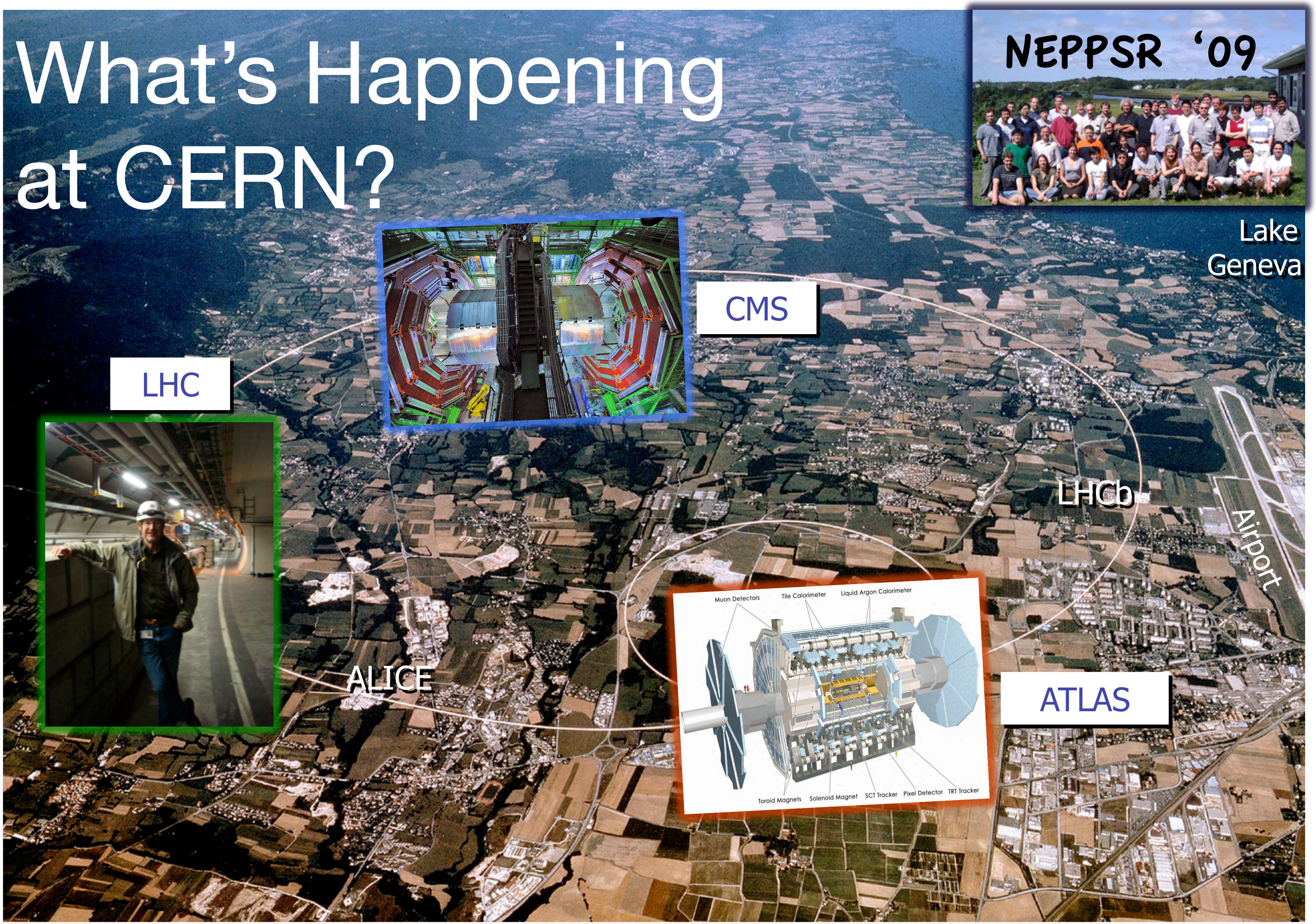
# What’s Happening at CERN?




George Brandenburg – Harvard/CERN – August 14, 2009

# Outline

- LHC problems, repairs, and plans…
- ATLAS and CMS preparations and readiness…
- Some fun publicity…
- A few thoughts…

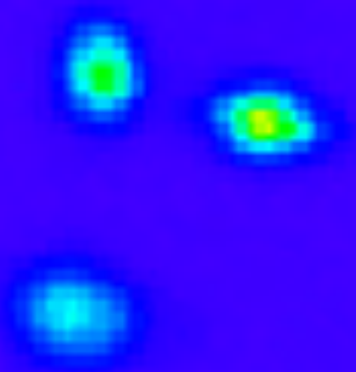
# The LHC Machine

Jörg Wenninger

CERN Beams Department

Operations group

Hadron Collider Summer School - June 2009



Video of talk available at:

http://cdsweb.cern.ch/record/1183849

# The price of high fields & high luminosity…

When the LHC is operated at 7 TeV with its design luminosity & intensity,

- the LHC magnets store a huge amount of energy in their magnetic fields:
  - per dipole magnet $E_{stored}$ = 7 MJ
  - all magnets $E_{stored}$ = 10.4 GJ
- the 2808 LHC bunches store a large amount of kinetic energy:
  - $E_{bunch} = N \times E = 1.15 \times 10^{11} \times 7$ TeV = 129 kJ
  - $E_{beam} = k \times E_{bunch} = 2808 \times E_{bunch}$ = 362 MJ

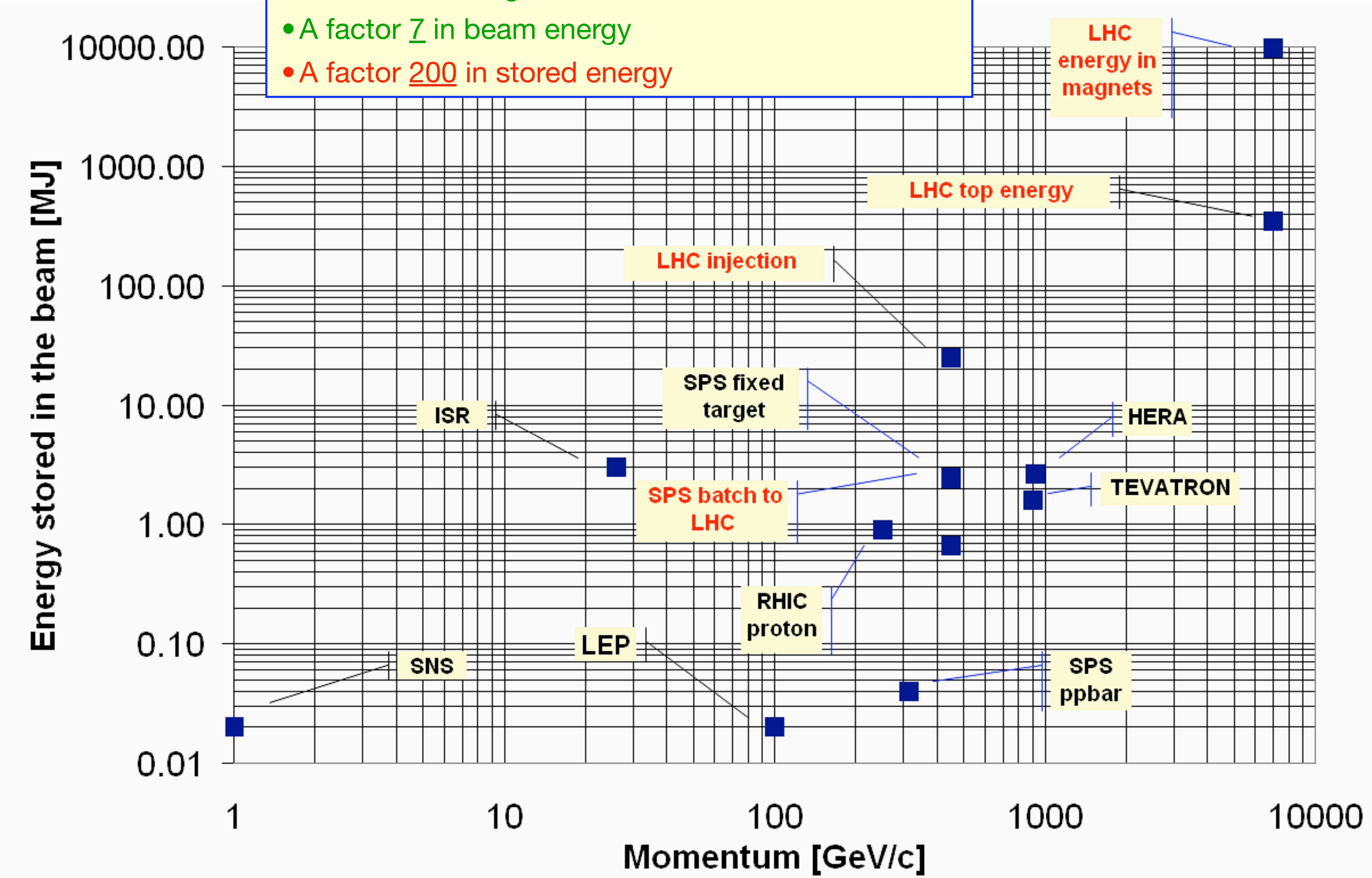
To ensure safe operation (i.e. without damage) we must be able to dispose of all that energy safely !

This is the role of Machine Protection !

# Stored Energy

Increase with respect to existing accelerators :

- A factor 2 in magnetic field
- A factor 7 in beam energy
- A factor 200 in stored energy



# Comparison…


The energy of an A380 at 700 km/hour corresponds to the energy stored in the LHC magnet system :

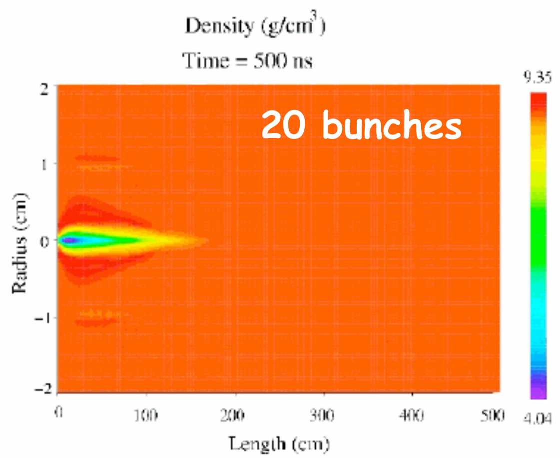
Sufficient to heat up and melt 15 tons of Copper!!

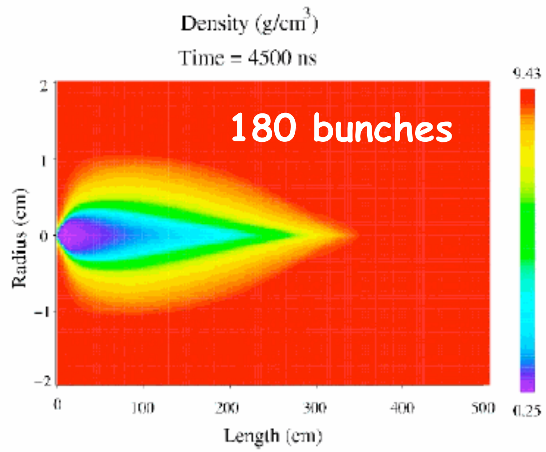
The energy stored in one LHC beam corresponds approximately to…

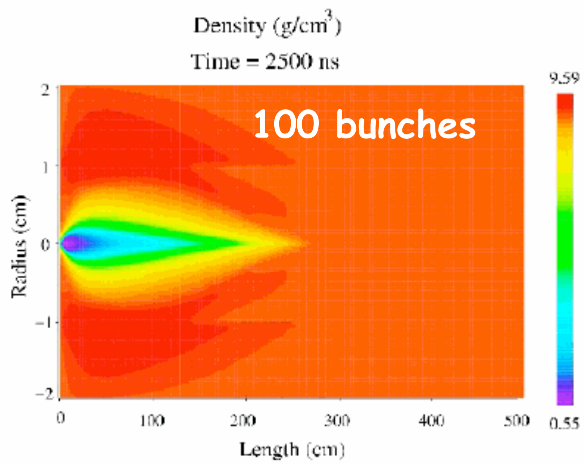
- 90 kg of TNT
- 10-12 litres of gasoline
- 15 kg of chocolate

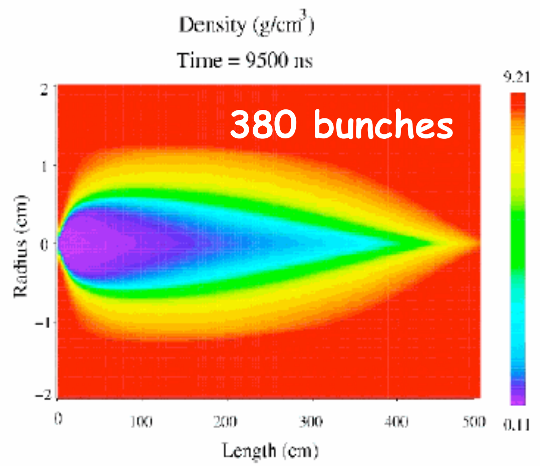
It's how easily the energy is released that matters most !!

# Beam impact in target : density



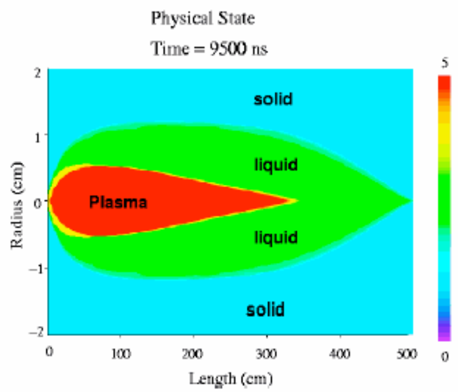



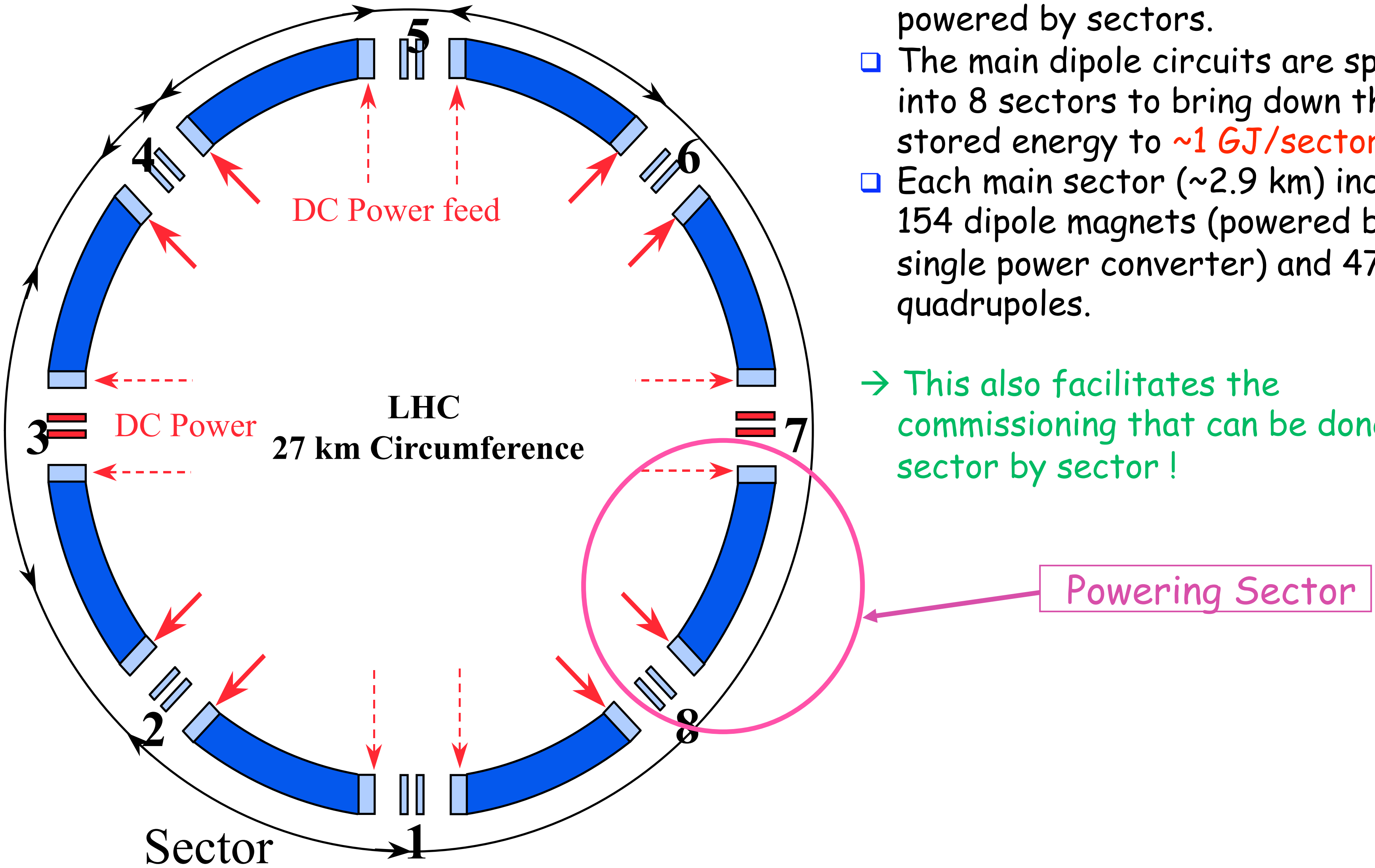




**The 7 TeV LHC beam is able to drill a hole through ~35 m of Copper (2808 bunches)**

## HEDP States



# LHC powering in sectors



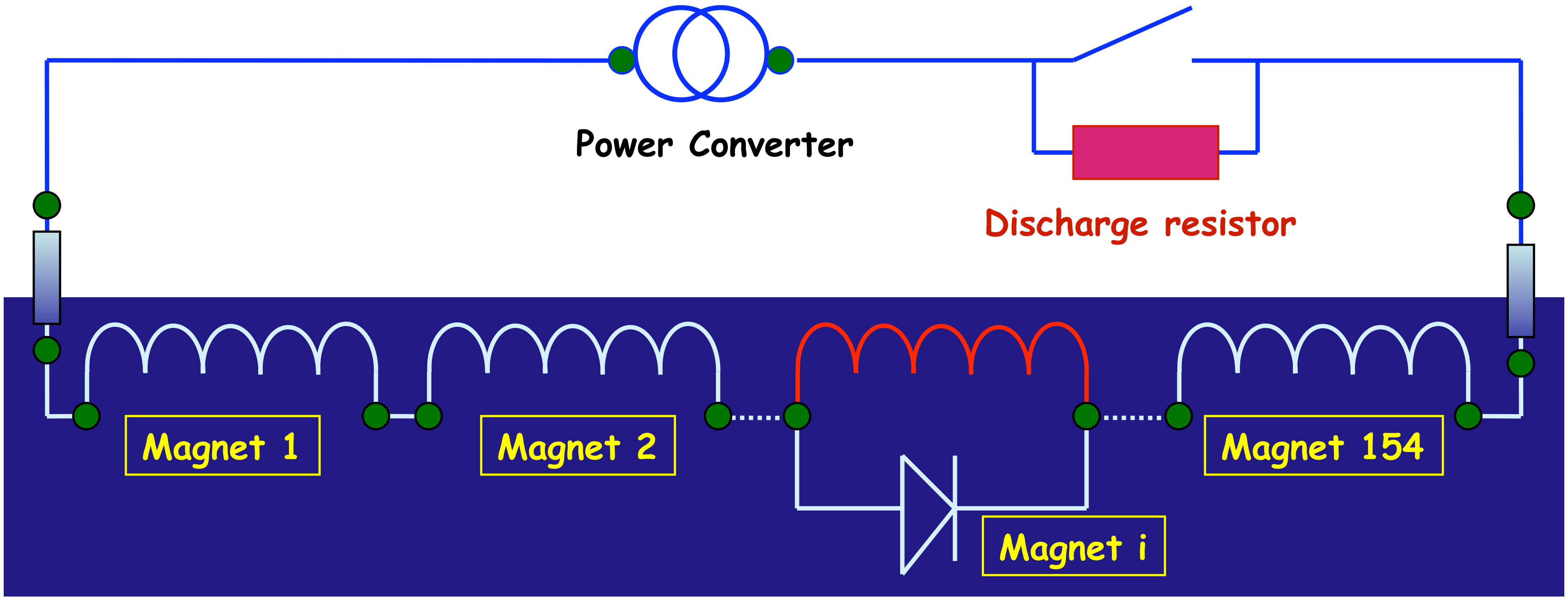

- To limit the stored energy within one electrical circuit, the LHC is powered by sectors.
- The main dipole circuits are split into 8 sectors to bring down the stored energy to ~1 GJ/sector.
- Each main sector (~2.9 km) includes 154 dipole magnets (powered by a single power converter) and 47 quadrupoles.

→ This also facilitates the commissioning that can be done sector by sector !

# Quench

- A quench is the phase transition from the super-conducting to a normal conducting state.
- Quenches are initiated by an energy in the order of few **milliJoules**
  - Movement of the superconductor by several μm (friction and heat).
  - Beam losses.
  - Cooling failures.
  - Imperfections.
  - ...
- When part of a magnet quenches, the conductor becomes resistive, which can lead to excessive local energy deposition. To protect the magnet:
  - The quench must be detected: a voltage appears over the coil ($R > 0$).
  - The energy release is distributed over the entire magnet by force-quenching the coils using quench heaters.
  - The magnet current has to be switched off within << 1 second.

# Quench - discharge of the energy

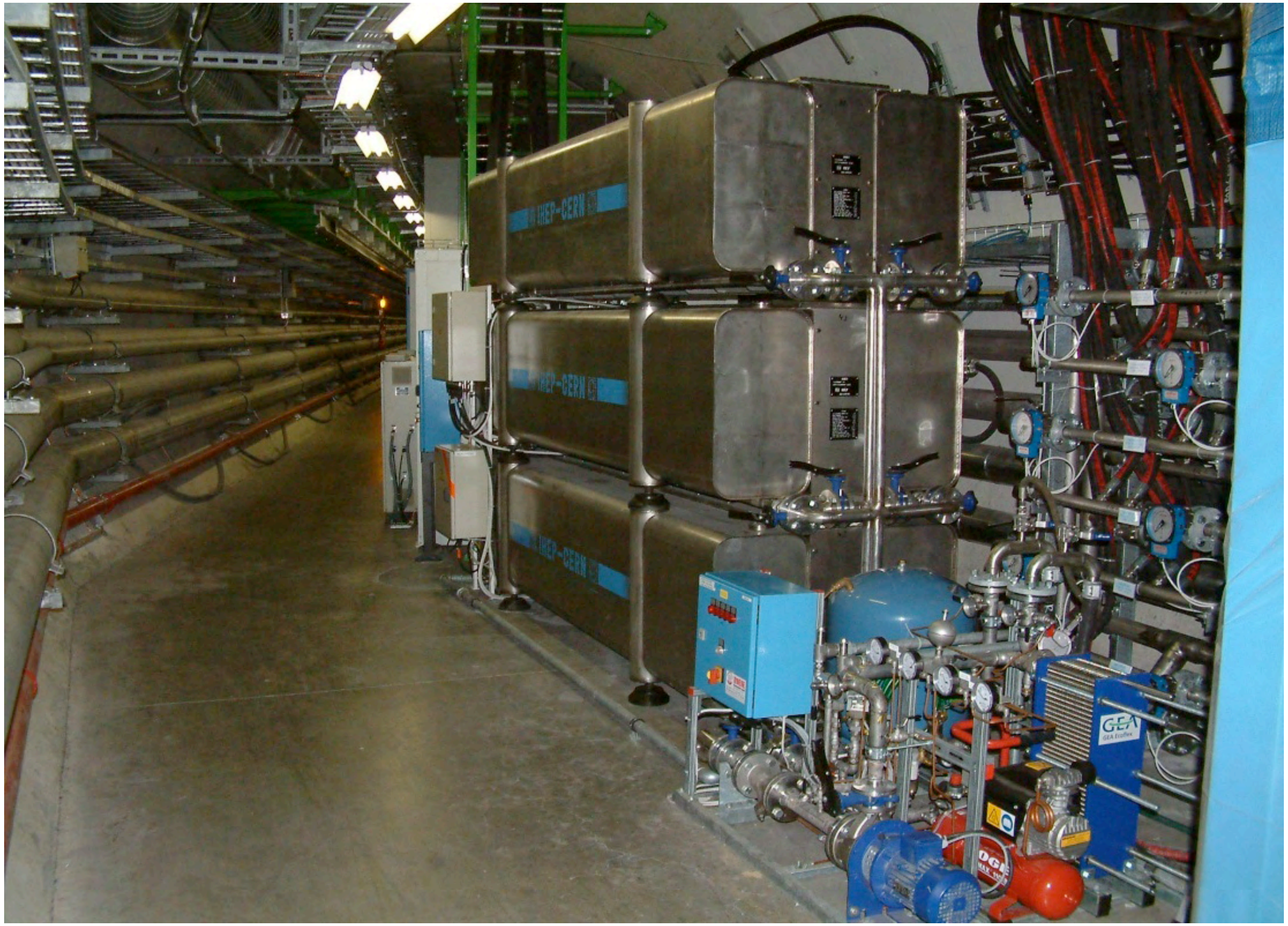



**Protection of the magnet after a quench:**

- The quench is detected by measuring the **voltage increase** over coil.
- The energy is distributed in the magnet by force-quenching using quench heaters.
- The current in the quenched magnet decays (in < 200 ms).
- The current flows through the bypass diode (triggered by the voltage increase over the magnet).
- The current of all other magnets is dischared into the dump resistors (minutes).

# Dump resistors

Those large air-cooled resistors can absorb the 1 GJ stored in the dipole magnets (they heat up to few hundred degrees Celsius).



# Event sequence on Sept. 19th

**Introduction:** on September 10th the LHC magnets had not been fully commissioned for 5 TeV.

*A few magnets were missing their last commissioning steps.*

*The last steps were to be finished the week after Sept. 10th.*

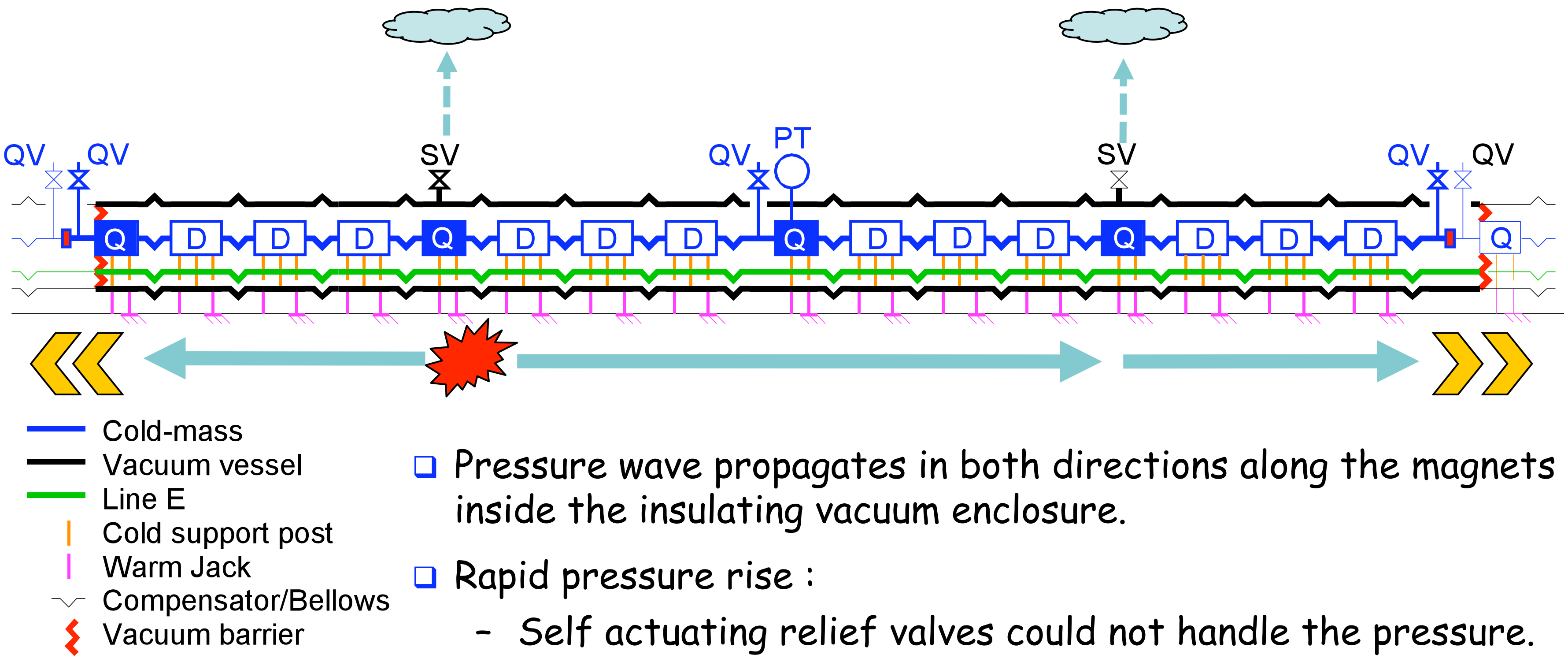
- Last commissioning step of the main dipole circuit in sector 34 : ramp to 9.3kA (5.5 TeV).
- At 8.7kA an electrical fault developed in the **dipole bus bar** (the bus bar is the cable carrying the current that connects all magnets of a circuit).
- An electrical arc developed which punctured the helium enclosure.

  *Secondary arcs developed along the arc.*

  *Around 400 MJ were dissipated in the cold-mass and in electrical arcs.*
- Large amounts of Helium were released into the insulating vacuum.

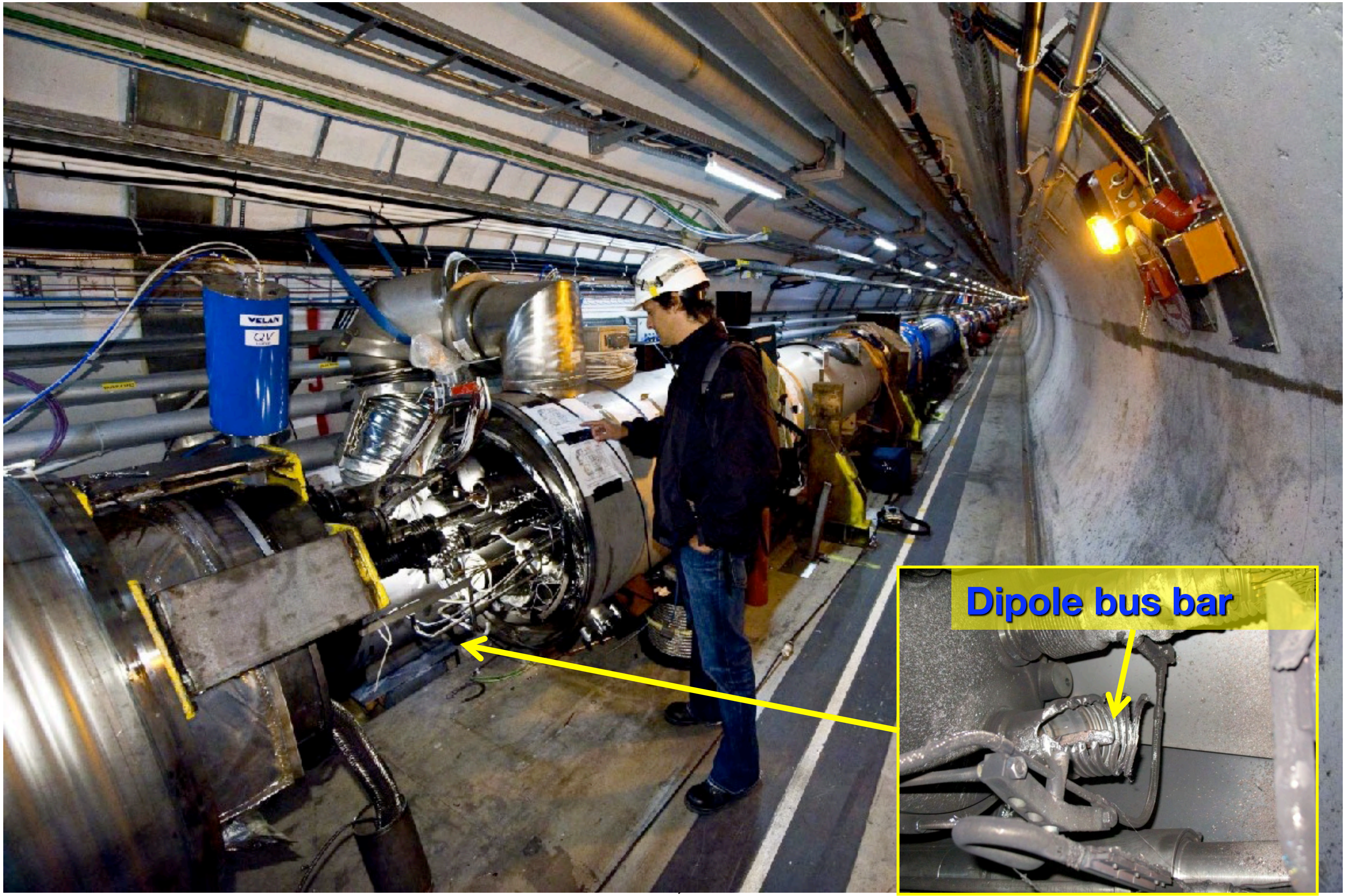
  *In total 6 tons of He were released.*

# Pressure wave

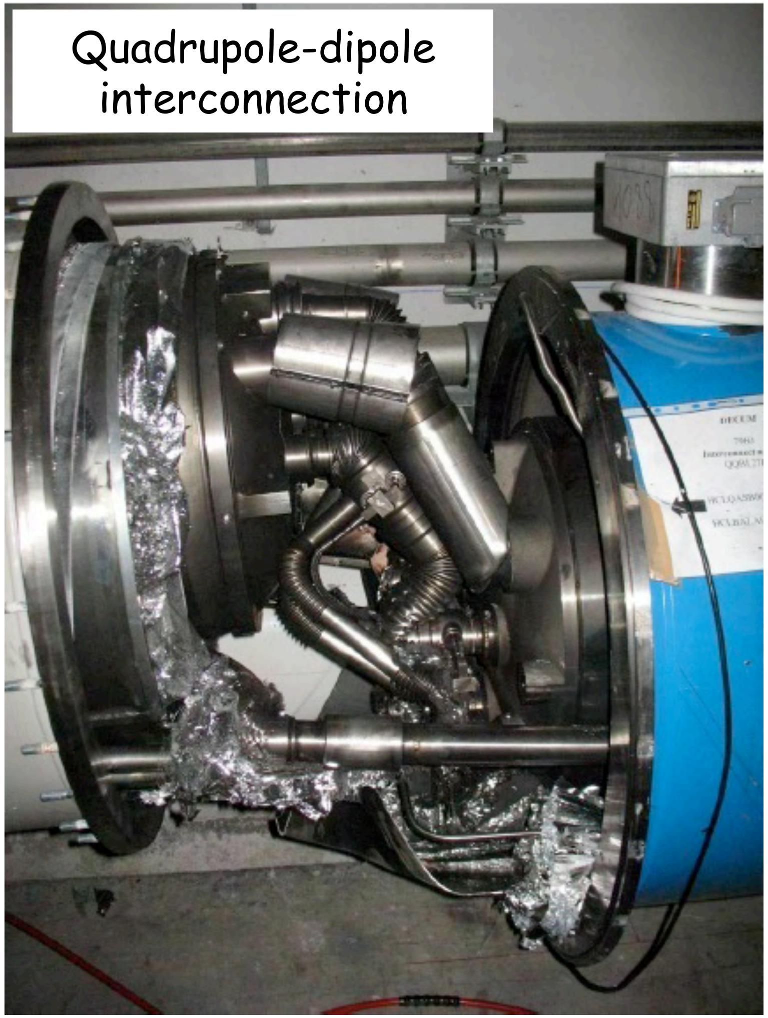


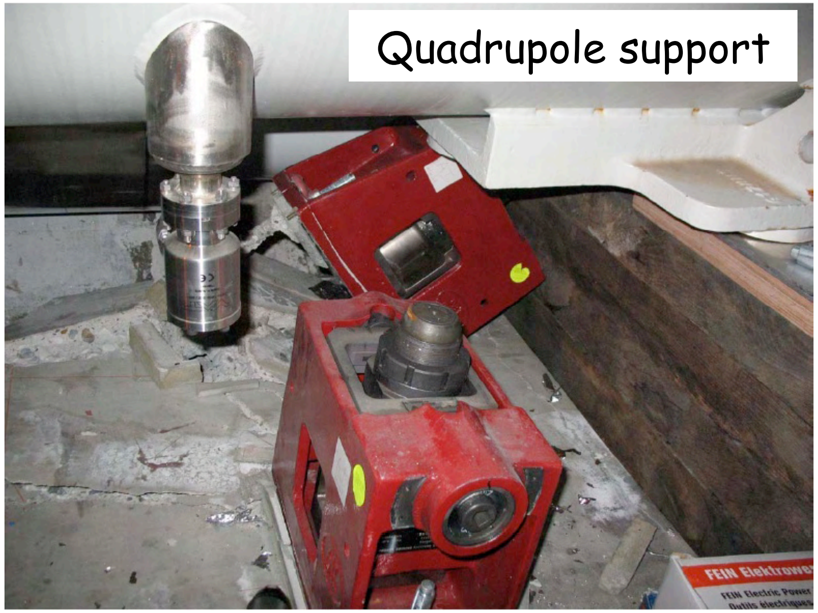

- Pressure wave propagates in both directions along the magnets inside the insulating vacuum enclosure.
- Rapid pressure rise :
  - Self actuating relief valves could not handle the pressure.
    *designed for 2 kg He/s, incident ~ 20 kg/s.*
  - Large forces exerted on the vacuum barriers (every 2 cells).
    *designed for a pressure of 1.5 bar, incident ~ 10 bar.*
  - Several quadrupoles displaced by up to ~50 cm.
  - Connections to the cryogenic line damaged in some places.
  - Beam vacuum to atmospheric pressure.

# Incident location



# Collateral damage : displacements



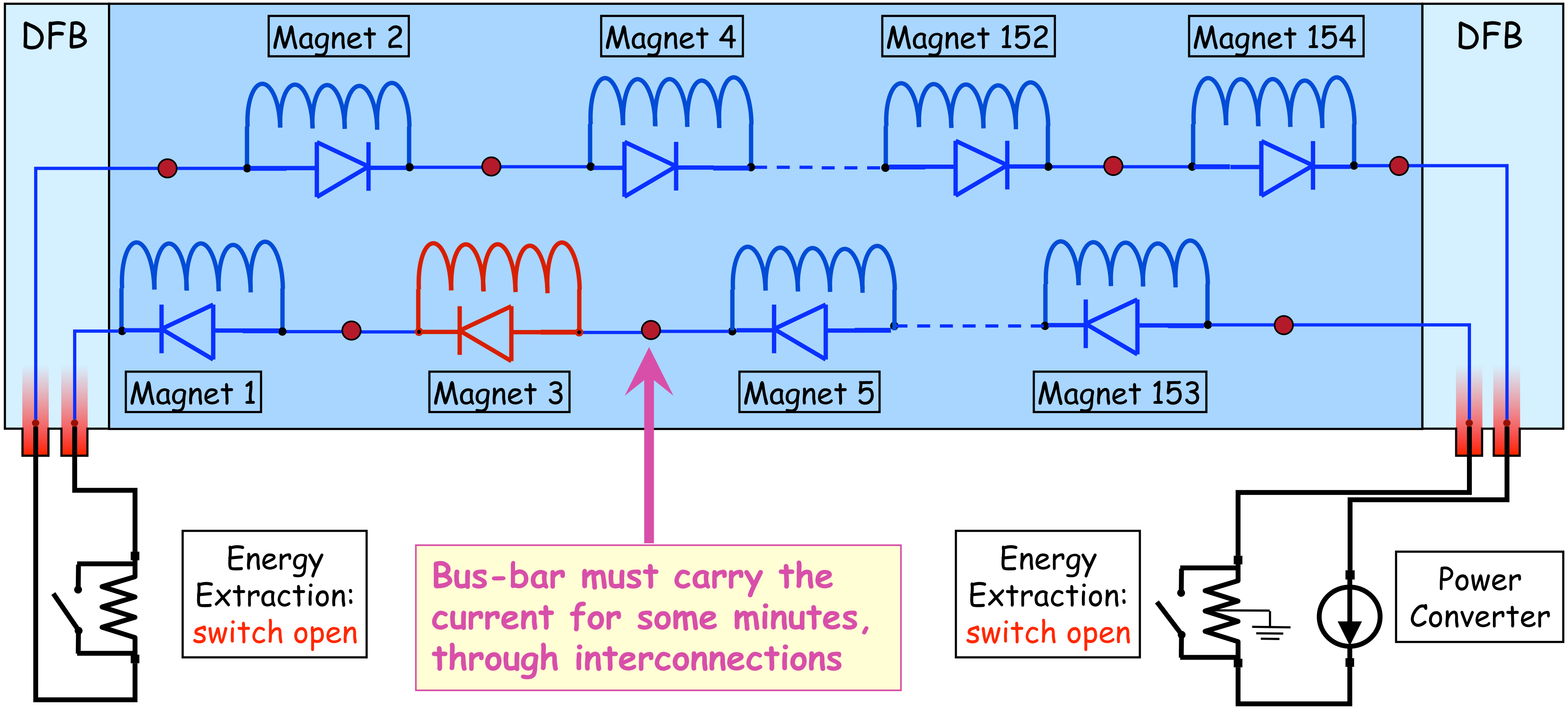




Main damage area ~ 700 metres.

- **39** out of 154 **dipoles**,
- **14** out of 47 **quadrupole** short straight sections

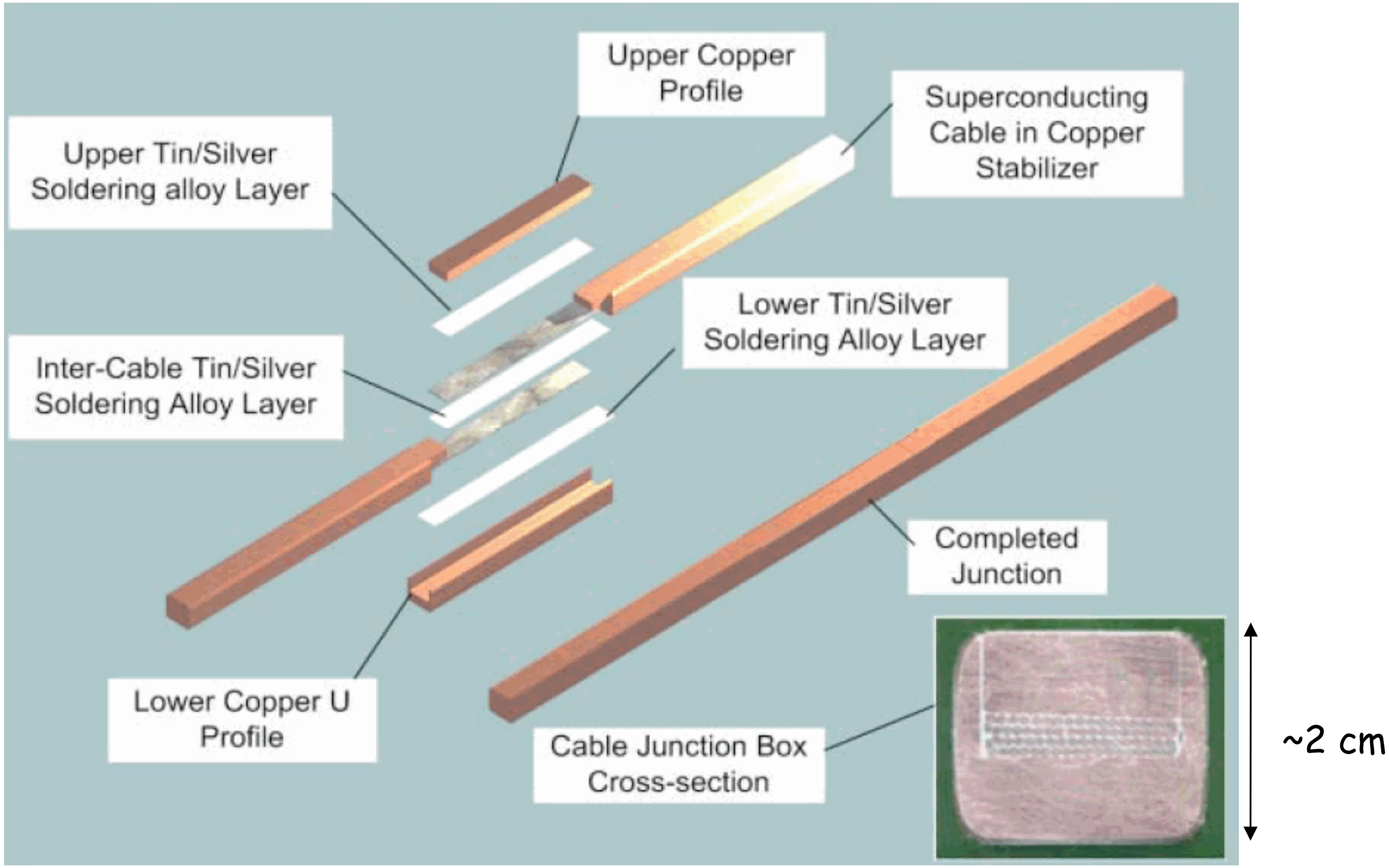
# Dipole magnet protection - again

- In case of a quench, the individual magnet is protected (quench protection and diode).
- Resistances are switched into the circuit: the energy is dissipated in the resistances (**current decay time constant of 100 s**).
  - >> the bus-bar must carry the current until the energy is extracted !

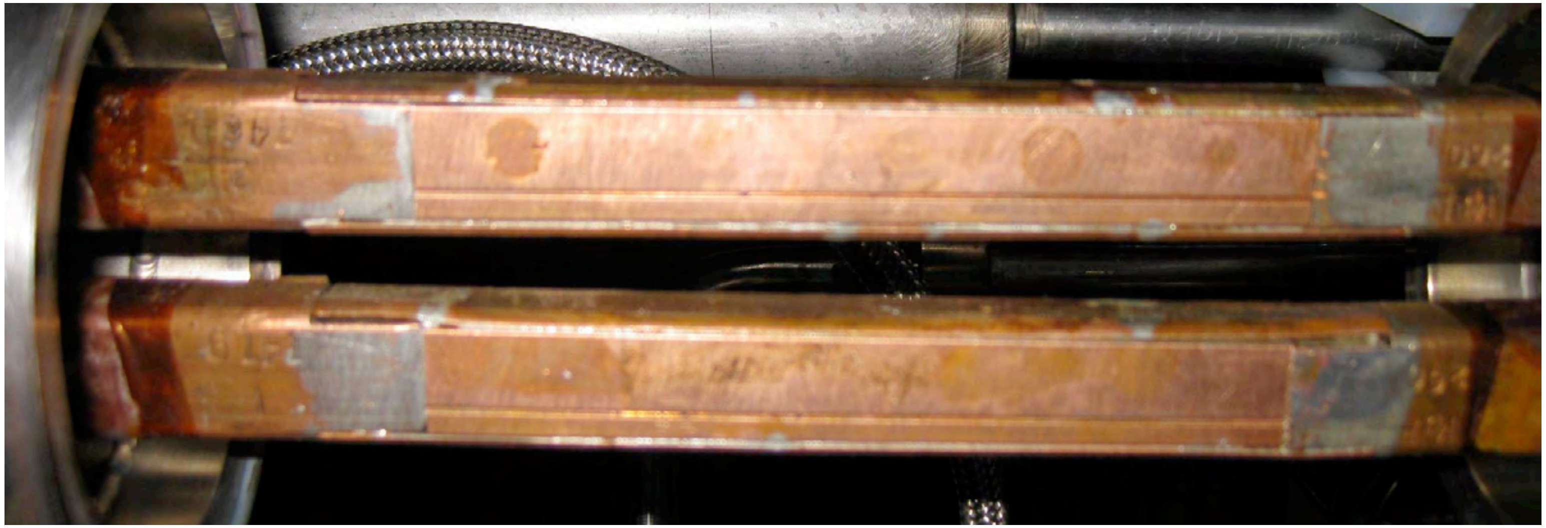


# Bus-bar joint (1)

- Superconducting cable embedded in Copper stabilizer.
- Bus bar joint is soldered (not clamped).
- Joint resistance ~0.35 nΩ (@ 1.9 K).
- Protection of the joint during quench relies on *good joint quality.*



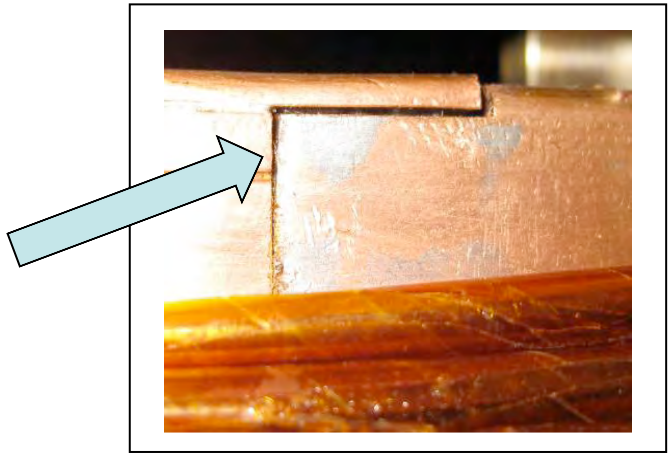
# Bus-bar joint (2)



- A post-mortem analysis of the data from the sector with the incident revealed the presence of a 200 nΩ anomalous resistance in the cell of the primary electrical arc. This acted as a heat source that quenched the superconducting cable.

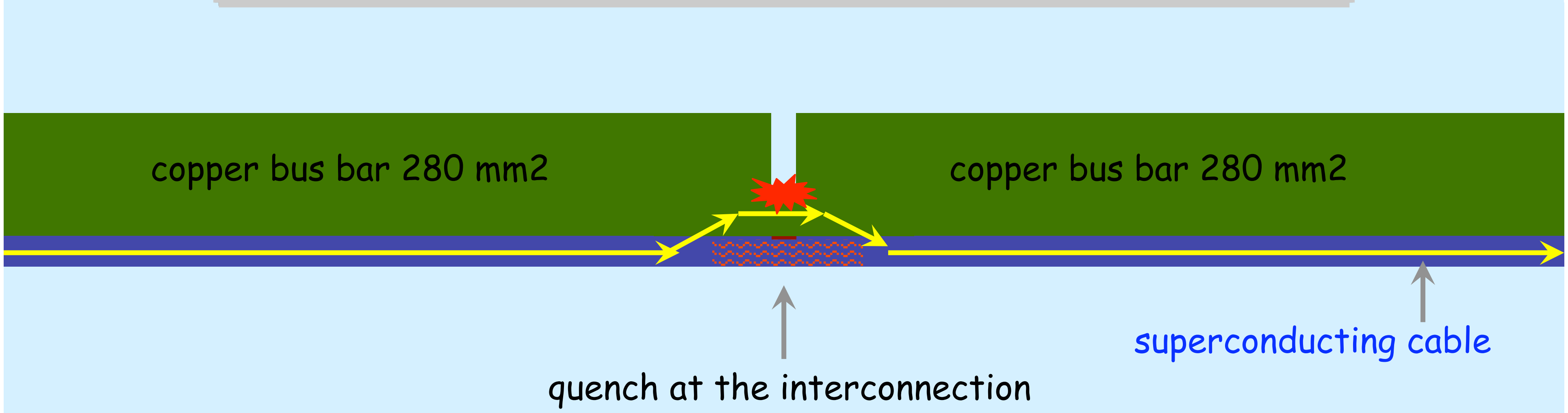
  >> Unfortunately the evidence is destroyed…

- An inspection of accessible joints revealed non-conformities like poor soldering and/or reduced electrical contact as in the example to the right.



# September 19th hypothesis

- Anomalous resistance at the joint heats up and finally quenches the joint – but quench remains very local.
- Current sidesteps into Copper that eventually melts because the electrical contact is not good enough.

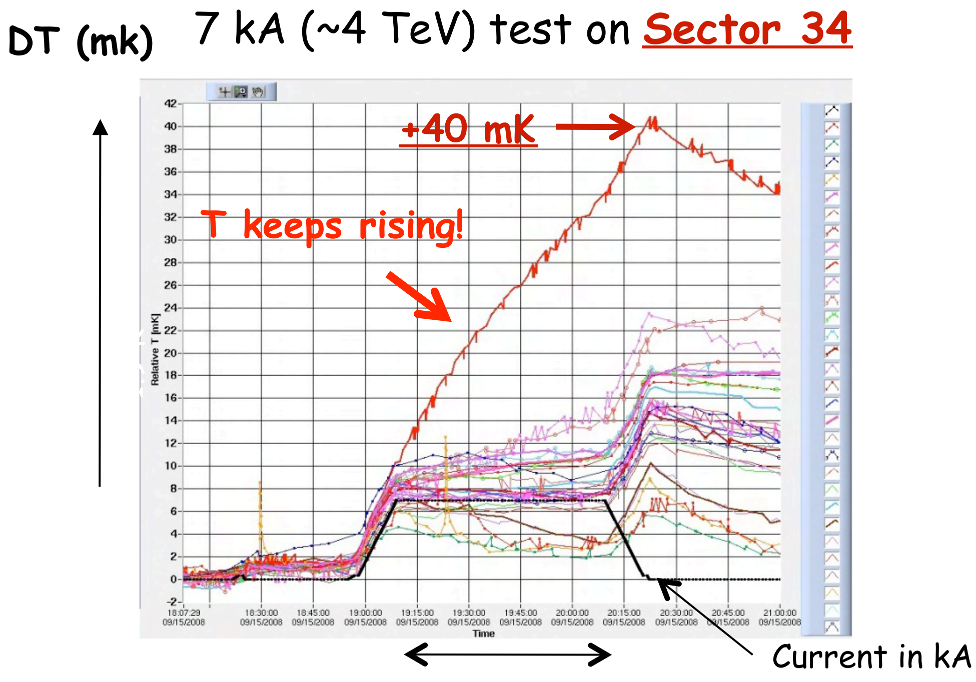



>> A new protection system will be installed this year to anticipate such incidents in the future.

# Identification of bad joints @ 1.9 K: temperature…

- Under controlled conditions, it is possible to localize anomalous heat sources down to ~ 40 nΩ from the temperatures.

  >> Will now be done systematically during commissioning and operation.




Powering test performed a few days before the incident on sector34. Early warning sign, but only discovered after the event.

# Repair and consolidation

- 39 dipoles and 14 quadrupoles short straight sections (SSS) brought to surface for repair or replacement.

  *All magnets are back in the tunnel. Interconnection work ongoing.*

- The vacuum chambers are cleaned in situ.

- Major upgrade of the quench protection system.

  - *Protection of all main quadrupole and dipole joints.*
  - *High statistics measurement accuracy to < 1 nΩ.*

  *>> protection against sector34-type incidents in the future.*

- Reinforcement of the quadrupole supports.

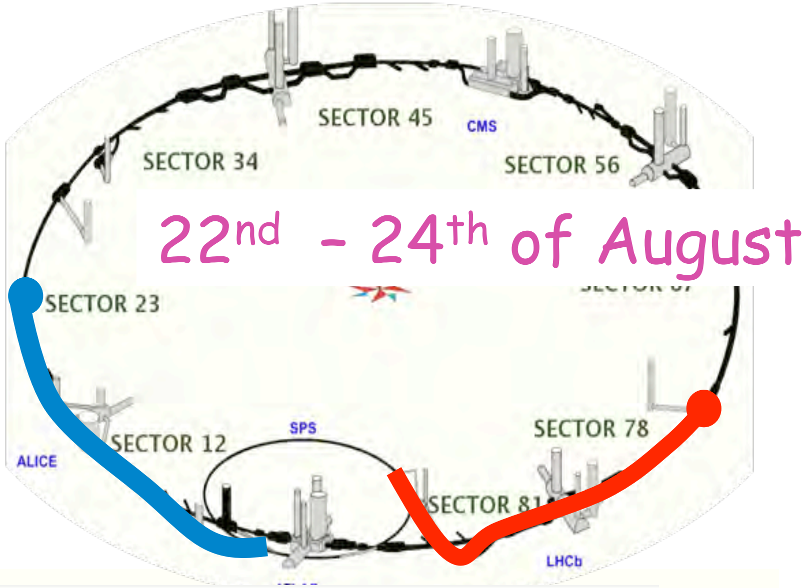
- Improved pressure relief valves for all dipole cryostats
  - Completed for all warm sectors
  - Cold sectors will be done later

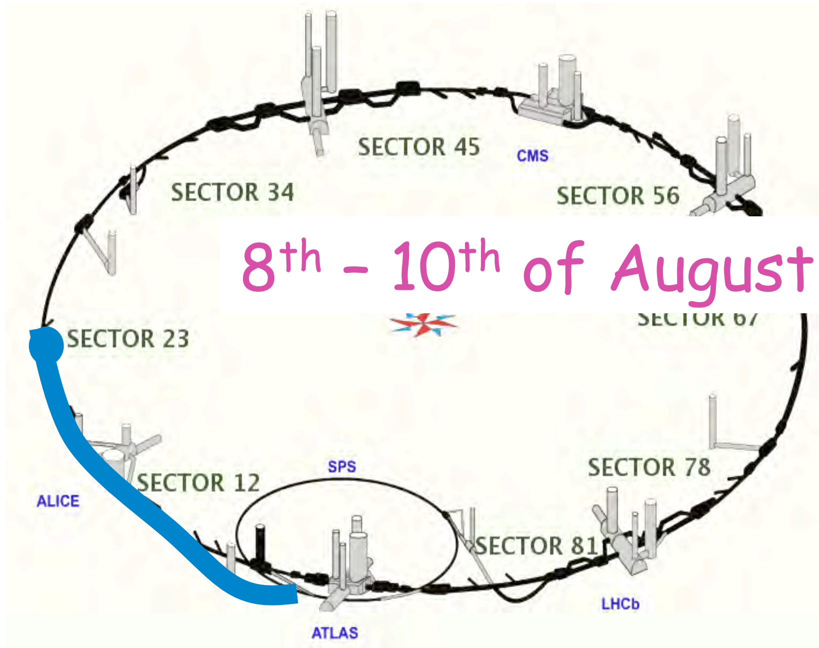
# Injection tests

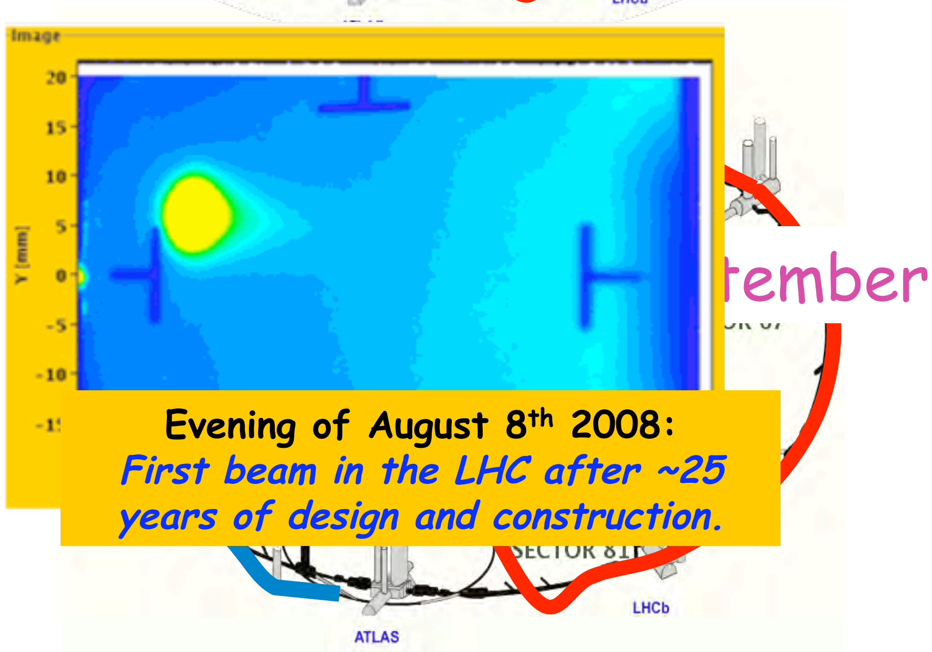
## August – September 2008:

- Injection tests of up to 4 adjacent sectors.
- Essential checks for all accelerator systems and software.
- Ended prematurely – power supply failure

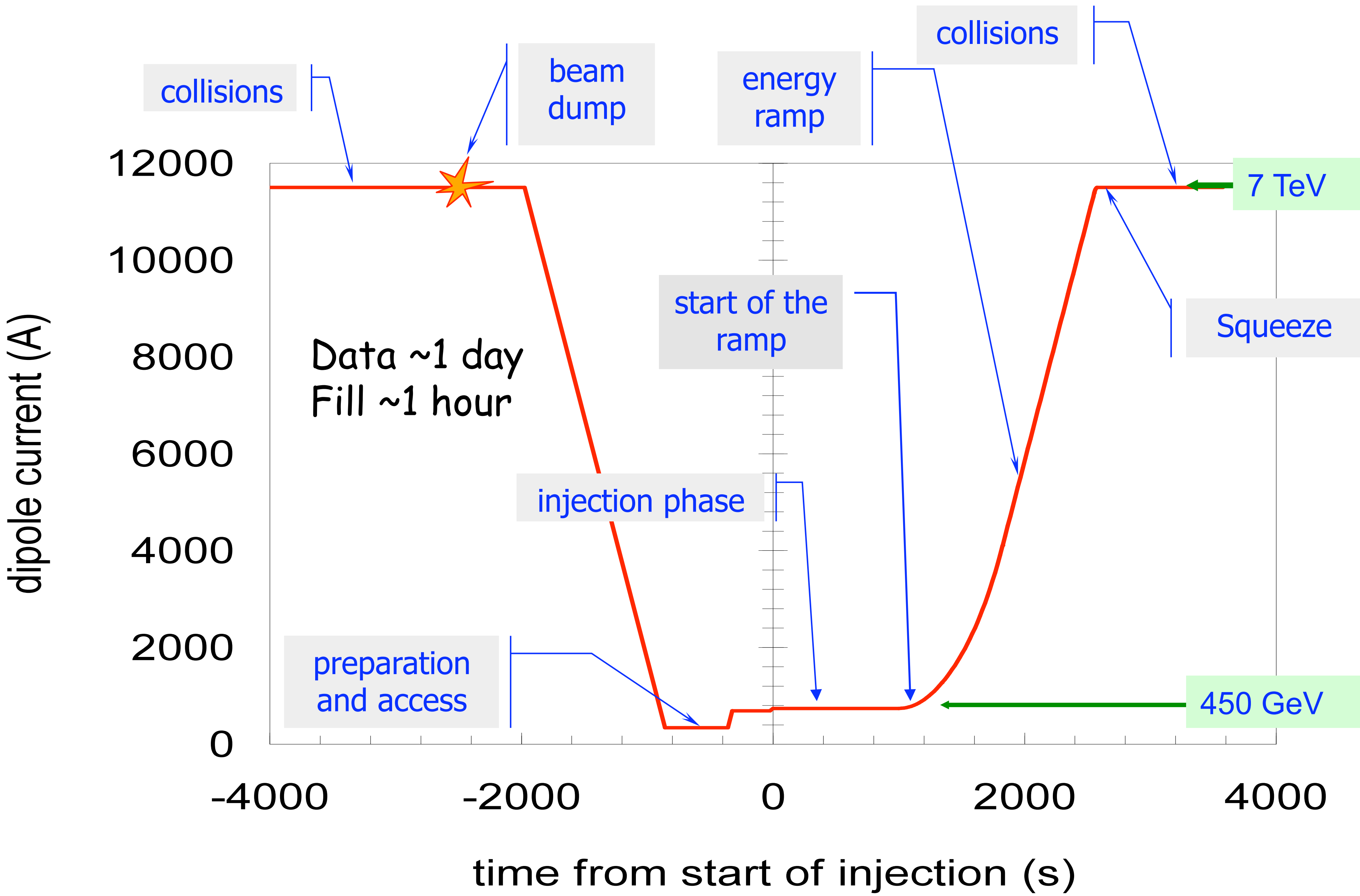
**>> Similar test will take place in Sept. 2009**



# The LHC machine cycle



# Some Dates…

- Tests of the transfer lines SPS-LHC:

  June-August (3 weekends)

- Injection tests into parts of the LHC:

  ~September (-> November*)

- First circulating beam and collisions at injection energy:

  ~October (-> early December?*)

- First collisions at a few TeV: *(Very low luminosity… )*

  ~November (-> before holidays?*)

*Partial warm up of sectors 23 and 81 to repair vac leaks (reported 20 July)

… then run for all of 2010 (followed by shutdown).

# Luminosity targets

- The presently installed collimation system limits the total intensity to ≈10-20% of the nominal intensity.

- Possible performance for the 2009/2010 run (5+5 TeV):

| No. bunches/ beam | Protons/ bunch | % of nominal intensity | Peak L ($cm^{-2}$ $s^{-1}$) |
|---|---|---|---|
| 43 | $5\times10^{10}$ | 0.7 | $6.9\times10^{30}$ |
| 156 | $5\times10^{10}$ | 2.4 | $5.0\times10^{31}$ |
| 156 | $1\times10^{11}$ | 4.8 | $2.0\times10^{32}$ |
| 720 (50 ns) | $5\times10^{10}$ | 11.1 | $1.2\times10^{32}$ |
| 2808 (full) | $1.15\times10^{11}$ | 100 | $1.0\times10^{34}$ |

Useful trivia:
$10^{30}$ $cm^{-2}$/sec
= 30 $pb^{-1}$/yr

Int. luminosity target of 200-300 pb-1 is achievable with ~40% availability.

- Latest news (Aug 6): 2010 running will be at 3.5+3.5 TeV to be safe

- Long shutdown (2011) necessary to train magnets for 7+7 TeV

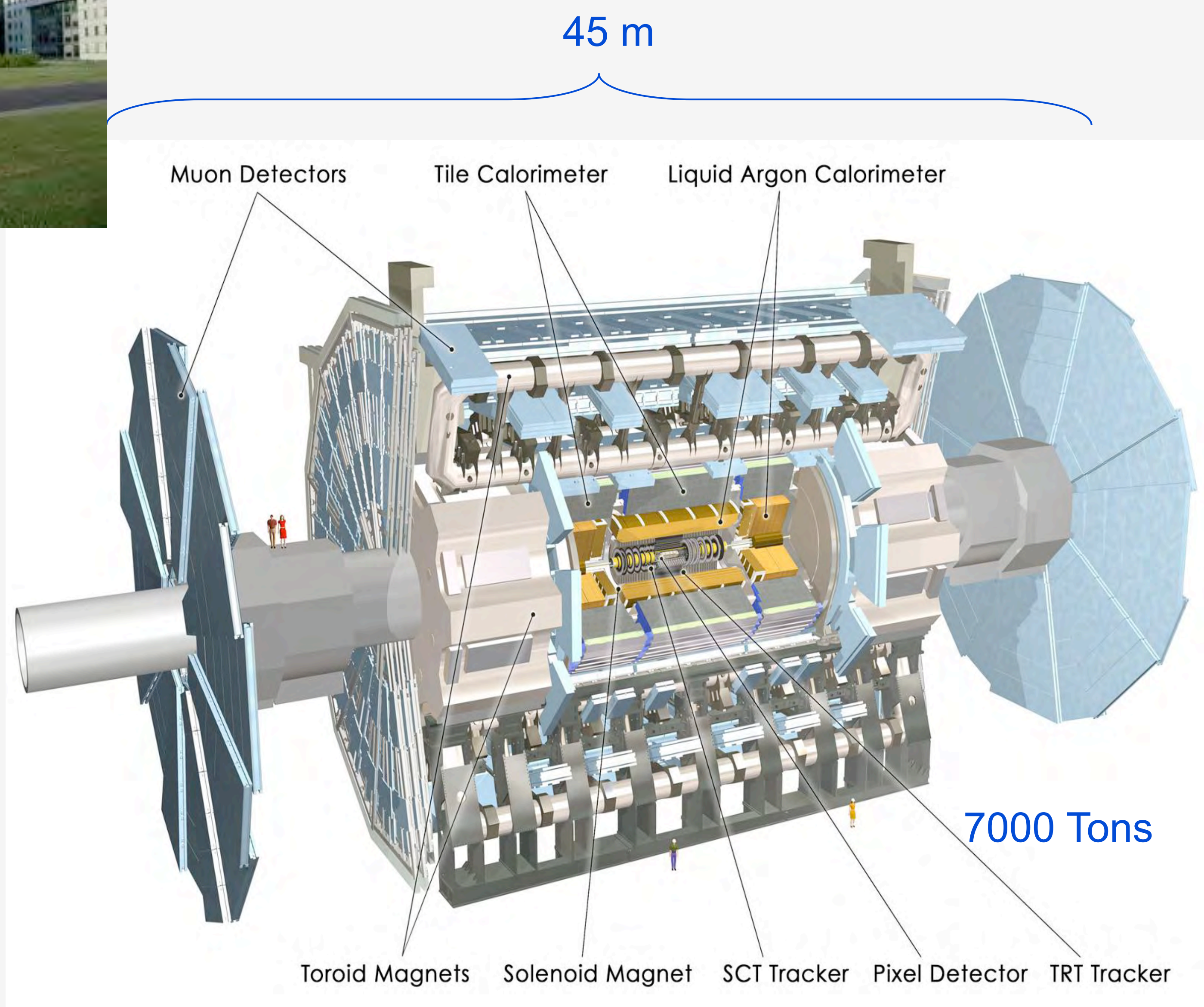
# LHC cool-down status

(http://lhc.web.cern.ch/lhc)


- Cold and ready: sectors 12, 56, 78
- Repaired and cooling down: sectors 34, 45, 67
- Partial warm up for vacuum leak repair: sectors 23, 81

# ATLAS Detector

ATLAS superimposed to the 5 floors of building 40 at CERN




Kerstin Jon-And talk at LepPho - Hamburg August 2009

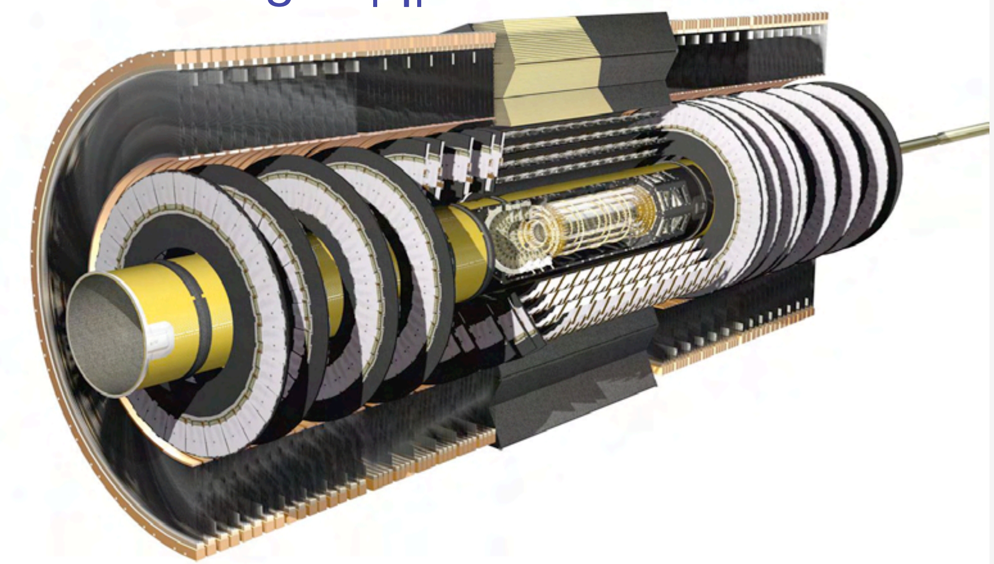
# ATLAS Collaboration

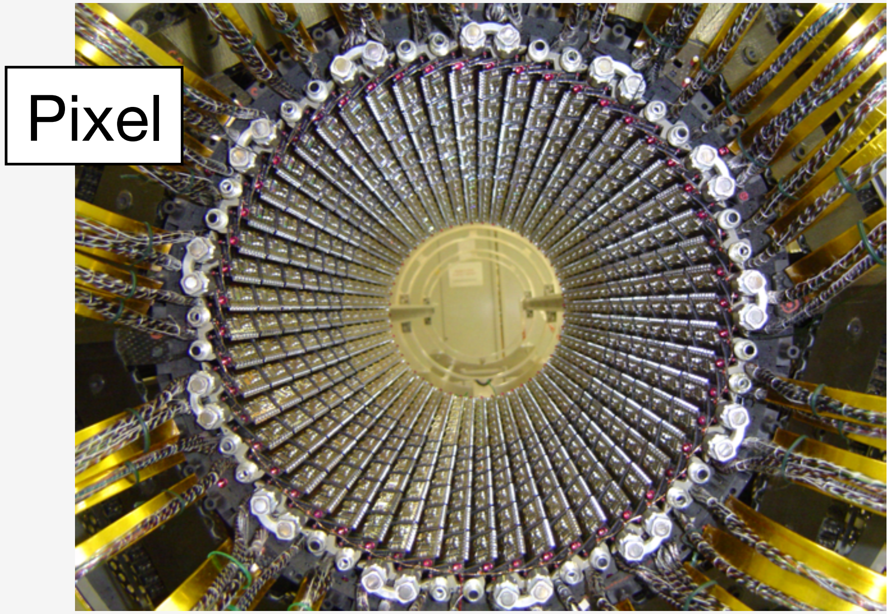
37 Countries
169 Institutions
~2800 Scientific Authors total
(~800 PhD students)

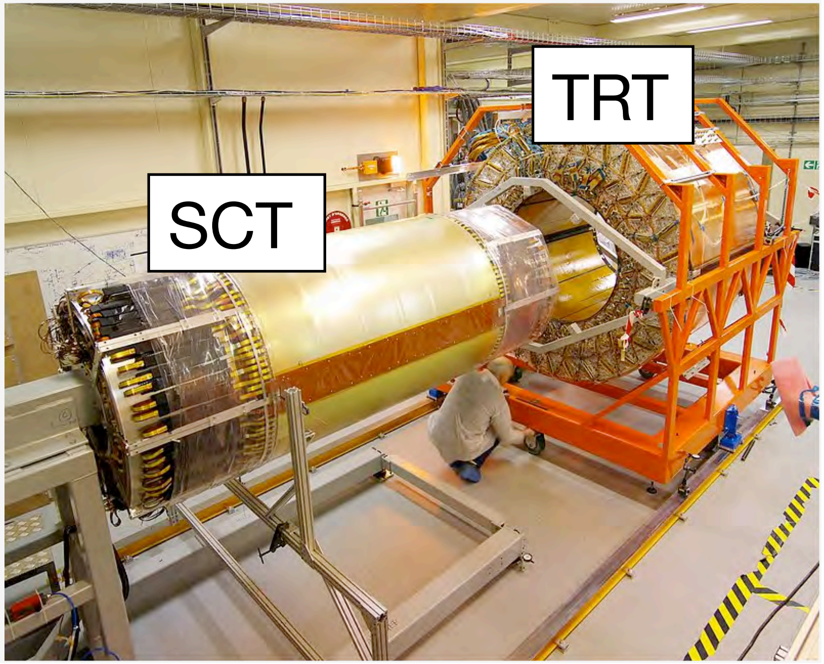

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, 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, 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

# Inner Detector

Tracking $|\eta|<2.5$ B=2T



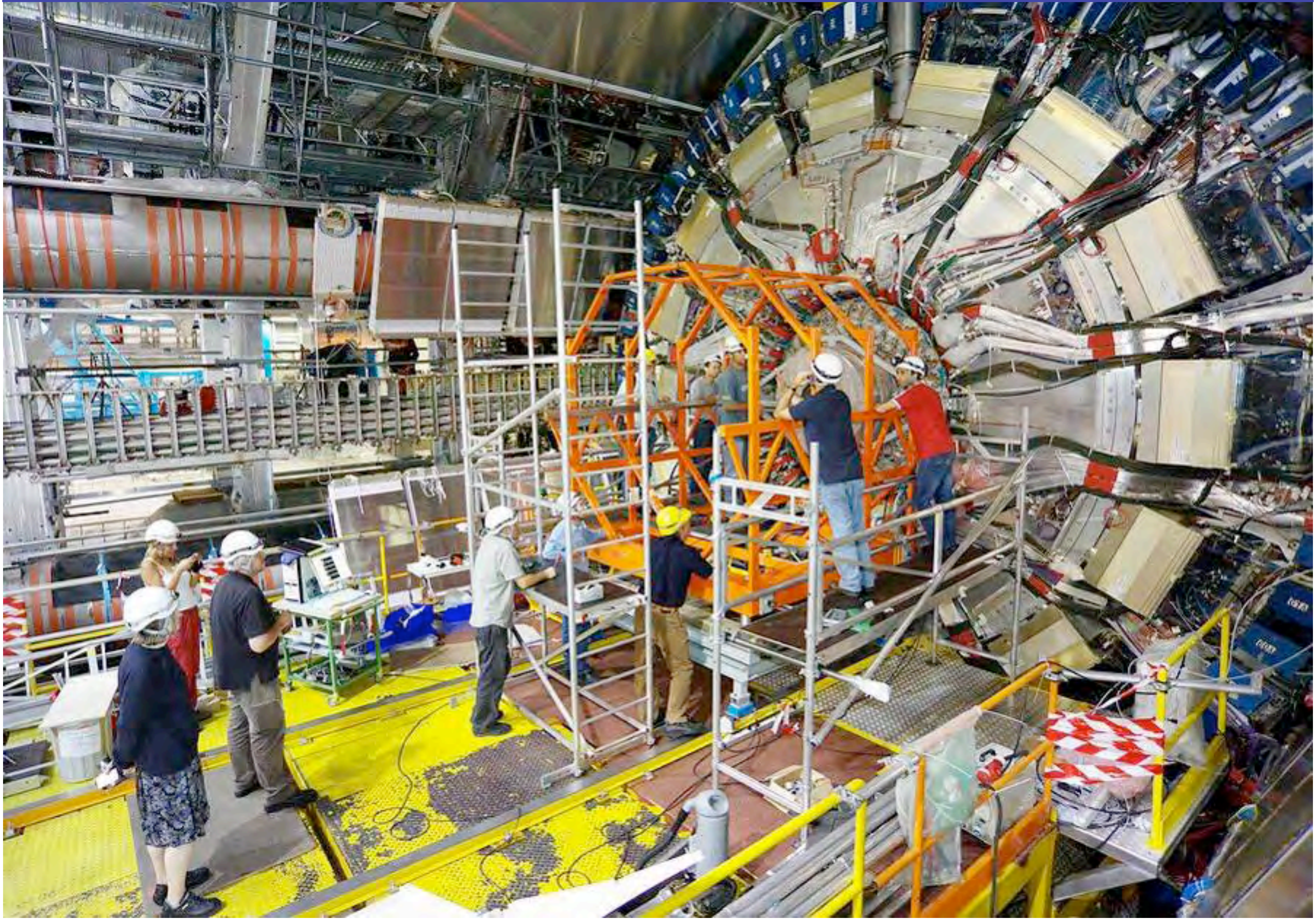


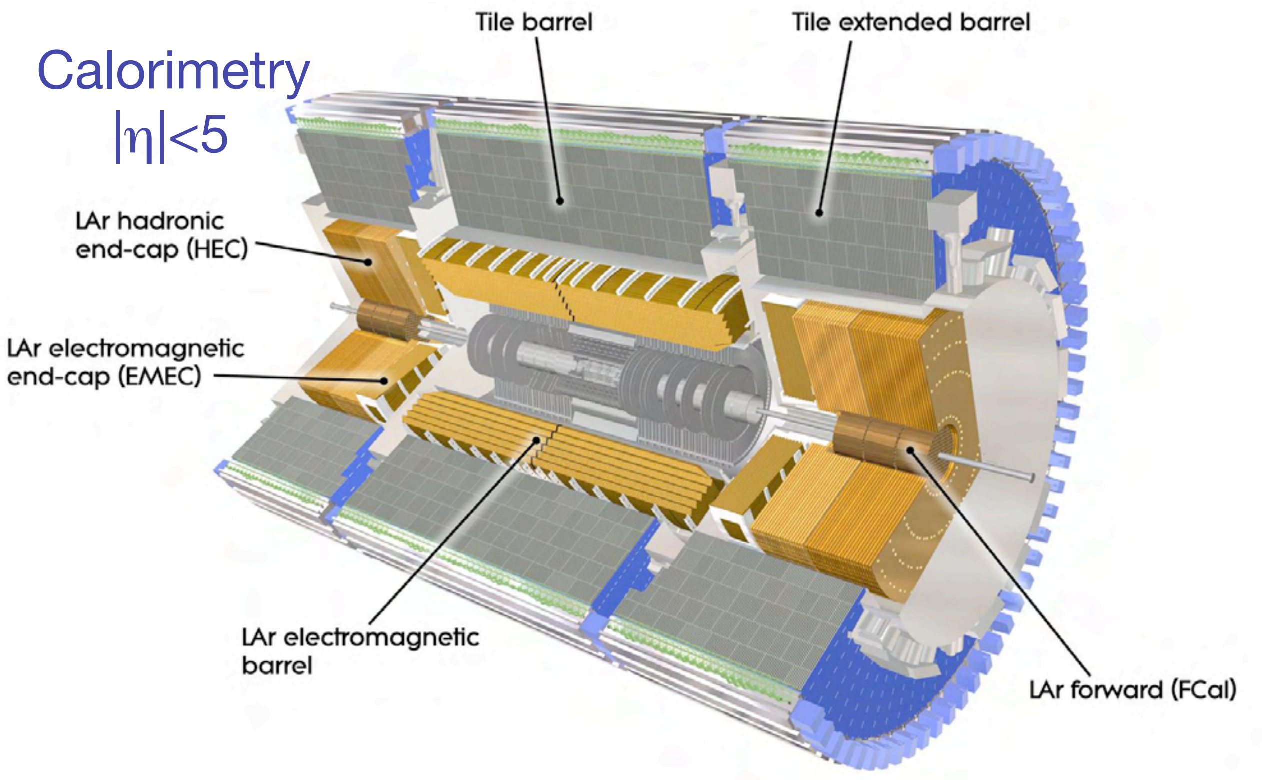

Silicon pixels **(Pixel)** : 0.8 $10^8$ channels
Silicon strips **(SCT)** : 6 $10^6$ channels
Transition Radiation Tracker **(TRT)** :
straw tubes (Xe), 4 $10^5$ channels
$e/\pi$ separation

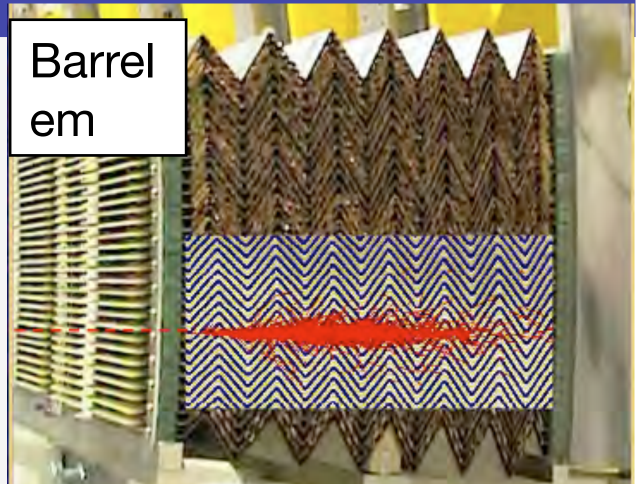
**Momentum resolution:**
**$\sigma/p_T \sim 3.8 \times 10^{-4}\, p_T\,(\mathrm{GeV}) \oplus 0.015$**

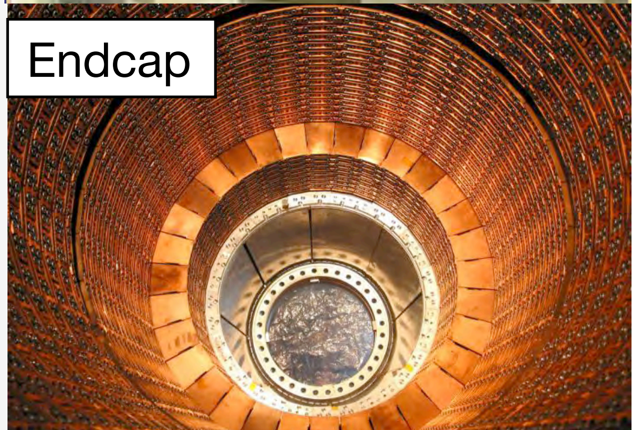
# Installation of the ATLAS barrel tracker (Aug 2006)



# Calorimetry





**Electromagnetic Calorimeter**

Barrel, Endcap: Pb-LAr

**~10%/√E energy resolution e/γ**

170000 channels: longitudinal segmentation

**Hadron Calorimeter**

Barrel Iron-Tile, EC/Fwd Cu/W-LAr (~19000 channels)

**$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$ pion (10 λ)**

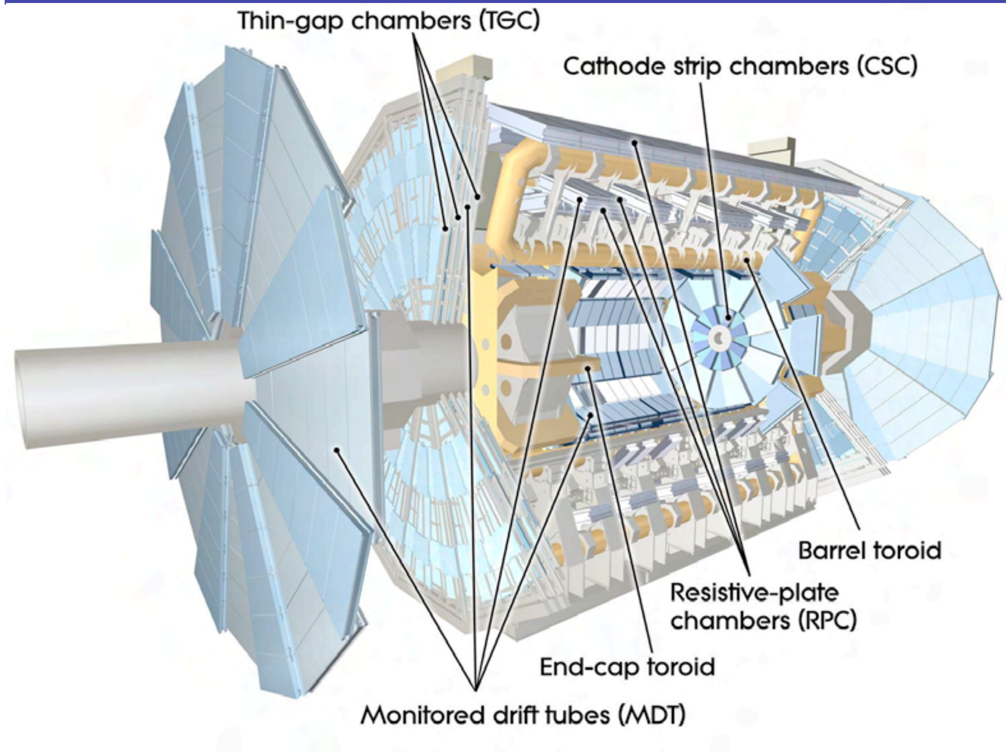
**Trigger and measurements for e/γ, jets, Missing $E_T$**

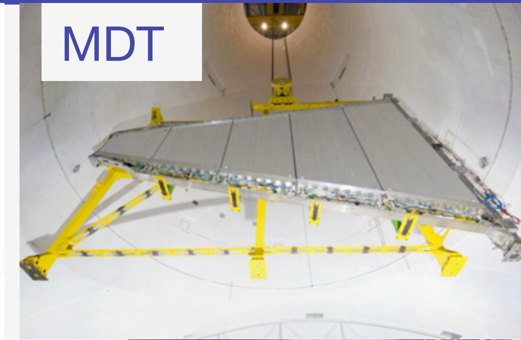
# Barrel calorimeter (EM Pb/LAr + Hadron Fe/scintillator) in its final position at Z=0


November 2005

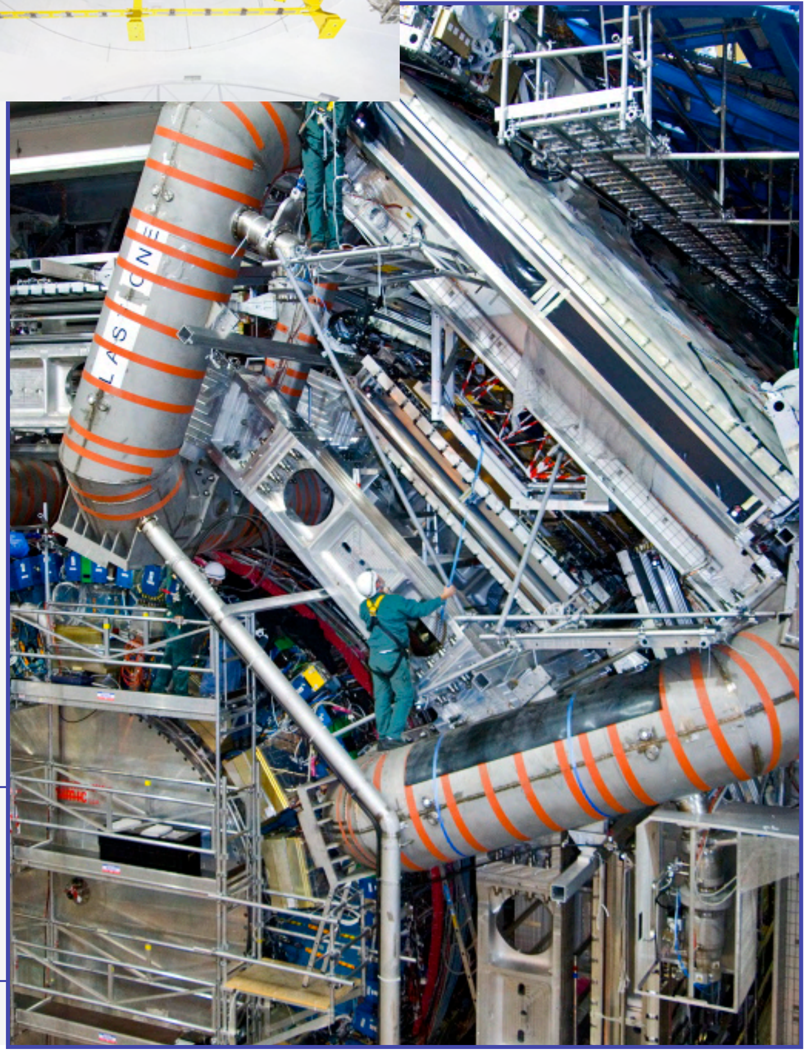

October 2004

# Muon System




Barrel chambers



Stand-alone momentum resolution
$\Delta pt/pt < 10\%$ up to $E_{\mu} \sim 1$ TeV

2-6 Tm $|\eta|<1.3$ 4-8 Tm $1.6<|\eta|<2.7$

**Barrel: ~**700 **MDT** (Monitored Drift Tubes) precision chambers for track reconstruction, ~ 600 **RPC** (Resitive Plate Chambers) for trigger

# Forward Muon Spectrometer

**Big wheels** (and end-wall wheels):
400 **MDT** precision chambers and
3600 **TGC** (Thin Gap Chambers)
trigger chambers

**Small wheels:** 80 **MDT** chambers
and 32 **CSC** (Cathode Strip
Chambers) precision chambers

February 2008

September 2007

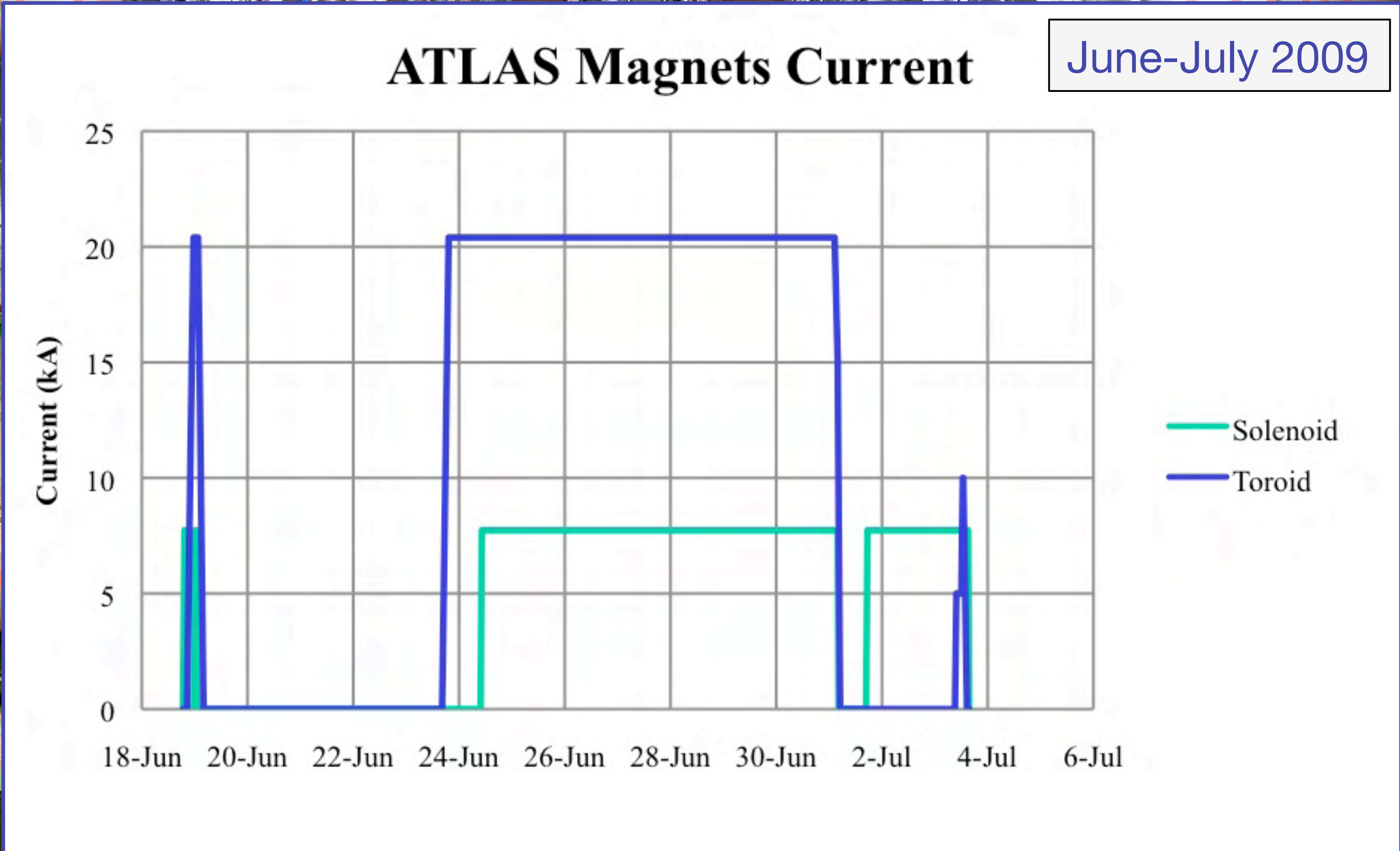
# Small Wheel Arrival

(a Boston area ATLAS production)

ATLAS cavern (-100 m) in June 2003

October 2005: full barrel toroid is in place
8 superconducting coils, 25 m long, 100 ton each, I=20 kA, T=4.5 K

**Since August 2008, the full magnet system (barrel toroid, end-cap toroids and central solenoid) has been operated at full current for long periods**



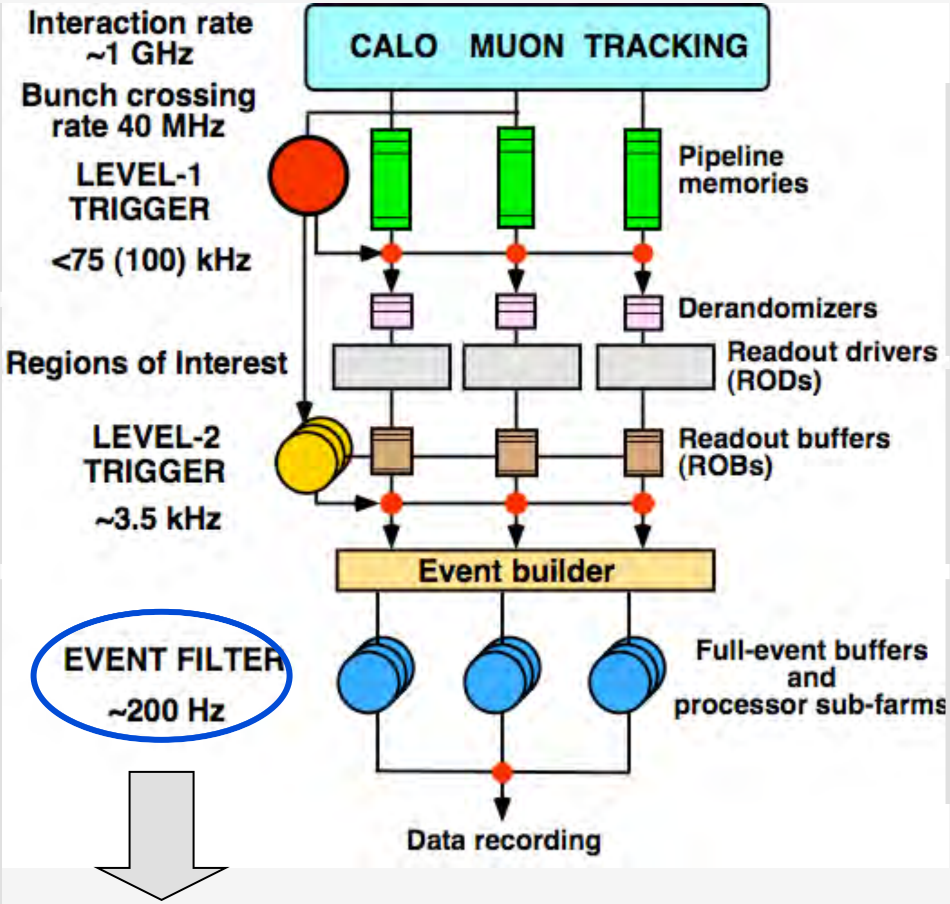
# Trigger / DAQ

**Level-1 Trigger**
Calorimeter
Muon System
Hardware based
Coarse granularity

**Level-2 Trigger RoI**
e/γ, μ, jet, ..
Full granularity in RoI
~ 500 PC (multi-core)

**Event Filter**
~1800 PC
(multi-core)
High bandwidth
Data Network

High Level Trigger (HLT)




**Front End Electronics**

**Readout Drivers**

**Readout System**
Custom built
buffers in PC farm

**Event Building**
More PC farms
on Data Network

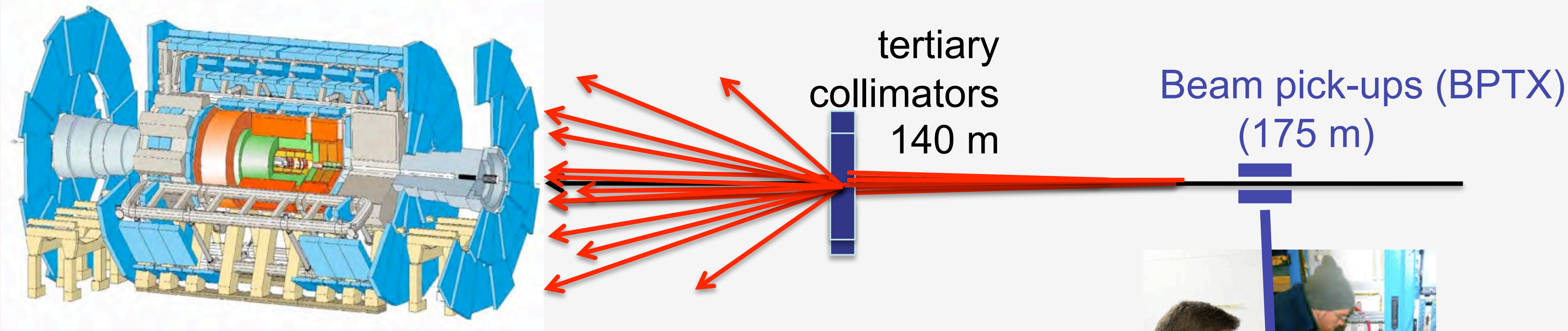
**300 MByte/s**
to Computer Center
~3 Pbytes stored / year

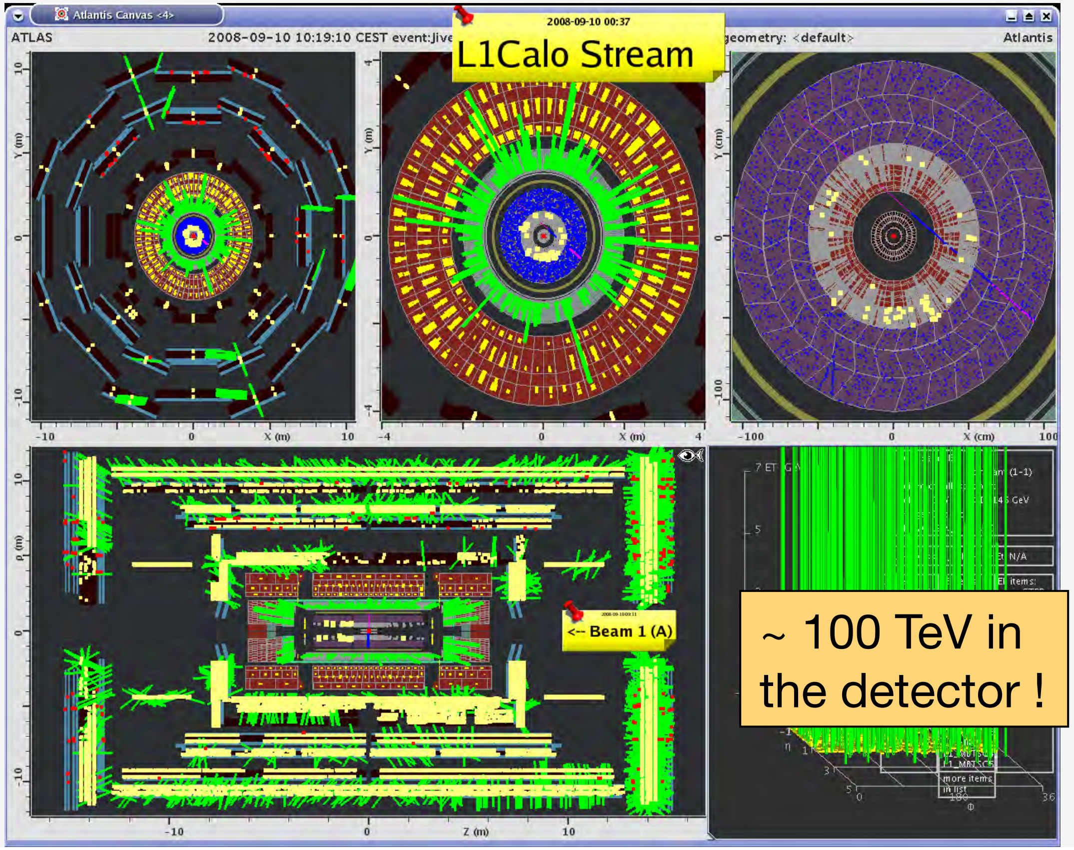
**DAQ software**
Control, configuration, monitoring
on Control Network

10 September 2008, ~10h am

Excitement in the ATLAS Control Room: waiting for first beams

# 10 September 2008, 10:19 am
# First ATLAS "beam splash event" recorded





Beam bunches ($2x10^9$ protons at 450 GeV) stopped by (closed) collimators upstream of experiments
→ "splash" events in the detectors
(debris are mainly muons)

# Detector present status (after Winter 2008-2009 shut-down)

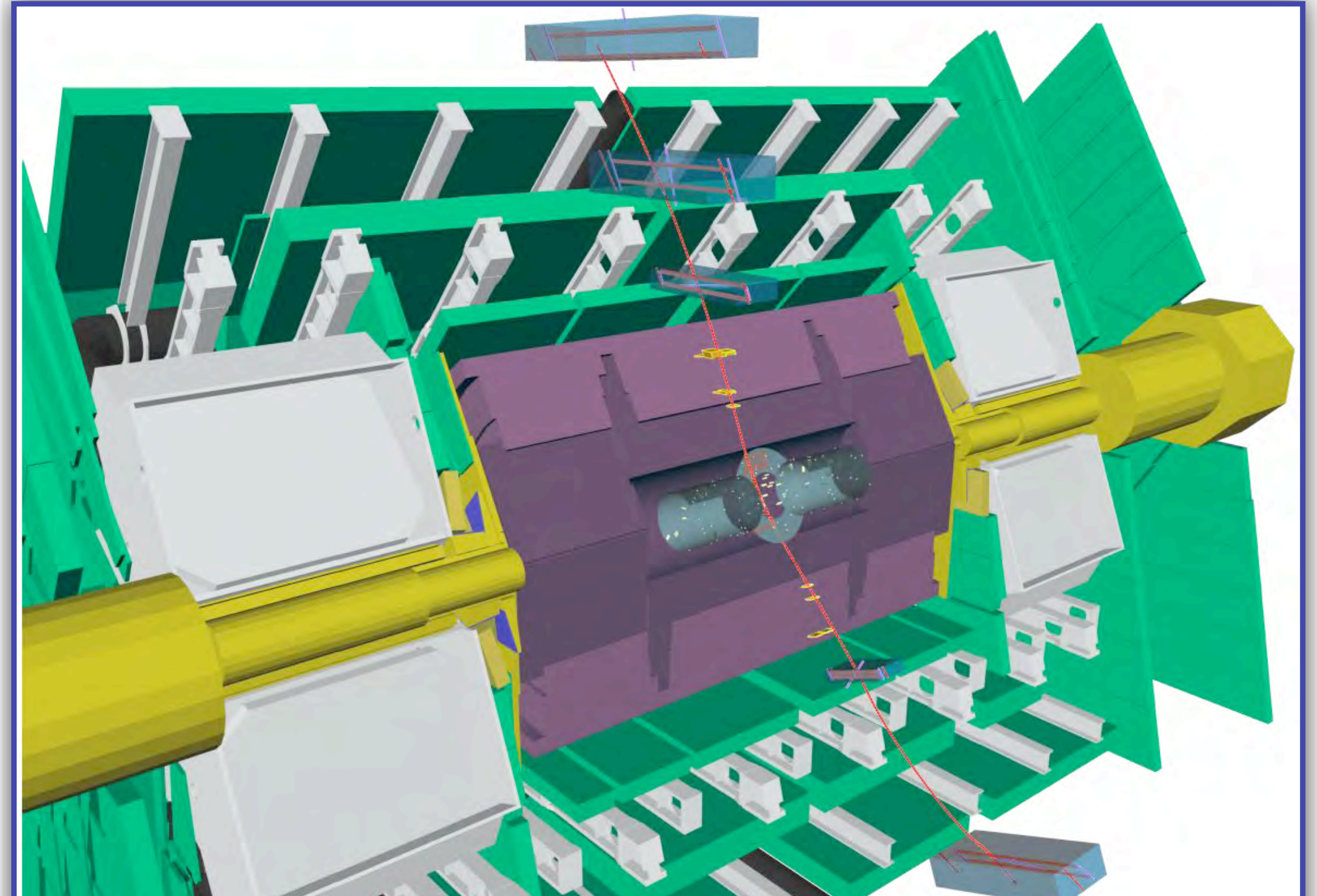
| Sub-detector | N. of channels | Fraction of working detector (%) |
|---|---|---|
| Pixels | $80 \times 10^6$ | 98.5 |
| Silicon strip detector (SCT) | $6 \times 10^6$ | ~99.5 |
| Transition Radiation Tracker (TRT) | $3.5 \times 10^5$ | 98.2 |
| LAr electromagnetic calorimeter | $1.7 \times 10^5$ | 99.5 |
| Fe/scintillator (Tilecal) calorimeter | 9800 | ~99.5 |
| Hadronic end-cap LAr calorimeter | 5600 | 99.9 |
| Forward LAr calorimeter | 3500 | 100 |
| Muon Drift Tube chambers (MDT) | $3.5 \times 10^5$ | 99.3 |
| Barrel muon trigger chambers (RPC) | $3.7 \times 10^5$ | ~ 95.5 (aim: > 98.5 by first beams) |
| End-cap muon trigger chambers (TGC) | $3.2 \times 10^5$ | > 99.5 |

Overall data taking efficiency: already ~ 83% during the last cosmics week (1-6 July 2009). Calculated over 6-14 hour long simulated LHC stores

**Concerns** are long-term reliability of some components:
Low-voltage power supplies of Liquid-Argon and Tile calorimeters;
Liquid-Argon readout optical links;
Inner detector cooling.
**Back-up solutions being prepared for installation in future shut-down.**

# One of many "golden" cosmic data events

A cosmic muon traversing the whole detector, recorded on 18/10/2008

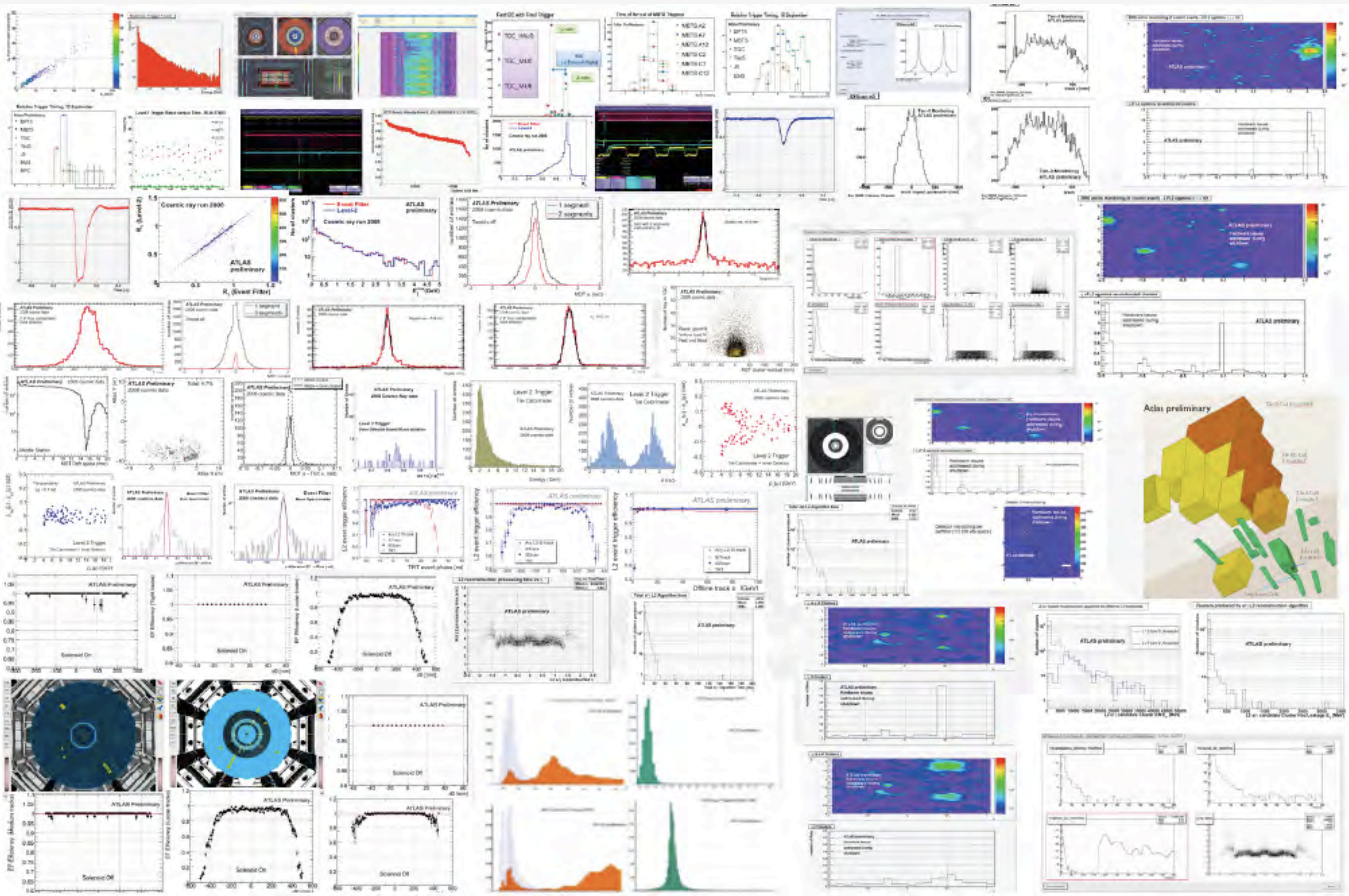


Cosmics rate in ATLAS: 1-700 Hz
(depending on the sub-detector size and location)

**Commissioning with cosmics:**

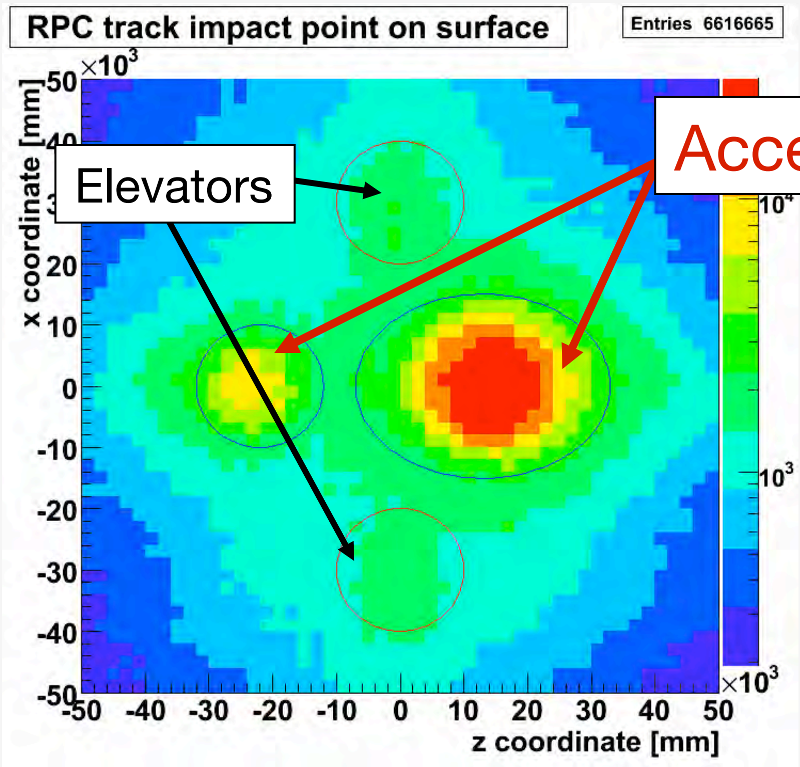
- Debug the experiment
  → fix problems
- First calibration and alignment studies
- Gain global operation experience in situ

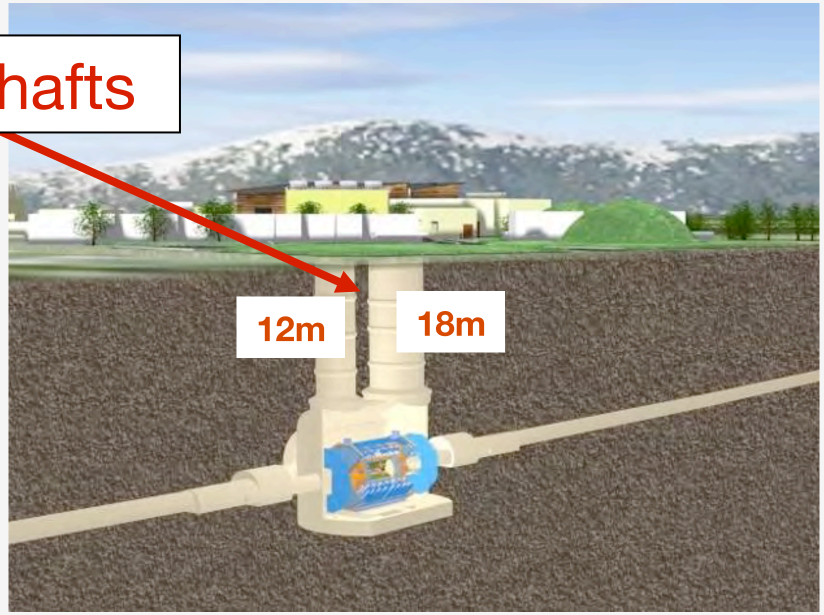
# Examples of a huge number of results …



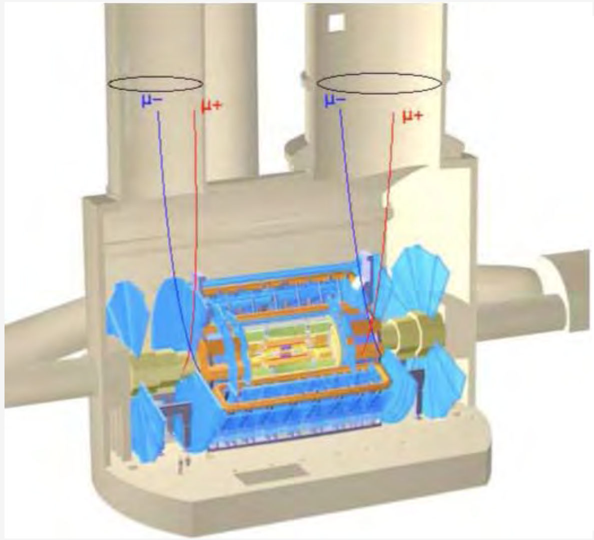
# Extrapolation to the surface of cosmic muon tracks

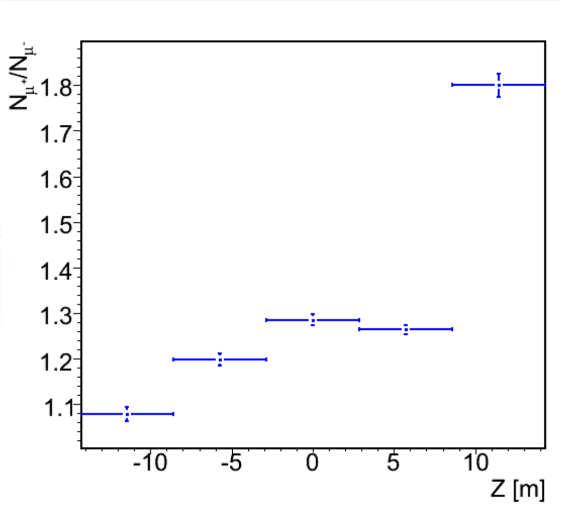
reconstructed by **RPC** trigger chambers

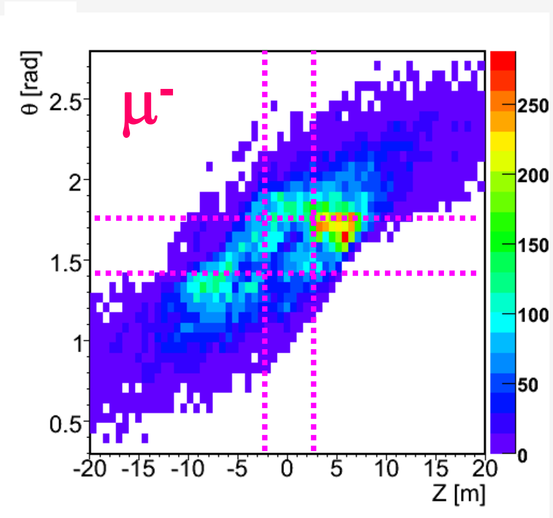


# Cosmic Muon Charge Asymmetry

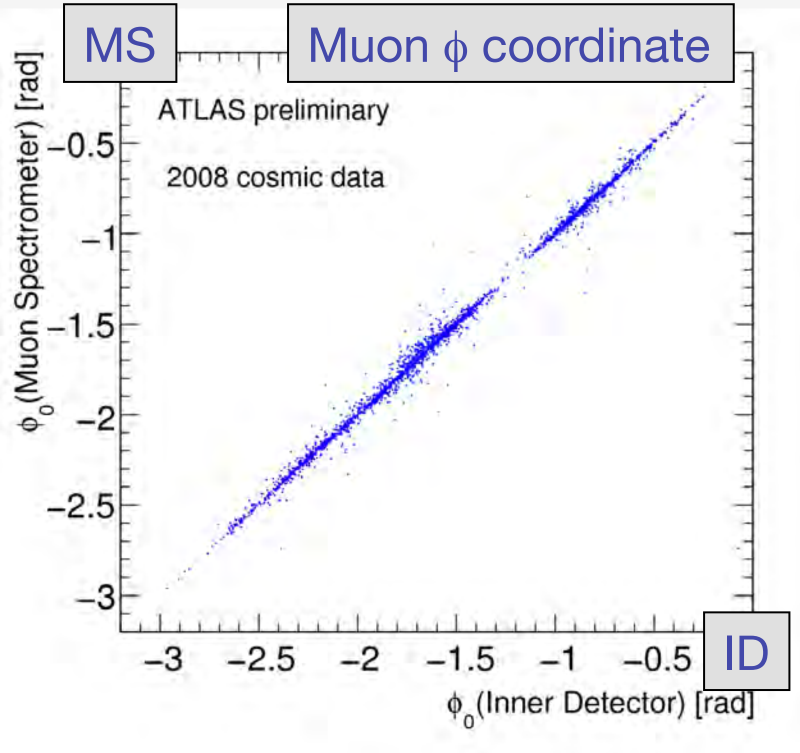


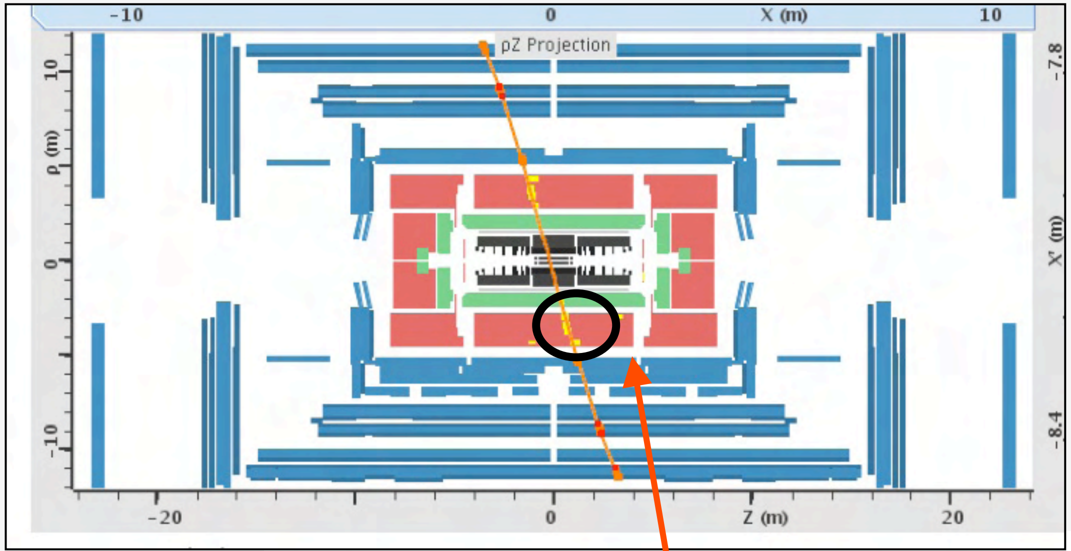



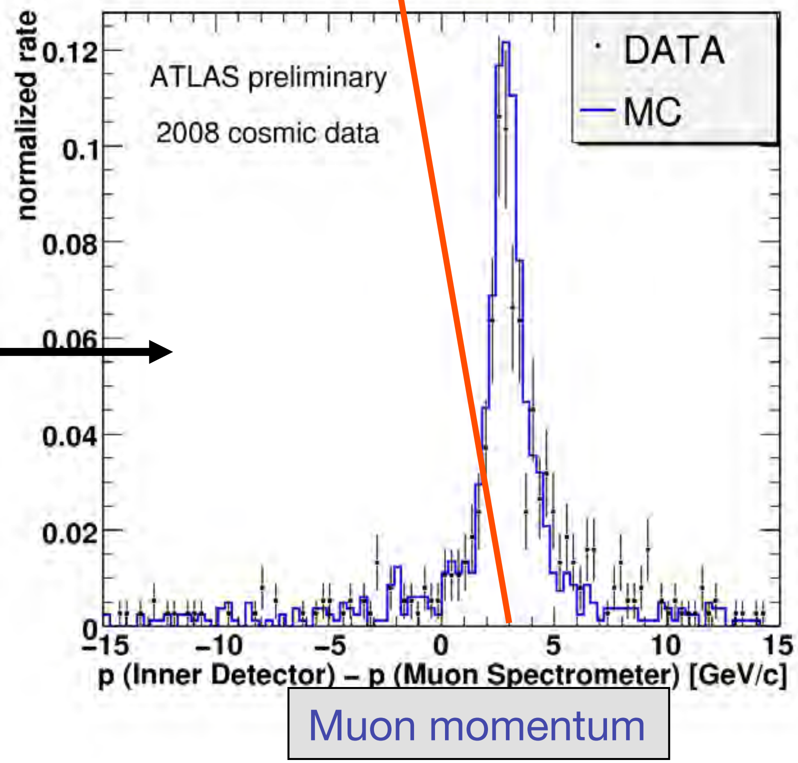




- Muons close to edges are bent outside the detector
  - Particularly under shafts, for low p muons
- Dramatic geometrically-dependent charge acceptance
  - Z and $\theta$ cuts can help limiting the dependence
- Rough estimate of asymmetry from central plot, at Z=0

# Correlation between the Inner Detector and Muon Spectrometer



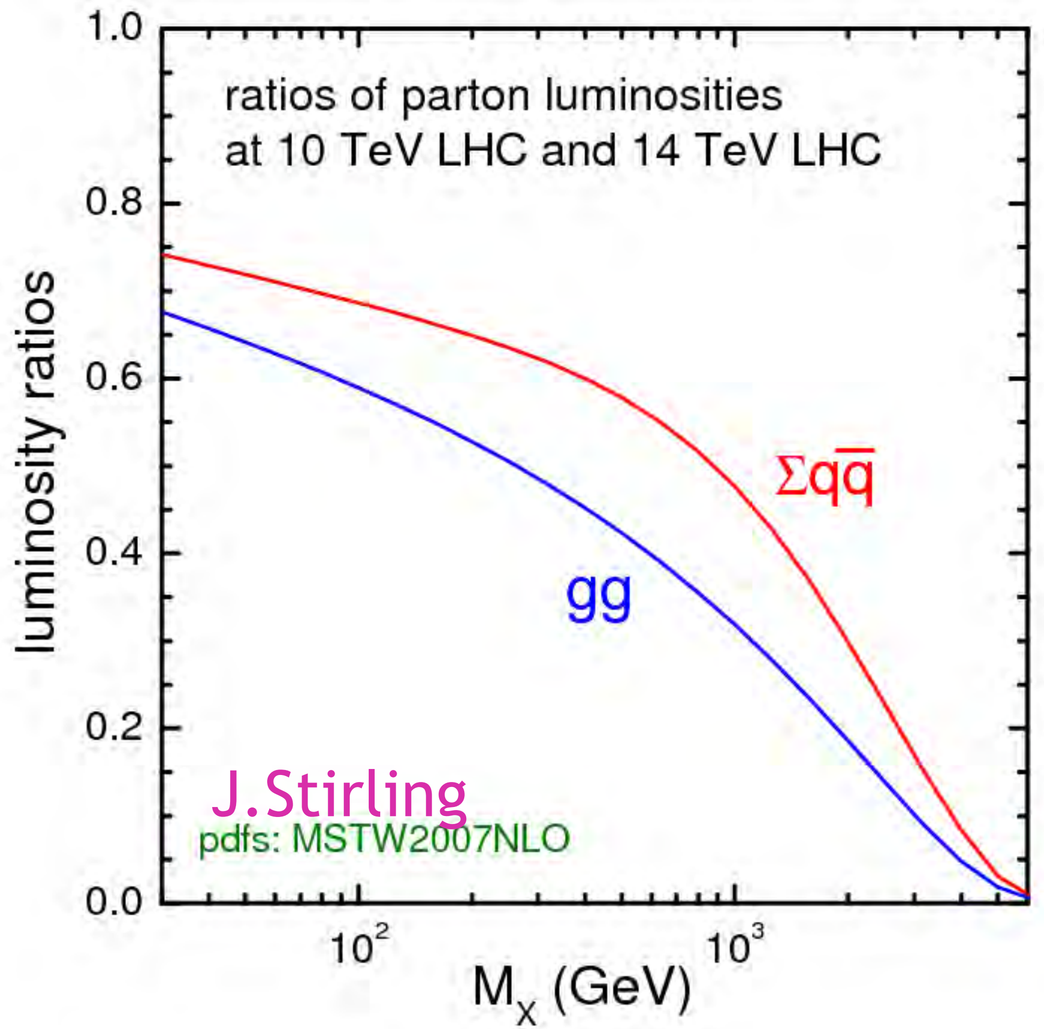




Difference between the muon momentum measured in the ID and in the MS for tracks in the bottom part of the detector (energy lost in the calorimeter: ~ 3 GeV as expected)

# 10 TeV vs 14 TeV

Ratios of cross-sections at 10/14 TeV for processes induced by gg and qq




At 10 TeV, more difficult to create high mass objects...

Below about 300 GeV, this suppression is <50% (process dependent ) e.g. tt ~ factor 2 lower cross-section

Above ~ 1 TeV the effect is more marked

# Expected data samples (examples) with 100 $pb^{-1}$

Note: expect up to 200 $pb^{-1}$ after first physics run at high energy

| Channels (examples) | Expected no of events in ATLAS after cuts $\sqrt{s}$ = 10 TeV, 100 $pb^{-1}$ |
|---|---|
| $J/\psi \to \mu\mu$ | ~$10^6$ |
| $\Upsilon \to \mu\mu$ | ~ 5 $10^4$ |
| $W \to \mu\nu$ | ~ 3 $10^5$ |
| $Z \to \mu\mu$ | ~ 3 $10^4$ |
| $tt \to WbWb \to \mu\nu + X$ | ~ 350 |
| QCD jets $p_T$ > 1 TeV | ~ 500 |
| $\tilde{g},\tilde{q}$ m ~ 1 TeV | ~ 5 |

## Goals in 2010:

1) Commission and calibrate the detector in situ using well-known physics samples
   e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, Muon chamber calibration and alignment, etc.
   - $tt \to bl\nu\ bjj$ jet scale from $W \to jj$, b-tag performance, etc.

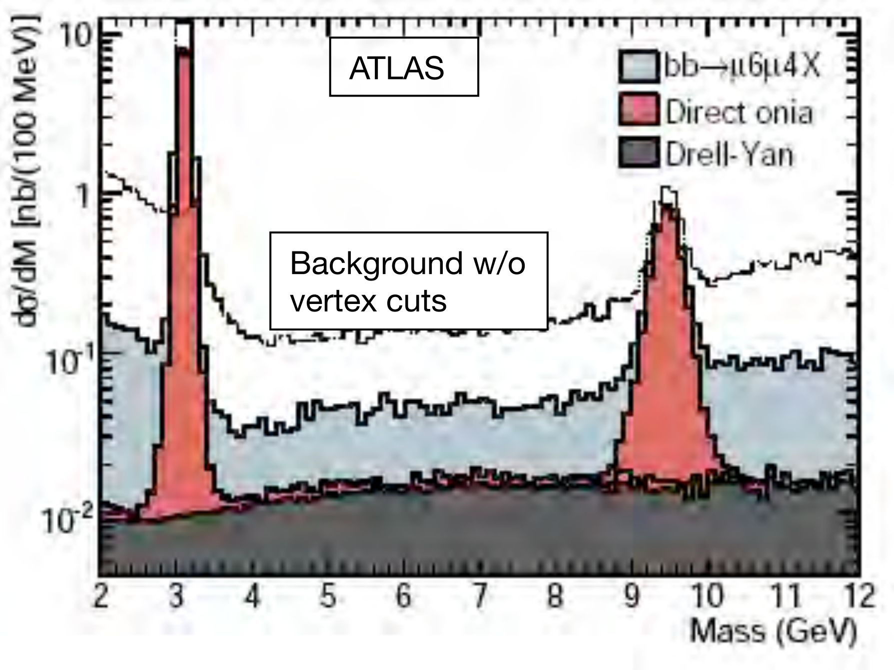
2) "Rediscover" and measure Standard Model at $\sqrt{s}$ ~ 10 TeV: W, Z, tt, QCD jets …
   (also because omnipresent backgrounds to New Physics)

3) Early discoveries ? Potentially accessible: Z', SUSY, …. surprises ?

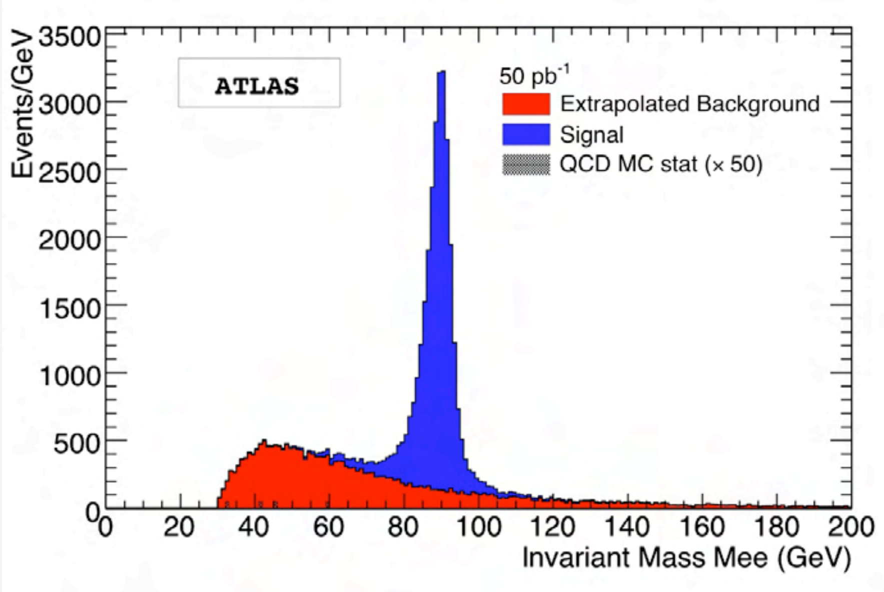
few $pb^{-1}$ → 50 $pb^{-1}$ → 100 $pb^{-1}$ → ….

# Early "signals", the SM "candles": J/ψ, ϒ, W, Z

First dilepton peaks with ~10 $pb^{-1}$




Z→ ee, 50 $pb^{-1}$, 14 TeV




Expected no of events after cuts per $pb^{-1}$ at 10 TeV

10000 J/ψ→ μμ 500 ϒ → μμ 600 Z → ee, μμ

→ Muon Spectrometer and ID alignment, ECAL calibration, energy/momentum scale of full detector, lepton trigger and reconstruction efficiency, …

# ATLAS Conclusions

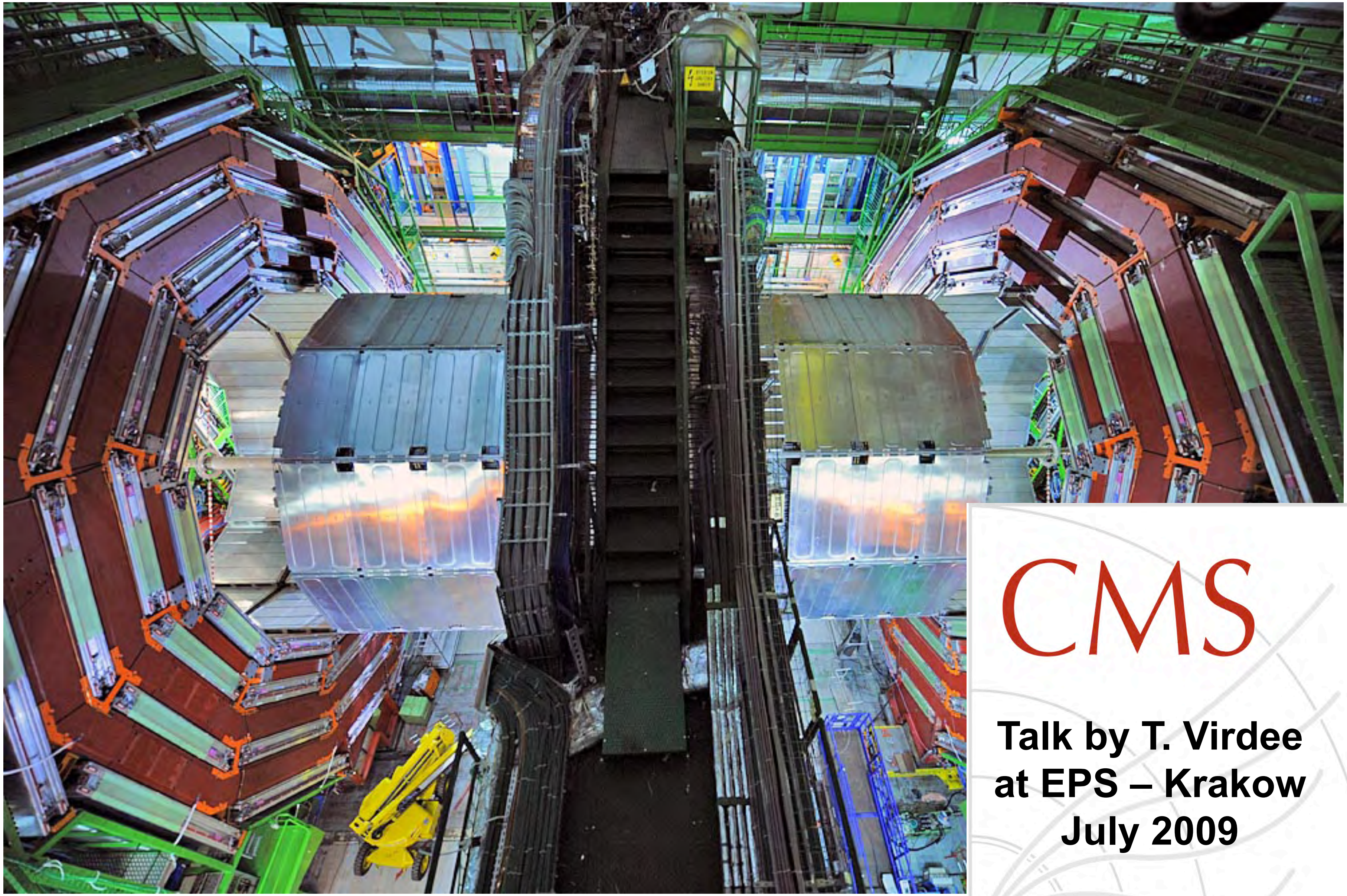
- The ATLAS experiment is in excellent shape

- The fraction of non-working channels is on the permille level

- Analysis of ~600 M cosmics events, as well as single beam data in Sept 2008, shows better detector performance than expected at this stage

- Software and computing have proven to be able to cope with simulation, analysis and world-wide distribution of massive amounts of data

- After 20 years of efforts building all aspects of the experiment: **ATLAS is eagerly waiting for LHC collisions data …**

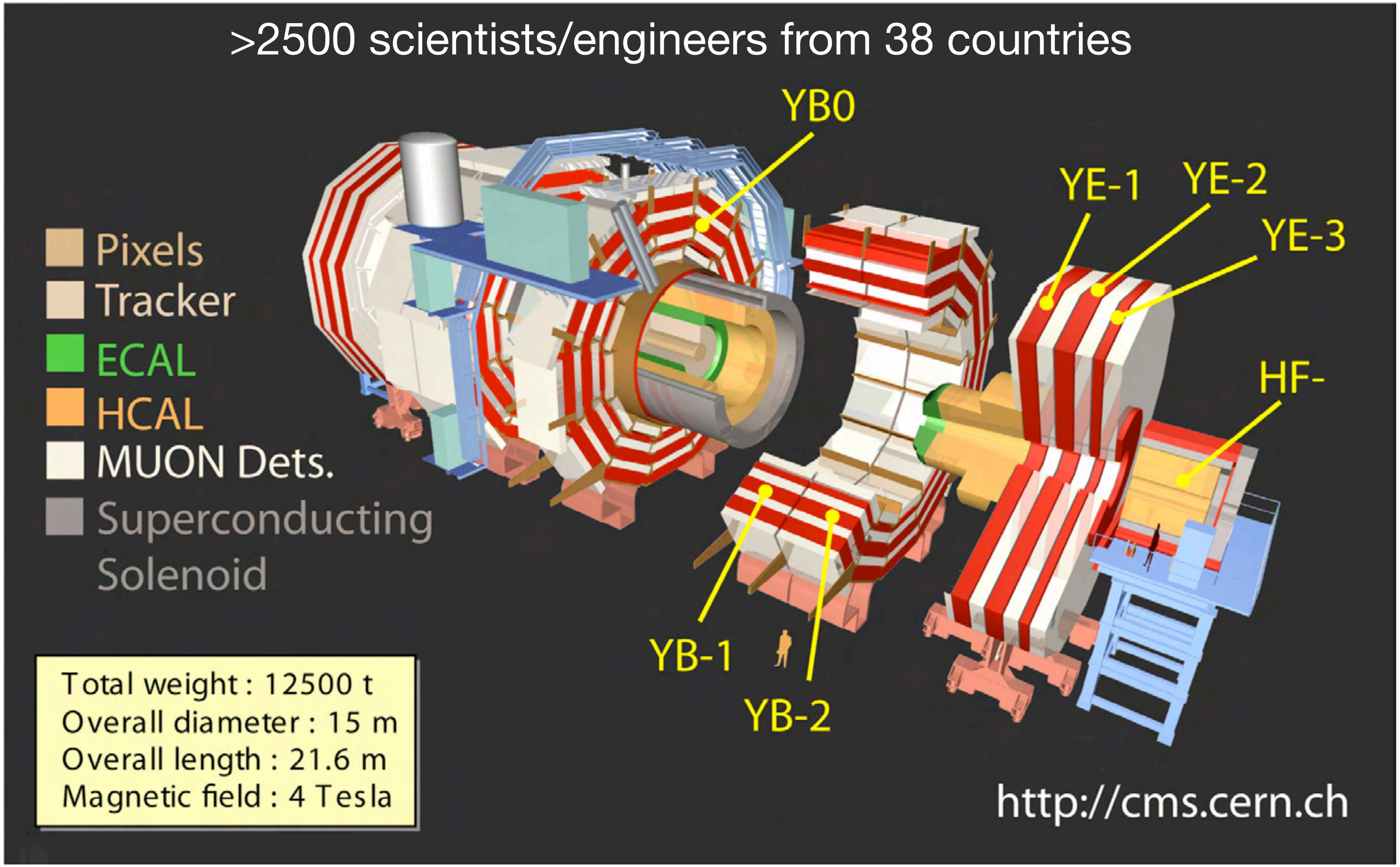


CMS

Compact Muon Solenoid

**Talk by T. Virdee at EPS – Krakow July 2009**

# The CMS Detector

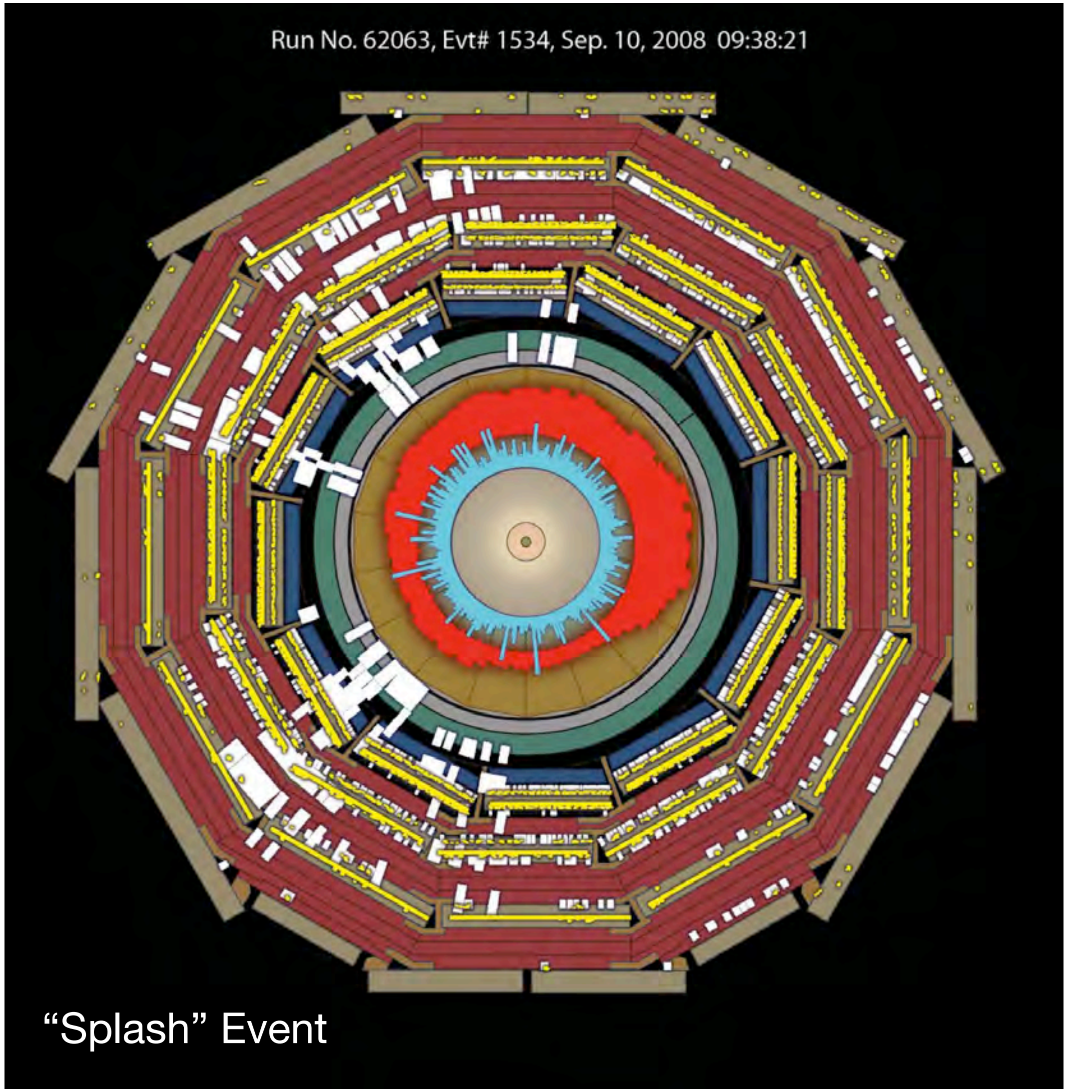



CMS comprises 66M pixel channels, ~10M Si microstrip ch, ~75k crystals, 150k Si preshower ch, ~15k HCAL ch, 250 DT chambers (170k wires), 450 CSC chambers (~200k wires), ~ 500 Barrel RPCs and ~ 400 endcap RPCs, muon and calorimeter trigger system, 50 kHz DAQ system (~ 10k CPU cores), Grid Computing (~ 50 k cores), offline (> 2M lines of source code).

# First LHC Beam in 2008

**Data-taking with LHC beam.**

- Wed, 10 Sept. 2008
  - “Splash” events observed when beam (450 GeV, 4.10$^9$ p) struck collimators 150m upstream of CMS
  - Halo muons observed once beam (uncaptured and captured) started passing through CMS



“Splash” Event

# ‘08-’09 Shutdown - CMS Activities

After the cosmics run ended (Nov ‘08), the detector was opened for **carefully selected maintenance, consolidation and repair activities**, as well as the **installation** of the preshower subdetector.
**Work progressed according to the schedule** laid down in Nov. 2008.

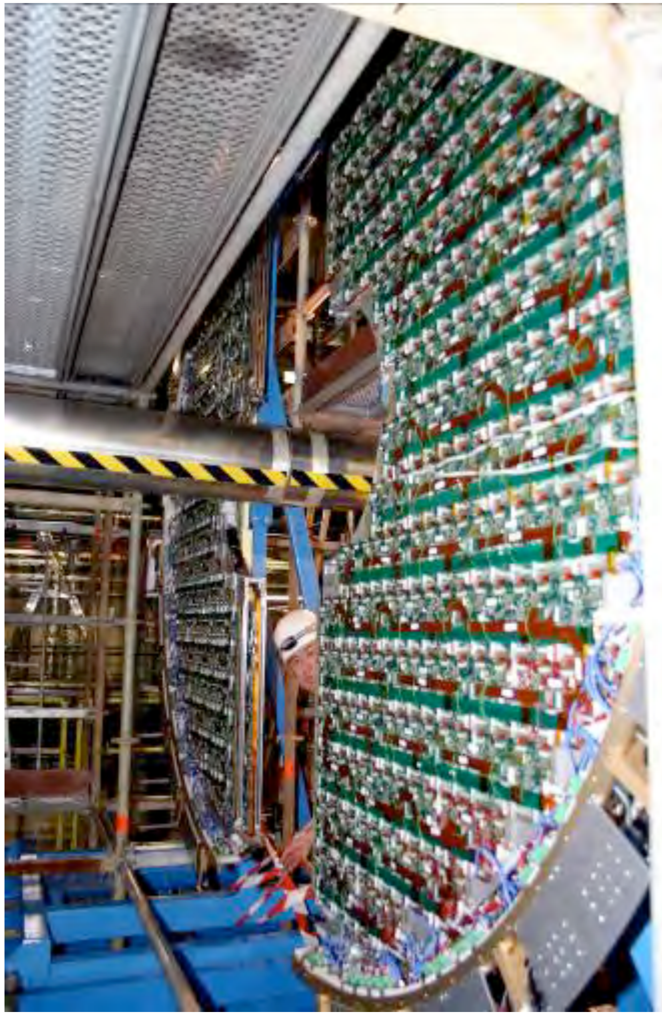
**Some highlights**:

- the installation and commissioning of the preshower (ES)
- the removal, repair, and re-insertion of the forward pixel system
- the revision of the tracker cooling plant
- Re-commissioning of CMS – Mid-Week Global Runs and CRUZET interspersed with final maintenance and consolidation activities.
- Preparation of s/w for 2009 data taking, improving stability & reliability of computing infrastructure, large MC production and analysis at 10 TeV.

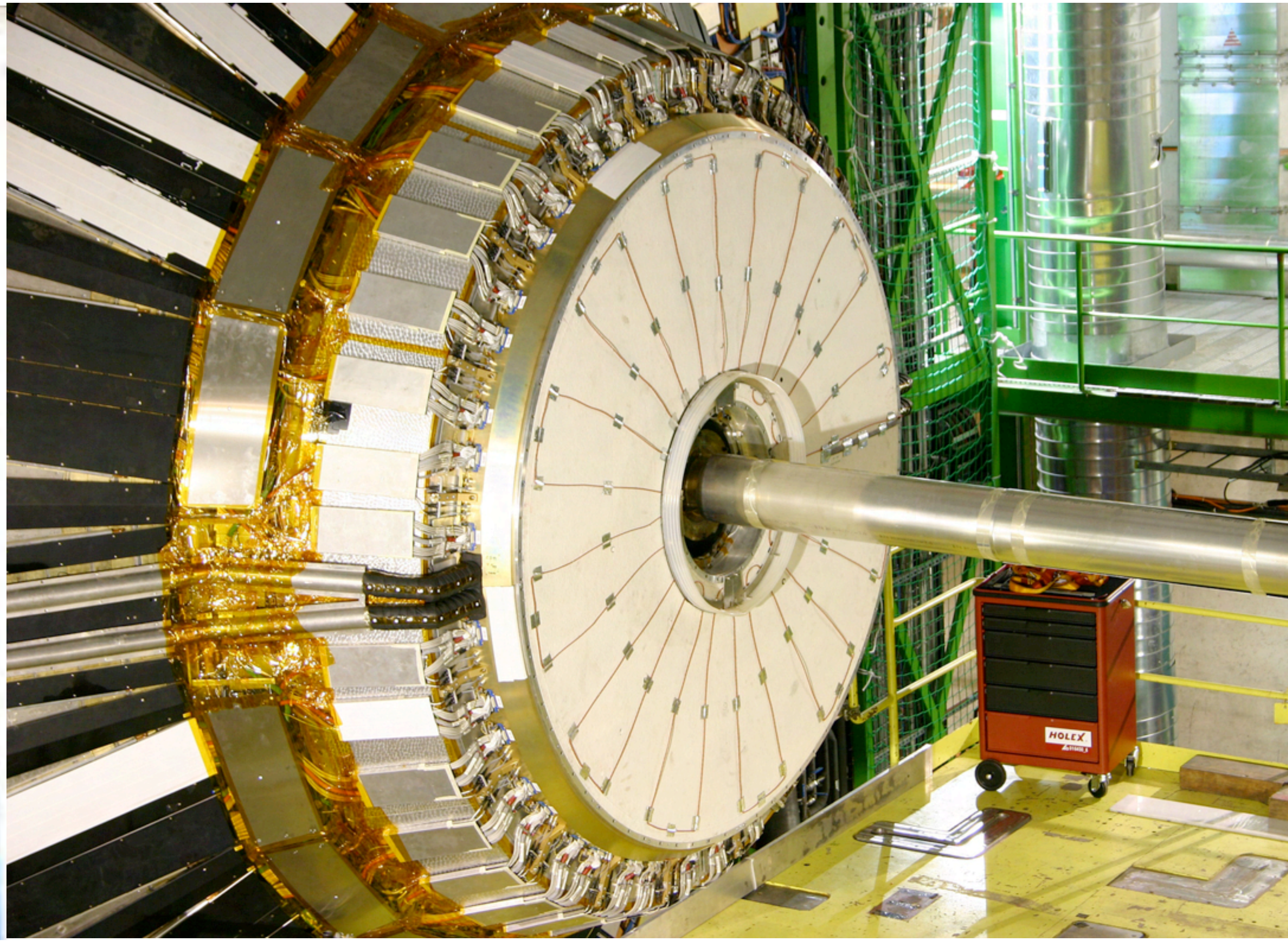
**Upcoming:**

Cosmics run at operating field (6 weeks starting end-July)
Move to stable data taking prior to LHC beam.

# Installation of the Si Preshower



The two separate ES Dees



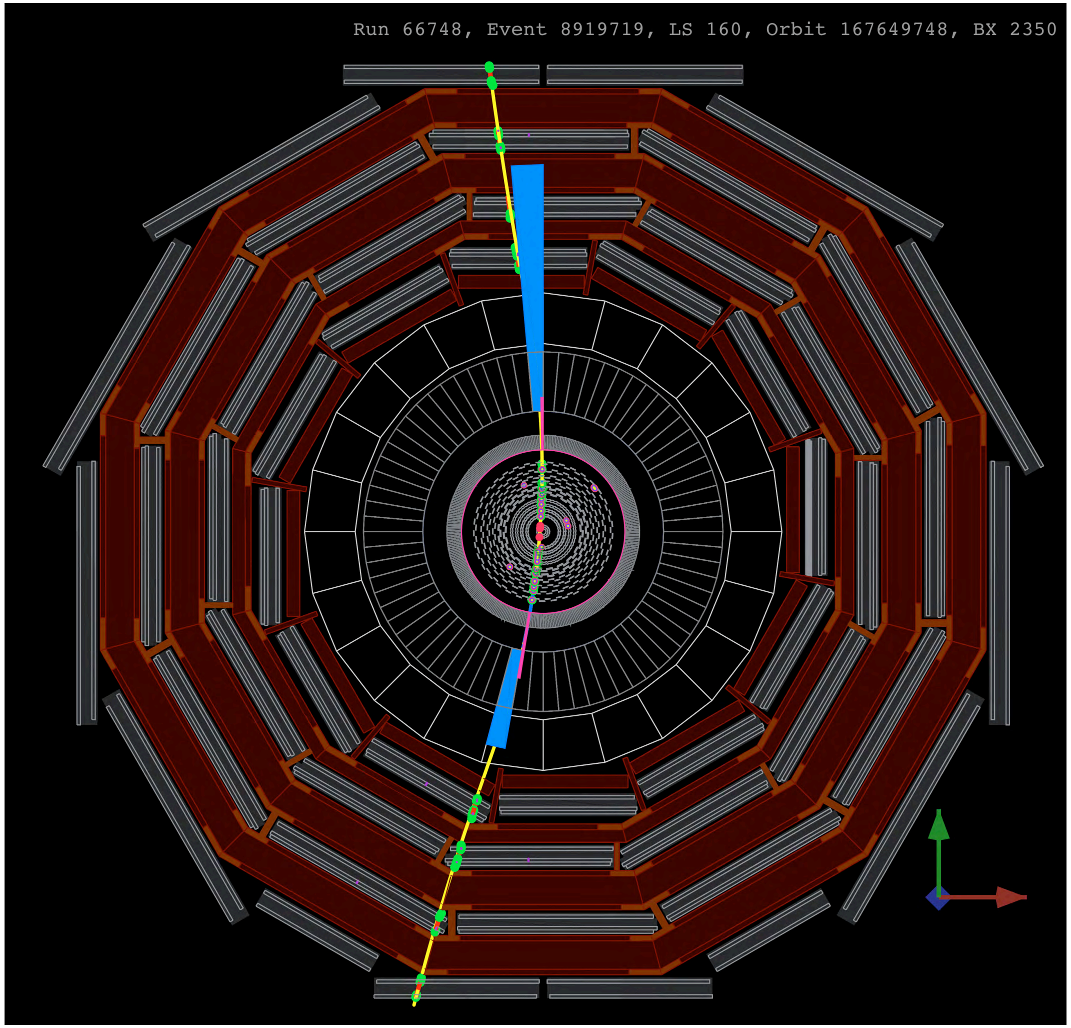

Installation completed in Apr'09

# Continuous Operation of CMS

## CRAFT*: Cosmics Run at Four Tesla

* Operating field of CMS is 3.8T

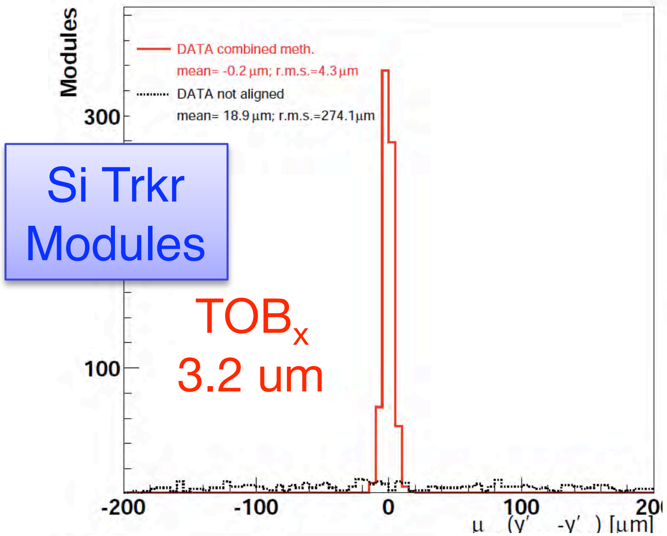
- **Ran CMS for 6 weeks** (Oct-Nov'08) continuously to gain operational experience, stability of infrastructure.
- **Collected 300M cosmic events**. About 400 TB of data distributed widely.
- **Efficiency ~ 70% (24/7)**

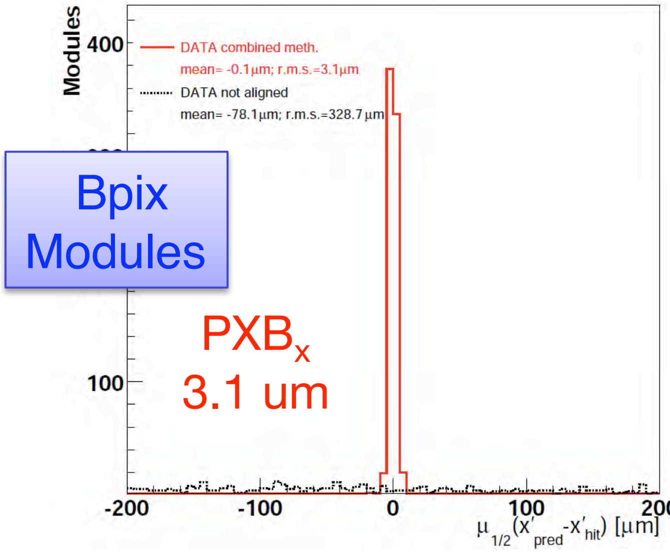


# CRAFT: Performance Plots

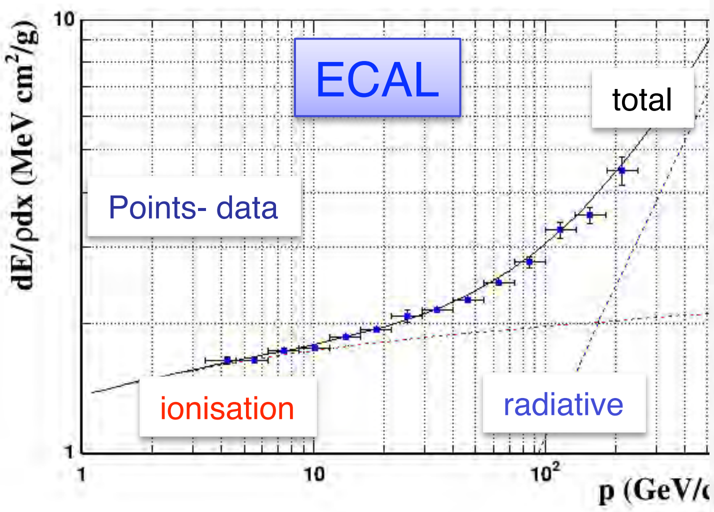
## Alignment in Inner Tracker

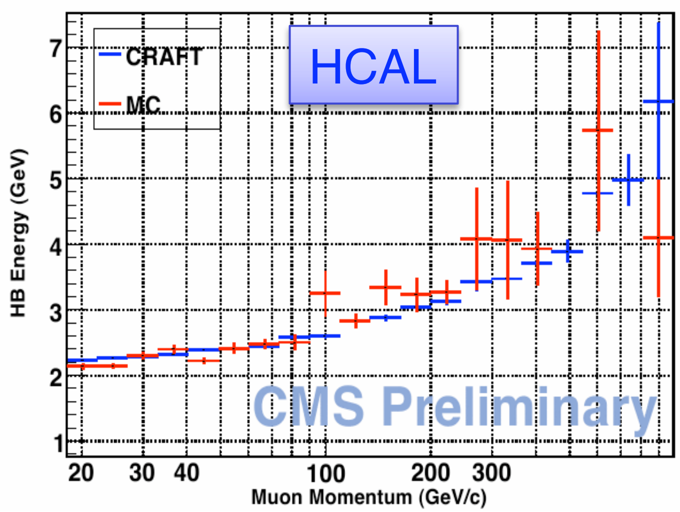
### Distn of Mean Residuals



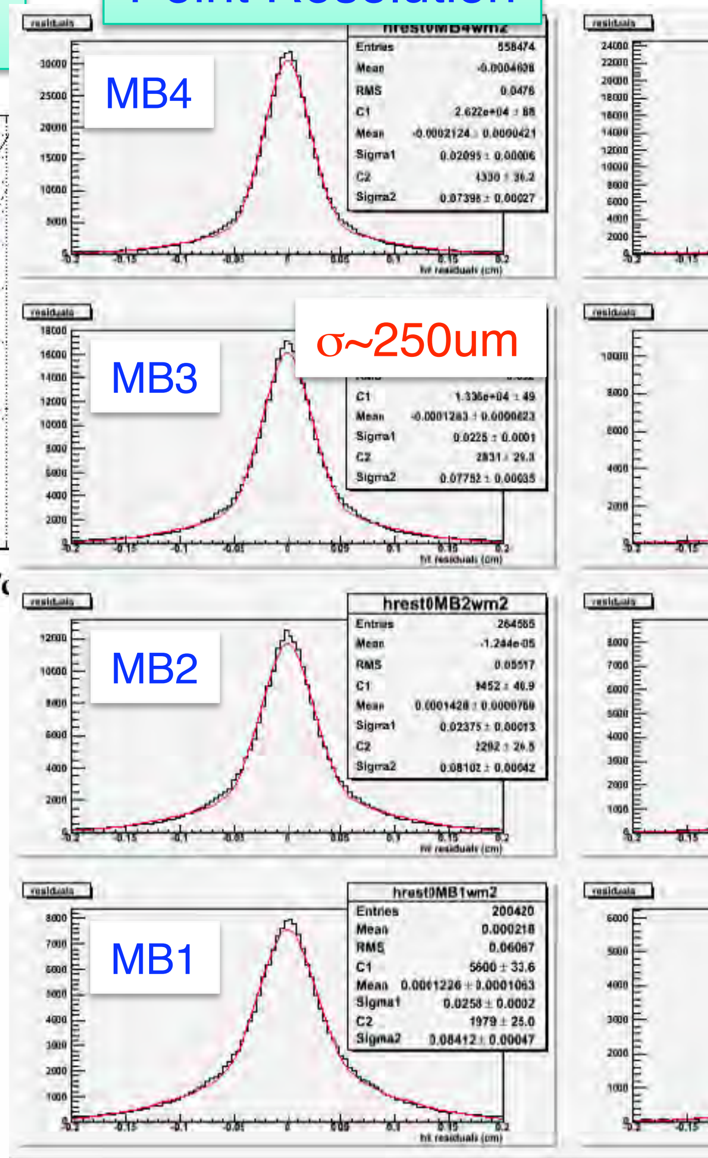




## Energy deposited by muons




## Muon Chambers Point Resolution



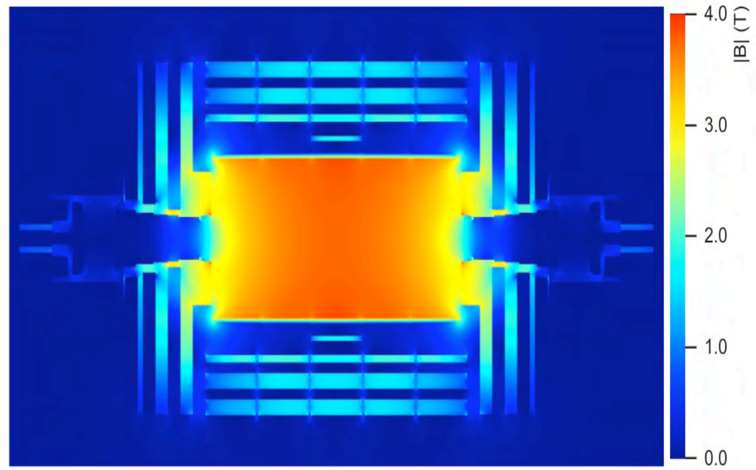
# CRAFT Results: CMS Magnetic Field Map

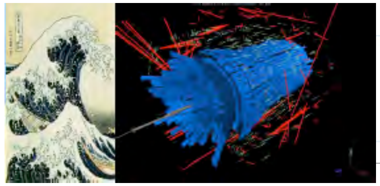
**In the Tracker Region**

Measured by Field Mapper (at 2, 3, 3.5, 3.8, 4 T) in 2006 MTCC

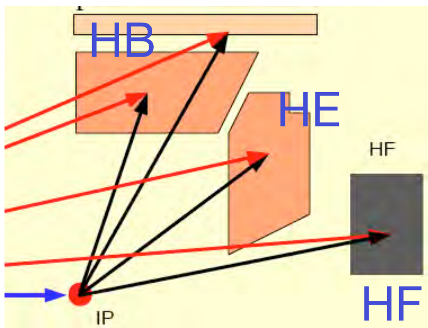
**TOSCA field map agrees < 0.1%**

NMR probes inside solenoid confirm agreement scale < 0.1% between 2006 and 2008



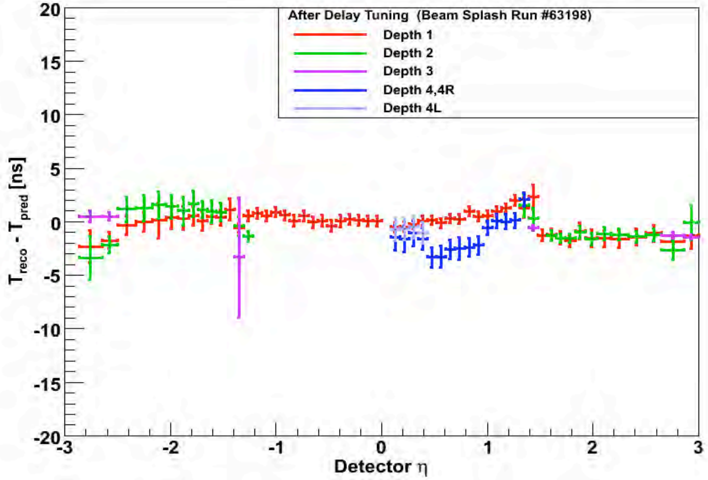


# LHC Beam: Timing (HCAL, Trigger)

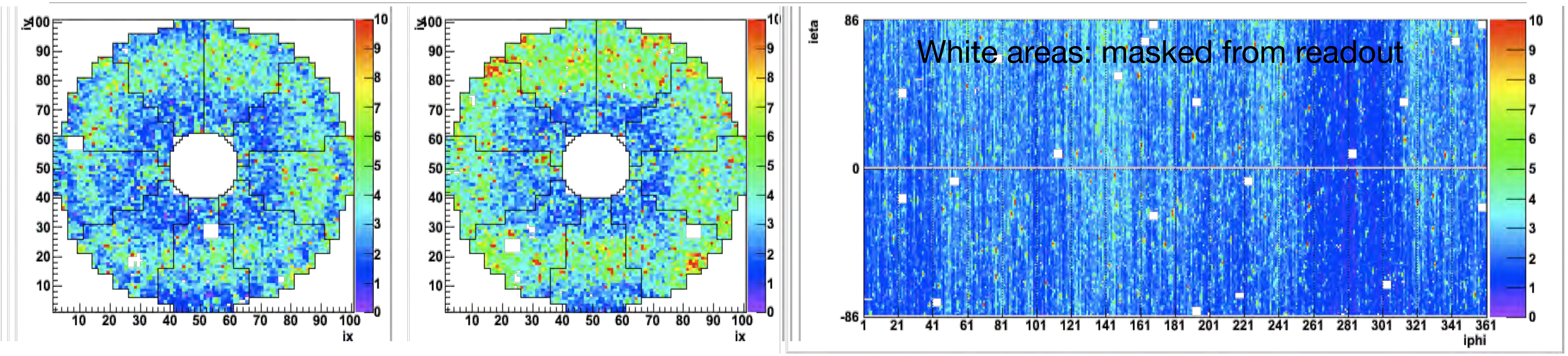



Before


After

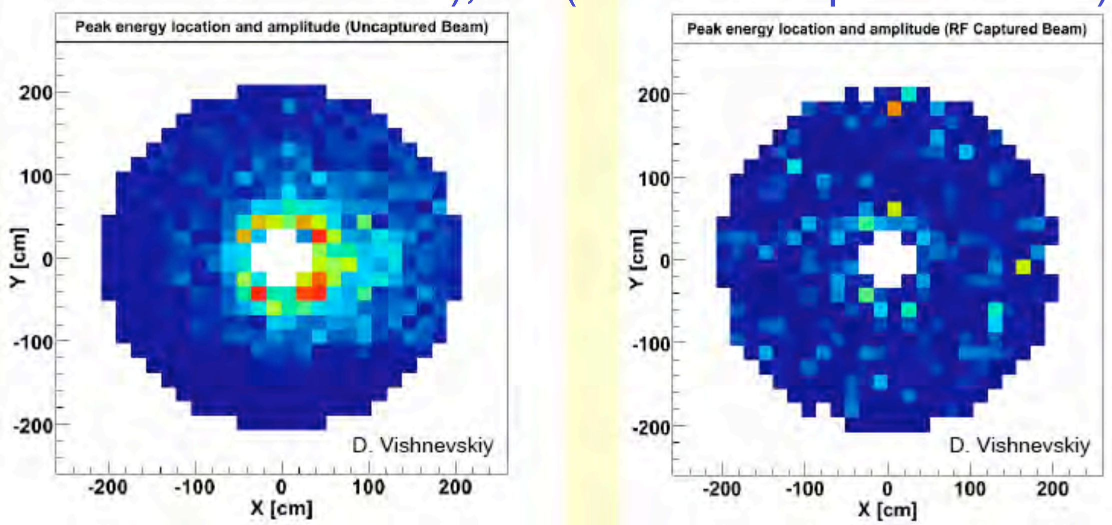


# LHC Beam: Energy Deposit in Calorimeters




**ECAL Endcaps (lhs), Barrel (rhs)**

> 99% of ECAL channels alive, ~200 TeV energy deposited in EB+EE
Inter-crystals timing established (< 1ns), inter-crystal calibration EB (1.5-2.5% - test beam + cosmics), EE (~7% from splash events)




**HCAL Endcap**: un-captured (lhs) and captured circulating beam (rhs)

# Outline: Early Physics Programme

- Detector commissioning – much already done using cosmics/ testbeam,..

- Early beam - collisions, up to $10pb^{-1}$ @ 10 TeV
  - Detector synchronization, alignment with beam-halo events, minimum-bias events. Earliest in-situ alignment and calibration
  - Commission trigger, start "physics commissioning" – "rediscover SM":
    - Physics objects; measure jet and lepton rates; observe W, Z, top
    - And, of course, first look at possible extraordinary signatures…

- Collisions, $100pb^{-1}$ measure Standard Model, start search
  - Per pb-1: 6000 $W \rightarrow l\,\nu$ ($l = e,\mu$); 600 $Z \rightarrow ll$ ($l = e, \mu$); 40 ttbar $\rightarrow \mu+X$
    - Improved understanding of physics objects; jet energy scale from $W \rightarrow j\,j'$; extensive use (and understanding) of b-tagging
    - Measure/understand backgrounds to SUSY and Higgs searches
  - Early look for excesses from SUSY & Z' resonances.

# CMS Conclusions

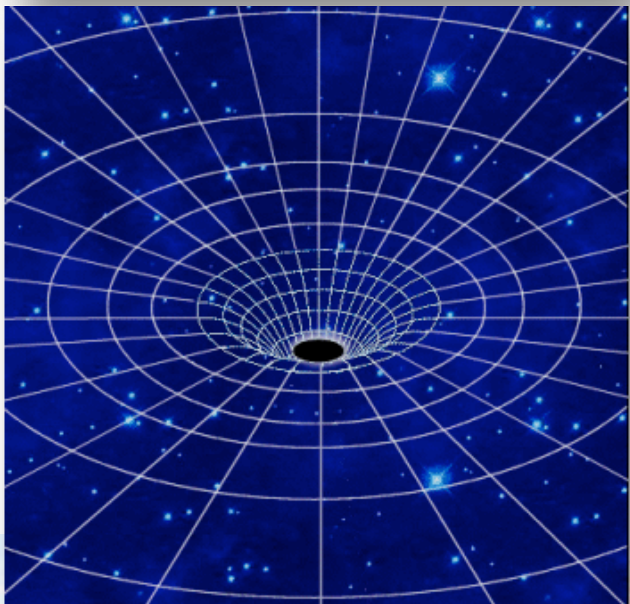
- During the autumn 2008 LHC beam & cosmics run, the sub-detectors, online, offline, computing and analysis systems all performed well.

- The ensuing shutdown included broad maintenance activities and a programme of carefully selected repairs interleaved with installation of the preshower detector.

- Much VERY useful information has been extracted from the CRAFT08 data. Plan to publish ~25 papers by end-Sept.

- The experiment is now closed and is being prepared for a long cosmics run to put it into “beam-ready” state.

- CMS will (again) be ready, and eager, for LHC beam.

# Mapping the Secrets of the Universe

## ...or will we all disappear in a Black Hole?!

ATLAS EXPERIMENT http://atlas.ch

# ANGELS & DEMONS


As scientists who also love good fiction, we were very appreciative to see *Angels and Demons* bring exciting physics at CERN to the the public's attention…

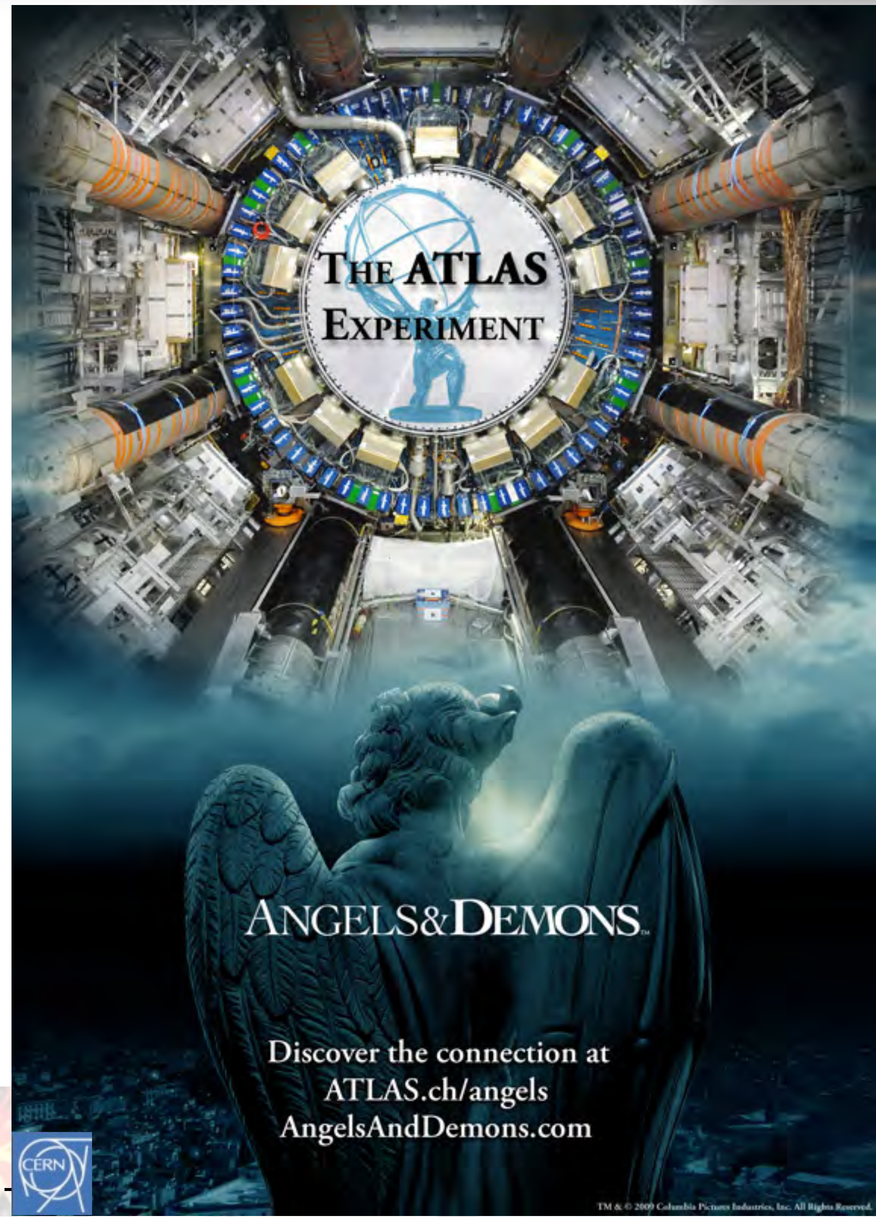
ATLAS.ch

and

AngelsAndDemons.com

and

angelsanddemons.cern.ch



# Tom Hanks et al. at CERN


ANGELS&DEMONS

Tom Hanks,
Ayelet Zurer,
Ron Howard

# Antimatter in the story of ANGELS & DEMONS




In the Angels and Demons story, the bad guys go to a laboratory called "CERN".

They steal half a gram (0.02 ounces) of antimatter in a magnetic canister, which they then take to Rome to use as a bomb.

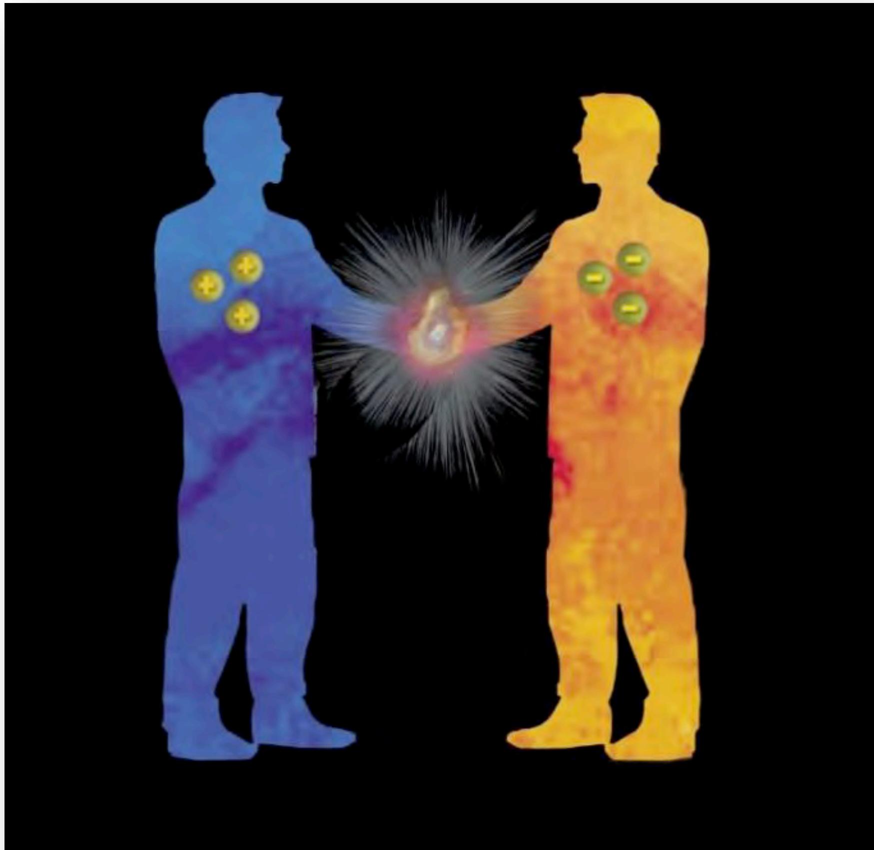
# Antimatter Annihilates with Matter


It is also true that

when matter and antimatter meet, they annihilate.

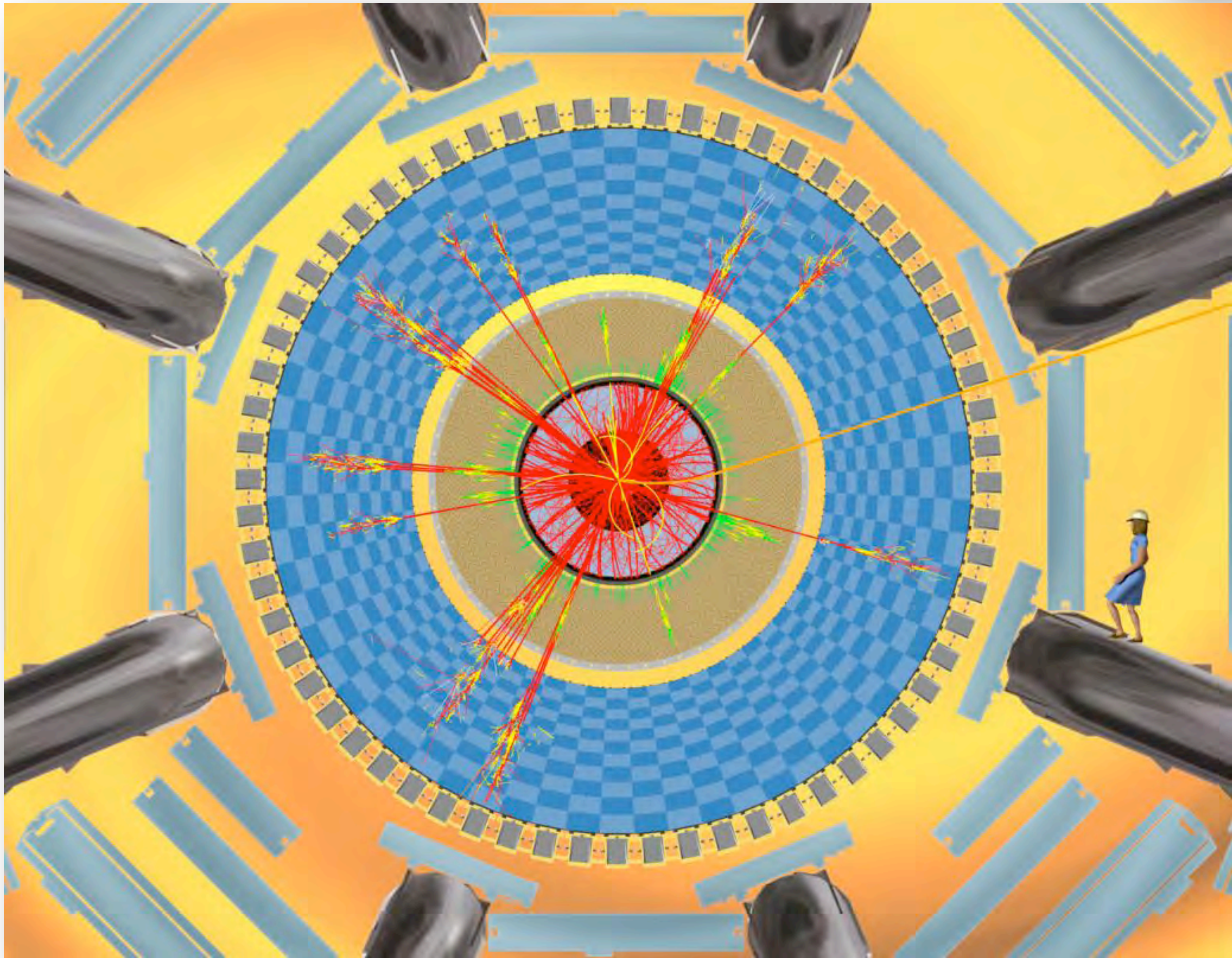
Their mass is converted to energy via Einstein's equation

$$E = mc^2$$



# Antimatter is Half of Everything Produced in Collisions in ATLAS

Half of the tracks shown are antiparticles



# But it all annihilates…


All the antimatter produced in ATLAS annihilates within a fraction of a second.

ANGELS&DEMONS

# If We Could Accumulate It


<u>If</u> we had some means to accumulate half a gram (0.02 ounces), and

<u>if</u> we could put it in a magnetic container and

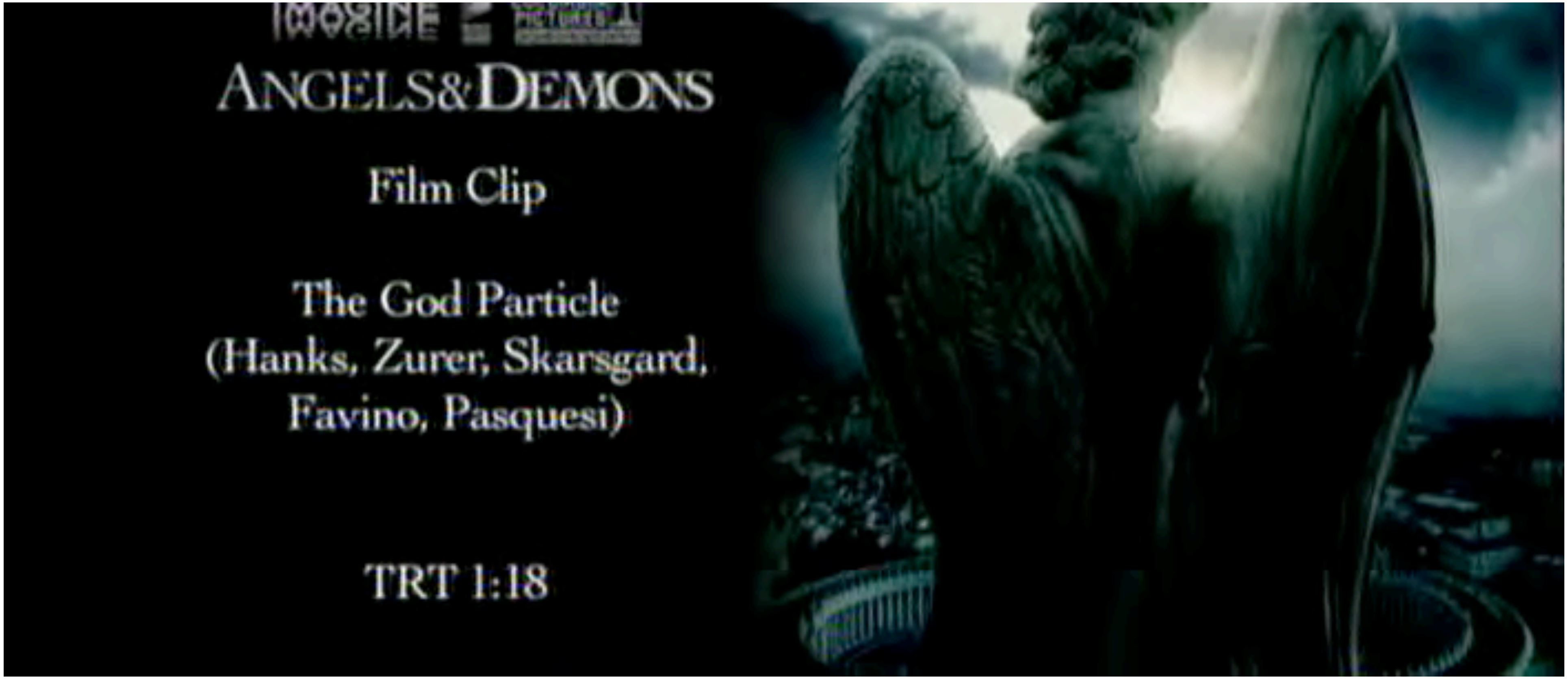
<u>if</u> we could transport it safely to another site,

It could indeed be a powerful bomb as in…

ANGELS&DEMONS


A dollar weighs a gram.
A feather weighs about ½ gram.

# A crucial scene from the movie…

# The Higgs Boson


Professor Peter Higgs proposed that all of space is permeated by a field, the Higgs field.

Quantum theory says that all fields have particles associated with them, so… in this case… a Higgs Boson.

(or sometimes called… the God Particle, thanks to Leon Lederman.)

The Higgs has already been discovered at the ATLAS Experiment, but it was Prof. Higgs, …not the Higgs Boson.

# Higgs Boson

To understand how the Higgs works,

imagine that a room full of people chattering quietly is like space filled with the Higgs field ...

# Higgs Boson


... a well-known scientist walks in, creating a disturbance as he moves across the room and attracting a cluster of admirers with each step ...

... this increases his resistance to movement, in other words, he acquires mass, just like a particle moving through the Higgs field...

-- Prof. David Miller

# How a Higgs boson event might look in ATLAS

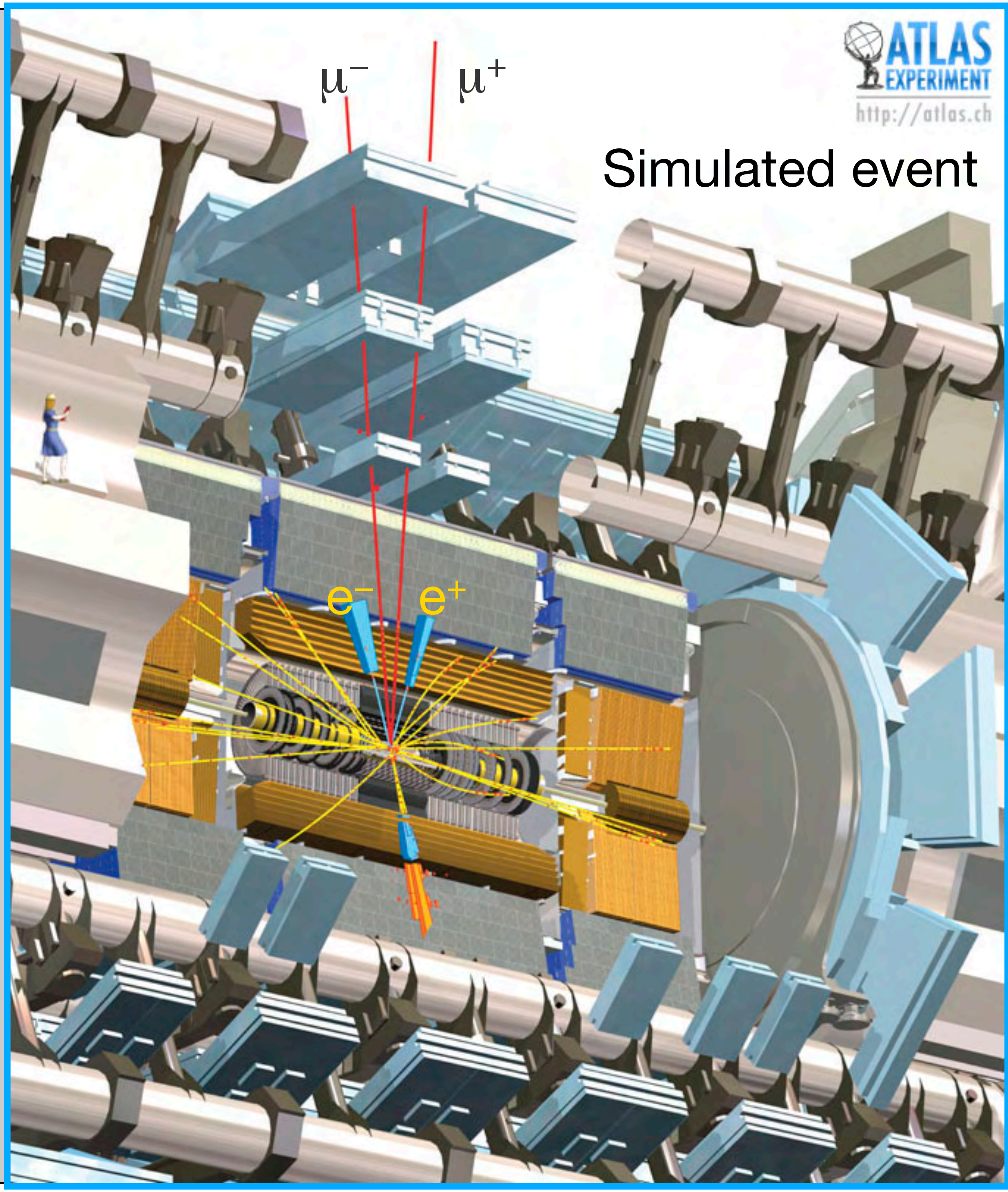
In this event, a cluster of particles was produced going downward,

and a Higgs was produced going upward but decayed almost instantly.

$H \rightarrow Z + Z$

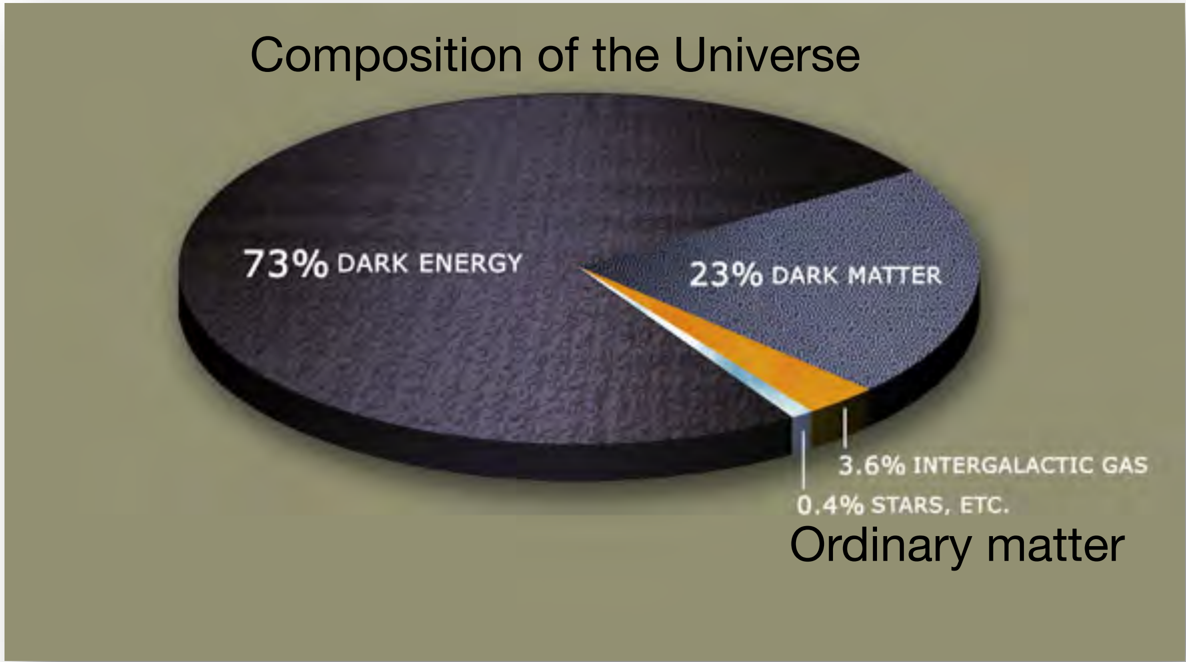
$Z \rightarrow e^- + e^+$

$Z \rightarrow \mu^- + \mu^+$



# But there is More than just Matter and Antimatter


Looking at our Universe we see much more than ordinary matter (or antimatter)




We call this extra stuff "dark matter" because we cannot see it.    But what is it?

# Astro-Evidence for Dark Matter


## In galaxies and galaxy clusters

There is not enough visible mass in rotating spiral galaxies to hold them together

Separation of dark matter and ordinary matter in the collision of two clusters of galaxies

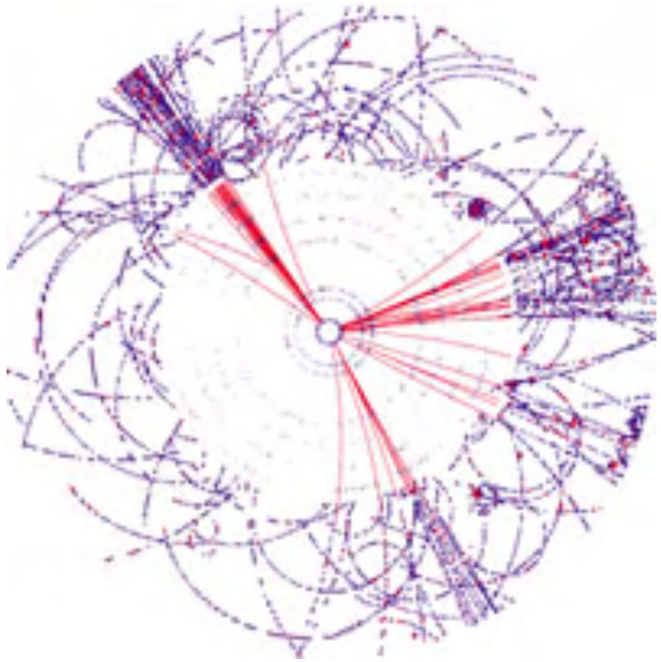

Photos courtesy of NASA

# What is Dark Matter?


We don't know

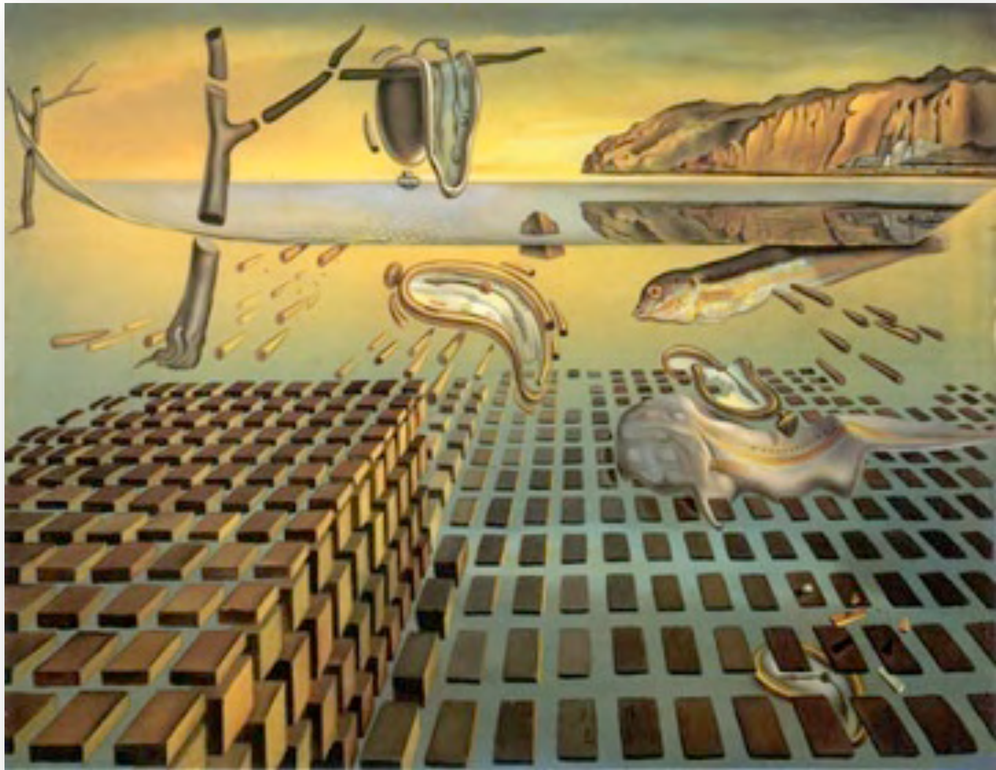
But there are theories…

And if the constituents of dark matter are new particles, then ATLAS may discover them and solve the mystery



# Is Matter also in Other Dimensions?

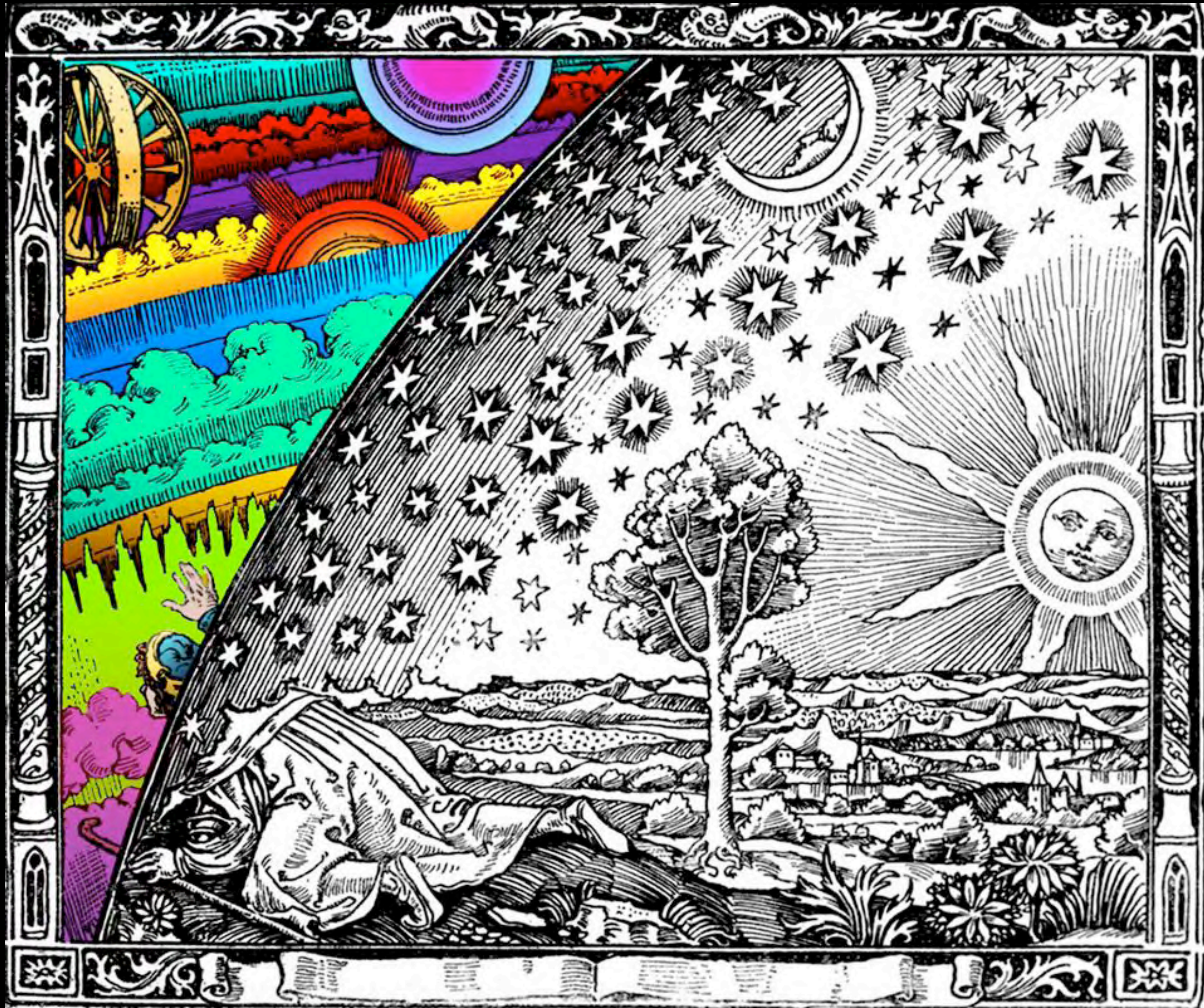

Are there extra dimensions of space that we cannot see?



(Dali, The Disintegration of the Persistence of Memory, 1954)

ATLAS EXPERIMENT
http://atlas.ch

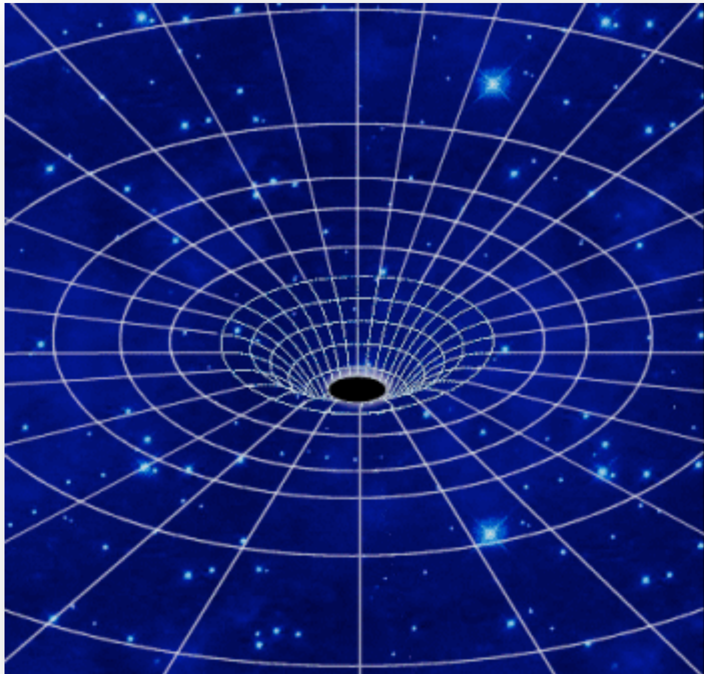
# Mysterious Extra Dimensions of Space

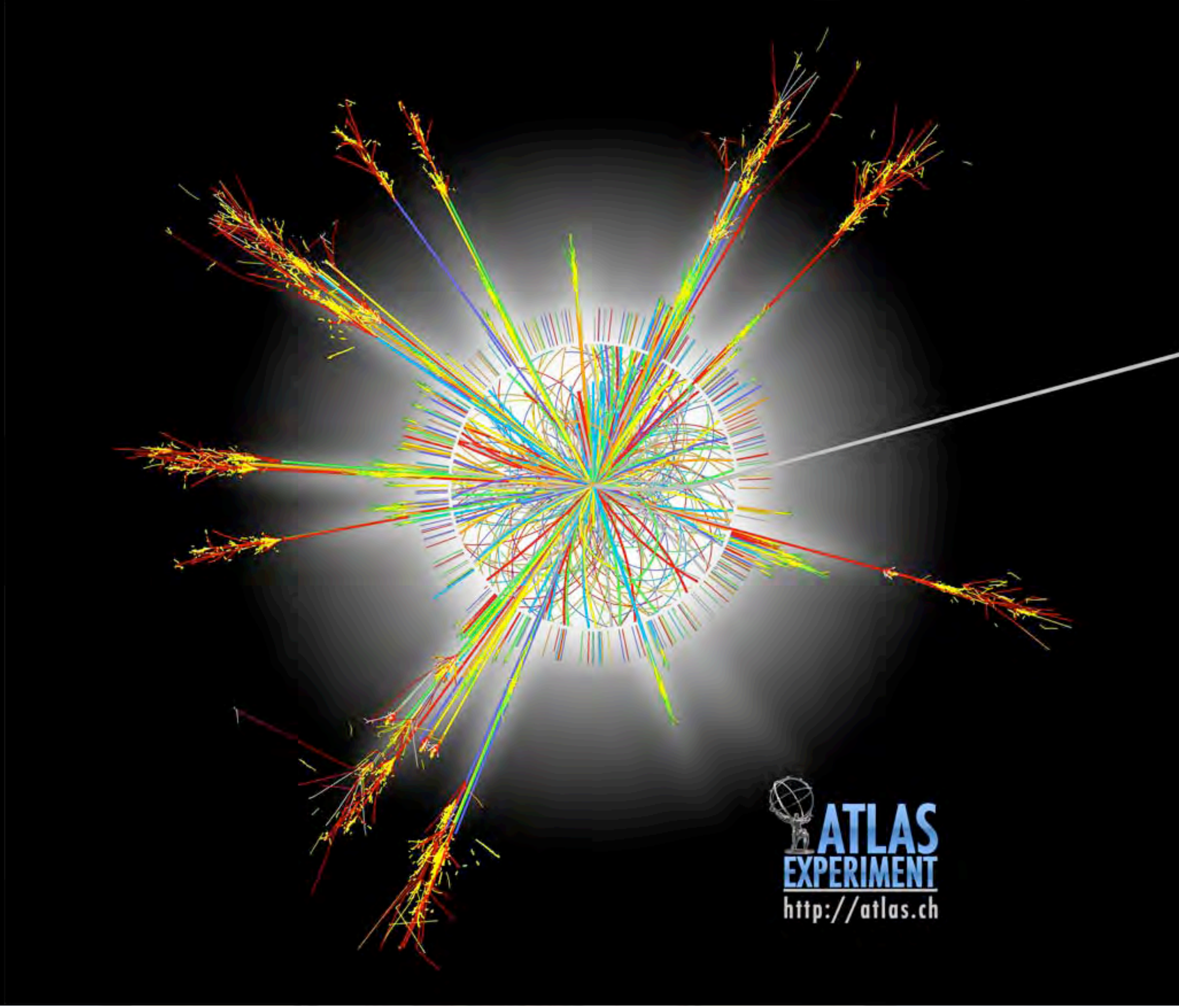
# Or Microscopic-Black Holes ?


According to some theoretical models, tiny black holes could be produced in collisions at the LHC.

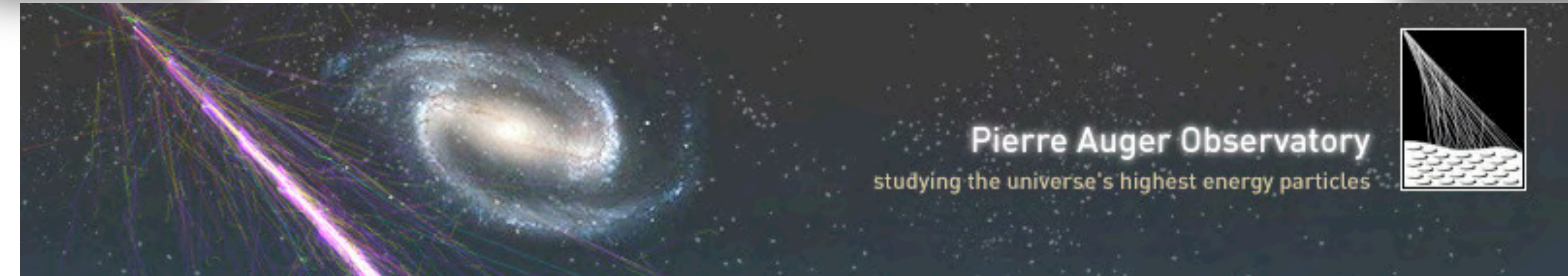
They would then very quickly decay and be detected by experiments (the tinier the black hole, the faster it evaporates).



# Microscopic-Black Hole Event

# Are Microscopic-Black Holes Dangerous?


Cosmic rays are continuously bombarding Earth's atmosphere with far more energy than protons will have at the LHC, so cosmic rays would produce everything LHC can produce.

They have done so throughout the 4.5 billion years of the Earth's existence, and the Earth is still here!

The LHC just lets us see these processes in the lab (though at a much lower energy than some cosmic rays).

So there is no danger at all. LHC is absolutely safe.

BUT, just to be sure…

# The definitive word from the Daily Show…


John Oliver: Roughly speaking what are the chances the world will be destroyed?
John Ellis (CERN Theory Division Head): There is zero percent chance – zero!
Walter Wagner (high school teacher): 50-50, since either it can happen or it can't!

http://www.thedailyshow.com/watch/thu-april-30-2009/large-hadron-collider

# Some Final Thoughts…