The Large Hadron Collider at CERN:

Entering a new era in unravelling the mystery of matter, space and time

SPS Annual Meeting

Basel, 21 June 2010

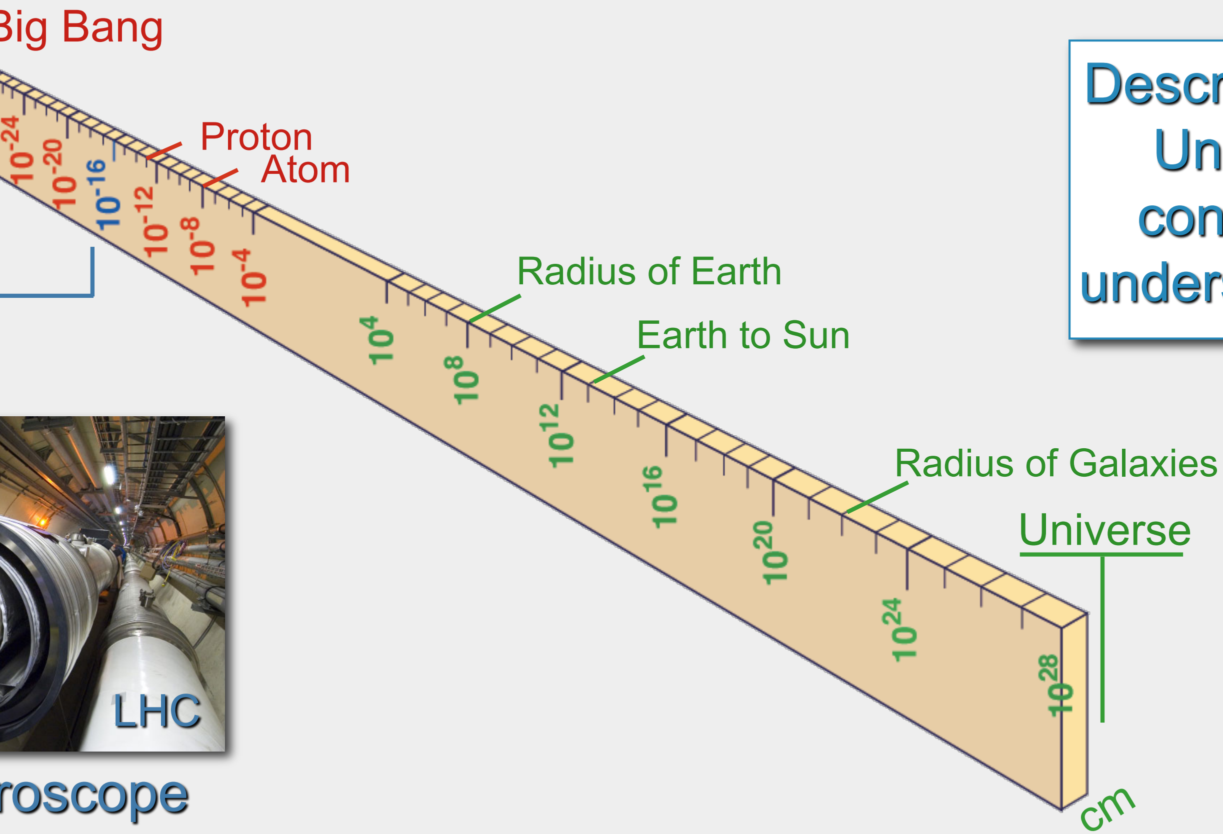
Felicitas Pauss

CERN and ETH Zurich

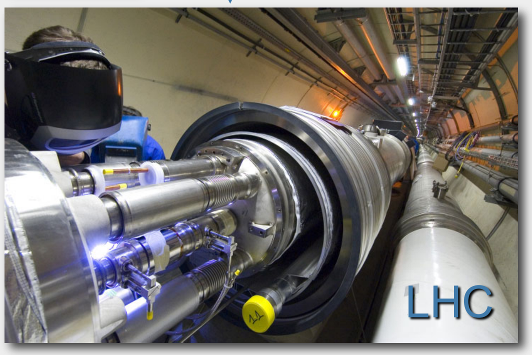
Particle Physics

Study the structure of the Universe at its most fundamental level:

explore the basic physics laws which govern the fundamental building blocks of matter and the structure of spacetime



Describing our Universe: consistent understanding?

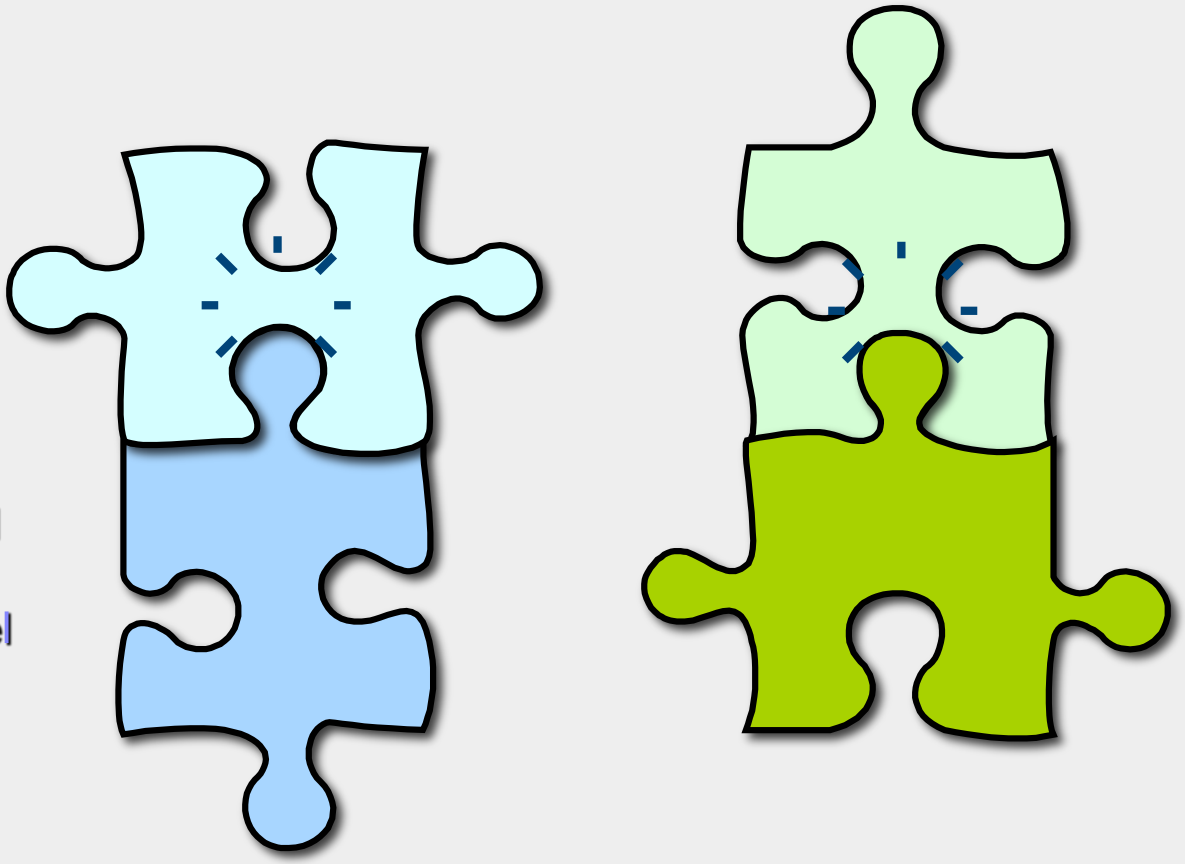


Super-Microscope

Describing the Universe

Particle Physics
Experiments
Accelerators
Underground

Quantum Field
Theory
Standard Model



Astrophysics
Experiments
Telescopes
Satellites

Standard
Cosmology
Model

10^{-18} m

10^{26} m

Describing the Universe

Particle Physics
Experiments
Accelerators
Underground

Quantum Field
Theory
Standard Model

Astrophysics
Experiments
Telescopes
Satellites

Standard
Cosmology
Model

Consistent understanding ?

10^{-18} m

10^{26} m

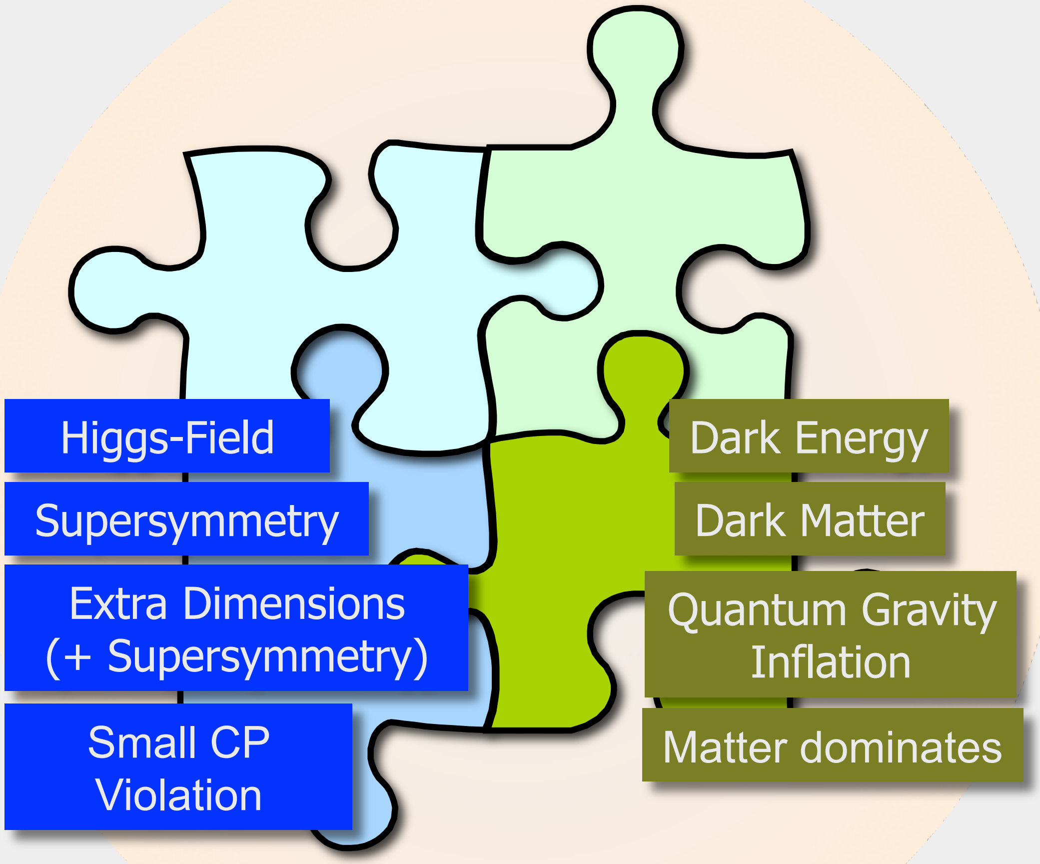
Describing the Universe

Particle Physics
Experiments
Accelerators
Underground

Astrophysics
Experiments
Telescopes
Satellites

Quantum Field
Theory
Standard Model

Standard
Cosmology
Model



Consistent understanding ?

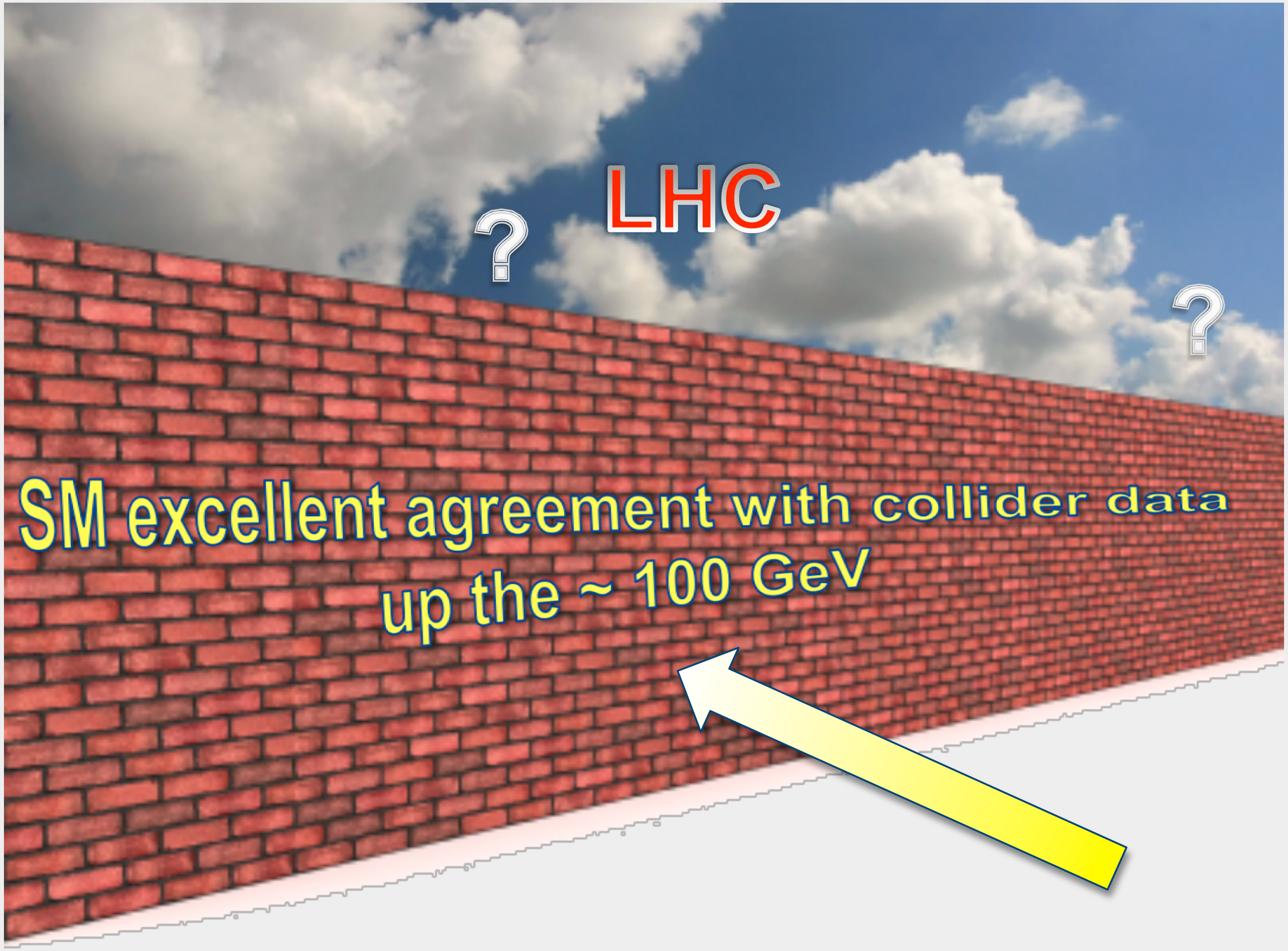
NO !

10^{26} m

Goal for LHC experiments:

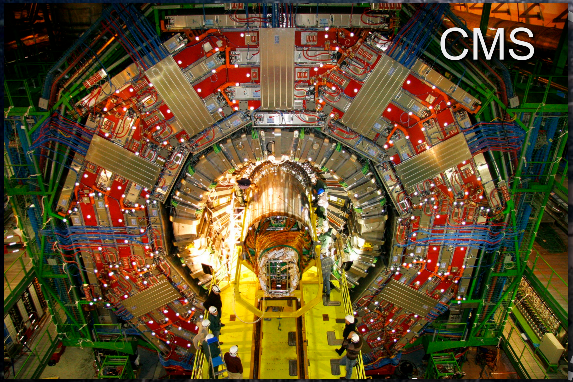
- Discover the Higgs particle! Scalar field!
- Discover Supersymmetry? Consistent with cosmic Dark Matter?
- Can we see evidence for large extra dimensions at LHC?
- LHC can complement the B-Factories in exploring CP-violation

New Landscape of Physics?



Enter a New Era in Fundamental Science

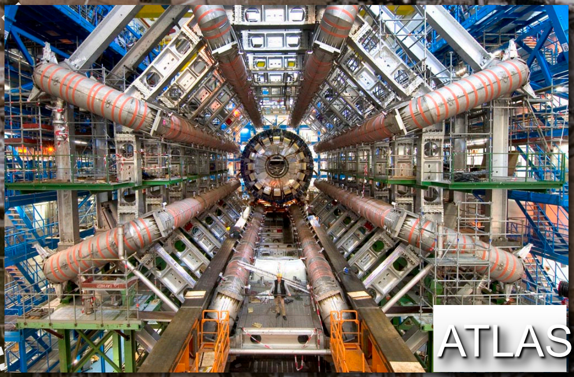
Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is a very exciting turning point in particle physics.

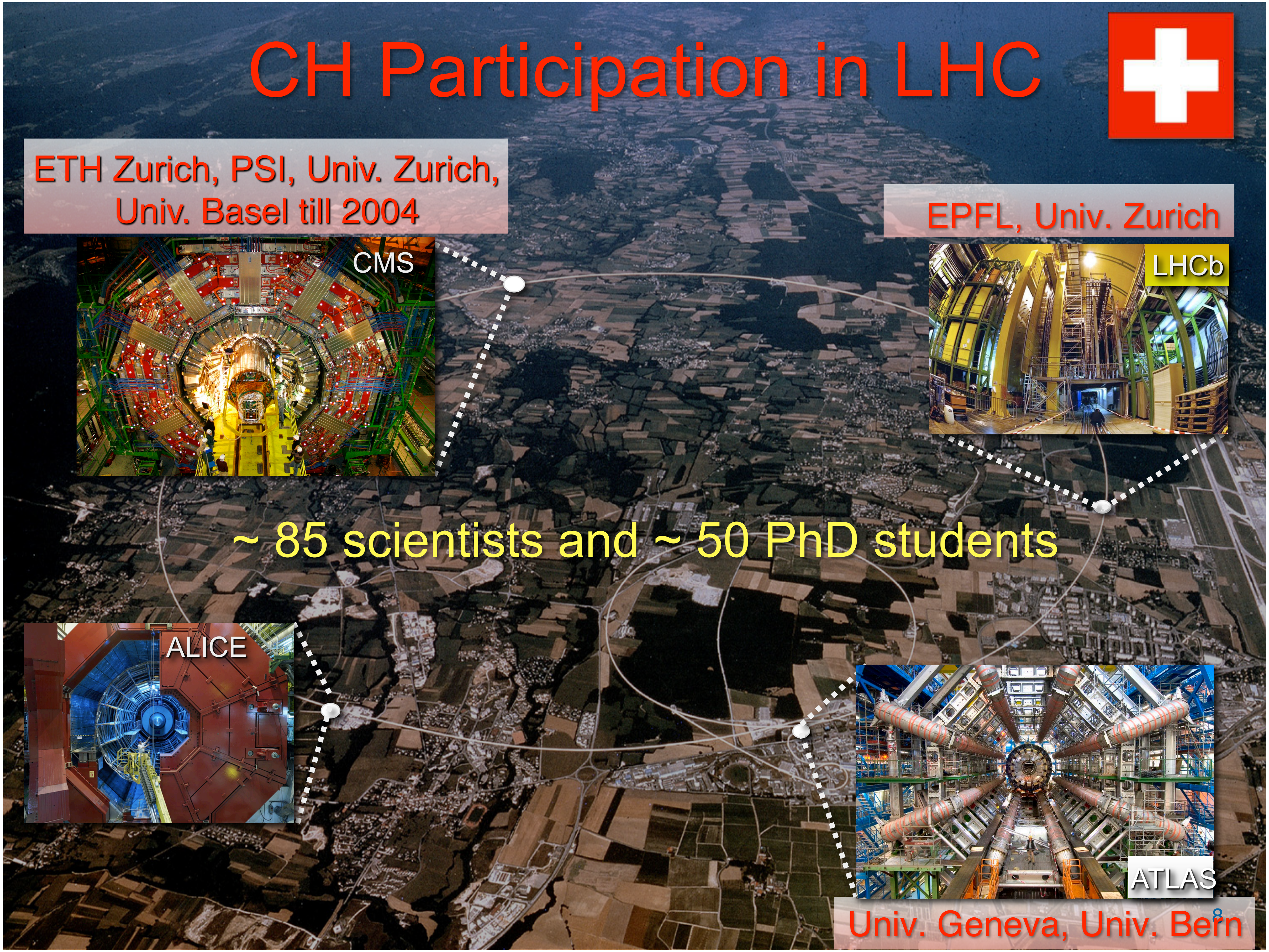


Exploration of a new energy frontier

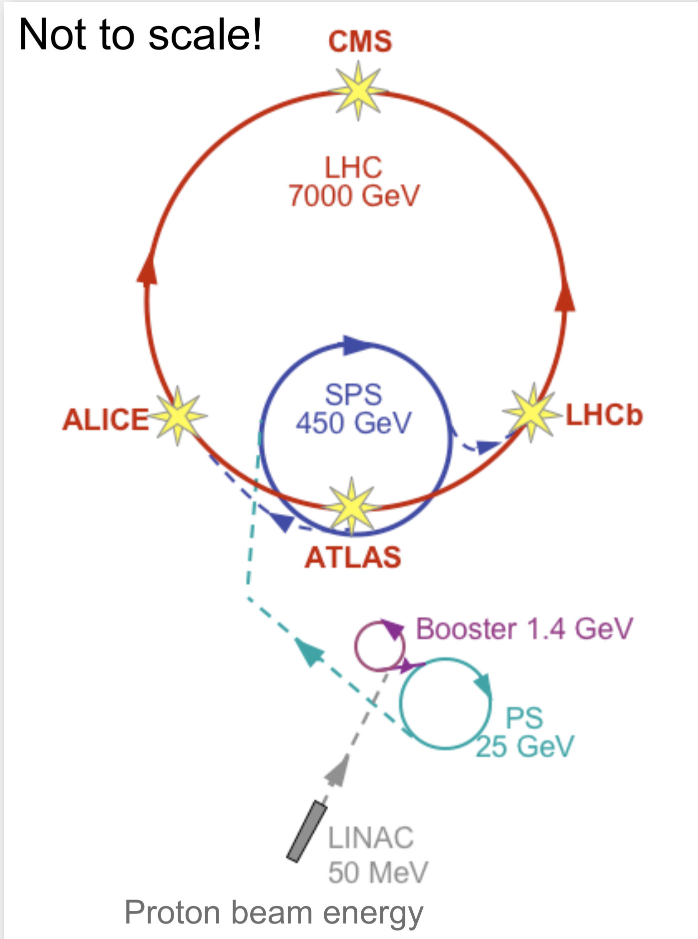
Proton-proton Collisions at E_{CM} = 14 TeV

Heavy Ion Collisions: Energy/nucleon = 2.75 TeV/u




CH Participation in LHC
ETH Zurich, PSI, Univ. Zurich, Univ. Basel till 2004
CMS
EPFL, Univ. Zurich
LHCb
~ 85 scientists and ~ 50 PhD students
ALICE
ATLAS
Univ. Geneva, Univ. Bern

The LHC


Not to scale!
CMS
LHC
7000 GeV
ALICE
SPS
450 GeV
LHCb
ATLAS
Booster 1.4 GeV
PS
25 GeV
LINAC
50 MeV
Proton beam energy

Major LHC challenges

Nominal LHC design: 3.2 × 10^{14} protons accelerated to 7 TeV

Beam energy	7 TeV
Nominal design Luminosity	10^{34} $cm^{-2}s^{-1}$
Dipole field at top energy	8.33 T
Number of bunches, each beam	2808
Particles / bunch	1.15 10^{11}
Typical beam size in ring	200 – 300 µm
Beam size at IP	16 µm
Energy stored in the magnet system	10 GJ
Energy stored in one (of 8) dipole circuits	1.1GJ (sector)
Energy stored in one beam	362 MJ
Energy to heat and melt one kg of copper	0.7MJ

High design E_{beam}

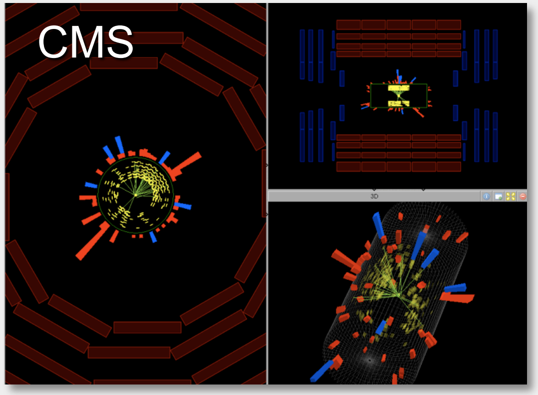
SC magnets, He cooling at 1.9K

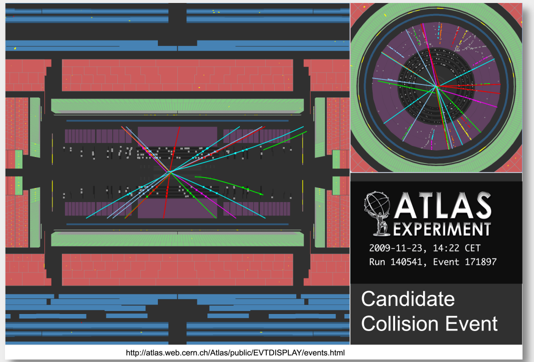
large amount of energy stored in magnets,
many bunches with large amount of energy stored in beams

Complexity and Reliability: Unprecedented complexity with ~10’000 magnets powered in 1’700 electrical circuits, complex active protection systems (beam loss monitors, interlocks), collimation for machine and experiments …..

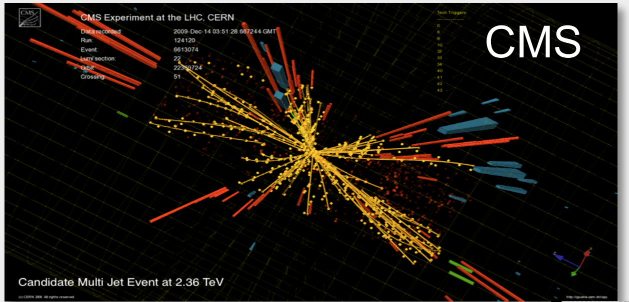
The LHC start-up in 2009

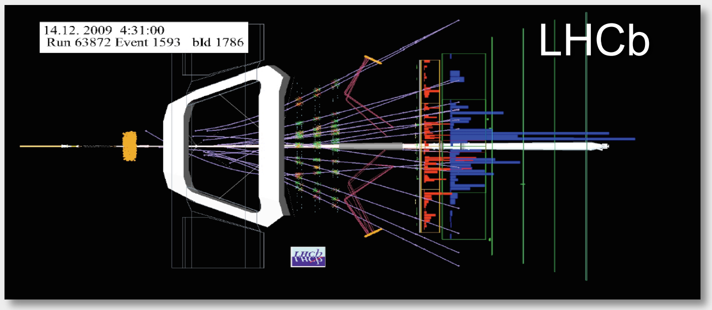
- 23 Nov 2009:
  First collisions at 0.9 TeV

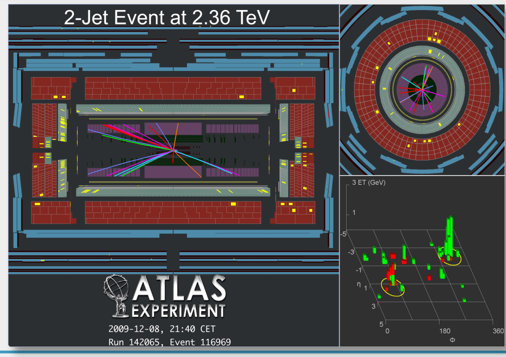


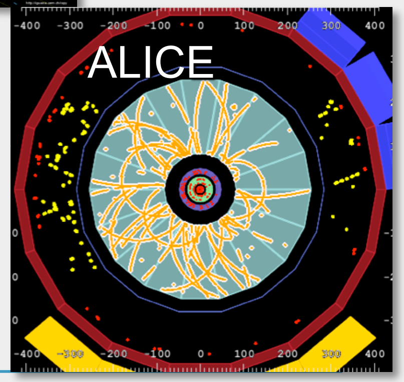


- 14 Dec 2009:
  First collisions at 2.36 TeV

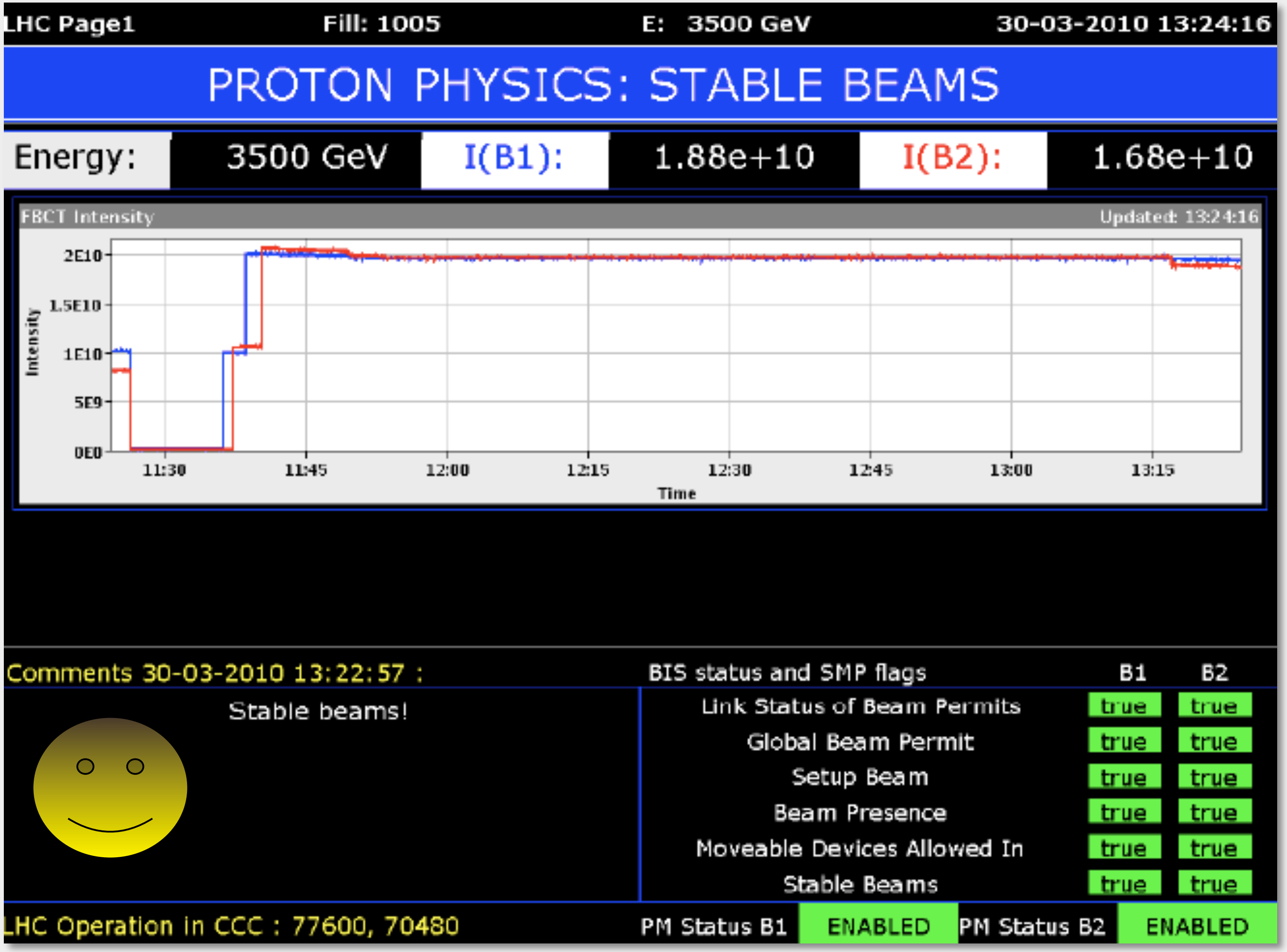




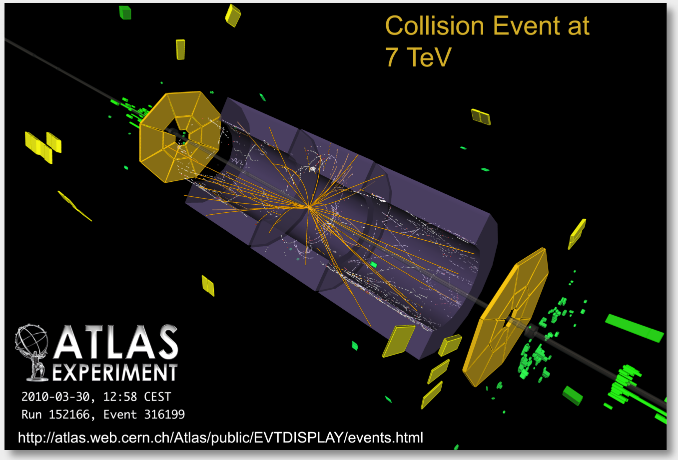


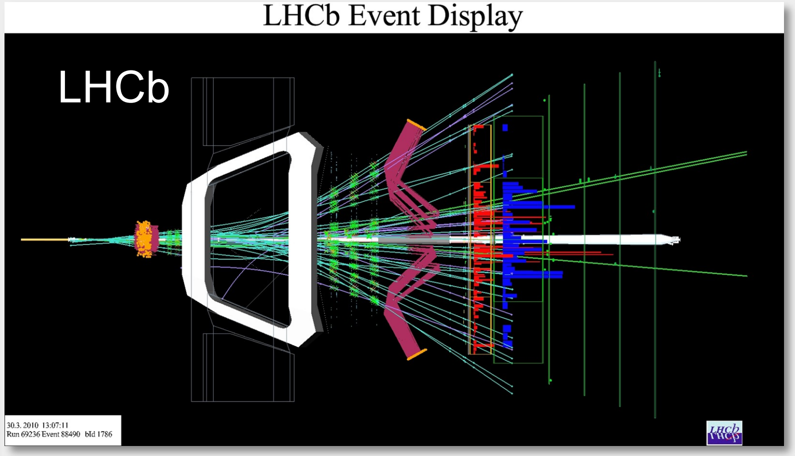


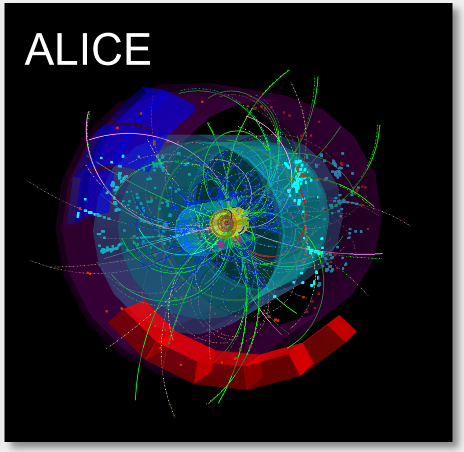
First Collisions at 7 TeV in 2010

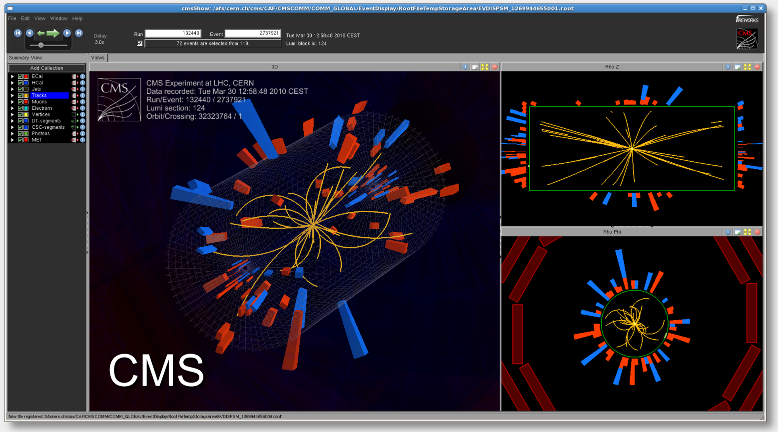


LHC: First collisions at 7 TeV on 30 March 2010



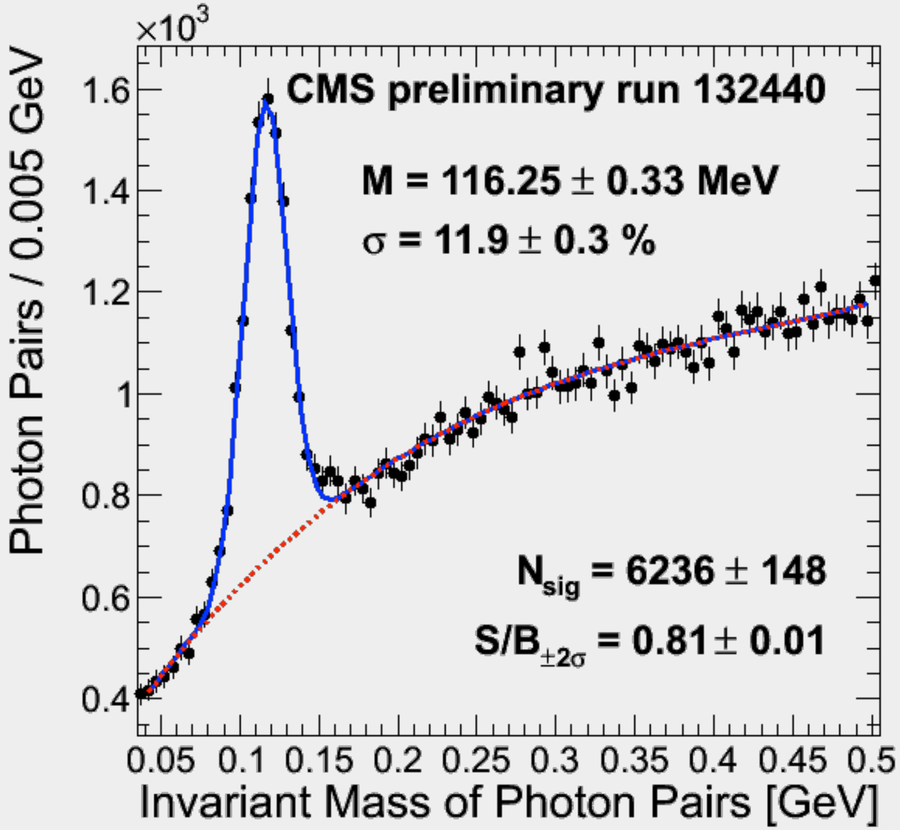






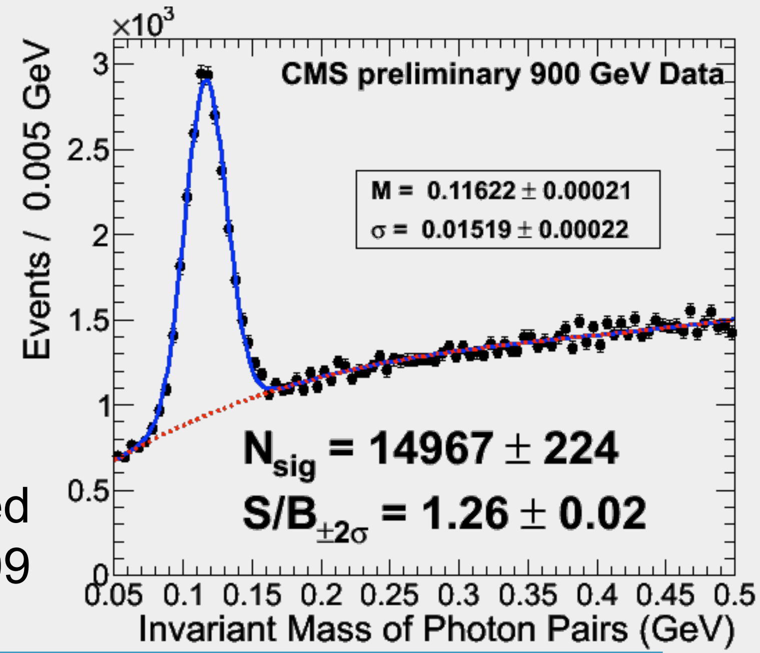
…. under the spot light (again) of the world-wide press

Shortly after the first 7 TeV collisions …



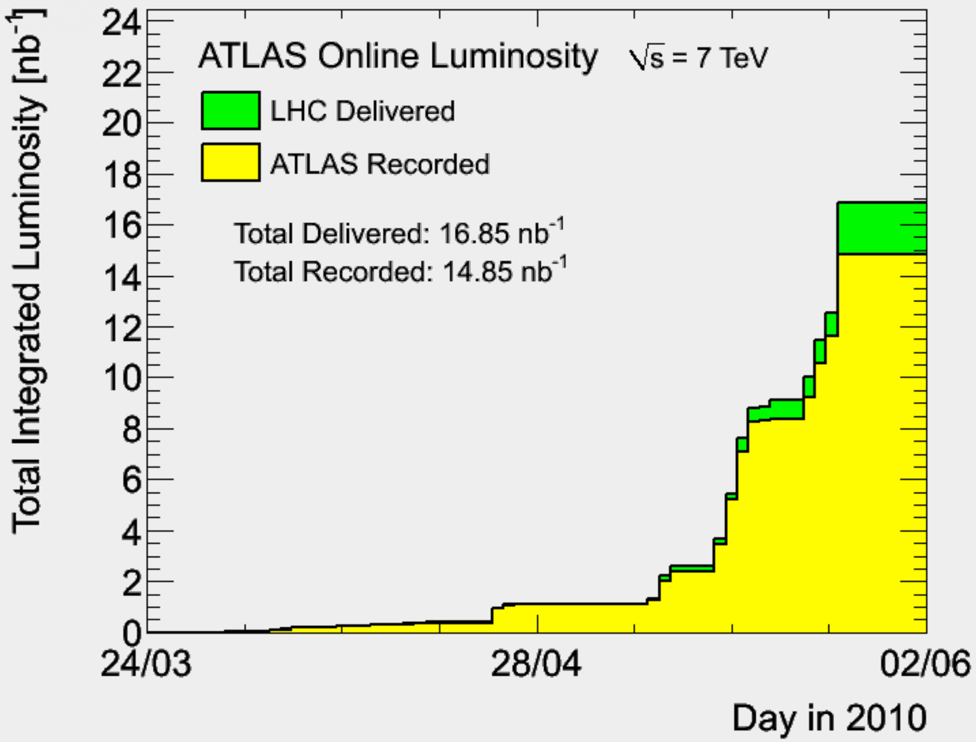
CMS on 30 March 2010:

- **13:10** - first approved event display images from CMS for 7 TeV collisions on CMS Web page
- **14:30** - fast analysis allowed CMS to reconstruct the **π^0 peak**

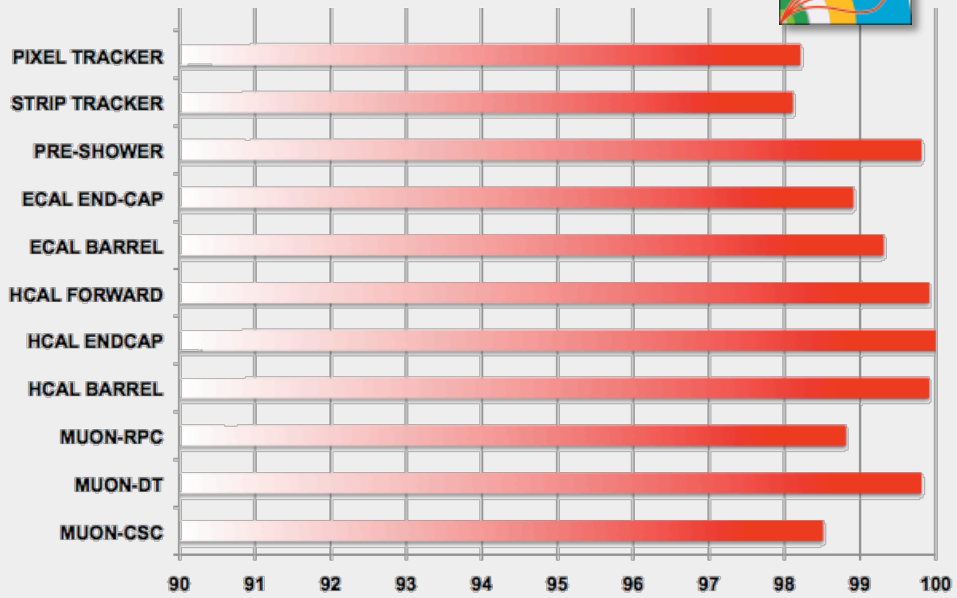


The result is consistent with what was obtained in the running at 900 GeV in late 2009

Integrated Luminosity since 30 March 2010



Sub-detectors operational status



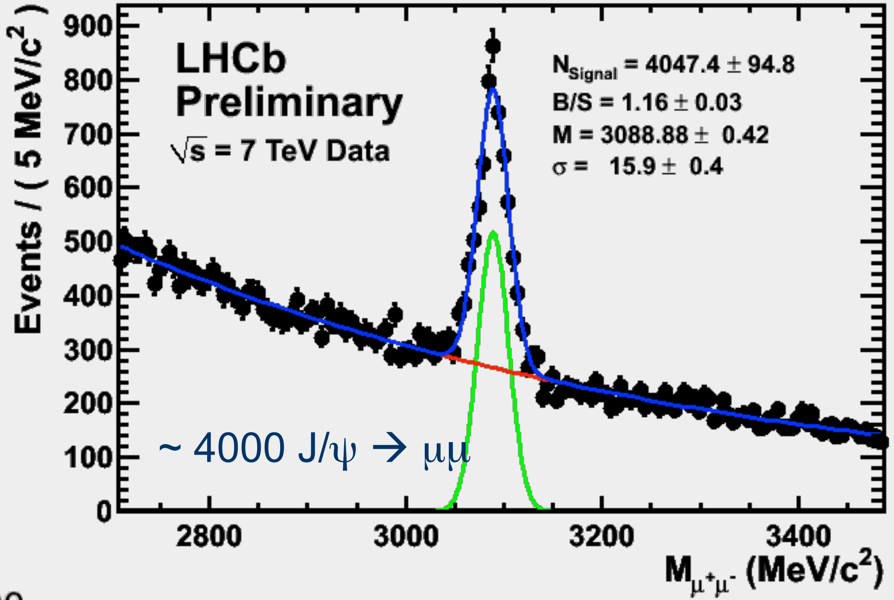
Reliable operations with ~18nb^{-1}delivered by LHC
Overall data taking efficiency ~ 92 %

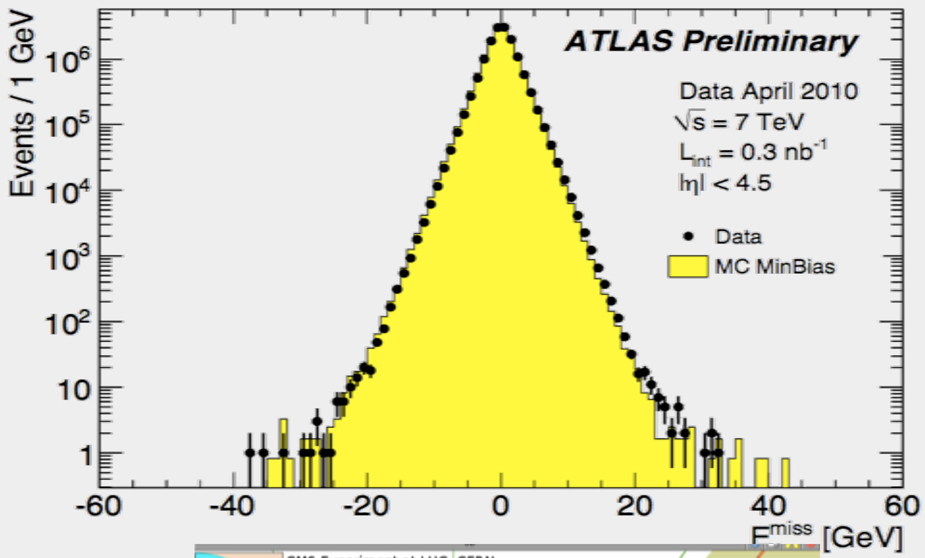
Preliminary performance and physics results

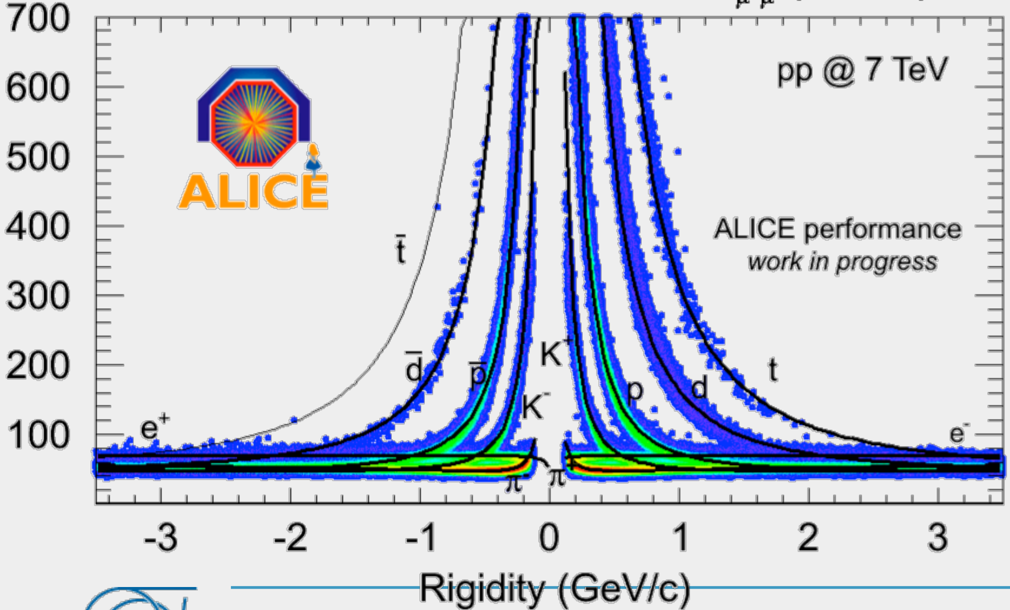
Only a few highlights …..

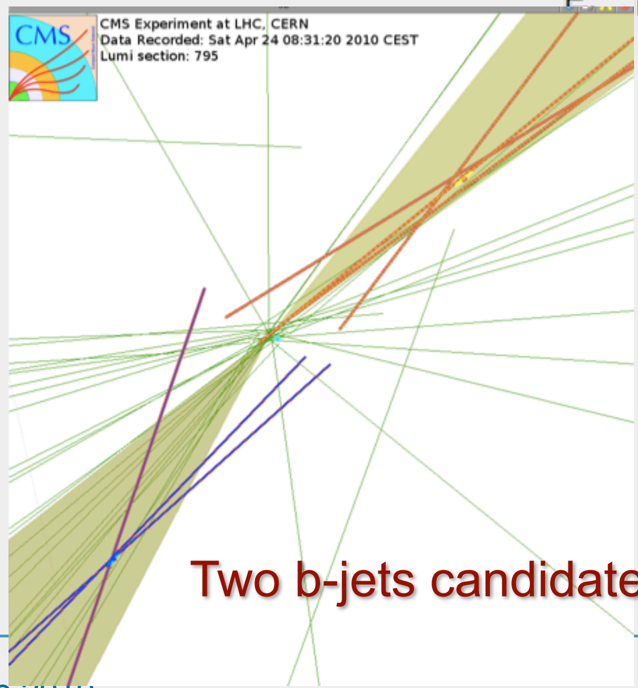
Much more in parallel session talks …

Detector Performances (examples)

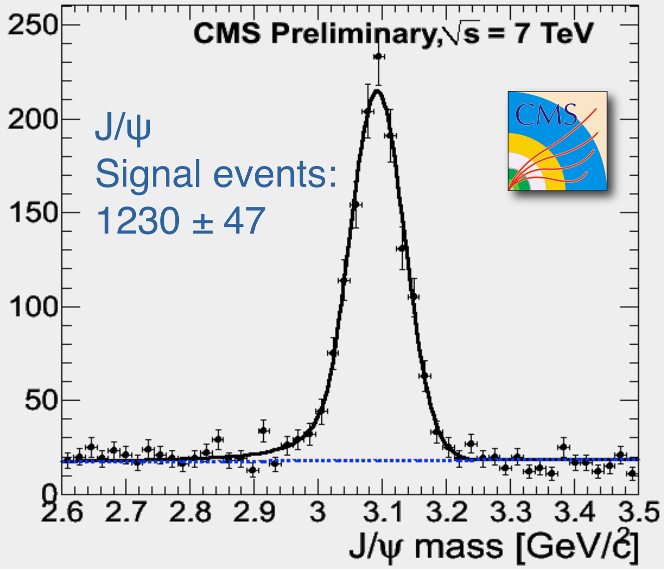


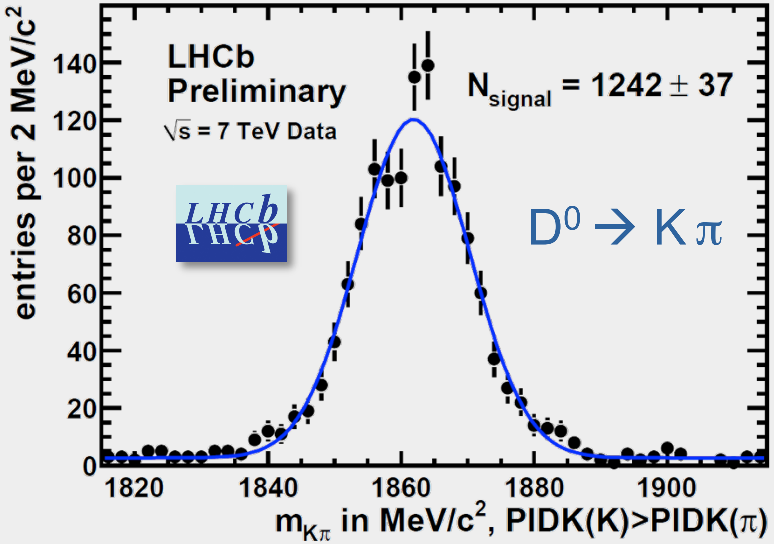


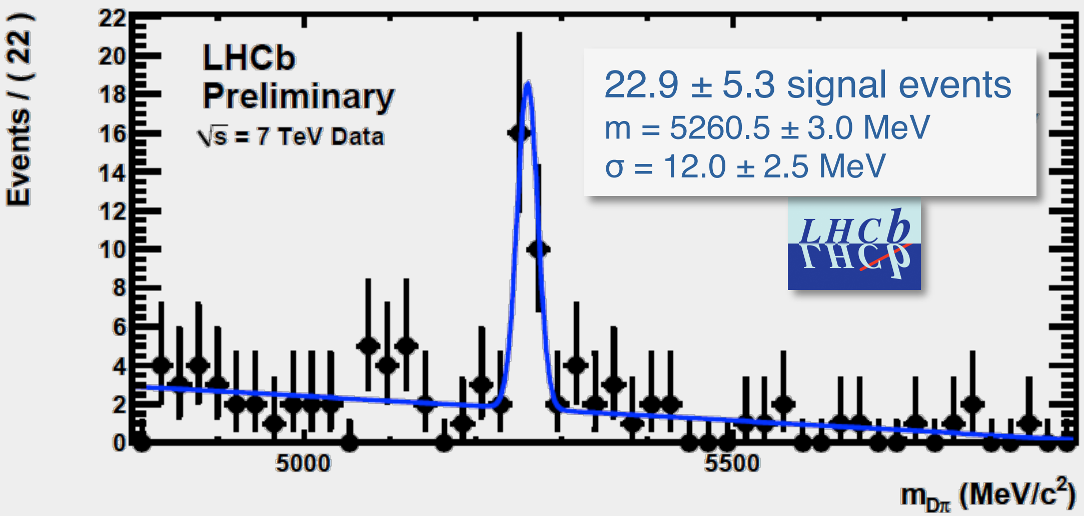




Detector Performances (examples)



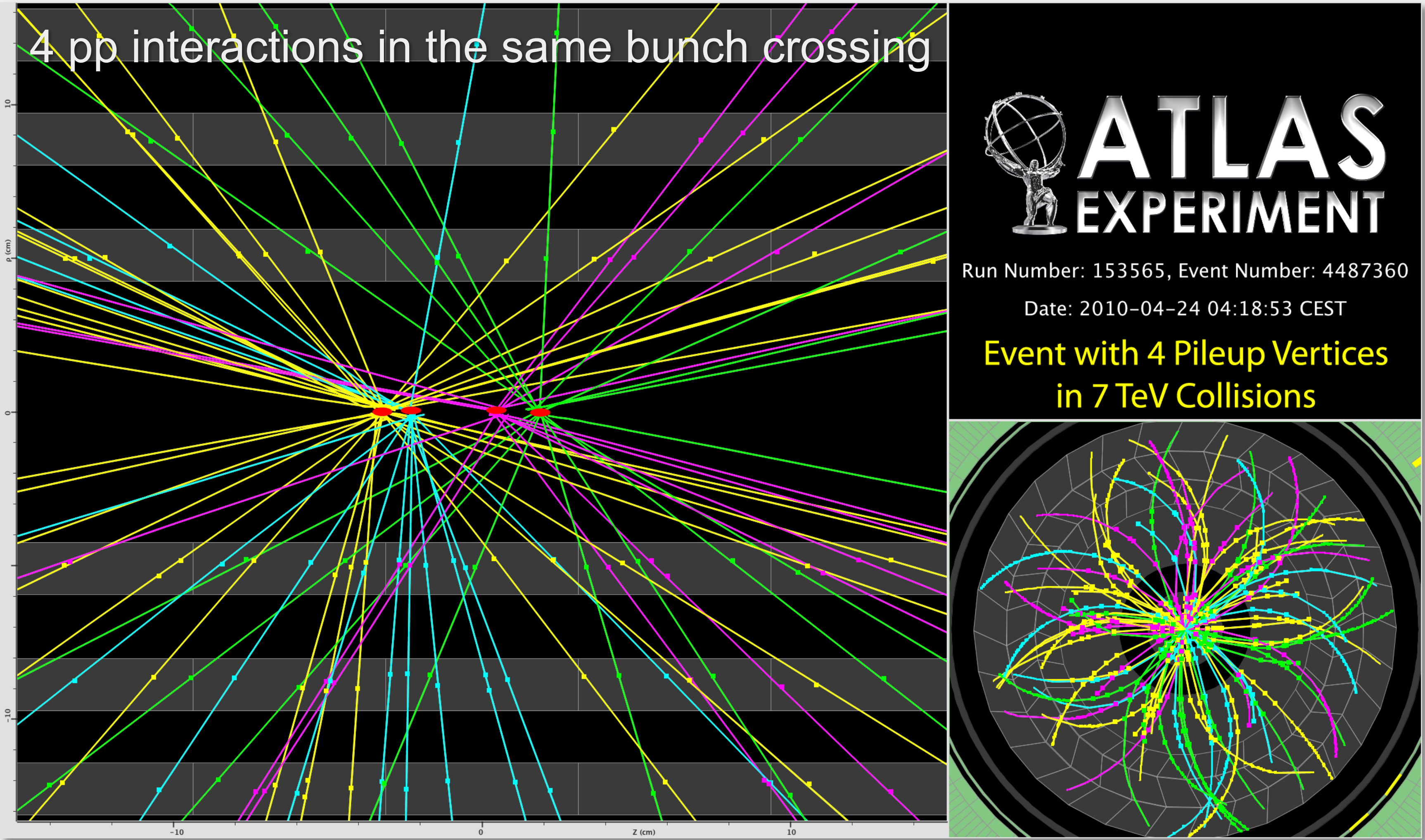




First fully reconstructed B mesons:

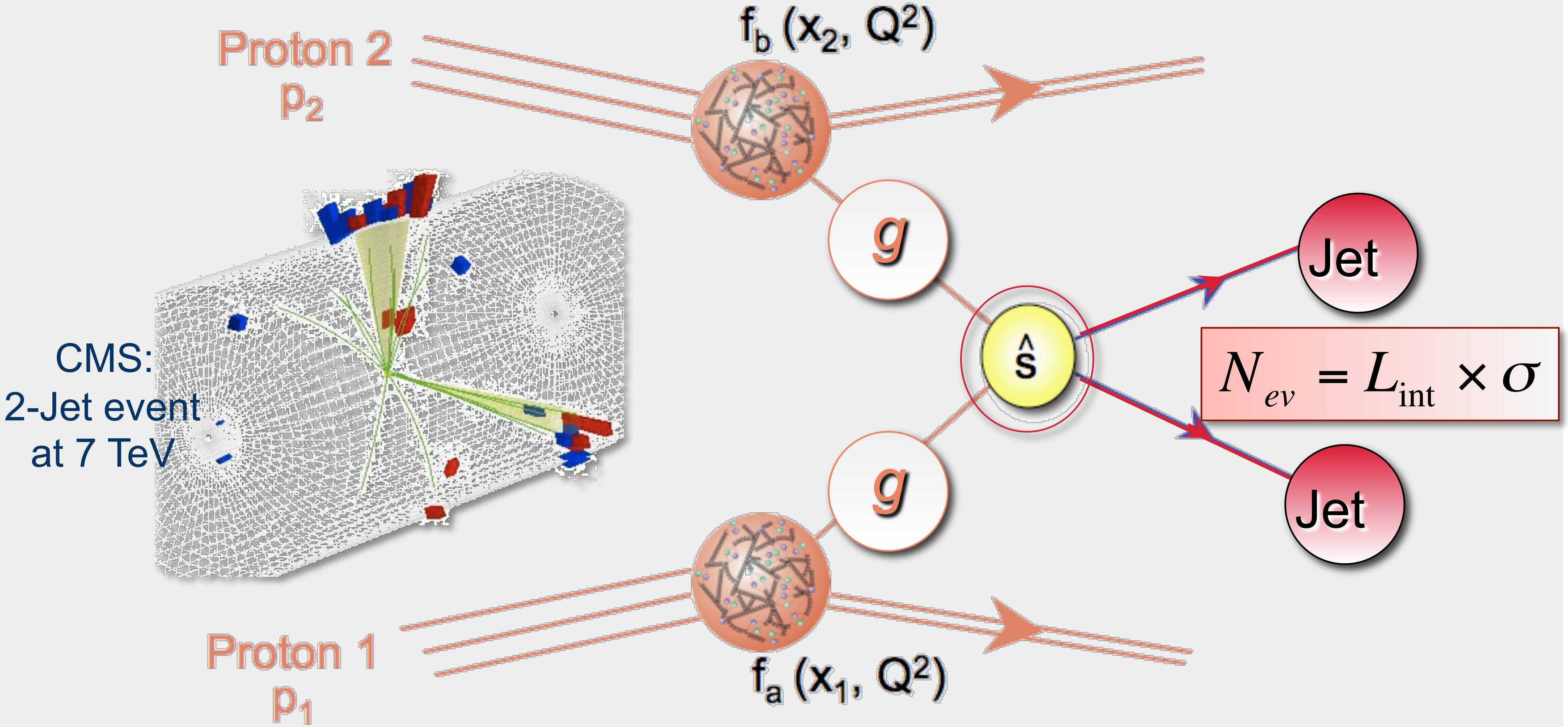
$B^o \rightarrow D^+\pi^-$ + $B^+ \rightarrow D^o\pi^+$

Detector Performances



vertex resolution better than ~200 µm

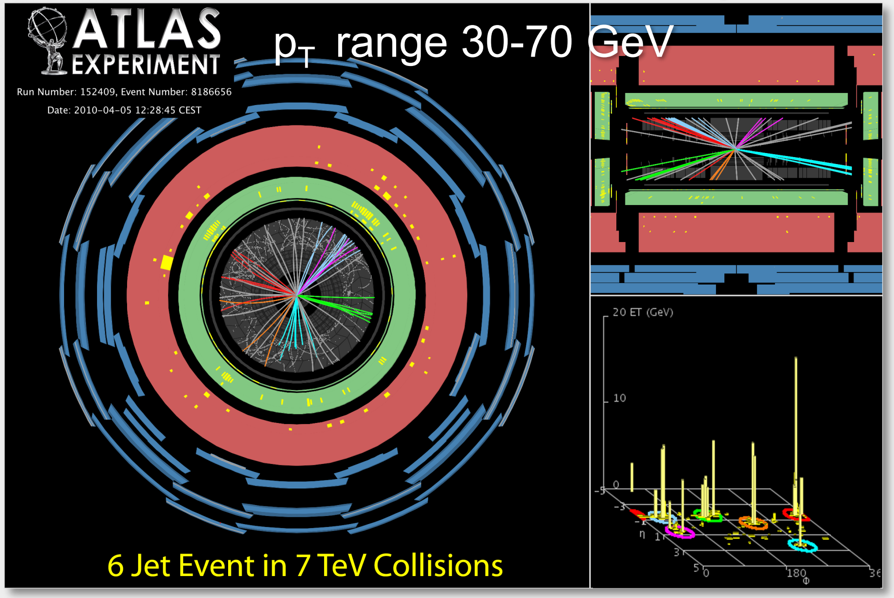
Basic processes at LHC

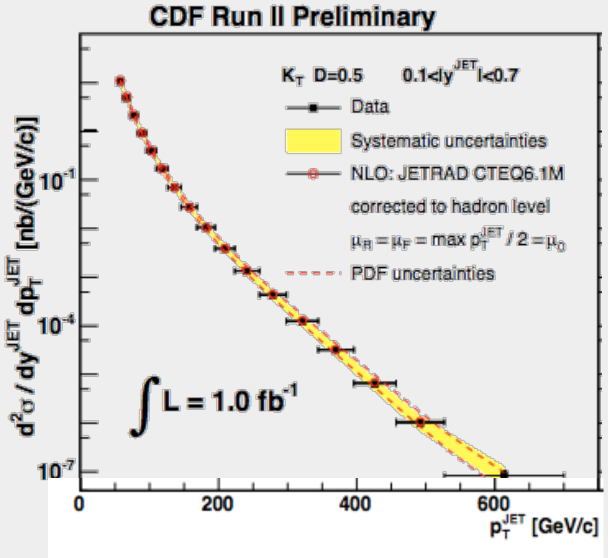


$$d\sigma(p_1 p_2 \to c\, d) = \int_0^1 dx_1 dx_2 \sum_{a,b} \left(f_a(x_1, Q^2)\, f_b(x_2, Q^2)\, d\hat{\sigma}^{ab \to cd} \right)$$

Jet production at 7 TeV

New Territory!

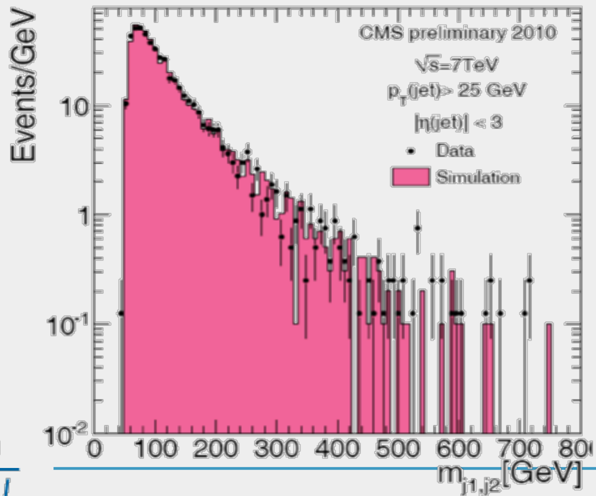


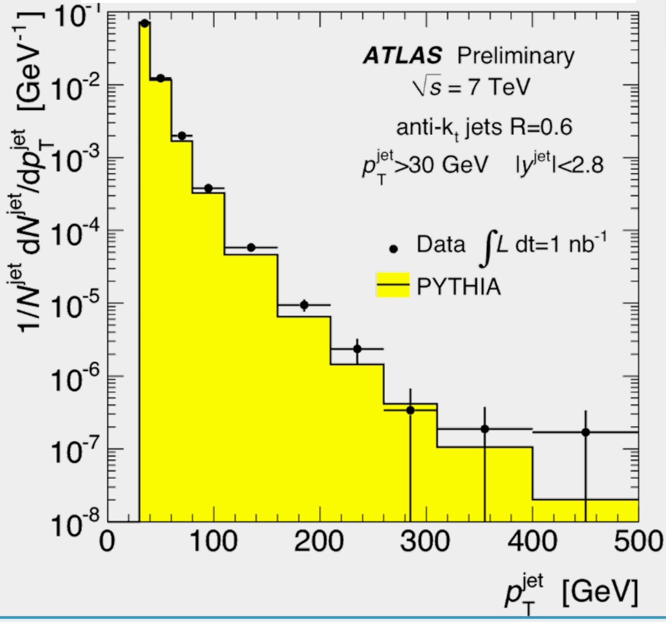


Tevatron
E_{CM}= 2 TeV

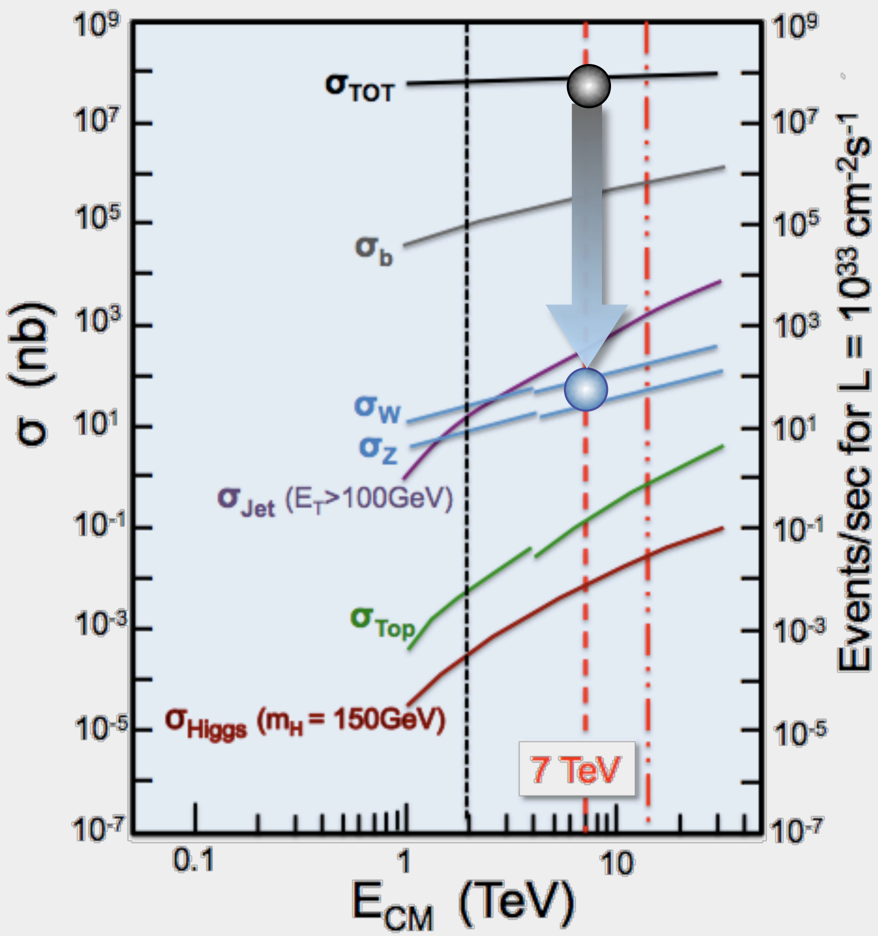
Factor 10^6 in integr. L

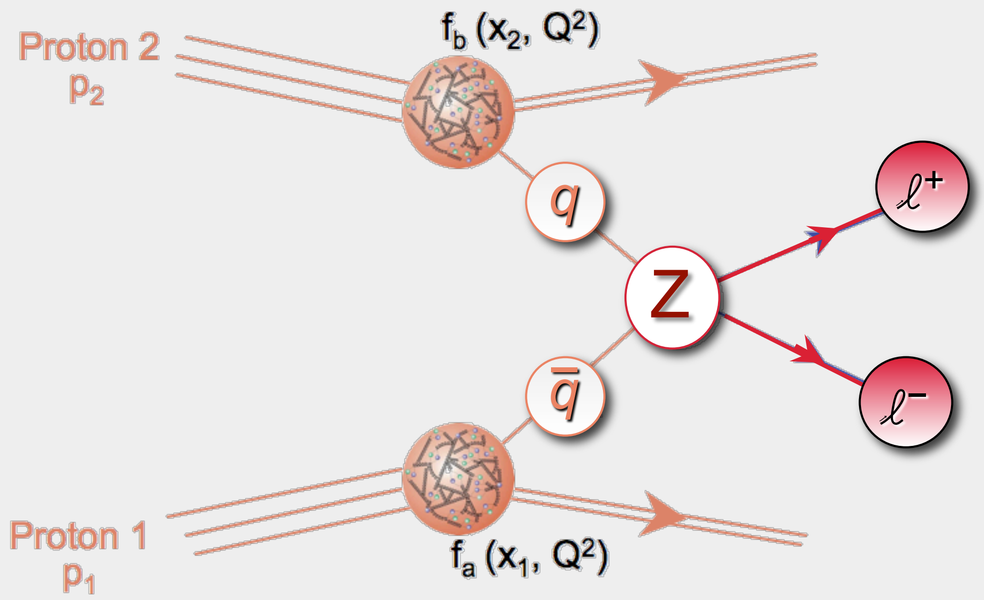
LHC
E_{CM}= 7 TeV

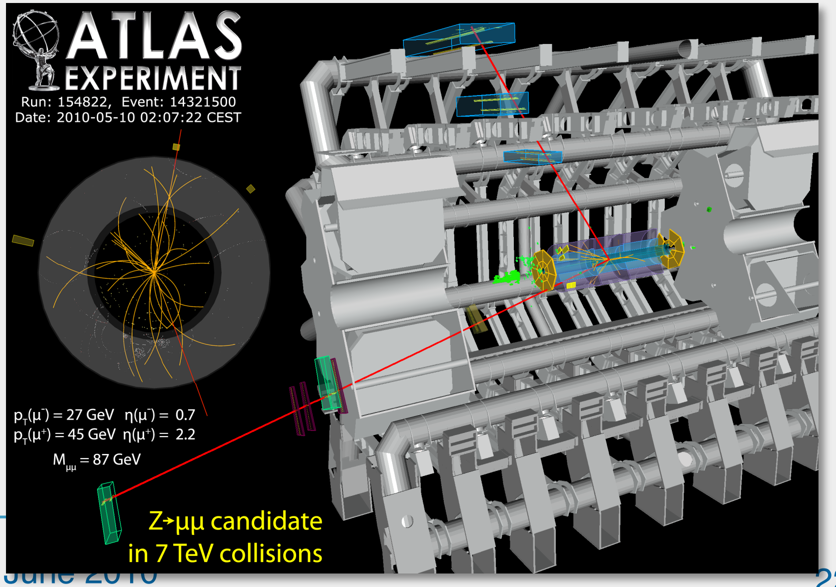




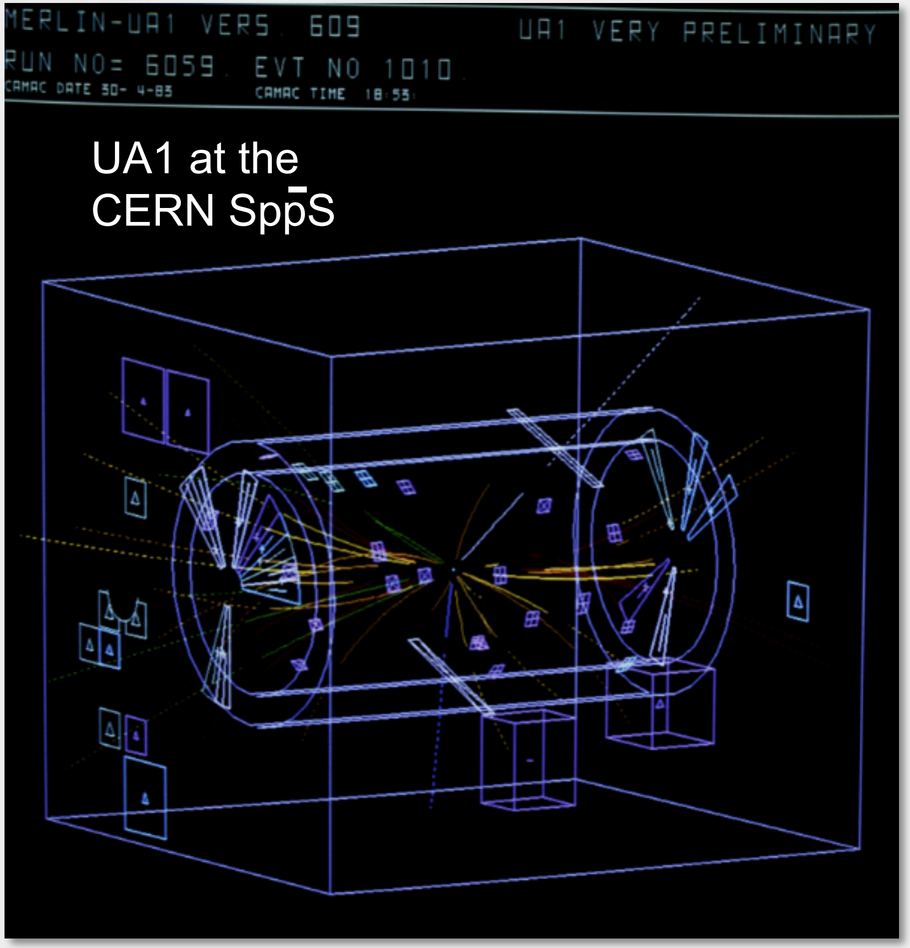
W and Z production at 7 TeV



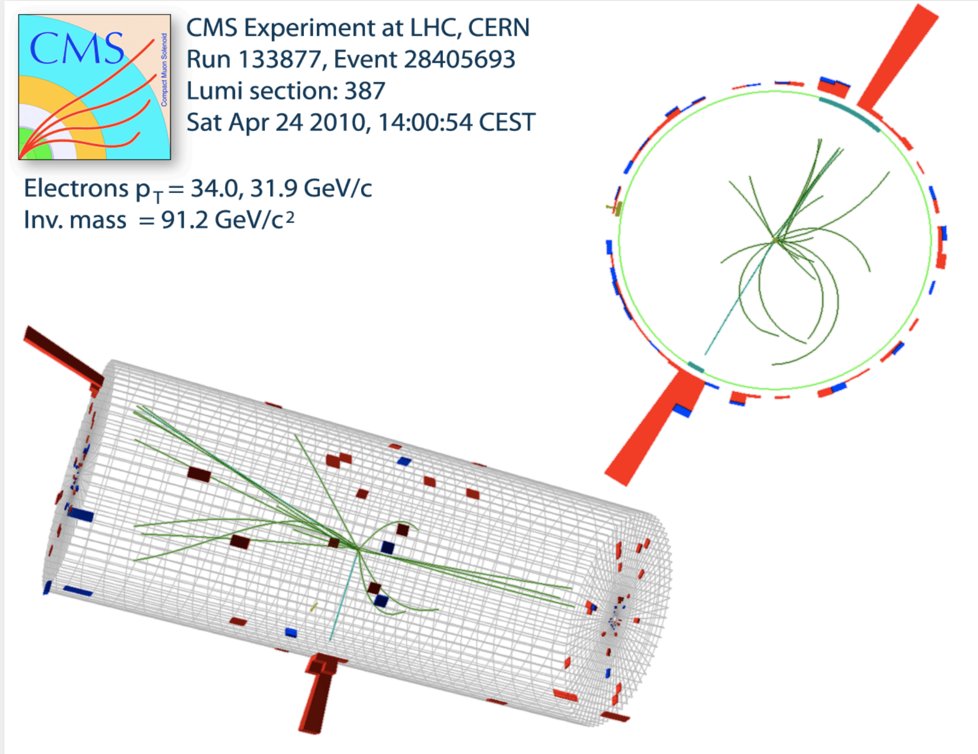




Z production at 7 TeV



1st Z event observed on 30 April 1983
at E_{CM} = 0.45 TeV



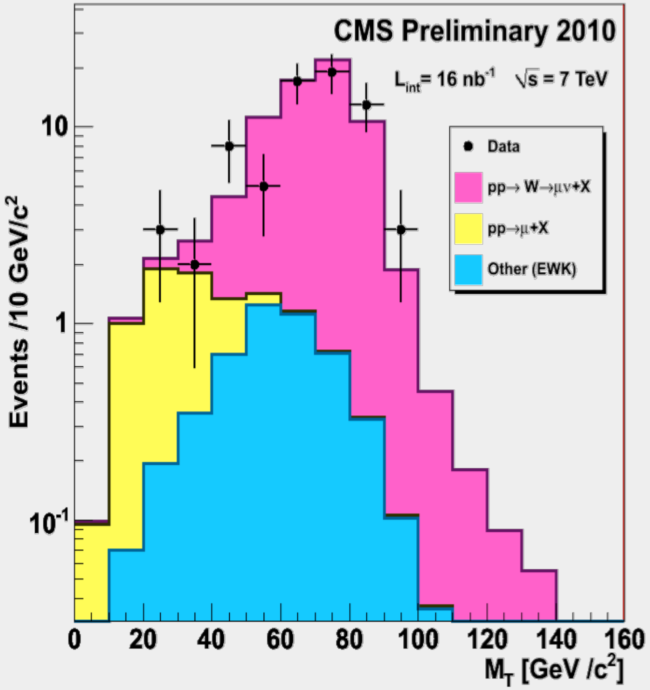
27 years later: Z's observed at LHC
at E_{CM} = 7 TeV

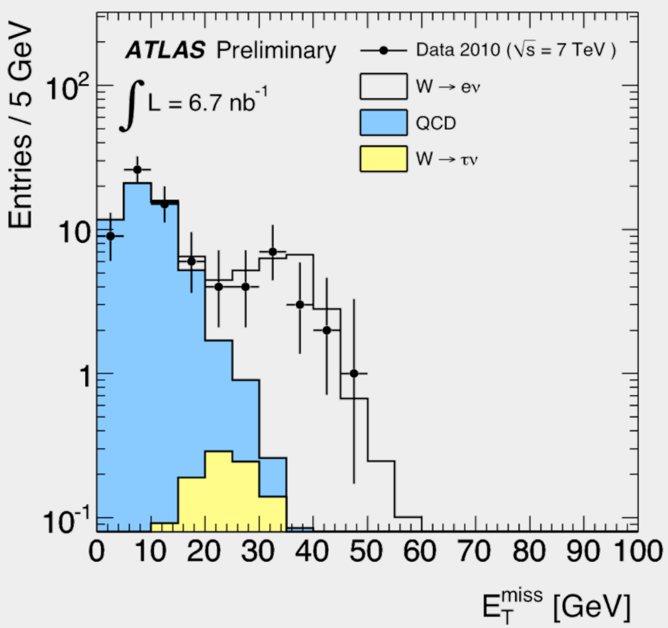
In the 1990's: Millions of Z events
analysed at LEP

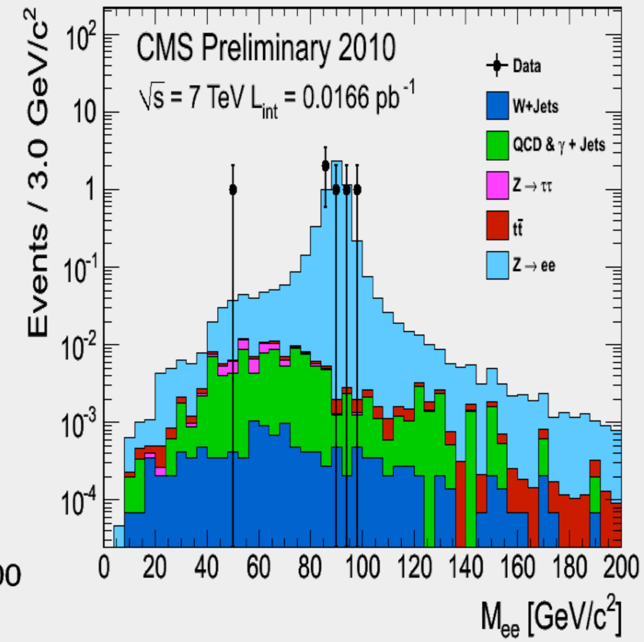
W and Z production at 7 TeV

Number of events presented at P-LHC Hamburg 7 June 2010

	CMS (~12nb^{-1})	ATLAS (~ 7nb^{-1})
W → eν	40	17
W → μν	57	40
Z → ee	5	1
Z → μμ	5	2







Experience from first periods of data taking

- Excellent performance of Collider:

  Highest p-p collisions ever produced

- Excellent readiness of experiments:

  High data taking efficiency, fast turn-around for results

- Overall good agreement data-simulation

- Efficient analysis chain: can extract results very quickly

LHC – Next Steps: 2010 - 2015

Years	2010	2011	2012	2013	2014	2015	....
LHC	DATA Taking		Shut down	DATA Taking		Shut down	

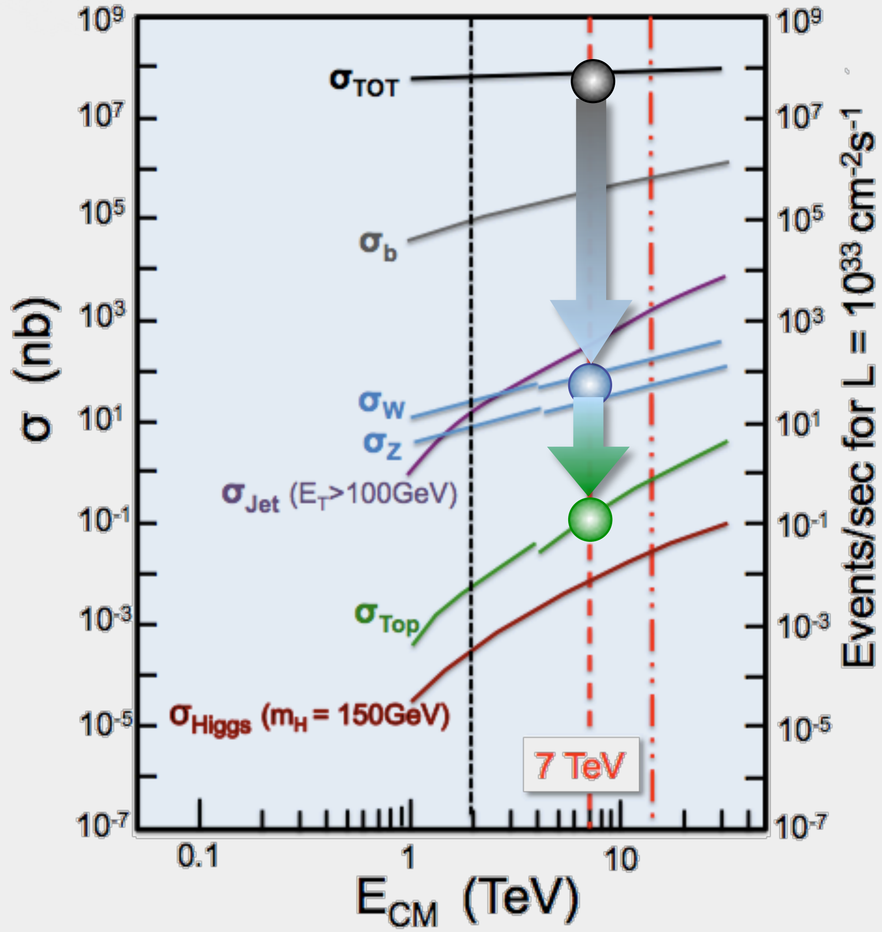
E_{CM} = 7 TeV
2010: L~10^{27} $cm^{-2}s^{-1}$
→ L~10^{32} $cm^{-2}s^{-1}$
2011: reach ~ $1fb^{-1}$
Heavy ion run at end of each year

E_{CM} ~ 14 TeV

Consolidation for LHC operation
- Repair and consolidate all splices with new clamped shunted ones
- Add remaining Helium pressure release ports, etc

Depending on what we find at 14 TeV

Physics at √s = 7 TeV: next steps

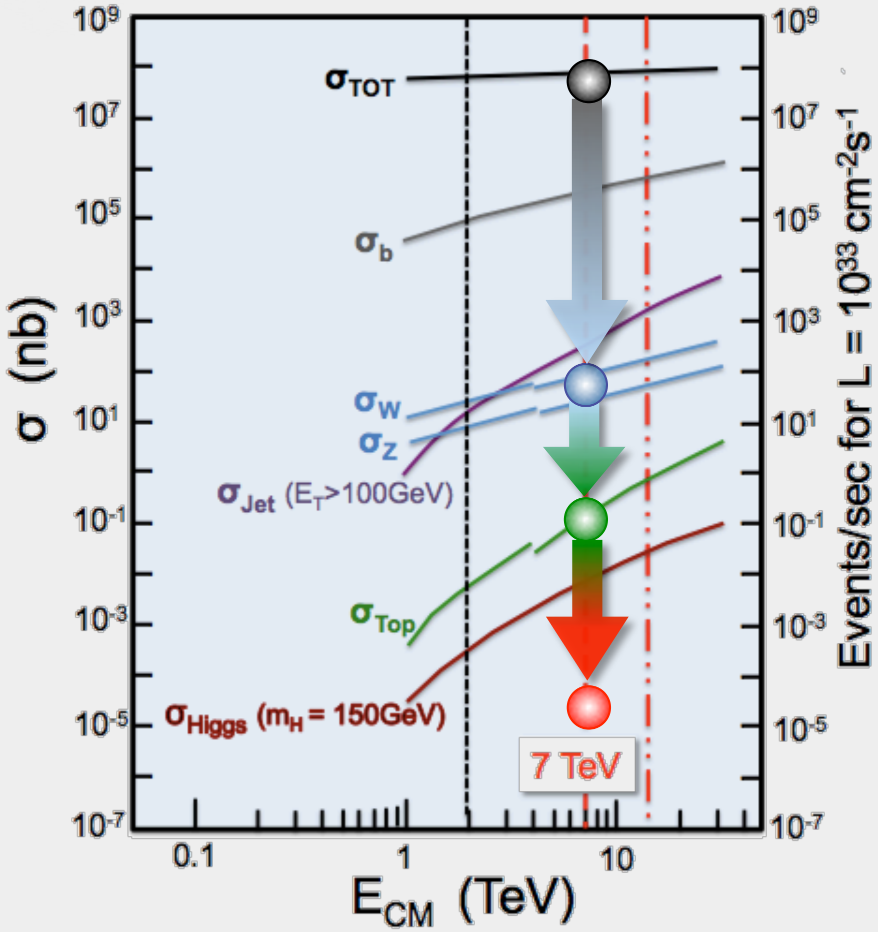


Re-discover the SM

- Test (re-establish) the SM and then go beyond
  - Measure W and Z production
  - Measure top-quark
- Most SM cross sections are significantly higher than at the Tevatron
  - Example: top-quark

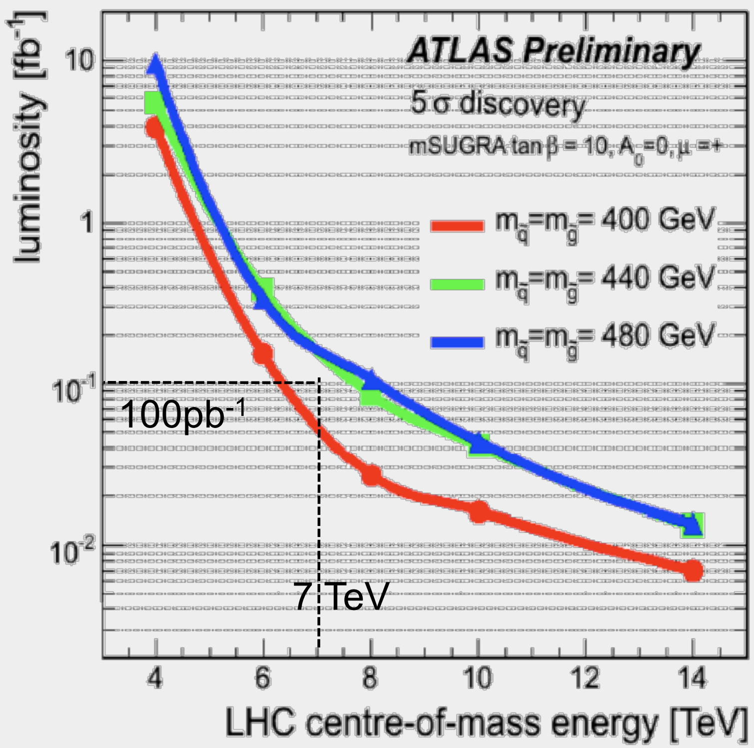
    @ 7TeV and 1fb^{-1} : expect ~ 2 times larger tt → l+jets events than CDF/D0 for 10fb^{-1}
  - The LHC is a b, top, W, Z … factory

Physics Examples beyond SM

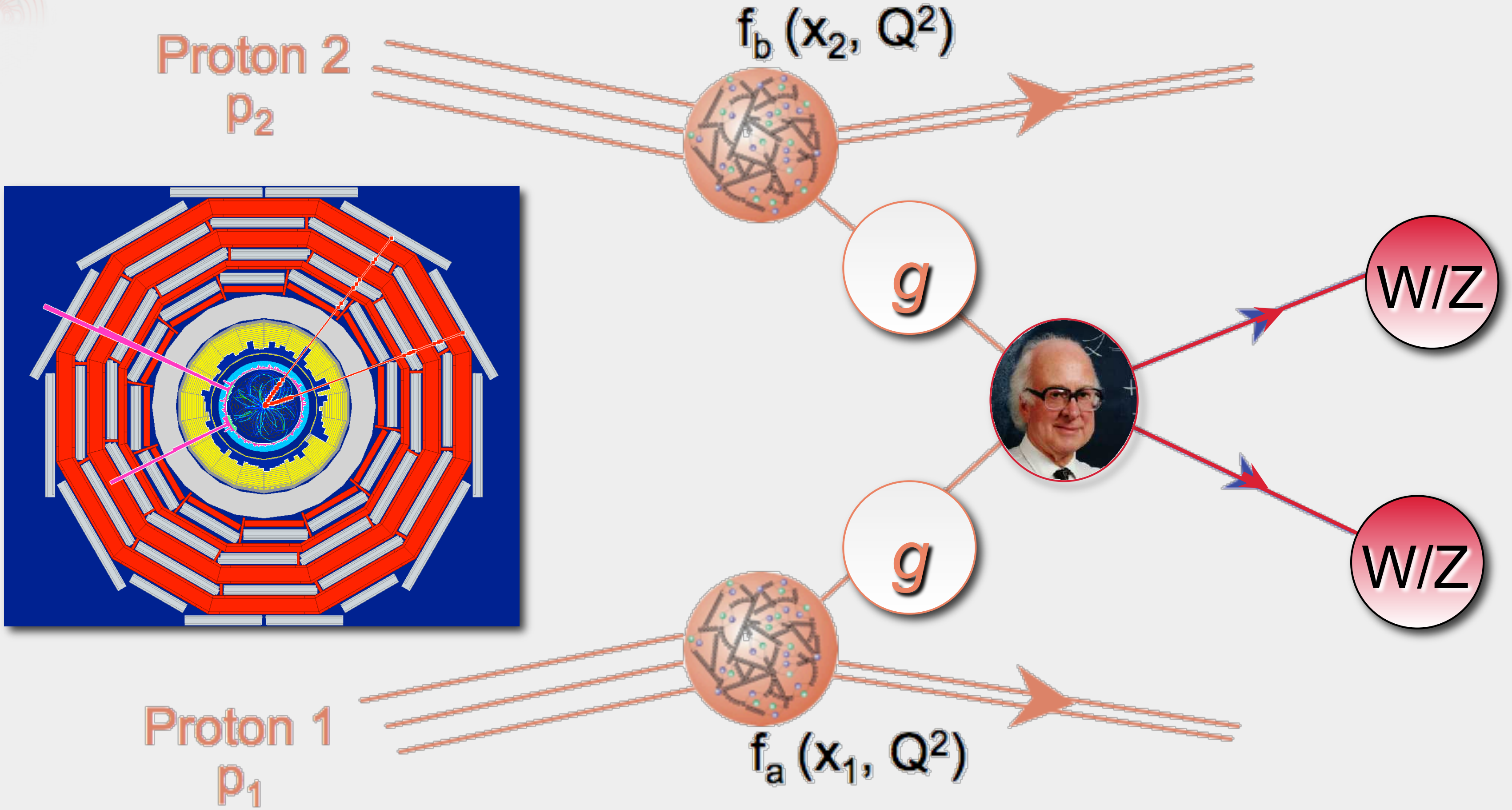


SUSY: for $m_{gluino} \sim m_{squark}$

@ 7TeV: 100pb^{-1} : ~ 400 GeV
similar to Tevatron
1fb^{-1} : discovery reach up to
~800 GeV



Basic processes at LHC (at $\sqrt{s}$ = 7TeV?)

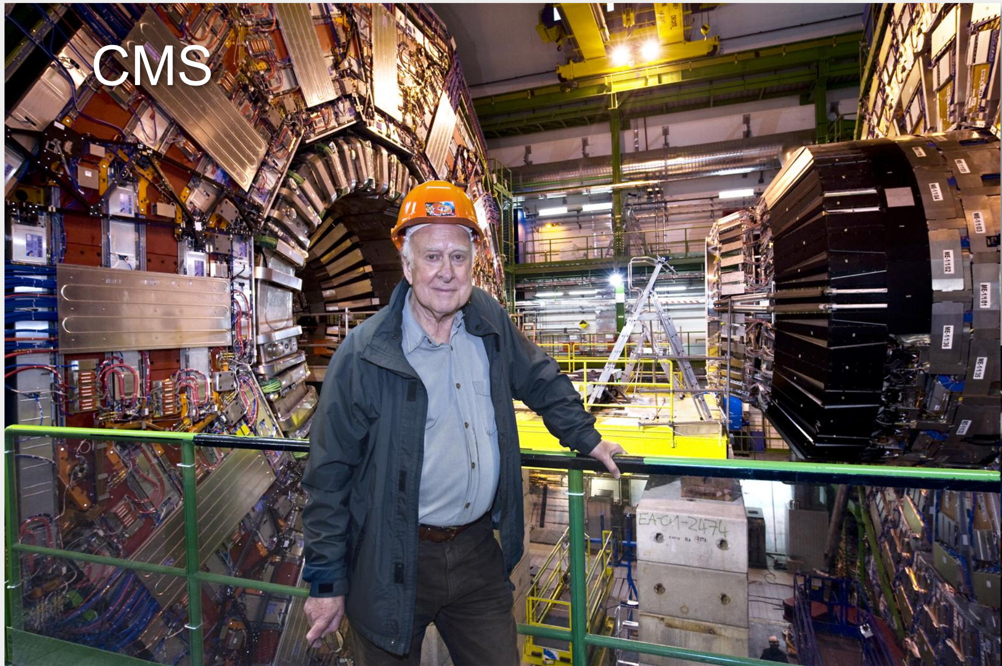


LEP: $m_H > 114$ GeV

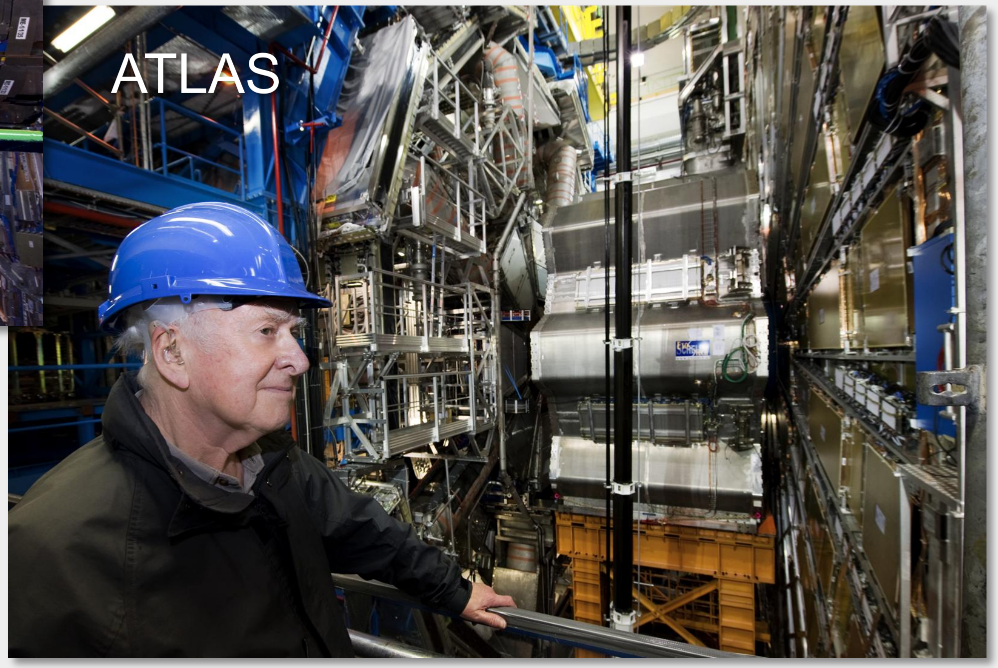
Tevatron exclusion limit: $163 < m_H < 166$ GeV

To challenge Tevatron limits at E_{CM} = 7 TeV, need ~300 pb^{-1} g.d. per exp.

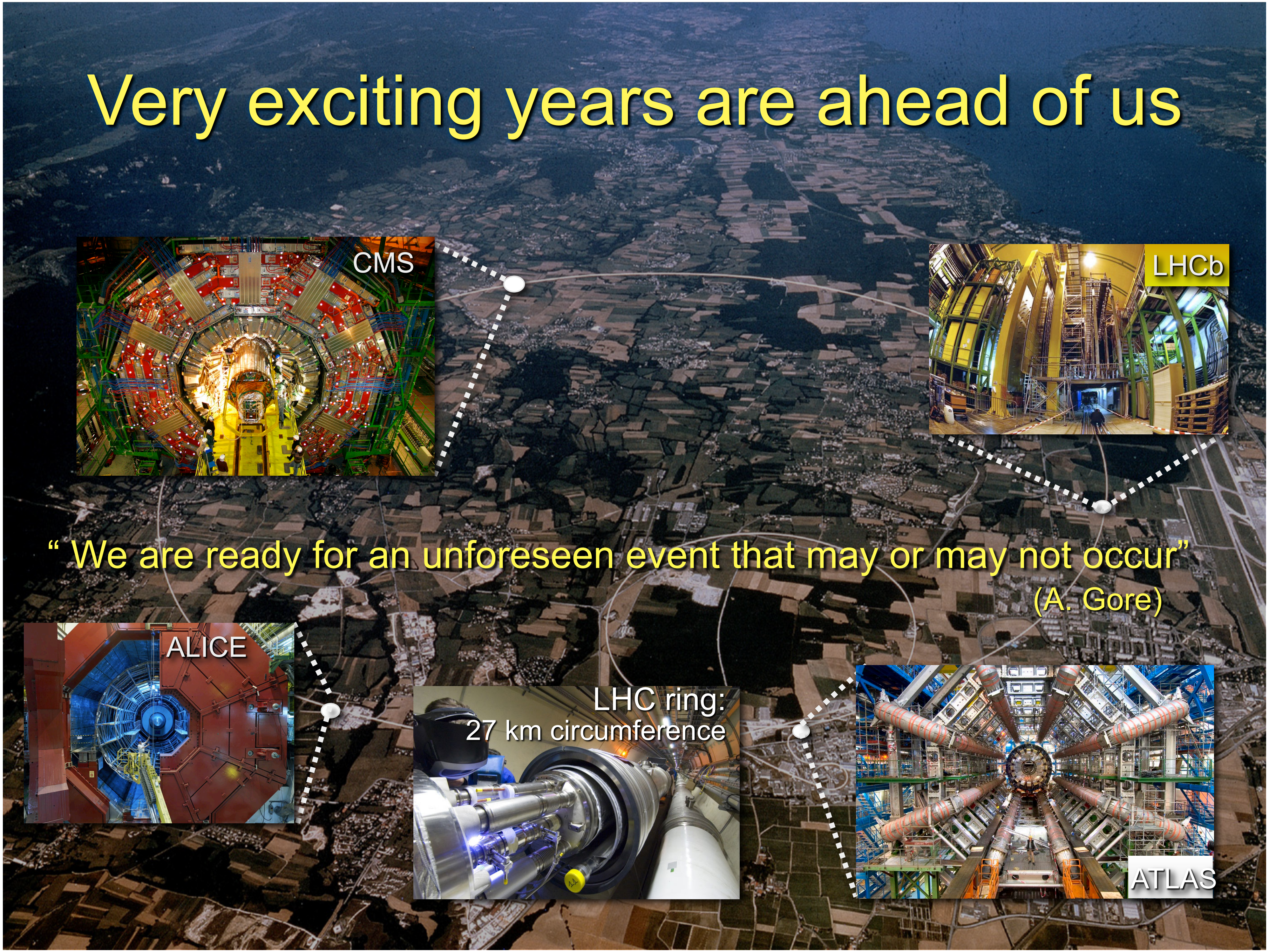
First “Higgs Event” …..



…. observed jointly in CMS and ATLAS …. (April 2008)



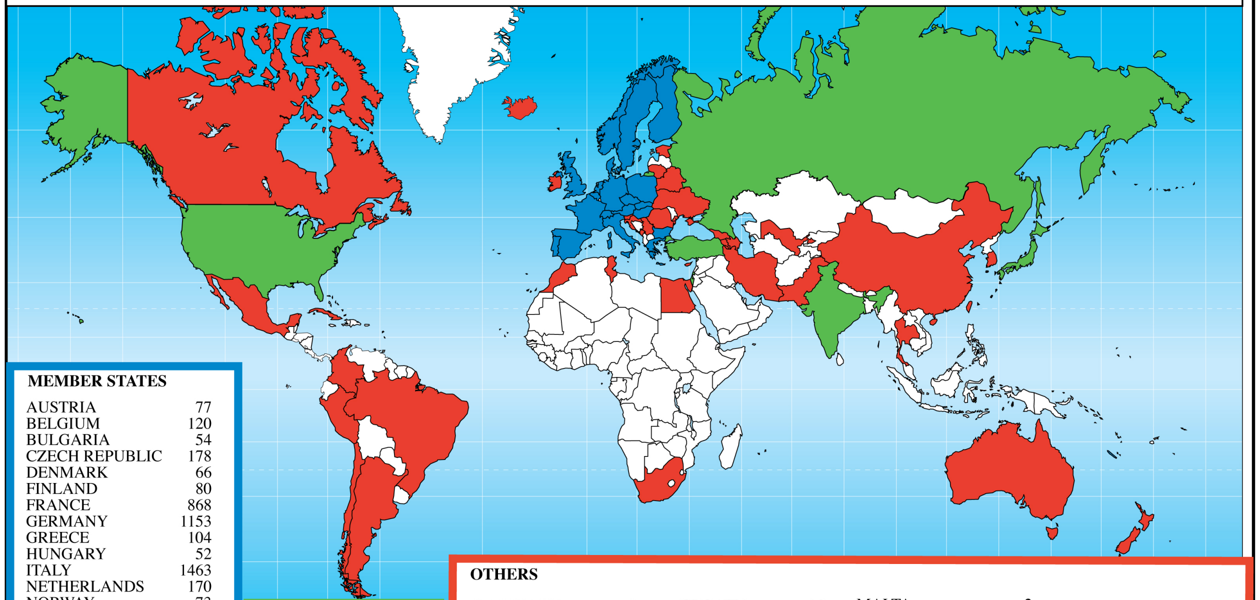
Very exciting years are ahead of us



" We are ready for an unforeseen event that may or may not occur"

(A. Gore)

Future of the High-Energy Frontier



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

762

CERN became a GLOBAL LABORATORY

Overall **increase** of CERN Users **since May 2001**: **~ 50%**

~30% Member States

~100% Observer States (India, Israel, Japan, Russia, Turkey, USA)

~ 125% Other States

} Due to LHC