Workshop on Magnet Technologies
CERN June 7 -8 th, 2006

Upgrading present installations (SLHC at ~10^{35} cm^{-2} s^{-1}) demands to detectors and machine

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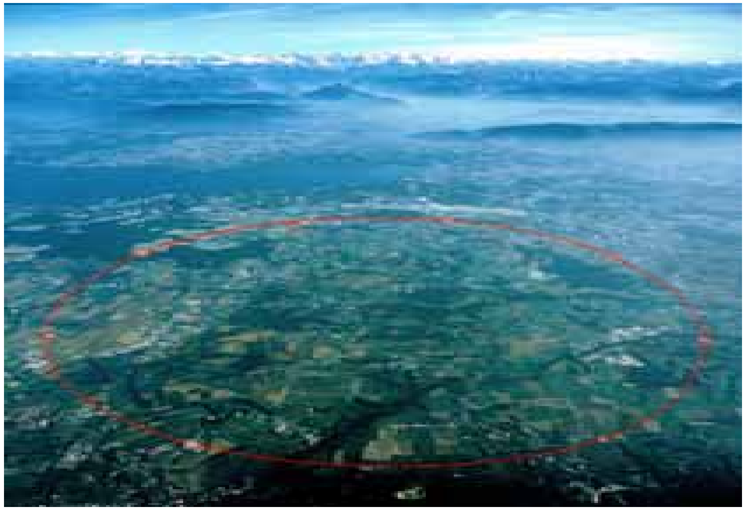
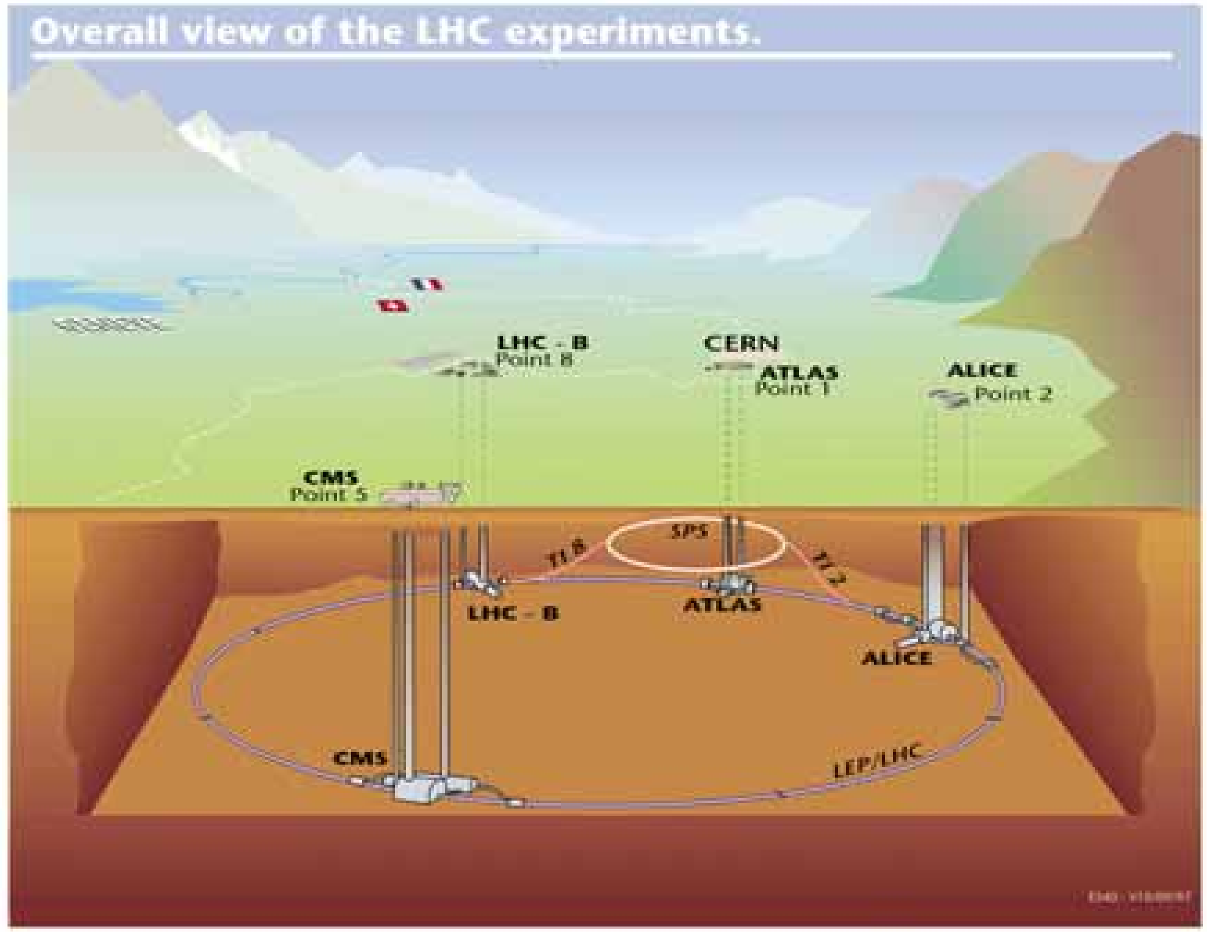
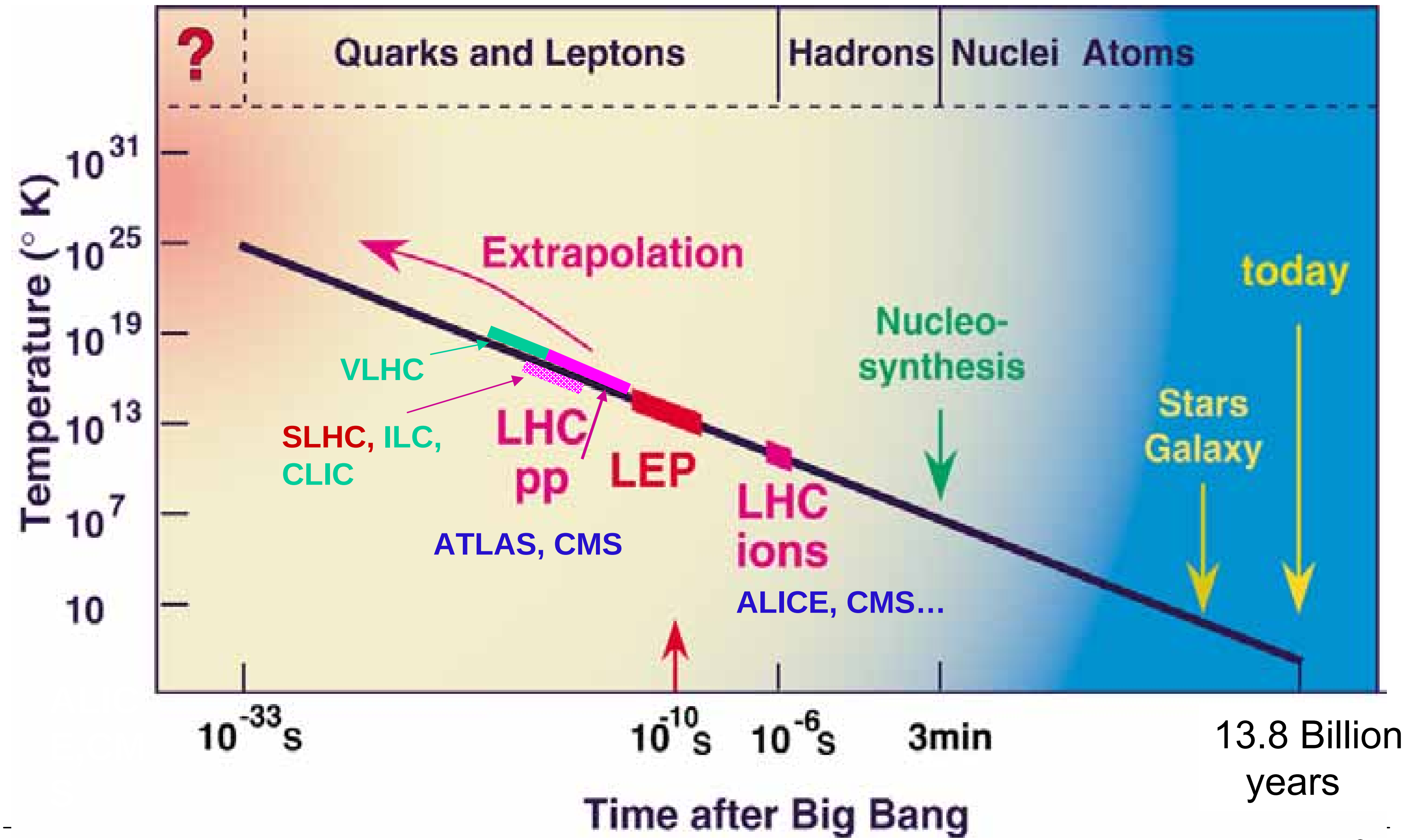
- motivations to go to higher energies/luminosities
- LHC and detectors at LHC
- SLHC and requirements on detectors
- VLHC/ other options / more distant future

LHC and experiments

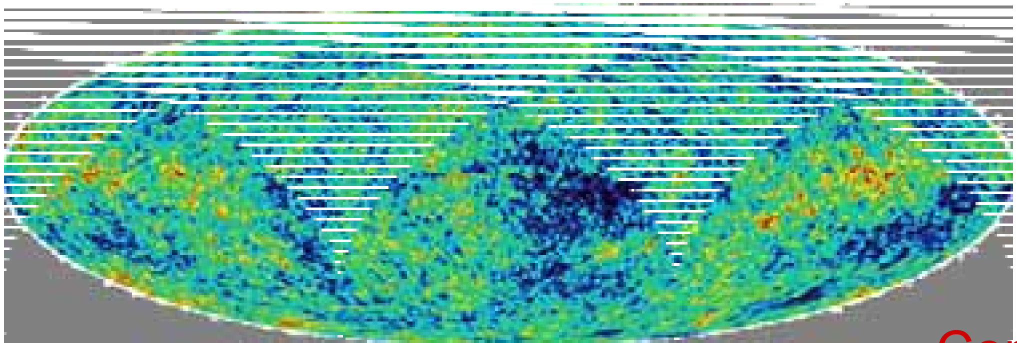




Connecting particle physics, the LHC and the Universe: towards the origin - the Big Bang



Universe - LHC connection
Dark Matter/Supersymmetry/LHC

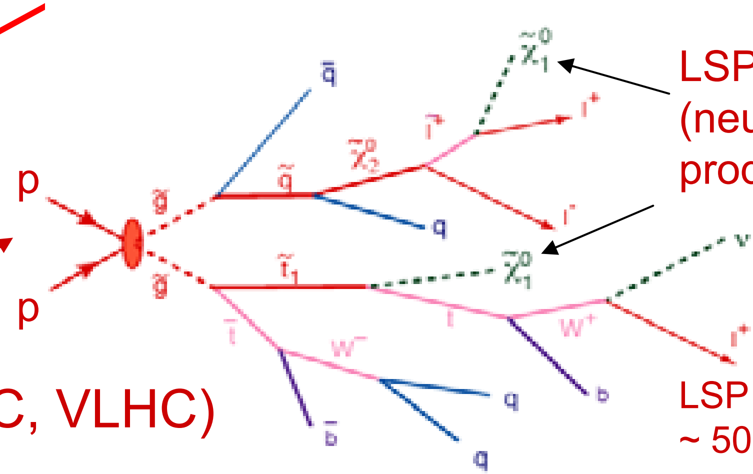


WMAP measurement of cosmic background anisotropies - evidence for density inhomogeneities seeding present day structures

Connection with SUSY and LHC

in terms of the critical density:

Baryon density : $\Omega_b = 0.044 \pm 0.004$
Dark Matter : $\Omega_m = 0.23 \pm 0.04$
Dark Energy : $\Omega_\Lambda = 0.73 \pm 0.04$



LSP-
(neutralino-1)
production

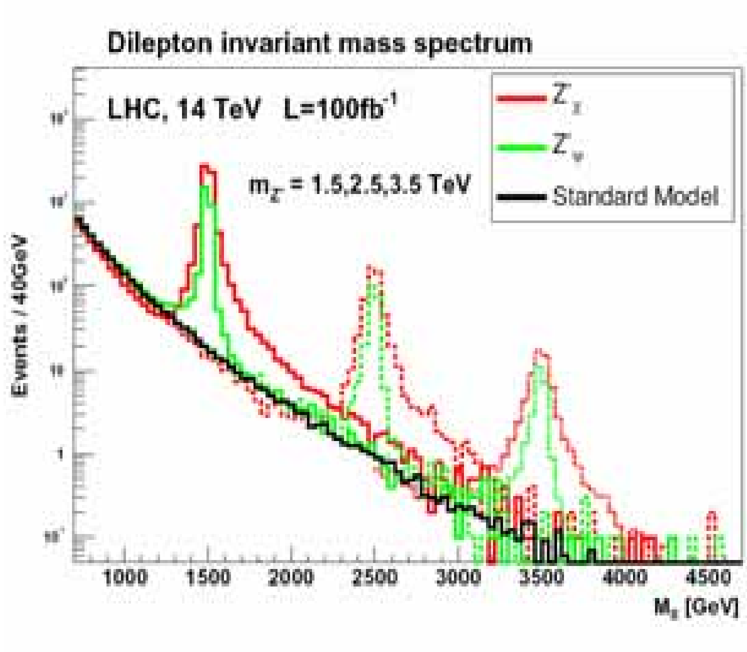
LSP mass:
~ 50 -1000 GeV

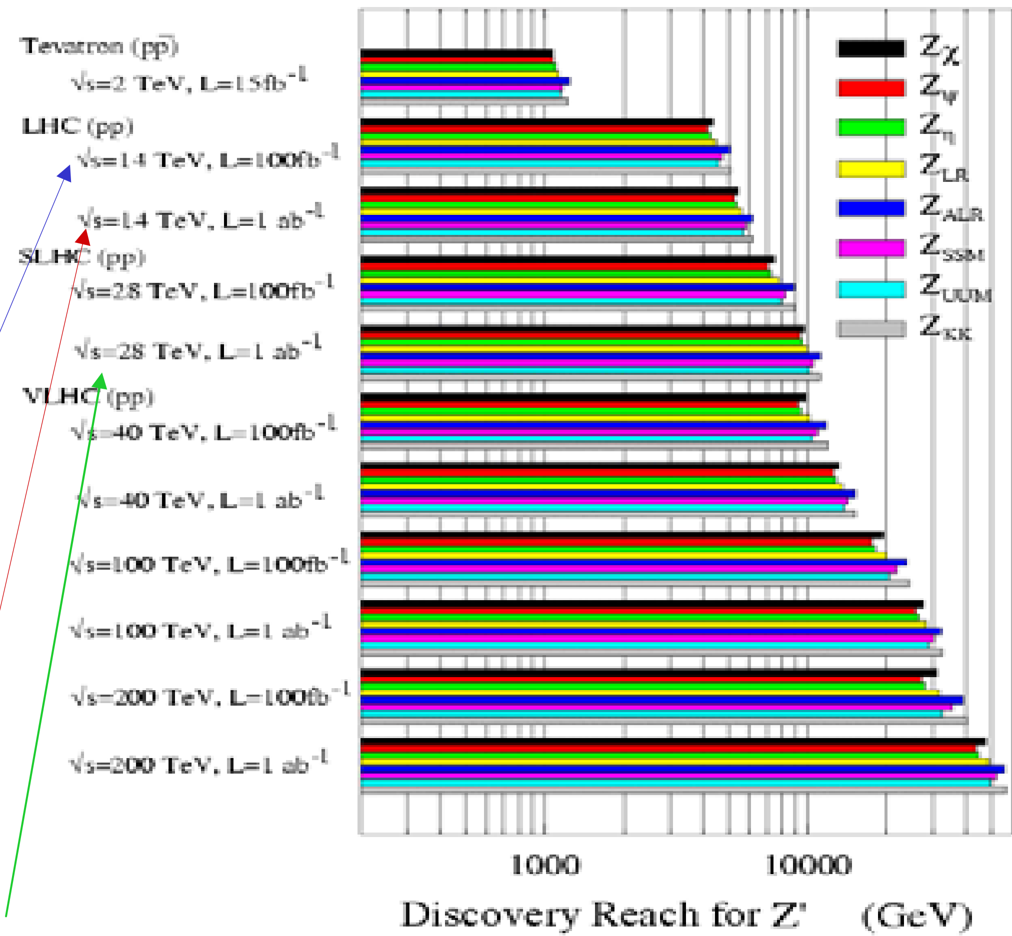
proton-proton collisions at LHC (SLHC, VLHC)

Data from WMAP significantly constrain the Dark Matter content of the Universe, this implies constraints on particle physics models, in particular on supersymmetry as the LSP (Lightest Supersymmetric Particle) is a plausible particle-physics candidate for DM this SUSY- LSP could be aboundantly produced at the LHC

New heavy bosons, VLHC/SLHC vs LHC

For new heavy gauge bosons (Z') or W_{KK}, Z_{KK}, mass reach at LHC, SLHC and VLHC





LHC reach ~ 4.0 TeV with 100 fb^{-1}

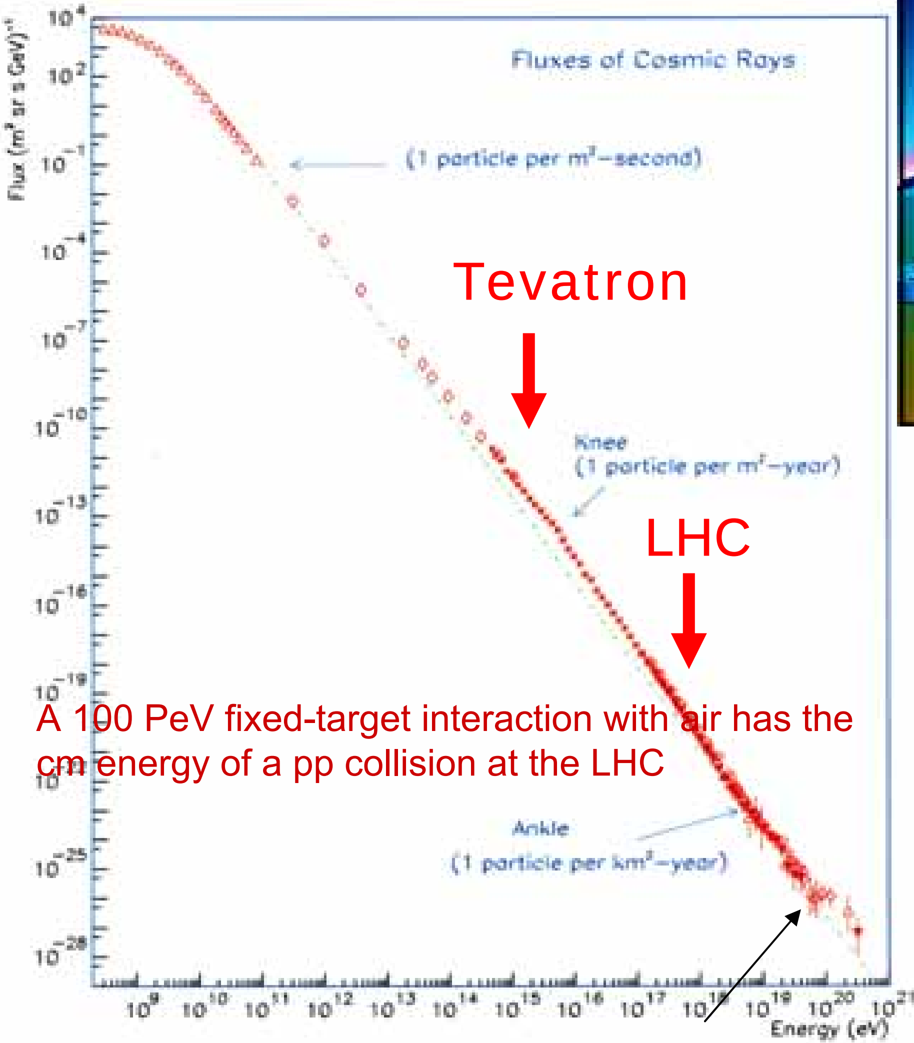
➡ gain in reach ~ 1.0 TeV i.e. 25-30% in going from LHC to SLHC

for massive objects larger center-of-mass energy is more profitable!

Need for a VLHC!!

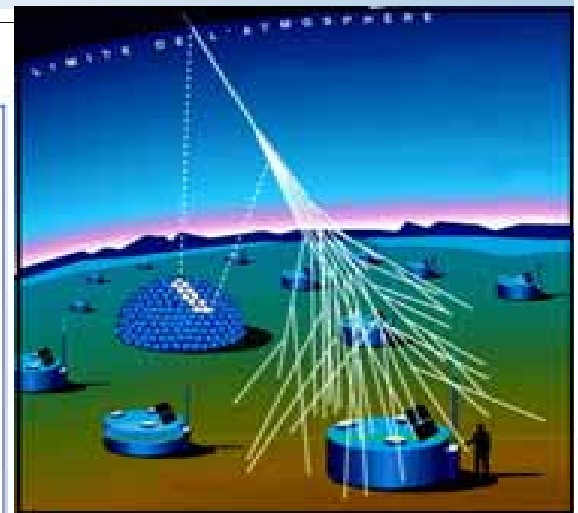
Cosmic rays, the LHC and beyond

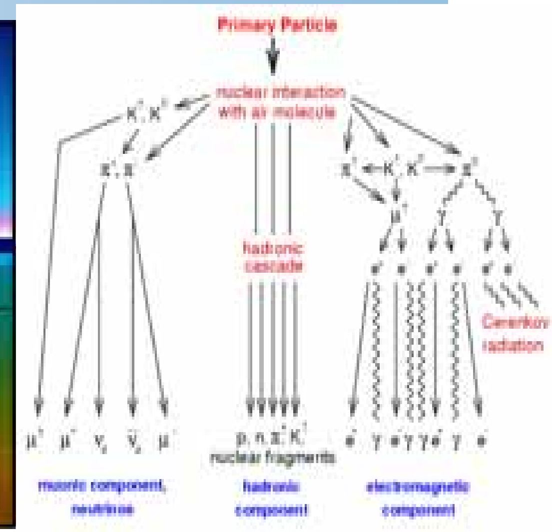
Cosmic ray spectrum



A 100 PeV fixed-target interaction with air has the cm energy of a pp collision at the LHC

AUGER

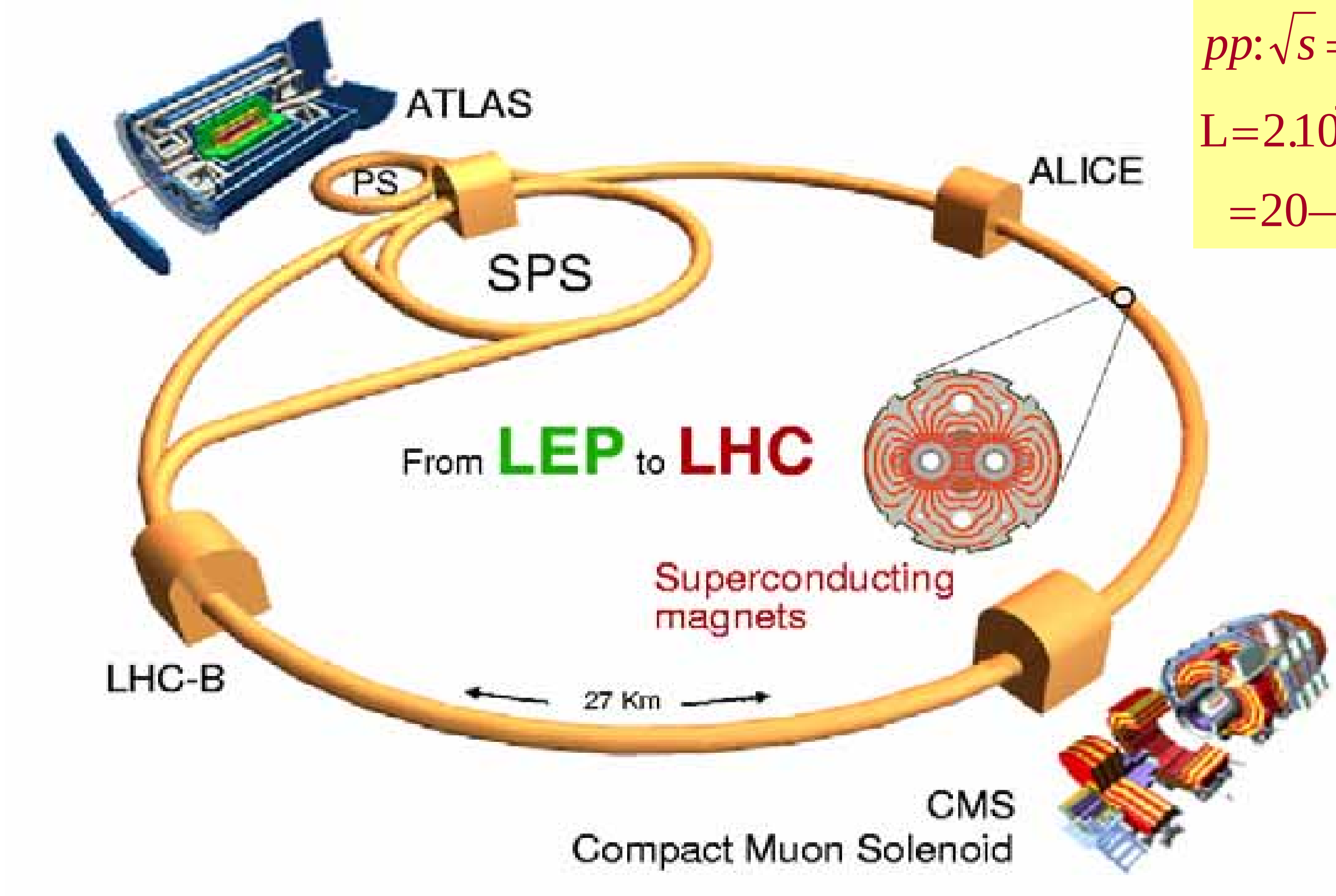




Correct simulation of interactions of primary cosmic rays with the atmosphere is essential to cosmic ray studies

LHC detectors (CMS +TOTEM in particular) with large acceptance/very large rapidity coverage will allow to understand and model pp, pA, A'A interactions giving rise to air-showers in the 10^{17-18} eV range. But the AUGER experiment is already testing the 10^{19-20} eV range range! One day we are going to need a VLHC/VVLHC!

LHC and experiments, accelerators and detectors



$pp: \sqrt{s} = 14\,\mathrm{TeV}$

$L = 2.10^{33} \rightarrow 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

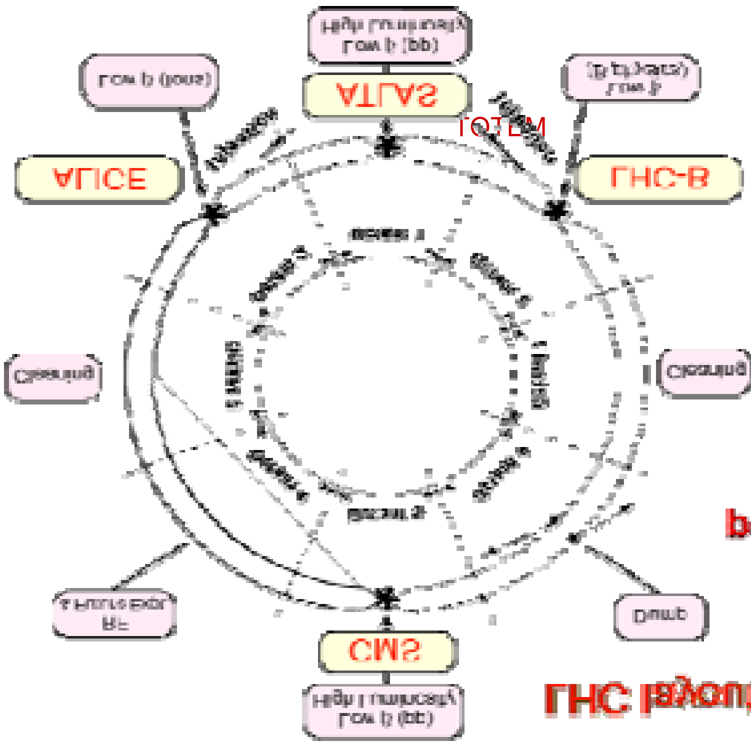
$= 20 \rightarrow 100\,\mathrm{fb}^{-1}/\mathrm{yr}$

also *AA* and *pA* collisions; for *PbPb* : 5.5 TeV/nucleon and $L = 10^{27}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

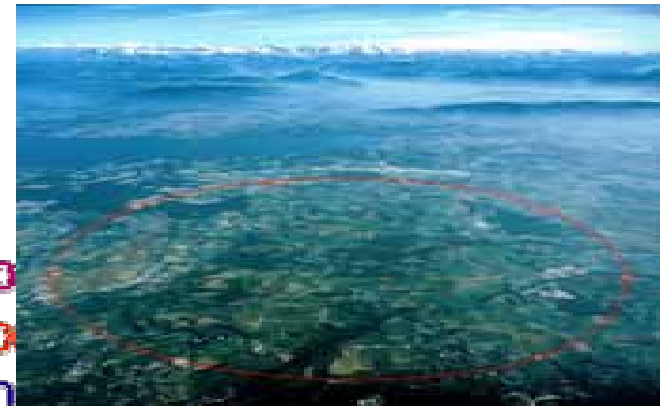
The Large Hadron Collider

Build the largest possible pp collider within the LEP tunnel - with highest achievable B field and luminosity - to have access to TeV scale parton-parton center-of-mass energies

~ 65% of the 27 km long circumference covered twice with B = 8.3T 1232 2-in-1 superconducting dipoles of 14.3m length operated at 1.9 ^oK, and 500 2-in-1 quadrupoles with 250T/m



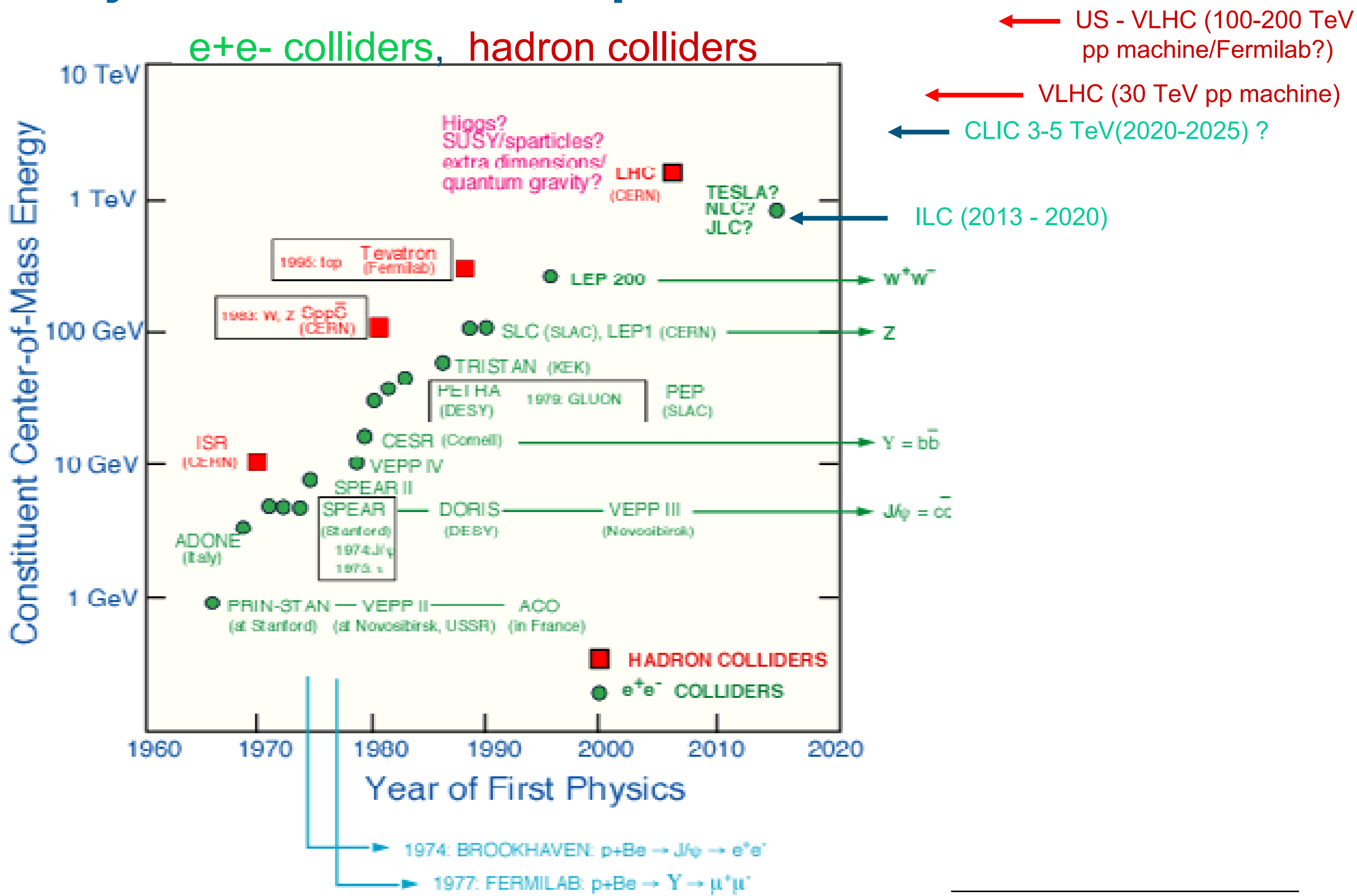
LHC layout and experiments



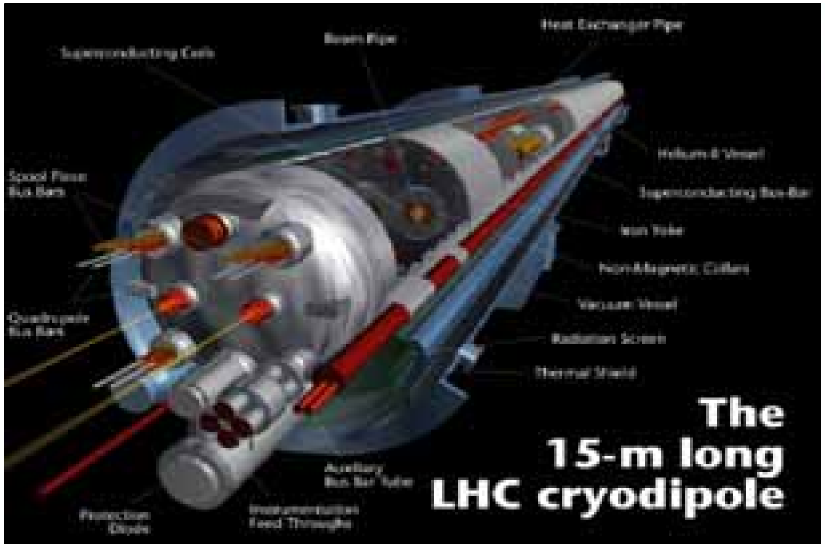
p = Beam

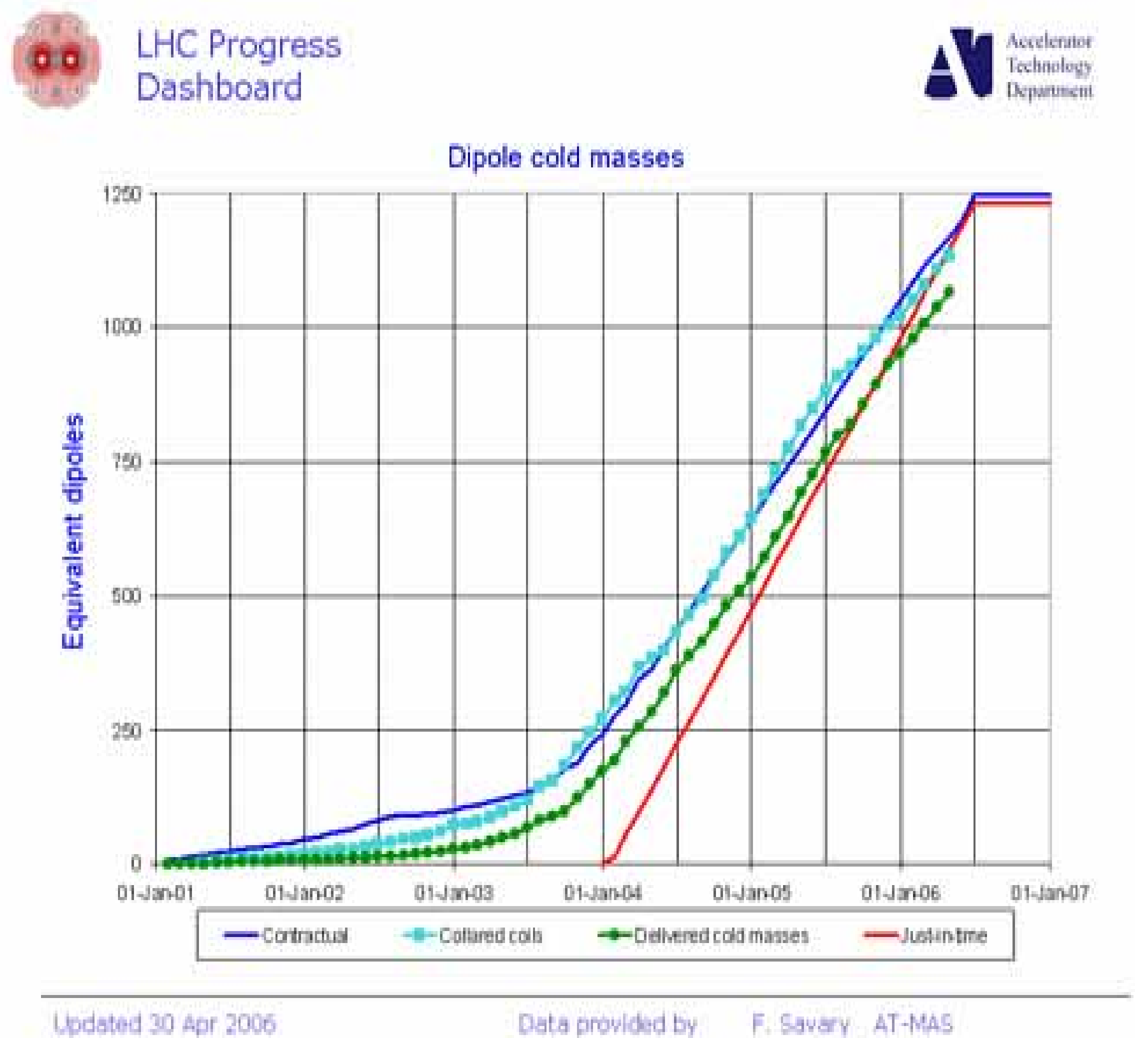
	Beams	cm energy	Luminosity
LHC	PbPb	1,312	
LHC	pp	14.0	
Tevatron	pp	2	
HERA	ep	300 GeV	$2 \cdot 10^{31}$ $cm^{-2} s^{-1}$
LEP	e^+e^-	200 GeV	10^{32} $cm^{-2} s^{-1}$
SLHC	pp	14.000 GeV	10^{35} cm^{-2} s^{-1}
VLHC	pp	30.000 GeV	10^{34} cm^{-2} s^{-1}

The two families of colliders, past evolution, major achievements, possible future evolution

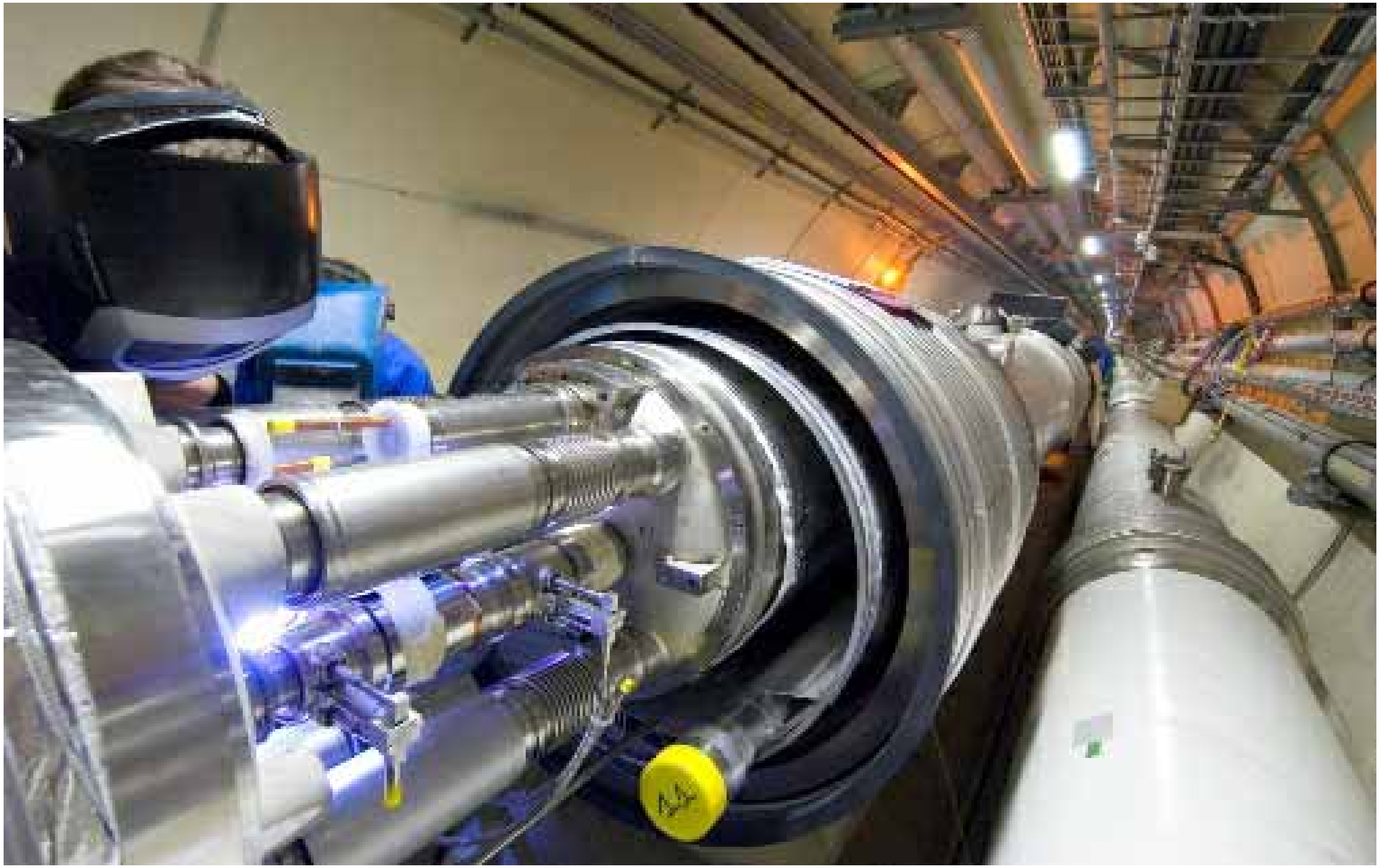


Progress on LHC construction
LHC dipoles production/cold masses



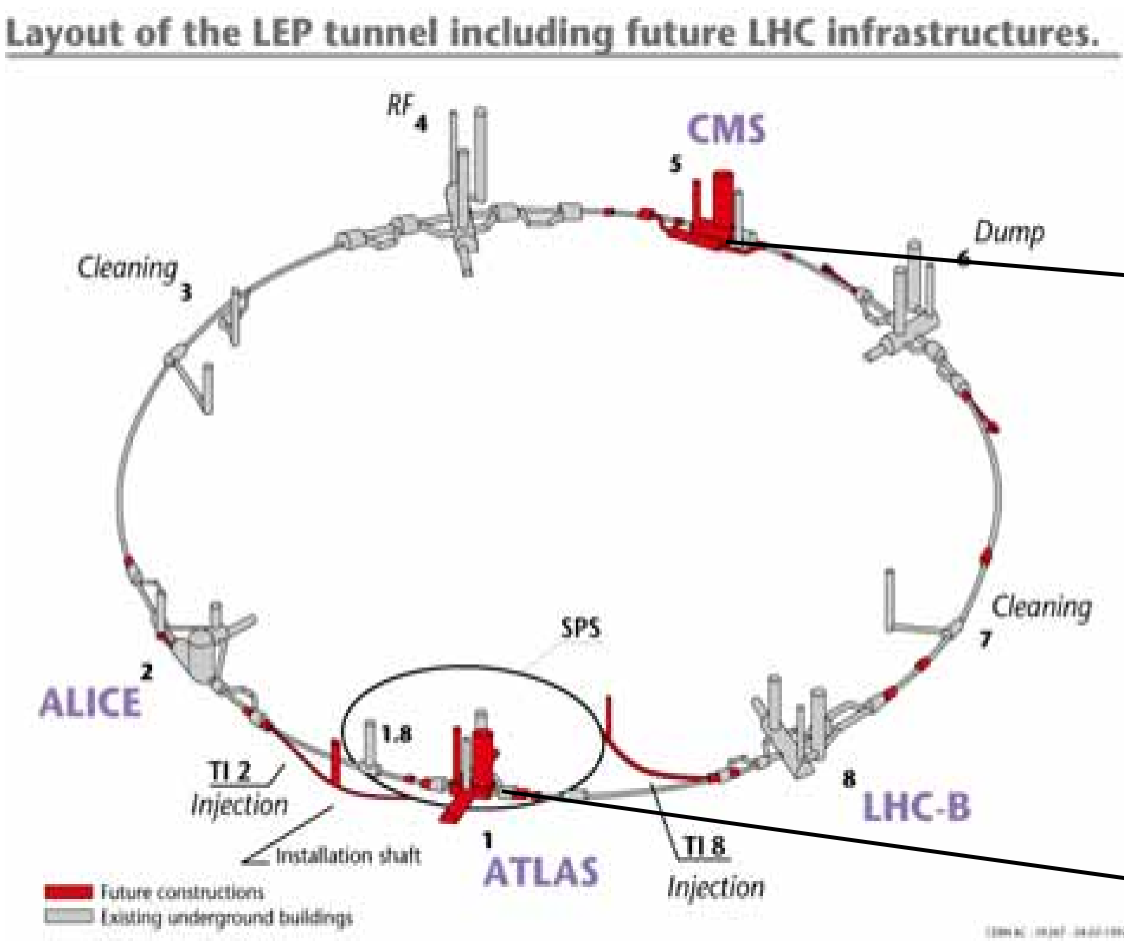


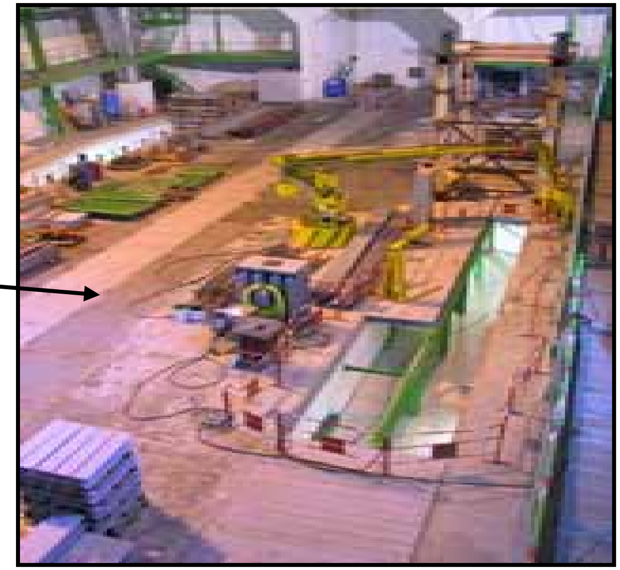
LHC installation - spring 2006

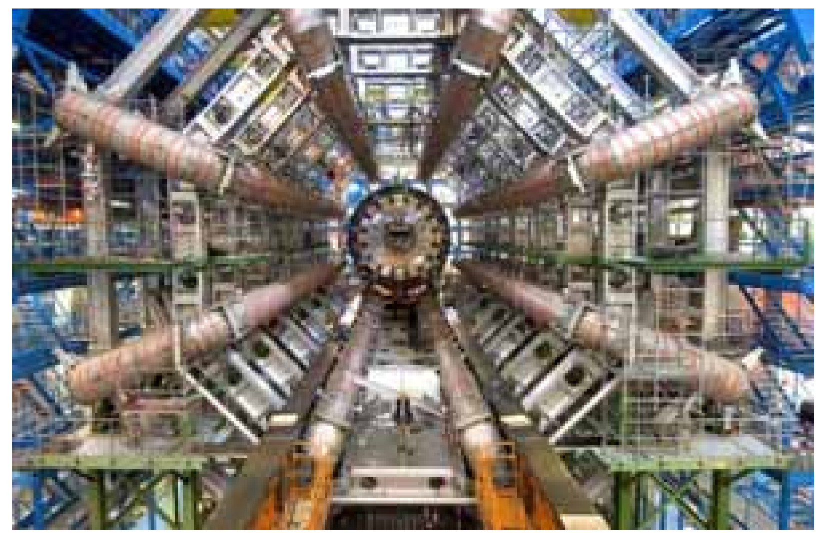


April 06: ~ 450 dipoles ~150 quads installed in the tunnel, ultimately they have to be aligned with 200μm precision

LHC infrastructures/ experimental halls

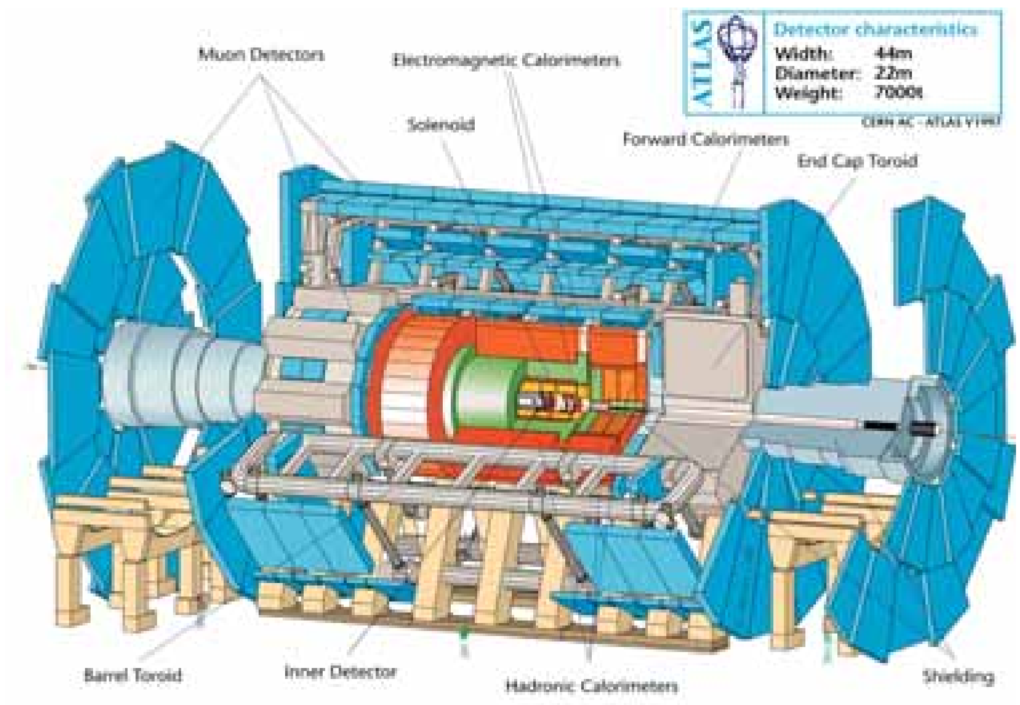


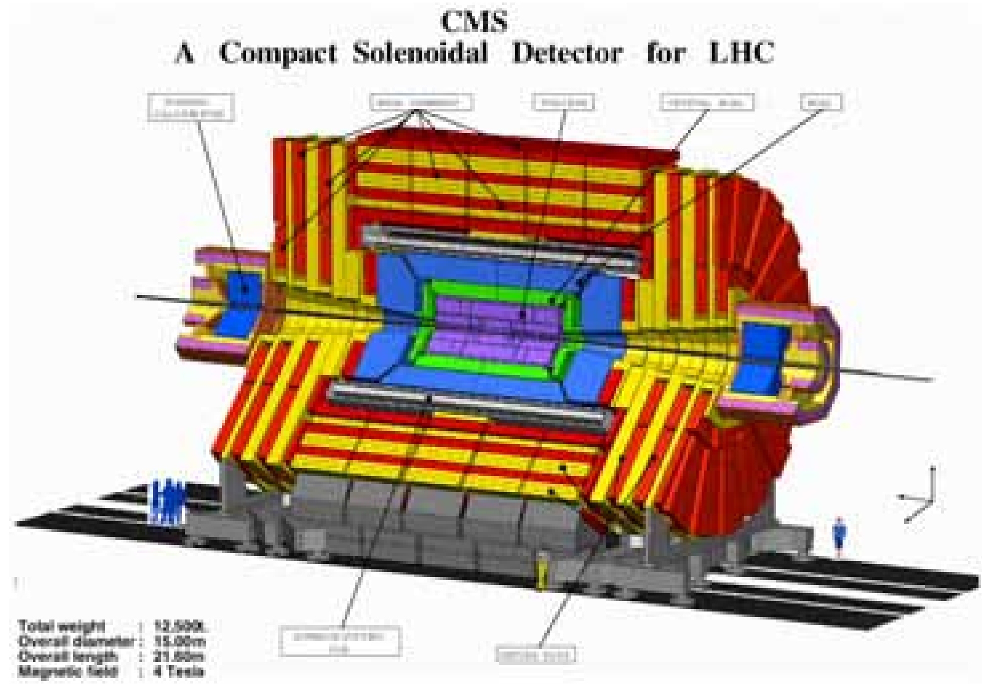




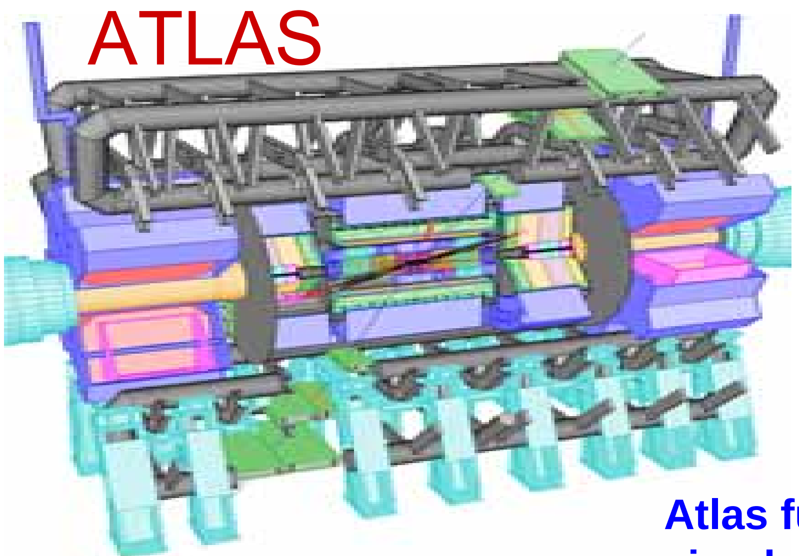
CMS is first assembled in a surface hall then lowered underground, ATLAS is directly assembled underground

ATLAS and CMS - two general-purpose LHC detectors

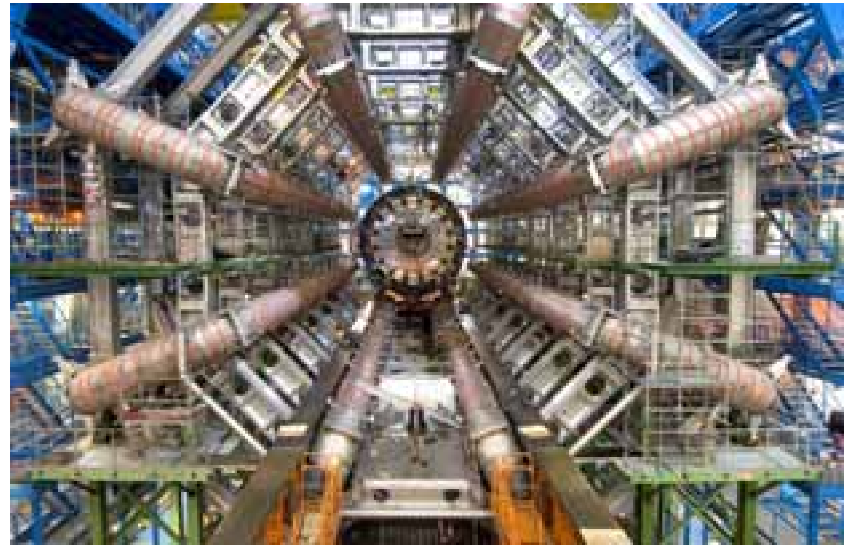




Physics goals: testing the Standard Model, QCD and electroweak sectors, looking for the Higgs, searching for Supersymmetry, evidence for extra-dimensions of space, understanding better matter-antimatter differences (CP/B), studying the quark-gluon plasma state of matter……

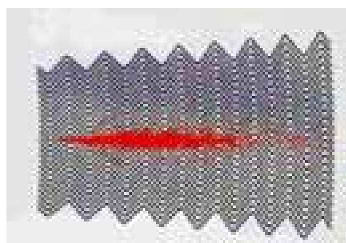


Atlas full simulation

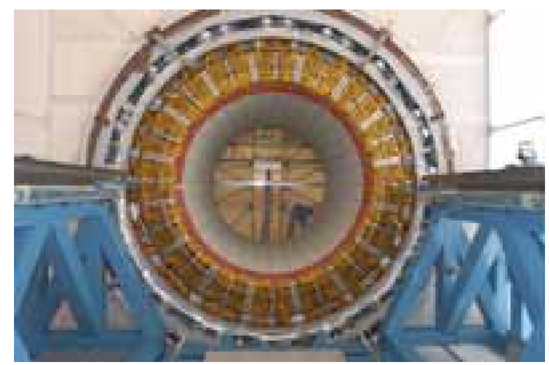


ECAL before inner solenoid insertion

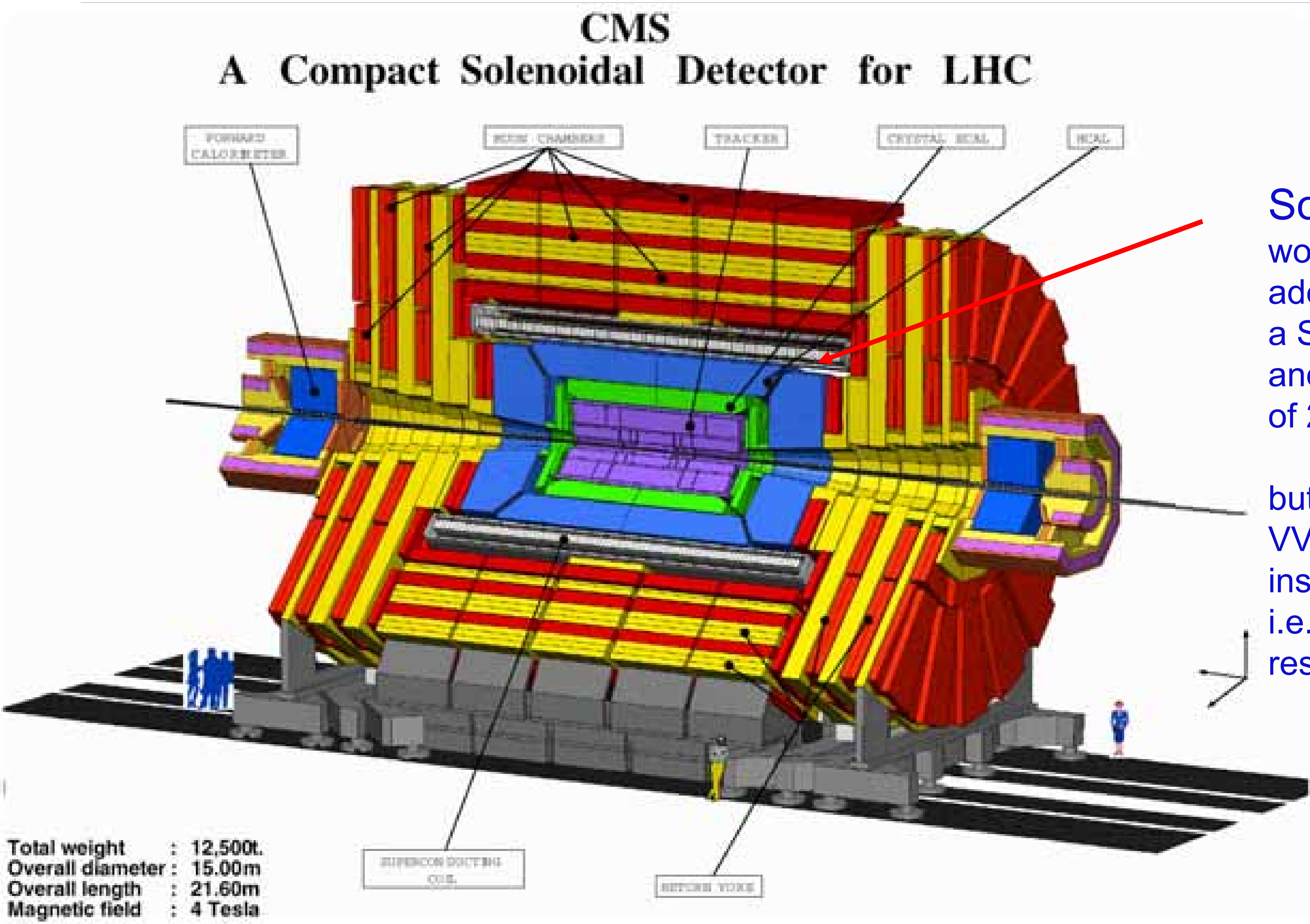
Barrel calo insertion



Atlas ECAL



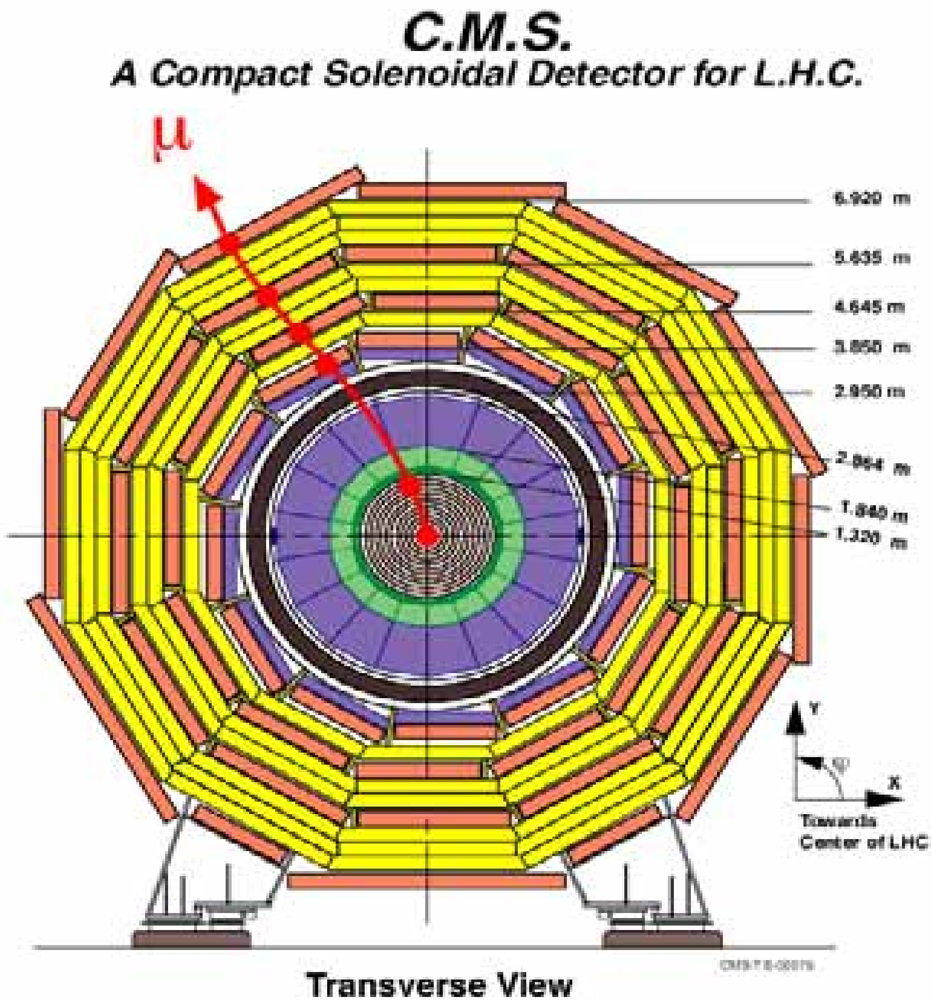
CMS - a general purpose LHC detector



Solenoid

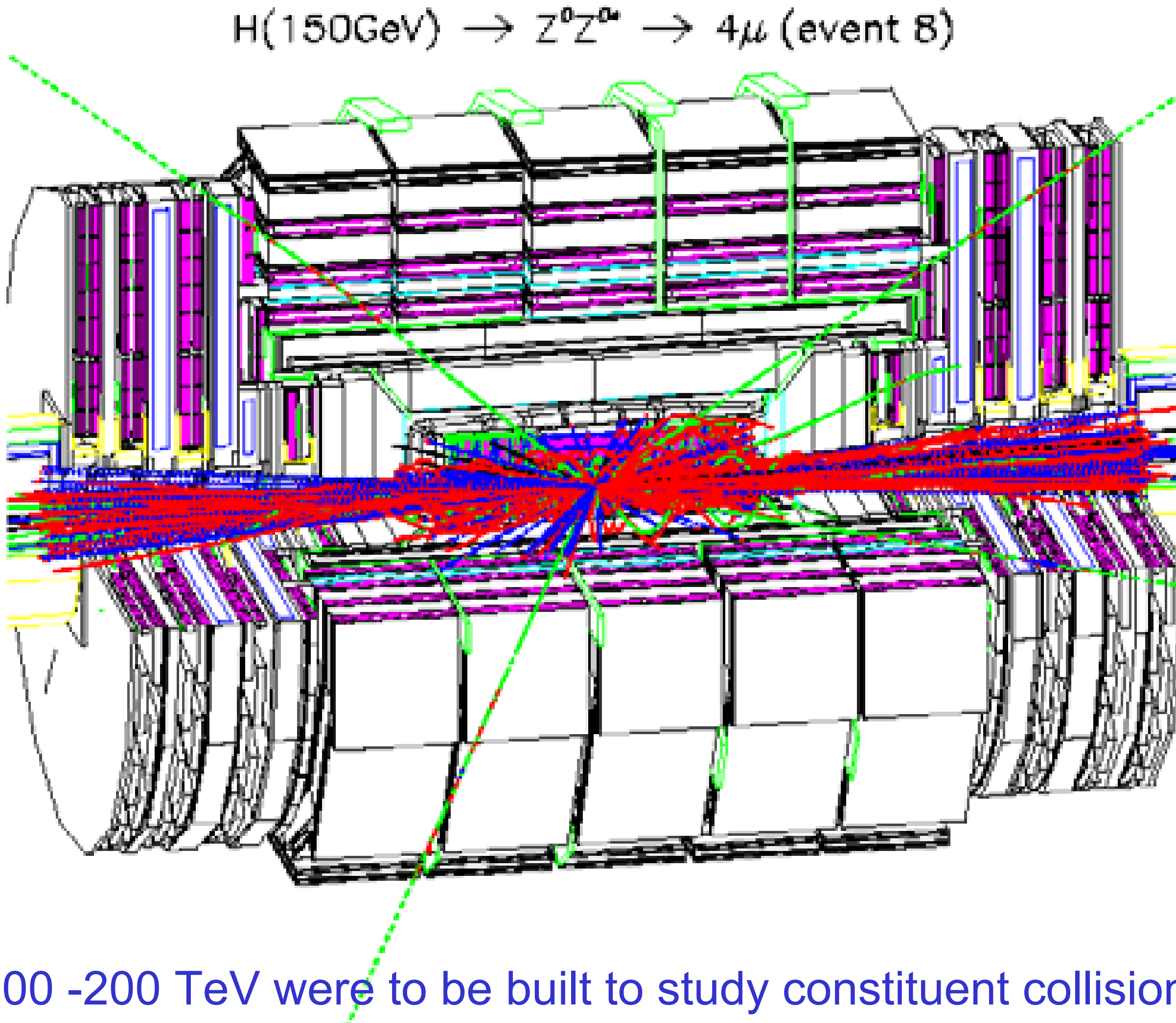
would be adequate for a SLHC (14 TeV, 10^{35}) and still for a VLHC of 25 - 30 TeV,

but not for a VVLHC of ~ 100 TeV insufficient bending i.e. momentum resolution



Muons measured twice

A Higgs event in CMS



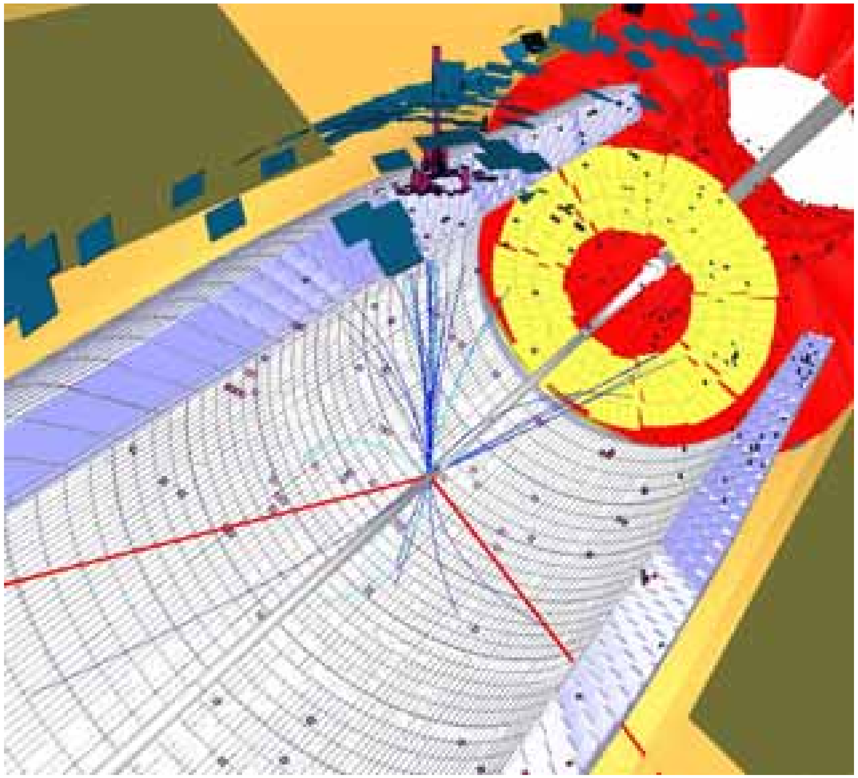
Muon measurements

If a VVLHC ~ 100 -200 TeV were to be built to study constituent collisions in the ~10-20 TeV range, a longer and probably stronger field magnet would be required, horizon ~ 2030

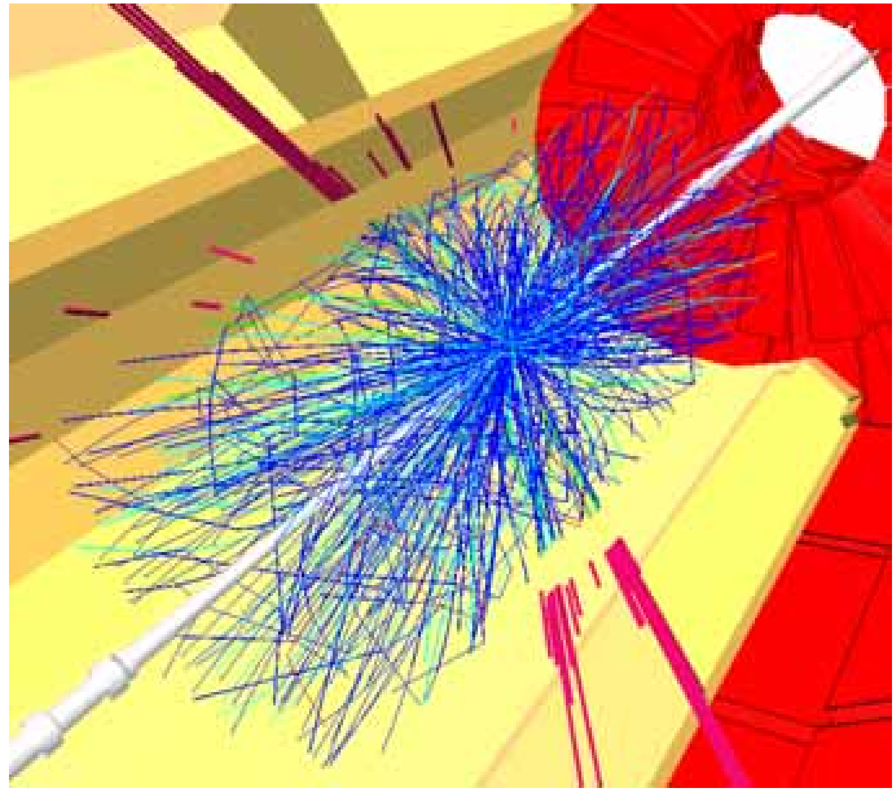
SUSY events simulations in CMS

Tracks need to be measured too! Not only muons!

This may require at a VVLHC rather a longer solenoid (rapidity coverage) that a stronger one



SUSY events (LM4 point: leptons, missing E_T)



SUSY events (HM1 point at $10^{34}cm^{-2}s^{-1}$)

Y. Osborne

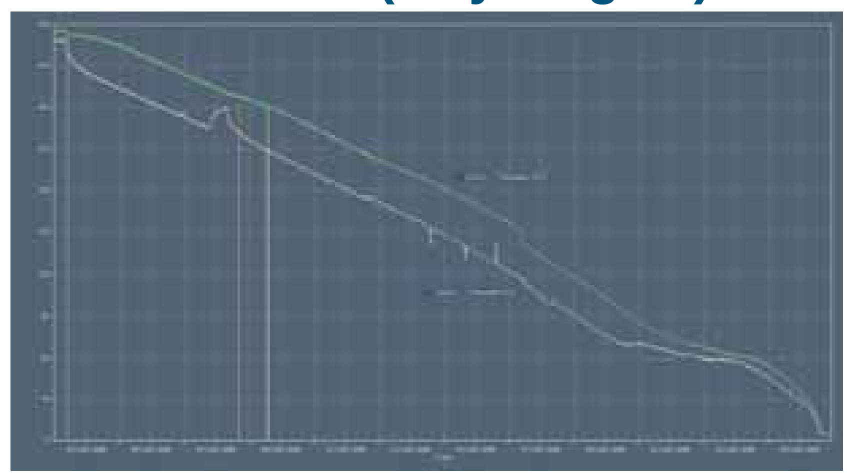
CMS Solenoid

Swivelling of coil 25 Aug 05

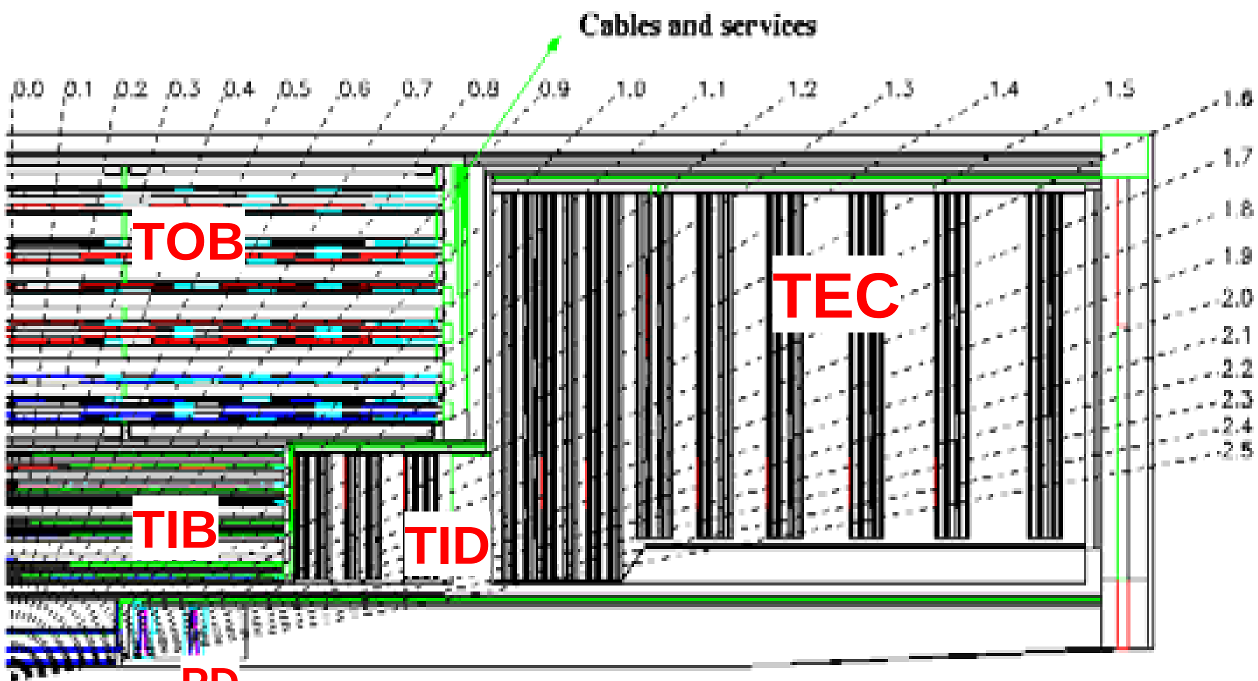
Coil inserted 14 Sep 05

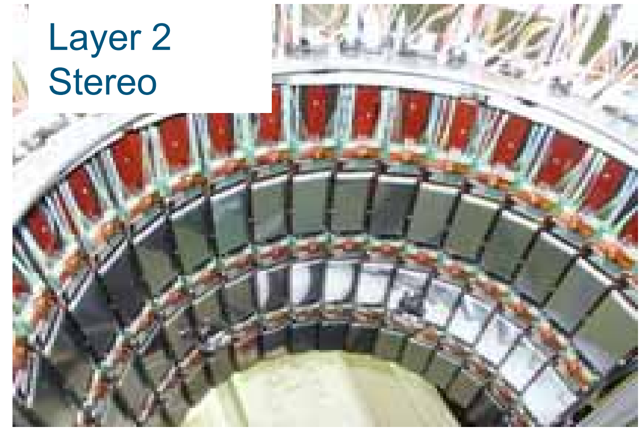
Vacuum Tank welded (Nov-Jan 06)

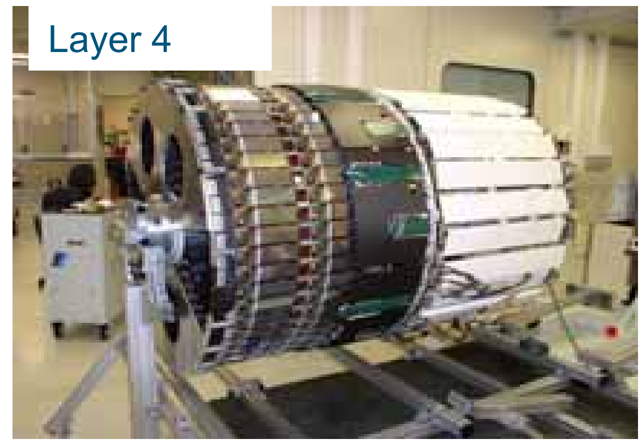
Coil Cooled to 4.5K in 25 days (Feb).
Test on Surface (May-Aug 06)



CMS tracker layout
inner barrel integration in Italy







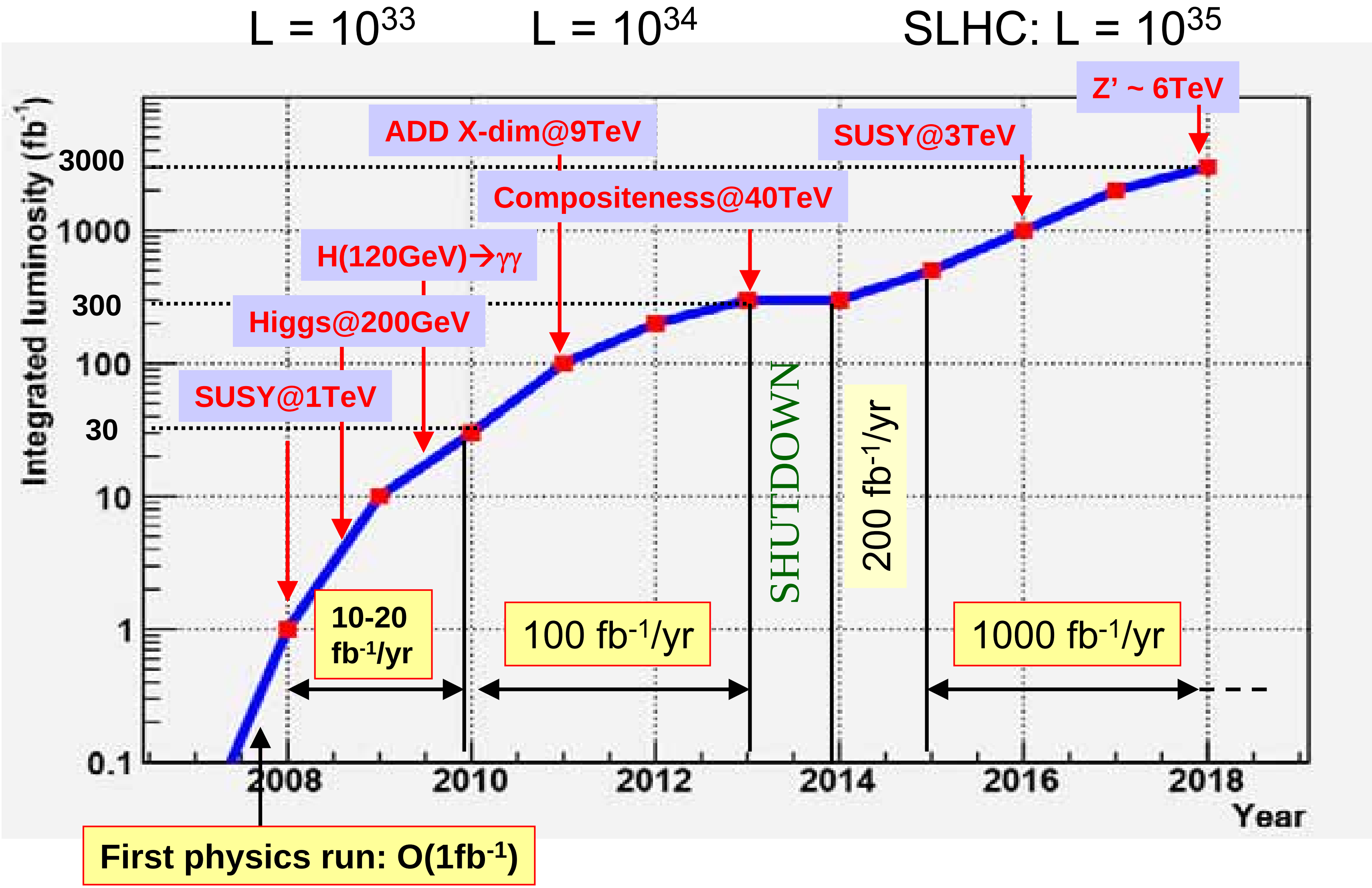
Some Numbers

6,136 Thin sensors - **3112 + 1512** Thin **modules** (ss +ds)
19,632 Thick sensors - **4776 + 2520** Thick **modules** (ss +ds)

223 m^2 of silicon sensors

26 M Bonds - **10.0 M strips** ≡ electronics channels - 78,256 APV chips

Probable/possible LHC luminosity profile - need for L-upgrade in a longer term



Upgrades considered, physics potential of the LHC at ~ 10^{35} cm^{-2} s^{-1} (SLHC)

Improvements in the physics reach operating the LHC at a luminosity of ~ 10^{35} cm^{-2} s^{-1} with an integrated luminosity ~ 1000 fb^{-1} per year at $\sqrt{s} \approx 14$ TeV i.e. retaining present LHC magnets/dipoles - essentially the high mass reach increased by ~ 30 %

➡ an upgrade at a relatively modest cost for machine (IR) + experiments (< ~ 0.5 GSF) for ~ 2013 -15

a more ambitious upgrade (but ~ 2 - 3 GSF!) would be to go for a $\sqrt{s} \approx 25 - 30$ TeV machine (2018 - 20) changing LHC dipoles (~15T, Nb_3Sn?) - just mentioned here

Nominal LHC and possible upgrades - overview

Nominal LHC: 7 TeV beams,

- injection energy: 450 GeV, ~ 2800 bunches, spacing 7.5 m (25ns)
- 1.1 $*10^{11}$ protons per bunch, β^* at IP : 0.5 m $\Rightarrow$ 10^{34} cm^{-2} s^{-1} (lumi-lifetime ~10h)

Possible upgrades/steps considered:

- increase up to 1.7 $*10^{11}$ protons per bunch (beam-beam limit) $\Rightarrow$ $2*10^{34}$ cm^{-2} s^{-1}
- increase operating field from 8.3T to 9T (ultimate field) $\Rightarrow$ $\sqrt{s} \approx 15$ TeV

minor hardware changes to LHC insertions or injectors:

- modify insertion quadrupoles (larger aperture) for $\beta^* = 0.5 \rightarrow 0.25$ m new quads!
- increase crossing angle 300 μrad $\rightarrow$ 424 μrad new IR dipoles!
- halving bunch spacing (12.5 nsec), with new RF system new electronics!

$\Rightarrow L \approx 5 * 10^{34}$ cm^{-2} s^{-1}

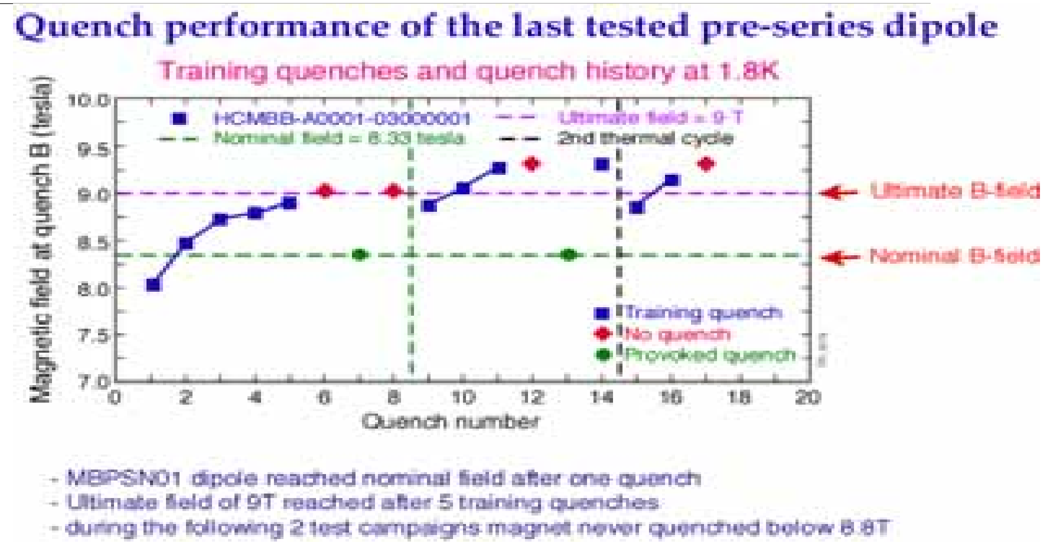
major hardware changes in arcs or injectors:

- SPS equipped with superconducting magnets to inject at $\approx$ 1 TeV $\Rightarrow L \approx 10^{35}$ cm^{-2} s^{-1}
- new superconducting dipoles at B $\approx$ 16 Tesla for beam energy $\approx$ 14TeV i.e. $\sqrt{s} \approx 28$ TeV for ~ 2018-2020

LHC and possible upgrades

-increase operating field from 8.3T to 9T
(ultimate field)

⇒ √s ≈ 15 TeV

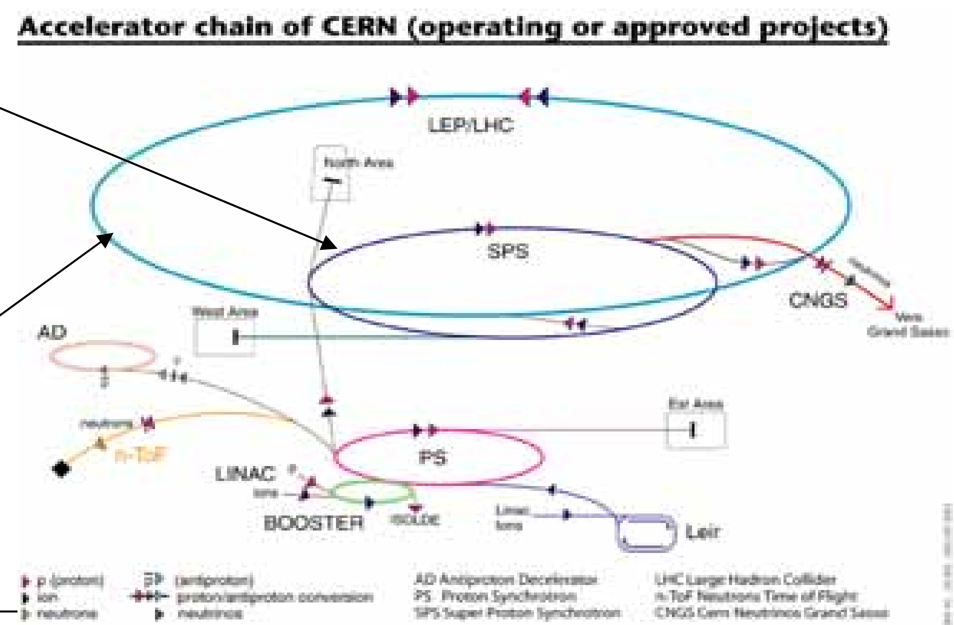


-In view of/first step in a possible energy upgrade of the LHC:

major hardware changes in arcs and injectors:

- SPS equipped with superconducting magnets to inject at ≈ 1 TeV (transfer lines and injector chain upgraded too)

⇒ Luminosity increase by factor ≈ 2

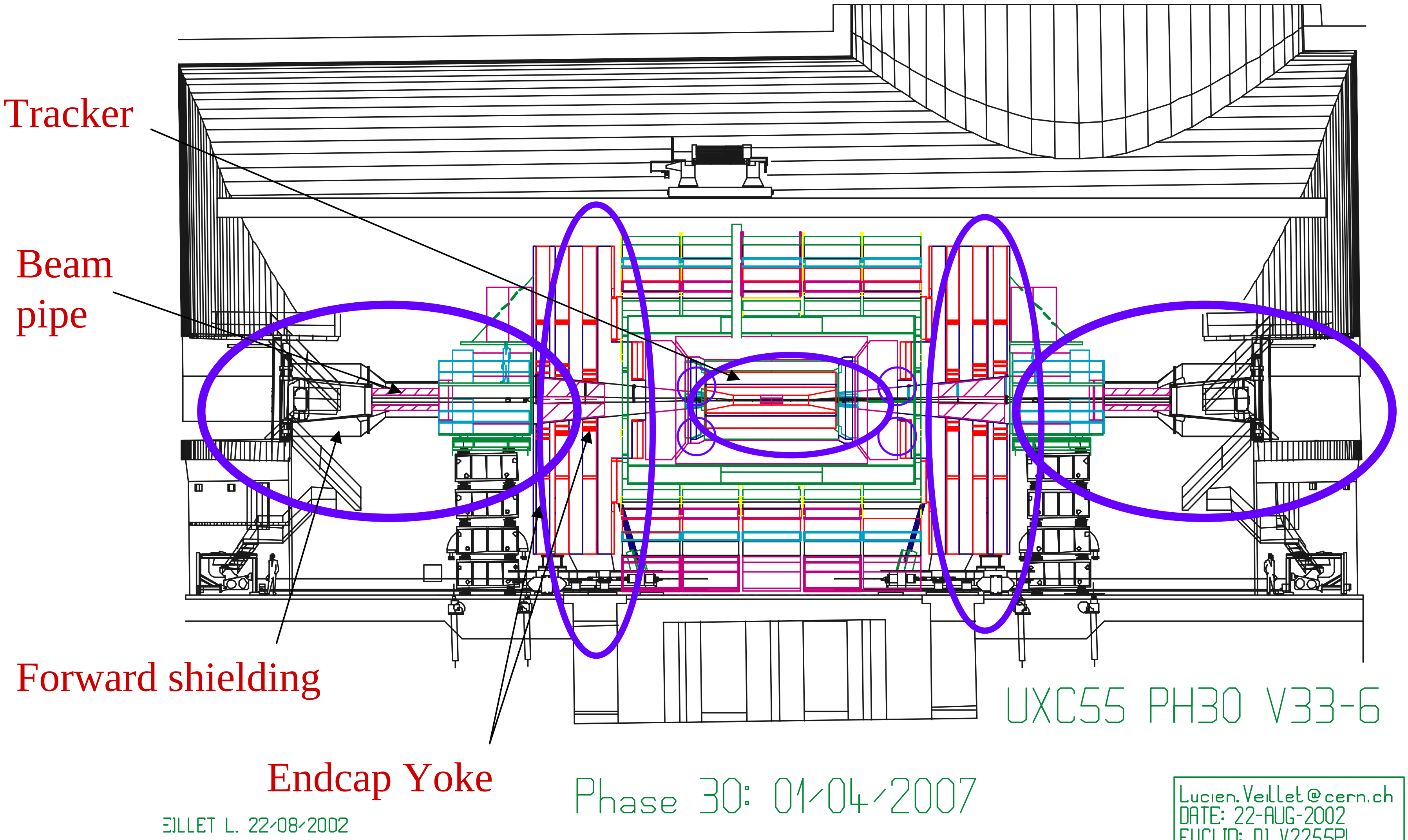


- new superconducting dipoles at B ≈ 15 Tesla (Nb_3Sn?) for beam energy ≈ 12.5 TeV i.e.

√s ≈ 25 TeV (~2020)

Last step would be very expensive…2 - 3 GSF.

Main CMS areas affected by LHC luminosity upgrade



Shielding between machine and HF

Basic functions of the shielding elements between the machine area and HF are:

-reduce the neutron flux in the cavern by 3 orders of magnitude

-reduce the background rate in the outer muon spectrometer (MB4, ME3,ME4) by 3 orders of magnitude

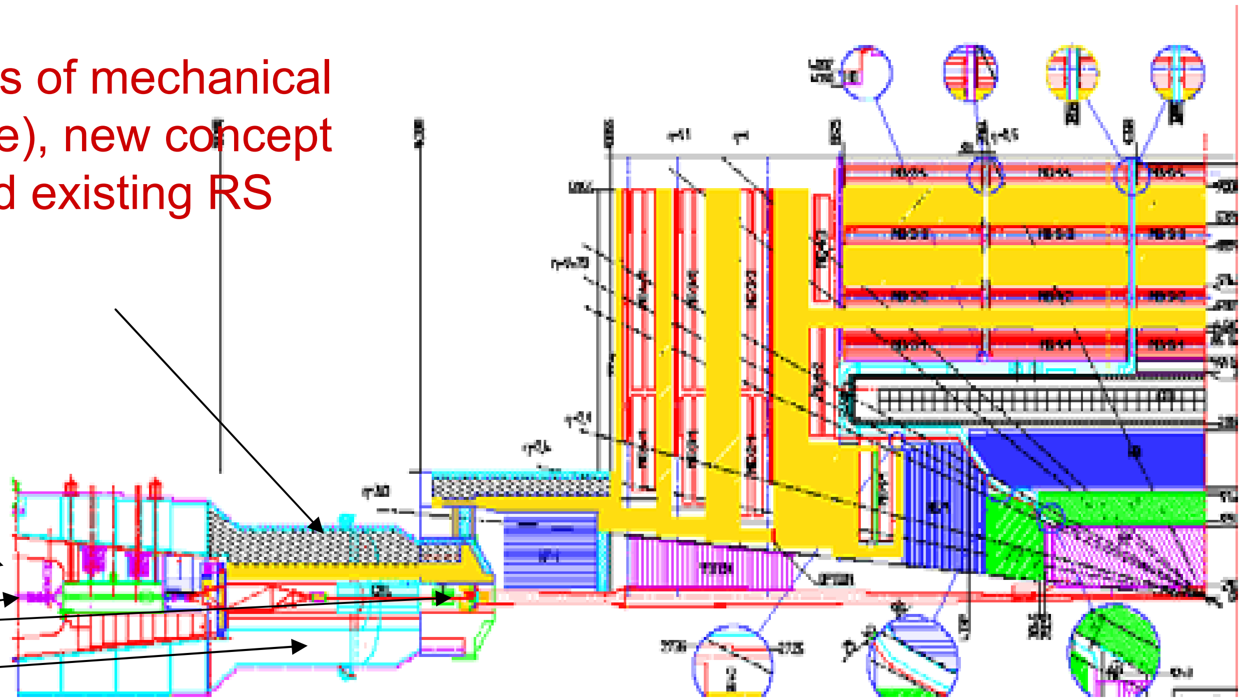
-reduce the radiation level at the HF readout boxes to a tolerable level

Rotating system is near the limits of mechanical strength (doubly hinged structure), new concept or supplementary system around existing RS needed for SLHC running,

inner quadrupole triplet

new quadrupoles !

forward shielding

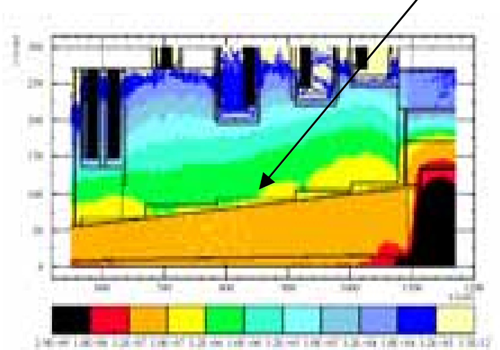


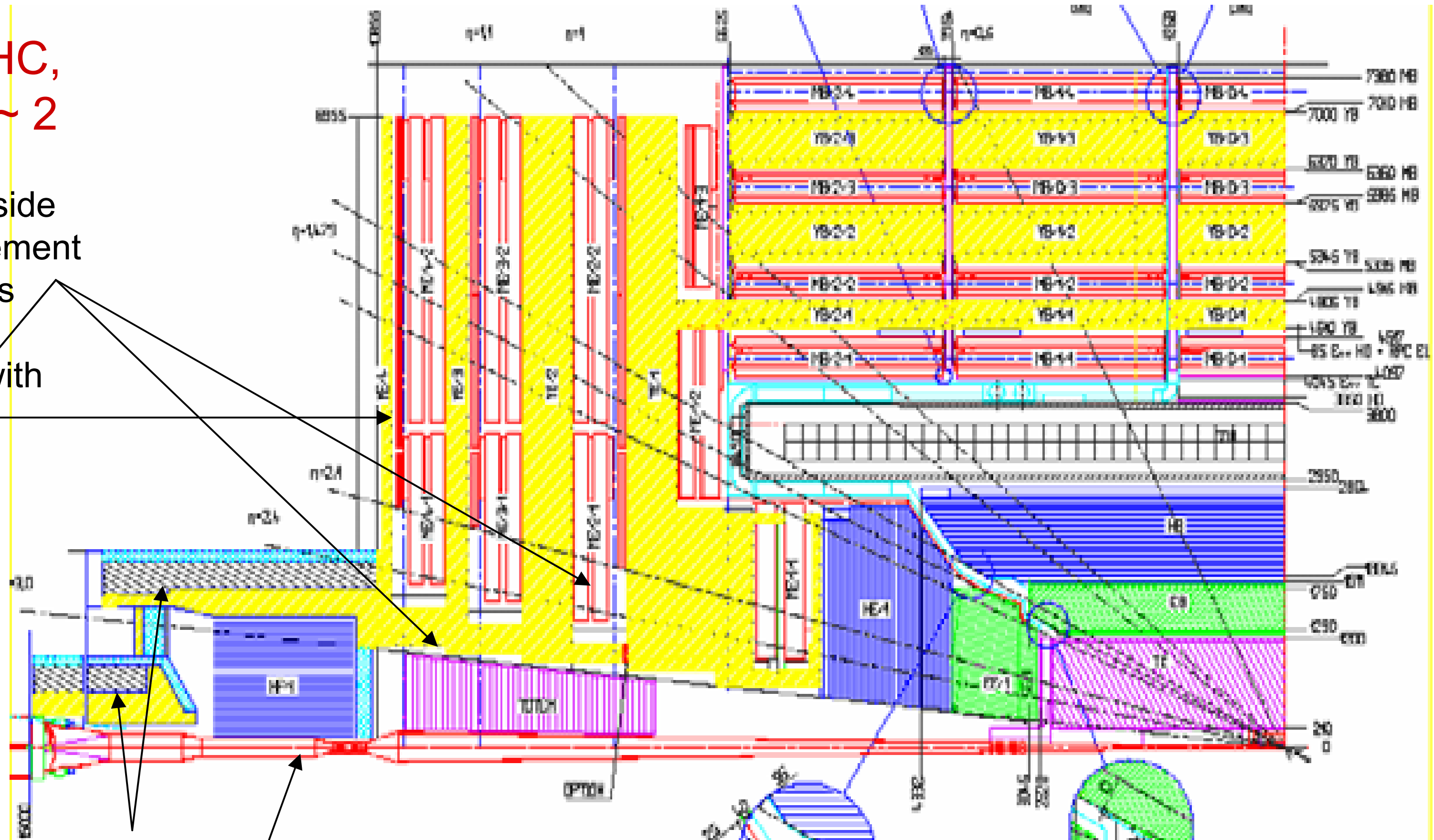
CMS yoke and forward detectors- modifications considered for SLHC

End cap yoke for SLHC, acceptance up to |η| ~ 2

Reinforced shielding inside forward muons, replacement of inner CSC and RPC's

Supplement YE4 wall with borated polythene





Improve shielding of HF PMT's

Quadrupoles here?

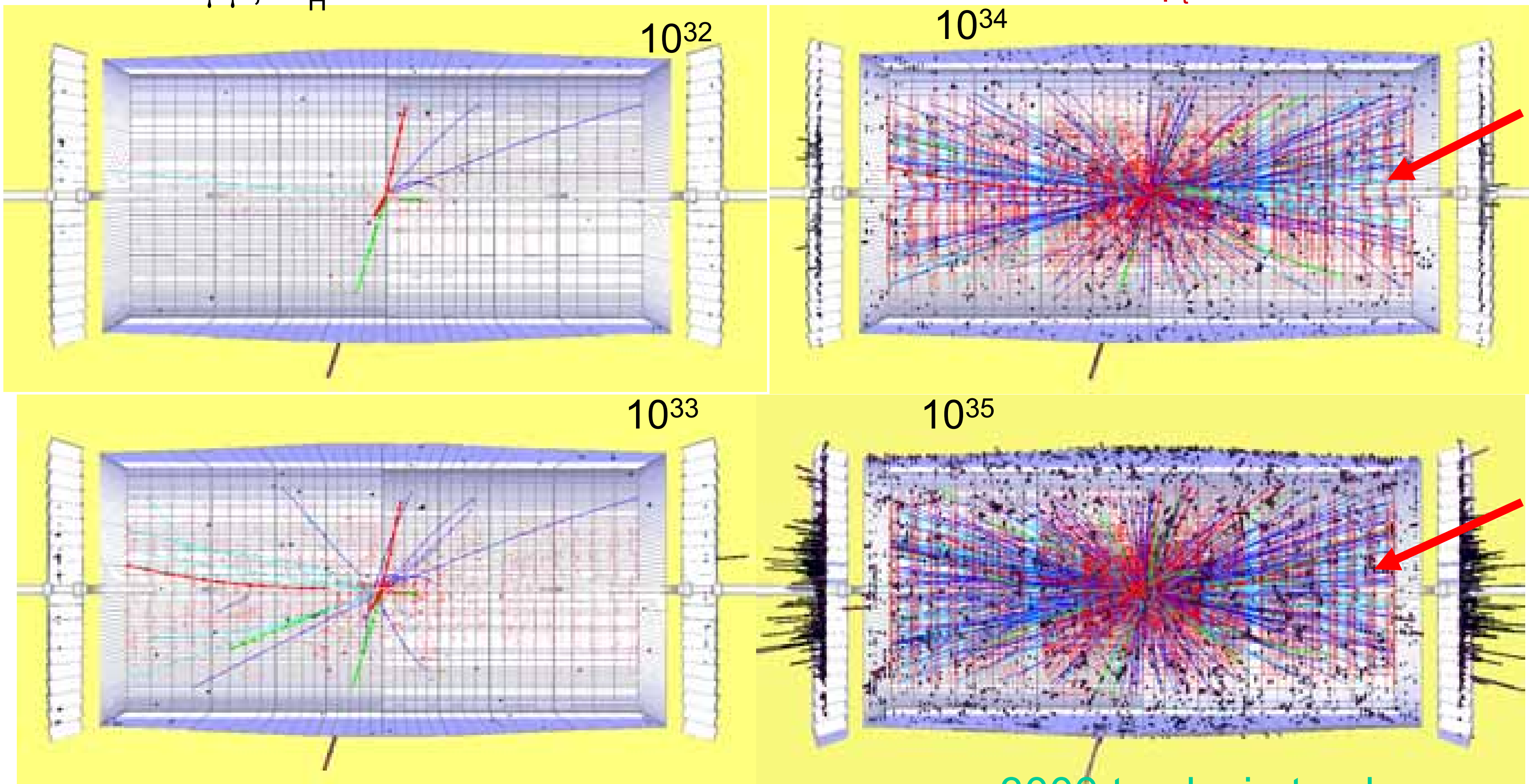
Free space in radius in the HF calo is : 14cm beam-pipe radius + 5cm clearance, the issue - if quads were to be located there or in the "TOTEM part", is the neutron albedo into CMS acceptable?

Experimental conditions at 10^{32-35} cm^{-2} s^{-1} central detectors, tracker, ECAL

H → eeμμ, m_H = 300 GeV in CMS

Generated tracks, p_t > 1 GeV/c cut

I. Osborne



LHC regime

SLHC regime

≈ 3000 tracks in tracker acceptance

If same granularity and integration time as now: tracker occupancy and radiation dose in central detectors increases by factor ~10, pile-up noise in calorimeters by ~ 3 relative to 10^{34}

CMS inner tracking for SLHC

From R.Horisberger

Pixels to be used to much larger radius, from ~10 cm up to ~ 60 cm

Technology and pixel size vary with radius, not too large an extrapolation in sensor technology, cost geometry optimization:

3 pixel systems proposed:

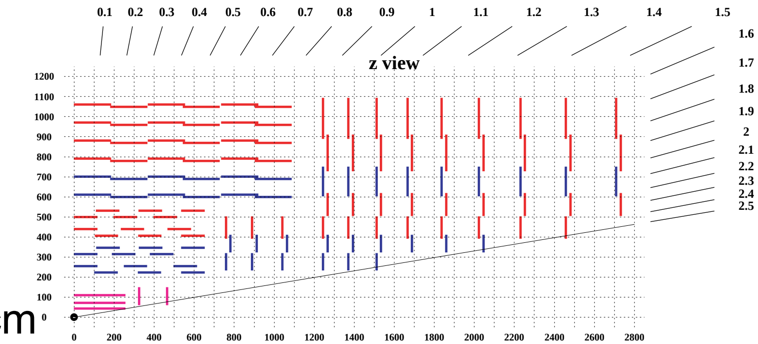
- system 1 - for maximal fluence and rate, two layers between ~ 10 -15 cm
.   ~ 400 CHF/cm^2

- system 2 - large pixel system, two layers between ~ 15 - 30 cm
.   ~ 100 CHF/cm^2

- system 3 - large area macro-pixel system, ~ four layers between ~ 30 - 60 cm
.   ~ 40 CHF/cm^2

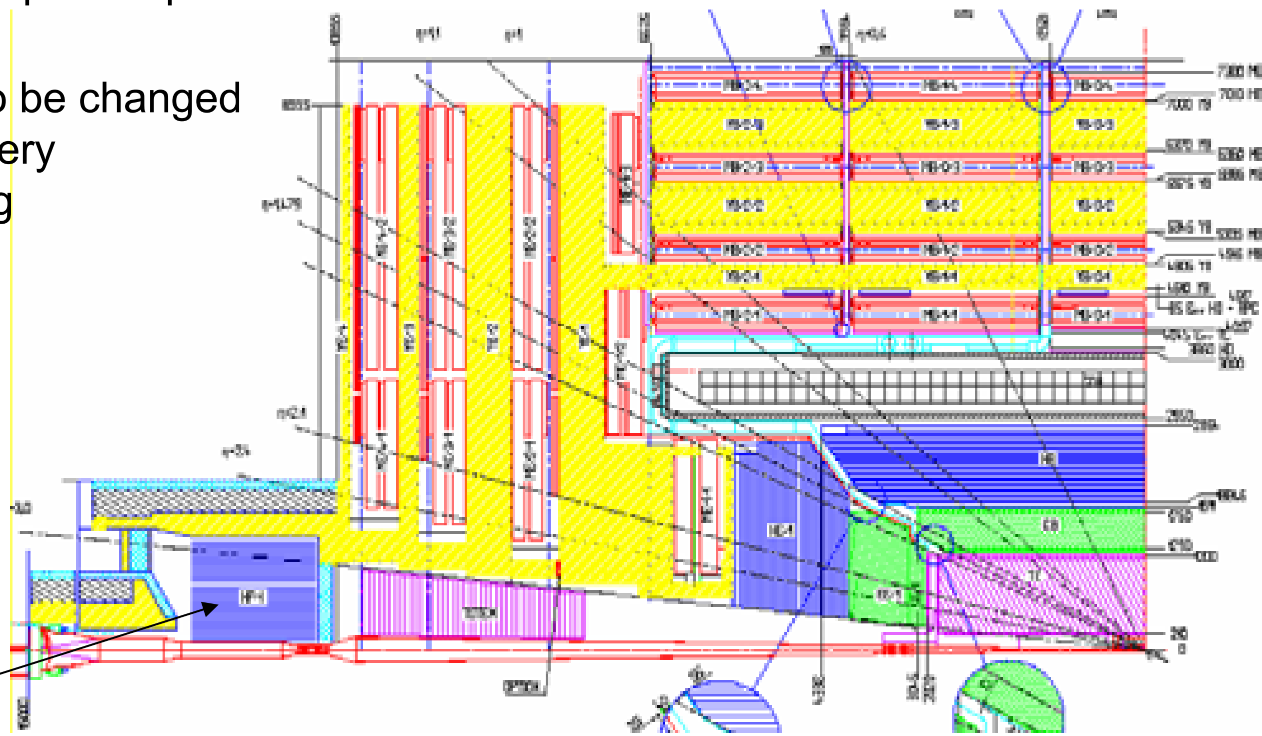
This 8 -layer system could eventually deal with up to 1200 tracks per unit of rapidity i.e. 10^{35} luminosity with 25 nsec bunch spacing.

Foreseeable changes to detectors for $10^{35}cm^{-2}s^{-1}$ overview



changes to CMS and ATLAS :

- Trackers, to be replaced due to increased occupancy to maintain performance, need improved radiation hardness for sensors and electronics
  - present Si-strip technology is OK at R > 60 cm
  - present pixel technology is OK for the region ~ 20 < R < 60 cm
  - at smaller radii(<~10 cm) new techniques required
- Calorimeters: ~ OK
  - endcap HCAL scintillators in CMS to be changed
  - desirable to improve granularity of very forward calorimeters - for jet tagging
- Muon systems: ~ OK
  - acceptance reduced to $|\eta| <\sim 2.0$ to reinforce forward shielding
- Trigger(L1), to be replaced,
  L1(trig.elec. and processor) for 80 MHz data sampling
  Front-end elec to be replaced



VF calorimeter for "jet tagging"

Conclusions on SLHC

In conclusion the SLHC ($\sqrt{s} \approx 14$ TeV, $L \approx 10^{35}$ cm^{-2} s^{-1}) would allow to extend significantly the LHC physics reach - whilst keeping the same tunnel, machine dipoles and a large part of "existing" detectors, however to exploit fully its potential inner/forward parts of detectors must be changed/hardened/upgraded, trackers in particular, to maintain performances similar to "present ones"; forward calorimetry of higher granularity would be highly desirable for jet tagging, especially if no Higgs found in the meantime!
Changes to the machine: only near-experiment optics

For a VLHC (~ 30 TeV) - more desirable from the physics point of view, but much more expensive ~ 3 GCHF - complete change of machine elements, dipoles in particular