Status of the ATLAS Detector and results from commissioning with cosmic rays and single beams

L. Hervas, CERN, Geneva
On behalf of the ATLAS Collaboration

LHC → ATLAS

Inner detector → Calorimeters → Magnets → Muon system

Global Commissionin → Perspective

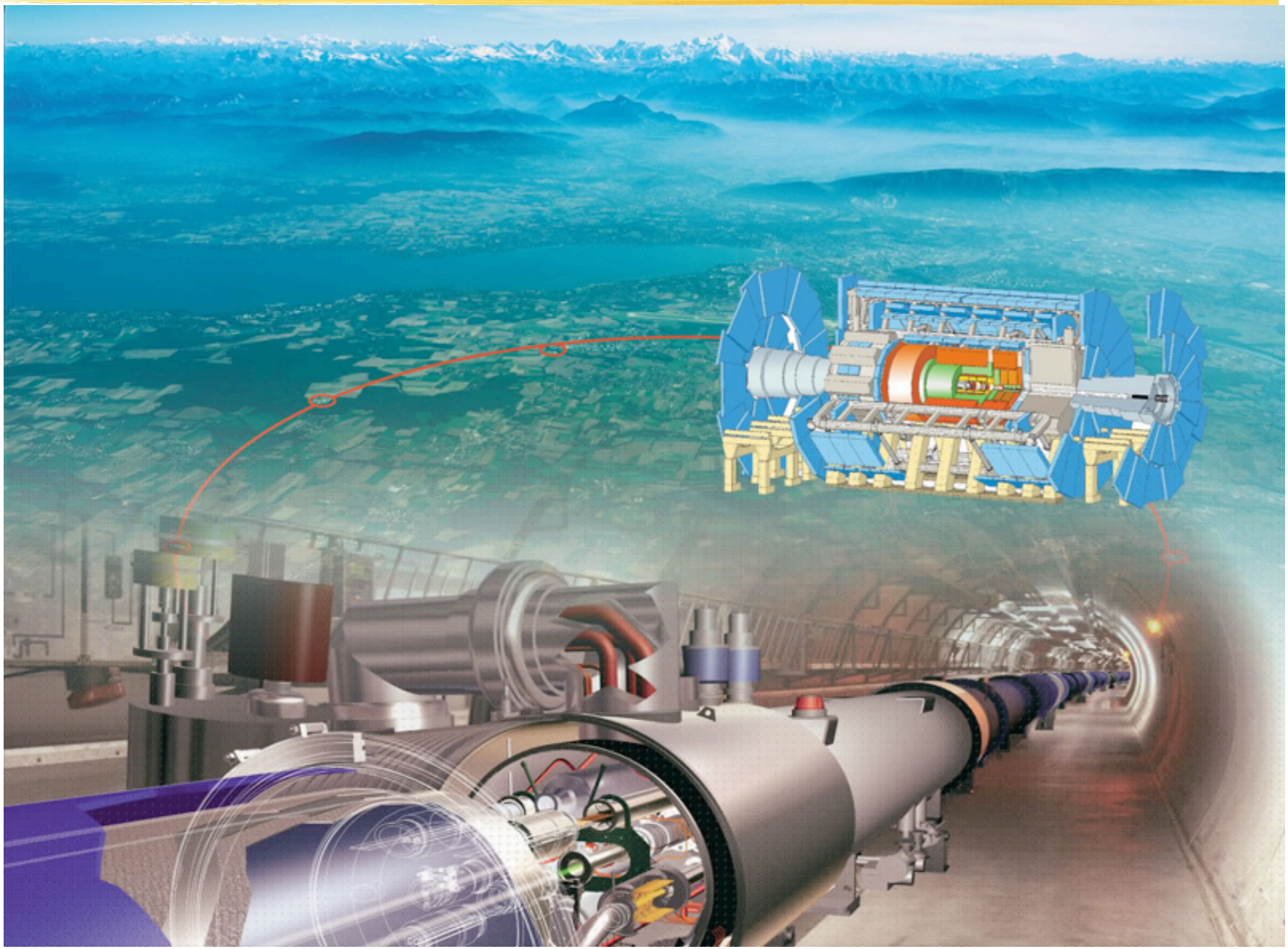
HEP-MAD 22.8.2009

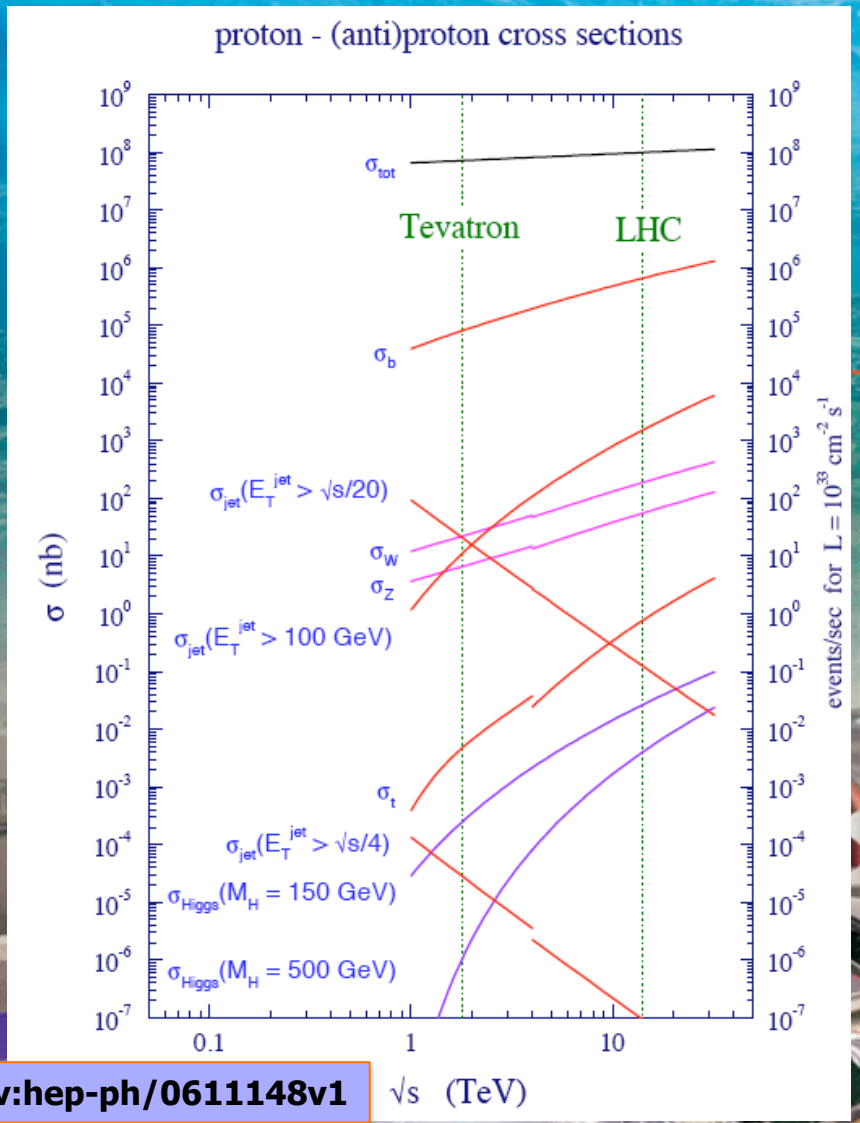
Large number of co-workers

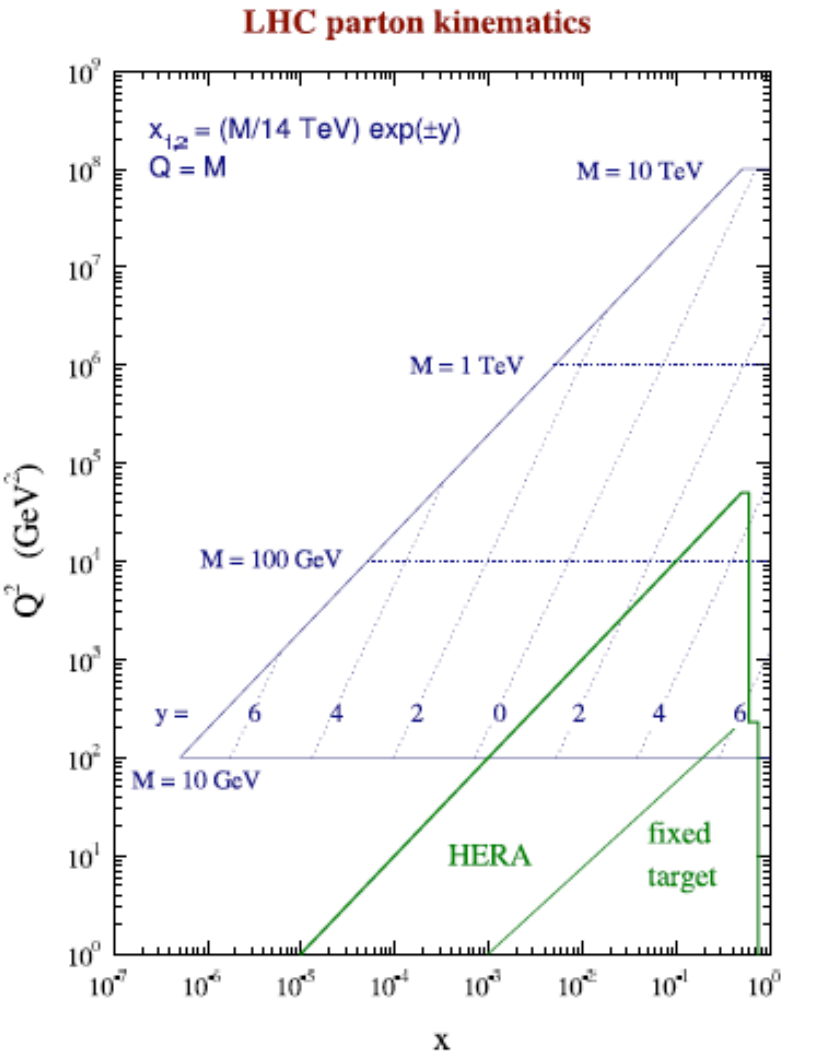
Part of the ATLAS collaborators at Building 40 at CERN

Large number of Institutions

L. Hervas (CERN)







arXiv:hep-ph/0611148v1

In a new x,Q^2 regime

Cross-sections essentially one order of magnitude beyond Tevatron

ATLAS project

proton - (anti)proton cross sections

LHC p

Challenge the Frontiers of the Standard Model

Road

1 fb-1
- ❖Higgs discovery sensitivity (M_H=130~500 GeV)
- ❖Explore SUSY to m ~ TeV
- ❖SM Precision measurements

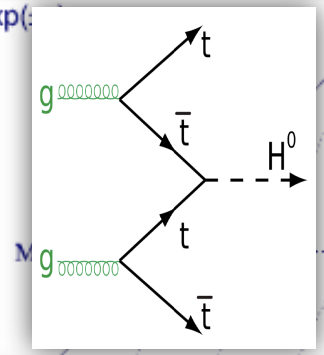
14 TeV

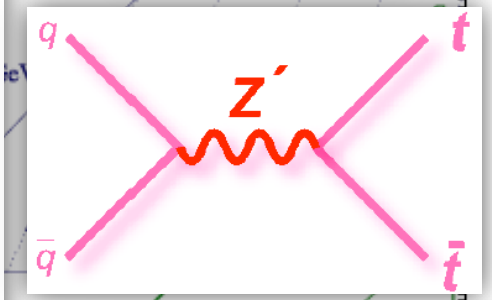
100 pb-1
- ❖Understand SUSY and Higgs background from SM
- ❖More accurate alignment & EM/Jet/ETmiss calibration
- ❖Early discoveries

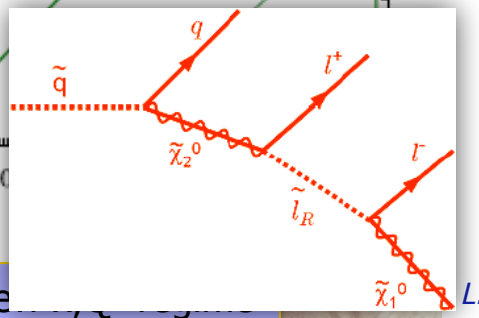
10 TeV

10 pb-1
- ❖Initial detector & trigger synchronisation, commissioning, calibration & alignment, material
- ❖Rediscover SM processes

time







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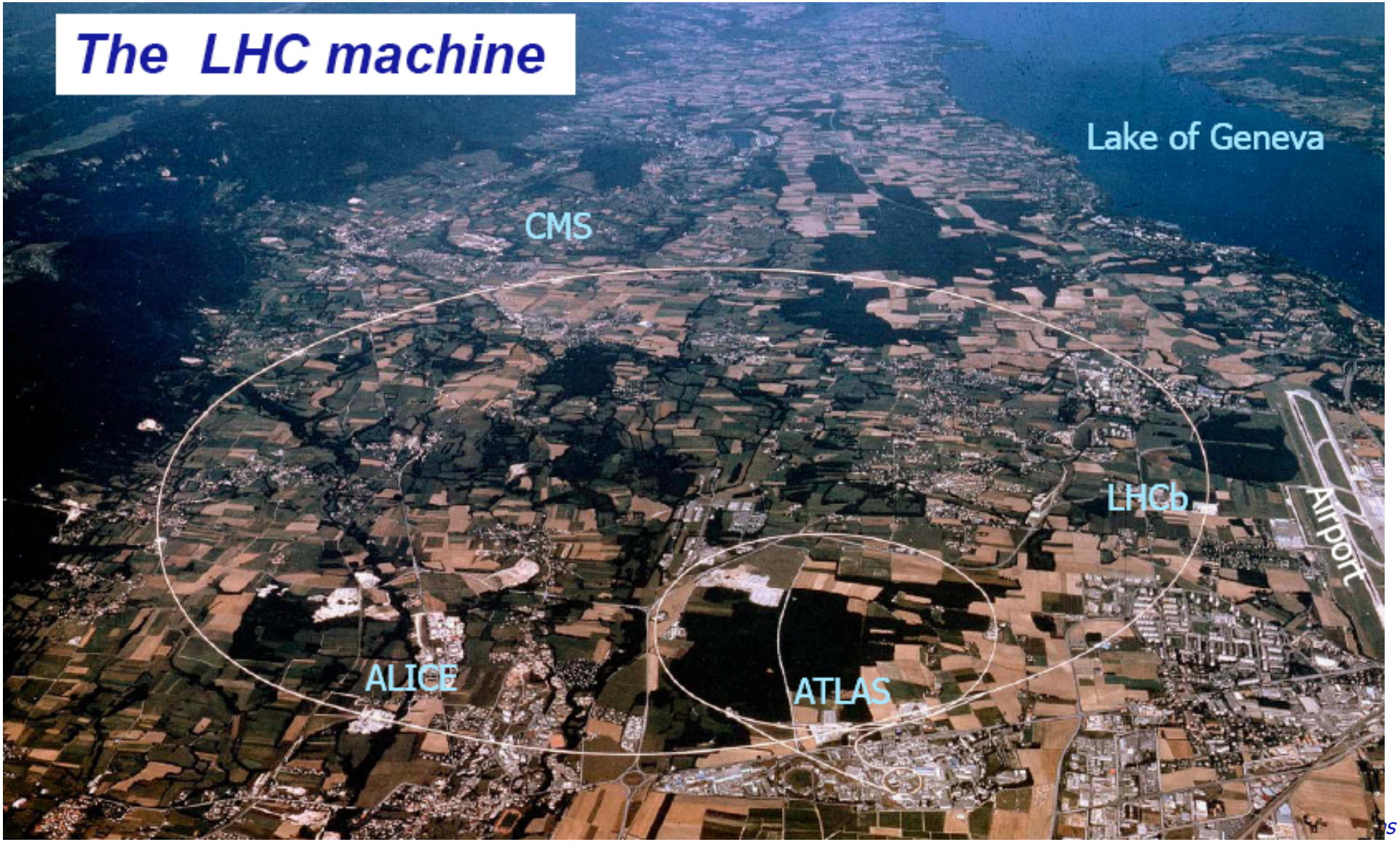
Cross-sections essentially one order of magnitude beyond Tevatron



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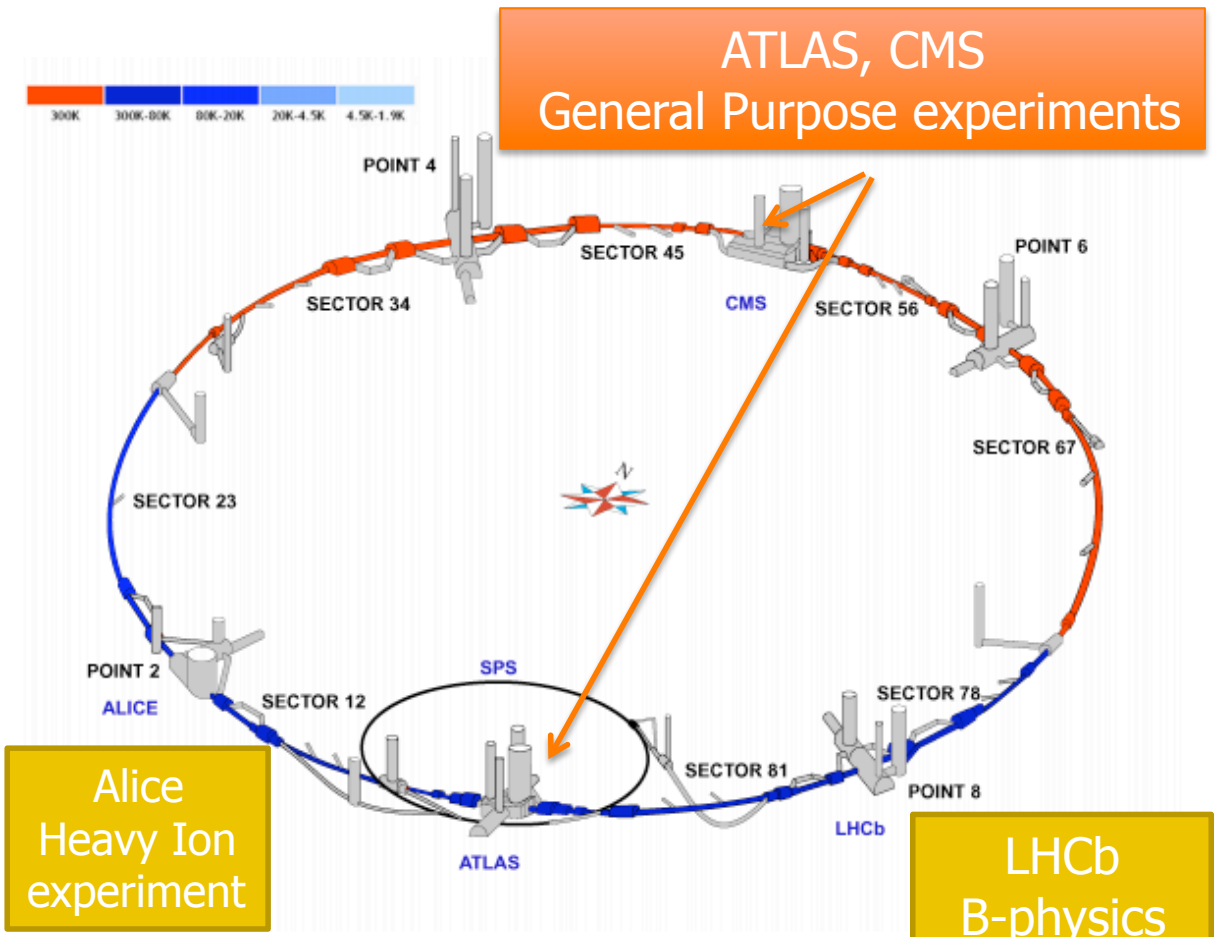
(CERN)



- LHC housed in
  LEP tunnel (~1980s)
- 26.7 km
  + all CERN accelerator complex

- pp collisions
  - $\sqrt{s}$=14Tev
  - $L=10^{34}$ cm^{-2} s^{-1}

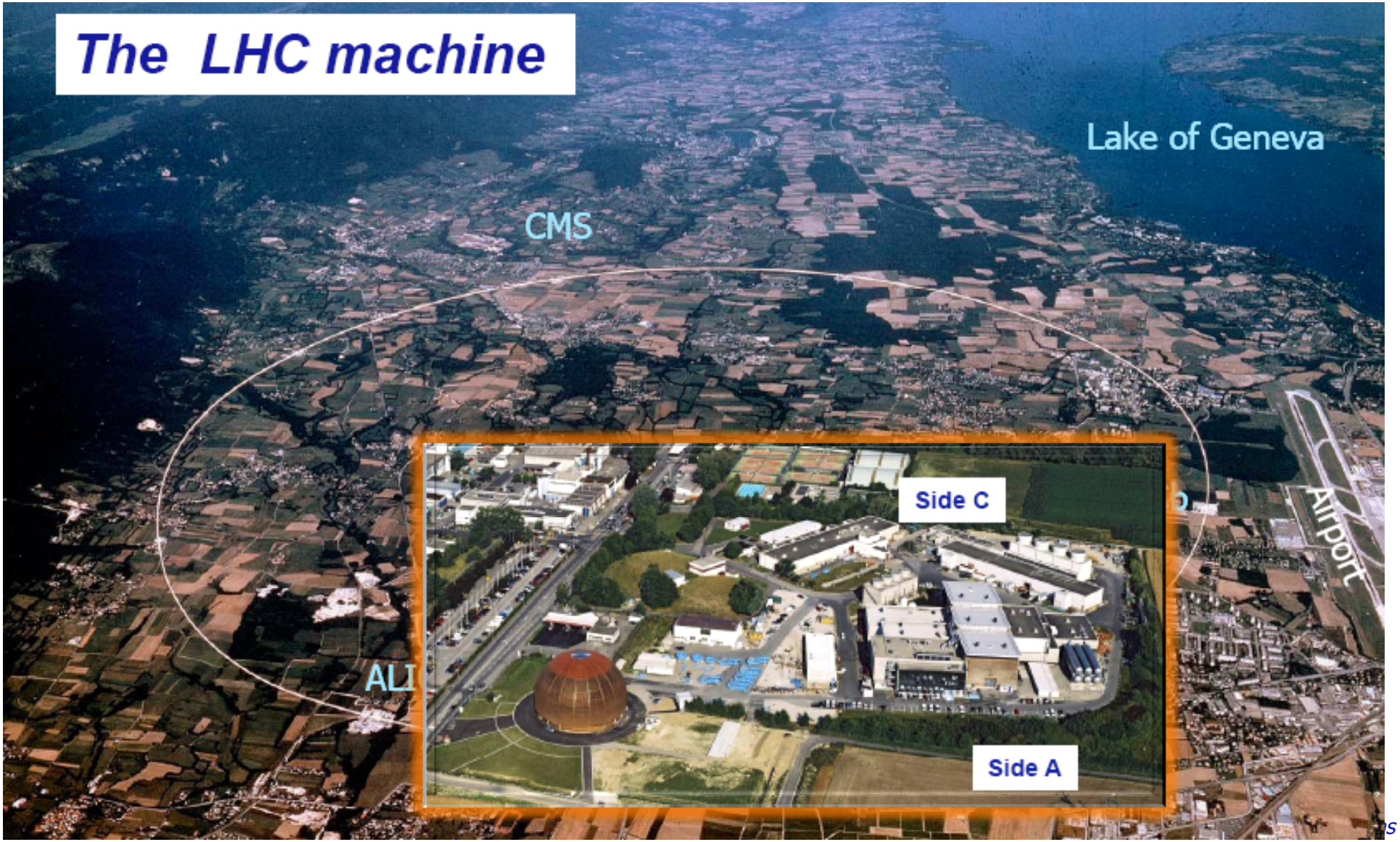
  2012

  - $\sqrt{s}$~7-10Tev
  - $L=x10^{33}$ cm^{-2} s^{-1}

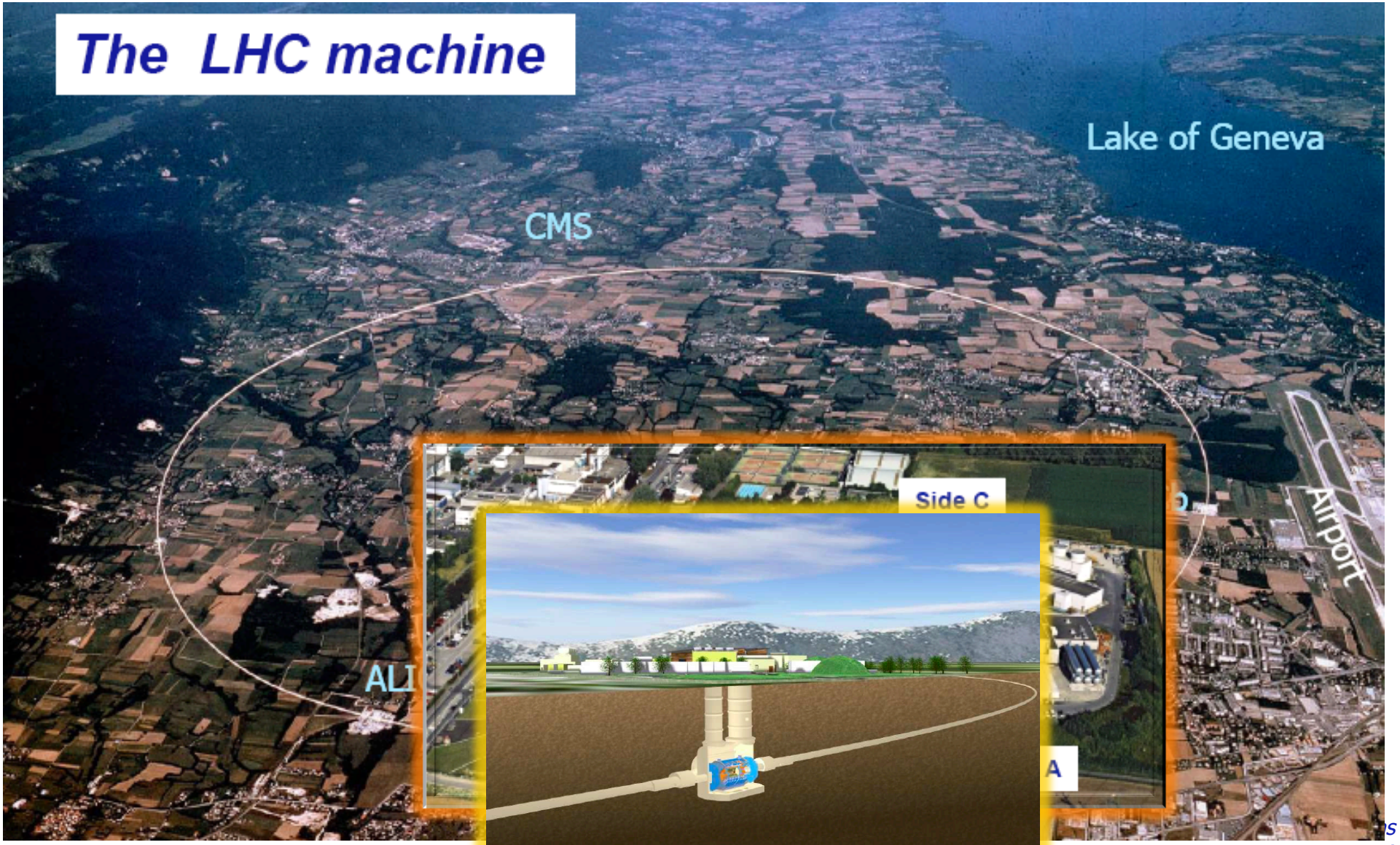
  2009-10

- 40 MHz bunch crossings
  25ns collisions,
  ~20 events/collision pileup
- Heavy ions :
  ~PeV (Pb-Pb e.g.)

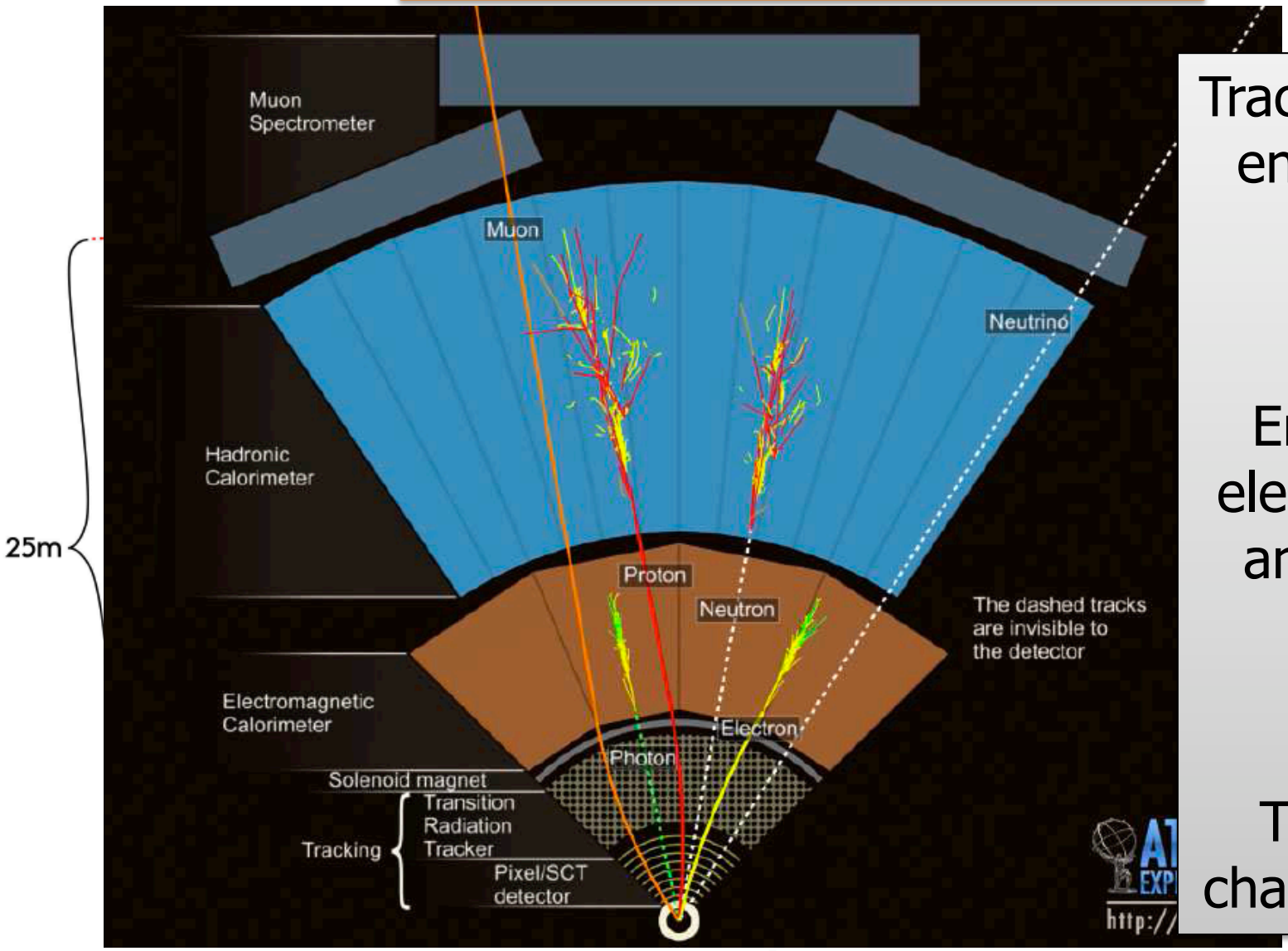
The LHC machine



The LHC machine



The Atlas Detector at LHC Point 1



Tracks from high energy muons

Energy from electromagnetic and hadronic particles

Tracks from charged particles

The Atlas Detector at LHC Point 1

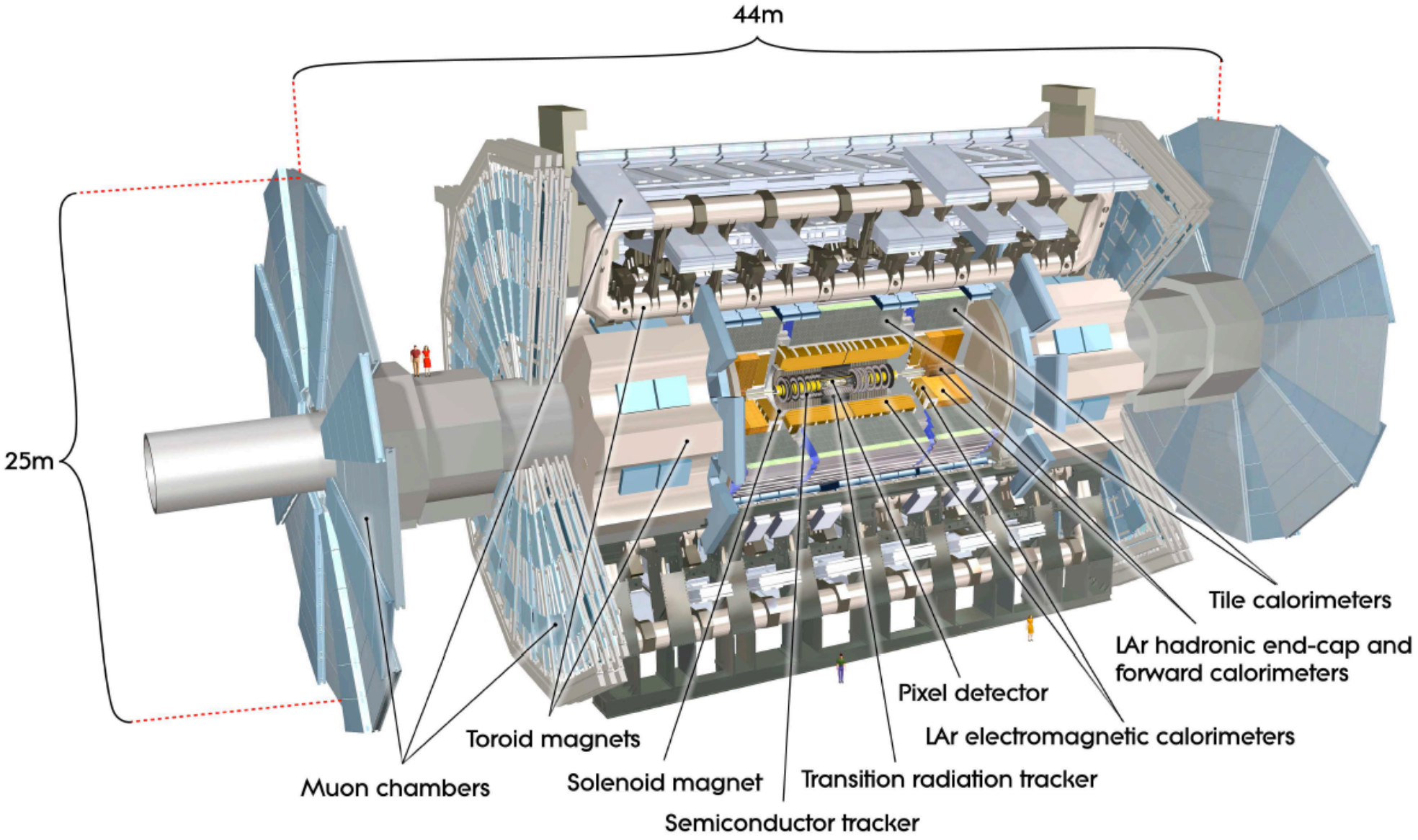
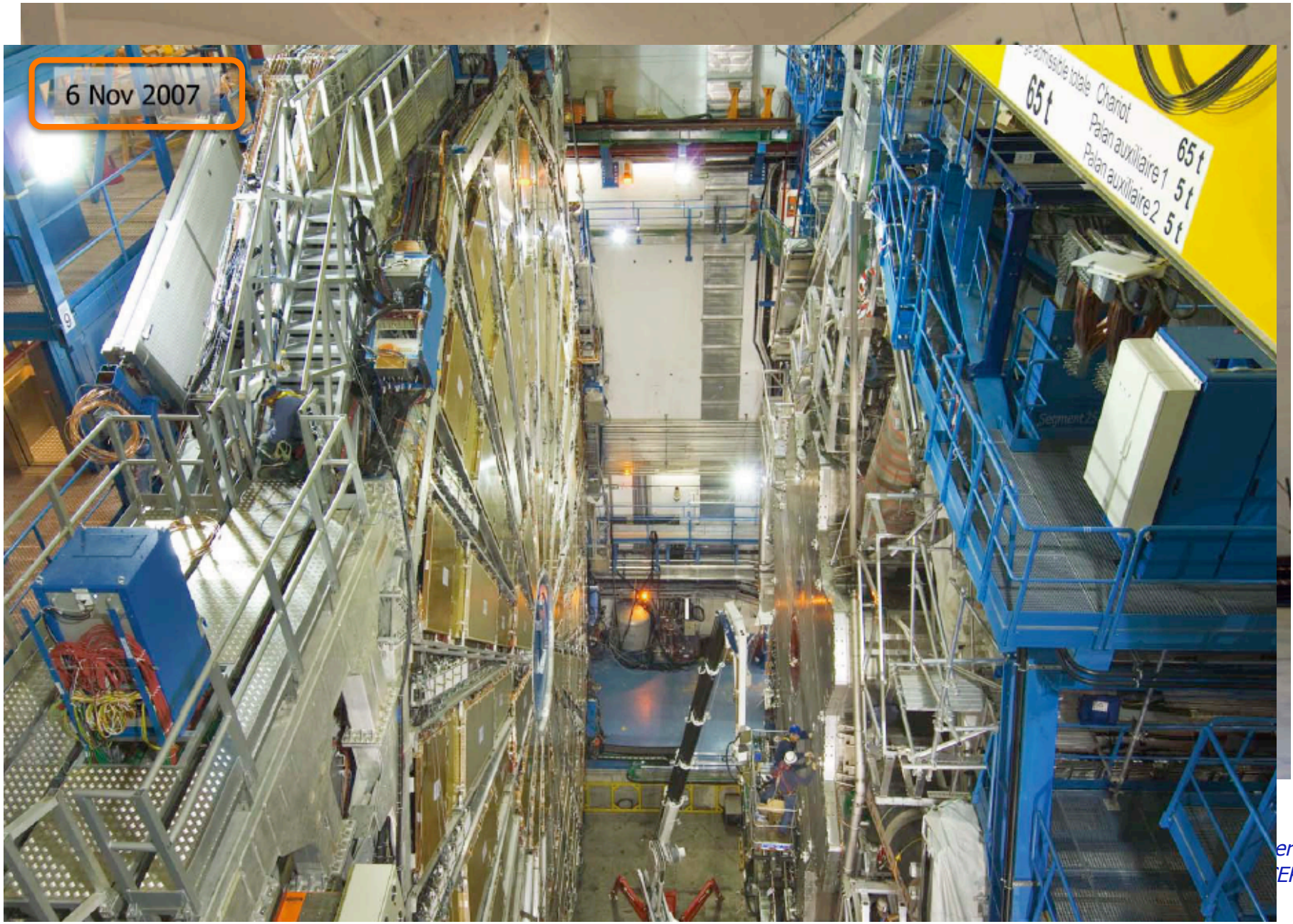
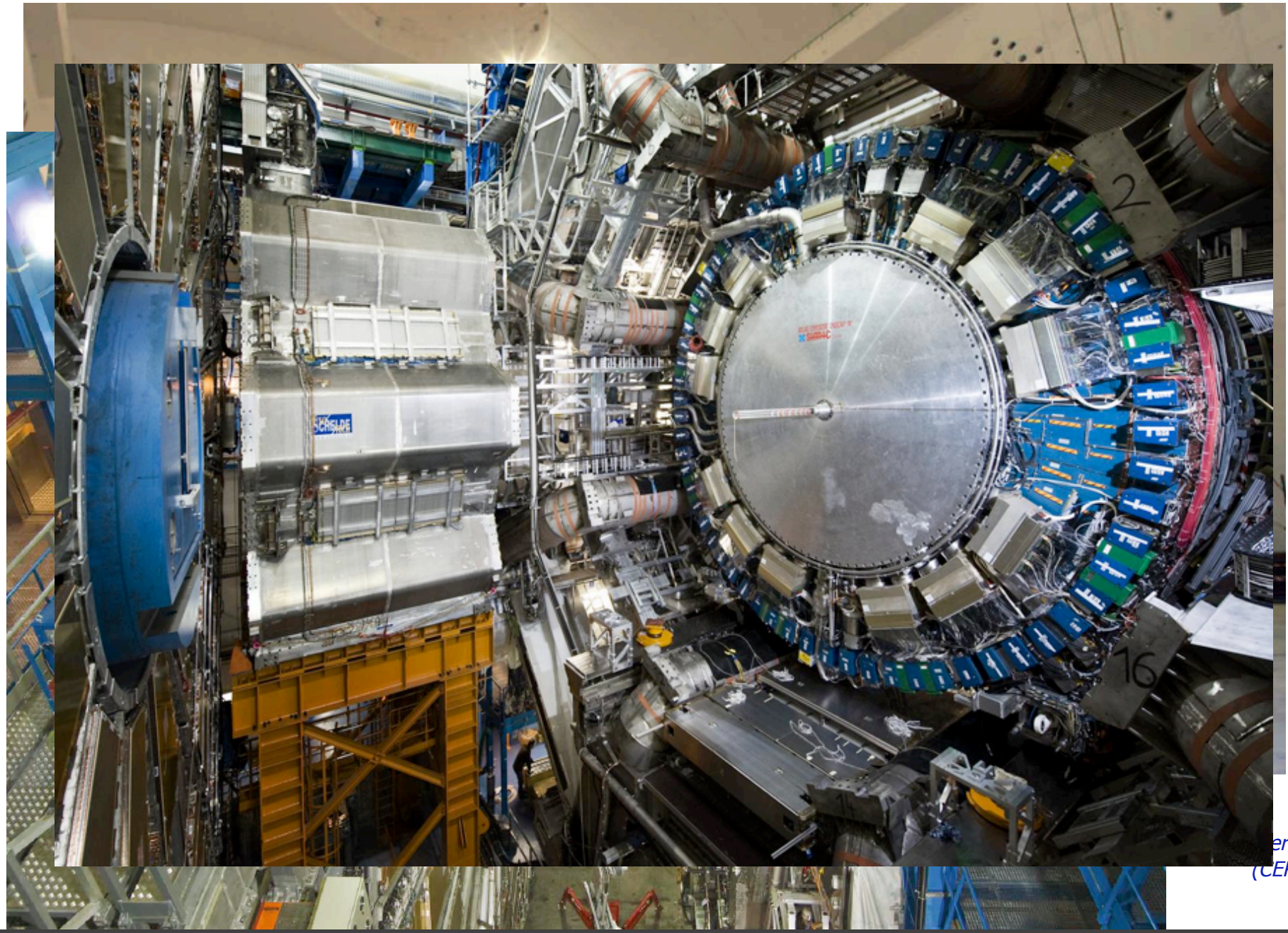


Photo 2003


6 Nov 2007
65 t
Chariot
65 t
Palan auxiliaire 1
5 t
Palan auxiliaire 2
5 t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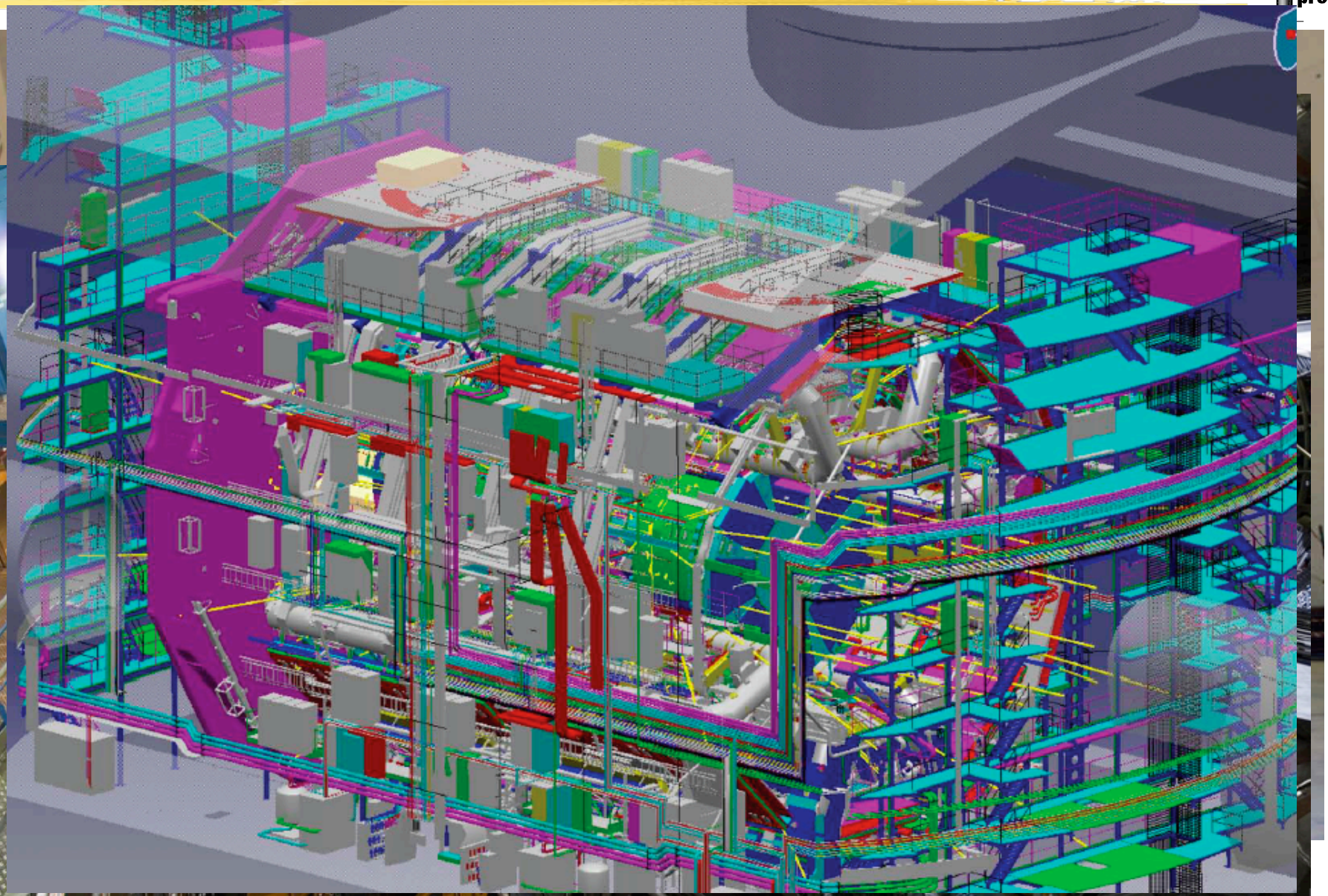
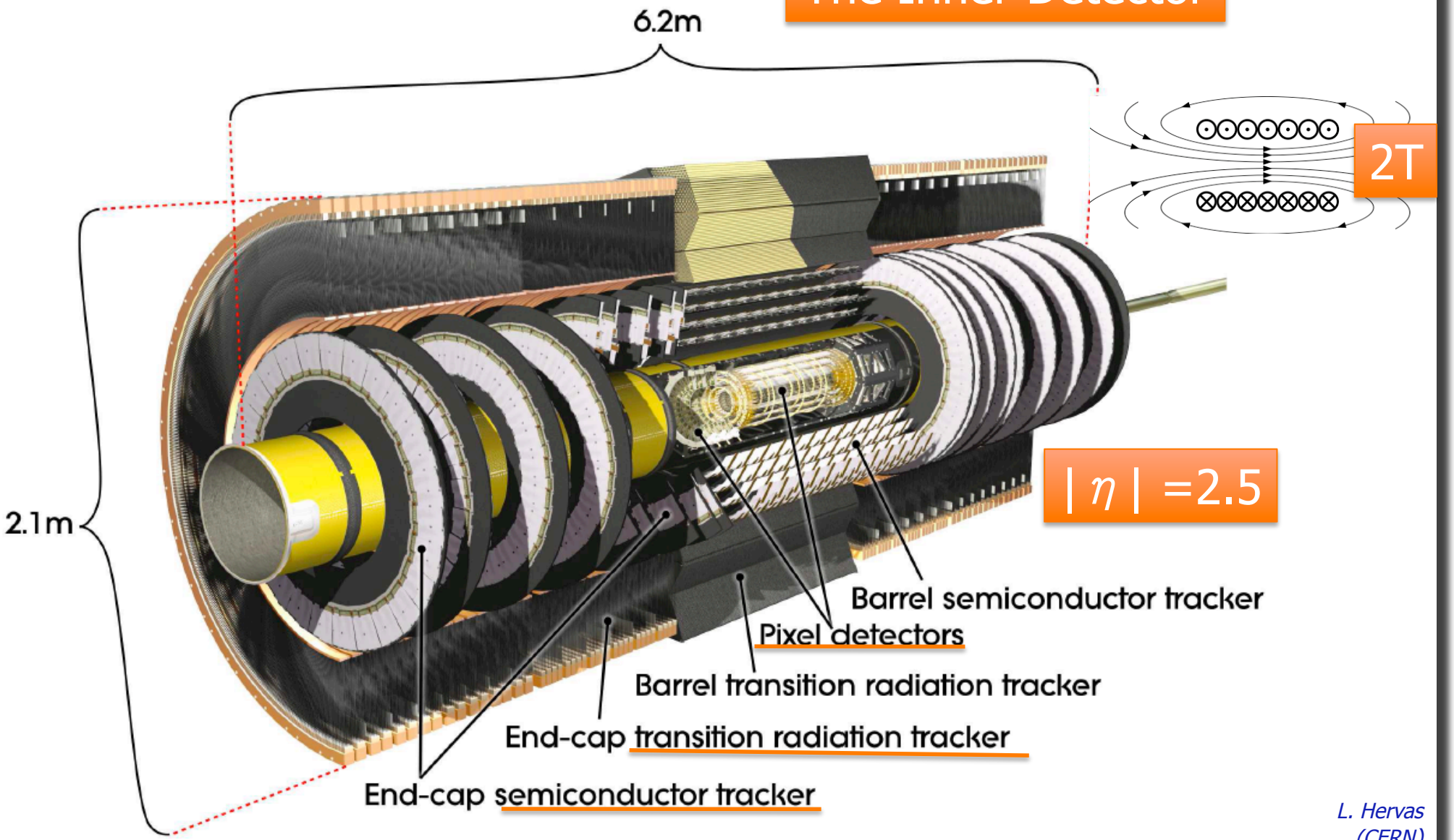
16



The Inner Detector



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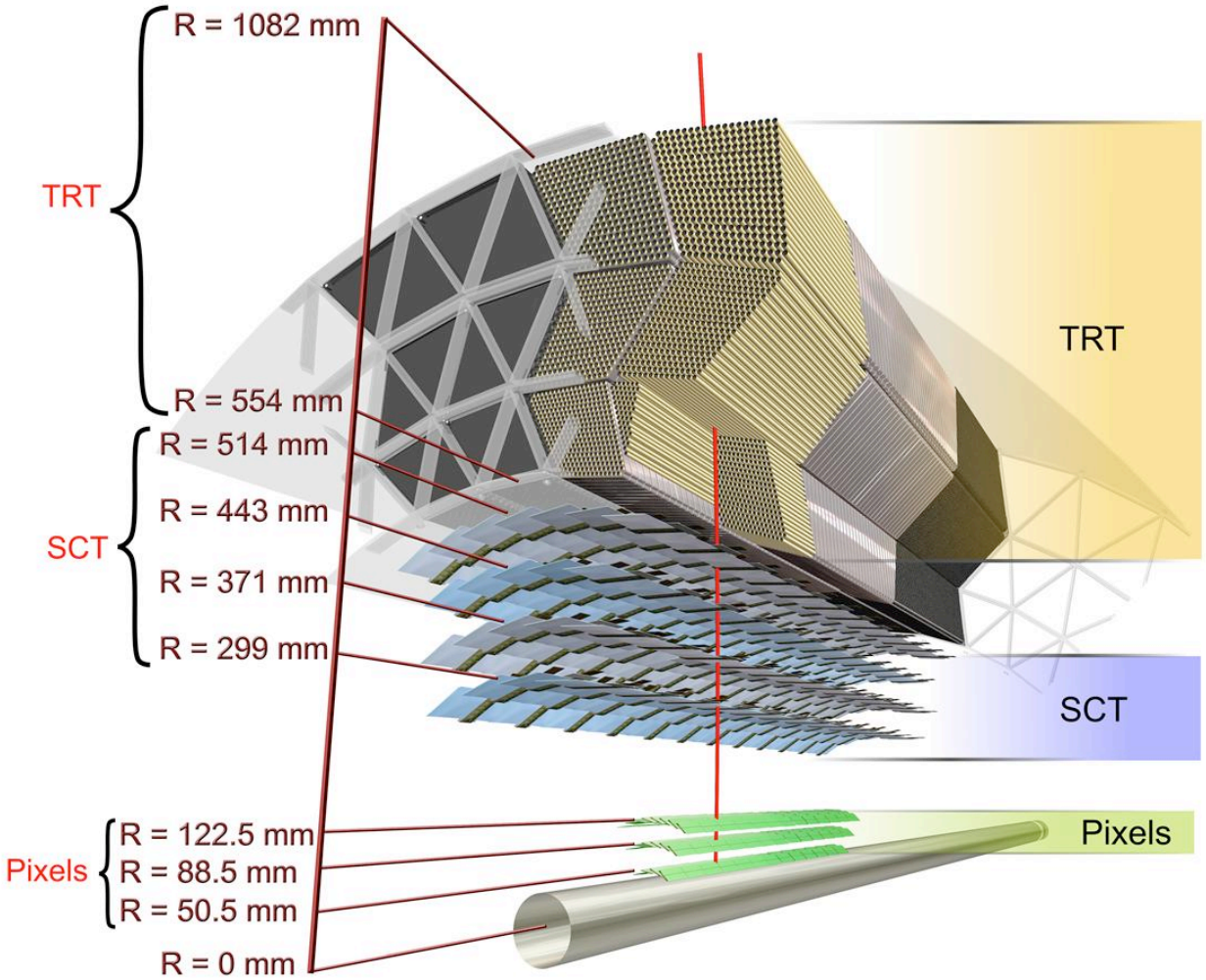
(CERN)

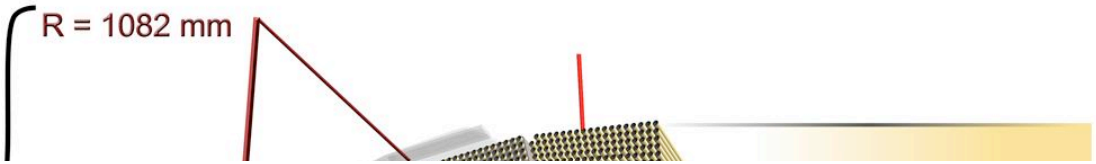


4 mm Ø [kapton] straws,
31 µm wires
Xe based gas
Typ. 36 hits/track,
~40 ns drift time
~130 µm resolution
(full chain with electronics)
Interleaved with
radiator material
350k channels

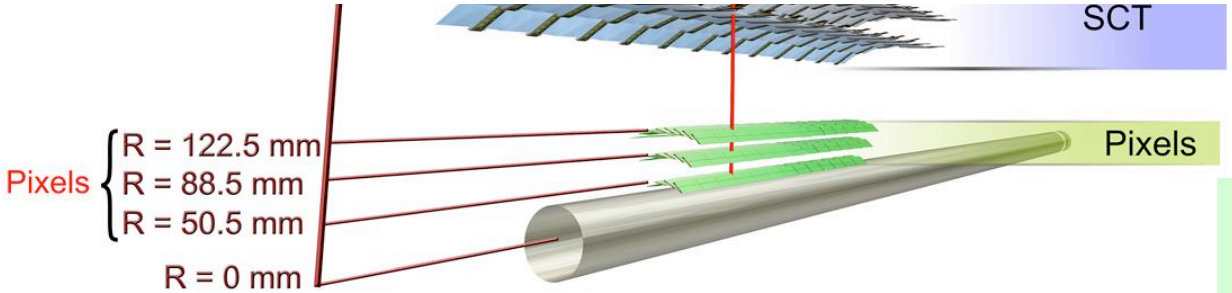
80 µm strips
17x580 µm resolution
63 m^2 of Si
~6M channels

50 x 400 µm pixel size
~80M channels

4 mm Ø [kapton] straws,
31 μm wires
Xe based gas
Typ. 36 hits/track

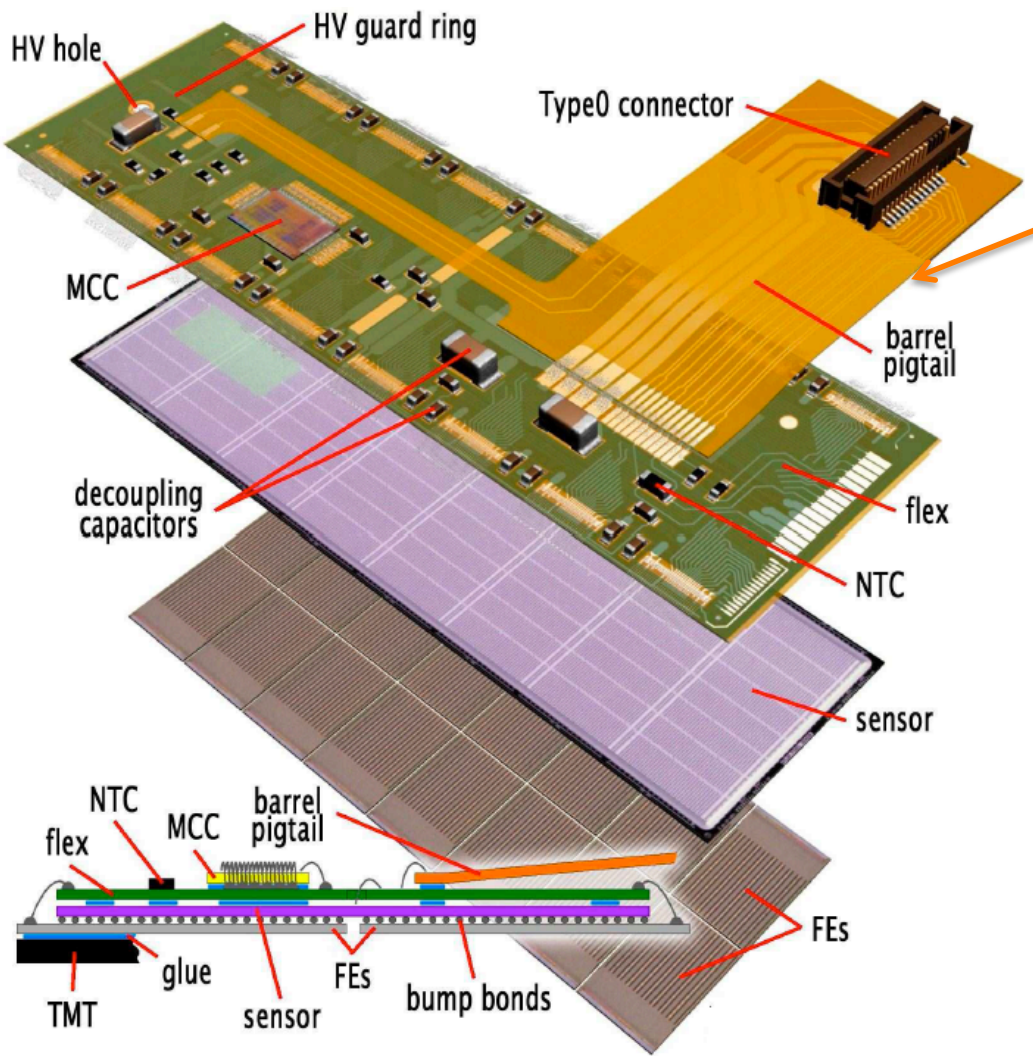


Detector component	Required resolution	η coverage	
		Measurement	Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\%\ p_T \oplus 1\%$	±2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	±3.2	±2.5
Hadronic calorimetry (jets)			
barrel and end-cap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	±3.2	±3.2
forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 < \lvert\eta\rvert < 4.9$	$3.1 < \lvert\eta\rvert < 4.9$
Muon spectrometer	σ_{p_T}/p_T=10% at p_T = 1 TeV	±2.7	±2.4

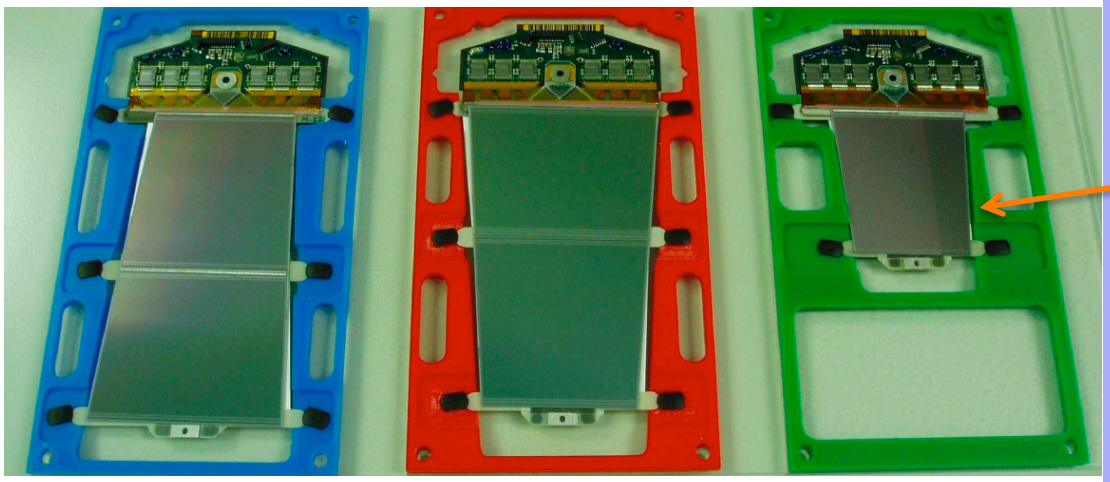


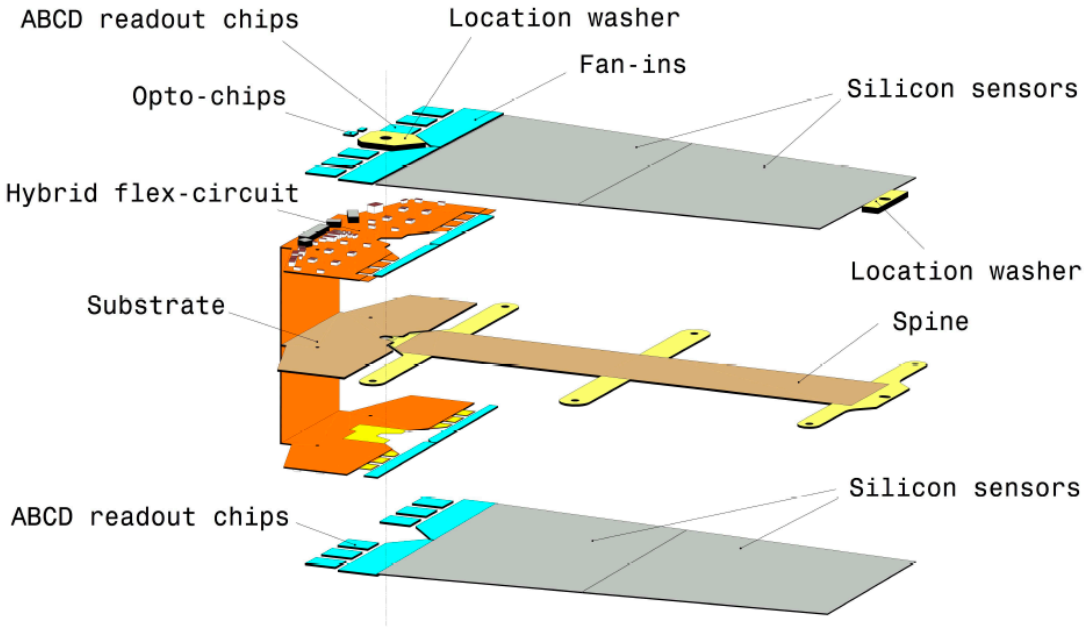
63 m² of Si
~6M channels

50 x 400 μm pixel size
~80M channels



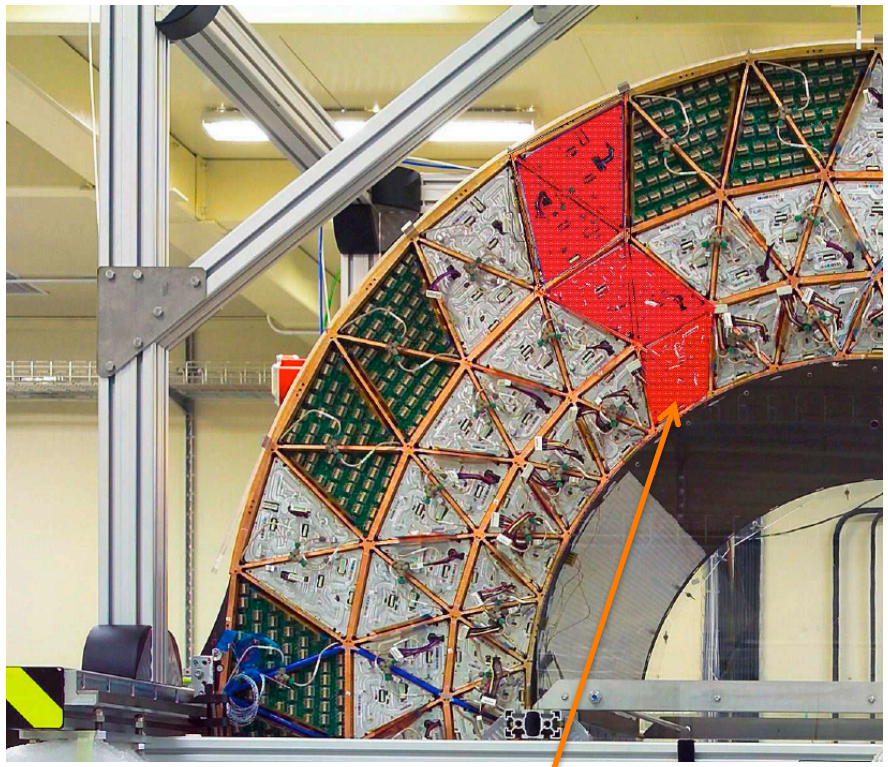
- 1744 modules like
- 250µm thick sensors
- 50 x 400 µm pixel size
- 3 layers in ladders on barrel
- 3 disks of 2 layers on EC
- FE is bump bonded to sensors
- Radiation hostile environment:
  - Design of Si
  - Biased -150V [year 1]… 600V
  - Operated @ -7ºC
- ~80M channels

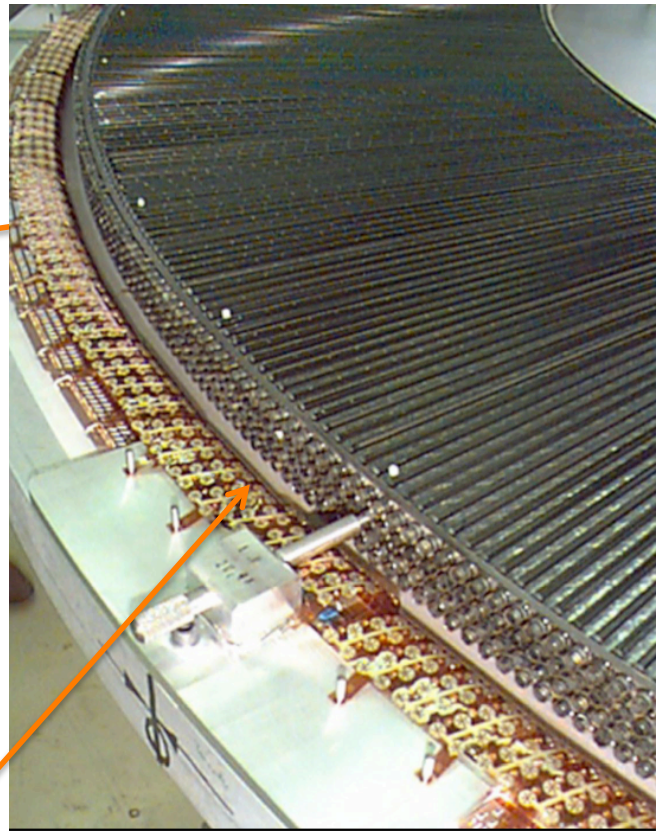




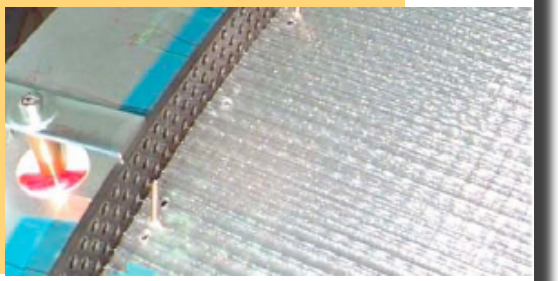
- 4088 modules in
  - 4 coaxial cylinders (barrel) and
  - 2 Endcaps with 9 disks
- 80 μm pitch strips, 285 μm thick sensors
- Two faces at ~40mrad stero angle
- Mechanical placements to 20μm
- Gives ≥ 4 precision points for tracks
- R &R-Φ
- FE is wire bonded to strips
- Radiation hostile environment ~pixels:
  - Design of Si
  - Biased -150V [year 1]… 600V
  - Operated @ -7°C
- ~6M channels, 63 m^2 of Si

TRT Detector

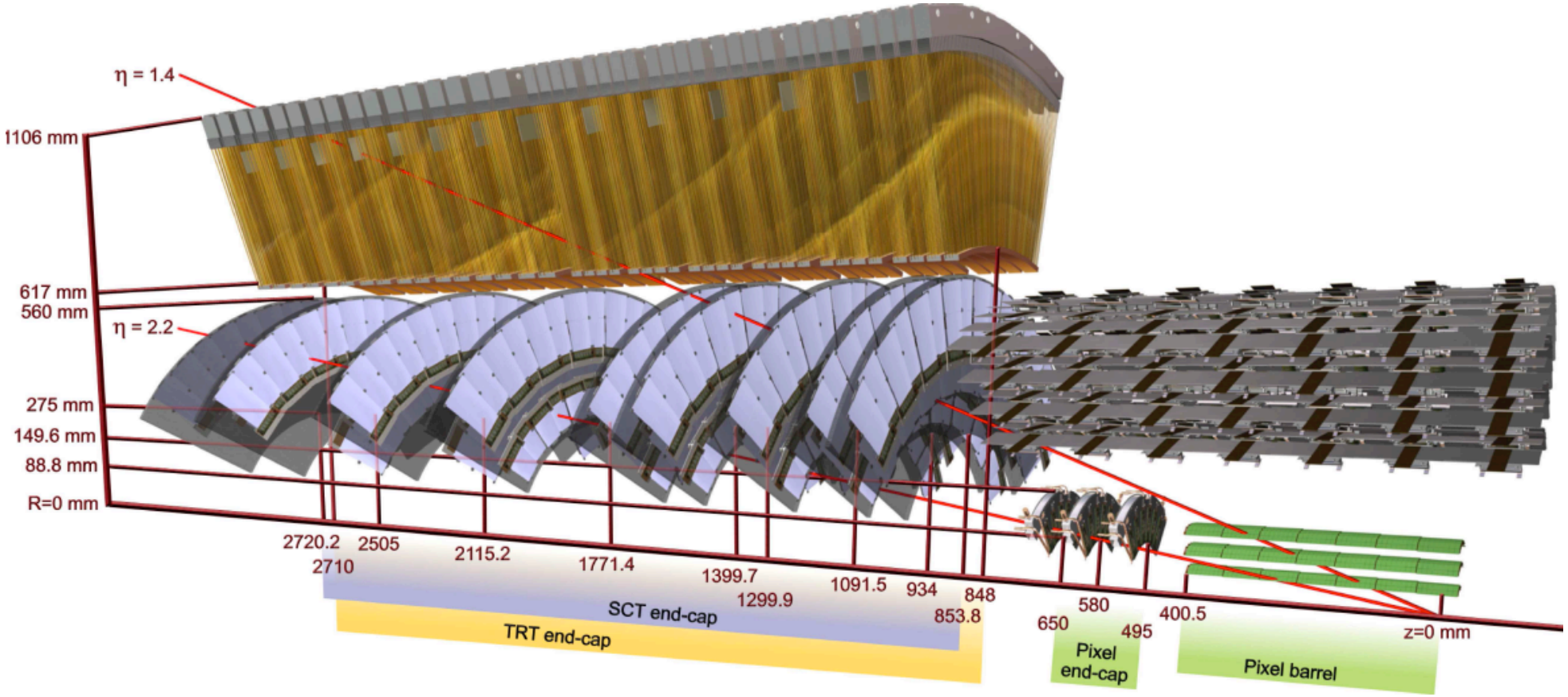




- [Barrel] 3 rings × 32 modules, [Ecs] 2 × 20 wheels × 8 layers of tubes
- Straw tubes interleaved with thin polypropilene foil or fibers
- Track hits min. 36 straws for p_T>0.5 GeV |η| <2.0
- e^- >2 GeV give 7-10 hits of TR
- e-π identification: 0.5 GeV < E < 150 GeV



A Track through the ID



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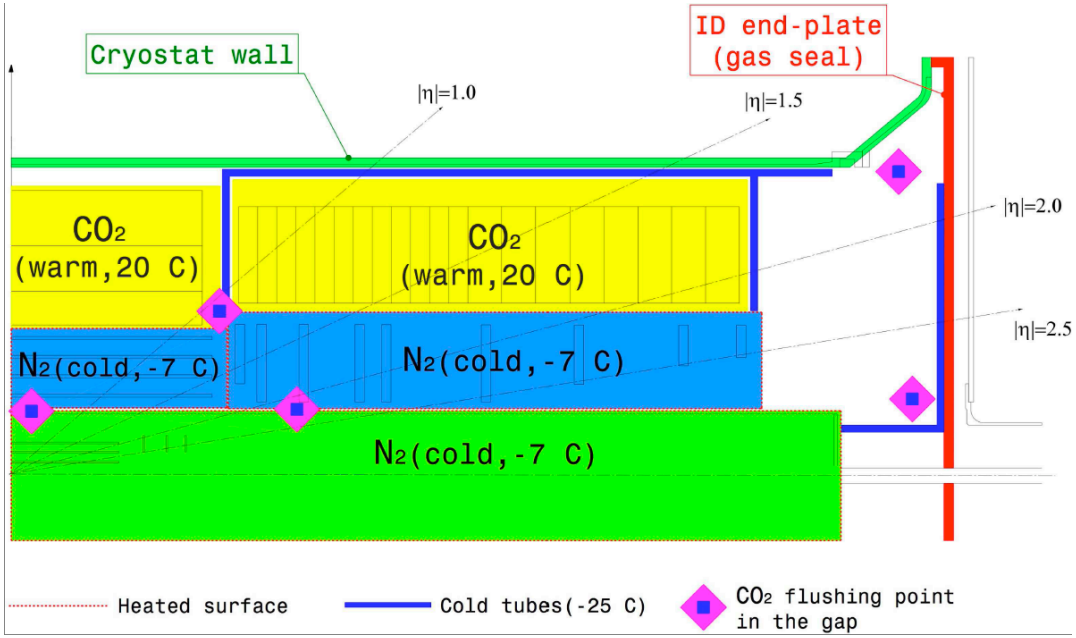

- ID volume is inside bore of solenoid 2T
- SC Solenoid is integrated in LAr Barrel cryostat. 0.66 X_0
- Al with Nb-Ti wire, 7.7kA
- He cooled to 4.5K

- ID volume is split in volumes
- Operating at very different temperatures
- N_2 volume to avoid condensation
- CO_2 to protect TRT
- Heater pads systems
- Evaporative Cooling system (C_3F_8)
- Heaters in the loops
- Removes 85 kW

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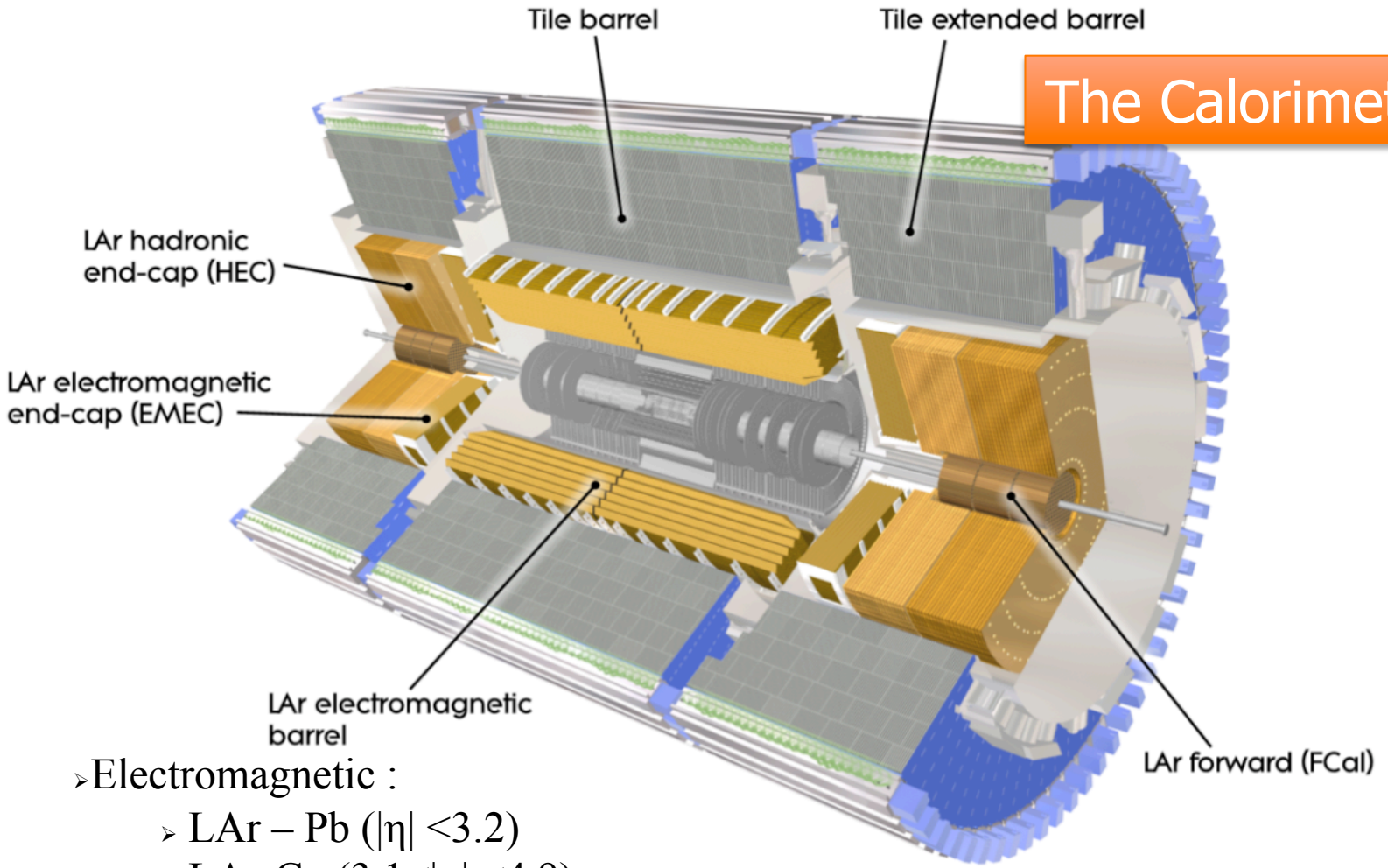
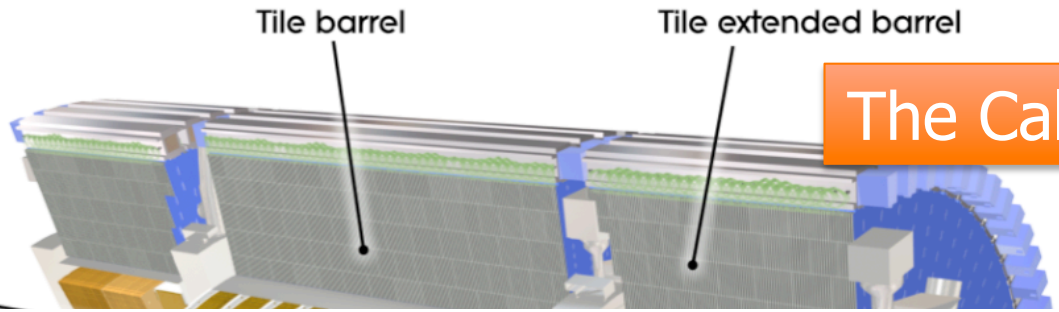
The Calorimeter System



- Electromagnetic :
  - LAr – Pb ($|\eta| < 3.2$)
  - LAr-Cu ($3.1 < |\eta| < 4.9$)
- Hadronic:
  - Sci- Fe ($|\eta| < 1.7$)
  - LAr- Cu ($1.5 < |\eta| < 3.2$)
  - LAr-W ($3.1 < |\eta| < 4.9$)

The Calorimeter System



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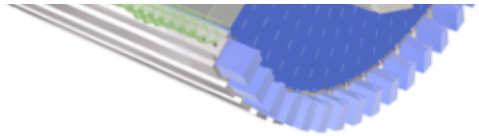
Muon spectrometer	σ_{p_T}/p_T=10% at p_T = 1 TeV	± 2.7	± 2.4



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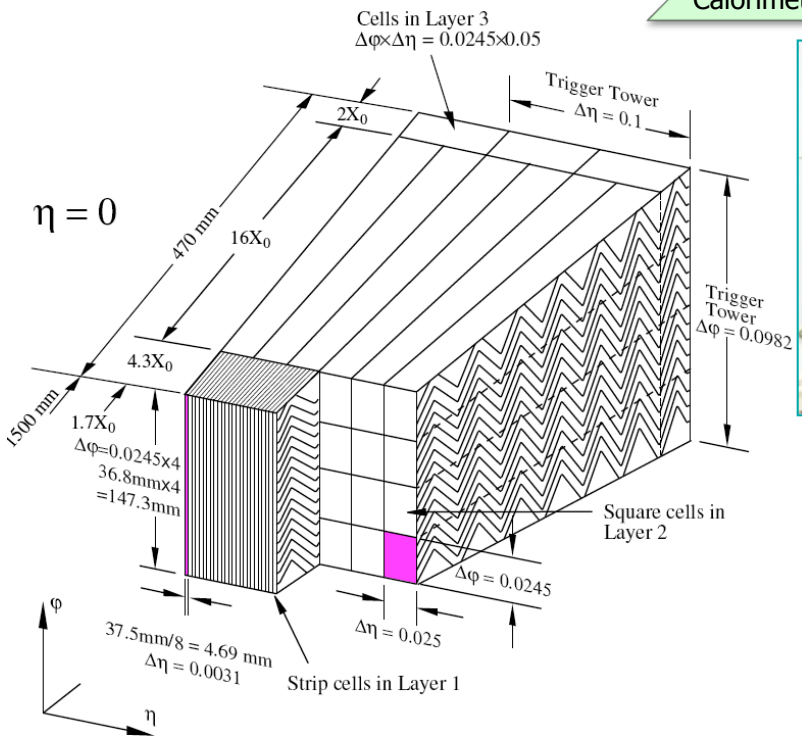
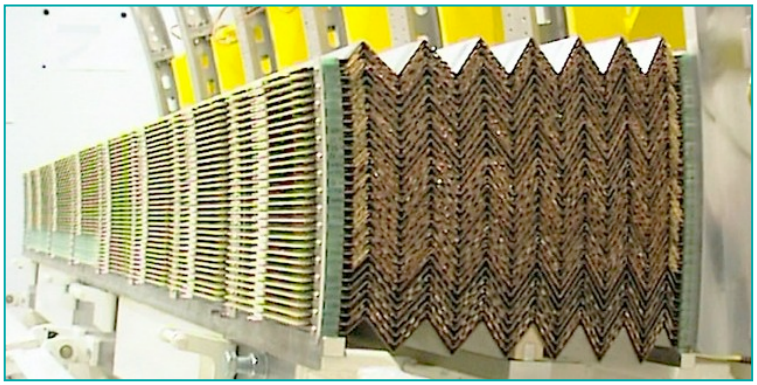
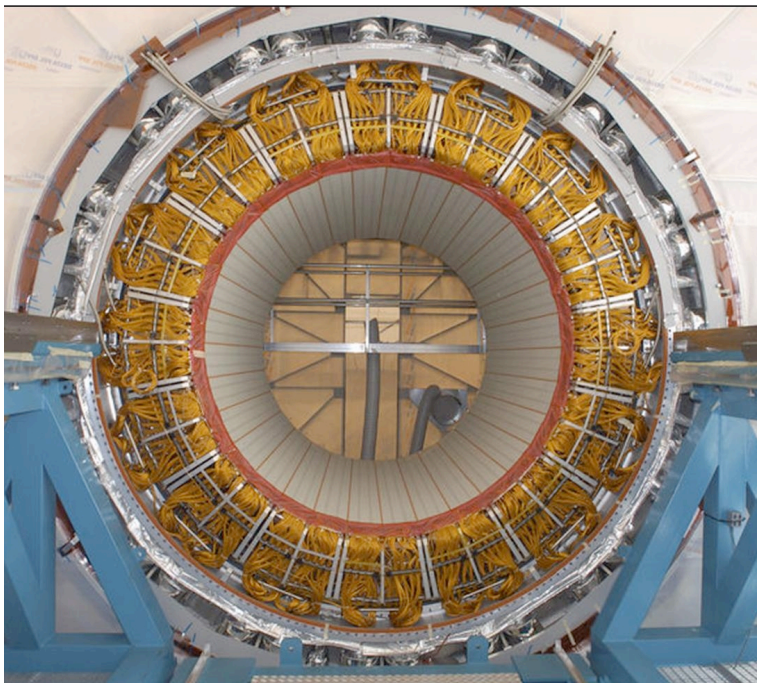
- Hadronic:
  - Sci- Fe (|η| <1.7)
  - LAr- Cu (1.5<|η| <3.2)
  - LAr-W (3.1<|η| <4.9)

LAr Calorimeter EM

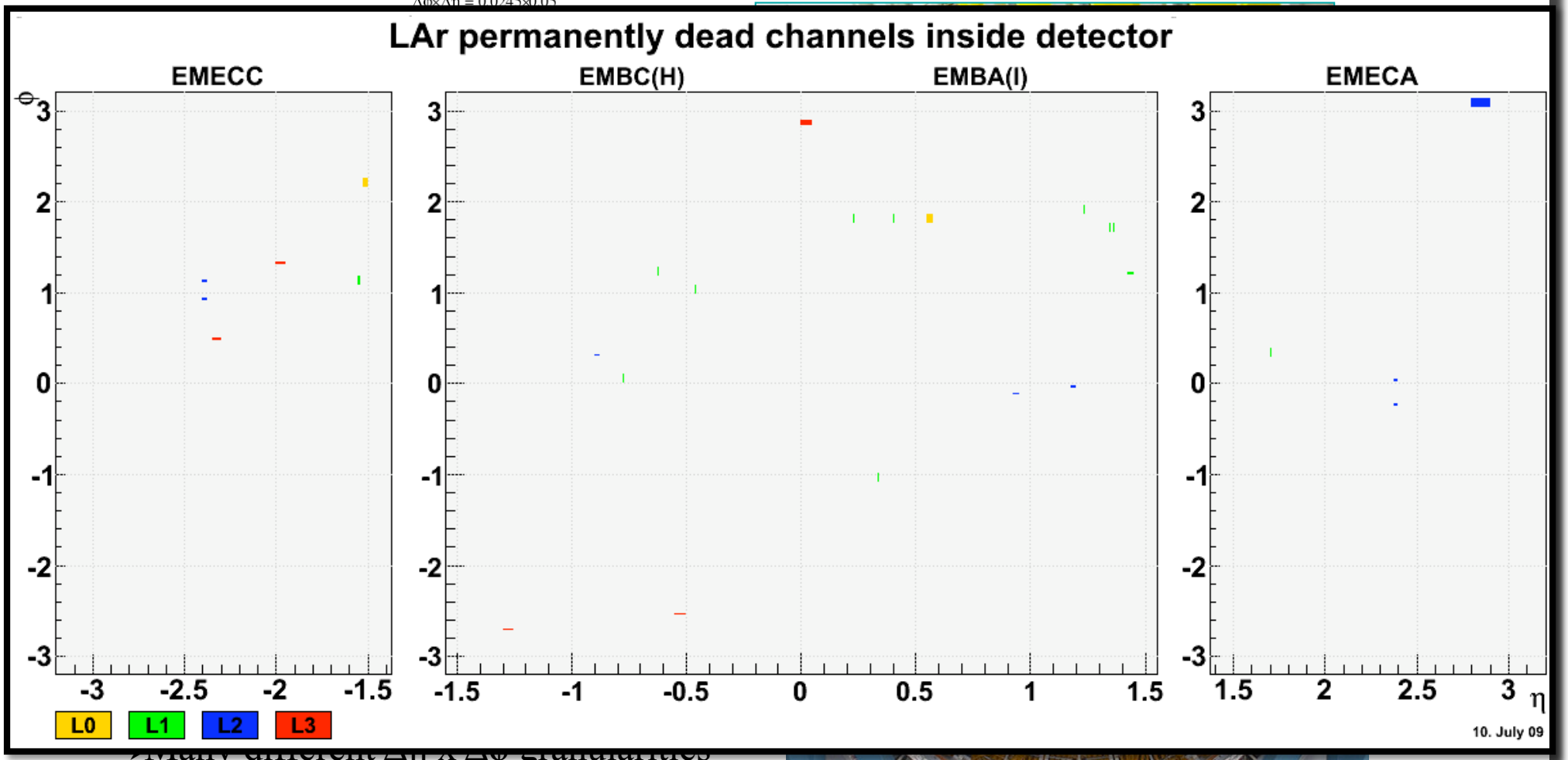






- Accordion geometry
- Typ. 3 readings in depth
- Pre-shower in front (|η| <1.8)
- Many different Δη x Δϕ granularities
  - In η and depth
  - Etching on kapton-Cu electrodes
- 180K channels
- In 3 cryostats @ ~80K

Cells in Layer 3
$\Delta\varphi \times \Delta\eta = 0.0245 \times 0.05$



- Many different $\Delta\eta \times \Delta\phi$ granularities
  - In η and depth
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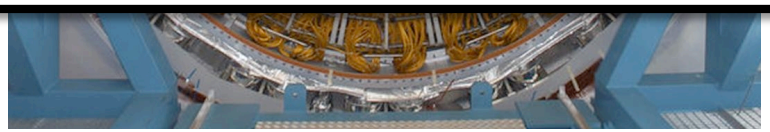
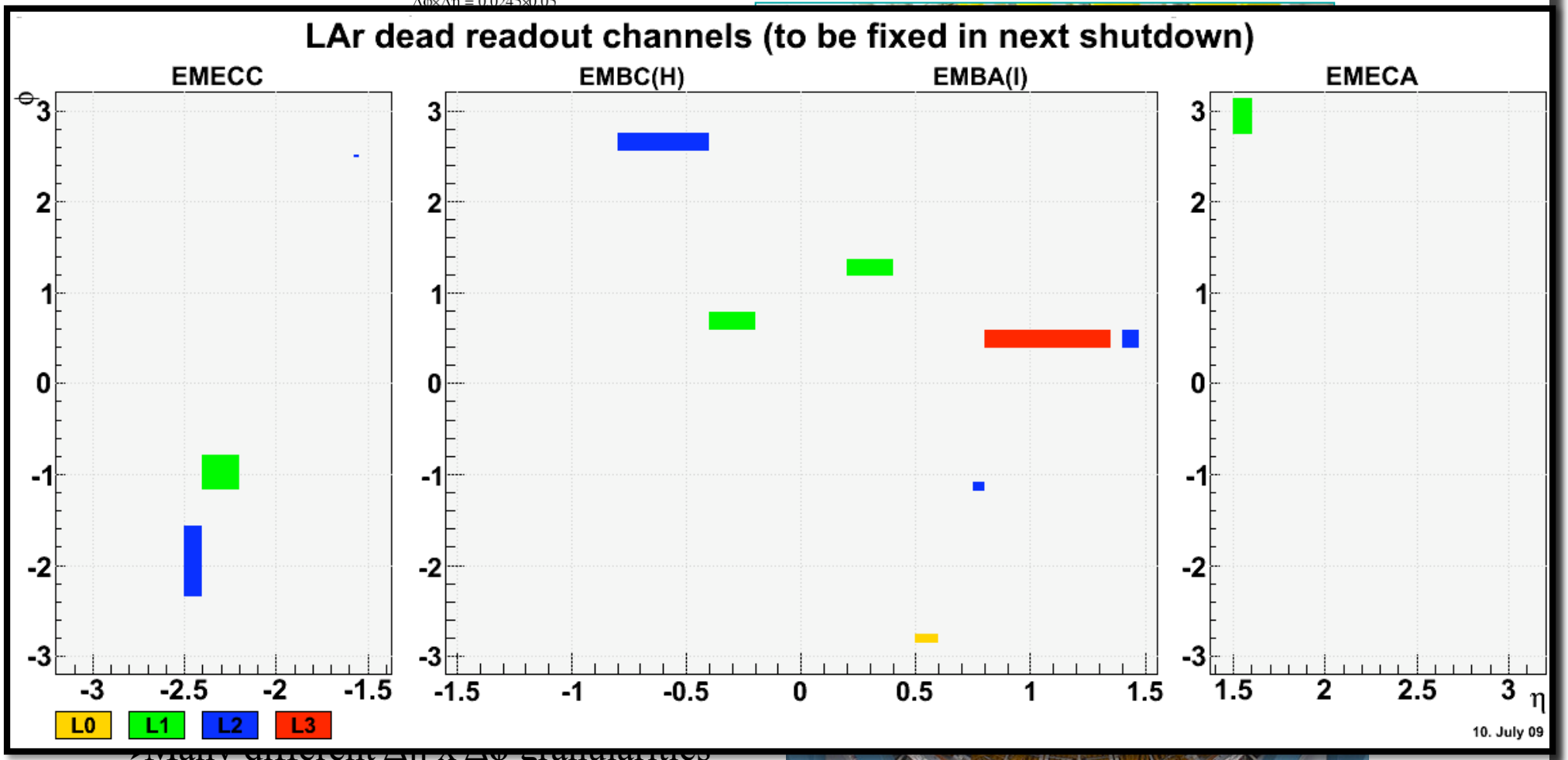


Cells in Layer 3
Δφ×Δη = 0.0245×0.05



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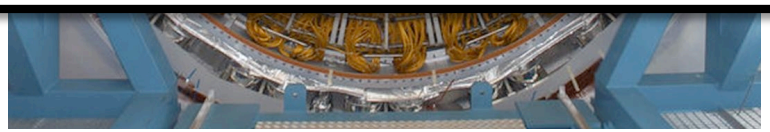
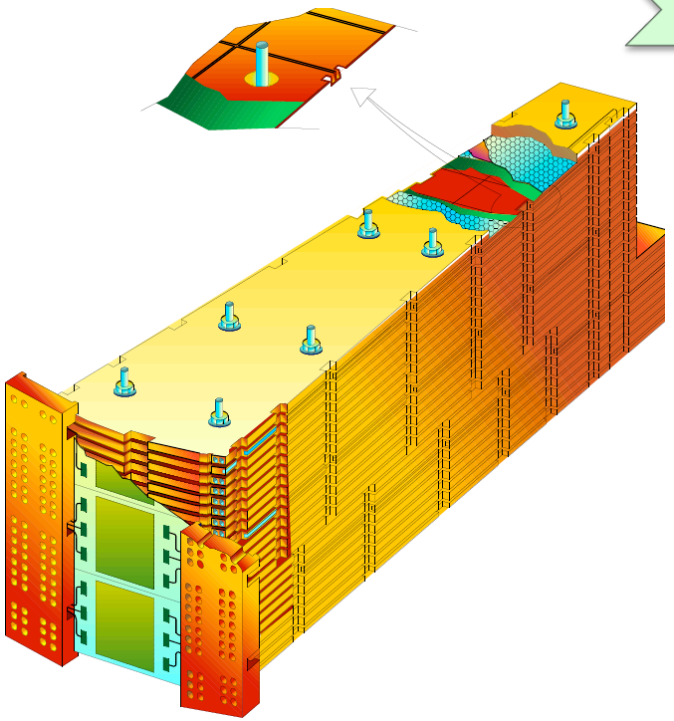
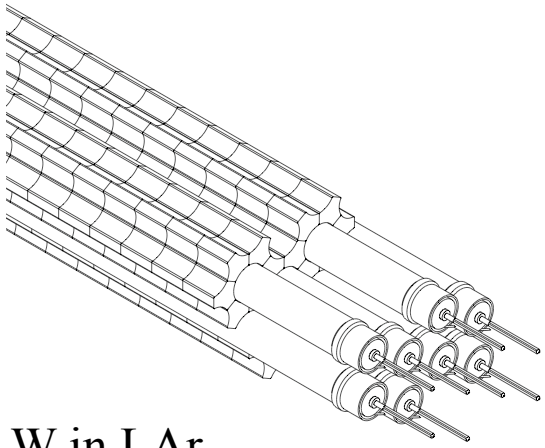


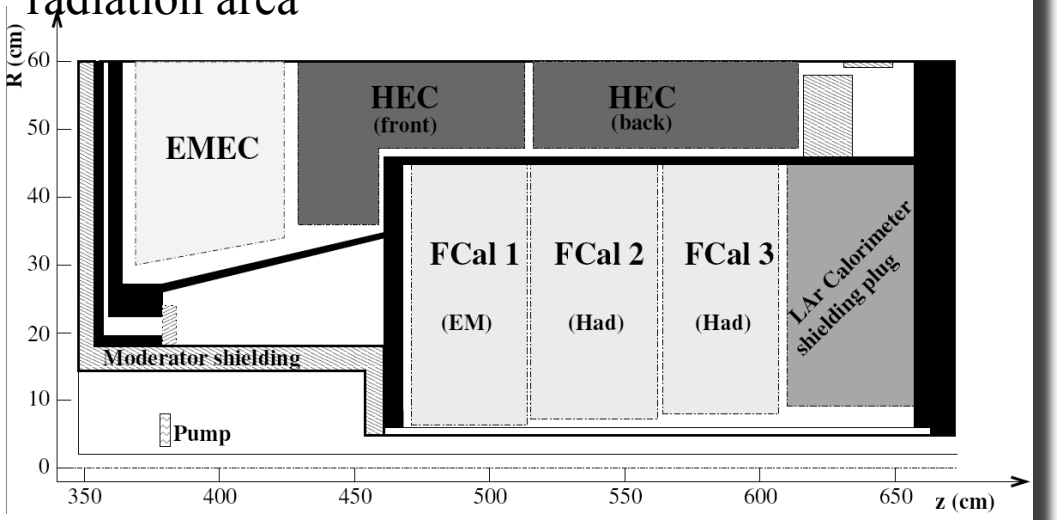




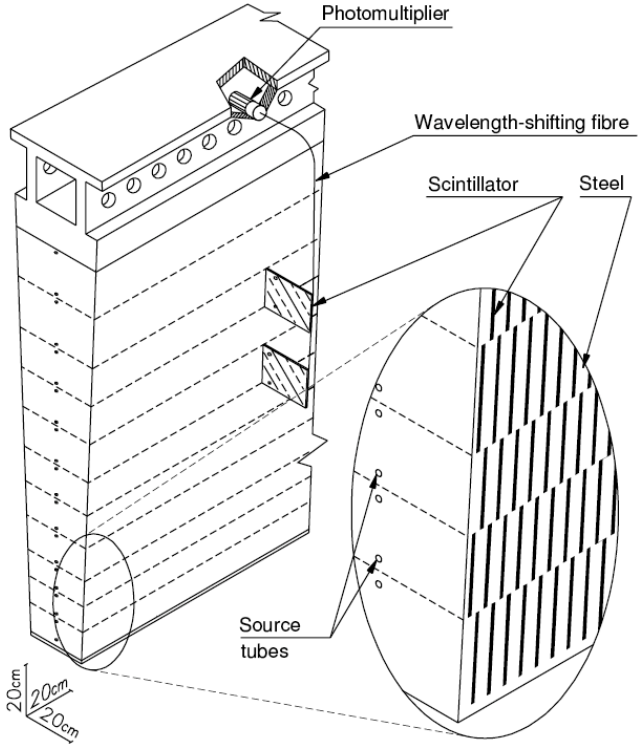
- Forward : Cu / W in LAr
- Absorber matrix with W slugs
- Rods inside Cu tubes with LAr in gaps
- Small LAr gaps 0.2-0.5 mm due to high radiation area

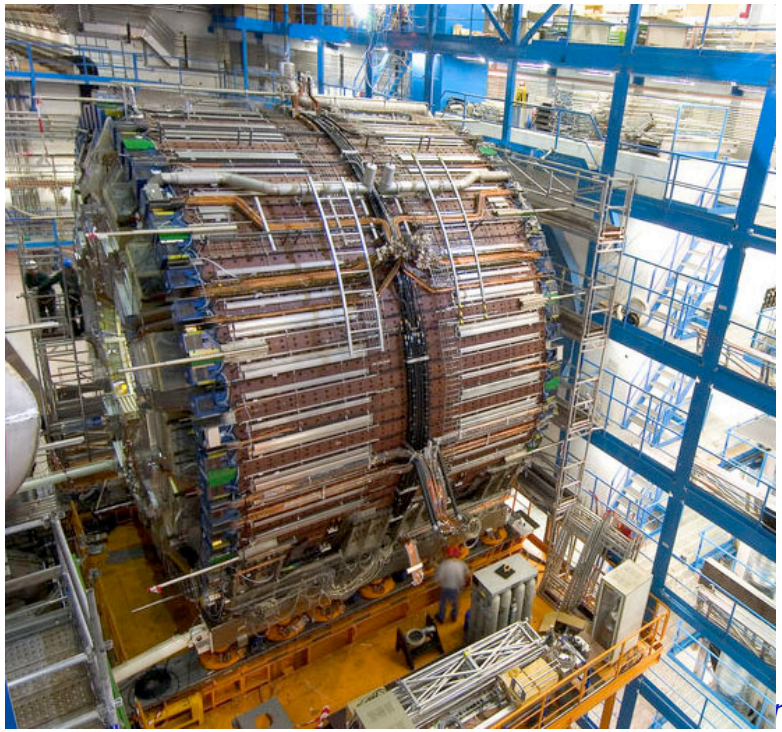
- Hadronic EC: Flat Cu in LAr

- Wedges mounted to wheels, 4 cells in depth
- Pads etched on electrodes, grouped to
  $\Delta\eta \times \Delta\phi$ 0.1x0.1 (0.2 for $|\eta| > 2.5$)
- GaAs Preamplifier at the outer R (in the LAr)



Tile Calorimeter





- Scintillator "Tiles" interleaved in Steel plates
- Light collected by WLS fibers to PMTs
- Fiber grouping forms cells
  - typ. $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
  - 3 depths sections
- Organized in 64 wedge modules each
  - Barrel + 2 Extended Barrel
- Calibration system with laser, Charge injection on Cs source

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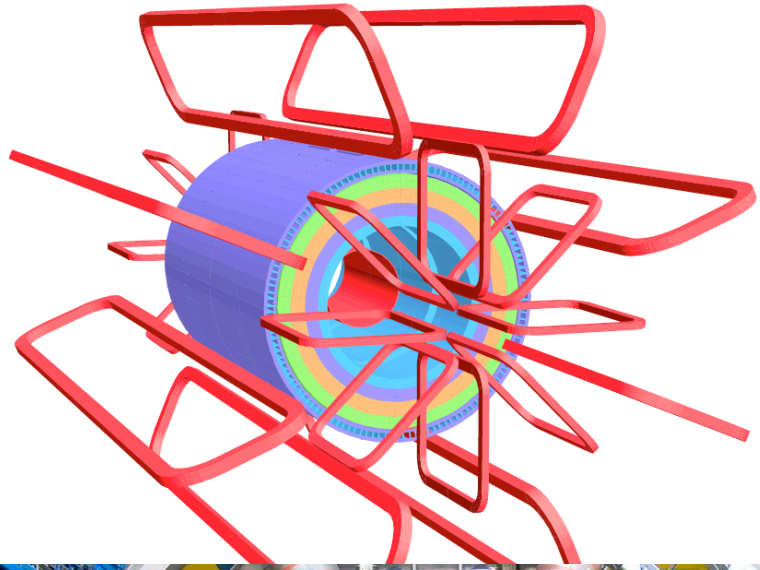
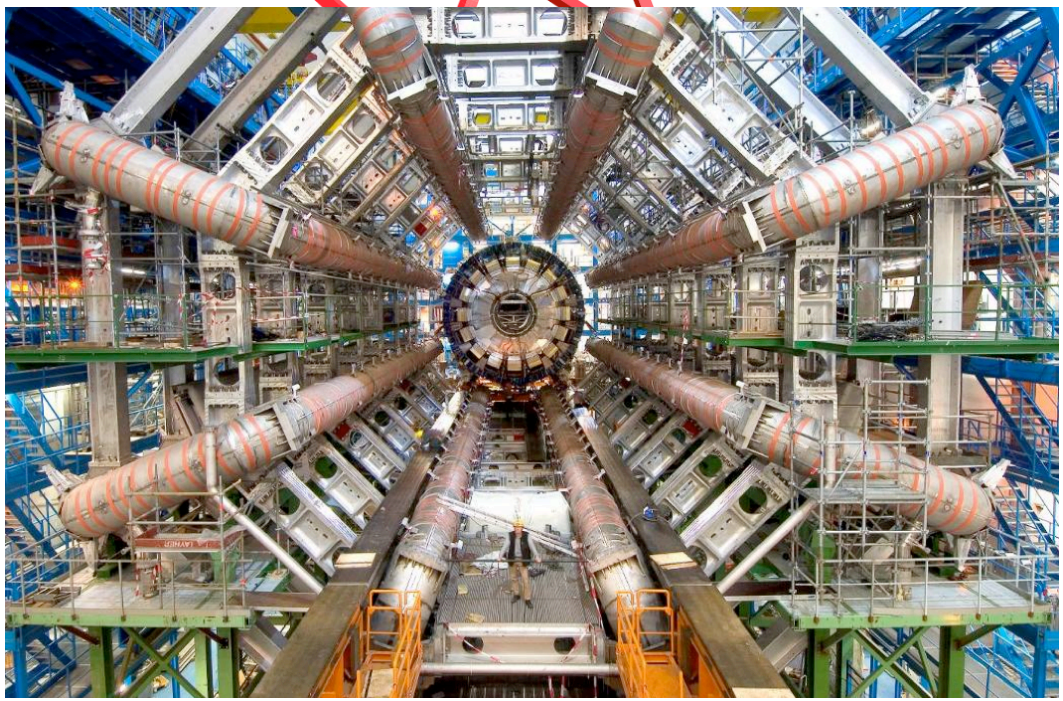
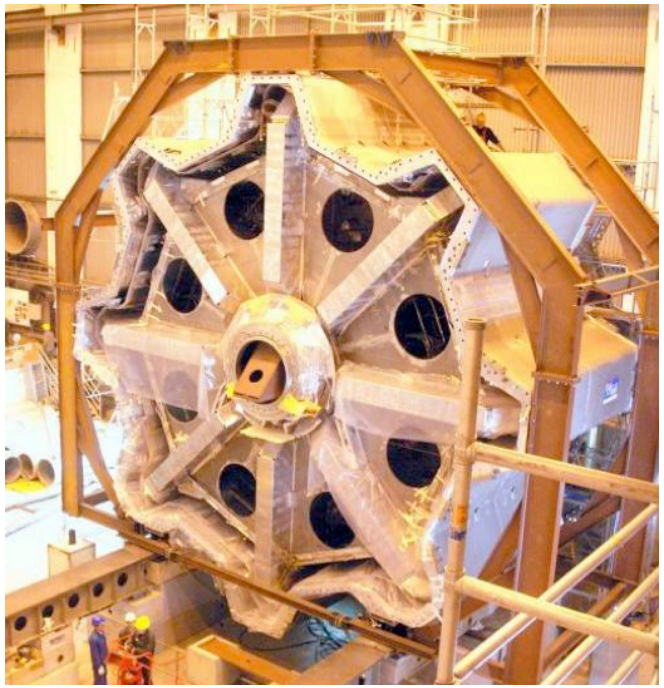
The Magnet System



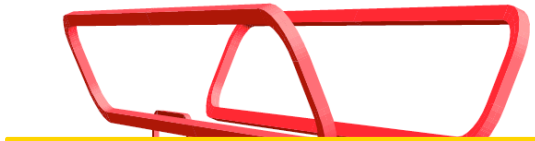
- Central solenoid (2T)
  - Return by the Tile iron
- Air core 8 fold structure (0.5 – 1 T useful)
  - Barrel toroids
  - EC toroids (240 tons objects)
- Sophisticated sensor and reconstruction of the B field map
- Heavy cryogenics system, Liquid He 4.5 K

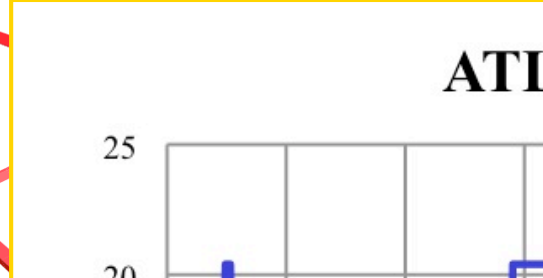


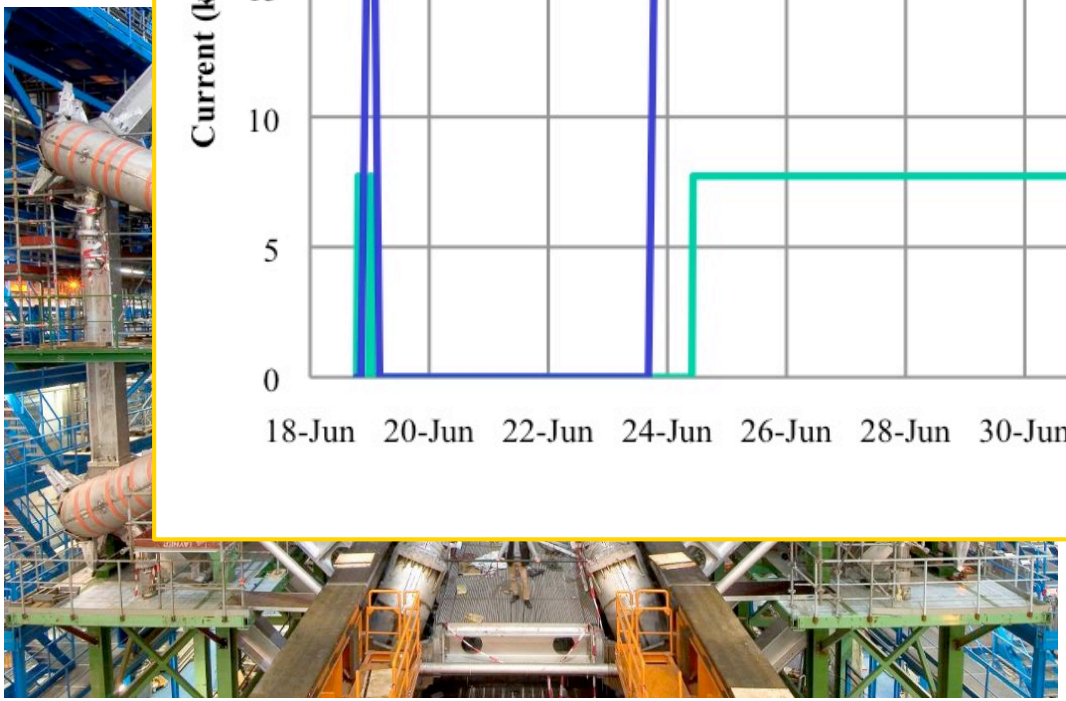


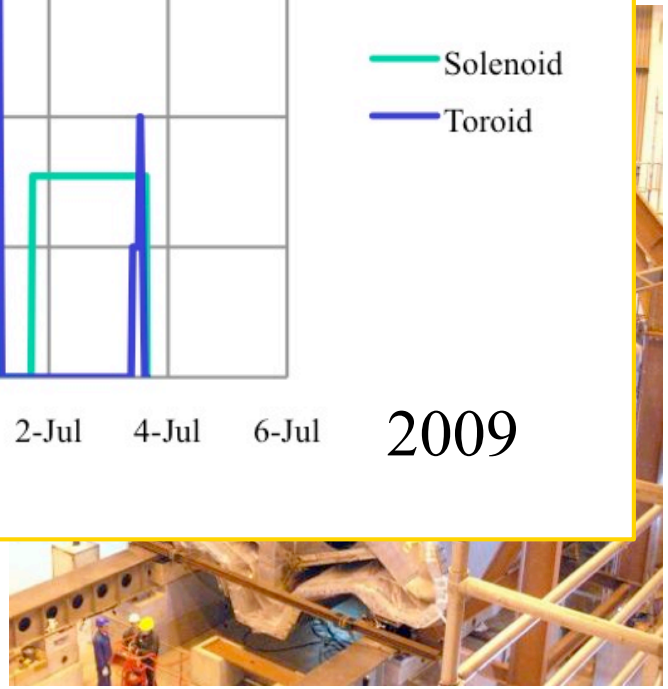
The Magnet System

- Central solenoid (2T)





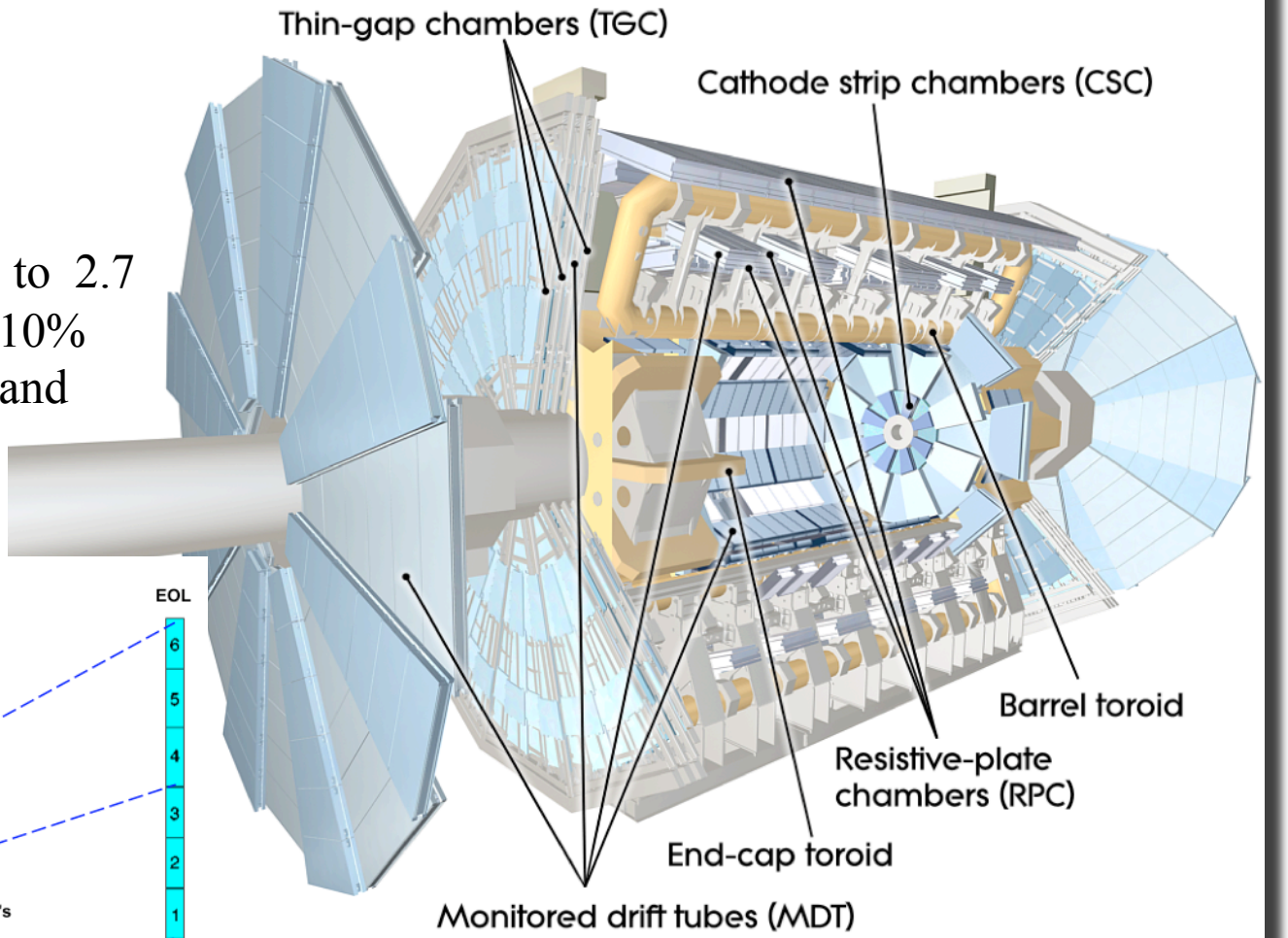


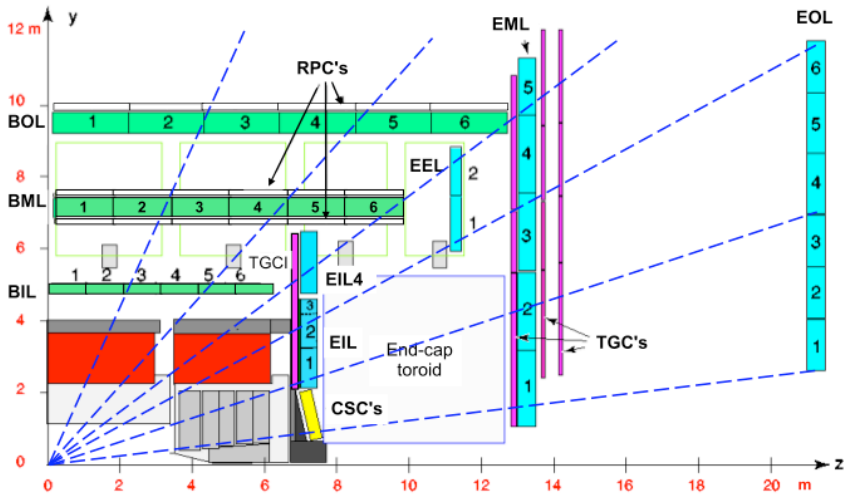


The Muon spectrometer

2 systems in one

- Precision chambers
  - Monitored Drift Tubes
  - Cathode Strip Chambers
- Trigger Chambers
  - Resistive Plate Chambers
  - Thin Gap Chambers
- Aim : $\Delta p_T/p_T = 10\%$ at 1 TeV up to 2.7
  - Equivalent to 500 μm with 10%
  - Constraints for positioning and alignment systems



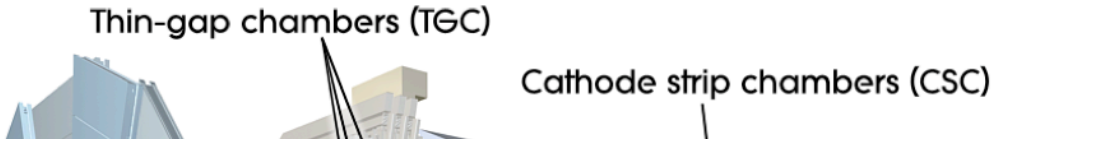


L. Hervas (CERN)

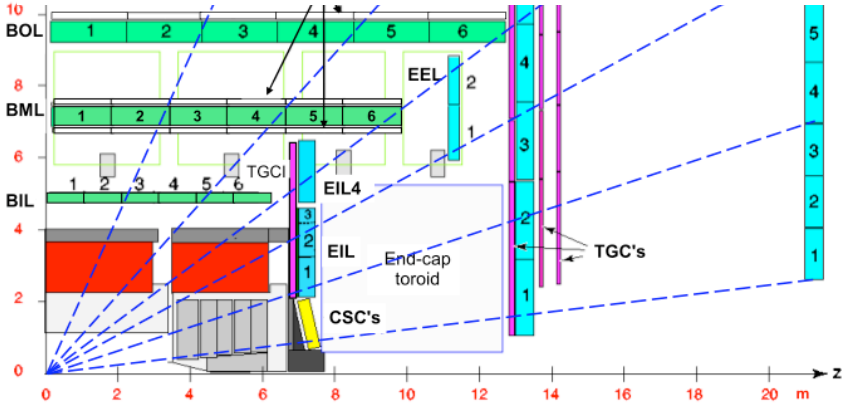
The Muon spectrometer

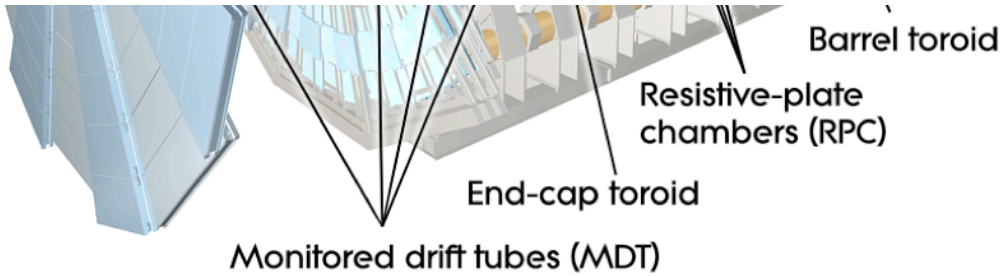
2 systems in one

- Precision chambers
  - Monitored Drift Tubes
  - Cathode Strip Chambers
- Trigger Chambers
- A



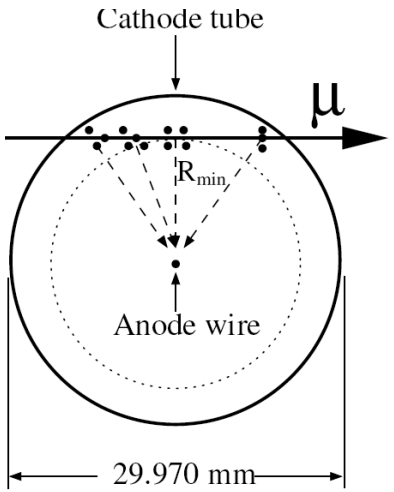
Detector component	Required resolution	η coverage	
		Measurement	Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\%\ p_T \oplus 1\%$	± 2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	± 3.2	± 2.5
Hadronic calorimetry (jets)			
barrel and end-cap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	± 3.2	± 3.2
forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 < \lvert\eta\rvert < 4.9$	$3.1 < \lvert\eta\rvert < 4.9$
Muon spectrometer	σ_{p_T}/p_T=10% at p_T = 1 TeV	± 2.7	± 2.4

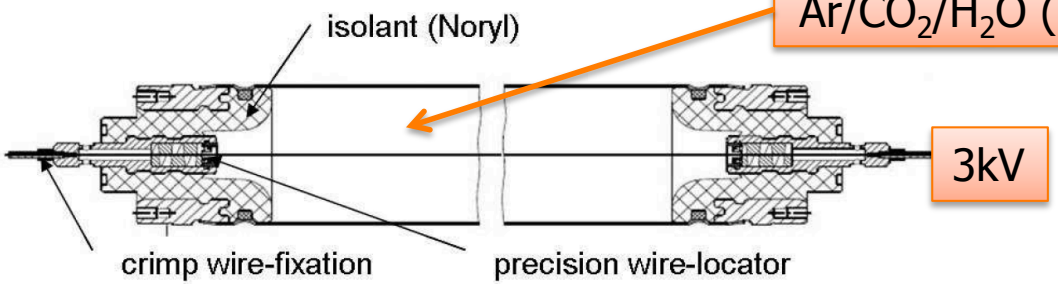




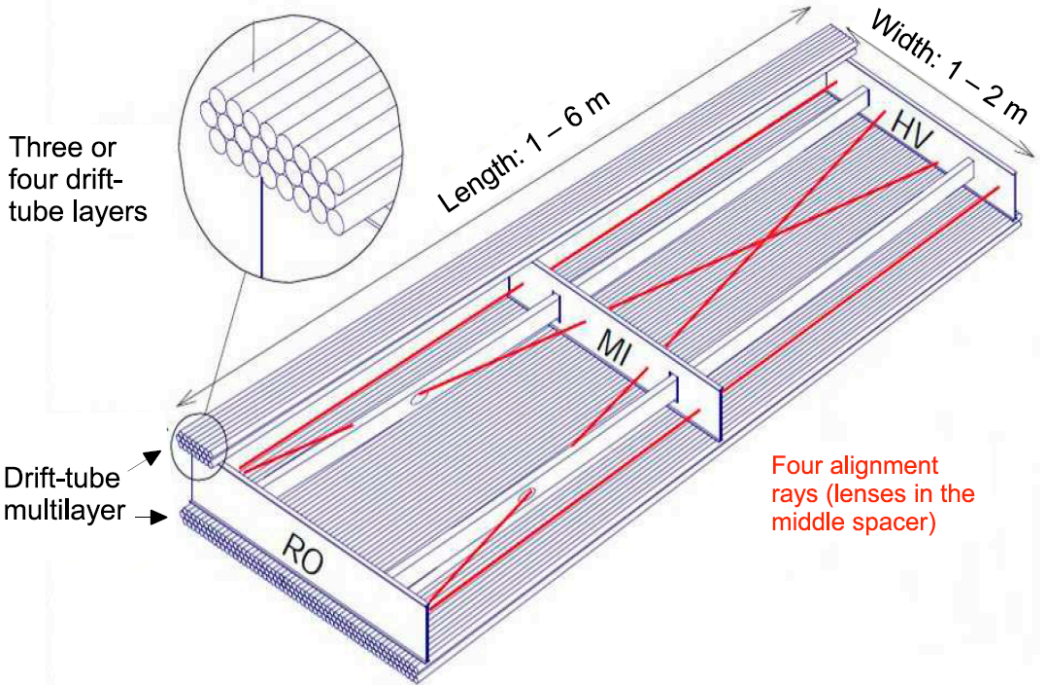
L. Hervas (CERN)

e.g. MDT tube



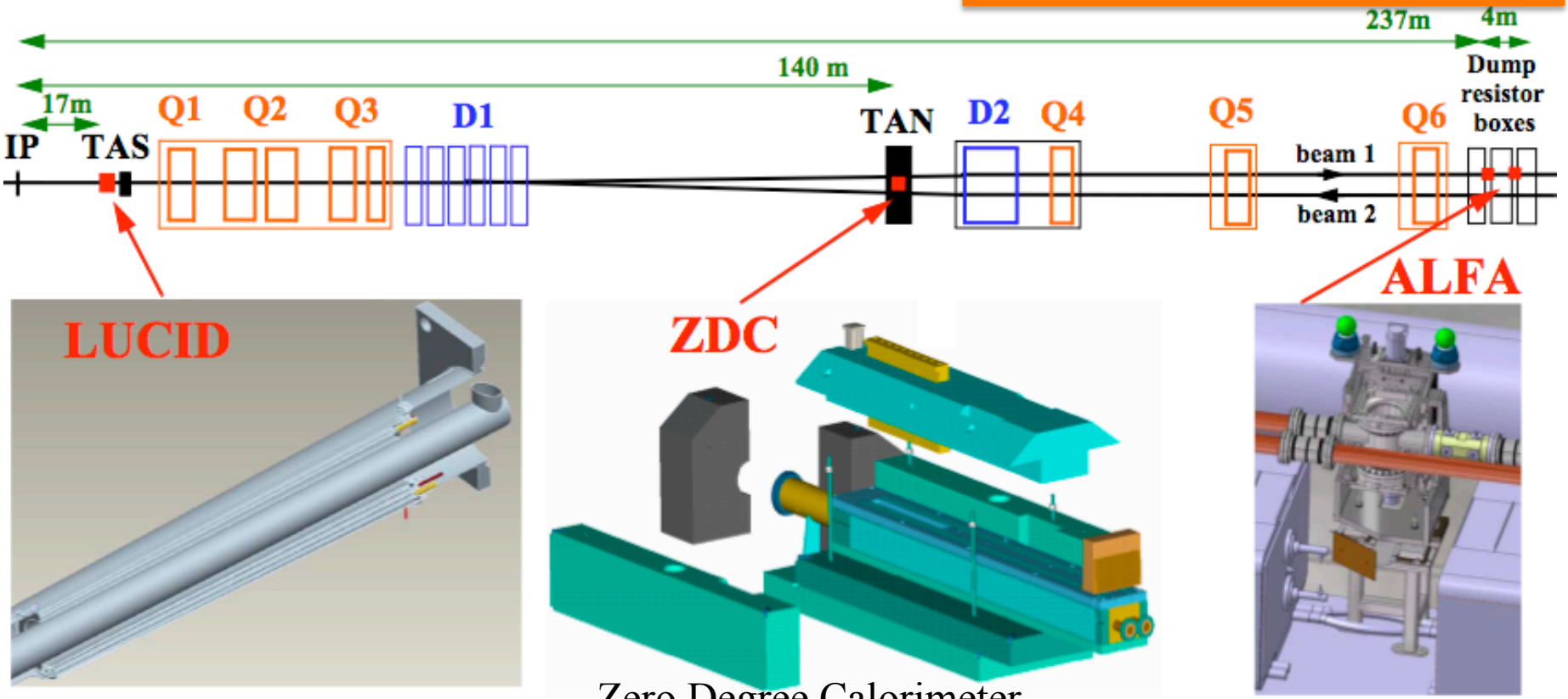


One MDT chamber



- 3 x2 layers of Al tubes
- Different lengths depending on the position
- Wires 50 μm Ø (W/Re)
- Alignment and deformation systems with LED/Optics/CDD built into the chambers

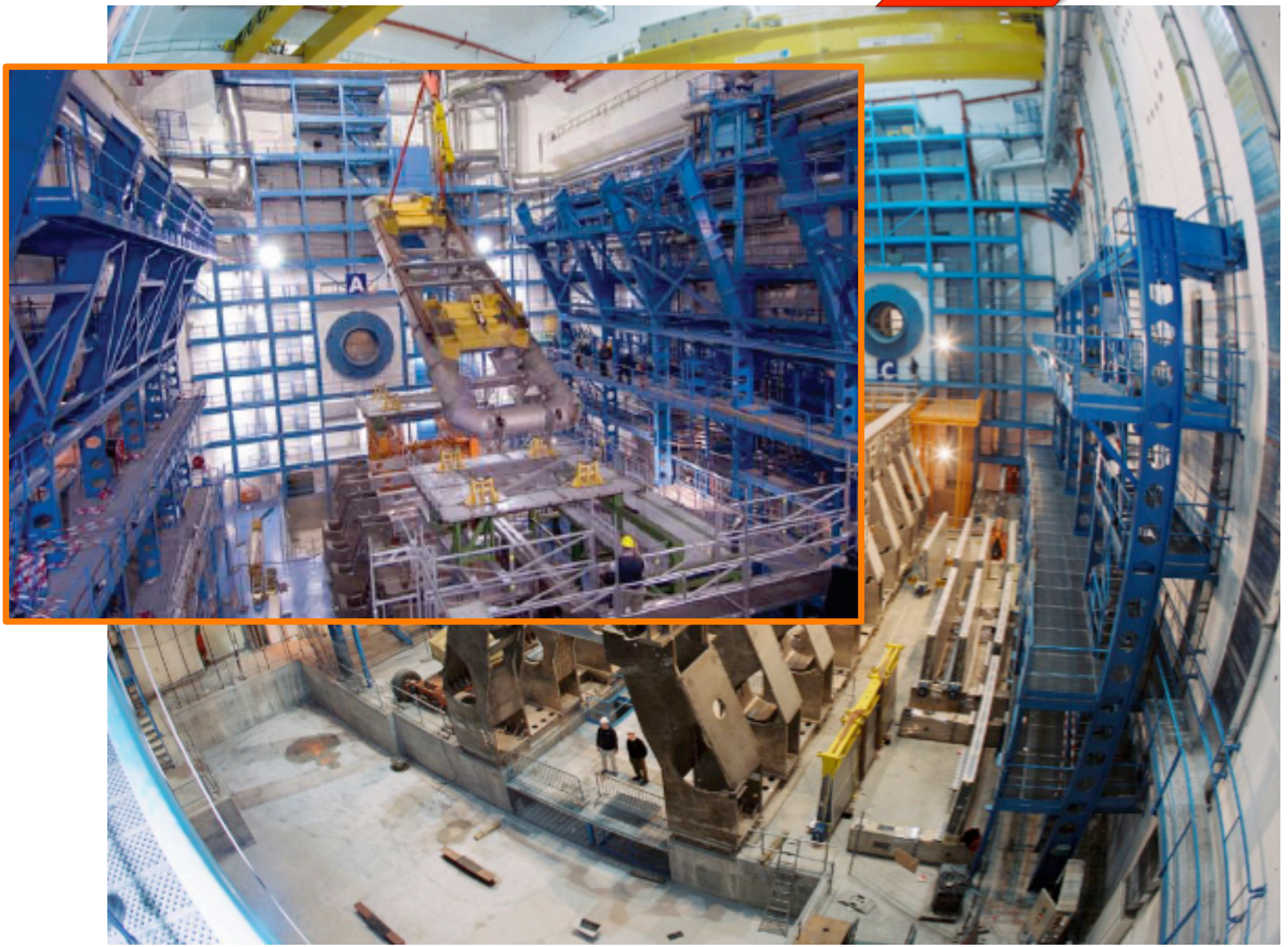
The Forward detectors

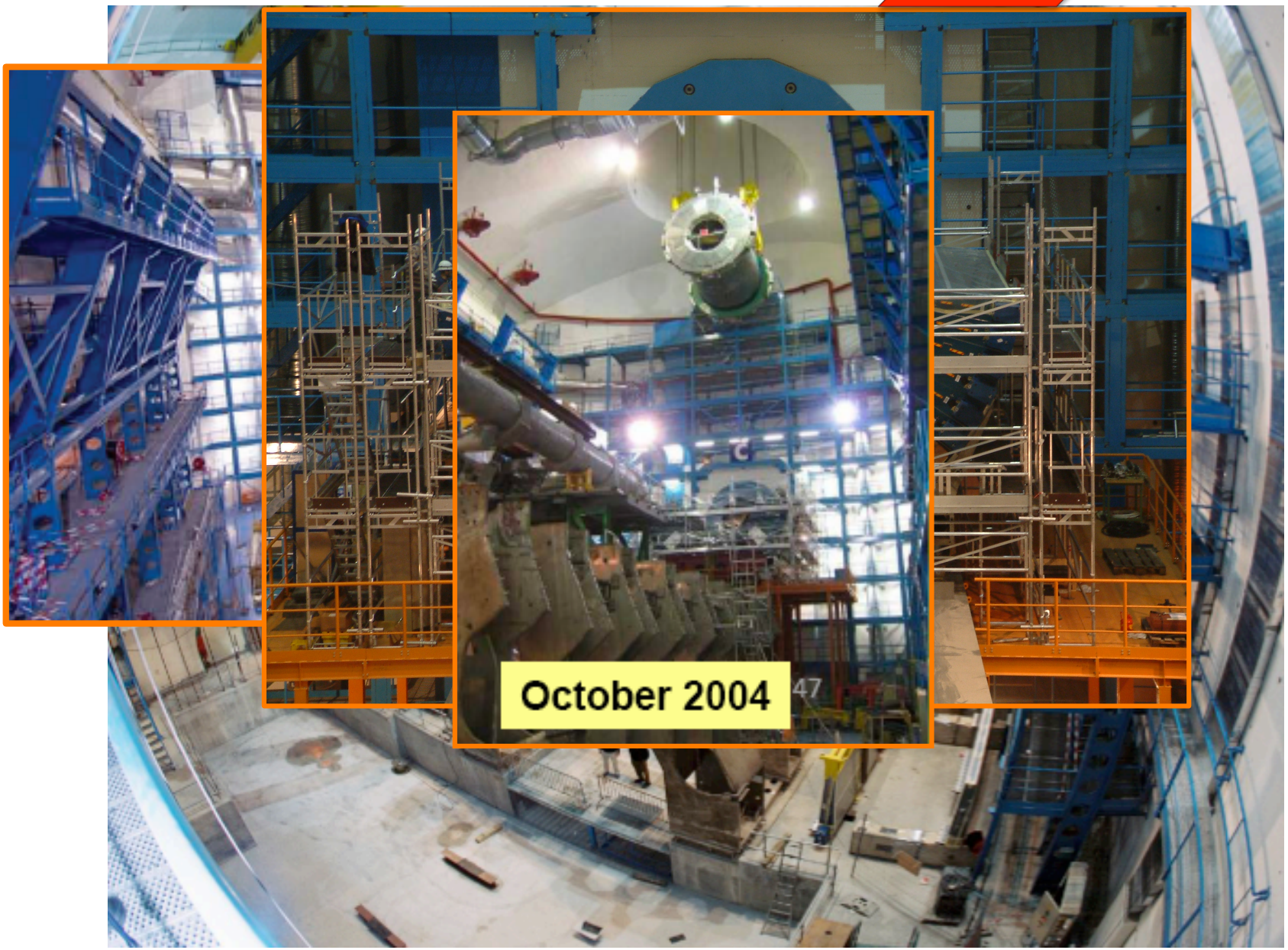


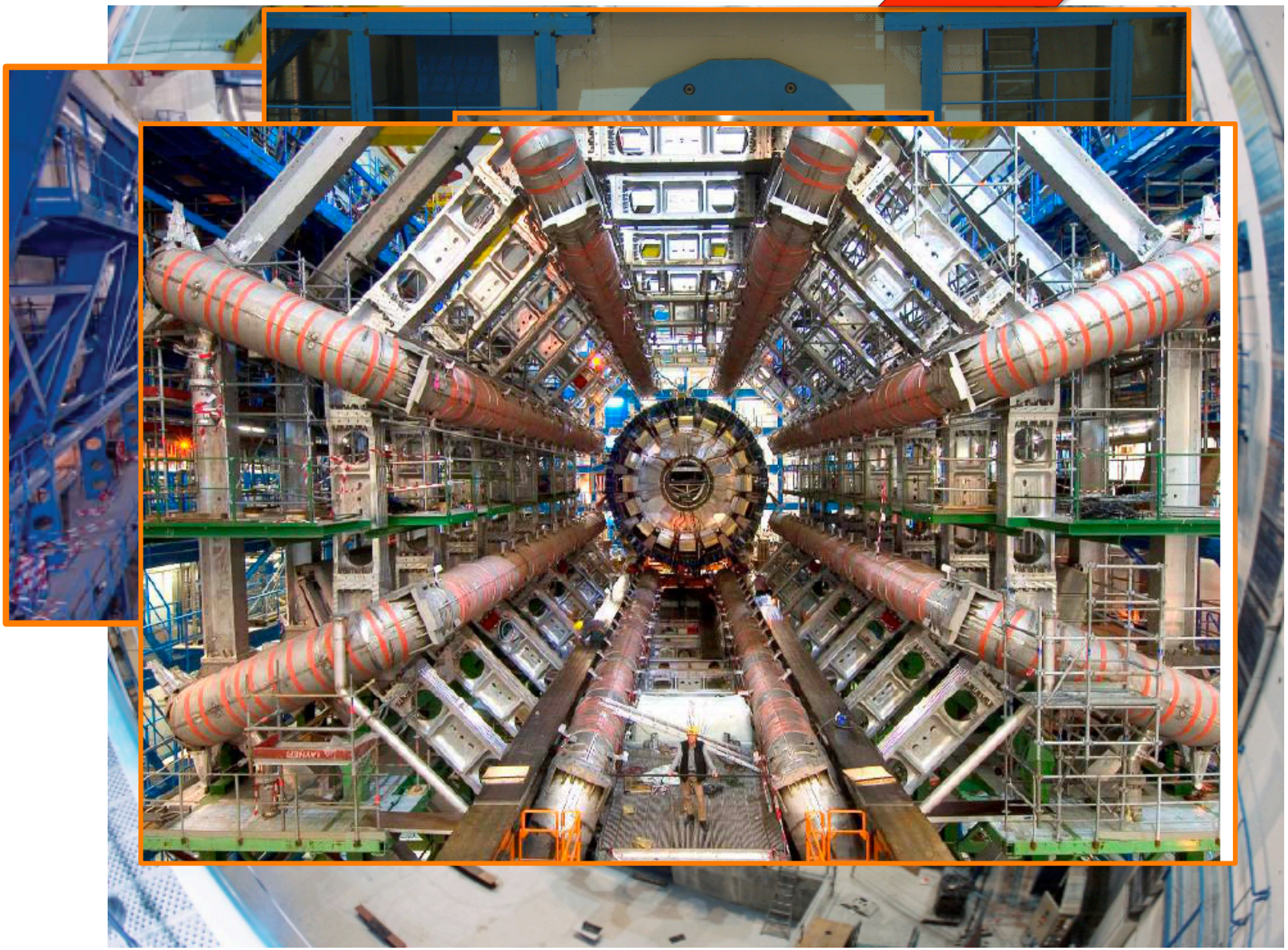
Lucid: relative luminosity with inelastic pp scattering
Cerenkov tubes around the BP

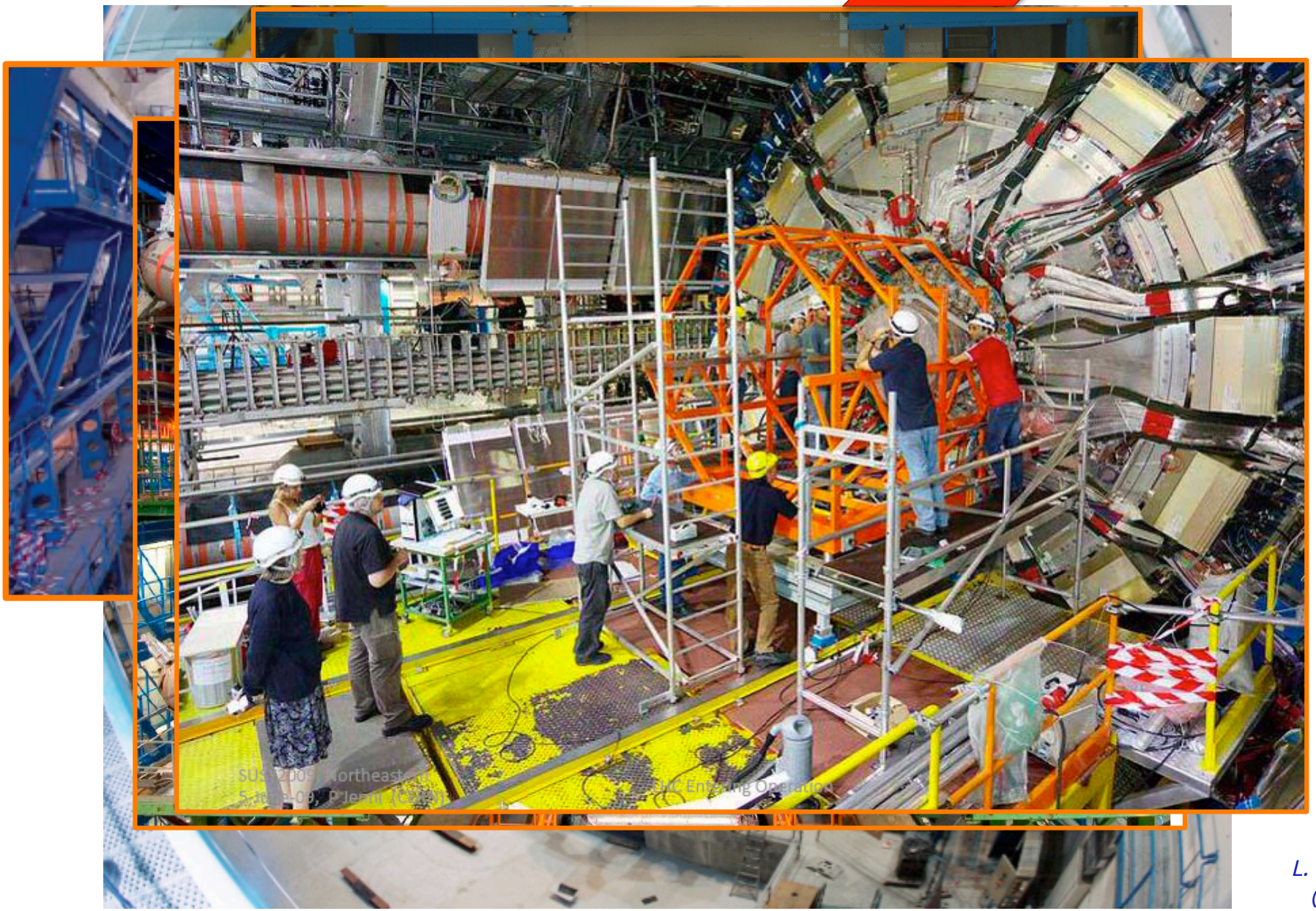
Zero Degree Calorimeter
W/Quartz
To detect forward neutrons in heavy ion collisions
Can help in vertex determination
in preliminary running

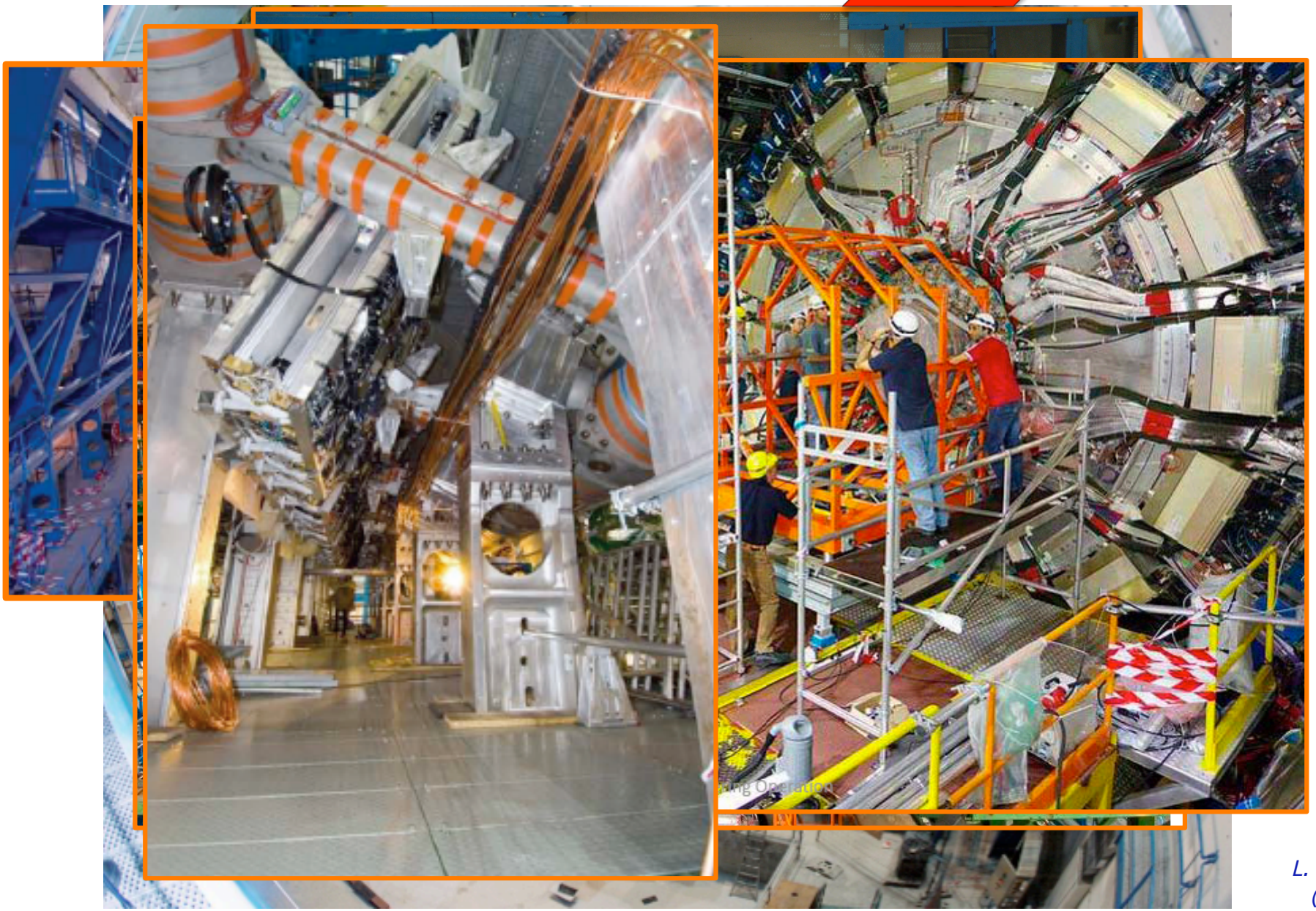
ALFA: absolute luminosity with elastic pp scattering at small angles
Sci fiber tracker placed in Roman pots

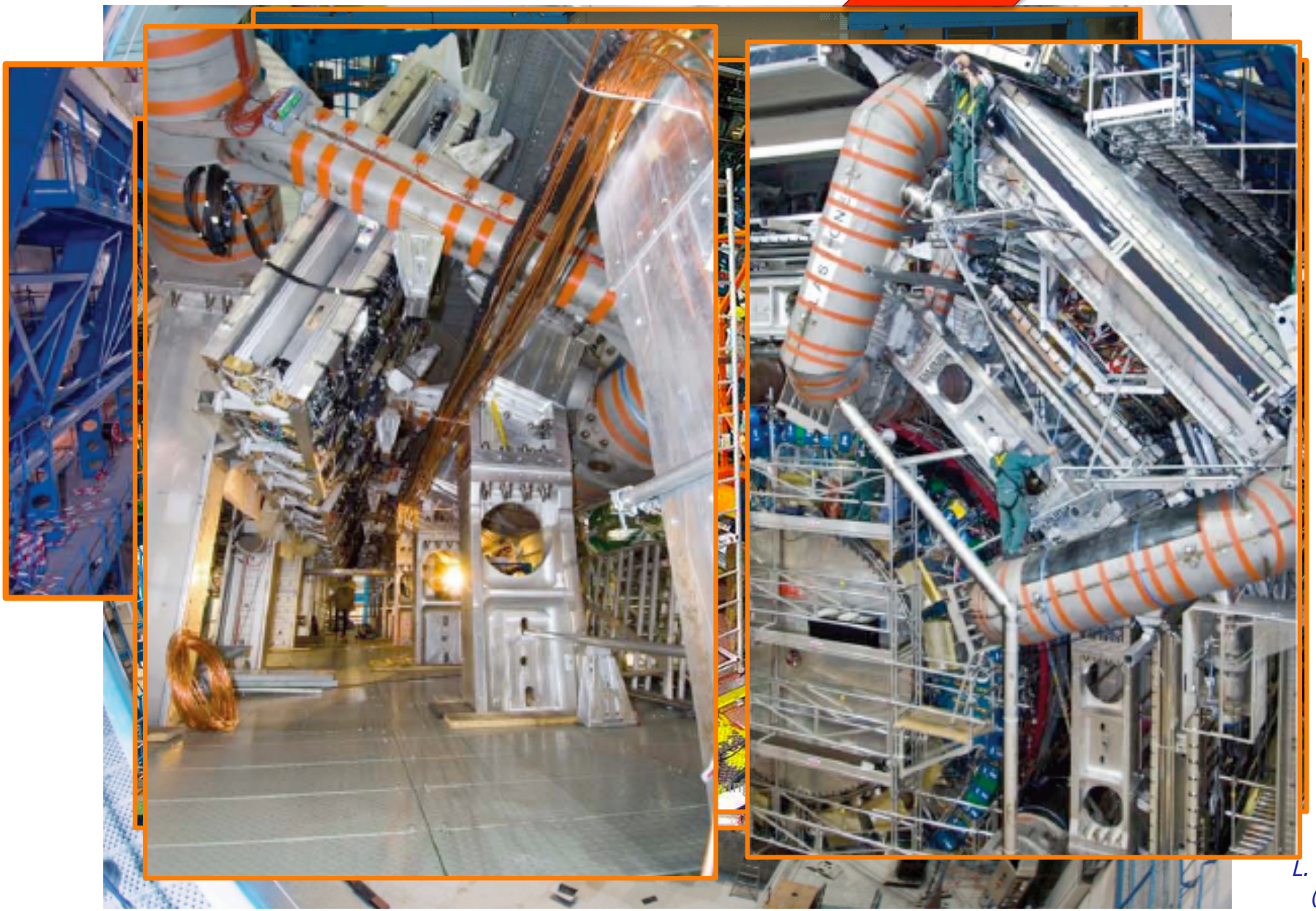


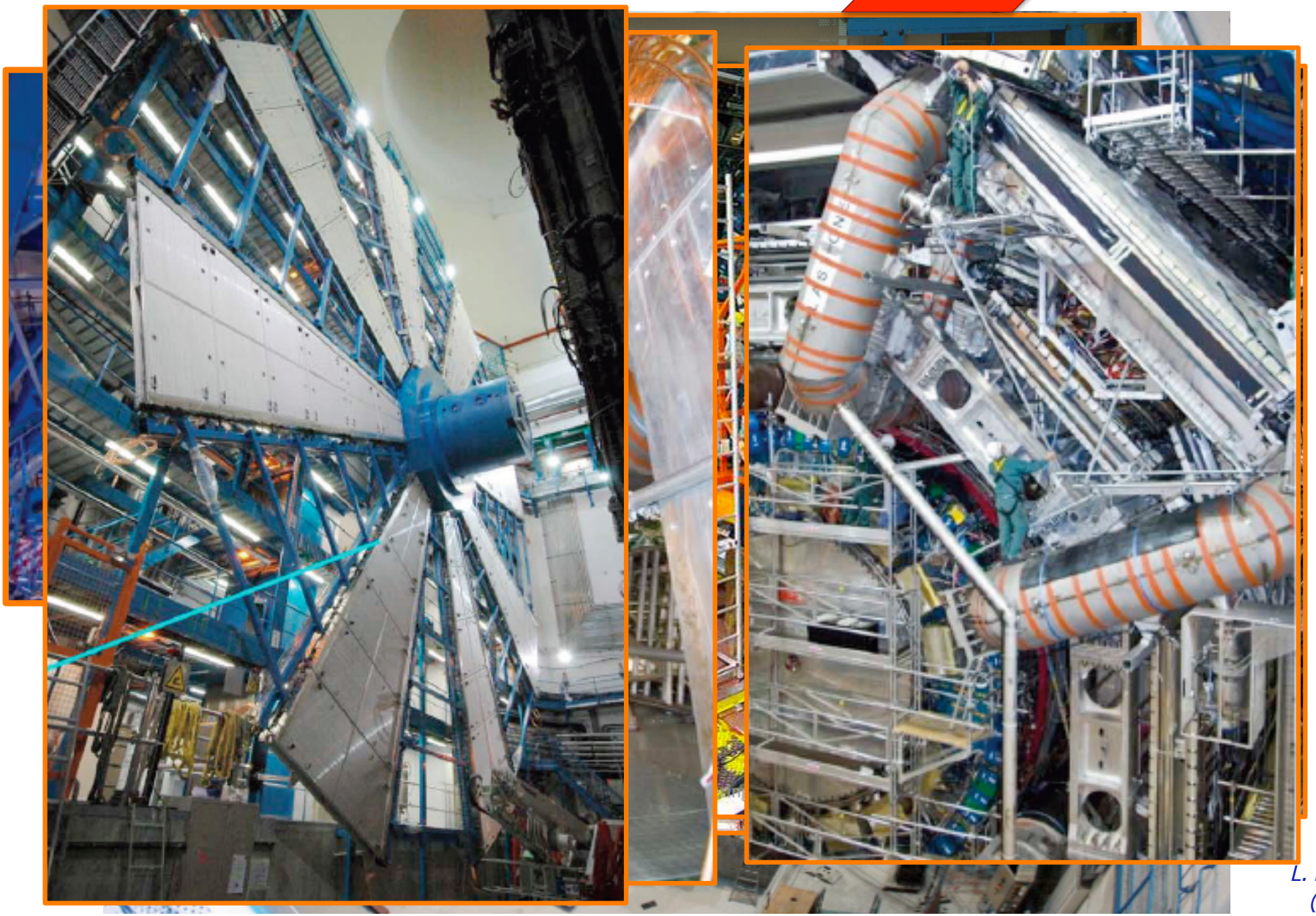

October 2004



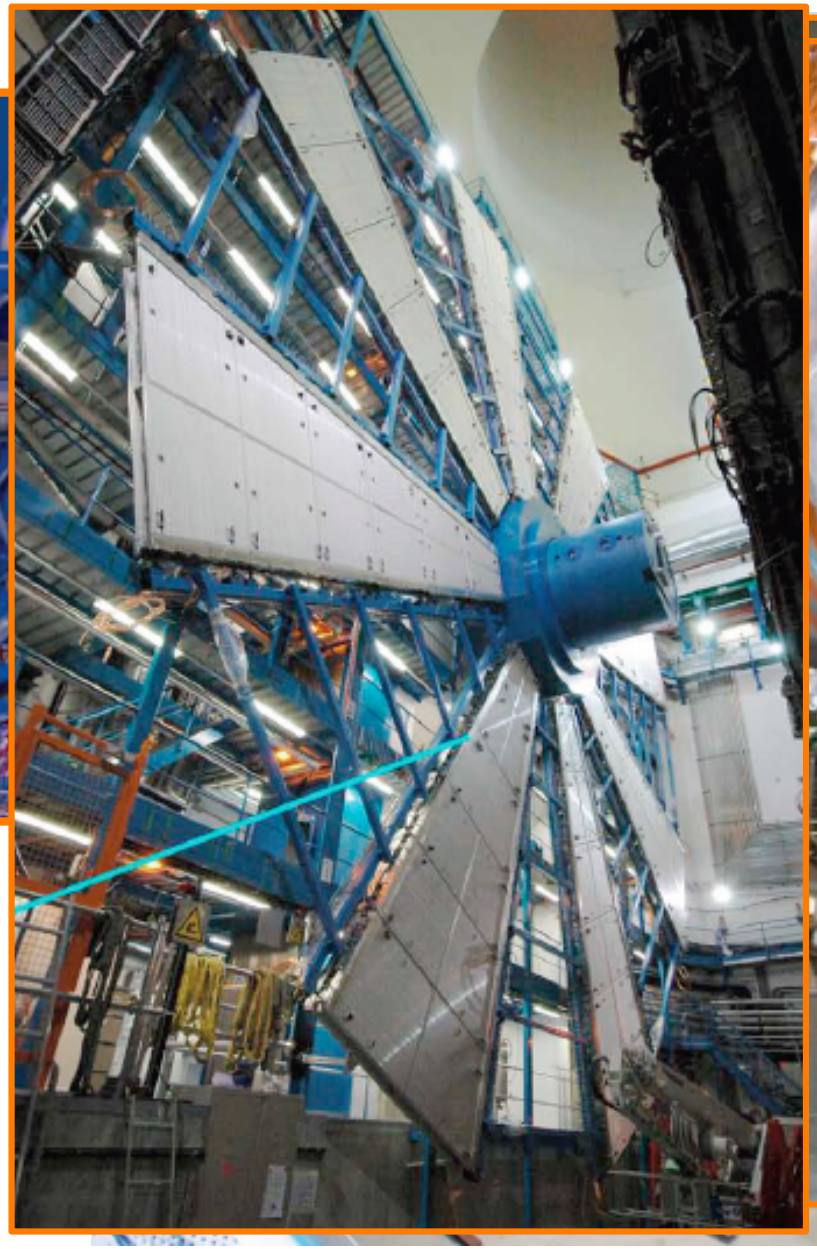


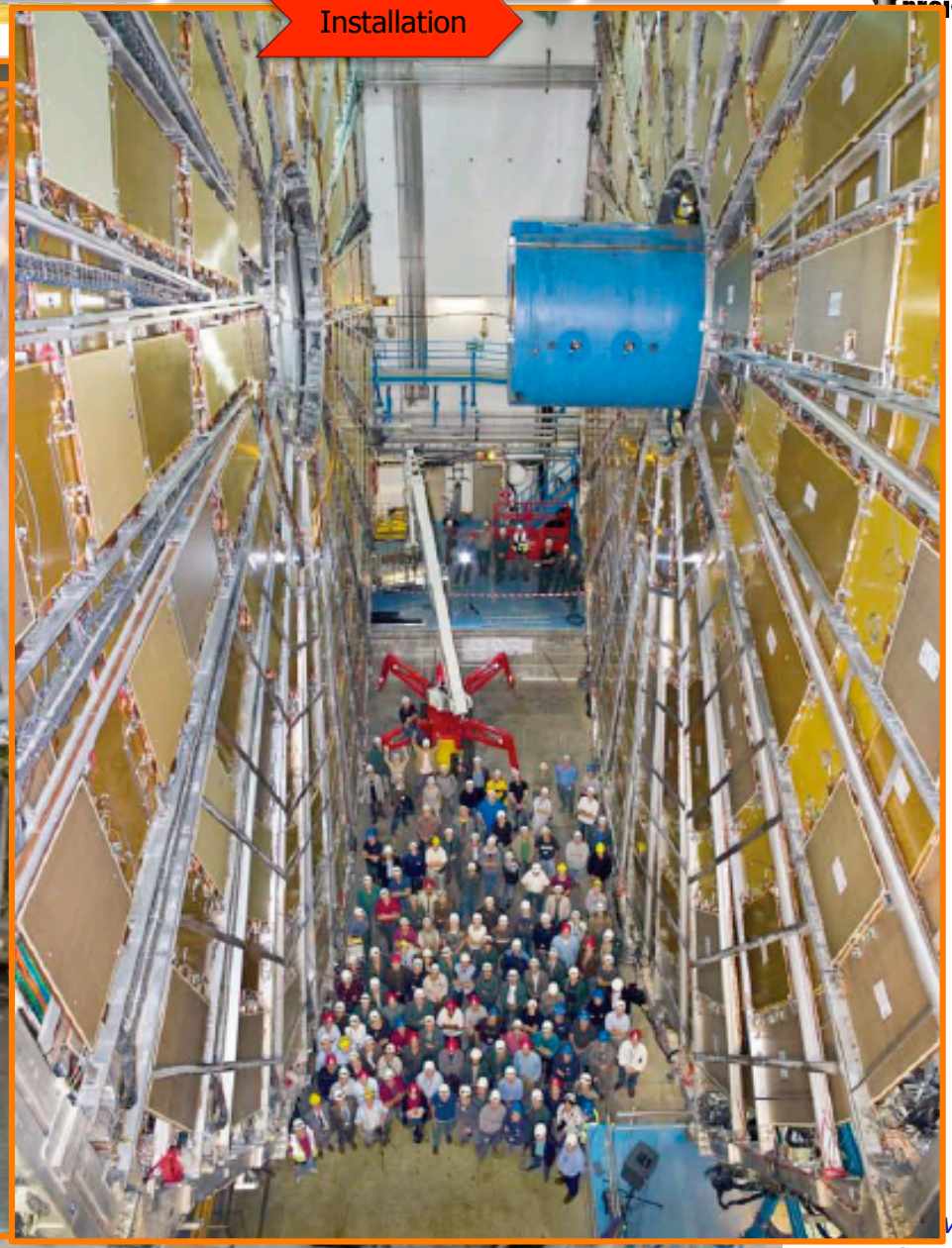






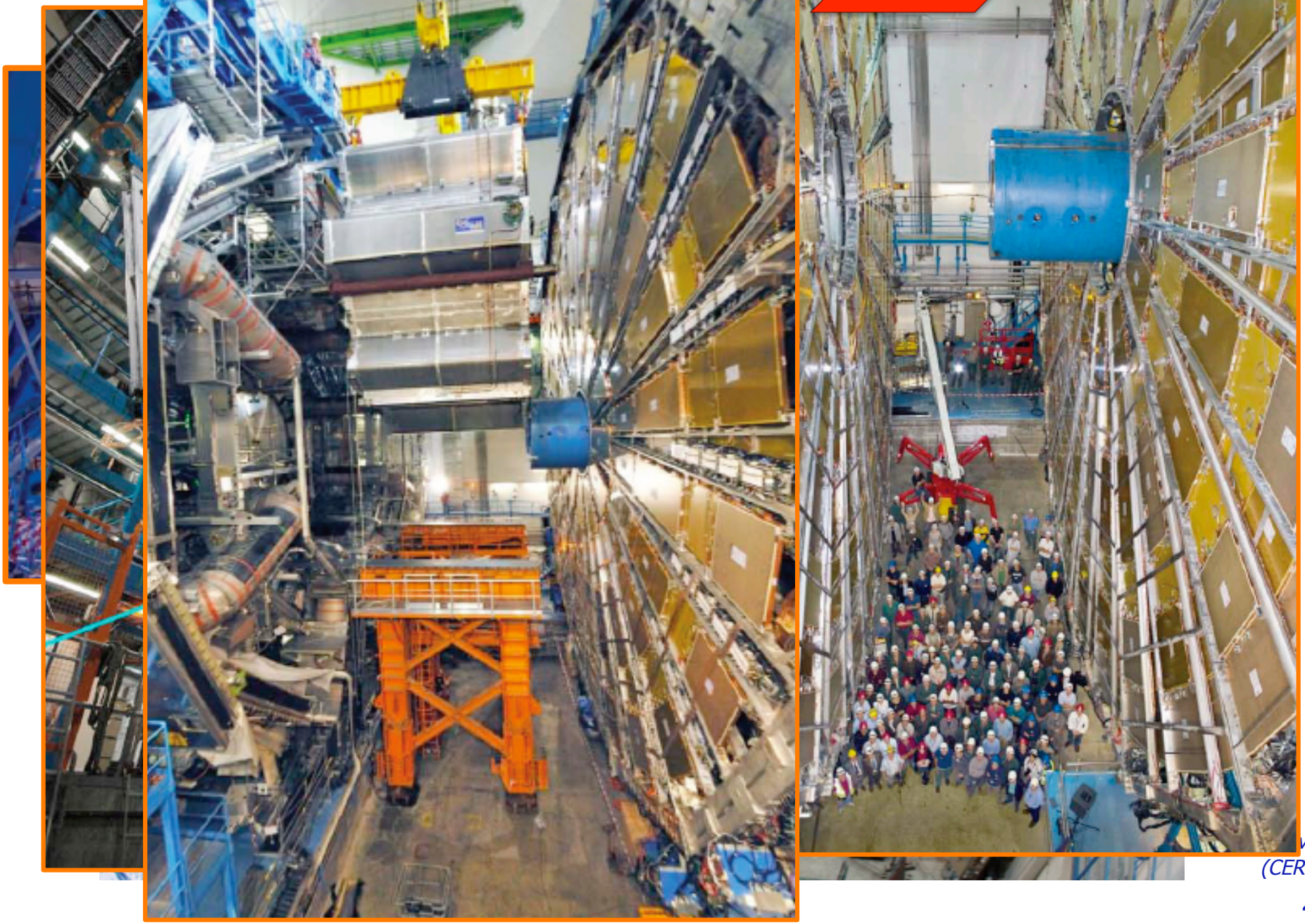
Installation

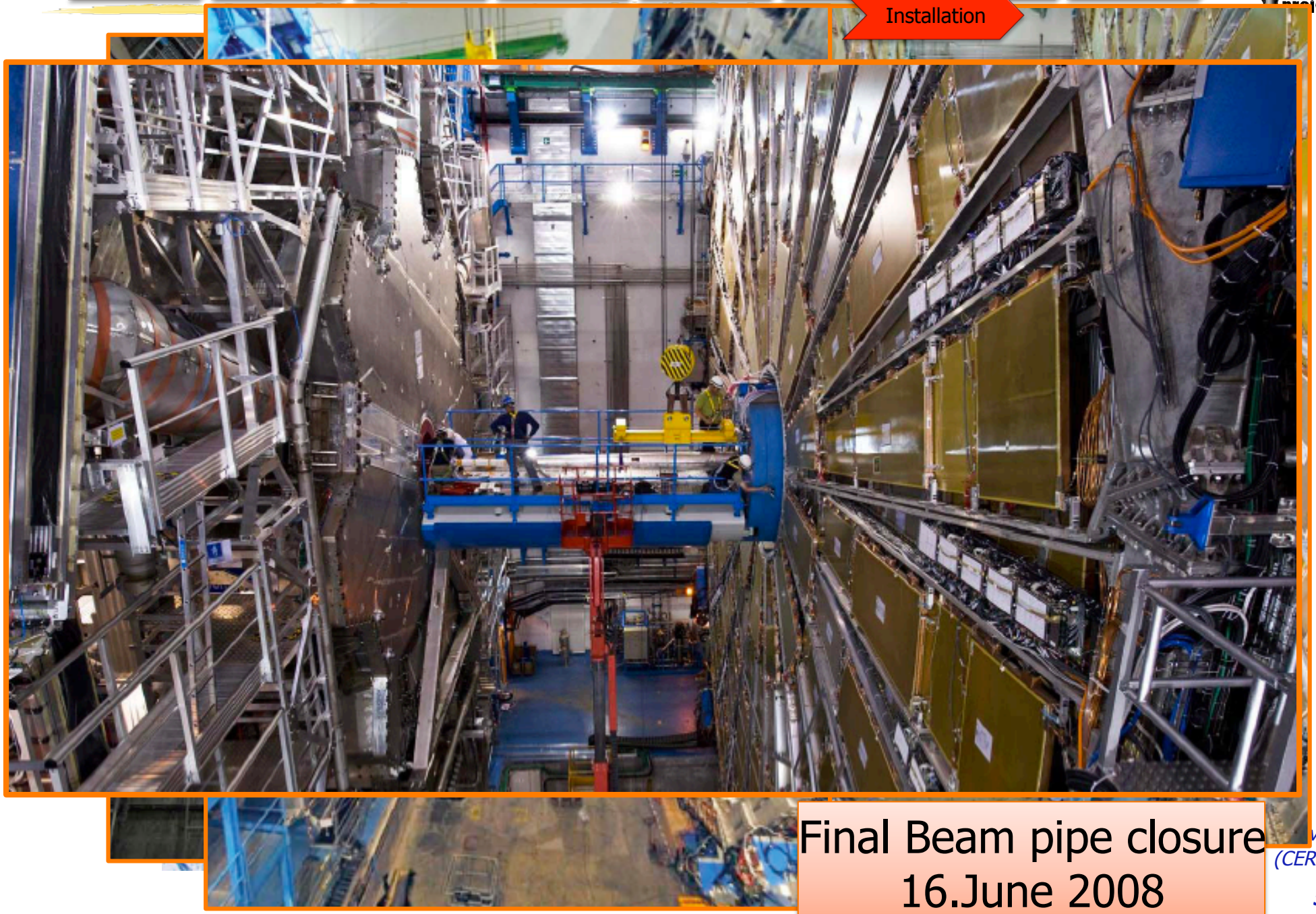




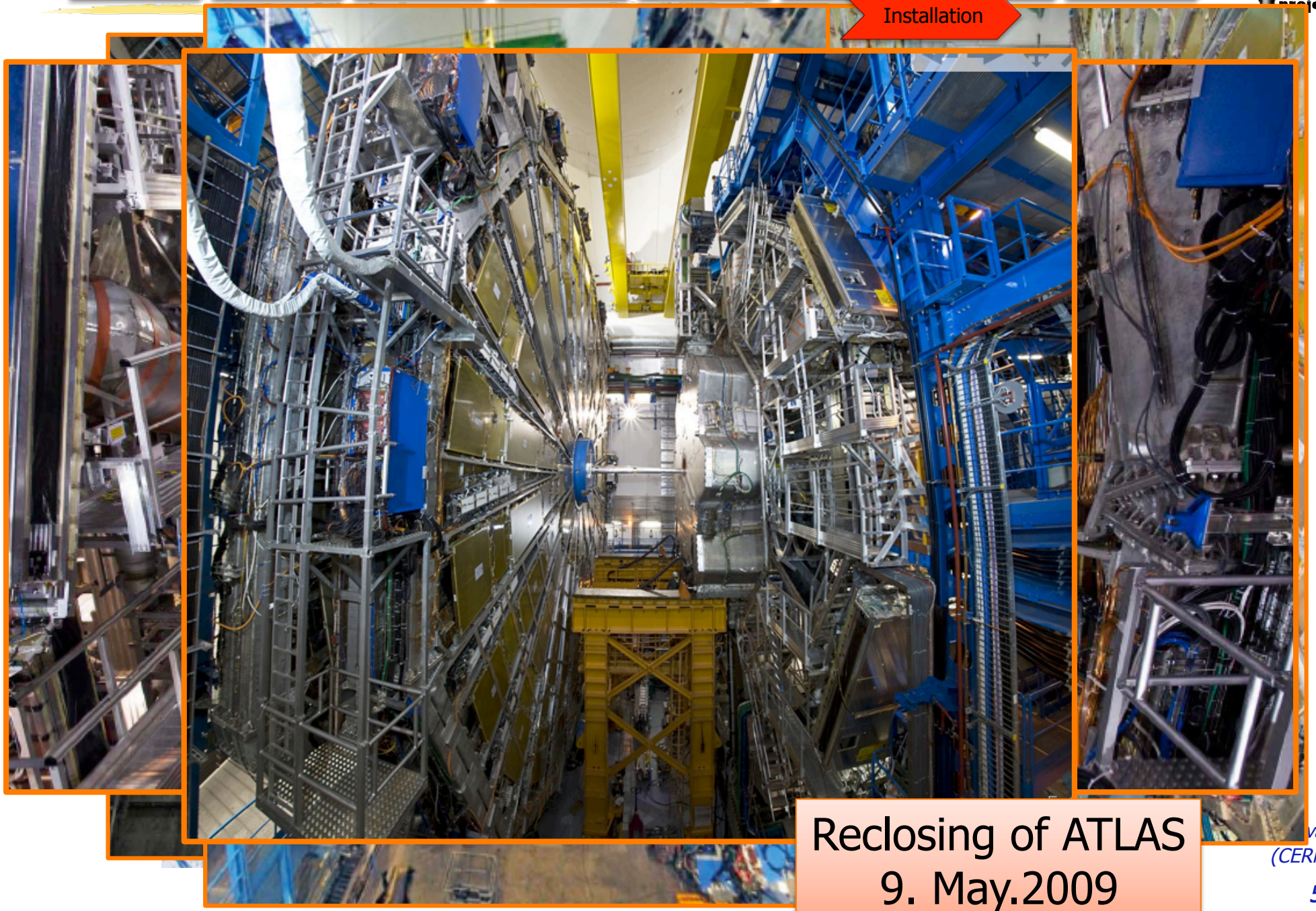
vas (CERN)

Installation



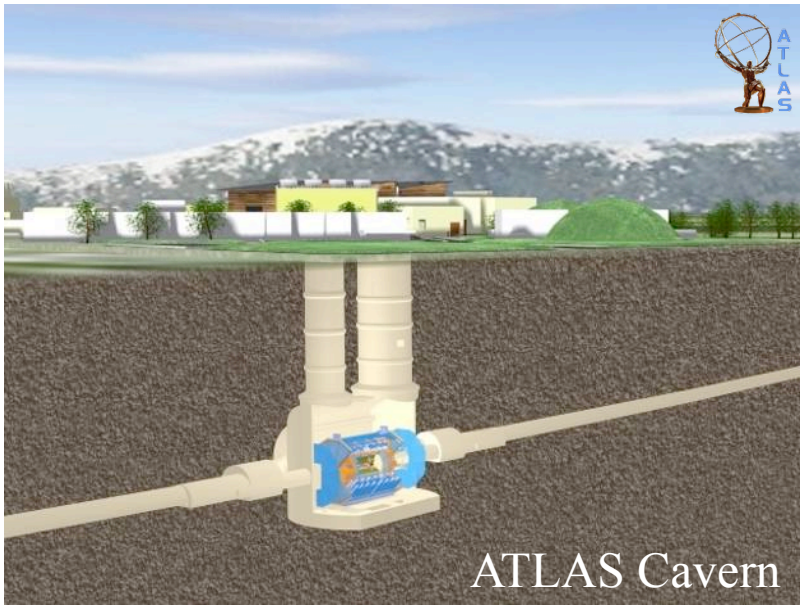


Final Beam pipe closure
16.June 2008

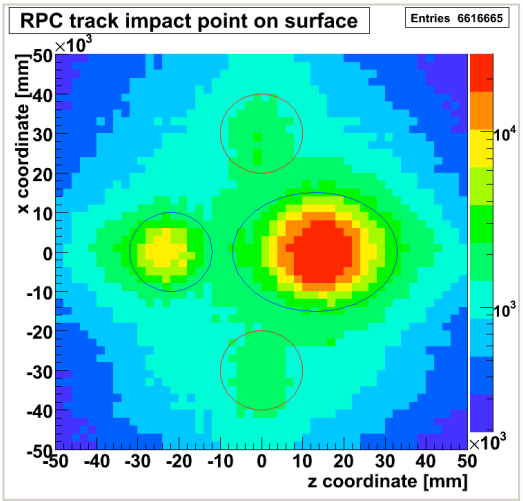


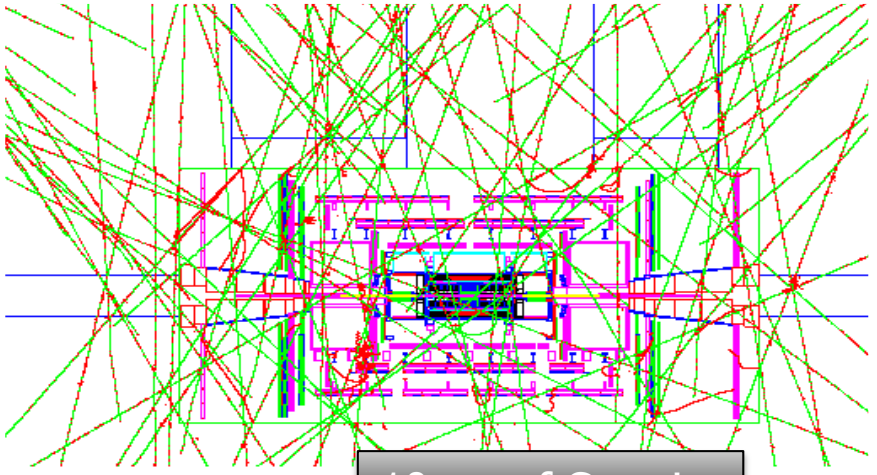
Reclosing of ATLAS
9. May.2009

Global Commissioning with cosmics

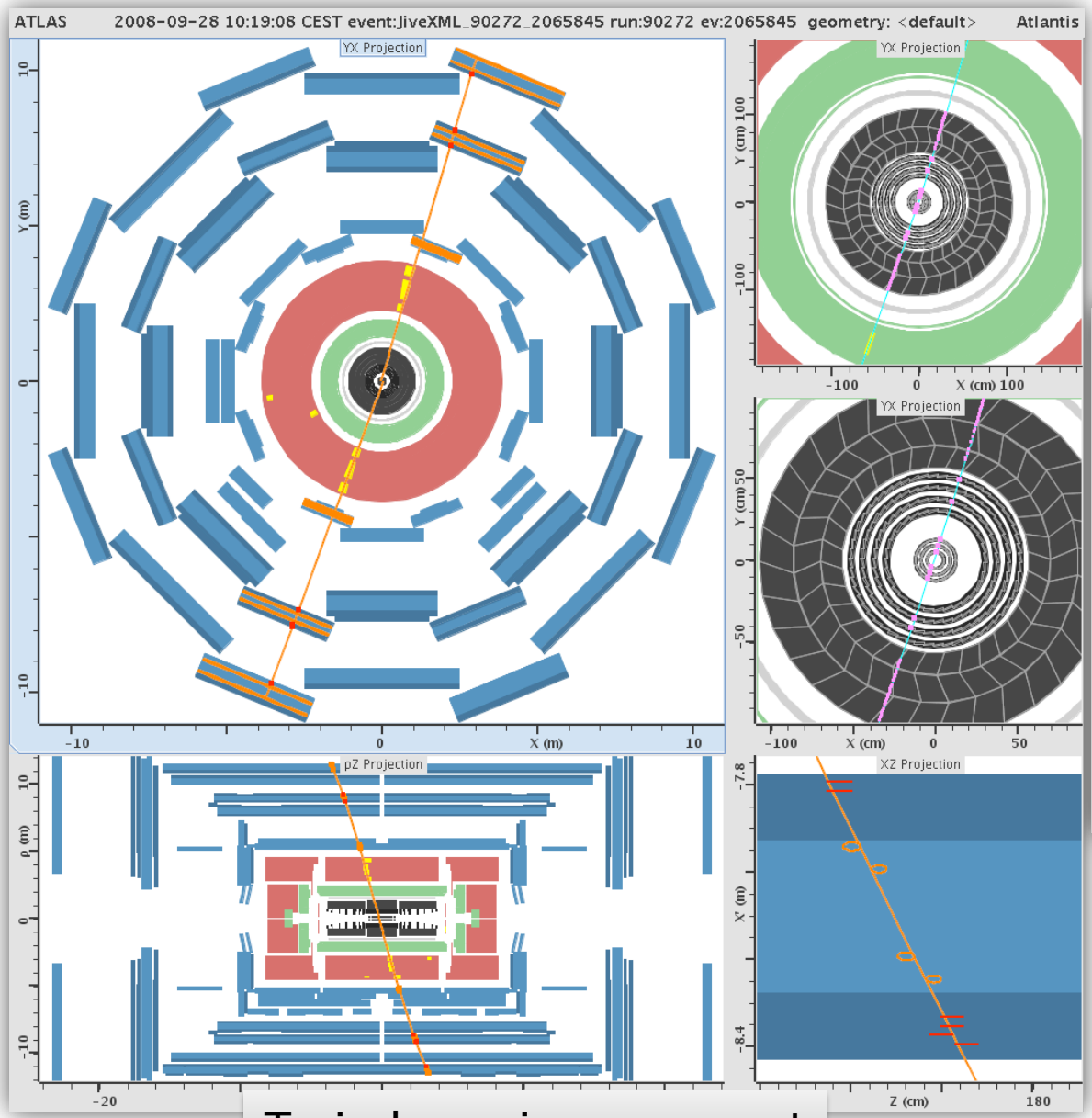


Ongoing since 2005
In parallel to detector installation and commissioning
~4 kHz in muon volume
~15 Hz in ID volume
Typ. ~ 4 GeV <E>

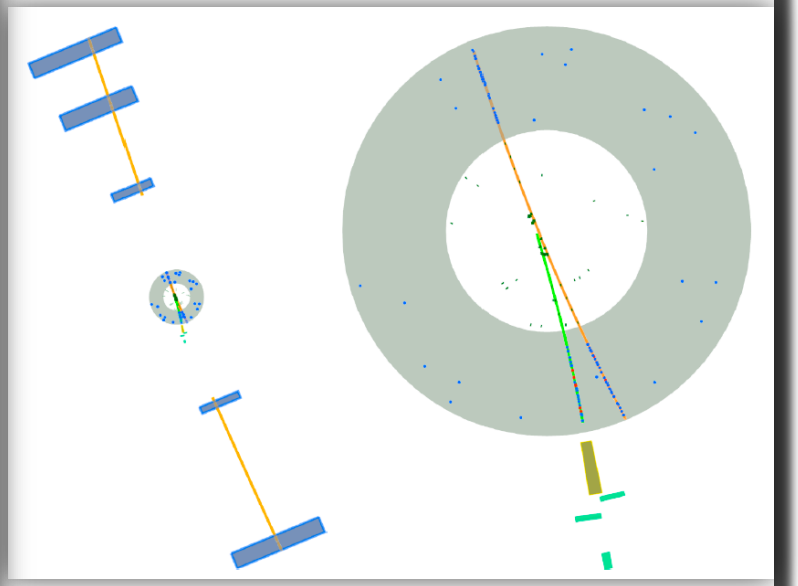




L. Hervas (CERN)



Typical cosmic muon event



Selected electron event
(from ionization)
~30 out of 3M events

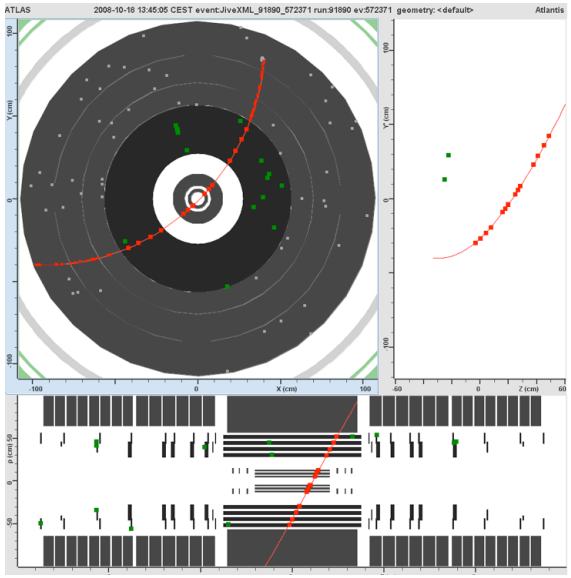
L. Hervas
(CERN)

Main objectives :

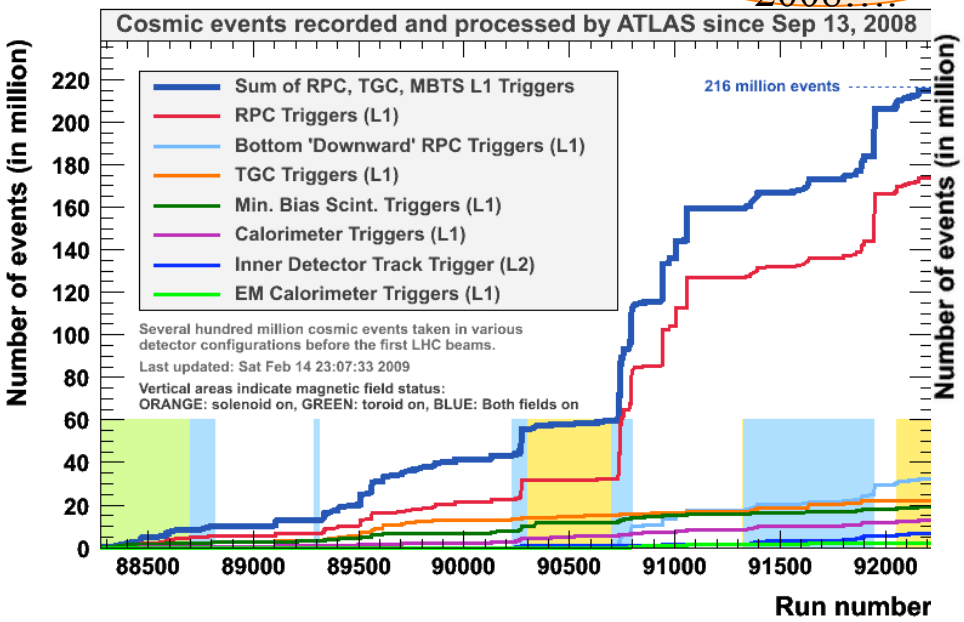
- Test readout of all detectors
  - Non-functioning channels
  - Noise
- Operation and Stability of all HW
- Online SW
- Detector performance
- Alignment, Calibration…

- Operate the full detector like “with beam”

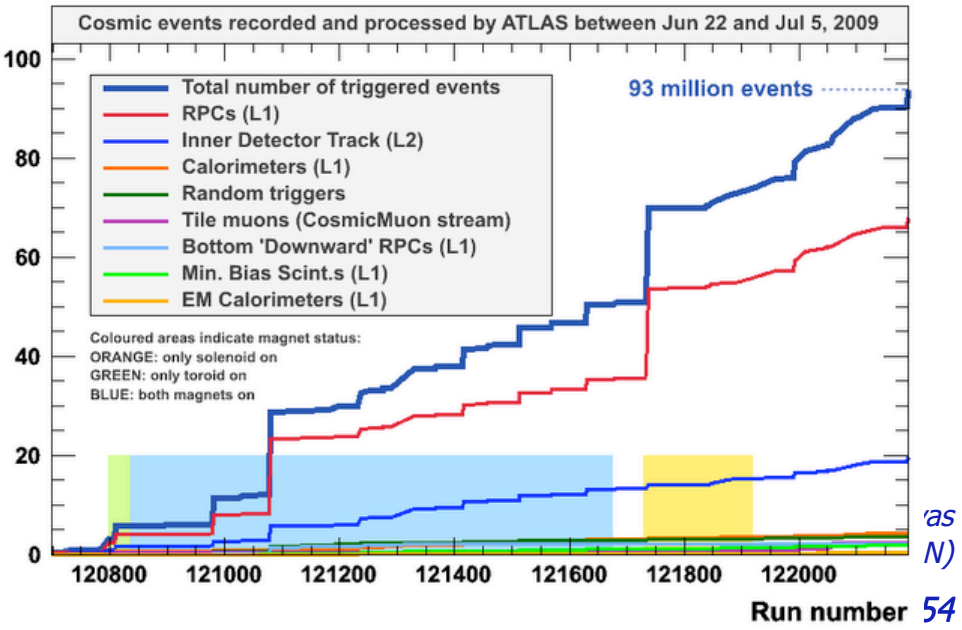
e.g. ID hits



2008….



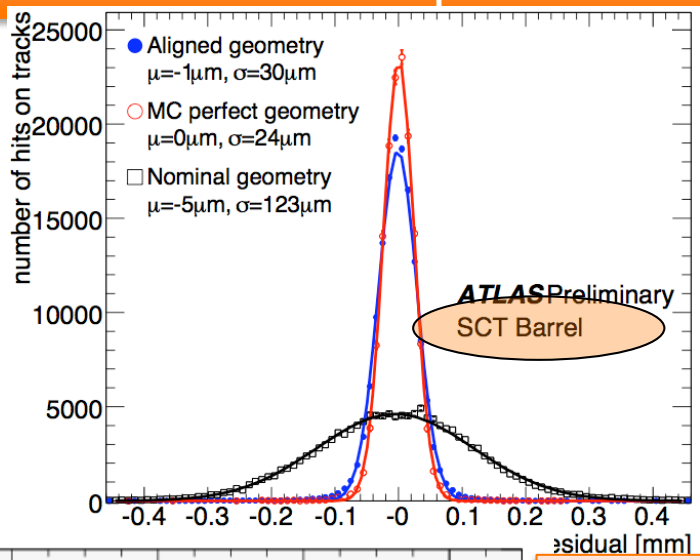
2009….

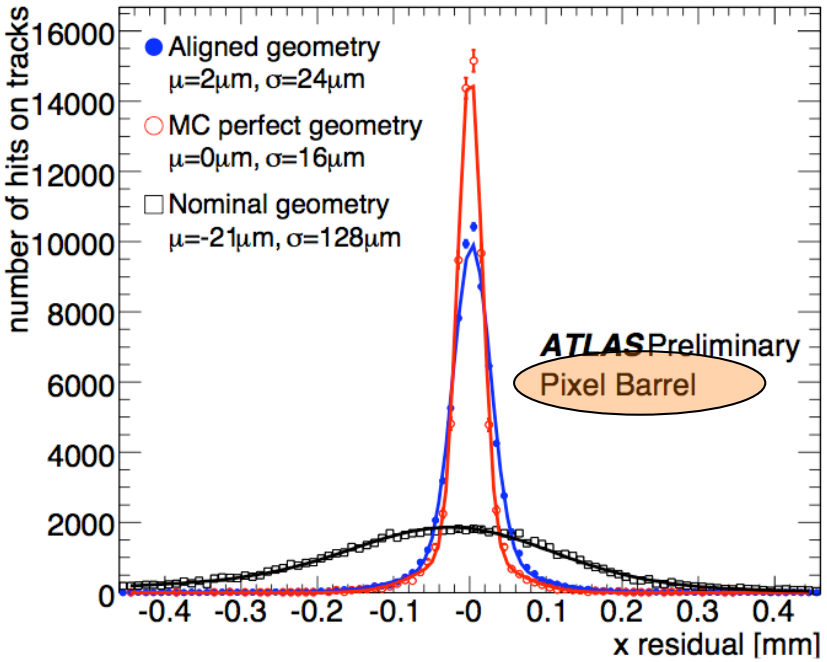


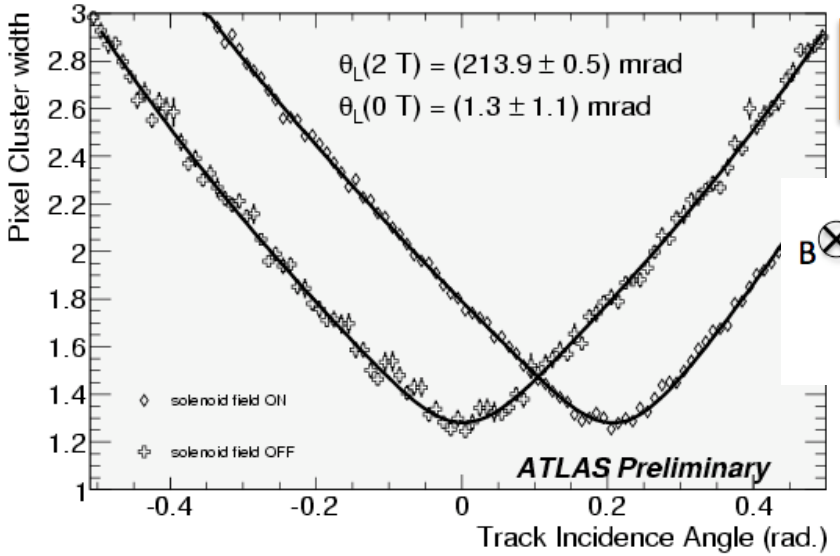
Few results of detector perfomance

ID Detectors alignment

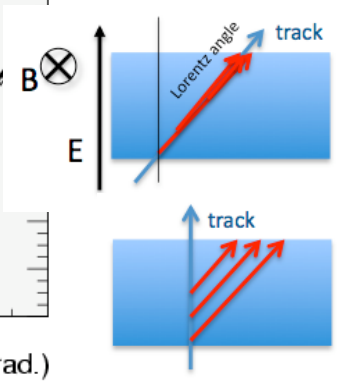
- Determine position (and rotation) of each module by minimization of hit residuals
  - (iterative procedure)
- Plot residuals before and after alignment
- Cuts : pt> 2 Gev, passing through inner pixel layer
- In Barrel : close to nominal position resolution







Expected 225 mrad @2T

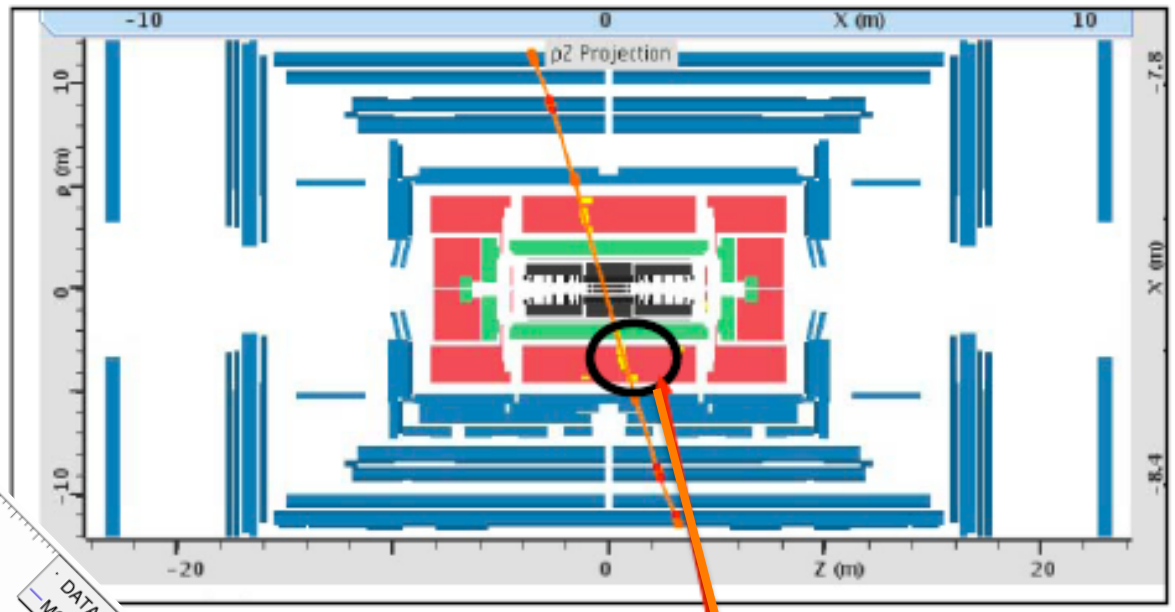


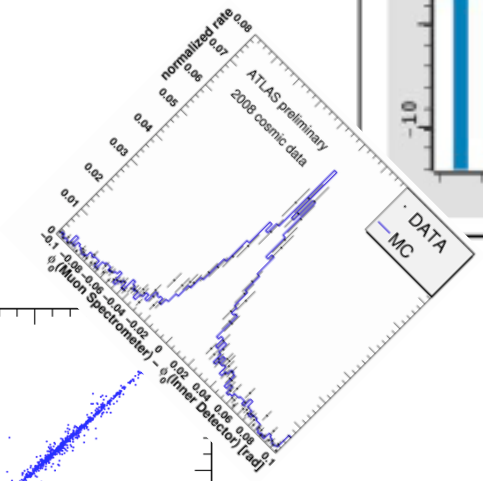
Lorentz angle in the pixels

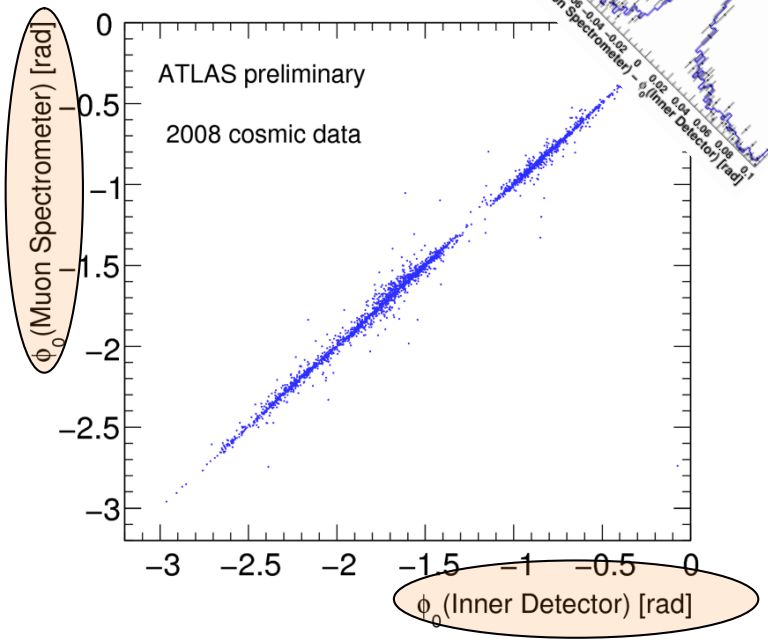
L. Hervas (CERN)

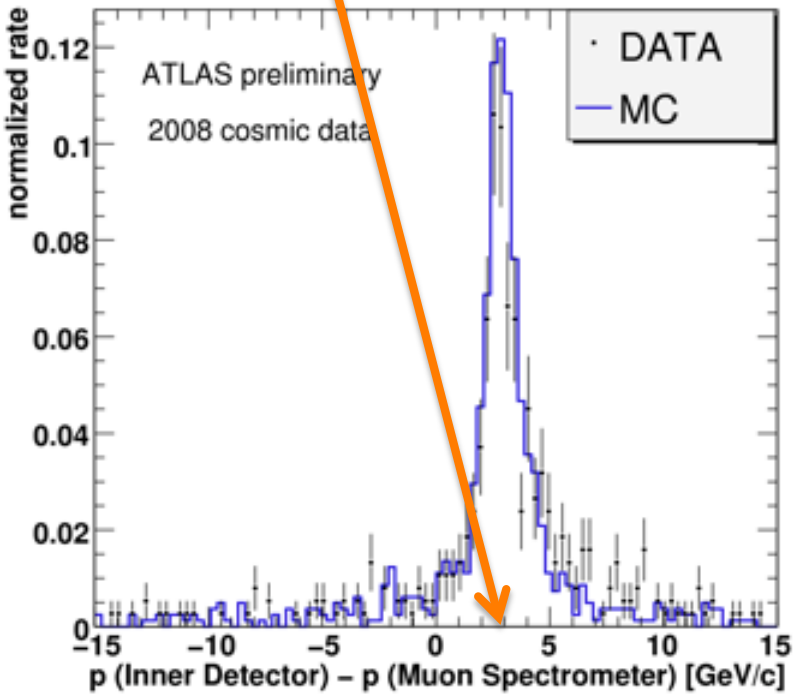
Combined Tracking

- Alignment between systems
- Muon momentum expected loss trough the calorimeter

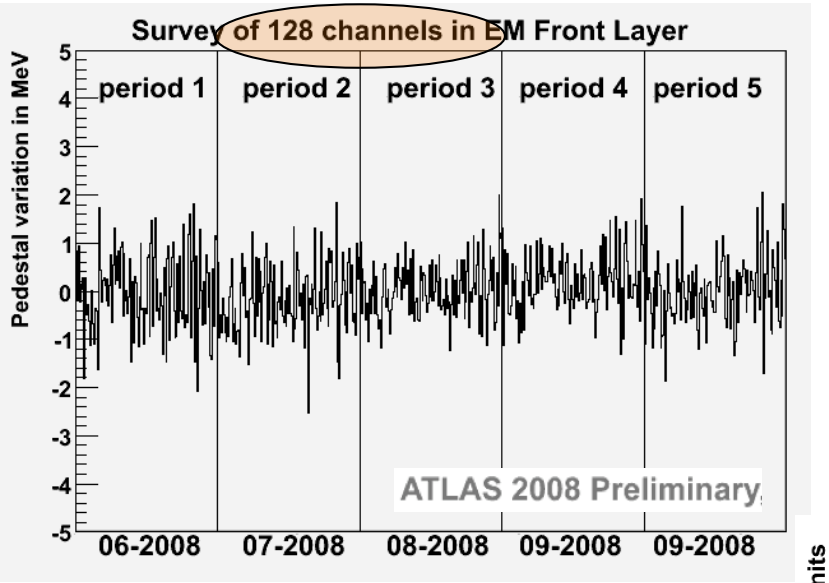




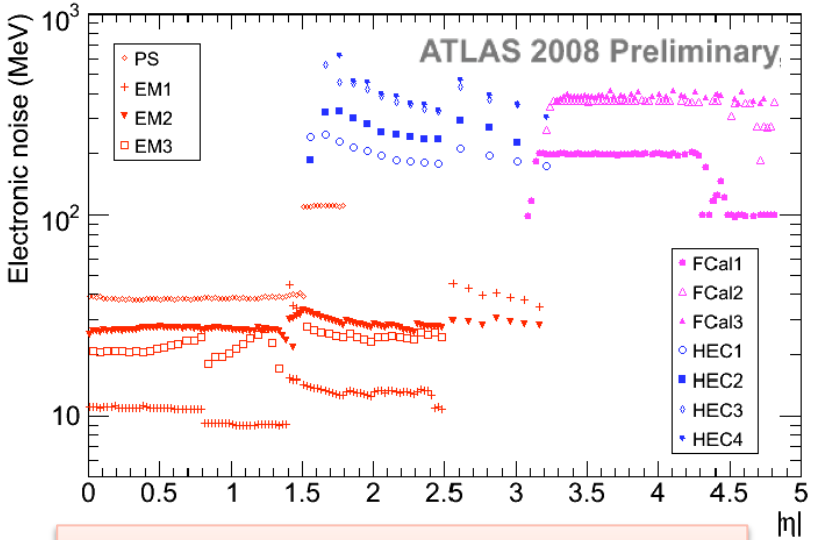




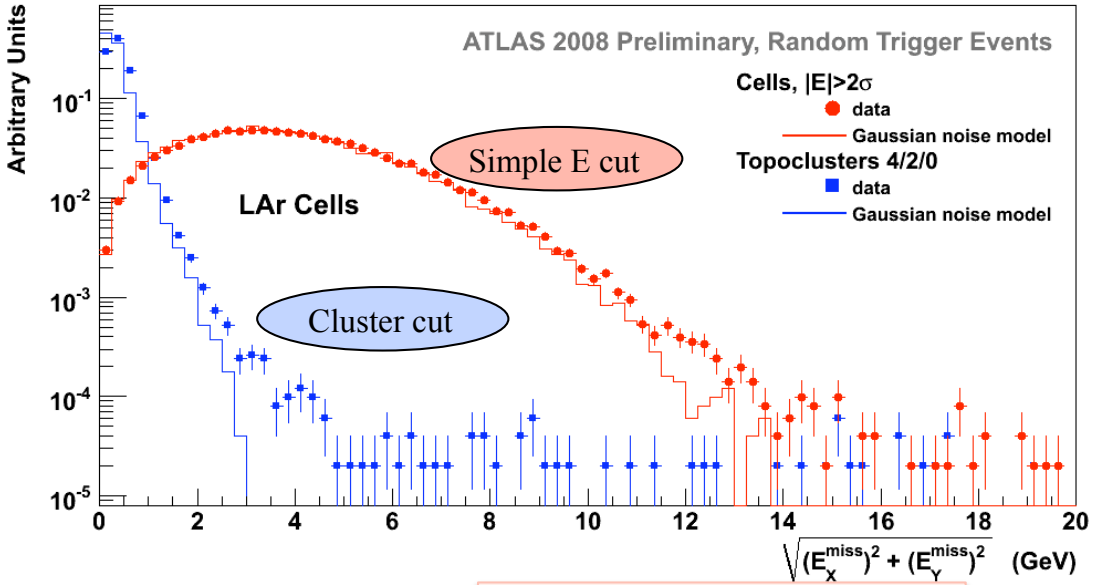
LAr Calorimeter performance



- e.g. Random triggers
  - Checking stability
  - Checking noise
  - Checking coherent noise
    - sums over many channels-> sensitive to many electronics, grounding …problems (some sources were found and fixed in shutdown)



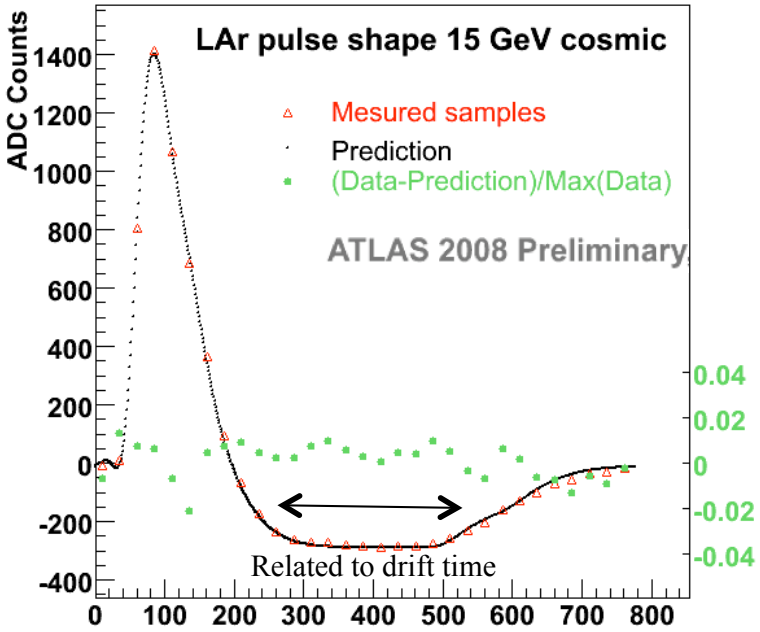
Cell noise
Structure follows capacitances of detector

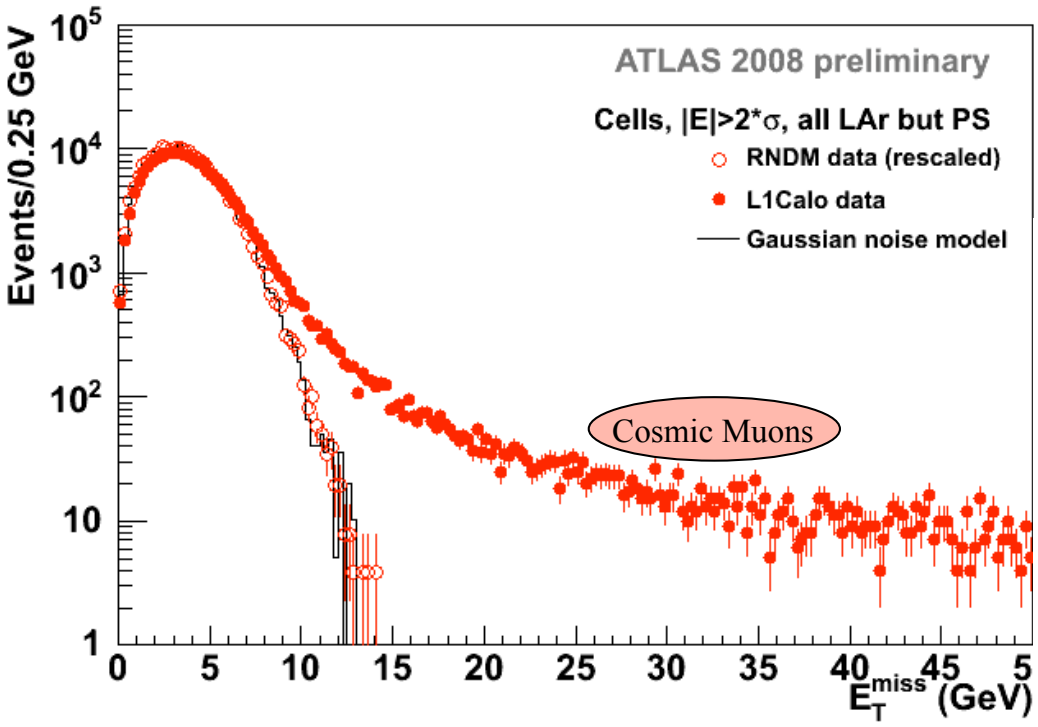


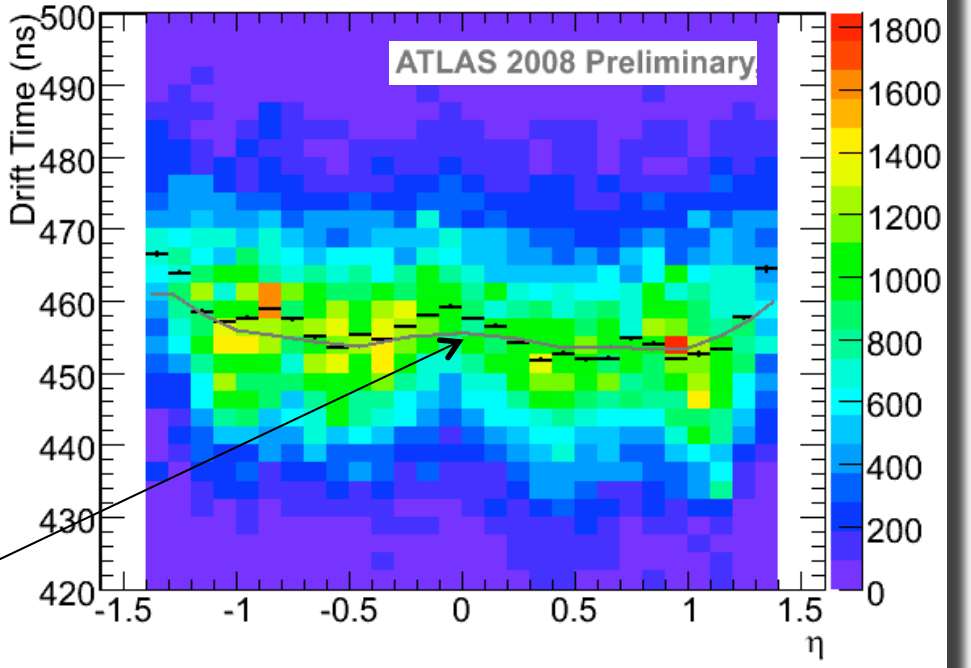
E_t^{miss} from ~180K cells

L. Hervas (CERN)

- Studies with particles
  - Pulse shape in LAr from physics events
  - e.g.: Drift time in LAr

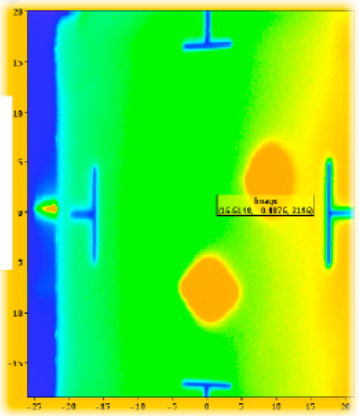




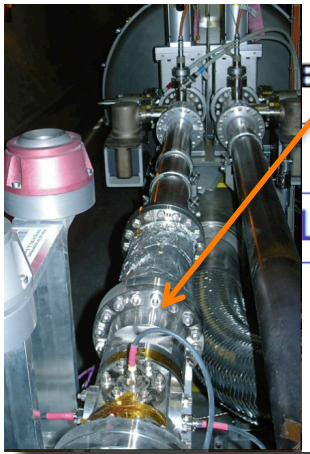


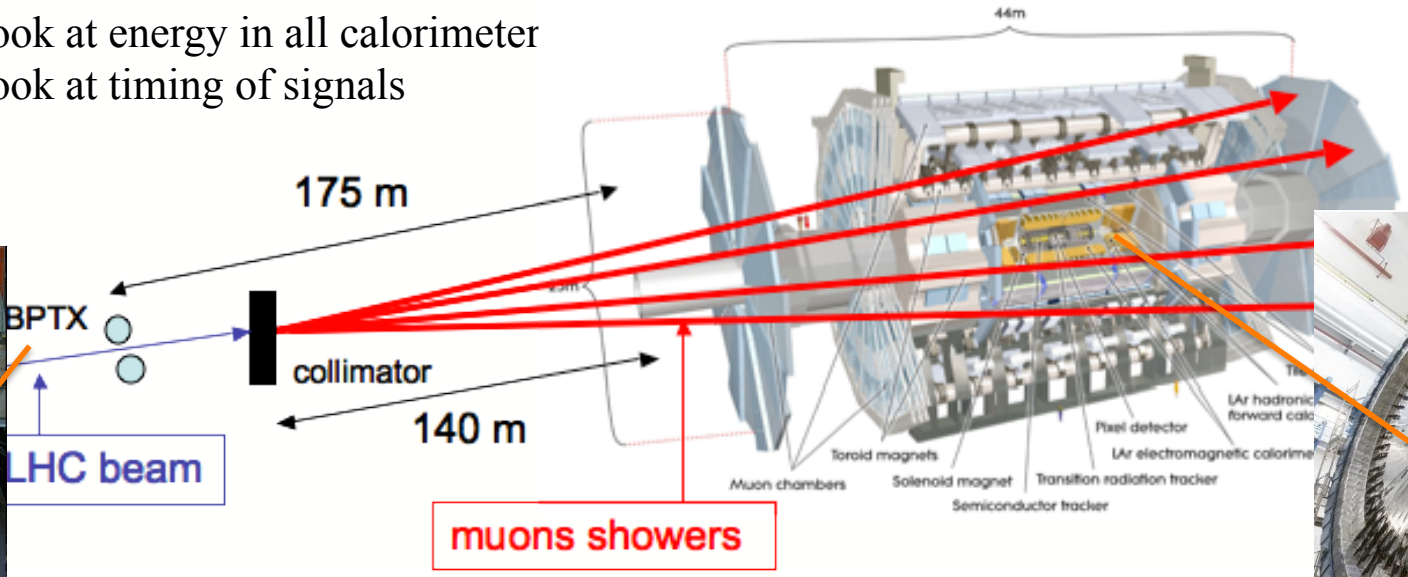
Related to construction data:
Pb plate thickness

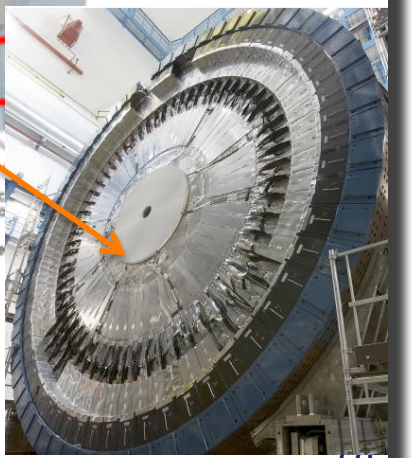
- Studies with Beam events (10-14 September 2008)
- LHC machine startup: managed to get beams circulating in both directions : major success (PR)
- Used to produce some ~100's of events onto detectors, splash events (beam against collimators)
- "Wire" a L1 Trigger:
  - Beam Timing Pickup
  - Minimum Bias Trigger Scintillator
  - LUCID
- Collect data to perform
  - Basic checks of detector readout
  - e.g. look at energy in all calorimeter
  - e.g. look at timing of signals



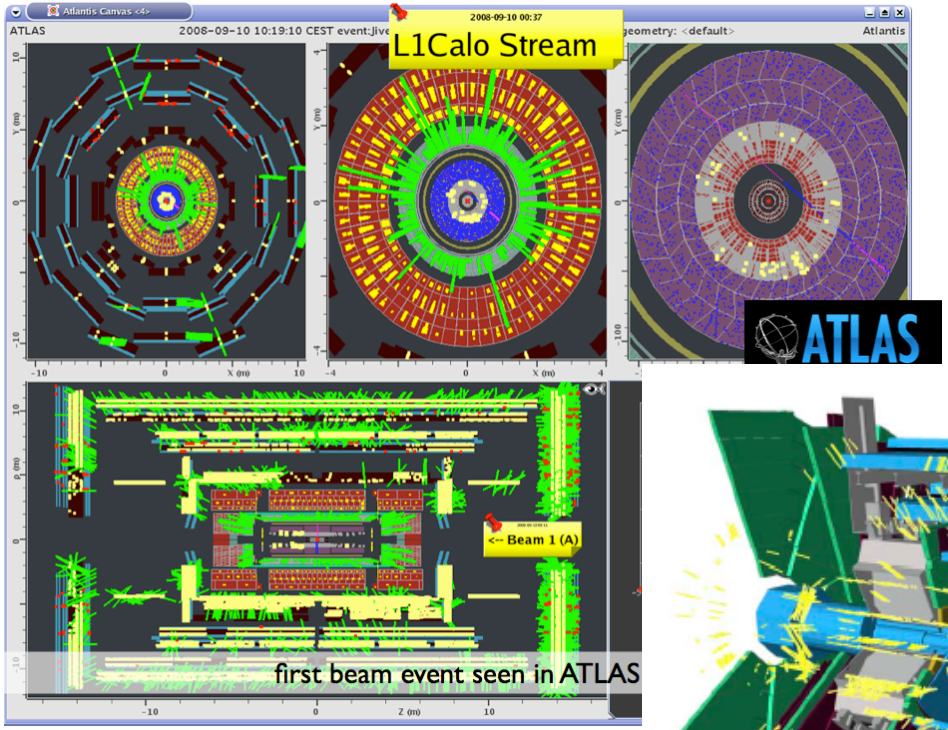
Beam makes 1st turn



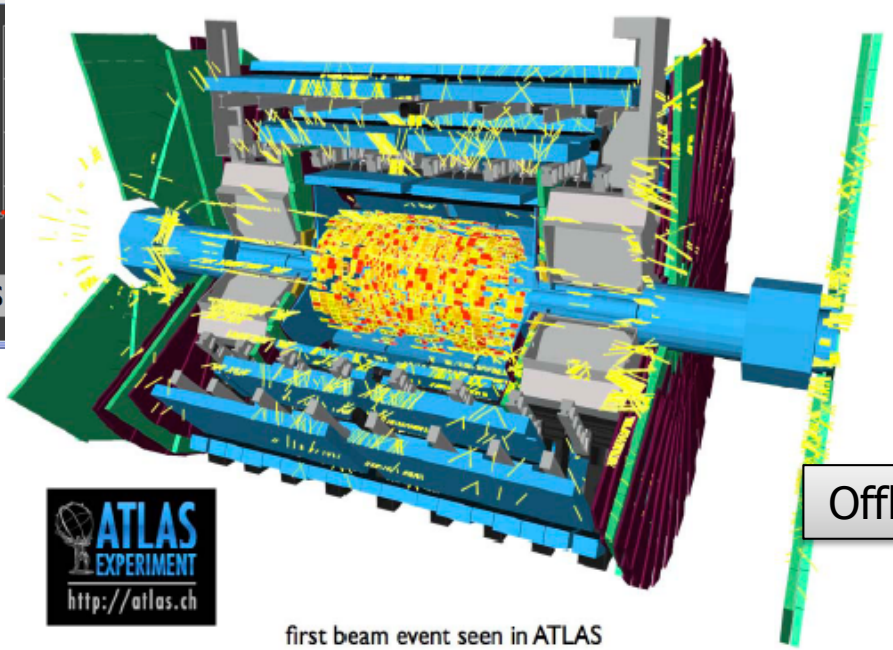




- Lots of energy deposited in the detector
- Lots of excitement in the control room
  - After many years of planning and construction
  - Finally object comes to life

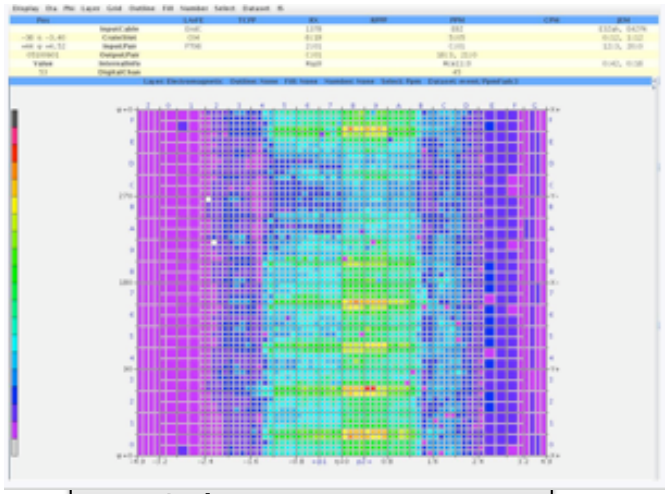


Online display

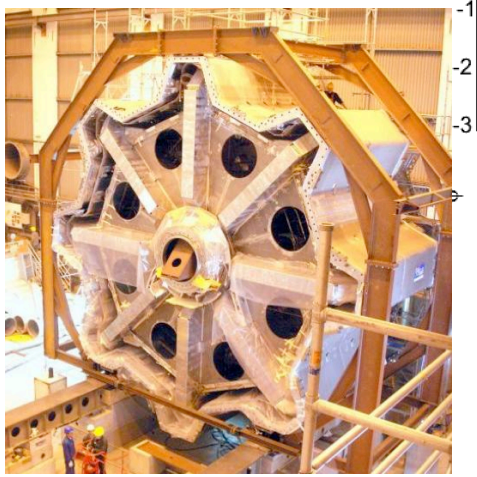


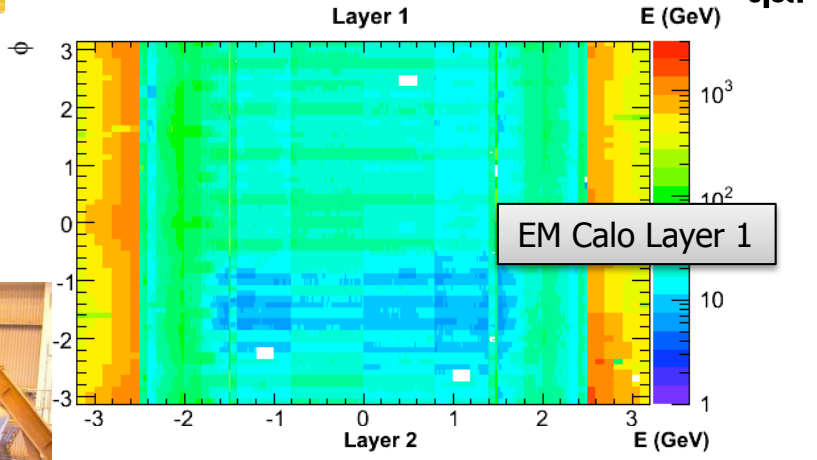
Offline display

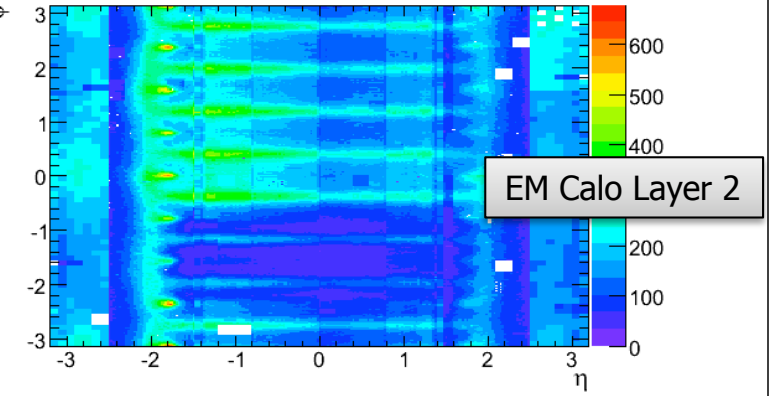
- Multi TeV deposits in the calorimeter
- Observe illumination in many cells at the same time
- Observe structure of magnets in "front" of calorimeters

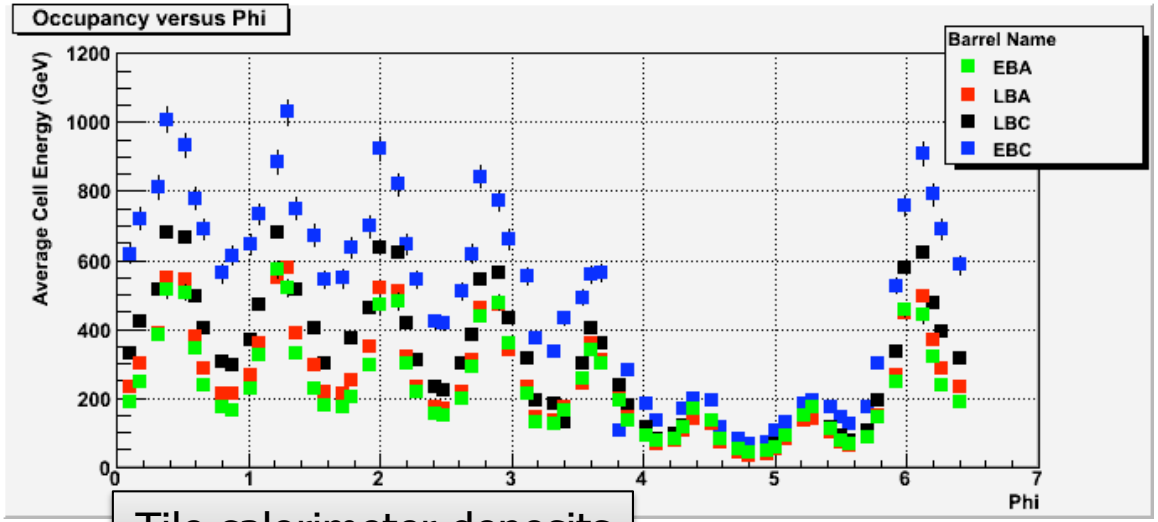


L1 Calo trigger system

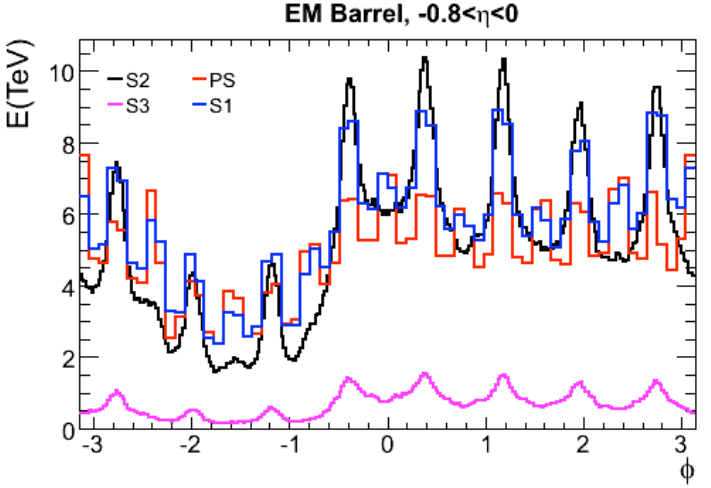


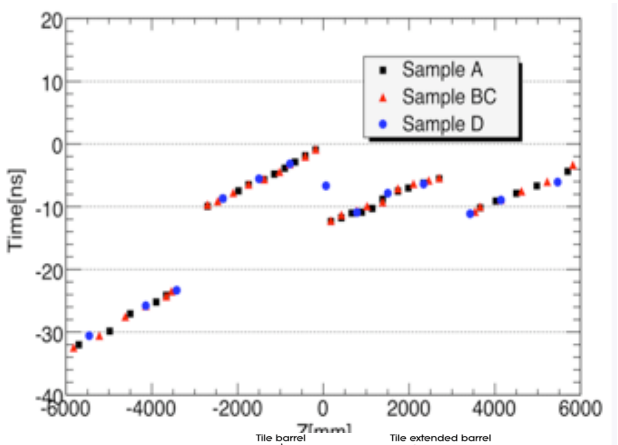


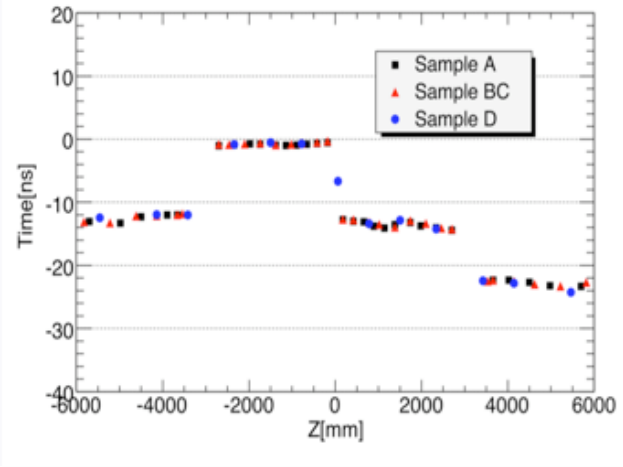




Tile calorimeter deposits

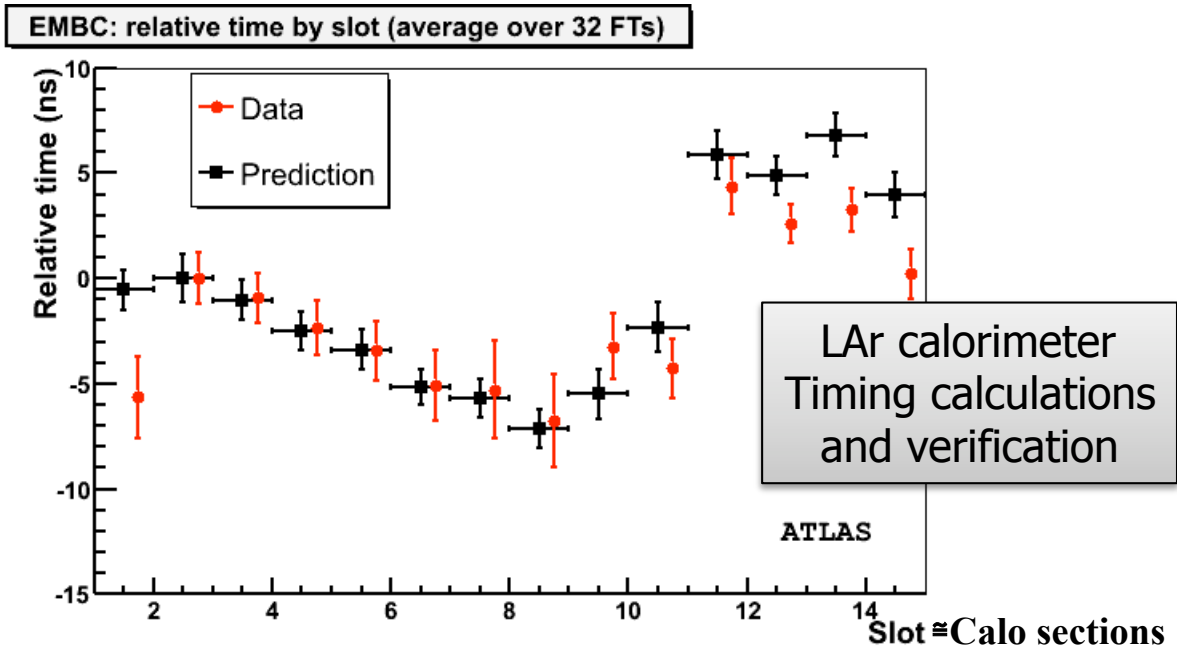






Timing of Tile calorimeter deposits
Corrected for Time of Flight

- Timing studies with Beam splash events



LAr calorimeter
Timing calculations
and verification

- Offline studies to determine constants
  - To be downloaded into electronics
  - Needed for physics pulses
  - Takes into account
    - trigger paths, fiber lengths, section delays …
  - Agreement at the 1-2 ns

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(CERN)

ATLAS Detector Status

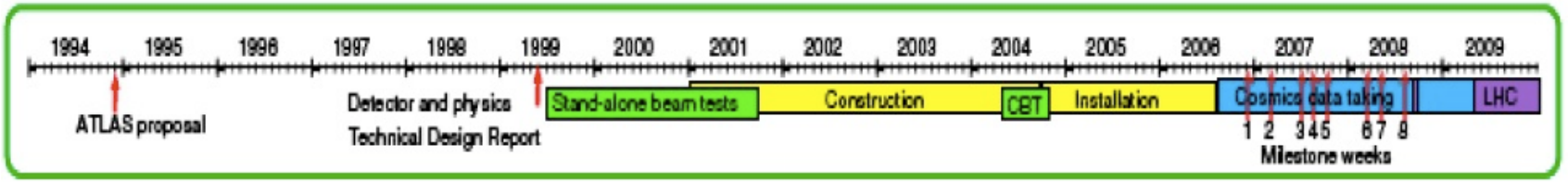
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	98.5%
SCT Silicon Strips	6.3 M	99.5%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter	170 k	99.1%
Tile calorimeter	9800	99.5%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
MDT Muon Drift Tubes	350 k	99.3%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Trigger	370 k	95.5%
TGC Endcap Muon Trigger	320 k	99.8%

Notes:

- Pixels & SCT: These are the values for startup, after replacing all the TX plugins, not the numbers during the June-July 2009 cosmic run.
- Muons do not include the EE chambers (under installation)
- RPC Barrel Muon Trigger: the target for collisions is >98.5%

From: https://twiki.cern.ch/twiki/bin/view/Atlas/ApprovedPlotsATLASDetector

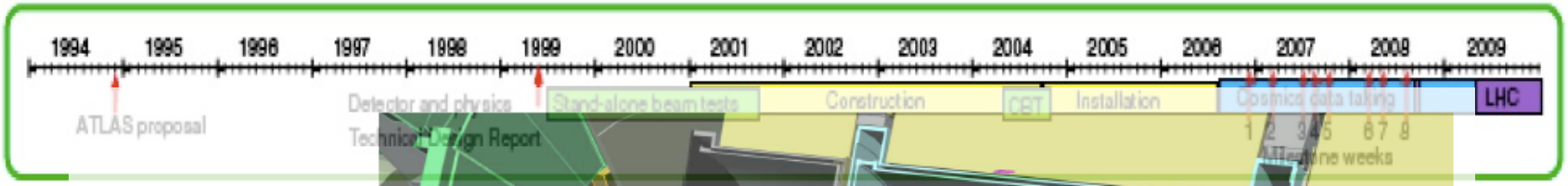
Very last steps of long process of ~15 years



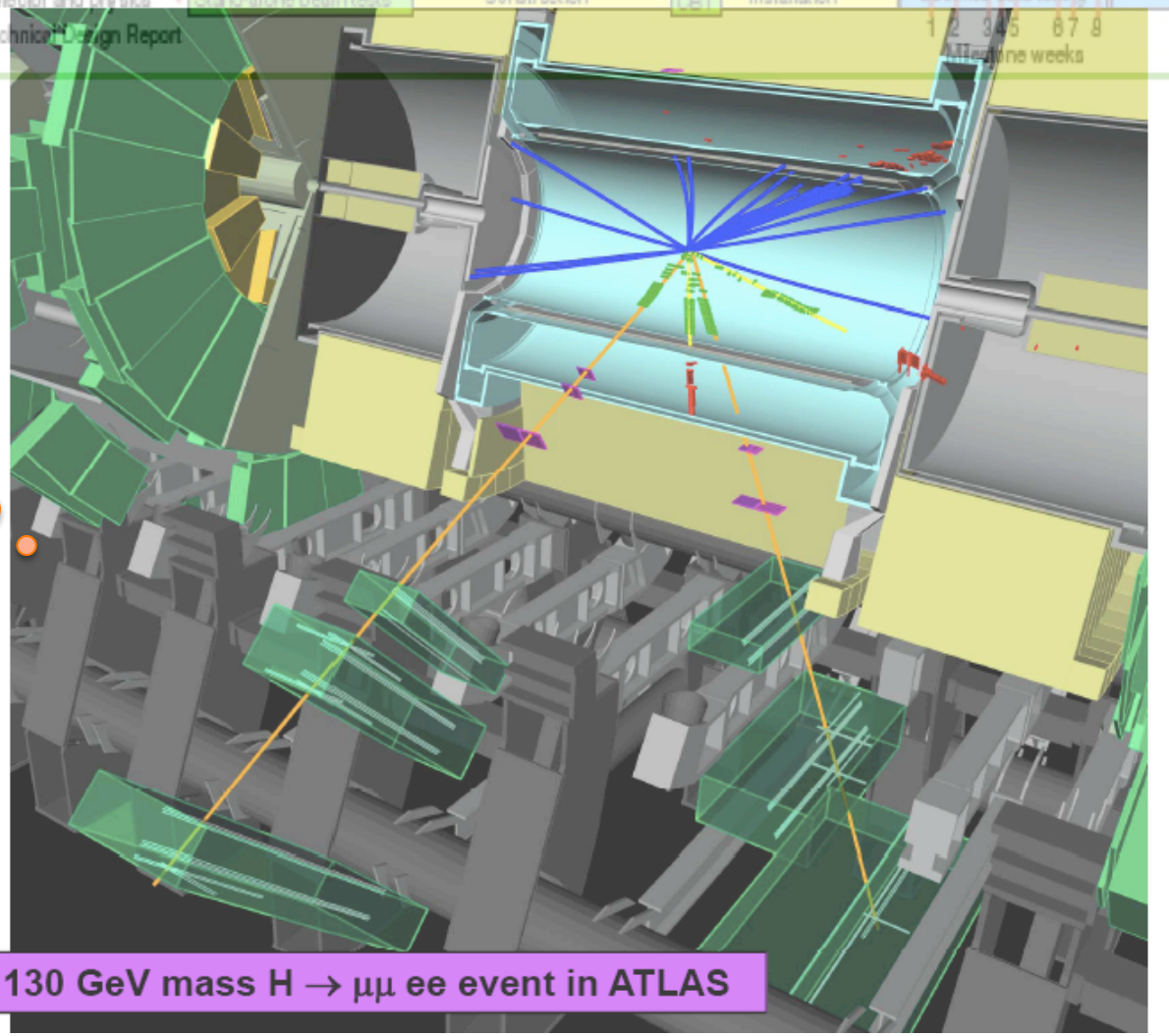
- ATLAS detector is installed in P1 UX15 cavern
- Commissioning started ~3 years ago and has incrementally increased our understanding of the detectors
- Cosmic rays running is ongoing regularly
- Allows to perform quite detailed detector performance studies (calibration, alignment, timing, bad channels ….)
- Good "training" for Detector Operation
- First particles were seen in September 2008
- Detector is in excellent health

- "Give us beam and you wont be disappointed" (M. Nessi, ATLAS TC, Nov 2007 Seminar)

Very last steps of long process of ~15 years



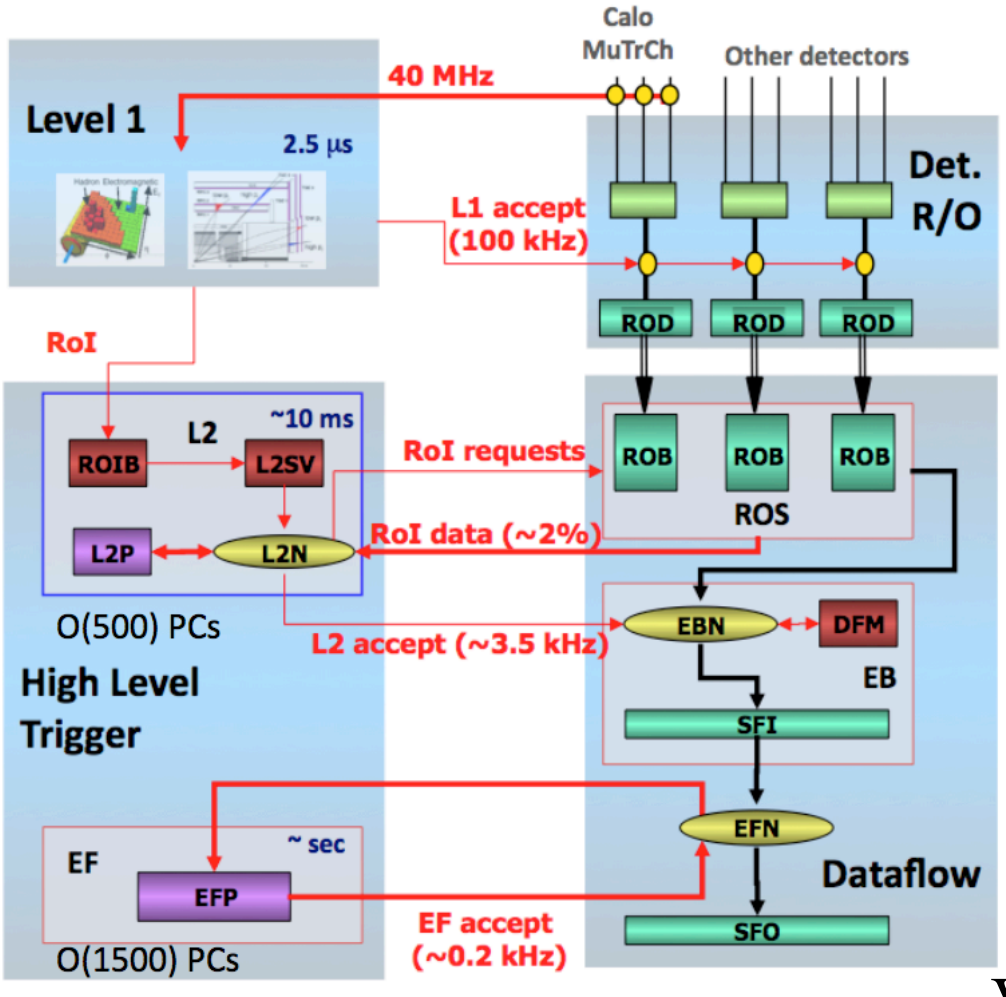
Soon to come



Simulation of a 130 GeV mass H → μμ ee event in ATLAS

Additional Slides

Trigger and Data Acquisition



Mostly soft (low p_T) events
10^9interactions/s
Calorimeter & Muon information
120 GB/s

Region Of Interest (from L1)
but full precision, all detectors

Event Building and filtering
PC farms ~offline

Very few hard (high p_T) events

Selection of 1 in 10.000.000.000.000

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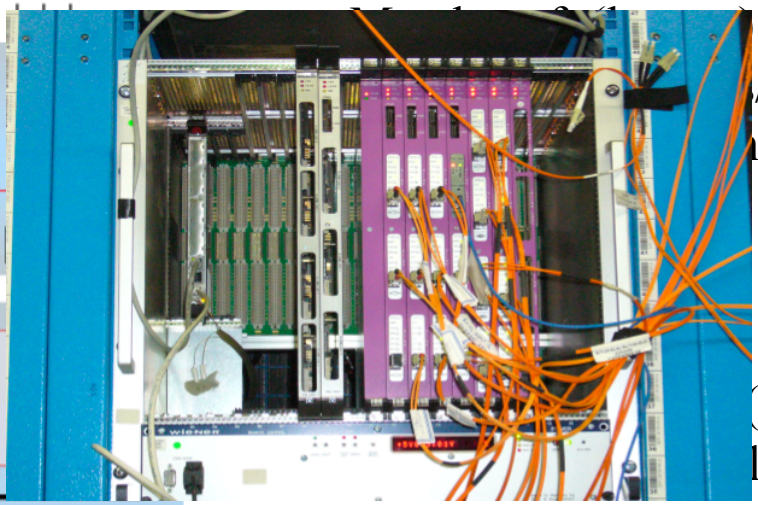
(CERN)

Trigger and Data Acquisition



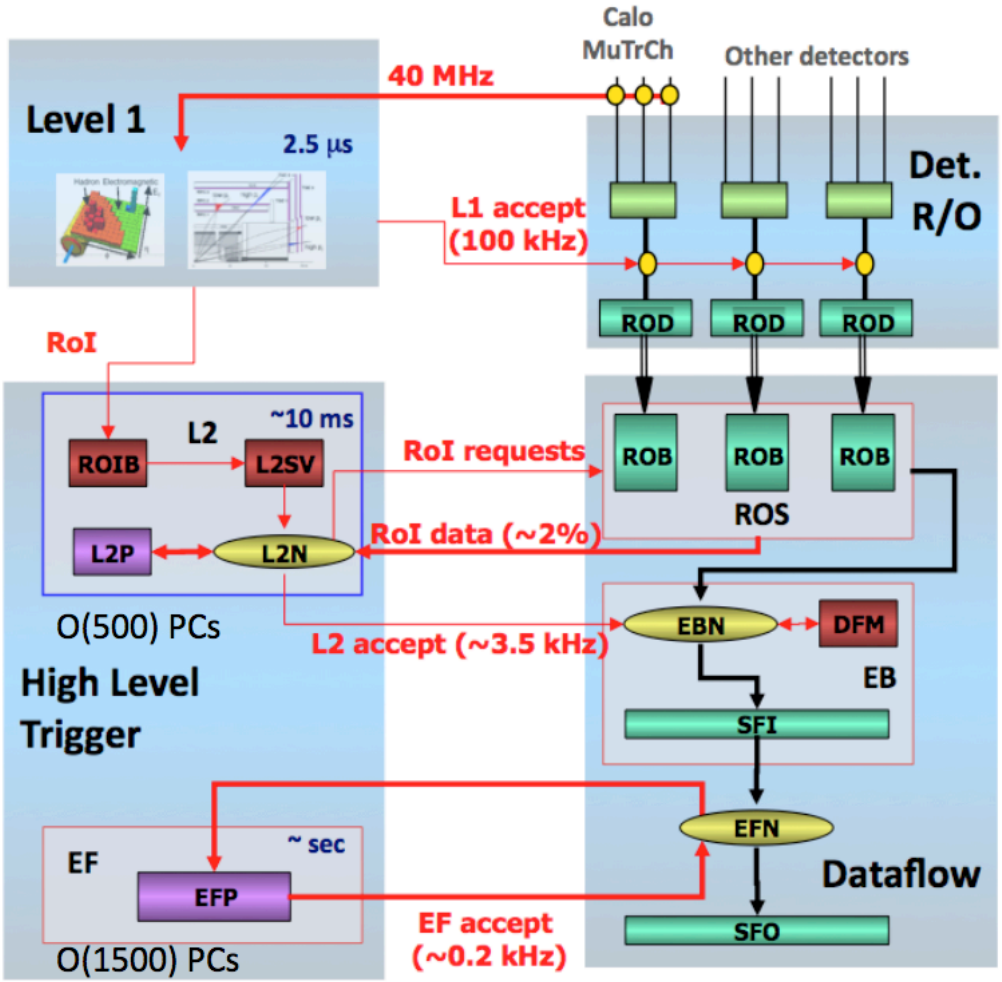
events
/s
formation

(from L1)
l detectors

nt Building and filtering
PC farms ~offline

hard (high p_T) events
000.000.000

Trigger and Data Acquisition



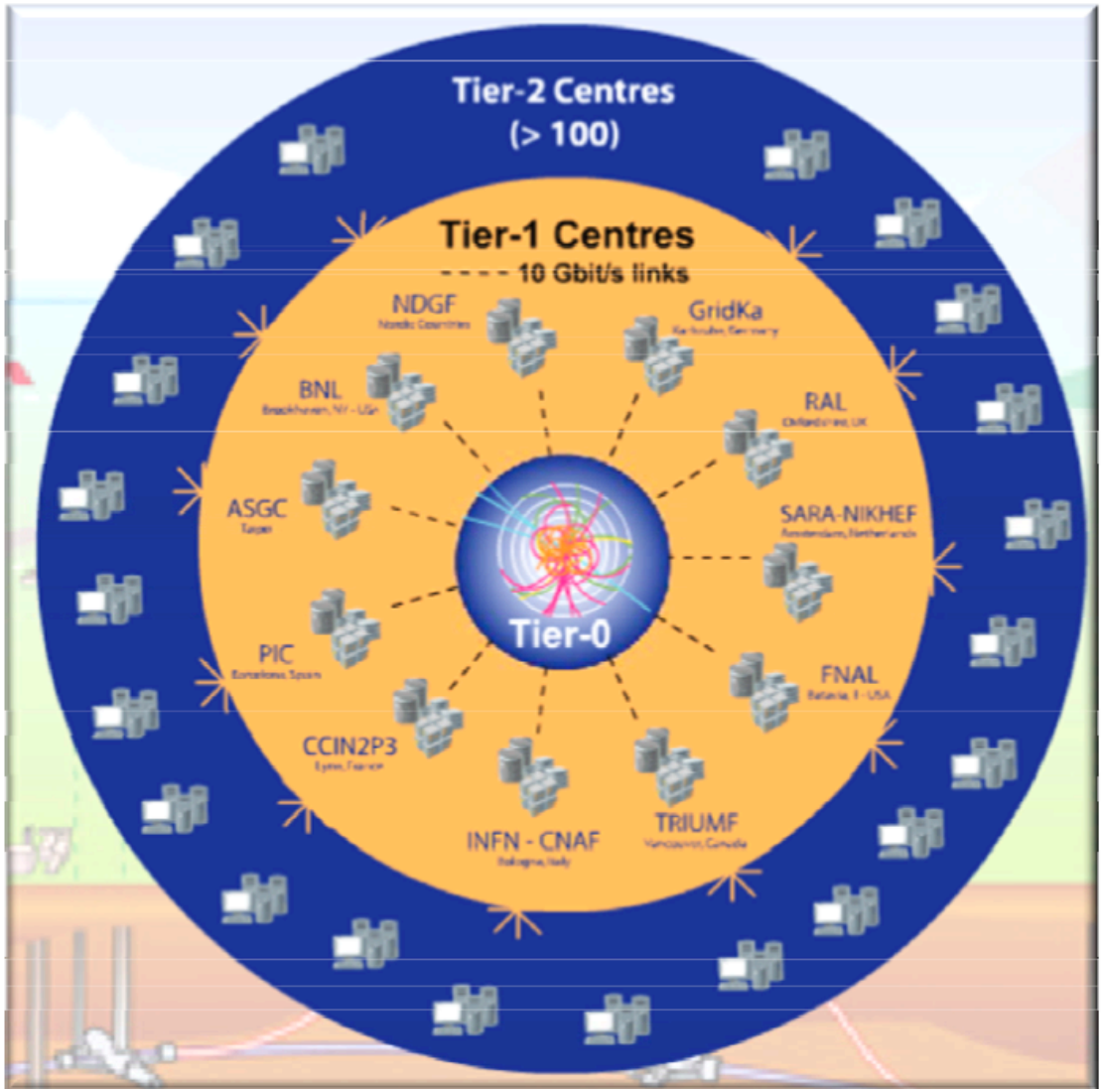
Running regularly at 75 kHz with random triggers

60KHz sustained rate

500 PCs installed (out of 500+1800 PCs finally)

Event Filter currently used to enrich cosmic sample for ID

The Worldwide LHC Computing Grid (wLCG)



Tier-0 (CERN):
- Data recording
- Initial data reconstruction
- Data distribution

Tier-1 (11 centres):
- Permanent storage
- Re-processing
- Analysis

Tier-2 (federations of ~130 centres):
- Simulation
- End-user analysis

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The Worldwide LHC Computing Grid (wLCG)