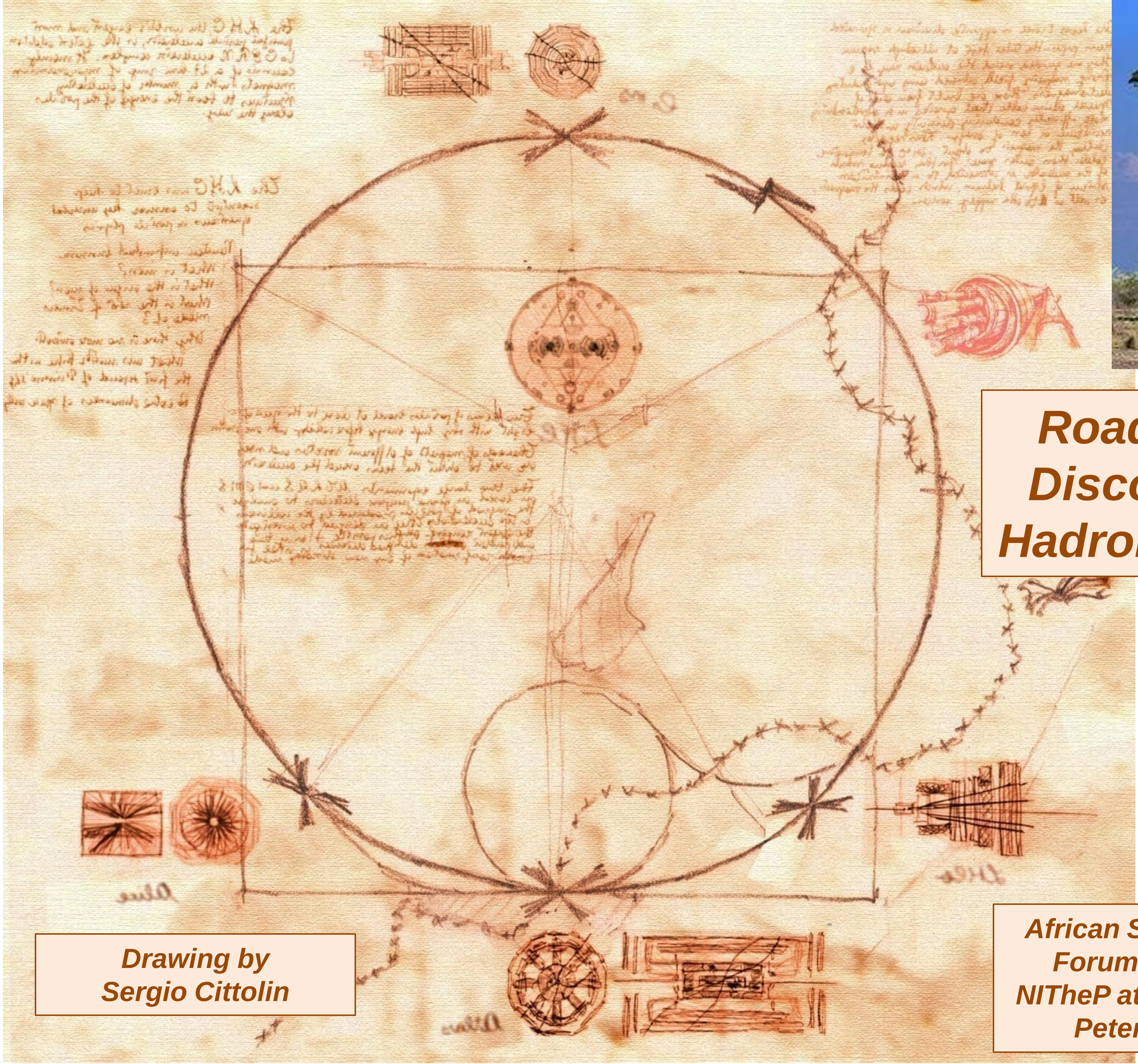


Drawing by
Sergio Cittolin

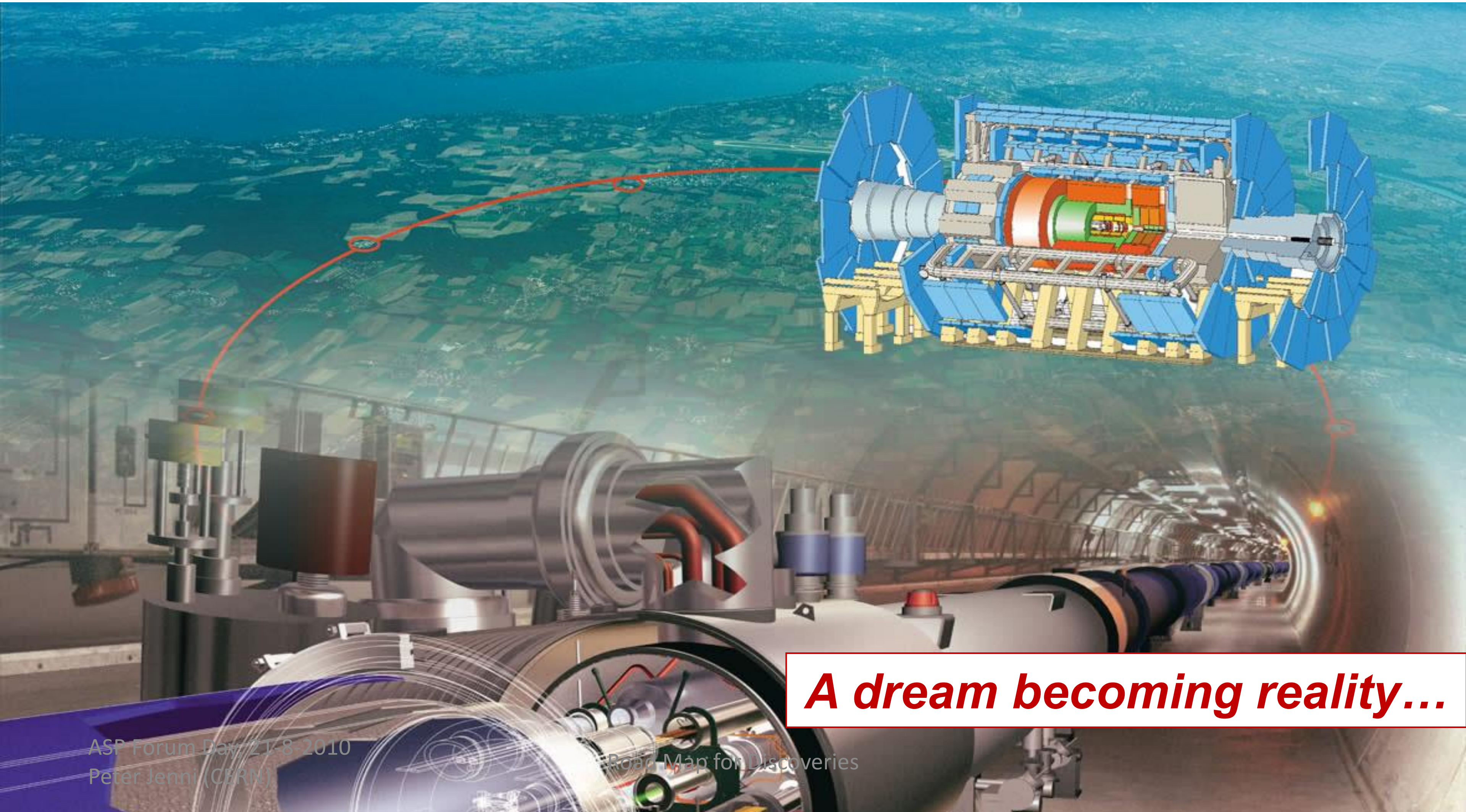
Road Map for Discoveries at Hadron Colliders

African School of Physics
Forum Day, 21-8-2010
NIThePP at Stellenbosch, SA

Peter Jenni, CERN

A lot will be about the Large Hadron Collider Project:

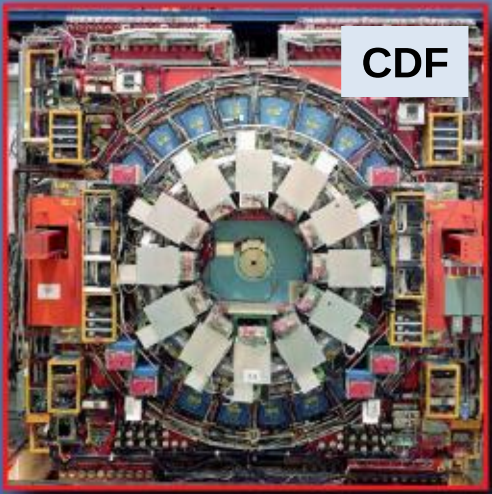
A Journey to Discover the Physics Shortly After the Big Bang

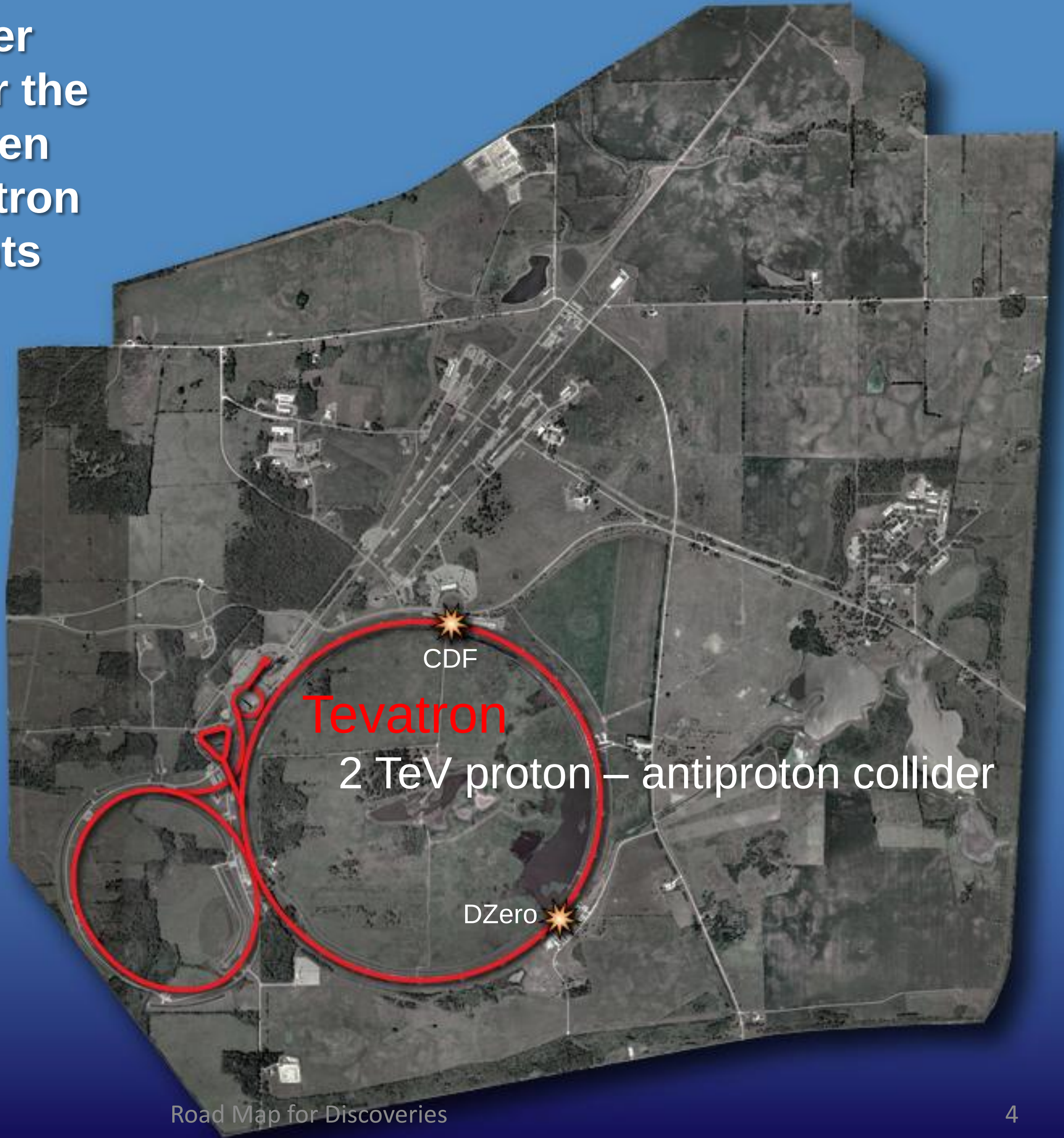


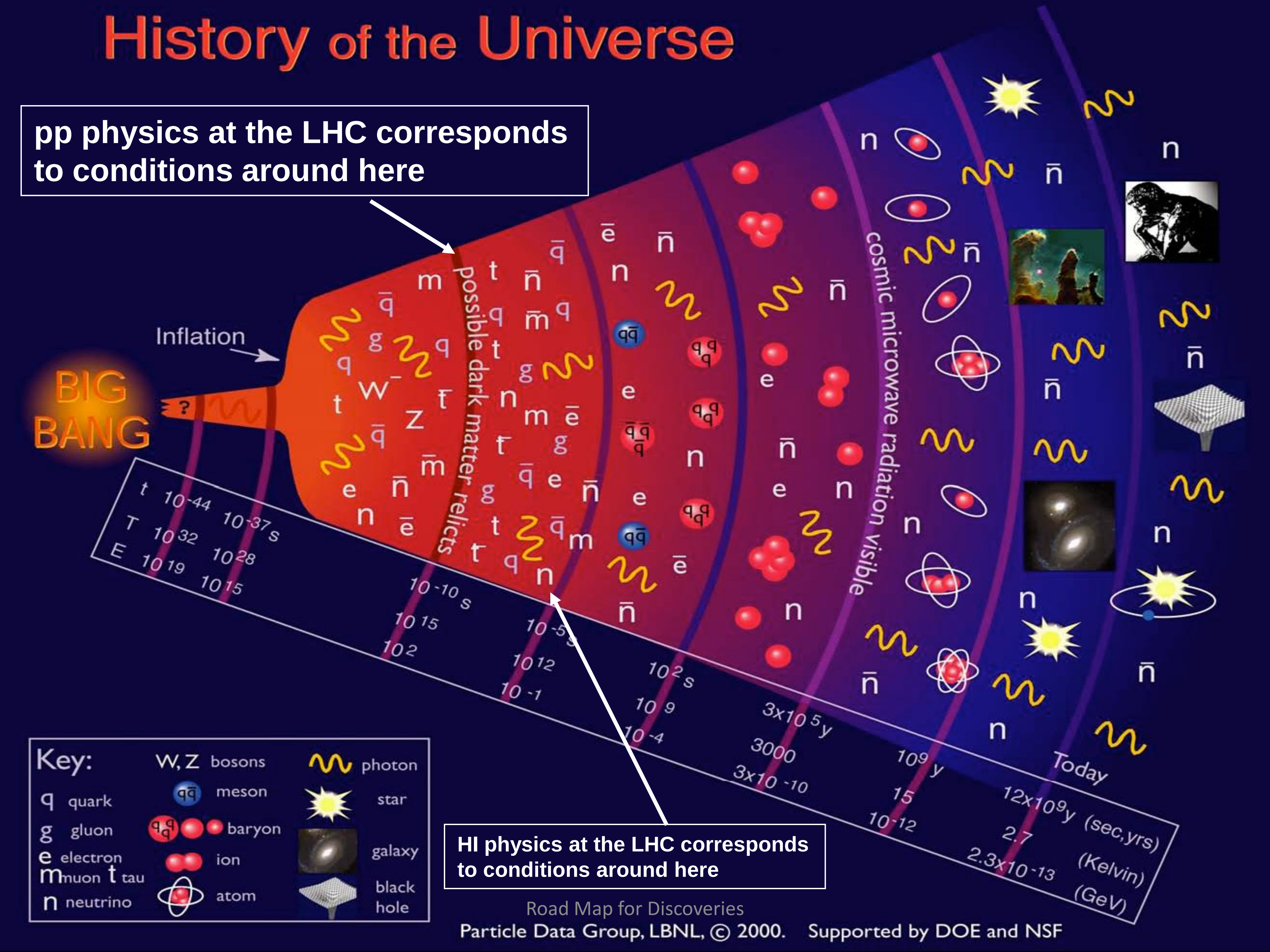
A dream becoming reality…

The Large Hadron Collider project has to be seen as a global scientific adventure, combining the accelerator and the experiments

The hadron collider physics chapter over the last decade has been 'written' by the Tevatron and its experiments



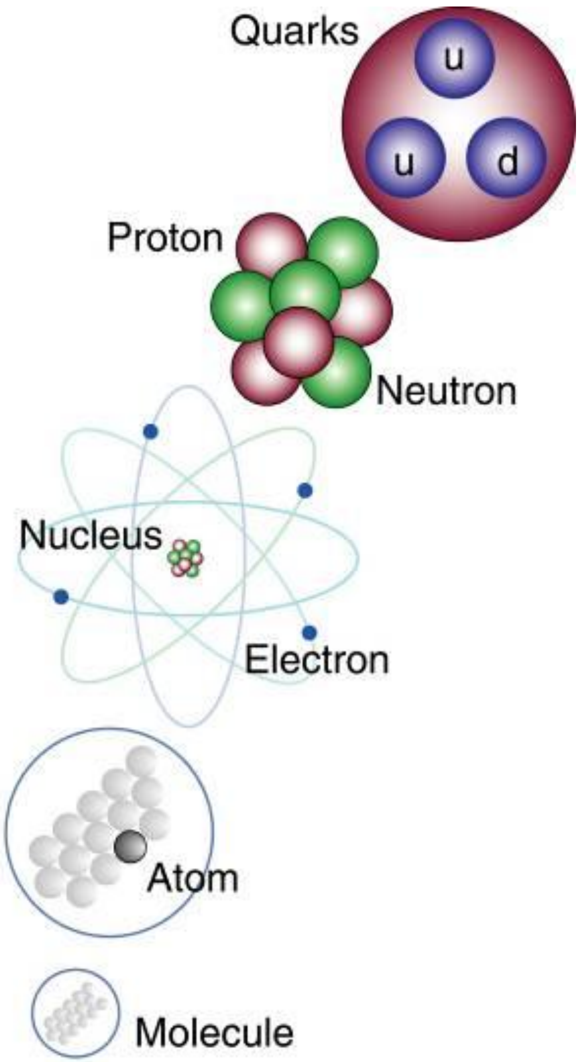


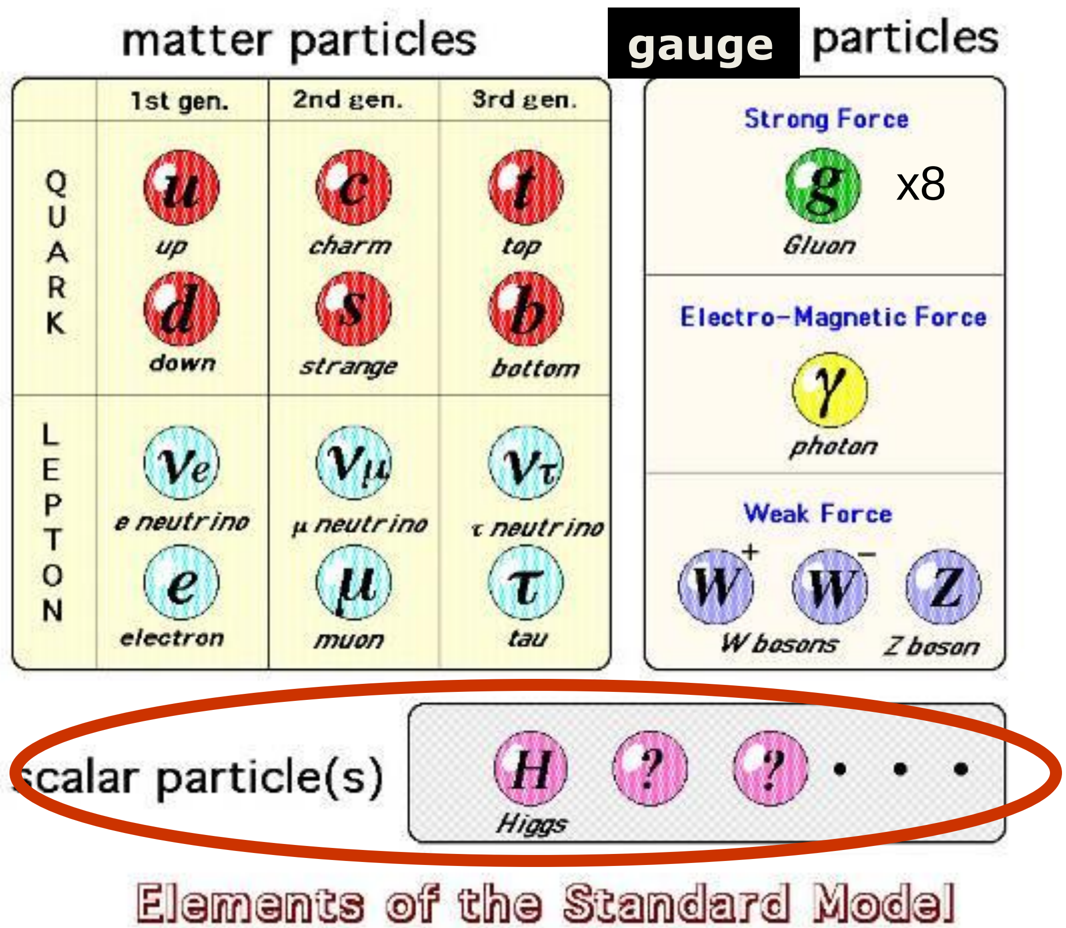


pp physics at the LHC corresponds to conditions around here

HI physics at the LHC corresponds to conditions around here

The study of elementary particles and fields and their interactions

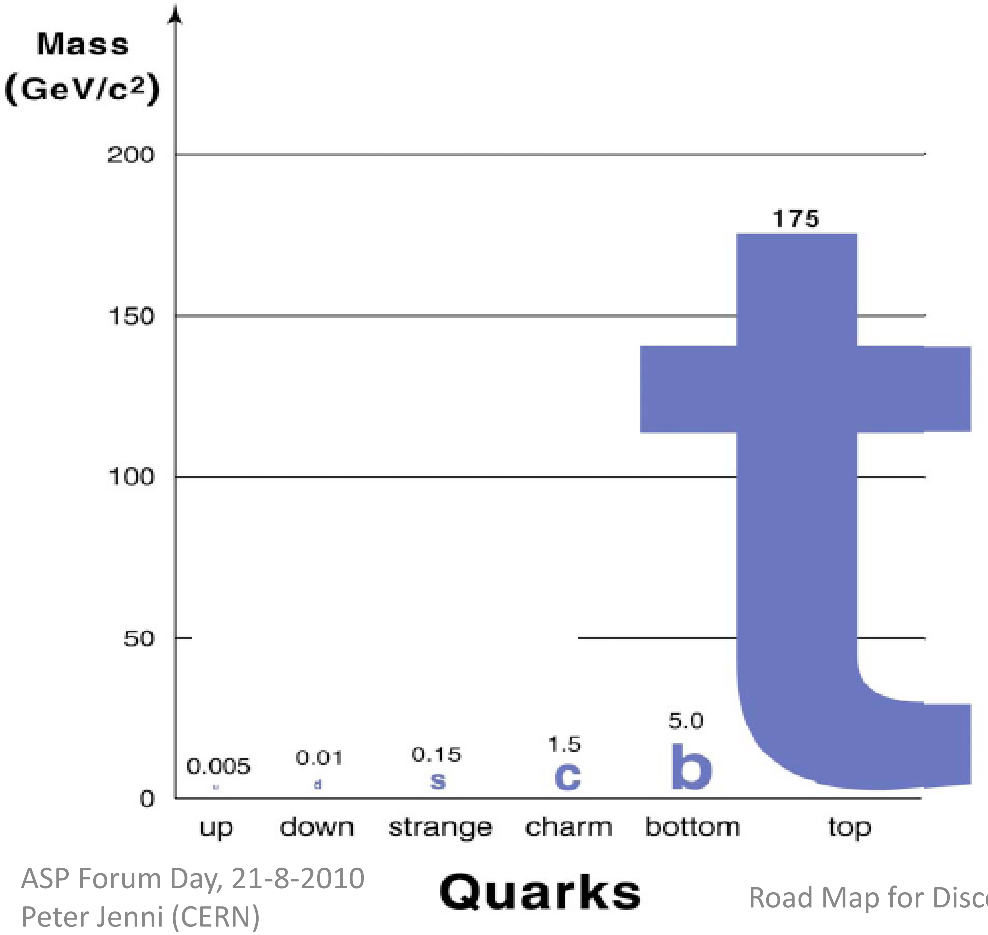




A most basic question is why particles (and matter) have masses (and so different masses)

Peter Higgs

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)



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

Supersymmetry (SUSY)

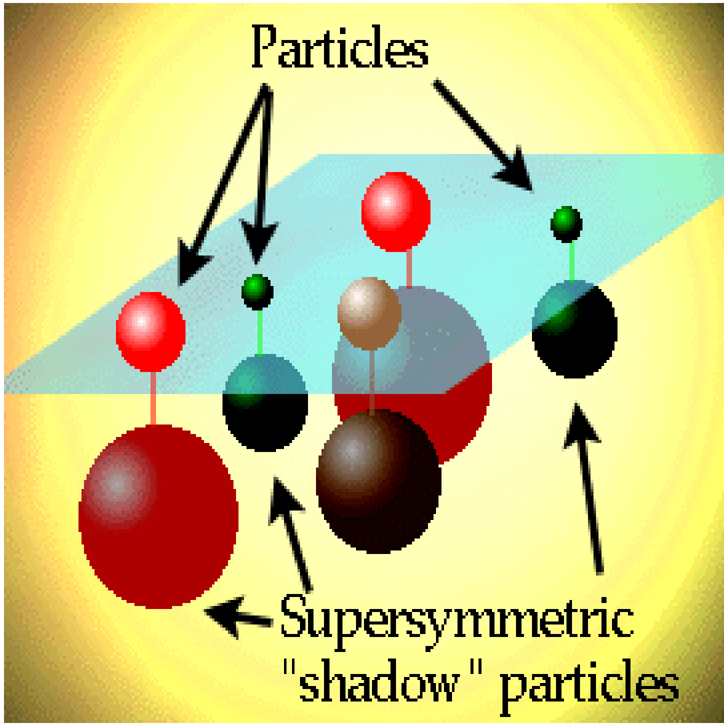
(Julius Wess and Bruno Zumino, 1974)

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

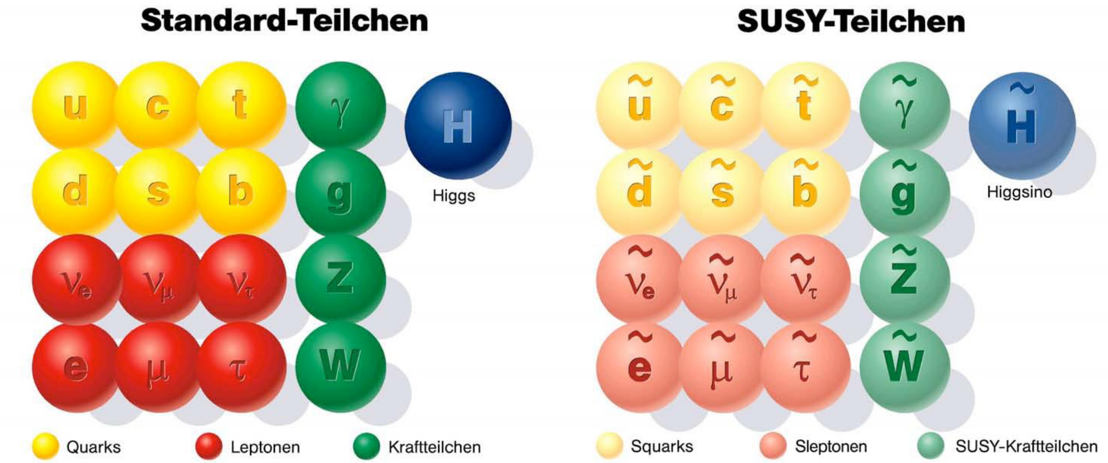
- Each particle p with spin s has a SUSY partner $\tilde{p}$ with spin s -1/2

- 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

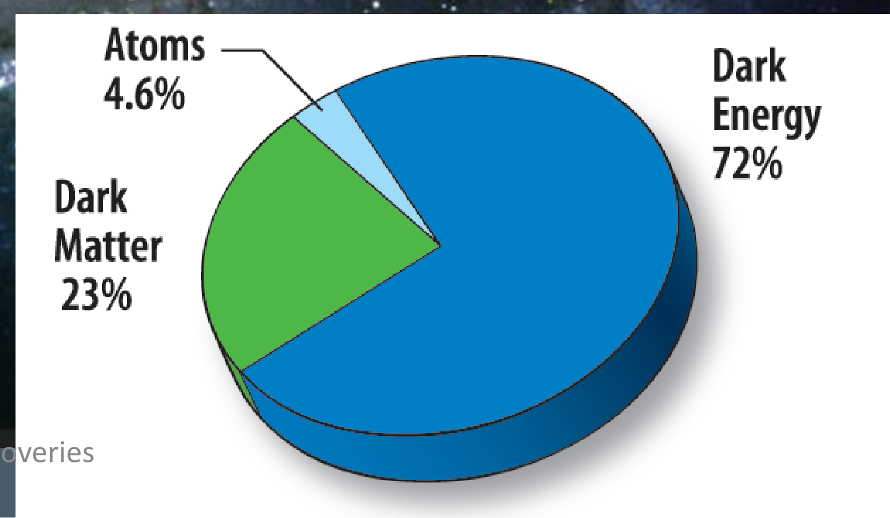
Dark Matter in the Universe

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

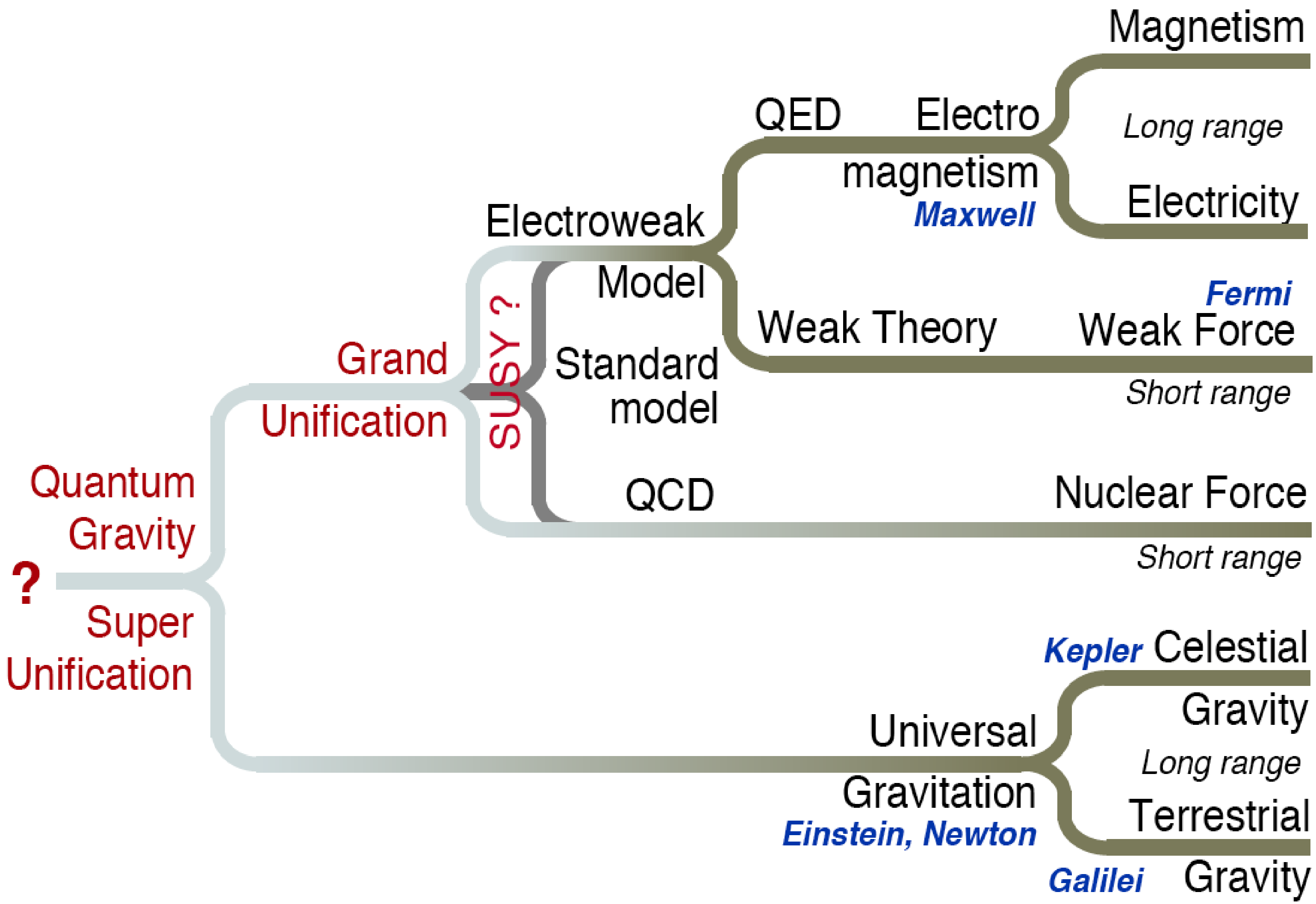
‘Supersymmetric’ particles ?

We shall look for them with the LHC

F. Zwicky 1898-1974



Unification of Forces



How the LHC came to be …

(see a nice article by Chris Llewellyn-Smith in Nature 448, p281)

Some early key dates

1977 **The community talked about the LEP project, and it was already mentioned that a new tunnel could also house a hadron collider in the far future**

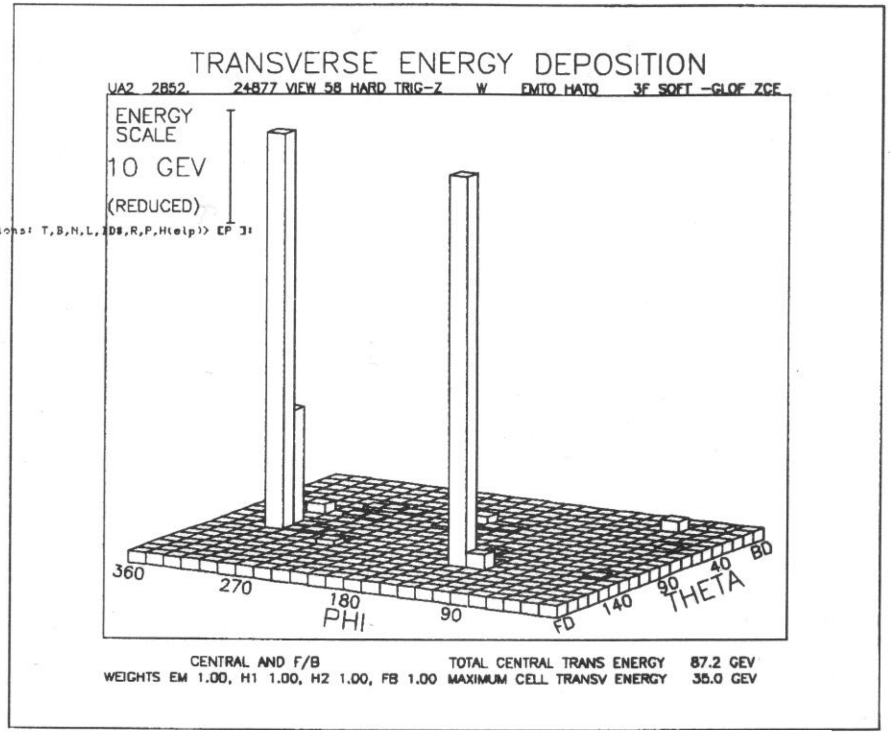
1981 **LEP was approved with a large and long (27 km) tunnel**

1983 **The early 1980s were crucial:**

The real belief that a 'dirty' hadron collider can actually do great discovery physics came from UA1 and UA2 with their W and Z boson discoveries at CERN

This also triggered a famous quote from a 1983 New York Times editorial:

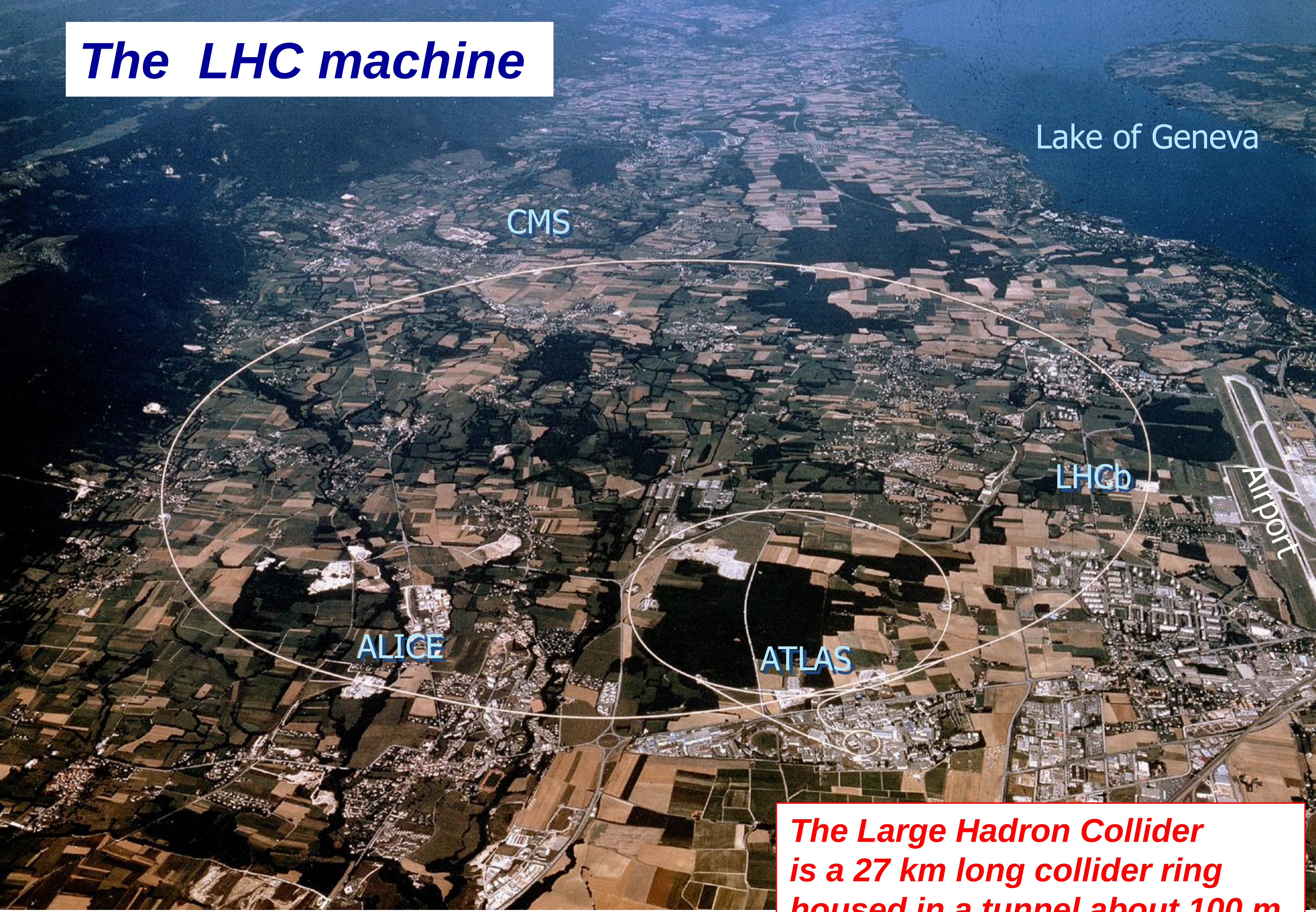
'Europe: 3 - US Not Even Z-Zero'



A very early Z → ee online display from one of the detectors (UA2)

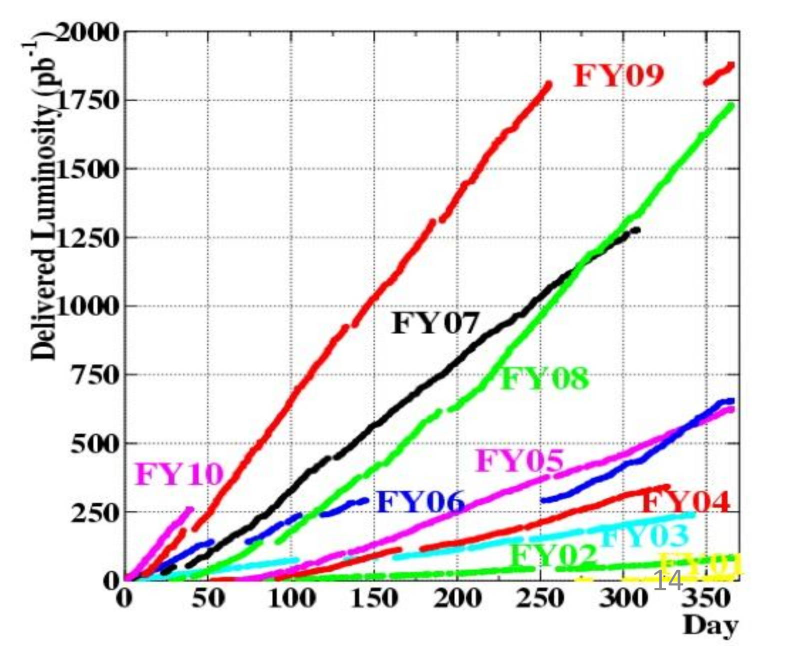
The first picture on the Web in 1992 !

The LHC machine



The Large Hadron Collider is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva

The Tevatron at Fermilab is performing in a superb way, and has still a major potential for great physics in the near future



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

Collision energy

Tevatron ($p\bar{p}$)

1.96 TeV

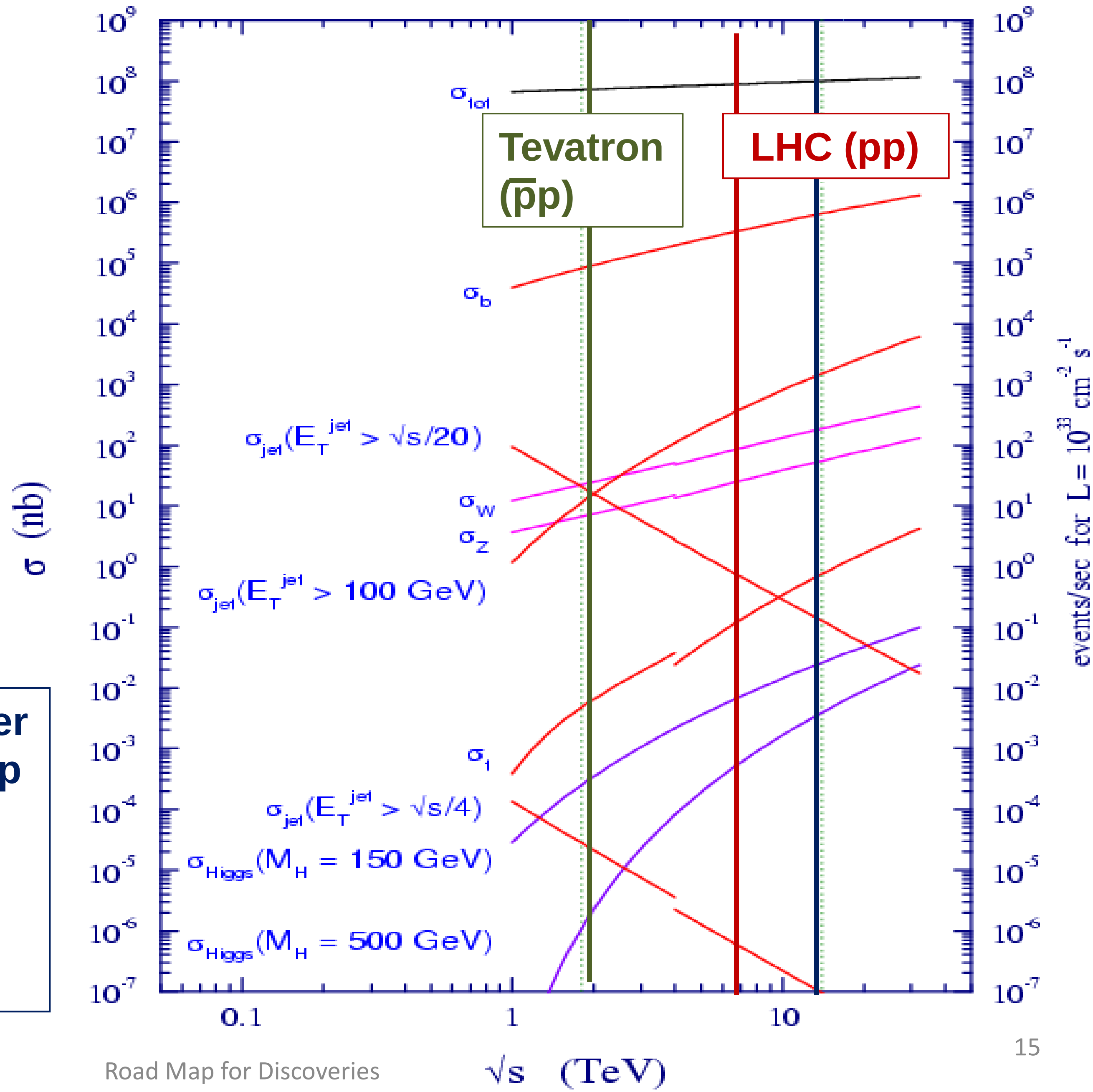
LHC (pp)

initially 7 TeV
later 14 TeV

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

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

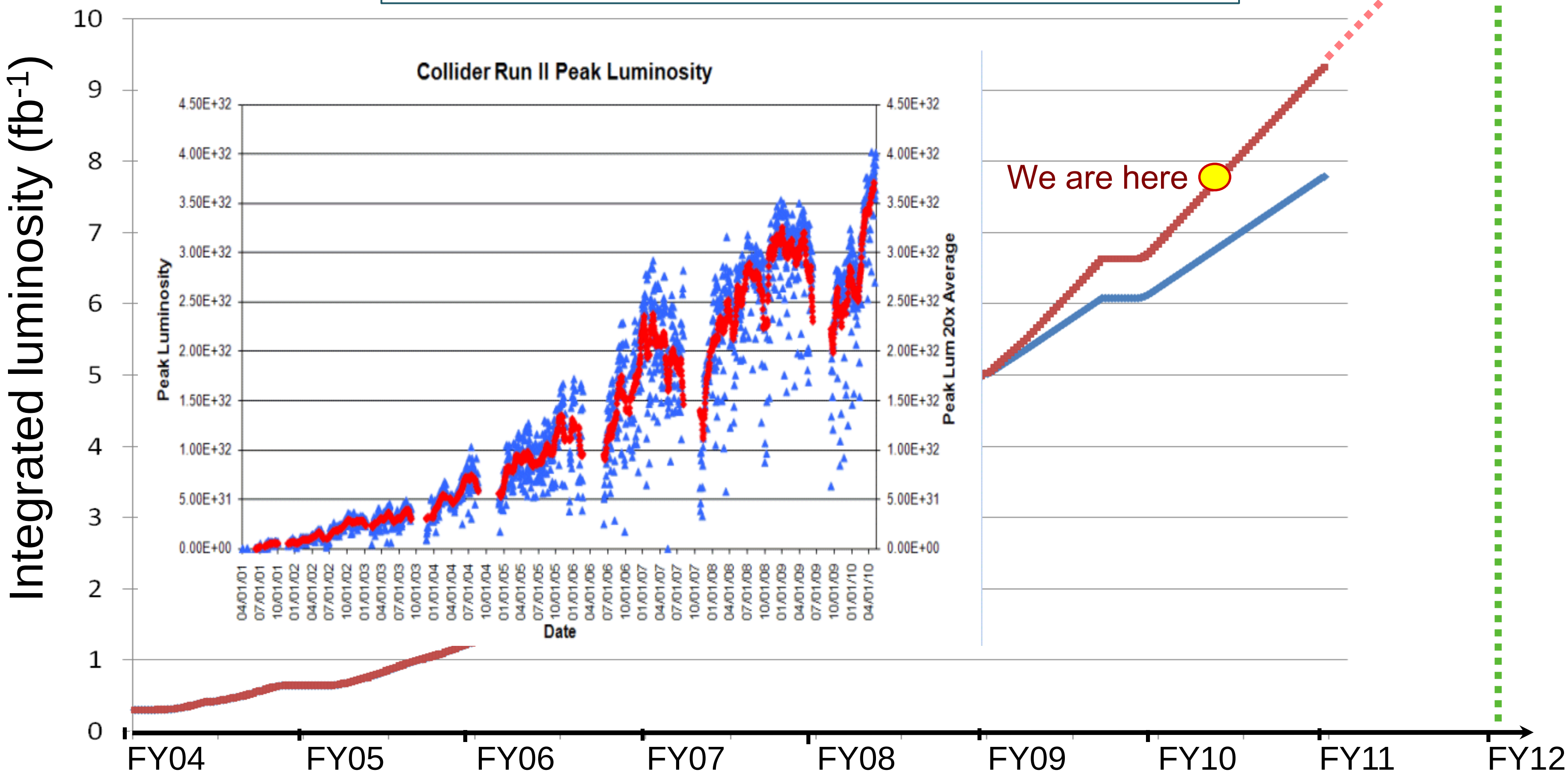
Some bench-mark cross-sections



Projection for the Tevatron

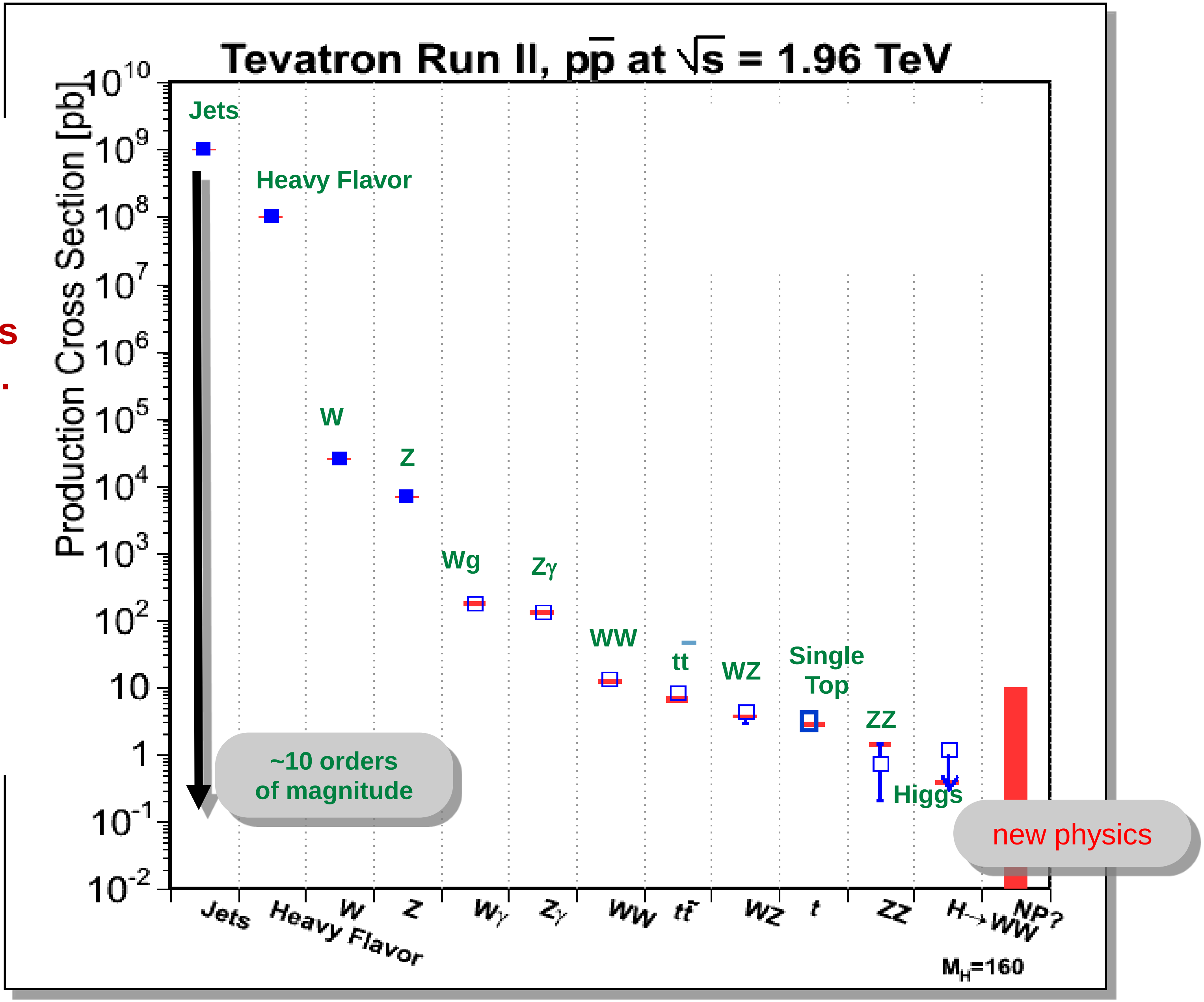
Expect about 2 fb^{-1} per year from now on → **~12 fb^{-1}**

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

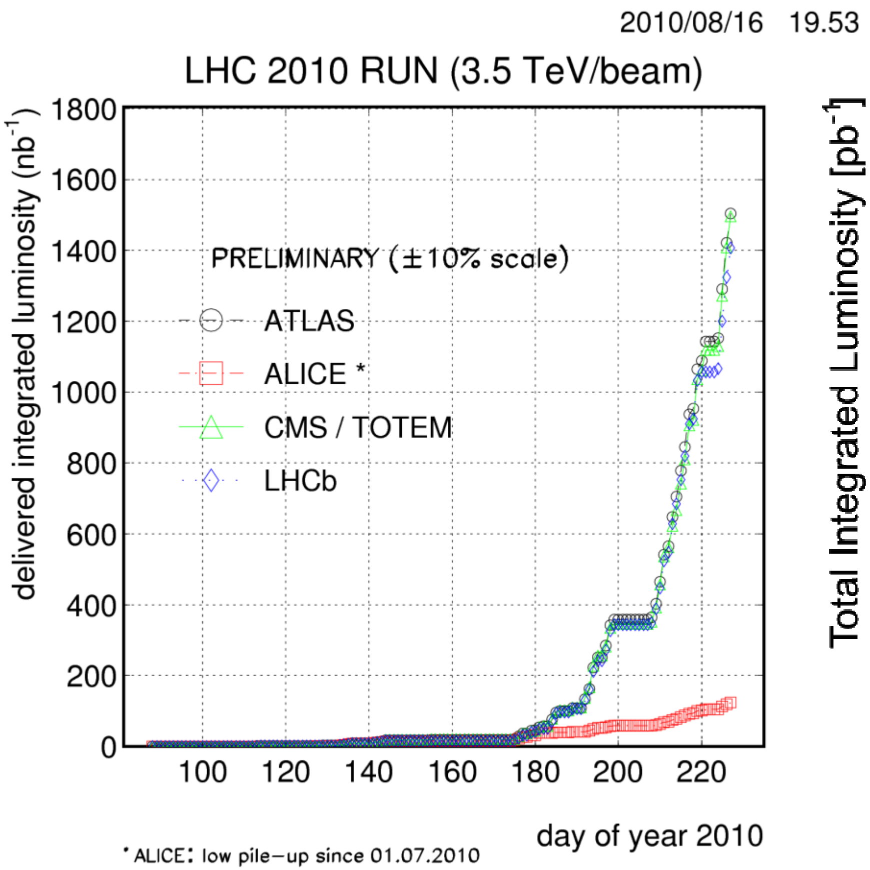


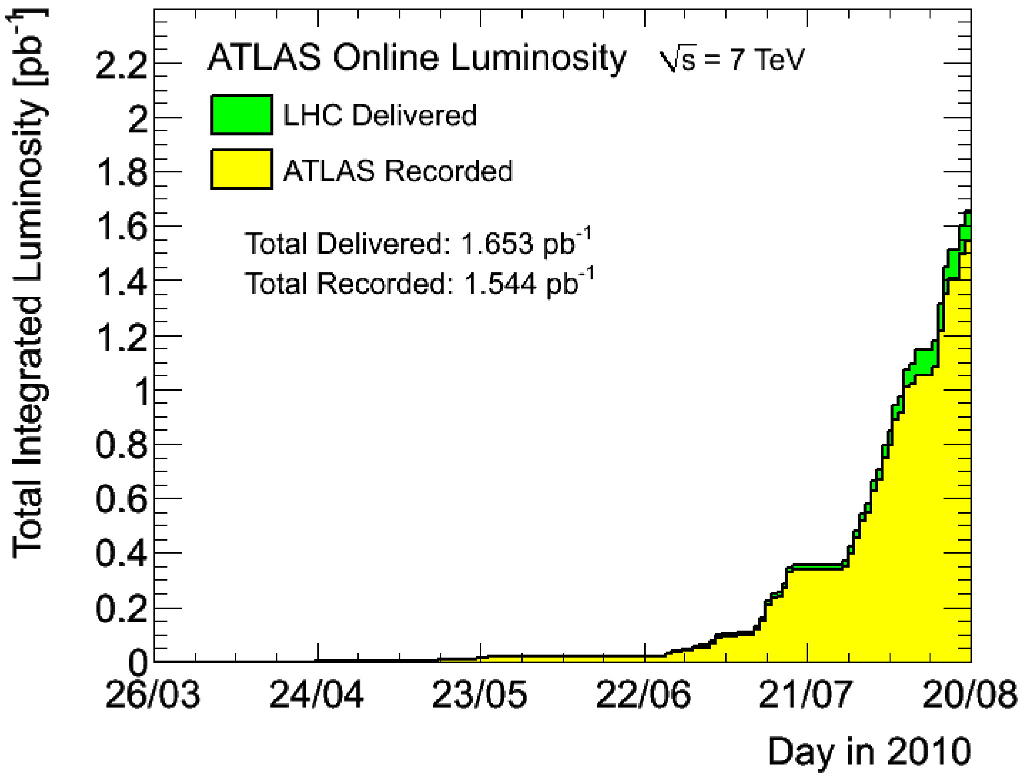
The Tevatron experiments have explored an impressive range of physics over the years…

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



Accumulated data so far (integrated luminosity)





Note the high efficiency of recorded data (93.4%)

Road Map of Expected Hadron Collider Performances

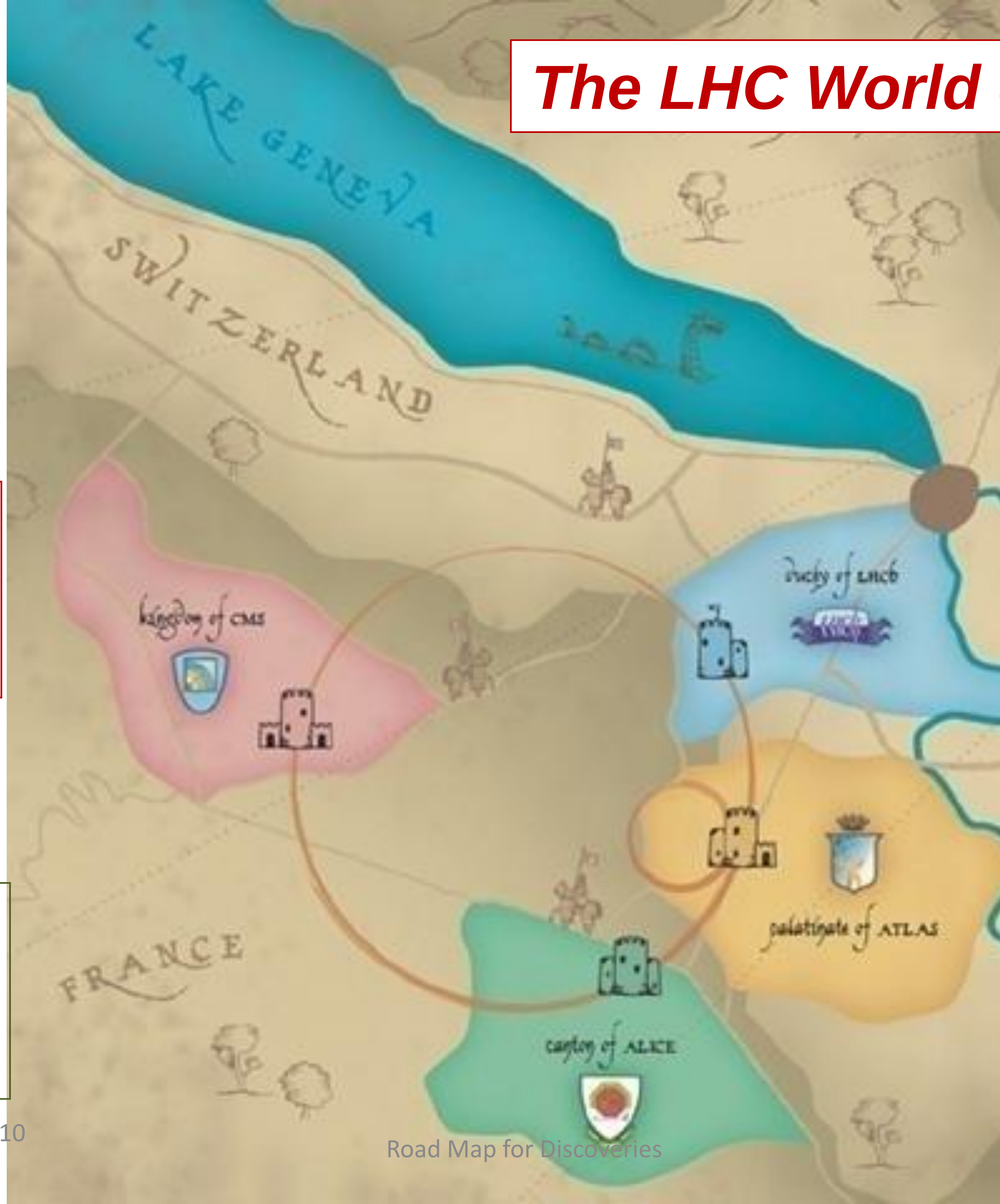
Now	Tevatron	2 TeV	7 fb^{-1} (analysed)
	LHC	7TeV	1.5 pb^{-1}
End 2011	Tevatron	2 TeV	10 fb^{-1}
	LHC	7 TeV	1 fb^{-1}
End 2014	LHC	14 TeV	30 fb^{-1}
End 2017	LHC	14 TeV	100 fb^{-1}
Early 2020ies	LHC	14 TeV	500 fb^{-1}
2030	(s)LHC	14 TeV	3000 fb^{-1} (ultimately…)

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

(1 fb^{-1} = 1000 pb^{-1})

The LHC World of CERN

Plus smaller local earldoms
LHCf (point-1)
TOTEM (point-5)
Moedal (point-8)



CMS
2900 Physicists
184 Institutions
38 countries
550 MCHF

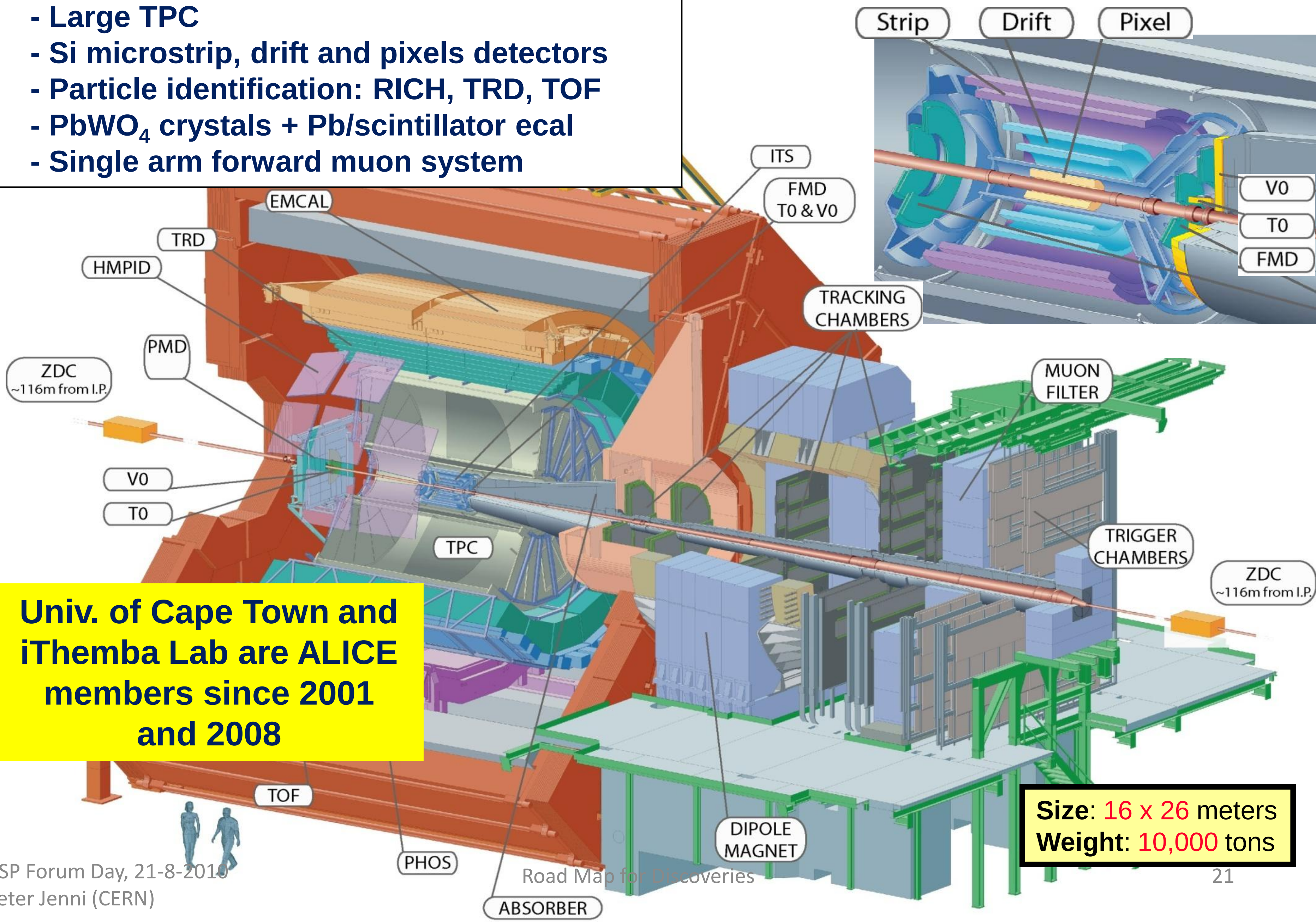
LHCb
730 Physicists
54 Institutions
15 countries
75 MCHF

ALICE
1000 Physicists
105 Institutions
30 countries
150 MCHF

ATLAS
3000 Physicists
174 Institutions
38 countries
550 MCHF

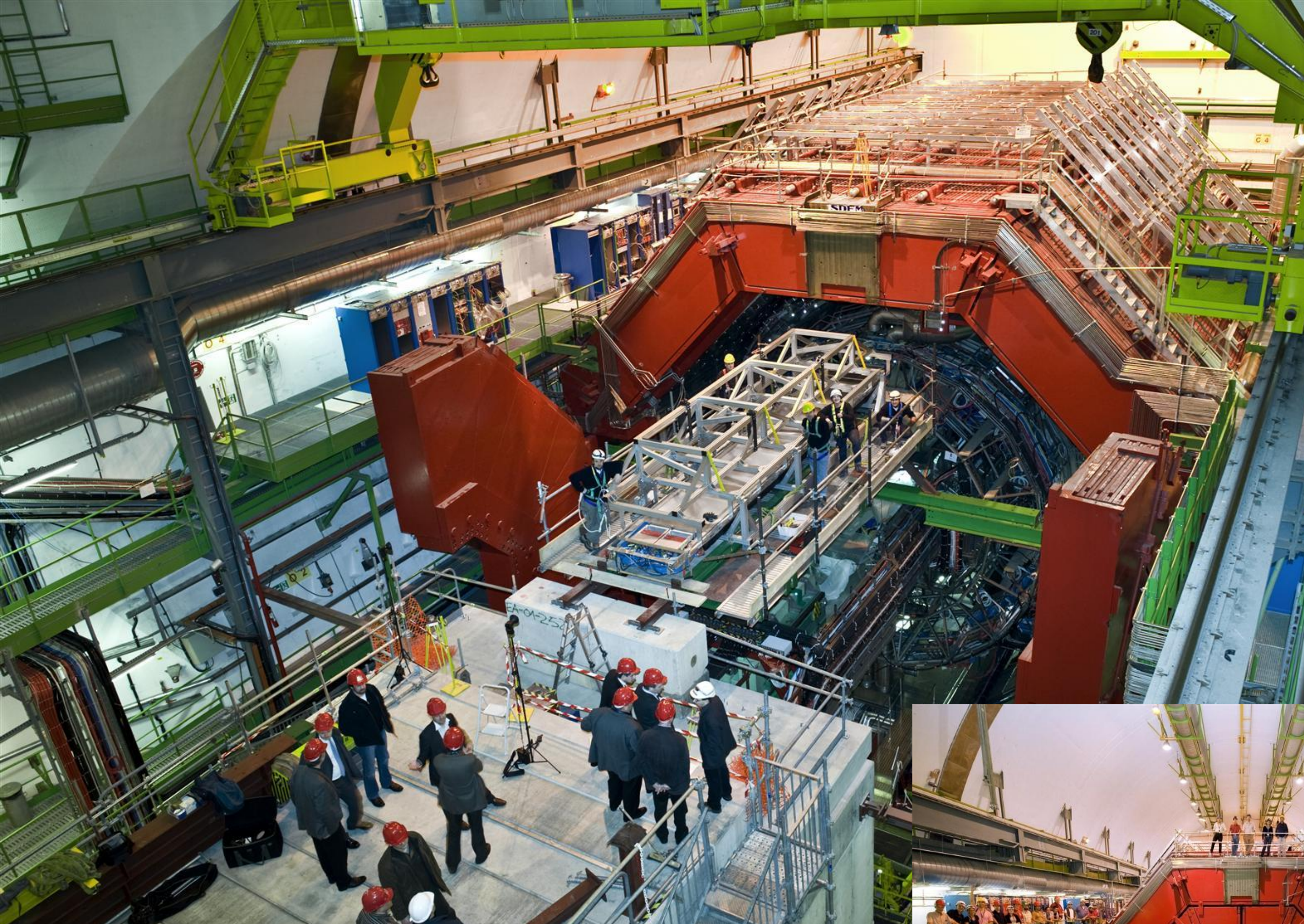
ALICE: study of quark-gluon plasma

- 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

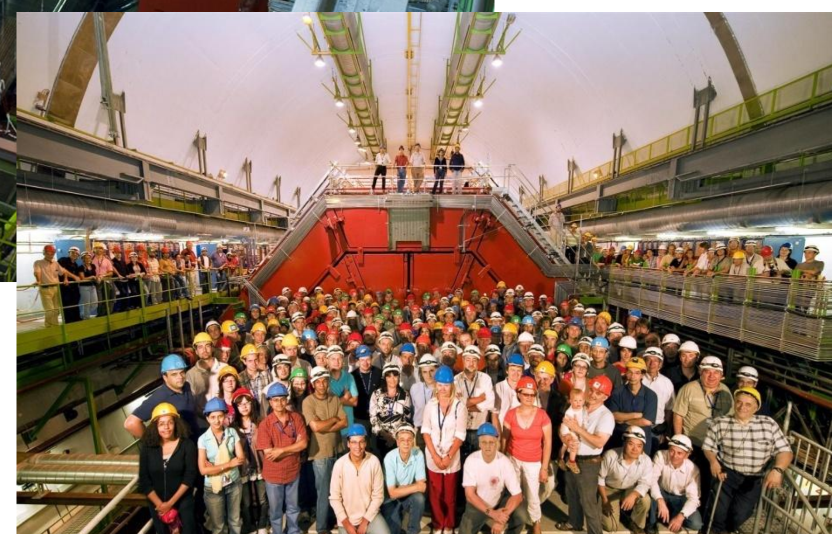


Univ. of Cape Town and iThemba Lab are ALICE members since 2001 and 2008

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



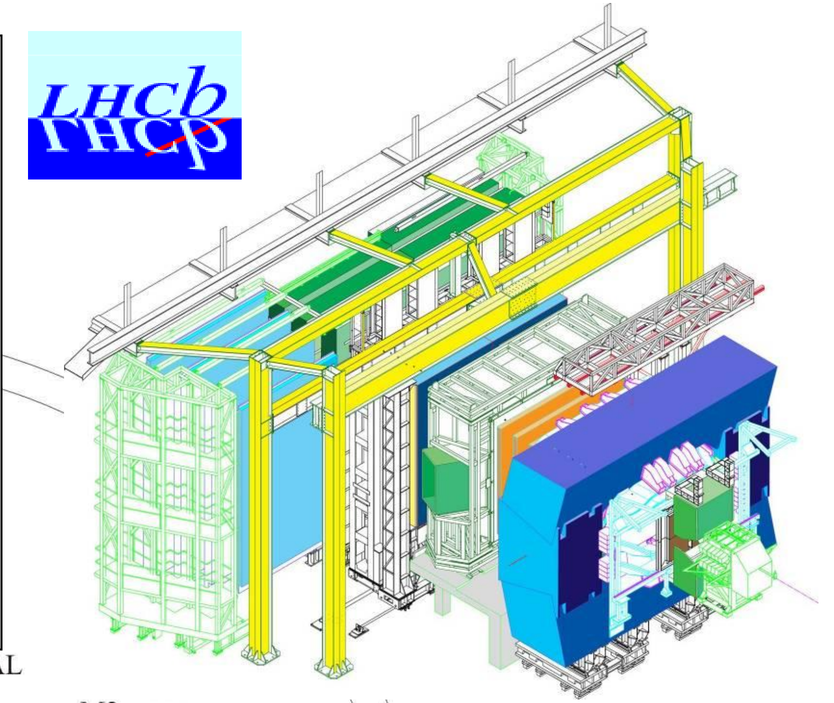
Installation of a ALICE TOF module May 2008

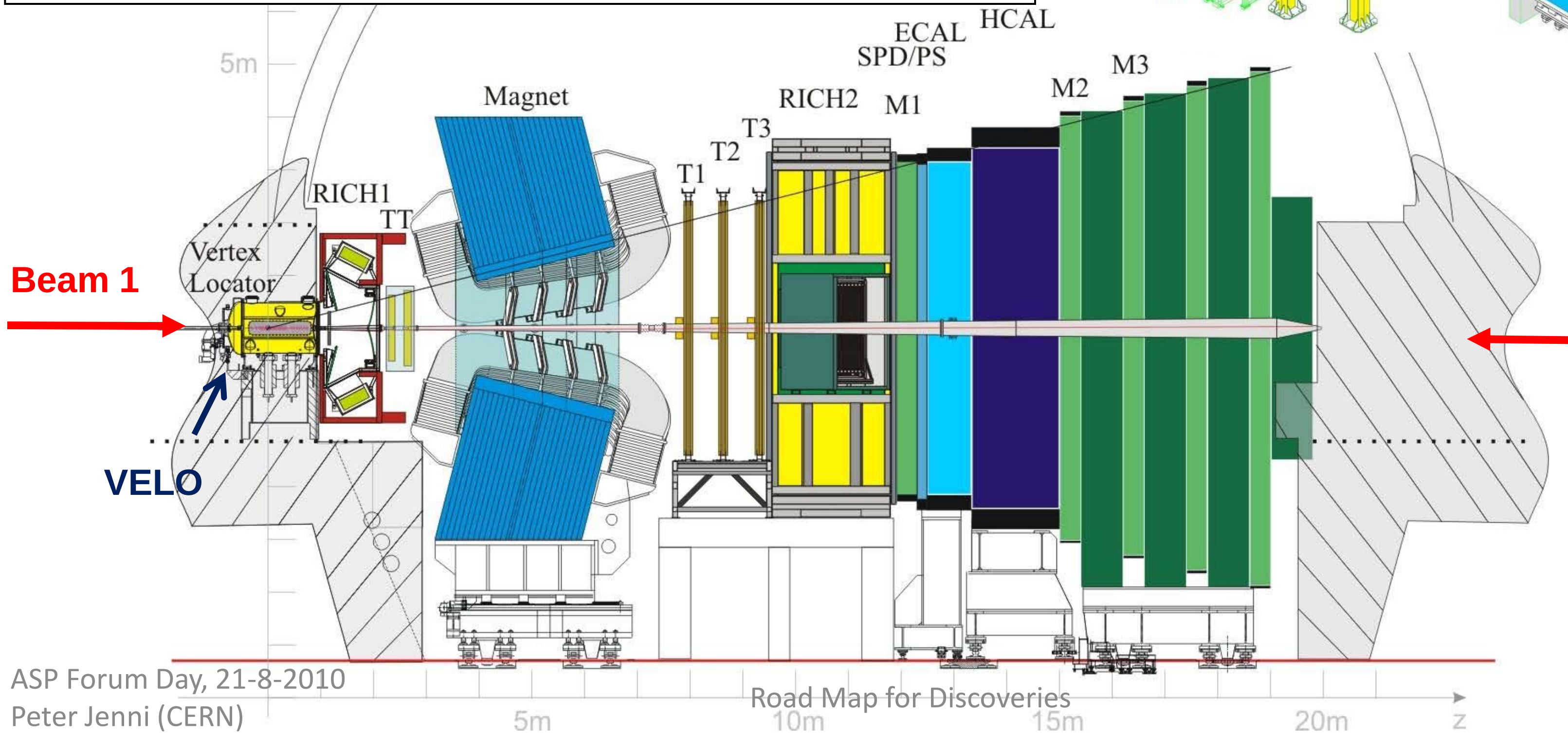


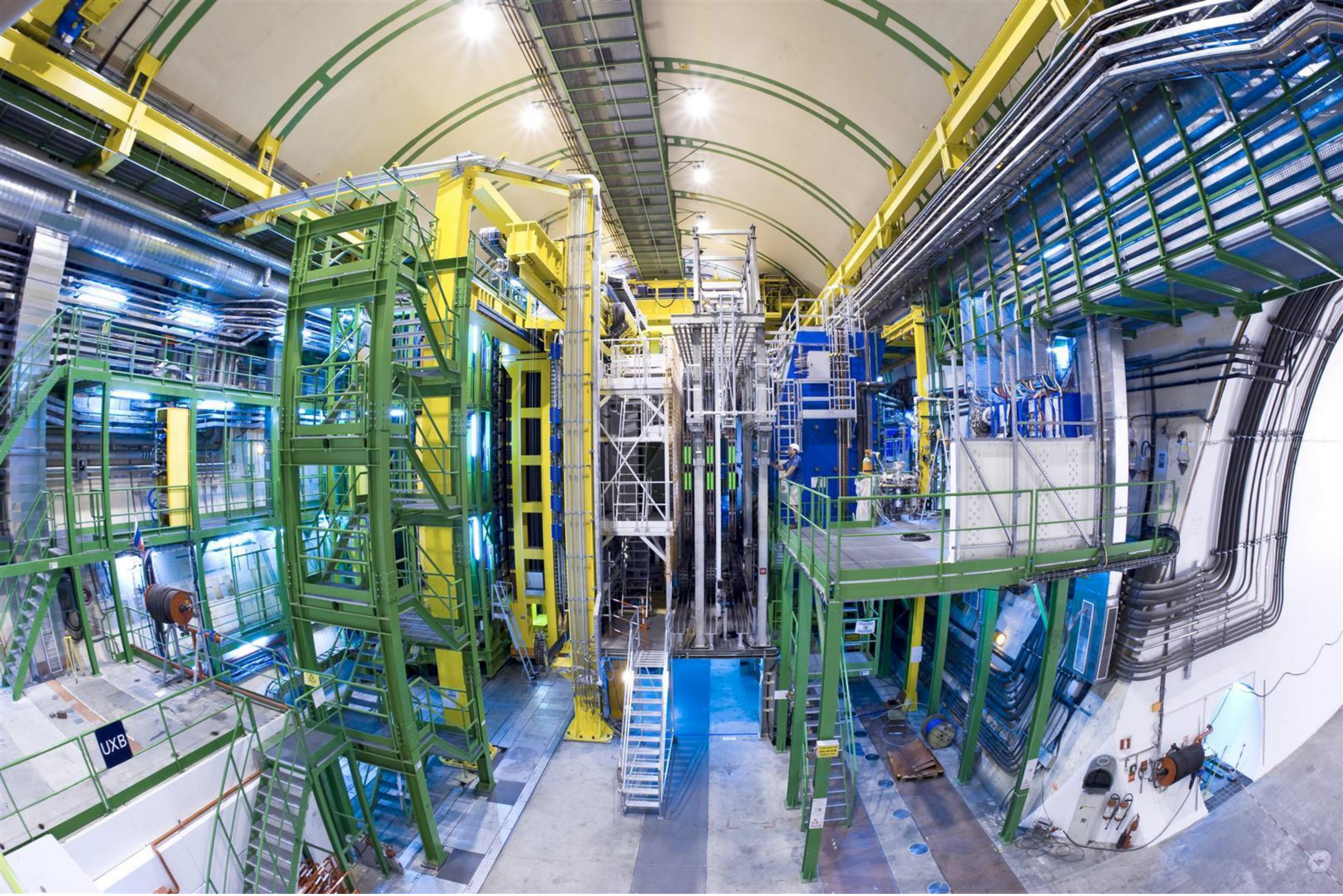
Formal end of ALICE installation July 2008

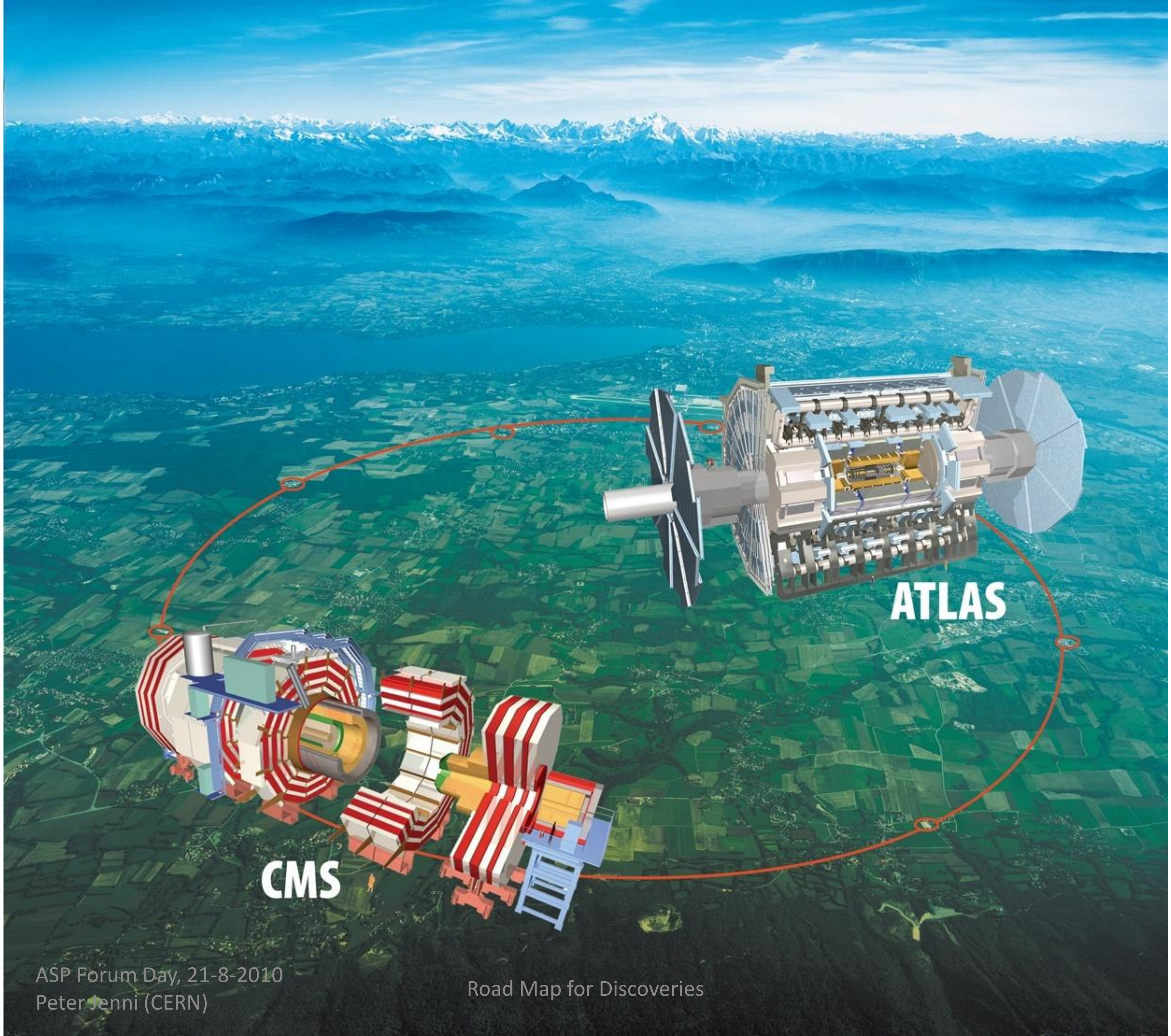
LHCb:
Study of B decays and CP Violation
(indirect search for New Physics)

- 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

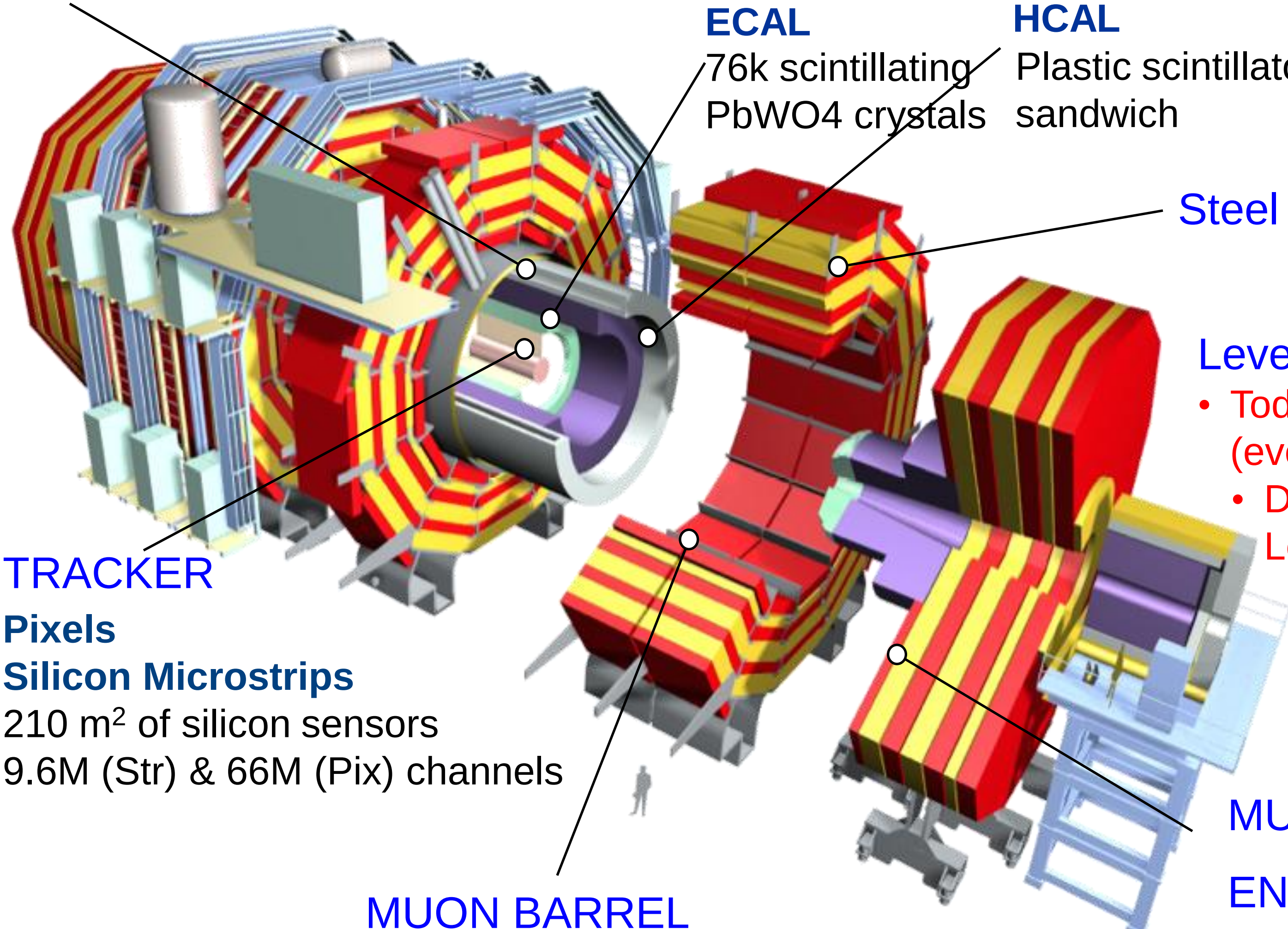




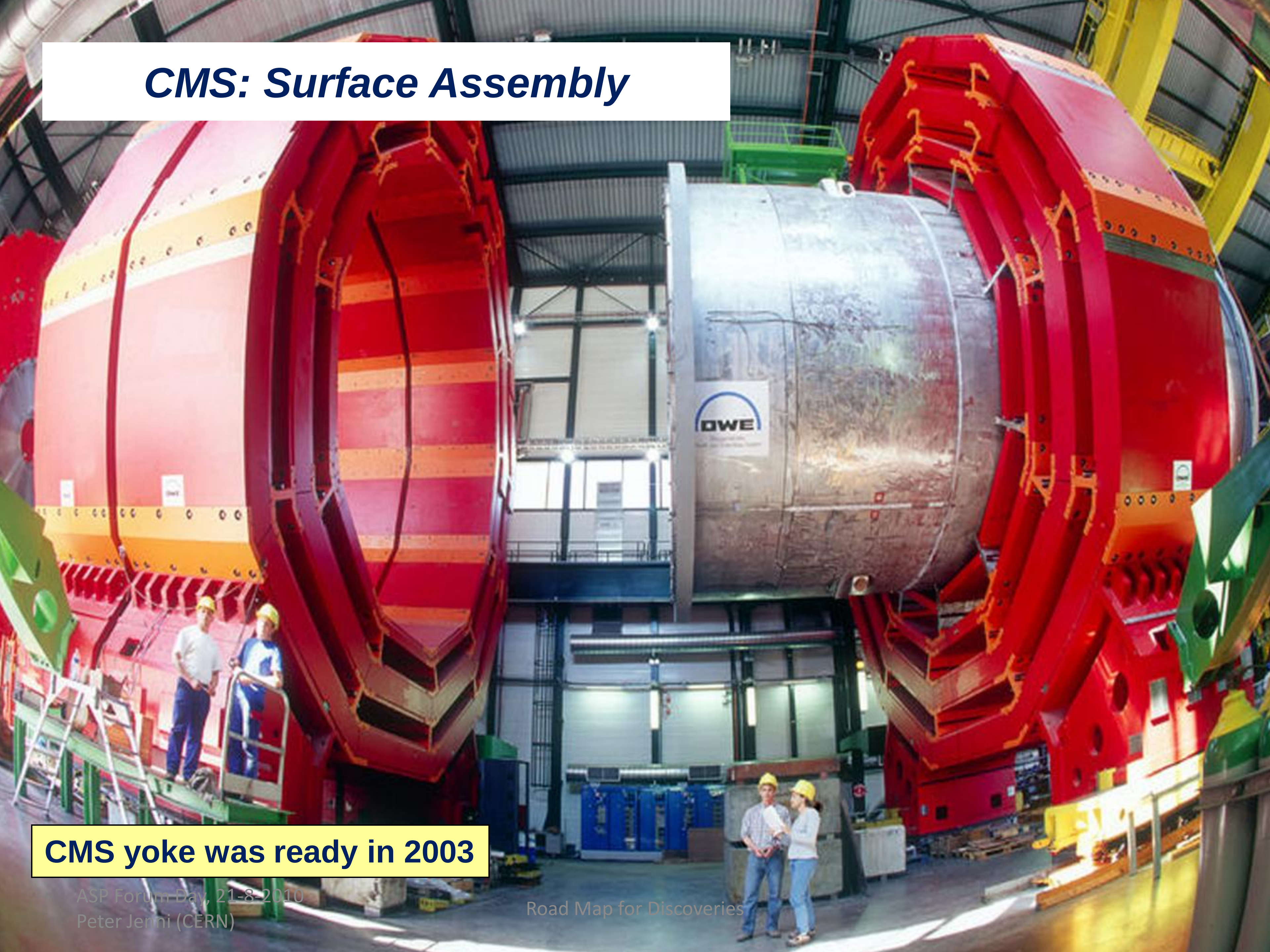

UXB


ATLAS
CMS

CMS Detector

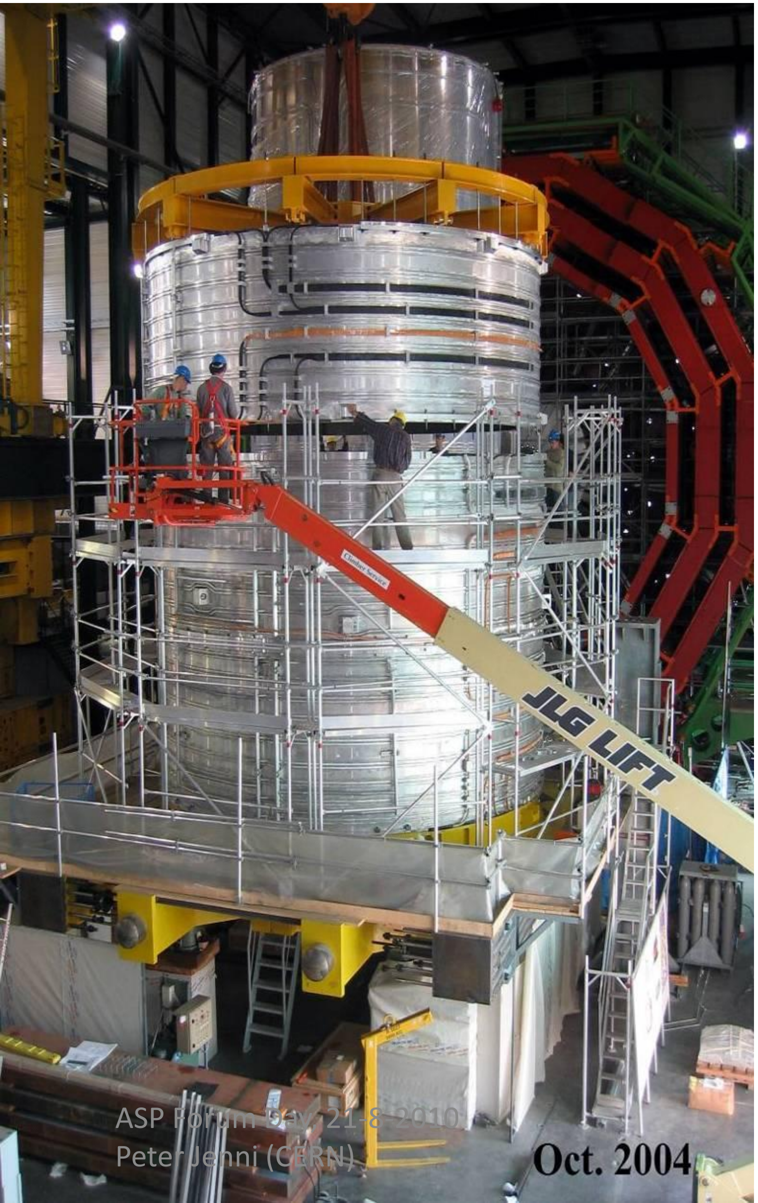


CMS: Surface Assembly



CMS yoke was ready in 2003

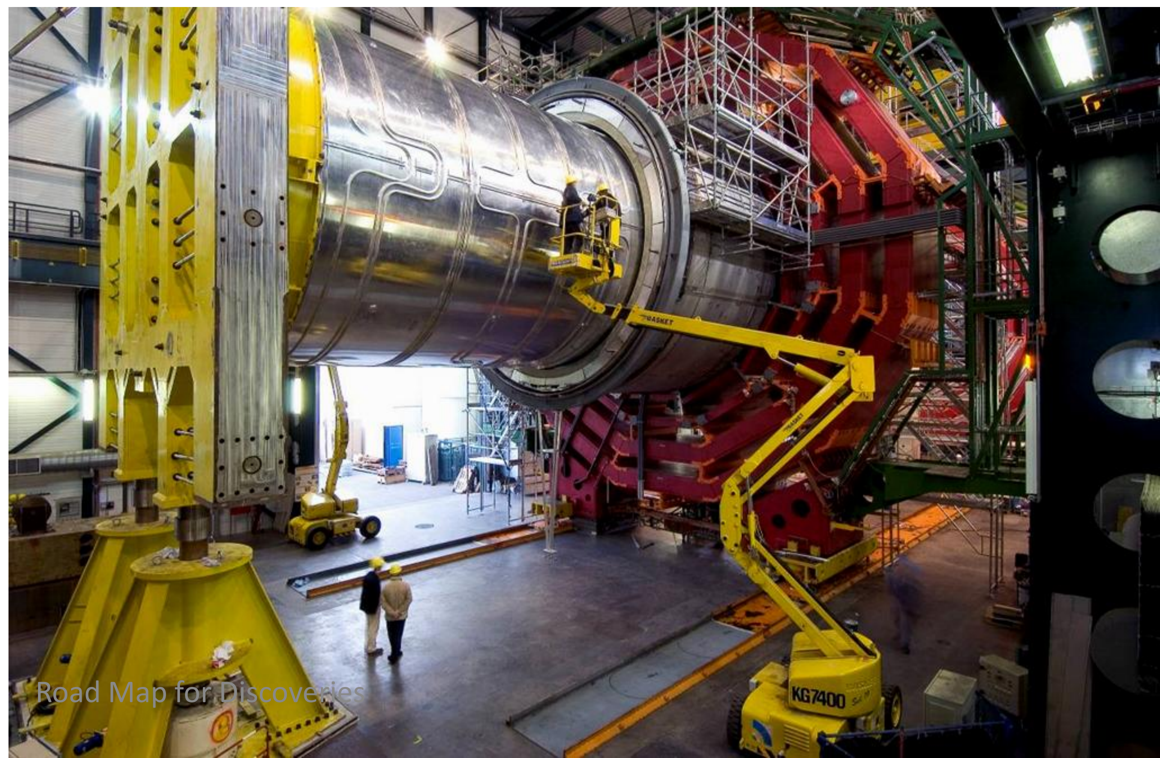
Example of an Engineering Challenge: CMS Solenoid



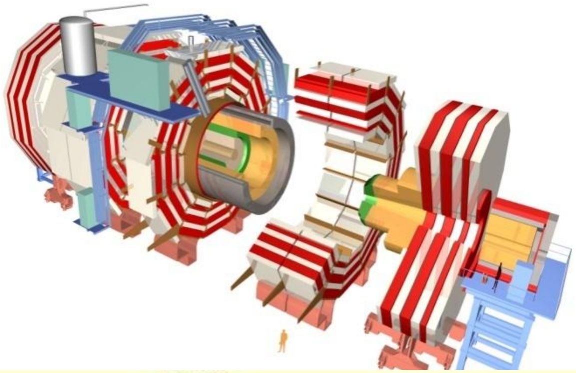
<u>CMS solenoid:</u>

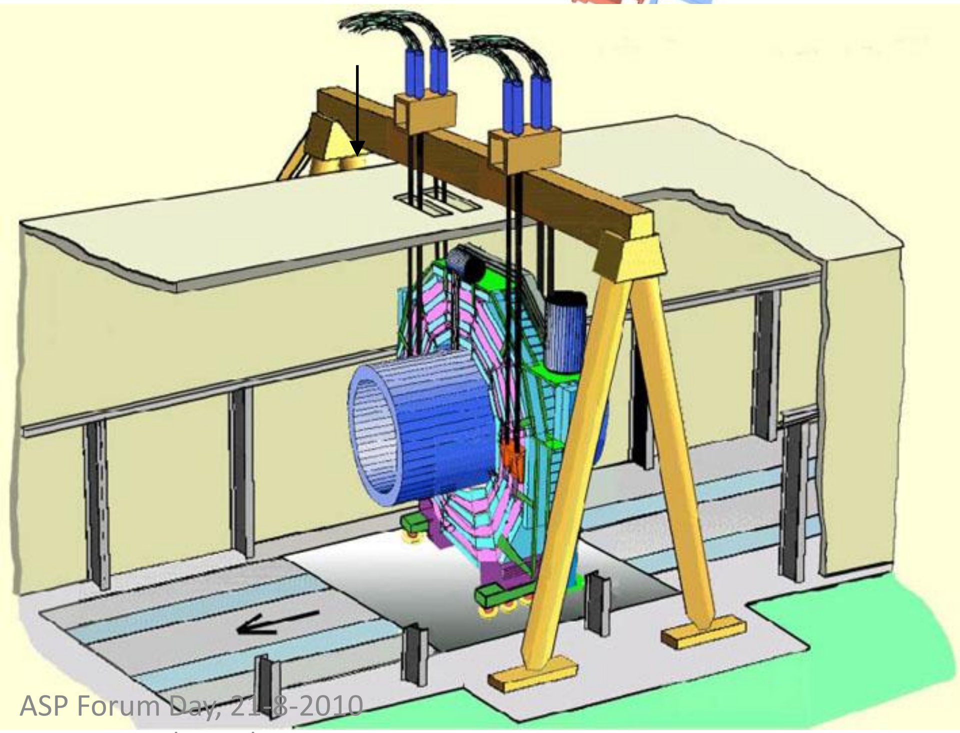
Magnetic length	**12.5 m**
Diameter	**6 m**
Magnetic field	**4 T**
Nominal current	**20 kA**
Stored energy	**2.7 GJ**

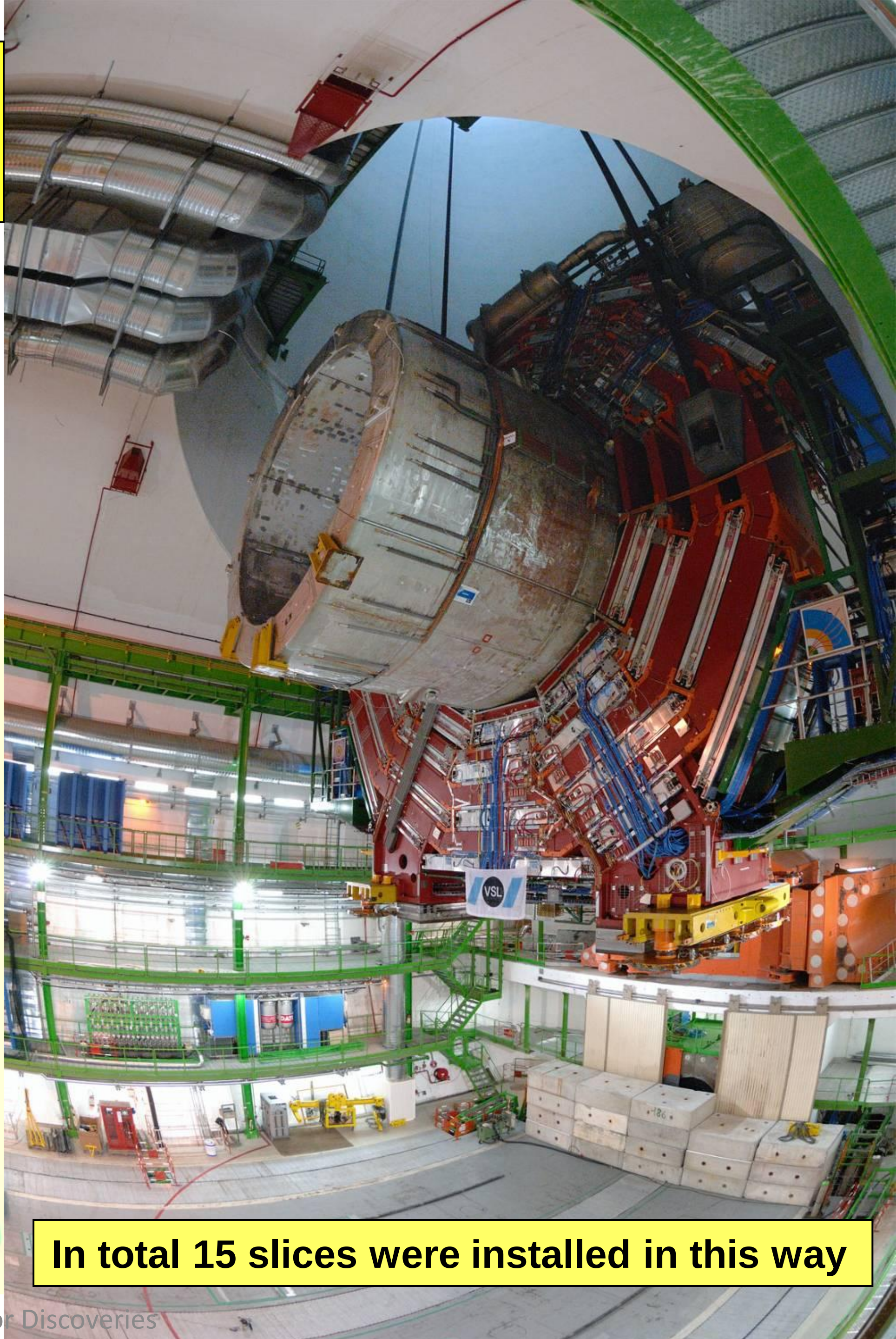
Tested at full current in Summer 2006



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



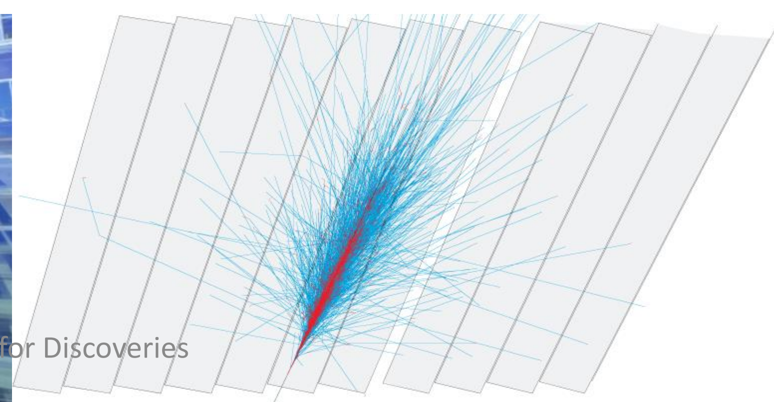




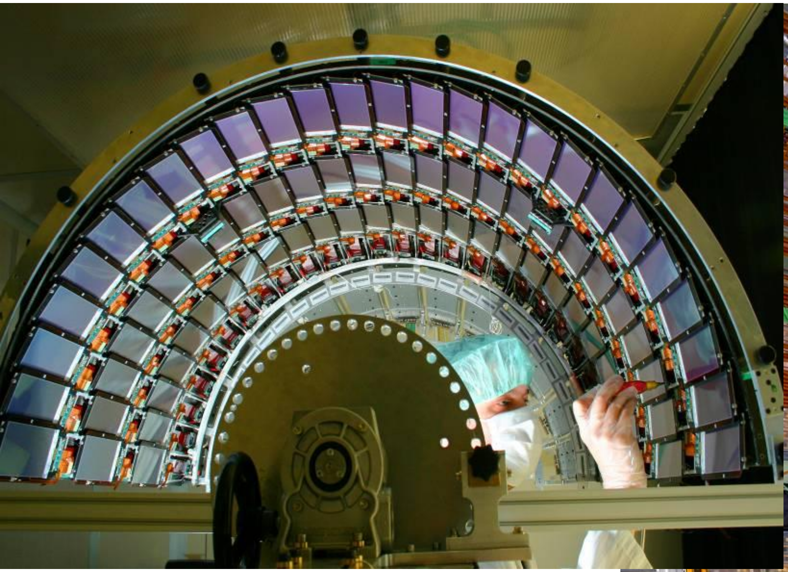
In total 15 slices were installed in this way

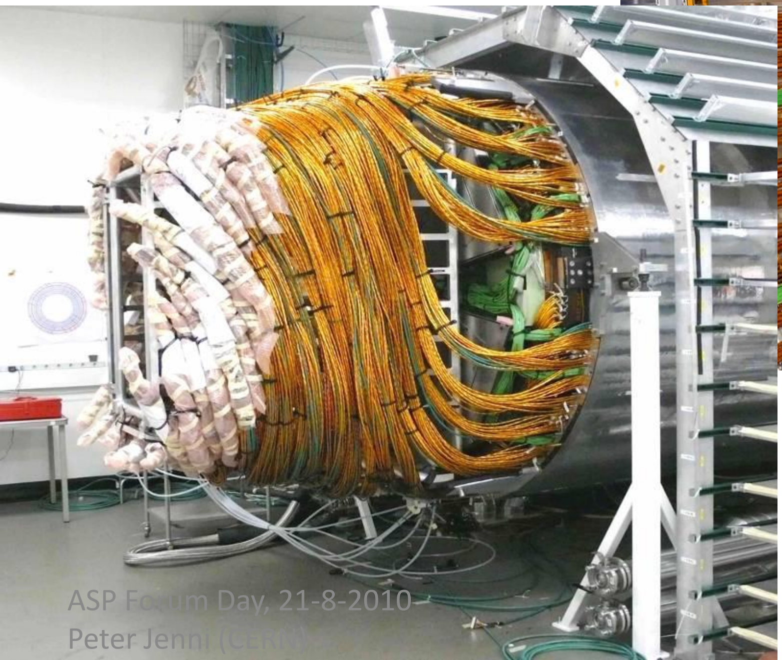
CMS Electron and Photon calorimeter: 76 000 $PbW0_4$ crystals

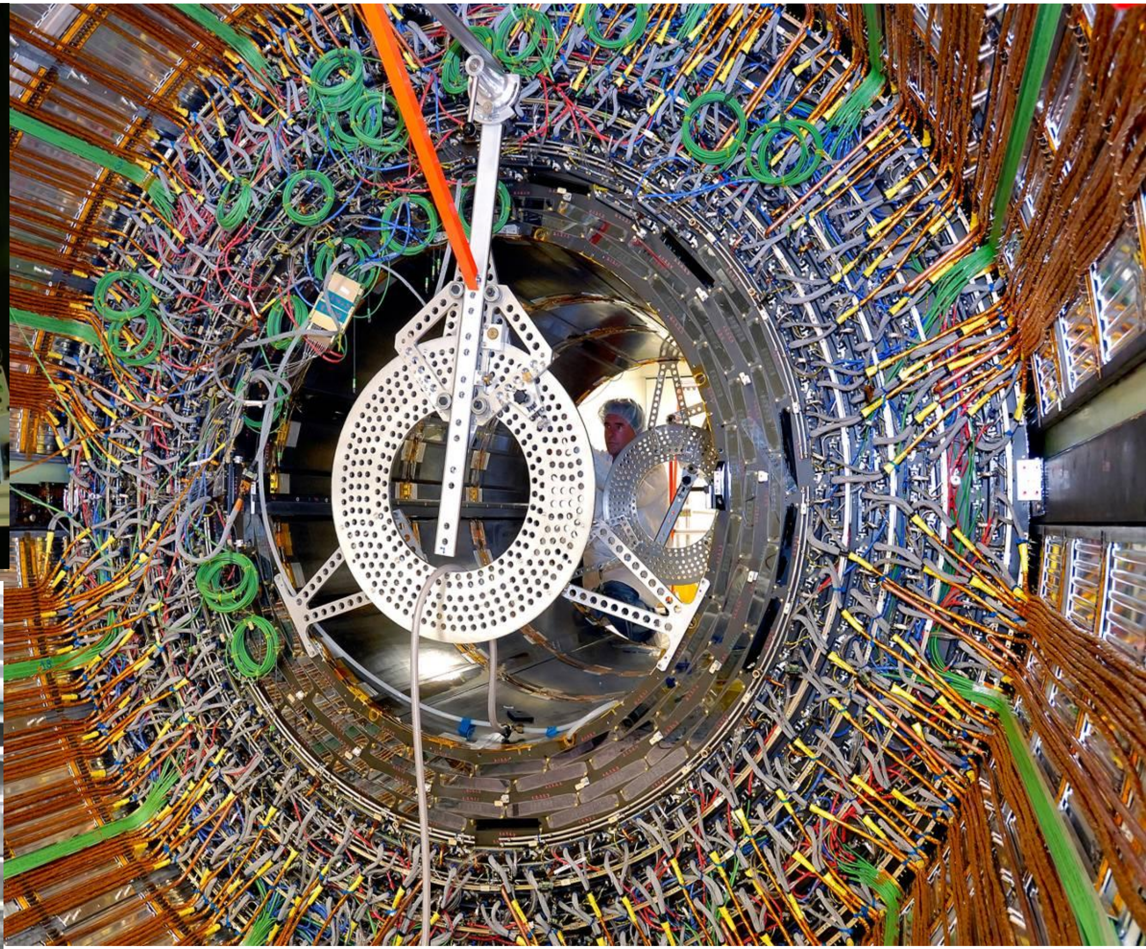
The End-cap was on the critical path for many years, but it was completed just in time before final closure, a major achievement by CMS



CMS Silicon Tracker







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

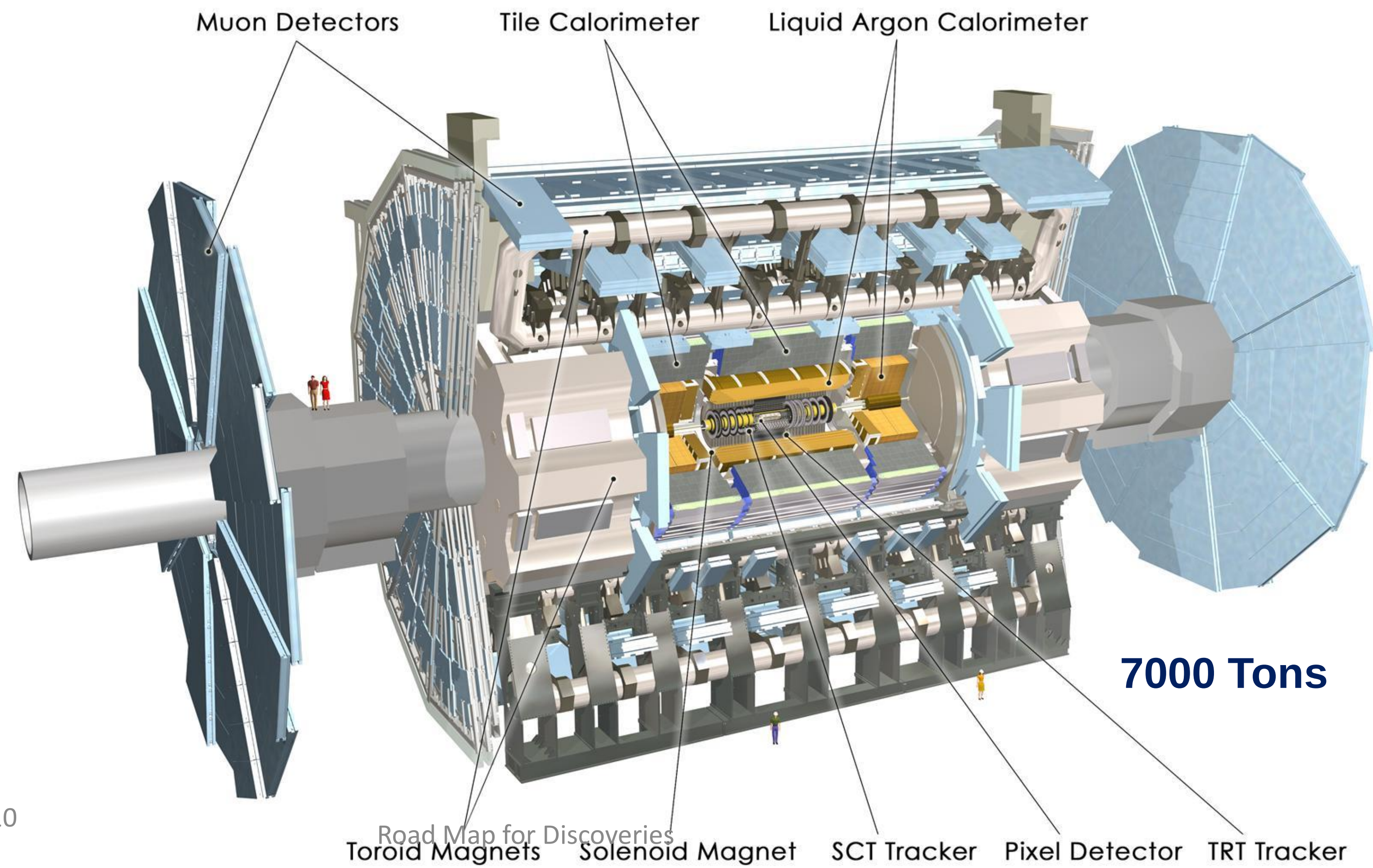
CMS before closure

ATLAS Detector

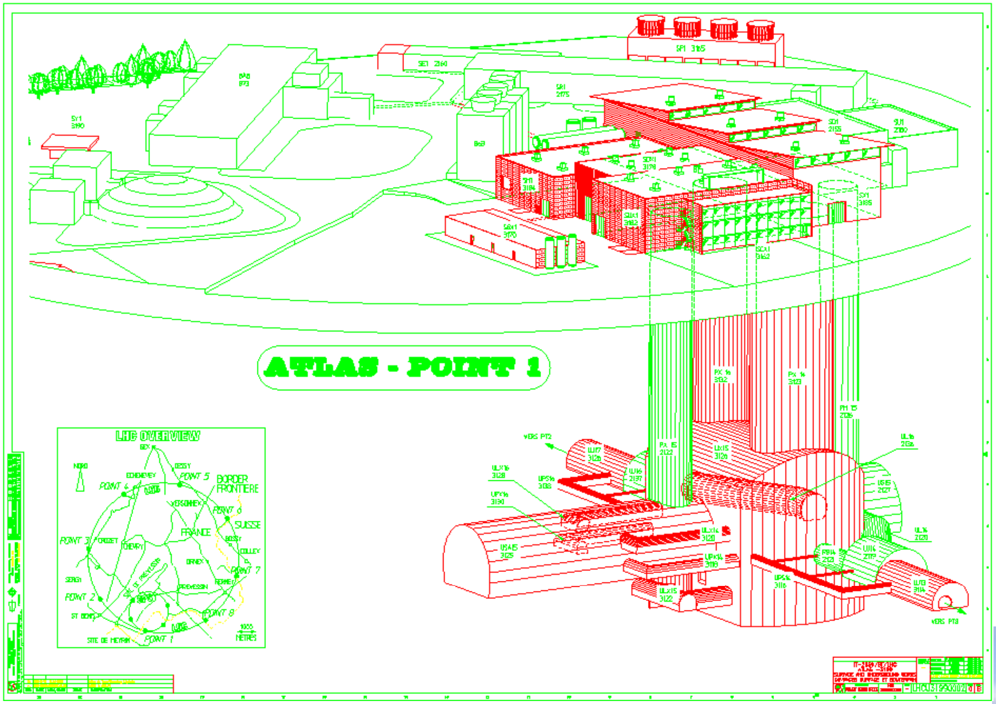
ATLAS superimposed to
the 5 floors of building 40

45 m

24 m

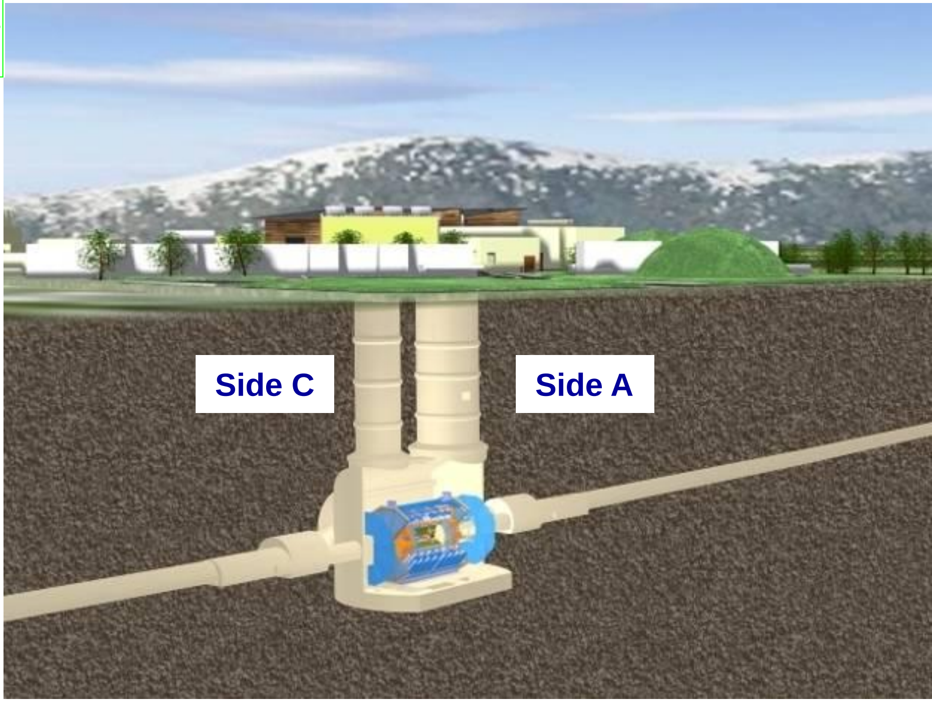


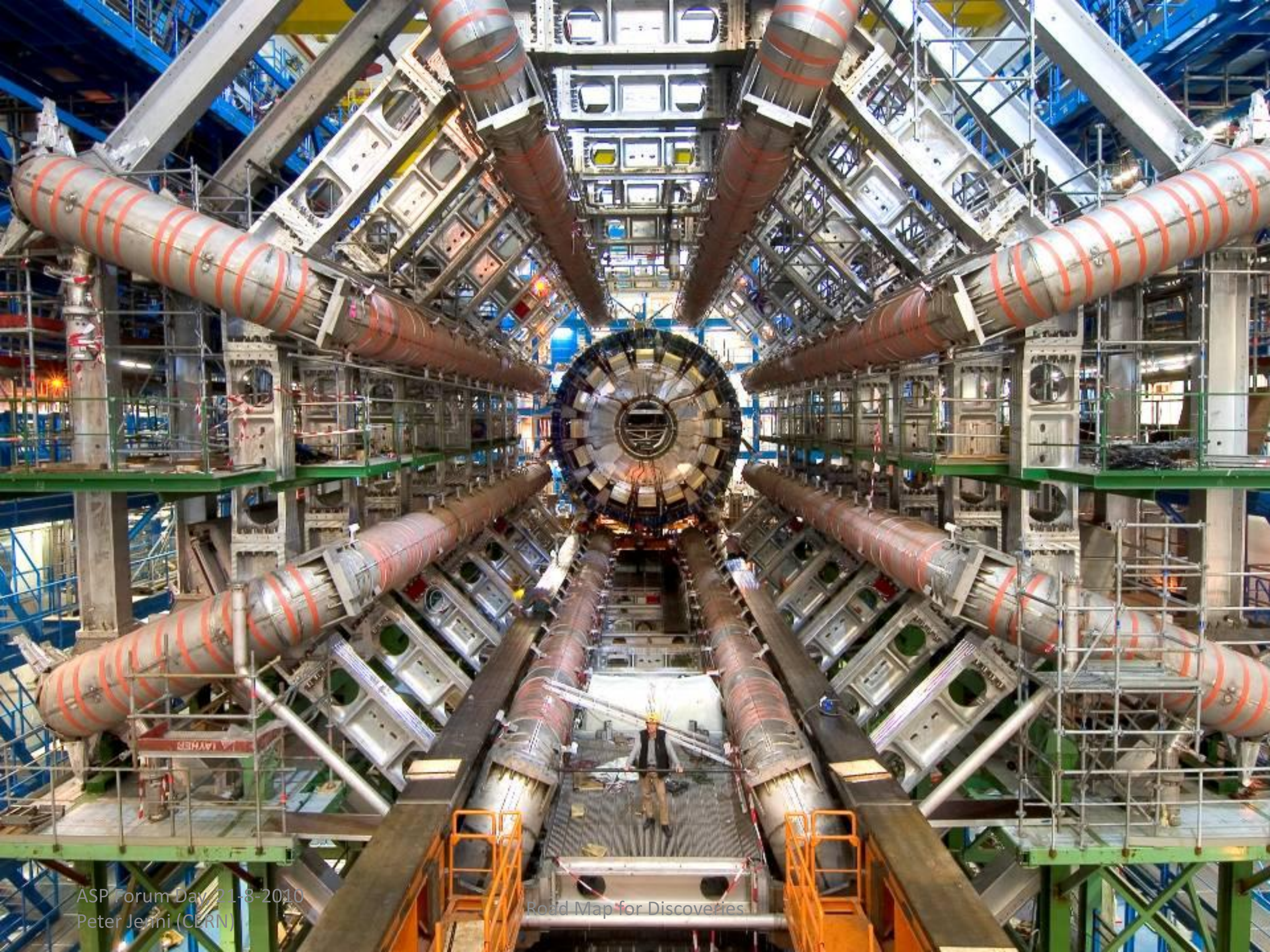
7000 Tons



The Underground Cavern at Point-1 for the ATLAS Detector

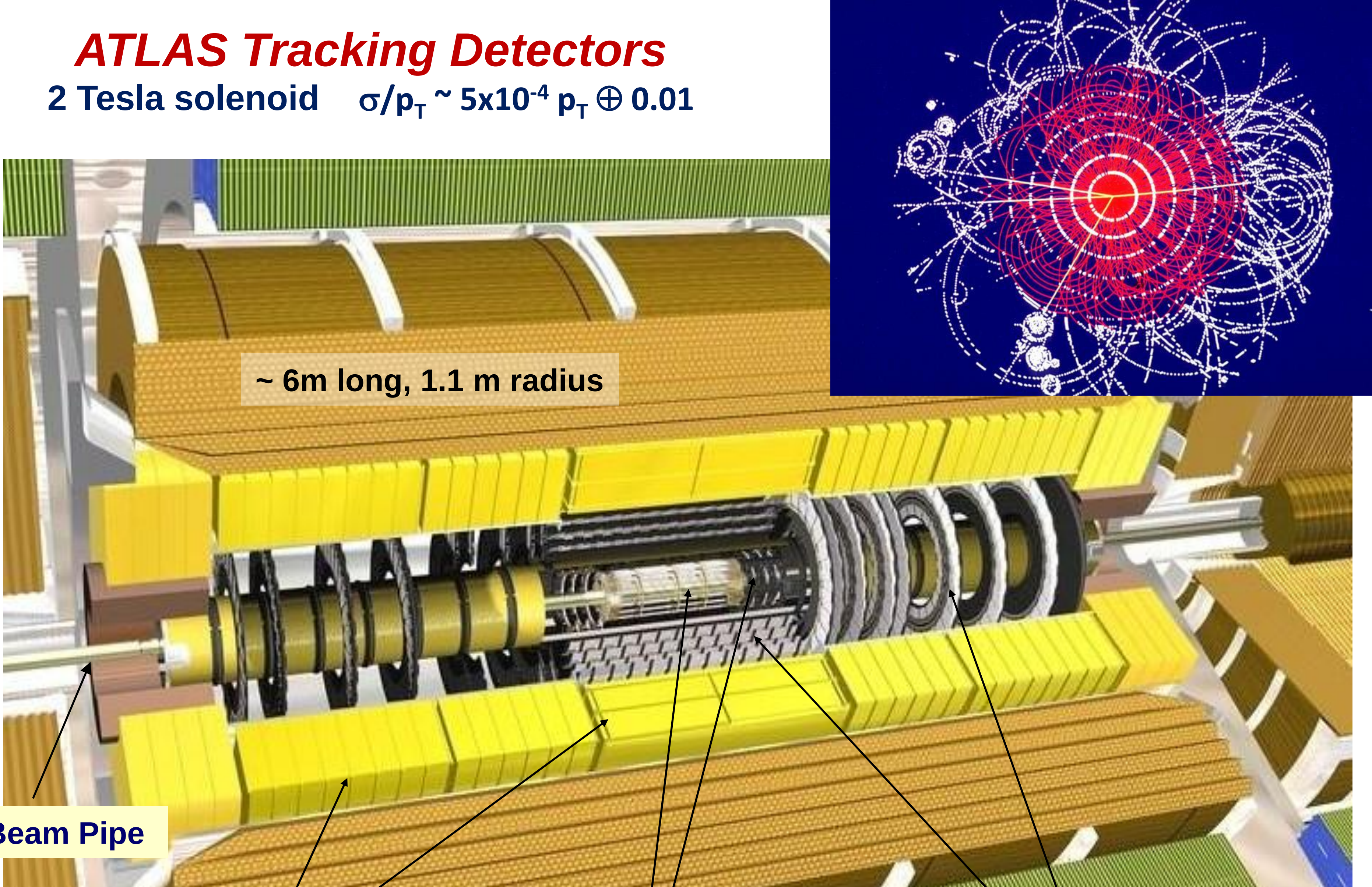
Length = 55 m
Width = 32 m
Height = 35 m



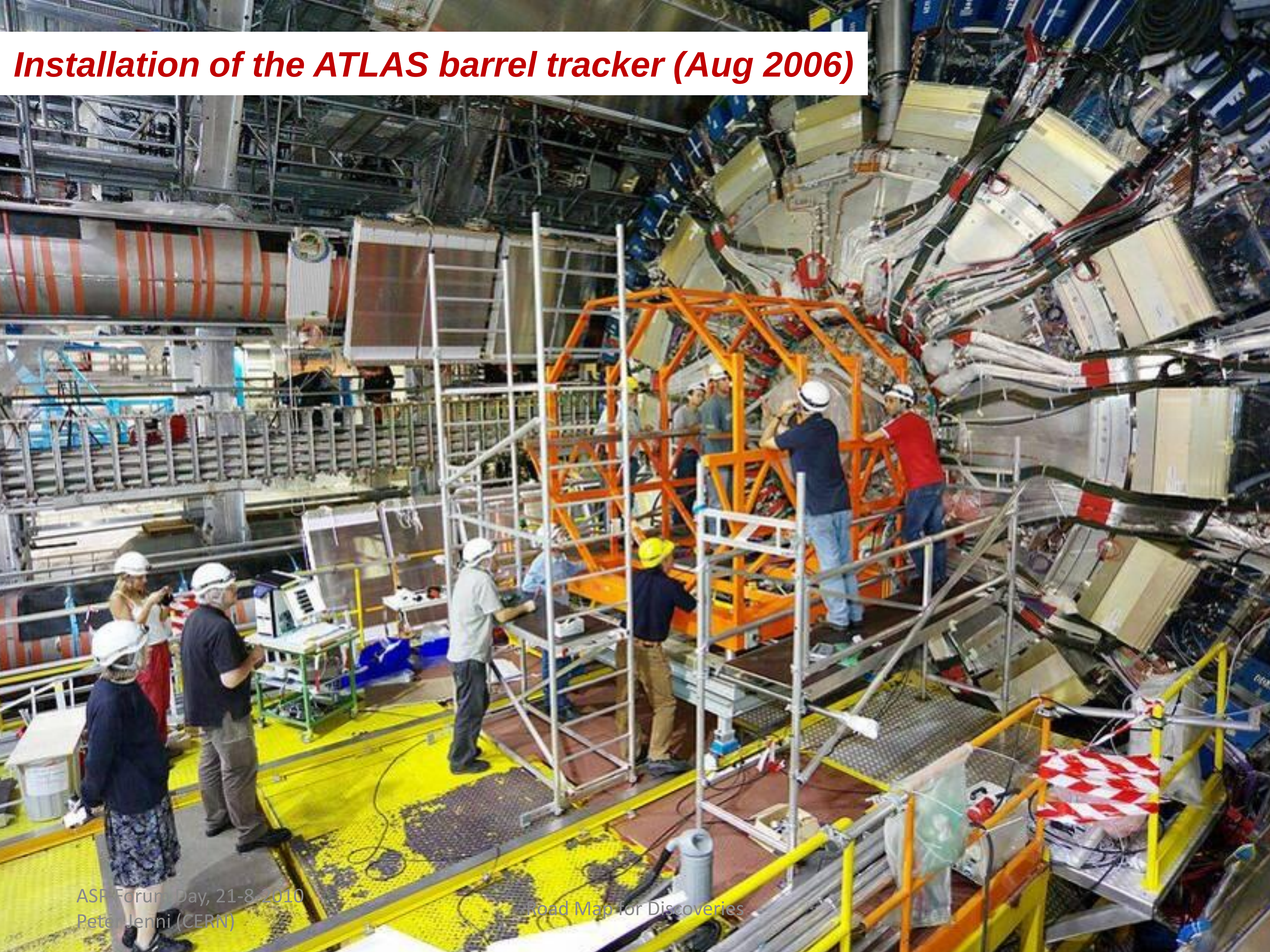


ATLAS Tracking Detectors

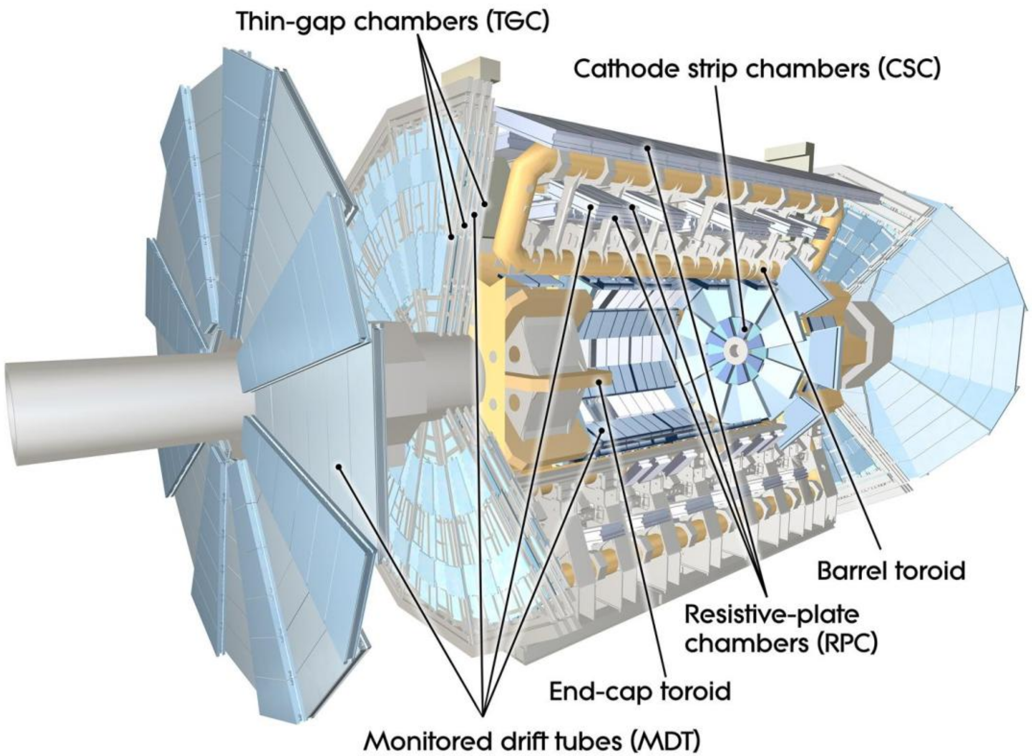
2 Tesla solenoid $\sigma/p_T \sim 5\times10^{-4}\, p_T \oplus 0.01$



Installation of the ATLAS barrel tracker (Aug 2006)



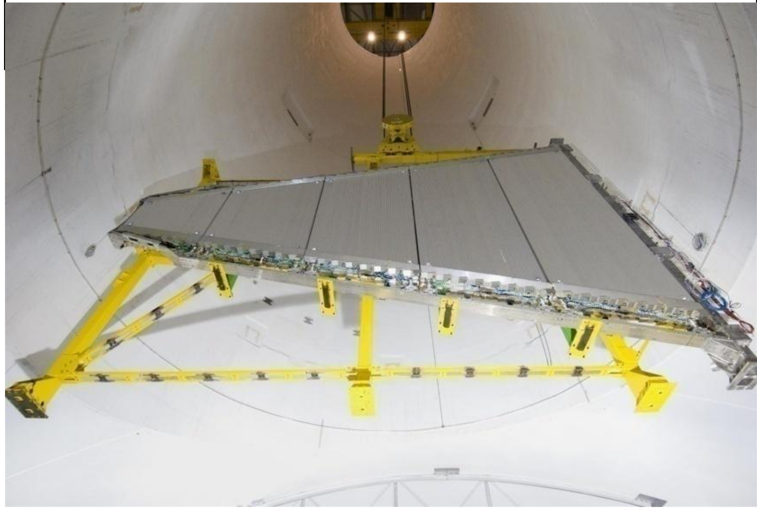
Muon System

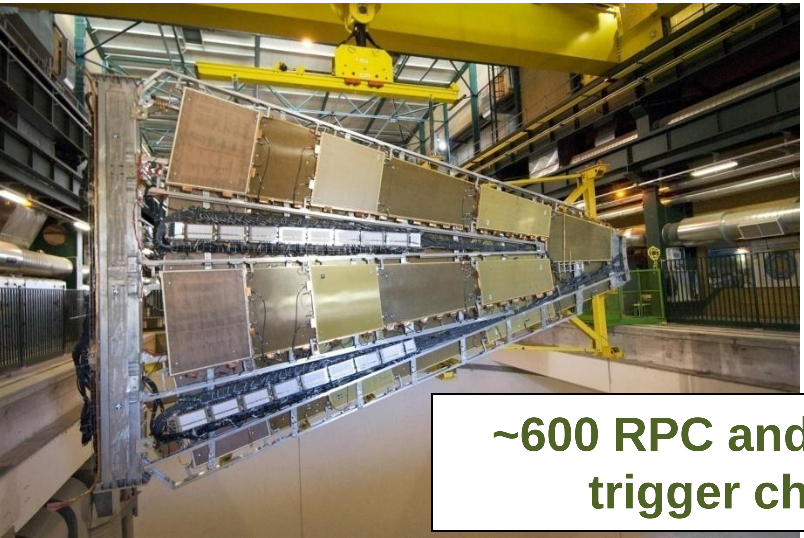


Stand-alone momentum resolution $\Delta pT/pT$ < 10% up to 1 TeV

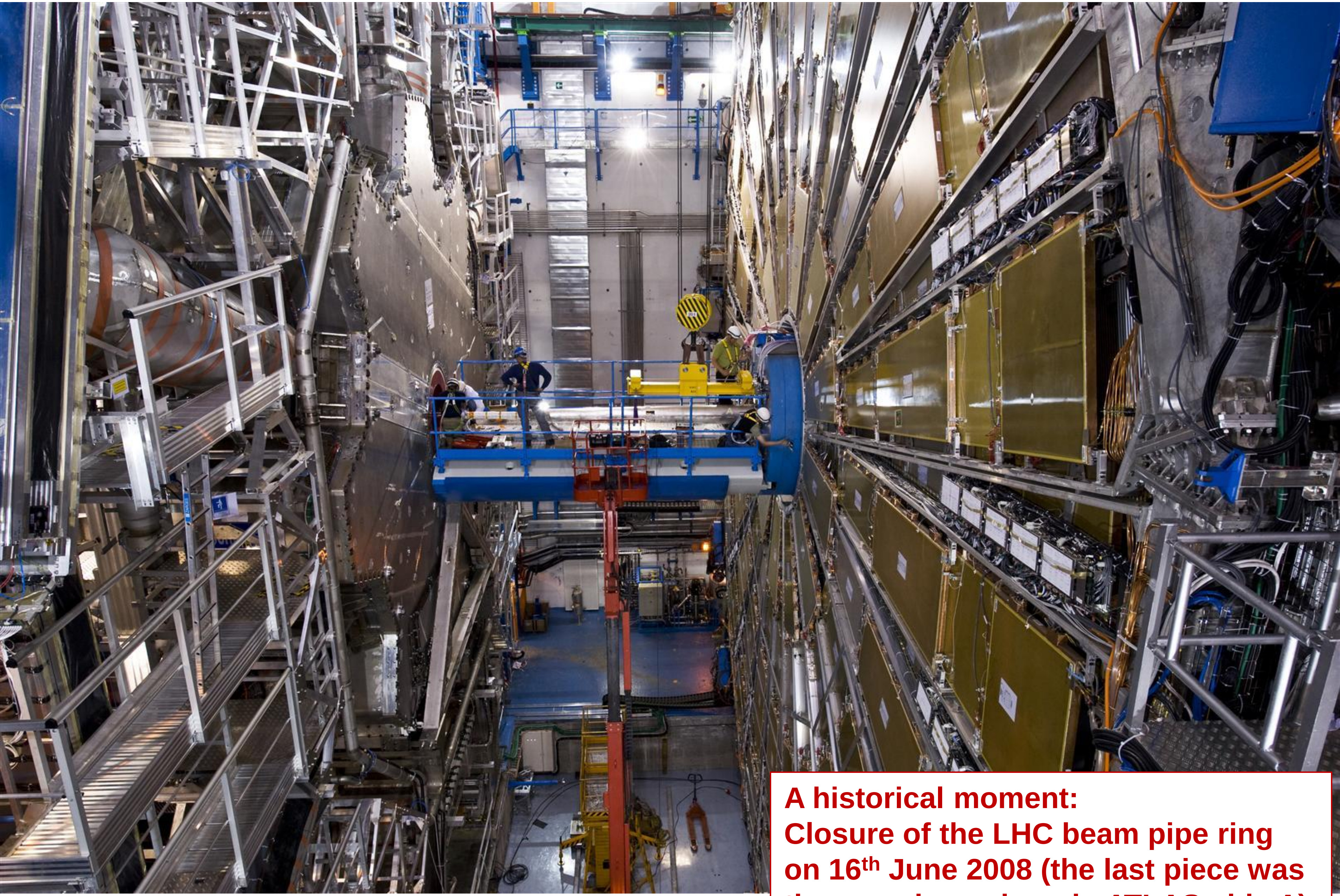
2-6 Tm $|\eta|<1.3$ 4-8 Tm $1.6<|\eta|<2.7$

~1200 MDT precision chambers for track



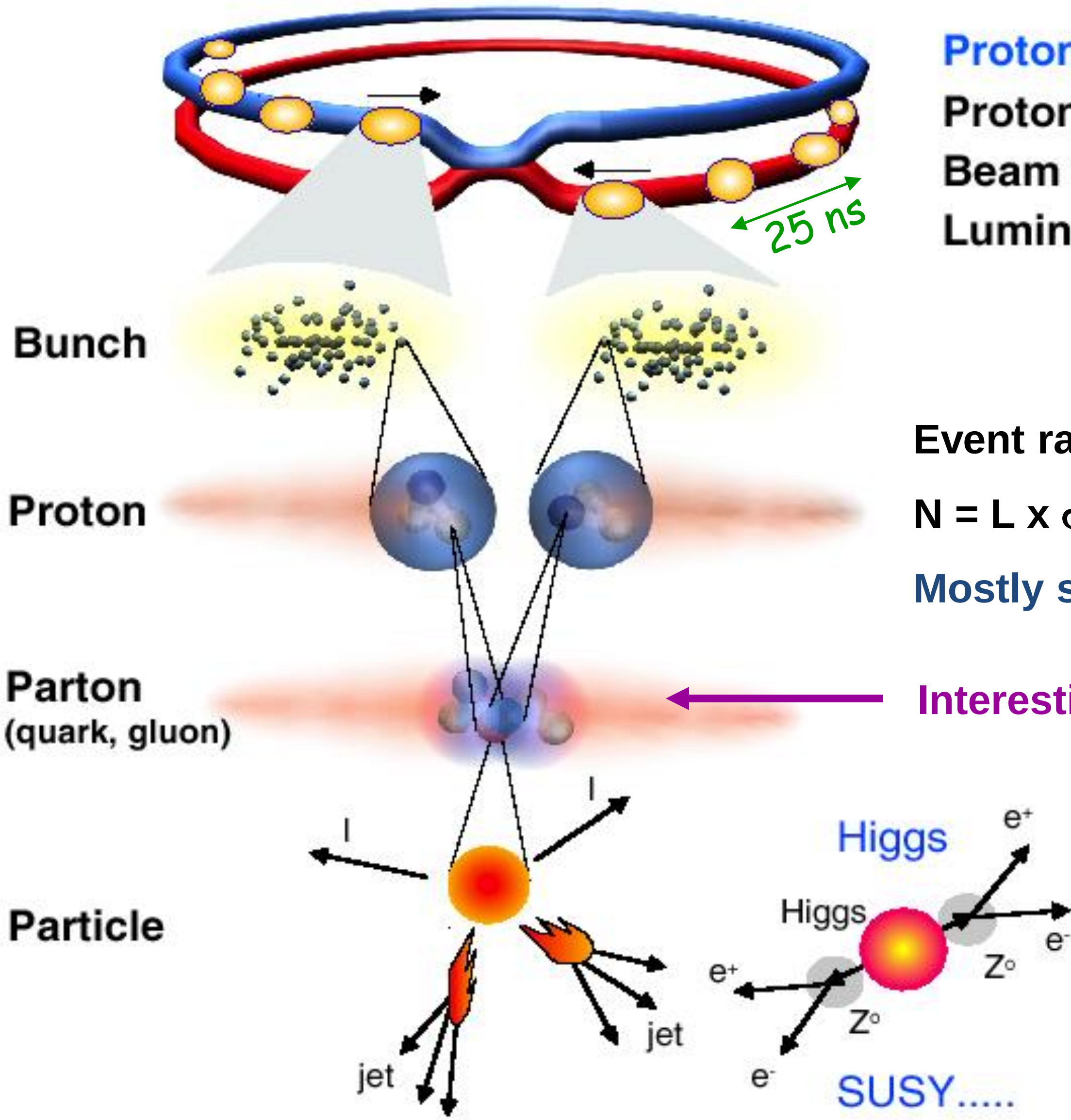


~600 RPC and ~3600 TGC trigger chambers



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) ≈ 10^9 interactions/s

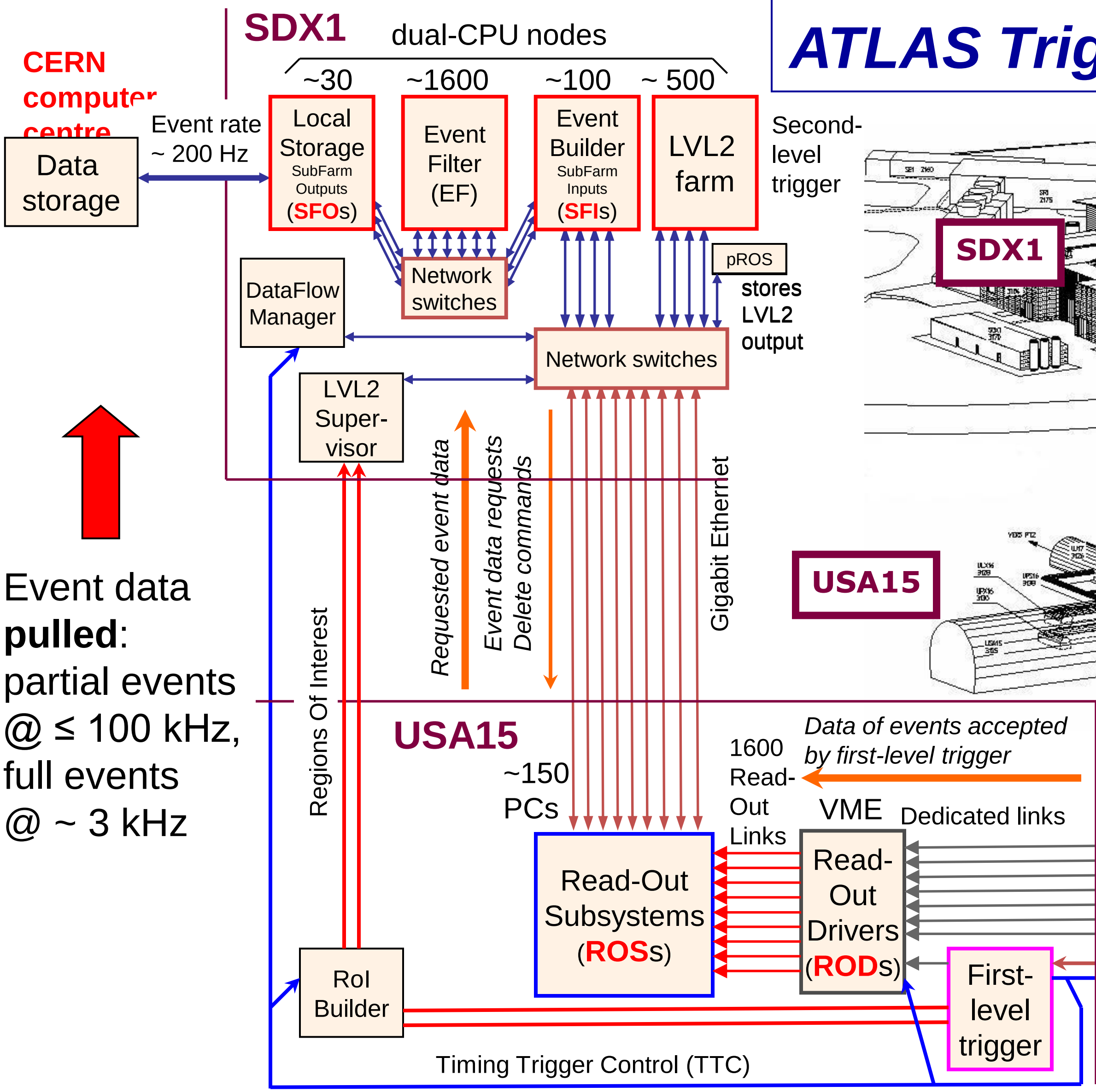
Mostly soft (low p_T) events

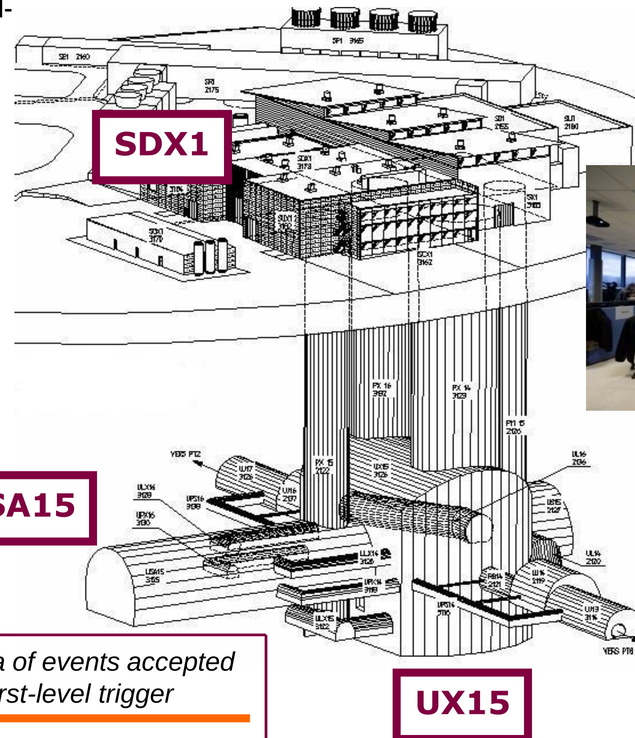
Interesting hard (high-p_T) events are rare

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

→ very powerful detectors needed

As an example: ATLAS Trigger / DAQ Data Flow





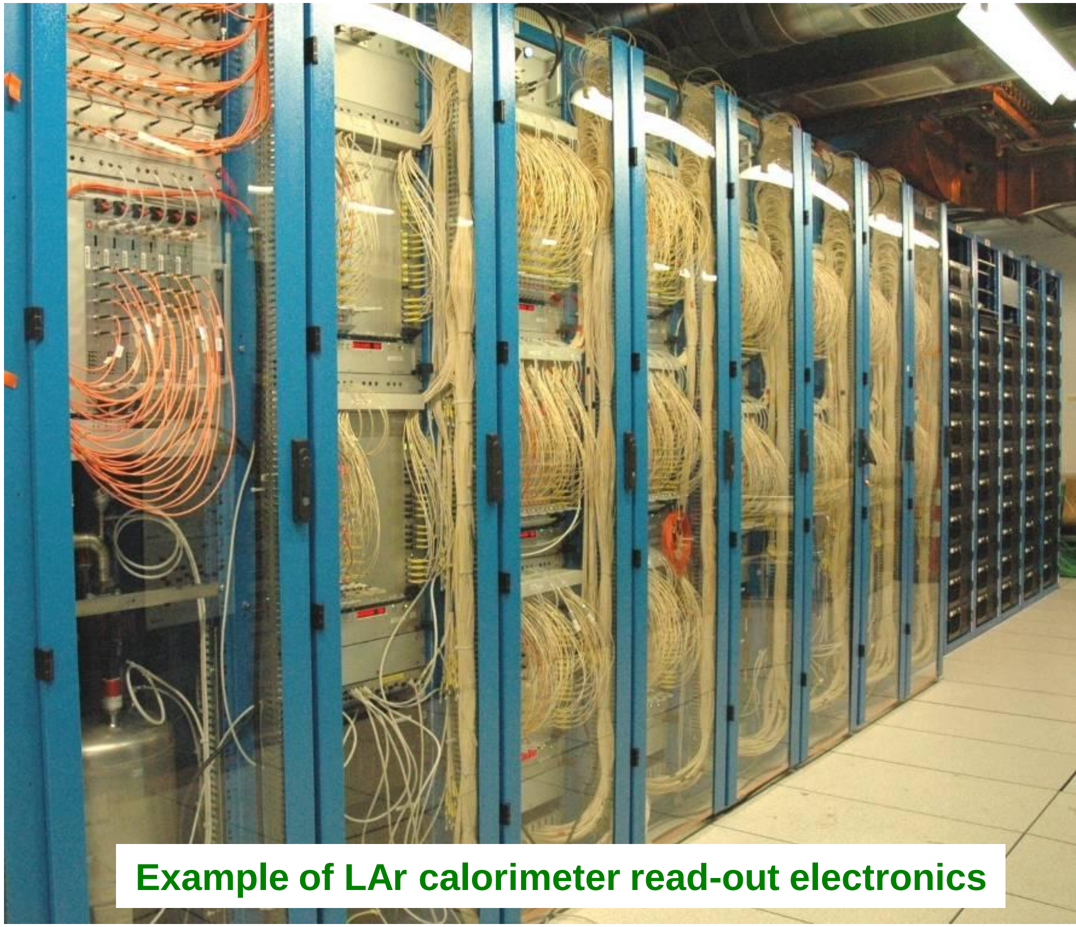
Event data **pulled**:
partial events @ ≤ 100 kHz,
full events @ ~ 3 kHz

Event data pushed @ ≤ 100 kHz,
1600 fragments of ~ 1 kByte each

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 Collaboration

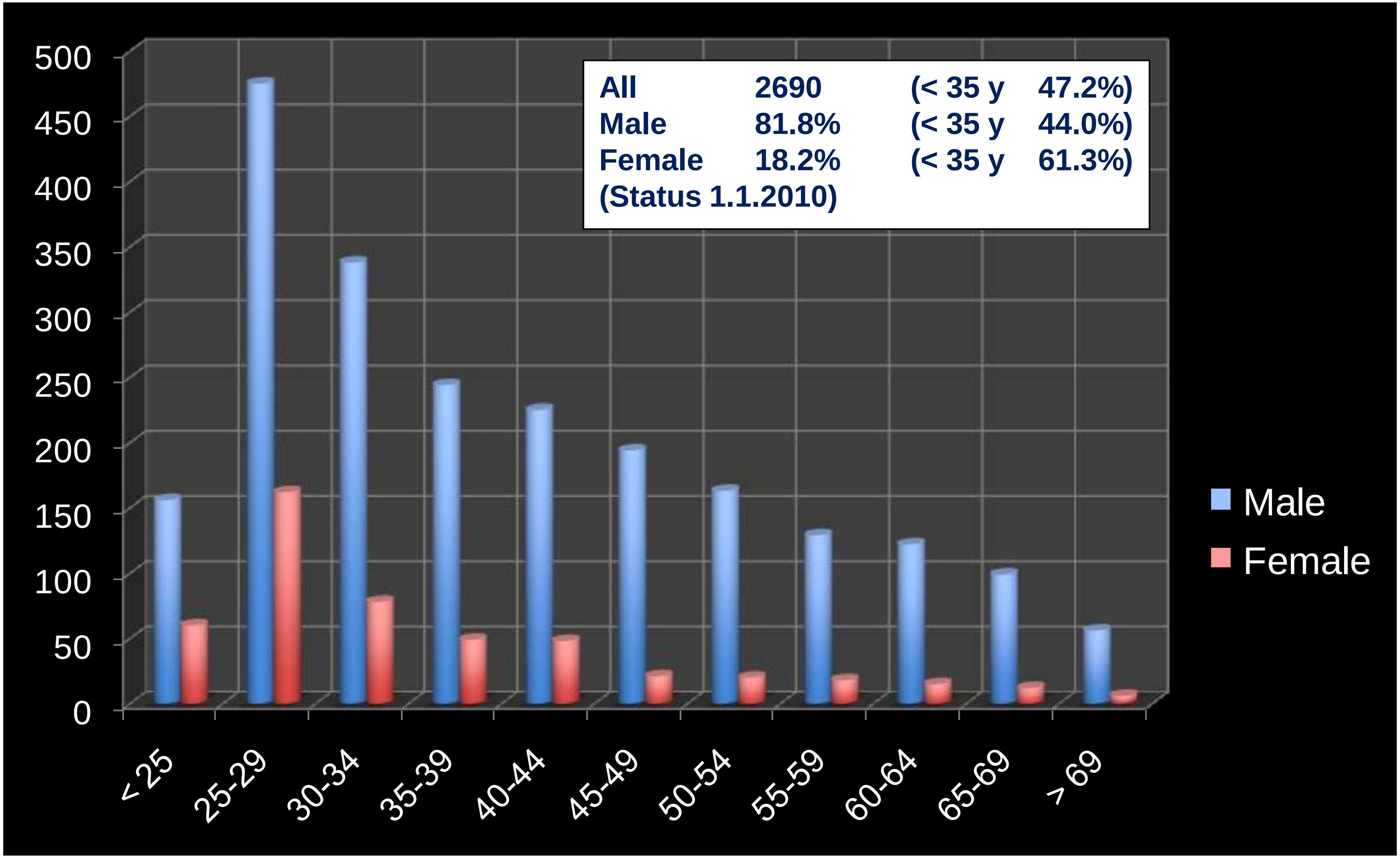
(Status August 2010)

38 Countries
174 Institutions
3000 Scientific participants total
(1000 Students)

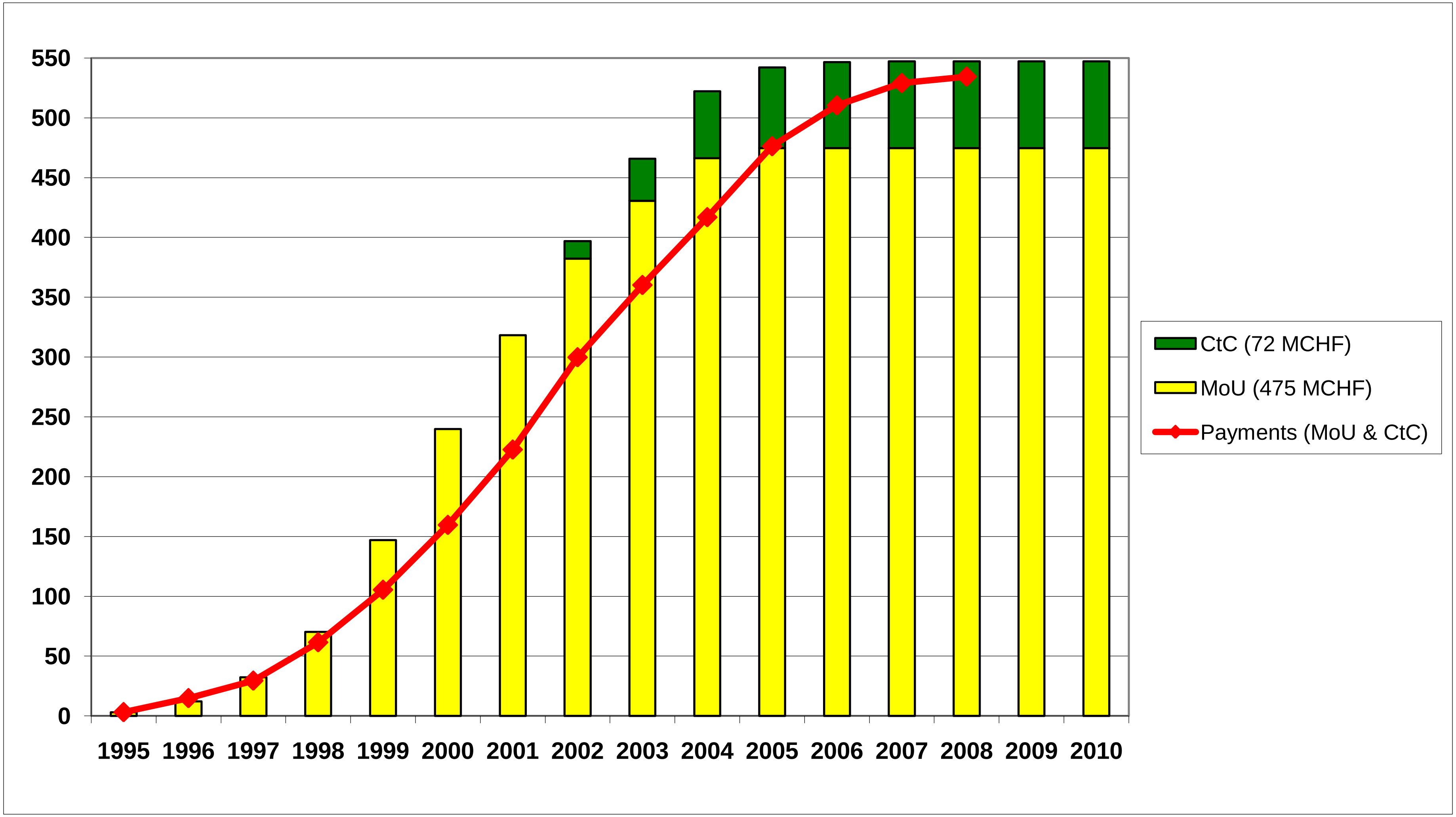
In July 2010 South Africa was unanimously admitted as Collaboration member, with the Institutes of the University of Johannesburg and the University of the Witwatersrand (and open to others in the future)

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, NPI Petersburg, 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, **South Africa**, 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

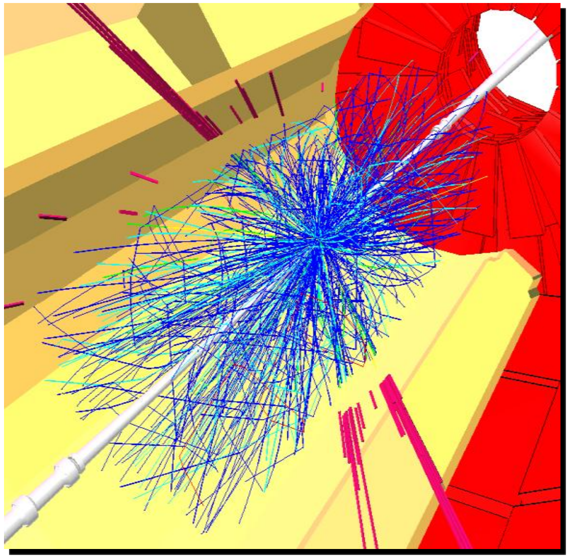
Age distribution of the ATLAS population



Overview of the integrated financial evolution of the 'CORE' costs of ATLAS (Construction MoU deliverables and Common Fund, Cost-to-Completion, in MCHF)



Worldwide LHC Computing Grid (wLCG)



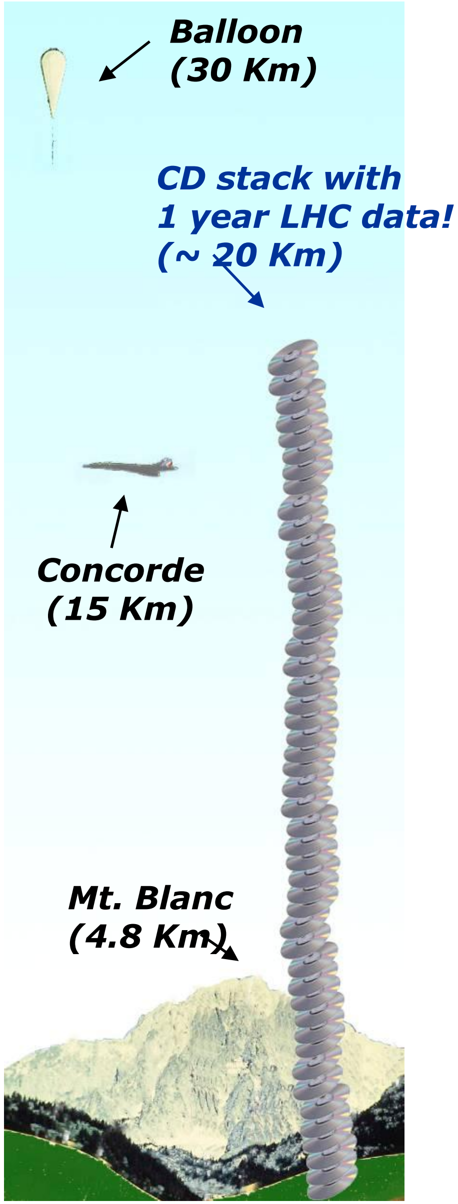
WLCG is a worldwide collaborative effort on an unprecedented scale in terms of storage and CPU requirements, as well as the software project's size

GRID computing developed to solve problem of data storage and analysis

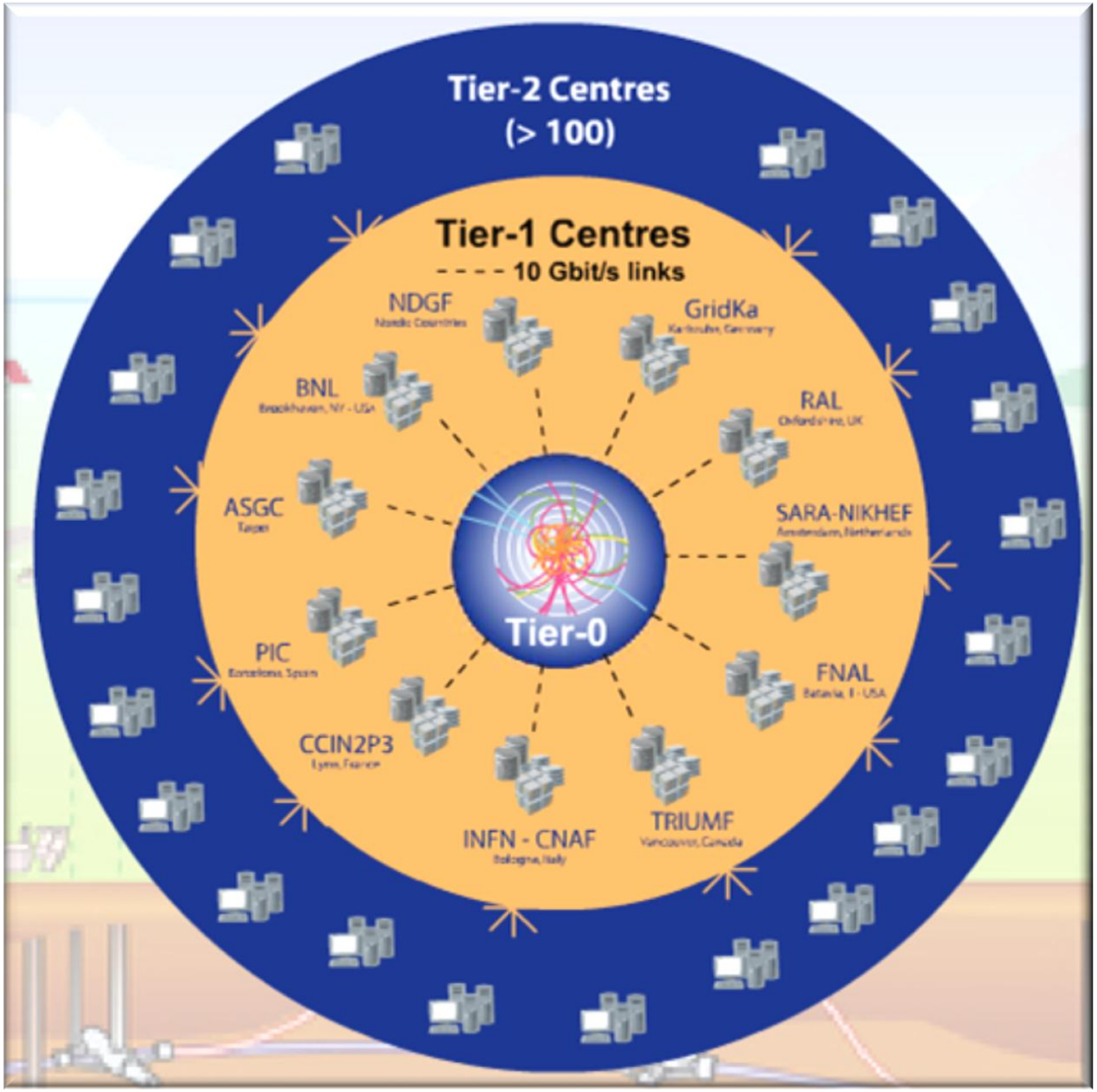
LHC data volume per year: 10-15 Petabytes

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

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



The Worldwide LHC Computing Grid (wLCG)



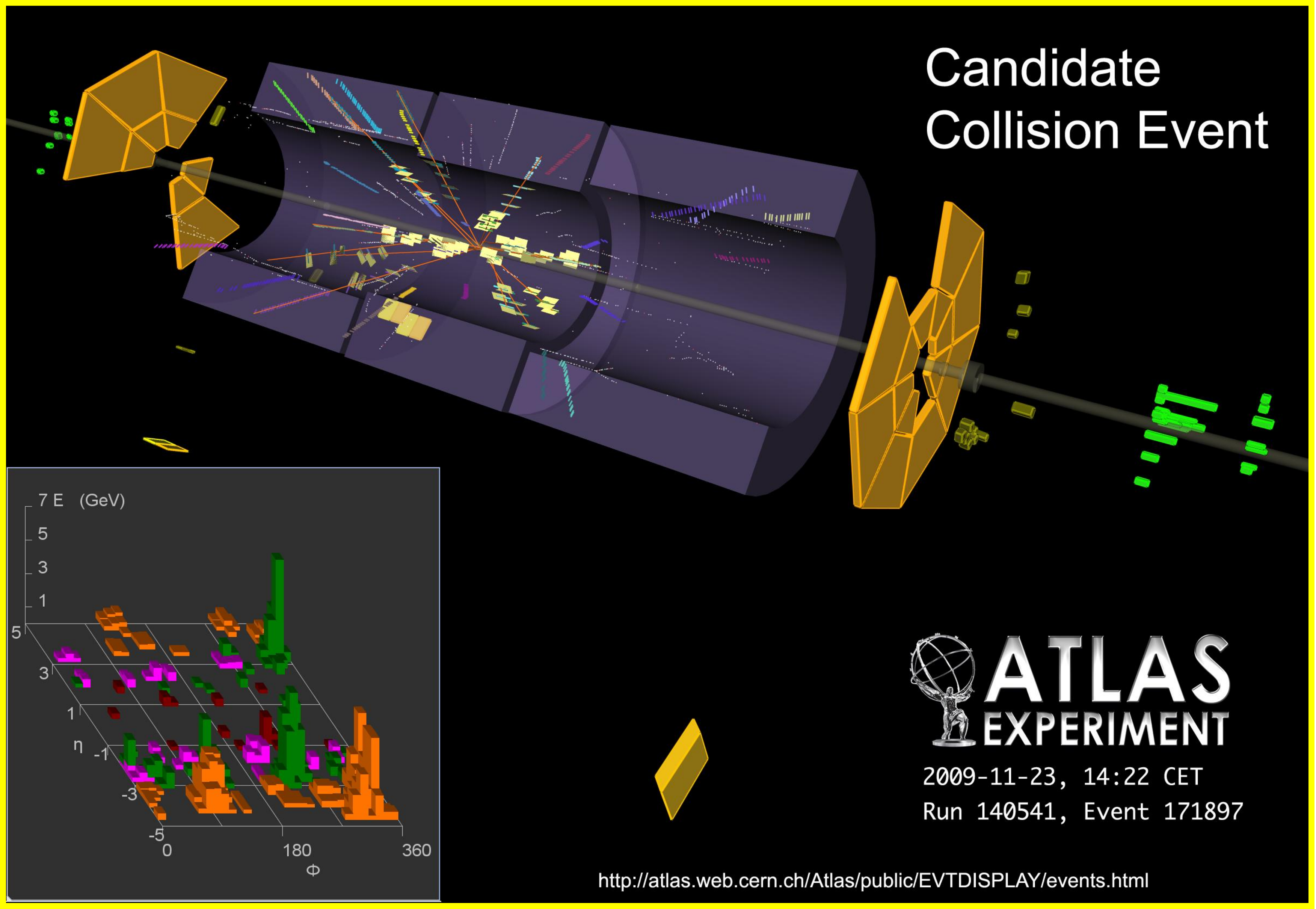
Tier-0 (CERN):
- Data recording
- Initial data reconstruction
- Data distribution

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

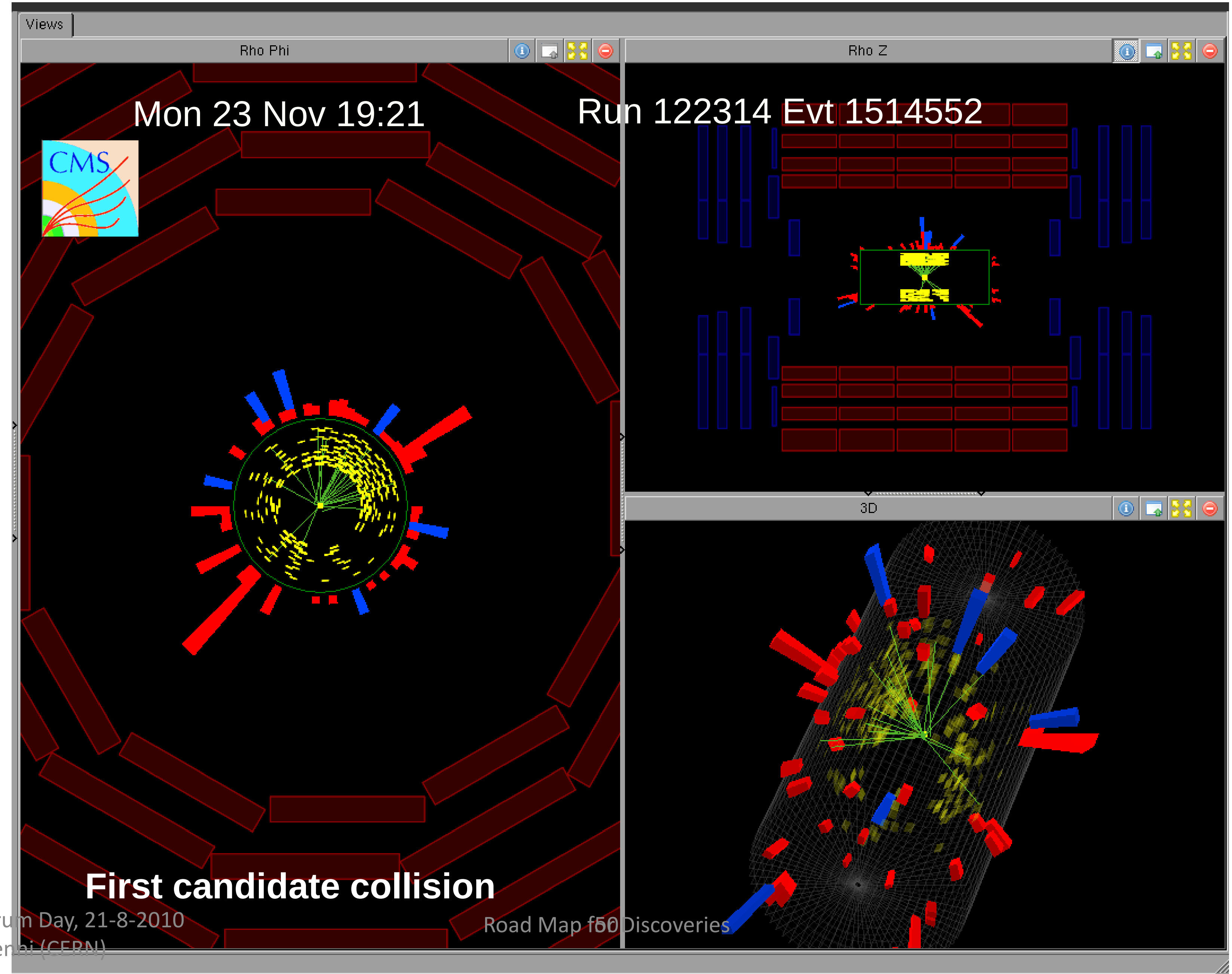
Tier-2 (federations of ~130 centres):
- Simulation
- End-user analysis

ATLAS Control Room when the first LHC beam collided....

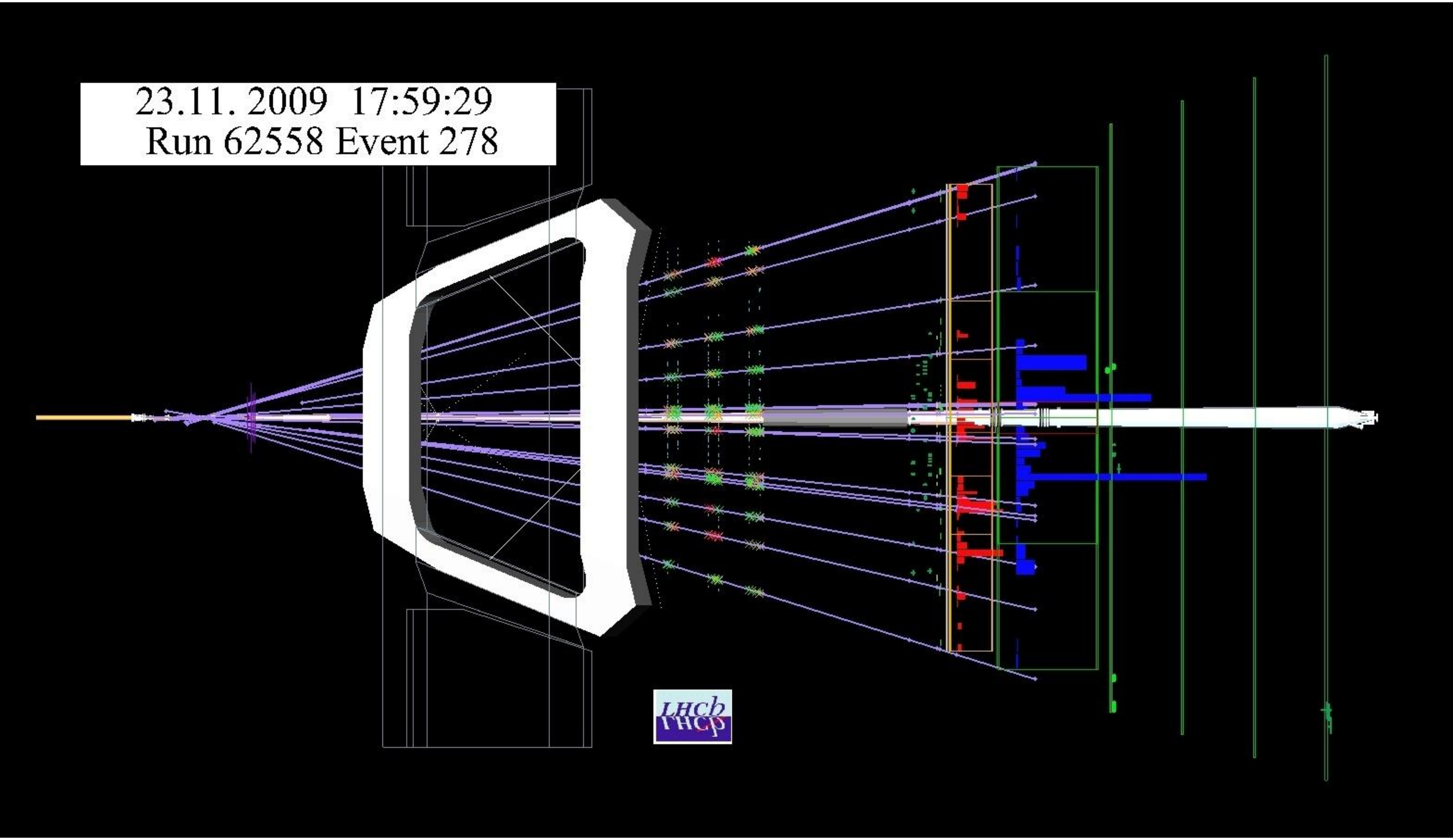
First collisions at the LHC end of November 2009



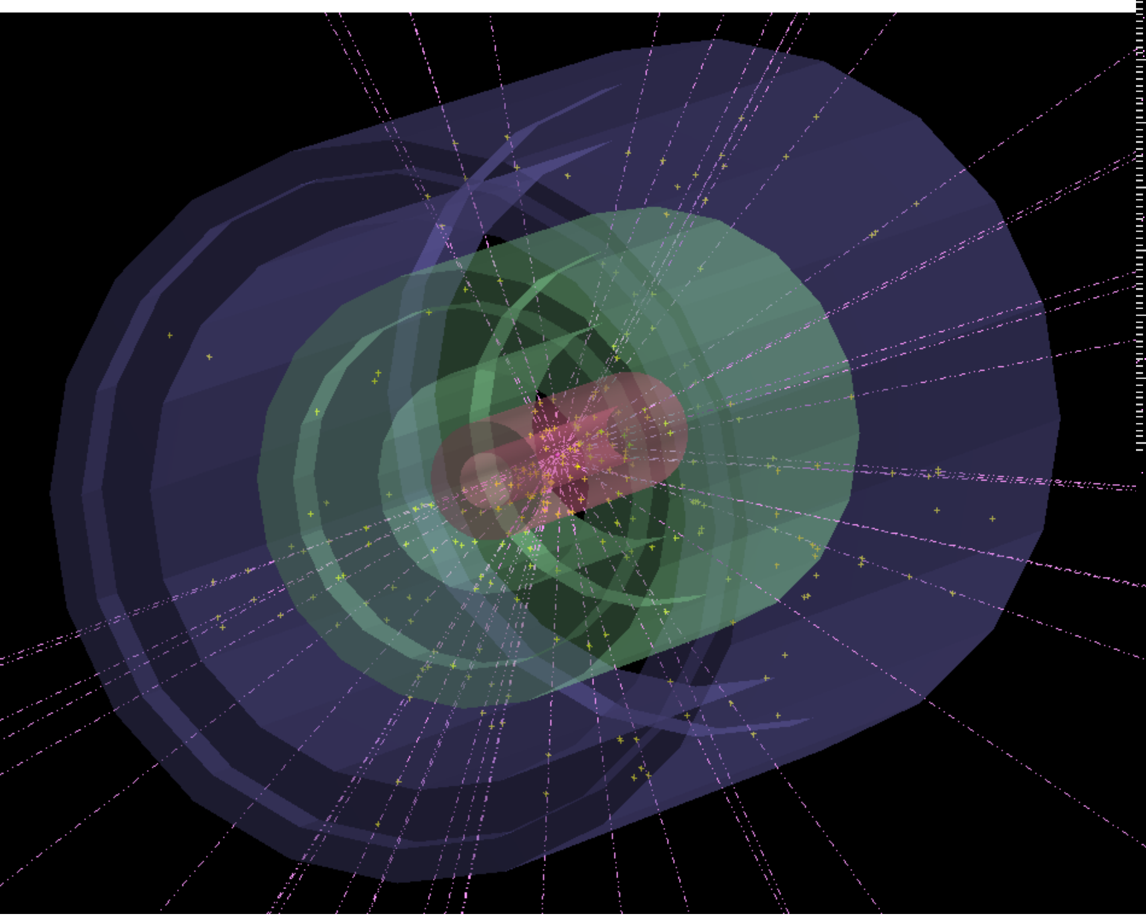
CMS event from the first day

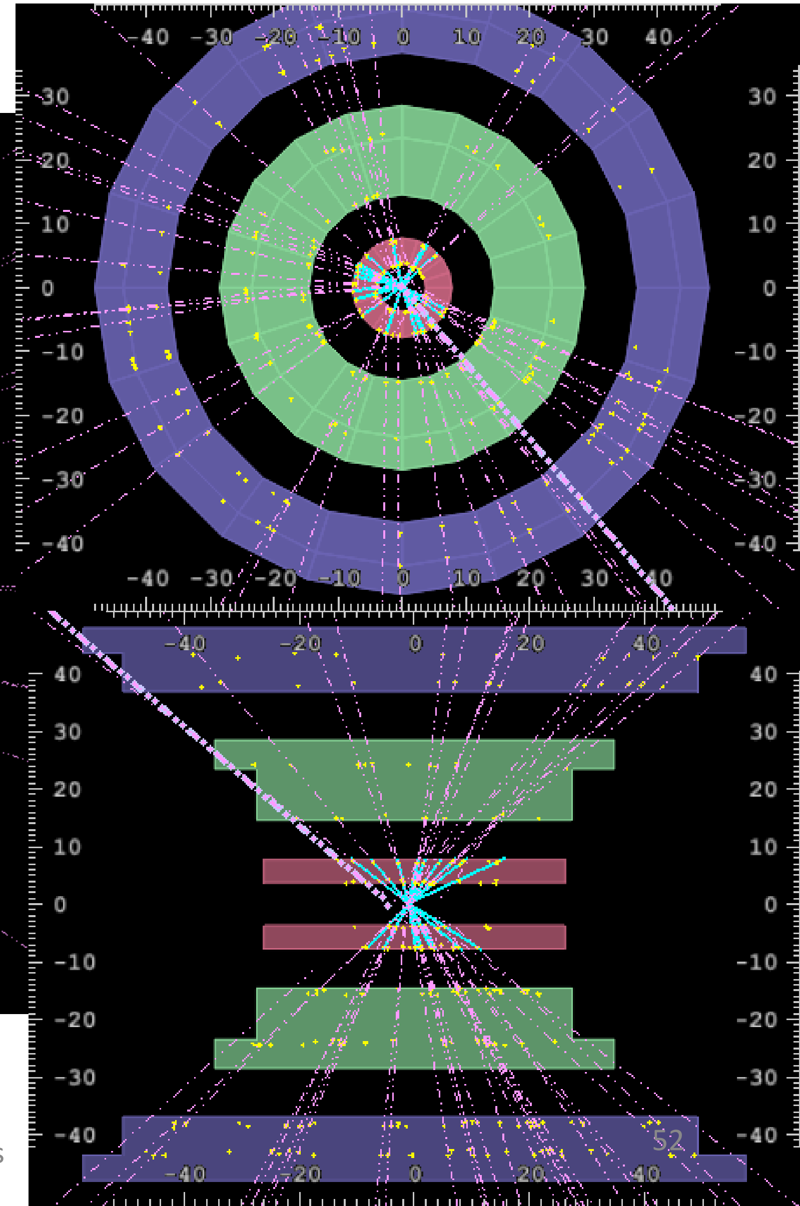


LHCb event from the first day

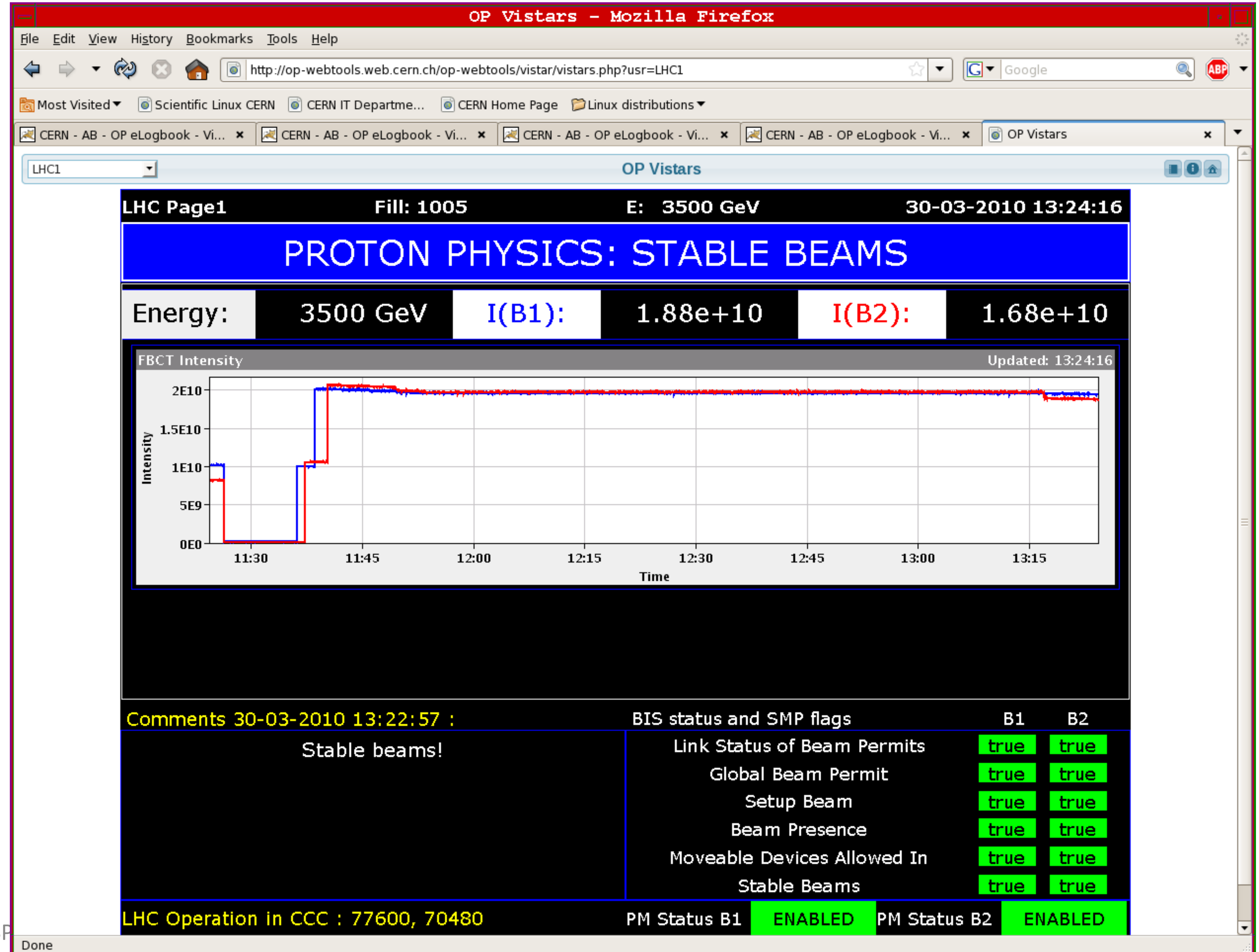


A high multiplicity ALICE event from the first day…



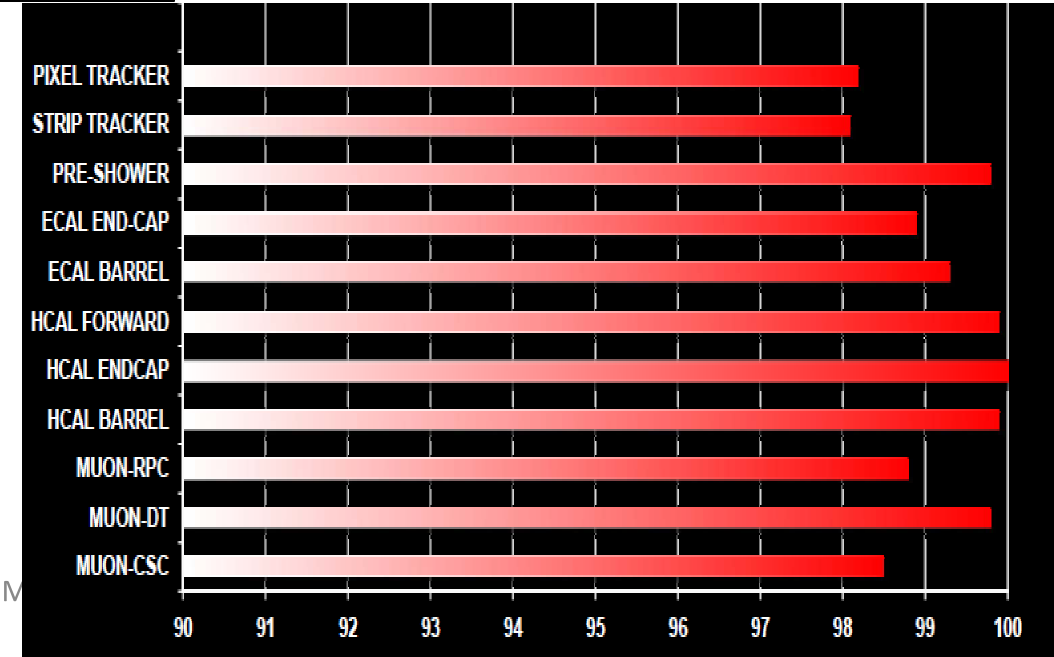


High-energy operation with 3.5 TeV beams started on 30th March 2010



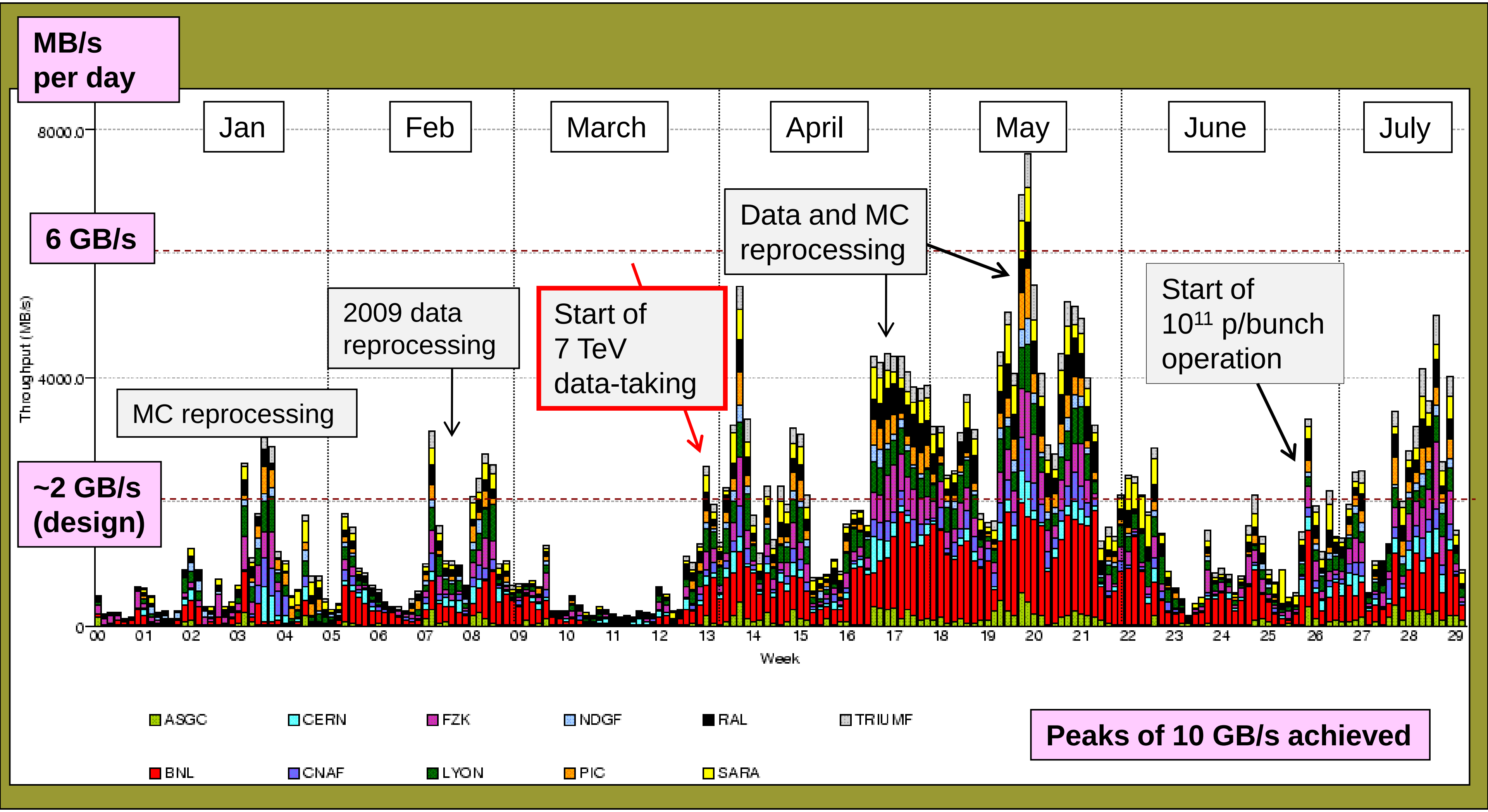
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.4%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	98.0%
LAr EM Calorimeter	170 k	98.5%
Tile calorimeter	9800	97.3%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

The complex detectors take data with an impressive fraction of operational channels, and high efficiencies



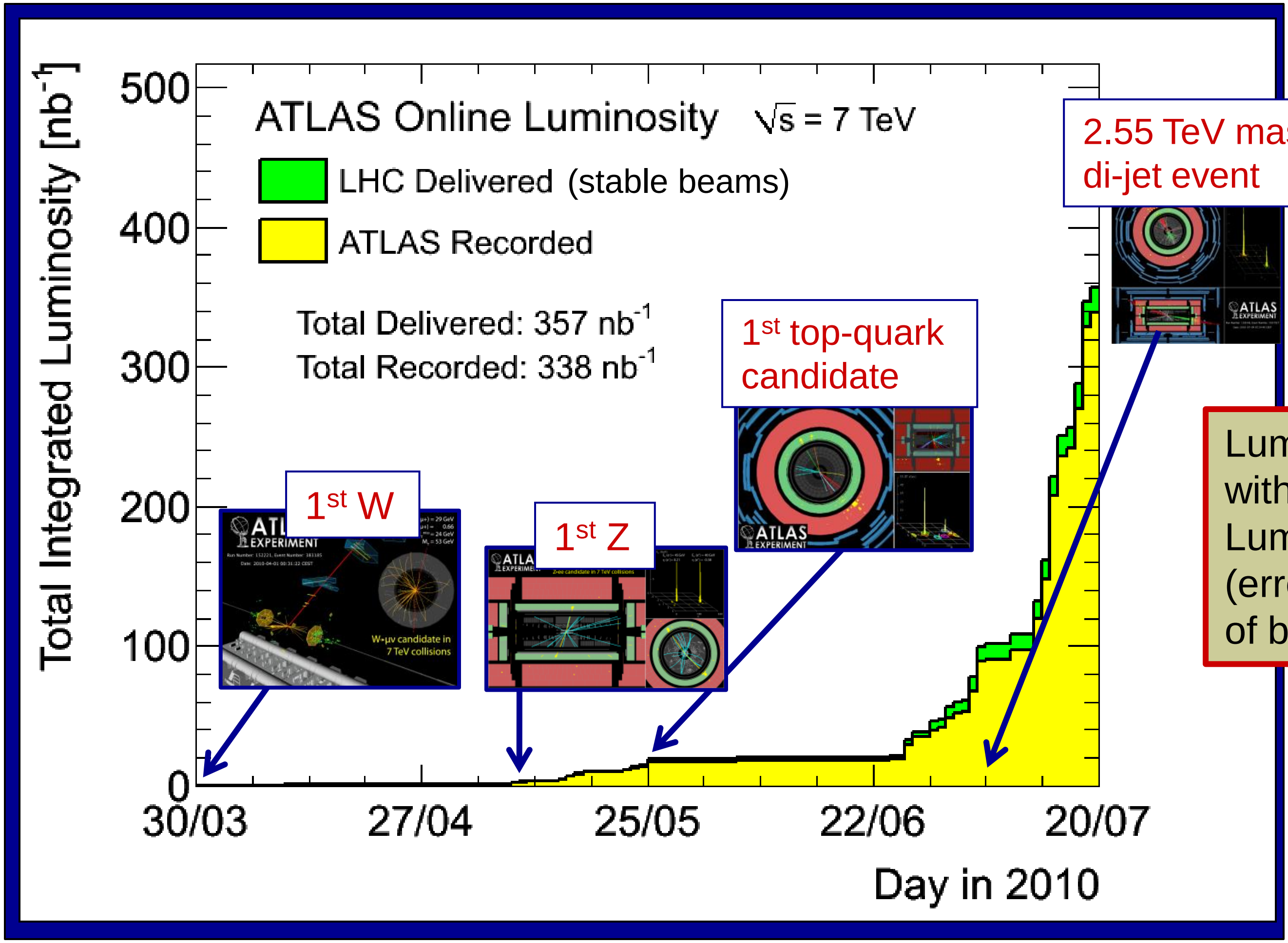
Worldwide data distribution and analysis

Total throughput of ATLAS data through the Grid: from 1st January until mid-July



GRID-based analysis in June-July 2010:
> 1000 different users, ~ 11 million analysis jobs processed

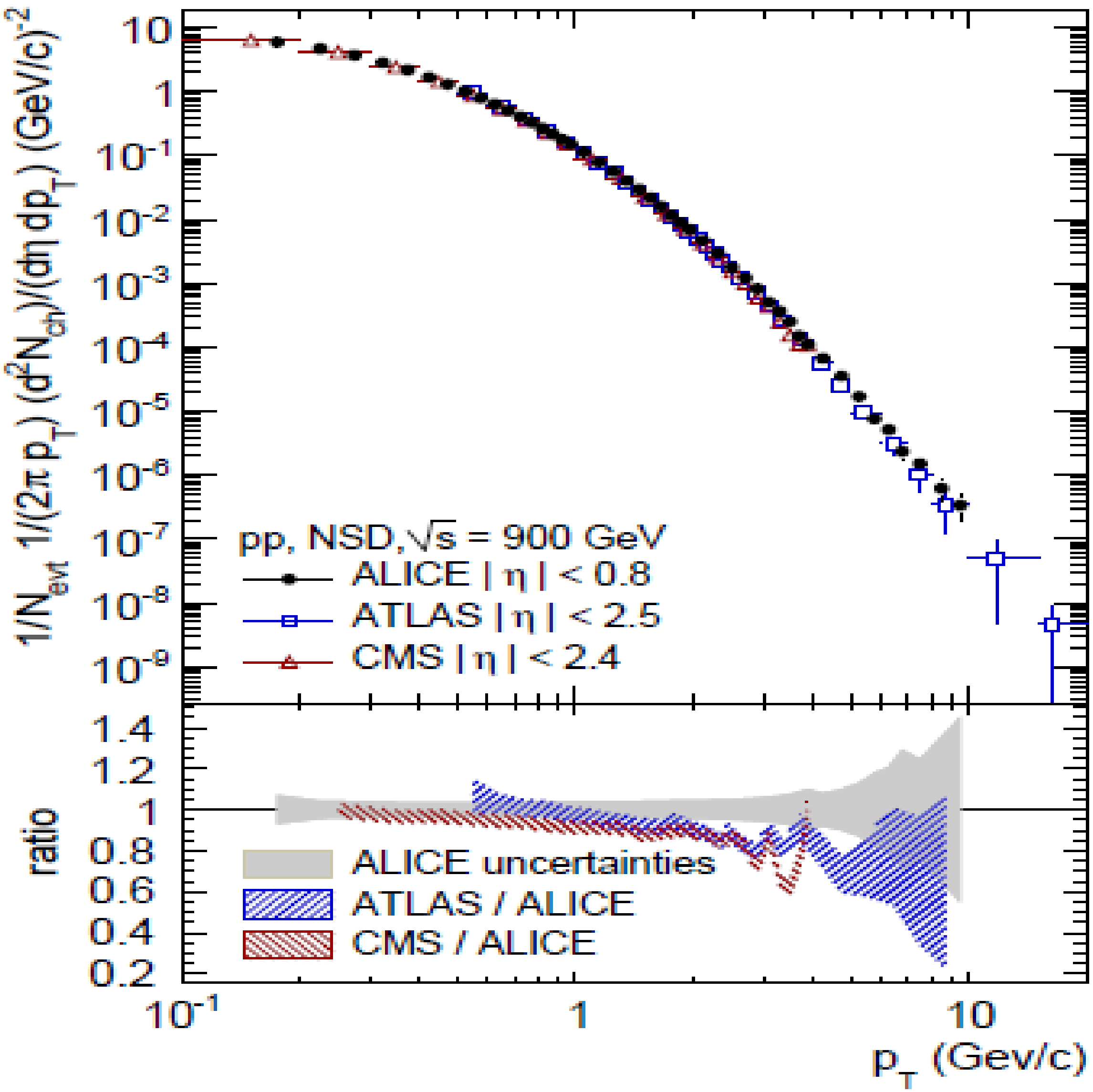
Integrated luminosity vs time
(from first √s =7 TeV collisions on 30 March to beginning of ICHEP on 22 July 2010)



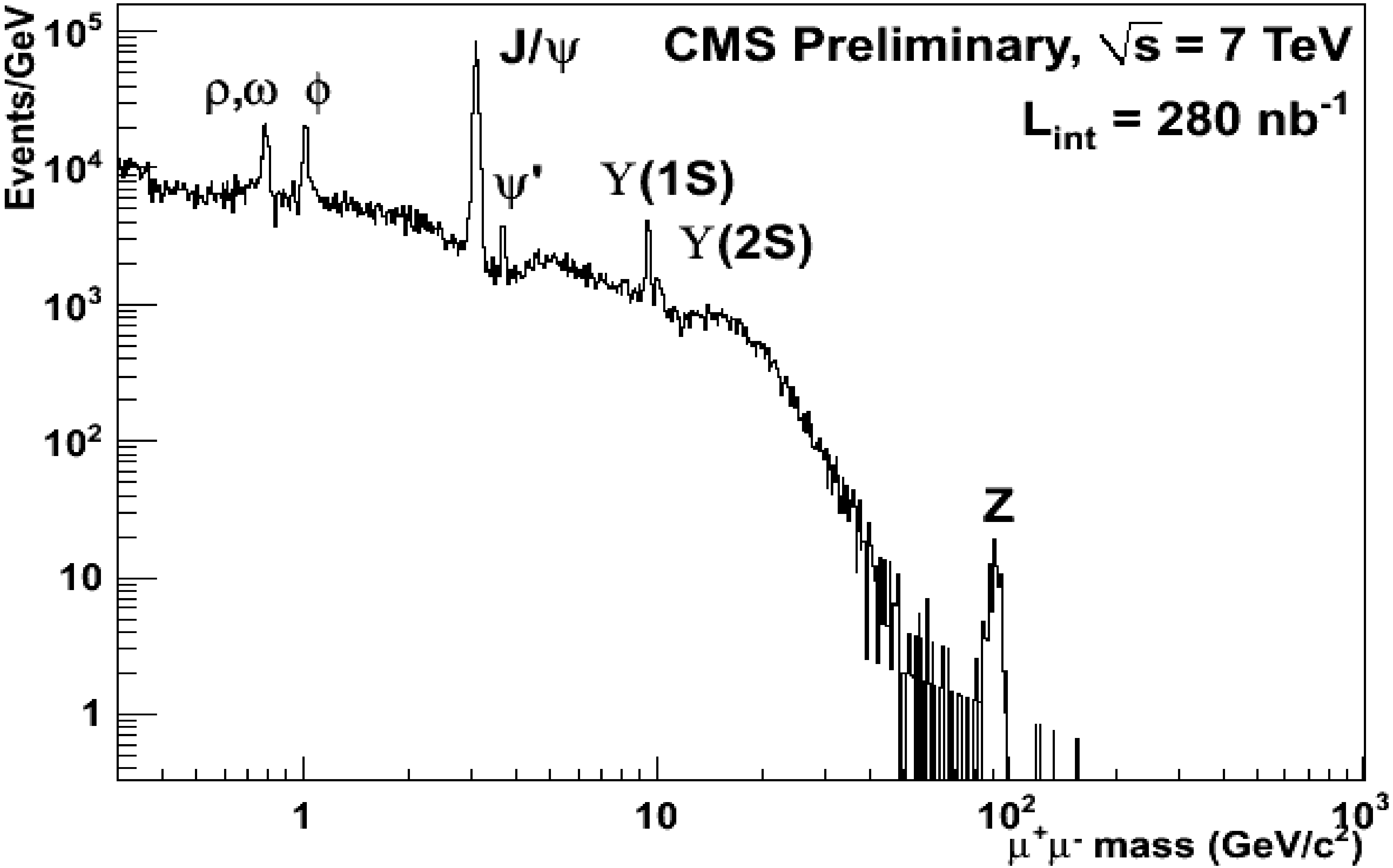
Luminosity detectors calibrated with van der Meer scans. Luminosity known today to 11% (error dominated by knowledge of beam currents)

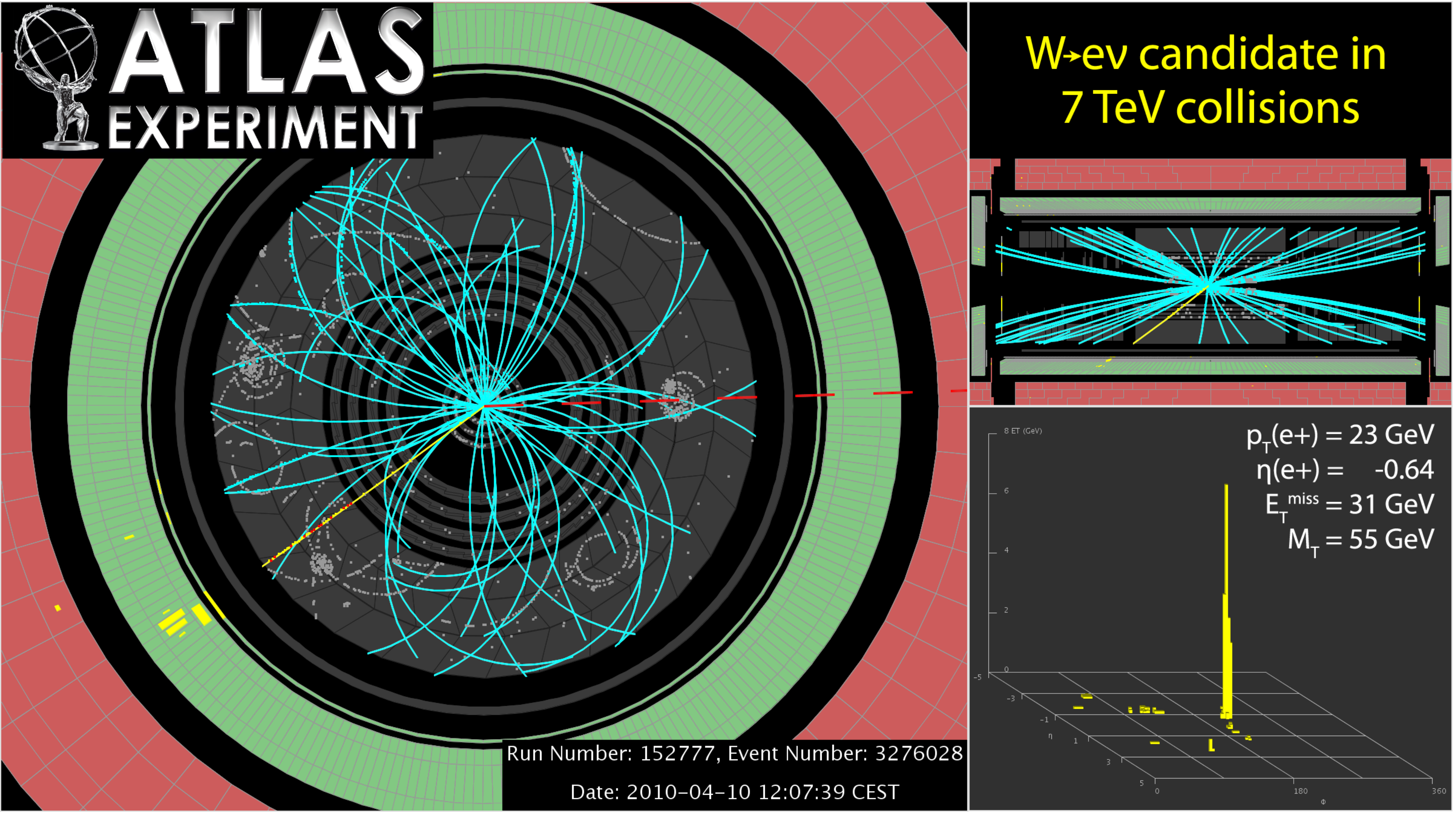
Most up-to-date LHC physics results were made public at the ICHEP Conference in Paris end of July 2010

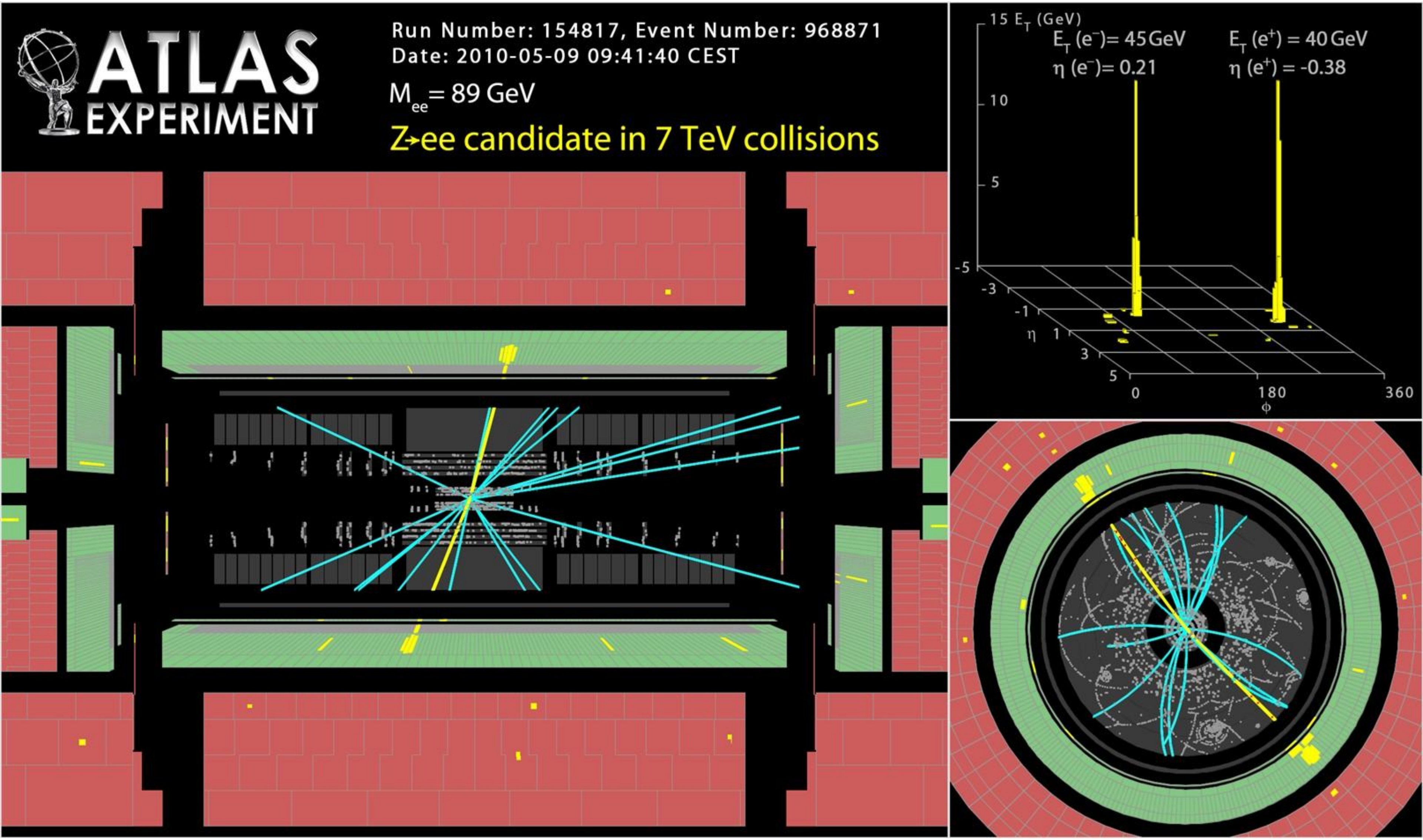
Charged particle transverse momentum distributions

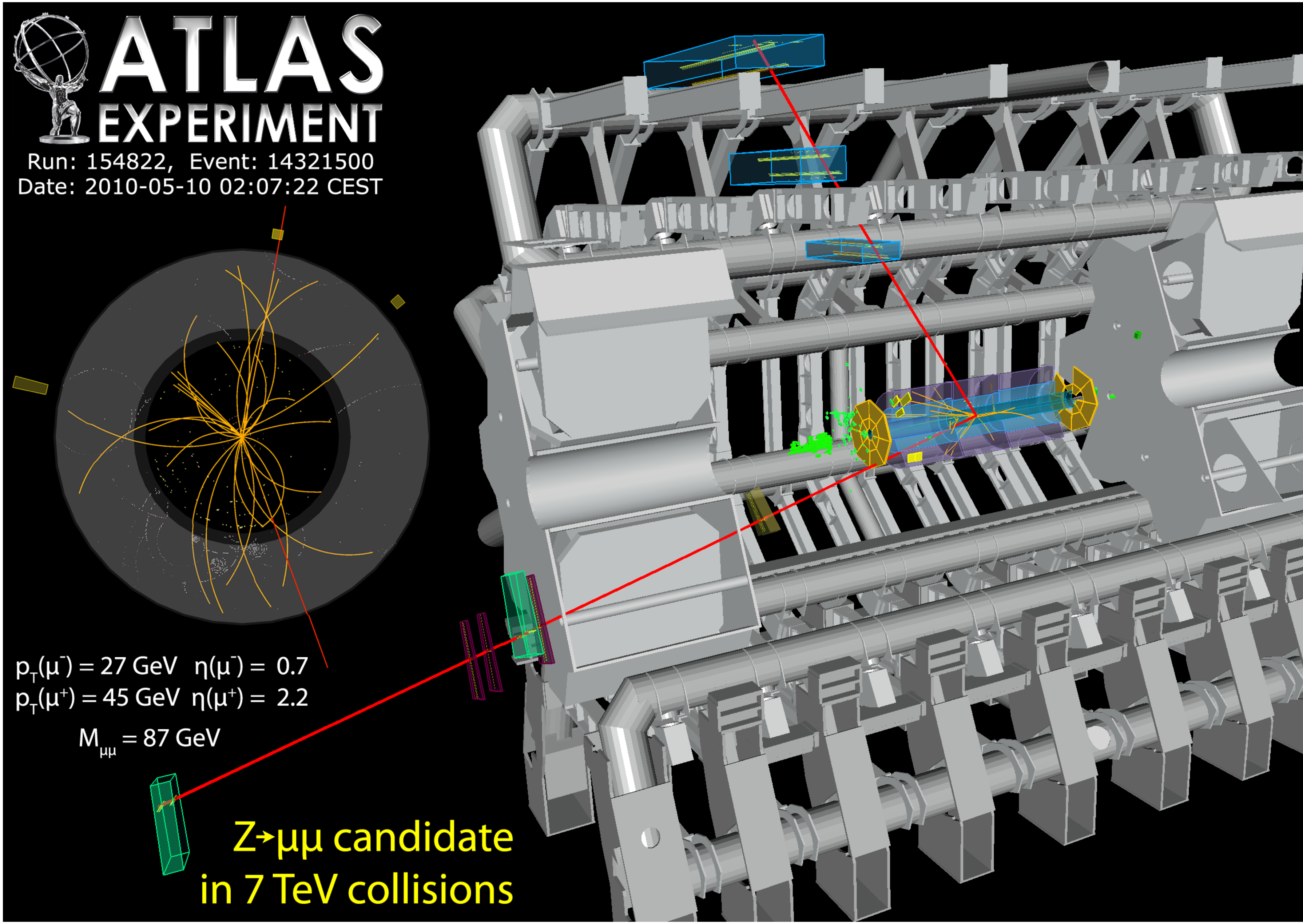


More than 30 years of physics history resumed in one plot from LHC …

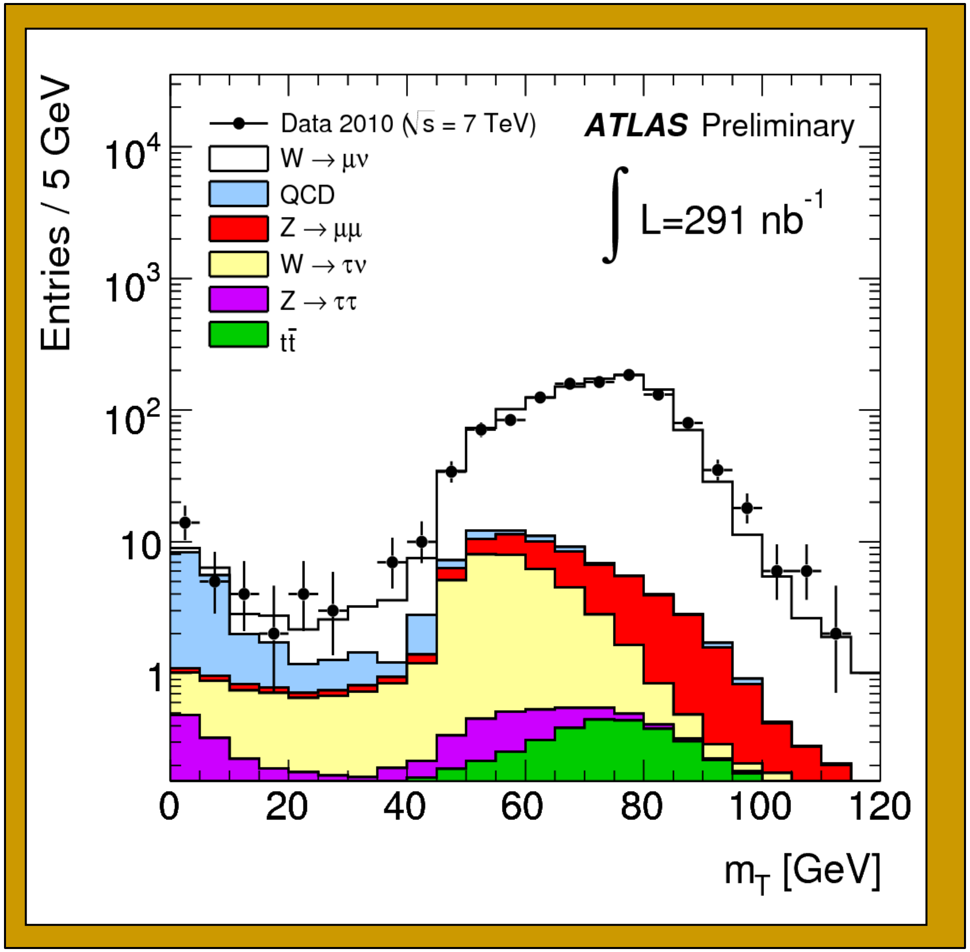


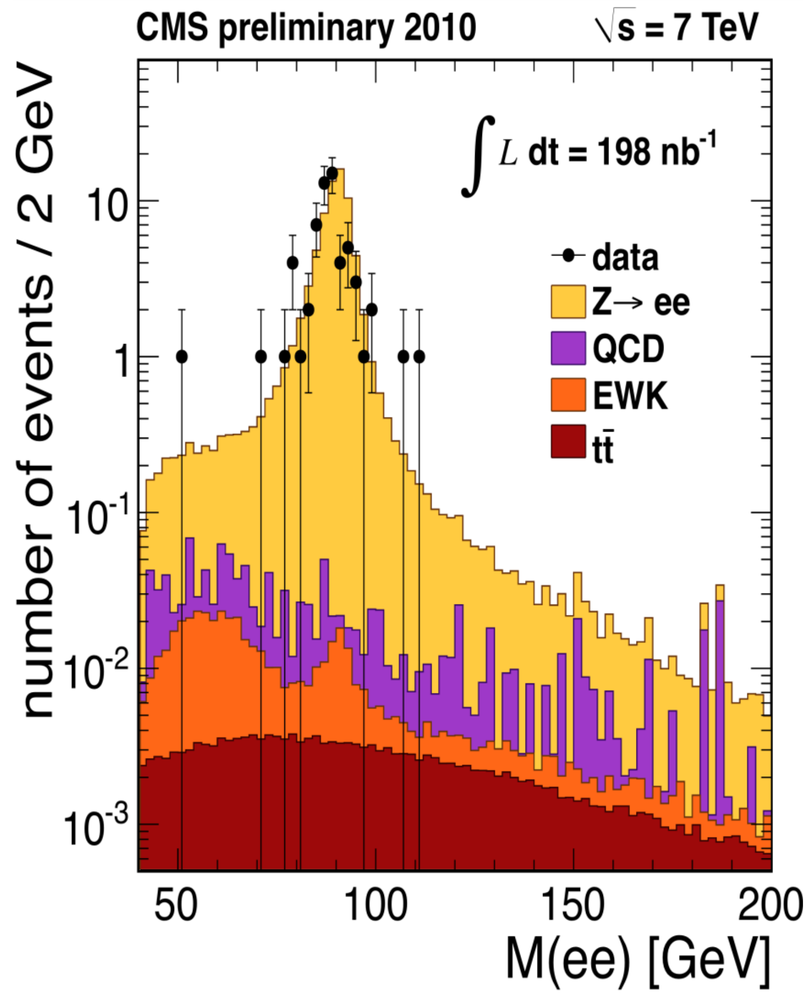

ATLAS
EXPERIMENT
W→eν candidate in
7 TeV collisions
p_T(e+) = 23 GeV
η(e+) = -0.64
E_T^{miss} = 31 GeV
M_T = 55 GeV
Run Number: 152777, Event Number: 3276028
Date: 2010-04-10 12:07:39 CEST

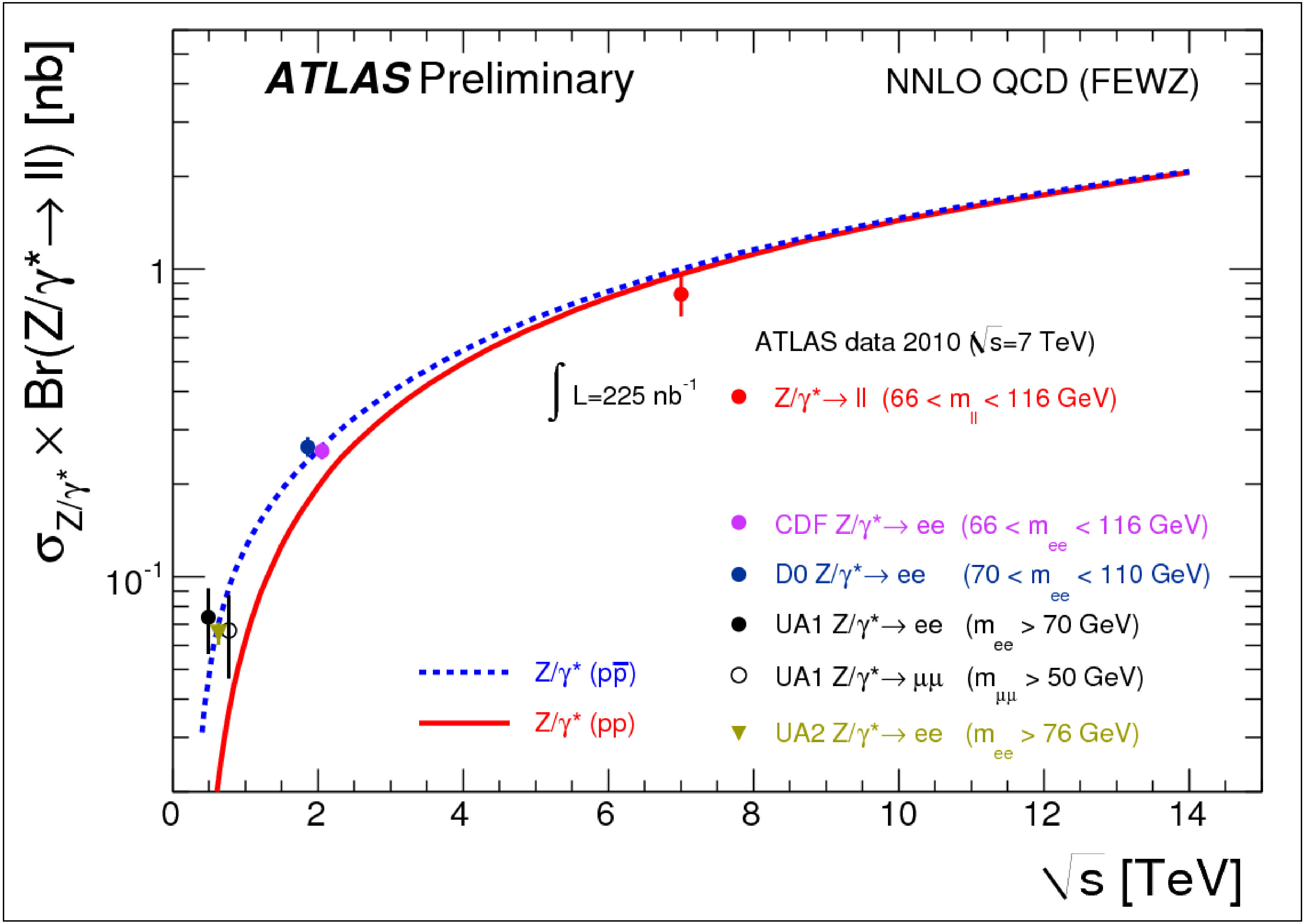

ATLAS EXPERIMENT
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST
M_{ee} = 89 GeV
Z→ee candidate in 7 TeV collisions
15 E_T (GeV)
E_T (e^-)= 45 GeV
η (e^-)= 0.21
E_T (e^+) = 40 GeV
η (e^+) = -0.38
10
5
-5
-3
-1
η 1
3
5
0
180
360
φ


ATLAS EXPERIMENT
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV
Z→μμ candidate
in 7 TeV collisions

Examples of the first W and Z distributions and measurements from ATLAS and CMS at the LHC



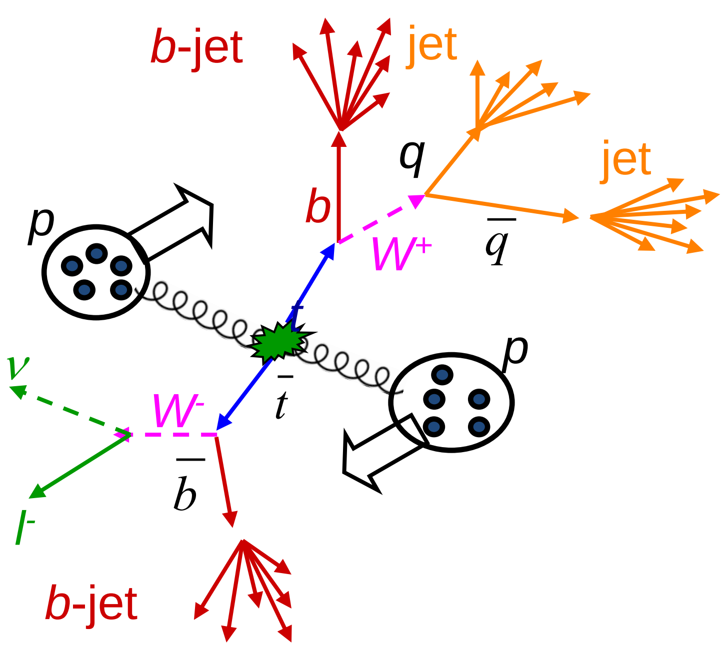



ATLAS Preliminary
NNLO QCD (FEWZ)
$\sigma_{Z/\gamma^*} \times Br(Z/\gamma^* \to ll)$ [nb]
1
10^{-1}
0
2
4
6
8
10
12
14
$\sqrt{s}$ [TeV]
ATLAS data 2010 ($\sqrt{s}$=7 TeV)
$\int L$=225 nb^{-1}
$Z/\gamma^* \to ll$ ($66 < m_{ll} < 116$ GeV)
CDF $Z/\gamma^* \to ee$ ($66 < m_{ee} < 116$ GeV)
D0 $Z/\gamma^* \to ee$ ($70 < m_{ee} < 110$ GeV)
UA1 $Z/\gamma^* \to ee$ ($m_{ee} > 70$ GeV)
UA1 $Z/\gamma^* \to \mu\mu$ ($m_{\mu\mu} > 50$ GeV)
UA2 $Z/\gamma^* \to ee$ ($m_{ee} > 76$ GeV)
Z/γ^* ($p\bar{p}$)
Z/γ^* (pp)

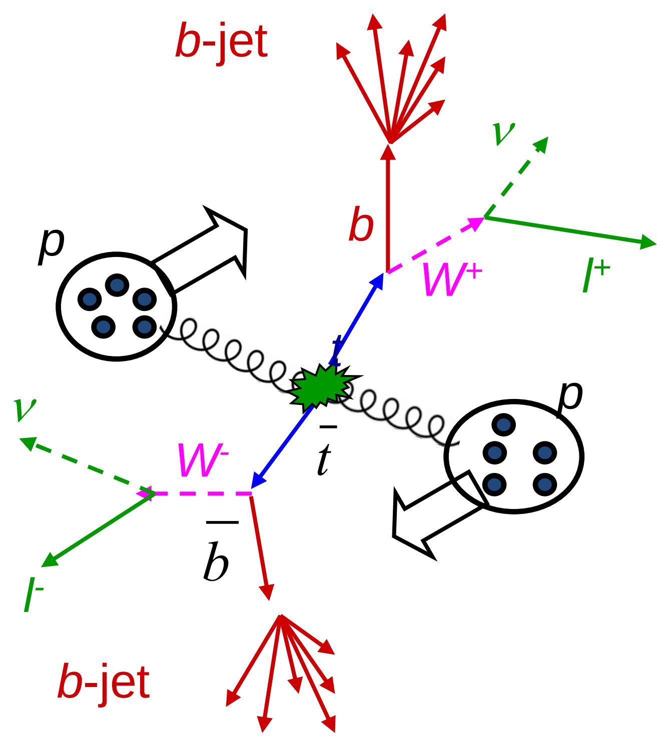
First Top Events from LHC

Up to ICHEP just a handful of candidates have been identified

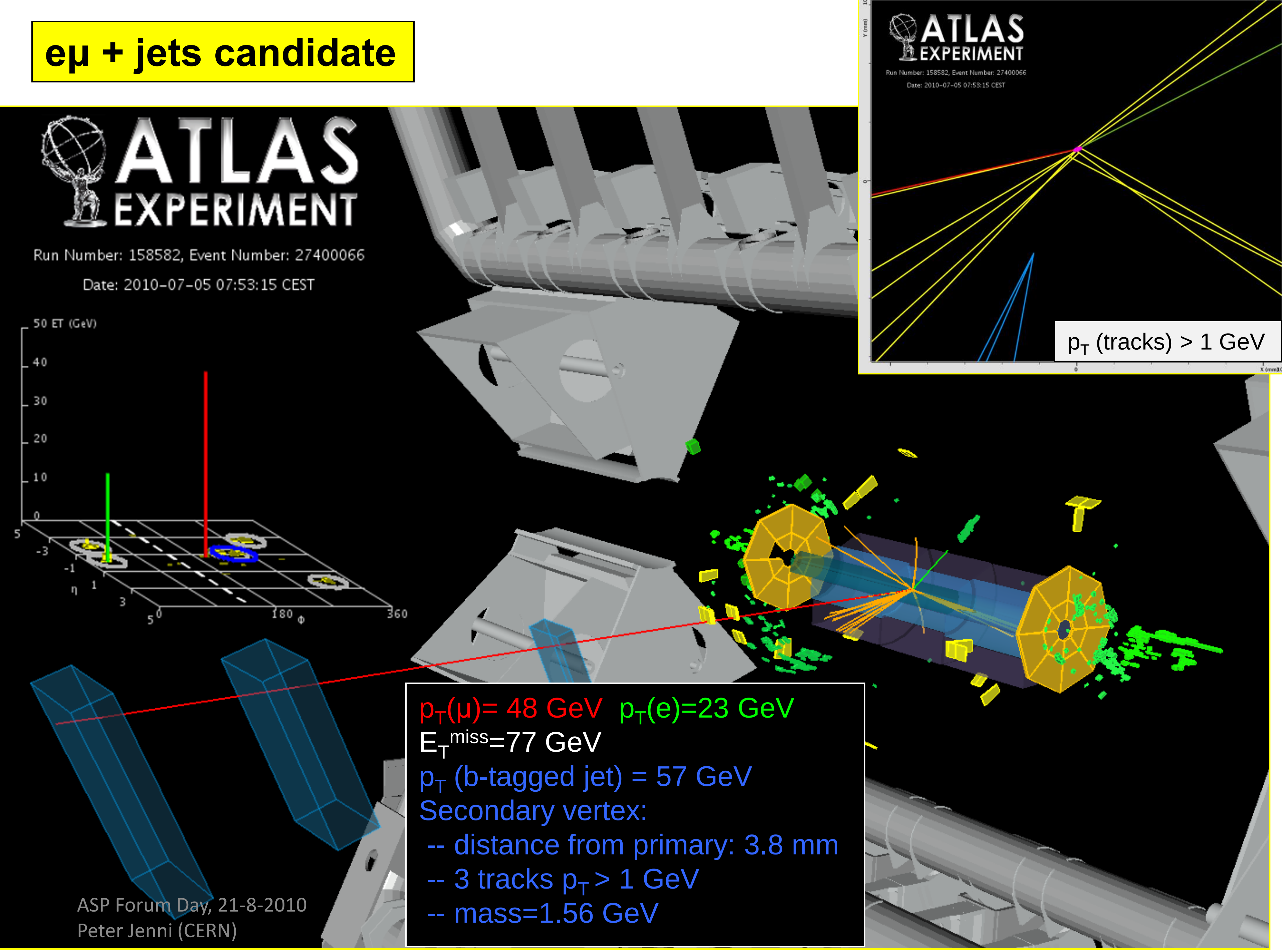
Standard channel with one lepton and jets in the final state, b-tagged



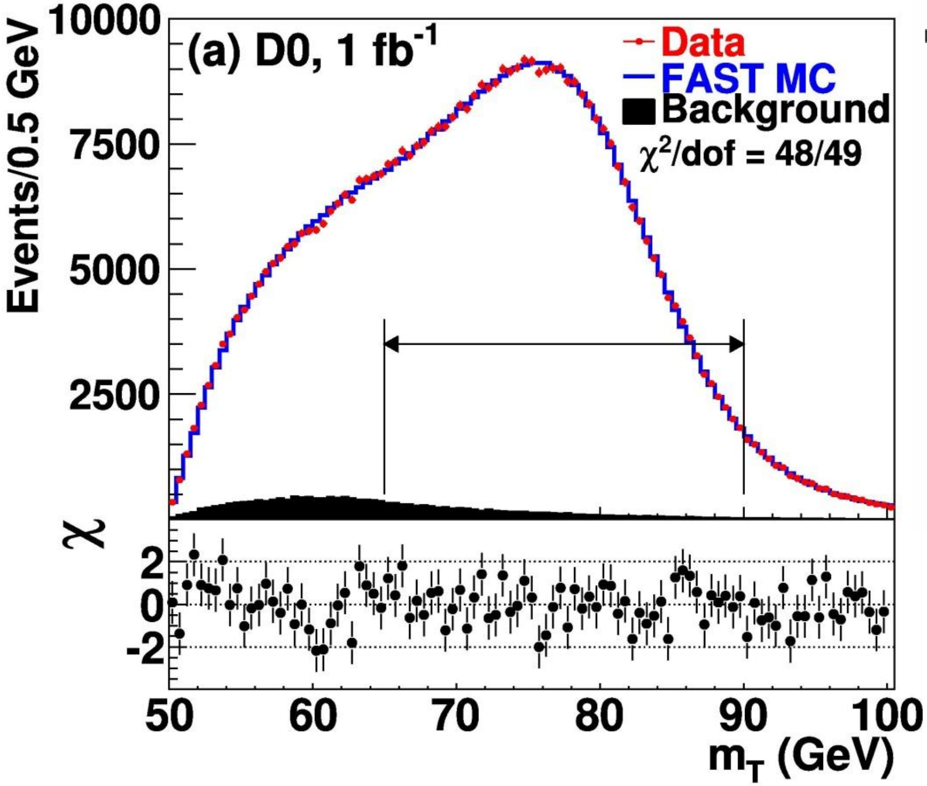
'Golden' channel with two leptons and jets in the final state, b-tagged



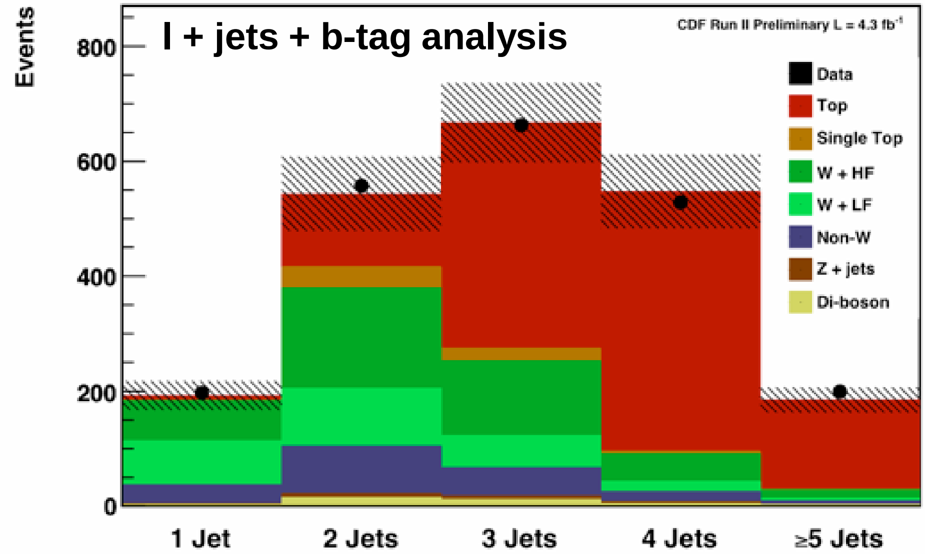
eμ + jets candidate



$p_T(\mu)$= 48 GeV $p_T(e)$=23 GeV
E_T^{miss}=77 GeV
p_T (b-tagged jet) = 57 GeV
Secondary vertex:
-- distance from primary: 3.8 mm
-- 3 tracks p_T > 1 GeV
-- mass=1.56 GeV

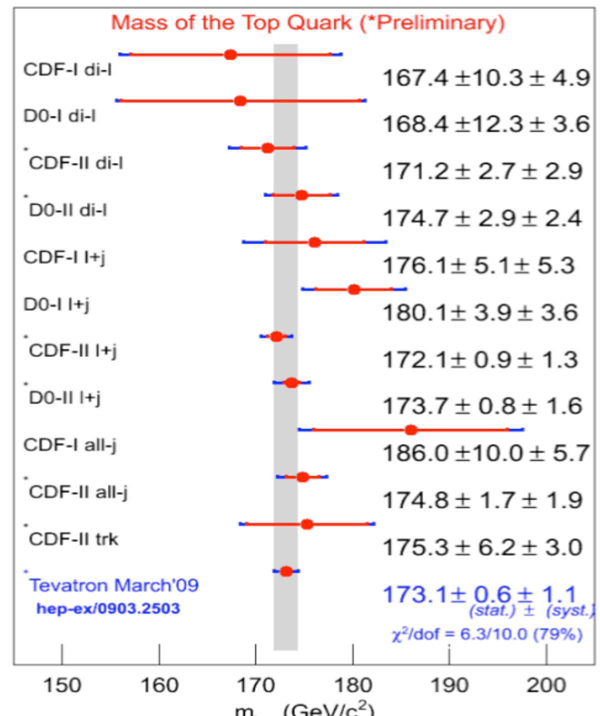


499830 W → eν candidates

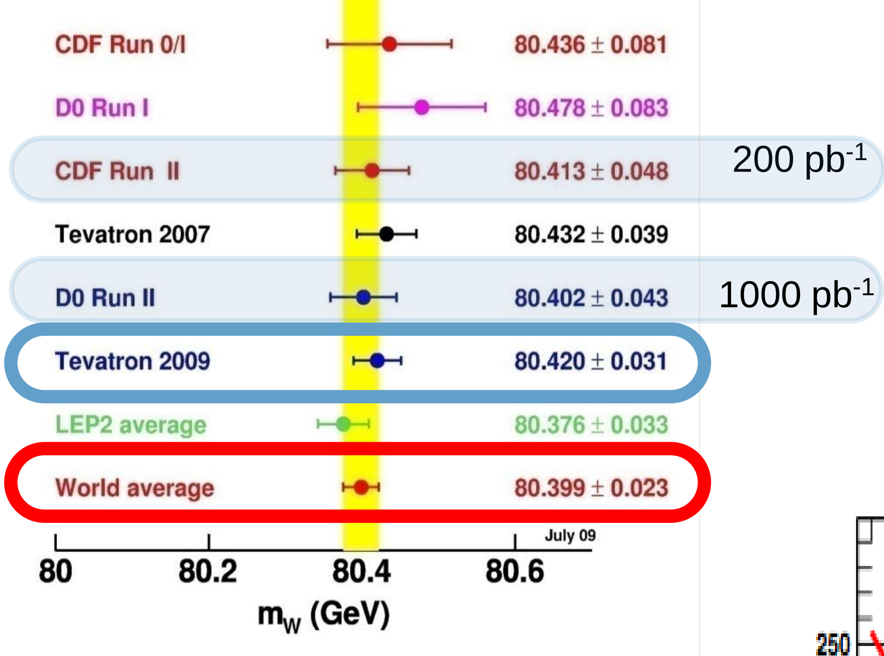


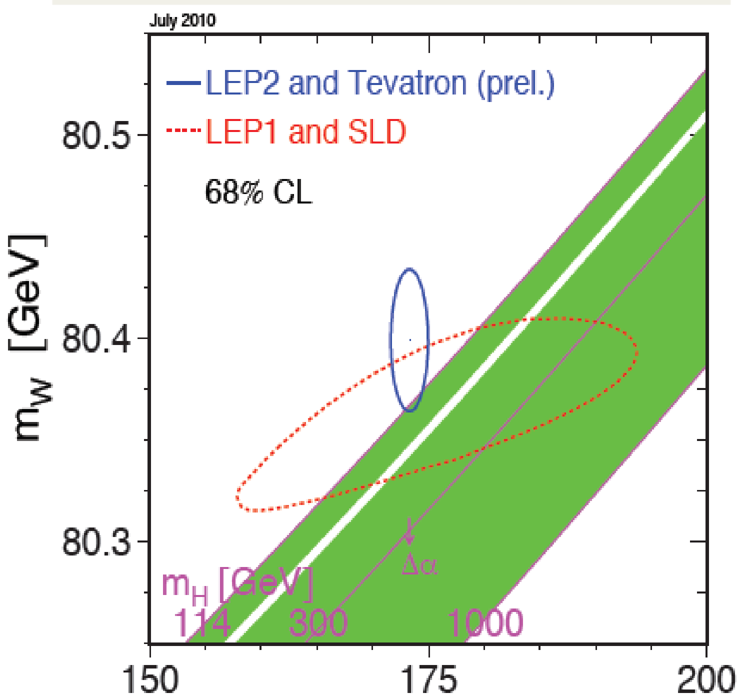
W, Z, and top analyses are in a very mature and advanced state at theTevatron, giving a wealth of detailed QCD and EW results

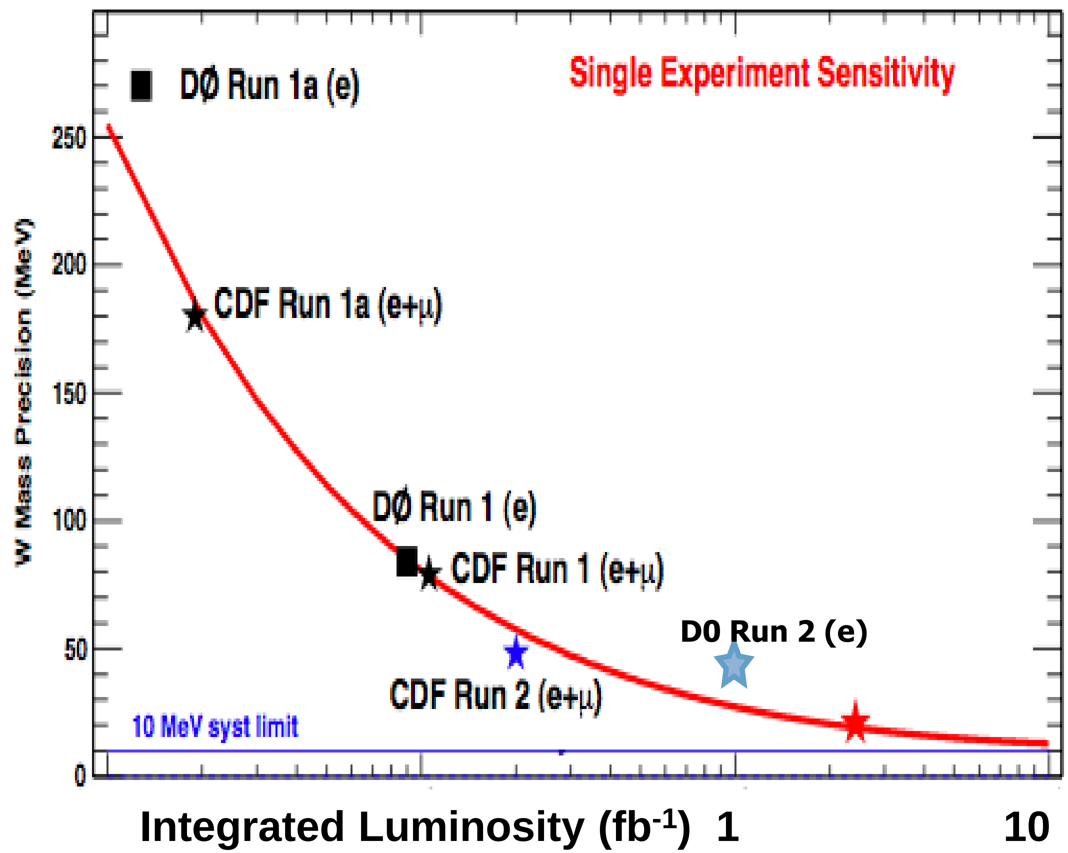
It will take some time to LHC to match this precision (~ 2013)



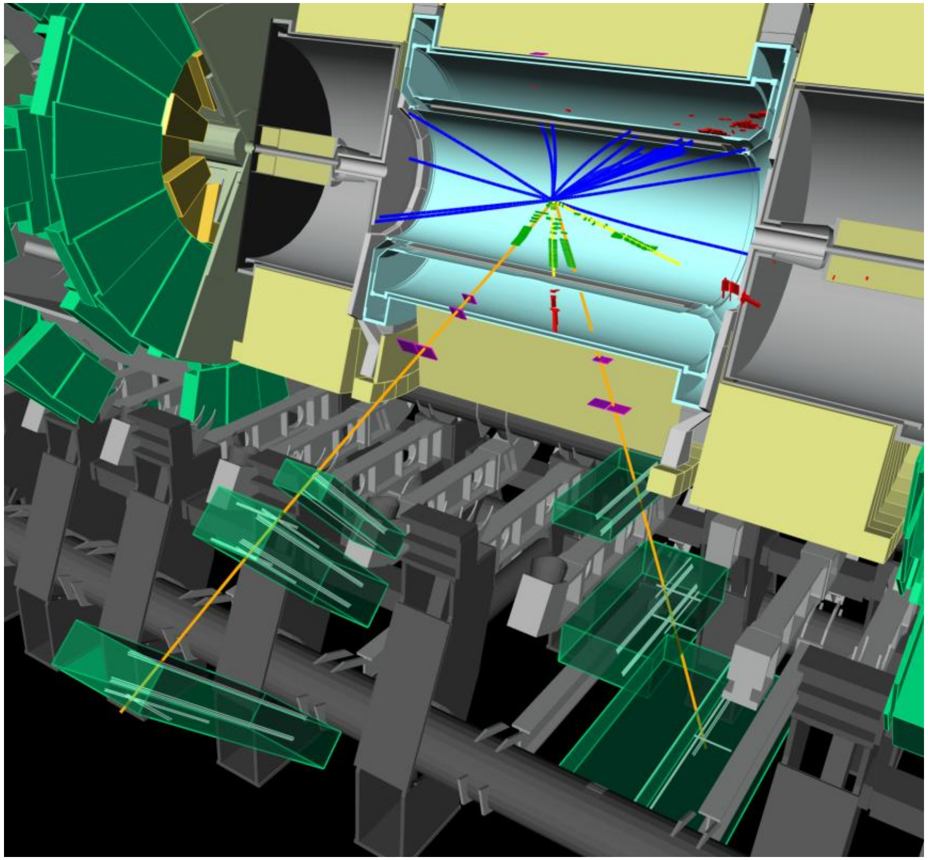
The W and Top mass measurements are testing the (consistency of the) Standard Model and the Higgs hypothesis



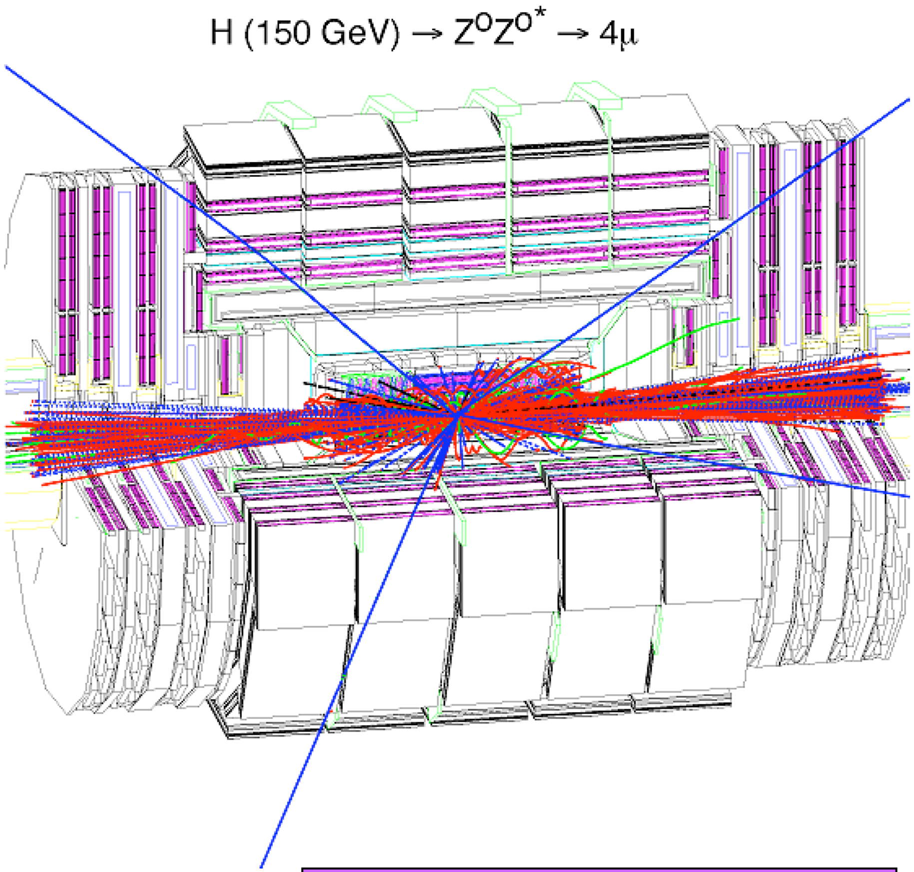




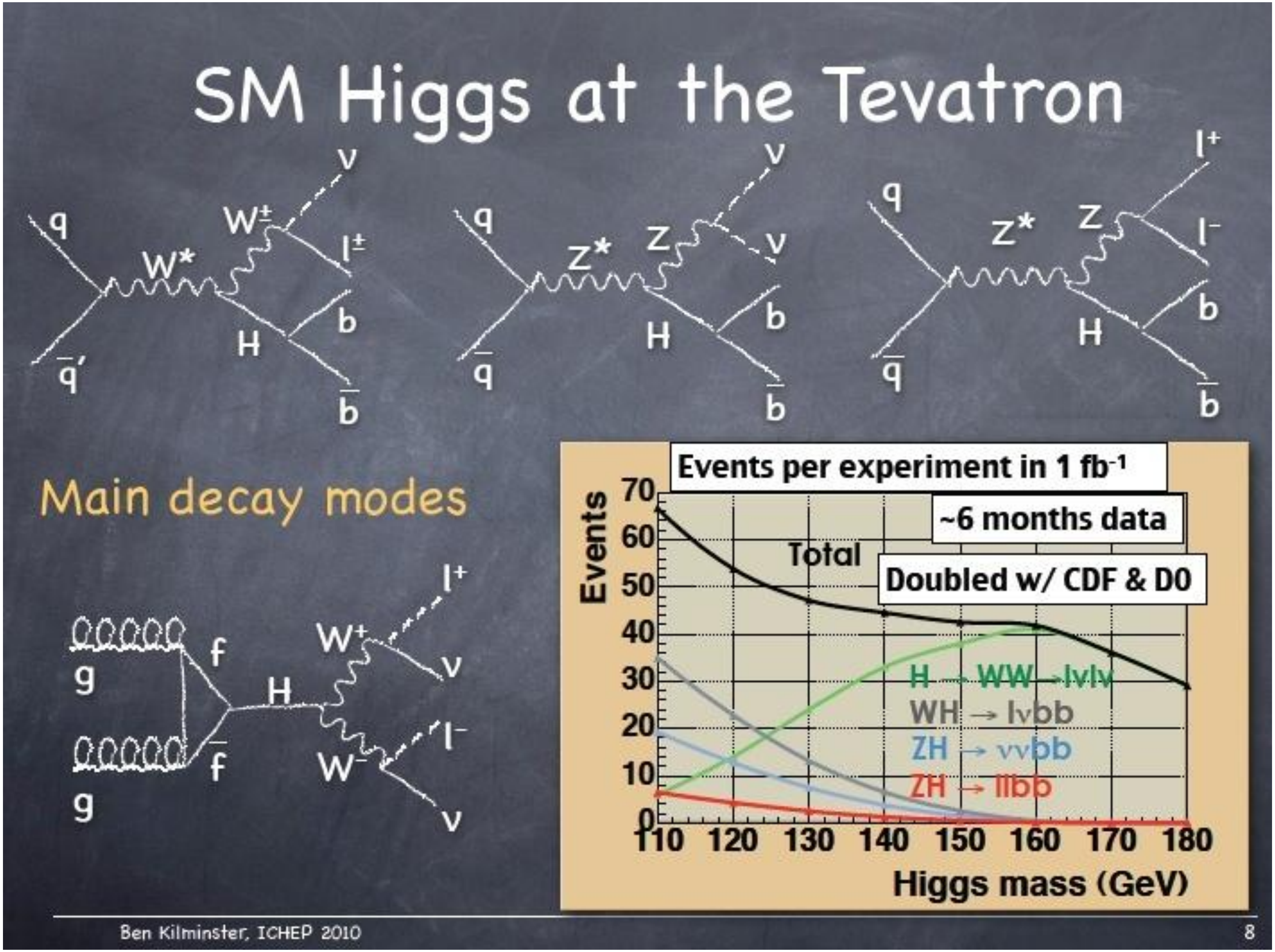
Higgs search



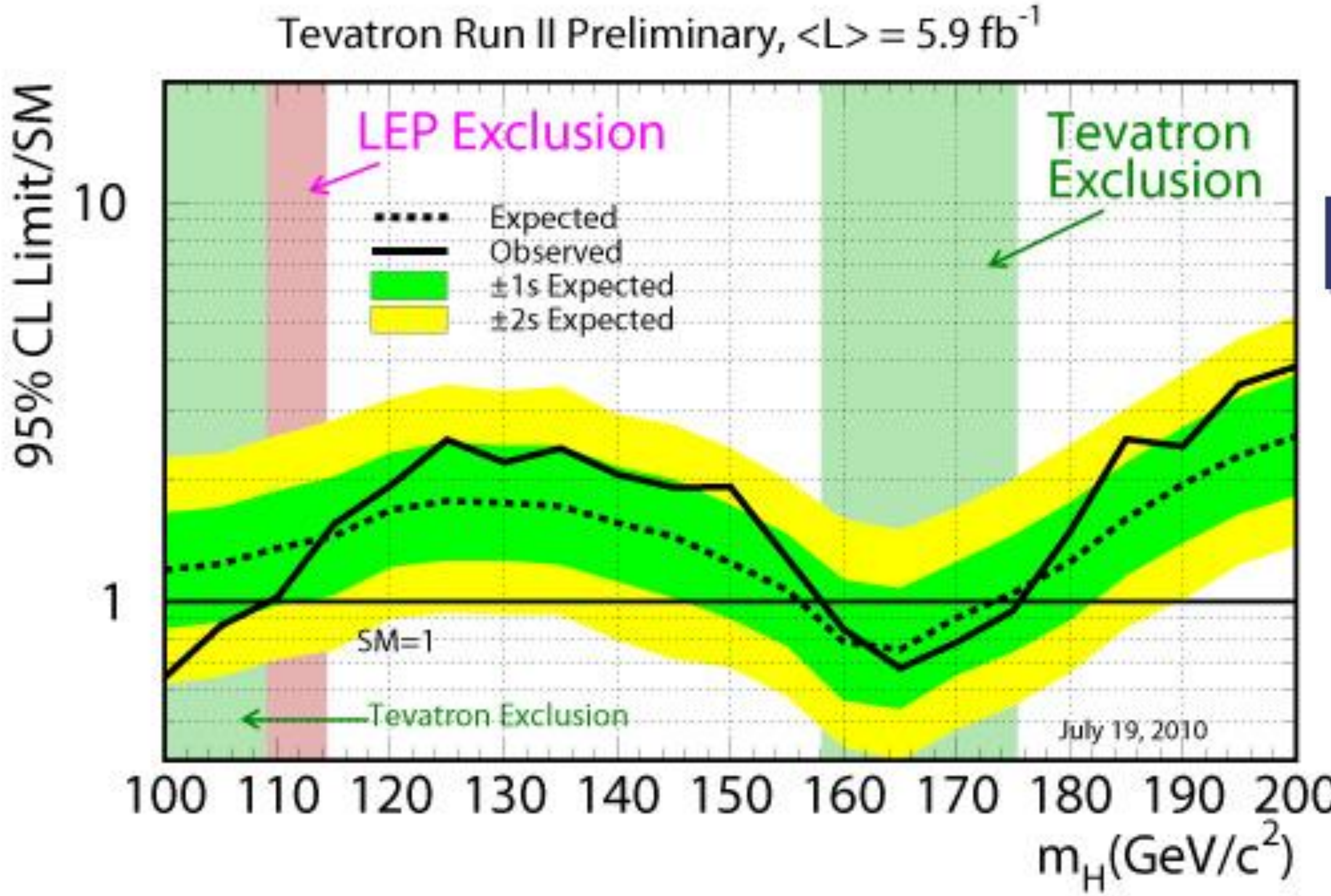
Simulation of a 130 GeV mass
$H \rightarrow \mu\mu$ ee event in ATLAS



Simulation of a 150 GeV mass
$H \rightarrow \mu\mu\ \mu\mu$ event in CMS

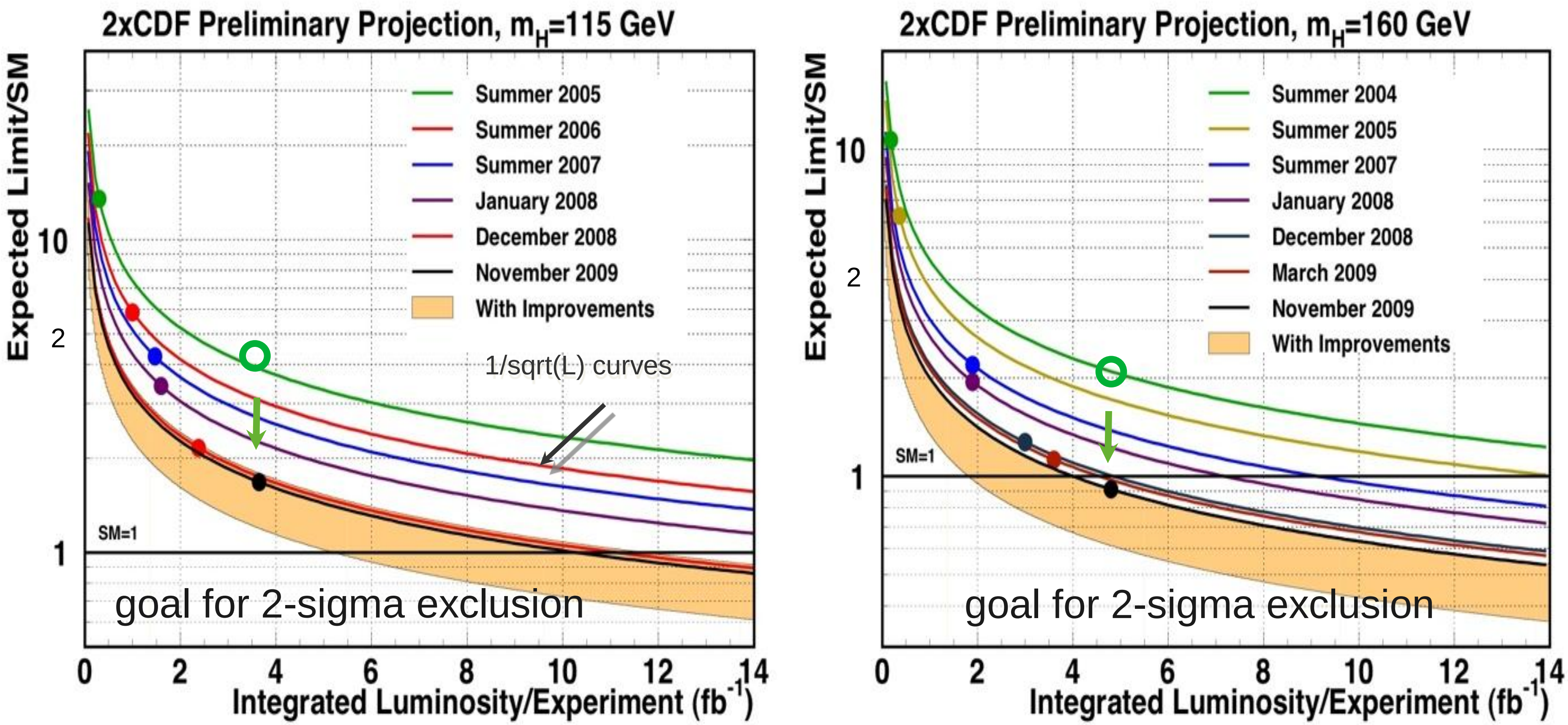

SM Higgs at the Tevatron
q
q̄′
W*
W±
ν
l±
H
b
b̄
q
q̄
Z*
Z
ν
ν
H
b
b̄
q
q̄
Z*
Z
l+
l−
H
b
b̄
Main decay modes
g
g
f
f̄
H
W+
W−
l+
ν
l−
ν
Events per experiment in 1 fb-1
~6 months data
Doubled w/ CDF & D0
Total
H → WW → lνlν
WH → lνbb
ZH → ννbb
ZH → llbb
Events
0
10
20
30
40
50
60
70
110
120
130
140
150
160
170
180
Higgs mass (GeV)
Ben Kilminster, ICHEP 2010
8

The new combined result published recently sets a new combined 95% CL exclusion for 158 – 175 GeV

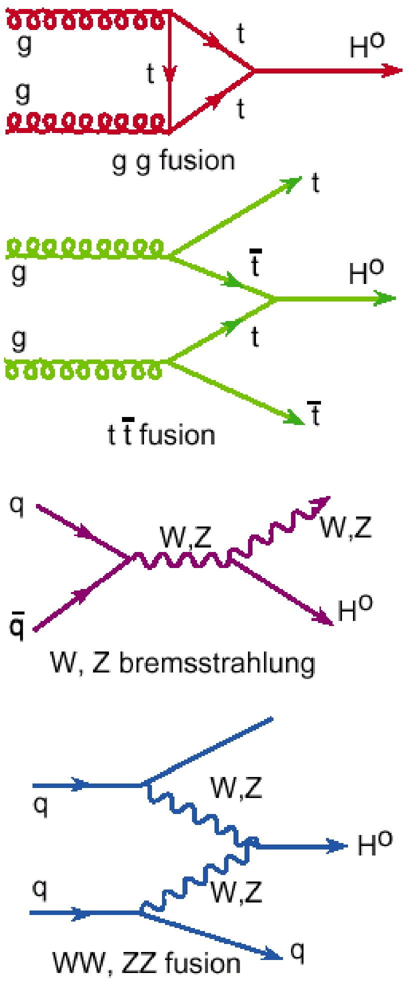


Combining the two experiments at this advanced stage turns out to be very powerful for the Tevatron

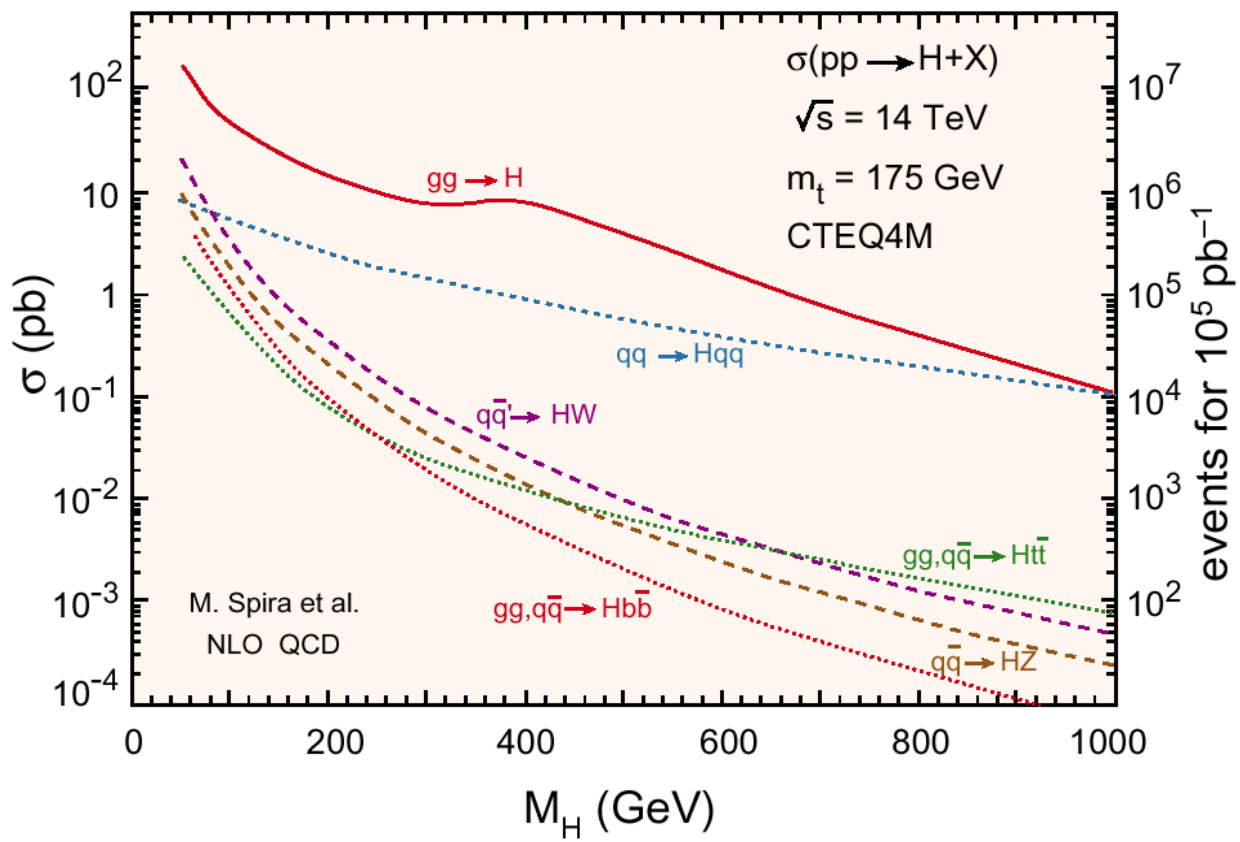
Tevatron Higgs Search Progress



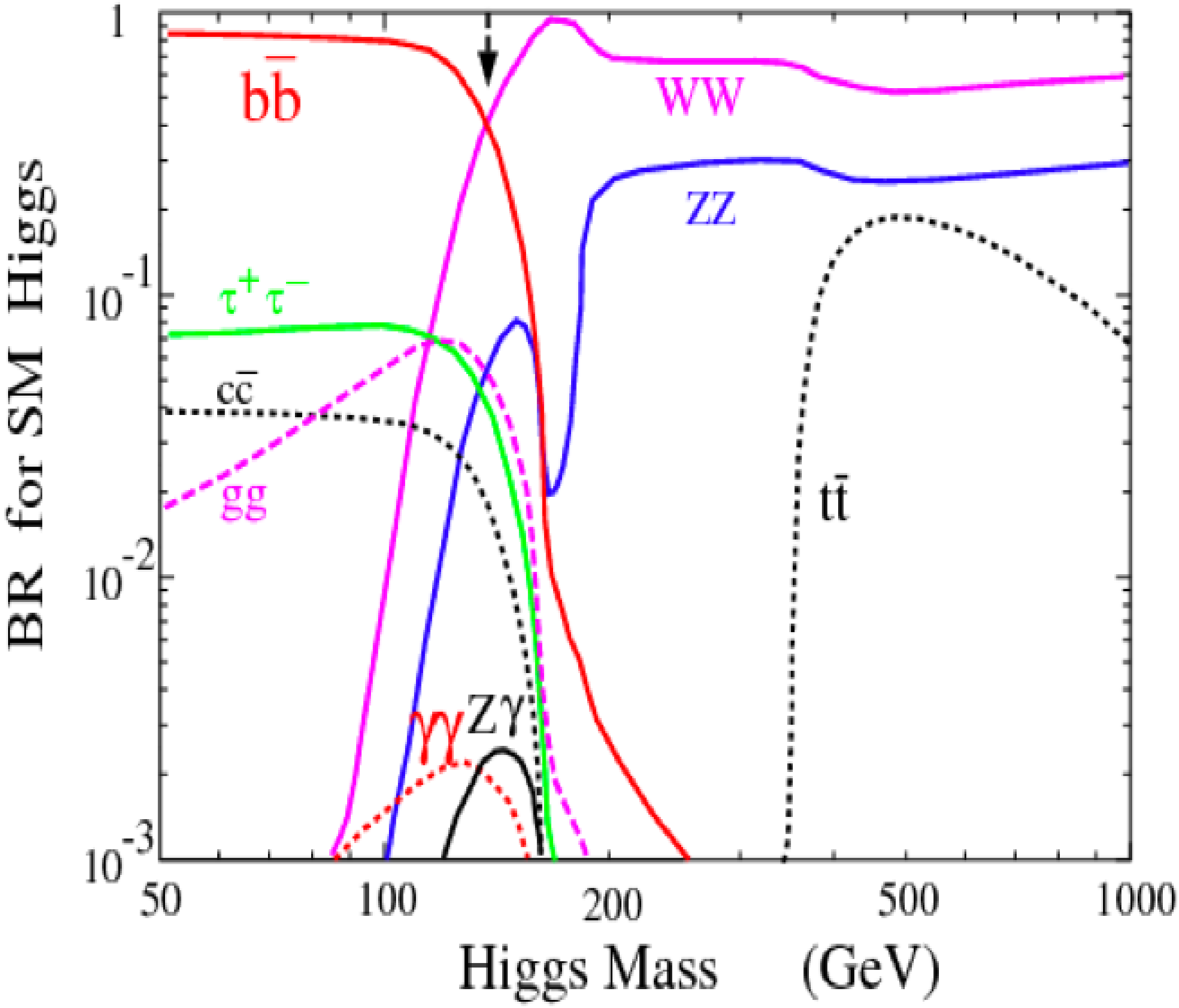
The Higgs Hunt at the LHC



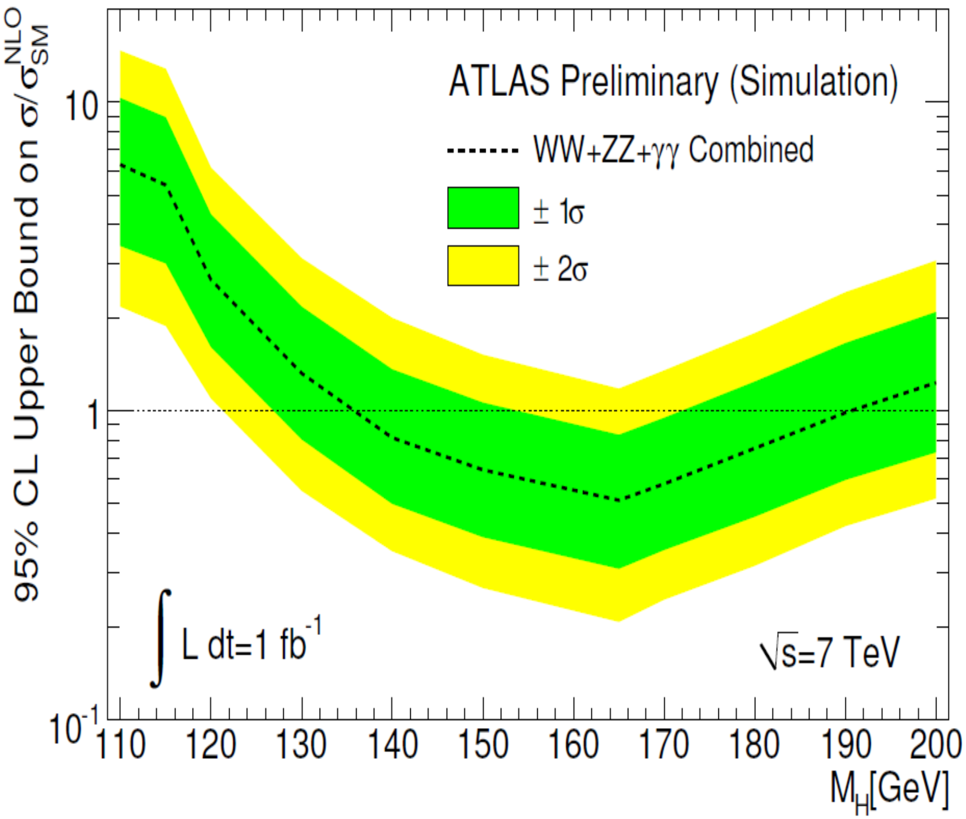
Higgs production cross sections at LHC

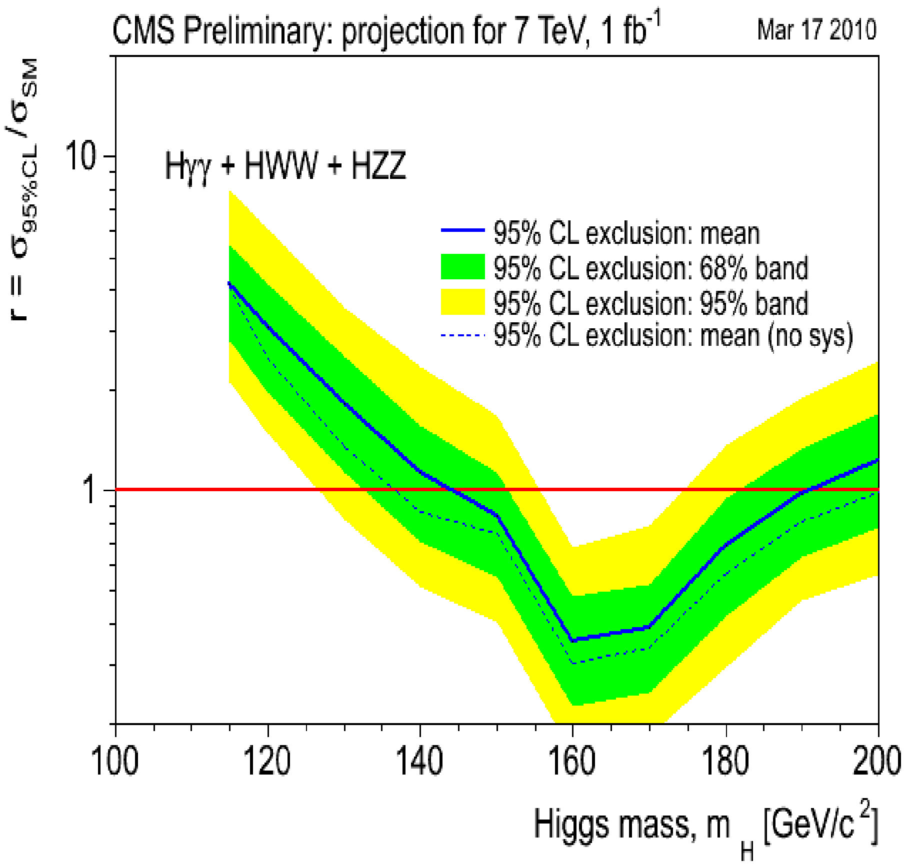


Higgs decay branching ratios



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

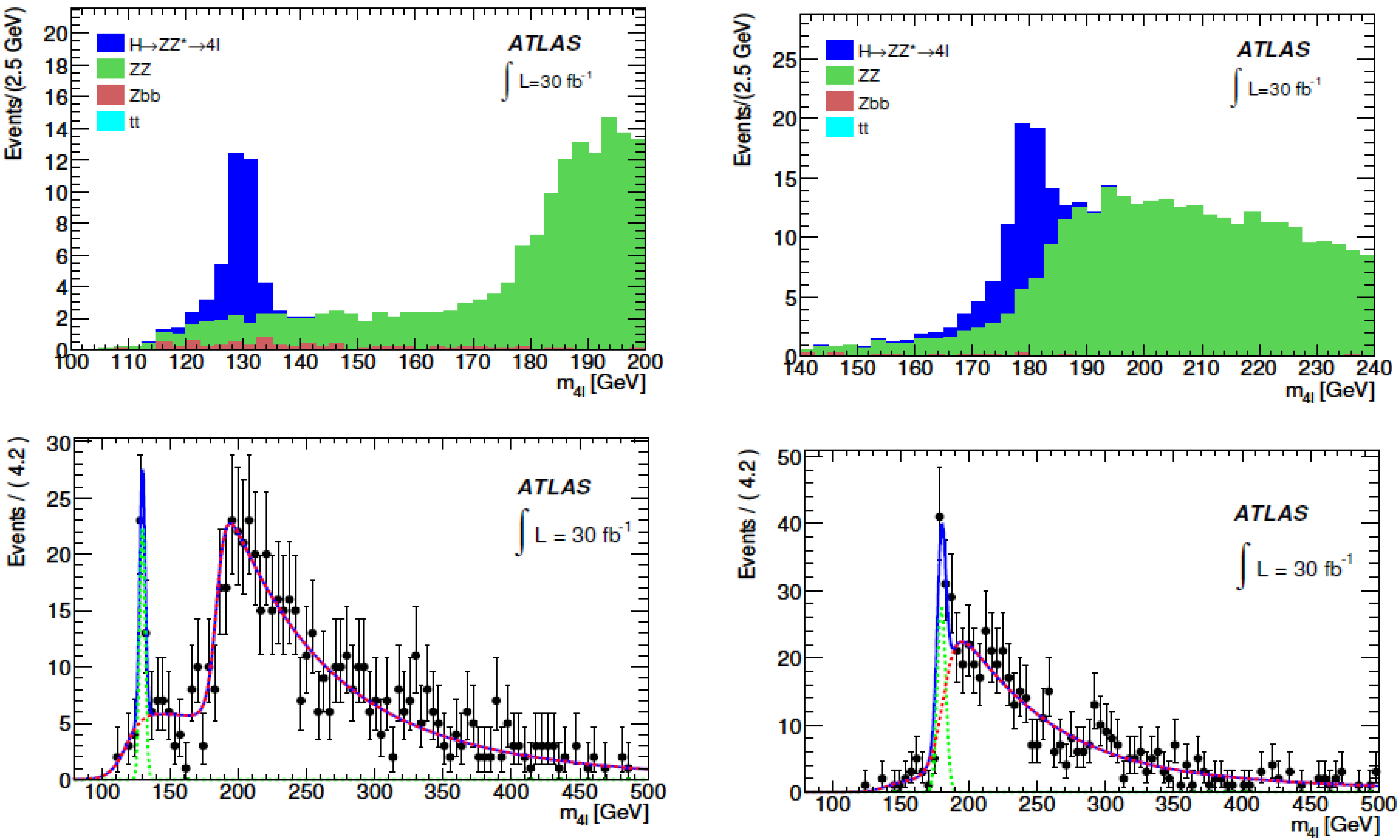




One can expect for the end of 2011 that ATLAS and CMS can exclude each the mass range 135 – 180 GeV, and that combined they could reach almost a 5 σ signal at a mass of 160 GeV

Higgs searches in the years 2014 and after …

14 TeV

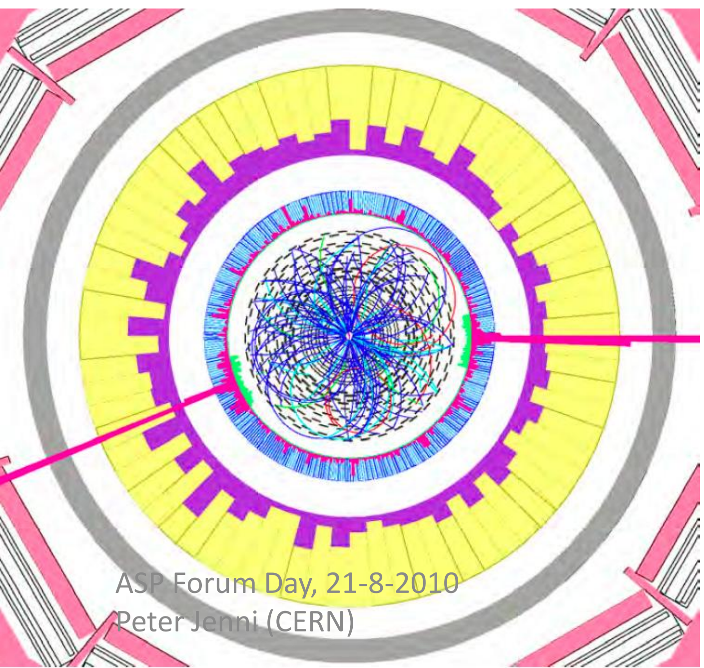


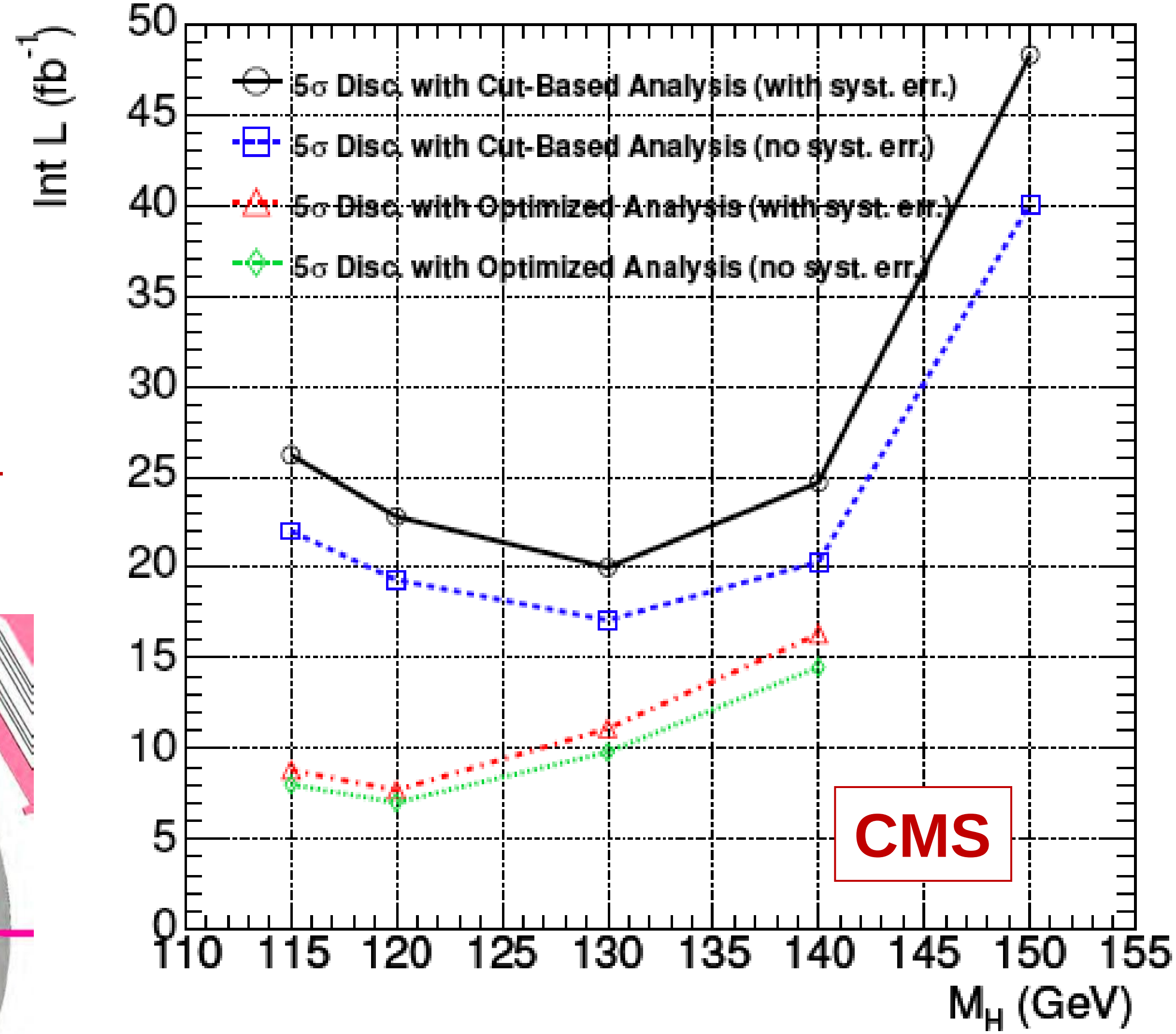
Examples for the 'gold-plated' 4 lepton channels (maybe sometimes in 2015), shown as smooth histogrammes and as a typical experimental distribution

Example of another channel for the low mass region

***H* → $\gamma\gamma$**

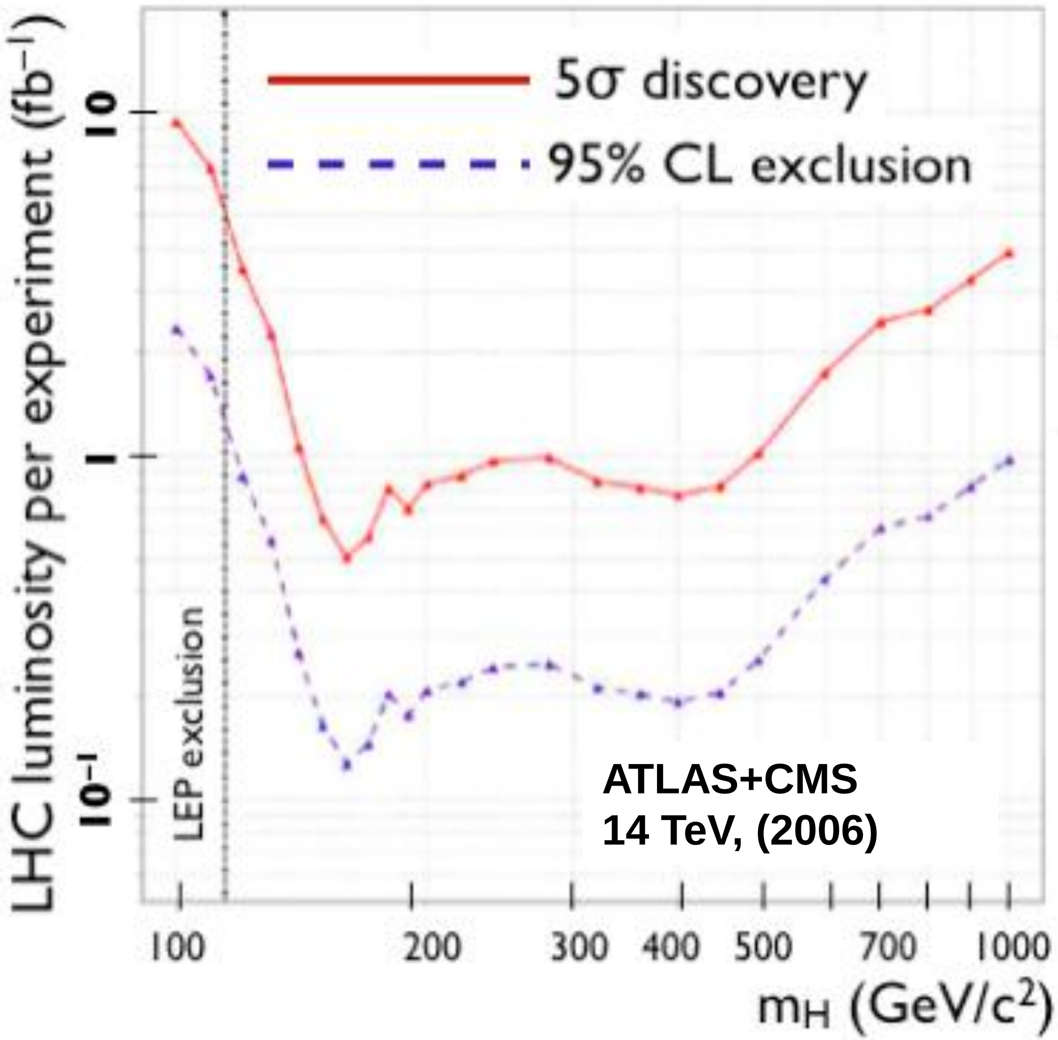
Optimized analysis: discovery with ~ 10 fb^{-1}



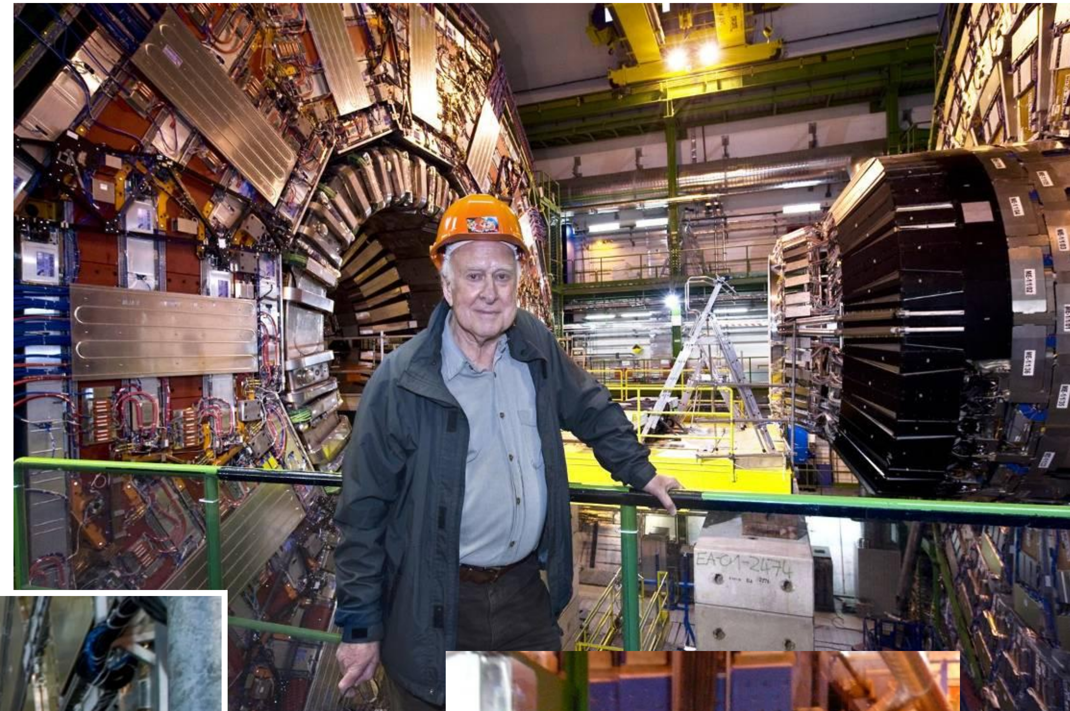


Summing up the Higgs search at the LHC with an old plot (still ~ valid)

→Around 2015 we should be able to conclude…



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



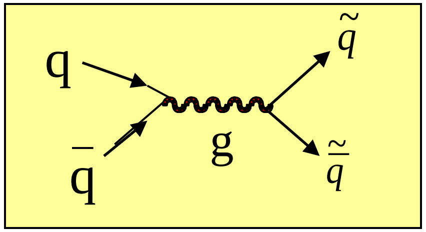
somewhat later, even in ALICE…

First discoveries at the LHC: Supersymmetry ?

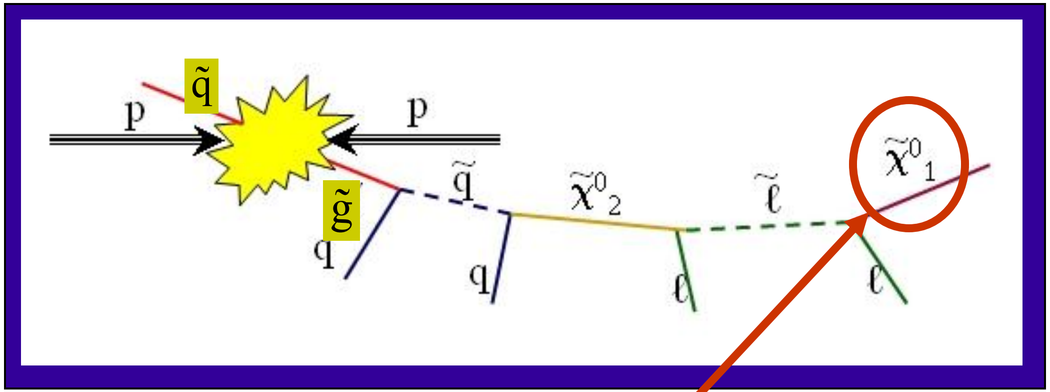
If it is at the TeV mass scale, it should be found "quickly" …. **thanks to:**

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

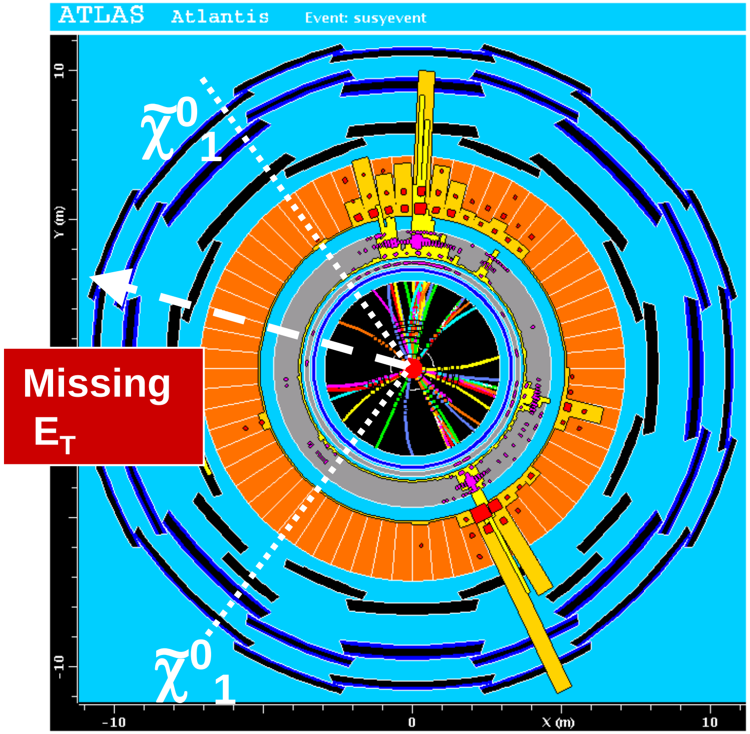
  For $m(\tilde{q},\tilde{g}) \sim 1$ TeV
  expect 1 event/day at $L=10^{31}\ cm^{-2}\ s^{-1}$



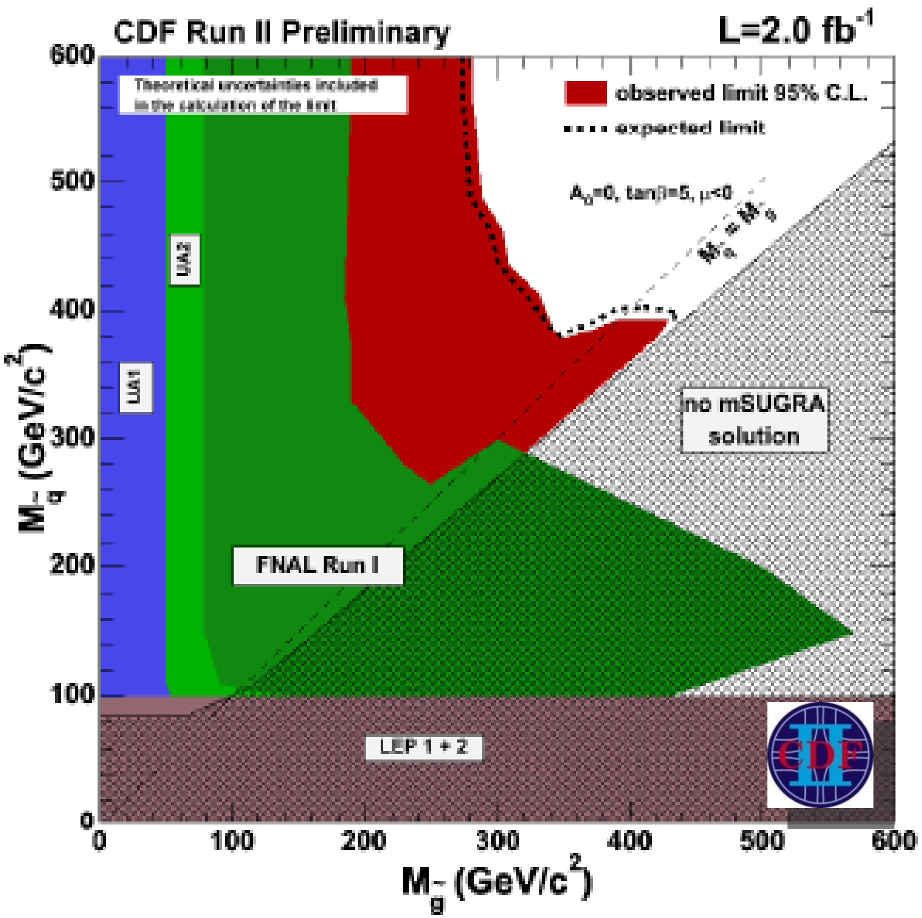
- **Spectacular final states (many jets, leptons, missing transverse energy)**

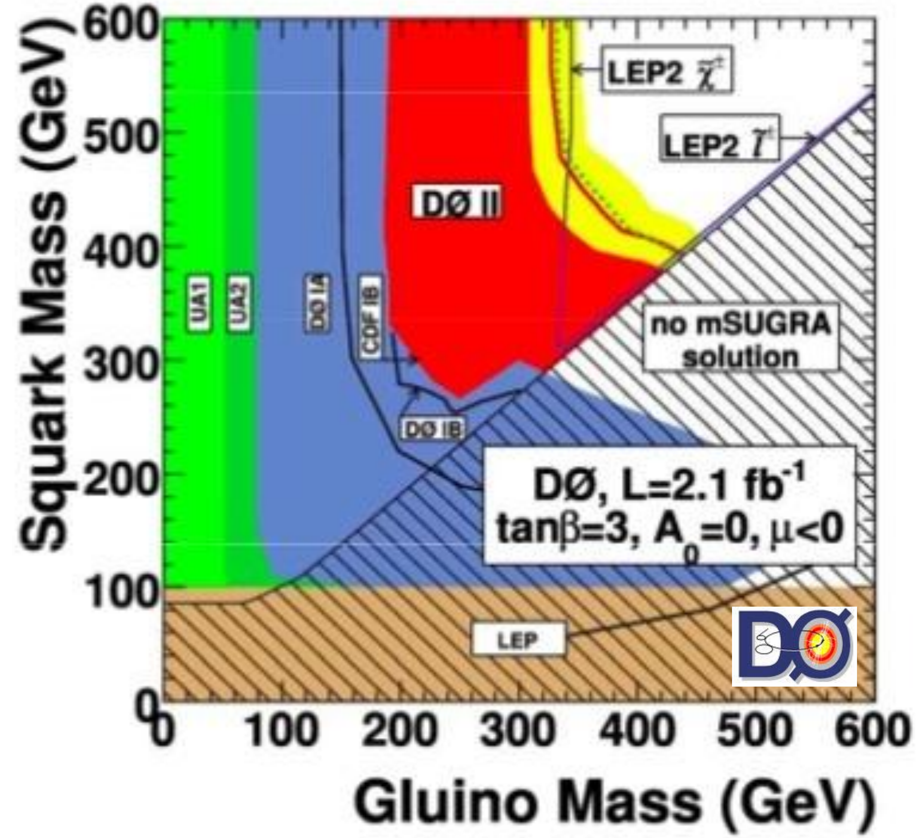


This particle (lightest neutralino) is stable, neutral and weakly interacting → escapes detection (like ν) → apparent missing energy in the final state



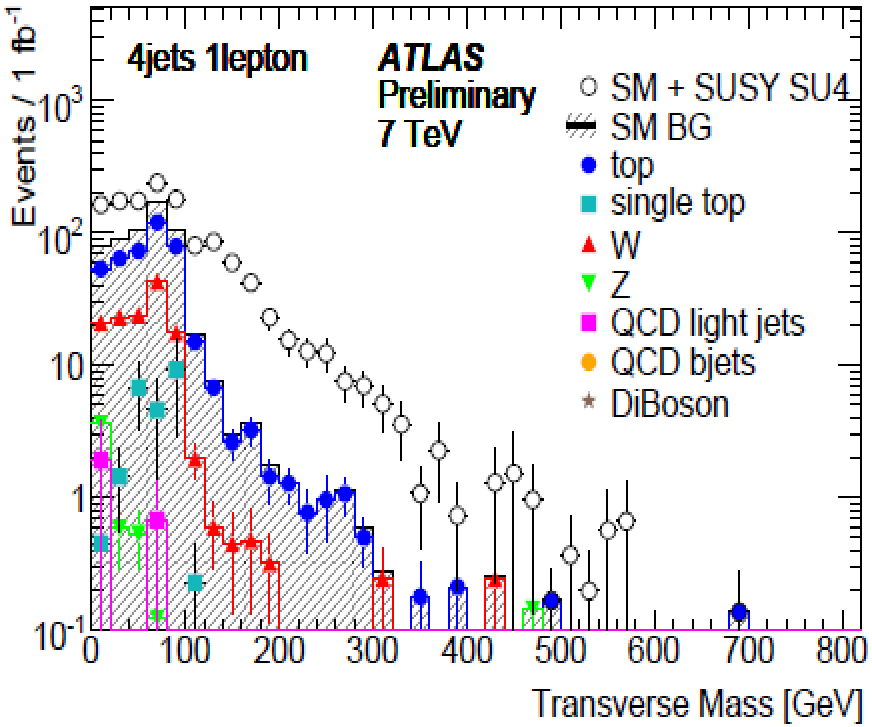
The Tevatron experiments have made very detailed studies investigating a large variety of possible signatures for SUSY

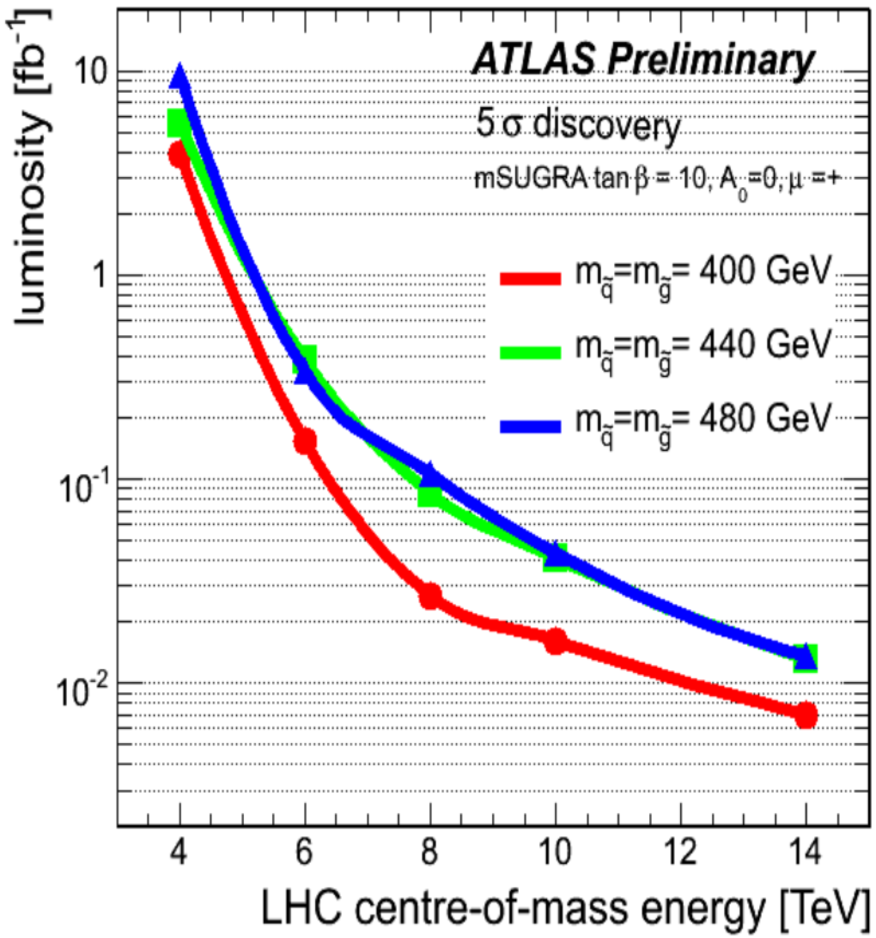




Exclusion plots (95% CL) for the most basic searches for squarks and gluinos

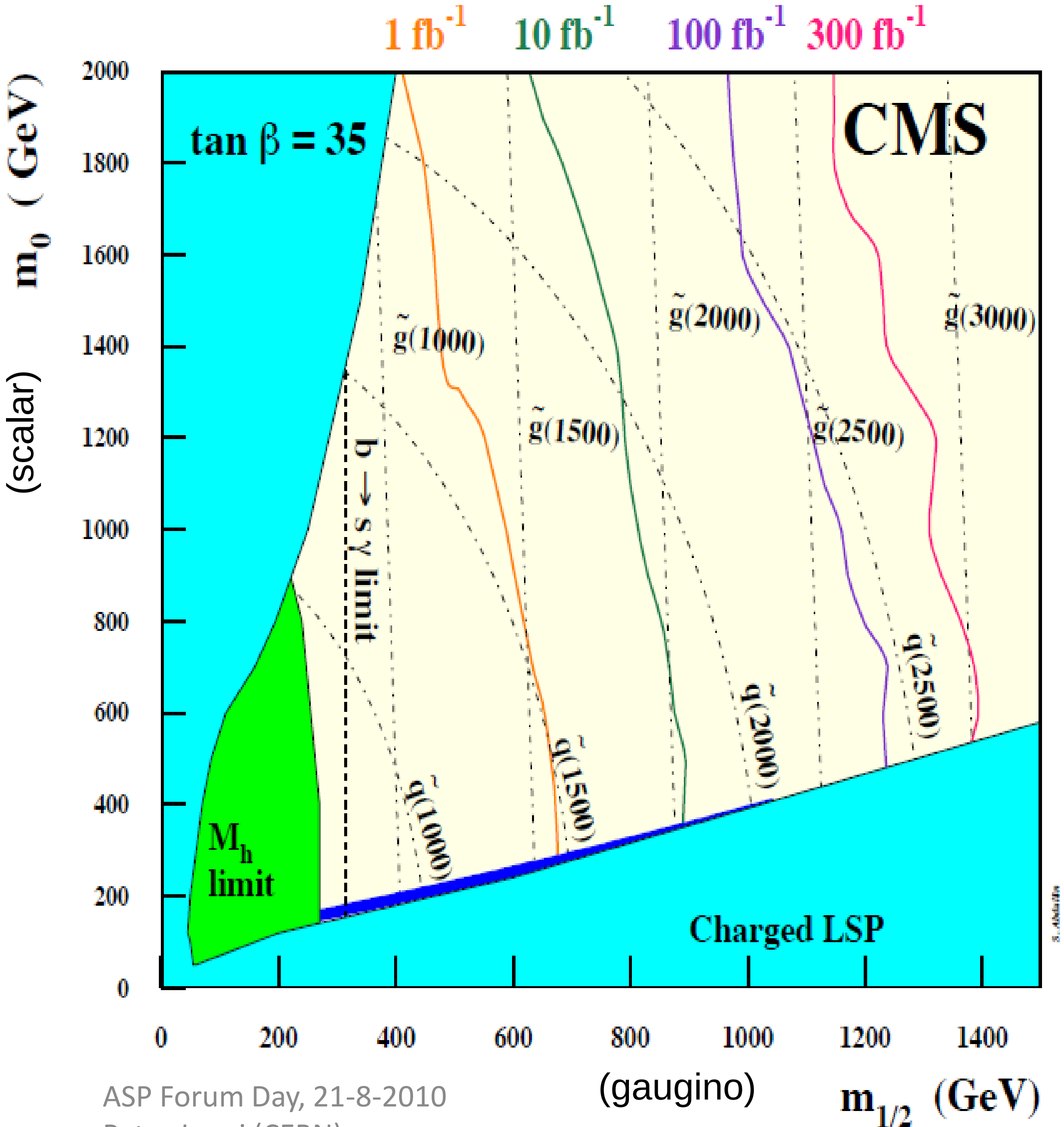
The initial LHC running will already match (maybe exceed) end of 2010 the Tevatron reach

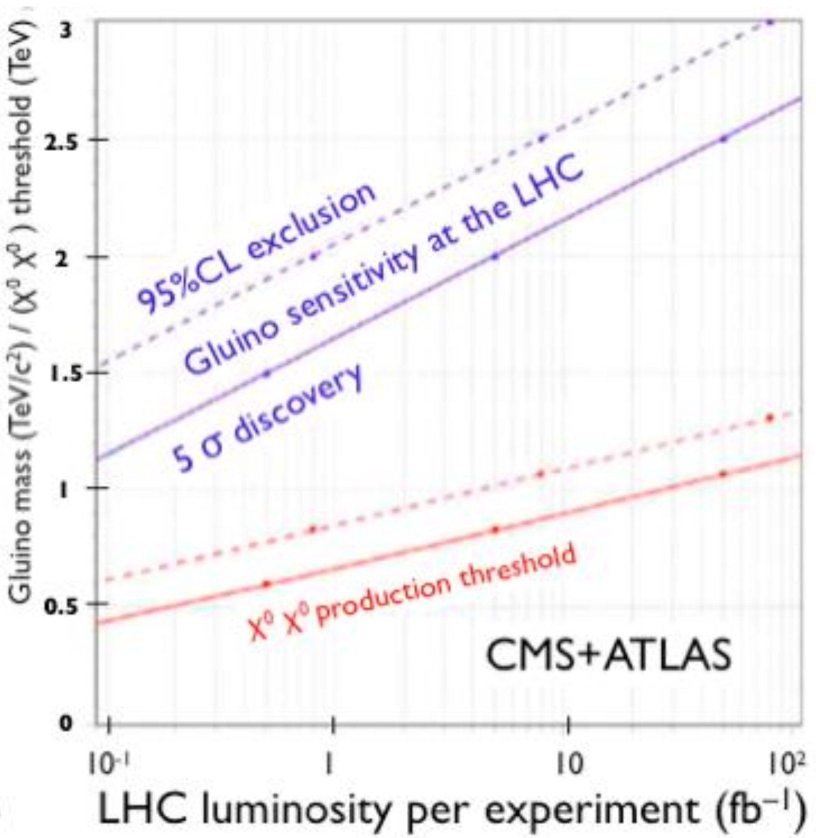




A typical example; note that the missing transverse energy performance enters directly the 'Transverse Mass', detectors must be well understood for these measurements

Ultimate discovery reach for SUSY particles at the LHC (indicative plots, model-dependent…)



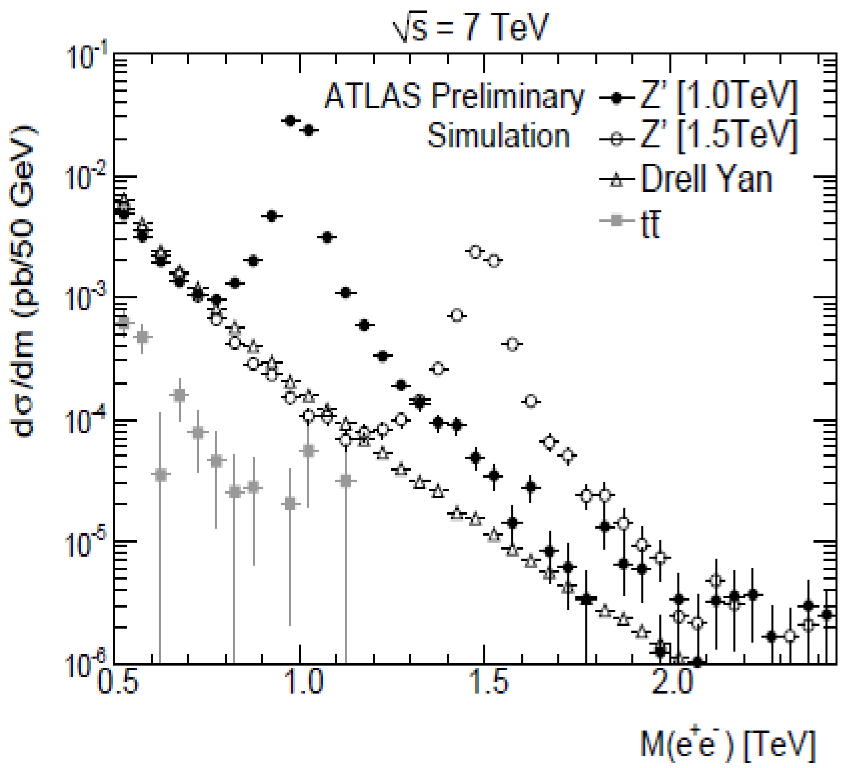


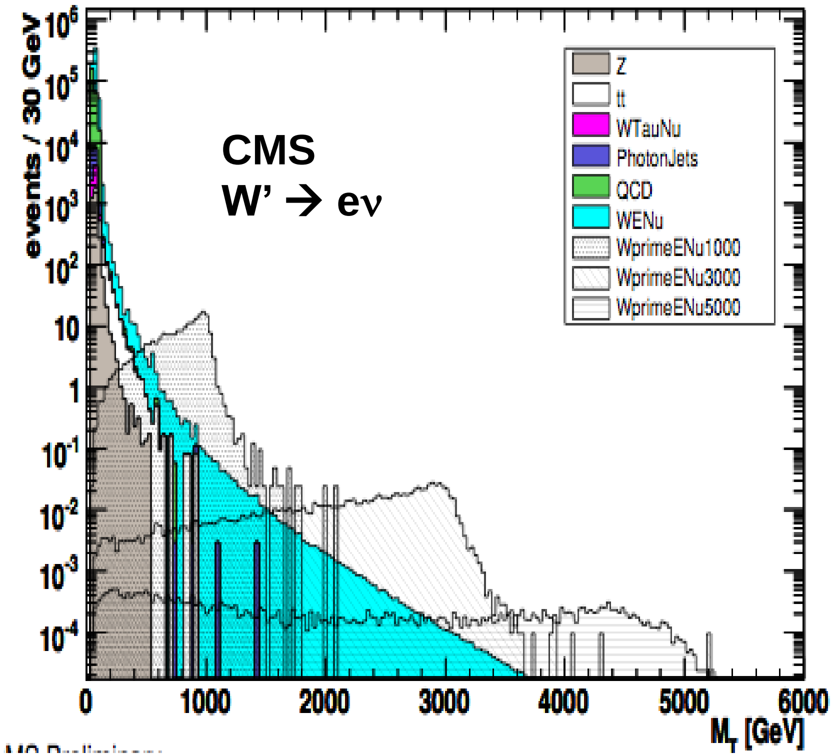
The mass scale probed for squarks and gluinos will be typically 2.5 TeV by 2017

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

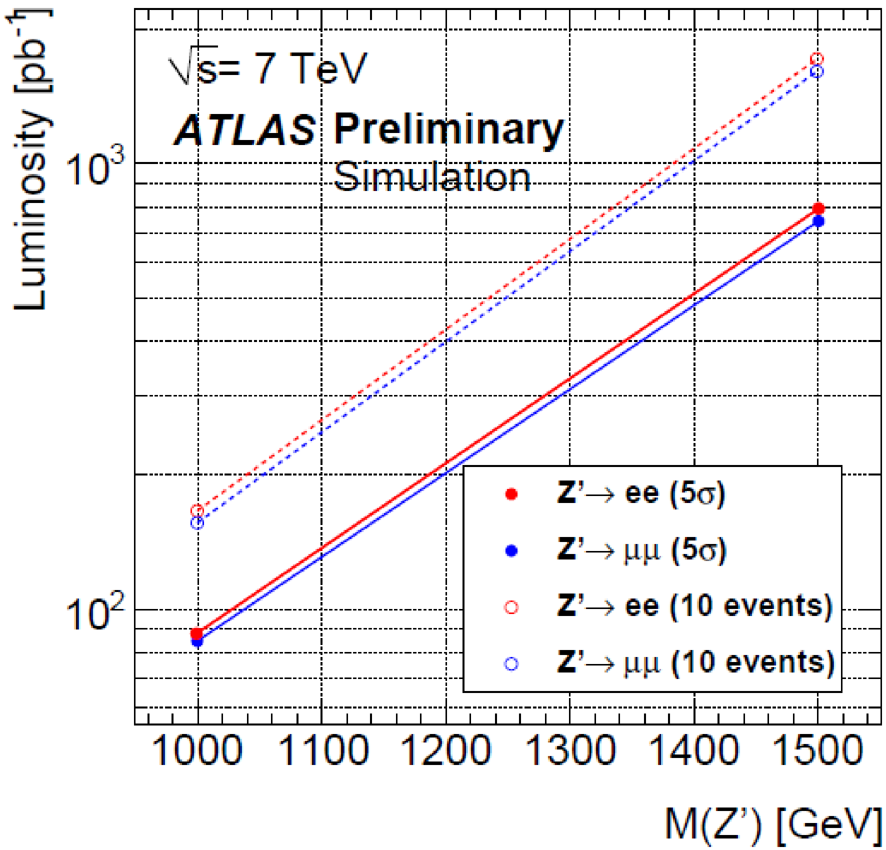
Leptonic decays with electrons or muons would give spectacular signatures

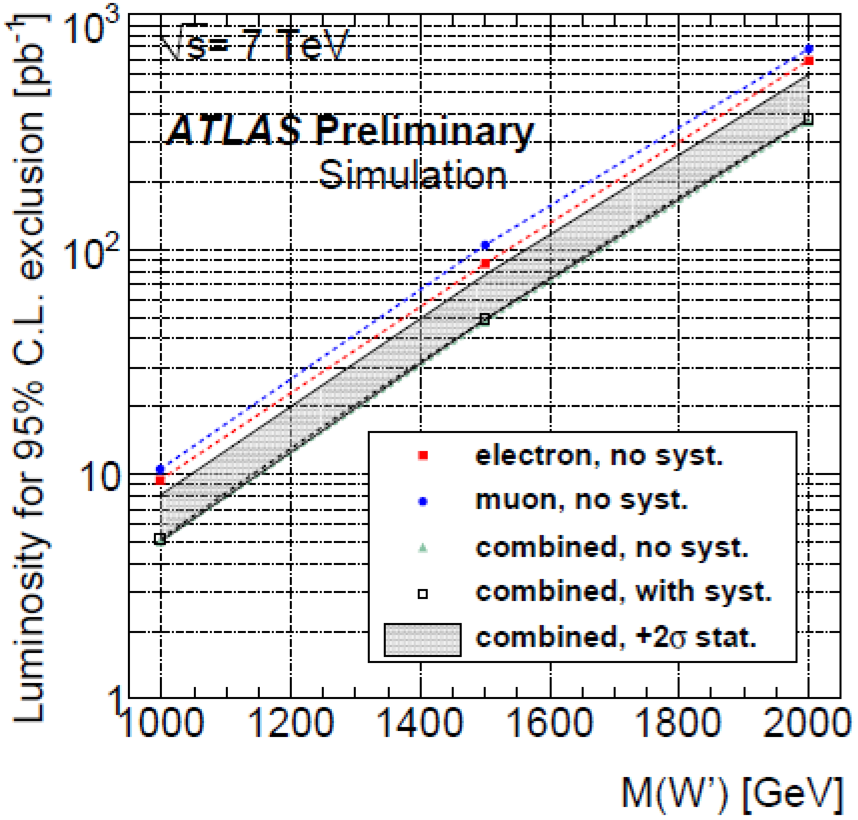
Many different models predict such objects, discoveries of a Z' and W' like particle would be a 'gold mine' for the field, other decay channels could contain yet more new particles!





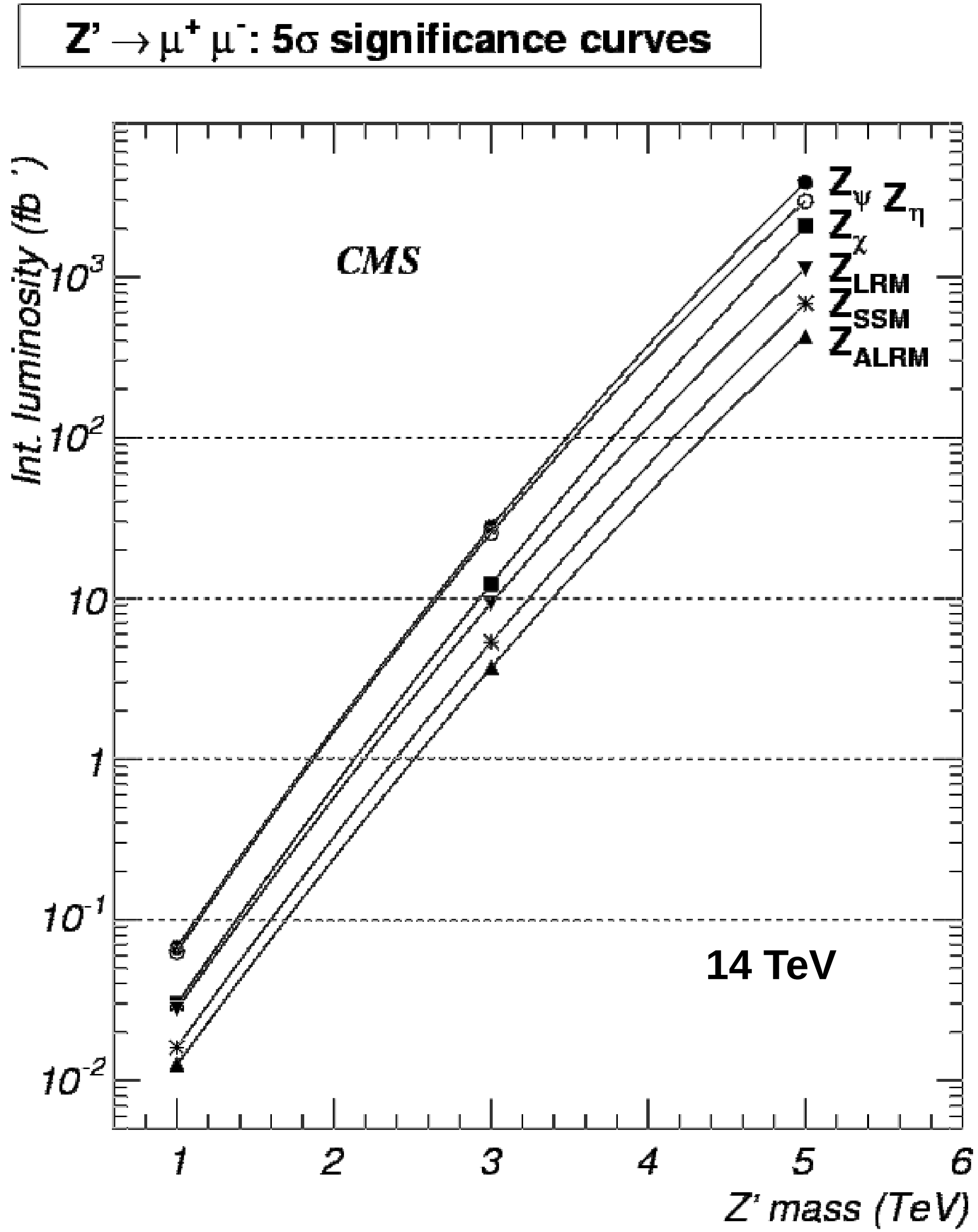
The LHC experiments will have access to the 1 TeV mass range very early on, still this year (2010)





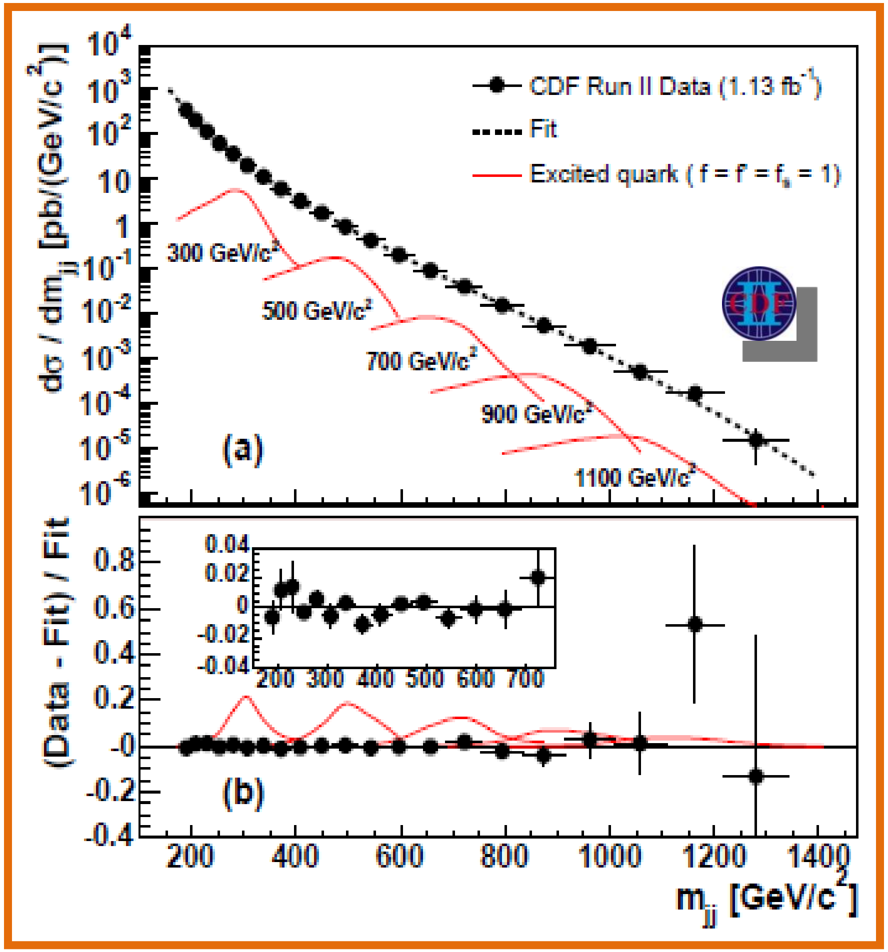
Discovery potential for ATLAS and CMS for the end of 2011, with 1 fb^{-1} at 7 TeV: up to 1.5 TeV for Z' and up to 1.9 TeV for W'

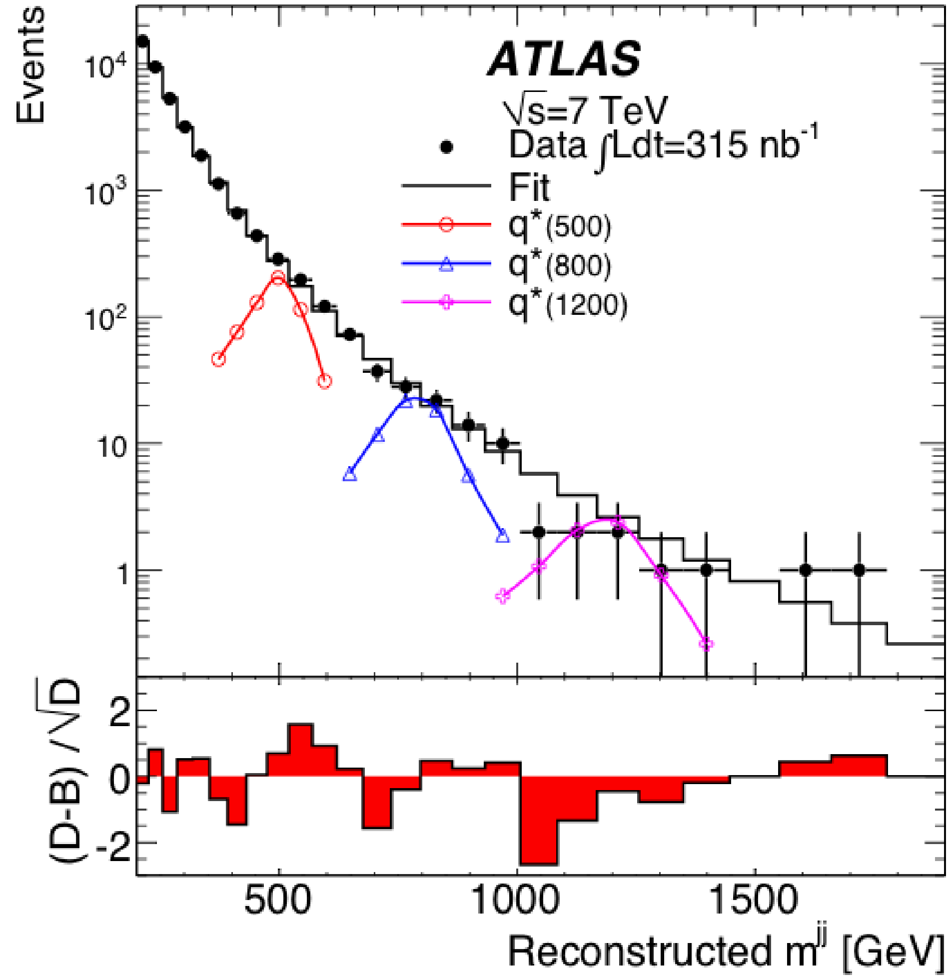
The ultimate discovery range at the LHC for heavy Z' and W' is very large, reaching 5 TeV and even beyond



(Note that the plot shows one channel for one experiment only)

Hunting for bumps in the di-jet mass distributions

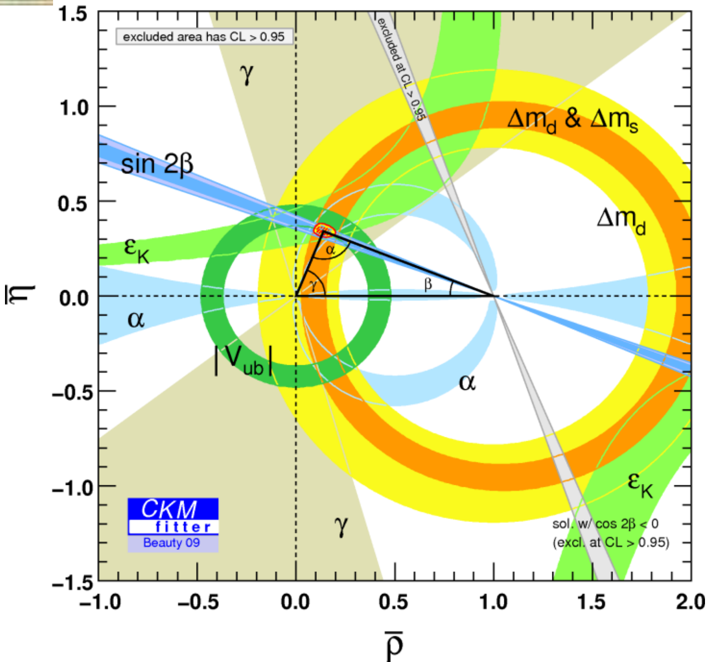




Best Tevatron limit m(Q*) > 870 GeV

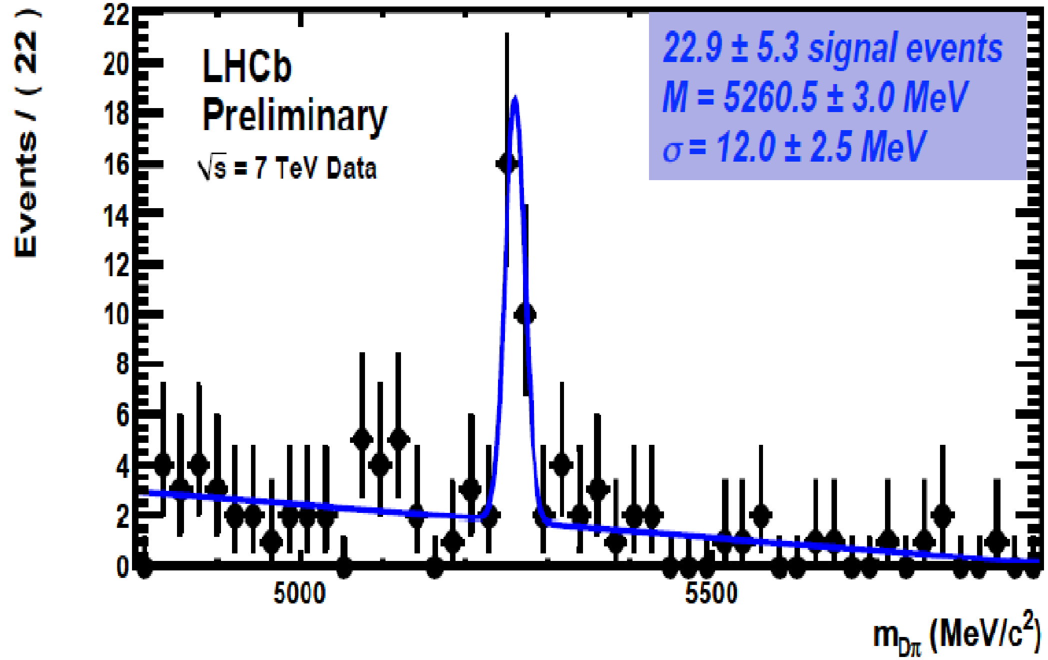
Even at this early stage the best LHC limit is already m(Q*) > 1.26 TeV

Early hints of news from 'Beyond the Standard Model' may come from 'beautiful' flavour physics...

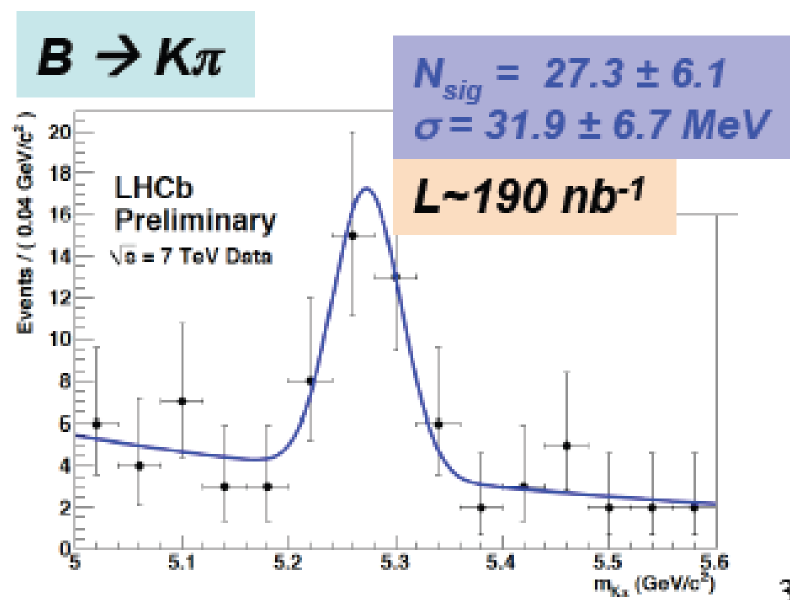


First fully reconstructed B mesons

$B^0 \rightarrow D^+\pi^- + B^+ \rightarrow D^0\pi^+$



Calibration of the mass scale and B-field is ongoing



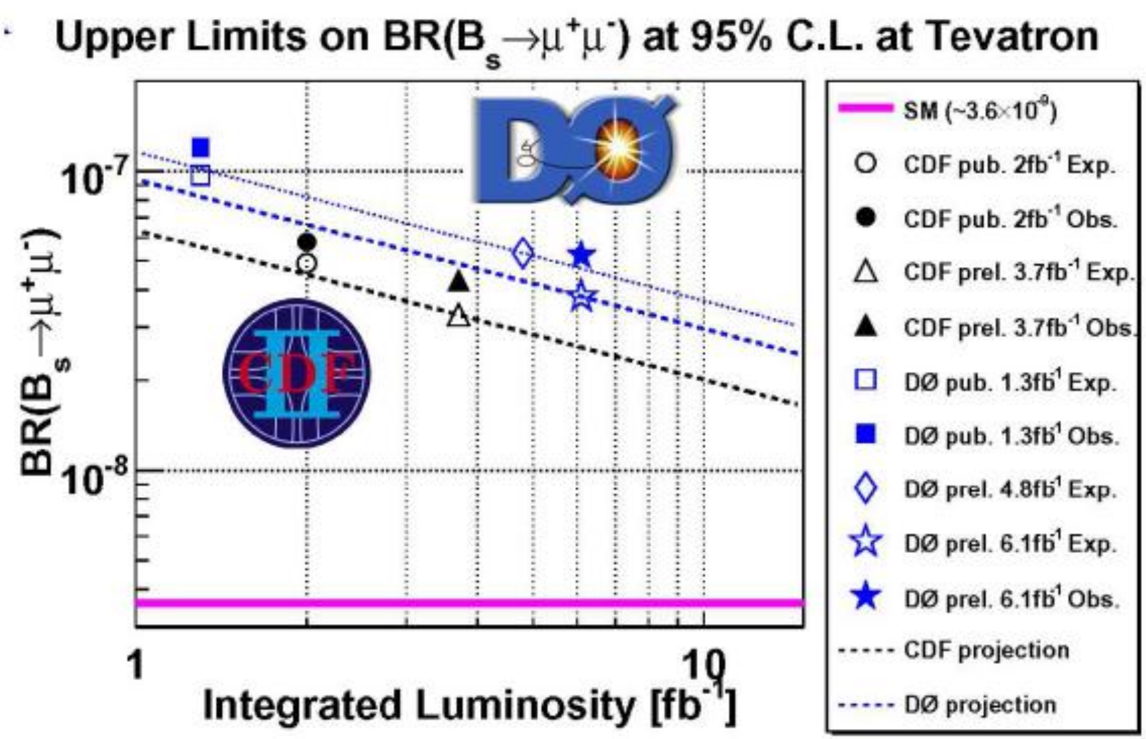
35

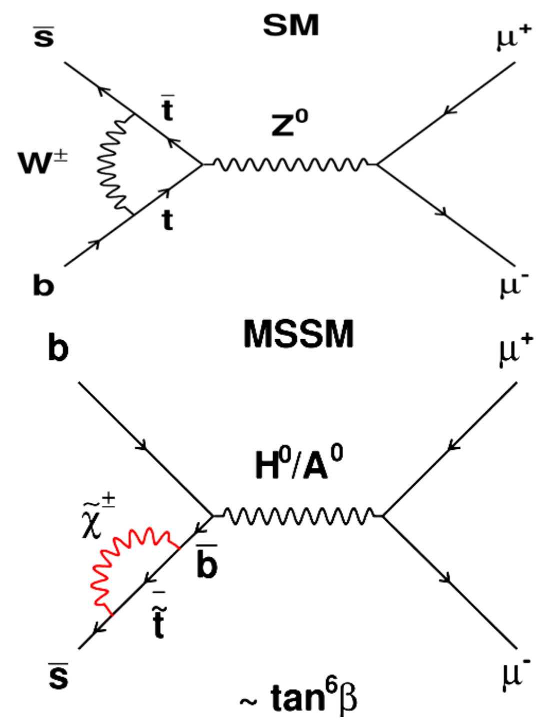
$B_s \rightarrow \mu\mu$

Small BR in SM: $(3.2 \quad 0.2) \times 10^{-9}$

Sensitive to NP

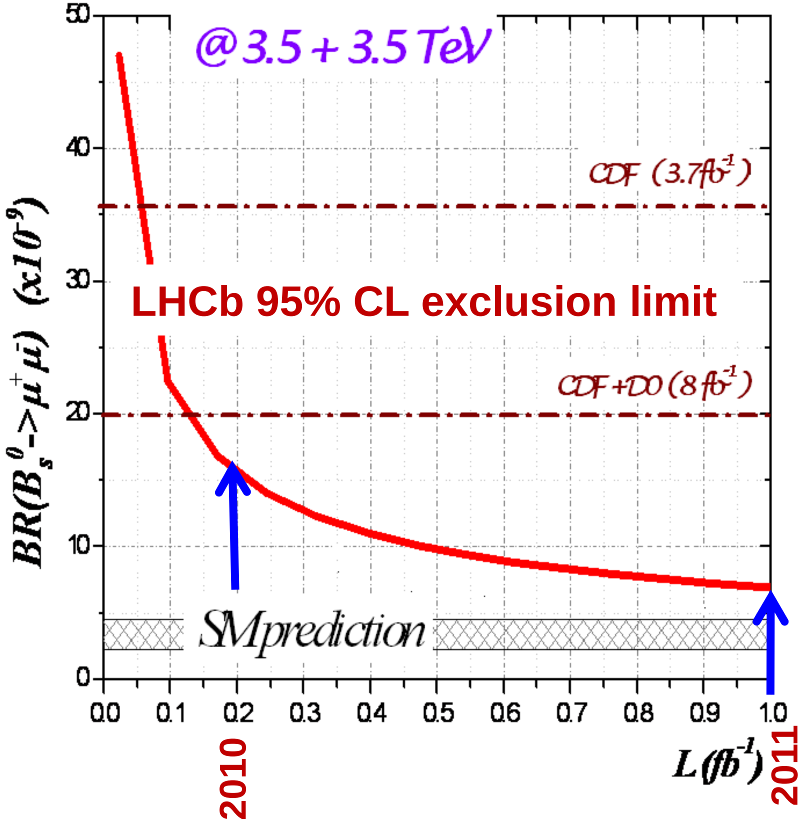
- **could be strongly enhanced in SUSY**
  - **In MSSM scales like ~$\tan^6\beta$**



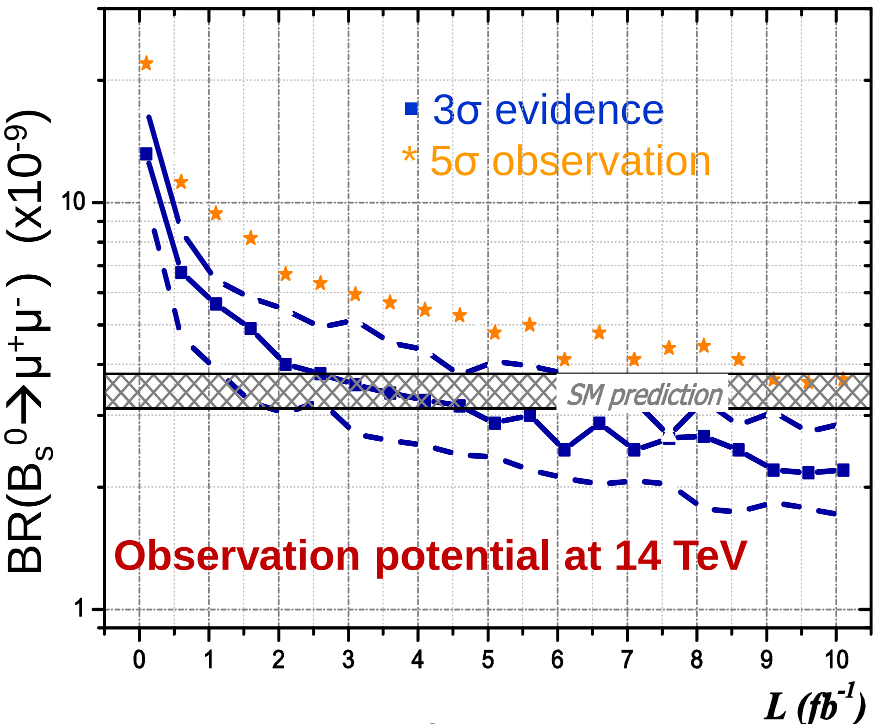


- CDF Preliminary, 3.7 fb^{-1}: $< 4.3 \cdot 10^{-8}$ at 95% C.L.
- DØ Preliminary, 6.1 fb^{-1}: $< 5.2 \cdot 10^{-8}$ at 95% C.L.

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



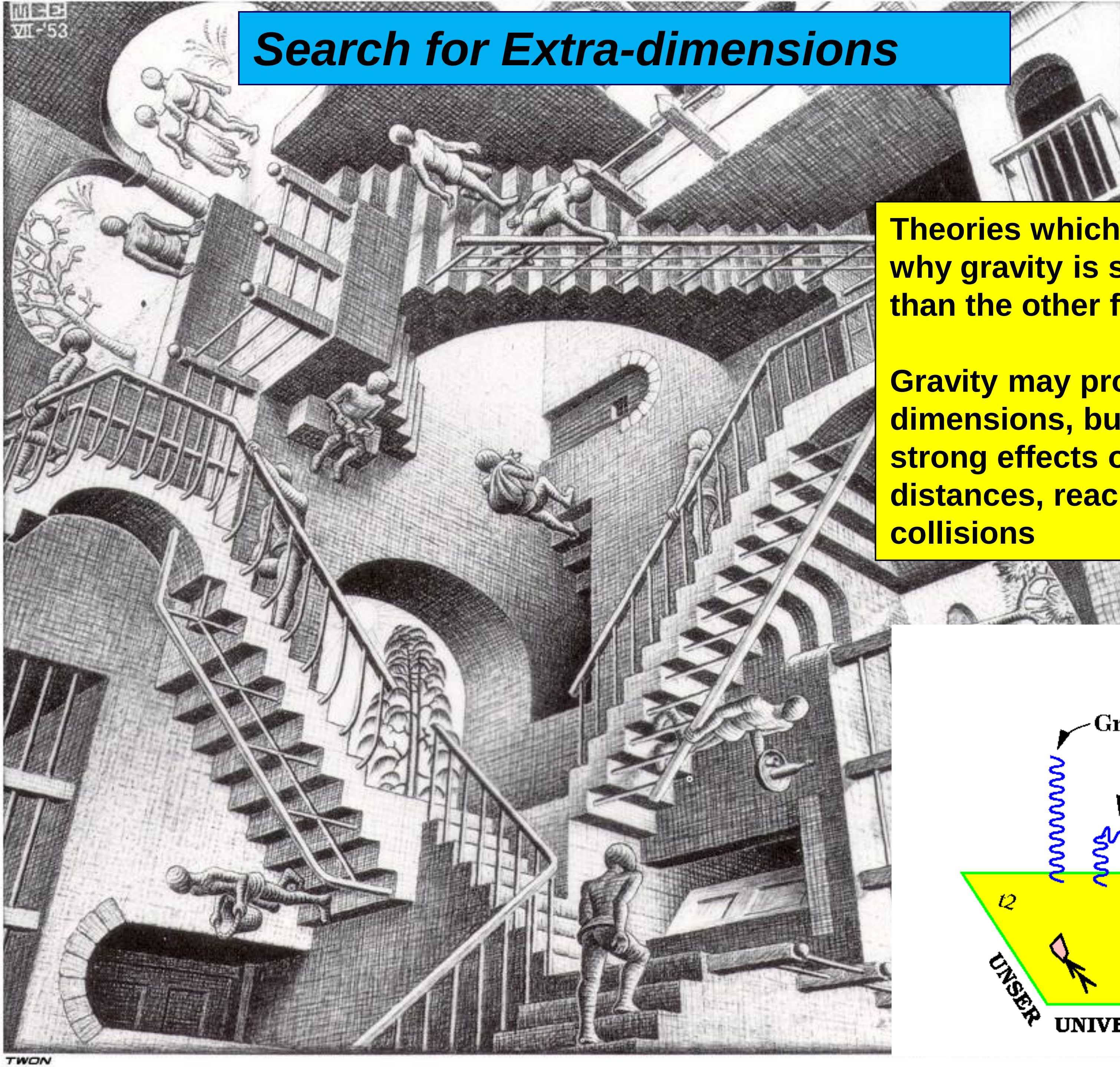
With ~0.2 fb^{-1} LHCb should improve on expected Tevatron limit



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

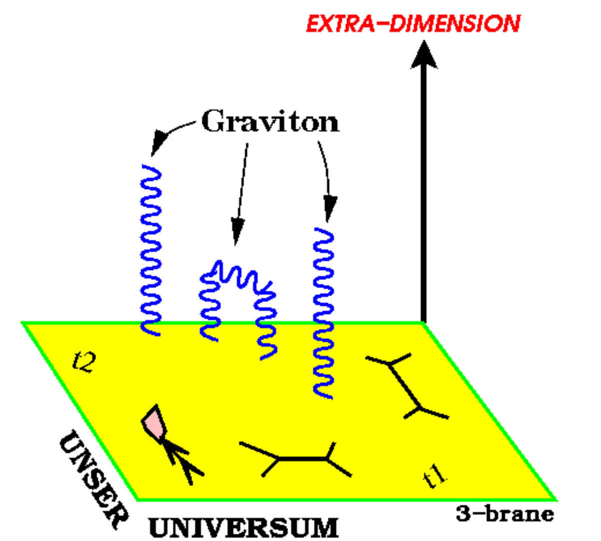
(Note: ATLAS/CMS will be competitive)

Search for Extra-dimensions

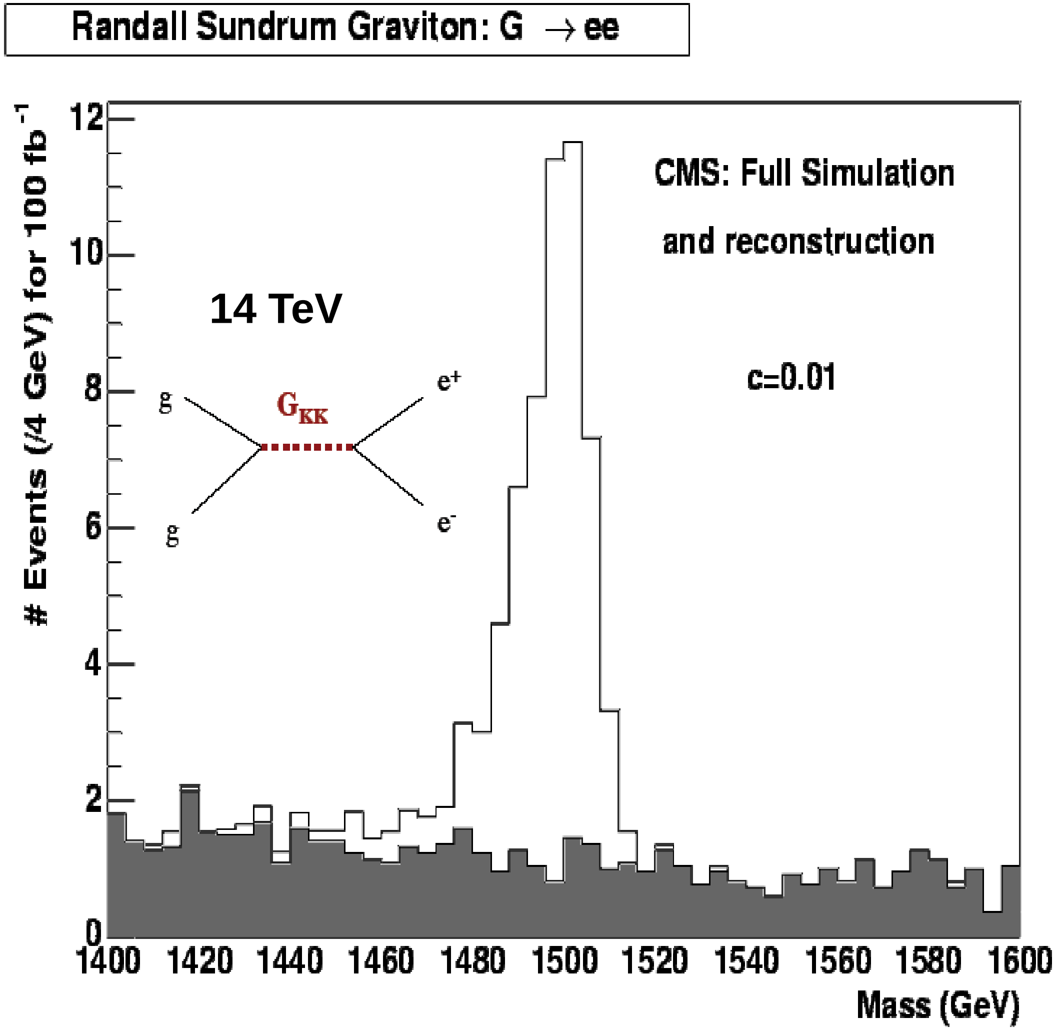


Theories which try to explain why gravity is so much weaker than the other forces

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



Sundrum
Randall
Gianotti

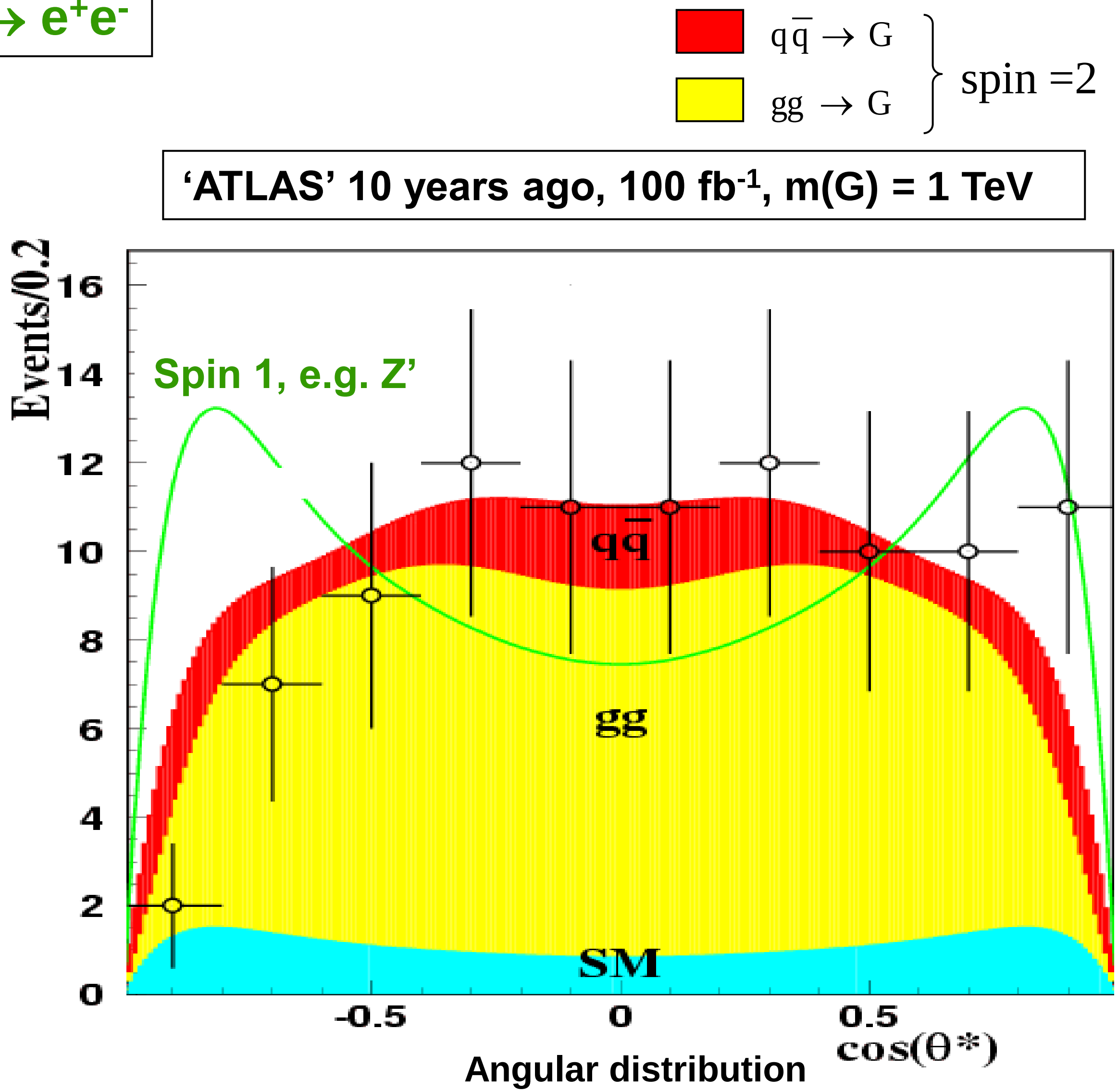
Signature: a resonance in the **di-electron** **or** **di-muon** **final state, as well as** **di-photons**, ***a priori*** **easy for the experiments**

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

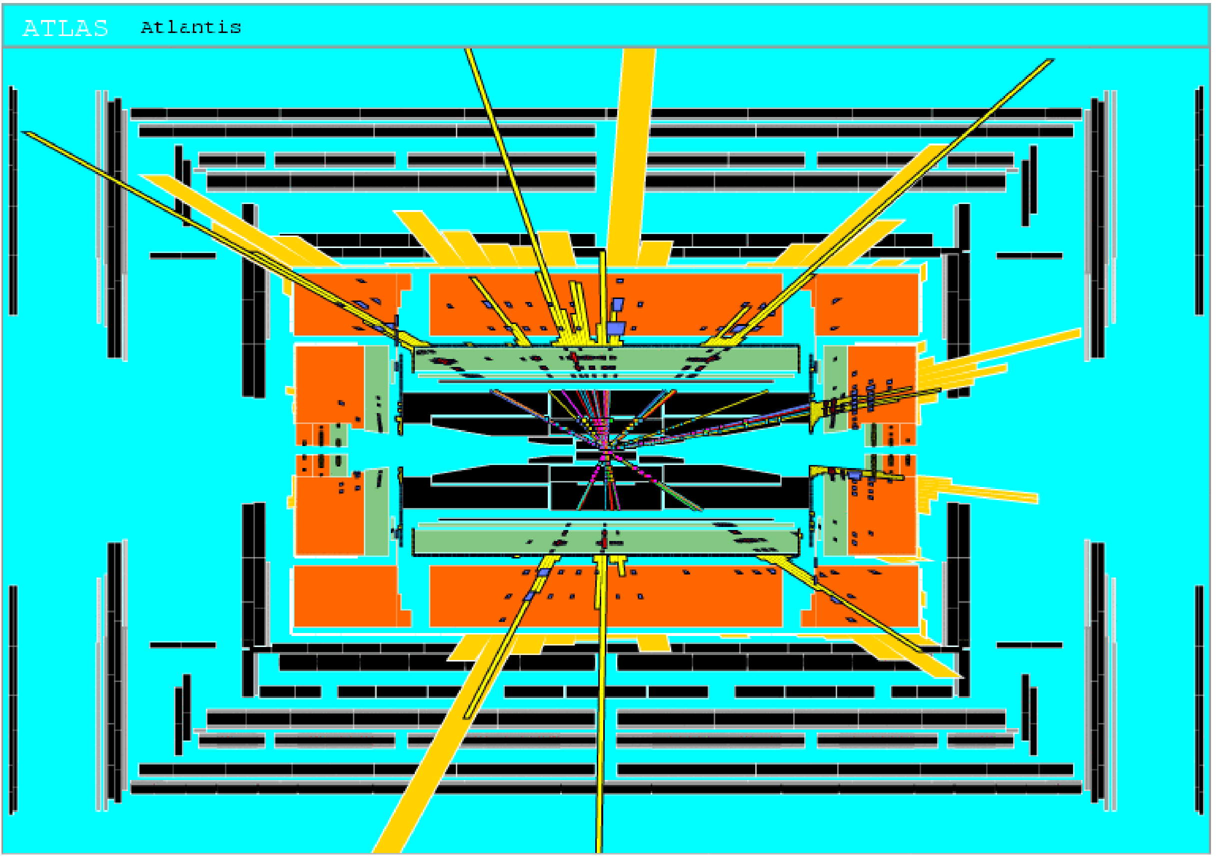
$qq, gg \rightarrow G \rightarrow e^+e^-$

'ATLAS' 10 years ago, 100 fb^{-1}, m(G) = 1 TeV

Lisa Randall visiting ATLAS



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

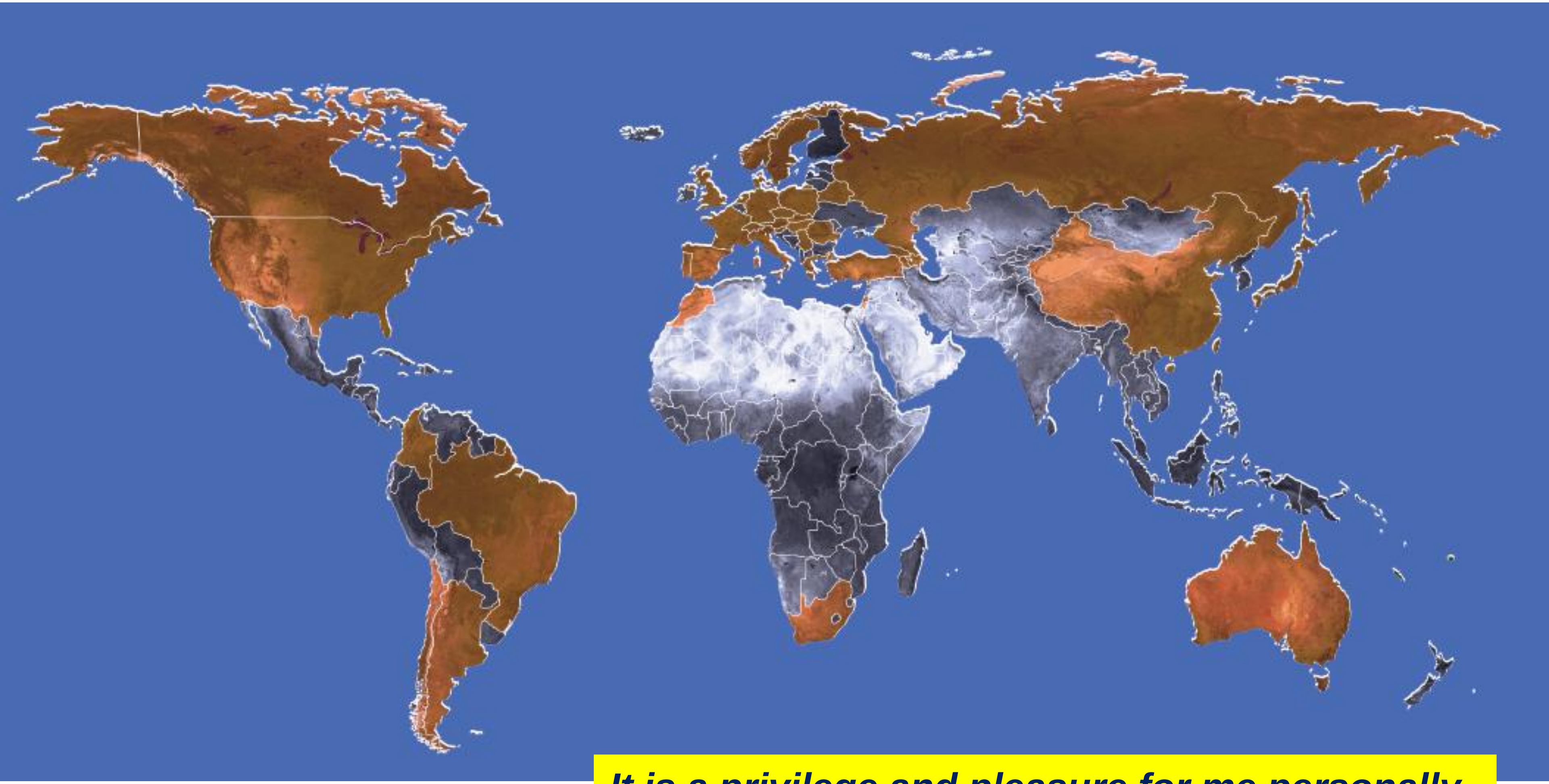


Simulation of a black hole event with M_{BH} ~ 8 TeV in ATLAS

They decay immediately through Stephen Hawking radiation

Exciting times are ahead of us!

Hadron colliders, and in particular the LHC, will show us the way forward in our global, world-wide field

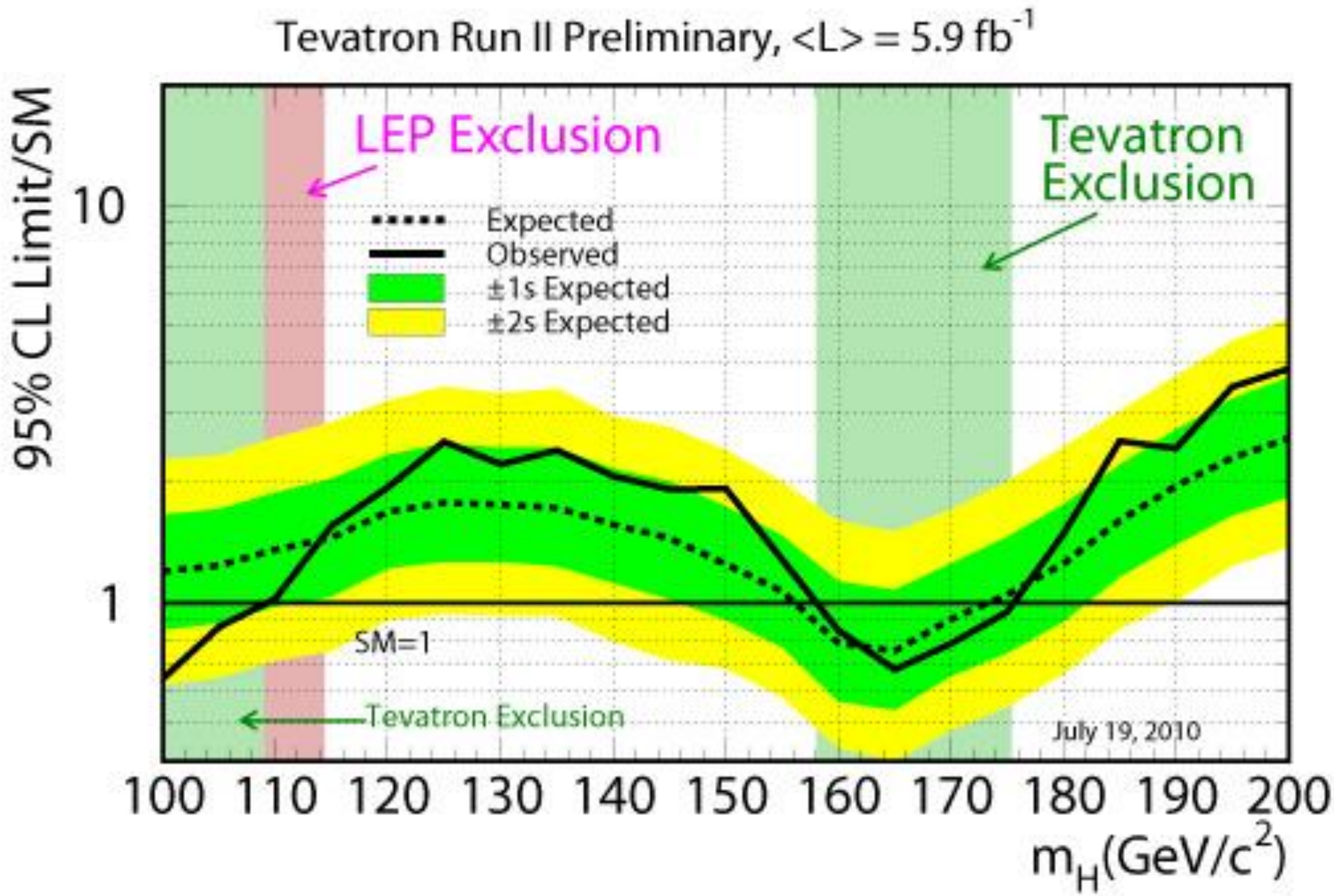


It is a privilege and pleasure for me personally to share this great scientific adventure with the South African physics community

…Pleasant memories from the Launch Event of the SA-CERN on 15th Dec 2008

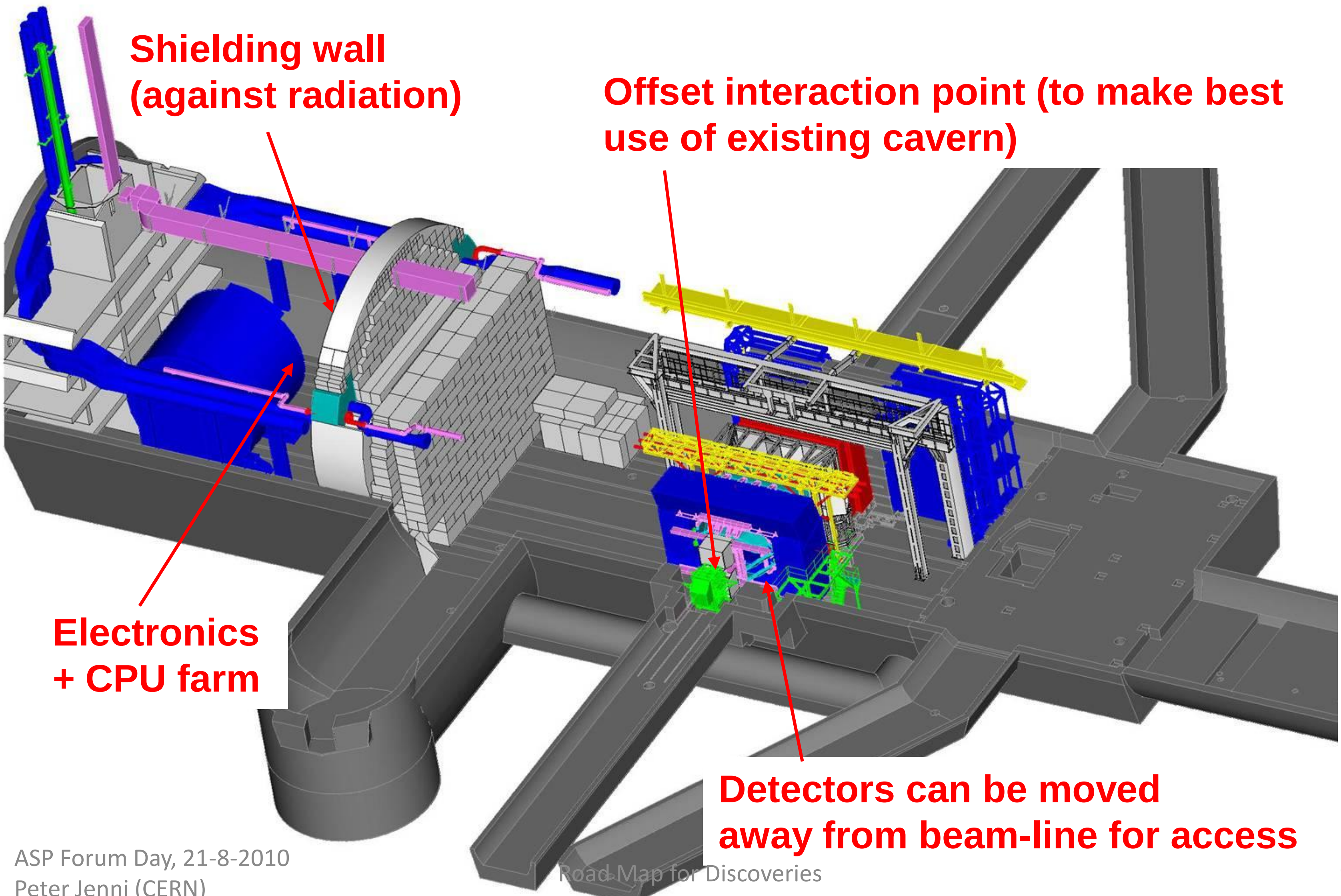
Builds on the long-standing excellent relations, formalized since 1992 in a CERN – South Africa Cooperation Agreement

Spares

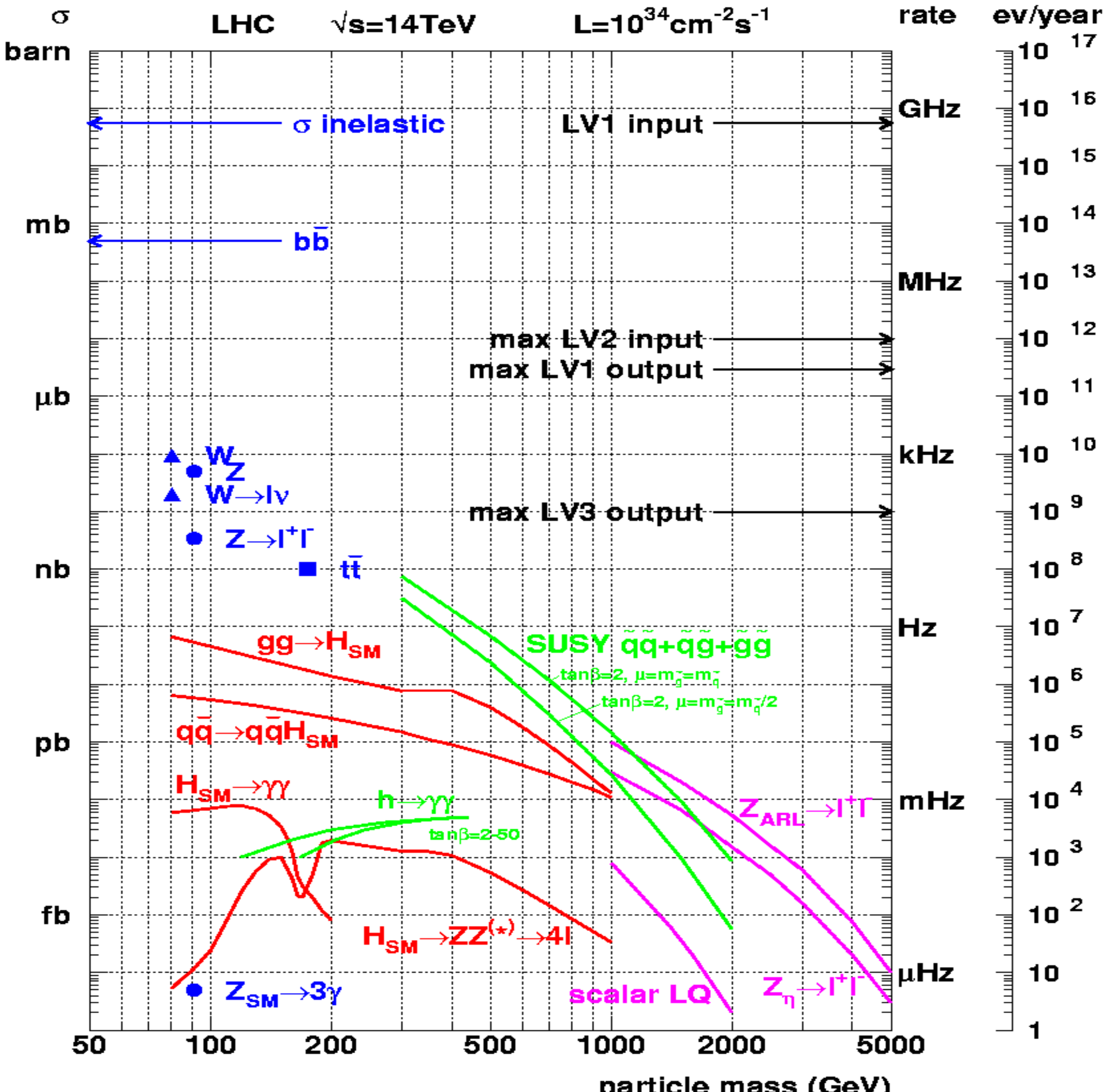


(Status ICHEP 2010)

LHCb in its cavern (~100 m deep)



Cross Sections and Production Rates

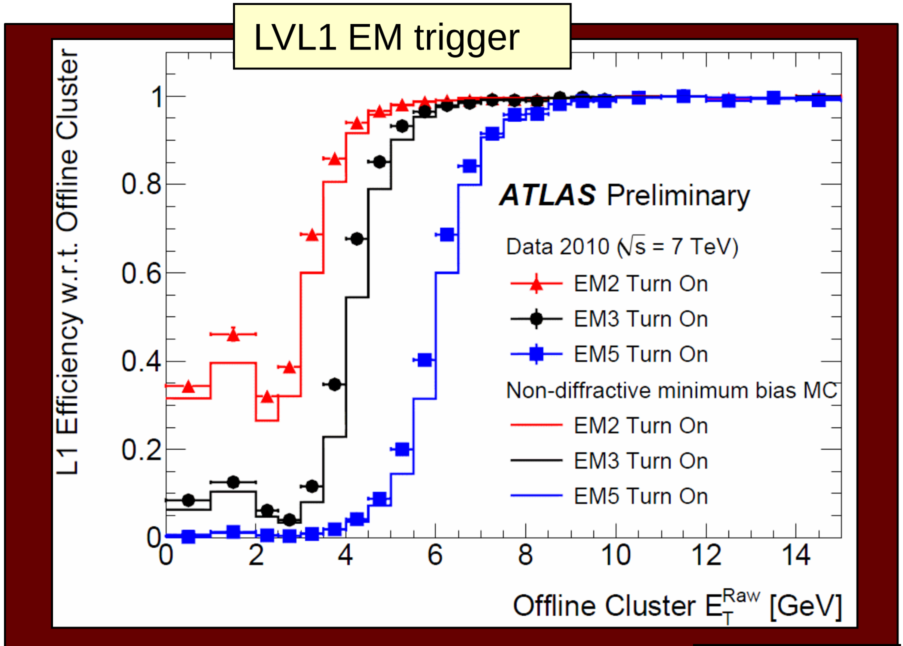


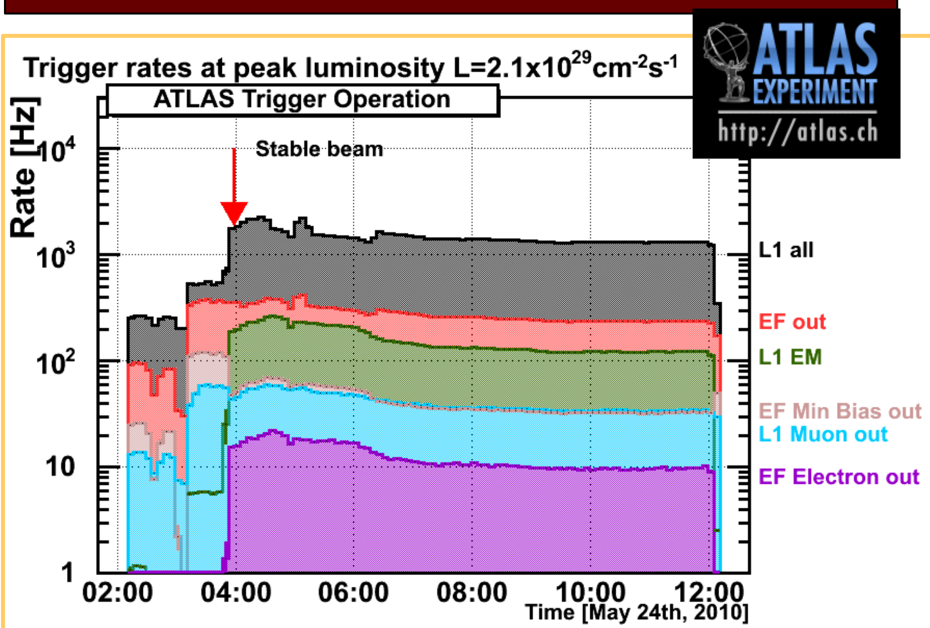
"Well known" processes, don't need to keep all of them …

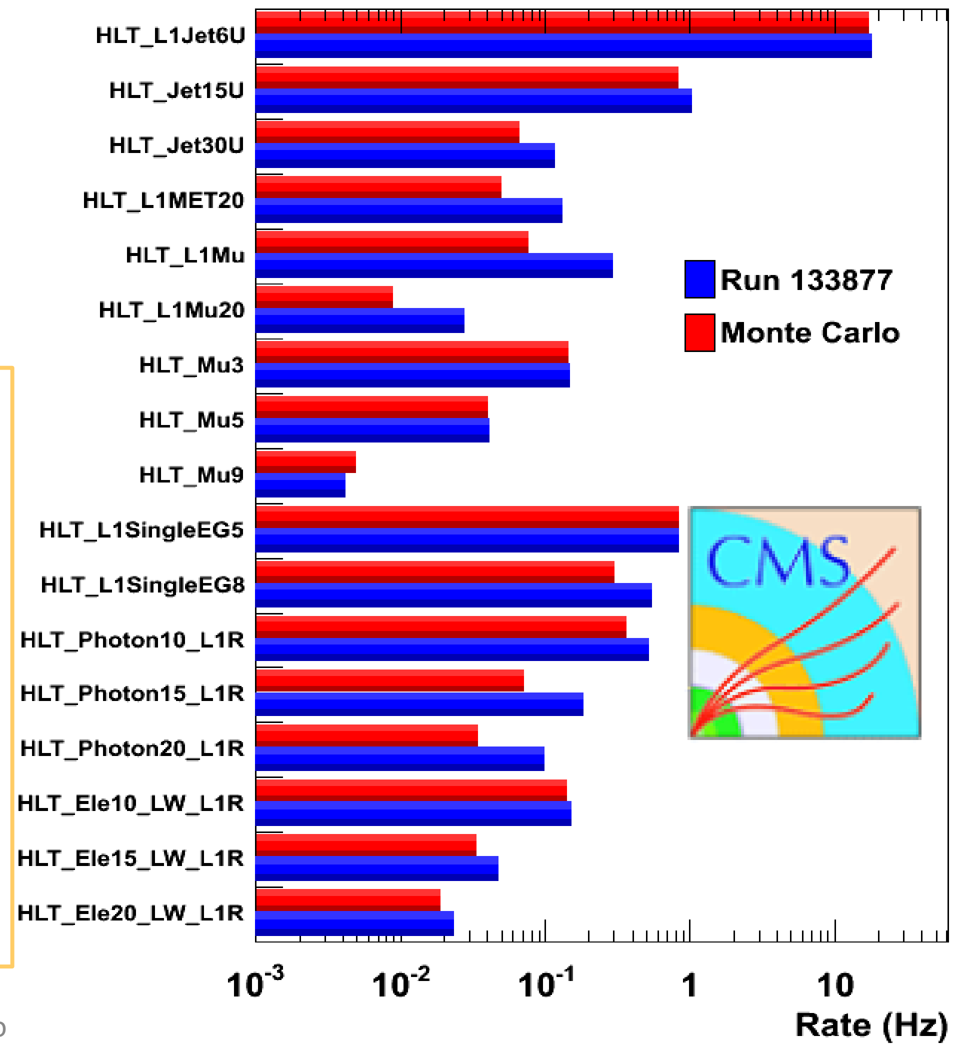
New Physics

This we want to keep!

Triggers work and are well understood, but did not yet have a 'hard' job to do…







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:

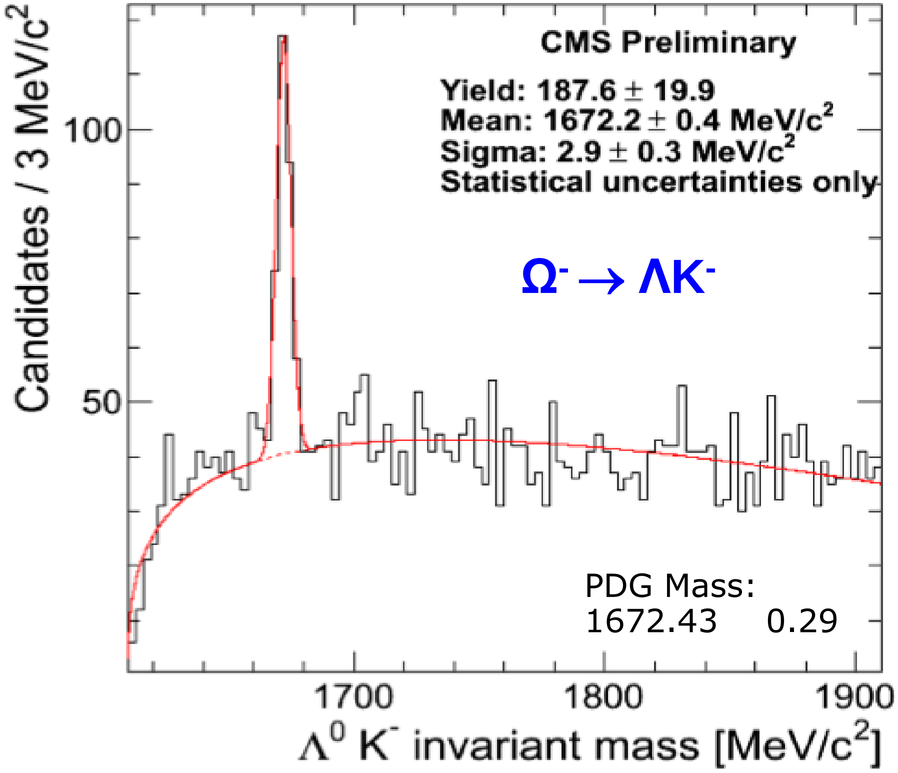
- Commission/calibrate detector/trigger in situ with physics (min.bias, Z→ll, …)
- "Rediscover" Standard Model, measure it at $\sqrt{s}$ = 10 TeV (minimum bias, W, Z, tt, QCD jets, …)
- Validate and tune tools (e.g. MC generators)
- Measure main backgrounds to New Physics (W/Z+jets, tt+jets, QCD-jets,…)

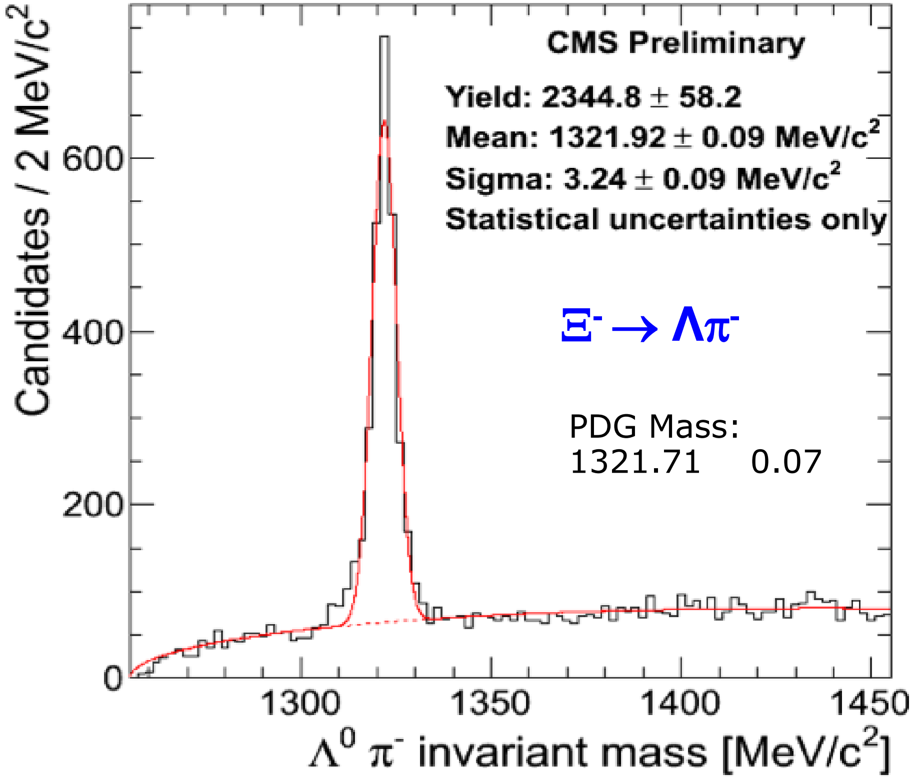
↓

Prepare the road to discoveries …

Enormous amount of tracking work, exploiting to the best also 100s of millions of cosmics, has led already to excellent performance for all experiments

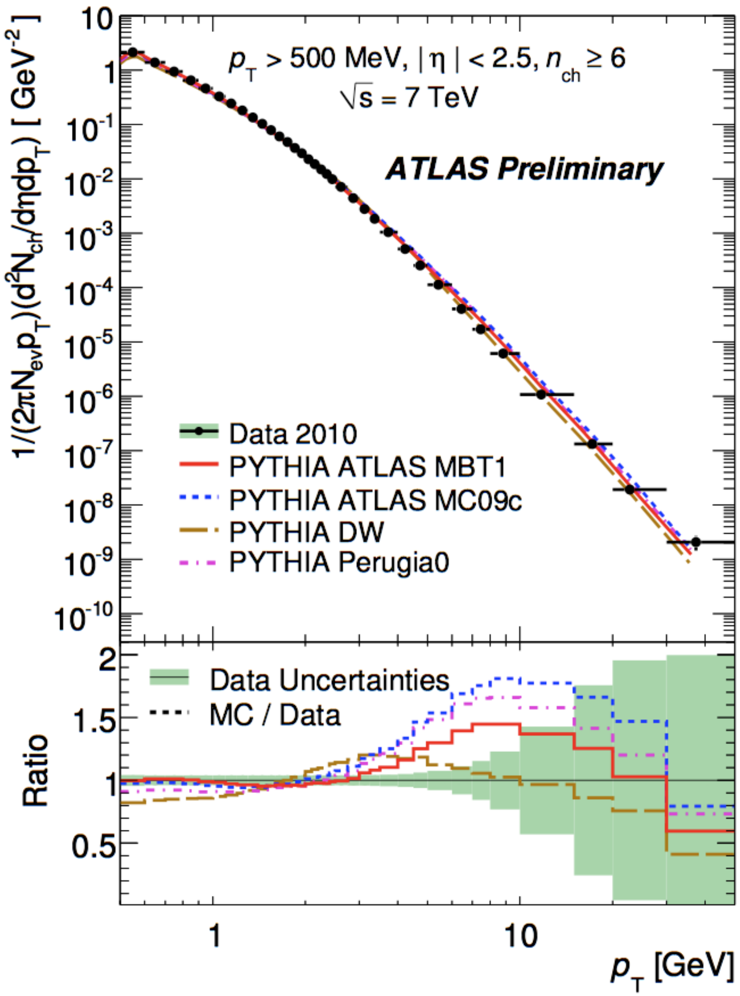
Here just a two examples from CMS, but ATLAS, LHCb and ALICE have a nice collection as well…

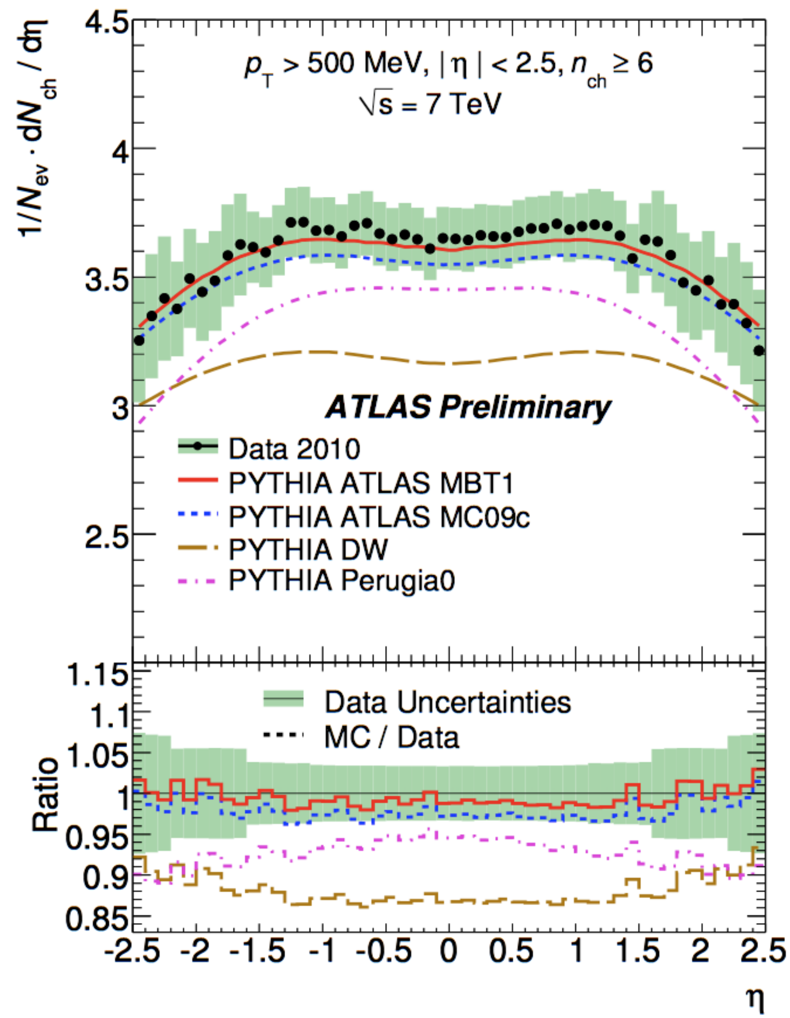




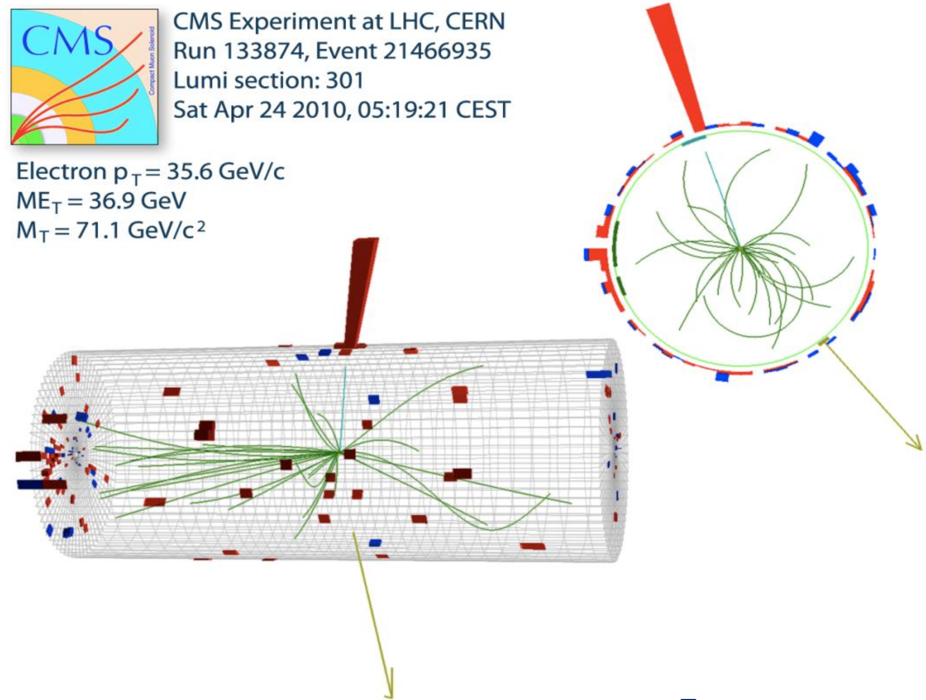
Data with minimal model dependence can be used for detailed MC tuning

Used for the tune
- ATLAS UE data at 0.9 and 7 TeV
- ATLAS charged particle densitites at 0.9 and 7 TeV
- CDF Run I underlying event analysis (leading jet)
- CDF Run I underlying event "Min-Max" analysis
- D0 Run II dijet angular correlations
- CDF Run II Min bias
- CDF Run I Z pT

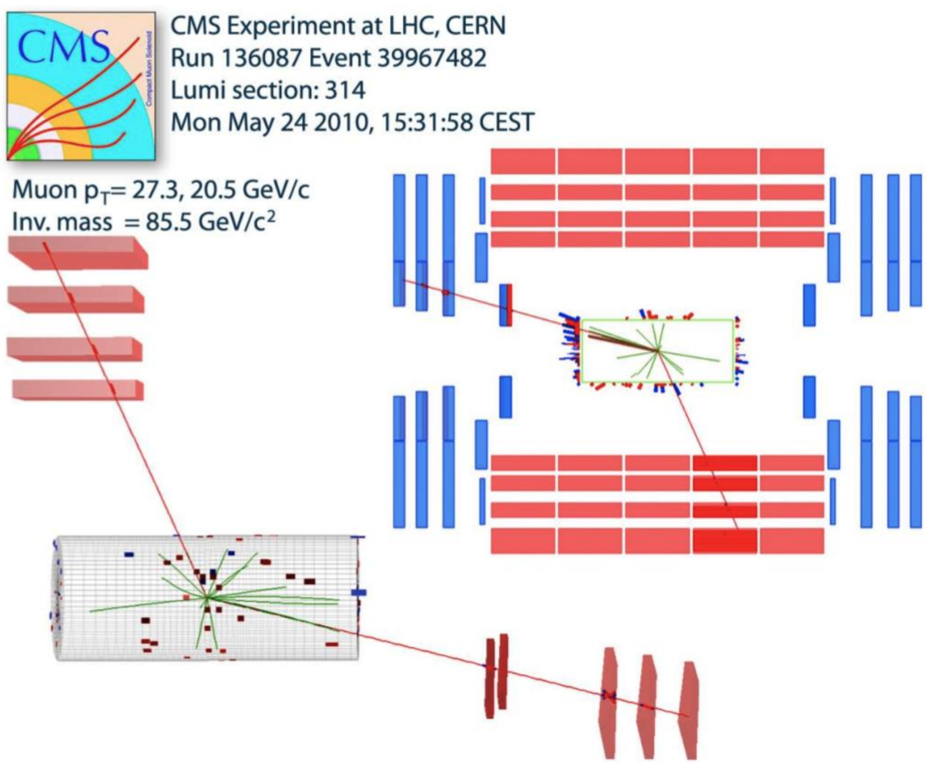




At the LHC we just enter the era of the W and Z …

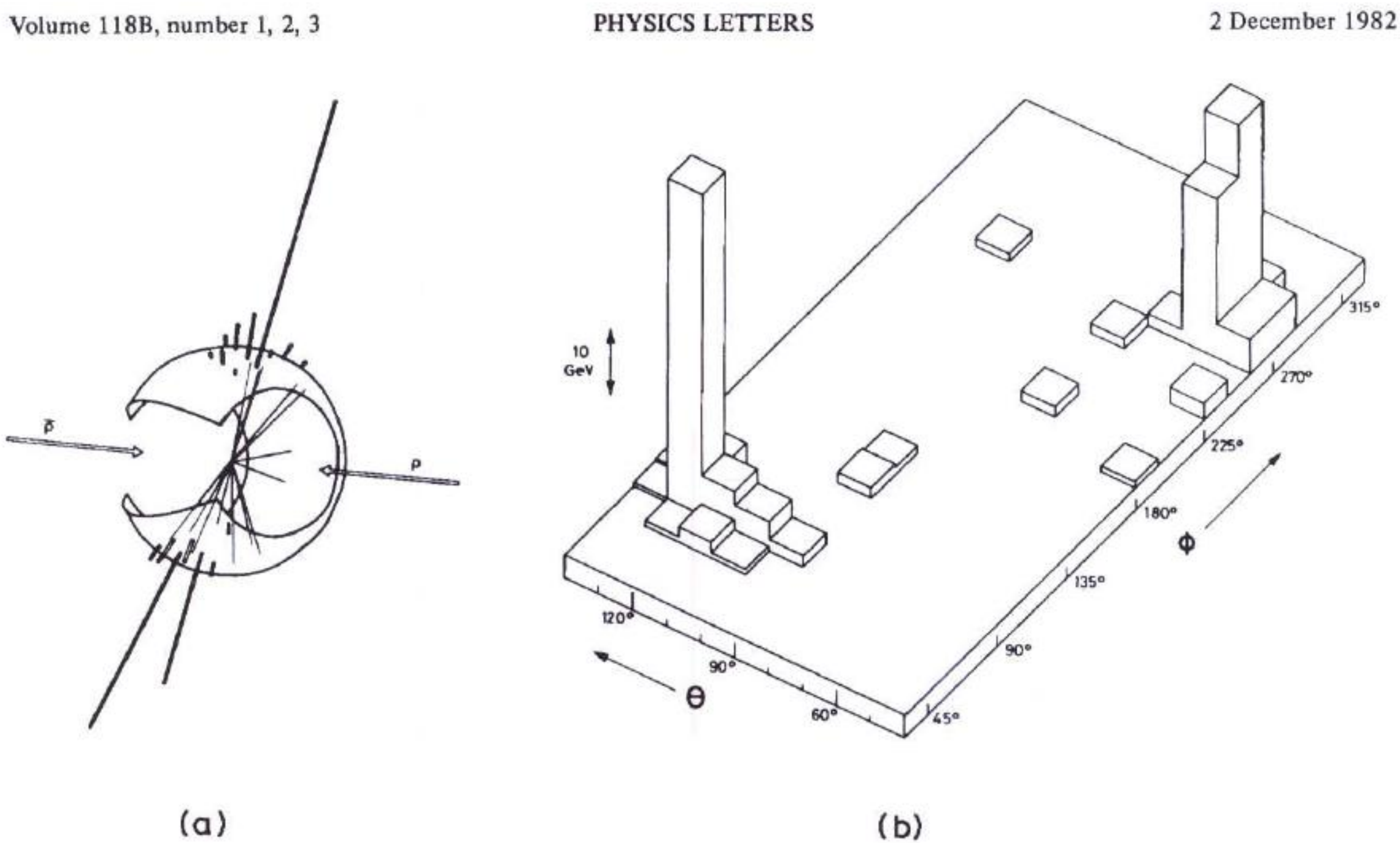


W → eν



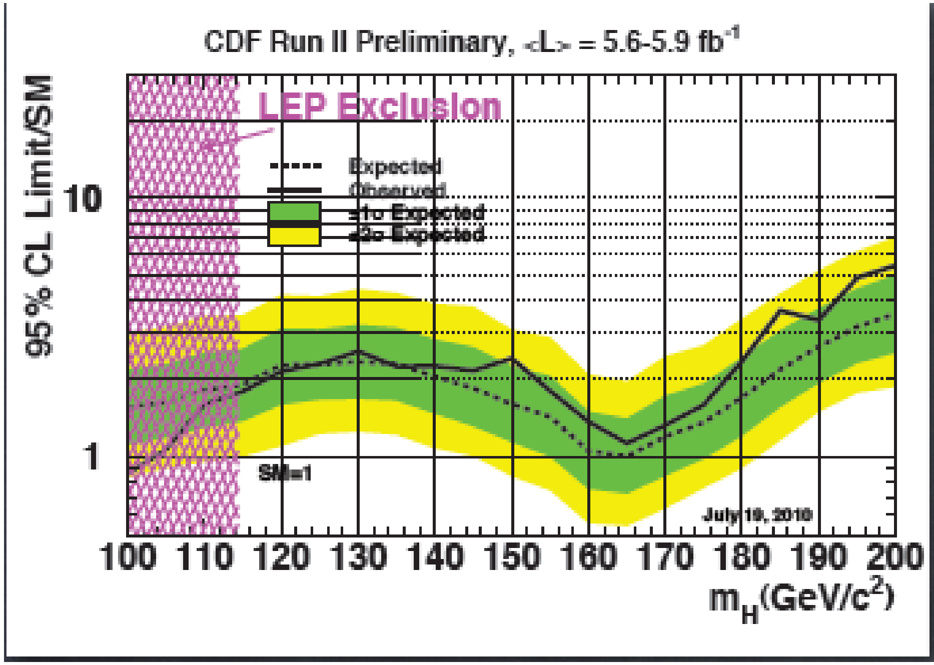
Z → $\mu^+\mu^-$

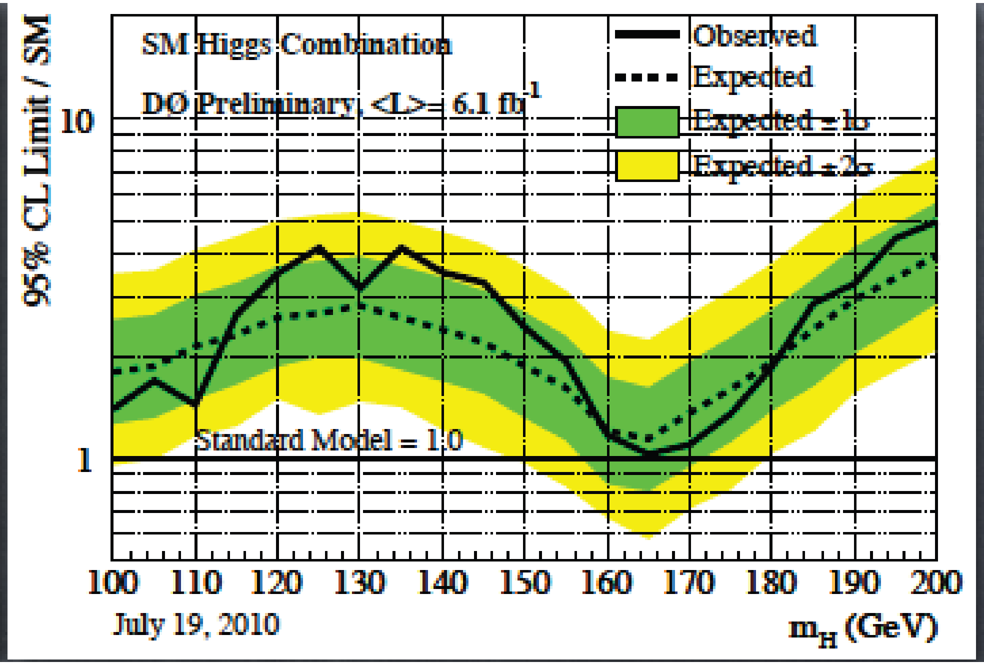
Note also that the event displays have become more sophisticated since the first spectacular events, hand-drawn, at a hadron collider …



Both Tevatron experiments have released new results (ICHEP)

The analyses are very sophisticated combining many final state channels and topologies, exploiting multi-variate analyses methods





Prospects for Higgs evidence

~16 fb^{-1} :*

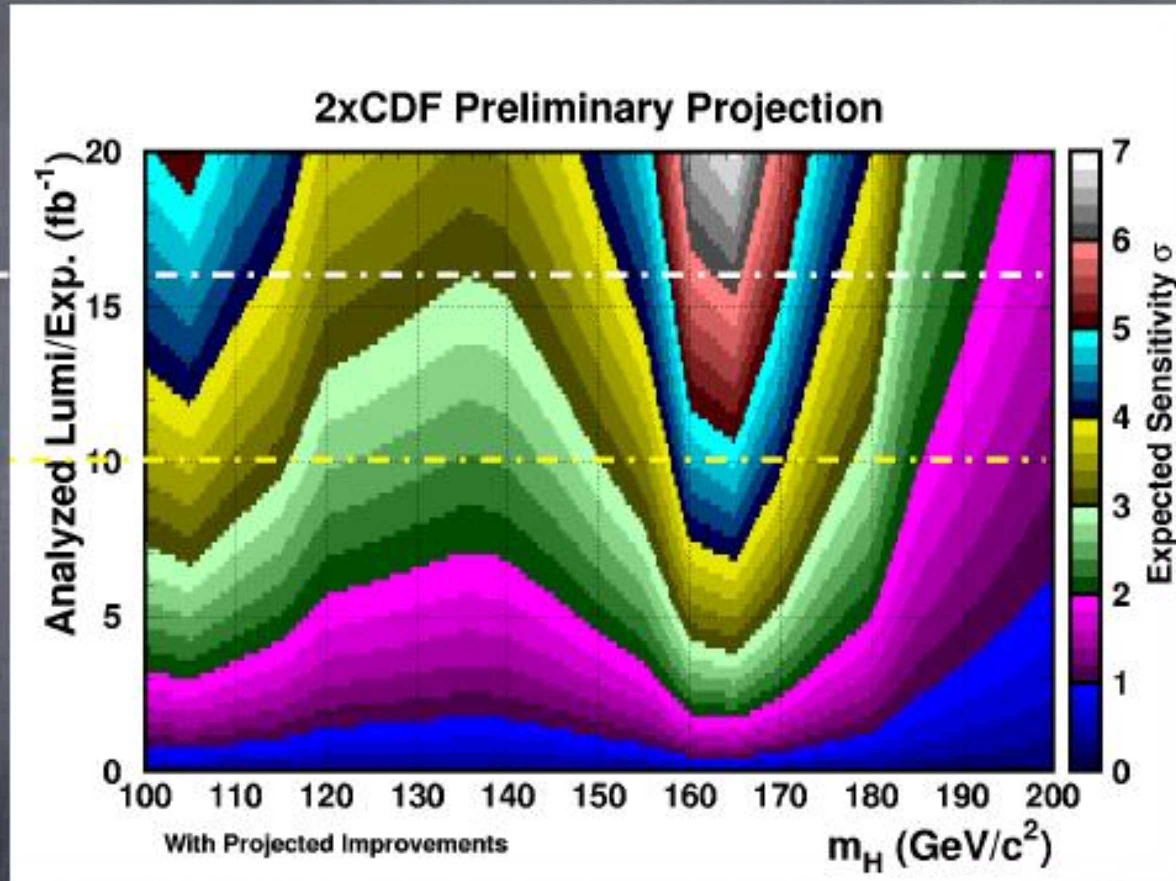
> 3 σ expected sensitivity from 100 – 185 GeV

4 σ @ 115 GeV

End of 2011:

> 2.4 σ expected sensitivity across mass range

3 σ at 115 GeV

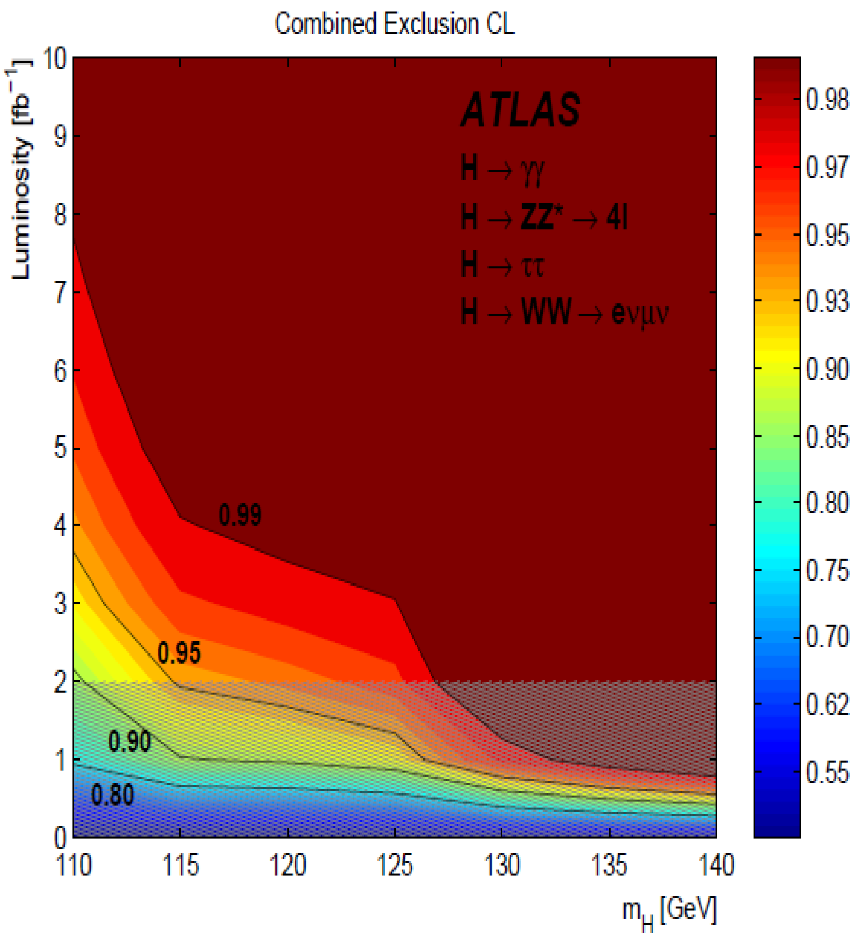


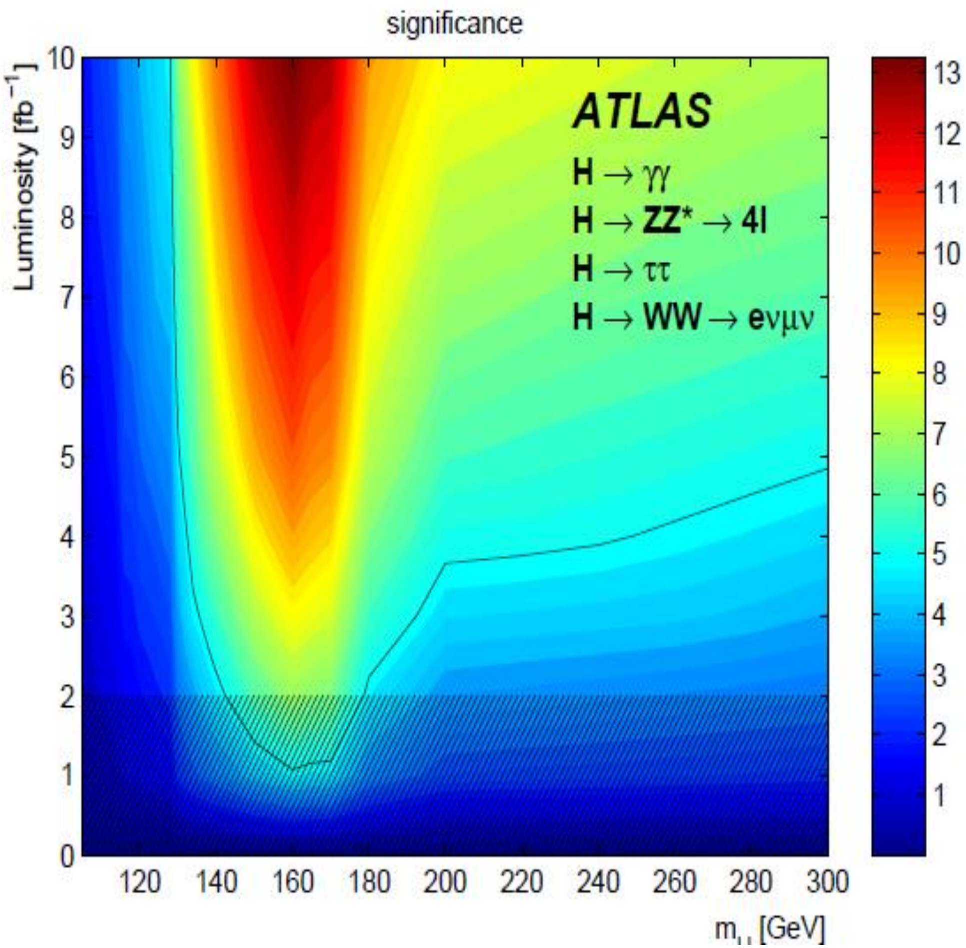
* 16 fb^{-1} : based on "Run III" proposal to run 3 more years

Ben Kilminster, ICHEP 2010 37

Combining several channels in a single experiment (ATLAS as example, of course CMS very similar)

14 TeV

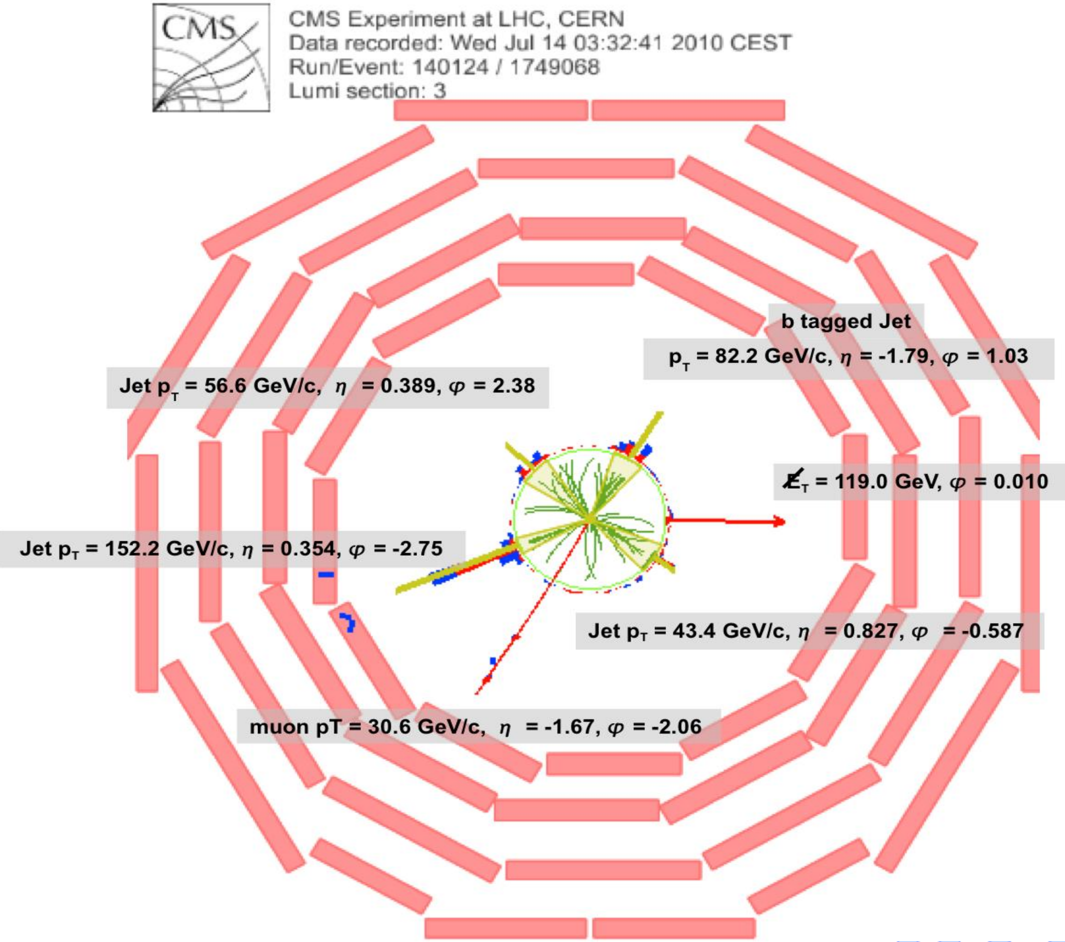


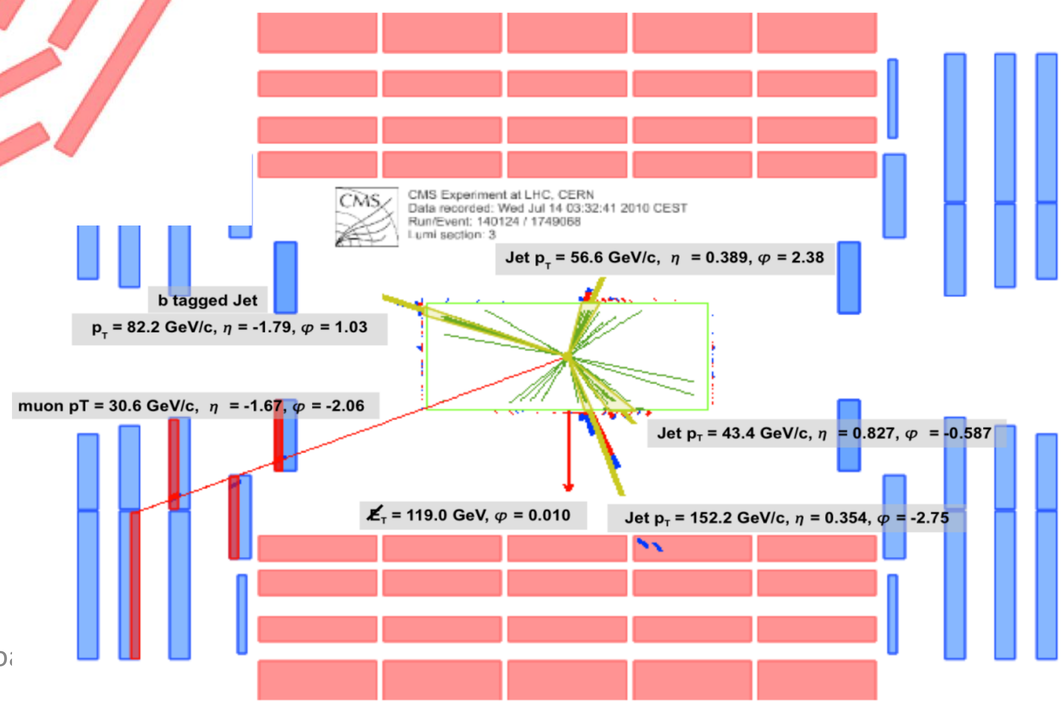


Exclusion confidence levels

Discovery significance levels in σ

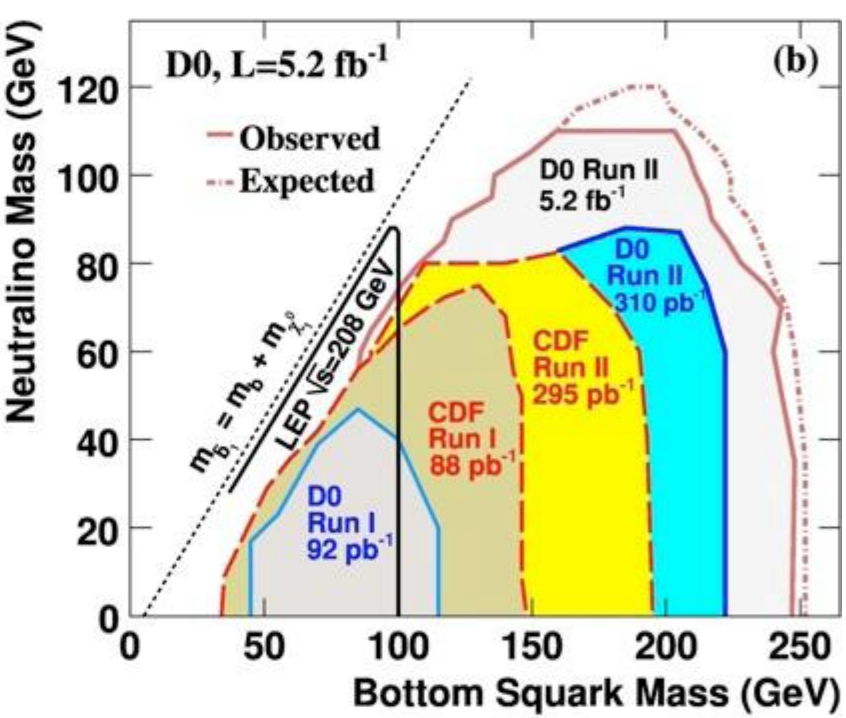
μ + jets candidate

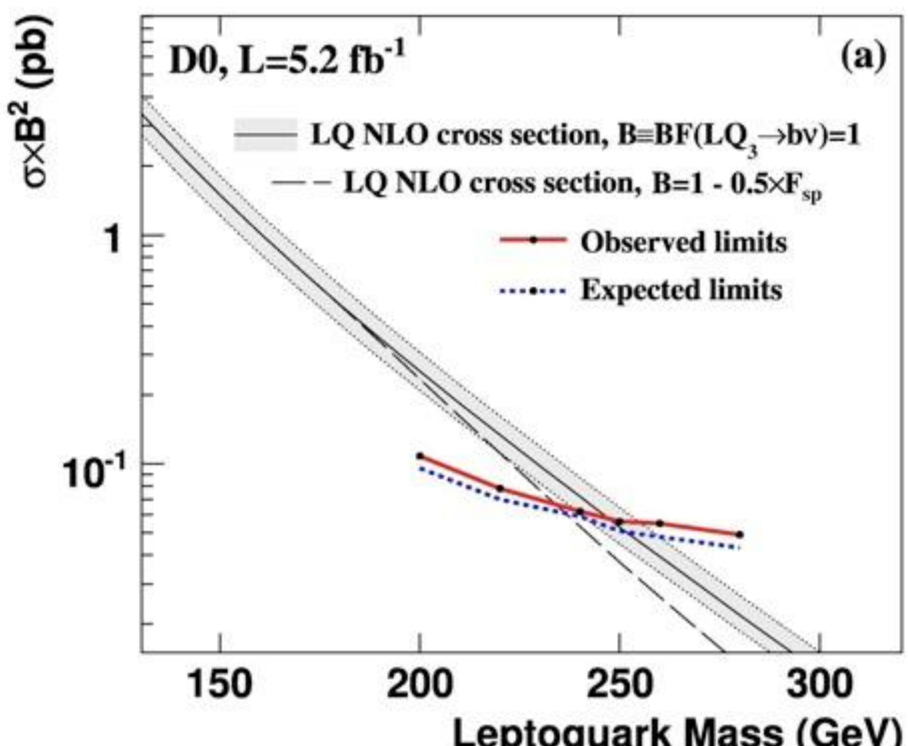




A very impressive spectrum of sophisticated searches have been reported from the Tevatron experiments, there is no way to do any justice here for this excellent work!

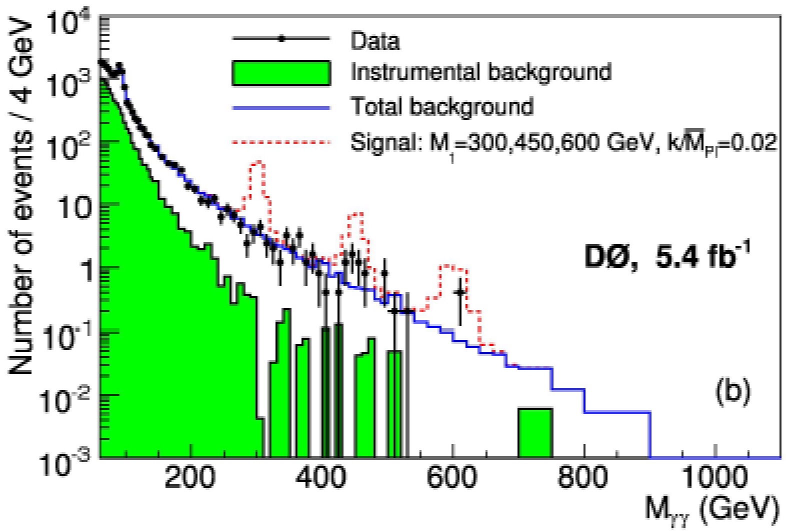
Just a few examples, which however also illustrate that it will be very difficult to push these searches much further, the LHC will have a much easier time thanks to the higher energy…

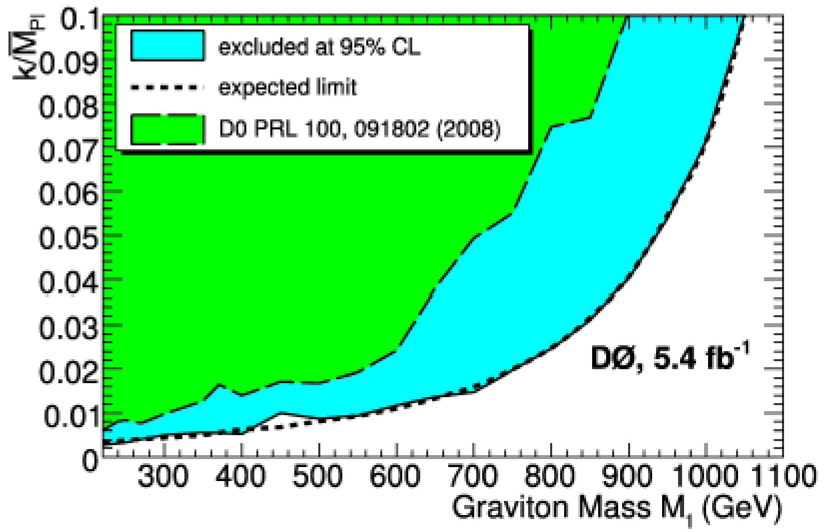




Extra Dimensions

- a solution to a hierarchy problem (Arkani-Hamed,Dimopulous,Dvali'99)
- warped extra dimensions (Randall, Sundrum'99) :
  - Kaluza-Klein excitations of a graviton, G^*, are coupled to SM particles and narrow
  - $B(G^* \to \gamma\gamma) \approx 2B(G^* \to l^+l^-)$



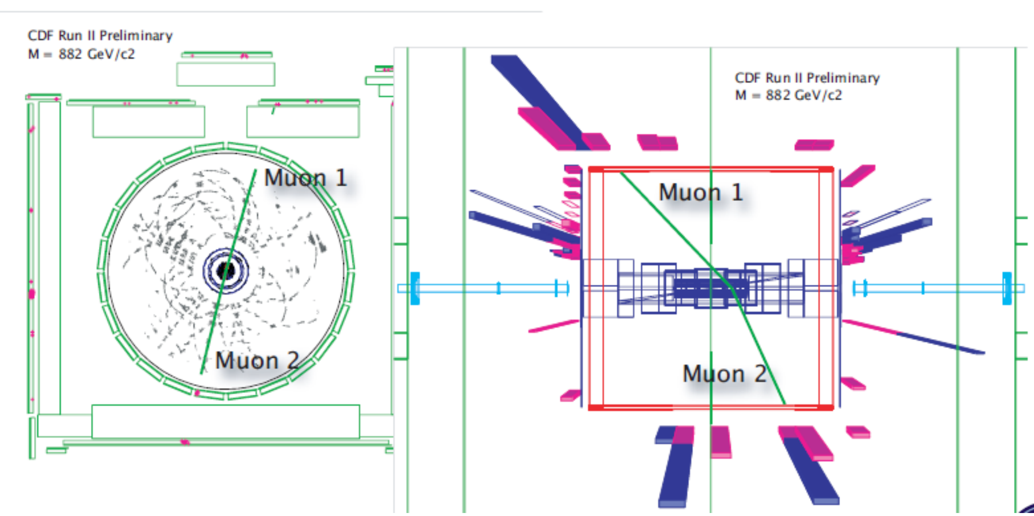


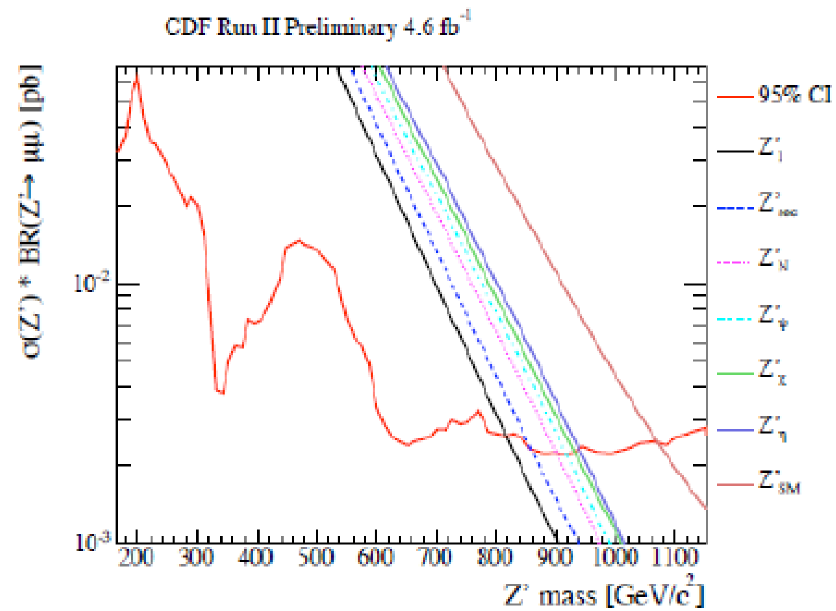
- excluded at 95% CL for $k/M_{Pl} = 0.1$:
  - D0'2010: $G^* \to \gamma\gamma, e^+e^-$: $M_{G*} <$ 1050 GeV PRL 104, 241802
  - CDF'2010: $G^* \to \gamma\gamma$: $M_{G*} <$ 976 GeV arXiv:0910.5170 [hep-ex]

Search for new heavy particles decaying into lepton pairs or jet pairs

The Tevatron limits reach typically at 1 TeV, and cannot improved much further because of the Collider energy

highest mass event: $m_{\mu\mu}$ = 882 GeV **CDF**



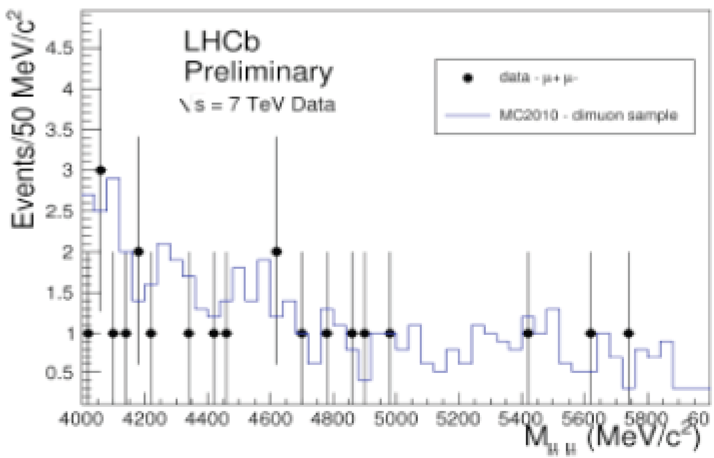


Z'_{SM} > 1.071 TeV (95% CL)

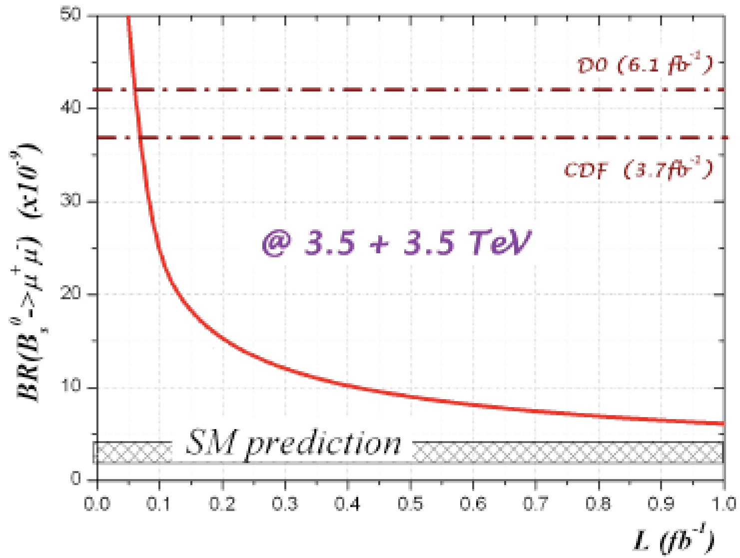
$B_s \rightarrow \mu\mu$

- Super rare decay in SM with well predicted $BR(B_s \rightarrow \mu\mu) = (3.2\pm0.2)\times10^{-9}$
  $BR(B_d \rightarrow \mu\mu) = (1.1\pm0.1)\times10^{-10}$
- Sensitive to NP, in particular new scalars
  In MSSM: $BR \propto \tan^6\beta / M^4_A$
- For the SM prediction LHCb expects 10 signal in 1 fb^{-1}.

Background expected from MC is so far in good agreement with data



Exclusion limit @ 90% C.L.



Exclusion of SM enhancement up to $BR(B_s \rightarrow \mu\mu) \sim 7\times10^{-9}$ should be possible with $L\sim1\ fb^{-1}$

Current limit can be improved with < 100 pb^{-1}

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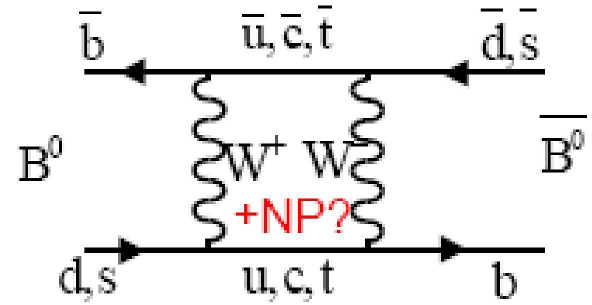
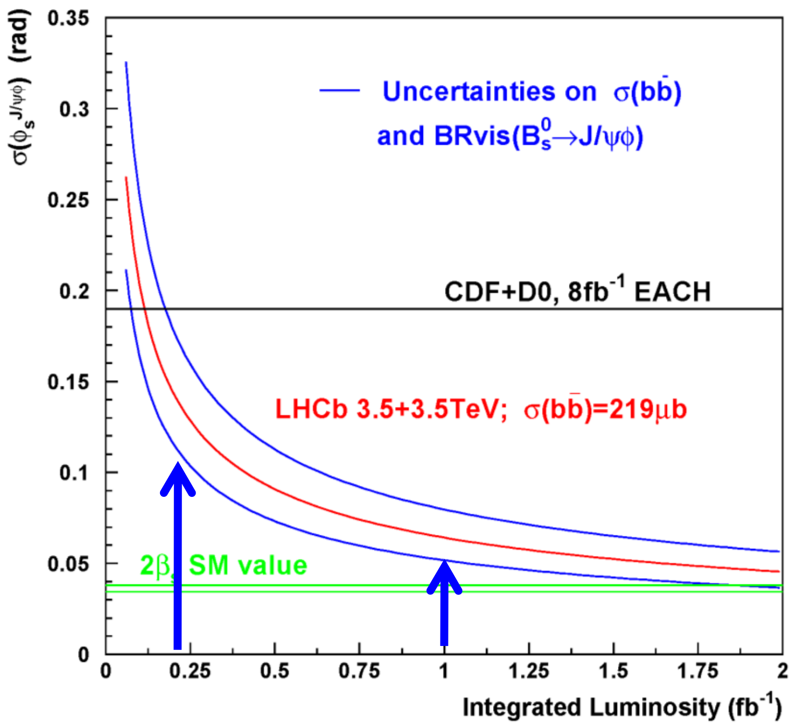
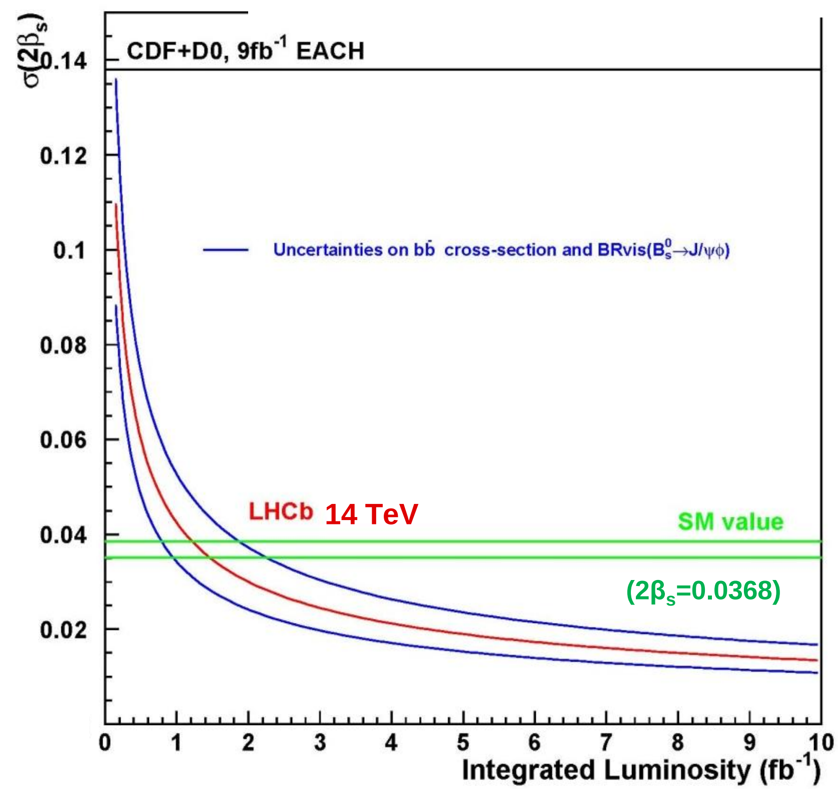
B_s-$\bar{B}_s$ mixing phase ϕ_s (from $B_s \rightarrow J/\psi\ \phi$)

Sensitive to New Physics effects in box diagrams

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



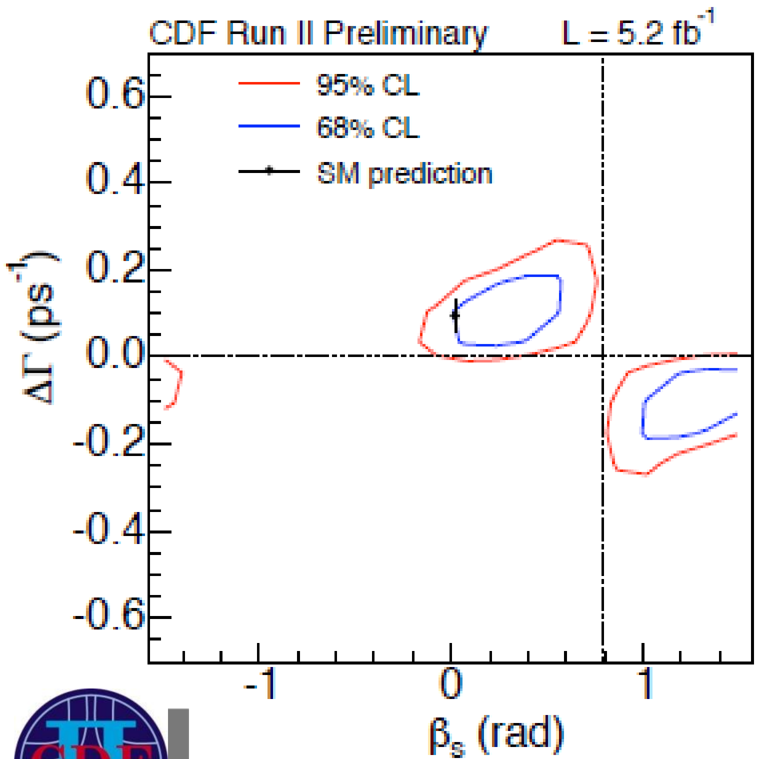


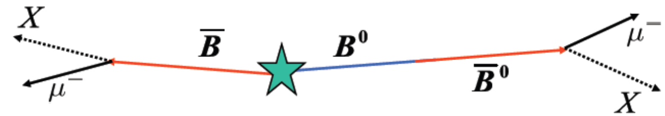


→ ***With ~0.2 fb^{-1} LHCb should improve on expected Tevatron limit***

Two new results which get a lot of attention (rightly so!)

Bs mixing phase (from $B_s \rightarrow J/\psi\ \phi$)





- Asymmetry in "same-sign" muons from decays of mixed neutral B mesons:

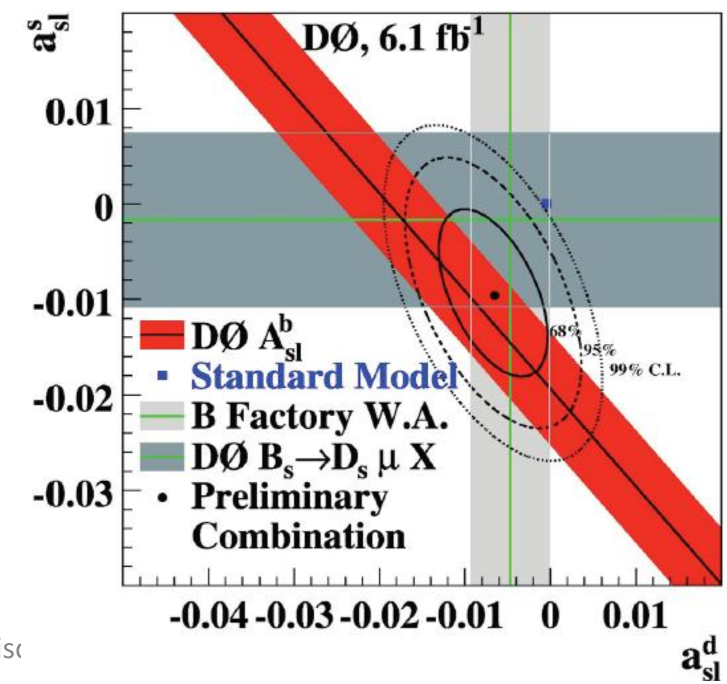
$$a^b_{sl} \equiv \frac{\Gamma\left(\bar{B} \rightarrow \mu^+ X\right) - \Gamma\left(B \rightarrow \mu^- X\right)}{\Gamma\left(\bar{B} \rightarrow \mu^+ X\right) + \Gamma\left(B \rightarrow \mu^- X\right)}$$

$$A^b_{sl} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

Grossman, Nir, Raz, Phys.Rev.Lett.97:151801,2006.

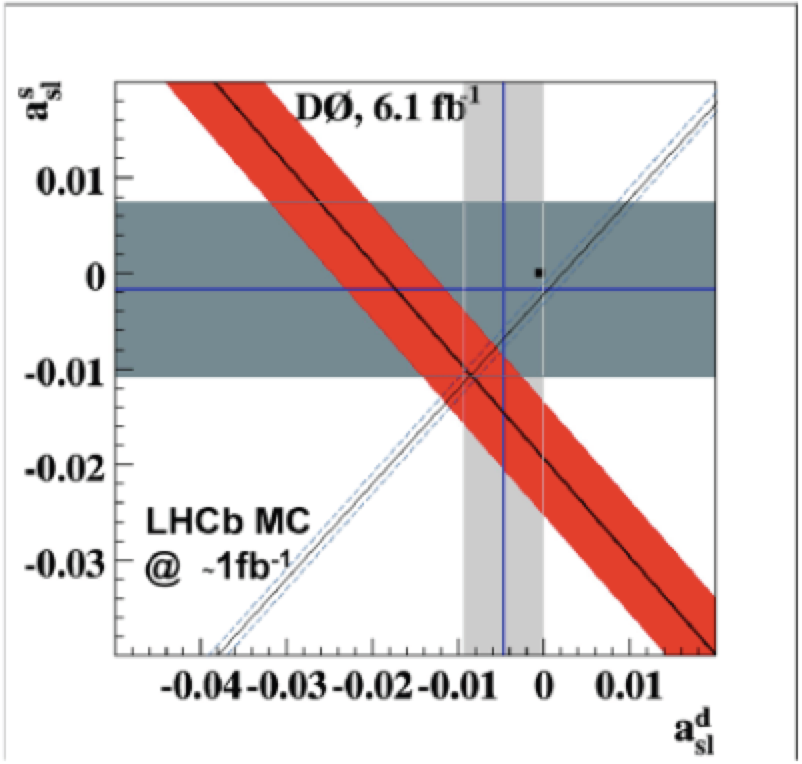
$$A^b_{sl} = \left(-0.957 \pm 0.251\,(\mathrm{stat}) \pm 0.146\,(\mathrm{syst})\right)\%$$

$$A^b_{sl}\,(\mathrm{SM}) = \left(-2.3^{+0.5}_{-0.6}\right) \times 10^{-4}$$



$\Delta A_{fs} = (a_{fs}(B_s) - a_{fs}(B_d)) / 2$ @ LHCb using semileptonic decays $B_{d,s} \rightarrow D\mu\nu$

- *Provide constrain "orthogonal" to recent D^0 measurement*
- *With 100 pb^{-1} expect statistical precision similar to that of D0*



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