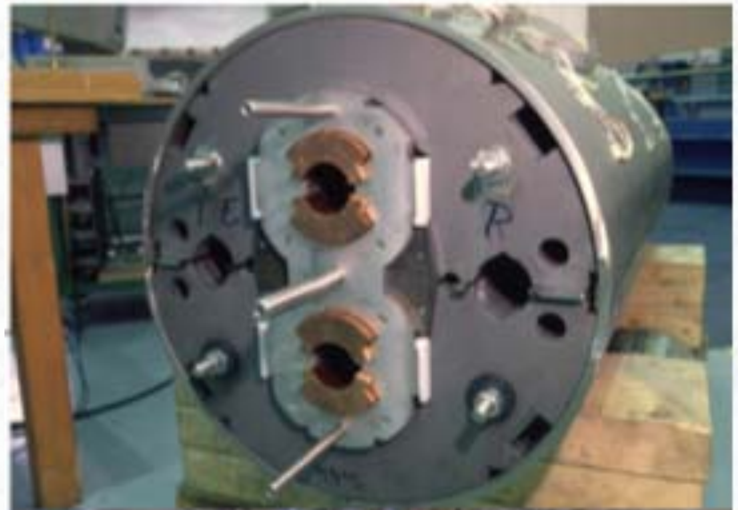
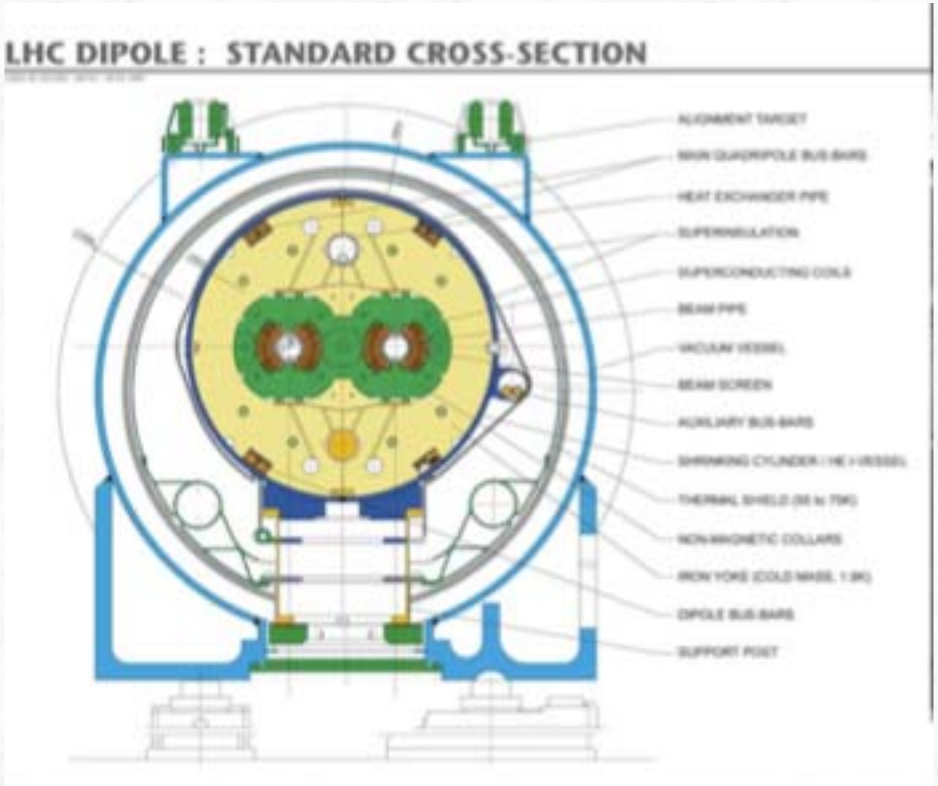
LHC dipole magnet





2 in 1 dipole magnet, 8.33 Tesla
15 m long, mass of 30 tons

Major LHC challenges

Centre-of-mass energy of 7 TeV in given (ex LEP) tunnel

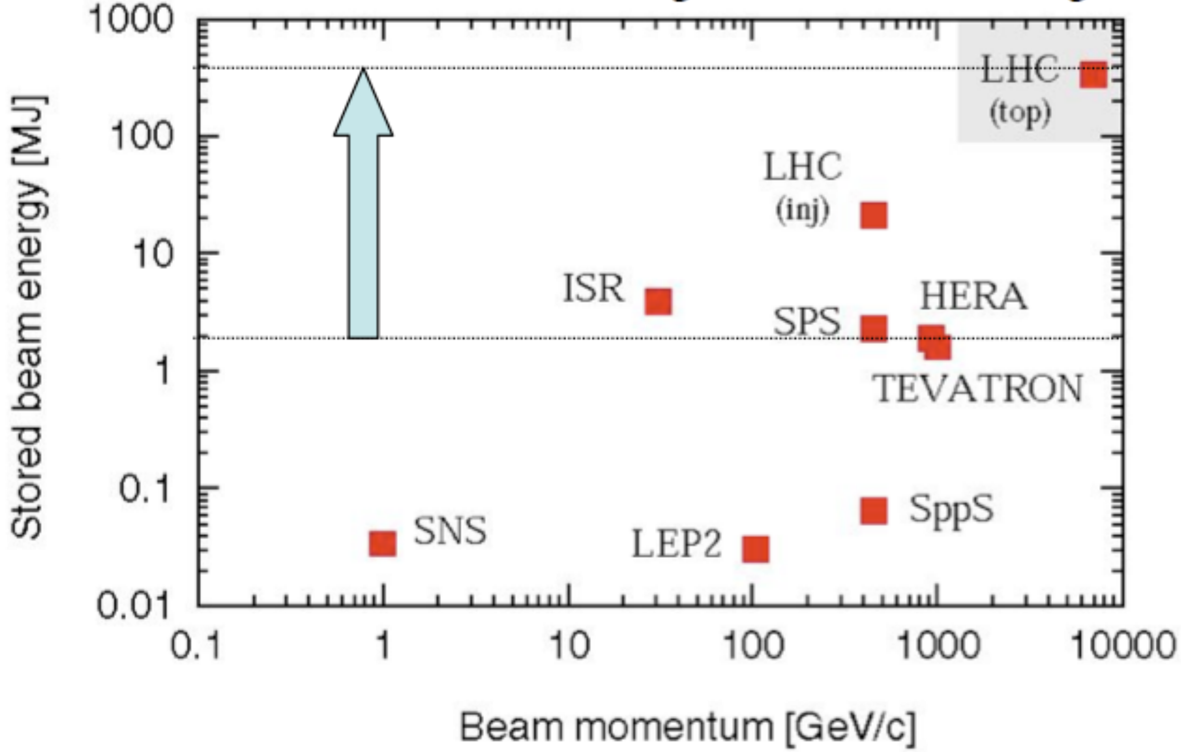
- **Magnetic field of 8.33 T with superconducting magnets**
- **Helium cooling at 1.9 K**
- **Large amount of energy stored in magnets**
- **"Two accelerators" in one tunnel with opposite magnetic dipole field and ambitious beam parameters pushed for very high of luminosity of 10^{34} cm^{-2} s^{-1}**
- **Many bunches with large amount of energy stored in beams**

Complexity and Reliability

- **Unprecedented complexity with 10000 magnets powered in 1700 electrical circuits, complex active and passive protection systems,….**

The total stored energy of the LHC beams

Nominal LHC design: 3×10^{14} protons accelerated to 7 TeV circulating at 11 kHz in a SC ring



LHC: > 100 x higher stored energy and small beam size: ~ 3 orders of magnitude in energy density and damage potential. Active protection (beam loss monitors, interlocks) and collimation for machine and experiments essential.
Only the specially designed beam dump can safely absorb this energy.

Beam parameters, LHC compared to LEP

	LHC	LEP2
Momentum at collision, TeV/c	7	0.1
Nominal design Luminosity, $cm^{-2}s^{-1}$	1.00E+34	1.00E+32
Dipole field at top energy, T	1	1
Number of bunches, each beam	2808	4
Particles / bunch	1.15E+11	4.20E+11
Typical beam size in ring, µm	200-300	1800/140 (H/V)
Beam size at IP, µm	16	200/3 (H/V)

- **Energy stored in the magnet system: 10 GJoule**
- **Energy stored in one (of 8) dipole circuit: 1.1 GJ**
- **Energy stored in one beam: 362 MJ**
- **Energy to heat and melt one kg of copper: 0.7 MJ**

Kin. energy of Airbus A380, 560t at 700 km/h.

the LEP2 total stored beam energy was about 0.03 MJ

LHC: From first ideas to realisation

26 y

1982 : First studies for the LHC project

1983 : Z discovered at SPS proton antiproton collider

1989 : Start of LEP operation ~ 92 GeV, Z-factory

1994 : Approval of the LHC by the CERN Council

1996 : Final decision to start the LHC construction

1996 : LEP2 operation towards ~ 200 GeV, W^+W^-

2000 : End of LEP operation

2002 : LEP equipment removed

2003 : Start of the LHC installation - infrastructure

2005 : Start of Magnet installation in LHC tunnel

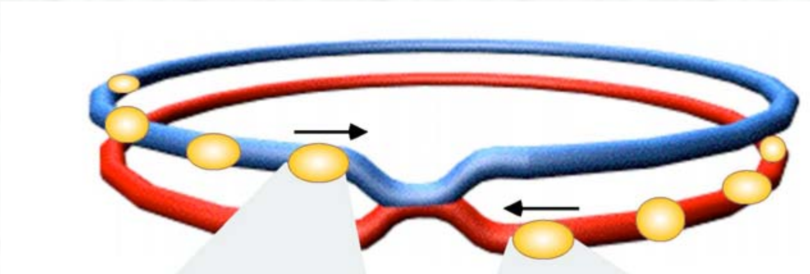
2007 : Installation complete, starting cooldown

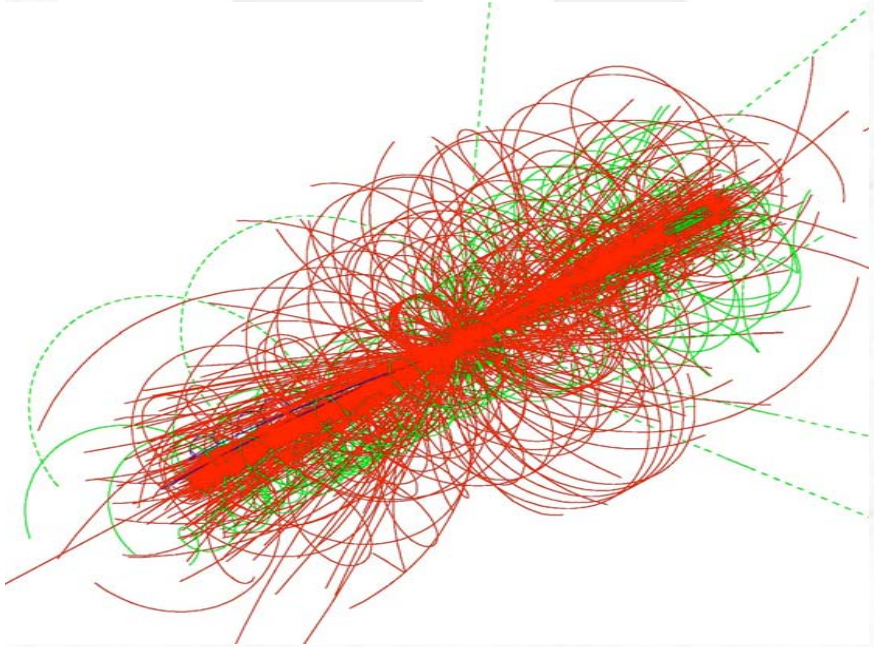
2008 : Commissioning with beam and first collisions

14 y

7 y

Proton-Proton Kollisionen am LHC





Proton – Proton:

2808 x 2808 Pakete (bunches)
Separation: 7.5 m (25 ns)

10^{11} Protonen / bunch
Kreuzungsrate der p-Pakete: 40 Mio / s
Luminosität: $L = 10^{34}$ cm^{-2} s^{-1}

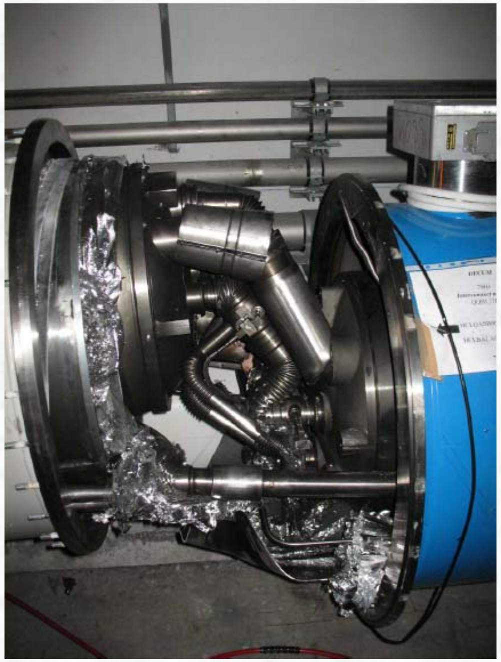
~10^9 pp Kollisionen / s
(Überlagerung von 23 pp-Wechselwirkungen
per Strahlkreuzung: **pile-up**)

~1600 geladene Teilchen im Detektor

⇒ Hohe Teilchendichten,
hohe Anforderungen an die Detektoren

An excellent LHC start: first beams – Sept 10, 2008

Incident on 19th Sep. 2008, repair, comeback…..

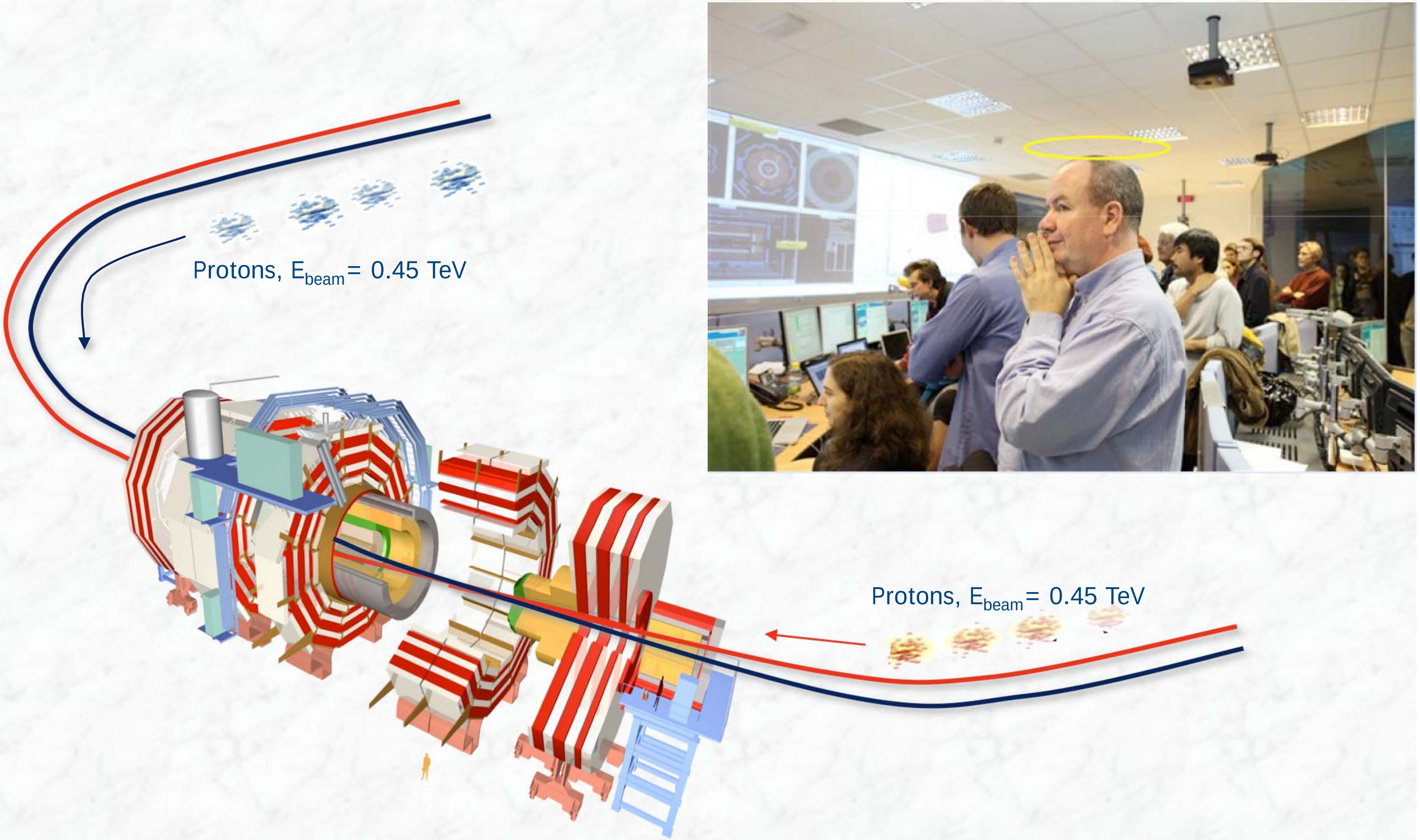


- A resistive zone developed in an electrical bus bar connection
- Electrical arc → punctured the helium enclosure
- Helium release under high pressure
- Relief discs unable to maintain the pressure rise below 0.15 MPa → large pressure forces

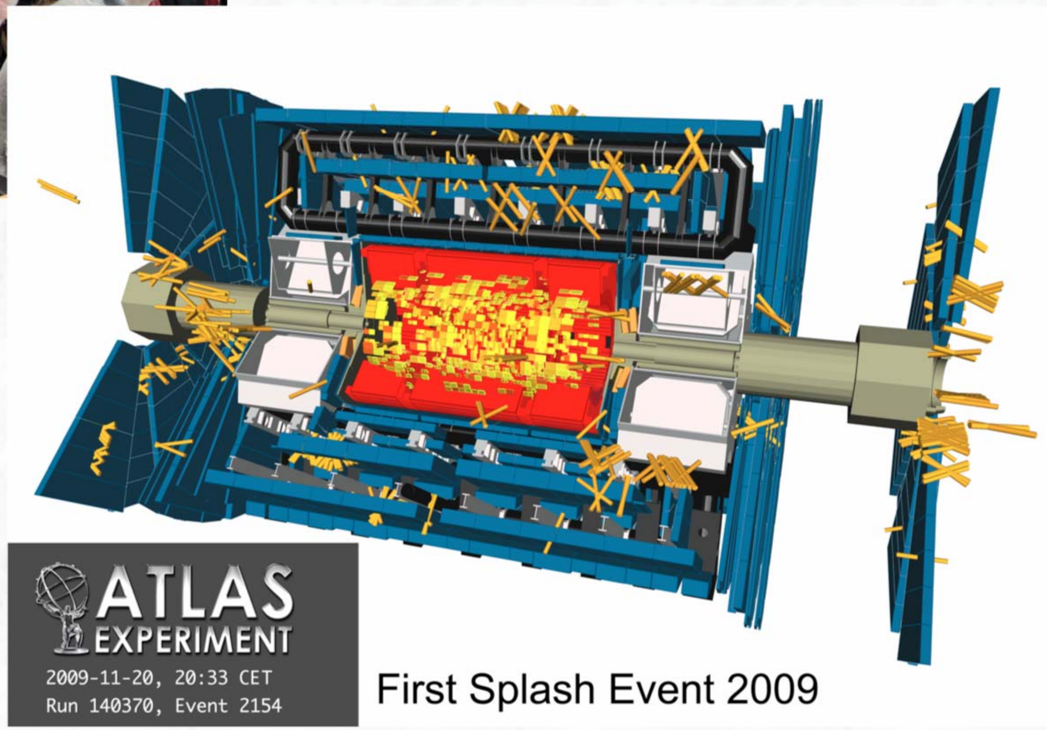
- Lot of repair work during 2009
(14 quadrupole and 39 dipole magnets replaced, electrical interconnections repaired, larger helium pressure release ports installed,…..)

- **A very successful re-start in Nov. 2009**

LHC re-start in Nov. 2009



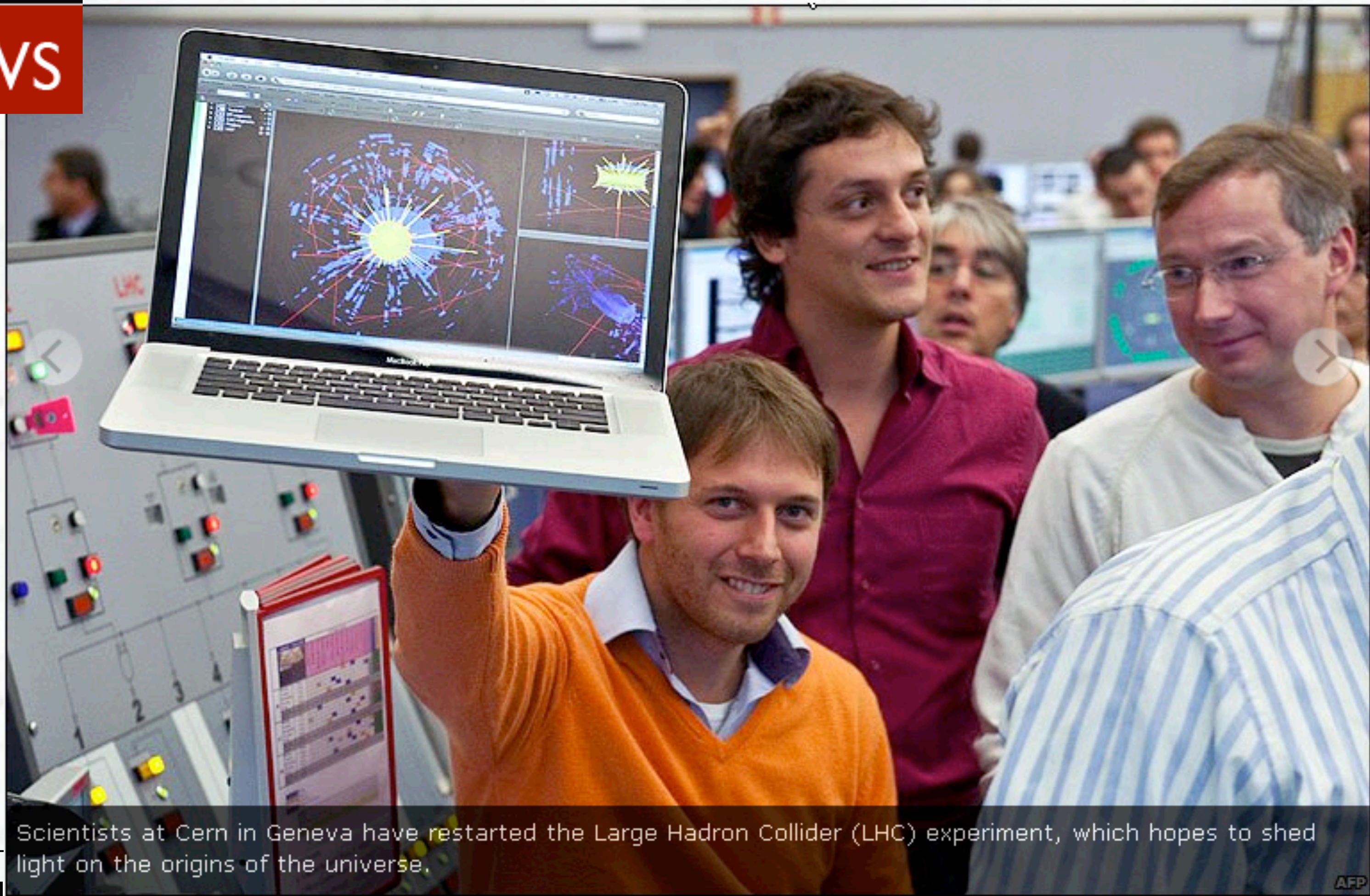
The first signals in the ATLAS experiment, 20. Nov 2009



CMS in the BBC news

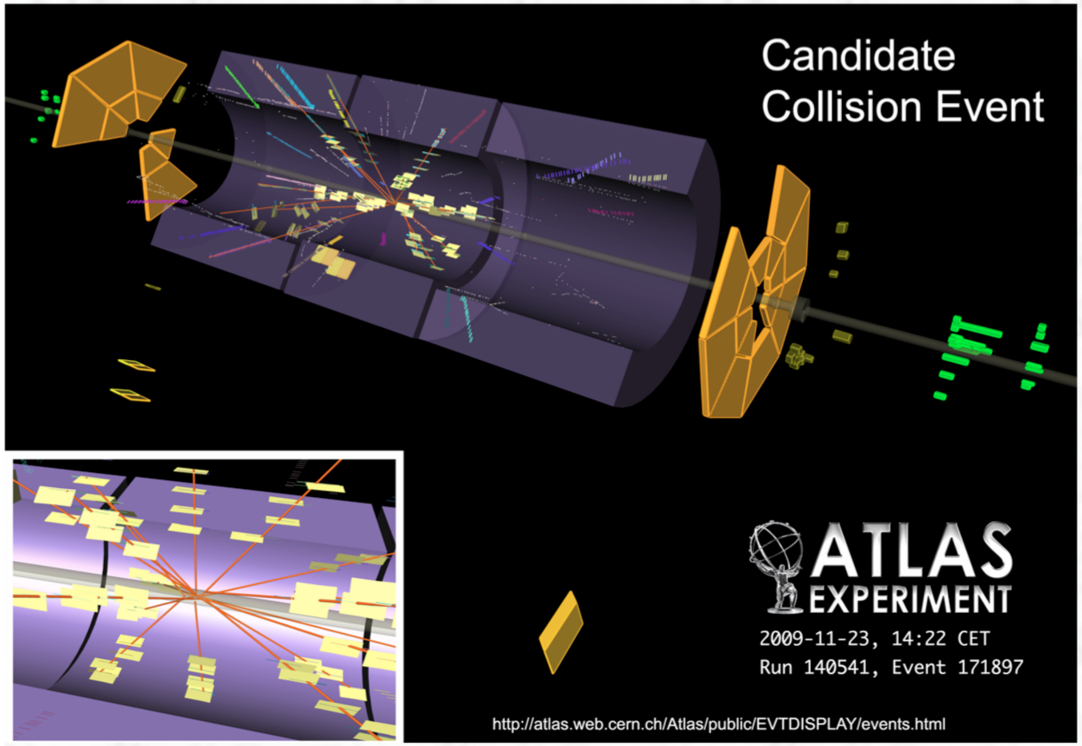
November 21, 2009

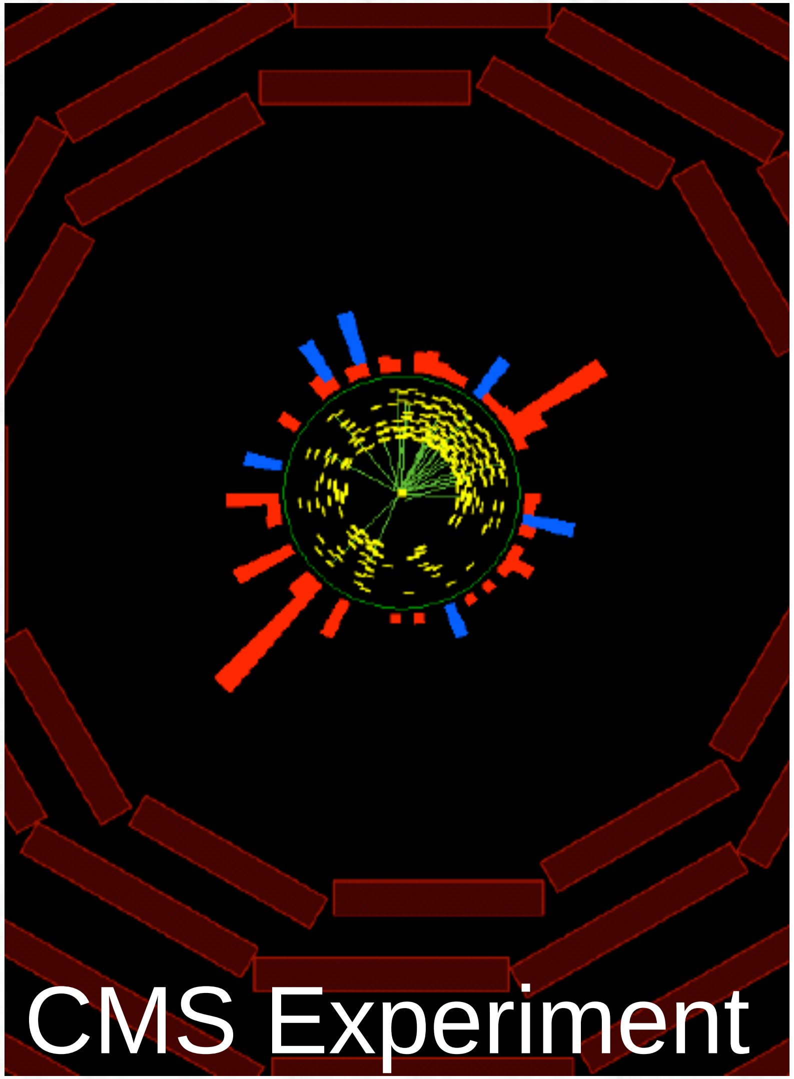
BBC NEWS



Scientists at Cern in Geneva have restarted the Large Hadron Collider (LHC) experiment, which hopes to shed light on the origins of the universe.

23. Nov 2009: First collisions at 900 GeV

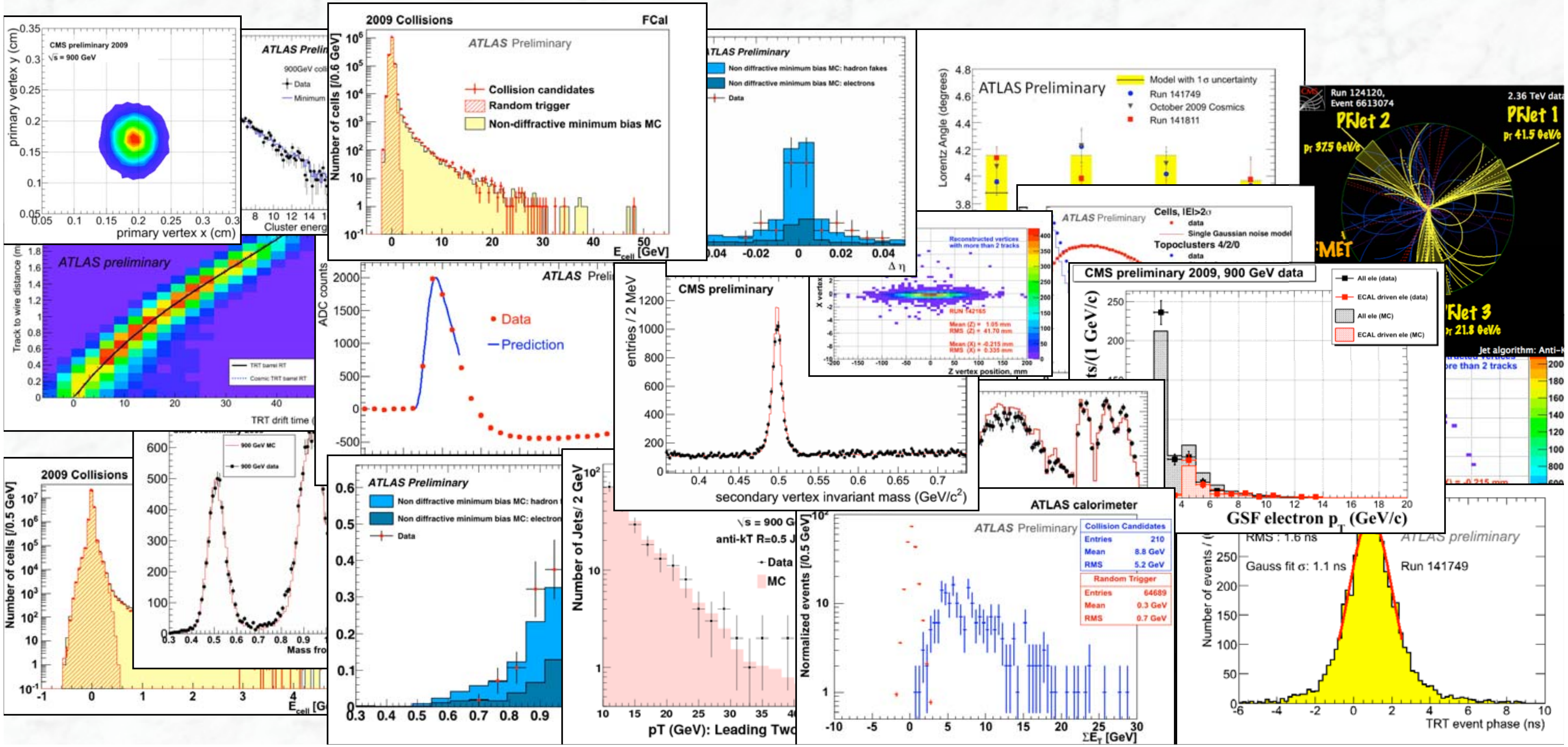




23rd Nov 2009

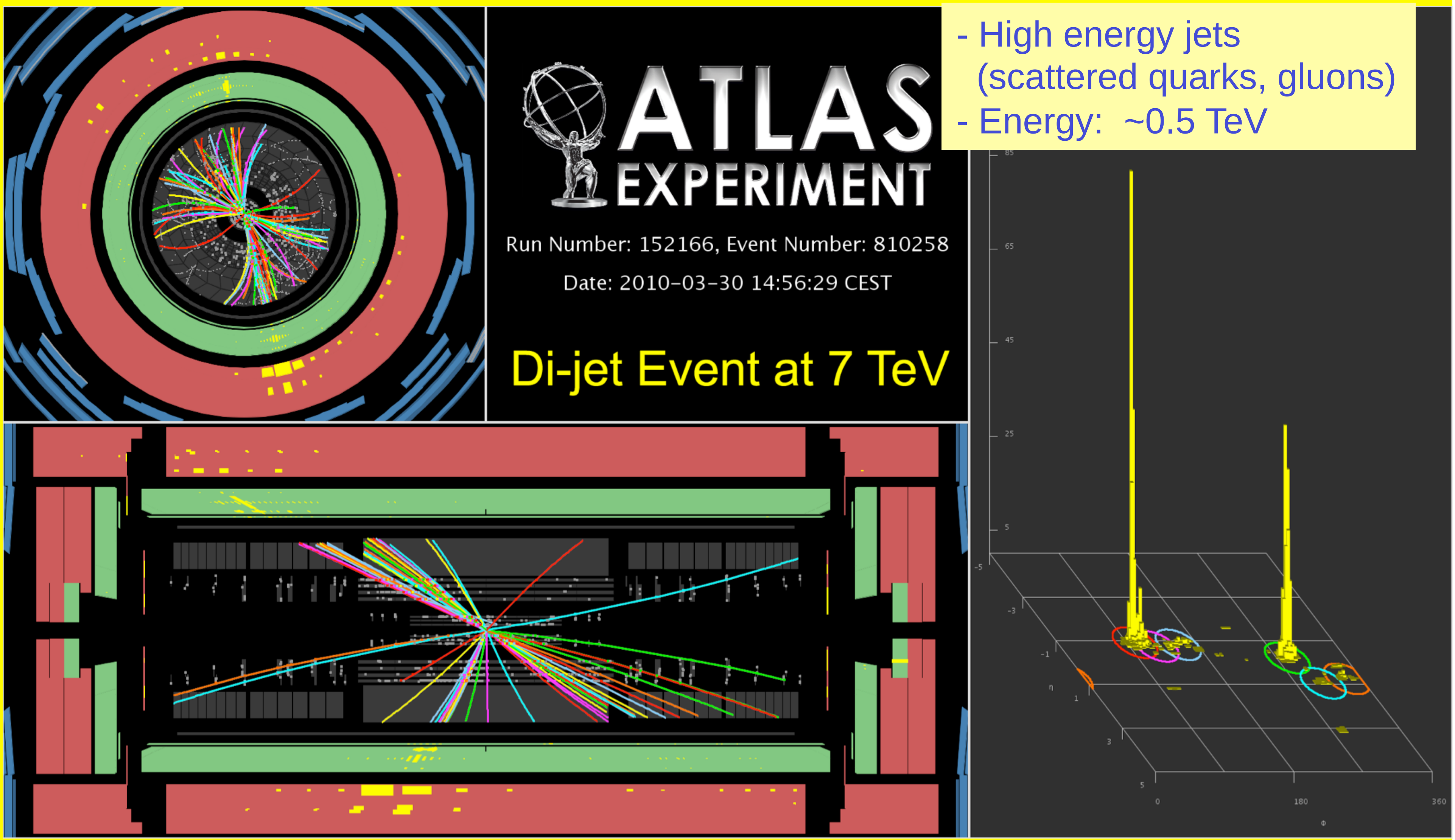
First results
on detector performance after only
a few days / weeks

First publications of physics results in Feb/March 2010



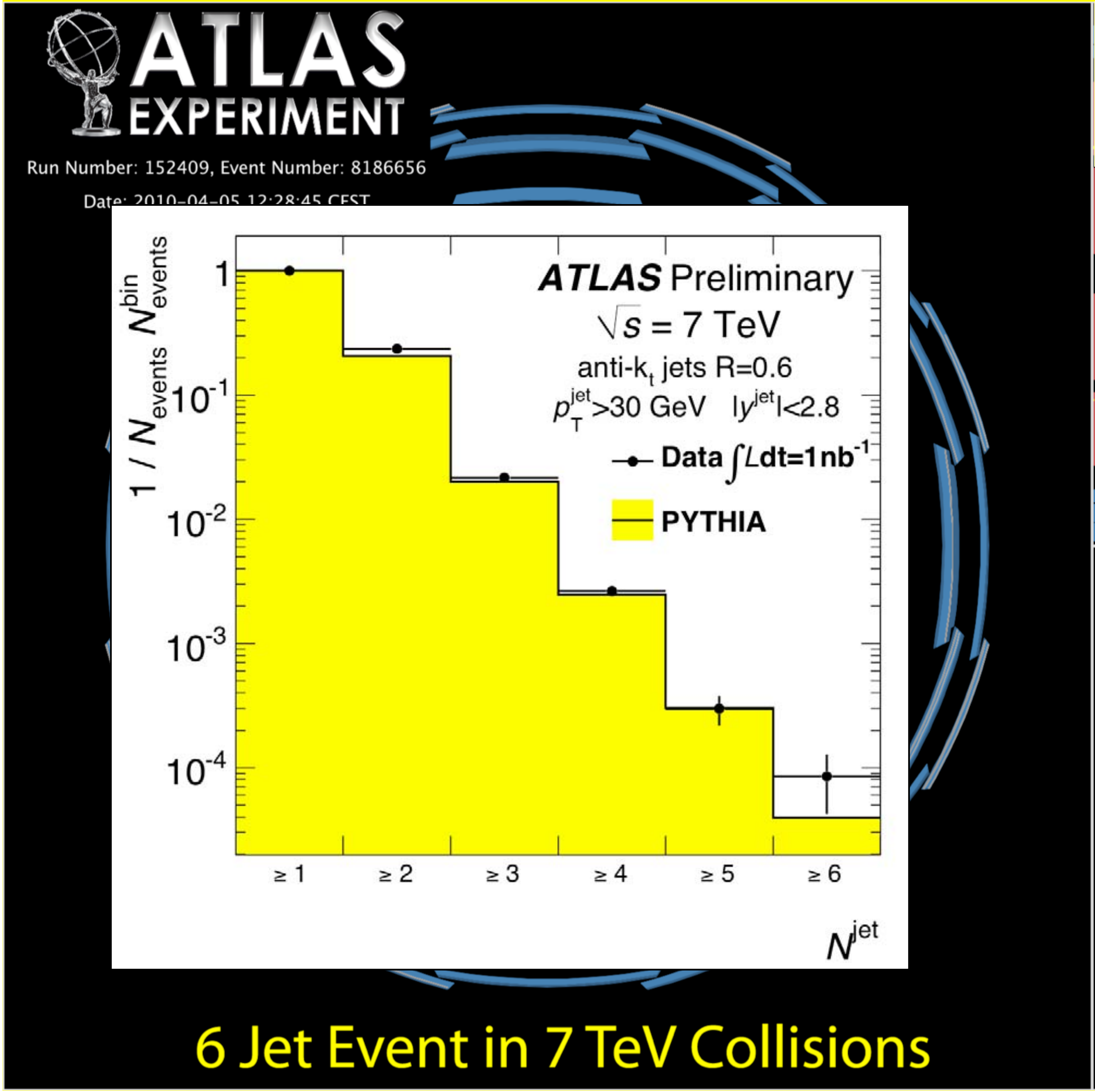
Since 30. March 2010: collisions at 7 TeV

(.... first interesting results appeared soon)

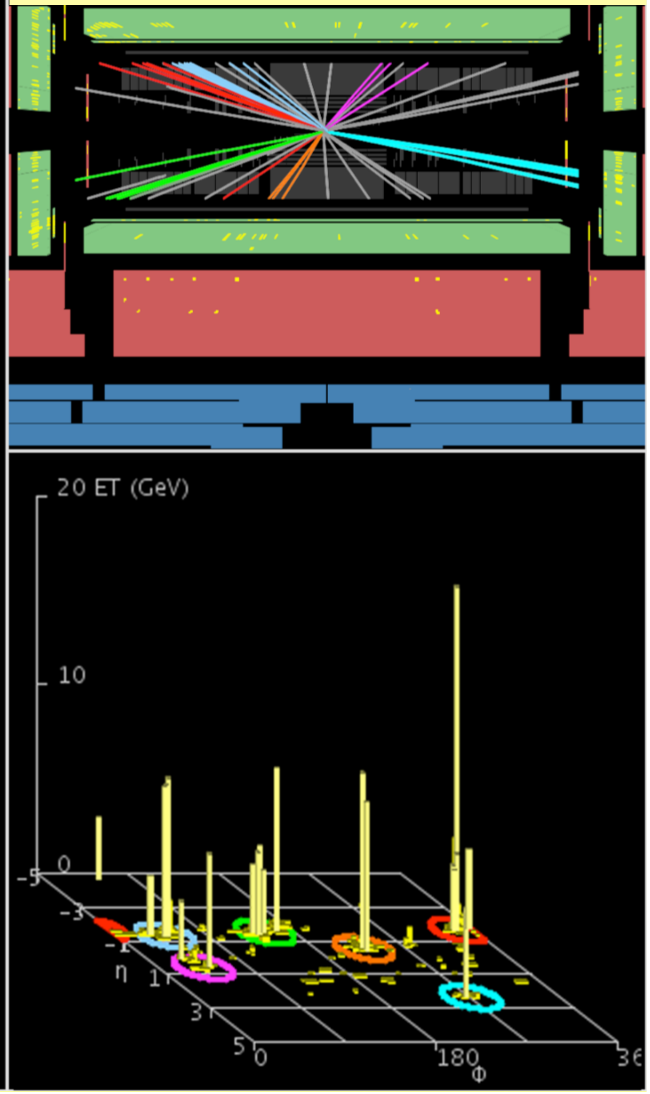


- High energy jets
  (scattered quarks, gluons)
- Energy: ~0.5 TeV

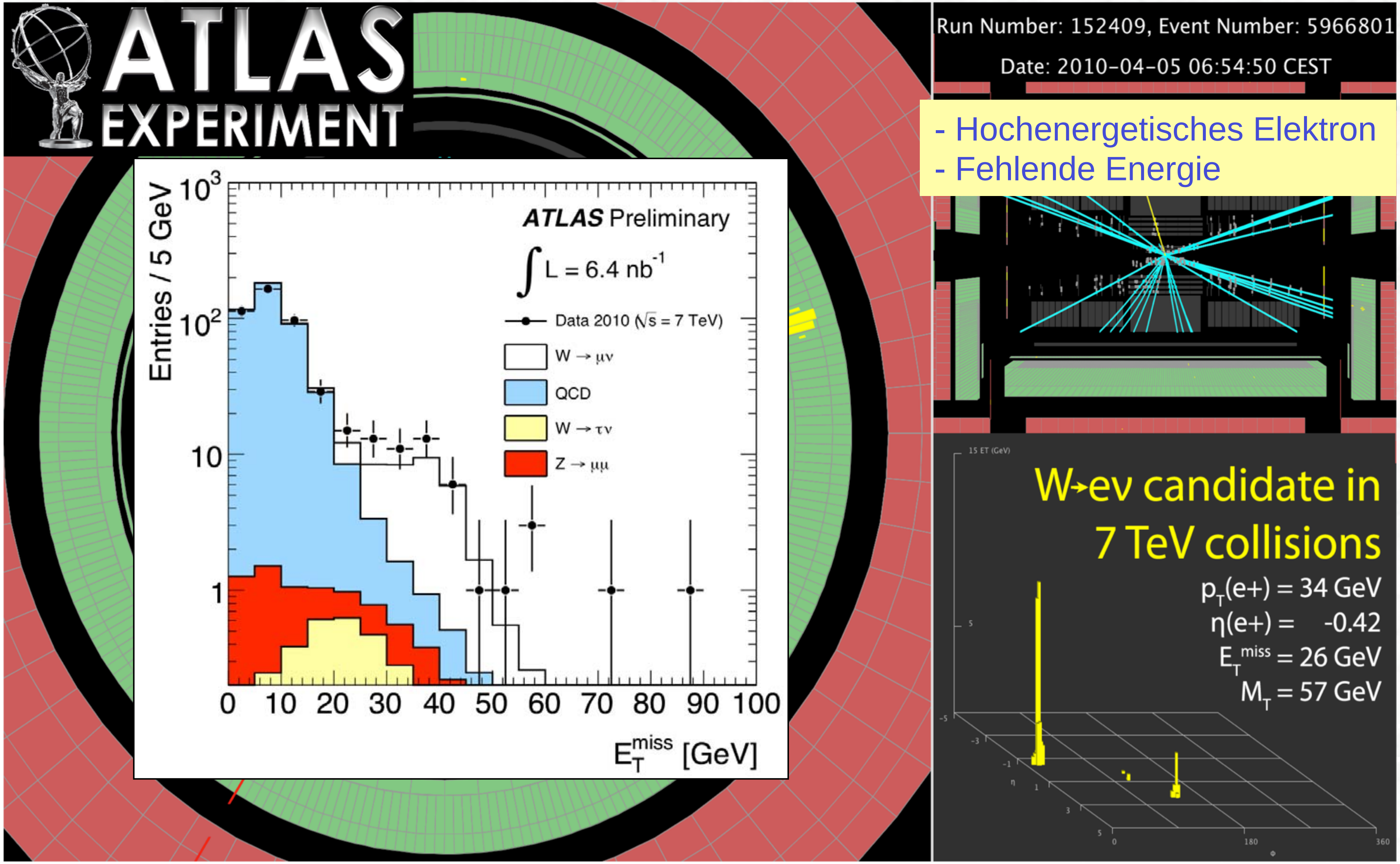
A six-jet event at 7 TeV



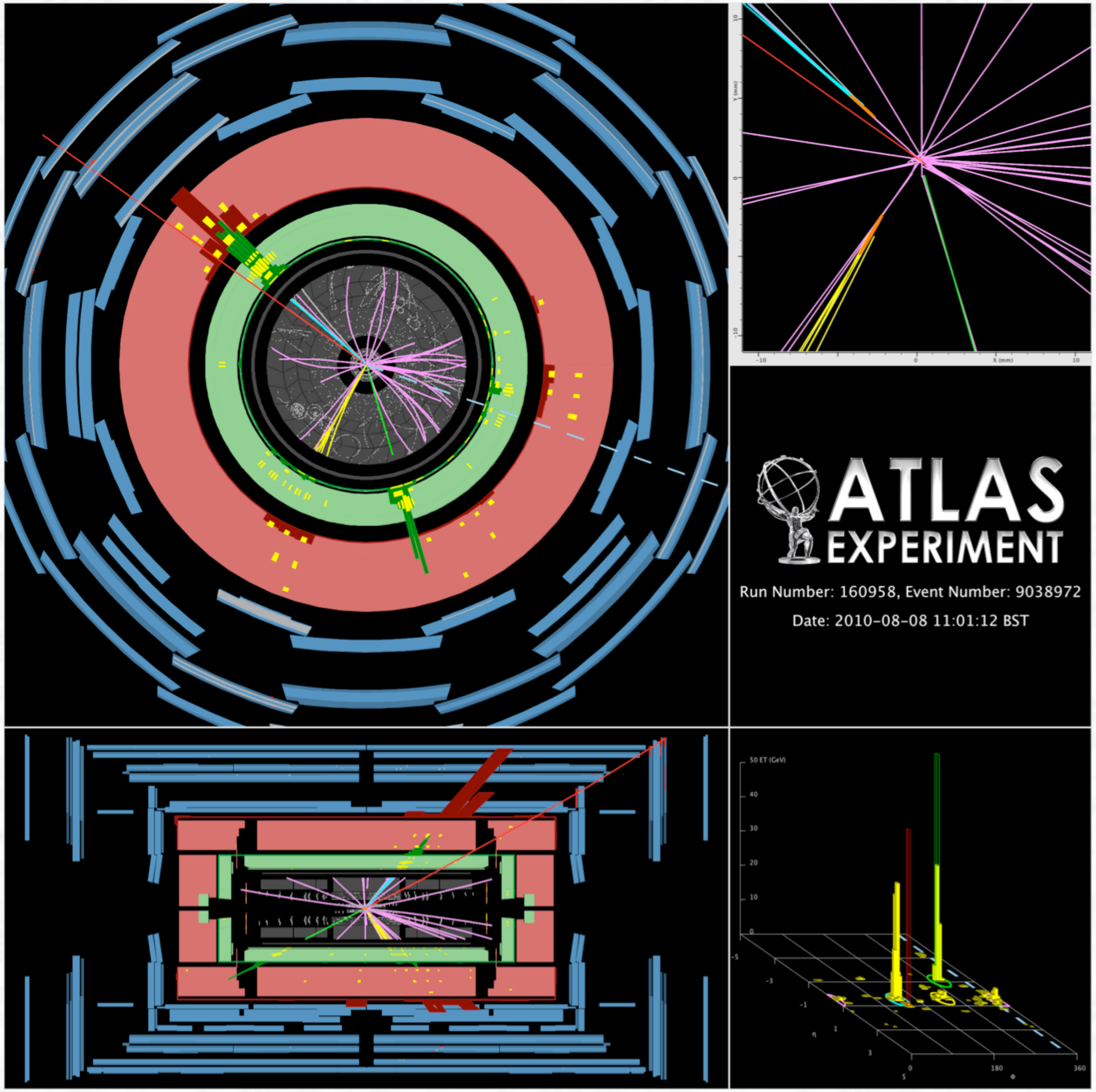
Hochenergetische Jets
(gestreute Quarks, Gluonen
abgestrahlte Gluonen)

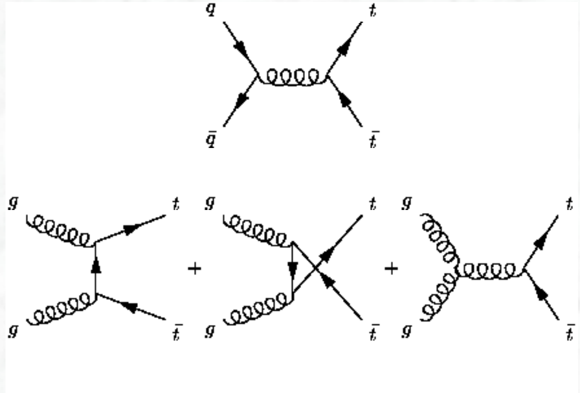


Production of W and Z bosons



Production of the first top quarks in Europe





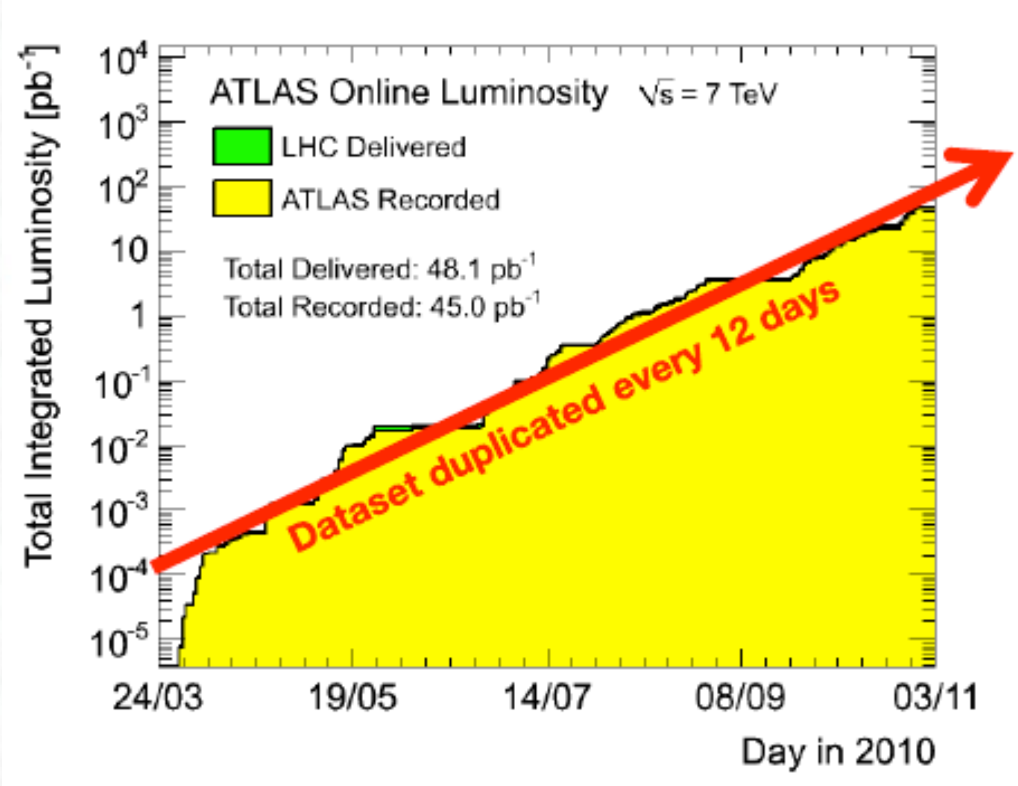
$tt \rightarrow Wb \;\; Wb \rightarrow e\nu b \; \mu\nu b$

The fragmentation products of b-quarks (B-Hadrons) have a life time of 1.5 ps

= decay distance of ~2.5 mm

Collected data in 2010:

~40 pb^{-1} recorded
~36 pb^{-1} used in analysis
(good quality)

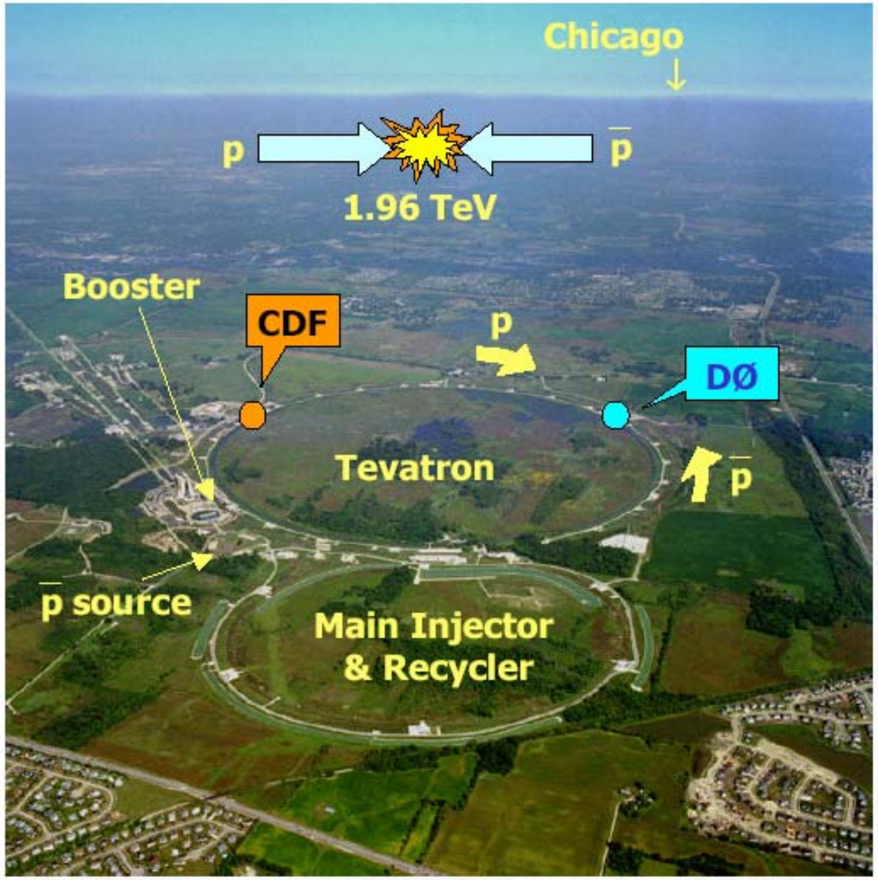


Running again since a few weeks

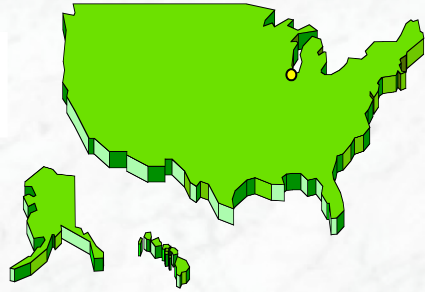
collected so far: > 100 pb^{-1}
expected for 2011: 1 – 2 fb^{-1}

World record in instantaneous luminosity on 22. April 2011: $4.67\ 10^{32}\ cm^{-2}\ s^{-1}$
so far: Tevatron record: $4.02\ 10^{32}\ cm^{-2}\ s^{-1}$

1.4 The Fermilab Tevatron collider



The Tevatron Collider at Fermilab

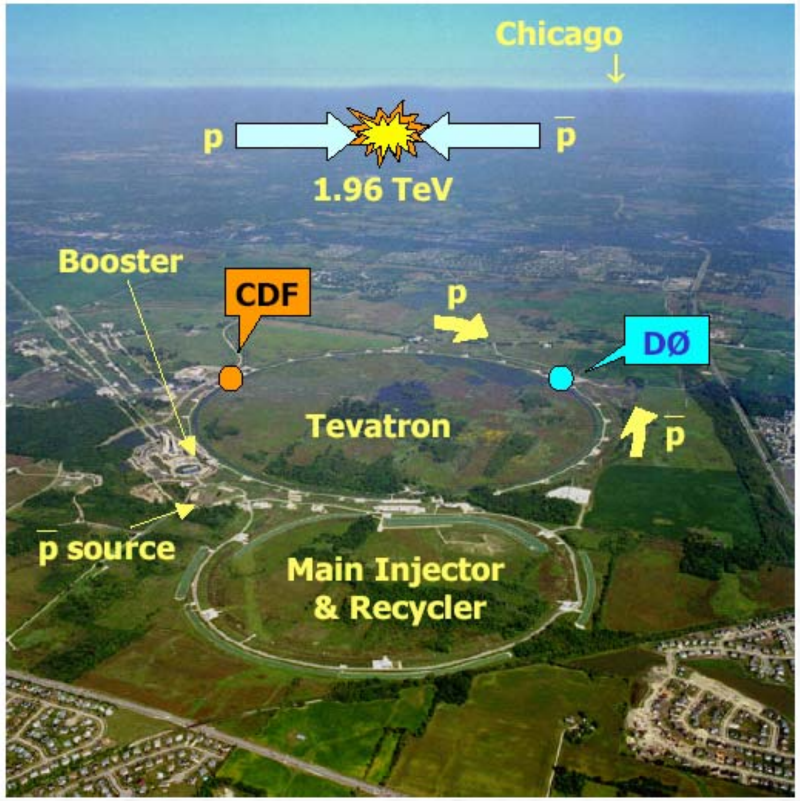


- <u>**Proton antiproton collider**</u>

  - 6.5 km circumference

  - Beam energy 0.98 TeV, **$\sqrt{s}$ = 1.96 TeV**

  - 36 bunches, 396 ns separation (time between crossings)



- **2 Experiments: CDF and DØ**

- **Main challenges:**

  - Antiproton production and storage

  → luminosity, stability of operation

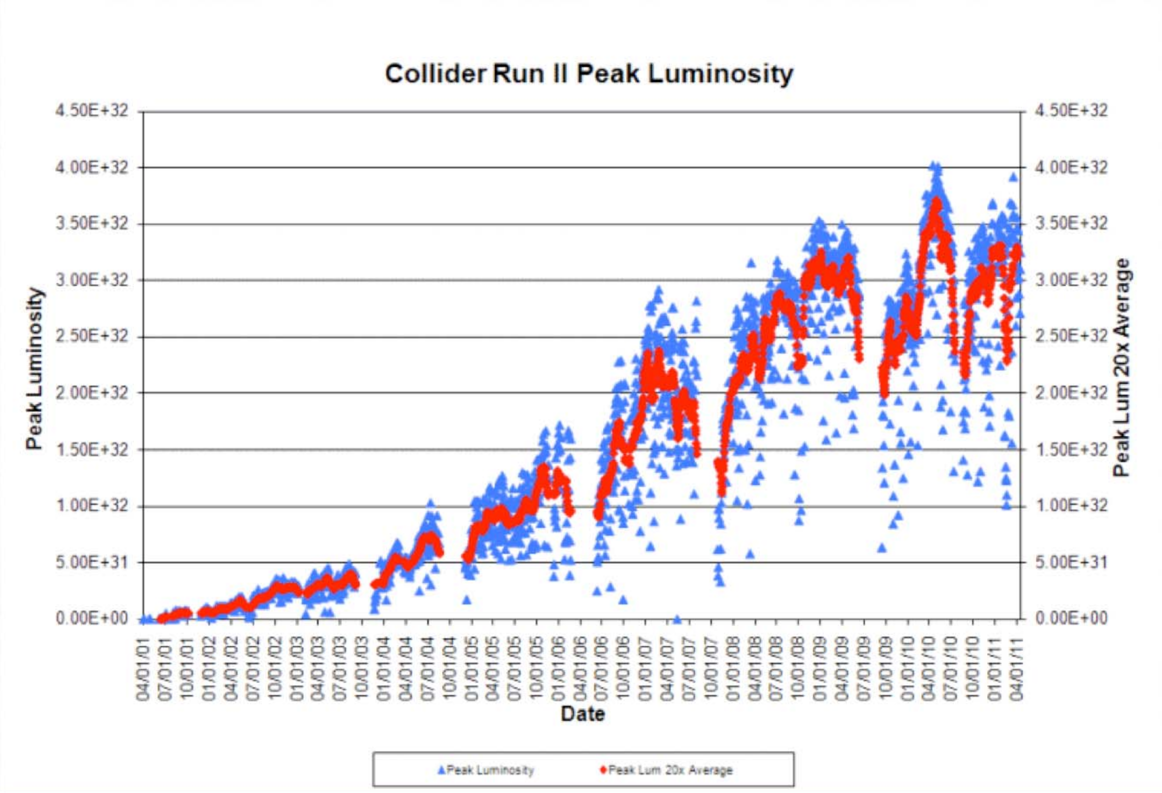
Collider is running in so called Run II (since 2001)

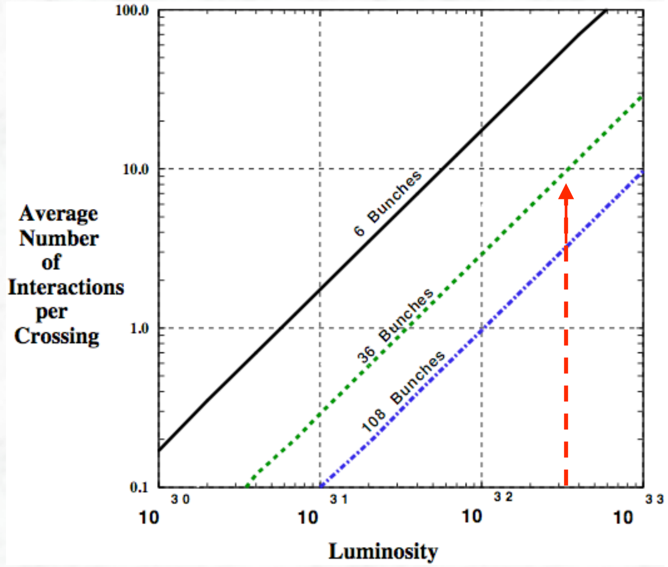
[Run I from 1990 – 1996, int. luminosity: 0.125 fb^{-1}, Top quark discovery]

- **March 2001 – Feb 2006:** **Run II a,** **$\int L\,dt$ = 1.2 fb^{-1}**
- **July 2006 - 2011:** **Run II b,** **$\int L\,dt$ = 10 -12 fb^{-1}**

Tevatron performance

Peak luminosities of the machine as a function of time



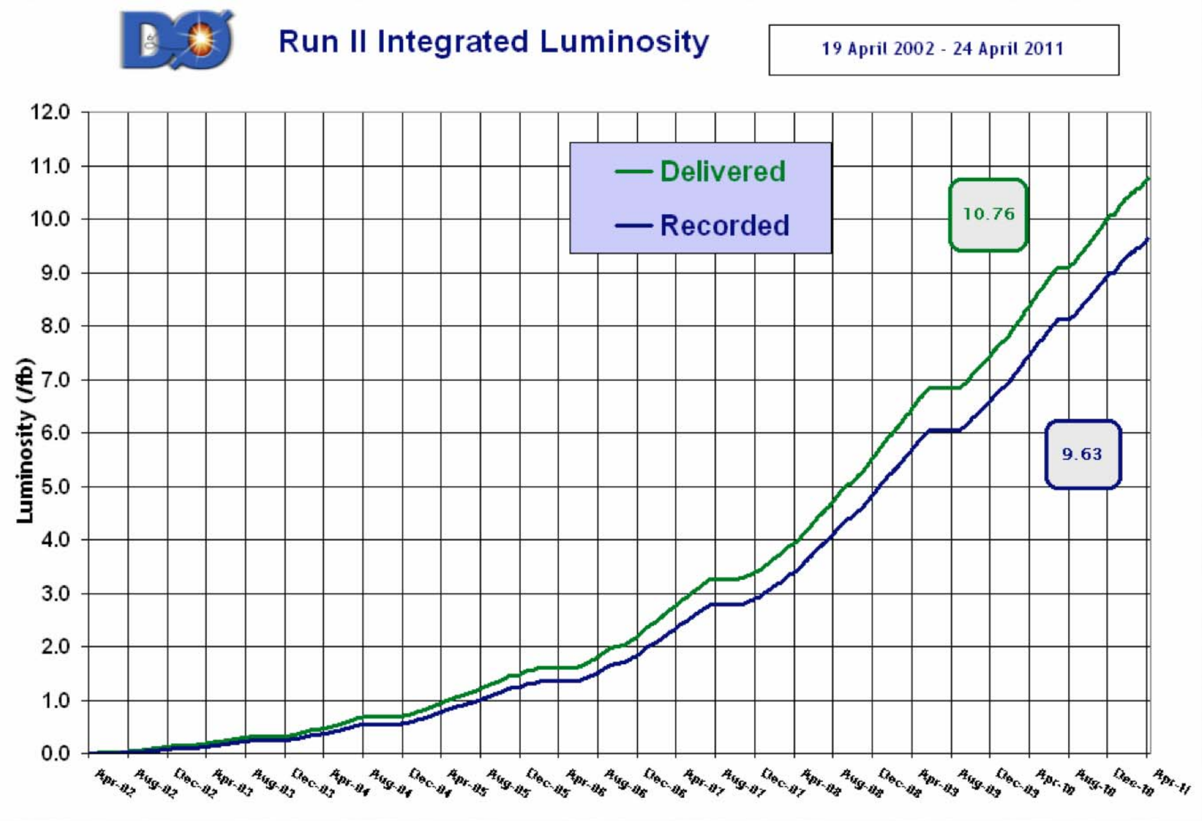


• Peak luminosity of $4 \cdot 10^{32}$ cm^{-2} s^{-1}

• Corresponds to ~10 interactions per bunch crossing
(superposition of minimum bias events on hard collision)

The integrated Tevatron luminosity (until April 2011)

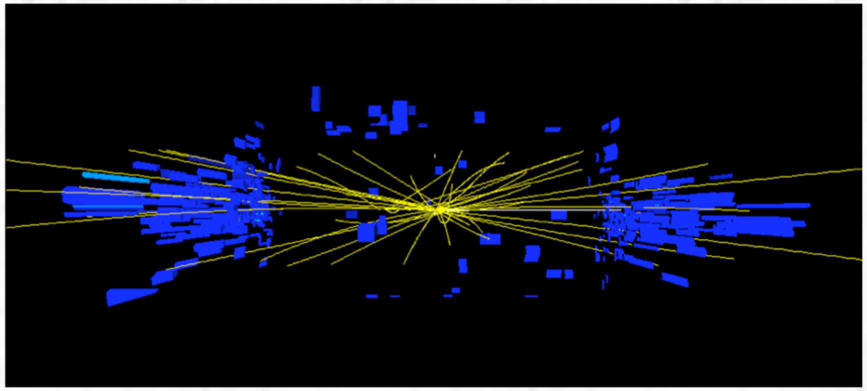
- After a slow start-up (2001 – 2003), the Tevatron accelerator has reached an excellent performance
- Today, Tevatron delivers a data set equal to Run I (~100 pb^{-1}) every 2 weeks
- Integrated luminosity delivered to the experiments so far ~ 10.8 fb^{-1}
- Anticipate an int. luminosity of ~12 fb^{-1} until end of 2011.



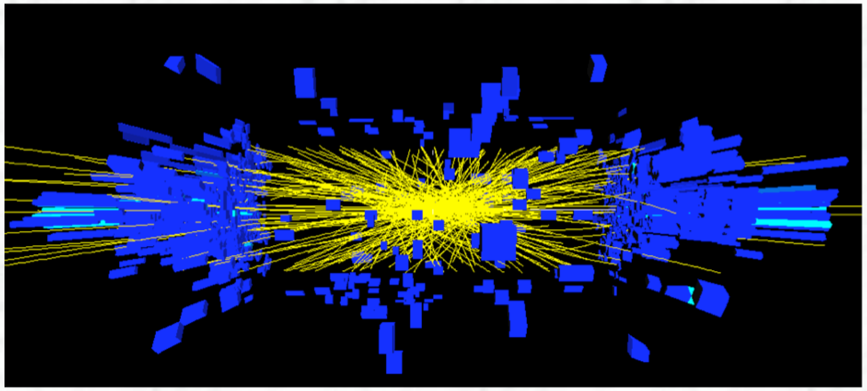
Data corresponding to an int. luminosity of up to ~8 fb^{-1} analyzed…

Challenges with high luminosity

Min. bias pileup at the Tevatron, at $0.6 \cdot 10^{32}$ cm^2s^{-1}



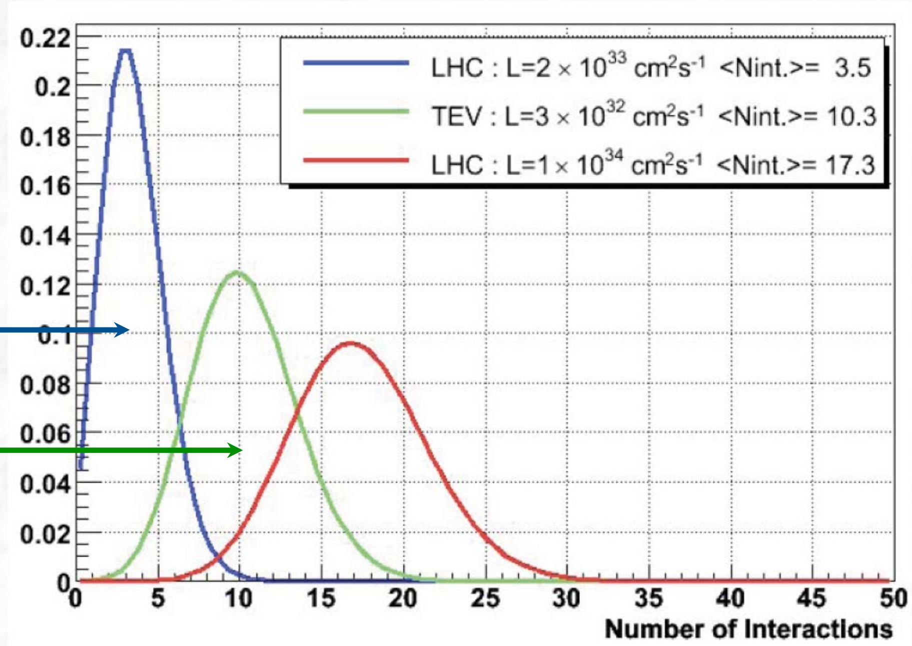
... and at $2.4 \cdot 10^{32}$ cm^2s^{-1}



Average number of interactions:

LHC: initial “low” luminosity run
(L=2 $\cdot 10^{33}$ cm^2s^{-1}): <N>=3.5

TeV: (L=3 $\cdot 10^{32}$ cm^2s^{-1}): <N>=10



Comparison of the LHC and Tevatron machine parameters

	LHC (design)	Tevatron (achieved)
Centre-of-mass energy	**14 TeV**	**1.96 TeV**
Number of bunches	**2808**	**36**
Bunch spacing	**25 ns**	**396 ns**
Energy stored in beam	**360 MJ**	**1 MJ**
Peak Luminosity	**10^{33}-10^{34} cm^{-2}s^{-1}**	**3.5 x 10^{32} cm^{-2}s^{-1}**
Integrated Luminosity / year	**10-100 fb^{-1}**	**~ 2 fb^{-1}**

– 7 times more energy (after initial 3.5 TeV phase)
– Factor 3-30 times more luminosity
– Physics cross sections factor 10-100 larger