Title: The Road to First Physics with ATLAS at the LHC

Date: Feb 27, 2009 01:00 PM

URL: http://pirsa.org/09020003

Abstract: The ATLAS experiment at the Large Hadron Collider (LHC) at CERN is completing final preparations for first high energy collisions in 2009. This talk will cover: the physics motivation of the LHC, highlights of the ATLAS experiment, commissioning, and prospects for new physics discoveries ahead.

2008:
Interest in LHC

Google Zeitgeist 2008

United Kingdom

Fastest Rising

1. iplayer
2. facebook
3. iphone
4. youtube
5. yahoo mail
6. large hadron collider
7. obama
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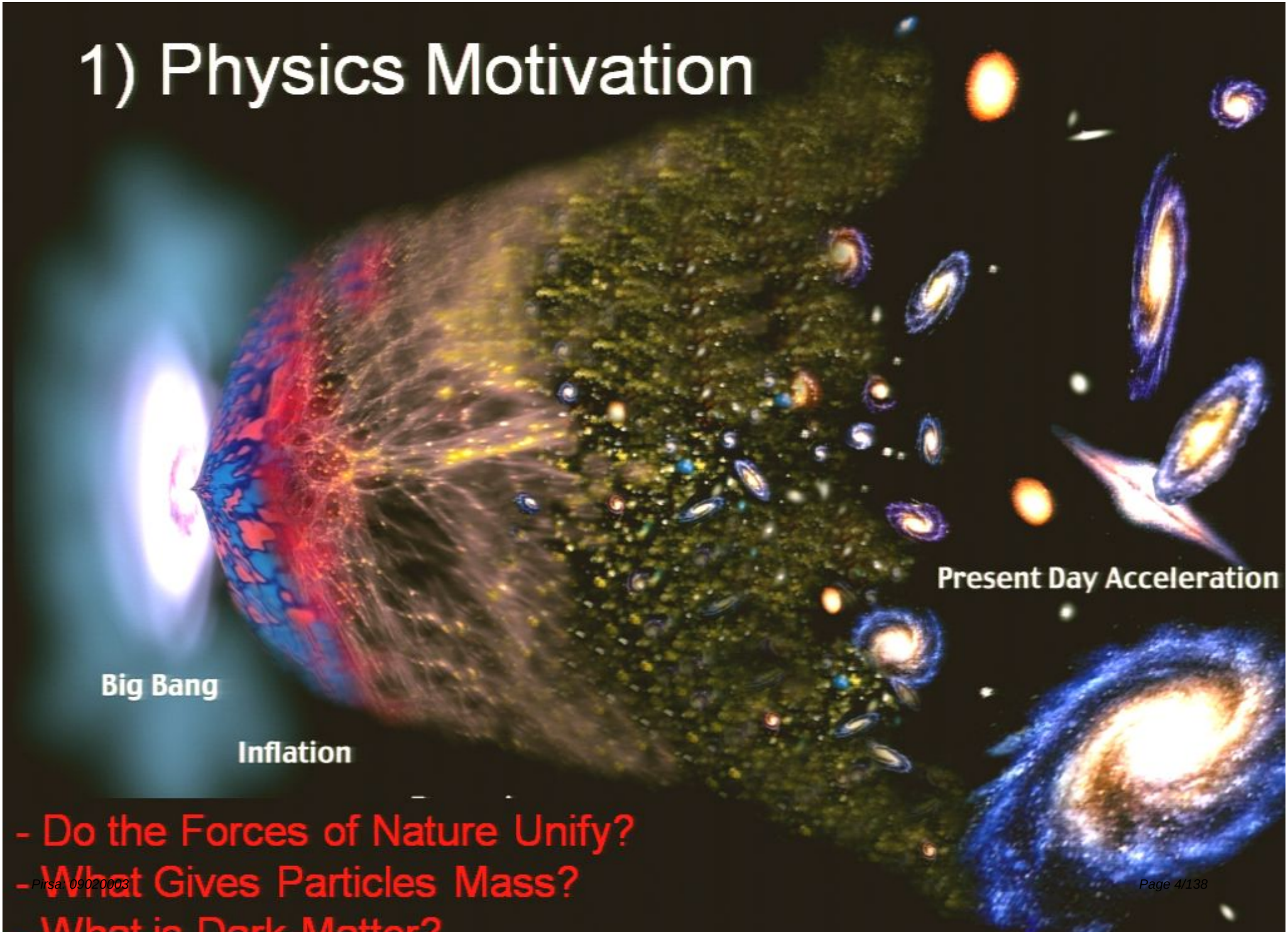
In 2008
LHC more popular than even Obama!


1) Physics Motivation
Present Day Acceleration
Big Bang
Inflation
- Do the Forces of Nature Unify?
- What Gives Particles Mass?

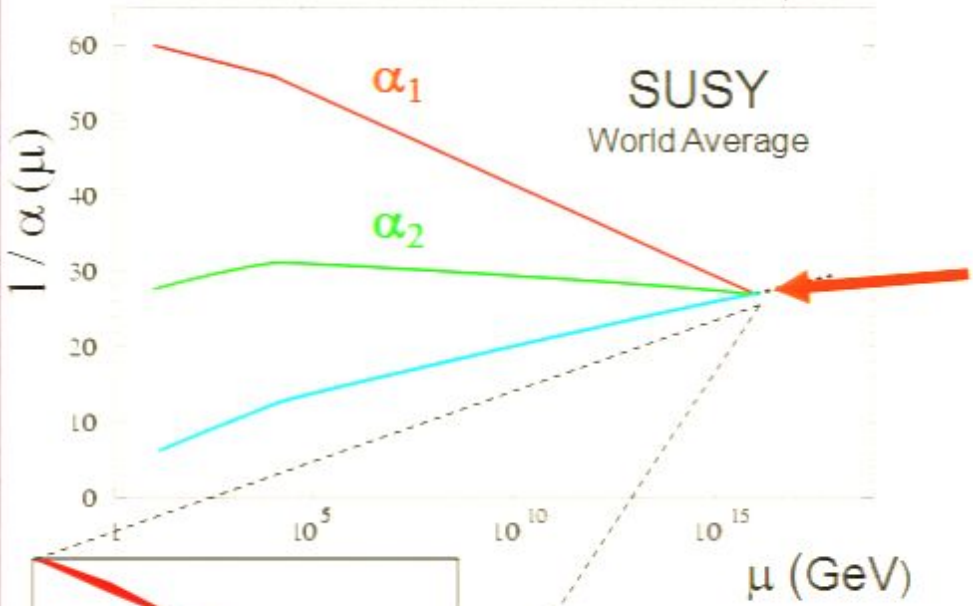
Q1: Do the Forces of Nature Unify?

Physics at electroweak scale 10^2 GeV well-understood.

α_1 = Electromagnetic coupling
α_2 = Weak coupling
α_3 = Strong coupling

Can we extrapolate the gauge couplings of the SM to the Planck scale 10^{19} GeV? *No unification.*

Q1: Do the Forces of Nature Unify?



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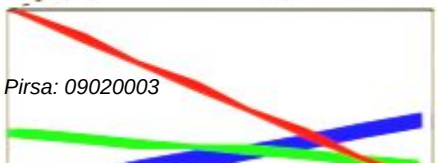
Can we extrapolate the gauge couplings of the SM to the Planck scale 10^{19} GeV? *No unification.*

If Supersymmetry (MSSM) is added, the forces unify at about 10^{16} GeV.

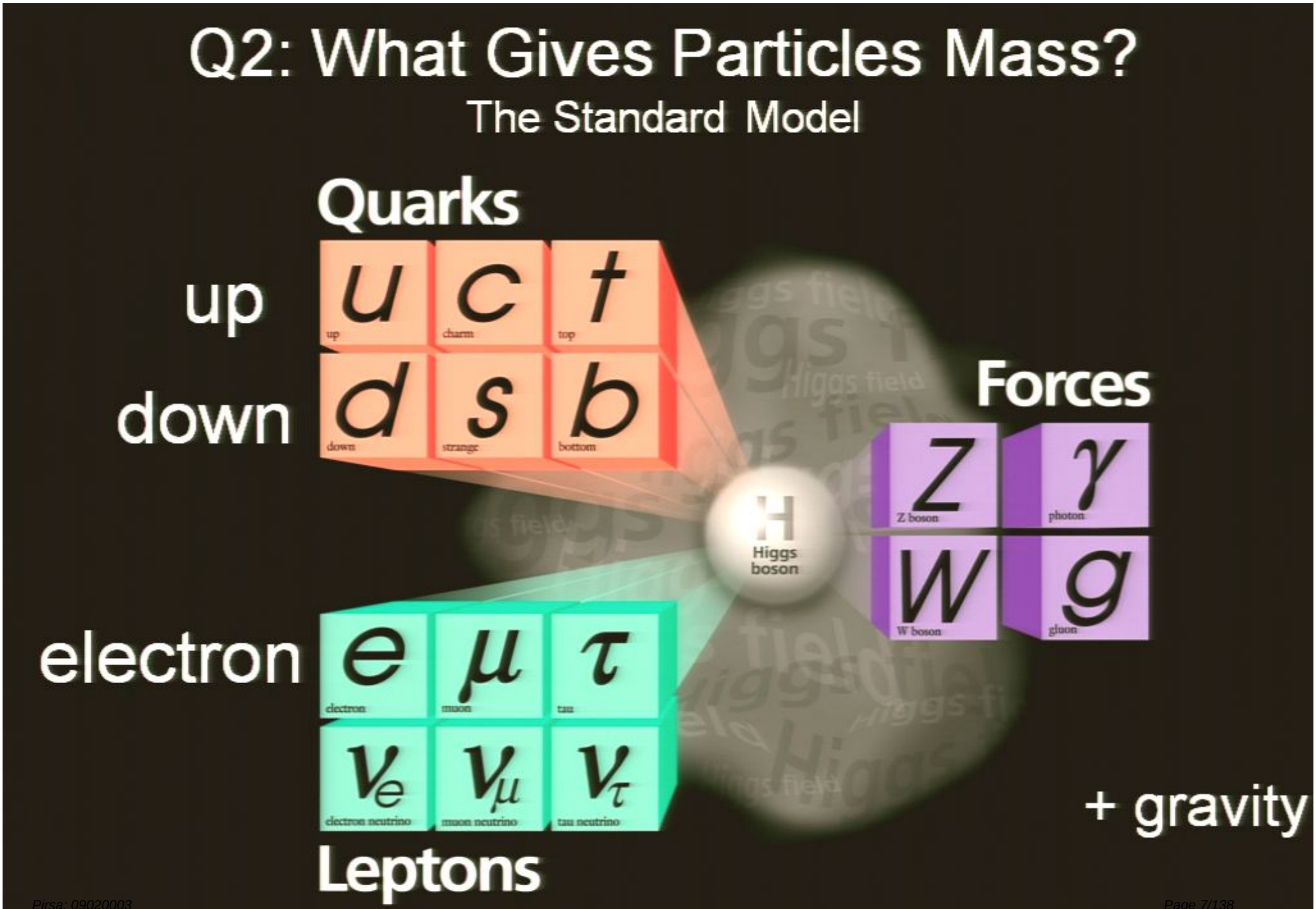
A hint that we're on the right track?



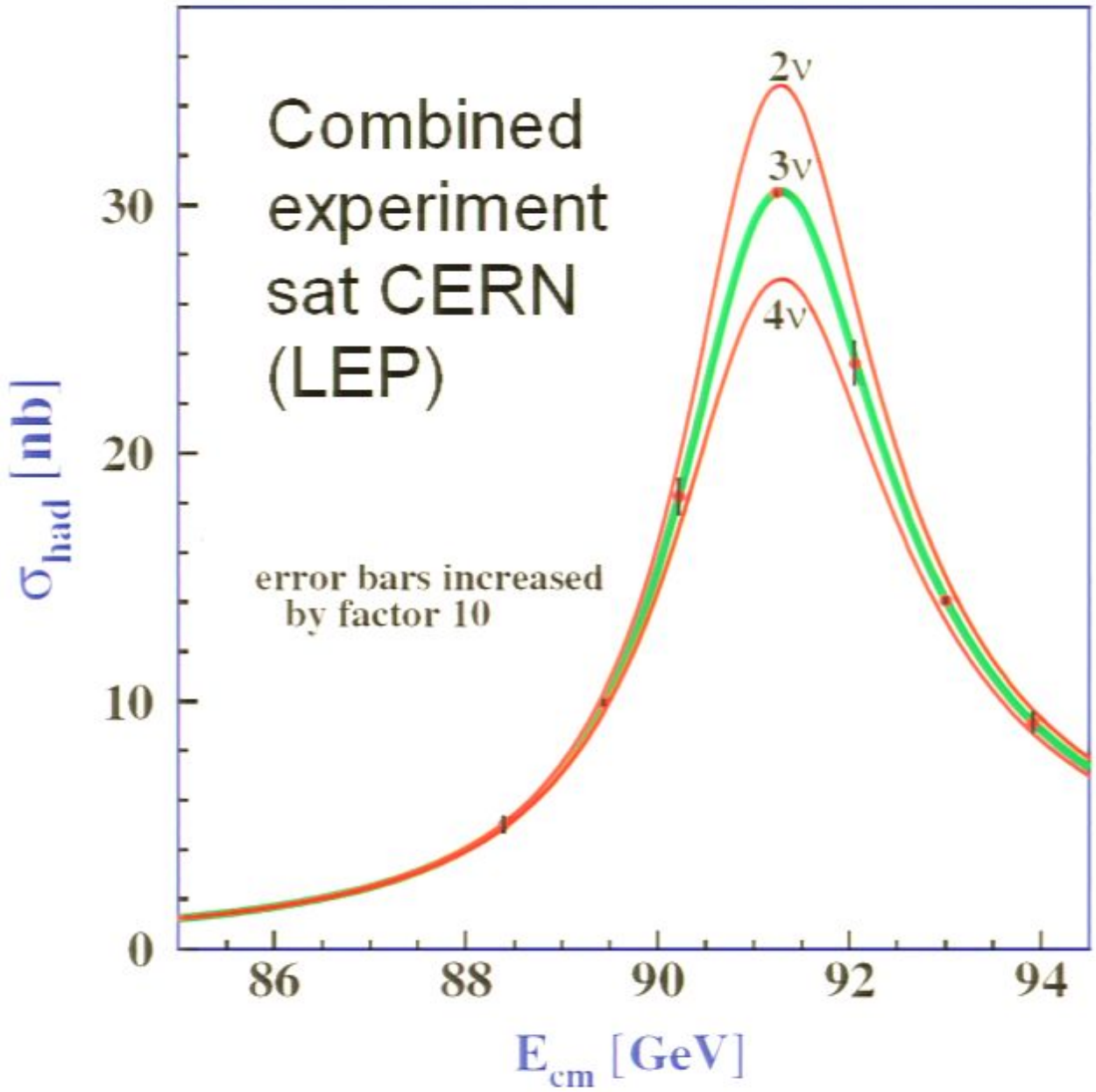
Not perfect match, but impressive for extrapolating over ~17 orders of magnitude

Q2: What Gives Particles Mass?

The Standard Model

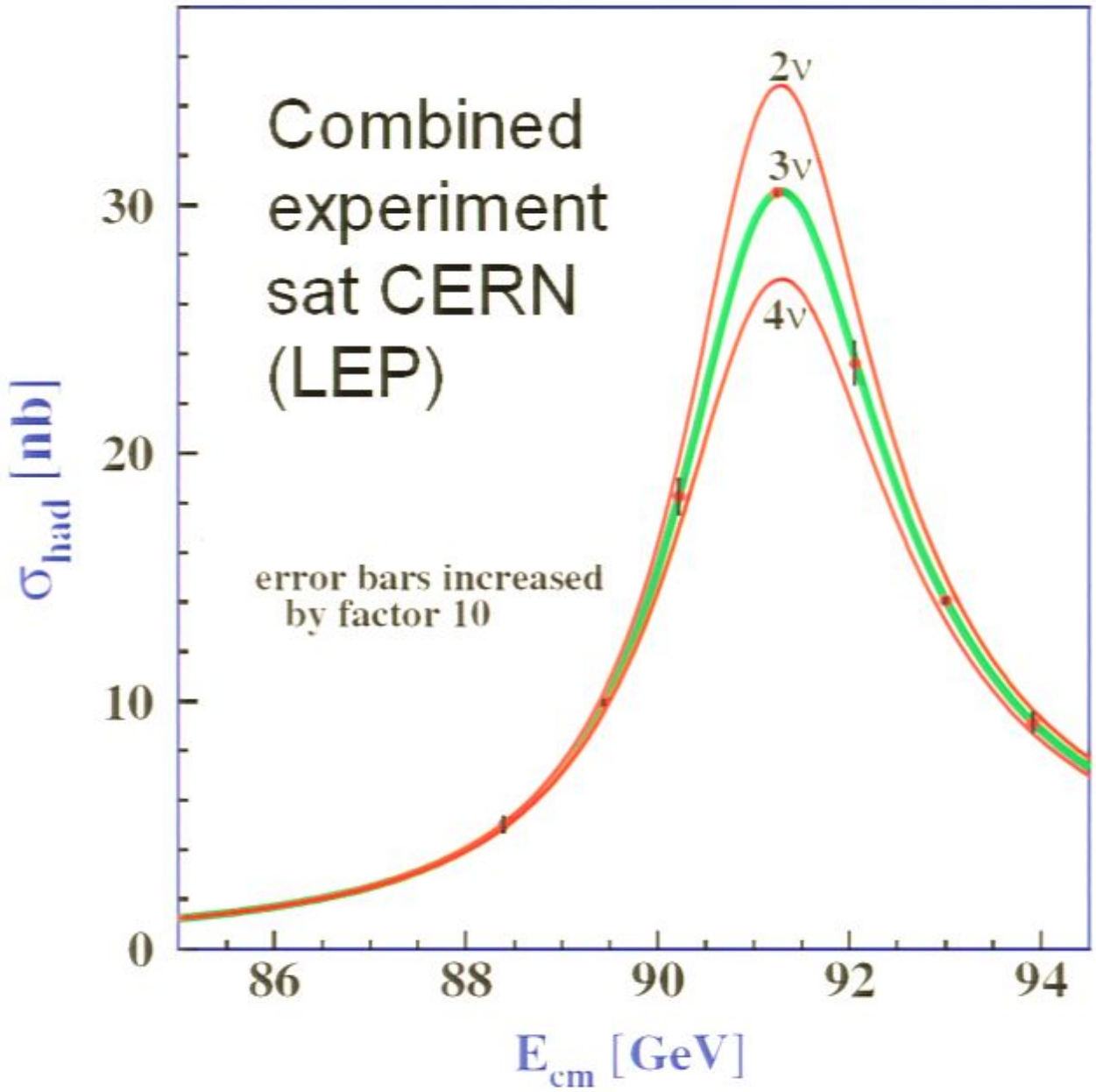


Three Families

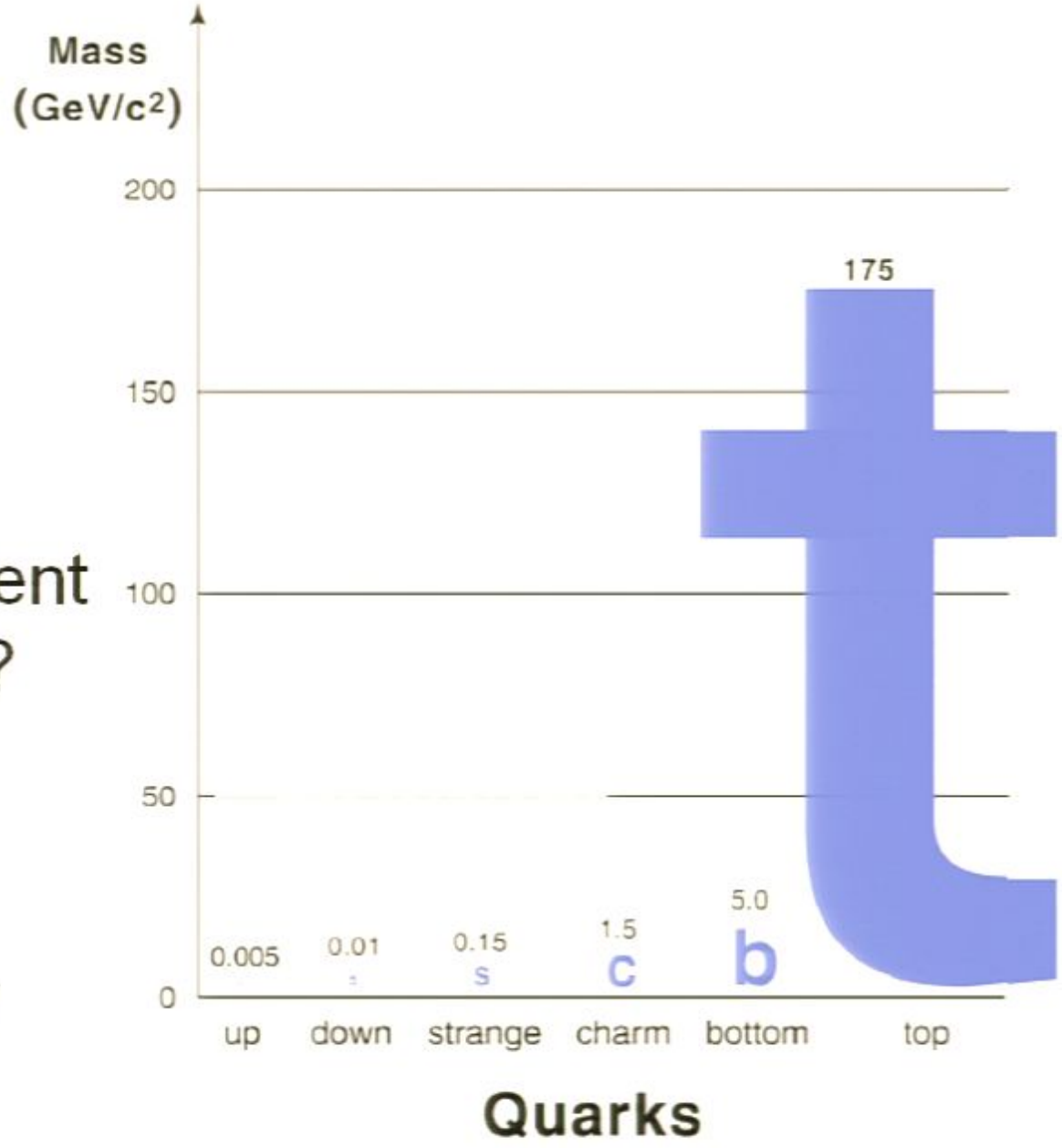


Three Families

$N = 2.9840 \pm 0.0082$



Quark Masses



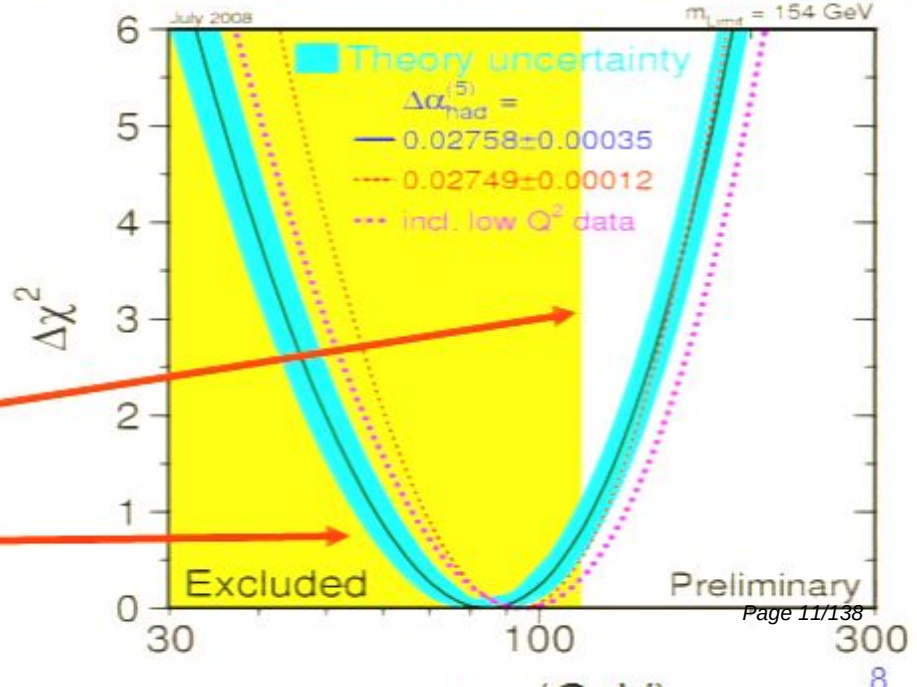
Why so different Masses?

Proton Mass = 1 GeV

Top Quark Discovered 1995 Tevatron Accelerator Fermilab, Chicago

Q2': What Gives Particles Mass?

- The missing piece of the SM is the Higgs (H)
  - Spin-0 particle forming a scalar field everywhere in the universe
  - Example of a scalar field (temperature)
- Coupling of the Higgs field to a particle generates its mass
  - n.b. proton / neutron mass from gluon fields + quark motion
  - Breaks electroweak symmetry: W,Z massive
- Higgs properties predicted – except its own exact mass
  - We know it must lie in the range 114 GeV < M_H < 1.2 TeV
  - Previous direct searches at LEP
  - Precision electroweak data (LEP. Tevatron)
    - $m_H = 84\ ^{+34}_{-26}$ GeV



What Gives Particles Mass?

The Higgs Mechanism

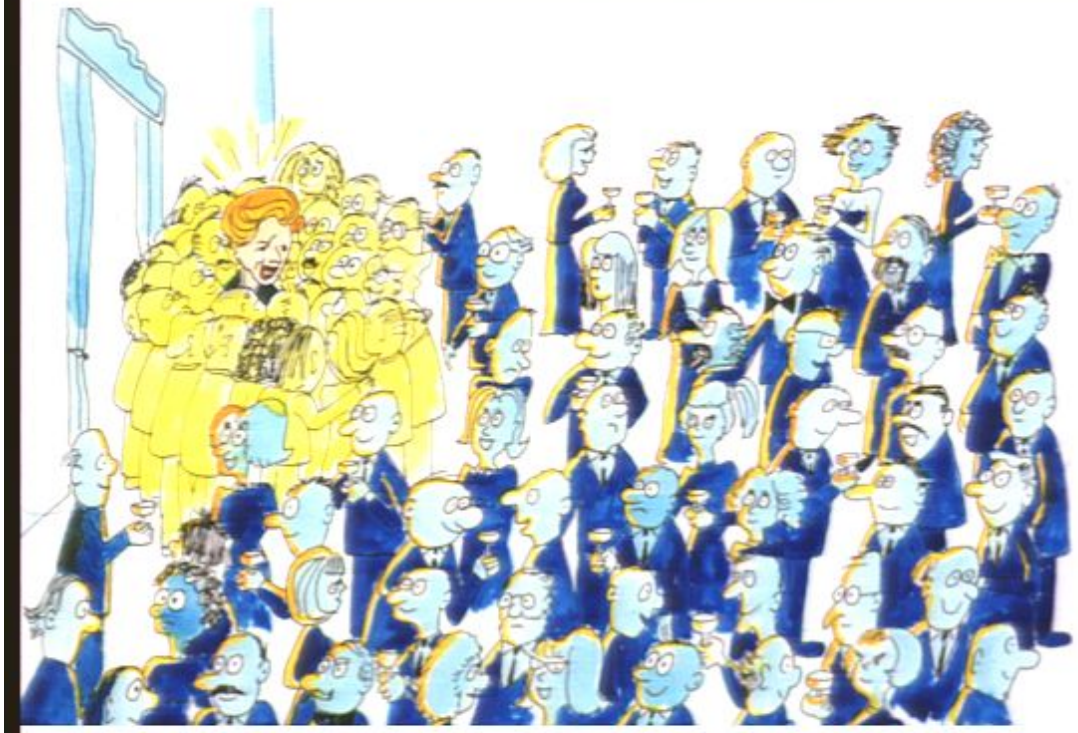
Imagine a room filled with journalists… (they are the Higgs field).

A famous politician walks in and the Journalists cluster, giving resistance to the movement of the politician and thereby 'mass'

Mass of the Higgs particle itself (self-interaction)

Imagine the same room, with someone at the door starting a rumour.

The rumour spreads, and people cluster, giving mass to the Higgs field.



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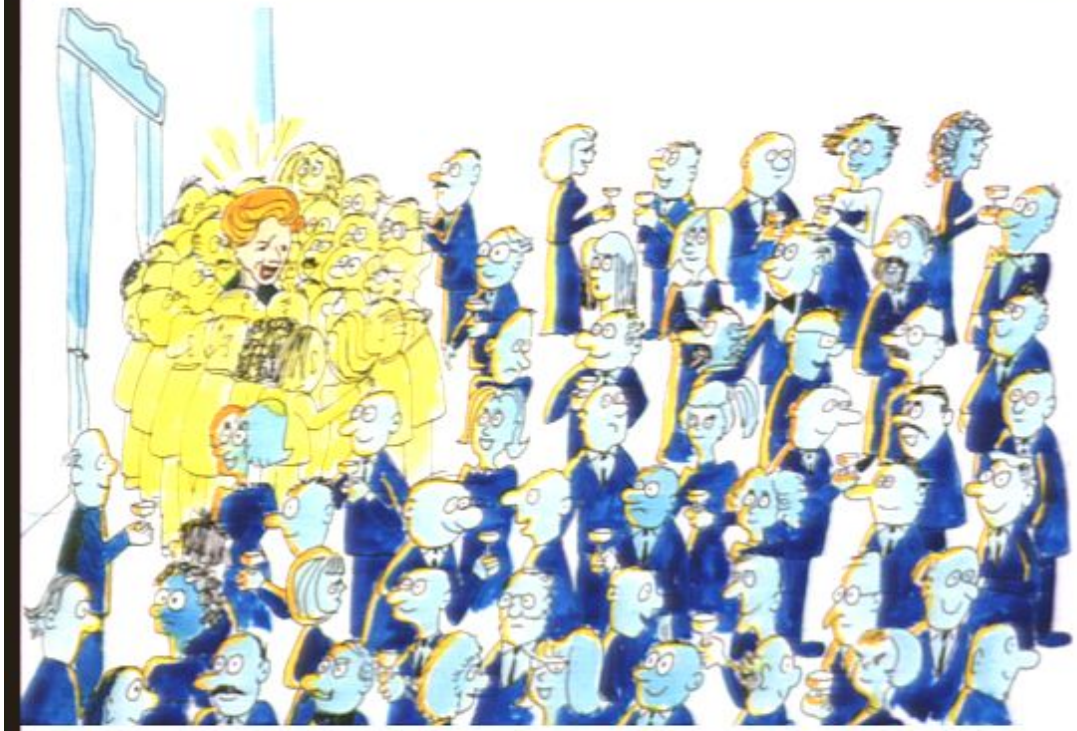

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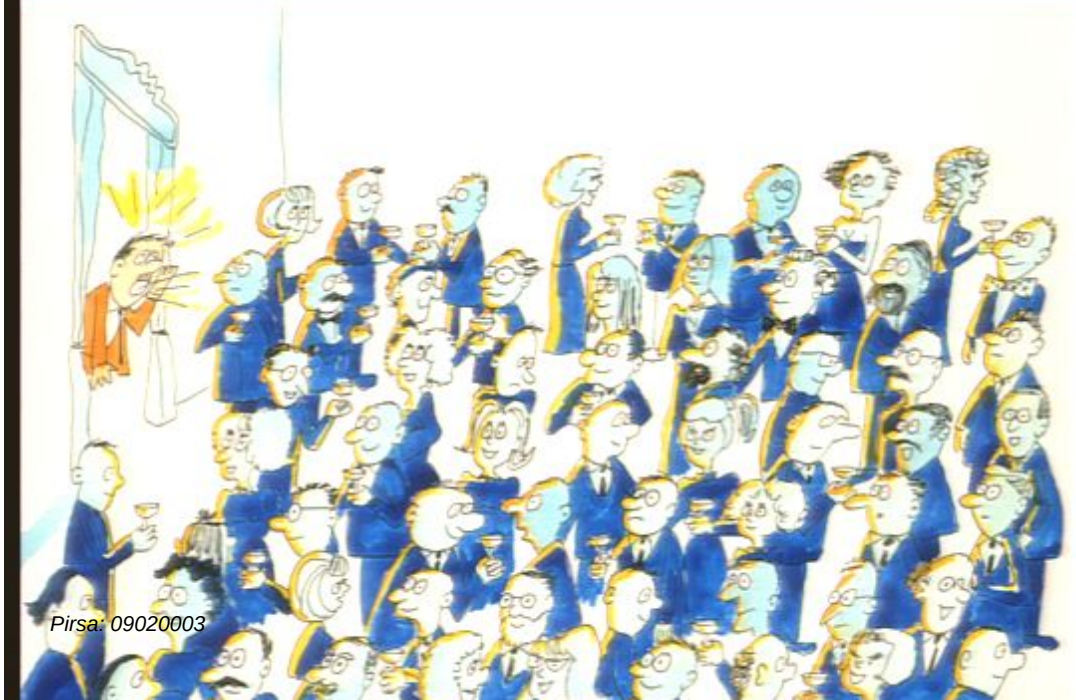

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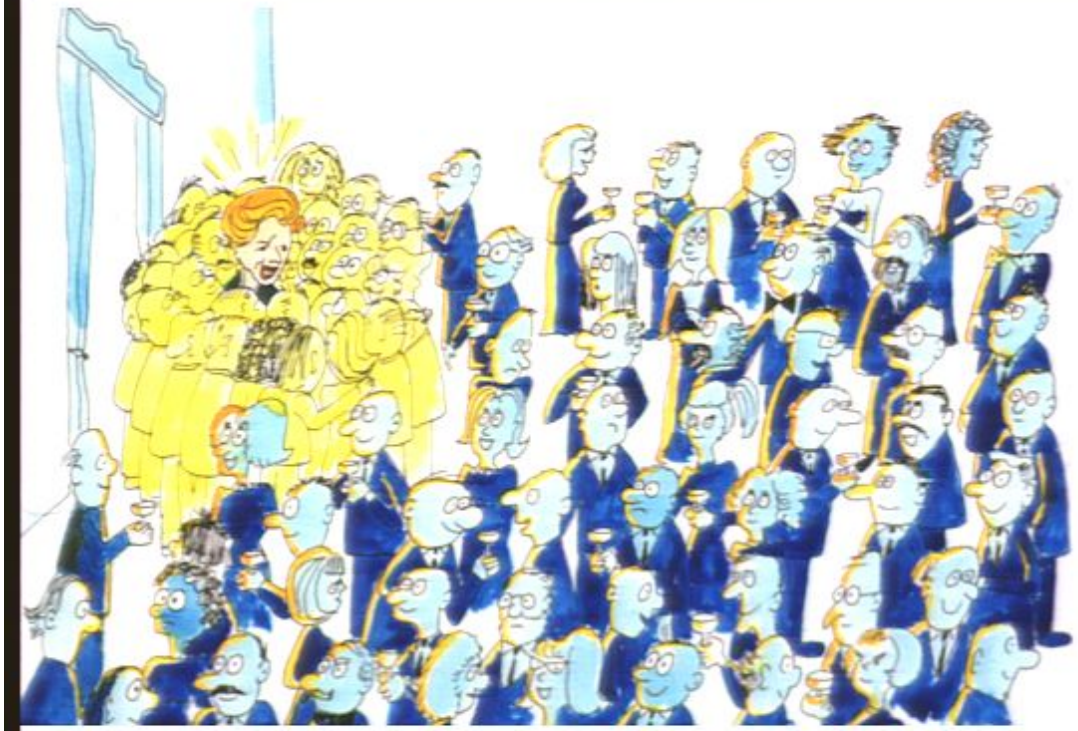

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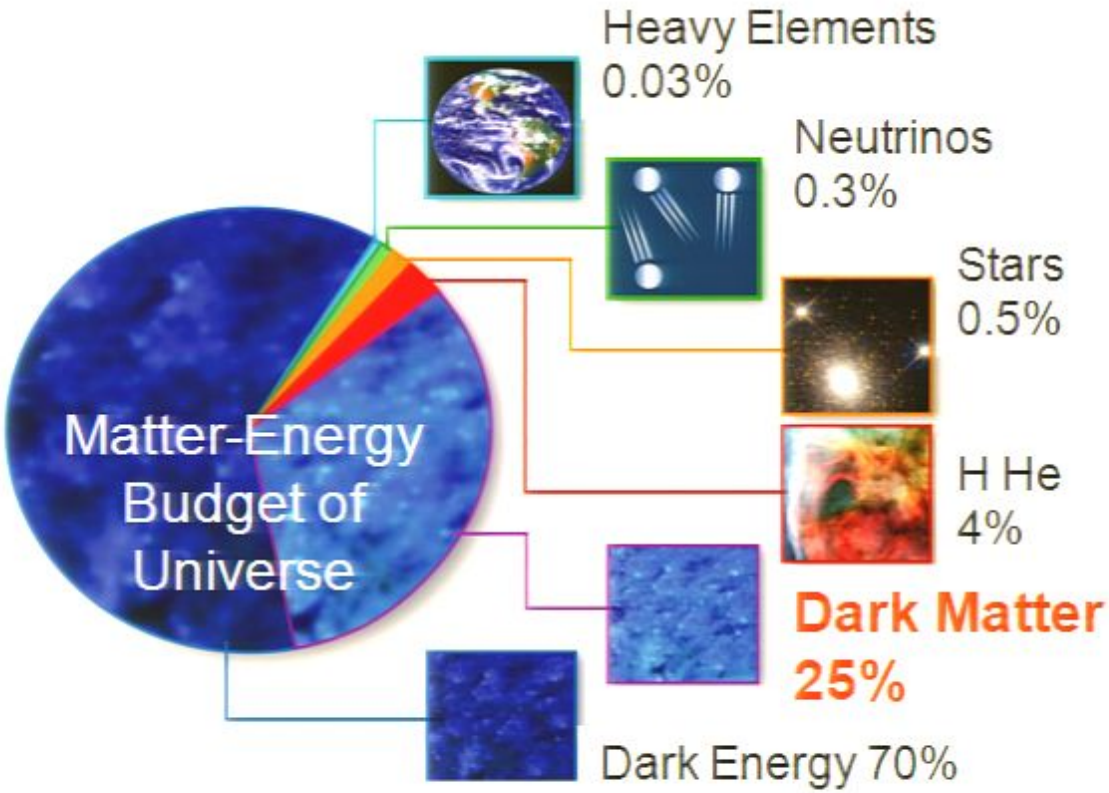
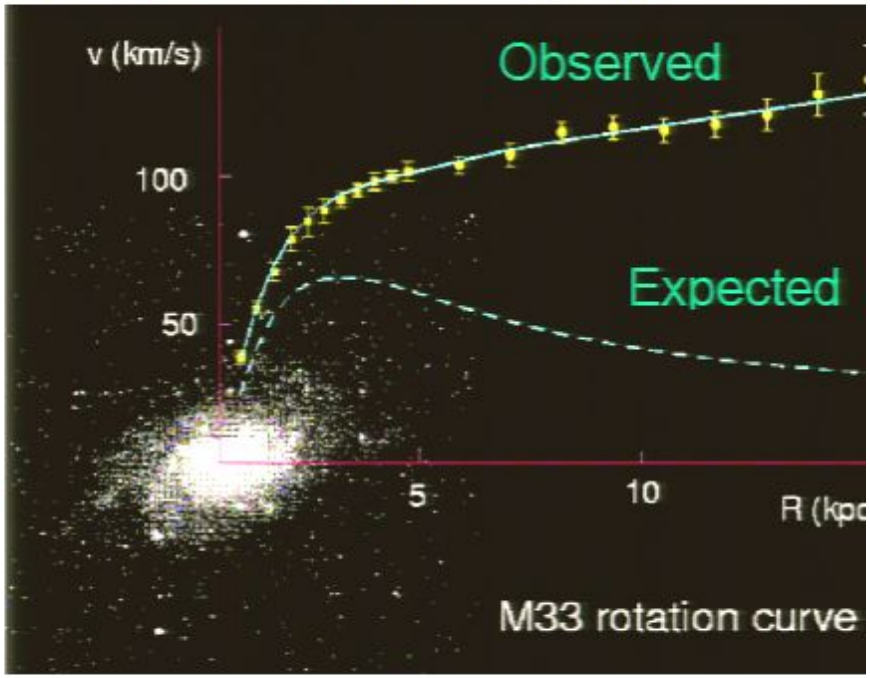
Q3: What is Dark Matter?

Planets, stars, H/He, n, ... make up ~5% of the universe.



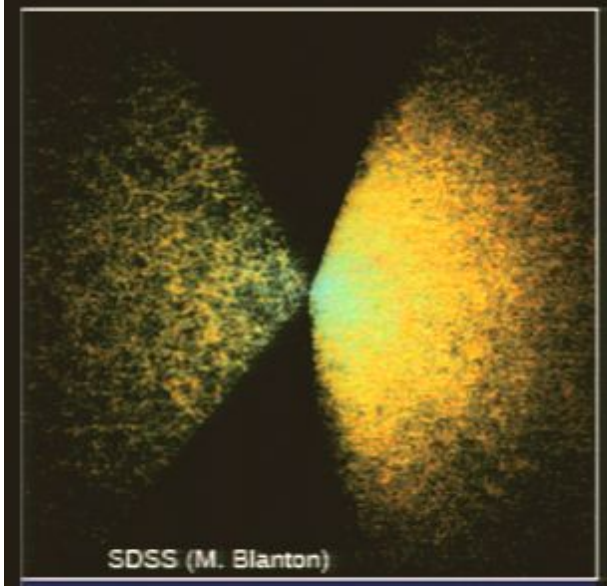
Evidence for dark matter: galaxy rotation

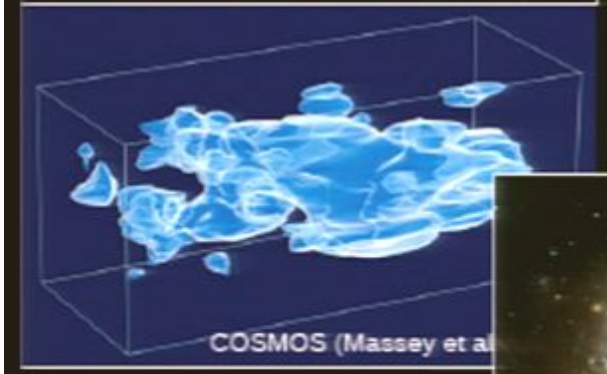


Cold Dark Matter Candidate: SUSY "Neutralino" χ
Another hint for SUSY?

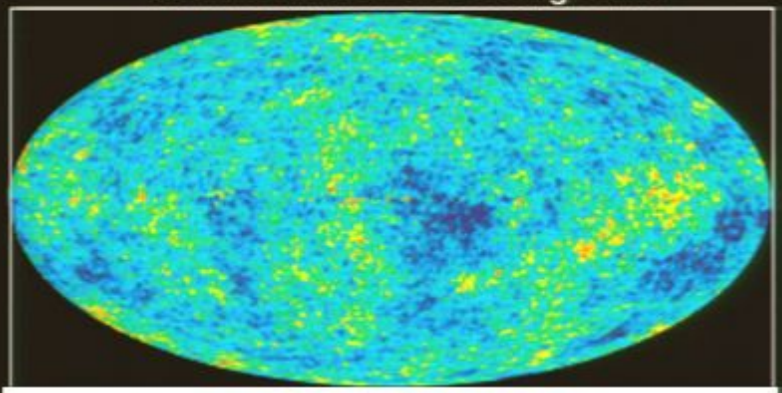
There's evidence for dark matter on many scales...

Large Scale Structure

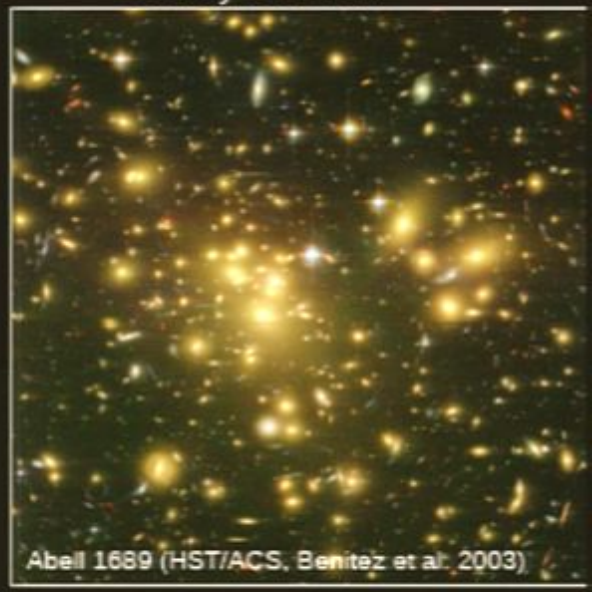


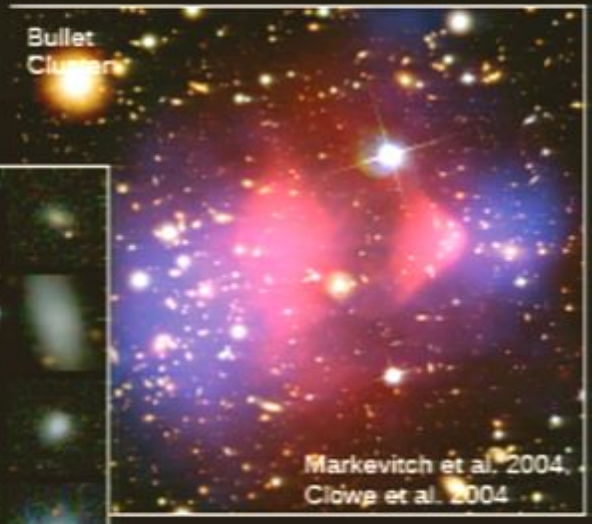


Cosmic Microwave Background



Galaxy Clusters





Galaxies

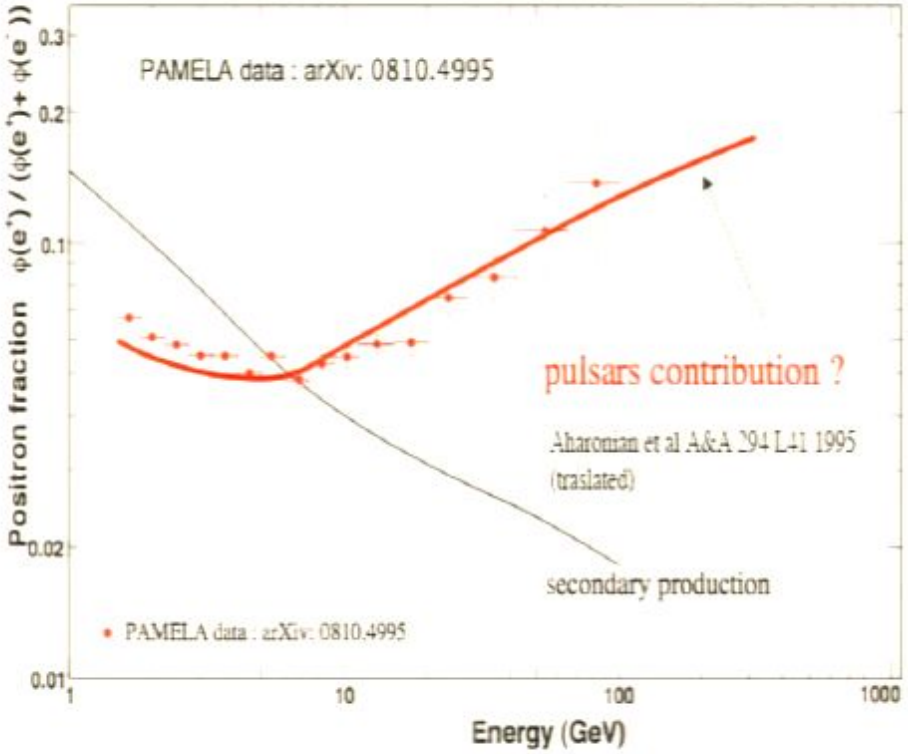
Dwarf Galaxies

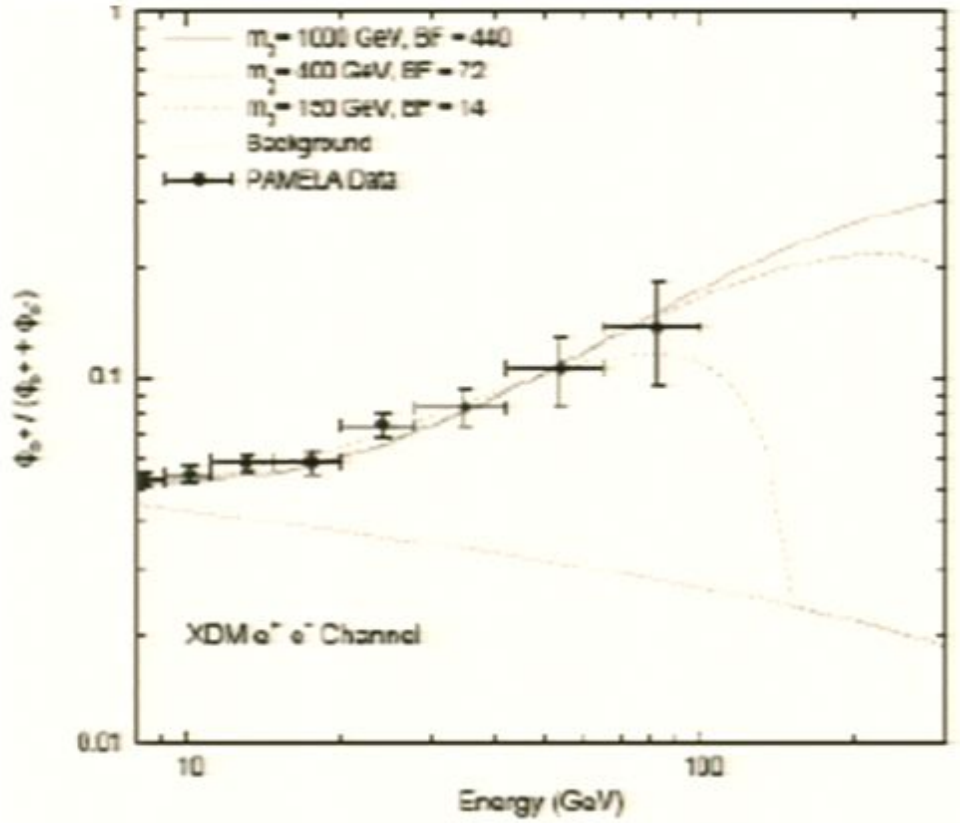
LHC-Dark Matter Workshop
January 2009

PAMELA

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics

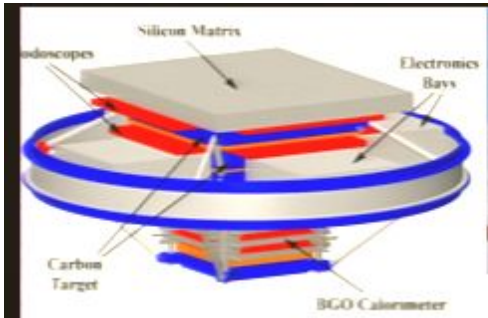
Positron ratio

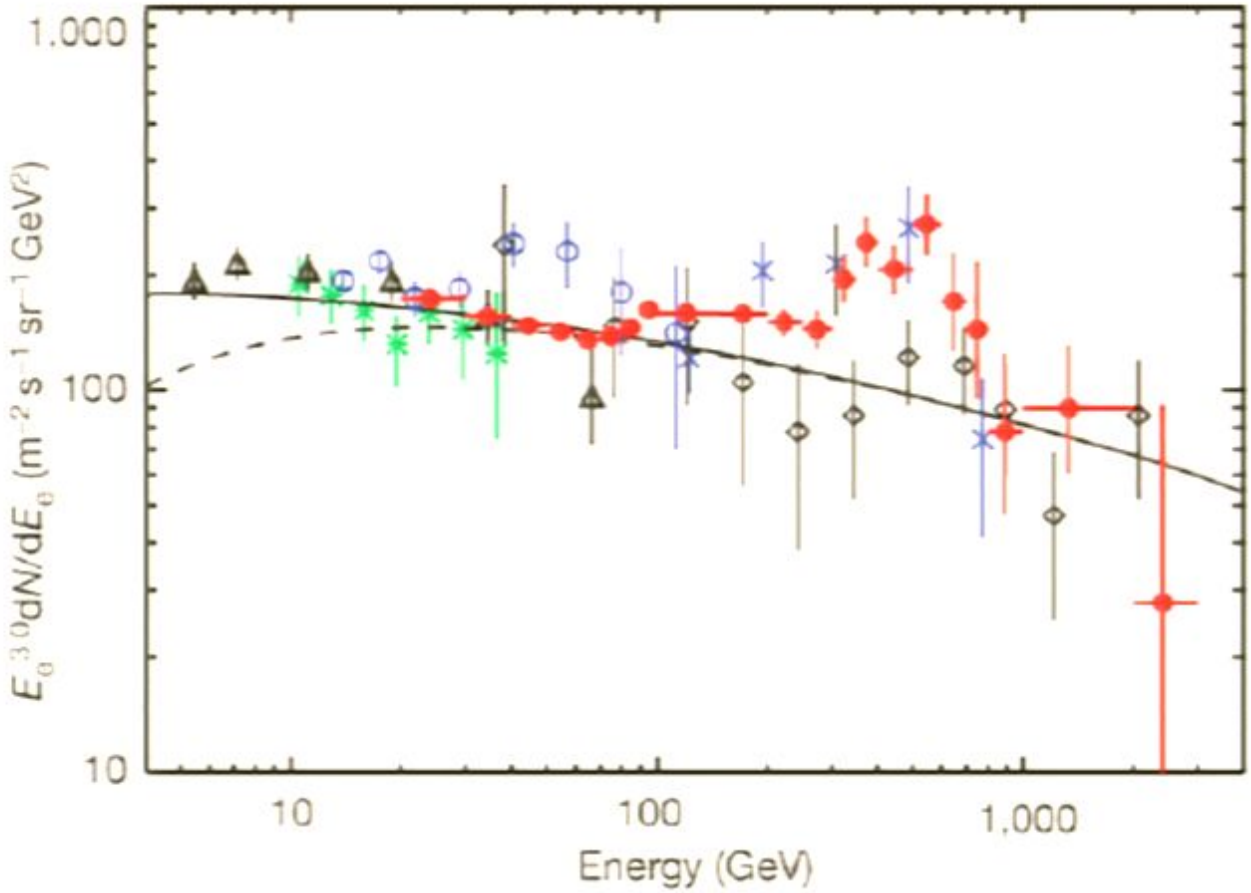




Example: pulsars

Example: DM





ATIC balloon experiment observes excess electron at energies of 300-800 GeV

Some claims that this can be explained by dark matter ~ 600 GeV

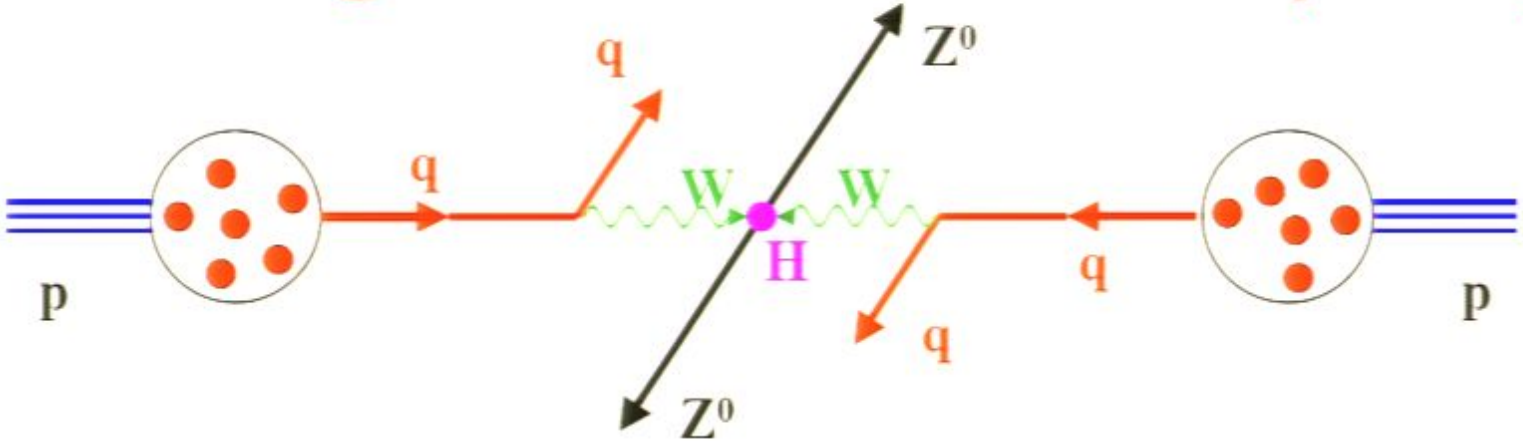
J. Chang *et al. Nature* 456, 362-365 (2008)

Both Accelerators and Telescopes Needed in Dark Matter Searches

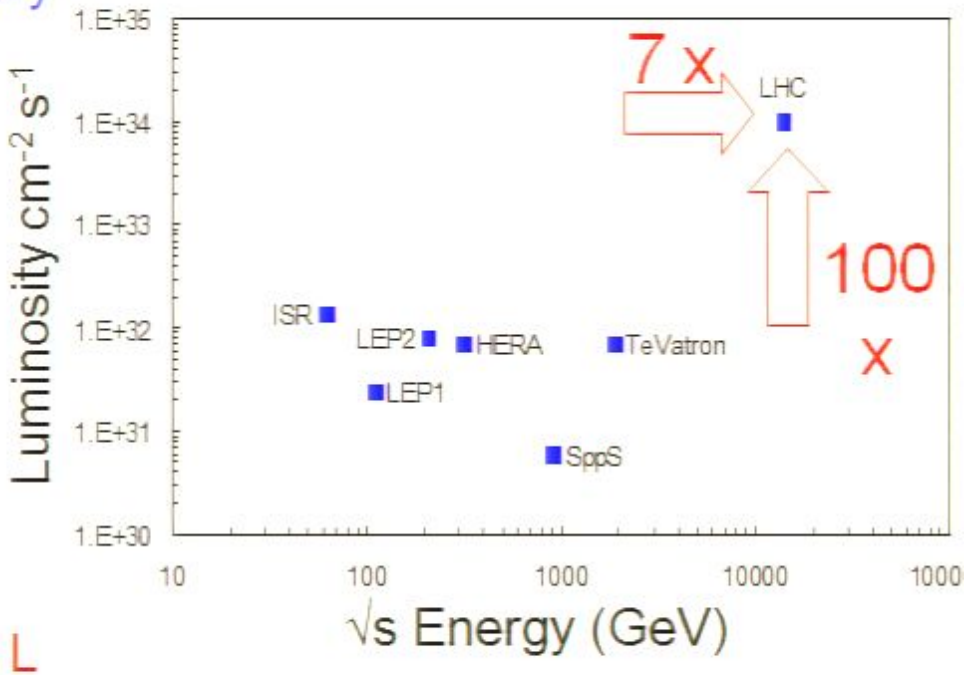
Symmetry Magazine

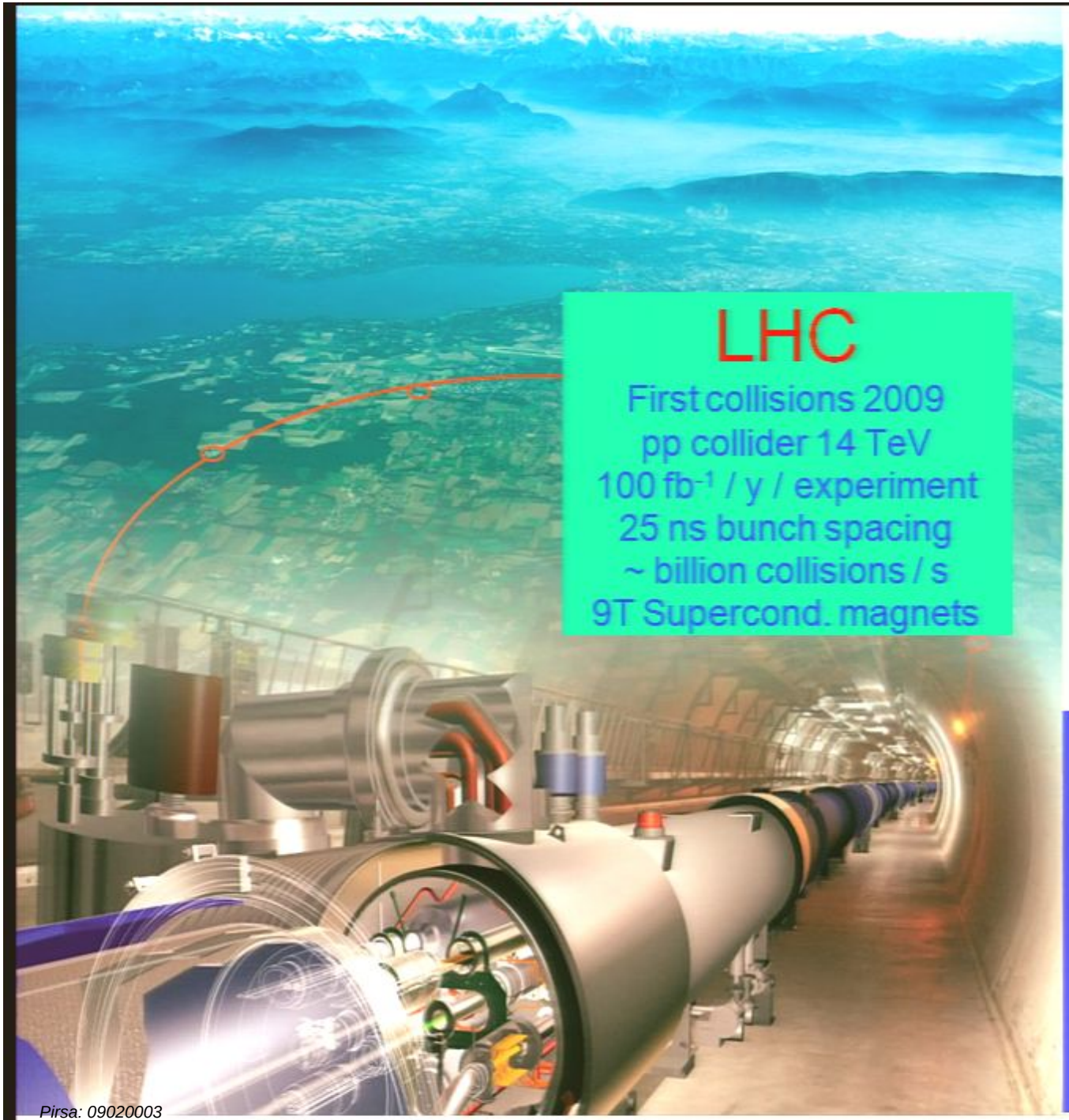
2. The LHC

The Large Hadron Collider (LHC)



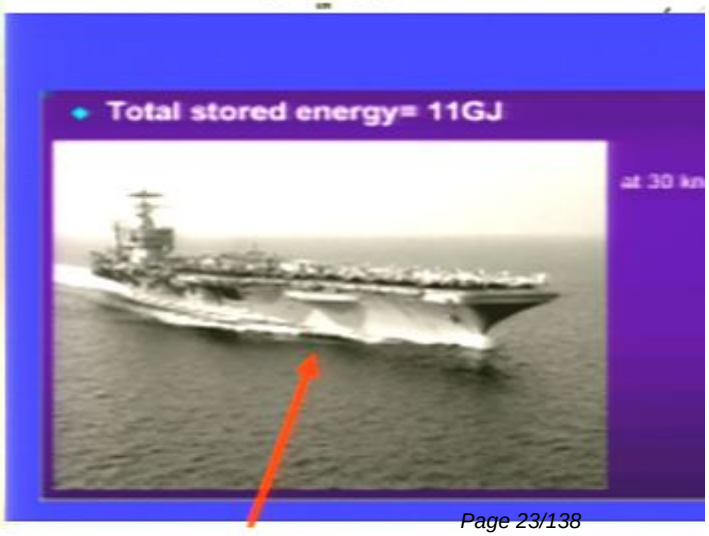
- We hope to answer questions about unification, dark matter, and the Higgs by probing physics at the TeV scale
- To reach ~ 1 TeV in p-p collisions, need:
  - E(quark) > 1 TeV
  - E(proton) > 6 TeV
- LHC p-p collider: 7 TeV x 7 TeV
- High luminosity:
  - Design luminosity of $L=10^{34}$ cm^{-2} s^{-1}
    - Physics Rate = L x σ
  - nb. s ~ 1/s -> 2*s requires factor 10 in L
  - Design 100 fb^{-1} / year per experiment





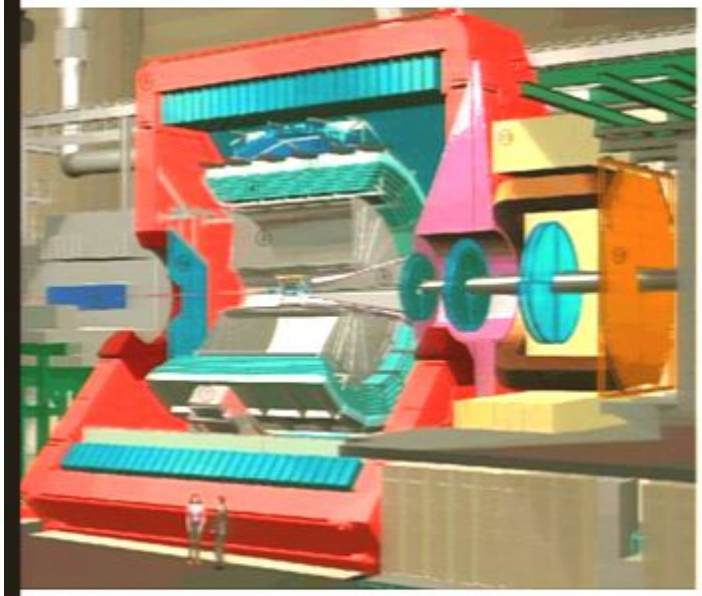
LHC

First collisions 2009
pp collider 14 TeV
100 fb^{-1} / y / experiment
25 ns bunch spacing
~ billion collisions / s
9T Supercond. magnets



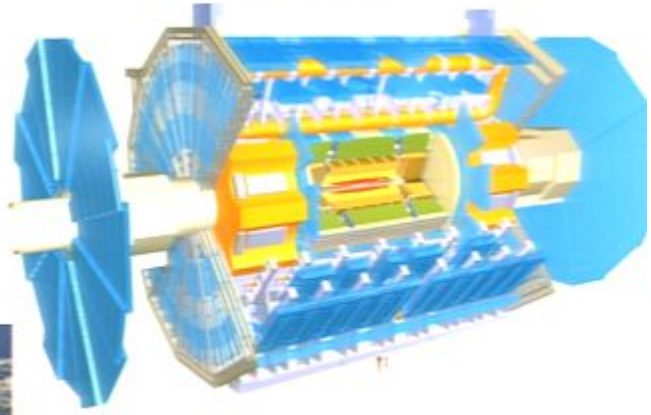
Energy (2 LHC beams) = 11 GJ = 7% of energy stored in an aircraft carrier at 30 knots

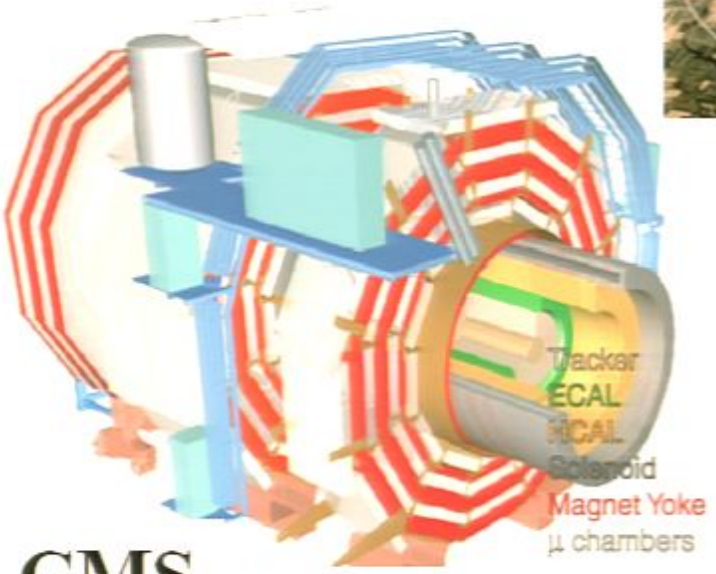
Alice Heavy-ion programme



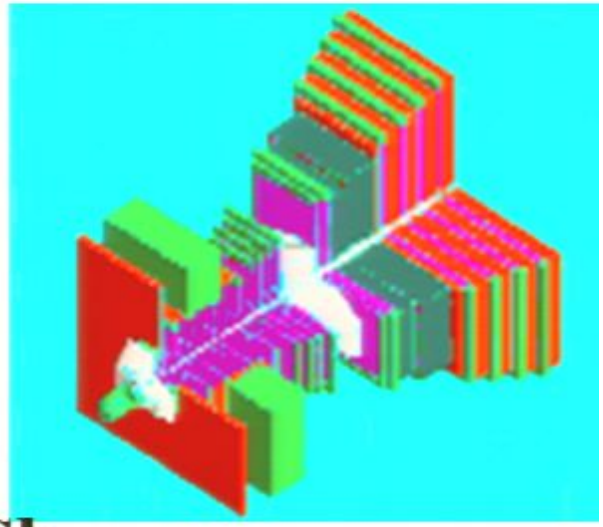
4 LHC Experiments

Atlas General-purpose detector



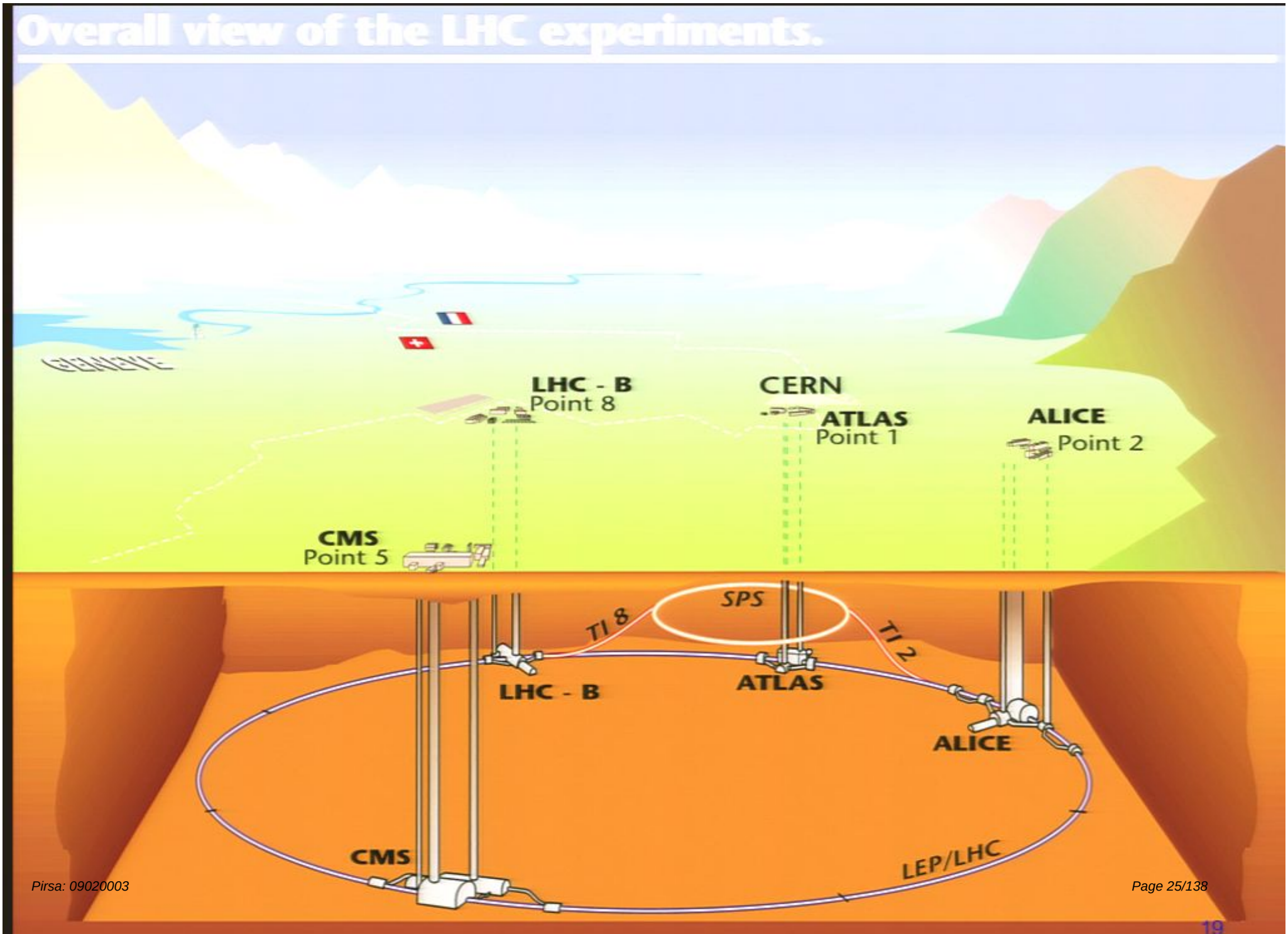


CMS General-purpose detector



LHCb Dedicated b-physics

Overall view of the LHC experiments.



Canada: LHC MQW magnets

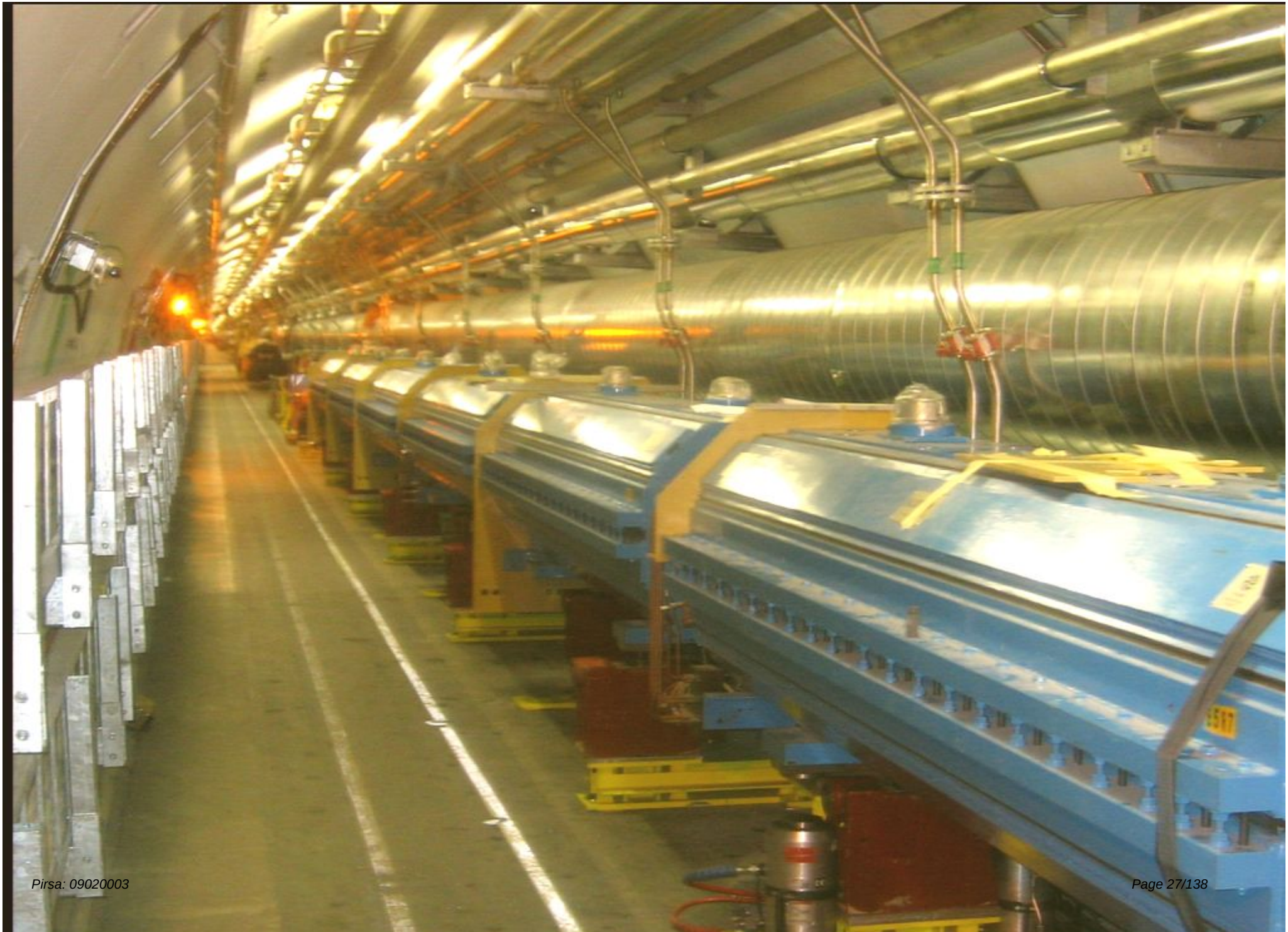
MQW line-up

MQWs in storage area

Built by ALSTOM Canada, Quebec.

Collaborative design by engineers at TRIUMF (Vancouver, BC) + CERN

MQWs in the workshop, seen towards the connection end



3. LHC Physics

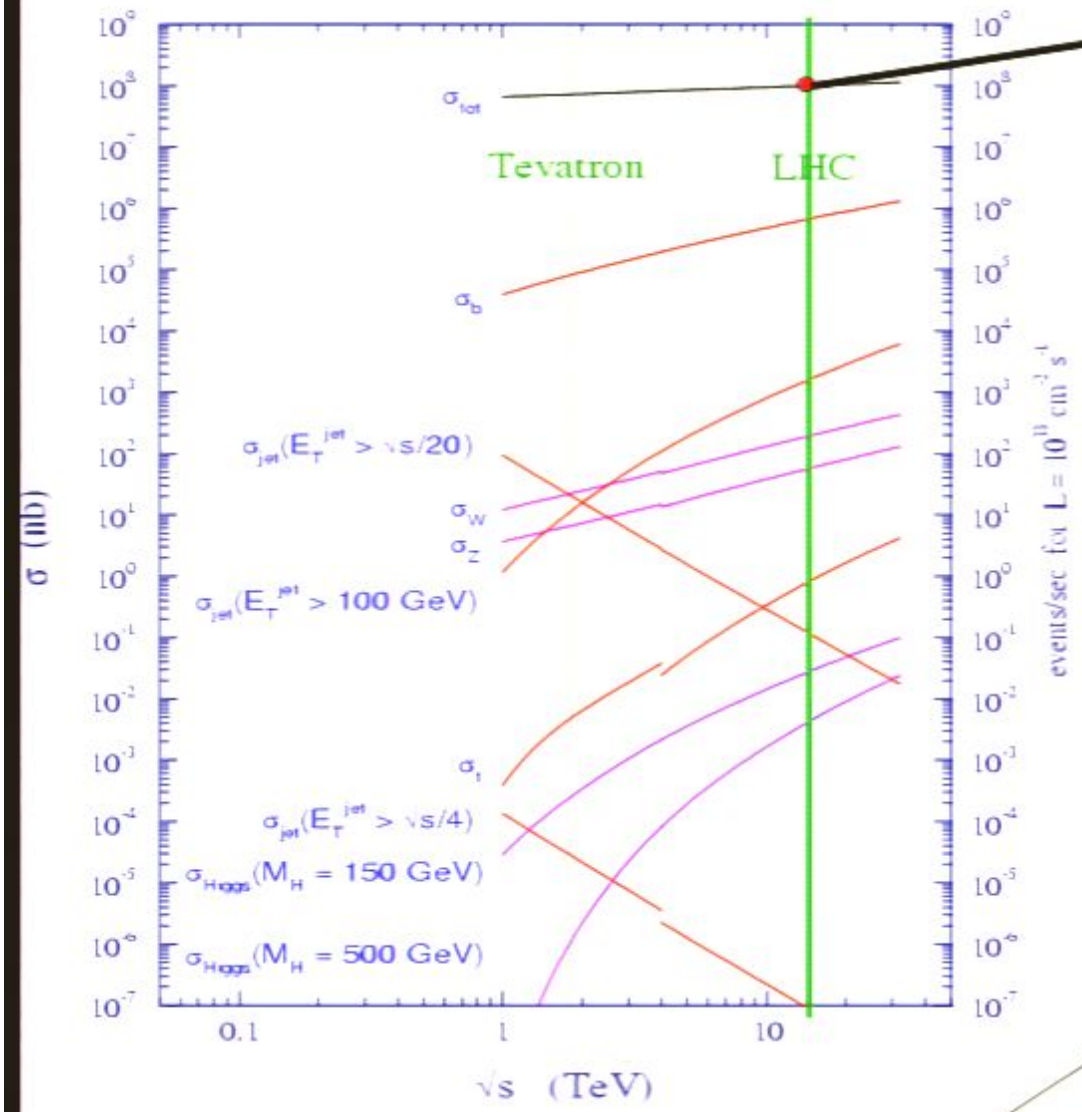
Production Rates for LHC at L = 10^{33} cm^{-2} s^{-1}

(10% design Luminosity)

	Process	Events/s	Events / year ($10\ fb^{-1}$)
SM	$W \rightarrow e\nu$	15	10^8
SM	$Z \rightarrow ee$	1.5	10^7
SM	$t\bar{t}$	1	10^7
SM	$b\bar{b}$	10^6	$10^{12} - 10^{13}$
SM	QCD jets ($p_T > 200$ GeV)	10^2	10^9
Higgs	H (m =130 GeV)	0.02	10^5
SUSY	$\tilde{g}\tilde{g}$ (m = 1 TeV)	0.001	10^4
Exotics	"Black holes" m > 3 TeV (M_D=3 TeV, n=4)	0.0001	10^3

Wealth of physics: LHC is a b-factory, top factory, W/Z factory, Higgs factory, SUSY factory, …

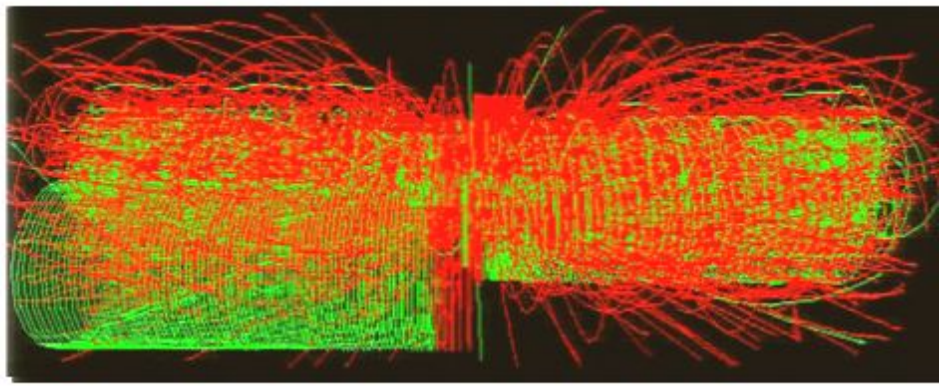
The Price: Pileup



Total event rate: $R = L \times \sigma_{inelastic}$ (pp)
$\approx 10^{34}$ cm^{-2} s^{-1} x 70 mb
≈ 700 MHz

~ 25 inelastic "minimum bias" low-p_T events produced on average in each bunch crossing of 25 ns
→ pile-up

e.g. "Golden" Higgs channel: $H \to ZZ \to 4\mu$



Reconstructed tracks with transverse momentum p_T>25 GeV

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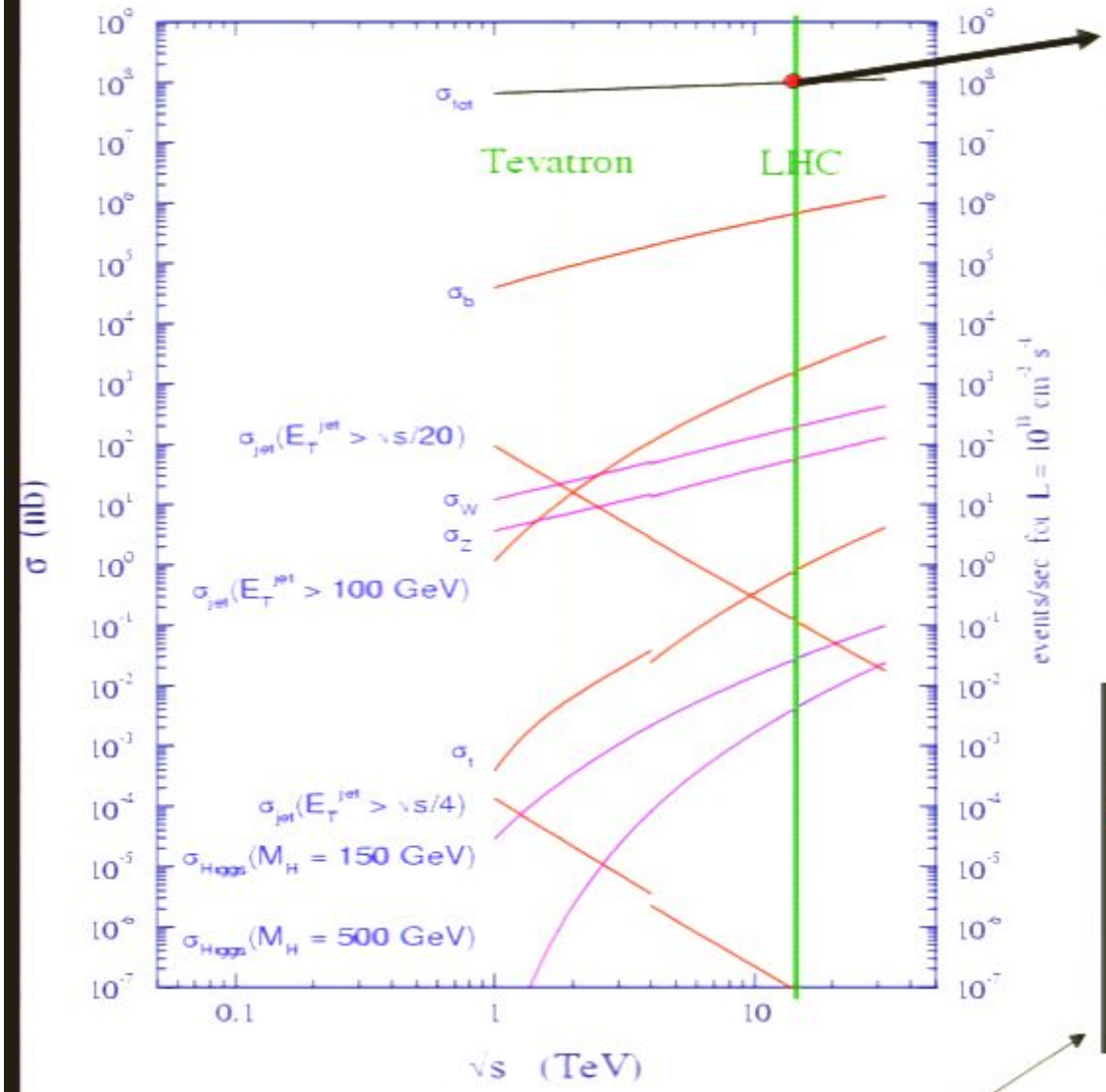

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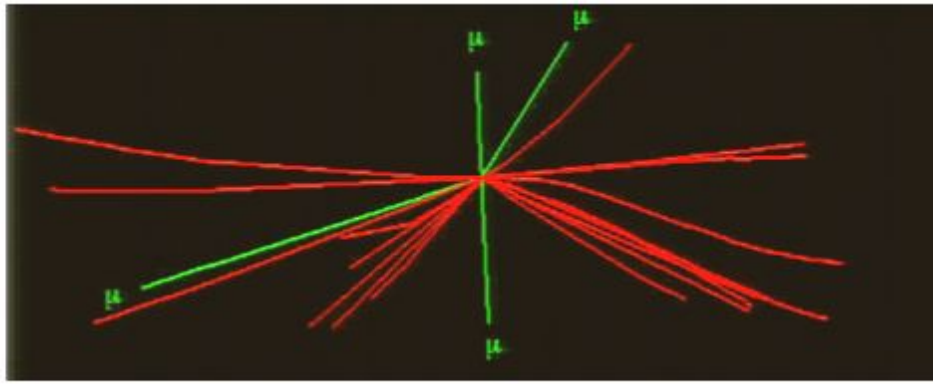

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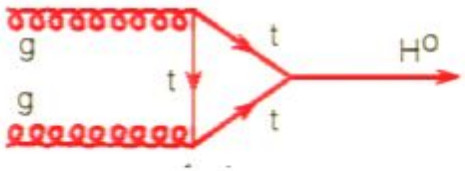
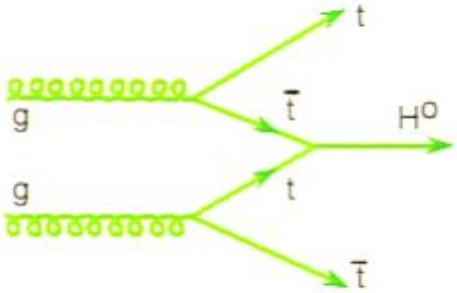
SM Higgs Production at LHC

4 processes:

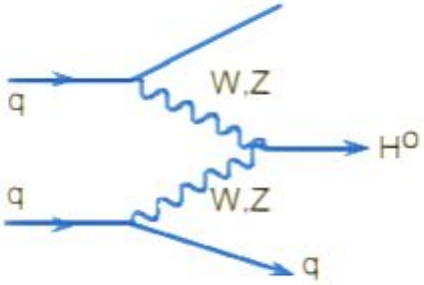


gg fusion

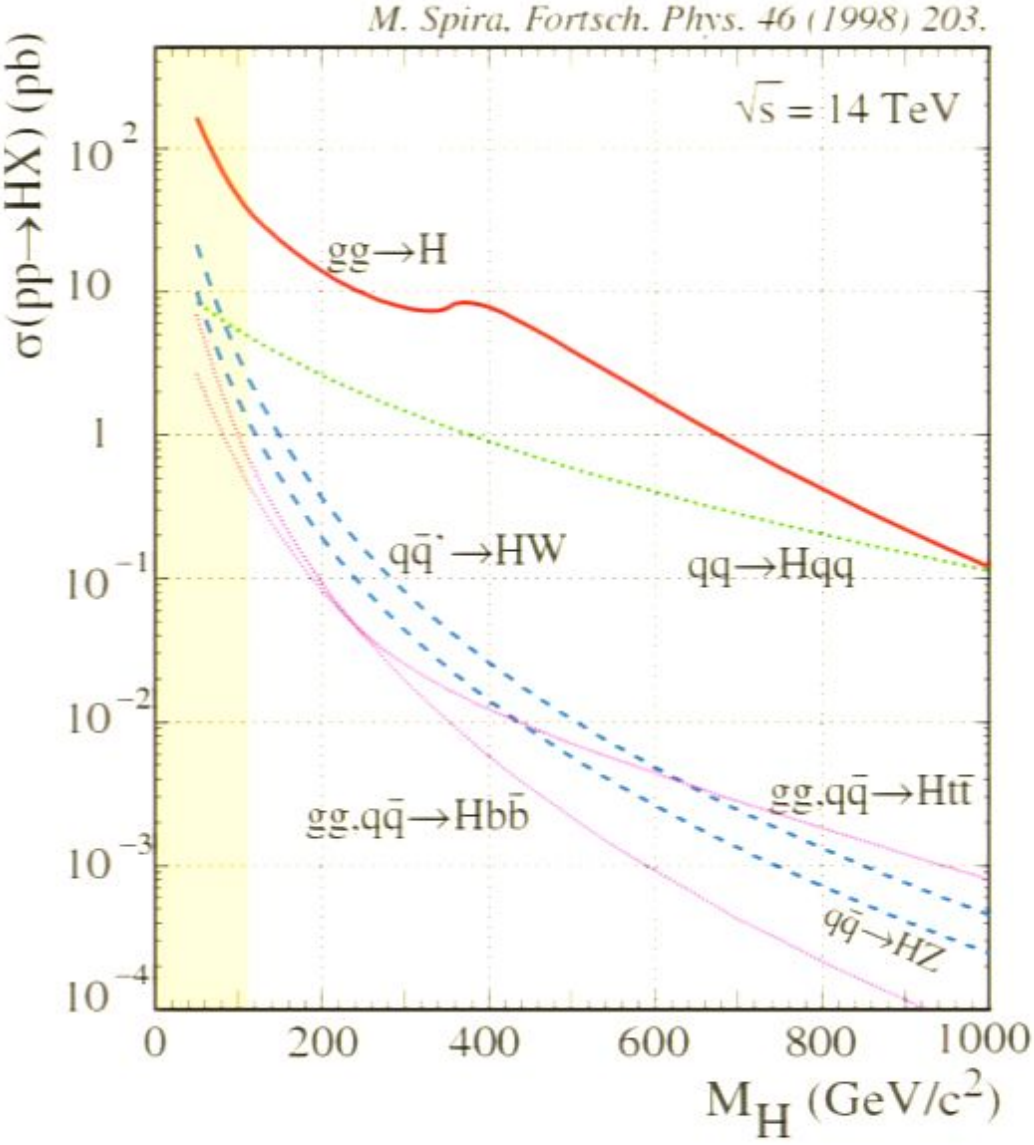


tt fusion

W,Z
Bremsstrahlung



WW,ZZ
Vector-Boson
Fusion



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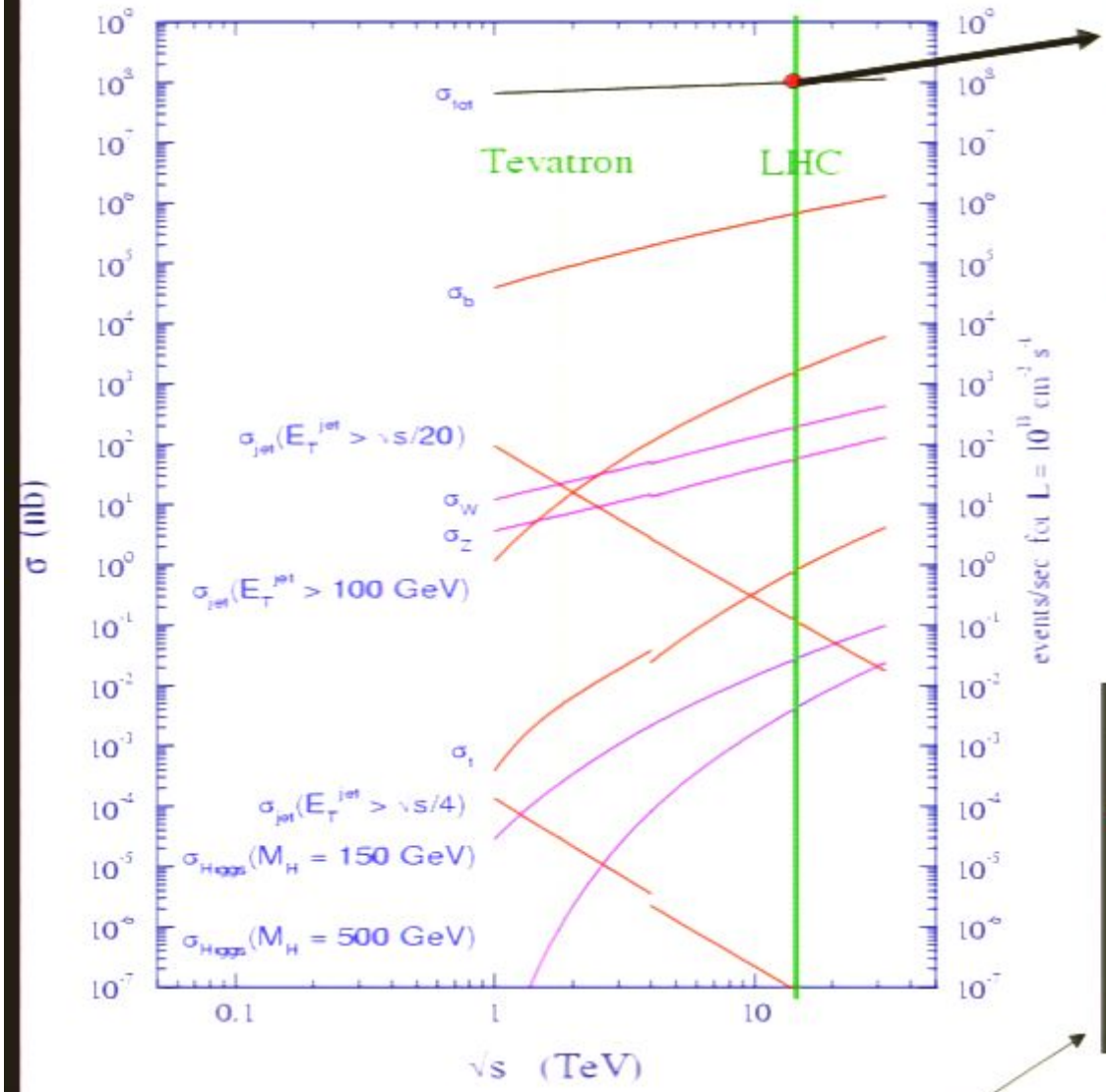

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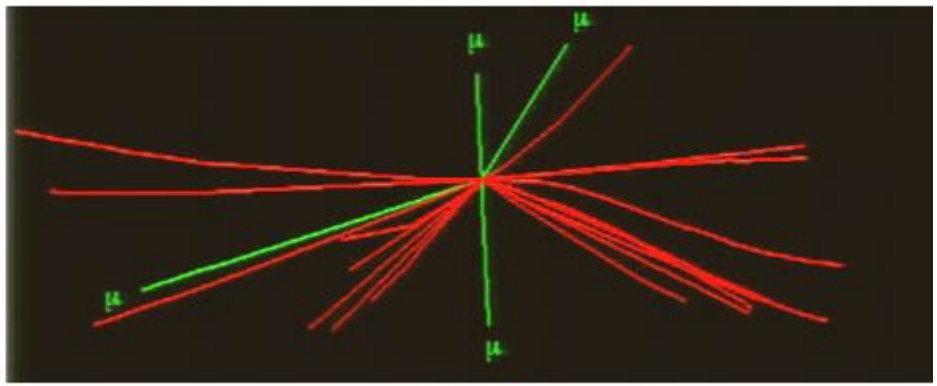

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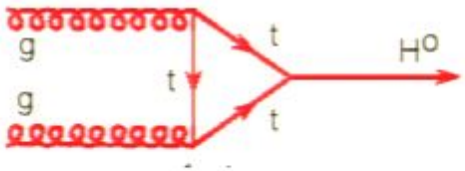
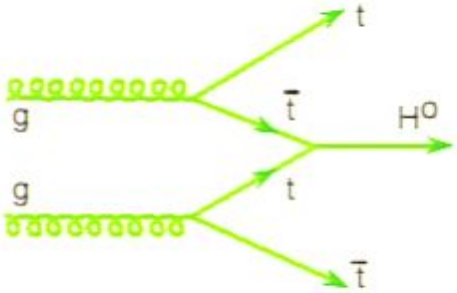
SM Higgs Production at LHC

4 processes:

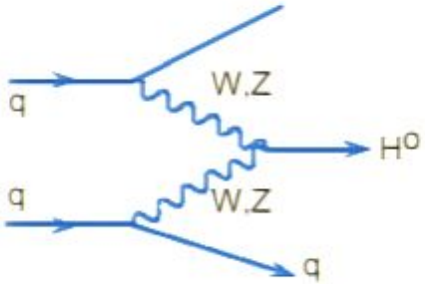


gg fusion

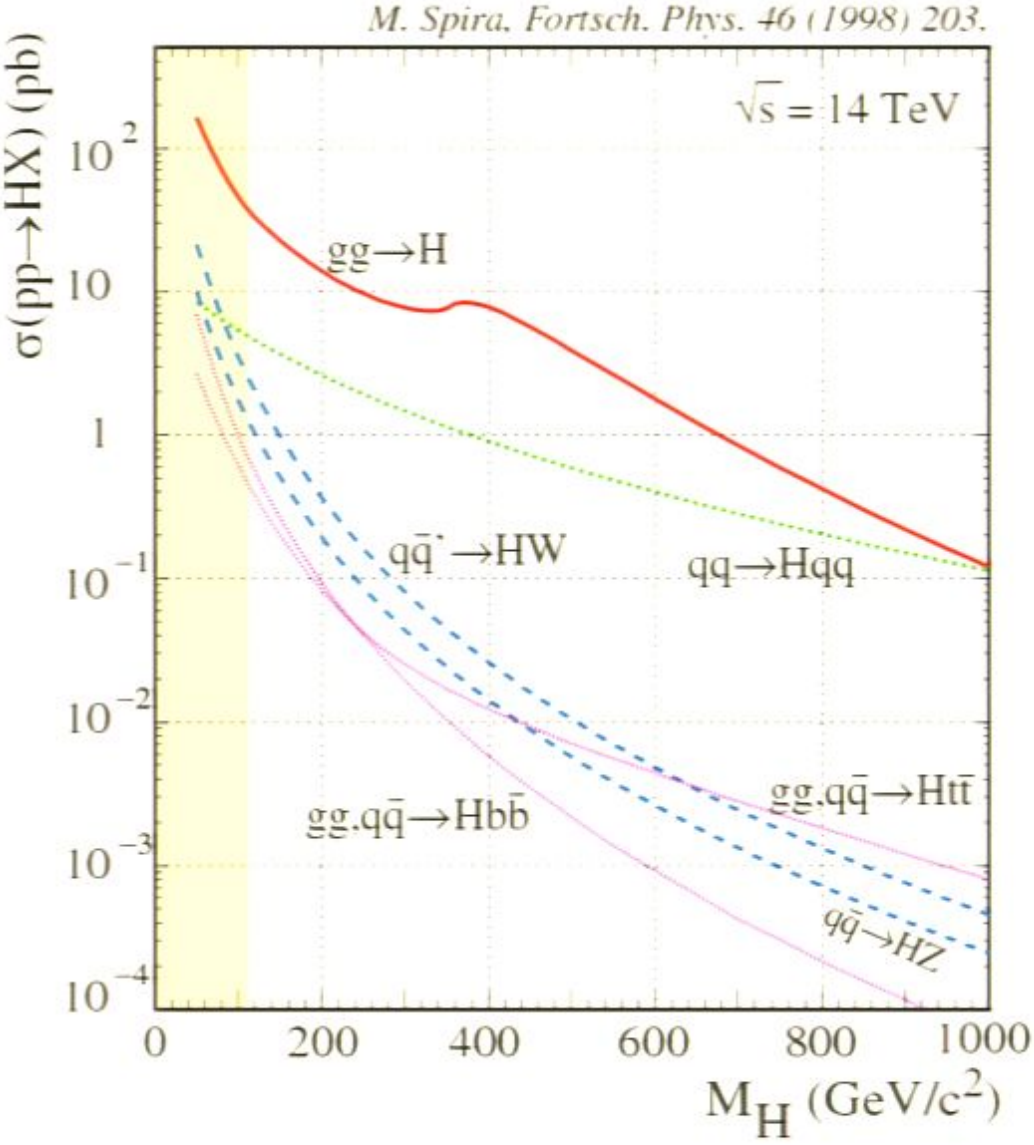


tt fusion

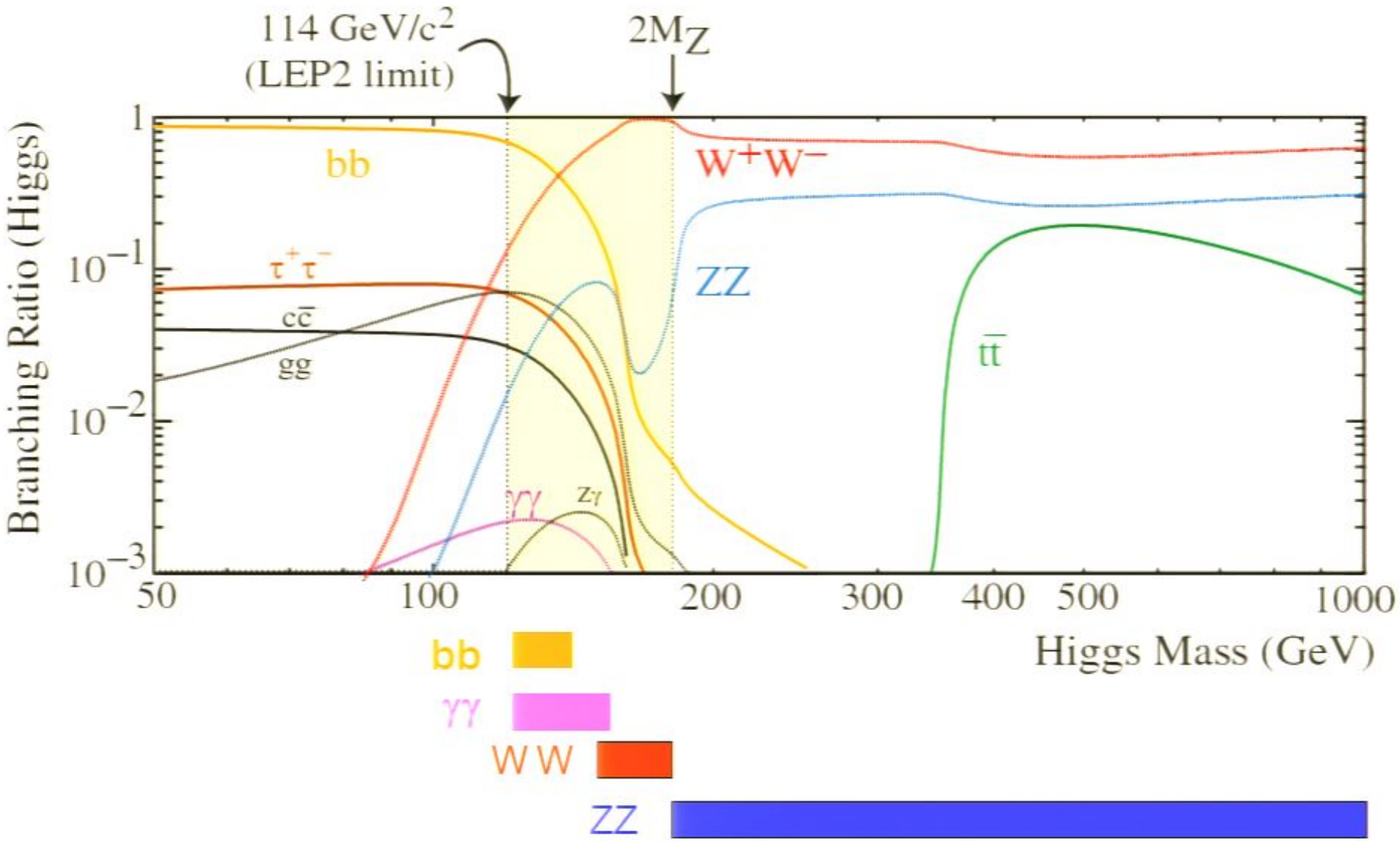
W,Z
Bremsstrahlung



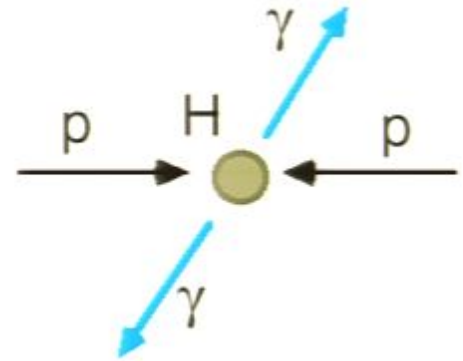
WW,ZZ
Vector-Boson
Fusion

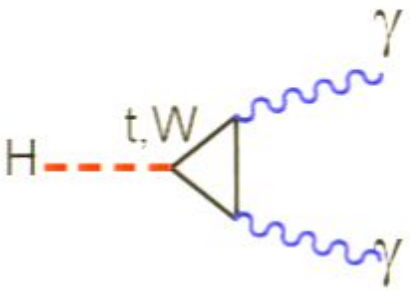


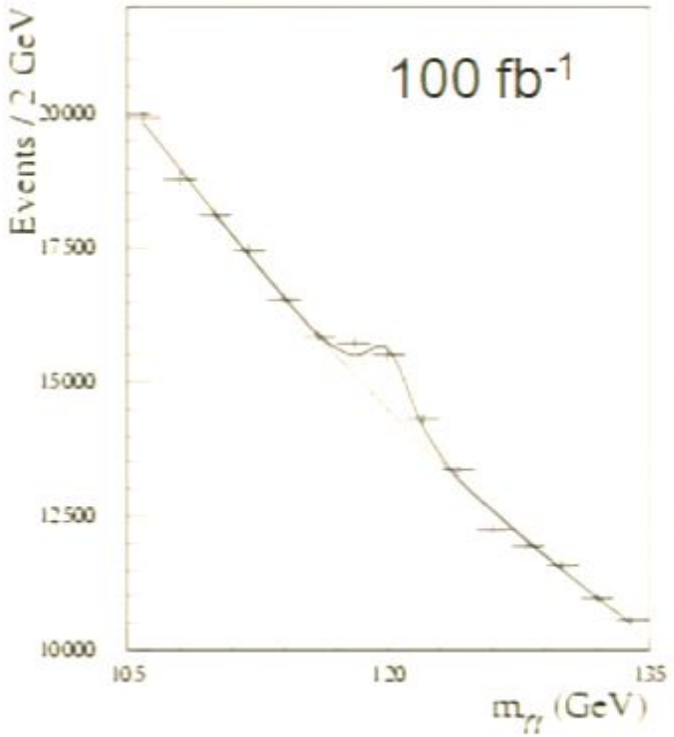
Search Channel Depends on M_H

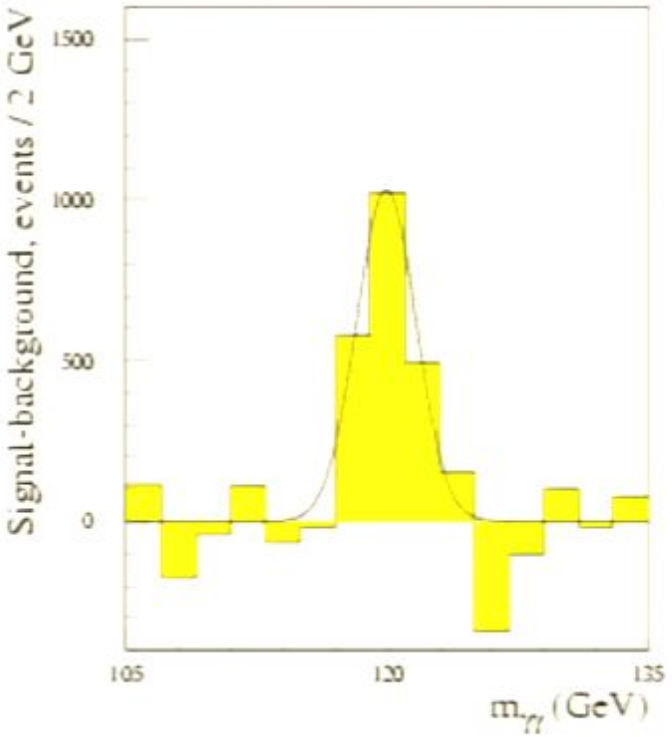


Low mass Higgs m_H<140 GeV : $H \rightarrow \gamma\gamma$





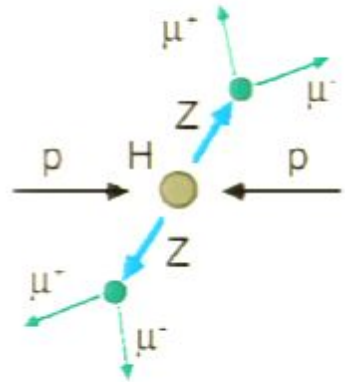




- $H \rightarrow \gamma\gamma$: decay is rare (BR ~ 10^{-3})
- Hardest region: small signal on large background
- With good calorimeter resolution can observe a mass peak
- Estimate background from sidebands

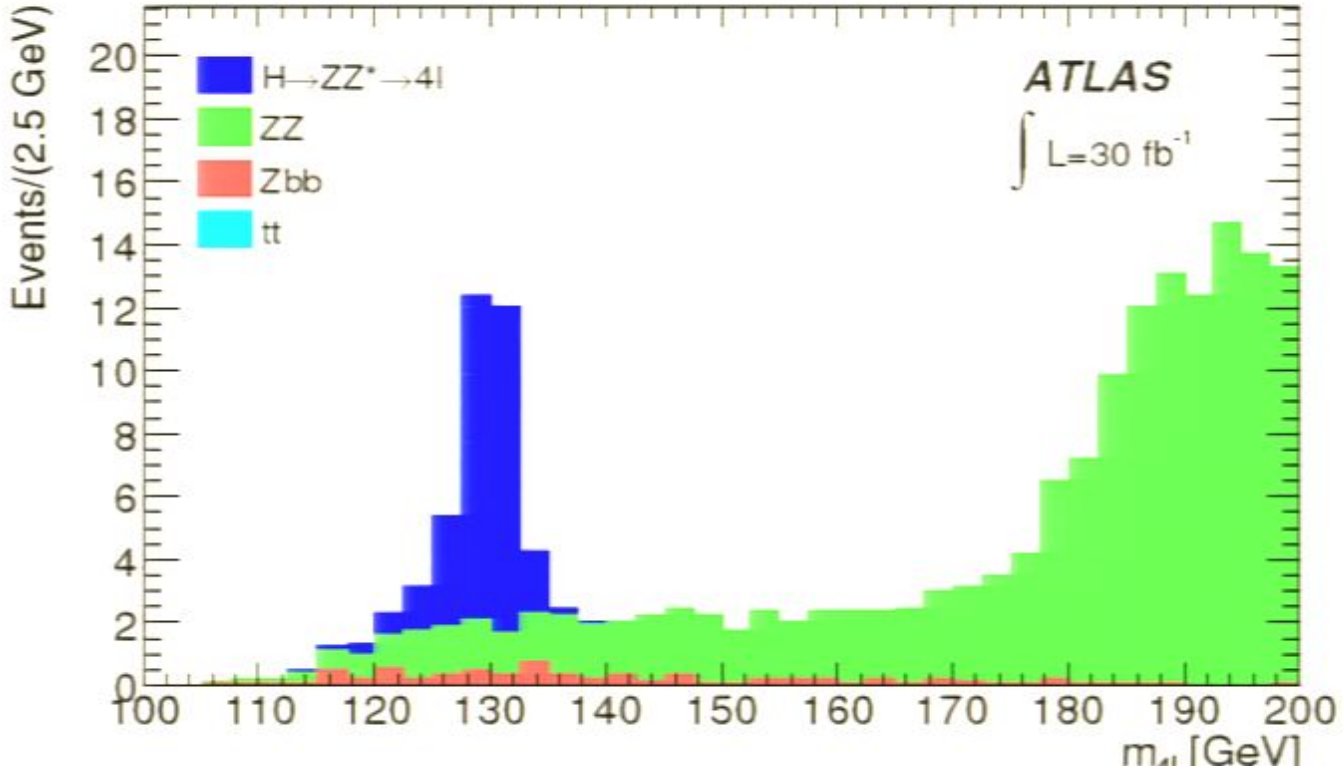
Intermediate Mass Higgs

$130 < M_H < 500$ GeV



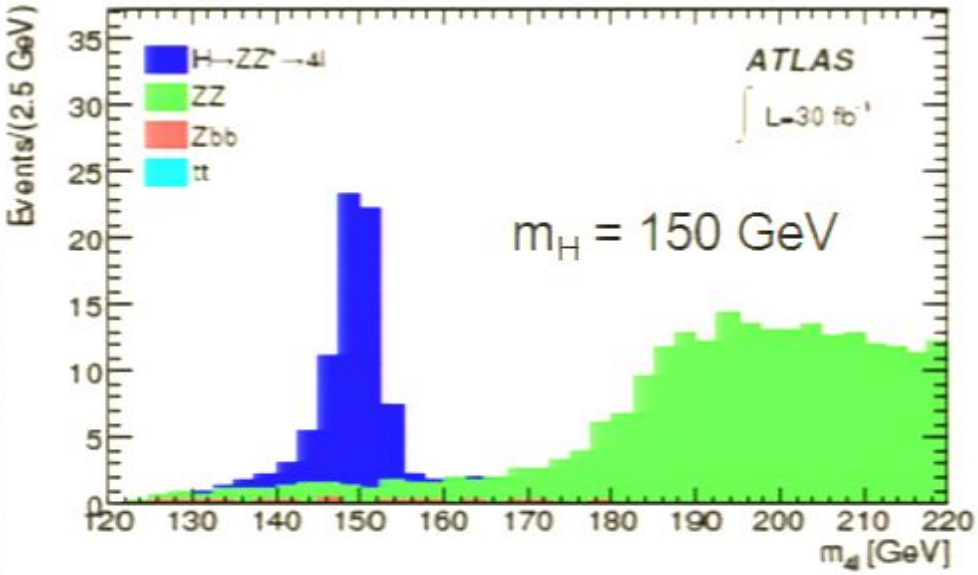
$$H \to ZZ \to l^+l^-l^+l^- \quad (l = e, \mu)$$

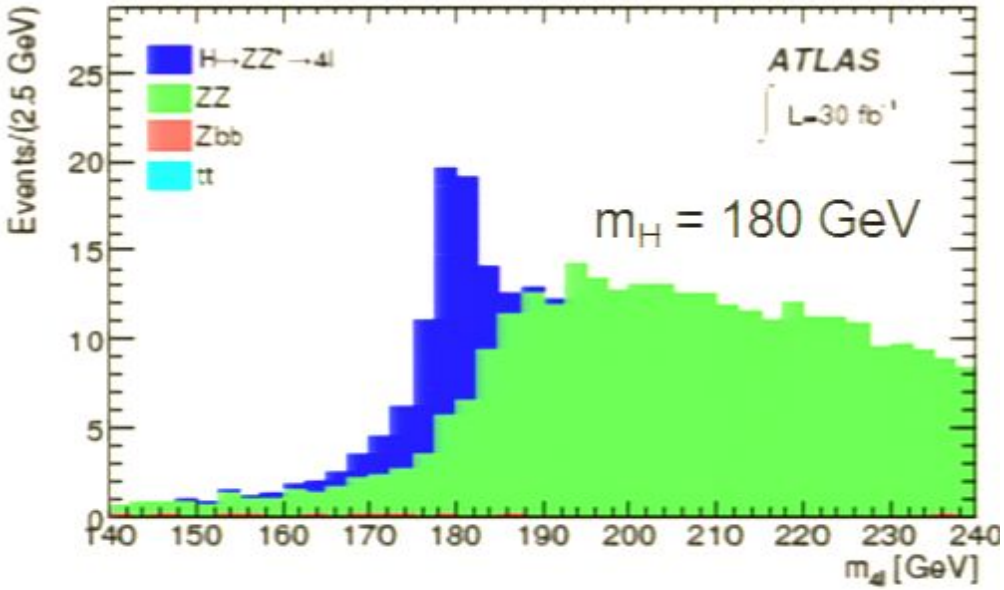
- 4 high p_T leptons – "golden channel"
- Narrow mass peak, small background

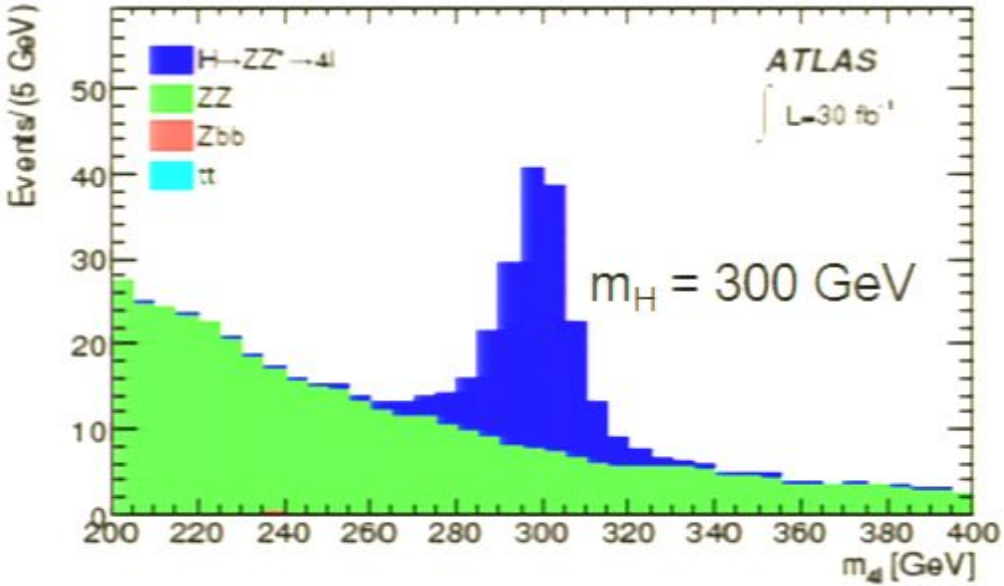


m_H = 130 GeV
30 fb^{-1}

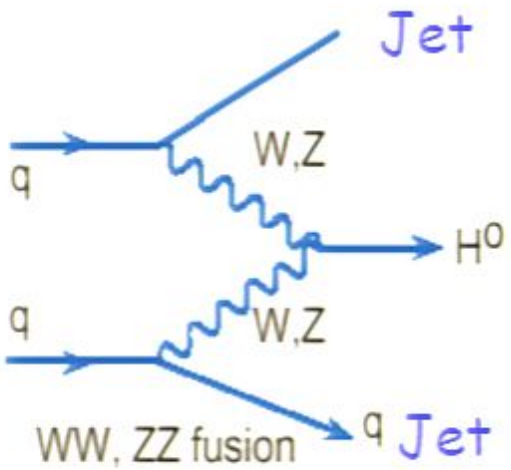
$$H \to ZZ \to l^+l^-l^+l^- \quad (l = e, \mu)$$



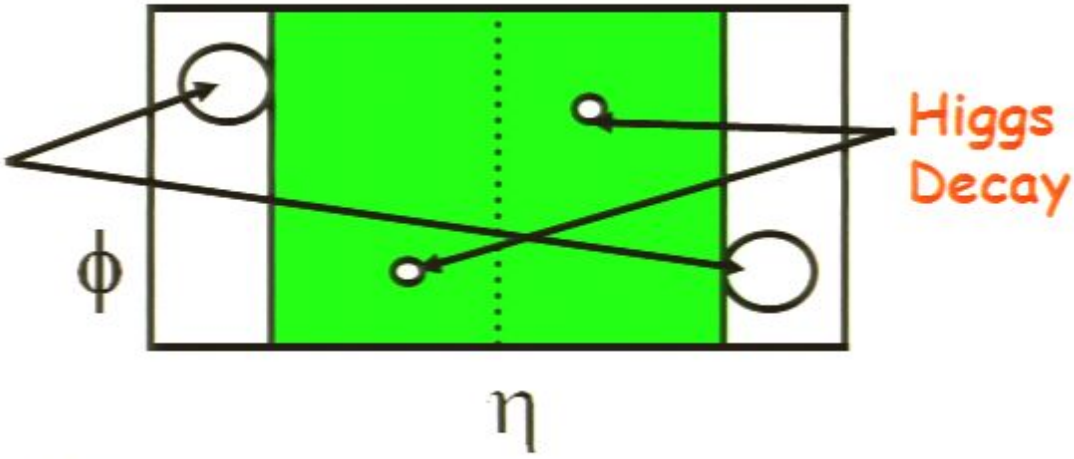




Vector Boson Fusion Channels



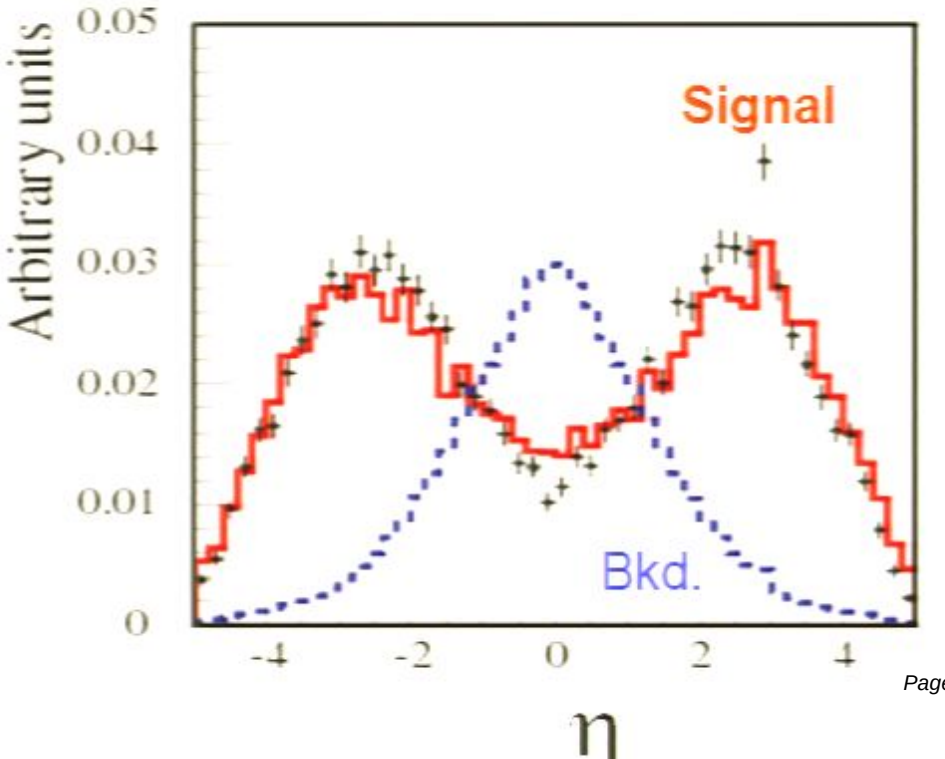
Forward tagging jets



Tag with two forward jets at large η, large Δη

Little activity in central detector

Good discovery potential for $M_H < 2M_Z$



But the Higgs has a Problem

- "Naturalness Problem": Higgs mass unstable with respect to quantum corrections:
  - $dM_H^2 \sim \Lambda^2$ (scale up to which SM is valid)
  - Solve by "fine tuning" parameters to many orders?

- "Hierarchy Problem" (differing scales)
  Why is $M_{EW}/M_{Planck} \sim 10^{-17}$?

One Solution: Supersymmetry

- Recall: symmetry between fermions and bosons
  - Q |boson> = |fermion>
  - Q |fermion> = |boson>
    - All SM particles have SUSY partners differing by spin ½ e.g. quark <> "squark"

$$Spin\tfrac{1}{2} : q \quad l, \nu$$

$$Spin0 : \tilde{q} \quad \tilde{l}, \tilde{\nu}$$

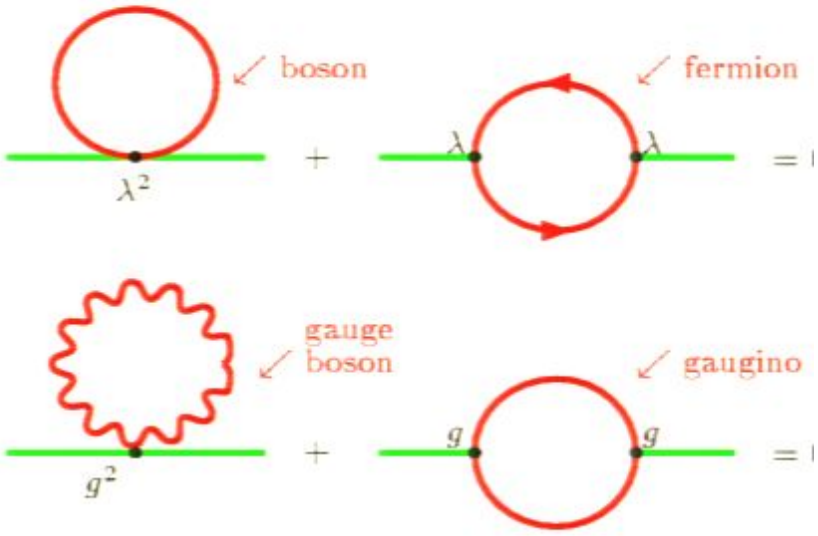
$$Spin1 / Spin0 : g, \quad W^{\pm}, H^{\pm} \quad \gamma, Z, H_1^0, H_2^0$$

$$Spin\tfrac{1}{2} : \tilde{g}, \quad \tilde{\chi}_{1,2}^{\pm}, \quad \tilde{\chi}_{1,2,3,4}^{0}$$

$$Two\ Higgs\ Doublets : h^0, H^0, A^0, H^{\pm}$$

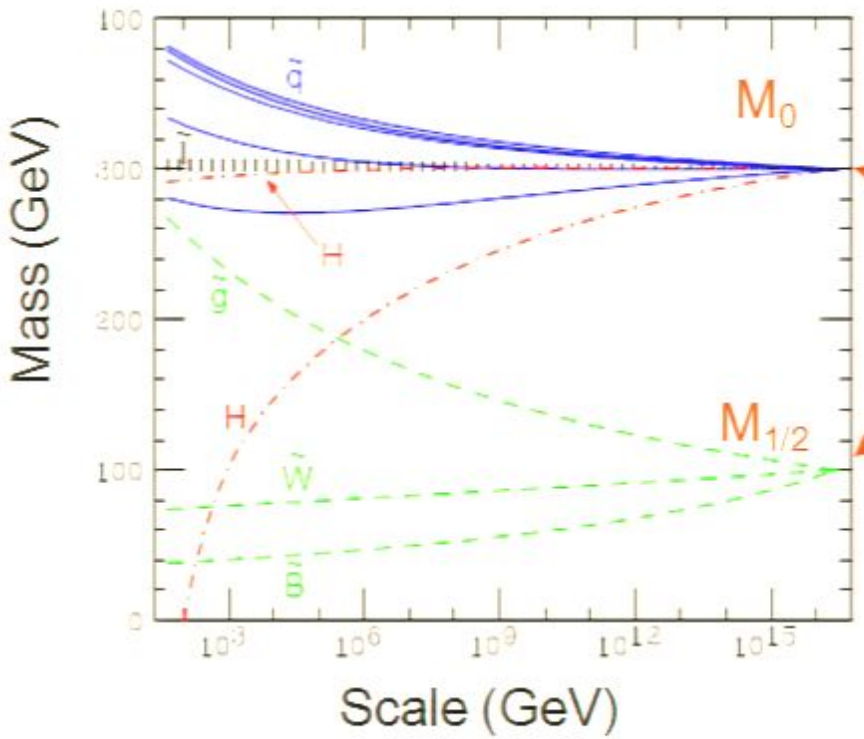
- Deeper than just doubling # of particles
  - SUSY is maximal extension of Poincaré group:
    - 4D spacetime translations
    - 3D rotations Lorentz group
  - Local SUSY implies gravity (mSUGRA)

- Corrections from SUSY particles cancel divergences to Higgs mass



- However, SUSY is "broken":
  - m(fermion) <> m(sfermion)
- Higgs mass still stable if superpartners mass $M_{SUSY} \leq 1$ TeV
- SUSY at TeV scale is an attractive solution to the naturalness/hierarchy problem

Reminder of SUSY Models



MSSM (Minimal SUSY) has >100 parameters

- Not very predictive

Constrained MSSM: At unification scale (similar to unification of forces)

- Spin 0 "Sfermions" unify to mass M_0
- Spin ½ "Gauginos" unify to mass $M_{1/2}$

5 parameters in total

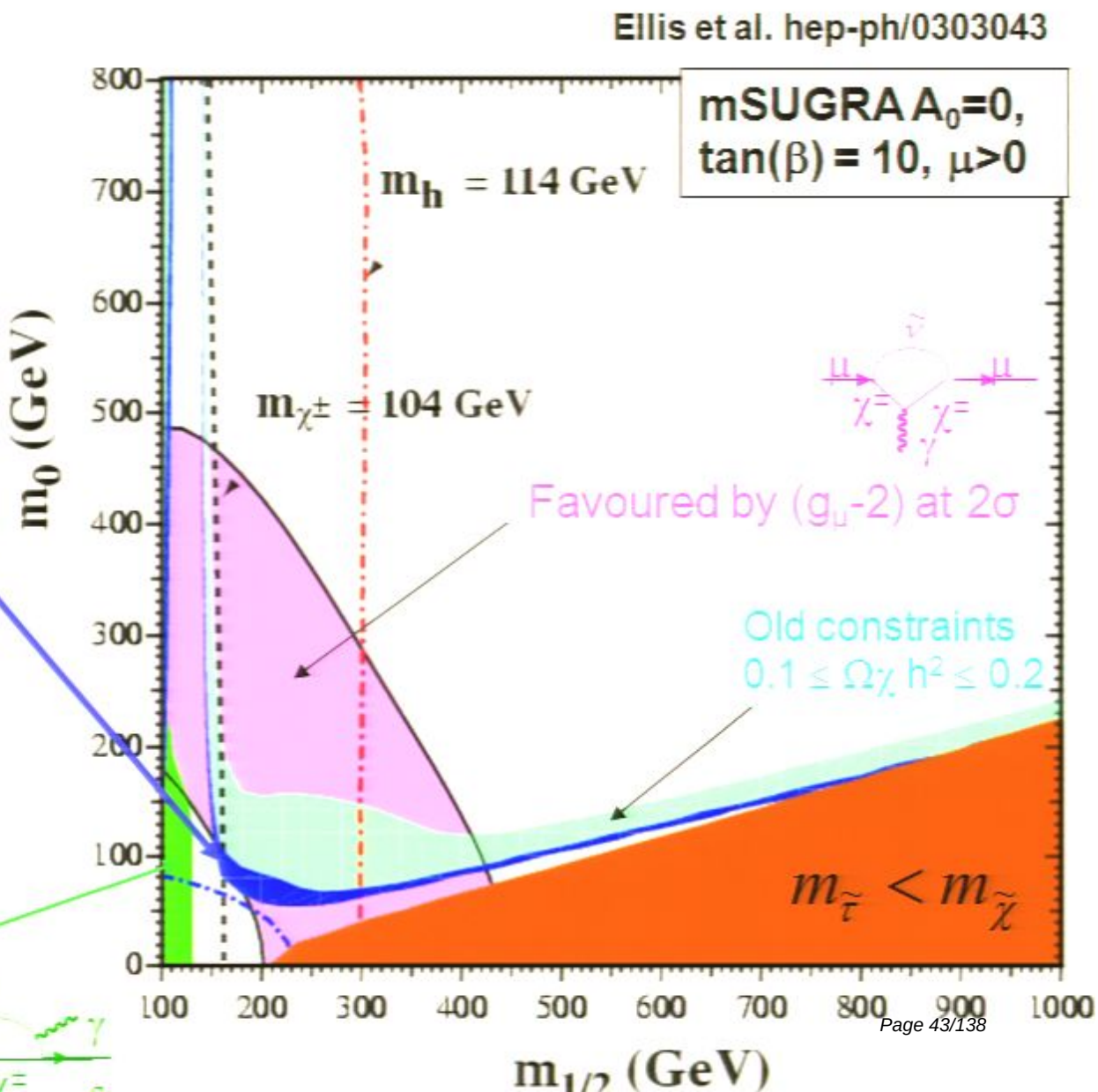
- $M_{1/2}$.
- M_0
- tan(β) : ratio of SUSY Higgs vacuum expectation values
- μ : Higgs mixing parameter
- A_0 : Higgs sfermion-sfermion coupling

Example: M_0= 300 GeV
$M_{1/2}$= 100 GeV

- R-parity = $(-1)^{3(B-L)+2S}$
  - SM: +1, MSSM: -1
- SUSY particles produced in pairs
  - Lightest SUSY particle (LSP) is stable -> Neutralino CDM candidate

Constraints on SUSY

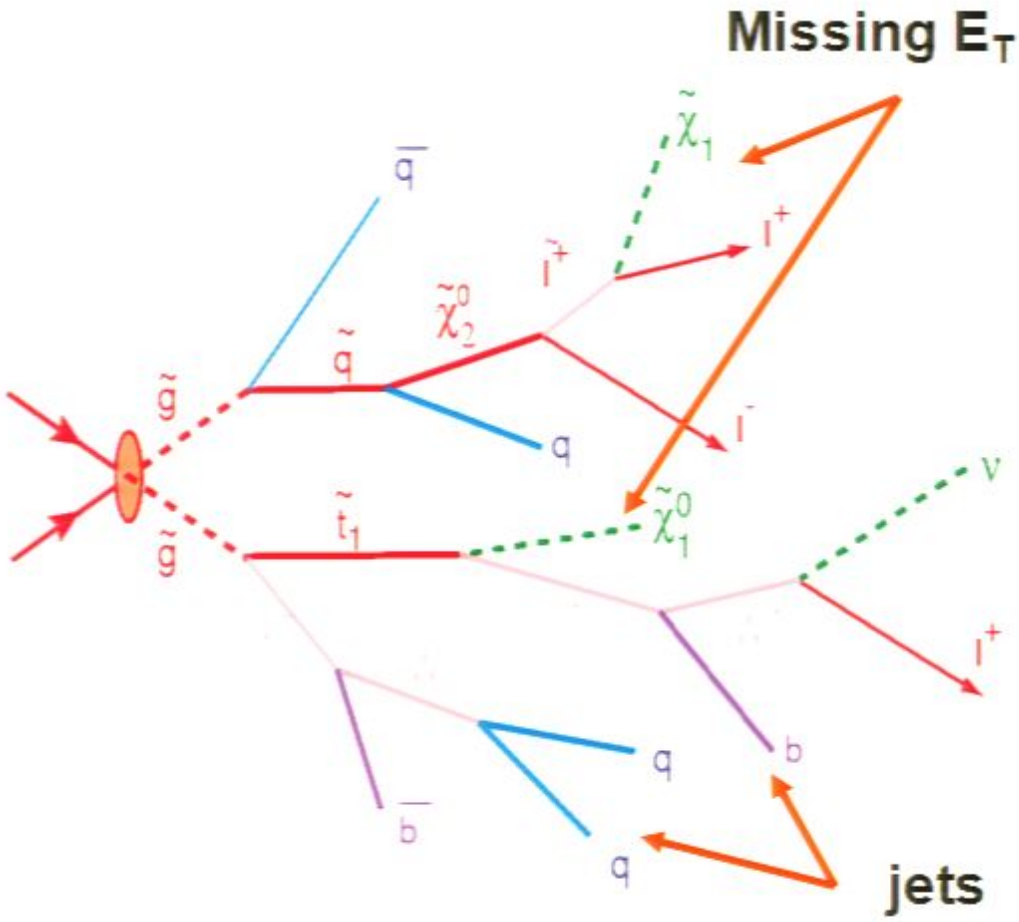
- SUSY is strongly constrained by cosmology – WMAP
  - New allowed region $0.094 \leq \Omega\chi\, h^2 \leq 0.129$
  - $\Omega\chi\, h^2 \sim m\chi\, n\chi$ (relic density) implies lighter neutralino
- Can we find SUSY?



Region Disfavoured by BR ($b \to s\gamma$) = $(3.2 \pm 0.5) \bullet 10^{-4}$ (CLEO, BELLE)

Strategy for SUSY Discovery at LHC

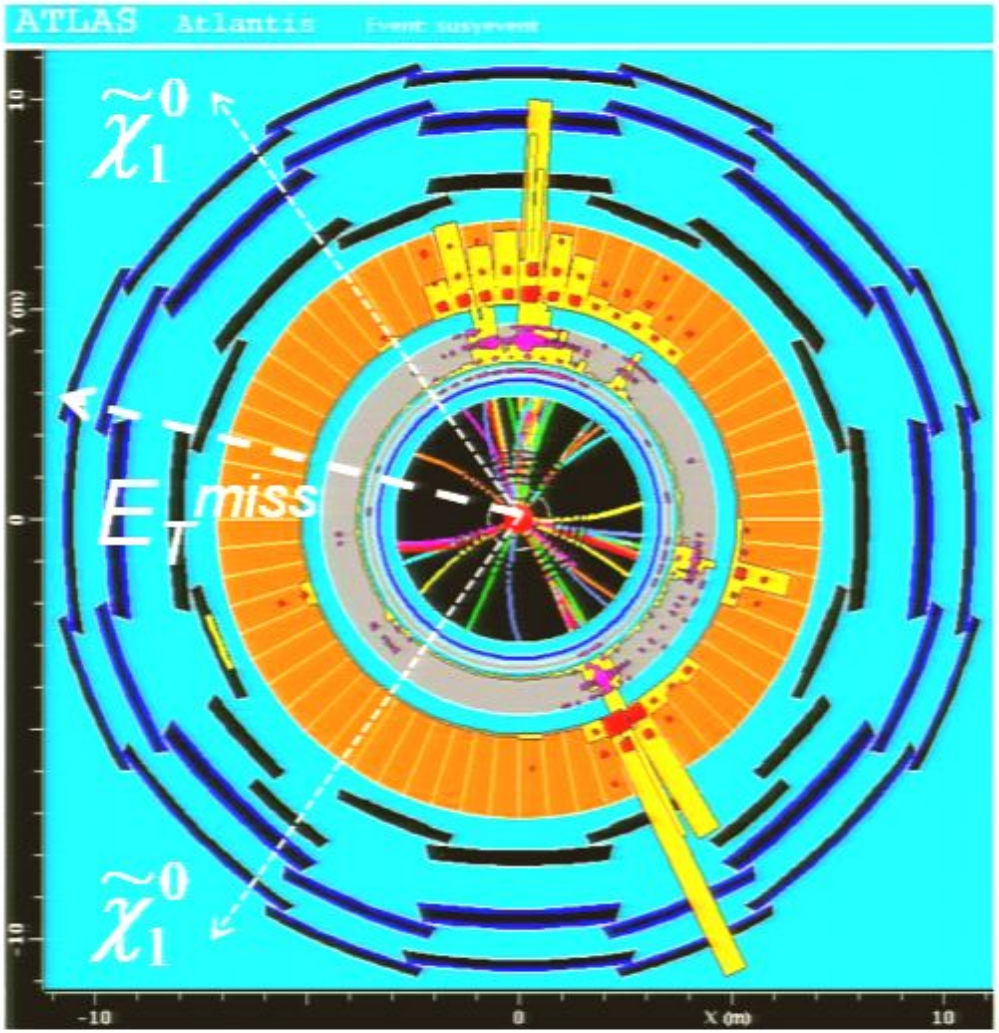
- R-Parity conserving SUSY search channels:
  - Large E_T^{miss};
  - Large jet multiplicity;
  - Large E_T^{sum}.
- Background estimation crucial
  - Estimations from data.



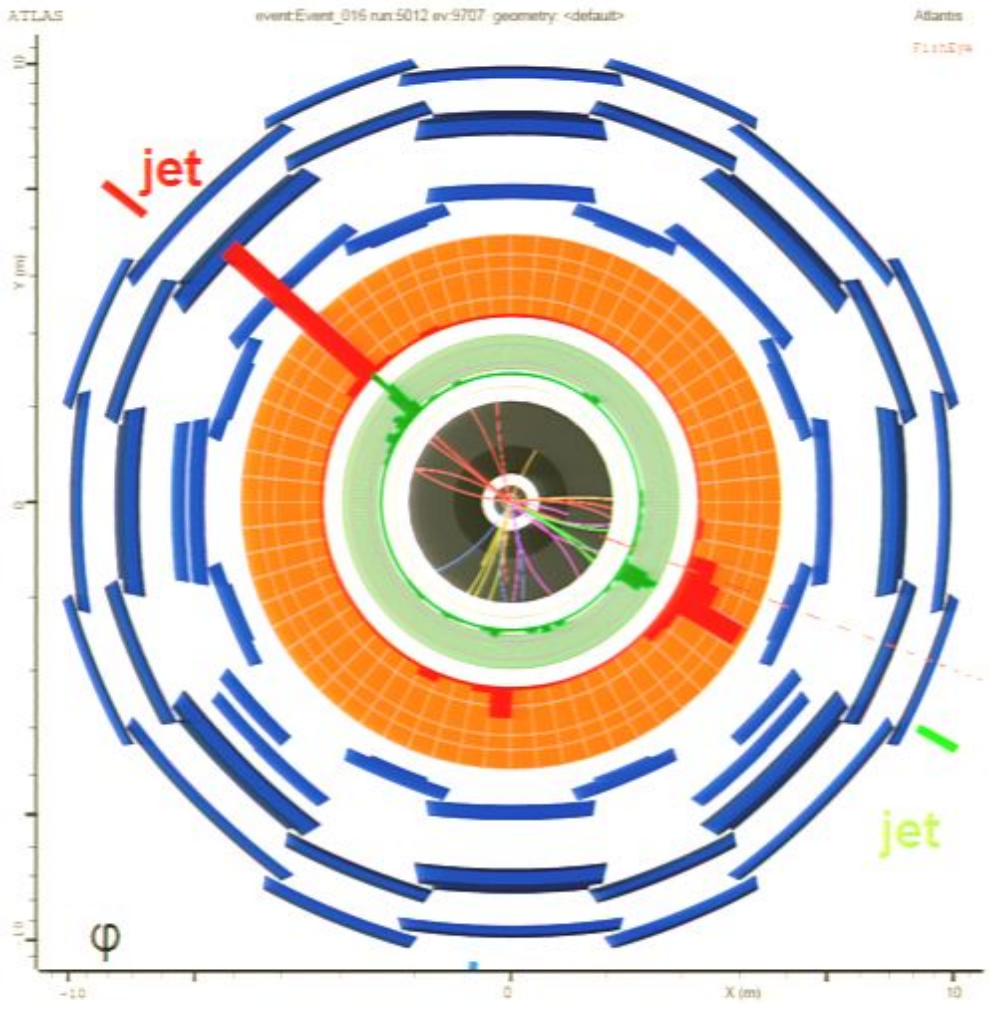
$$pp \to \tilde{g}\tilde{g} \to cascade\ decay$$

Topologies: SUSY vs QCD Background

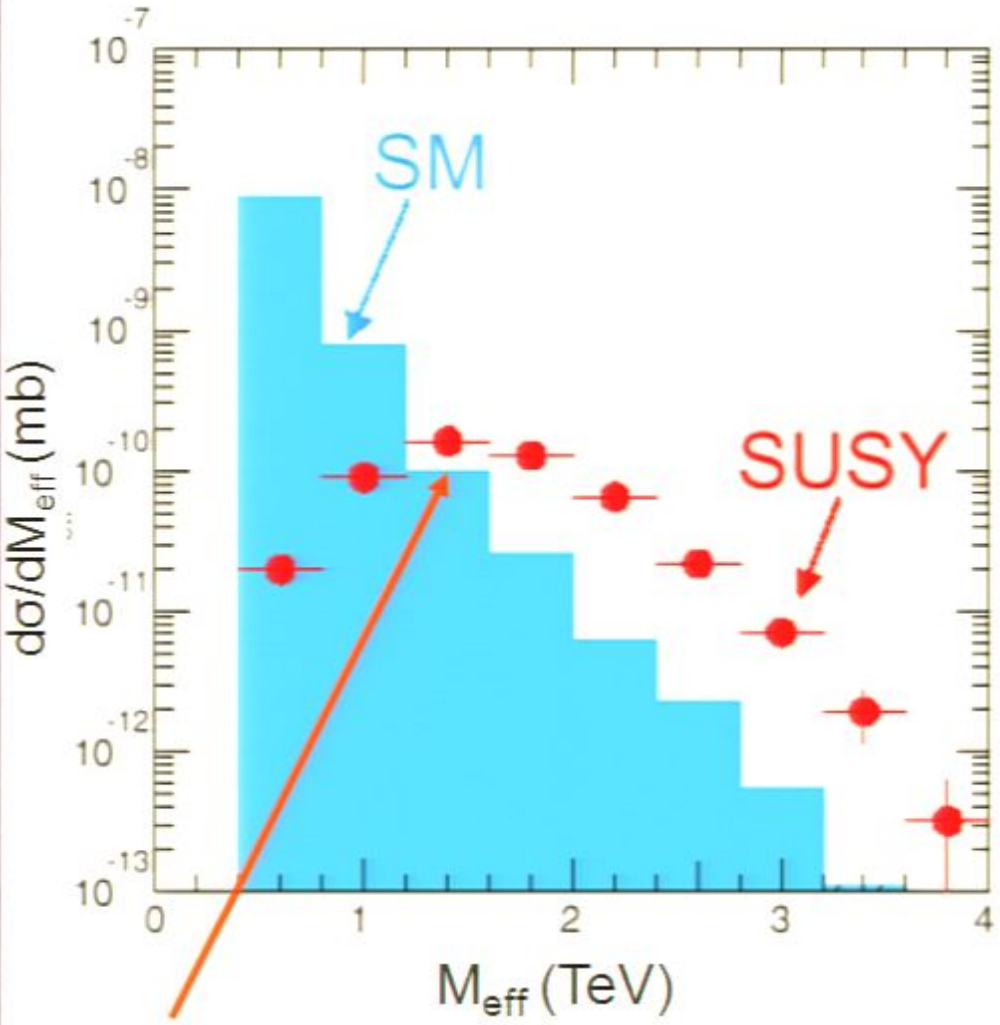
SUSY: $E_T^{miss} > 100$ GeV



QCD: jets, low E_T^{miss}



Signal of a SUSY Discovery

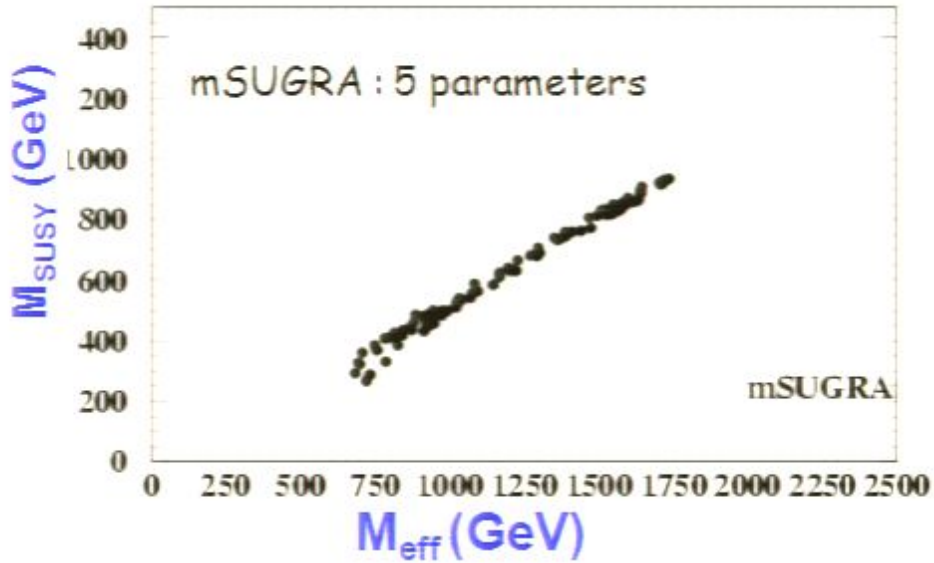


Peak position correlated to M_{SUSY}

Area ~ SUSY cross-section

Powerful background rejection using "effective mass":

$$M_{eff} = E_T^{miss} + \sum_{i=1}^{4} p_T(jet_i) \quad (GeV)$$

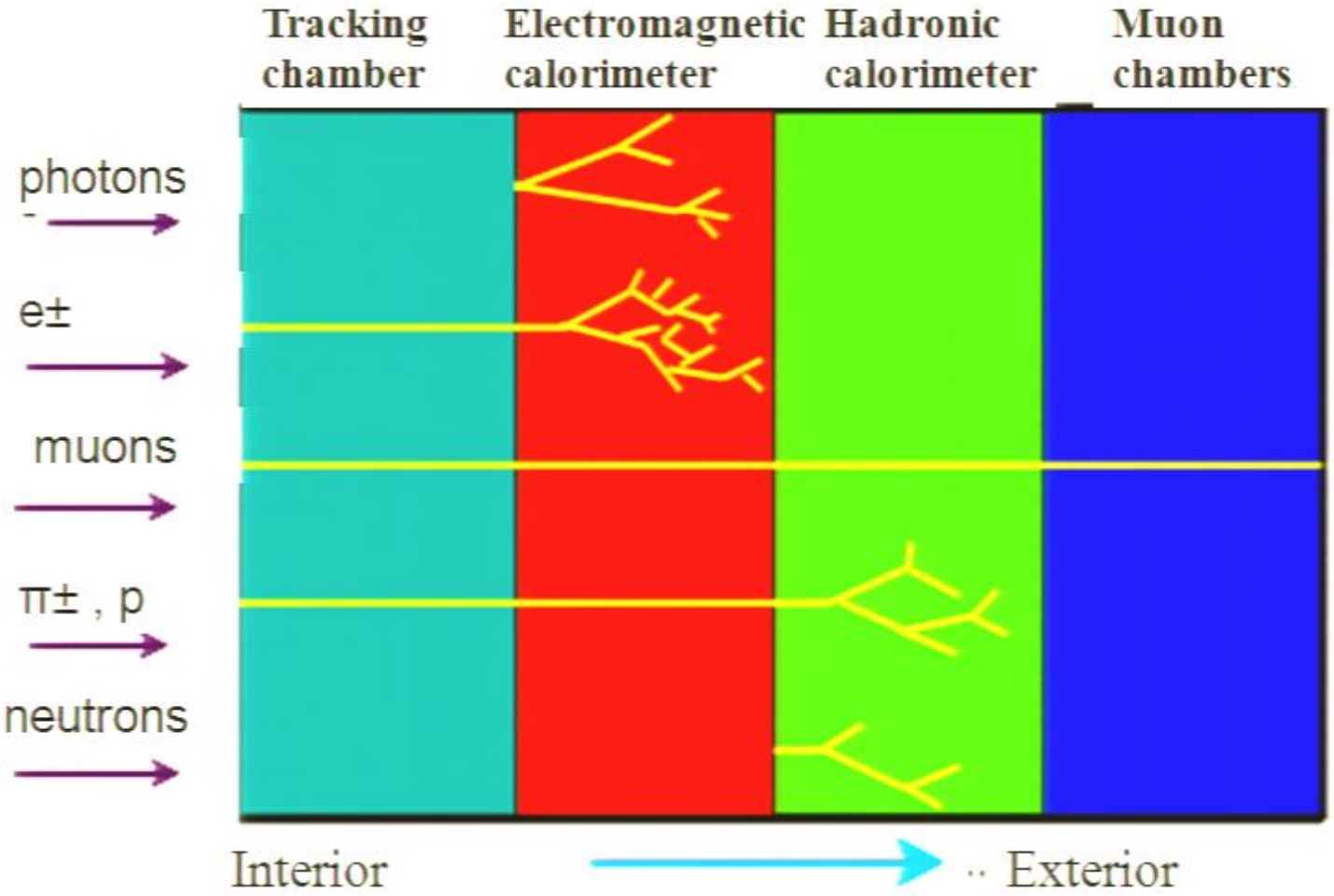


Effective mass "tracks" SUSY scale

Note on Trigger: Jet + E_T^{miss} with p_T jet > 70 GeV and E_T^{miss} > 70 GeV

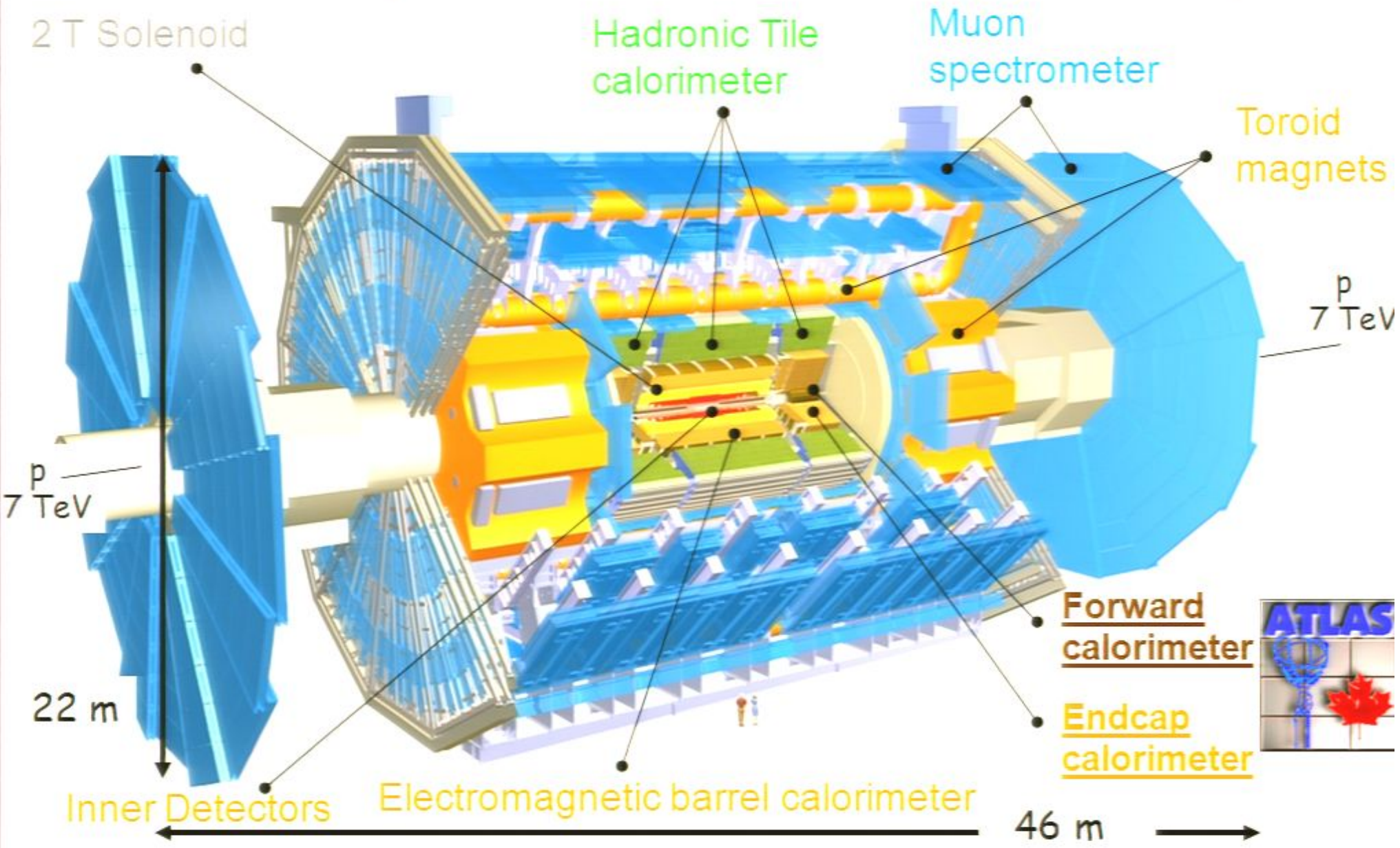
4. The ATLAS Experiment

Basic Detector Components



"Hadros" = Greek for "strong"

ATLAS (A Toroidal LHC ApparatuS)



Total mass ~ 7000 tonnes, as much steel as the Eiffel tower

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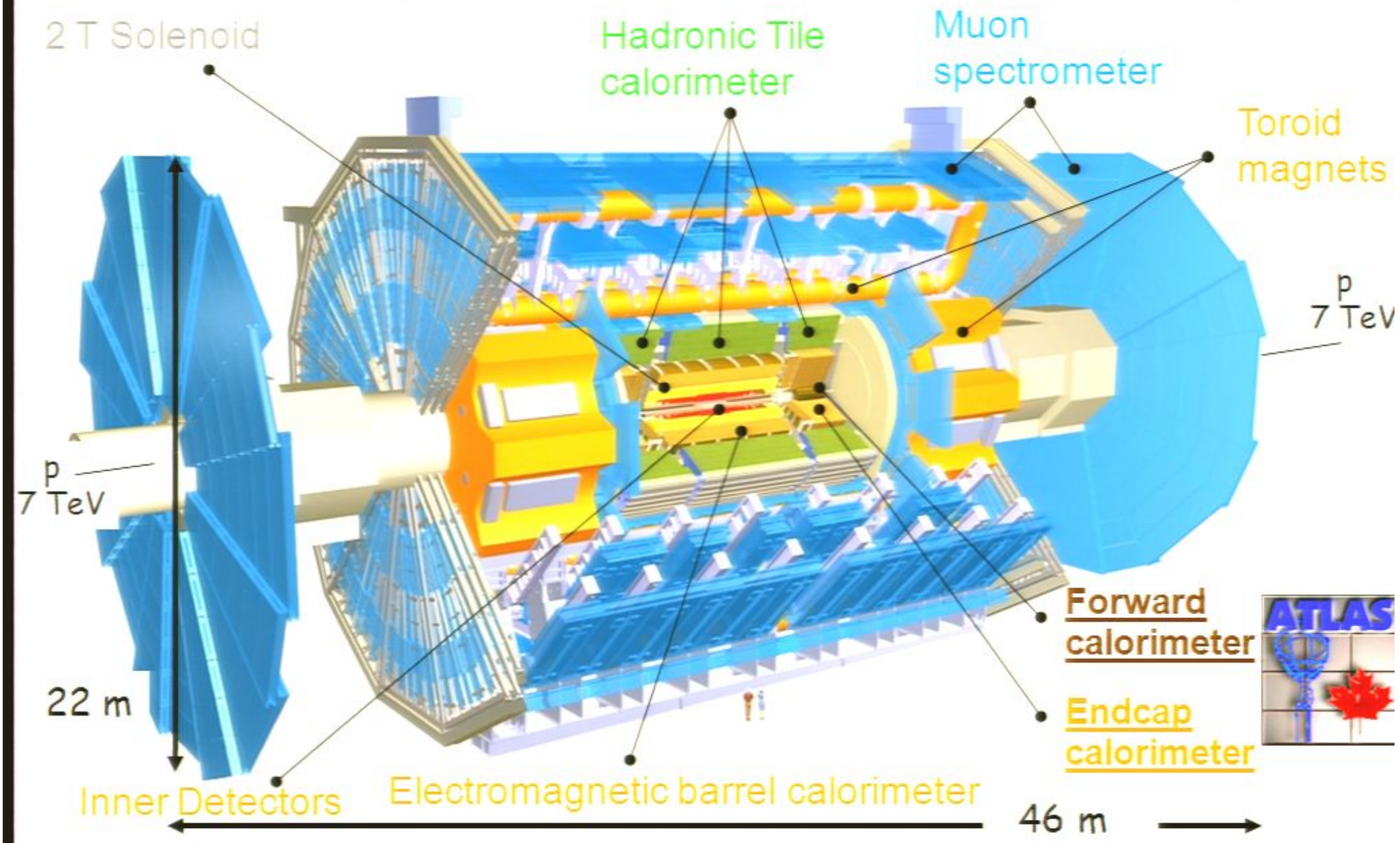

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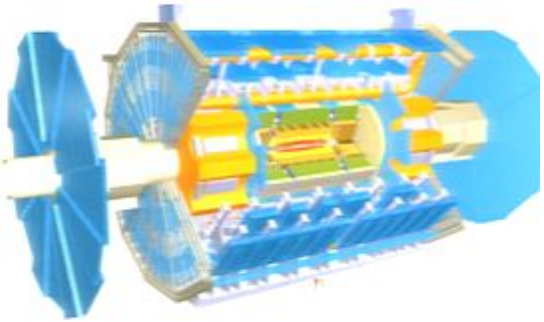
Scale of ATLAS

92 m

ATLAS assembled
92 m below ground
at CERN




ATLAS Collaboration
- 37 Countries
- 169 Institutions
- 2500 Scientific Authors
total
ATLAS
Collaboration
C
D

ATLAS Canada

Alberta
Carleton
McGill
Montréal
Simon Fraser
Regina
Toronto
TRIUMF
UBC
Victoria
York

43 University/Lab.physicists About 150 people, including Engineers, Technicians, Students

Includes 5 IPP Research Scientists

Educational Role
12 UG Summer Students
64 Graduate Students
26 Post Docs

Initial Focus on Liquid Argon Calorimetry

- 4 NSERC Funded Construction Projects

Completed in 2004

Endcap Hadronic Calorimeter

Forward Hadronic Calorimeter

Front-End-Board Electronics

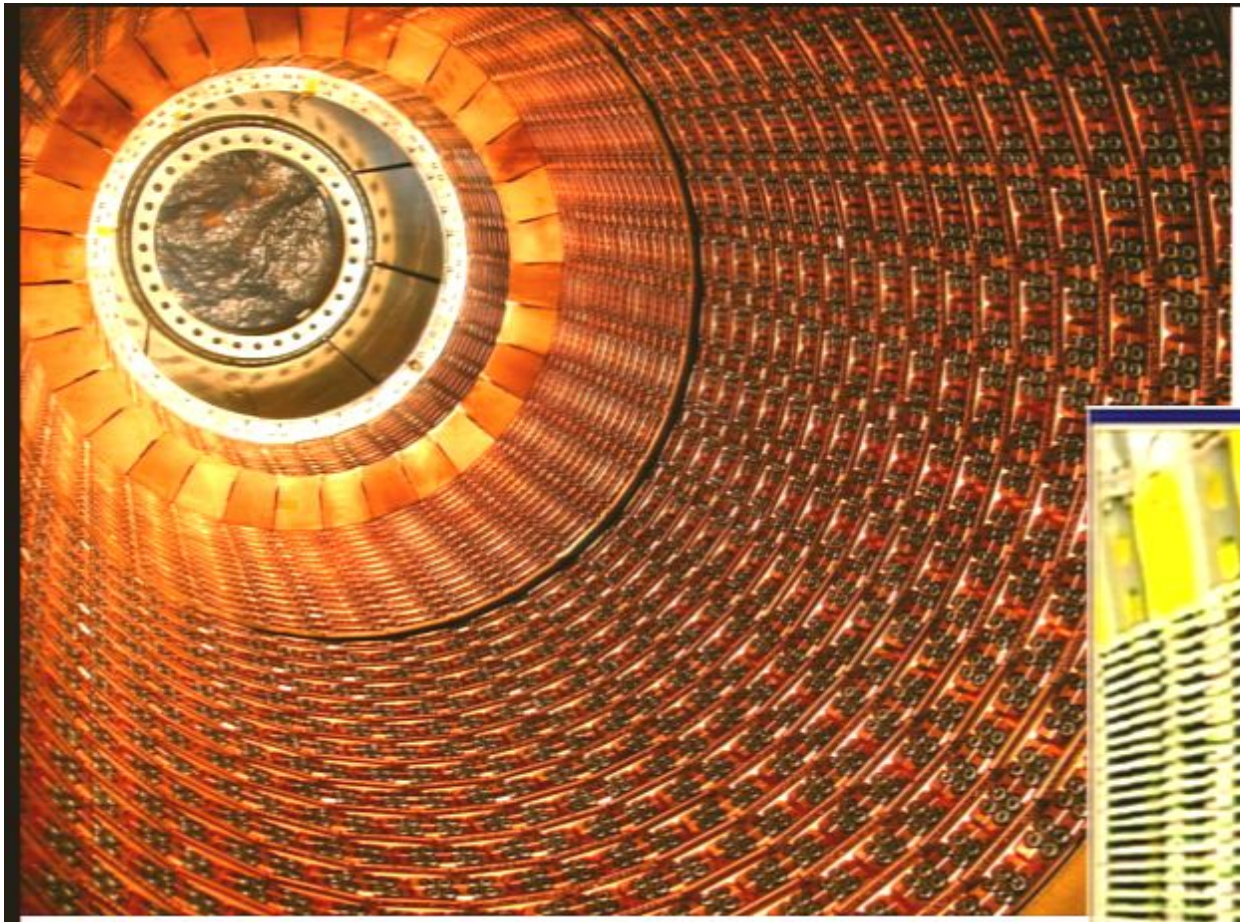
Endcap Signal Cryogenics Feedthroughs

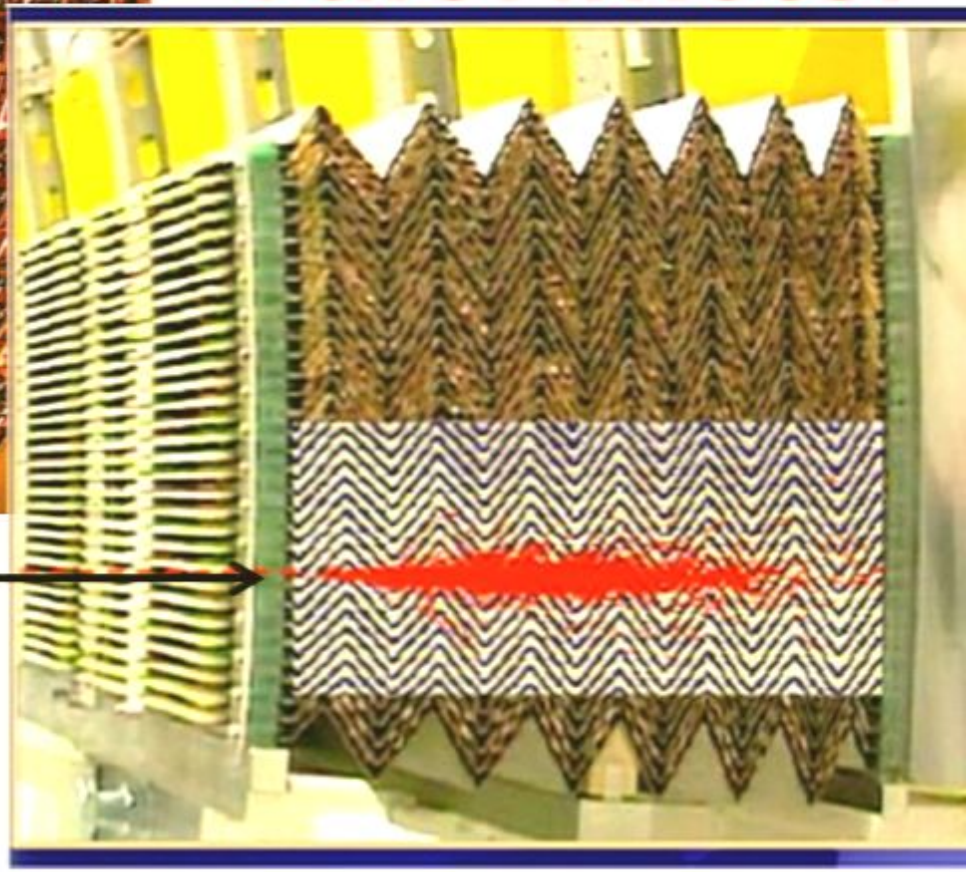
Commissioning ongoing

- Ongoing/Future Activities

Analysis of Beam Tests
Calorimeter Calibration
Preparation for Physics
Event Filter Processor Farm
Computing - soft/hard
STC Electronics
Beam Condition Monitors

Canada: Liquid Argon Calorimeter





- Electron / photon identification
- Lead absorber initiates shower
- Particles ionize liquid Argon,
- High Voltage between plates cause ions and electrons to drift
- Collected charge is proportional to energy of incident particle

$|\eta| < 3$:

$\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 0.7\%$

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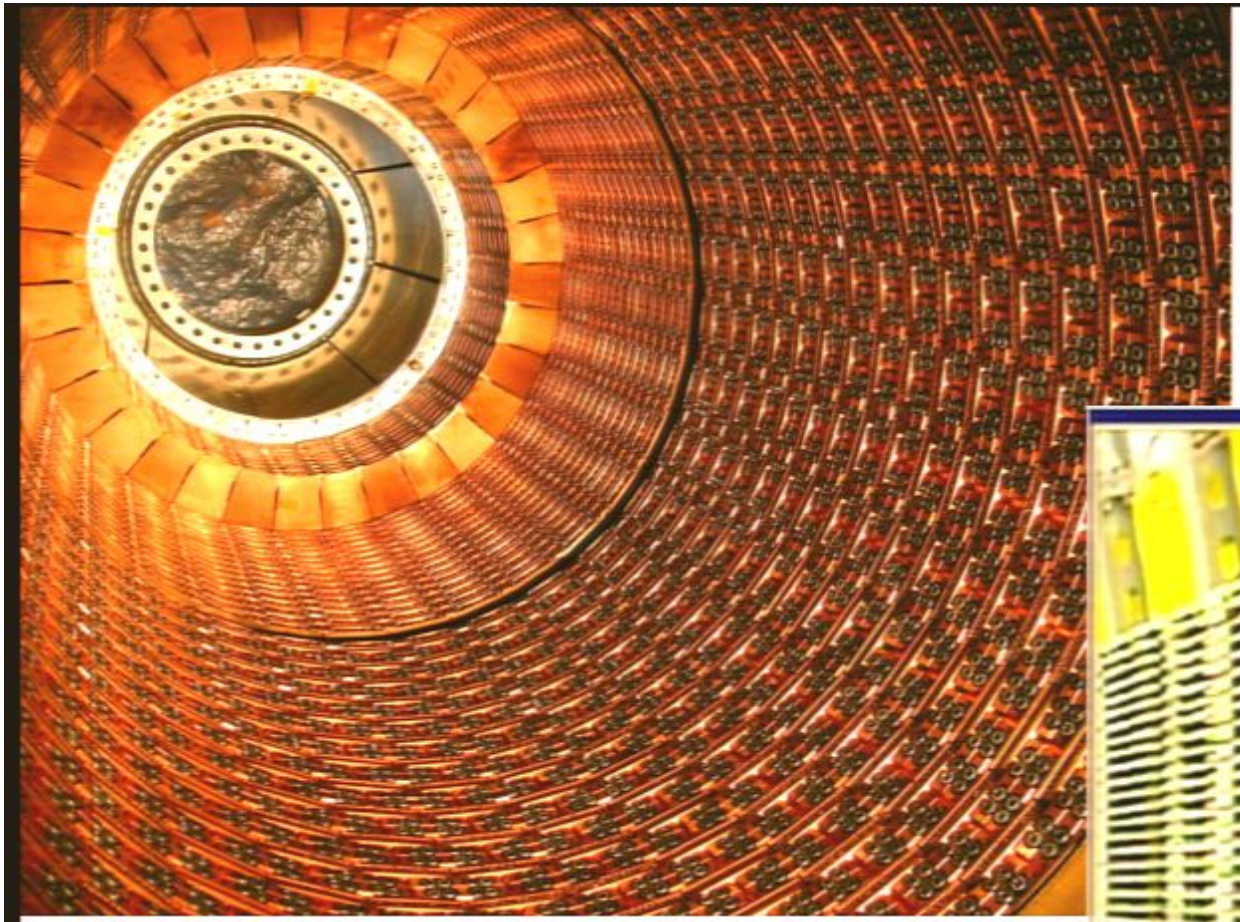

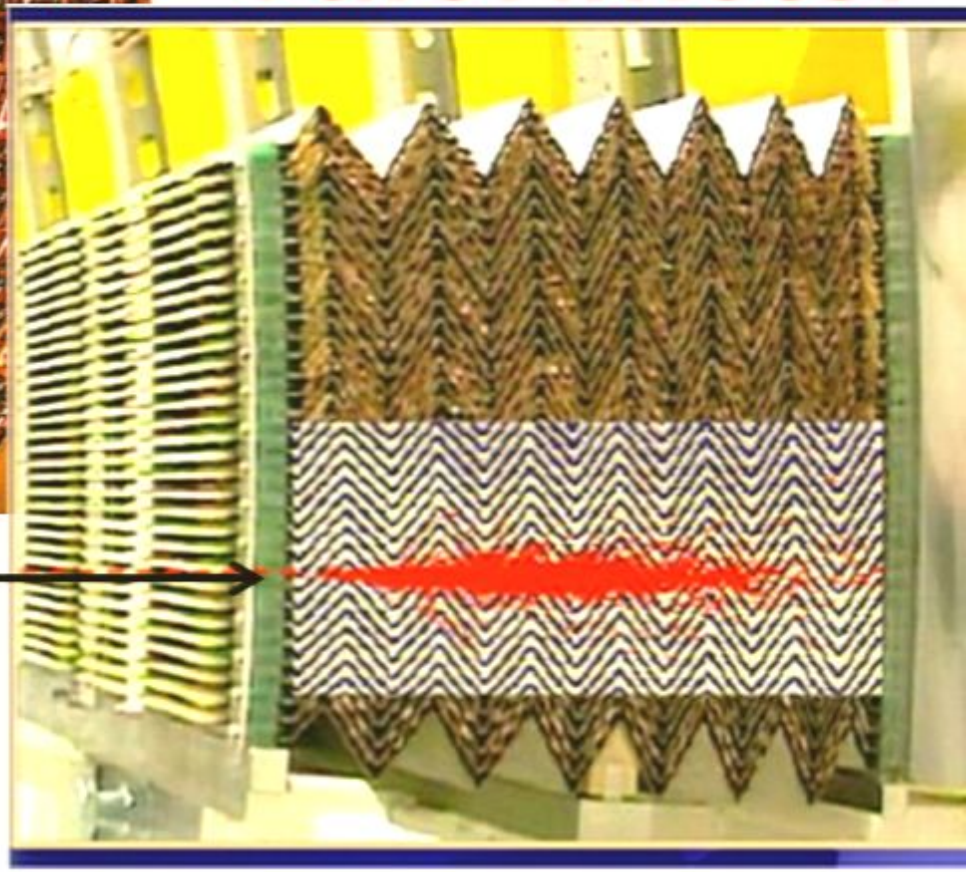

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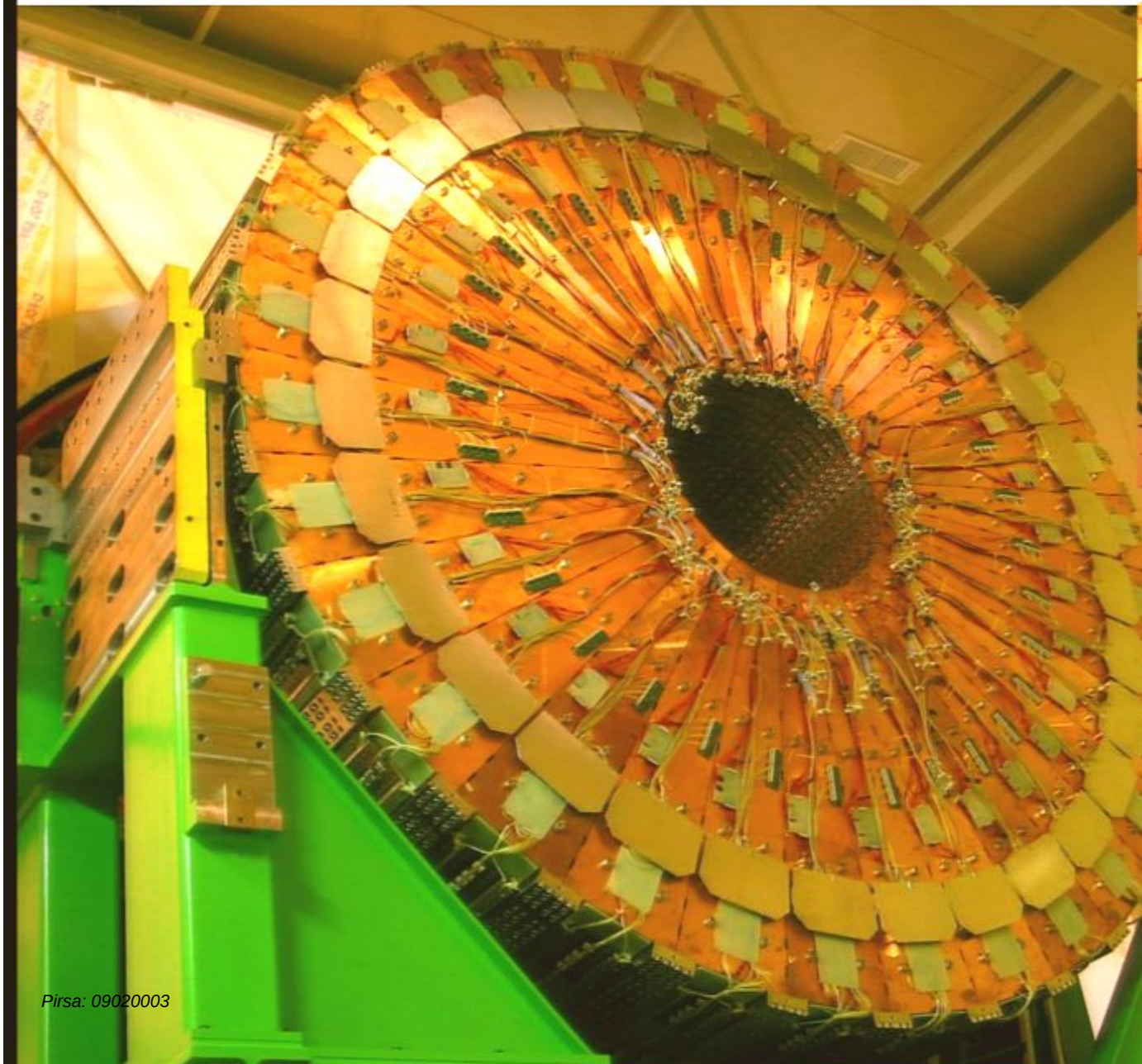
Canada: Hadronic End Cap calorimeter
On the insertion stand, Aug. 2004



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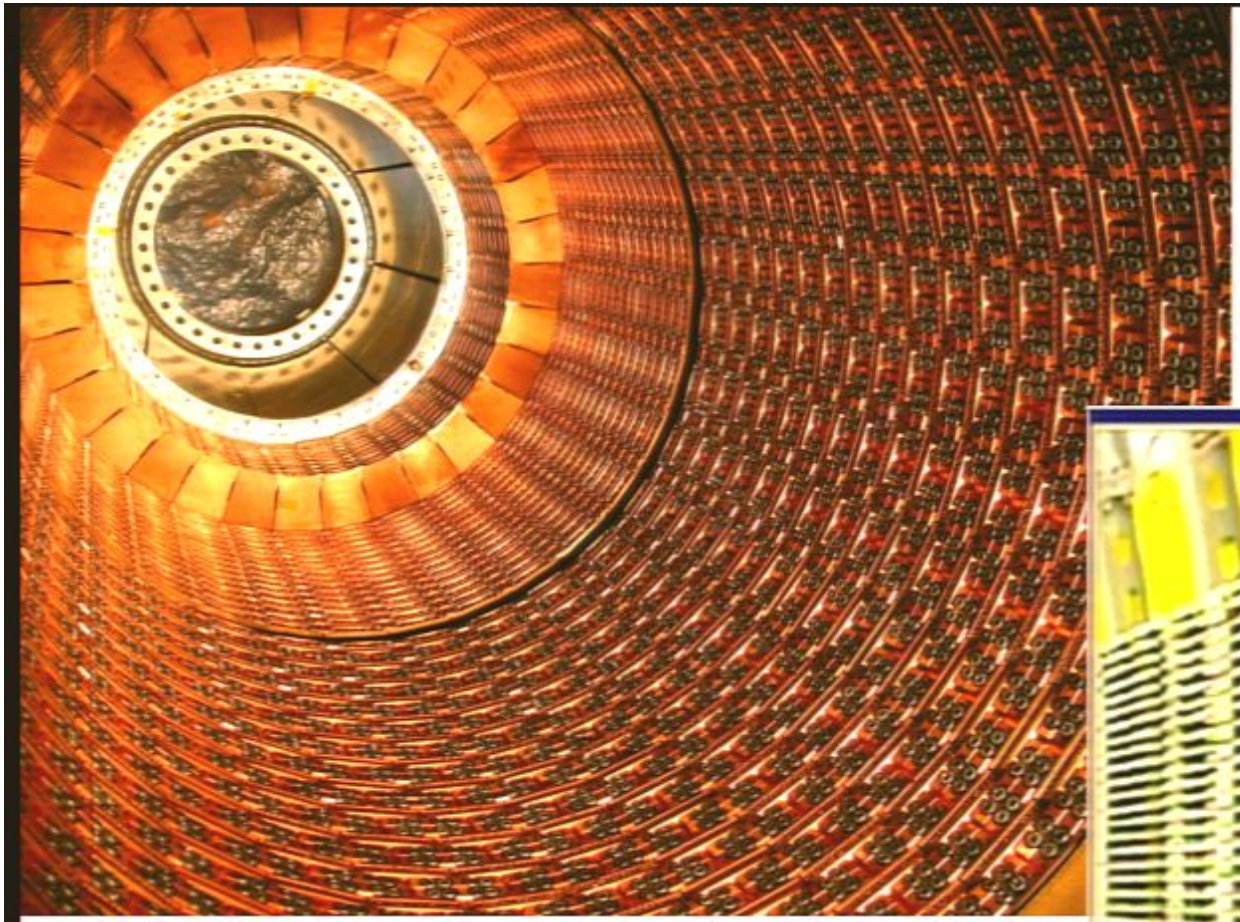

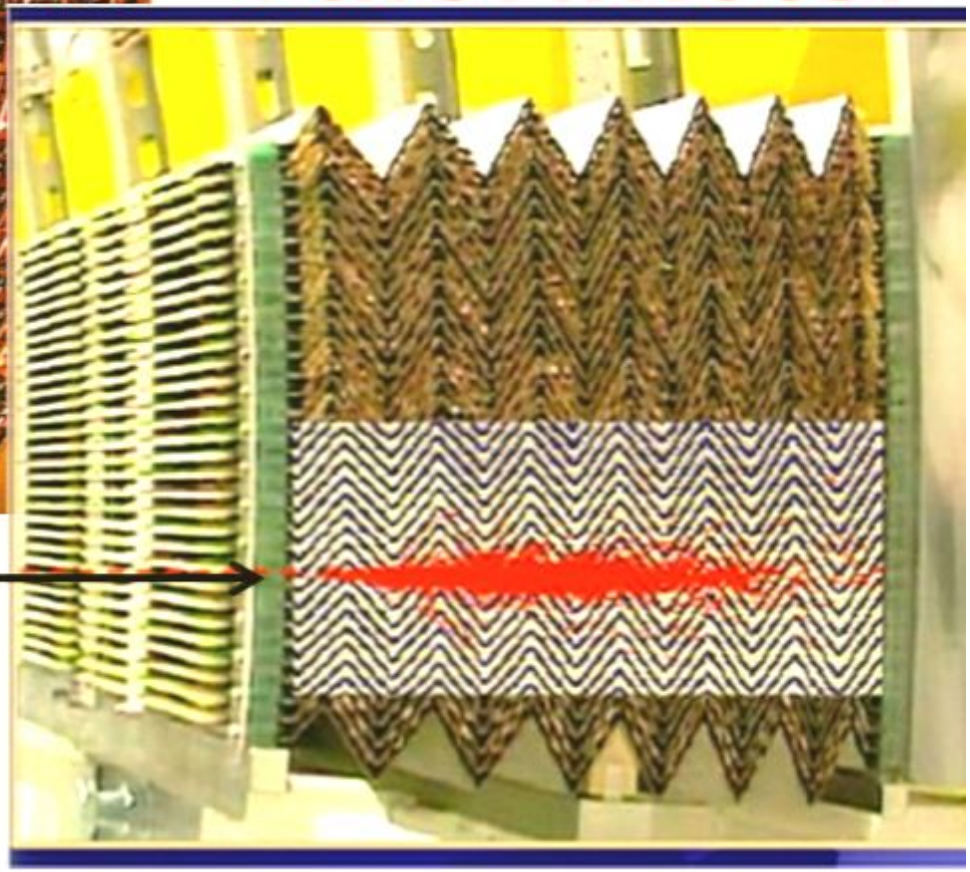

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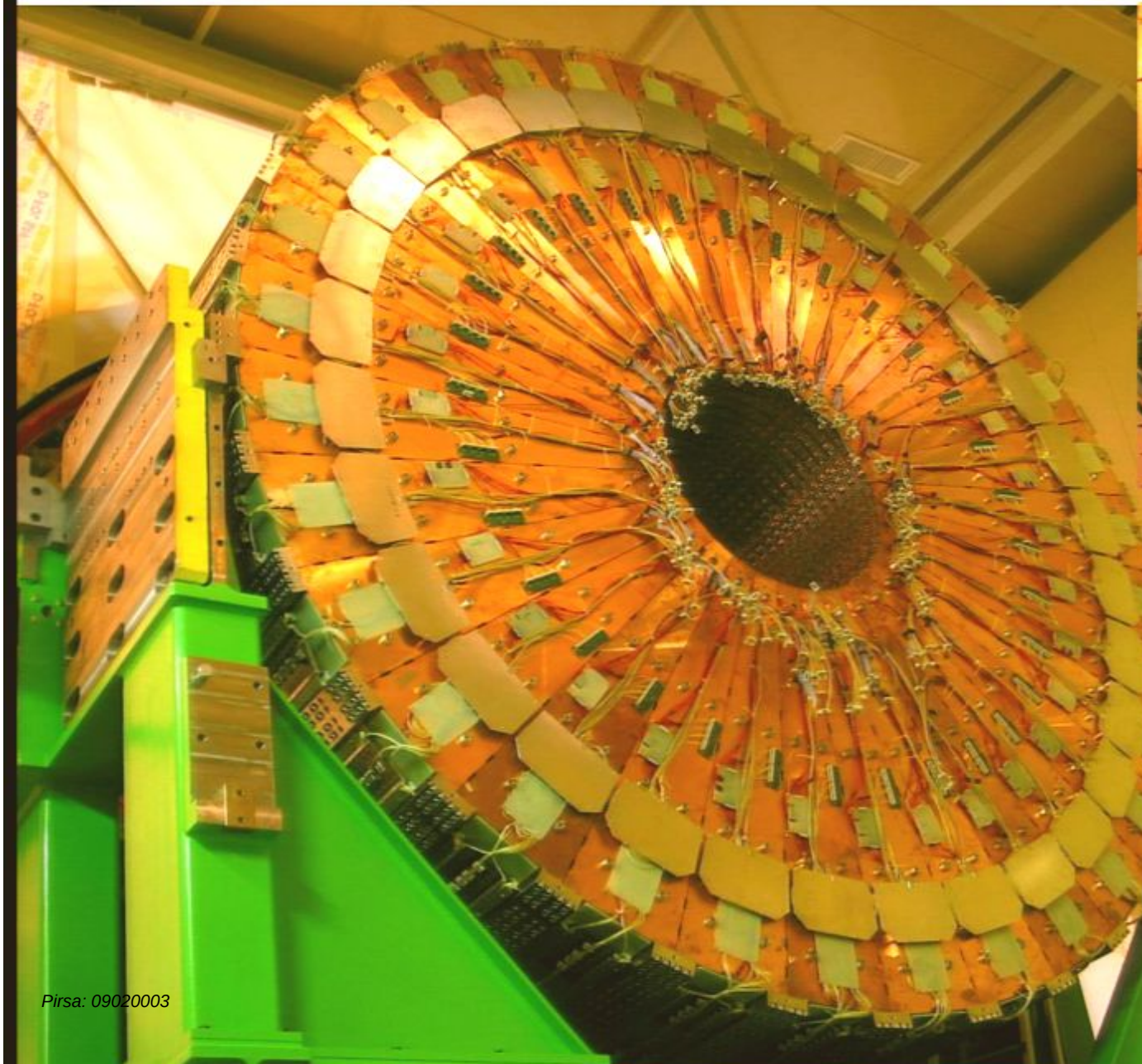
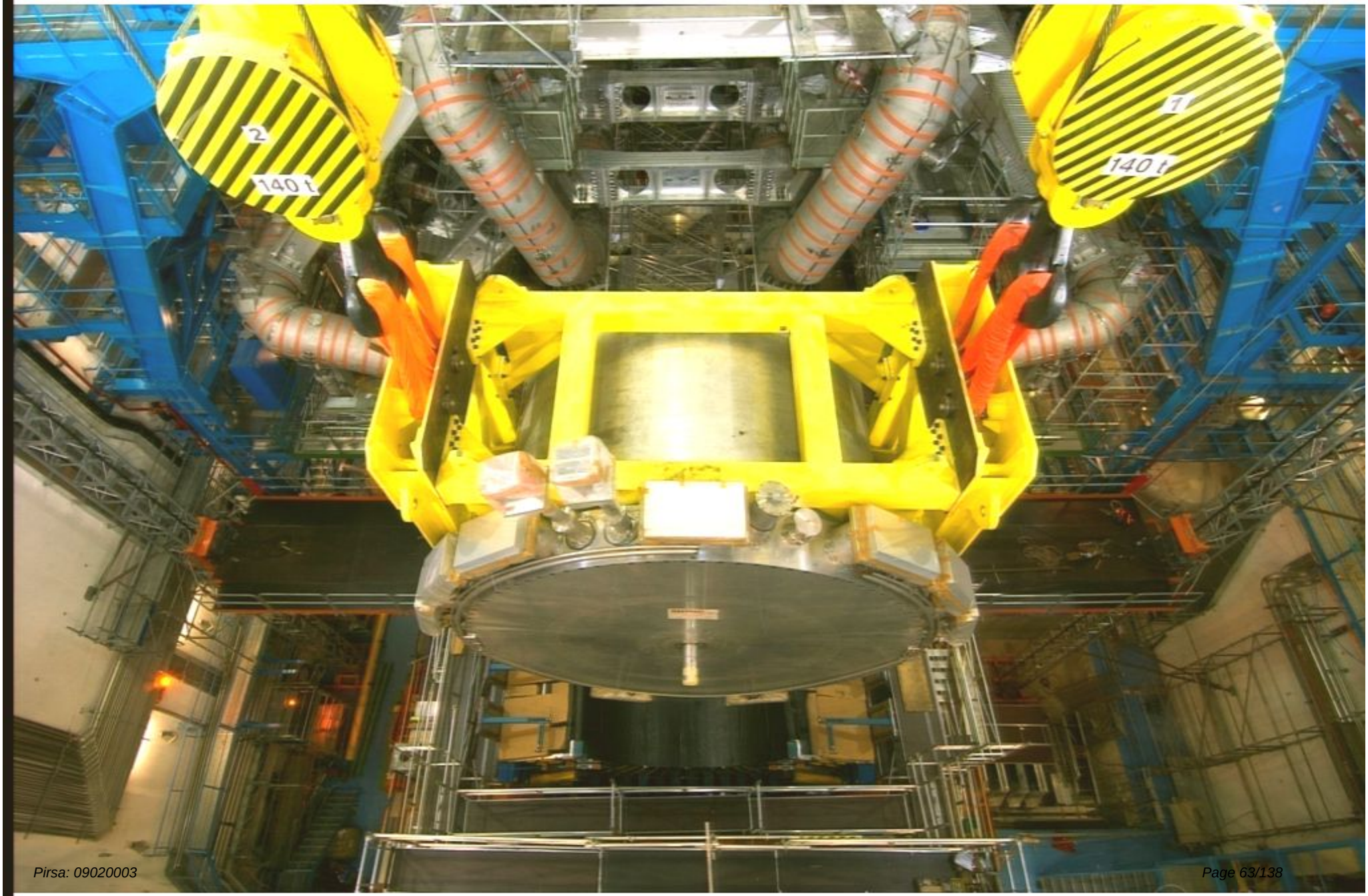
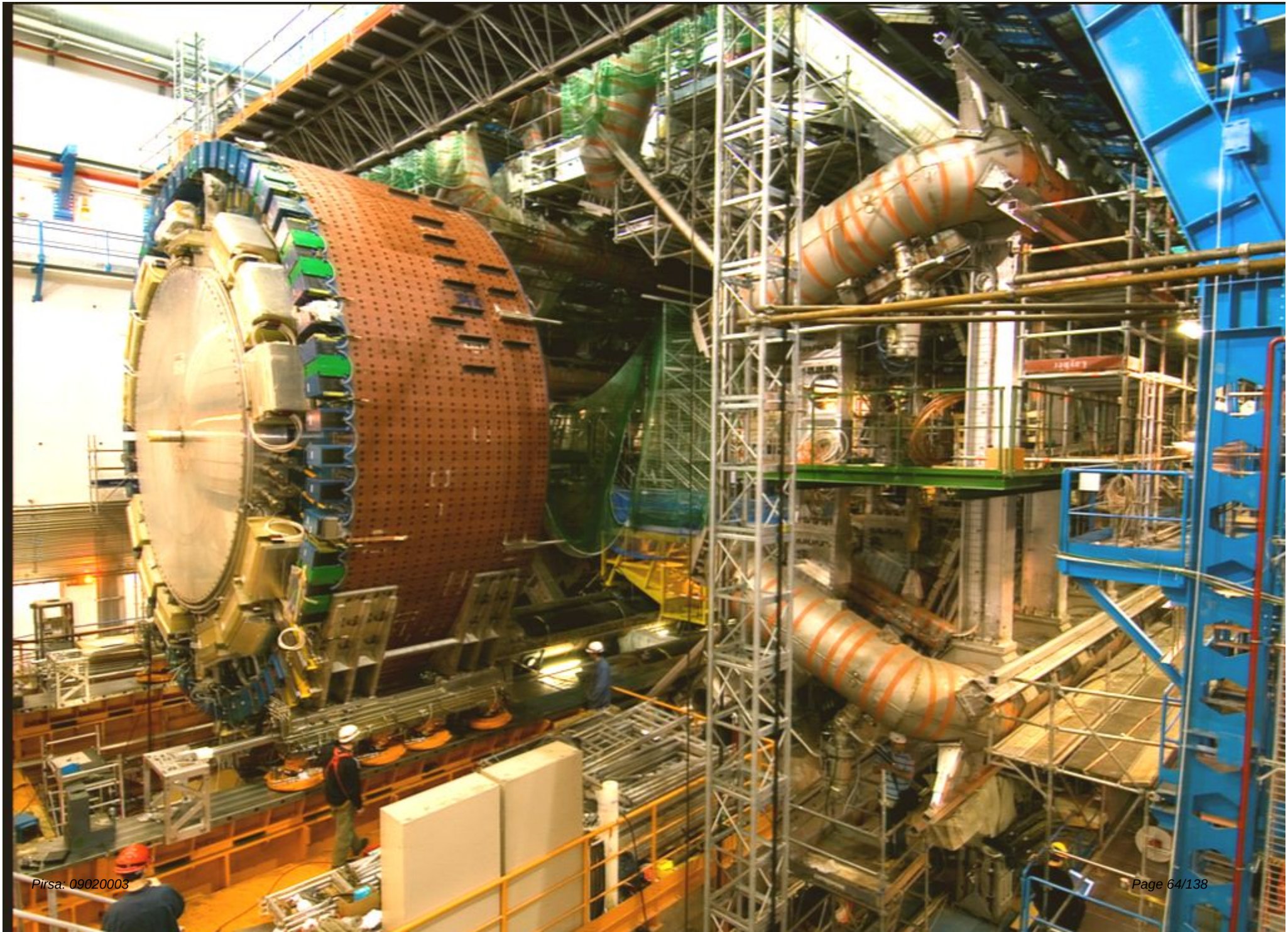


Transport of 1 Endcap calorimeter to ATLAS underground pit, CERN, September 2005


2
140 t
1
140 t

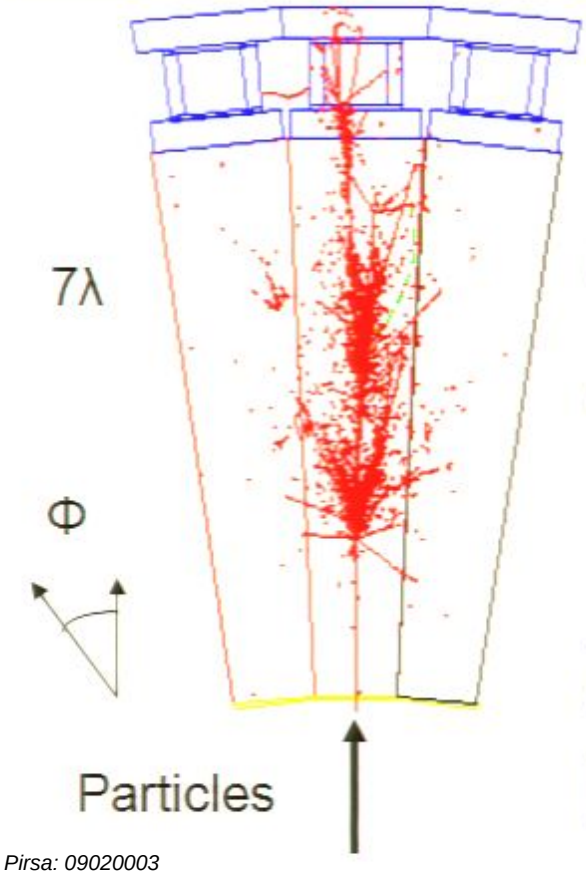


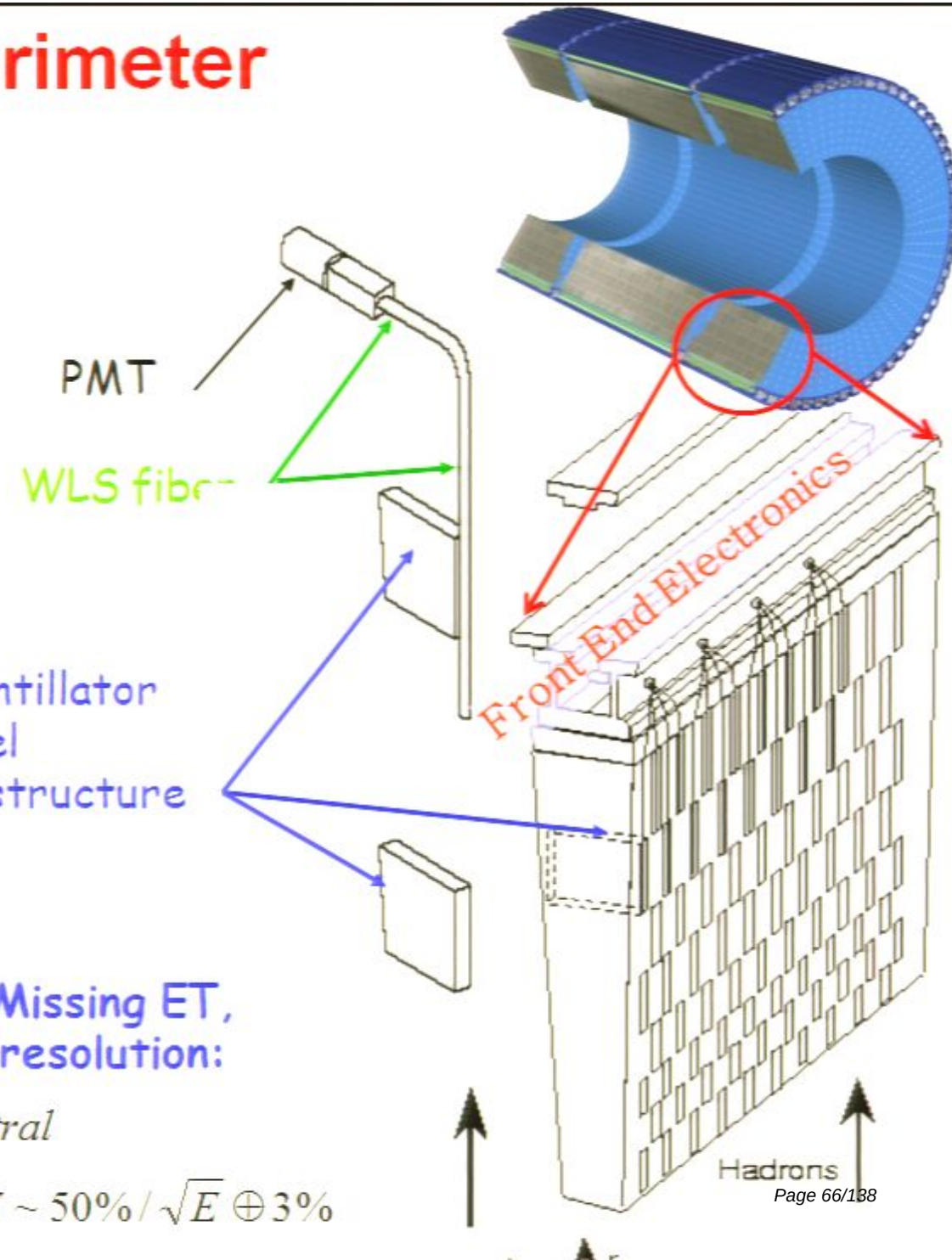
ATLAS Design Characteristics

- High resolution and acceptance for electrons and photons
  - High granularity LAr calorimeter with longitudinal sampling
  - Transition Radiation Tracker (TRT) detector.
  - Good two-photon separation (important for Higgs→2 photons).
- Hermetic calorimeters (full coverage) for high resolution measurements of missing ET and E(jet).
  - Down to $\eta = 5$, *where* $\eta = -\log\{\tan(\theta/2)\}$
- High resolution and high acceptance MUON measurements, by measuring momentum
  - Air-Core Toroid (to avoid large energy loss)
- Good vertex resolution (with 3 layers of pixel)
  - Detection of secondary vertices, even in a high background environment
  - important for b and Tau tagging, in various searches for various Higgs production modes
- Electronics readout at 40 MHz LHC bunch crossing rate

Hadronic Tile Calorimeter (TileCal)

Measure light produced by charged particles in plastic scintillator.





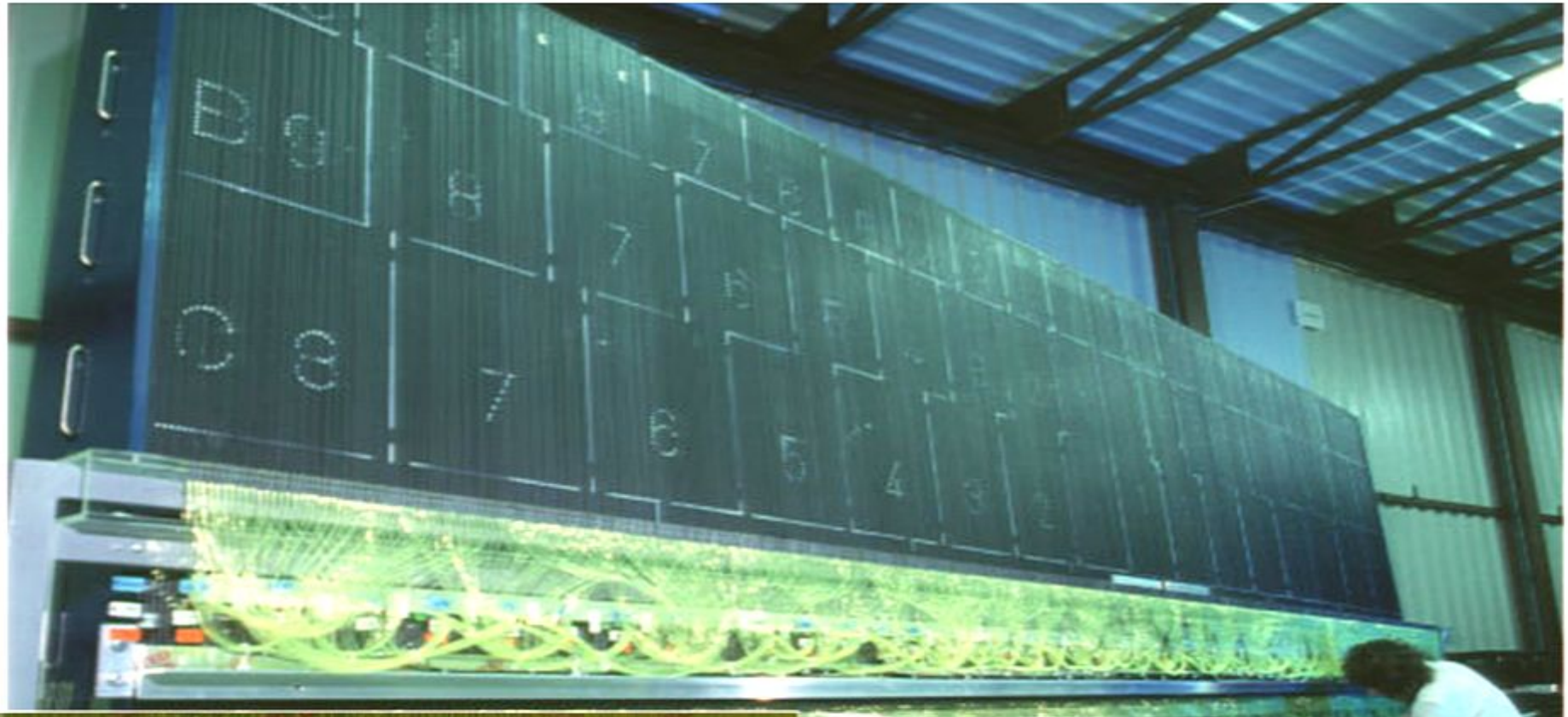
Plastic scintillator inside steel absorber structure

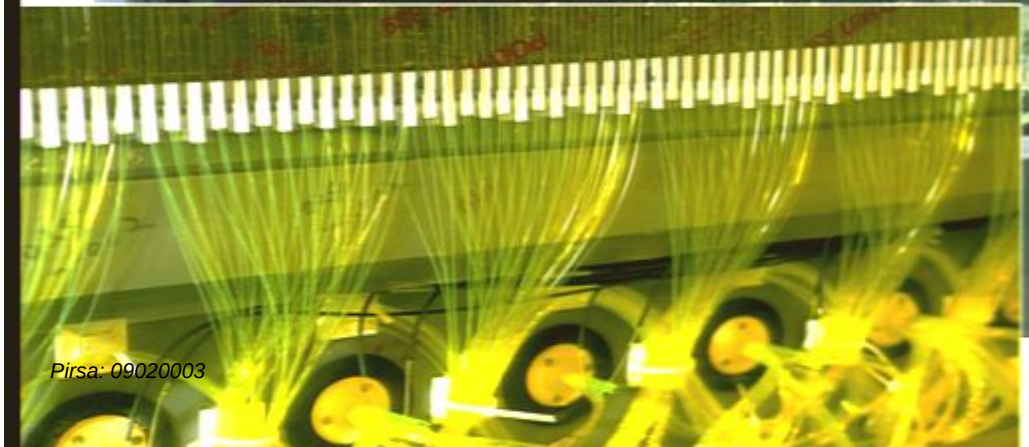
Jets and Missing ET, Combined resolution:

$|\eta| < 3$: *central*

$$\sigma(E)/E \sim 50\%/\sqrt{E} \oplus 3\%$$

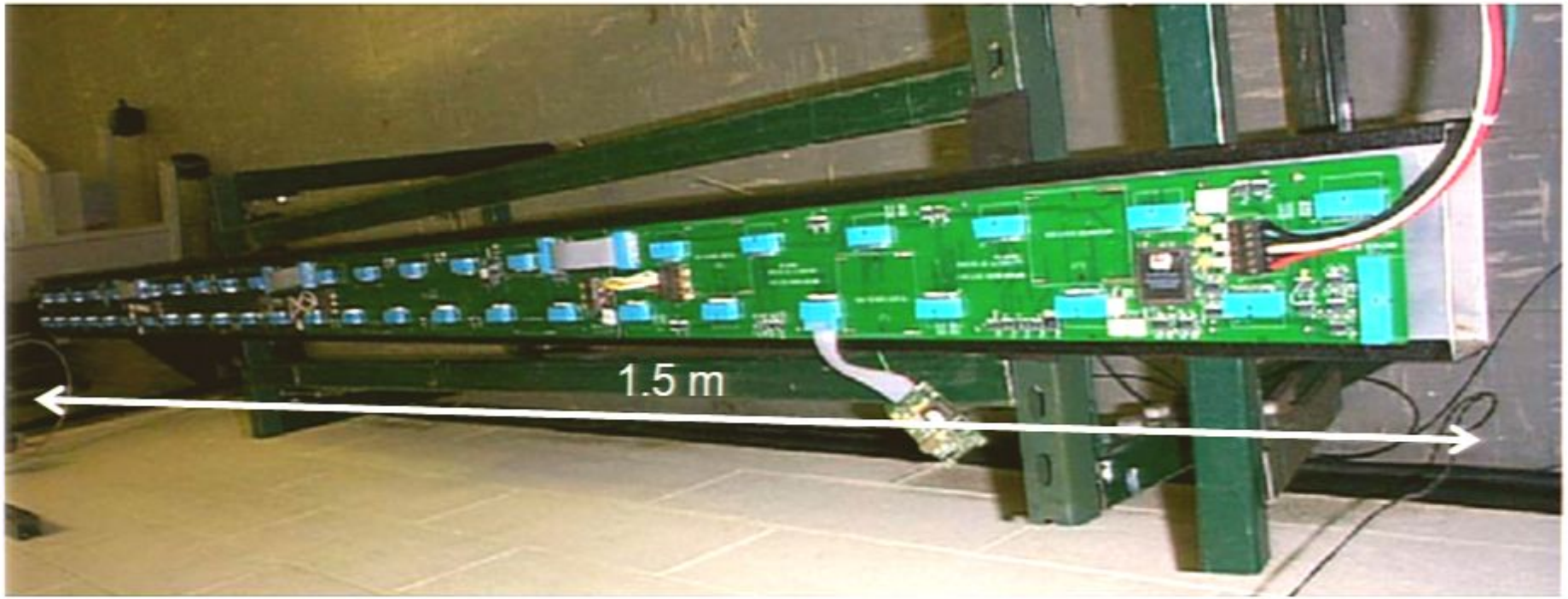
One TileCal Barrel Module





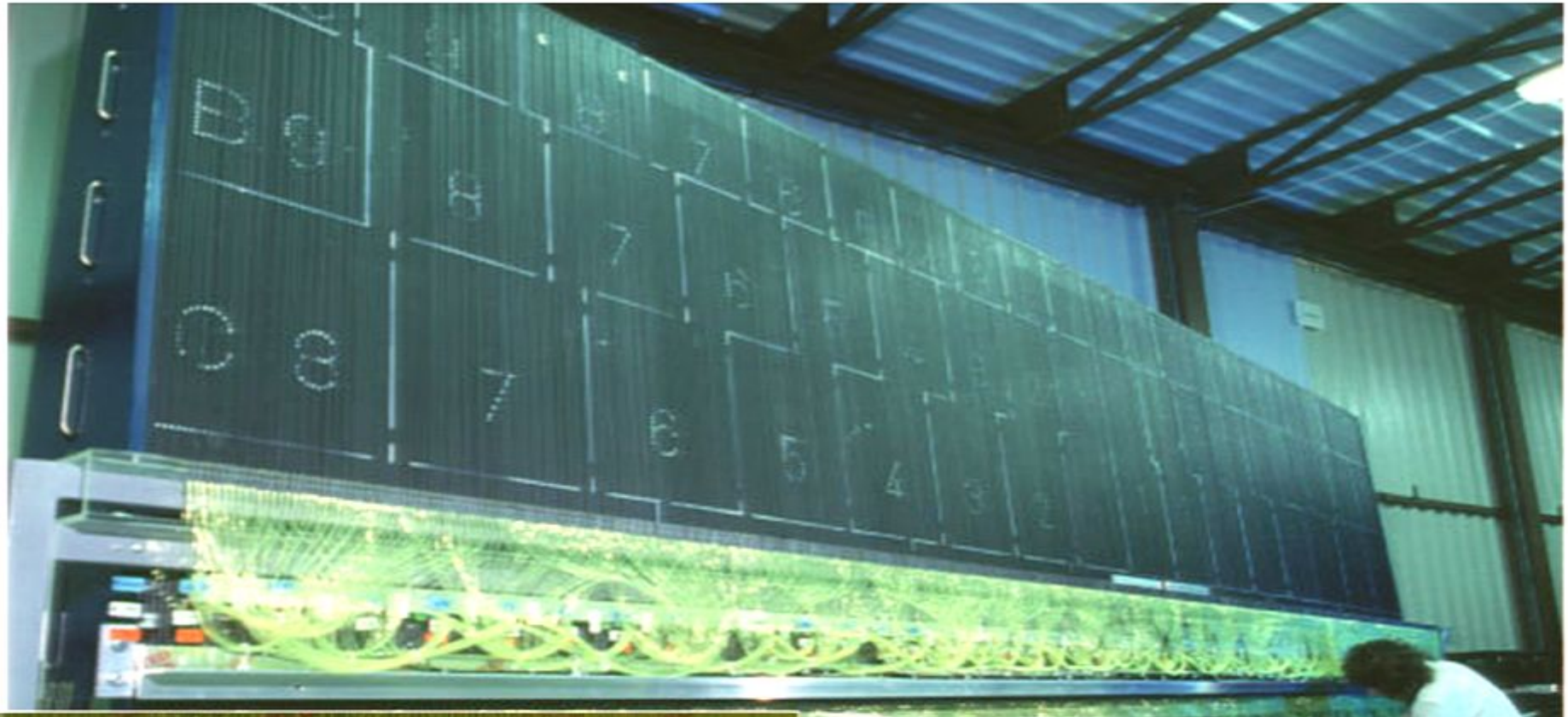
Fibre bundles

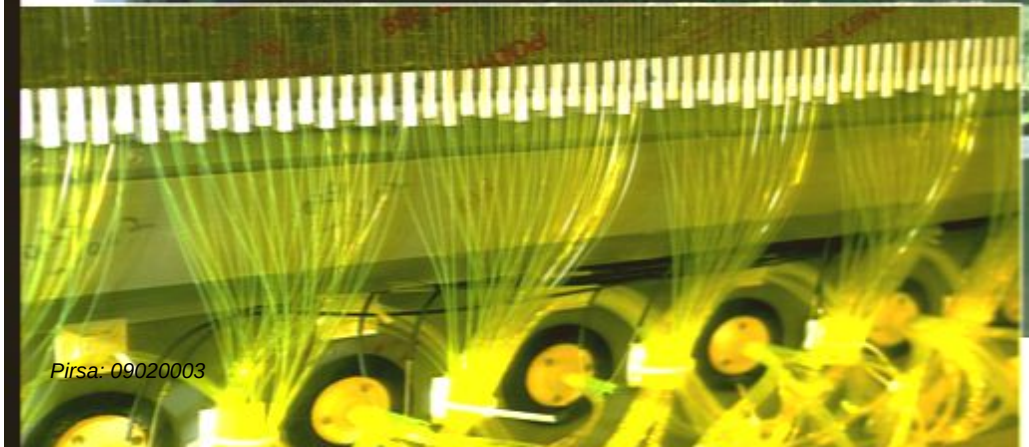
TileCal Front End Electronics



- On-detector front-end electronics
  - Mother Boards:1.5 m long, 50 kg each
  - 256 MB in ATLAS TileCal
  - Services and control signals, fast shaping electronics of PMT signal
- Digitizer Boards
- Optical Interface Card
  - Transmission of data over fibre optics to counting room

One TileCal Barrel Module

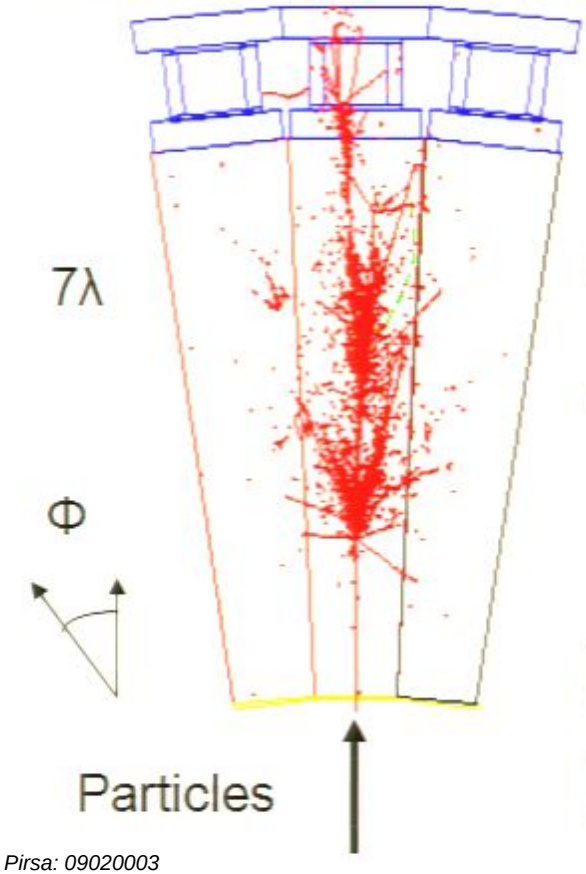


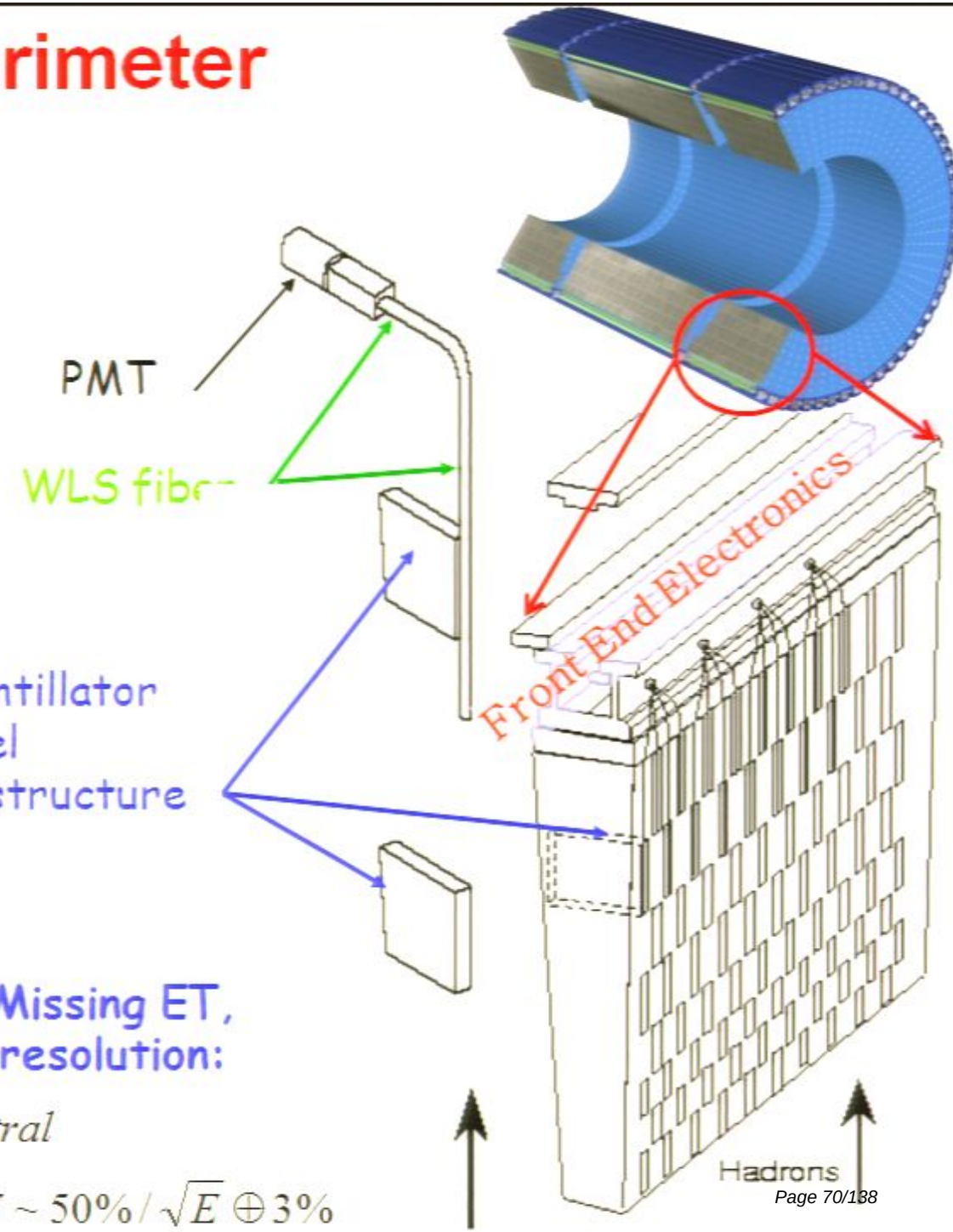


Fibre bundles

Hadronic Tile Calorimeter (TileCal)

Measure light produced by charged particles in plastic scintillator.





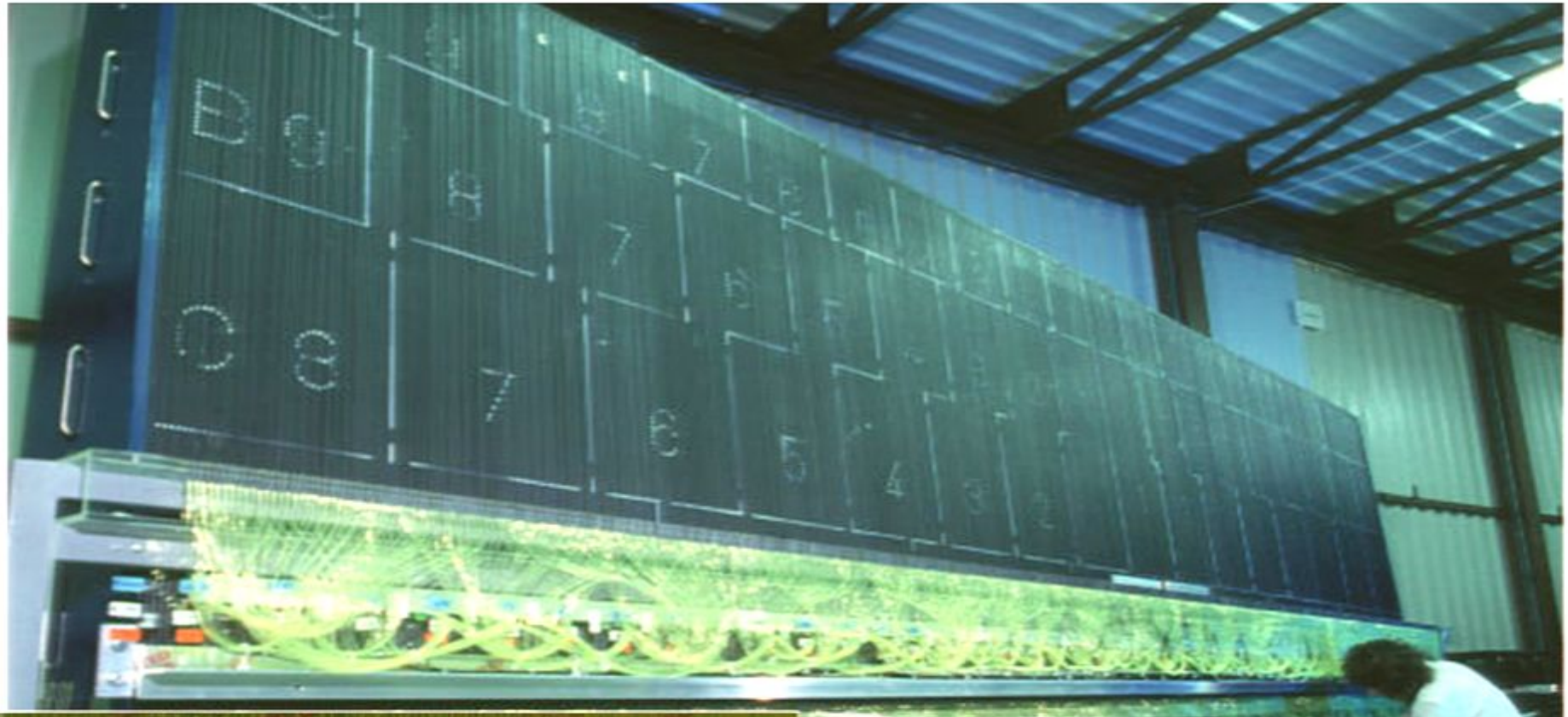
Plastic scintillator inside steel absorber structure

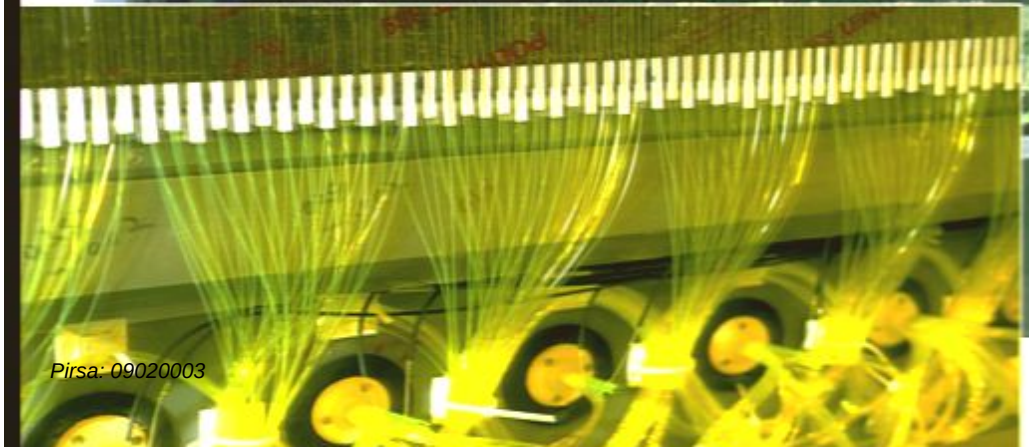
Jets and Missing ET, Combined resolution:

$|\eta| < 3$: *central*

$$\sigma(E)/E \sim 50\%/\sqrt{E} \oplus 3\%$$

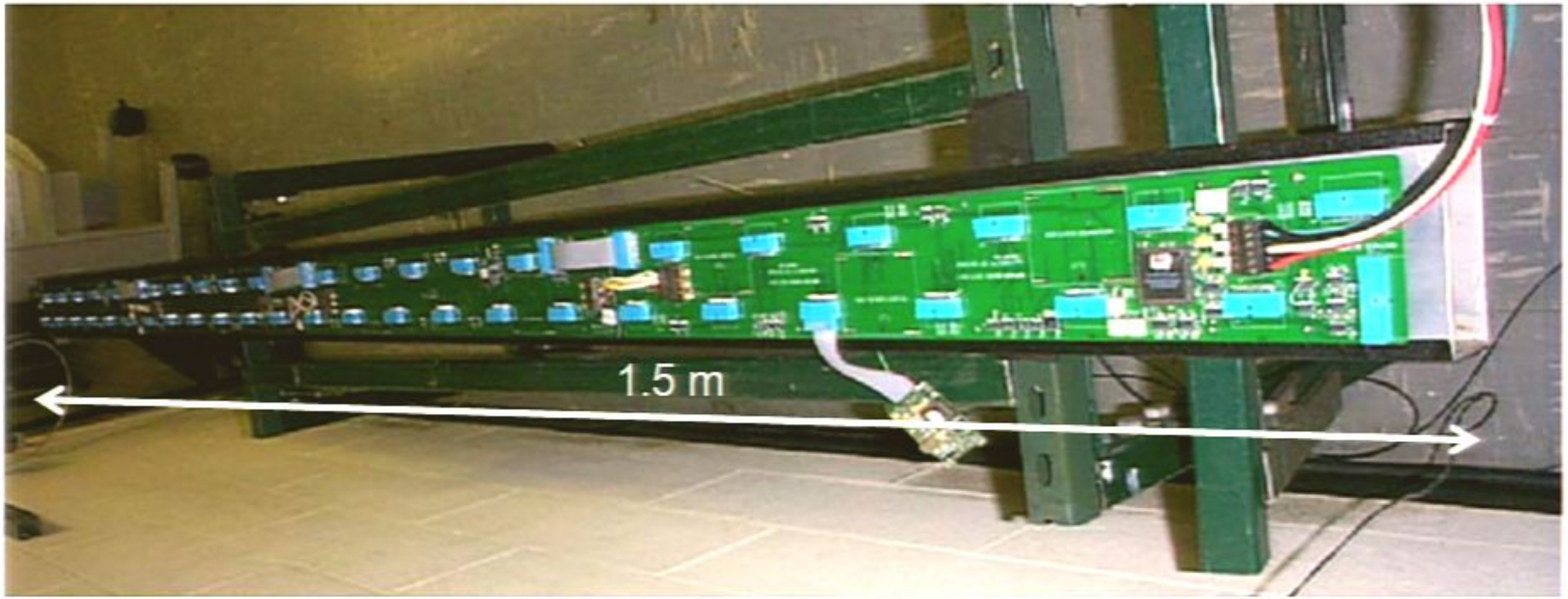
One TileCal Barrel Module





Fibre bundles

TileCal Front End Electronics



- On-detector front-end electronics
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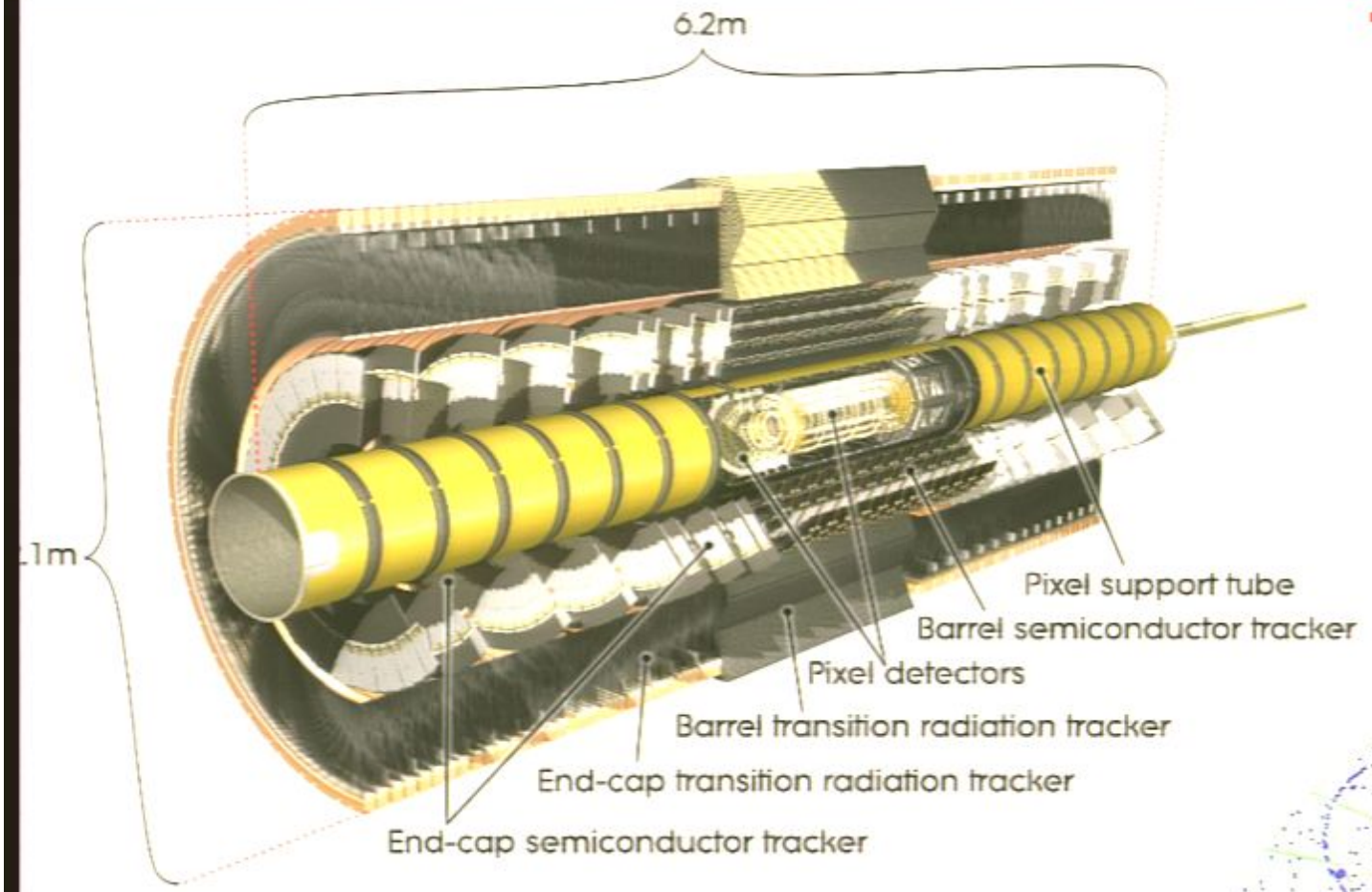
  - Services and control signals, fast shaping electronics of PMT signal
- Digitizer Boards
- Optical Interface Card
  - Transmission of data over fibre optics to counting room

Tracking



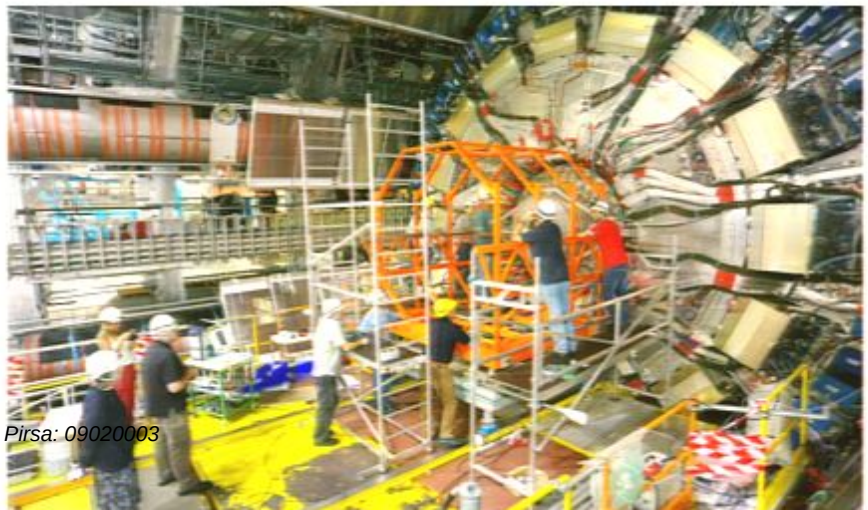
Resolution:

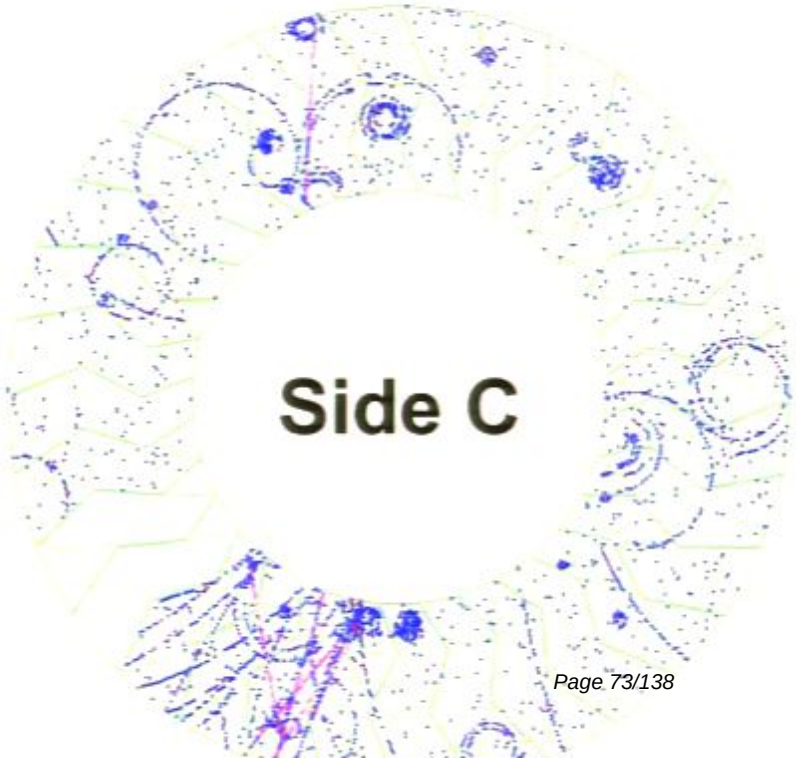
30% at p_T=500 GeV

$|\eta|<2.5$

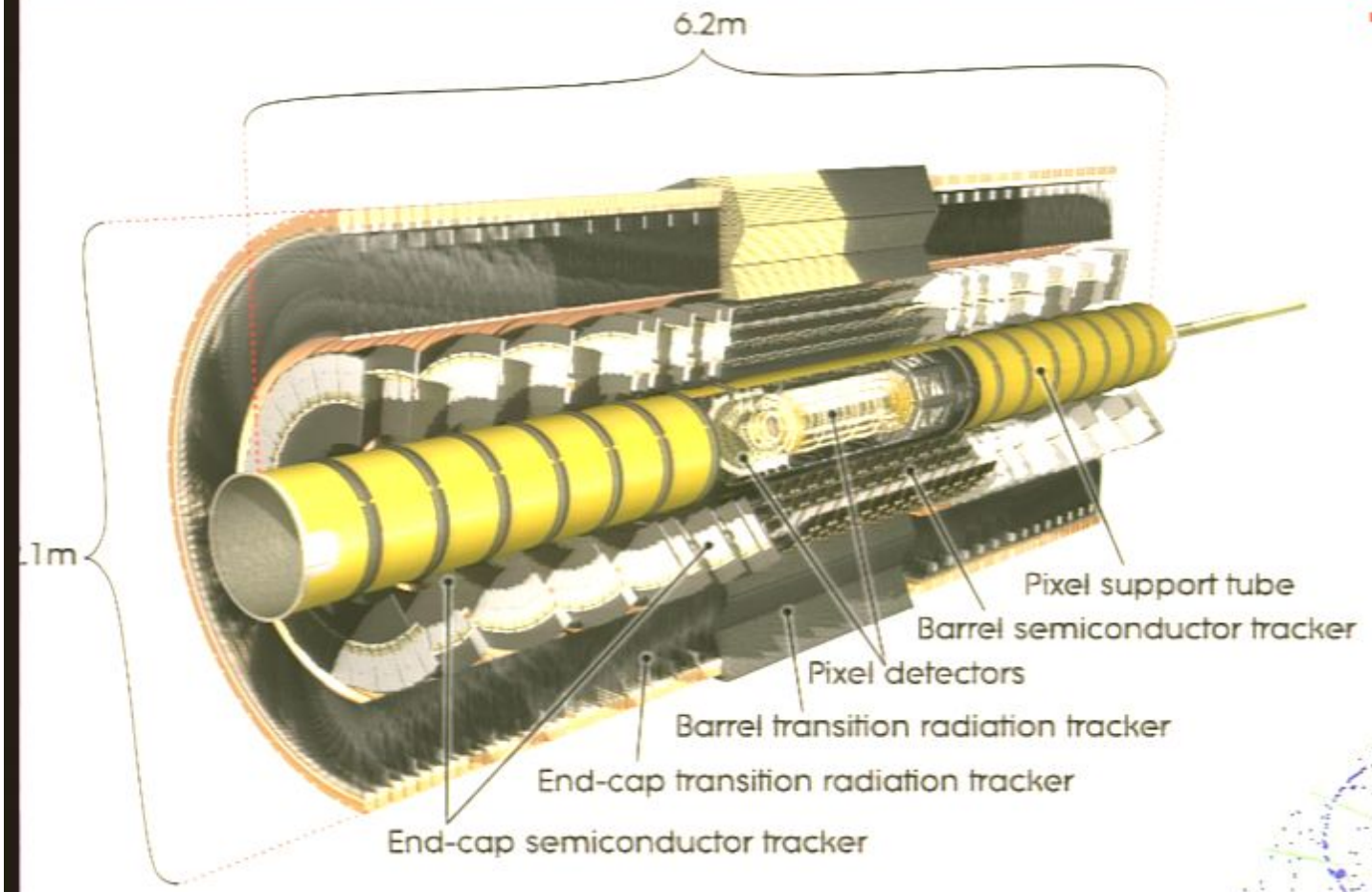
10 microns

Tracking for hi p_T lepton momentum, b-tag, tau





Tracking



Resolution:

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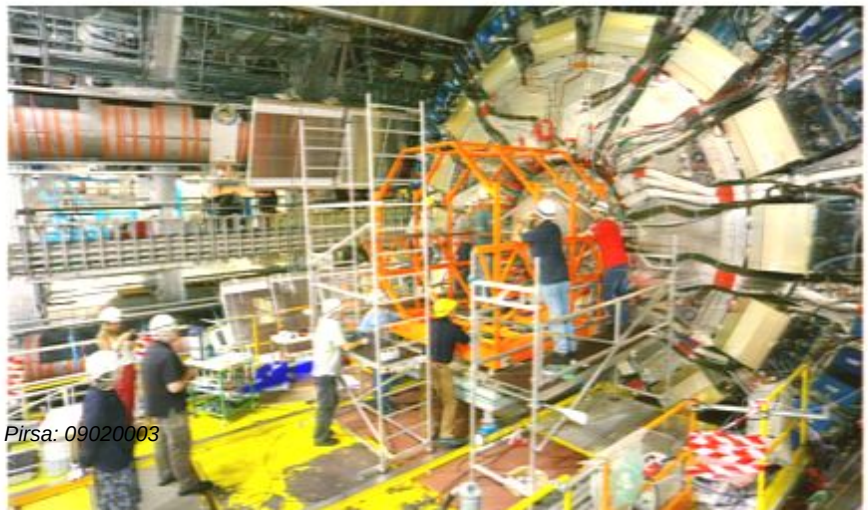
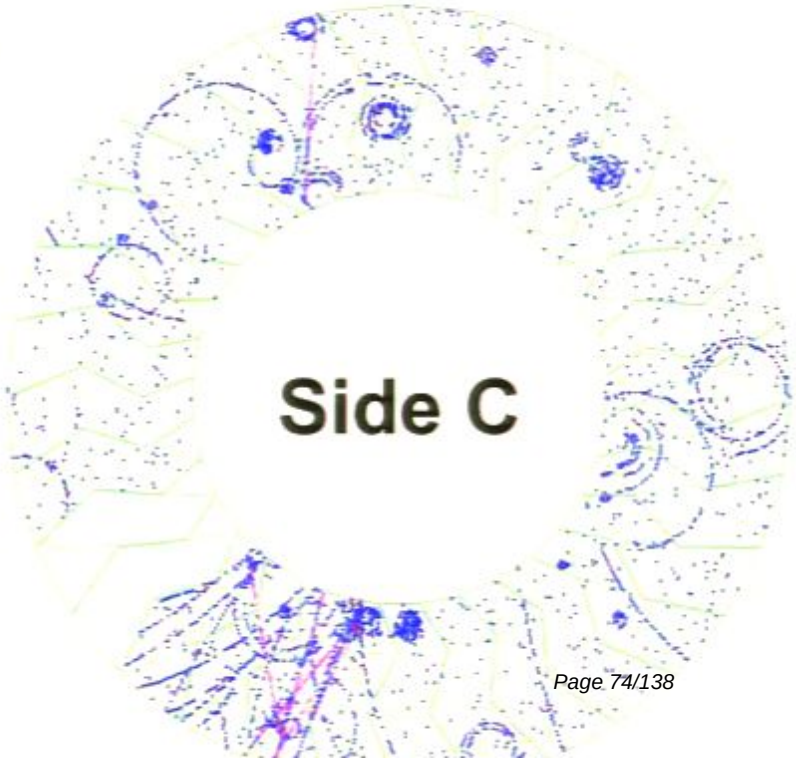
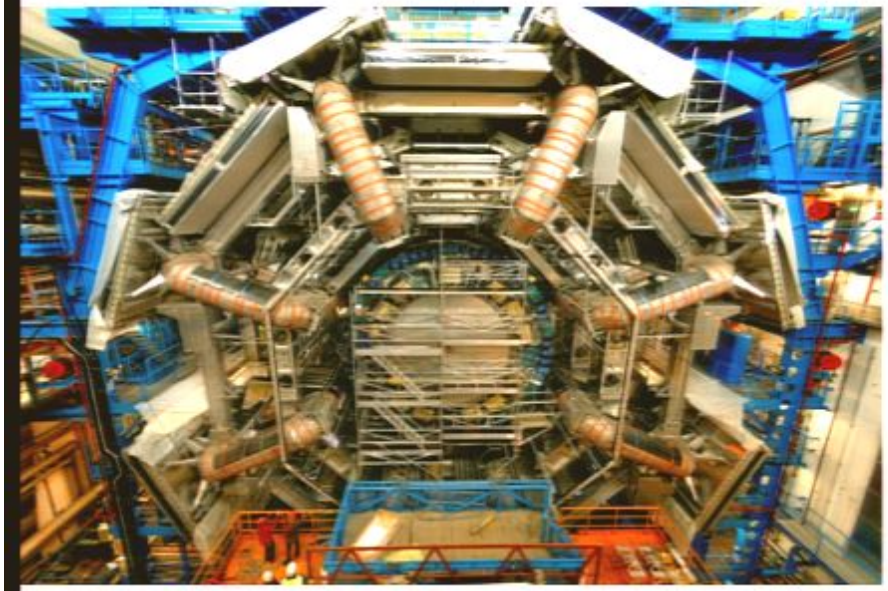
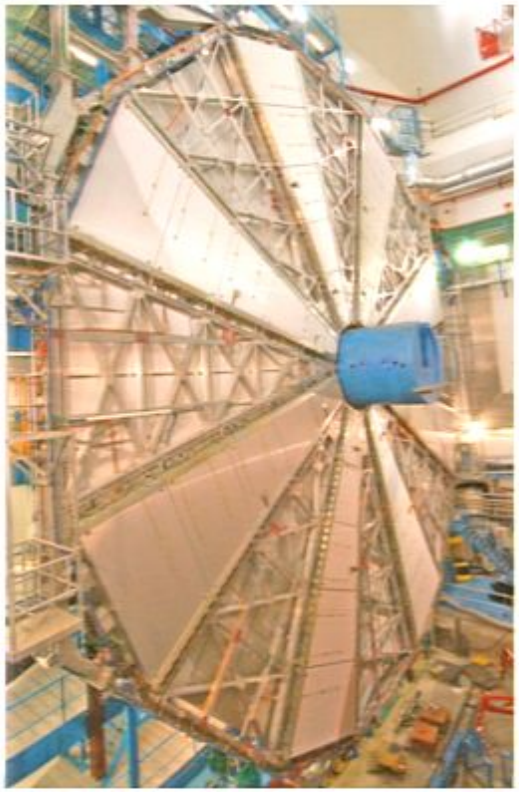
Tracking for hi p_T lepton momentum, b-tag, tau

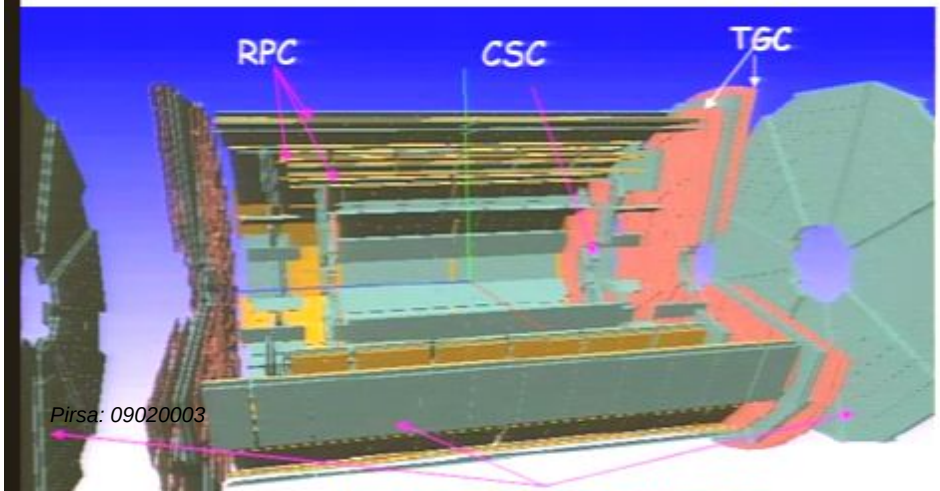




MUON Spectrometer fully installed and operational



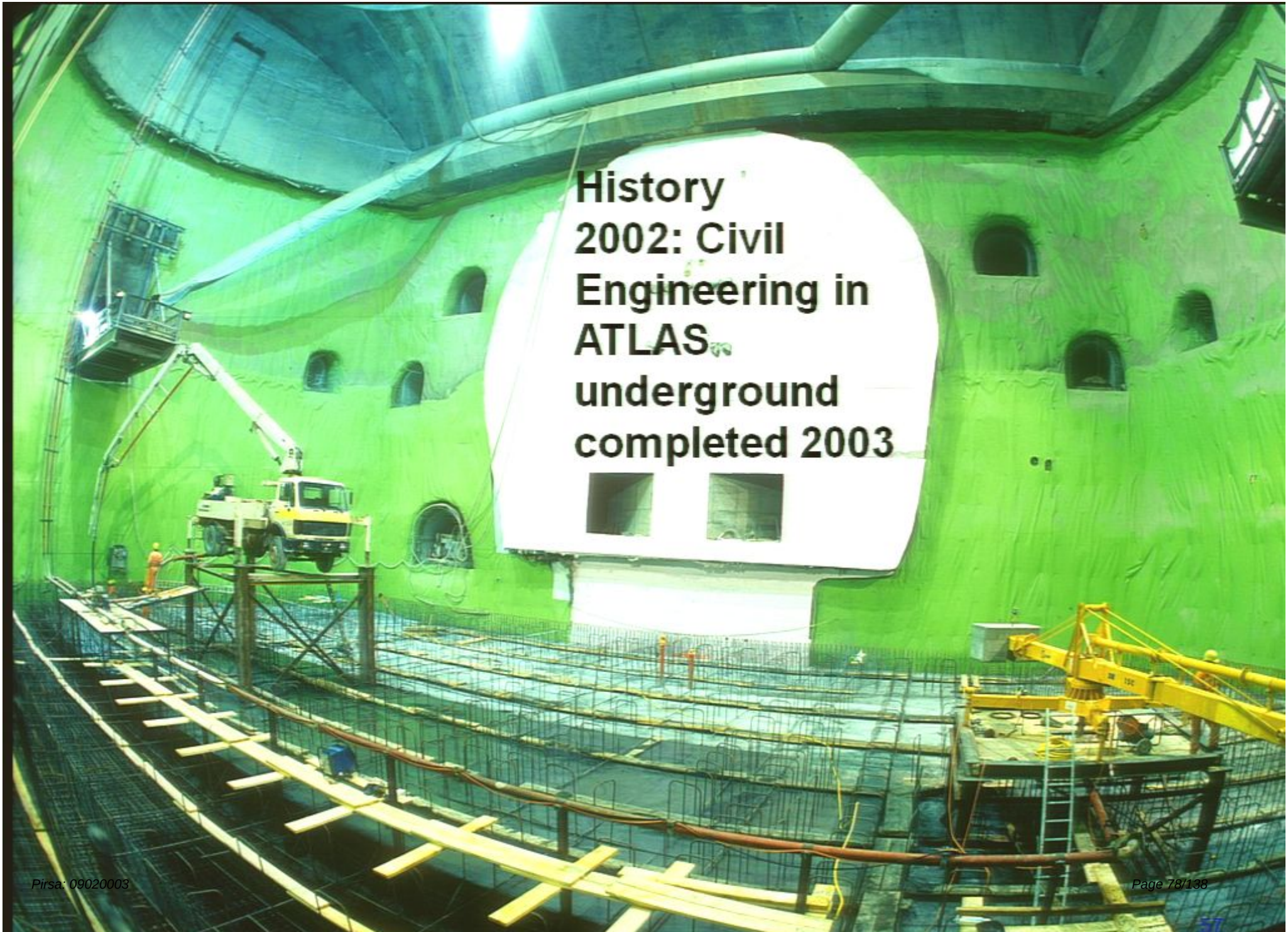




- 1.5 10E6 channels, all operational
- Resolution 10% at p_T= 1 TeV
- Identify resonances, provide muon trigger

2000: Civil Engineering in ATLAS Cavern

2002: ATLAS Underground

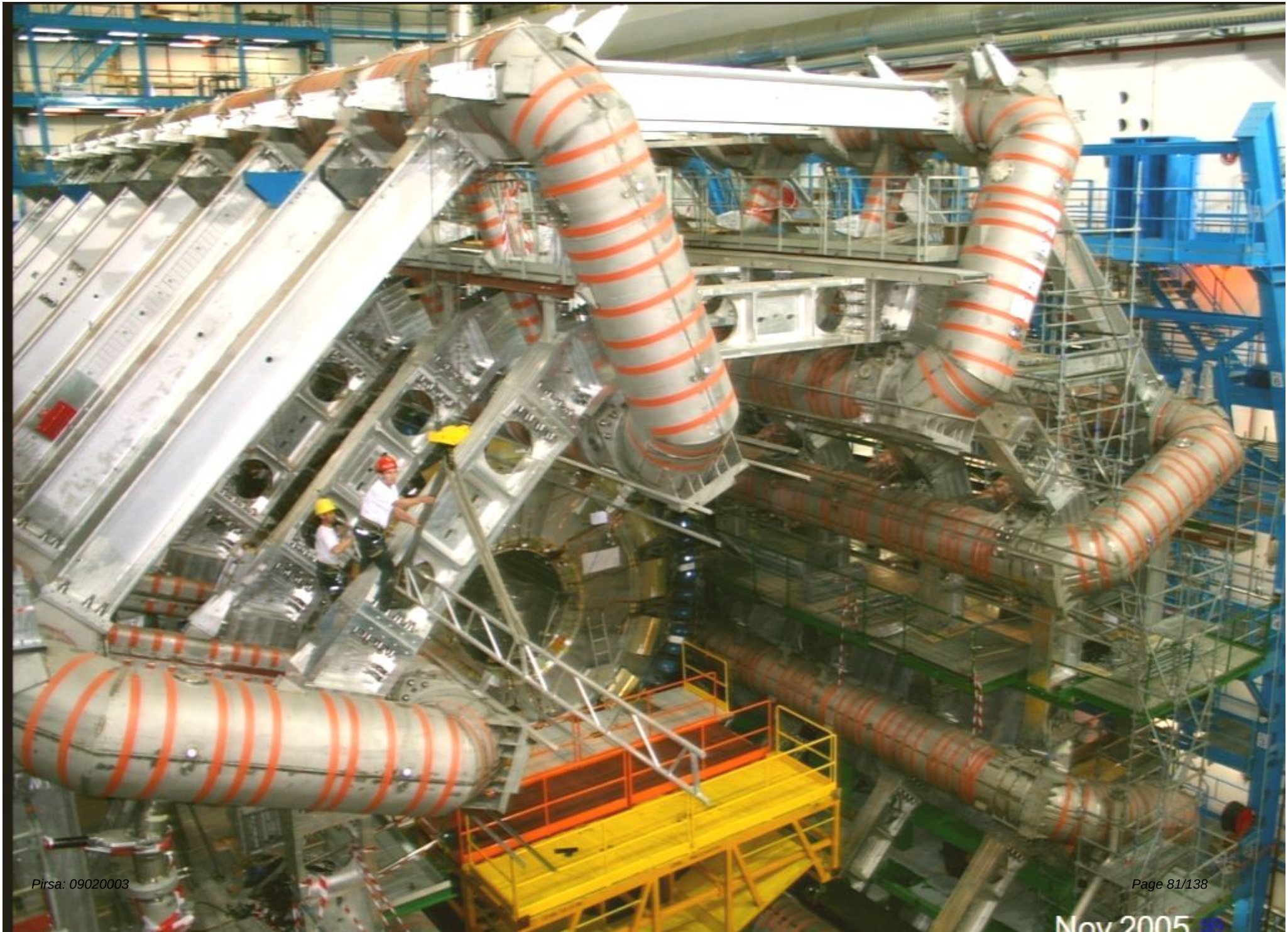

History
2002: Civil
Engineering in
ATLAS
underground
completed 2003

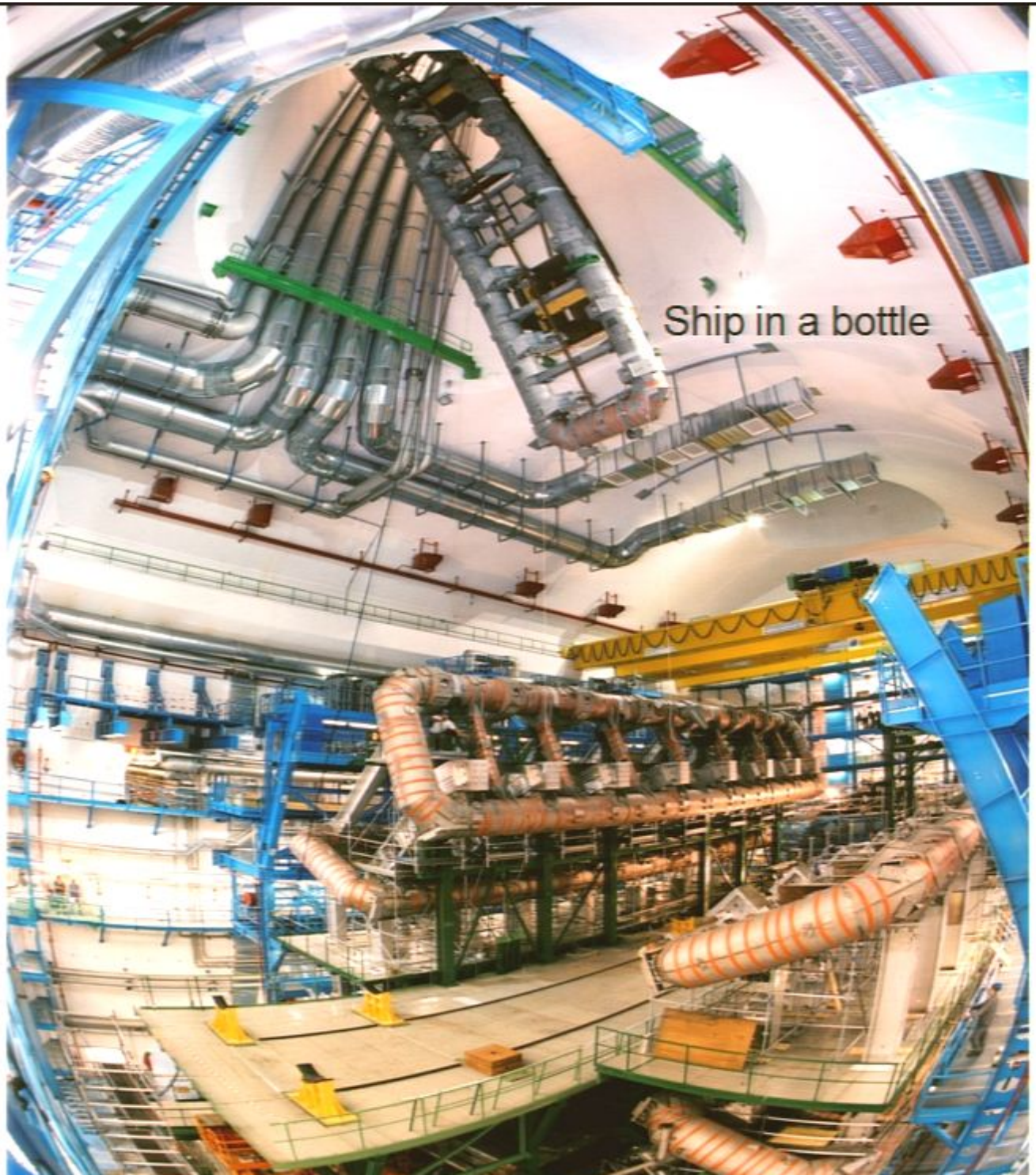
Typical work day in ATLAS

Photo from Sept. 2004

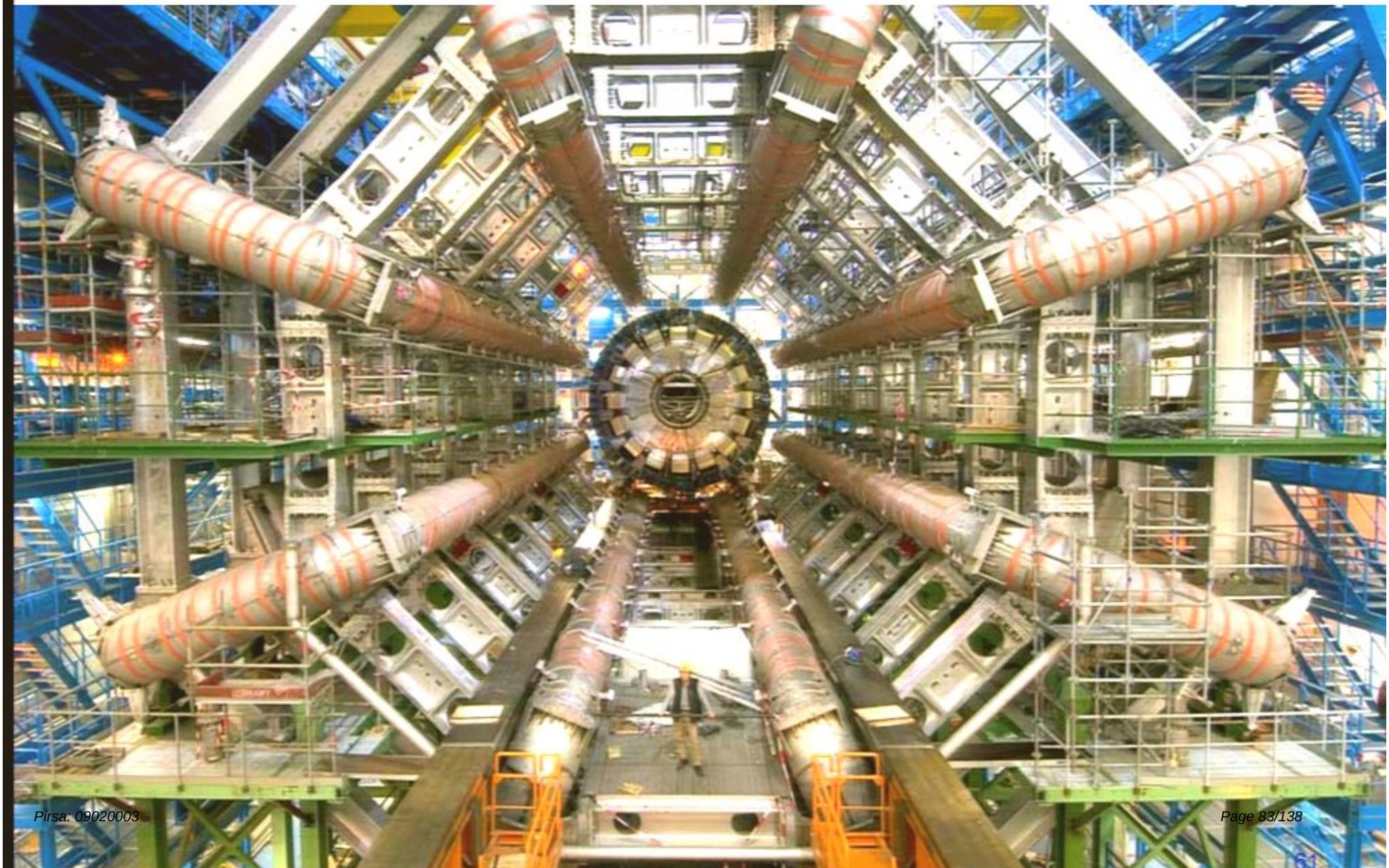
Typical work day in ATLAS

Photo from Sept. 2004


Nov 2005


Ship in a bottle

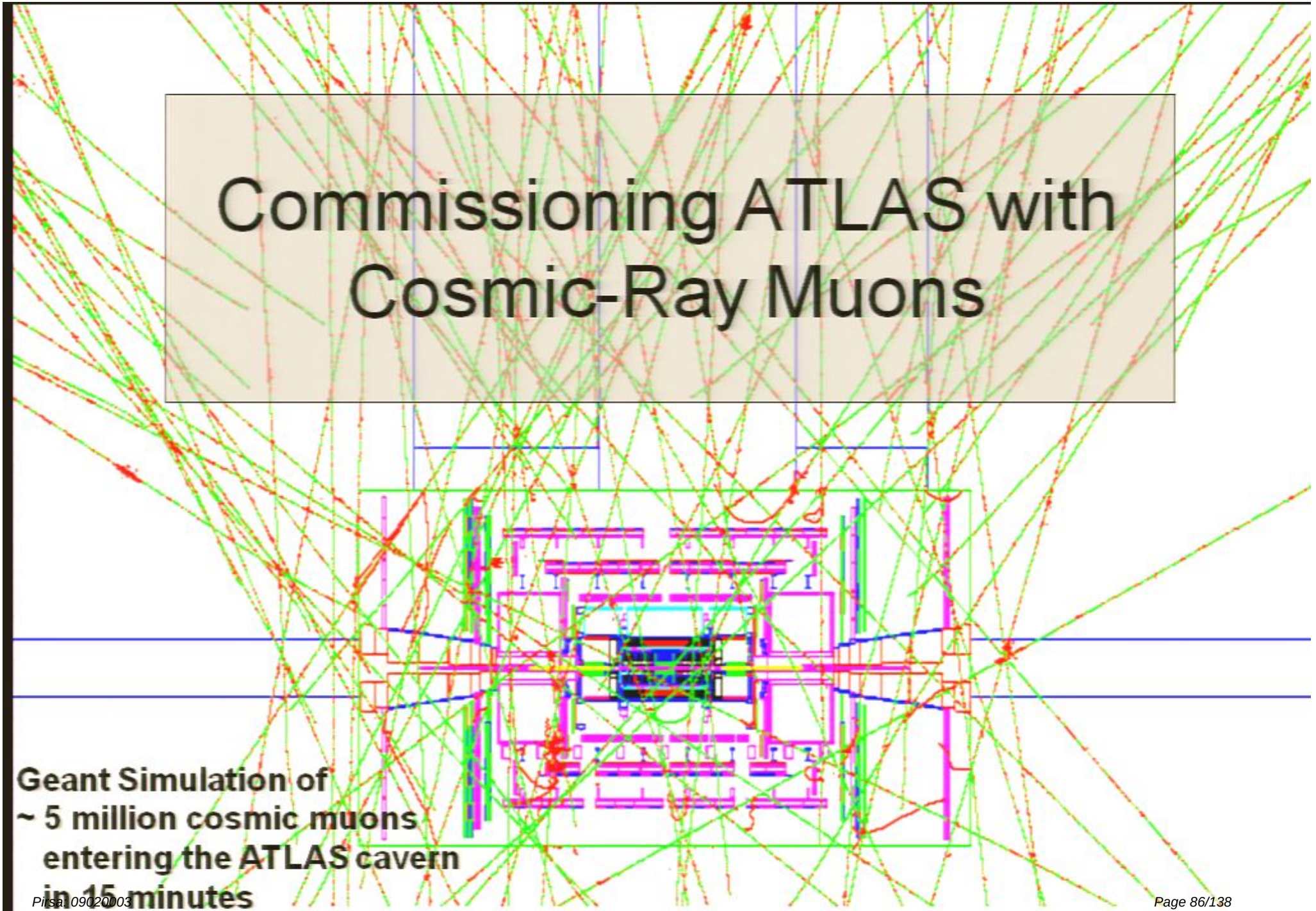
ATLAS: ~ 20 years of research and development worldwide.
2003: underground installation started.
2008: installation complete



Colleague from McMaster / Perimeter Institute visits ATLAS

Commissioning ATLAS with Cosmic-Ray Muons

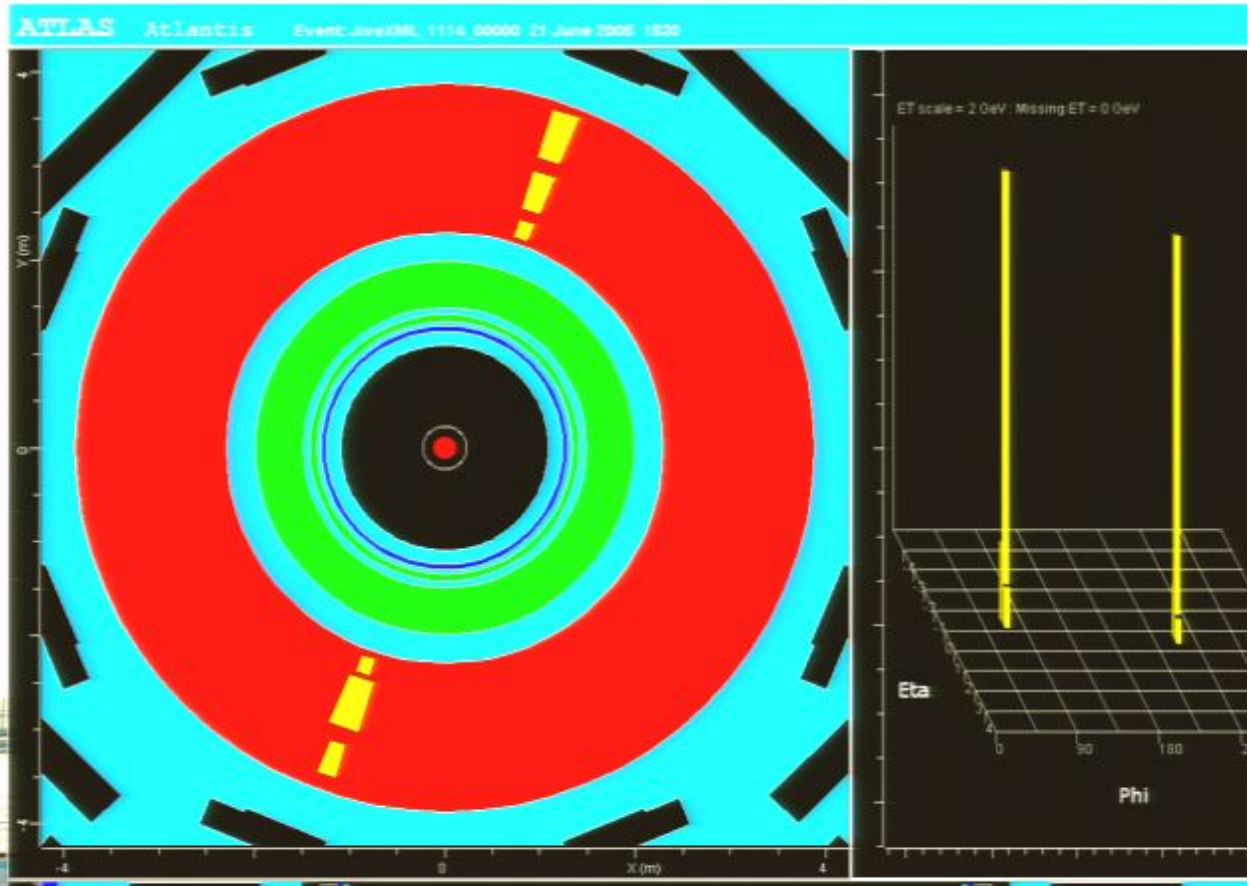
Commissioning ATLAS with Cosmic-Ray Muons

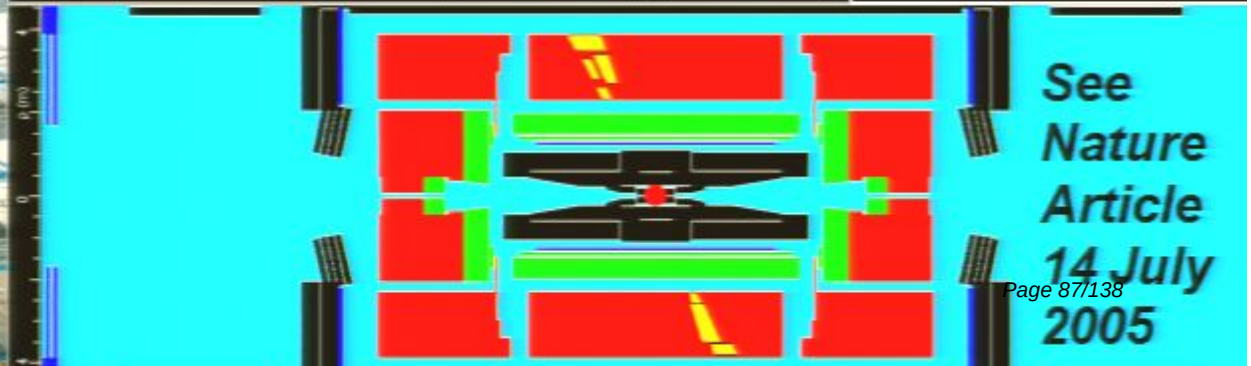


Geant Simulation of
~ 5 million cosmic muons
entering the ATLAS cavern
in 15 minutes

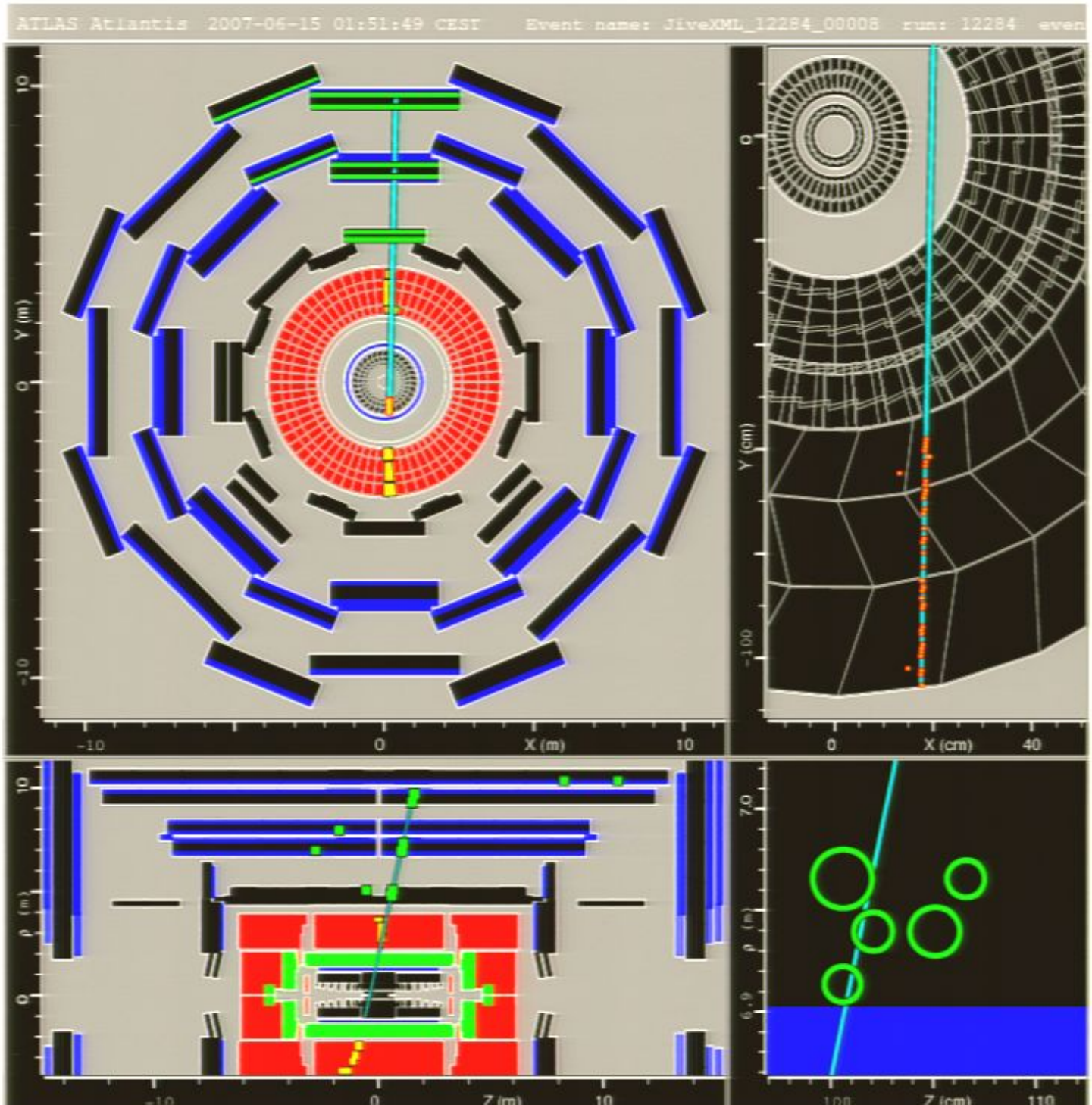
First Cosmic Ray Data

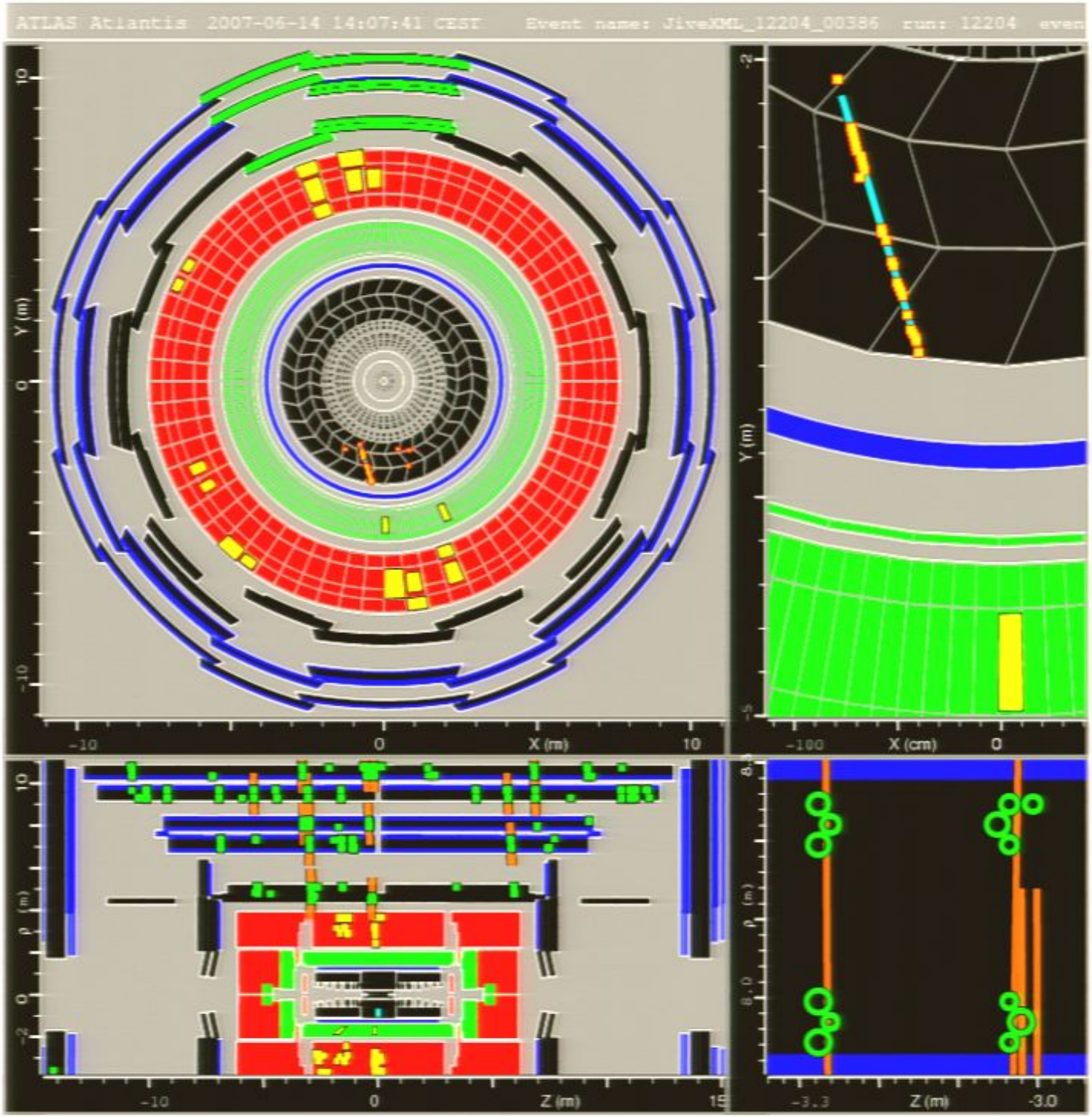
- *Not a simulation!* June 21: first cosmic ray data from ATLAS pit
- Barrel hadronic Tile Calorimeter (TileCal) custom trigger on back-to-back cosmic rays no external scintillators
- Test full chain from front-end electronics to offline software.



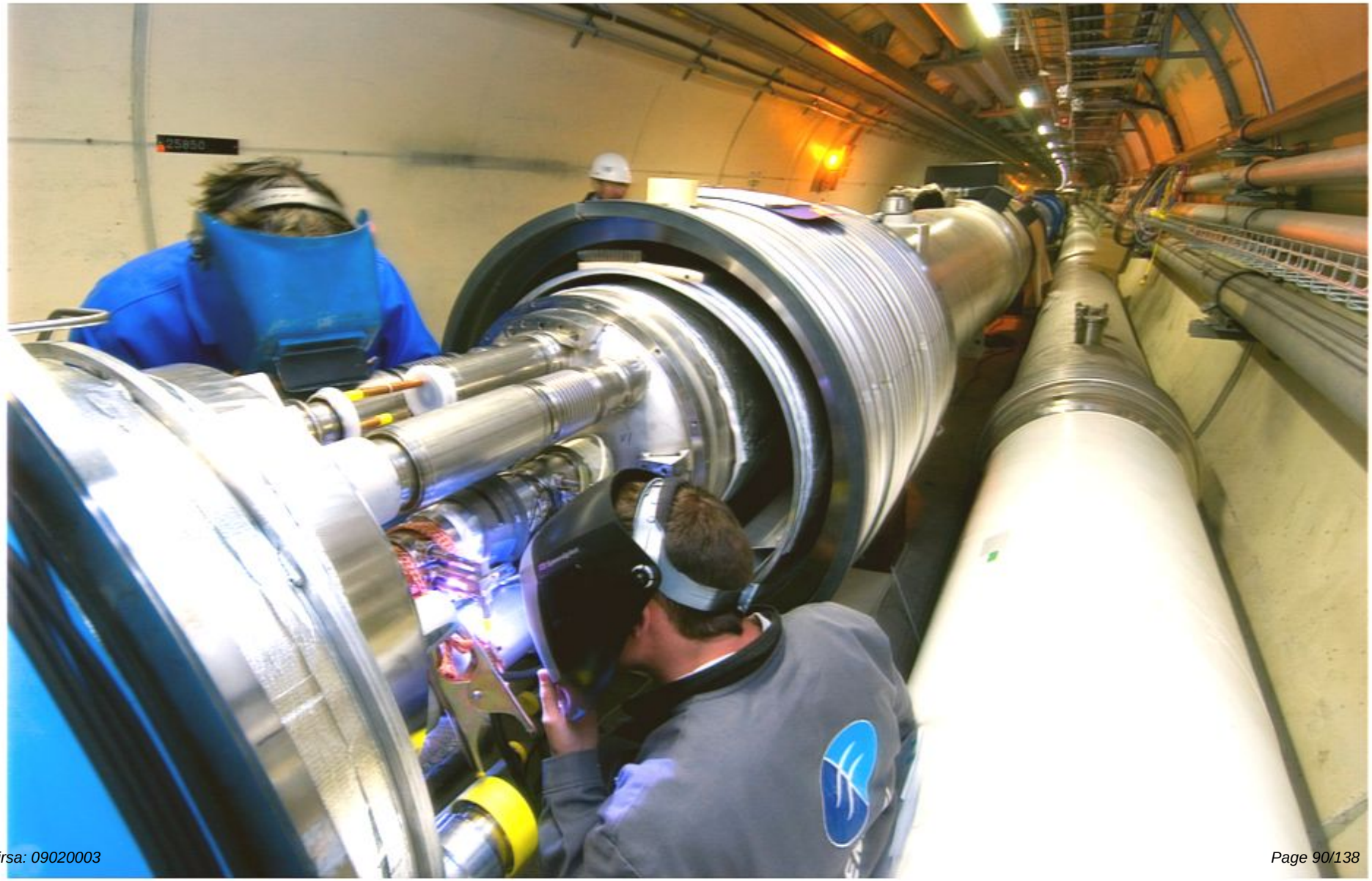


See Nature Article 14 July 2005

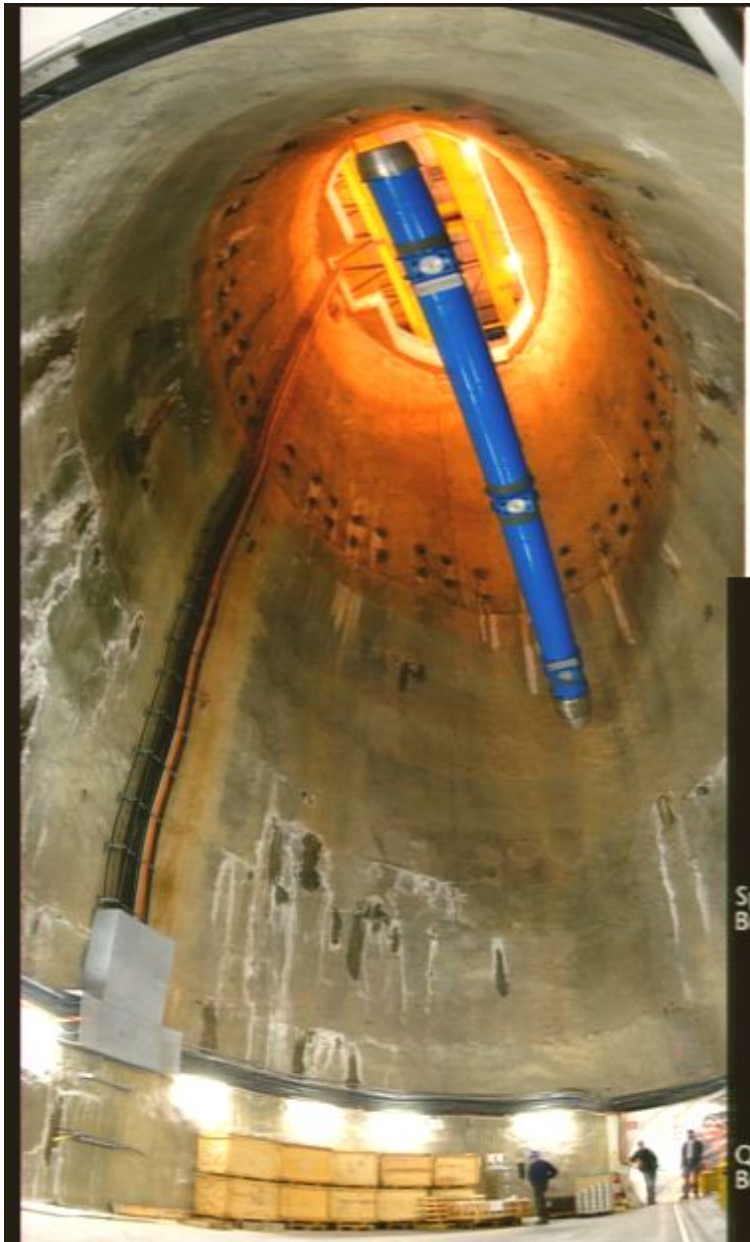

ATLAS Atlantis 2007-06-15 01:51:49 CEST
Event name: JiveXML_12284_00008 run: 12284 even
Y (m)
X (m)
Y (cm)
X (cm)
ρ (m)
Z (m)
ρ (m)
Z (cm)


ATLAS Atlantis 2007-06-14 14:07:41 CEST Event name: JiveXML_12204_00386 run: 12204 even
Y (m)
X (m)
Y (m)
X (cm)
Z (m)
Z (m)

5) Commissioning with Beam



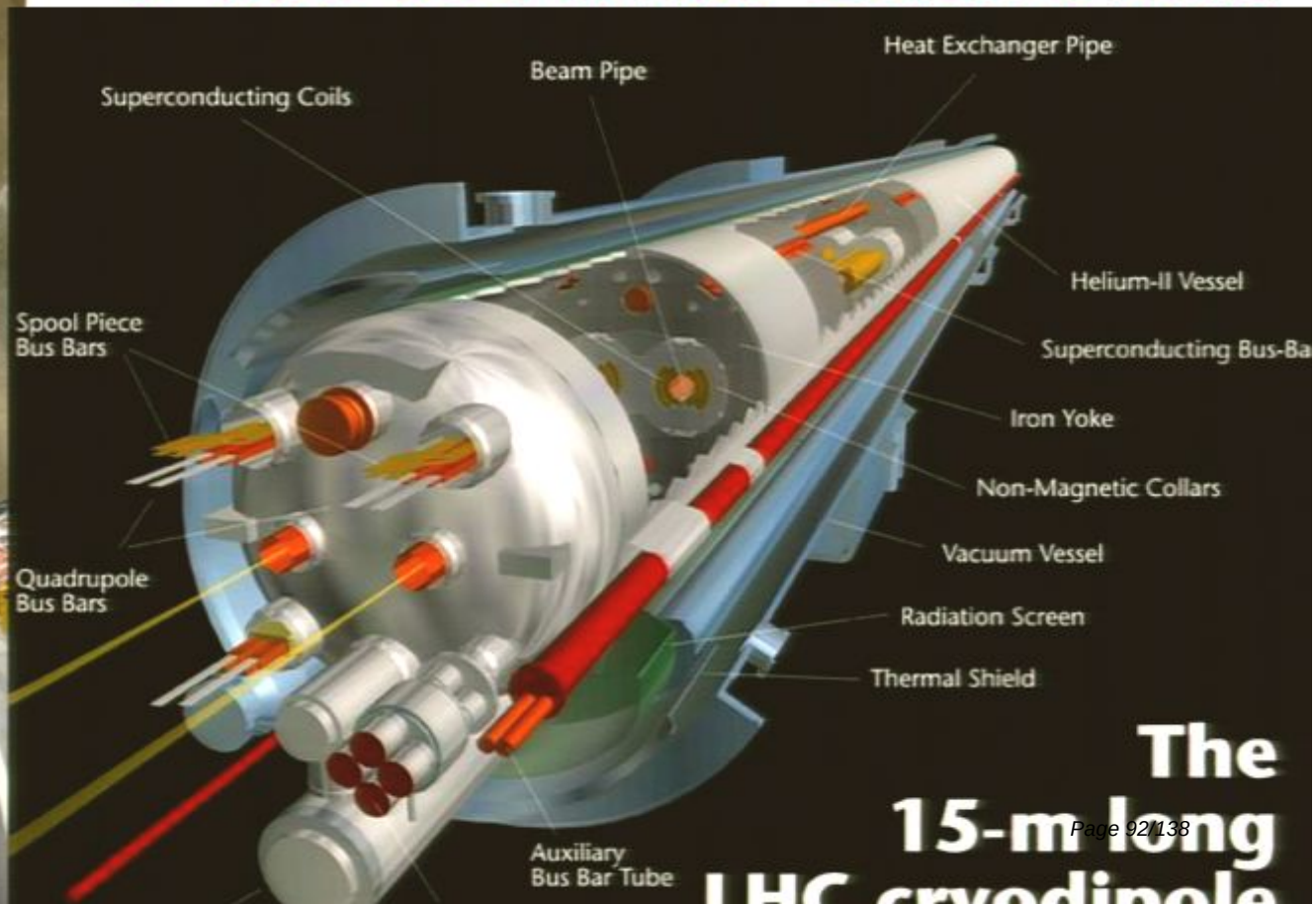
Nov ‘06: Last LHC dipole delivered to CERN



April 2007
Last dipole lowered into
LHC tunnel

One LHC dipole magnet

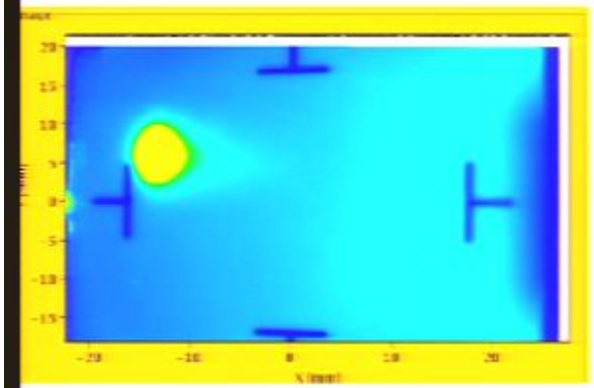
- 15 m long
- 1232 magnets total
- 8.7 Tesla magnetic field
  → 300 000 times Earth's field

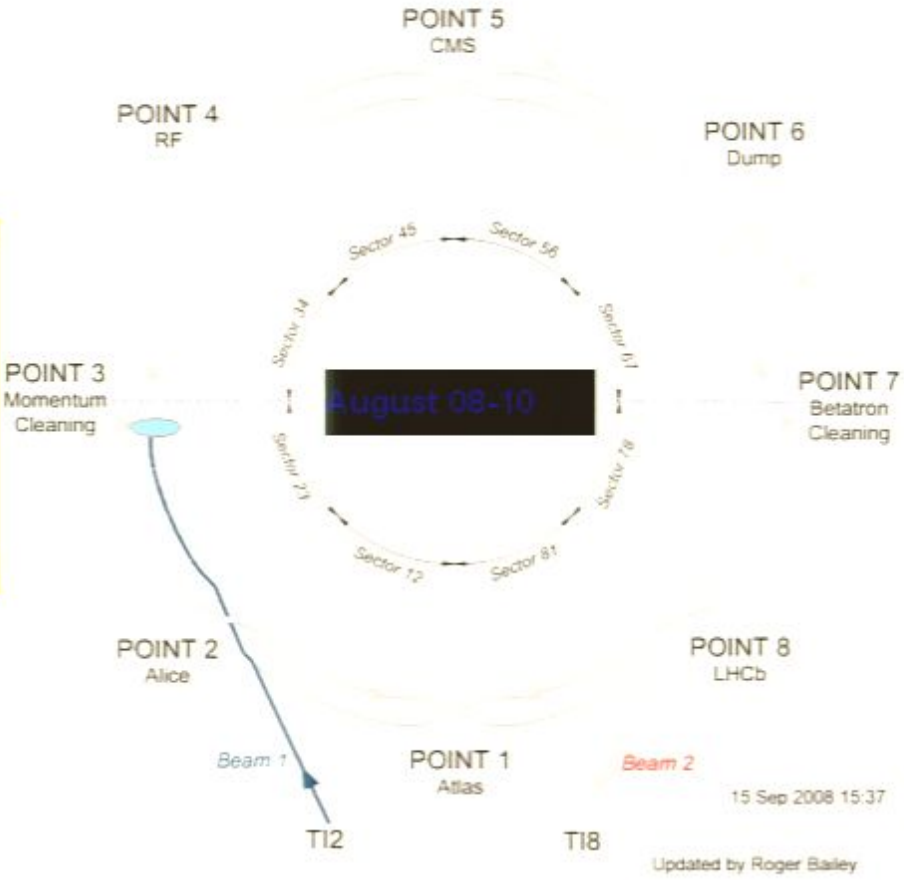


The 15-m long LHC cryodipole

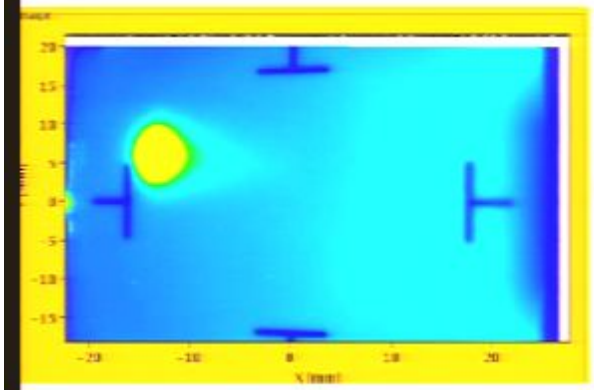
Closing LHC beam pipe in ATLAS June 16 2008

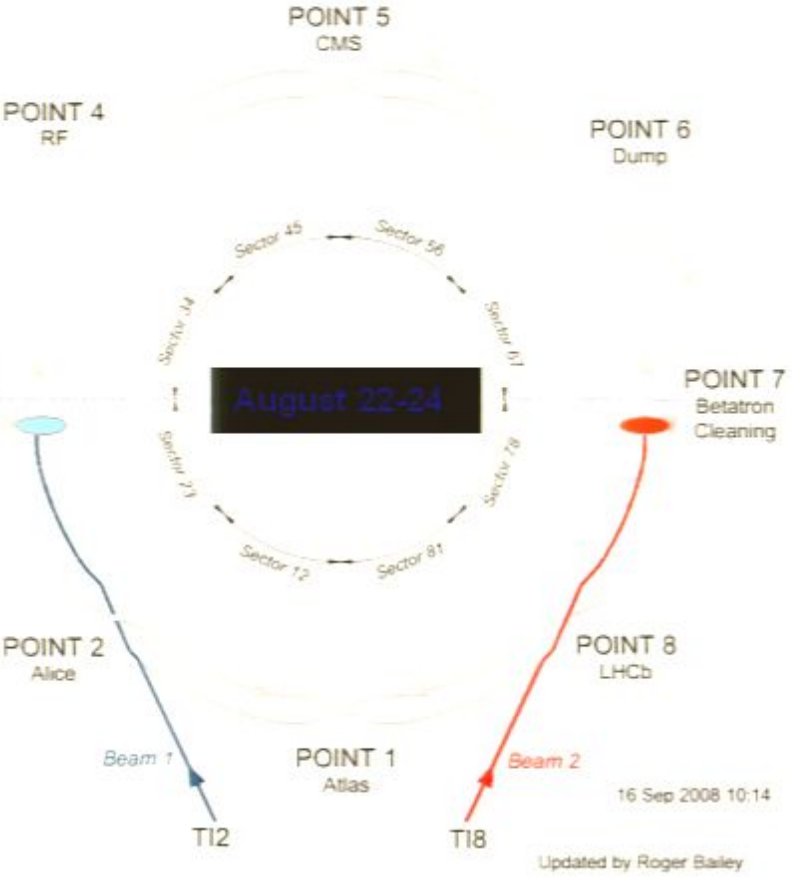
First LHC Beam, Sept. 10, 2008

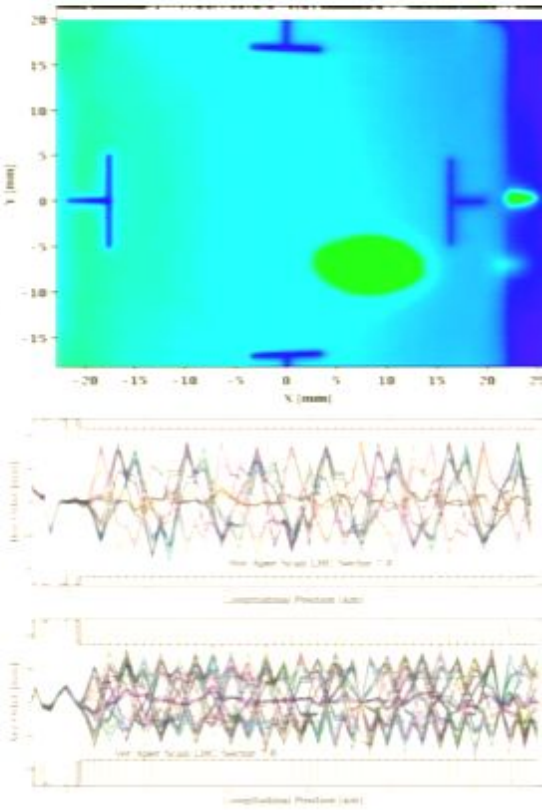




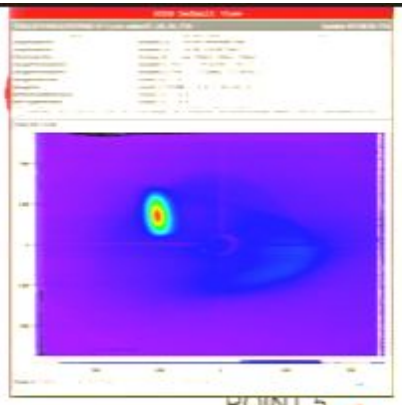
First LHC Beam, Sept. 10, 2008

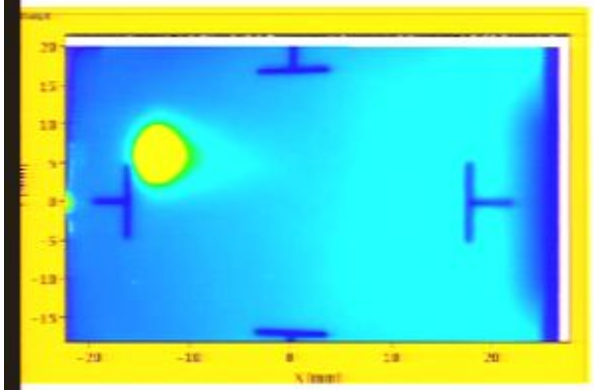


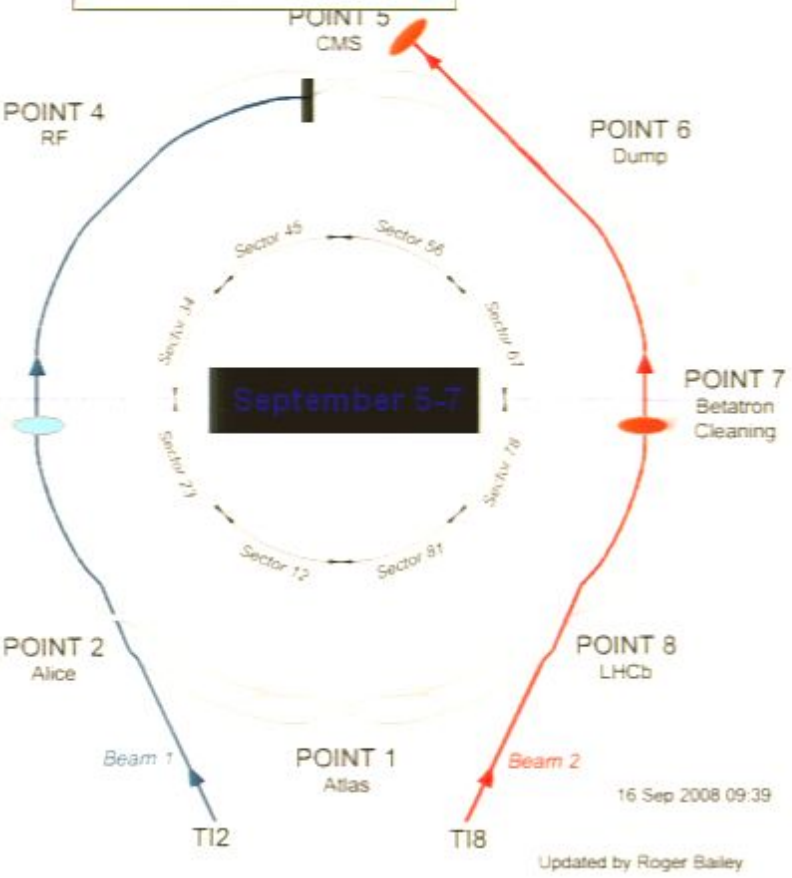


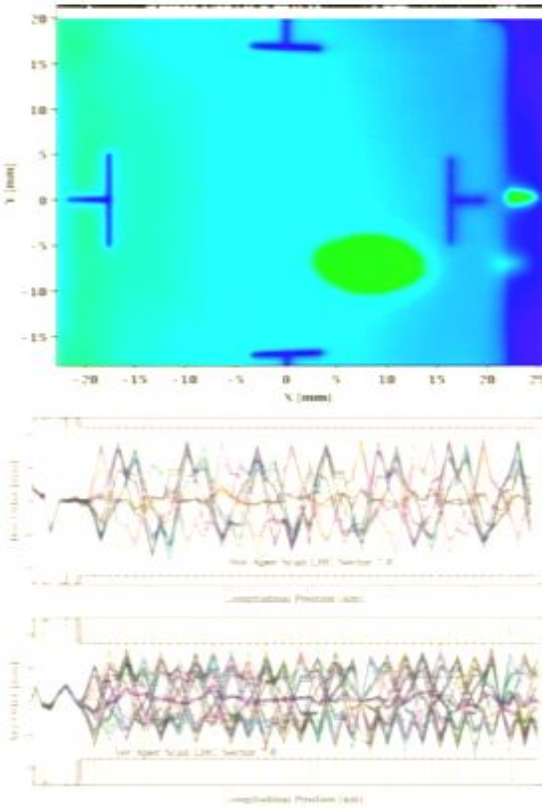


First LH Sept. 10, 2008

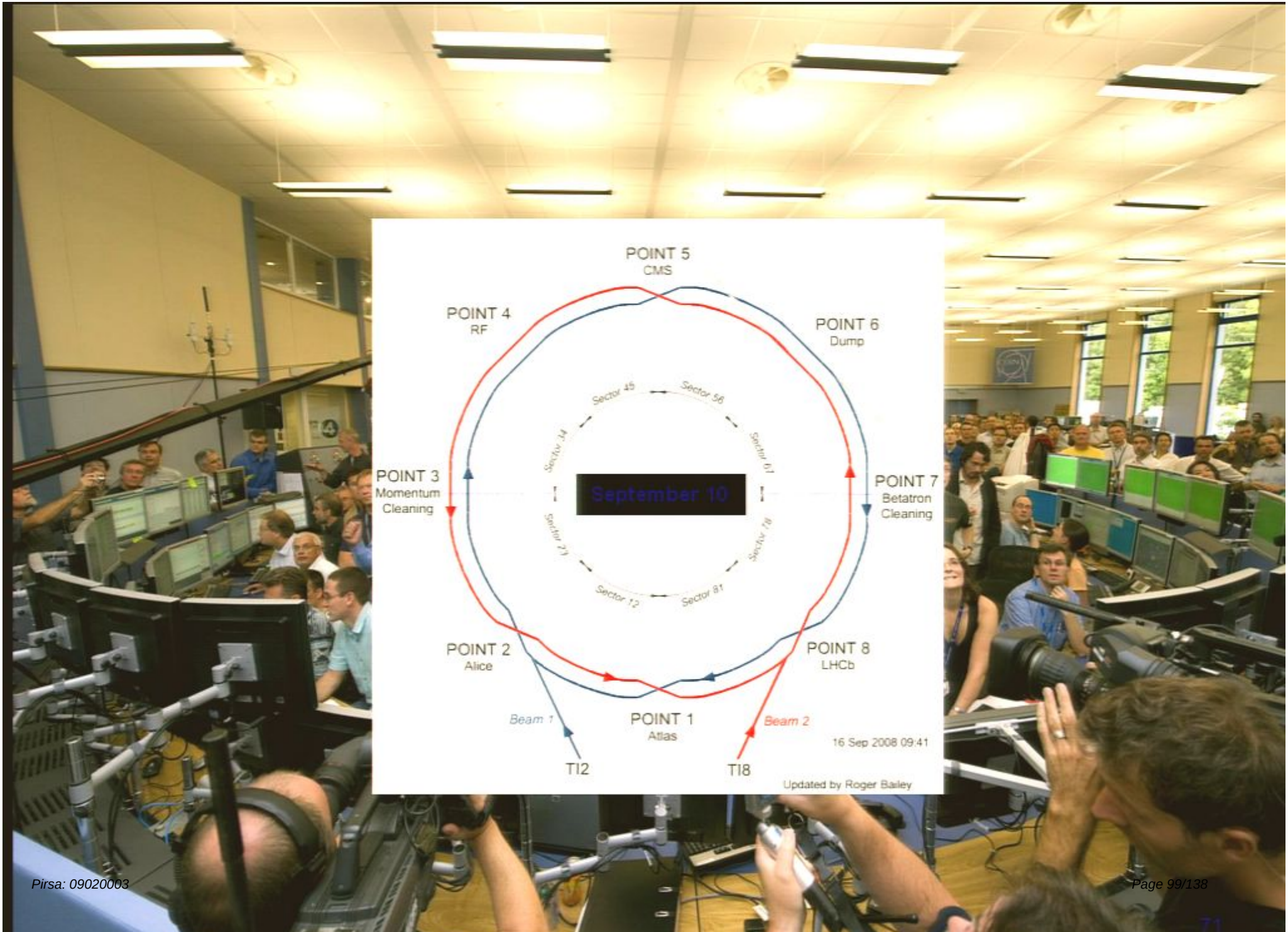




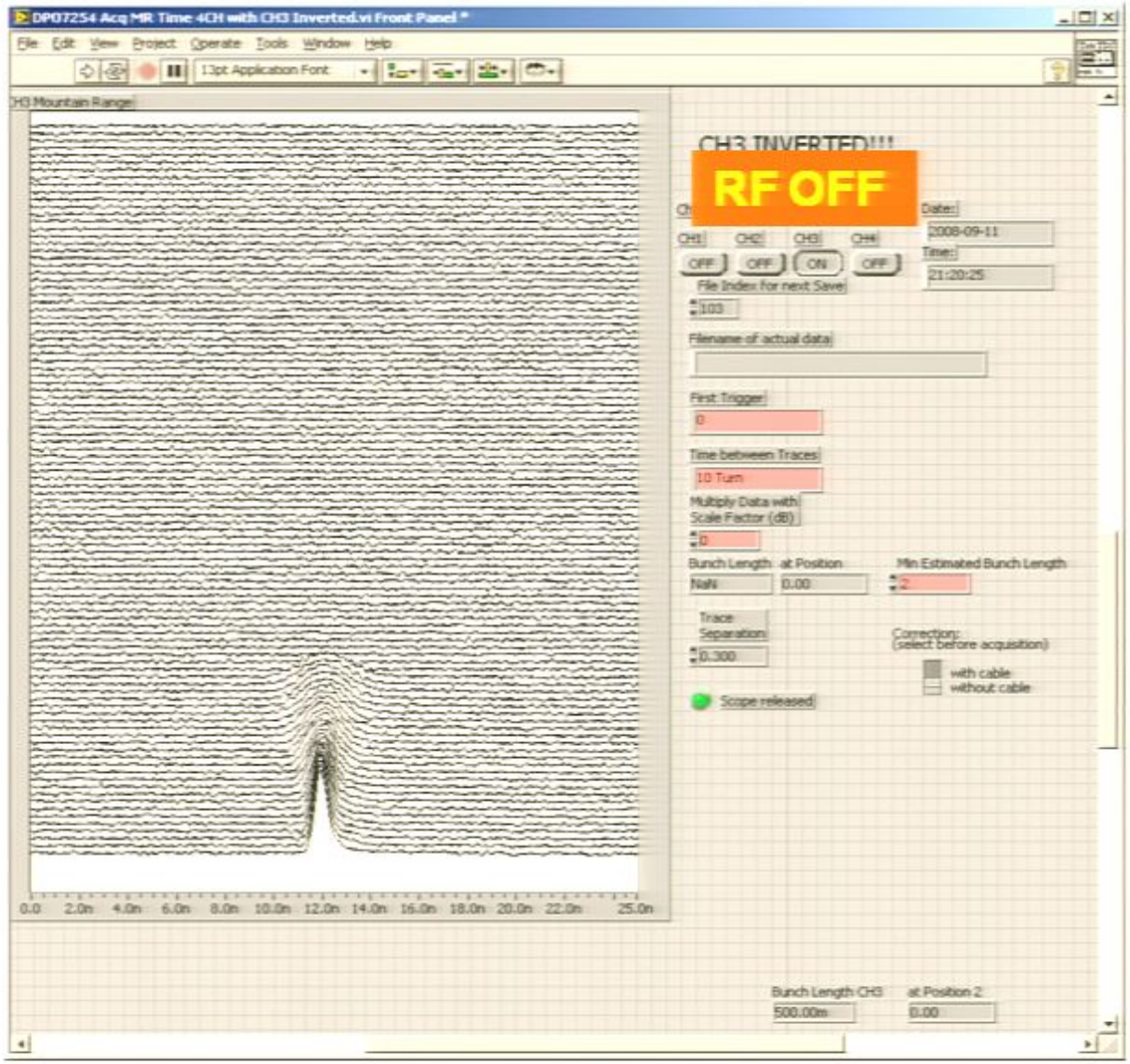




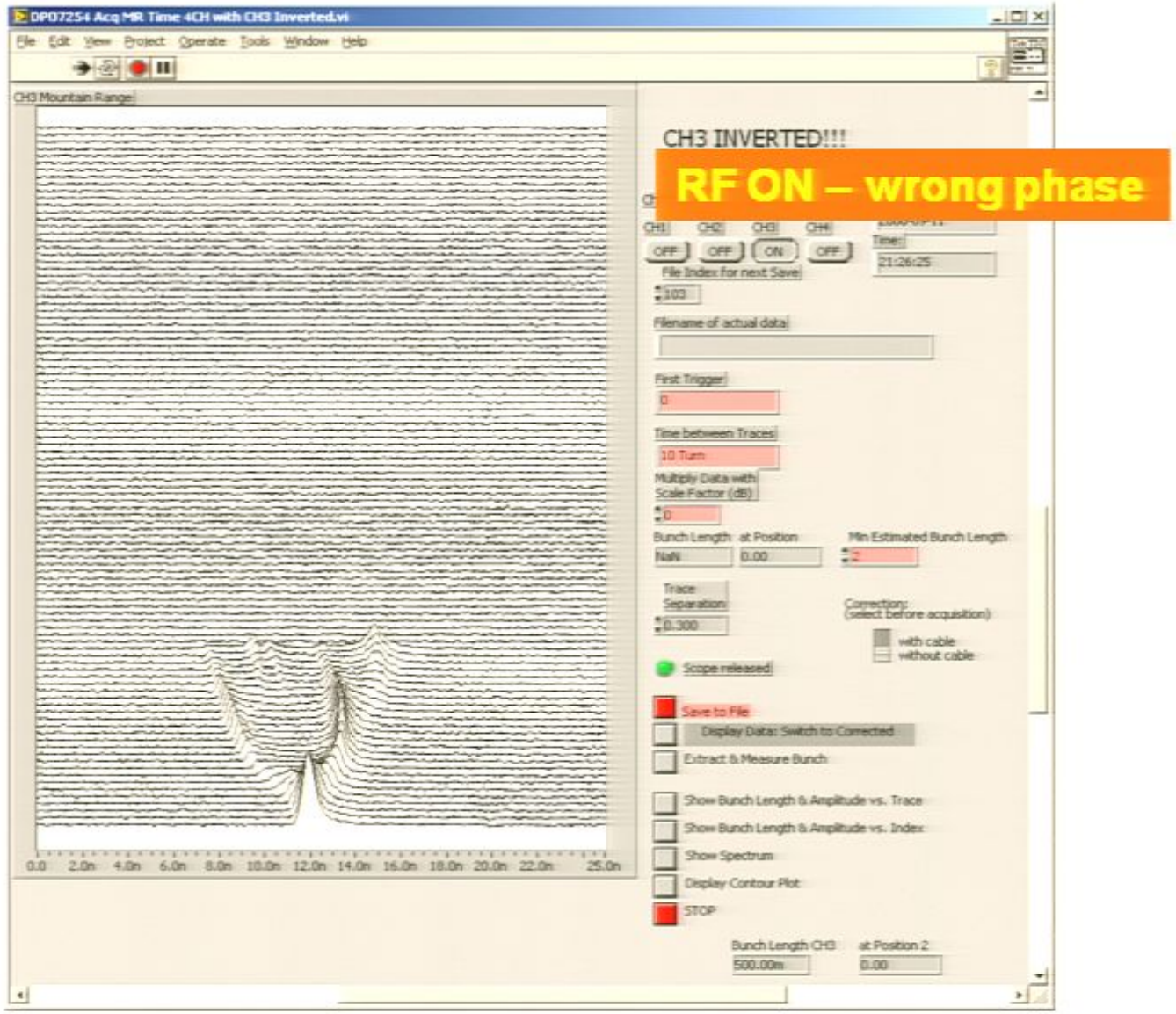

September 10


POINT 5
CMS
POINT 4
RF
POINT 6
Dump
POINT 3
Momentum
Cleaning
POINT 7
Betatron
Cleaning
POINT 2
Alice
POINT 8
LHCb
POINT 1
Atlas
Sector 45
Sector 56
Sector 34
Sector 67
Sector 23
Sector 78
Sector 12
Sector 81
September 10
Beam 1
Beam 2
TI2
TI8
16 Sep 2008 09:41
Updated by Roger Bailey

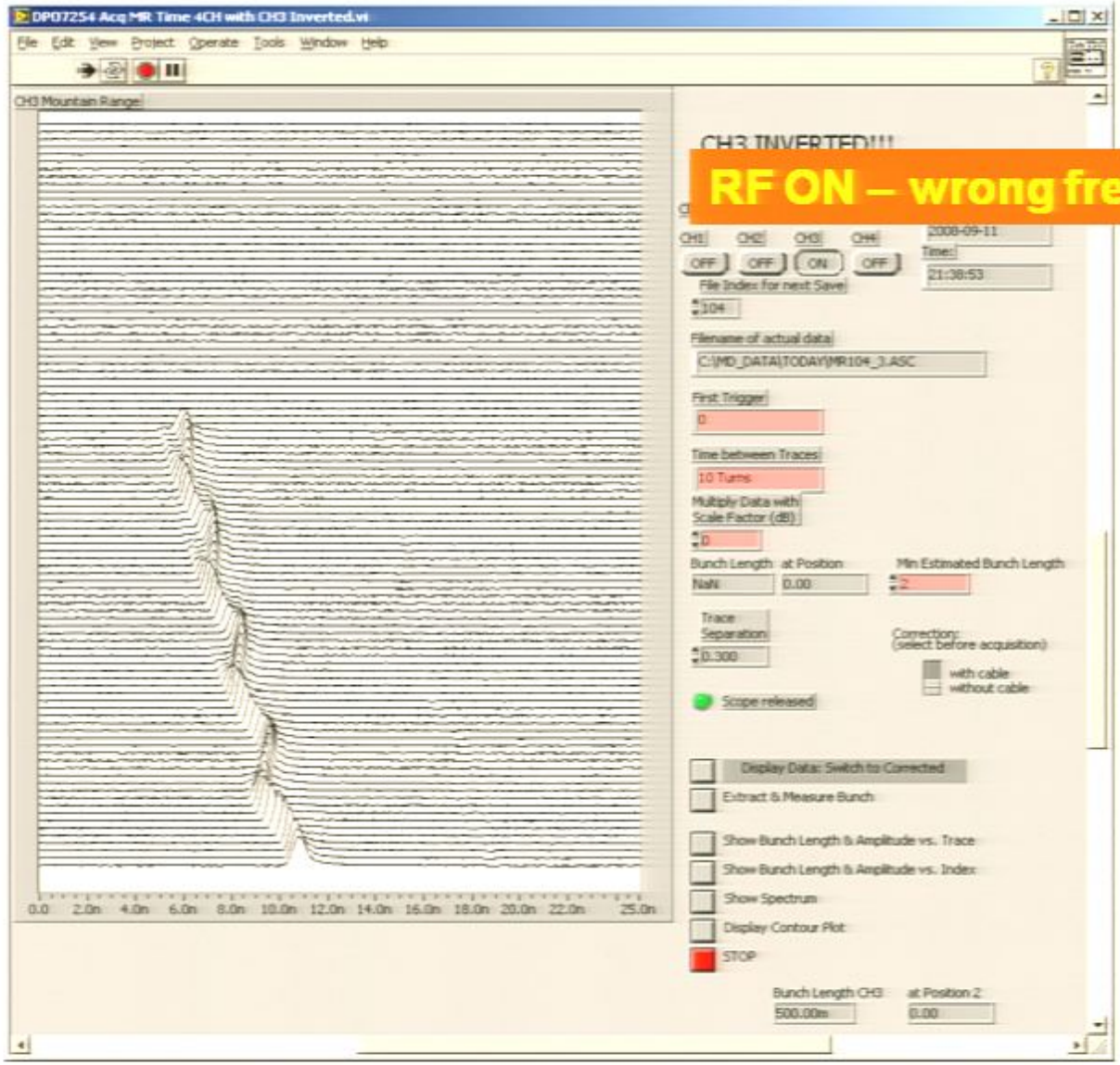
Beam 2 – RF capture



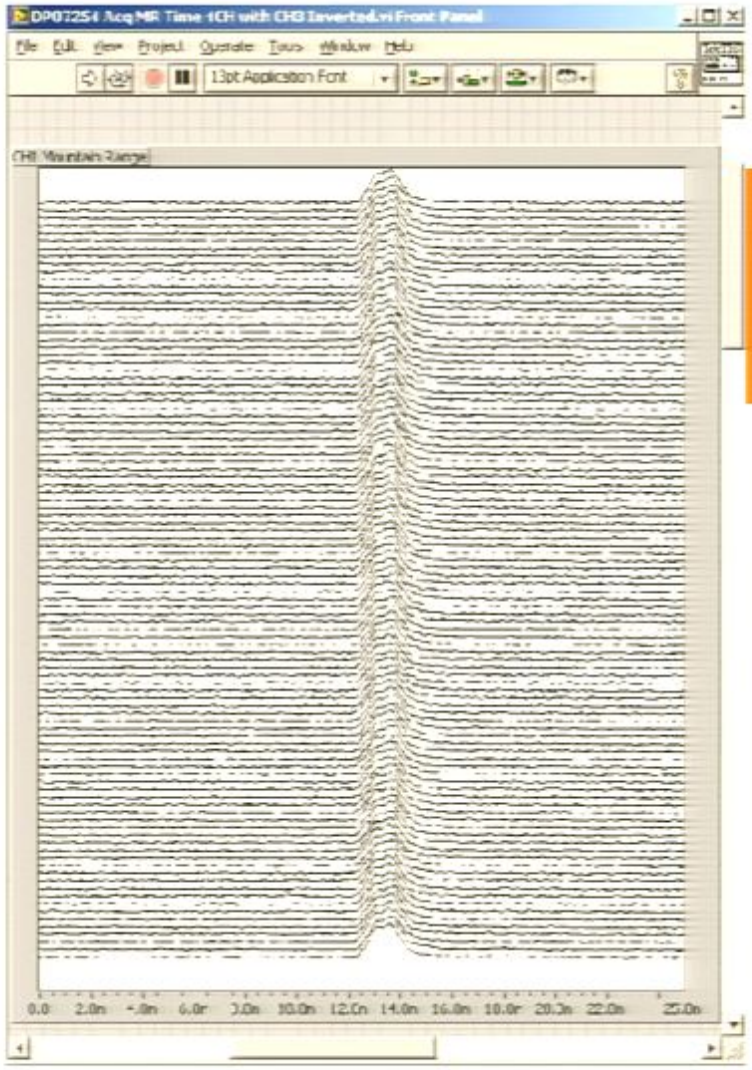
Beam 2 – RF capture



Beam 2 – RF capture

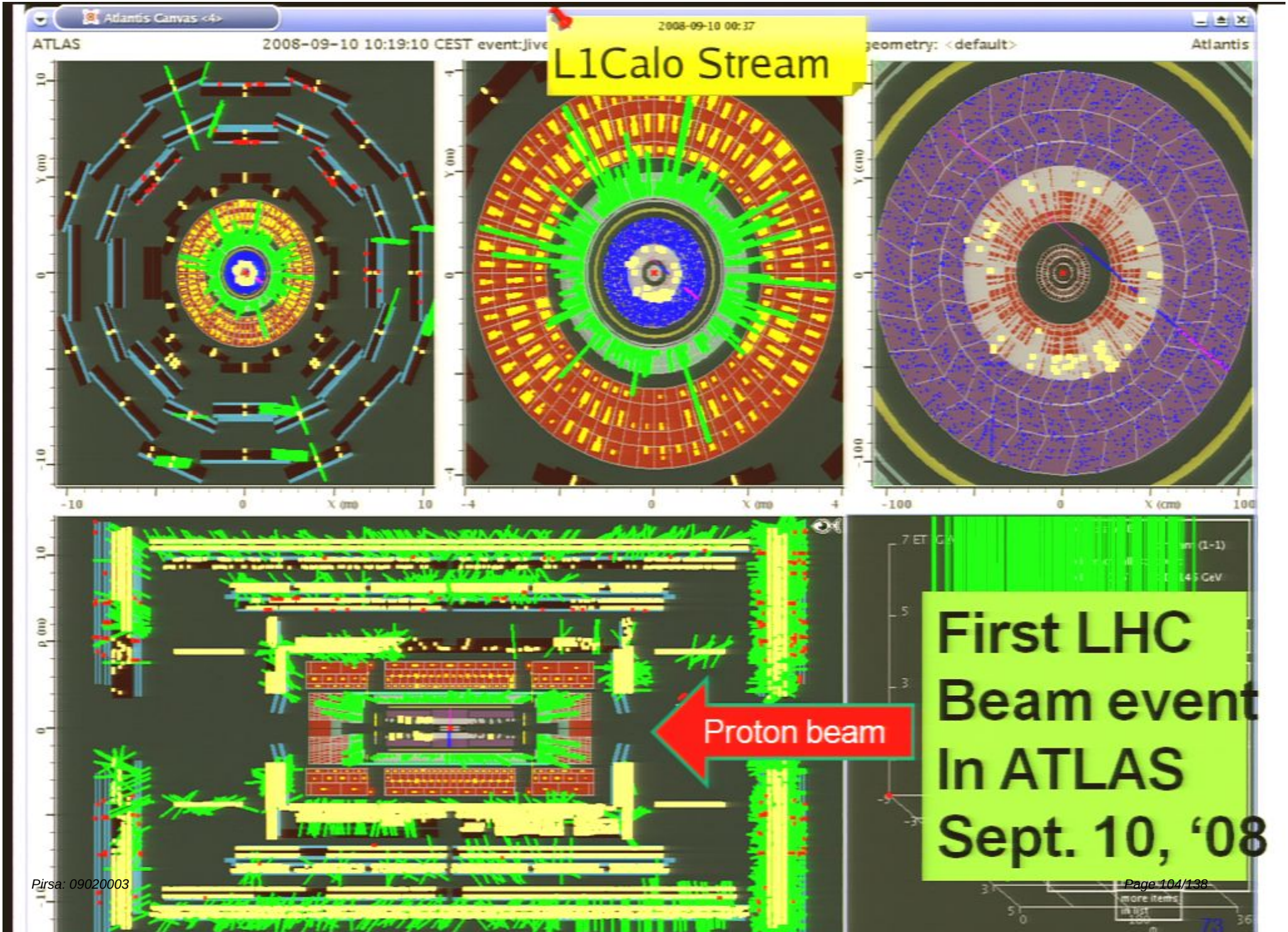


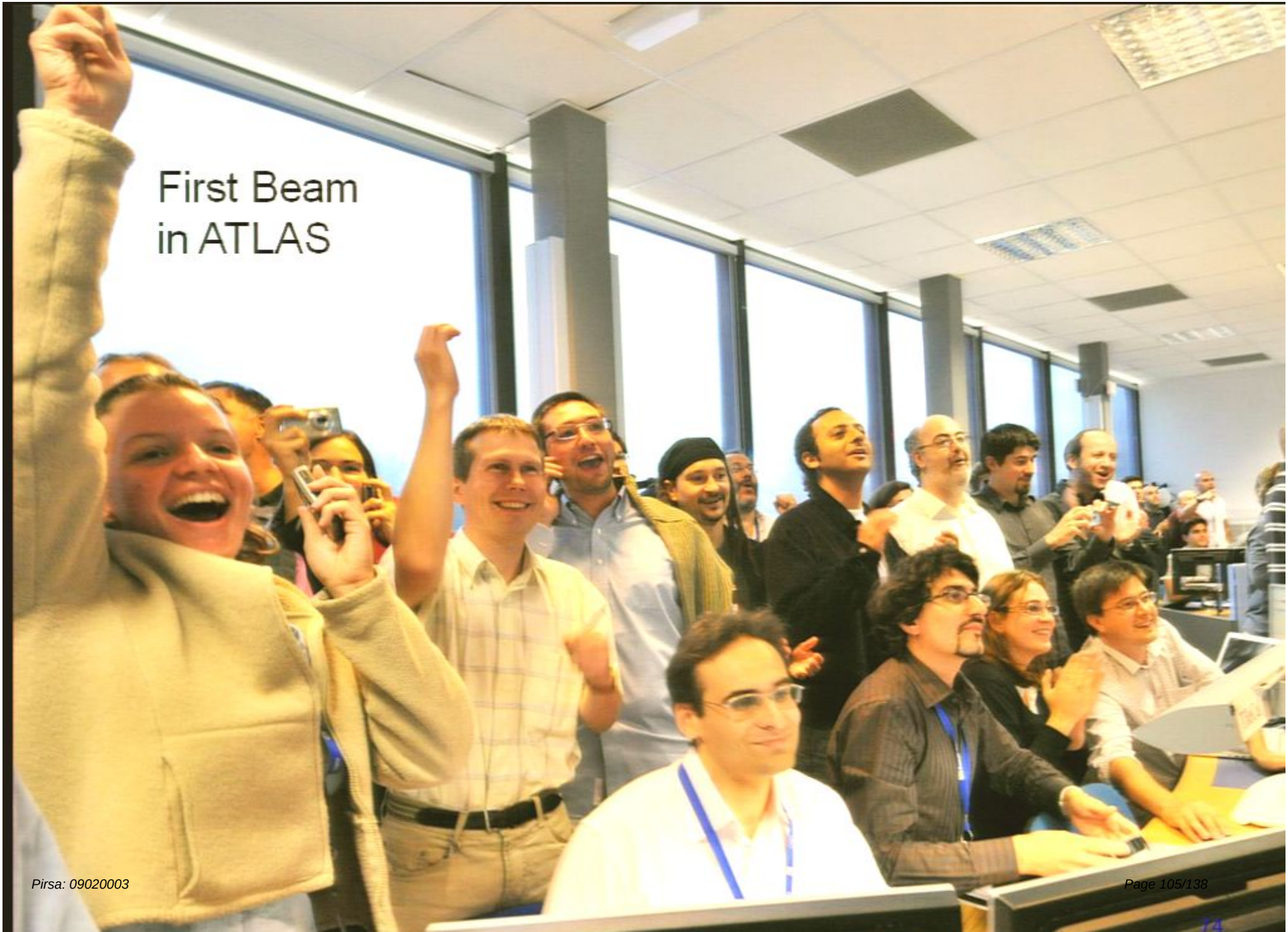
Beam 2 – RF capture

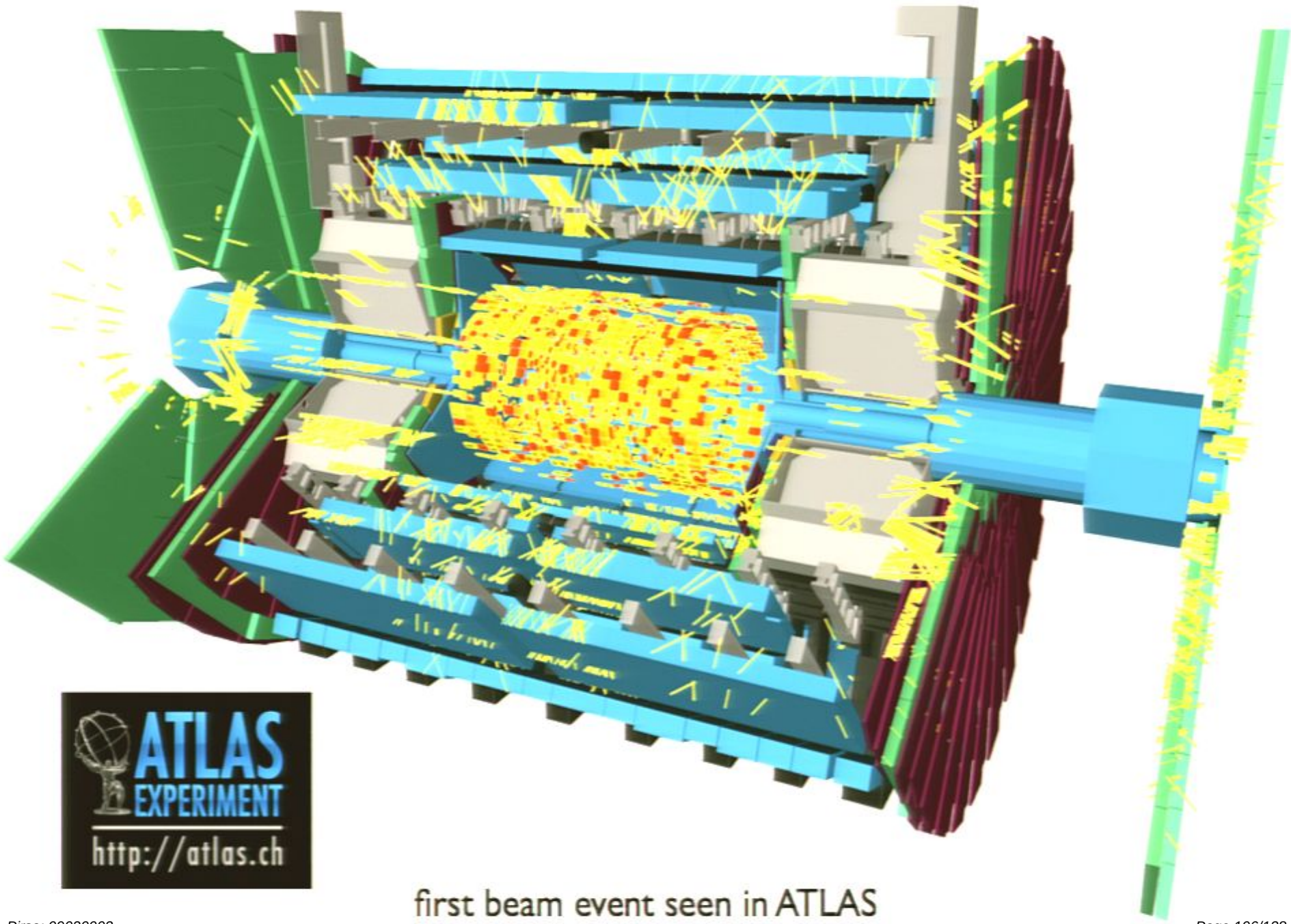


RF ON – correct injection phase and frequency:

beam captured !


Atlantis Canvas <4>
ATLAS
2008-09-10 10:19:10 CEST event:Jive
2008-09-10 00:37
L1Calo Stream
geometry: <default>
Atlantis
Proton beam
First LHC
Beam event
In ATLAS
Sept. 10, '08

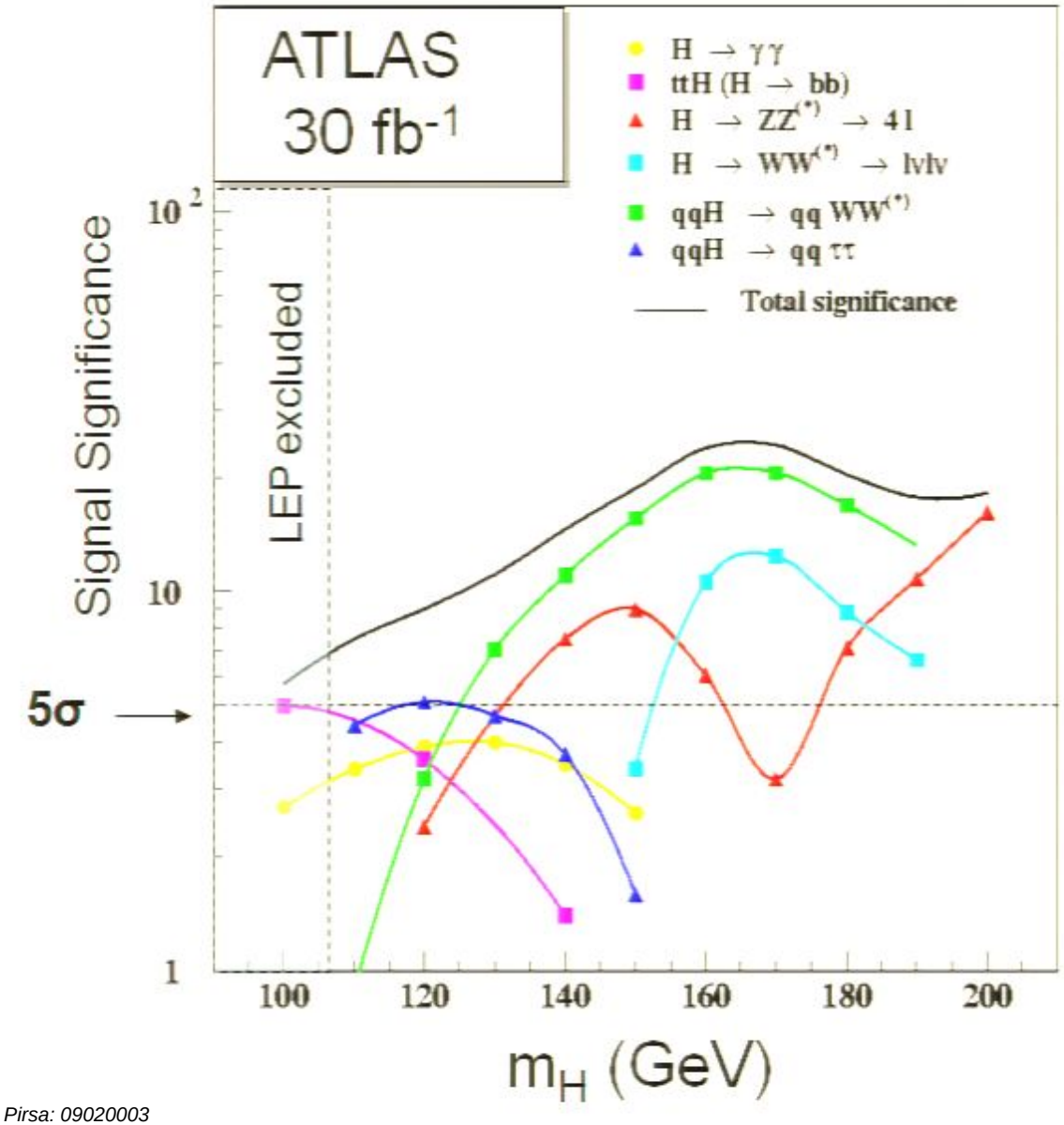

First Beam
in ATLAS



first beam event seen in ATLAS

Future: Road to Higgs Discovery

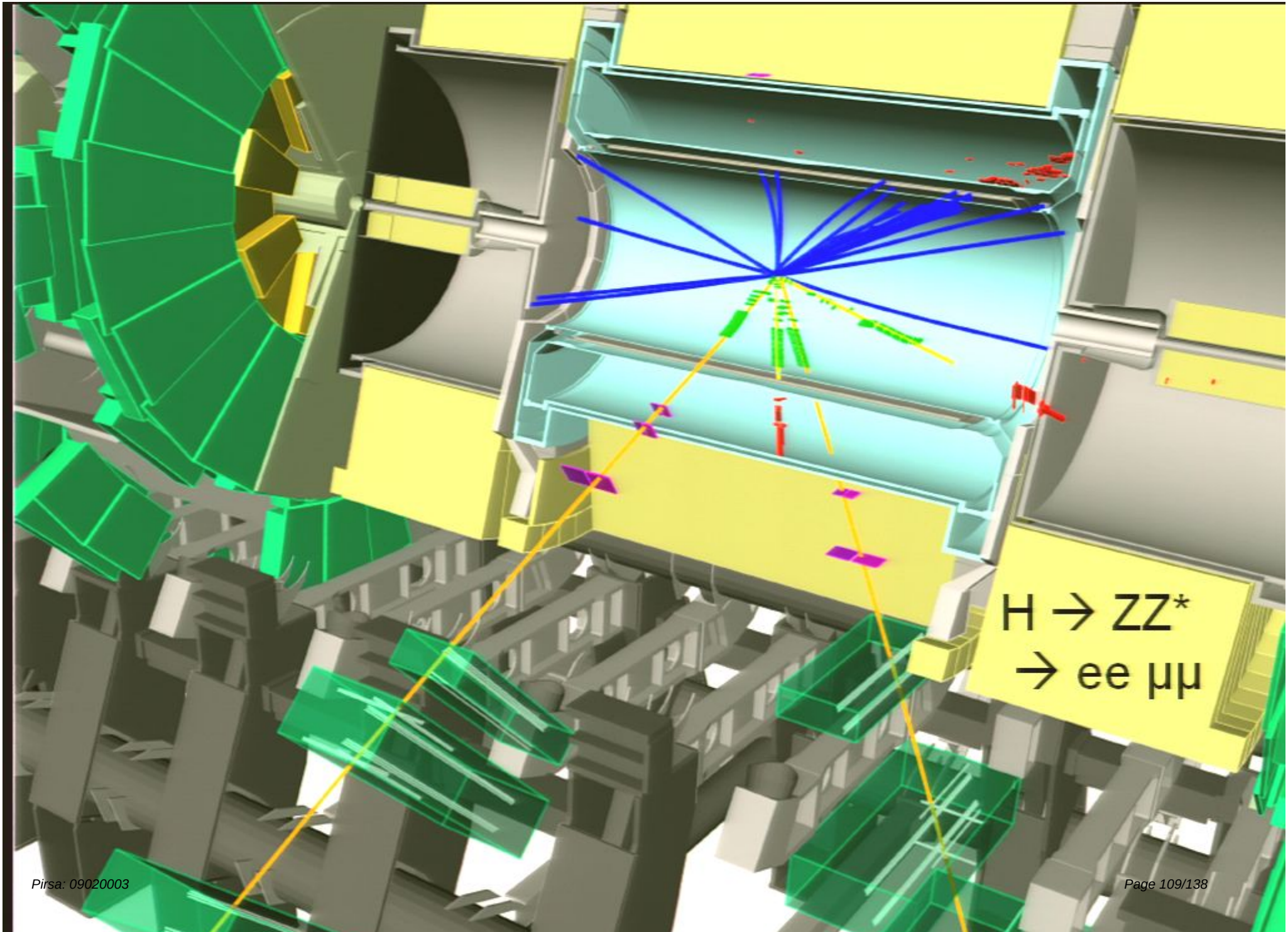
Strategy for Higgs Discovery



LHC can probe full range of "allowed" Higgs masses.

5σ observation possible after few years at L = 2x10^{33}

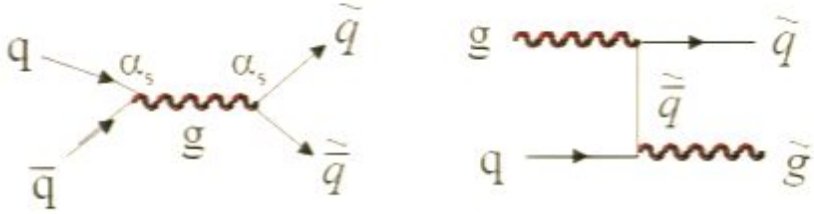
Eur.Phys.J. C32S2 (2004) 19-54


H → ZZ*
→ ee μμ

The First Higgs in ATLAS

P.W. Higgs, April 4, 2008

SUSY at LHC



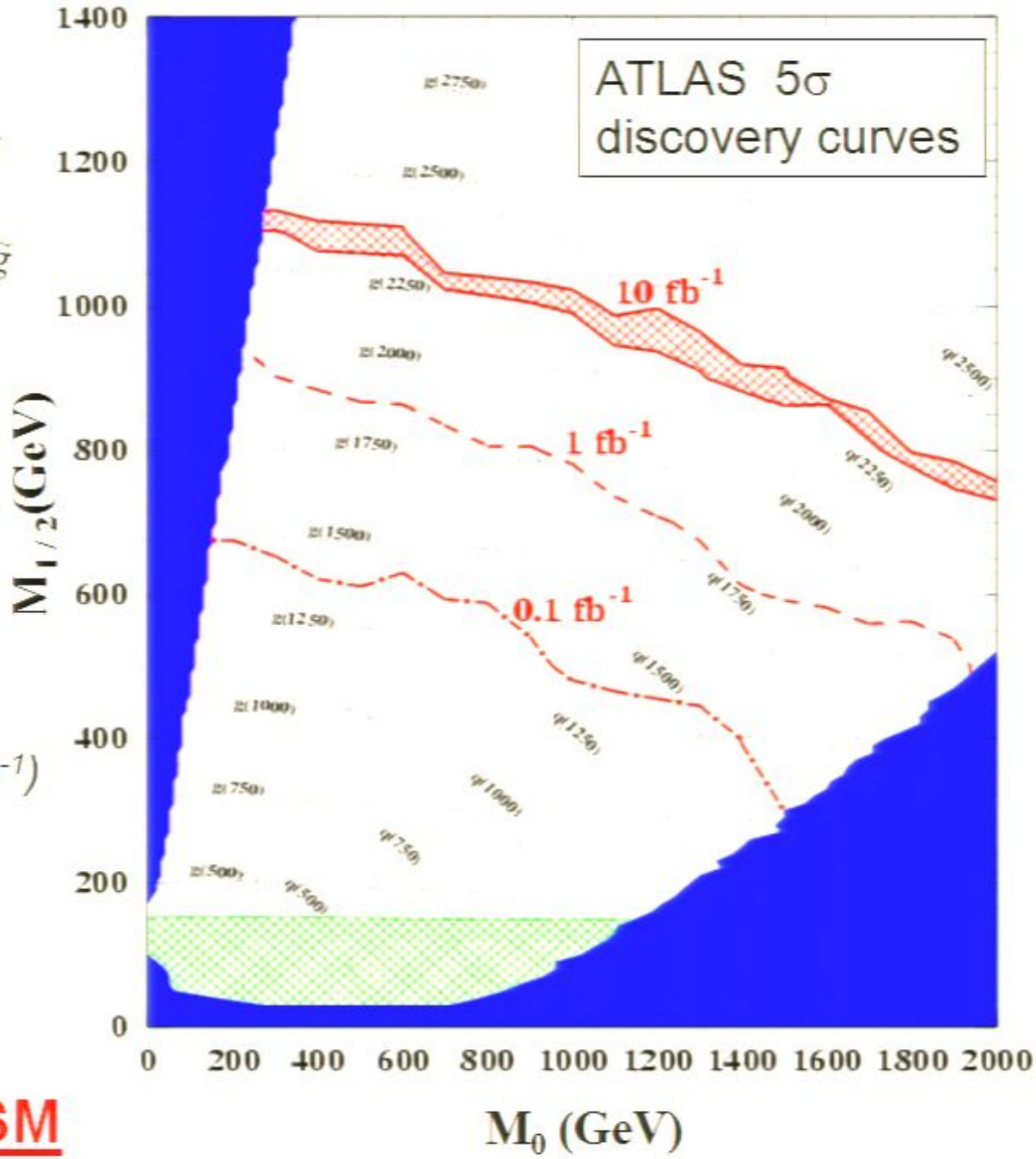
Large cross-sections for squark and gluino production at LHC

With L= 10^{33}, mass reach:

M ~ 1.3 TeV in 1 week
M ~ 1.8 TeV in 1 month

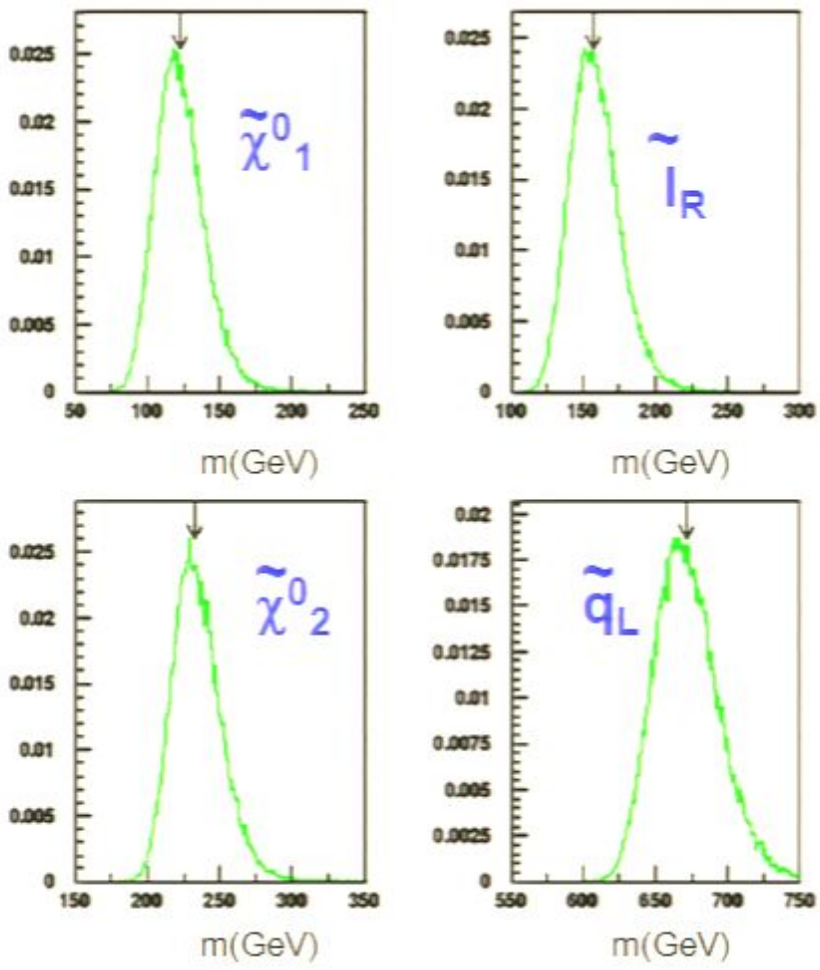
M ~ 2.5 – 3.0 TeV (ultimate 300 fb^{-1})

→ Main limitation not statistics but understanding the detectors



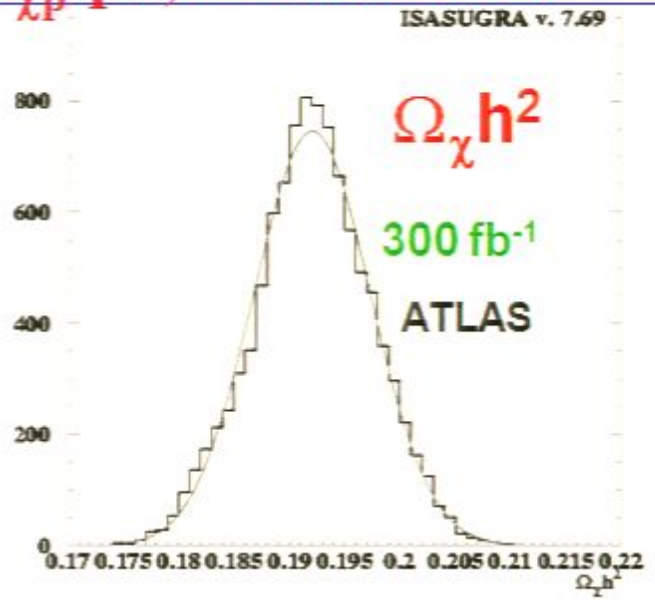
SUSY may be the first discovery beyond the SM at the LHC

Prospects for Measuring SUSY Parameters



Allanach et al., ATL-PHYS-2002-005

$$\Omega_\chi h^2 = 0.1921 \pm 0.0053$$
$$\log_{10}(\sigma_{\chi p}/\mathrm{pb}) = -8.17 \pm 0.04$$



Polesello et al.,
ATL-PHYS-2004-008

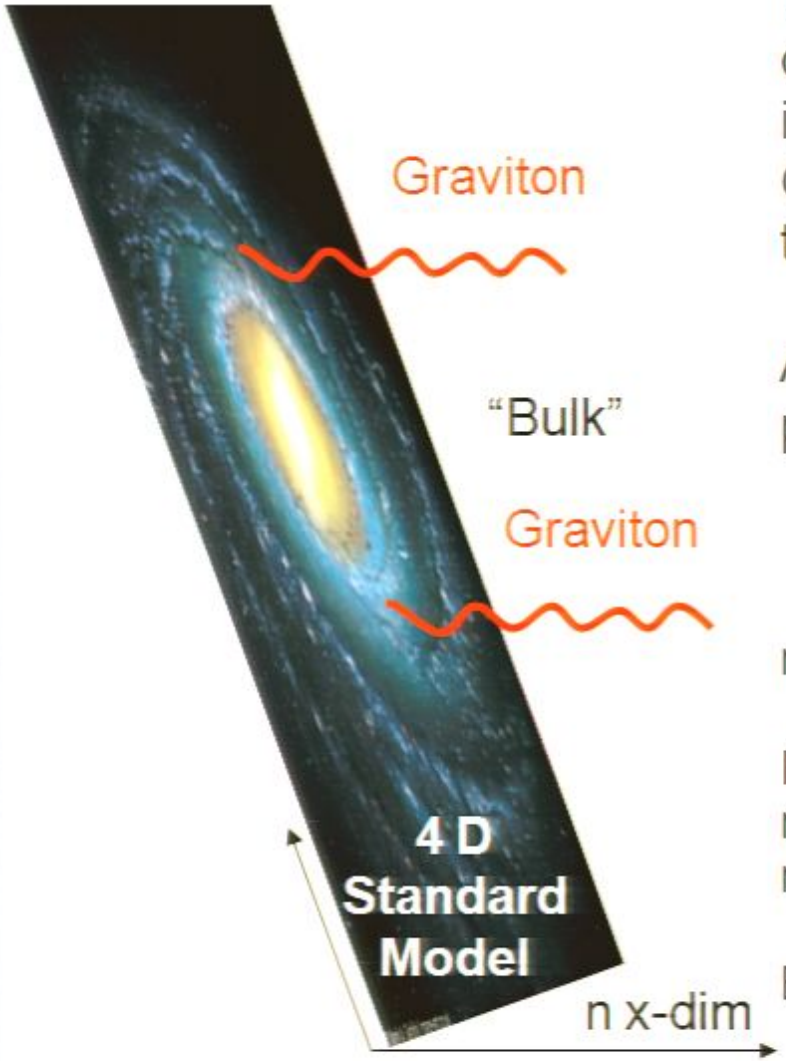
Sparticle mass	Expected precision 100 fb^{-1}
squark left	± 3%
χ^0_2	± 6%
slepton mass	± 9%
χ^0_1	± 12%

Exercise done in JHEP 05 (2004) 071 using SPS1a, 300 fb^{-1} simulated

Many other physics searches

- Excited quarks: $q^* \rightarrow q\gamma\gamma$, up to ~ 6 TeV
- Leptoquarks: $X \rightarrow l + q$, up to ~ 1.5 TeV
- Compositeness: dijets up to 40 TeV
- Lepton flavour violation: $\tau \rightarrow \mu\gamma$ up to 10^{-6} to 10^{-7}
- Monopoles, 4th generation fermions, extra dimensions…

One Possibility: Extra Dimensions



The weakness of gravity compared to the SM forces could be explained by extra dimensions beyond 4D, inspired by string theory.
Gravity leaks into the extra dimensions and appears to be weaker.

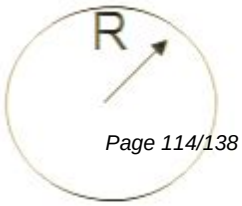
A gravity (string) scale of $M_S \sim 1$ TeV is then possible. A solution to the hierarchy problem!

$$M_{Planck}^2 \sim M_S^{n+2} R^n$$

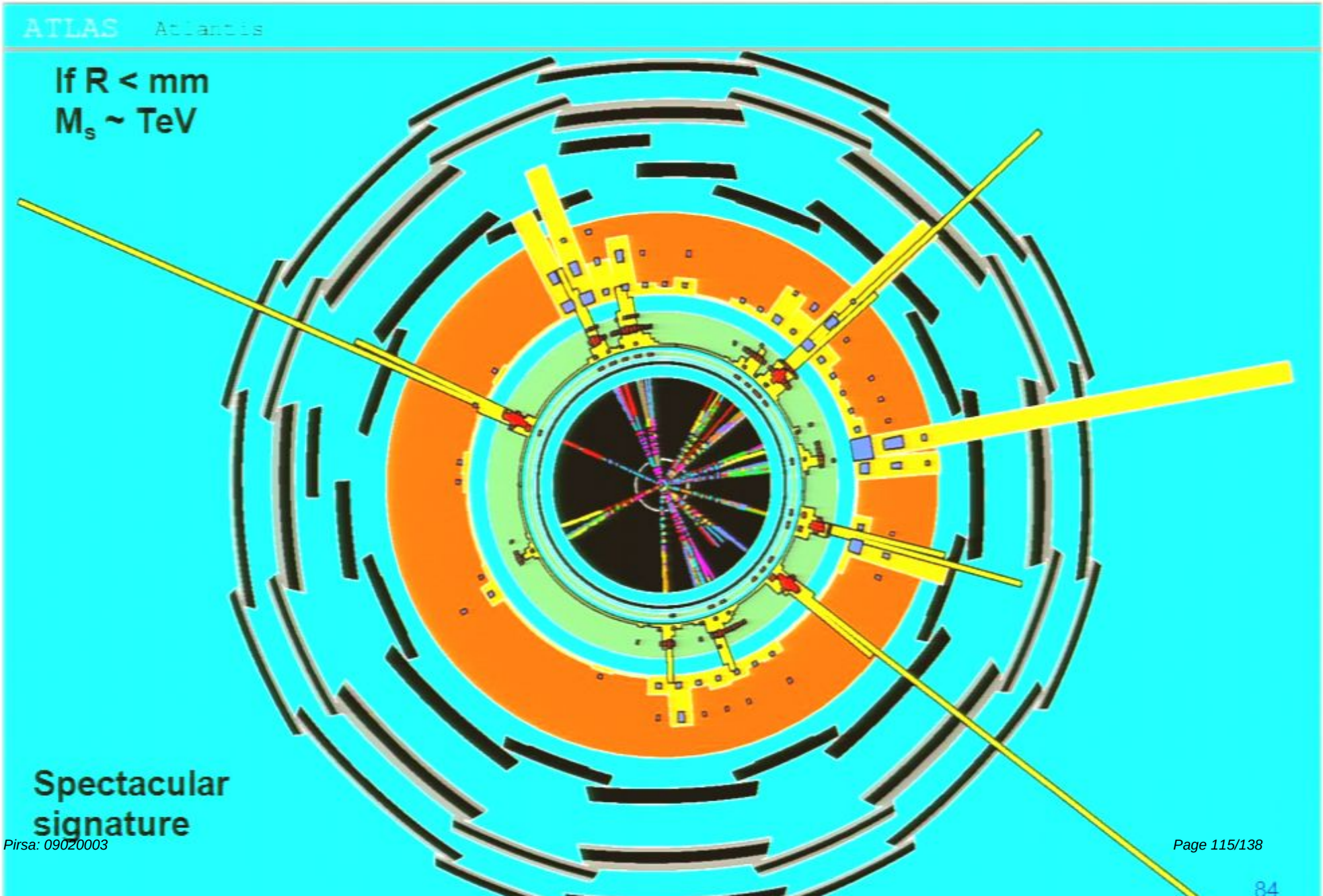
n, R = number and size of extra dimensions

If Ms ~ 1 TeV:
n = 1 -> R = 10^{13} m (excluded by macroscopic gravity)
n = 2 -> R = 0.7 mm (limit of small-scale gravity expts)

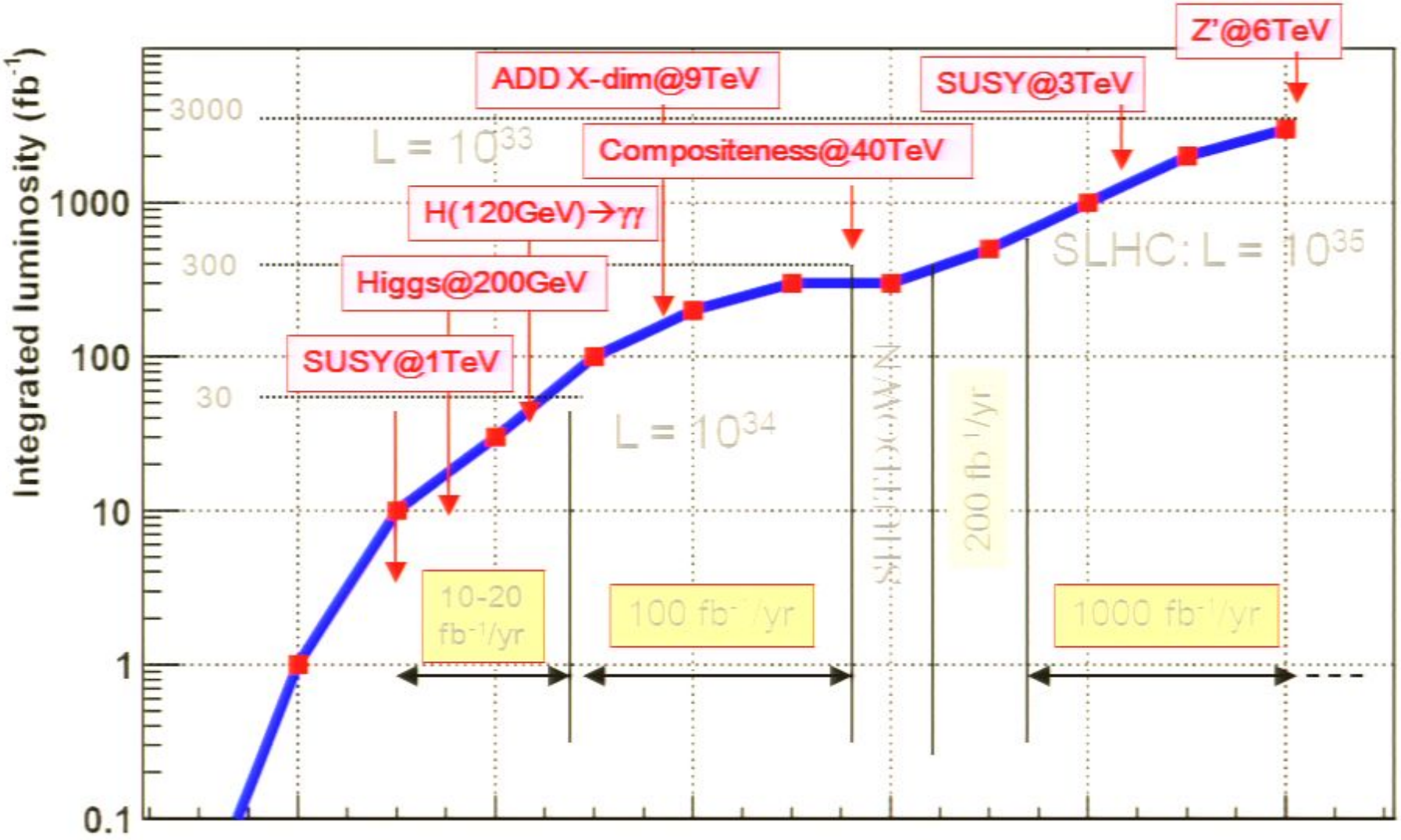
Extra dimensions compact over R < mm



Black Hole Production at LHC



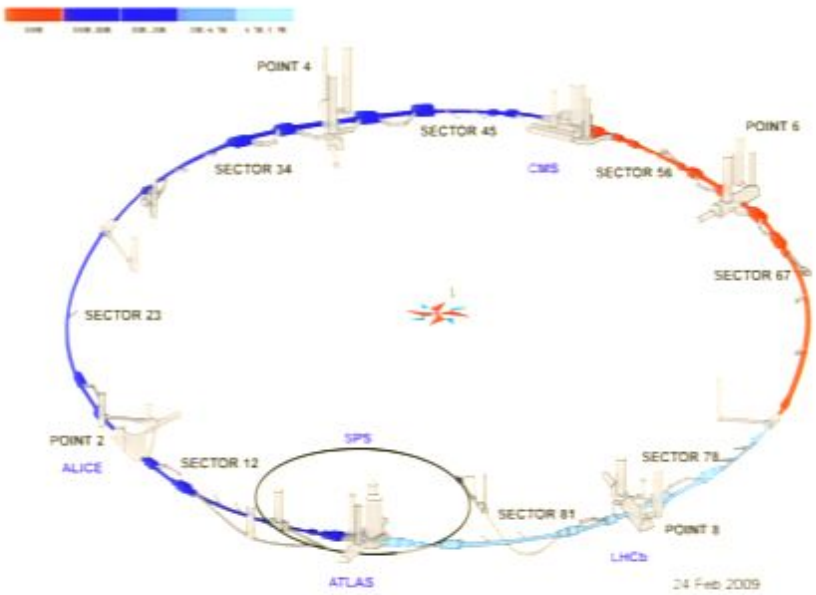
LHC luminosity profile and physics reach

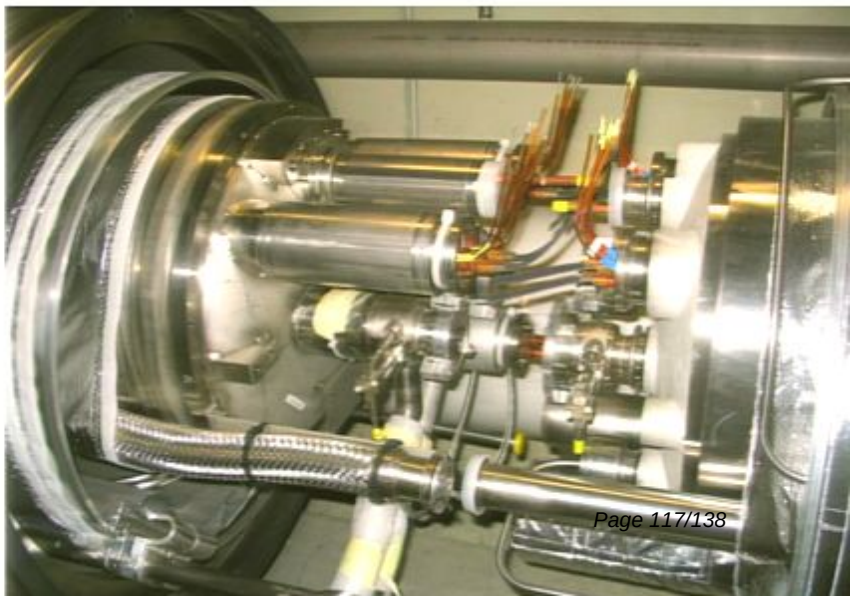


Update Feb '09: Expectation 2009-2010 is 150 to 300 pb^{-1} at 10 TeV

CERN Report on September 19th 2008

- On 19 September 2008, during powering tests of the main dipole circuit in sector 3-4 of the LHC, an electrical fault occurred resulting in mechanical damage and release of helium from the magnet cold mass.
- Proper safety procedures were in force, safety systems performed as expected, and no one was put at risk.
- The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25.
- The number of magnets to be repaired is at maximum 5 quadrupoles (in Short Straight Sections) and 24 dipoles.
- Repairs required warming up the sector (3-4 weeks)





LHC summary CERN 24-Feb-09

- LHC repairs well underway
  - Replacement magnets being installed undeground
  - All replacement magnets cryostated
  - Enhanced quench protection system being installed
- Planned restart September 2009
- First collisions after 1-2 months
- Exceptionally plan to run LHC during winter '09-10 → 11 month run
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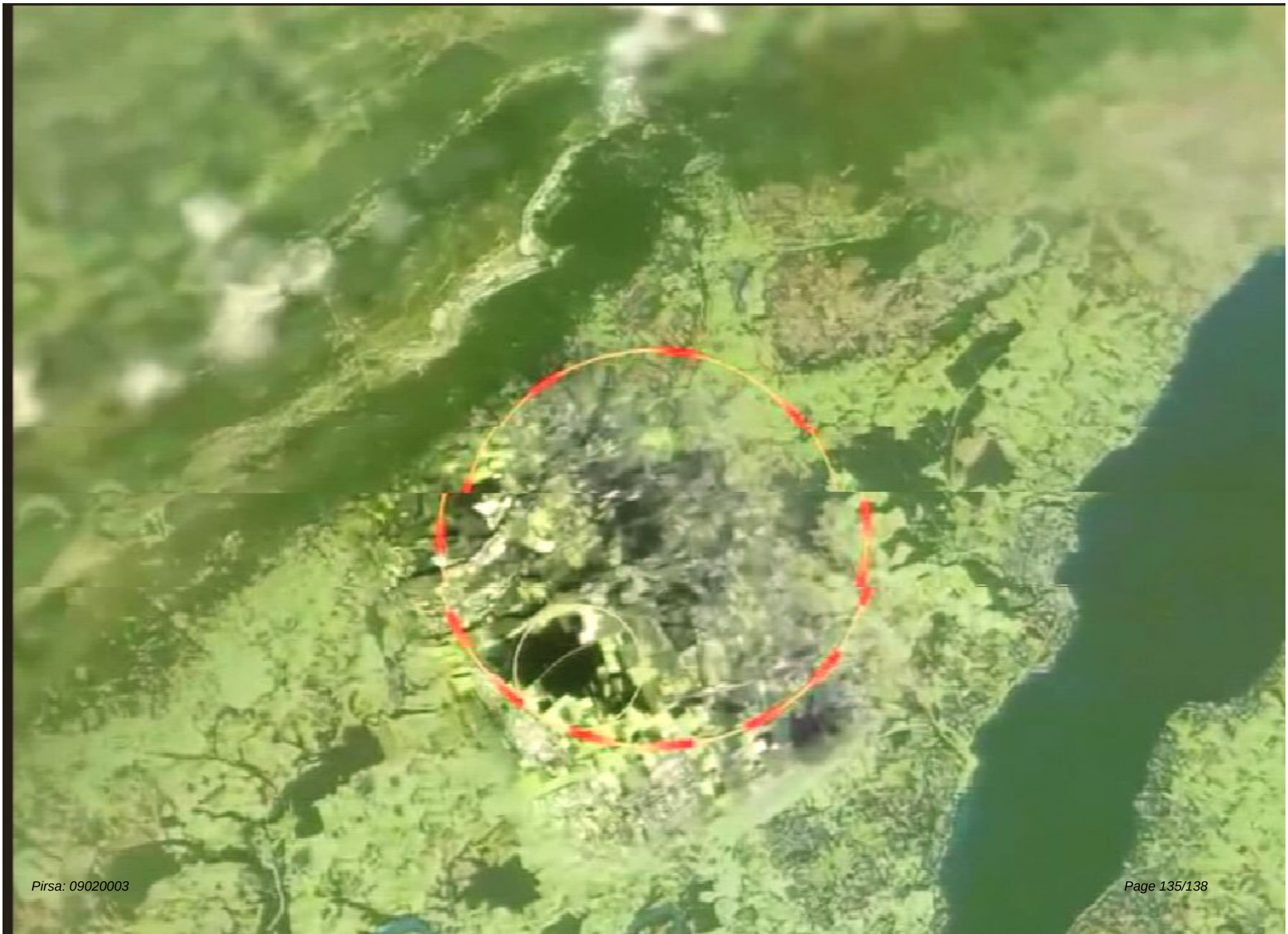

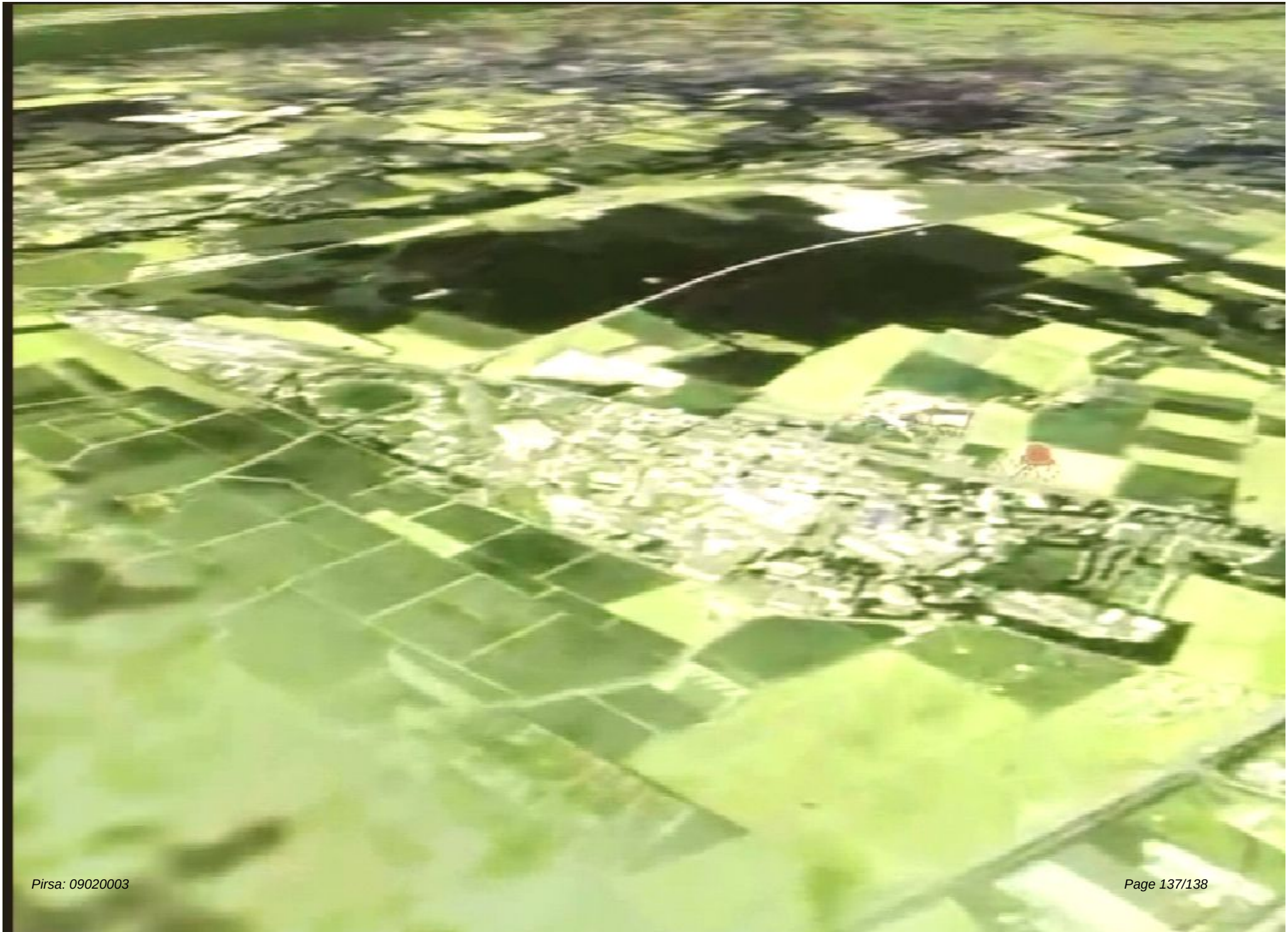


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