The ATLAS Experiment at CERN LHC

AAAS09 Collider Symposium

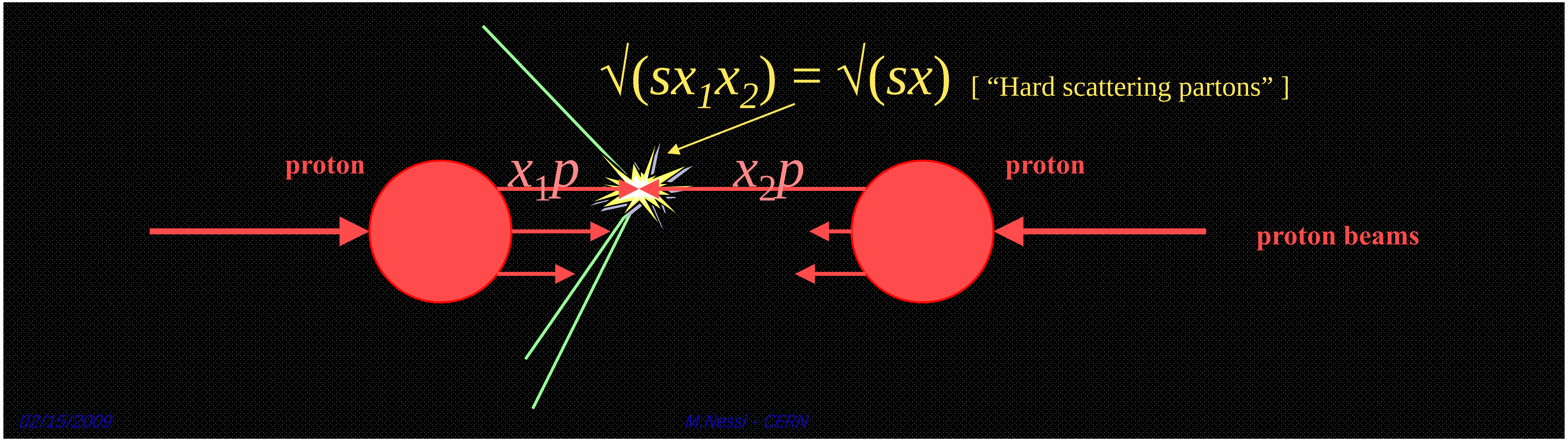
Marzio Nessi

Chicago, 15th February 2009

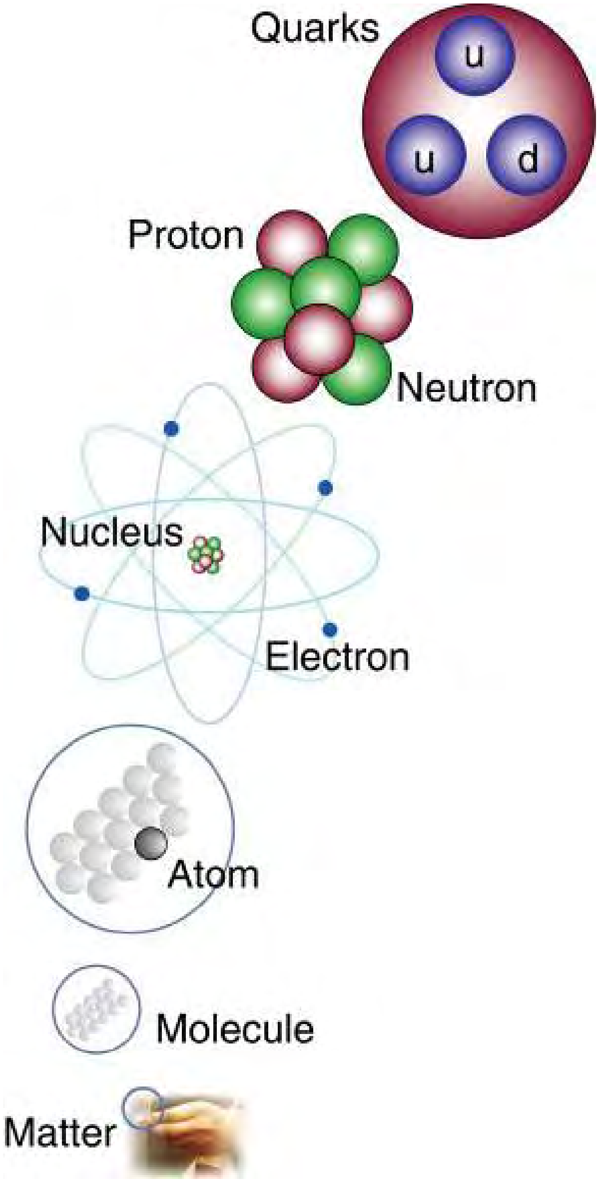
Our Mission

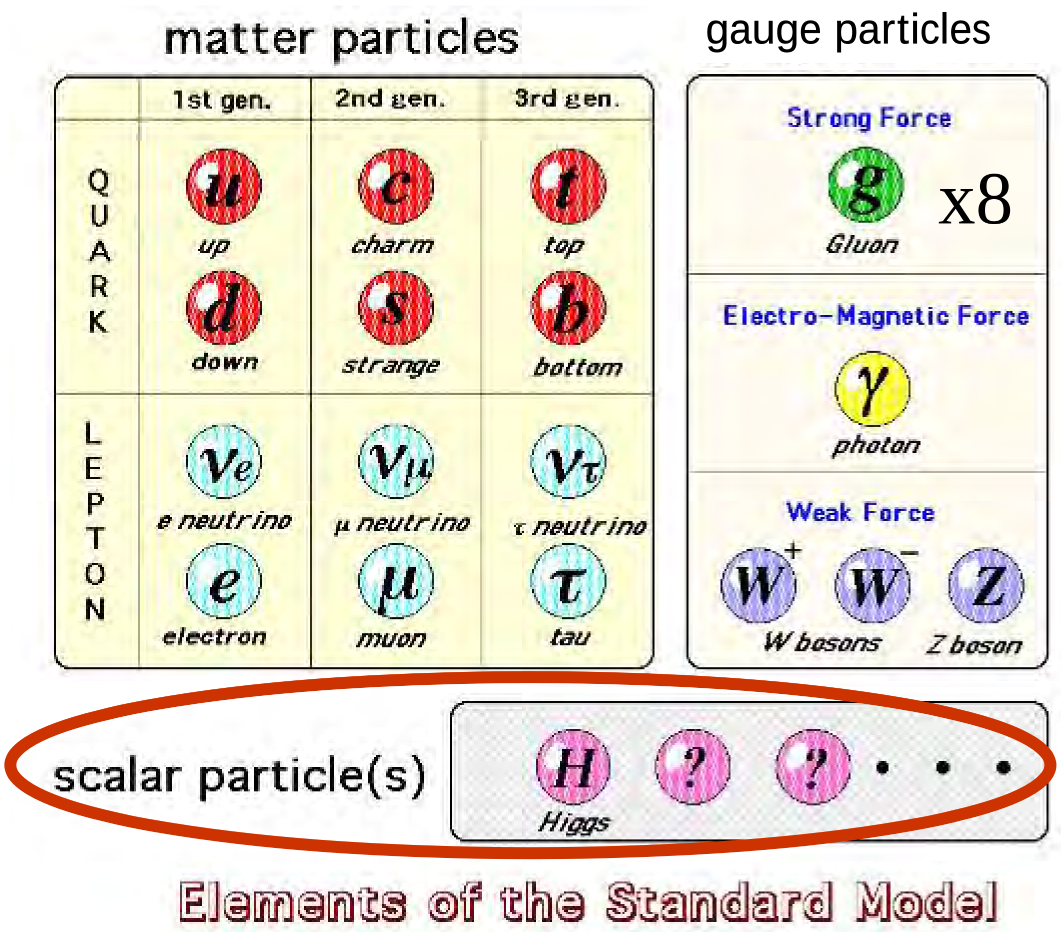
LHC will deliver proton-proton collisions at 14 (7 + 7) TeV.
This will allow us to explore a new energy domain were the matter constituents (partons) will collide with an unprecedented centre-of-mass energy up to 14 TeV

…. with expected peak collision rates ~ 30 MHz for a beam
Luminosity= 10^{34} cm^{-2} s^{-1}



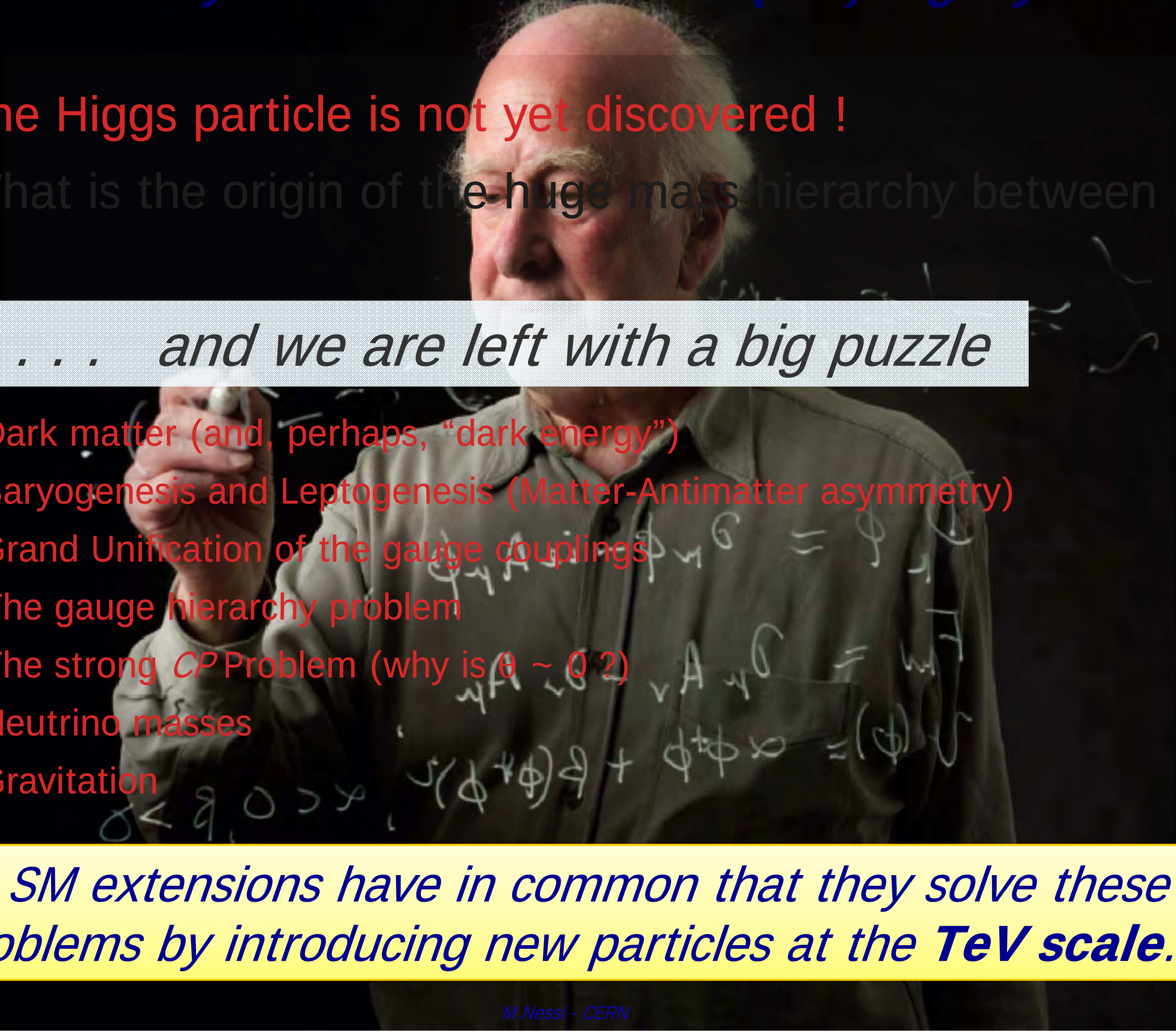
Over several decades, the study of elementary particles and fields and of their interactions has consolidated the present Standard Model





Today the Standard Model (SM) legacy is :

- The Higgs particle is not yet discovered !
- What is the origin of the huge mass hierarchy between particles ?

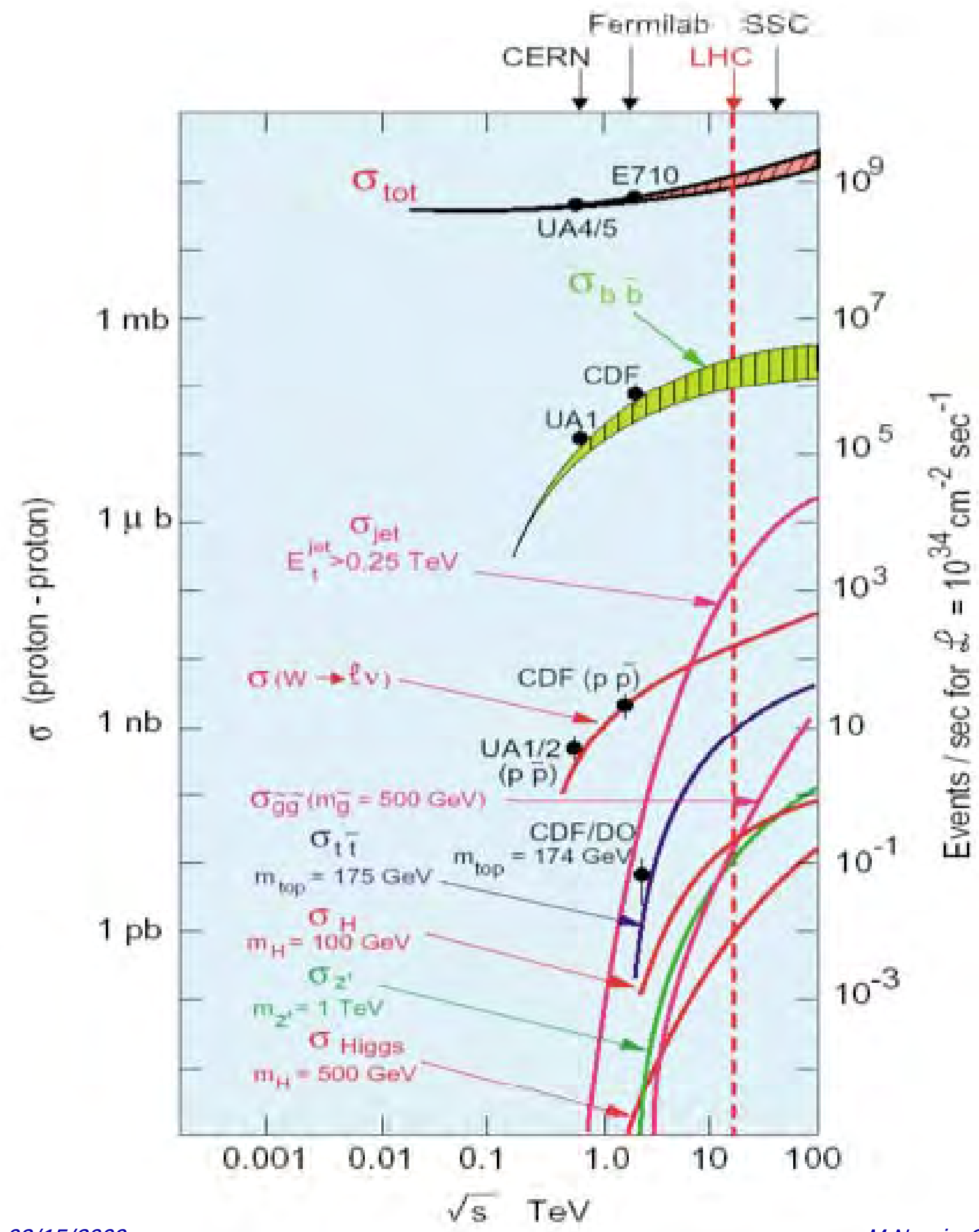


. . .   and we are left with a big puzzle

- ✓ Dark matter (and, perhaps, “dark energy”)
- ✓ Baryogenesis and Leptogenesis (Matter-Antimatter asymmetry)
- ✓ Grand Unification of the gauge couplings
- ✓ The gauge hierarchy problem
- ✓ The strong *CP* Problem (why is $\theta \sim 0$?)
- ✓ Neutrino masses
- ✓ Gravitation

*All SM extensions have in common that they solve these problems by introducing new particles at the **TeV scale**.*

Cross Sections and Production Rates at 14 TeV (LHC)

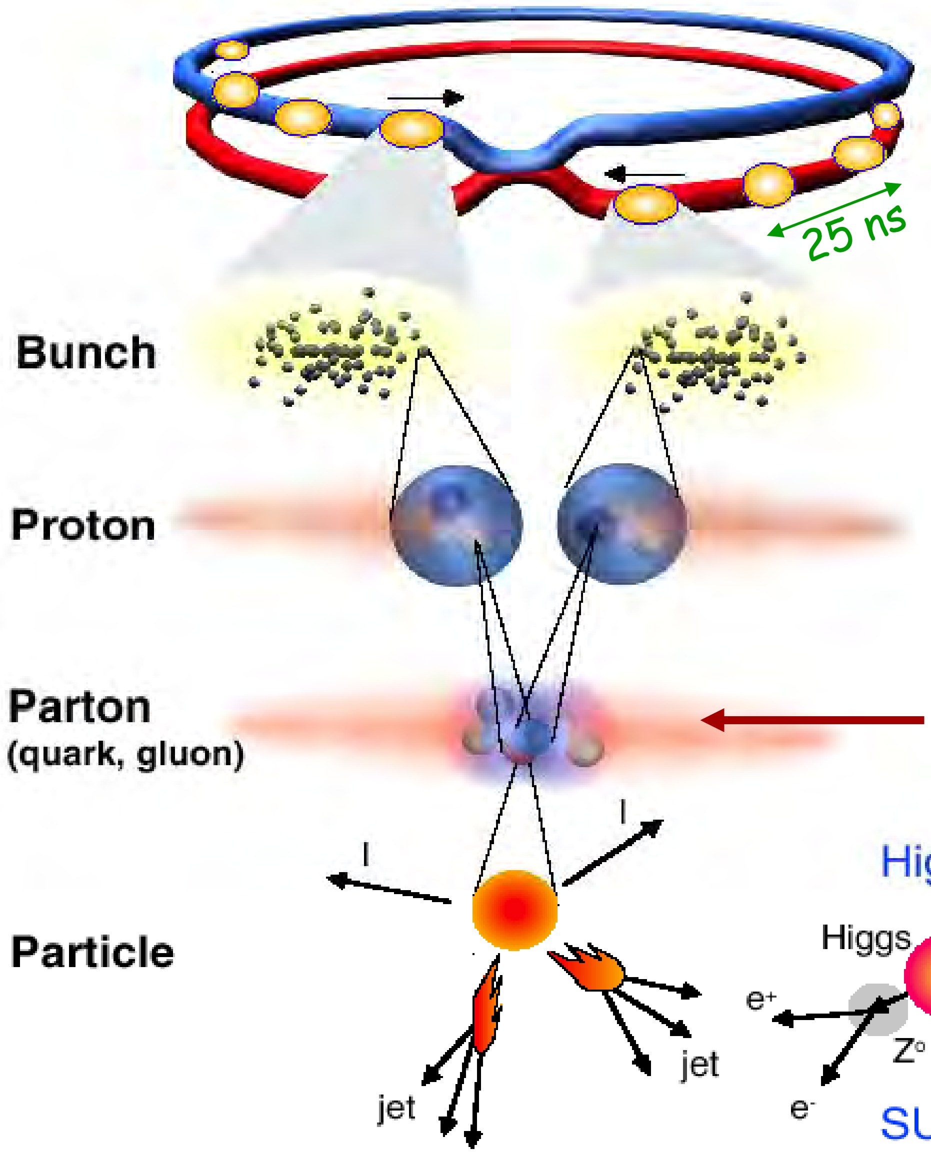


Rates for $L = 10^{34}\ cm^{-2}\ s^{-1}$: (LHC)

- ✓ Inelastic proton-proton reactions: 10^9 / s
- ✓ bb pairs $5x10^6$ / s
- ✓ tt pairs 8 / s
- ✓ $W \rightarrow e\ \nu$ 150 / s
- ✓ $Z \rightarrow e\ e$ 15 / s
- ✓ Higgs (150 GeV) 0.2 / s
- ✓ Gluino, Squarks (1 TeV) 0.03/ s

(The challenge: we have to detect them !)

But it will not be so easy ….



Proton-Proton

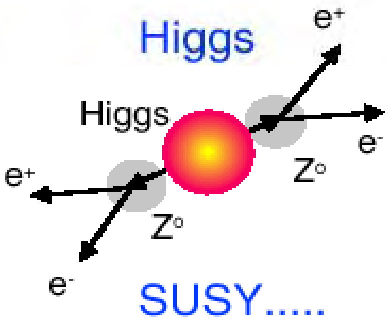
Protons/bunch	10^{11}
Beam energy	7 TeV ($7x10^{12}$ eV)
Luminosity	10^{34} cm^{-2} s^{-1}

Event rate:

N = L x σ (pp) ≈ 10^9 interactions/s

Mostly soft (low p_T) events ~20

Interesting hard (high-p_T) events are rare



Selection of 1 in
10,000,000,000,000

100 M open channels/ detector

MB of data collected every 25 ns

30 MHz of bunch collisions→ ~ PB/sec

Unfold energy from other collisions

Big reduction factor necessary ~10^6

Survive severe radiation environment (MRAD)

300-600 MB/s can be stored on disk

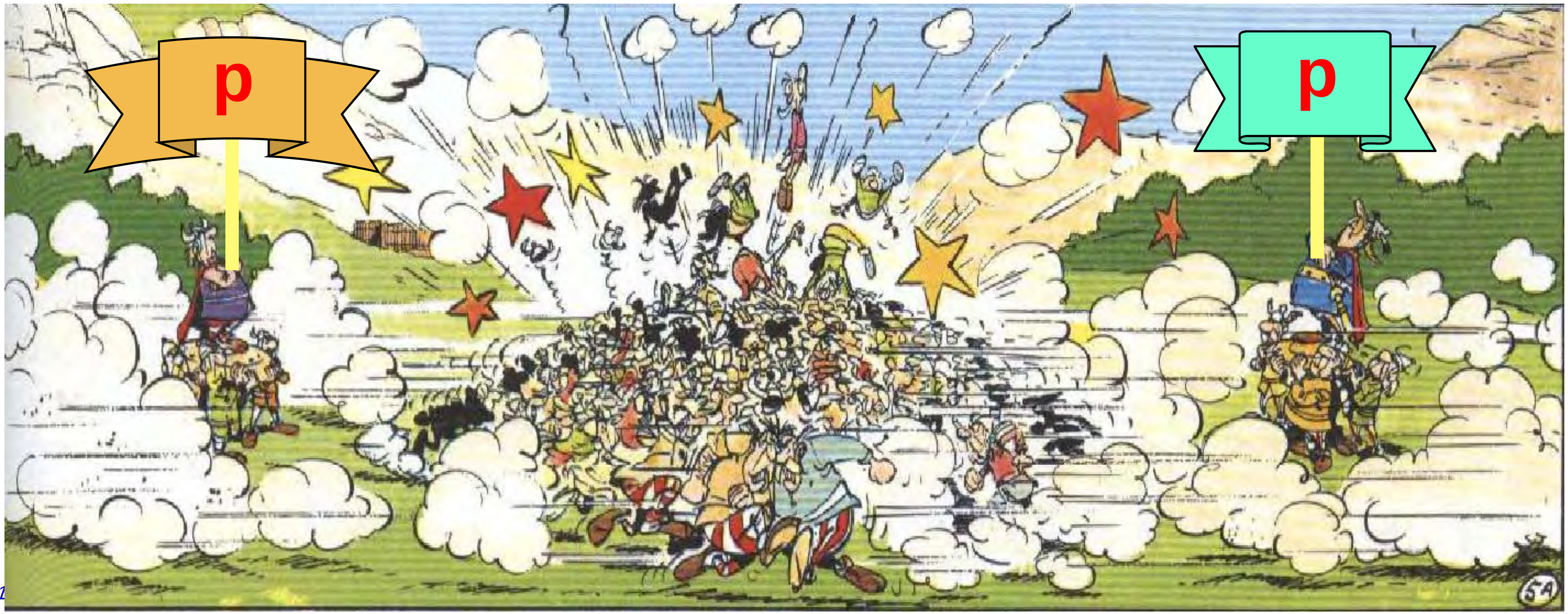
7-8 months of data storage/year → few PB/year

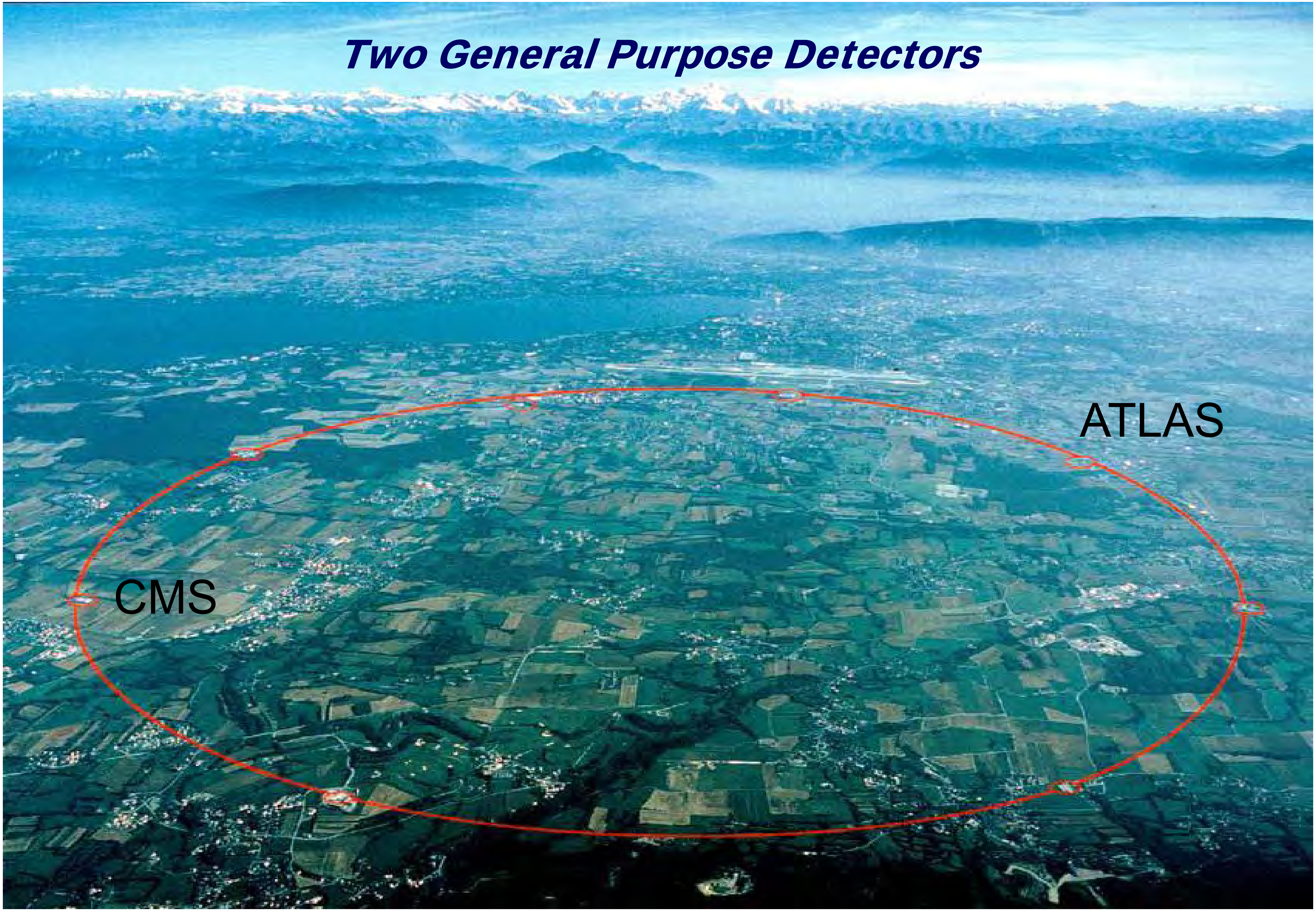
to be distributed everywhere for offline analysis

So what we need is

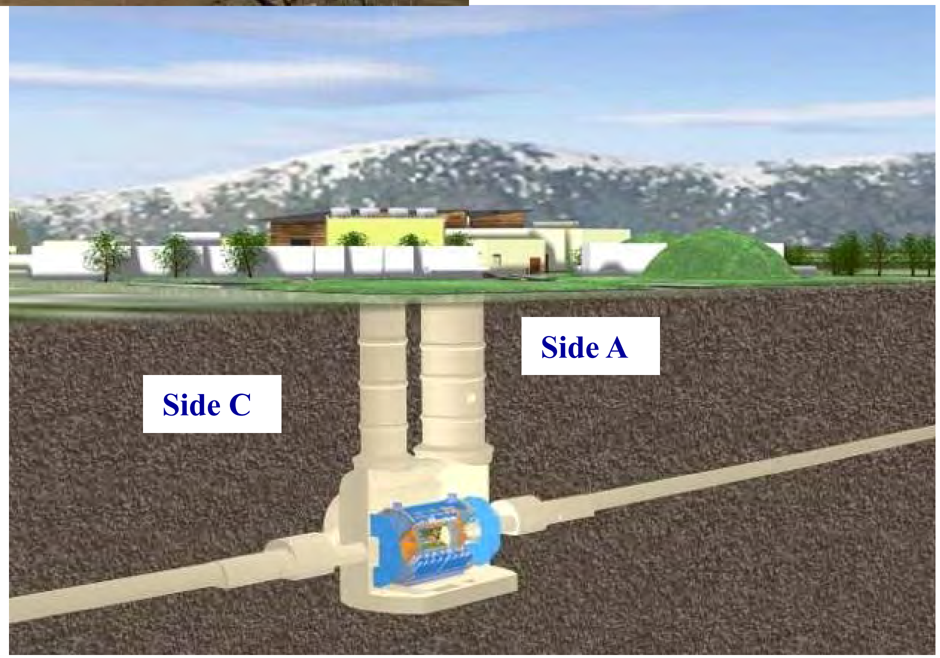
- ✓ A solid experimental program, strongly supported by the scientific community

- ✓ Complex detectors around the interaction point:
  - *capable of facing such an environment (high energy, large backgrounds, fast timing, huge amount of data)*
  - *capable of exploring the variety of signals and energy deposition pattern*
  - *capable of facing new physics, ready for surprises*



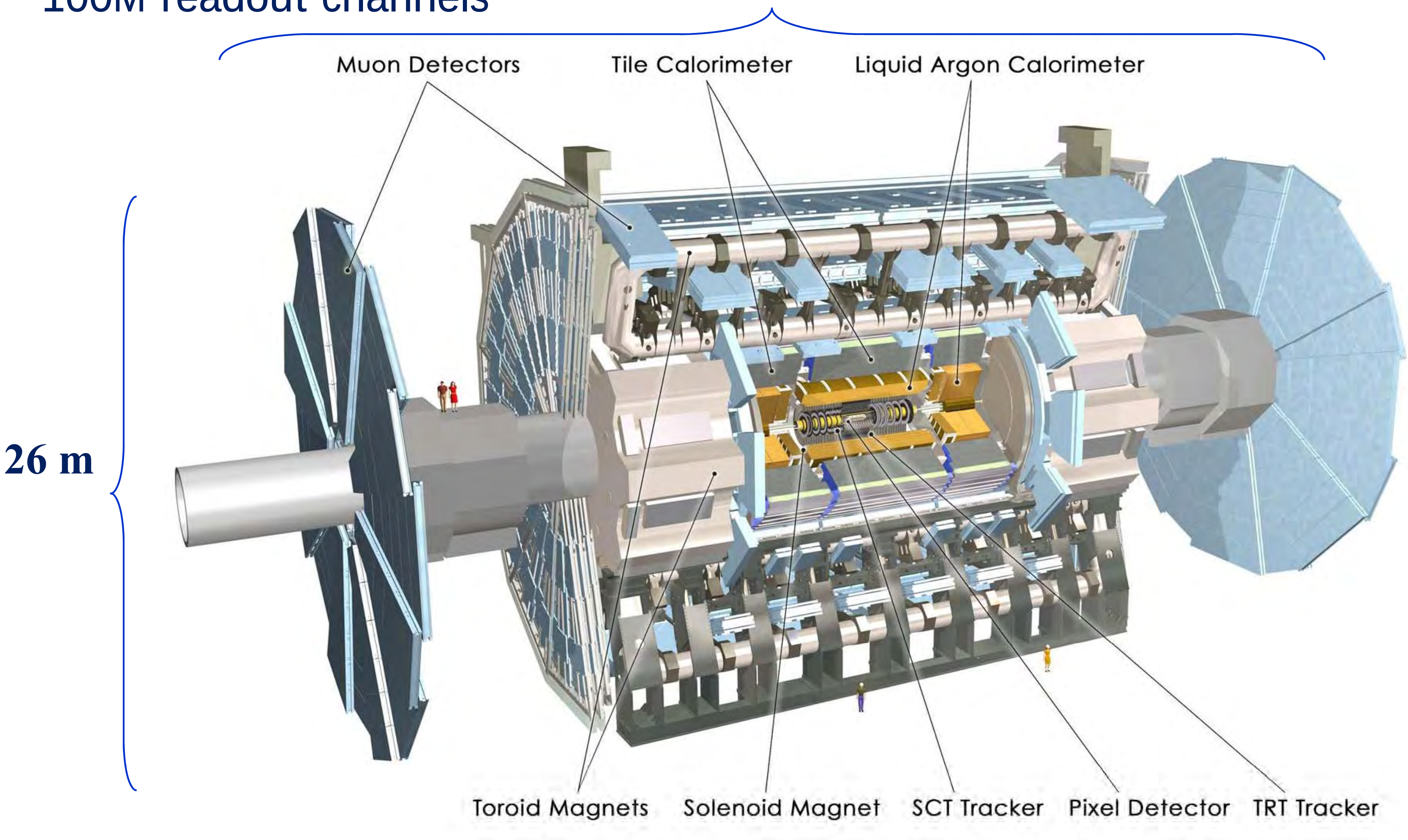

Two General Purpose Detectors
ATLAS
CMS

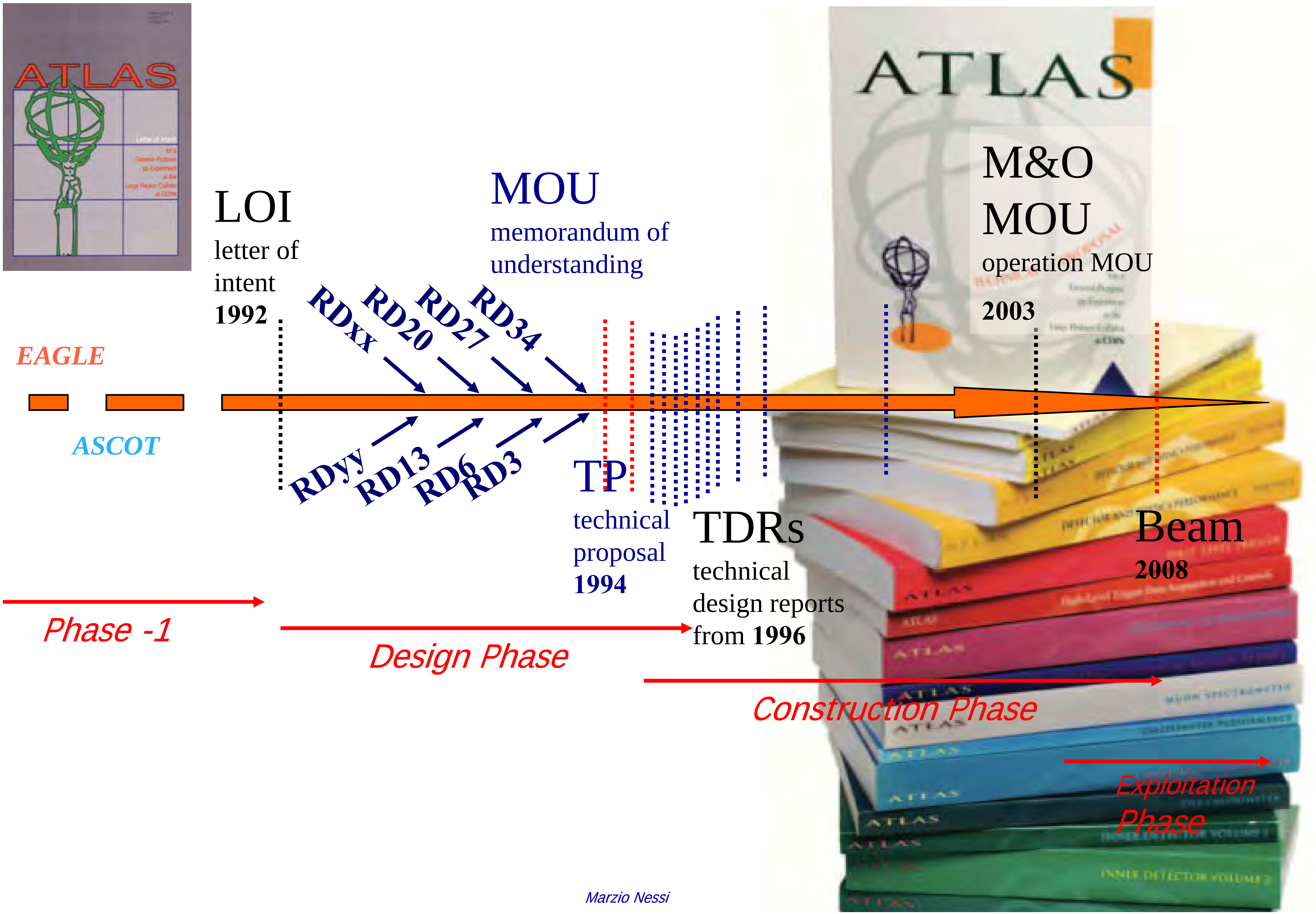
The Underground Cavern at Point-1 for the ATLAS Detector



~7000 tons,
~100M readout channels

46 m




ATLAS
LOI
letter of
intent
1992
EAGLE
ASCOT
MOU
memorandum of
understanding
RDxx
RD20
RD27
RD34
RDyy
RD13
RD6
RD3
TP
technical
proposal
1994
TDRs
technical
design reports
from 1996
ATLAS
M&O
MOU
operation MOU
2003
Beam
2008
Phase -1
Design Phase
Construction Phase
Exploitation
Phase

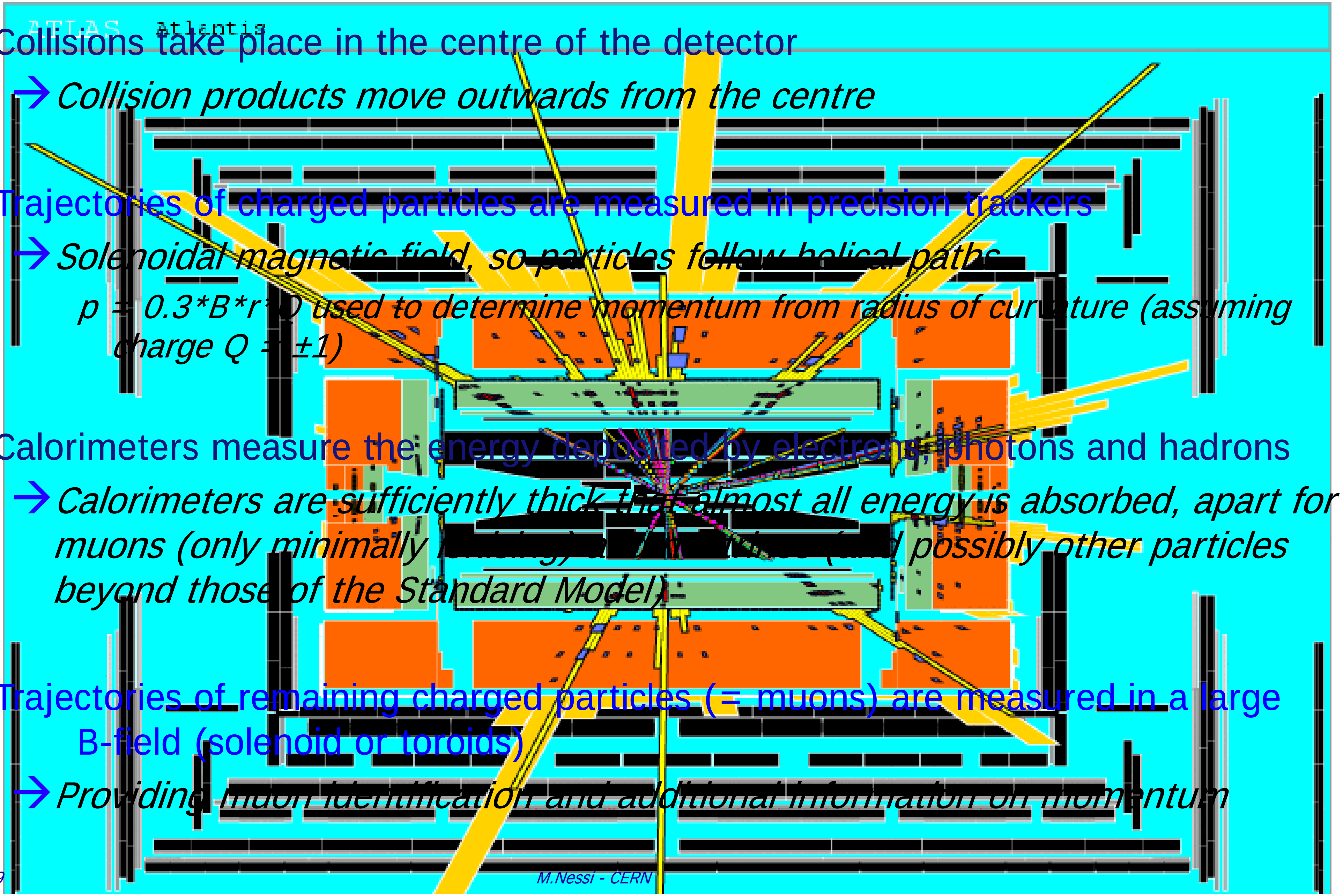

37 Countries
169 Institutions
2800 Scientific Authors
(1850 " " with a PhD)
ATLAS
Collaboration

A GLOBAL PROJECT

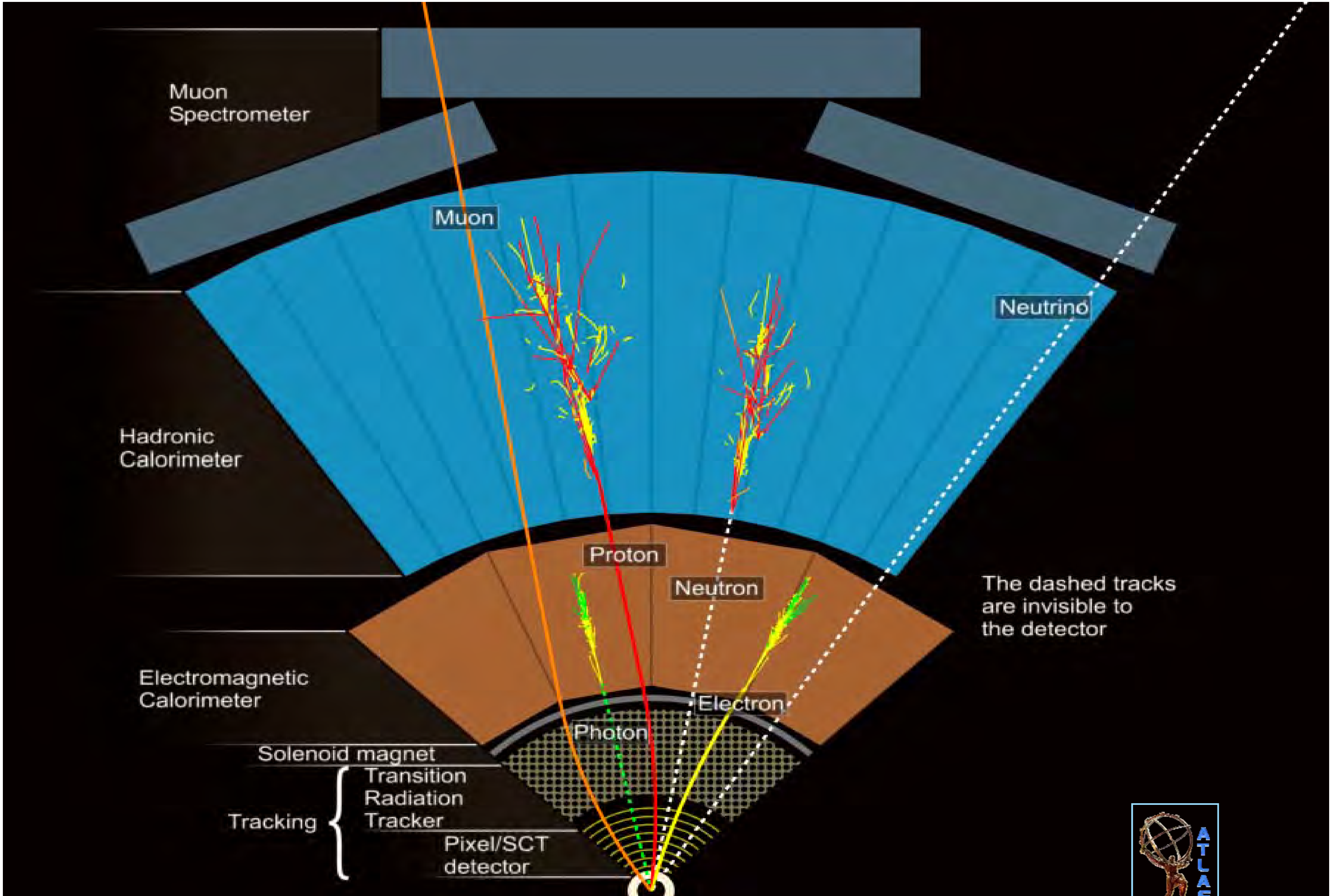
Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, 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, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, 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/ICTP, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

among them, 38 US institutions, counting ~ 590 scientific authors

Detector concept

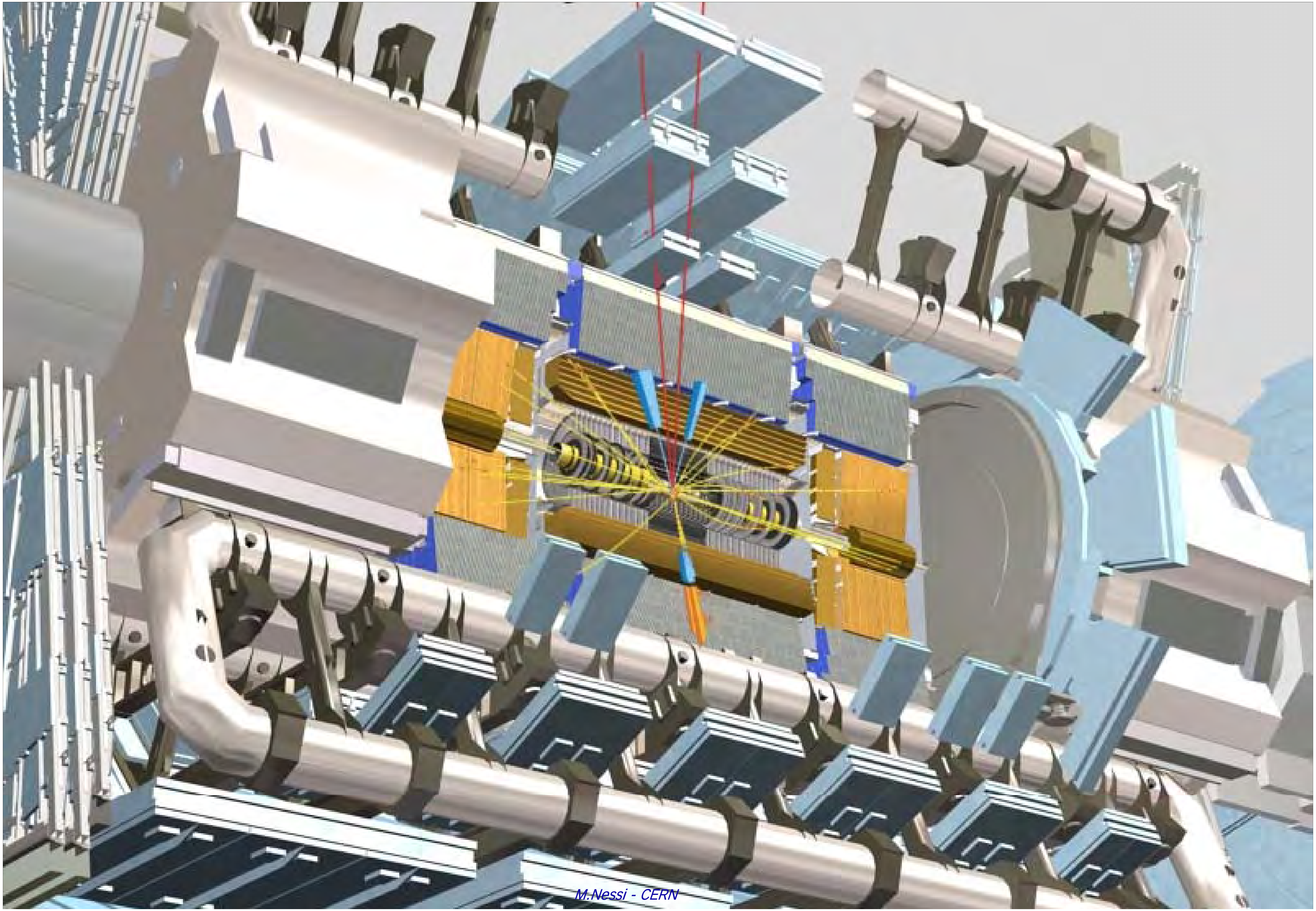


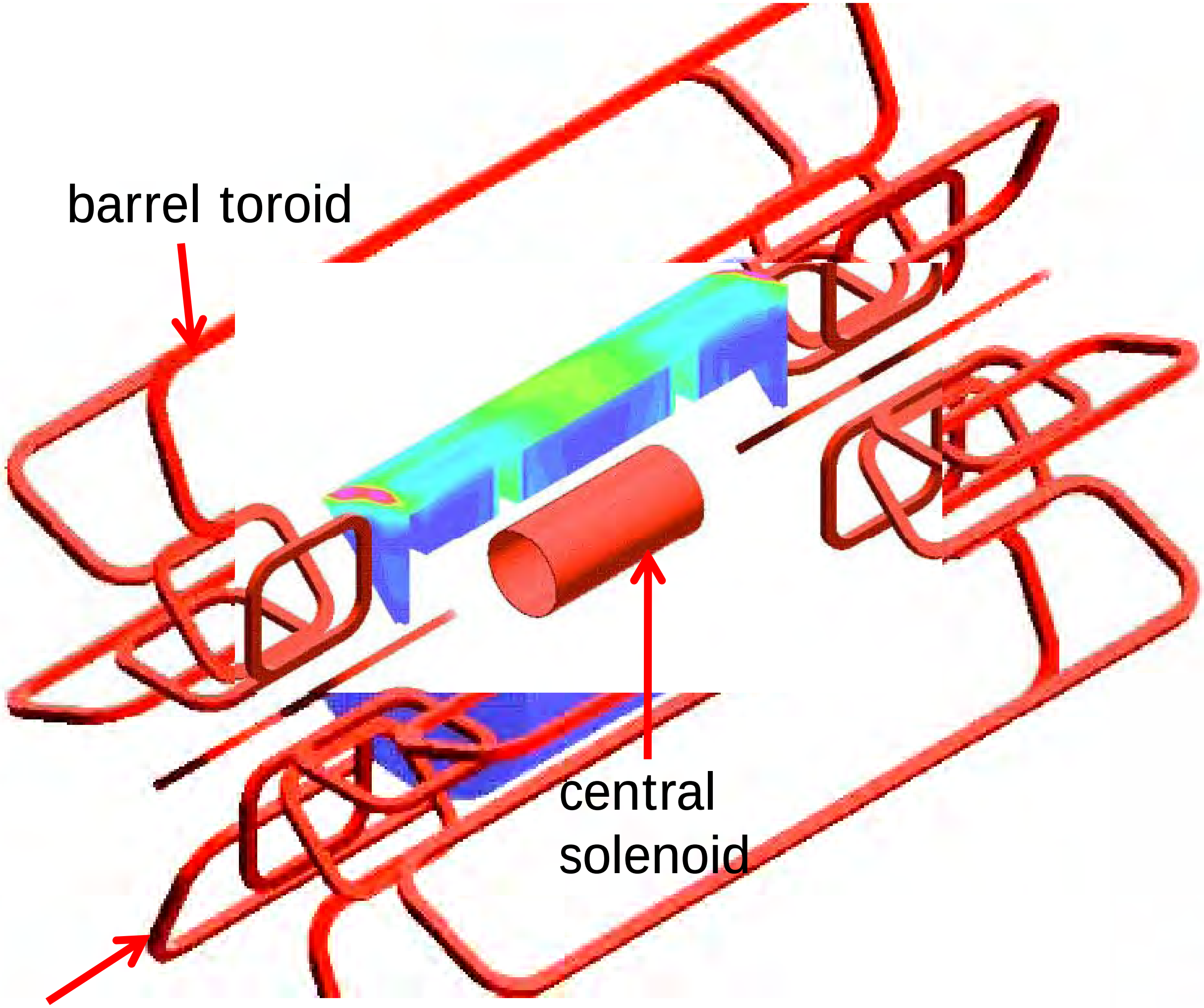
- Collisions take place in the centre of the detector
  - → *Collision products move outwards from the centre*
- Trajectories of charged particles are measured in precision trackers
  - → *Solenoidal magnetic field, so particles follow helical paths*
    - *p = 0.3*B*r*Q used to determine momentum from radius of curvature (assuming charge Q = ±1)*
- Calorimeters measure the energy deposited by electrons, photons and hadrons
  - → *Calorimeters are sufficiently thick that almost all energy is absorbed, apart for muons (only minimally ionising) and neutrinos (and possibly other particles beyond those of the Standard Model)*
- Trajectories of remaining charged particles (= muons) are measured in a large B-field (solenoid or toroids)
  - → *Providing muon identification and additional information on momentum*



Muon
Spectrometer
Hadronic
Calorimeter
Electromagnetic
Calorimeter
Solenoid magnet
Tracking
Transition
Radiation
Tracker
Pixel/SCT
detector
Muon
Neutrino
Proton
Neutron
Electron
Photon
The dashed tracks
are invisible to
the detector
ATLAS

02/15/2009

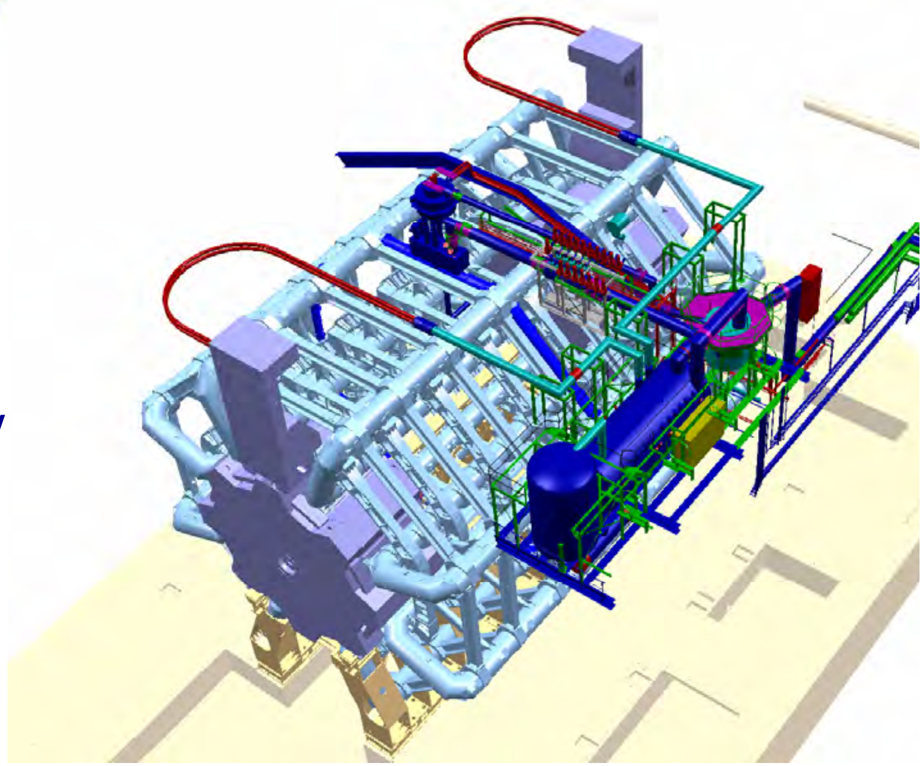

M.Nessi - CERN

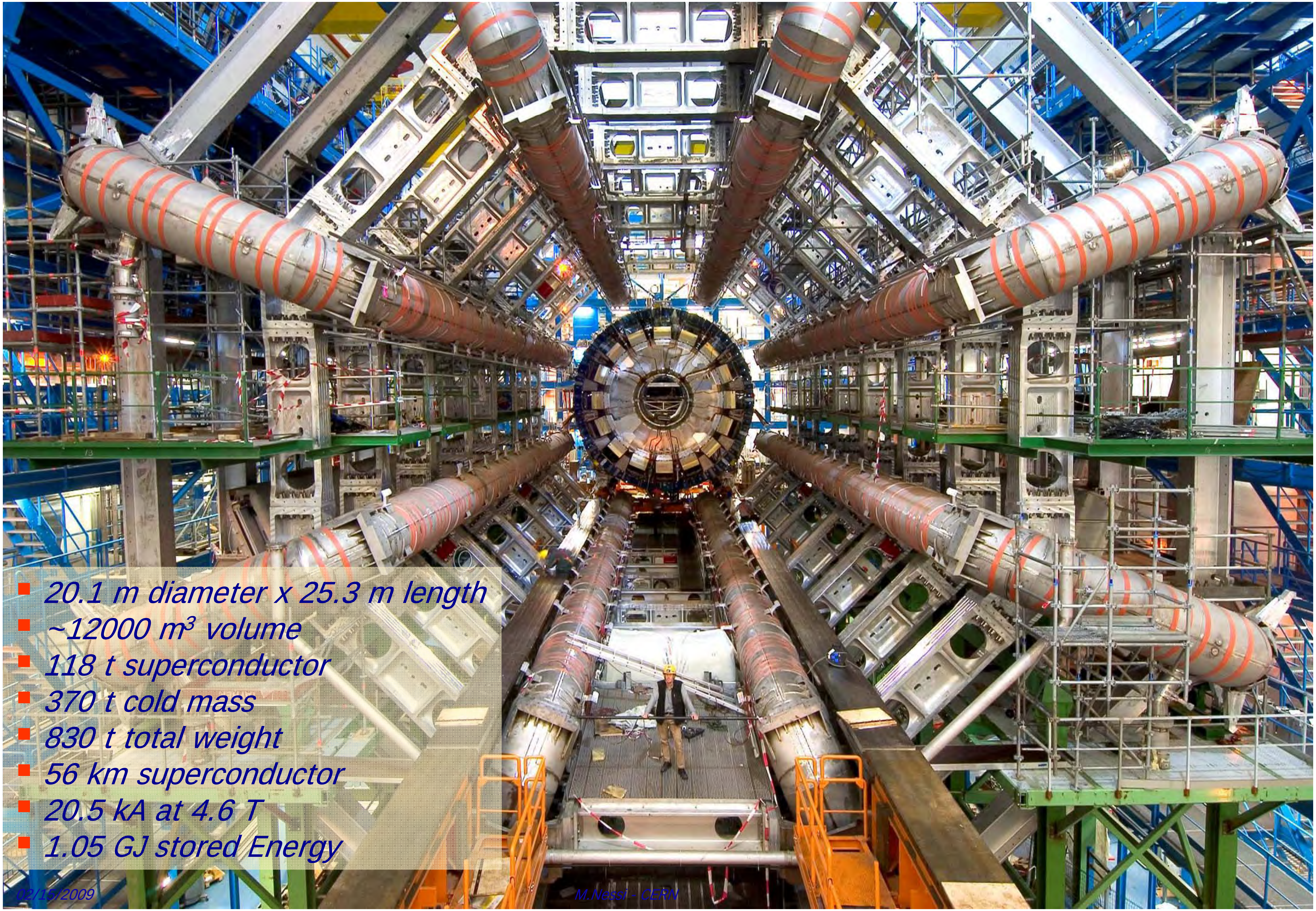


ATLAS has a complex magnet system (4 independent magnets)

- 2 T central solenoid, around the inner detector with return flux via the hadron tile calorimeter

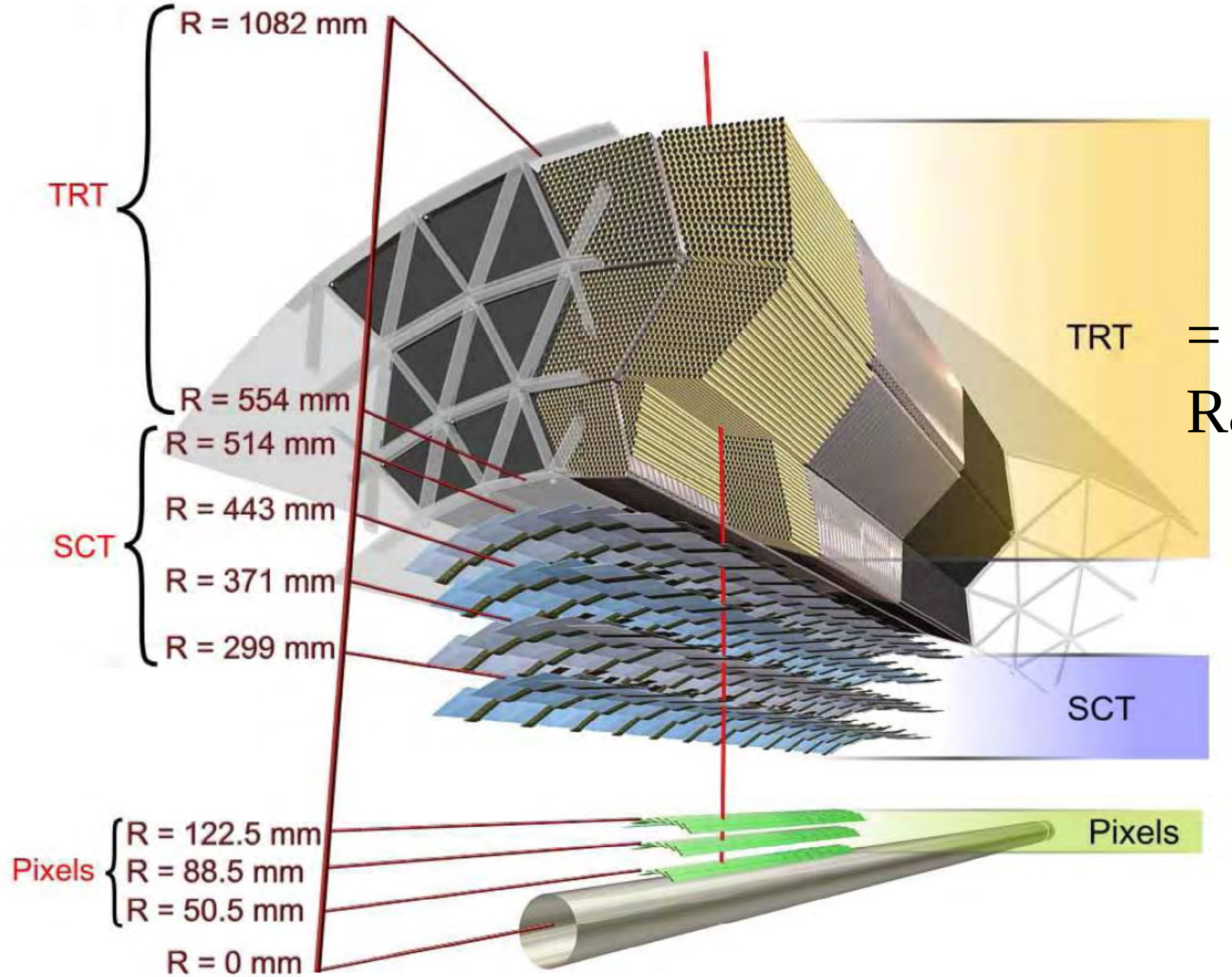
1 barrel and 2 end-cap toroids, each one built out of 8 individual superconducting coils





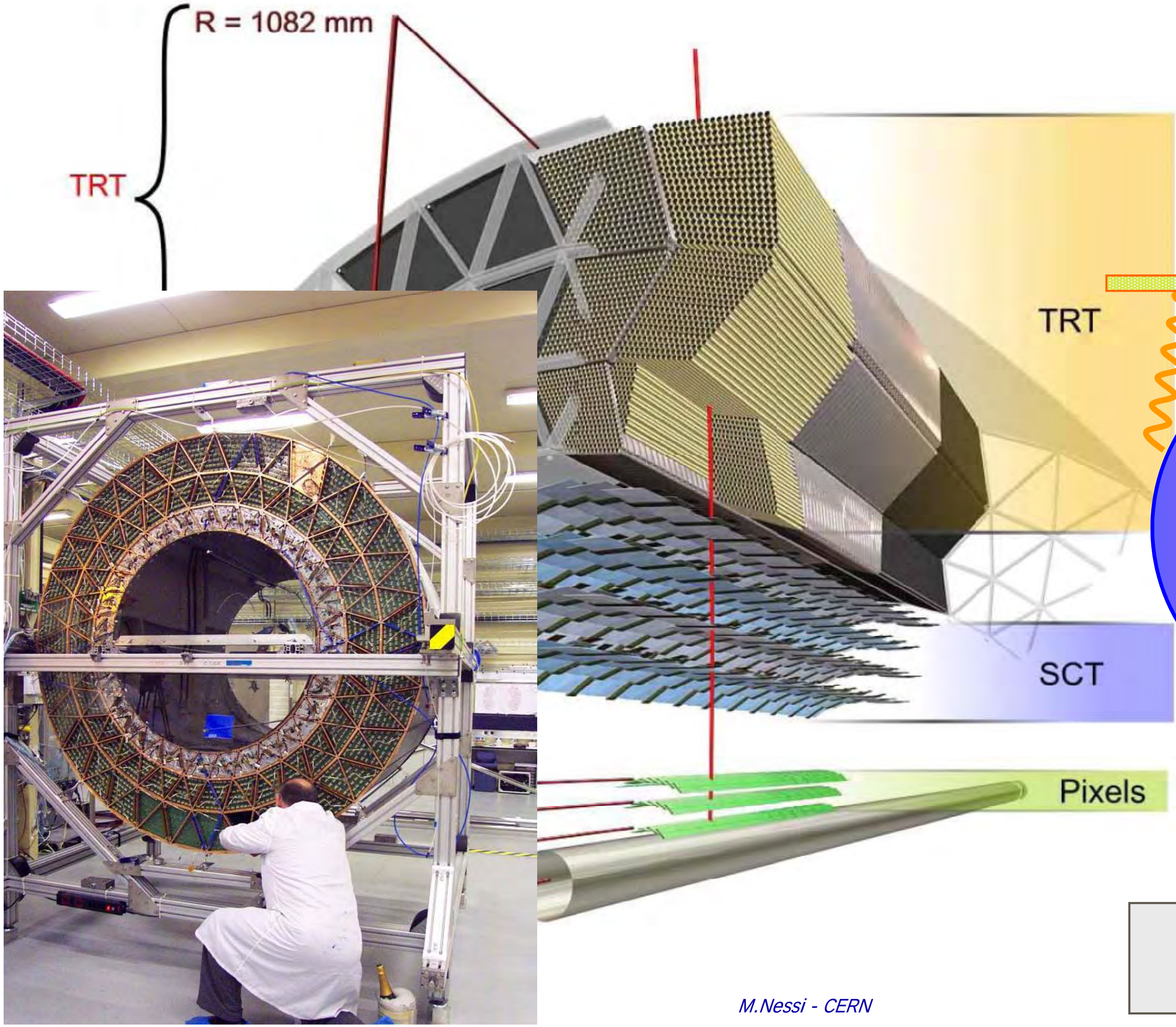
- 20.1 m diameter x 25.3 m length
- ~12000 m^3 volume
- 118 t superconductor
- 370 t cold mass
- 830 t total weight
- 56 km superconductor
- 20.5 kA at 4.6 T
- 1.05 GJ stored Energy

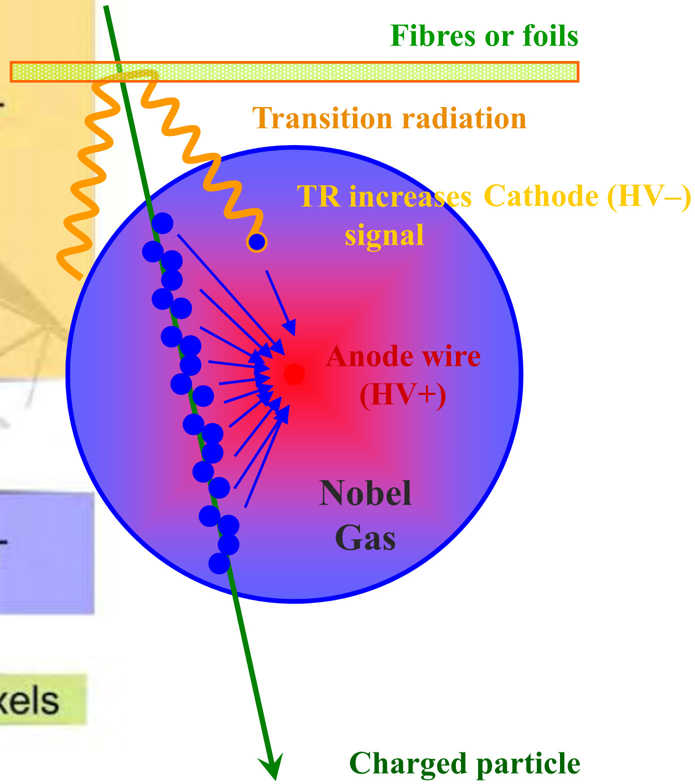
Inner Detector Barrel



= Transition RadiationTracker

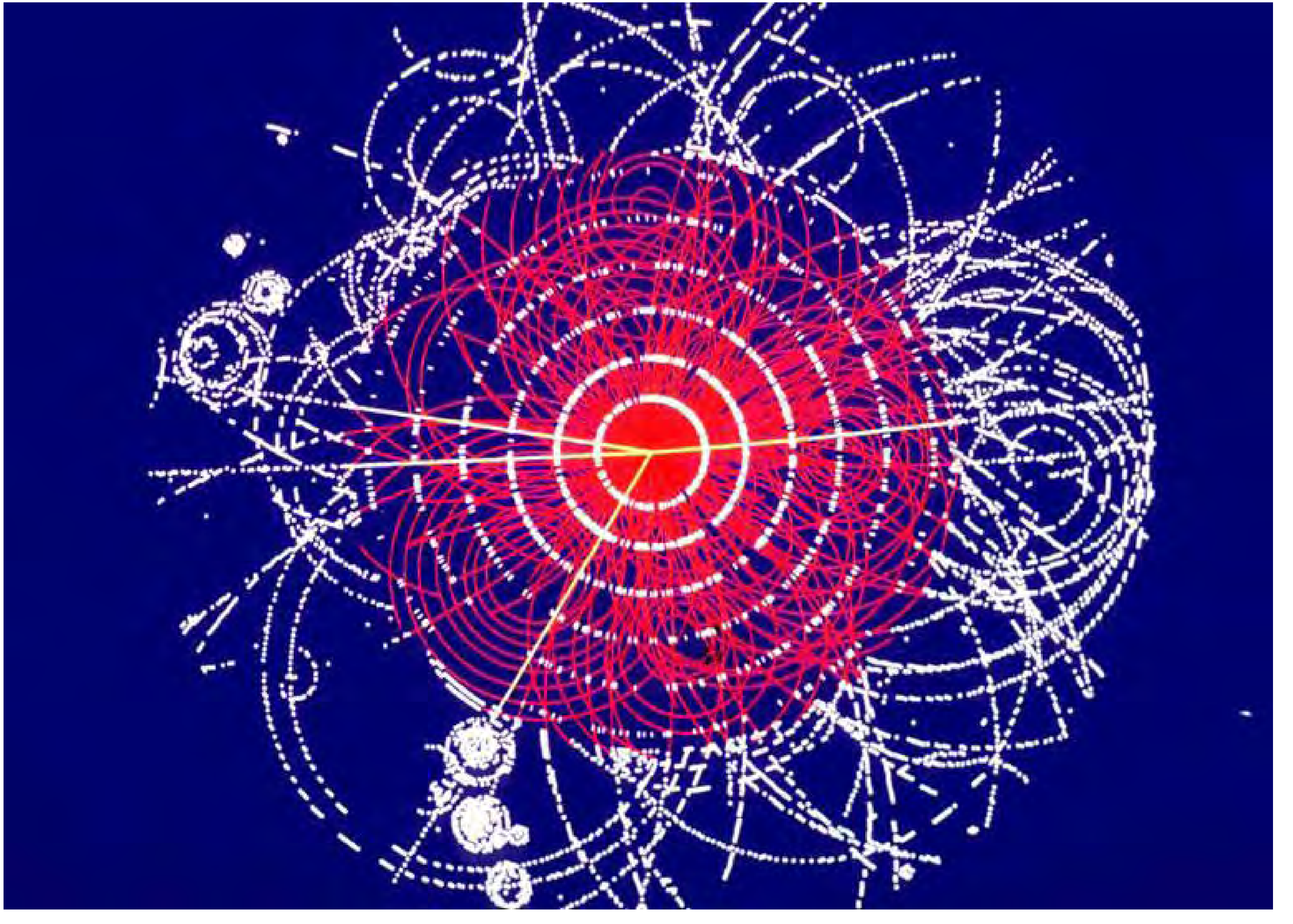
Inner Detector Barrel



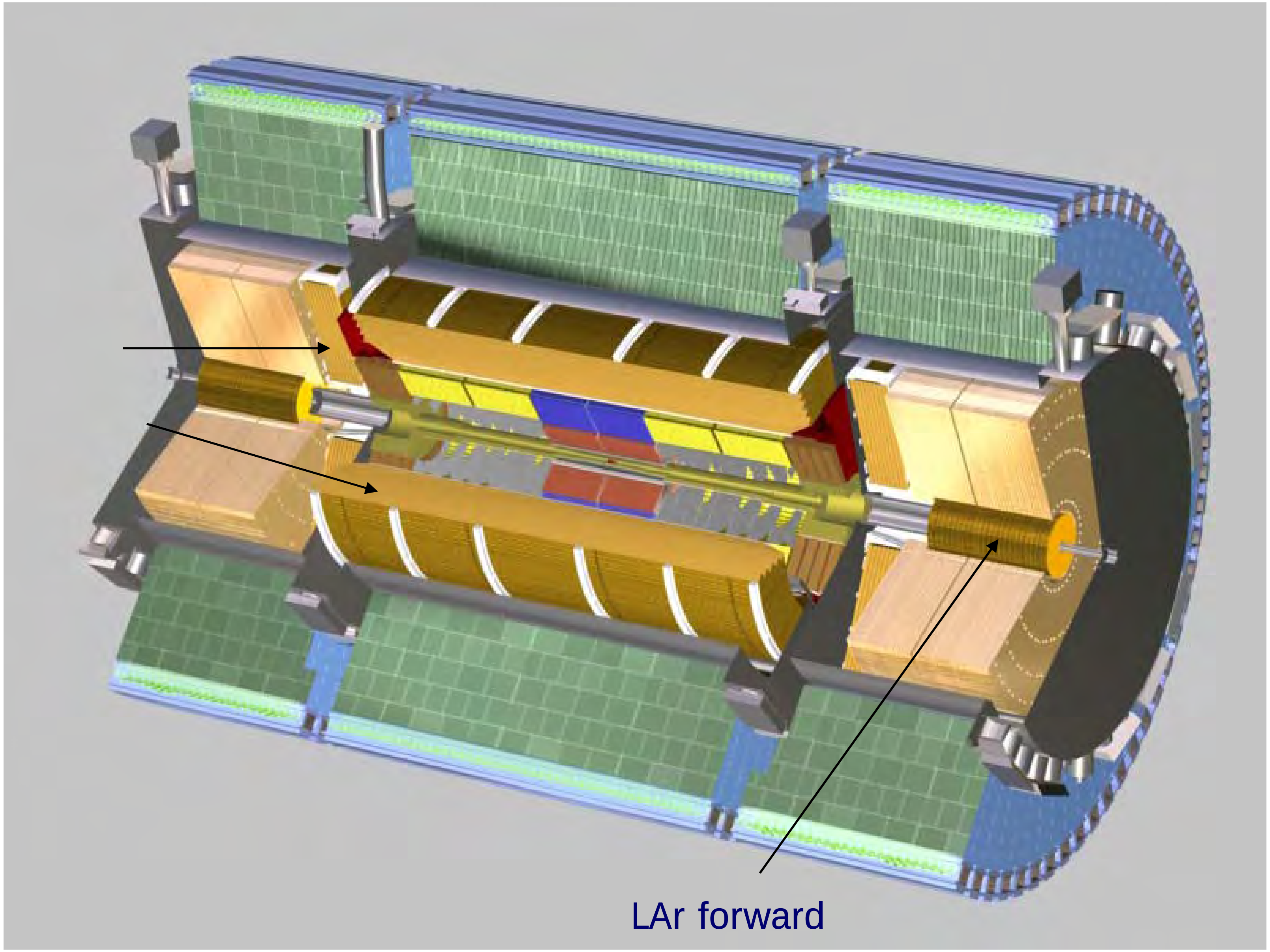


Electrons radiate more → higher signal; info by counting high threshold hits

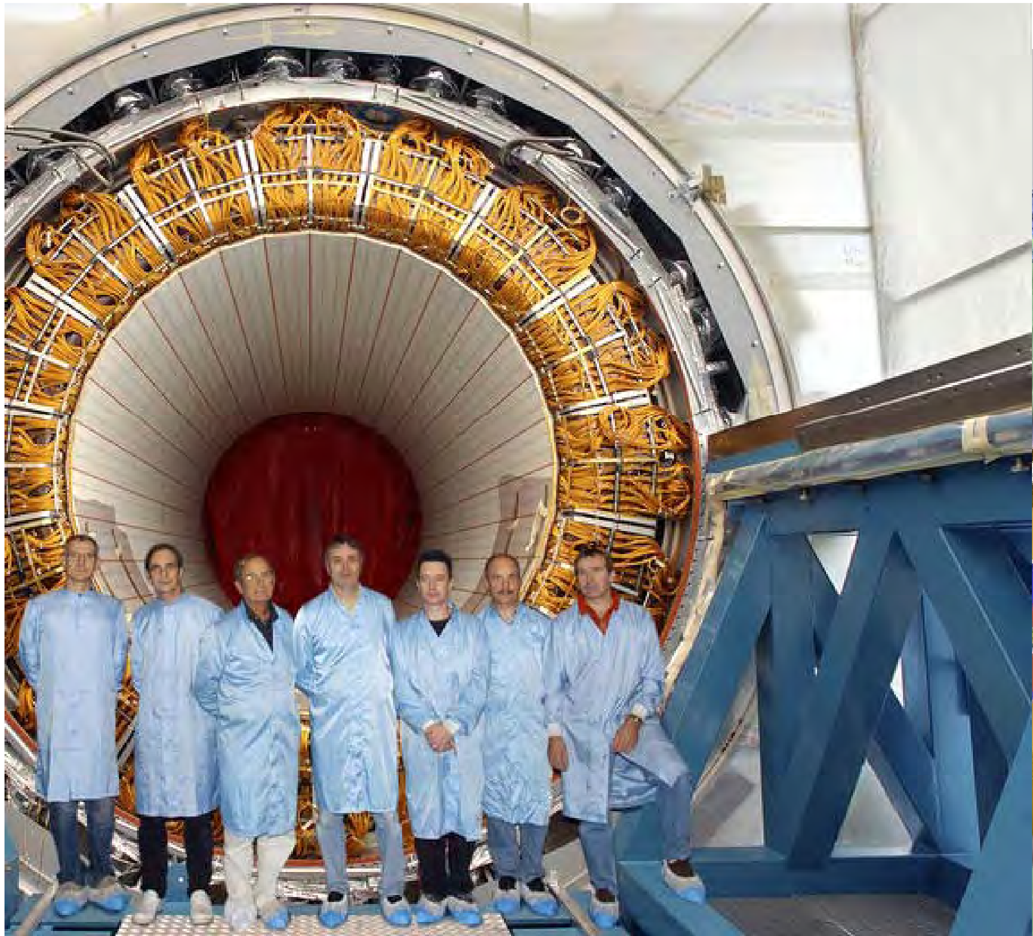
Inner Detector Barrel

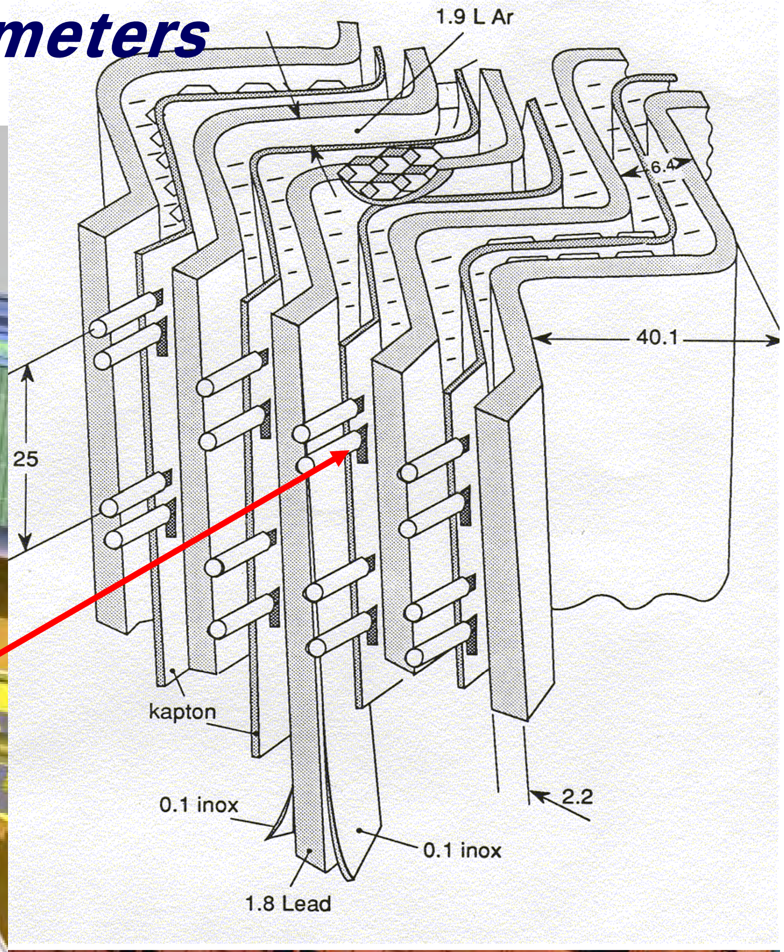


Liquid Argon Calorimeters



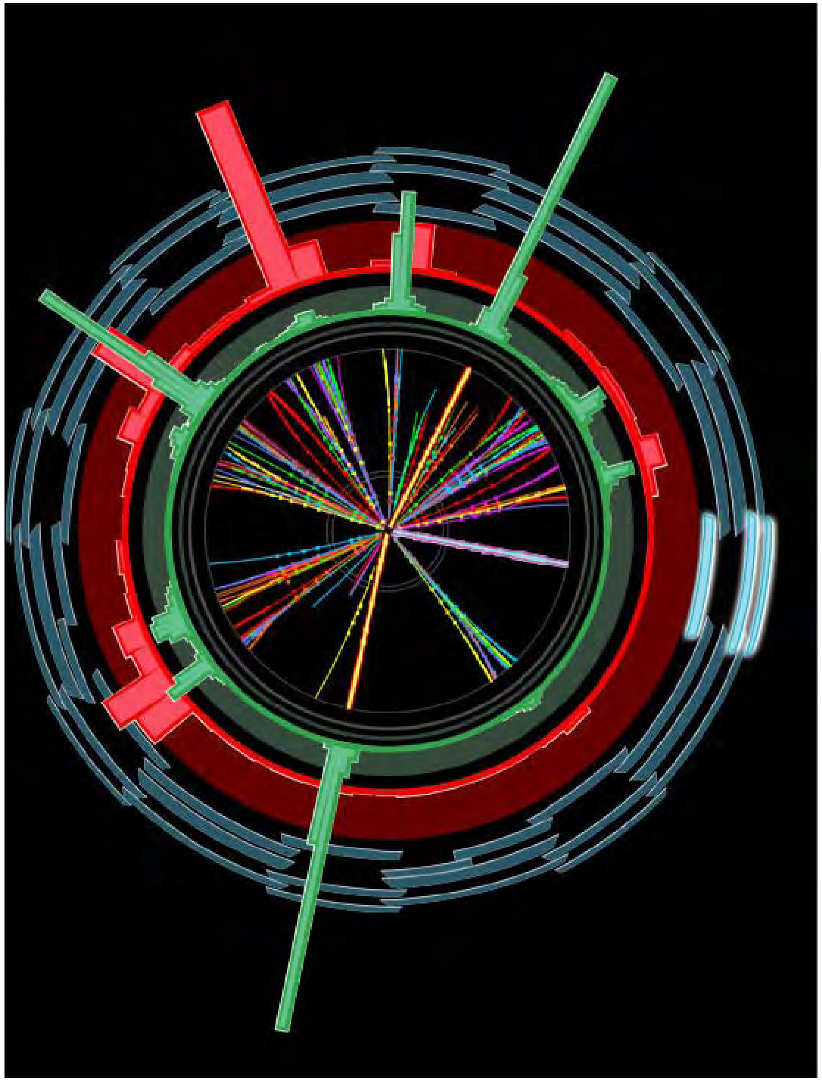
Liquid Argon Calorimeters

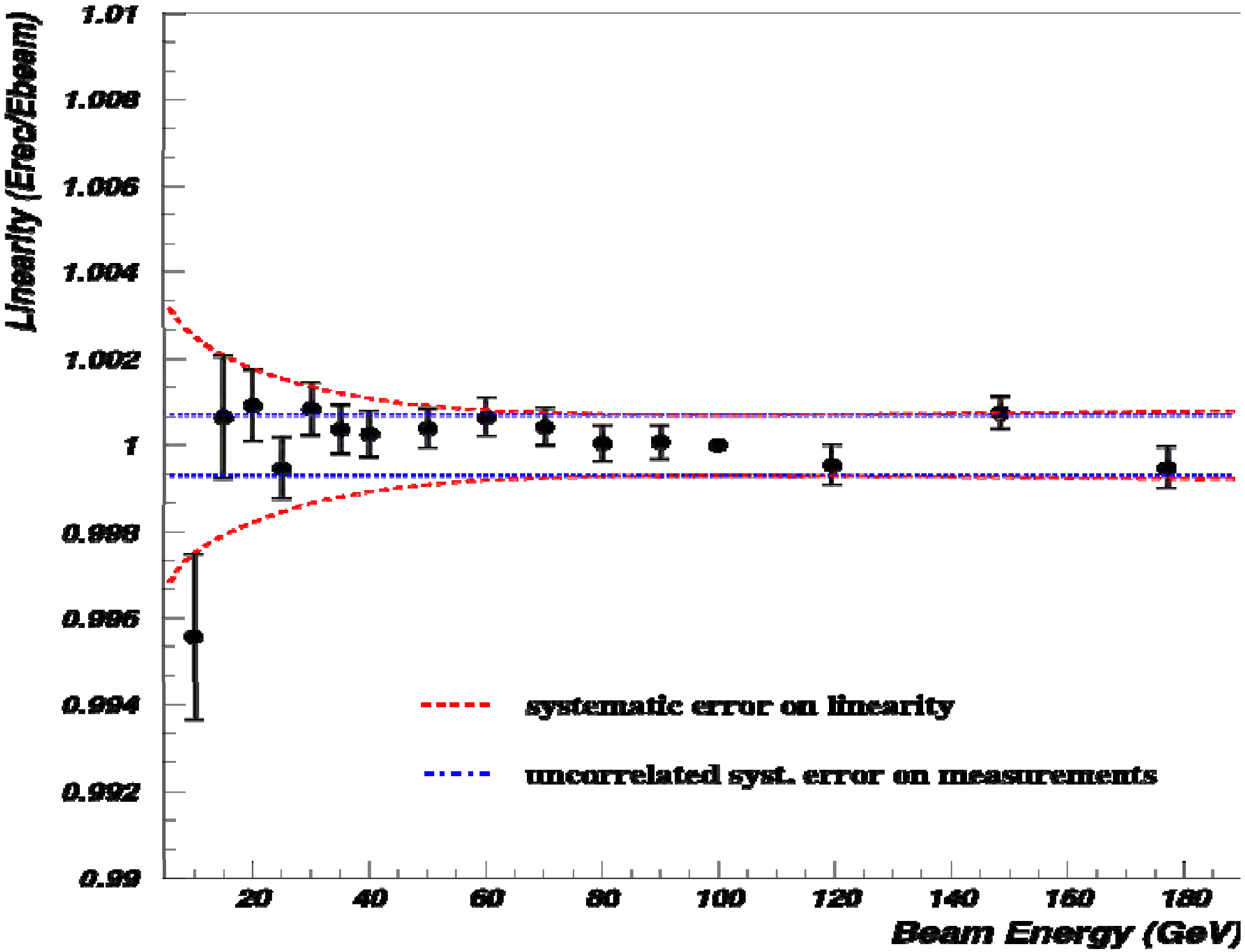




- a very stable and radiation-hard detector
- easy to calibrate
- a lot of freedom in spacial resolution

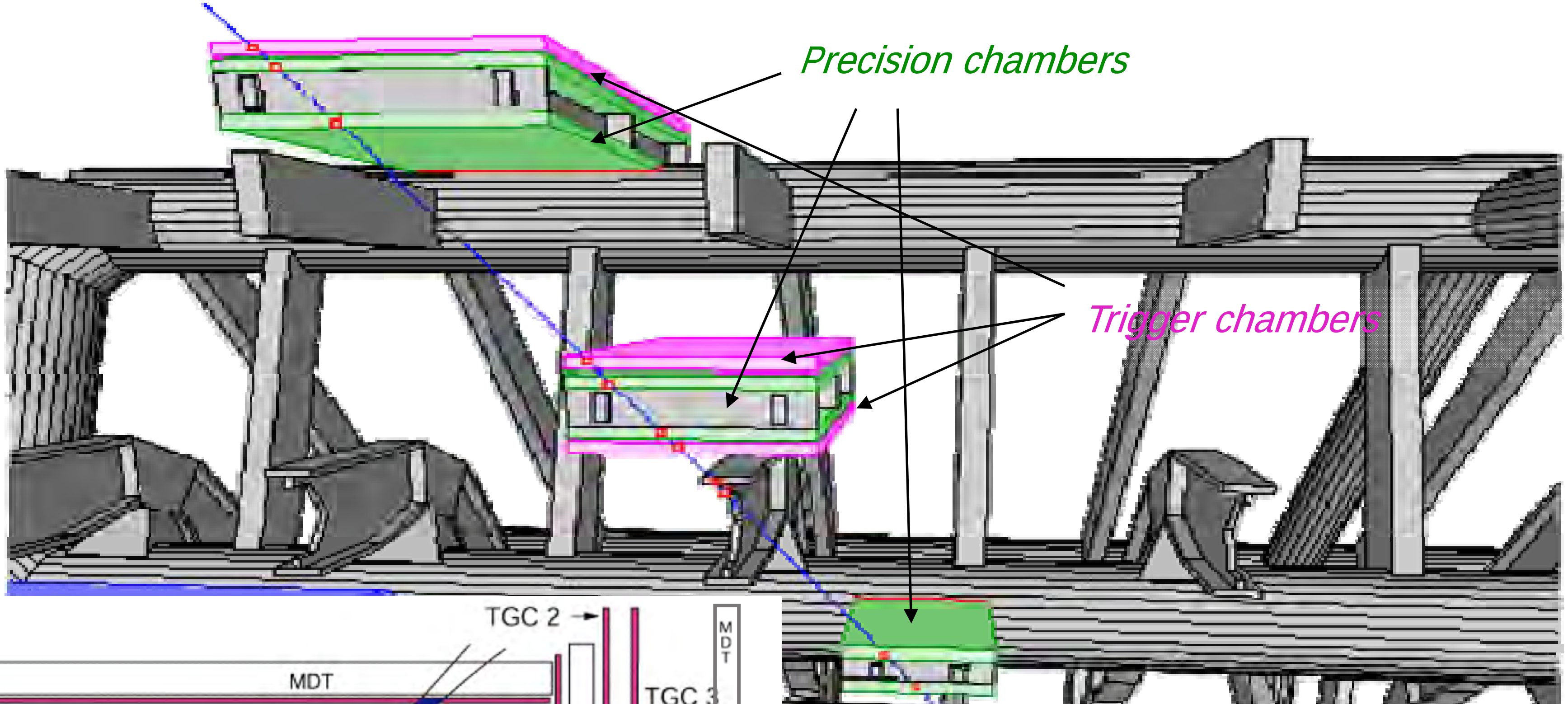
- .... difficult to construct ... because of cryogenics

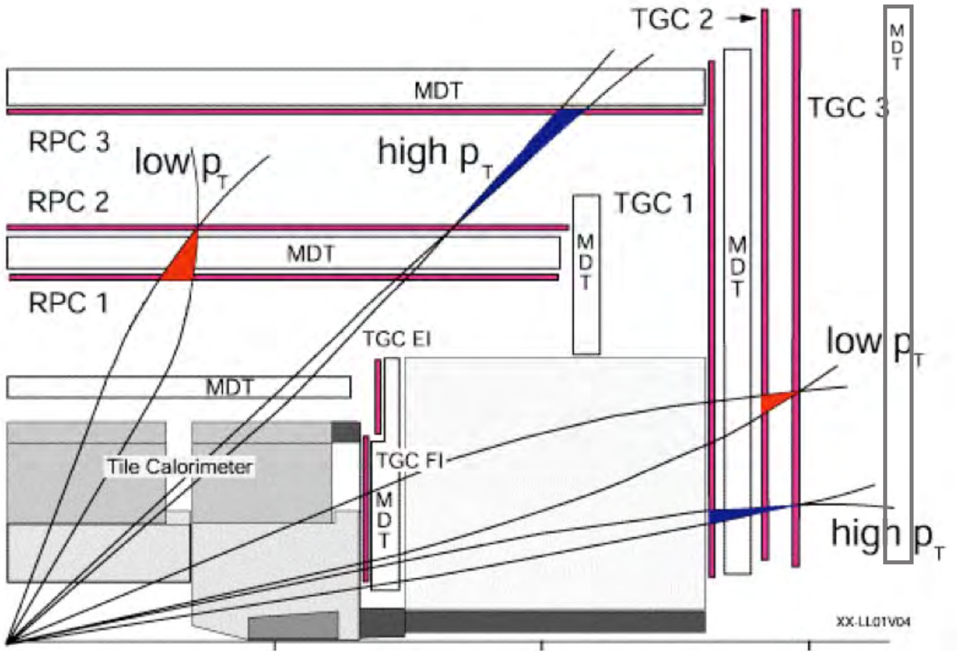


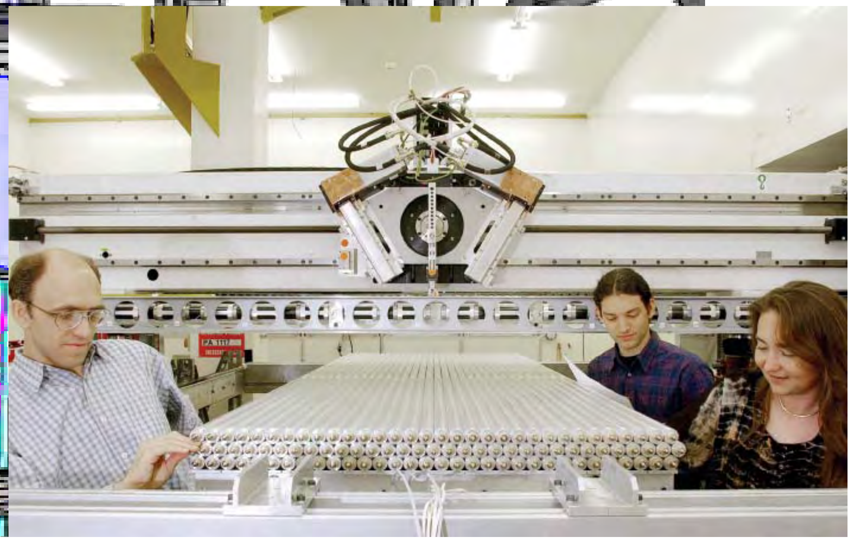


Detector linear within ±0.25% (± 0.1%) for E >10 (40) GeV

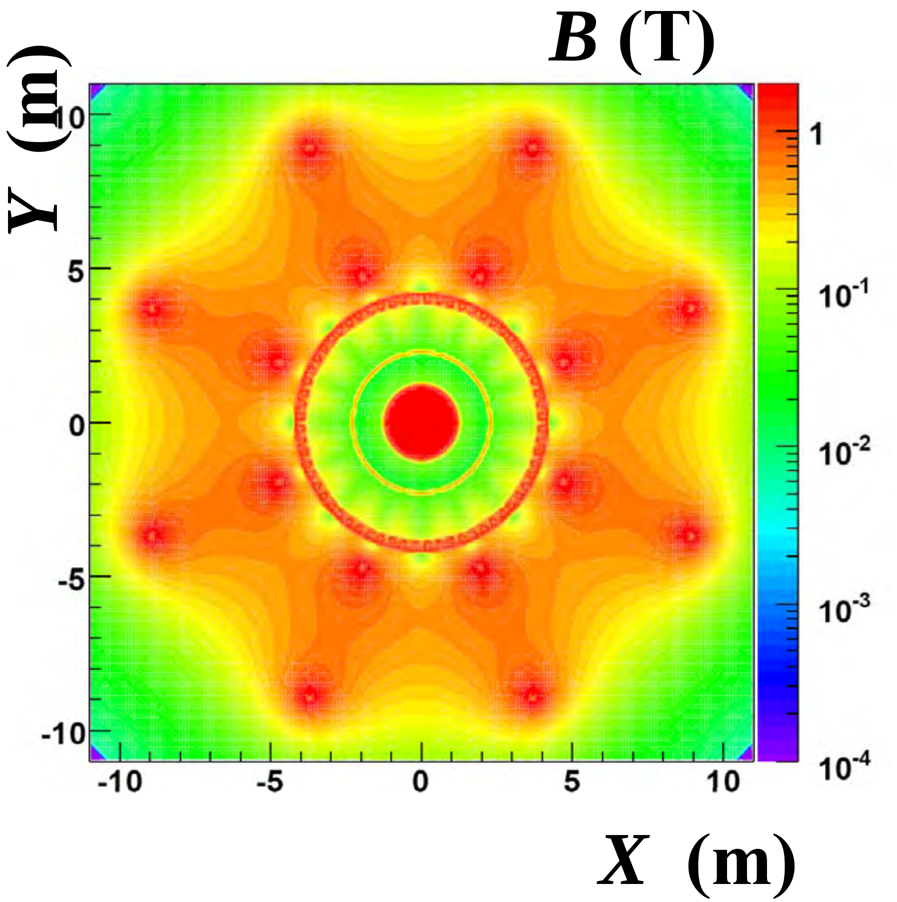
Muon Spectrometer



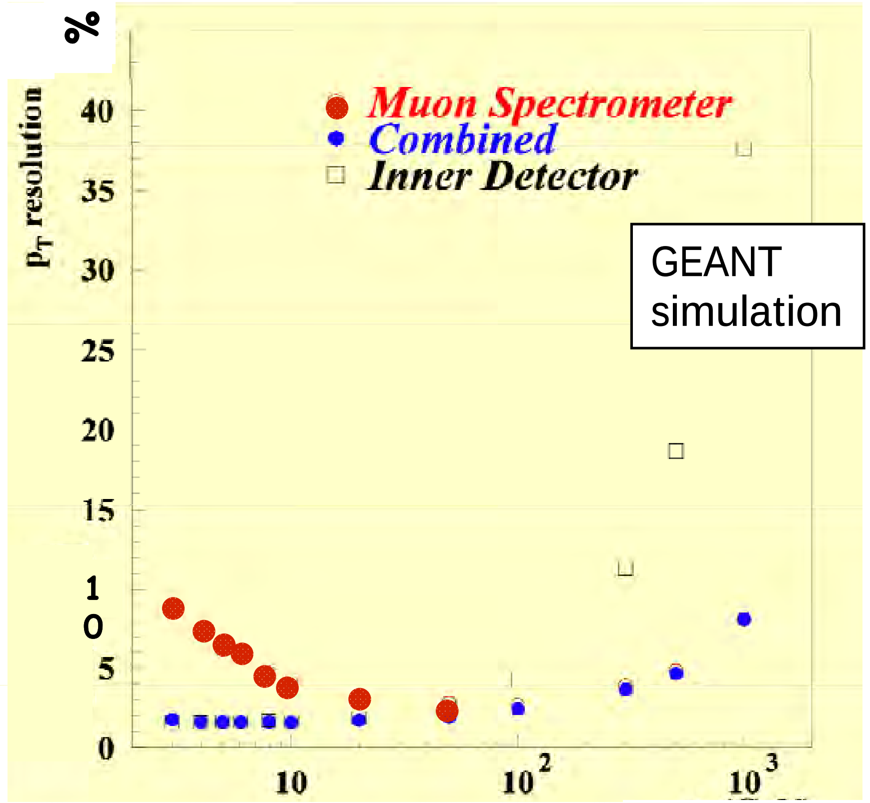




Muon Spectrometer (with stand-alone capability)



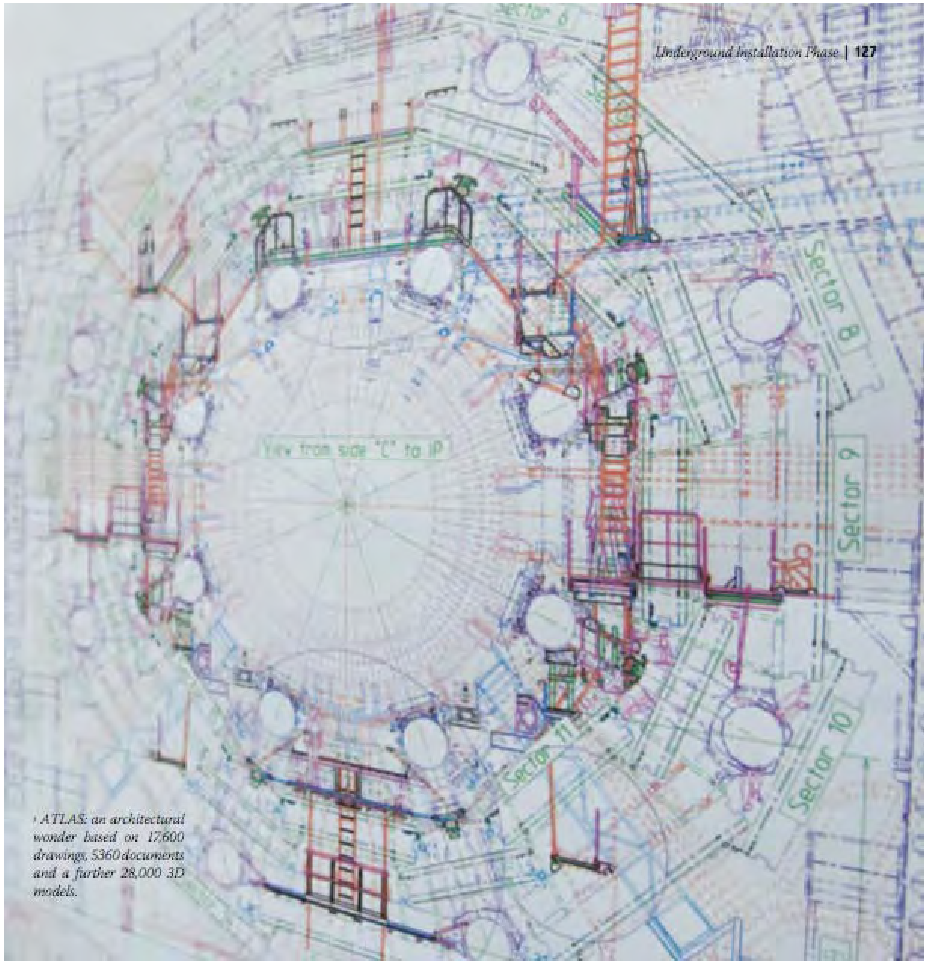
Muon momentum resolution



p_T (GeV)

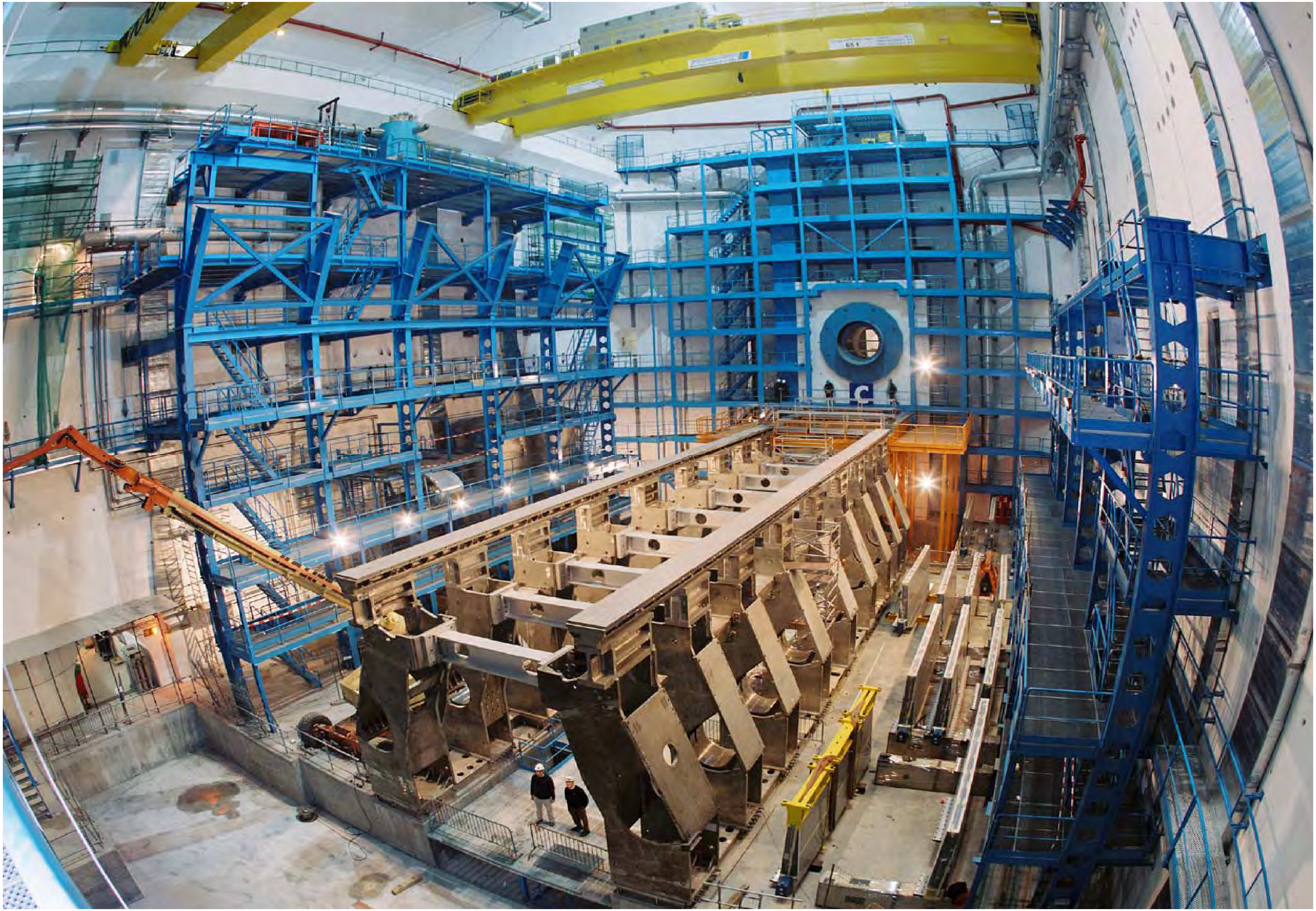
Underground installation

A gigantic 3D puzzle of 20’000 m^3
..... 5 years of great fun !




1998


June 2003





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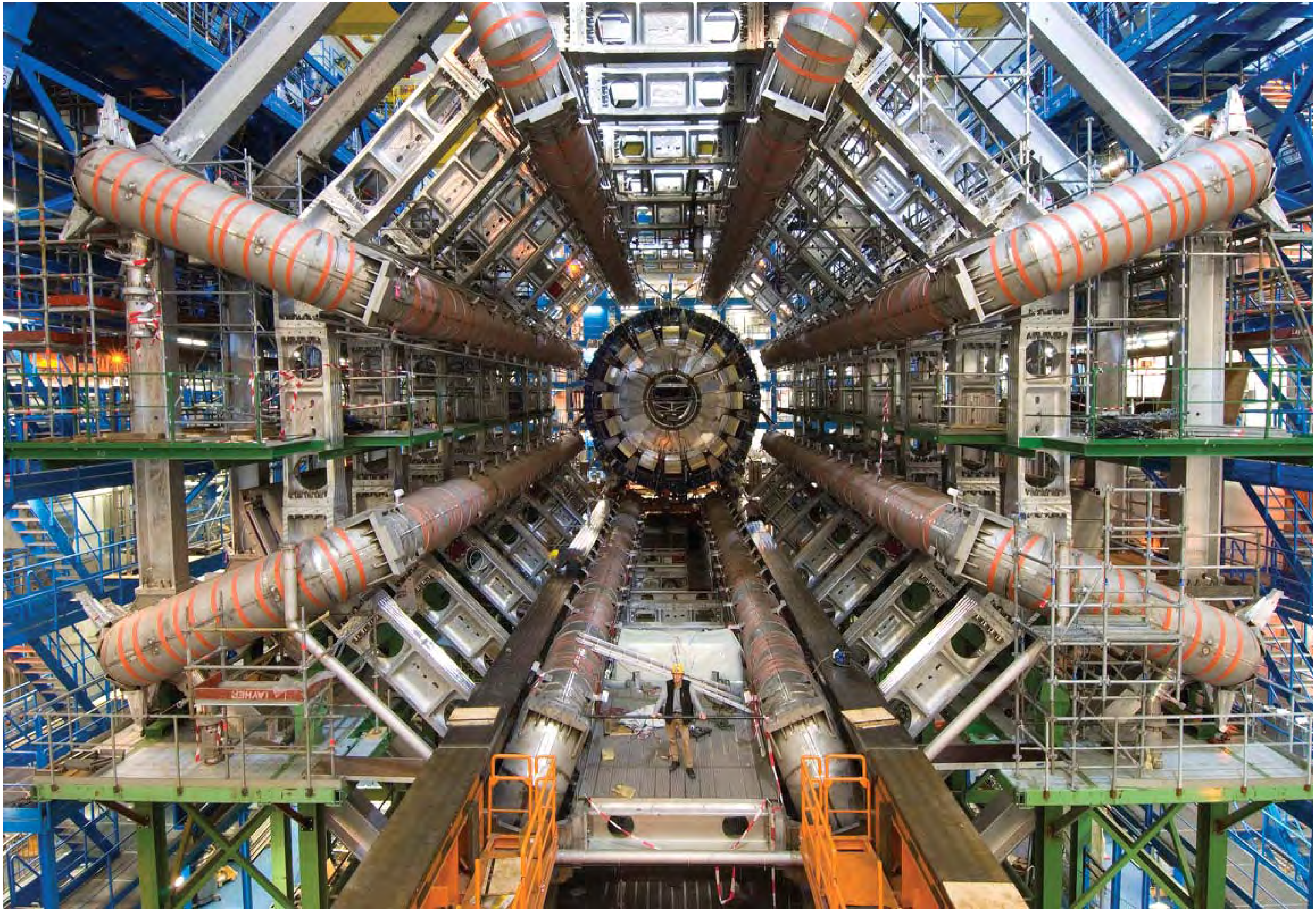
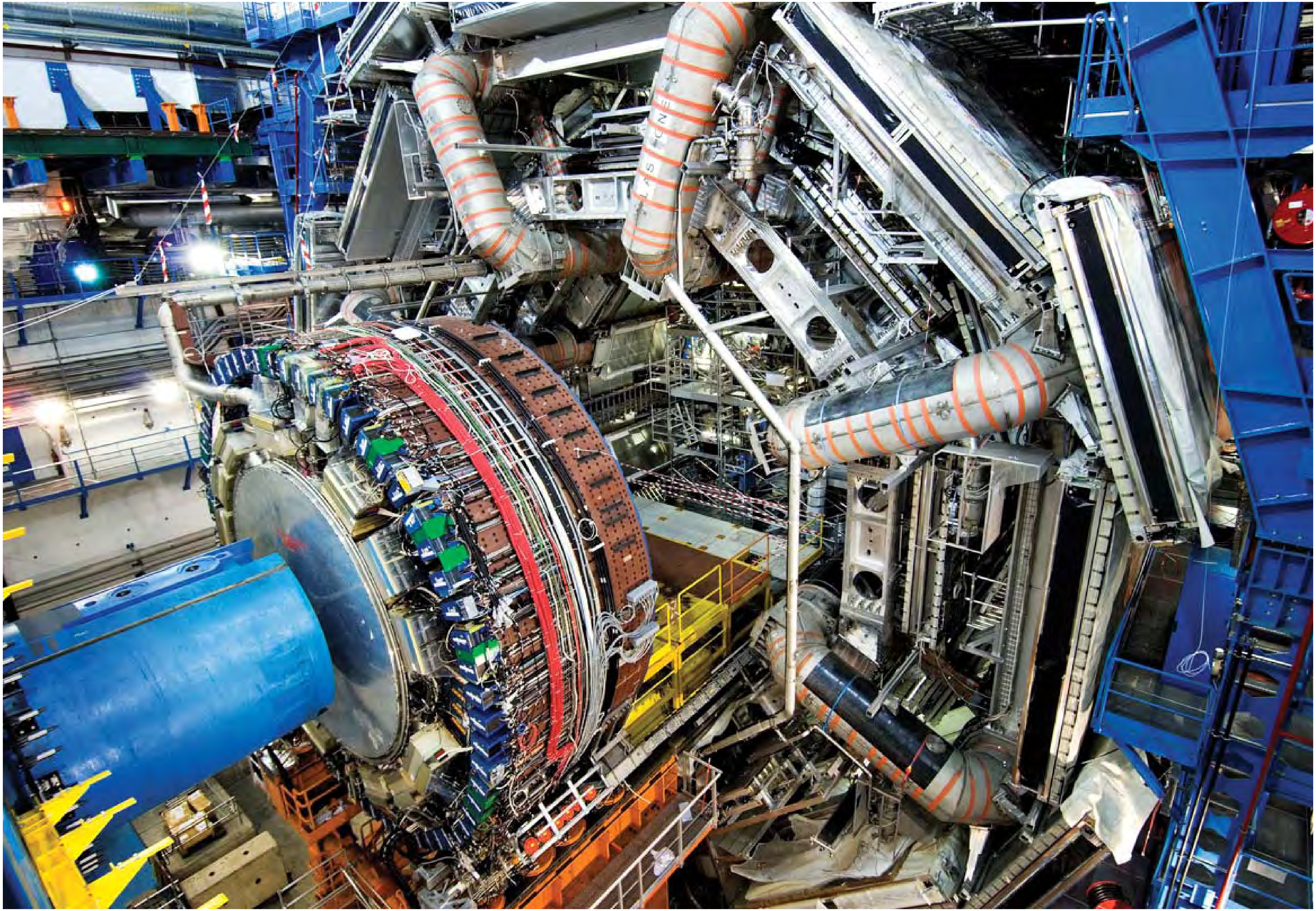
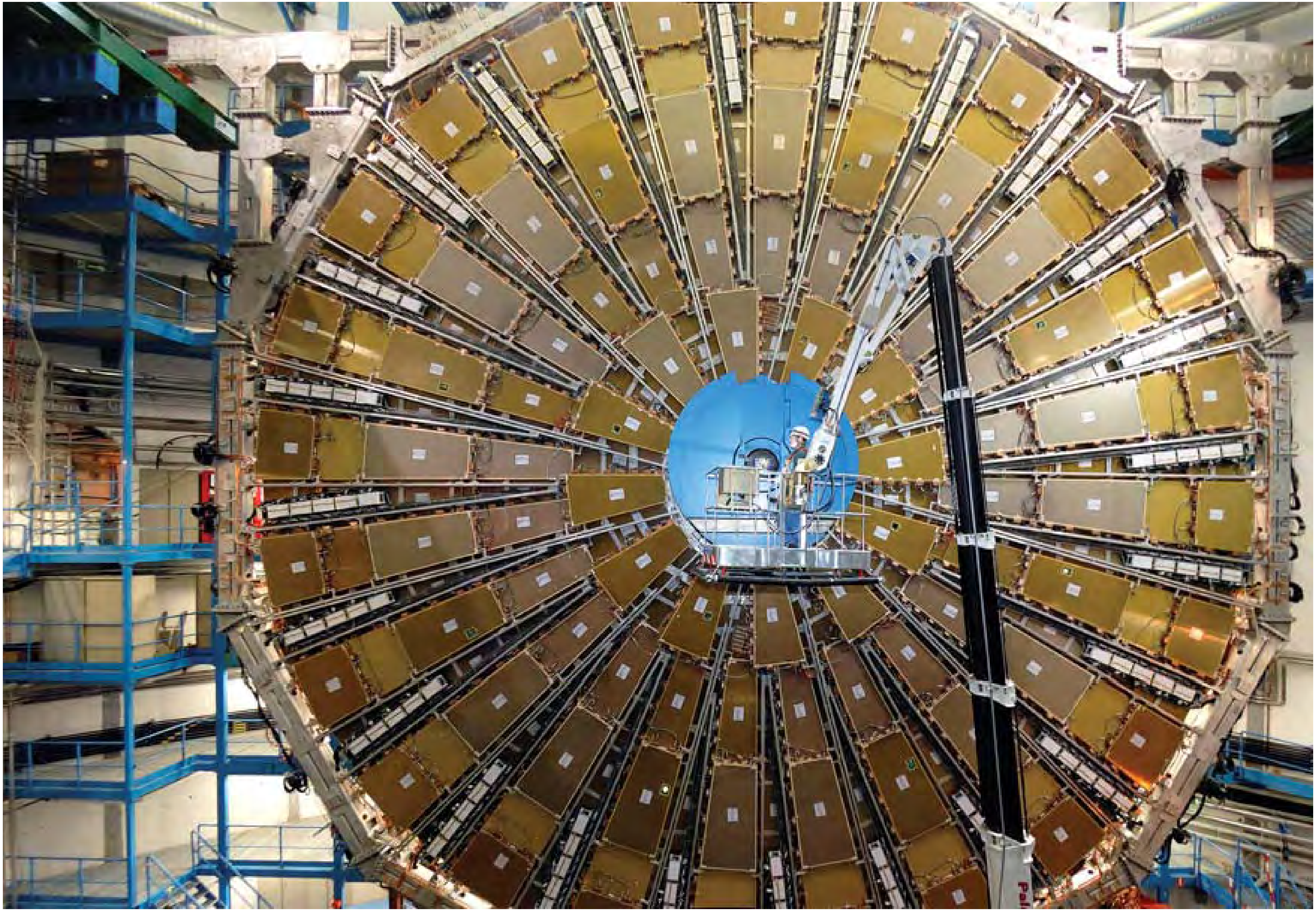
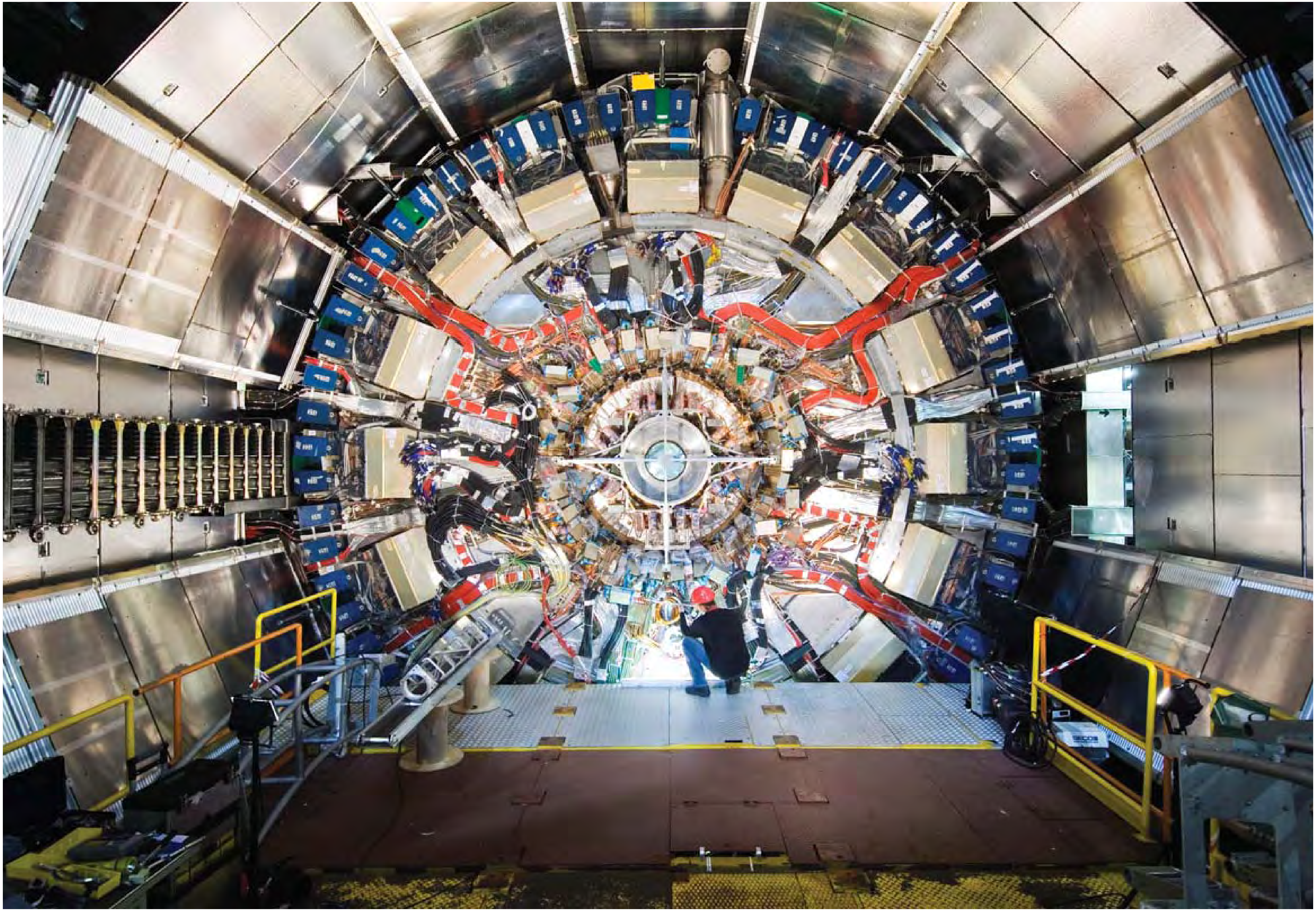
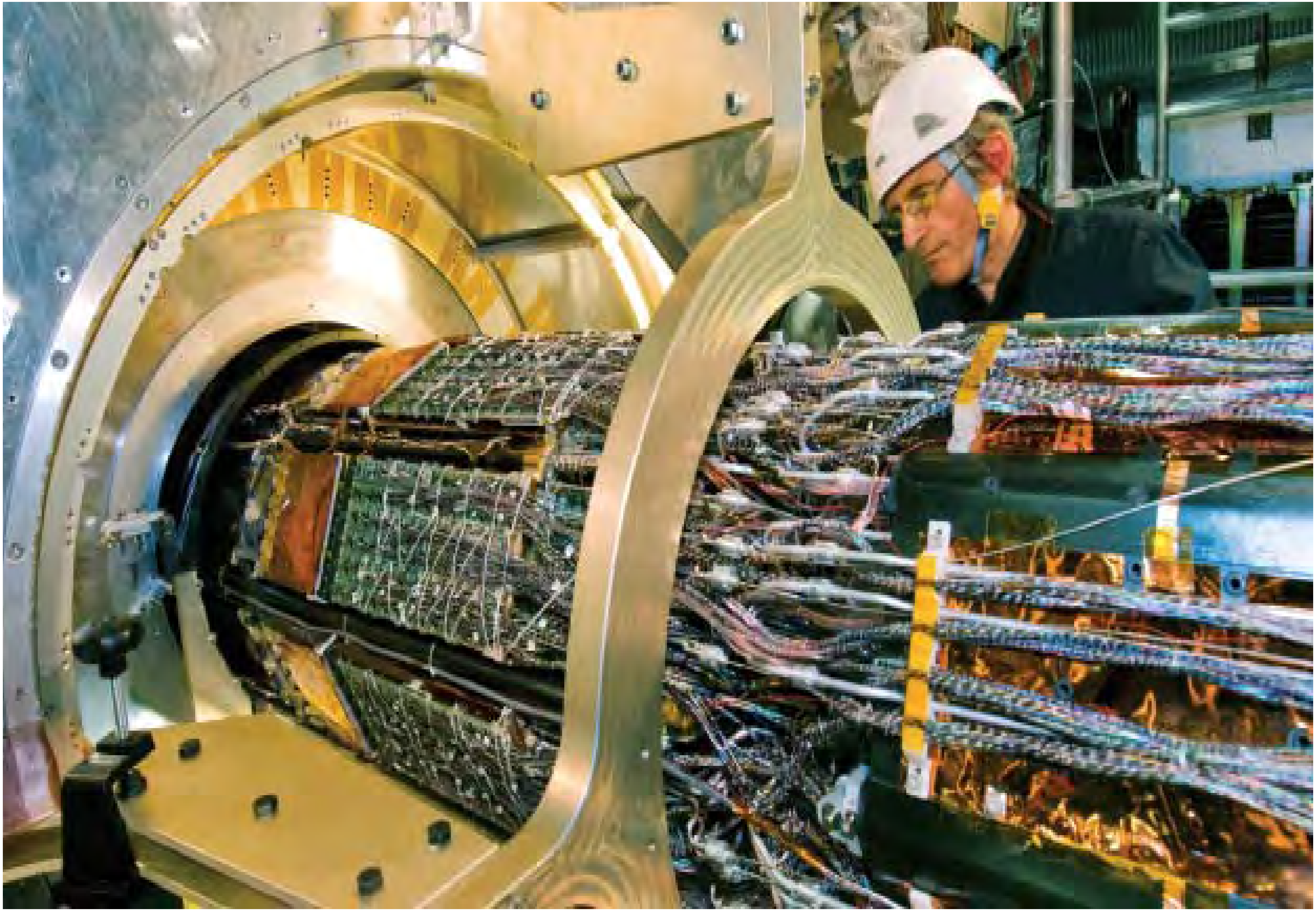
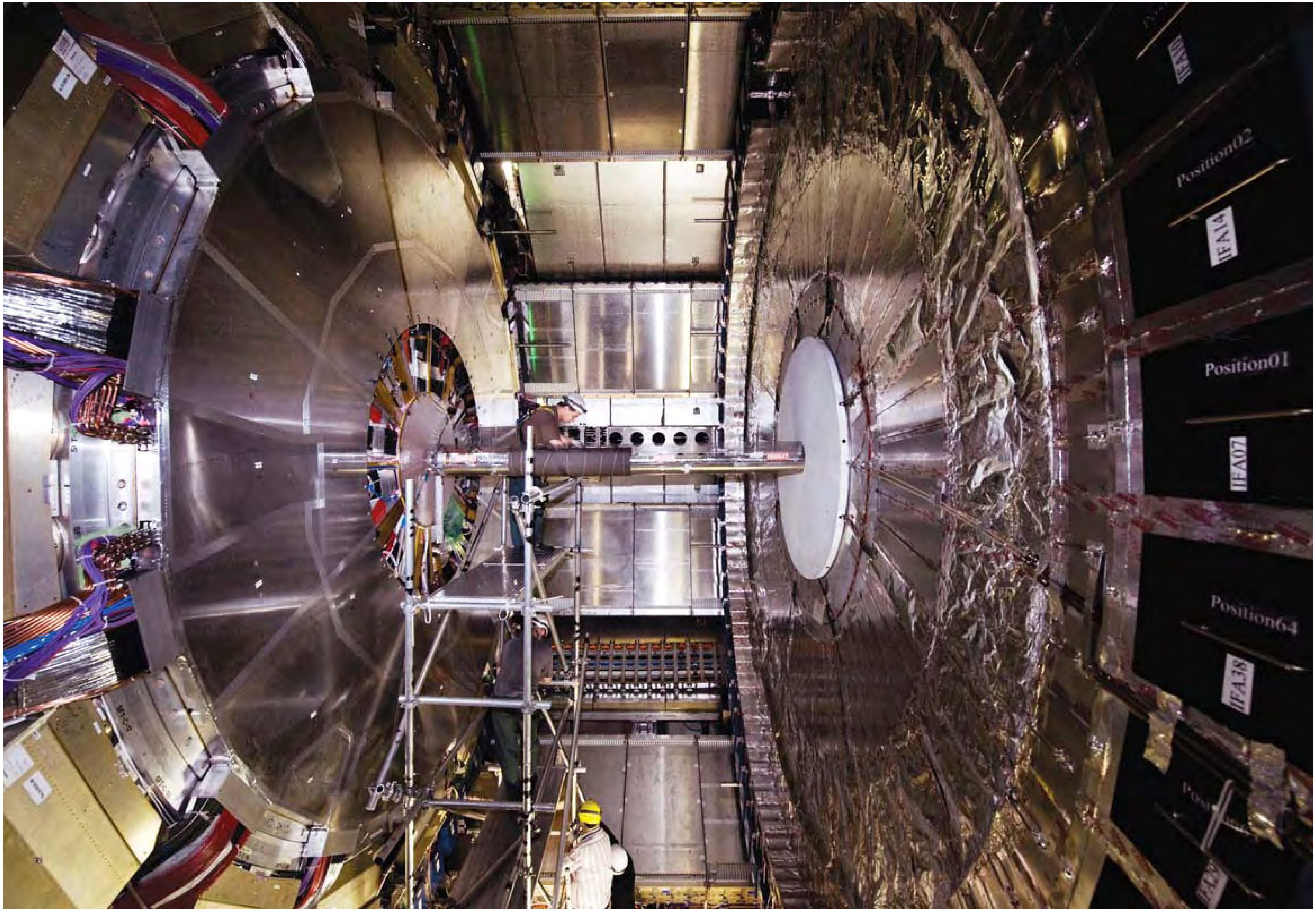


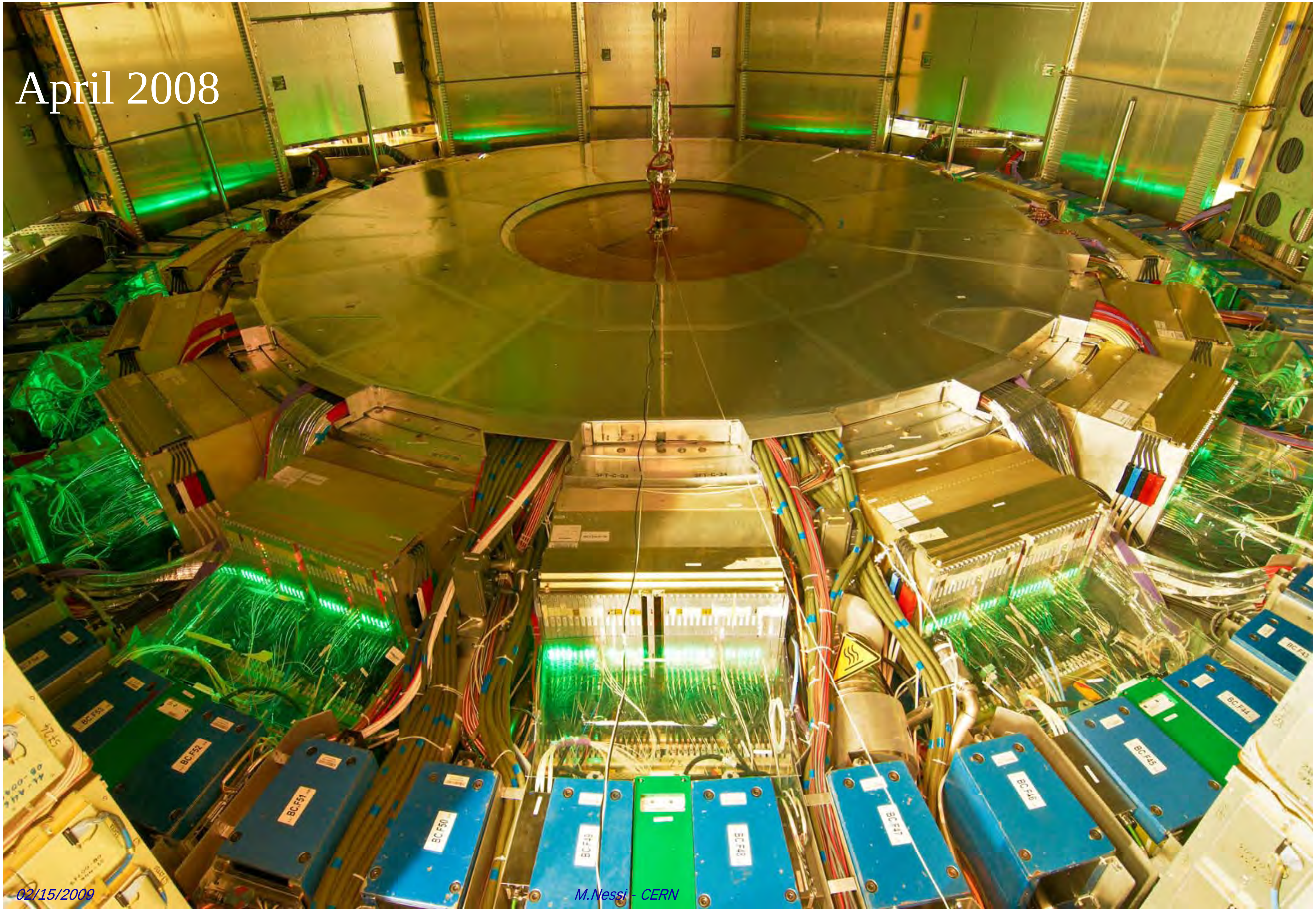


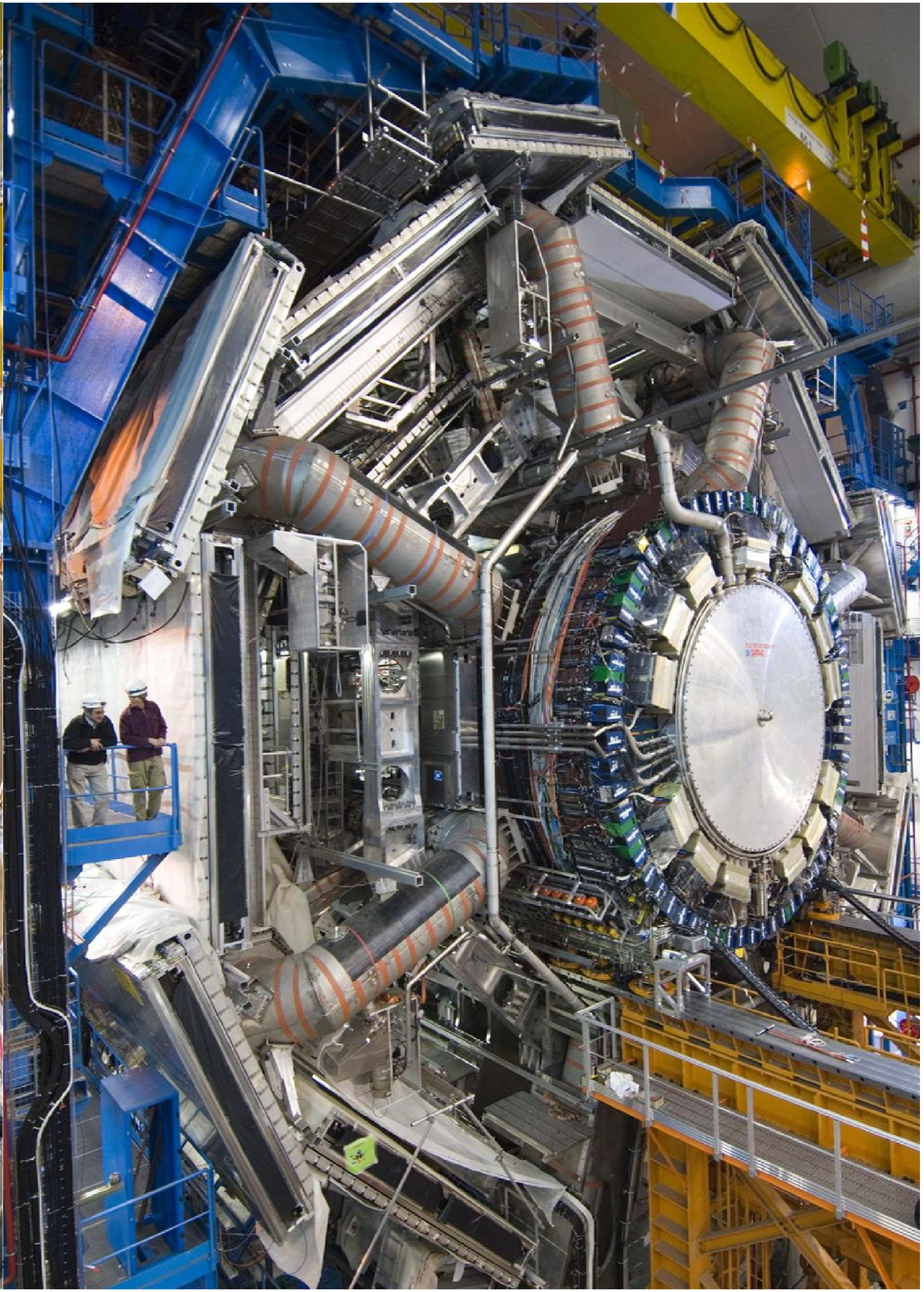




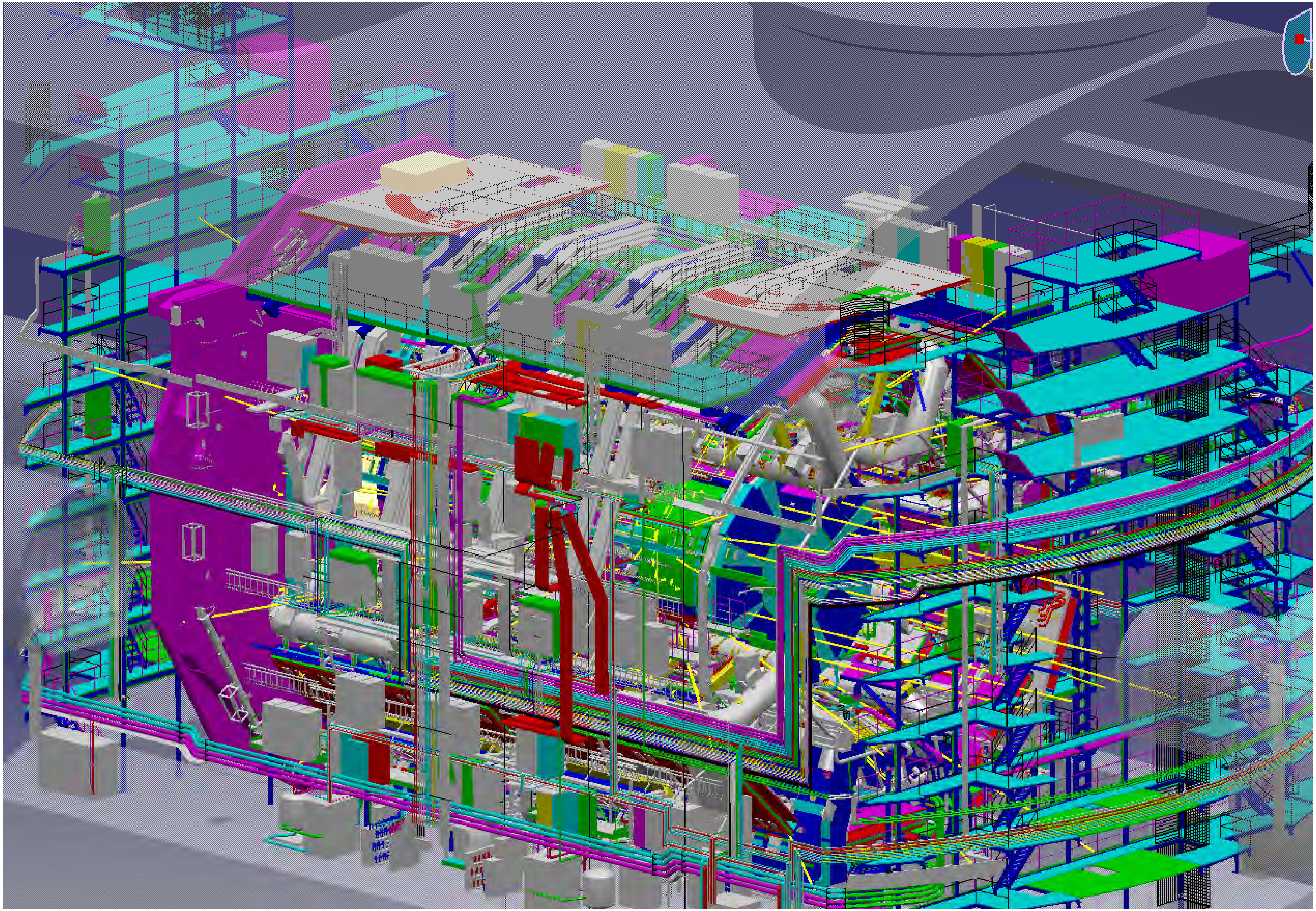


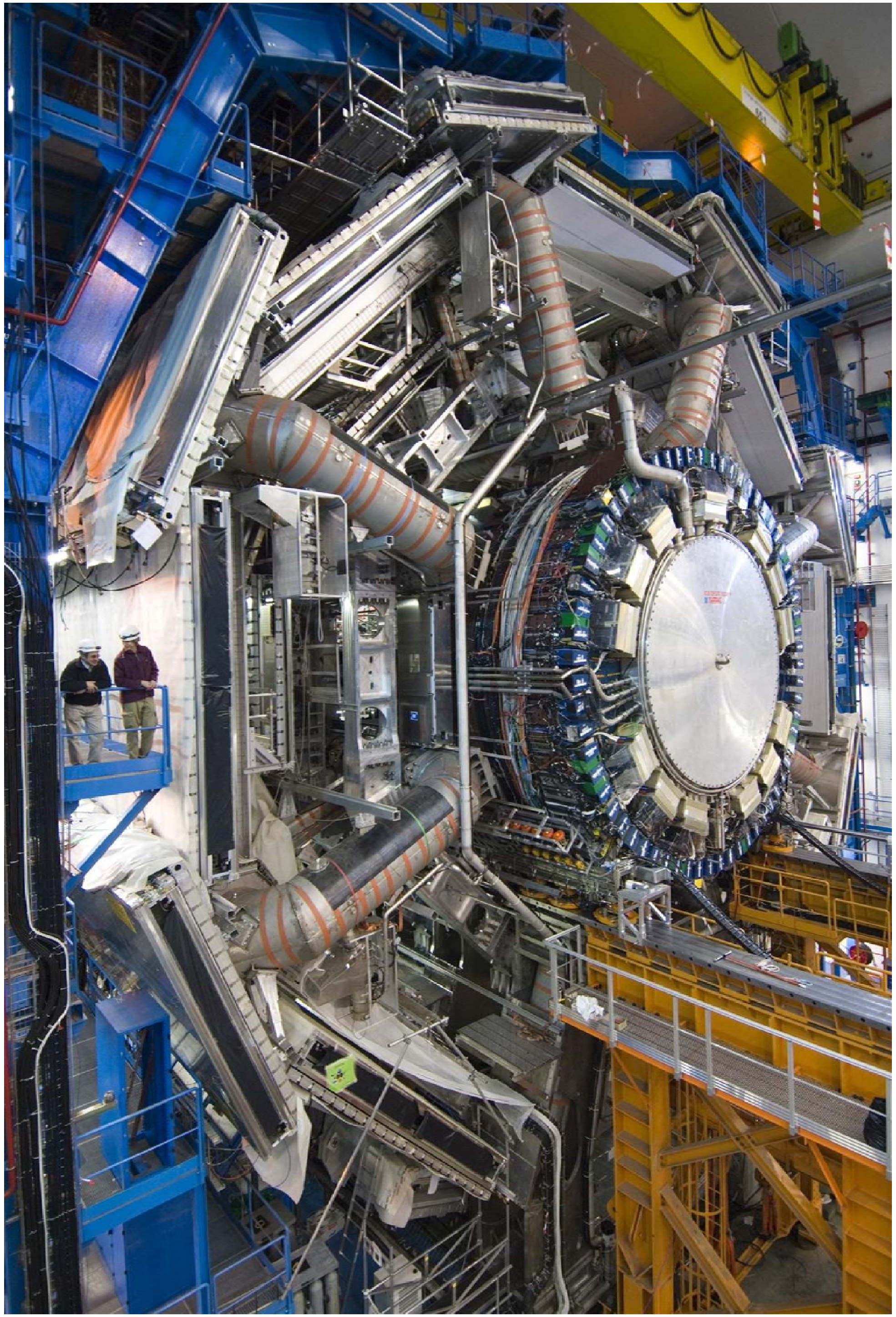

Position02
IFA14
Position01
IFA07
Position64
IFA38


April 2008
BC F52
BC F51
BC F50
BC F48
BC F47
BC F46
BC F45
BC F44

July 2008





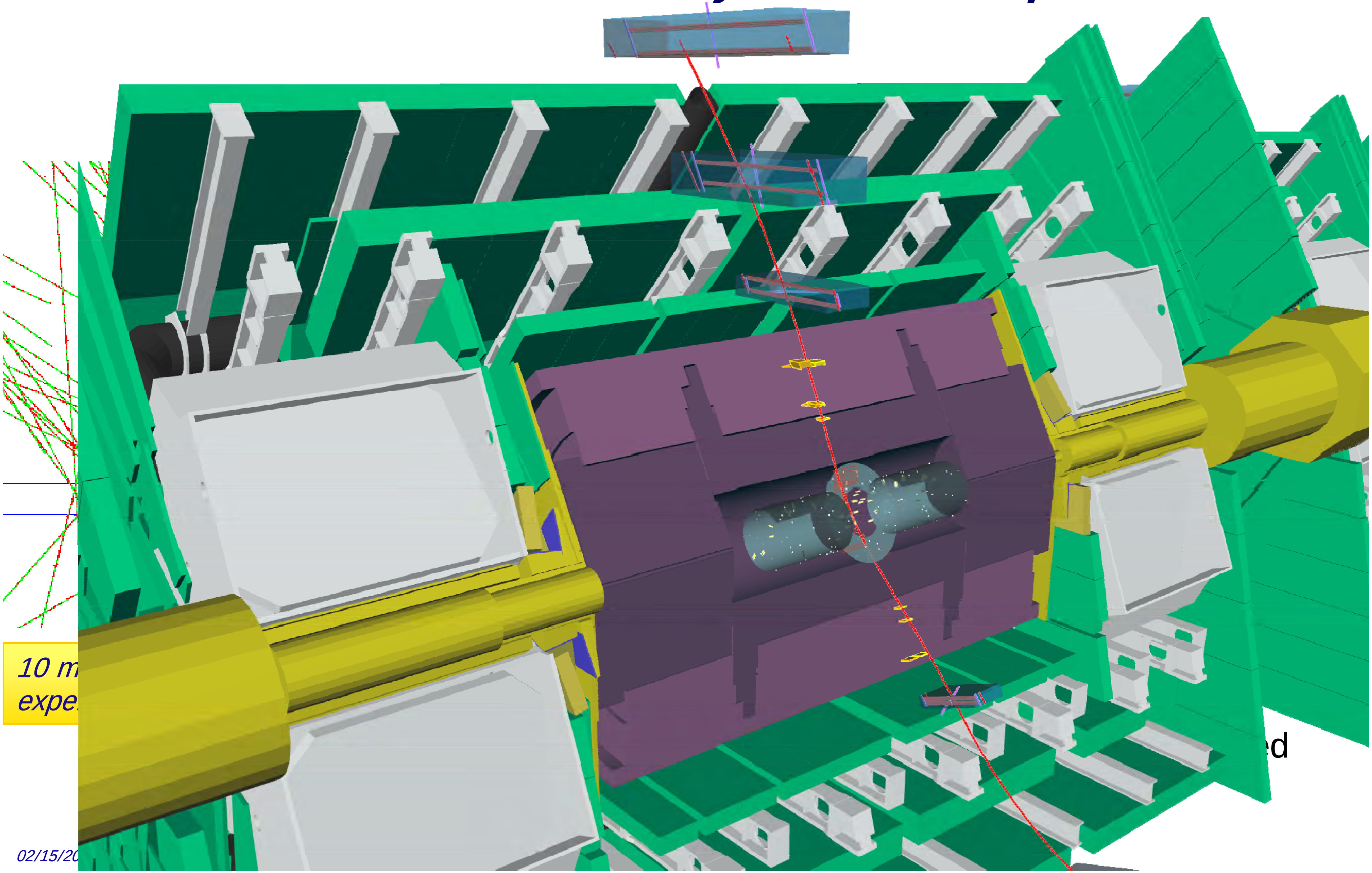
..... but does it really work ?

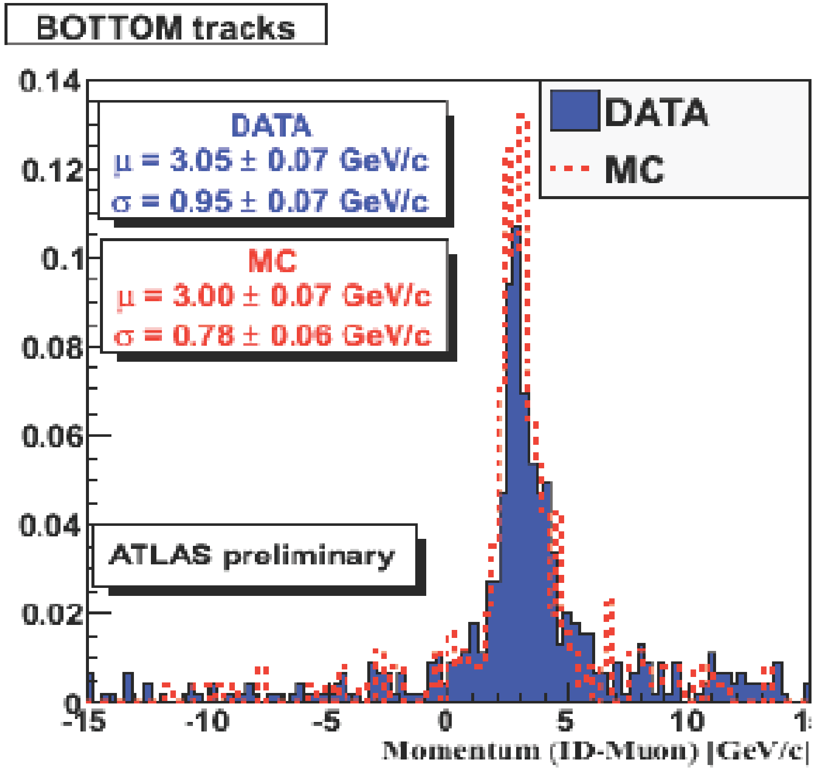
Over the years we have exposed some % of it to particle beams (SPS, reactors,..)

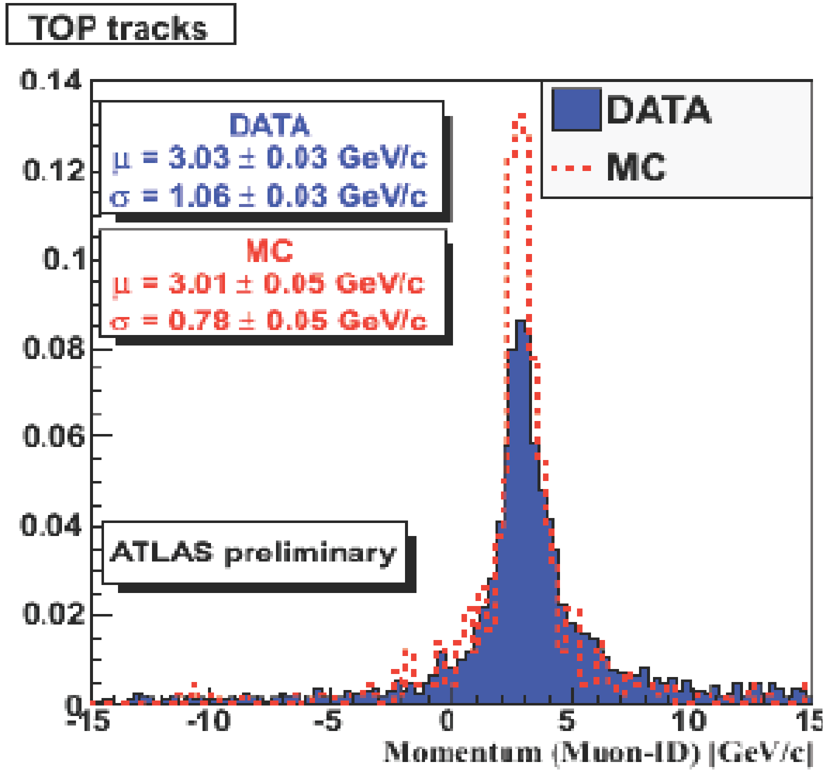
During assembly we collected millions of cosmics events

10-11 September 2008 first LHC beams

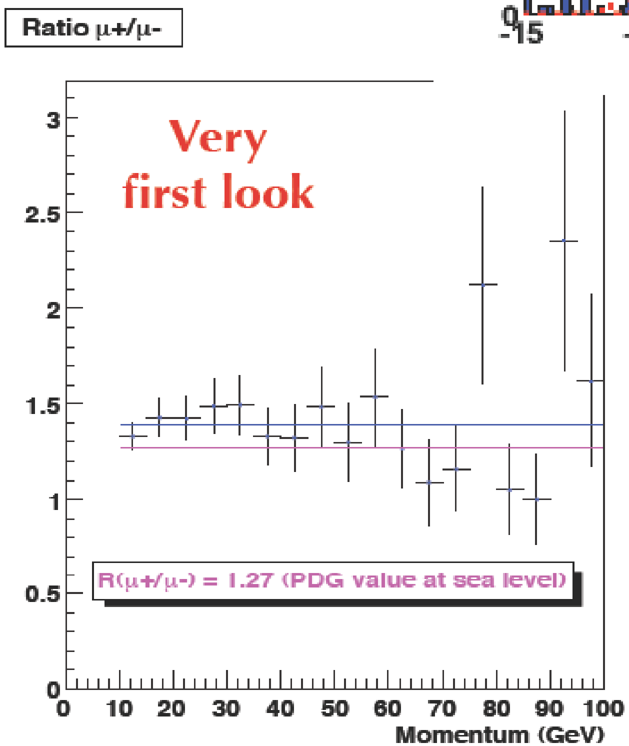
Thanks to cosmic rays … a nice help







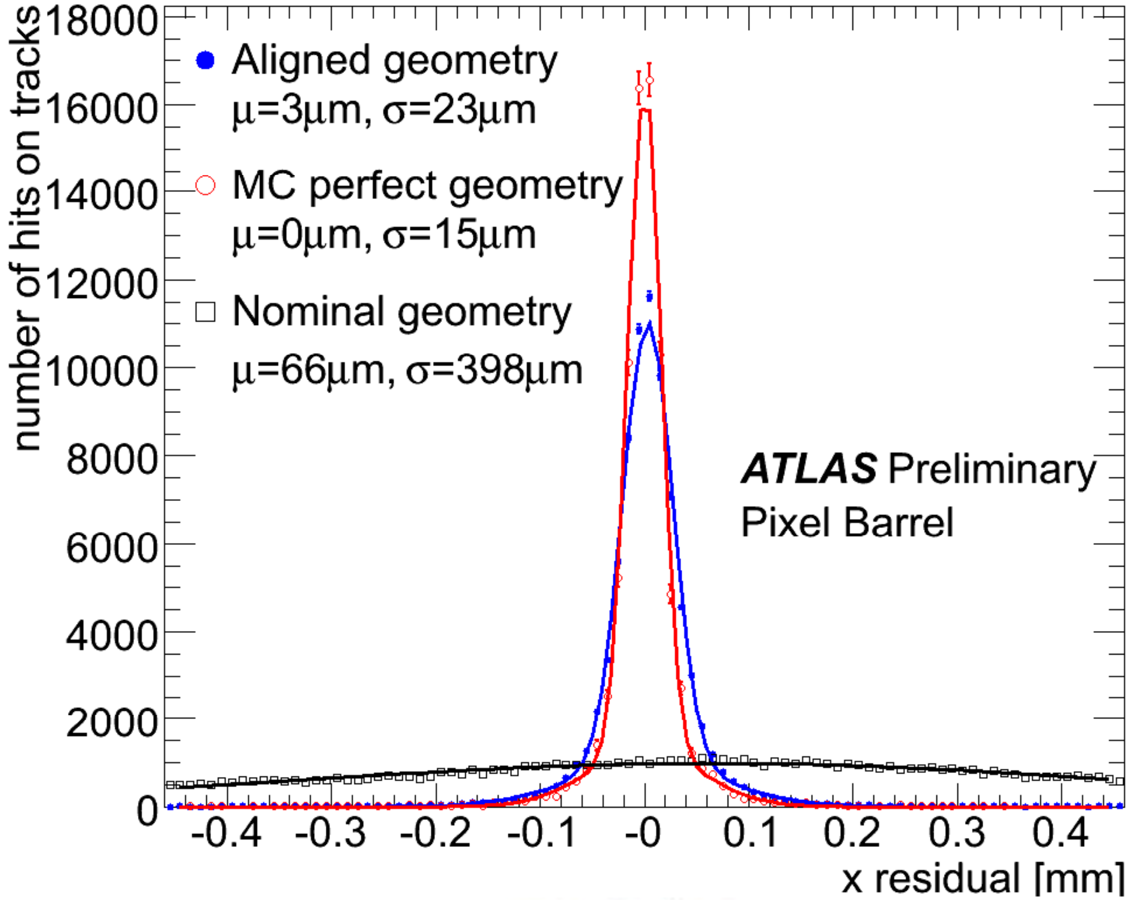
muon energy loss in the calorimeters



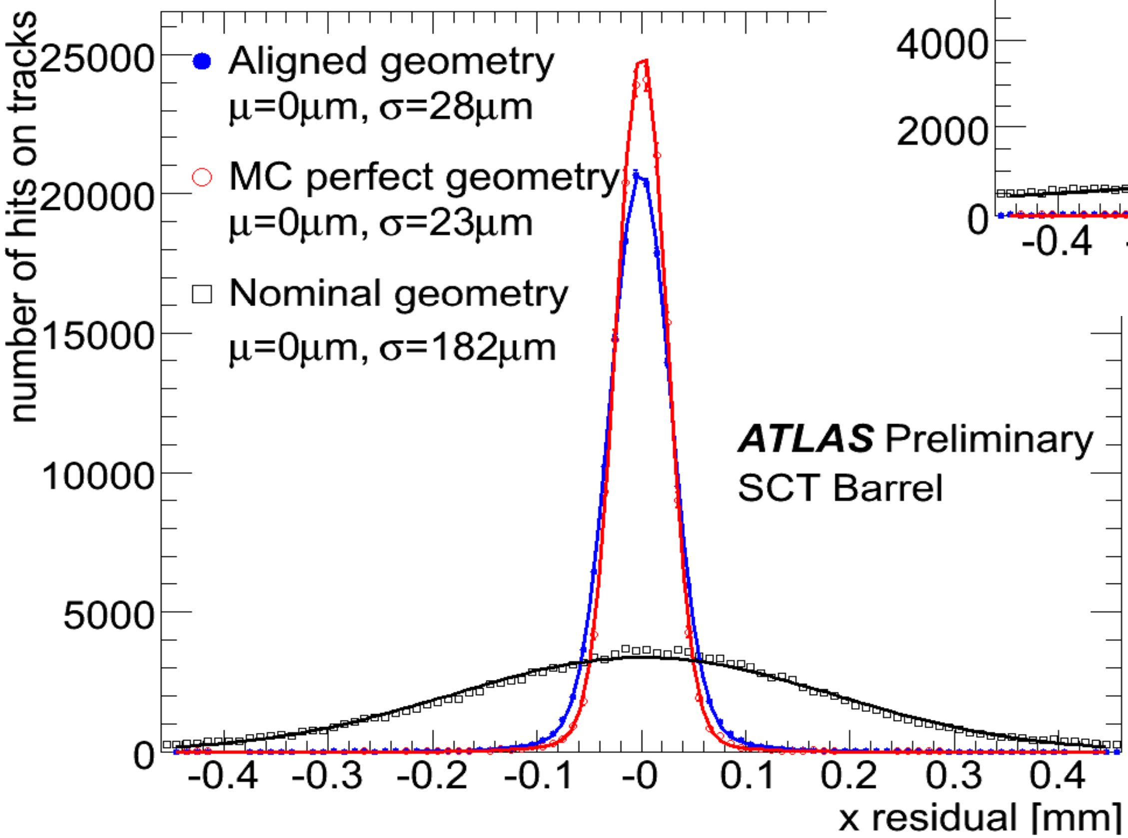
cosmic muons

+ and -

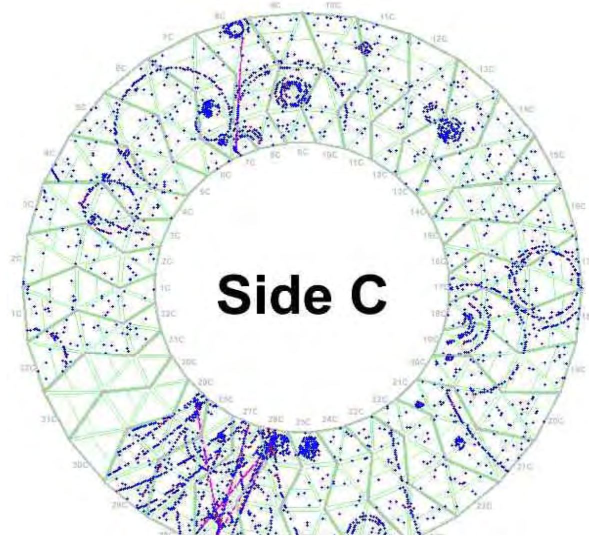
Cosmic rays



number of hits on tracks
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Aligned geometry
μ=3μm, σ=23μm
MC perfect geometry
μ=0μm, σ=15μm
Nominal geometry
μ=66μm, σ=398μm
ATLAS Preliminary
Pixel Barrel
-0.4 -0.3 -0.2 -0.1 -0 0.1 0.2 0.3 0.4
x residual [mm]

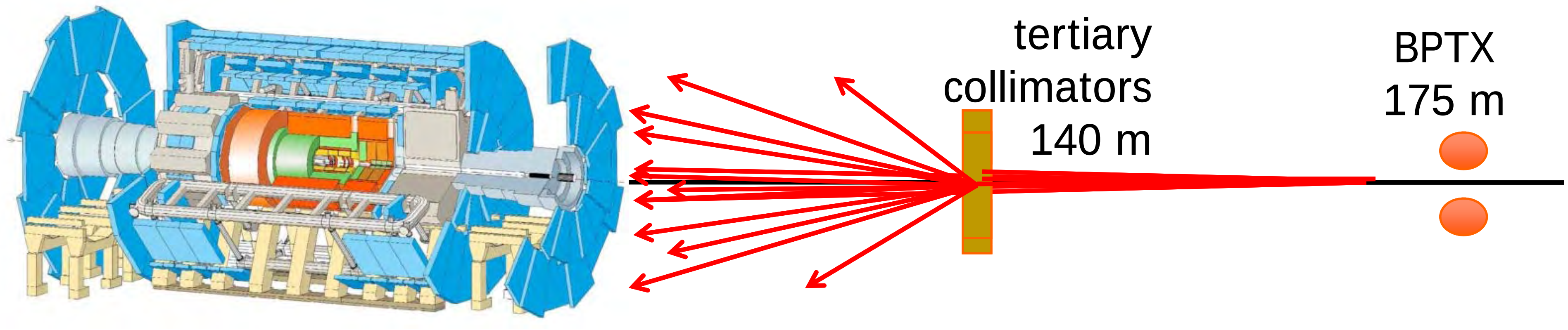


number of hits on tracks
25000
20000
15000
10000
5000
0
Aligned geometry
μ=0μm, σ=28μm
MC perfect geometry
μ=0μm, σ=23μm
Nominal geometry
μ=0μm, σ=182μm
ATLAS Preliminary
SCT Barrel
-0.4 -0.3 -0.2 -0.1 -0 0.1 0.2 0.3 0.4
x residual [mm]



Side C

10 September: first beam

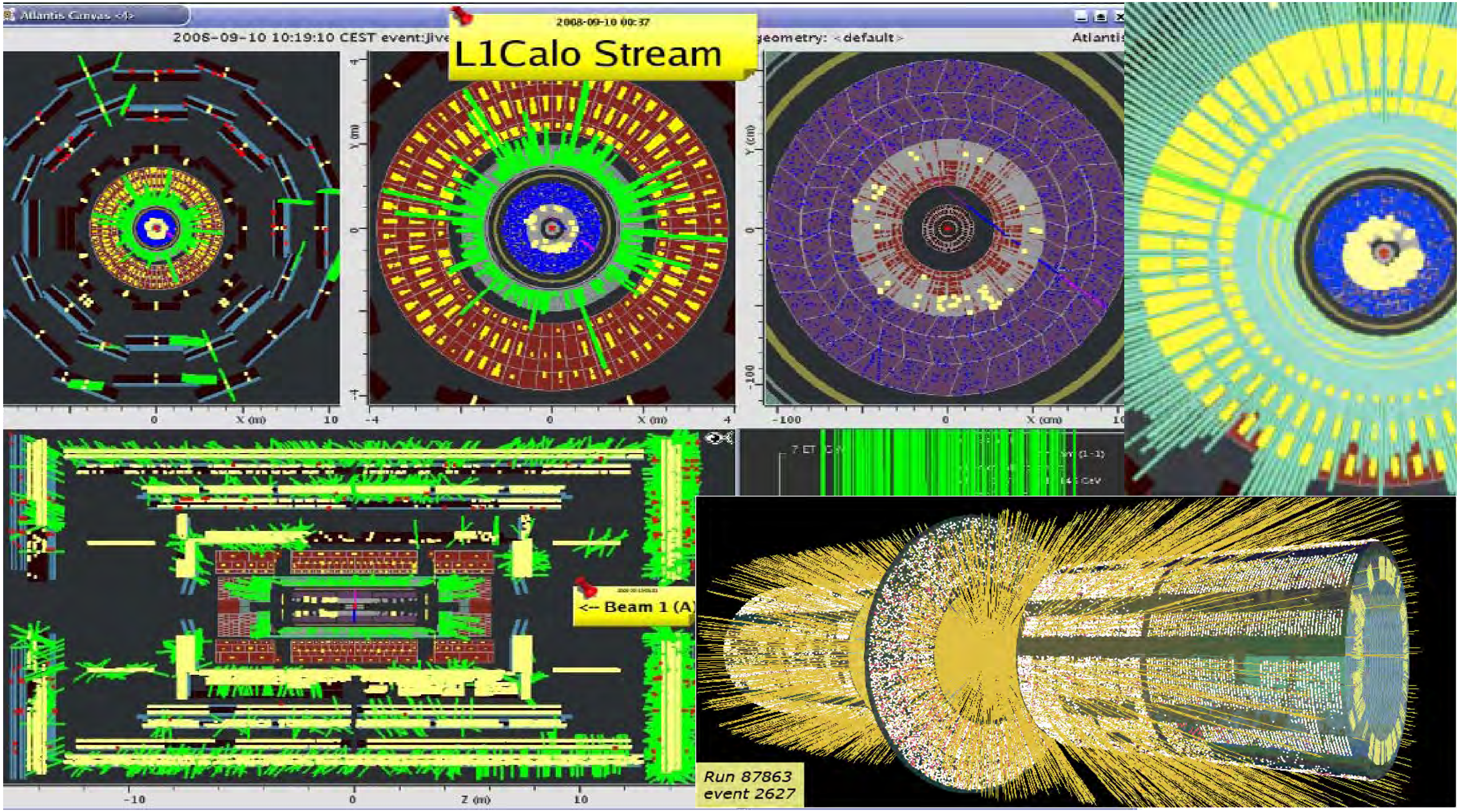


We had no chance to have some beam in advance to test our readout synchronization, all was extrapolated from cosmics runs

Active detectors near to the beam pipe (inner tracker, forward calorimeters,....) were set at reduced HV .... Pixel detector off

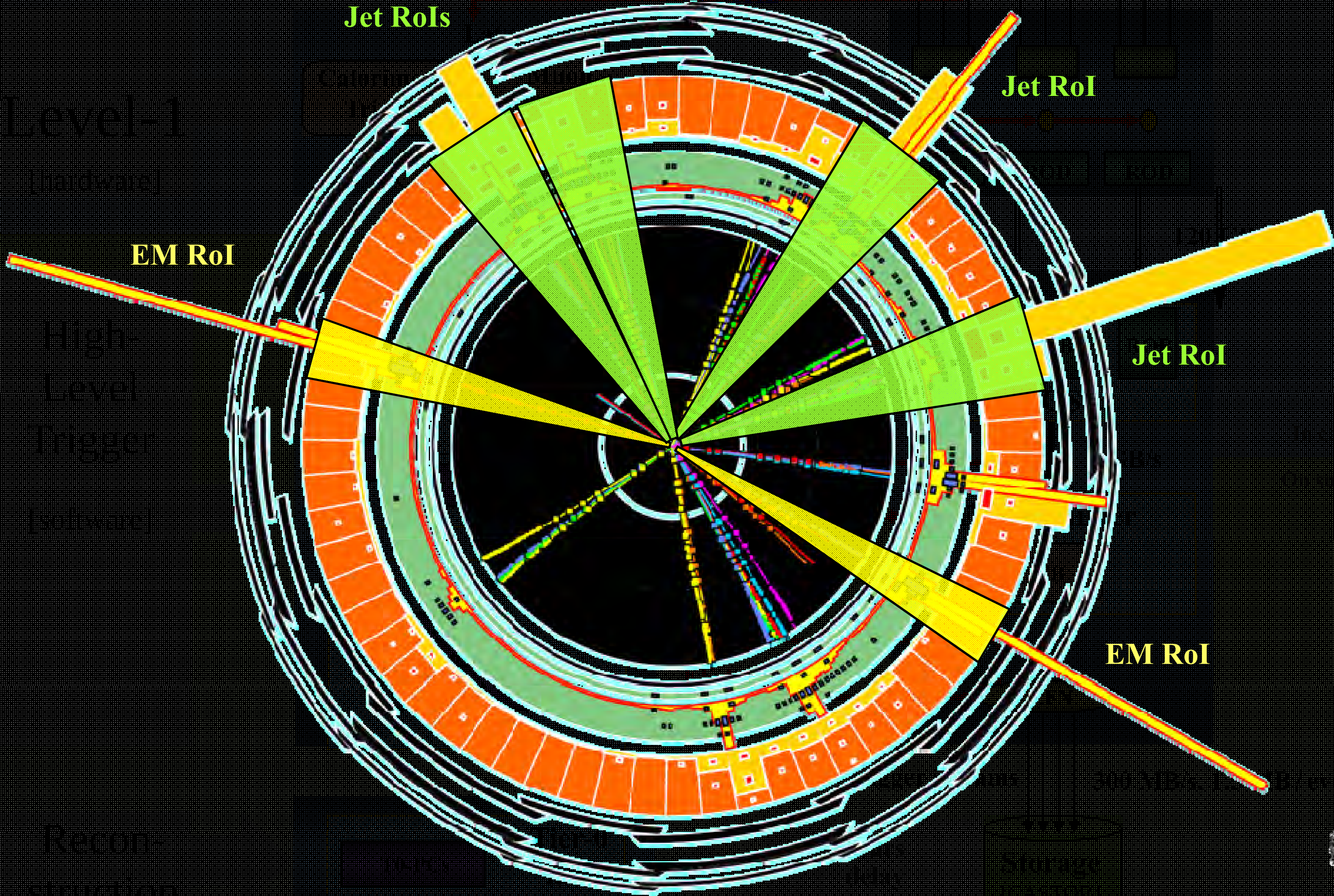
..... and it worked ... first shots, first detector pictures ... a lot of energy released in the detector

..... once beam RF captured, we started looking for beam halo

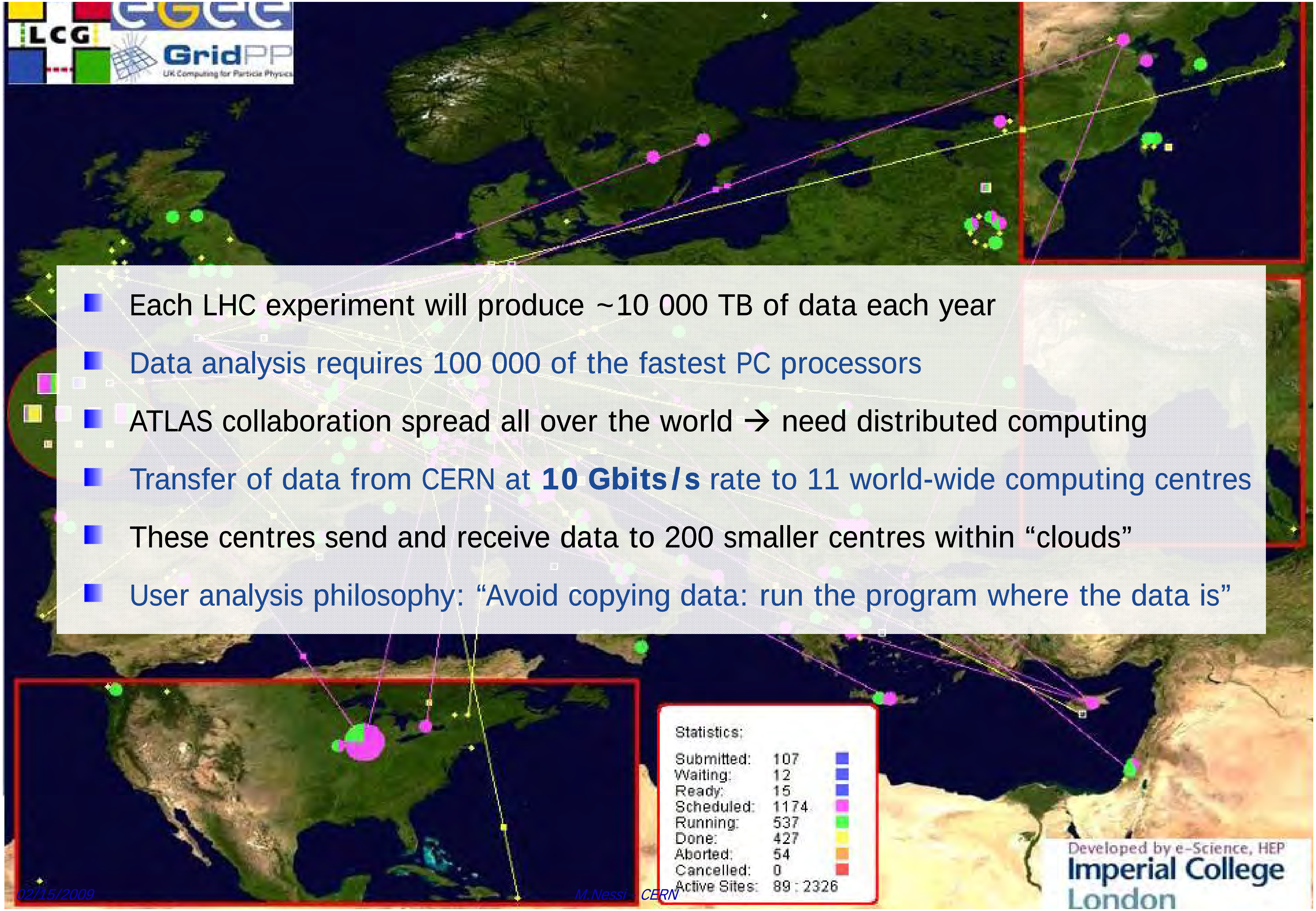


Atlantis Canvas <4>
2008-09-10 10:19:10 CEST event:jive
2008-09-10 00:37
L1Calo Stream
geometry: <default>
Atlantis
<-- Beam 1 (A)
Run 87863
event 2627

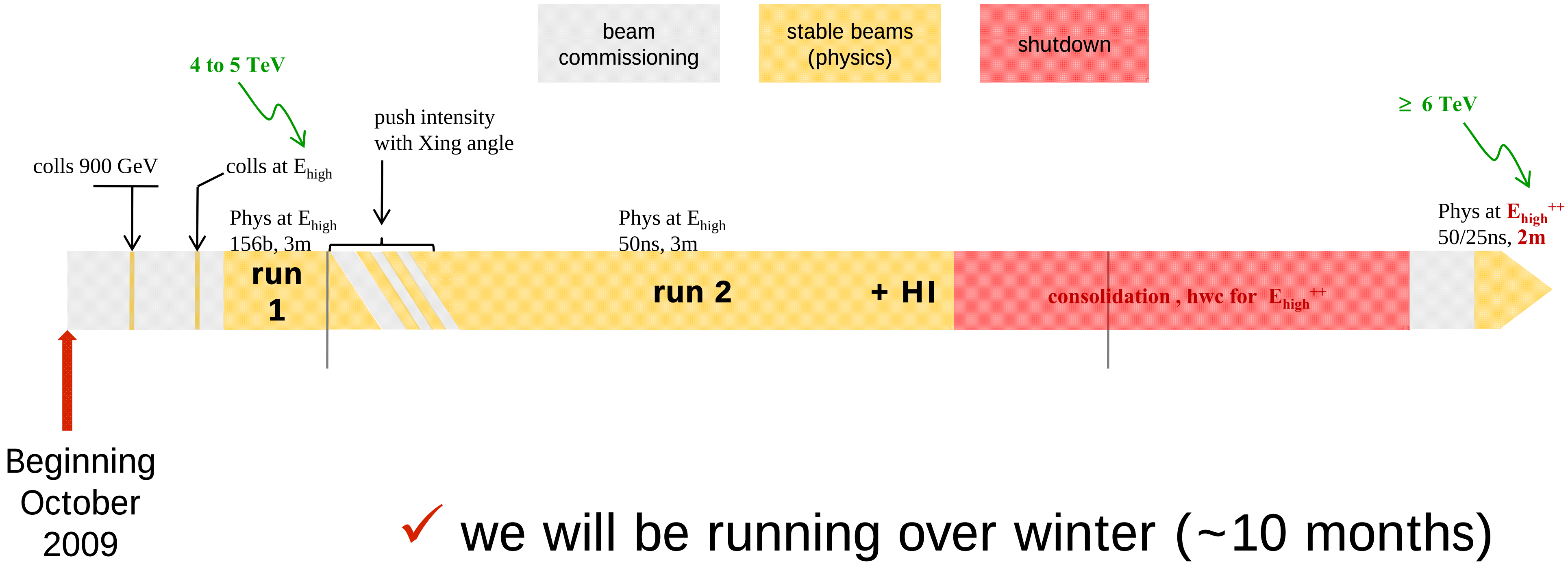
Regions of Interest (RoI)



- Each LHC experiment will produce ~10 000 TB of data each year
- Data analysis requires 100 000 of the fastest PC processors
- ATLAS collaboration spread all over the world → need distributed computing
- Transfer of data from CERN at **10 Gbits/s** rate to 11 world-wide computing centres
- These centres send and receive data to 200 smaller centres within "clouds"
- User analysis philosophy: "Avoid copying data: run the program where the data is"

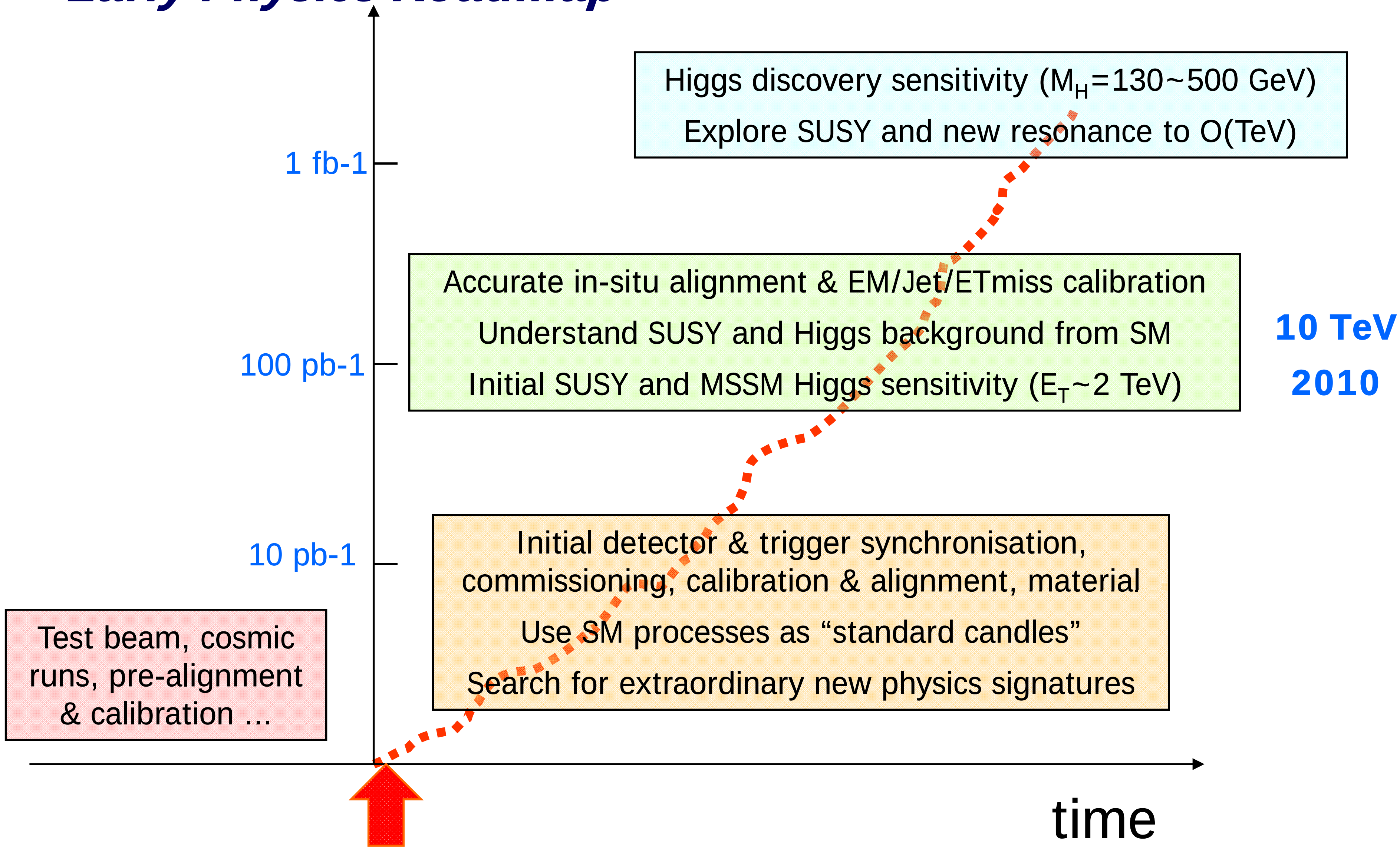


What is next (experiments desiderata) ?



- ✓ we will be running over winter (~10 months)
- ✓ 4+4 going to 5+5 TeV in 2010
- ✓ ~100 pb^{-1} to match today's Tevatron statistics
- ✓ ~200 pb^{-1} to open discovery windows

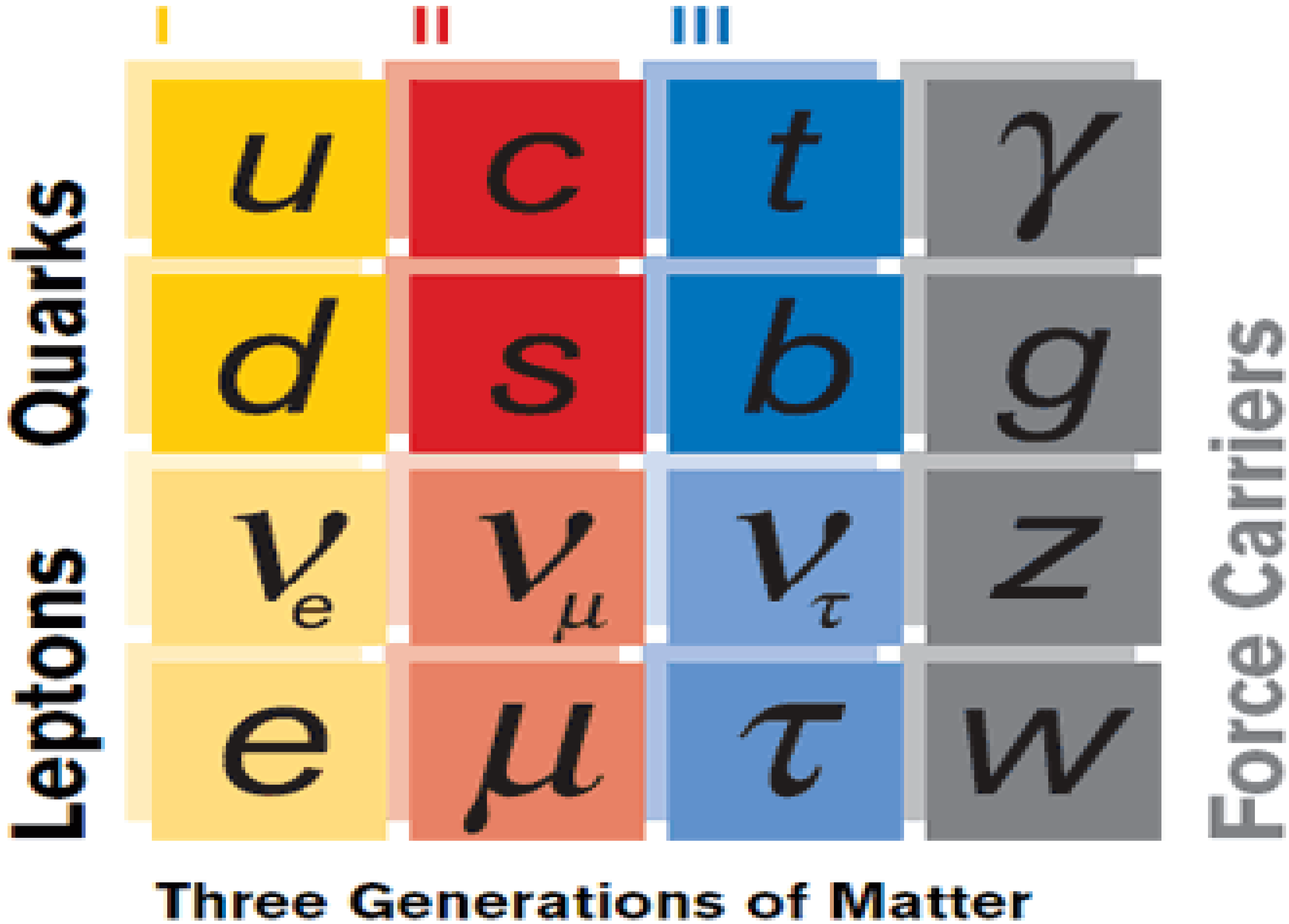
Early Physics Roadmap



Recall: $1\ pb^{-1} = 10^{36}\ cm^{-2}$

1 second at $L = 10^{31}\ cm^{-2}s^{-1} \rightarrow \int L dt = 10^{-5}\ pb^{-1}$

10h running day at $L = 10^{31}\ cm^{-2}s^{-1} \rightarrow \int L dt = 0.36\ pb^{-1}$


I
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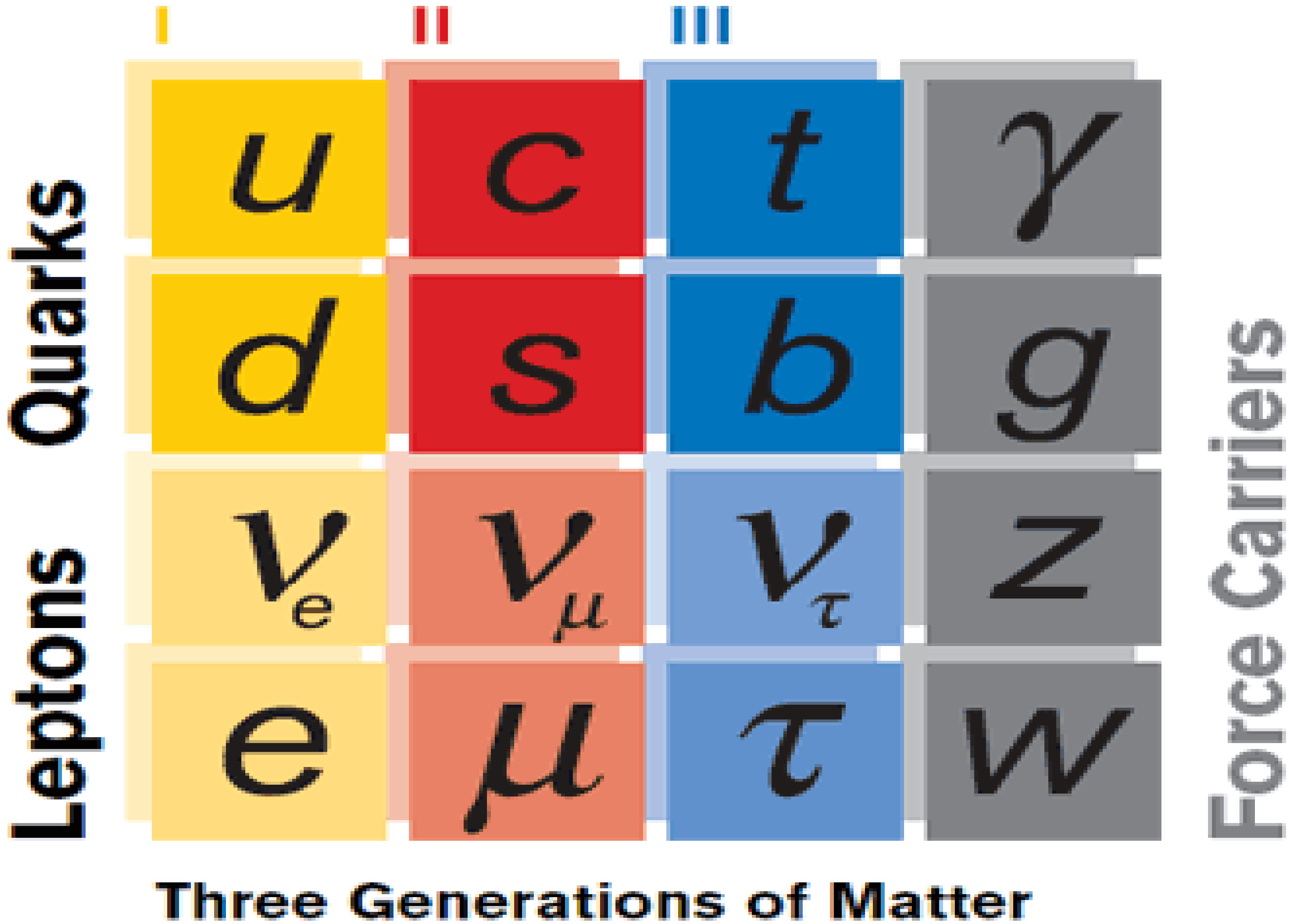
W
Force Carriers
Three Generations of Matter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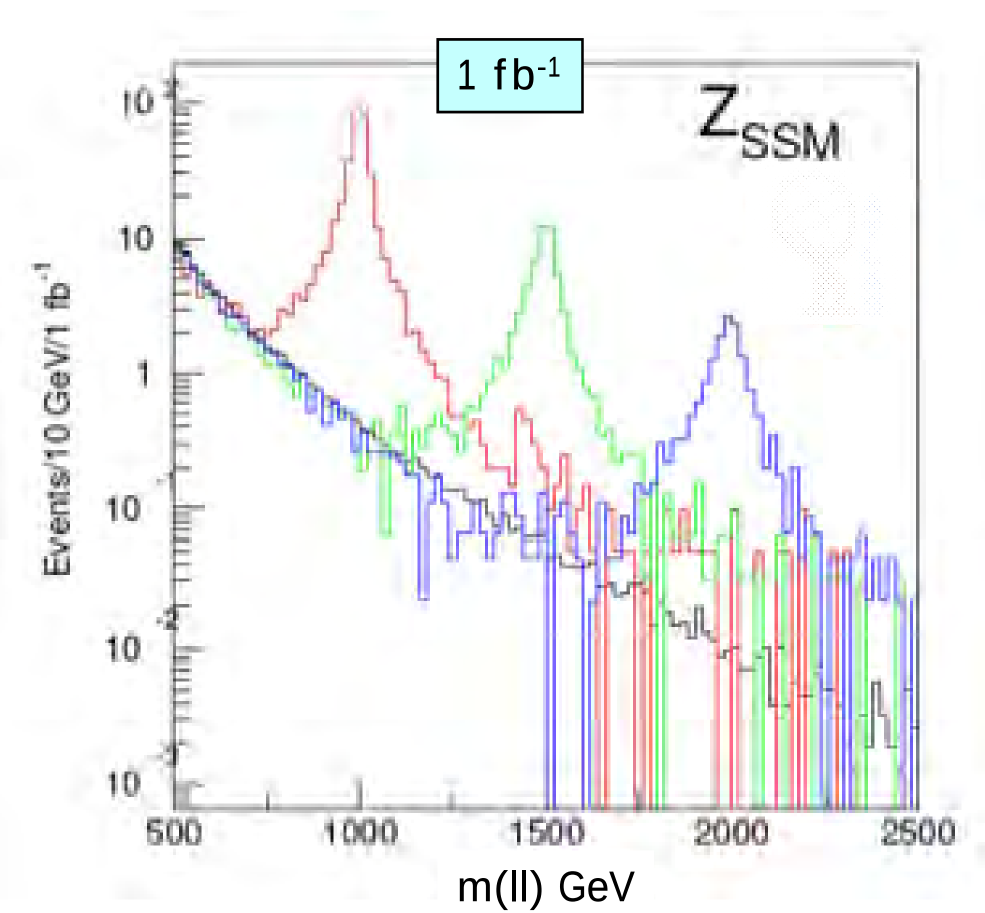
Three Generations of Matter

What about new physics
~ 200 pb^{-1} ?

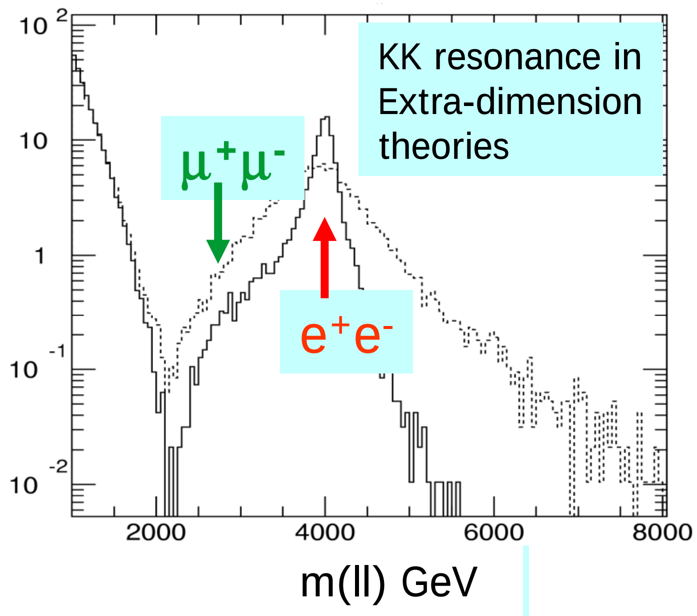
mid-end 2010 ?

Easiest .... Heavy di-Lepton Resonances

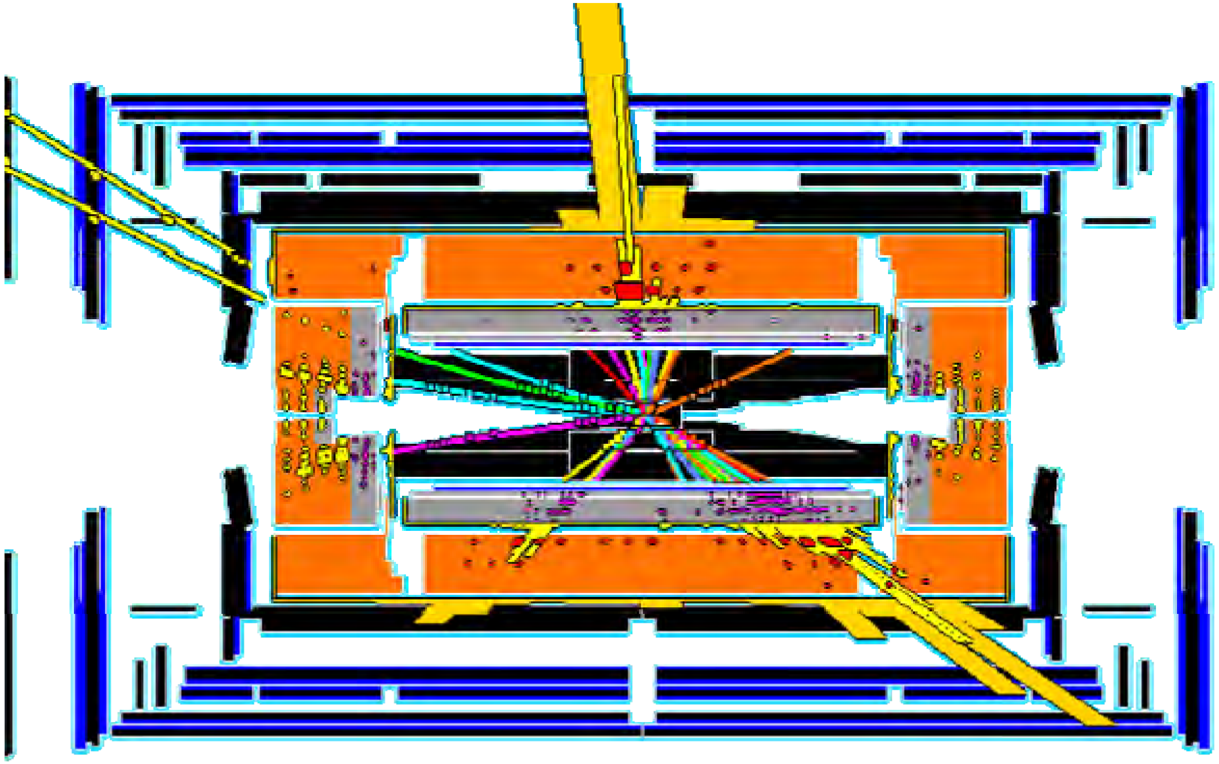


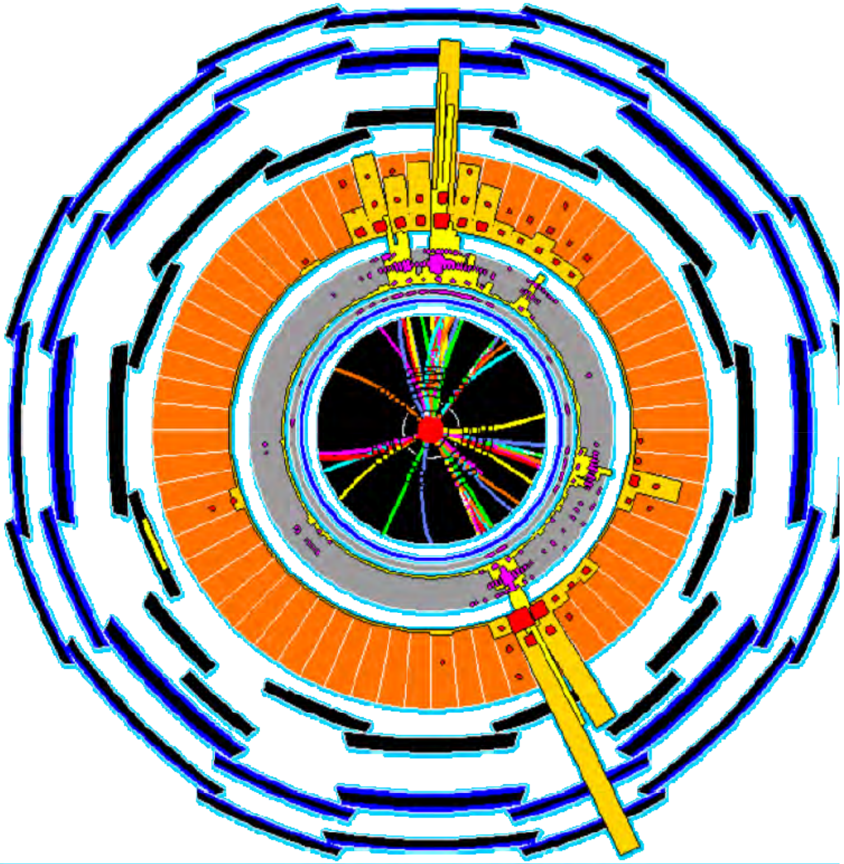
$Z' \to l^+l^-$ with SM-like couplings (Z_{SSM})

Discovery (10 events $\mu^+\mu^-$, 1TeV, >5σ) with 100 pb^{-1}, possible at E_{cm}=10 TeV



Simulation of a Supersymmetry event in ATLAS





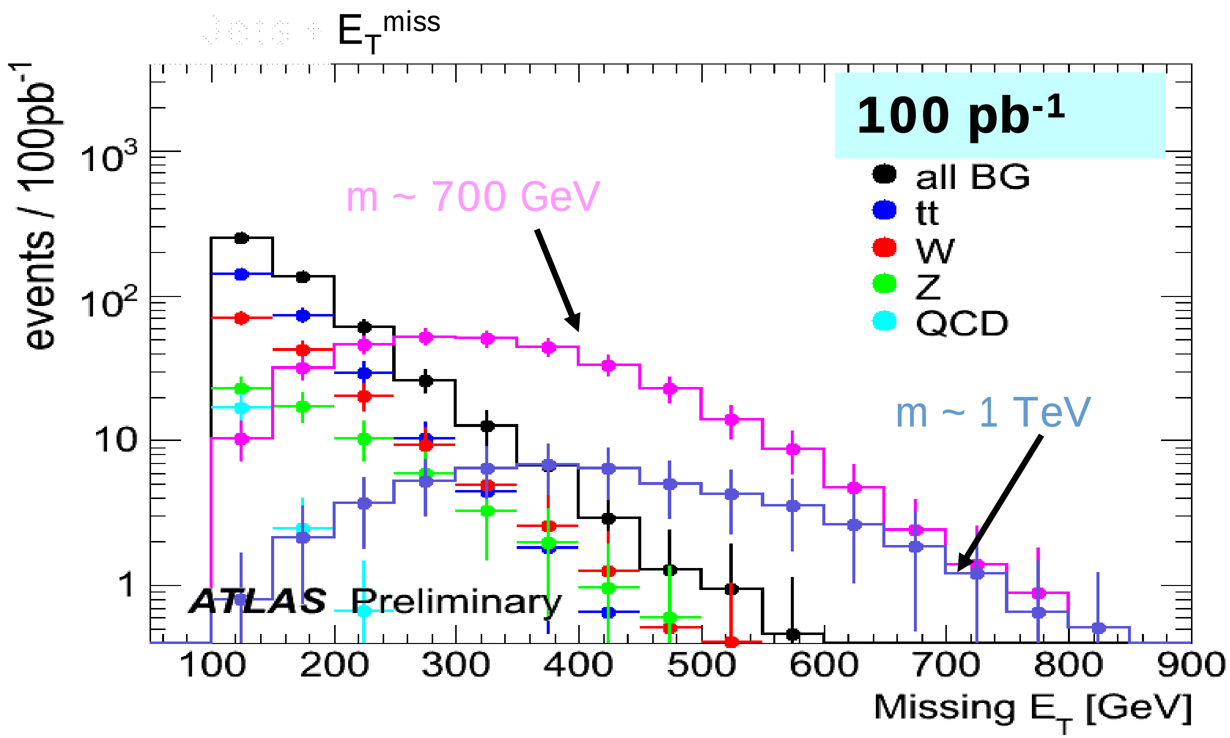
→ **spectacular signatures**
(many jets, missing transverse energy, leptons)

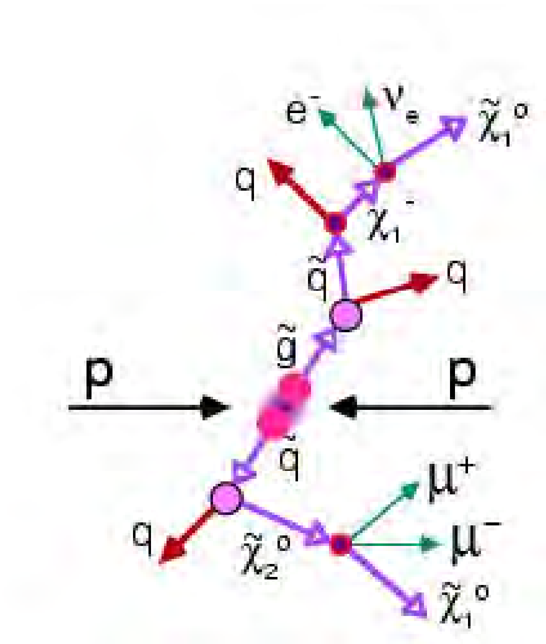
For $m(\tilde{q},\tilde{g}) \sim 1$ TeV
expect 10 evts/day at L=10^{32}

What about SUSY discovery in 2010 ?

Finding the signal already at 100-200 pb^{-1} should not be a problem

→ the problem is to be sure it is real

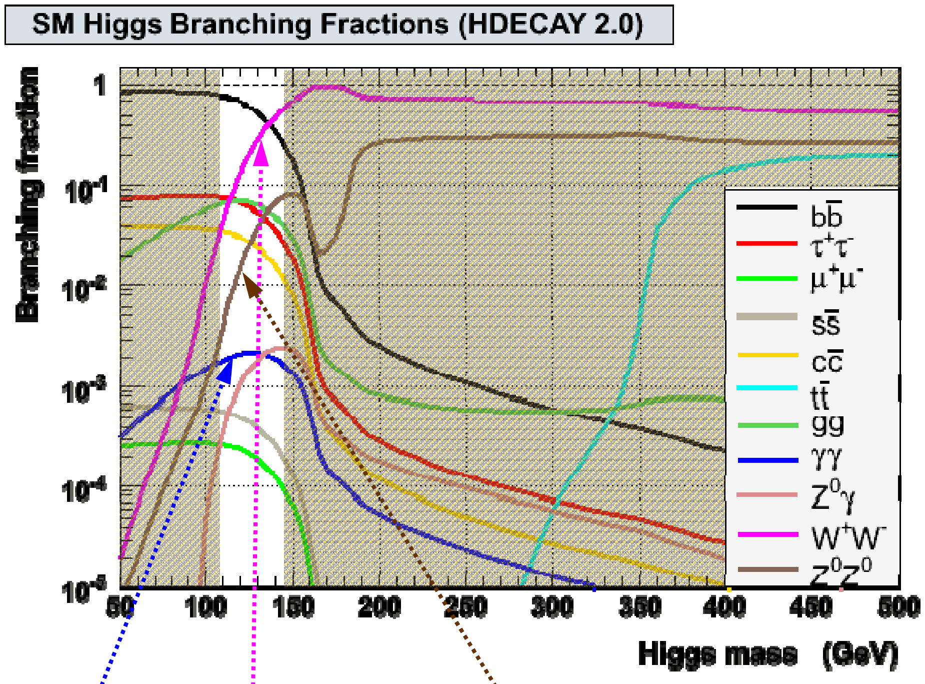




5σ discovery beyond current limits possible with ~20 pb^{-1} at 10 TeV

Higgs discovery will need time

Inclusive SM Higgs production cross section and branching fractions



H → γγ : rare, but clean

H → *WW** : abundant, but not clean

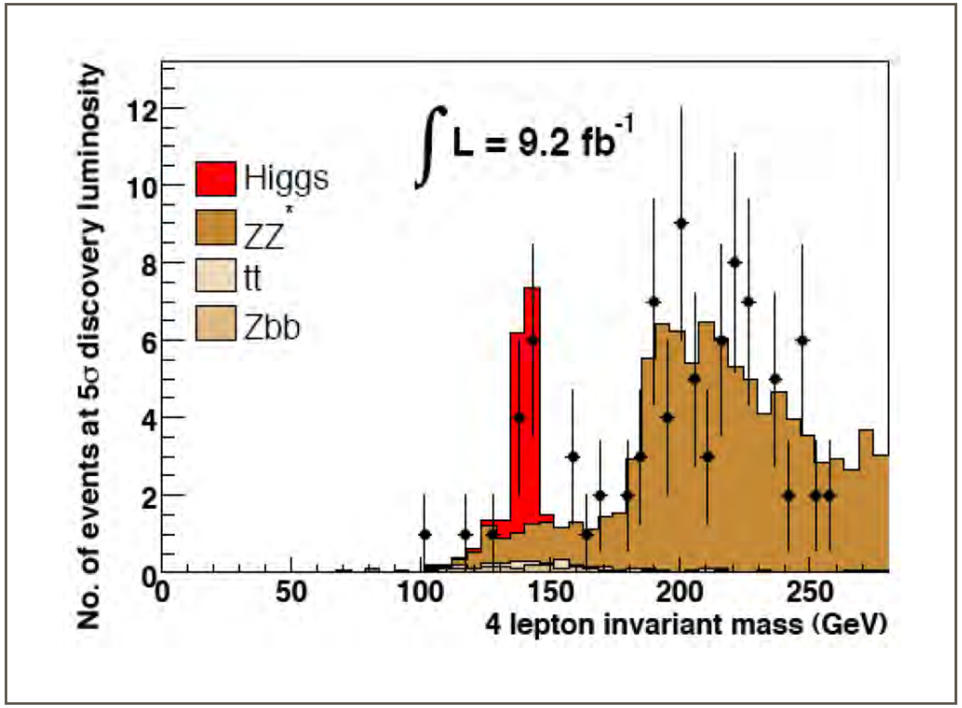
H → *ZZ** : sizable branching fraction, and clean

Golden search modes

Higgs discovery will need time (few years)

The "golden" channel
$H \to ZZ^* \to 4l$

2011-2012 ?



Most difficult region:
very low mass region of 120 GeV
need to combine many
channels
(e.g. $H \to \gamma\gamma$, $H \to ZZ^* \to 4l$)

•Higgs discovery channel in the mass range from 130-500 GeV with 30fb^{-1}
(except ~ 160 GeV WW turn on)

•A 160-170 GeV Higgs (to WW ->ll) could be discovered with 1 fb^{-1} :

We have never been so ready for big discoveries !!!!