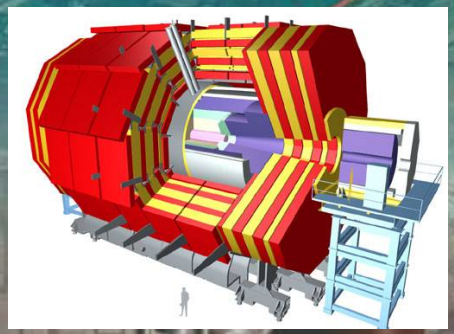
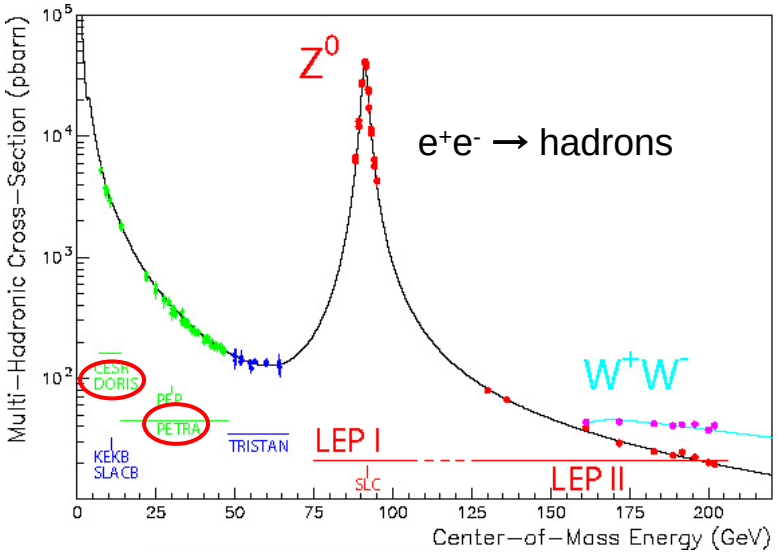
Status and Outlook of LHC

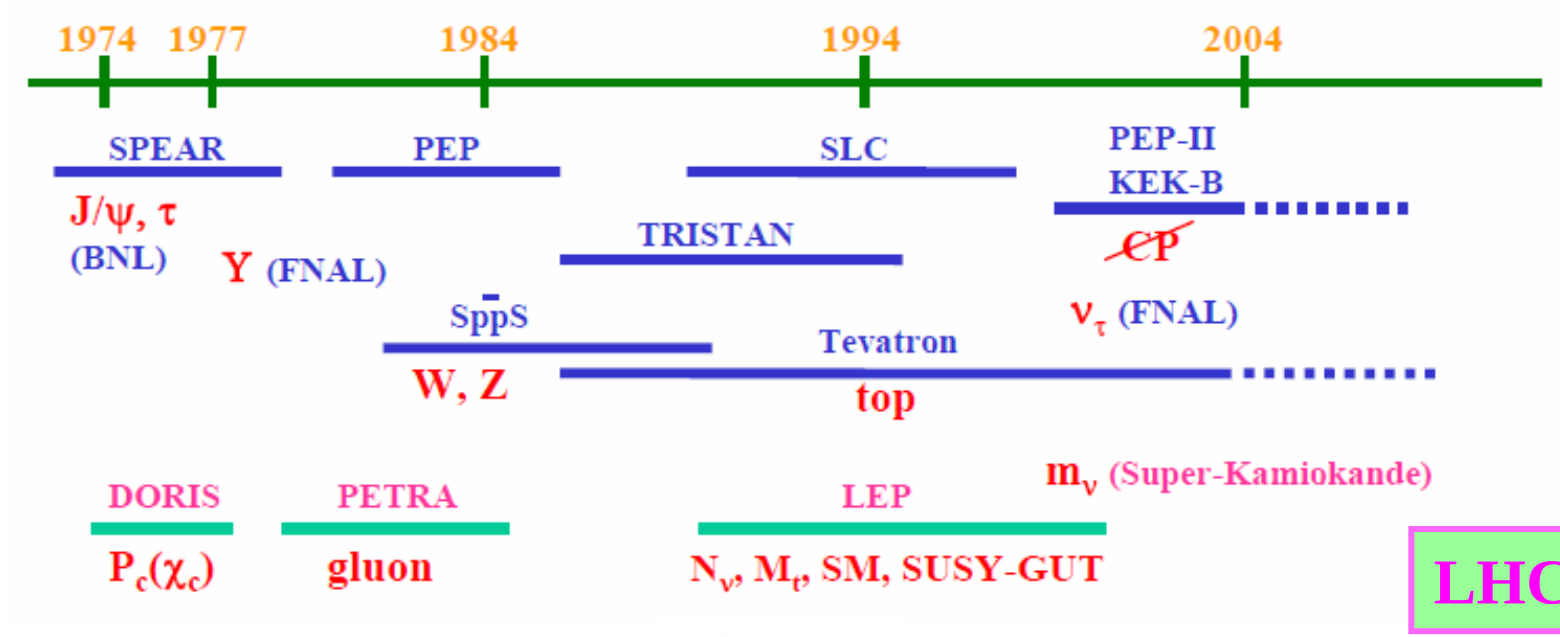
Introduction
Machine status and schedule
Status of experiments
Physics prospects
Summary



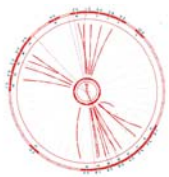
14. May. 2007
PPC2007 at Texas
T. Kobayashi
(Univ. of Tokyo / ICEPP)

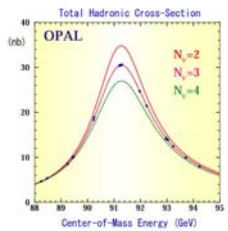


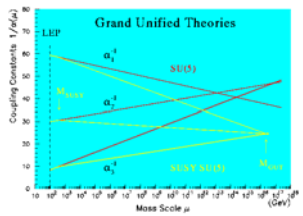
History of Particle Physics and ICEPP (Univ. of Tokyo)



ICEPP founded







LHC

Higgs
SUSY
??

History of LHC (Large Hadron Collider at CERN)

1991.12 Council LHC approval in principle

Constr. cost ~ 2000 MCHF

1992 EoI, LoI of experiments

1993.10 Termination of SSC

1994.12 Council LHC approval

Construction in 2 steps (10TeV → 14TeV)

1995.5 1-st capital cooperation from Japan (¥5B)

1996 Cooperation from India, Russia, Canada

Approval of ATLAS and CMS

1996.12 2-nd cooperation from Japan (¥3.85B)

Construction in 1 step by 2005

1997.12 Cooperation from US ($200M)

1998.5 3-rd cooperation from Japan (¥5B)

2000.11 LEP finished operation

2001-2002 Construction cost problem → LHC start in summer 2007

2006.6 900 GeV run from Nov.2007, 14TeV physics run from June 2008

LHC Physics Prospects Then and Now

Oct. 1992

LHCでの物理

From my talk at JPS in Niigata

pp collider

- Higgs粒子探索 (80GeV<M_H<1TeV)

  strong Higgs sector (technicolor?)

  MSM~OK ⇒ EW対称性破れの機構解明 (main stream)

  Mechanism of EWSB

- SUSY Higgs (h, A, H, $H^{\pm}$)
- SUSY粒子 ($\tilde{g}$, $\tilde{q}$, ---)
- top quark
- 標準理論の研究 (WWγ coupling, ---)
- Extended Gauge models (Z'粒子)
- quark の構造 (~10^{-18}cm)
- CP-violation ($B^0_d \rightarrow J/\psi K^0_s$)
- unexpected new physics

May 2007

Light Higgs
Vector Boson Fusion

Little Higgs, Higgsless, --

SUGRA, GMSB, AMSB,
split SUSY, --

Extra dimensions
(large, warped, universal, --)
Black holes

LHC Machine Parameters

Proton-Proton Collider

Circumference: 26.7 km (using LEP tunnel)

Beam Energy: **7 TeV** (Injection E: 450 GeV, PS→SPS→LHC)

1232 MR dipoles **B=8.33 Tesla**, L=14.3m, 1.9K (**2-in-1 magnets**)

368 MR quads B'=223 T/m, L=3.1m

No. of Bunches: 2808

Bunch spacing: 24.95 ns

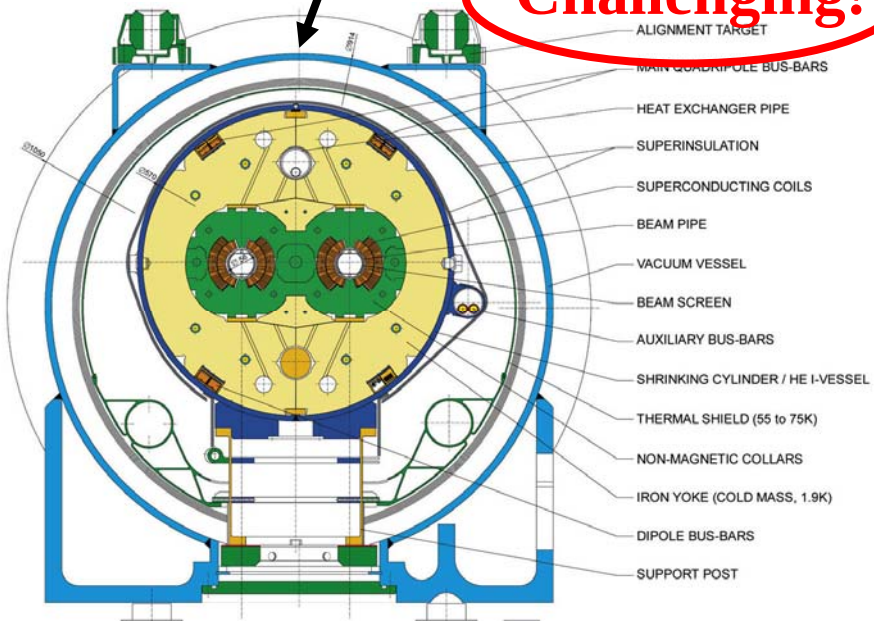
Bunch size at IP: 16 μm

Bunch length at IP: 77 mm

Half crossing angle: 160 μrad

Luminosity: 10^{34} $cm^{-2}s^{-1}$

Challenging!

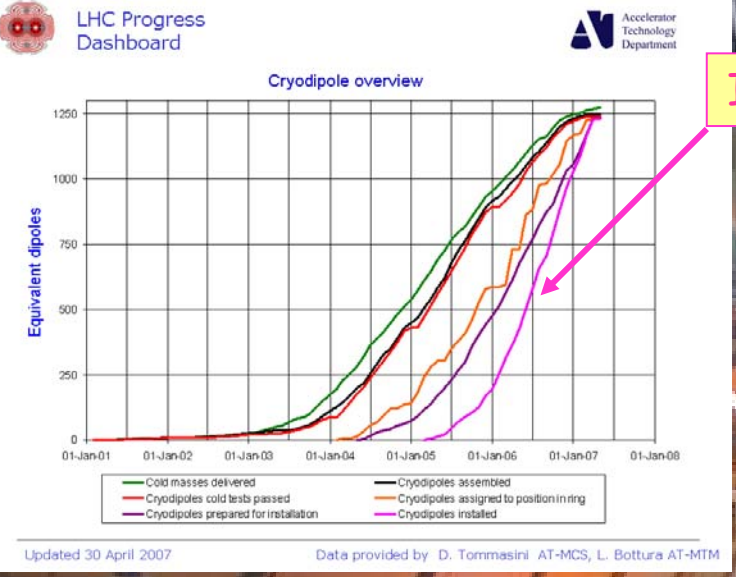


Heavy Ion Collider

Pb-Pb E_{cm} : 1148 TeV

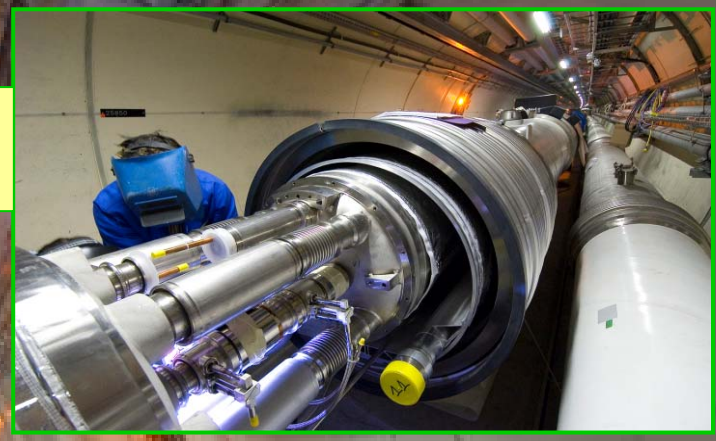
Pb-Pb Luminosity: 10^{27} $cm^{-2}s^{-1}$

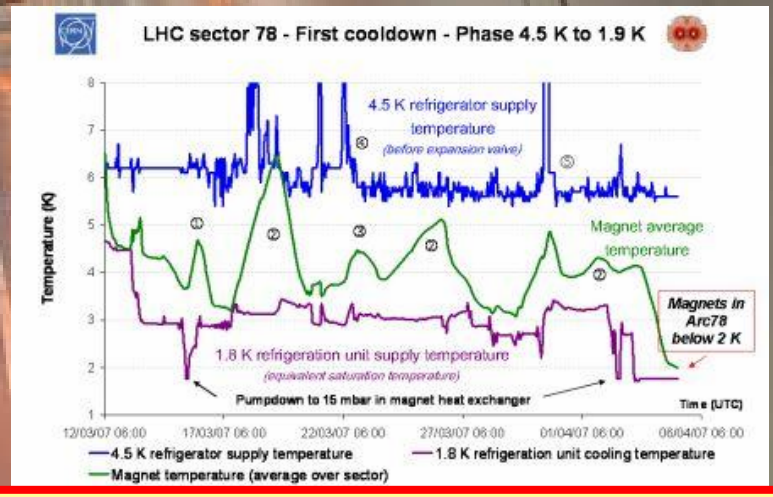
~23 pp collisions/crossing



Installation in the tunnel (took 2 years)

Interconnection is now going on

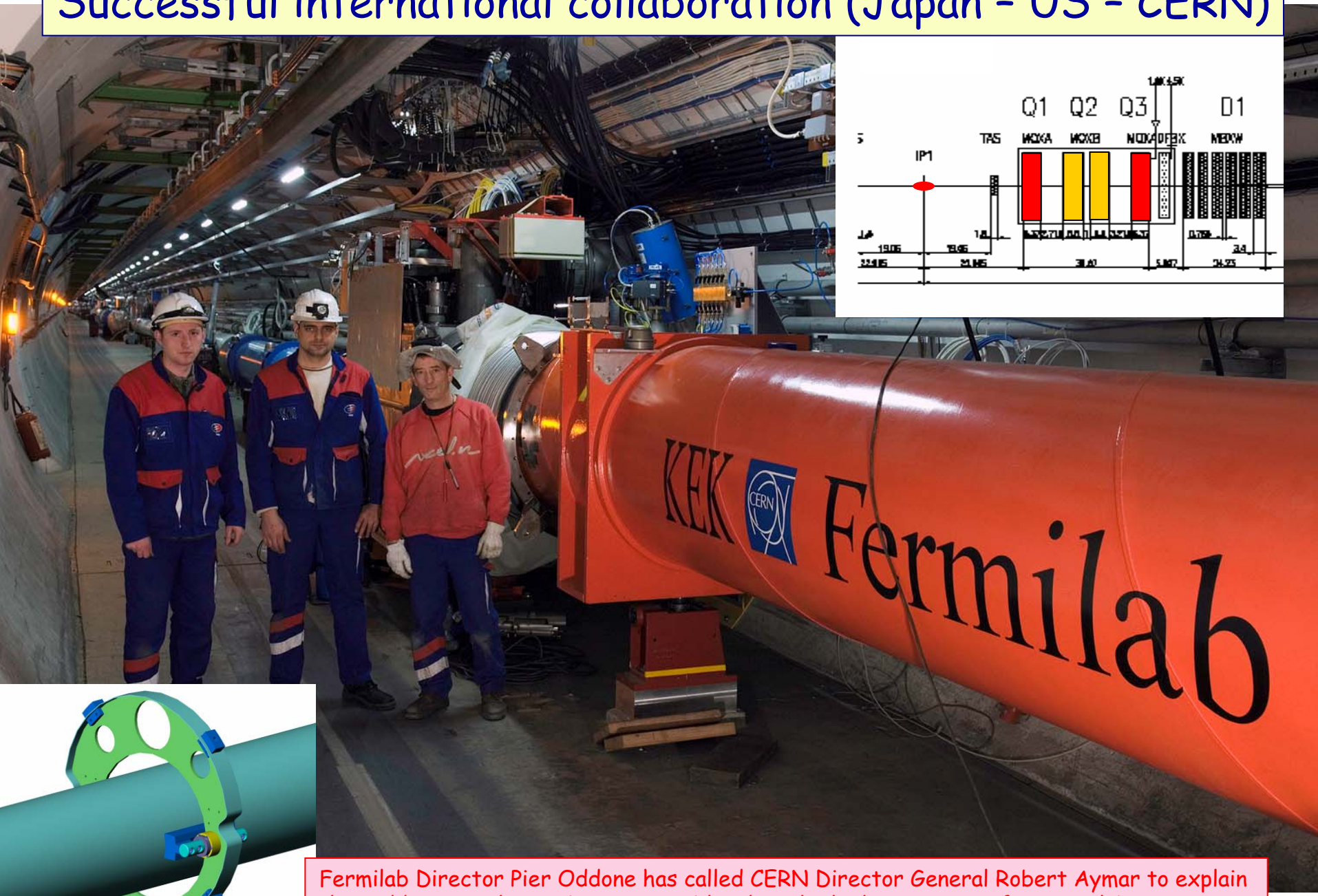




CERN Press Release (10.Apr.2007)

The first sector of LHC has reached a temperature of 1.9 K, colder than deep outer space!

Successful international collaboration (Japan – US – CERN)



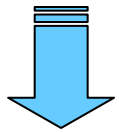
Fermilab Director Pier Oddone has called CERN Director General Robert Aymar to explain that addressing the LHC magnet problem has the highest priority for Fermilab and that the laboratory will do whatever is necessary to get things back on track.

(Revised) LHC schedule

- Last magnet installed : March 2007
  Machine and experiments closed : 31 August 2007
- First collisions ($\sqrt{s}$ = 900 GeV, L~10^{29} cm^{-2} s^{-1}) : November 2007
  Commissioning run at injection energy until end 2007, then shutdown (3 months ?)
- First collisions at $\sqrt{s}$=14 TeV : Spring 2008
  (followed by first physics run)

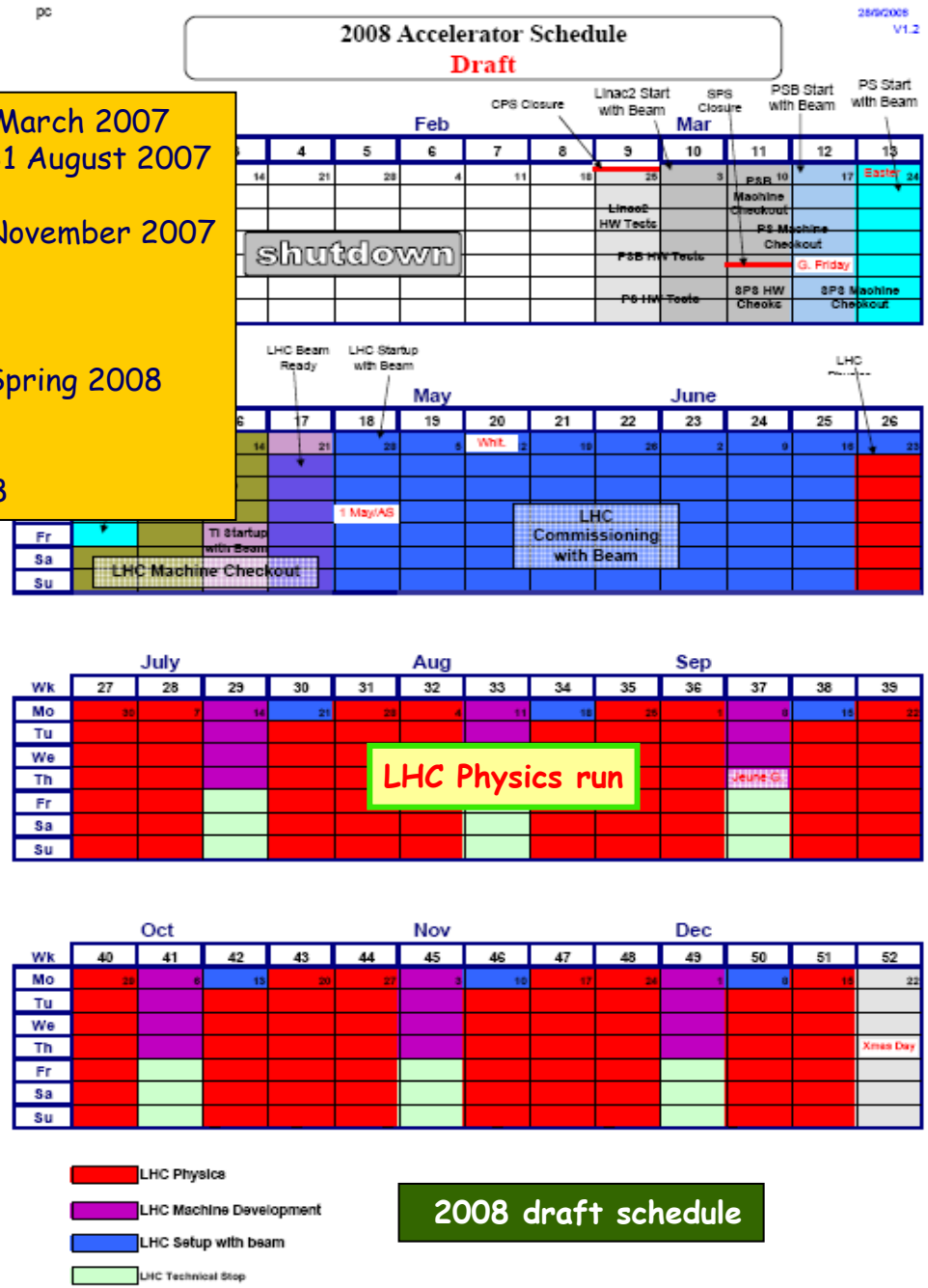
Goal : deliver integrated luminosity of few fb^{-1} by end 2008

L. Evans (CERN Council, 23/6/2006)



- Before the IT problem, we were about 5 weeks behind schedule.
- Once the full extent of the damage is known and the in-situ repair validated, we will publish a new schedule. It now looks unlikely that the engineering run can occur at the end of the year but all effort will be made to maintain a physics run in 2008 as foreseen.

L. Evans (RRB, 23/4/2007)

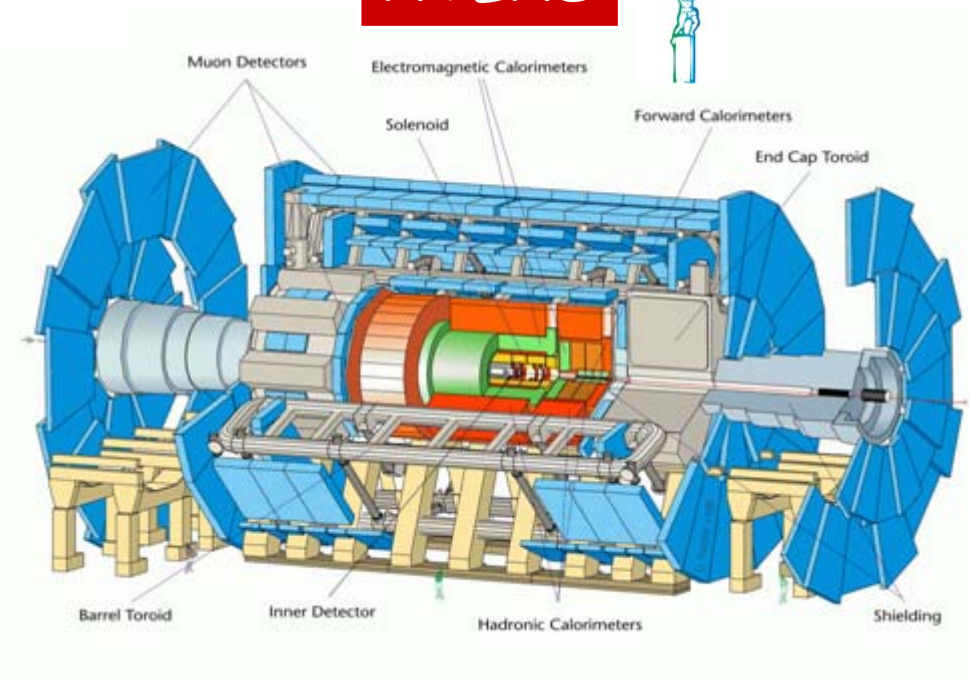


2008 draft schedule

General purpose detectors for pp collisions

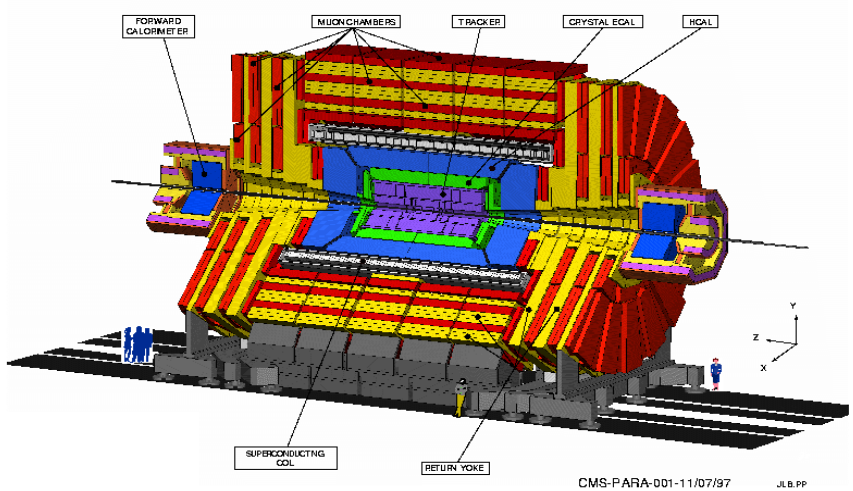
+ LHCb, ALICE
(and TOTEM, LHCf, MOEDAL, FP420, --)

ATLAS



Length : ~45 m
Diameter : ~24 m
Weight : ~ 7,000 tons
Electronic channels : ~ 10^8
Solenoid : 2 T
Air-core toroids

CMS

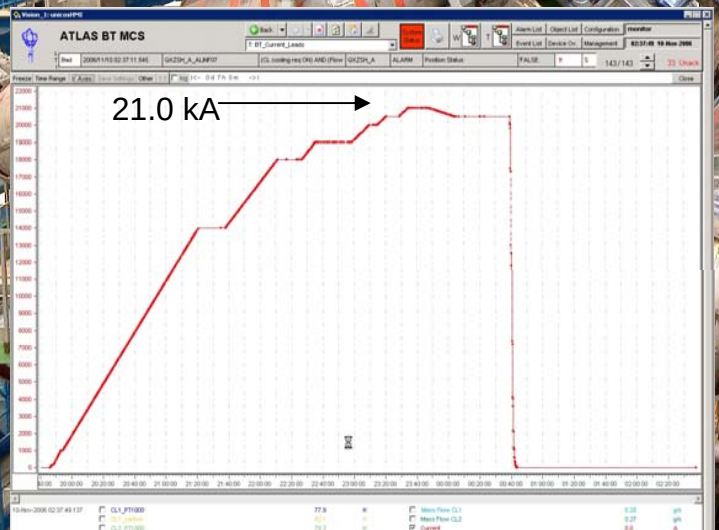


Length : ~22 m
Diameter : ~14 m
Weight : ~ 12,500 tons
Solenoid : 4 T
Fe yoke
Compact and modular

Detector elements

	ATLAS	CMS
TRACKER	Si pixels + strips TRT → particle identification $\sigma/p_T \sim 5\times10^{-4}\ p_T \oplus 0.01$	Si pixels + strips No particle identification $\sigma/p_T \sim 1.5\times10^{-4}\ p_T \oplus 0.005$
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 segmentation
HAD CALO	Fe-scint. + Cu-liquid argon ($\geq 10\ \lambda$) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Brass-scint. ($\geq 5.8\ \lambda$ + catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	MDT, CSC, RPC, TGC $\sigma/p_T \sim 7$ % at 1 TeV standalone	DT, CSC, RPC $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker

Oct. 2005



- ATLAS barrel toroid (world's largest s.c. magnet) reached full field(20.5 kA) on 9.Nov.2006

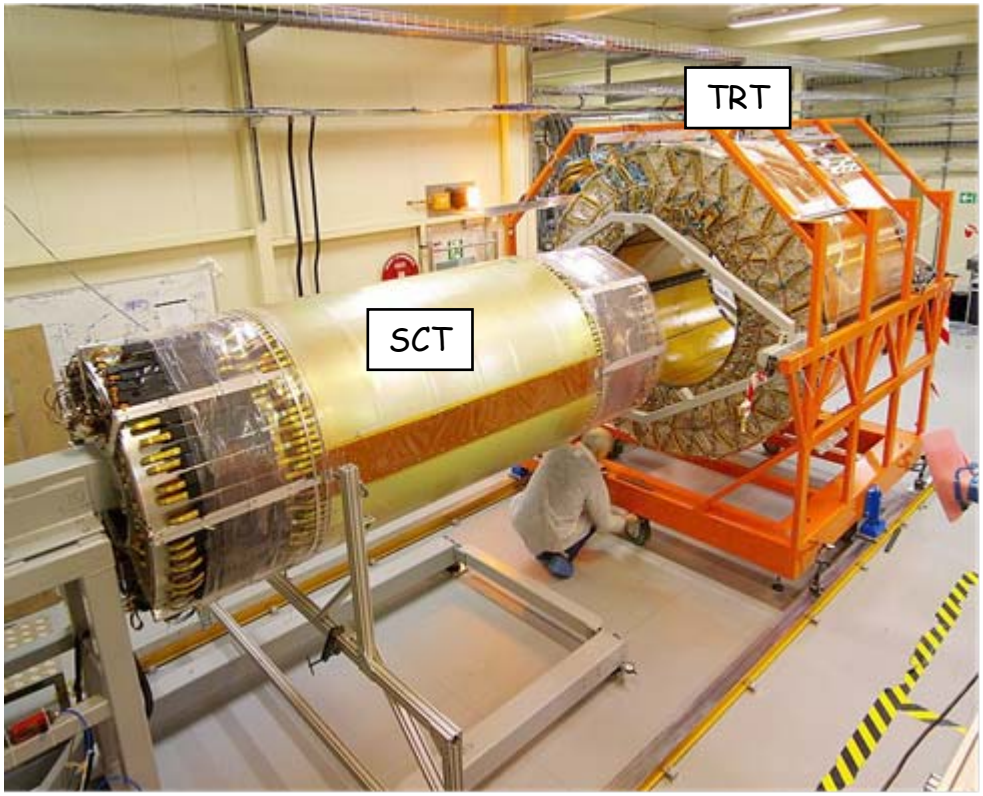
- Barrel calorimeter (LAr EM + HAD Fe/Scint. Tilecal) in final position at Z=0 since Nov. 2005

Feb. 2006

Feb. 2007

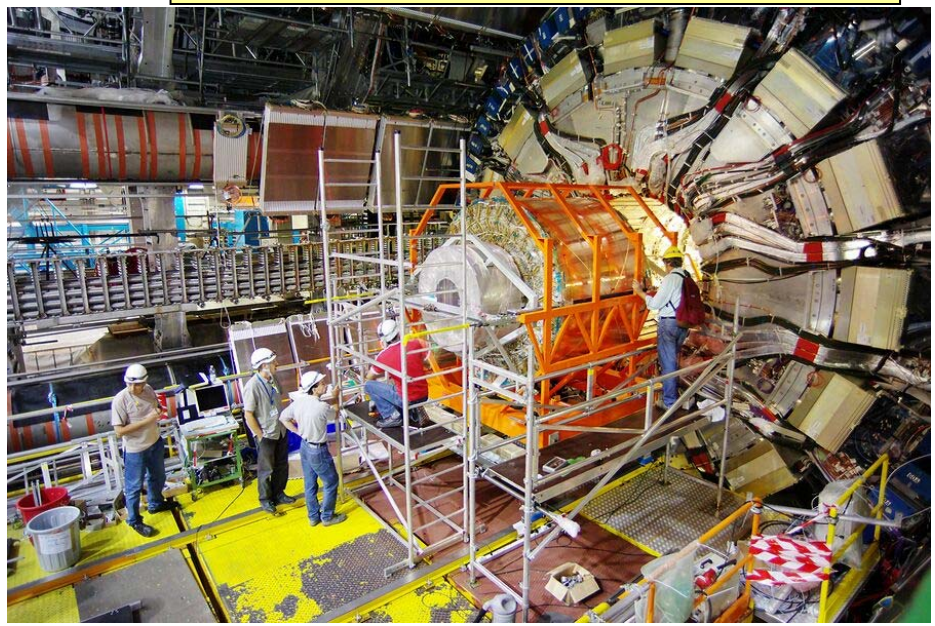
End-cap calorimeter:
(LAr EM + HAD + Forward inside same cryostat, surrounded by HAD Fe/Scint. Tilecal)
being moved inside the barrel toroid
→ All calorimeters ready

End-cap toroid:
cooling down and tests on surface,
installation in June (2-nd one in July)

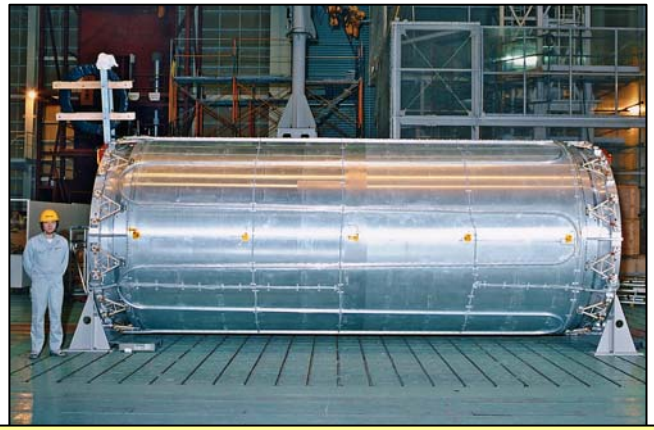


Barrel Si detector(SCT) was inserted into barrel TRT in Feb. 2006.

Installation in the pit in Aug. 2006

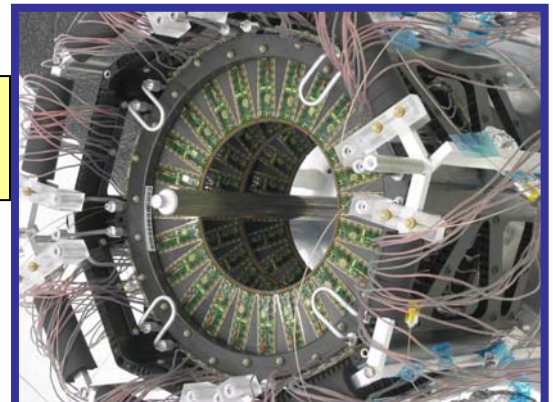


A problem in the cooling system(Feb.2007) will delay the installation of the end-cap units, pixels, ECT → critical path now



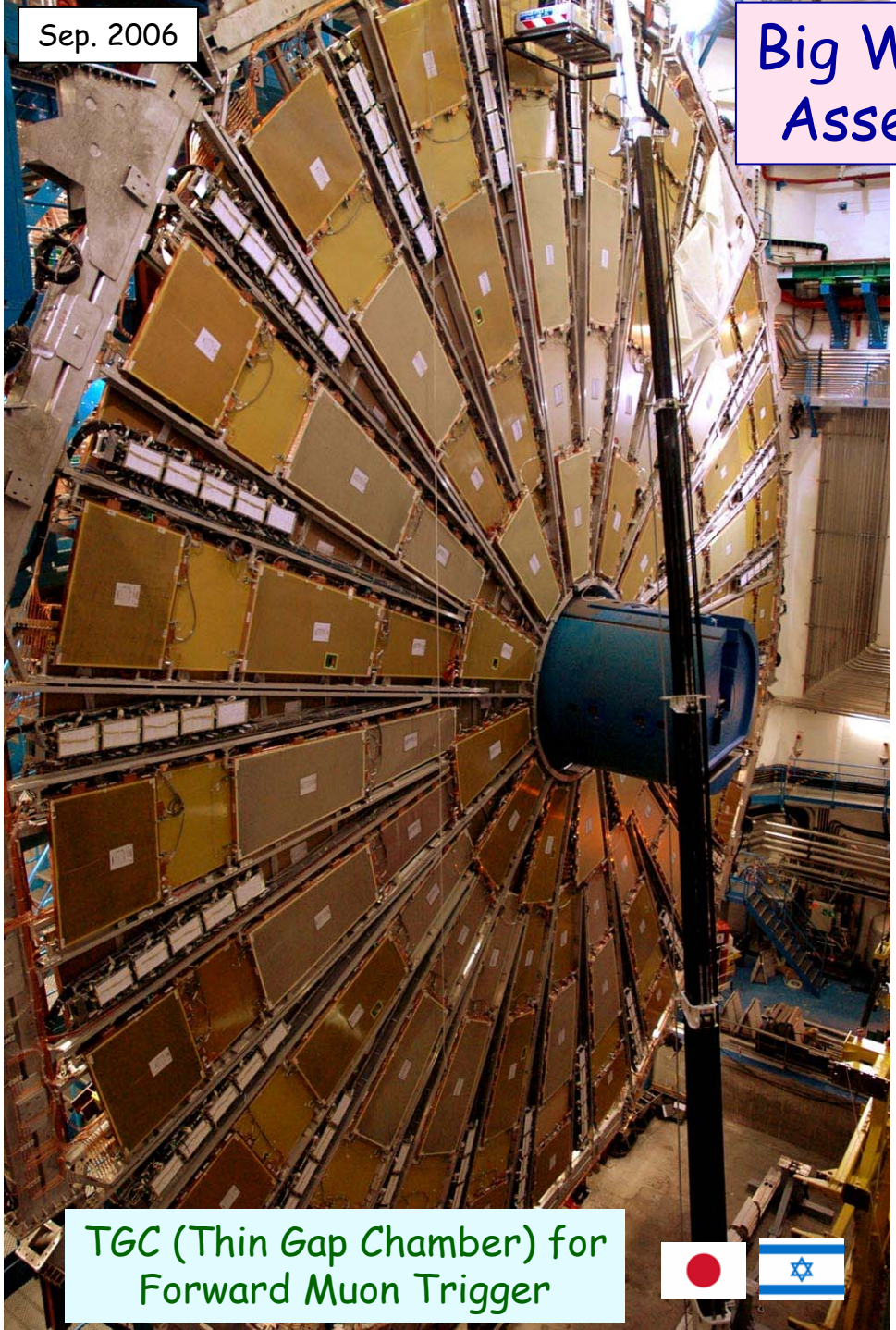
Central Solenoid:
fully commissioned (2T) in-situ in Aug. 2006, and field mapping meas. done

Three completed Pixel disks (one end-cap)



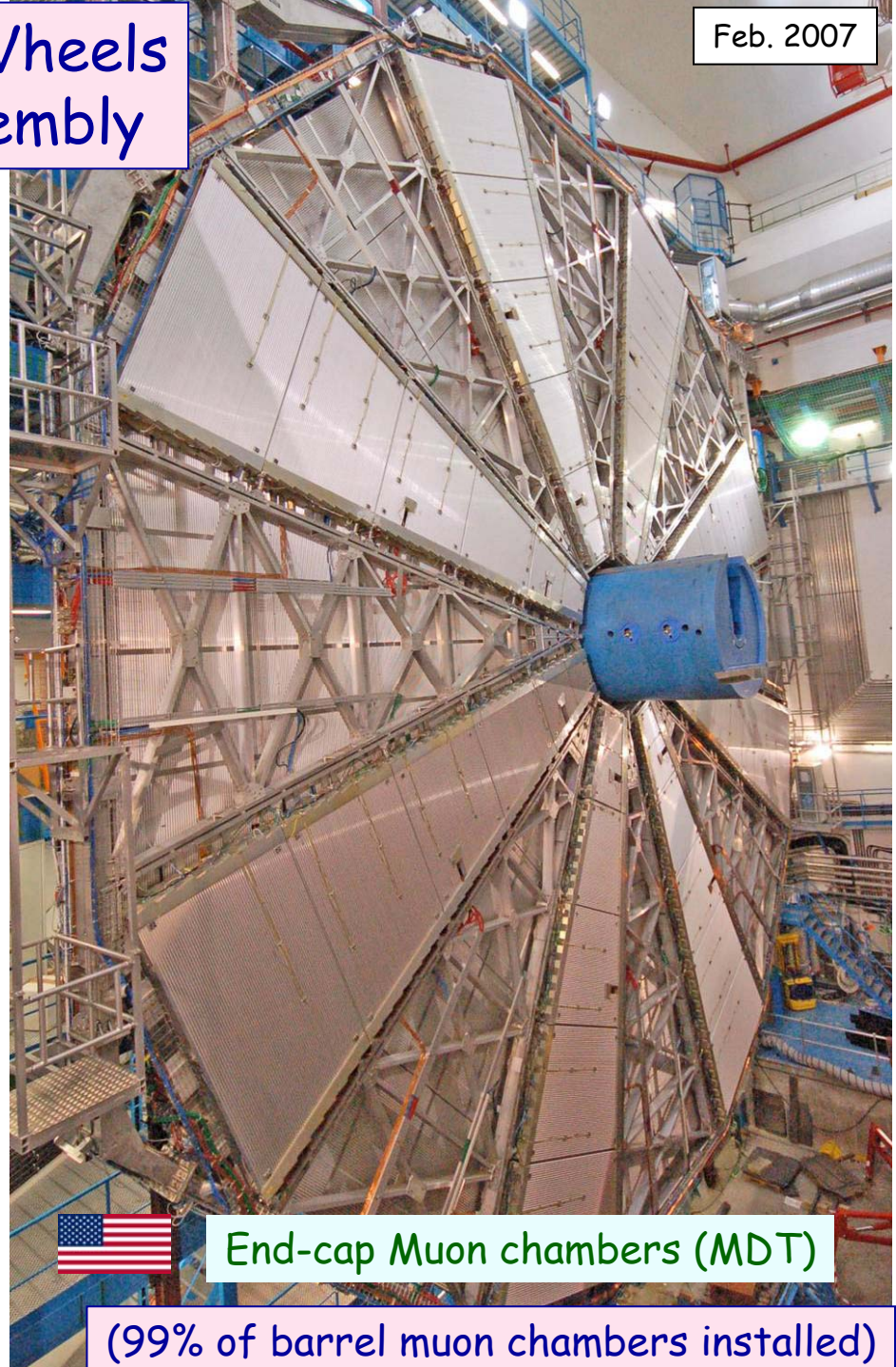
Big Wheels Assembly

Sep. 2006



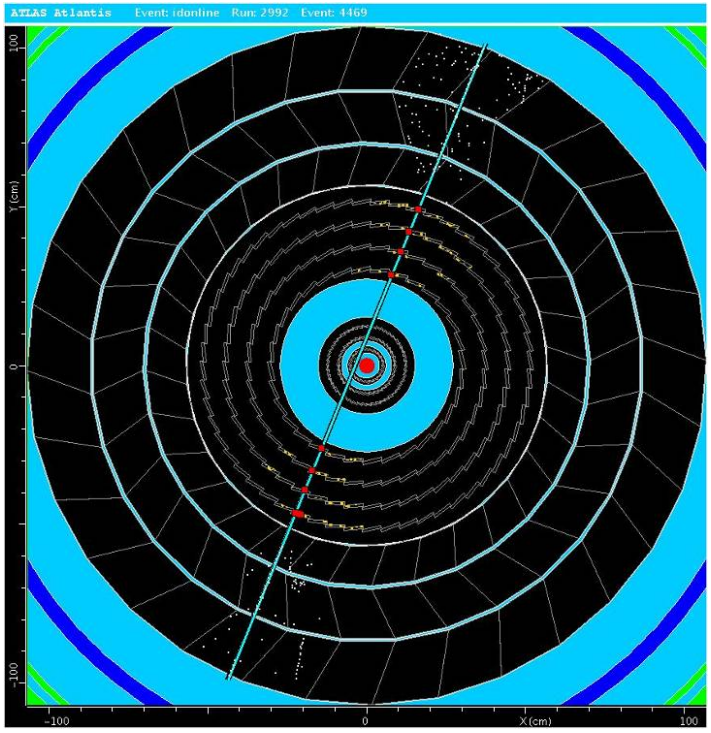
TGC (Thin Gap Chamber) for Forward Muon Trigger

Feb. 2007

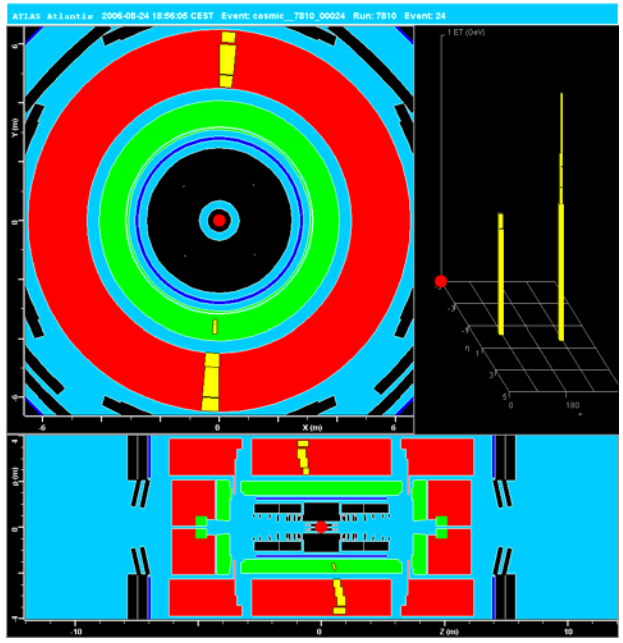


End-cap Muon chambers (MDT)

(99% of barrel muon chambers installed)

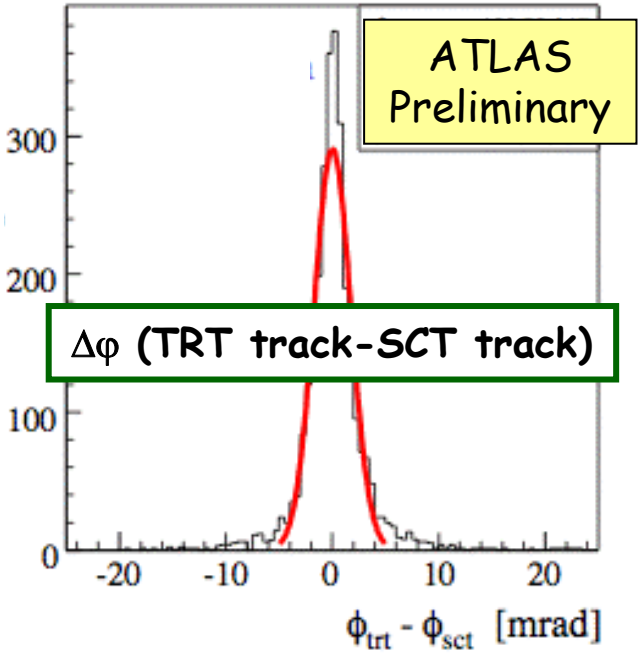


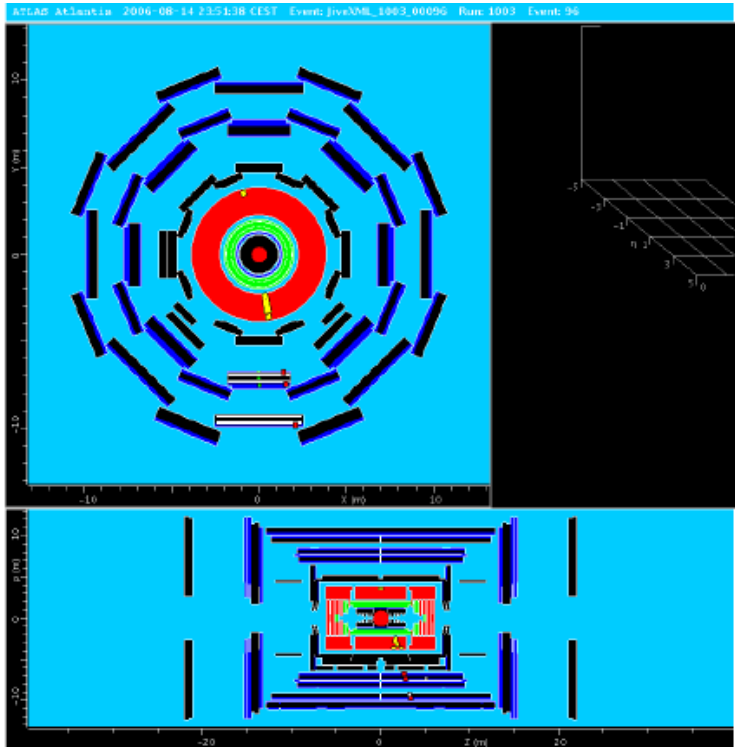
Cosmics data taken in barrel SCT+TRT

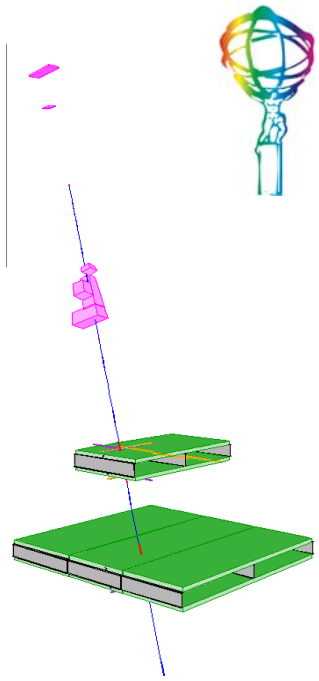


and in barrel LAr+Tile

and also in MDT+RPC(LVL-1)+Tile

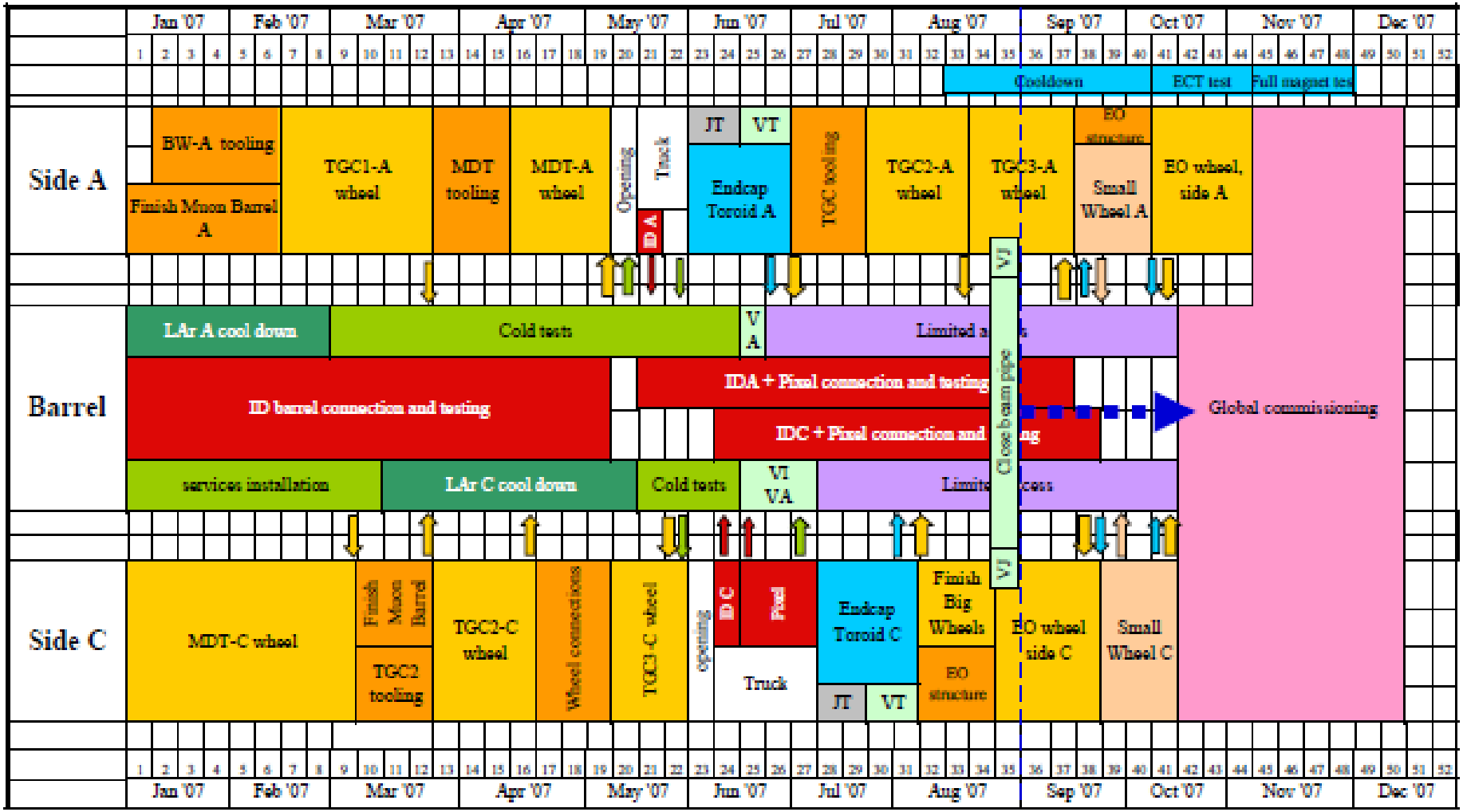


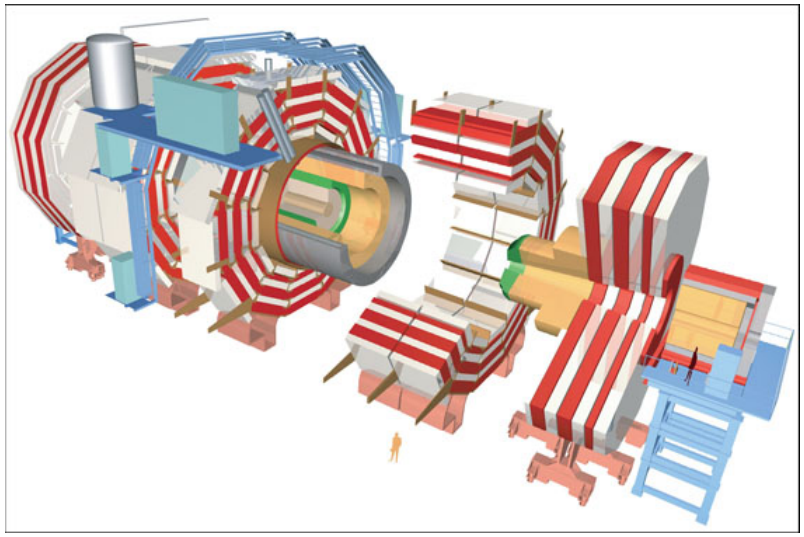




ATLAS Installation schedule version 9.1

20-Apr-2007

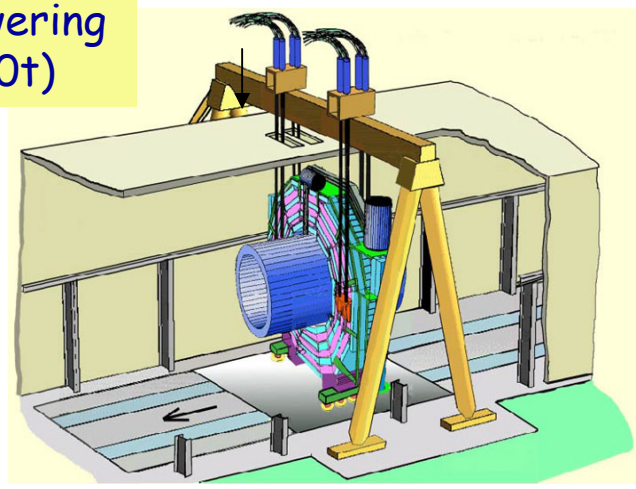




- Compact and modular
- Assembled at the surface and lowered in the cavern piece by piece by "gantry" crane

→ "15-piece jigsaw puzzle" (A. Ball)

YB0 lowering (2000t)



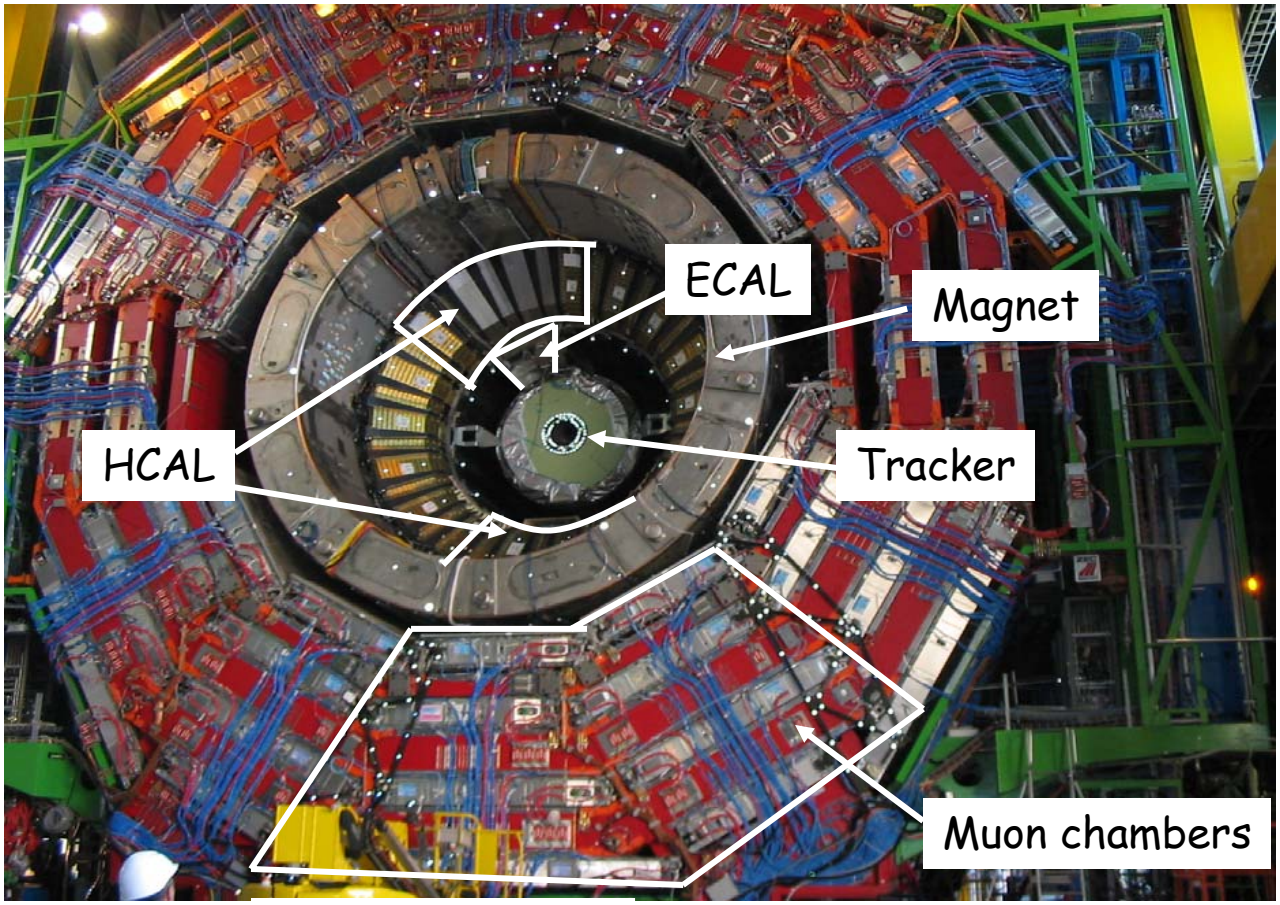
ATLAS

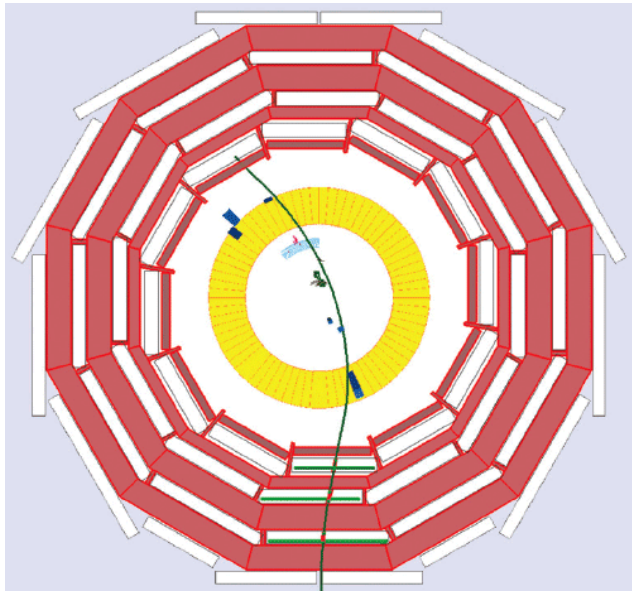
Magnet Test and Cosmic Challenge (MTCC)

Cosmics run of a ~full detector slice (few percent of CMS coverage) inside 4T field.

Test: detector installation and closing; magnet commissioning and field map; combined operation of full chain detector-electronics-DAQ-trigger-DCS-software identical to final experiment; timing, calibration, alignment procedures

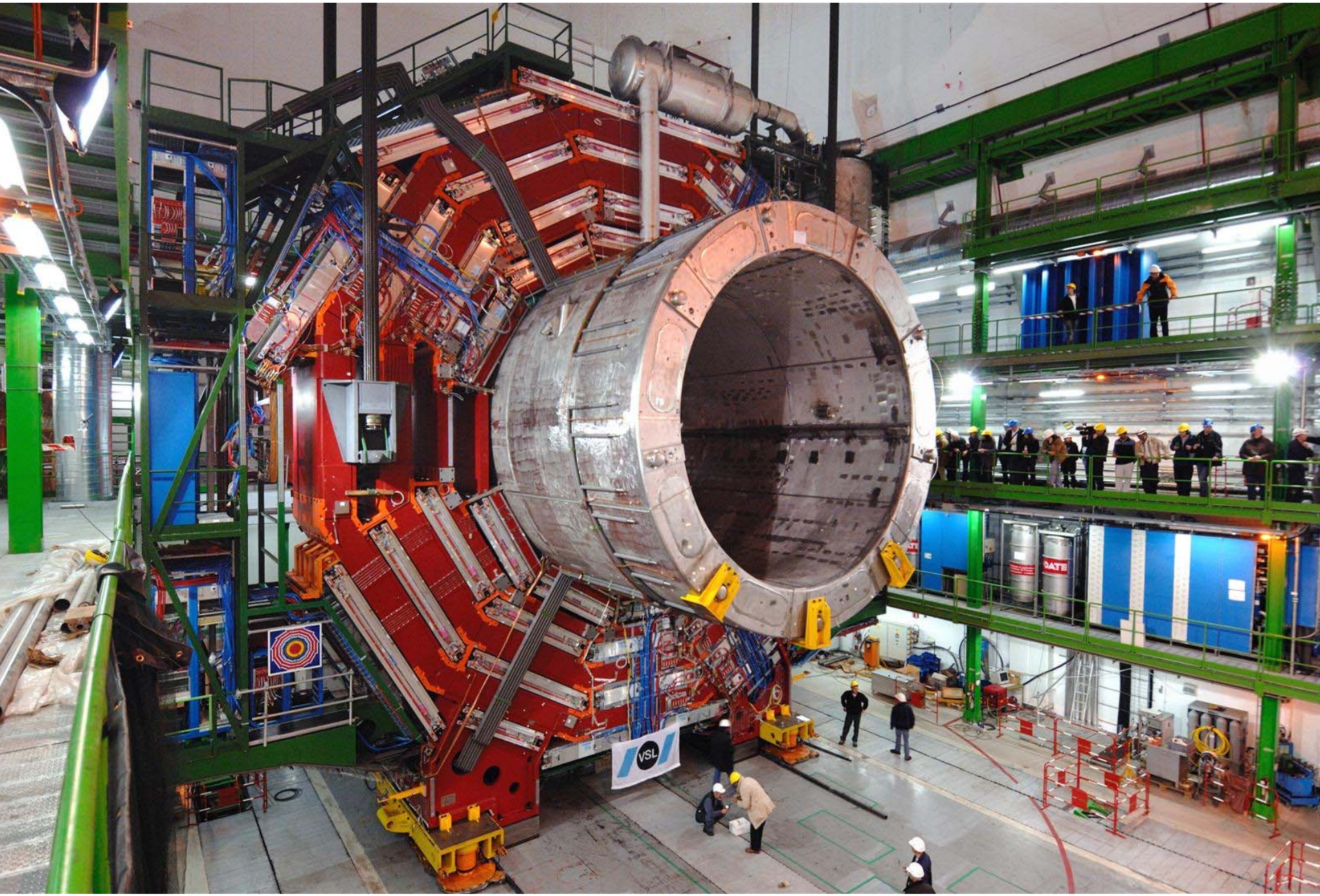
→ very successful
→ now playing "jigsaw puzzle"





A cosmic track recorded at full field(4T) in a "slice" of CMS detector (Aug. 2006)

YB0 landing in the CMS experimental hall (28. Feb. 2007)



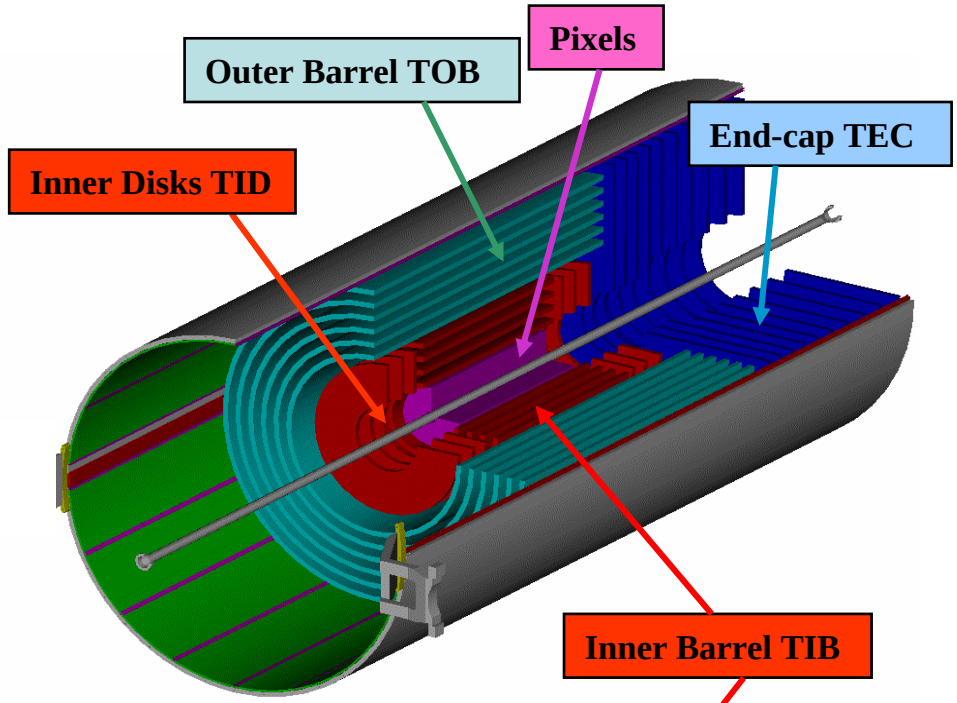
Inner tracker:

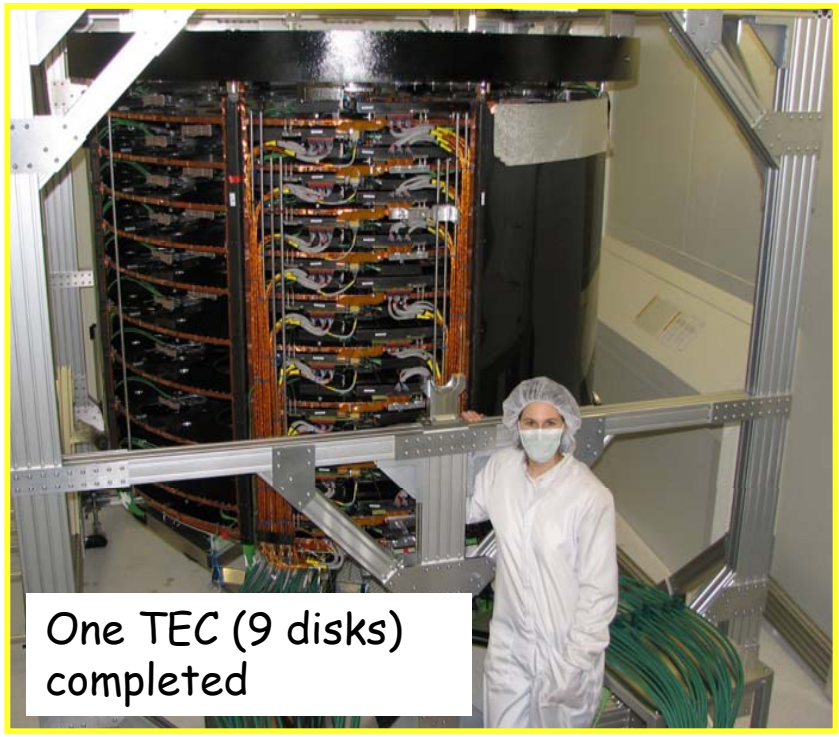
~ 220 m^2 of Si sensors
10.6 million Si strips
65.9 million Pixels

("16-th piece")

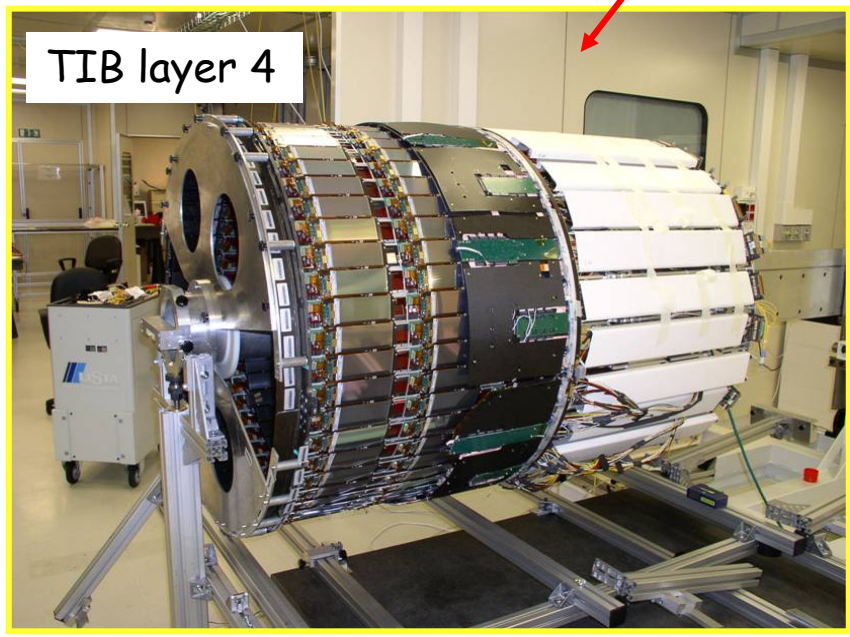
- Assembly of all 16000 modules completed
- Integration finished and commissioning with cosmics on-going
- Installation at Point 5 in Aug. 2007

(Pixel detector will be installed in the first quarter of 2008, and be ready for the first physics run in 2008.)





One TEC (9 disks) completed



TIB layer 4

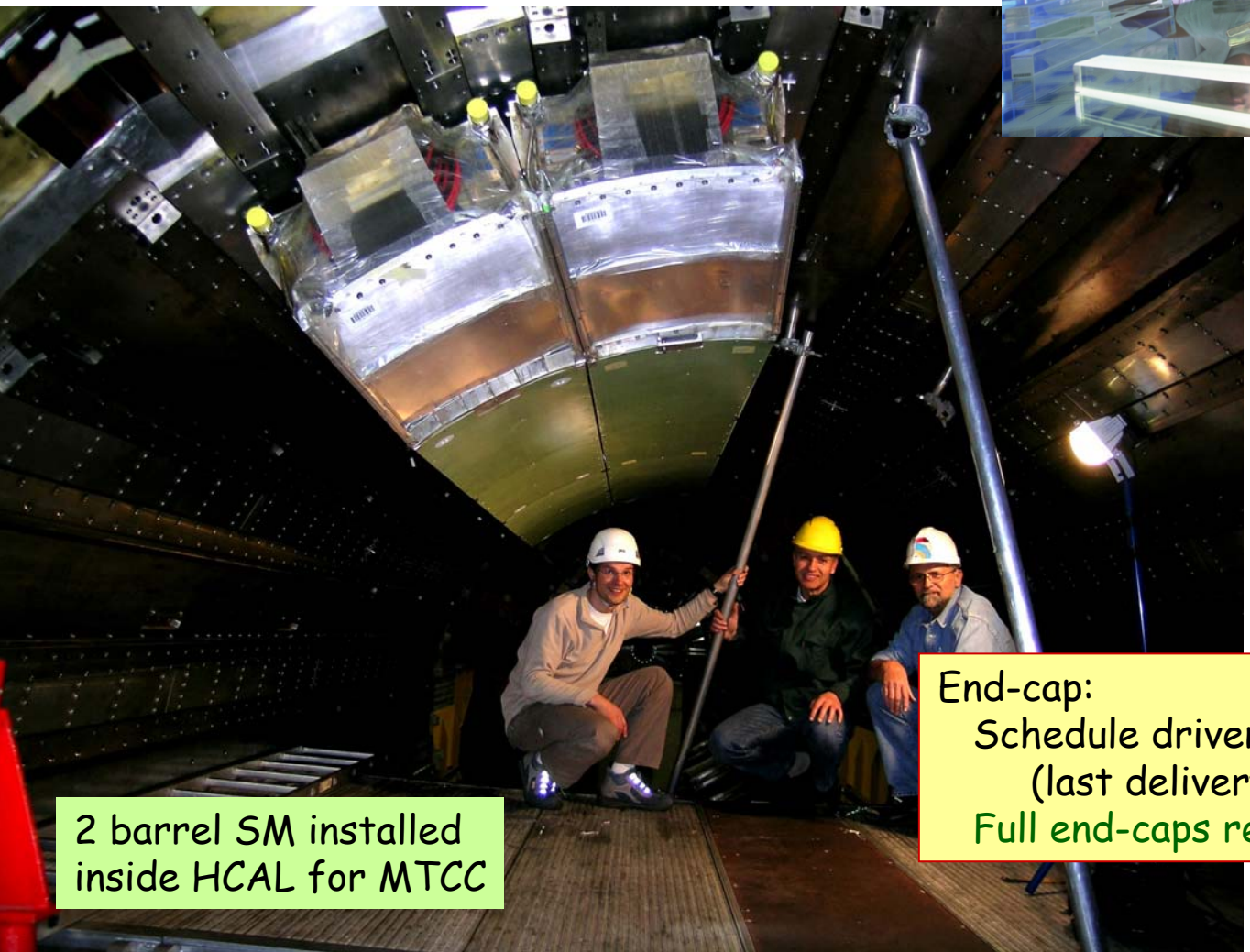
Electromagnetic calorimeter

Barrel :

All 61200 crystals delivered

35 (out of 36) SuperModules (SM) assembled

All SM will be installed undeground by end-June.



2 barrel SM installed inside HCAL for MTCC

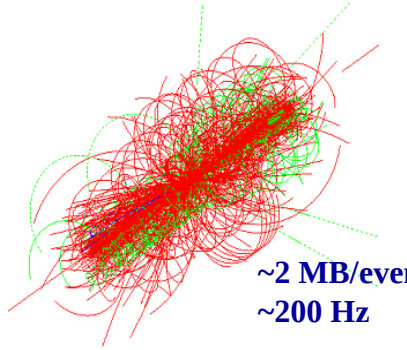
Critical item

End-cap:

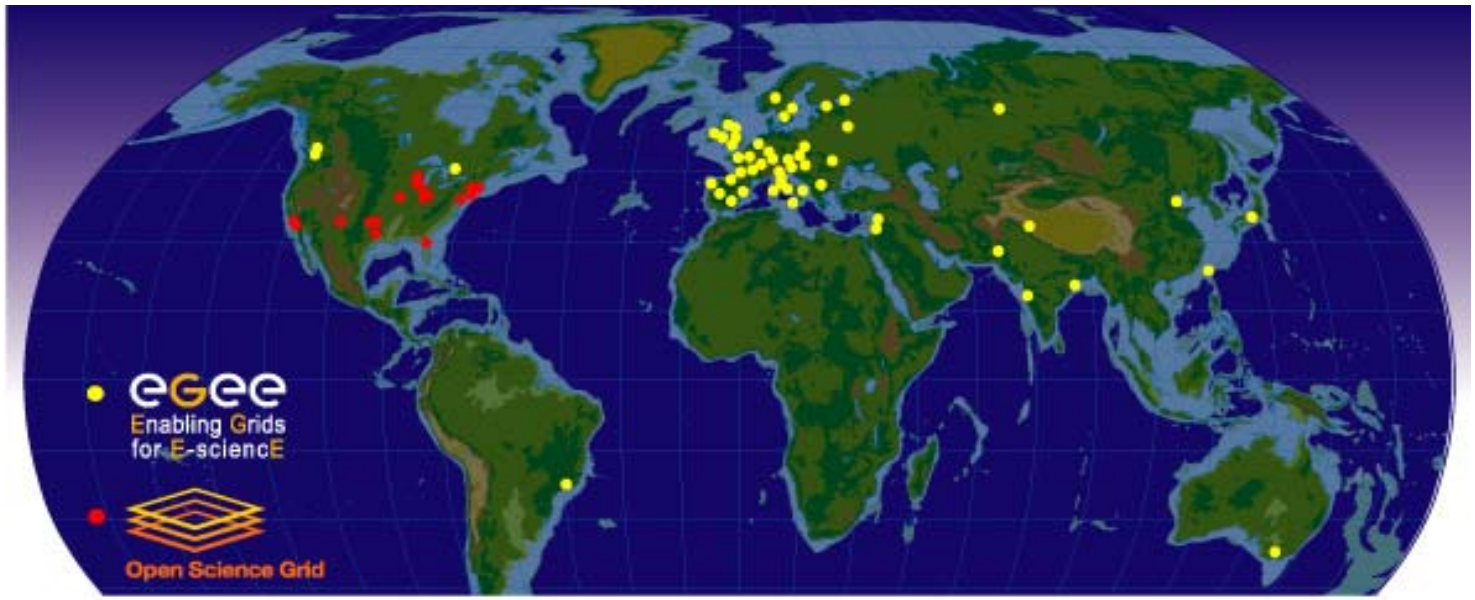
Schedule driven by crystal delivery (last delivery in Feb.2008)

Full end-caps ready for 2008 physics run

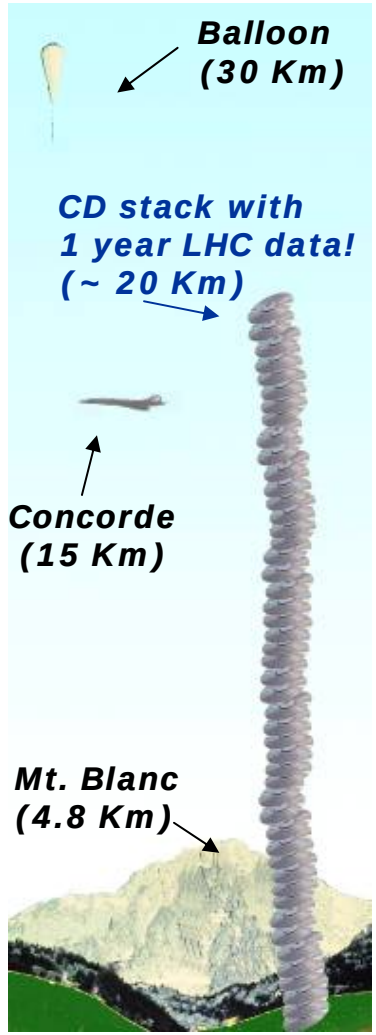
WLCG Collaboration



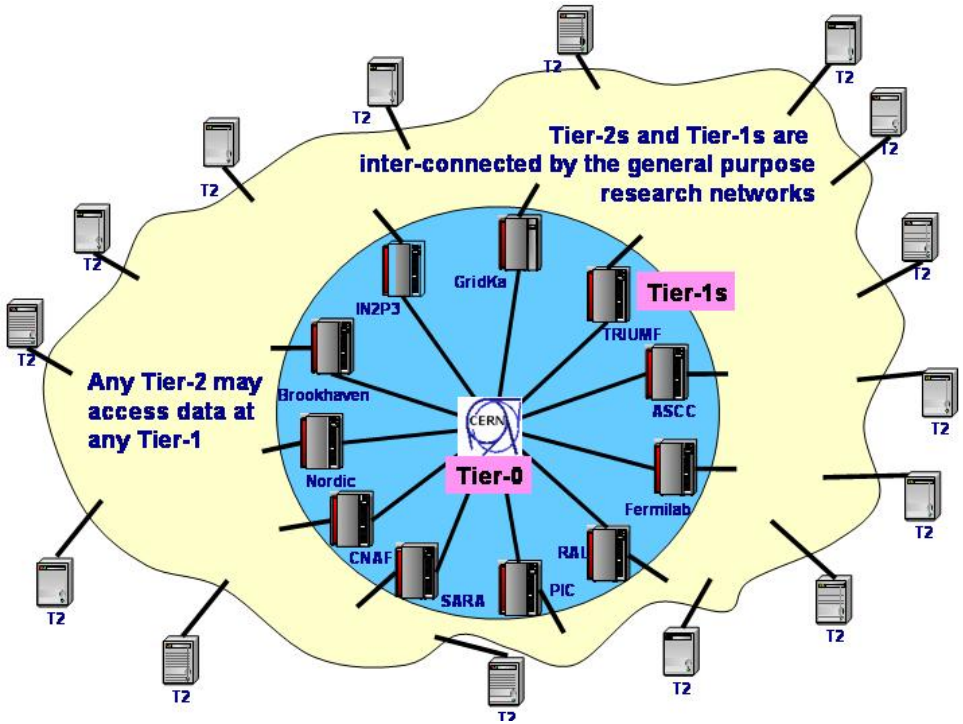
- 4 LHC experiments (→ large amount of data)
- ~120 computing/analysis centers in ~40 countries
- Computing grid infrastructures:
  EGEE, OSG, Nordic Grid
  (→ Interoperability is crucial.)



A map of the worldwide LCG infrastructure operated by EGEE and OSG.



WLCG: Distribution of Computing Services

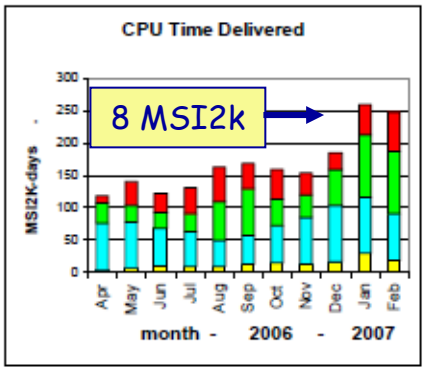


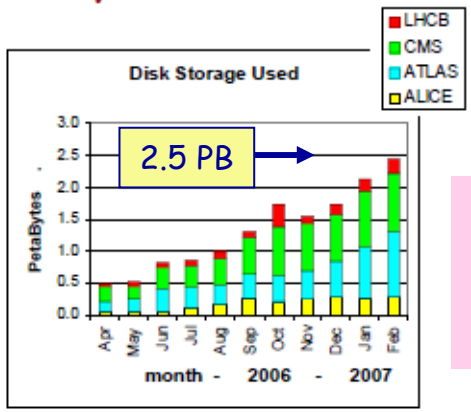
Tier-0 (CERN)
- Data acquisition & initial processing
- Data storage
- Distribution of data → Tier-1 centers

Tier-1 (11 centers)
- Data-heavy analysis
- Data storage

Tier-2 (~100 centers in ~40 countries)
- Simulation
- End-user analysis

Grid Activity





× 2 (end 2007)
× 3 (mid 2008)
...

... distributed in all over the world

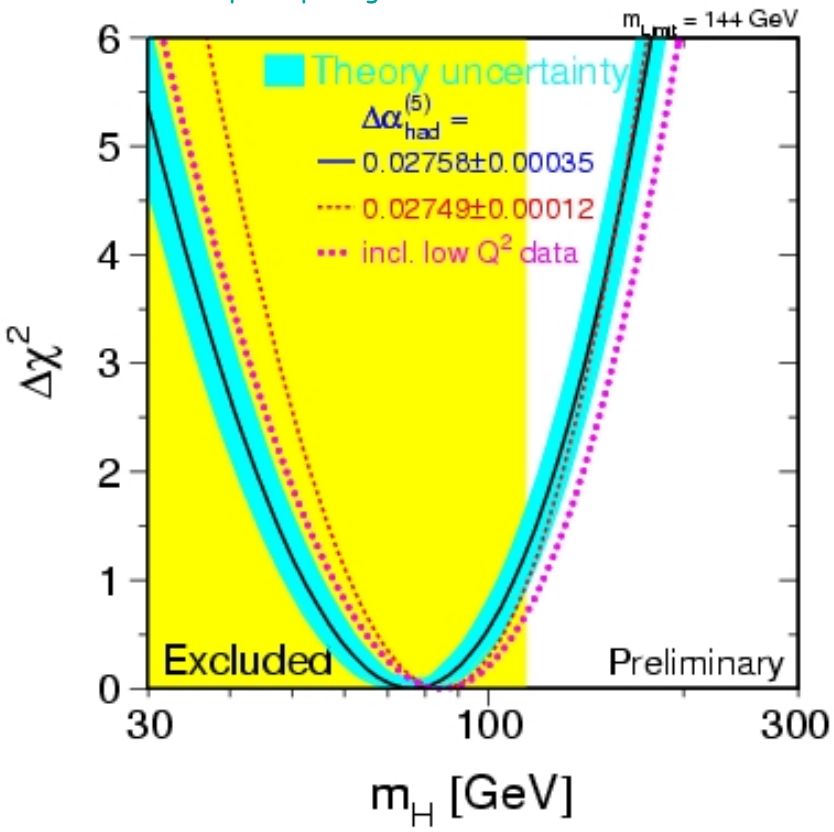
Tier-1s and CERN
- CPU usage increased by factor of 2 over past year
- Disk usage by a factor of 4.9

Facing another big challenge!

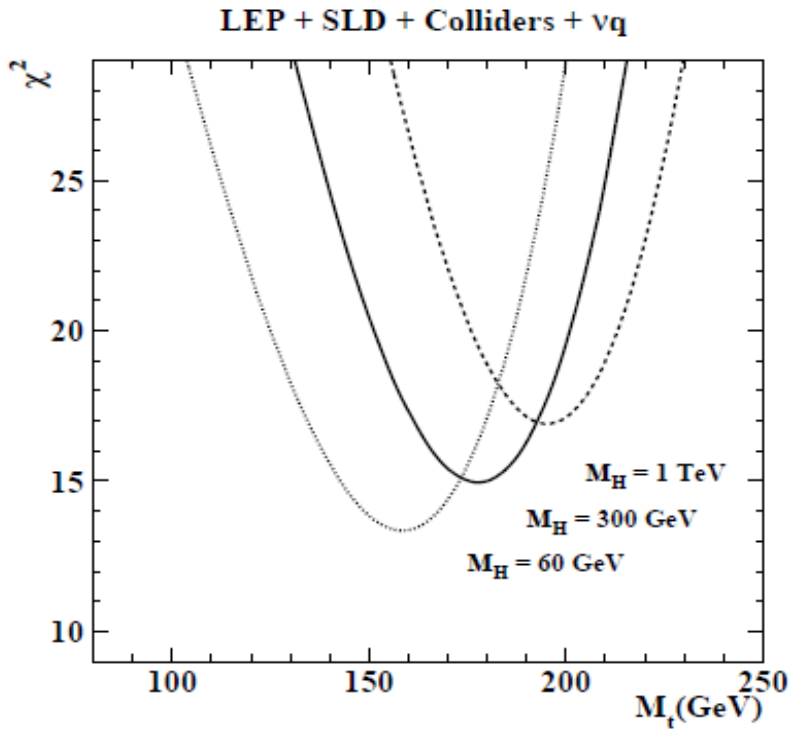
SM Higgs Boson Search

Higgs boson mass (Mar.2007)

http://lepewwg.web.cern.ch/LEPEWWG/



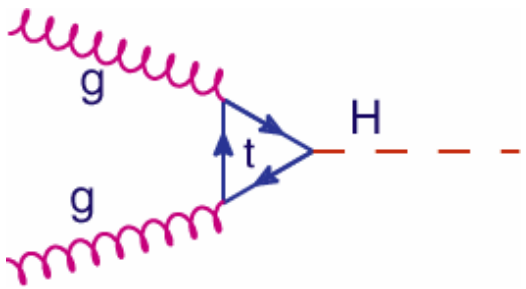
Top quark mass (1994)

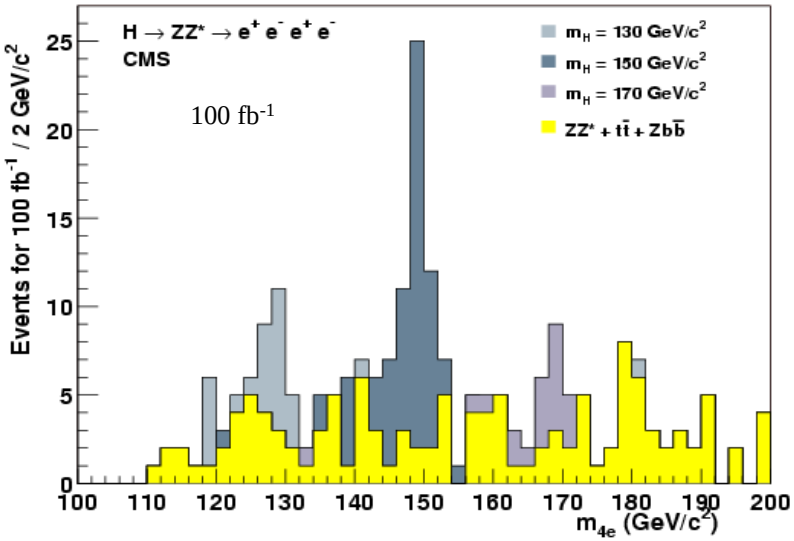


Now, Higgs boson mass is lower:
m_H between 114 GeV and 144 (182) GeV

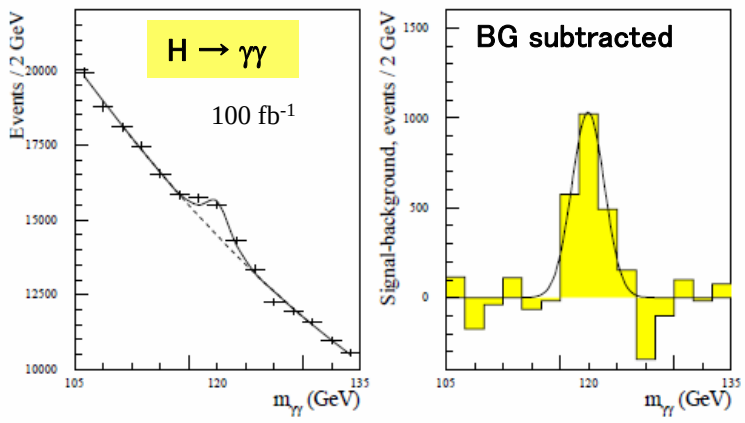
Maybe history repeats ···

If history repeats, ···

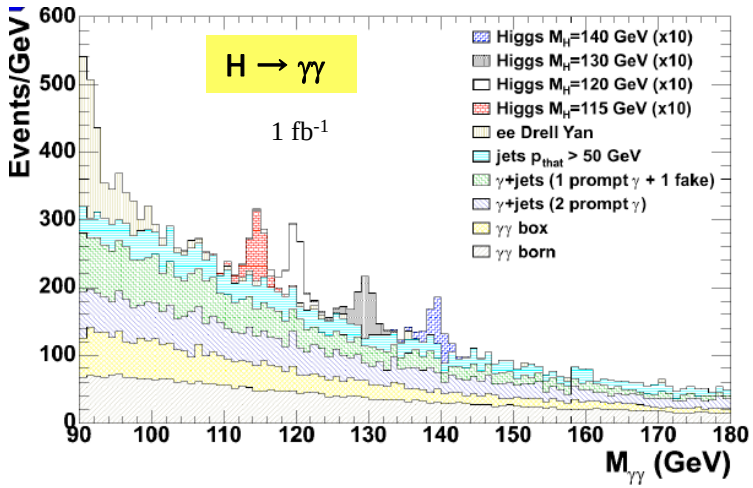




ATLAS Physics TDR (May 1999)

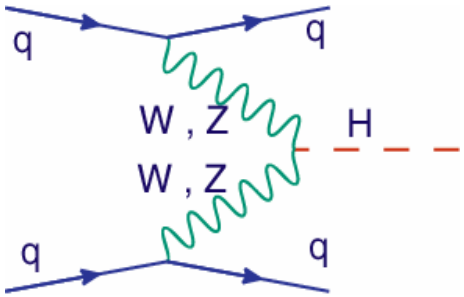


CMS Physics TDR (June 2006)



Vector Boson Fusion Process

D.L.Rainwater, D.Zeppenfeld, K.Hagiwara (1999)

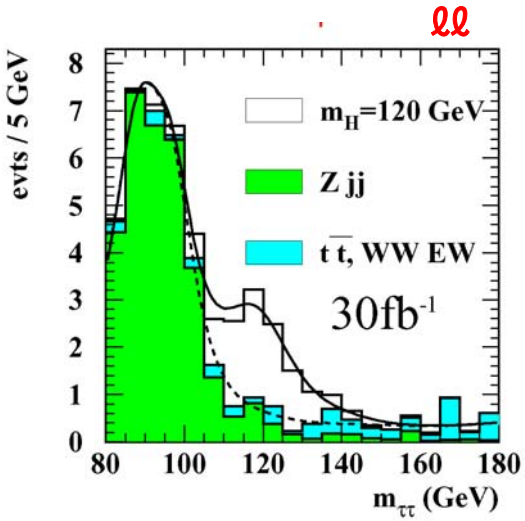


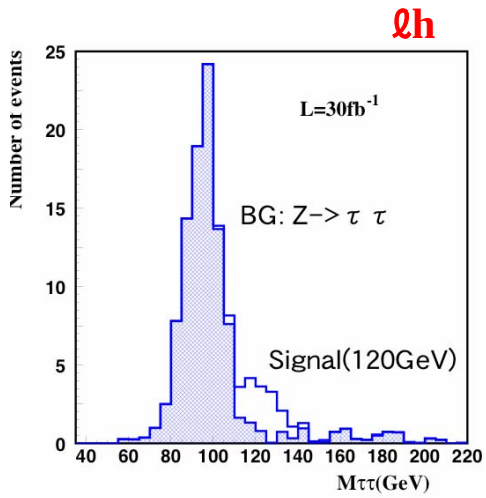
Feature of VBF Process:

- Cross-section is lower than the gluon fusion process
- High P_T jet in the forward region
- Higgs decay products observed in the central rapidity gap (no color flow)

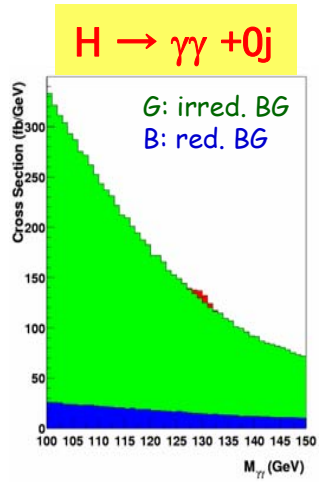
➔ Large reduction of background

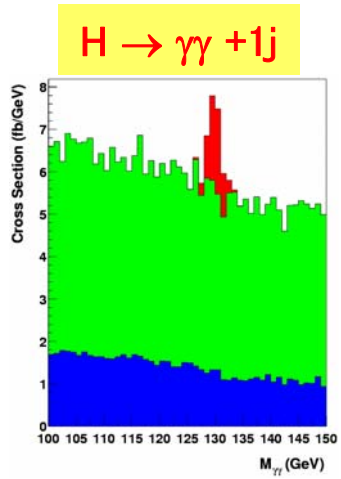
$qq\,H \rightarrow qq\,\tau\,\tau$
$\rightarrow qq\ \ell\nu\nu\ \ell\nu\nu$
$\rightarrow qq\ \ell\nu\nu\ h\nu$

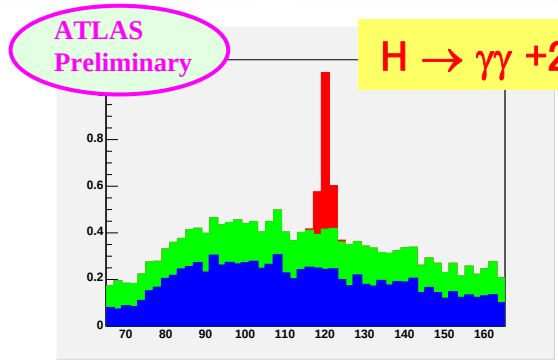




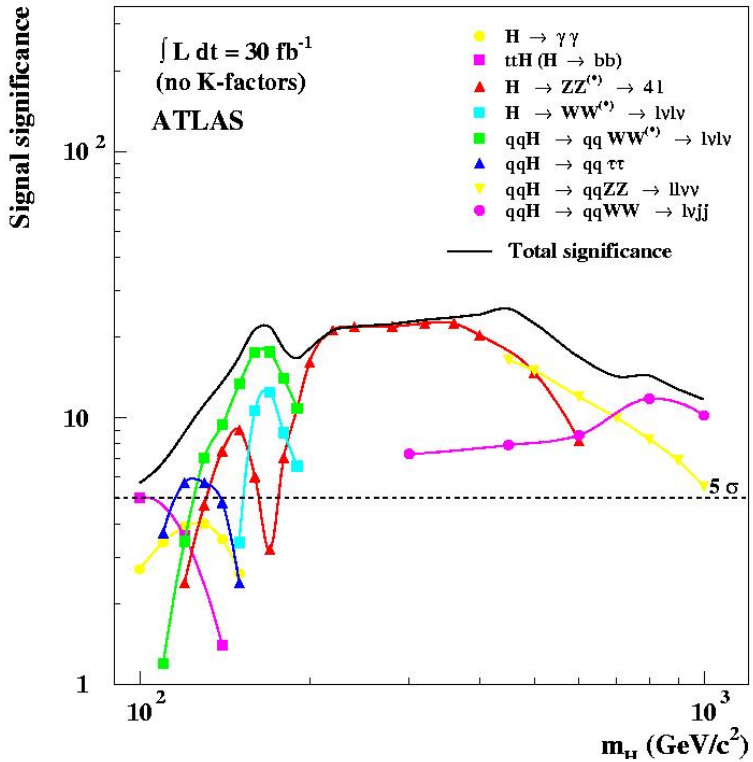
ATLAS

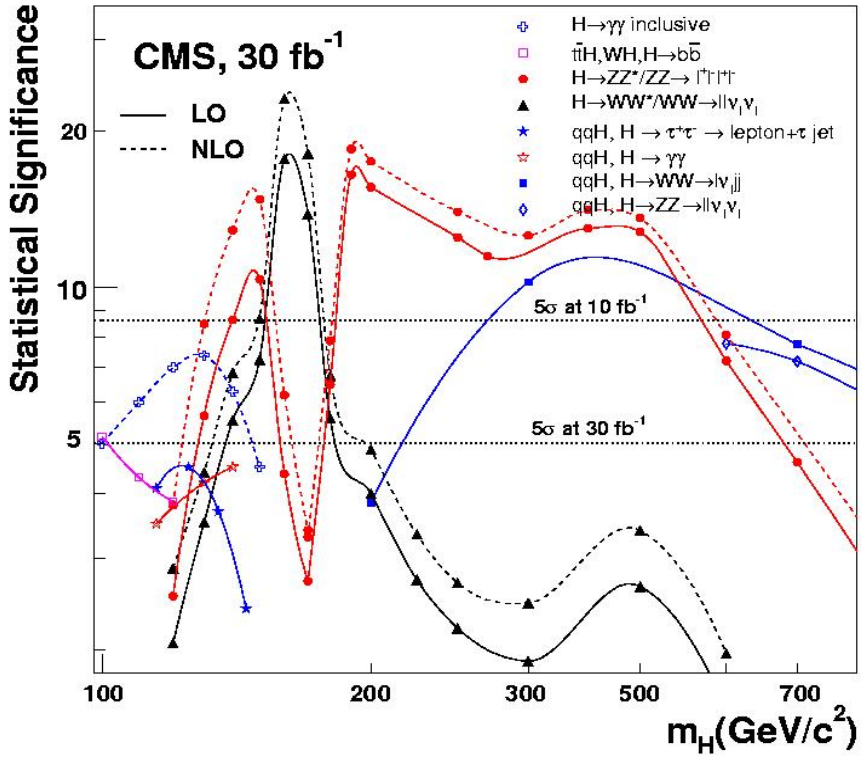




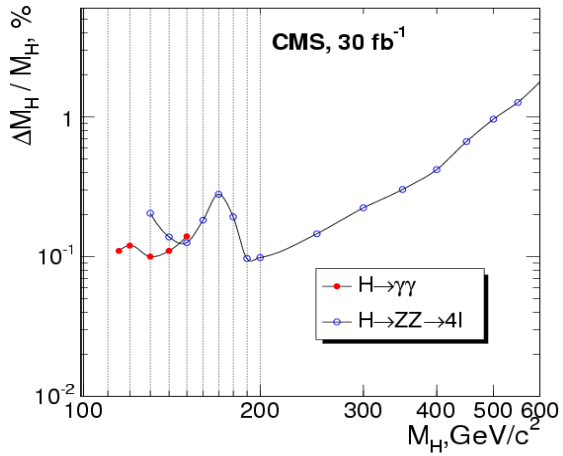


SM Higgs boson discovery would be made in early years of LHC run (2009/2010?)

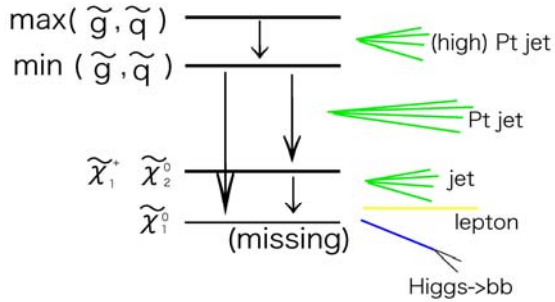


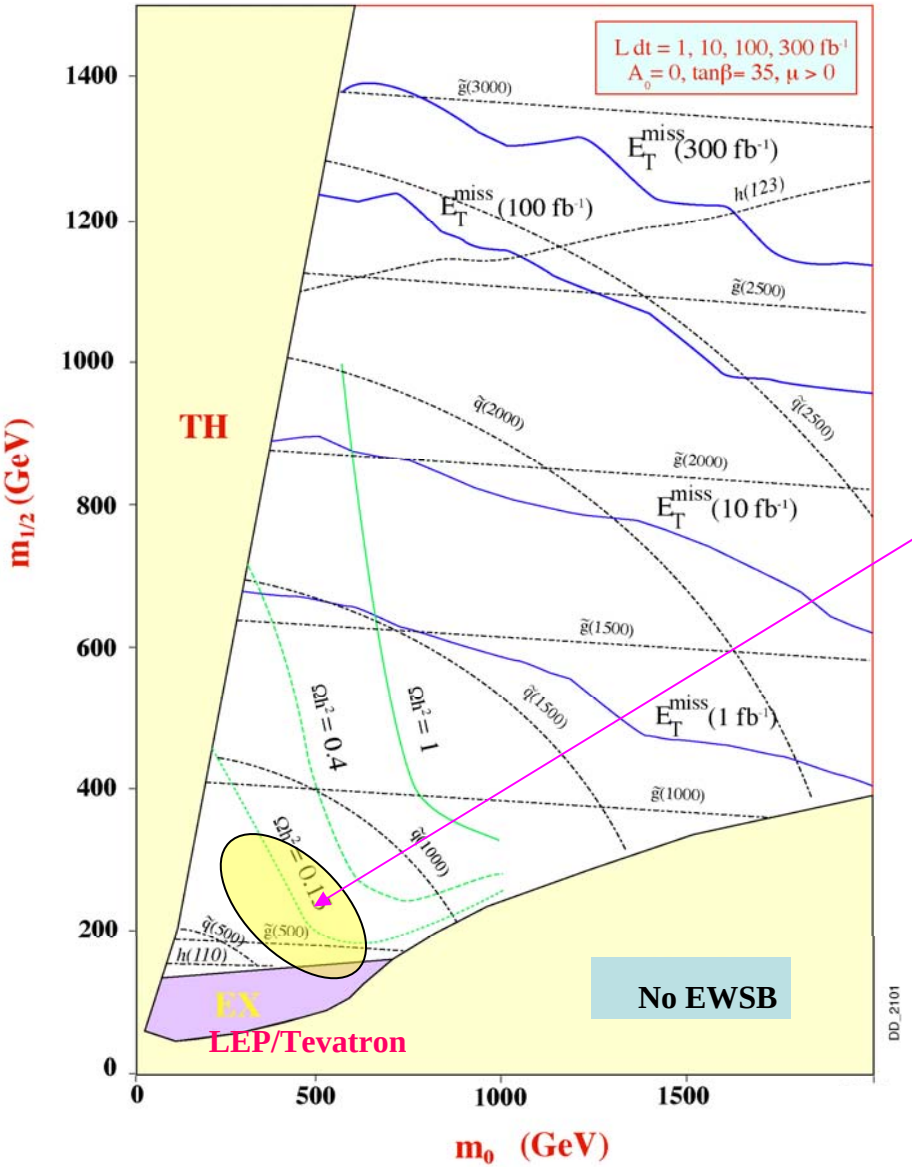


For low mass Higgs, studies of various decay channels are possible, as well as the measurements of mass, ...



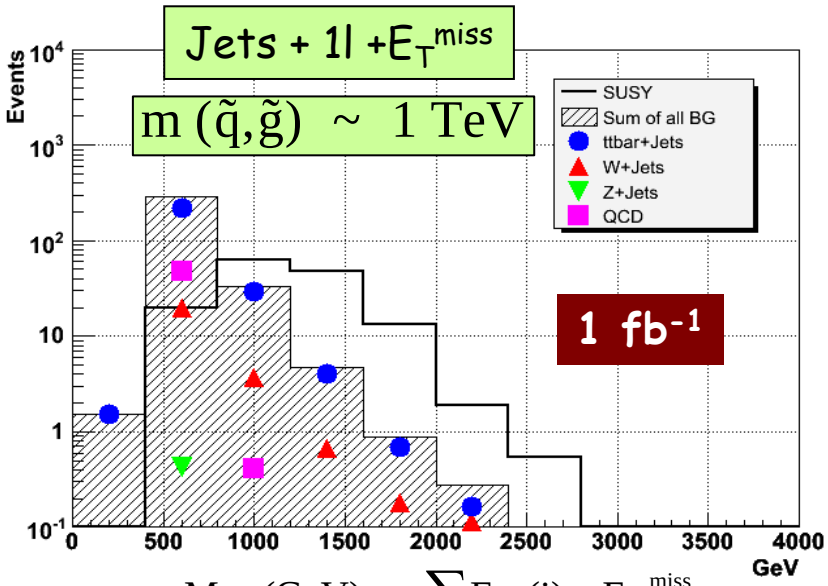
Discovery Potential of SUSY (mSUGRA)





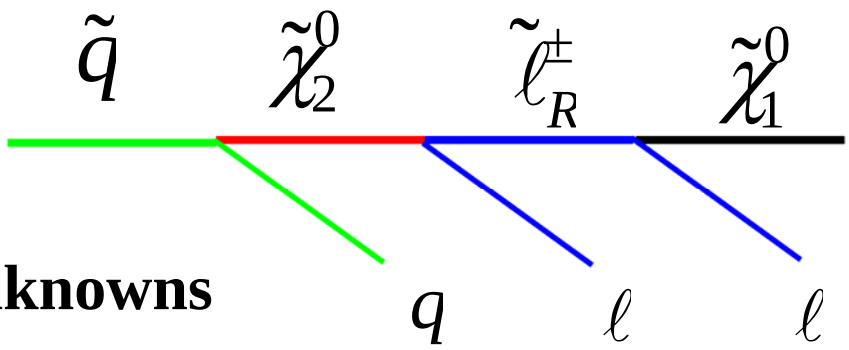
- If low energy Supersymmetry exists, LHC will almost certainly observe it
- Squarks and Gluinos detectable up to 2.5-3 TeV mass with 300 fb^{-1}

Need only a short time to cover the interesting region for Cold DM

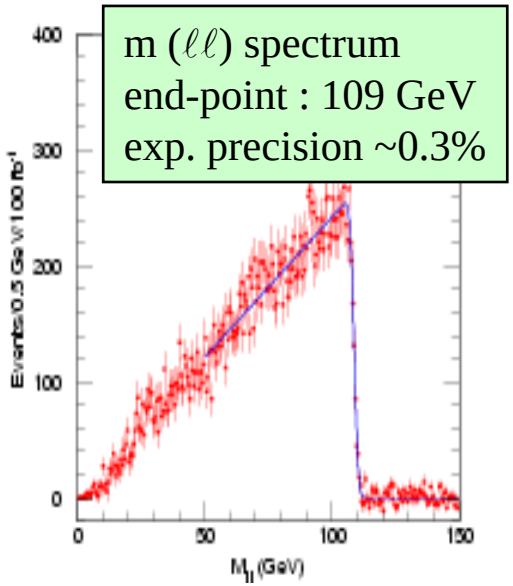


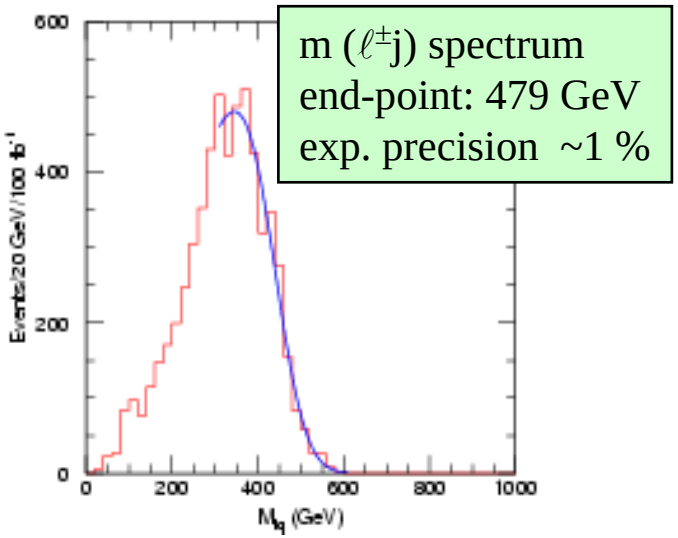
$$M_{eff}\ (\mathrm{GeV}) = \sum_{i=1,4} E_T\ (i) + E_T^{miss}$$

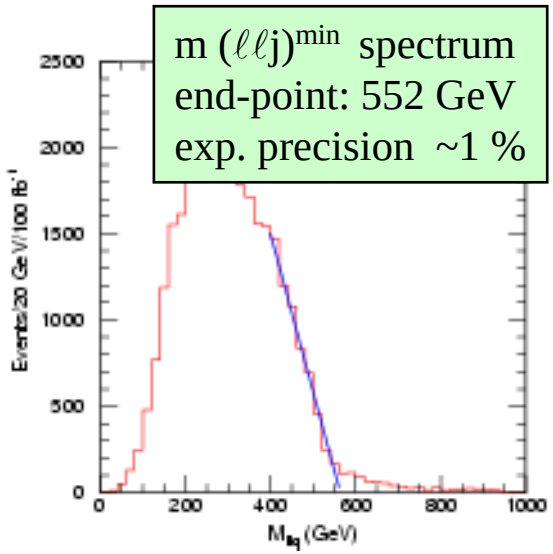
If we are lucky, ---

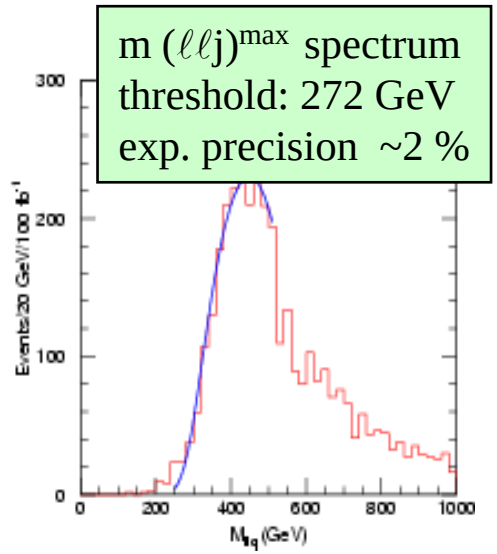


4 unknowns









4 constraints → We can determine the masses.
(3-12% for 700-800 GeV squark, gluino)

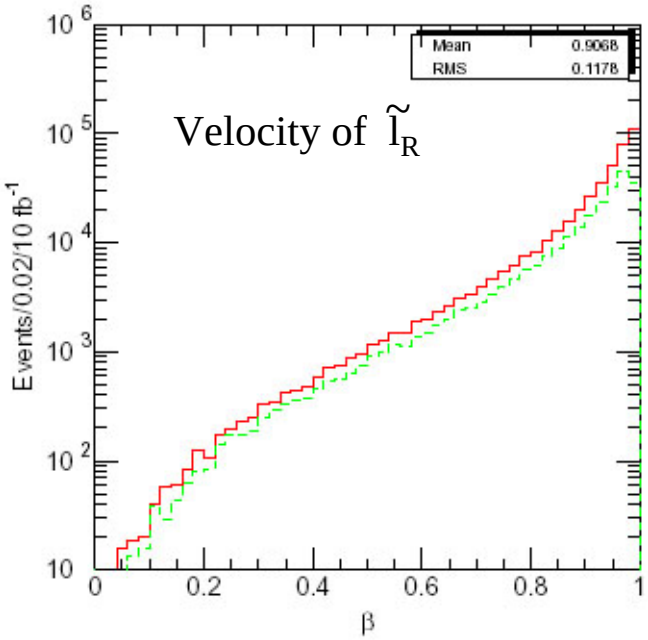
If we are very lucky, ---

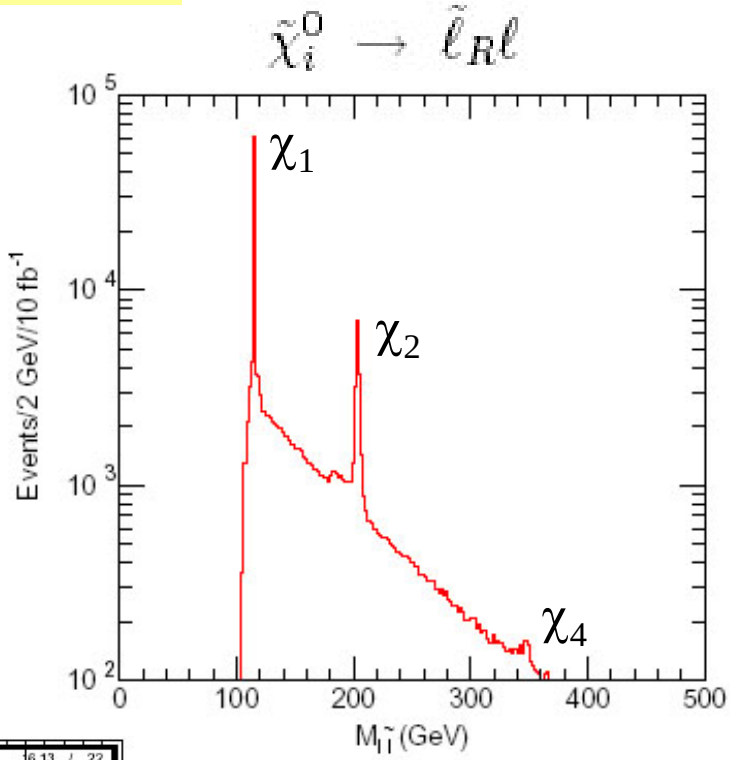
(GMSB scenario)

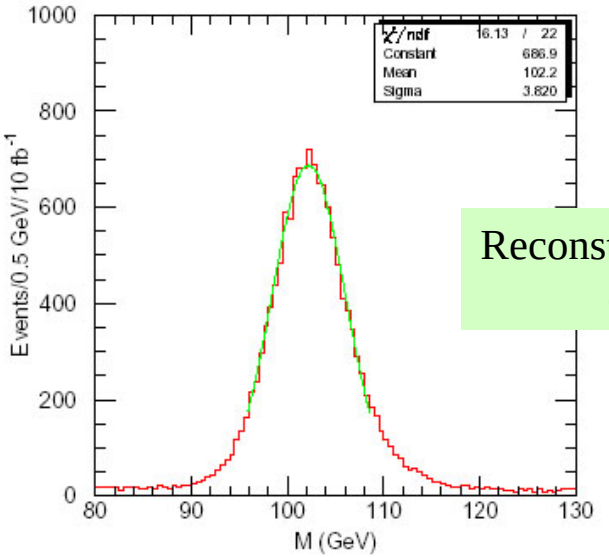
NLSP = $\tilde{\tau}_1$ and $c\tau \approx 1\,\mathrm{km}$

$\tilde{e}_R$ and $\tilde{\mu}_R$ are also long-lived

➔ stable heavy charged leptons



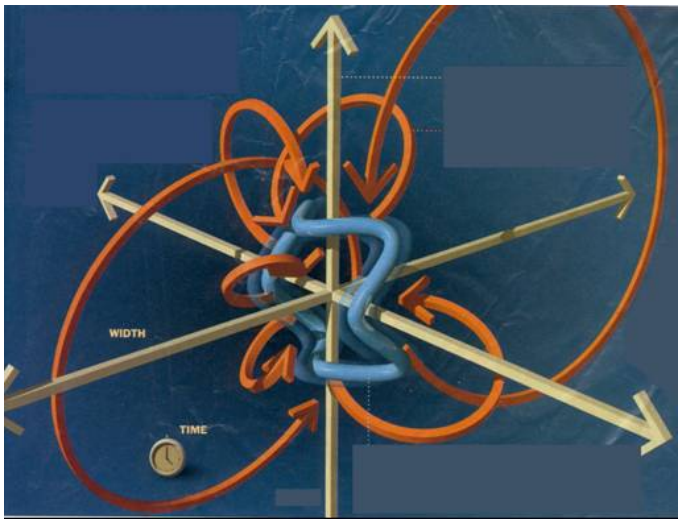




Reconstructed slepton mass
σ_M / M ~ 4%

ATLAS MDT → σ_t ~ 1ns

Extra Dimensions
(TeV scale gravity)



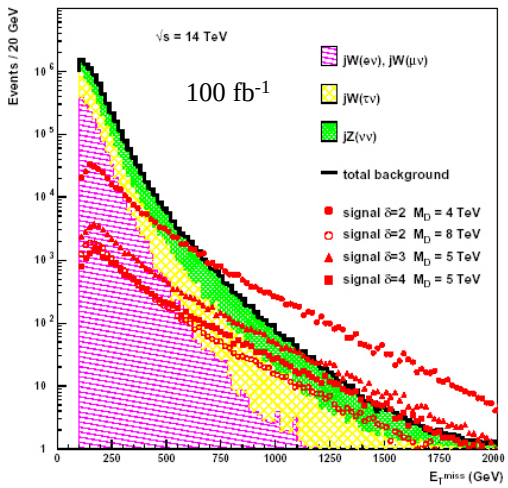
Large Extra Dimensions (ADD)
- Gravity in bulk / flat space
- Missing energy / interference / black holes

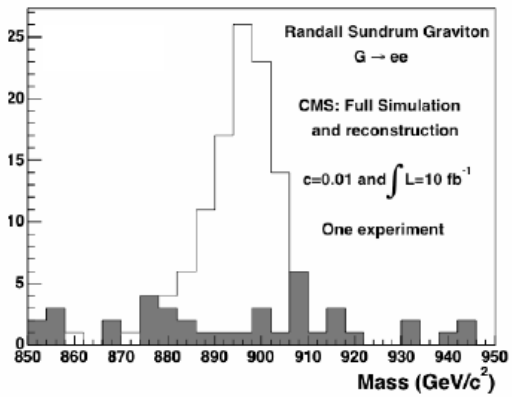
Warped Extra Dimensions (RS)
- Gravity in bulk / curved space
- Spin 2 resonances in >TeV range / black holes

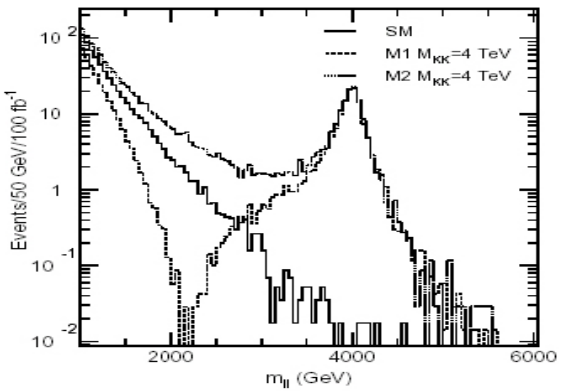
TeV Scale Extra Dimensions
- Gauge bosons / Higgs in bulk
- Spin 1 resonances in >TeV range
- Interference with Drell-Yan

Universal Extra Dimensions
- Everybody in the bulk!
- Fake SUSY spectrum of KK states

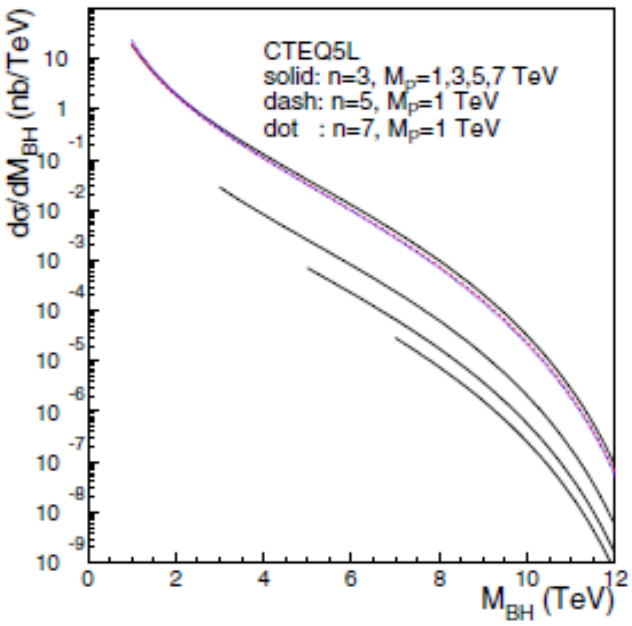
$E_T(jet) > 1$ TeV

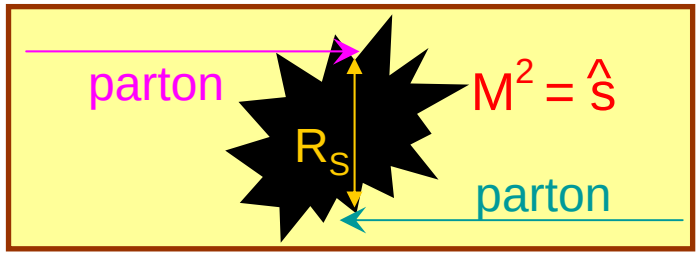




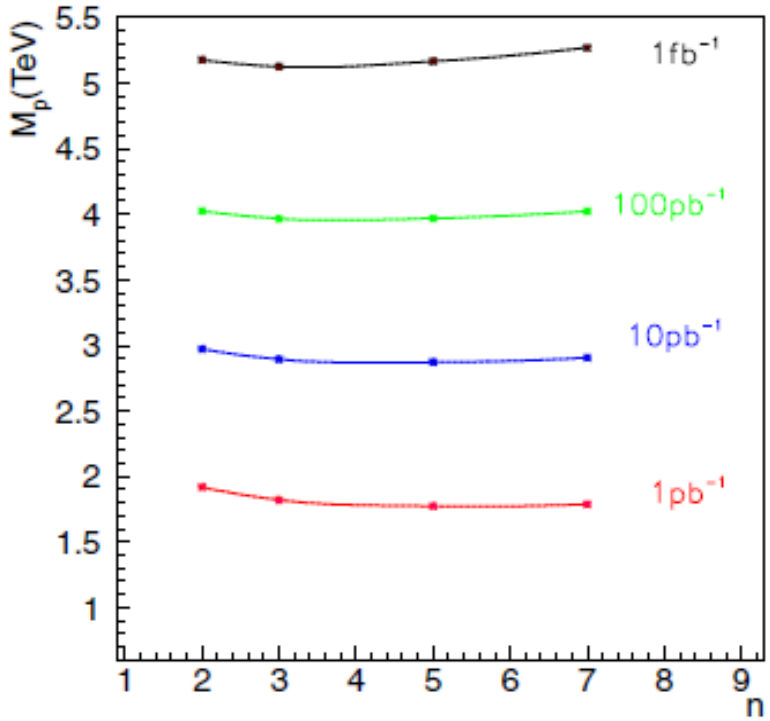


Black Hole Production at LHC

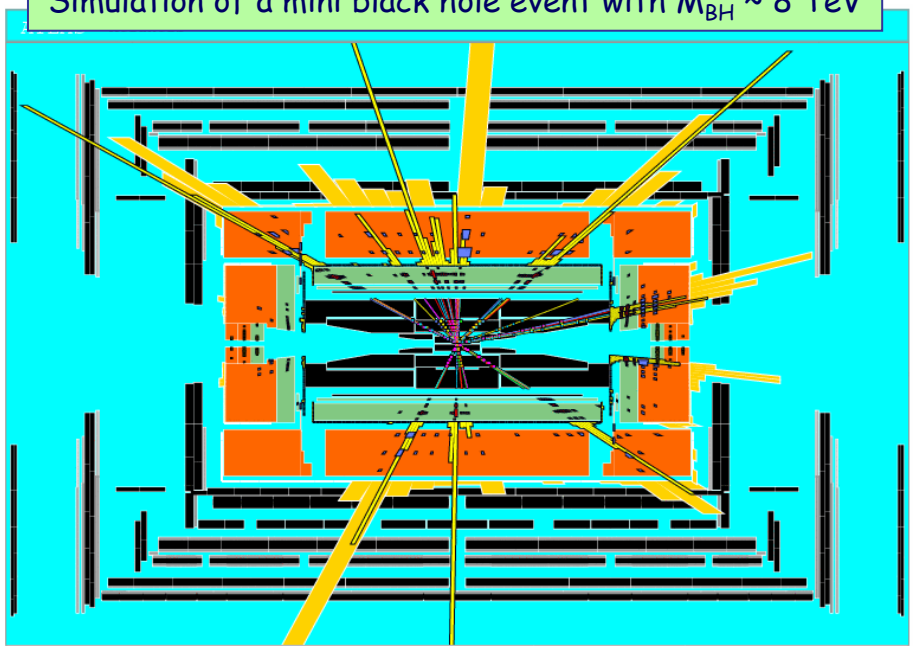




Contours of int. luminosity in (M_p, n) plane



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



→ Leading to the study of quantum gravity

Summary of LHC New Physics Reach

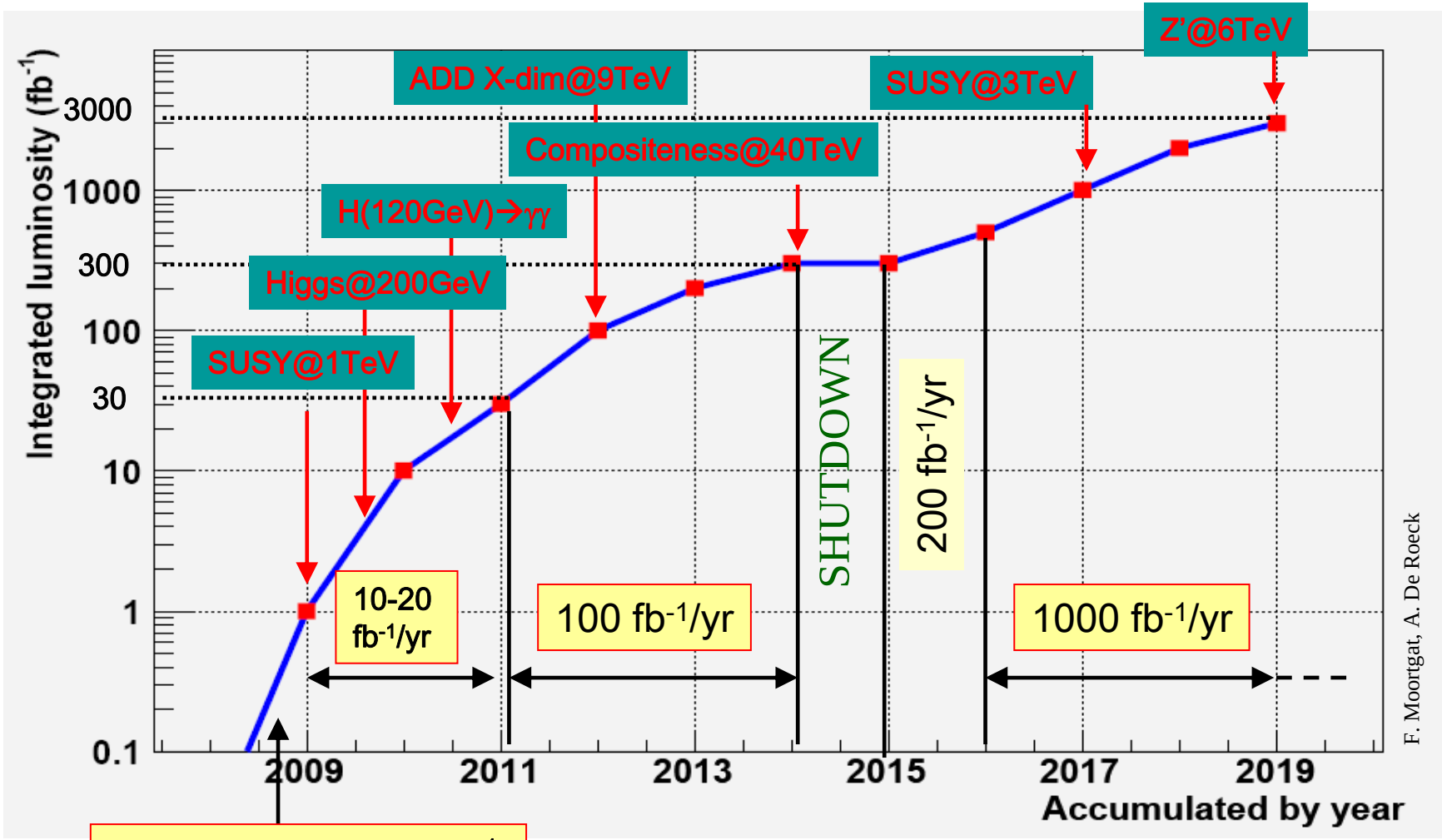
SM Higgs	100 GeV ~ 1 TeV
MSSM Higgs	covers full (m_A, tanβ)
SUSY (squark, gluino)	2.5 - 3 TeV (300 fb^{-1})
New gauge bosons (Z')	< 4.5 TeV (100 fb^{-1})
Quark substructure (Λ_C)	< 25/40 TeV (30/300 fb^{-1})
q*, l*	< 6.5/3.4 TeV (100 fb^{-1})
Large ED (M_D for n=2,4)	< 9/5.8 TeV (100 fb^{-1})
Small ED (M_C)	< 5.8 TeV (100 fb^{-1})
Black holes	< 6 ~ 10 TeV
M(top quark)	σ_M ~ 1 GeV (~ 0.5 %)
M_W	σ_M ~ 15 MeV
CP-violation in B-decay	σ(sin2β) ~ 0.016 (30 fb^{-1})
Rare B-decay ($B_S \rightarrow \mu\mu$)	~ 5σ (130 fb^{-1})

→ Discovery for sure + some measurements

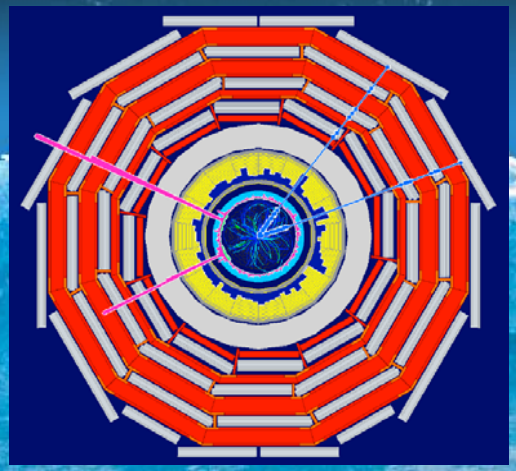
→ can say "final word" about (low E) SUSY

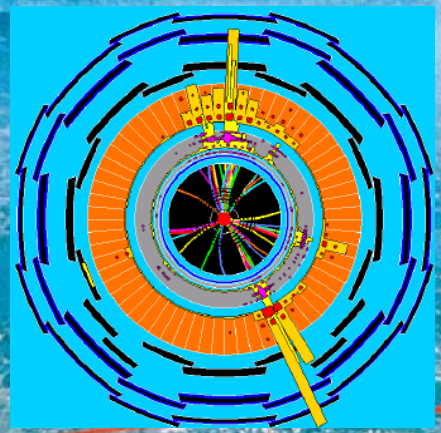
Both experiments can cope with the new physics possibilities which were not even foreseen at the beginning of the project.

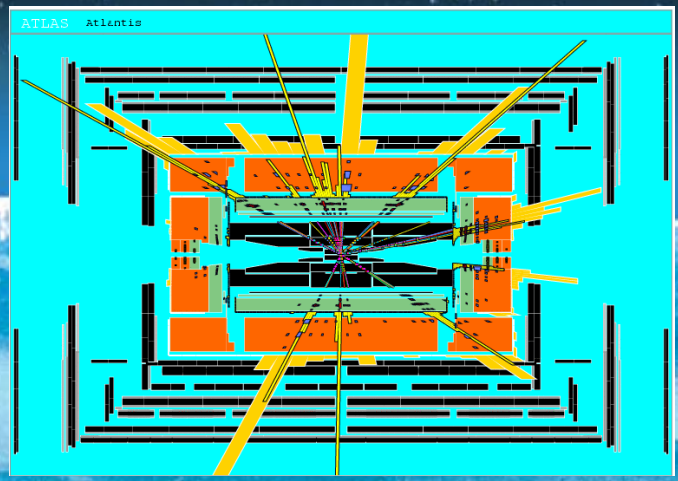
Discovery/Luminosity Roadmap?



Next 10 years would be a very exciting period in the history of Particle Physics (and Cosmology).







Any one of those would change the understanding of our universe !