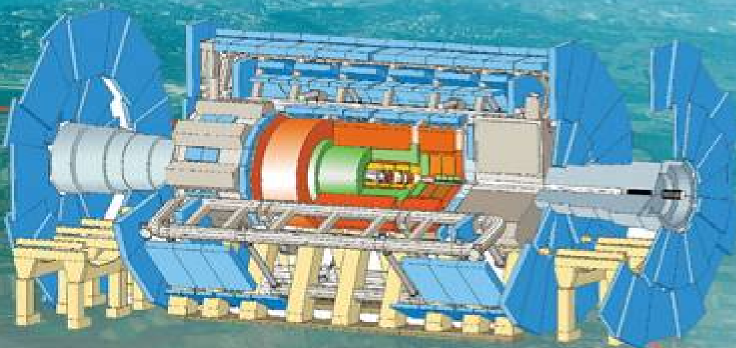
The ATLAS Experiment:
status of the project and early physics

Sandro Palestini – CERN

HEP 2006 – Ioannina – 15 April 2006



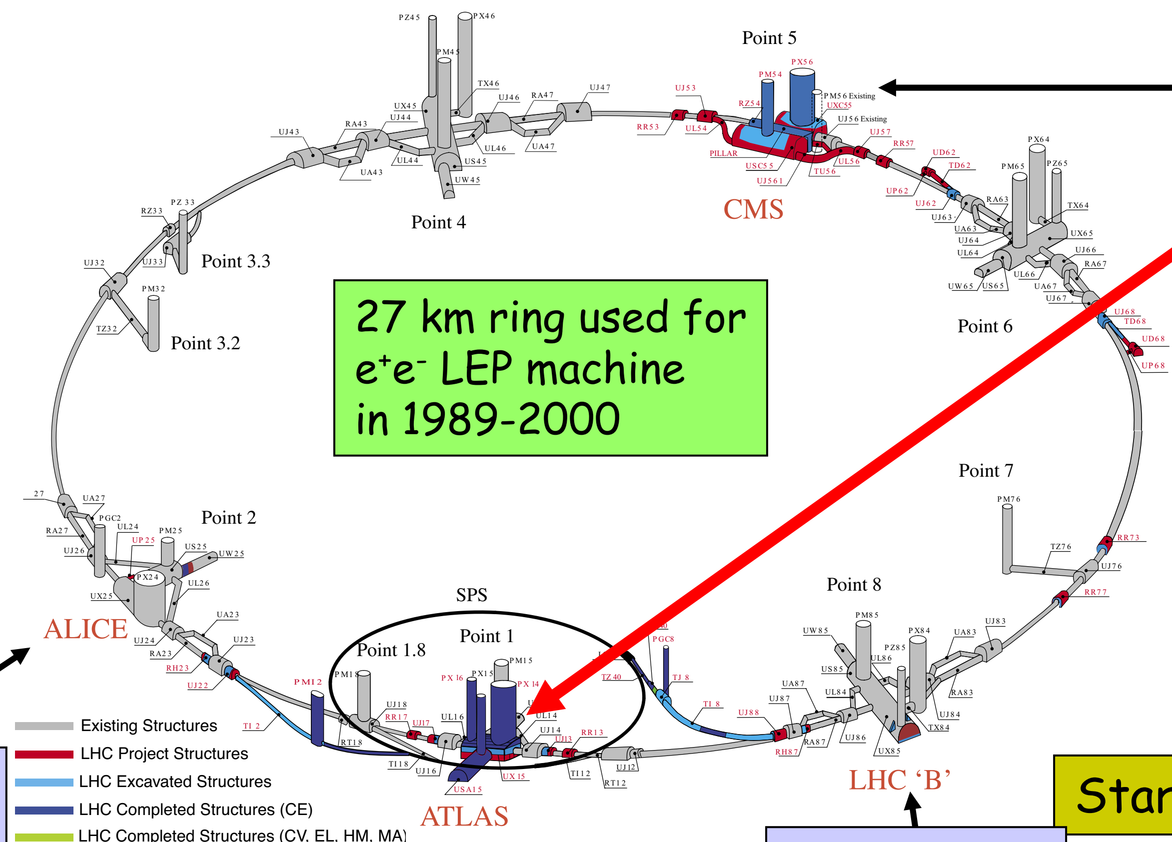
I – The LHC project

LHC

pp

- $\sqrt{s}$ = 14 TeV (7 times higher than Tevatron/Fermilab)
  → search for new massive particles up to m ~ 5 TeV

- $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ (>10^2 higher than Tevatron/Fermilab)
  → search for rare processes with small σ ($N = L\sigma$)



27 km ring used for e^+e^- LEP machine in 1989-2000

ATLAS and CMS : pp, general purpose

ALICE : heavy ions

LHCb : pp, B-physics

Start : Summer 2007

LHC Machine Parameters

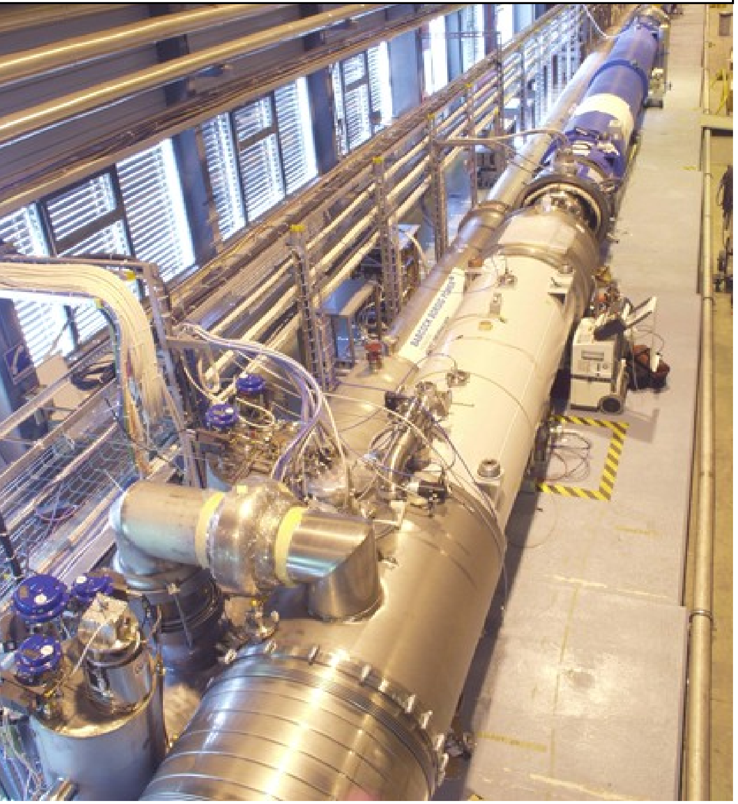
Energy	E	[TeV]	7.0
Dipole field	B	[T]	8.4
Luminosity	L	[cm^{-2} s^{-1}]	10^{34}
Beam–beam parameter	ξ		0.0034
Total beam–beam tune spread			0.01
Injection energy	E_i	[GeV]	450
Circulating current/beam	I_{beam}	[A]	0.53
Number of bunches	k_b		2835
Harmonic number	h_{RF}		35640
Bunch spacing	τ_b	[ns]	24.95
Particles per bunch	n_b		$1.05\ 10^{11}$
Stored beam energy	E_s	[MJ]	334
Normalized transverse emittance $(\beta\gamma)\sigma^2/\beta$	ε_n	[μm.rad]	3.75
Collisions			
β-value at I.P.	β^*	[m]	0.5
r.m.s. beam radius at I.P.	σ^*	[μm]	16
r.m.s. divergence at I.P.	σ'^*	[μrad]	32
Luminosity per bunch collision	L_b	[cm^{-2}]	$3.14\ 10^{26}$
Crossing angle	ϕ	[μrad]	200
Number of events per crossing	n_c		19
Beam lifetime	τ_{beam}	[h]	22
Luminosity lifetime	τ_L	[h]	10

Limiting factor for √s: Bending power needed to keep beams in 27 km LHC ring

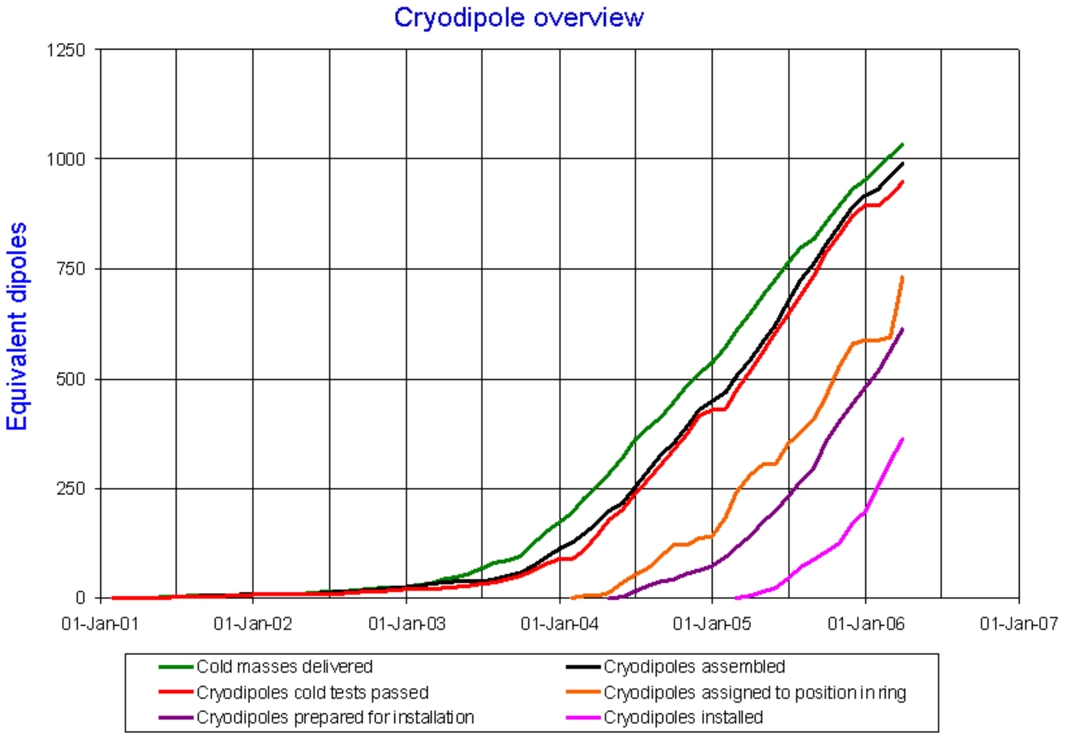
p(TeV) = 0.3 B(T) R(km)

With the typical magnet packing factor of ~ 70%, the 1232 dipoles with B = 8.4 T give 7 TeV beams

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



LHC Progress Dashboard



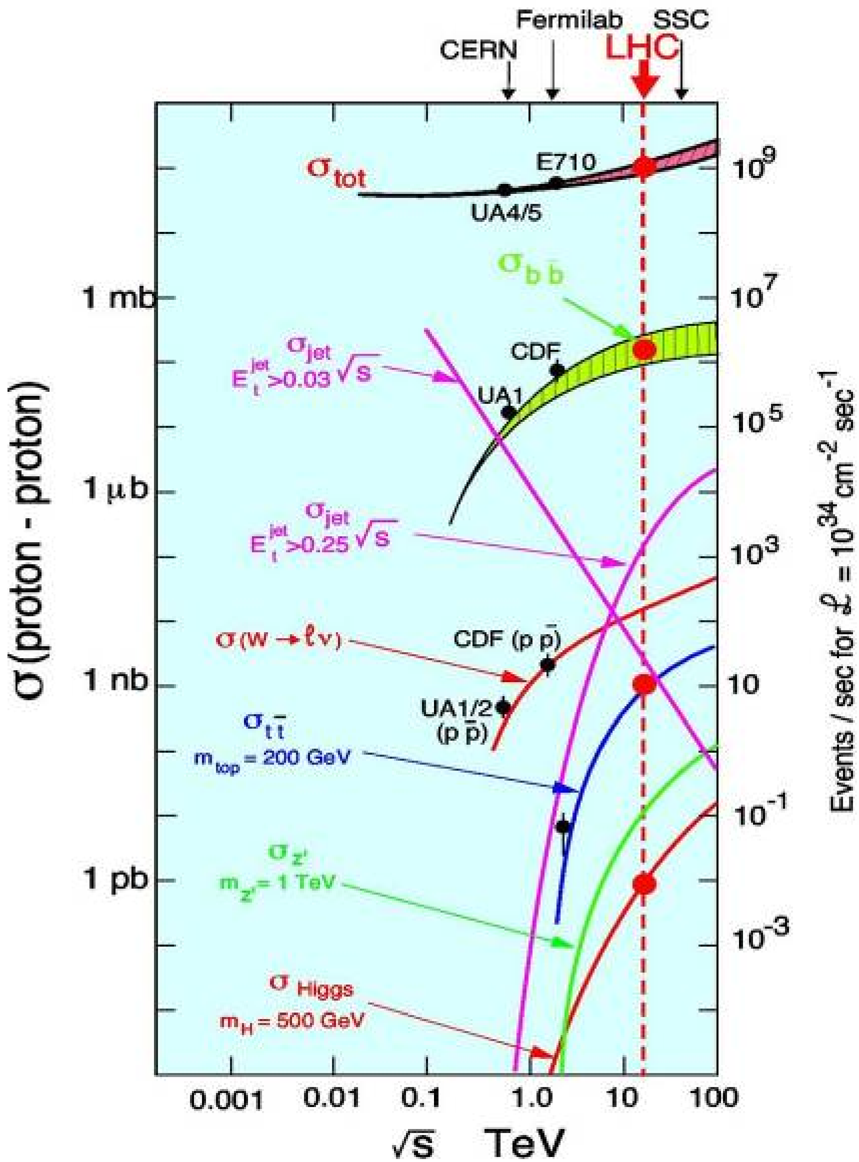
Updated 31 Mar 2006 Data provided by D. Tommasini AT-MAS, L. Bottura AT-MTM

First 600 m of cryoline (QRL) successfully cooled down on September 14, followed by cool-down of full cryoline sector 8-1 end of November 2005

Installation of dipoles – now at the rate of 20 per week – is expected to be completed in Feb 07

All dipoles are tested at warm (magnetic tests) and at cold (quench behaviour)
15% are also subject to detailed magnetic tests at cold

Cross Sections and Production Rates



Rates for L = 10^{34} cm^{-2} s^{-1}: (LHC)

• **Inelastic proton-proton reactions:**	**10^9 / s**
• **bb pairs**	**5 10^6 / s**
• **tt pairs**	**8 / s**
• **W → e ν**	**150 / s**
• **Z → e e**	**15 / s**
• **Higgs (150 GeV)**	**0.2 / s**
• **Gluino, Squarks (1 TeV)**	**0.03 / s**

LHC is a factory for:
top-quarks, b-quarks, W, Z, ……. Higgs, ……

(The challenge: you have to detect them !)

Which physics the first year(s) ?

Expected event rates at production in ATLAS at L = 10^{33} cm^{-2} s^{-1}

Process	Events/s	Events for 10 fb^{-1}	Total statistics collected at previous machines by '07
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tevatron
$Z \to ee$	1.5	10^7	10^7 LEP
$t\bar{t}$	1	10^7	10^4 Tevatron
$b\bar{b}$	10^6	$10^{12} - 10^{13}$	10^9 Belle/BaBar ?
H m=130 GeV	0.02	10^5	?
$\tilde{g}\tilde{g}$ m= 1 TeV	0.001	10^4	---
Black holes m > 3 TeV (M_D=3 TeV, n=4)	0.0001	10^3	---

Already in first year, large statistics expected from:
-- known SM processes → understand detector and physics at $\sqrt{s}$ = 14 TeV
-- several New Physics scenarios

II – The ATLAS project
collaboration, design and current status

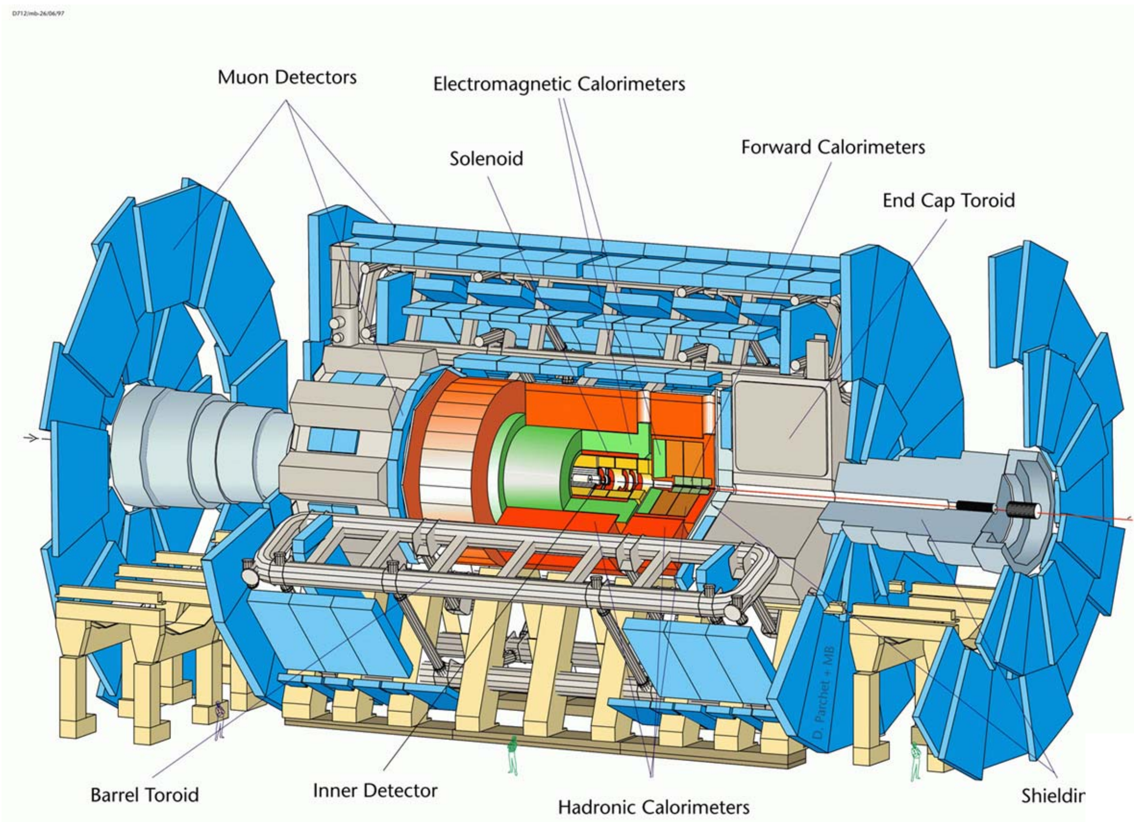
ATLAS Collaboration

(As of the March 2006)

35 Countries
158 Institutions
1650 Scientific Authors total

Recent applications:
DESY, Humboldt U Berlin (Germany)
SLAC, New York U (US)

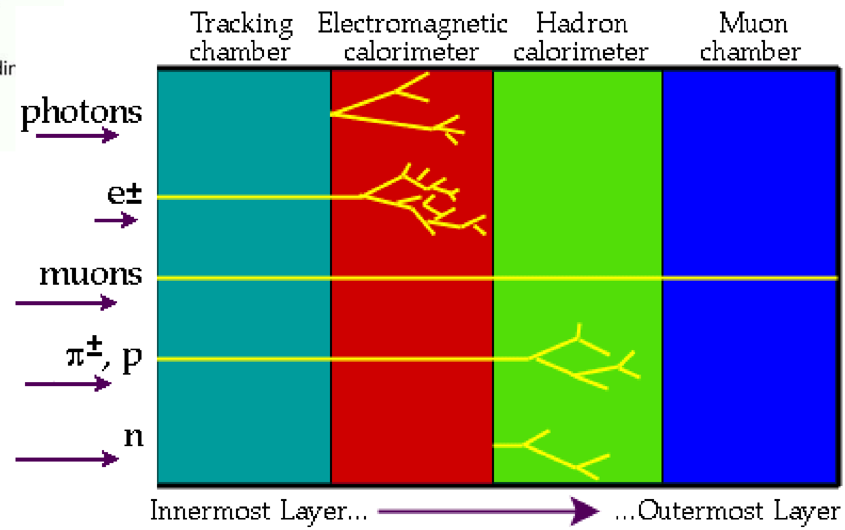
Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, INP Cracow, FPNT Cracow, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Naples, Naruto UE, New Mexico, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Ritsumeikan, UFRJ Rio de Janeiro, Rochester, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, Wisconsin, Wuppertal, Yale, Yerevan



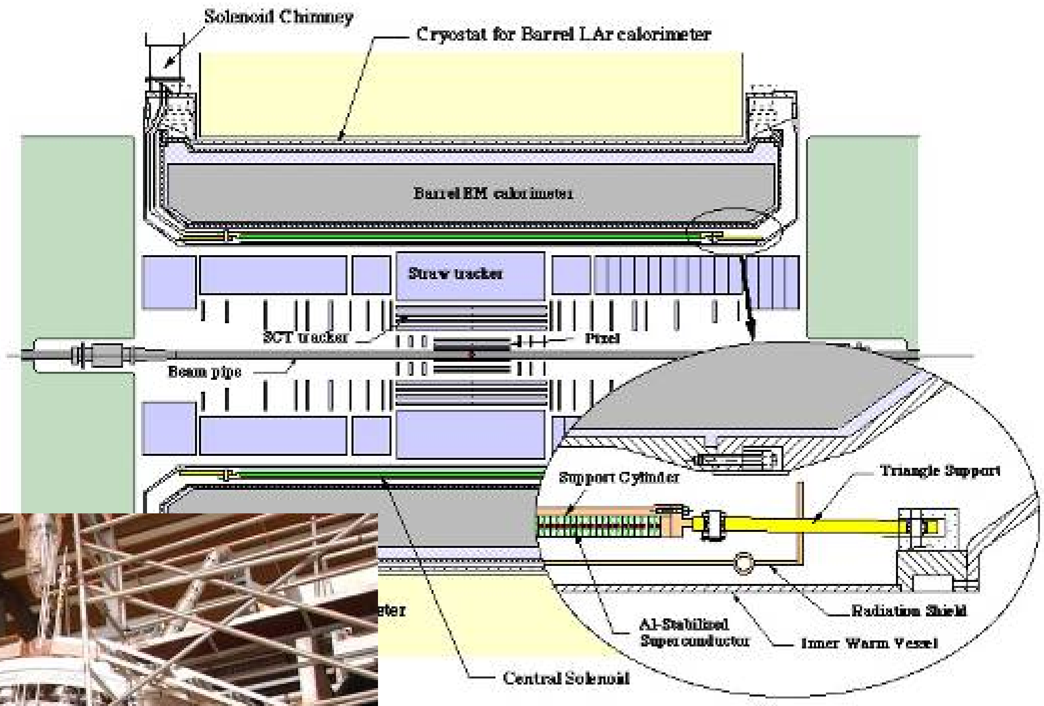
ATLAS

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~ 10^8 electronic channels
~ 3000 km of cables

- **Tracking (|η|<2.5, B=2T) :**
  - **-- Si pixels and strips**
  - **-- Transition Radiation Detector (e/π separation)**
- **Calorimetry (|η|<5) :**
  - **-- EM : Pb-LAr**
  - **-- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)**
- **Muon Spectrometer (|η|<2.7) :**
  air-core toroids with muon chambers



Magnet System



Central Solenoid

2T field with a stored energy of 38 MJ

Integrated design within the barrel LAr cryostat

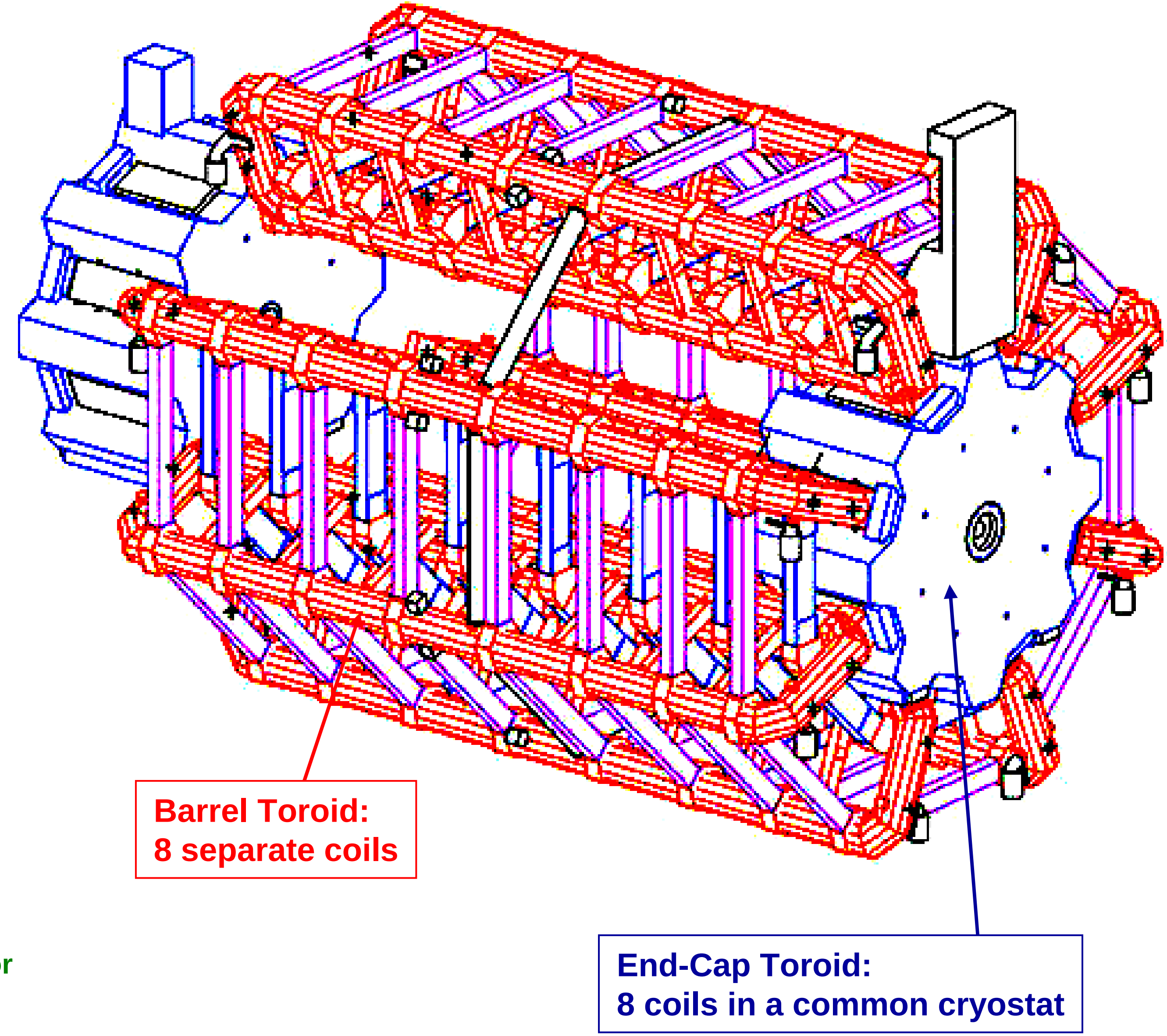
The solenoid has been inserted into the LAr cryostat at the end of February 2004, and it was tested at full current (8 kA) during July 2004.

Full tests and magnetic map planned for June 06

Toroid system

Barrel Toroid parameters
25.3 m length
20.1 m outer diameter
8 coils
1.08 GJ stored energy
370 tons cold mass
830 tons weight
4 T on superconductor
56 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point
2-4 Tm field integral

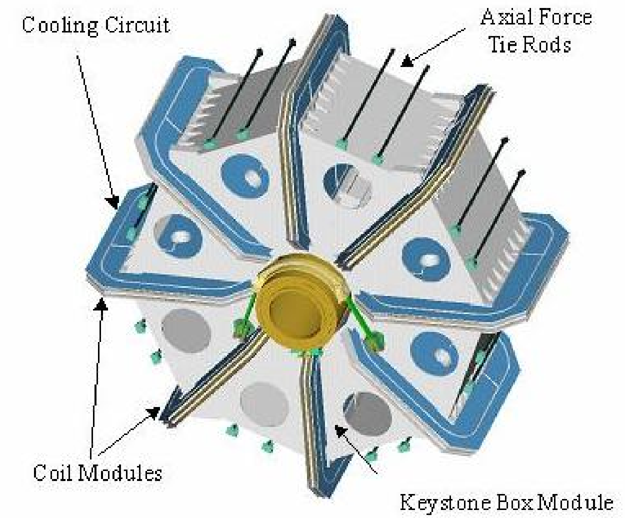
End-Cap Toroid parameters
5.0 m axial length
10.7 m outer diameter
2x8 coils
2x0.25 GJ stored energy
2x160 tons cold mass
2x240 tons weight
4 T on superconductor
2x13 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point
3-8 Tm field integral



The last coil was moved into position on 25th August 2005

Currently, the BT is being prepared for cool-down (pumped to vacuum). Full test planned for end of spring

End-Cap Toroids



All components are fabricated, and the assembly is now ongoing at CERN

The ECTs will be tested at 80 K on the surface, before installation and excitation tests in the cavern

The first ECT will move to the pit in August 2006, the second one in November 2006

The first of the two ECT cold masses ready for insertion into the large vacuum vessel

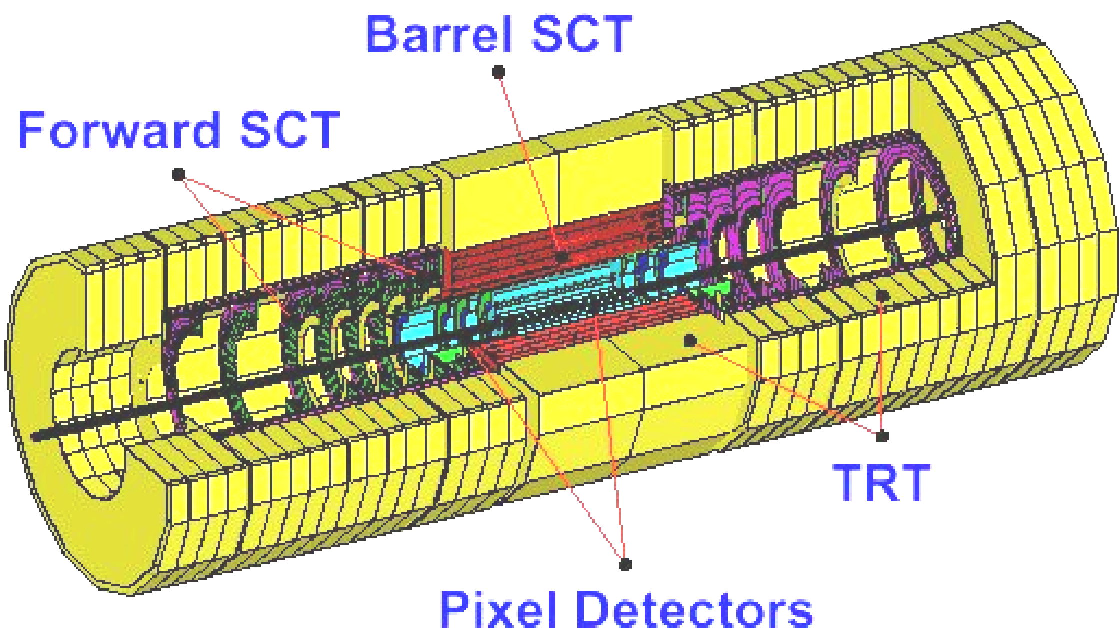
Inner Detector (ID)

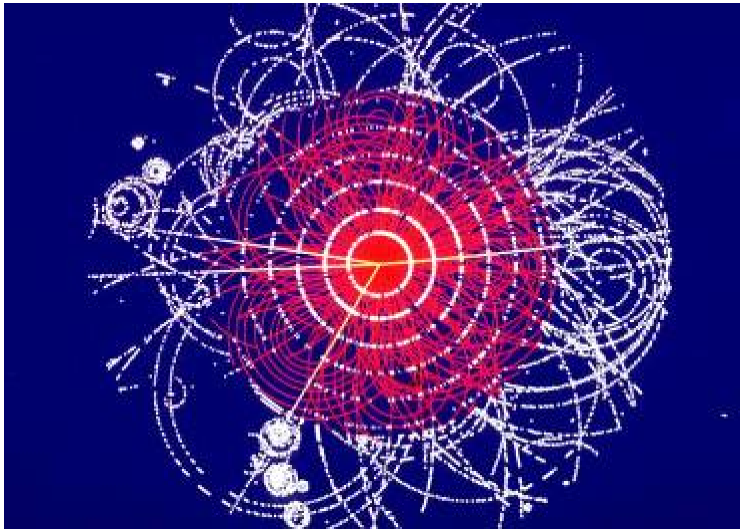
The Inner Detector (ID) is organized into four sub-systems:

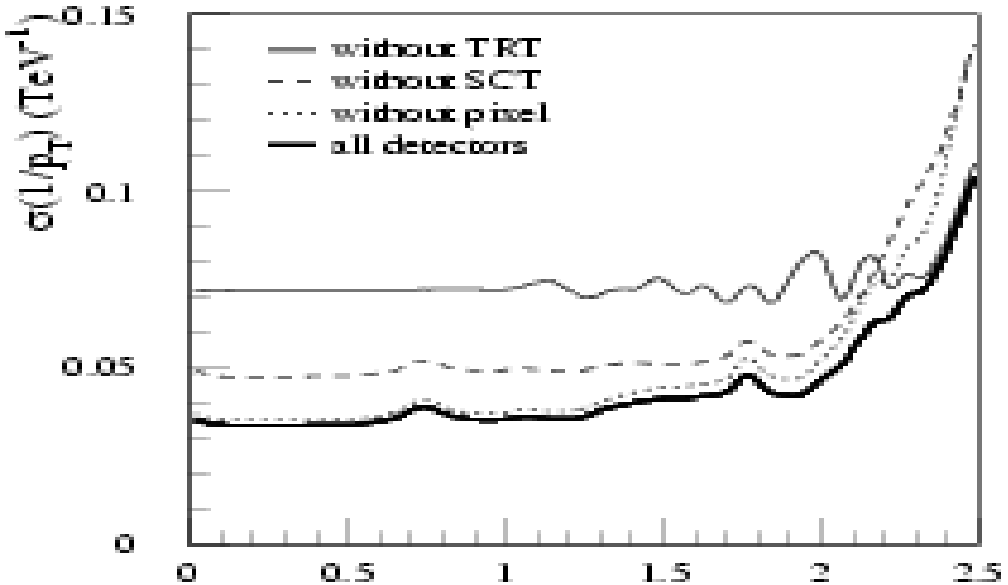
Pixels (3 barrel layers and 3+3 endcap wheels - 0.8 10^8 channels)

Silicon Tracker (SCT) (4 barrel layers and 9+9 endcap wheels - 6 10^6 channels)

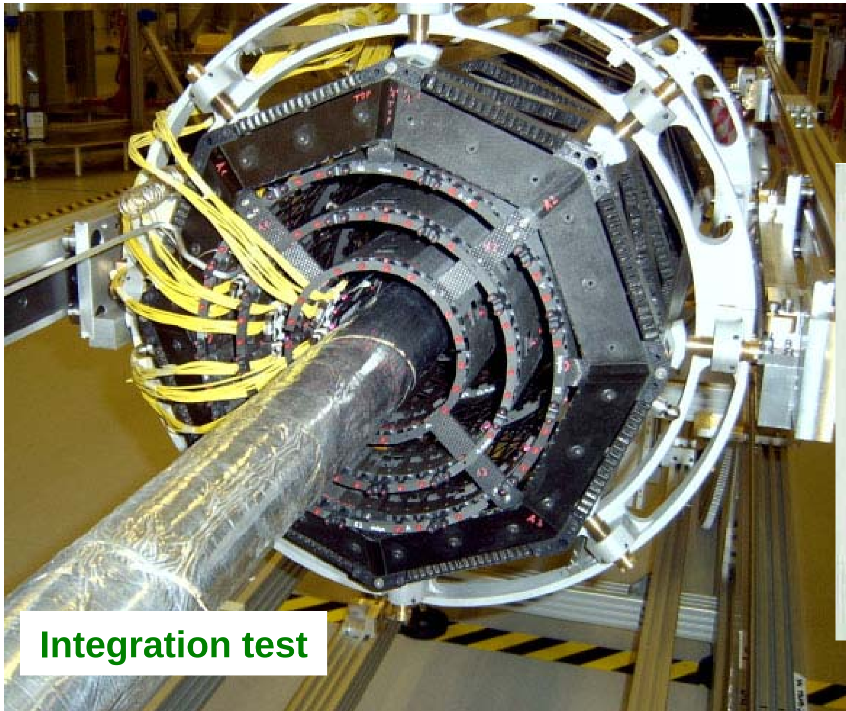
Transition Radiation Tracker (TRT) (*continuous* tracking, barrel section and endcap sections - 4 10^5 channels)





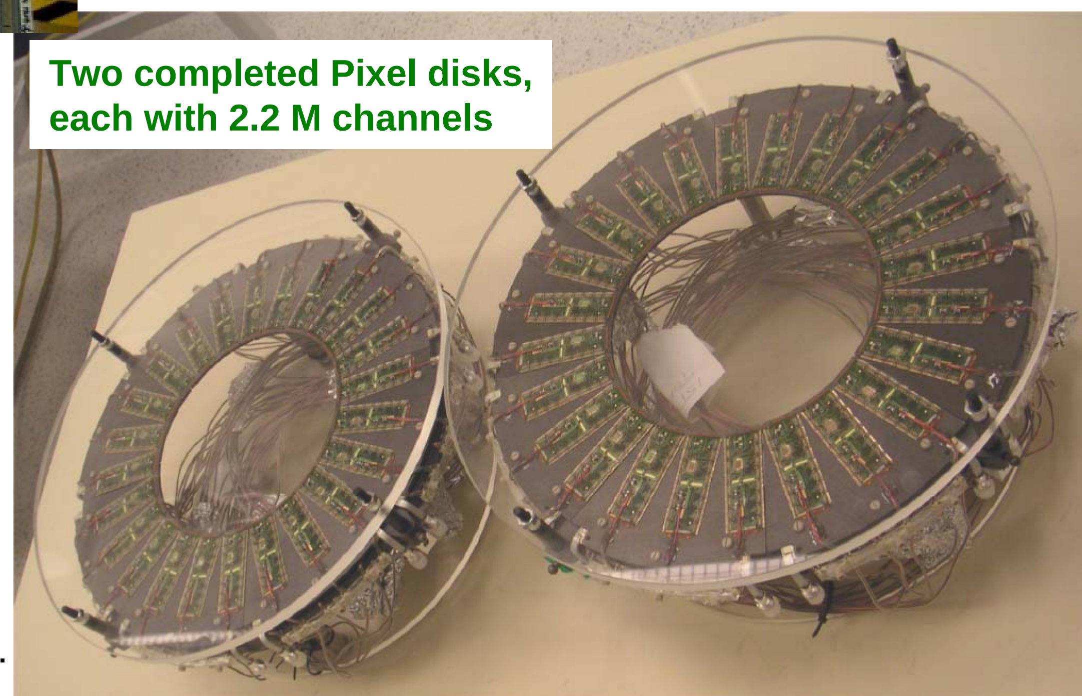


Pixels



Integration test

Bi-stave assembly

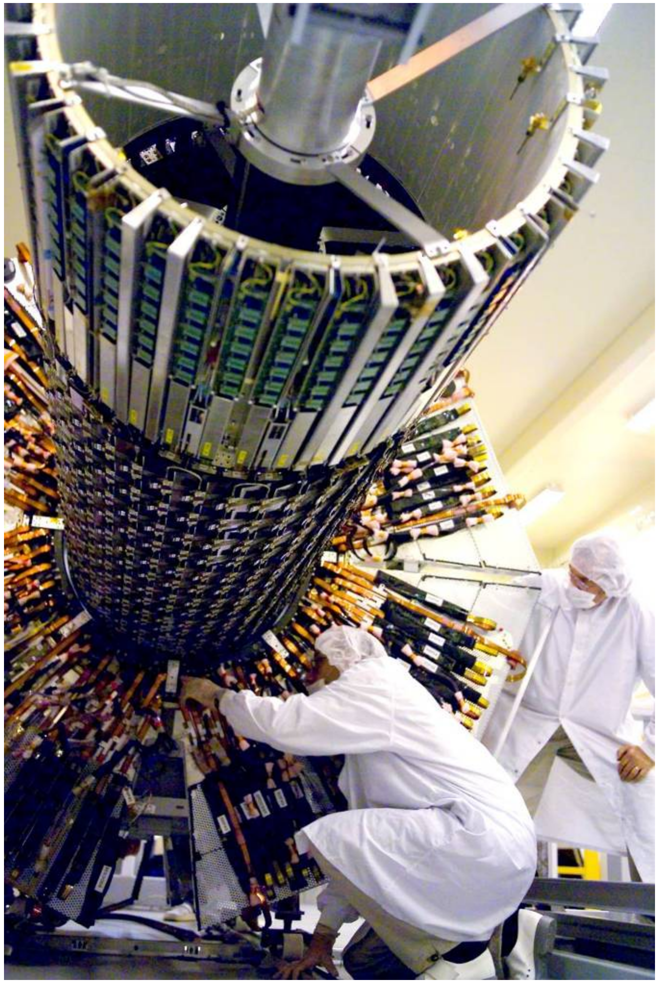


Two completed Pixel disks, each with 2.2 M channels

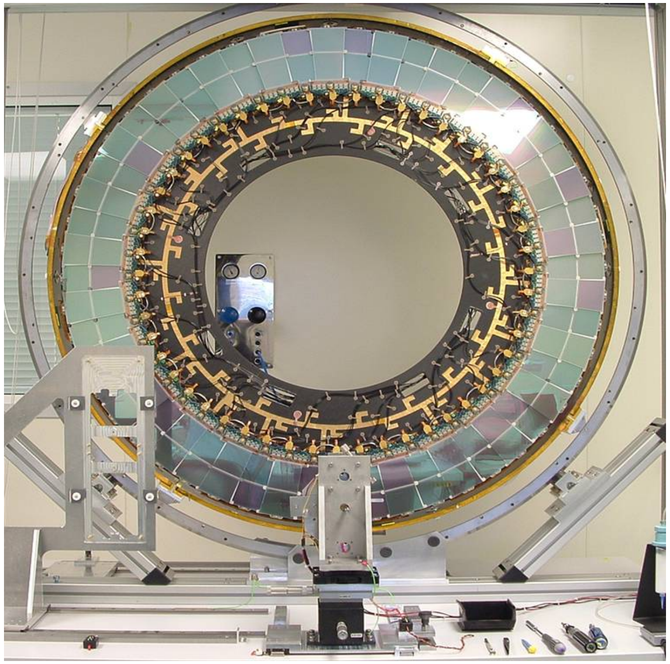
Integration and assembly have been slowed down by some difficulties with the cooling system – now solved. The installation – which is independent from the rest of the ID - is planned for spring 2007

Silicon Tracker (SCT)

All four barrel cylinders are complete and at CERN

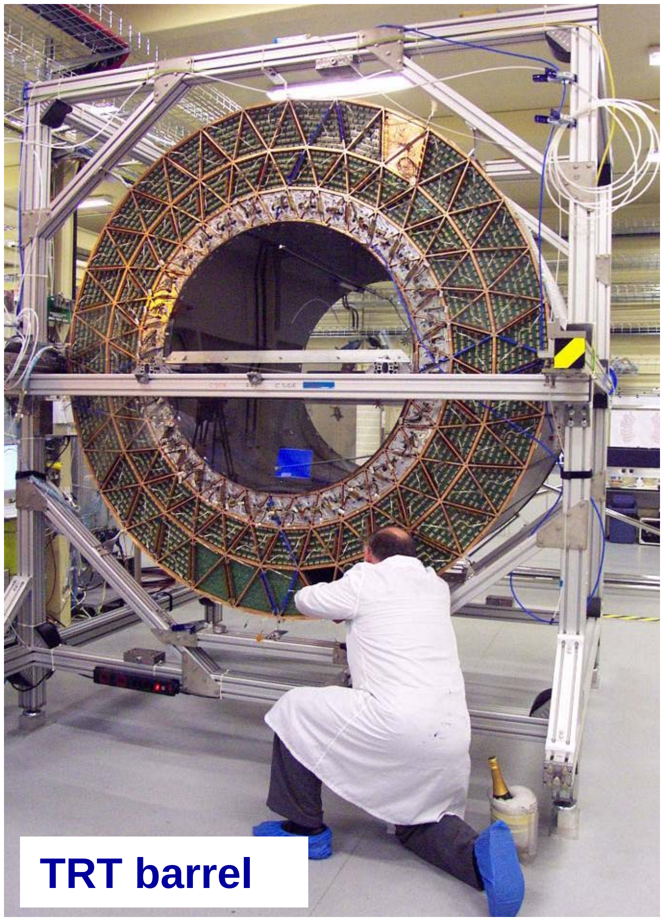


End cap disks also completed – one endcap at CERN.
The SCT is scheduled to be installed in summer-fall 2006, together with the TRT

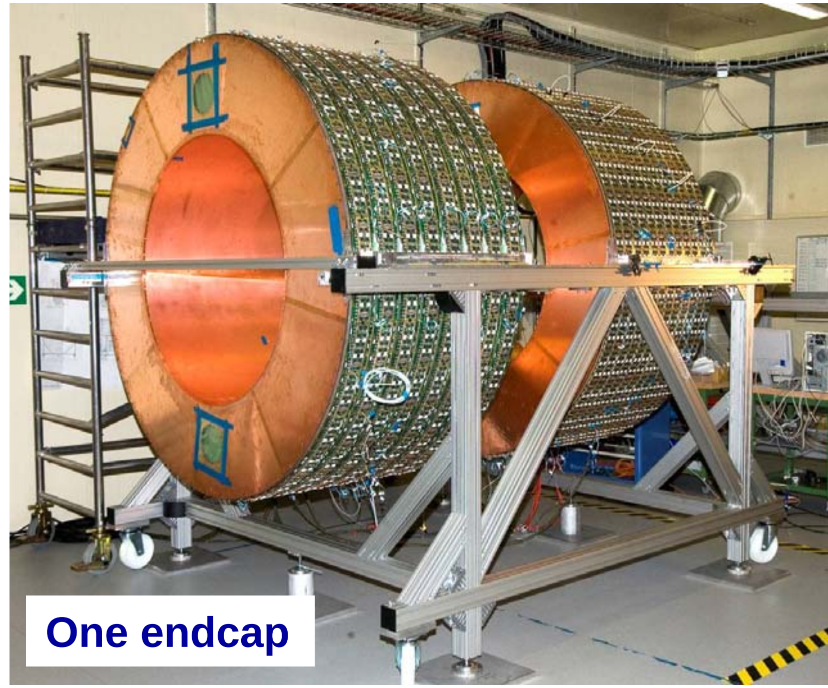


Transition Radiation Tracker (TRT)

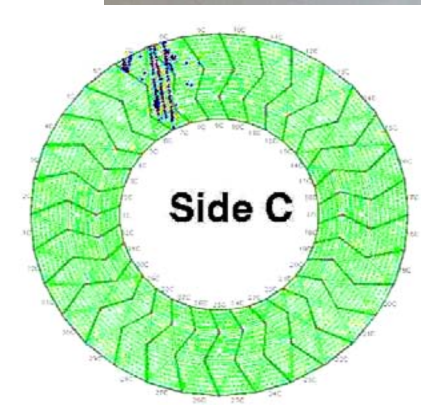
tracking, and electron identification by detecting transition radiation X-rays in a gas mixture containing ~ 70% Xe

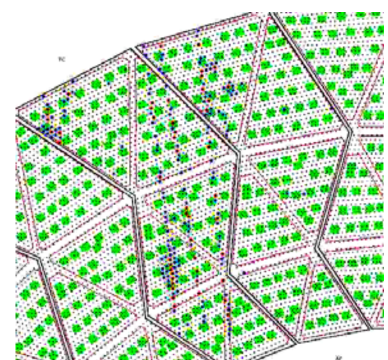


TRT barrel



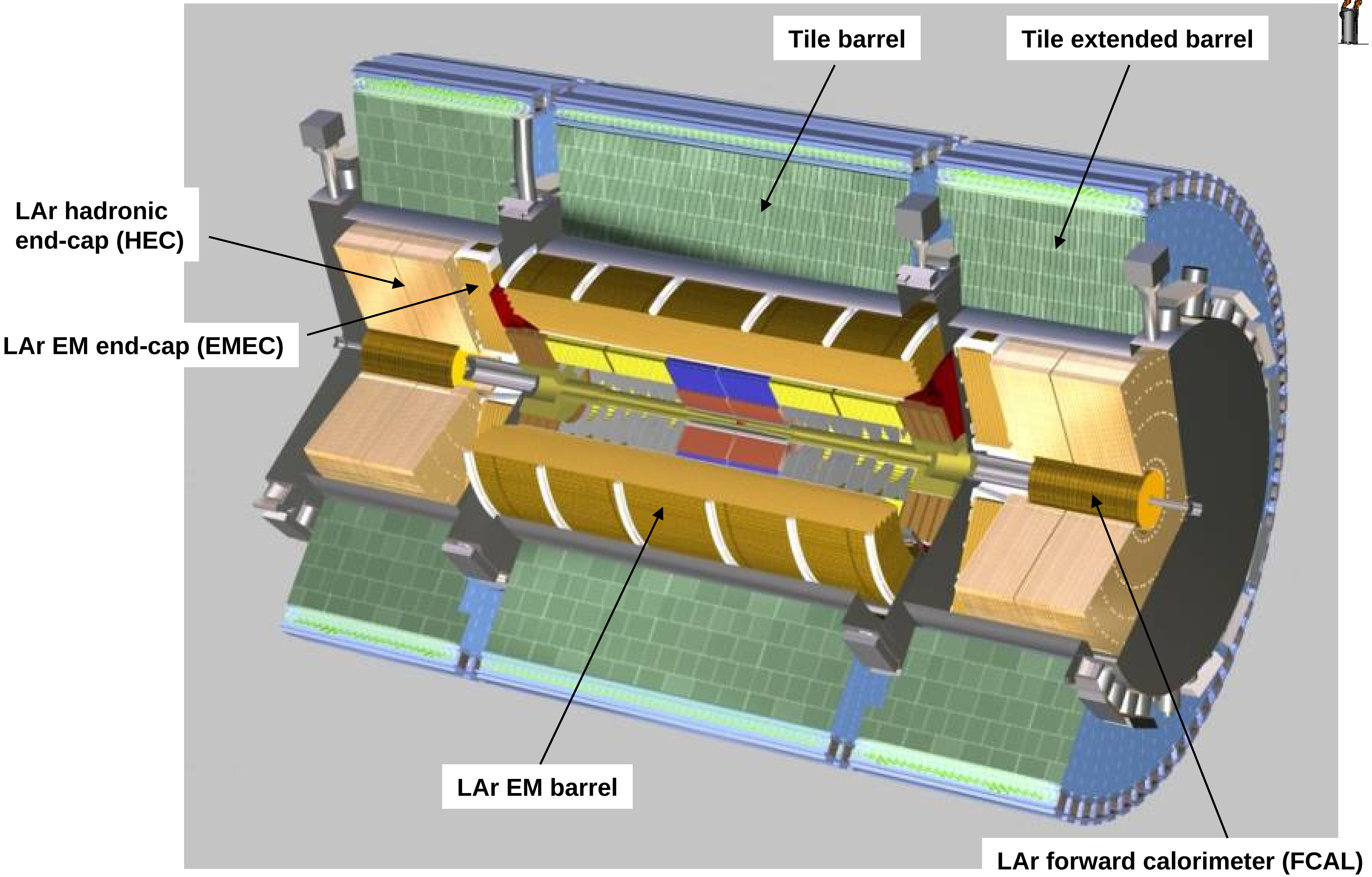
One endcap



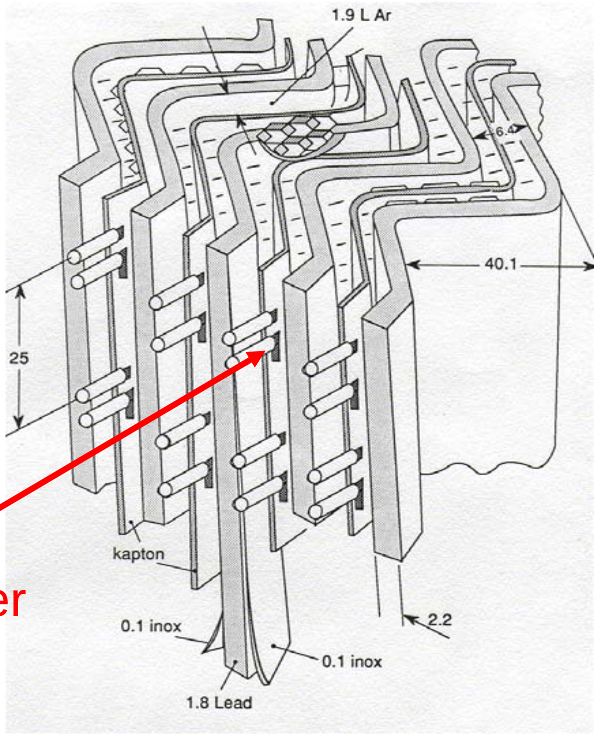


Cosmic ray event

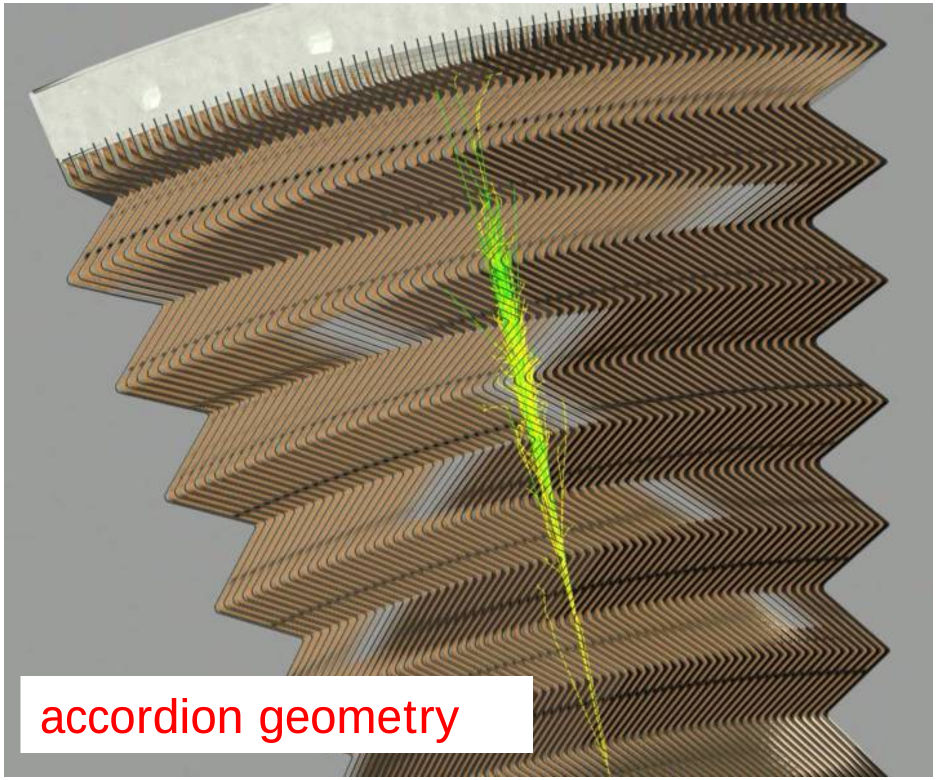
LAr and Tile Calorimeters



LAr e.m. calorimeter

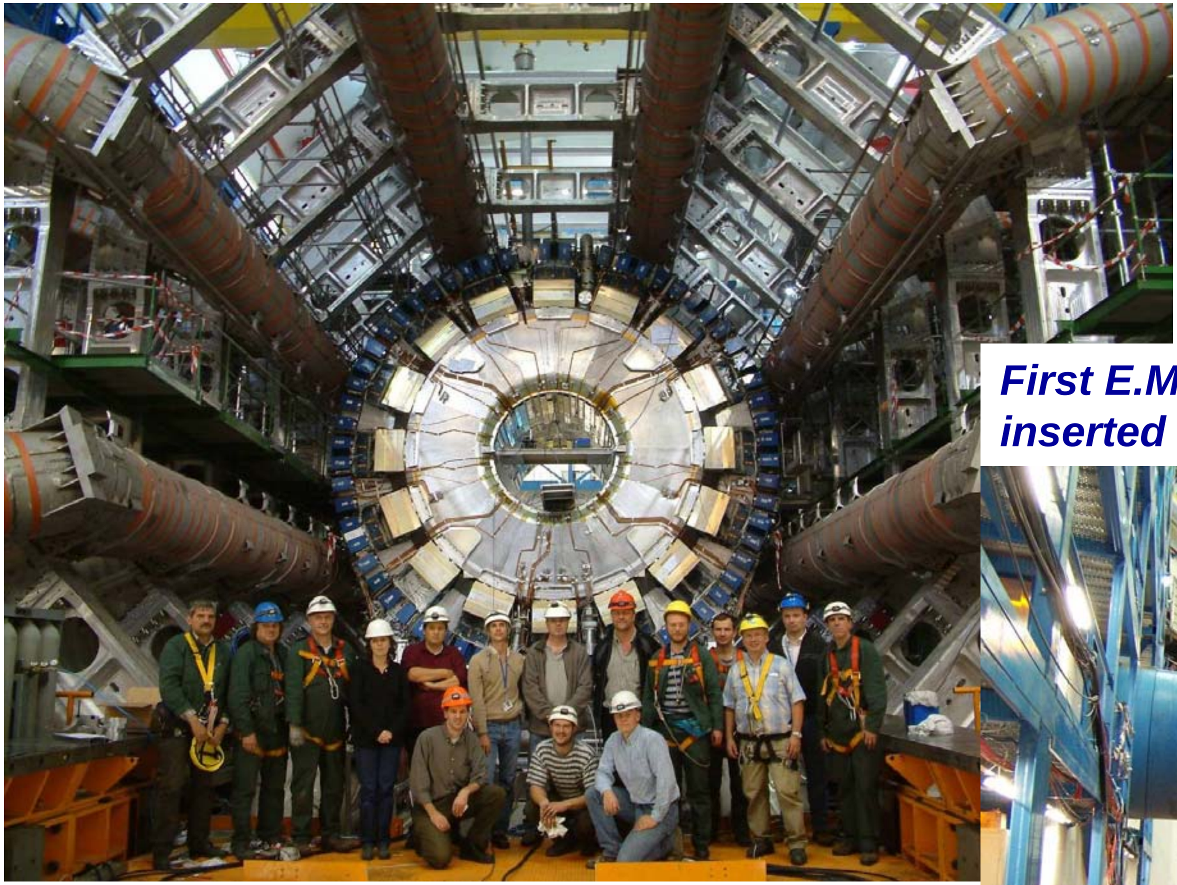


Shower axis

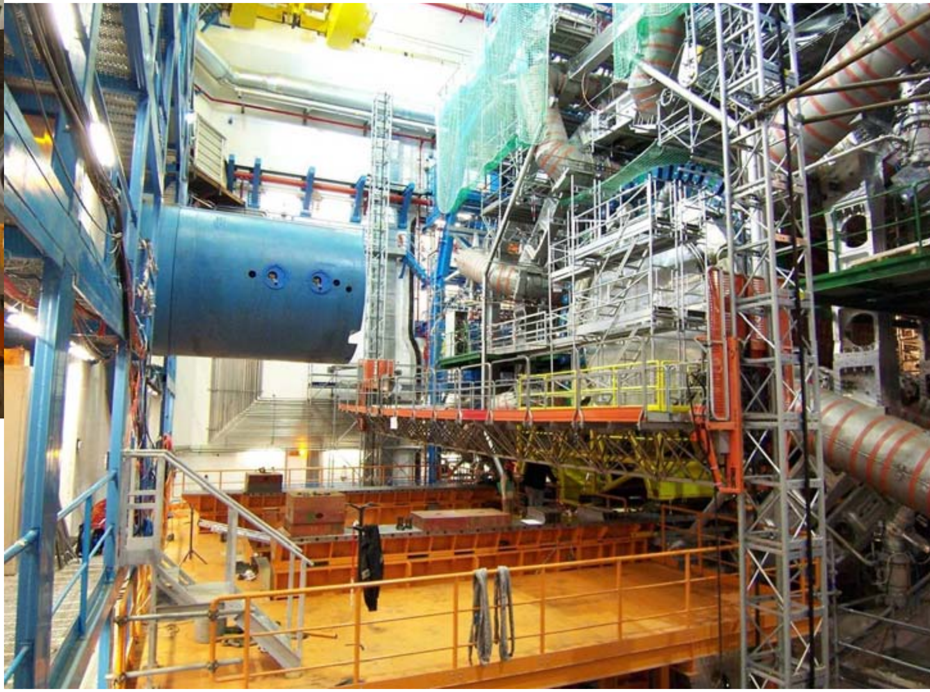


accordion geometry

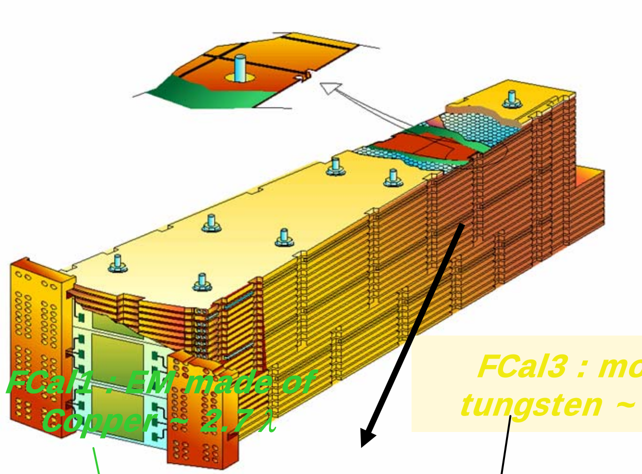
E.M. Calorimeter barrel after its move inside the ATLAS detector (Nov. 4, 2005)



First E.M. End Cap A Calorimeter partially inserted in the ATLAS detector (Mar. 2006)

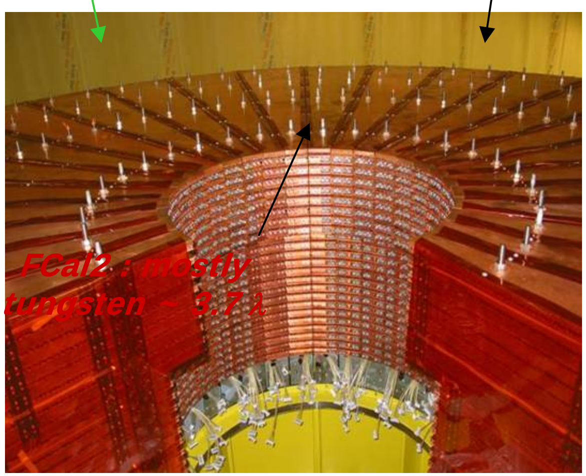


LAr Hadronic Forward calorimeter

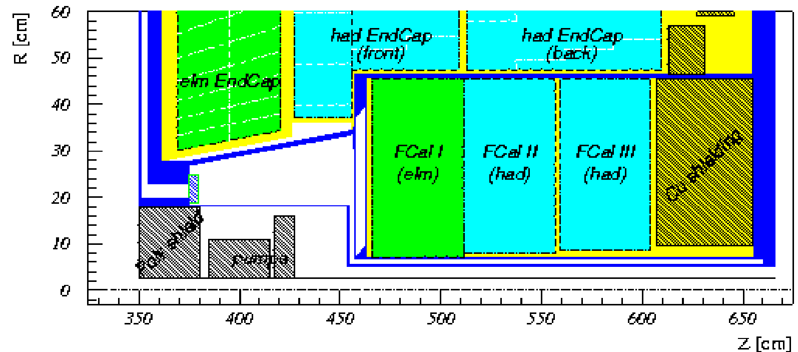


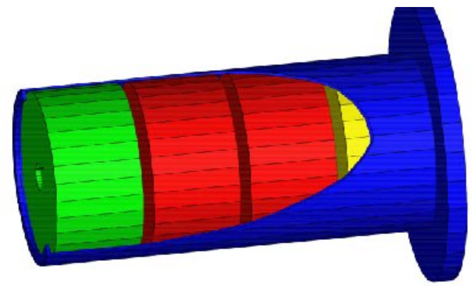
FCal1 : EM made of Copper ~ 2.7 λ

FCal3 : mostly tungsten ~ 3.6 λ

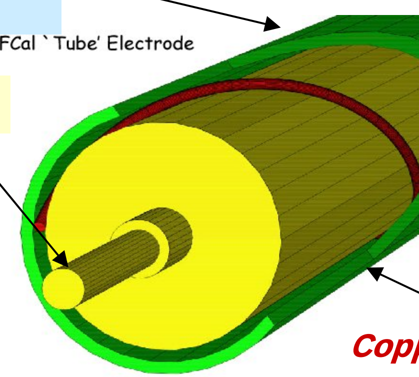


FCal2 : mostly tungsten ~ 3.7 λ





LAr gap

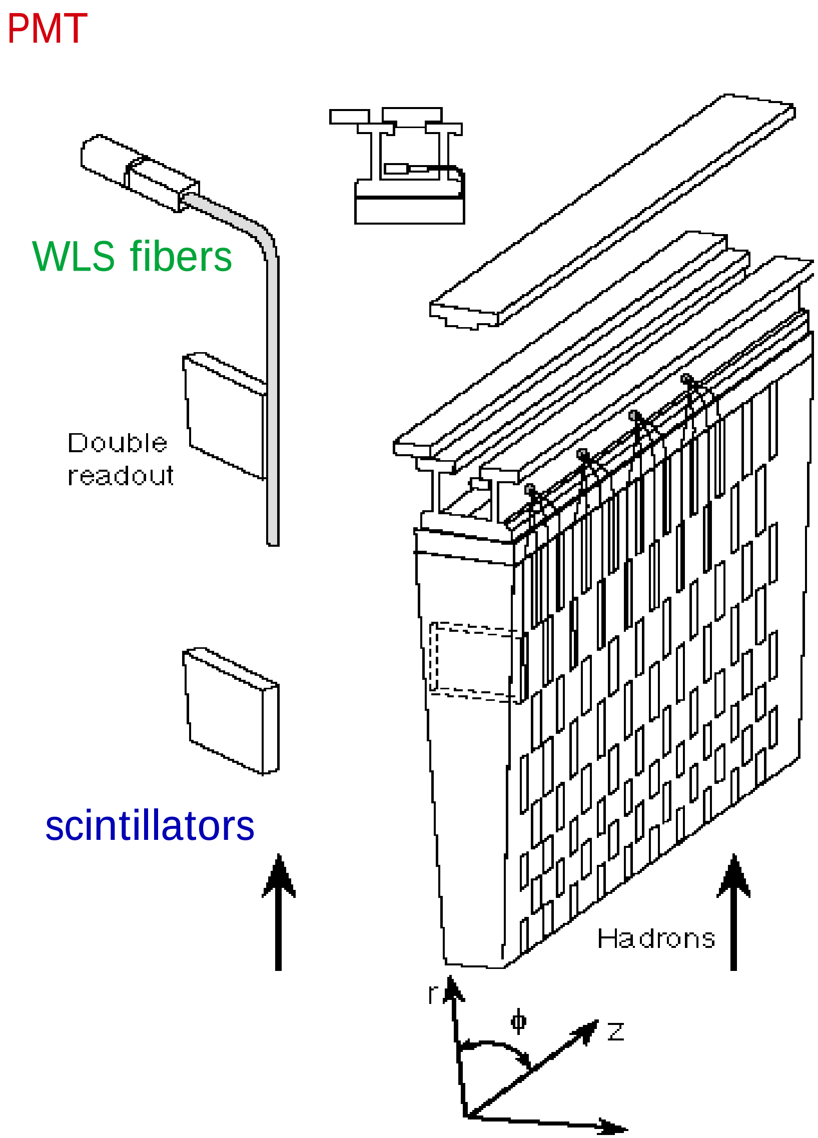


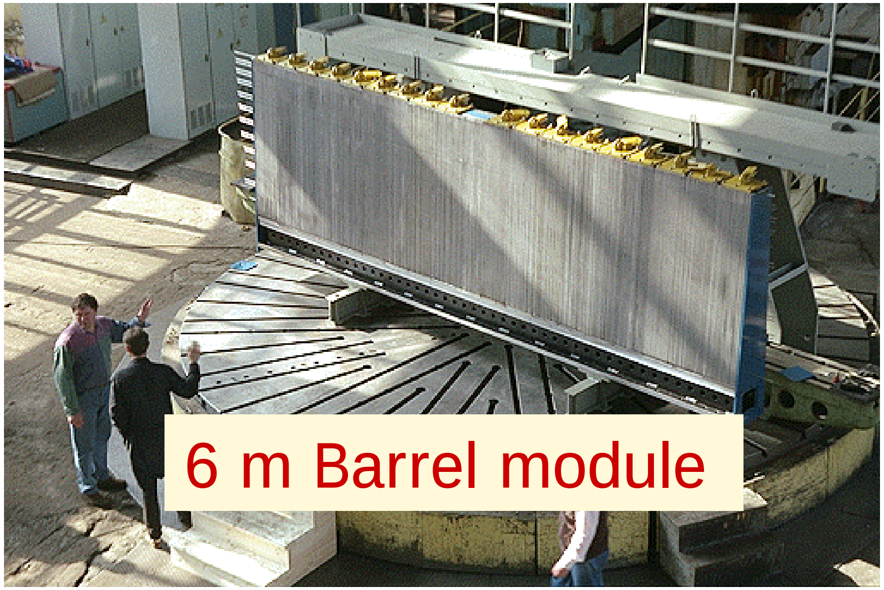
Signal pin

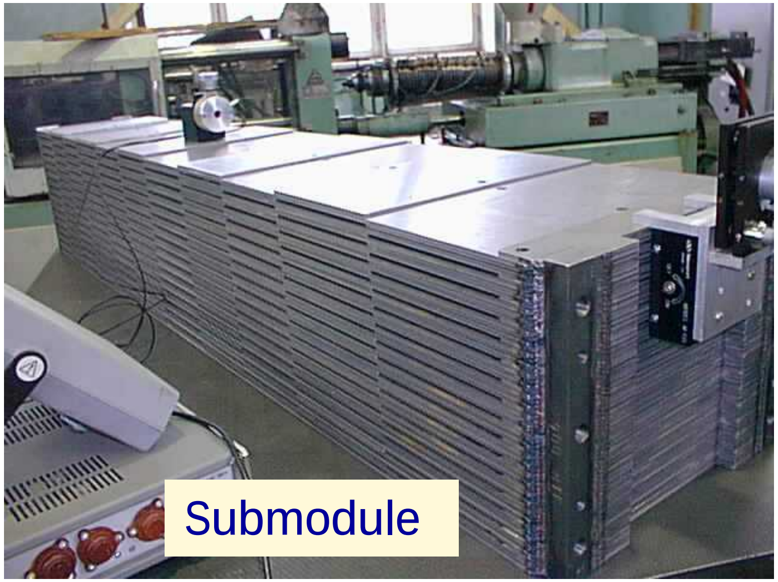
Electrode

Copper tube

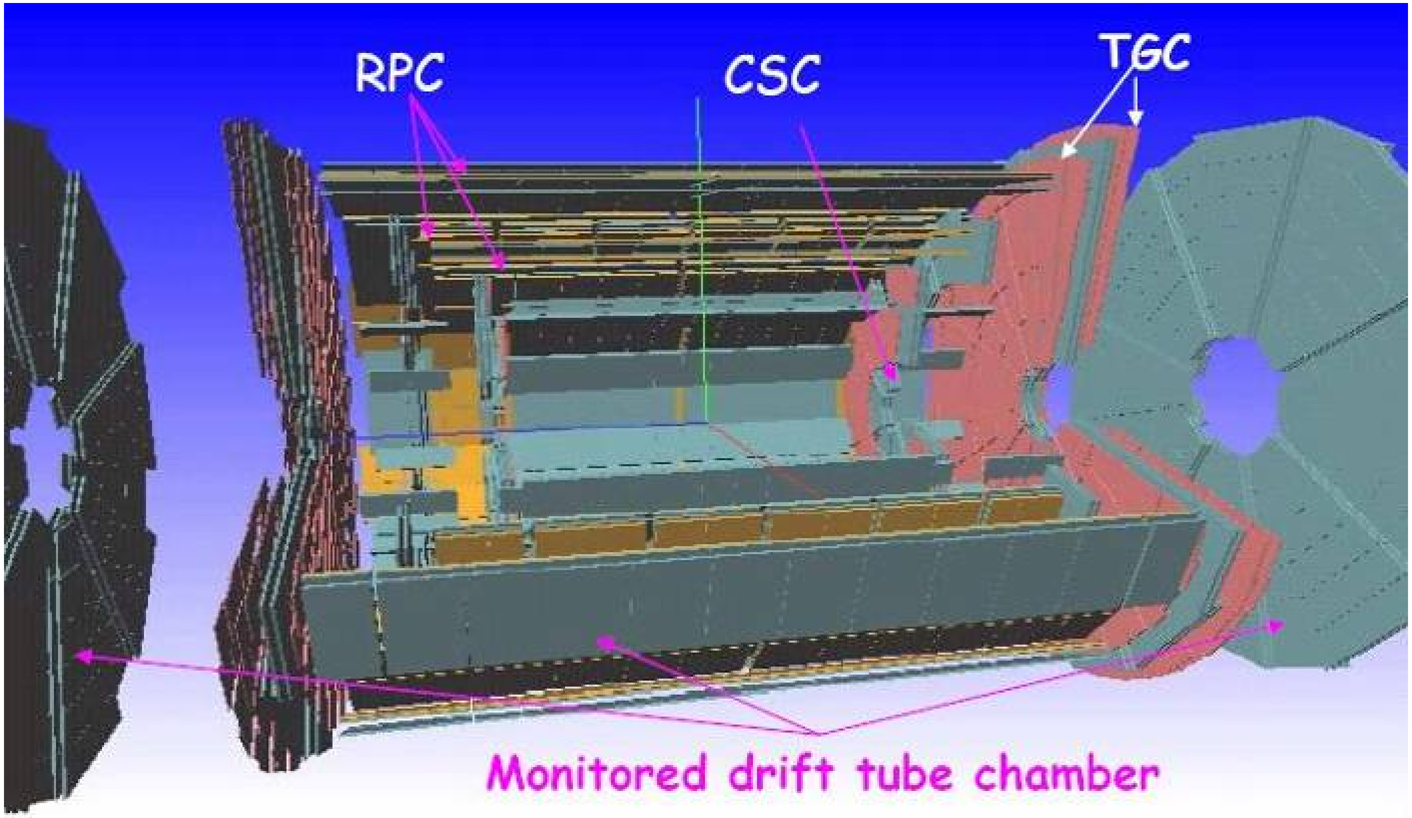
ATLAS Tile Calorimeter







Muon Spectrometer Instrumentation

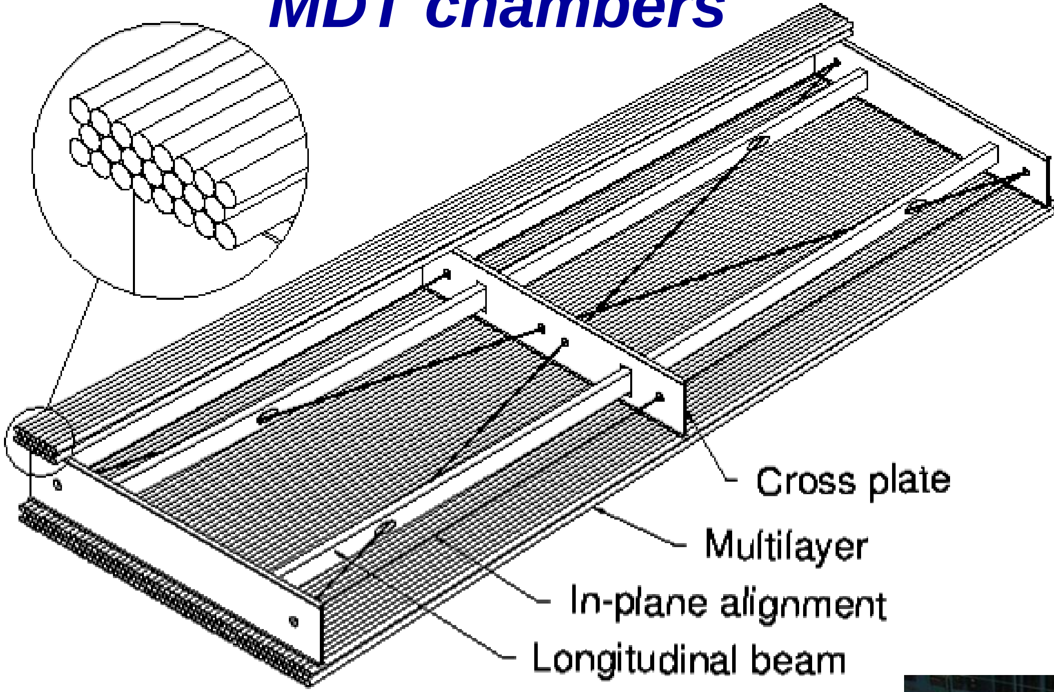


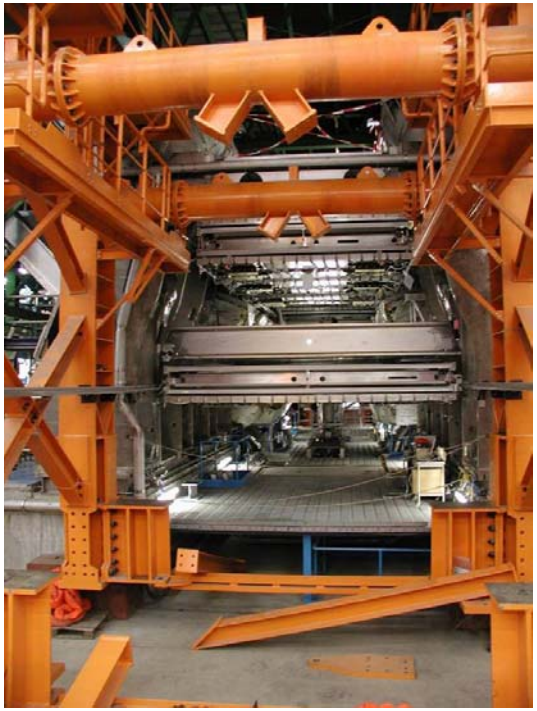
The Muon Spectrometer is instrumented with precision chambers and fast trigger chambers

A crucial component to reach the required accuracy is the sophisticated alignment measurement and monitoring system

Precision chambers:
- MDTs in the barrel and end-caps
- CSCs at large rapidity for the innermost end-cap stations
Trigger chambers:
- RPCs in the barrel
- TGCs in the end-caps

MDT chambers





A major effort is spent in the preparation and testing of the barrel muon stations (MDTs and RPCs for the middle and outer stations) before their installation in-situ

The electronics and alignment system fabrications for all MDTs are on schedule

End-cap muon chamber sector preparations

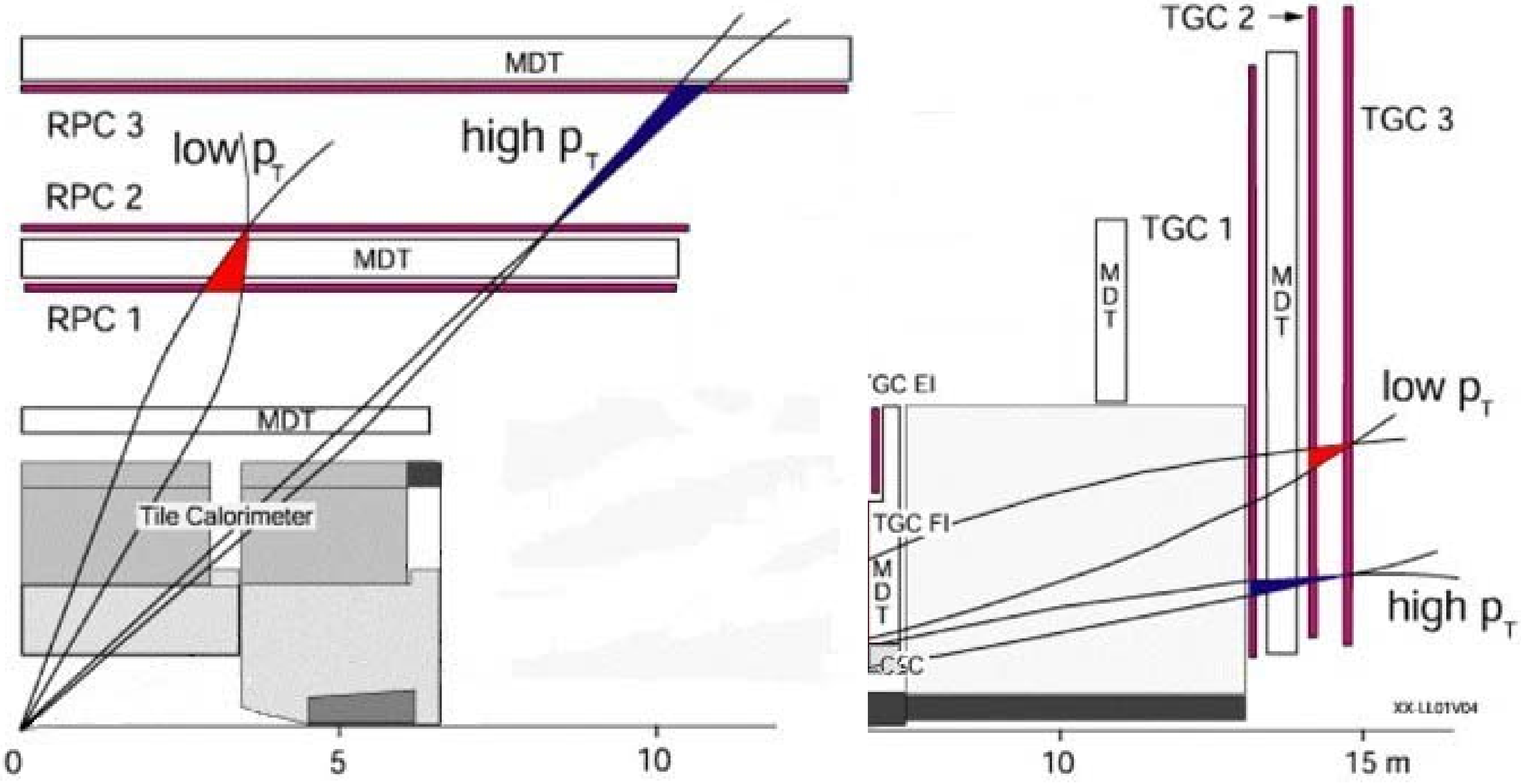
'Big Wheel' end-cap muon MDT sector assembled in Hall 180

'Big Wheel' end-cap muon TGC sector assembled in Hall 180

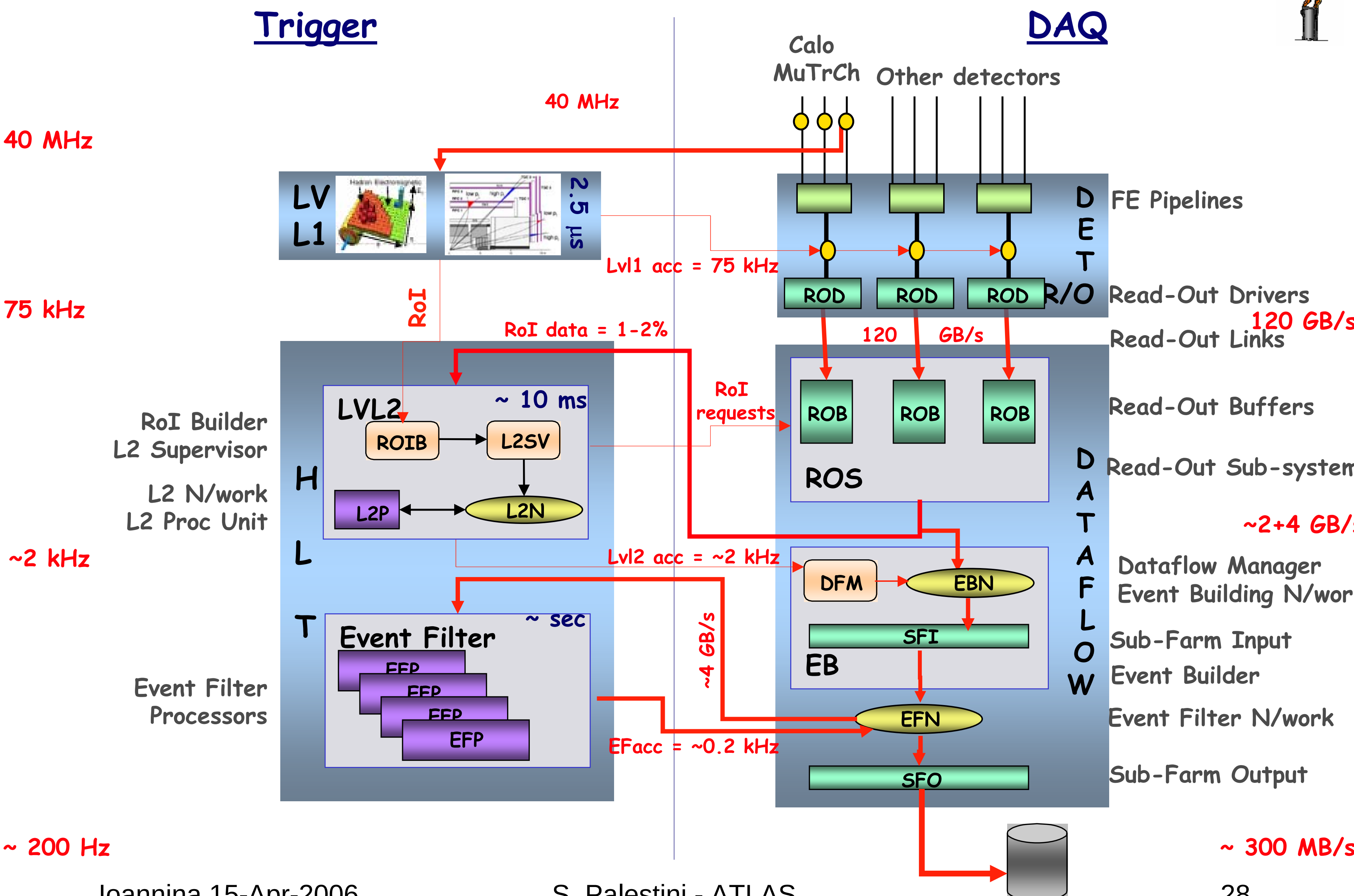
72 TGC and 32 MDT 'Big-Wheel' sectors have to be assembled

This work is now in full swing in the hall where previously the Barrel Toroid and the LAr integration and tests were done

Muon Level-1 trigger



Trigger and DAQ



Progress of Trigger-DAQ-DCS

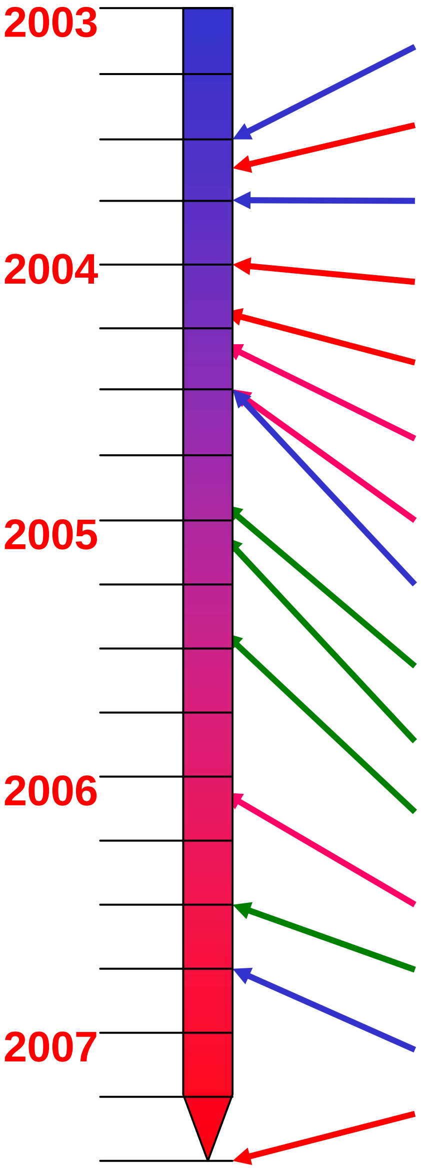
The calorimeter and the muon level-1 trigger worked successfully at the combined test beam in 2004 (tested with 25 ns bunched beam)
Final improvements were implemented and series production started.

The Central Trigger Processor is on schedule

DAQ prototypes were also tested successfully in 2004.
The pre-series of the final system is now operational at Point-1.

The Detector Control System is operative in Point-1 with the detectors being commissioned.

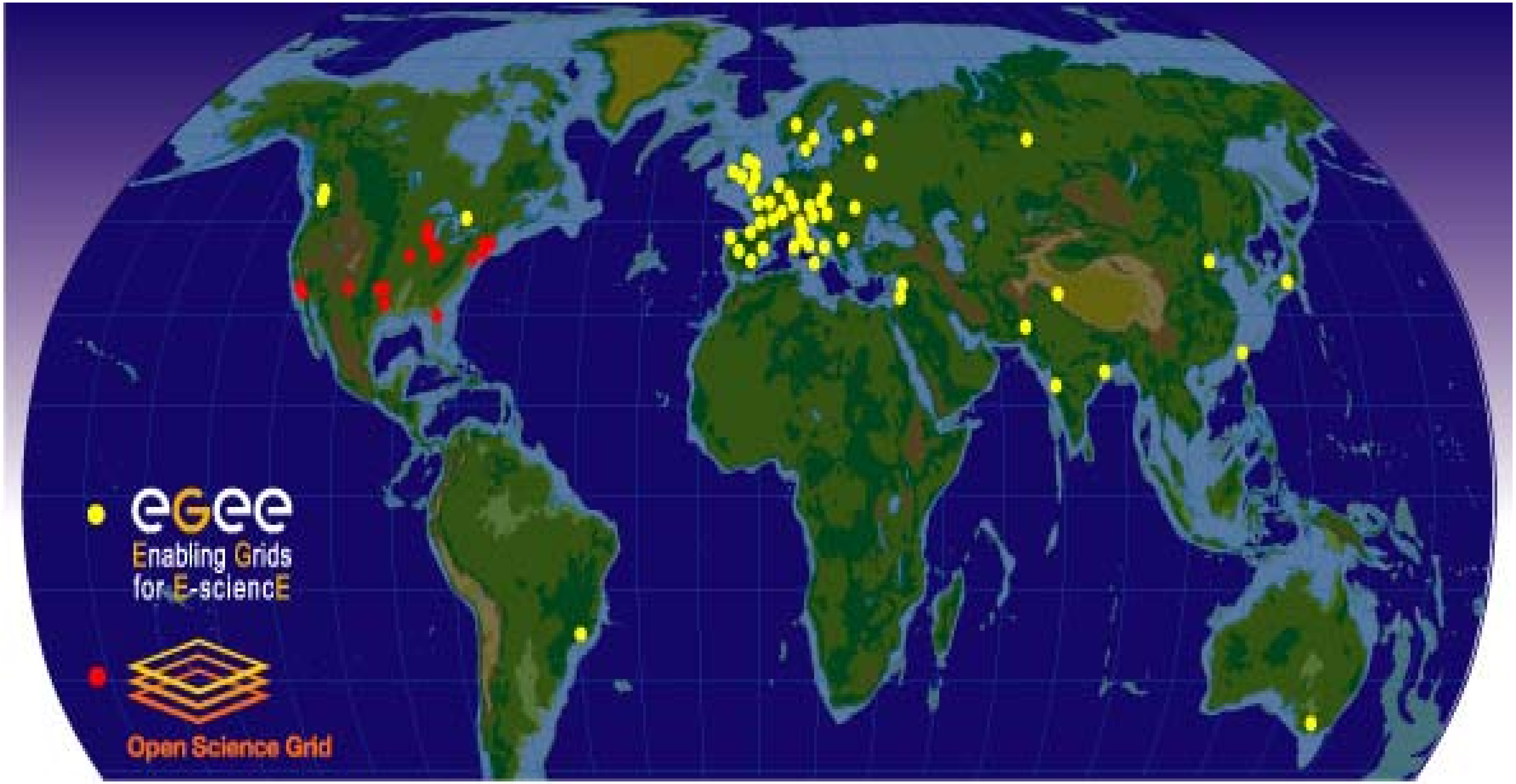
ATLAS Computing Timeline



- POOL/SEAL release (done)
- ATLAS release 7 (with POOL persistency) (done)
- LCG-1 deployment (done)
- ATLAS complete Geant4 validation (done)
- ATLAS release 8 (done)
- **DC2 Phase 1: simulation production (done)**
- **DC2 Phase 2: intensive reconstruction (re-scheduled)**
- **Combined test beams (barrel wedge) (done)**
- **Computing Model paper (done)**
- Computing Memorandum of Understanding (in progress)
- **ATLAS Computing TDR and LCG TDR (done)**
- **Start of Computing System Commissioning**
- **Physics Readiness Reports**
- **Start cosmic ray run**
- GO!

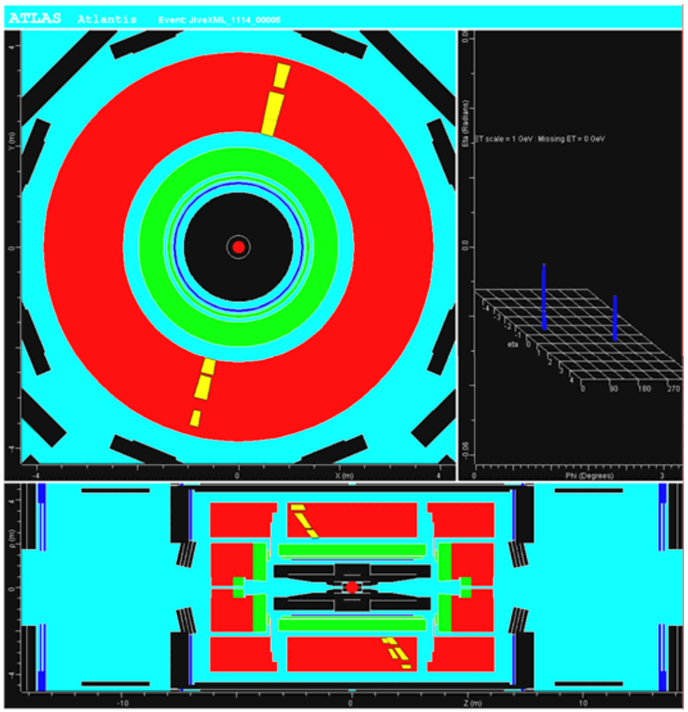
Worldwide LHC Computing Grid (WLCG)

Common infrastructure for the computing resources for the four LHC experiments

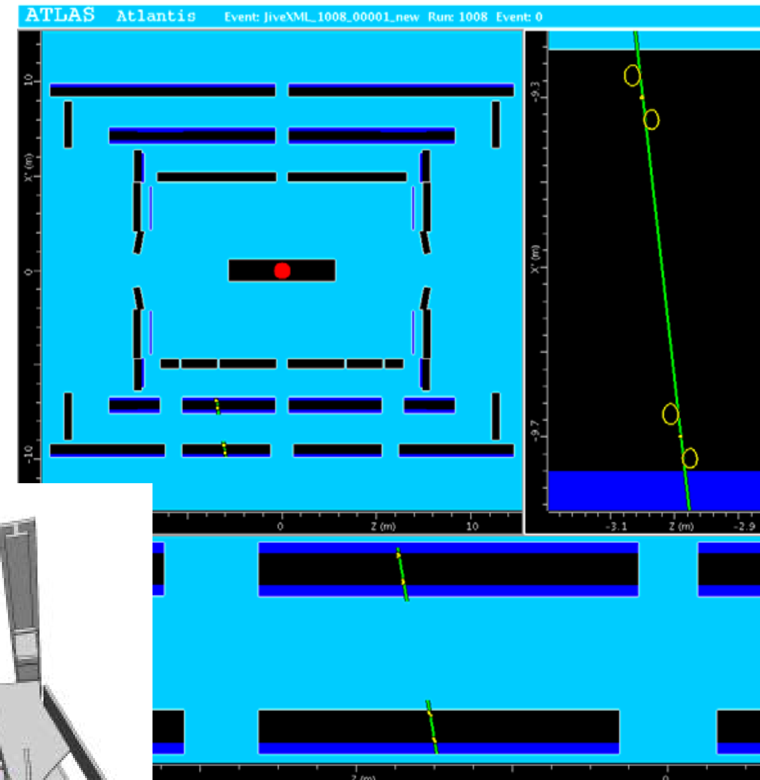


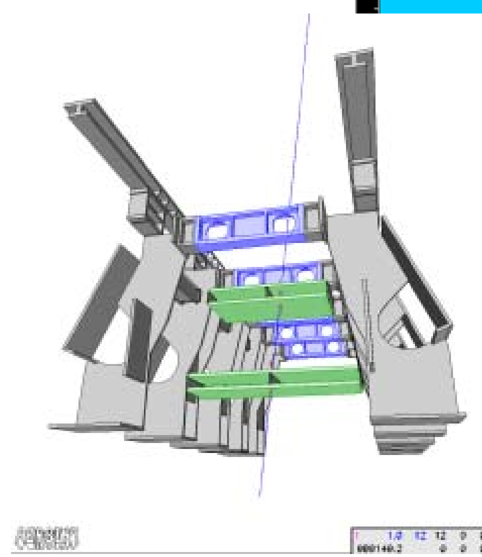
A map of the worldwide LCG infrastructure operated by EGEE and OSG.

Commissioning of sub-detectors with cosmic rays



A cosmic ray muon detected in the barrel Tile Calorimeter





A cosmic ray in the muon chambers of the bottom sector

III – Expectations for early physics

Early physics : presumable scenario

- First collisions (2nd half of 2007):
  - Complete commissioning and shake-down of detector, first analyses
- First physics run (2008)
  - The performance of the accelerator is uncertain, consider the range:
    - 100 pb^{-1} (pessimistic)
    - to 10 fb^{-1} (optimistic)

First objective: tune-up the detector

Tracking systems alignment/calibration

- Alignment of Inner Detector
- Alignment and calibration of Muon system

  If the tools are in place, the first few 10's of pb^{-1} should allow to reach the requirements needed for the first 10 fb^{-1}. Minimum bias events are useful for this purpose.

Uniformities, mass scales : calorimeters and Muon system

- $Z \rightarrow ee, \mu\mu$: 0.5-1 Hz at $10^{+33} cm^{-2} s^{-1}$

  nearly uniform in η/φ

  useful for large scale calibration and alignment

Calibration of jet measurement

- W $\rightarrow jj$ will constraint the measurement of the jet energy, for events with identified W *(see below)* :
  - Good statistics, easily trigger and small background
  - However: limited range in energy and in η
  - And also: only for light-quark jets

Top production for physics and calibration

σ_{tt} (LHC) ≈ 250 pb
for gold-plated
semi-leptonic channel

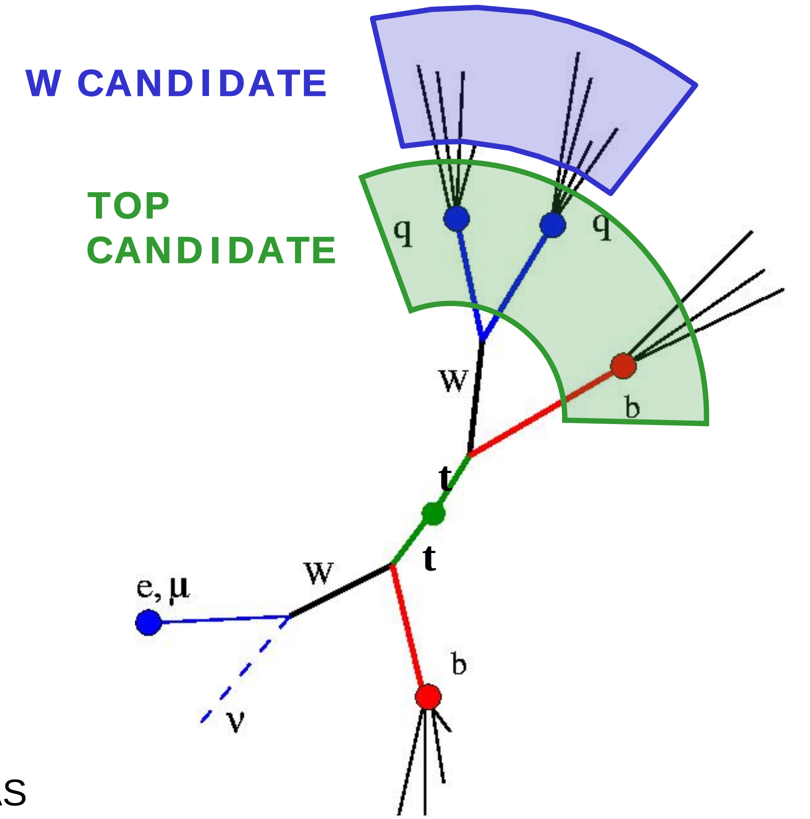
- use <u>simple and robust</u> selection cuts:
  - p_T (l) > 20 GeV
  - E_T^{miss} > 20 GeV
  - only 4 jets with p_T > 40 GeV

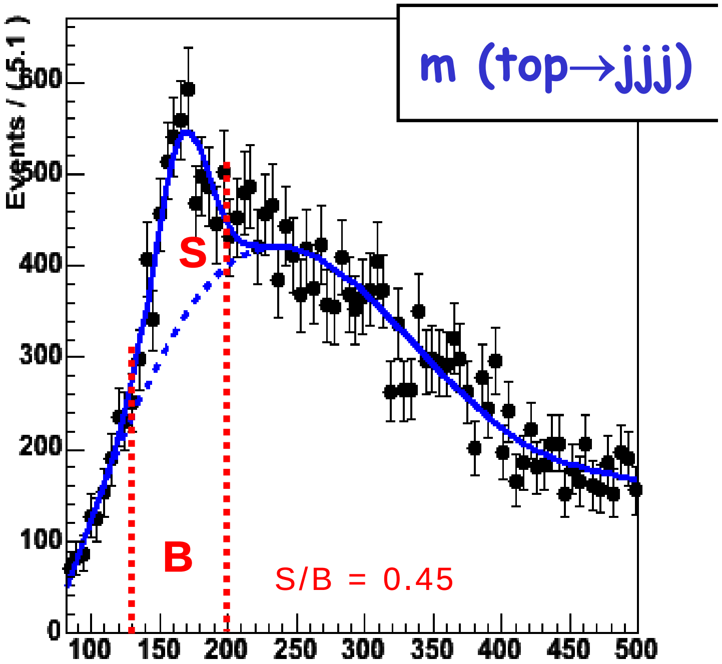
  } ε ~ 5%

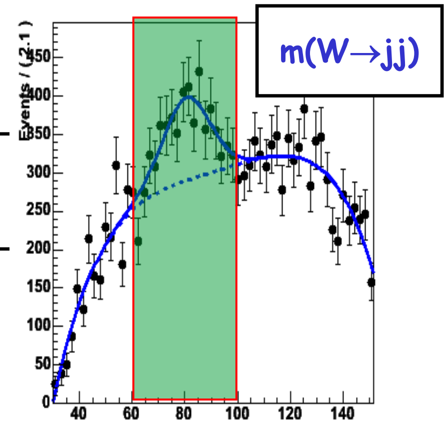
- <u>no b-tagging required</u> (early days …)

- m (top → jjj) from invariant mass of 3 jets giving highest top p_T
- m (W→jj) from 2 jets with highest momentum in jjj CM frame

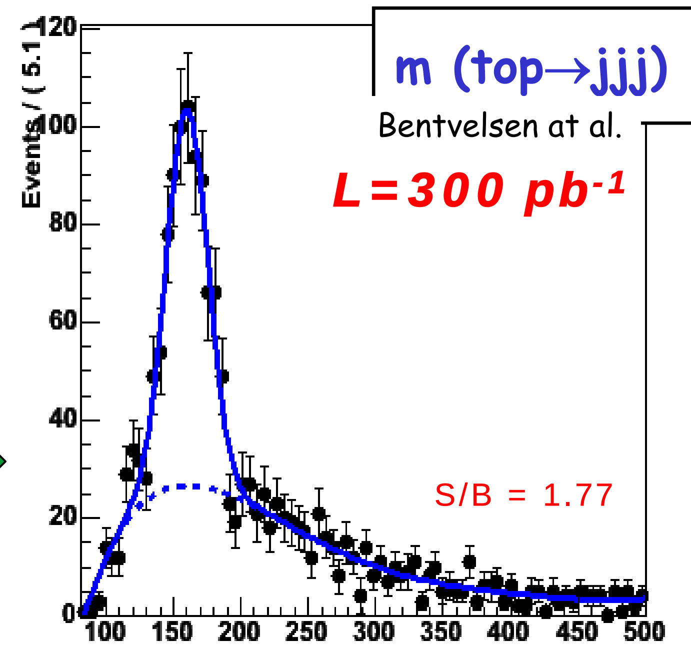
Total efficiency ~ 1.5% (preliminary)







$|m_{jj}-m_W| < 10$ GeV



Expect ~ 100 events inside mass peak for 30 pb^{-1}

→top signal observable in early days with no b-tagging and simple analysis

→Top mass measured to ~3 Gev/c^2

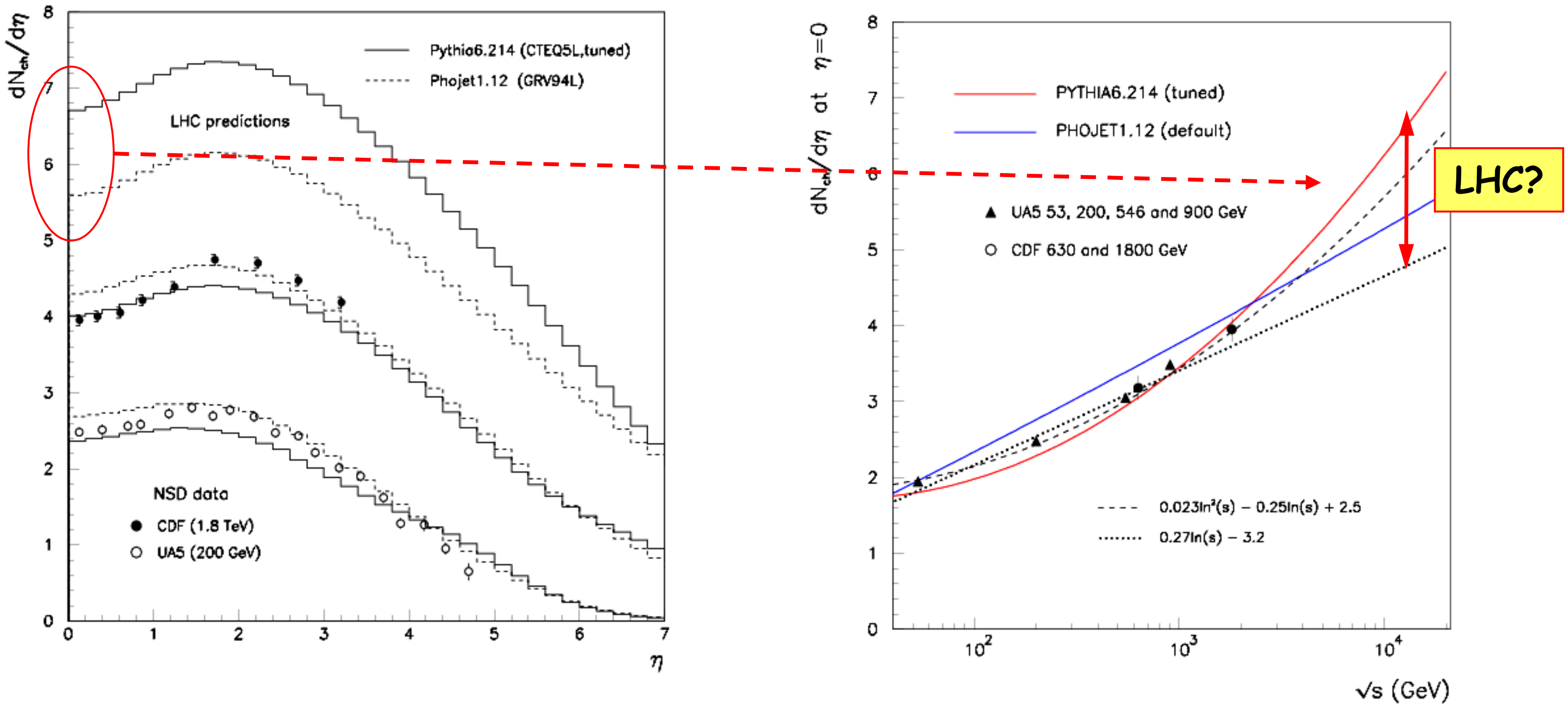
→Useful to calibrate:

- **→light-quark jets from W→jj decay**
- **→b-tagging**

Other early physics studies:

Charged particle multiplicity:

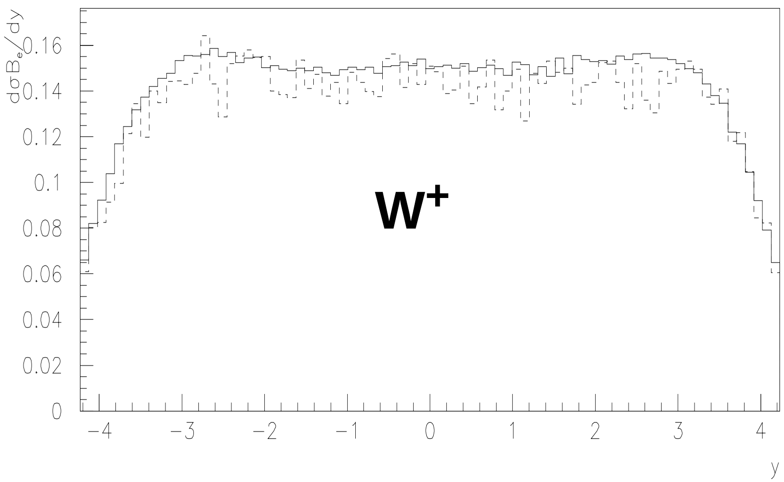
Discriminate between ln(s) and $\ln^2(s)$ behavior

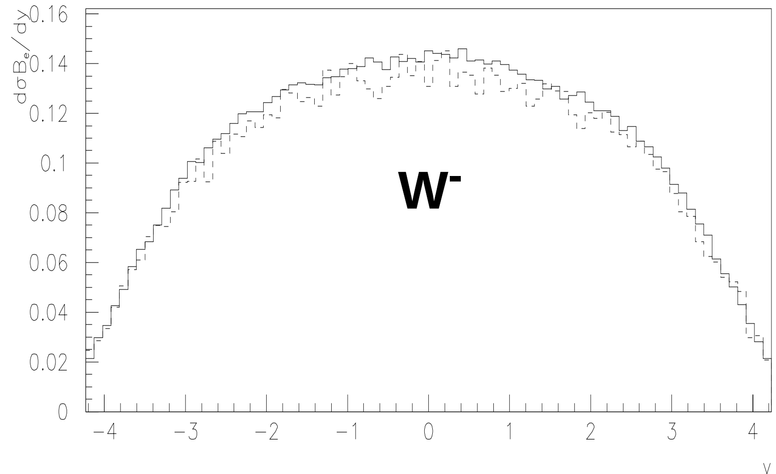


There is no problem with statistics, but this study is limited by systematic uncertainties (e.g.: reconstruction efficiency, limited range in η and in (low) P_t)

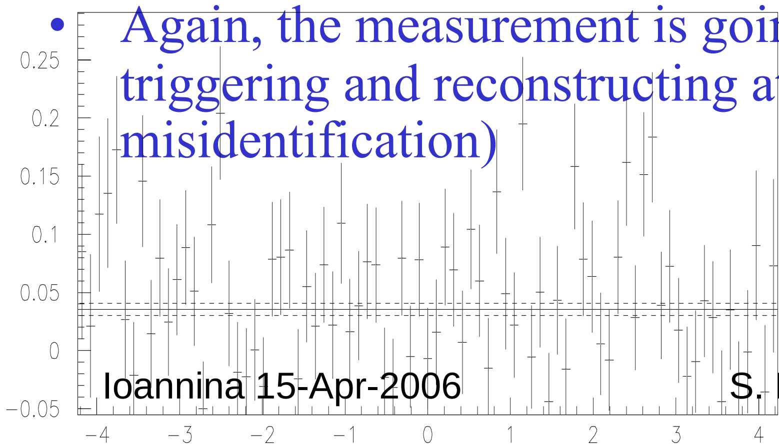
W production asymmetry

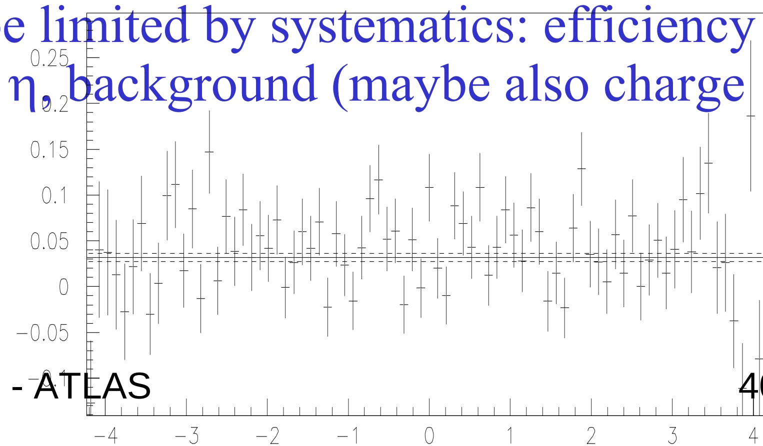
- In proton-proton collisions, W^+ and W^- production is not symmetric
  - Depends on parton content of proton – sea distributions important (low-*x*)
  - Interesting to measure – provides information on Parton Distribution Functions



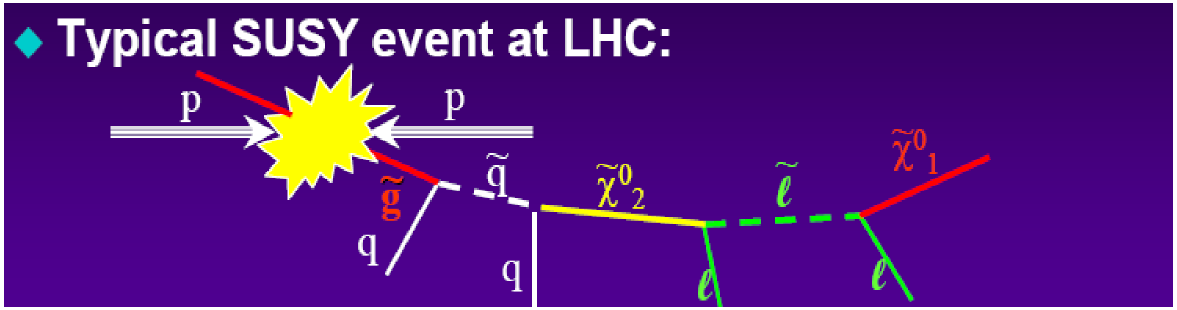


- Again, the measurement is going to be limited by systematics: efficiency for triggering and reconstructing at large η, background (maybe also charge misidentification)



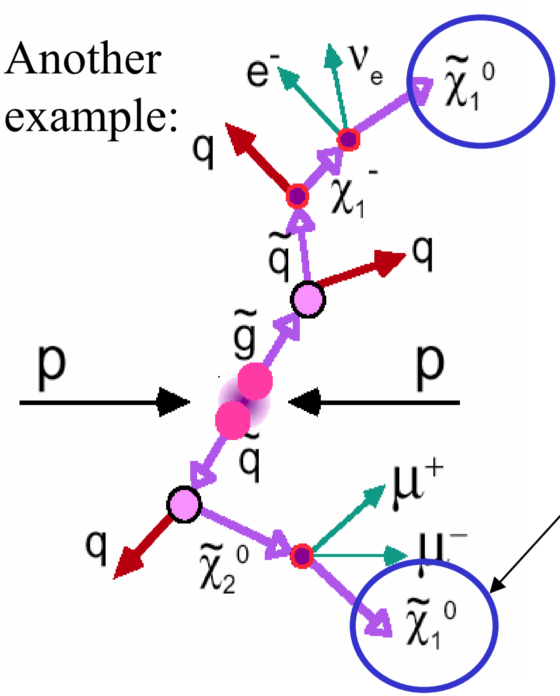


Supersymmetric particles and dark matter



Cross section may be large; look for high P_t jets and leptons, missing E_t , background from top production

Another example:



This particle (neutralino) is a good candidate for the universe dark matter

ATLAS discovery reach

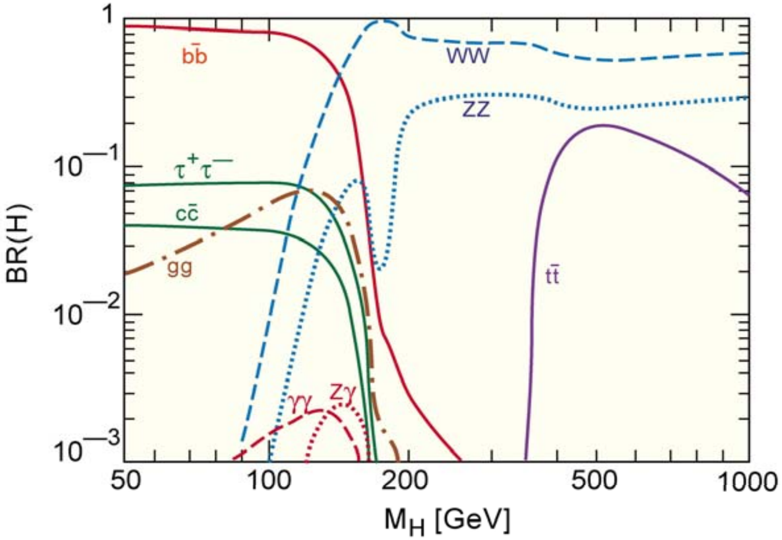
Time @10^{33}	reach in squark/gluino mass
1 month	~ 1.3 TeV
1 year	~ 1.8 TeV
3 years	~ 2.5 TeV
ultimate	up to ~ 3 TeV

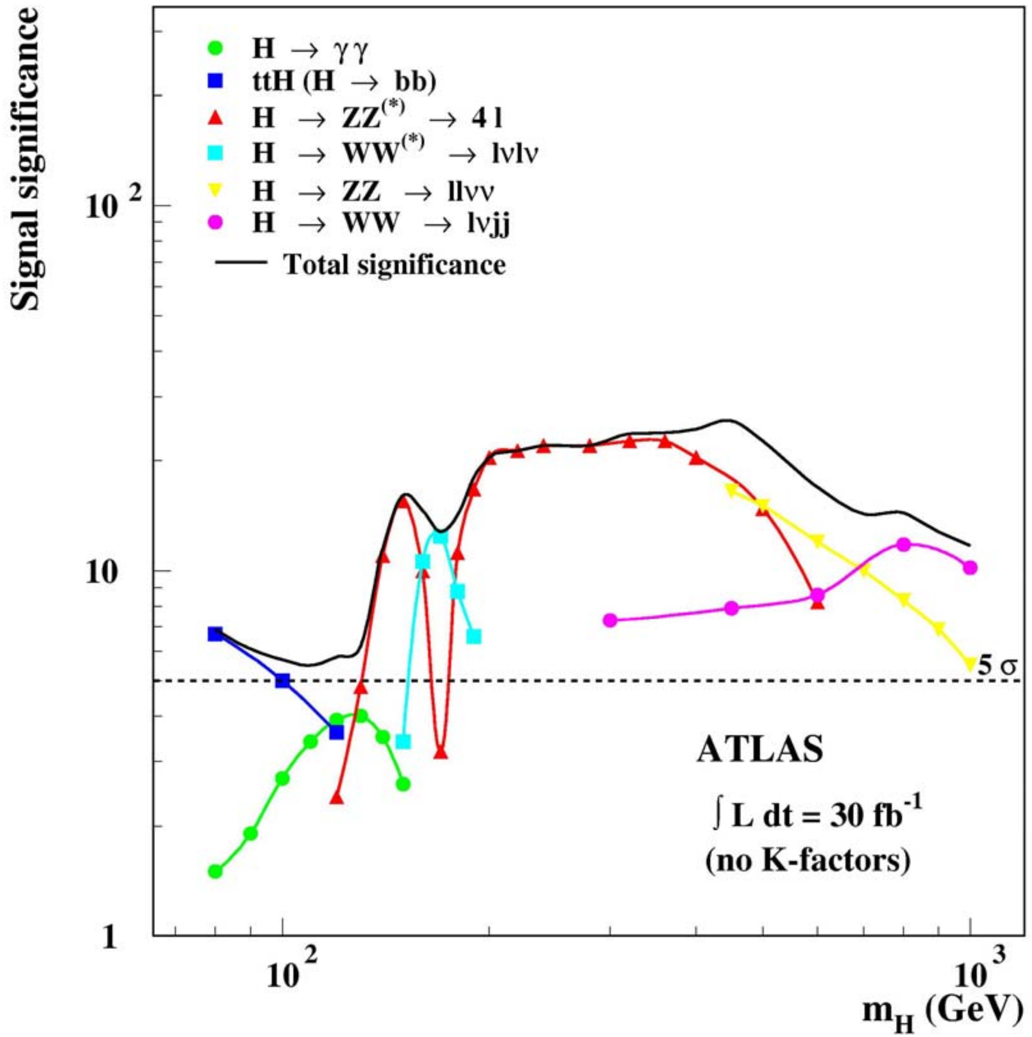
Neutralino mass can be measured to 10% → SUSY discovery and neutralino mass measurement at LHC can solve problem of universe cold dark matter

Higgs production

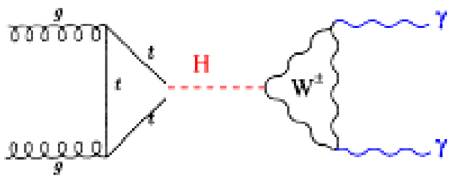
(Plots not showing the limit from LEP)

SM Higgs branching ratios

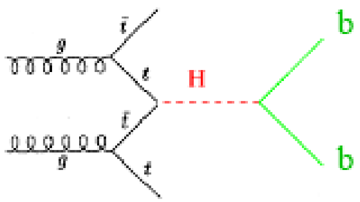




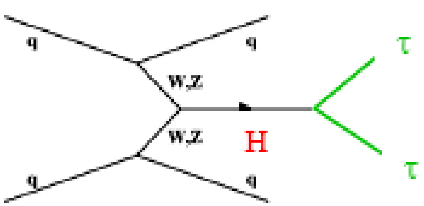
$H \to \gamma\gamma$



$t\bar{t}H \to t\bar{t}\, b\bar{b} \to b\ell\nu\, bjj\, b\bar{b}$

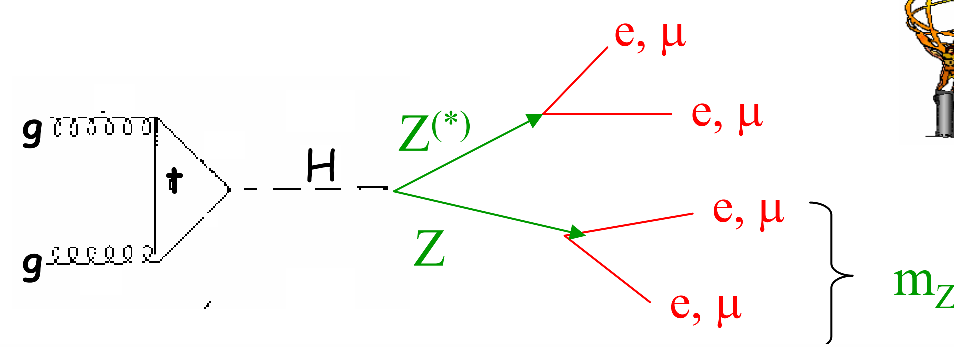


$qqH \to qq\tau\tau$



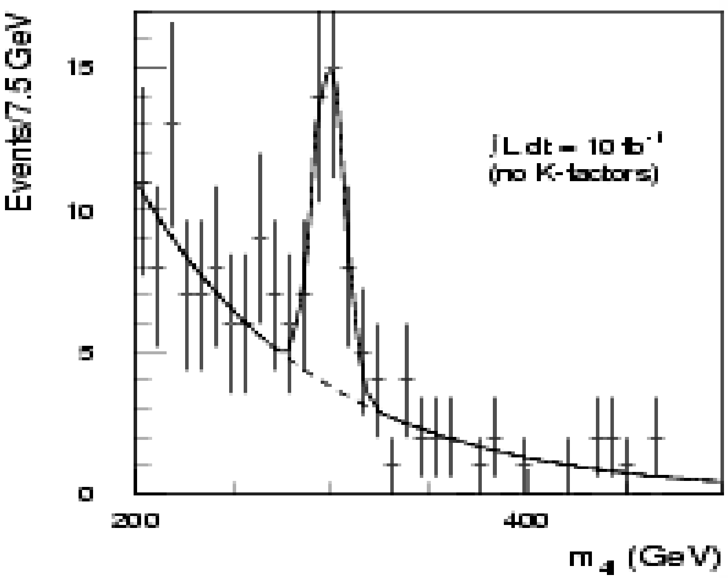
- For M_H < 130-140 Gev/c^2, the measurement is difficult for statistics and systematic:
  - Resolution in γγ mass (uniformity of response)
  - Good b-tagging, control of QCD background and understanding of hadronic transverse mass
  - Forward jet reconstruction

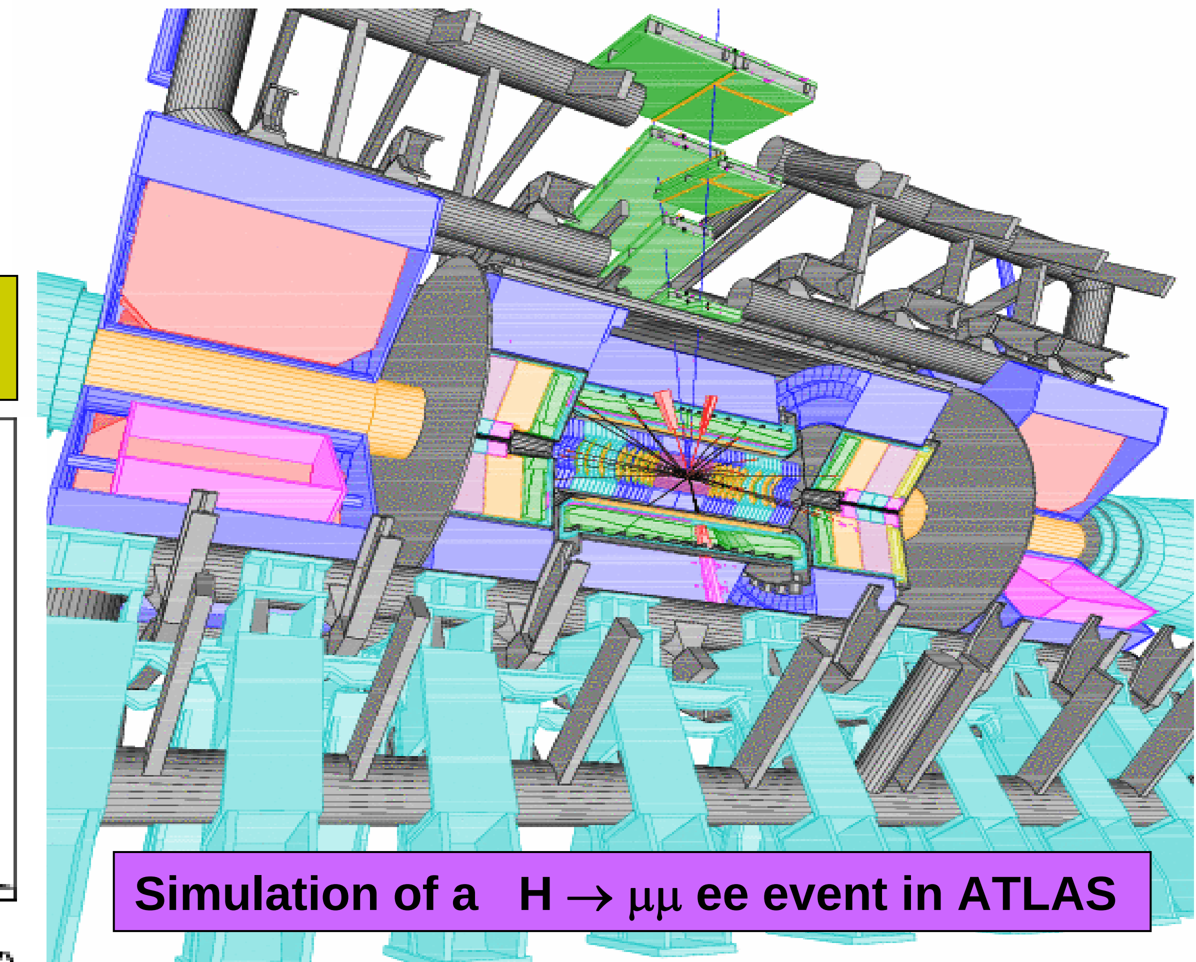
At higher mass, the discovery would be simpler



$H \to ZZ \to 4\ \ell$

Signal expected in ATLAS after 1 year of LHC operation





Simulation of a $H \to \mu\mu$ ee event in ATLAS

Conclusions

The CERN Management and the LHC machine project team are most strongly committed to deliver first collisions in Summer 2007, thereby opening a new chapter in particle physics to be exploited in a truly world-wide collaborative effort

Many important milestones have been passed in the construction, pre-assembly, integration and installation of the ATLAS detector components

Very major software and computing activities are underway as well, using the Worldwide LHC Computing Grid (WLCG) for distributed computing resources

Commissioning and planning for the early physics phases has started

→The ATLAS Collaboration is highly motivated, and on track, for LHC physics in 2007-2008

→Of course, the path ahead of us is very challenging, but the perspectives for physics discoveries justify all efforts.