Large Hadron Collider: a Status Report

Lepton Photon Conference

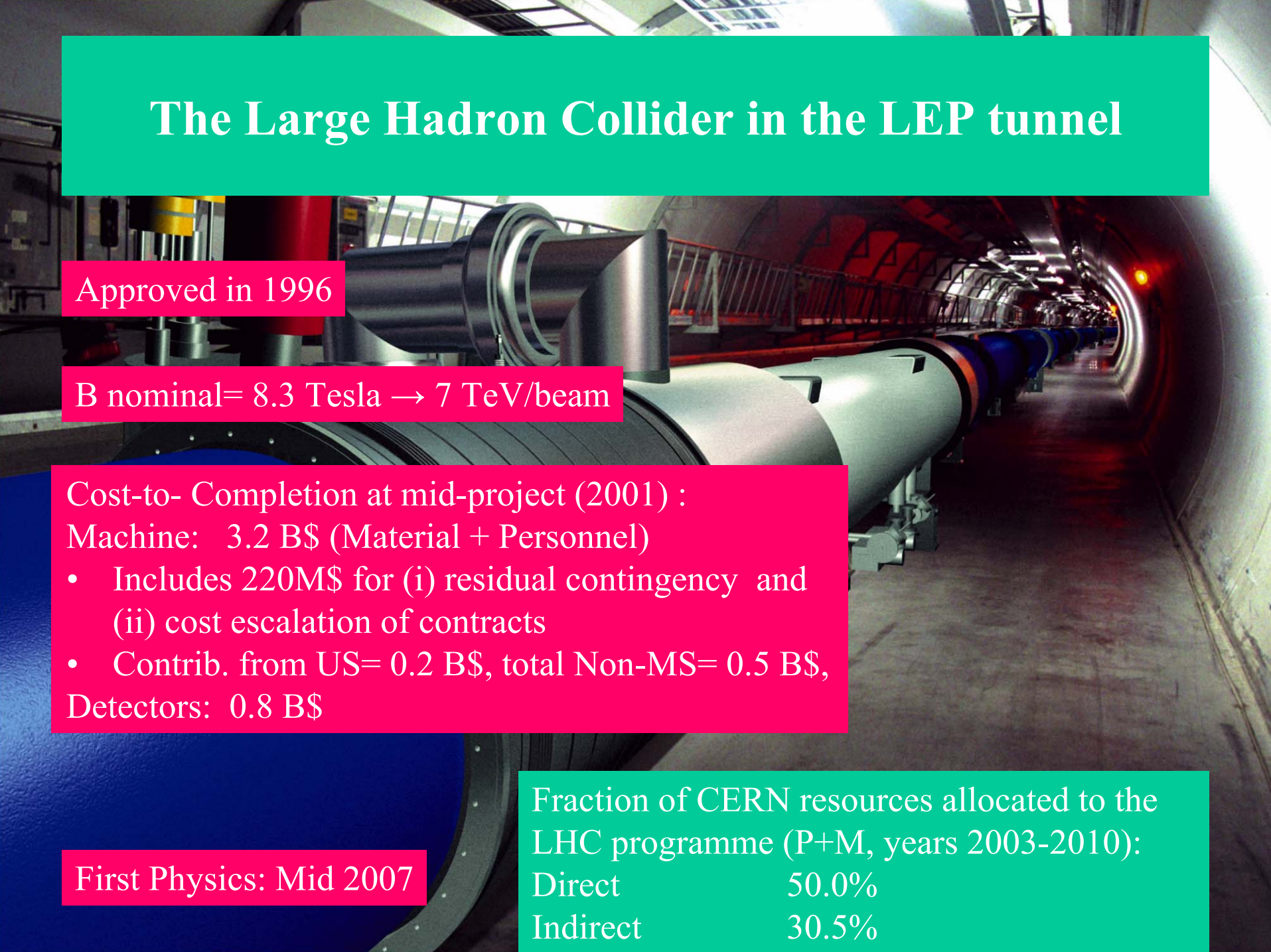
FermiLab, August 16, 2003

Luciano Maiani. CERN. Geneva

SUMMARY

1. Introduction
2. LHC Physics at High Energy
3. LHC Construction:
   - Civil Engineering
   - Machine components
   - Installation in the Tunnel
   - LHC hardware from CERN non-Member States
4. LHC Detectors
5. Computing
6. Conclusions

The Large Hadron Collider in the LEP tunnel



Approved in 1996

B nominal= 8.3 Tesla → 7 TeV/beam

Cost-to- Completion at mid-project (2001) :
Machine: 3.2 B$ (Material + Personnel)

- Includes 220M$ for (i) residual contingency and (ii) cost escalation of contracts
- Contrib. from US= 0.2 B$, total Non-MS= 0.5 B$,

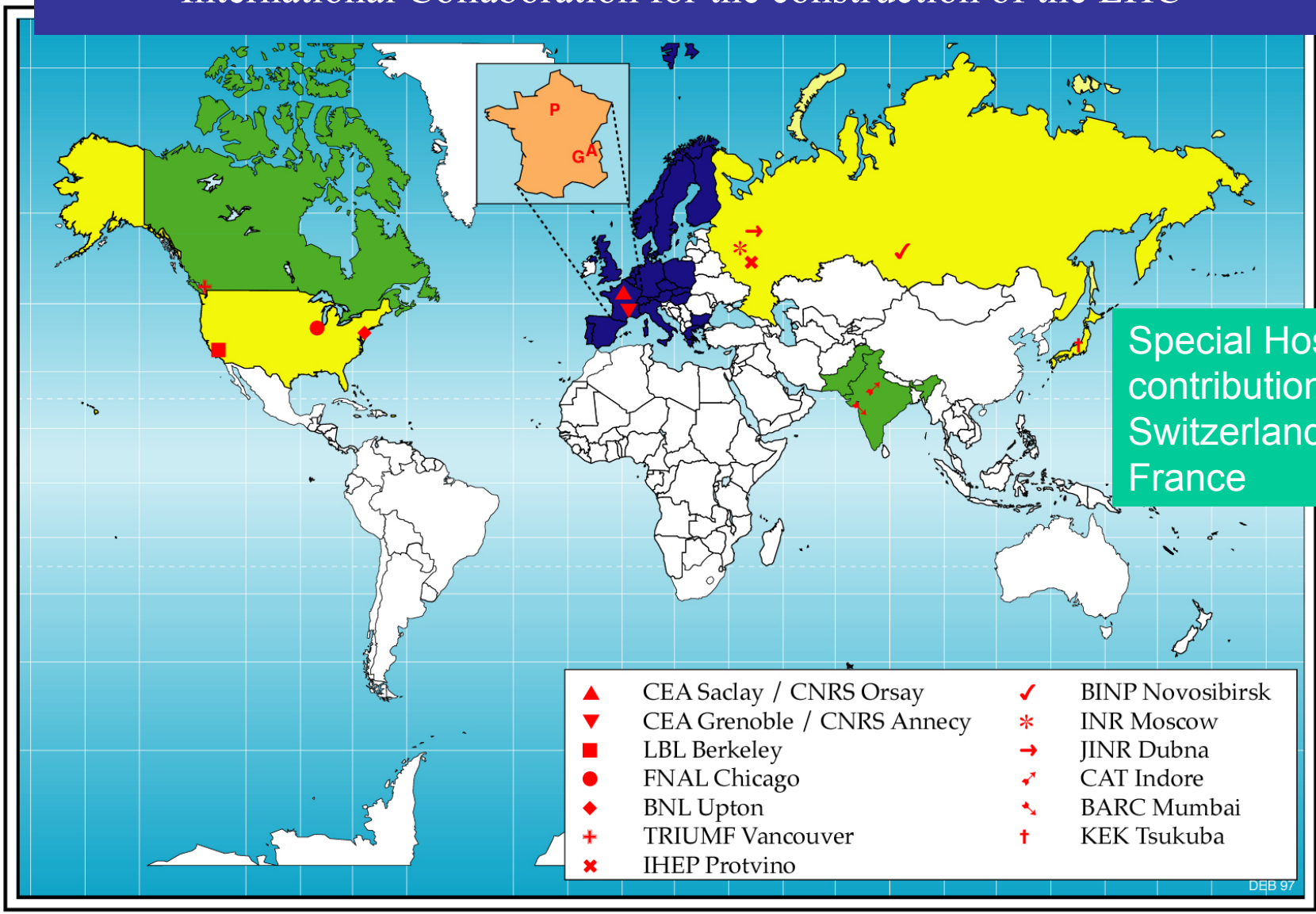
Detectors: 0.8 B$

First Physics: Mid 2007

Fraction of CERN resources allocated to the LHC programme (P+M, years 2003-2010):

Direct	50.0%
Indirect	30.5%

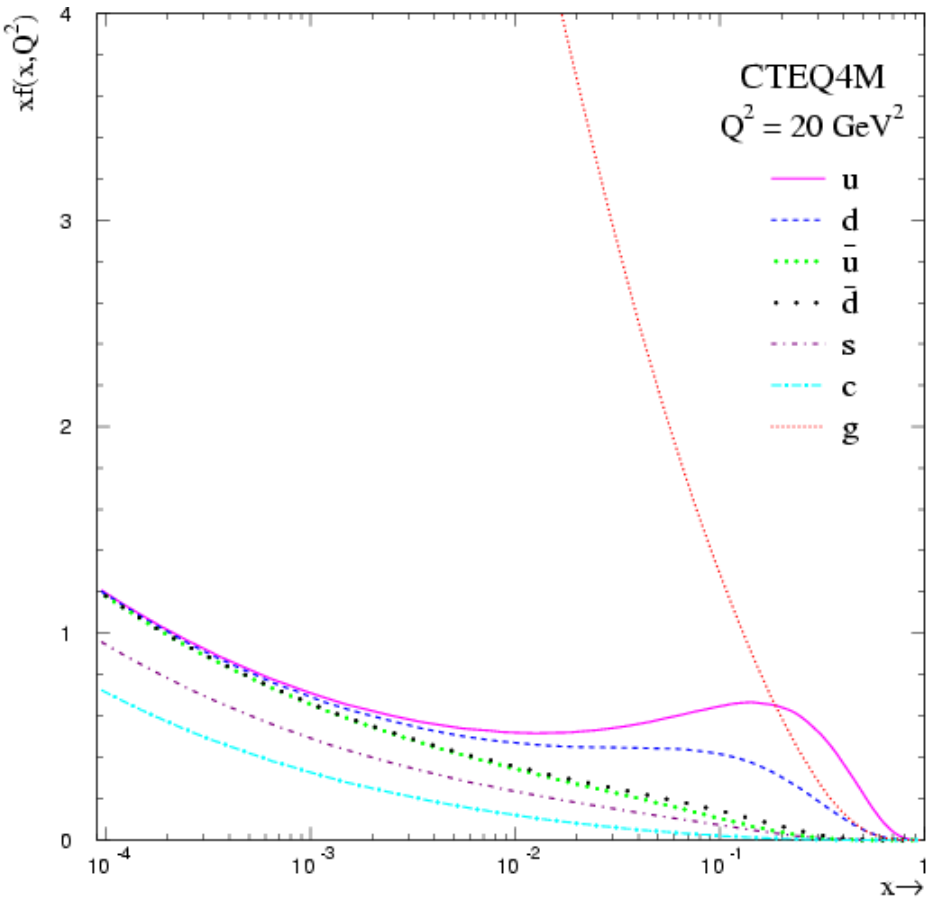
International Collaboration for the construction of the LHC

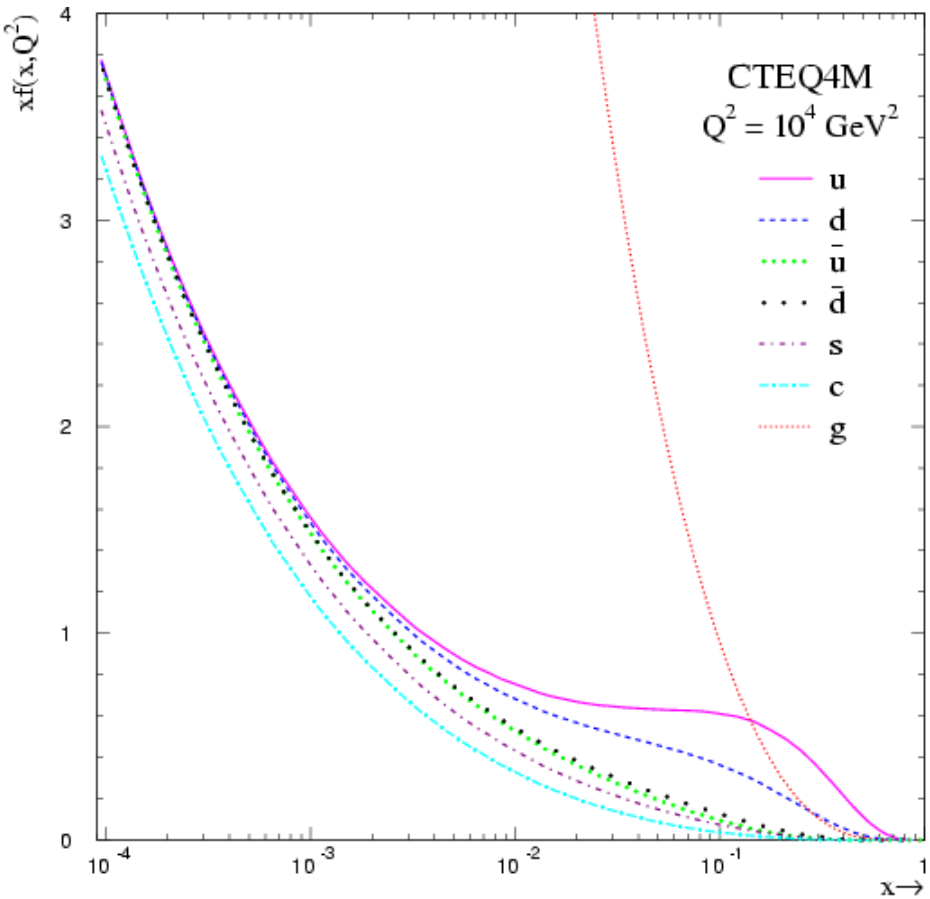


Special Host-State contributions from Switzerland and France

2. Physics at High Energy

Parton composition of High Energy protons





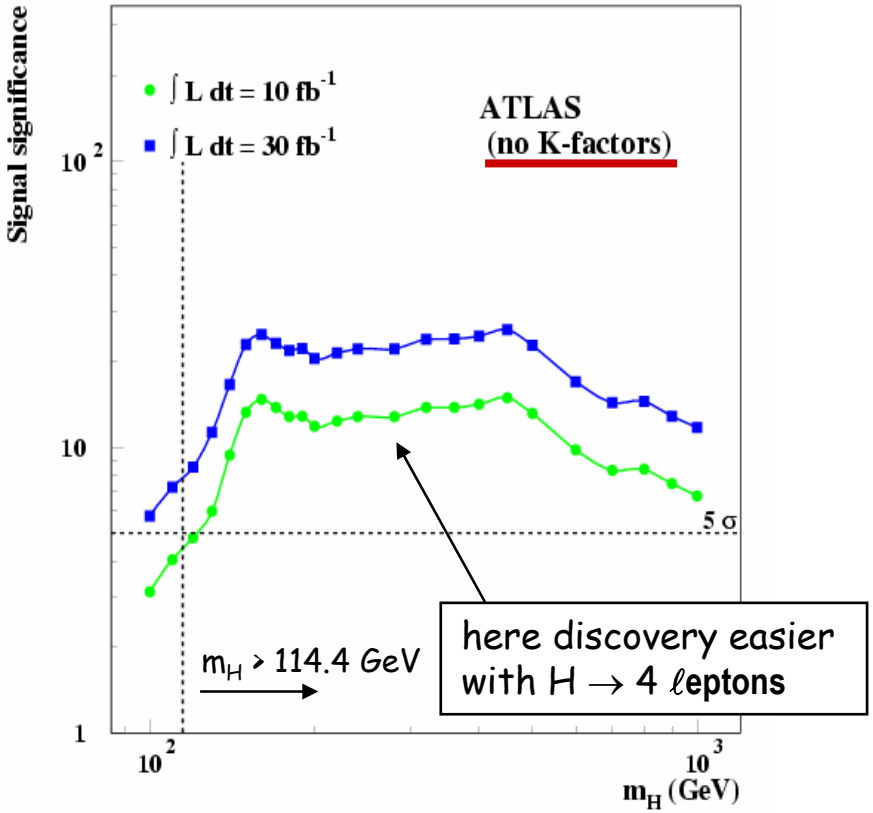
Main asset of LHC physics potential: huge event statistics thanks to high √s and L

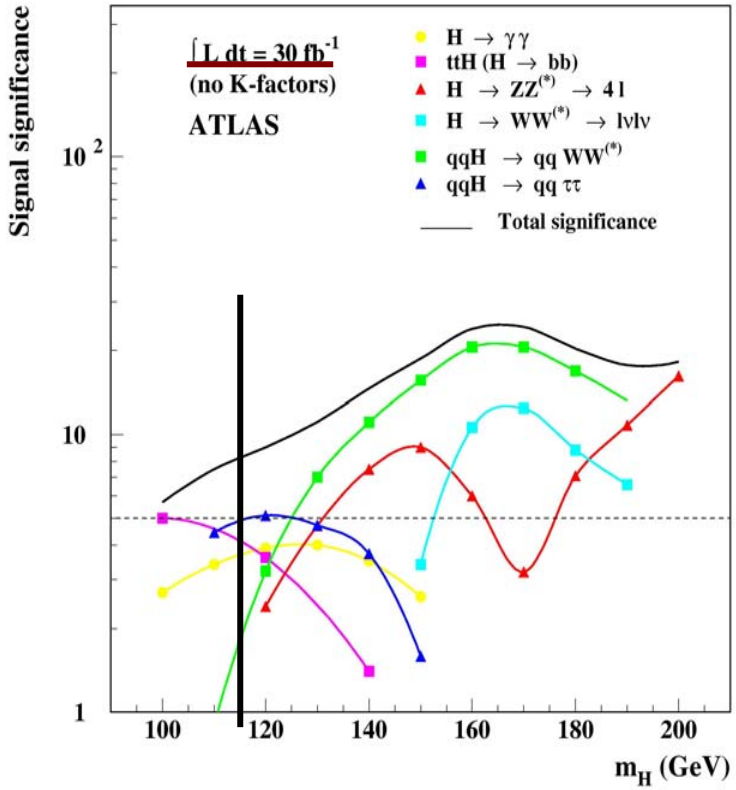
Expected event production rates in ATLAS or CMS for some (known and new) physics processes at the initial "low" luminosity of $L = 10^{33}\ cm^{-2}\ s^{-1}$

Process	Events/s	Events per year	Total statistics collected at previous machines by 2007
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tevatron
$Z \to ee$	1.5	10^7	10^7 LEP
$t\bar{t}$	1	10^7	10^4 Tevatron
$b\bar{b}$ **LHC-b**	10^6	$10^{12} - 10^{13}$	10^9 Belle/BaBar ?
H m=130 GeV	0.02	10^5	?
$\tilde{g}\tilde{g}$ m= 1 TeV	0.001	10^4	---
Black holes m > 3 TeV (M_D=3 TeV, n=4)	0.0001	10^3	---
	+ Ion Collisions		

→ LHC is a "you-name-it factory": top, W/Z, Higgs, SUSY, etc….
→ mass reach for discovery of new particles up to m ~ 5 TeV

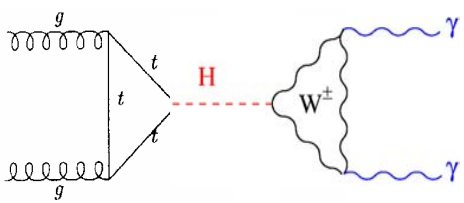
Standard Model Higgs



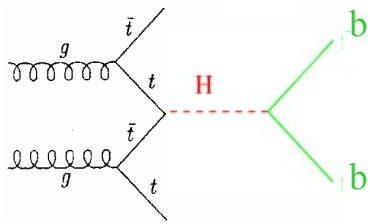


For m_H ~ 115 GeV and 10 fb^{-1}, 3 complementary channels accessible:

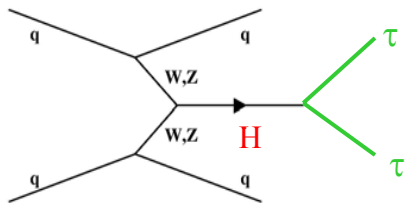
H → γγ (2 σ)



ttH → tt bb → bℓν bjj bb (2.2 σ)

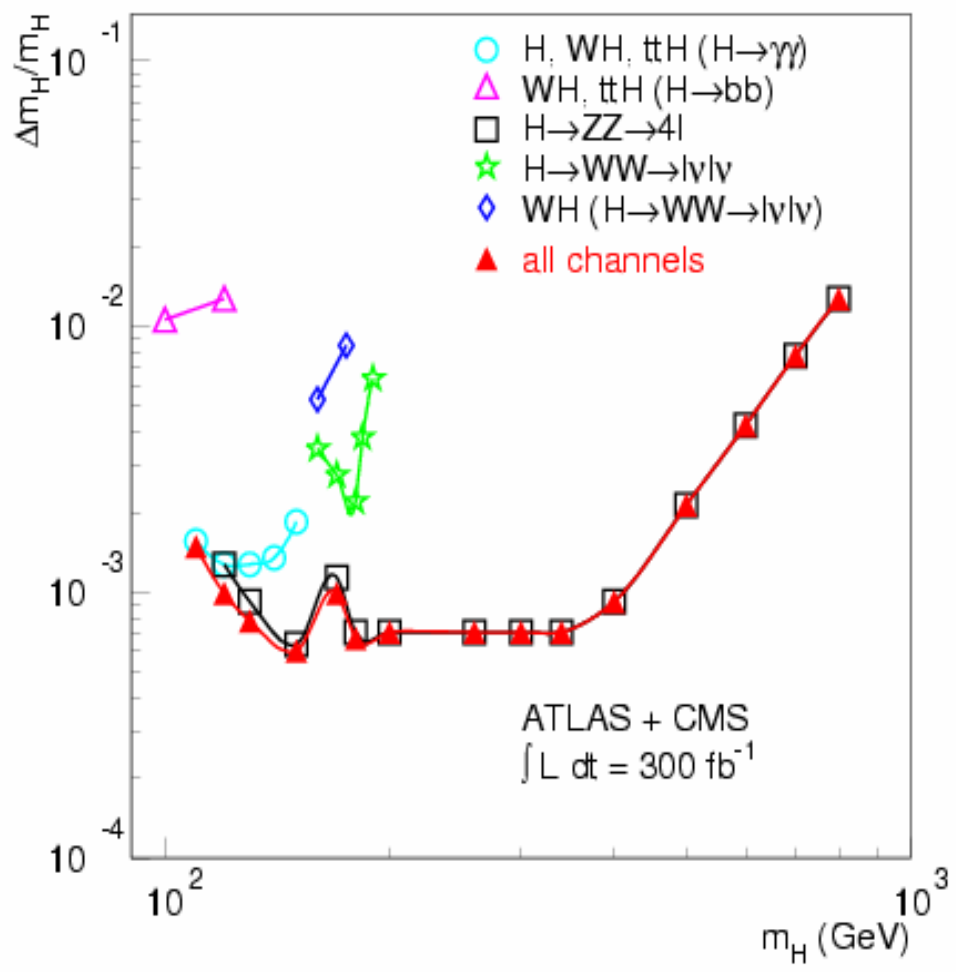


qqH → qqττ (2.7 σ)



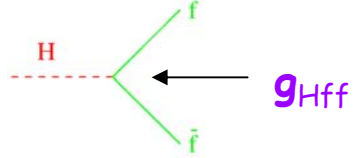
Precision

Measurement of the SM Higgs mass at the LHC



Expected experimental
Systematic errors included.
No theoretical uncertainty

Measurement of the SM Higgs couplings

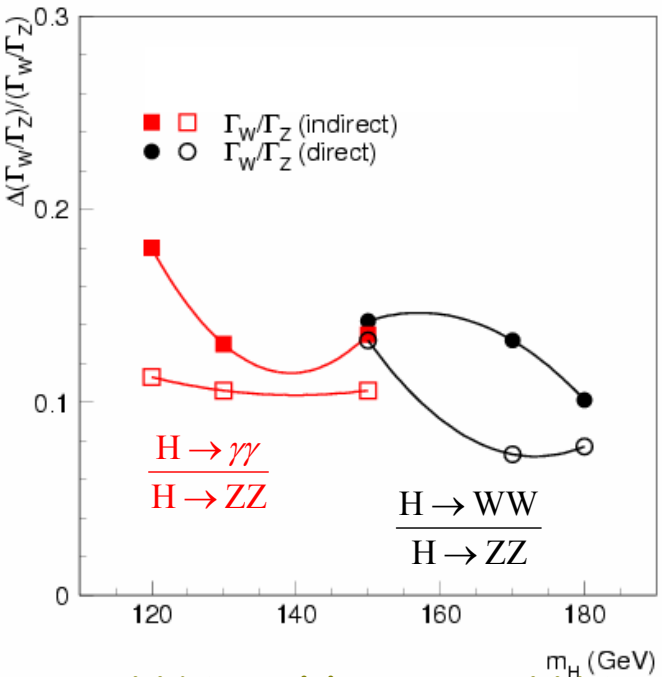


Couplings can be obtained from measured rate in a given production channel:

$$R_{ff} = \int L\,dt \bullet \sigma(e^+e^-, pp \to H + X) \bullet BR(H \to ff) \qquad BR(H \to ff) = \frac{\Gamma_f}{\Gamma_{tot}}$$

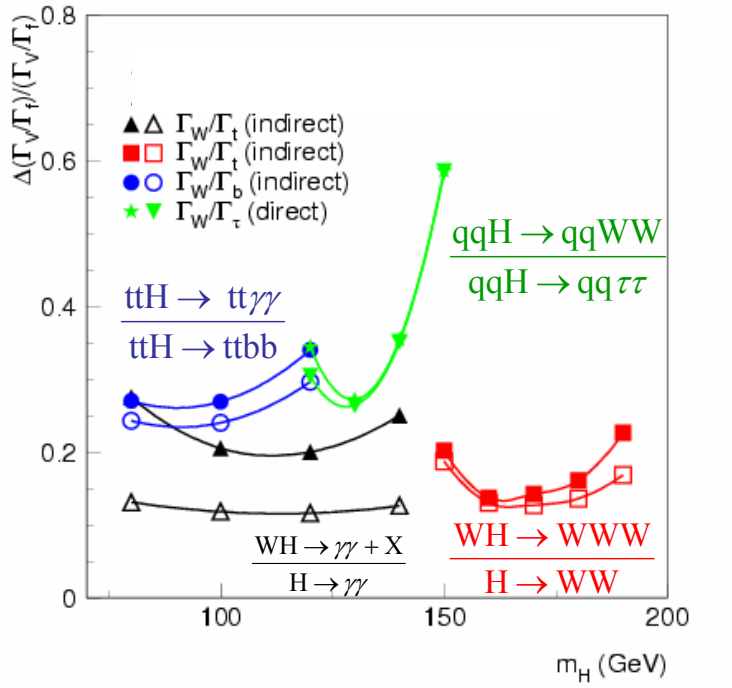
→ deduce $\Gamma_f \sim g^2_{Hff}$

Γ_{tot} and $\sigma(pp \to H+X)$ from theory → without theory inputs measure ratios of rates in various channels (Γ_{tot} and σ cancel) → $\Gamma_f/\Gamma_{f'}$ → several theory constraints



Closed symbols:
LHC 600 fb^{-1}

Open symbols:
SLHC 6000 fb^{-1}



-- SLHC could improve LHC precision by up to ~ 2 before first LC becomes operational
-- Not competitive with LC precision of ≈ %

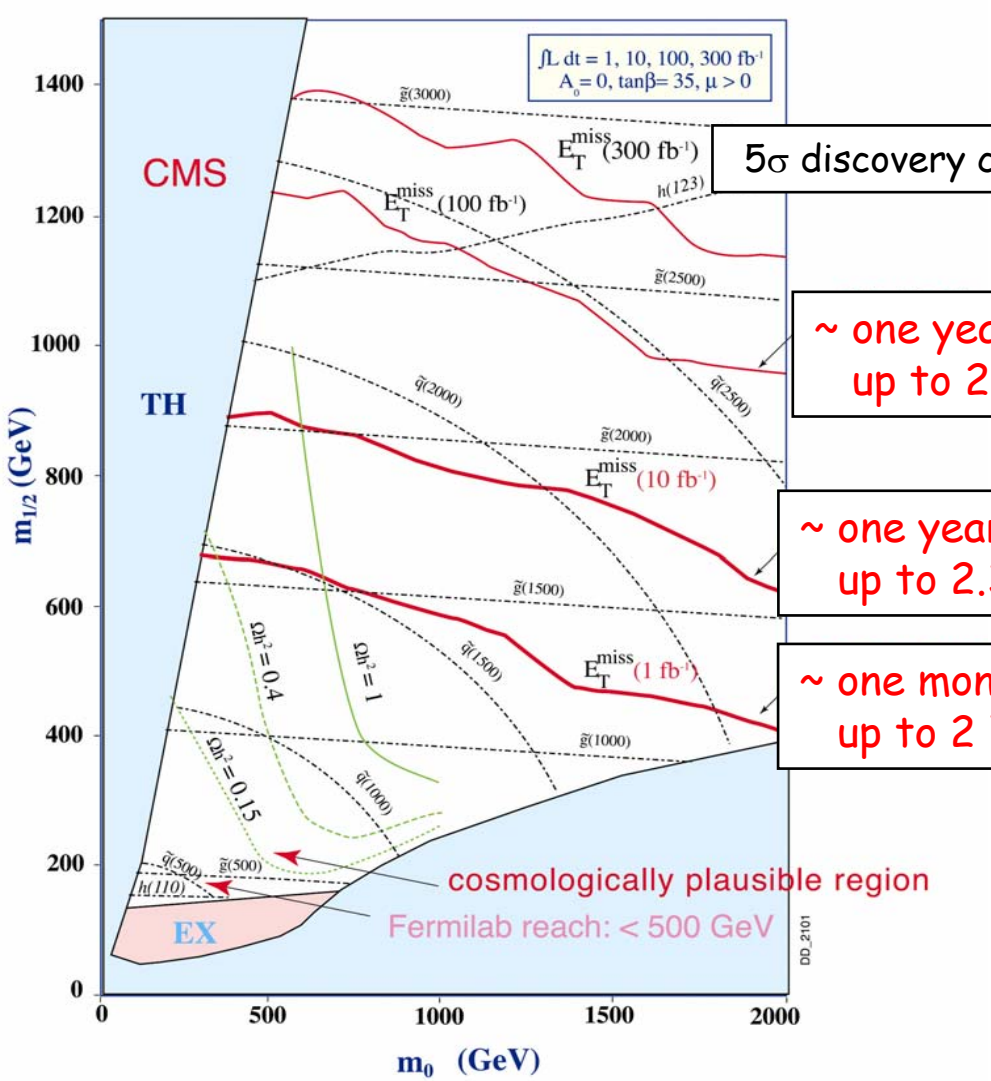
Naturalness

- The Higgs boson mass is generally not protected against quantum corrections to become of the order of the largest physical mass ($M_{planck} = 10^{19}$ GeV, in the Standard Theory).
- Known solutions:
  - New strong forces at the TeV scale, TECHNICOLOR: strongly disfavoured by LEP/Tevatron data;
  - Supersymmetry in the TeV region: compatible with LEP and Tevatron data; suggested by cold dark matter;
  - Additional space dimensions, “strong” fundamental gravity, gravity cut-off at TeV.
- LHC should tell !

SUPERSYMMETRY

Large $\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ cross-section → ≈ 100 events/day at 10^{33} for:

$m(\tilde{q}, \tilde{g}) \sim 1$ TeV



5σ discovery curves

Reach of Multijet + E_T^{miss} searches (most powerful and model-independent signature if R-parity conserved)

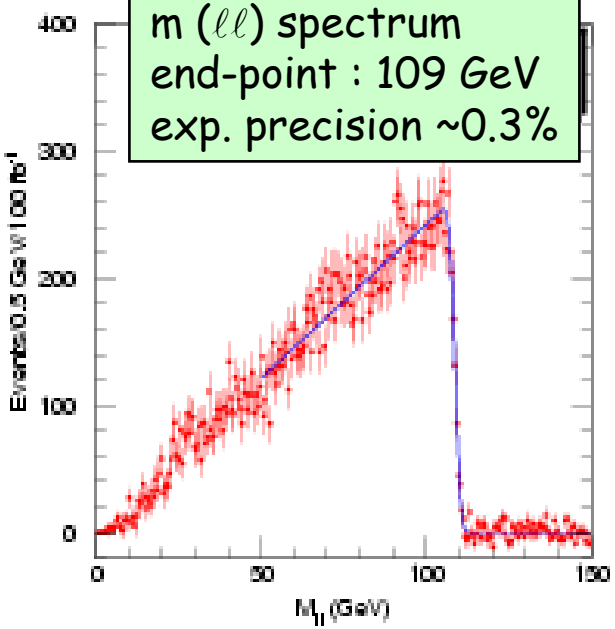
~ one year at 10^{34}: up to 2.8 TeV

~ one year at 10^{33} : up to 2.3 TeV

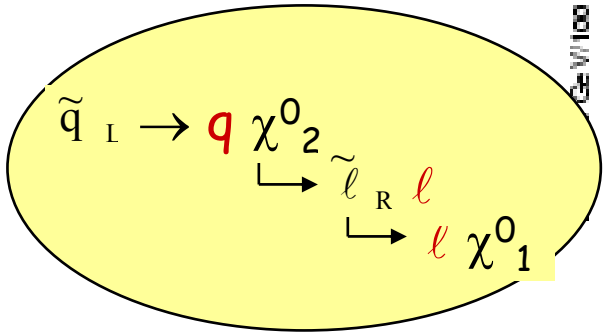
~ one month at 10^{33} : up to 2 TeV

→ **SUSY could be found quickly**

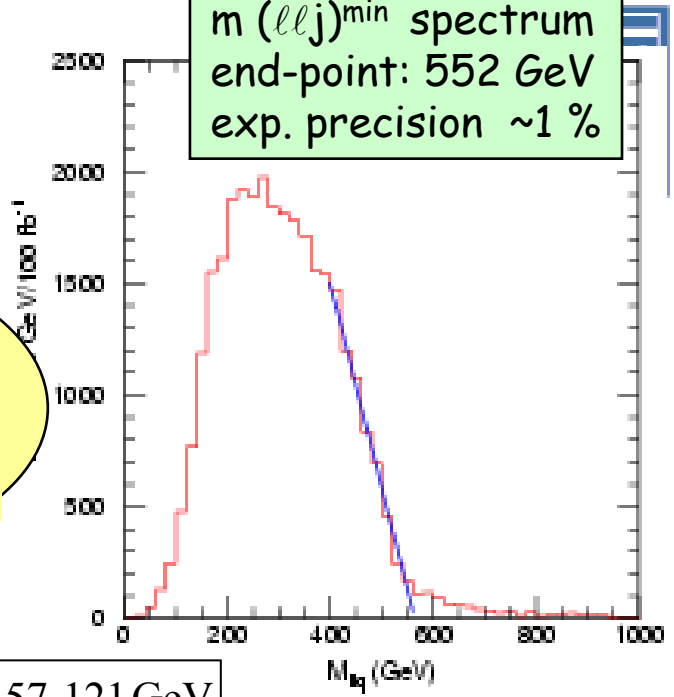
m ($\ell\ell$) spectrum
end-point : 109 GeV
exp. precision ~0.3%



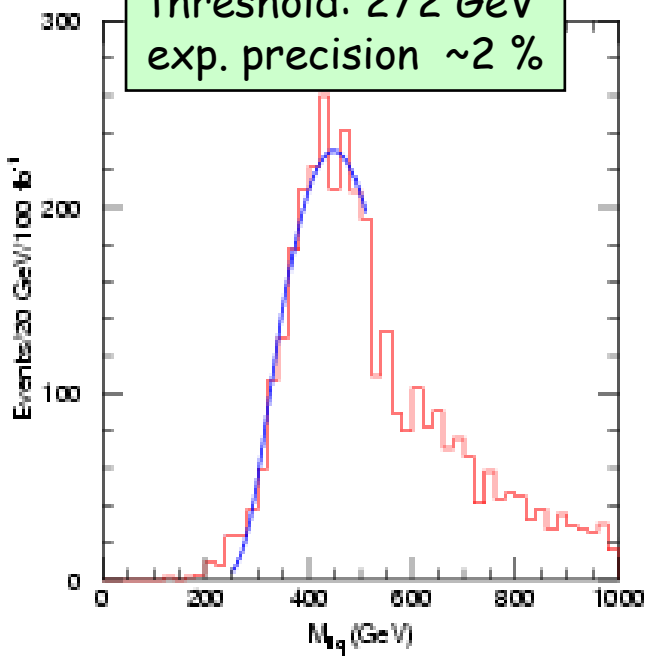
Example of
a typical chain:



m ($\ell\ell$j)^{min} spectrum
end-point: 552 GeV
exp. precision ~1 %



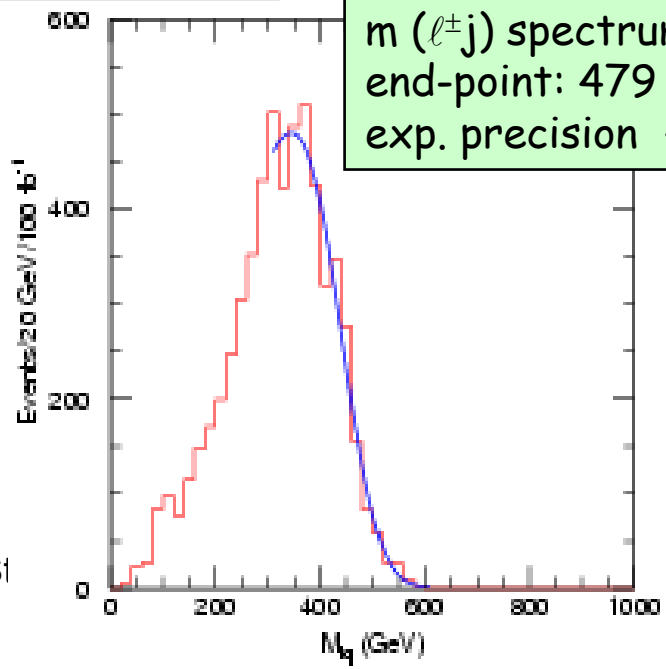
m ($\ell\ell$j)^{max} spectrum
threshold: 272 GeV
exp. precision ~2 %

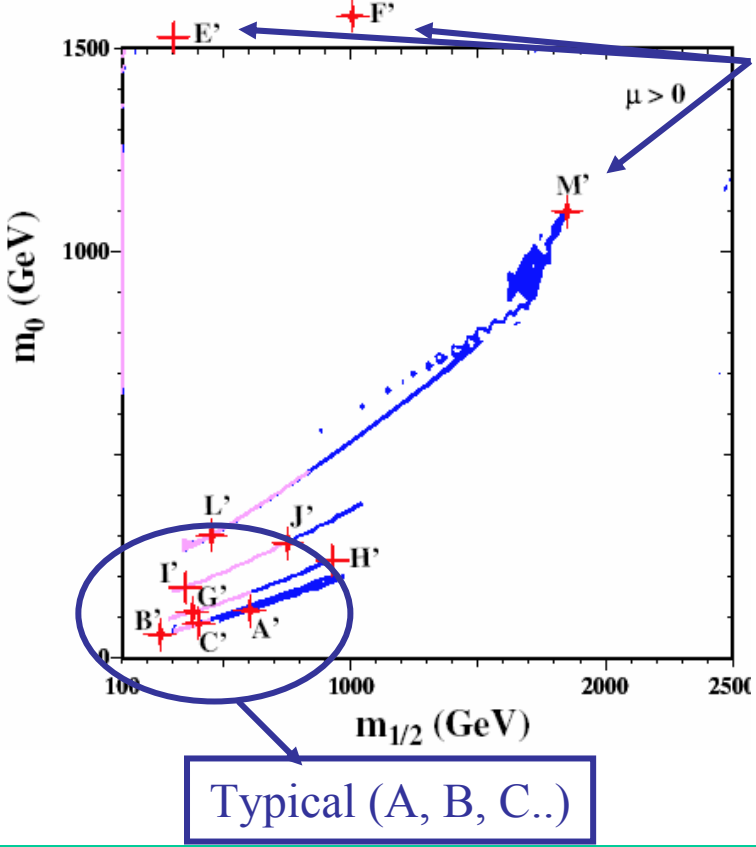


$m(\tilde{q}_L, \chi^0_2, \tilde{\ell}_R, \chi^0_1) = 690, 232, 157, 121\ \text{GeV}$

ATLAS
100 fb^{-1}
LHC Point 5

m ($\ell^{\pm}$j) spectrum
end-point: 479 GeV
exp. precision ~1 %



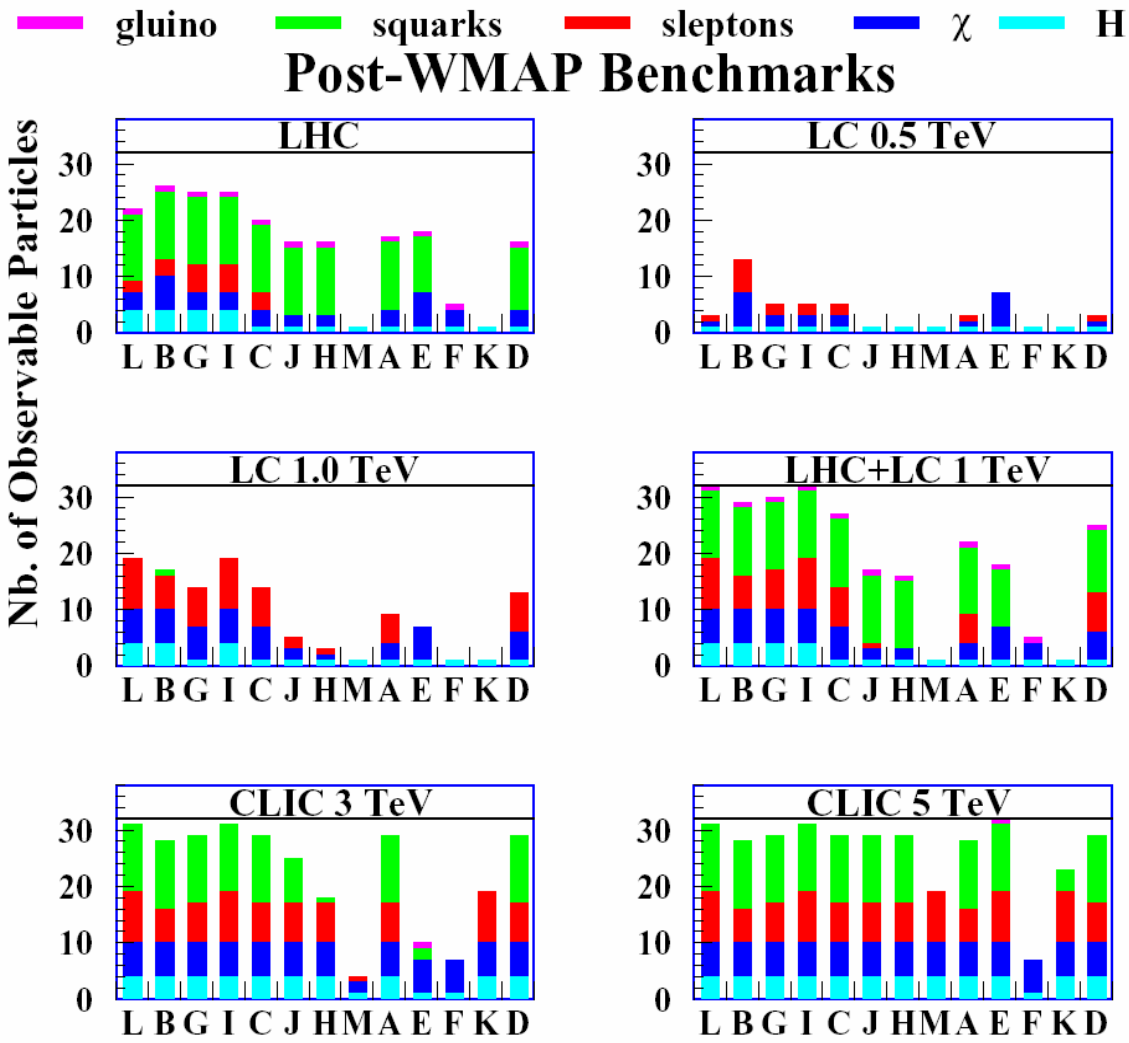


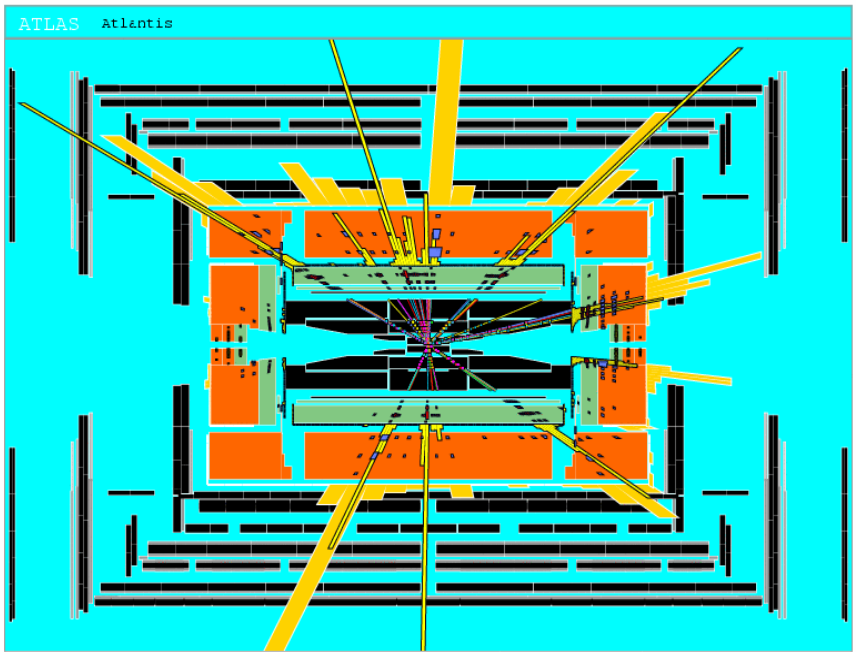
Fine-tuned

Typical (A, B, C..)

Benchmarking MSSMs restricted by Cosmological & Particle physics data

M. Battaglia et al., June 2003
hep-ph/0306219





Strong gravity in 4+δ dimensions

A black hole event with M_{BH} ~ 8 TeV in ATLAS

From preliminary studies : reach is M_D ~ 6 TeV for any δ in one year at low luminosity.

Precise measurements of M_{BH} and T_H(from lepton and photon spectra)

By testing Hawking formula → proof that it is BH + measurement of M_D, δ

$$\log T_H = -\frac{1}{\delta+1}\log M_{BH} + f(M_D, \delta)$$

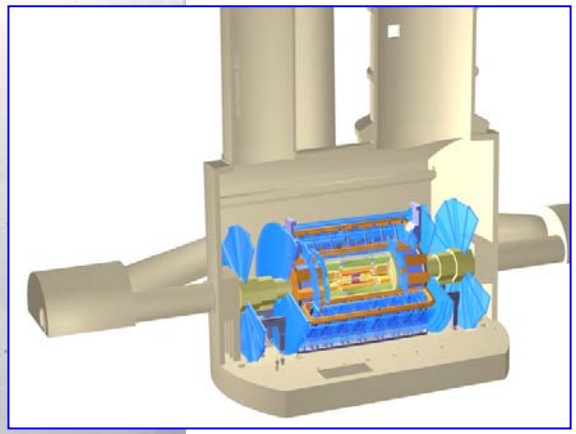
Note: mini-BH should also be produced by ultra-high-energy cosmic neutrinos and observed by Auger (Feng and Shapere, hep-ph/0109106)

Very personal views

- LHC will explore the TeV region with very good efficiency
- A sub-TeV Linear Collider is needed for precision Higgs boson physics – in case of a light Higgs boson;
- The LC would be also useful to distinguish SM from Minimal Supersymmetric SM…
- Multi TeV capability is needed to really understand Supersymmetry .

3. LHC Construction: Civil Engineering

The ATLAS Cavern (July 03)

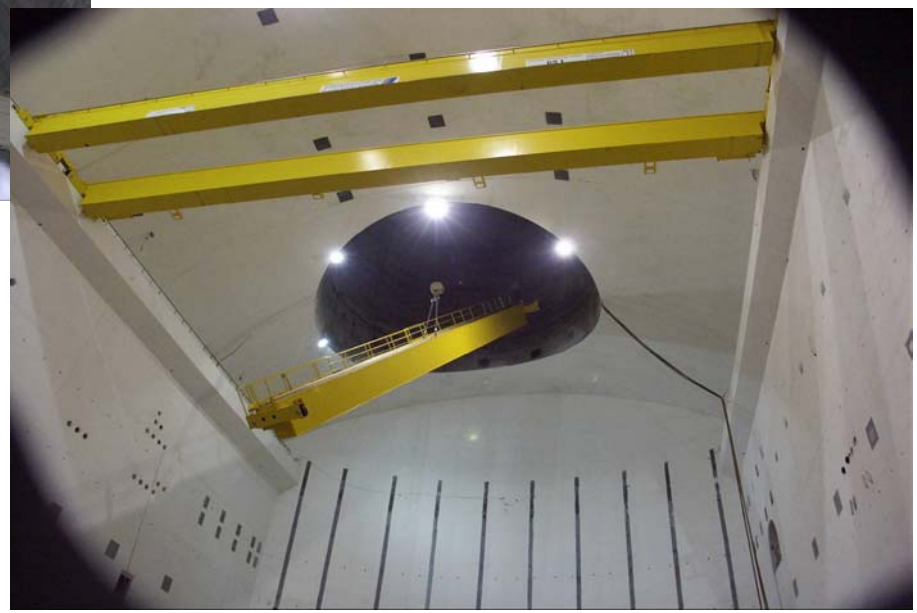


Metallic Structure:
13 floors on both sides
(25.07.2003)

38 work packages active at Point 1

We are on schedule !

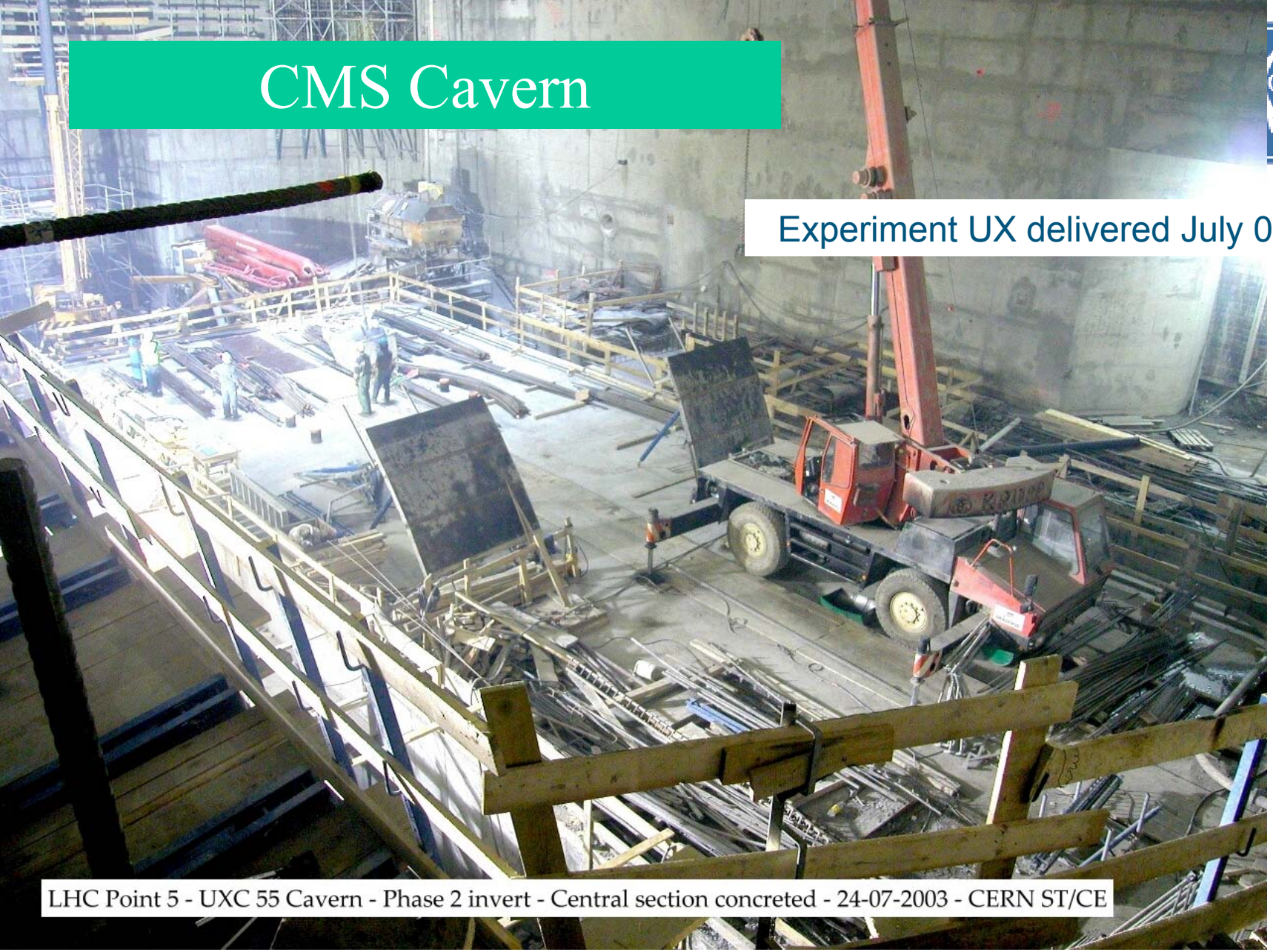
ATLAS main cavern : cranes



ATLAS Control Room

LeptonPhotonConf.
August 16, 2003

CMS Cavern

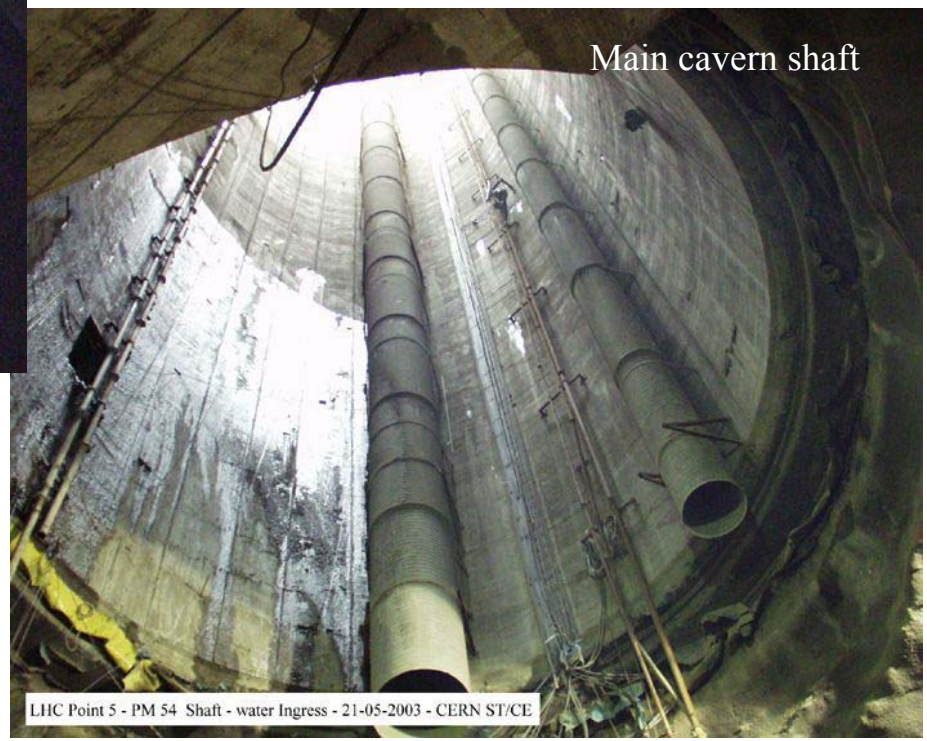


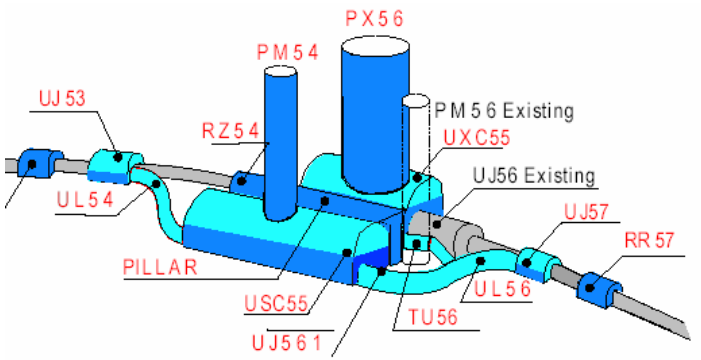
Experiment UX delivered July 04

LHC Point 5 - UXC 55 Cavern - Phase 2 invert - Central section concreted - 24-07-2003 - CERN ST/CE

CMS, Point 5

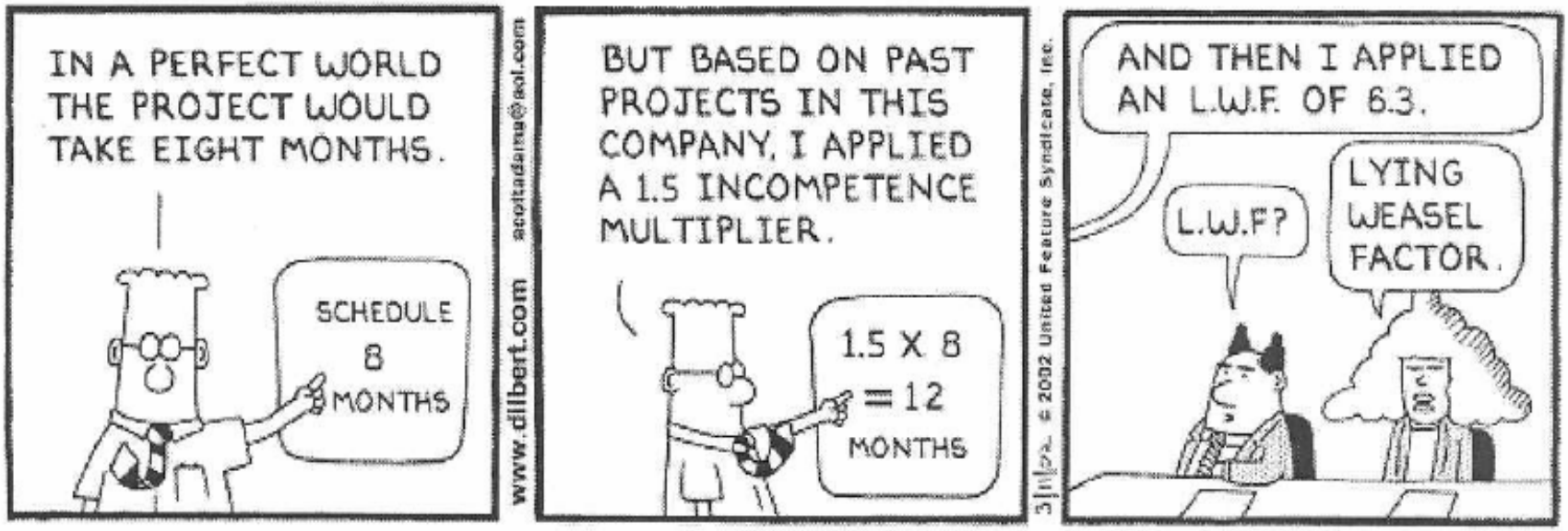
- Cracks have appeared in the shaft of the CMS service caverns, with water leaks. This is considered to be "normal", but must be repaired. The delay for CMS is under evaluation.





LHC Construction: Machine components

How about the Schedule?



LHC Magnets review, June 2003 ·

…Vendors lye

The LHC Dashboard

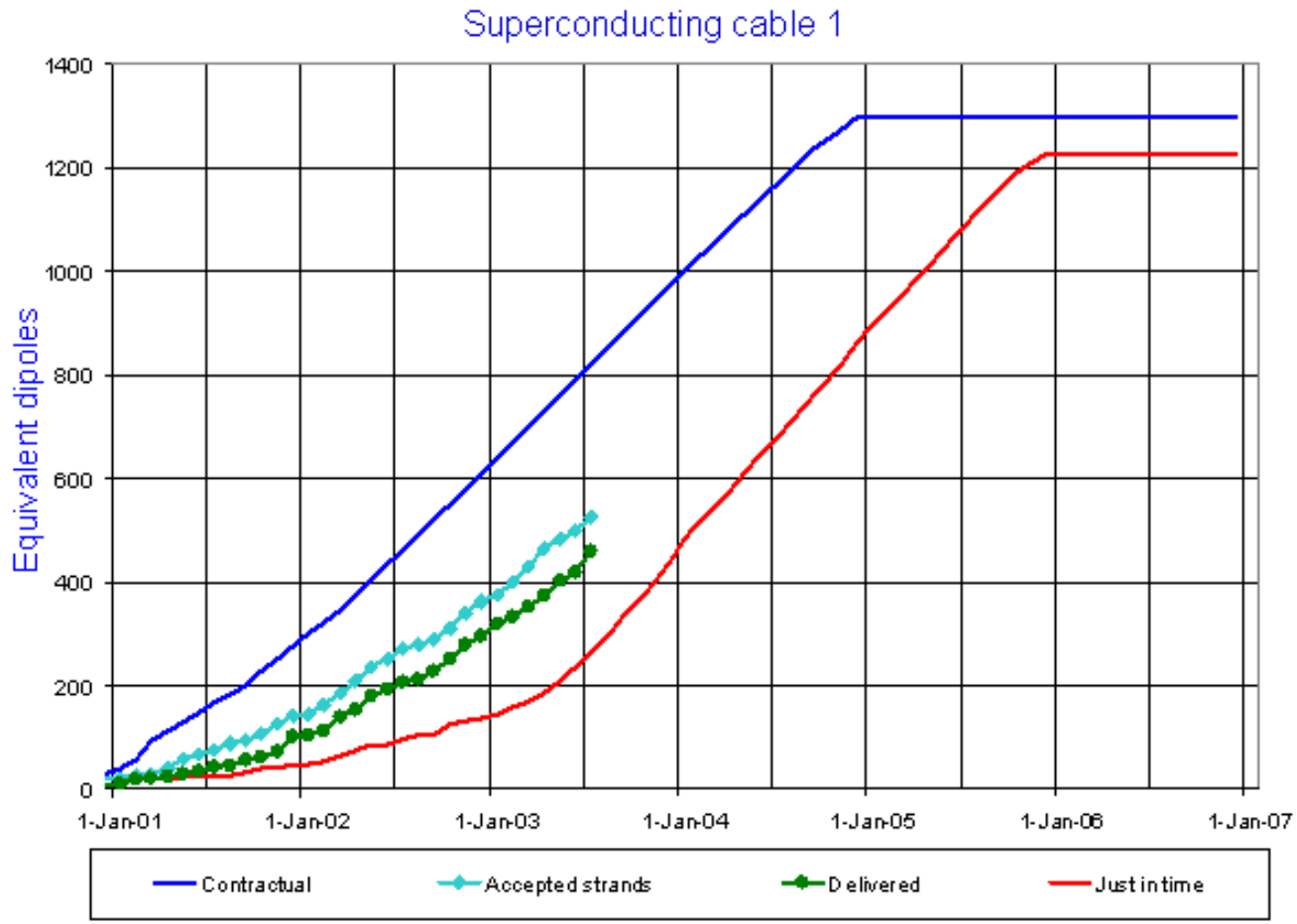
- To monitor the progress of LHC components production
- Can be accessed from the LHC project home page:
- http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/
- Shows progress of:
  - SC Cables
  - Dipole assembly
  - Progress of installation
  - …..
- Note the Disclaimer:
  - Not a contractual document
  - Does not engage CERN
- … but we hope it will increase transparency of the process

Cable

LHC Progress Dashboard

Accelerator Technology Division

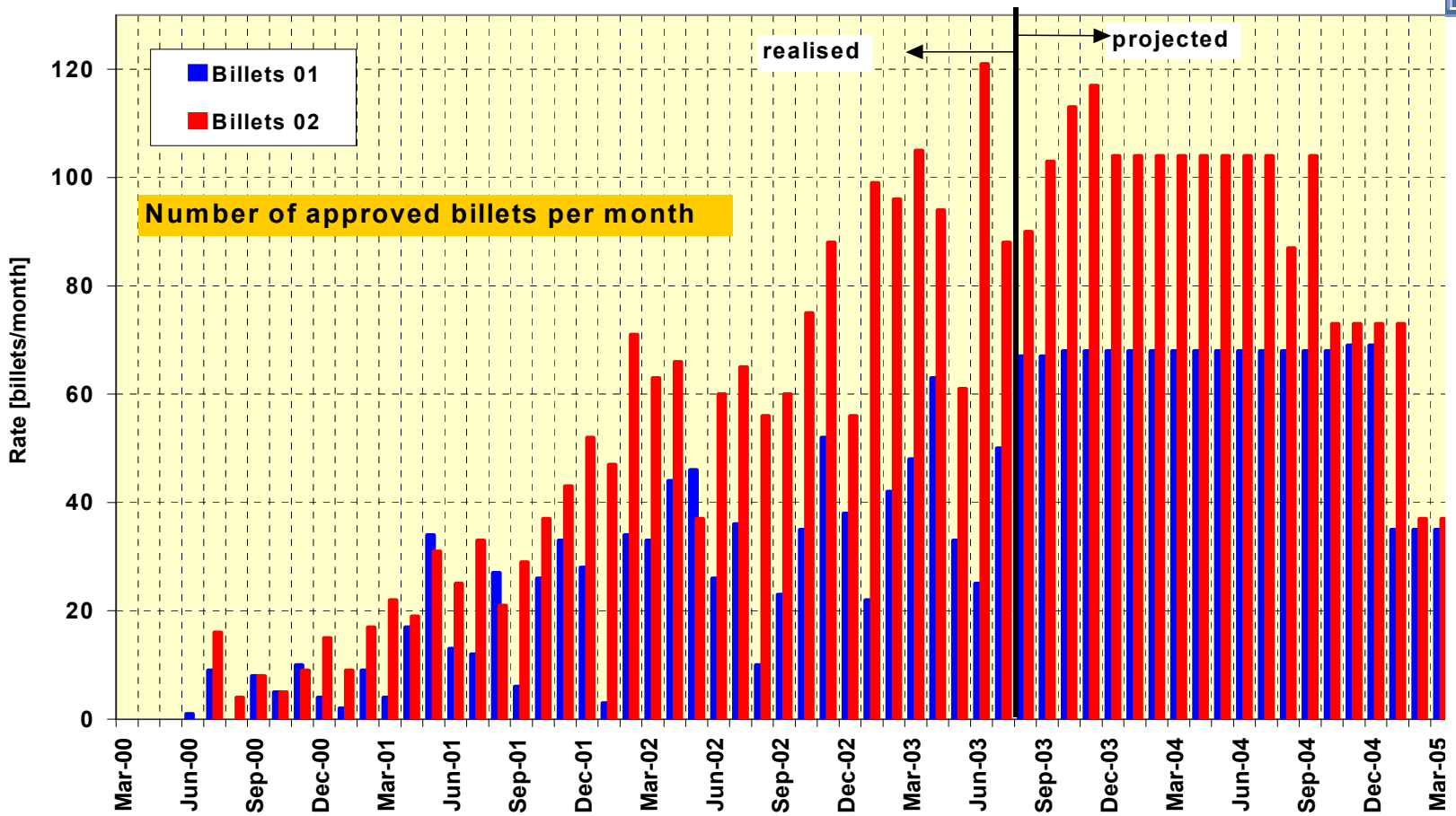
CERN



Updated 31 Jul 2003

Data provided by A. Verweij AT-MAS

Billets production



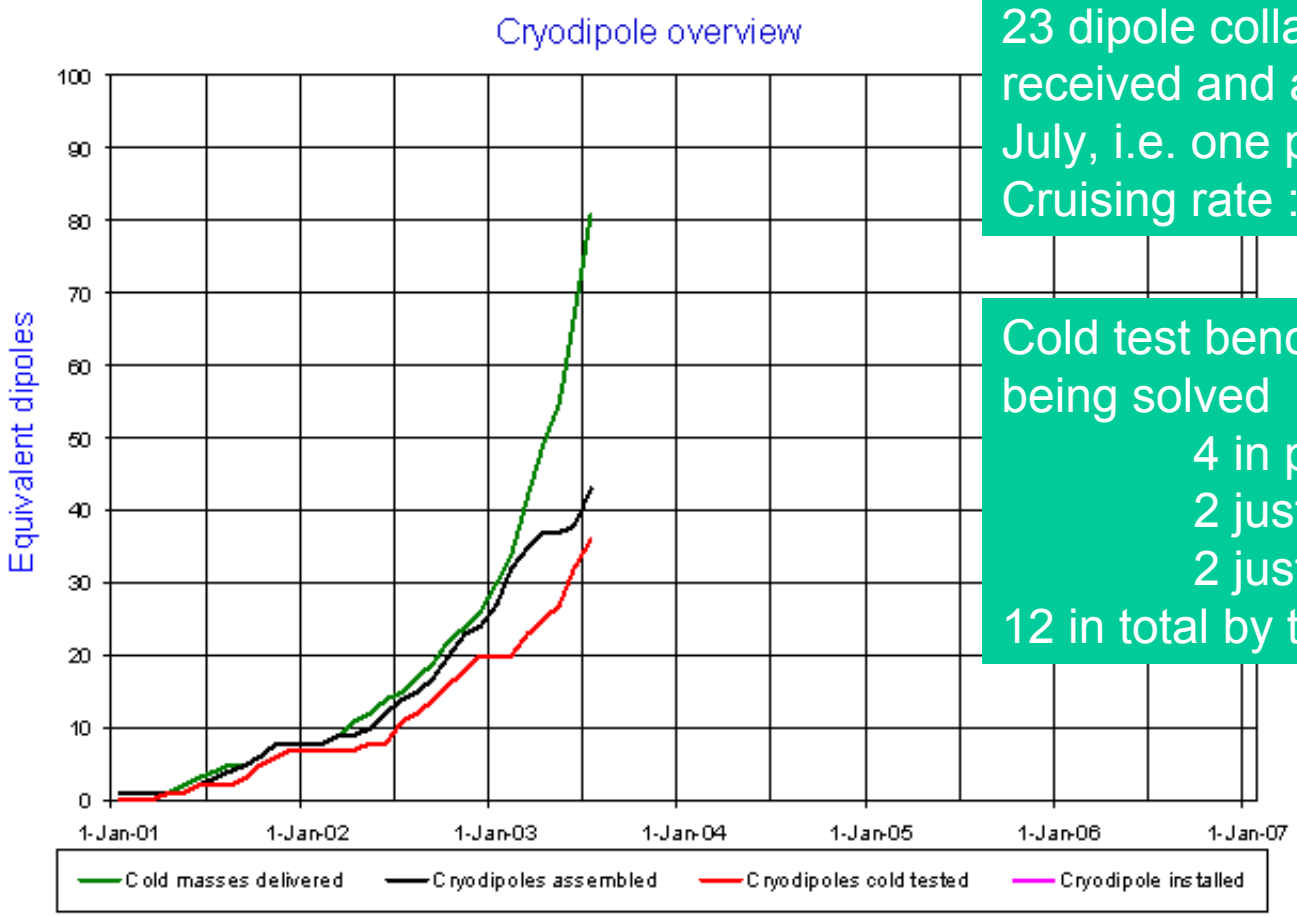
About 40.6% of the 01 billets and 49% of the 02 billets manufactured and approved

This is equivalent to 3 octants of the 02/03 cables

Dipoles

LHC Progress Dashboard

Accelerator Technology Division



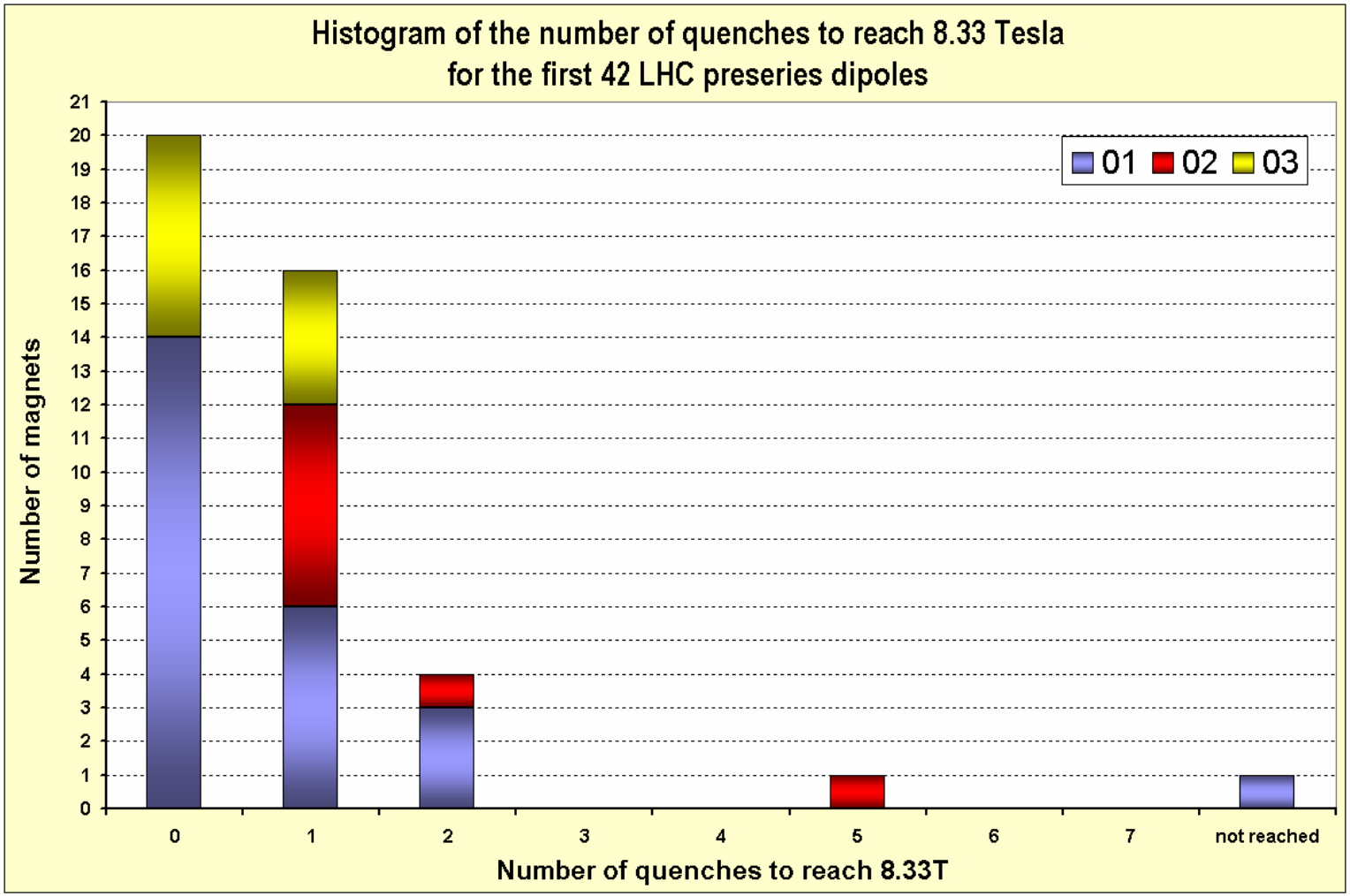
23 dipole collared coils received and approved in July, i.e. one per working day
Cruising rate : 35 cc/month

Cold test benches bottleneck is being solved
- 4 in place
- 2 just commissioned
- 2 just arrived

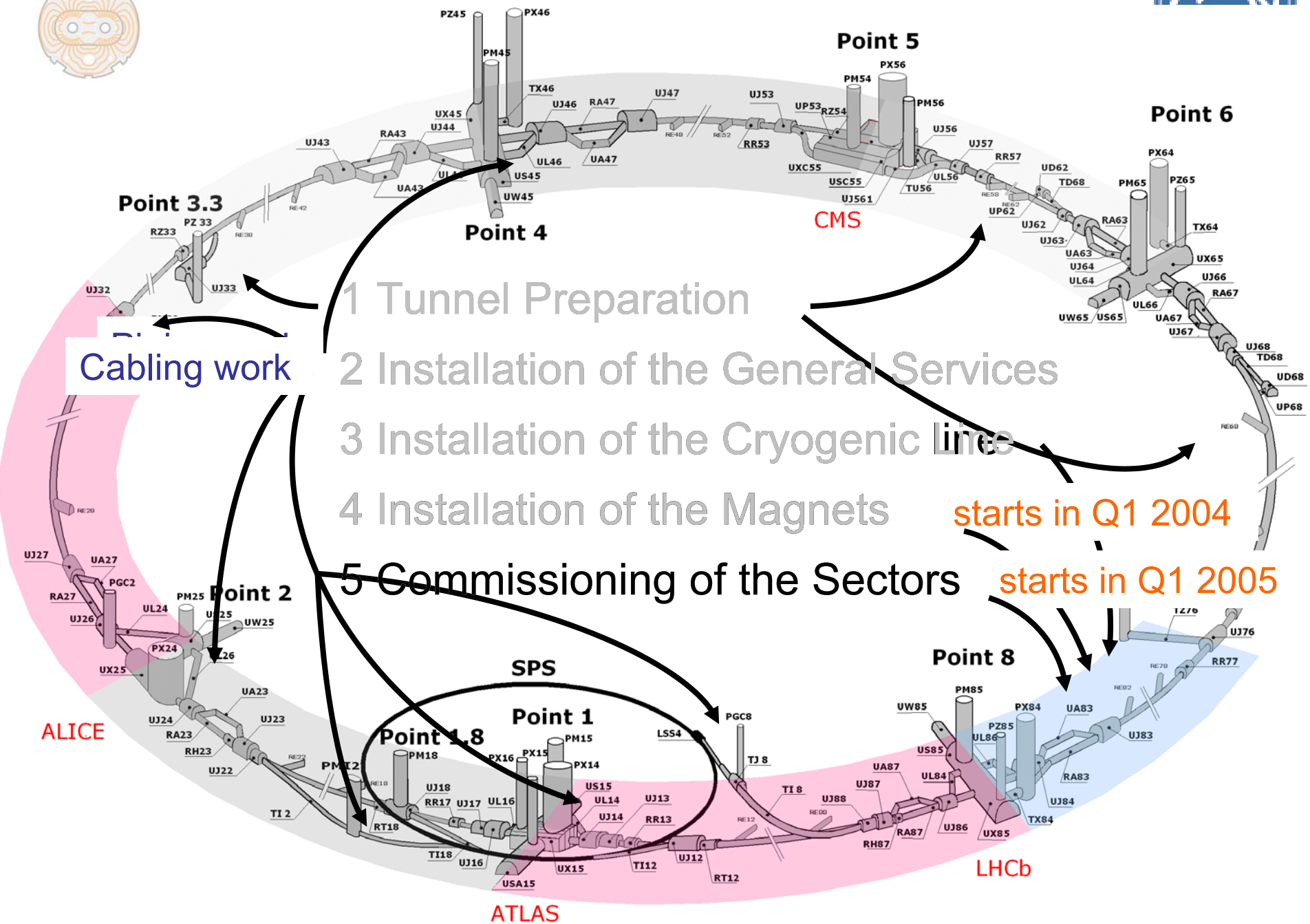
12 in total by the end of the year

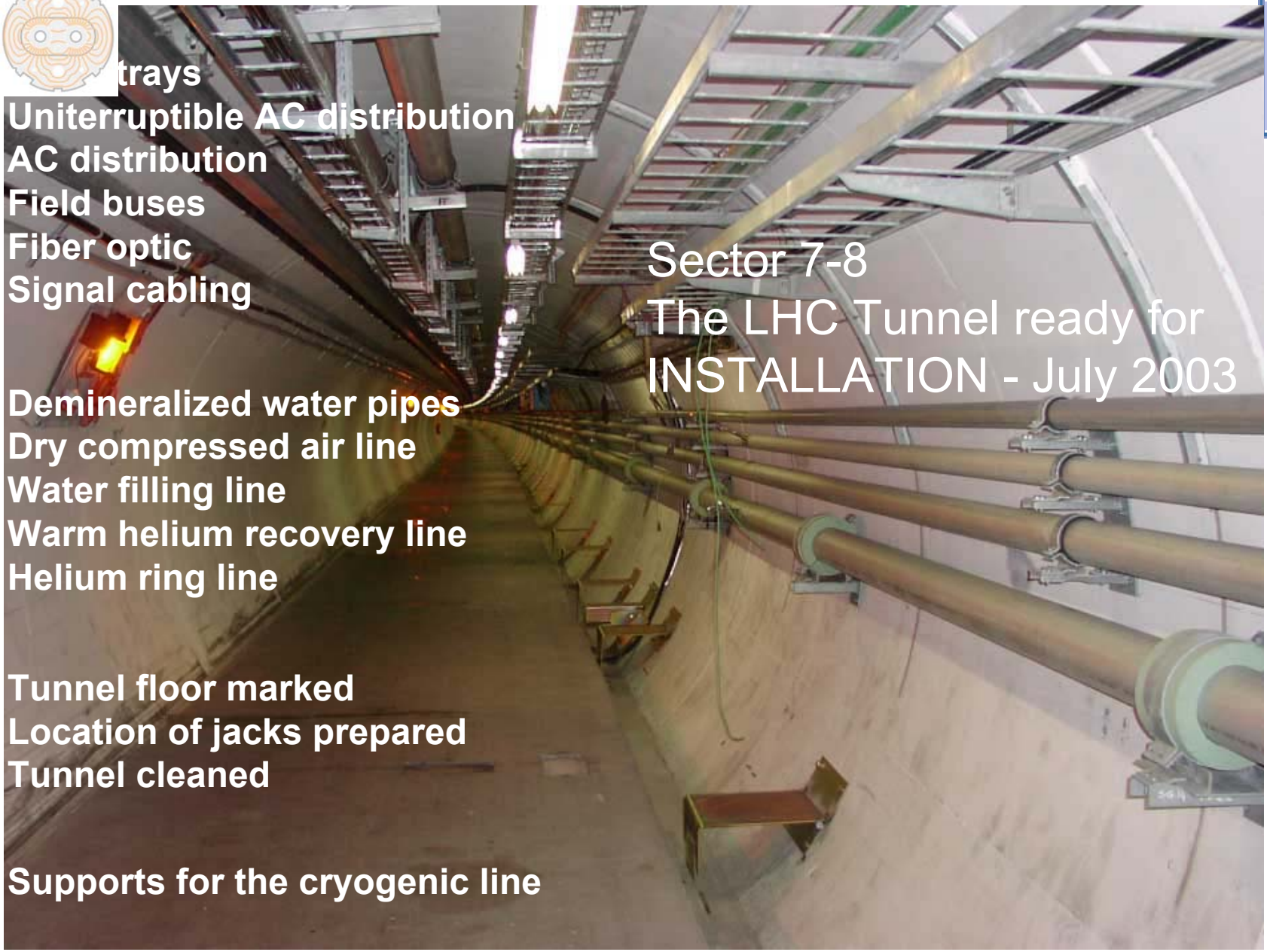
Cold masses stored at CERN

Dipoles


Histogram of the number of quenches to reach 8.33 Tesla
for the first 42 LHC preseries dipoles
01
02
03
Number of magnets
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
not reached
Number of quenches to reach 8.33T

status of the installation - July 2003




trays
Uniterruptible AC distribution
AC distribution
Field buses
Fiber optic
Signal cabling
Demineralized water pipes
Dry compressed air line
Water filling line
Warm helium recovery line
Helium ring line
Tunnel floor marked
Location of jacks prepared
Tunnel cleaned
Supports for the cryogenic line
Sector 7-8
The LHC Tunnel ready for
INSTALLATION - July 2003

UJ68 cavern, at the junction between transfer line from SPS and the LHC tunnel, July 2003

Cryoline Installation

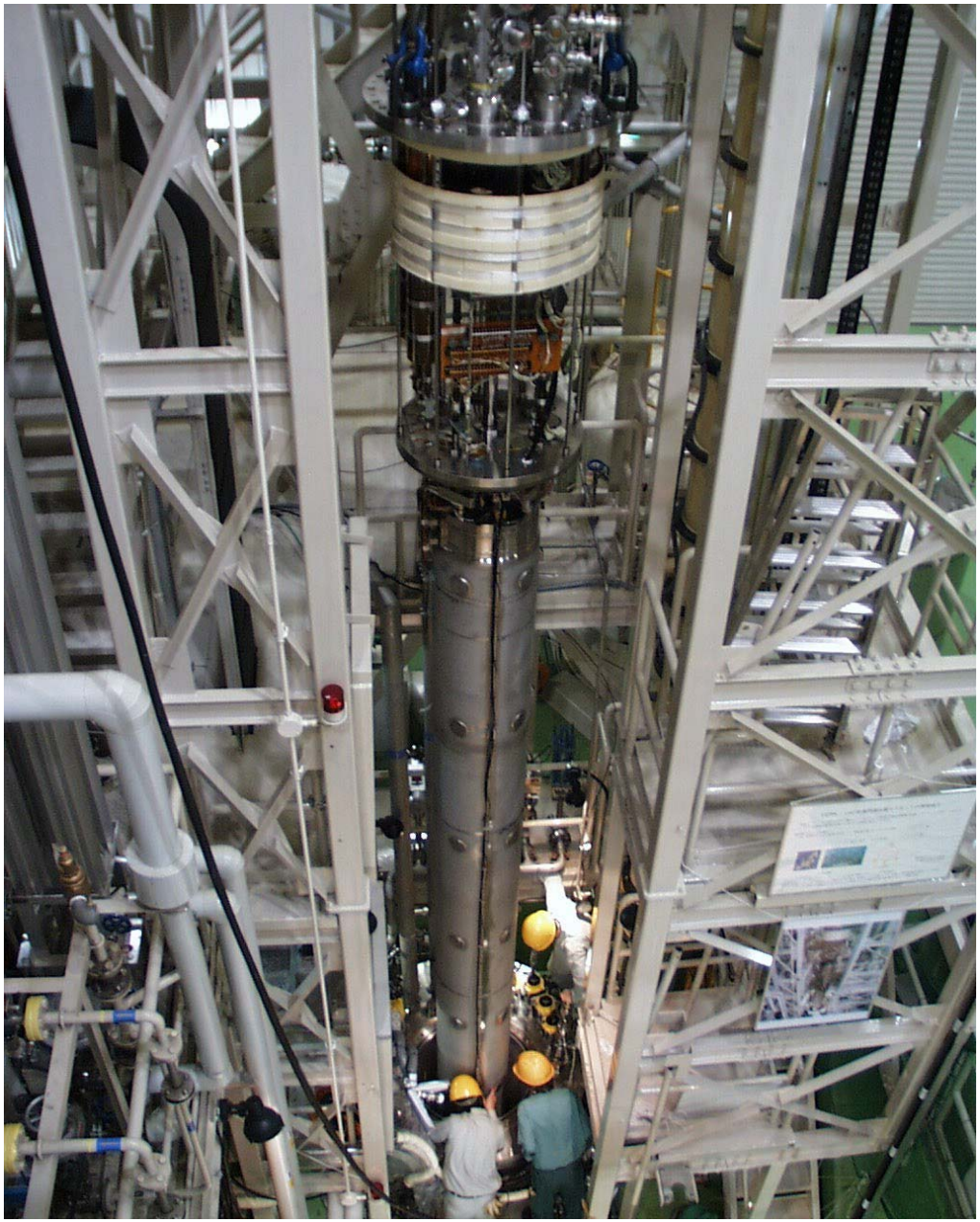
Installation: July 30

1. The installation of the general services of the first sector was terminated on time. The sector was ready to receive the cryogenic distribution line on July 21.
2. Some delay in isolated areas - 6 week delay in cryo-line installation – can be recuperated.
3. Click on *General Coordination Schedule* in the LHC Dashord:
    - yellow line: where we should be (updated every month)
    - Black line: where we are
    - Red line: position of last month

4. LHC hardware from CERN non-Member States

Russia

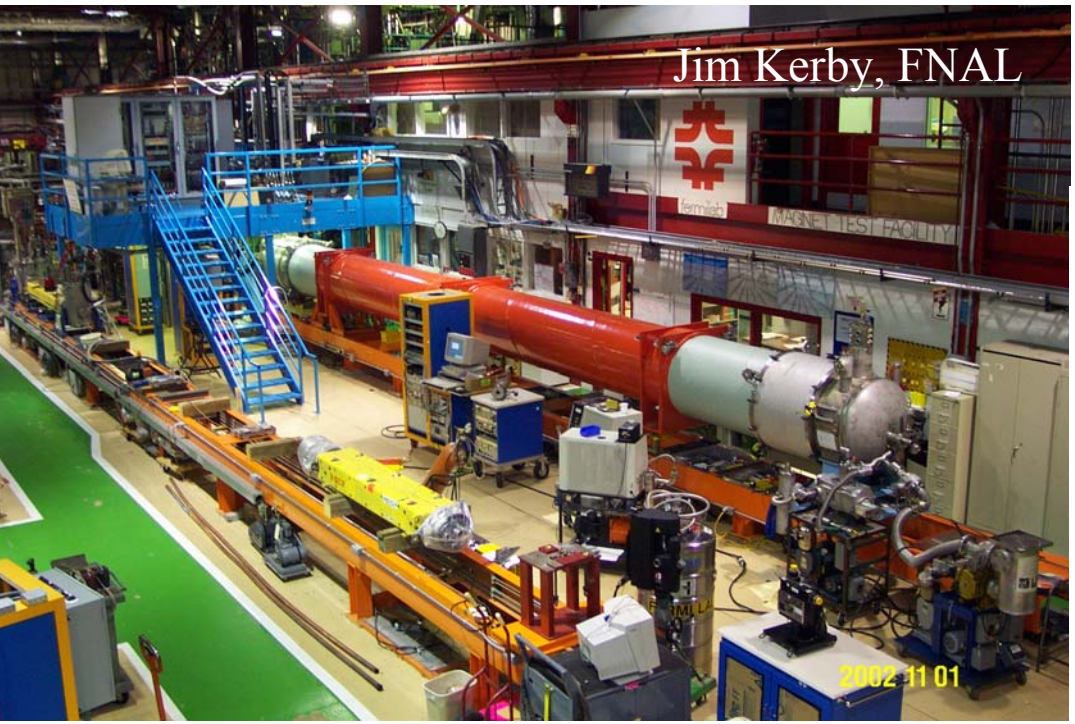
Warm dipoles



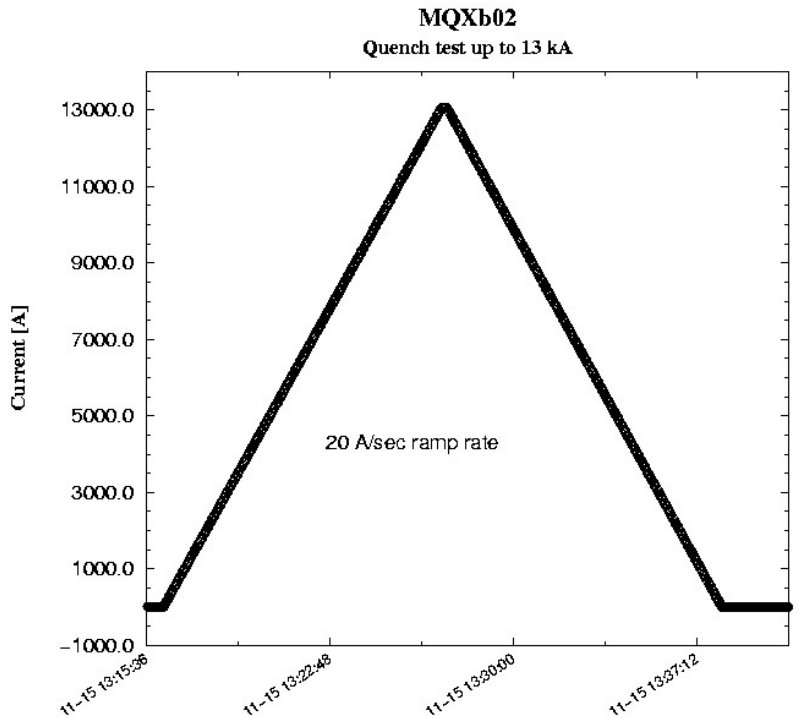
Japan:
Inner triplet sc-quadrupole

USA: Sc Quadrupole production at FERMILAB

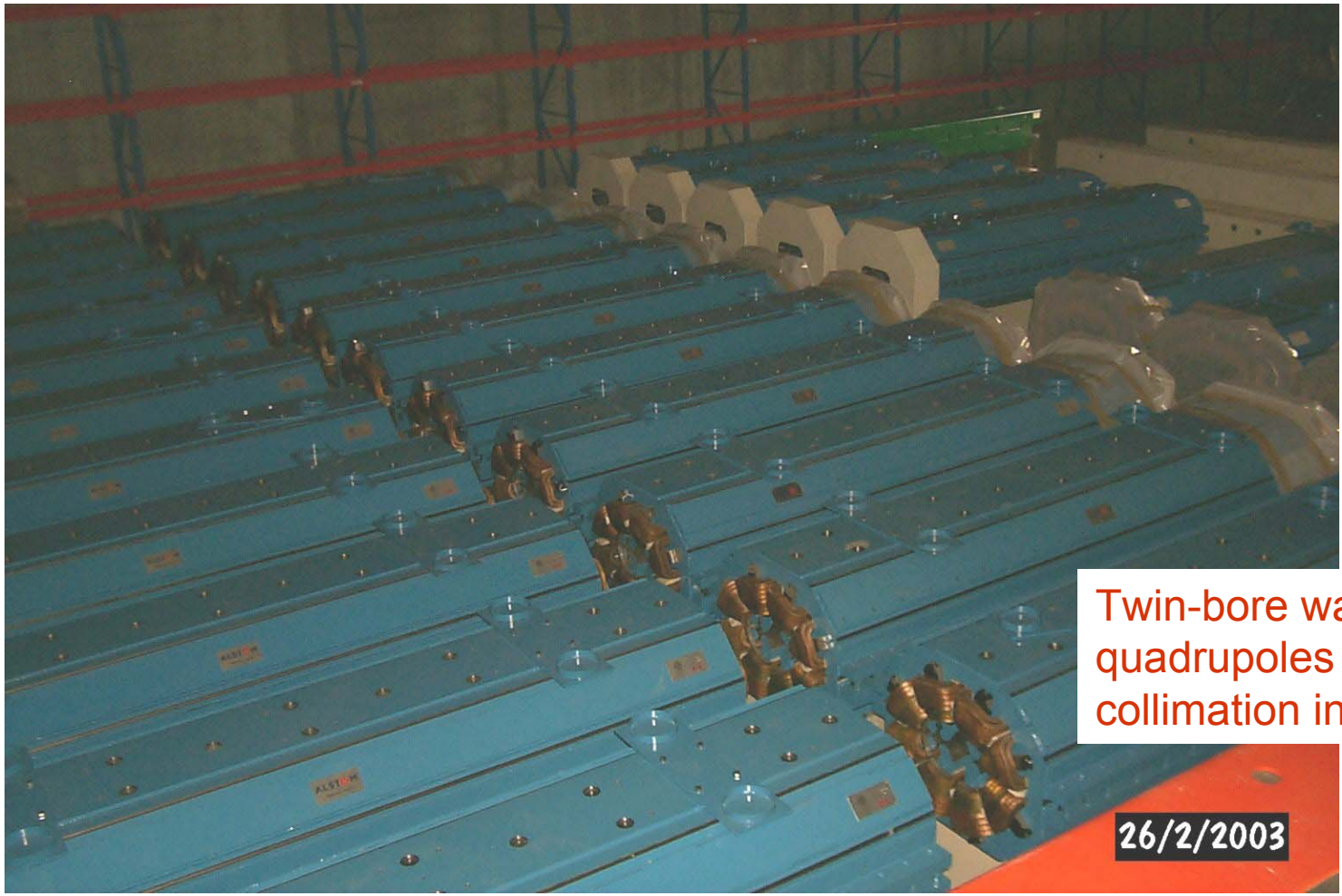
The first sc-quadrupole on the test stand at FNAL



…getting to the nominal current with no quench

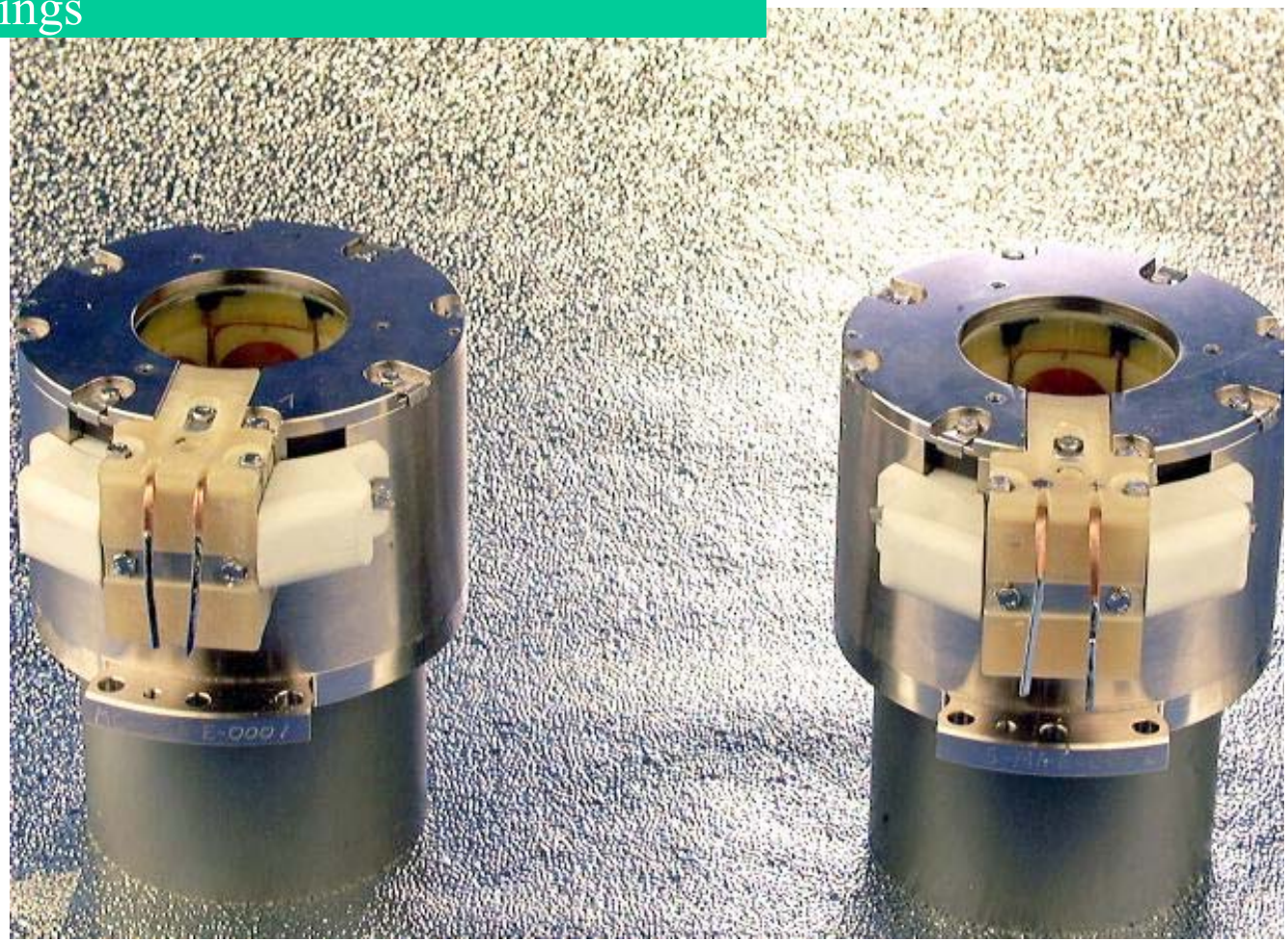


Canada



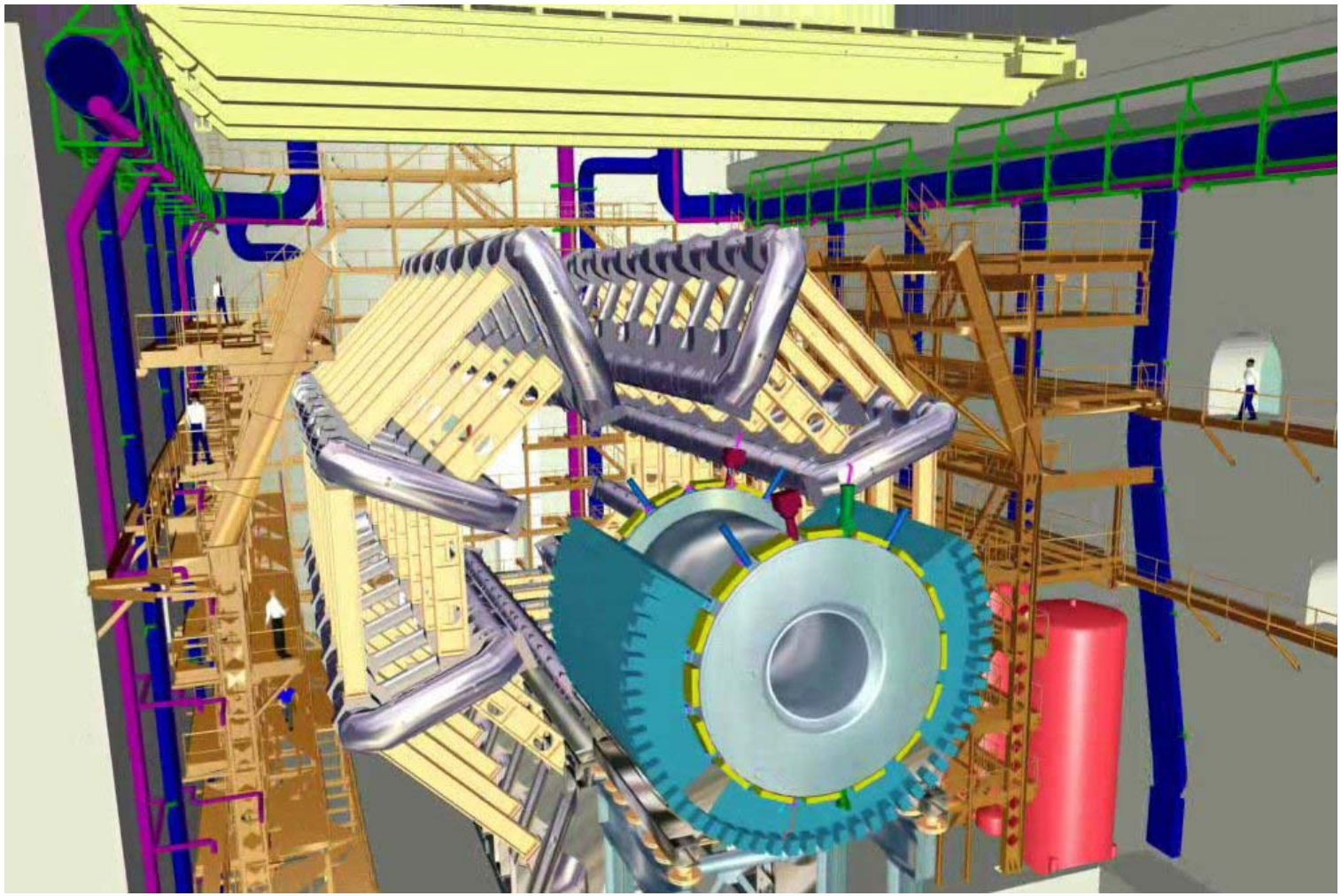
Twin-bore warm quadrupoles for the LHC collimation insertions

India:
Superconducting, sextupole, octupole and decapole correction windings



LHC Detectors

ATLAS as planned for October 2004



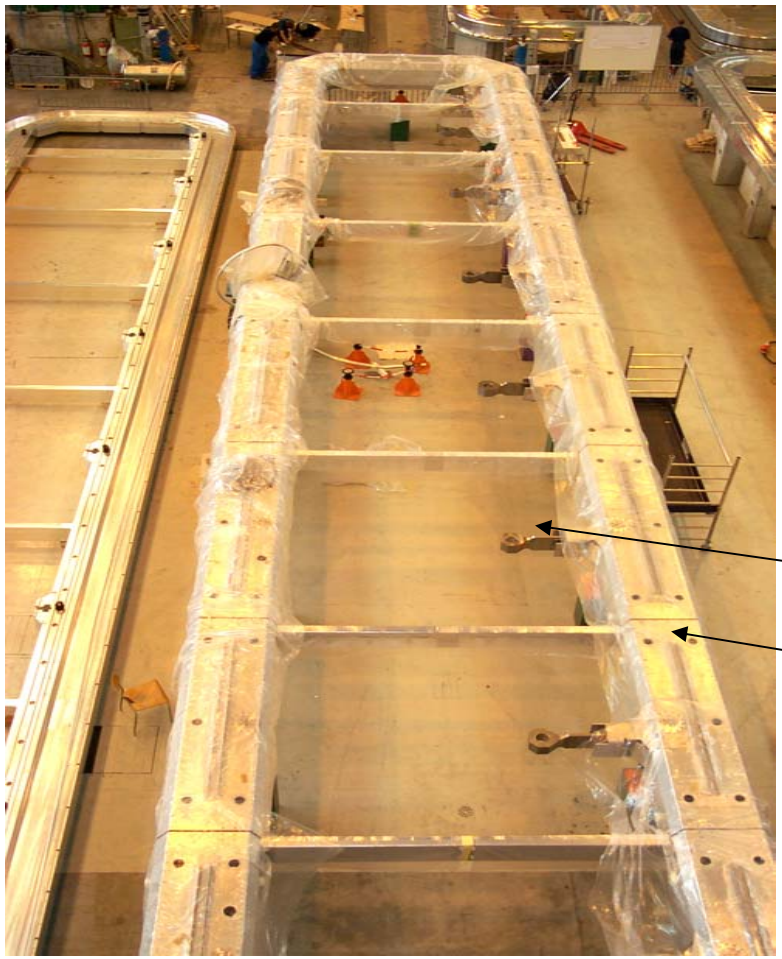
Barrel Toroid – Integration 1

Integration 1 well advanced : 6 coils done

Coil 7 started

Coil 6 finished

Barrel Toroid – Integration 2



Coil 1 status :

1. **instrumentation done**
2. **cooling pipes installed**
3. **tie rods installed**
4. **heat shields installed**

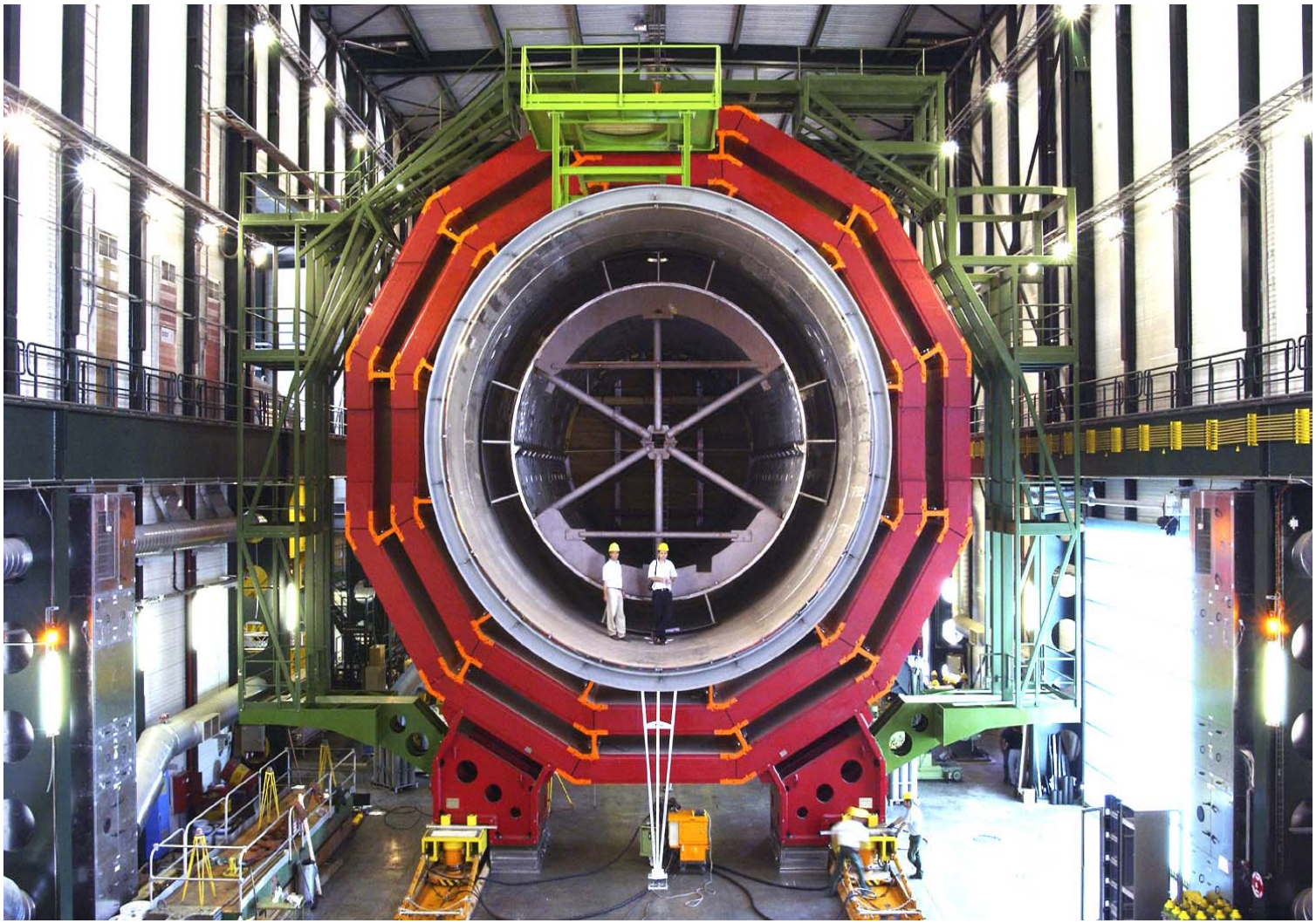
Coil 2 status :

1 to 3 practically done

heat shield missing

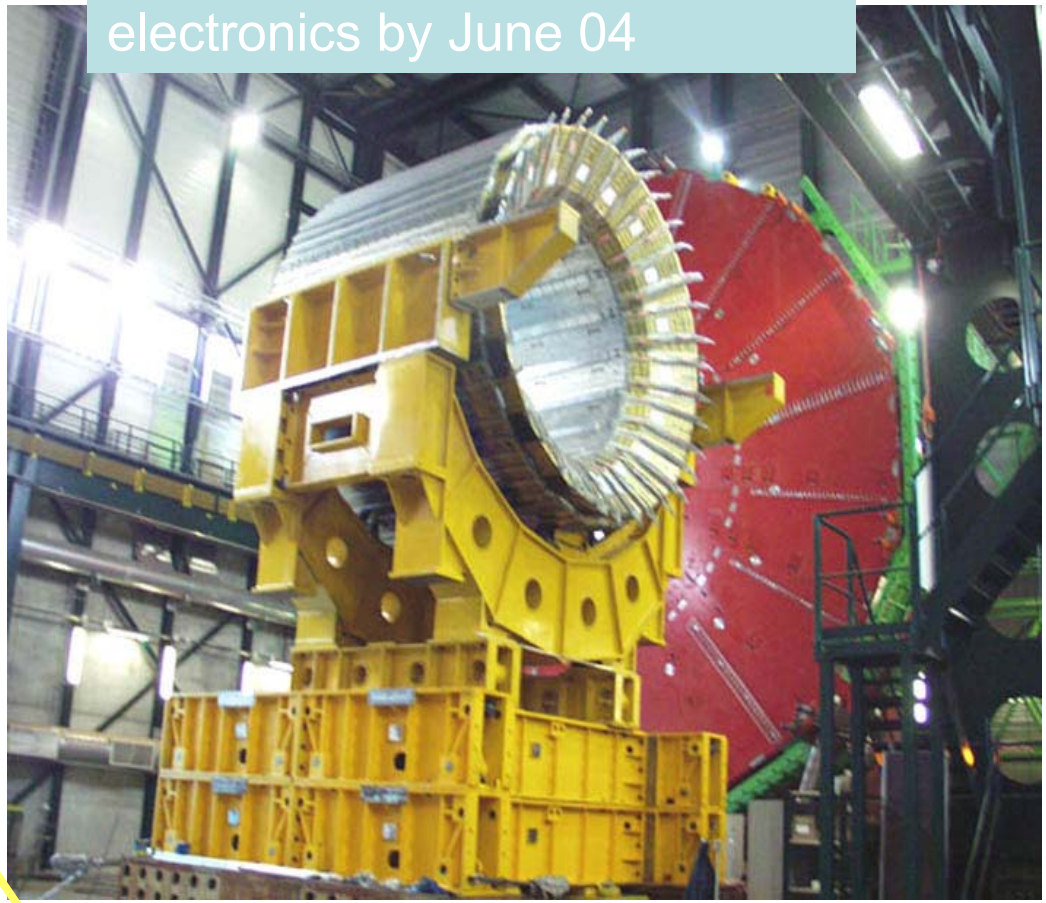
About 5 months delay accumulated

COIL INSTALLATION: Coil Insertion Test



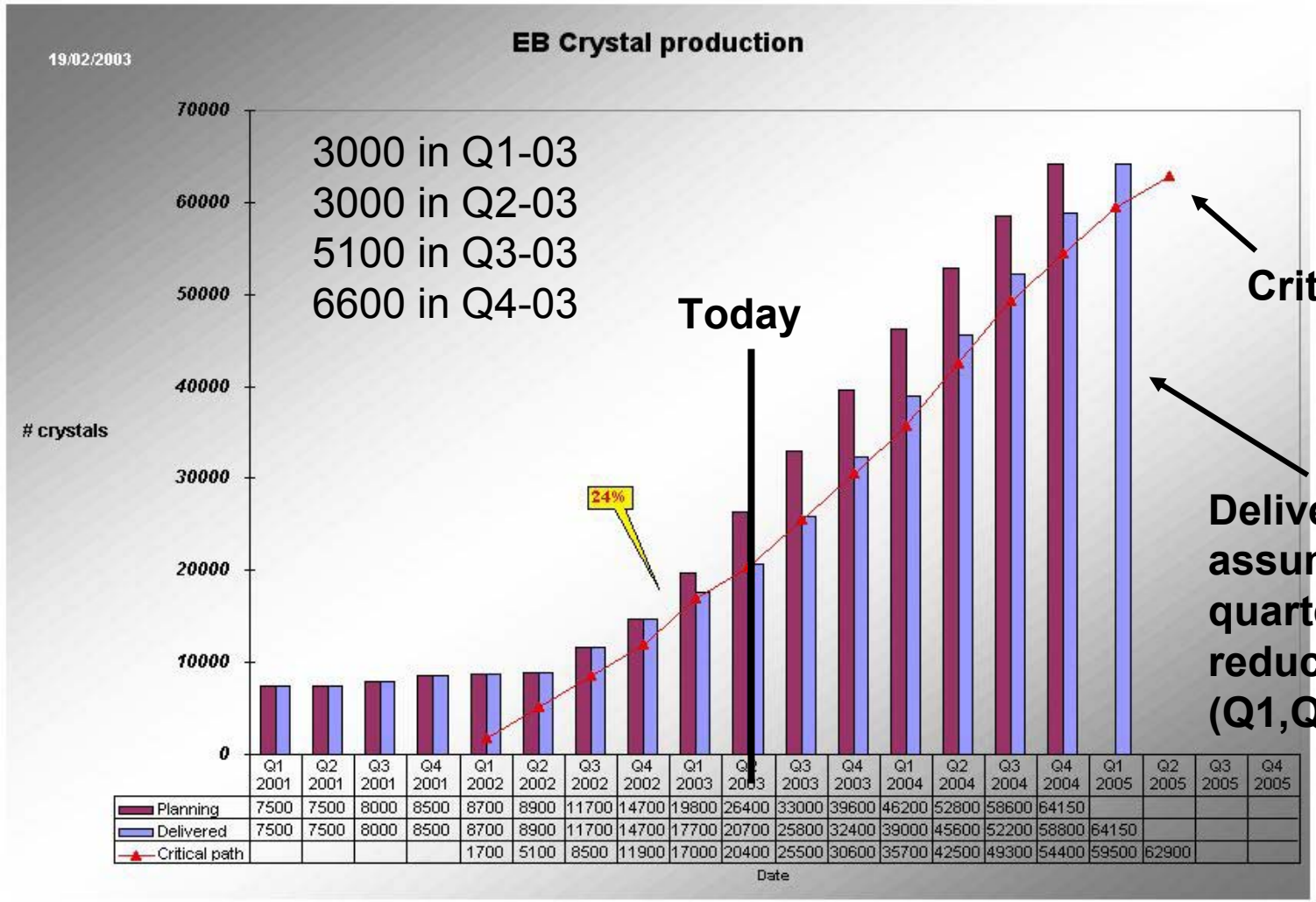
HCAL : HB and HE

HB complete, install on board electronics by June 04



HE-1 complete, HE+1 installed Dec-03

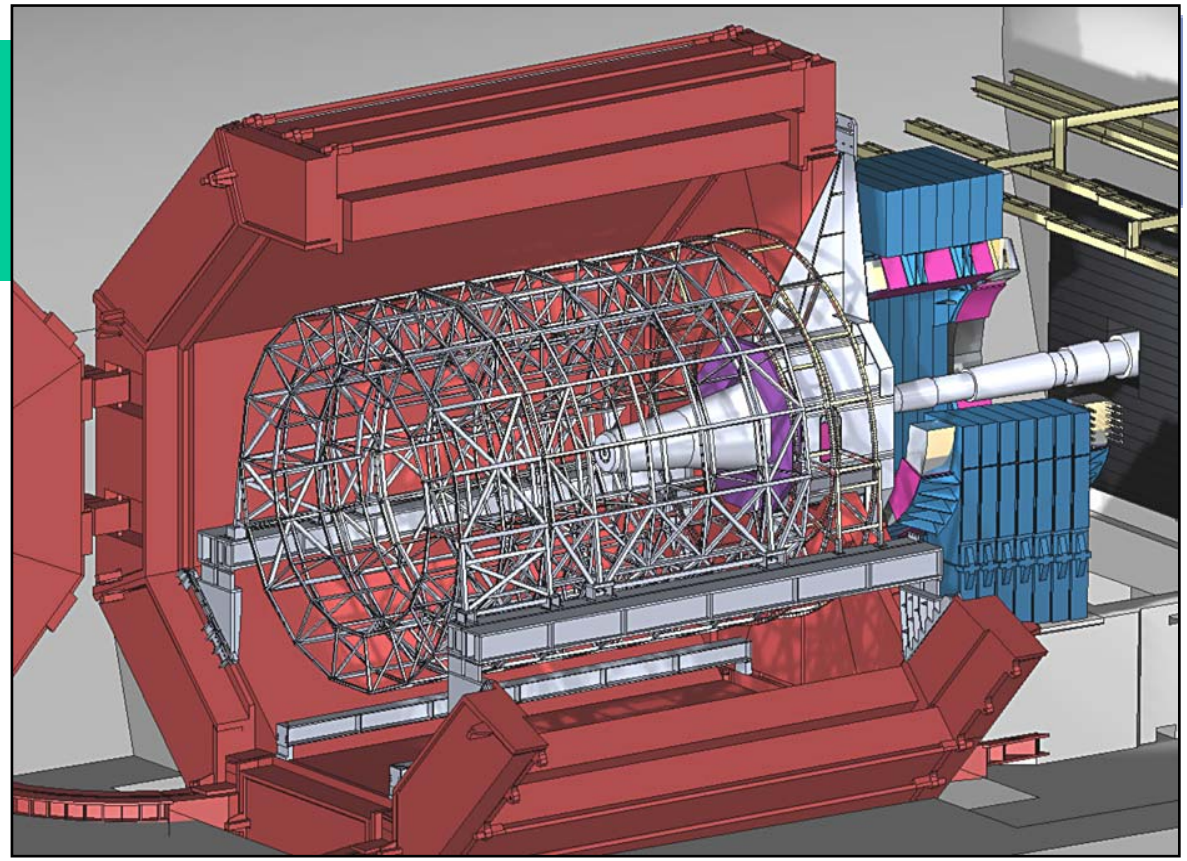
Crystal Delivery



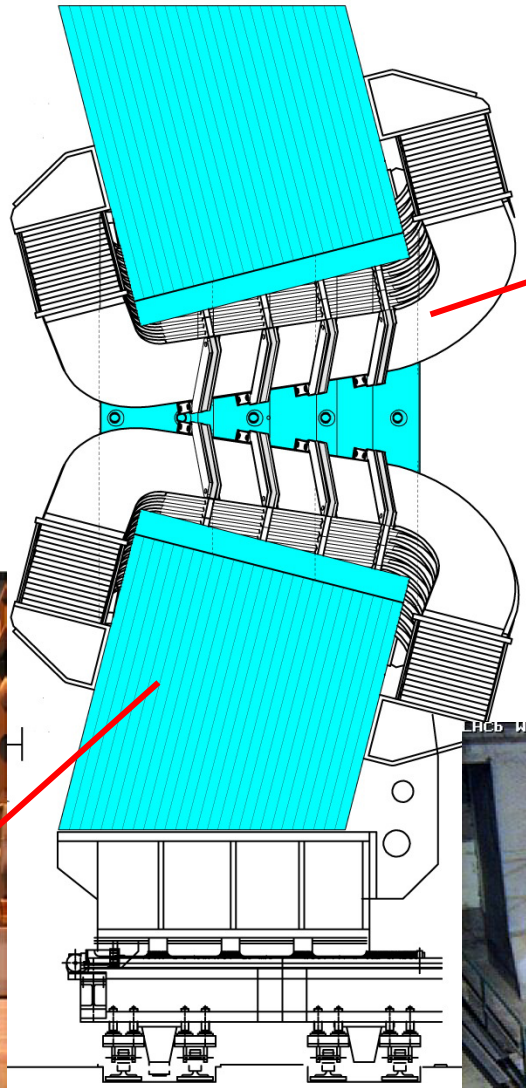
ALICE Today (June 2003)


ITALMEC
ITALMEC
S TOTAL
2.4T

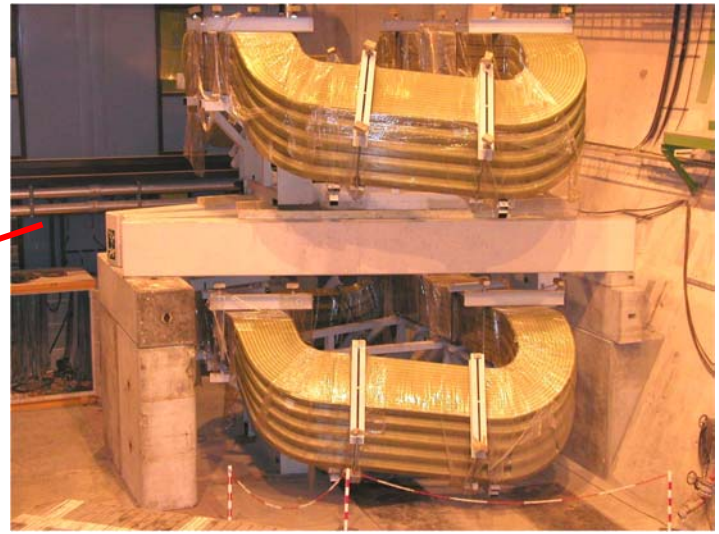
End of installation PHASE 1 according schedule :
June 2005



Magnet

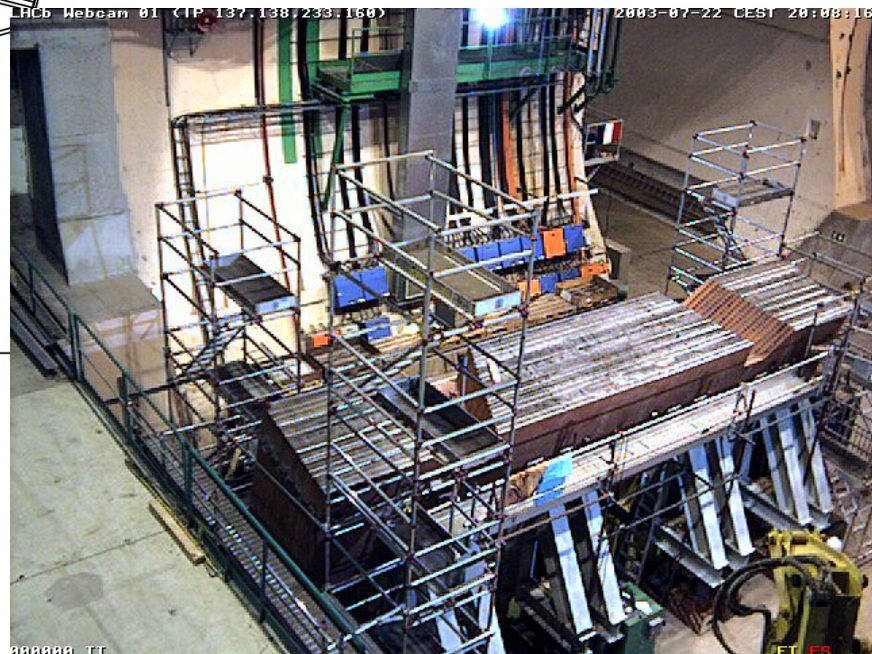


Al coil



Fe plate for the yoke

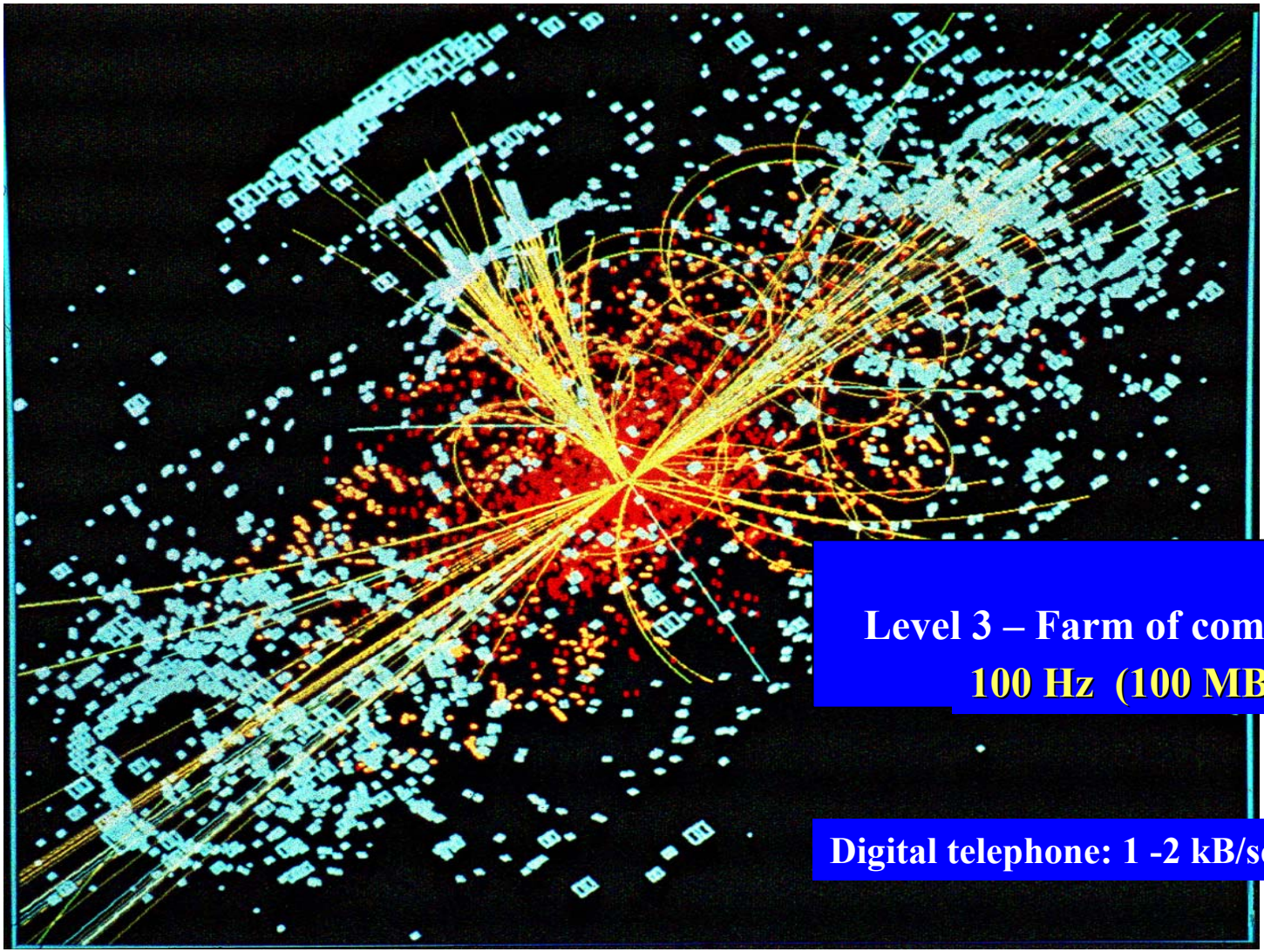
yoke assembly



Conclusions: Concerns in the Experiments

- ATLAS
  - Barrel Toroid Schedule
  - TRT schedule
  - Production of DMILL electronics by ATMEL
- CMS
  - ECAL production
  - Si tracker mass production
- ALICE
  - TPC Production
- Tight Schedules and Resources

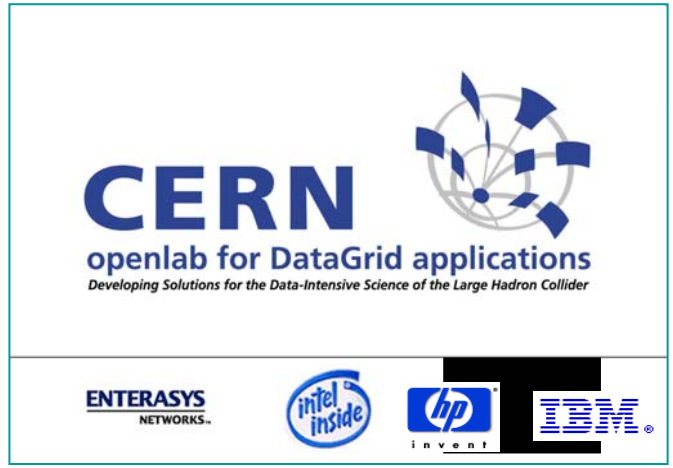
Computer reconstruction of an LHC collision

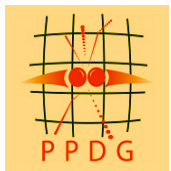


Level 3 – Farm of commodity CPU
100 Hz (100 MB/sec)

Digital telephone: 1 -2 kB/sec

Grid & Network Projects





EGEE: Enabling Grids for E-science in Europe

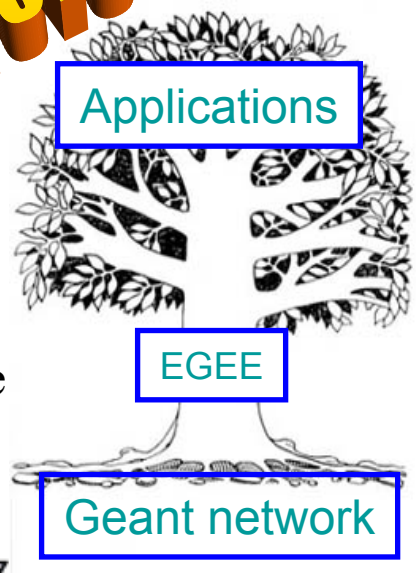
Goals

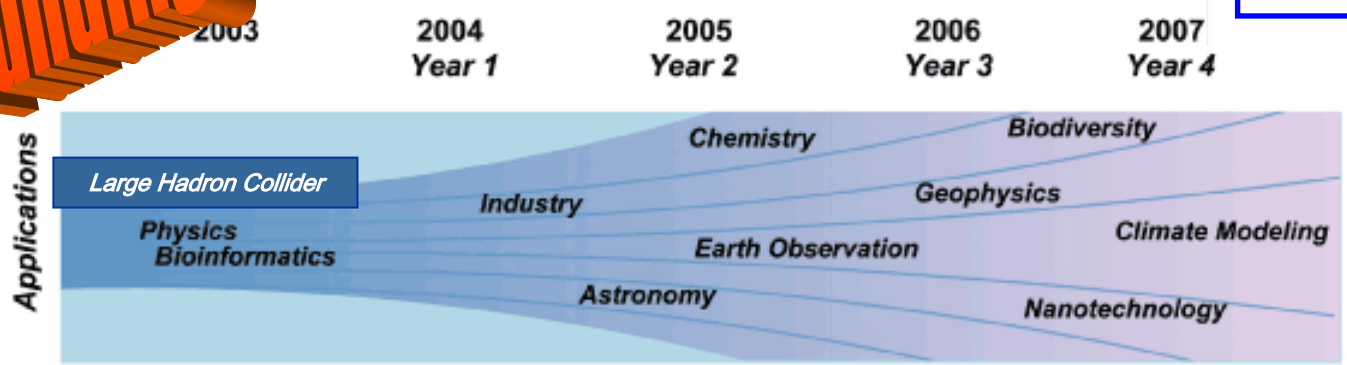
- **Create a wide European Grid Infrastructure for the support of research in all scientific areas**
- **Establish the EU part of a world-wide Grid infrastructure for research**

Strategy

- Leverage national and regional Grid programmes (e.g. LCG)
- Build on EU and EU member states investments in Grid technology
- Build on pioneering prototype results from previous and projects
- Exploit International collaboration (US, Asia Pacific)
- Work with industrial Grid developers and National Reseach Networks
- Become the natural EU counterpart of the US NSF Cyber-infrastructure

Funding of 32ME over two years approved by EU

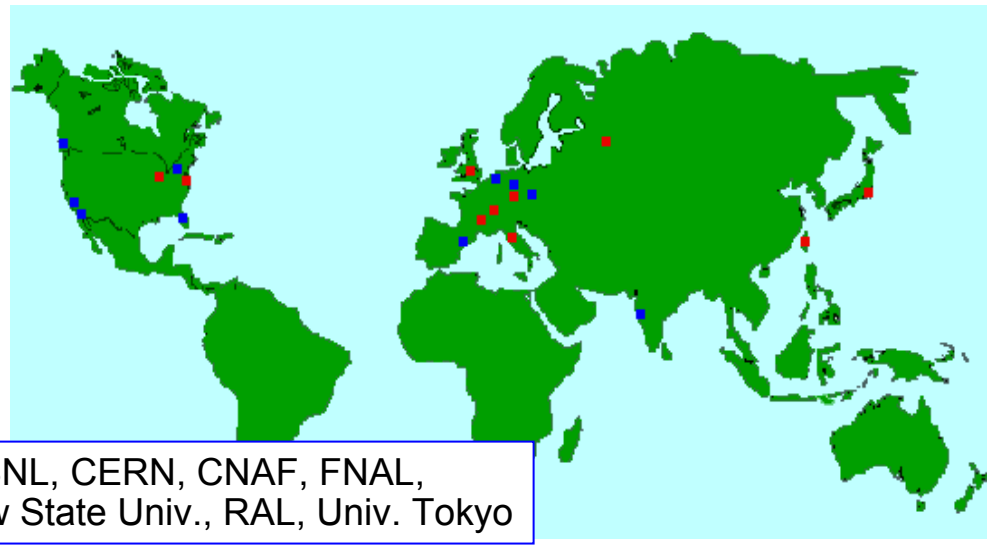




LCG1 - Grid Deployment

- Certification and distribution process established
- Middleware package – components from –
  - European DataGrid (EDG)
  - US (Globus, Condor, PPDG, GriPhyN) → the Virtual Data Toolkit
- Agreement reached on principles for registration and security
- RAL (Oxford, UK) to provide the initial grid operations centre
- FZK (Karlsruhe, Germany) to operate the call centre

- Initial service being deployed now to 10 centres
  US, Europe, Asia
- Expand to other centres as soon as the service is stable



Academia Sinica Taipei, BNL, CERN, CNAF, FNAL, FZK, IN2P3 Lyon, Moscow State Univ., RAL, Univ. Tokyo

Grid Middleware for the Longer Term

Requirements –

- A second round of specification of the basic grid requirements is being completed now - HEPCAL II
- A team has started to specify the higher level requirements for distributed analysis – batch and interactive – and define the HEP-specific tools that will be needed

For basic middleware the current strategy is to assume

- that the US DoE/NSF will provide a well supported Virtual Data Toolkit based on Globus Toolkit 3
- that the EGEE project, funded by EU 6th framework, will develop the additional tools needed by LCG

8. Conclusions: where are we ?

- Sept. 2001:
  - extra cost-to-completion of the LHC programme was declared, of about 800 MCHF (machine, detectors, computing, missing extra contributions w.r.t. 1996 plan);
- Dec. 2001:
  - main remaining contracts adjudicated (cold mass assembly, cryoline…);
- March 2002:
  - LHC commissioning rescheduled to April 2007, to comply with the industrial production rate of the main components (e.g. cables);

Conclusions (cont'd)

- June 2002:
  - Following internal reviews and recommendations by the External Review Committee, Management proposed a "balanced package" of measures, ***to absorb the extra cost in a constant CERN budget*** (approximate figures!):
  - 400 MCHF programme reduction, focusing of personnel on LHC, savings, extra external resources (e.g. for computing);
  - 100 MCHF rescheduling LHC to 2007;
  - 300 MCHF full repayment of the LHC reported to 2010 from 2008
- Dec. 2002:
  - Management's plan, 2003-2010, approved by Council;
  - A long term loan (300 MEUROs) was obtained by the European Investment Bank, to cover cash-flow peak.

LHC back on track!

Conclusions (cont'd)

Today:

- LHC Progress is gauged by ***new specific control tools*** in addition to the classical peer committee reviews:
  - **Machine:**
    - Data collection for Earned Value Management concerning the material budget is completed and reporting has started;
    - Cost & Schedule Annual Review;
    - *LHC Dashboard* allows monthly update on production and installation
  - **Detectors:**
    - Regular Integration reviews
    - Periodic machine-detector meetings
- LHC cost remains stable;
- Production of machine and detector components, installation and integration are approaching the cruising speed;
- Several old concerns have been overcome, new concerns appear, no show stopper.

- CERN has profited from Cost-to-Completion crisis in 2001 to enforce real changes;
- A leaner programme, a well-focused Laboratory;

- With less reservation than last year, we can confirm the LHC schedule:
  - completion of the LHC machine in the last quarter of 2006,
  - first beams injected during the spring of 2007
  - First collisions mid 2007.

ADDENDA

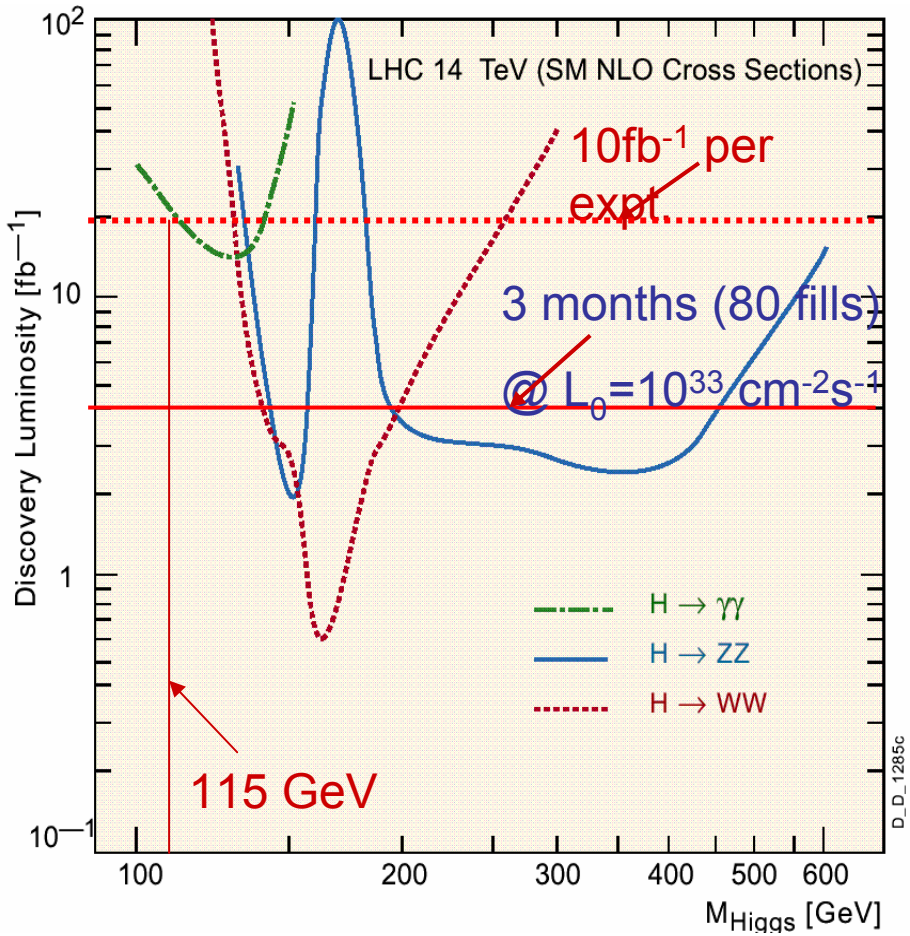
Physics at Startup

Example SM Higgs Discovery Reach (5σ): ATLAS +CMS

At $L_0=10^{33}$ cm^{-2}s^{-1}
1 month ~ 0.7 fb^{-1}
At $L_0= 3.10^{33}$ cm^{-2}s^{-1}
1 month ~ 2 fb^{-1}

Assumptions: 14hr run
and 10hr to refill
i.e. 1 fill/day
t_L ~ 20 hr, Efficiency of 2/3

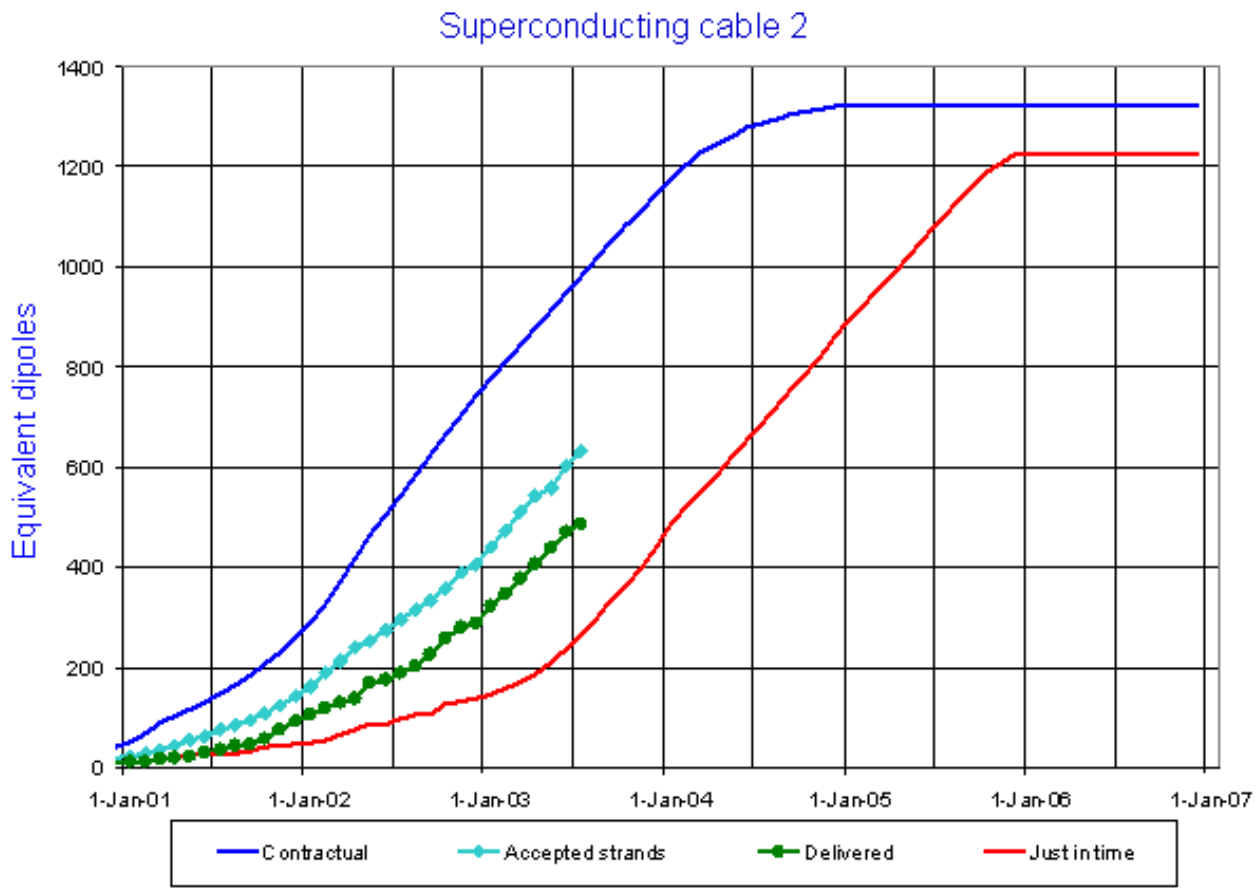
ATLAS +CMS



Cable

LHC Progress Dashboard

Accelerator Technology Division



Updated 31 Jul 2003

Data provided by A. Verweij AT-MAS

Quadrupoles and SSS

- Corrector supply is still a problem.
- The contract for SSS assembly will be extended for up to one more year (with no effect on the overall planning but some extra cost) to compensate.

United States:
Superconducting D1 dipole

Conclusions: LHC Machine & Areas

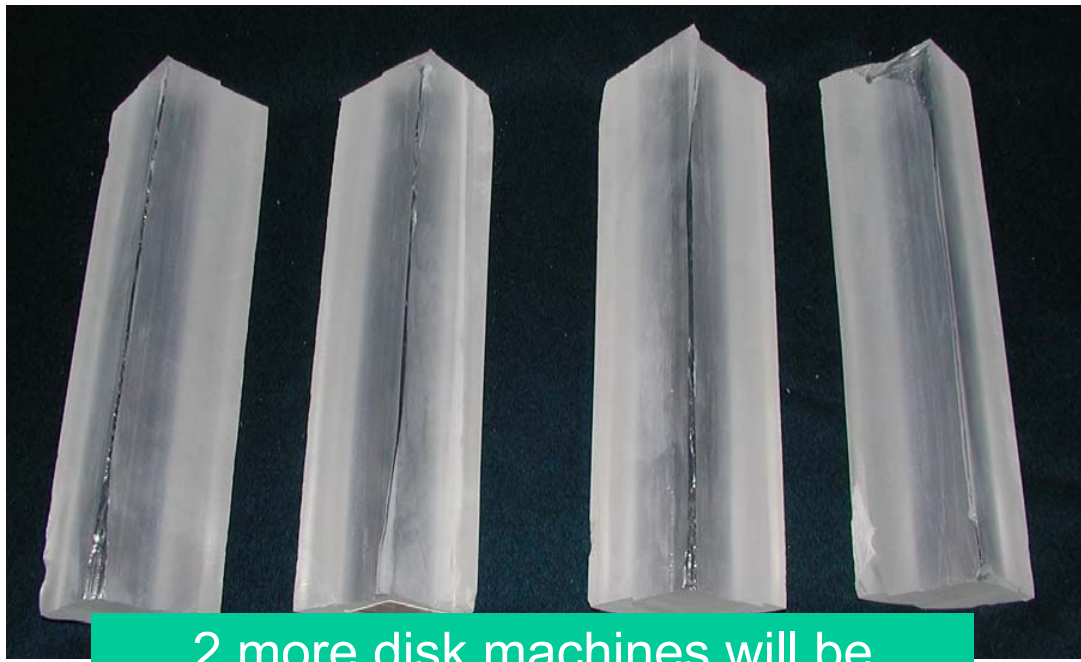
- In brief
  - Insolvency cases occurred in 2002 have been dealt with without impacting on the overall project schedule (but some increase in CtC).
  - Superconducting cable production has about reached its nominal rate.
  - Cryo-dipole production is ramping up in all 3 firms
  - The LHC master schedule can be found at the project home page :

  http://lhc-new-homepage.web.cern.ch/lhc-new-homepage
- Concerns:
  - Cracks at CMS shafts
  - production of correctors for the SSS quadrupoles
  - Late production of cold feed boxes is delaying dipole cold testing at CERN

Crystal Production: Cutting ‘4 in 1’

Longitudinal cut before annealing
Diamond disk, sweep mode

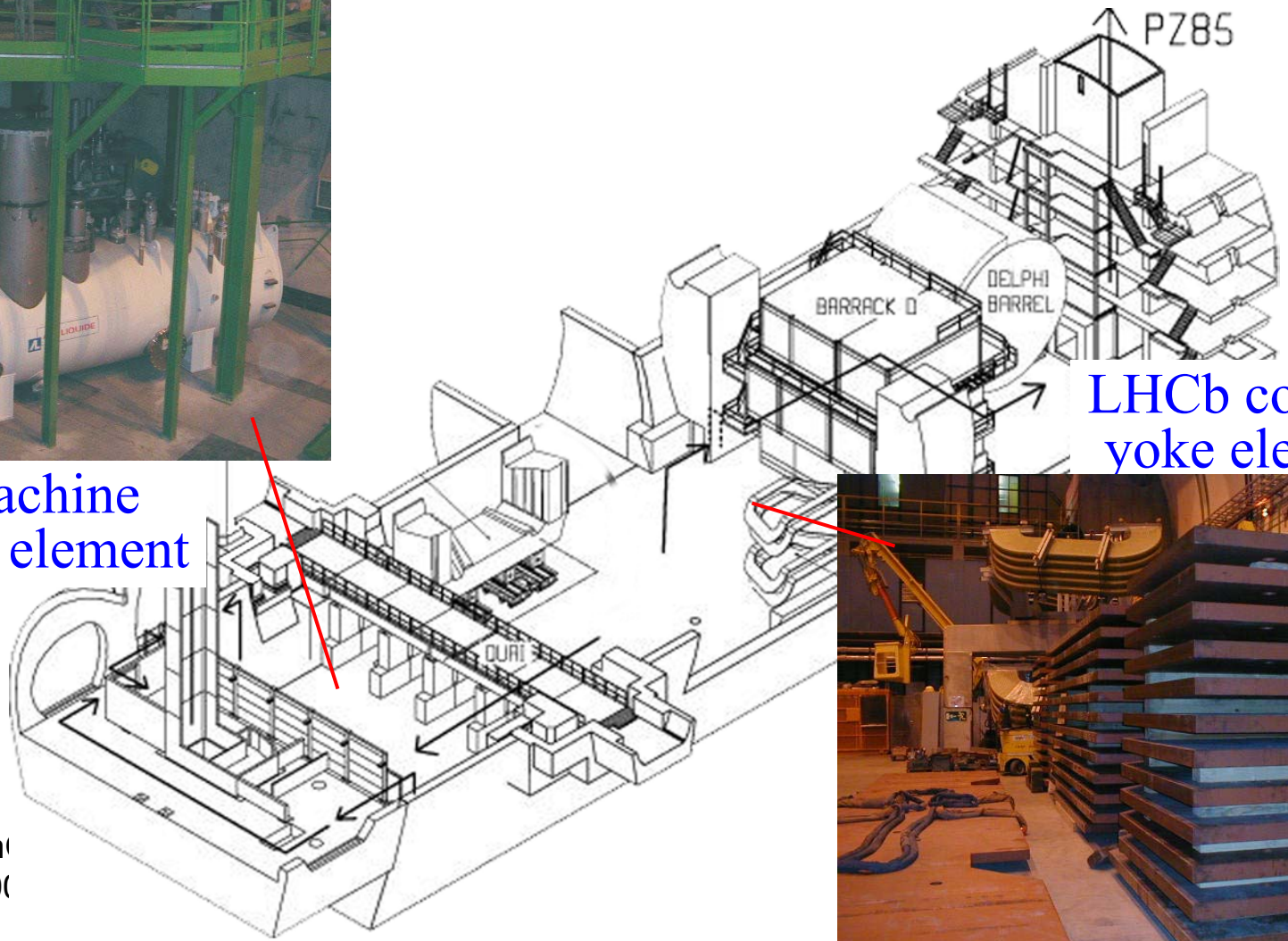
Final cut after annealing
Diamond disk, sweep mode



2 more disk machines will be installed in Bogoroditsk in July
(3 already operating)

UX8 Experimental area

LHC machine cryogenic element



LHCb coils and yoke elements