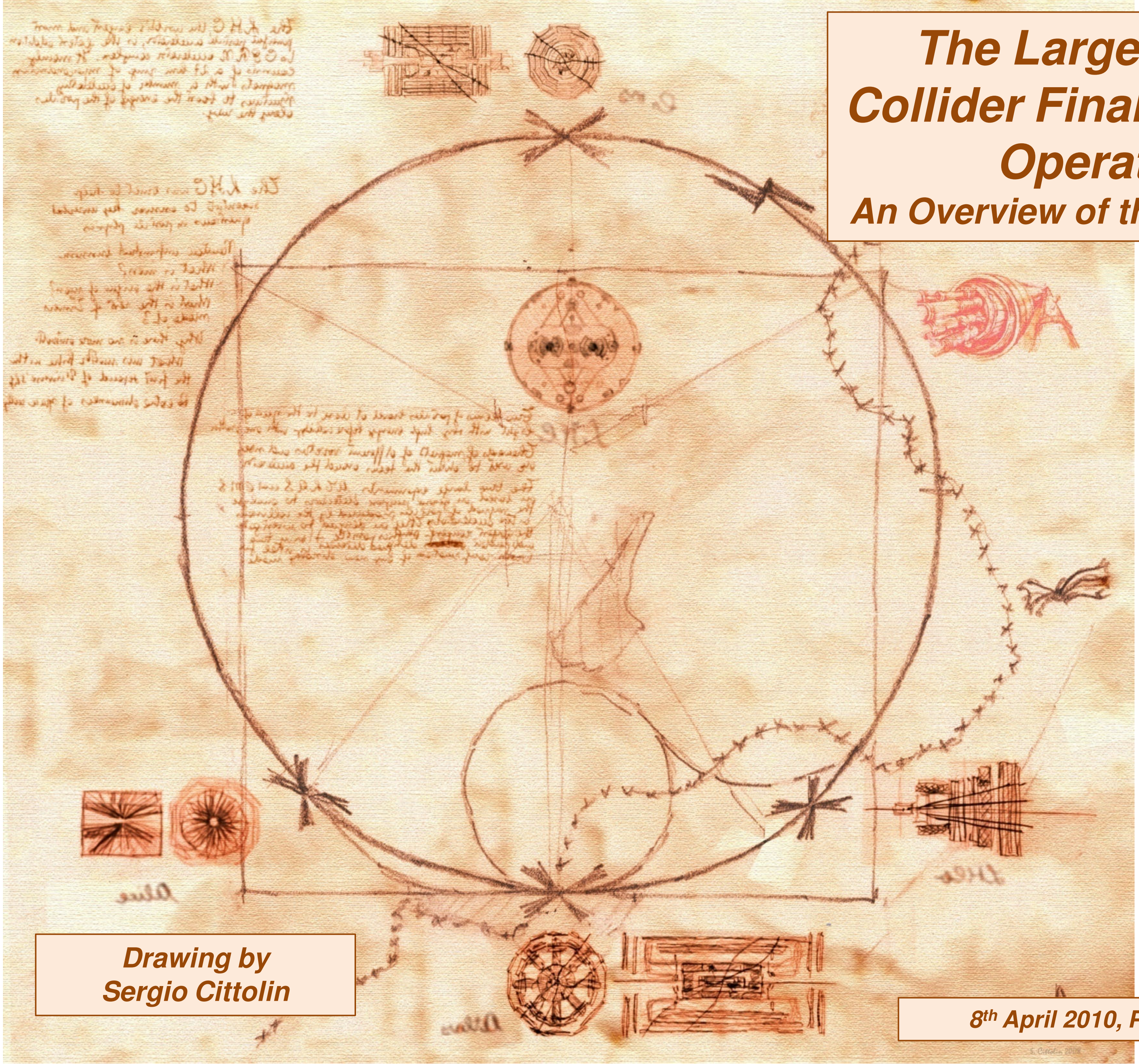


The Large Hadron Collider Finally Entering Operation:

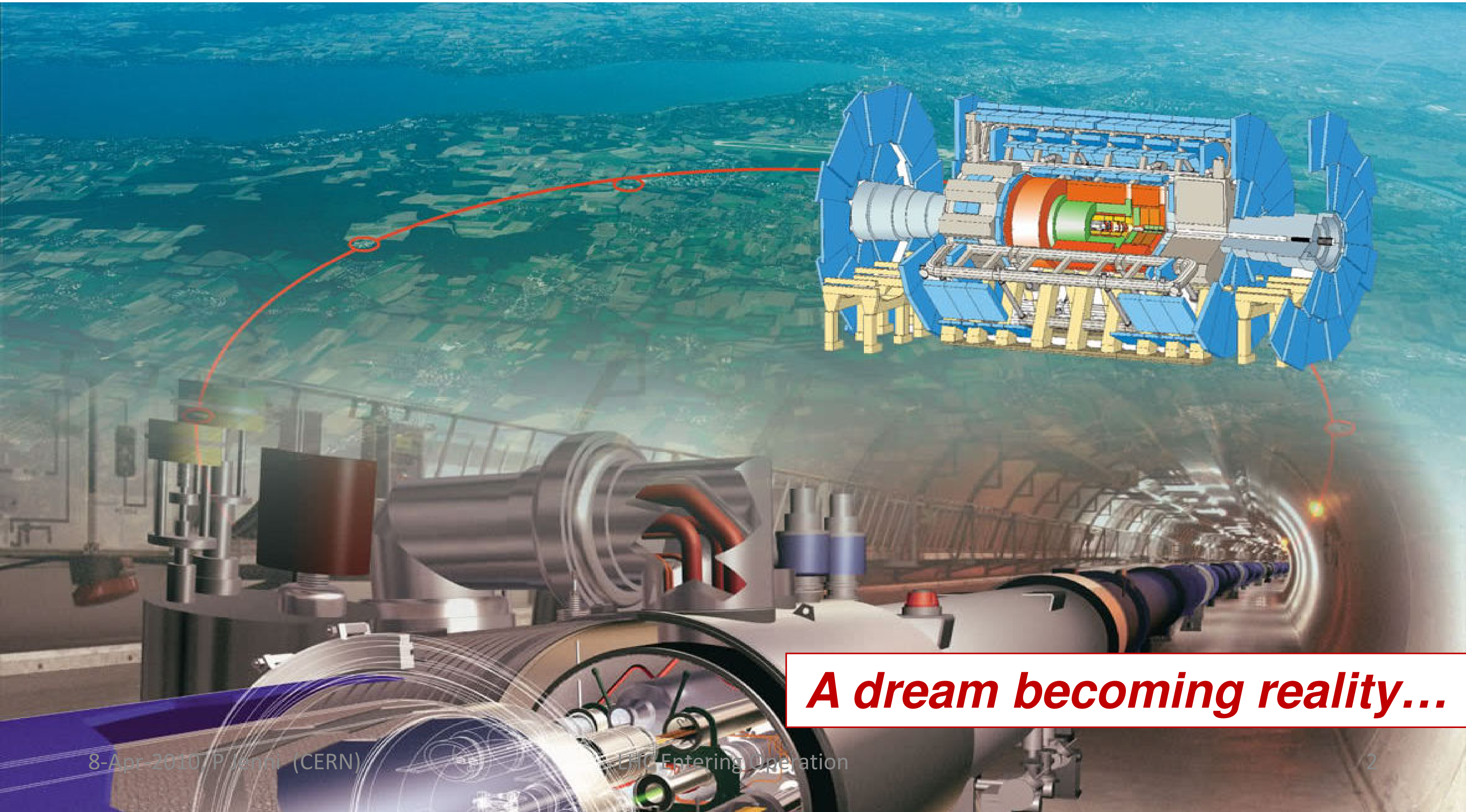
An Overview of the LHC Project

Drawing by Sergio Cittolin

8th April 2010, Peter Jenni, CERN

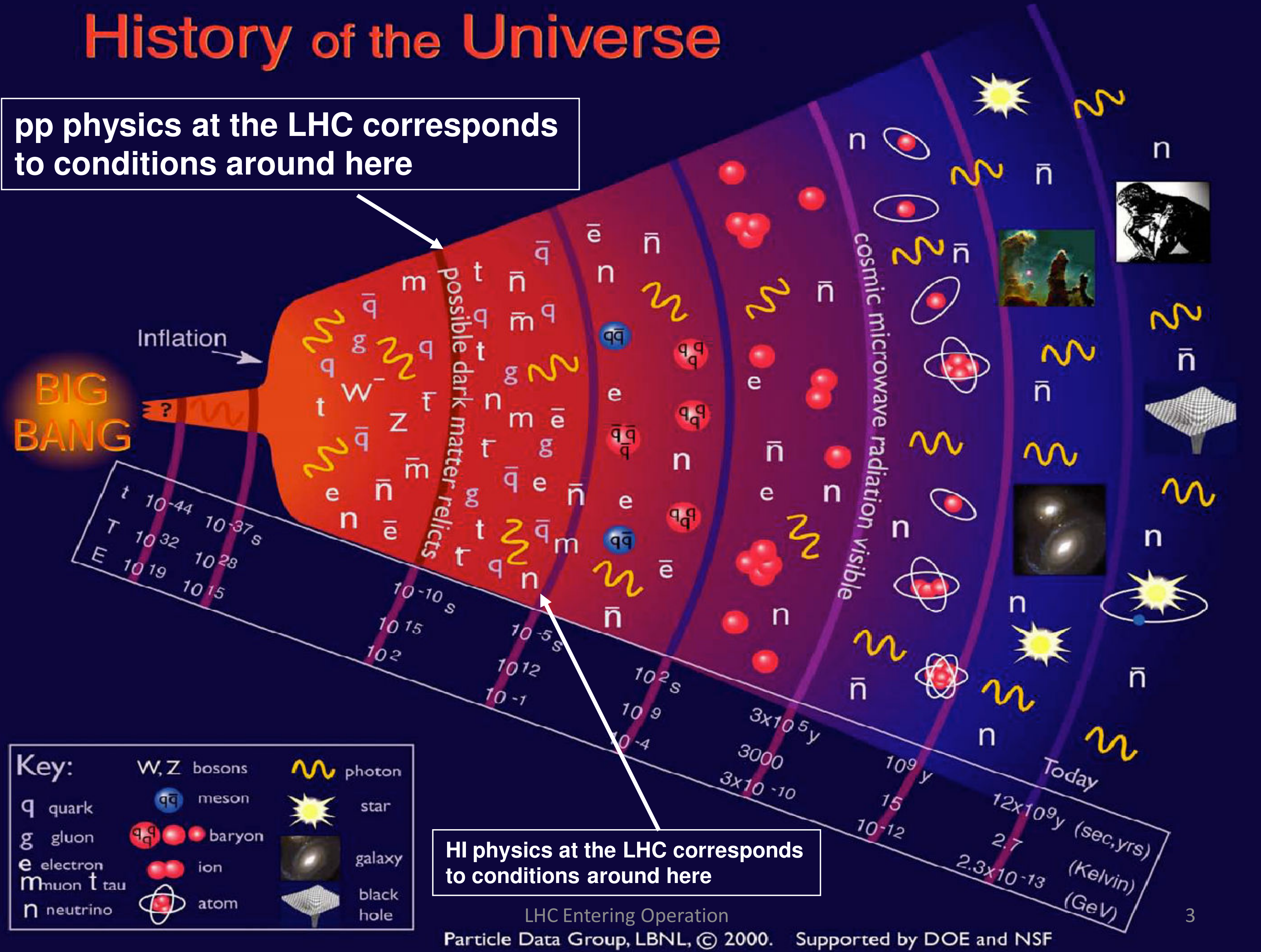
The Large Hadron Collider Project:

A Journey to Discover the Physics Shortly After the Big Bang



A dream becoming reality…

pp physics at the LHC corresponds to conditions around here

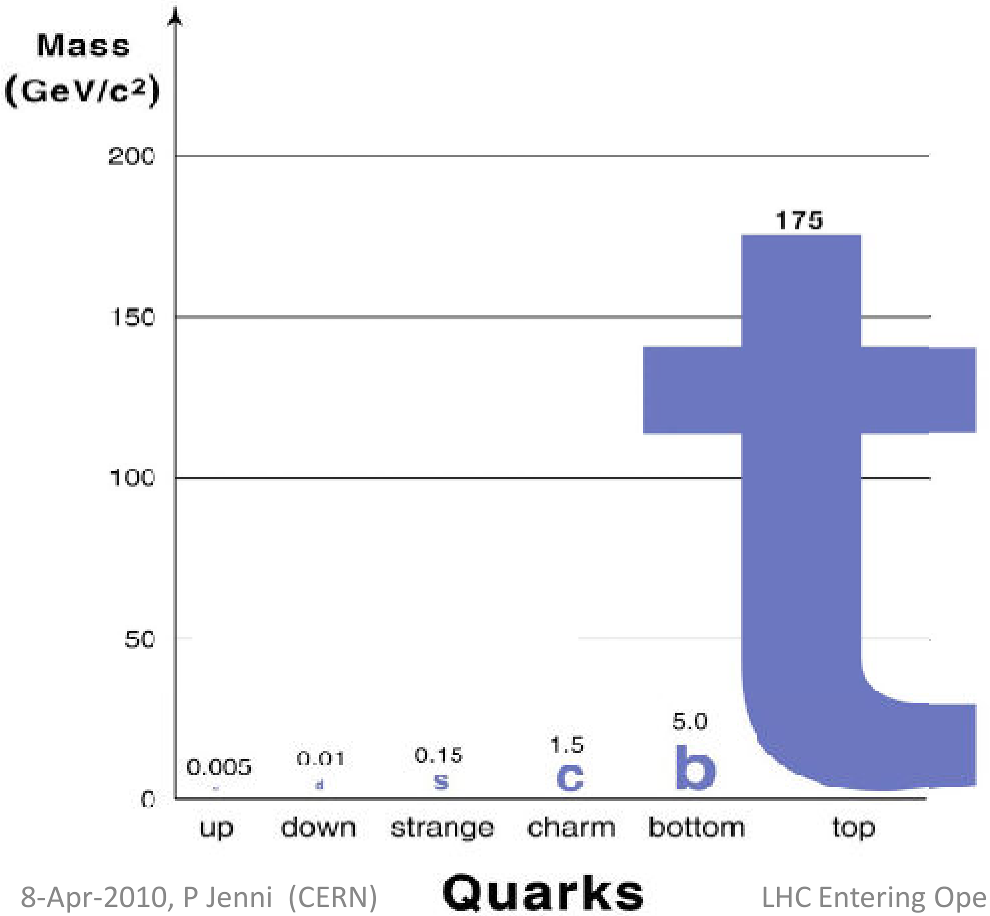


HI physics at the LHC corresponds to conditions around here

A most basic question is why particles (and matter) have masses (and so different masses)

The mass mystery could be solved with the ‘Higgs mechanism’ which predicts the existence of a new elementary particle, the ‘Higgs’ particle (theory 1964, P. Higgs, R. Brout and F. Englert)

Peter Higgs



The Higgs (H) particle has been searched for since decades at accelerators, but not yet found…

The LHC will have sufficient energy to produce it for sure, if it exists

Francois Englert

CDF/D0 Conclusion at HCP2009:

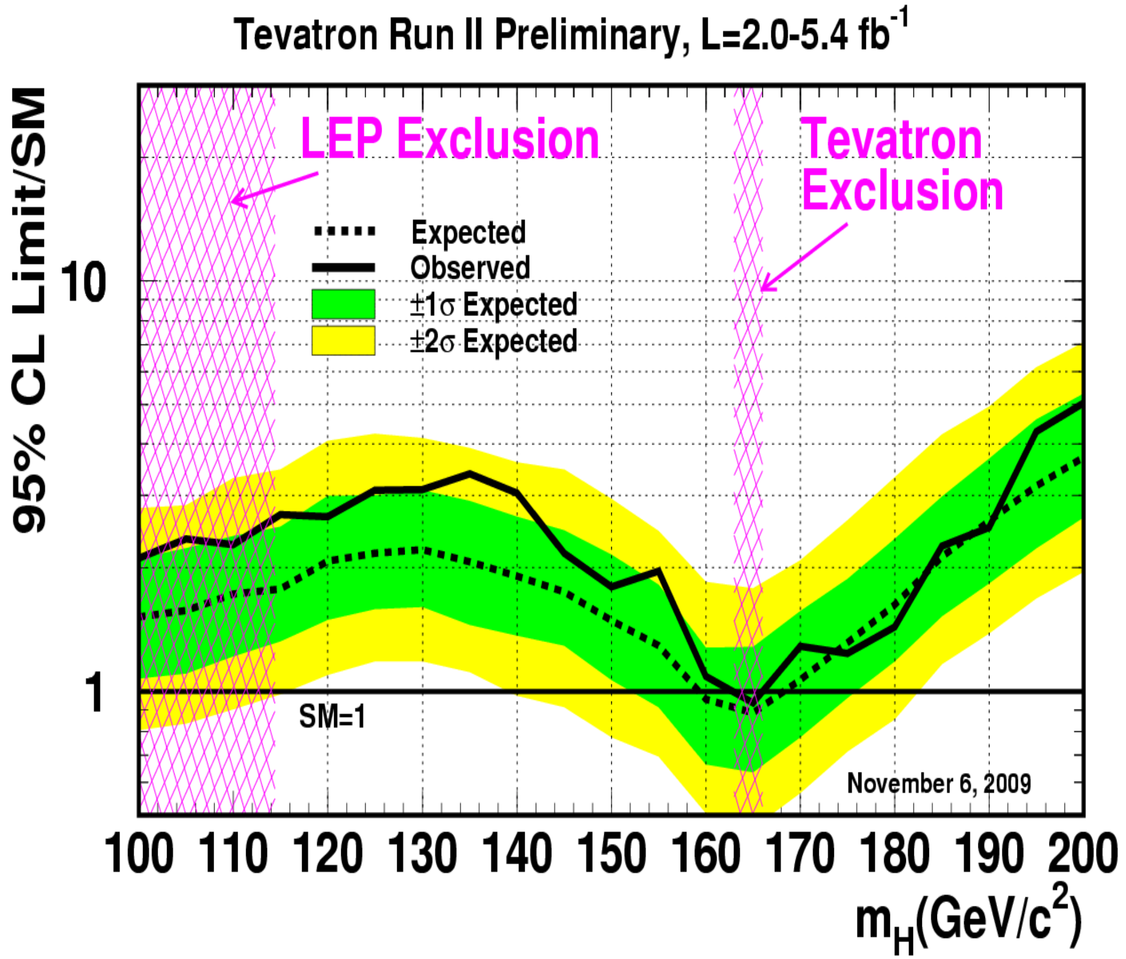
Great results from both experiments in both low and high-mass sectors

SM Higgs exclusion in the range 163-166 GeV @95% CL

Expected exclusion range 159-168 GeV

Better than 2.2xSM sensitivity at all masses below 185 GeV

Stay tuned for further Tevatron improvements in Higgs searches



Supersymmetry (SUSY)

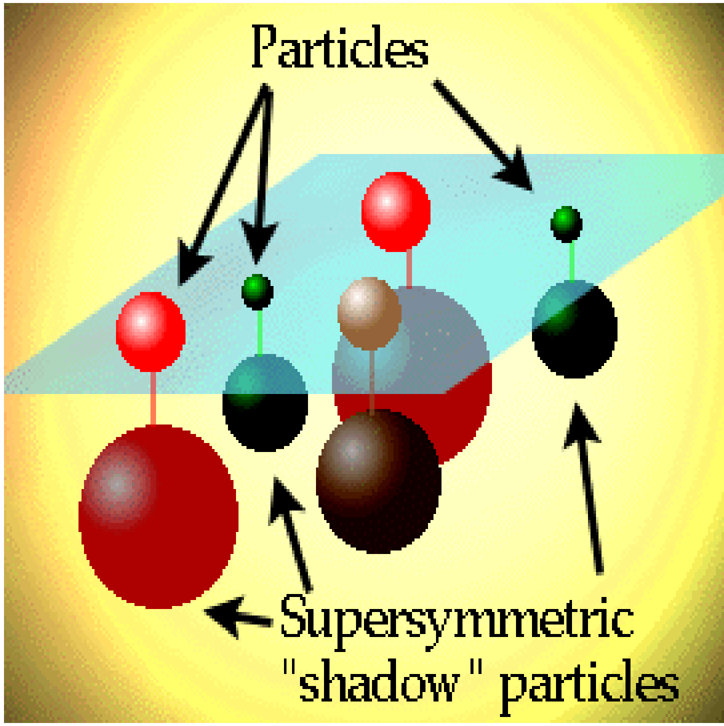
(Julius Wess and Bruno Zumino, 1974)

Establishes a symmetry between fermions (matter) and bosons (forces):

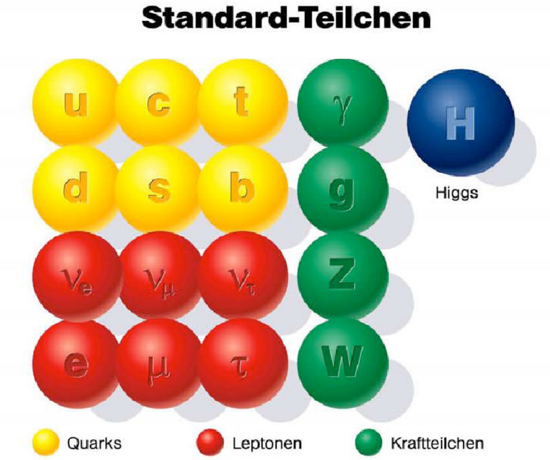
- Each particle p with spin s has a SUSY partner $\tilde{p}$ with spin s -1/2

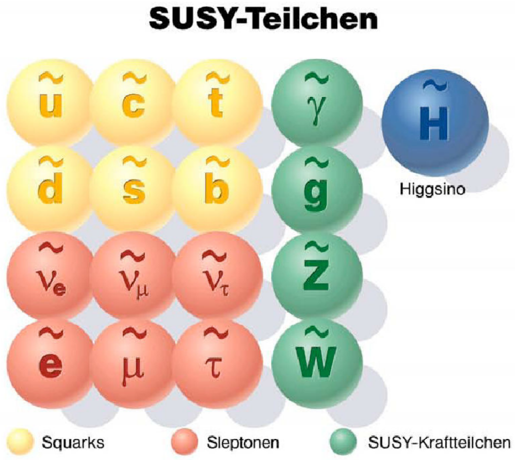
- Examples q (s=1/2) → $\tilde{q}$ (s=0) squark

g (s=1) → $\tilde{g}$ (s=1/2) gluino



Our known world **Maybe a new world?**





Motivation:

- Unification (fermions-bosons, matter-forces)
- Solves some deep problems of the Standard Model

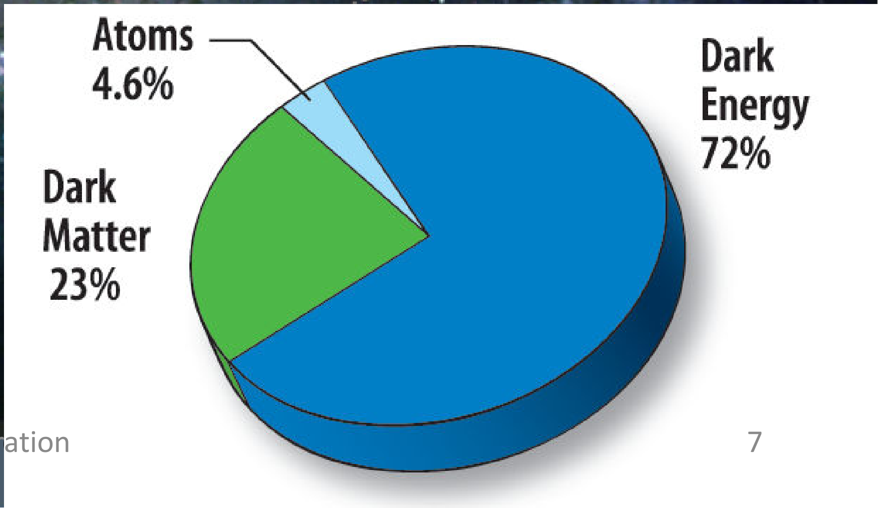
Dark Matter in the Universe

Astronomers say that most of the matter in the Universe is invisible Dark Matter

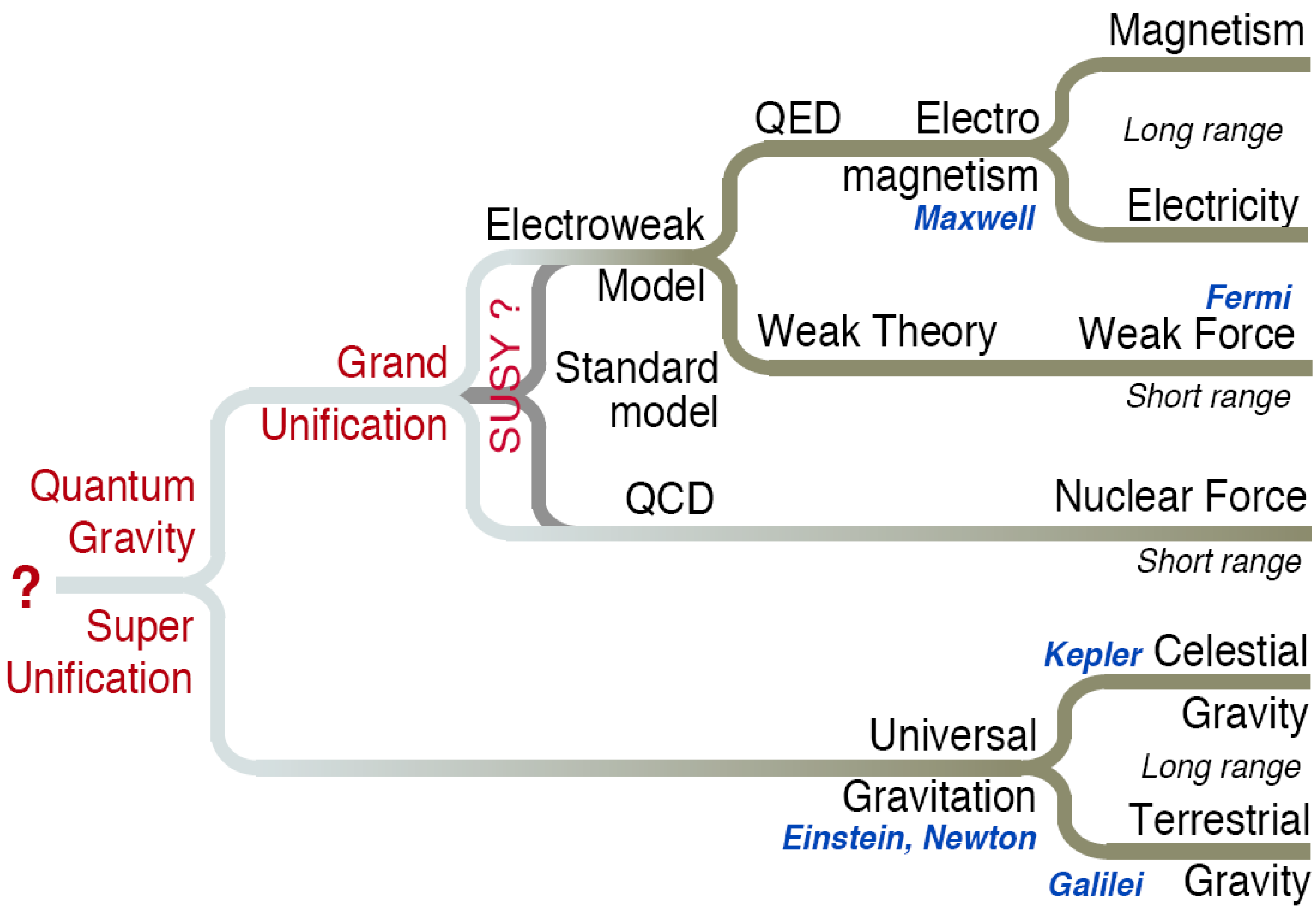
'Supersymmetric' particles ?

We shall look for them with the LHC

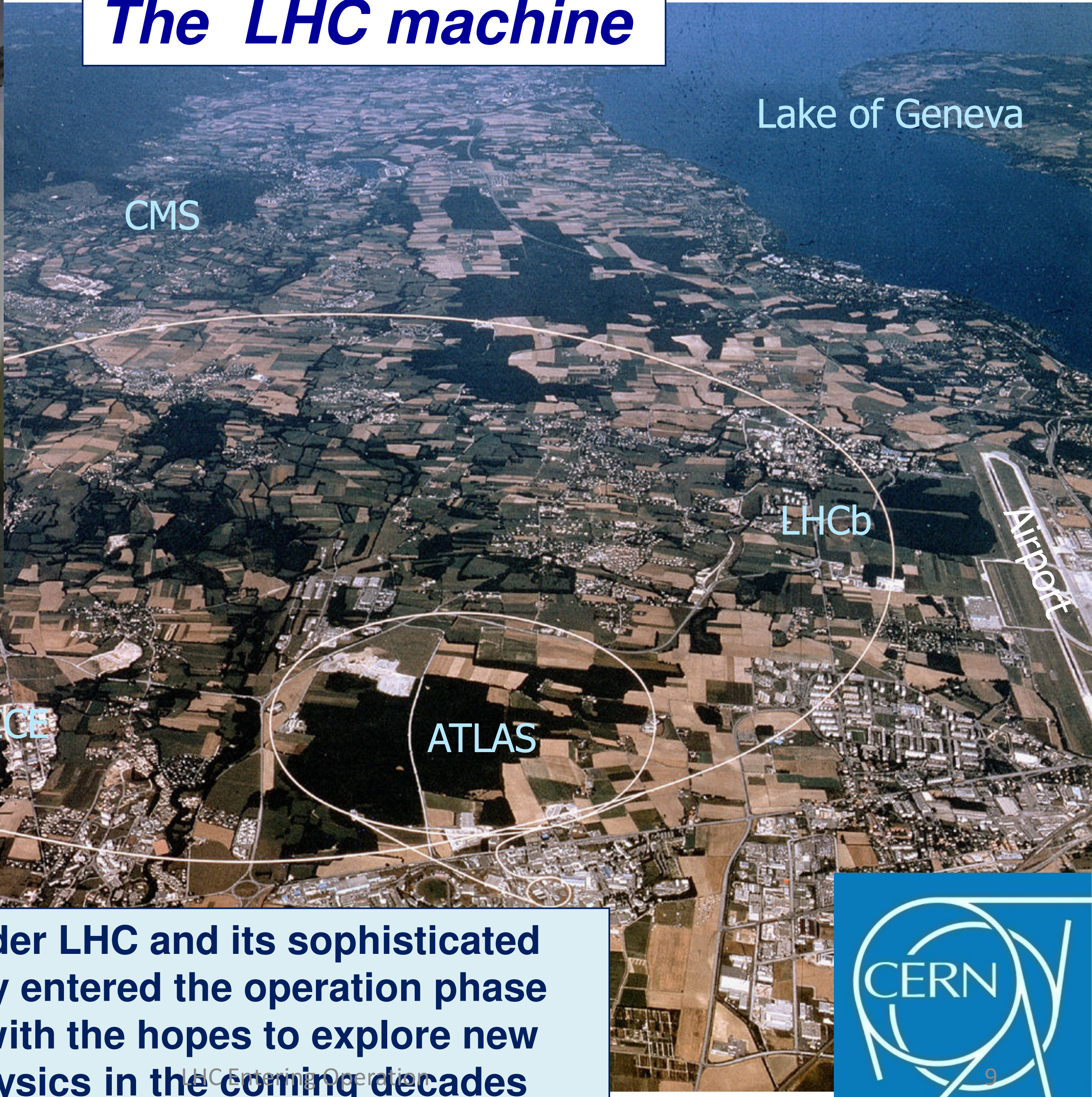
F. Zwicky 1898-1974



Unification of Forces



The LHC machine



The Large Hadron Collider LHC and its sophisticated experiments have finally entered the operation phase at the end of last year, with the hopes to explore new territories of particle physics in the coming decades

Conseil Européen *pour la* Recherche Nucléaire

CERN

Member States

Observer States: Israel, Turkey, India, Japan, Russia, USA
Other Observers: EC, UNESCO

Candidate: Romania

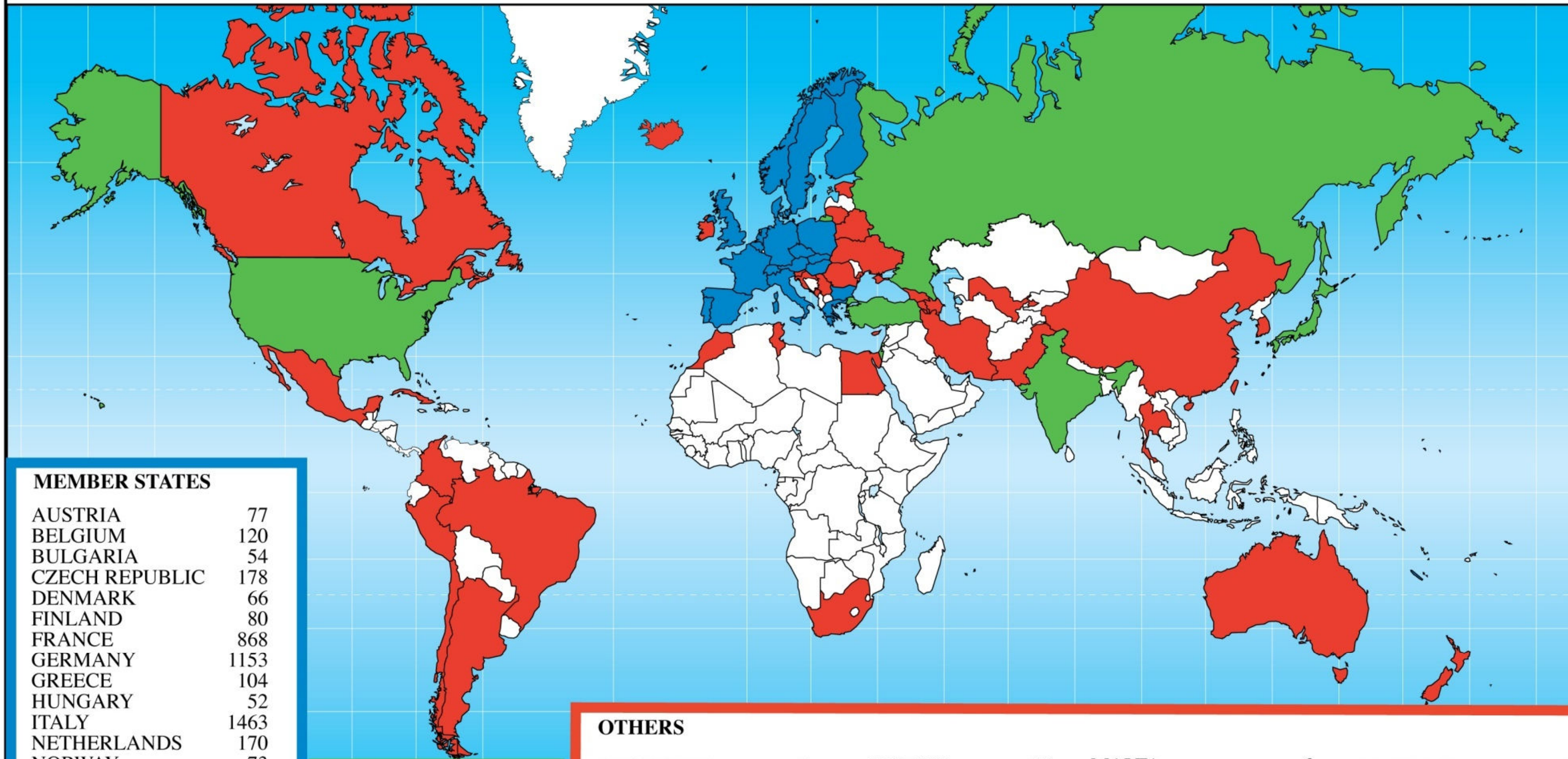
Applications: Cyprus, Israel, Serbia, Slovenia, Turkey

Member States (Dates of Accession)

AUSTRIA (1959)	DENMARK (1953)	GREECE (1953)	NORWAY (1953)	SPAIN (1/1961-12/1968-1/1983)
BELGIUM (1953)	FINLAND (1991)	HUNGARY (1992)	POLAND (1991)	SWEDEN (1953)
BULGARIA (1999)	FRANCE (1953)	ITALY (1953)	PORTUGAL (1986)	SWITZERLAND (1953)
CZECH FR ([illegible])	GERMANY (1953)	NETHERLANDS (1953)	SLOVAK FR (1993)	UNITED KINGDOM (1953)

CERN in Numbers

Distribution of All CERN Users by Nation of Institute on 20 January 2010



MEMBER STATES

AUSTRIA	77
BELGIUM	120
BULGARIA	54
CZECH REPUBLIC	178
DENMARK	66
FINLAND	80
FRANCE	868
GERMANY	1153
GREECE	104
HUNGARY	52
ITALY	1463
NETHERLANDS	170
NORWAY	73
POLAND	191
PORTUGAL	122
SLOVAKIA	55
SPAIN	311
SWEDEN	71
SWITZERLAND	362
UNITED KINGDOM	732

6302

OBSERVER STATES

INDIA	91
ISRAEL	49
JAPAN	204
RUSSIA	901
TURKEY	60
USA	1618

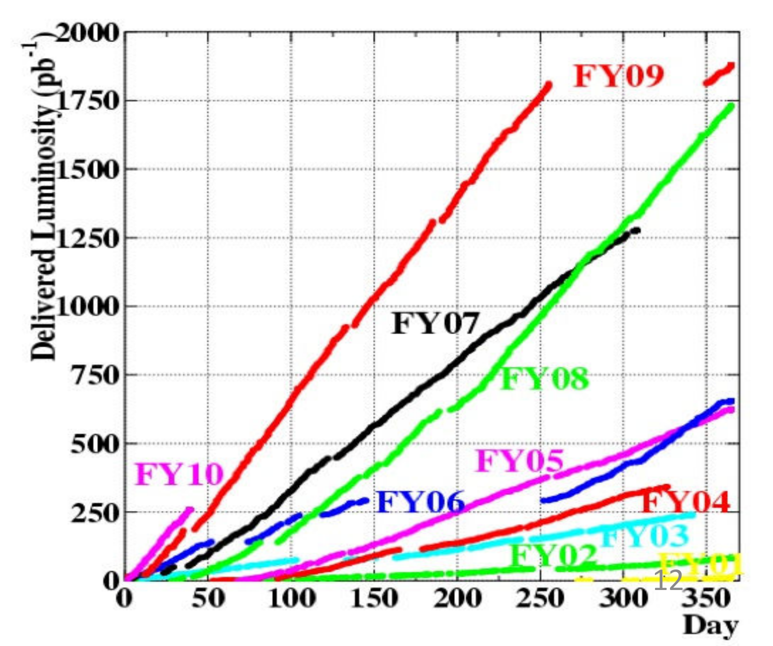
2923

OTHERS

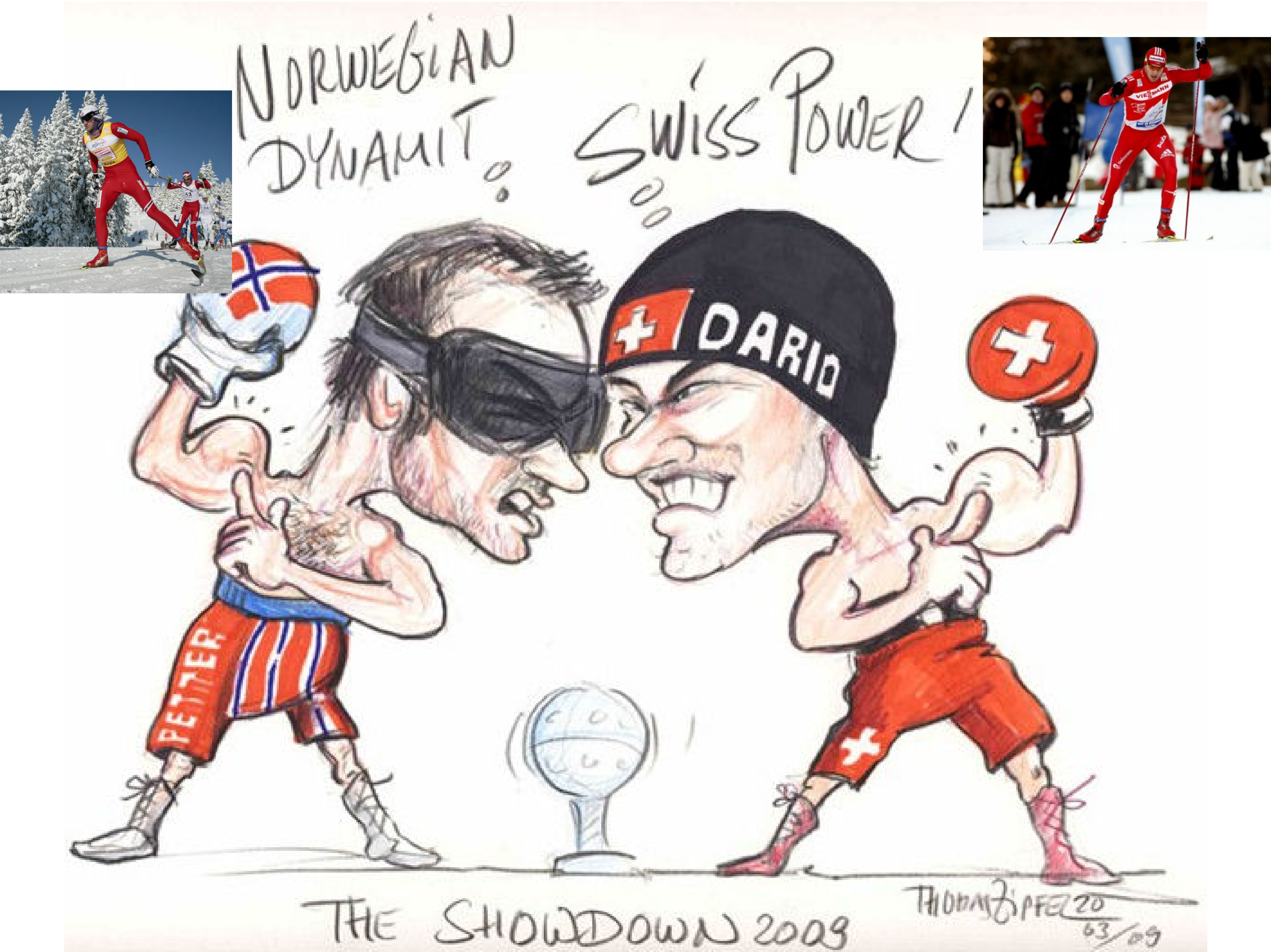
ARGENTINA	8
ARMENIA	16
AUSTRALIA	17
AZERBAIJAN	1
BELARUS	19
BRAZIL	77
CANADA	141
CHILE	2
CHINA	78
CHINA (TAIPEI)	53
COLOMBIA	9
CROATIA	18
CUBA	4
CYPRUS	8
EGYPT	3
ESTONIA	9
GEORGIA	10
ICELAND	1
IRAN	15
IRELAND	14
KOREA	64
LITHUANIA	5
MALTA	2
MEXICO	33
MONTENEGRO	1
MOROCCO	6
NEW ZEALAND	8
PAKISTAN	15
PERU	1
ROMANIA	59
SERBIA	20
SLOVENIA	17
SOUTH AFRICA	8
THAILAND	1
TUNISIA	1
UKRAINE	17
UZBEKISTAN	1

762

Competitor: TeVatron at Fermilab



The TeVatron is a very mature machine with well understood detectors operated by collaborations with highly developed analysis skills



NORWEGIAN DYNAMIT
SWISS POWER!
DARIO
PETTER
THE SHOWDOWN 2009

Collision energy

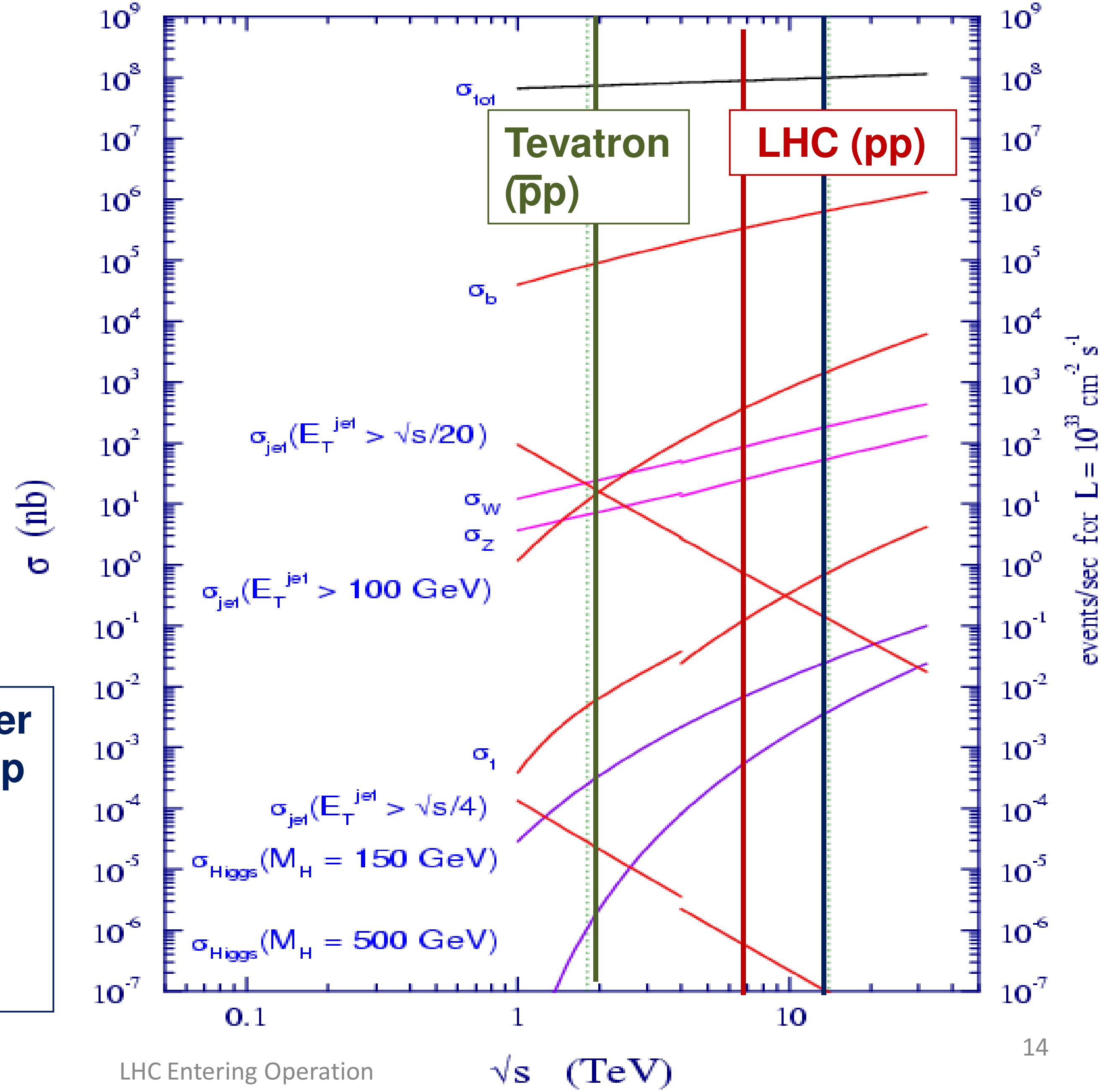
Tevatron ($p\bar{p}$)

1.96 TeV

LHC (pp)

initially 7 TeV
later 14 TeV

Some bench-mark cross-sections



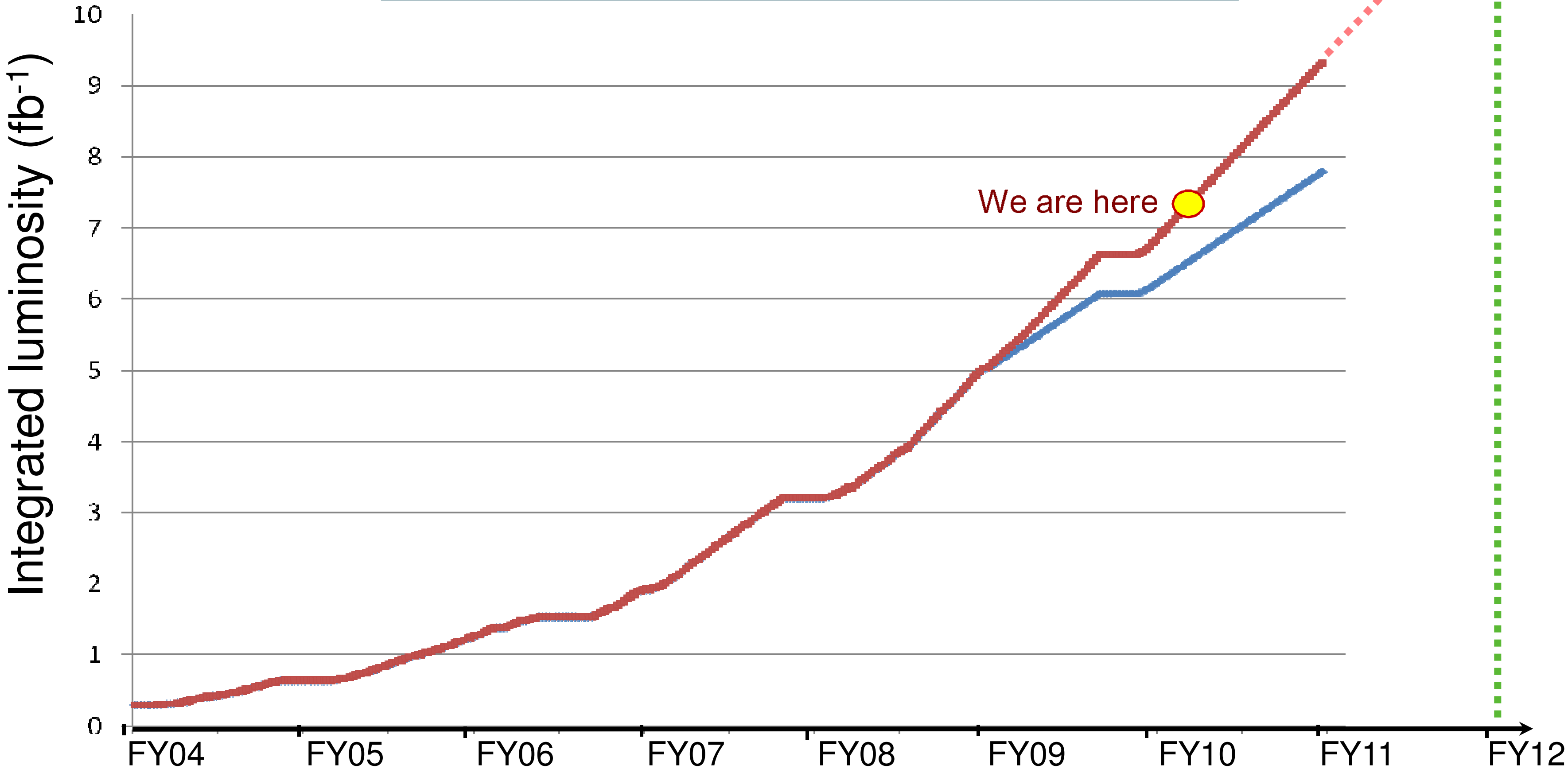
The other key parameter for setting the road map for discoveries is the integrated luminosity

$$N_{events} = \sigma \int L \, dt$$

Projection for the Tevatron

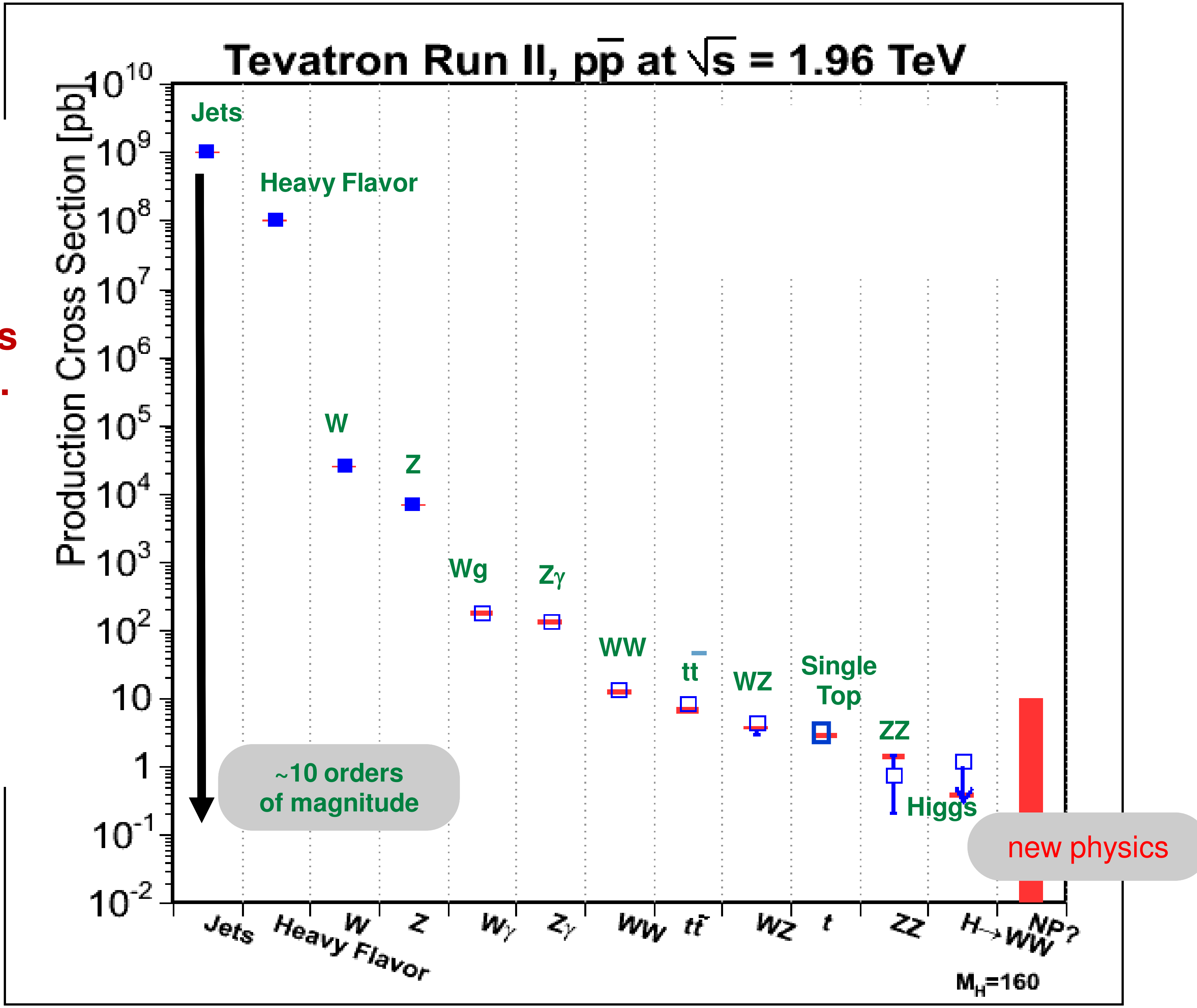
Expect about 2 fb^{-1} per year from now on → **~12 fb^{-1}**

→Reach at the end of 2011 some 10 – 12 fb^{-1} analyzable/delivered integrated luminosity



The Tevatron experiments have explored an impressive range of physics over the years…

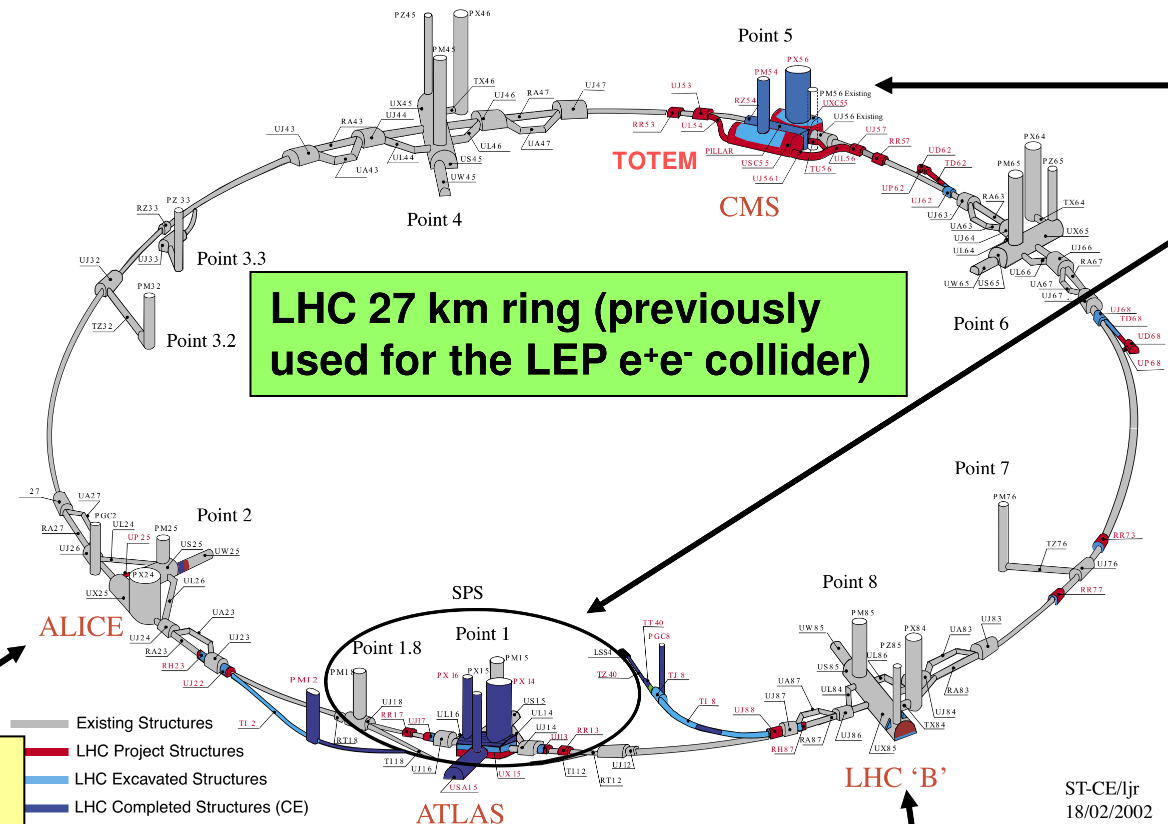
…both in direct observations of processes as well as in precision measurements



pp $\sqrt{s}$ = 14 TeV $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ (after 2013)

7 TeV $L_{initial} <$ few x $10^{33}\ cm^{-2}\ s^{-1}$ (before)

Heavy ions (e.g. Pb-Pb at ~ 1150 TeV)



ATLAS and CMS: general purpose

LHC 27 km ring (previously used for the LEP e^+e^- collider)

ALICE: Heavy Ions

Plus two much smaller experiments with very forward detectors at
Point-1: LHCf
Point-5: Totem

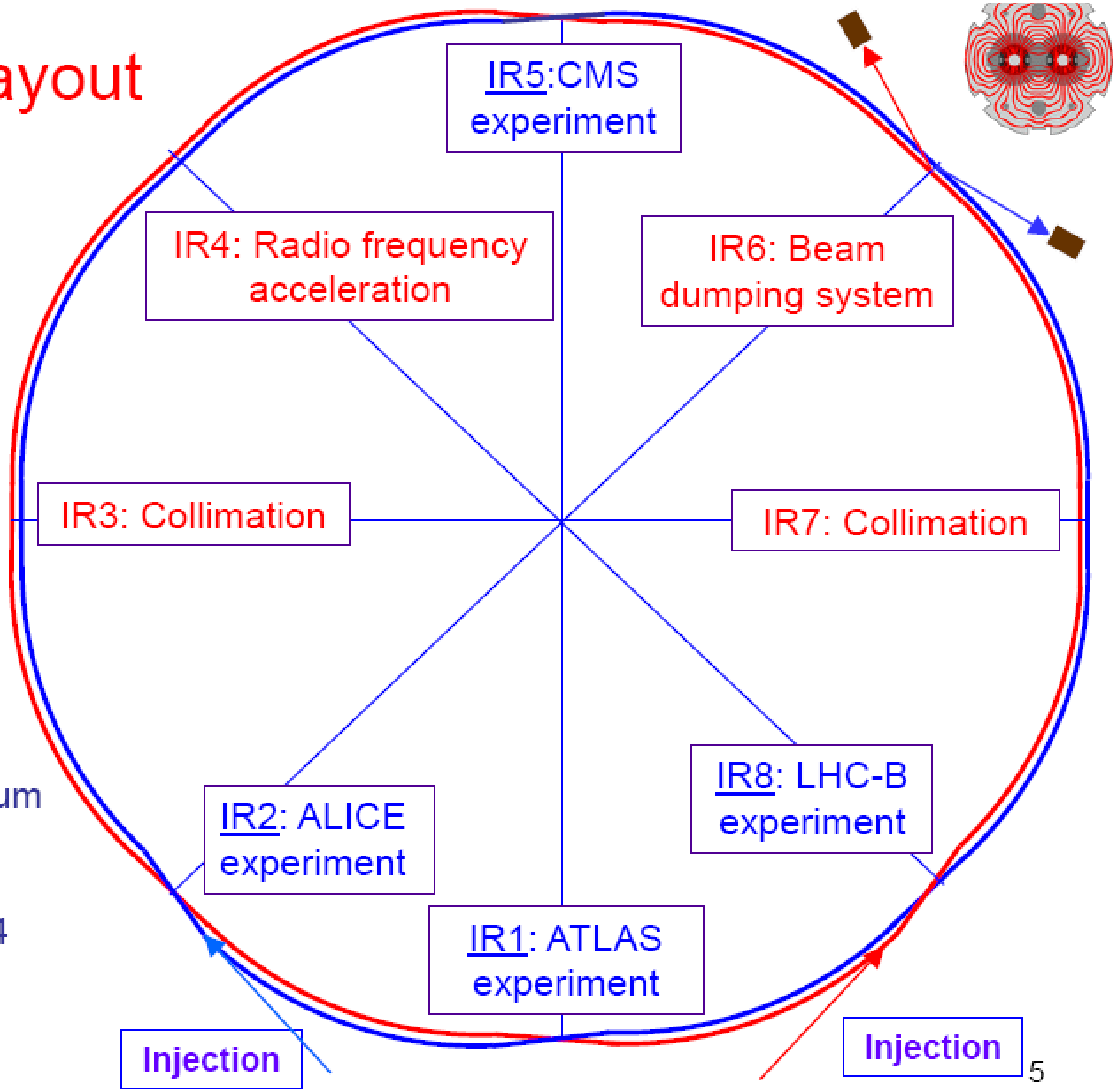
LHCb: B-physics, CP-violation

LHC Layout

- 8 arcs (sectors)
- 8 long straight sections (700 m long):

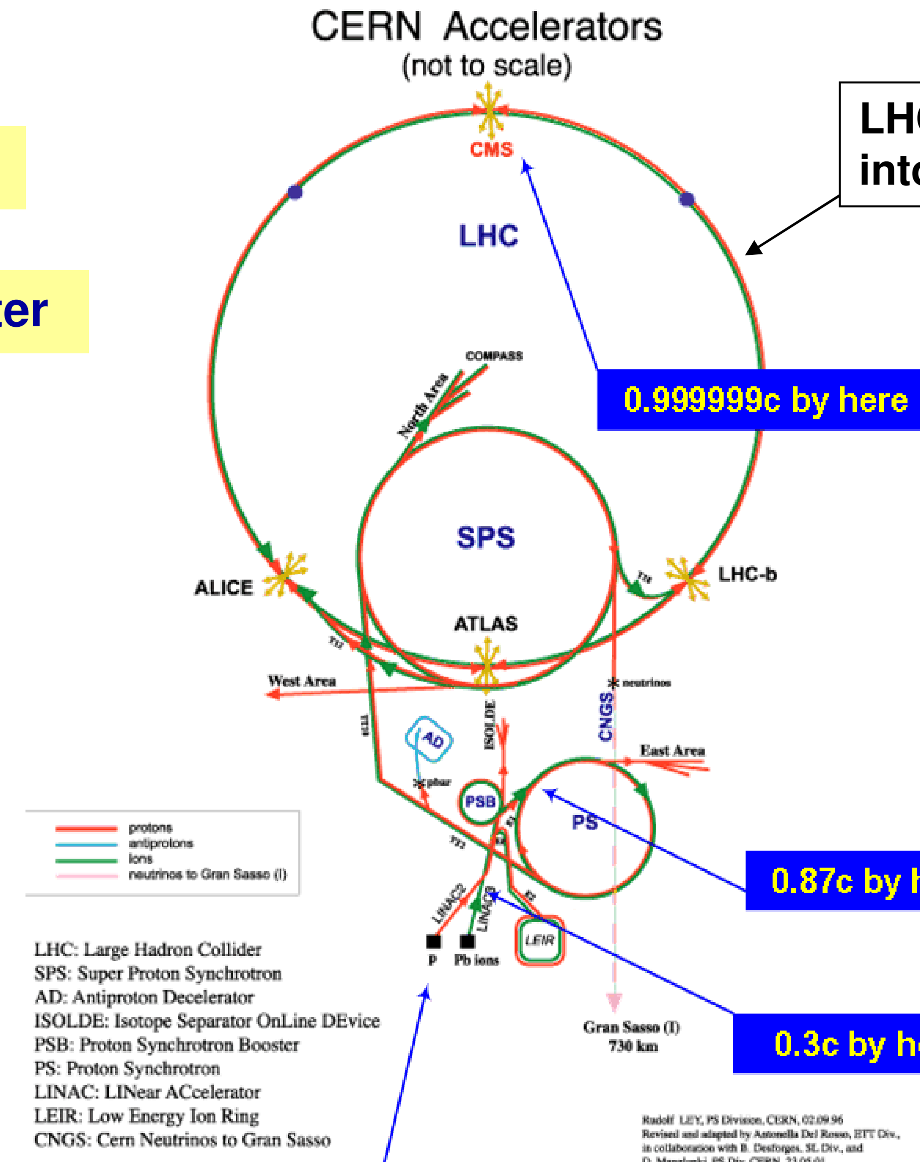
  IR1 to IR8

- 2 separate vaccum chambers
- beams cross in 4 points



The full LHC accelerator complex

Linac → **Booster** → **PS** → **SPS** → **LHC**



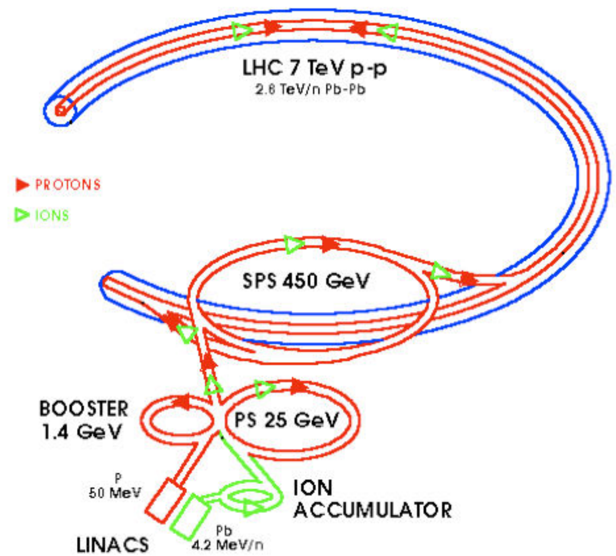
LHC ring is divided into 8 sectors

0.999999c by here

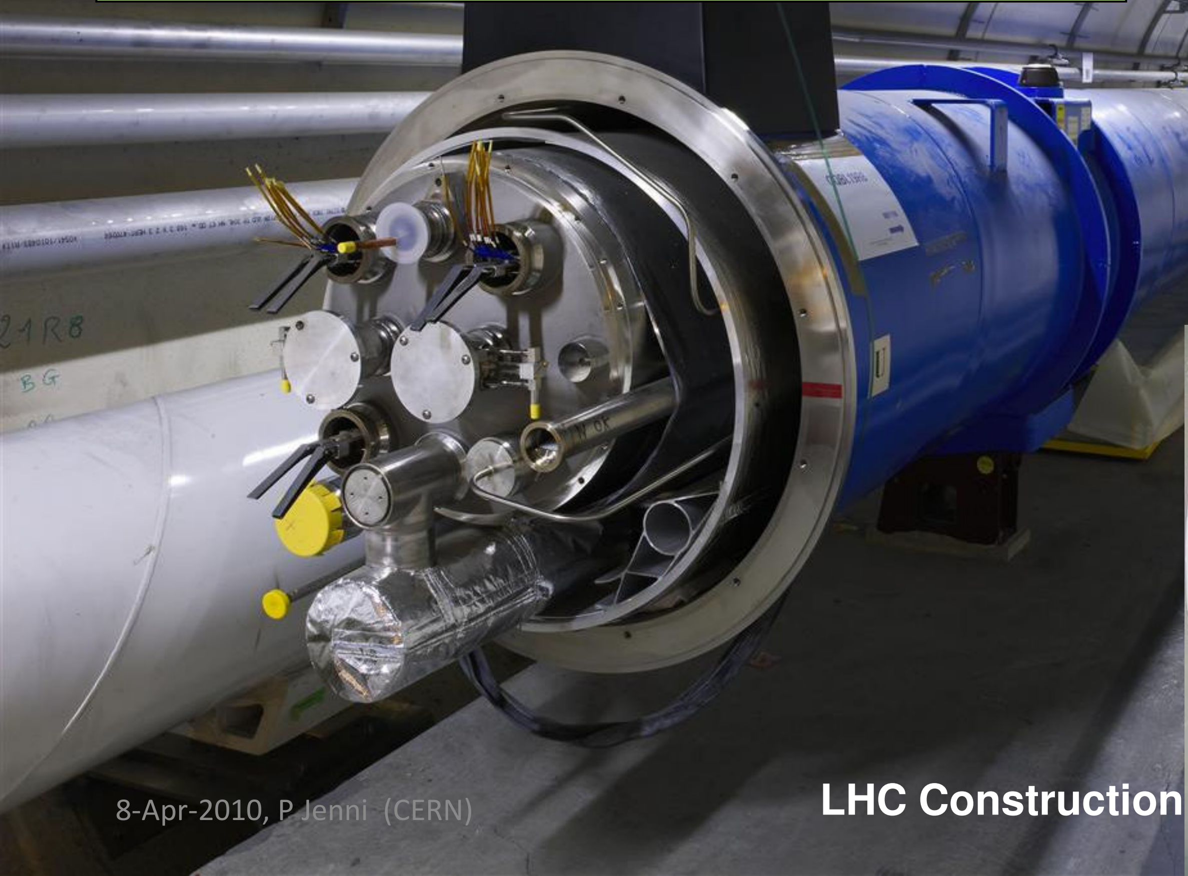
0.87c by here

0.3c by here

Start the protons out here



> 50 years of CERN history still alive and operational

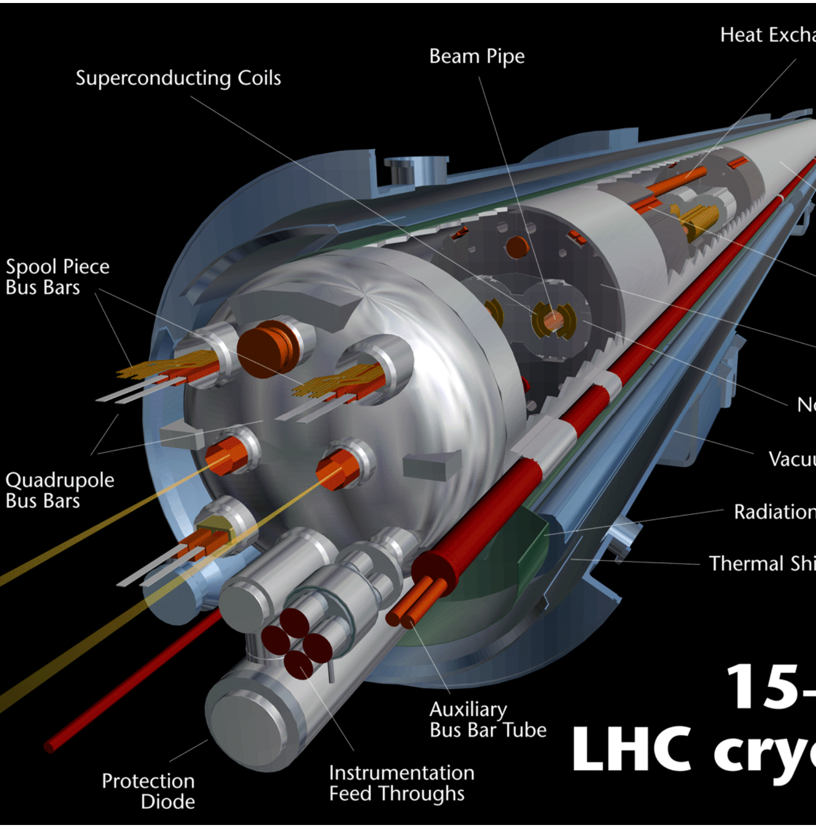


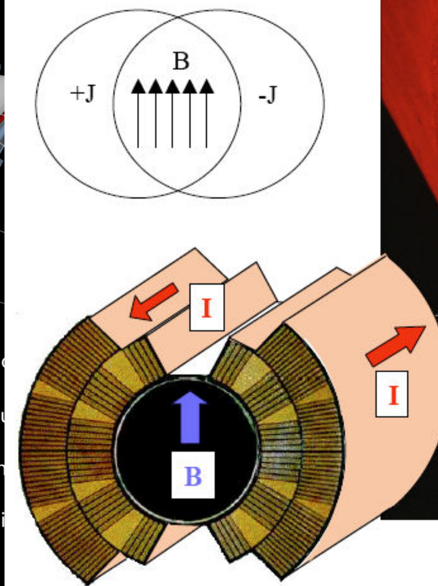
The most challenging components are the 1232 high-tech superconducting dipole magnets

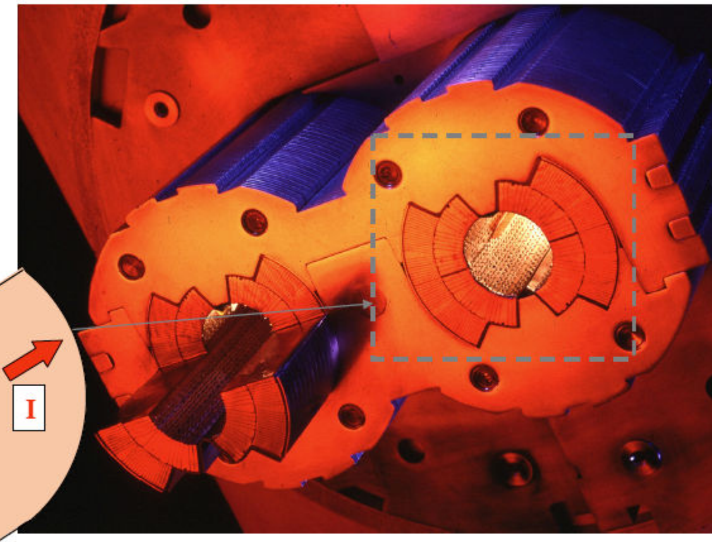
Magnetic field: 8.4 T
Operation temperature: 1.9 K
Dipole current: 11700 A
Stored energy: 7 MJ
Dipole weight: 34 tons
7600 km of Nb-Ti superconducting cable

LHC Construction Project Leader Lyndon Evans

LHC Accelerator Challenge: Dipole Magnets







Magnetic Field for Dipoles
p (TeV) = 0.3 B(T) R(km)

For p = 7 TeV and R = 4.3 km
⇨ B = 8.4 T
⇨ Current 12 kA

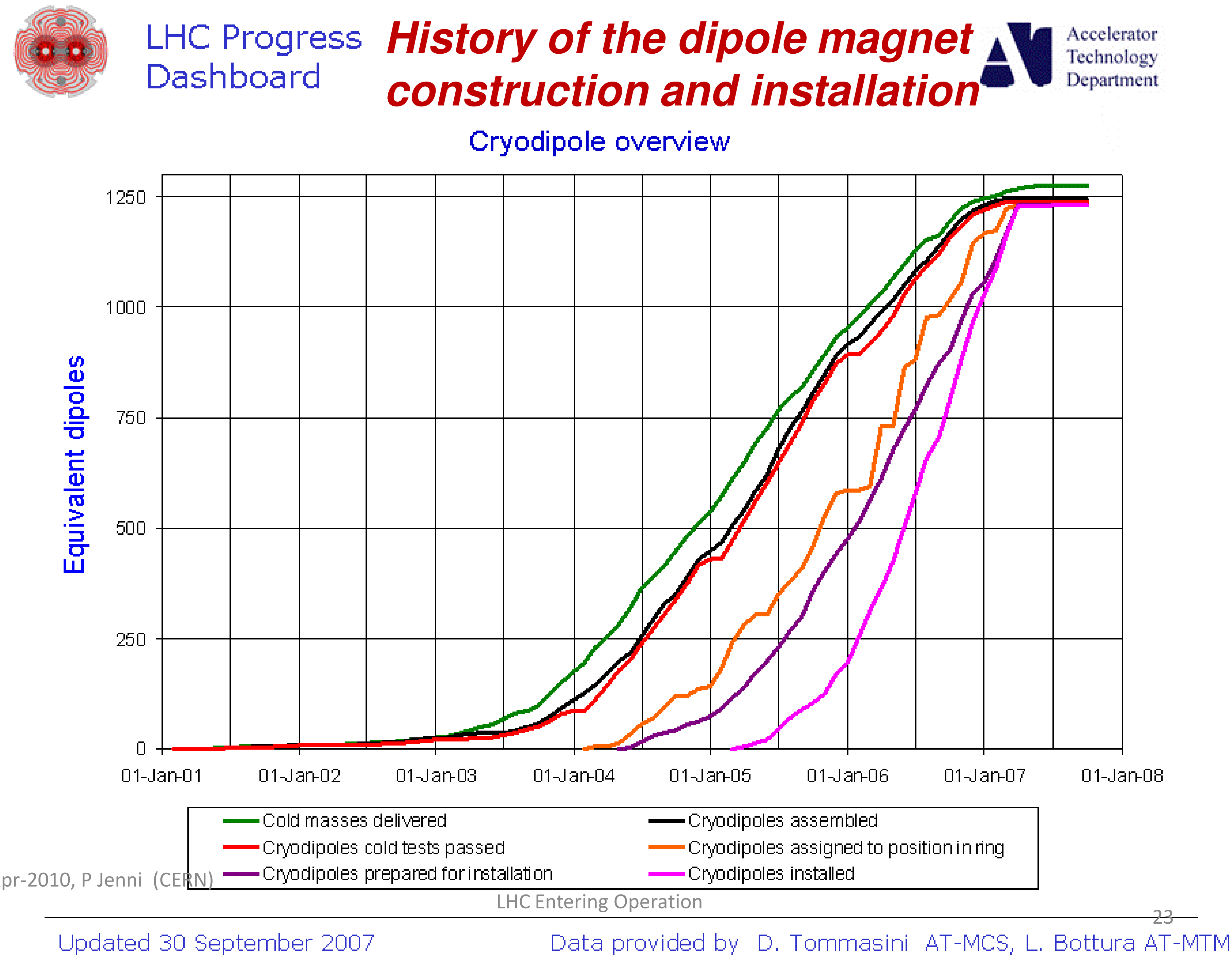
Coldest Ring in the Universe ?
1.9 K (CMBR is about 2.7 K)

LHC magnets are cooled with pressurized superfluid helium

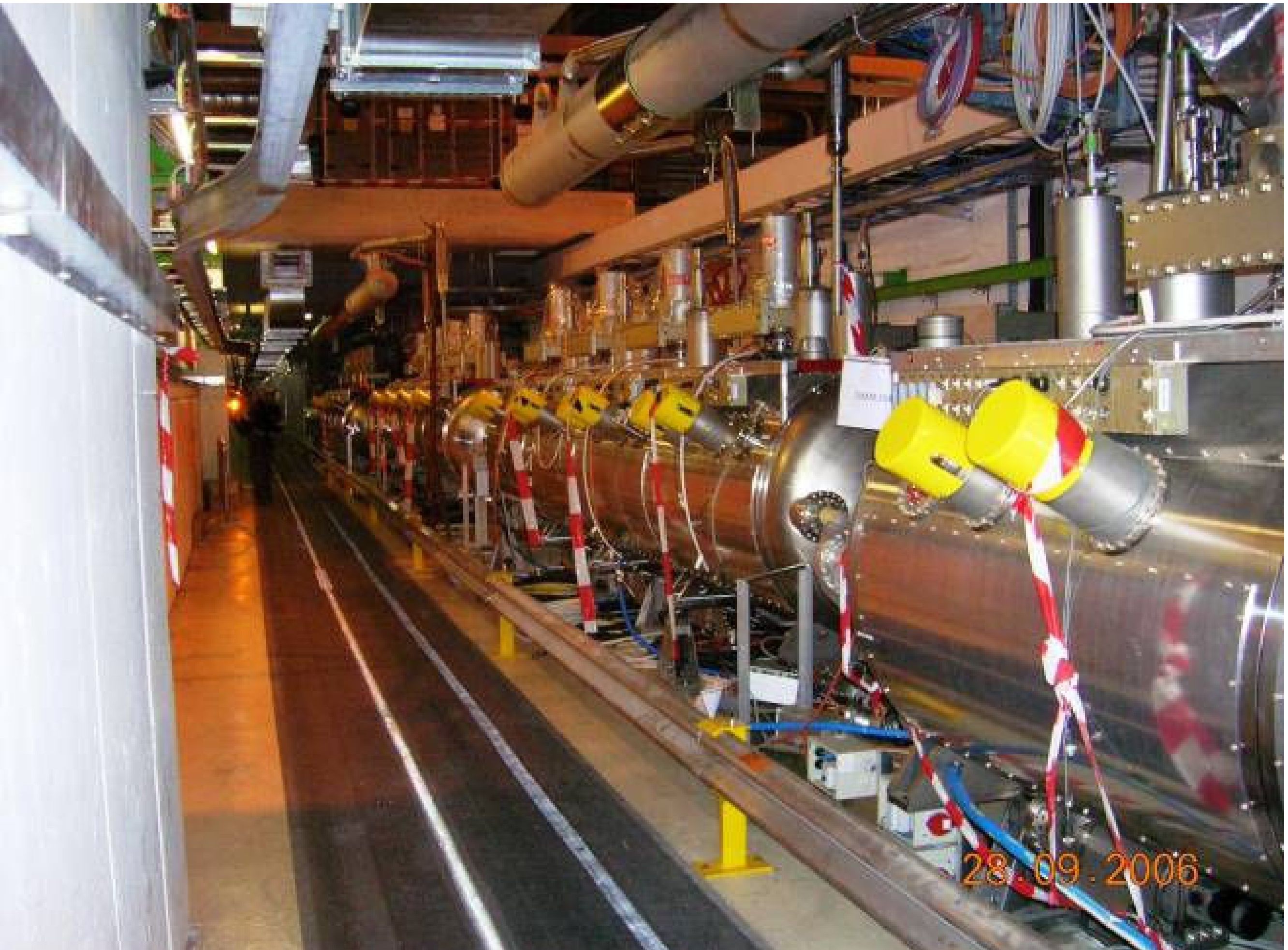
Descent of the last dipole magnet, 26 April 2007

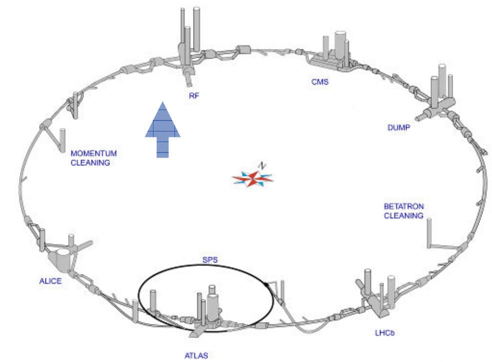
30’000 km underground transports at a speed of 2 km/h!

History of the dipole magnet construction and installation



The particle beams are accelerated by superconducting Radio-Frequency (RF) cavities

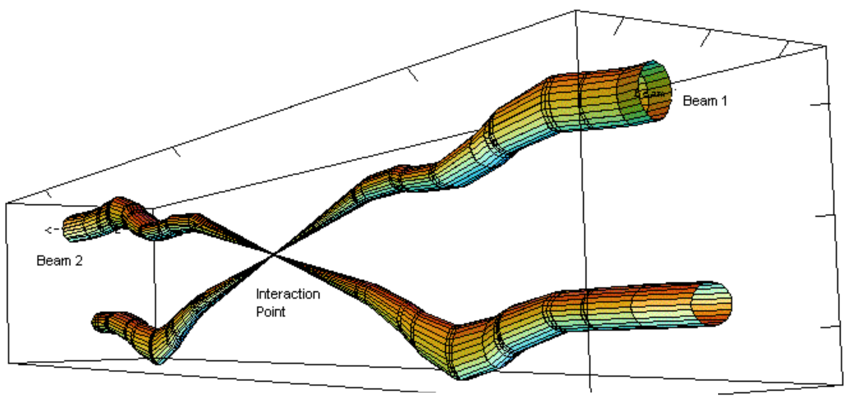




Note: The acceleration is not such a big issue in pp colliders (unlike in e^+e^- colliders), because of the ~ $1/m^4$ behaviour of the synchrotron radiation energy losses [~ E^4_{beam}/Rm^4]

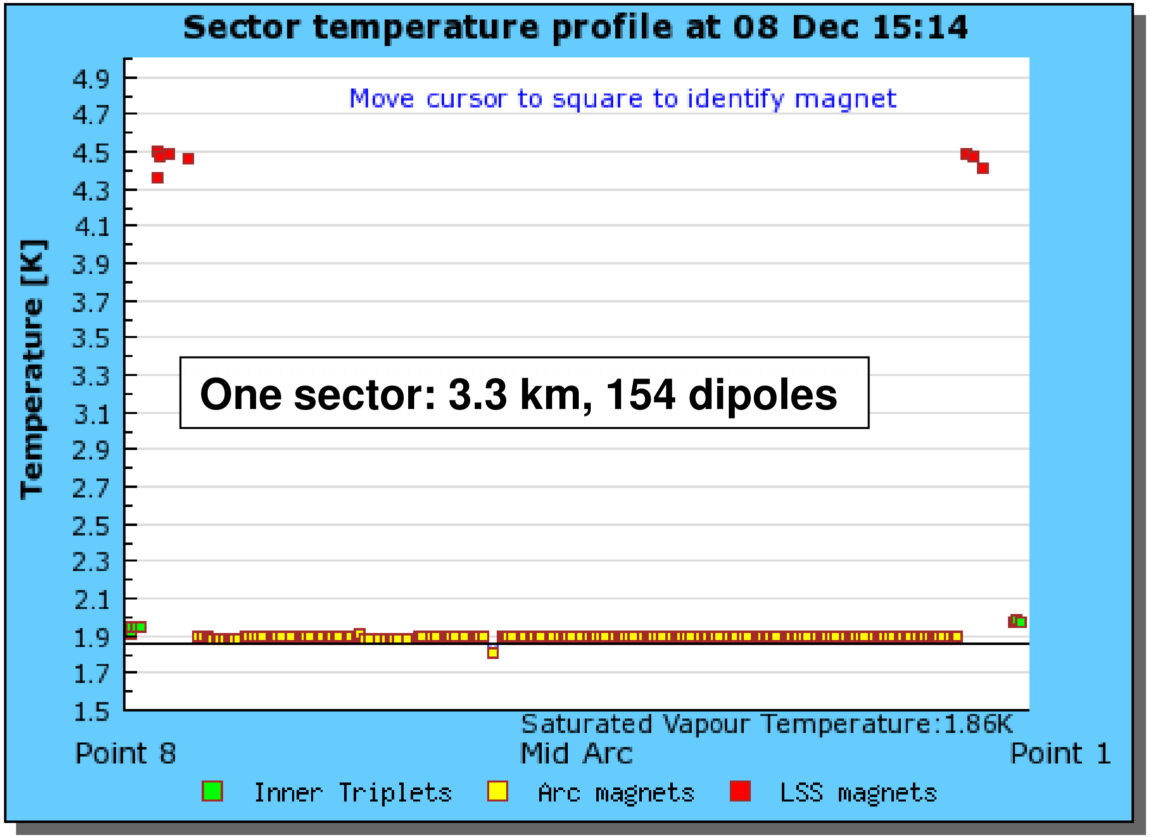
	LHC at 7 TeV	LEP at 100 GeV
Synchrotron radiation loss	6.7 keV/turn	3 GeV/turn
Peak accelerating voltage	16 MV/beam	3600 MV/beam

Special quadrupole magnets ('Inner Triplets') are focussing the particle beams to reach highest densities ('luminosity') at their interaction point in the centre of the experiments



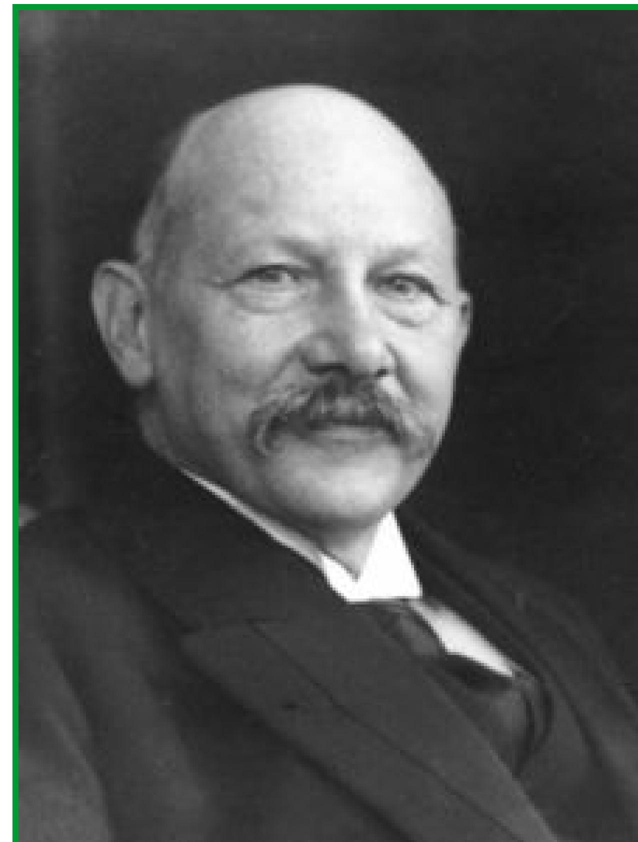
Relative beam sizes around the collision point

The LHC is the largest cryogenic system on earth, cooler than outer space



Magnets cooled down in a bath of ~120 tons of superfluid Helium (excellent thermal conductor)

H K Onnes
Nobel Prize in Physics 1913



- **~100 years ago, on 10 July 1908: Heike K Onnes first liquefied Helium (60 ml in 1 hour) in Leiden**
- **LHC today: 32000 He liters liquefied per hour by eight big cryogenic plants (the largest refrigerator in the world)**

Main parameters of the machine

	Design operation	
Beam energy	7	TeV
Instantaneous luminosity L	10^{34}	$cm^{-2}s^{-1}$
Integrated luminosity/year	~ 100	fb^{-1}
Dipole field	8.4	T
Dipole current	11700	A
Circulating current/beam	0.53	A
Number of bunches	2808	
Bunch spacing	25	ns
Protons per bunch	10^{11}	
R.m.s. beam radius at IP1/5	16	μm
R.m.s. bunch length	7.5	cm
Stored beam energy	360	MJ
Crossing angle	300	μrad
Number of events per crossing	20	
Luminosity lifetime	10	hours

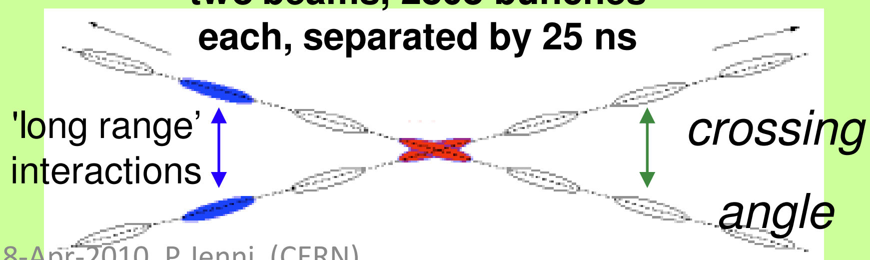
$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y}$$

n. of protons per bunch (N); n. of bunches (k_b); n. of turns per second (f)

beam size at IP ($\sigma_{x,y}$ = 16 μm)

N = L x σ (pp → X)

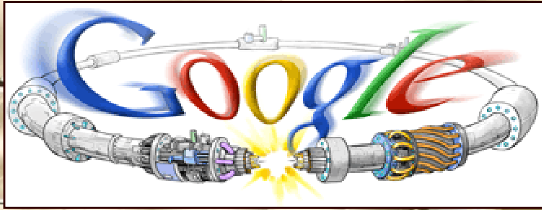
two beams, 2808 bunches each, separated by 25 ns



x200 Tevatron

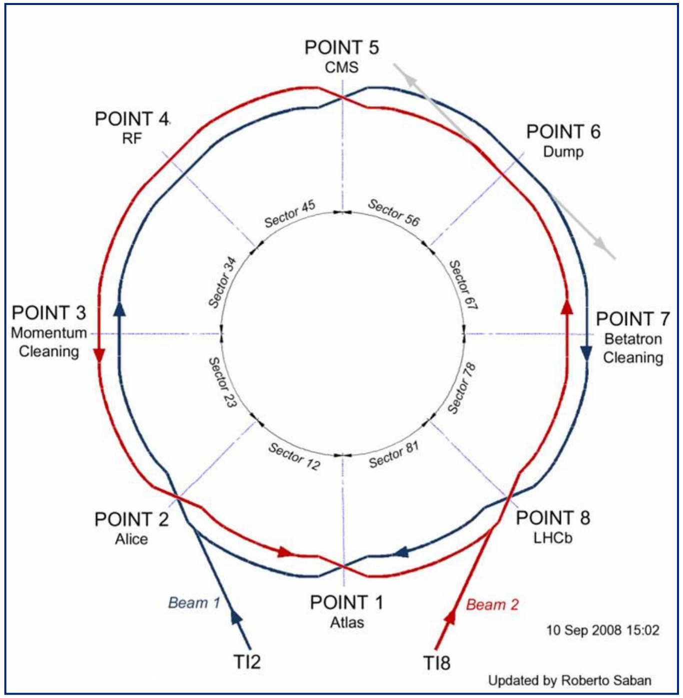
10 September 2008: LHC inauguration day

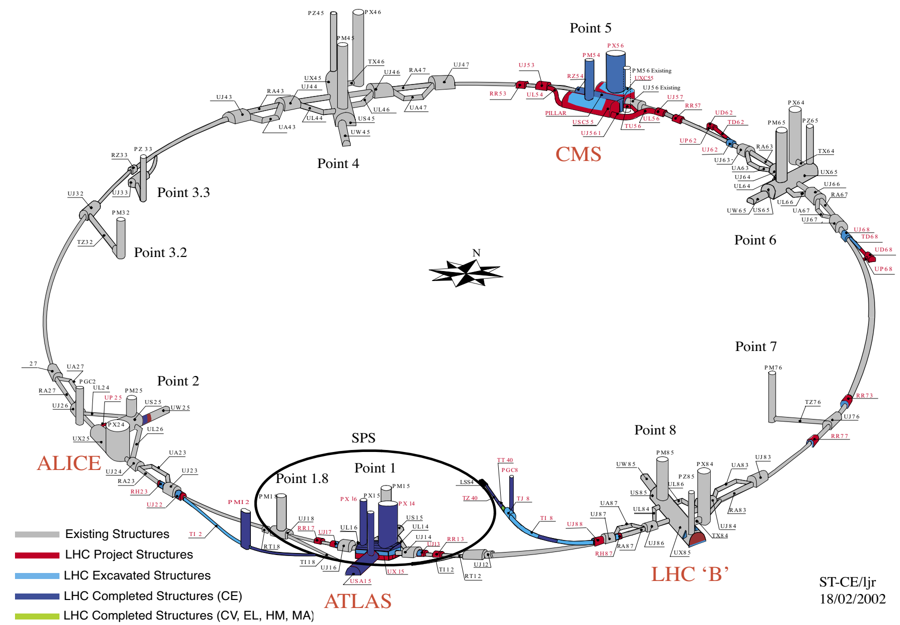
First (single) beams circulating in the machine

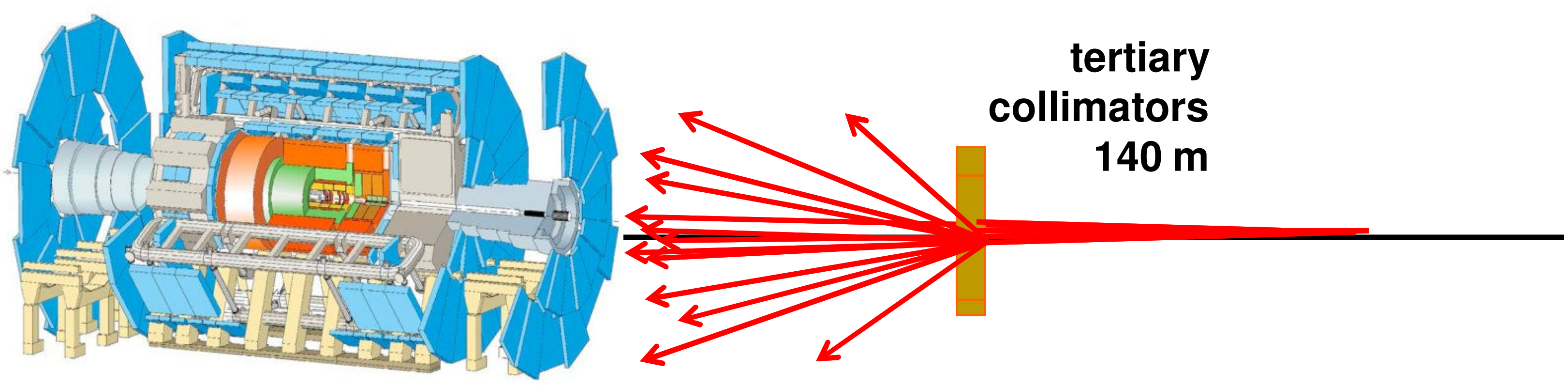


Five CERN DGs, from conception to realization: Schopper, Rubbia, Llewellyn Smith, Maiani, Aymar (from right to left)

First LHC Single Beam on 10th September 2008

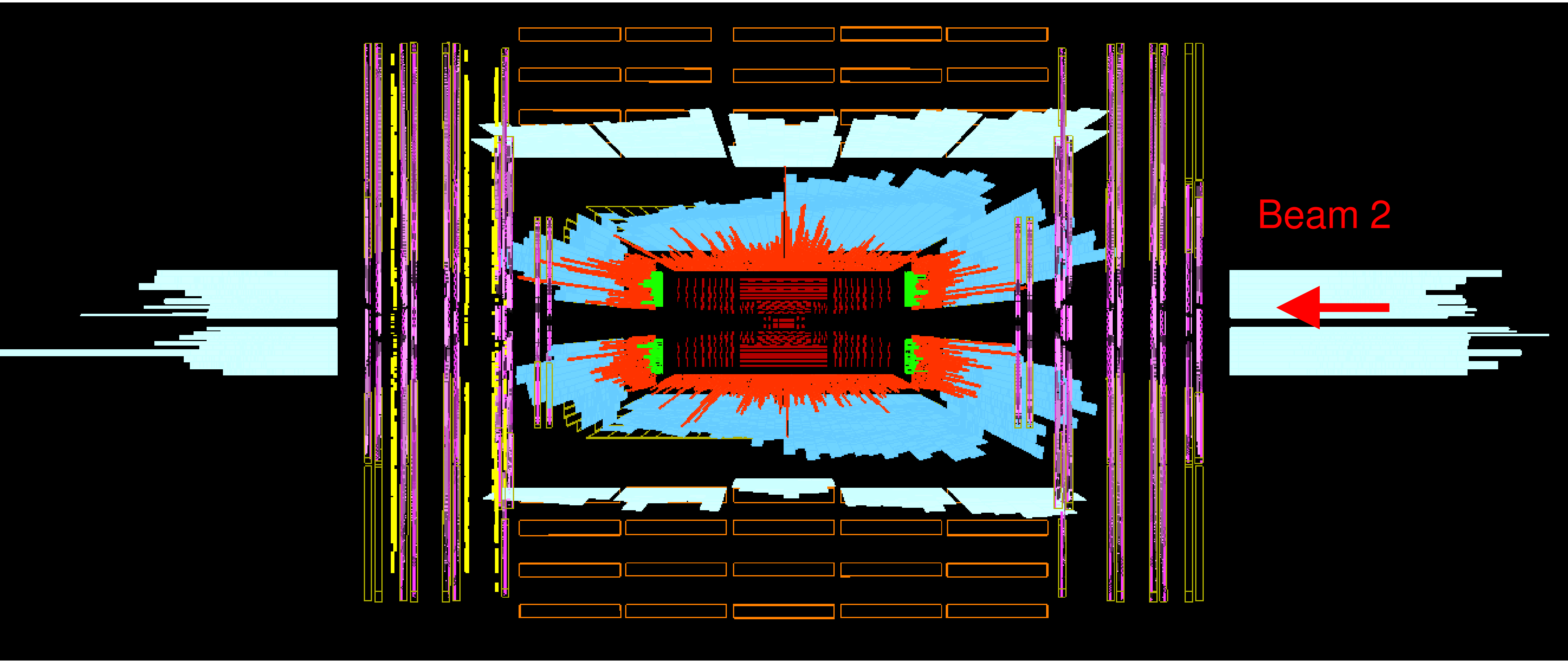






Excitement in the ATLAS Detector Control Room:
The first LHC event on 10th September 2008

CMS Splash '09 Event Display



ECAL energy deposits in red, Preshower in green,
HCAL energy deposits in blue (light blue for HF and HO),
RPC muon hits are in yellow,
and CSC muon hits are in magenta.

Incident on 19th September 2008

On the beam startup date not all the circuits had been fully commissioning for 5 TeV beam operation. The last steps were completed a week later…

- **During the last commissioning step of the last main dipole circuit an electrical fault developed at ~5.2 TeV in the dipole bus bar at the interconnection between a quadrupole and a dipole magnet**

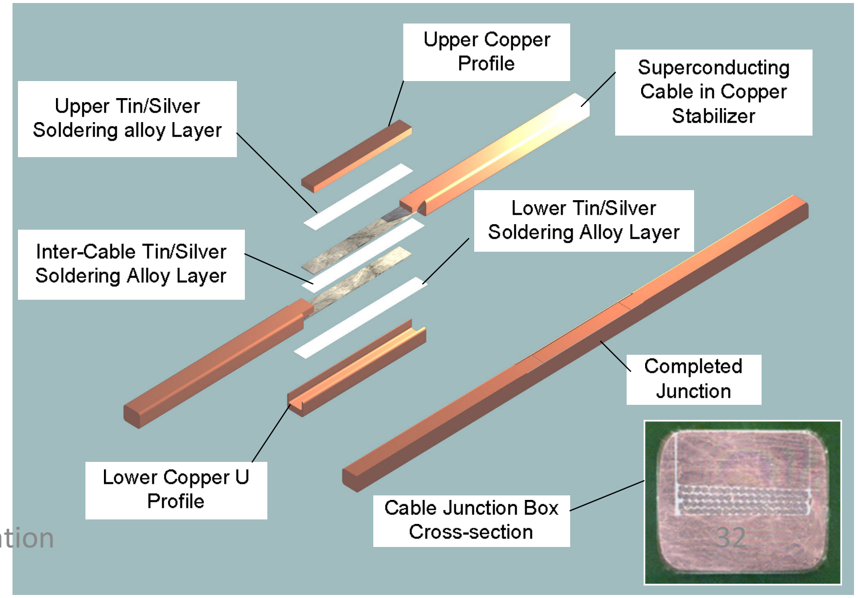
  Later correlated to quench due to a local R ~220 nΩ – nominal 0.35 nΩ

- **An electrical arc developed and punctured the helium enclosure**

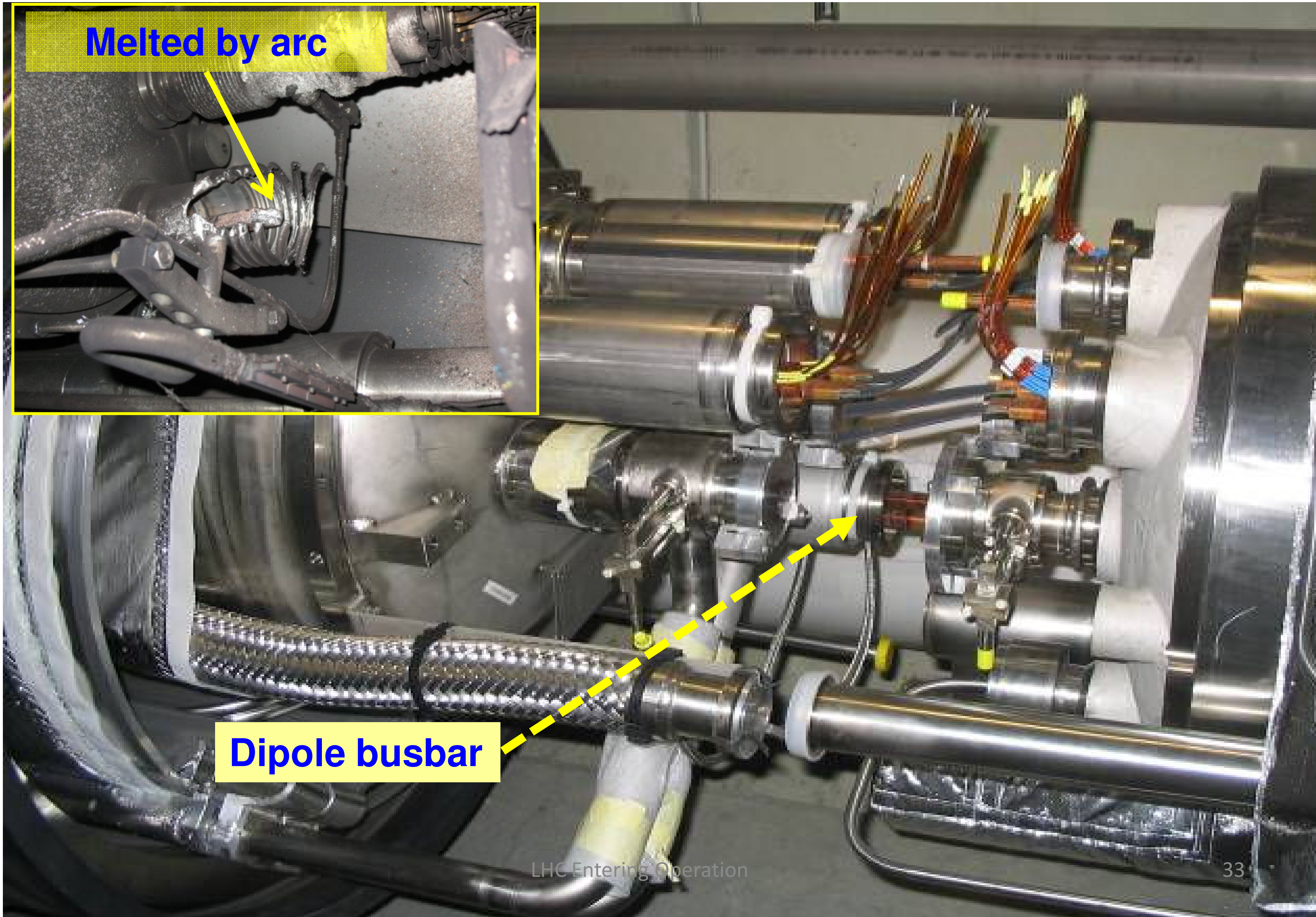
  Around 400 MJ from a total of 600 MJ stored in the circuit were dissipated in the cold-mass and in electrical arcs

- **Large amounts of Helium were released into the insulating vacuum**

  The pressure wave due to Helium flow was the cause of most of the damage (collateral damage).



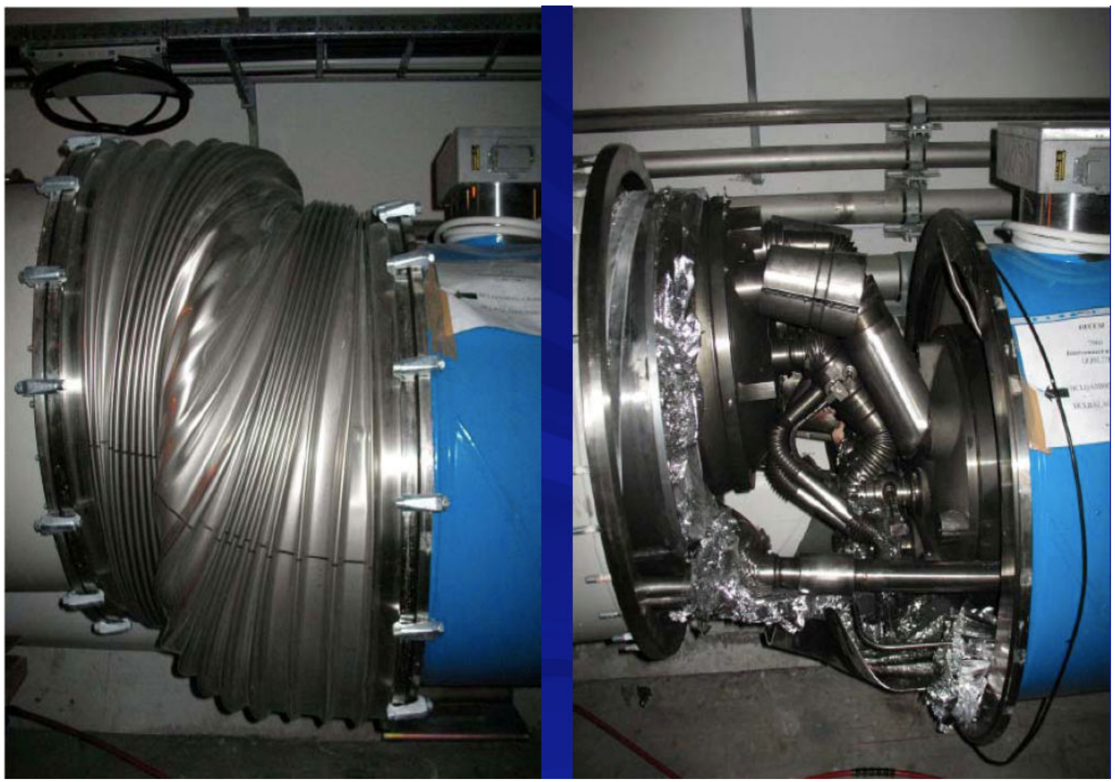
Magnet Interconnection



Examples of collateral damage

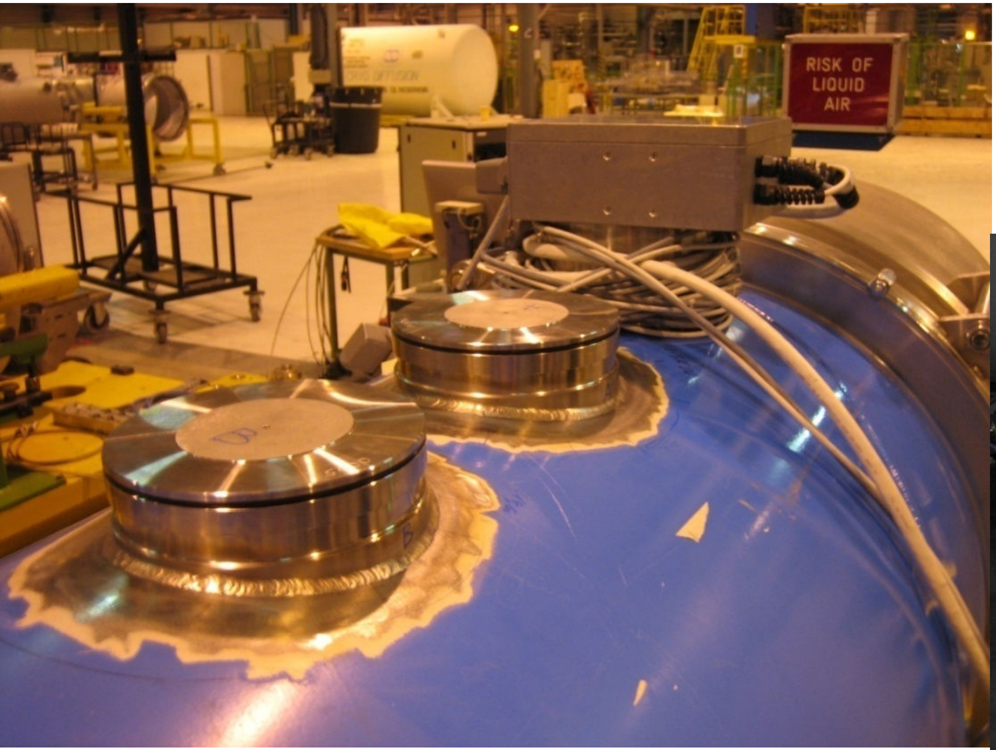
High pressure build-up damaged the magnet interconnects and the super-insulation

Perforation of the beam tubes resulted in pollution of the vacuum system with soot from the vaporization and with debris from the super insulation.



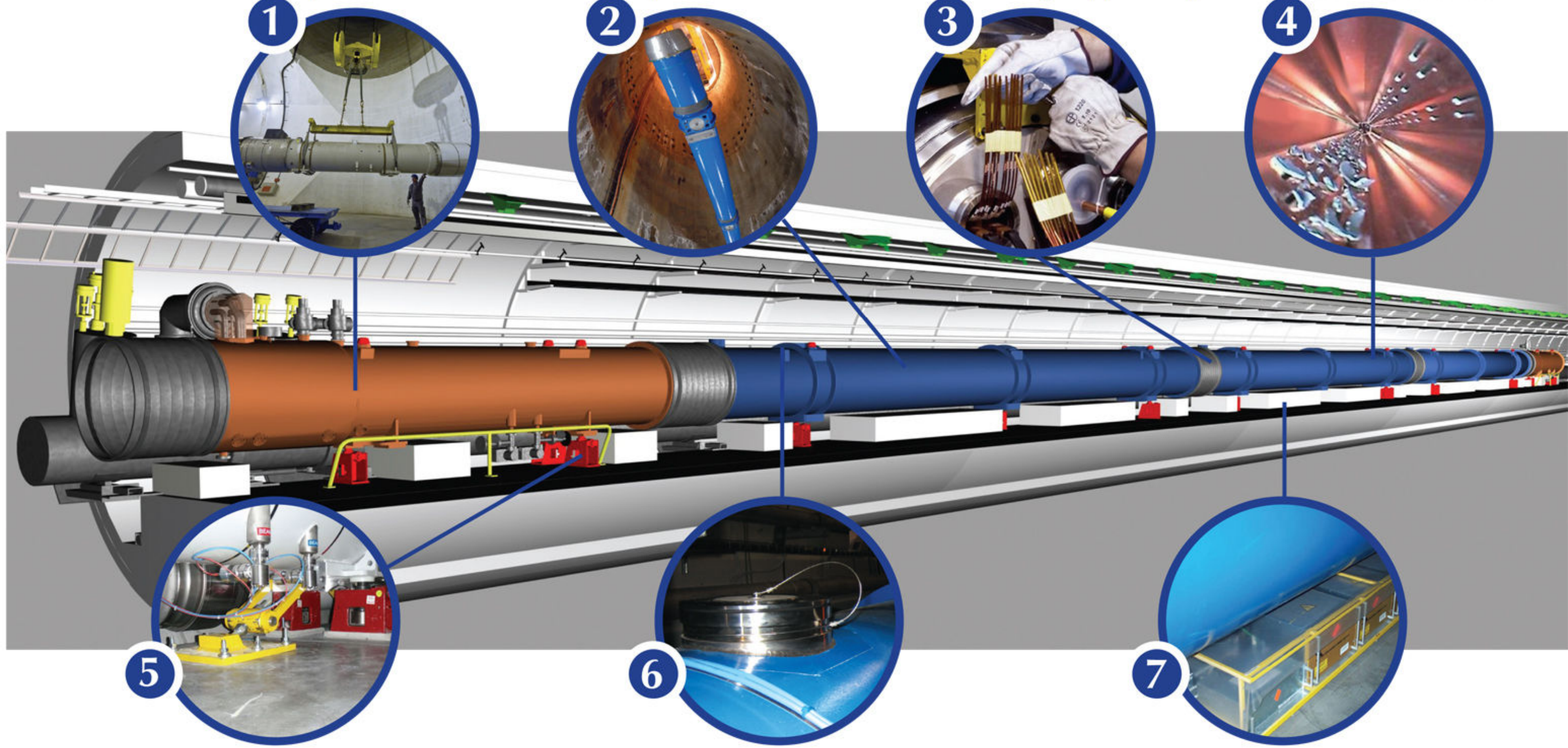
Illustrating some of the preventive measures

New additional anchoring system



Pressure relieve valves on dipoles

The LHC repairs in detail



Operating energy

- **Highest energy where LHC can be operated safely depends on:**
  - **Joint quality (max. excess resistance)**
  - **Quench propagation between magnets (→ trigger of bus-bar quench)**
  - **Speed of energy extraction: time constant of current decay**

- **Based on models and experimental tests:**
  - **In the present situation the LHC cannot be operated above 3.5 TeV without taking a significant risk**

→ LHC run 2010/2011 at 3.5 TeV / beam

  - **A major verification and repair campaign must be performed on all magnet interconnection to reach 7 TeV / beam – shutdown in 2012.**

LHC planning and scenario for the coming 8 years

This scenario is based on the outcome of the recent 'Chamonix' meeting (two months ago) where the machine experts, the experiments and the CERN Management have reviewed the current LHC situation

($cm^{-2}s^{-1}$) (integrated luminosities in fb^{-1})

Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2010	8	3.5	2.5	7 e10	720	1.2 e32	-	0.2	0.2
2011	8	3.5	2.5	7 e10	720	1.2 e32	0.1	0.8	1.0
2012									
2013	6	6.5	1	1.1 e11	720	1.4 e33	1.1	7	8
2014	7	7	1	1.1 e11	1404	3.0 e33	2.3	16	24
2015	**4**	7	1	11 e10	2808	6 e33	4.6	18	43
2016	7	7	0.55	11 e10	2808	1 e34	7.4	52	96

Note:
- **Long shutdown in 2012 for preparing design-energy running**
- **6 months shutdown in 2015 to bring in LINAC4**
- **Nominal LHC design performance aimed at 2016**
- **Likely a long shutdown in 2017 (or around that time)**

The LHC World of CERN

CMS
2900 Physicists
184 Institutions
38 countries
550 MCHF

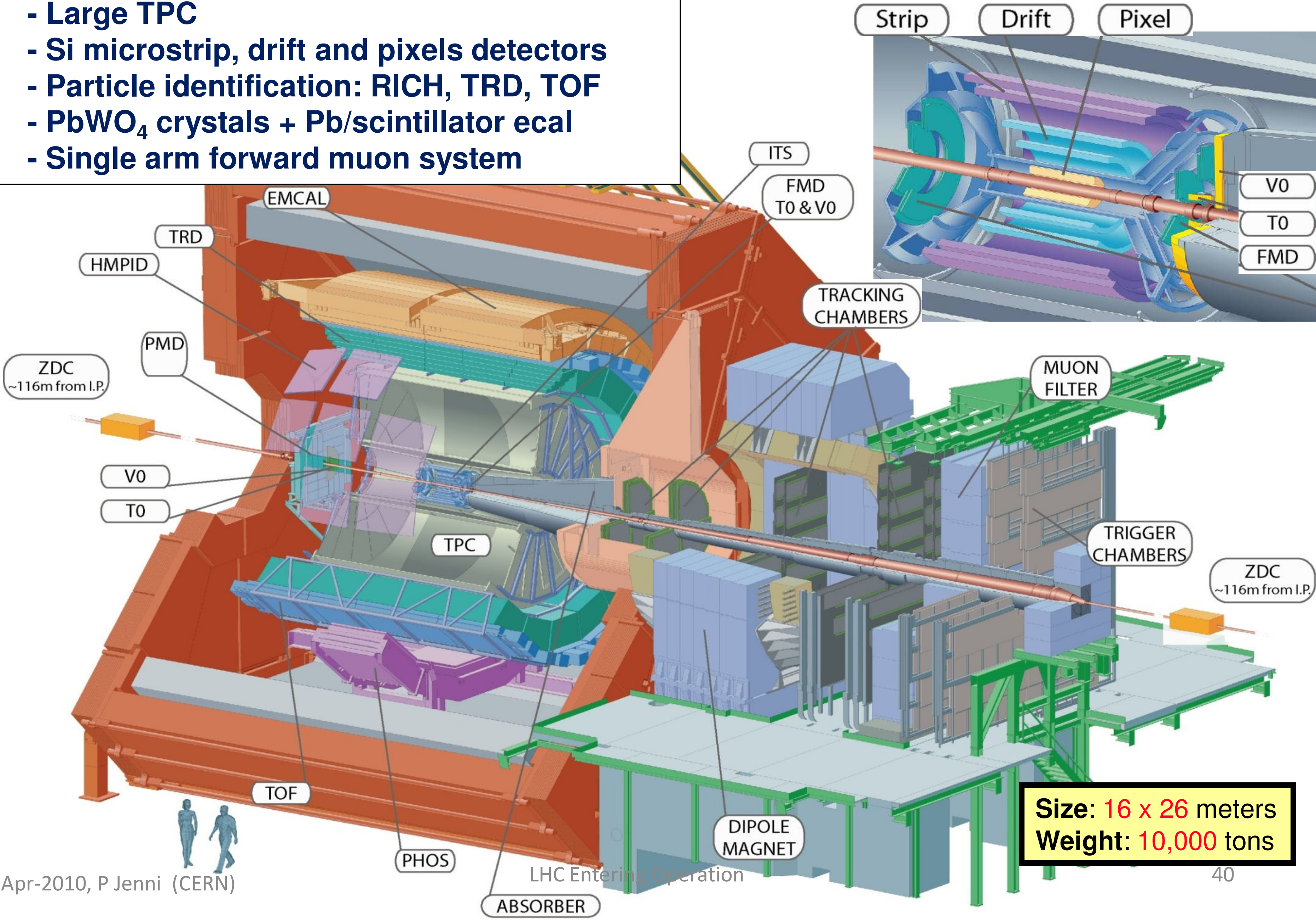
LHCb
700 Physicists
52 Institutions
15 countries
75 MCHF

ATLAS
2900 Physicists
172 Institutions
37 countries
550 MCHF

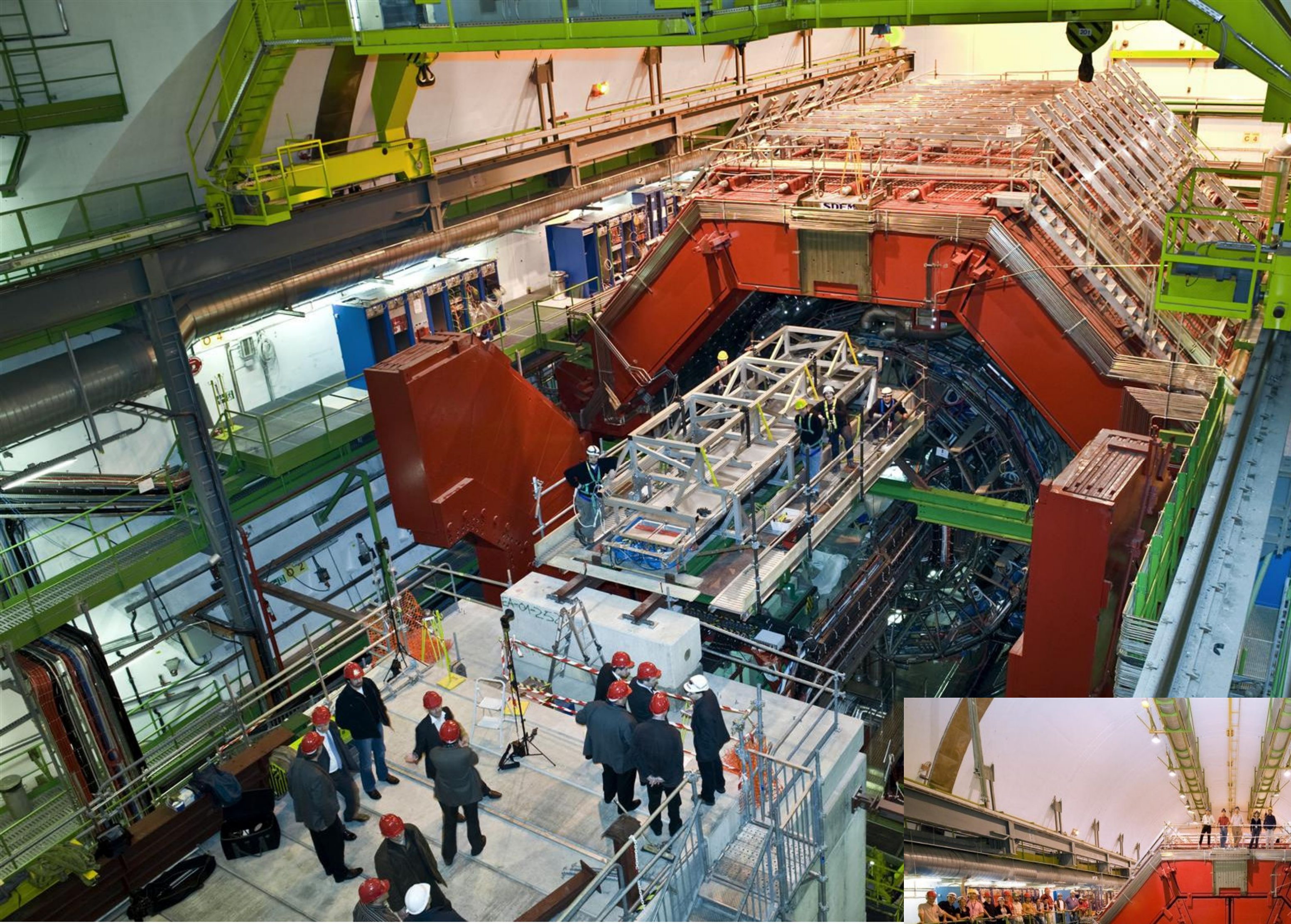
ALICE
1000 Physicists
105 Institutions
30 countries
150 MCHF

ALICE: study of quark-gluon plasma

- L3 solenoid
- Large TPC
- Si microstrip, drift and pixels detectors
- Particle identification: RICH, TRD, TOF
- $PbWO_4$ crystals + Pb/scintillator ecal
- Single arm forward muon system



Size: 16 x 26 meters
Weight: 10,000 tons

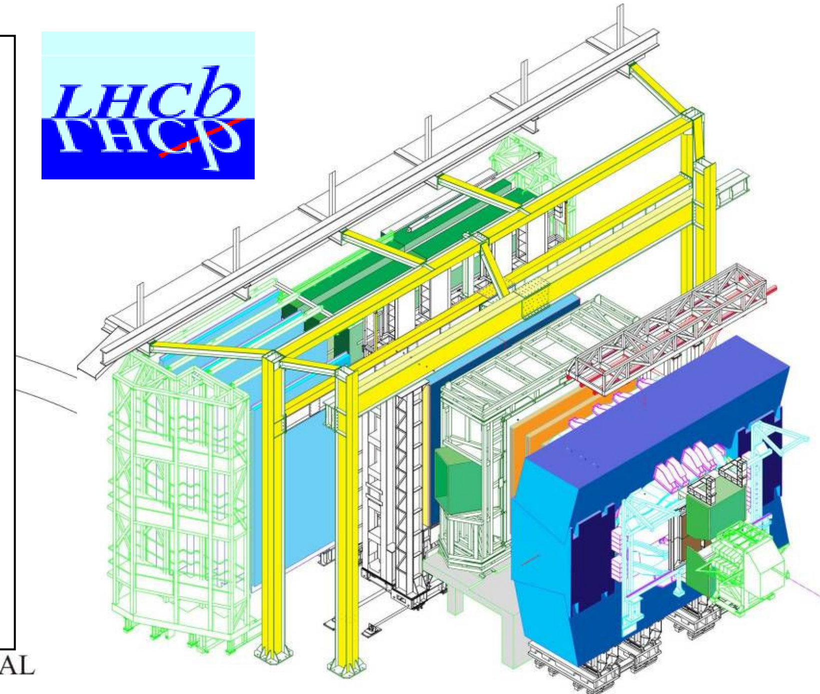


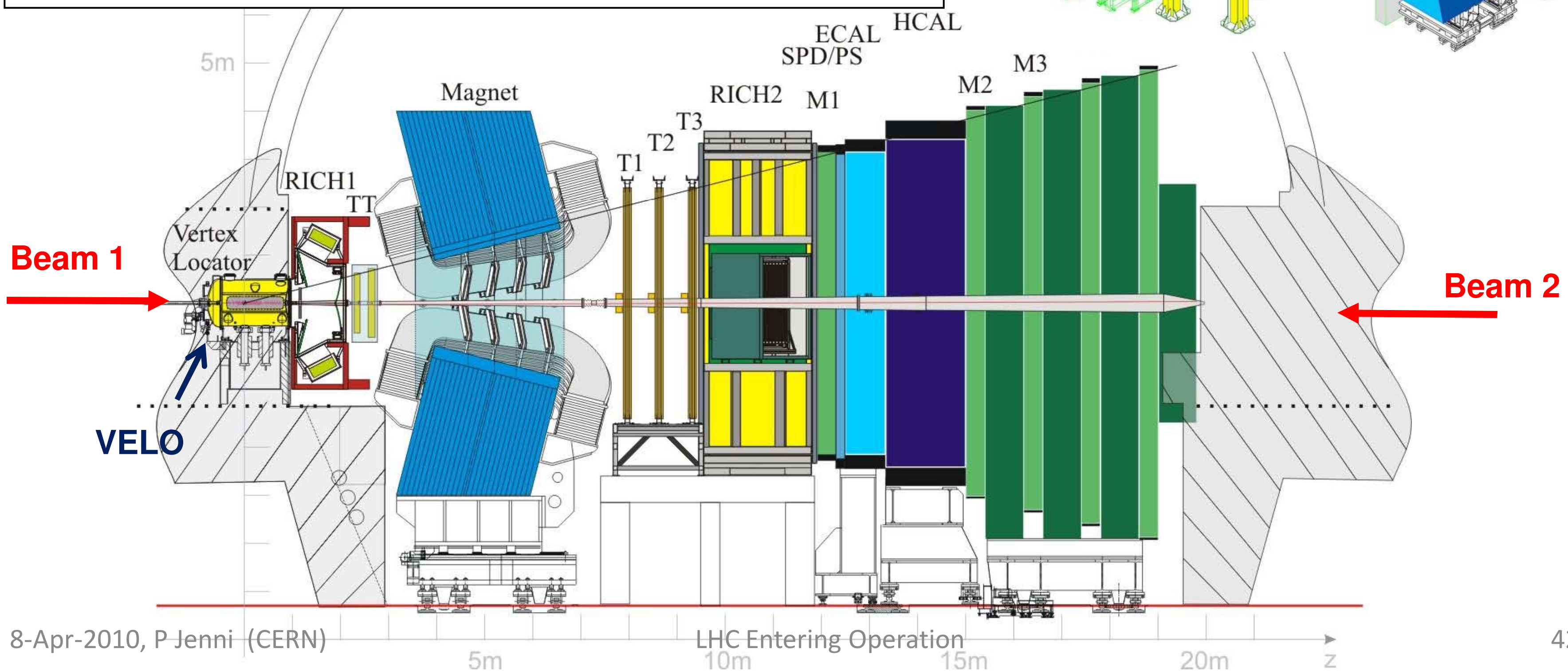
Installation of a ALICE TOF module May 2008

Formal end of ALICE installation July 2008

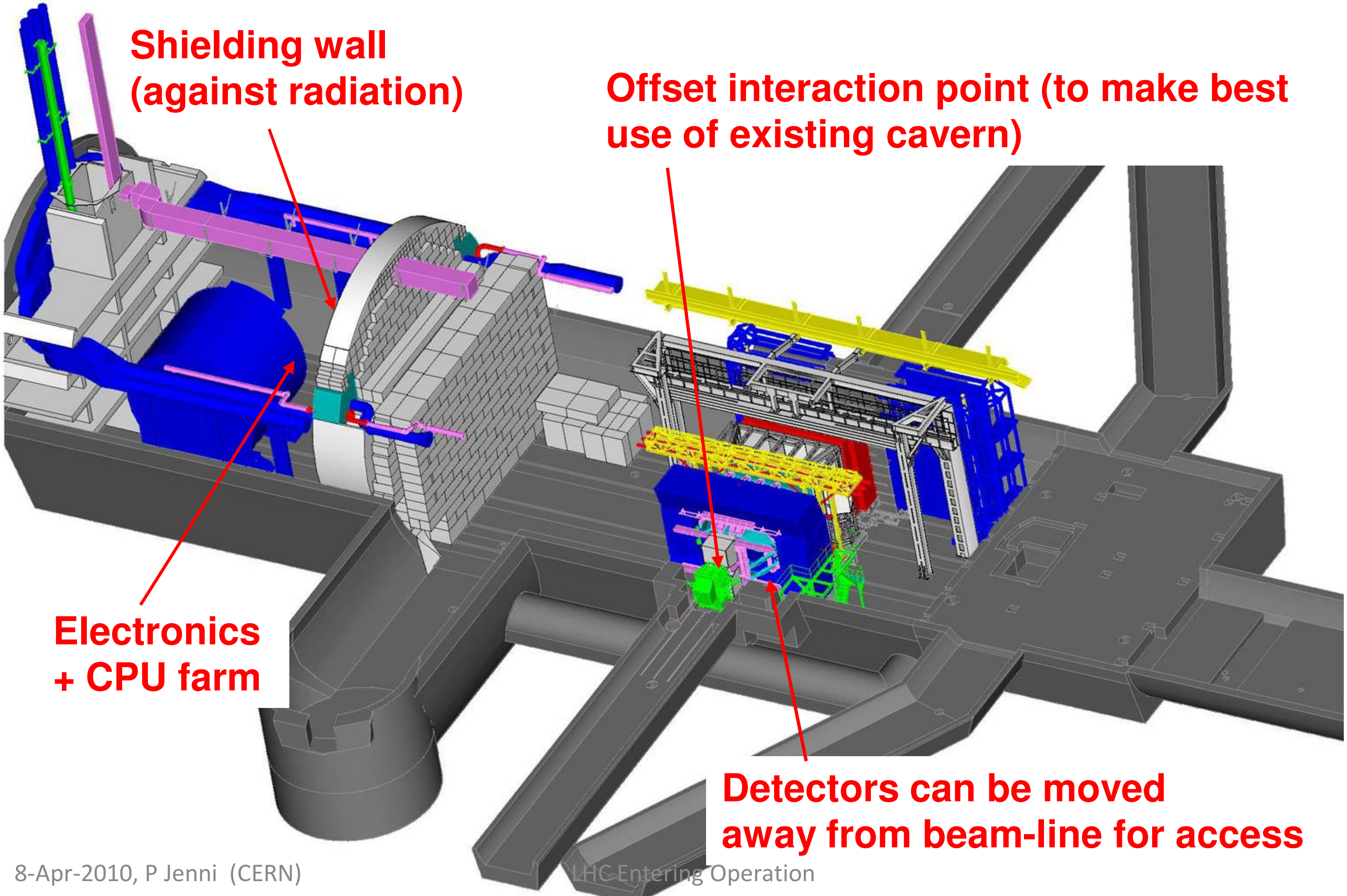
LHCb:
Study of B decays and CP Violation
(indirect search for New Physics)

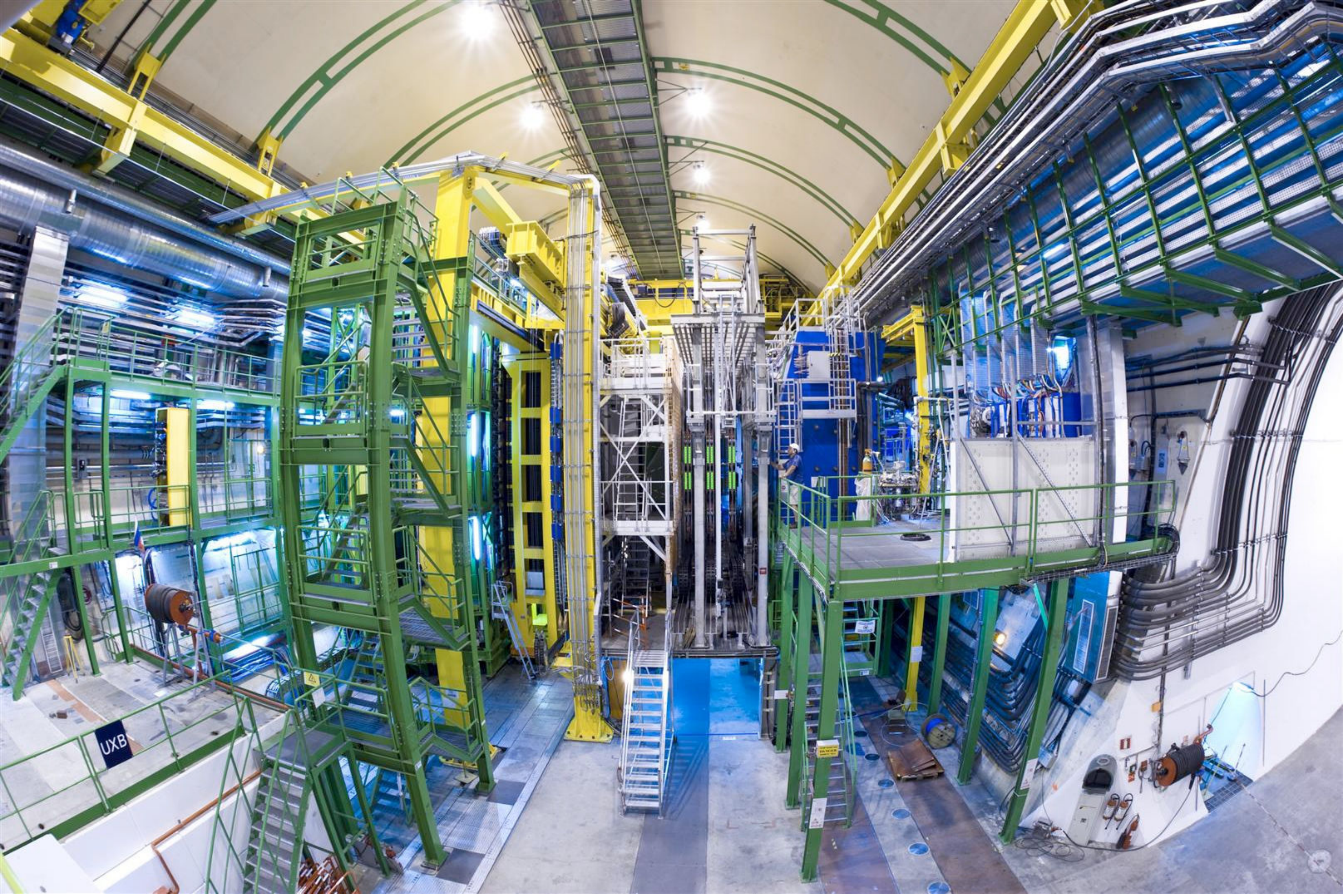
- Dipole magnet (4 T.m)
- Particle Identification (2 RICH)
- 21 layer of Si microstrip vertex locator (VELO)
- Tracking: Silicon + long straw tubes
- Shashlik (Pb/scint) em calorimeter
- HCAL (Fe/scint),
- MWPC muon system

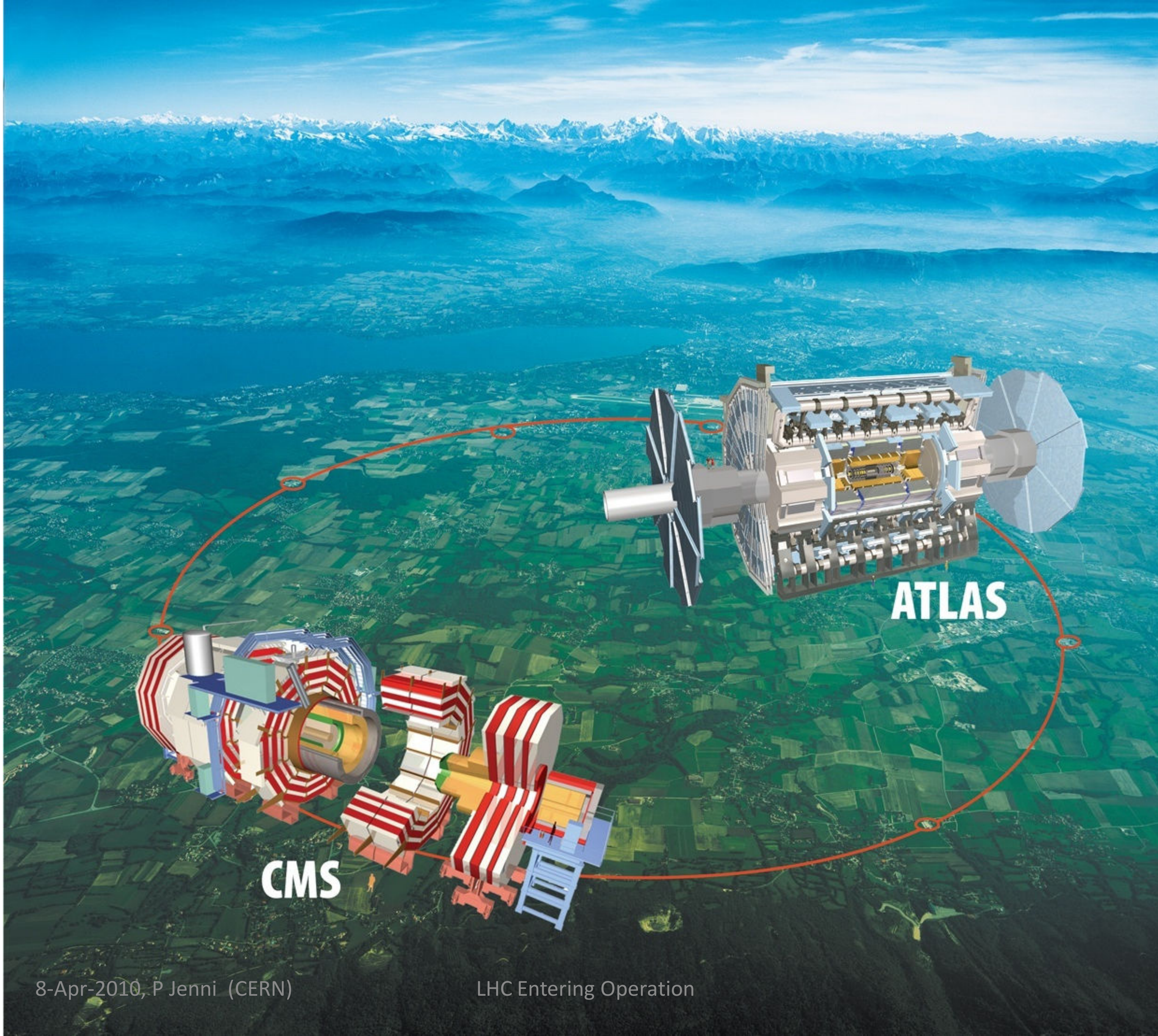




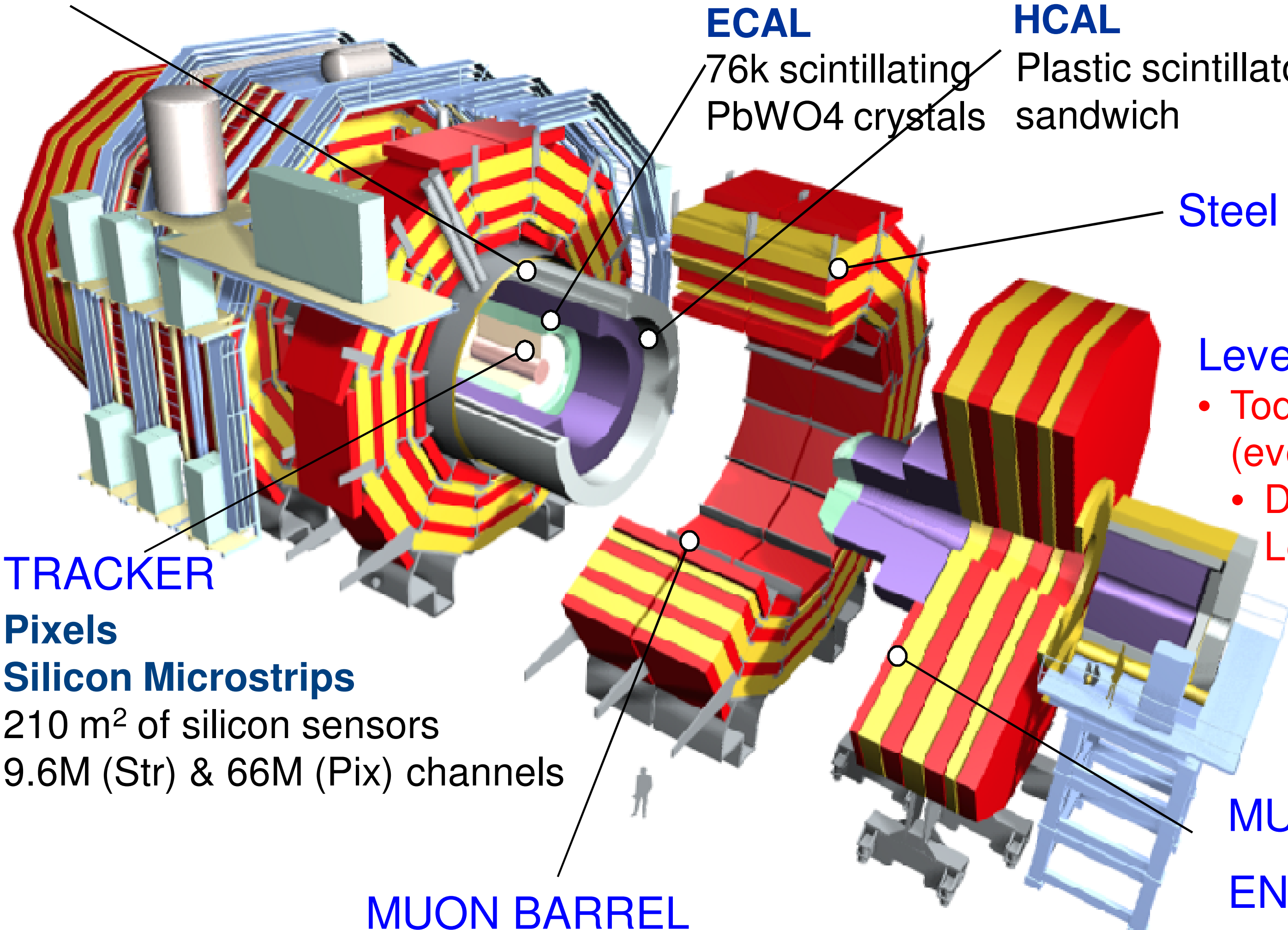
LHCb in its cavern (~100 m deep)



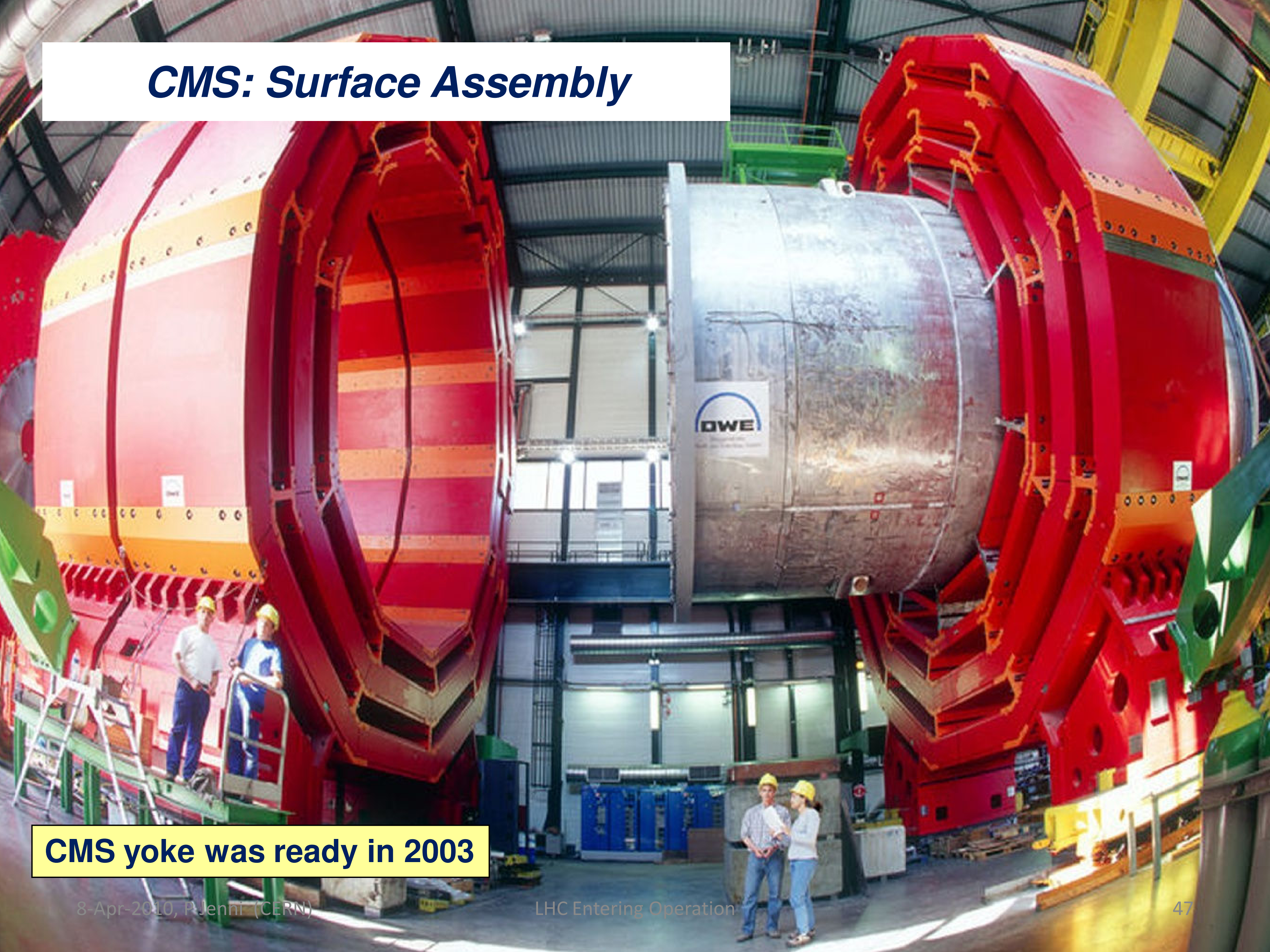

UXB


ATLAS
CMS

CMS Detector

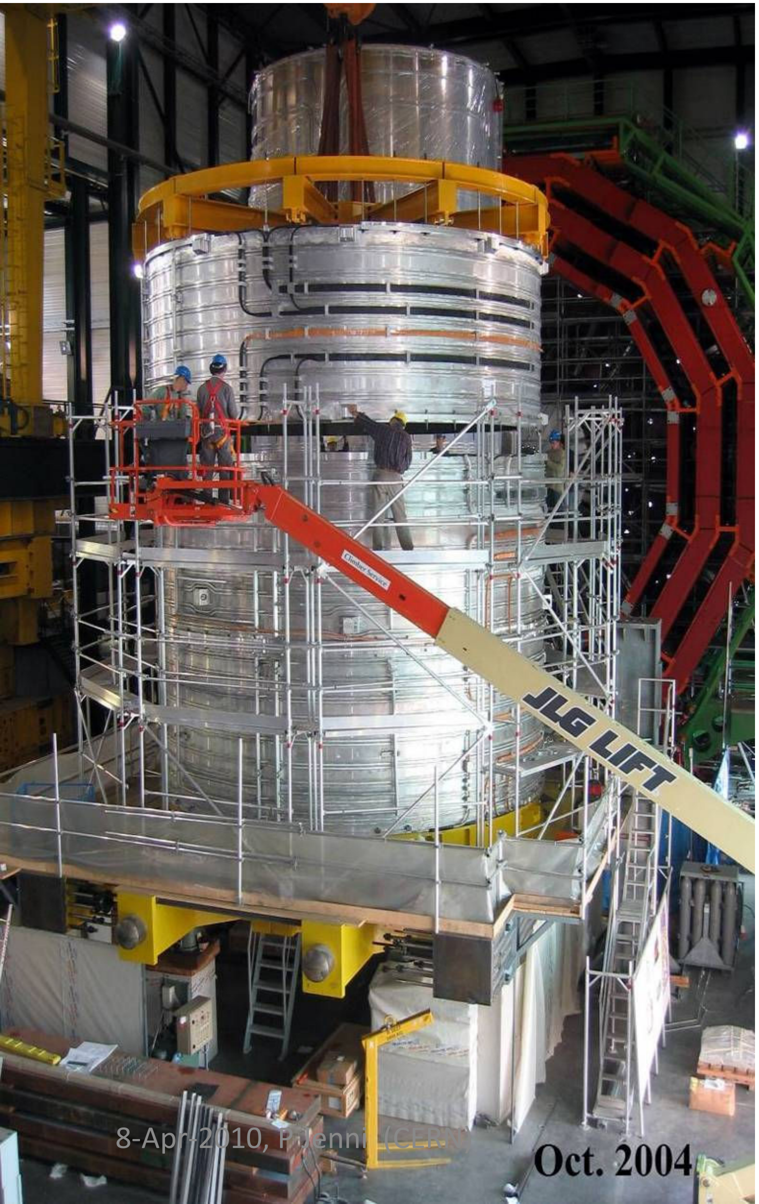


CMS: Surface Assembly



CMS yoke was ready in 2003

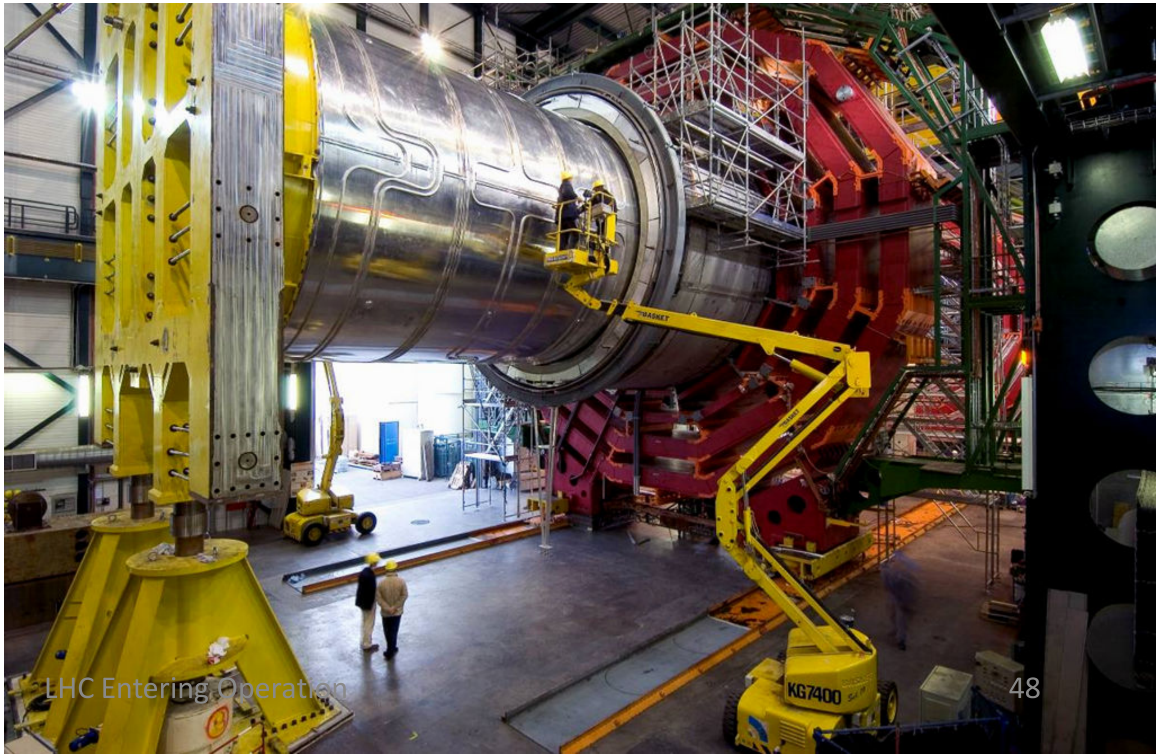
Example of an Engineering Challenge: CMS Solenoid



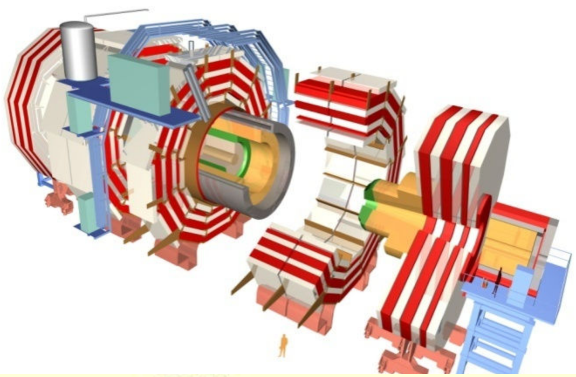
CMS solenoid:

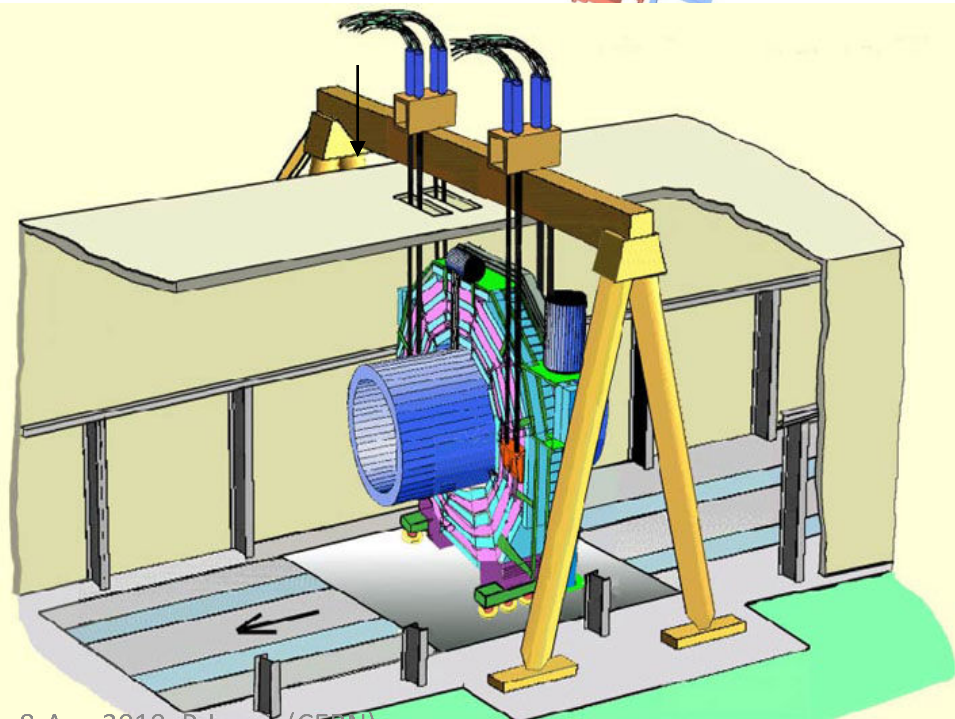
Magnetic length	12.5 m
Diameter	6 m
Magnetic field	4 T
Nominal current	20 kA
Stored energy	2.7 GJ

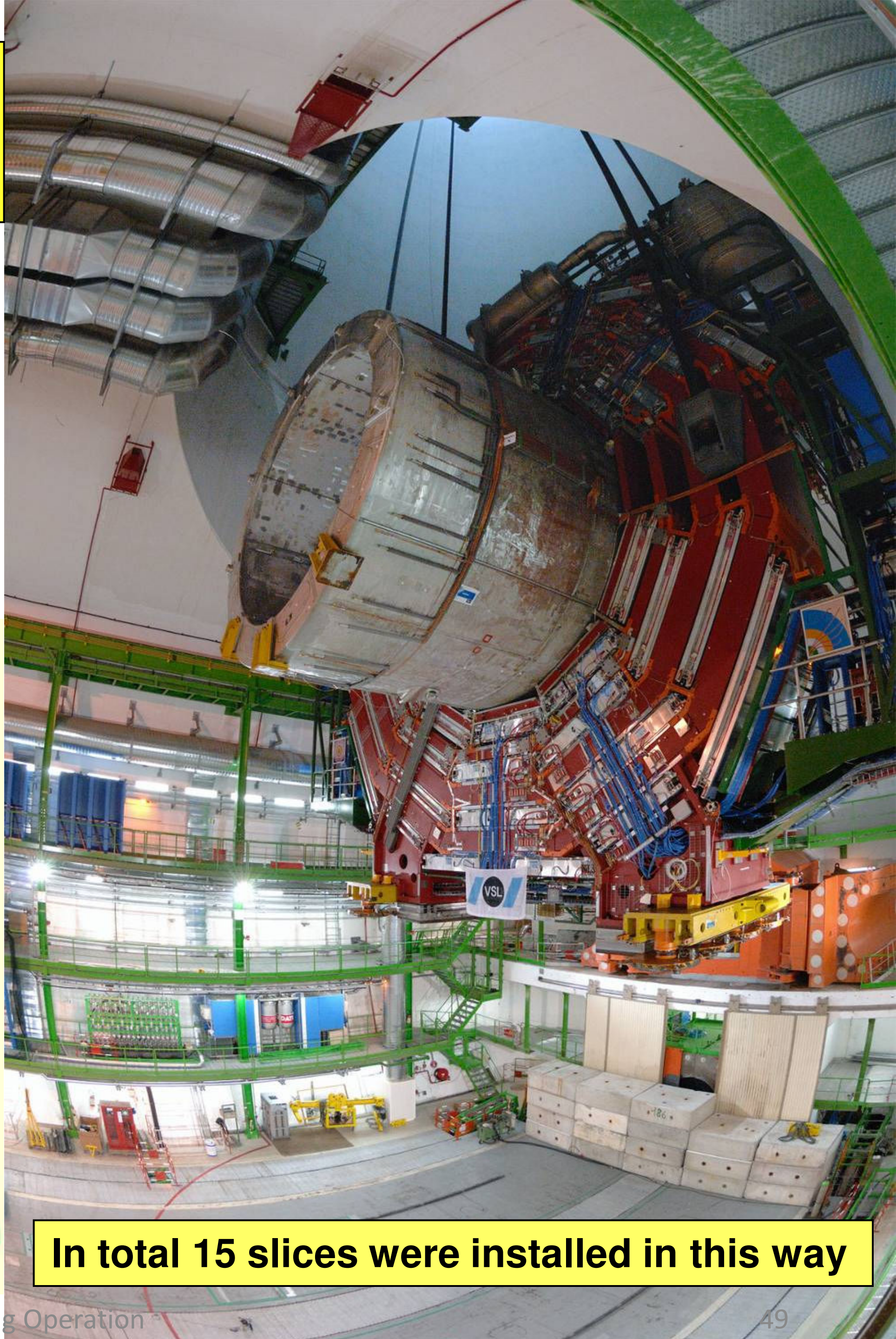
Tested at full current in Summer 2006



The central, heaviest slice (2000 tons) including the solenoid magnet lowered in the underground cavern in Feb. 2007





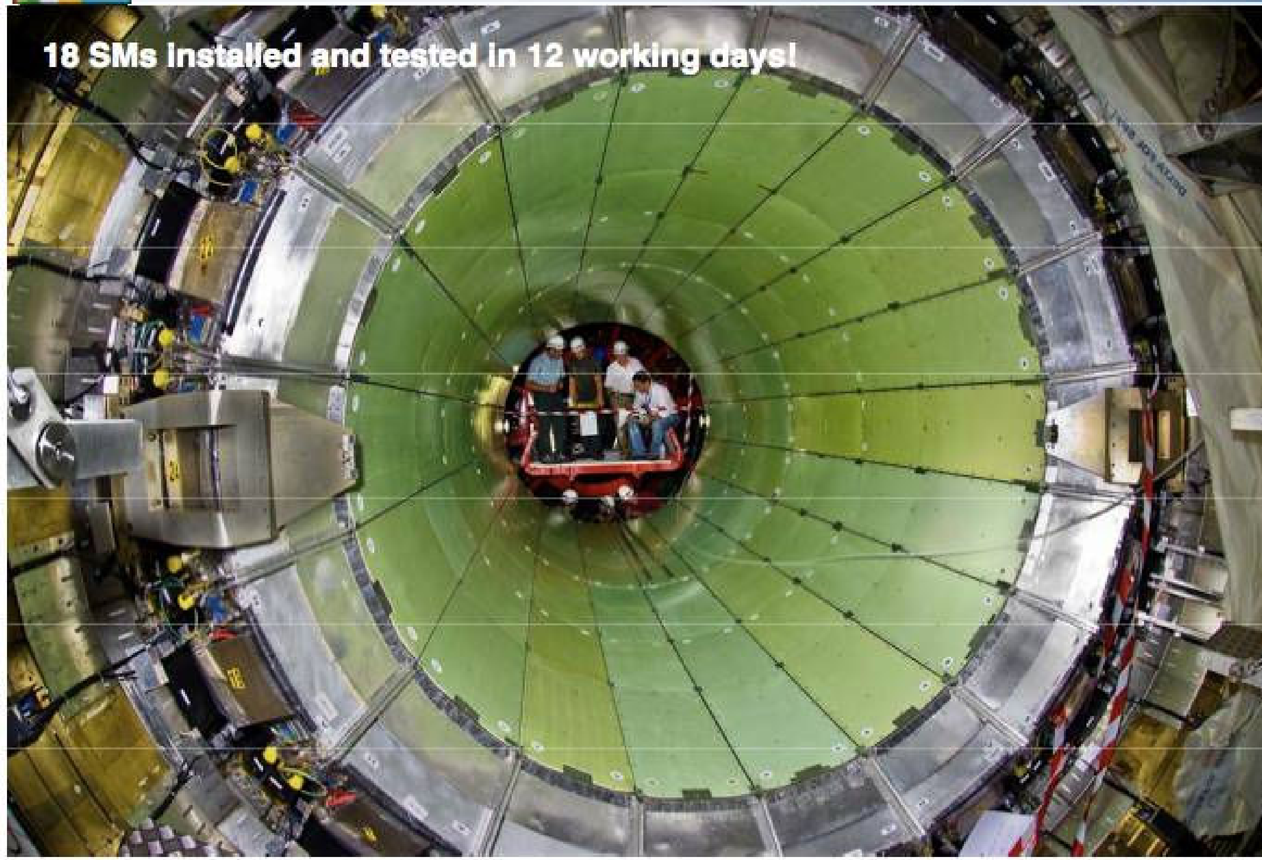


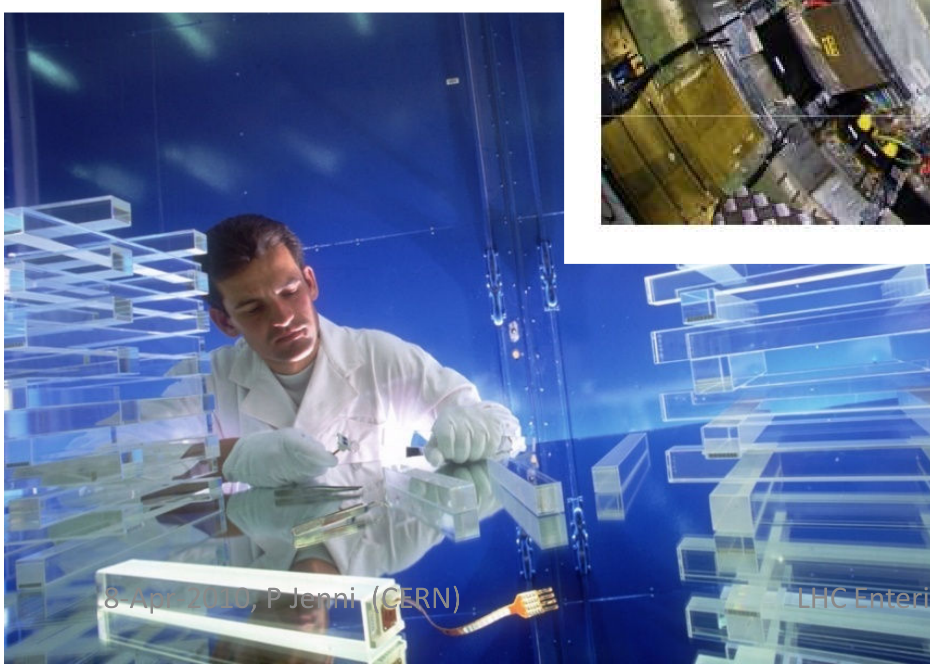
In total 15 slices were installed in this way

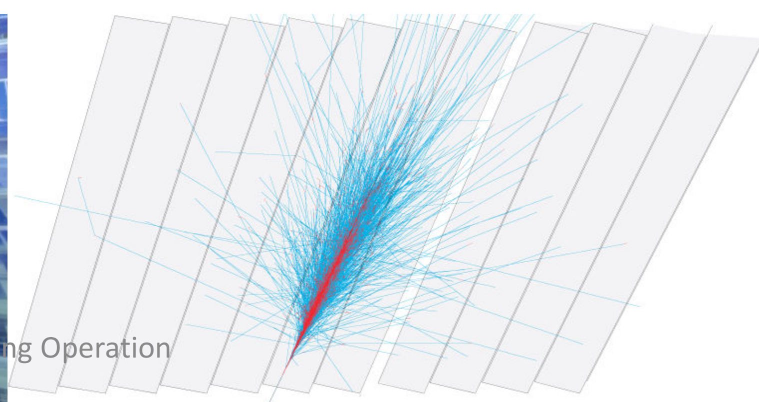
Barrel ECAL Installation Completed: 27 July 07

CMS Electron and Photon calorimeter: 76 000 $PbW0_4$ crystals

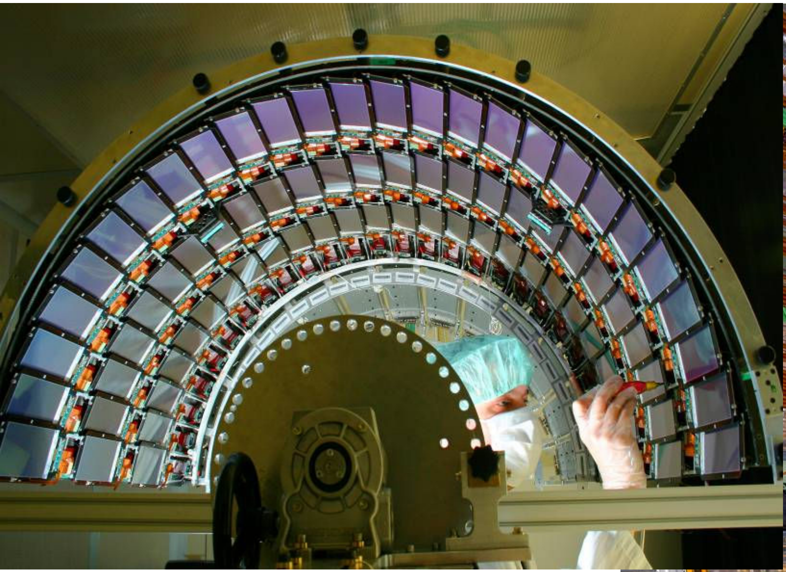
The End-cap was on the critical path for many years, but it was completed just in time before final closure, a major achievement by CMS

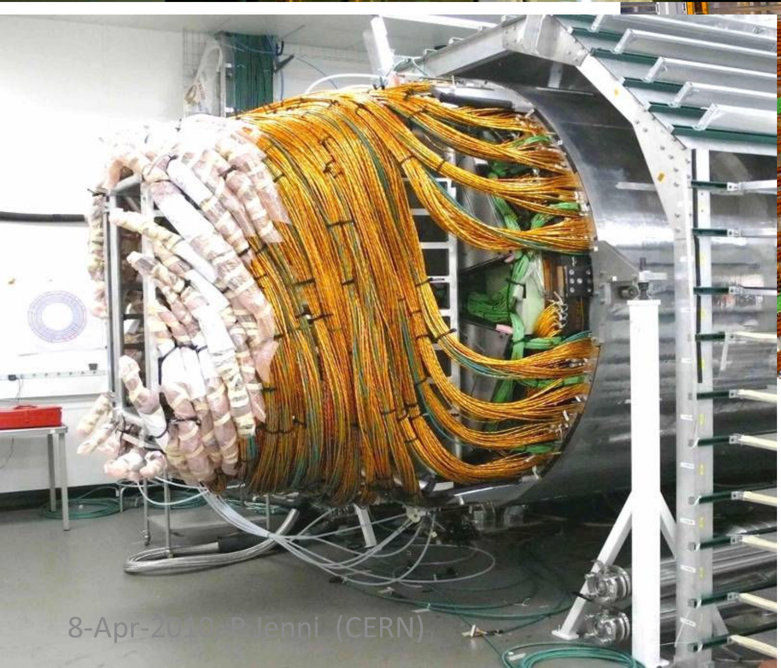


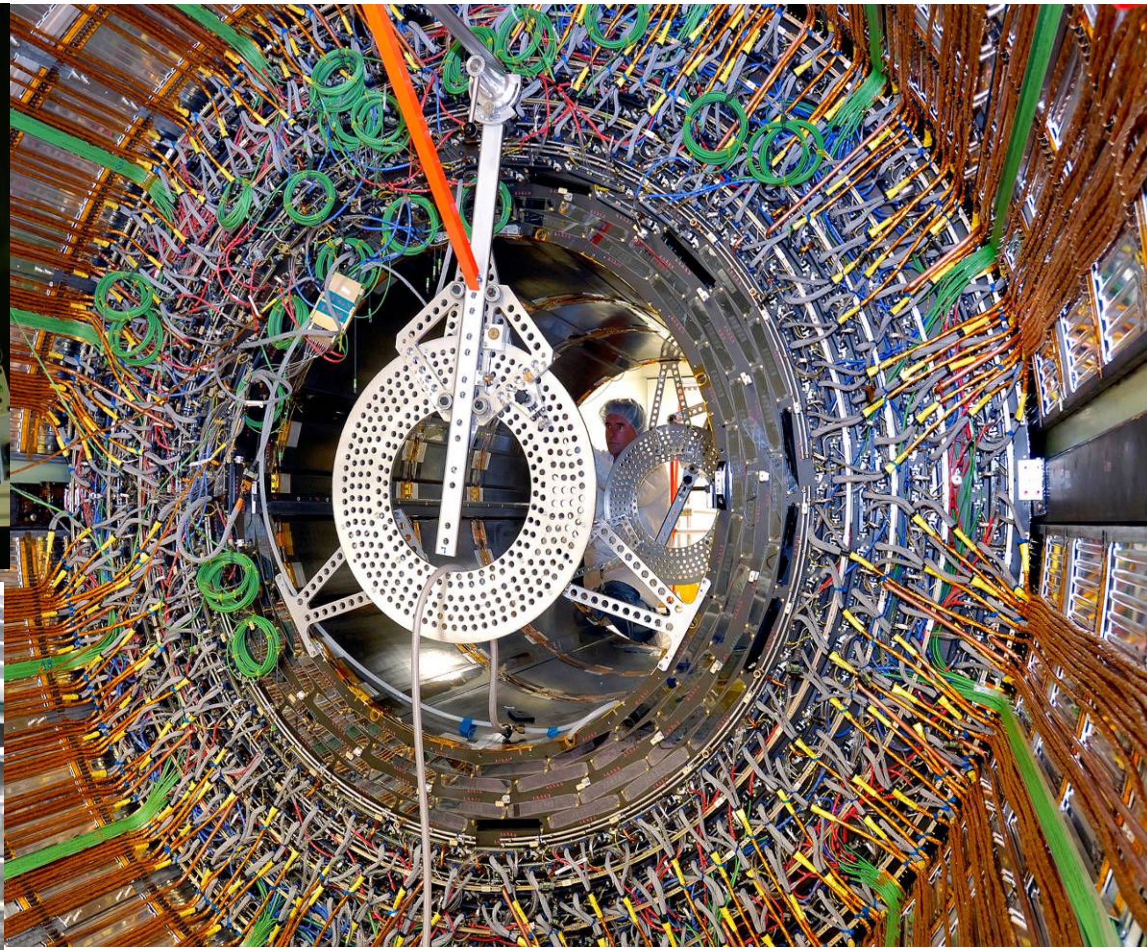




CMS Silicon Tracker







The Silicon tracker (200m^2) has 10 M channels
Operating temperature -15℃

CMS before closure

ATLAS Collaboration

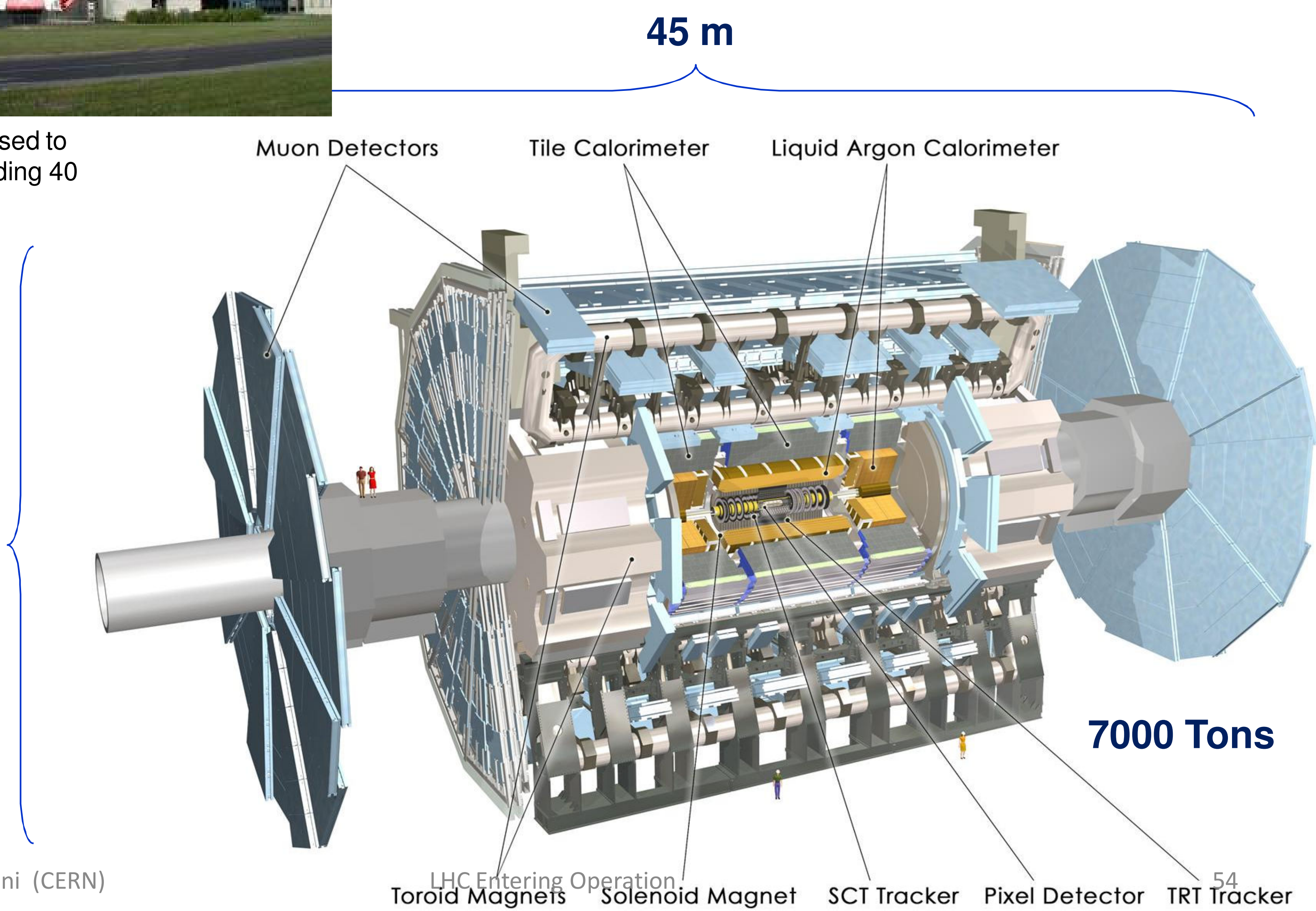
(Status March 2010)

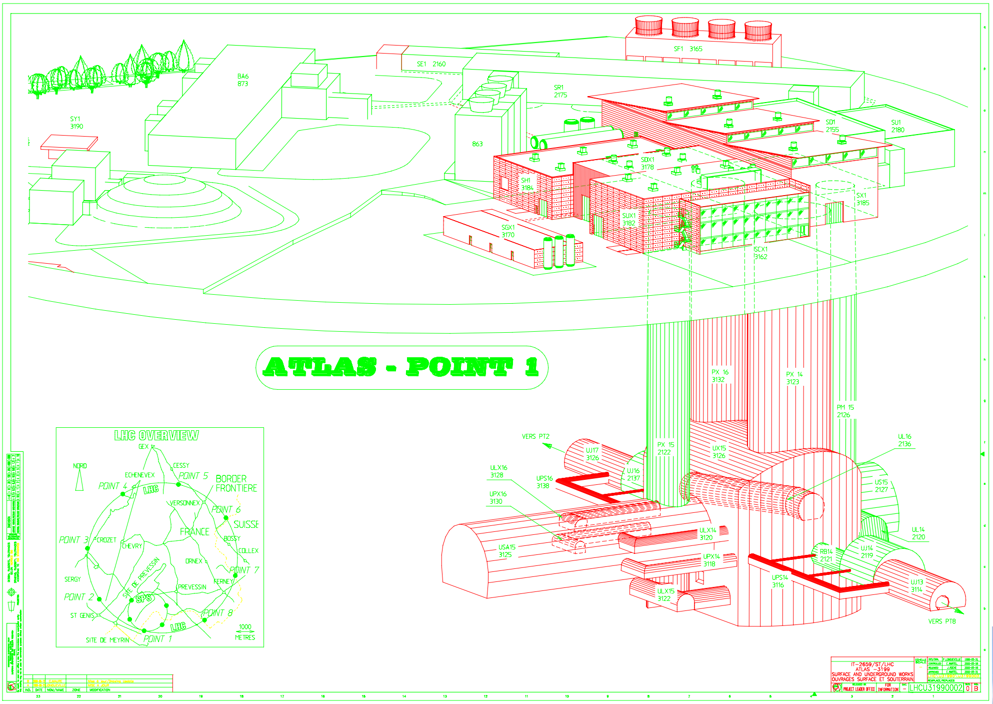
37 Countries
173 Institutions
3000 Scientific participants total
(1100 Students)

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, Brasil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, LMU Munich, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, Northern Illinois, 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, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBC Vancouver, Victoria, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

ATLAS Detector

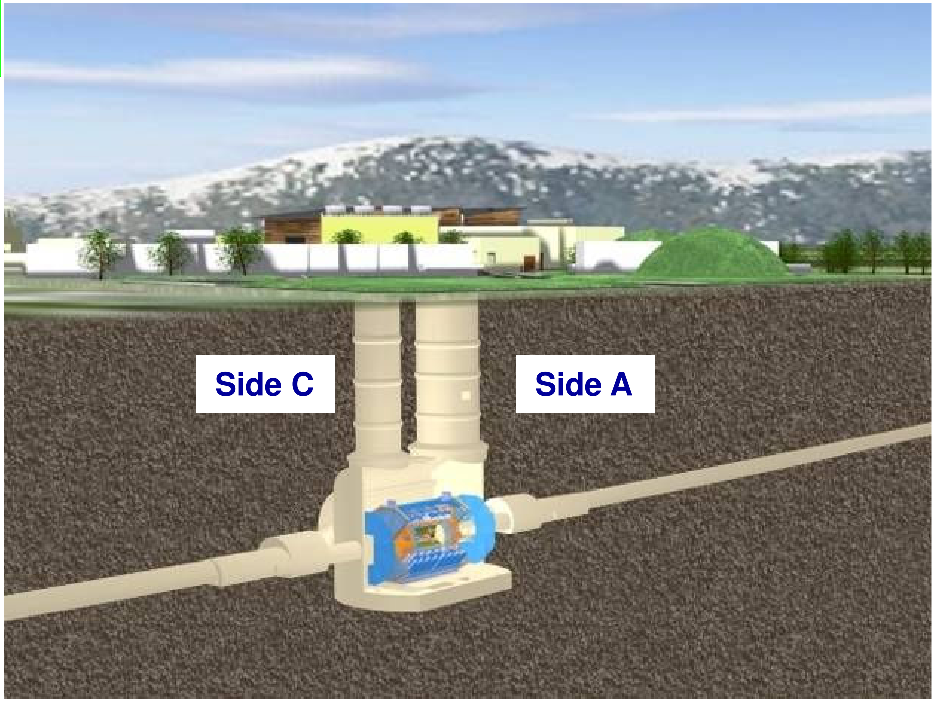
ATLAS superimposed to
the 5 floors of building 40

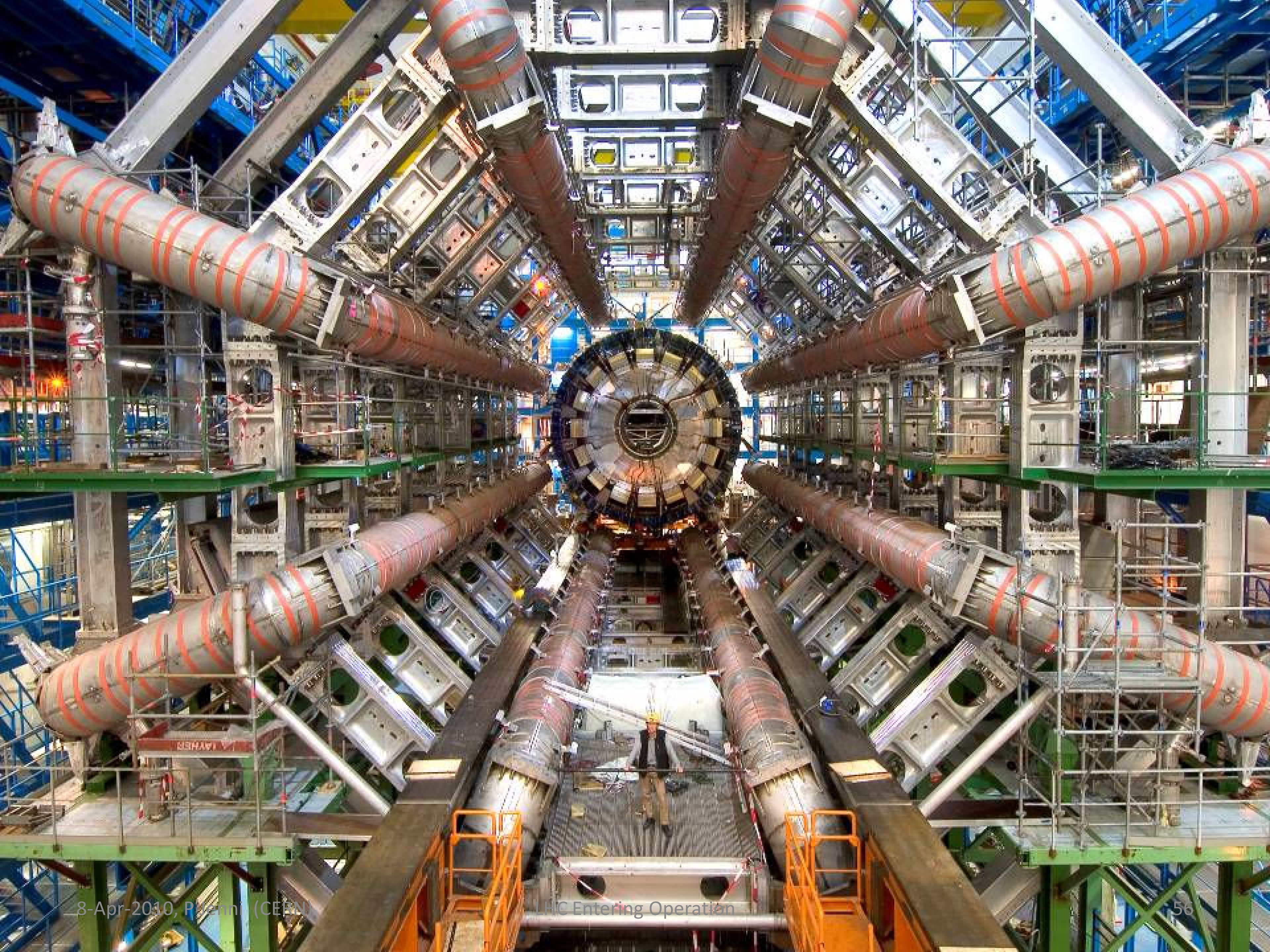


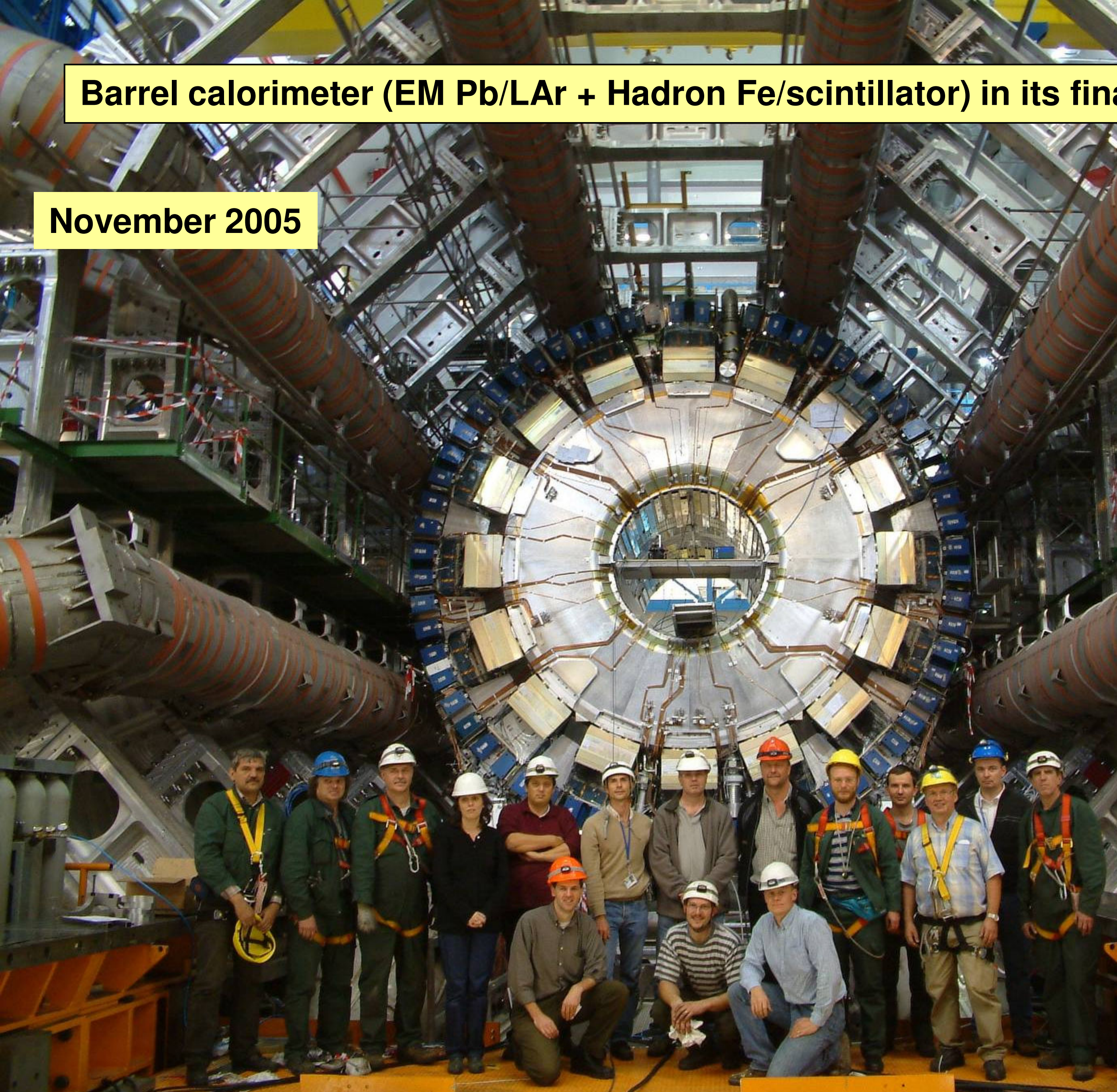


The Underground Cavern at Point-1 for the ATLAS Detector

Length = 55 m
Width = 32 m
Height = 35 m



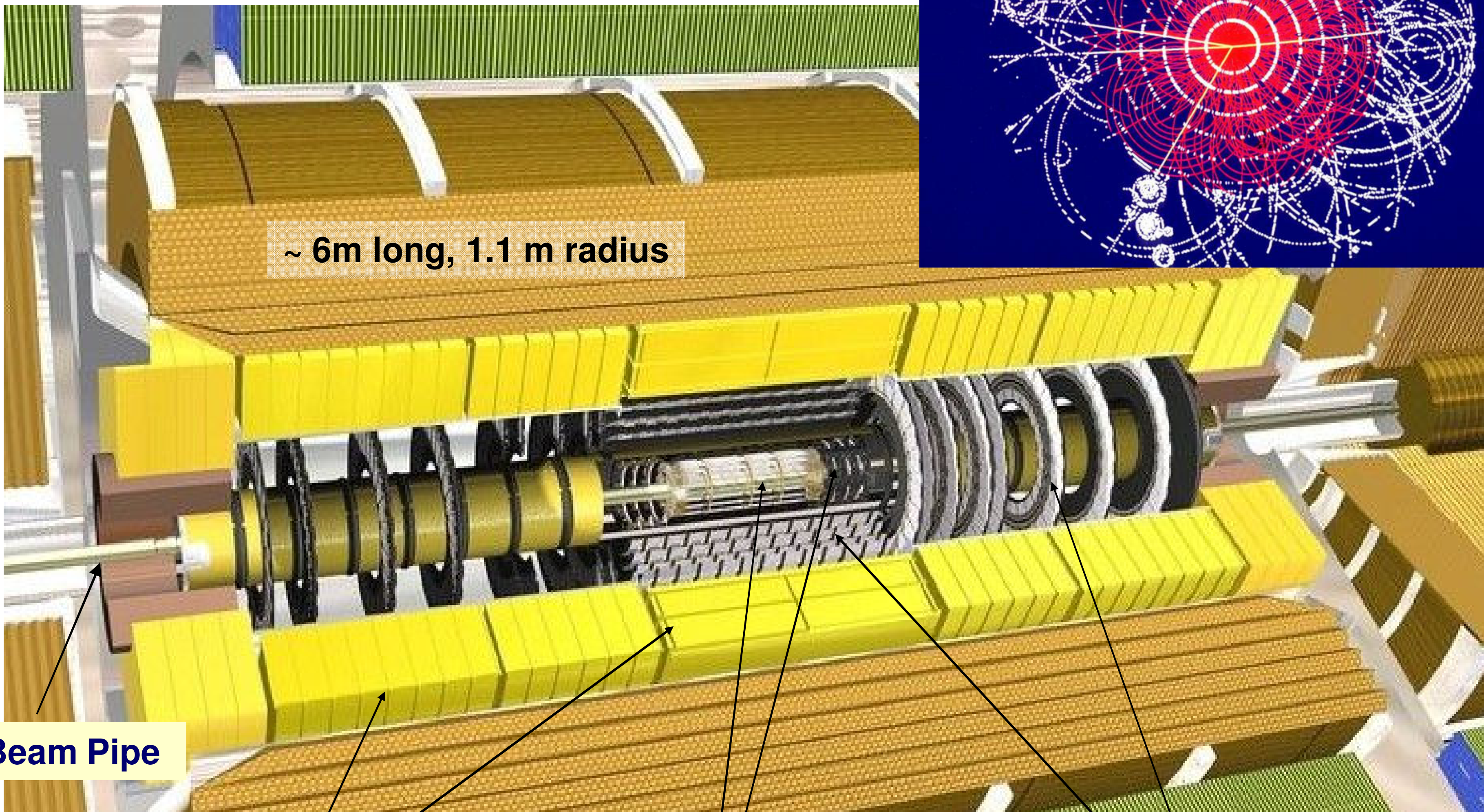



Barrel calorimeter (EM Pb/LAr + Hadron Fe/scintillator) in its final position at Z=0
November 2005


October 2004

ATLAS Tracking Detectors

2 Tesla solenoid $\sigma/p_T \sim 5\mathrm{x}10^{-4}\, p_T \oplus 0.01$



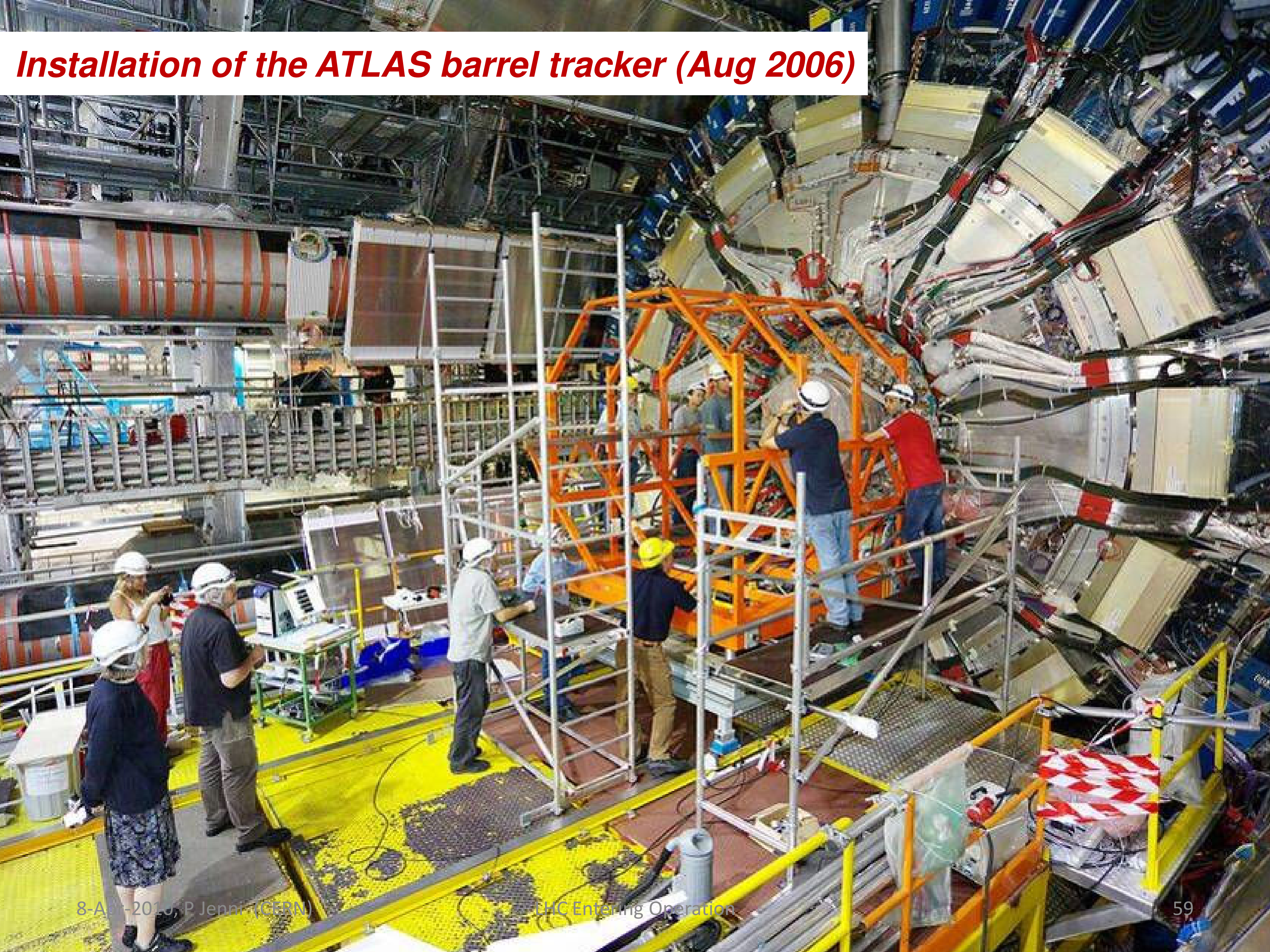
Beam Pipe

Transition Radiation Tracker (TRT)
(4 10^5 channels) with e/π separation

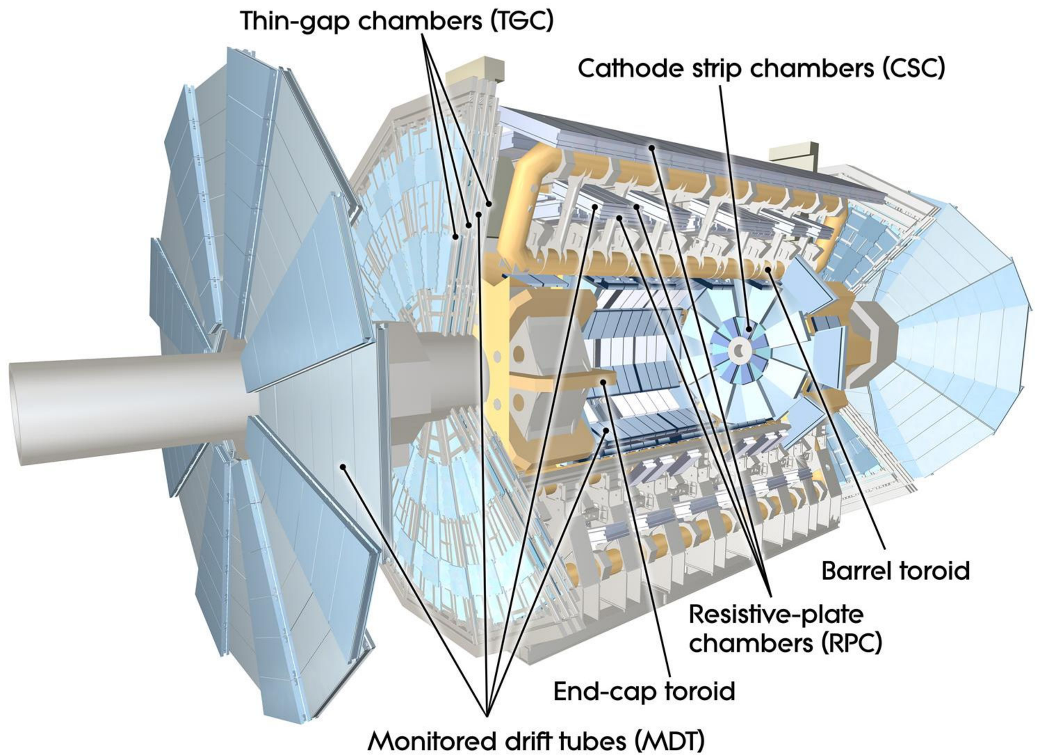
Pixels
(0.8 10^8 channels)

Si Strips Tracker (SCT)
(6 10^6 channels)

Installation of the ATLAS barrel tracker (Aug 2006)



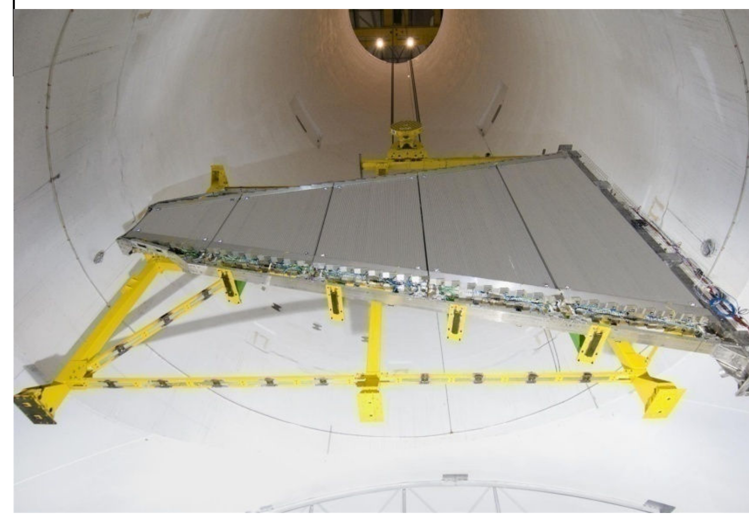
Muon System

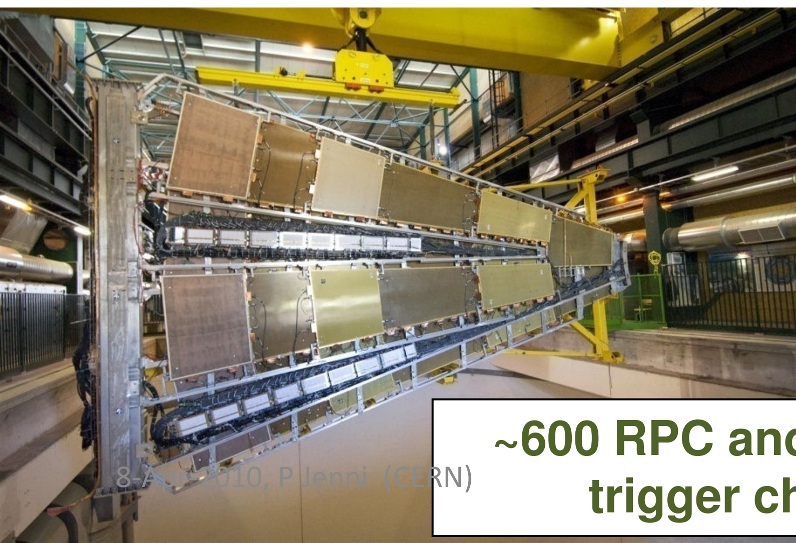


Stand-alone momentum resolution $\Delta pT/pT$ < 10% up to 1 TeV

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

~1200 MDT precision chambers for track

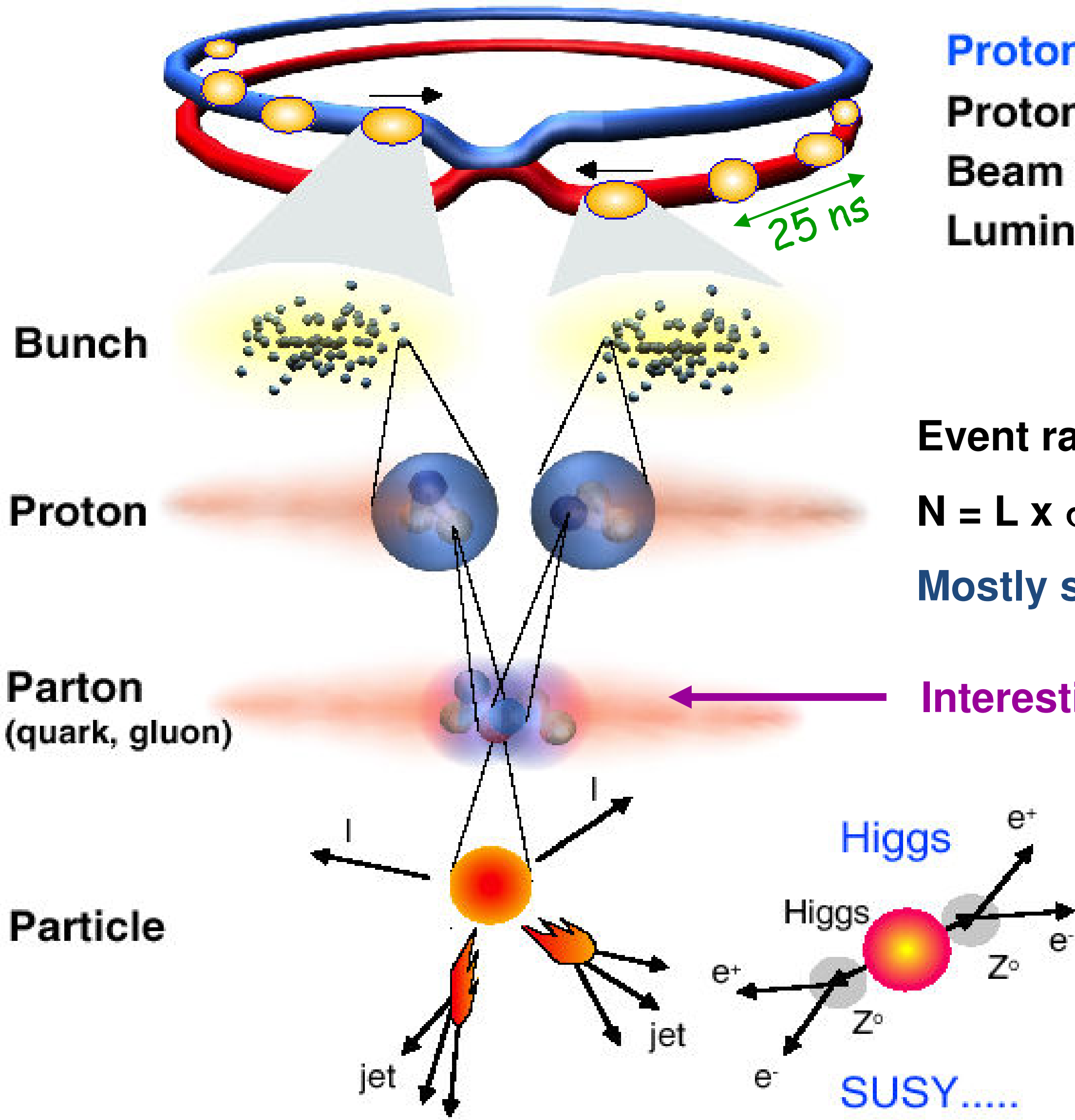




~600 RPC and ~3600 TGC trigger chambers

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

Collisions at LHC



Proton-Proton

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

Event rate:

$N = L \times \sigma\,(pp) \approx$ 10^{9} interactions/s

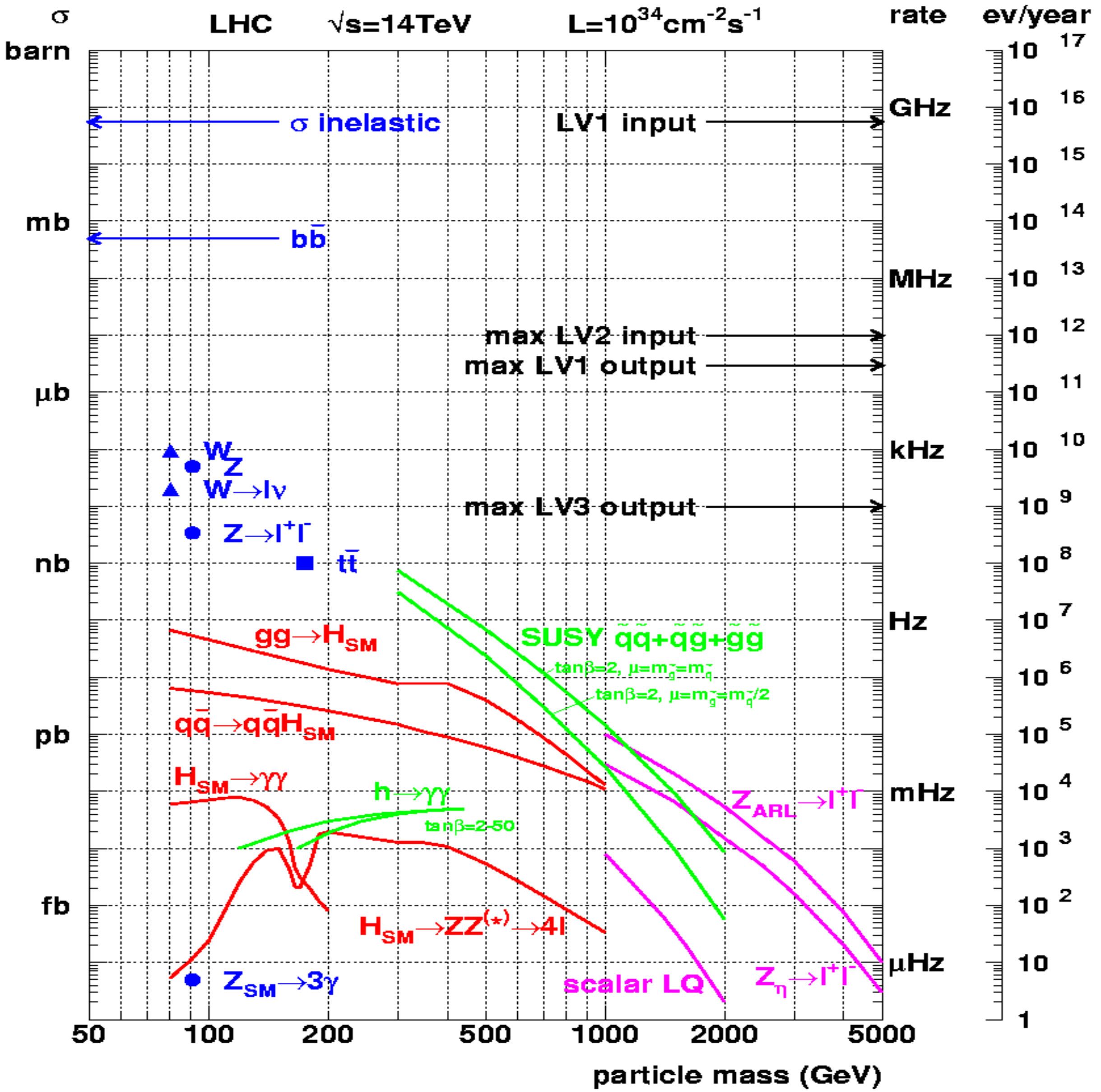
Mostly soft (low p_T) events

Interesting hard (high-p_T) events are rare

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

→ very powerful detectors needed

Cross Sections and Production Rates

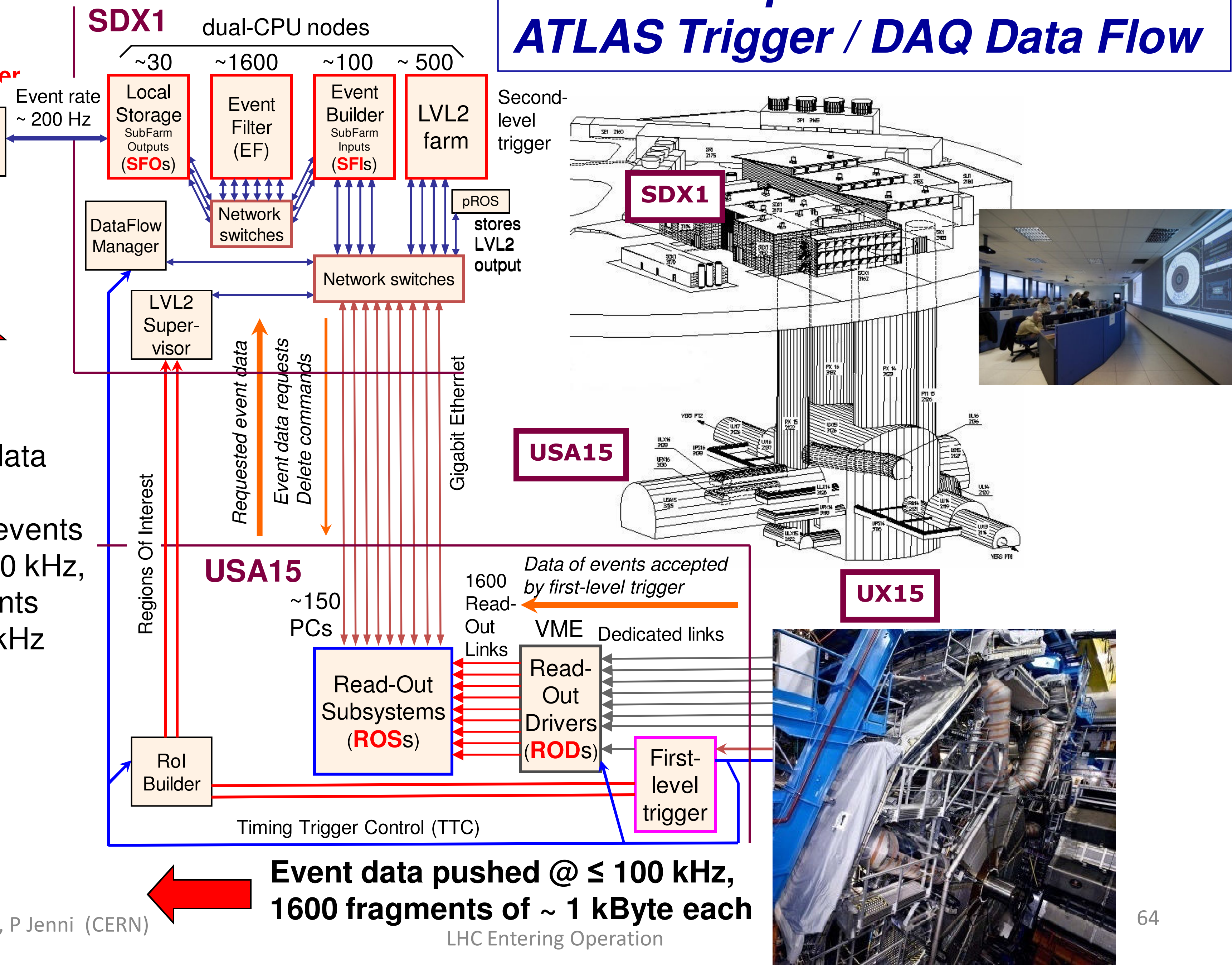


"Well known" processes, don't need to keep all of them …

New Physics

This we want to keep!

As an example: ATLAS Trigger / DAQ Data Flow

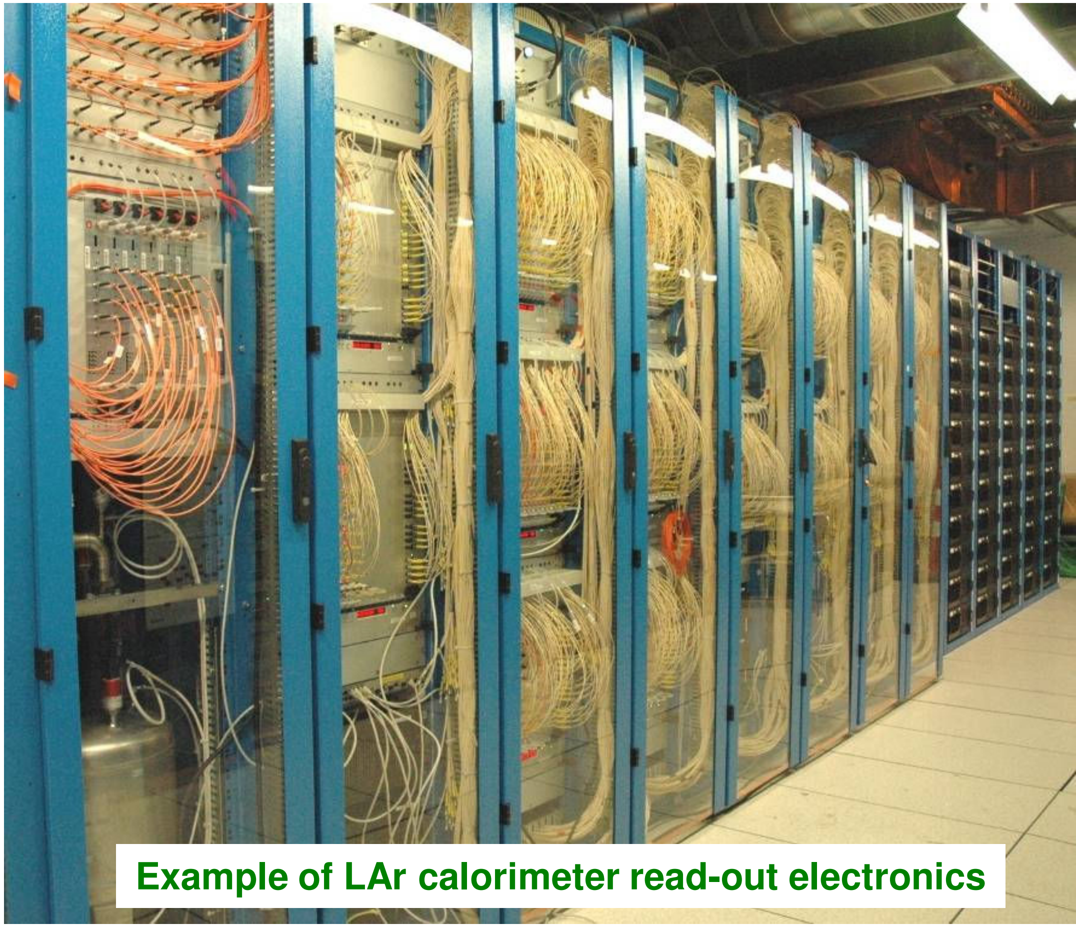


Event data **pulled**:
partial events @ ≤ 100 kHz,
full events @ ~ 3 kHz

The read-out electronics, trigger, DAQ and detector control systems have been brought into operation gradually over the past years, along with the detector commissioning with cosmics

(Examples from ATLAS)

Example of Level-1 Trigger electronics



Example of LAr calorimeter read-out electronics

In total about 300 racks with electronics in the underground counting rooms

ATLAS HLT Farms (as an example for staged implementation)

Final size for max L1 rate ***(TDR)***

~ ***500 PCs for L2 + ~ 1800 PCs for EF***

(multi-core technology)

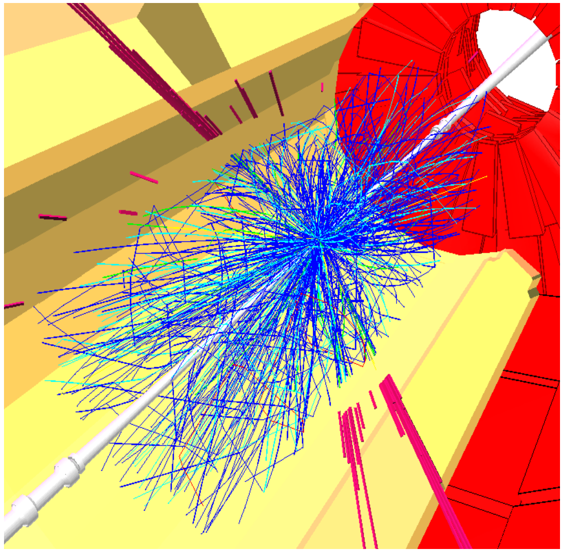
For 2009: **850 PCs installed**
total of 27 XPU racks = 35% of final system

(1 rack = 31 PCs)
(XPU = can be connected to L2 or EF)

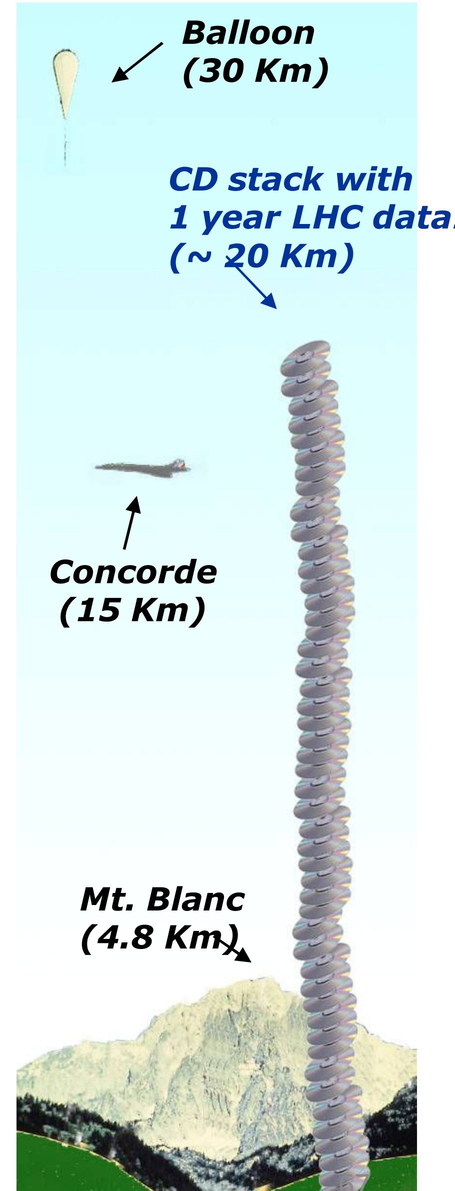
- ***x 8 cores***
- ***CPU: 2 x Intel Harpertown quad-core 2.5 GHz***
- ***RAM: 2 GB / core, i.e. 16 GB***

Final system : total of 17 L2 + 62 EF racks

Worldwide LHC Computing Grid (wLCG)



WLCG is a worldwide collaborative effort on an unprecedented scale in terms of storage and CPU requirements, as well as the software project's size



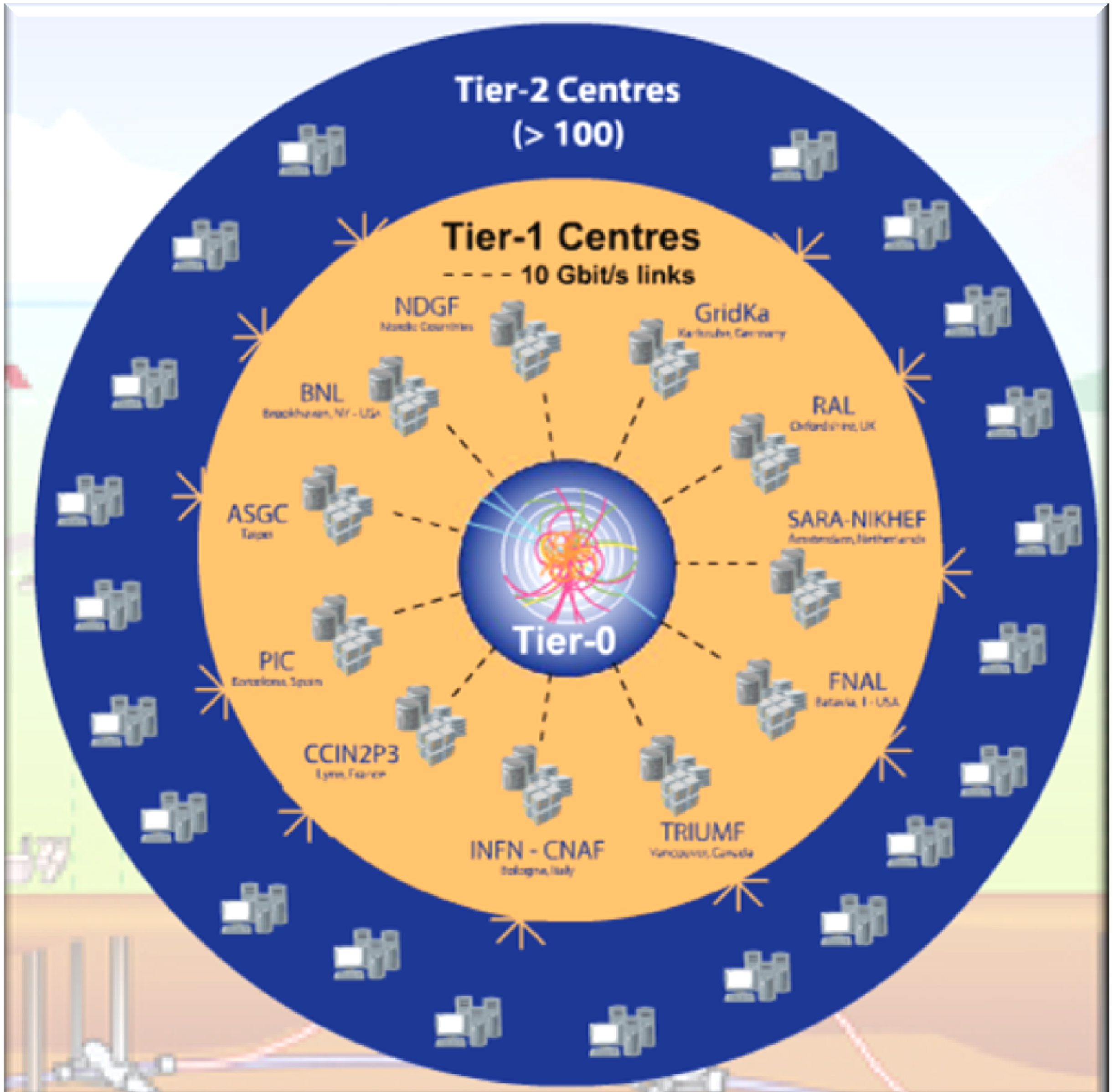
GRID computing developed to solve problem of data storage and analysis

LHC data volume per year:
10-15 Petabytes

One CD has ~ 600 Megabytes
1 Petabyte = 10^9 MB = 10^{15} Byte

(Note: the WWW is from CERN...)

The Worldwide LHC Computing Grid (wLCG)



Tier-0 (CERN):
- Data recording
- Initial data reconstruction
- Data distribution

Tier-1 (11 centres):
- Permanent storage
- Re-processing
- Analysis

Tier-2 (federations of ~130 centres):
- Simulation
- End-user analysis

Strategy toward physics

Before data taking starts:

- Strict quality controls of detector construction to meet physics requirements
- Test beams (a 15-year activity culminating with a combined test beam in 2004) to understand and calibrate (part of) detector and validate/tune software tools (e.g. Geant4 simulation)
- Detailed simulations of realistic detector "as built and as installed" (including misalignments, material non-uniformities, dead channels, etc.) → test and validate calibration/alignment strategies
- Experiment commissioning with cosmics in the underground cavern

With the first data:

- Commission/calibrate detector/trigger in situ with physics (min.bias, Z→ll, …)
- "Rediscover" Standard Model, measure it at $\sqrt{s}$ = 10 TeV (minimum bias, W, Z, tt, QCD jets, …)
- Validate and tune tools (e.g. MC generators)
- Measure main backgrounds to New Physics (W/Z+jets, tt+jets, QCD-jets,…)

↓

Prepare the road to discoveries …

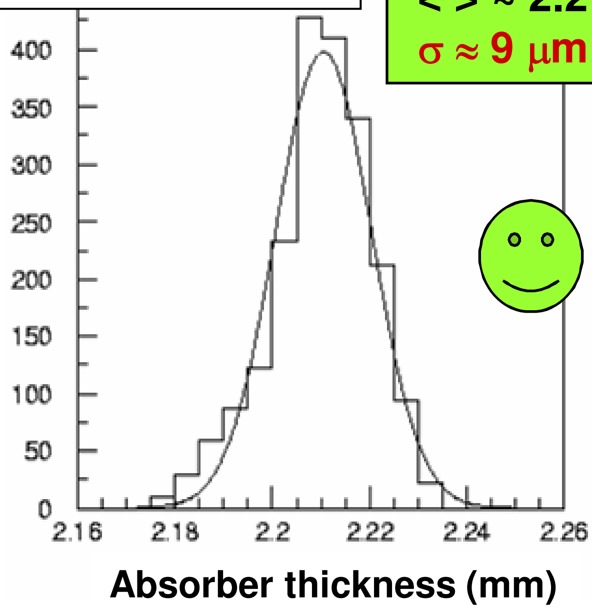
Example: ATLAS LAr em Accordion Calorimeter

Construction quality

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

End-cap: 1536 plates

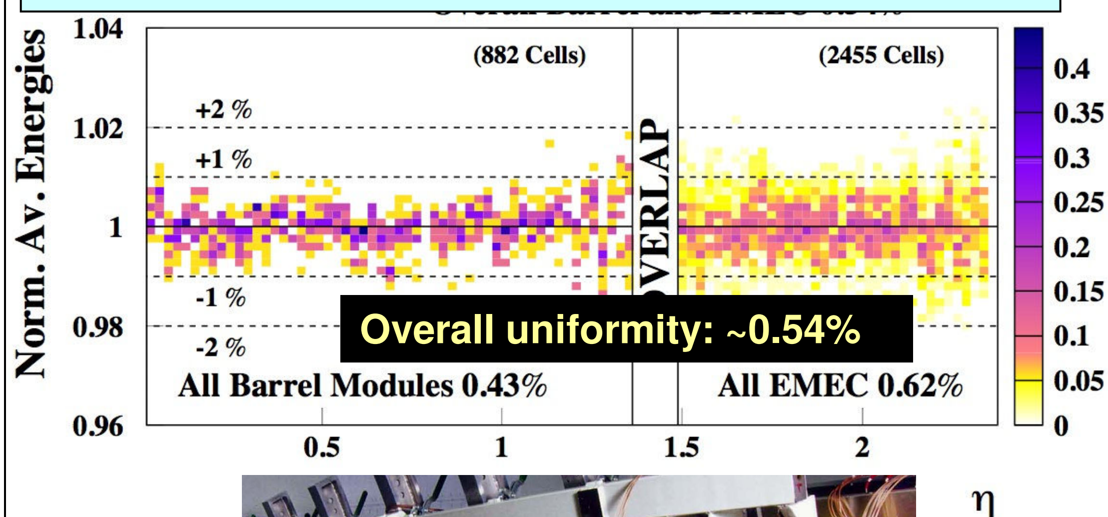
< > ~ 2.2 mm
σ ≈ 9 μm



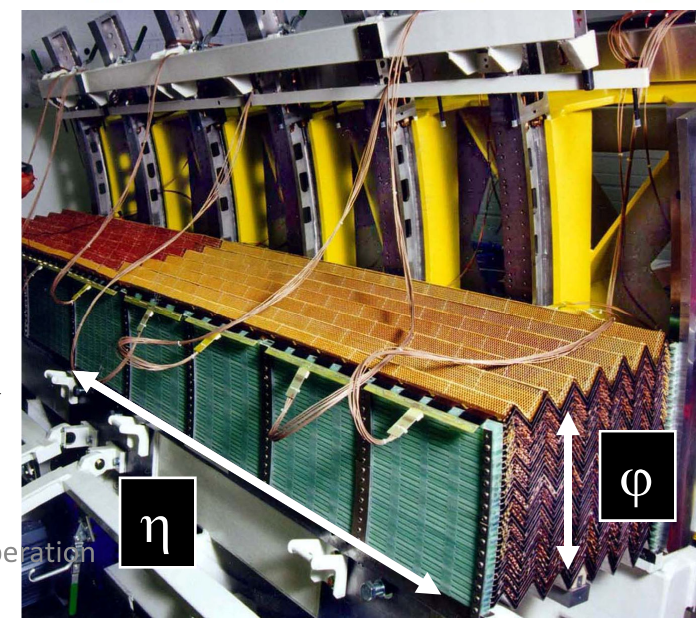
Test-beam measurements

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

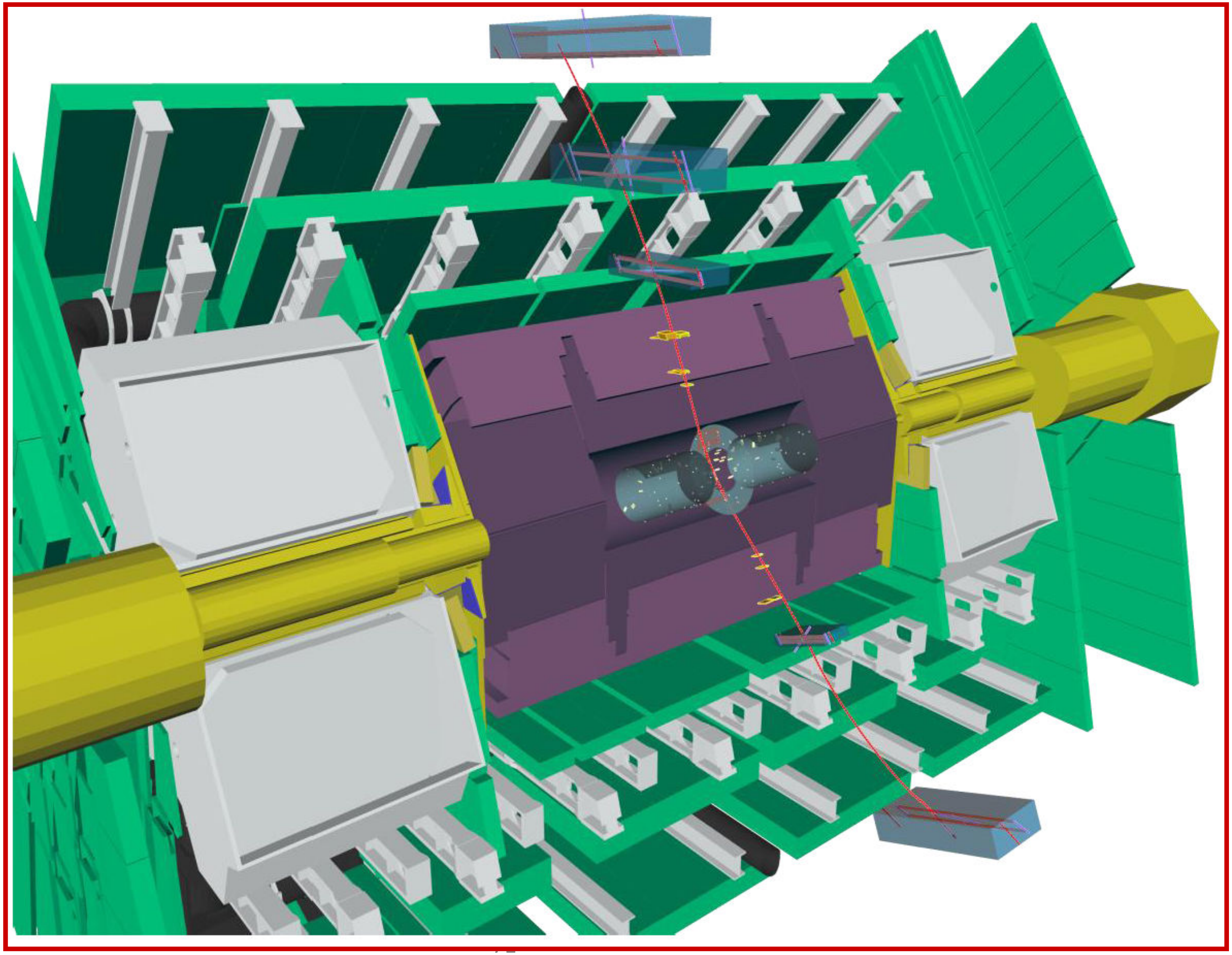
Scans with 120-245 GeV electrons (all 7 tested modules)



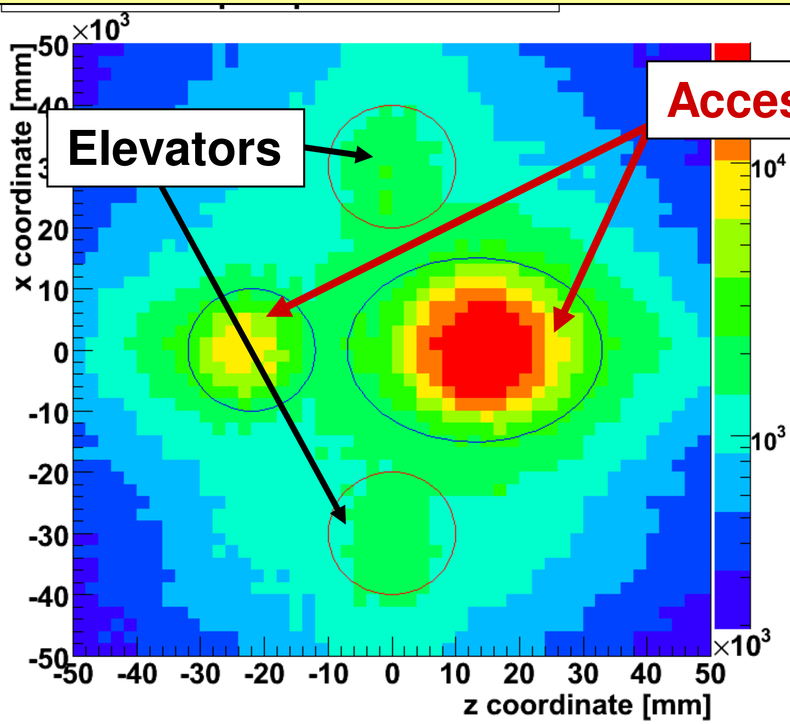
1 barrel module:
$\Delta\eta \times \Delta\varphi = 1.4 \times 0.4$
≈ 3000 channels

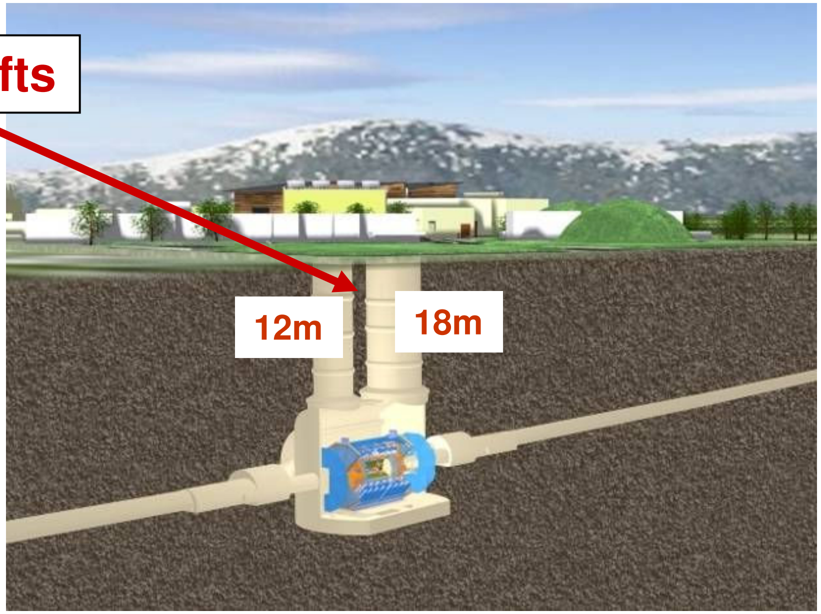


A cosmic muon traversing the whole ATLAS detector



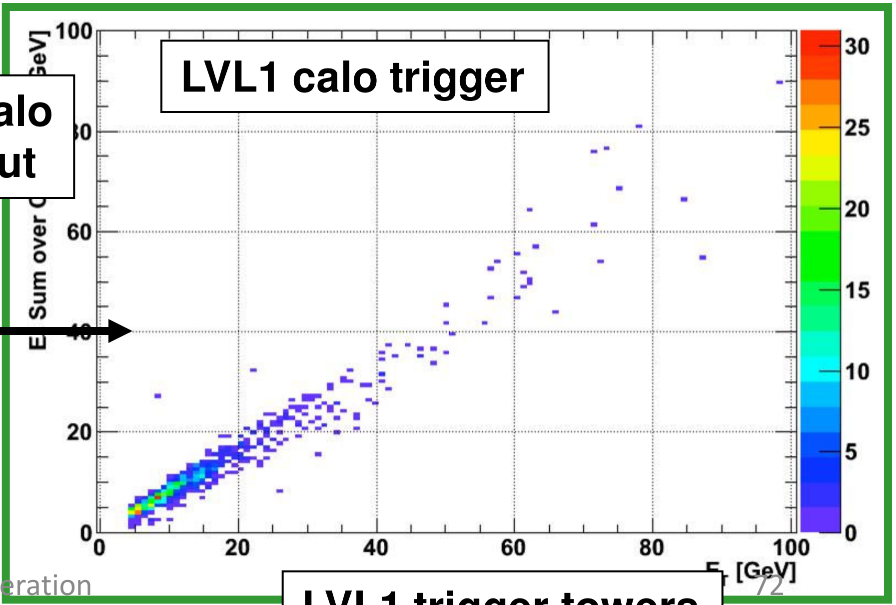
Extrapolation to the surface of cosmic muon tracks reconstructed by RPC trigger chambers



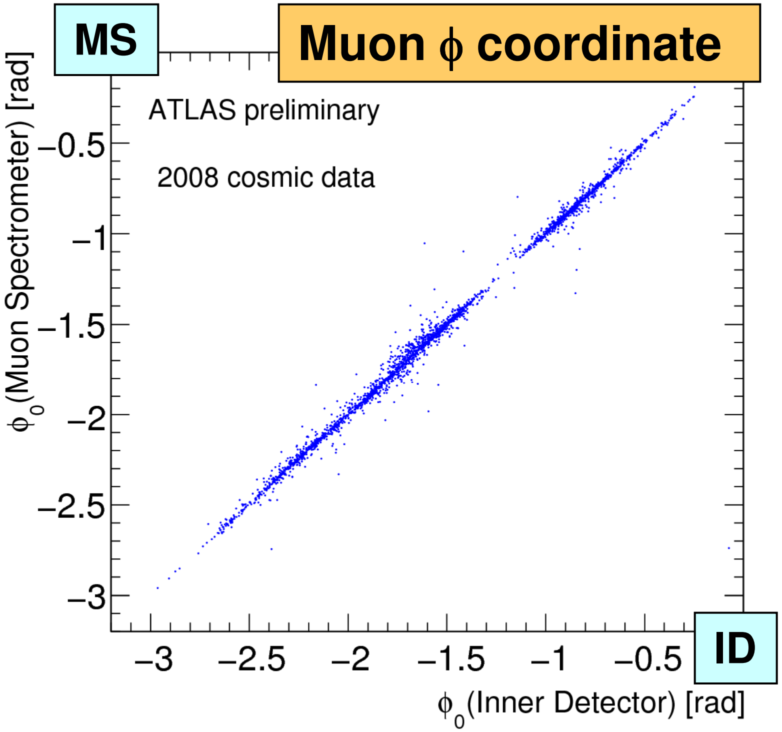


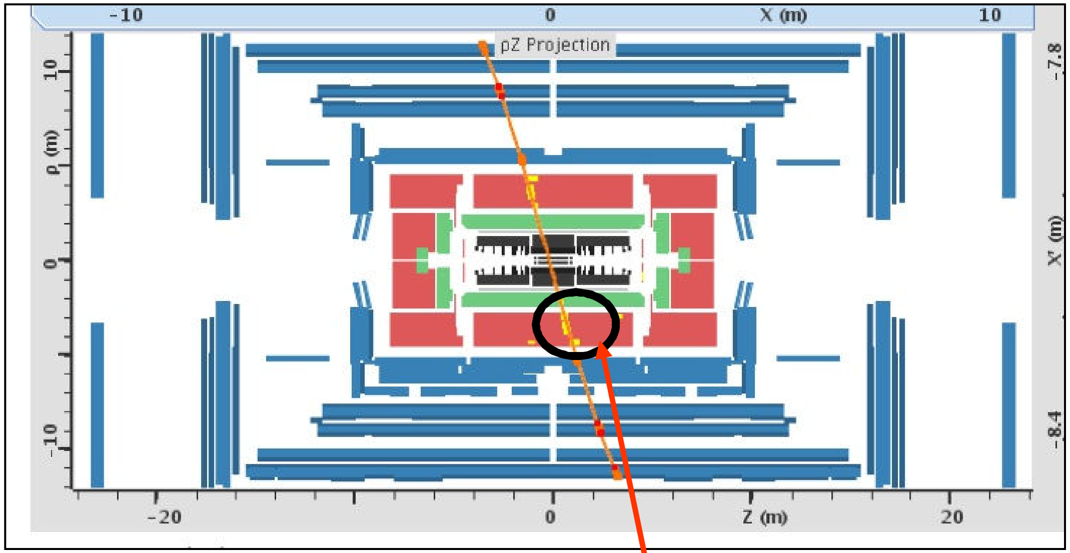
Muon (shower) energy measured with full calorimeter readout vs energy measured in trigger towers (ηxϕ=0.1x0.1) by level-one calorimeter trigger

With initial calibration (final calibration will reduce the spread)

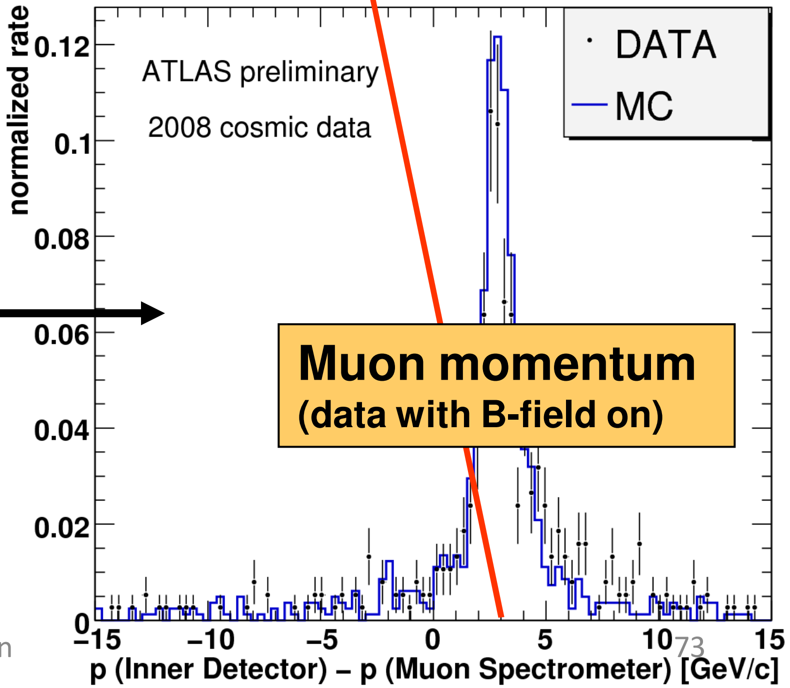


Correlation between measurements in the ATLAS Inner Detector and Muon Spectrometer





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



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- Validate and tune tools (e.g. MC generators)
- Measure main backgrounds to New Physics (W/Z+jets, tt+jets, QCD-jets,…)

↓

Prepare the road to discoveries …

Steve Myers, CERN 26th November 2009:

LHC is back!

‘From the dark days after September 19, 2008 to the bright days of late November 2009’

Friday November 20th, 2009

18:30 Beam 1

19.00 beam through CMS (23, 34, 45)

- beam1 through to IP6 19.55 Starting again injection of Beam1
- corrected beam to IP6, 7, 8, 1

20.40 Beam 1 makes 2 turns

- Working on tune measurement, orbit, dump and RF
- Beam makes several hundred turns (not captured)

20.50 Beam 1 on beam dump at point 6

21.50 Beam 1 captured

22:15 Beam 2

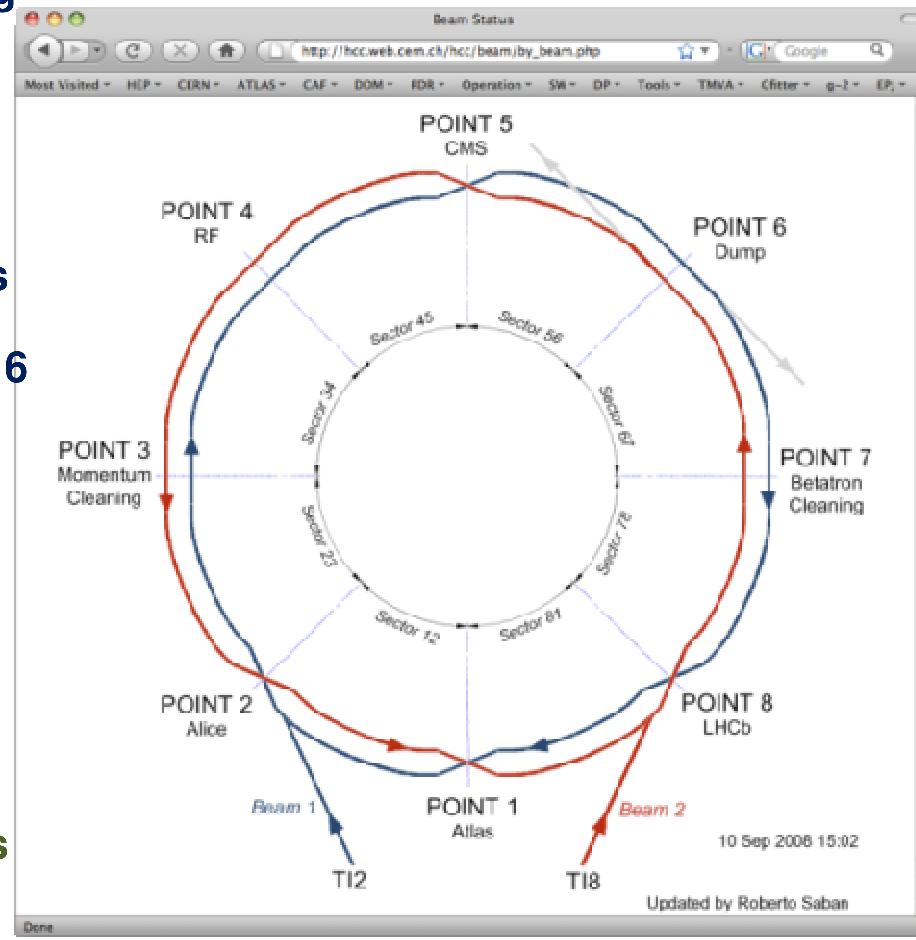
23.10 Start threading Beam 2

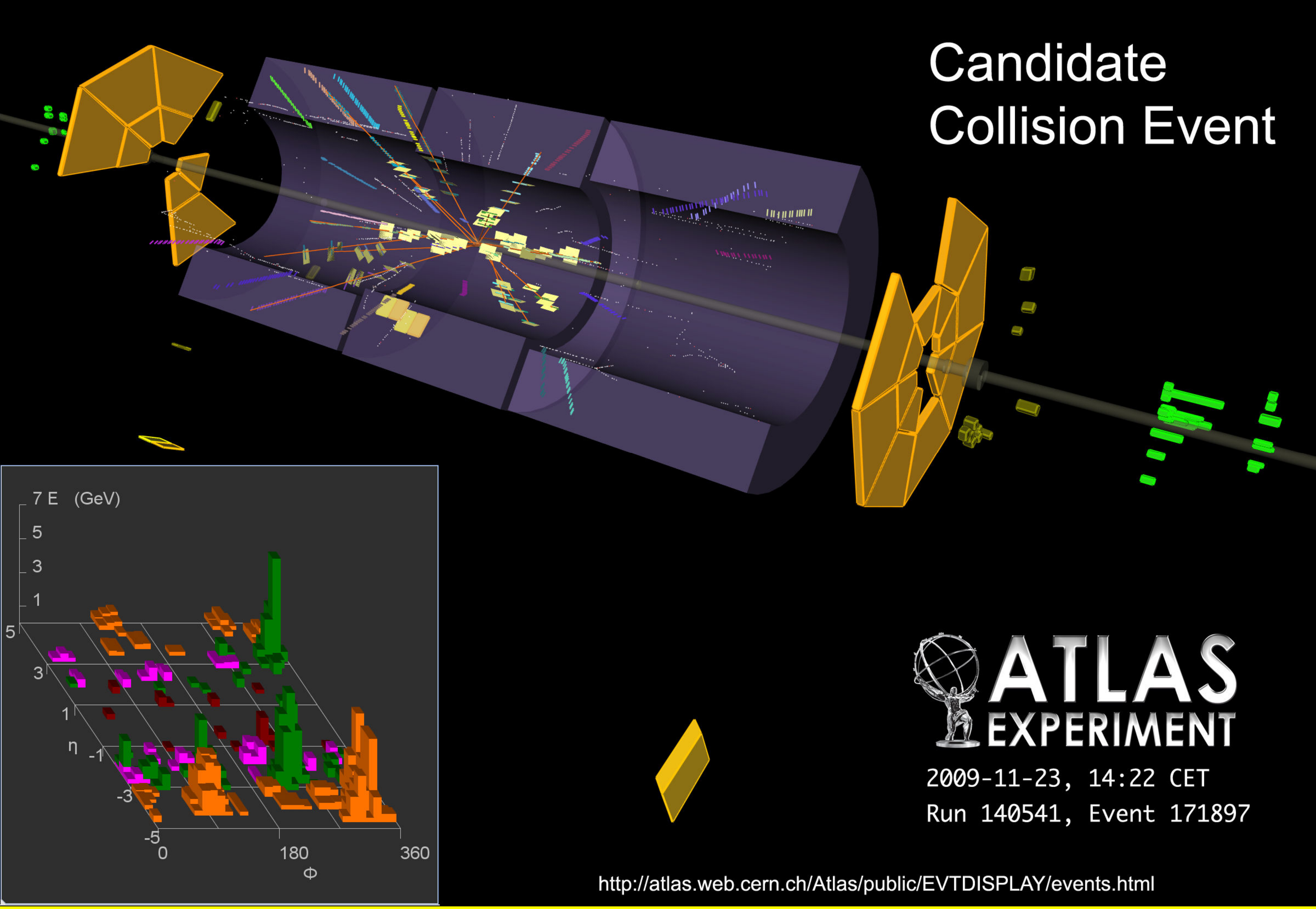
- Round to 7 6 5 2 1

23.40 First Turn Beam 2

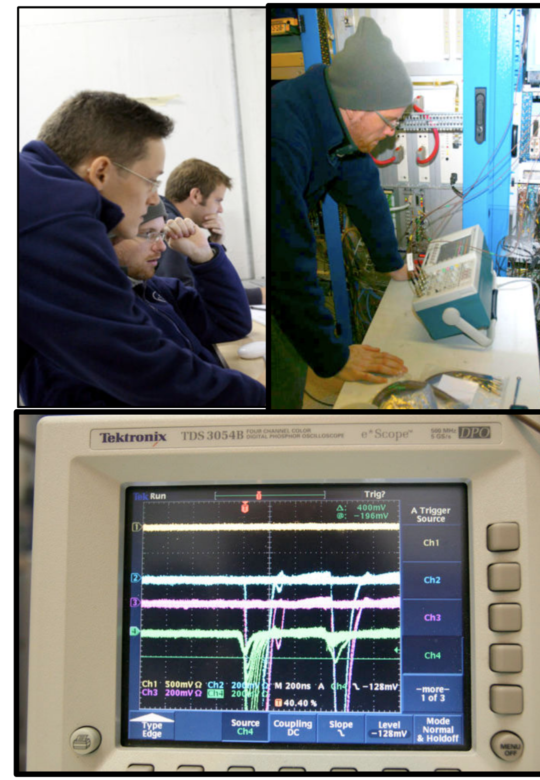
- Working on tune measurement, orbit, dump and RF
- Beam makes several hundred turns (not captured)

24.10 Beam 2 captured

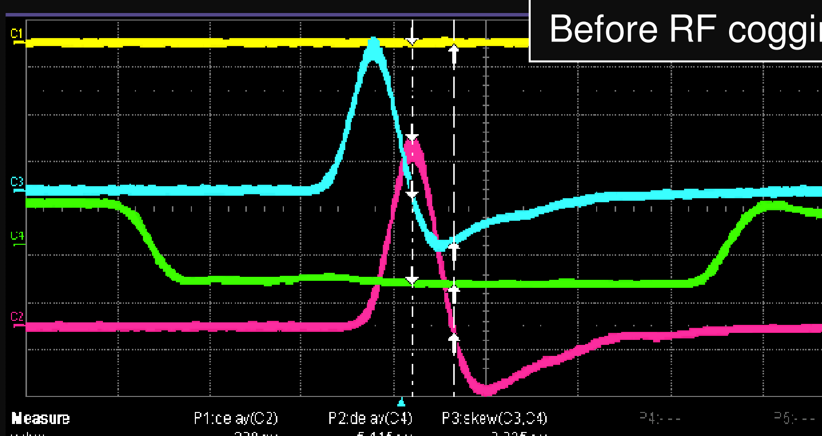



Candidate
Collision Event
7 E (GeV)
5
3
1
5
3
1
η
-1
-3
-5
0
180
360
Φ
ATLAS
EXPERIMENT
2009-11-23, 14:22 CET
Run 140541, Event 171897
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

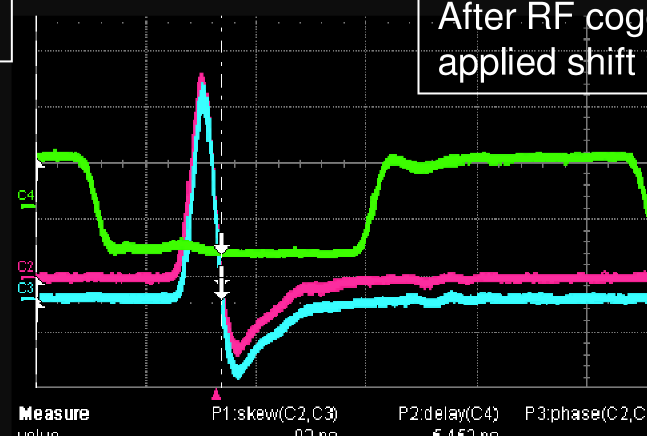
Examples of early optimization work …
and "handshake" between
ATLAS and LHC operation team



First collision events on 23 November:
ATLAS beam pickups showed phase shift of 900 ps, causing the primary vertex to be shifted by -13.5 cm in Z → based on this information, the machine team corrected the RF cogging

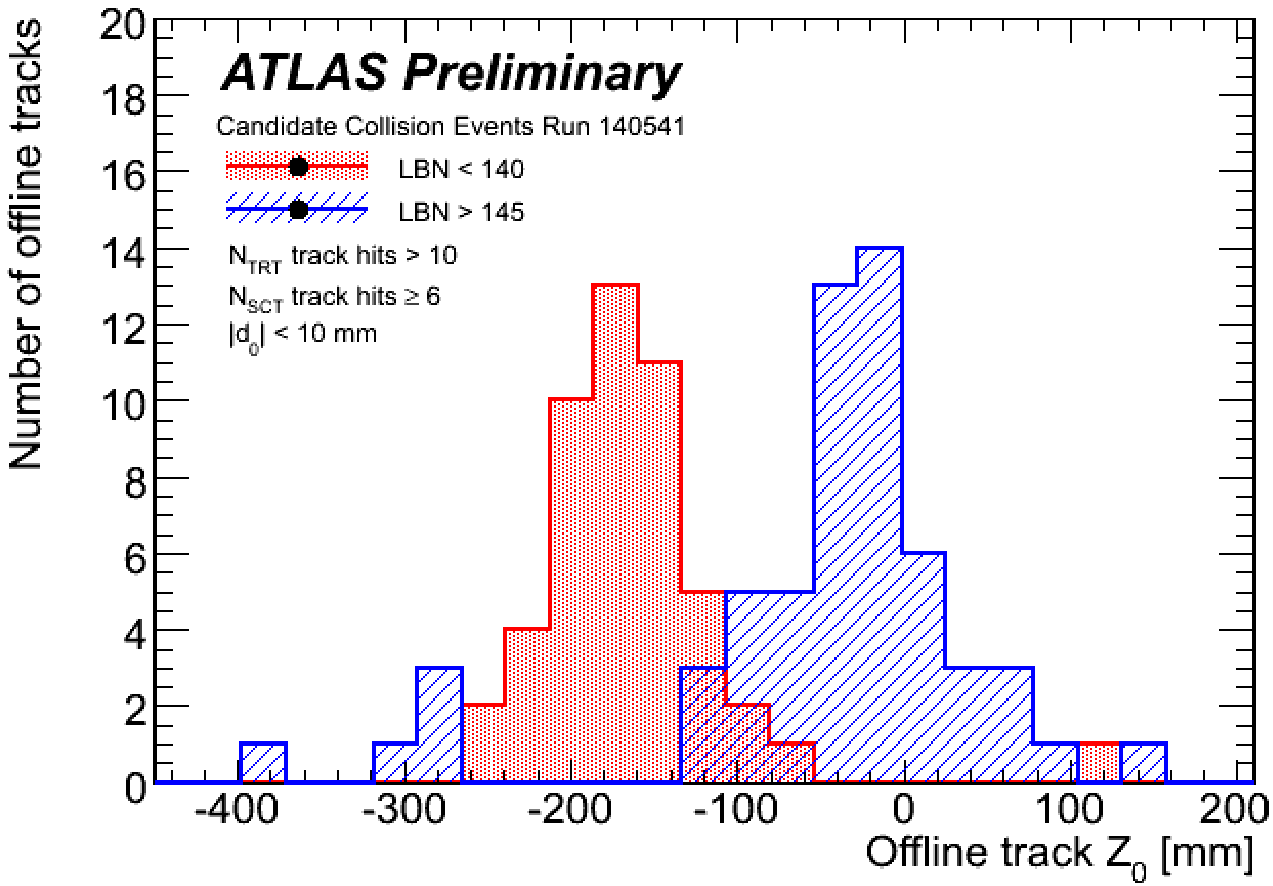


Beam pickup scope shots, beam 1 & 2



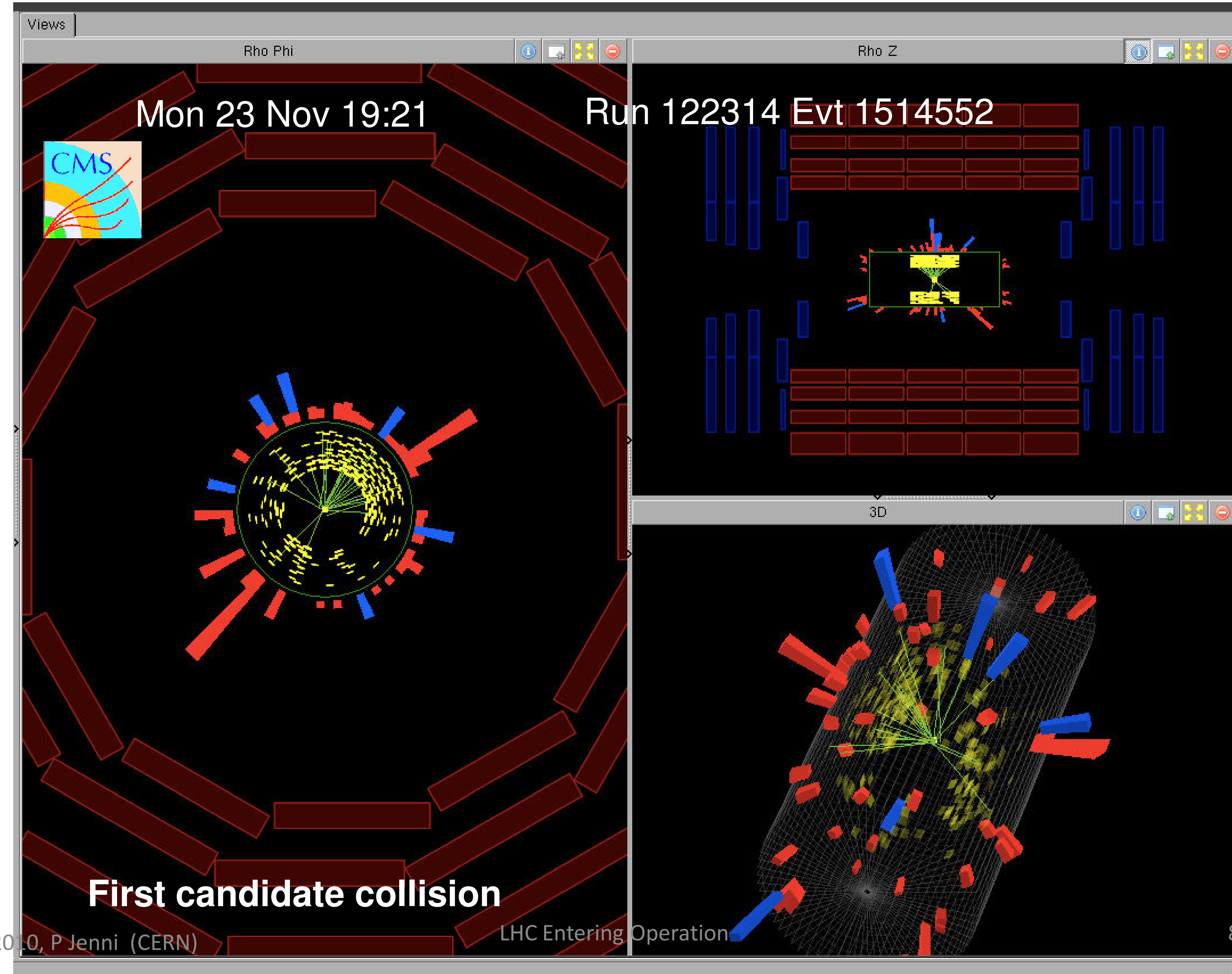
Bunches stable within 20 ps (rms)

Track *Z* distribution of collision candidate events as obtained before and after RF cogging. Observed shift: ~ +12 cm

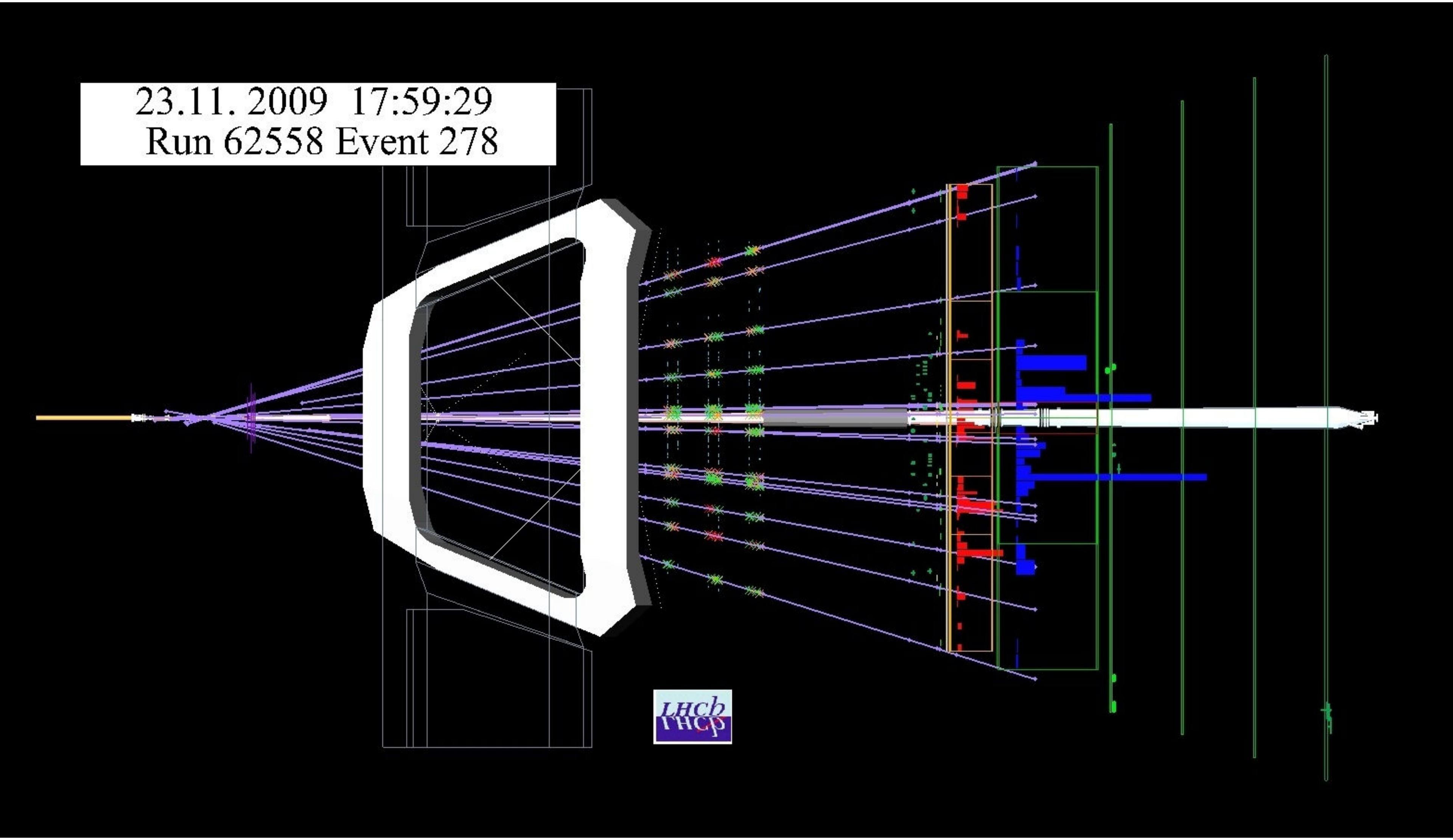


Note: beams were not yet stable → Pixels off and SCT at reduced voltage

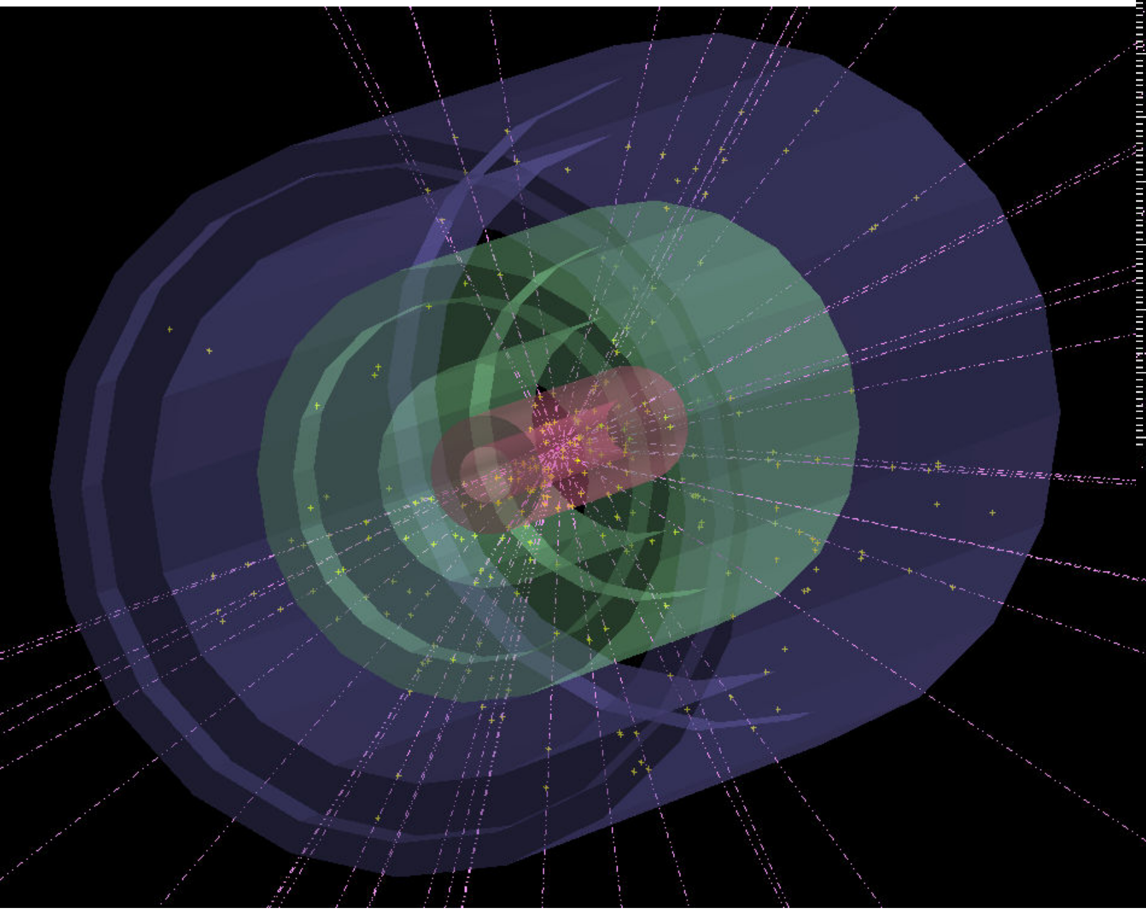
CMS event from the Evening Fill

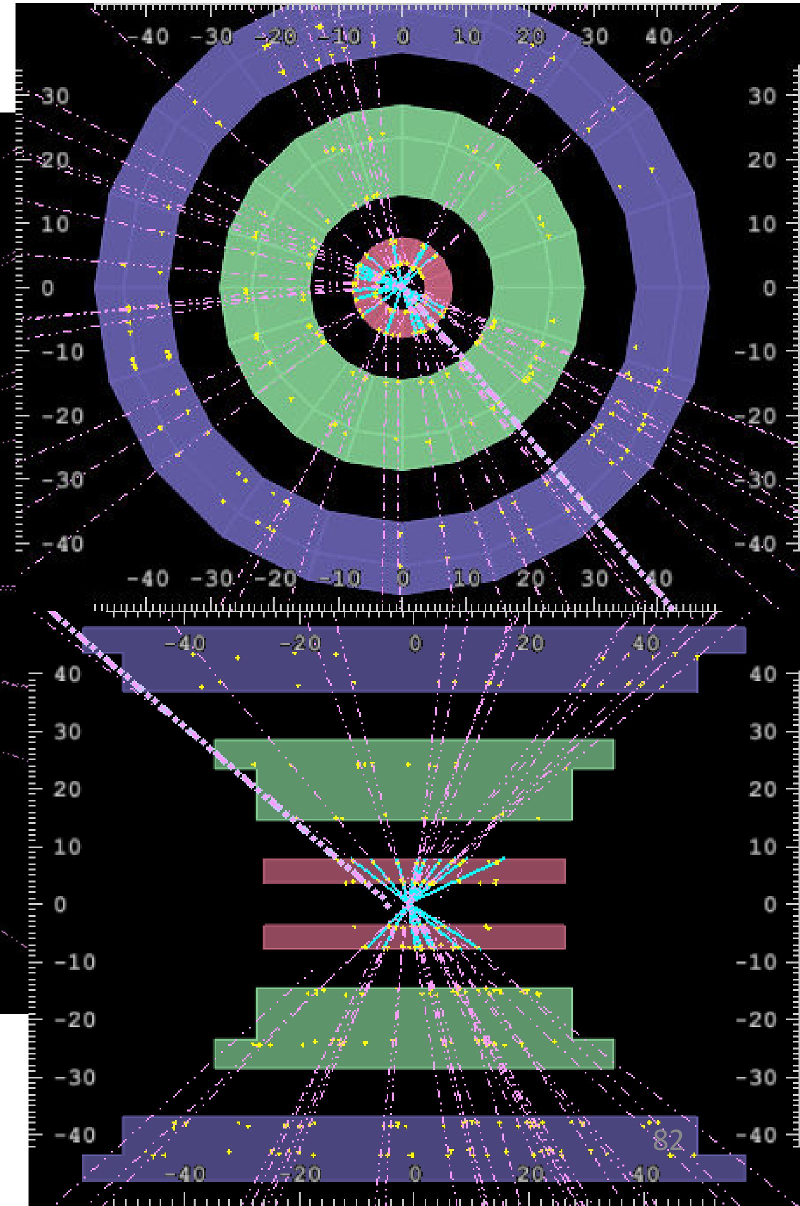


LHCb events have nice vertices (extrapolating OT tracks)

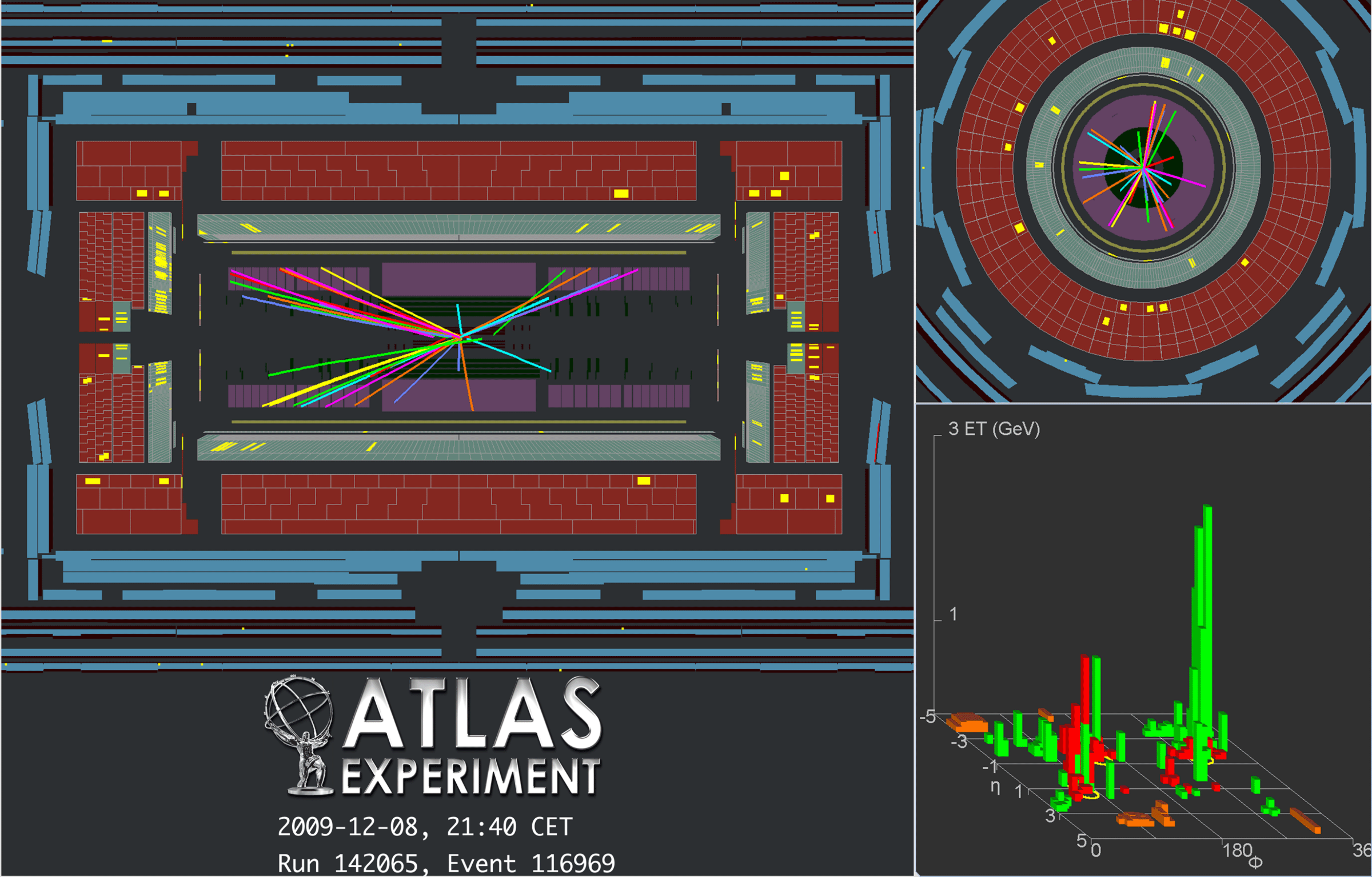


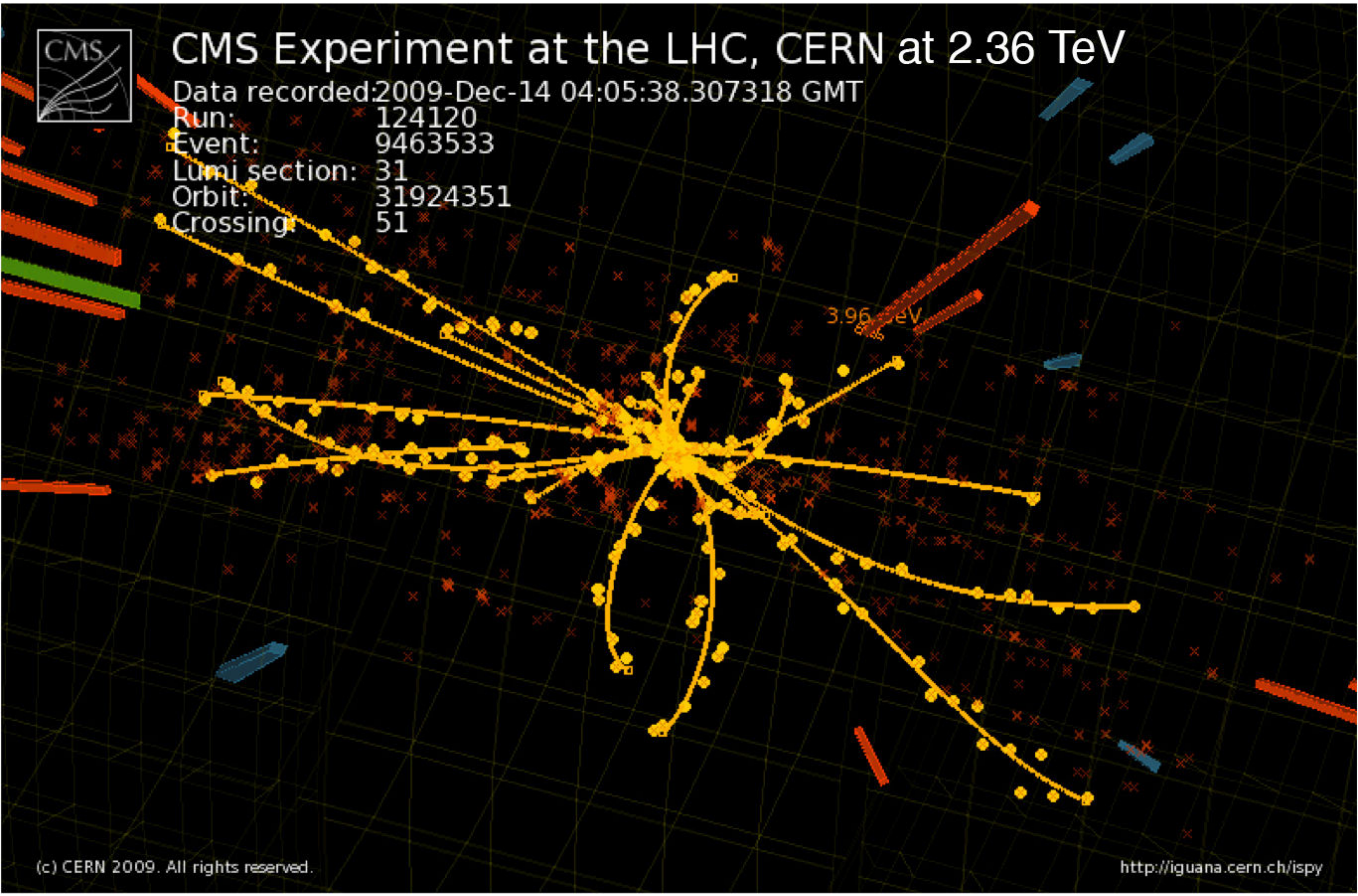
A high multiplicity Alice event…





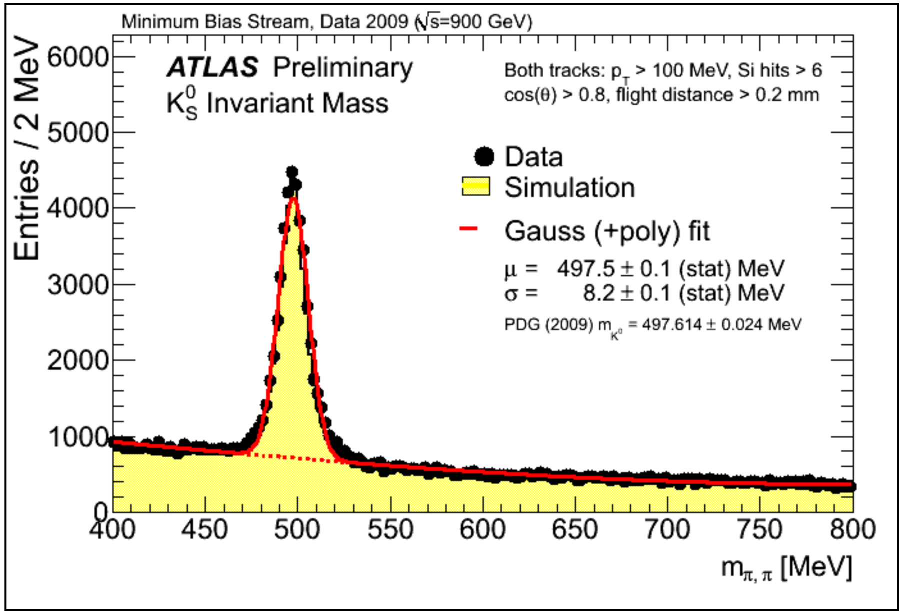
2-Jet Event at 2.36 TeV

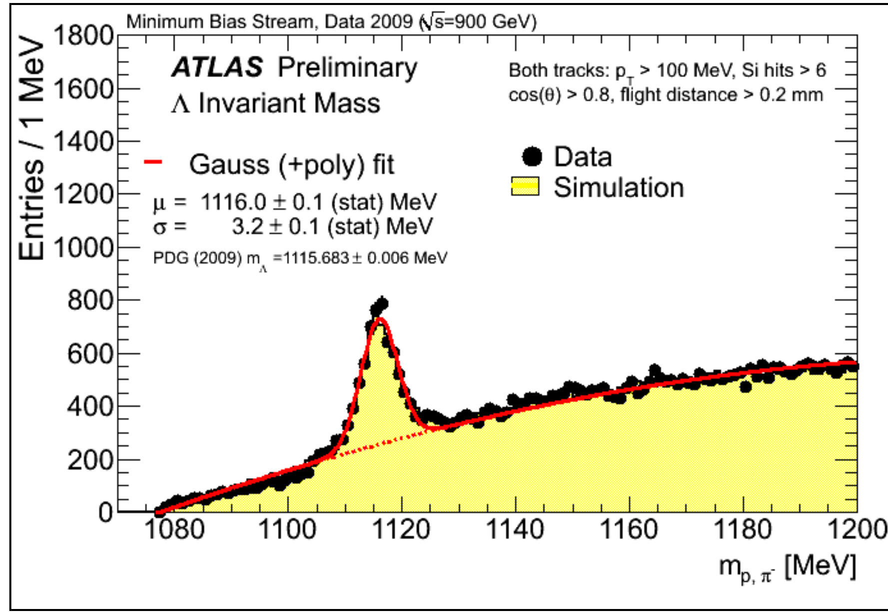


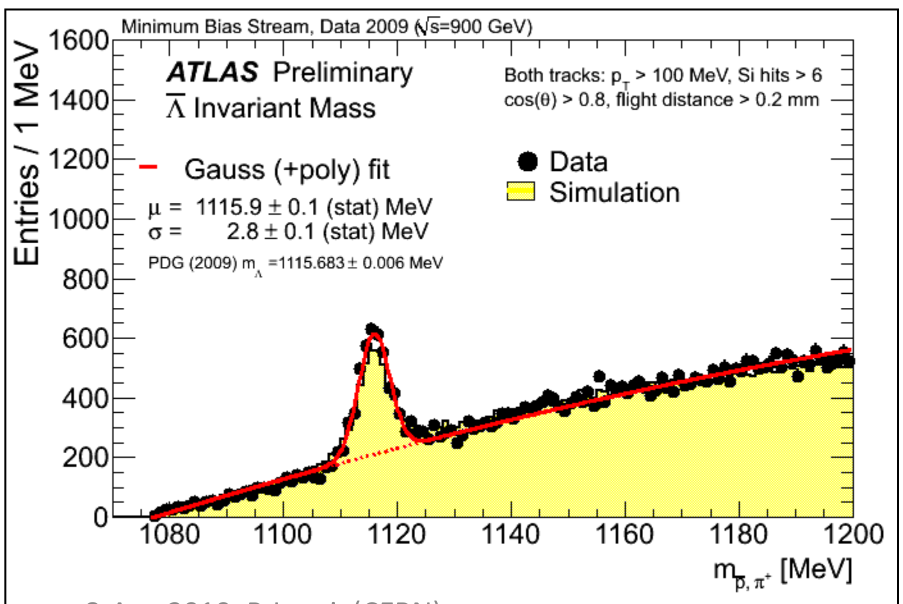

CMS
CMS Experiment at the LHC, CERN at 2.36 TeV
Data recorded:2009-Dec-14 04:05:38.307318 GMT
Run: 124120
Event: 9463533
Lumi section: 31
Orbit: 31924351
Crossing: 51
(c) CERN 2009. All rights reserved.
http://iguana.cern.ch/ispy

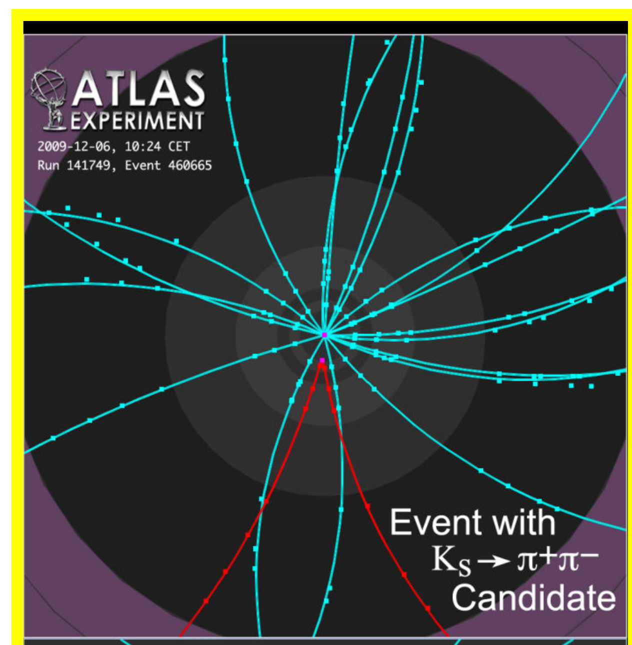
$K^0_s \to \pi^+\pi^-, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

p_T (track) > 100 MeV
MC signal and background normalized independently

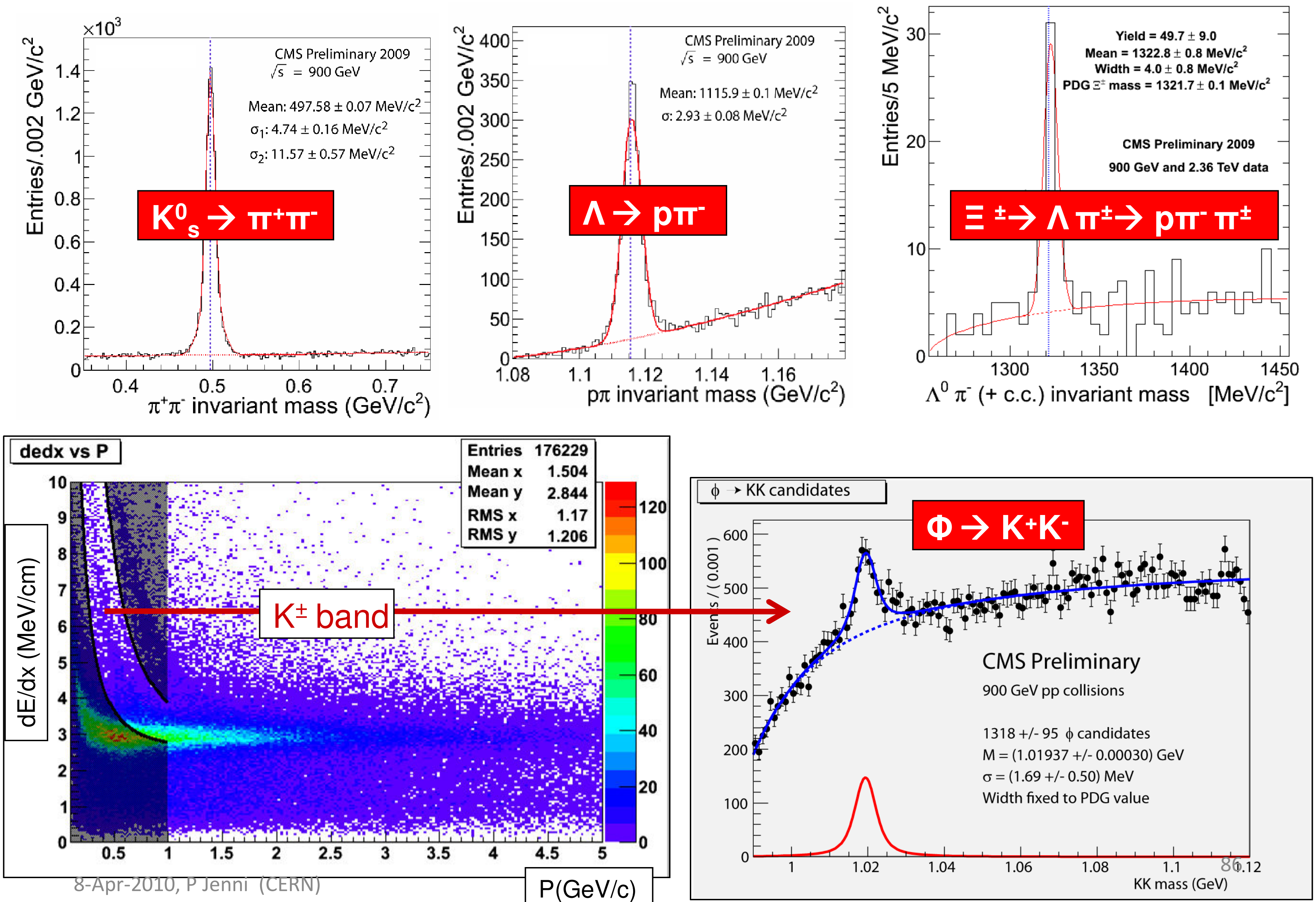


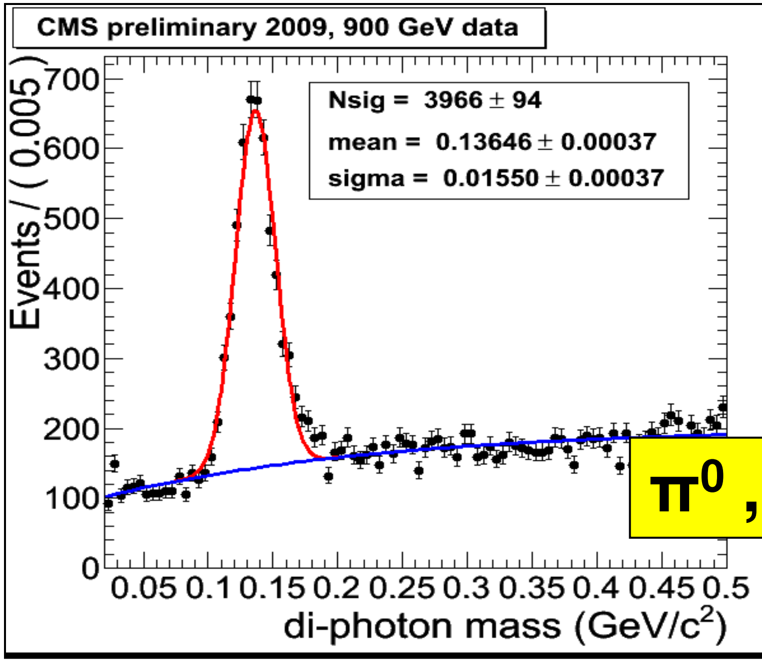




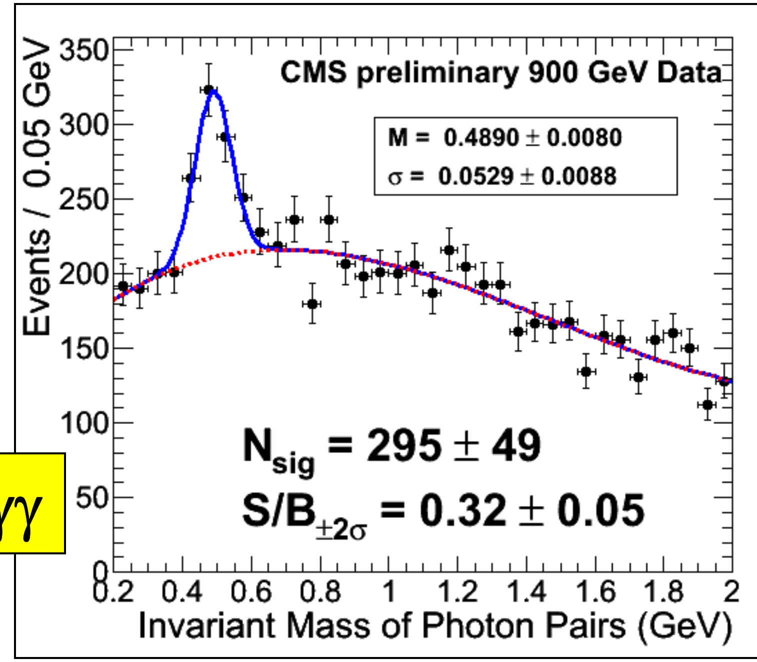


Resonances in the CMS tracker

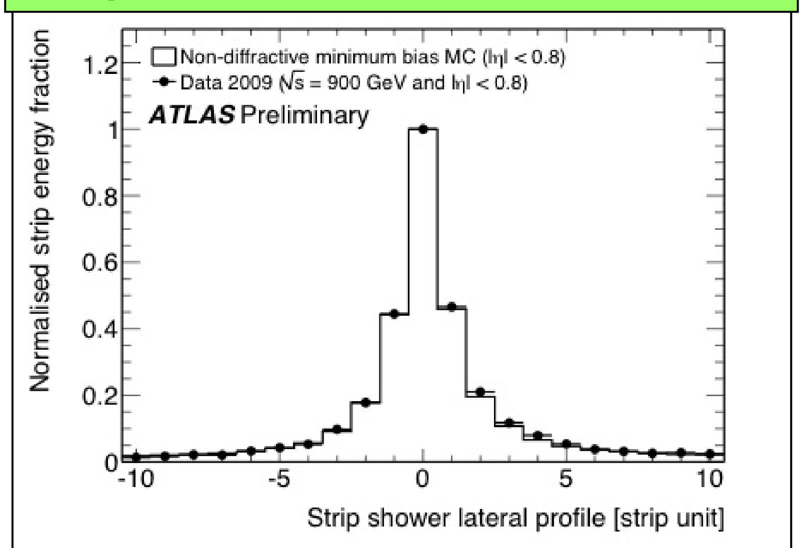


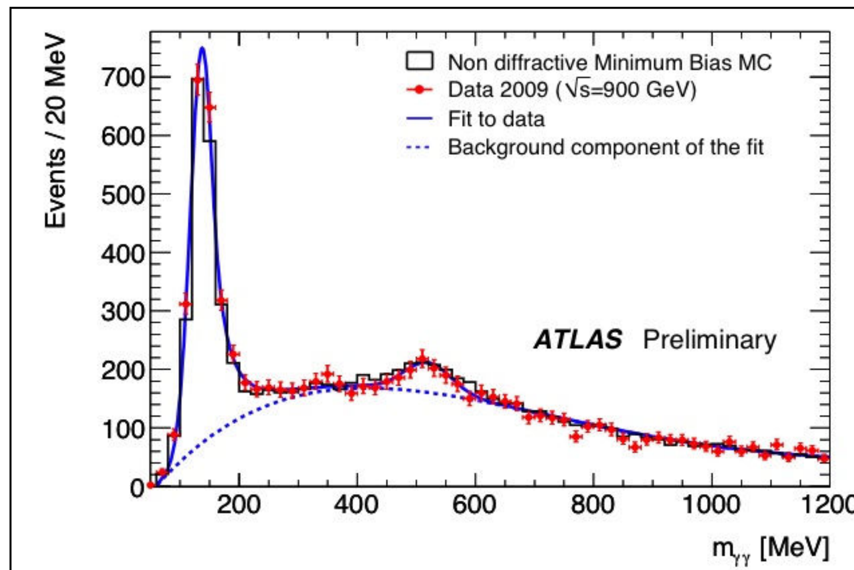


π^0 , $\eta \rightarrow \gamma\gamma$



Photon shower shape in the first compartment of ATLAS EM calorimeter

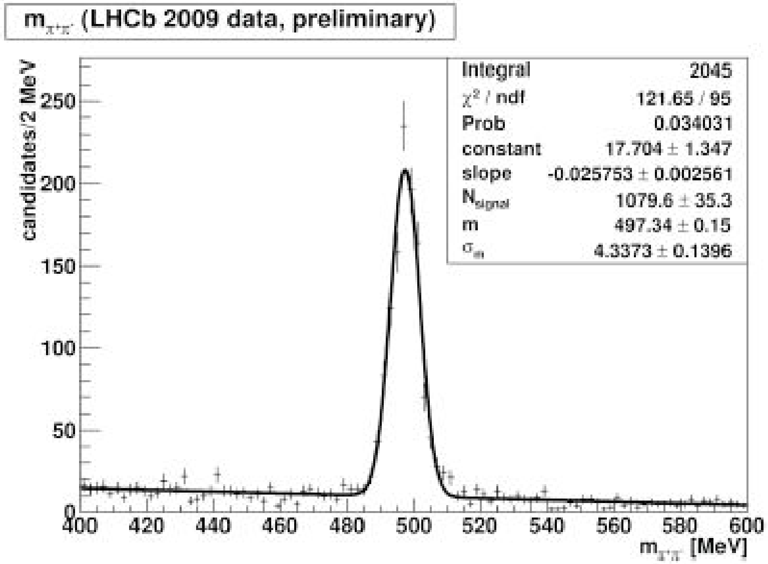


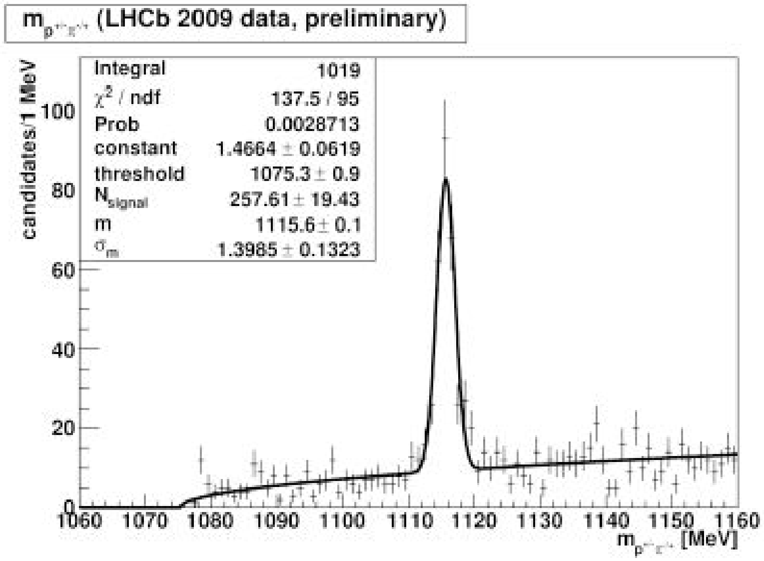


Note: soft photons are challenging in ATLAS: lot of material in front of EM calorimeter (cryostat, coil): ~ 2.5 X_0 at η=0

The masses of the reconstructed K_S and Λ in agreement with the PDG values

Using full tracking power, including VELO





$M(K_S) = 497.3 \pm 0.2\ MeV/c^2$
$\sigma = 4.3 \pm 0.1\ MeV/c^2$

$M(K_S^{PDG}) = 497.7\ MeV/c^2$

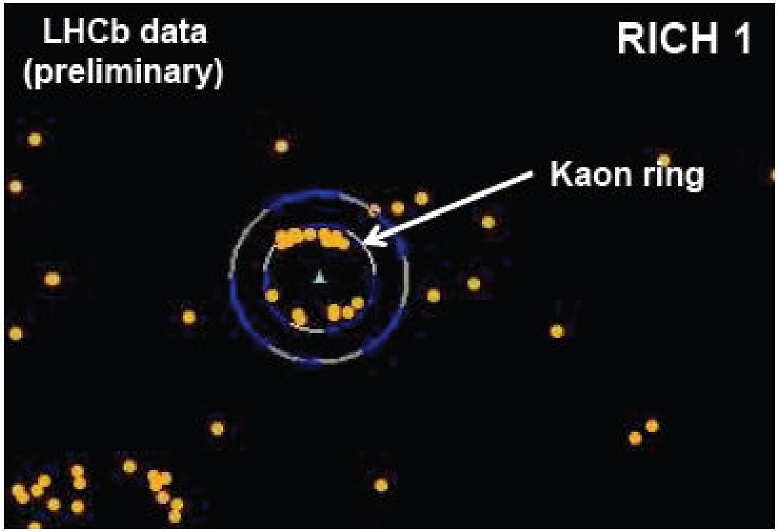
$M(\Lambda) = 1115.6 \pm 0.1\ MeV/c^2$
$\sigma = 1.4 \pm 0.1\ MeV/c^2$

$M(\Lambda^{PDG}) = 1115.7\ MeV/c^2$

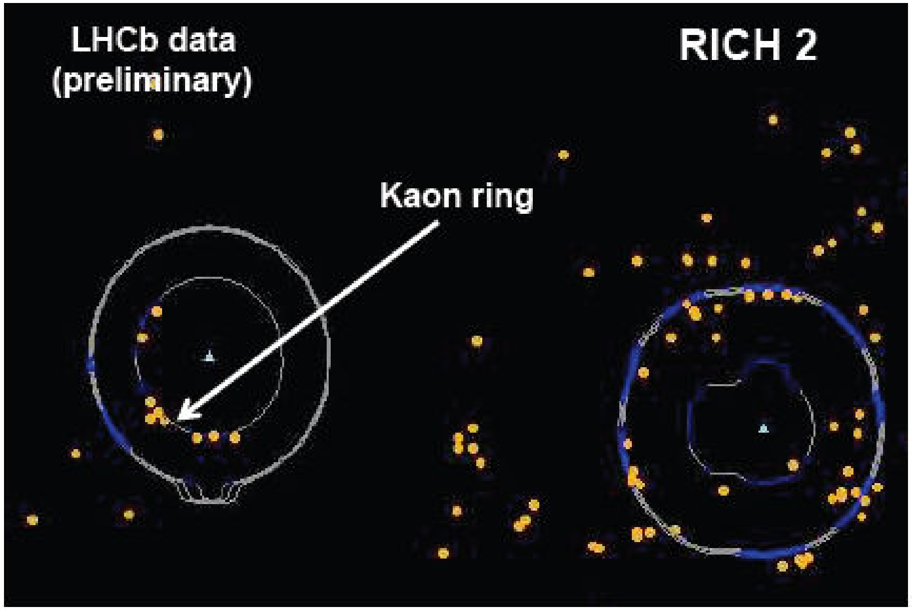
Accuracy will be further improved after complete alignment

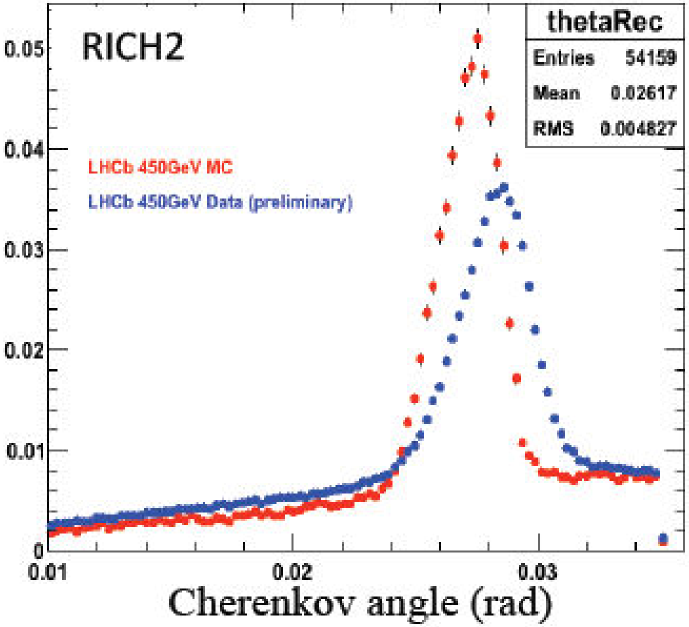
5

RICH identifies charged kaons



Orange points – photon hits
Continuous lines – expected distribution for each particle hypothesis (proton below threshold)

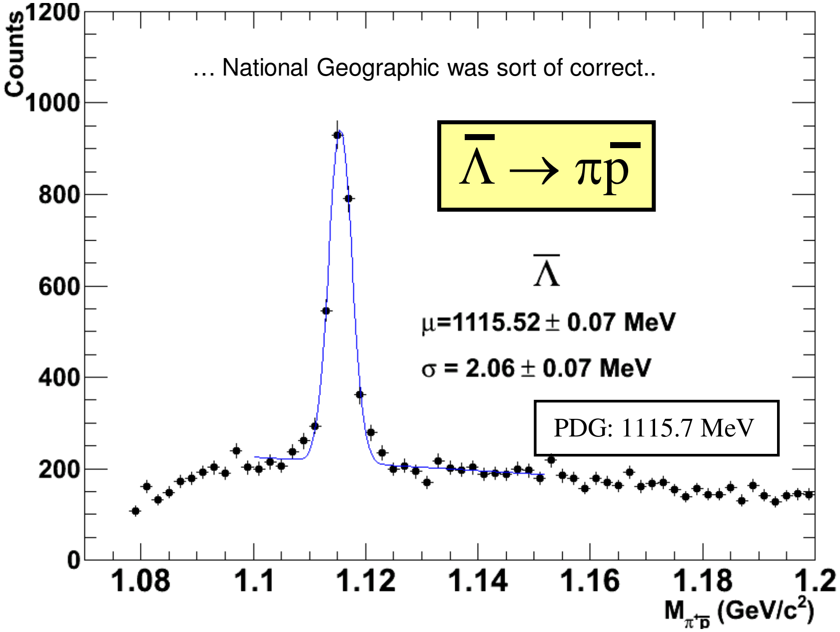


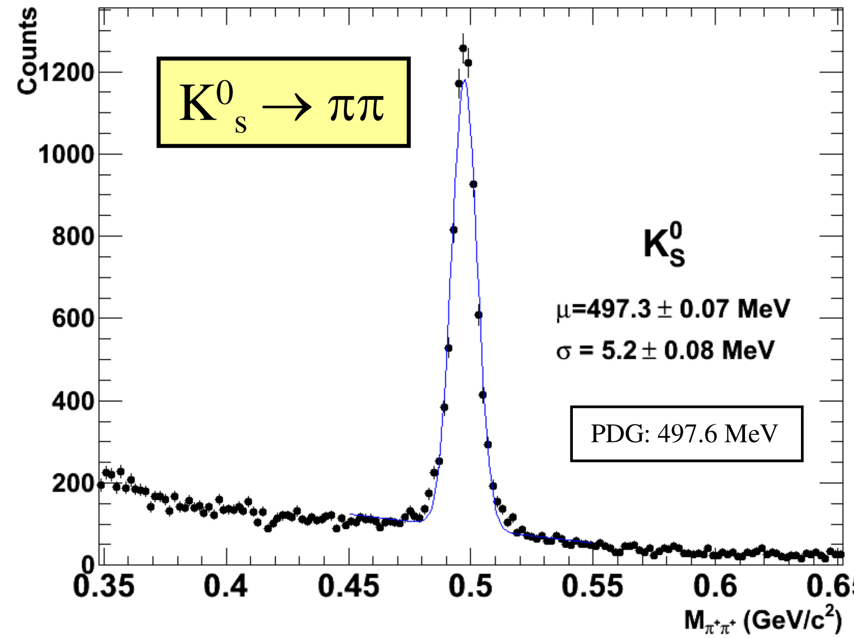


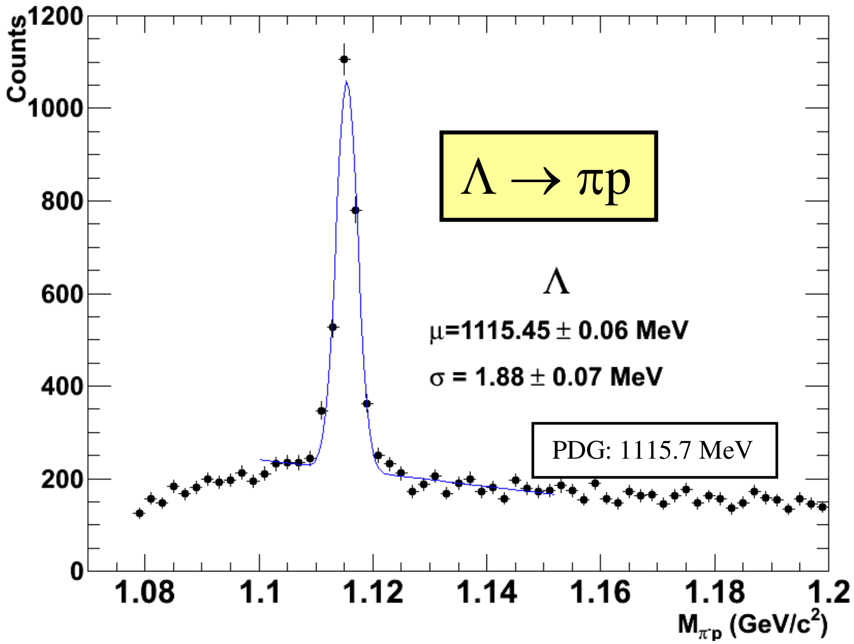
Detailed calibration and alignment in progress

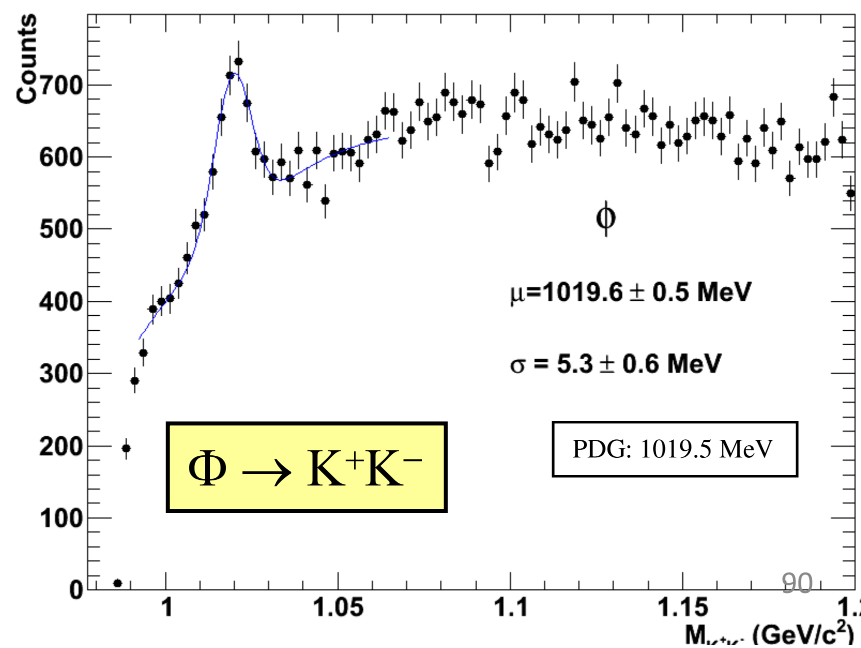
8

ALICE: ‘The Particle Zoo Revisited’





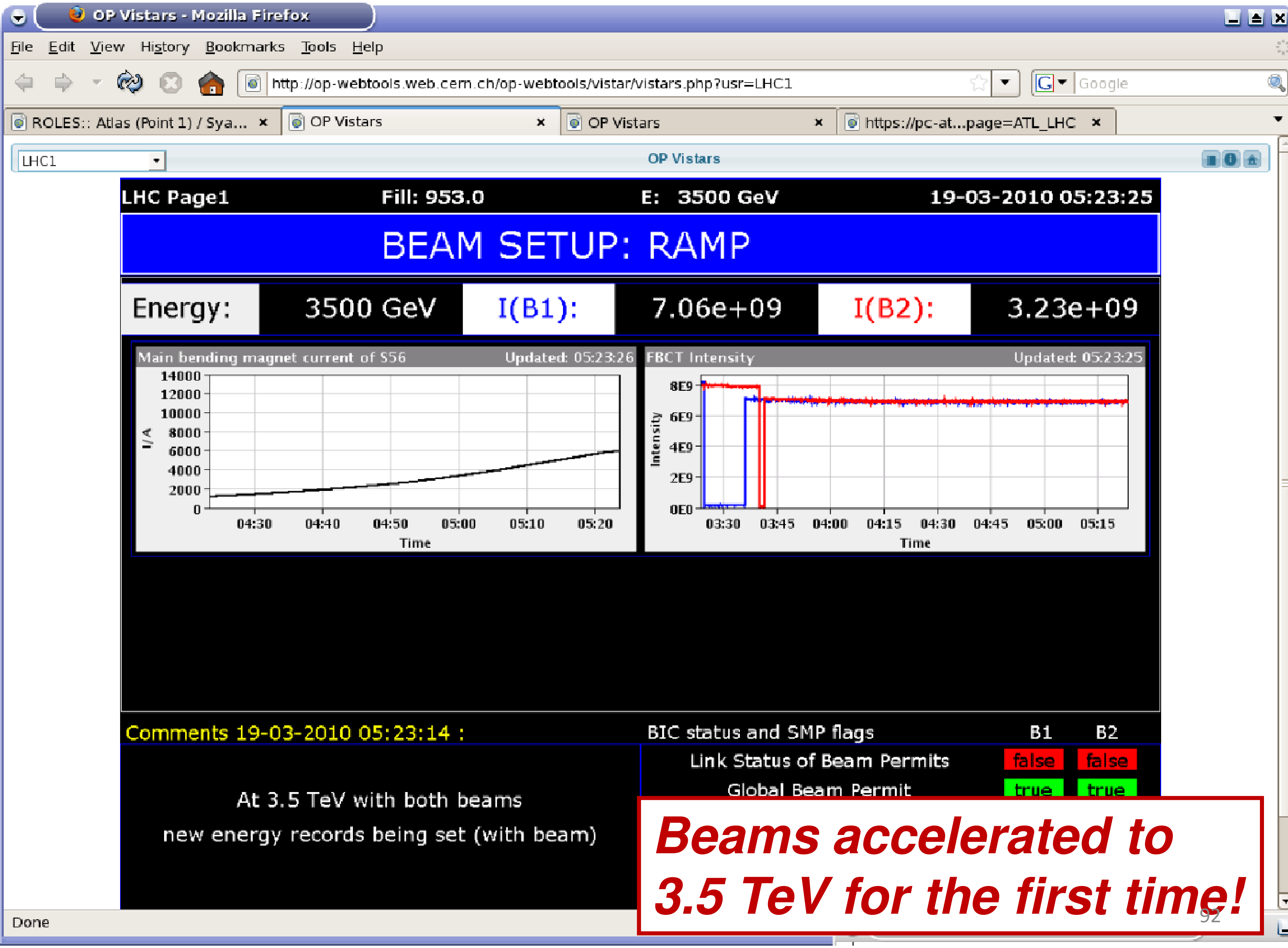




LHC physics goals

What is the origin of the particle masses ?	ATLAS, CMS
What is the nature of the Universe dark matter ?	ATLAS, CMS
What is the origin of the Universe matter-antimatter asymmetry ?	LHCb, ATLAS, CMS
What were the constituents of the Universe primordial plasma ~10 μs after the Big Bang ?	ALICE, ATLAS, CMS
What happened in the first instants of the Universe life (10^{-10} s after the Big Bang) ?	ATLAS, CMS

Etc. etc.



Beams accelerated to 3.5 TeV for the first time!

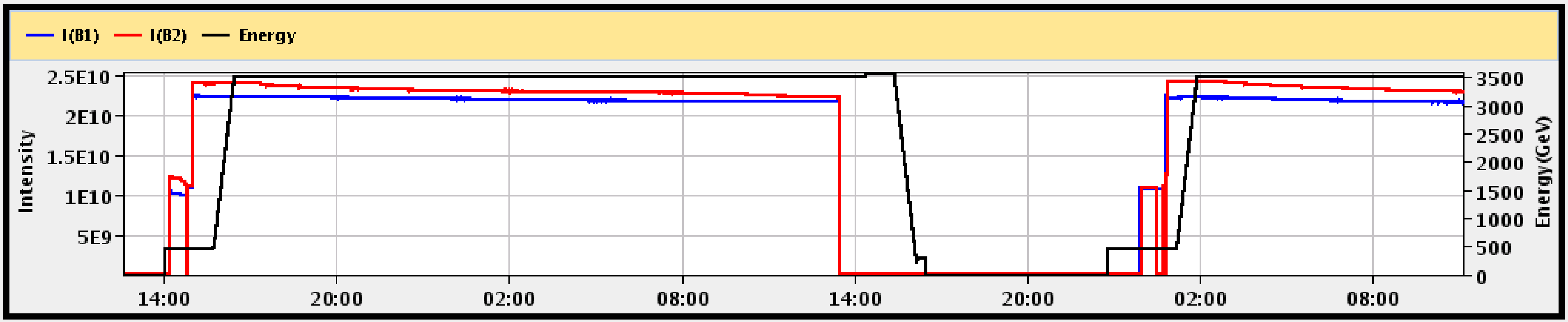

LHC First Physics
ATLAS control room
ATLAS EXPERIMENT
YES! 3.5TeV COLLISIONS!
30-3-10 12:57

06-Apr-2010 11:09:31 Fill #: 1023 Energy: 3500.3 GeV I(B1): 2.16e+10 I(B2): 2.29e+10

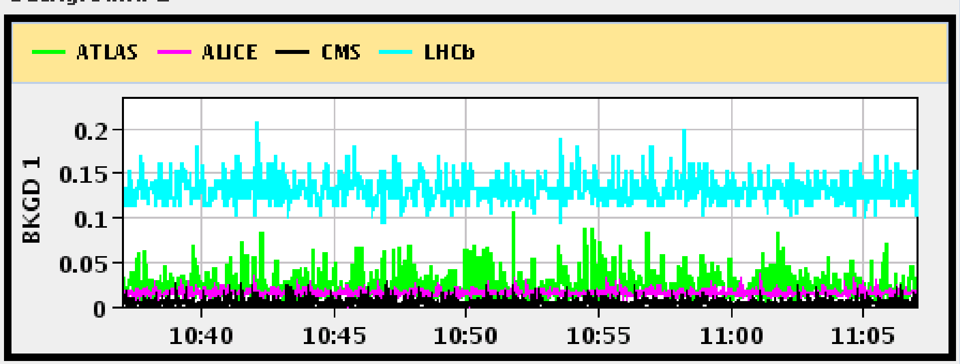
	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Luminosity	1.118e-03	0.000e+00	1.410e-03	0.000e+00
BRAN Count Rate	4.884e+01	1.102e+01	5.561e+01	3.041e+01
BKGD 1	0.009	0.014	0.002	0.131
BKGD 2	0.000	2.600	0.518	0.002
BKGD 3	0.000	0.007	0.003	0.032

LHCf PHYSICS Count(Hz): 0.000 | LHCb VELO Position IN Gap: -0.0 mm | TOTEM: CALIBRATION

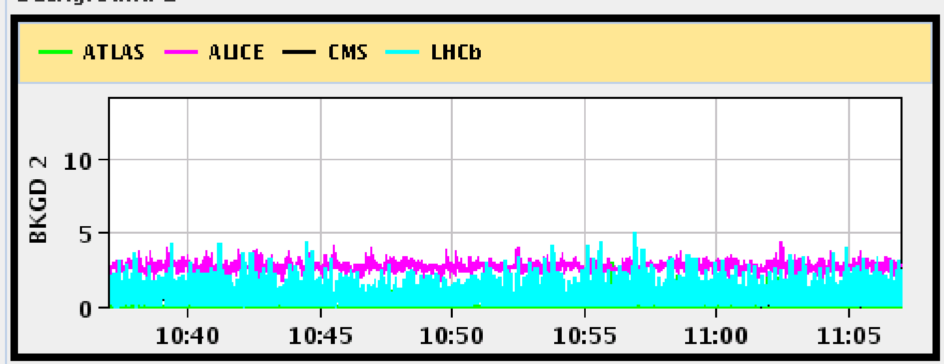
Performance over the last 12 Hrs

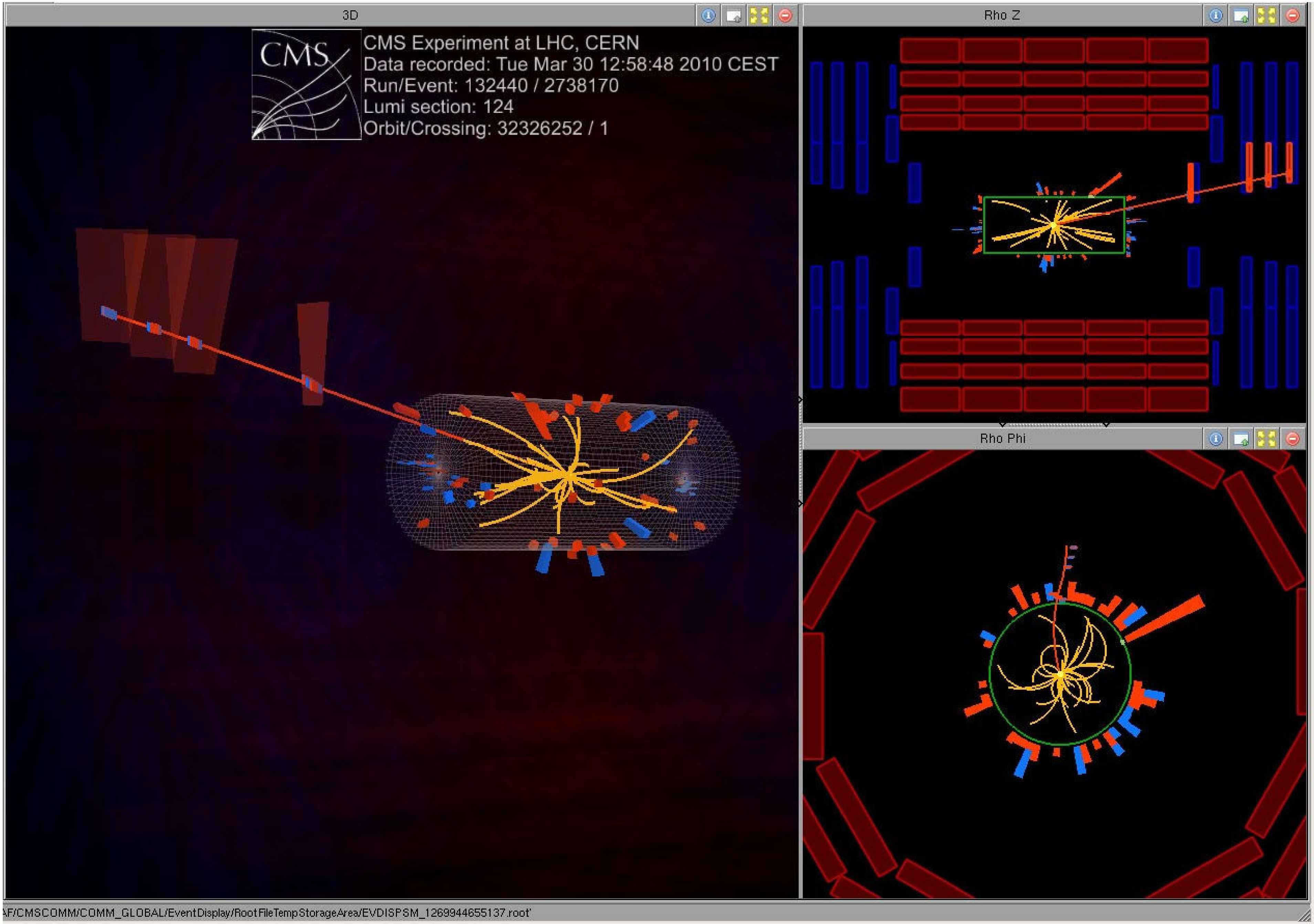


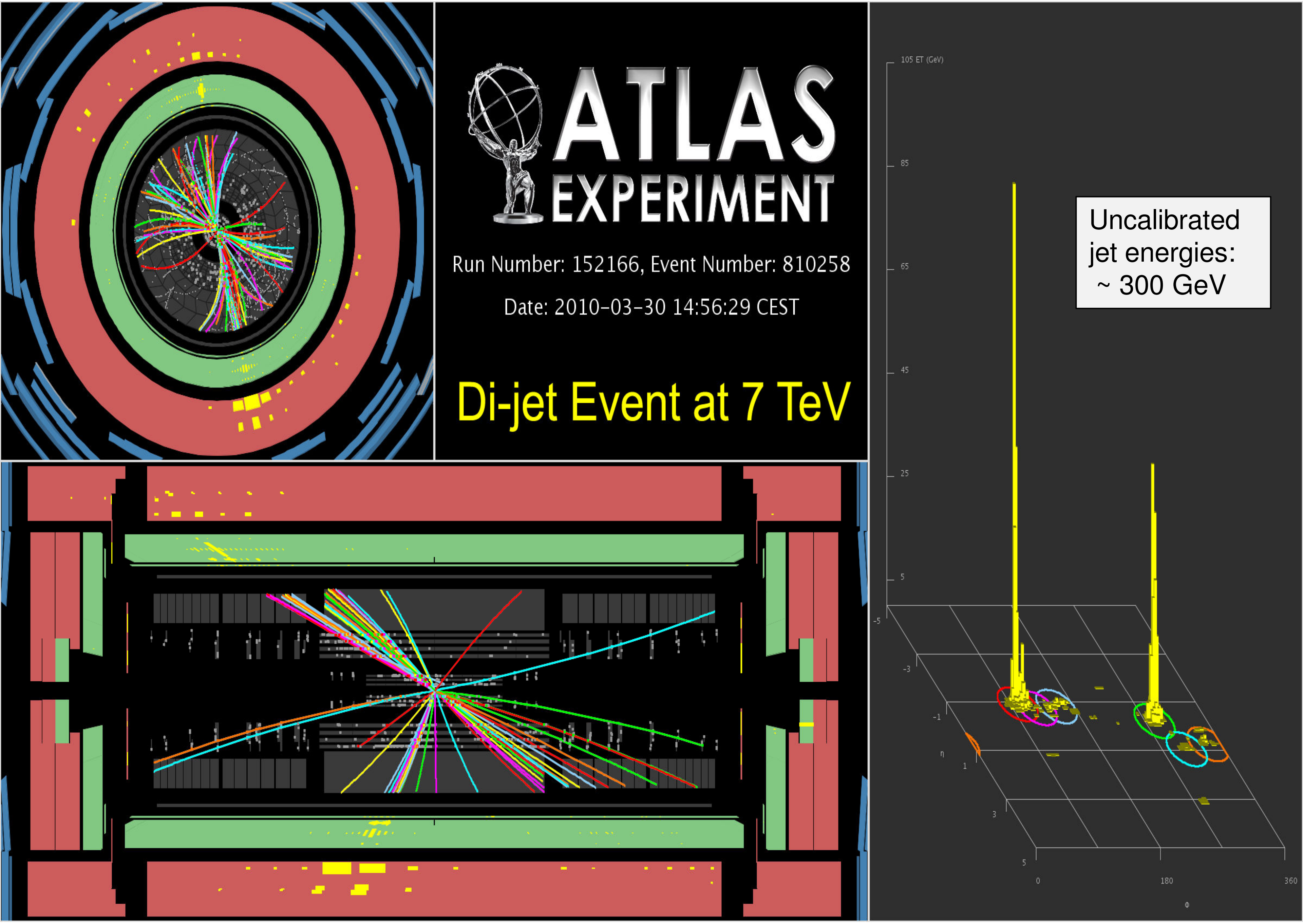
Background 1



Background 2




3D
Rho Z
Rho Phi
CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Mar 30 12:58:48 2010 CEST
Run/Event: 132440 / 2738170
Lumi section: 124
Orbit/Crossing: 32326252 / 1
AF/CMSCOMM/COMM_GLOBAL/EventDisplay/RootFileTempStorageArea/EVDISPSM_1269944655137.root'


ATLAS
EXPERIMENT
Run Number: 152166, Event Number: 810258
Date: 2010-03-30 14:56:29 CEST
Di-jet Event at 7 TeV
Uncalibrated
jet energies:
~ 300 GeV
105 ET (GeV)
85
65
45
25
5
-5
-3
-1
η
1
3
5
0
180
360
Φ

QCD jet spectrum

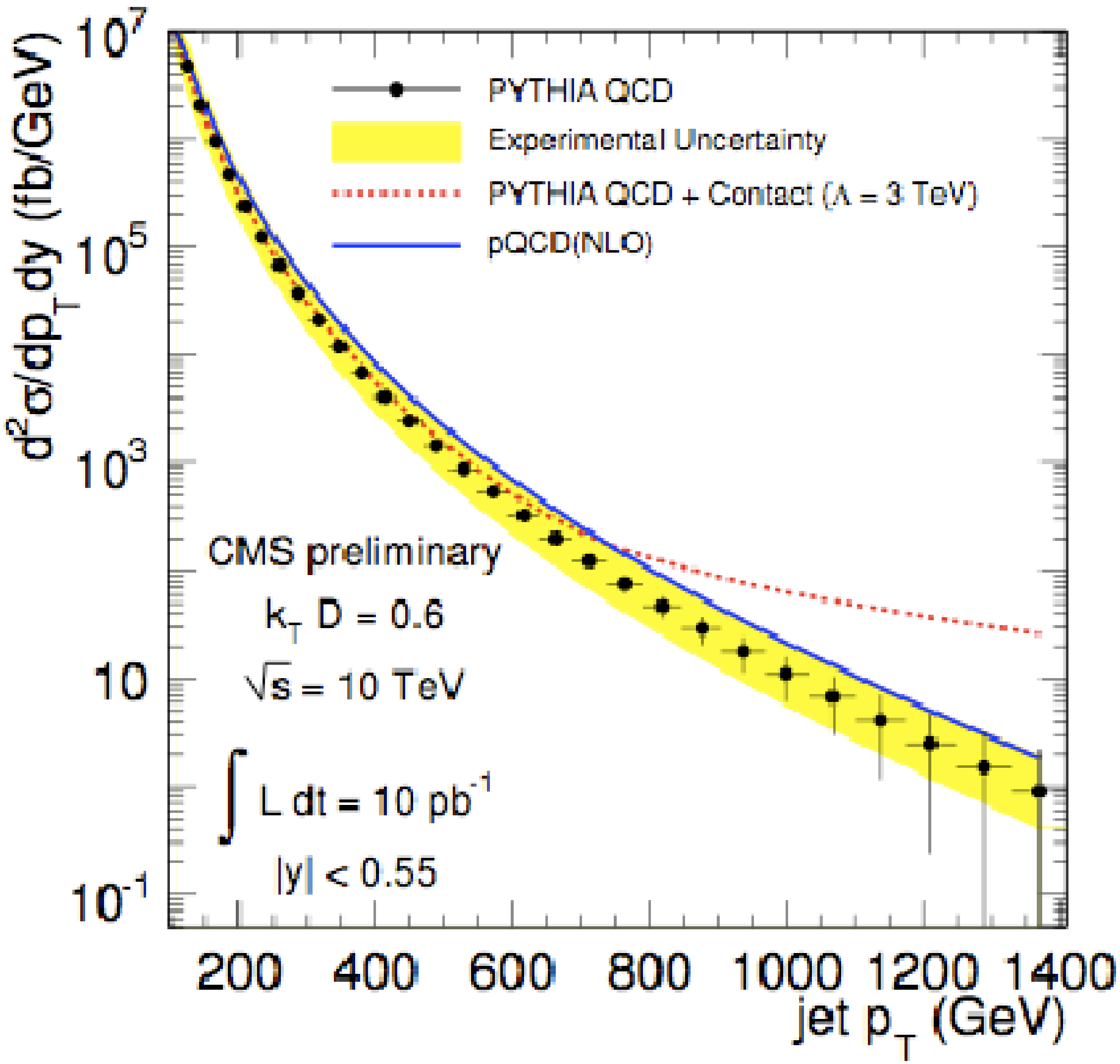
From the first 10 pb^{-1} of data, the differential inclusive cross-section can be measured

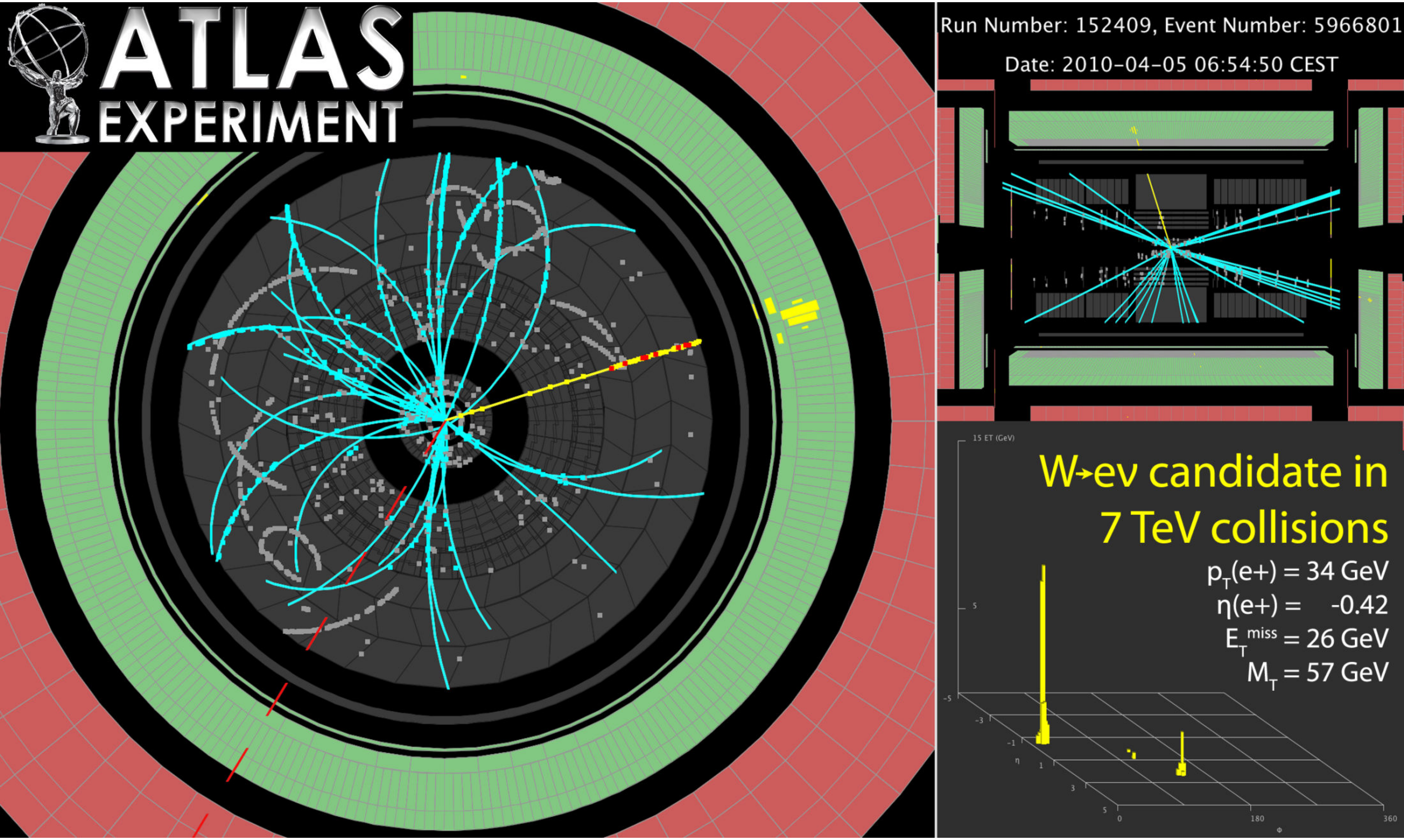
- **100 GeV < p_T^{jet} < 1.4 TeV**
- **central rapidity**

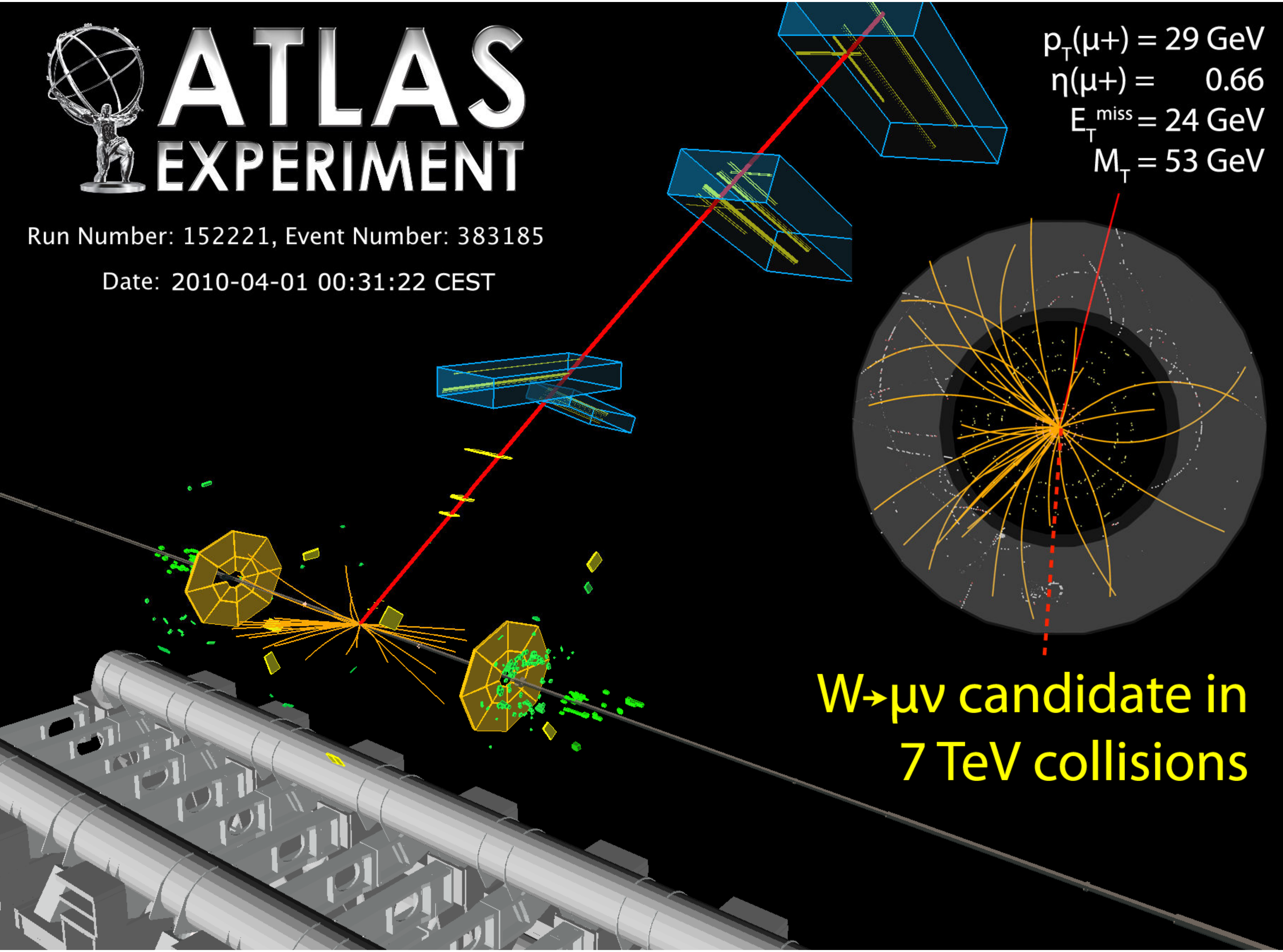
Systematic errors will go down as more events are collected

Any large deviation from QCD prediction

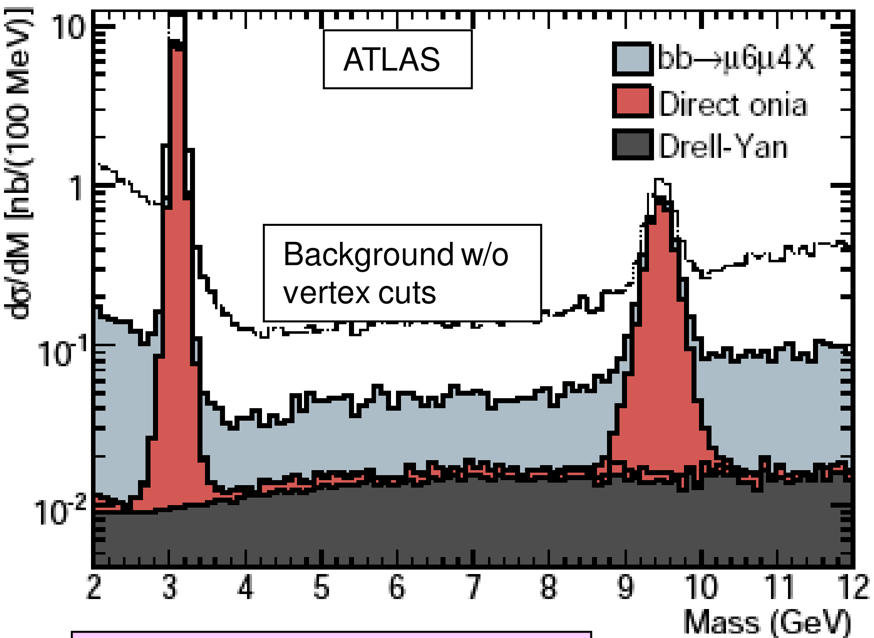
- ***will be studied carefully***
- ***may be sign for new physics***




ATLAS EXPERIMENT
Run Number: 152409, Event Number: 5966801
Date: 2010-04-05 06:54:50 CEST
W→eν candidate in
7 TeV collisions
$p_T(e+) = 34$ GeV
$\eta(e+) = -0.42$
$E_T^{miss} = 26$ GeV
$M_T = 57$ GeV

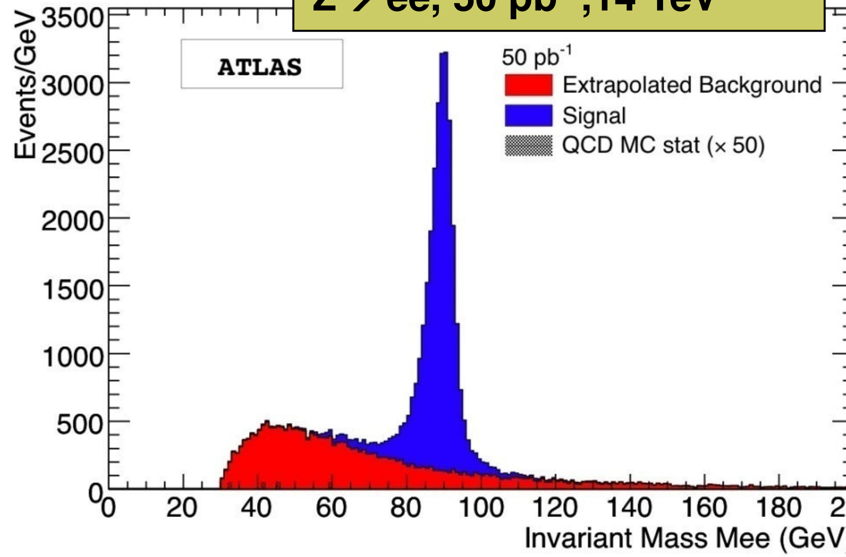

ATLAS EXPERIMENT
Run Number: 152221, Event Number: 383185
Date: 2010-04-01 00:31:22 CEST
$p_T(\mu+) = 29$ GeV
$\eta(\mu+) = 0.66$
$E_T^{miss} = 24$ GeV
$M_T = 53$ GeV
W→μν candidate in
7 TeV collisions

SM "candles": J/ψ, Y, W, Z, top

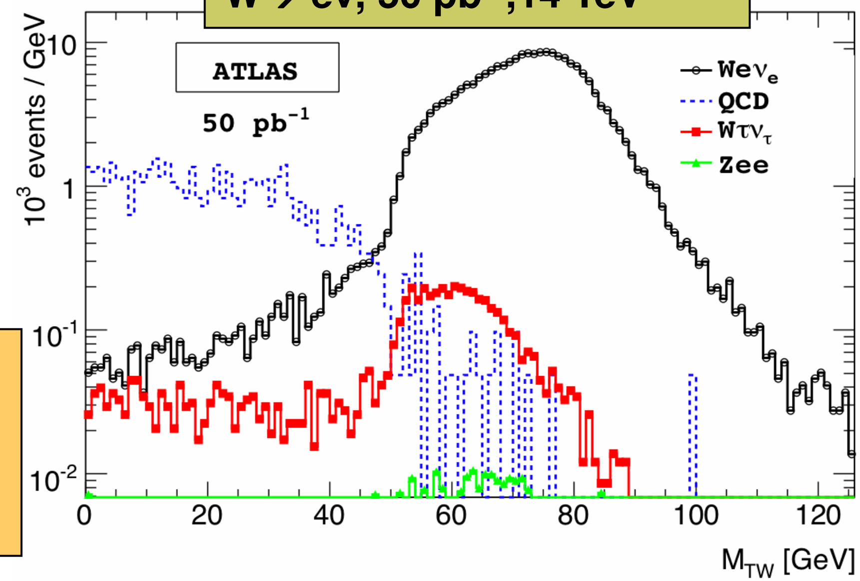


$100\ pb^{-1}$, $\sqrt{s}$ = 4-10 TeV:
~ 3-12 10^5 J/ψ→ μμ
~ 3-7 10^5 W → μν,eν
~ 3-7 10^4 Z → ee, μμ

Z→ ee, 50 pb^{-1},14 TeV



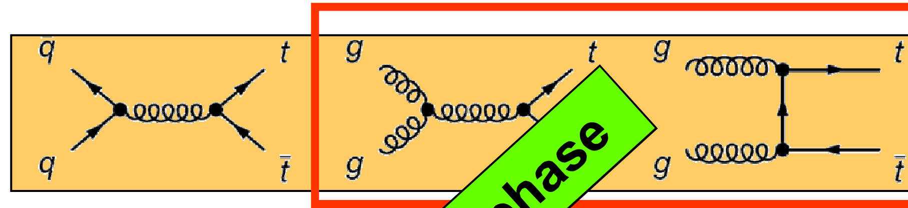
W→ eν, 50 pb^{-1},14 TeV



- **→ Muon Spectrometer and ID alignment, ECAL calibration, detector energy/momentum scale, lepton trigger and reconstruction efficiency, …**
- **→ First SM measurements and MC tuning**

Precision on σ (Z→μμ) with 100 pb^{-1}:
~ 4% (experimental error, dominated by systematics), ~10-20% (luminosity)

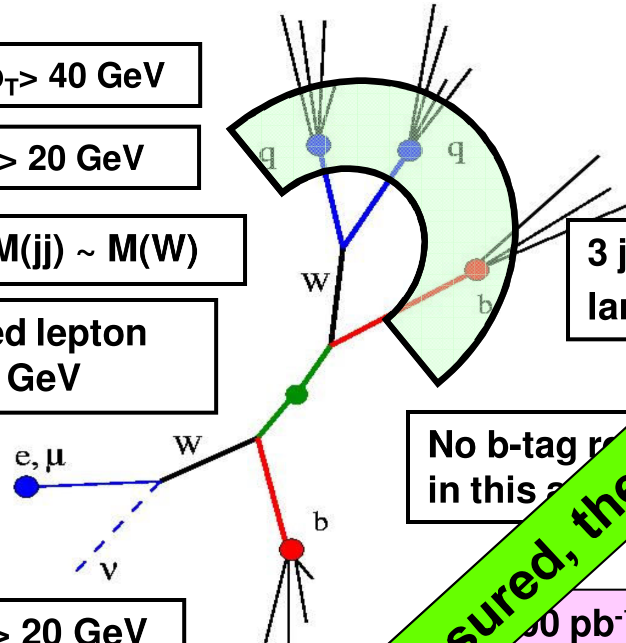
Early top measurements



10 TeV:

$\sigma_{tt} \approx$ 140 pb for tt → bW bW → blν bjj

σ_{tt}(LHC)/σ_{tt}(Tevatron)~50



3 jets p_T> 40 GeV

1 jet p_T> 20 GeV

2 jets M(jj) ~ M(W)

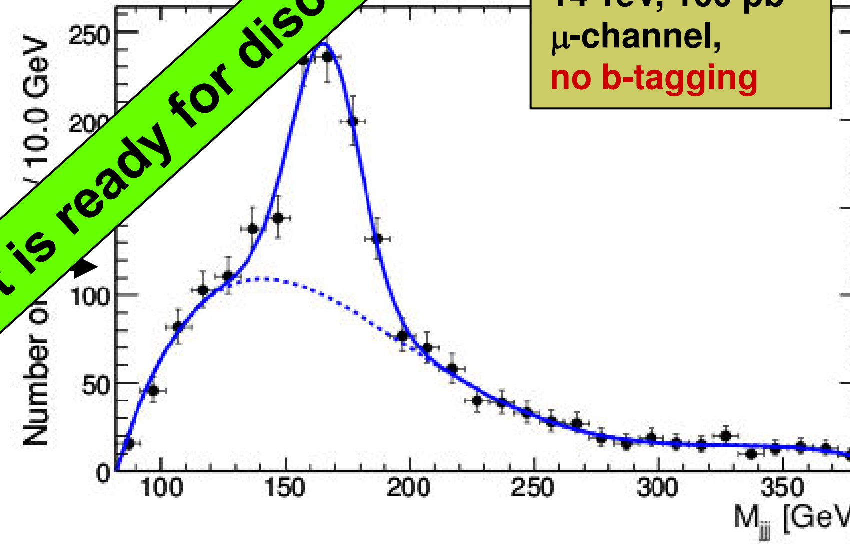
Isolated lepton p_T> 20 GeV

E_T^{miss} > 20 GeV

3 jets with largest ∑ p

No b-tag r... in this a... s

14 TeV, 100 pb^{-1} μ-channel, no b-tagging



...0 pb^{-1}, √s = 4-10 TeV, after cuts: ~ 200-3000 events tt→ bjj blv
→ Top signal observable with O(10 pb^{-1}), no b-tagging and simple analysis even at intermediate energy steps as low as 4 TeV

→ when top measured, the experiment is ready for discovery phase

- S/B ~2-3, large... ...gh to see clean peak. However, pure sample for detector commissioni... ...0, 200, 400 events in narrow peak at √s = 4, 7, 10 TeV) limited by statistics below 7 TeV
- tt final states contain most physics objects: leptons, jets, E_T^{miss} , b-jets
- tt is background to ~ all searches → essential milestone in the path to discoveries

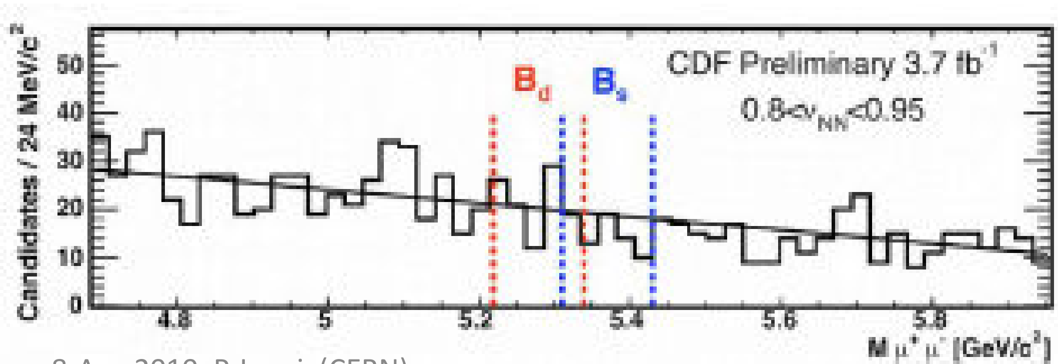
Prospects for most competitive LHCb measurements in 2010

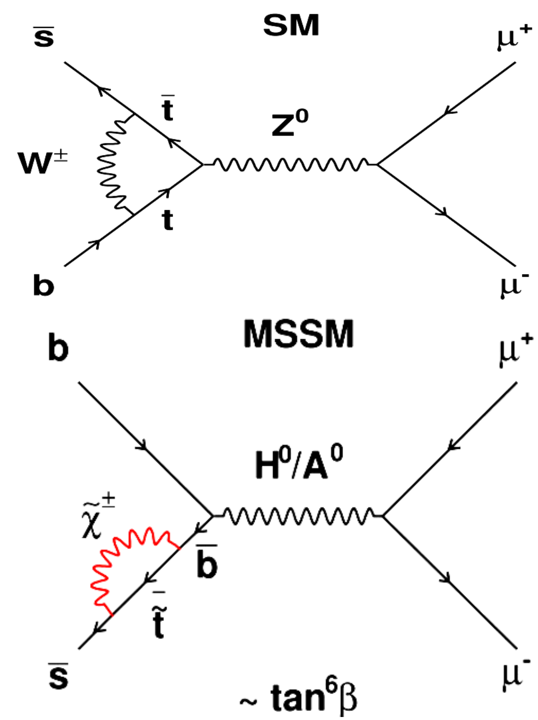
$B_s \rightarrow \mu\mu$

Small BR in SM: $(3.6 \pm 0.3) \times 10^{-9}$
(Buras arXiv:0904.4917v1)

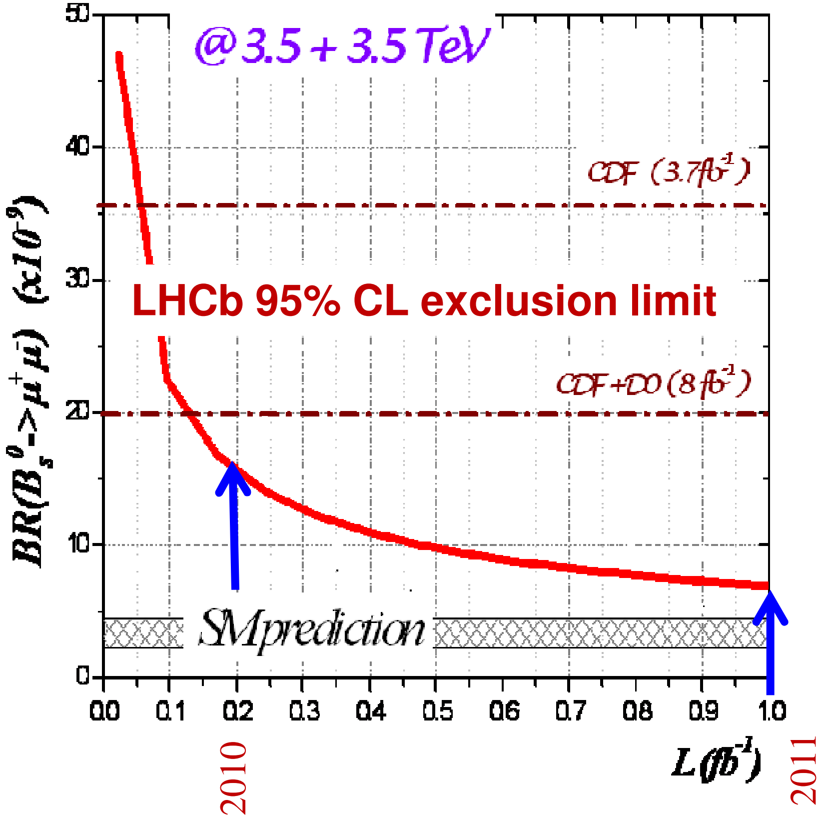
Sensitive to NP
- could be strongly enhanced in SUSY
  - In MSSM scales like $\sim\tan^6\beta$

Current Tevatron limits are around
$< 35 \times 10^{-9}$ with 2 - 4 fb^{-1}

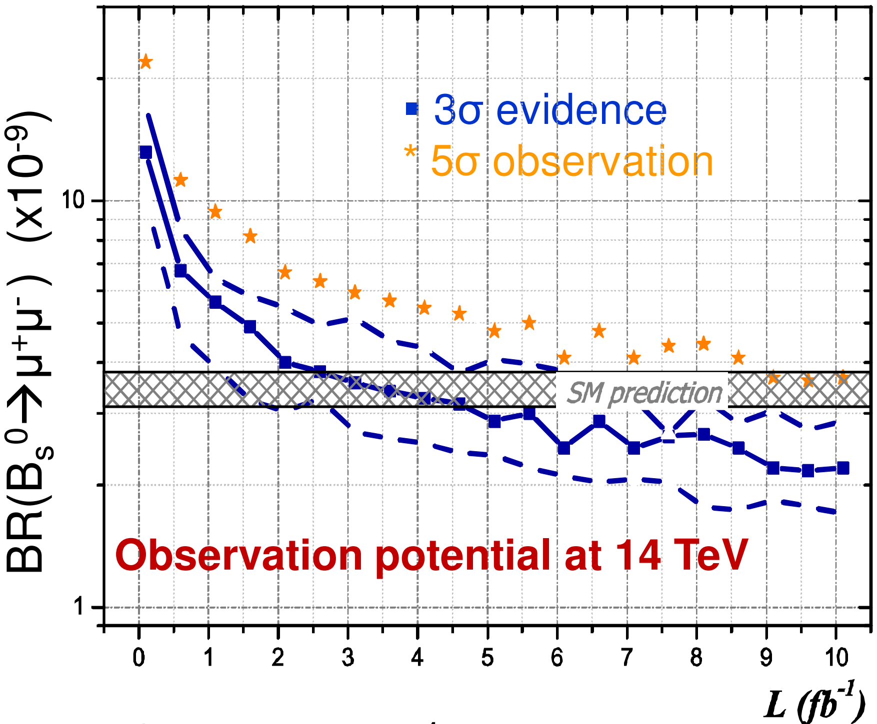




Physics reach for BR($B_s^0 \to \mu^+\mu^-$) as function of integrated luminosity (and comparison with Tevatron)



With ~0.2 fb^{-1} LHCb should improve on expected Tevatron limit



→ **Collect ~3 fb^{-1} for 3σ evidence of SM value and ~10 fb^{-1} for 5σ observation of SM**

(Note: ATLAS/CMS will be competitive)

What about direct discoveries ?
(coming back to ATLAS and CMS)

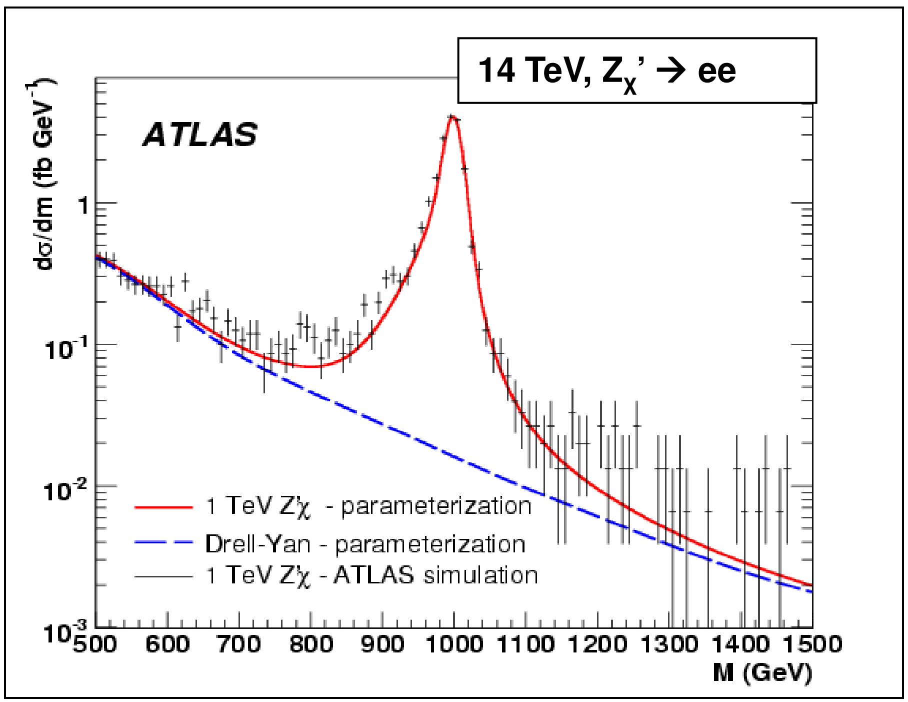
Three cases are usually considered for illustration
(luminosities shown here refer to $\sqrt{s} \sim 10$ TeV)

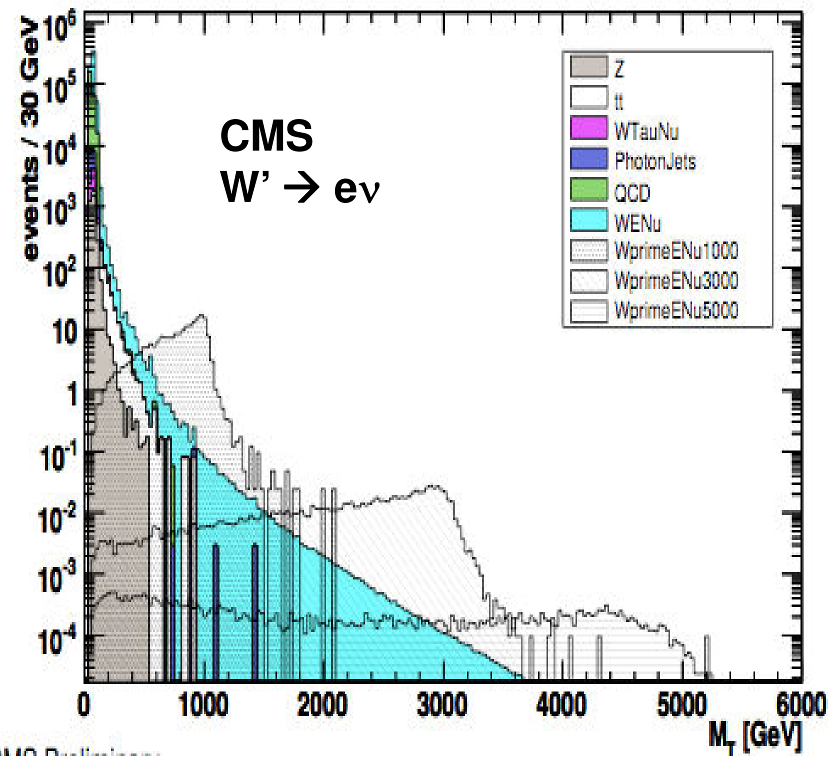
■ ~ 1 TeV new resonance $X \to ll$	needs ~ 100 pb^{-1}	new forces ? new dimensions ?
■ Supersymmetry (~ 1 TeV $\tilde{q}, \tilde{g}$)	needs few 100 pb^{-1}	dark matter ?
■ Light Higgs boson	1 - few fb^{-1}	origin of mass

An easy case: searches for heavy Z' and W'

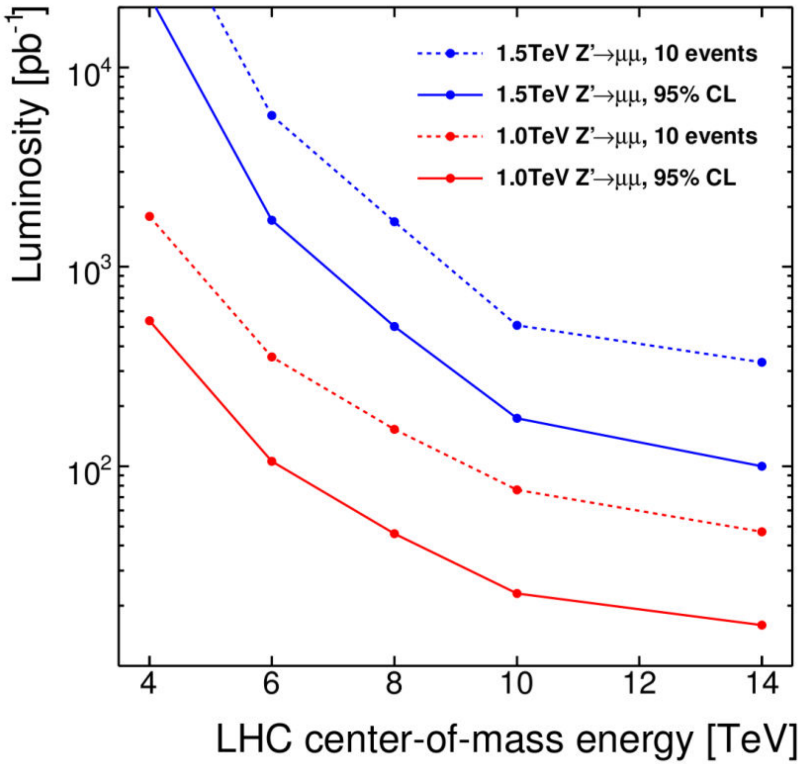
Leptonic decays with electrons or muons would give spectacular signatures

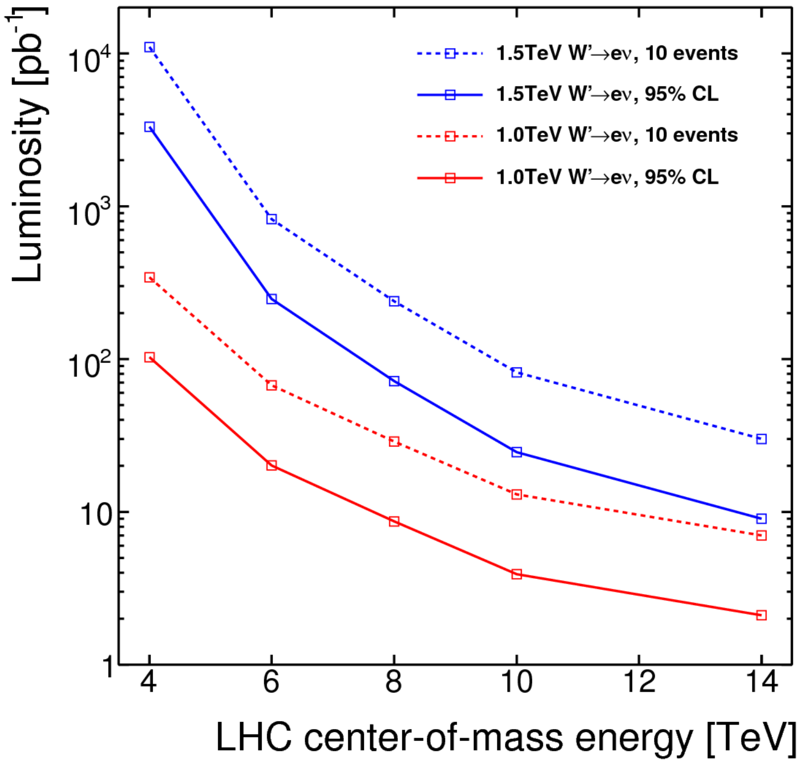
Many different models predict such objects, discoveries of a Z' and W' like particle would be a 'gold mine' for the field, other decay channels could contain yet more new particles!





The LHC experiments will have access to the 1 TeV mass range very early on, still this year (2010)!





Discovery potential for ATLAS and CMS for the end of 2011, with 1 fb^{-1} at 7 TeV:

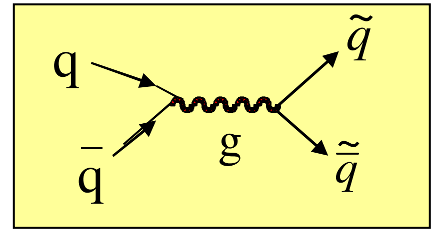
up to 1.5 TeV for Z' and up to 1.9 TeV for W'

First discoveries: Supersymmetry ?

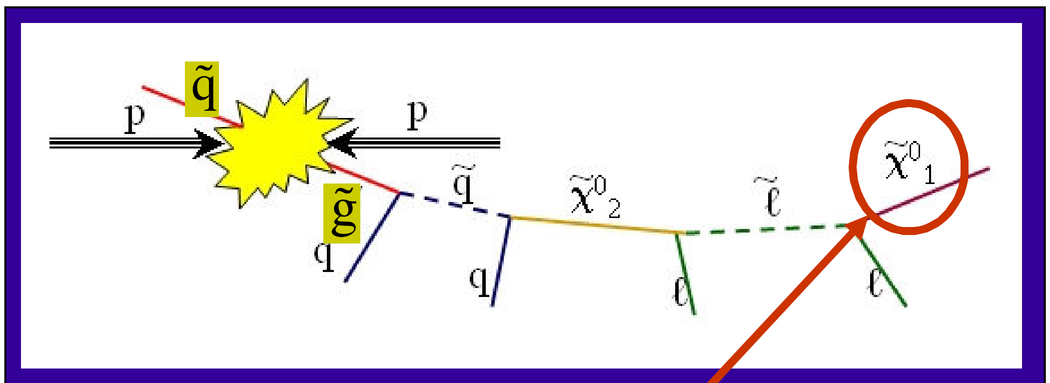
If it is at the TeV mass scale, it should be found "quickly" …. thanks to:

- **Huge production rate for** $\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}$ production

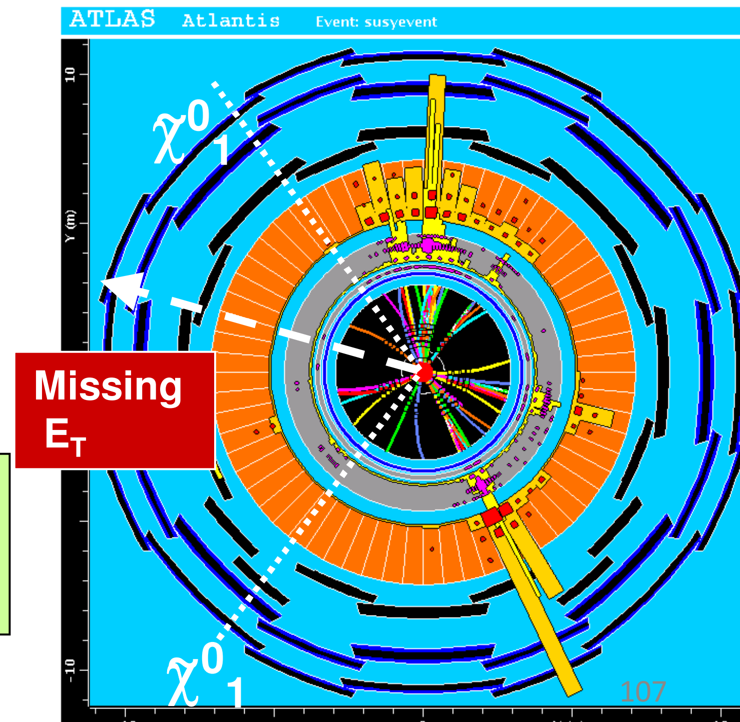
  For $m(\tilde{q},\tilde{g}) \sim 1$ TeV
  expect 1 event/day at L=10^{31} cm^{-2} s^{-1}



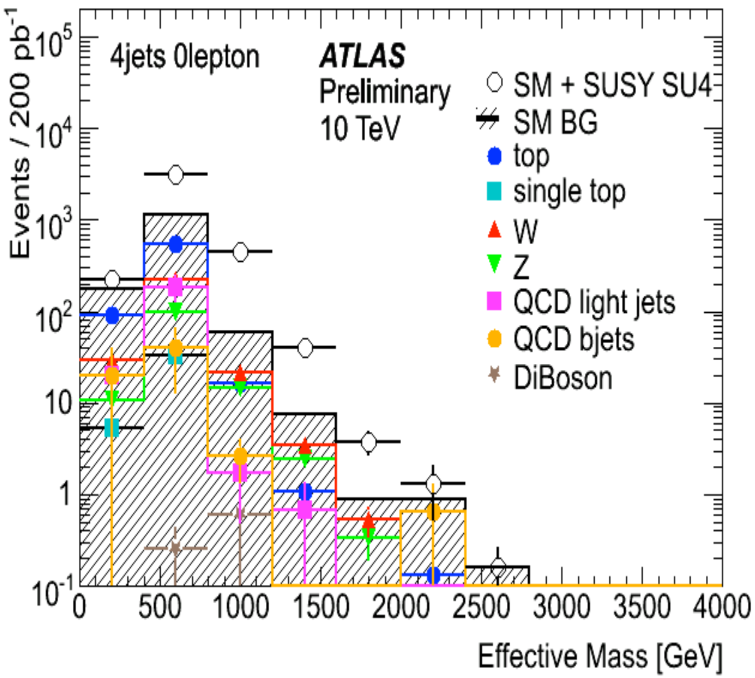
- **Spectacular final states (many jets, leptons, missing transverse energy)**

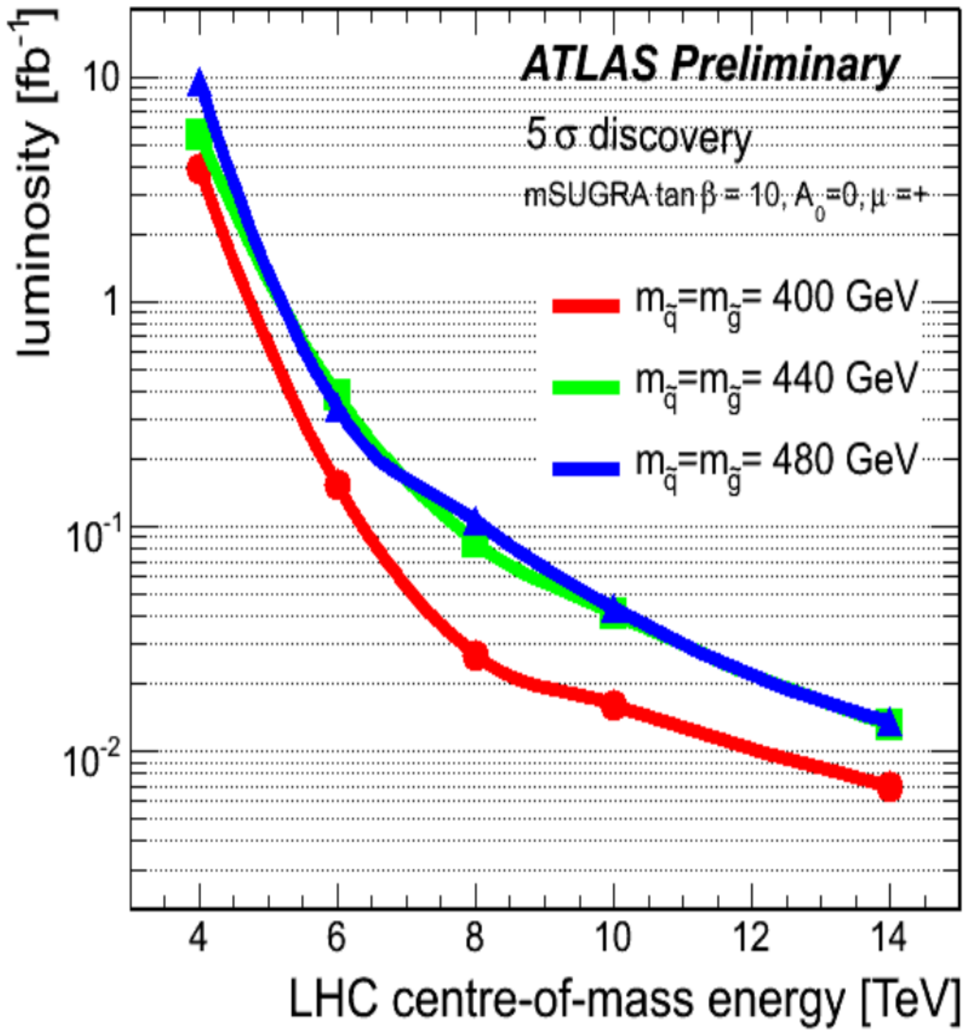


This particle (lightest neutralino) is stable, neutral and weakly interacting → escapes detection (like ν) → apparent missing energy in the final state



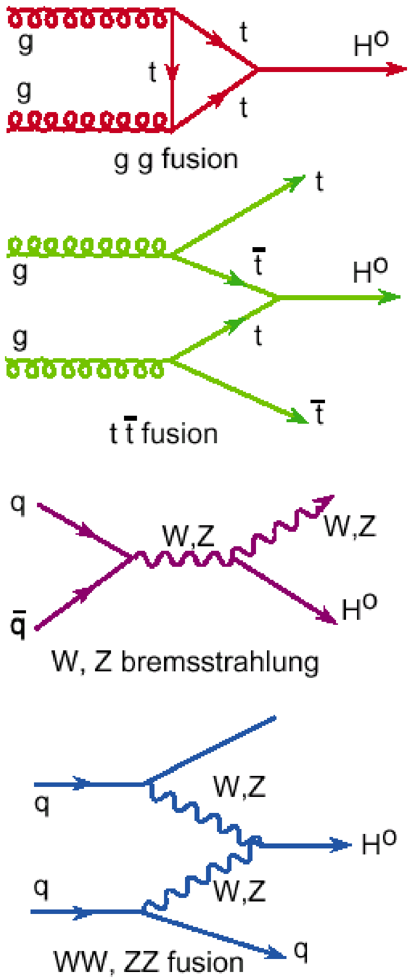
The initial LHC running will already match (and exceed) in 2010 the Tevatron reach

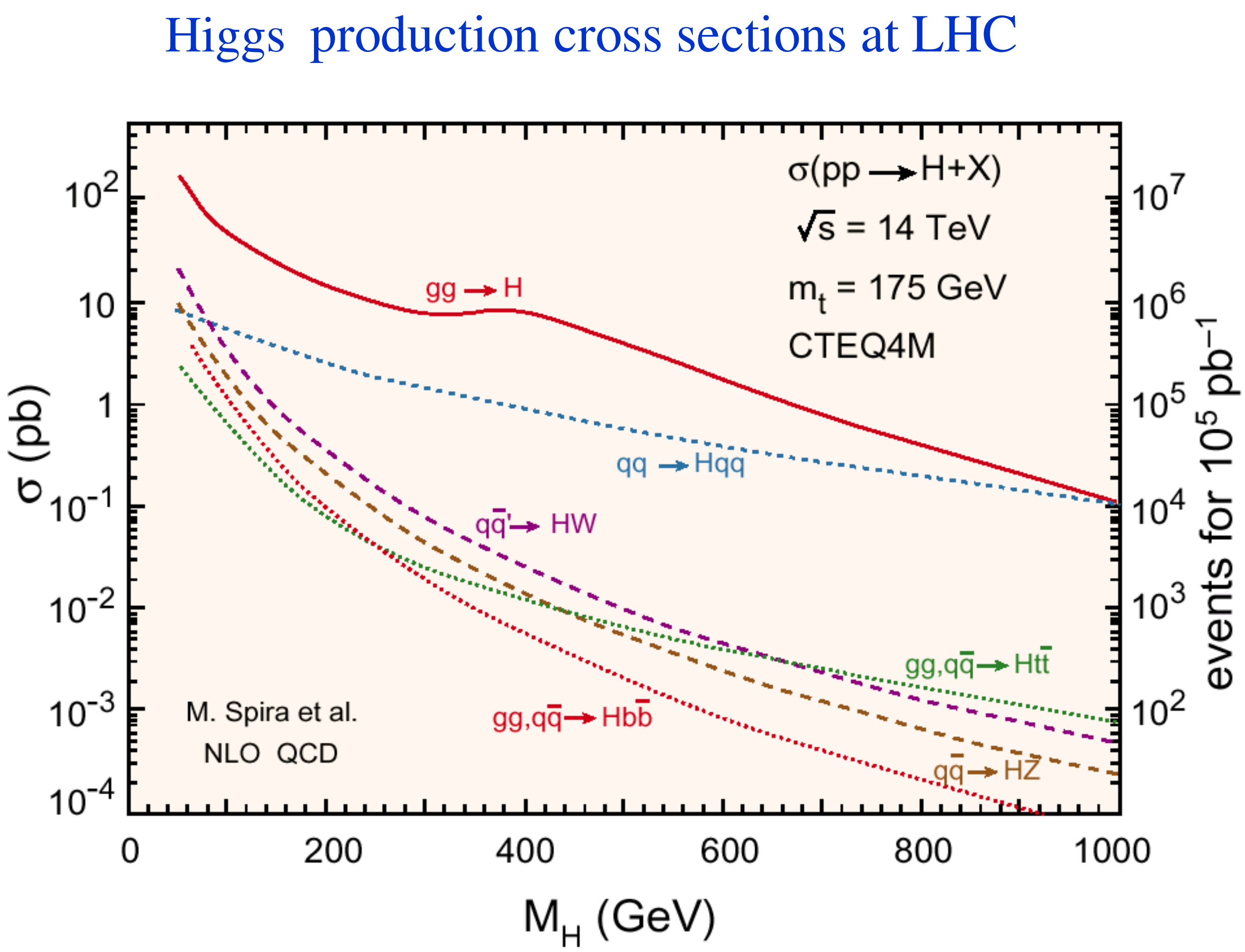




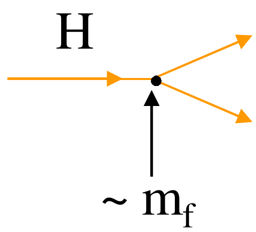
A typical example; note that the missing transverse energy performance enters directly the 'Effective Mass', detectors must be well understood for these measurements

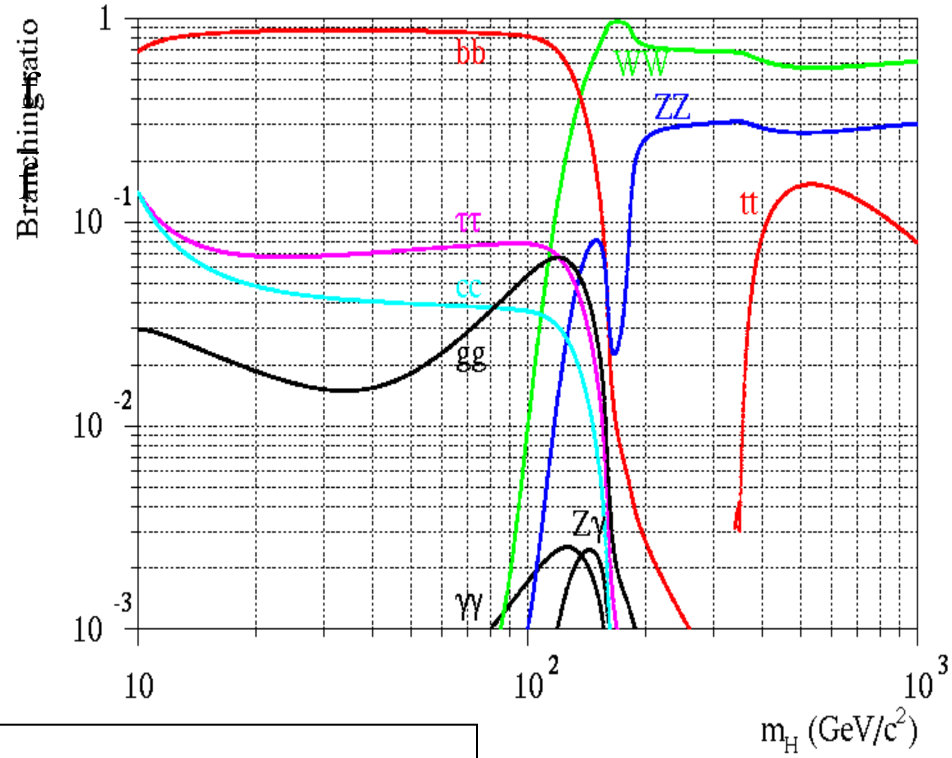
The Higgs Hunt





Higgs decay modes





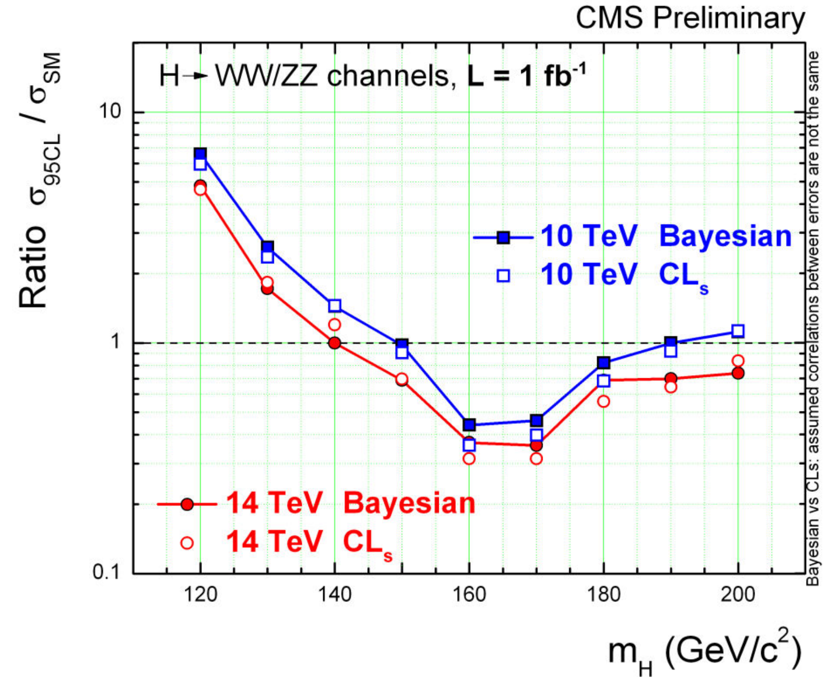
Remember: light fully-hadronic final states cannot be extracted from QCD background at hadron colliders

m_H < 130 GeV : H → bb, ττ dominate
→ best search channels at the LHC : qqH→qq ττ, ttH → bb l+X (?)
H → γγ (rare decay mode)
This is the most difficult region (S/B <<1) !

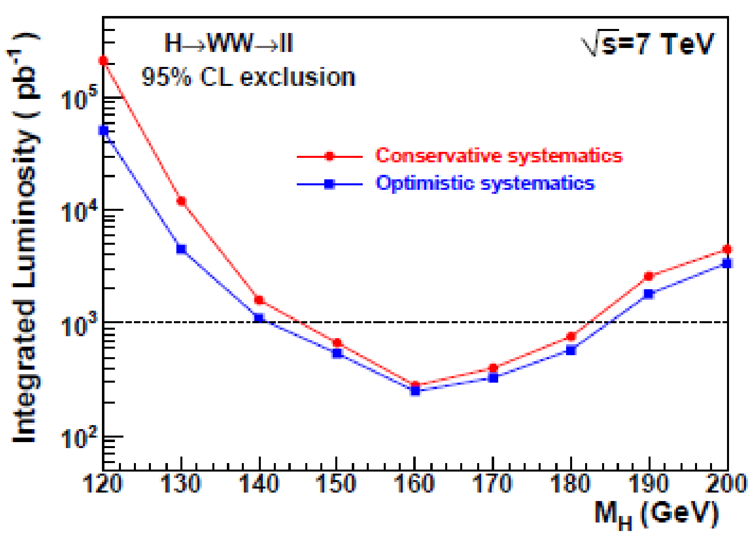
m_H > 130 GeV : H → $WW^{(*)}$, $ZZ^{(*)}$ dominate
→ best search channels at the LHC : H → $ZZ^{(*)}$ → 4l (gold-plated)
H → $WW^{(*)}$ → lν lν

Especially in the region m_H<130 GeV, excellent detector performance needed to suppress the huge backgrounds: b-tag, l/γ E-resolution, γ/j separation, missing E_T resolution, forward jet tag, etc.
→ Higgs searches used as benchmarks for ATLAS and CMS detector design

The first physics run with 7 TeV at the LHC, with the goal of 1 fb^{-1} towards the end of 2011, will be 'catching up' the Tevatron

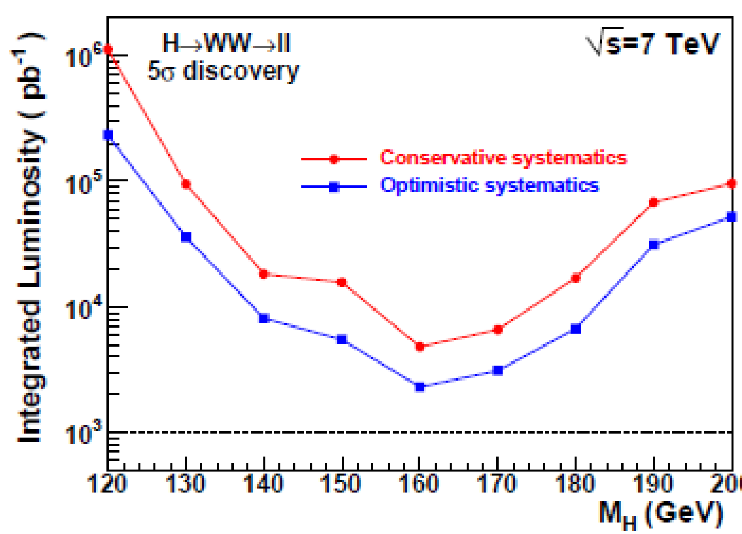


(work in progress…)



95% C.L. Exclusion

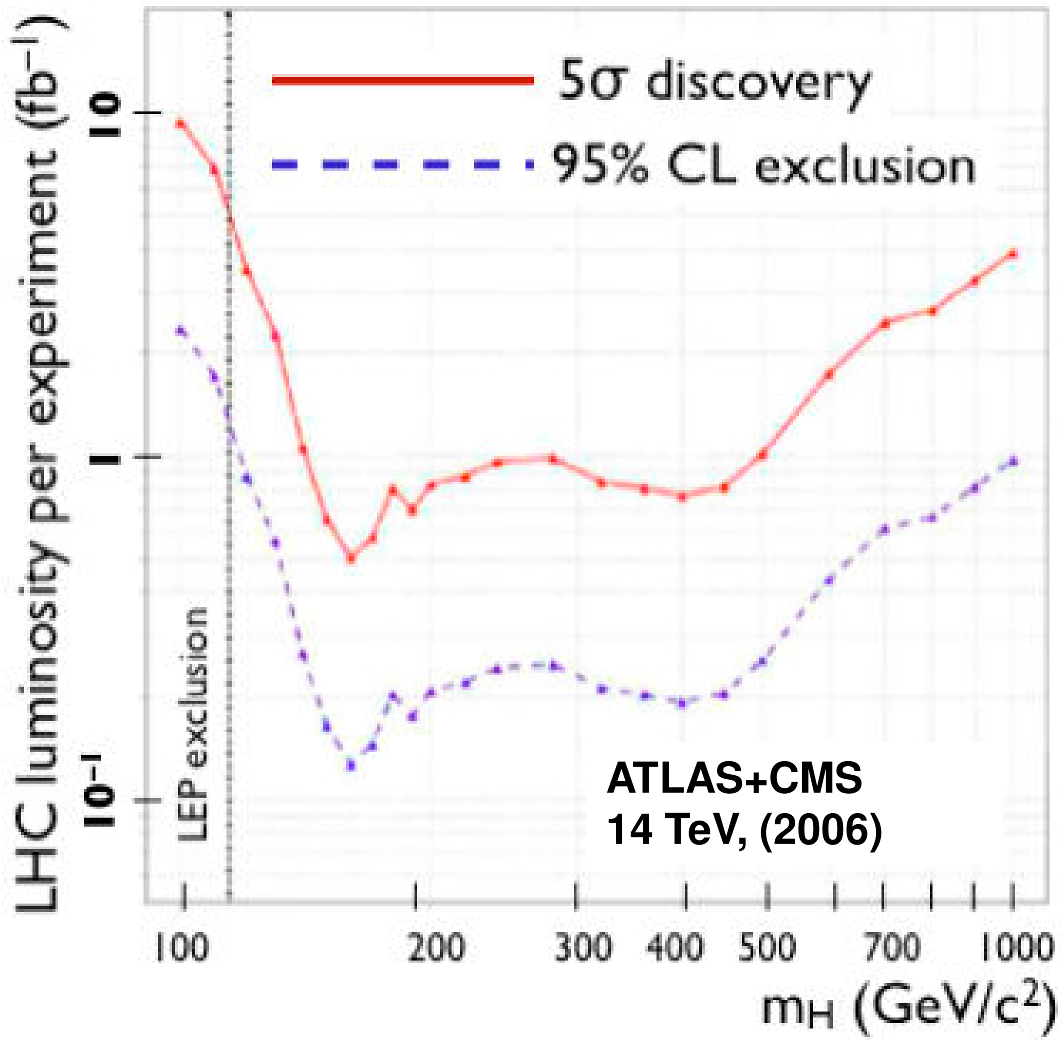
(work in progress…)



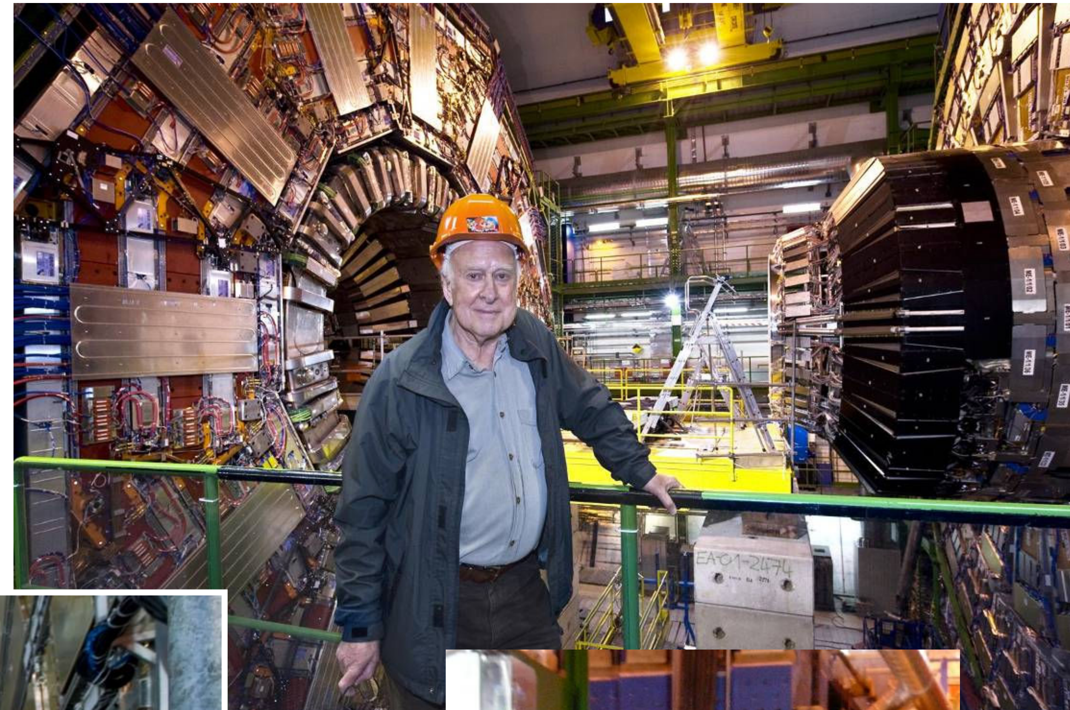
5σ Discovery

Summing up the Higgs search at the LHC with an old plot (still ~ valid)

→After the 2013 run we should be close to conclude…

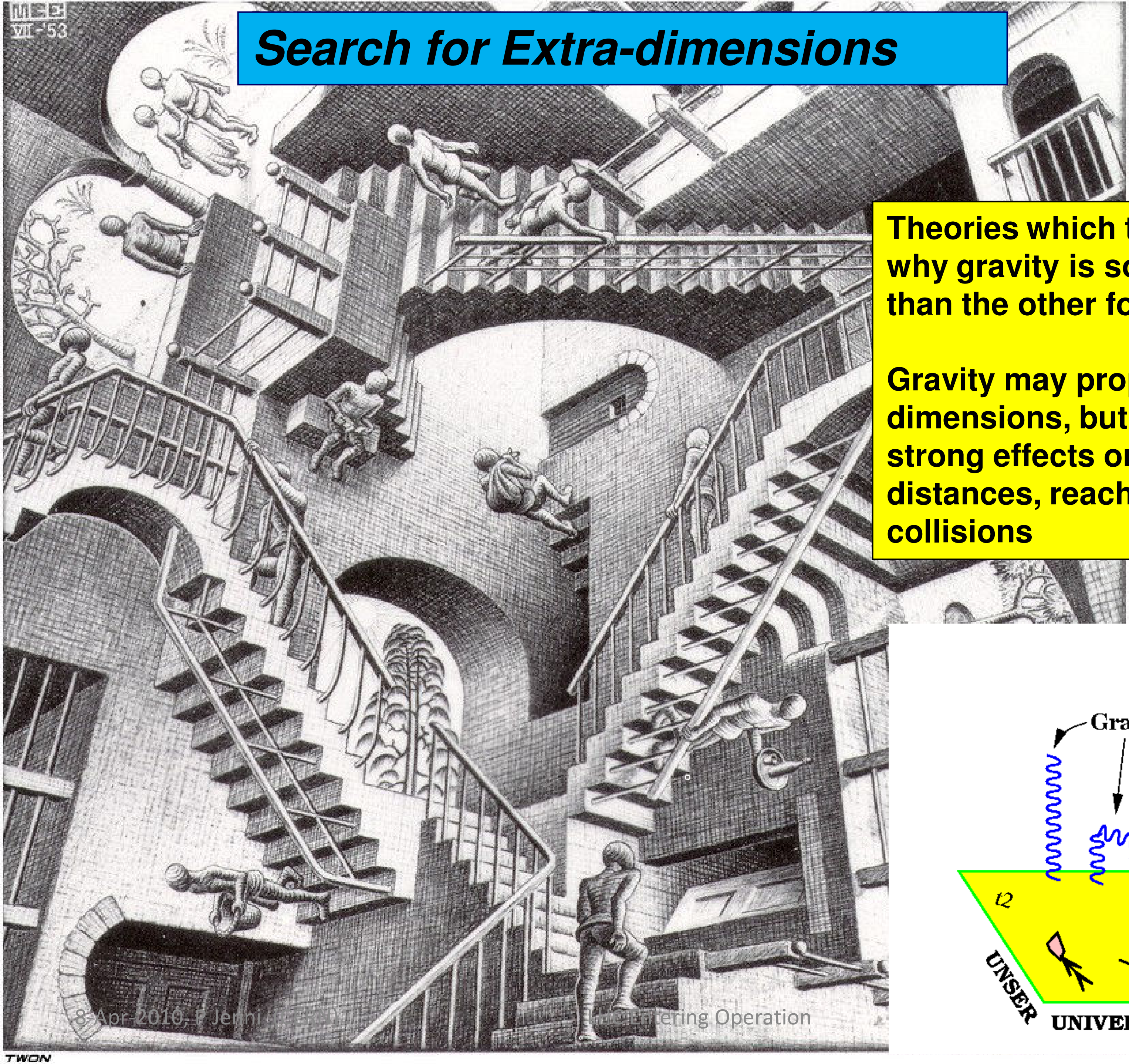


The first “Higgs” events observed jointly in CMS and ATLAS … (April 2008)



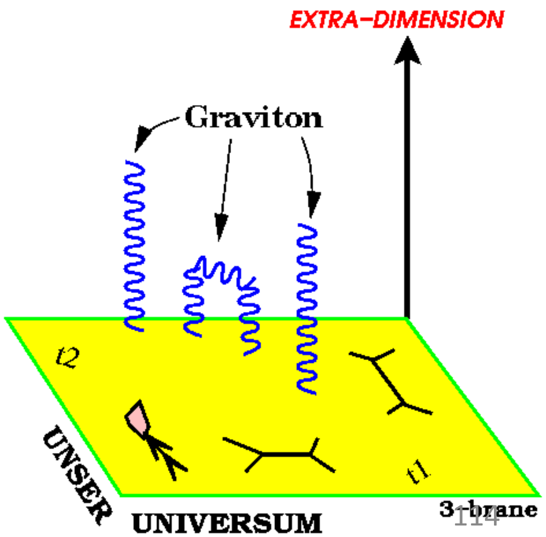
somewhat later, even in ALICE…

Search for Extra-dimensions

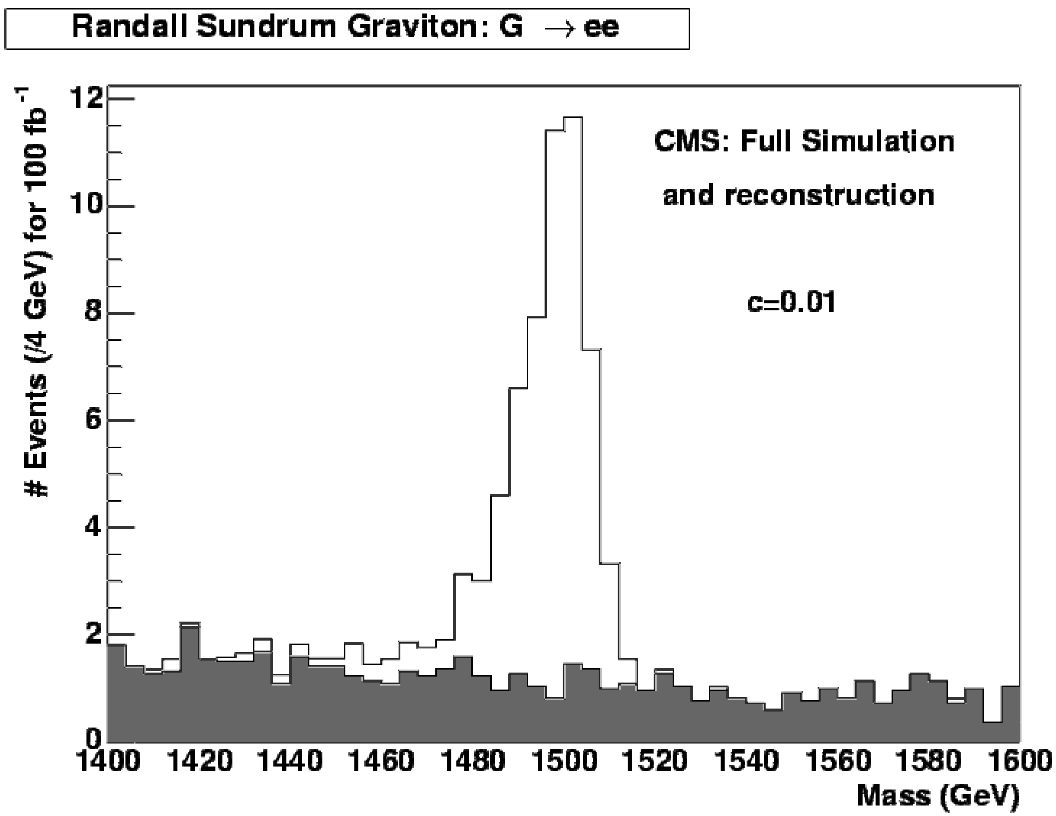


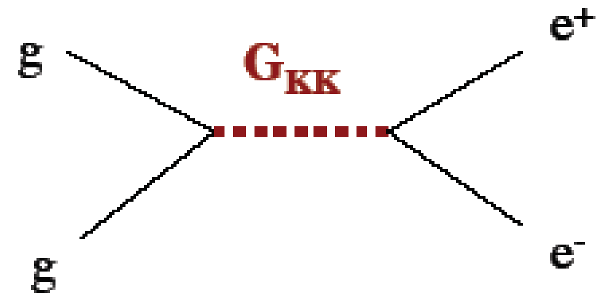
Theories which try to explain why gravity is so much weaker than the other forces

Gravity may propagate in 4+n dimensions, but we could see strong effects only at very small distances, reachable in pp LHC collisions



Warped Extra-dimensions (Randall-Sundrum models): production of narrow Graviton resonances





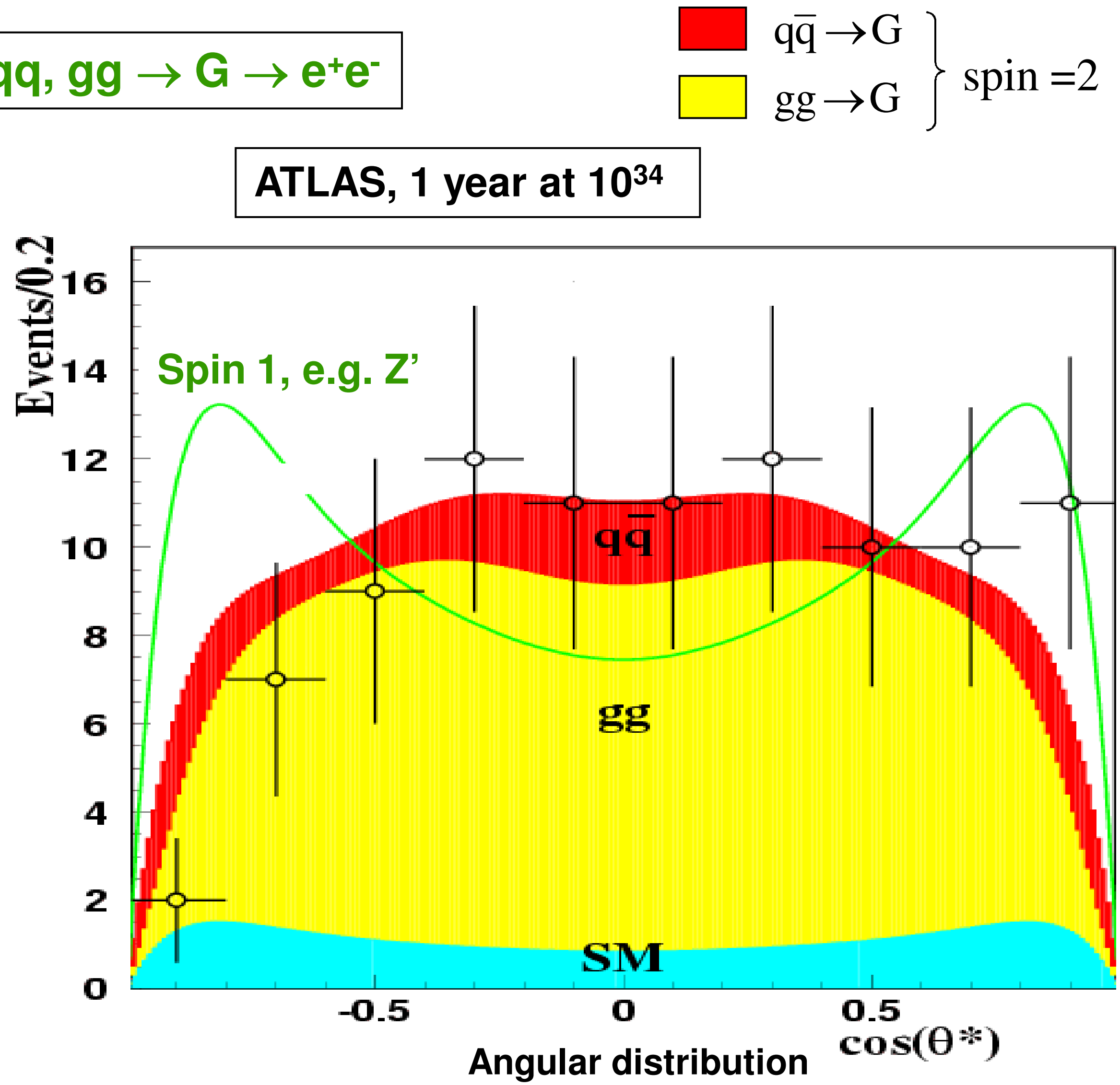
Signature: a resonance in the di-electron or di-muon final state a priori easy for the experiments

Caveat: new developments suggest that G_{KK} would couple dominantly to top anti-top…

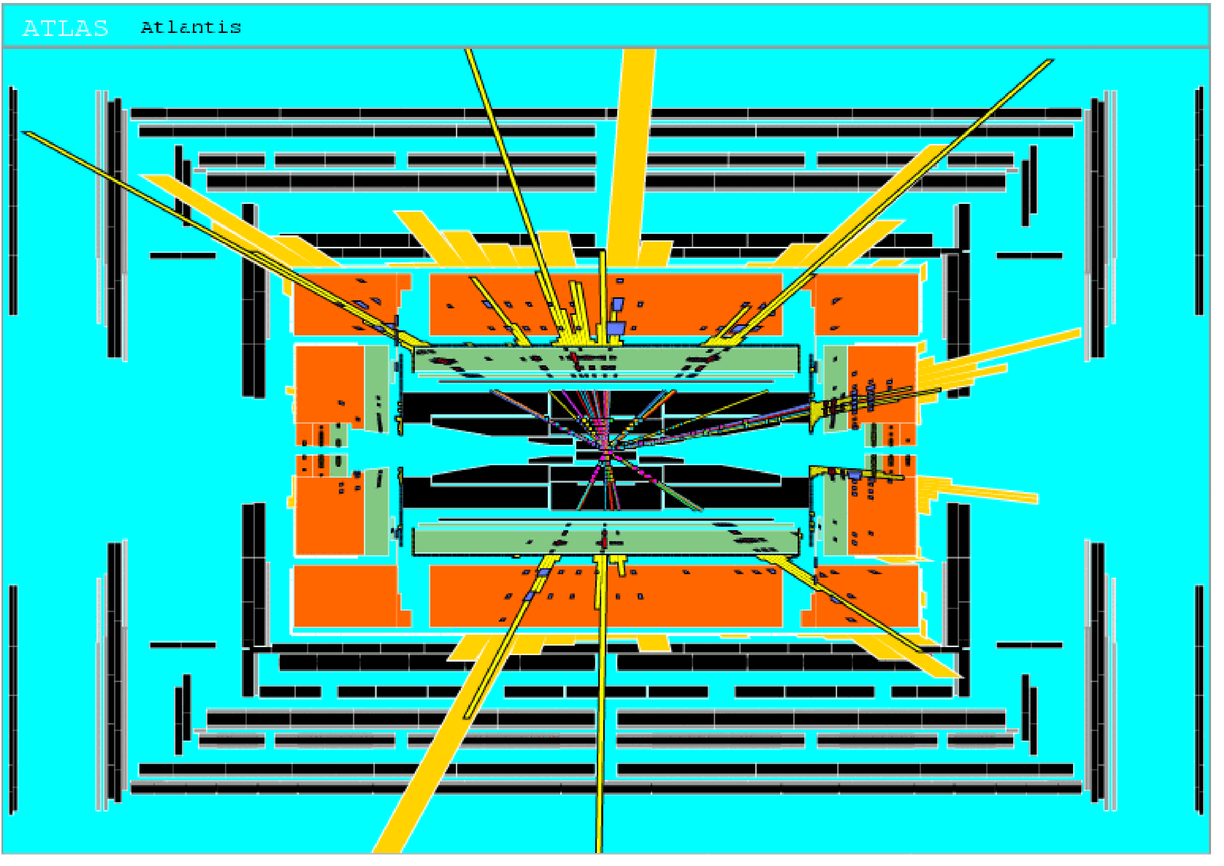
Warped Extra-dimensions (Randall-Sundrum models): production of narrow Graviton resonances

discovery channel : $qq, gg \rightarrow G \rightarrow e^+e^-$

Lisa Randall visiting ATLAS



If theories with Extra-dimensions are true, microscopic black holes could be abundantly produced and observed at the LHC



Simulation of a black hole event with M_{BH} ~ 8 TeV in ATLAS

They decay immediately through Stephen Hawking radiation

Finally the LHC Project is in Operation

All experiments have collected successfully first LHC collision data

The experiments operated remarkably well, from data taking to data transfer worldwide, and produced first results that confirm initial hopes to reach the expected performances

→ ***All hopes are permitted for the physics to come!***

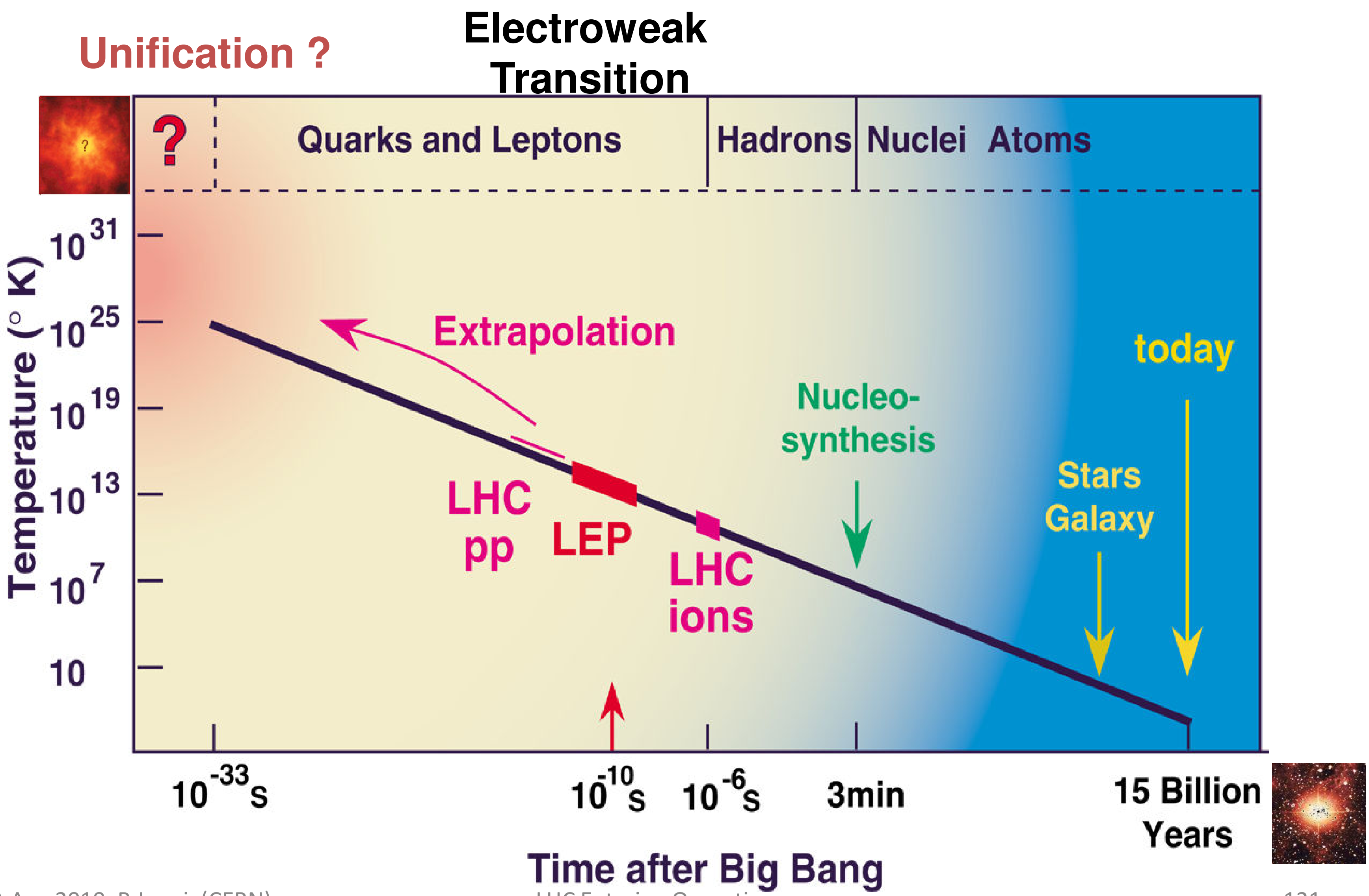
The machine turned on in an extraordinary manner, and all compliments have to go to the LHC team

It is also clear that the machine and the experiments have still a long way to go, but the enthusiasm is great to do so

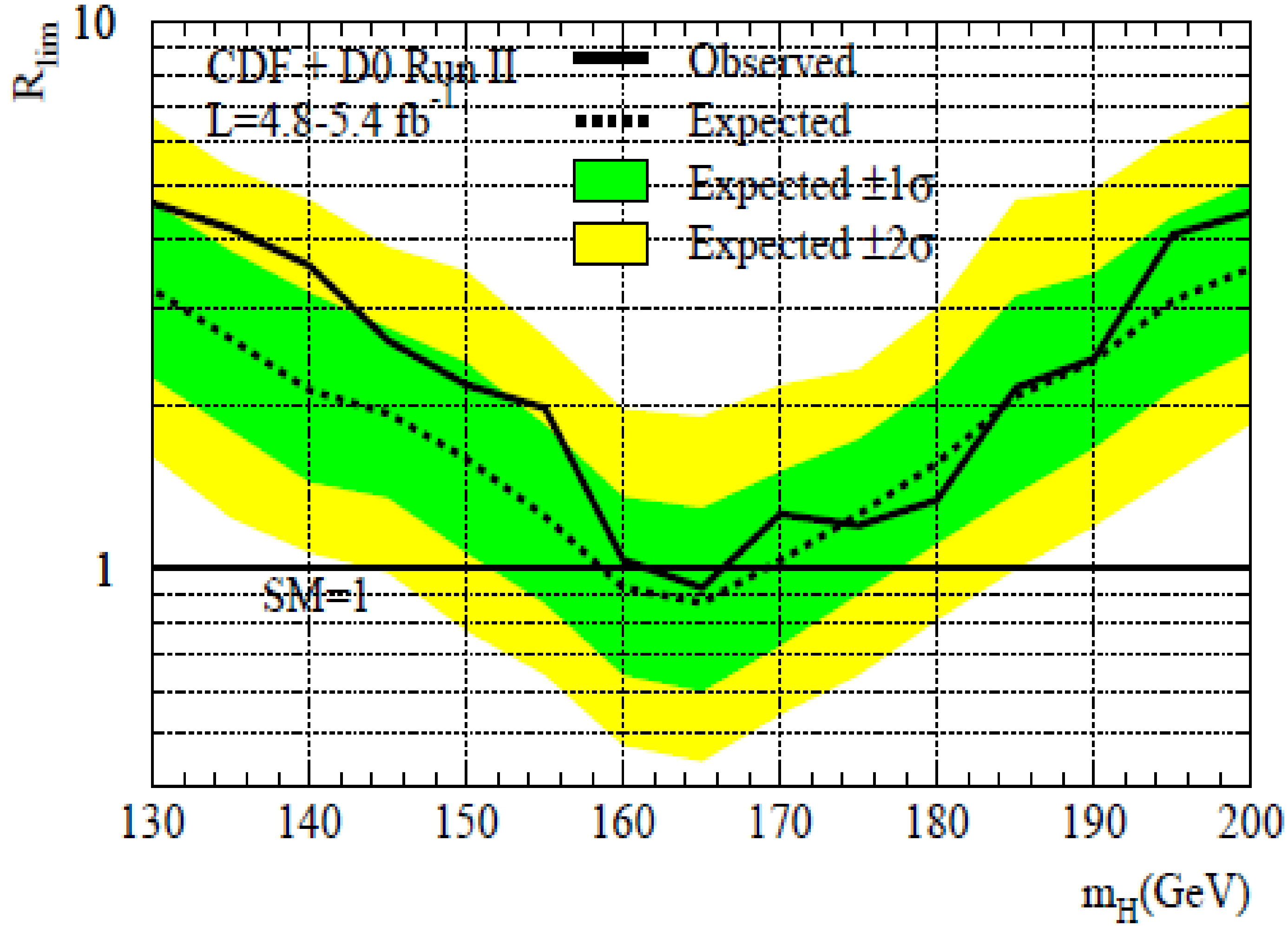
Thank you for your attention!

And many thanks to several colleagues from whom I ‘borrowed’ material: in the first place to Fabiola Gianotti, the Spokesperson of ATLAS, as well as to CMS, Alice and LHCb colleagues, and last but not least to the LHC machine team

Understanding the Universe …

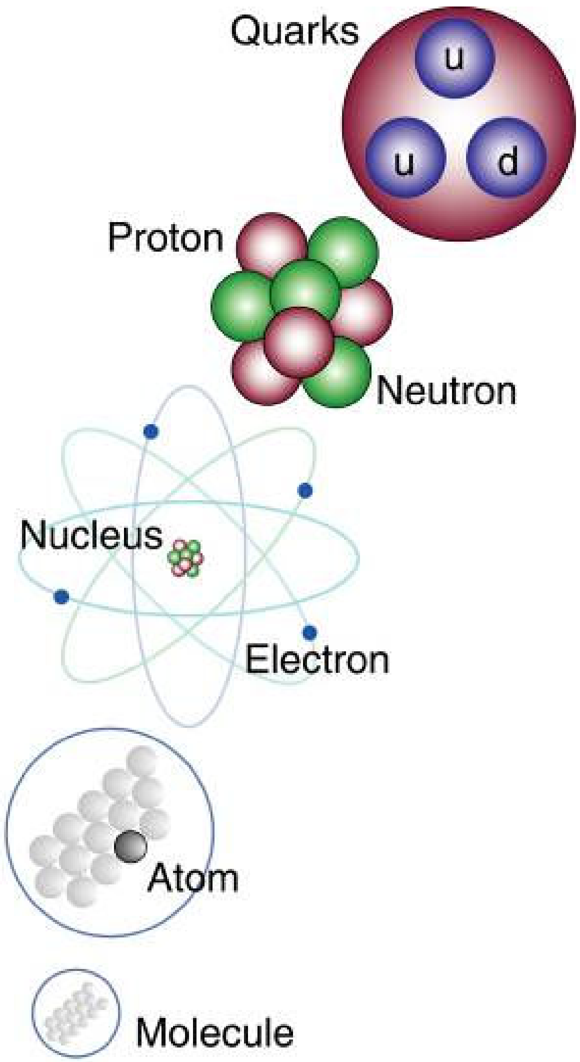


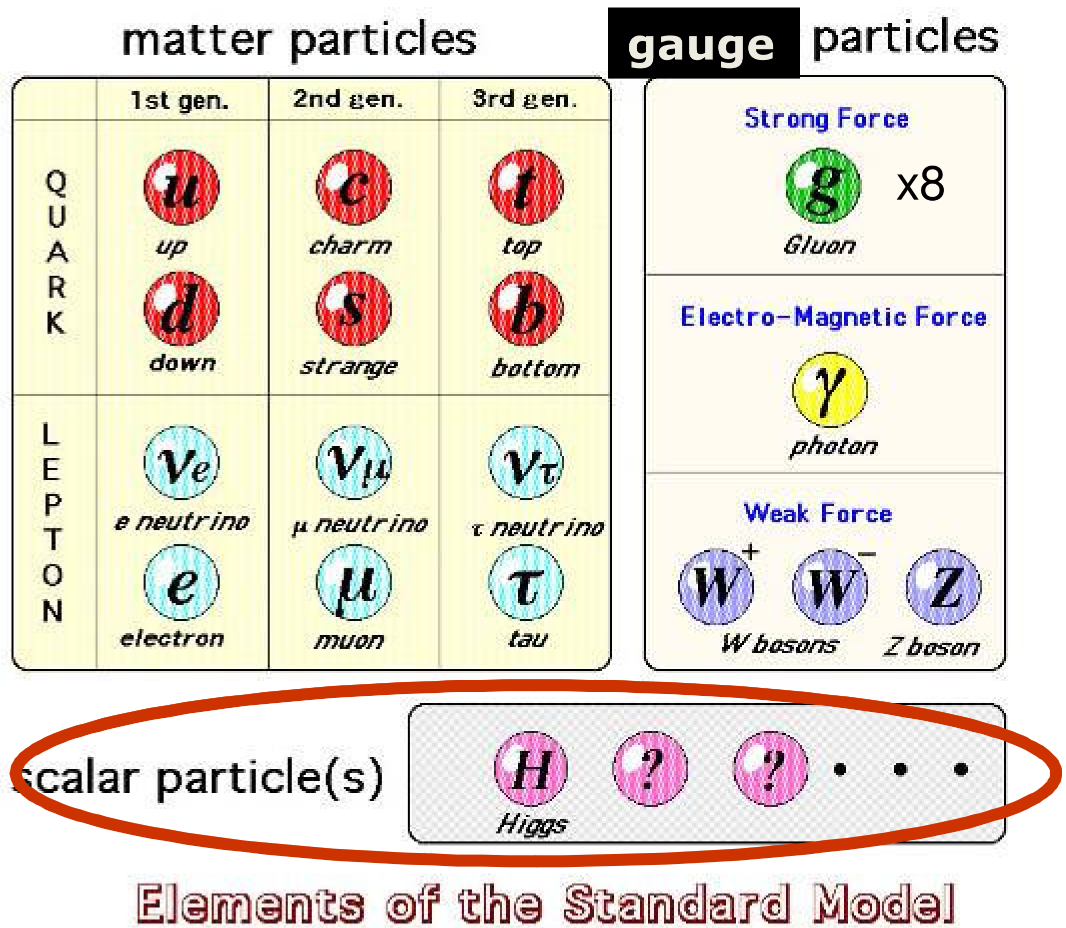
The new combined result published very recently sets a new combined 95% CL exclusion for 162 – 166 GeV



Combining the two experiments at this advanced stage turns out to be very powerful for the Tevatron

The study of elementary particles and fields and their interactions

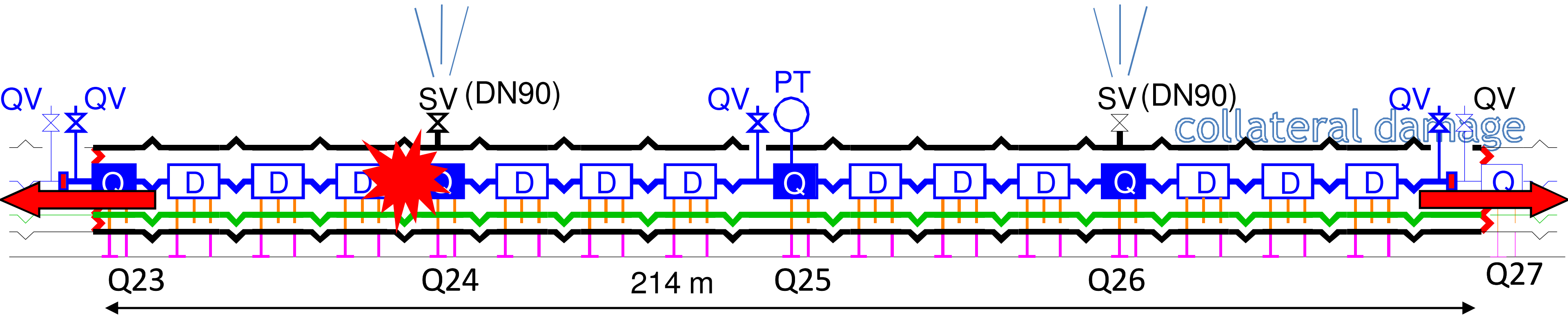




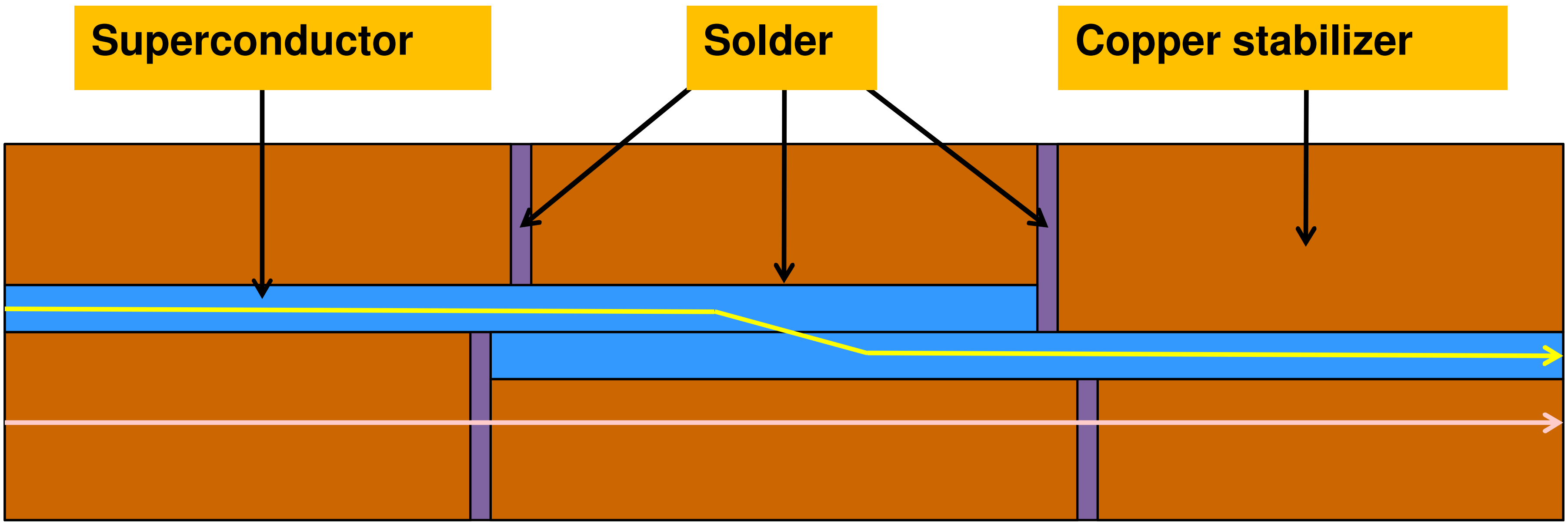
Most likely, an electrical arc developed, which punctured the Helium enclosure

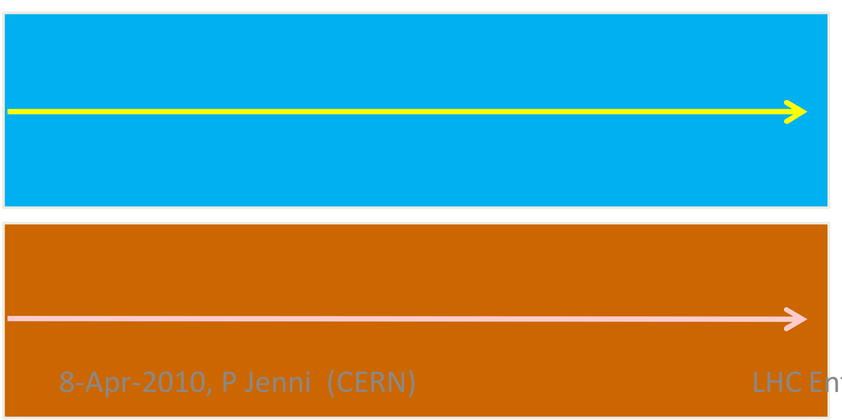
Large amounts of Helium gas were released into the insulating vacuum of the cryostat:

- **Self actuating relief valves opened, releasing large amount of He in the tunnel, but could not handle huge pressure**
- **Hence, large pressure waves traveled along the accelerator both ways**
- **Large forces exerted on the vacuum barriers located every 2 machine cells**
- **These forces displaced several quadrupoles by up to ~50 cm**
- **Beam pipes broke as well, vacuum contaminated**



Energy presently dictated by LHC Interconnects





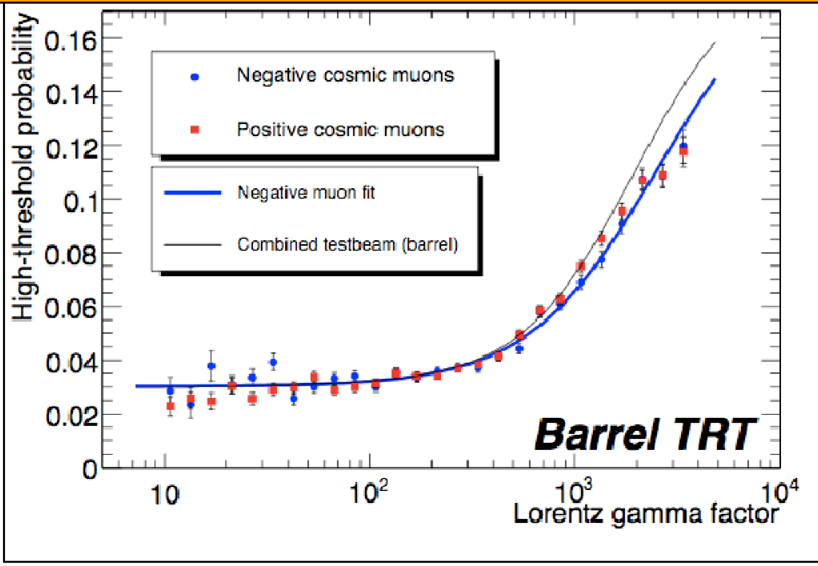
Current flow at 1.9K

Good joint resistance < 1 nΩ

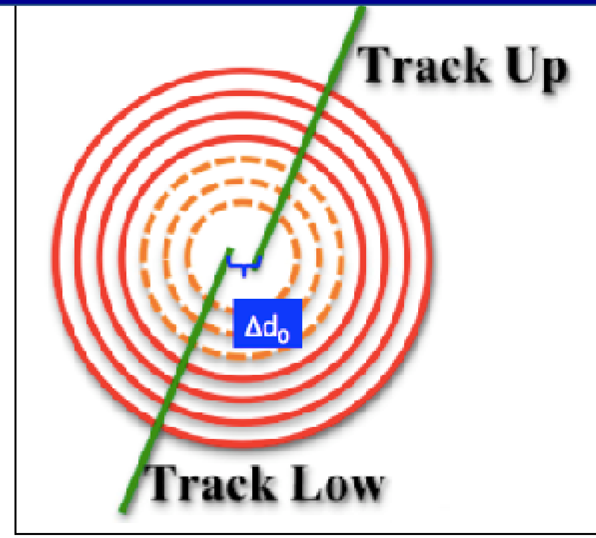
Current flow after a quench

Good joint resistance < 10 μΩ

Transition radiation intensity is proportional to particle γ-factor: onset at high γ (E~100 GeV for muons)

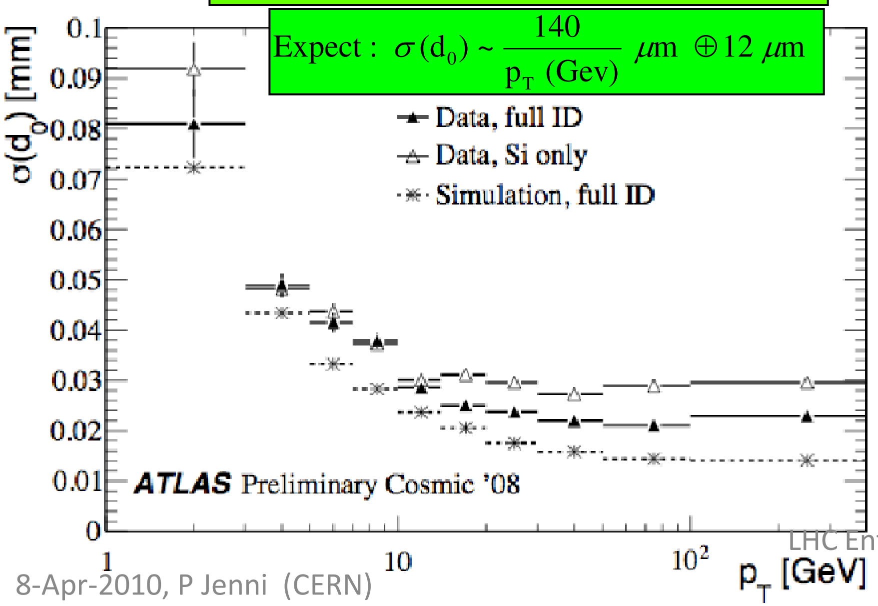


Tracks are split in the center and refit separately → can measure resolutions and biases from data

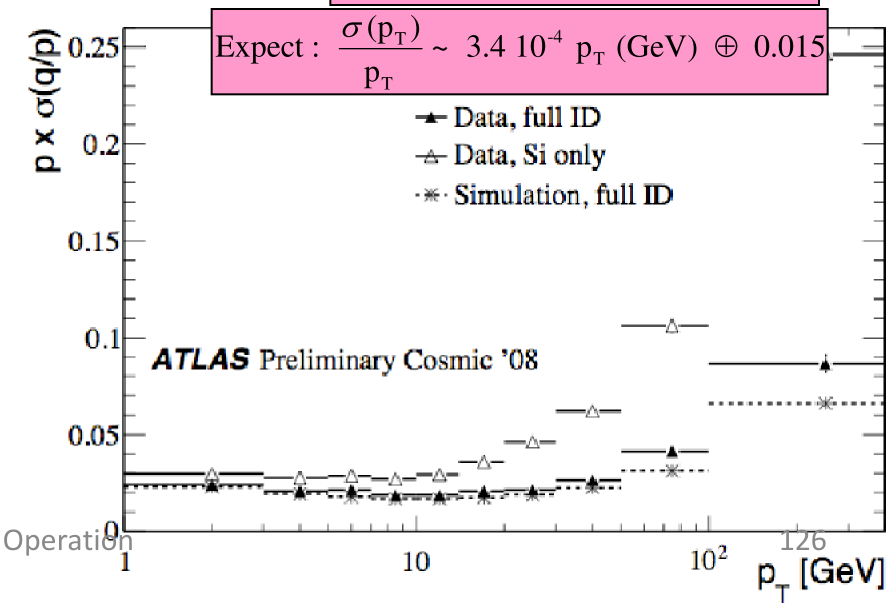


Split tracks

Impact parameter resolution



Momentum resolution



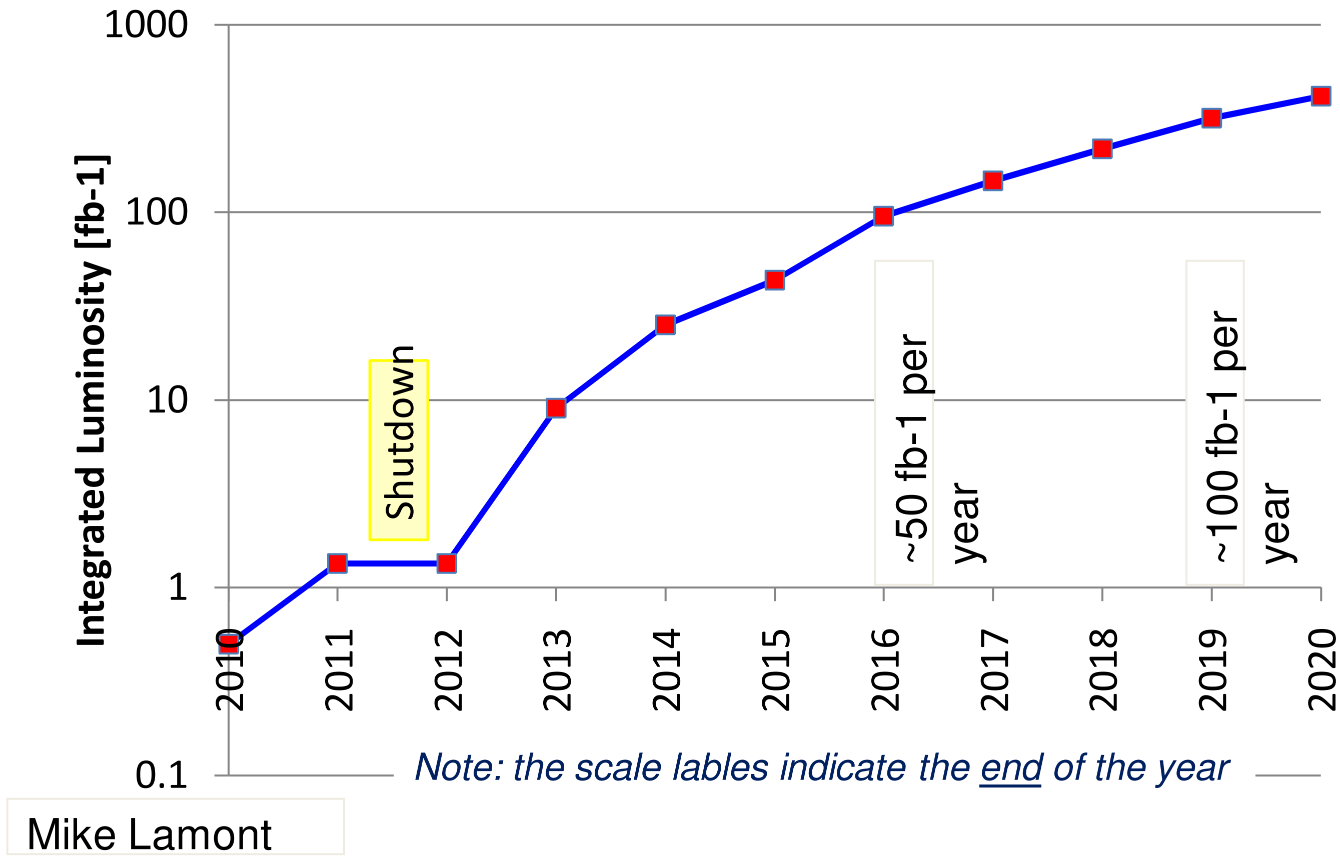
Higher Energies

- Route to energies > 5 TeV blocked by 3 things
  - Pressure relief valves needed on dipoles in sectors 23 45 78 81
  - Interconnects
    - Only 3.5 TeV is sure
    - Intervention needed to go higher
  - Retraining of dipole magnets
    - All magnets reached 7 TeV in the SM18 tests
    - Installed sectors (with one notable exception!) all reached 5TeV
    - Detraining seen when pushing to higher fields in 2008 (sector 56)
      - Storage ?
      - Transport ?
      - Thermal cycle ?
      - Interconnections ?
    - Status (Chamonix 2009)
      - 6 TeV looks easy (~10 quenches)
      - 6.5 TeV looks harder (~100 quenches)
      - 7 TeV looks harder still (~1000 quenches)

Task force launched end of October
Define how to get to 7 TeV
Conclude by mid 2010

Can't investigate empirically until interconnects are sorted out

Projecting even further….



Note: **- Further long shutdown(s) have to be added (~ 2017?)**

- Initial detector designs were for typically 600 fb^{-1}, a guess when this could be reached is in the early 2020ies

- Ultimate exploitation of LHC is foreseen with 3000 fb^{-1}, often referred to as sLHC upgrade (even though there could be a gradual improvement path), has likely a time-scale of 2030

Road Map of Expected Hadron Collider Performances

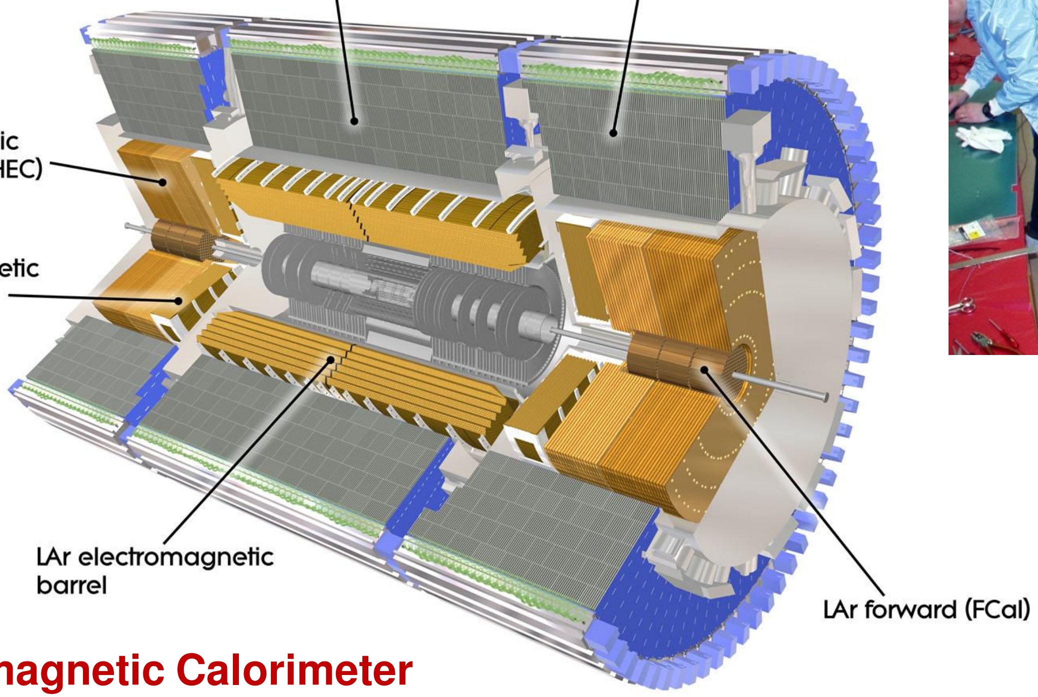
Now	Tevatron	2 TeV	5 fb^{-1} (analysed)
	LHC	0.9 and 2.4 TeV	10 - 20 μb^{-1}
End 2011	Tevatron	2 TeV	10 fb^{-1}
	LHC	7 TeV	1 fb^{-1}
End 2014	LHC	14 TeV	25 fb^{-1}
End 2016	LHC	14 TeV	100 fb^{-1}
Early 2020ies	LHC	14 TeV	500 fb^{-1}
2030	(s)LHC	14 TeV	3000 fb^{-1} (ultimately…)

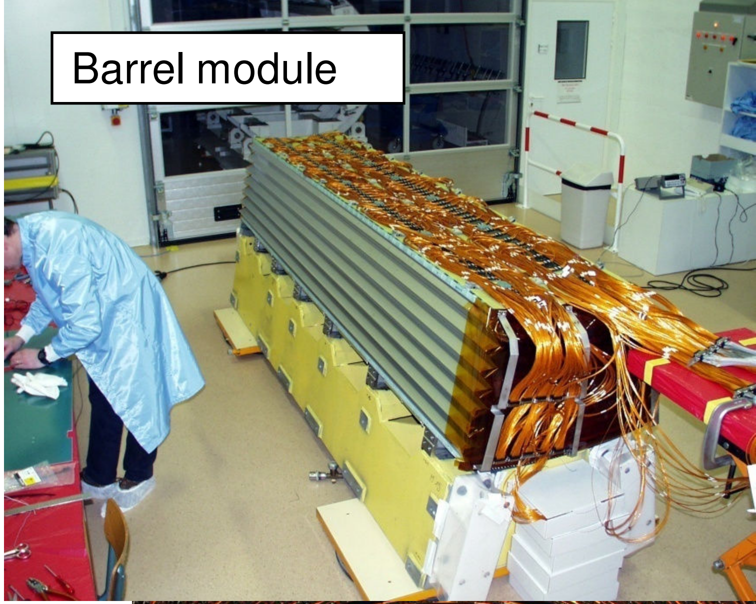
(These are round numbers and estimates, just to give a rough idea…)

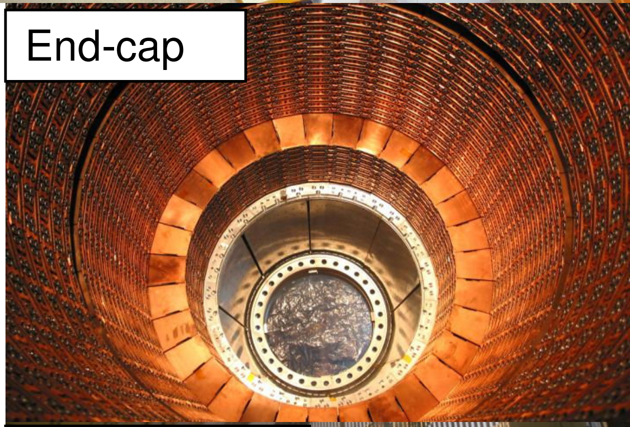
Many LHC simulations have been made for 10 TeV, an energy previously (before Chamonix 2010) considered as an intermediate operation point for LHC on its way to the design collision energy

Calorimetry

Coverage
|η|<5



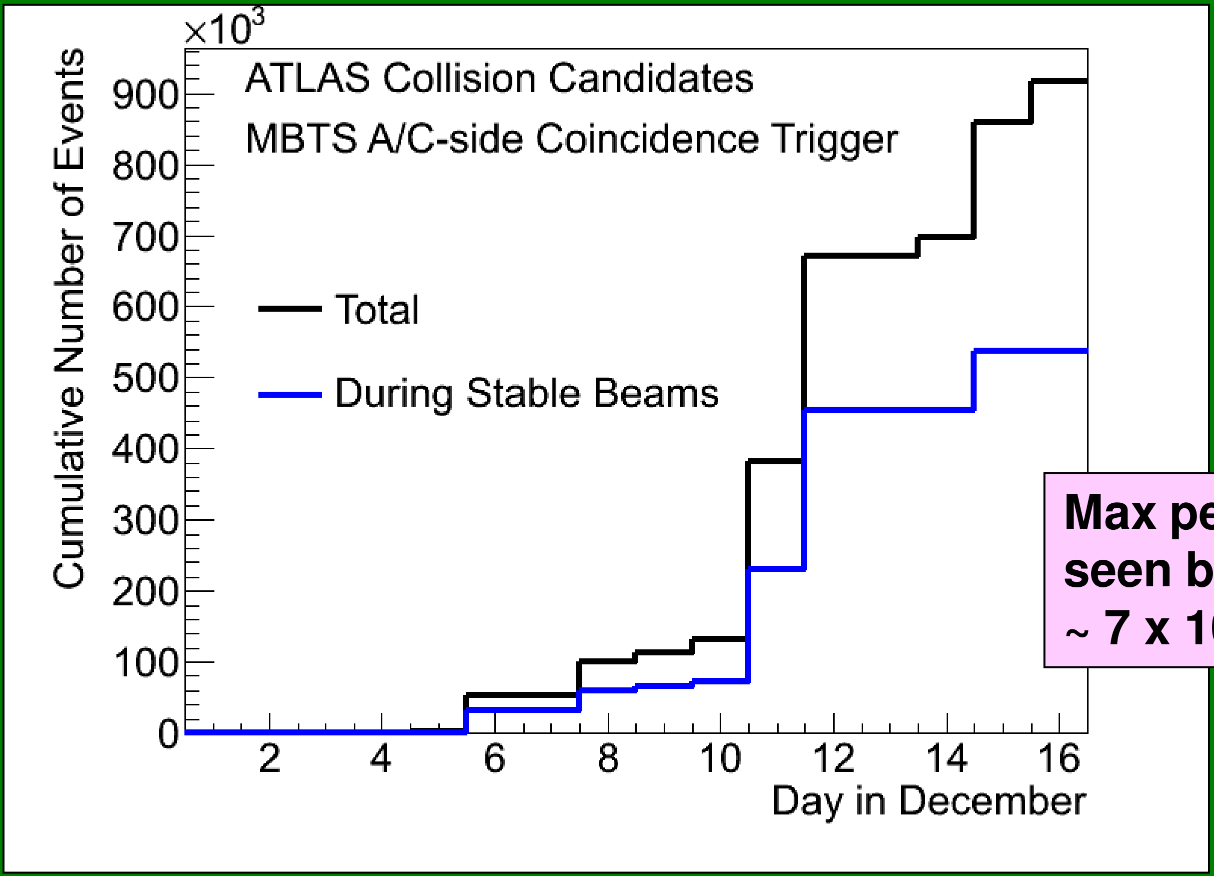




Electromagnetic Calorimeter
barrel, end-cap: Pb-LAr
~10%/√E energy resolution e/γ
180'000 channels: longitudinal segmentation

Hadron Calorimeter
barrel Iron-Tile, EC/Fwd Cu/W-LAr (~20000 channels)
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$ pion (10 λ)

Trigger for e/γ , jets, missing E_T ,etc

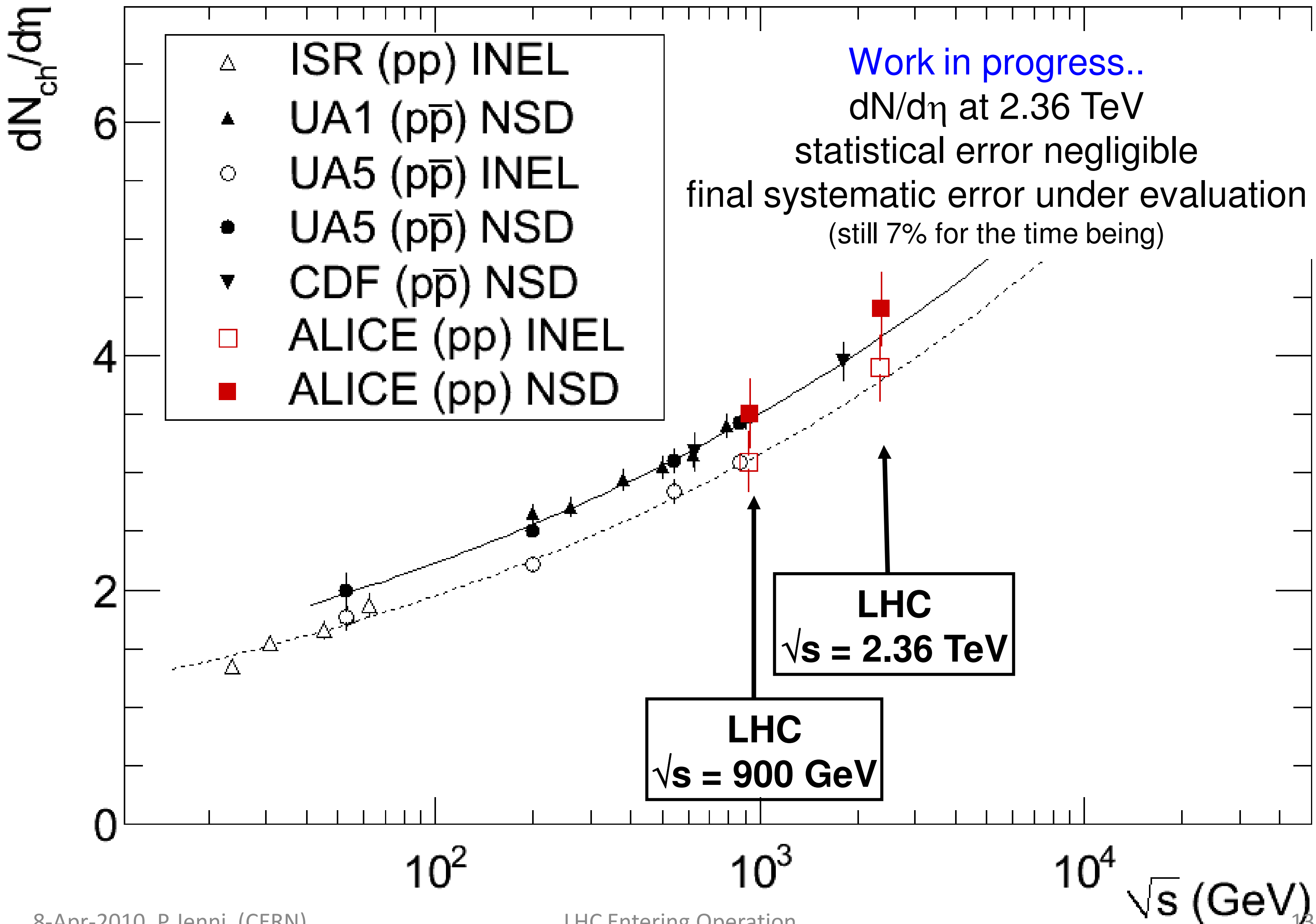


Max peak luminosity seen by ATLAS : ~ 7×10^{26} cm^{-2} s^{-1}

Recorded data samples	Number of events	Integrated luminosity (< 30% uncertainty)
Total	~ 920k	~ 20 μb^{-1}
With stable beams (→ tracker fully on)	~ 540k	~ 12 μb^{-1}
At $\sqrt{s}$=2.36 TeV (flat top)	~ 34k	≈ 1 μb^{-1}

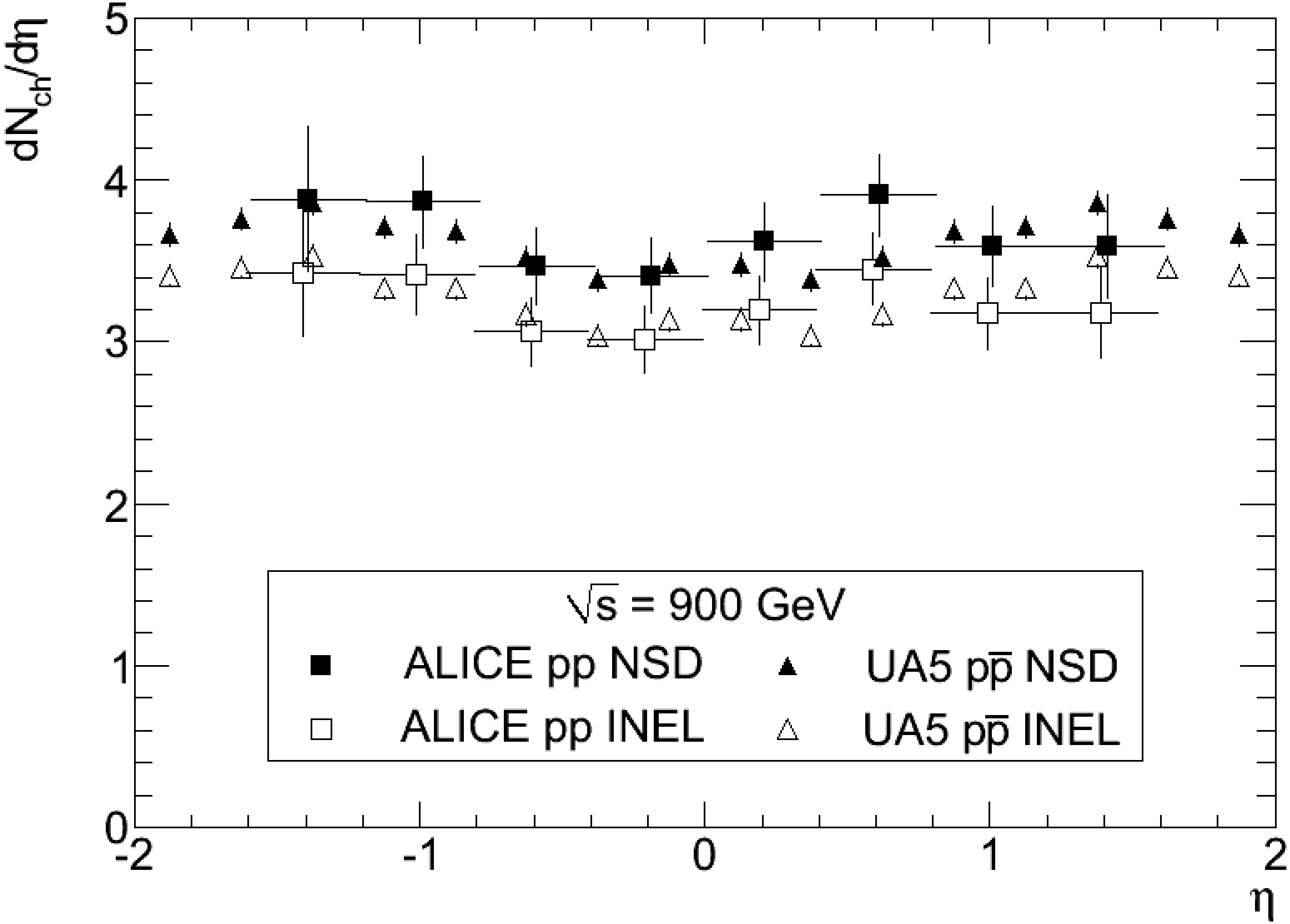
Average data-taking efficiency: ~ 90%

ALICE



dN_ch/dη
6
4
2
0
ISR (pp) INEL
UA1 (pp̄) NSD
UA5 (pp̄) INEL
UA5 (pp̄) NSD
CDF (pp̄) NSD
ALICE (pp) INEL
ALICE (pp) NSD
Work in progress..
dN/dη at 2.36 TeV
statistical error negligible
final systematic error under evaluation
(still 7% for the time being)
LHC
√s = 2.36 TeV
LHC
√s = 900 GeV
10^2
10^3
10^4
√s (GeV)

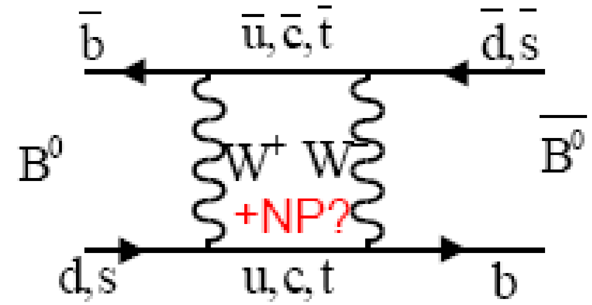
ALICE (paper accepted by EPJ C)

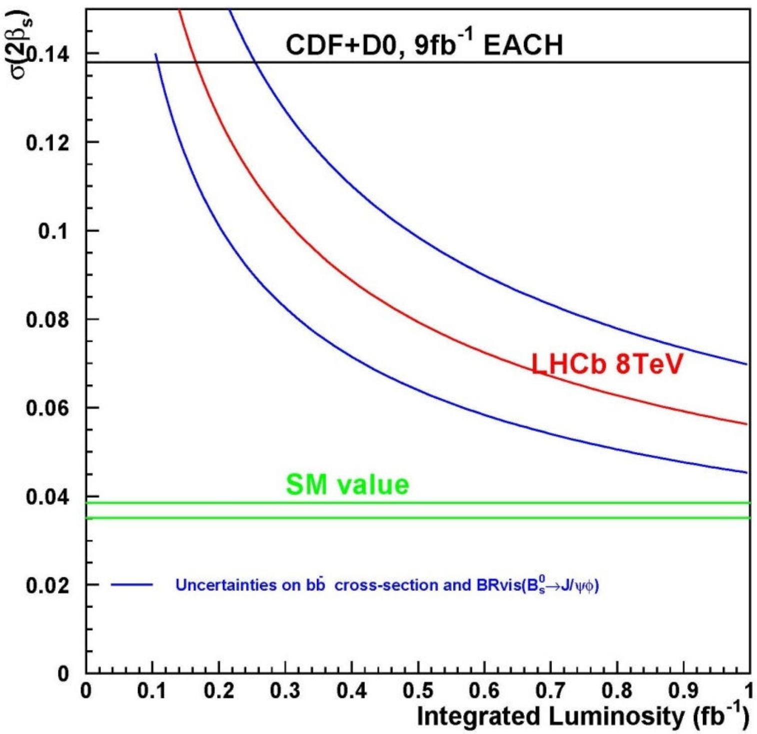


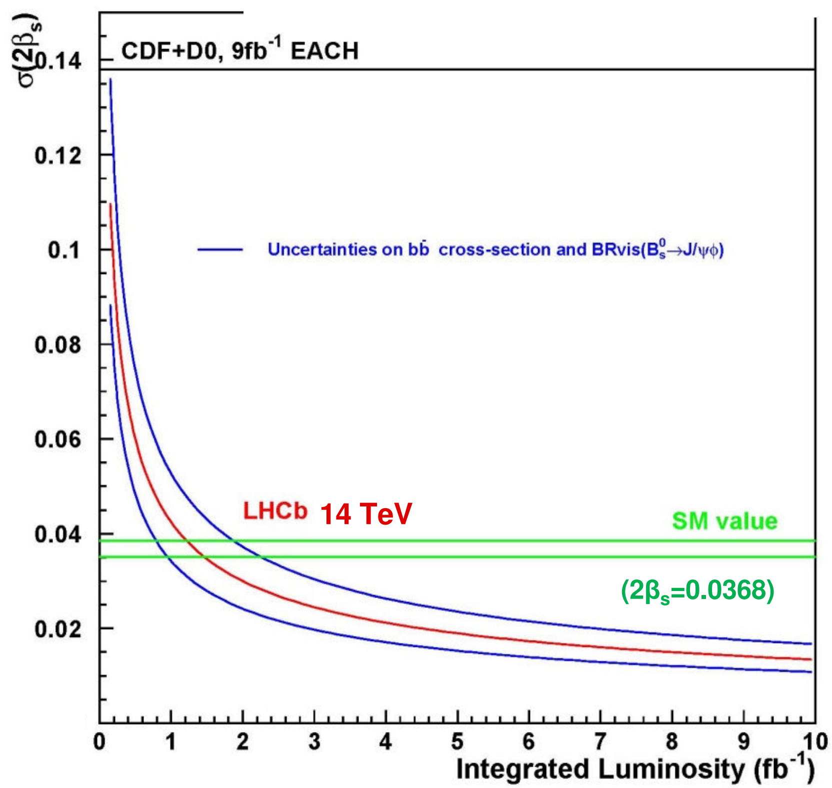
B_s-$\bar{B}_s$ mixing phase ϕ_s (from $B_s \rightarrow J/\psi\ \phi$)

Sensitive to New Physics effects in box diagrams

- $\phi_s = \phi_{s(SM)} + \phi_{s\ (NP)}$
- $\phi_{s(SM)} = -2\beta_s = -2\lambda^2\eta \sim -0.04$





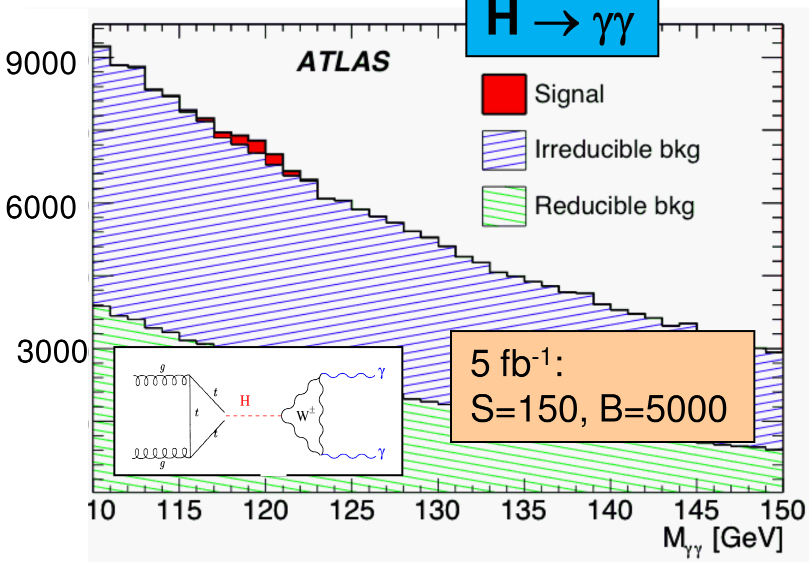


→ ***With ~0.2 fb^{-1} LHCb should improve on expected Tevatron limit***

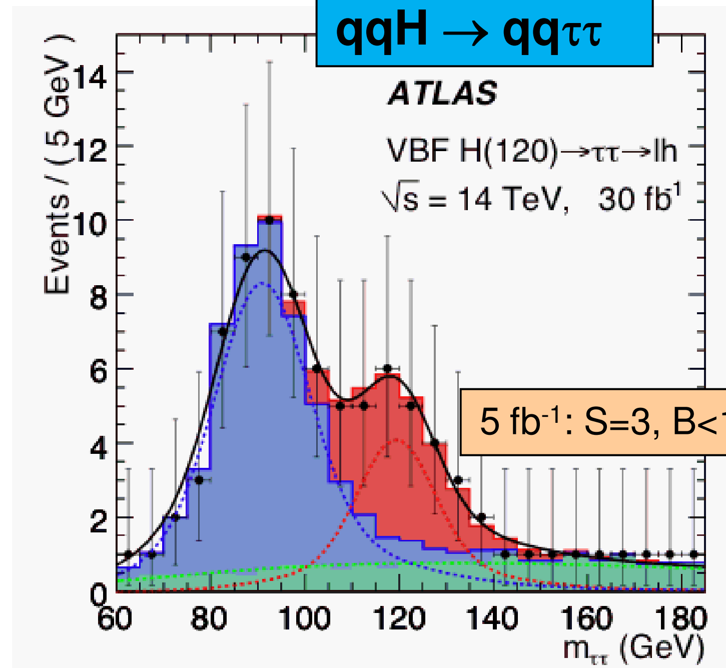
Light Higgs

30 fb^{-1}

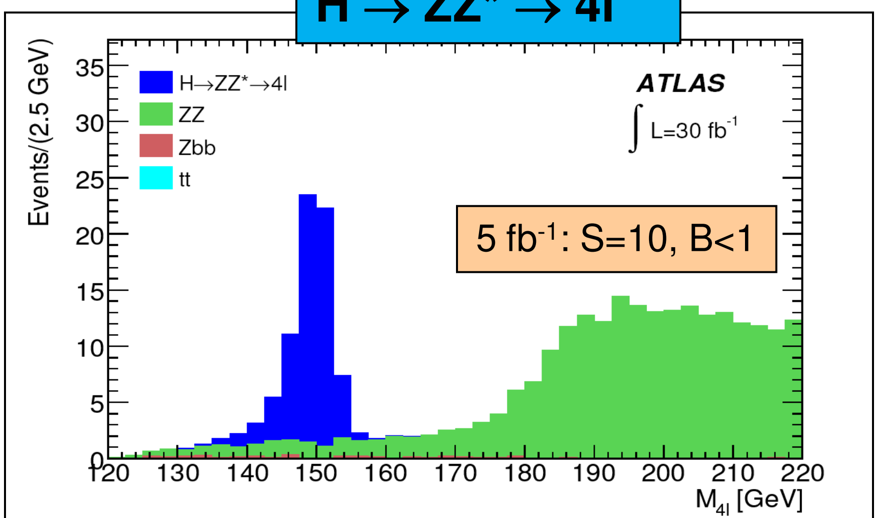
H → γγ



qqH → qqττ



H → ZZ* → 4l



- **m_H < 130 GeV: most difficult region: need to combine many channels with small S or S/B**
- **m_H > 130 GeV: discovery easier with H → 4l (narrow mass peak, small B)**
- **H → WW → lνlν (dominant for 160-185 GeV) is a counting experiment (no mass peak)**

With more time and more data ….

The LHC will explore in detail the highly-motivated TeV-scale with a direct discovery potential up to m ≈ 5-6 TeV

→ if New Physics is there, the LHC should find it

→ it will say the final word about the SM Higgs mechanism and many TeV-scale predictions

→ it may add crucial pieces to our knowledge of fundamental physics → impact also on astroparticle physics and cosmology

→ most importantly: it will most likely tell us which are the right questions to ask, and how to go on