years HIGGS boson discovery

The Genesis of ATLAS -
The long journey to the Higgs boson discovery

Peter Jenni, CERN and
Albert-Ludwigs-Universität Freiburg

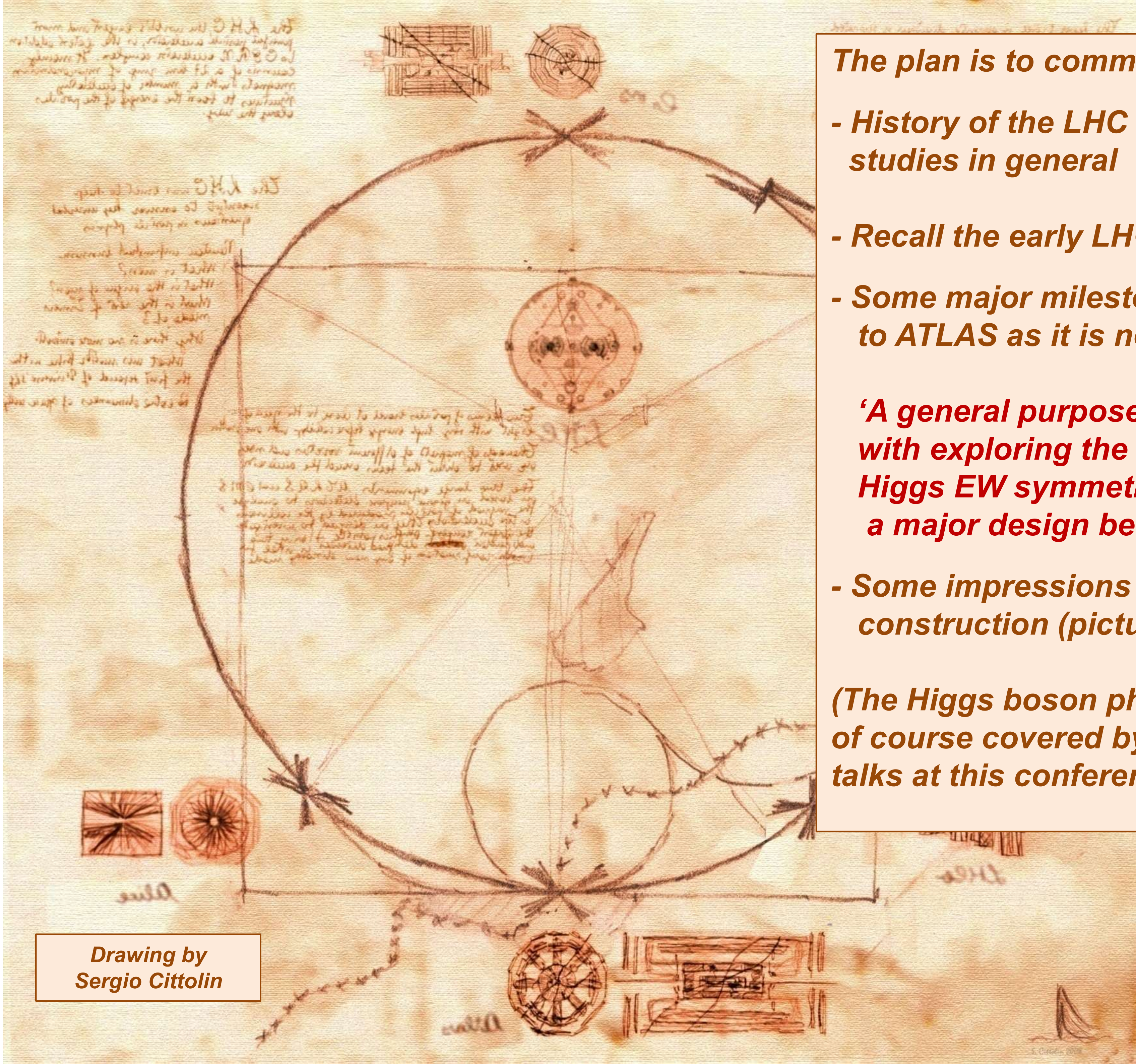
The plan is to comment a bit on:

- *History of the LHC experiment studies in general*
- *Recall the early LHC project history*
- *Some major milestones leading to ATLAS as it is now, namely:*

  'A general purpose experiment with exploring the Brout-Englert-Higgs EW symmetry breaking as a major design benchmark'

- *Some impressions of the ATLAS construction (pictures…)*

(The Higgs boson physics results are of course covered by the many main talks at this conference)



Drawing by Sergio Cittolin

How the LHC came to be …

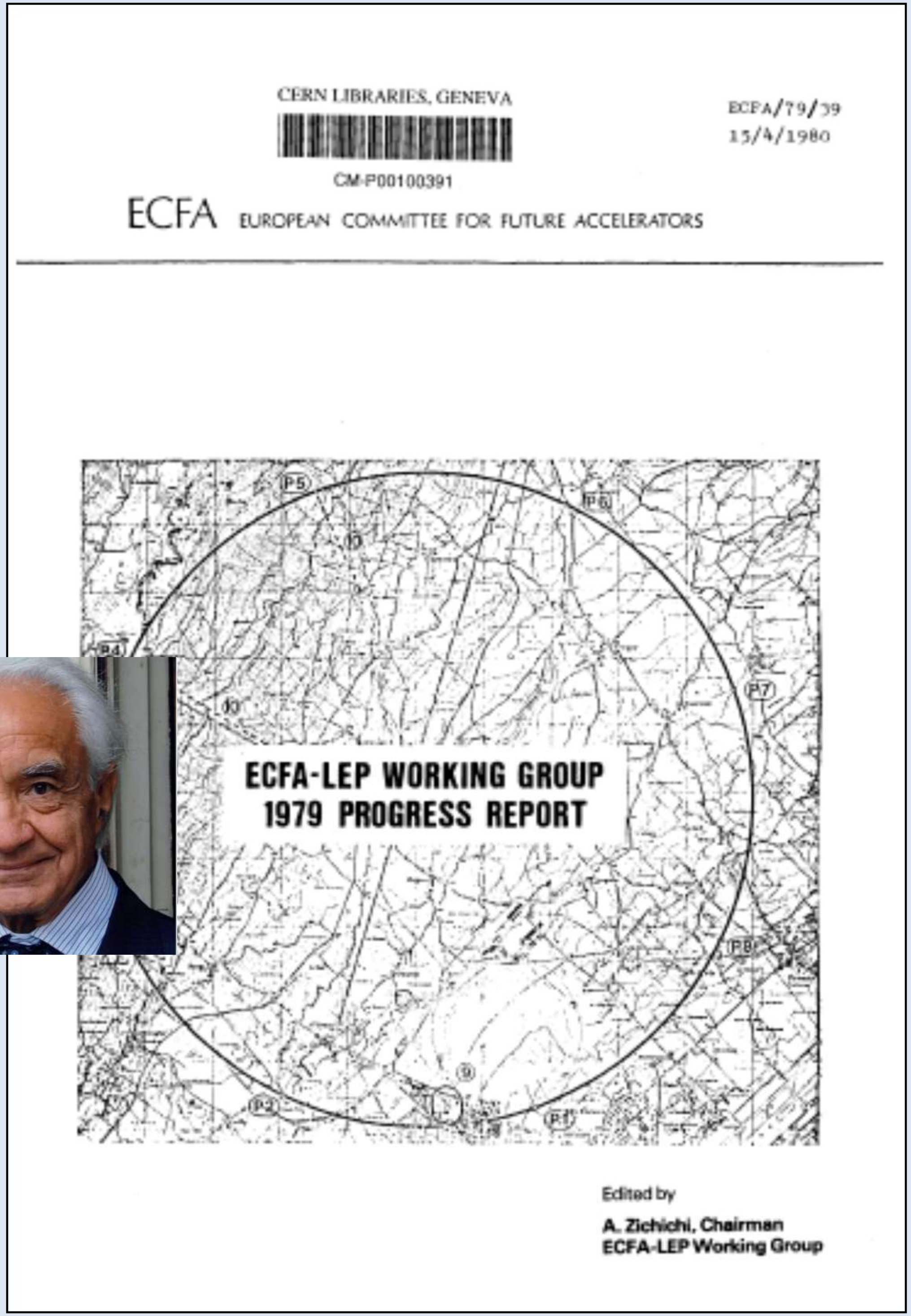
Some very early key dates

1977 The community talked about the LEP project, and it was already mentioned that a new tunnel could also house a hadron collider in the far future

1979 LEP White Book:

ECFA-LEP Working Group 1979 chaired by A Zichichi

‘Tunnel with 27 km circumference and a diameter of 5 m, with a view to the replacement of LEP at the end of its activities by a proton-proton Collider using cryogenic magnets’


CERN LIBRARIES, GENEVA

CM-P00100391

ECFA/79/39
15/4/1980

ECFA EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

ECFA-LEP WORKING GROUP
1979 PROGRESS REPORT

Edited by

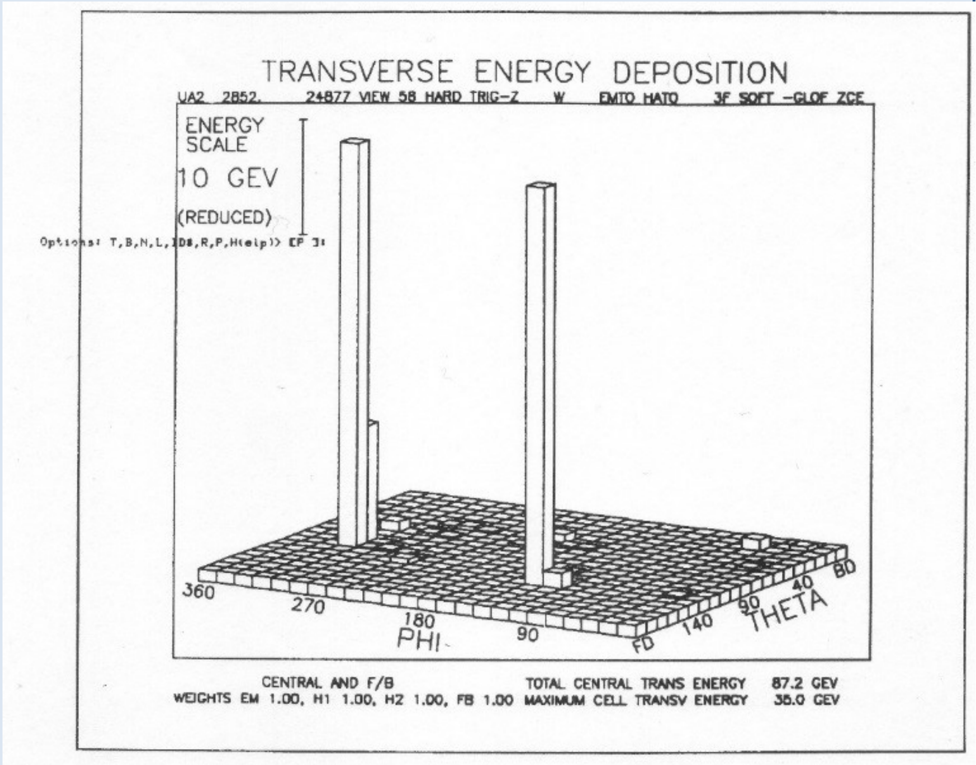
A. Zichichi, Chairman
ECFA-LEP Working Group

1981 LEP was approved with a large and long (27 km) ring tunnel

Herwig Schopper
CERN DG 1981 - 1988

1983 The early 1980s were crucial

The real belief that a 'dirty' hadron collider can actually do great discovery physics came from UA1 and UA2 with their W and Z boson discoveries at CERN



A very early Z → ee online display from one of the detectors (UA2)

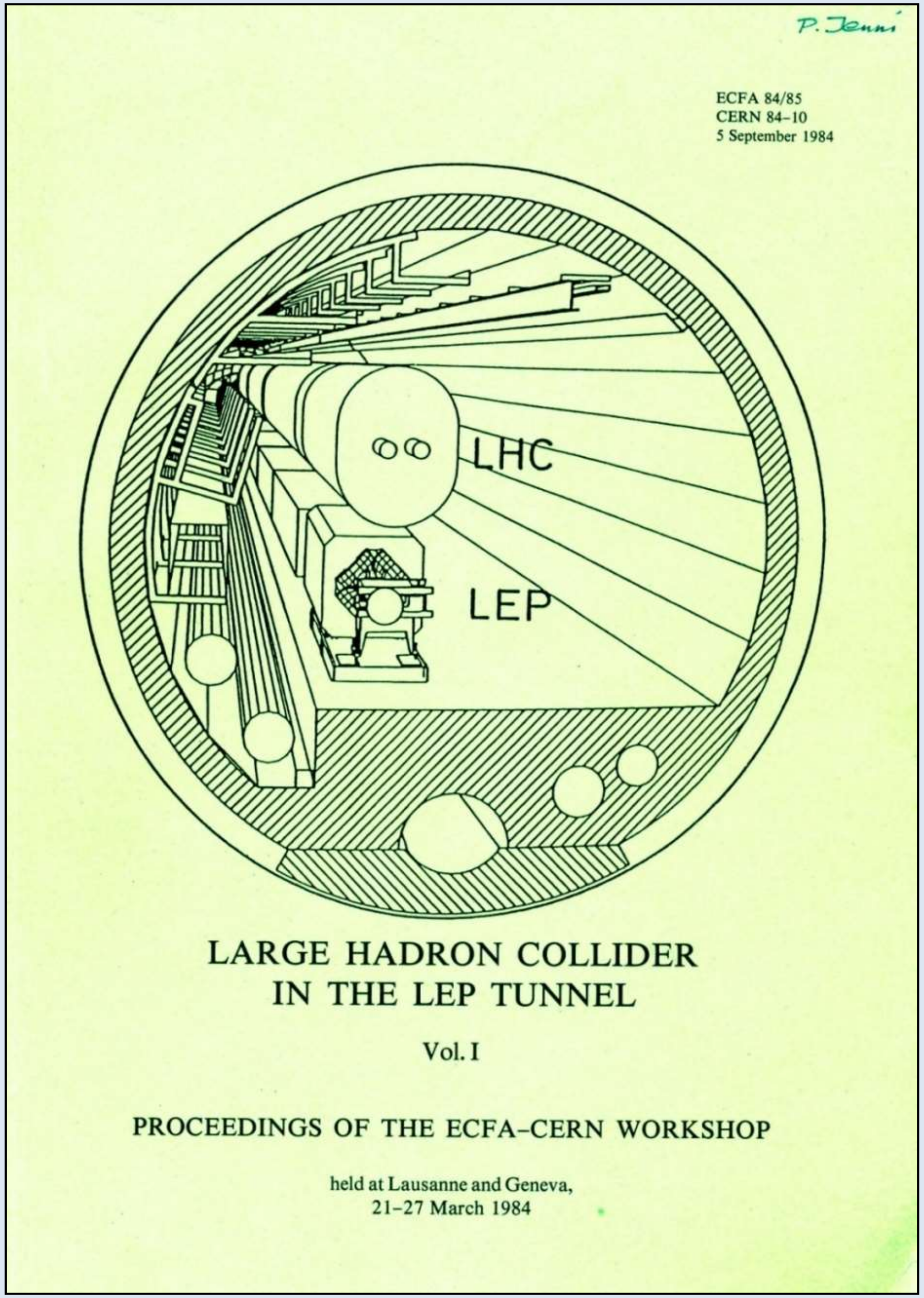
1984 For the community it all started with the CERN - ECFA Workshop in Lausanne on the feasibility of a hadron collider in the future LEP tunnel

Giorgio Brianti was leading the LHC machine studies until 1993

1986 LAA R&D on new detector technologies started, later followed by the DRDC

1987 La Thuile Workshop

Many LHC colleagues were already involved in this WS set up by Carlo Rubbia as part of the Long Range Planning Committee



P. Jenni

ECFA 84/85
CERN 84-10
5 September 1984

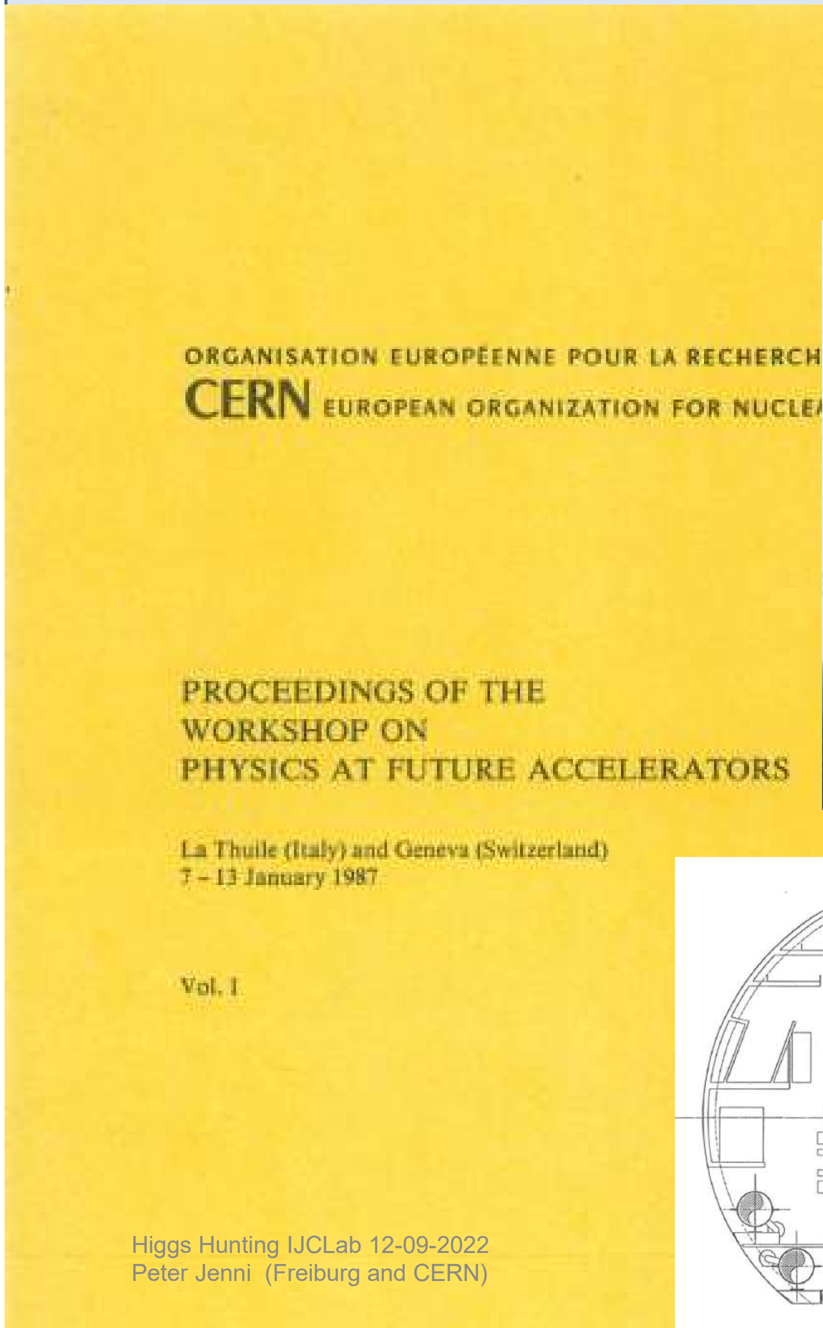
LARGE HADRON COLLIDER
IN THE LEP TUNNEL

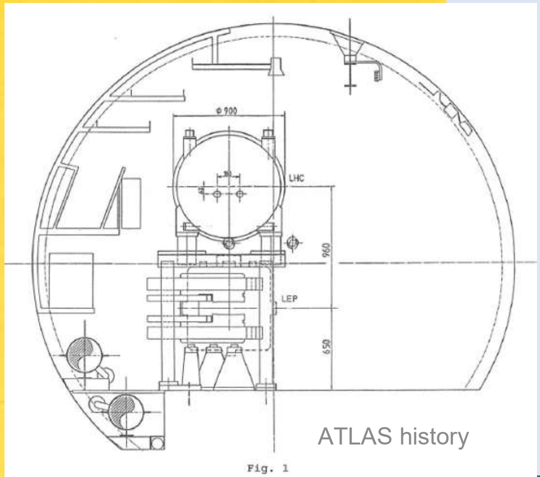
Vol. I

PROCEEDINGS OF THE ECFA-CERN WORKSHOP

held at Lausanne and Geneva,
21-27 March 1984

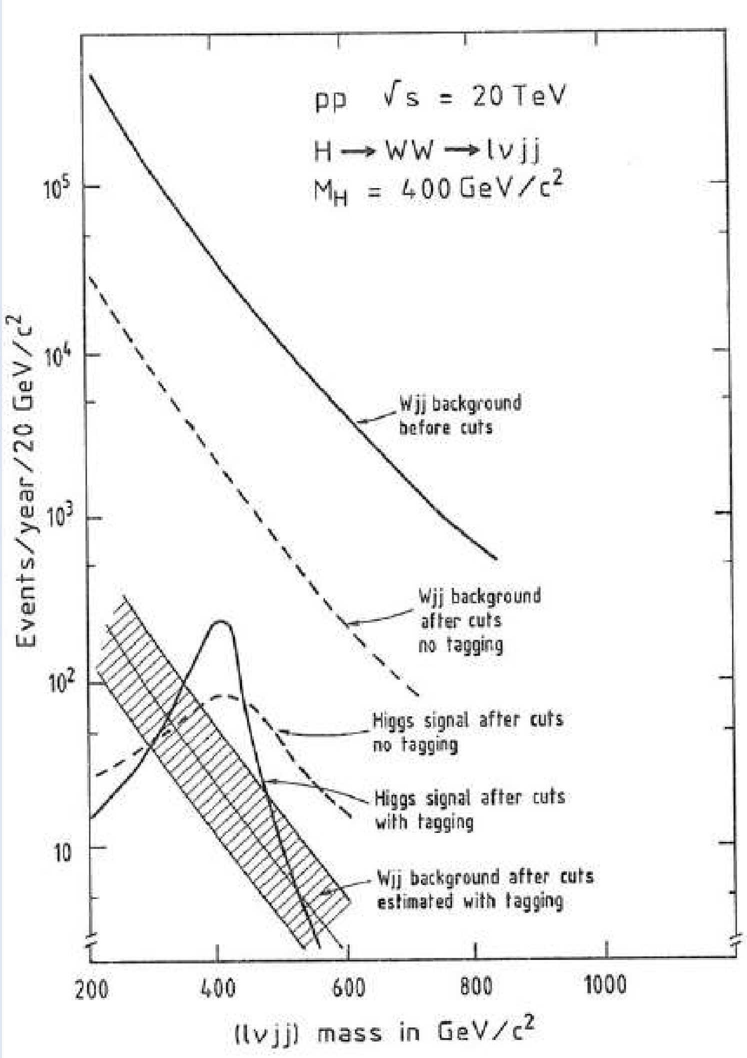
La Thuile 7 – 13 January 1987
(Carlo Rubbia's Long Range Planning Committee)





Collider parameters

Machine		$\sqrt{s}$ (TeV)	L ($cm^{-2} s^{-1}$)
LHC	pp	16	$10^{33} \rightarrow 10^{34}$
	ep	1.3	10^{32}
		1.8	10^{31}
CLIC	e^+e^-	2	$10^{33} \rightarrow 10^{34}$



Arguing around the mid-1980s of being ambitious and design a general purpose detector …

A very simplified summary:

detector signature	accessible physics process
$\mu^\pm$	$H \to ZZ \to 4\mu^\pm$ $Z' \to \mu^+\mu^-$ (σ_m ?)
$\mu^\pm$, jets, $\not{p}_T$	add: $H \to ZZ \to \mu^+\mu^-\nu\bar{\nu}$ $W' \to \mu^\pm\nu$ compositeness $\tilde{q}, \tilde{g}$ (direct decays) jet spectroscopy
e, $\mu^\pm$, jets, $\not{p}_T$ (non-)magnetic central part (<u>reduced</u> tracking)	add: 4× rate $H \to ZZ \to 4e^\pm$ 2× rate $H \to ZZ \to e^+e^-\nu\bar{\nu}$ 2× rate Z', W' $\tilde{q}, \tilde{g}$ (also cascade decays) mass resolution $e\mu$ heavy Q, L $H \to \gamma\gamma$
$e^\pm$, $\mu^\pm$, $\tau^\pm$, jets, $\not{p}_T$ full momentum and tracking	add: more redundancy and cross-checks on above, H^+, SUSY-H, heavy flavour tags

Lepton detection at LHC is crucial. Small rates are expected for many potential signals

⇒ detection of e <u>and</u> μ

Muons are relatively easy to identify but hard to measure well

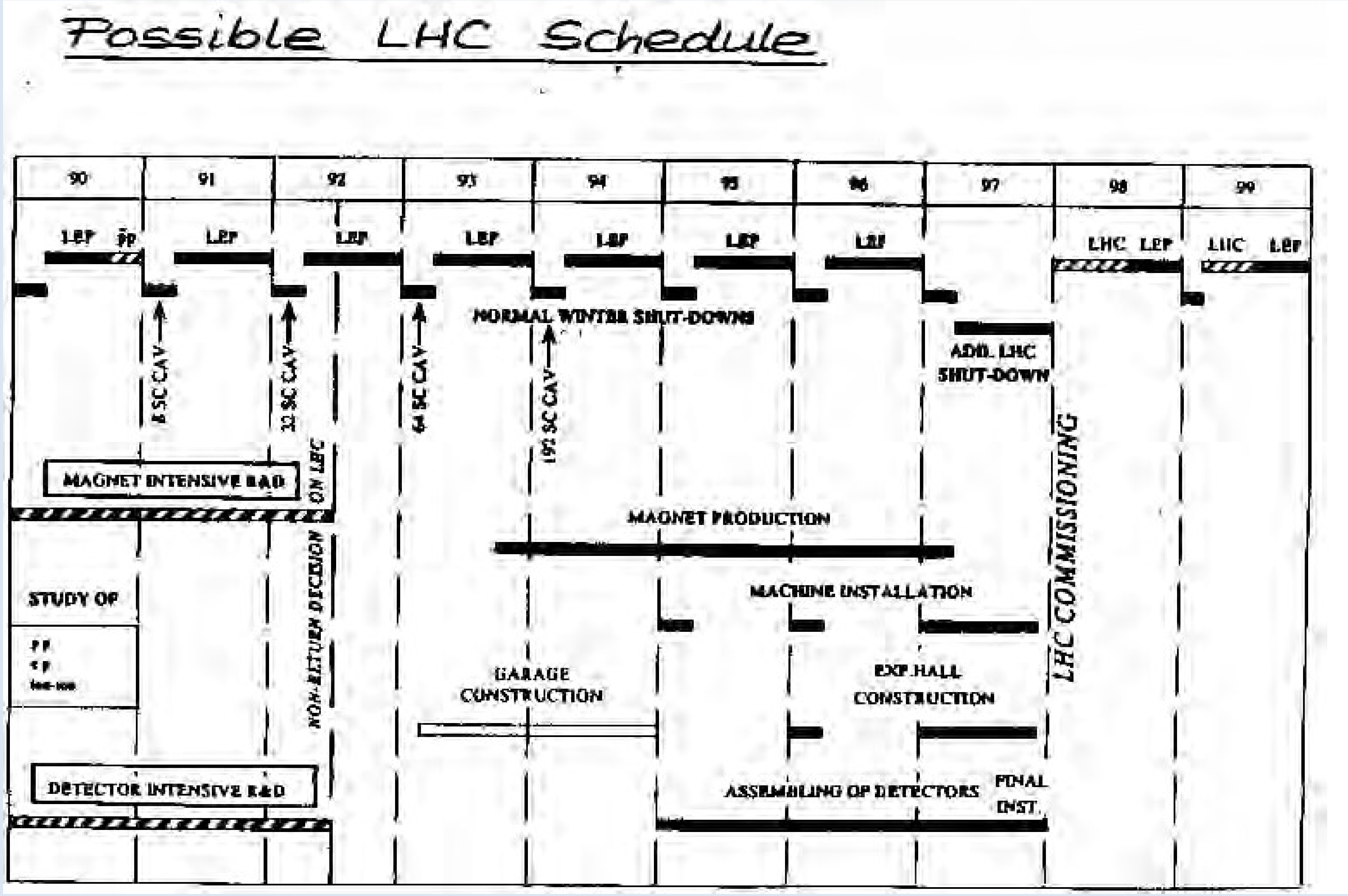
(precise μ measurements may mean hundreds of MCHF)

Electrons are relatively easy to measure but hard to identify at 10^{34}

(radiation-hard inner detector)

Lepton isolation criteria are also important to reject backgrounds from heavy flavour decays

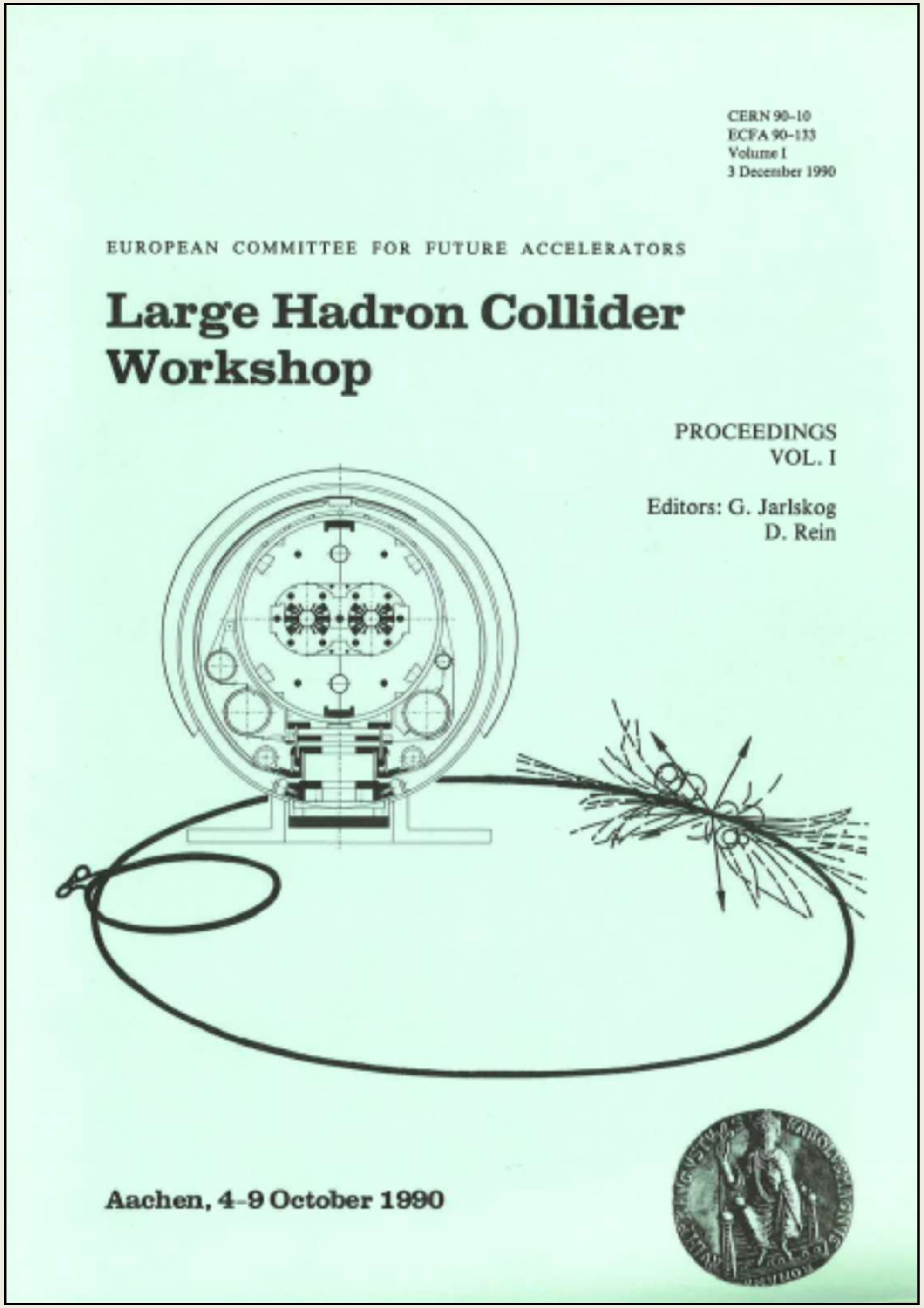
From an early talk about the LHC, must have been around 1986/7 …



1989 ECFA Study Week in Barcelona for LHC instrumentation
(forming of first proto-Collaboration)

1990 Large Hadron Collider Workshop Aachen (CERN - ECFA)
(First serious R&D results and detailed realistic Monte Carlo studies, first ideas of detector concepts)

1992 CERN – ECFA meeting 'Towards the LHC Experimental Programme' in Evian



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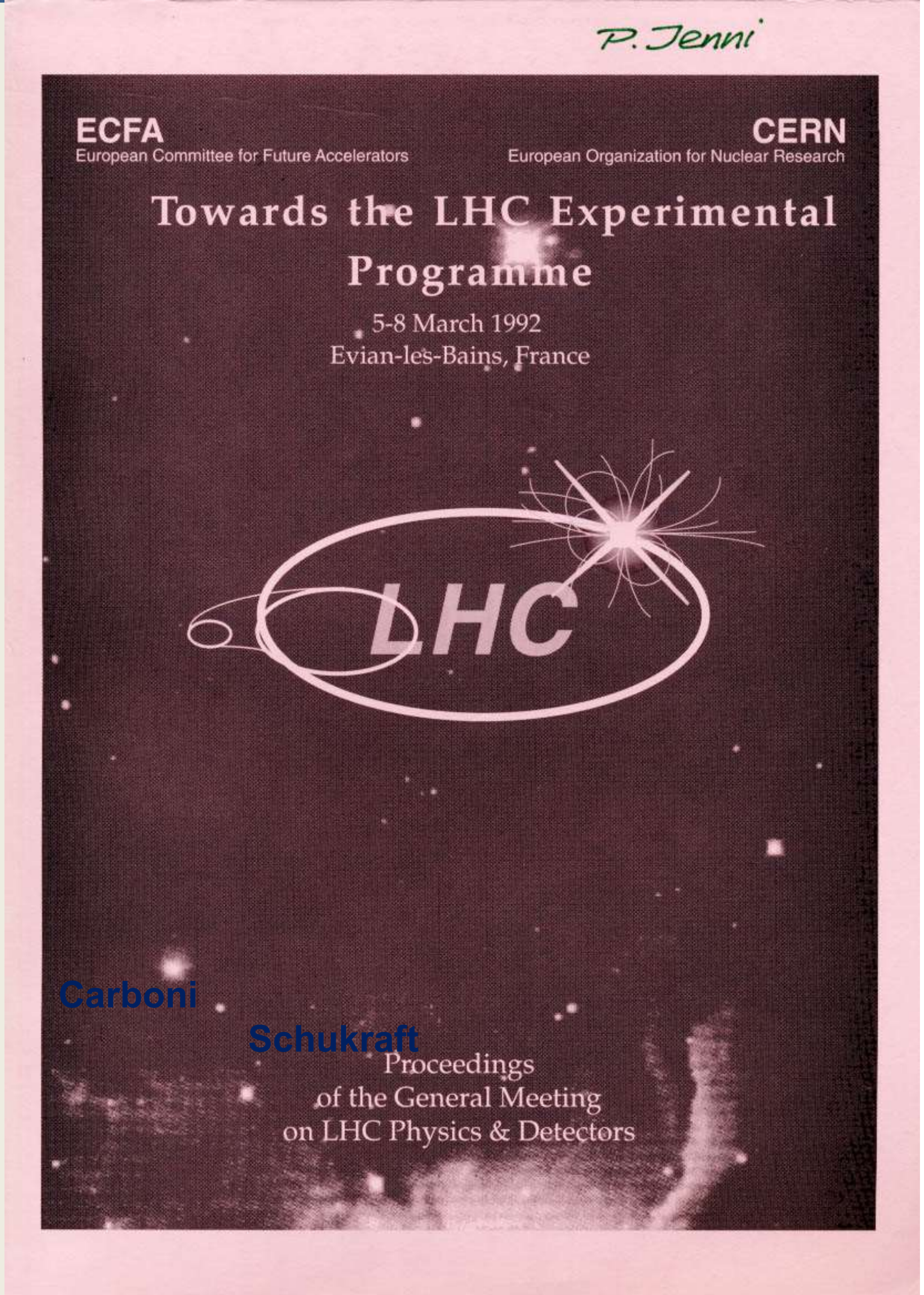
Four general purpose experiments: (ASCOT, CMS, EAGLE, and L3+1)

Six other experiments:
(LHC Beauty Collider, B extracted beam, B gas jet, Neutrino at LHC, LHC HI, and DELPHI LHC HI)



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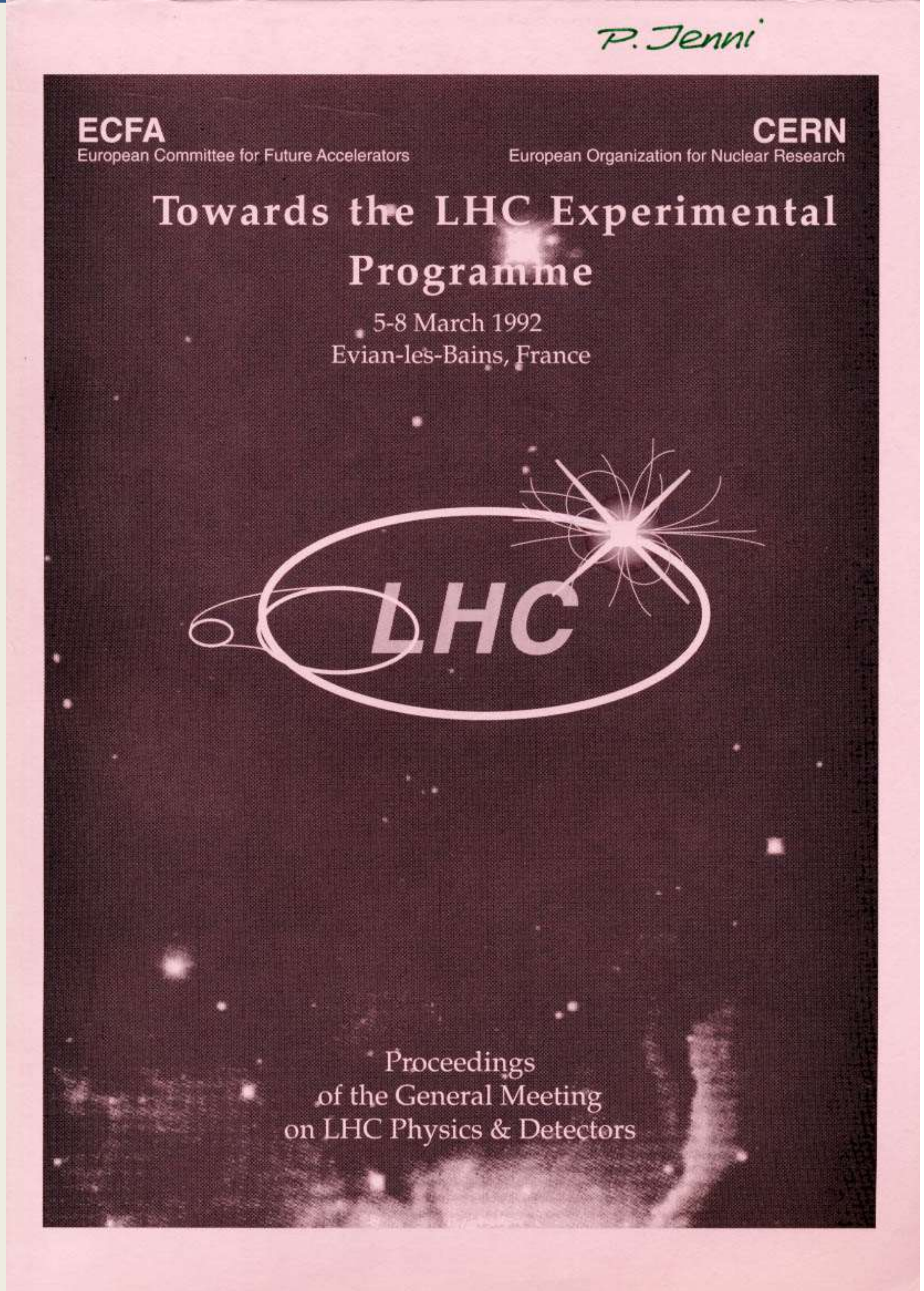
See more 'pre-history' accounts for the LHC at:

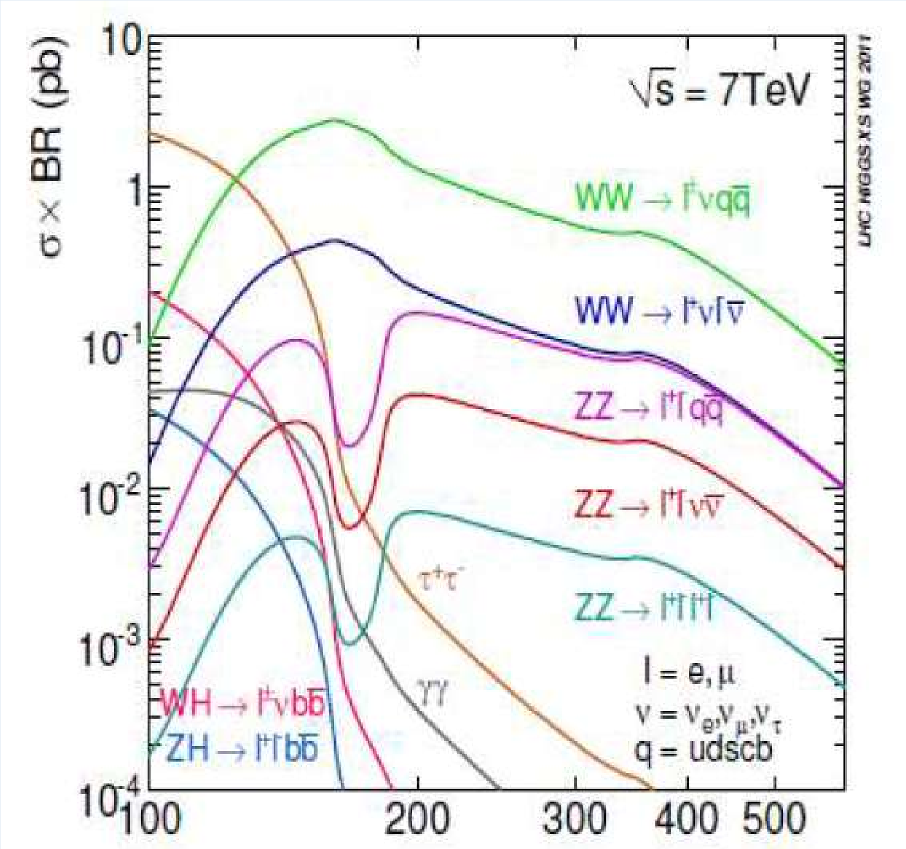
Symposium 25 Years of LHC Experimental Programme CERN, 15th December 2017

https://indico.cern.ch/event/653848/timetable/?print=1&view=standard



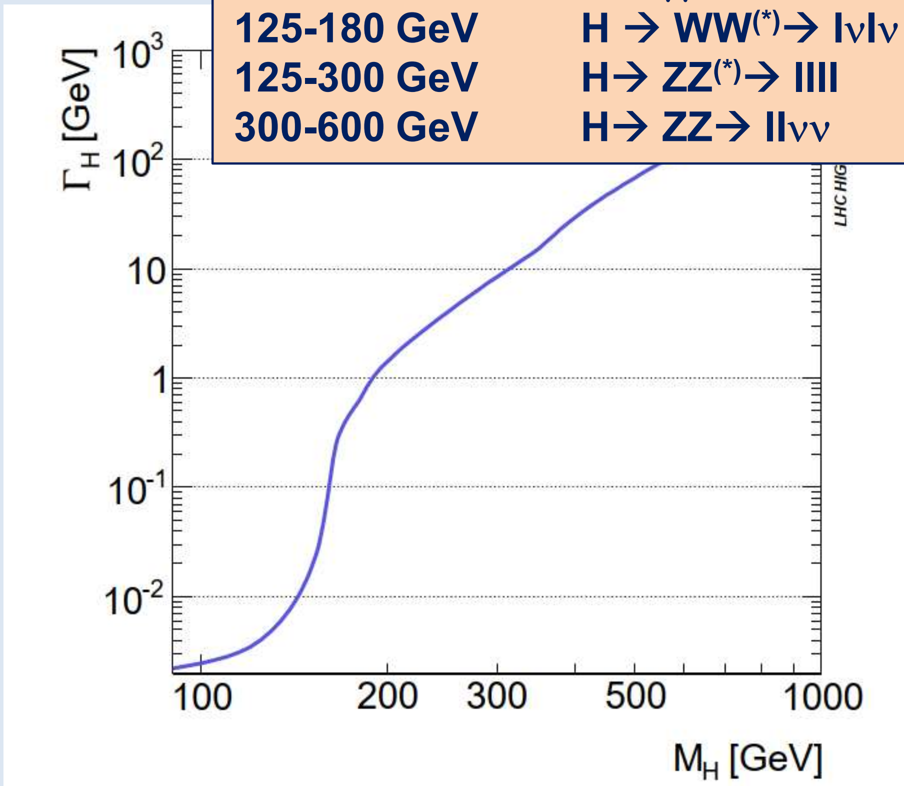
Sensitivity for all yet unexplored Higgs boson masses (in the late 1980s) called for a detector concept offering as many final state signatures as possible

It was also clear for the lower mass range that the instrumental resolution would dominate the width of the reconstructed H mass peak, and thus determine the signal/background ratio



Best channels at the LHC:

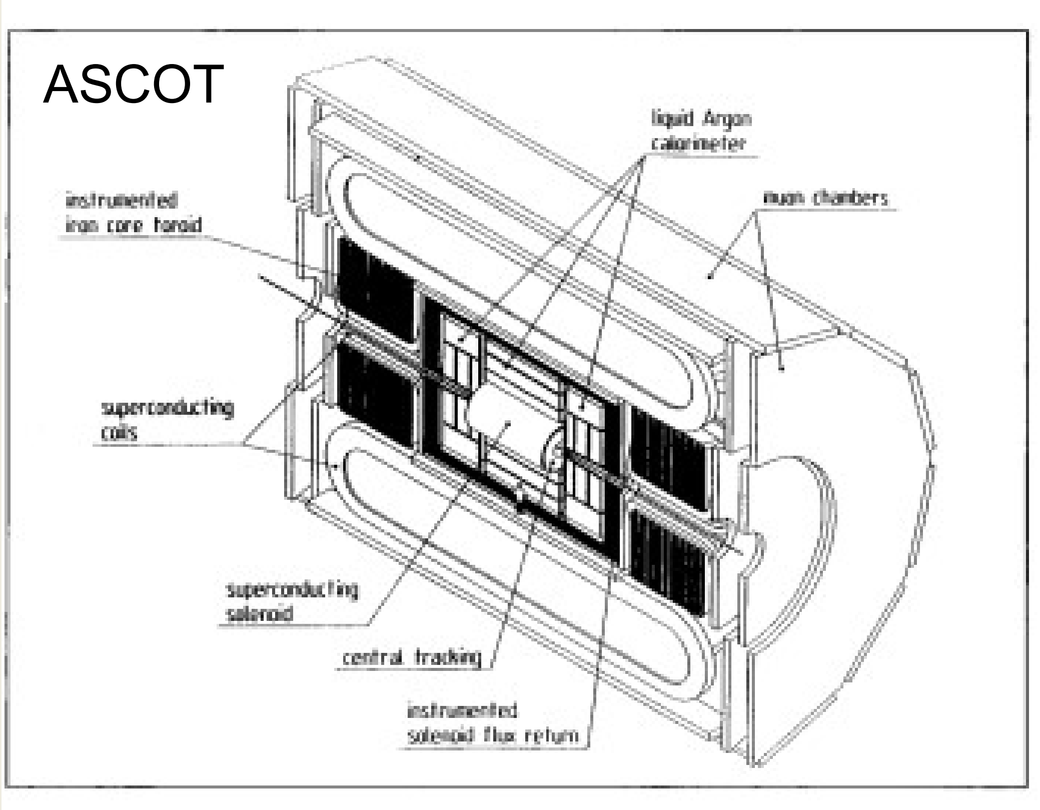
< 130 GeV	H→ $\gamma\gamma$
125-180 GeV	H → $WW^{(*)}$→ $l\nu l\nu$
125-300 GeV	H→ $ZZ^{(*)}$→ llll
300-600 GeV	H→ ZZ→ $ll\nu\nu$



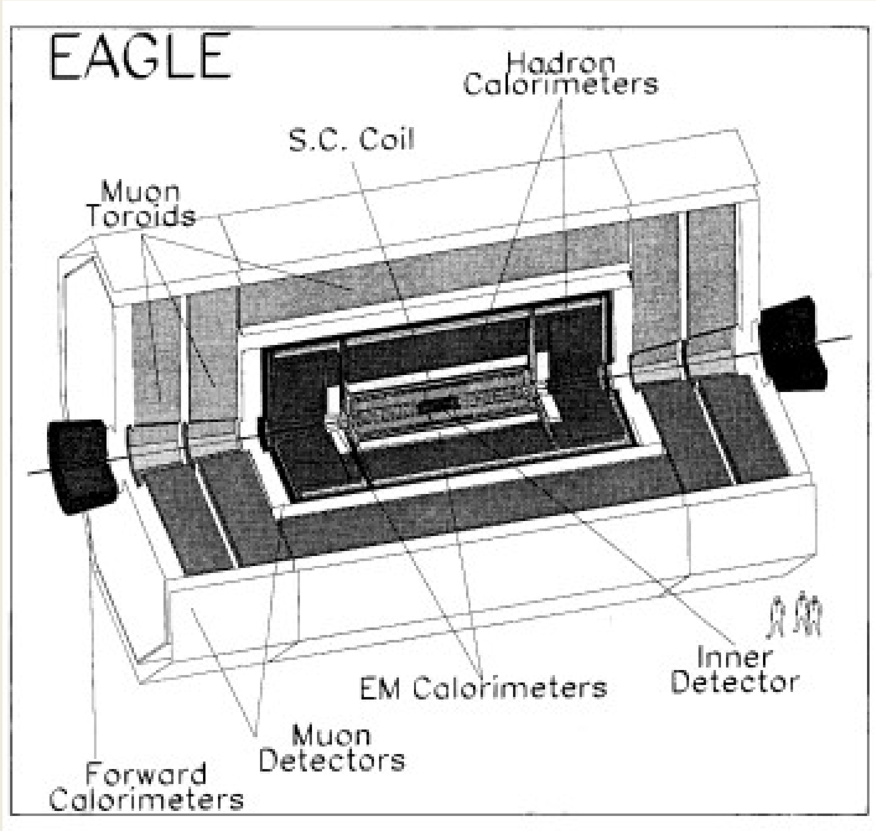
Cross-section times branching ratios (left) and the natural width (right) from the Handbook of LHC Higgs cross-sections, Yellow Report CERN-2011-002 (for the LHC start-up energy)

The ASCOT and EAGLE proto-collaborations both presented detector concepts with a toroid magnet configuration for the muon spectrometer at the Evian meeting

From their Expressions of Interest



ASCOT with a superconducting air-core barrel and warm iron end cap toroids



EAGLE with warm iron barrel and end cap toroids

The birth of ATLAS

March 1992 – Summer 1992

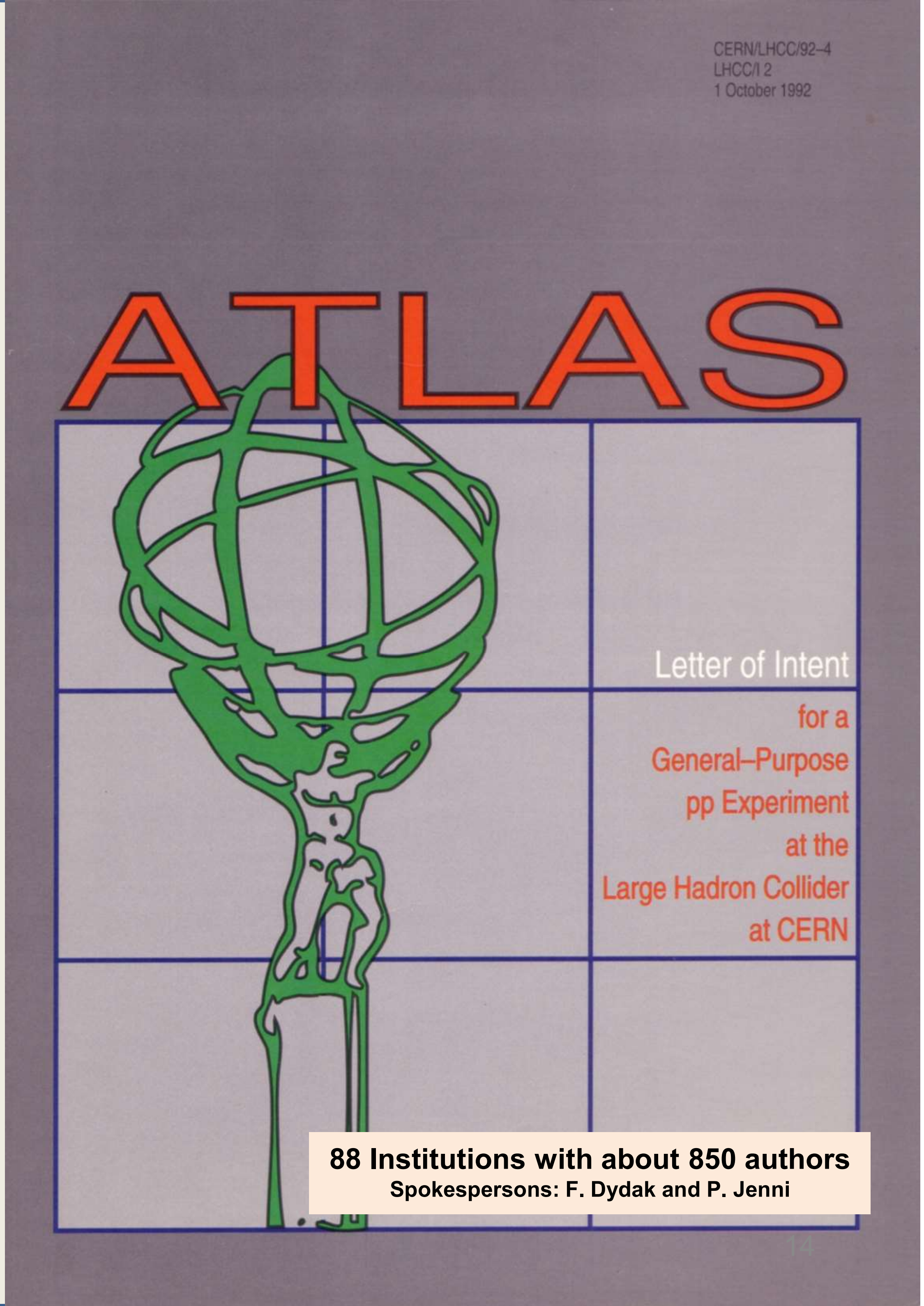
Merging of ASCOT and EAGLE

September 1992: Decision on the name taken in vote at the Collaboration Board based on many names suggested by Collaboration members

1st October 1992

ATLAS LoI submitted to the LHCC

'Official birth of the ATLAS Collaboration'

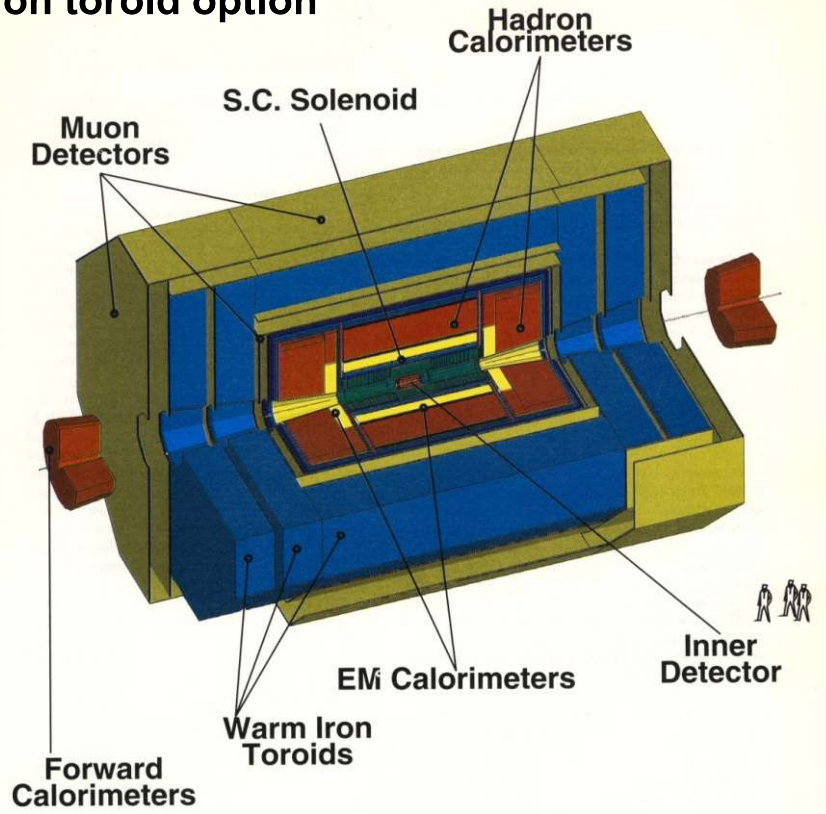


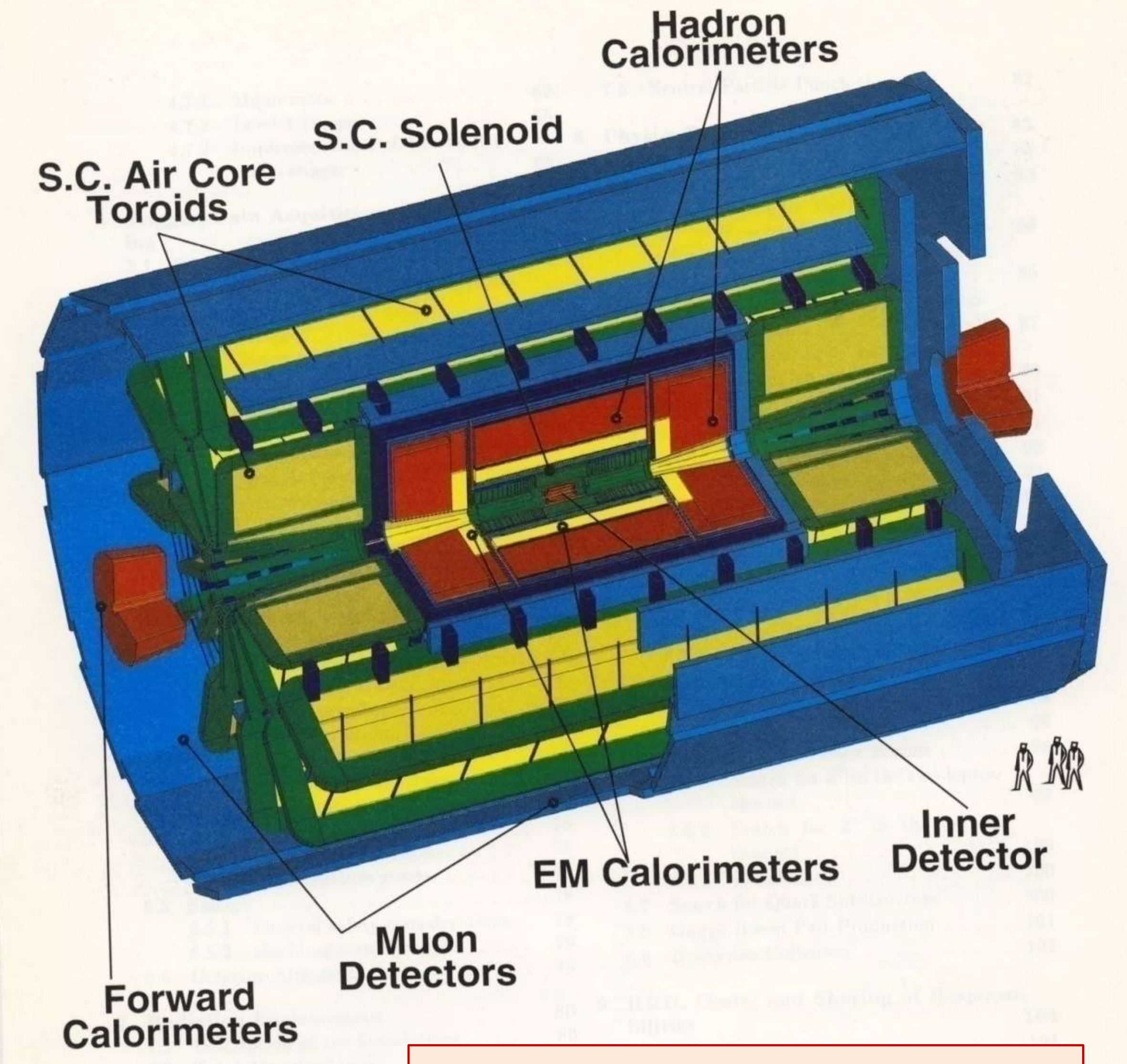
88 Institutions with about 850 authors
Spokespersons: F. Dydak and P. Jenni

The LoI still had two toroid options, one full iron and one all superconducting air-core

Shortly after ATLAS decided for the *superior air-core magnet*

Iron toroid option

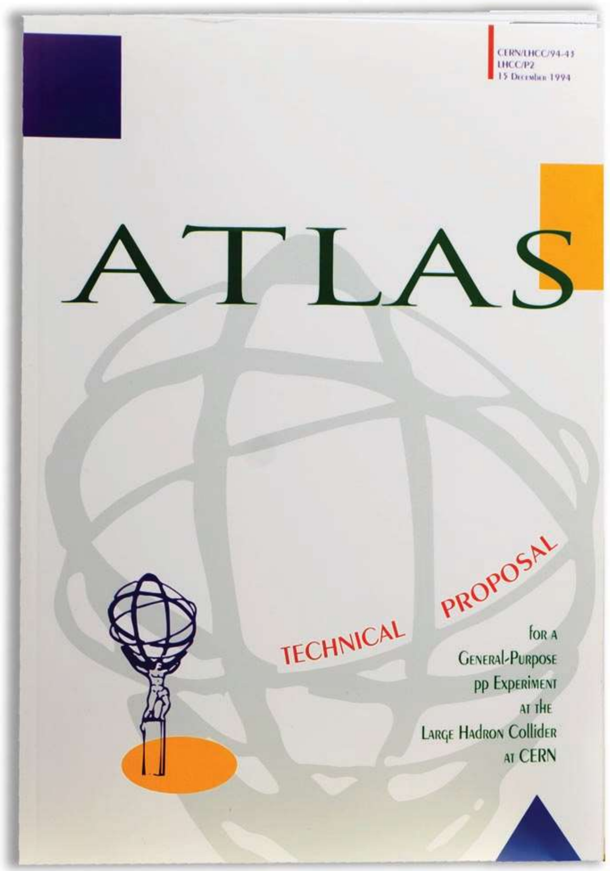




Superconducting air-core option, initially with 12 coils, then redesigned with 8 coils (mainly for cost reductions)

ATLAS was then (June 1993) invited by LHCC to work out a Technical Proposal

(Submitted on 15th December 1994, presented on 19th January 1995)



ATLAS Collaboration

(Status: Technical Proposal, 15 December 1994)

Alberta, Alma Ata, NIKHEF Amsterdam, LAPP Annecy, Argonne NL, Arizona, Arlington UT, Athens, NTU Athens, Baku, UA Barcelona, Berkeley LBL and UC, Bern, Birmingham, Bonn, Boston, Brandeis, Bratislava, Brookhaven NL, IAP Bucharest, Cambridge, Carleton/CRPP, CERN, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, INP Cracow, FPNT Cracow, Dortmund, JINR Dubna, Duke, Edinburgh, Florence, Frascati, Freiburg, Fukui, Geneva, Genoa, Glasgow, ISN Grenoble, Technion Haifa, Hamburg, Harvard, Hawaii, Heidelberg, SEFT Helsinki, Hiroshima IT, Hiroshima, Indiana, Innsbruck, Irvine UC, Istanbul Bogazici, Jena, KEK, Kobe, Kosice, Kyoto UE, Lancaster, Lecce, Lisbon, Liverpool, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, MIT, Melbourne, Michigan SU, Milano, Minsk, Montreal, ITEP Moscow, Lebedev Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Naples, Naruto UE, Nijmegen, Northern Illinois, BINP Novosibirsk, LAL Orsay, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, COPPE Rio de Janeiro, Rochester, Rockefeller, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinsu, Siegen, Southern Methodist, IFMO St. Petersburg, NPI St. Petersburg, Stockholm, KTH Stockholm, Ansto Sydney, Tbilisi AS, Tbilisi SU, Tel-Aviv, Thessaloniki, Tokyo CU, Tokyo ICEPP, Tokyo MU, Tokyo AT, Toronto, TRIUMF, Tufts, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, Wisconsin, Wuppertal, Yerevan

(140 Institutions with about 1500 authors)

From the TP presentation

ATLAS

is a general-purpose pp detector designed to exploit the full discovery potential of LHC

The primary goal is to operate at high luminosity (10^{34} $cm^{-2}s^{-1}$) with as many signatures as possible (e, γ, μ, jet, E_T^{miss}, b-tagging, ...)

---> *robust and redundant physics measurements with the ability of internal cross-check*

Emphasis is also put on the performance necessary for the physics accessible during initial lower luminosity (10^{33} $cm^{-2}s^{-1}$) using in addition more complex signatures (τ and heavy-flavour tags from secondary vertices, ...)

The design goals are achieved using a magnet configuration combining

- inner superconducting solenoid around the inner detector cavity
- superconducting air-core toroids consisting of independent coils arranged in an eight-fold symmetry outside the calorimetry

This concept offers

- *almost no constraints on calorimetry and inner detector*
- *high-resolution, large-acceptance and robust stand-alone muon spectrometer*

From the TP presentation

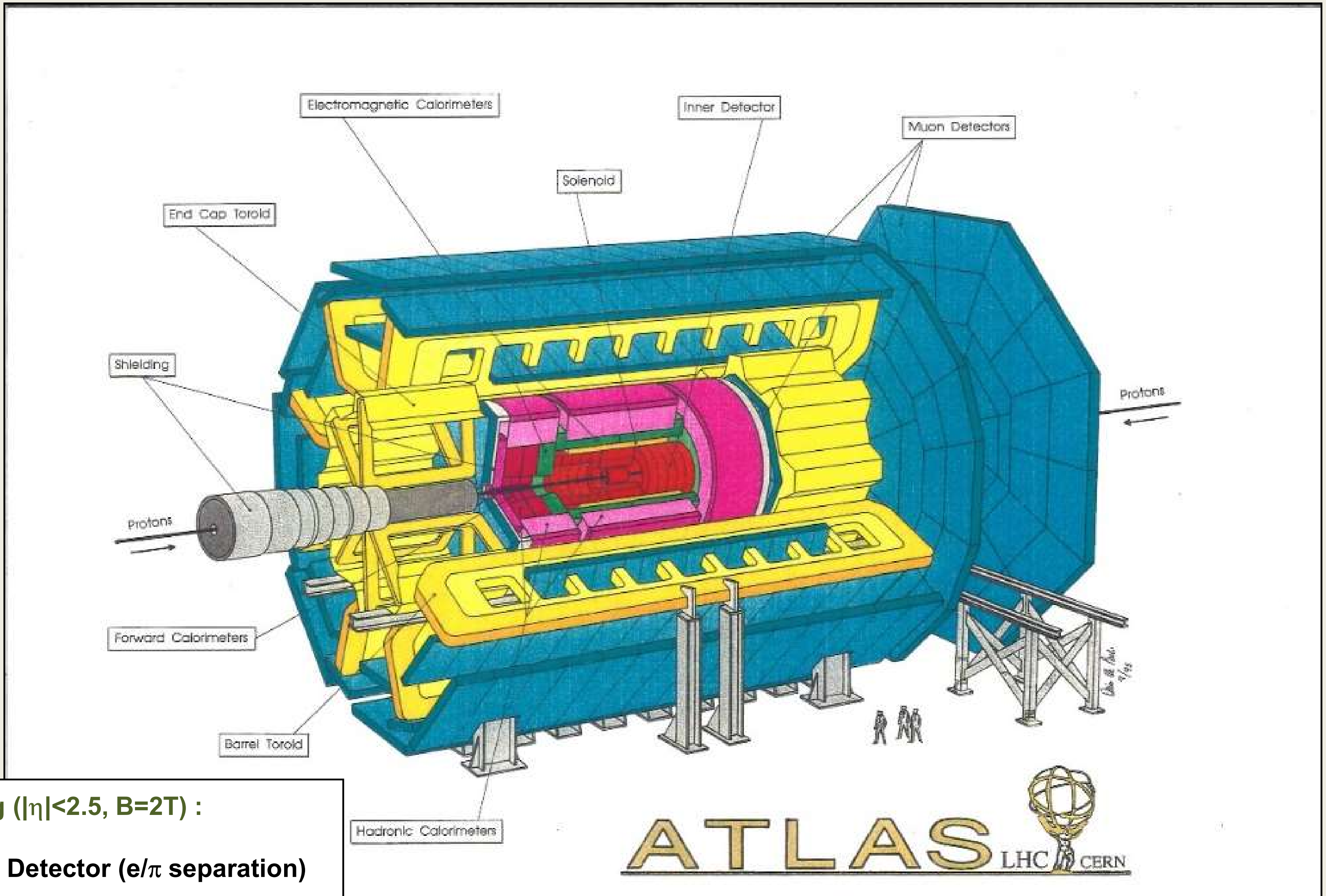


Figure from the TP presentation

- **Inner Detector 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 (end-caps/fwd)**
- **Muon Spectrometer (|η|<2.7) :**
  - **-- air-core toroids with precision (MDT and CSC) and trigger (RPC and TGC) muon chambers**

But again, we were too expensive!

→ Act two of cost reduction: the famous 'Pilcher' Task Force for global descoping

A major ingredient was:

'Reduction of detector dimensions and magnetic fields, leading to an adequate safety margin in the cavern size'

ATLAS Internal Note
Gen-No-014
24th November 1995

Report of the Global Descoping Task Force

Abstract

The work and recommendations of the ATLAS Global Descoping Task Force are presented. The revised configuration is believed to be one which retains good integrated physics performance of the detector and reduces the cost by 24.8 MCHF.

1

But again, we were too expensive!

→ Act two of cost reduction:
the famous ‘Pilcher’ Task Force
for global descoping

A major ingredient was:

‘Reduction of detector dimensions and magnetic fields, leading to an adequate safety margin in the cavern size‘

HOWEVER, AS WE SEE NOW WITH THE BENEFIT OF HINDSIGHT:

It was crucial to resist as much as possible to major descoping of specific detector systems, like for example the granularity of the calorimeters

Thanks to this ATLAS can exploit now with - at the time - unforeseen advanced analysis methods a lot of physics well beyond the initial dreams …

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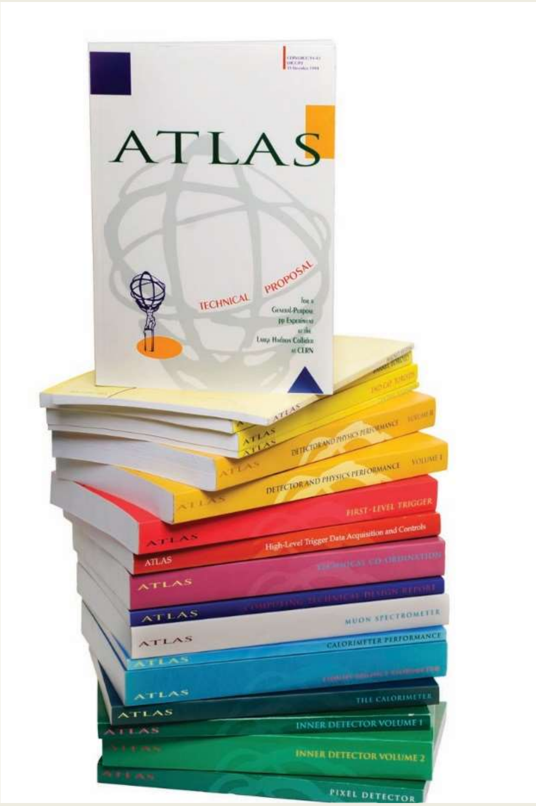
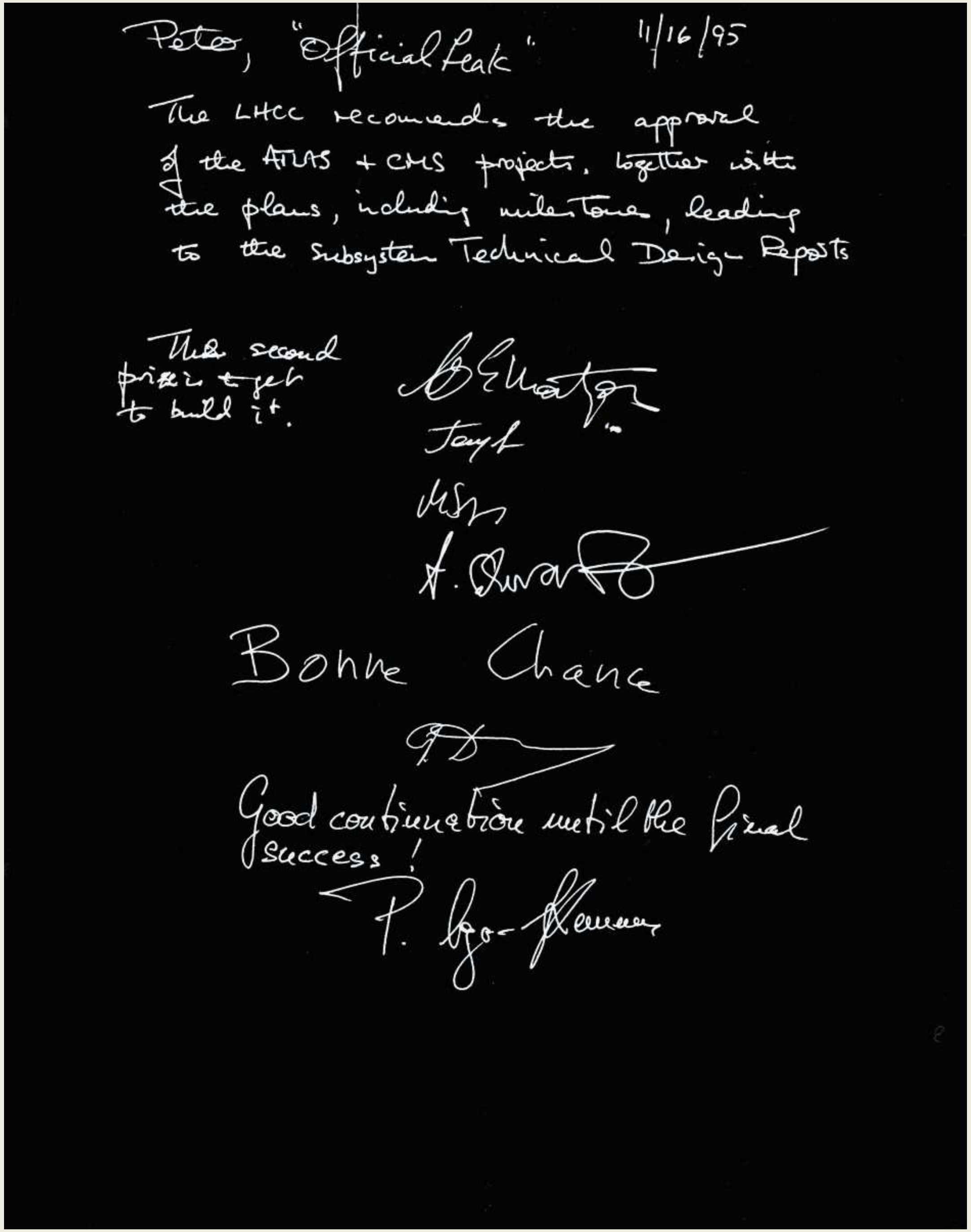
1

The Technical Proposal evaluations concluded by the end of 1995

It was a long way to convincing the LHC Experiment Committee (LHCC), but finally, on 16th November 1995, our referees were happy, and Hugh Montgomery, ATLAS main referee at that time, gave us the following 'official leak' from the committee…





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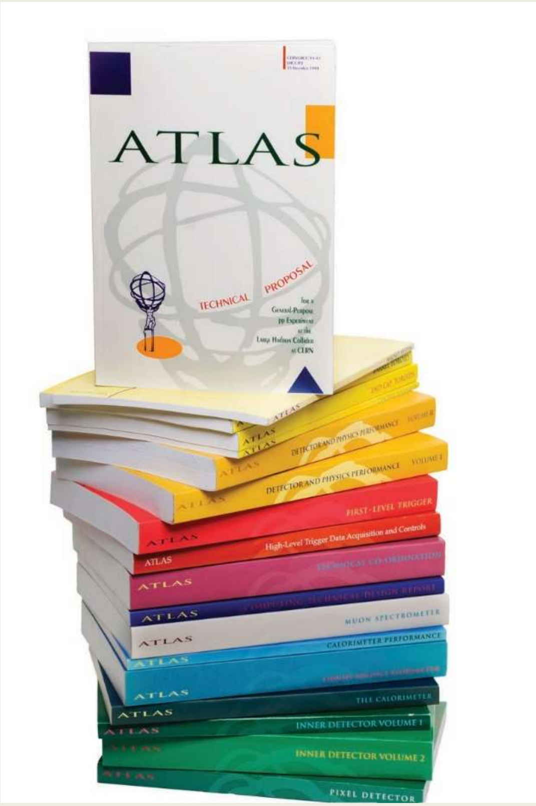

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

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Fax: (41.22) 767 89 95
E-mail: Christopher.Llewellyn.Smith@cern.ch

Dr Peter Jenni
PPE Division
CERN

Our Ref. DG/mnd/2540

Geneva, 1st July 1997

Dear Peter,

Following the thorough discussion of the status of ATLAS and CMS by Council and its Committees two weeks ago, the way is now open for construction to begin. I am therefore pleased to inform you that I have decided to *i)* set the cost ceiling for ATLAS at 475 MCHF (1995 prices), and *ii)* approve the TDR of the ATLAS calorimeters on the following basis formulated by the LHCC and endorsed by the Research Board at its meeting on 12th June:

*"The LHCC **recommends general approval** of the ATLAS Calorimetry Technical Design Report describing design, performance, construction, and installation in 2004. The review **identified some concerns** in limited areas, which require resolution (LHCC 97–27). The LHCC considers that the schedules and milestones given in the TDR are reasonable, and these will be used by the committee to measure and regulate the future progress of the project."*

Yours sincerely,

Chris

Chris Llewellyn Smith

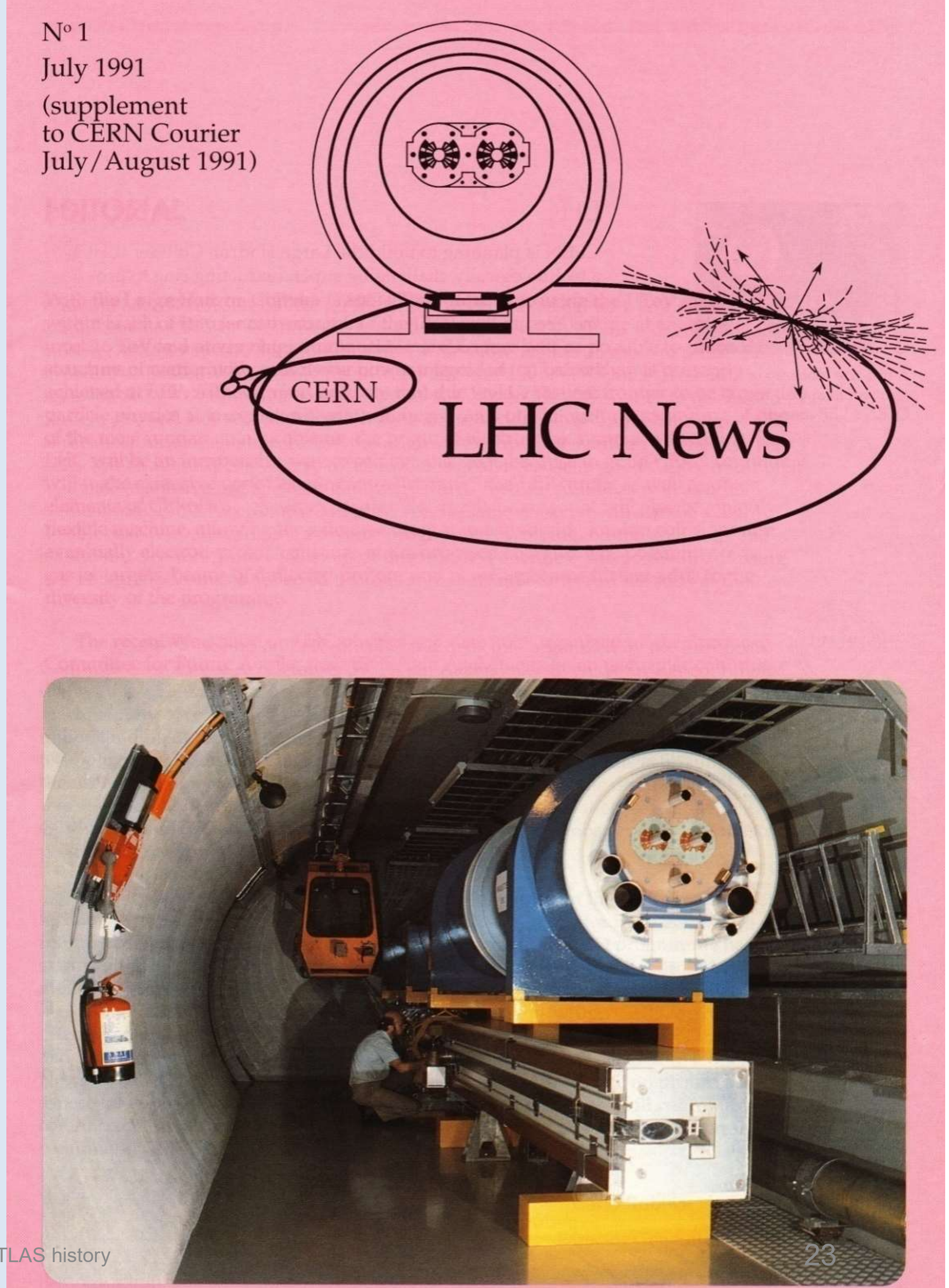
cc: L Foà
E Iarocci

The formal construction approval was then given with the approval of the first TDRs (25 years ago)

1991 December CERN Council: 'LHC is the right machine for advance of the subject and the future of CERN' (thanks to the great push by DG C Rubbia)

1993 December proposal of LHC with commissioning in 2002

Minister Boris Saltykov and DG Carlo Rubbia signing an updated Cooperation Agreement Russia and CERN (28 June 1993)



1994 **In order to have any chance at all of approval, the idea of a staged construction was worked out by the then new CERN DG Chris Llewellyn-Smith**

June 1994 Council:

Staged construction was proposed, but some countries could not yet agree, so the Council session vote was suspended until

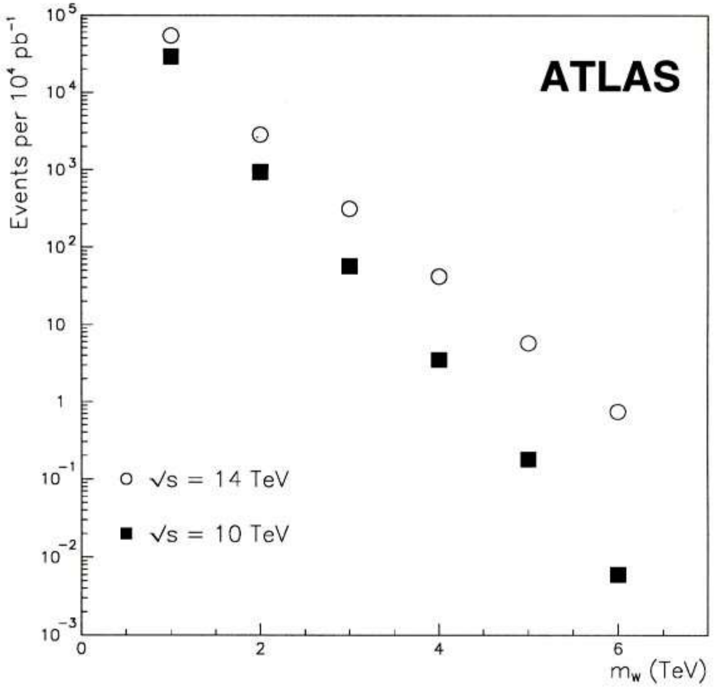
16 December 1994 Council:

Two-stage construction of LHC was approved

ATLAS provided comparisons between 10 and 14 TeV…
→ worthwhile to start with

Search for new, heavy, gauge bosons

Number of W' decays into eν or μν for 10^4 pb^{-1}



The accessible mass range is affected by both the lower energy and luminosity

The two-stage approval of LHC was understood to be modified in case sufficient CERN non-member state contributions would become available

A lot of LHC campaigns and negotiations took place in the years 1995 - 1997, including also the experiments

Japan, Russia, JINR, India, Canada and the USA were agreeing in that phase to contribute to the LHC

(Israel contributed all along to the full CERN programme and LHC)

1996

December Council approved finally the single-stage 14 TeV LHC for completion in 2005

Signature of the Japan-CERN agreement on 1st June 1995

(K Yosana – Japanese Minister, H Curien – Council President, C Llewellyn-Smith – CERN DG, with the famous Daruma doll)

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Signature of the US-CERN agreement on 19th December 1997: R Eisenstein (NSF), C Llewellyn Smith (CERN DG), M Krebs (DOE)

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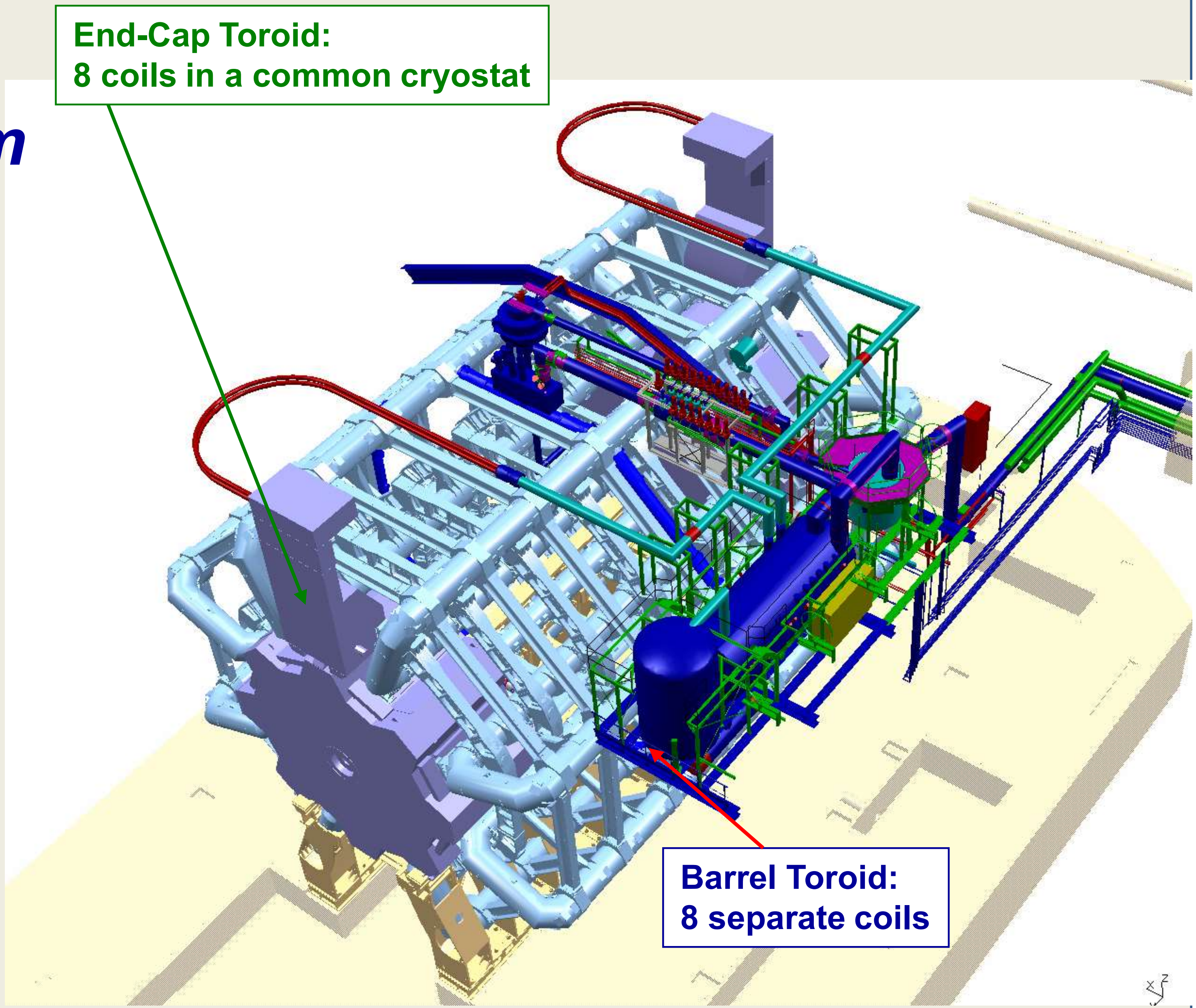
Delivery of the last dipole for the LHC injection lines from Russia (15th June 2001), with L Maiani and A Skrinsky in the centre

Few examples of the many technical challenges for the ATLAS detector construction

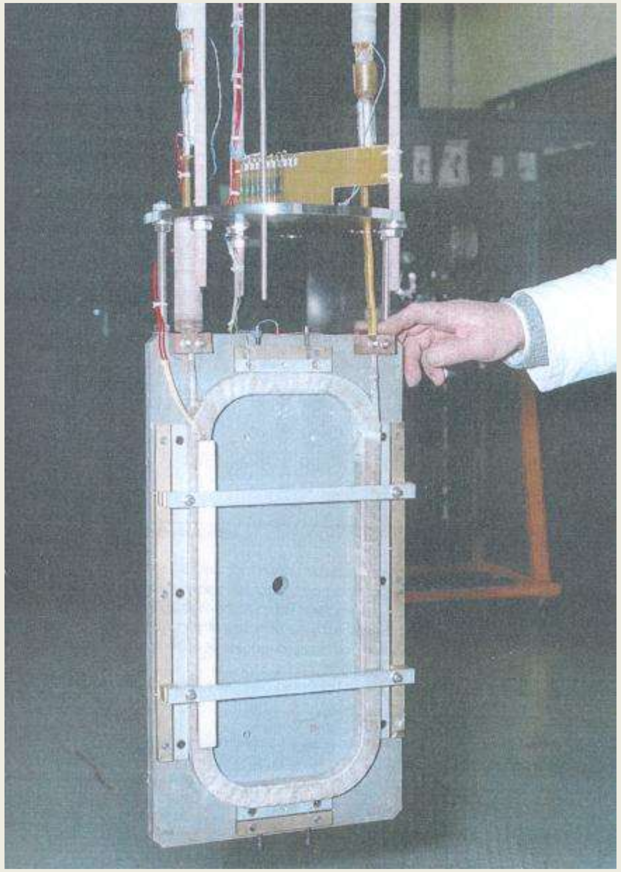
ATLAS Toroid Magnet System

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

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



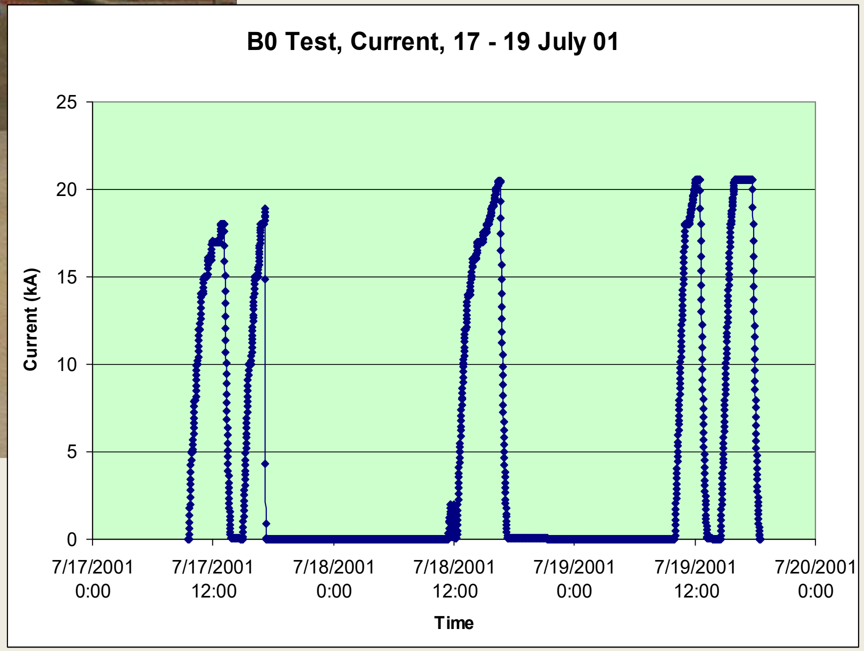
From small to big:
Important first steps towards the ATLAS Barrel Toroid



Micro-B coil (Saclay R&D)

The ATLAS Race-Track coil at Saclay (tests ~1995, picture 1999)

The B0 model coil reaching full current of 20.5 kA (July 2001) at CERN

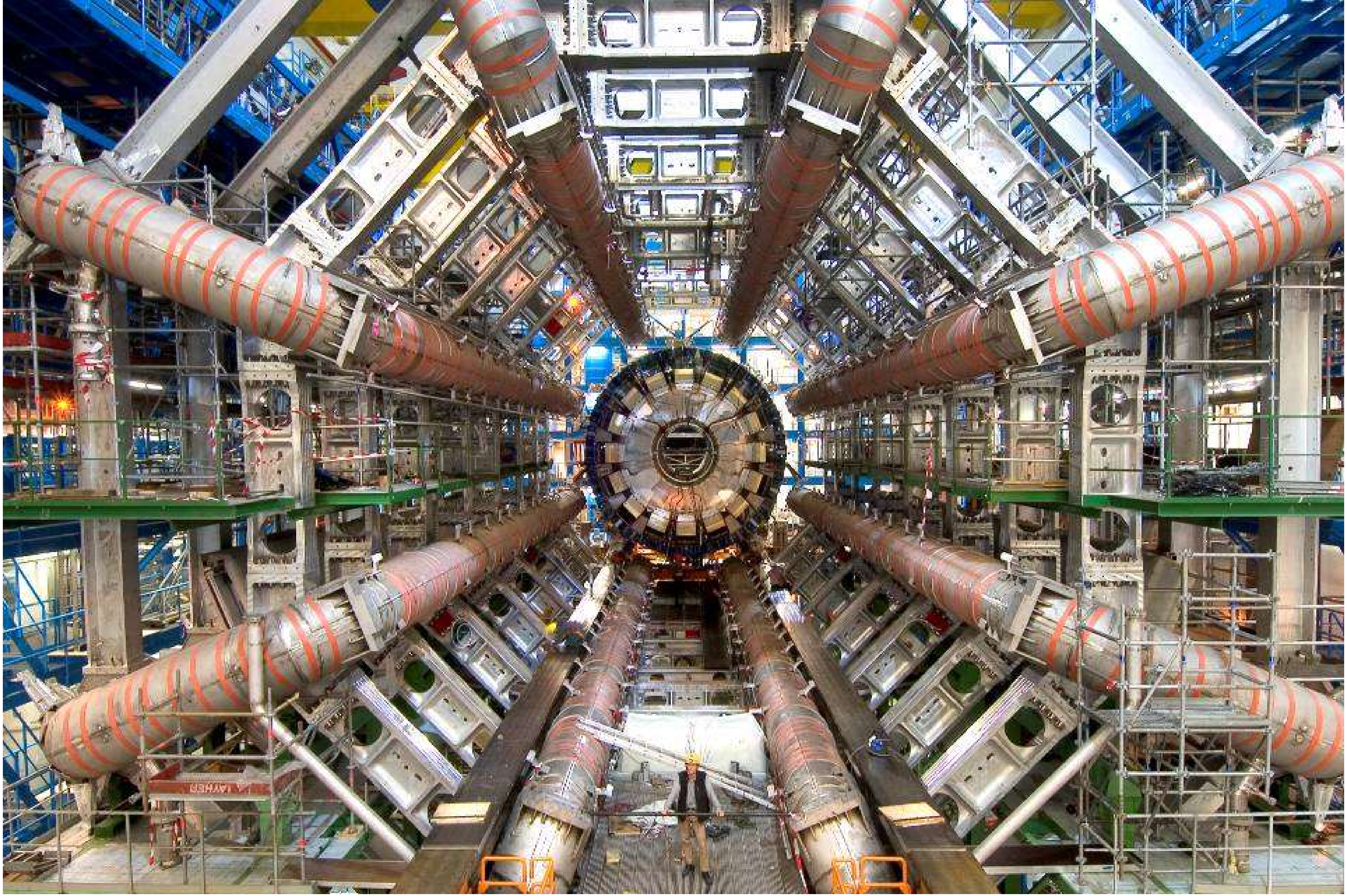


Barrel Toroid coil integration and testing in Hall 180

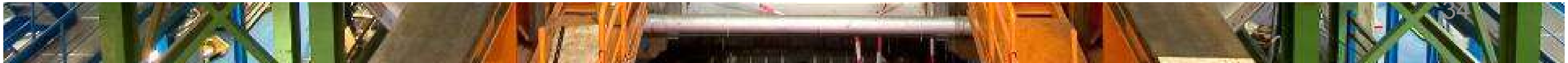
Point-1 Civil Engineering 1998-2003
(underground cavern 56 x 32 x 35 m^3)

LHC Point 1 - UX 15 Cavern - Concrete walls 6th lift - 20-02-2003 - CERN ST-CE

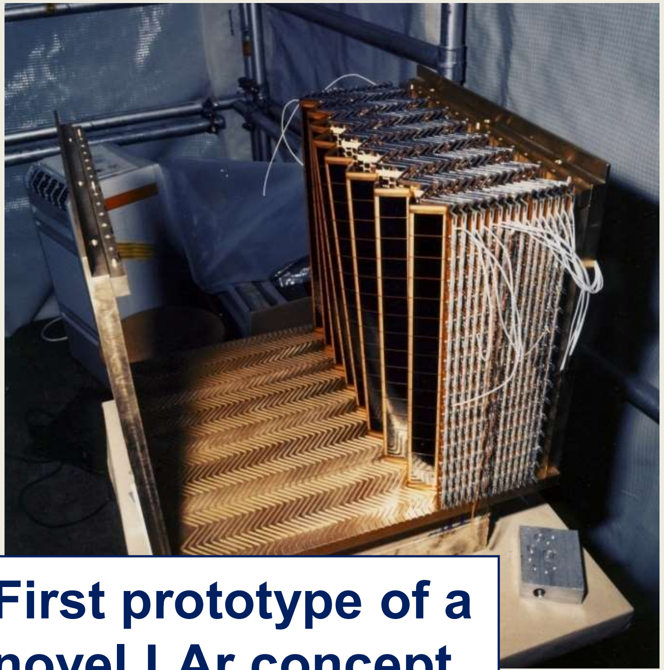
Formal inauguration of the point-1 cavern on 4th June 2003



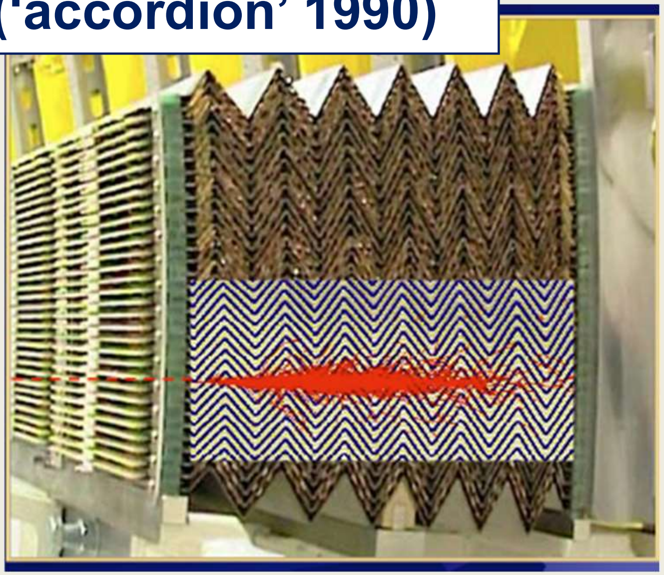
Barrel toroid and barrel calorimeter (plus solenoid) installations 2004-2005



Tile calorimeter Module-0 at the JINR Dubna workshop, April 1996



First prototype of a novel LAr concept ('accordion' 1990)

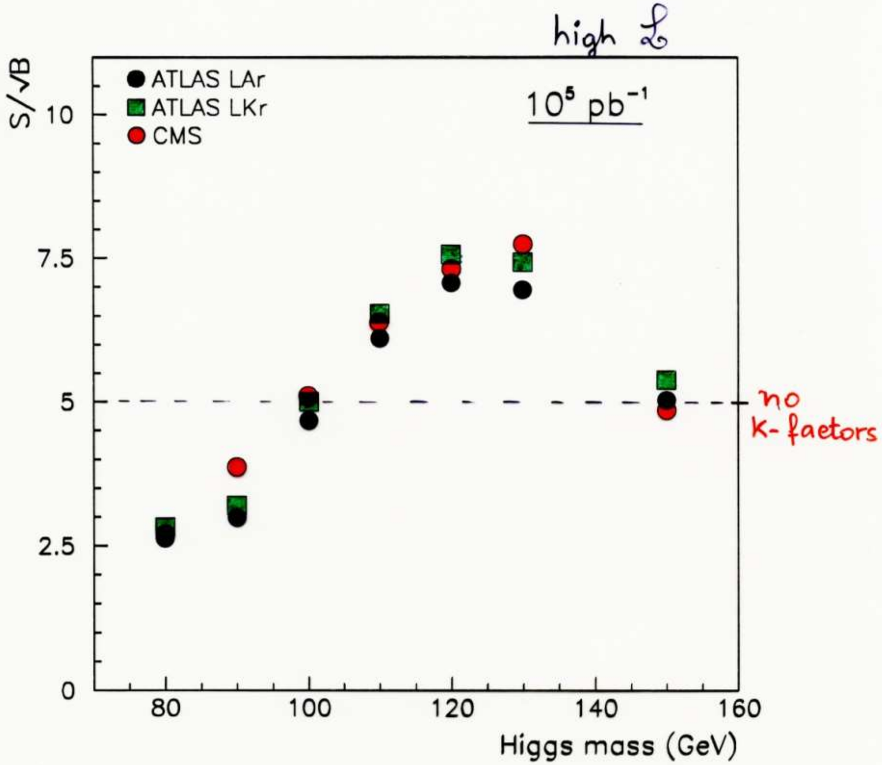


LAr EM calorimeter construction 1999 - 2004

We had quite some intense discussions within the Collaboration and with the LHCC about performance issues in the 1990s, here as example on the EM resolution…

$H \rightarrow \gamma\gamma$ SIGNIFICANCE

LKr : ~ 7% better than LAr



CMS : à la ATLAS : no K-factors
jet bckgr. included
etc.

low $\mathcal{L}$: CMS ~ 20% better than ATLAS LAr
~ 12% LKr

$H \rightarrow \gamma\gamma$ m_H = 100 GeV

Contributions to σ_m

high $\mathcal{L}$

	LAr (MeV)	LKr (MeV)	
SAMPLING TERM	900	687	←
CONSTANT TERM (0.7%)	490	490	
PILE-UP ⊕ NOISE	500	390	←
VERTEX	400	403	
TOTAL ⊕ high $\mathcal{L}$	1250 ± 30	1040 ± 30	20% ± 4%
TOTAL low $\mathcal{L}$	1050 ± 30	860 ± 30	
Mass bin $\varepsilon \approx 80\%$ (high $\mathcal{L}$)	3430	3080	~ 11%

Gain in $S/\sqrt{B} \approx 7\%$

Original slides from F. Gianotti

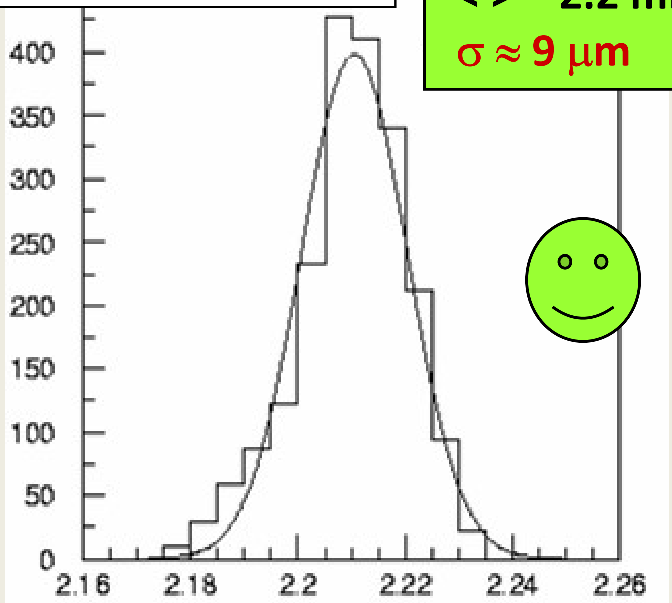
An example of constant quality checks (done on all ATLAS components, here shown for the LAr EM calorimeter)

Construction quality

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

End-cap: 1536 plates

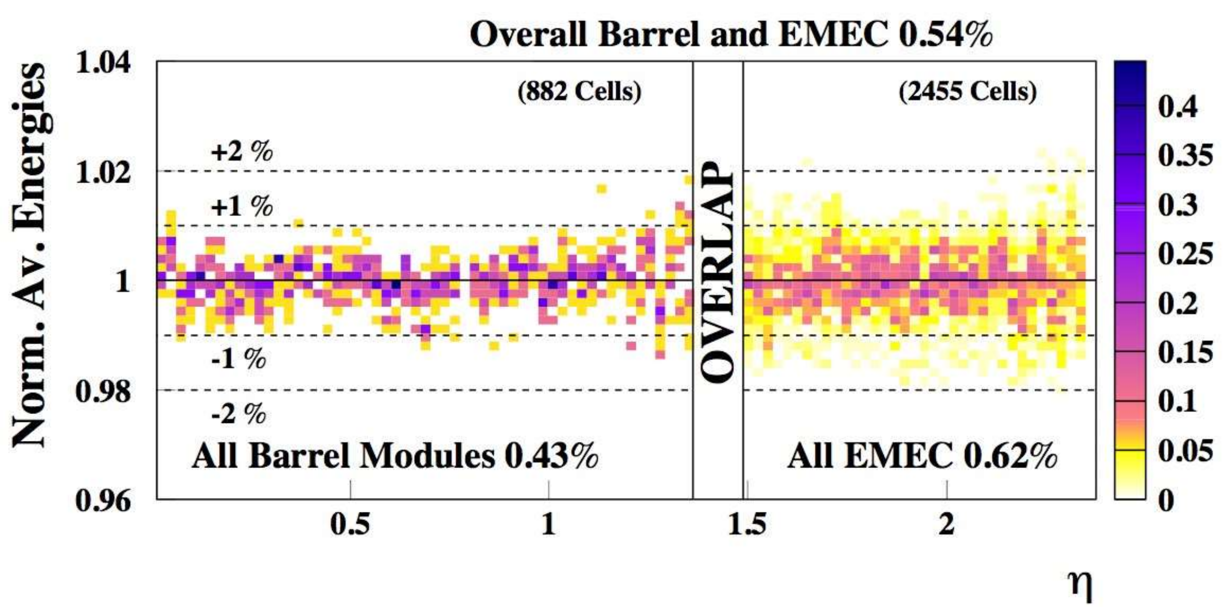
< > ~ 2.2 mm
σ ≈ 9 μm



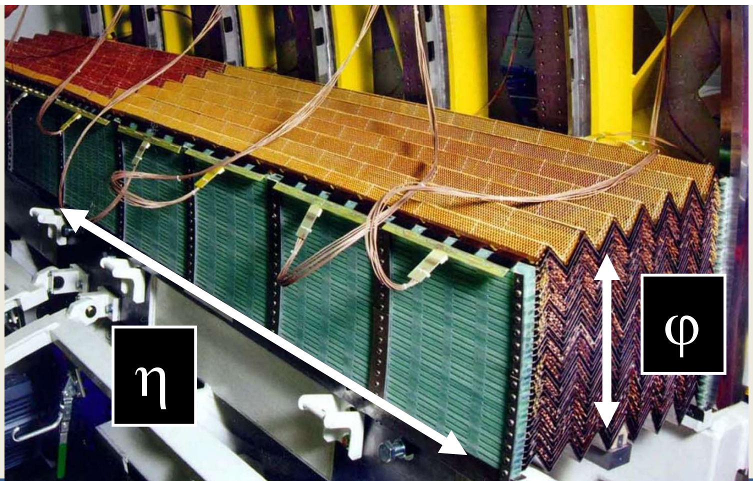
Test-beam measurements

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

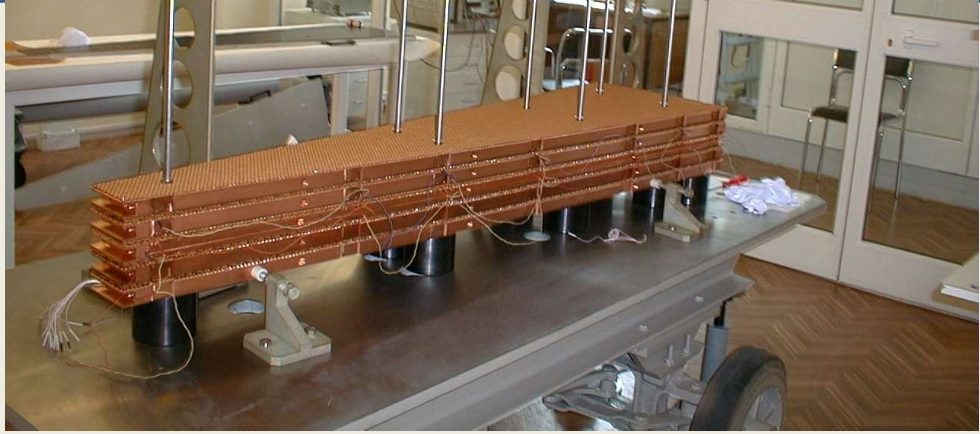
Scans with 120-245 GeV electrons (all 7 tested modules)

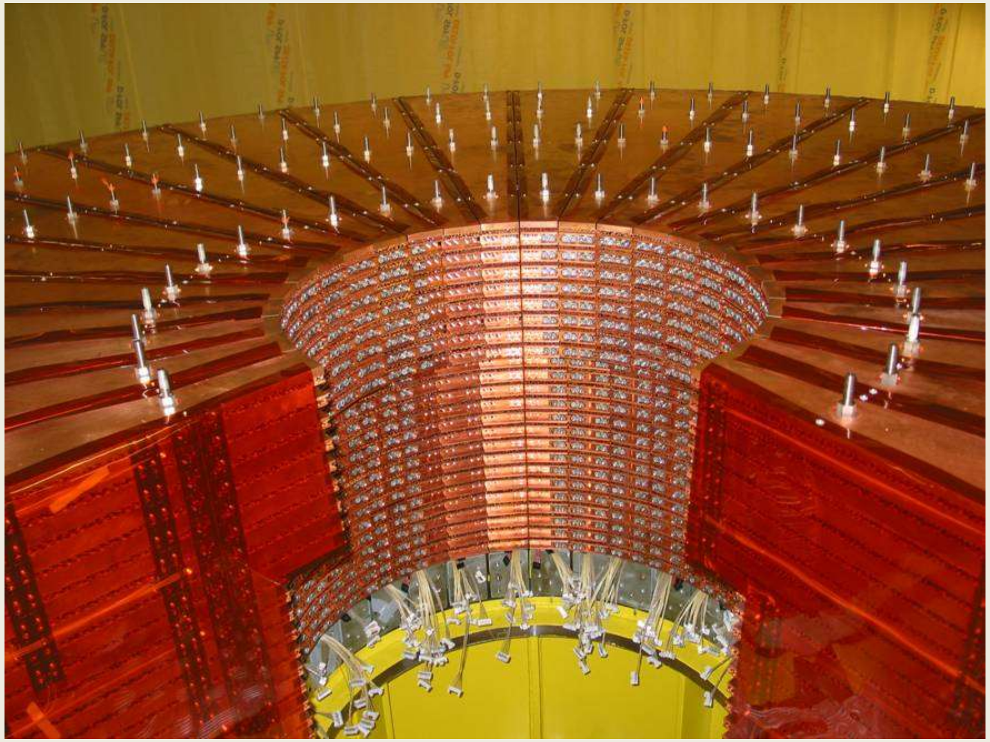


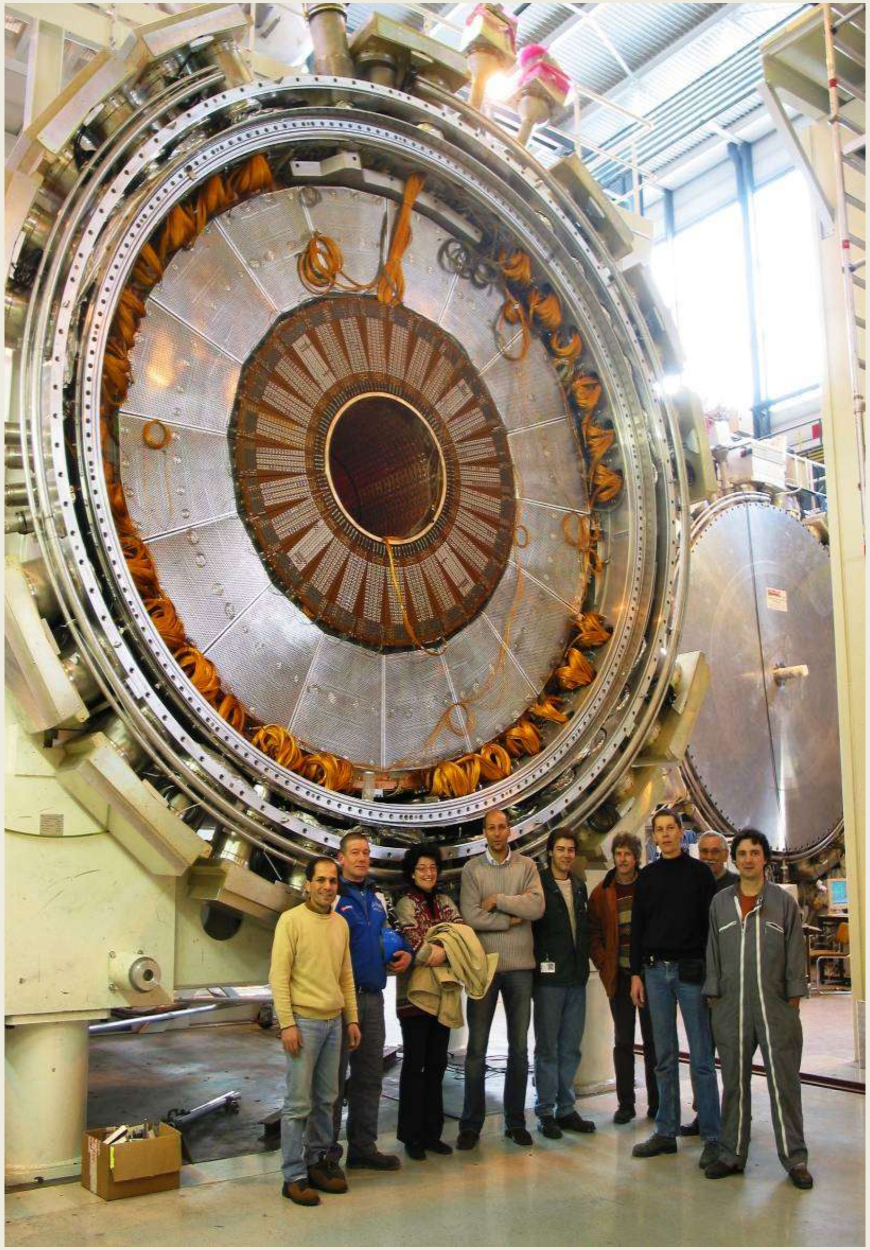
1 barrel module:
Δη x Δφ = 1.4 x 0.4
≈ 3000 channels



Insertion of the solenoid into the LAr EM calorimeter barrel cryostat







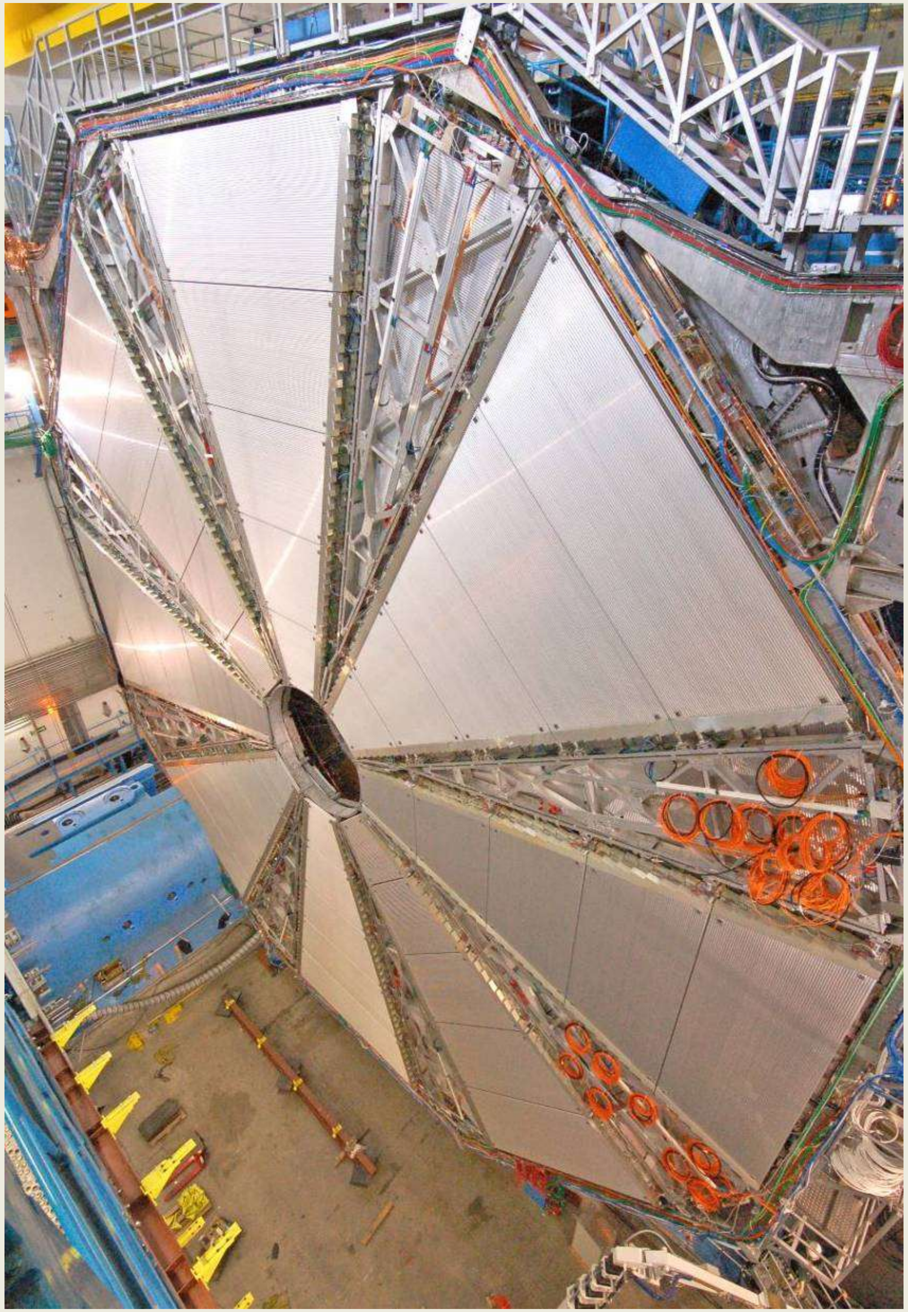
LAr hadronic End-Cap Calorimeters (pictures show stacking 2000, wheel assembly 2003 and cryostat before closing 2005)

1st EC calorimeter transport 22nd Sep 2005

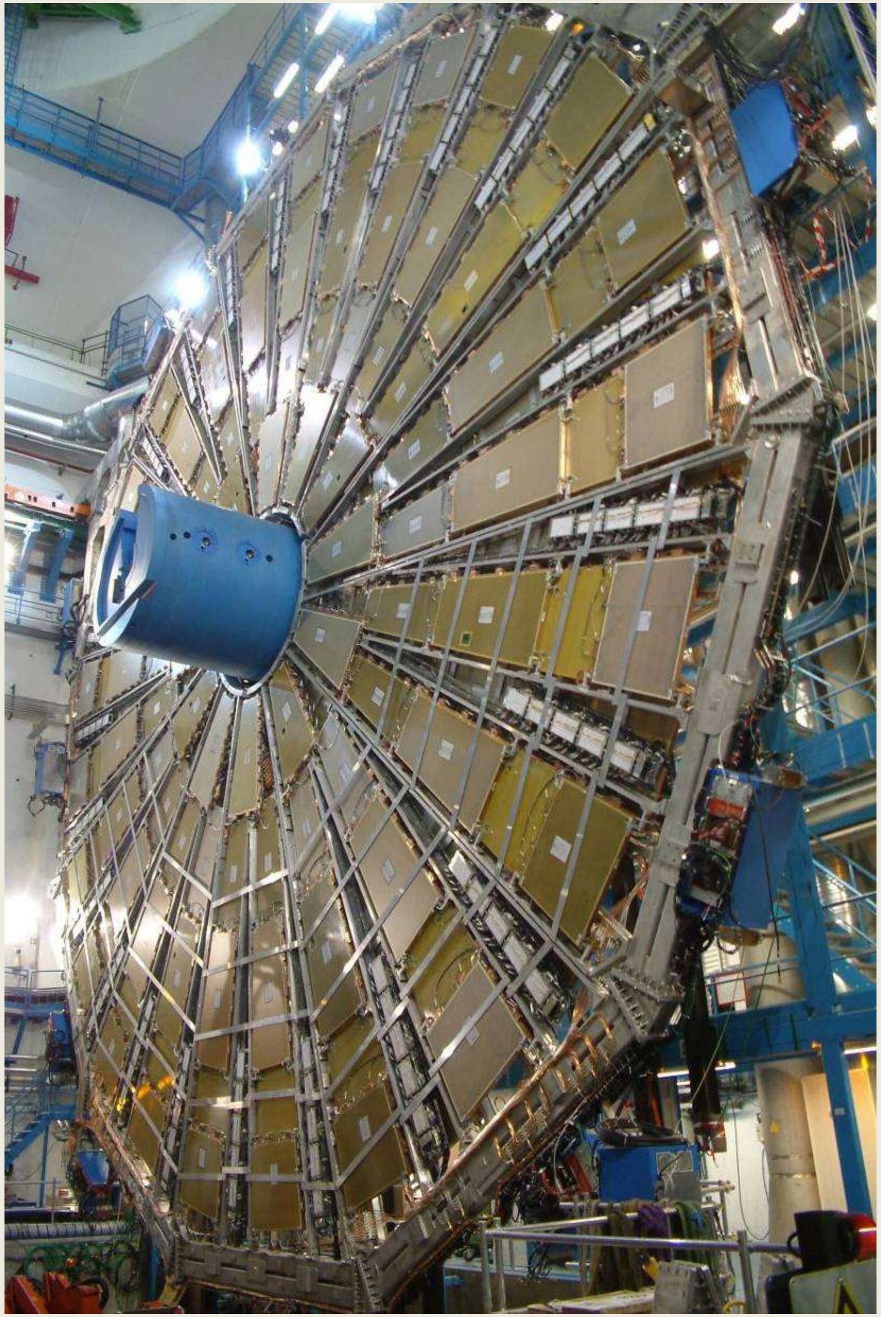
First barrel muon chamber installation (January 2005)

Israel-Japan-Pakistan: Teams working together in assembling TGC Big Wheel sectors (Hall 180, March 2006)

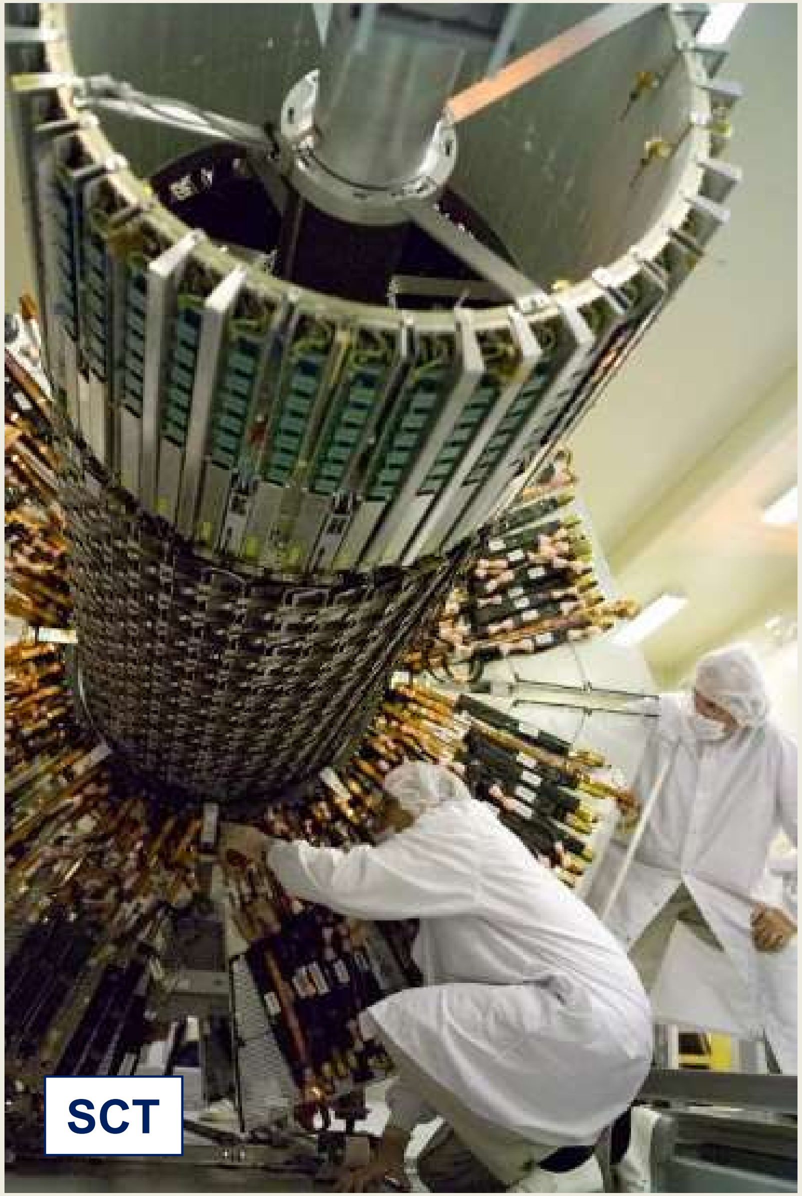
MDT Big Wheel
(one plane on both sides)

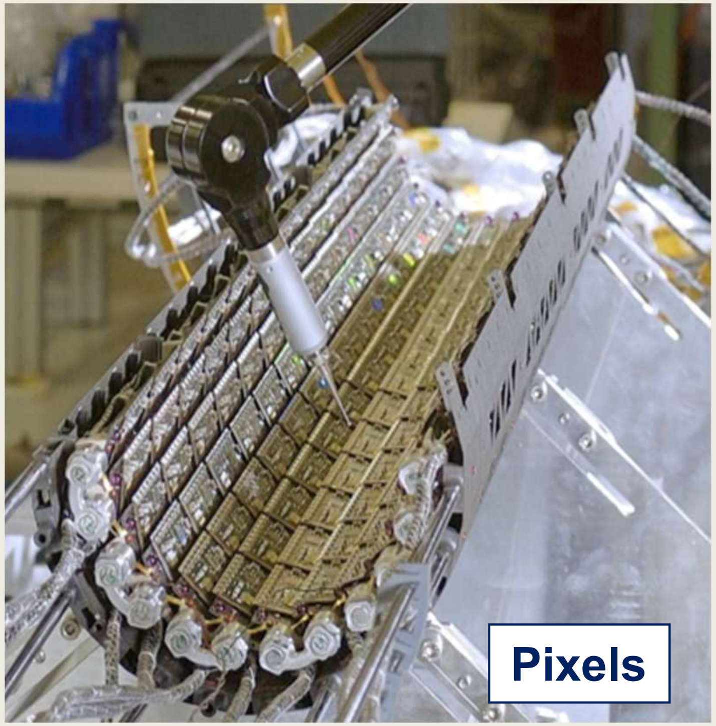


TGC Big Wheel
(three planes on both sides)



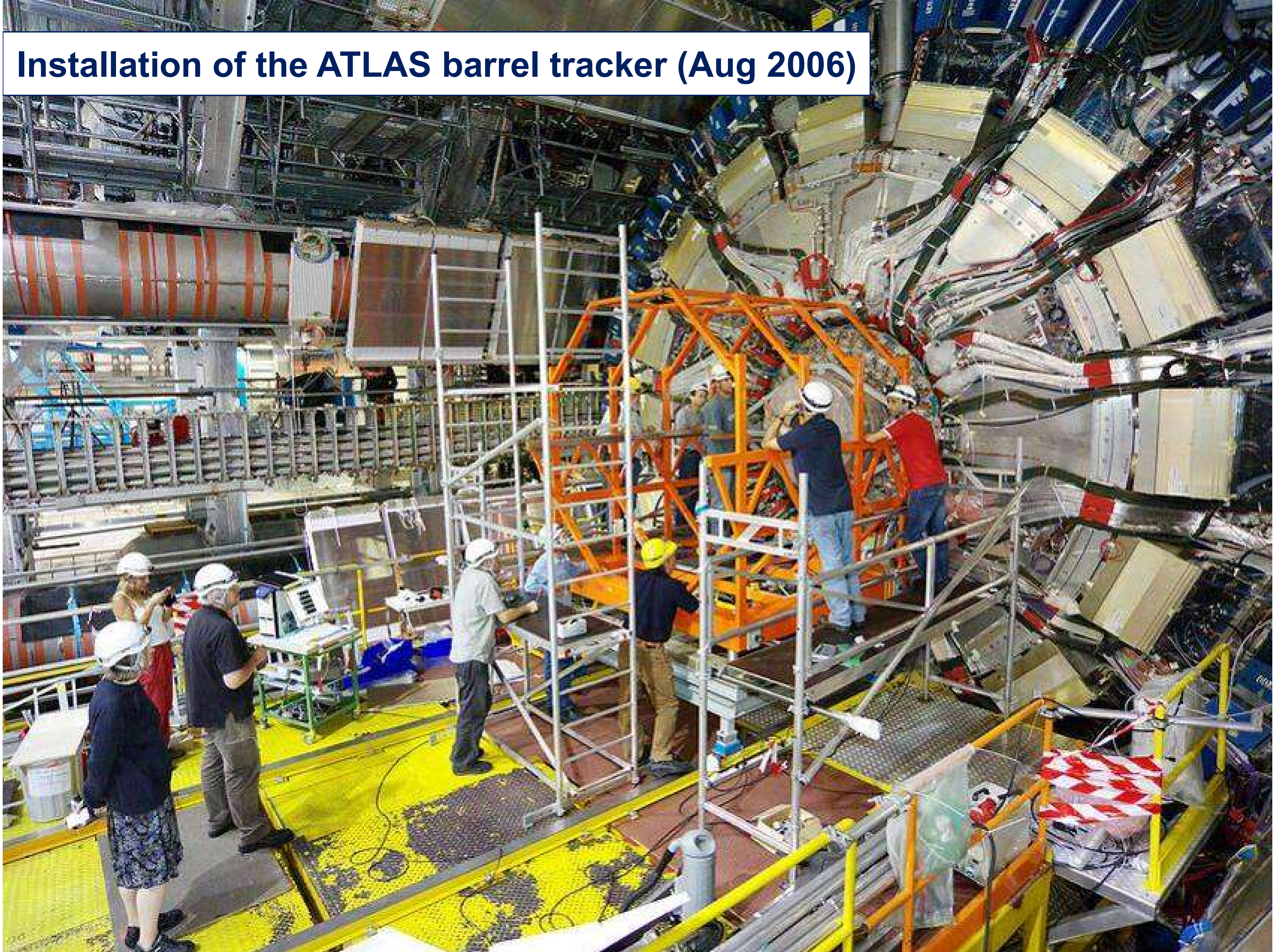
Snapshots from the Inner Detector construction years (2001 – 2007)



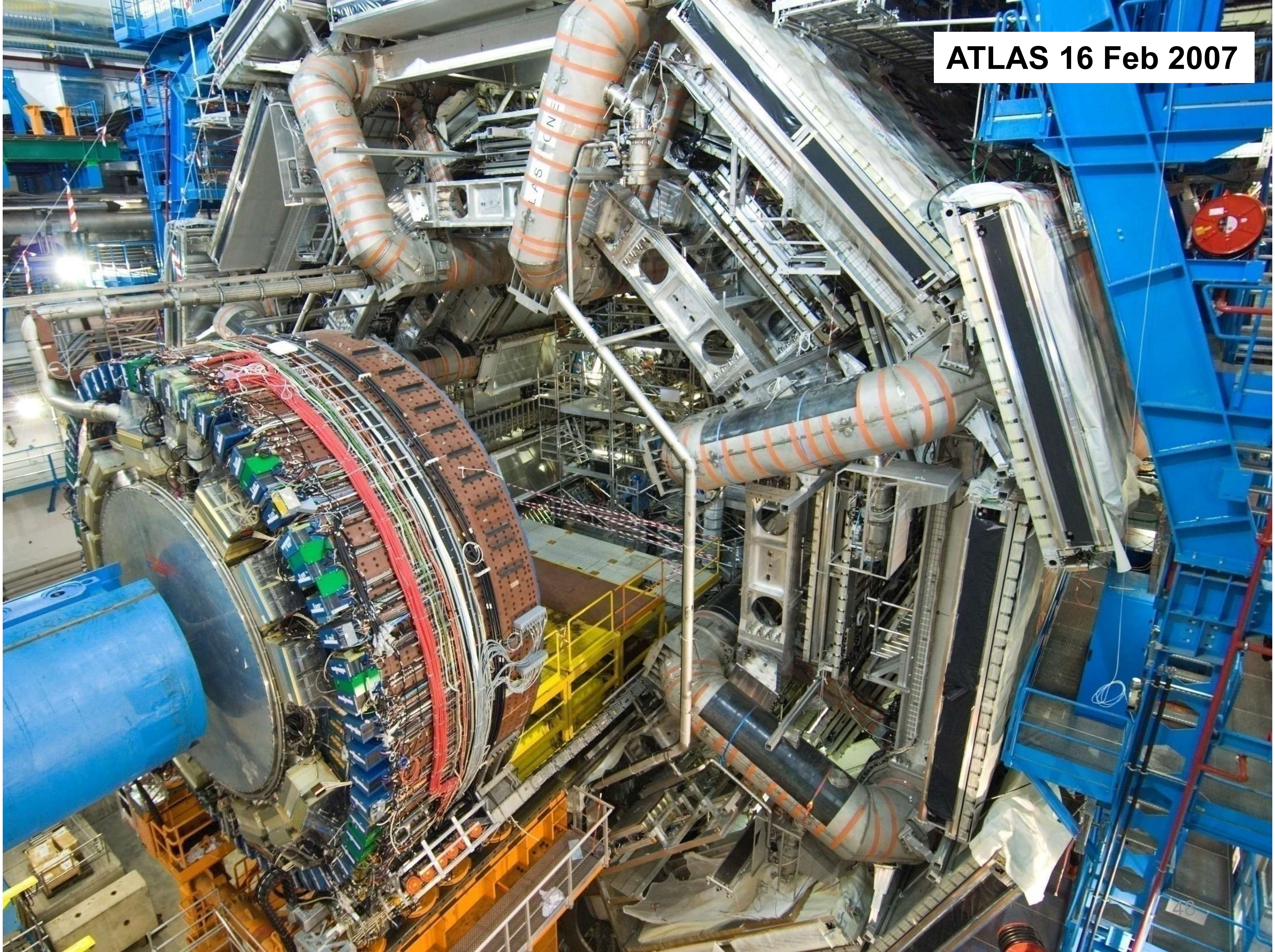


February 2006: the barrel SCT was inserted into the barrel TRT

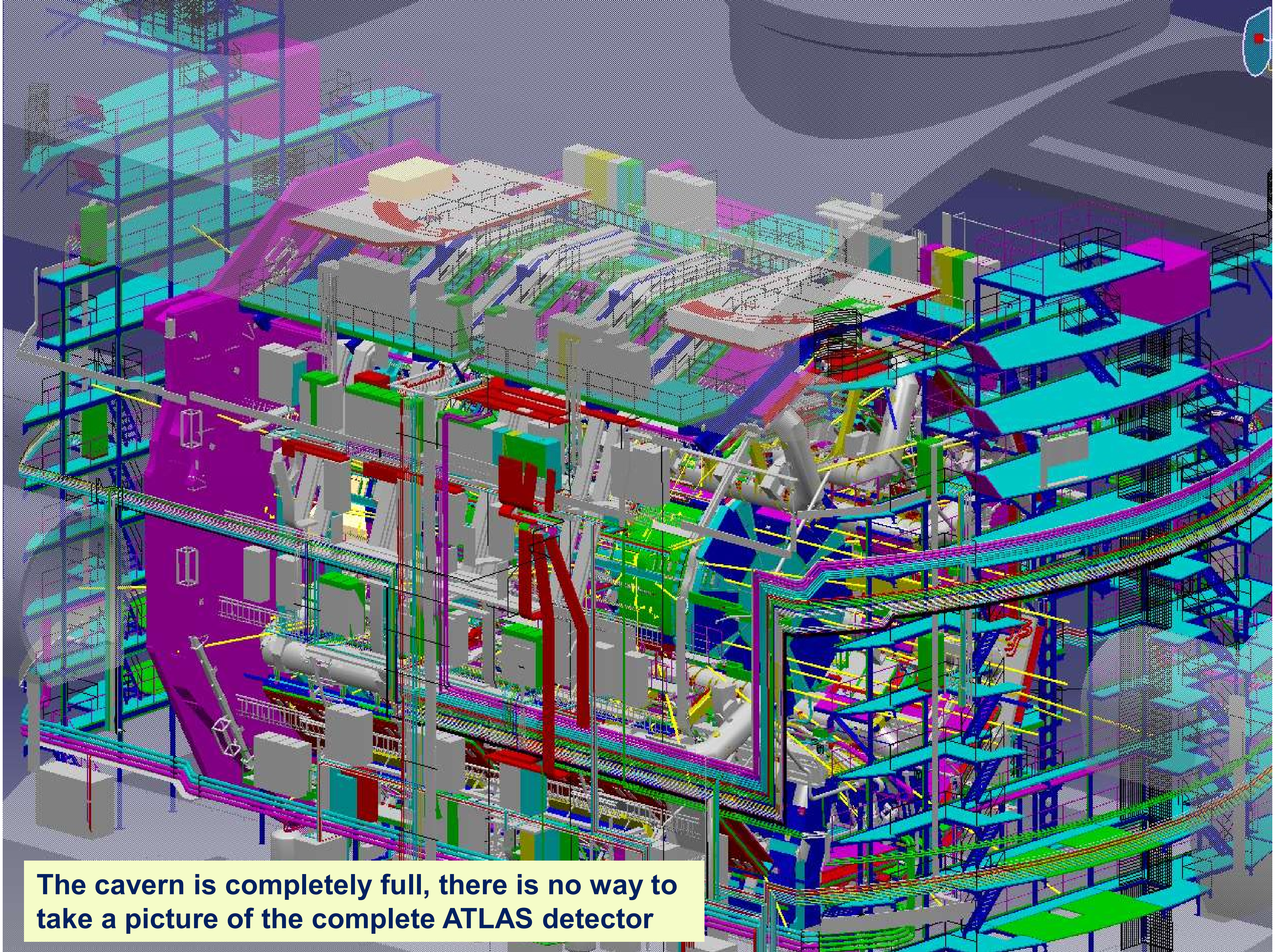
Installation of the ATLAS barrel tracker (Aug 2006)



ATLAS 16 Feb 2007



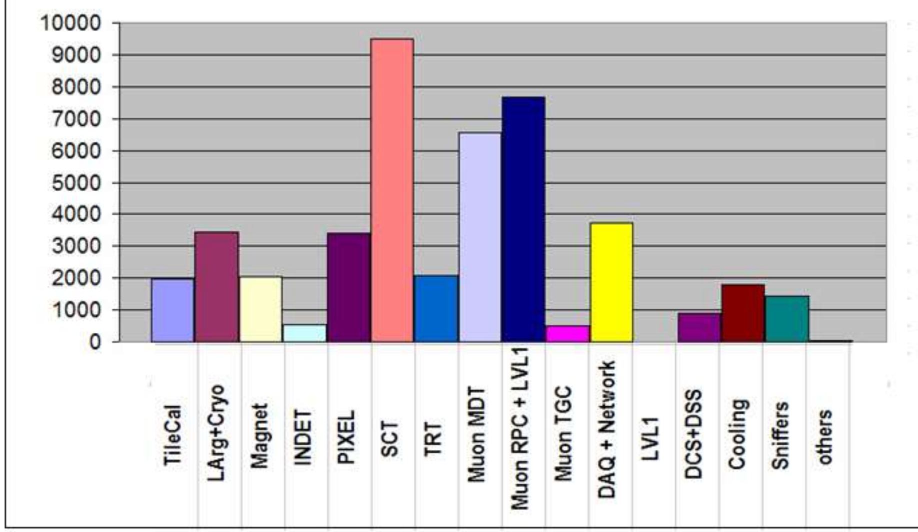
End-Cap Toroid A on its way to Point-1 (29 May 2007)

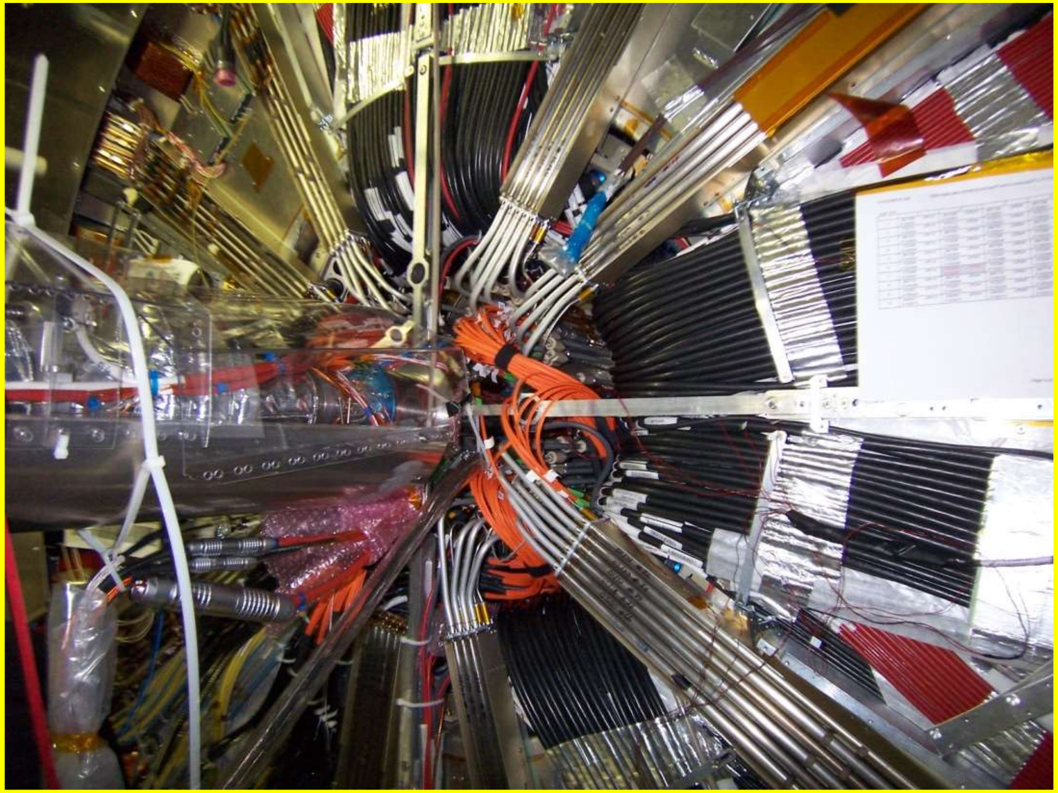


The cavern is completely full, there is no way to take a picture of the complete ATLAS detector

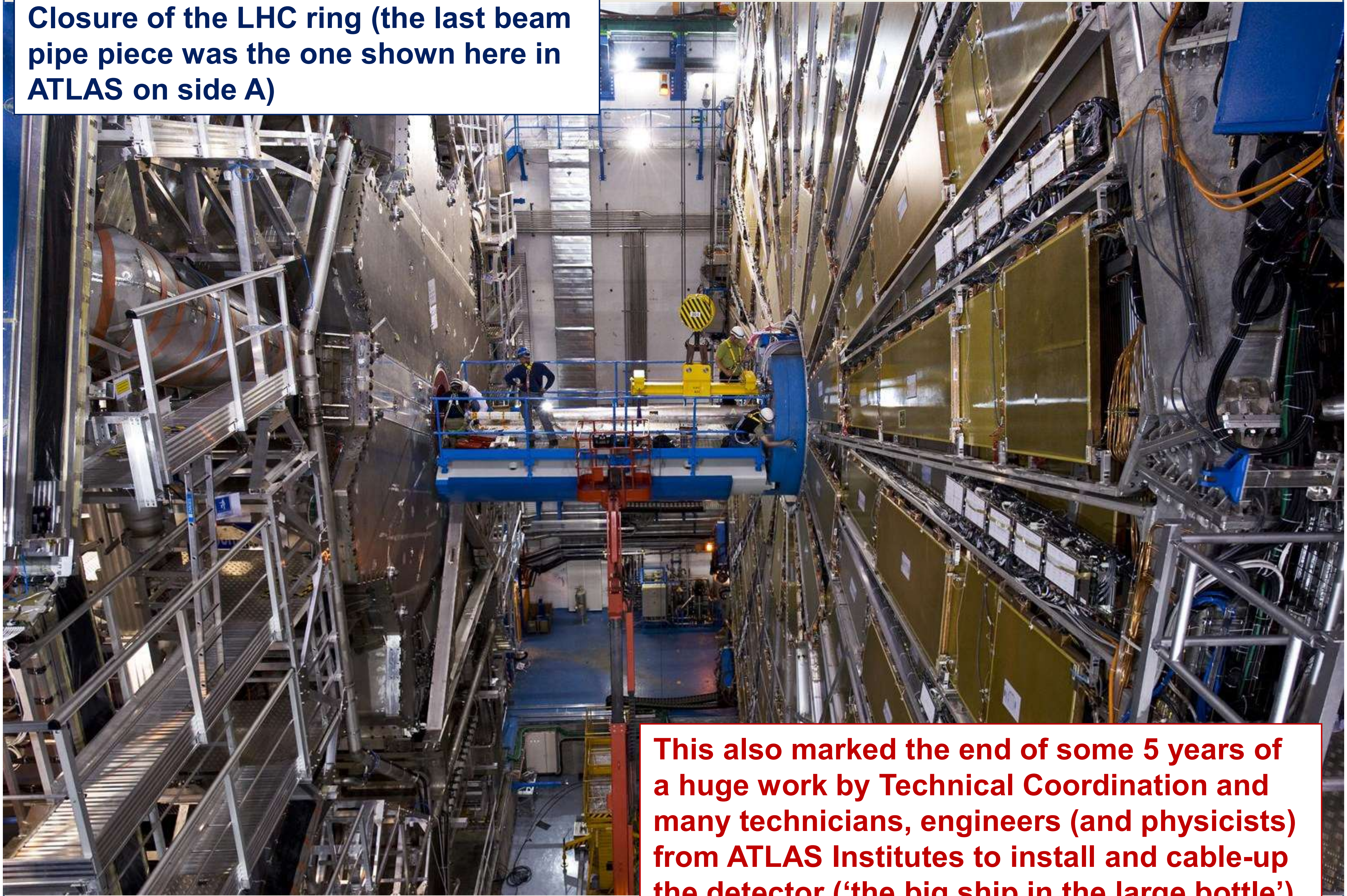
A lot of cables and pipes

> 50000 cables and pipes installed





A historical moment on 16th June 2008: Closure of the LHC ring (the last beam pipe piece was the one shown here in ATLAS on side A)

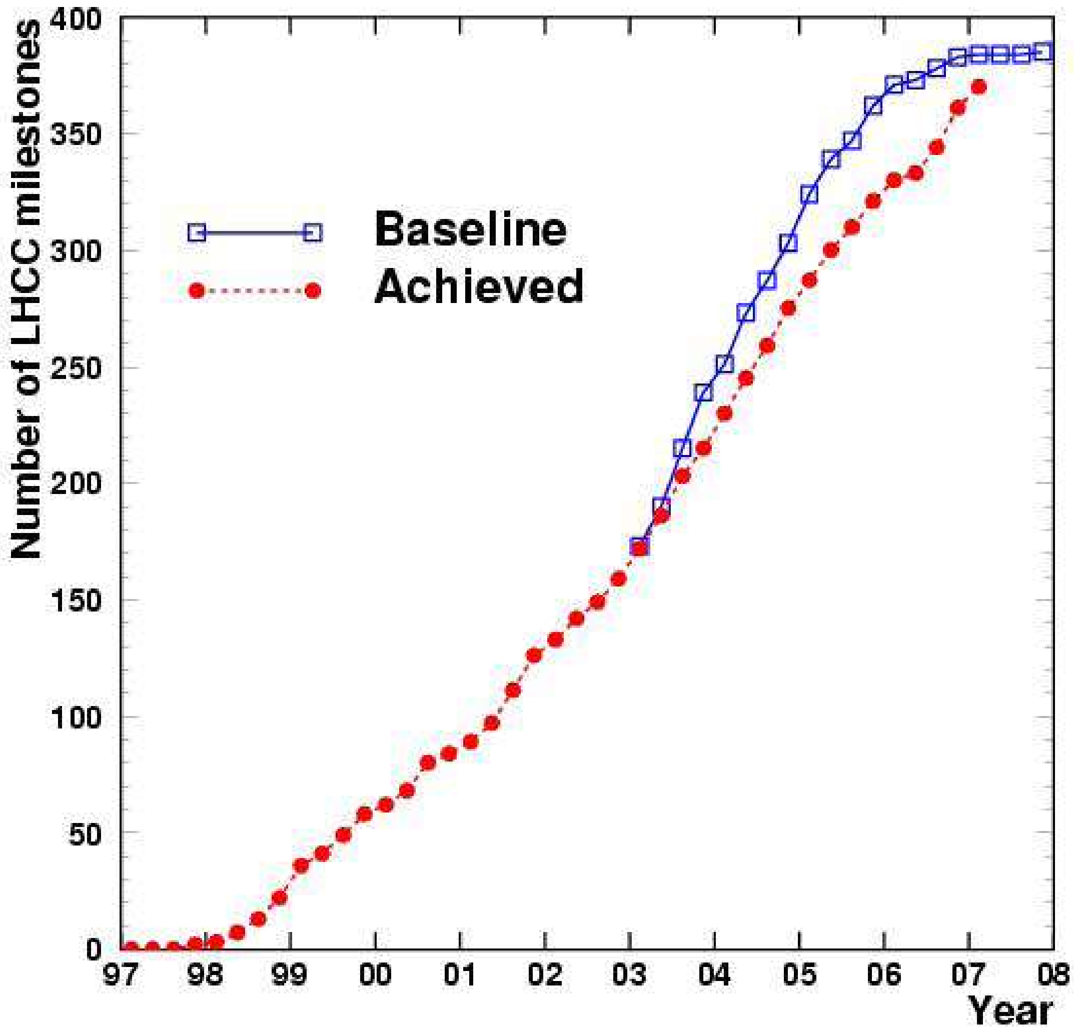


This also marked the end of some 5 years of a huge work by Technical Coordination and many technicians, engineers (and physicists) from ATLAS Institutes to install and cable-up the detector ('the big ship in the large bottle')

from a 2007 slide:

Construction follow-up: LHCC milestones evolution

The technical and scientific progress of the project was frequently (6x per year…) reviewed by an external expert committee (‘LHCC’) that reports to the CERN Directors



Construction issues and risks (‘Top-Watch List’)

A list of these issues is monitored monthly by the TMB and EB, and it is publicly visible on the Web, including a description of the corrective actions undertaken

Famous visitors in ATLAS

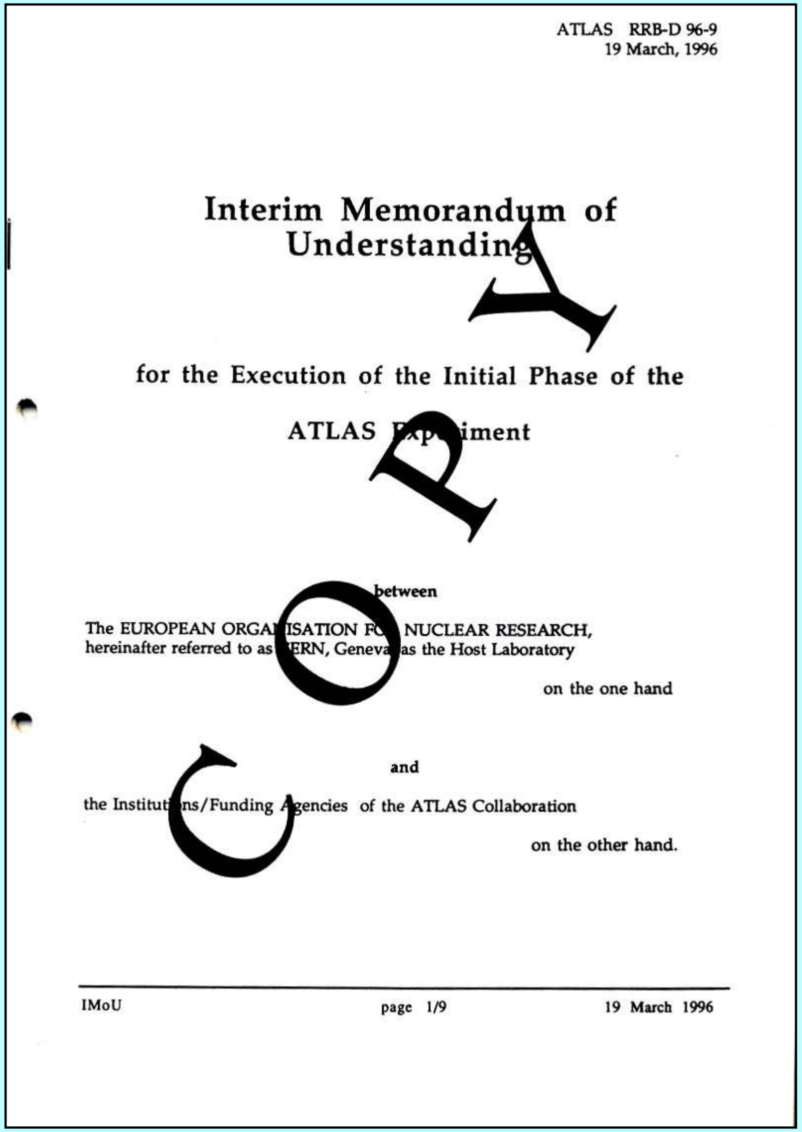
Francois Englert
6 Dec 2007

Peter Higgs
4 April 2008

Since 1995 there are ATLAS Resources Review Board meetings twice a year

20-Oct-1997

At the RRB the legal ('best effort') resources framework for ATLAS were/are agreed, in two stages for the initial construction, and later for the operation (M&O) and computing, and now for the upgrades …



ATLAS RRB-D 96-9
19 March, 1996

Interim Memorandum of Understanding

for the Execution of the Initial Phase of the

ATLAS Experiment

between

The EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH, hereinafter referred to as CERN, Geneva, as the Host Laboratory

on the one hand

and

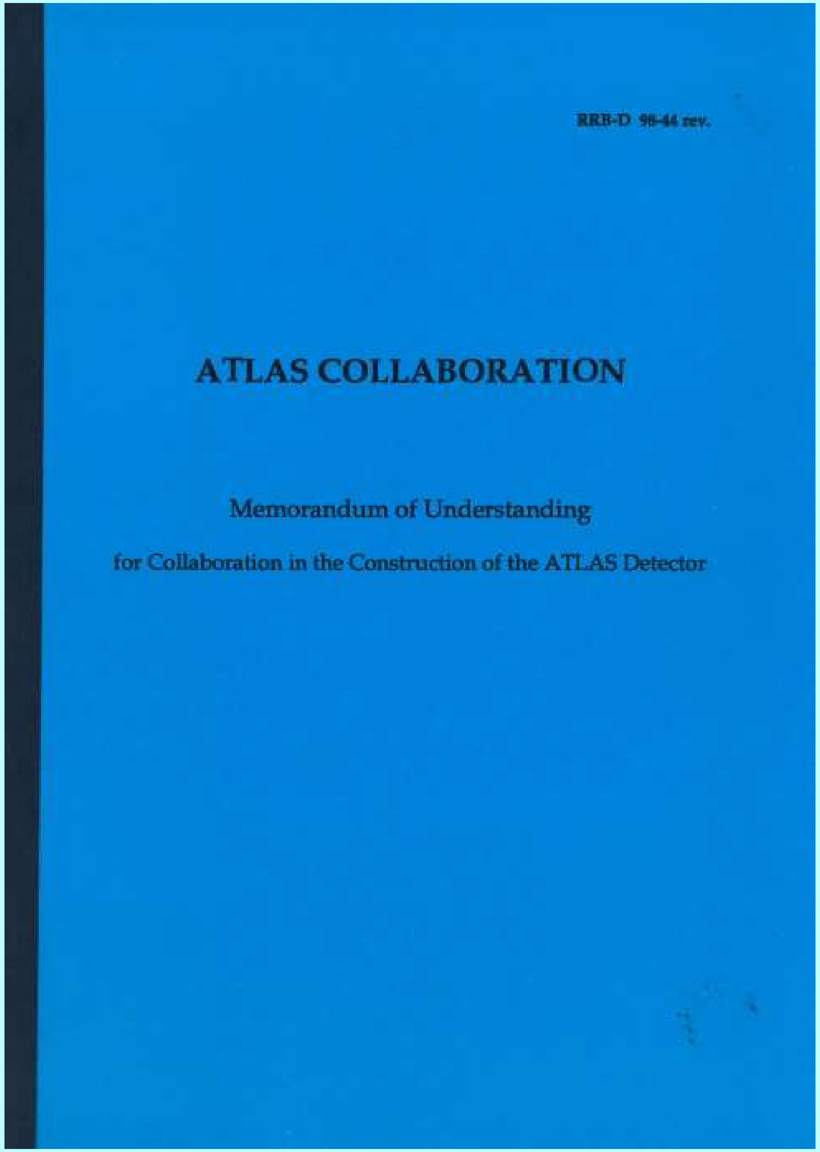
the Institutions/Funding Agencies of the ATLAS Collaboration

on the other hand.

COPY

IMoU page 1/9 19 March 1996

19th March 1996



RRB-D 98-44 rev.

ATLAS COLLABORATION

Memorandum of Understanding

for Collaboration in the Construction of the ATLAS Detector

28th April 1998

The Construction MoU was signed by all initial ATLAS Funding Agencies in 1998-1999

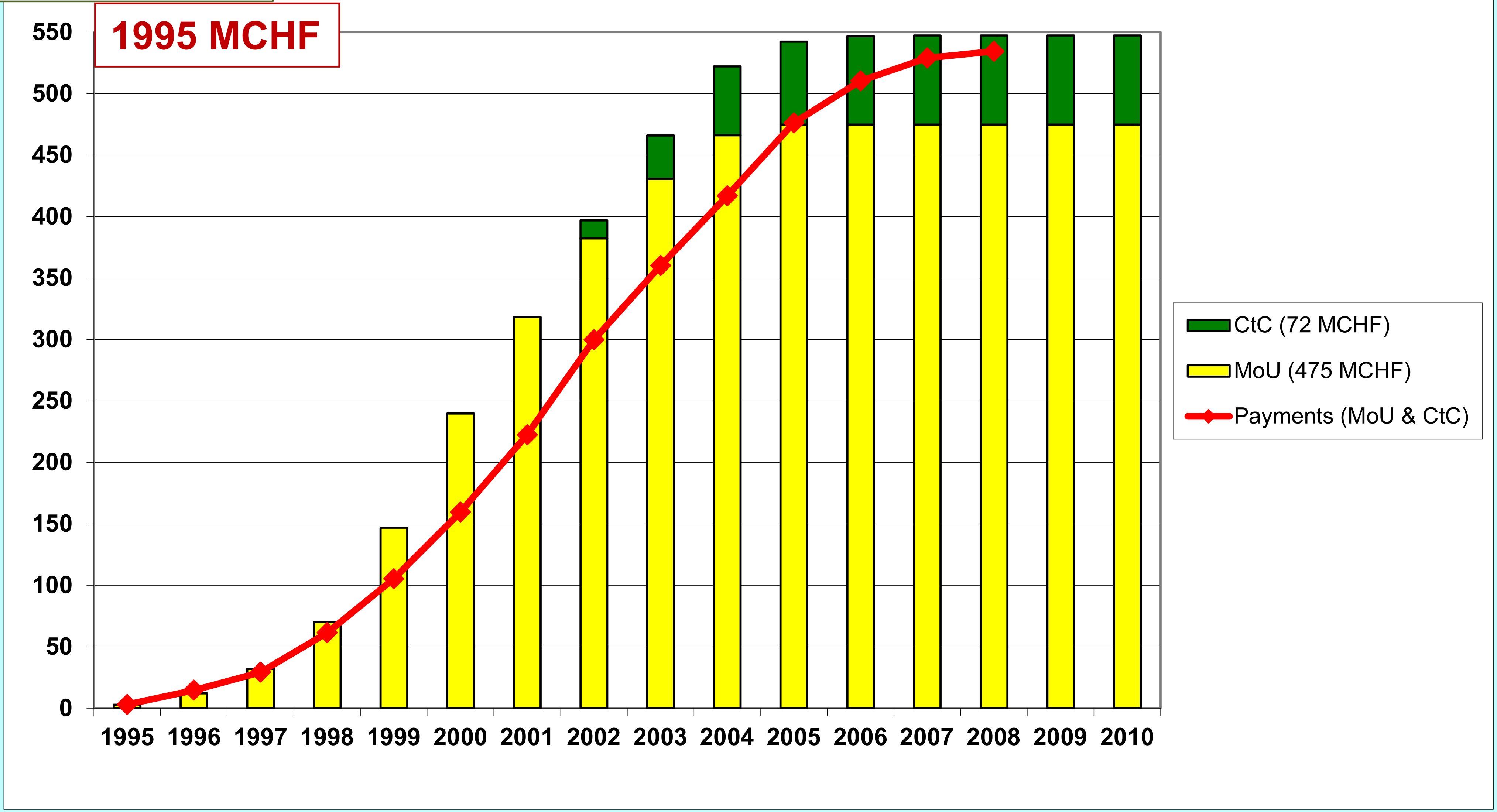
And new partners also signed Addenda to the MoU as they joined later on

Today is also a very appropriate occasion to thank all Funding Agencies for their support

	signed date	signed by
Armenia	10/7/98	R. Mkrtchyan
Australia	26/5/98	S. Tovey
Austria	18/6/98	R. Kneuker
Azerbaijan	30/6/98	N. Guliyev
Belarus	24/6/98	V.A. Gaisyonok
Brazil	6/9/99	E. Mirra de Paula e Silva
Canada	26/4/99	N. Lloyd
China	30/11/99	N. Wang
Czech Republic	26/5/98	F. Suransky, J. Niederle
Denmark	26/5/98	E. Larsen
Finland	26/5/98	E. Byckling
FRANCE CEA	6/1/99	C. Cesarsky
France IN2P3	8/6/98	C. Detraz
Georgia	22/11/99	A. Tavkhelidze
Germany BMBF	12/6/98	H. Schunck
Germany MPI	22/4/99	V. Soergel
Greece	15/6/98	E. Floratos
Israel	1/6/98	D. Horn
Italy	28/5/98	L. Maiani
Japan	23/6/98	H. Sugawara
JINR	10/6/98	A.N. Sissakian
Morocco	1/6/98	S. Belcadi
Netherlands	15/10/98	G. van Middelkoop
Norway	22/6/98	K. Kveseth
Poland	28/5/98	J. Frackowiak
Portugal	5/6/98	A. Trigo de Abreu
Romania	30/7/98	V. Lupei
Russia	10/10/98	N. Kirpichnikov
Slovak Republic	7/7/98	O. Nemcok
Slovenia	15/12/99	L. Marincek
Spain	30/4/98	F. Aldana
Sweden	29/4/99	G. Oequist
Switzerland	26/5/98	B. Fulpius, Ch. Schäublin
Turkey	2/6/98	D. Ulkü
United Kingdom	14/7/98	I.G. Halliday
US DoE + NSF	26/10/98	. O'Fallon, N. Lightbody, T. Kirk, W. Willis
CERN	26/6/98	V.G. Goggi

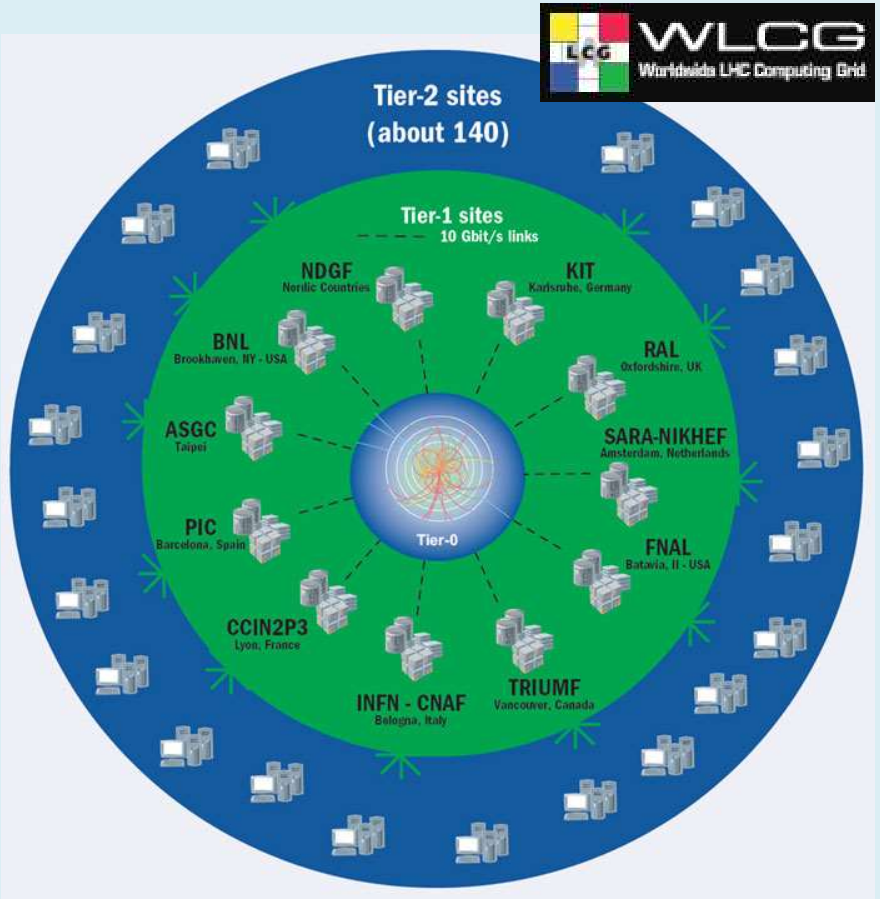
Overview of the integrated financial evolution of the 'CORE' costs of ATLAS (Constr. MoU deliverables and Common Fund, Cost-to-Completion, in 1995 MCHF)

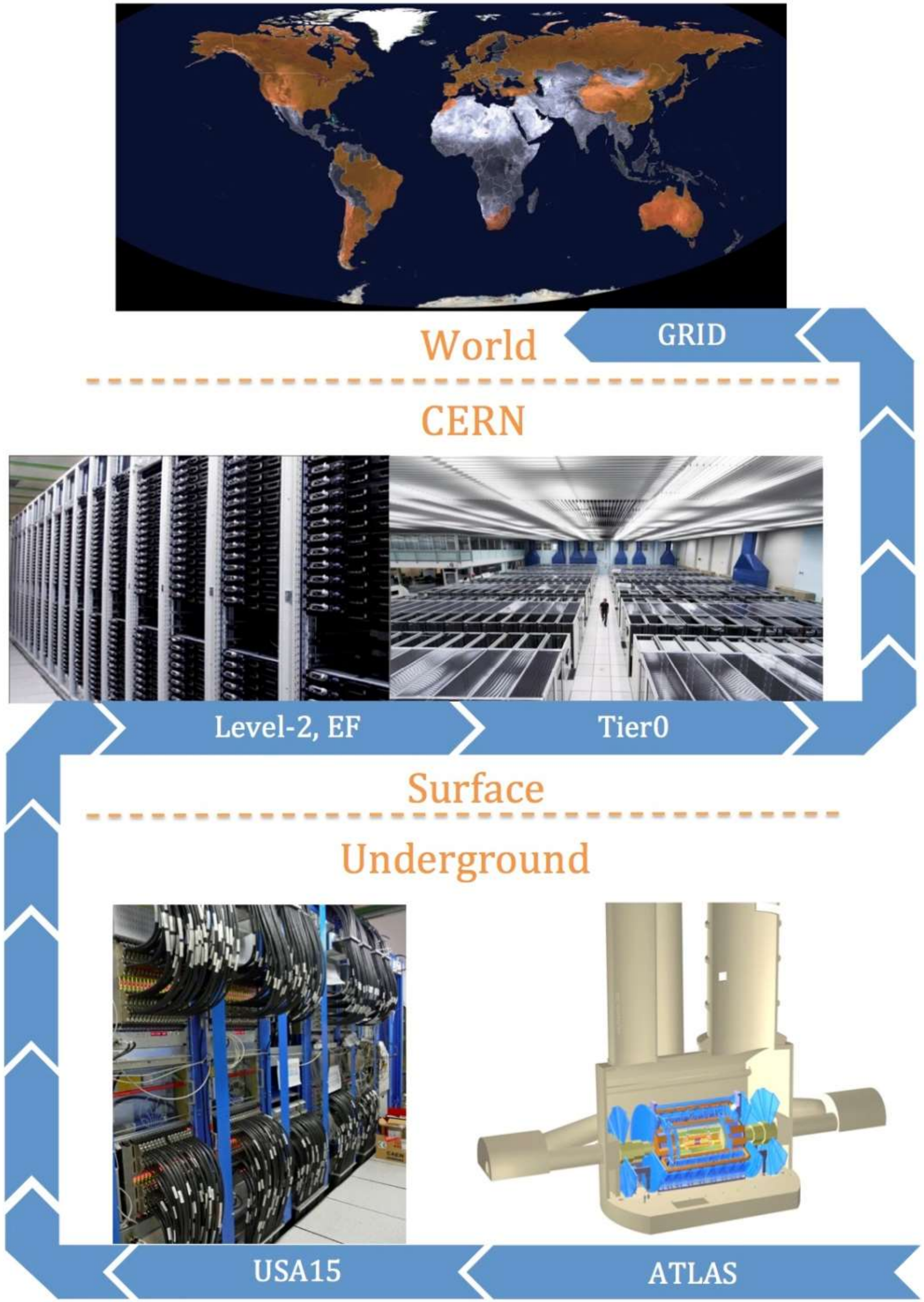
'Investments'



Trigger, DAQ, Software and Computing

(An absolutely essential part of the success story, only left out for time…)



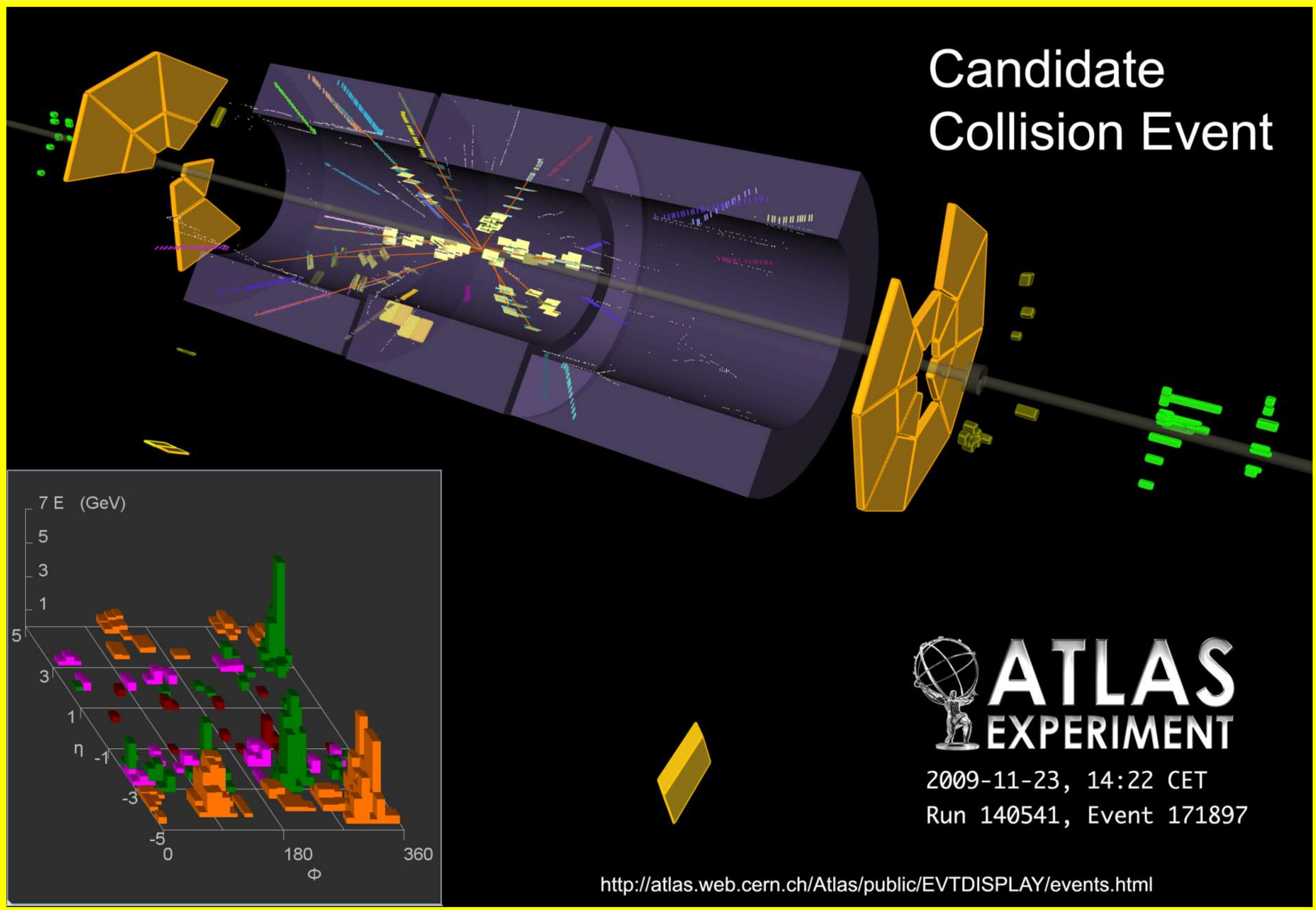


Data flow

Expecting in the ATLAS Control Room the first LHC beam to collide on November 23rd, 2009....

The joy in the ATLAS Control Room when the first collisions were appearing on the display

First collisions in ATLAS 23rd November 2009 with LHC beams at the injection energy of 450 GeV

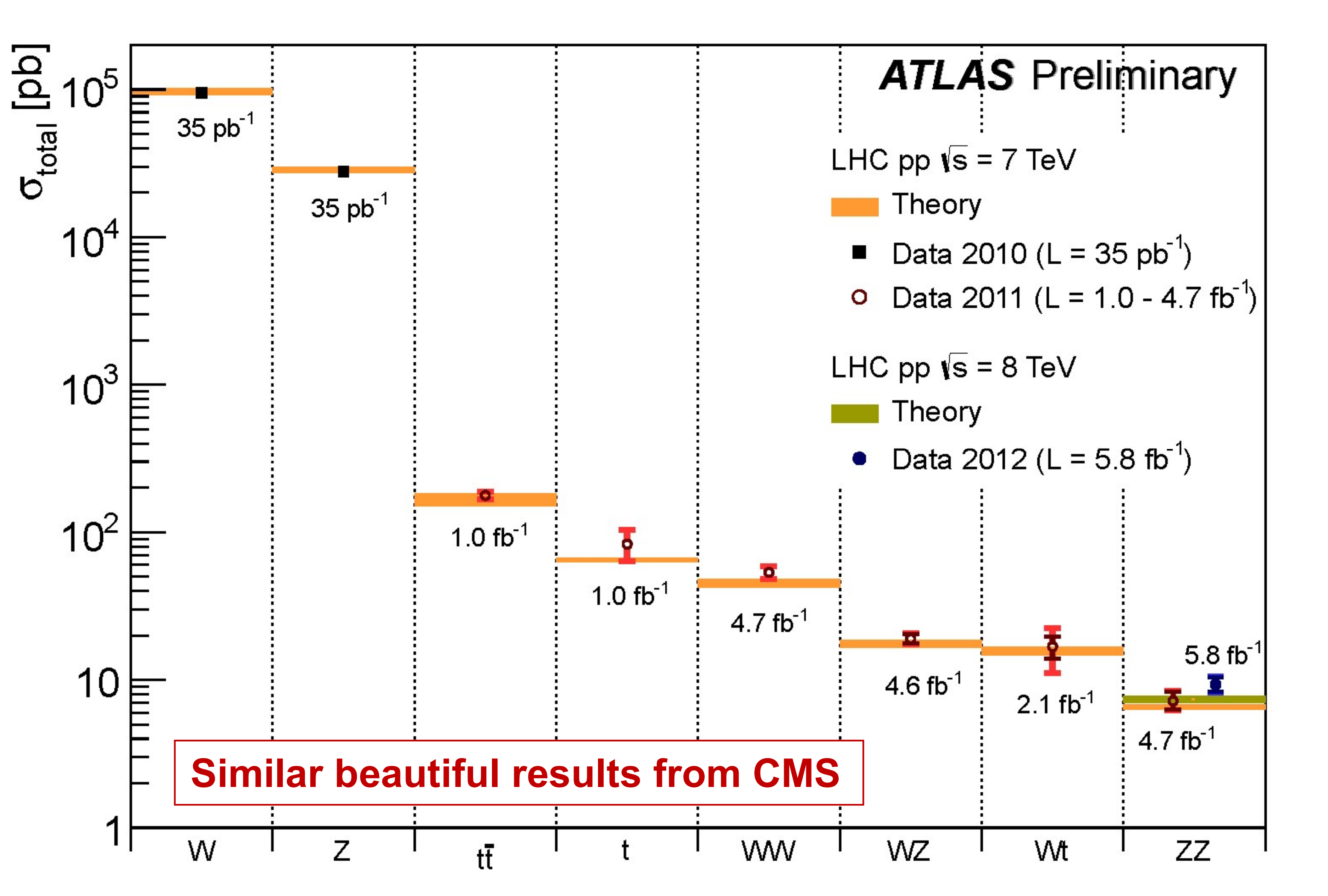


A well-deserved toast to all who have built such a marvelous machine, and to all who operate it so superbly

(first 7 TeV collisions on 30^{th} March 2010)

2012

A summary of Standard Model measurements

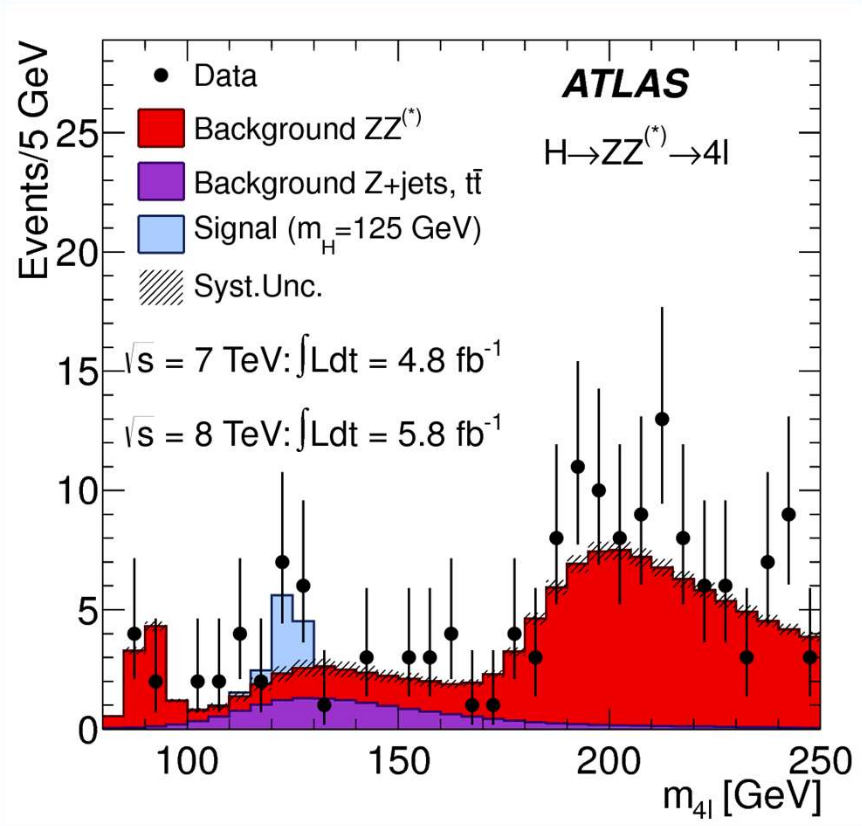


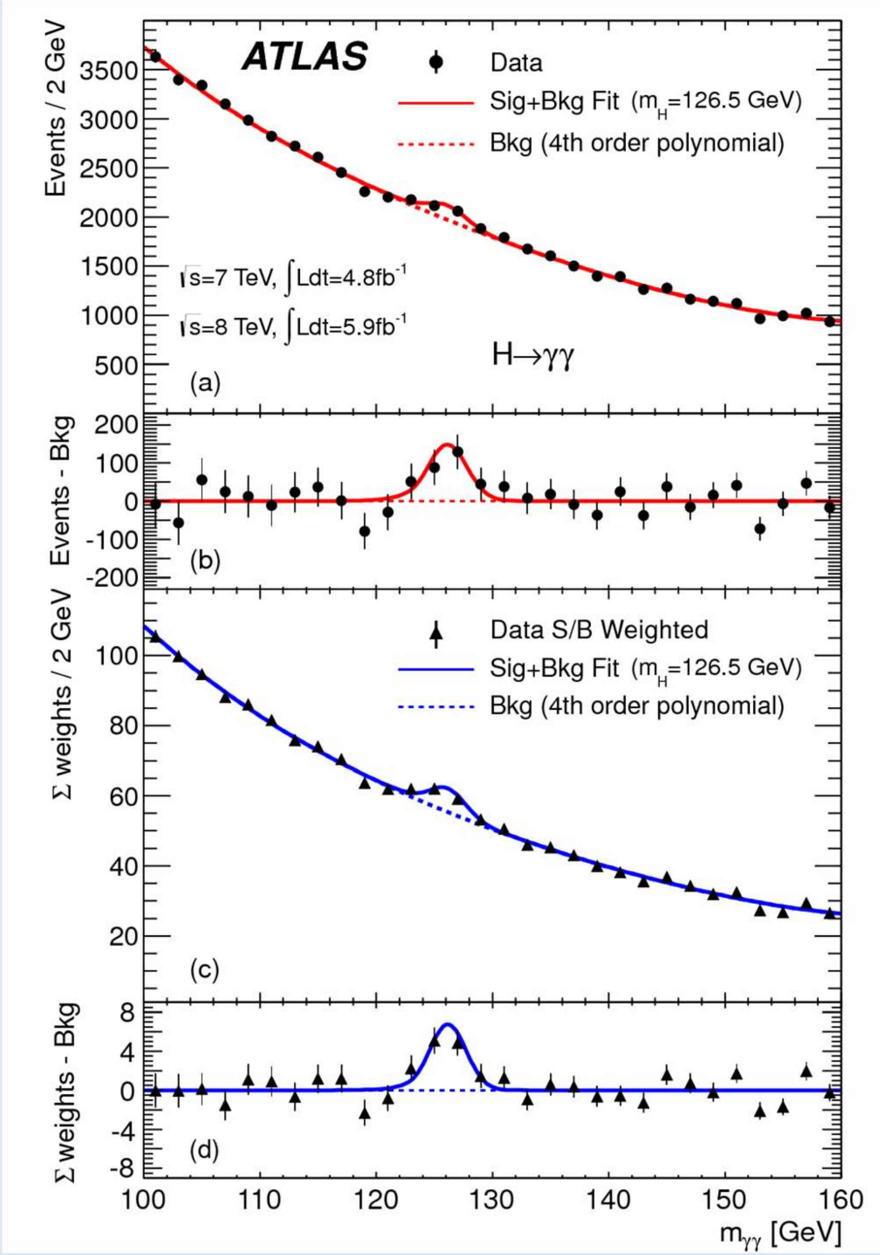
Similar beautiful results from CMS

The excellent performance in measuring Standard Model physics gives confidence for the readiness of the two experiments to search for New Physics

Happy faces after the announcement of the Higgs boson discovery at CERN (and at ICHEP Melbourne) on 4th July 2012

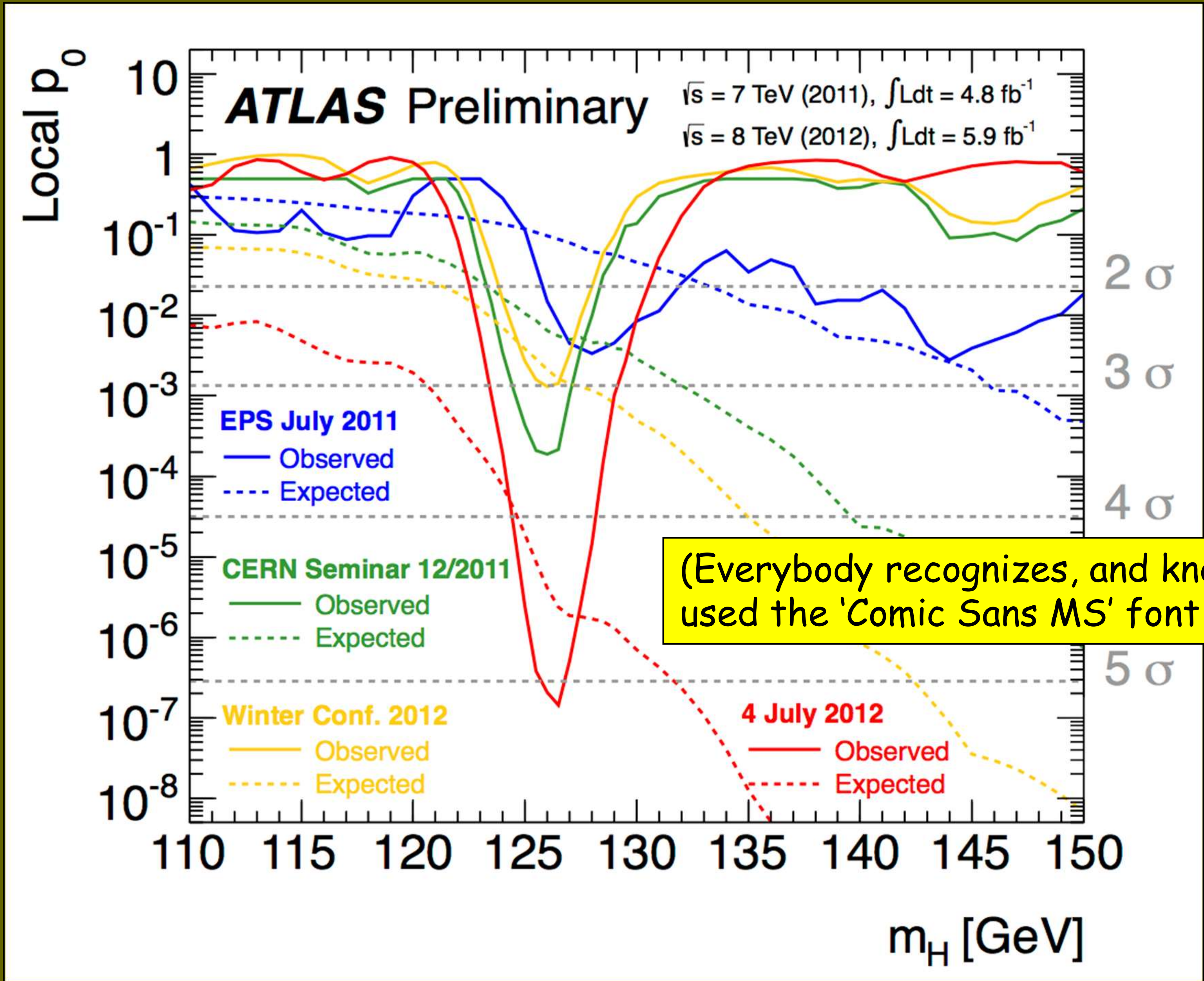
ATLAS Higgs boson discovery signal peaks, 10 years ago





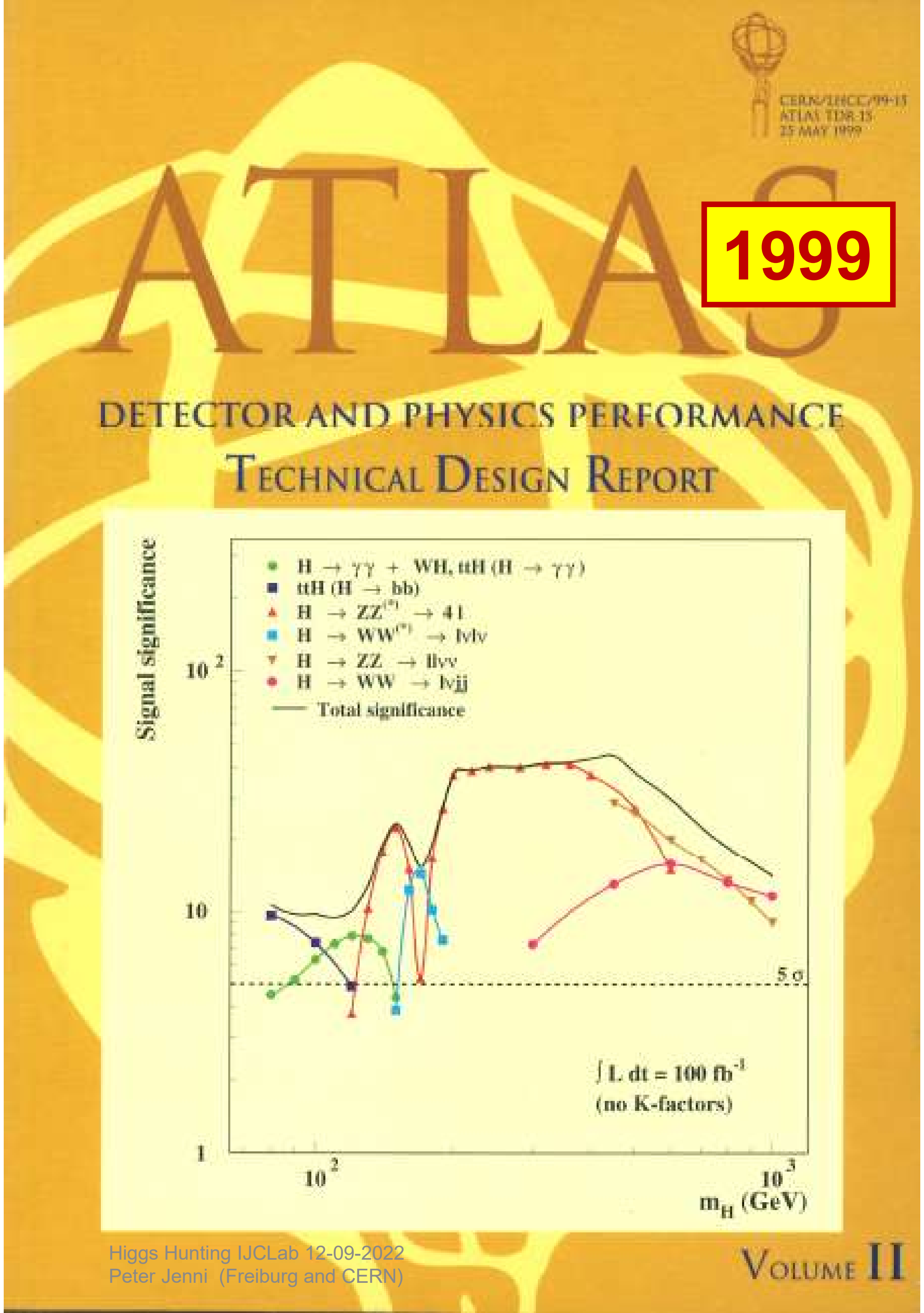
Phys. Lett. B716 (2012) 1-29, dated 31 July 2012, which includes also the H → WW channel

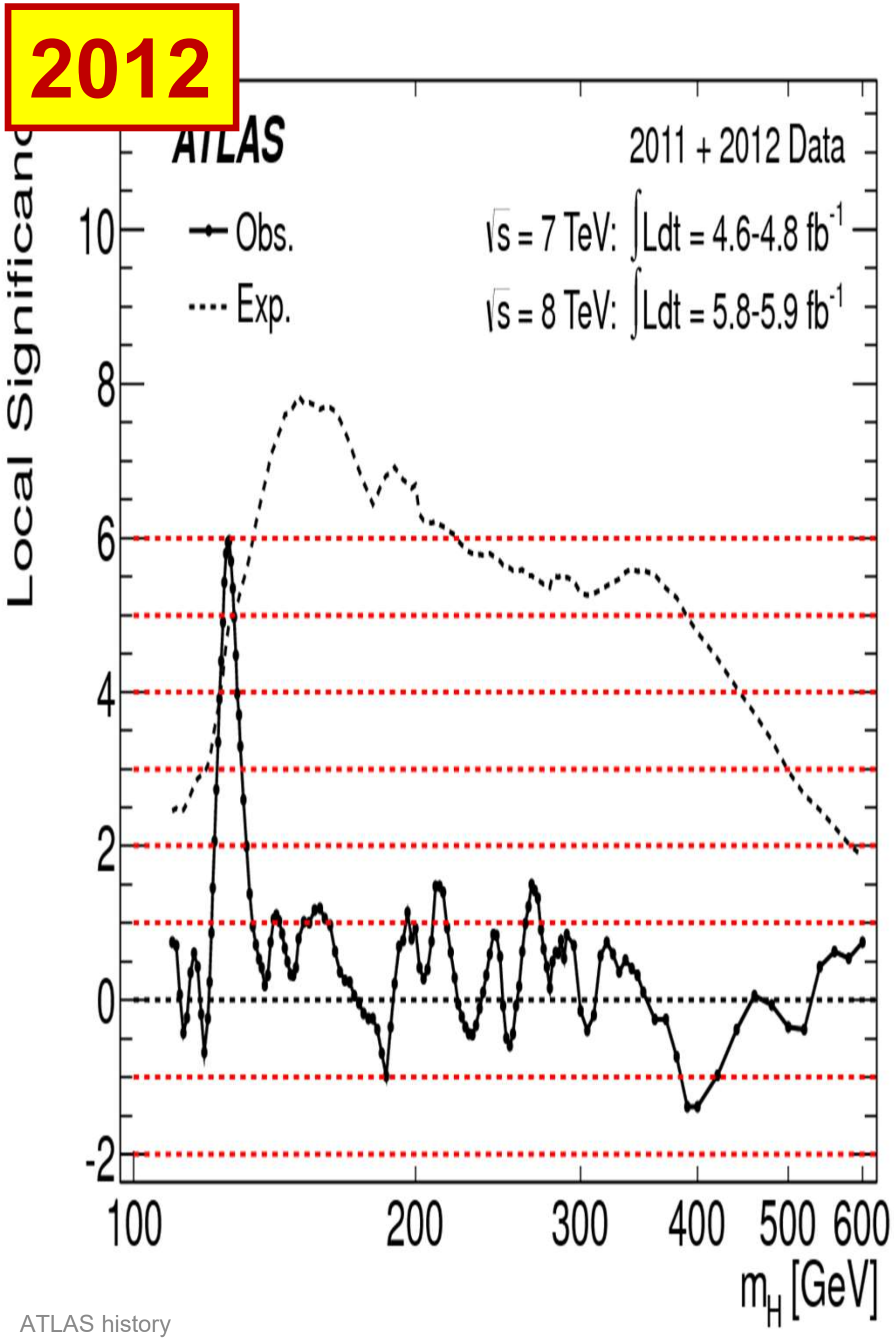
Evolution of the excess with time



(Everybody recognizes, and knows, who used the 'Comic Sans MS' font ...!)

A dream became true much faster than anticipated long ago





Status: June 2022

A big ‘thank you’ to CERN, all the Funding Agencies, Universities, Laboratories, Computing Centres, and to all the other bodies which made this experiment possible

Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Mongolia
Morocco
Netherlands
Norway
Palestine
Philippines
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
South Africa
Spain
Sweden
Switzerland
Taiwan
Türkiye
UAE
UK
USA
CERN
JINR

ATLAS Collaboration

181 institutions (244 institutes) from 42 countries

- Active ATLAS Members (Physicists, Engineers, Technicians, Students, Administrators)	~	6000
- Scientific Authors		2932
- With PhD, contributing to M&O share		1960
- PhD Students	~	1200
- Master / Diploma Students	~	480

ATLAS EXPERIMENT

Spares

A comprehensive insider story of all aspects of the ATLAS history and highlights of the first 25 years of the experiment

OPEN ACCESS

ISSN 1793-1339

Advanced Series on
Directions in High Energy Physics — Vol. 30

ATLAS

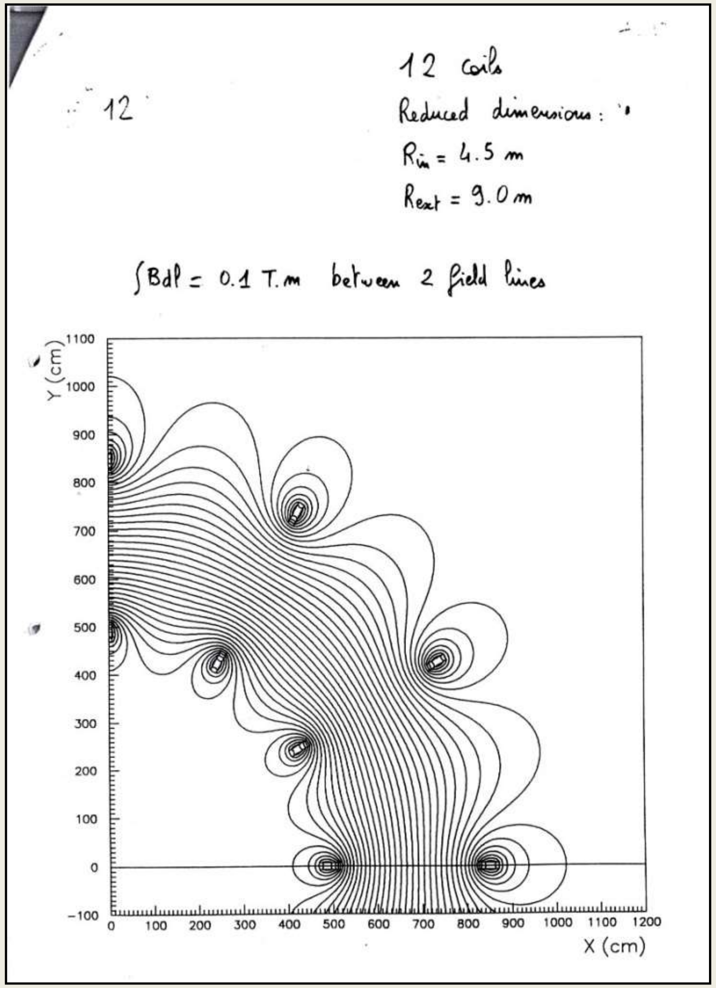
A 25-Year Insider Story of the LHC Experiment

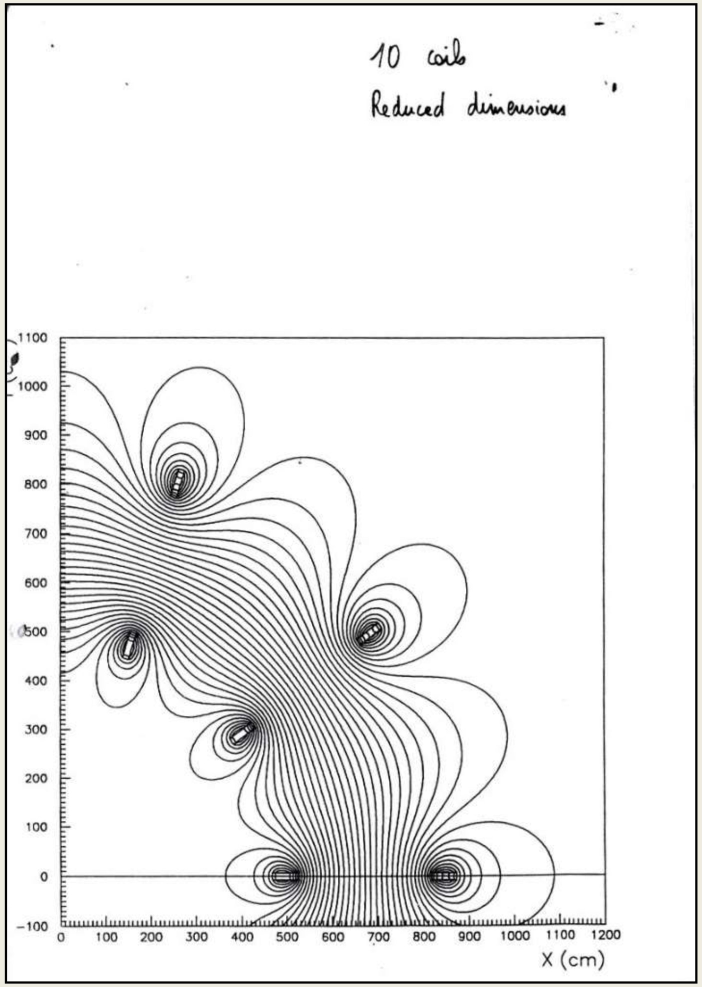
by **The ATLAS Collaboration**

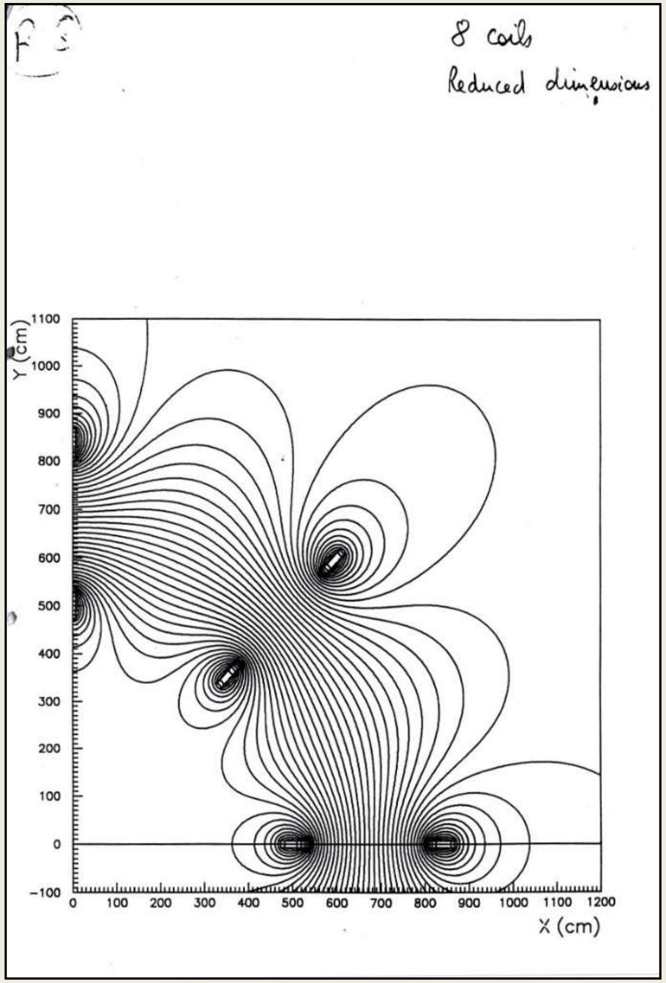
World Scientific

First reaction of the LHCC to the LoI in December 1992: It was well received, but a long saga started for ATLAS about costs and funding …

One of many ingredients… reduced number of coils from 12 to 8 in the toroid system

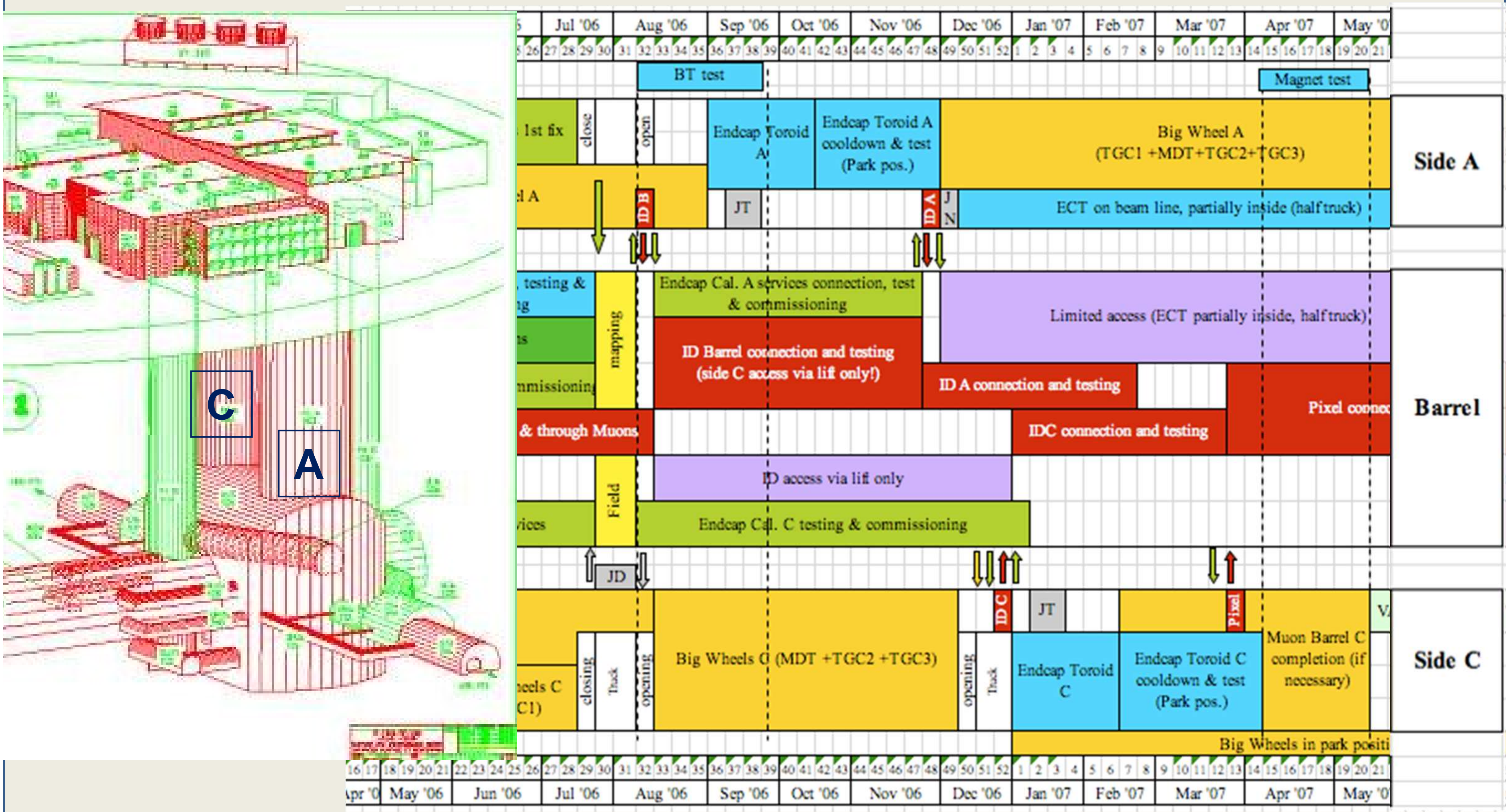




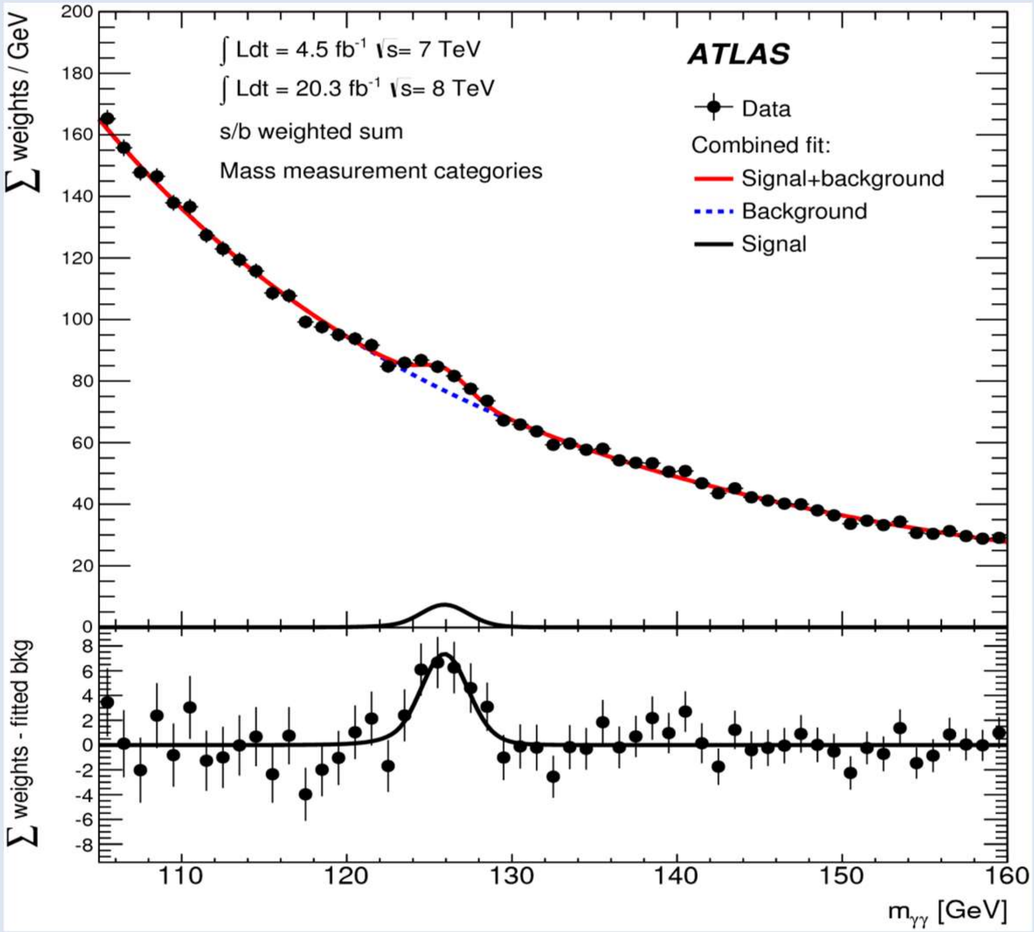


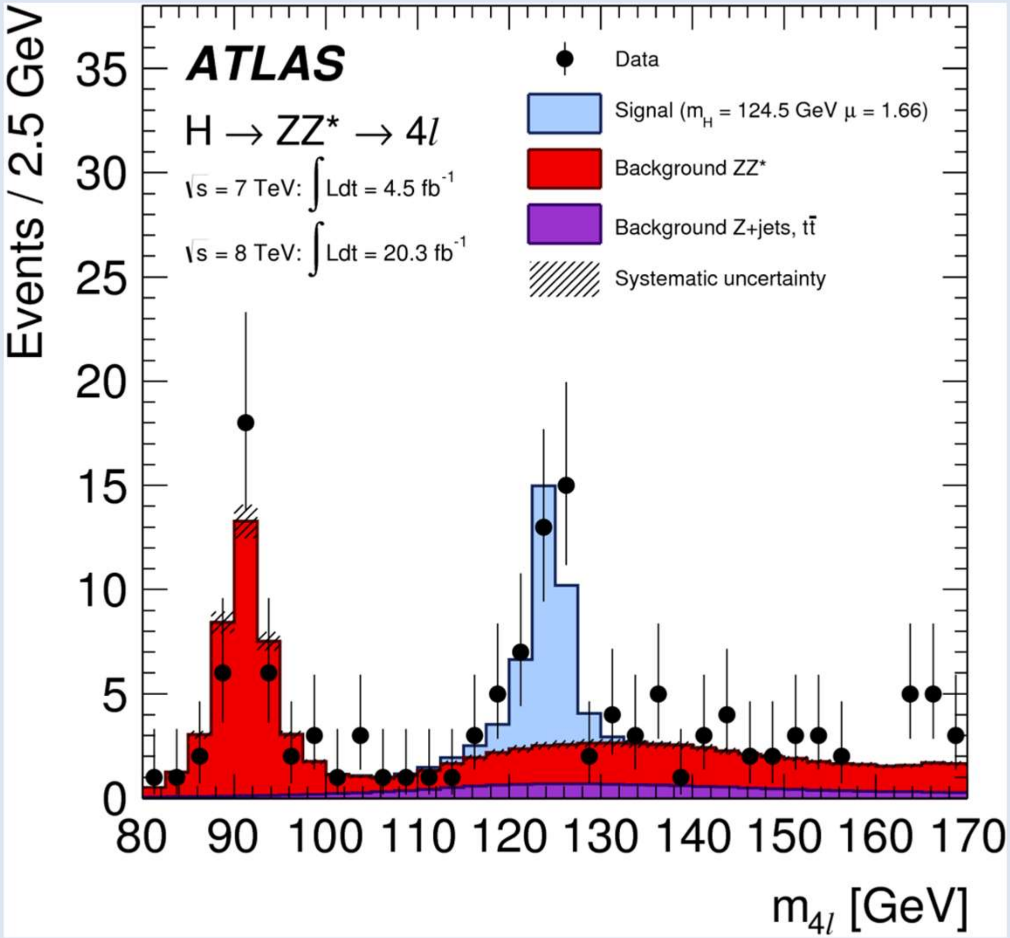
Transport of a muon end-cap sector to LHC interaction Point-1 (Dec 2006)

A snapshot of the many parallel installation and commissioning activities in the cavern in both end-cap regions A and C under the shafts, as well as in the barrel region: a huge, successful activity of the Technical Coordination



ATLAS Run-1 Higgs boson signal peaks

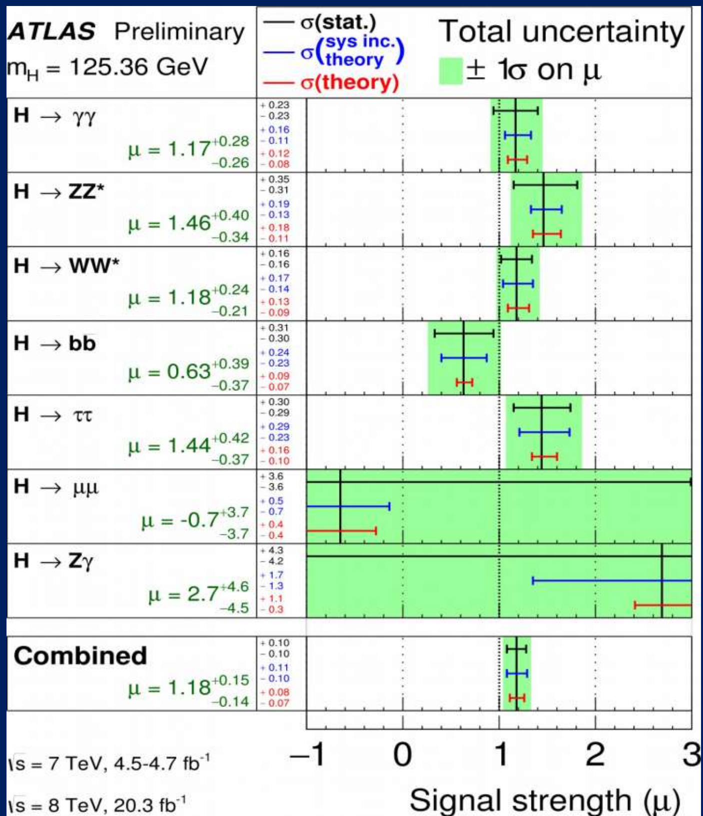


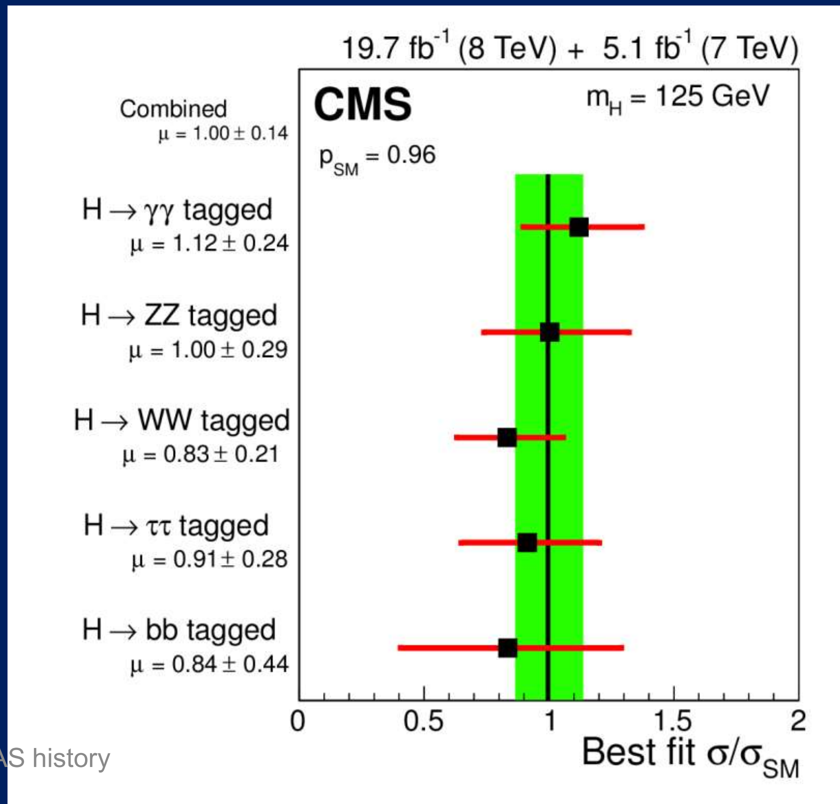


Phys. Rev. D 90 (2014) 052004

Complementary technologies provided comparable performances in term of significance of the signals (Run-1) !

Experiment	ATLAS		CMS	
Decay mode/combination	Expected (σ)	Observed (σ)	Expected (σ)	Observed (σ)
γγ	4.6	5.2	5.3	5.6
ZZ	6.2	8.1	6.3	6.5
WW	5.8	6.1	5.4	4.7
bb	2.6	1.4	2.6	2.0
ττ	3.4	4.5	3.9	3.8





MUON NEW SMALL WHEELS (NSW)

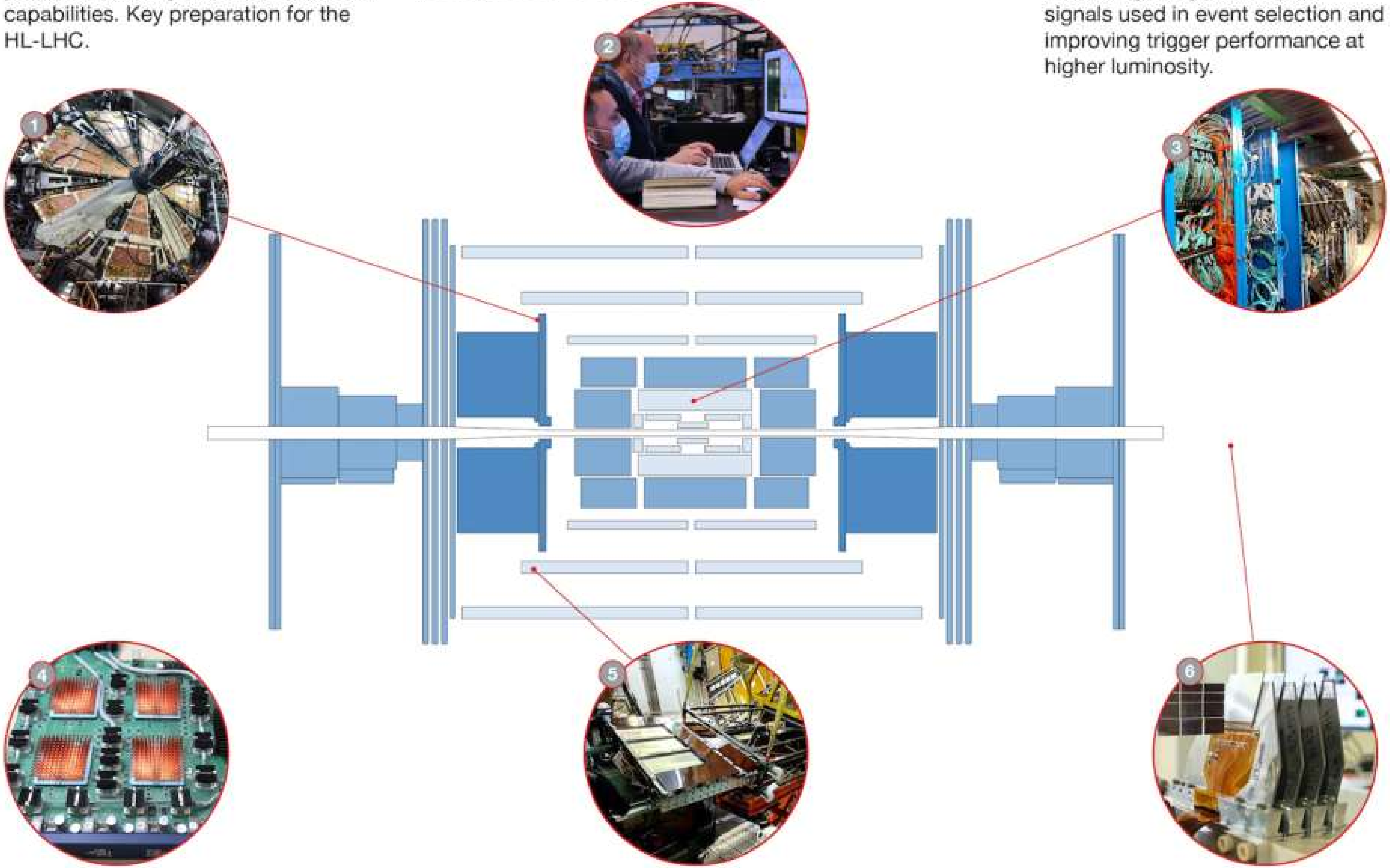
Installed new muon detectors with precision tracking and muon selection capabilities. Key preparation for the HL-LHC.

NEW READOUT SYSTEM FOR THE NSWs

The NSW system includes two million micromega readout channels and 350 000 small strip thin-gap chambers (sTGC) electronic readout channels.

LIQUID ARGON CALORIMETER

New electronics boards installed, increasing the granularity of signals used in event selection and improving trigger performance at higher luminosity.



TRIGGER AND DATA ACQUISITION SYSTEM (TDAQ)

Upgraded hardware and software allowing the trigger to spot a wider range of collision events while maintaining the same acceptance rate.

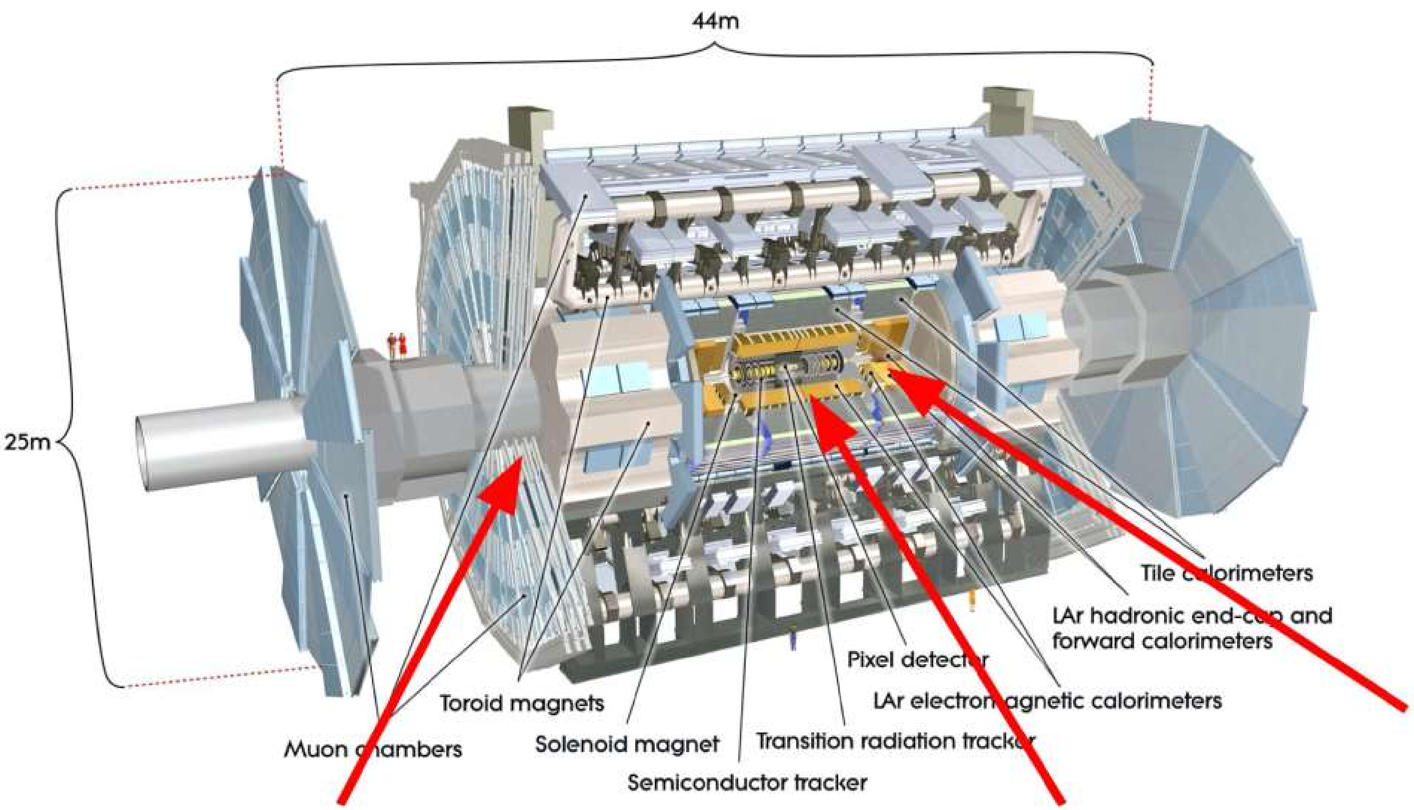
NEW MUON CHAMBERS IN THE CENTRE OF ATLAS

Installed small monitored drift tube (sMDT) detectors alongside a new generation of resistive plate chamber (RPC) detectors, extending the trigger coverage in preparation for the HL-LHC.

ATLAS FORWARD PROTON (AFP)

Re-designed AFP time-of-flight detector, allowing insertion into the LHC beamline with a new “out-of-vacuum” solution.

Overview of ATLAS Phase-II Upgrades



Upgraded Trigger and Data Acquisition system

- Level-0 Trigger at 1 MHz
- Improved High-Level Trigger
- (150 kHz full-scan tracking)

Electronics Upgrades

- On-detector and off-detector electronics upgrades of:
- LAr Calorimeter
- Tile Calorimeter
- Muon Detectors

High Granularity Timing Detector (HGTD)

- Forward region
- Precision time recon. (30 ps) with Low-Gain Avalanche Detectors (LGAD)

New Muon Chambers

- Inner barrel region with new Resistive Plate Chambers and new Monitored Drift Tubes (sMDT) detectors

New Inner Tracking Detector (ITk)

- All silicon (9 layers), up to $|\eta| = 4$

Additional small upgrades

- Luminosity detectors (1% precision)
- HL-ZDC (Heavy Ion physics)

34