Physics at LHC

Ian Hinchliffe
LBNL
UK Theory meeting

Thanks to ATLAS and CMS (Plots are from both)

Outline

- A reminder of why the LHC is being built
- The machine and its status: comments on old “bad news”
- The experiments (Atlas and CMS only in this talk)
- Quick Tour of the physics
  - very large scope: LHC is a discovery machine: Many candidate models
- Remember that this is a **Huge Enterprise**
  - Atlas and CMS have about 2K collaborators each
    - Better to think of them as facilities rather than experiments
  - Costs and timescale are very long
    - LHC will run for many years: upgrade plans are already well advanced
- I can only give you a taste before the chairman pulls me off the stage

The motivation

- Once W/Z were discovered 25 years ago:New issues arose
  - What generates their masses?
  - Why is $M_W << M_{Plank}$?
  - Why pattern of quark/lepton masses?
- Something must show up below 1 TeV: Very simple argument (and old)
  - Compute WW ==>WW at high energy:
  - No Higgs $\Rightarrow$ Unphysical cross section:
  - Either Higgs or something else below 1 TeV
- Theory arguments are nice and can give valuable guidance but need some data
- Other issues have arisen since 1982 such as Dark Matter: LHC may contribute here: But the basic motivation is still valid

Delays, delays.....

Fermi National Accelerator Laboratory

FERMILAB-Pub-84/17-T
LBL-16875
DOE/ER/01545-345
February, 1984

Supercollider Physics

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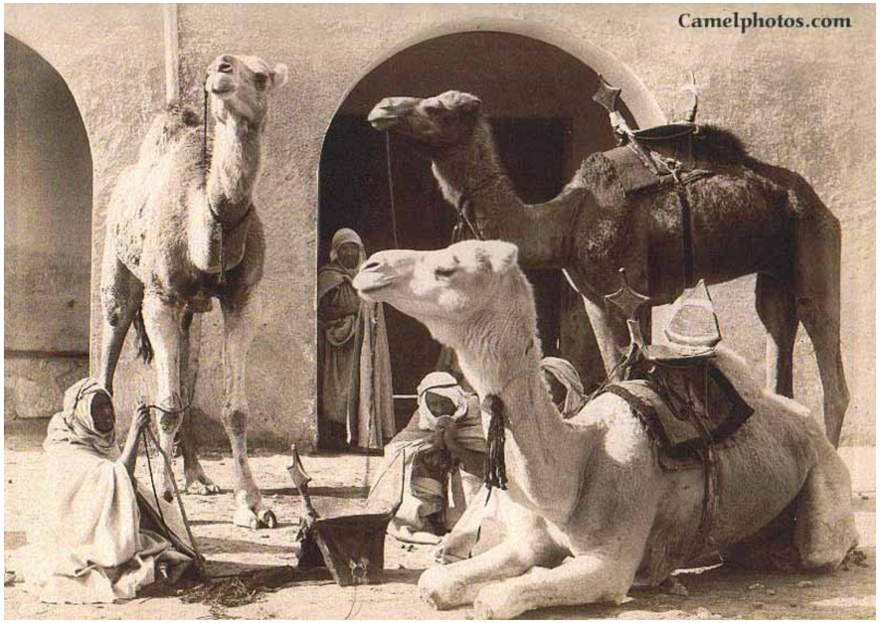
...rsities Research Association Inc. under contract with the United States Department of Energy

Unfortunately this paper was not rendered obsolete yet.



Some of us have waited a while!

A bit more delay we can live with!

When was t=0? 1982? 1988?

Physics marched on.....

- W/Z properties measured
- Top found and measured
- SM proved correct at quantum level
- CKM accounts for CP violation

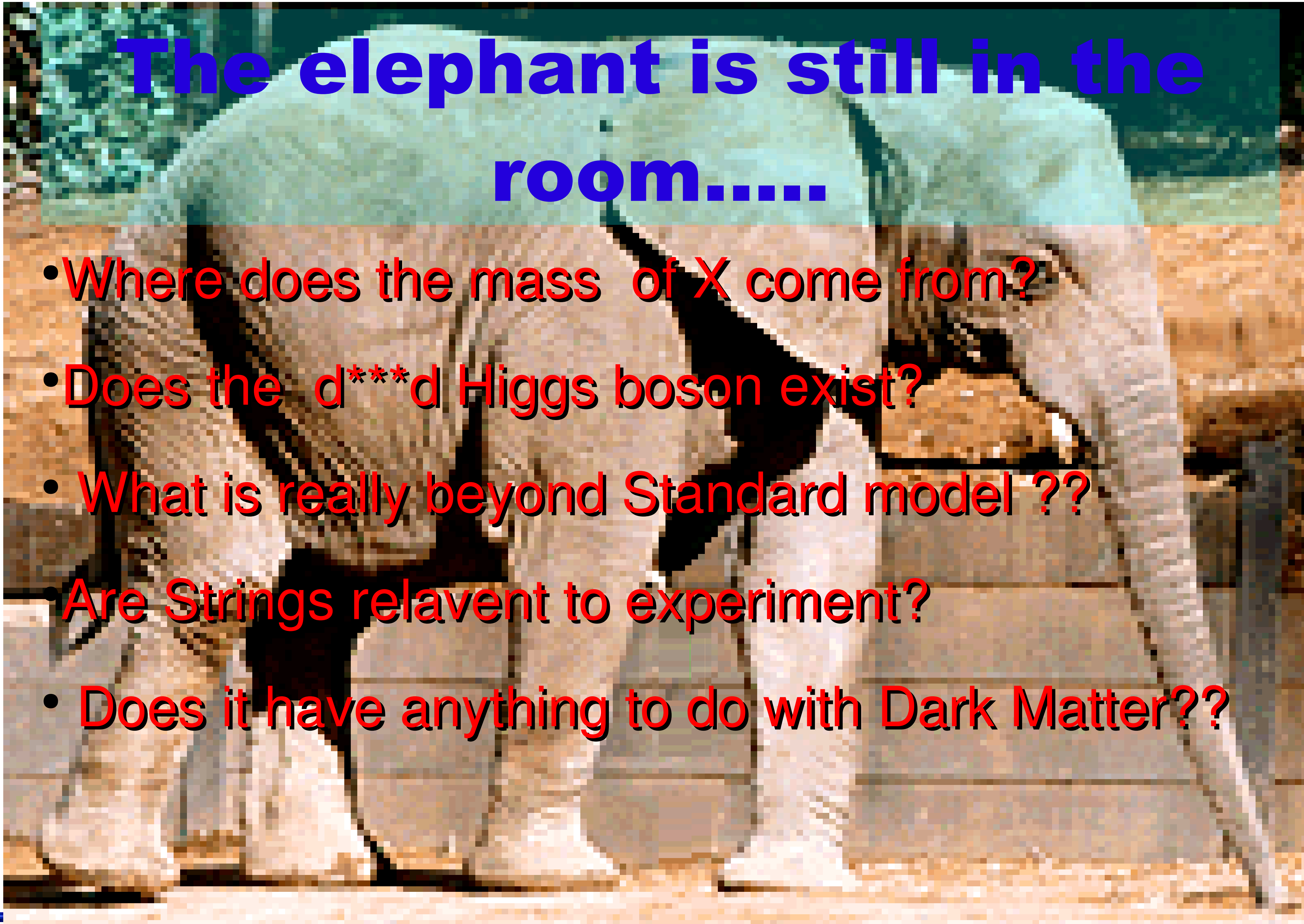
No big surprises but a huge achievement for both theory and experiment

Basic problem remains

- New discoveries
- Individual lepton number not conserved (neutrino oscillations)
- Dark matter/energy

Unexpected, don't fit comfortably in Standard Model

Are these related to electro weak symmetry breaking?

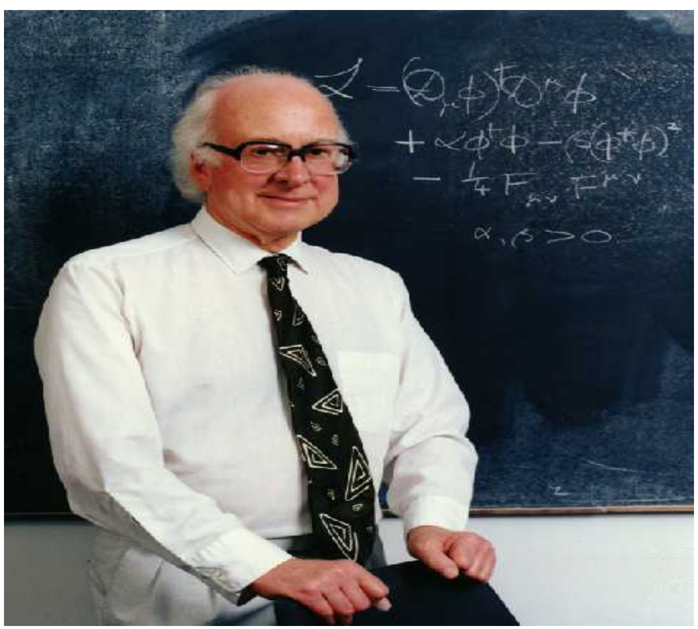


The elephant is still in the room.....

- Where does the mass of X come from?
- Does the d***d Higgs boson exist?
- What is really beyond Standard model ??
- Are Strings relavent to experiment?
- Does it have anything to do with Dark Matter??

We looked for the Holy Grail...

- Higgs not found at LEP
- Not found (yet) at Tevatron
- Tevatron could still find it???
- The end is in sight. SM dead if LHC doesn't get it

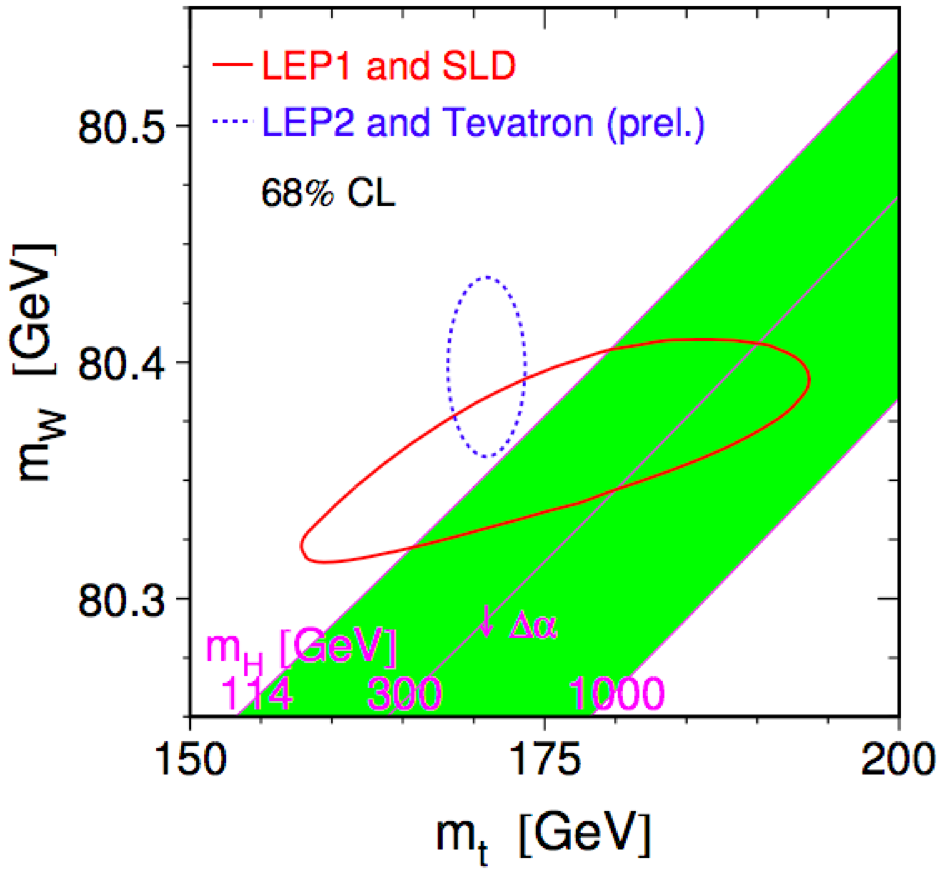


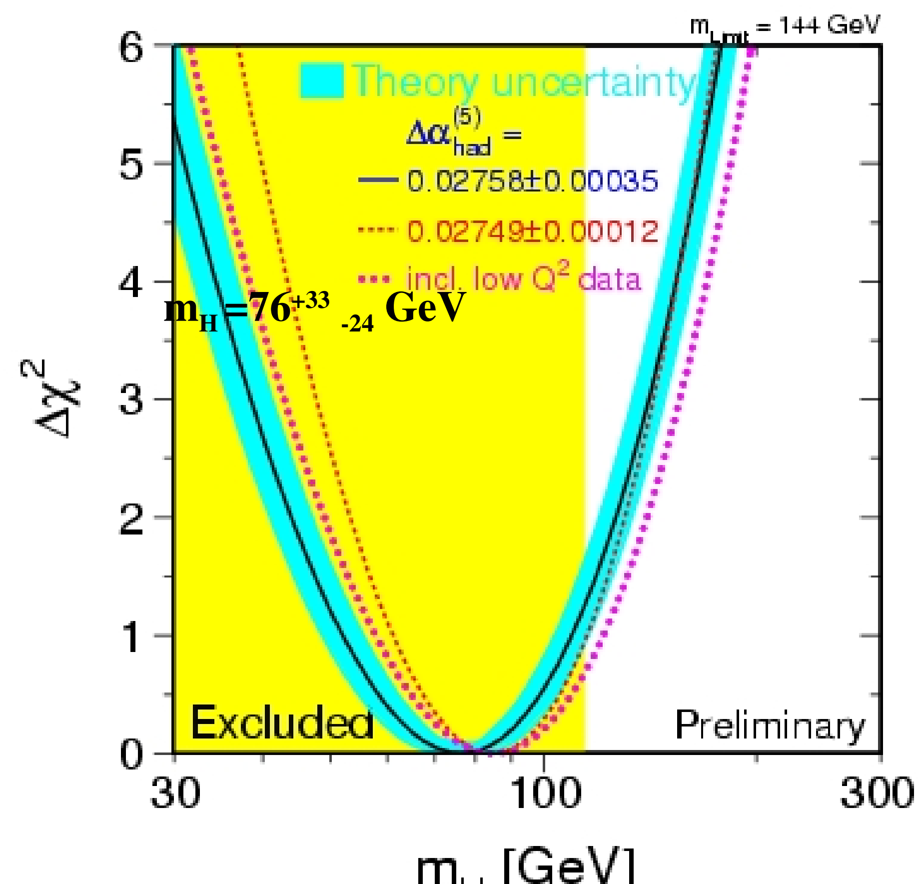
Only this Higgs seen to date

Standard Model Higgs status in one slide

el

LEPEWWG 07/07

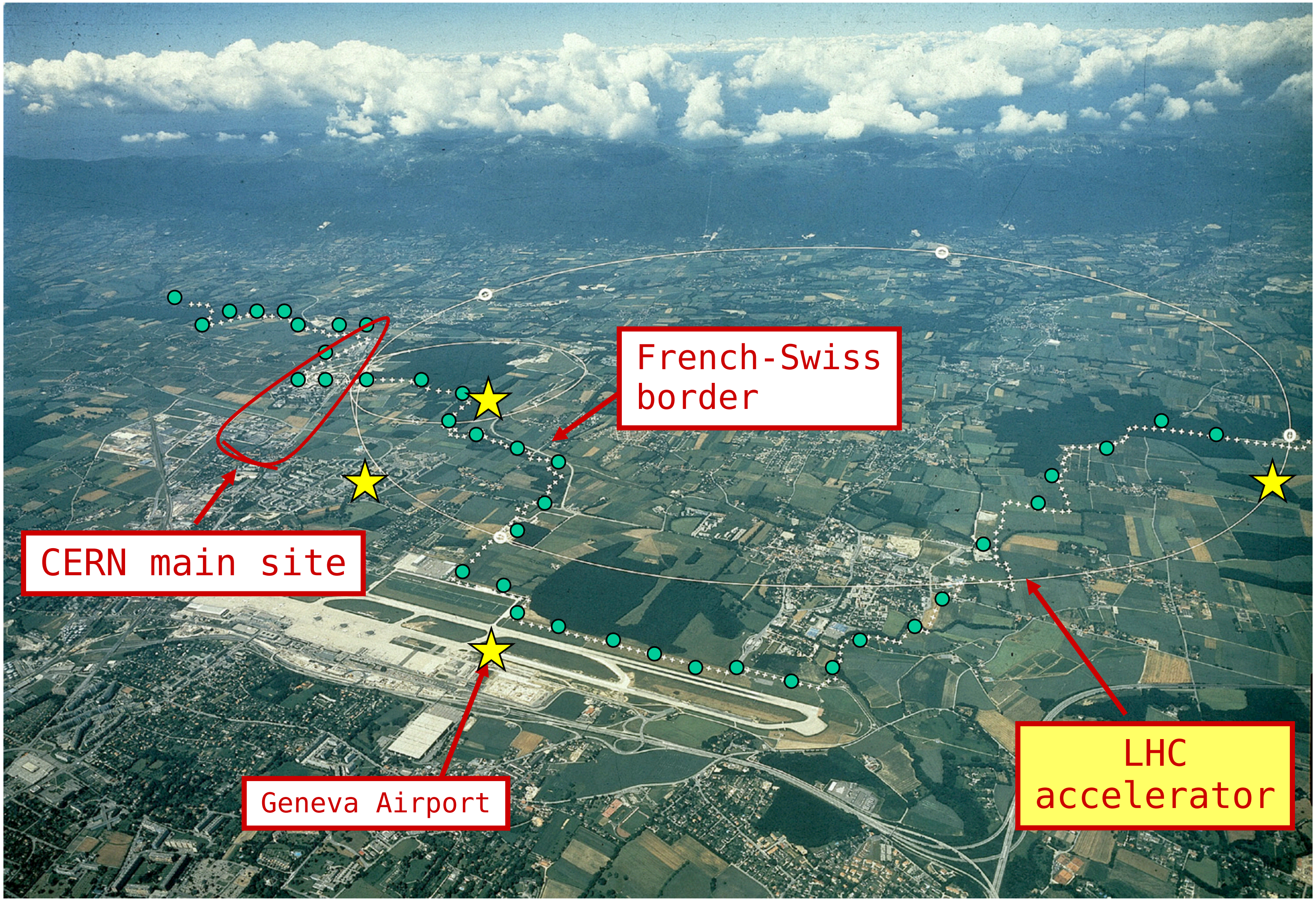




Direct searches at LEP2:
m_H>114.4 GeV @95%CL

Indirect constraints:
m_H<144 GeV @95%CL

The Large Hadron Collider (LHC) : pp $\sqrt{s}$ = 14 TeV



LHC basics

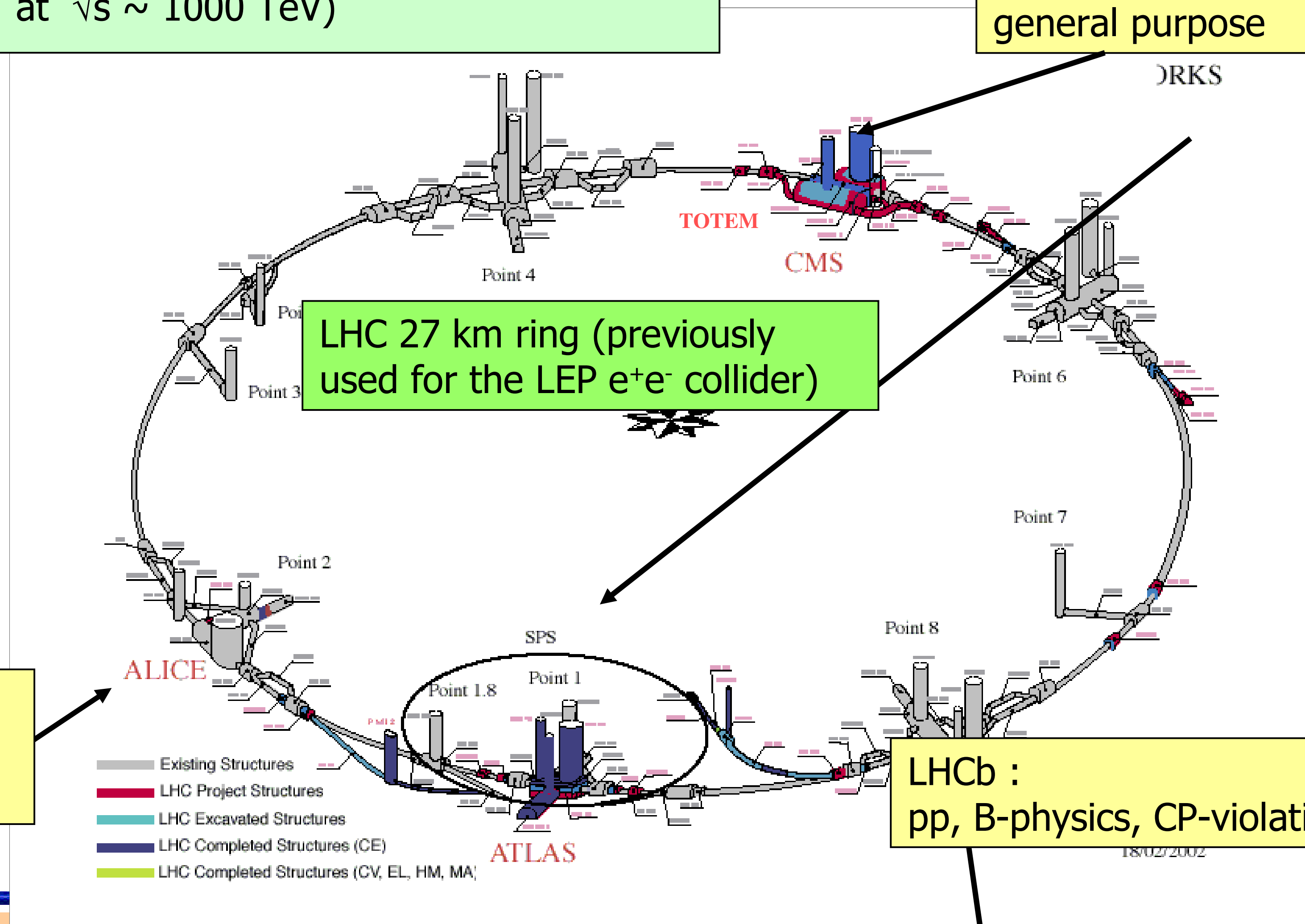
- pp $\sqrt{s}$ = 14 TeV x7 Tevatron
  L_{design} = 10^{34} cm^{-2} s^{-1} (after 2010) x100 Tevatron
  $L_{initial}$ < few x 10^{33} cm^{-2} s^{-1} (before)
- Heavy ions (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)

ATLAS and CMS : general purpose

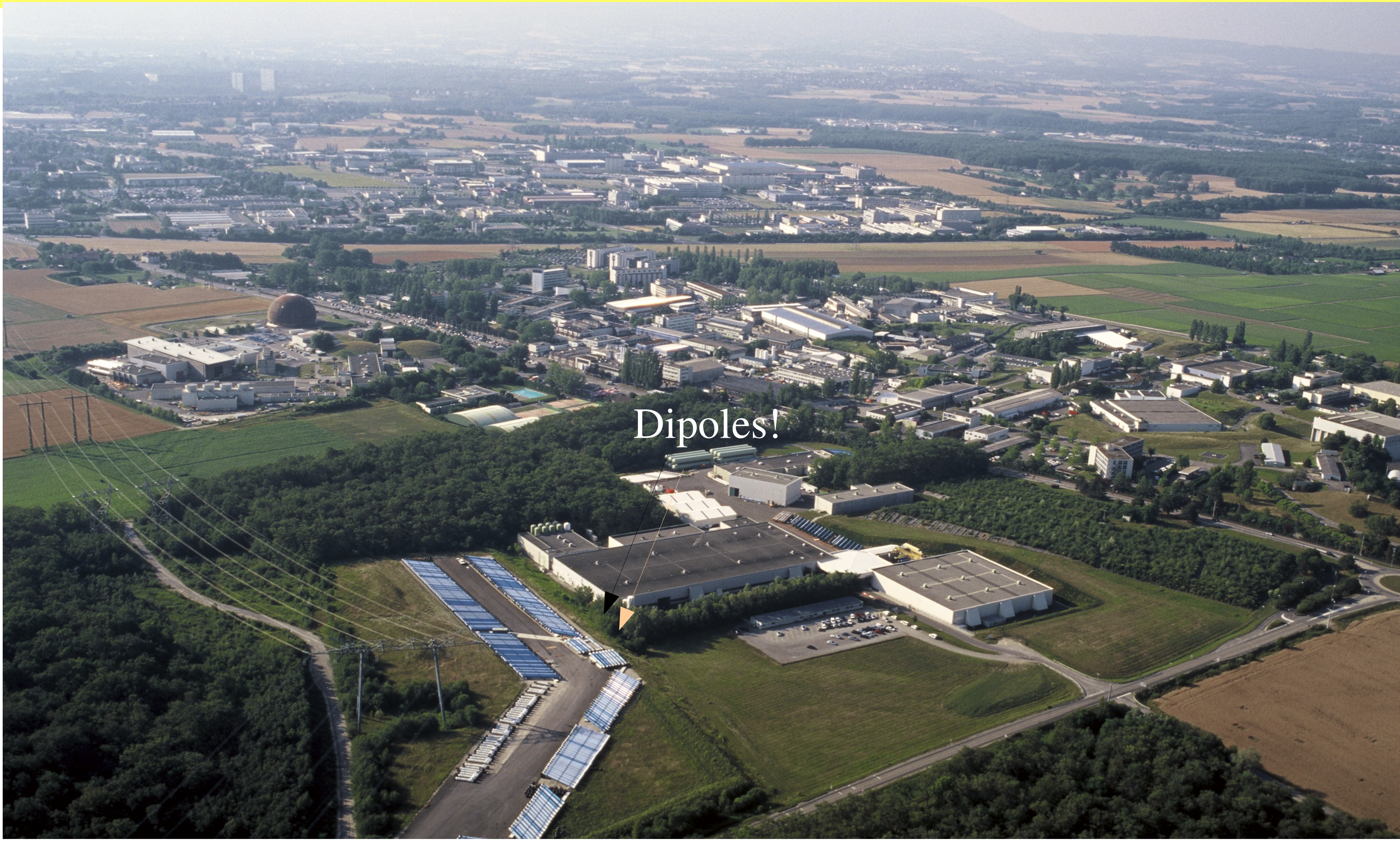
LHC 27 km ring (previously used for the LEP e^+e^- collider)

ALICE : ion-ion, p-ion

LHCb : pp, B-physics, CP-violation



LHC status



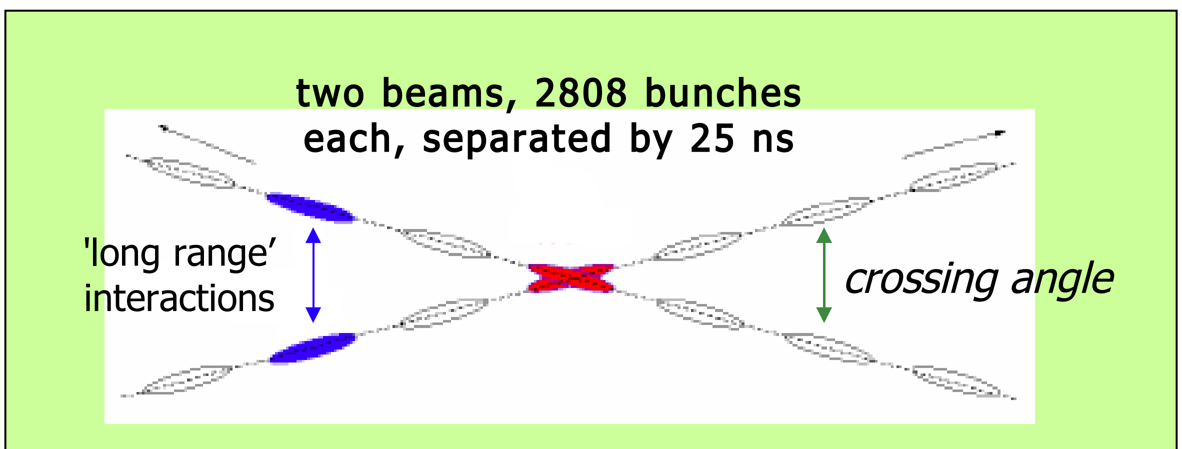
Main machine parameters for design luminosity operation

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

x100 Tevatron (Instantaneous luminosity)

x200 Tevatron (Stored beam energy)

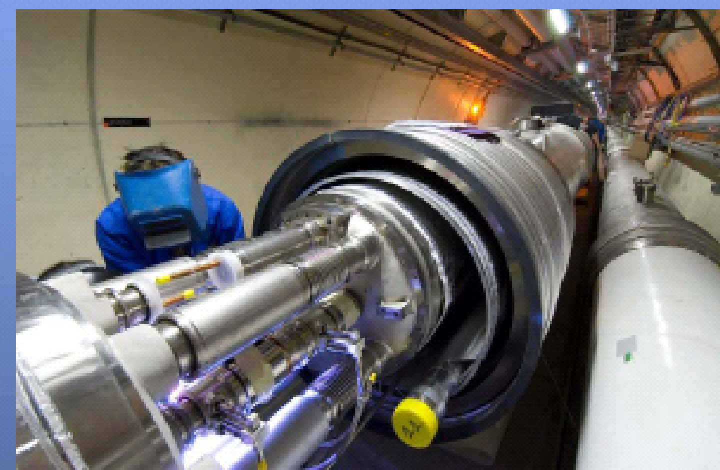
$$N = \int L dt \times \sigma (pp \rightarrow X)$$

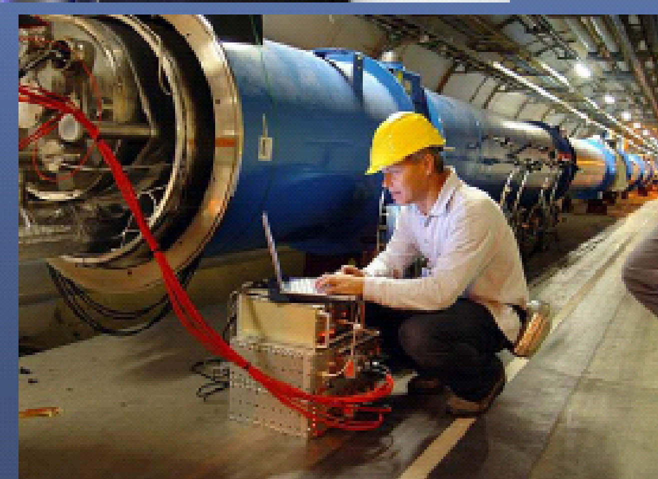


$$L = \frac{N^2 k_b f}{4\pi \sigma_x \sigma_y}$$

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)

Underground

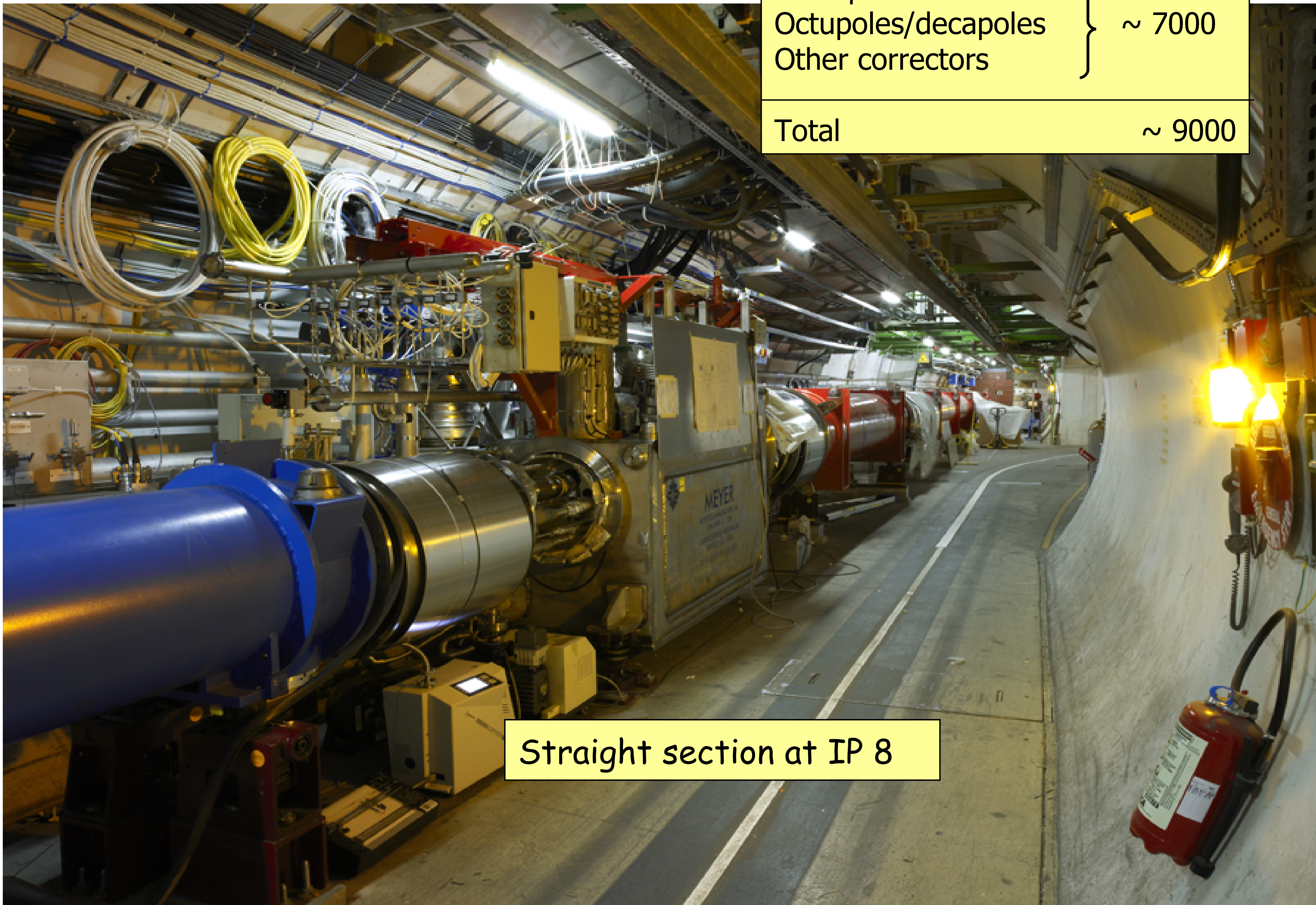


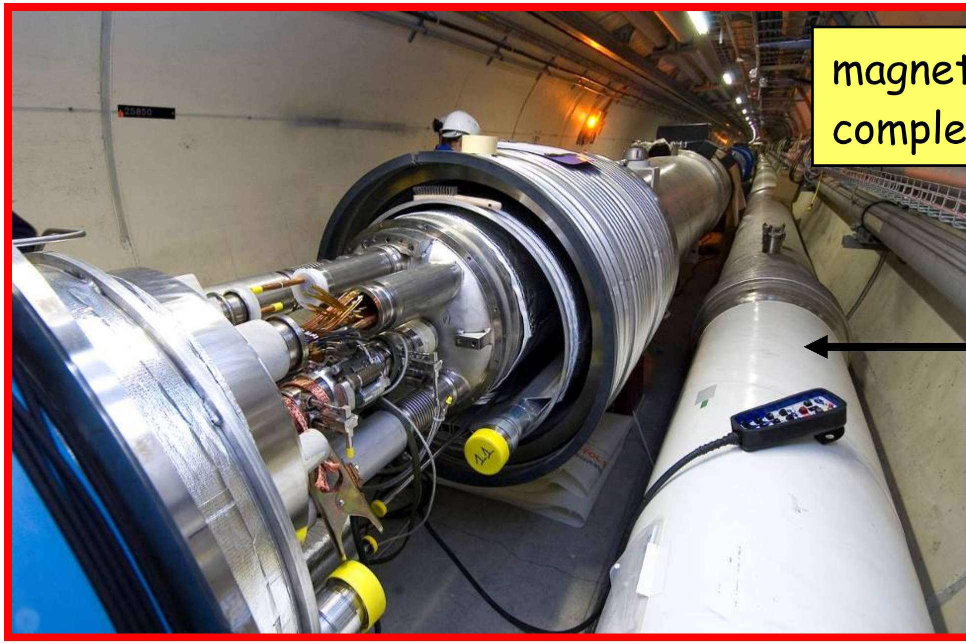


L.R. Evans

A look in the tunnel

Main dipoles	1232
Quadrupoles	~ 400
Sextupoles, Octupoles/decapoles, Other correctors	~ 7000
Total	~ 9000





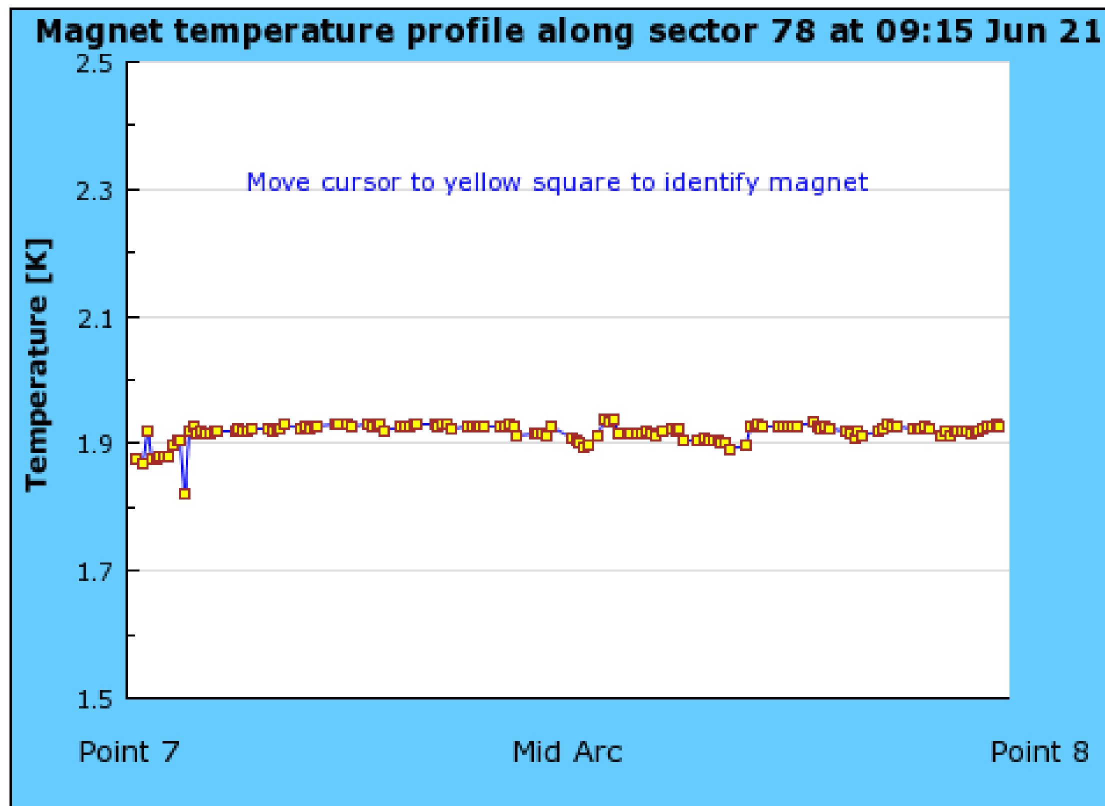
magnet interconnection work complete

Cryogenic line

The first of eight sectors (7-8) cooled down to 1.9 K in first half of 2007. Sector 4-5 reached 1.9 K recently

Both sectors will be warmed up and cooled-down again after connection of the inner triplets

One sector: 3.3 km, 154 dipoles



LHC: A complex object

- This is complex and challenging object: problems should be expected with both machine and experiments.
- Problems are news: Successes are not
  - "man bites dog" sells newspapers
- A look at some problems overcome

LHC: many problems overcome I

Triplets – Heat exchanger problem

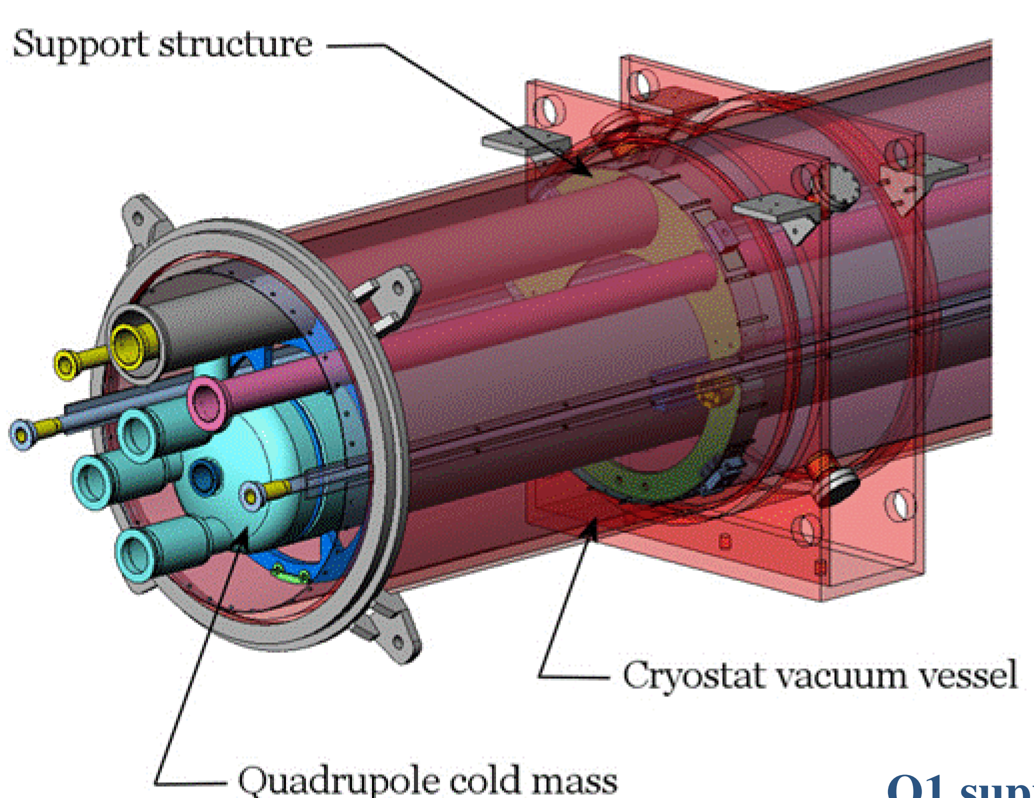
R Bailey

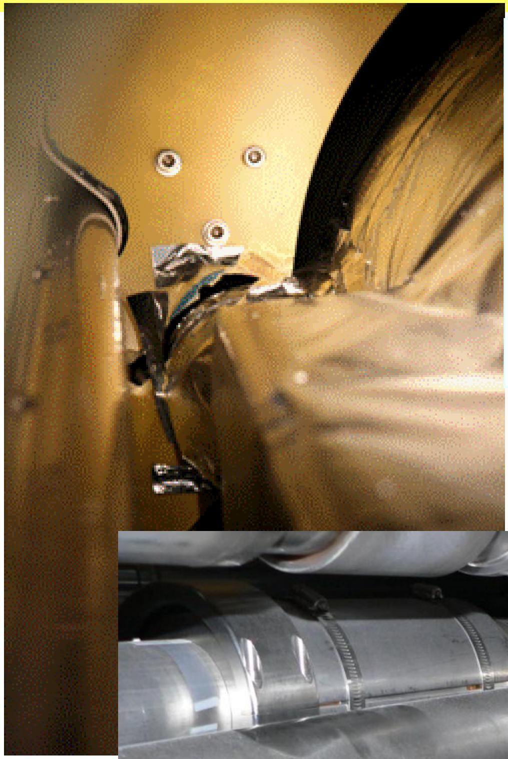
- Design and execution of the brazed joints anneals the extremities of the tubes (including fixed points in Q1 and Q3).
- Length of heat affected zone ~ 250-300 mm.
- Absence of mechanical support in the heat affected length.

All low-beta quadrupoles need to be repaired.

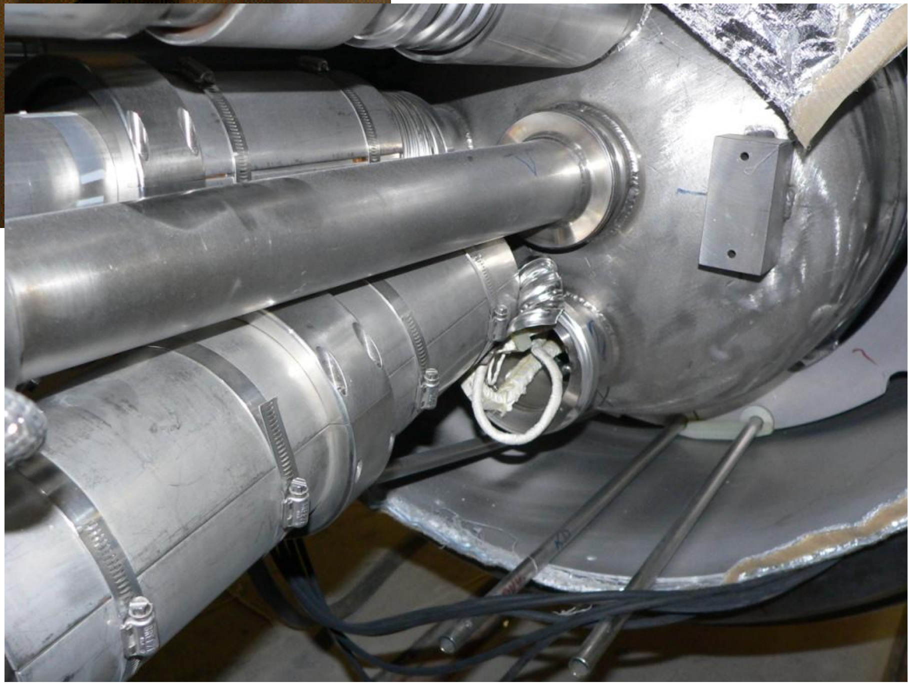
- During the pressure test of Sector 7-8 (25 November 2006) the corrugated heat exchanger tube in the inner triplet failed by buckling at 9 bar (external) differential pressure.
- The inner triplet was isolated and the pressure test of the whole octant was successfully carried out to the maximum pressure of 27.5 bar, thus allowing it to be later cooled down.
- Reduced-height of corrugations and annealing of copper near the brazed joint at the tube extremities accounted for the insufficient resistance to buckling.
- New tubes were produced with higher wall thickness, no change in corrugation height at ends, and e-beam welded collars to increase distance to the brazed joint.
- Installation of these tubes was made *in situ*.

LHC many problems overcome II





- Status
  - All triplets repaired by September
  - Problem solved



Q1 supports at IP 5L

On Tuesday March 27 2007 there was a serious failure in a high-pressure test at CERN of a Fermilab-built "inner-triplet" series of three quadrupole magnets

R Bailey

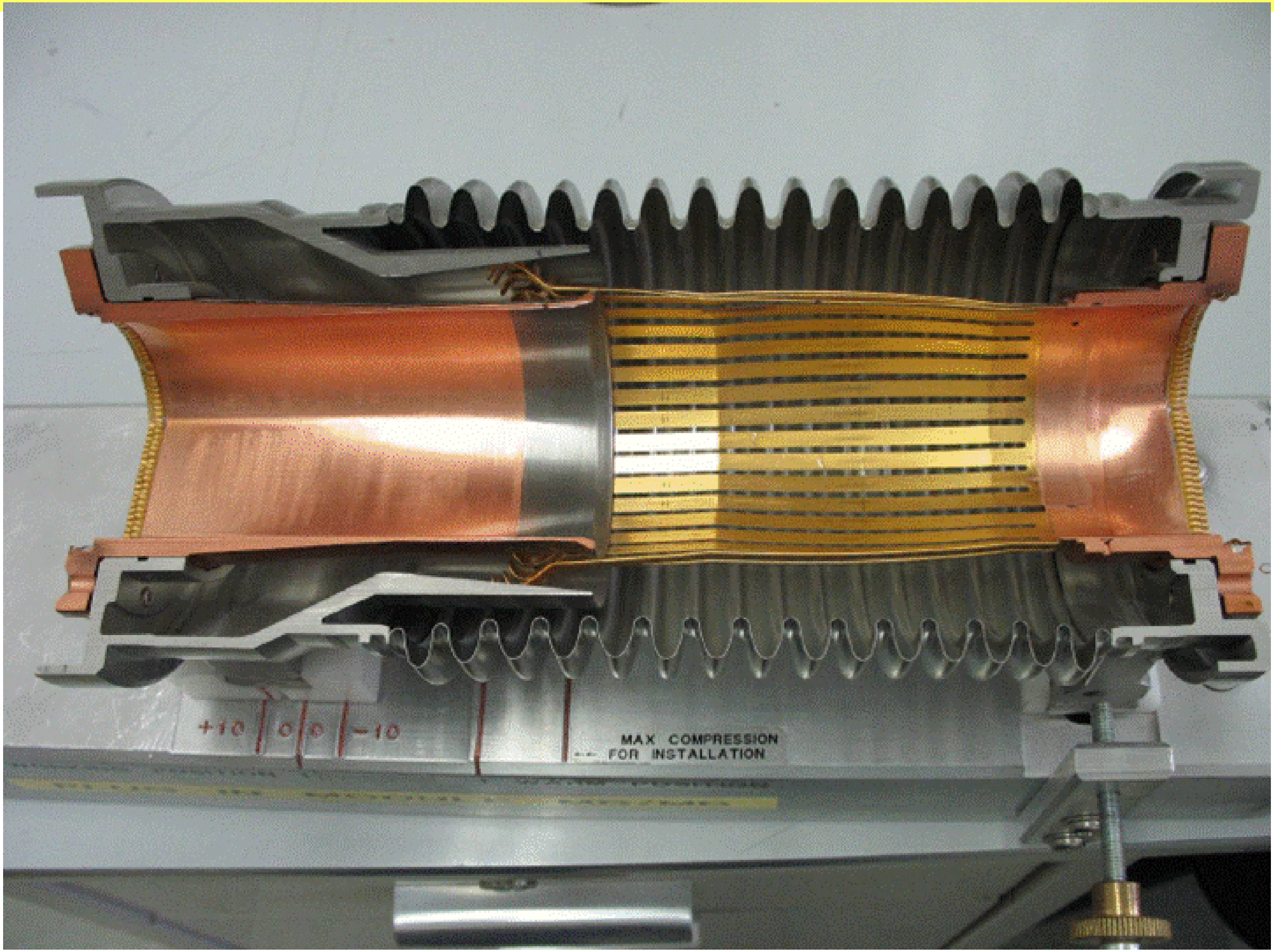
LHC: latest problem overcome

- The problem
  - Contact fingers in an arc interconnect have buckled into the beam aperture
  - Post-mortem examination shows this took place during sector warm-up
  - Was a major worry (there are 4000 of them!) but limited extent (% level)
  - Understood why it happened (manufacturing problem)

R Bailey

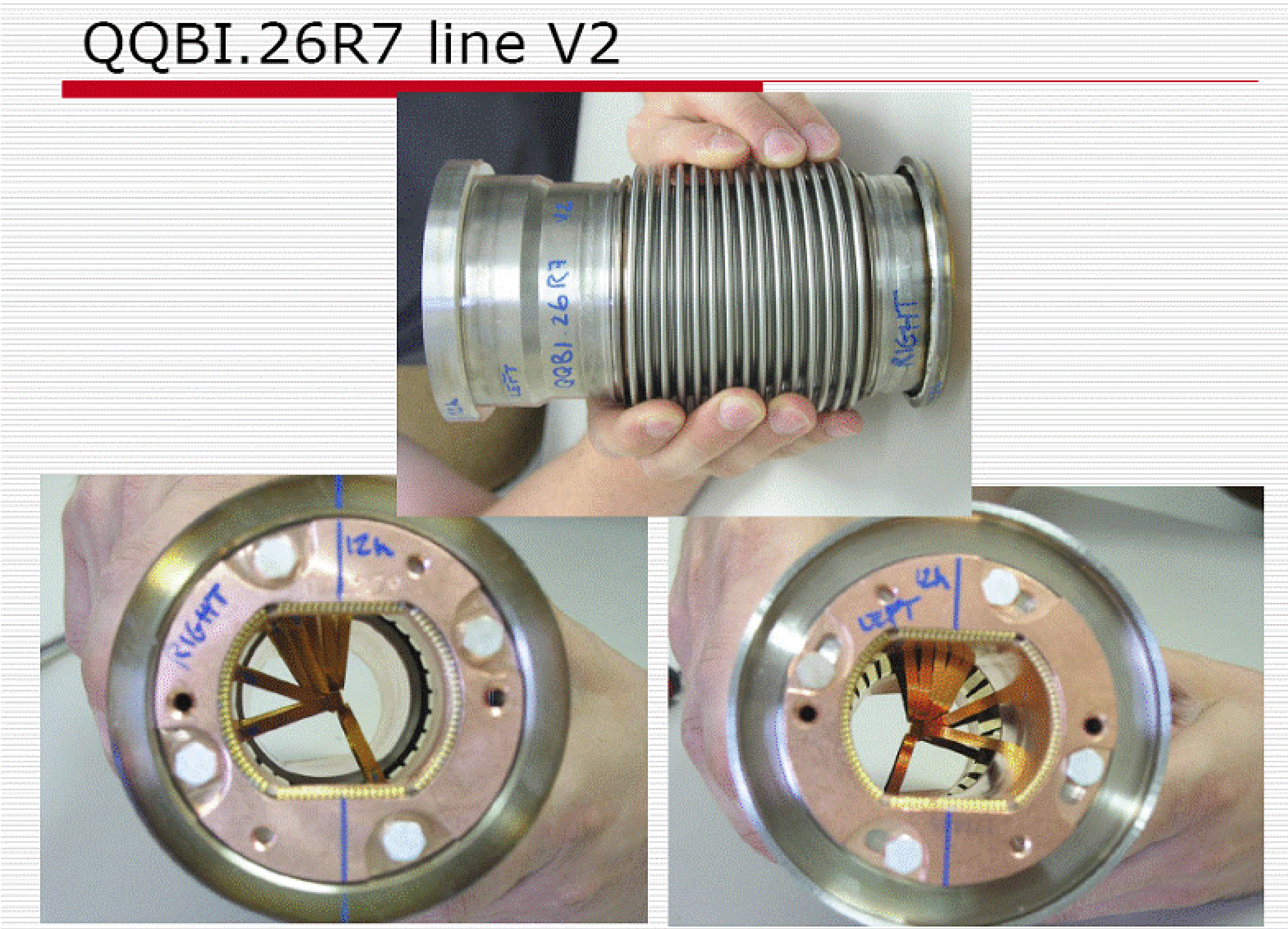
- Solutions being implemented for first beam
  - The LHC is being closed with components corrected to be within original specification and working as close as possible to nominal conditions
  - The aperture is being systematically checked before cooldown, and will be after each warm-up
- Longer term perspective
  - The data used to make the PIM design is being double-checked, and detailed FE analysis is in progress both to simulate the failures and check the robustness of the design
  - Once this procedure is complete, and the reasons for the manufacturing defects understood, a long term strategy will be adopted
  - There is now no reason why this problem should have further impact on the machine schedule

LHC: latest problem overcome



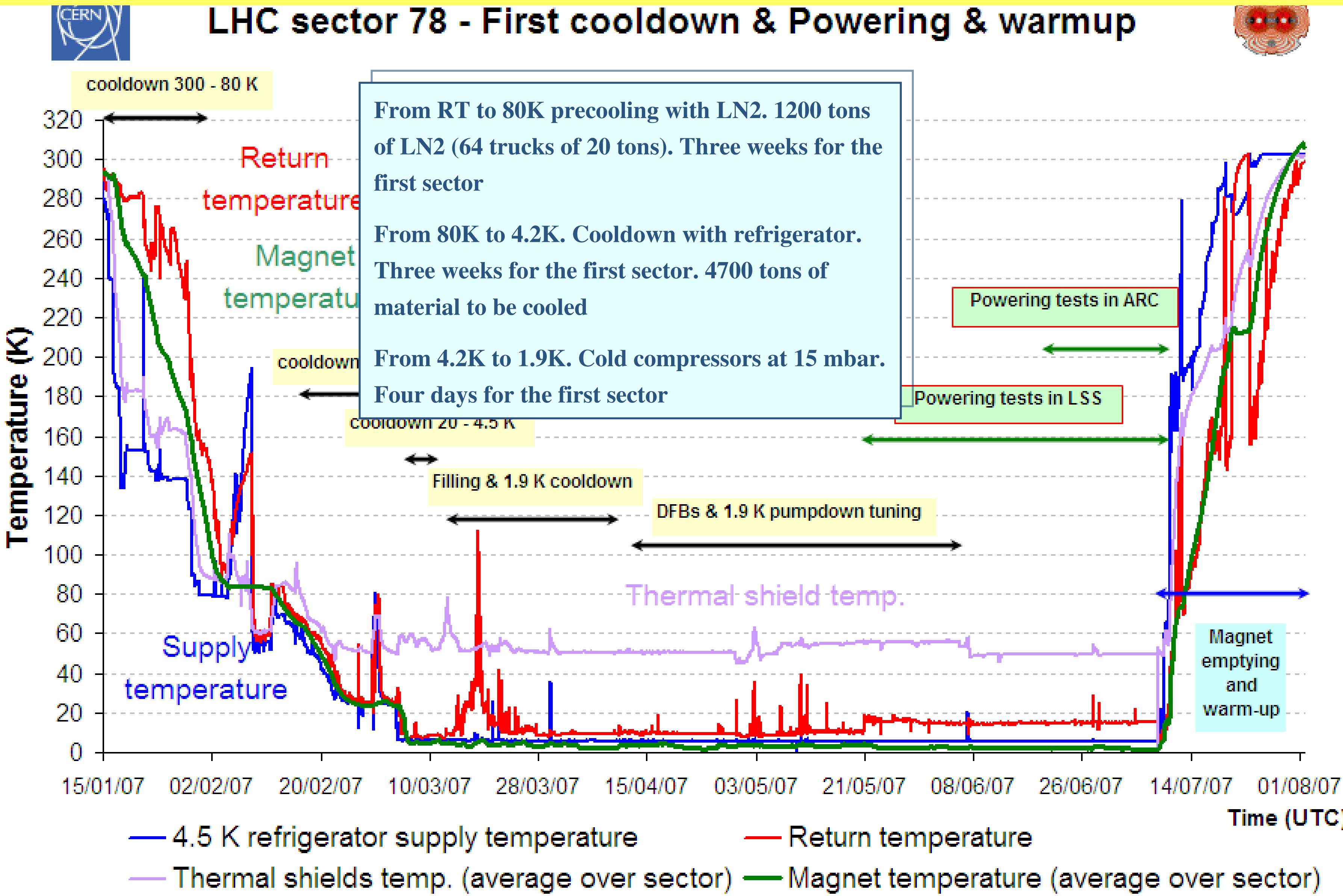
R Bailey

LHC: latest problem overcome



R Bailey

LHC: First sector cool down



R Bailey

Latest milestones, end November

End of Powering Tests on wk 6 to be confirmed

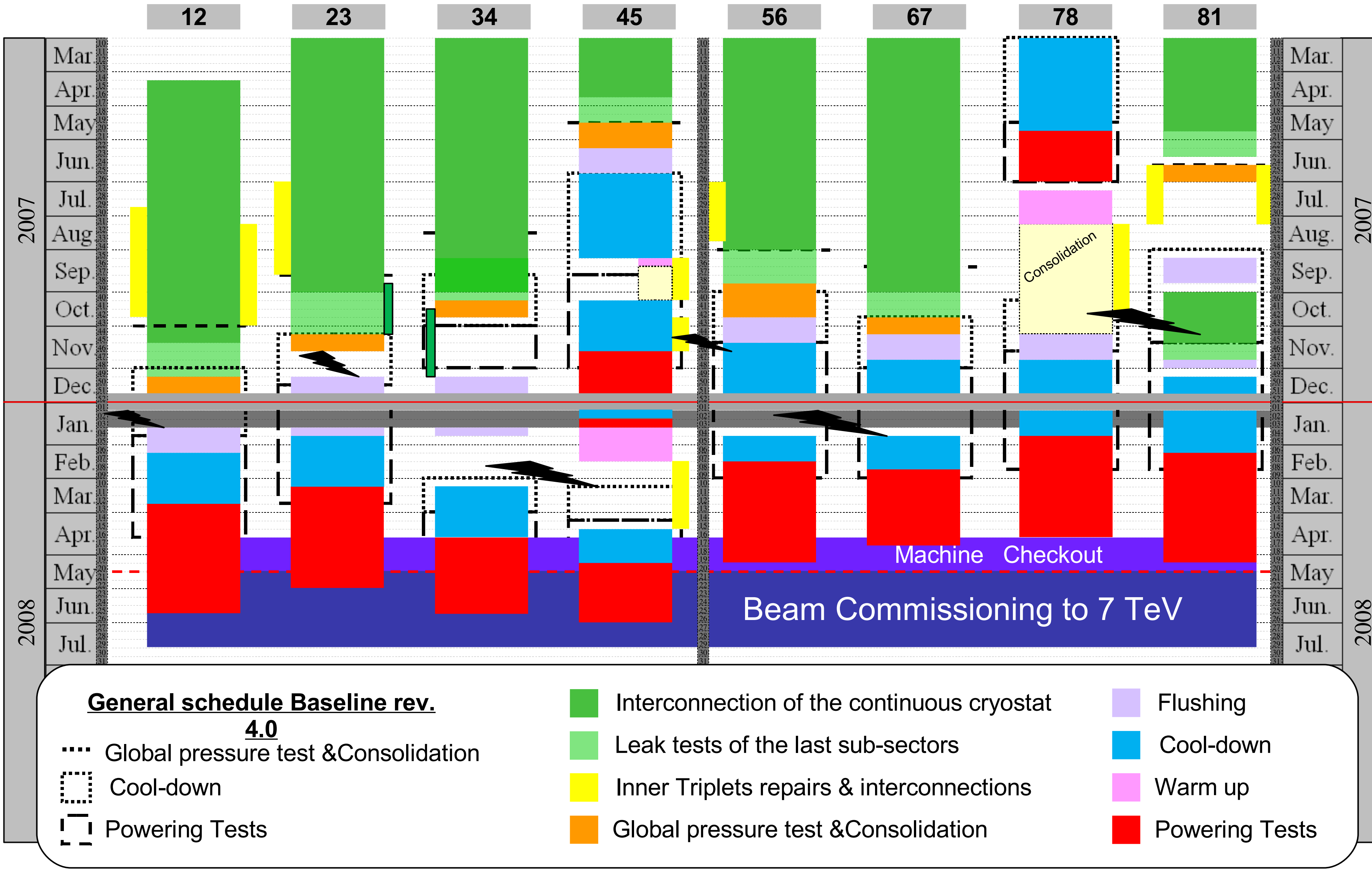
	Pressure test	Cool-down		Powering tests	
Sector 12	wk. 49 (2007)	wk. 07 (2008)	wk. 12 (2008)	wk. 13 (2008)	wk. 25 (2008)
Sector 23	*Done*	wk. 06 (2008)	wk. 11 (2008)	wk. 12 (2008)	wk. 23 (2008)
Sector 34	*Done*	wk. 10 (2008)	wk. 15 (2008)	wk. 16 (2008)	wk. 24 (2008)
Sector 45 1	*Done*	*Started*	wk. 48 (2007)	wk. 49 (2007)	wk. 03 (2008)
Sector 45 2		wk. 14 (2008)	wk. 17 (2008)	wk. 18 (2008)	wk. 25 (2008)
Sector 56	*Done*	wk. 49 (2007)	wk. 07 (2008)	wk. 09 (2008)	wk. 19 (2008)
Sector 67	*Done*	wk. 05 (2008)	wk. 11 (2008)	wk. 12(2008)	wk. 20 (2008)
Sector 78 1	*Done*	*Done*	*Done*	*Done*	*Done*
Sector 78 2	*Done*	wk. 04 (2008)	wk. 10 (2008)	wk. 11 (2008)	wk. 22 (2008)
Sector 81	*Done*	wk. 51 (2007)	wk. 09 (2008)	wk. 10 (2008)	wk. 22 (2008)

Beam 1

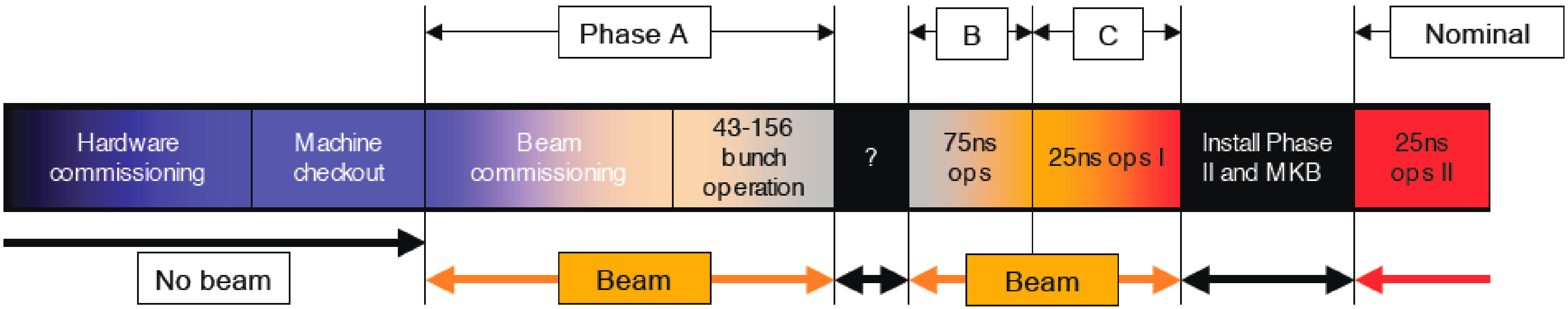
Beam 2

BERKELEY LAB

Schedule



12
23
34
45
56
67
78
81
2007
2008
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Consolidation
Machine Checkout
Beam Commissioning to 7 TeV
General schedule Baseline rev. 4.0
Global pressure test &Consolidation
Cool-down
Powering Tests
Interconnection of the continuous cryostat
Leak tests of the last sub-sectors
Inner Triplets repairs & interconnections
Global pressure test &Consolidation
Flushing
Cool-down
Warm up
Powering Tests

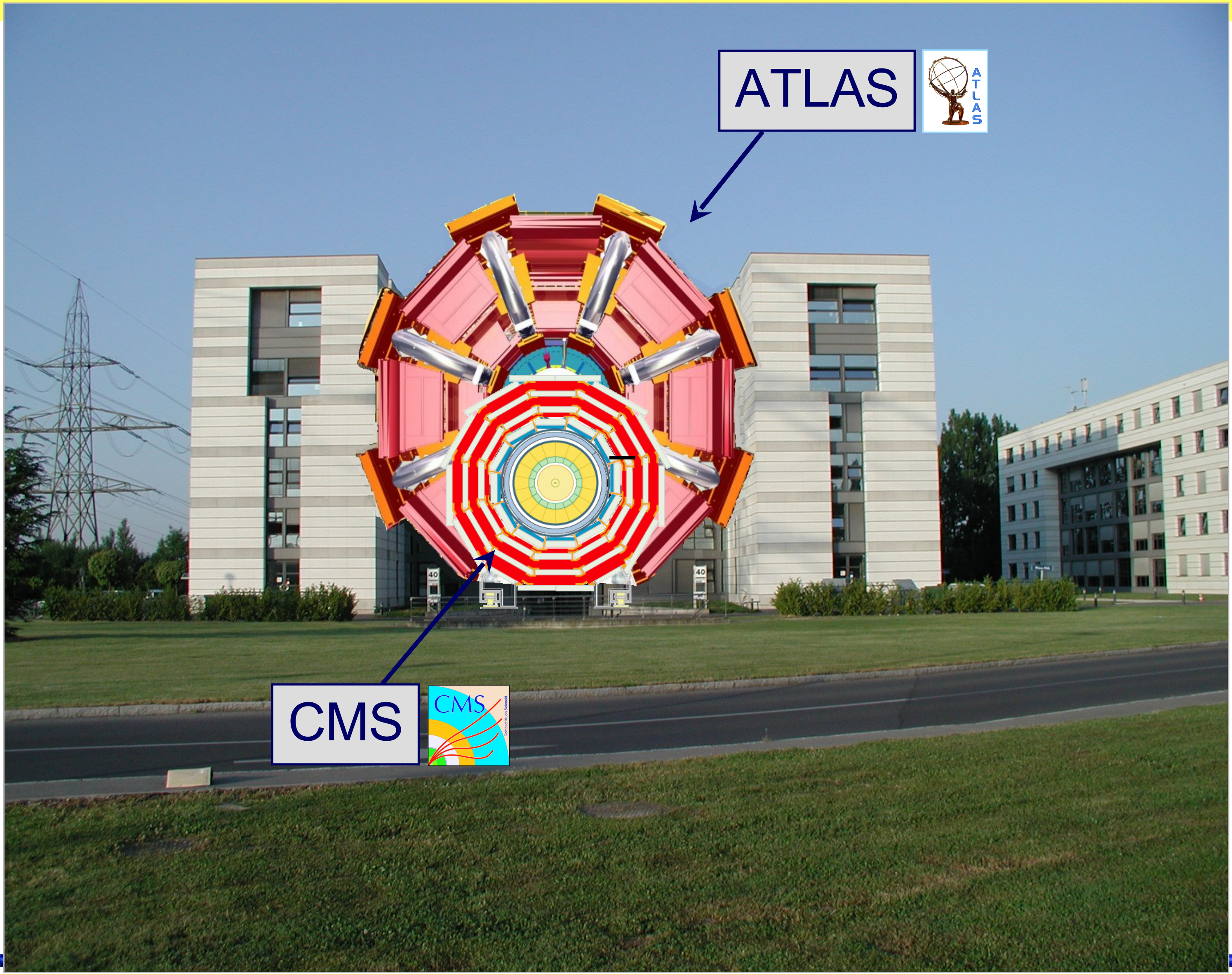


Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μrad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ^* (μm, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	6×10^{30}-10^{32}	10^{32}-10^{33}	$(1-2)\times10^{33}$	10^{34}
Year (?)	2008	2009	2009-2010	> 2010

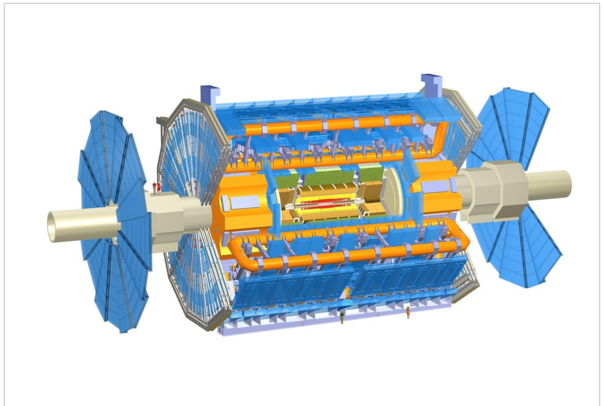
Where are we? (my observations)

- Known problems fixed much faster than expected: prophets of doom have been proved wrong so far
- Schedule has no contingency ("success oriented")
- Cool down of sectors 5-6 and 8-1 deferred until early January
  - Currently 2-3 weeks behind previous page
- The machine will be closed in April 2008
- Beam commissioning starts May 2008
- First collisions at 14 TeV in Summer 2008?
- Pilot run pushed to 156 bunches for reaching 10^{32} cm^{-2} s^{-1} by end 2008?

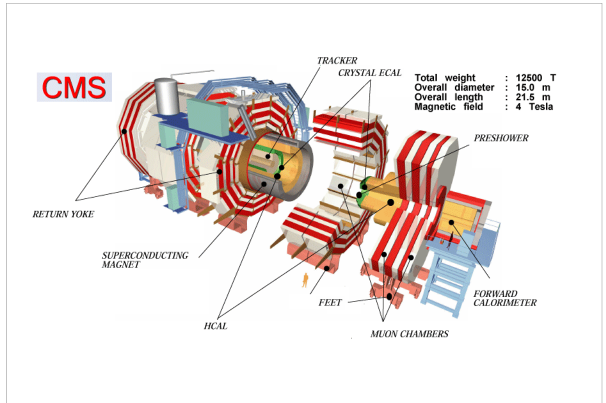
We need the detectors to do physics



ATLAS



CMS



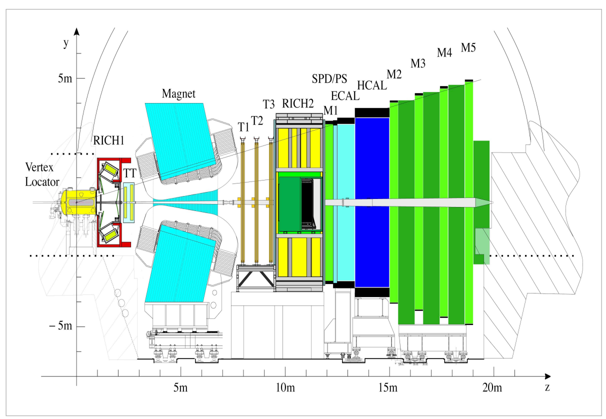
ALTAS and CMS have same physics goals: concentrate on "high-p_T" discovery physics

The detector concepts are however different: this provides necessary redundancy and fruitful competition

ALICE

LHCb looks like a fixed-target experiment (though it is not!), because it concentrates on low-p_T B physics

LHCb



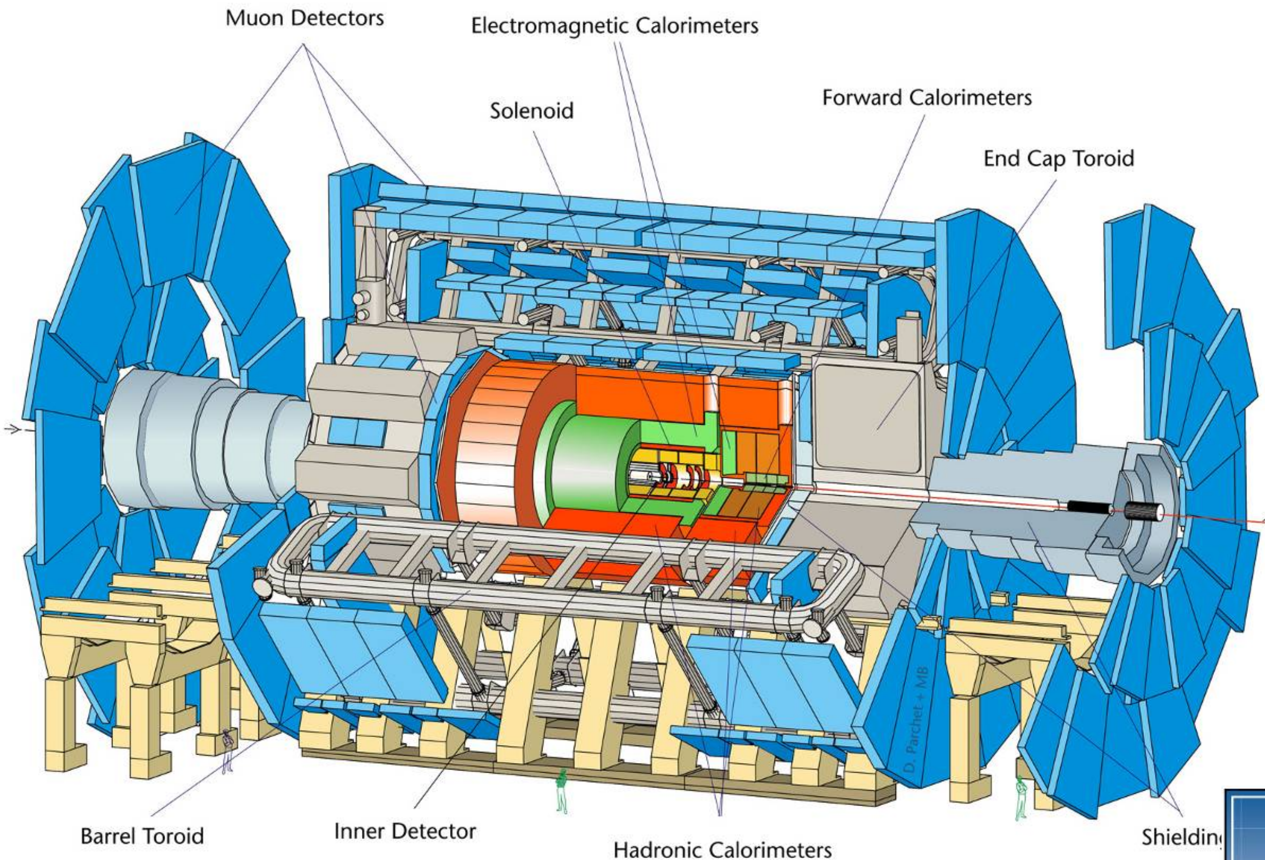
ALICE will exploit high-energetic nucleus-nucleus ("heavy-ion") collisions

What Detectors must do

- No matter what the new physics is: it must decay into standard model particles. Must detect all these
- Muons: Penetrates: tracking system and muon spectrometer
- Photons: absorbed in EM calorimeter
- Electrons: Tracking system, EM calorimeter
- Tau: hadronic decay, thin jet with few tracks
- Quarks, gluons: Jets of particles, absorbed in calorimeter
- B-quarks: Decay away from primary interaction: precision tracking
- Neutrinos: Must detect "nothing", hermetic detector
- ATLAS and CMS have similar philosophy: technology is different: precision determined by physics signals and backgrounds

ATLAS and CMS

	ATLAS ≡ A Toroidal LHC ApparatuS	CMS ≡ Compact Muon Solenoid
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5\times10^{-4}\, p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim 10\%$ at 1 TeV standalone (~ 7% combined with tracker)	Fe → $\sigma/p_T \sim 15\text{-}30\%$ at 1 TeV standalone (5% with tracker)

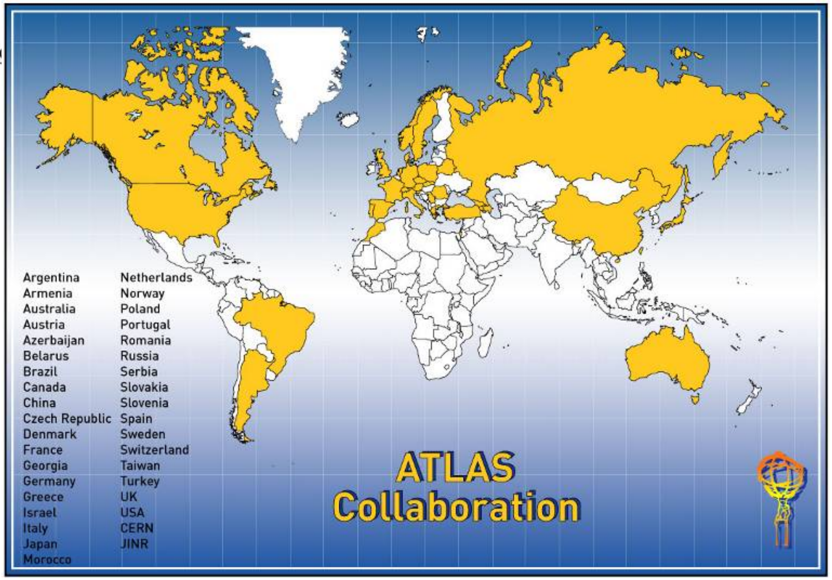


ATLAS

Length : ~46 m
Radius : ~12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

2000 physicists from
167 Institutions from 37 countries

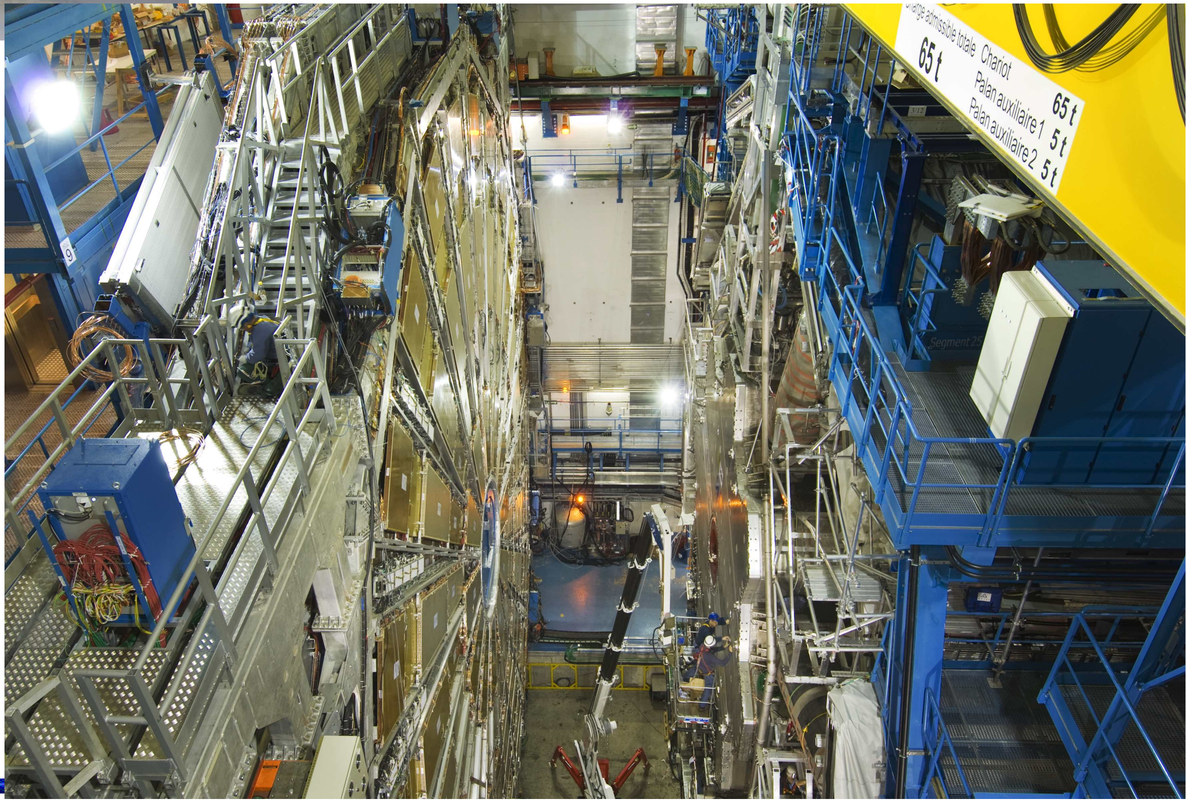
- Tracking ($|\eta|<2.5$, B=2T) :
  - -- Si pixels and strips
  - -- Transition Radiation Detector (e/π separation)
- Calorimetry ($|\eta|<5$) :
  - -- EM : Pb-LAr
  - -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer (|□|<2.7) :
  air-core toroids with muon chambers

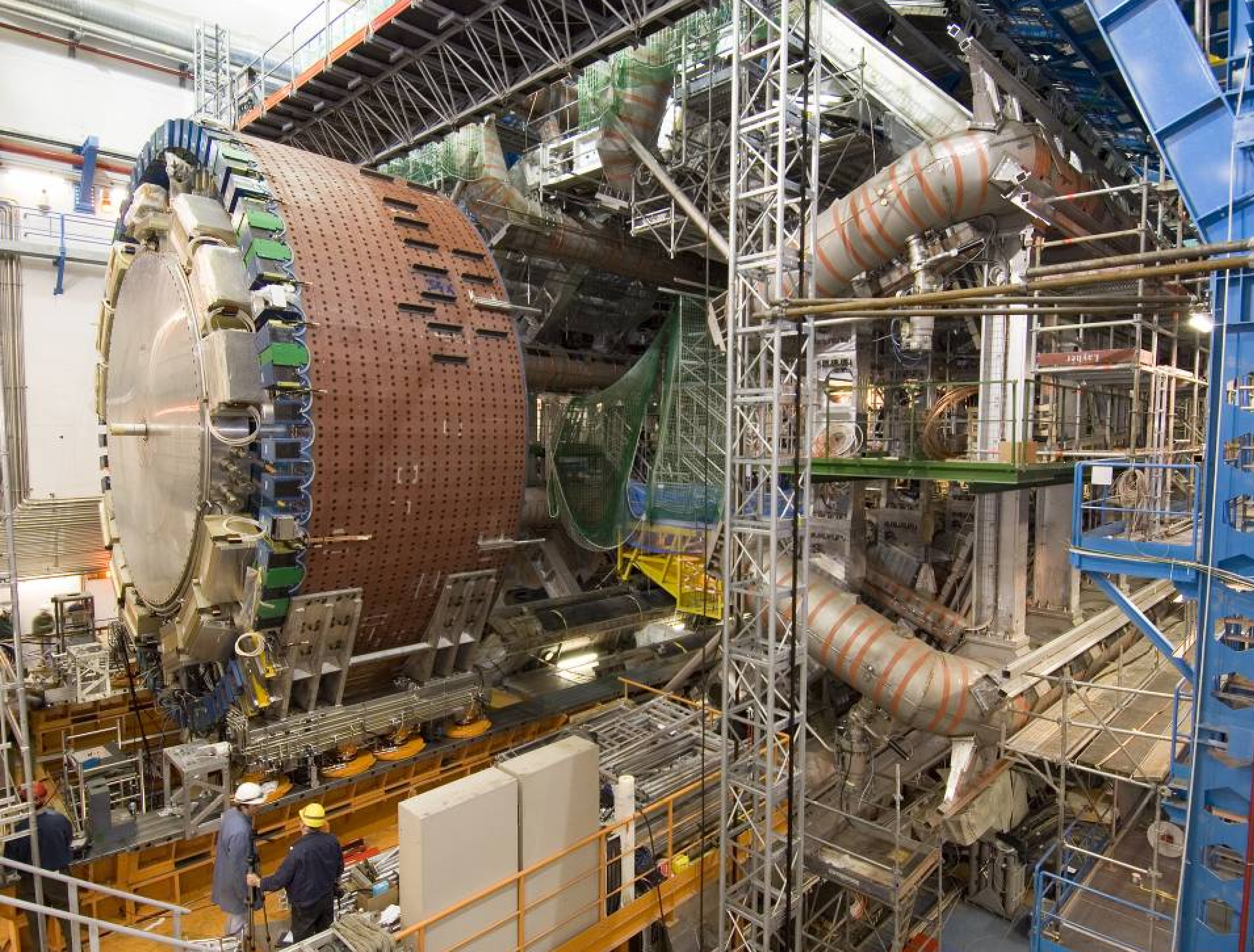


June 2003

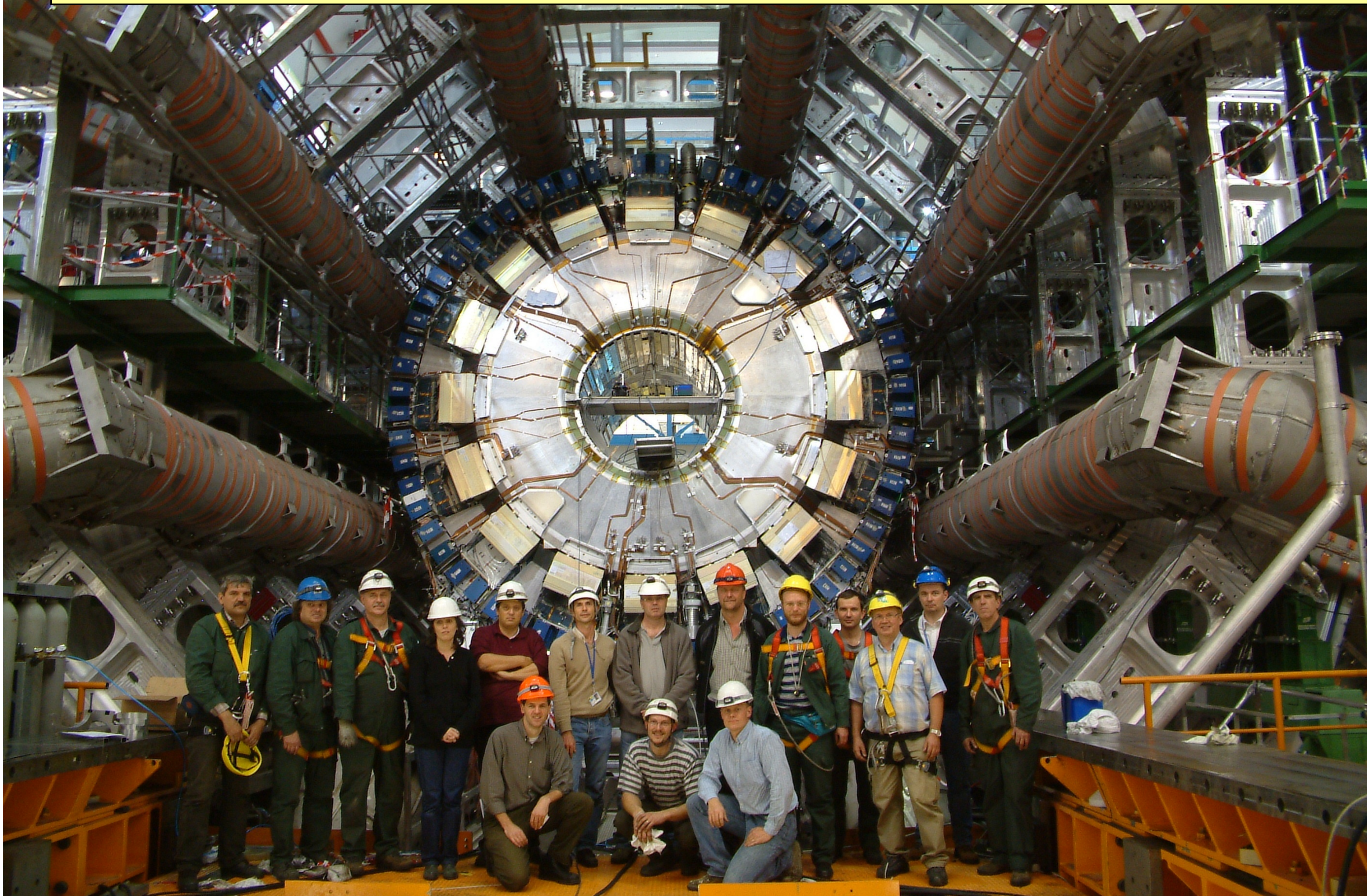
ATLAS progress

November 2007



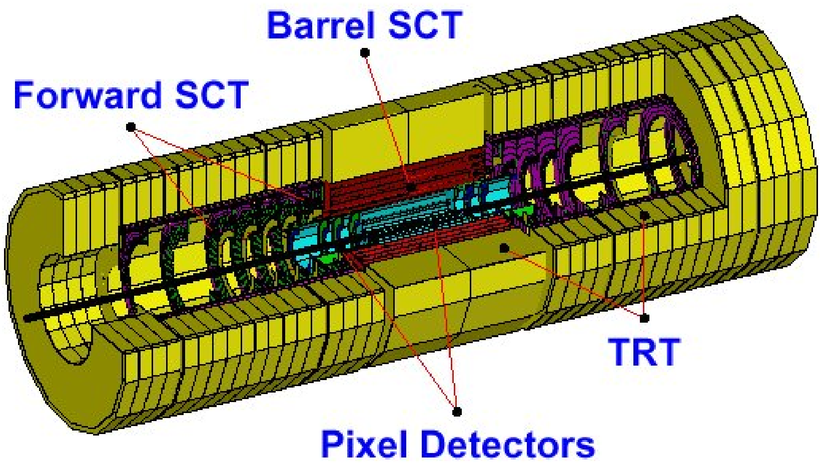


November 2005: barrel calorimeter (EM Pb/LAr + HAD Fe/scintillator Tilecal)
in its final position at Z=0 inside barrel toroid system.
Today: cryostat is filled with LAr and cold (87 K); taking cosmics data.



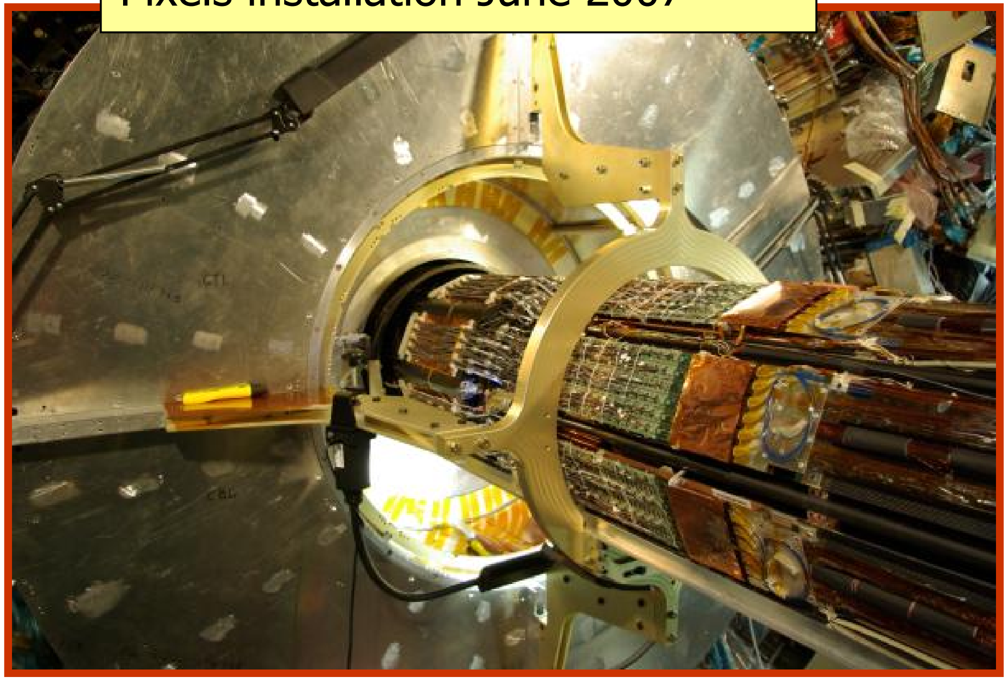
Inner detector

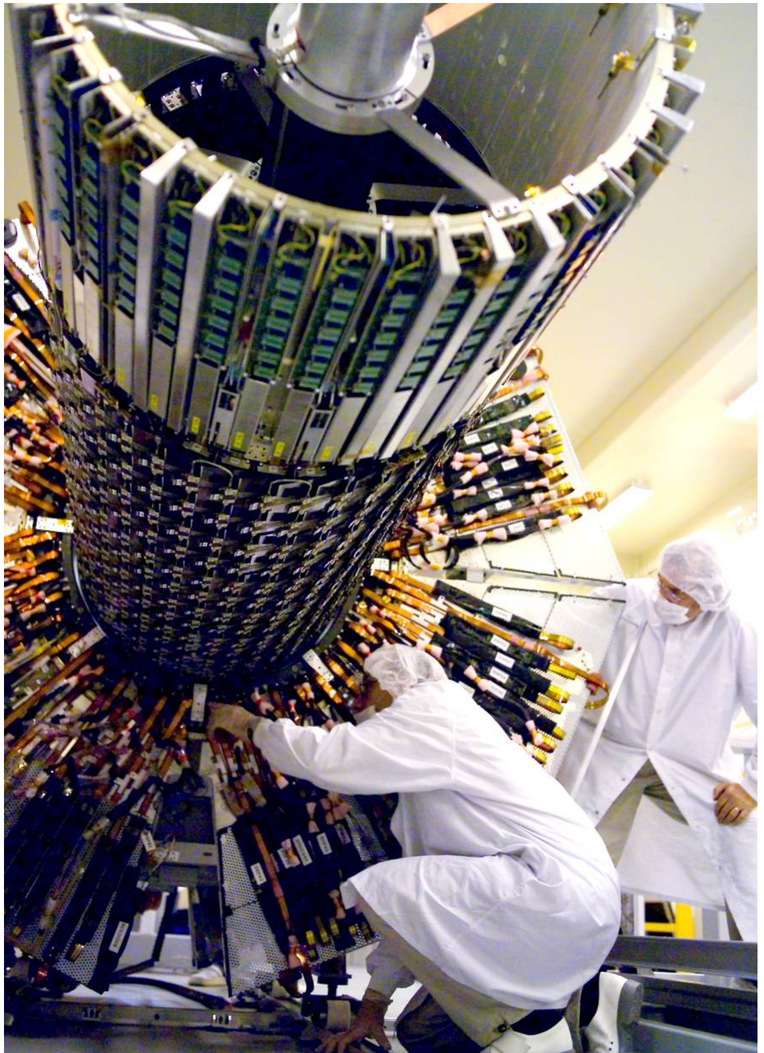
3 sub-systems:
Silicon pixels : 80 10^6 channels
Silicon strips (SCT) : 6 10^6 channels
Transition Radiation Tracker (TRT) :
straw tubes filled with gas, 4 10^5 channels
Installation in the underground cavern completed

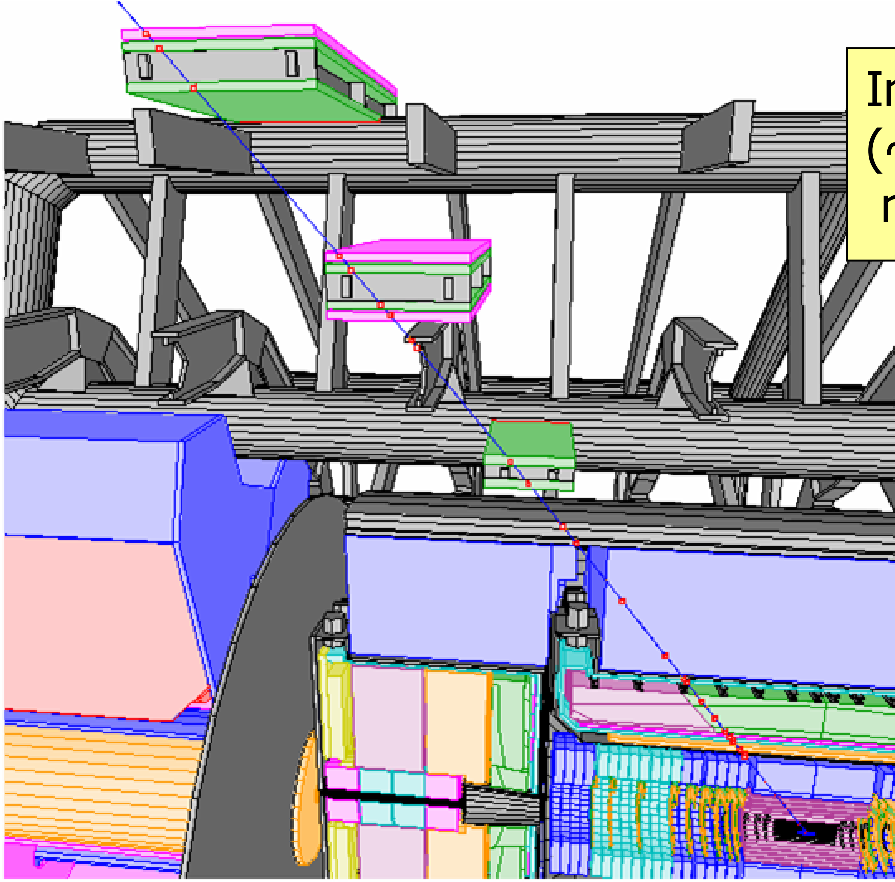


Pixel chips : 50μm wide, 400μm long, 250μm thick
Must have resolution to resolve B-meson lifetime

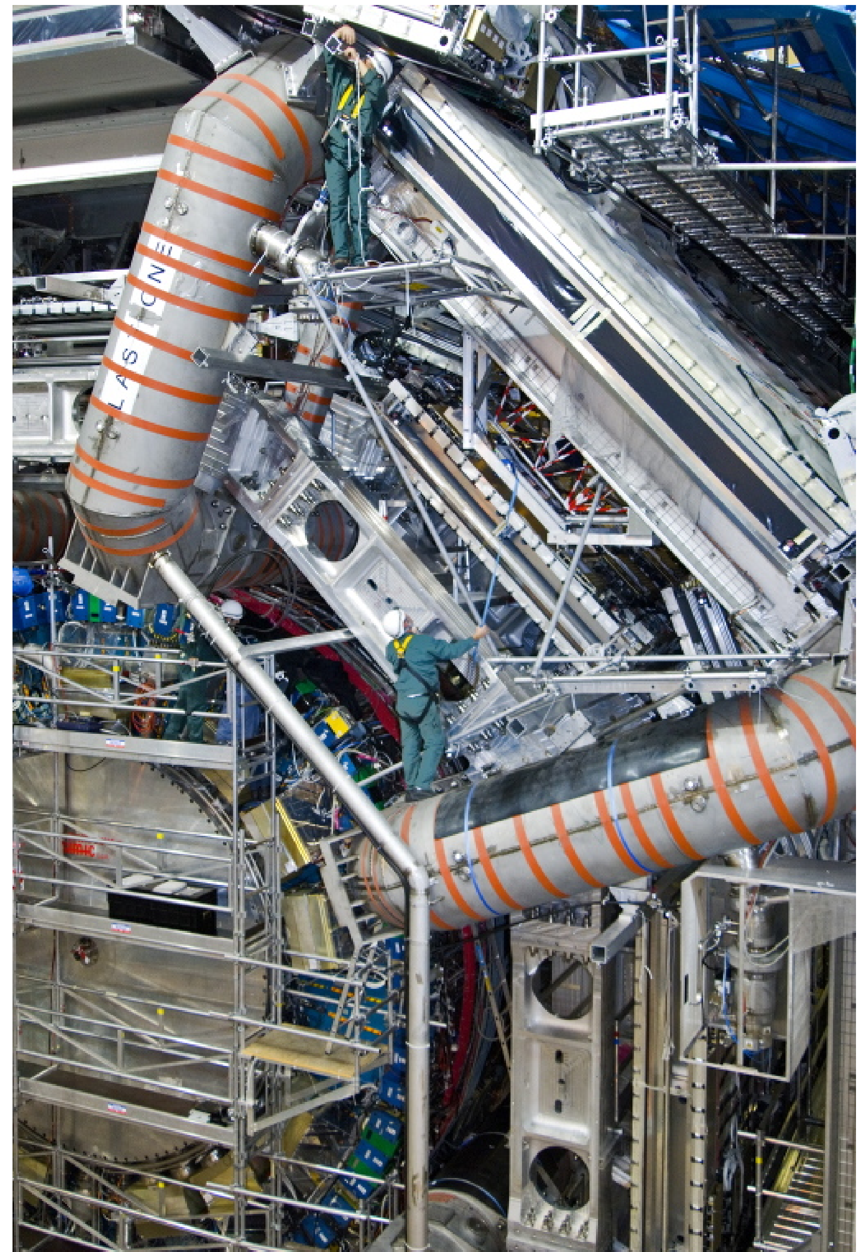
Pixels installation June 2007



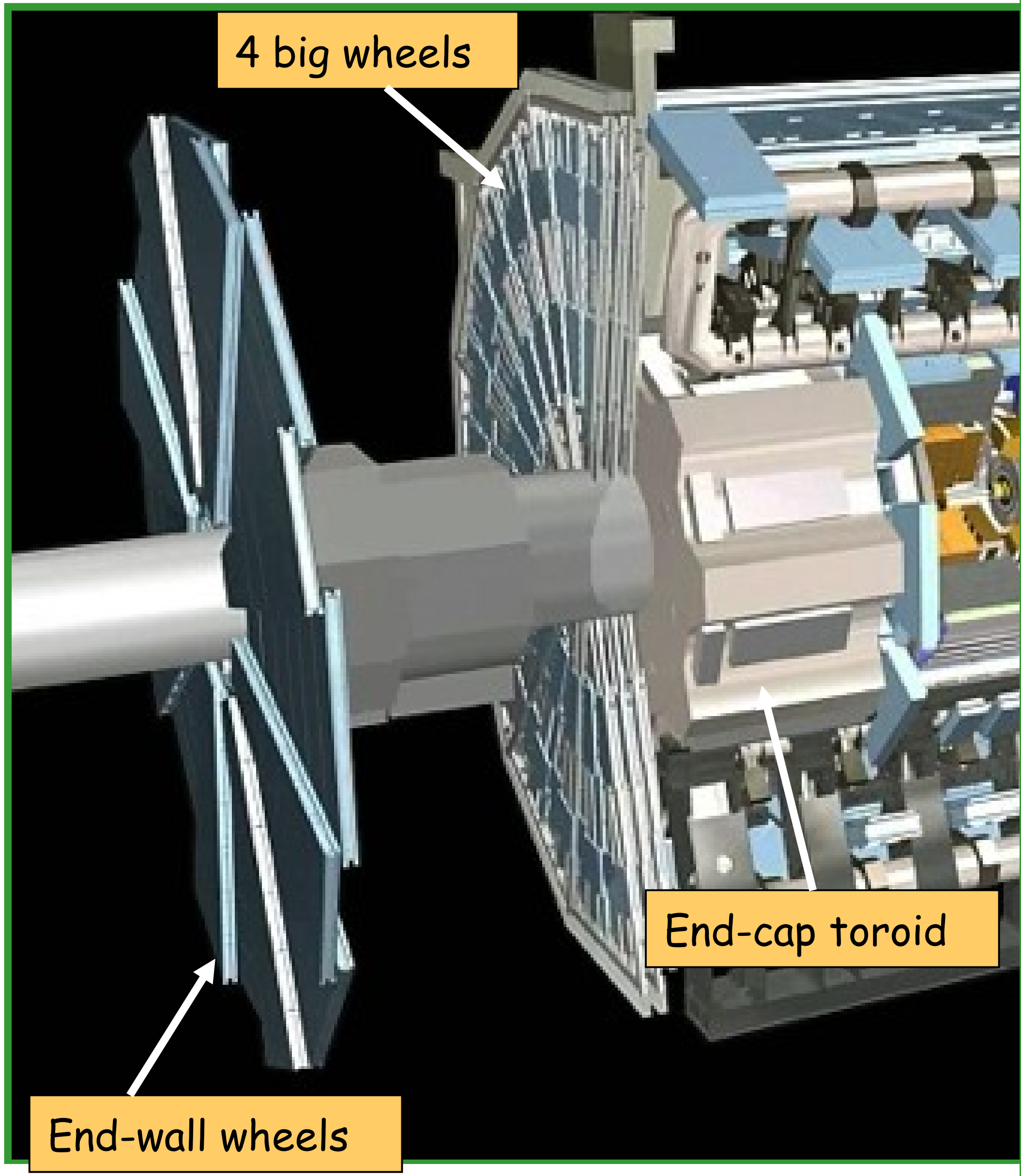


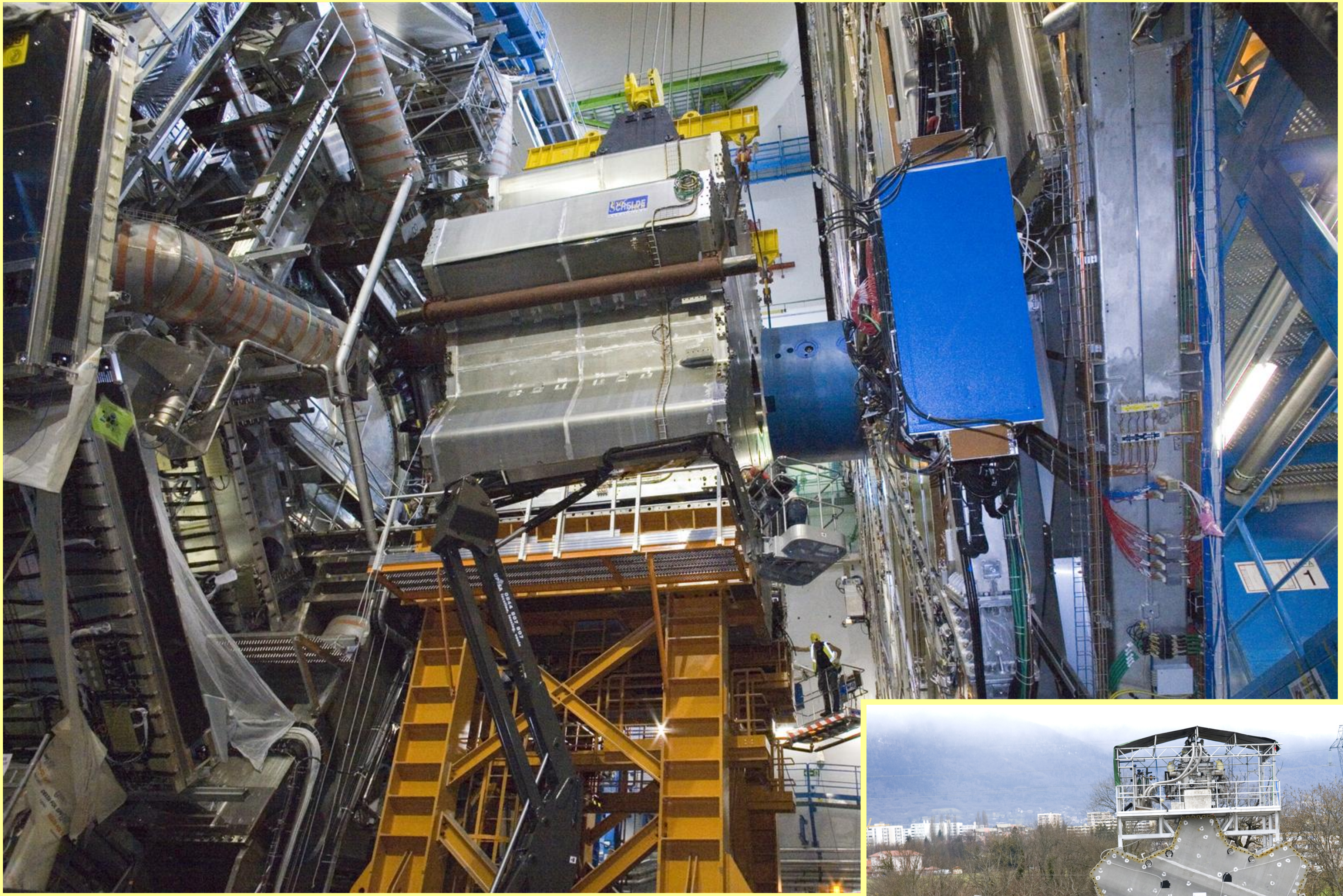


Installation of barrel muon chambers
(~ 700 stations) started in December 2005,
now completed.



Forward Muon Spectrometer: big wheels installed, end-wall wheel installation started





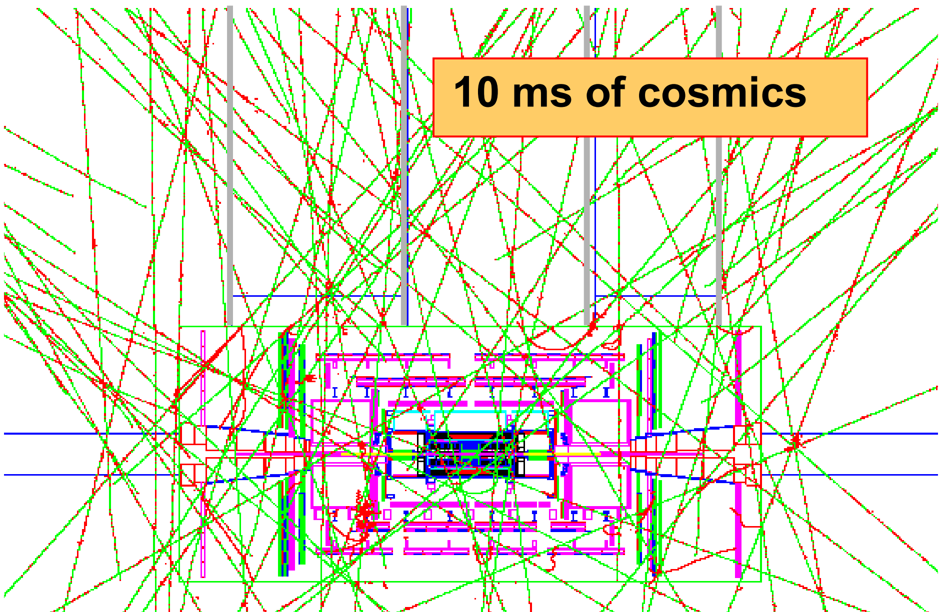
The two end-cap superconducting toroid magnets
installed in June-July 2007; both cooled down,
one being tested with current now.
Final magnet test (barrel+end-cap) March 2008

Commissioning with cosmics in the underground cavern

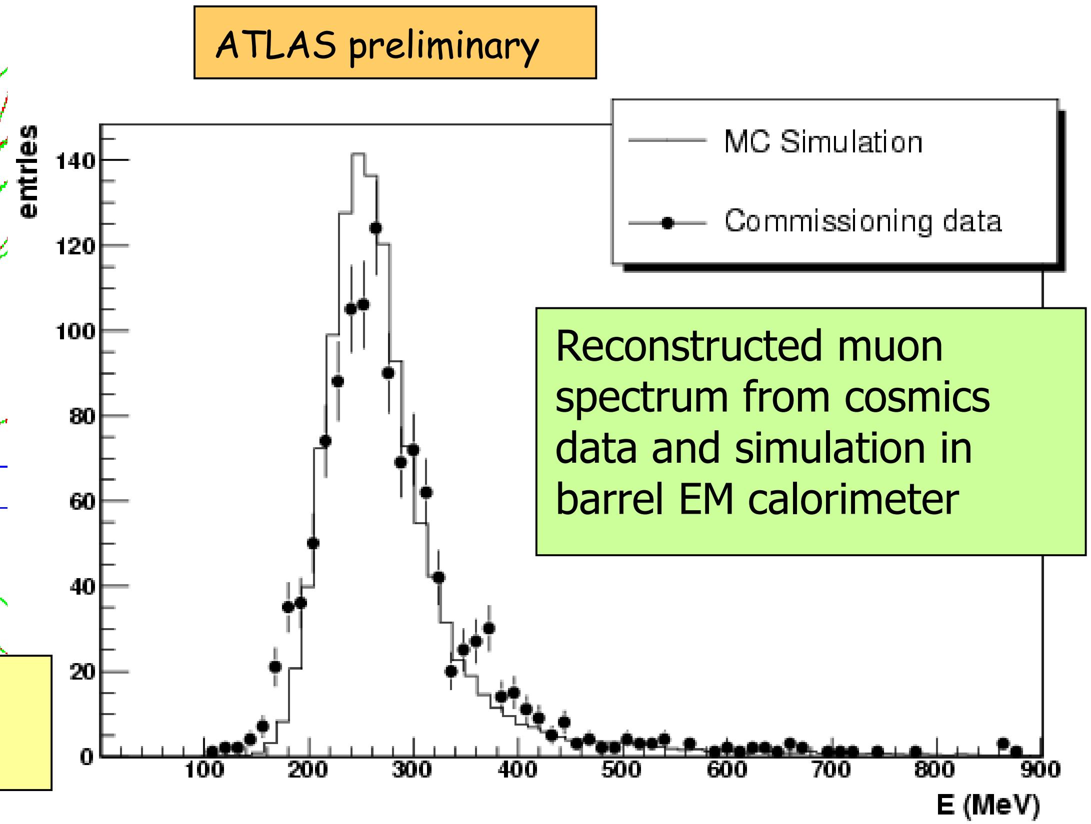
(Data taking has started)

Started about one year ago. Vital:

- Run an increasingly more complete detector with final trigger, data acquisition and monitoring systems. Data analyzed with final software
- Shake-down and debug the experiment in its final position
- Gain global operation experience in situ before collisions start



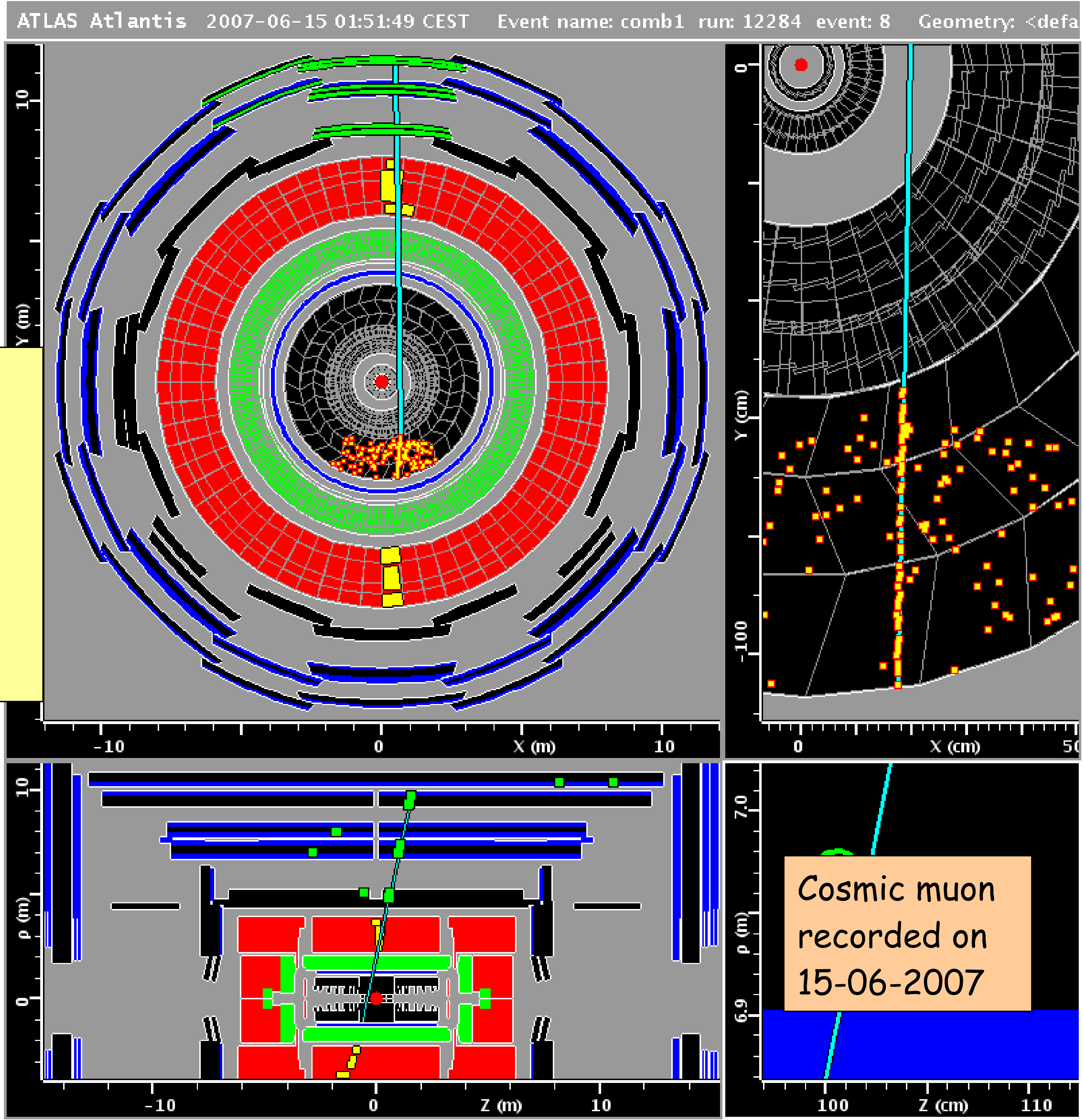
Rate of cosmics in the detector: 1-100 Hz (depending on cuts)

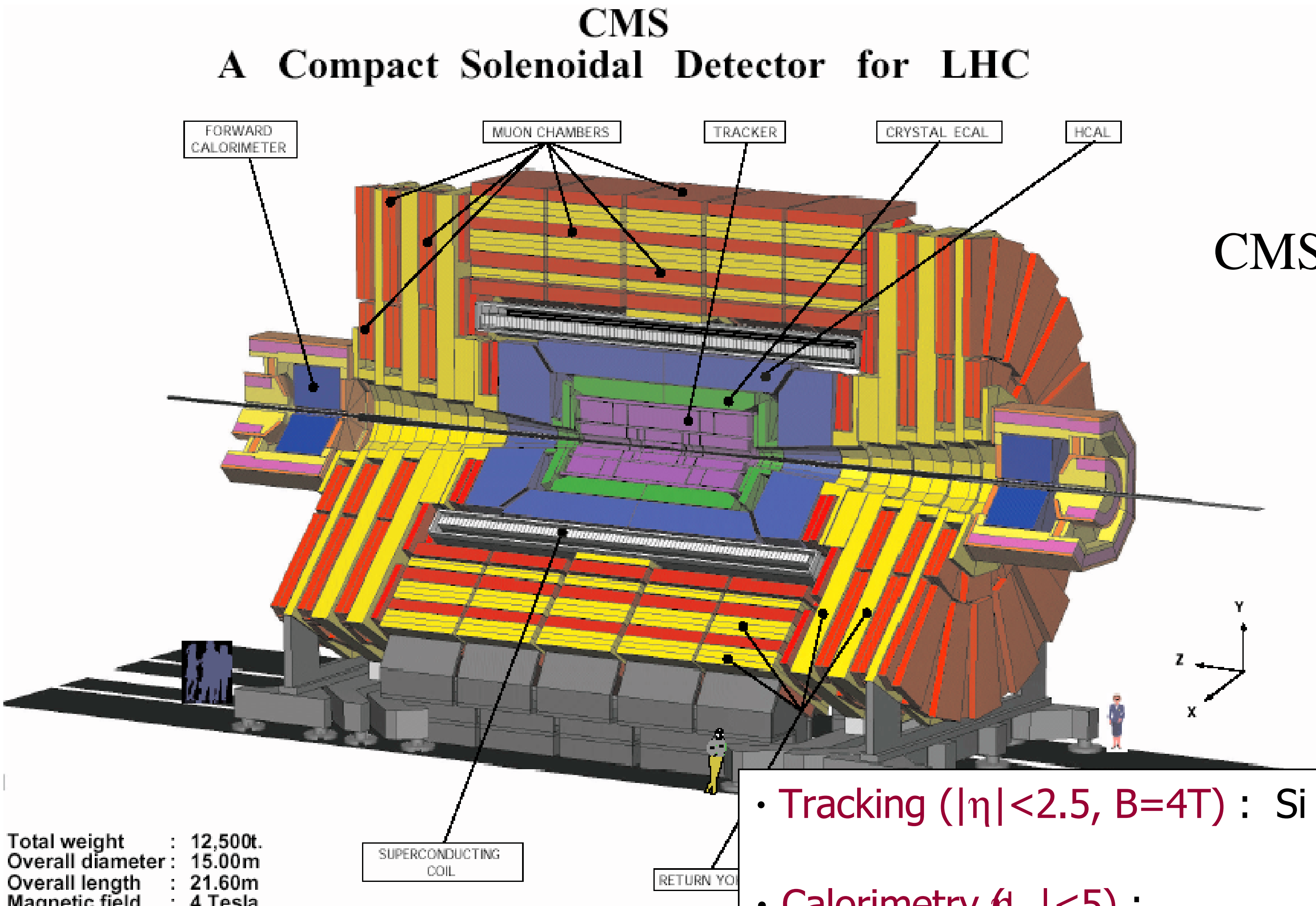


Reconstructed muon spectrum from cosmics data and simulation in barrel EM calorimeter

Global cosmics runs:
combined operation
of several detectors.
Until now:

- Muon Spectrometer
- All calorimeters
- TRT
- Pixels and SCT readout



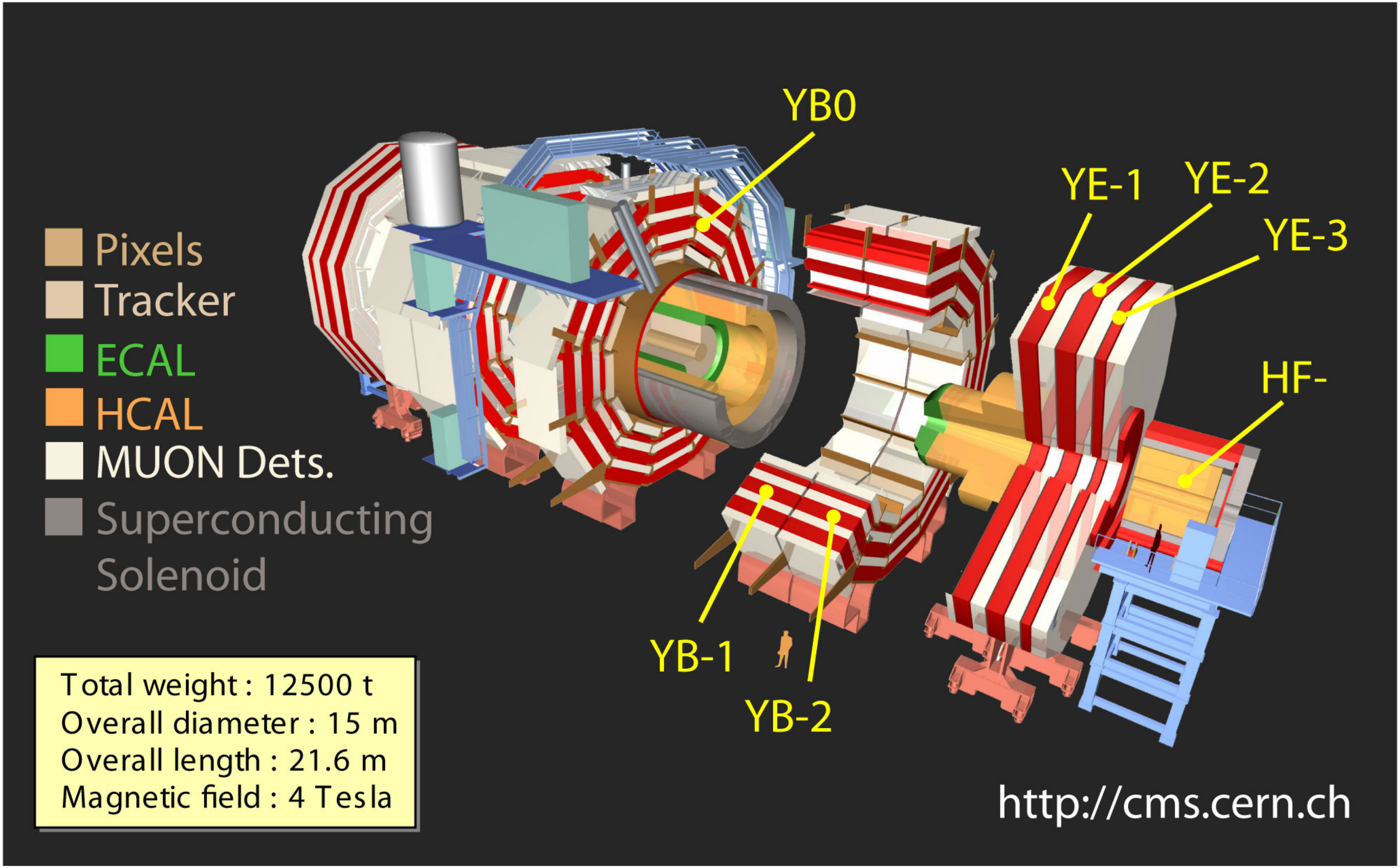


CMS

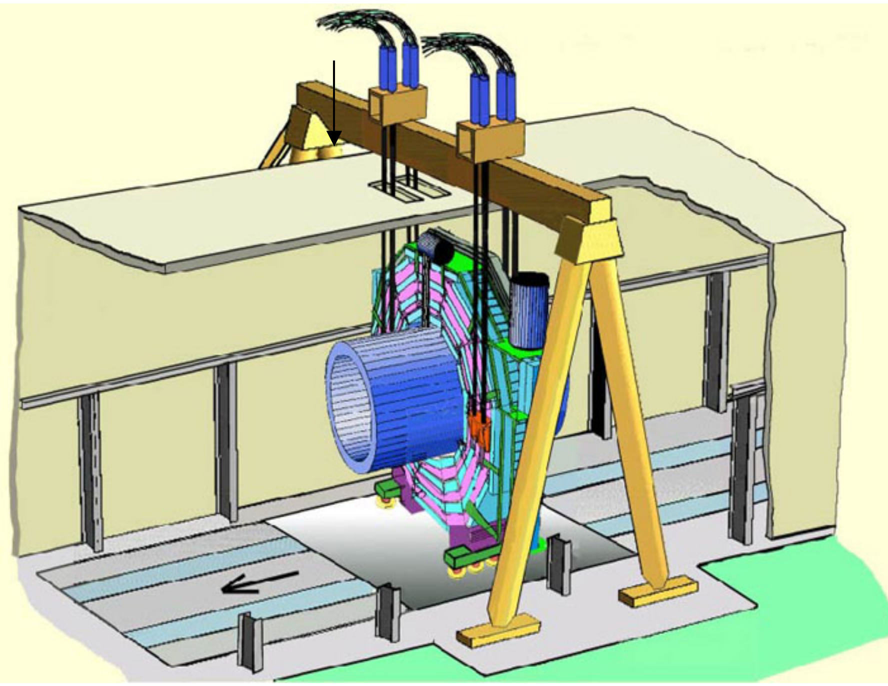
2000 physicists from
174 Institutions from 38 countries

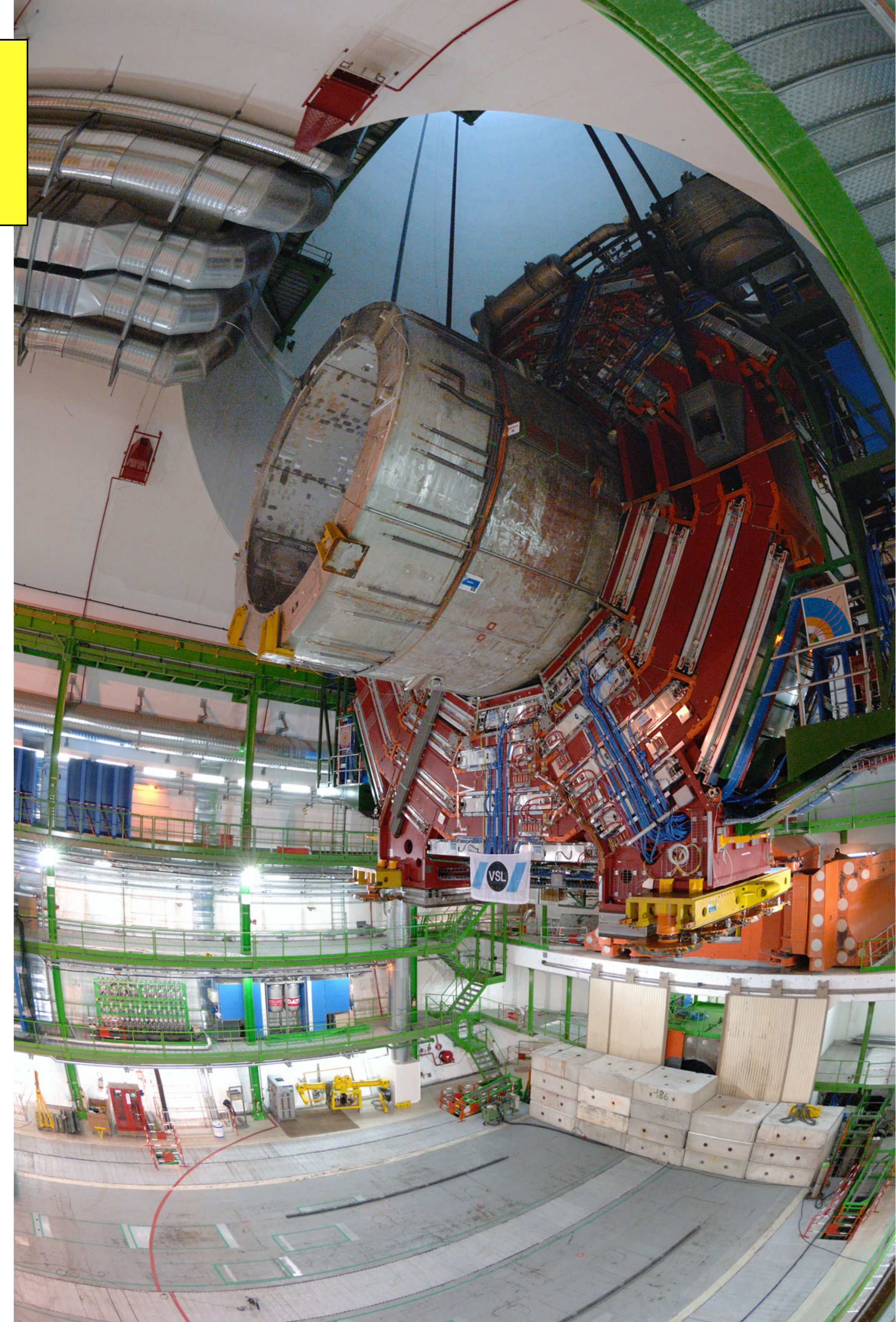
Compact and modular : assembled at the surface
lowered in the cavern
slice by slice (12 out of 15 slices installed)

- Tracking ($|\eta|<2.5$, B=4T) : Si pixels and strips
- Calorimetry ($|\eta|<5$) :
  -- EM : $PbWO_4$ crystals
  -- HAD: brass/scintillator (central+ end-cap),
  Fe/Quartz (fwd)
- Muon Spectrometer ($|\eta|<2.5$) : return yoke of solenoid instrumented with muon chambers


Pixels
Tracker
ECAL
HCAL
MUON Dets.
Superconducting Solenoid
YB0
YE-1
YE-2
YE-3
HF-
YB-1
YB-2
Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
http://cms.cern.ch

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



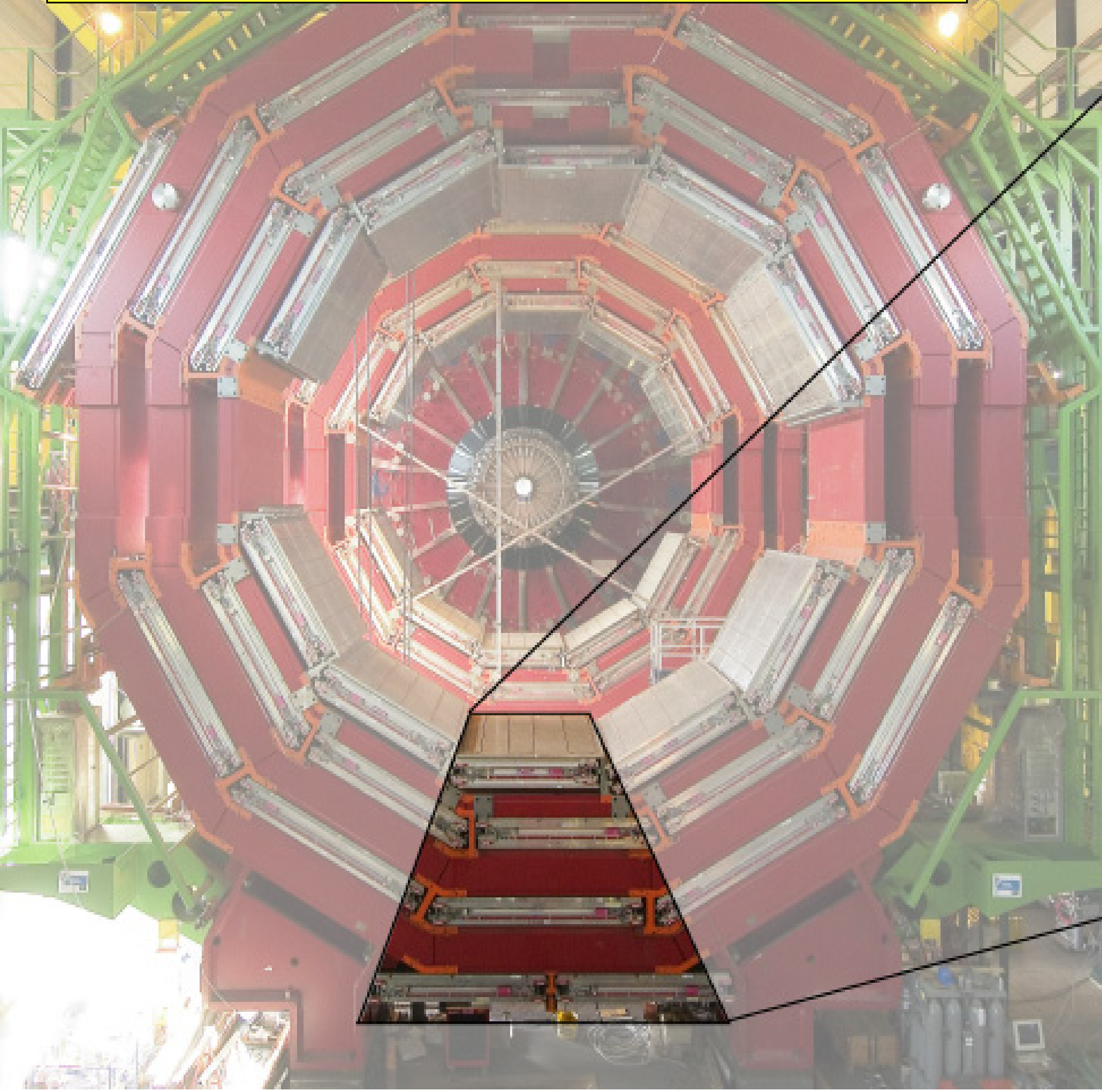


<u>CMS solenoid:</u>

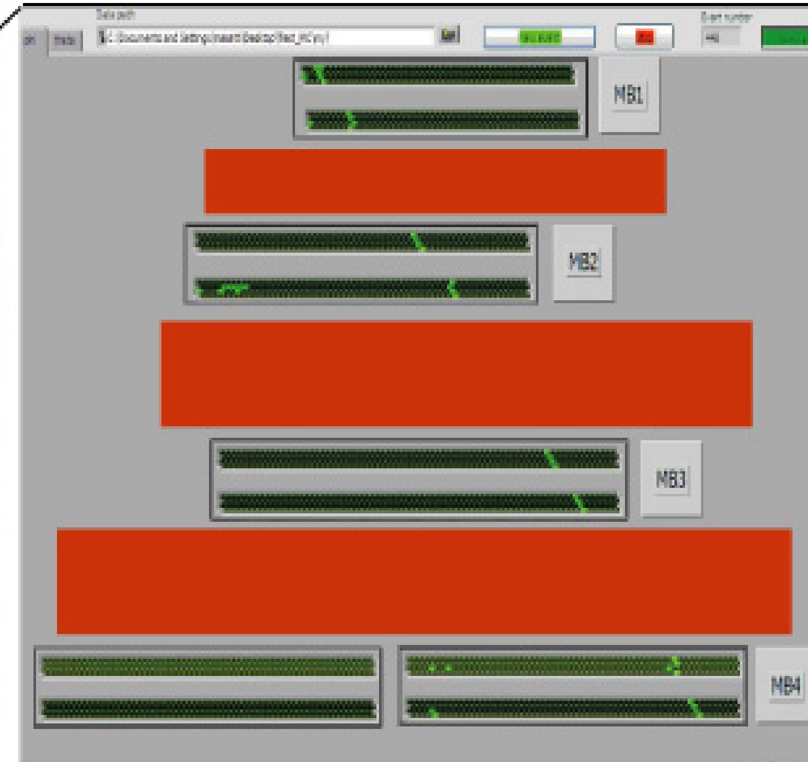
Magnetic length	12.5 m
Diameter	6 m
Magnetic field	4 T
Nominal current	20 kA
Operation temp.	4.5 K
Stored energy	2.7 GJ

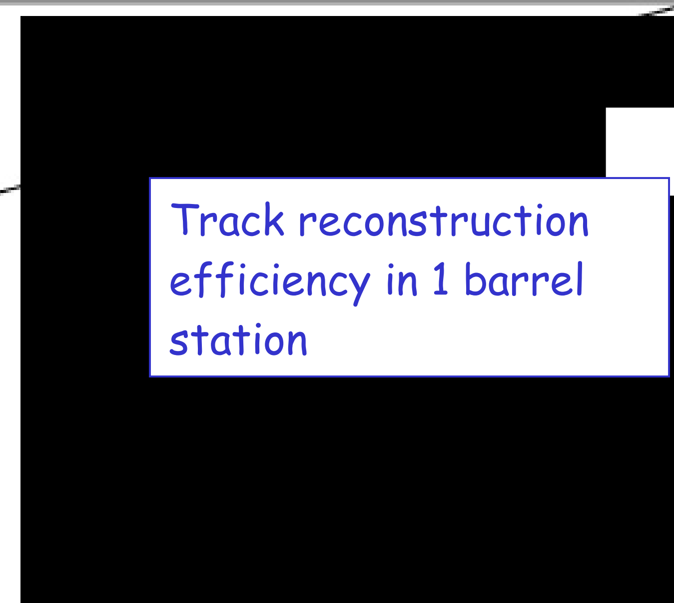
Tested at full current in Summer 2006

Muon station installation completed



December 2005: cosmic muons in CMS (surface hall)

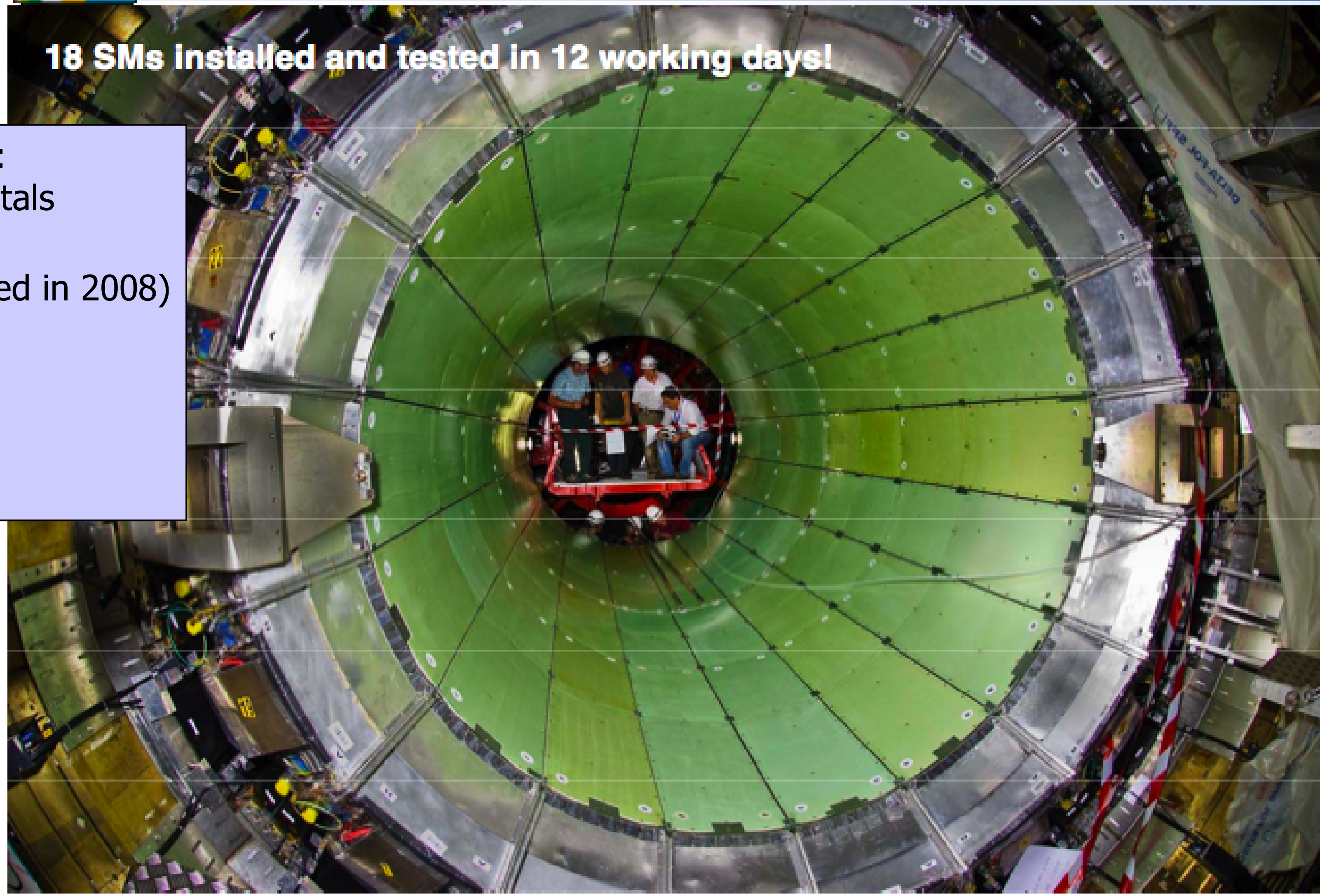




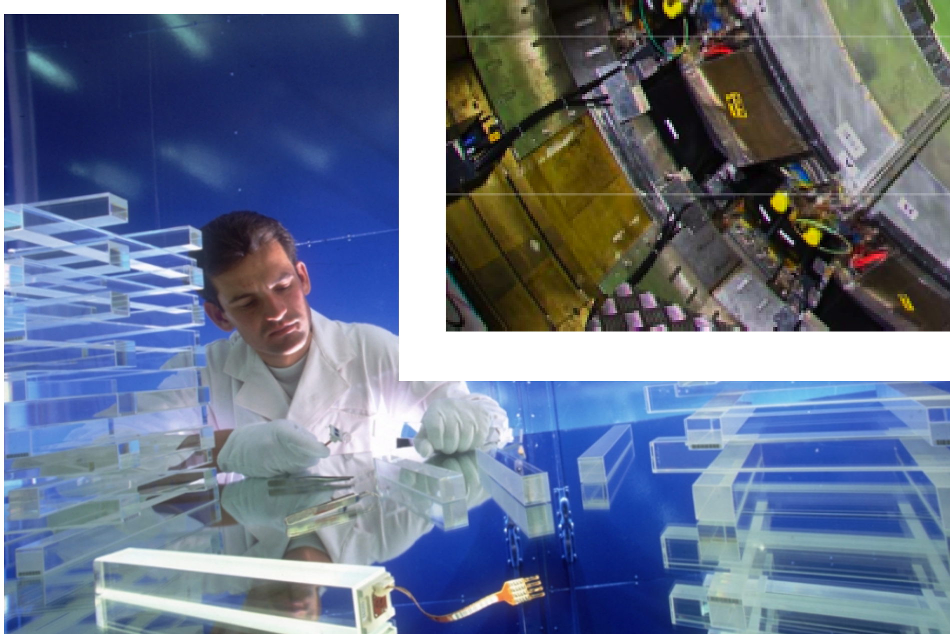
Track reconstruction efficiency in 1 barrel station

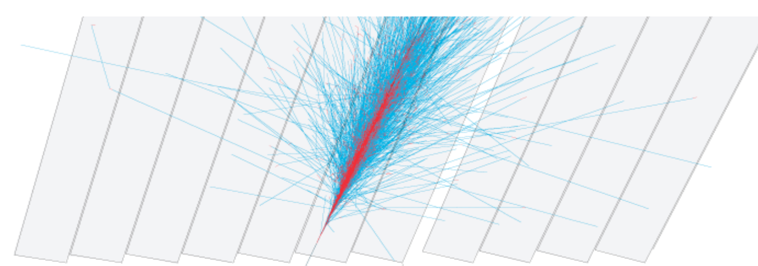
Rate is 0.5-1 kHz at surface

Barrel ECAL Installation Completed: 27 July



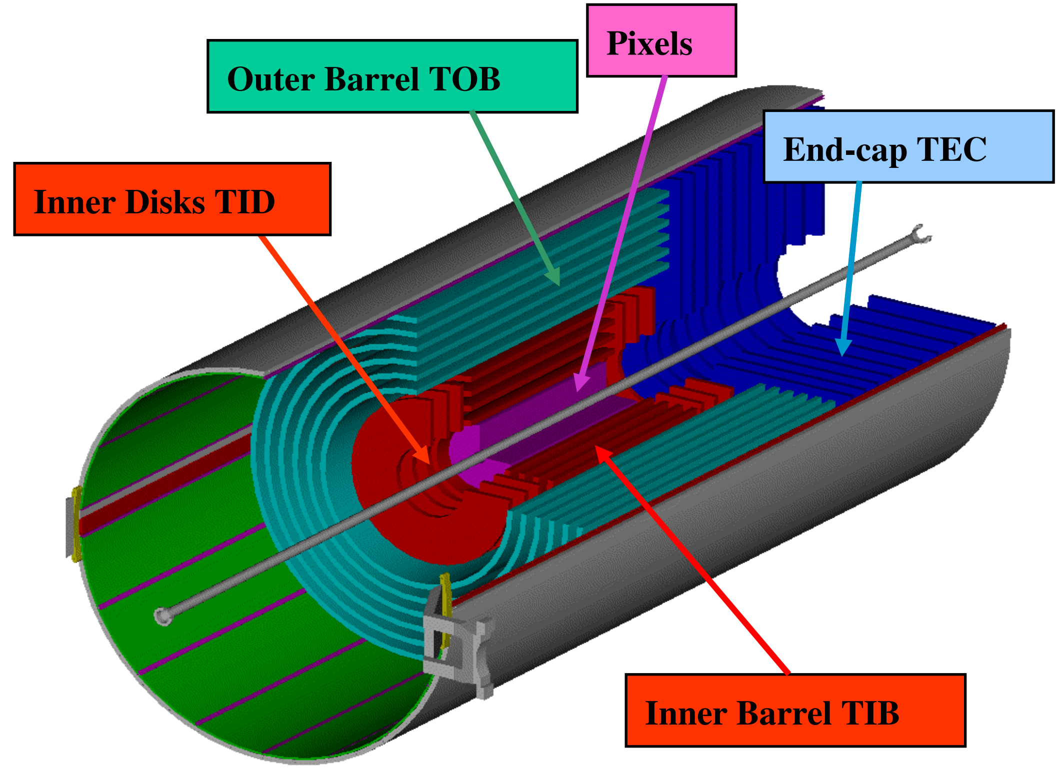
CMS EM calorimeter:
~ 80000 $PbW0_4$ crystals
End-cap on critical
path (to be completed in 2008)

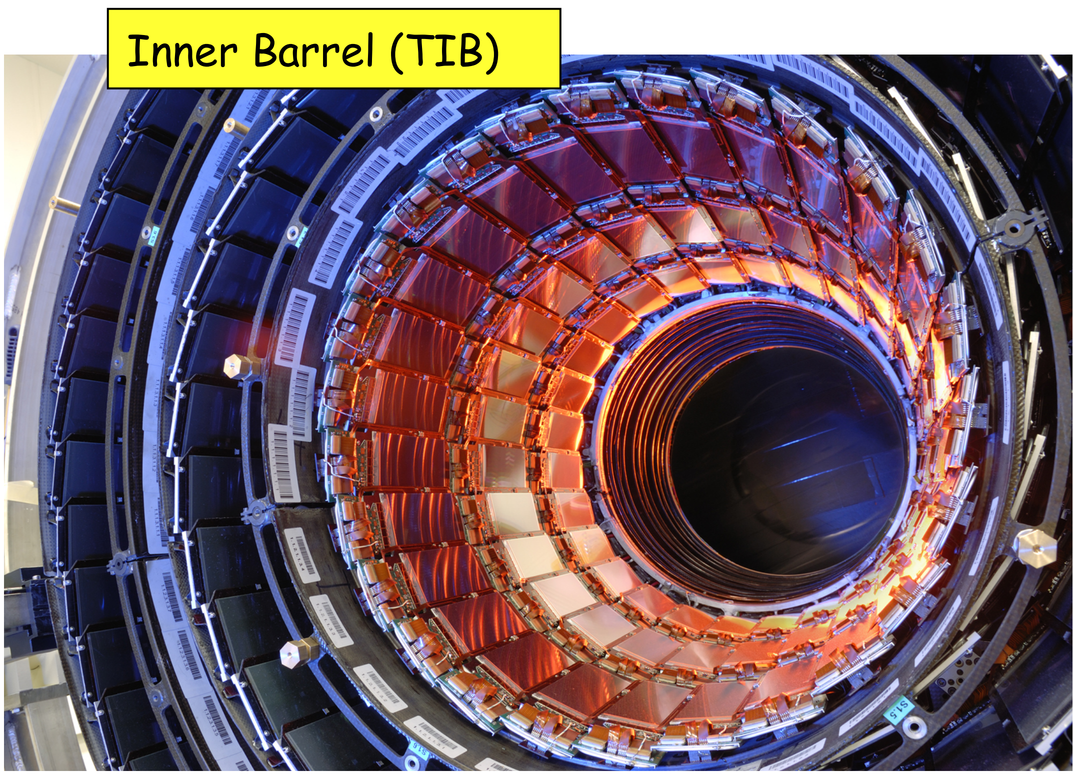




CMS Inner tracker:
~ 220 m² of Si sensors
10.6 million Si strips
65.9 million Pixels

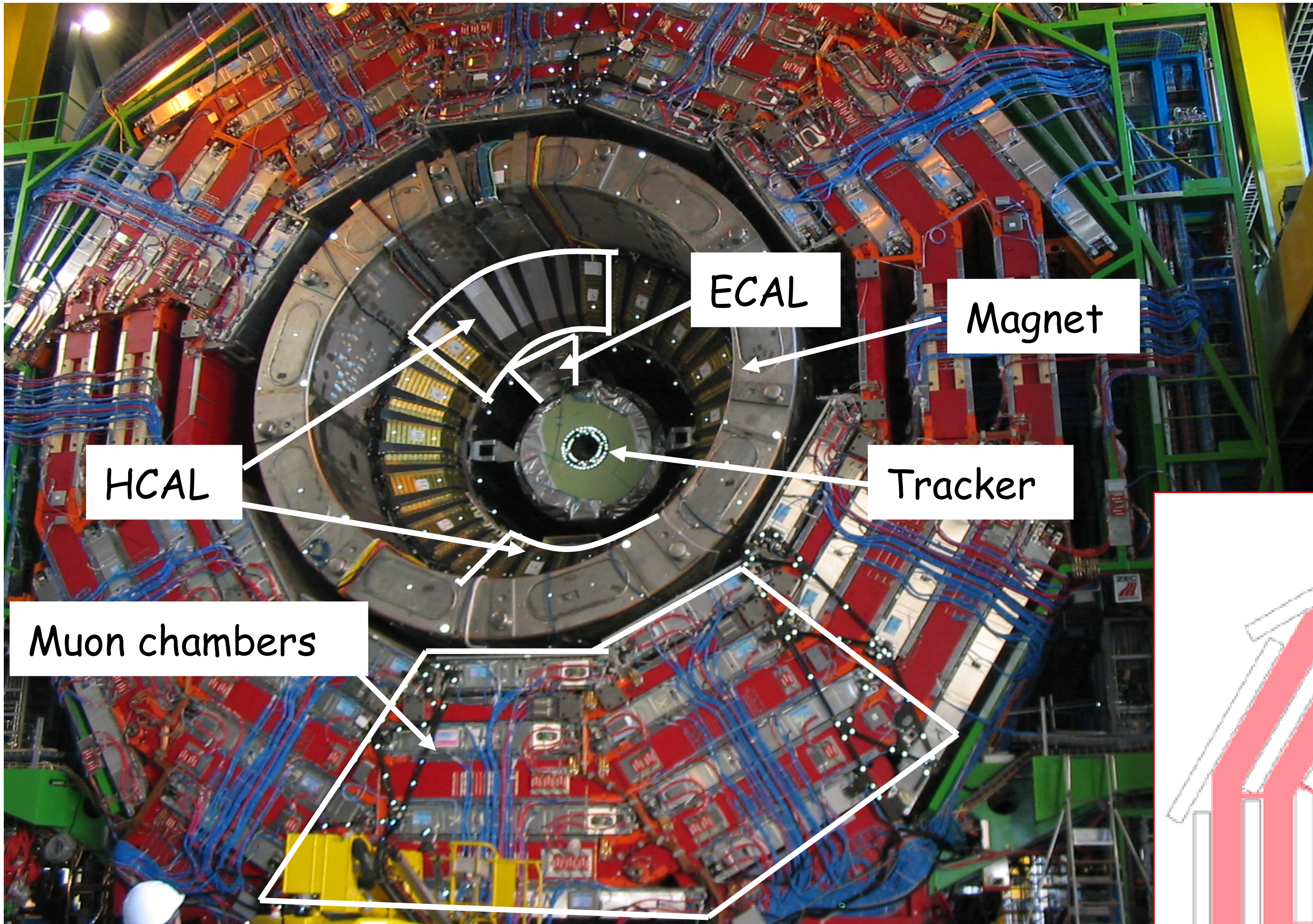
Assembly of Si layers completed, installation in underground cavern in December

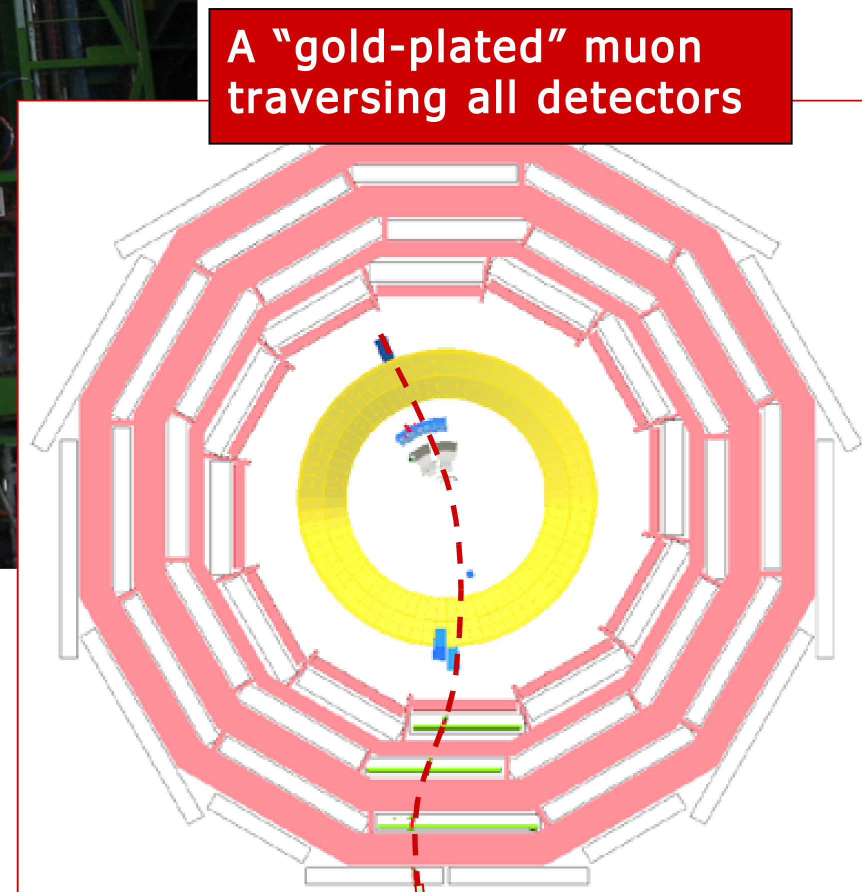




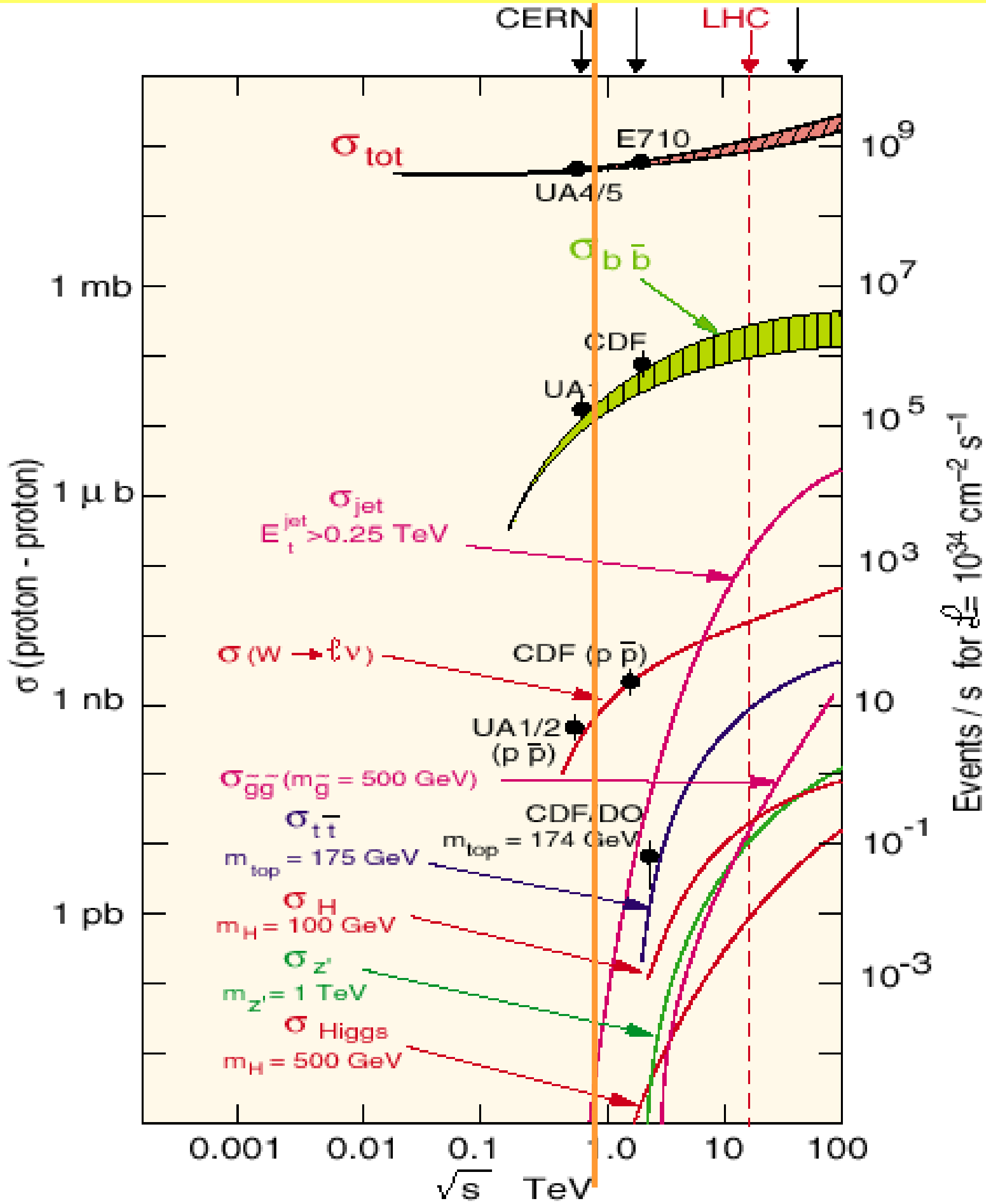
CMS Magnet Test and Cosmic Challenge in August-October 2006

Cosmics run of a ~ full detector slice (few percent of CMS coverage) inside 4T field.
200 million cosmic muons collected in the surface hall (rate is 0.5-1 kHz at surface)





PP Physics Program

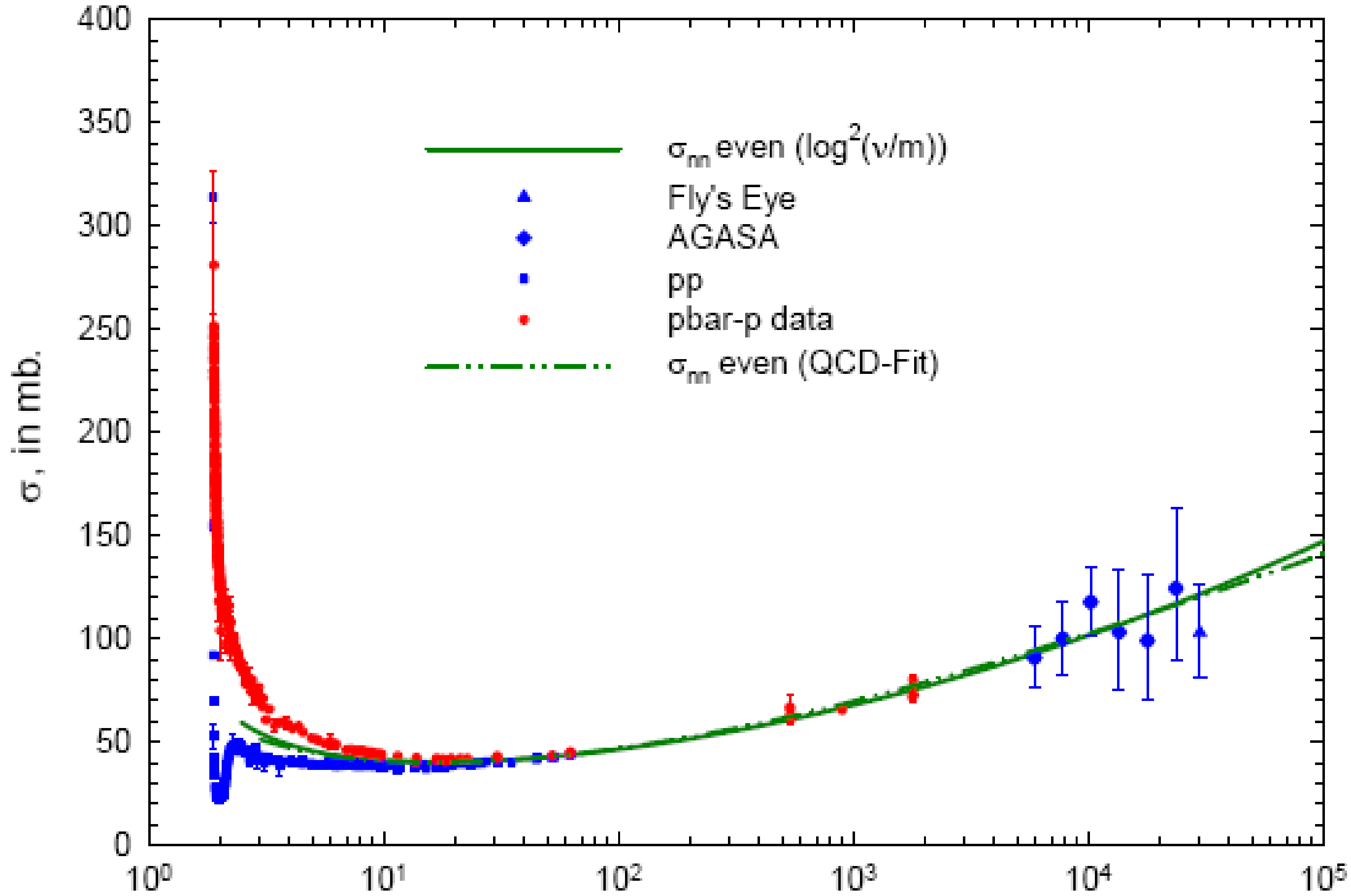


Process	σ(nb)	Ns^{-1}	$L=10pb^{-1}$	$L=10fb^{-1}$
Minimum bias	10^8	10^7	10^{12}	$\sim 10^{15}$
Inclusive jets – p_T>200GeV	100	100	10^6	$\sim 10^9$
W → ev	15	15	10^5	$\sim 10^8$
Z → e^+e^-	1.5	1.5	10^4	$\sim 10^7$
Dibosons	0.2	10^{-3}	10	10^4

Physics Program

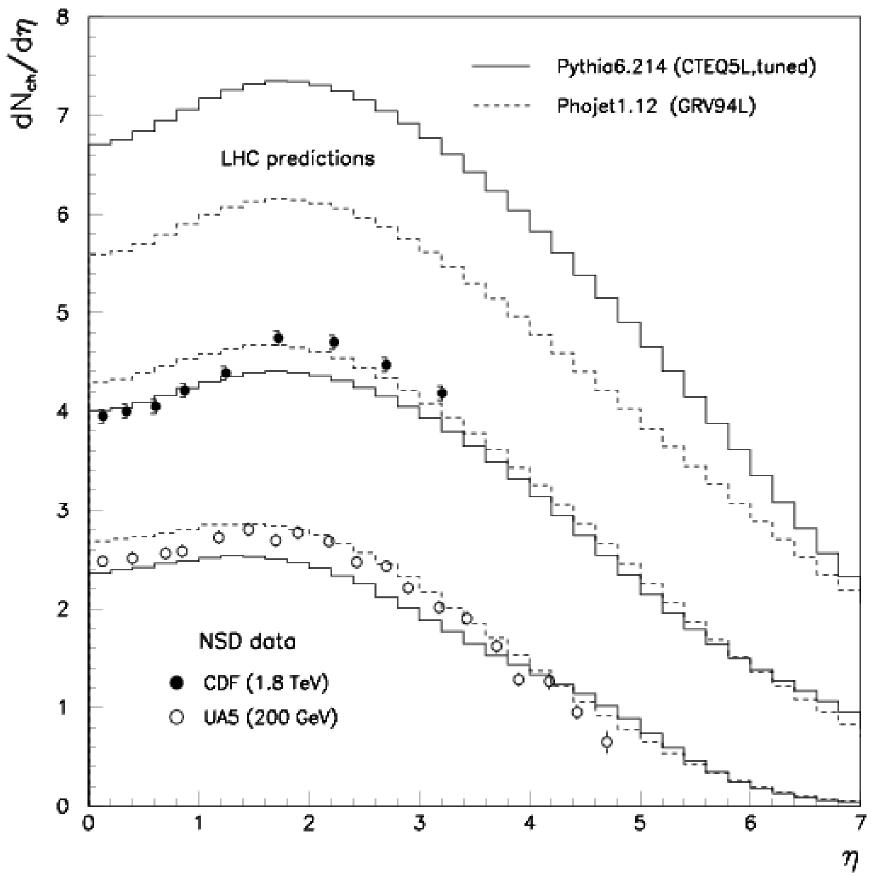
- Start by "rediscovering standard model" in new energy regime and new detectors
- Some QCD needed for "engineering" of Monte Carlo: e.g. Min bias and underlying events
- Top and W/Z production are well understood theoretically, start with inclusive and move to exclusive states that are harder for theory
- Some important results will come as soon as detectors are understood sufficiently
- Theorists should pay attention during this phase: which predictions are poor and why? If you wait for "new physics" you may be too late
- Don't believe new "pink elephant" discovery if SM is not understood

Total rate



This cannot be calculated from the underlying theory. It is soft QCD, but can be extrapolated with small uncertainty

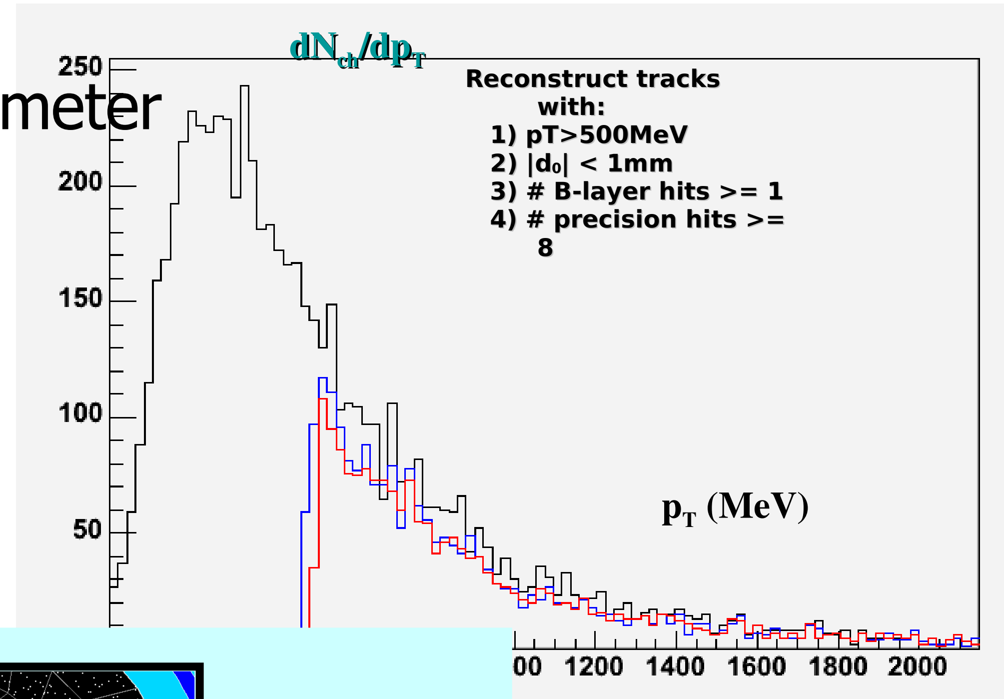
Min Bias



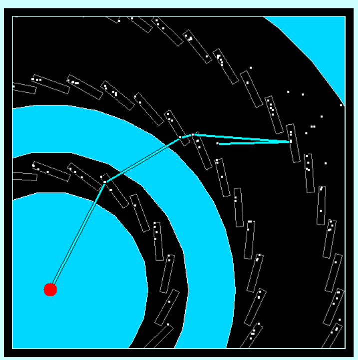
- Difficult to predict this.
- Extrapolate from Tevatron
- Measure with 1 inverse millibarn (minutes of operation)
- Affects some expectations for "ultimate physics reach"
- Amount of "pileup" is determined by this
- This is QCD: can someone please calculate it

Standard model min bias

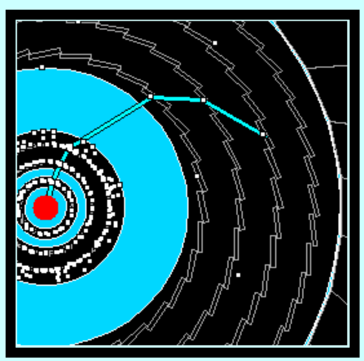
Soft Tracks do not make it to calorimeter



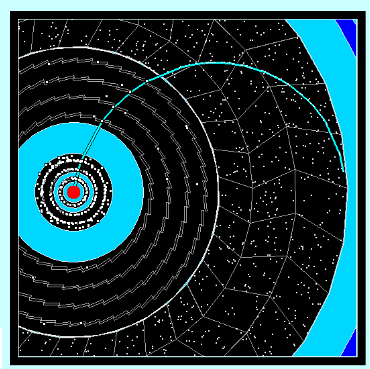
ATLAS



50 MeV tracks: reach all Pixel layers



150 MeV tracks: reach last SCT layer

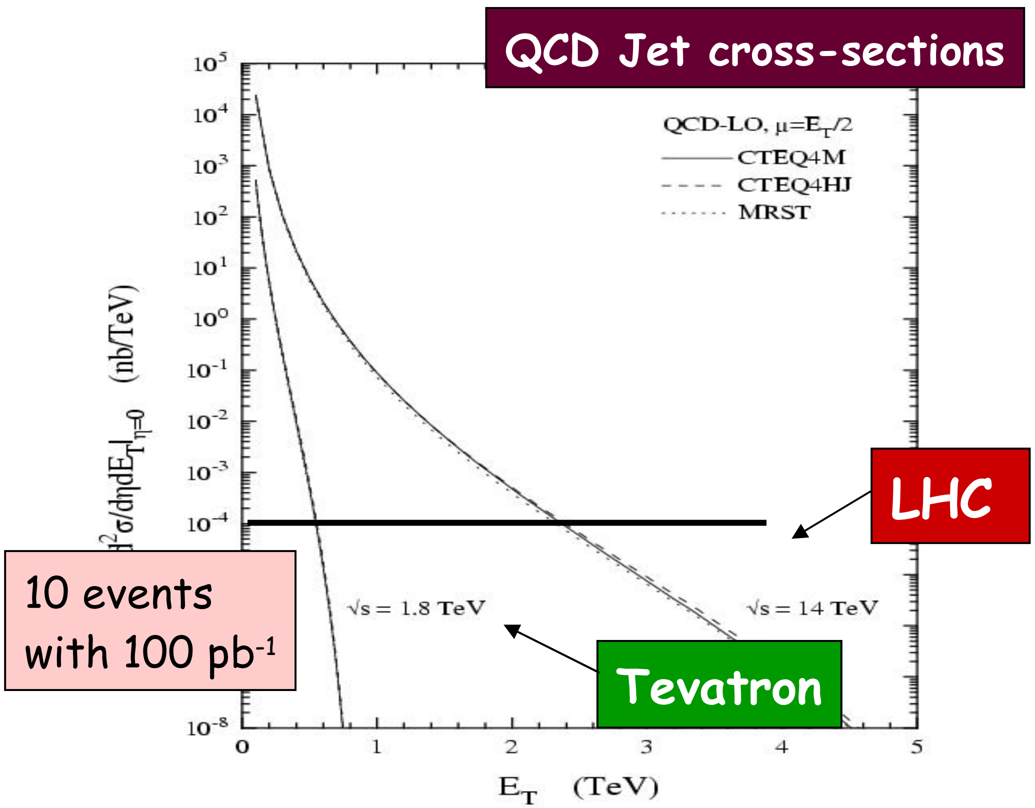


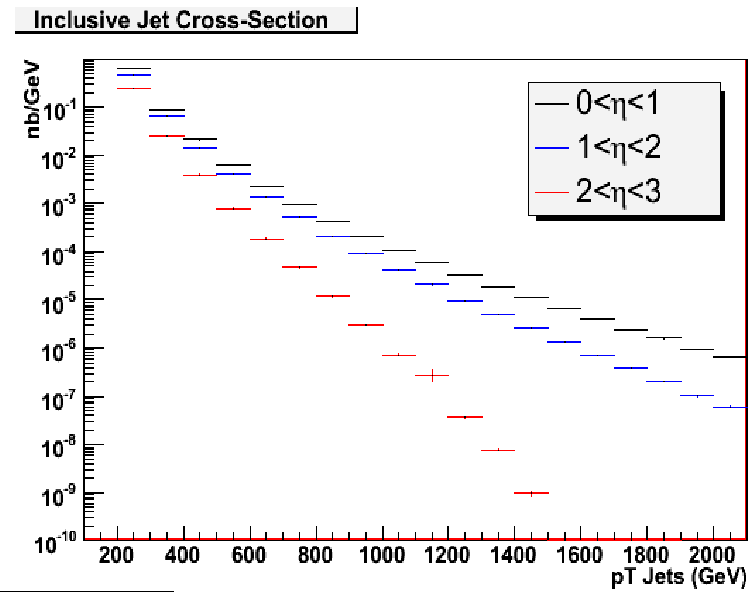
400 MeV tracks: reach end of TRT

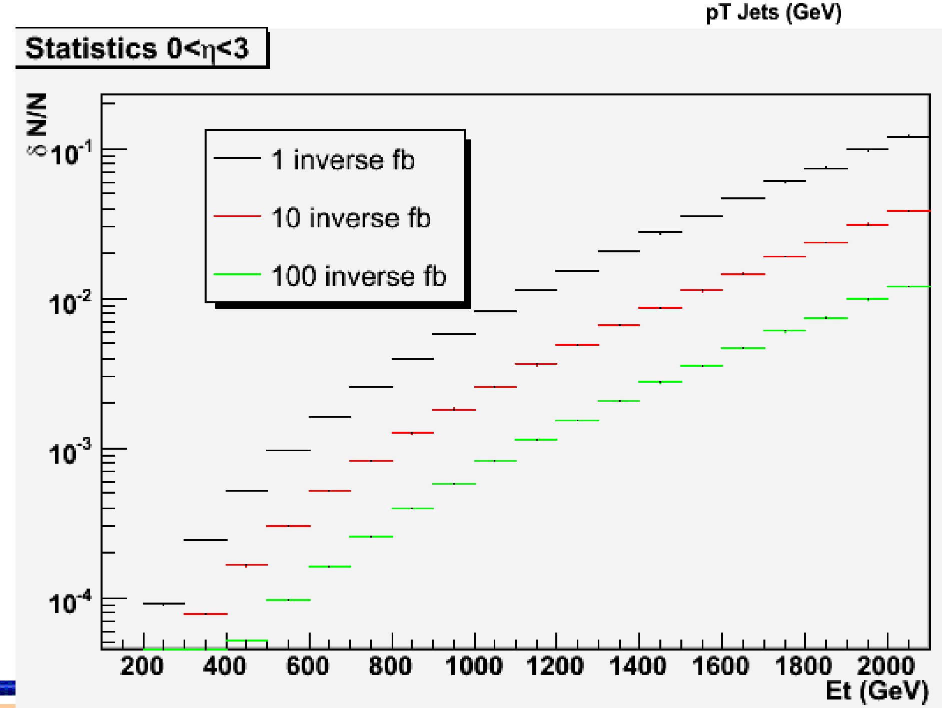
CMS has smaller radius, higher field

Jets

New physics will show up at high pt if detector is not working!

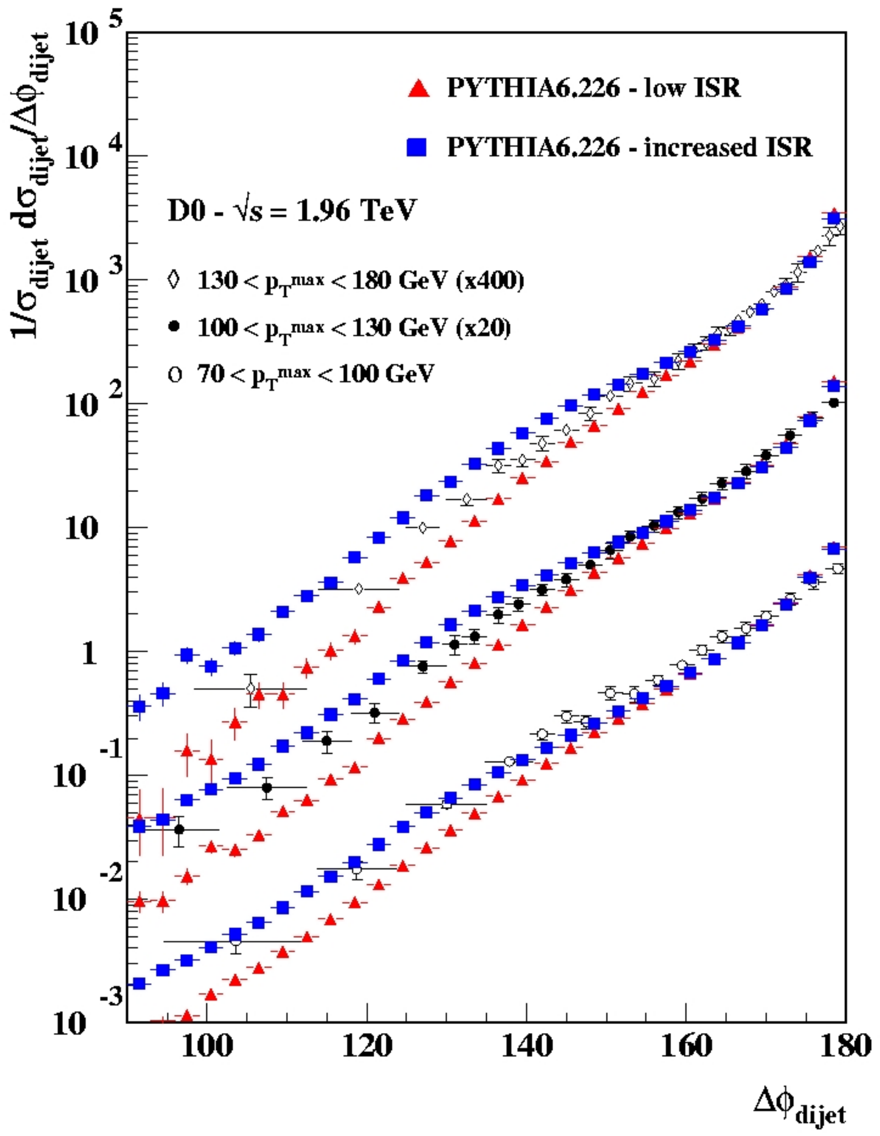


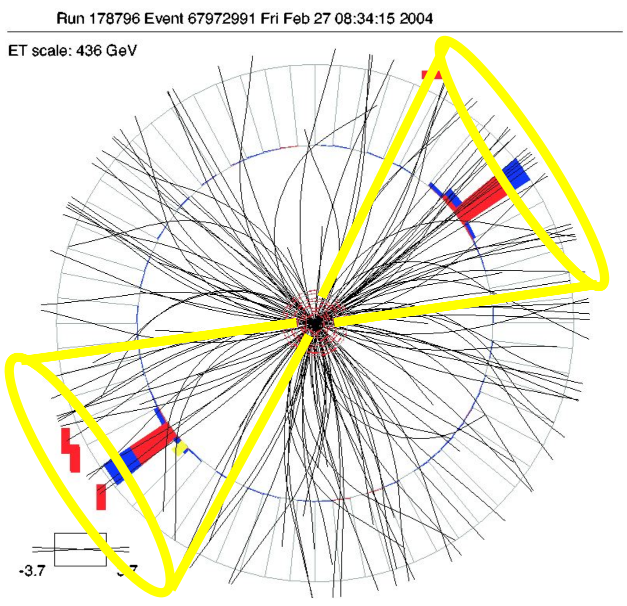




This program starts on Day 1 and never ends

Dijet phi correlations

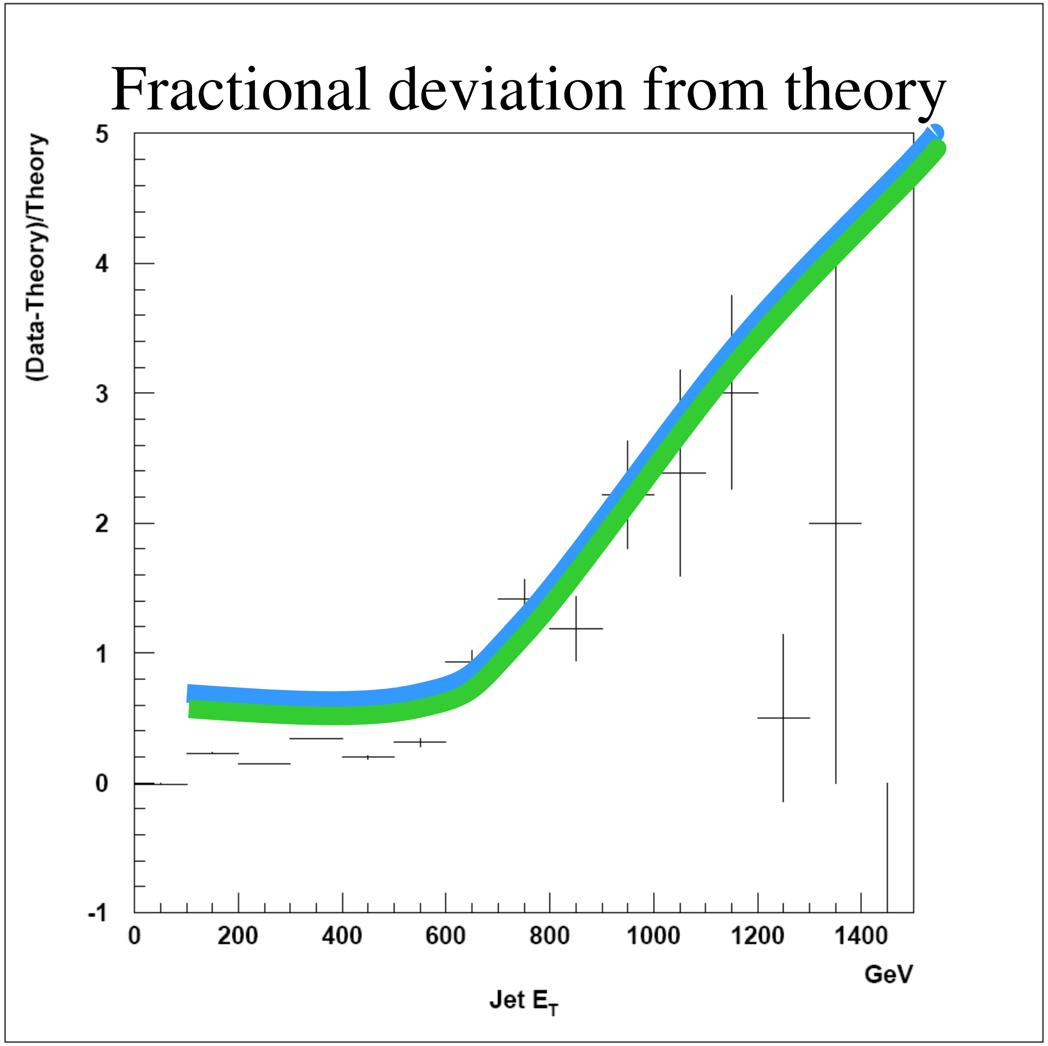




Data from D0 compared to MC decorrelation should increase at large rapidity separation

This should be early LHC result

Dijets: fake new physics



Black: one week's running at 1% of design luminosity.

Blue: Expectations for a contact interaction term of ~4 TeV (SM is a line at 0)

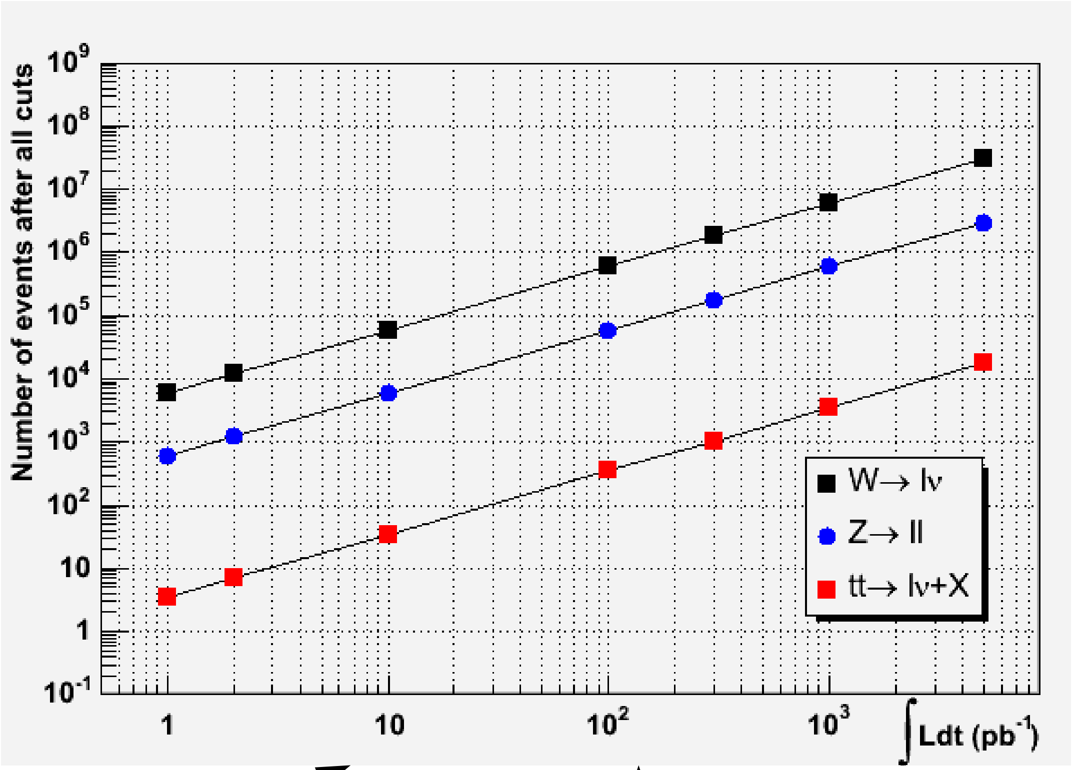
Green: A miscalibration selected to look like a contact interaction

Some care needs to be taken before announcing a major discovery.

This is the wrong variable, need something less sensitive to detector issues

Standard model W/Z

- Large W/Z rates
- Clean samples of e and mu
- Calibrate e/m calorimeter, muons. tracking
- Understand electron fakes
  - Vital for Higgs search

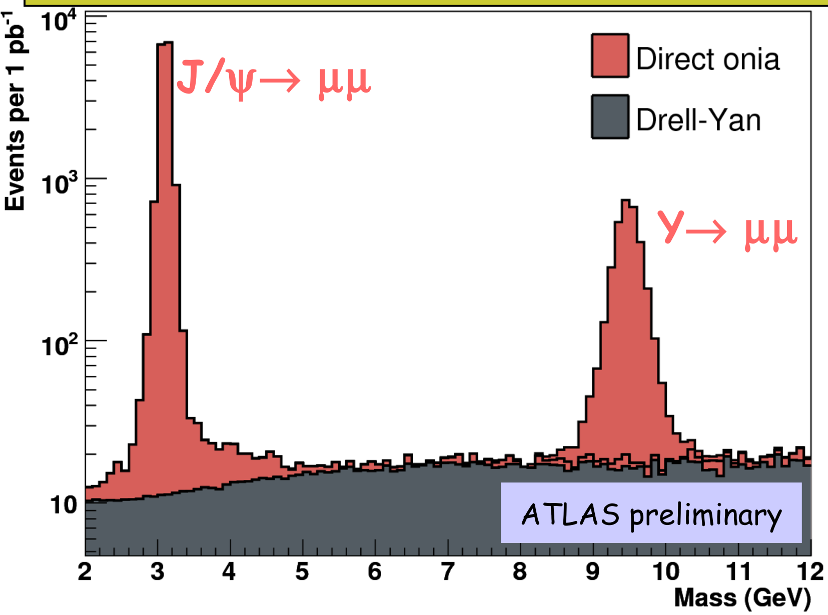


~10 pb^{-1} ≡ 1 month at 10^{30} and < 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ few days at 10^{32} , ε=50%

Some peaks

1 pb^{-1}≡3 days at 10^{31} at 30% efficiency

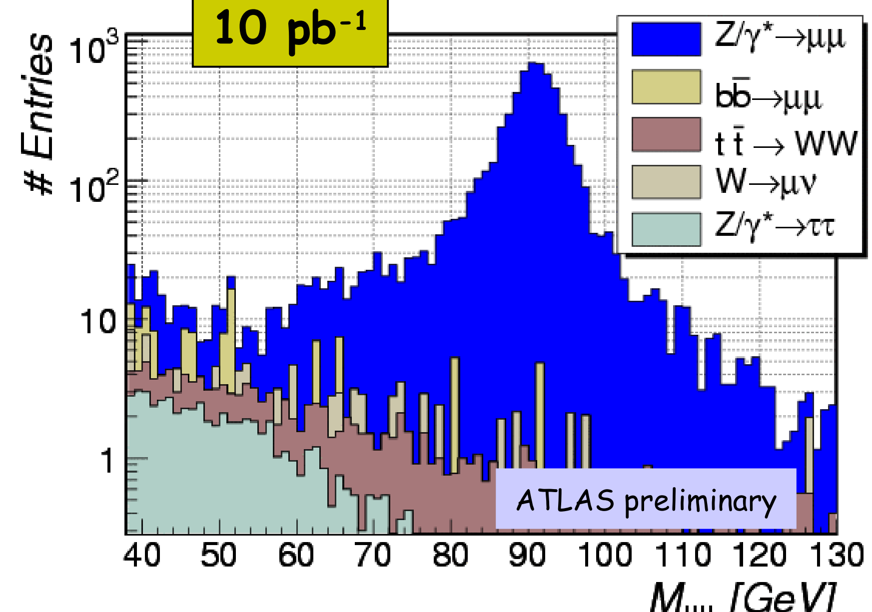


After all cuts:
~ 4200 (800) J/ψ (ϒ)→μμ evts per day at L = 10^{31}
(for 30% machine x detector data taking efficiency)

→ tracker momentum scale, trigger performance, detector efficiency, sanity checks, …

After all cuts:
~ 160 Z→μμ evts per day at L = 10^{31}
Note: σ_Z(LHC)/σ_Z(Tevatron)~10

10 pb^{-1}



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

Top

LHC

σ ~850 pb

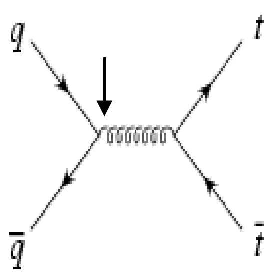
10% qq, 90% gg

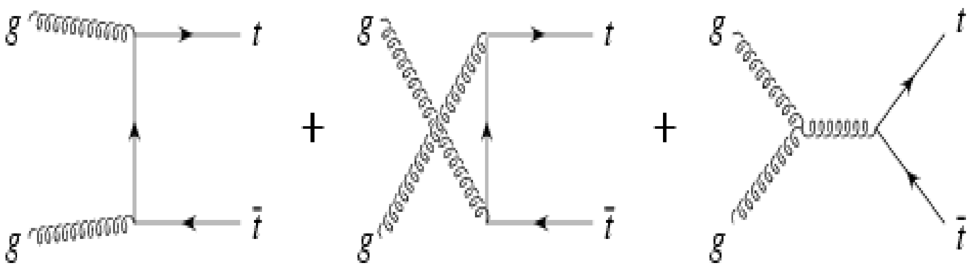
Tevatron

$\sigma \simeq$7 pb

85% qq, 15% gg

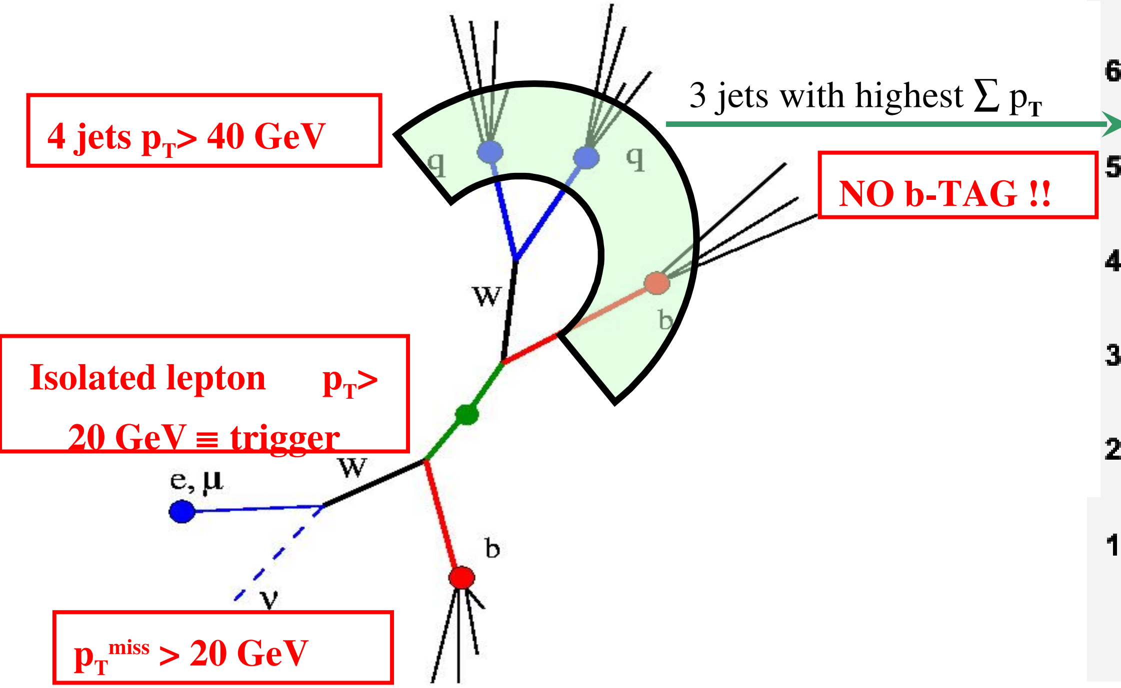
- Production fully described by QCD
- Mass known
- Ideal benchmark for detector calibrations

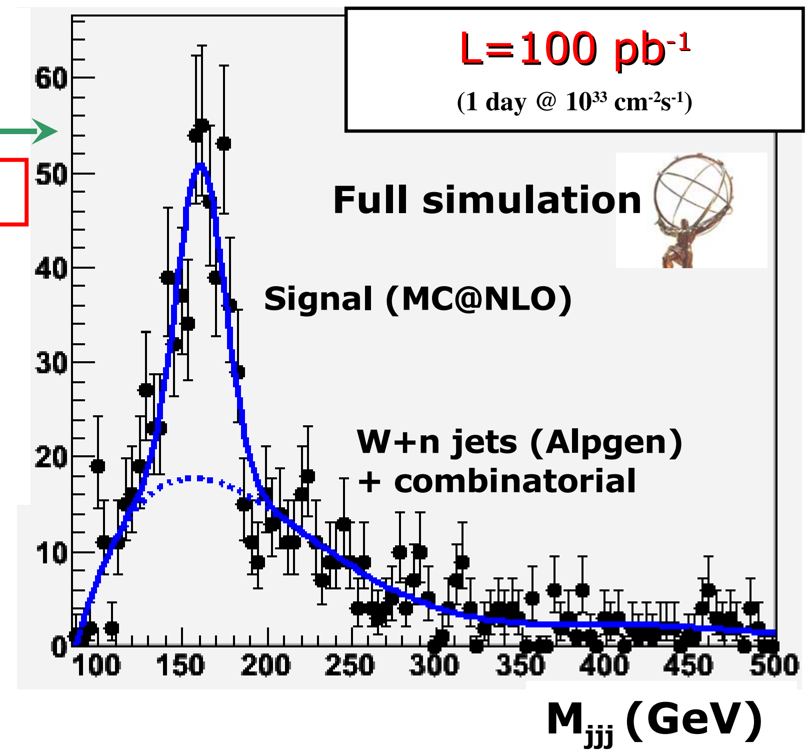




1.8 Hz at "low" luminosity

Top w/o btag

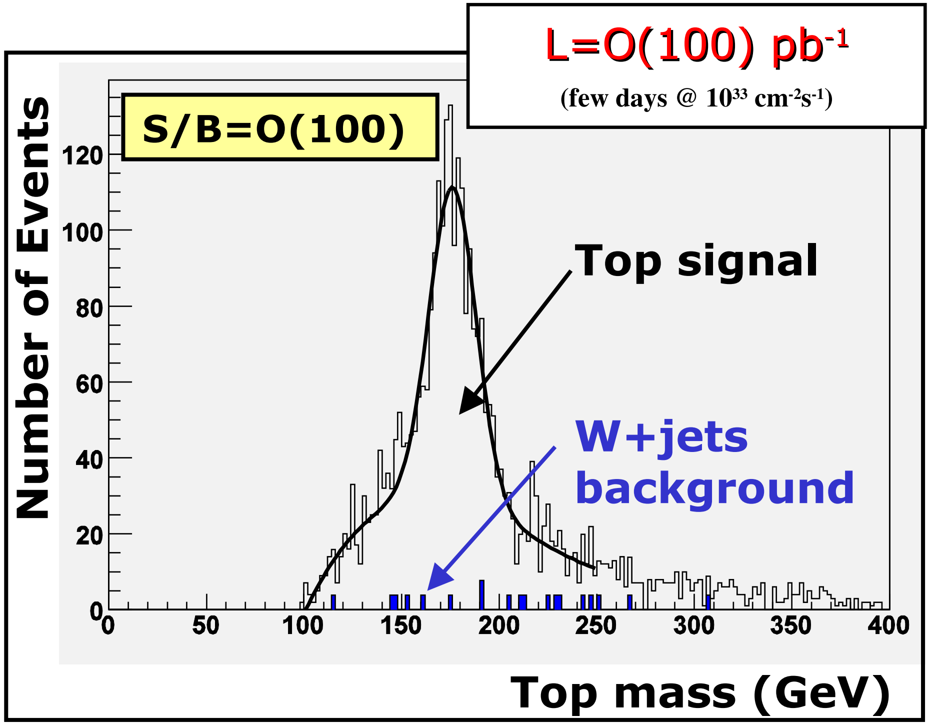




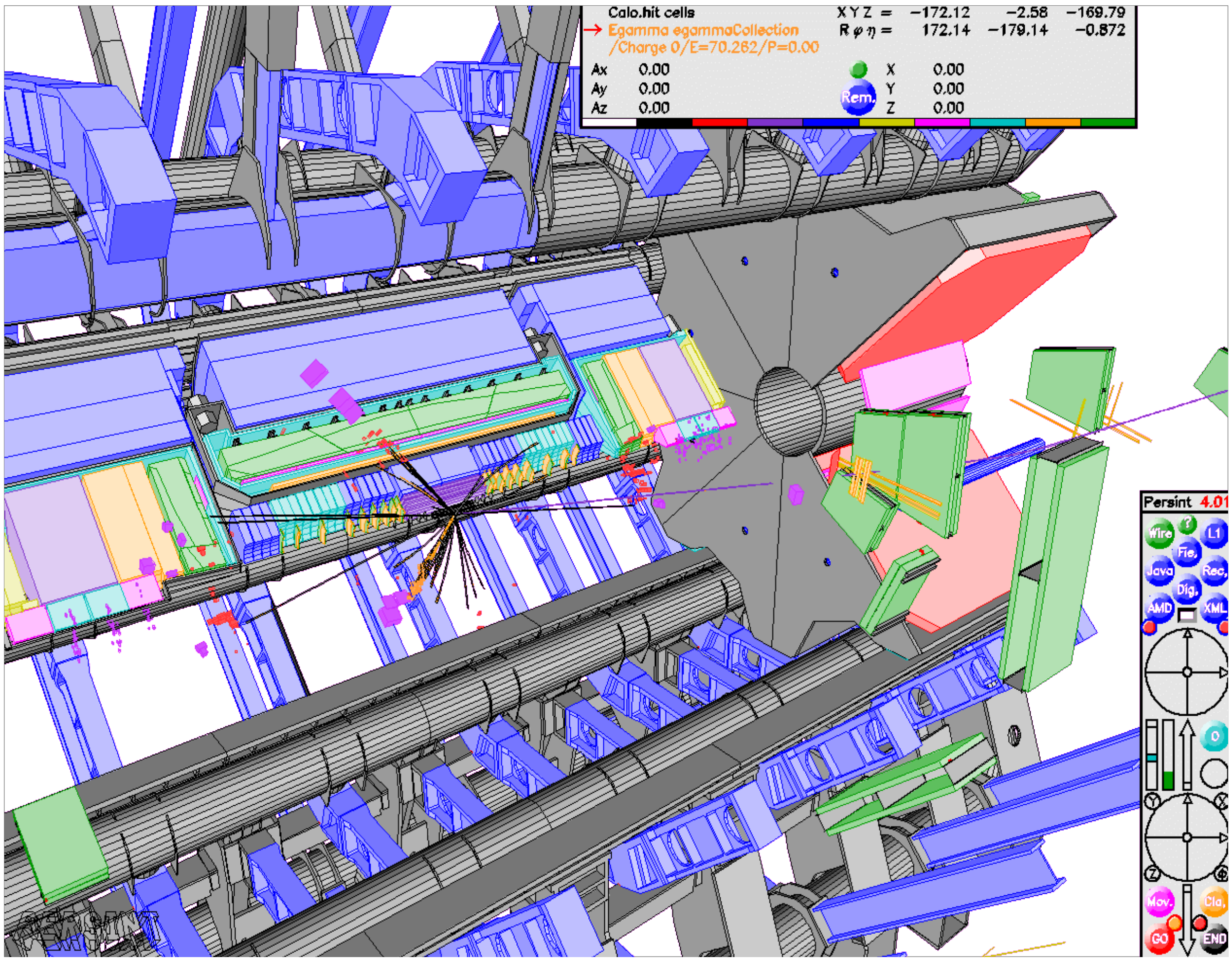
Now we have sample of bjets without using tracker
Use these to calibrate the b-tagging

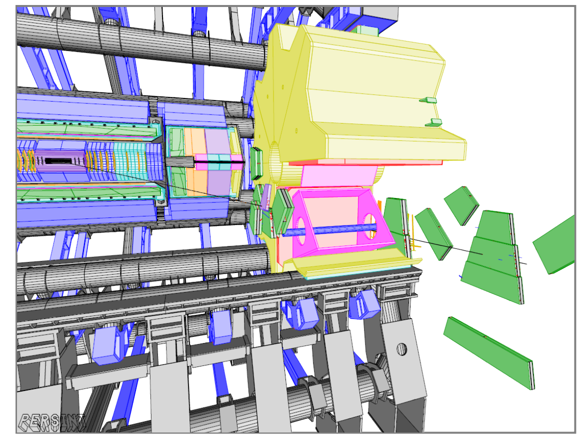
Top w/o any background

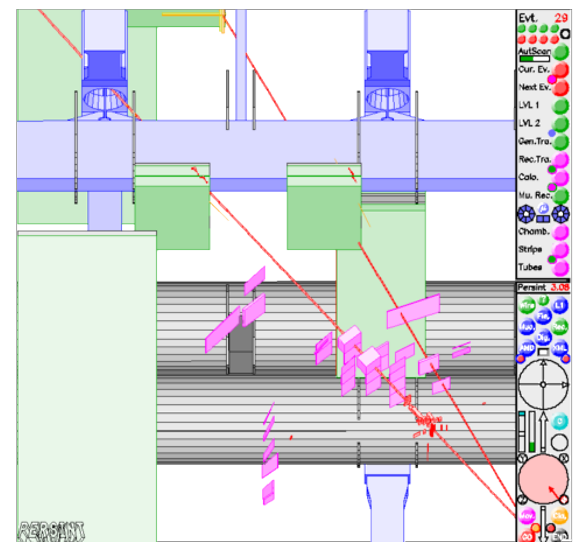
- Very low background with everything working
- 1 lepton, missing Et, two identified b-jets



Top in atlas

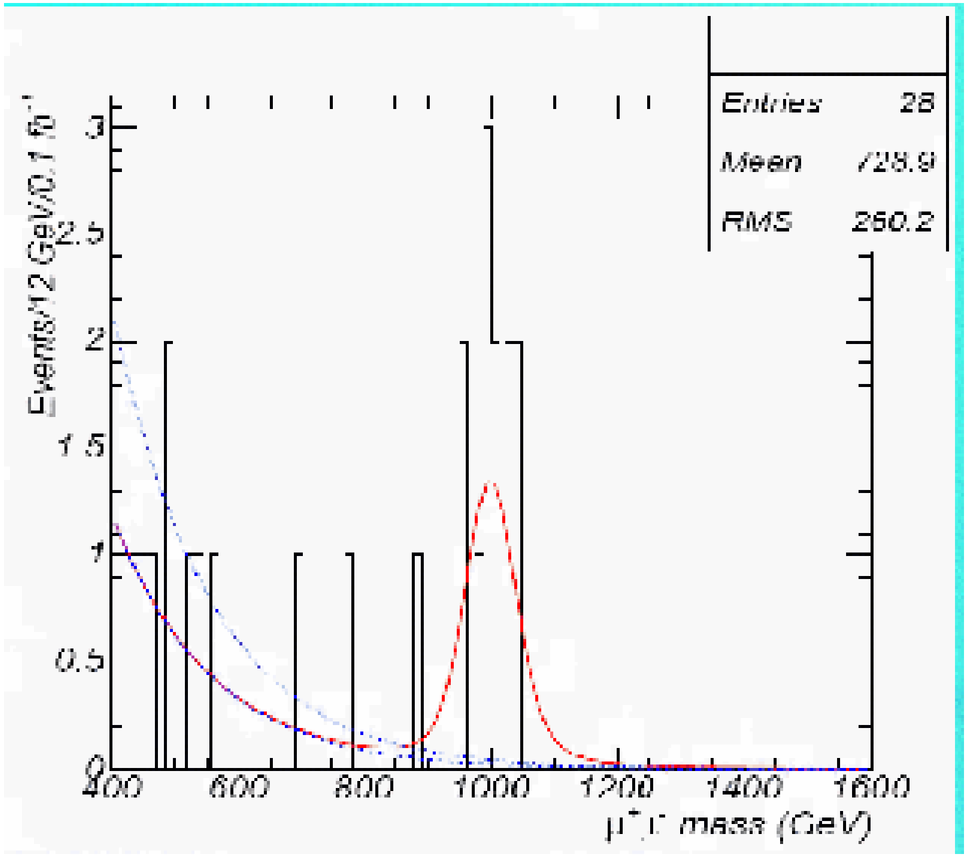

Calo.hit cells
Egamma egammaCollection
/Charge 0/E=70.262/P=0.00
X Y Z = −172.12 −2.58 −169.79
R φ η = 172.14 −179.14 −0.872
Ax 0.00
Ay 0.00
Az 0.00
X 0.00
Y 0.00
Z 0.00
Rem.
Persint 4.01
Wire
Fie.
L1
Java
Rec.
Dig.
AMD
XML
Mov.
Cla.
GO
END

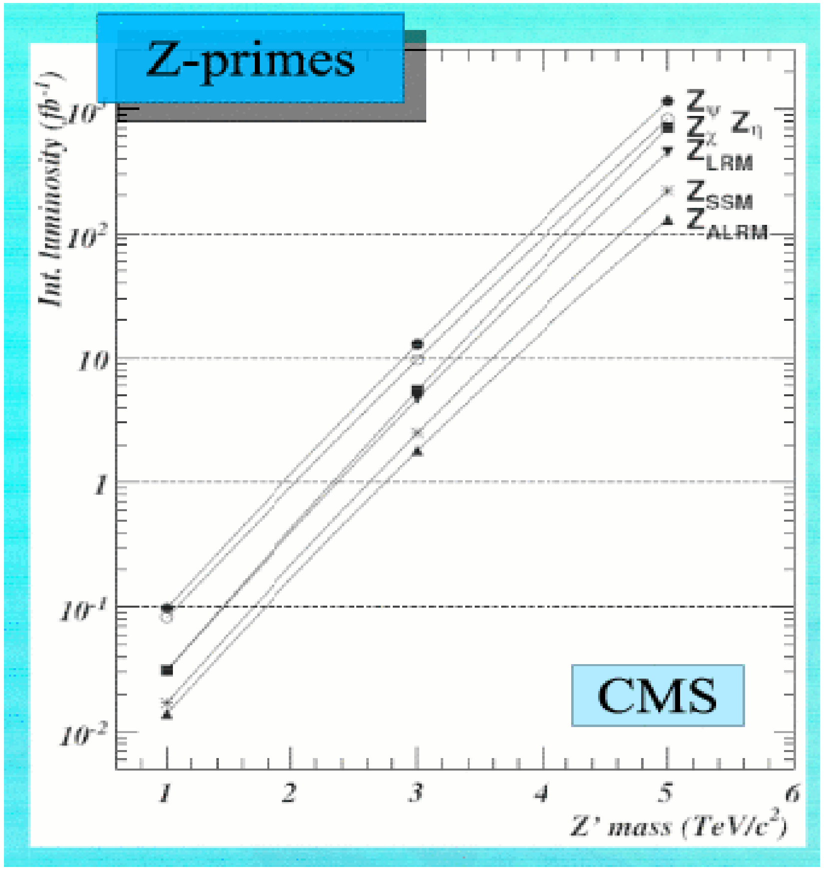




Easy new physics:Z primes

Follow the dilepton invariant mass from Z upwards





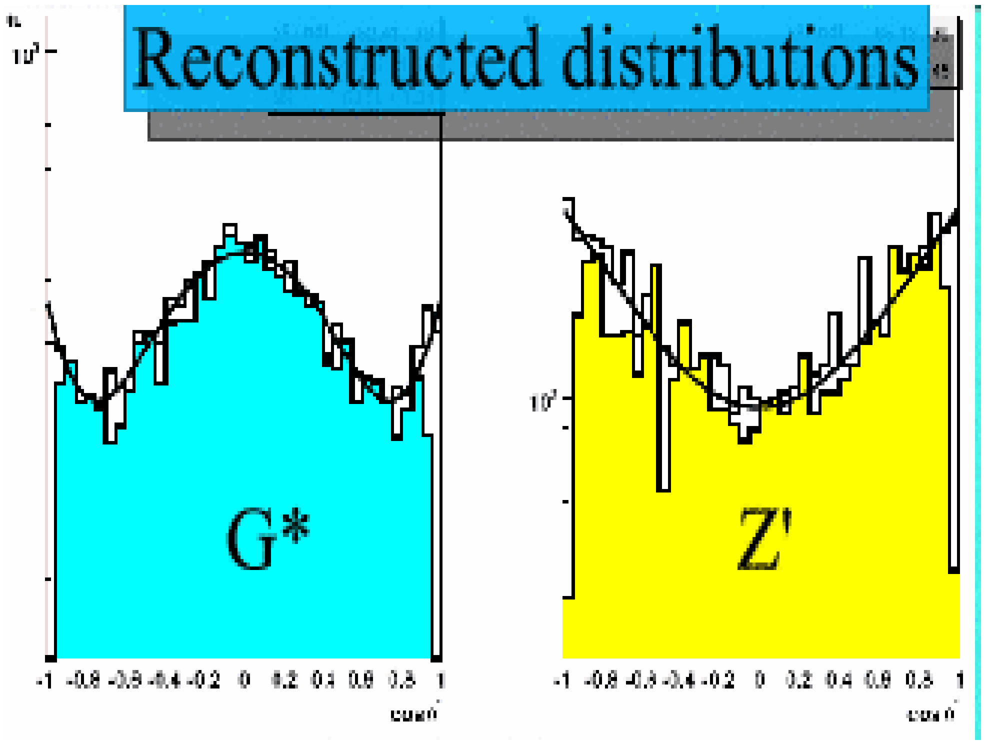
100 inverse picobarns

Easy new physics:Z primes

The CMATLAS experiment operating at LHC has observed 4 dimuon and two dielectron events where the invariant mass if the lepton pair is between 1.13 and 1.15 TeV. No other events with invariant mass above 900 GeV have been seen. These events are consistent with the production and decay of a heavy particle of mass 1.14 TeV and an effective production cross section of aaa pb. Such an effect could be production of a Z', Kaluza Klein graviton.

An abstract you may seen in 2009

Discovery is just the start:Z prime: type



CMS

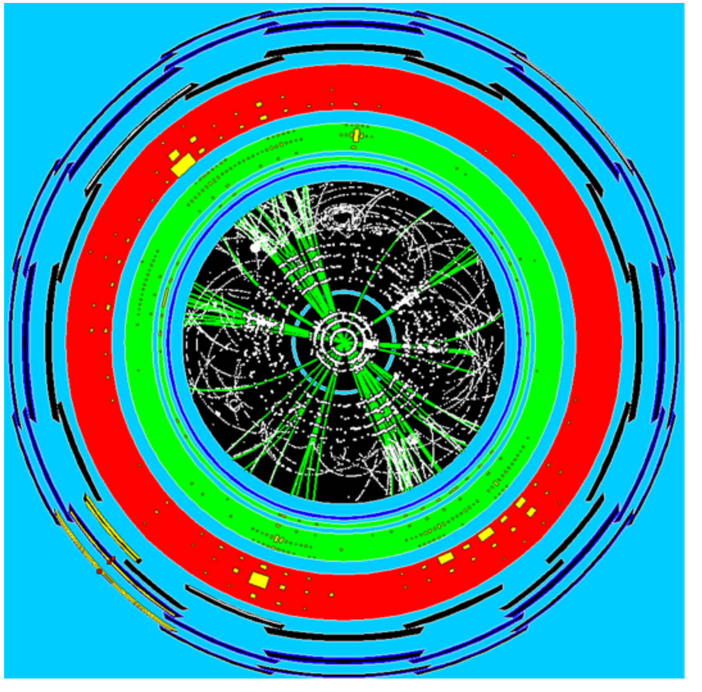
- Is it spin 1 or spin 2?
- Look at angular dist
- This comes later!

Black hole anyone?

Distinguishing features

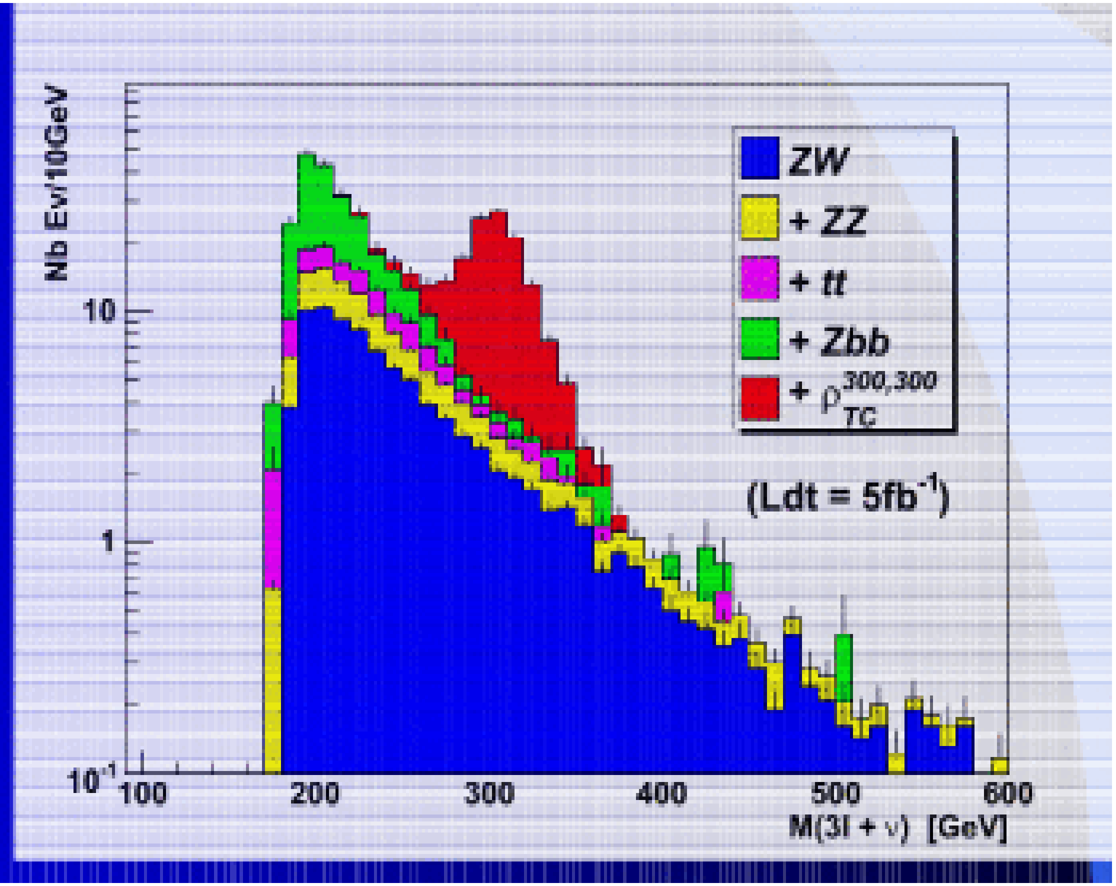
- High Multiplicity
- High ΣE_T
- High Sphericity
- High Missing P_T
- Democratic Decay

Sensitivity Dominated by Theoretical uncertainty



ATLAS

Techicolor ("rumors of my death are greatly exaggerated")

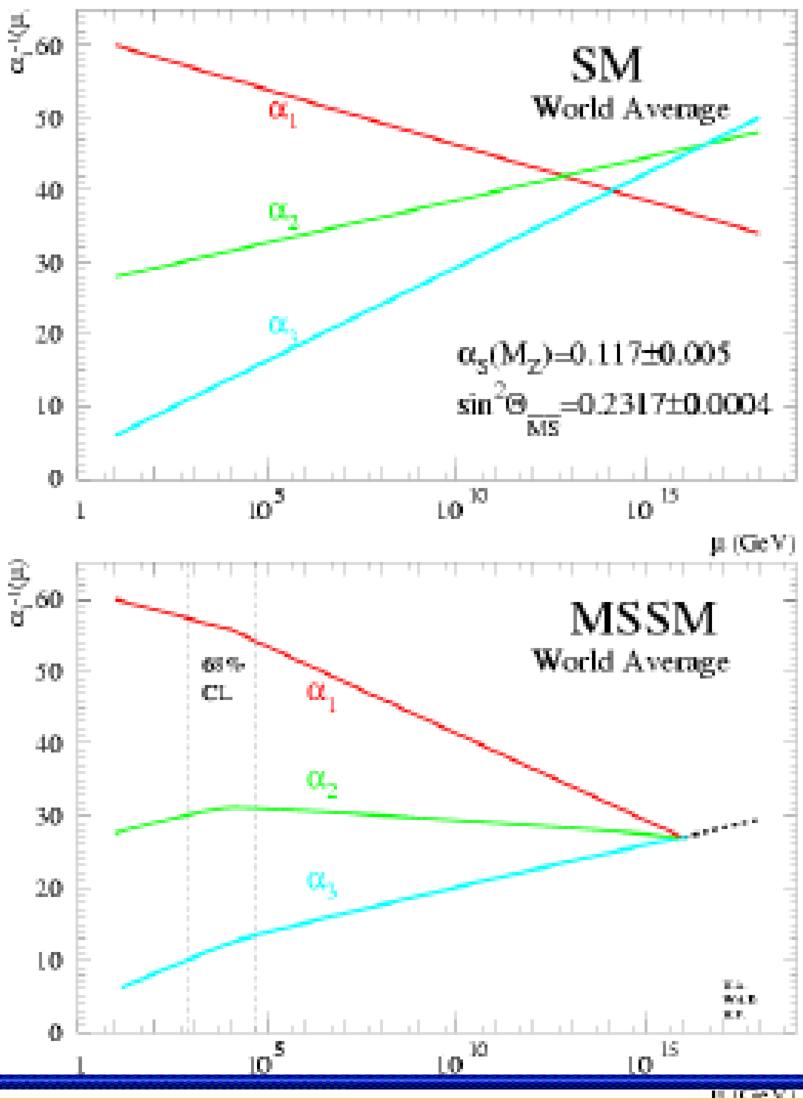


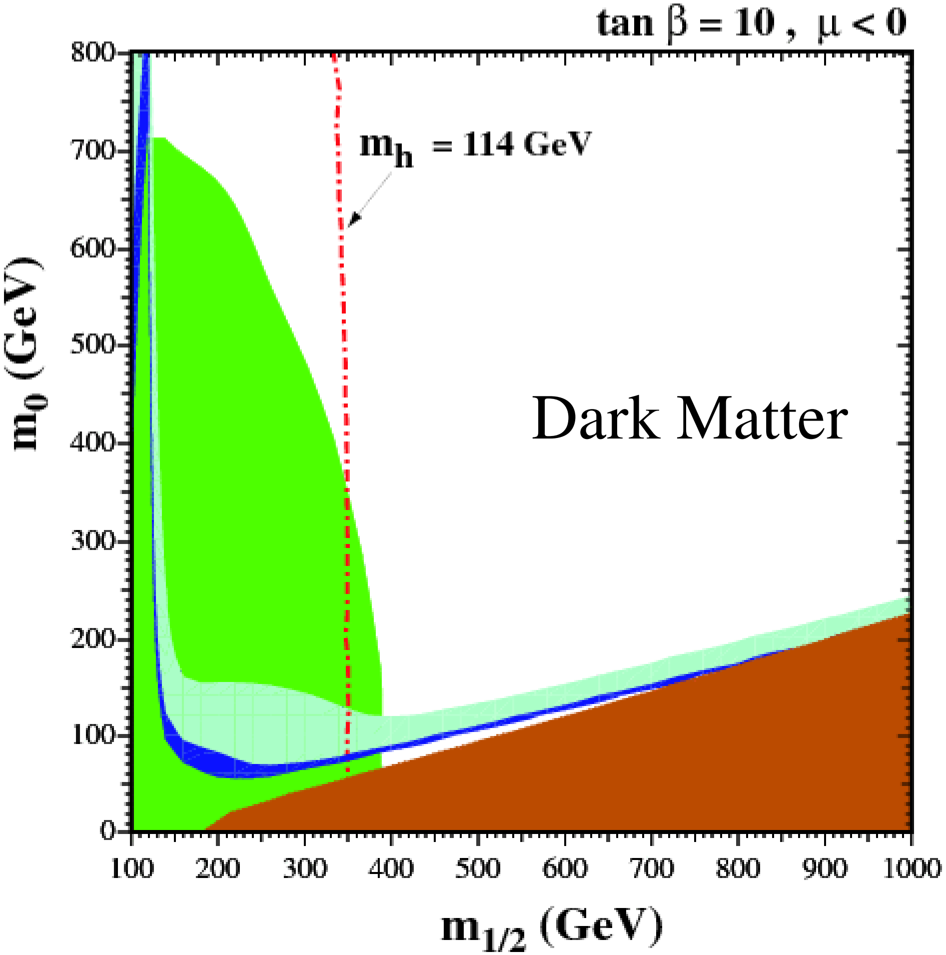
CMS

- TechiRho to WZ
- 3 lepton final state
- Clean
- Not very likely in my opinion (therefore a good chance to be seen??)

SUSY: arguments for

Coupling constants unify?

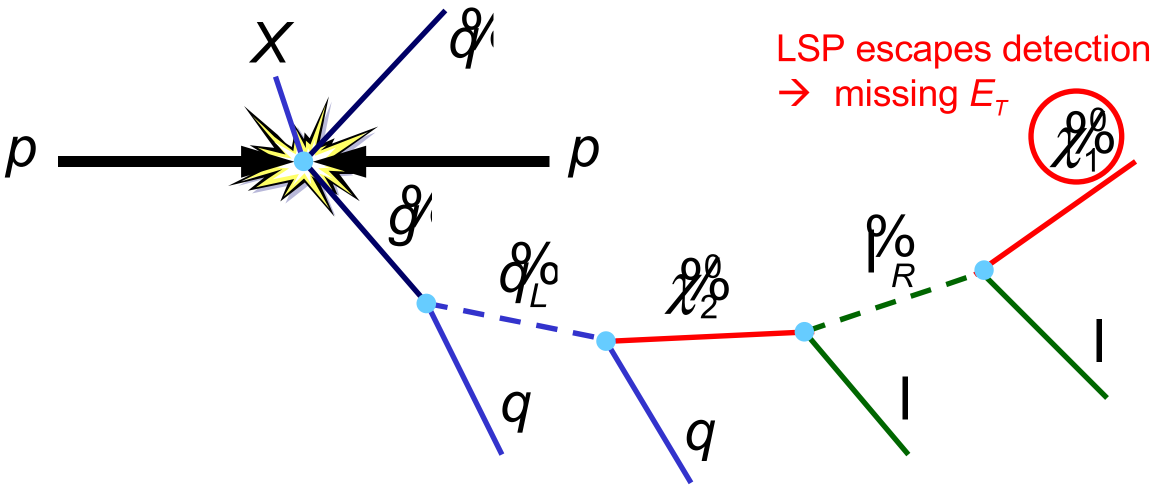




This is not evidence.....
SUSY has provided theory employment for many years

Susy: phenomenolgy in one page

- Conserved ***R*-parity** requires existence of a **lightest stable SUSY particle (LSP)**. Since no exotic strong or EM bound states (isotopes) have been observed, the LSP should be neutral and colourless **WIMP:** LSP signature just as heavy neutrino
- The LSP is typically found to be a spin- **neutralino**, a linear combination of gauginos (in much of the SUSY parameter space the neutralino is a mixture of photino and zino)
- With *R*-parity: **SUSY** production in **pairs requires energy 2 □SUSY mass** !



"Typical" SUSY decay chain at the LHC

Missing E_T ?

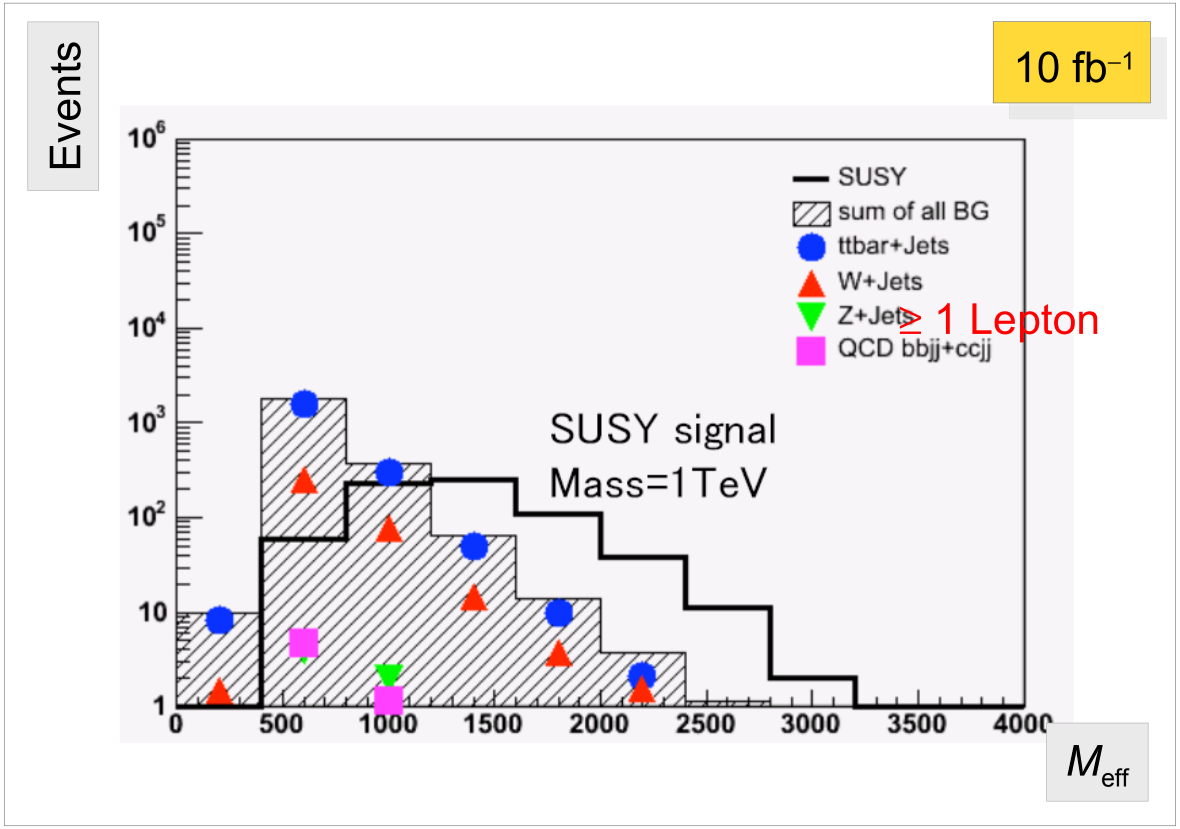
The hard-scattering processes are balanced

Longitudinal energy goes down beam: detector not closed!

Fortunately, the events are transversely balanced !

Susy:inclusive search

- A sensitive variable to detect SUSY decays is the "**effective mass**":



$$M_{eff} = E_{T,miss} + \sum_{\text{jets, leptons}} p_T$$

Works in many models

- Requiring ≥1 lepton reduces QCD background by factor of 20–30, with signal loss of only factor of ~3 (production through weak interaction): better S/B than fully inclusive analysis

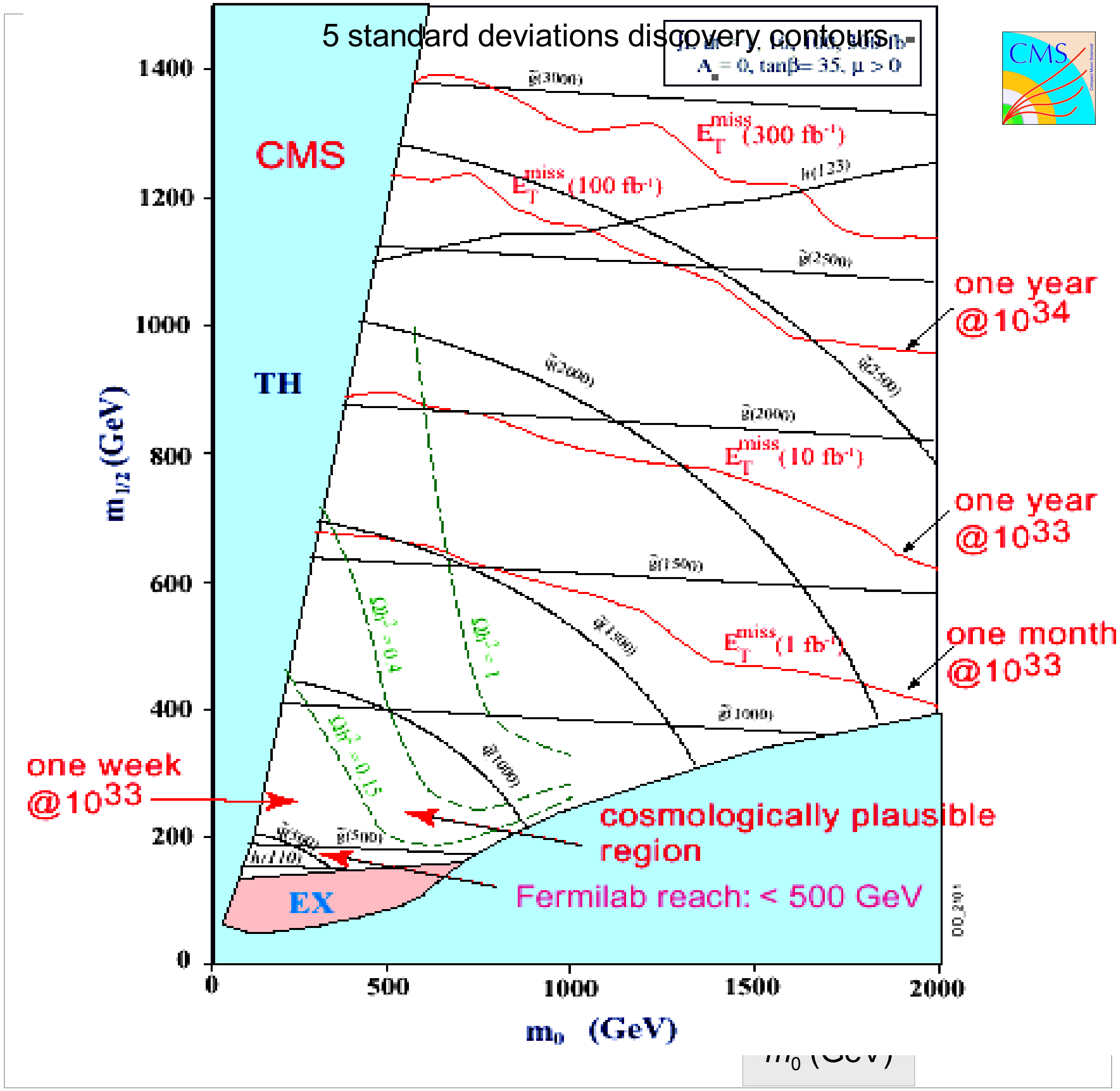
Susy:inclusive search

- Current mSUGRA limits on squark and gluino masses from D0 (Tevatron)

- Experiments evaluate their SUSY discovery potential using some "standard" mSUGRA setup

5σ discovery reach for SUSY:

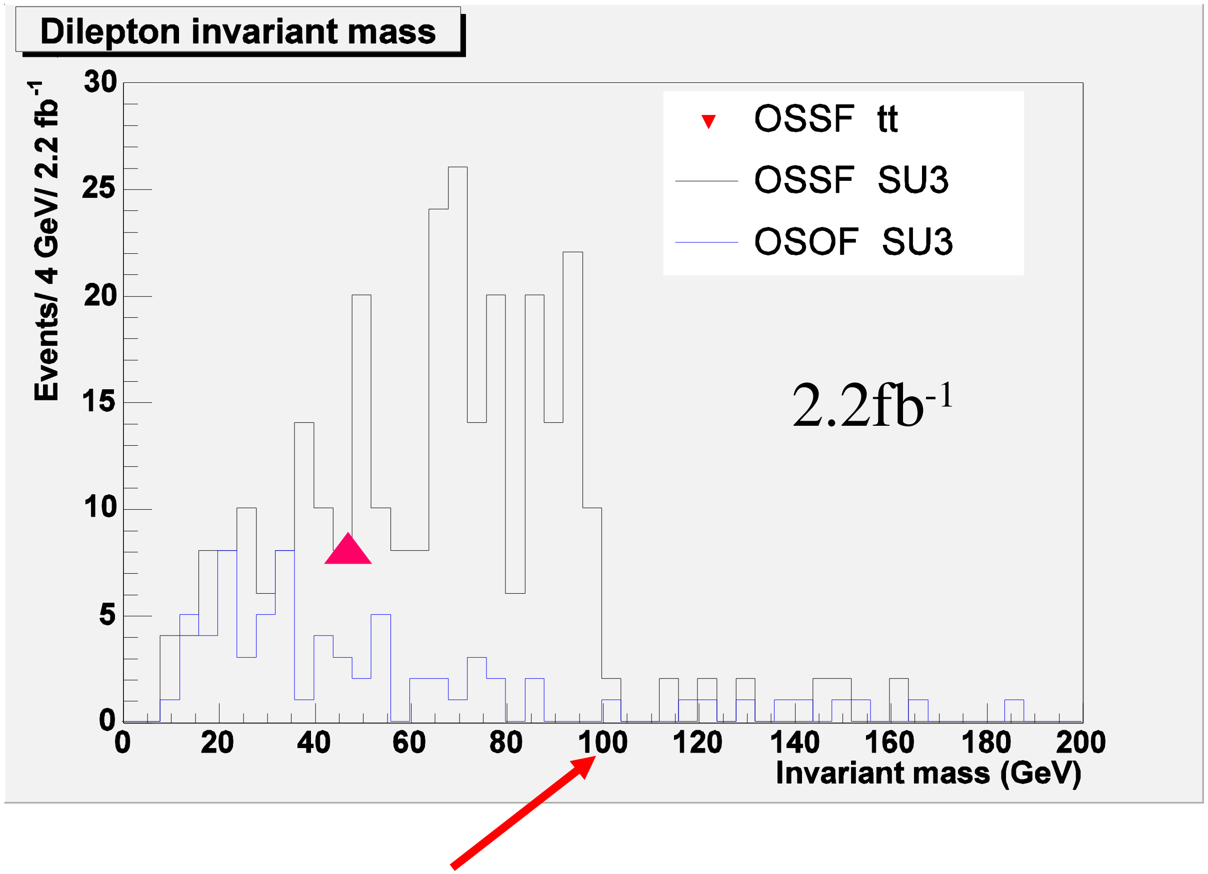
Time period	Luminosity [$cm^{-2}s^{-1}$]	squark/gluino masses
1 month	10^{33}	~1.3 TeV
1 year	10^{33}	~1.8 TeV
1 year	10^{34}	~2.5 TeV
Ultimate	$\int$ = 300 fb^{-1}	~2.5–3 TeV
D0 & CDF	$\int$ = 0.3 fb^{-1}	$>_{(2\sigma)}$ 0.35 TeV



Susy

Kinematic structure is more convincing

You cannot see the SM background here



This would be much better evidence but its still not SUSY....

New physics

The CMATLAS experiment operating at LHC has observed an excess of 9 dimuon and 11 dielectron events in events selected to have 4 jets with pt>50 GeV. The invariant mass if the lepton pair is below 109 GeV and has no peak. These events are inconsistent with the standard model expectation of 2 events. They are consistent with the cascade decay of a two or more new particles. This signal could due for example, to SUSY or UED.

CMS SUSYBSM discovery plan

- Search for SUSY (Evidence for excess) in $\geq$1 lepton+E_T^{miss}+jets at 14 TeV in the electron and muon channels (100 pb^{-1}).
- Search for SUSY (Evidence for excess) in opposite sign dilepton pairs+ E_T^{miss}+jets at 14 TeV in the electron and muon channels (20 pb^{-1})
- Search for SUSY (Evidence for excess) in same-sign dilepton pairs + E_T^{miss}+jets at 14 TeV in the electron and muon channels (200 pb^{-1})
- Search for SUSY (Evidence for excess) in Z^0 leptonic decays+ E_T^{miss}+jets at 14 TeV in the electron and muon channels (100 pb^{-1})
- Search for LVF SUSY (Evidence for excess) in $e+\mu$ final state at 14 TeV (500 pb^{-1})
- Search for SUSY (Evidence for excess) in trileptons + jets at 14 TeV. ($\sim fb^{-1}$)
- Search for SUSY (Evidence for excess) in $b\bar{b}$ + 1 lepton at 14 TeV.
- Search for SUSY (Evidence for excess) in 0 lepton + E_T^{miss}+jets at 14 TeV (10 pb^{-1})
- Search for SUSY (Evidence for excess) in $b\bar{b}$ + E_T^{miss} + jets at 14 TeV (100 pb^{-1})
- Search for SUSY (Evidence for excess)in top hadronic decays+ E_T^{miss} at 14 TeV (200 pb^{-1})
- Serach for SUSY (Evidence for excess) in opposite-sign ditau + E_T^{miss} at 14 TeV (200 pb^{-1})
- Search for GMSB (Evidence for excess) in prompt photon final states at 14 TeV (500 pb^{-1})
- Search for GMSB (Evidence for excess) in non-pointing photons at 14 TeV (1 fb^{-1})
- Search and reconstruction of heavy stable charged particles at 14 TeV using TOF and dE/dx (500 pb^{-1})
- ....

Best laid plans of mice and men

Susy vs UED?

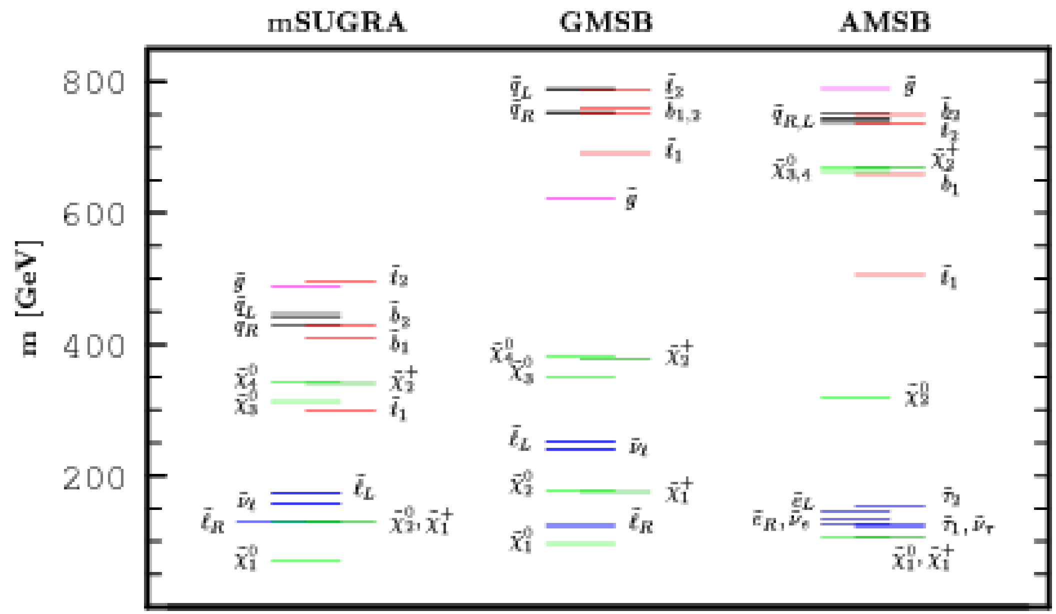
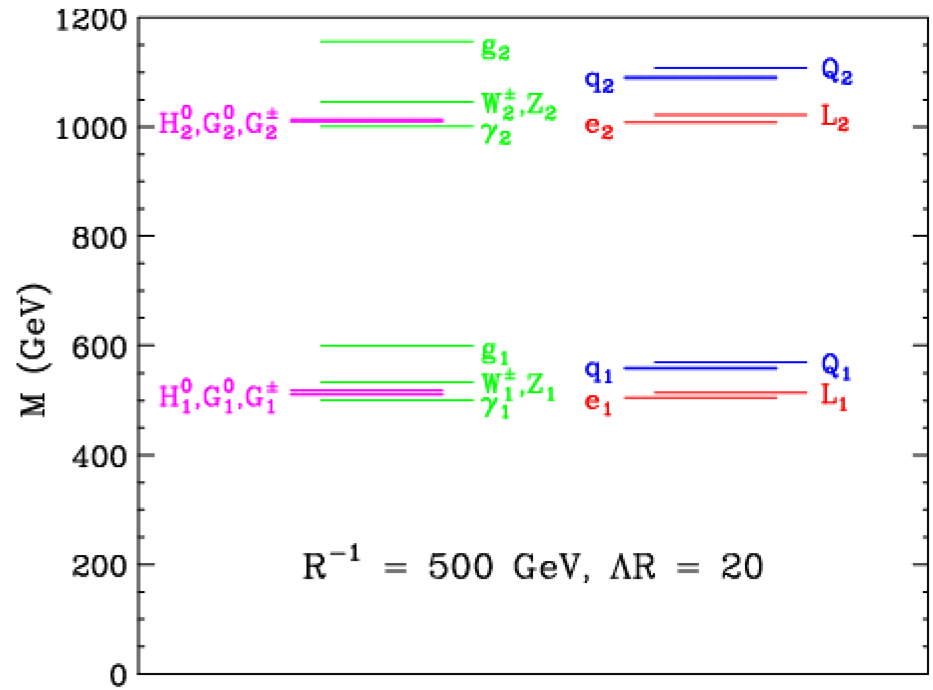


Figure 3.0.1: *Examples of mass spectra in mSUGRA, GMSB and AMSB models for* $\tan\beta = 3$, *sign* $\mu > 0$. *The other parameters are* $m_0 = 100$ *eV*, $m_{1/2} = 200$ *GeV for mSUGRA;* $M_{mess} = 100$ *TeV*, $N_{mess} = 1$, $\Lambda = 70$ *TeV for GMSB; and* $m_0 = 200$ *GeV*, $m_{3/2} = 35$ *TeV for AMSB.*



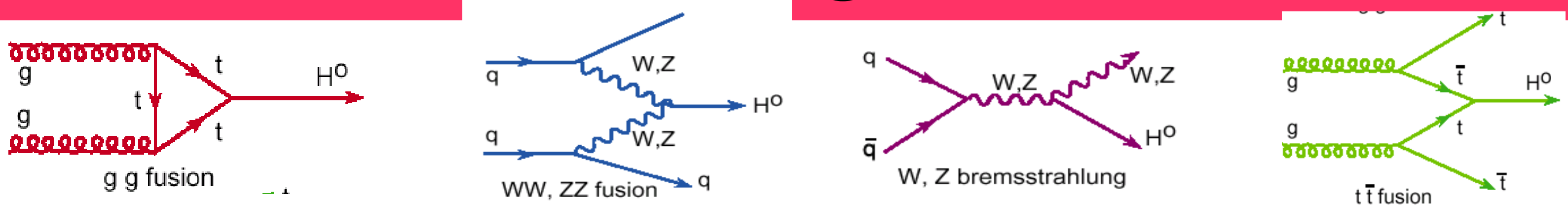
Much theoretical angst over this problem

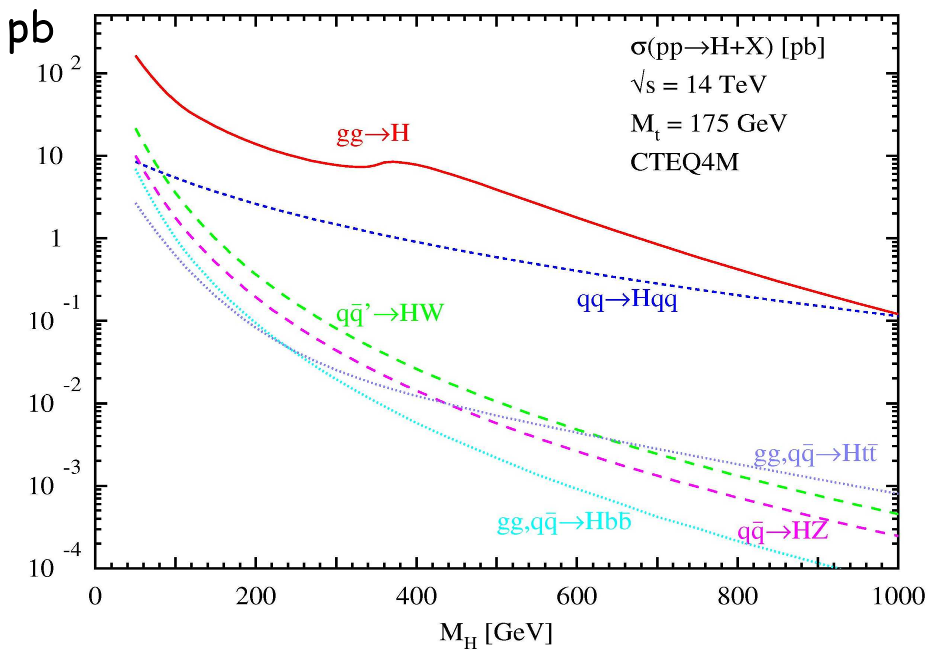
This is a problem that we need to keep us all busy!!

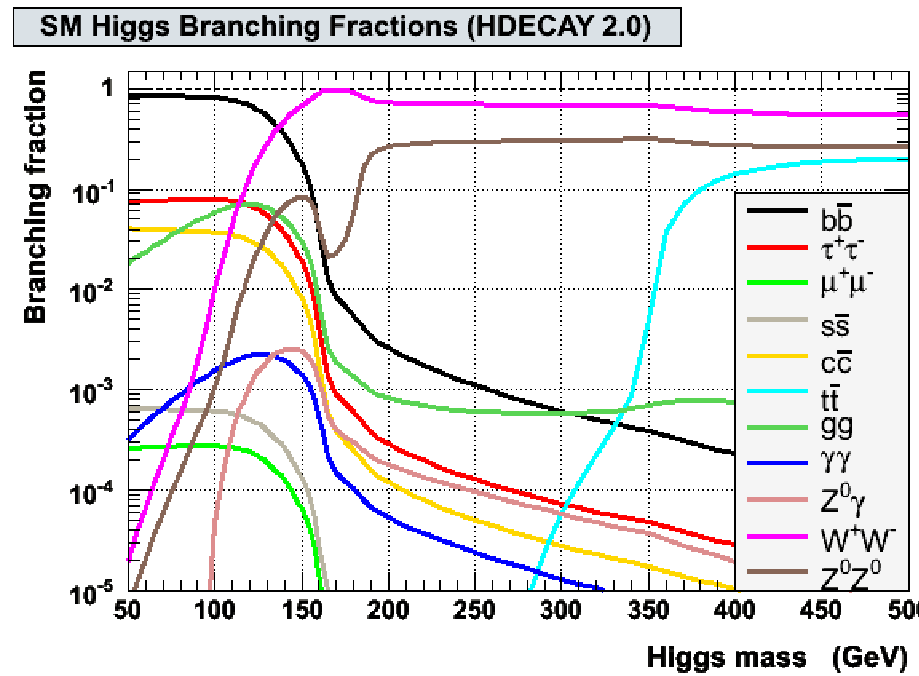
New physics for theorists (and) realists

- If Tevatron did not see it and it's inside their mass reach, apply strong health warning
- If it looks "totally crazy", it probably is
- Beware of "counting experiments" until SM is calibrated or S/B is huge
- Beware 4σ peaks in expected places
- Beware "old men in a hurry"
- Finally remember the Motivation....

LHC Higgs in one slide







m_H < 130 GeV : H ⇒ bb, ττ dominate

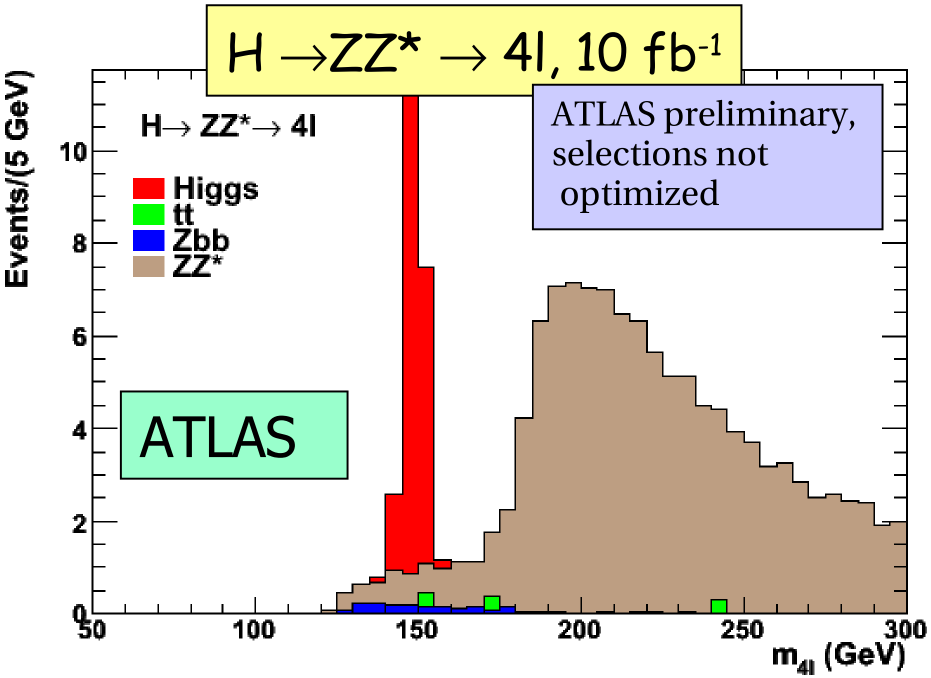
⇒ best search channels at LHC: qqH → qqττ, ttH→ lbbX, H →γγ

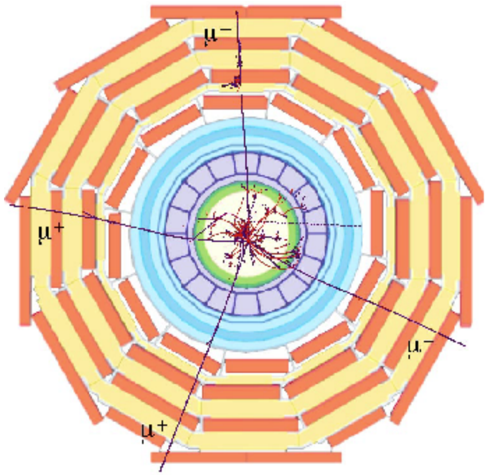
m_H > 130 GeV : H → WW$^{(*)}$, ZZ$^{(*)}$ dominate

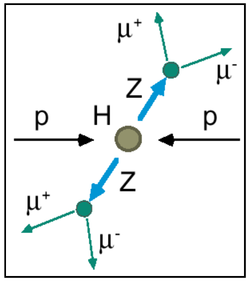
⇒ best search channels at LHC: H → ZZ$^{(*)}$ → 4l (gold-plated), H → WW$^{(*)}$ ⇒ lν lν

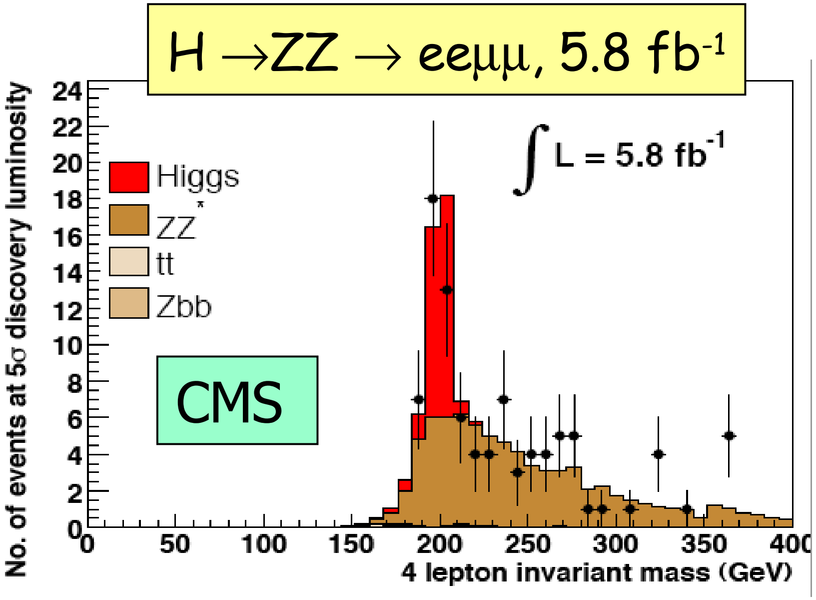
Especially in the region m_H<130 GeV, excellent detector performance needed:
b-tag, γ E-resolution, γ/j separation, E_T^{miss} resolution, forward jet tag, etc.

⇒ Higgs searches used as benchmarks for ATLAS and CMS detector design

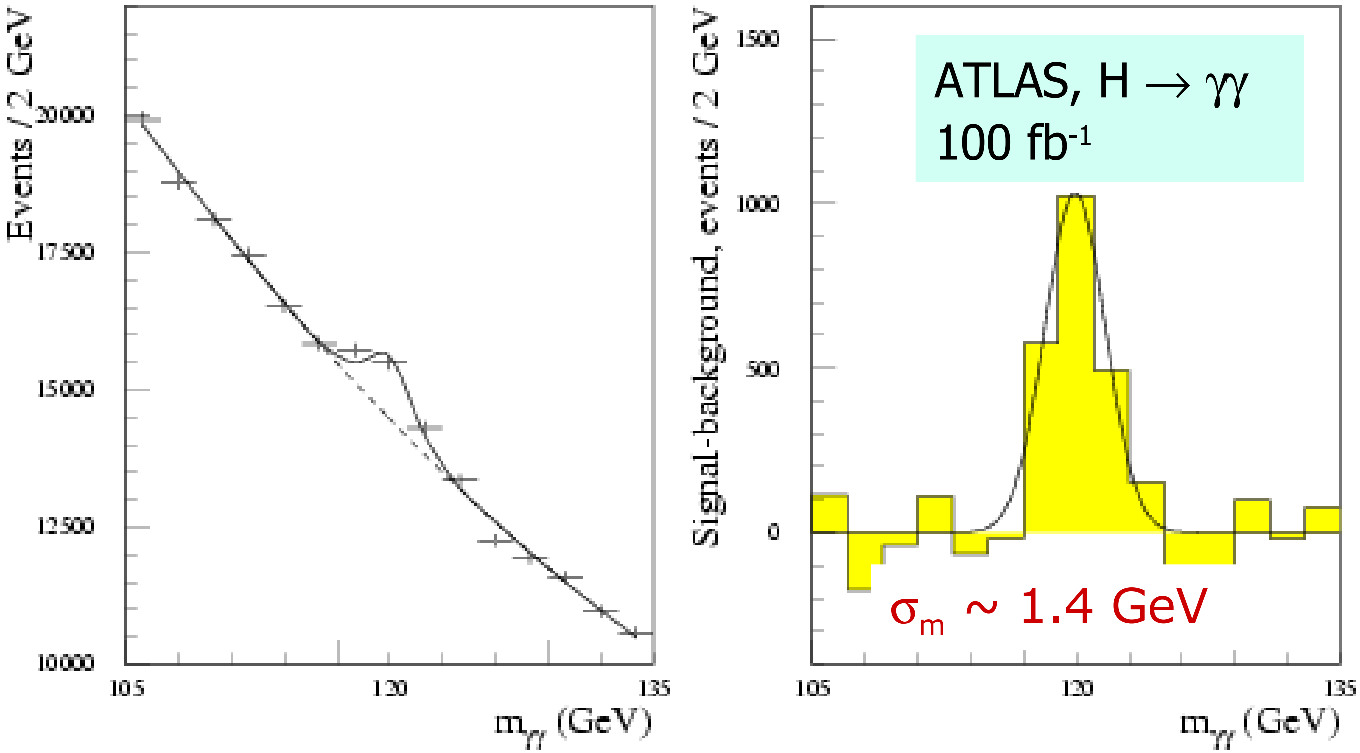








Gold-plated channel at LHC
(~ background free …)



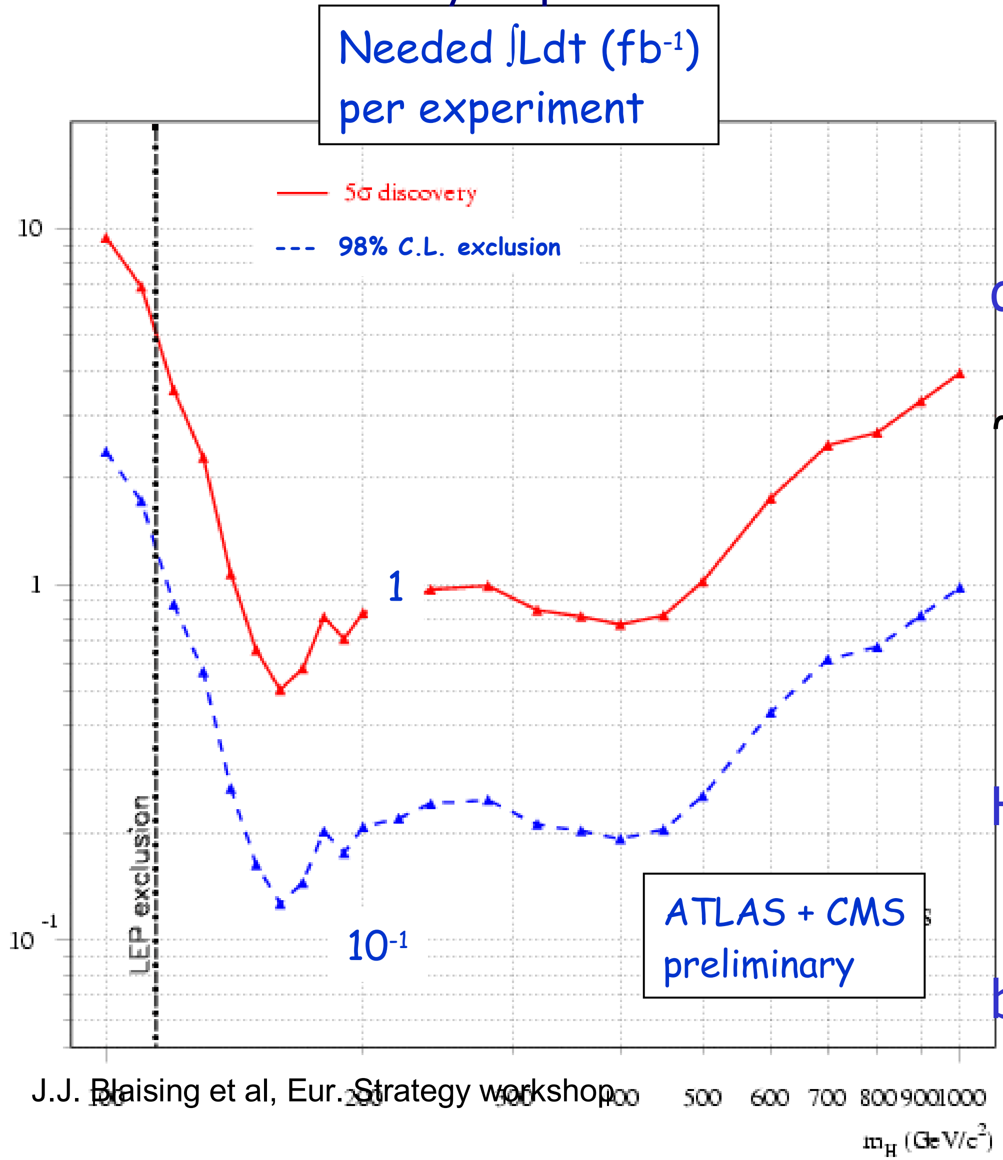
It will need a perfectly understood detector in terms of photon identification, calorimetry, tracking, ….

BG dominated by irreducible components

2010 ?

Combined ATLAS + CMS discovery potential

- Luminosity required for a 5σ discovery or a 95% CL exclusion -



J.J. Blaising et al, Eur. Strategy workshop

~ 5 fb^{-1} needed to achieve a 5σ discovery
(well understood and calibrated detector)

~ < 1 fb^{-1} needed to set a 95% CL limit
(low mass ~ 115 GeV/c^2 more difficult)

comments:
- present curves assume the old ttH, H→ bb performance
- systematic uncertainties assumed to be luminosity dependent (no simple scaling, σ√L, possible)

Perhaps we might find the Grail(Higgs)?

Galahad aka ATLAS

But we hope for something more revolutionary

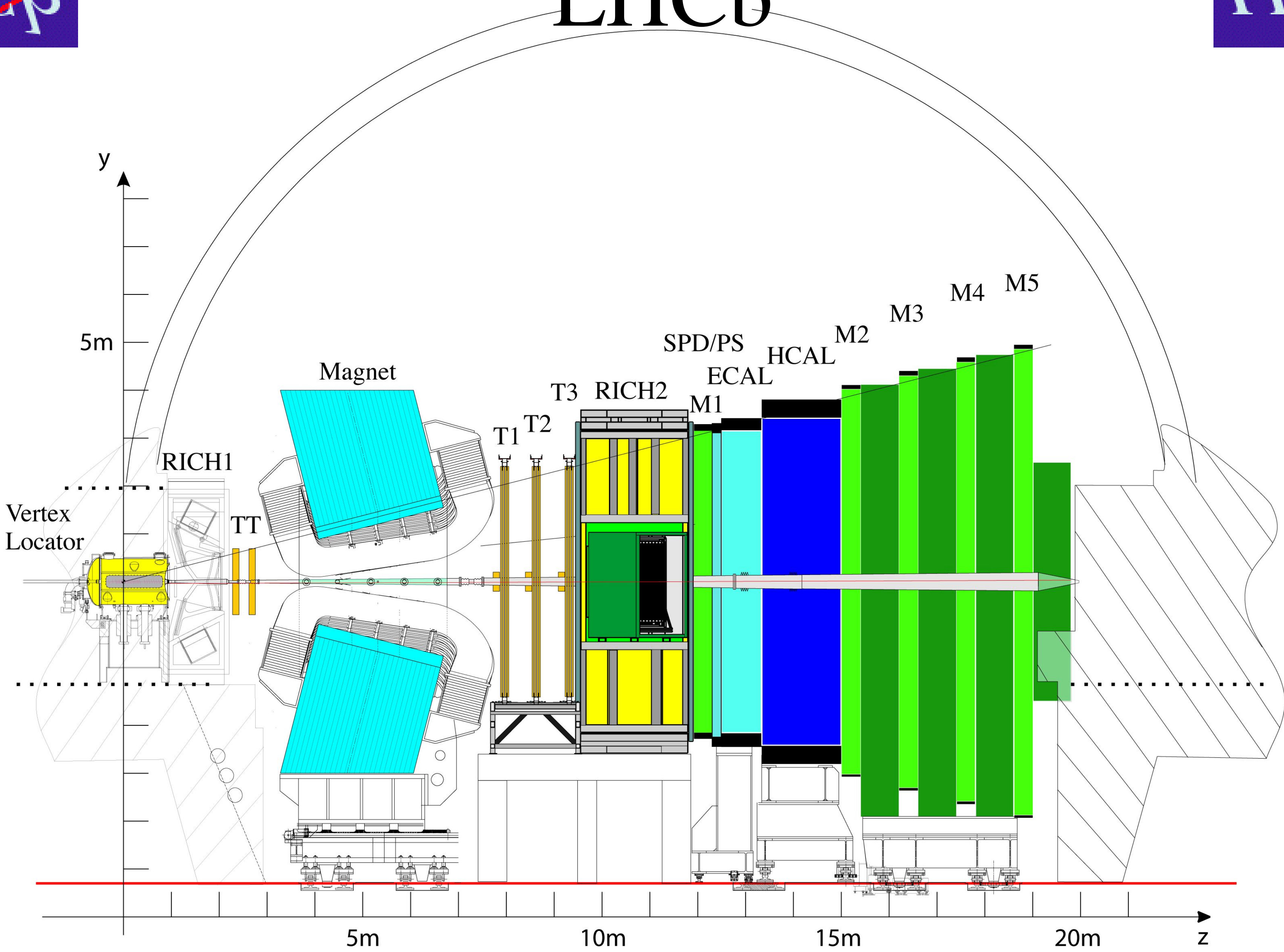
Expect an exciting time for experment and theory

- We all expect/hope that LHC will revolutionize field.
- Recall J/Psi, charm, tau......
- I was in high school the last time we had a comparable leap in effective energy: DONT BLOW IT!

- Come back for the 2009/2010 when one of you will be trying to explain what LHC has seen

Additional Material

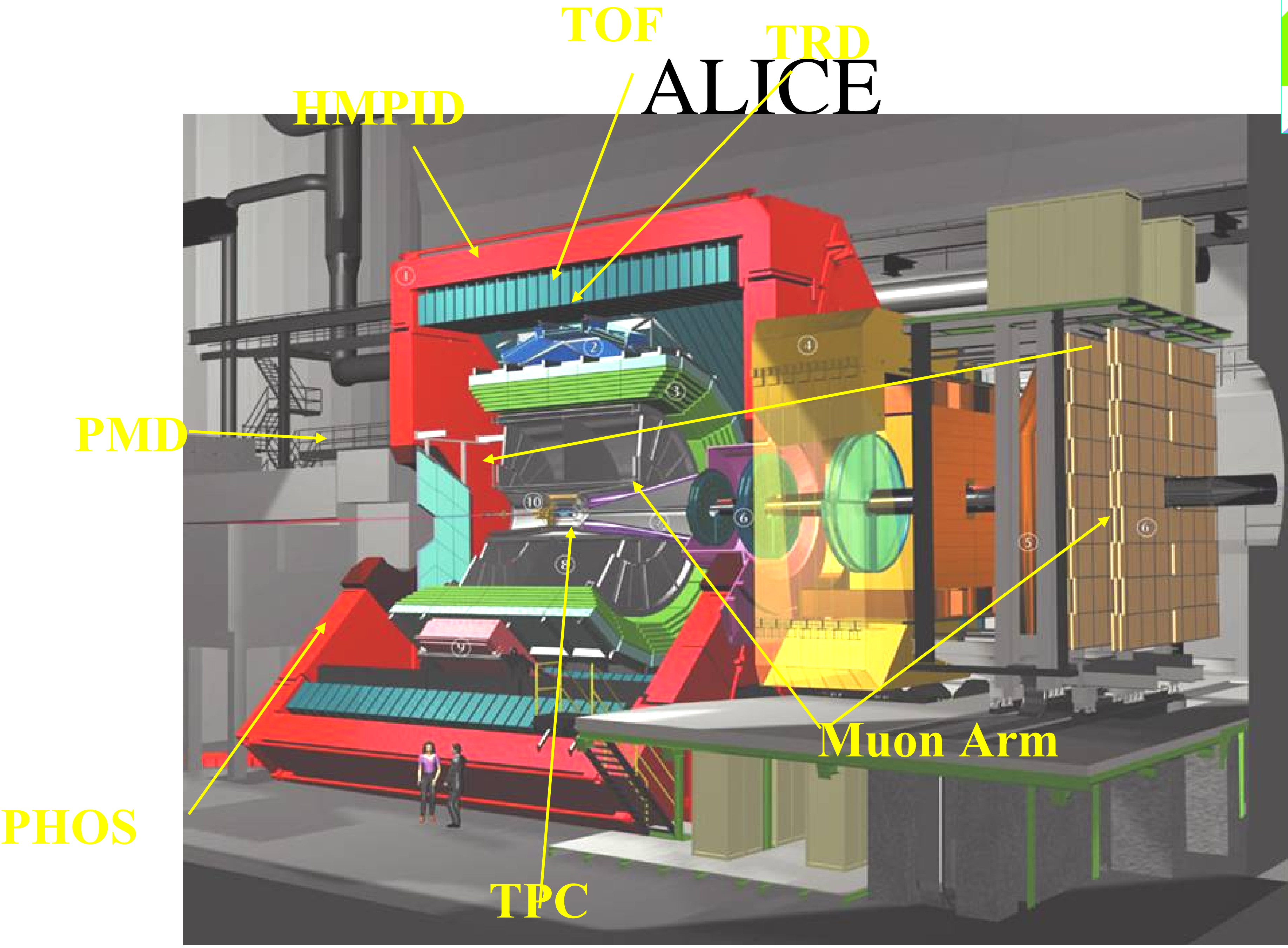
LHCb



y
5m
Magnet
RICH1
Vertex
Locator
TT
T1
T2
T3
RICH2
M1
SPD/PS
ECAL
HCAL
M2
M3
M4
M5
5m
10m
15m
20m
z

LHCb installation

ALICE



ALICE

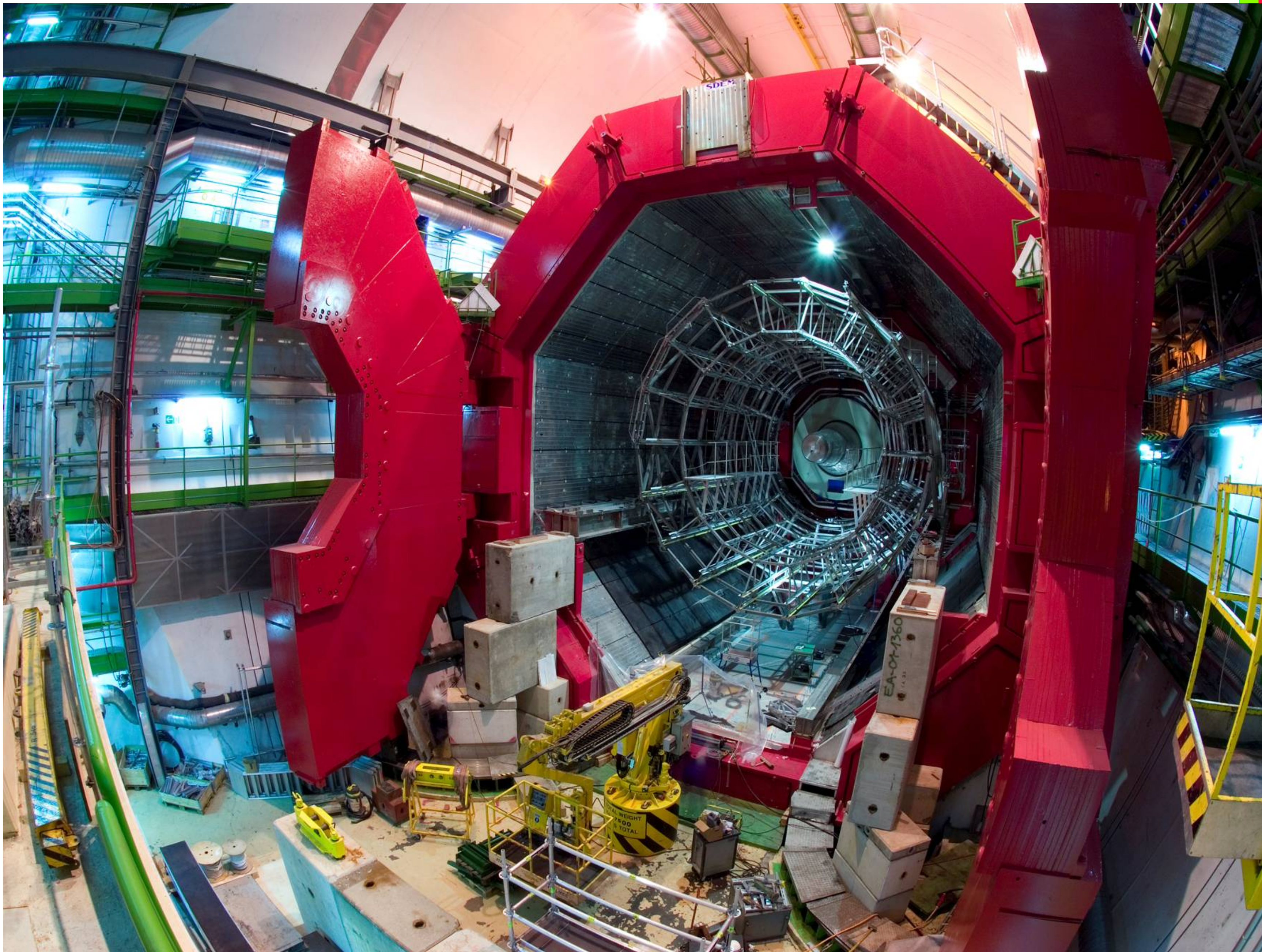
- Infrastructure (large structures, μ-absorbers, magnets,..)
  - installed and commissioned

- Detector Construction
  - **completed:** TPC, HMPID, PHOS, ZDC, Muon trigger, cosmic trigger array
  - **nearing completion:** Muon tracking, TOF, TRD, ITS,

    forward (V0, T0, PMD, FMD)
    - **critical path: Silicon Vertex Detector (ITS)**

- Detector Installation
  - **precomissioning** of all detectors **on surface,** started
  - **Installation:**
    - **Muon Spectrometer:** June 06 to March 07
    - **Central Barrel:** Sept. 06 to April 07
  - **Installation after summer 2007**: parts of TRD, TOF, PHOS

S



S

Bottom and Charm

	14 TeV	900 GeV
Total LHC bb cross section	500 μb	25 μb
Total LHC inelastic σ	70 mb	40 mb
bb → μ6(5) X	4000 nb	60 nb
bb → μ6(5) μ3 X	200 nb	2 nb
bb → J/ψ (μ6(5) μ3) X	7 nb	0.1 nb
pp → J/ψ (μ6(5) μ3) X	28 nb	1 nb
pp → ϒ (μ6(5) μ3)	9 nb	1.7 nb

***) pT cuts for 14TeV are μ6 μ3 and for 900 GeV μ5μ3**

For both muons |η|<2.5

Bs to μμ

Less advantage over Tevatron because cross section rises slowly

Integral LHC Luminosity	Signal ev. after cuts	BG ev. after cuts	ATLAS upper limit at 90%	CDF&D0 upper limit at 90% CL
100 pb^{-1}	~ 0	~ 0.2	6.4×10^{-8}	8×10^{-8}
10 fb^{-1}	~ 7	~ 20	7.0×10^{-9}	
30 fb^{-1}	~ 21	~ 60	6.6×10^{-9}	

ATLAS

LHC dipoles (the last one)

Measuring Z rates

Need to trigger on either e or mu

Use mass constraint to calibrate both

Measure track effic by starting with good e and e-m energy

Measure trigger effic by comparing to offline

Very rapidly reach systematic limit on cross-section

$$\varepsilon^{trig} = f(N_1^Z, N_2^Z)$$

$$R = \sigma \cdot L \cdot (2\varepsilon - \varepsilon^2) \cdot A_Z \cdot \varepsilon_Z$$

σ_{Zee} = 1.87nb → L $= 10^{31} cm^{-2} s^{-1}$

R ≈ 2.2 mHz

Statistical uncertainty	Time ε≈87%	Time ε≈60%
20%	20 min	2 hours
10%	72 min	8.3 hours
5%	5 hours	
2%	30 hours	33 hours
1%	5 days	8.6 days

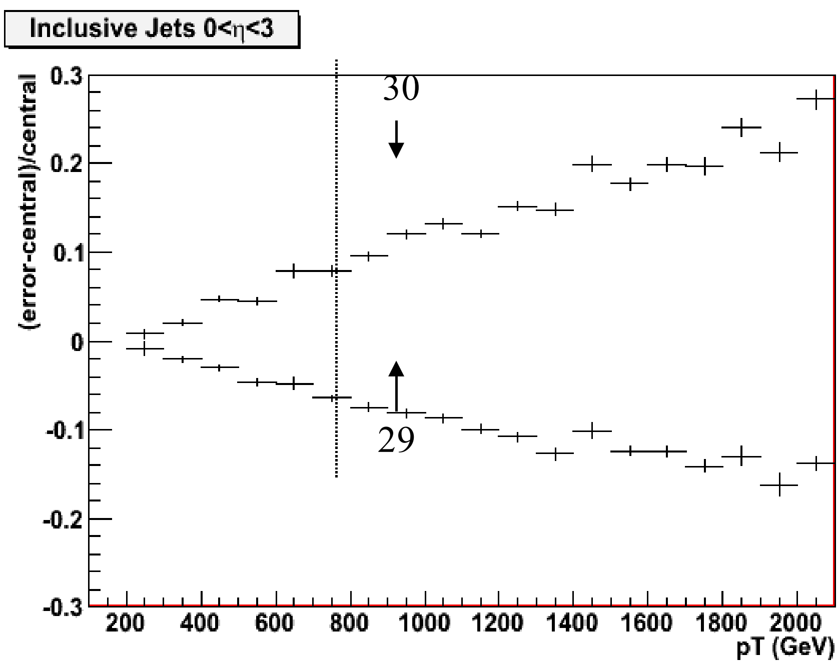
$A_Z \times \varepsilon_Z \approx 12\%$ (acceptance X reconst. eff.)

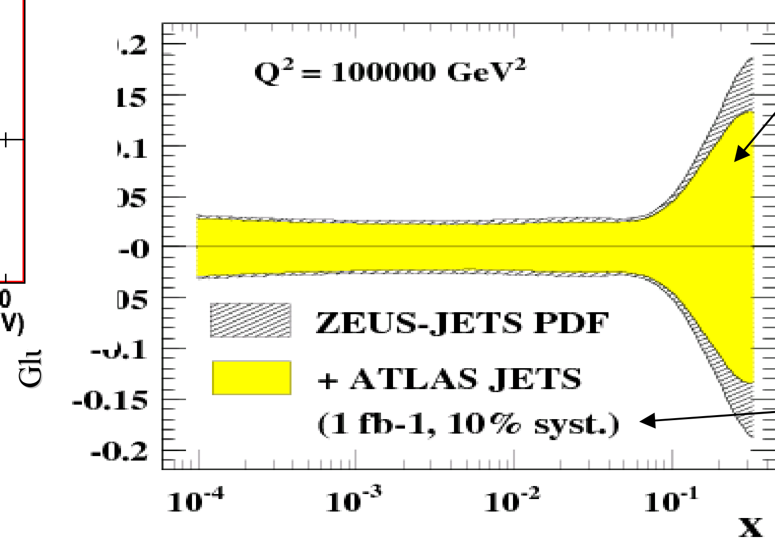
$\varepsilon \approx 87\%$ (HLT single electron efficiency)

PDF's are constrained by data

- Grids were generated for the inclusive jet cross-section at ATLAS in the pseudorapidity ranges $0<\eta<1$, $1<\eta<2$, and $2<\eta<3$ up to p_T=3TeV (NLOJET).
- In addition pseudo-data for the same process was enerated using JETRAD.

The pseudo-data was then used in a global (ZEUS) fit) assess the impact of ATLAS data on constraining DFs:





Preliminary indications suggest that ATLAS data can constrain the high x-gluon.

Systematic errors are uncorrelated, 10fb-1=1 year of nominal data-taking

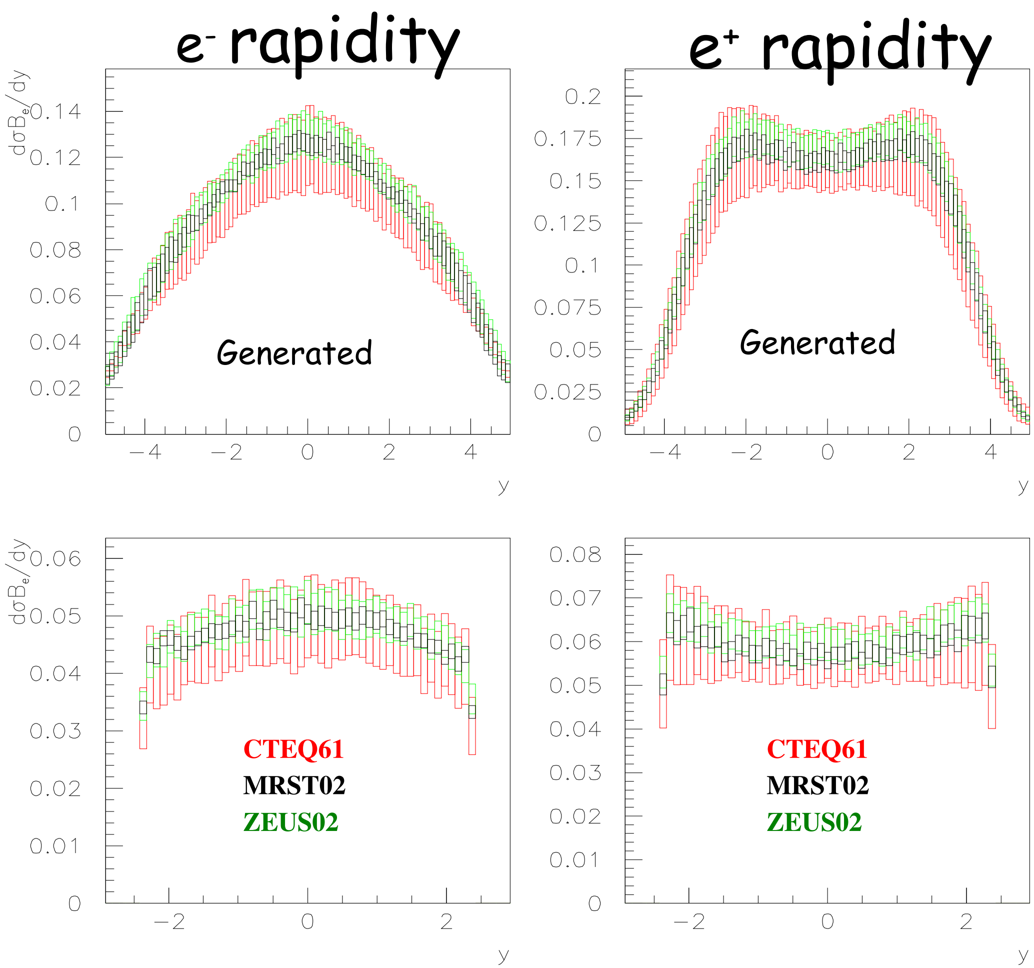
PDF uncertainties

$$u\bar{d} \rightarrow W^+ \rightarrow e^+\nu$$

$$d\bar{u} \rightarrow W^- \rightarrow e^-\bar{\nu}$$

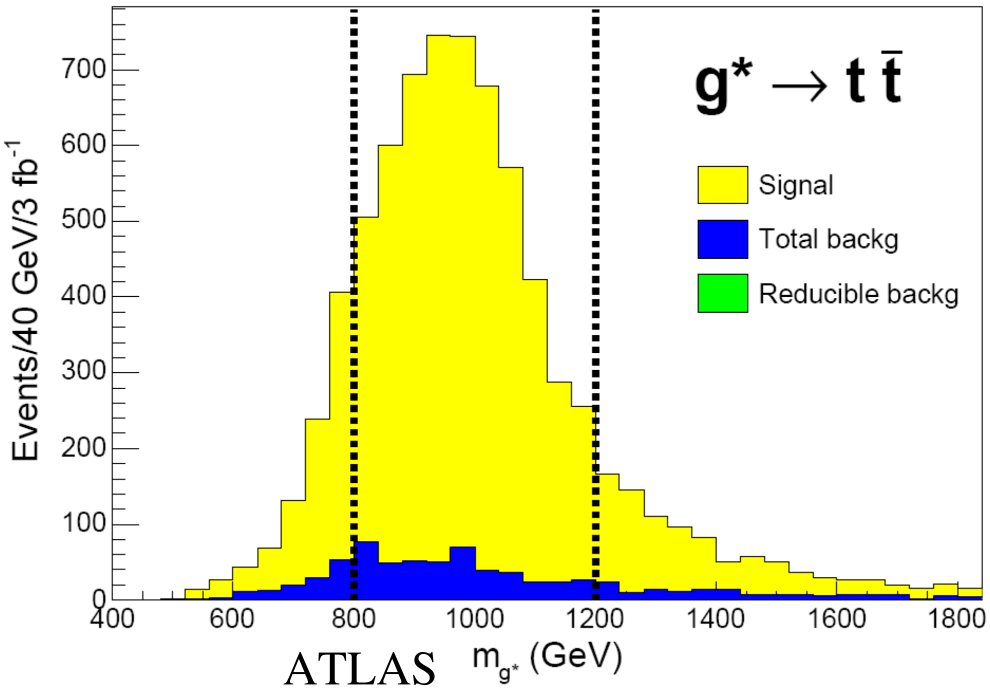
Large rapidity is sensitive to quarks at large x.

Less well measured now

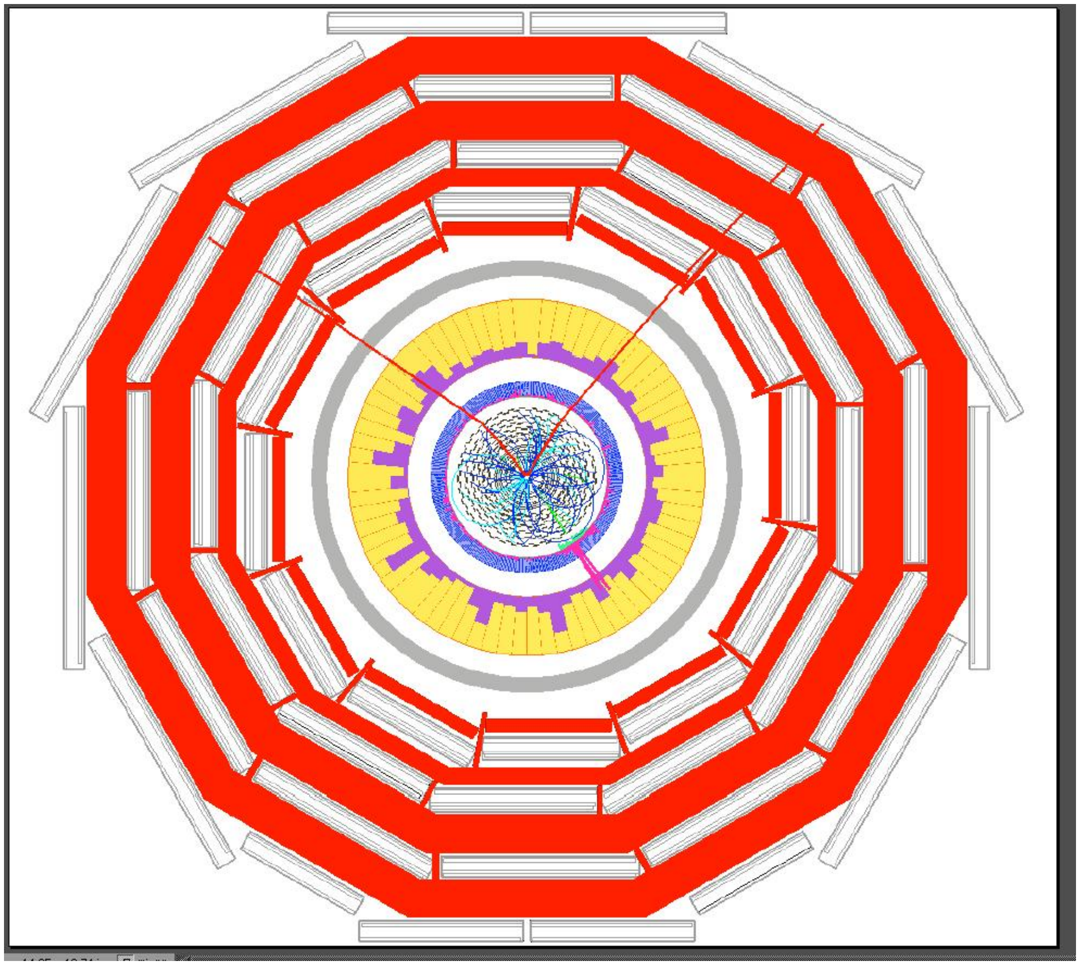


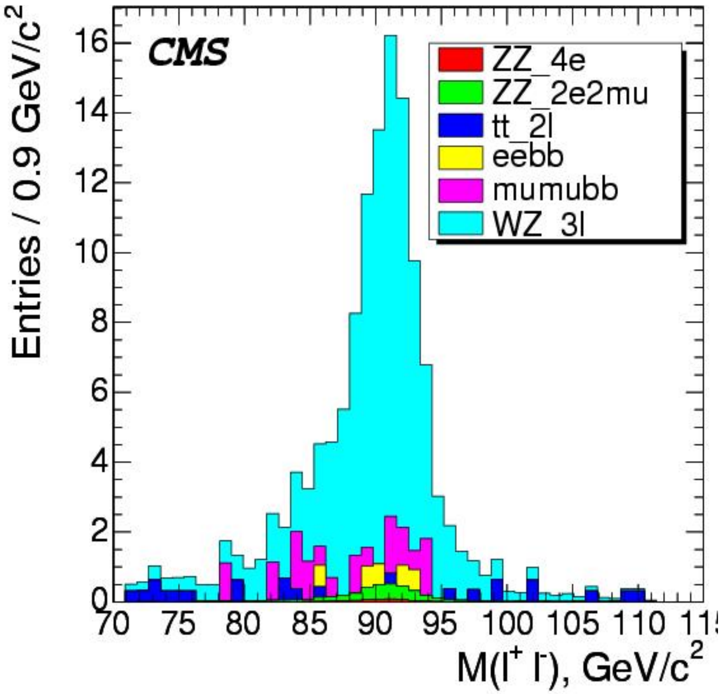
Extra dimension resonance

- Gluon excitation decaying to ttbar
- Look at ttbar mass distribution after top is measured



W/Z pairs

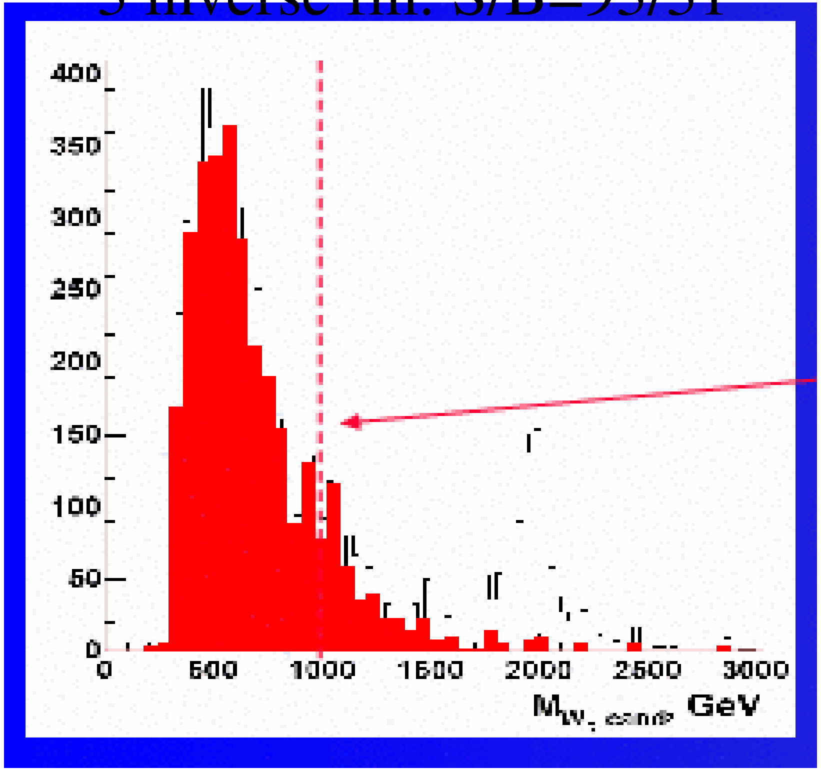


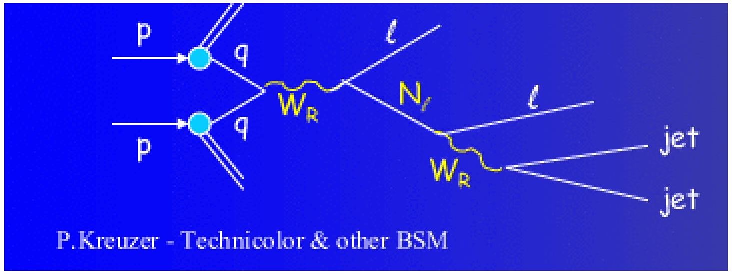


CMS 1 inverse fb

W'

3 inverse fm: S/B=93/31





CMS (Kreuzer)