The ATLAS Liquid Argon Calorimeters

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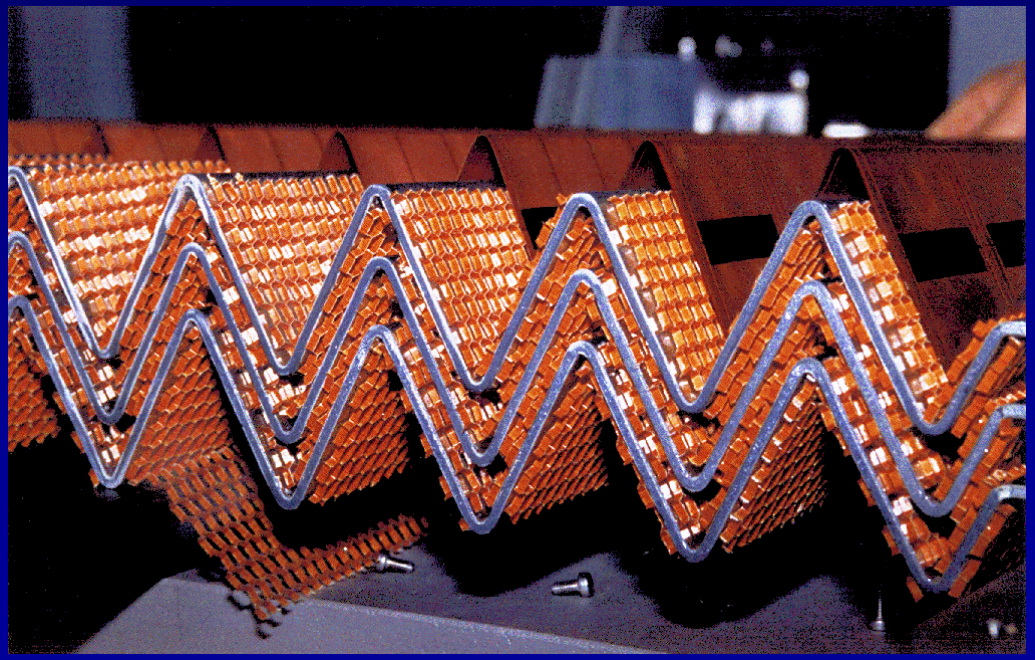
LHC Days in Split
Split, Croatia

5 October 2006



Outline

- The ATLAS detector
- The Liquid Argon calorimeters
  - General and physics requirements
  - Geometry description
  - Current status
- The Liquid Argon readout electronics
  - General description
  - Installation and commissioning
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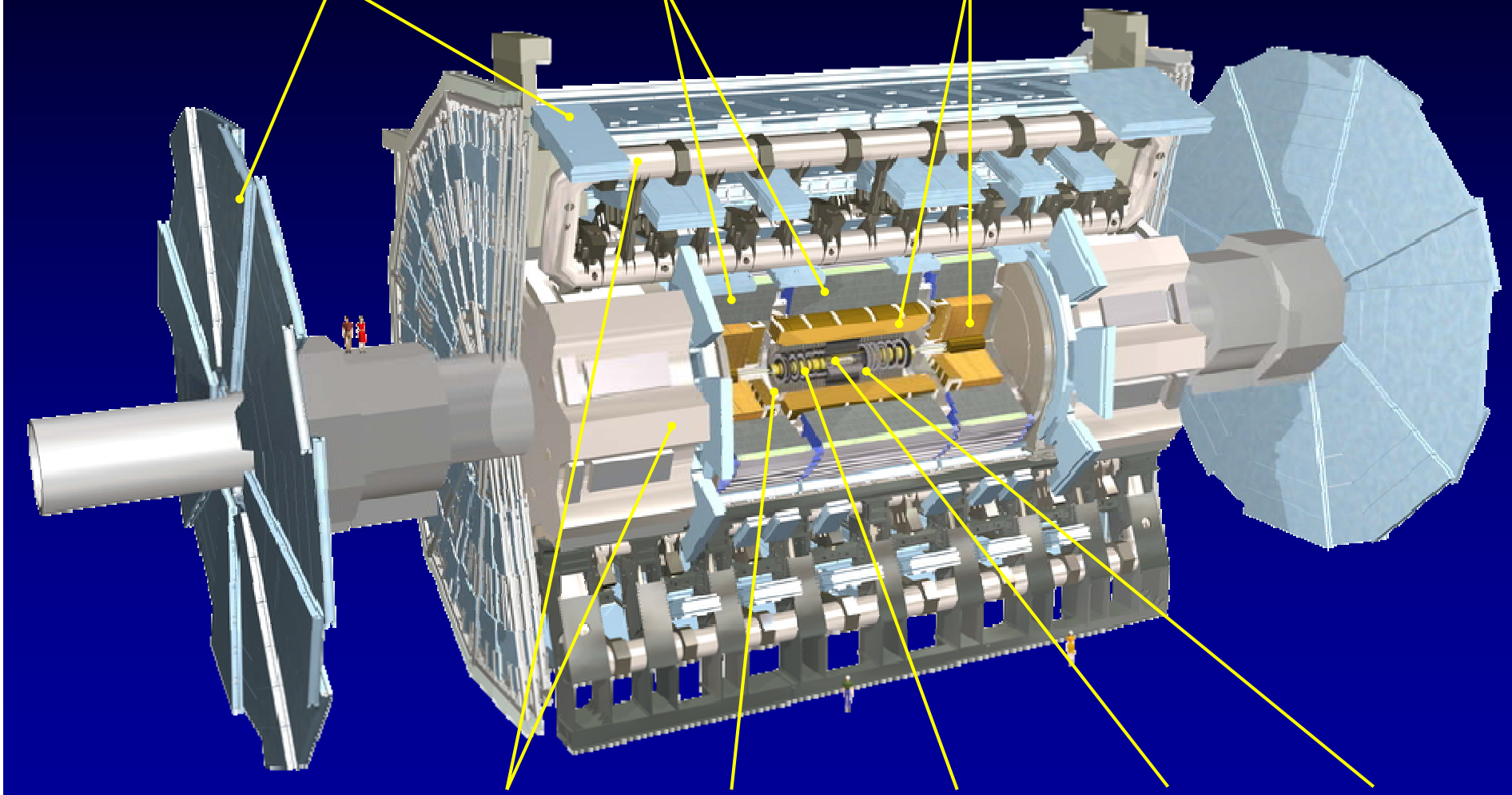
The ATLAS detector



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ATLAS calorimeters: physics requirements

- In General, the ATLAS EM calorimeters should be designed to trigger on and to provide very good electromagnetic measurements and identification of electrons and photons.

- Driven by the Higgs physics with decays in $\gamma\gamma$ or 4 $e^{\pm}$, the ATLAS calorimeters are expected to have:
  - Good energy resolution for electron/photon
  - A linearity better than 0.1%
  - Particle identification: $e^{\pm}$/jets, photon/pion separation
  - Angular measurements: 50 mrad/$\sqrt{E}$
  - Time measurement: 100 ps constant term
  - Large energy dynamic range: from 20 MeV to 2 TeV

- General requirements:
  - Fast readout scheme with high segmentation to reduce occupancy
  - Largest possible acceptance
  - Radiation resistant (key constraint)
  - Uniformity of response
  - Long term stability

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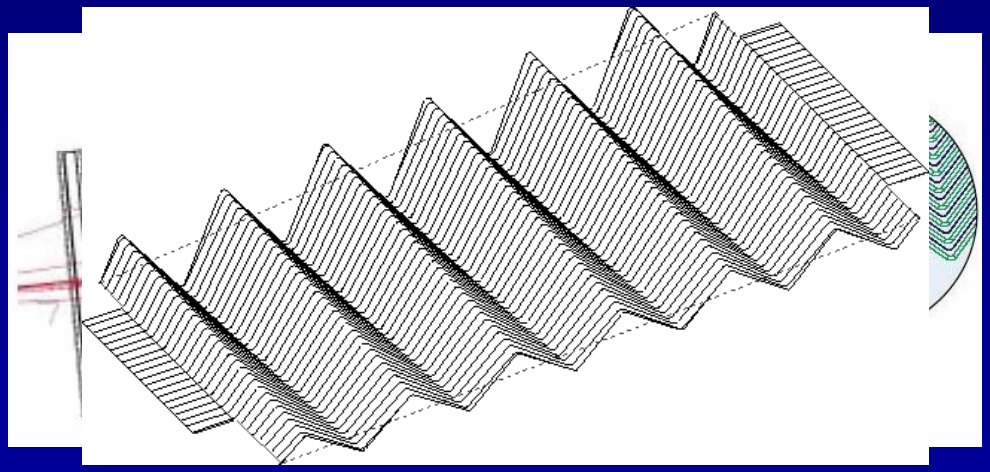
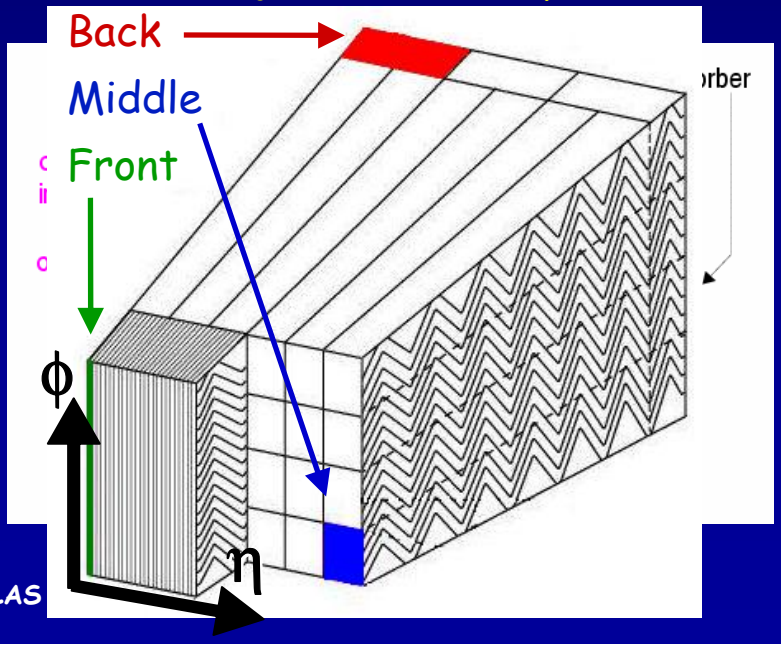
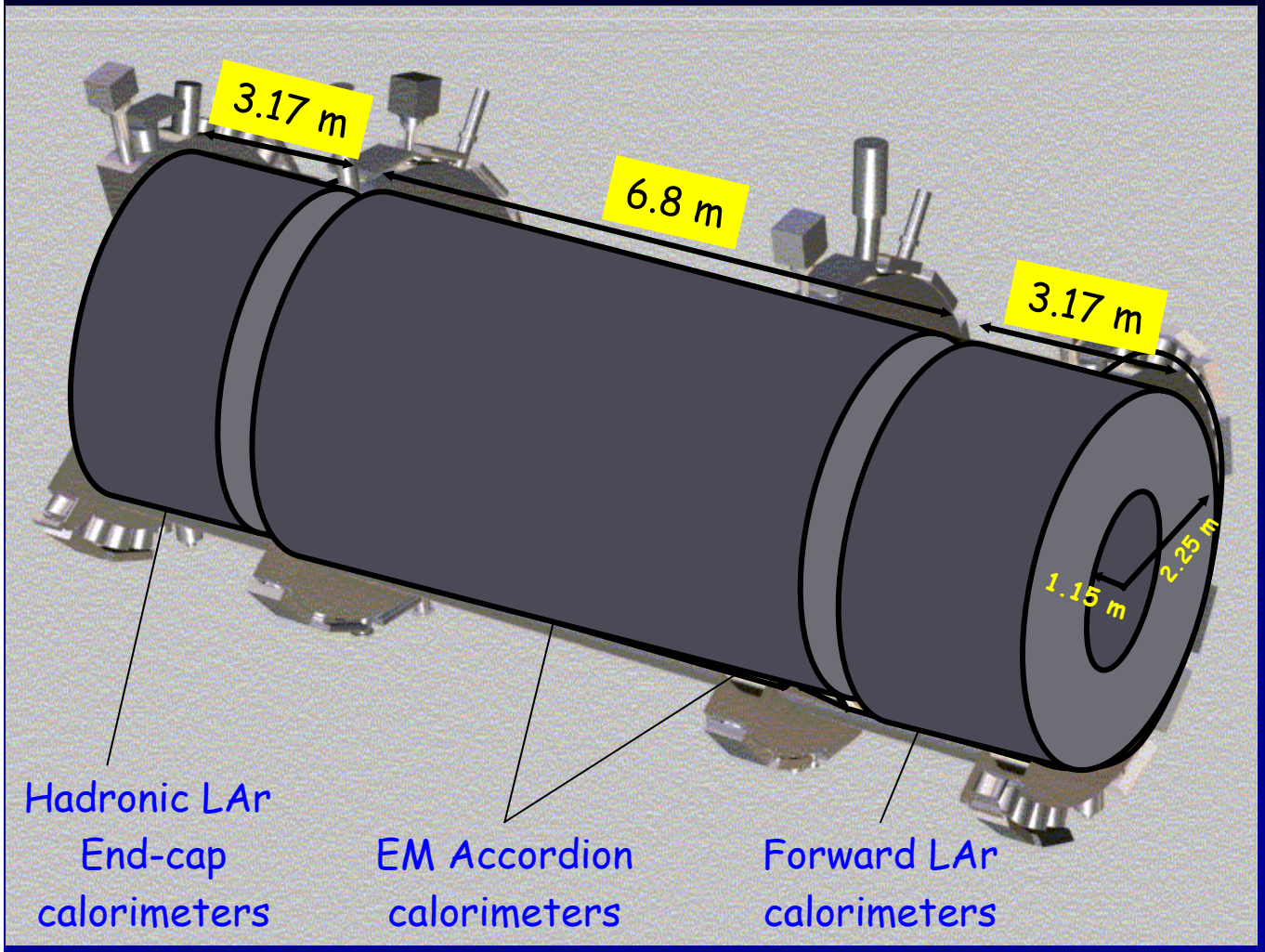
EM calorimeters: geometry description

- Liquid Argon sampling calorimeter with accordion-shape electrodes:
  - Advantages:
    - hermetic coverage (no cracks): full azimuthal symmetry
    - longitudinal segmentation: front, middle, back + pre-sampler ($|\eta|<1.8$)
    - inherent linearity and radiation hard
    - high granularity (~ 175 000 readout channels)
    - fast readout possible
  - It has a thickness of >24 X_0 in the barrel and >26 X_0 in the end-caps





The ATLAS LAr calorimetry overview



EMB: Pb-LAr ($|\eta|<1.475$)

EMEC: Pb-LAr ($1.375<|\eta|<3.2$)

HEC: Cu-LAr ($1.5<|\eta|<3.2$)

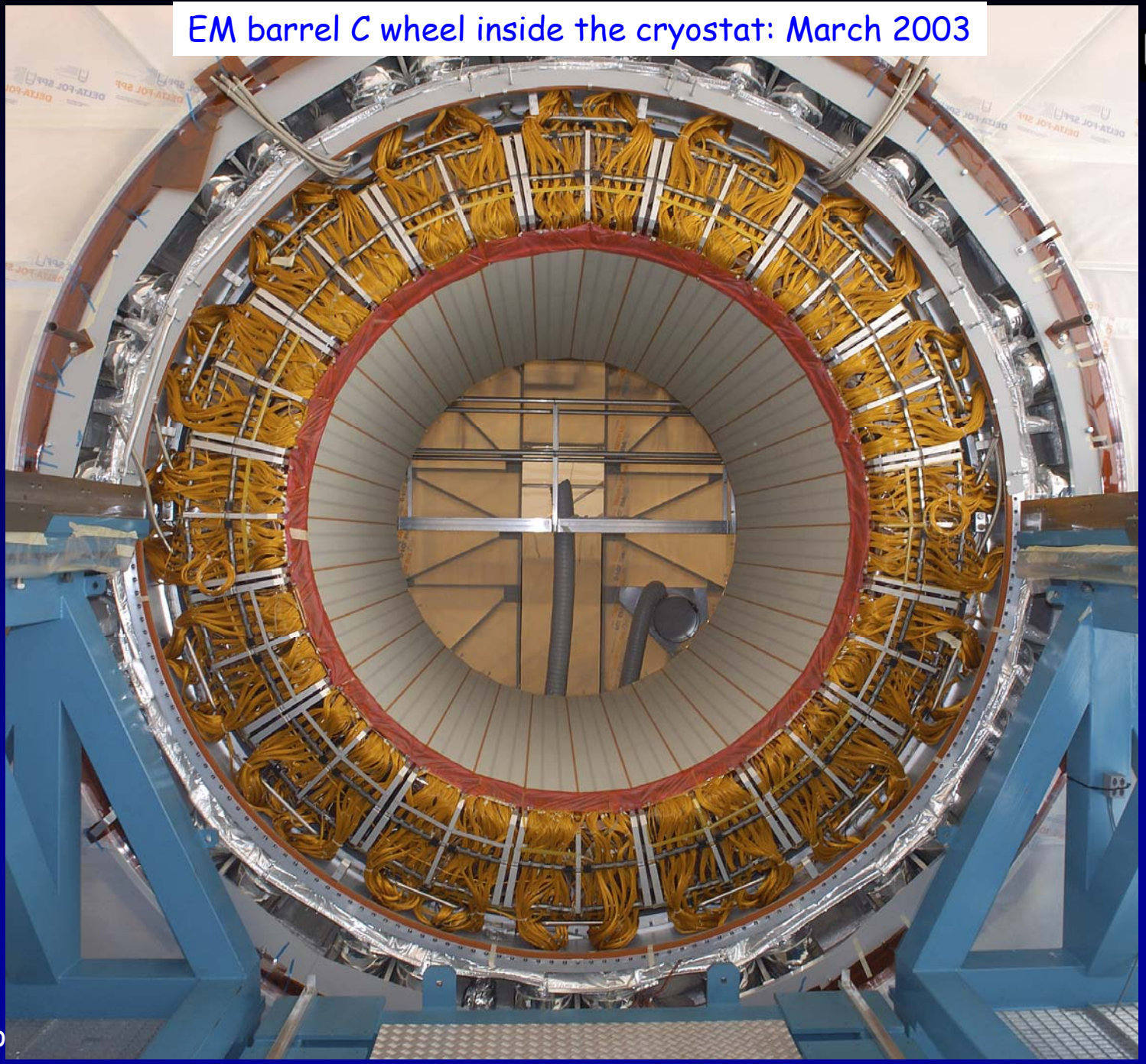
FCAL: Cu, W-LAr ($3.2<|\eta|<4.9$)

~ 190 000 readout channels

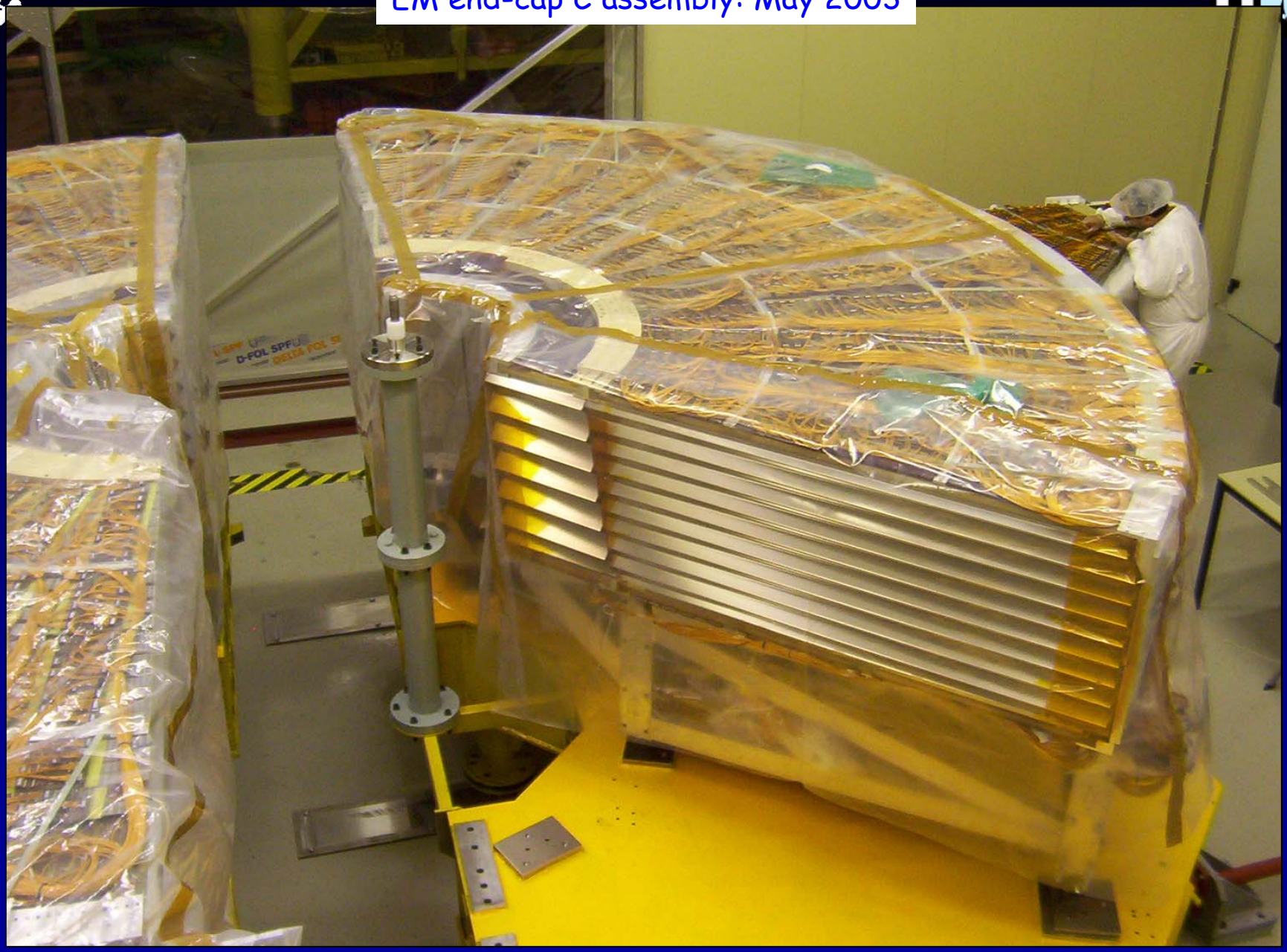
Result of <10 years R&D

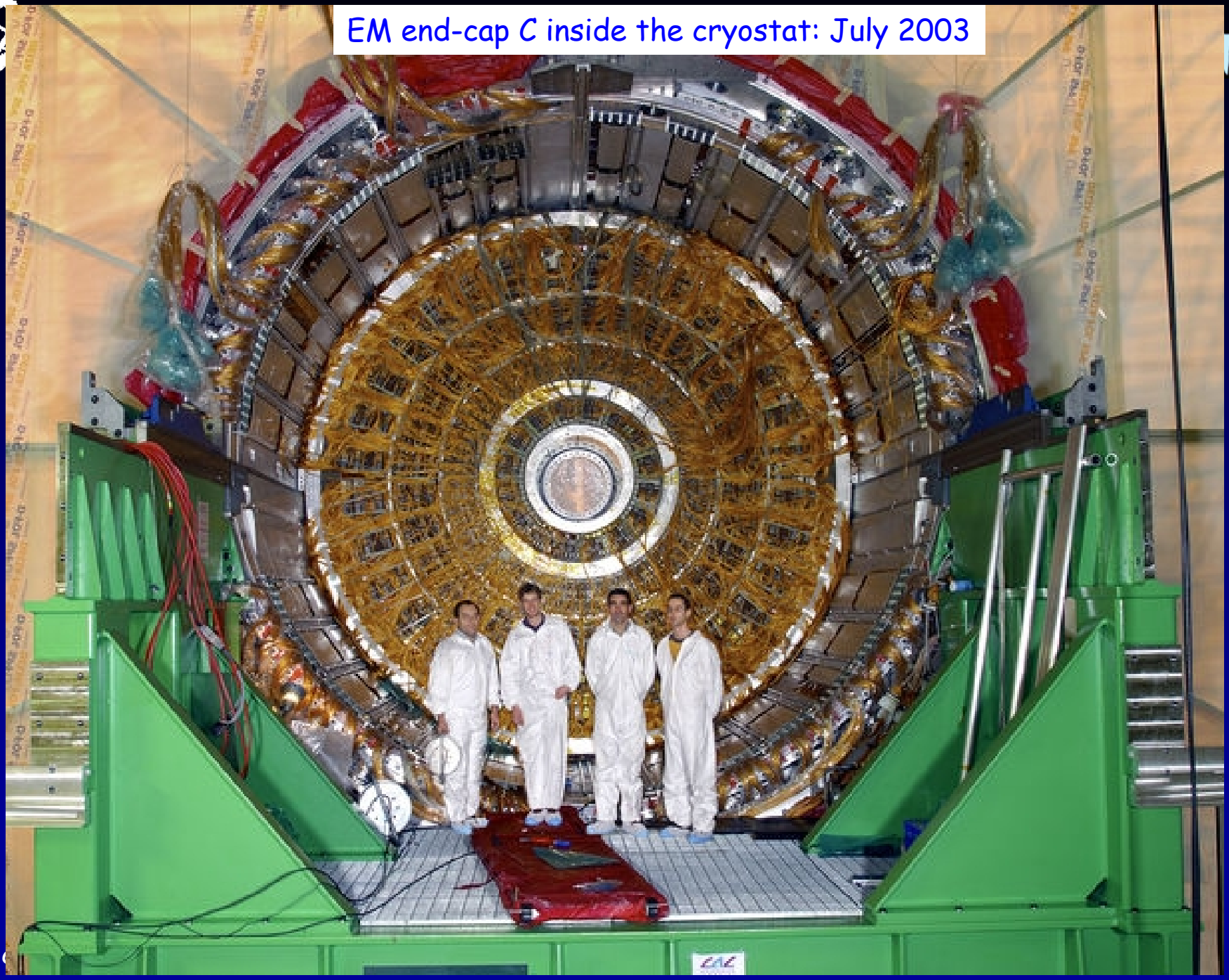
Closing EM barrel A wheel: May 2003

EM barrel C wheel inside the cryostat: March 2003



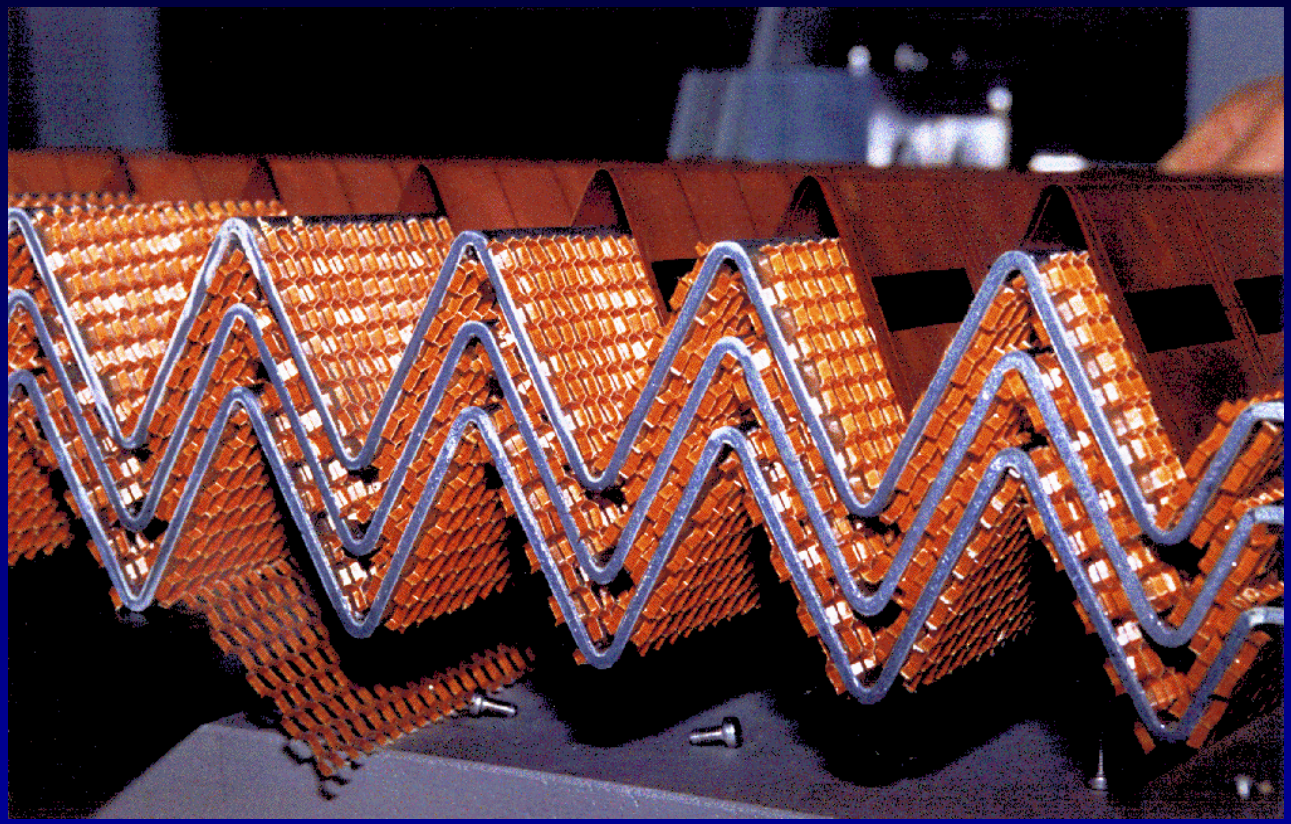
EM end-cap C assembly: May 2003





EM end-cap C inside the cryostat: July 2003

Result of <10 years R&D



A tribute to engineering:

- ~ 20 000 m^2 of honeycomb spacers to maintain flexible electrodes centered in the gap.
- After commissioning (at 87K) and before final installation in the pit:
  - 31 dead readout channels in the EM barrel (0.03%)
  - 14 dead readout channels in the EM end-caps (0.025%)

>99.9% of the detector channels work!

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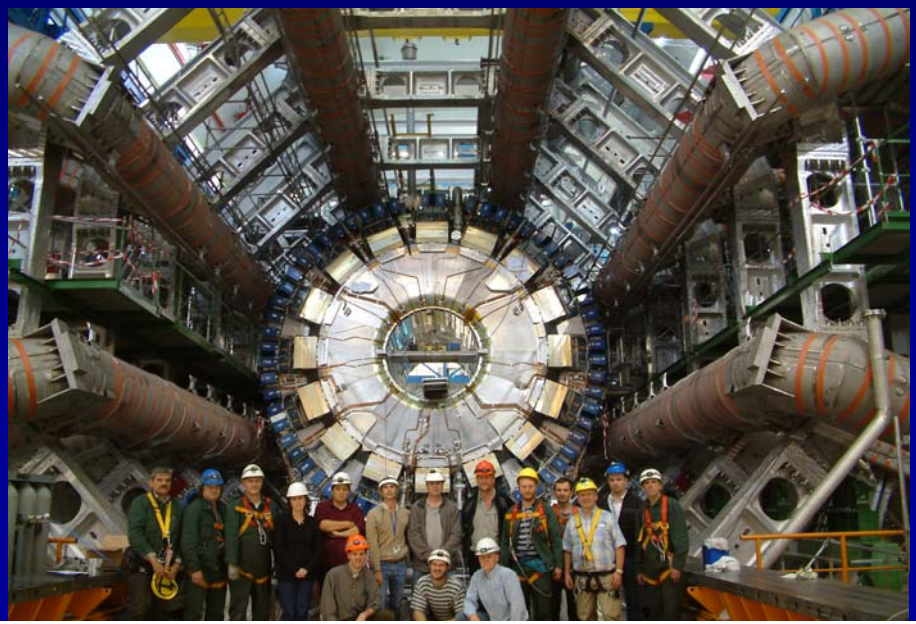
ATLAS EM barrel: the last step of the trip

ATLAS EM barrel cryostat being transported to point 1: October 2004

ATLAS EM barrel cryostat being lowered into the pit: October 2004

Lowering EM barrel into the pit:
October 2004

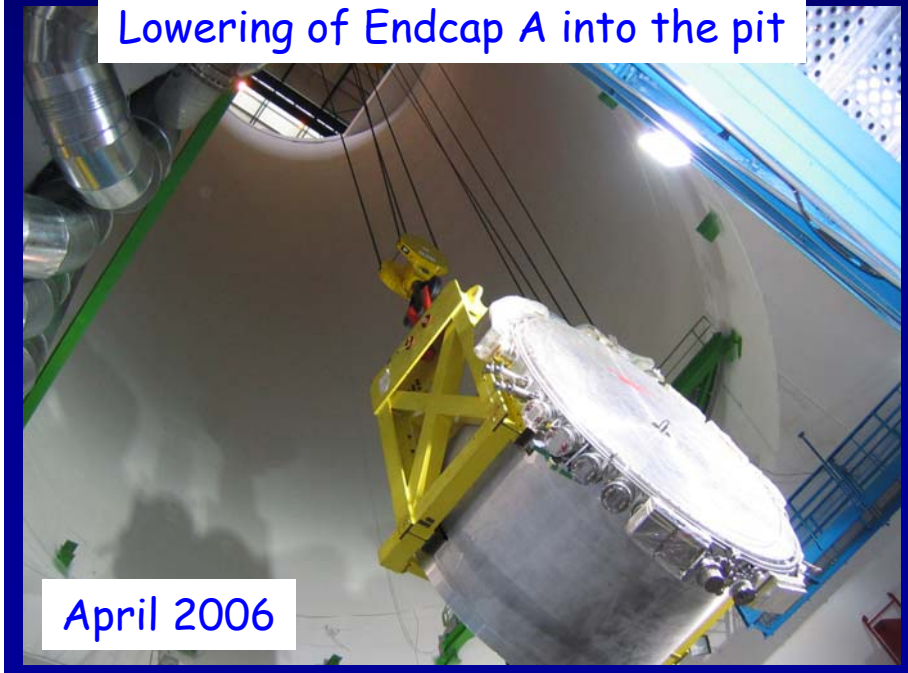
EM barrel positioned inside Tilecal

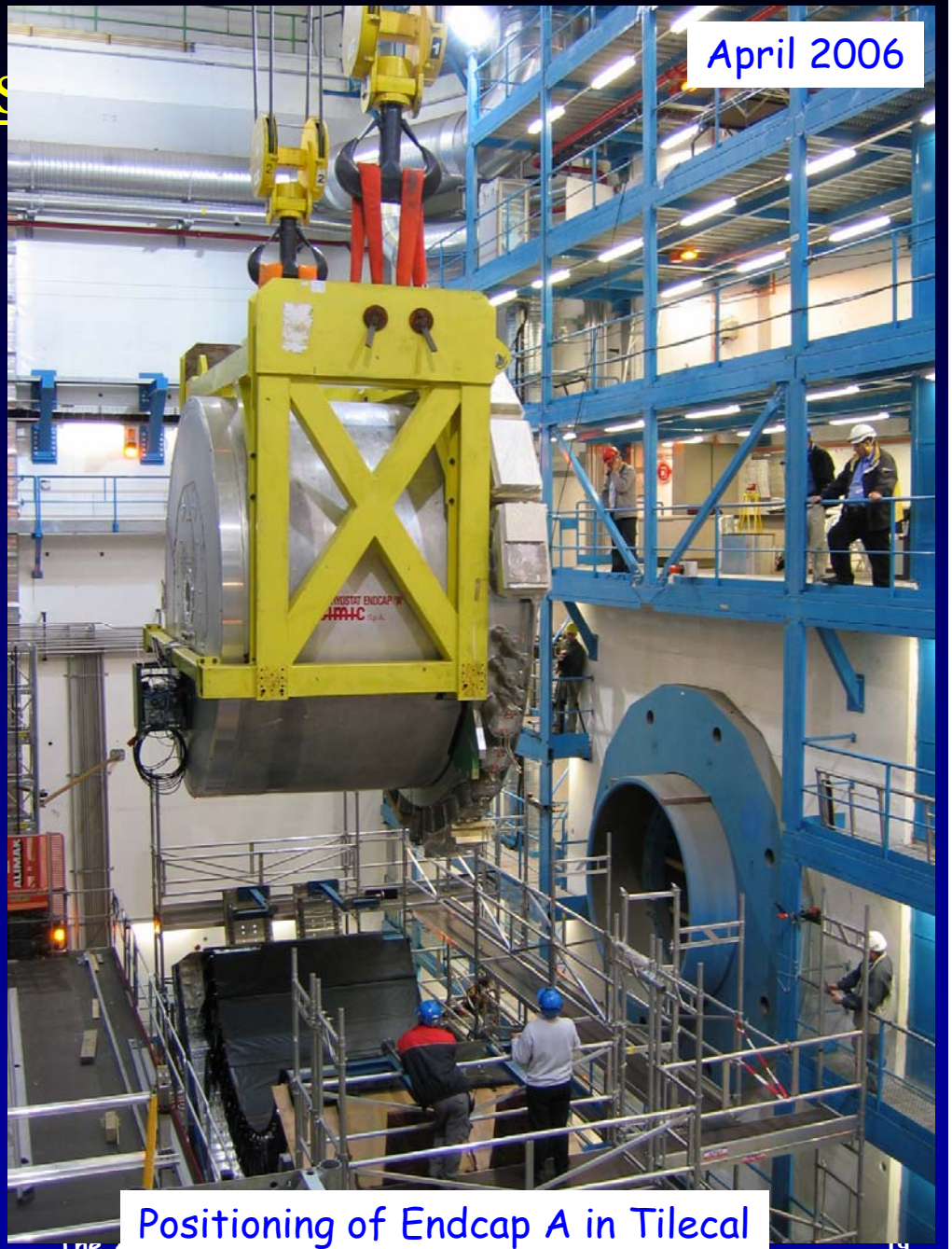


EM barrel moved to int. point: October 2005

Transportation of Endcap A to point 1

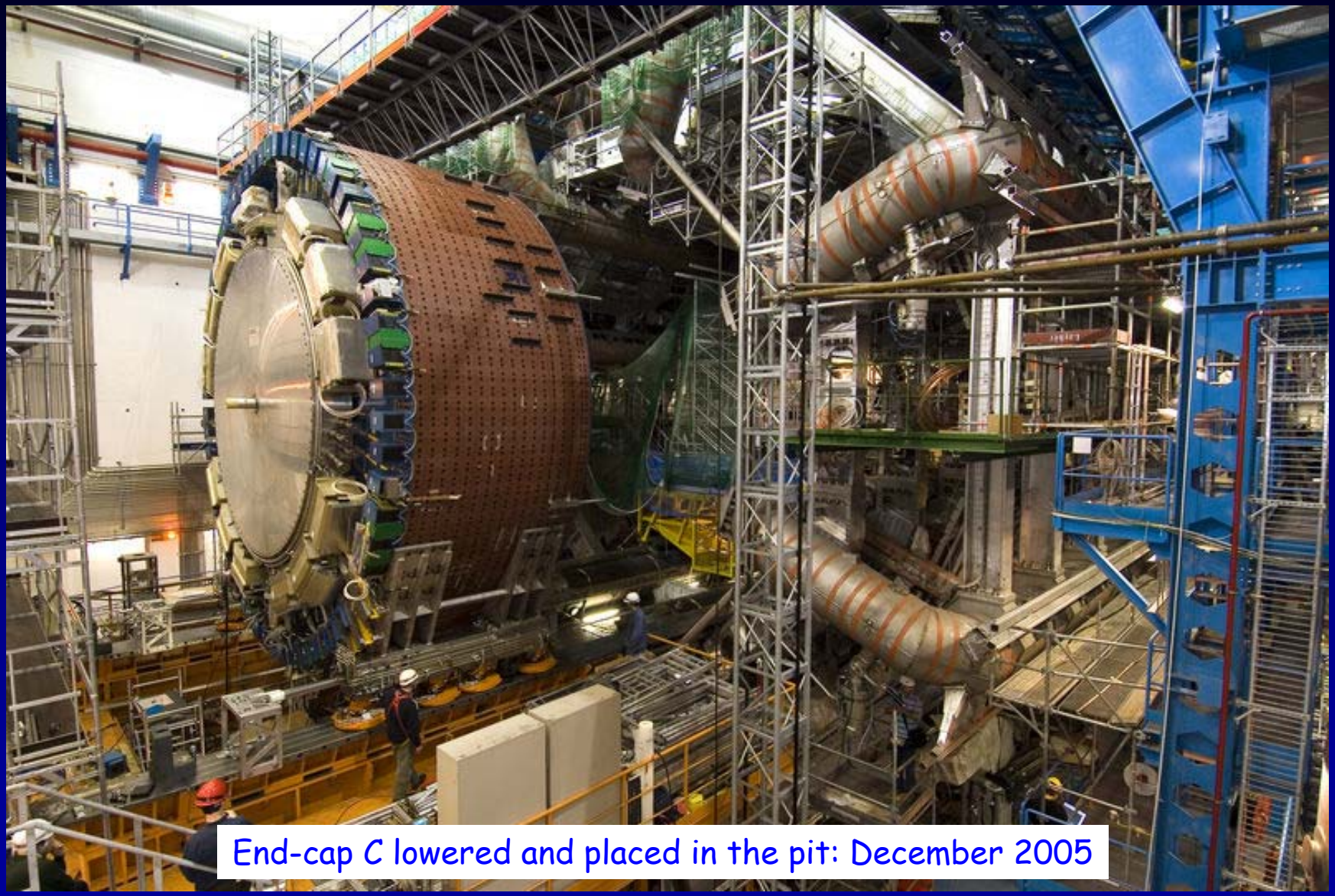
Lowering of Endcap A into the pit





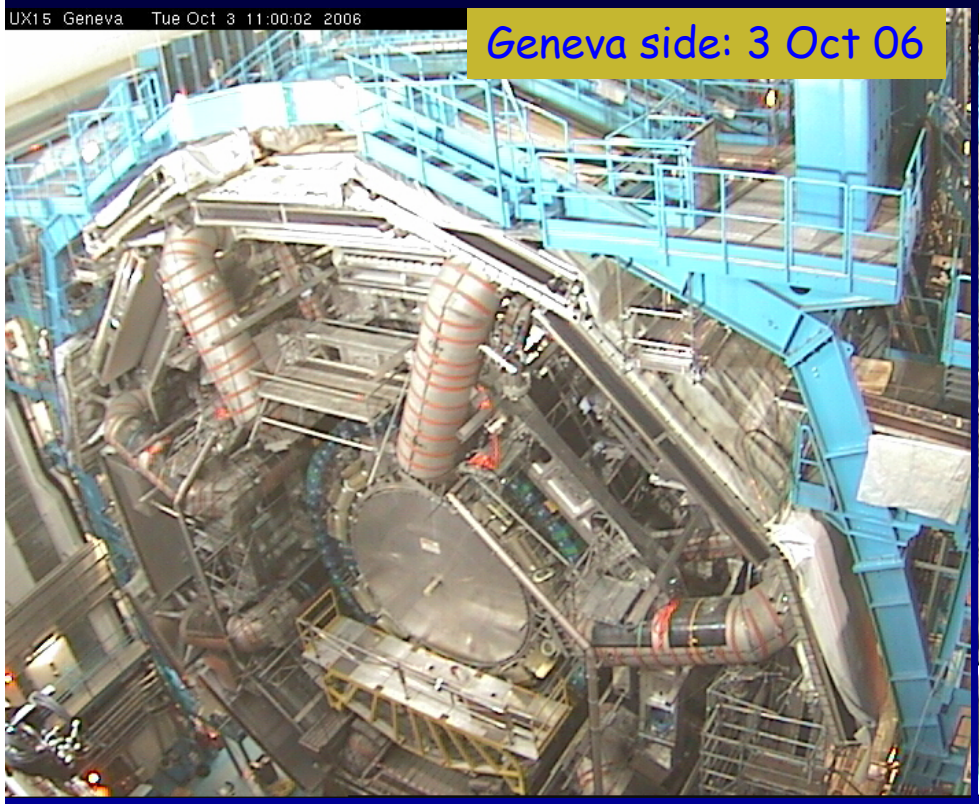
Positioning of Endcap A in Tilecal

Similarly for end-cap C

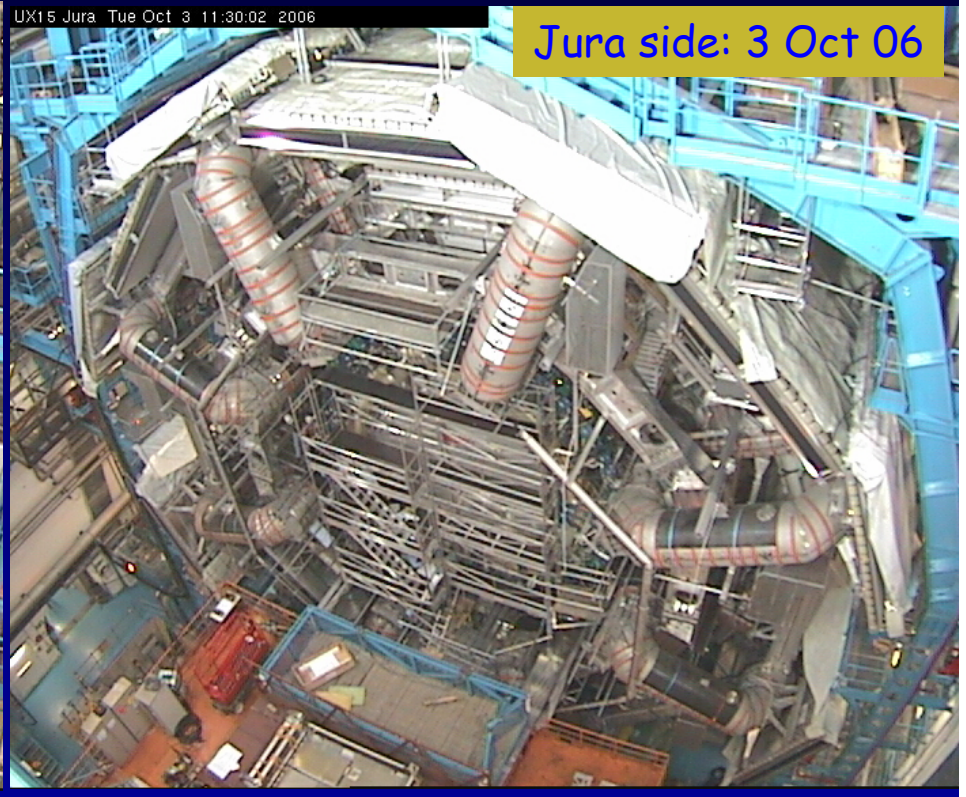


End-cap C lowered and placed in the pit: December 2005

Recent photo of the ATLAS cavern



Geneva side: 3 Oct 06



Jura side: 3 Oct 06

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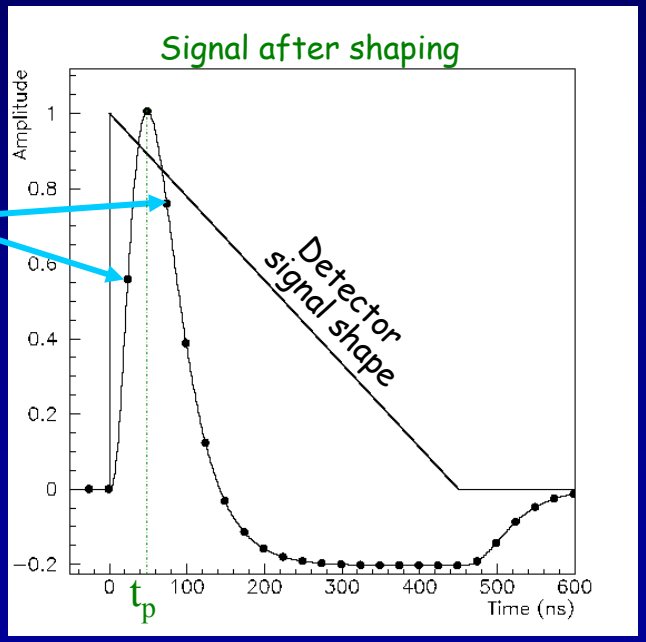
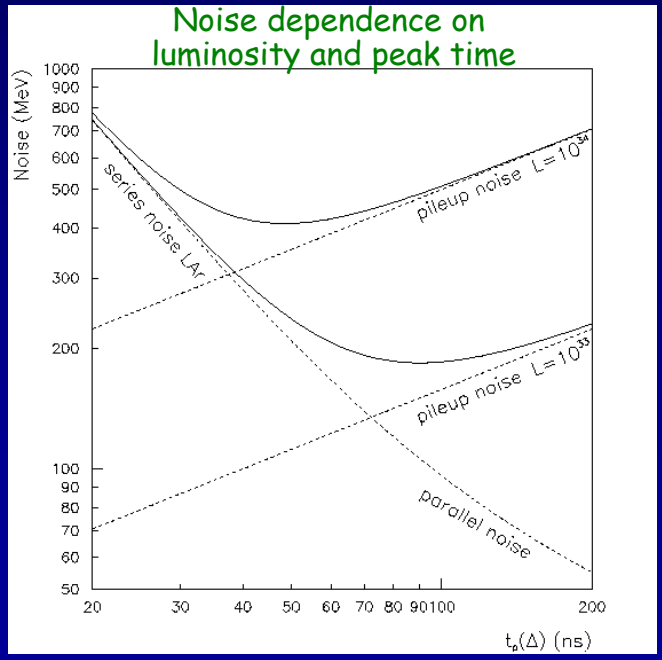
LAr readout electronics: a challenge

- Large dynamic energy range: [20 MeV - 2TeV] ⟶ 16 bits !
- The bunch crossing (BX) rate at LHC is 40 MHz (each 25 ns):
  ⇒ For a signal of 600 ns, the pile-up takes up to 24 BXs.
- Required relative energy resolution: ~ 10% / √E:
  ⇒ Pile-up and electronic noise should be minimized.
  ⇒ Good calibration of the electronics response.
- Electronic boards with high density readout channels and low power (0.8W/channel)

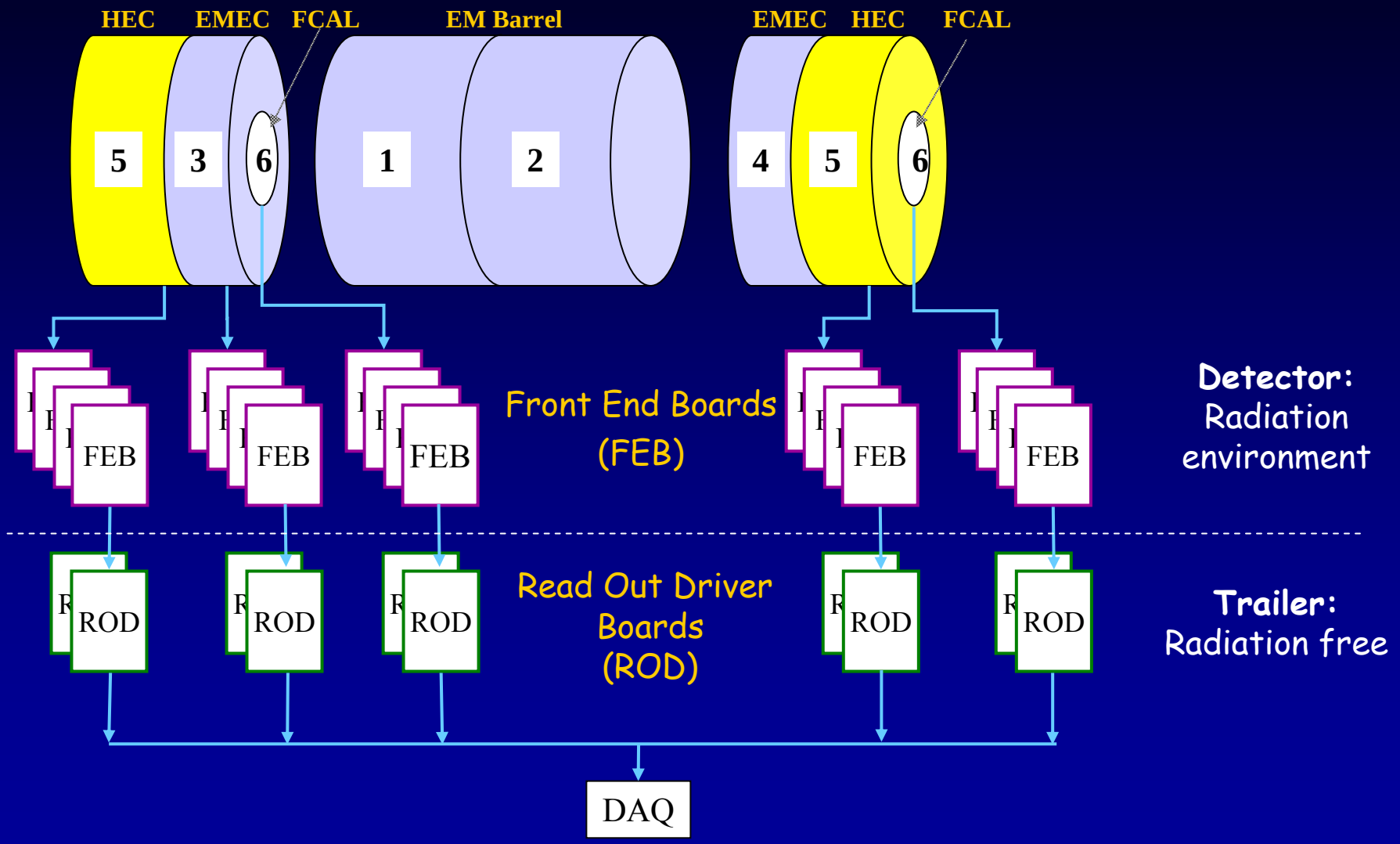
Different BXs





Optimization of the peaking time

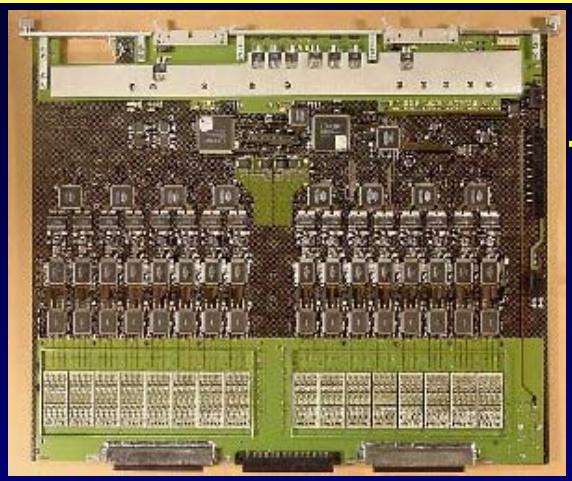
The LAr readout architecture



FEB and ROD boards: overview

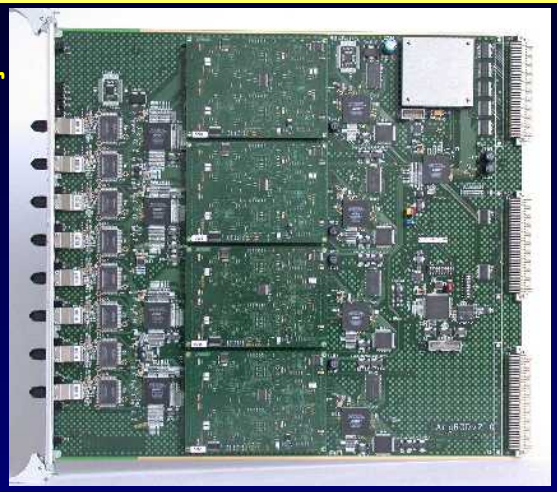
FEB: 1524 boards @ 128 channels

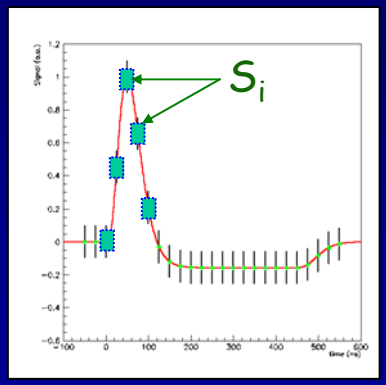
ROD: 192 boards @ 1024 channels



~100 m optical fiber

8





$$E = \sum_{i=1}^{5} a_i \cdot (S_i - Ped)$$

$$E \cdot t = \sum_{i=1}^{5} b_i \cdot (S_i - Ped)$$

$$\chi^2 = \sum_{i=1}^{5} (S_i - Ped - E \cdot g_i)^2$$

- Radiation tolerant board.
- Fast signal shaping (~ 50 ns).
- Digitizes (typically) 5 points using three gains in the ratio 1/10/100.

- Computes time, energy and shape quality flag (χ^2) in $\leq$ 10μs.
- a_i, b_i are optimal filtering coefficients.
- Use Digital Signal Processors (DSP).

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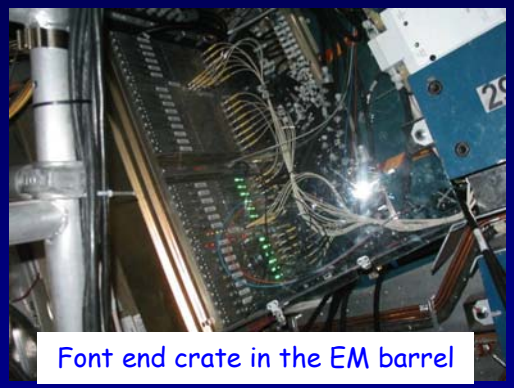
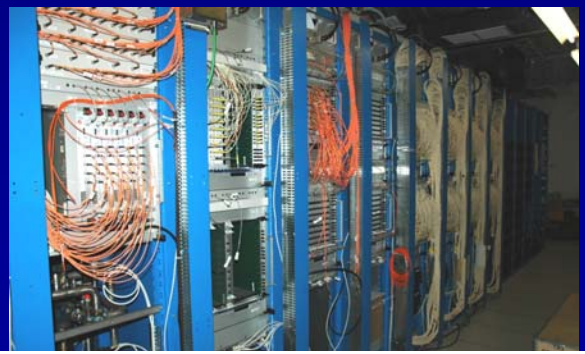
Electronics installation and commissioning

Installation

- Installation and connection of FEBs on the barrel cryostat finished and on the end-caps ongoing.
- Readout electronics installed in the underground service area.



Font end crate in the EM barrel

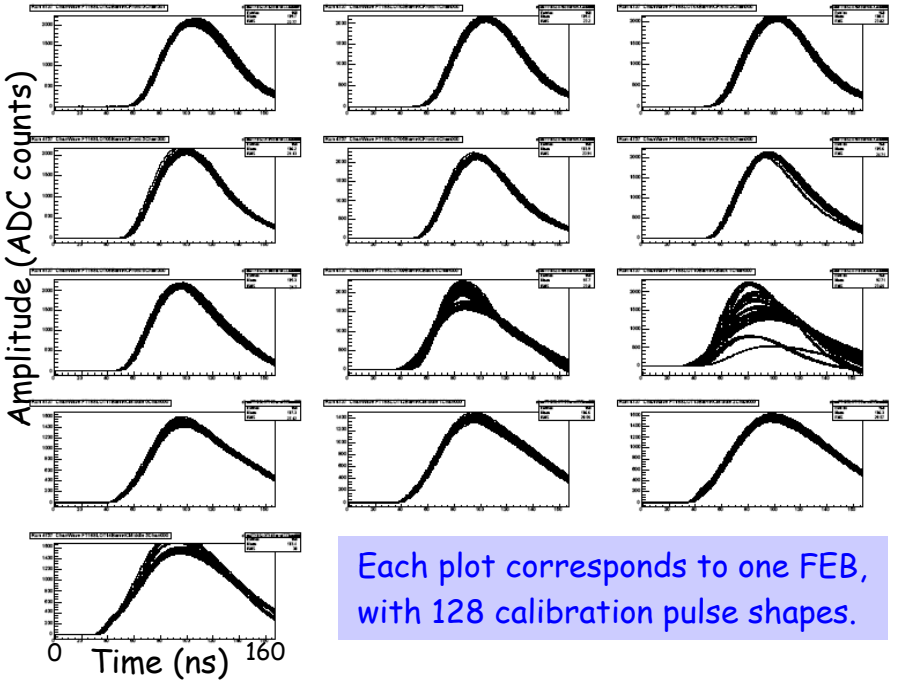


Optical fibers connected between FEBs and RODs

Commissioning

- Commissioning of each of the FEBs installed is ongoing:
- Calibration pulses are injected into the detector modules and read back using the readout chain.

FEB calibration pulse shapes



Each plot corresponds to one FEB, with 128 calibration pulse shapes.

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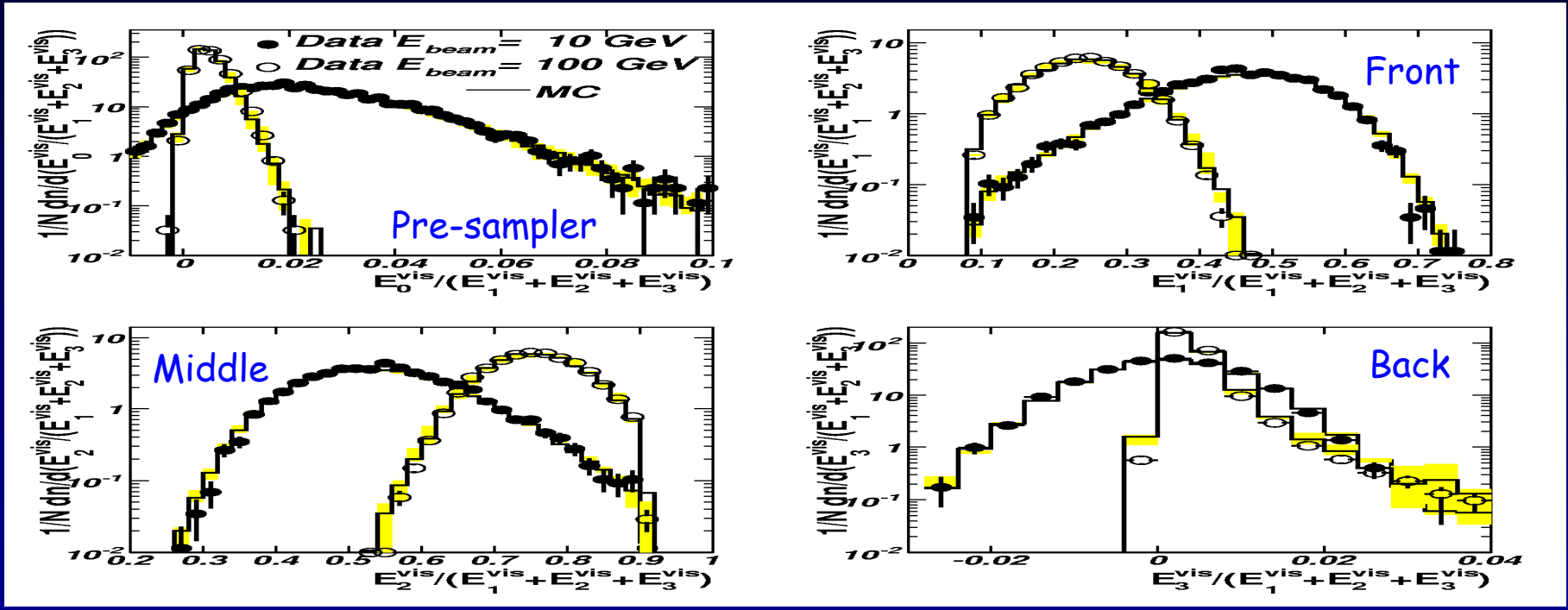
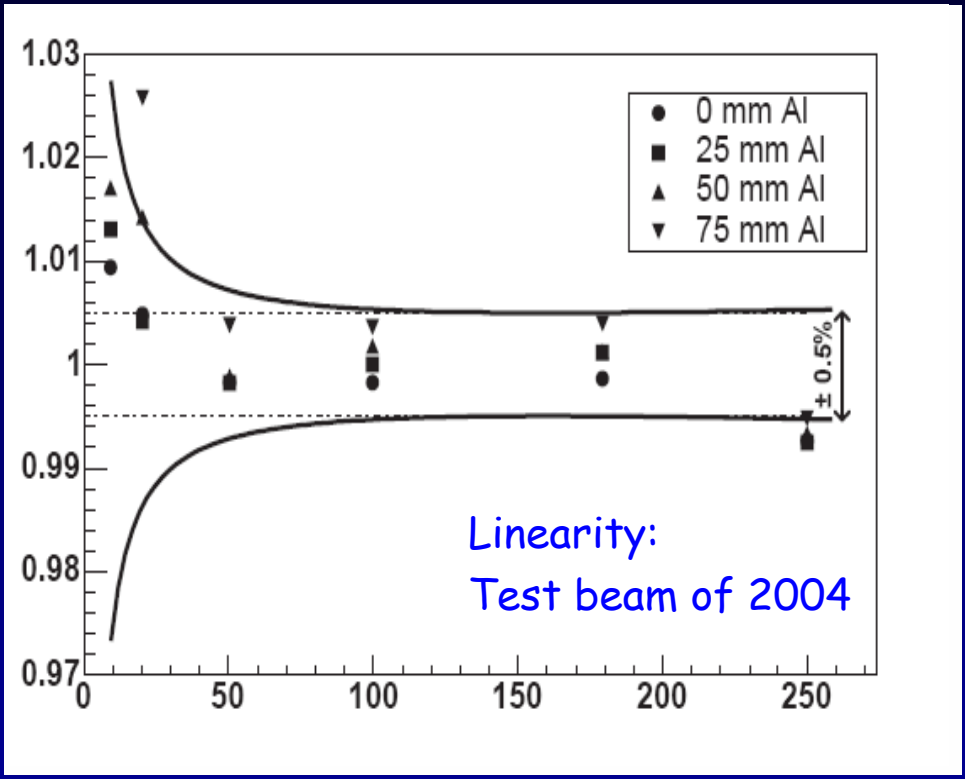
Test beam results:

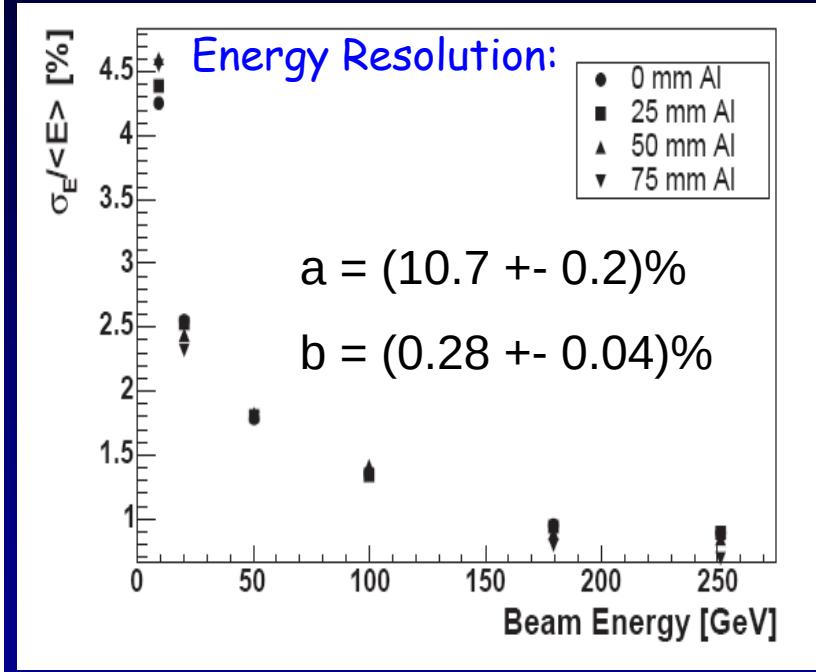
Data/MC comparison



The fraction of energy distribution on the pre-sampler and the three longitudinal segmentations of the EM calorimeter compare well between data and Monte Carlo.

Test beam results:
linearity and resolution



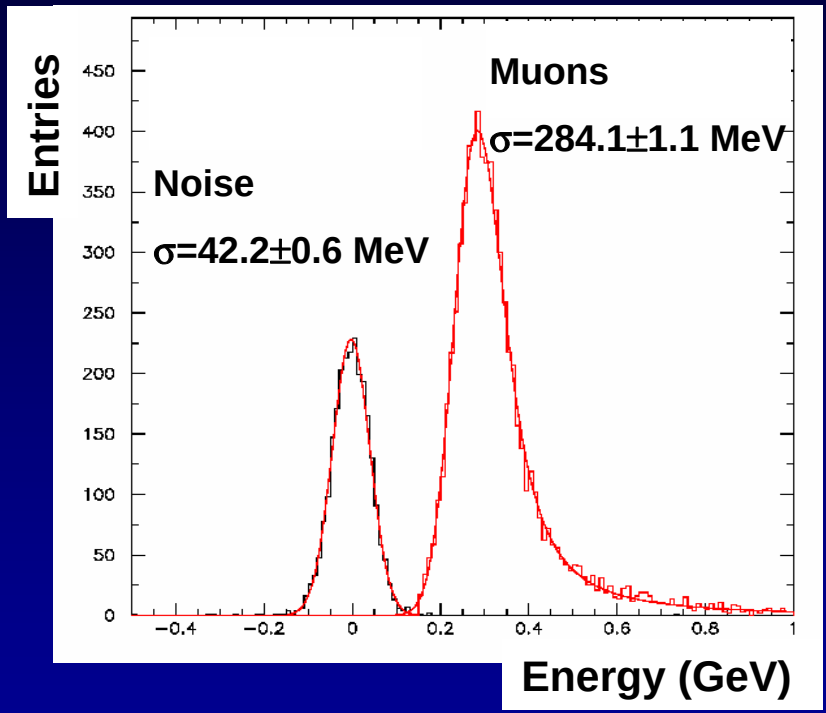


Linearity of 0.1% achieved in 2002.
In testbeam 2004, detector linear ±0.5%
(beam energy uncertainty of 1%)

Resolution:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

Test beam results:
muon response



Muons at 6σ from noise

LAr EM tests: some publications

- Some publications of LAr EM modules tests, which started ~1990 with the RD3 collaboration:
  - "Performance of a large scale prototype of the ATLAS accordion electromagnetic calorimeter", NIM A364 (1995) 290-306.
  - "Performance of an end-cap prototype of the ATLAS accordion electromagnetic calorimeter", NIM A389 (1997) 398-408.
  - "Results from a new combined test of an electromagnetic liquid argon calorimeter with a hadronic scintillating-tile calorimeter", NIM A449 (2000) 461-477
  - "Test beam results of the ATLAS electromagnetic calorimeter prototype modules", NIM A494 (2002) 346-354
  - "Performance of the ATLAS electromagnetic calorimeter end-cap module 0" NIM A500 (2003) 178-201
  - "Performance of the ATLAS electromagnetic calorimeter barrel module 0", NIM A500 (2003) 202-231
  - "Construction, assembly and tests of the ATLAS electromagnetic barrel calorimeter", NIM A558 (2006) 388-418
  - "Energy linearity and resolution of the ATLAS electromagnetic barrel calorimeter in an electron test-beam", NIM A (2006) in progress

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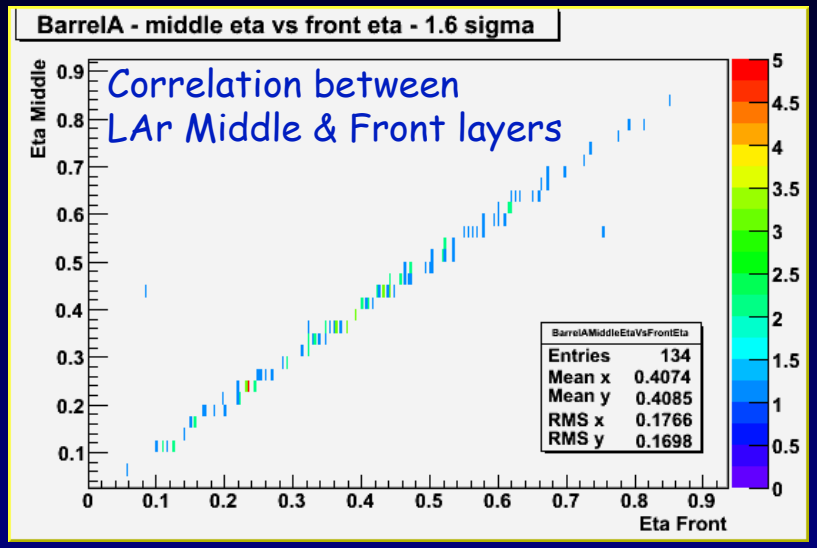
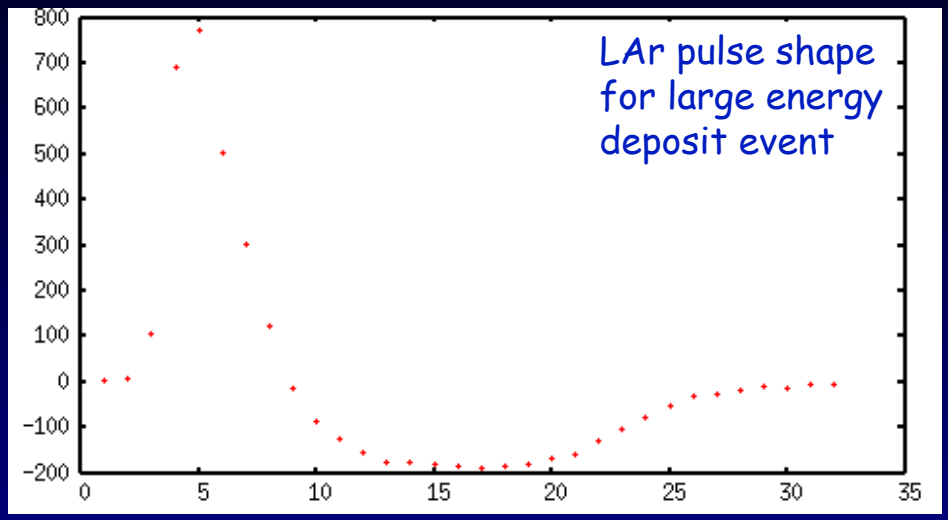
Summary

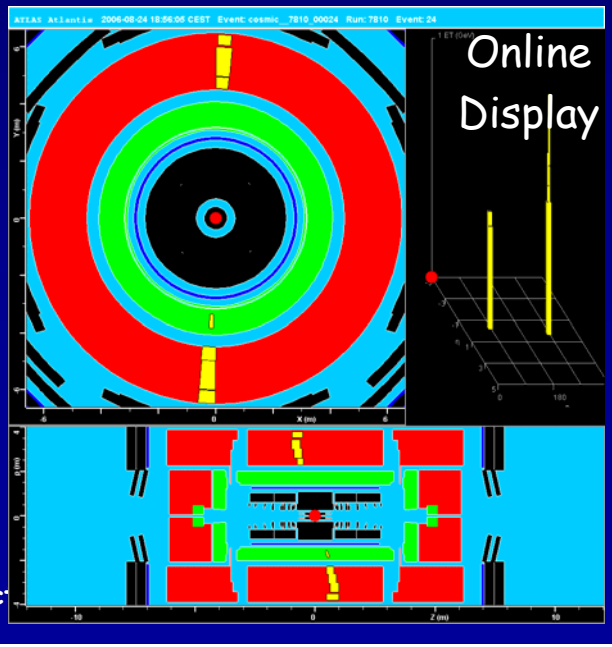
- The test beam results until now show that the detector reach the physics requirements for the LHC.
- The construction of the Liquid Argon calorimeters and integration into the cryostats have successfully come to an end in 2004.
- Cold tests on the surface show an excellent condition of the calorimeters (more than 99.9% of channels work).
- The installation of the three cryostats into the ATLAS cavern took place between 2004 and 2006 and the EM barrel calorimeter is already at the ATLAS interaction point.
- At present the LAr calorimeters and electronics are being commissioned in the ATLAS pit by using cosmics triggered by the Tile hadronic Calorimeter.
- The Liquid Argon calorimeters are looking forward for PHYSICS after a commissioning phase during 2006 until middle 2007.

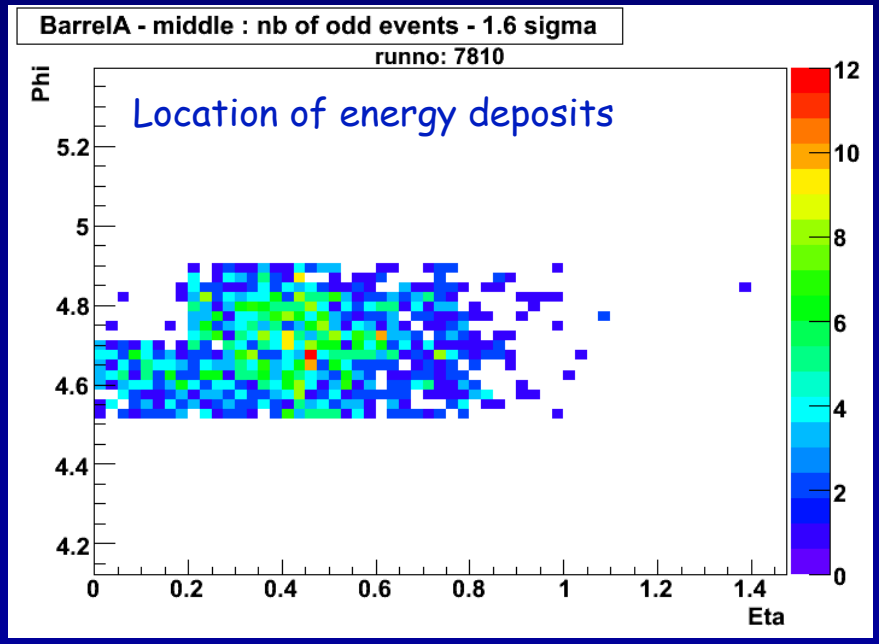
Muons seen by the calorimeter in point 1

Cosmic Run with TileCal – First Look at the Data









Calorimeters commissioning plans

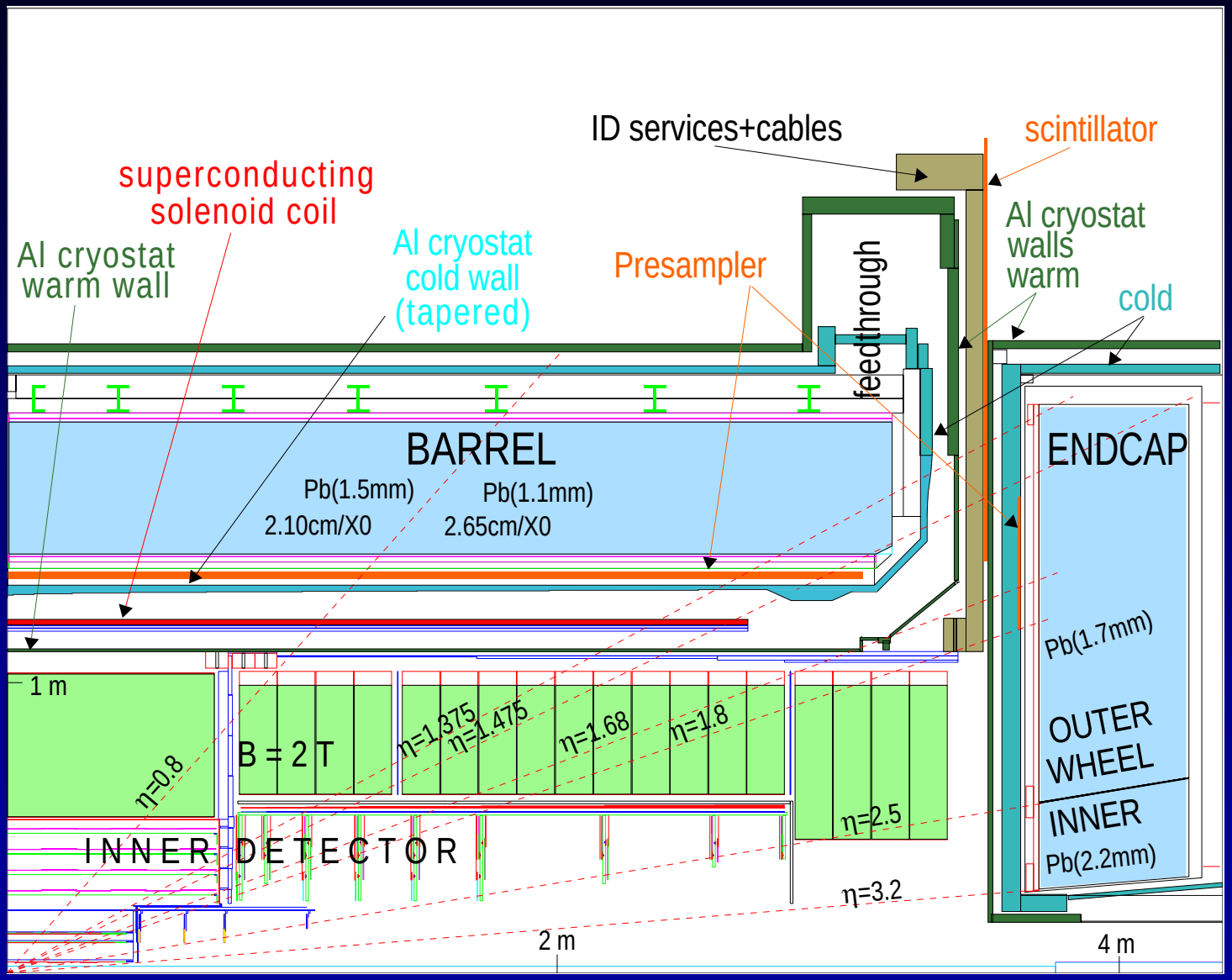
"Expert weeks" are taking place both for the barrel and end-cap calorimeters since Spring and Summer 2006.

Date	Task
July 06 till Dec 06	Barrel cosmic runs
Sept 06 till Nov 06	End-cap A cold
Dec 06 till Feb 07	End-cap A cosmic runs
Dec 06 till Jan 07	End-cap C cold
Feb 07 till Apr 07	End-cap C cosmic runs

Thanks!
Specially to the organizers!

Backup slides

Detector overview

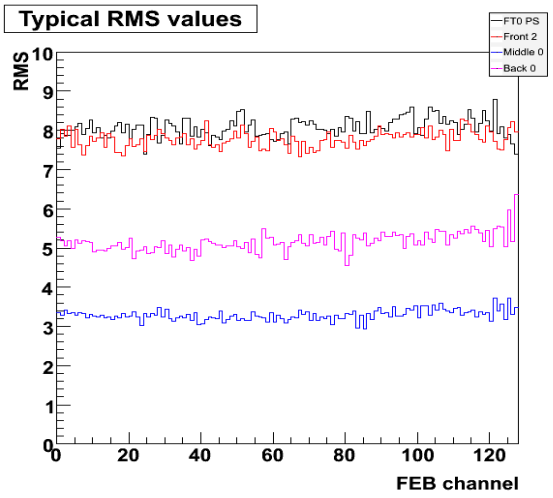


LAr electronic calibration runs

pedestals and noise

FEB are read with no input signal to obtain:

- Pedestal
- Noise
- Noise autocorrelation (OFC computation)

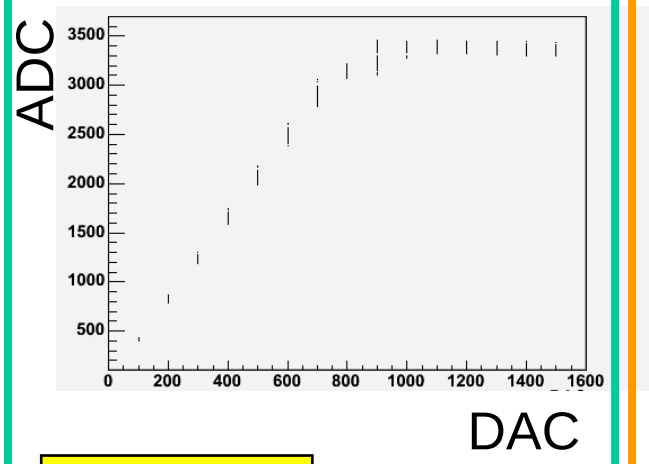


Every 8 hours

ADC → MeV conversion

$F = ADC2DAC \times DAC2\mu A \times \mu A2MeV \times f_{samp}$

- Scan input current (DAC)
- Fit DAC vs ADC curve with a second order polynomial, outside of saturation region

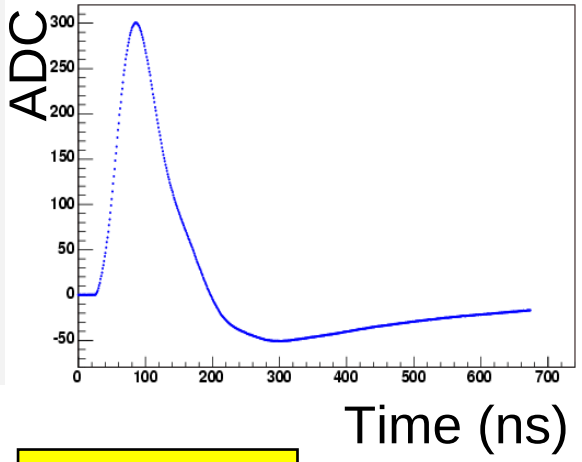


Every 8 hours

response to current pulse

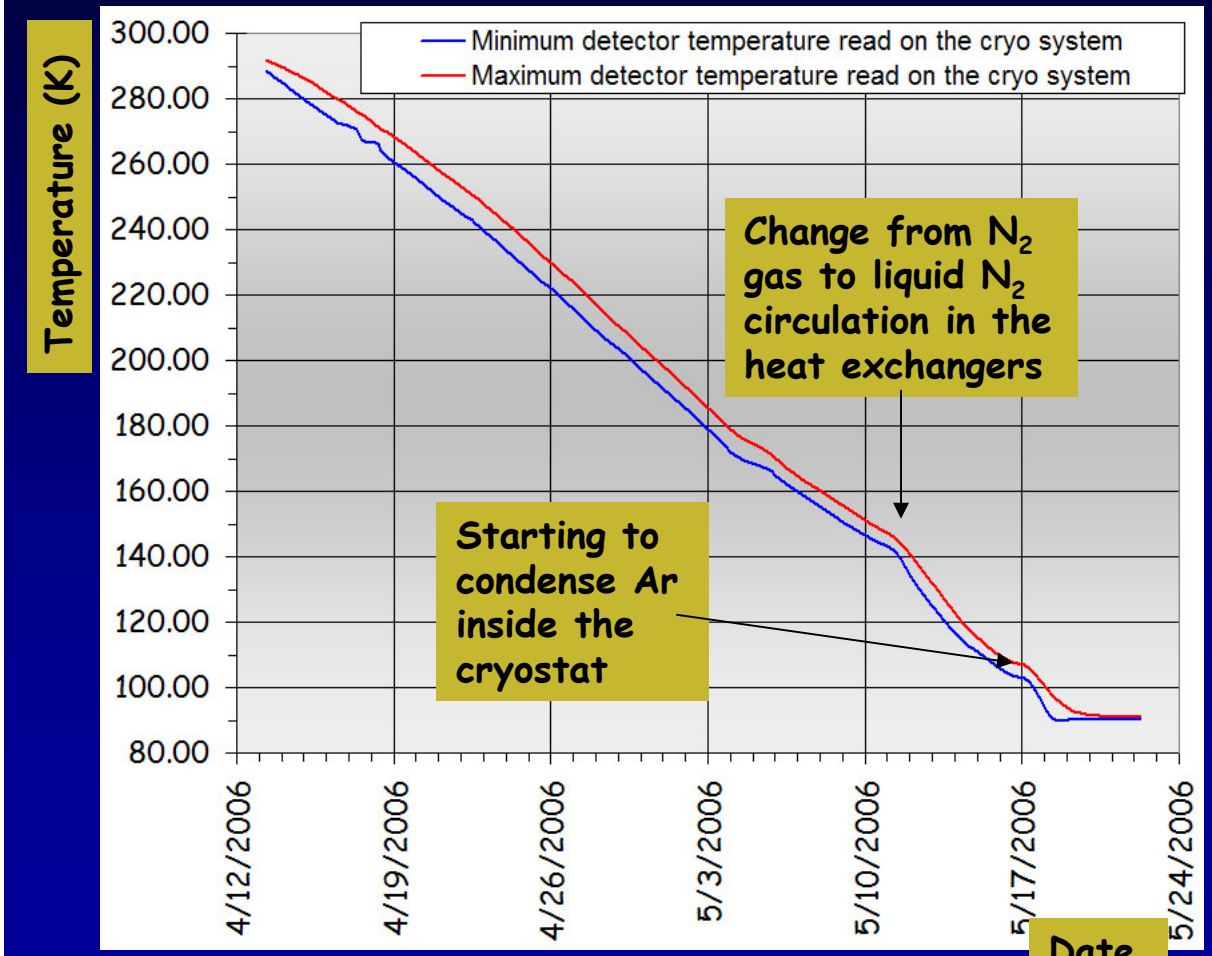
All cells are pulsed with a known current signal:

- A delay between calibration pulses and DAQ is introduced
- The full calibration curve is reconstructed (Δt=1ns)



Every change of cabling

Barrel Cryostat Cool Down



- Cool down started mid April 06
- Filling with LAr since May 17 (condensing Ar gas) for 2 weeks
- Now cryostat filled
- HV situation checked regularly
- Ramping up the HV
- After that the barrel detector is operational
- Continue connecting front end electronics
- Cosmic muon data taking in summer 2006.