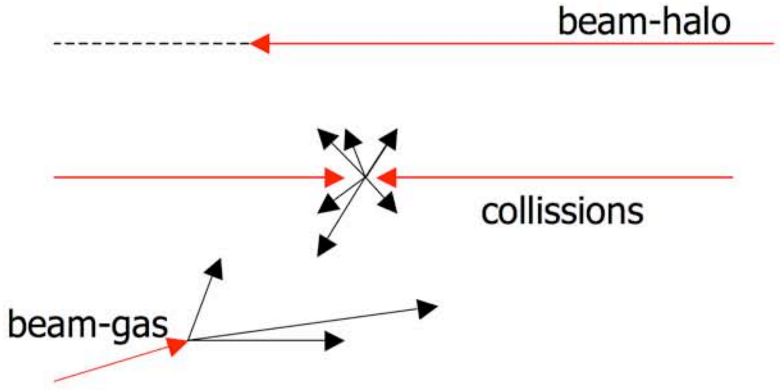
Year ? (present schedule) $\int$ Ldt ? (guess)	2008 up to 100 pb^{-1}	2009 1-few fb^{-1}	2009-2010 O(10 fb^{-1})	> 2010 O(100 fb^{-1})

LHC delivery guess !!

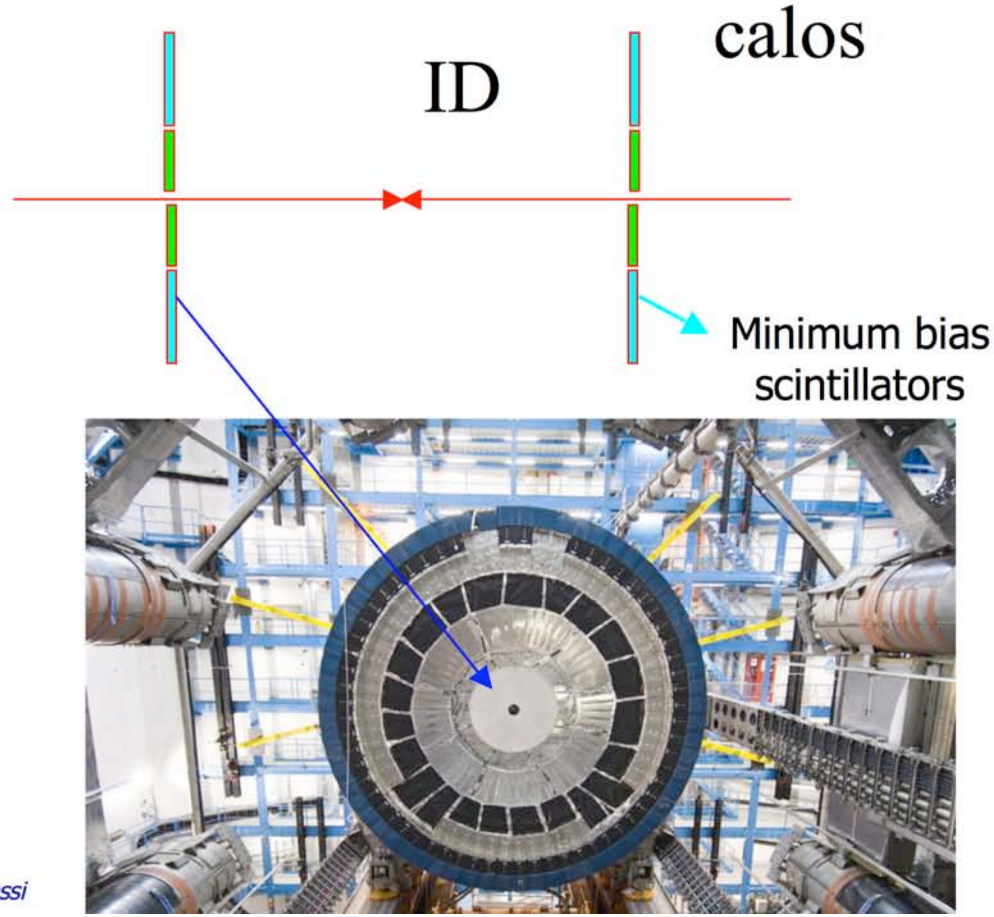
Sub-phase	Bunches	Bun. Int.	β*	Luminosity	Time	Int lumi
First Collisions	1 x 1	4×10^{10}	17 m	1.6×10^{28}	12 hours	0.6 nb^{-1}
Repeat ramp	-	-	-	-	2 days @ 50%	1.2 nb^{-1}
Multi-bunch at injection & through ramp -collimation	-	-	-	-	2 days	-
Physics	12 x 12	3×10^{10}	17 m	1.1×10^{29}	2 days @ 50% in physics	6 nb^{-1}
Physics	43 x 43	3×10^{10}	17 m	4.0×10^{29}	2 days @ 50% in physics	30 nb^{-1}
Commission squeeze	-	-	-	-	2 days	-
Measurements squeezed	-	-	-	-	1 day	-
Physics	43 x 43	3×10^{10}	10 m	7×10^{29}	3 days - 6 hr t.a. - 70% eff.	75 nb^{-1}
Squeeze to 2m.	-	-	-	-	3 days	-
Physics	43 x 43	3×10^{10}	2 m	3.4×10^{30}	3 days - 6 hr t.a. - 70% eff.	0.36 pb^{-1}
Commission 156 x 156	-	-	-	-	1 day	
Physics	156 x 156	2×10^{10}	2 m	5.5×10^{30}	2 days - 6 hr t.a. - 70% eff.	0.39 pb^{-1}
Physics	156 x 156	3×10^{10}	2 m	1.2×10^{31}	5 days - 5 hr t.a. - 70% eff.	2.3 pb^{-1}
					28 days total	

M. Lamont AB/OP presentation to ATLAS

First make sure we will see collisions…



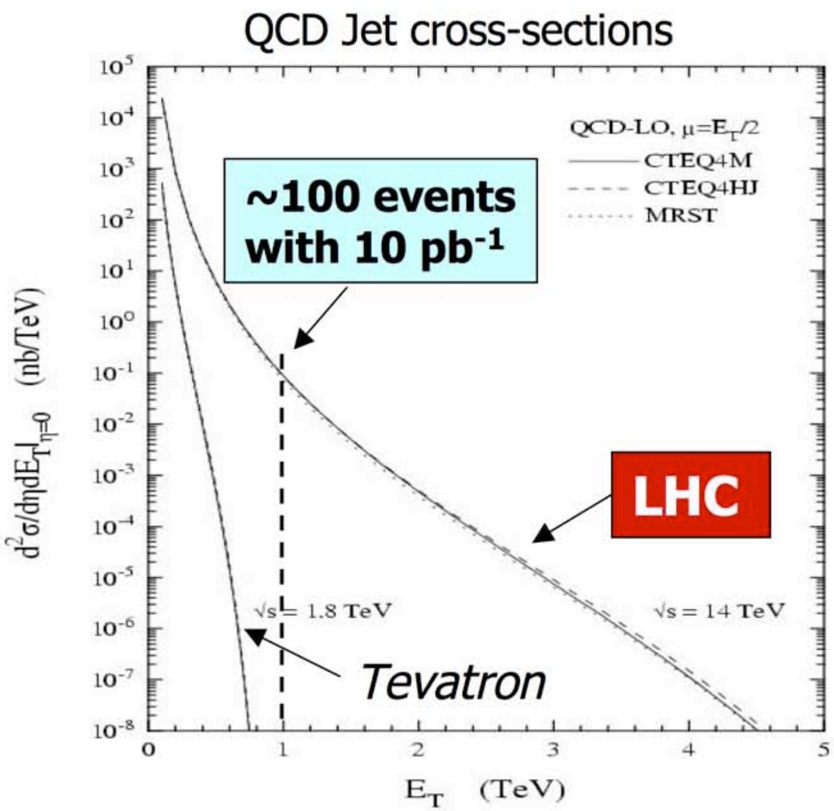
Just to make sure not to miss this moment we have instrumented ATLAS with an array of scintillators which cover the end plates region of the ID (η,ϕ granularity)

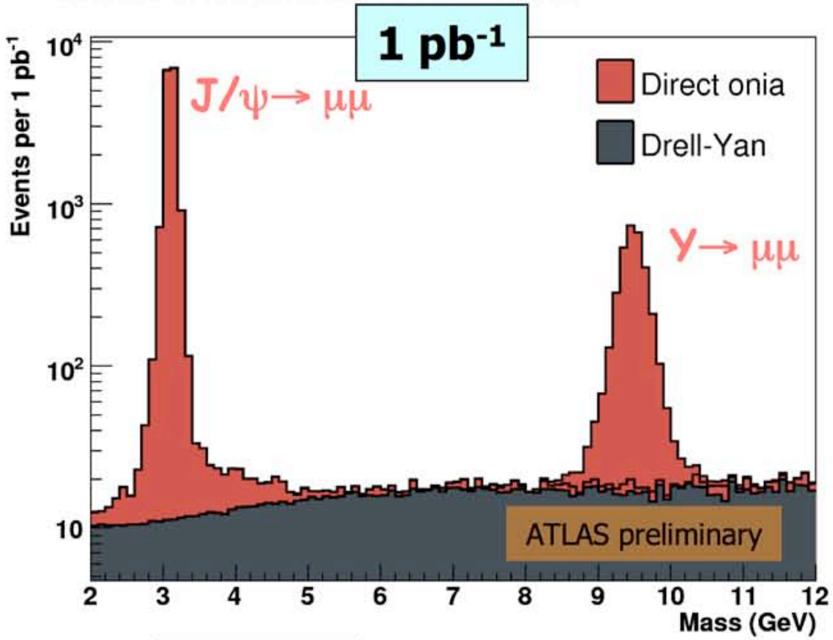


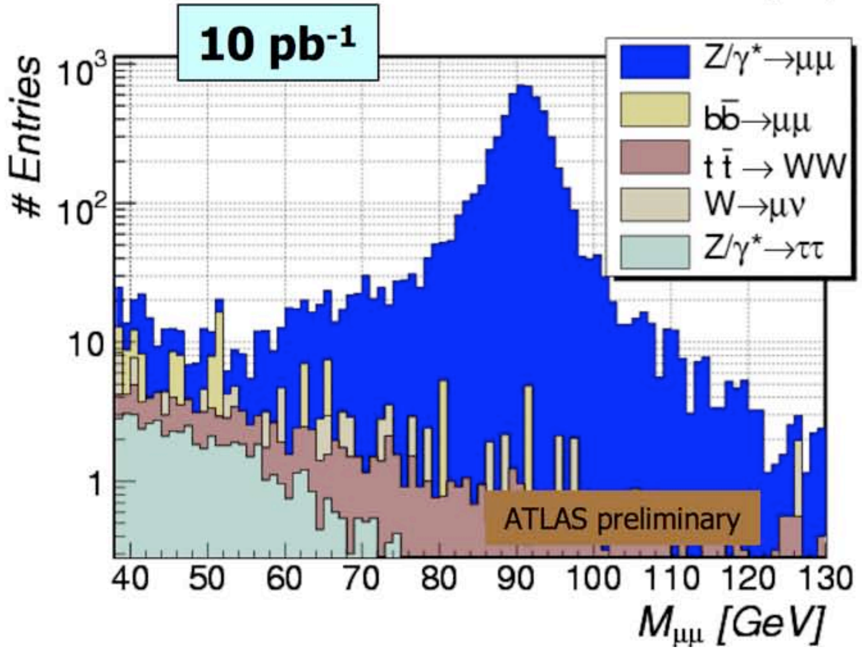
Discriminate real beam collisions from beam-halo interaction, beam-gas interactions upstream of IP

Make use of first beams to synchronize the readout and the trigger and associate to each event the right beam crossing identification

... then look for the first physics







What about Top Physics

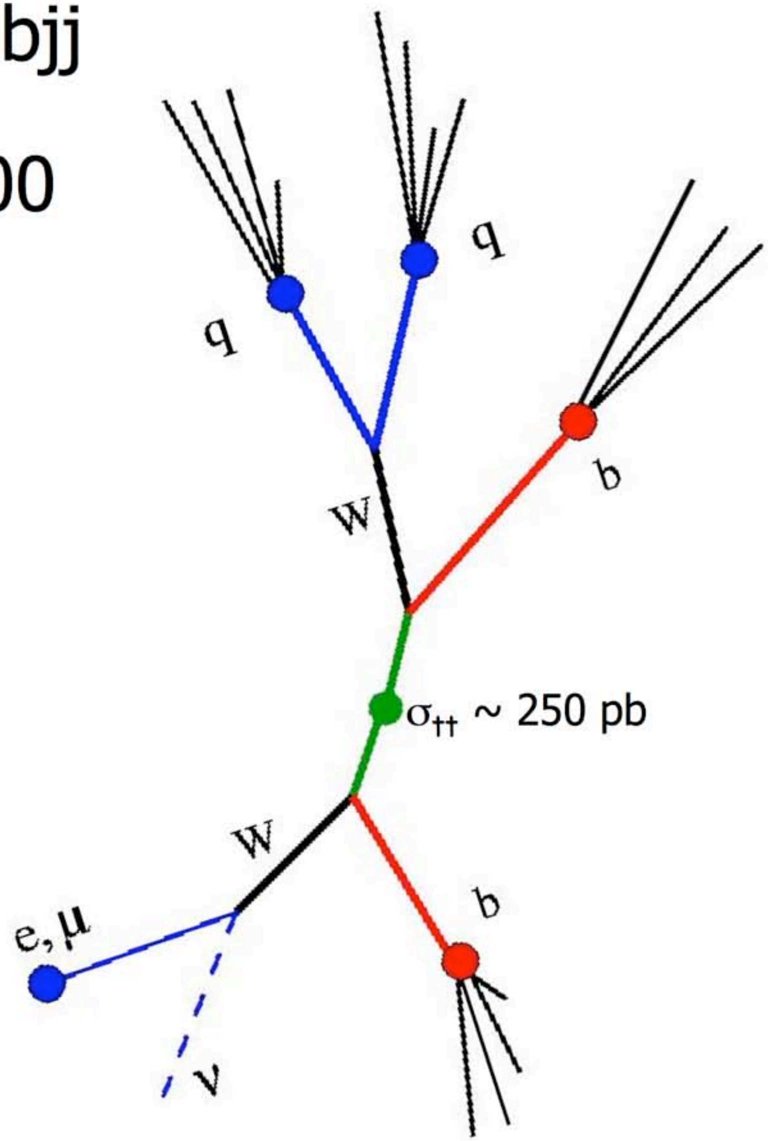
$\sigma_{tt} \approx 250$ pb for $tt \rightarrow bW\ bW \rightarrow bl\nu\ bjj$

Note: σ_{tt}(LHC)/σ_{tt}(Tevatron)~100

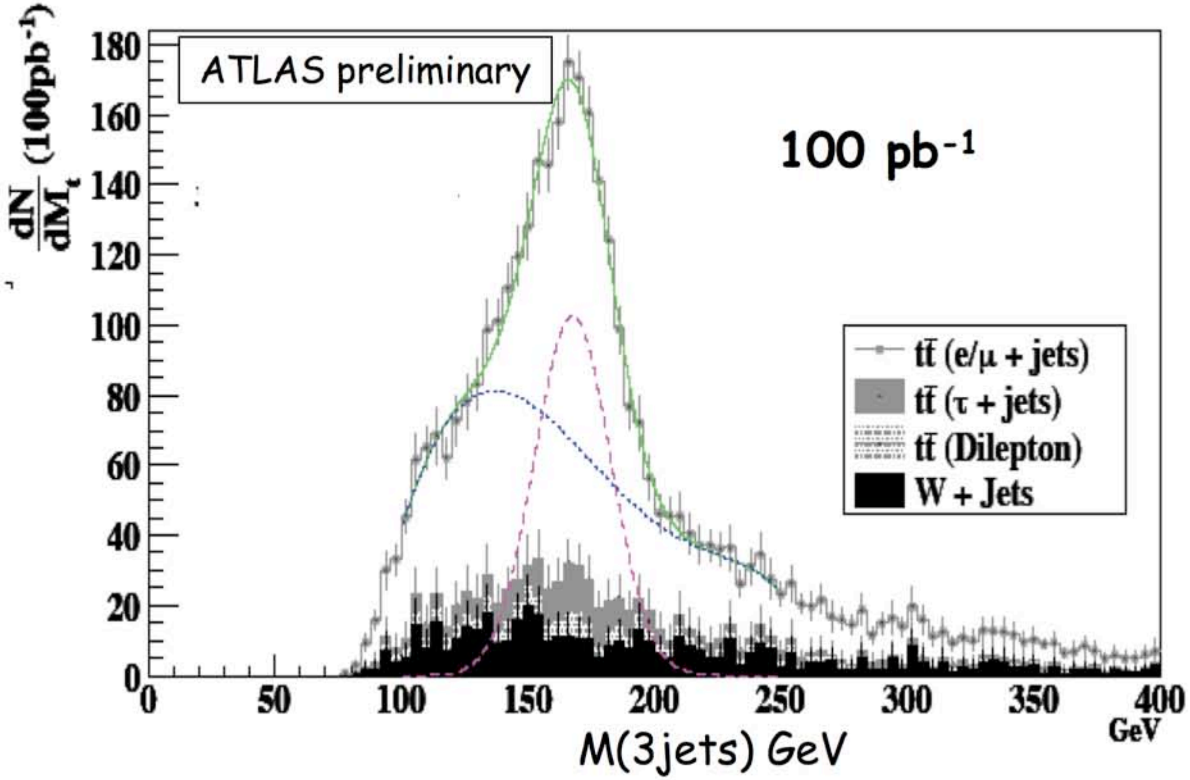
✓ *use <u>simple and robust</u> selection cuts:*

p_T (l) > 20 GeV
E_T^{miss} > 20 GeV
only 3 jets with p_T > 40 GeV
1 jet with p_T > 20 GeV

✓ *<u>no b-tagging required</u> (too early to begin with …)*



What about Top Physics



Invariant mass of the 3 jets with largest $\sum p_T$

(~1000 evts for 30 pb^{-1})

→ measure σ_{tt} to ~20%

This will represent a fantastic sample to

- *commission b tagging*
- *calibrate the jet energy scale using $W \rightarrow jj$ peak*
- *tune various MC generators (e.g. using P_T spetra)*

…Then we will go step by step

Goal # 1 Understand and calibrate detector and trigger in situ, using well-known physics samples

e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, e-ID, Muon chambers calibration/alignment, …
- $t\bar{t} \to bl\nu\ bjj$ jet scale from $W \to jj$, b-tag performance, etc.

Understand basic SM physics at $\sqrt{s}$ = 14 TeV --> first tuning of Monte Carlo

Main candles: W, Z, tt, minimum bias, QCD jets
e.g. - measure cross-sections (initially to ~ 20 %),
look at basic event features, first constraints of PDFs, etc.
- measure top mass (to ~ 7 GeV) → give feedback on detector performance
Note : statistical error negligible after a few weeks of run

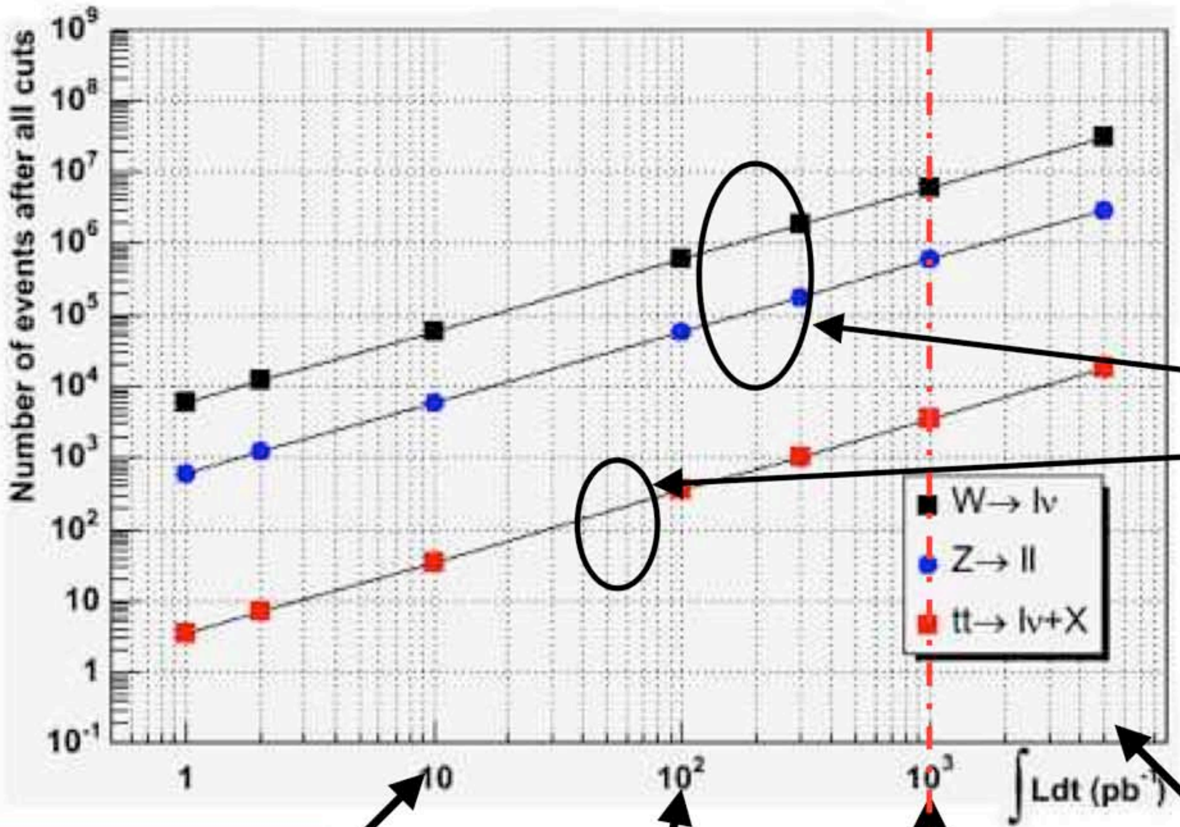
it will take time

Goal # 2 Prepare the road to discovery:
measure backgrounds to New Physics : e.g. tt and W/Z+ jets (omnipresent …)

Goal # 3 Look for New Physics potentially accessible in first year(s)
(e.g. $Z' \to ee$, SUSY, some Higgs ? …)

W, Z, tt, jets samples @ 1 fb^{-1}

ATLAS project



+ > 10^6-10^7 minimum bias and QCD jets p_T> 150 GeV (if 1% of trigger bandwidth)

similar statistics to CDF, D0 today

l ≡ e or μ

10 pb^{-1} ≡ 1 month at 10^{30} + 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ a few days at 10^{32} , ε=50%

1 fb^{-1} ≡ 6 months at 10^{32}, ε=50%

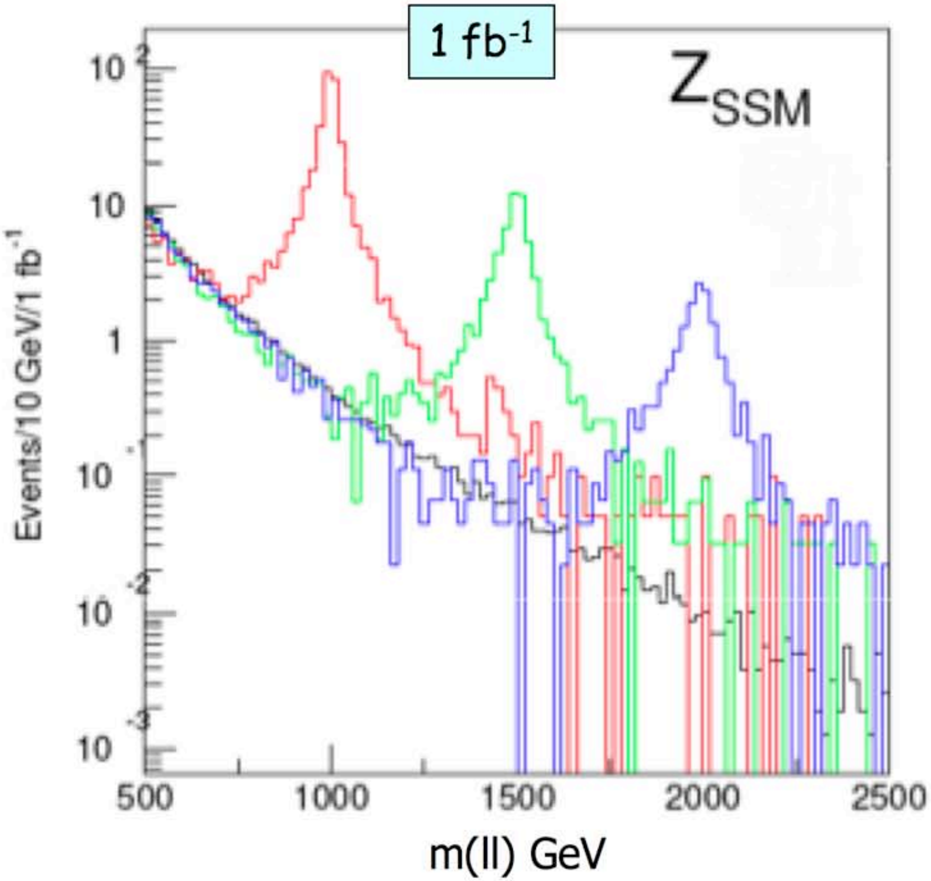
5 fb^{-1} ≡ 3 months at 10^{32} + 3 months at 10^{33}, ε=50%

mid-end 2009 ?

What about new physics ~ 1 fb^{-1} ?

1 $fb^{-1} \equiv$ 6 months at 10^{32}, ε=50%

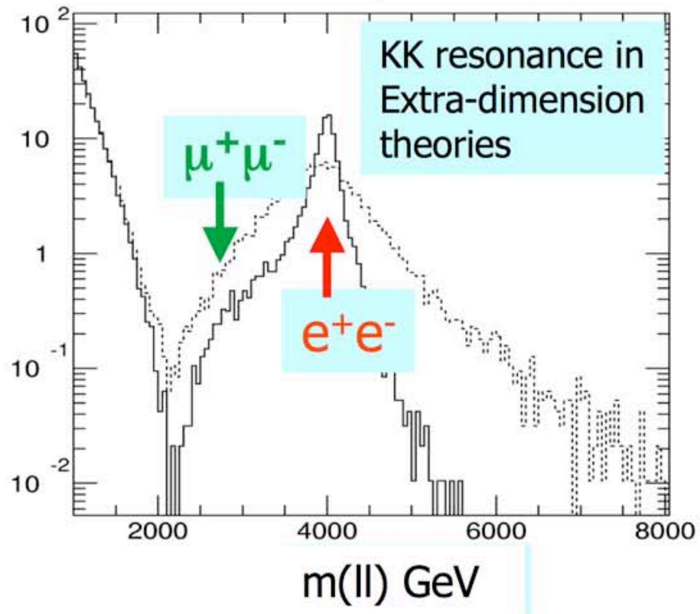
Easiest …. Heavy di-Lepton Resonances



$Z' \rightarrow e^+e^-$ with SM-like couplings (Z_{SSM})

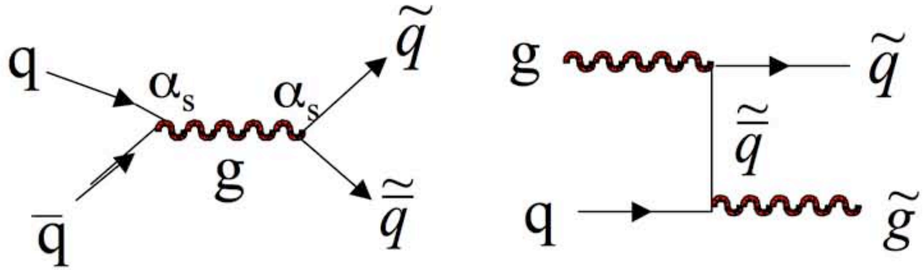
Mass	#events for 1 fb^{-1} (after all cuts)	discovery Lum. (10 observed evts)
1 TeV	~ 160	~ 70 pb^{-1}
1.5 TeV	~ 30	~ 300 pb^{-1}
2 TeV	~ 7	~ 1.5 fb^{-1}

Ultimate ATLAS reach (300 fb^{-1}): ~ 5 TeV



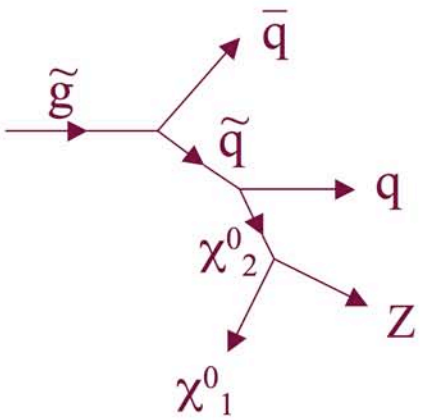
What about SUSY discovery < 1 fb^{-1} ?

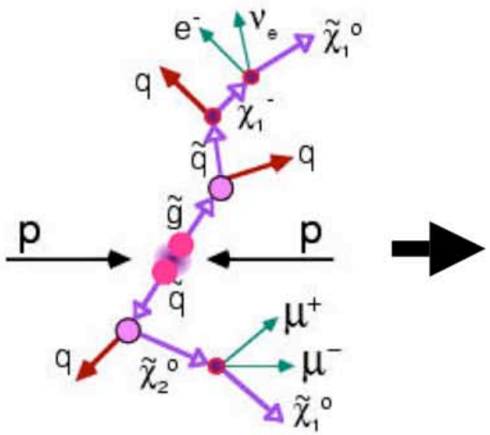
Squarks and gluinos produced via strong processes → large cross-section



M(TeV)	σ(pb)	Ev/fb^{-1}
0.5	100	10^5
1.0	1	10^3
2.0	0.01	10

$\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ production are dominant SUSY processes at LHC, if accessible





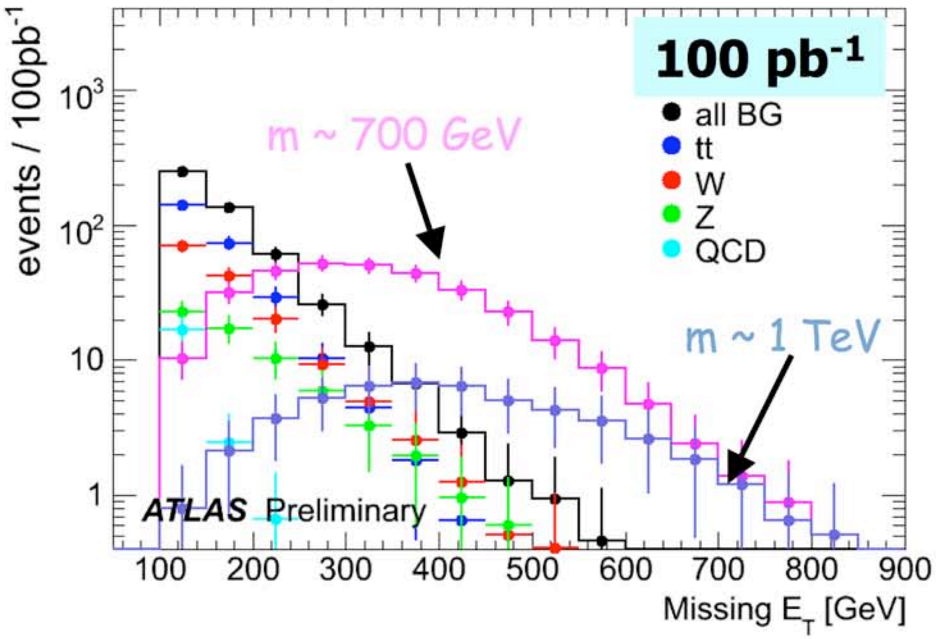
→ **spectacular signatures**
(many jets, missing transverse energy, leptons)

For $m(\tilde{q},\tilde{g}) \sim 1$ TeV
expect 10 evts/day at L=10^{32}

What about SUSY discovery < 1 fb^{-1} ?

Finding the signal already at 100 pb^{-1} should not be a problem

→ **the problem is to be sure it is real**



… very difficult BG

- W/Z + jets with $Z \to \nu\nu$, $W \to \tau\nu$; tt; etc.
- QCD multijet events with fake ETmiss from jet mis-measurements (calorimeter resolution and non-compensation, cracks, …)
- cosmics, beam-halo, detector problems overlapped with high-p_T triggers, …

How to clean the sample?

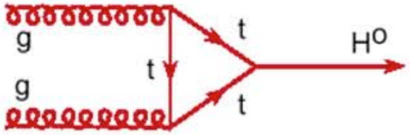
✓ at least 2-3 jets with p_T>100 GeV, E_T^{miss} > 100 GeV
✓ good event vertex
✓ no jets in detector cracks
✓ p_T^{miss} vector not pointing along or opposite to a jet in transverse plane

Hints with only 100 pb^{-1} up to m~1 TeV, but understanding backgrounds requires ~1 fb^{-1}

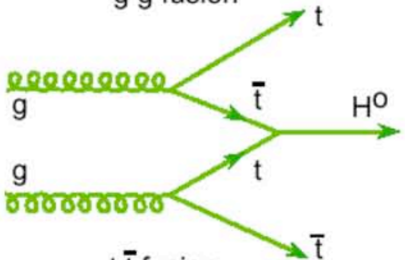
We will need to control our enthusiasm

… and finally the Higgs

- m_H < 120 GeV: H → bb dominates
- 130 GeV < m_H < 2 m_Z : H → $WW^{(*)}$, $ZZ^{(*)}$
- m_H > 2 m_Z : 1/3 H → ZZ , 2/3 H → WW
- important rare decays : H → γγ

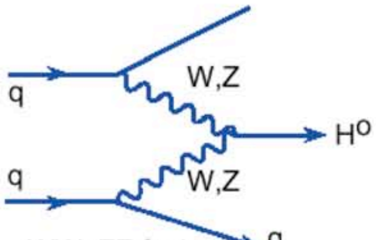


g g fusion

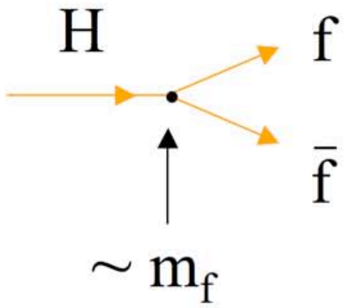


t t̄ fusion

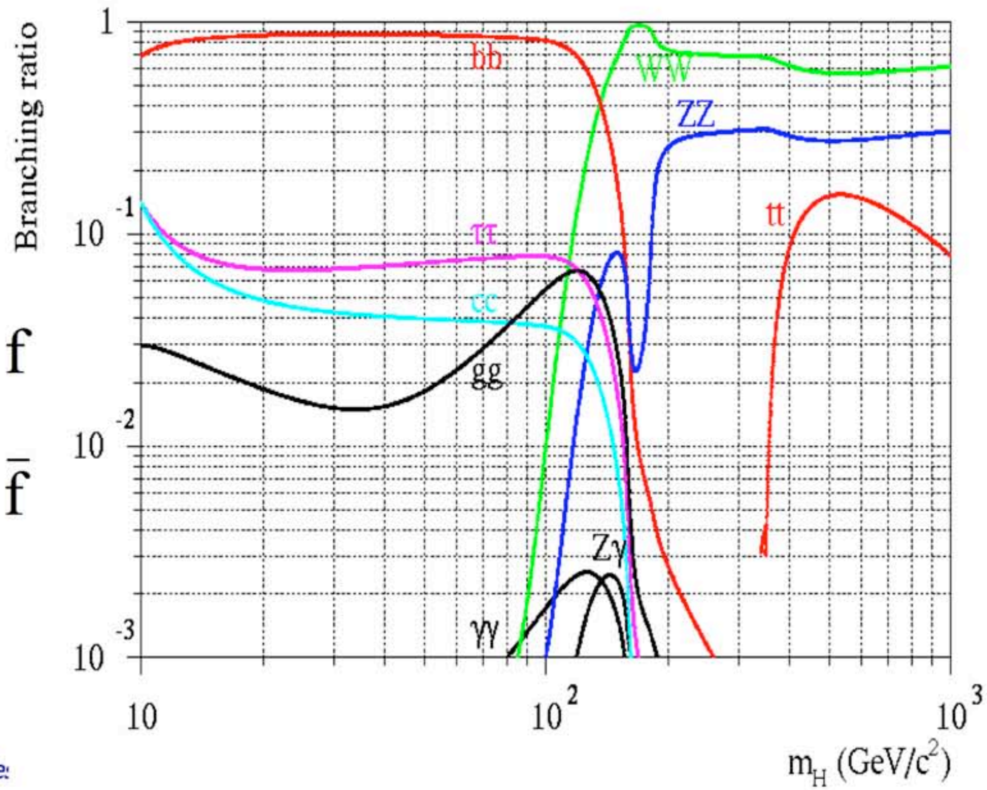
W, Z bremsstrahlung



WW, ZZ fusion

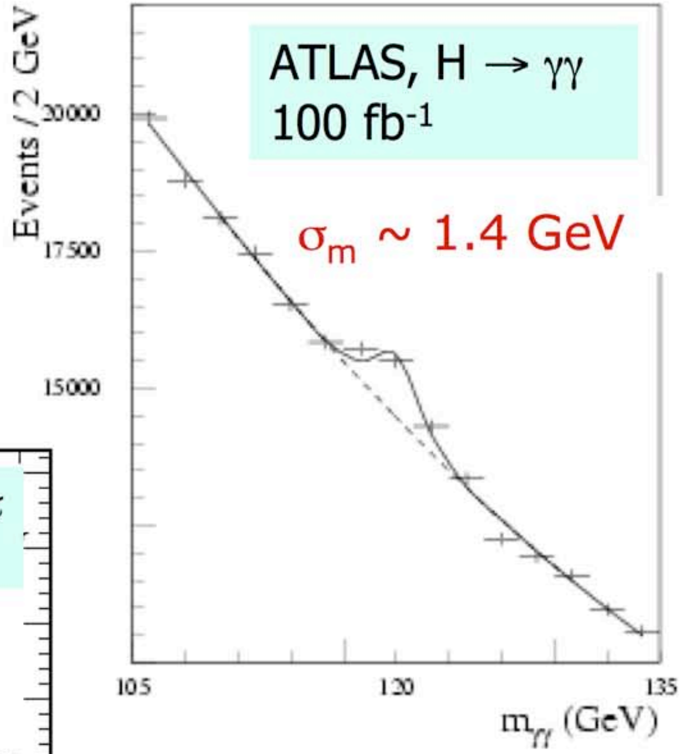


N. B.: $\Gamma_H \sim m_H^3$

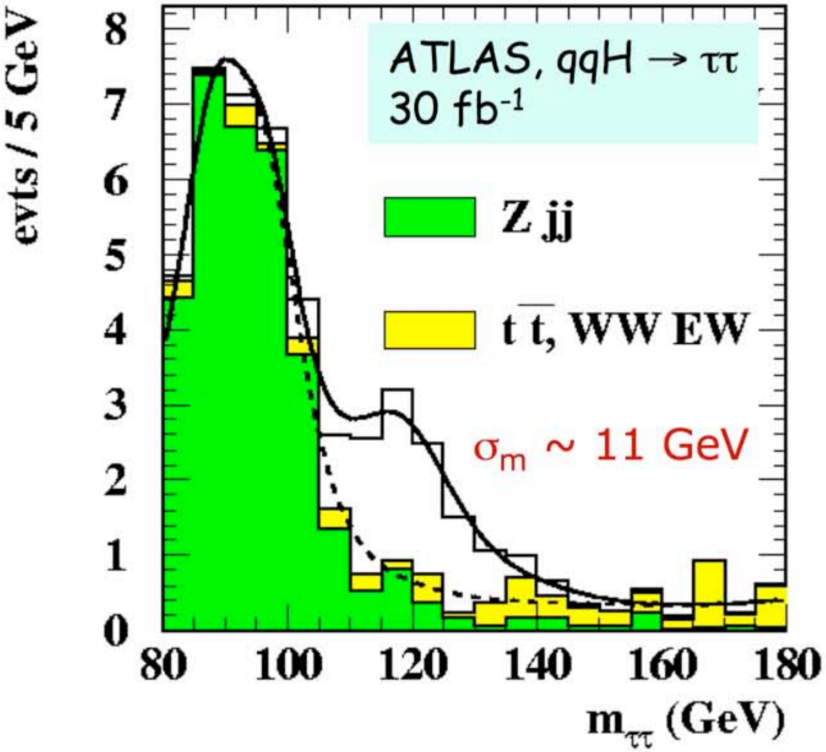


A light Higgs will not be easy at the beginning

$m_H \sim 120$ GeV



It will need a perfectly understood detector in terms of photon identification, tracking, ….



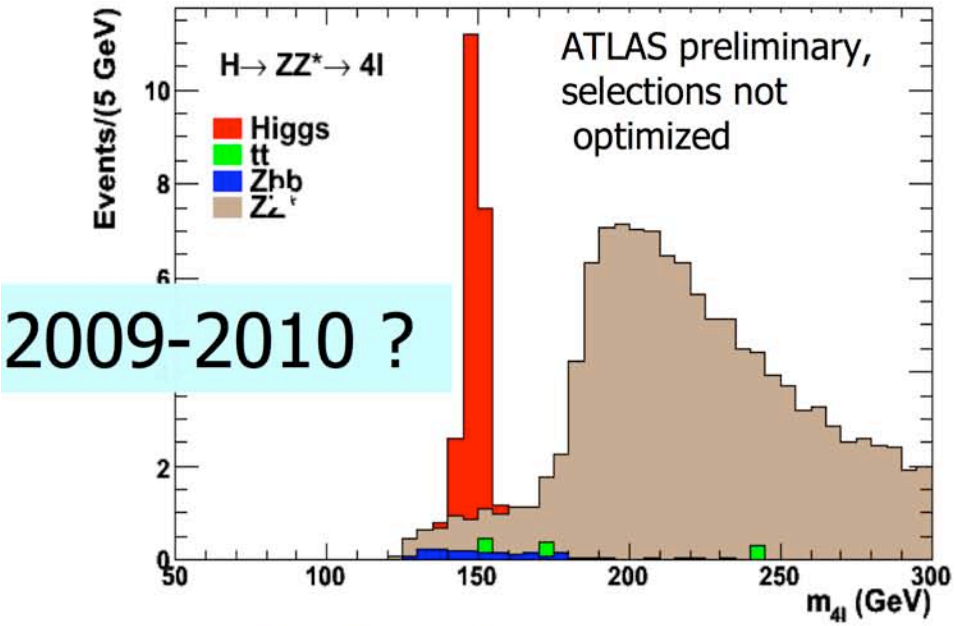
BG dominated by irreducible components

2010 ?

$M_H > 130$ … is easier

$m_H > 130$ GeV : $H \rightarrow ZZ^{(*)} \rightarrow 4l$ (gold-plated), $H \rightarrow WW^{(*)} \rightarrow l\nu\, l\nu$

$H \rightarrow ZZ^* \rightarrow 4l$, 10 fb^{-1}



May be observed with 3-4 fb^{-1}

$H \rightarrow 4l$: low-rate but very clean : narrow mass peak, small background

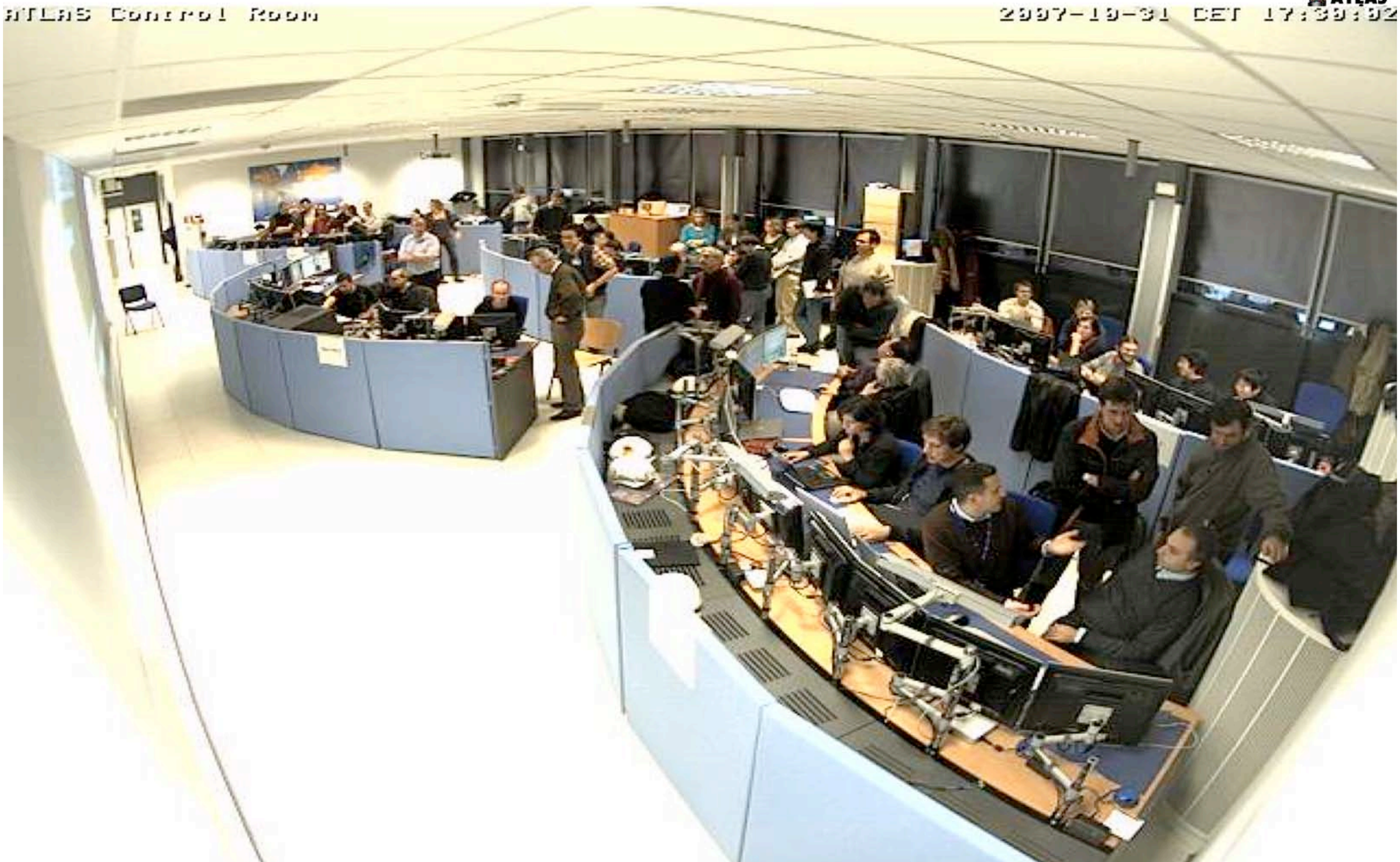
- requires:
  - ~ 90% e, μ efficiency at low p_T
  - $\sigma/m \sim 1\%$, tails < 10% → good quality of E, p measurements in ECAL and tracker
- background dominated by irreducible ZZ production (tt and Zbb rejected by Z-mass constraint, and lepton isolation and impact parameter)

$H \rightarrow WW \rightarrow l\nu l\nu$: high rate (~ 100 evts/expt) but no mass peak

→ not ideal for early discovery …

Conclusion

- ✓ The ATLAS detector is there. The last few % of the work are the most difficult ones. Still a technical problem to be fully solved related to the cooling of the Si inner detectors where we have to pay major attention
- ✓ We see now how important it has been to invest in 12-15 years in test beams. We have cumulated an important knowledge of the various detector parts in terms of performance and operation
- ✓ Thanks God for having invented the universe. The cosmic rays are a very powerful debugging/calibration tool for the ATLAS detector
- ✓ We have a clear idea on how to organize ourselves during the first months of beam, we know what needs to be done to prepare the detector for major discoveries (in situ calibration, in situ alignment, BG studies, trigger studies,.....)
- ✓ Give us beam, and you will not be disappointed!


ATLAS Control Room
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