Status and Future of the LHC

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CERN TE MSC

Channeling 2012

September 23-28, 2012, Alghero, Italy

Outline

- Where do we come from
- The present production at the LHC
- The foreseeable LHC future
- Beyond the LHC
- A final message

An insider view

And a special eye for technology

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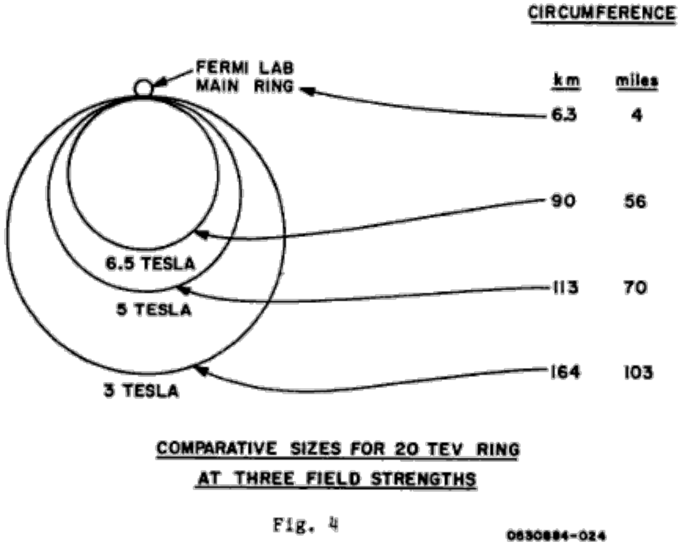
1984…

Big Brother is in full control and rules



The National Reference Design Study (RDS) for a 20 TeV proton machine, hosted by LBNL, DOE recommends proceeding with R&D for a **Sine-qua-non Accelerator** (the **SSC**)

Diego Maradona goes to **SSC** (Societa' Sportiva Calcio) Napoli from FC Barcelona for a ridiculous **13.5 billions** Lire

1984 ECFA – Lausanne

CERN COURIER

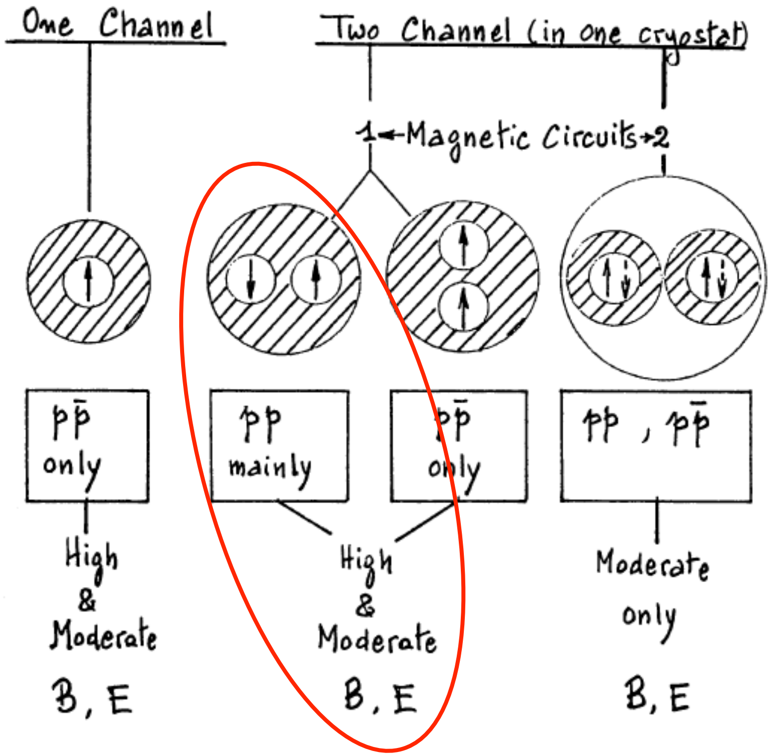
CERN COURIER

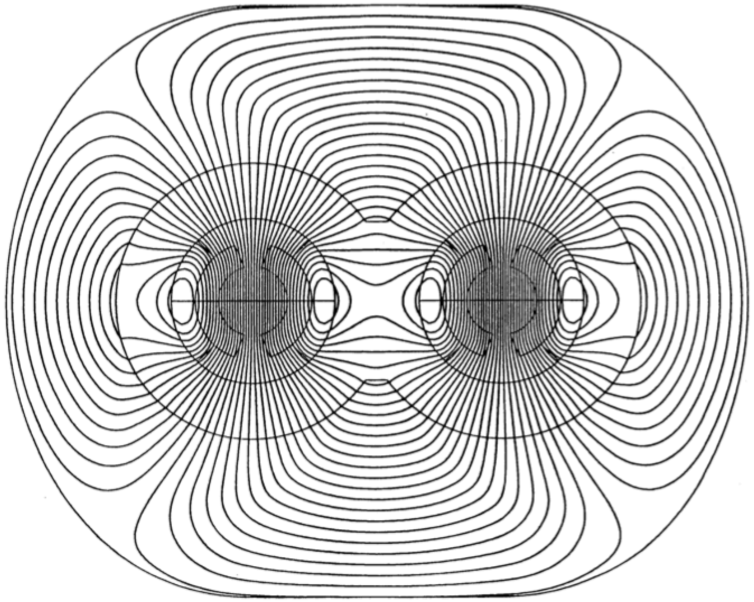
Sep 19, 2008

Early days: Lausanne LHC workshop (archive)

In March 1984 a major workshop provided a chance to look to the next step beyond the construction and exploitation of LEP.

G. Brianti

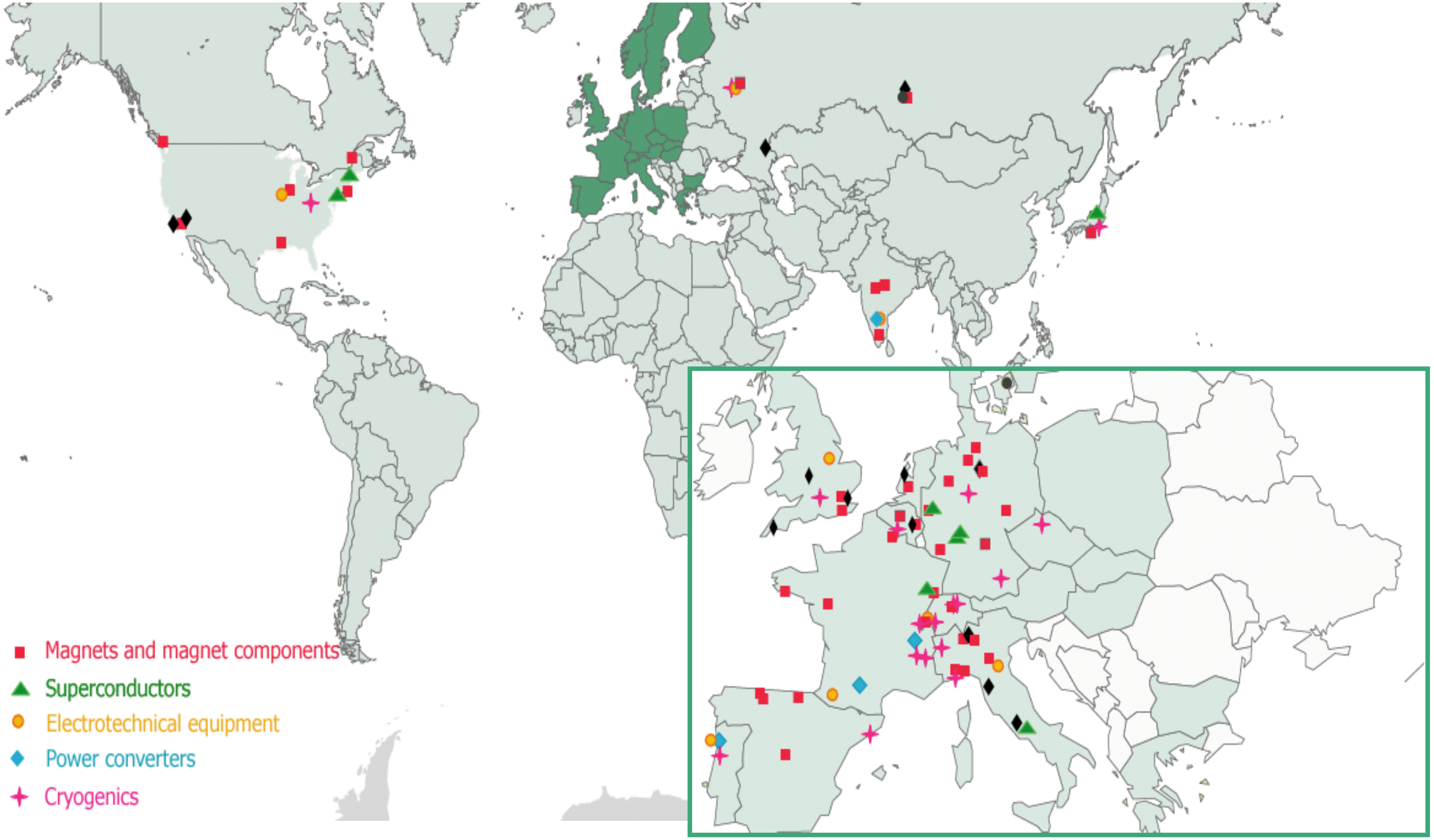




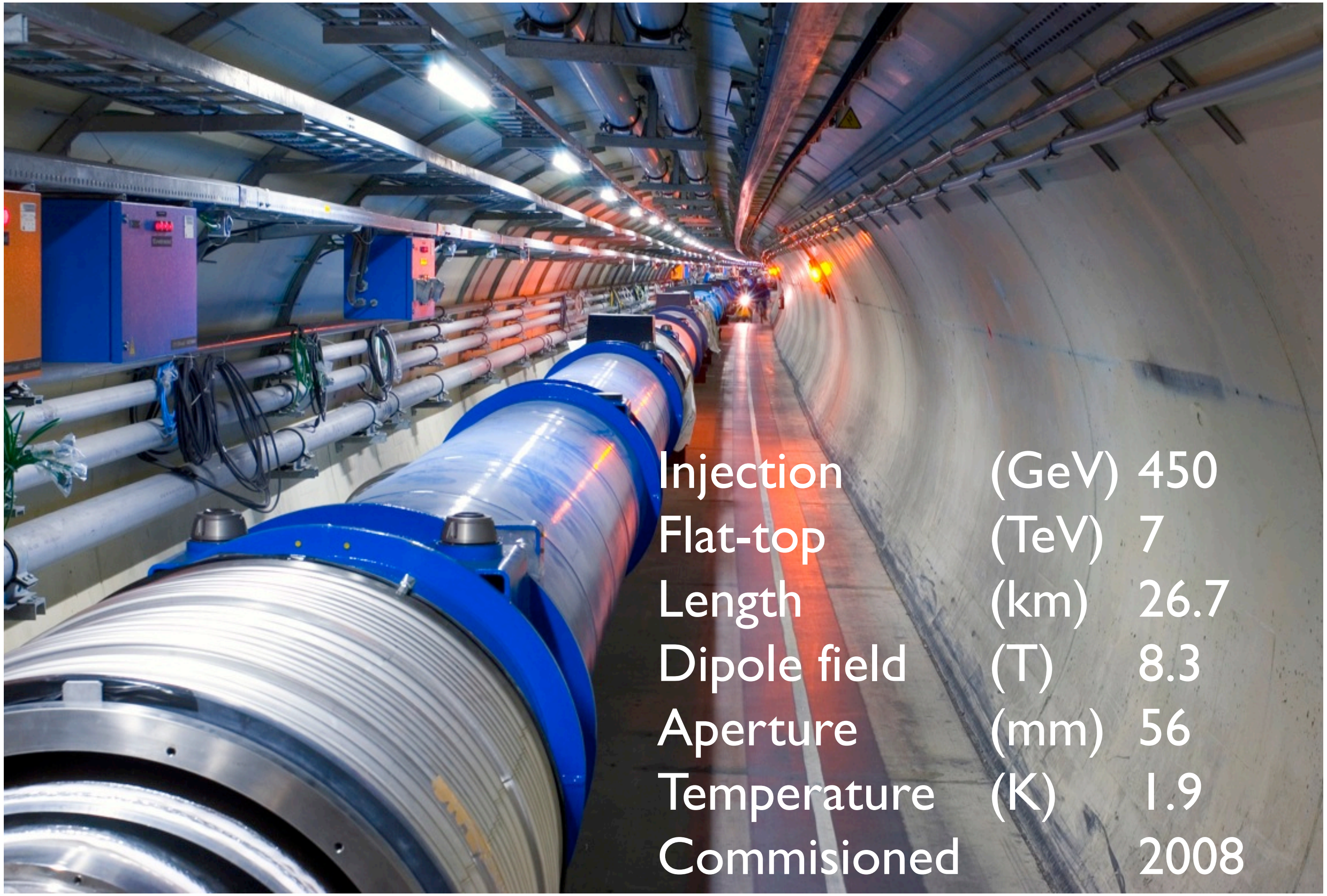
CERN 87-05, G. Brianti and K. Hubner Ed.

World-Wide Works

Approximately 100 contracts and international contributions

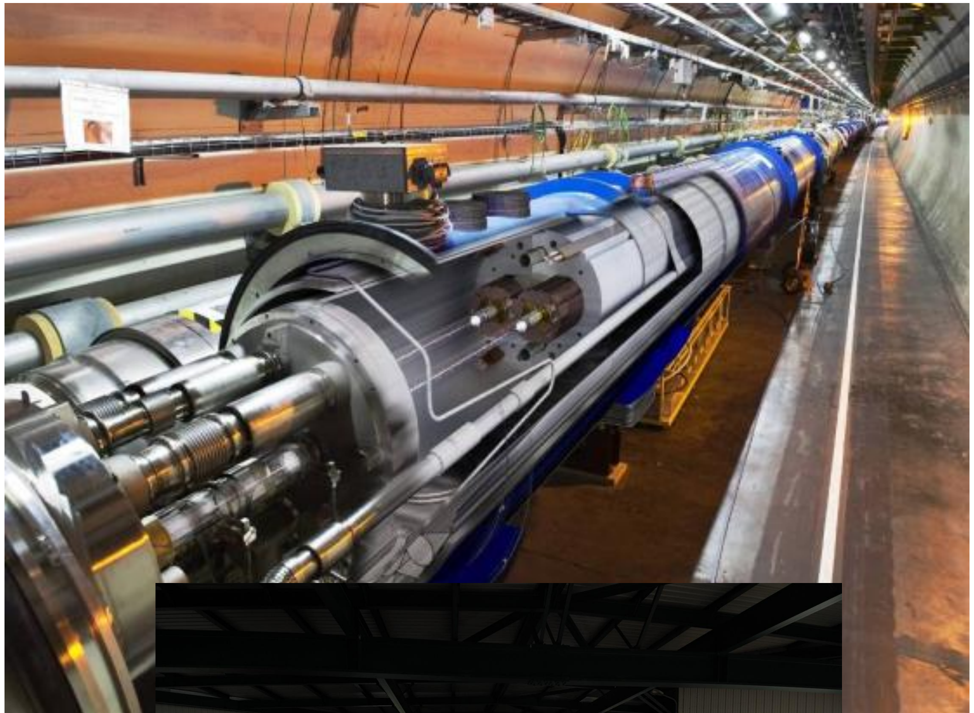


LHC !



Injection	(GeV)	450
Flat-top	(TeV)	7
Length	(km)	26.7
Dipole field	(T)	8.3
Aperture	(mm)	56
Temperature	(K)	1.9
Commisioned		2008

What is so special about the LHC ?



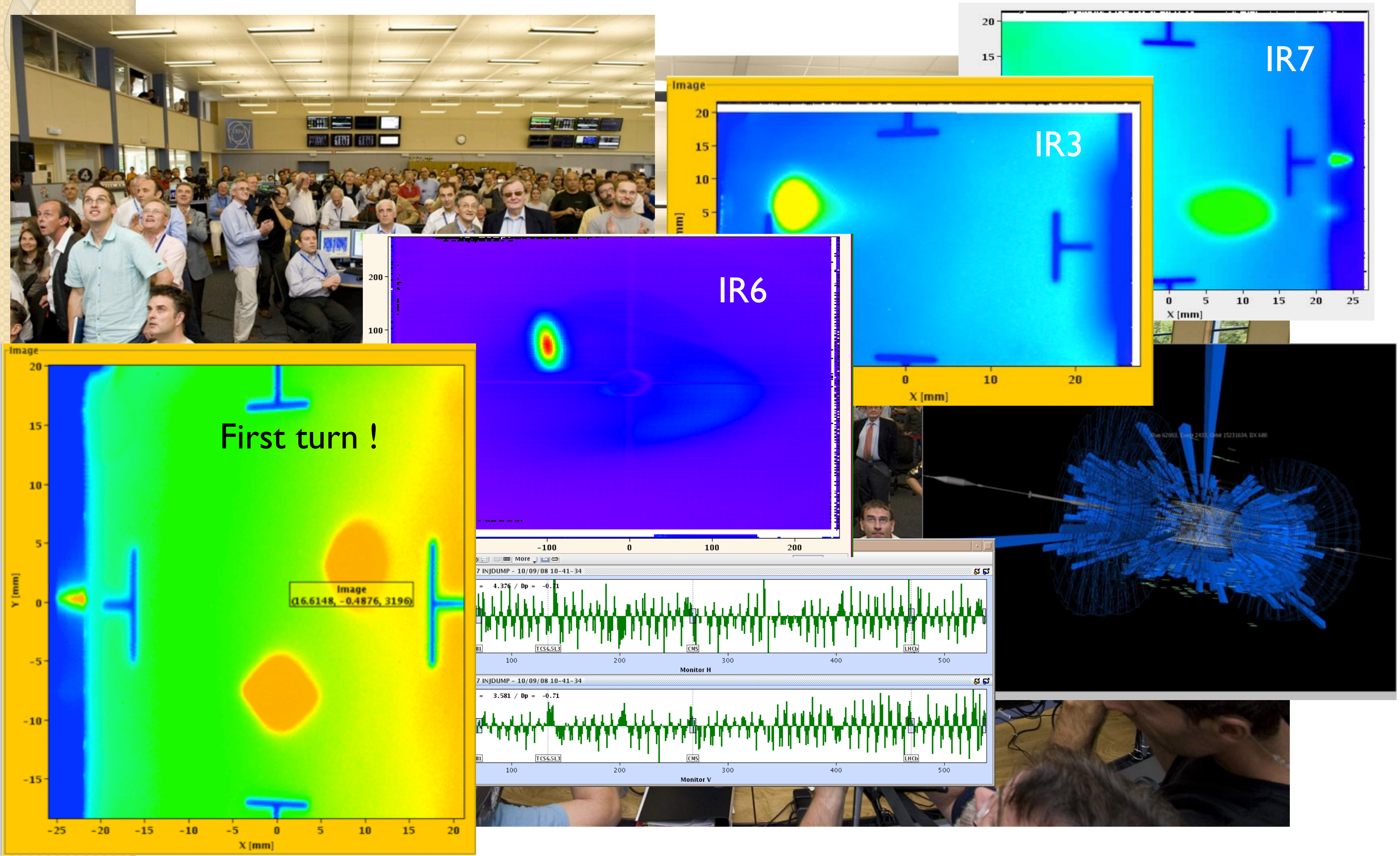
Those who made it !

- The highest field accelerator magnets: 8.3 T (9 T ultimate)
- The largest superconducting magnet system: ~8000 magnets (~50000 tons)
- The largest 1.9 K cryogenics installation (superfluid helium)
- A sophisticated and ultra-reliable magnet control and quench protection system

Some of the LHC challenges

Circumference (km)	26.7	*100…150 m underground*
Number of Dipoles	1232	*Nb-Ti, 37000 tons cold mass*
Dipole Length (m)	14.3	*35 tons aligned to 0.3 mm*
Dipole Field Strength (Tesla)	8.33	*Limit of beam energy (7 TeV)*
Operating Temperature (K)	1.9	*Super-fluid helium*
Current in dipole SC coils (A)	13000	*1 ppm resolution*
Beam Intensity (A)	0.5	*2.2×10^{-6} loss causes quench*
Stored Beam Energy (MJ)	2*360	*Melt one ton of copper*
Magnet Stored Energy (GJ)	≈ 10	*Airbus 380 at 700 km/h*
Sector Powering Circuit	8	*1612 different electrical circuits*

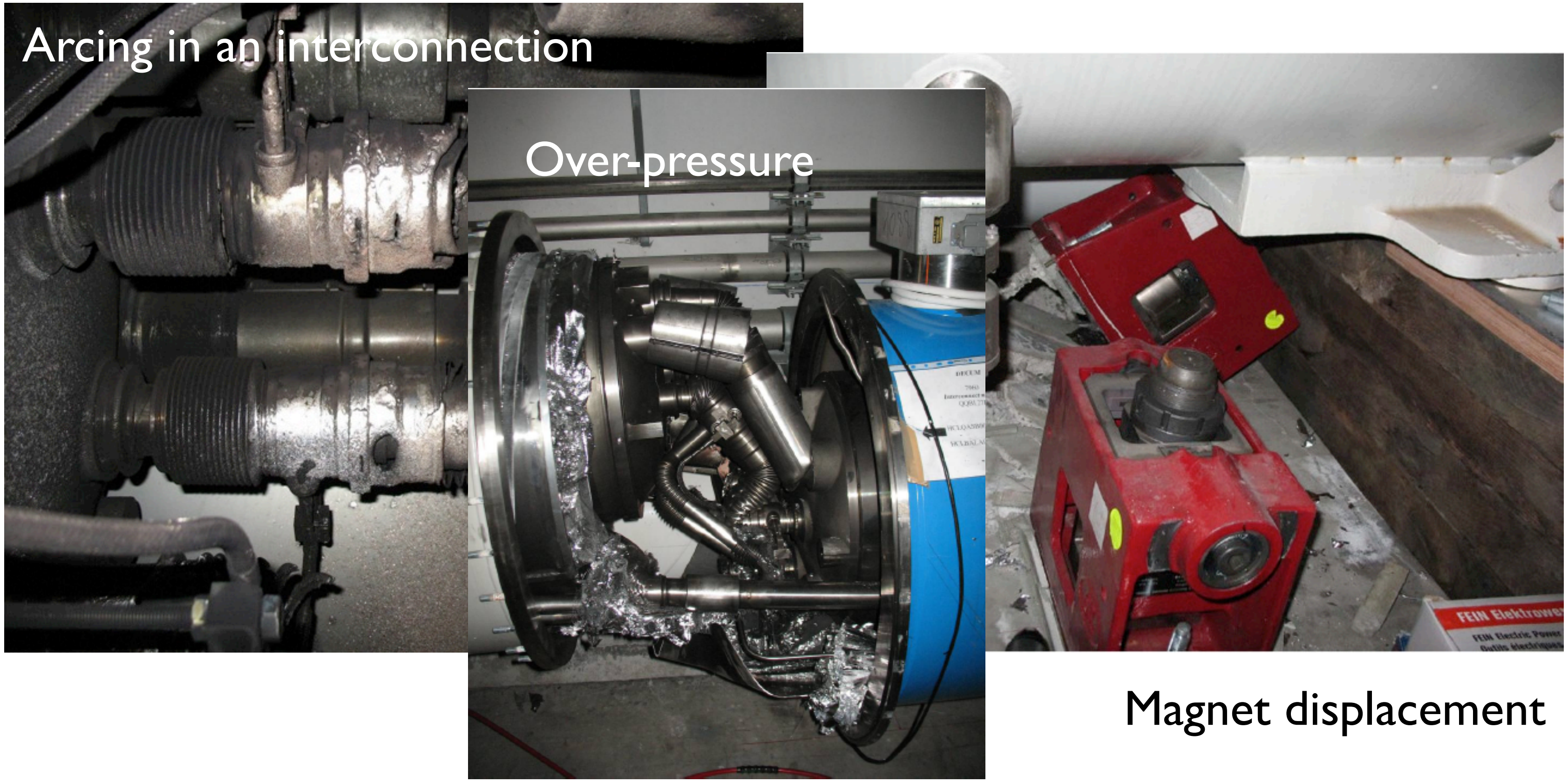
September 10th, 2008…



…September 19th, 2008…

Initiated by an **unprotected quench** of defective joint

NOTE: this is an intentional defect built for testing purposes



Magnet displacement

…November 30th, 2009…

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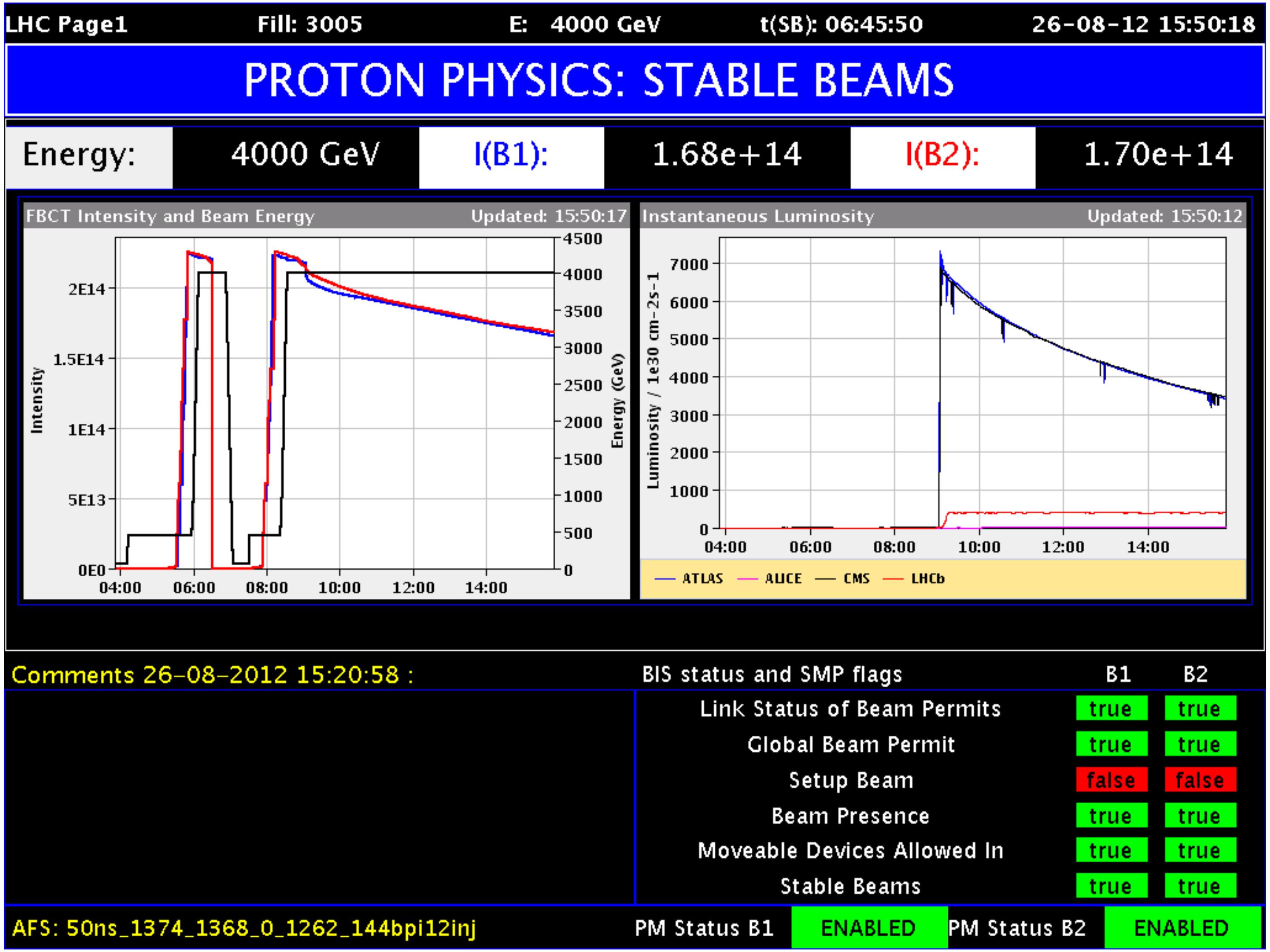
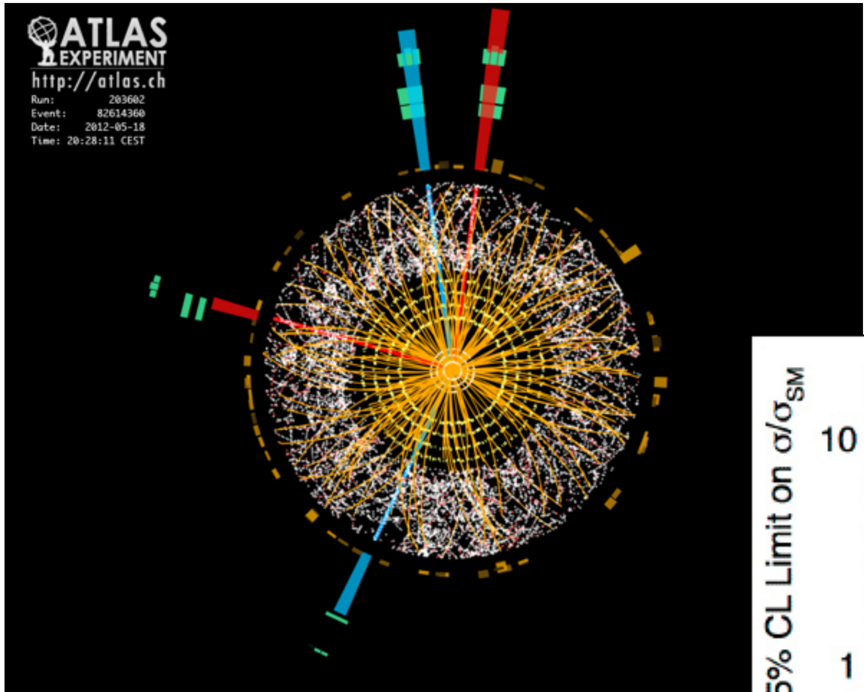
LHC operation today

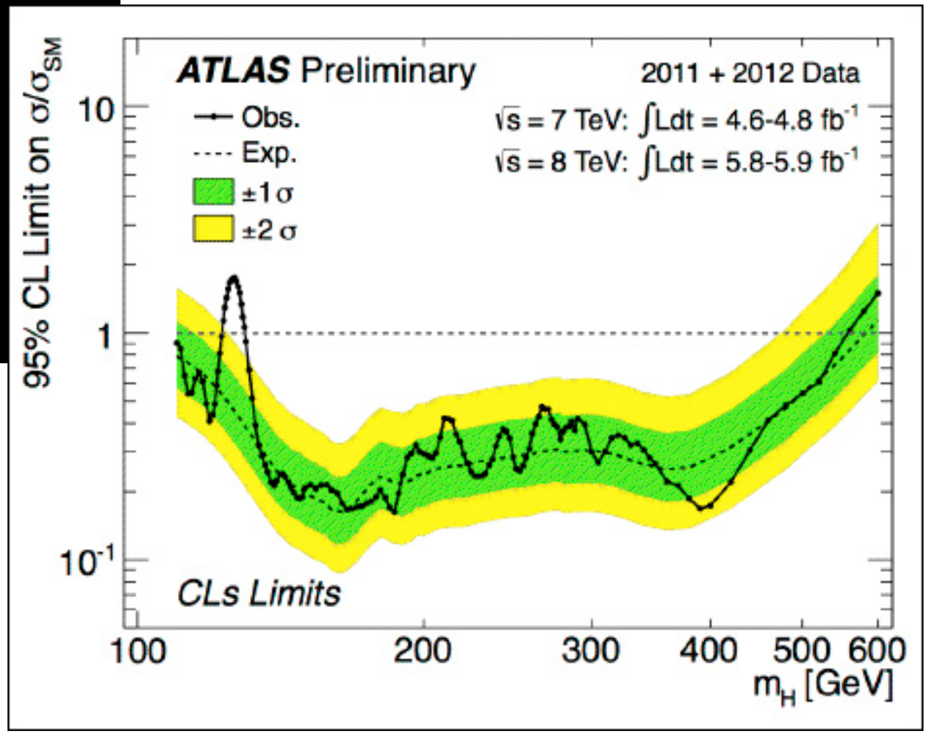


Results from ATLAS



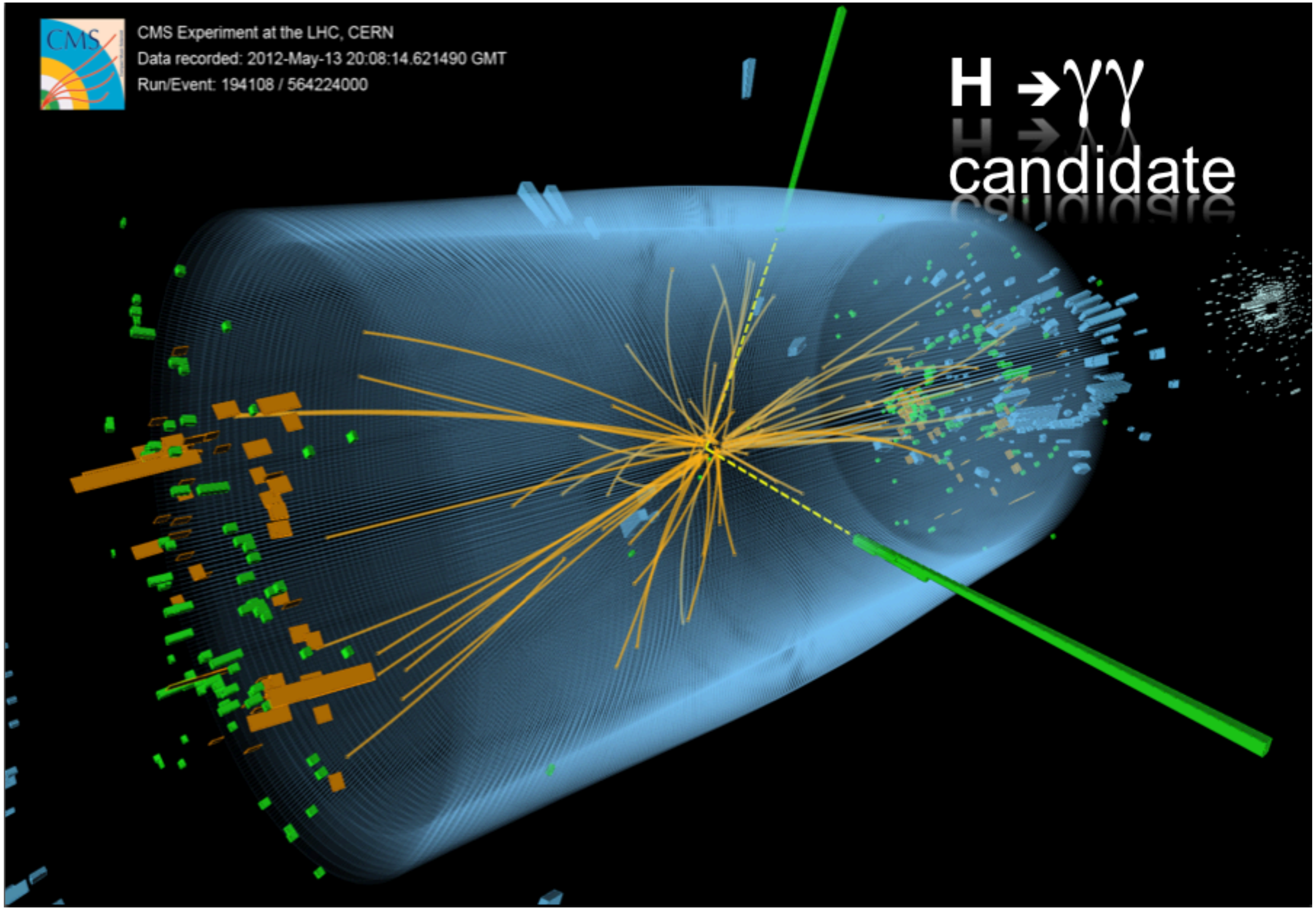
Candidate for a *$4\text{-}e^-$ decay* of the Higgs boson

Exclusion limits for the existence of a new particle in the range of 100 to 600 GeV



Fabiola Giannotti, ATLAS, Status of the SM Higgs Boson Search, July 4th, 2012

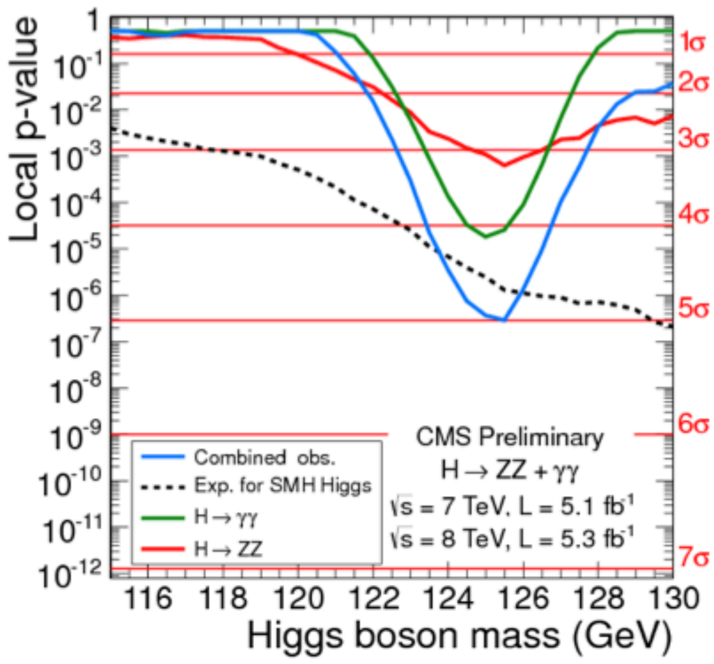
Results from CMS – 1/2



J. Incandela, CMS, Status of the SM Higgs Boson Search, July 4th, 2012

Results from CMS – 2/2

Characterization of excess near 125 GeV

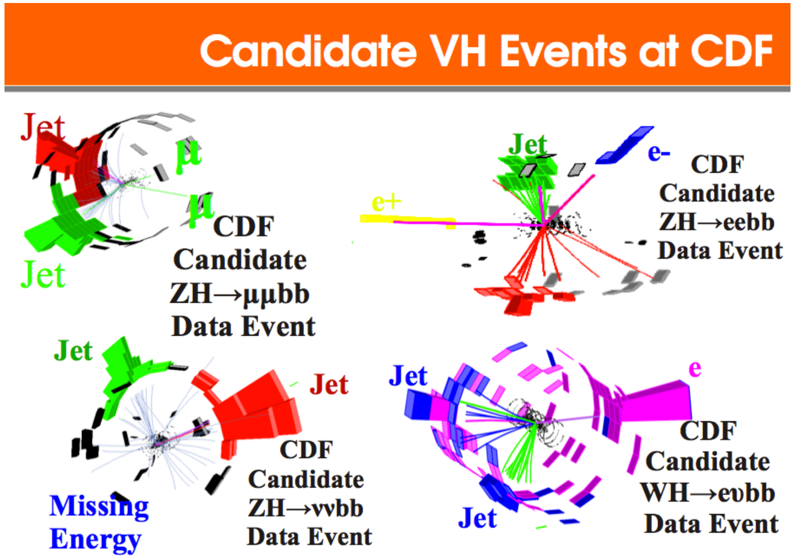


July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

- **high sensitivity, high mass resolution channels: γγ+4l**
  - γγ: 4.1 σ excess
  - 4 leptons: 3.2 σ excess
  - near the <u>same mass</u> 125 GeV
- comb. significance: **5.0 σ**
- **expected significance for SM Higgs: 4.7 σ**

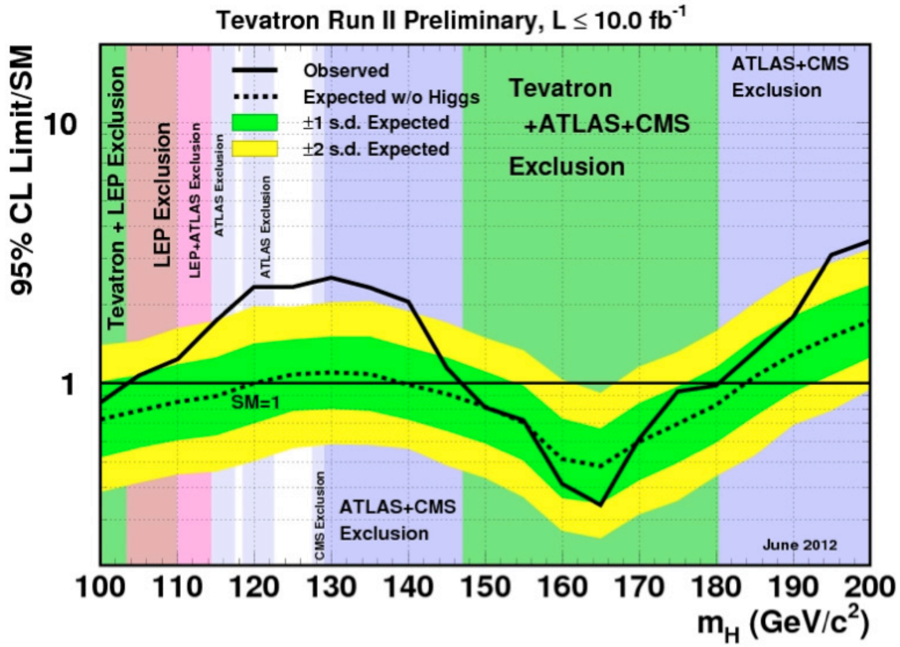
J. Incandela, CMS, Status of the SM Higgs Boson Search, July 4th, 2012

To be fair, results from Tevatron



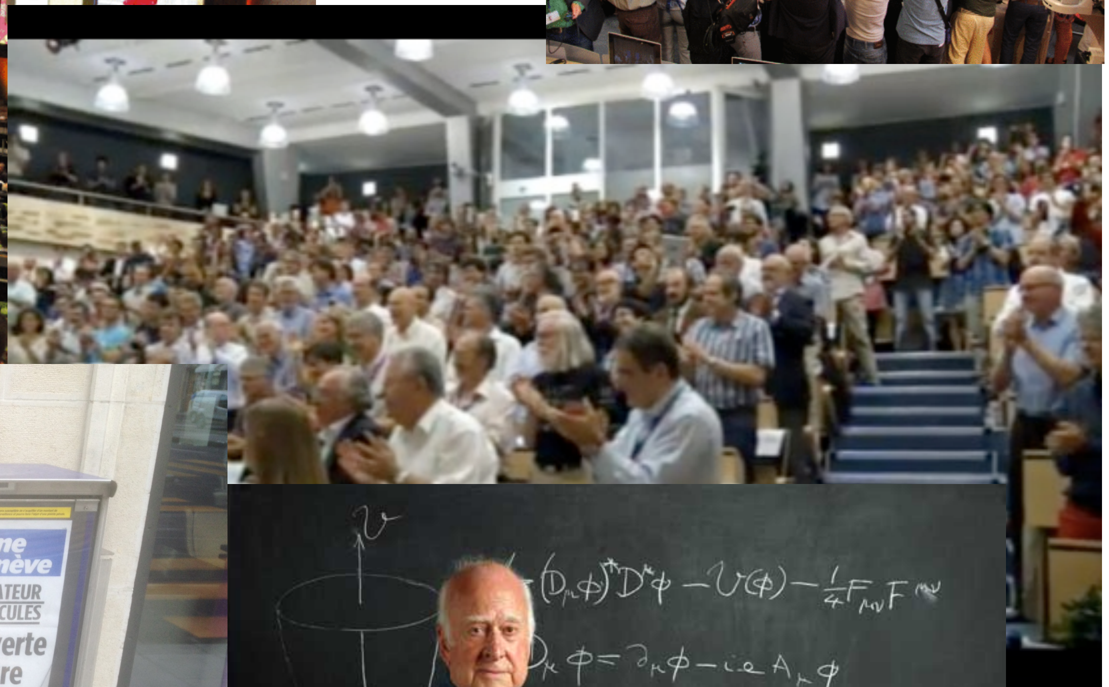
Candidate events for Higgs boson decays at CDF

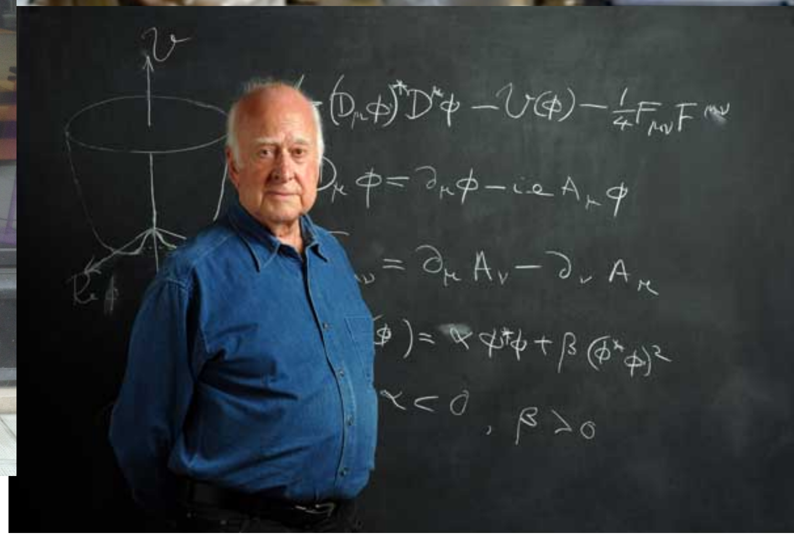
Exclusion limits for the existence of a new particle in the range of 100 to 200 GeV



Homer Wolfe, CDF, The Search For The Brout-Englert- Higgs Boson, March 7th, 2012

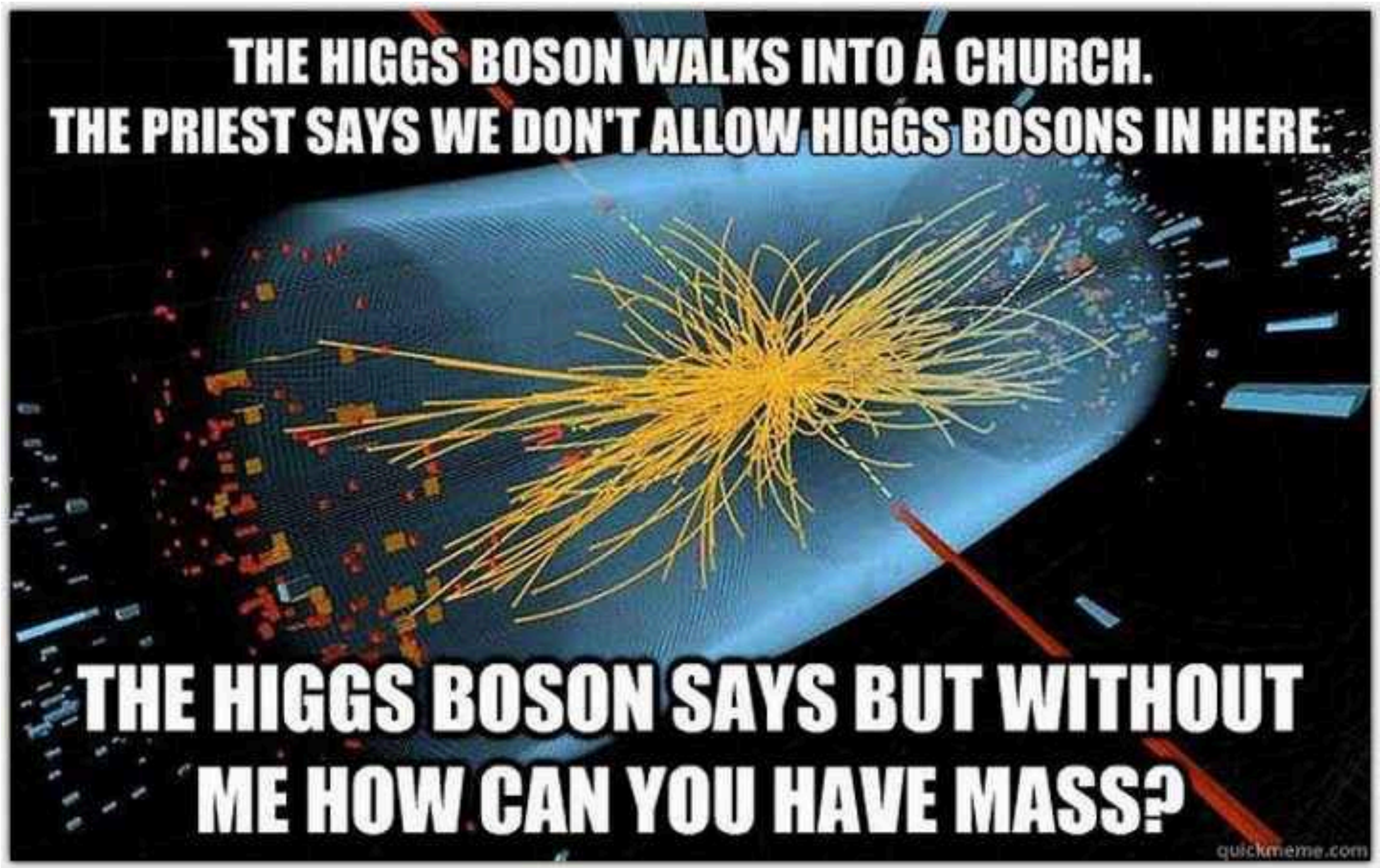
The “Higgs” is there !?!



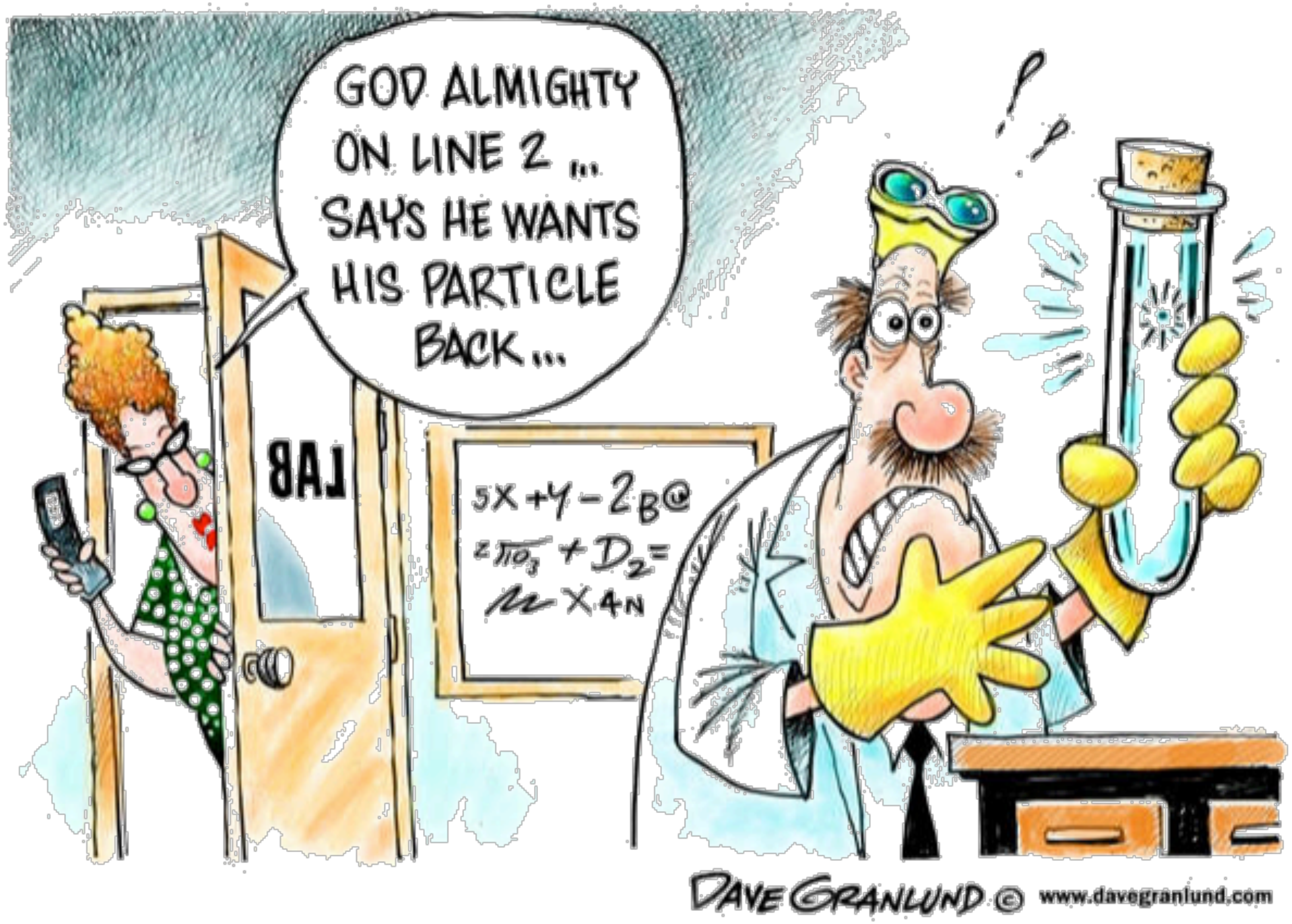


Cuddle your Higgs

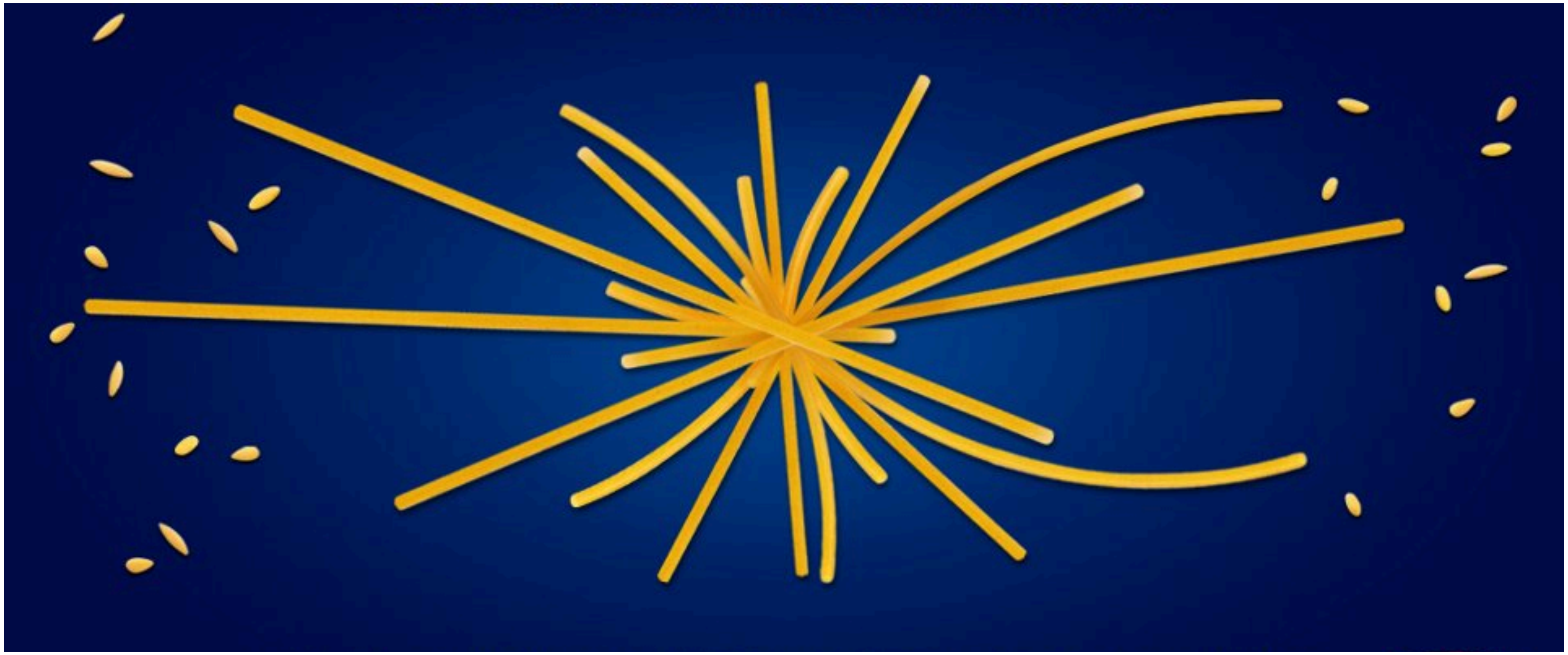
No Higgs in Catholic church ?



Somebody is jealous…



A Higgs event in CMS ?



Do not forget heavy ions physics

To conclude:

p-Pb run coming up

Salgado

Proton-nucleus at the LHC

2/2013 pPb run

...nditions, nuclear PDFs

...ce (best experimental option

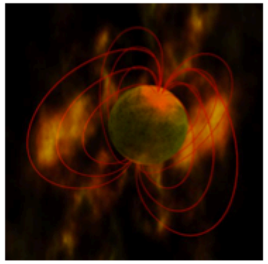
[talk P. Newman]

Heavy Ions theory 25

How strong?

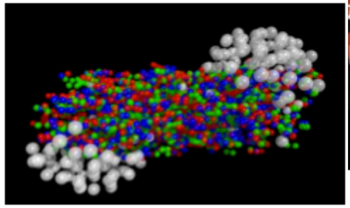
1 Tesla = 10^4 Gauss

10^{17}—10^{18} Gauss
$\sqrt{eB} \sim 1 - 10\ m_\pi$:
Noncentral heavy-ion coll. at RHIC and LHC
Also strong Yang-Mills fields $\sqrt{gB} \sim 1 -$ a few GeV



10^{15}Gauss : Magnetars

4×10^{13} Gauss : "Critical" magnetic field of electrons
$\sqrt{eB_c} = m_e = 0.5$MeV



45 Tesla : strongest steady magnetic field
(High Mag. Field. Lab. In Florida)

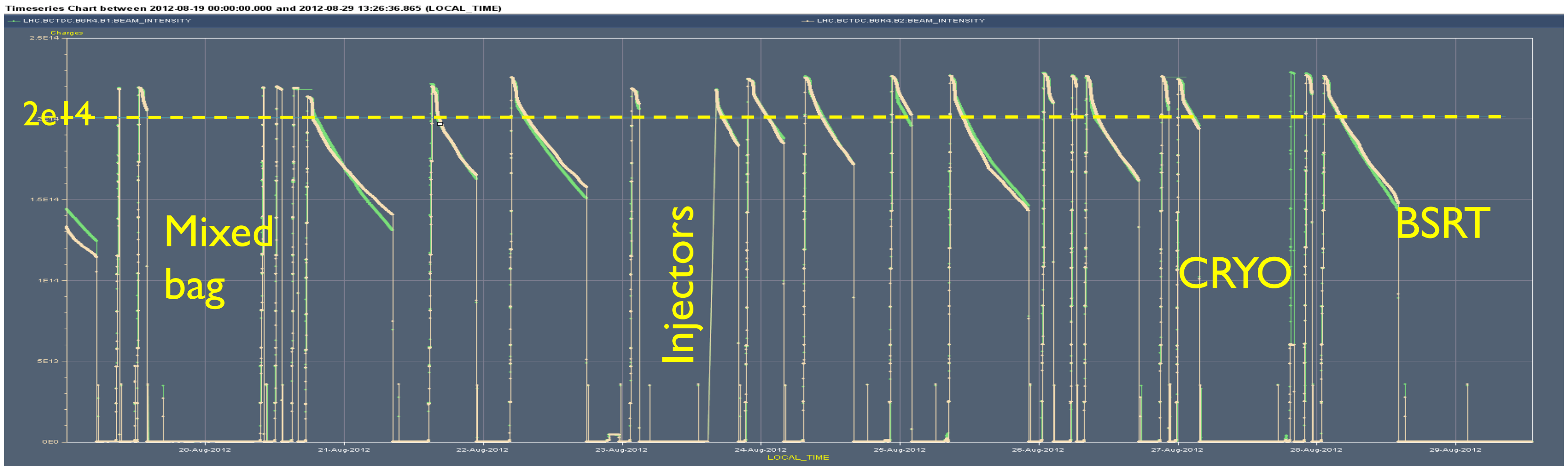
10^8Tesla=10^{12}Gauss:
Typical neutron star surface

8.3 Tesla :
Superconducting magnets in LHC

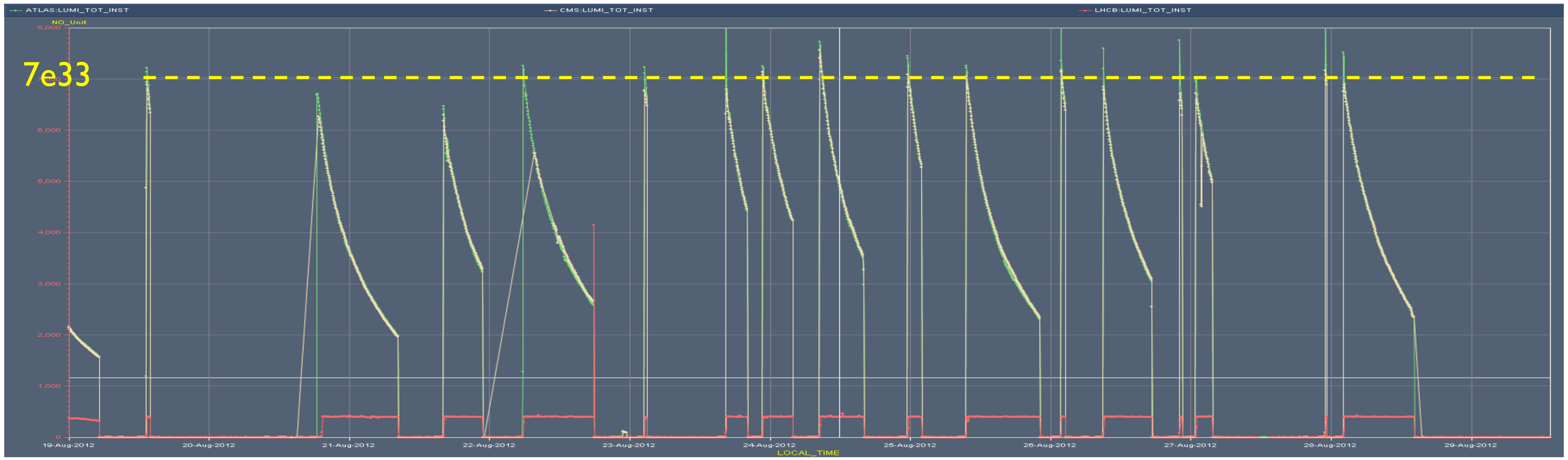
Super critical magnetic field may have existed in very early Universe. Maybe after EW phase transition? (cf: Vachaspati '91)

Fascinating physics !

Not always plain sailing…



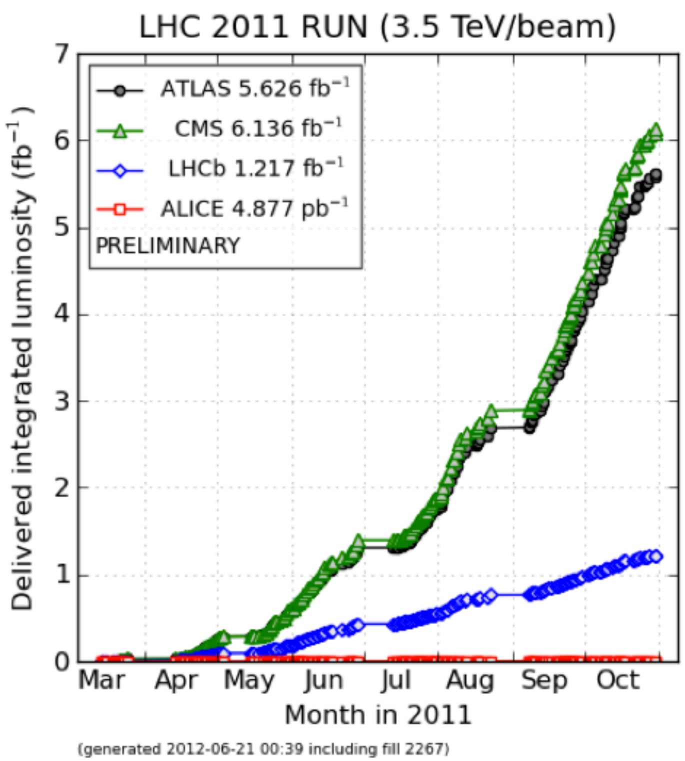
Beam intensity from weeks 34 and 35 (20th to 29th August 2012)

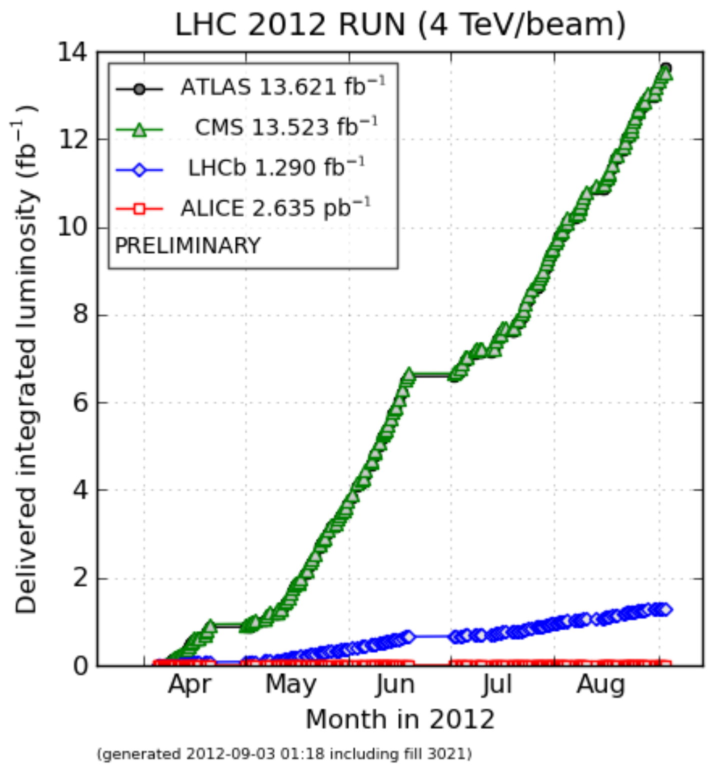


Luminosity logs from weeks 34 and 35 (20th to 29th August 2012)

LHC luminosity production

- Peak luminosity 7.7 10^{33} 1/cm^2 s
- LHC operation has reached good routine to deliver the promised 15 fb^{-1} by the end of 2012





What did we learn?

- LHC is **magnetically very reproducible** on a month to month time scale
- **High precision** of the powering system
  - (8 independent sectors !)
- **High availability of the cryogenics** and hardware system
- Head on beam-beam limit higher than foreseen
- Aperture better than foreseen
- Not a single magnet quenched due to beam
  - (>3 GJ stored in the magnets)
- Careful increase of the number of bunches and intensities OK (up to 150 MJ per beam)

Concerns of intensity and energy

- **Single event upsets (SEU)** that depend on beam intensity and luminosity (Radiation to Electronics)
- Localized short losses, commonly referred to as UFOs (**Unidentified Falling Objects : dust ?**)
- **Beam induced heating** of injection kickers, collimators, beam screens, beam instrumentation, RF fingers, …
- Electron cloud and dynamic pressure rise at very high bunch intensities

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The predictable future: LHC time-line

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and luminosity

Run 2: Ramp up luminosity to design (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — **Injector and LHC Phase-I upgrades** to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x design, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2021/22 — **Phase-II: High-luminosity LHC**. New focussing magnets and CRAB cavities for very high luminosity with luminosity levelling

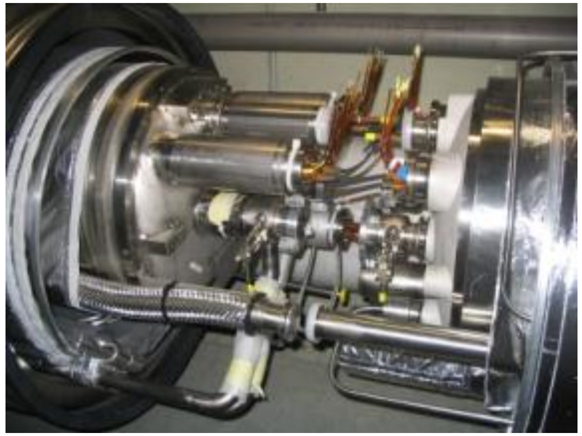
Run 4: Collect data until > 3000 fb^{-1}

2030 — End of the LHC Era ? a Big Party !

By courtesy of R. Heuer CERN DG

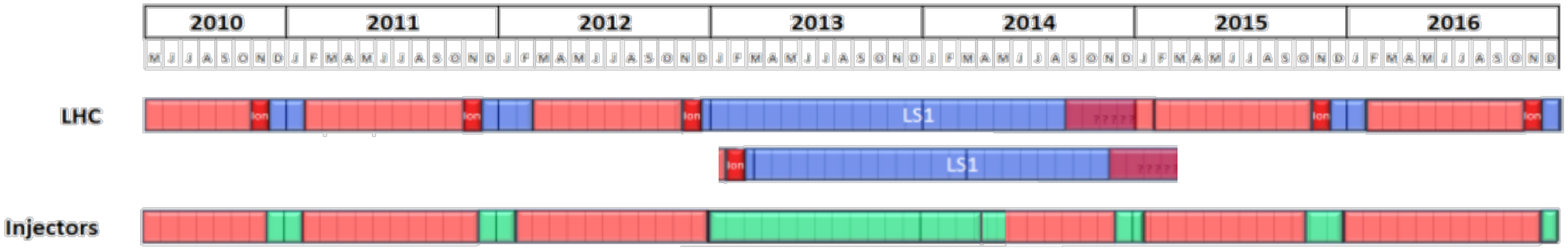
LS1 scope and schedule

- Repair defective interconnects
- Consolidate all interconnects with new design
- Finish off pressure release valves (DN200)
- Exchange magnets with non-conformities
- Repair He leaks (sectors 3-4 and 4-5)
- Maintenance of all the systems after 3 years operation
- Bring all necessary equipment up to the level needed for 7TeV/beam

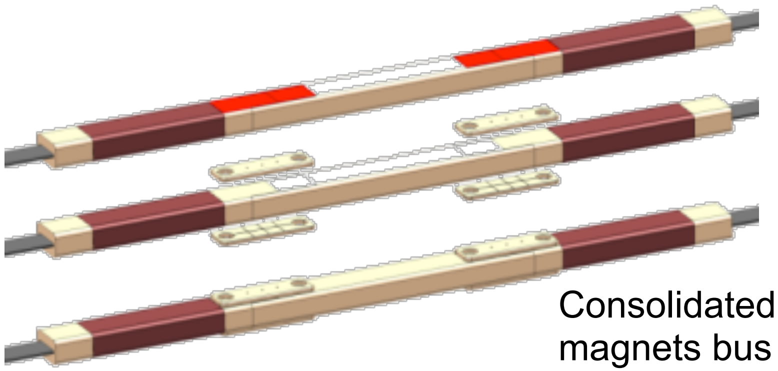


10-15 % of interconnections to be opened and to be re-welded
100% (10'000) to be consolidated

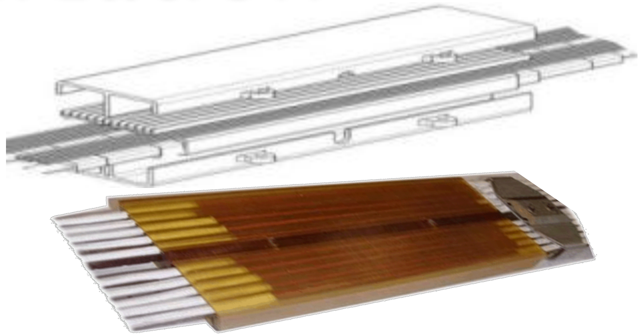
Schedule is now consolidated, the countdown runs !



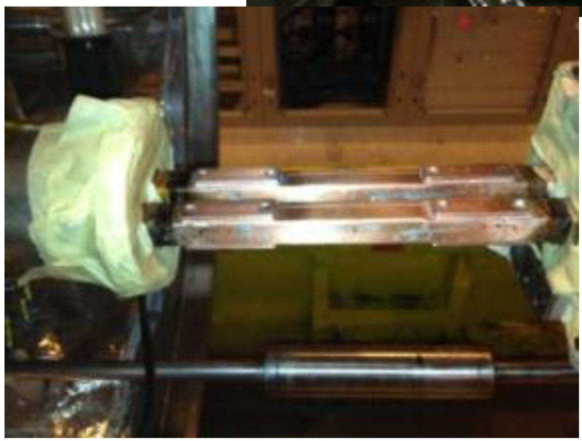
13 kA splice consolidation



Consolidated dipole magnets bus splice



Consolidated electrical insulation

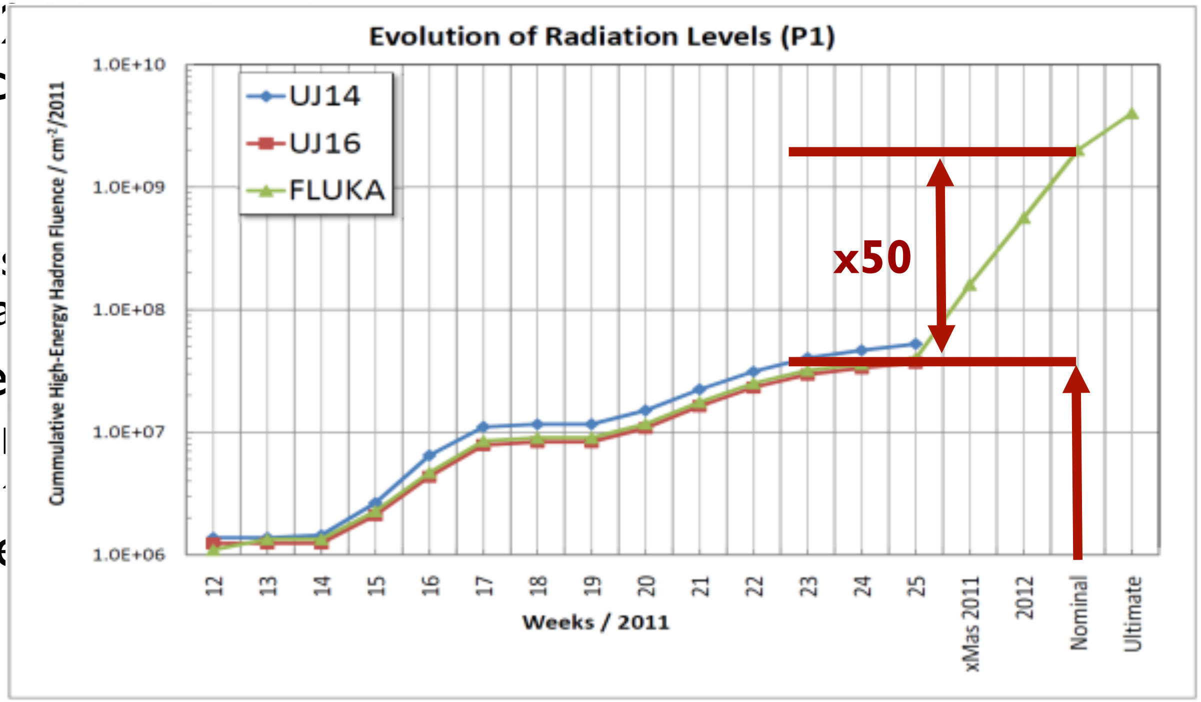


Final validation test on a laboratory interconnect:
- 13 KA quench
- 20 kCycles
- Thermal cycles

Radiation to Electronics (R2E)

- Operation in 2011 has identified most critical equipment
- Mitigation measures integrated "on-the-fly" if and when possible
- 2011/20121
  (and Technic
  - Relocation elements
  - Additional critical area
- Aim for ope is to dodge (no limit to performance

- LS1 (2013-2014): relocate & shield all critical areas
- Beyond LS1: major action required for power converters and other electronics in the tunnel



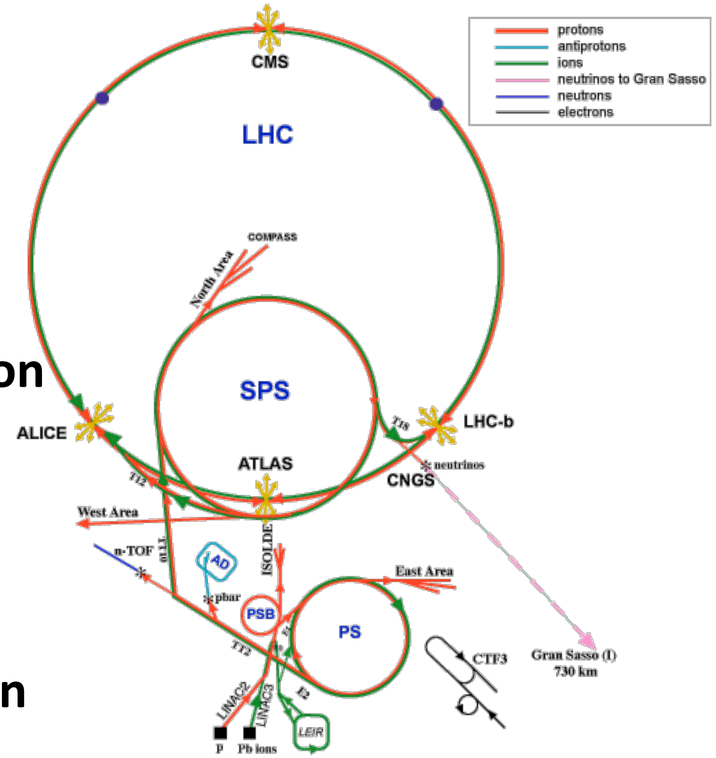
LS2 (2018): Injector Upgrades

Connect Linac4 to PS Booster,

- New PS Booster injection channel

Upgrade PS Booster 1.4 → 2.0 GeV

- New Power Supplies, RF system etc.
- Upgrade transfer lines & instrumentation



Upgrades the PS

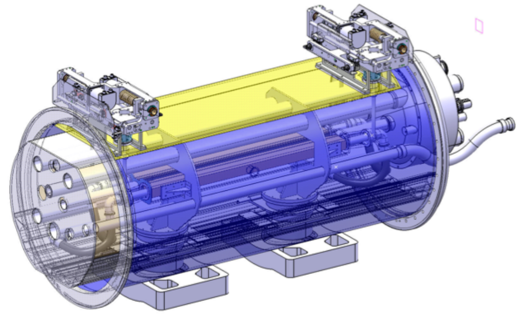
- Injection region for 2.0 GeV Injection
- New/Upgraded RF systems
- Upgrades to Feedbacks/Instrumentation

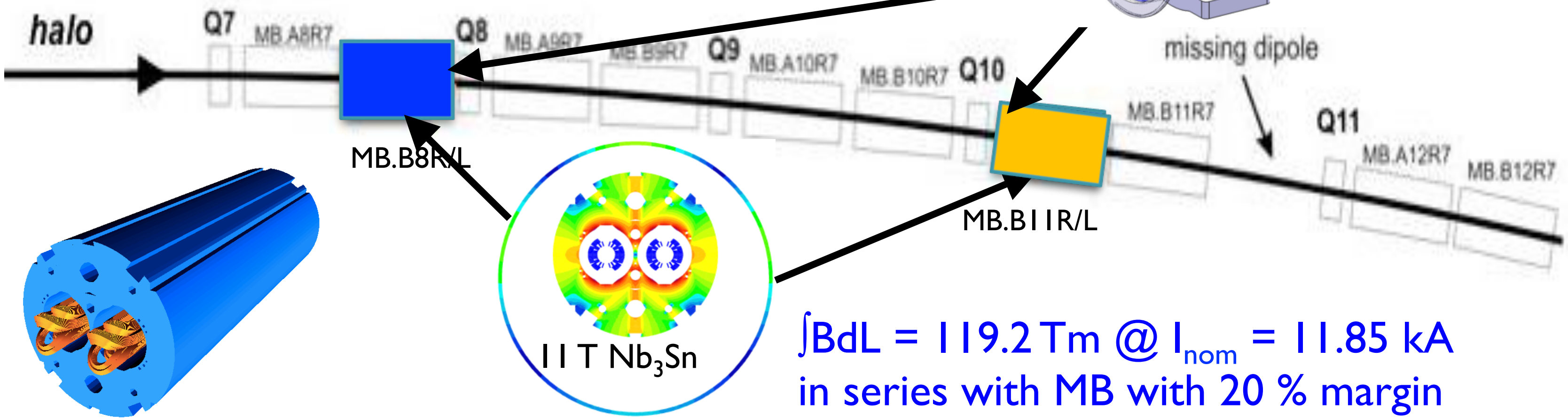
Upgrades to the SPS

- Electron Cloud mitigation – strong feedback system, or coating of the vacuum system
- Impedance reduction, improved feedbacks
- Large-scale modification to the main RF system

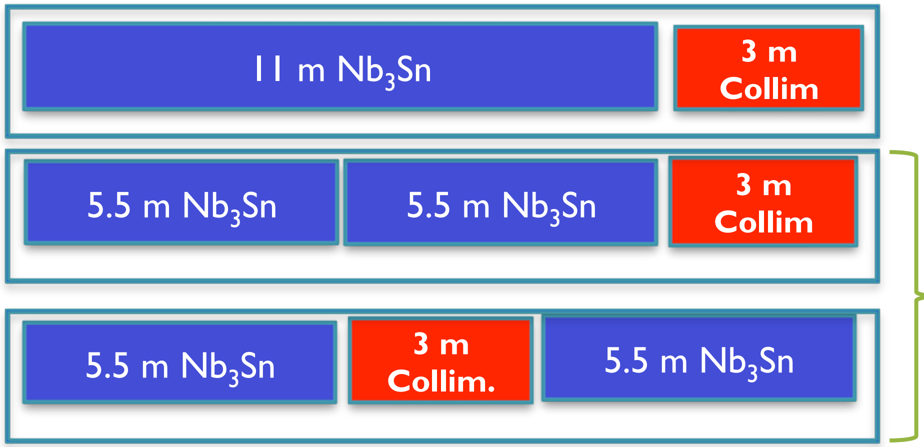
DS Upgrade: collimators & 11 T

- LS2 2017-2018: Point-3,7 & IR-2
- LS3 2021-2022: IR1,5 as part of HL-LHC





$\int BdL$ = 119.2 Tm @ I_{nom} = 11.85 kA
in series with MB with 20 % margin



LS2: 12 coldmass + 2 spares = 14 CM
LS3: 8 coldmass + 2 spares = 10 CM
Total 24 CM

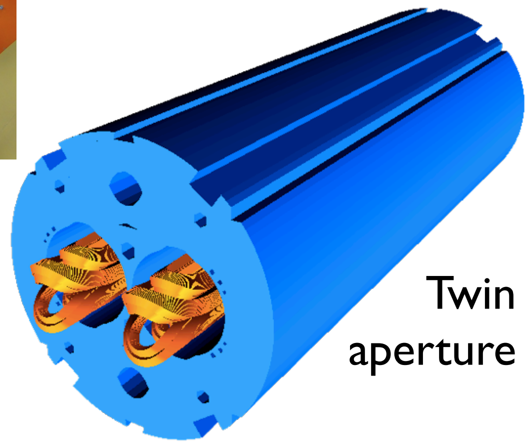
LS2: 24 coldmass + 4 spares = 28 CM
LS3: 16 coldmass + 4 spares = 20 CM
Total 48 CM

11 T DS models

- Single aperture demonstrator (MBHSP1) tested at FNAL
- CERN model manufacturing started
- Design of twin aperture in progress

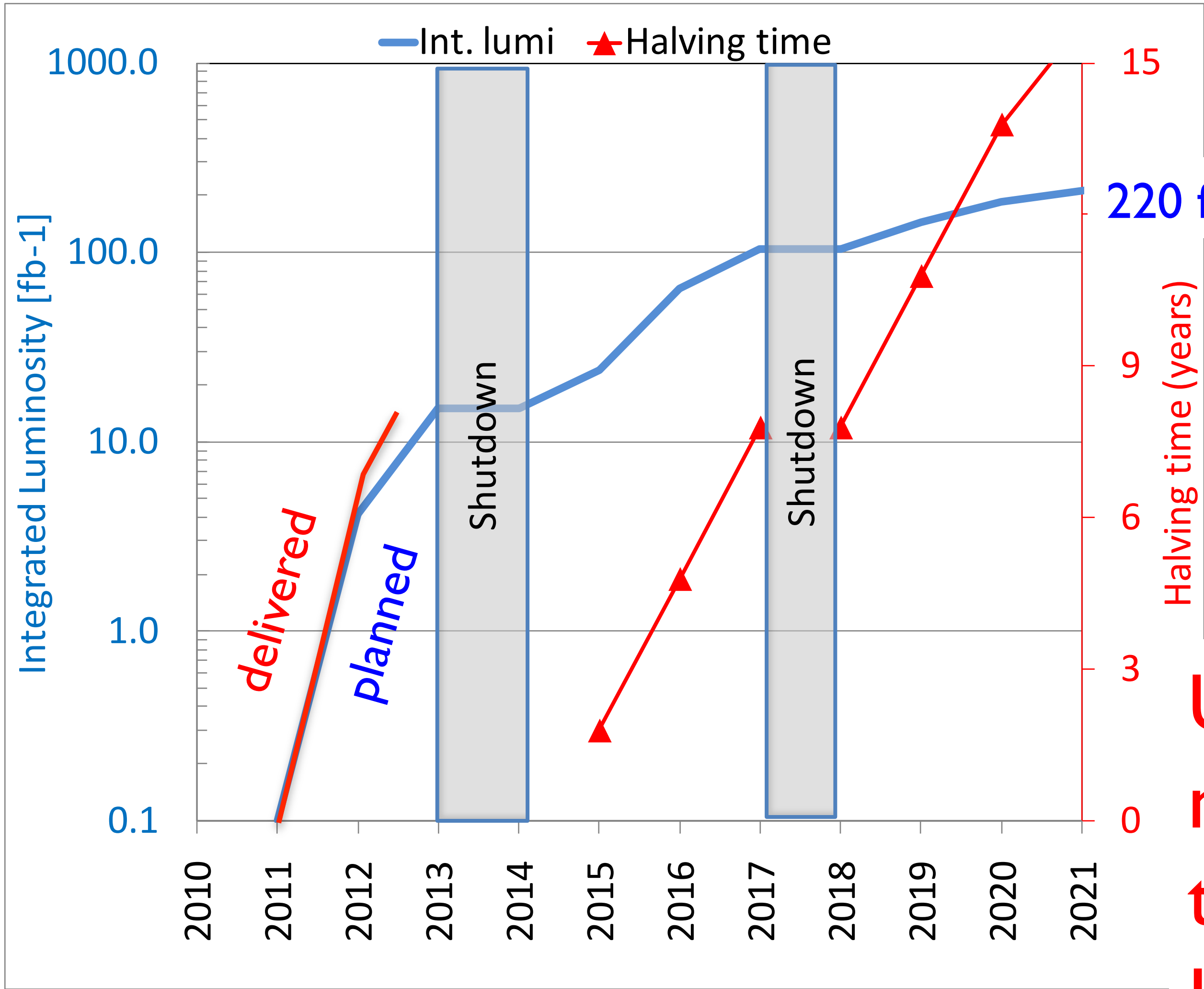
MBHSP1 at FNAL

First 11 T copper coil winding completed at CERN



Twin aperture

LHC luminosity expectations



LHC target is **3000 fb^{-1}**

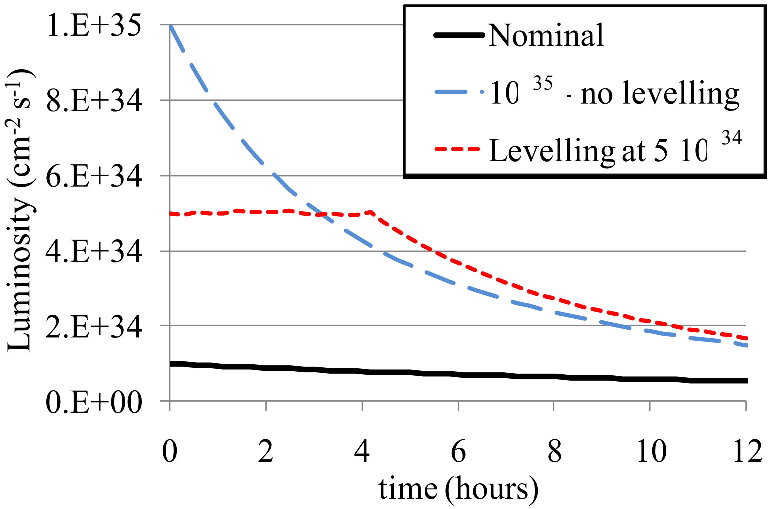
220 fb^{-1} by 2020

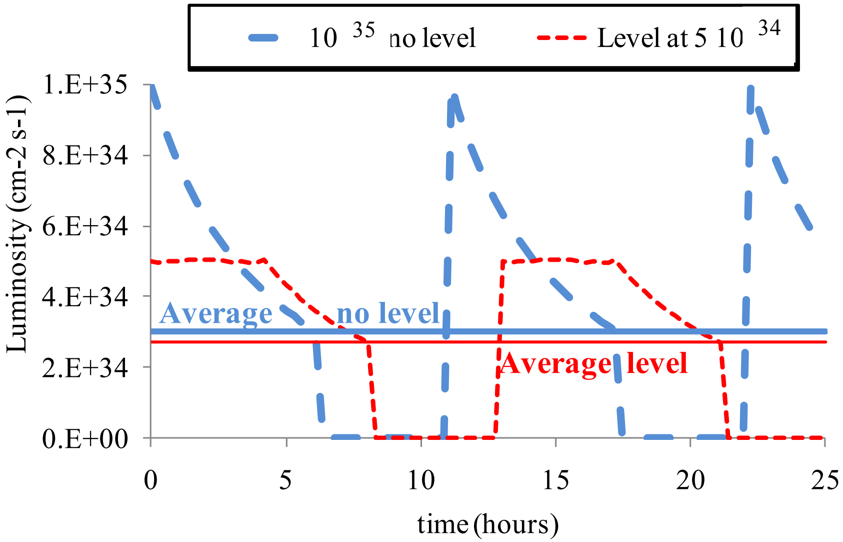
Upgrade needed by the 2020's: HL-LHC

Lumi plot from M. Lamont (CERN)

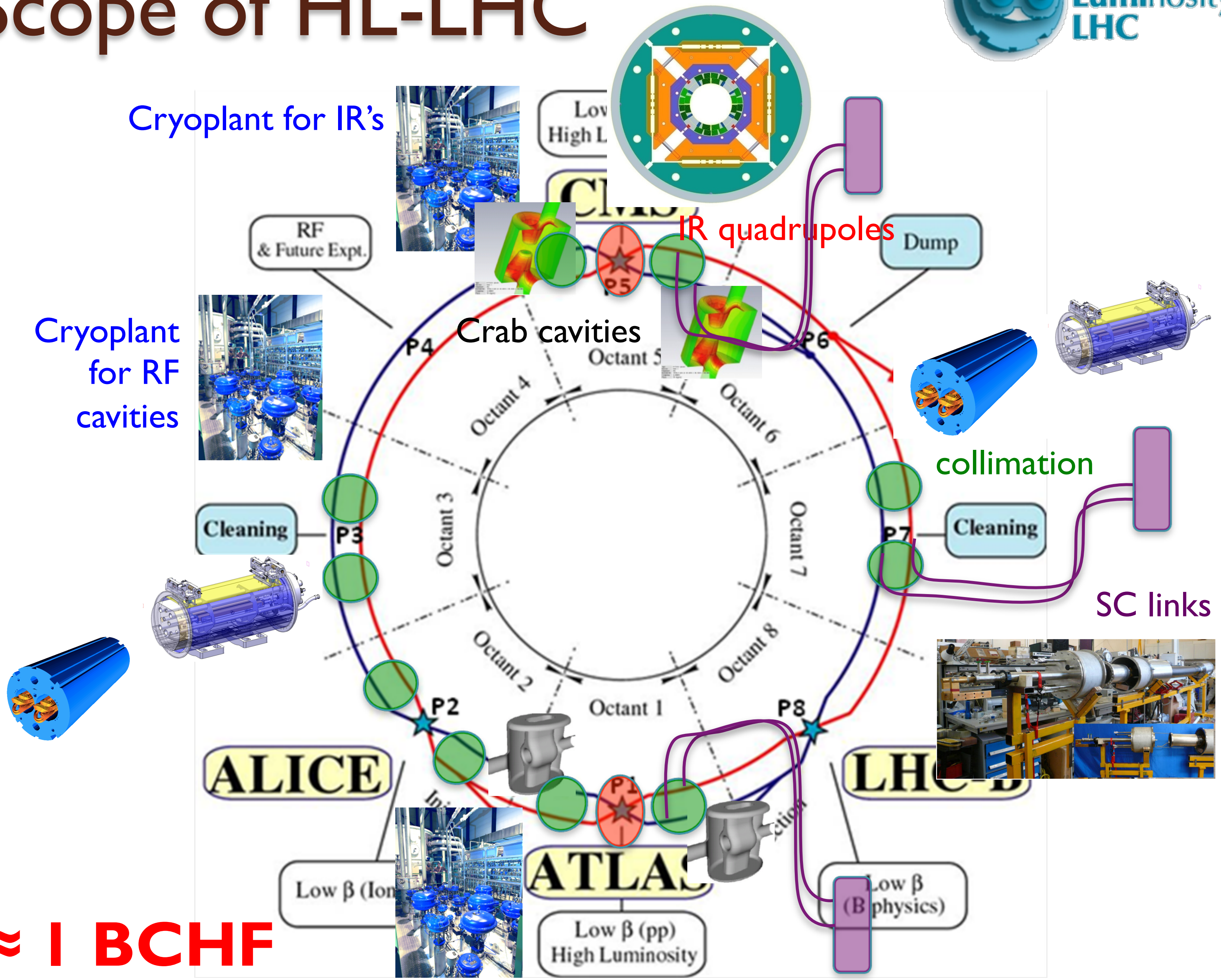
High-Luminosity LHC: Goal

- Implement a hardware configuration and a set of beam parameters that will allow to reach a peak luminosity of 5×10^{34} cm^{-2}s^{-1} with levelling, and integrated luminosity of 250-300 fb^{-1} per year (10 times the present LHC)



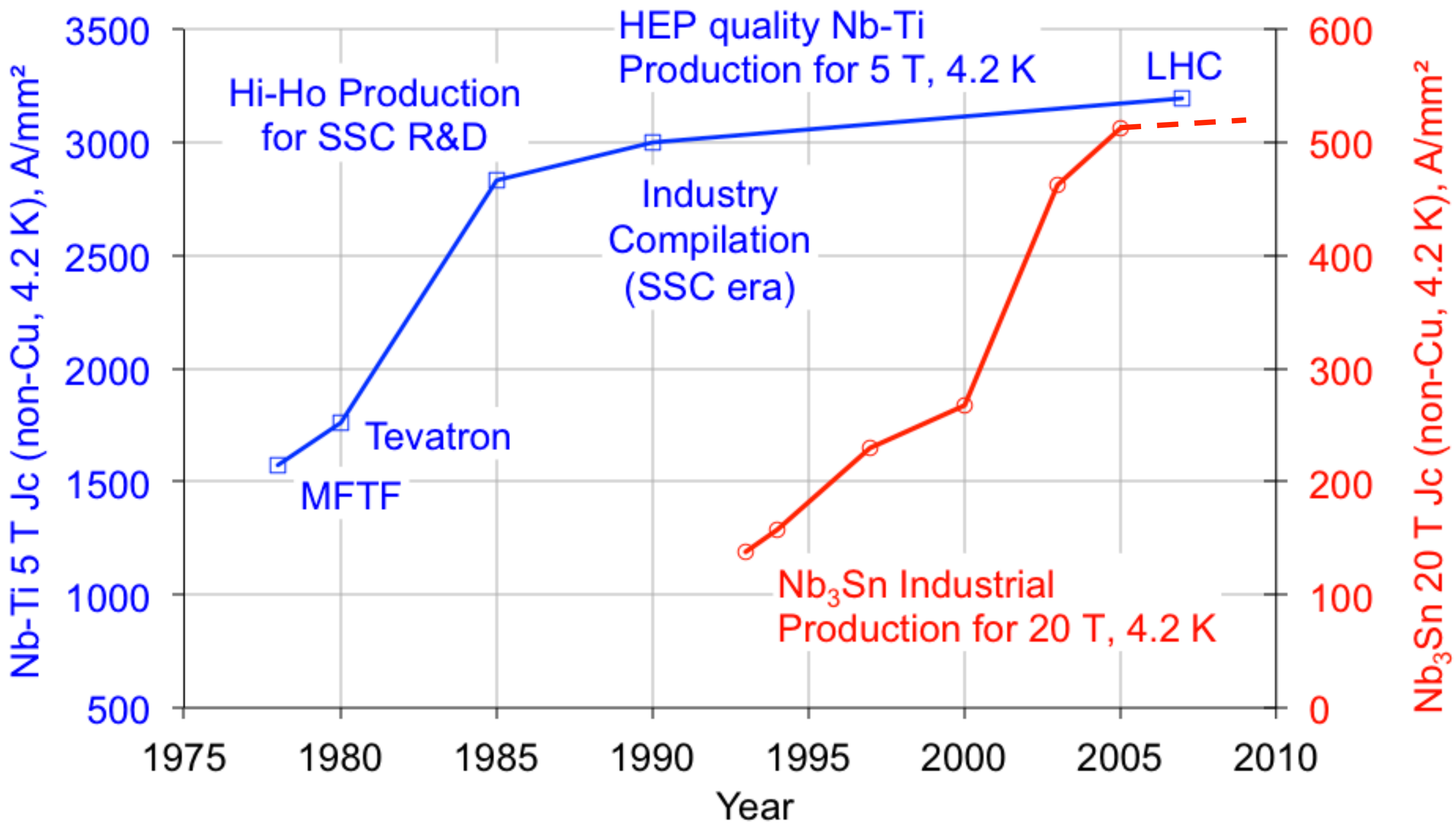


Scope of HL-LHC



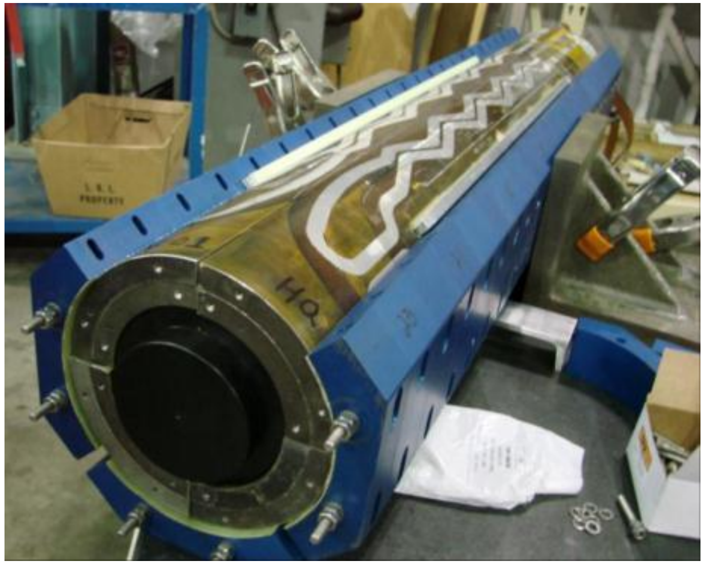
≈ 1 BCHF

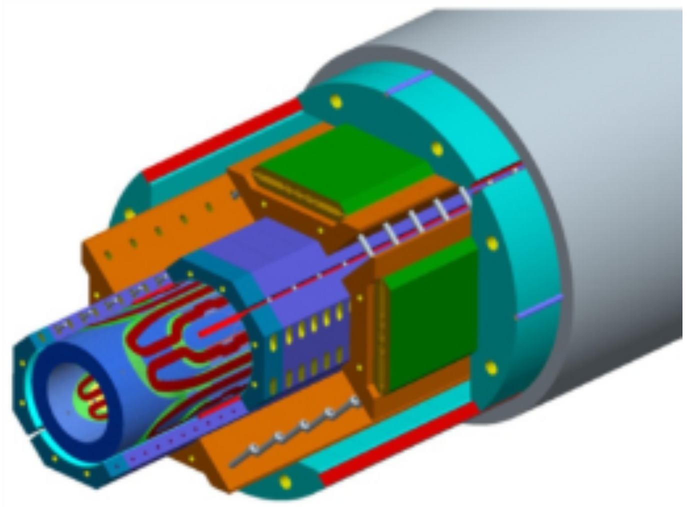
Nb_3Sn knocks at the door



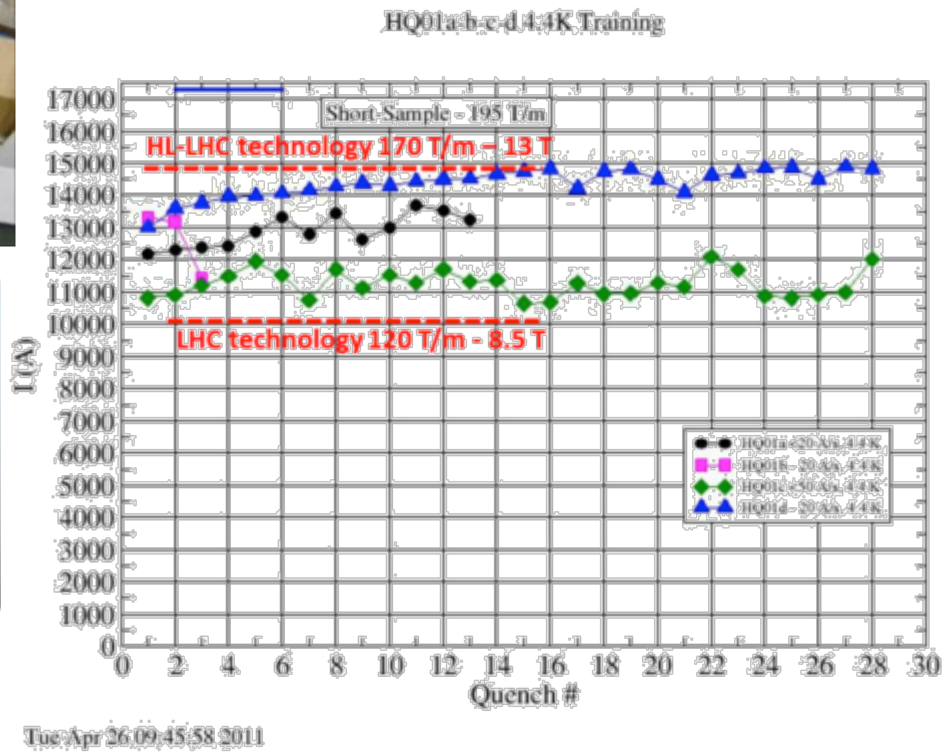
By courtesy of J. Parrell (OST)

LARP HQ (120 mm- 13 T)





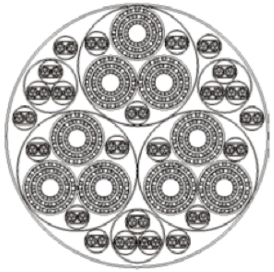
Nb3Sn has the potential to give a 50 % benefit in gradient (for the same aperture), or larger aperture (for the same gradient), at much increased temperature margin (factor 2 to 3)



By courtesy of A.Ballarino, CERN

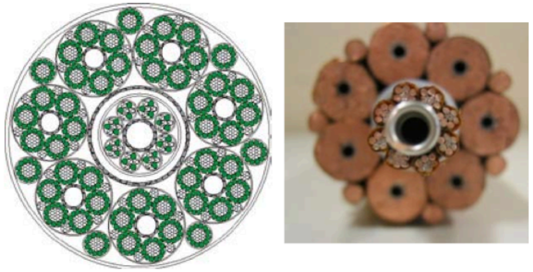
SC links

HTS tapes



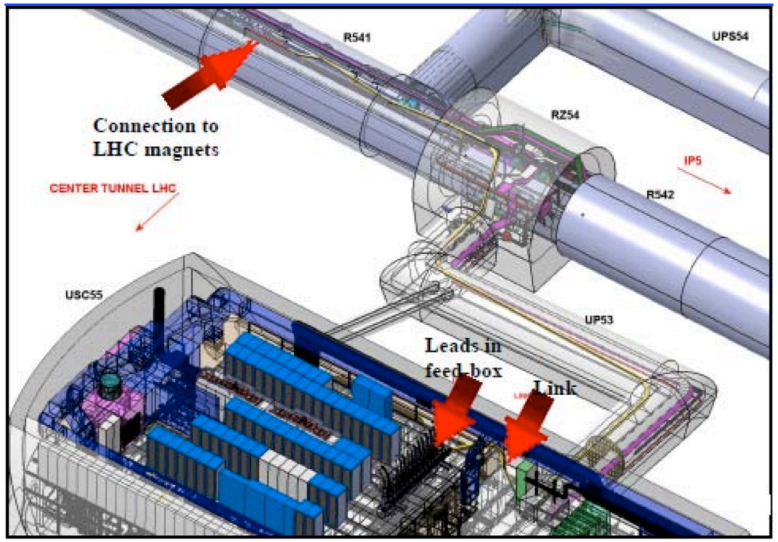
Φ= 75 mm
Itot =190 kA @ 25 K (2 × 95 kA)

Round wires



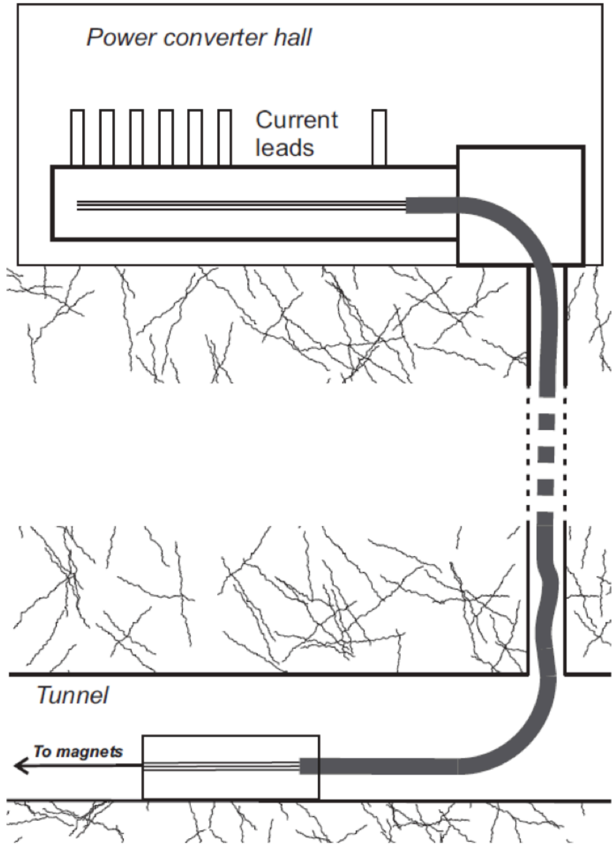
Φ= 60 mm
Itot =100 kA @ 25 K (2 × 50 kA)

A. Ballarino, paper 5LY-133 at ASC-2010

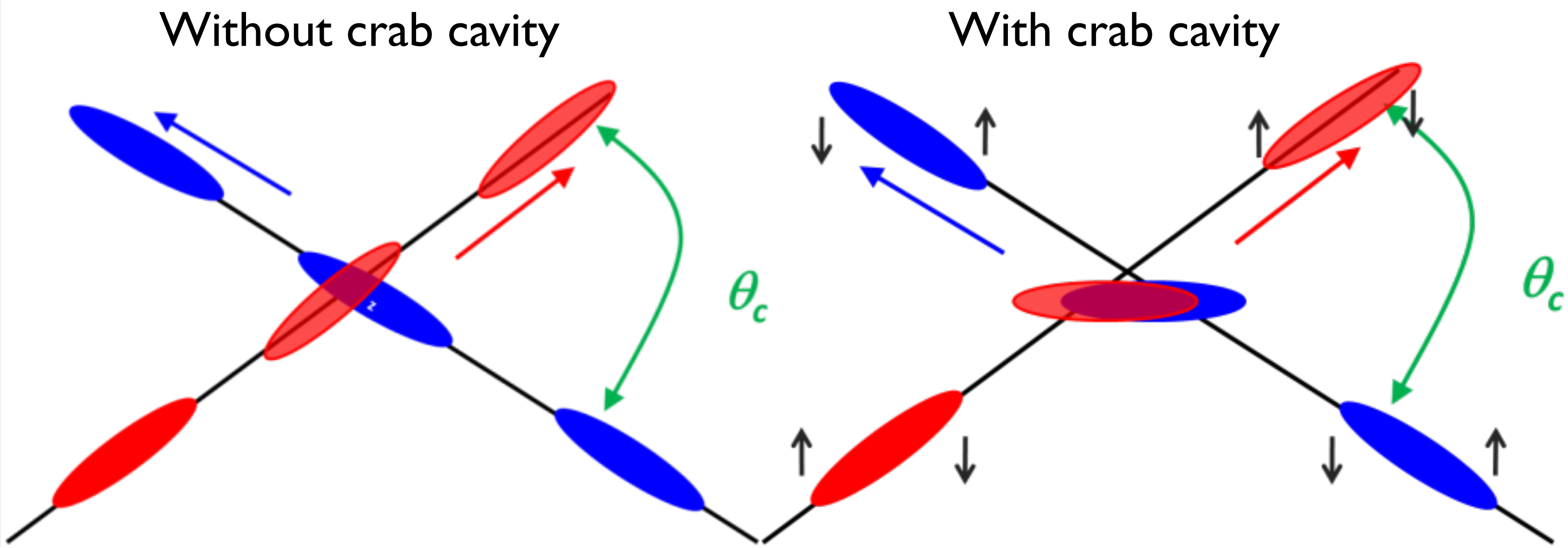


Repositioning the converters in the cavern

Removal of the converters from the cavern



Role of crab cavities



- RF crab cavities deflect head and tail in opposite directions so that the collision is effectively head-on and the luminosity is maximized
- The same principle can be used for luminosity leveling using the crab cavities at variable angle

Outline

- Where do we come from
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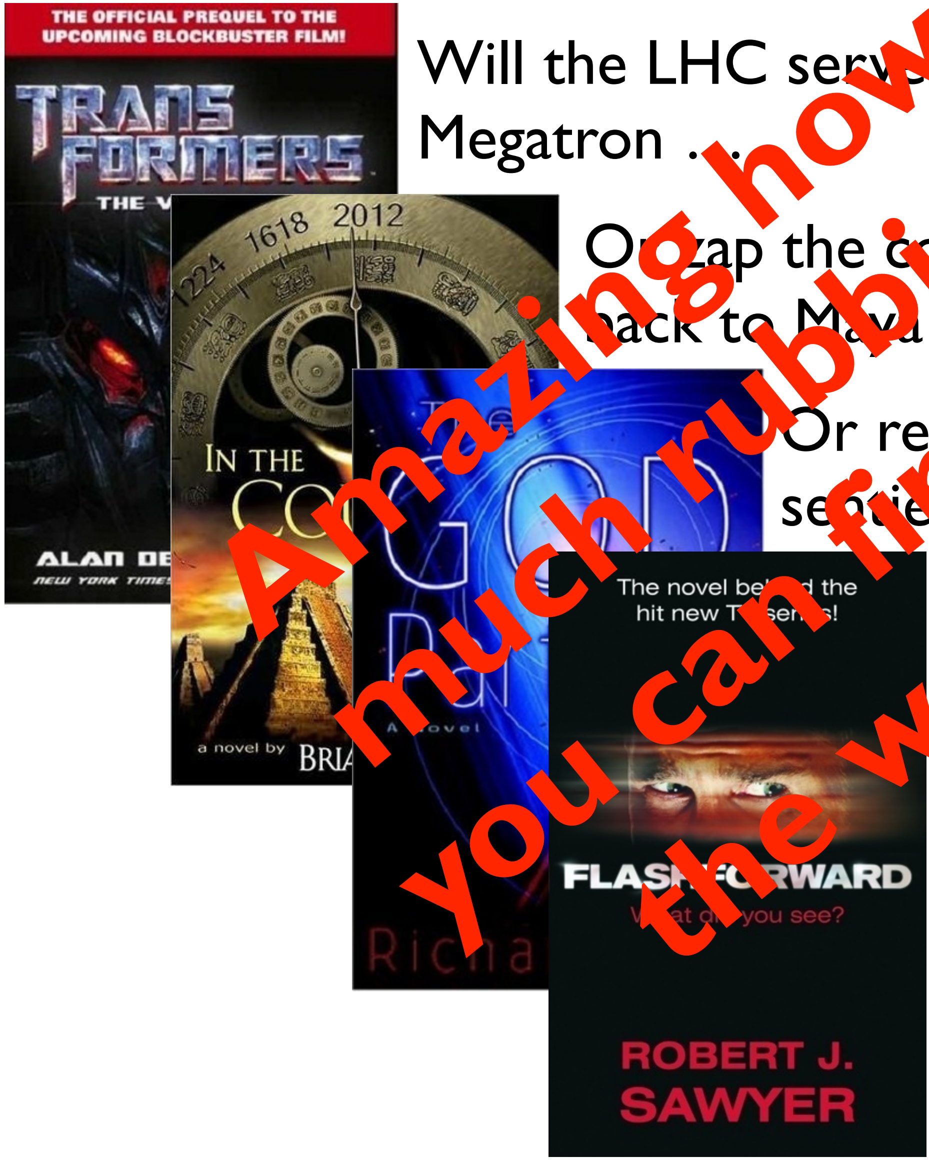
Is there a physics beyond the LHC ?



Will the LHC serve the Decepticons to revive Megatron ...

Or zap the conscience of Jed de Landa back to Maya time ...

Or reveal that the Universe is a sentient being ...

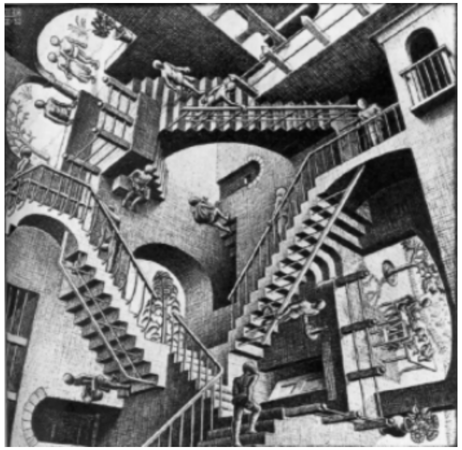
Or cause everybody to black-out and see a vision of the future ?

Amazing how much rubbish you can find on the web !!!

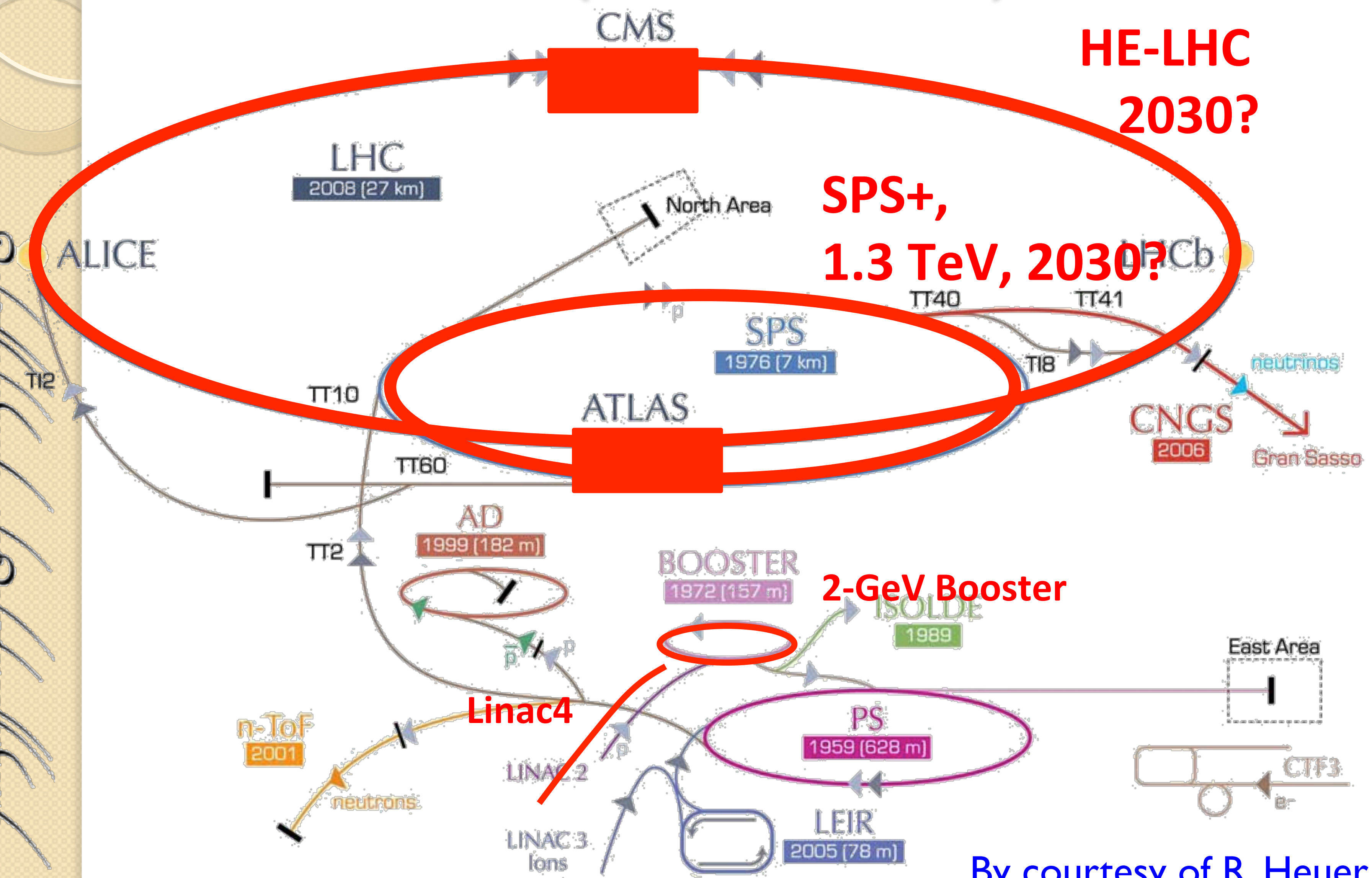
HE-LHC Scope

- *"[…] a 33 TeV centre-of-mass energy proton–proton accelerator in the LHC tunnel […] and the need for new injectors, possibly with 1 TeV energy"*. (The High-Energy Large Hadron Collider, CERN–2011–003, also EuCARD–Conf–2011–001)
- Technicolor, Supersymmetry, Extra dimensions: *"[…] the need to explore the high energy frontier will remain. We will always be able to make that case, today and tomorrow"*. (Elements of a Physics Case for a High-Energy LHC, J.D.Wells, pp. 1-5, CERN–2011–003, 2011)
- *"A project on the scale and innovation level of the HE-LHC has a long preparation lead time"*. (CERN Accelerator Strategy, S. Myers, pp. 6, CERN–2011–003, 2011)

technicolor



HE-LHC – (33 TeV cms)

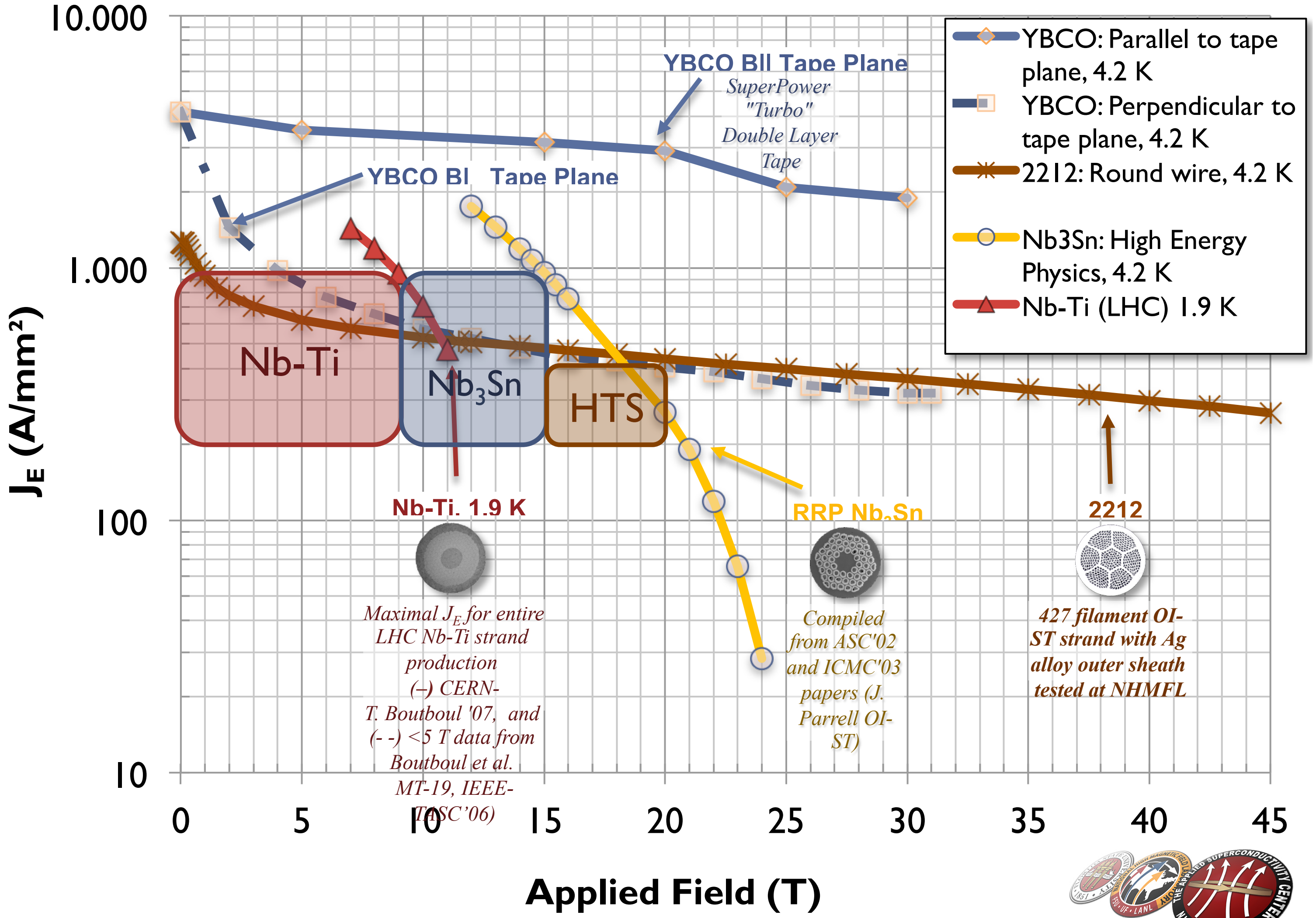


By courtesy of R. Heuer

HE-LHC magnet challenges

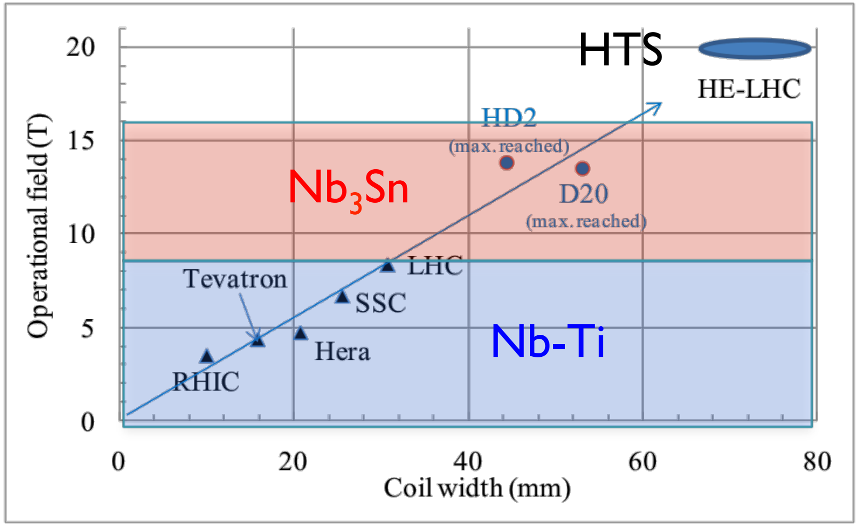
- 27 km of very high field, accelerator grade magnets
  - 40 mm bore, 20 T dipoles
  - 40 mm bore, 500 T/m arc quadrupoles
  - 50 mm bore, 400 T/m IR quadrupoles
- 7 km of pulsed accelerator magnets with low loss
  - 100 mm bore, 5 T dipoles
- 5.6 km of transfer lines, from a SPS+ to HE-LHC
- Field swing and field quality
- Mechanics, protection, powering and stray field in the constrained LHC tunnel space
- Increased heat loads (e.g. a factor 20 on $q_{Synchrotron}$)
- Cost and material availability
- **Dismantle the LHC to make space for the new ring**

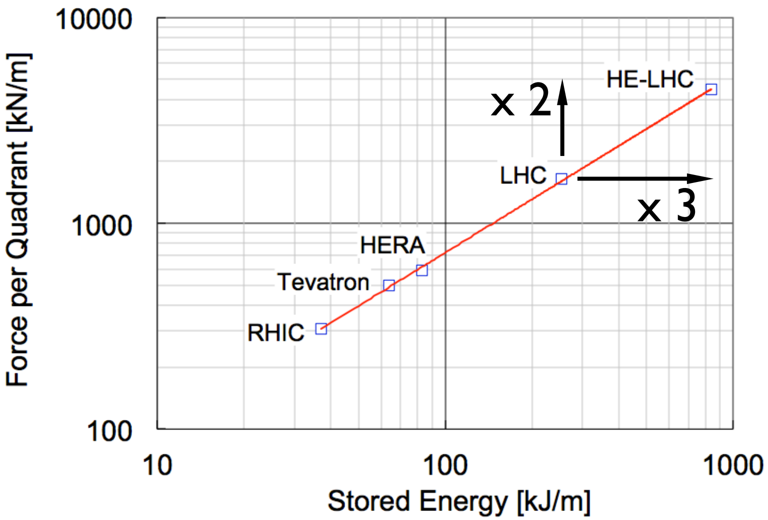
Technical superconductors

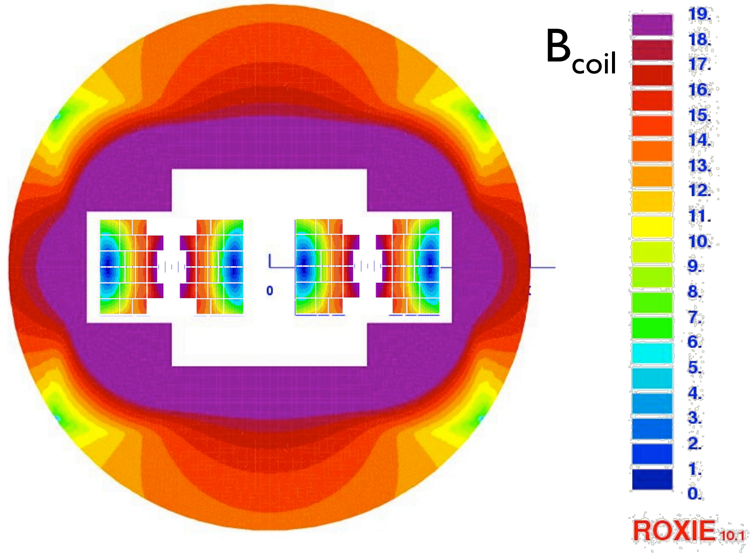


A *really high field* dipole

- Engineering extrapolation is difficult, but does not seem impossible
- May require a *genetic mutation* in the art of SC magnet design an construction

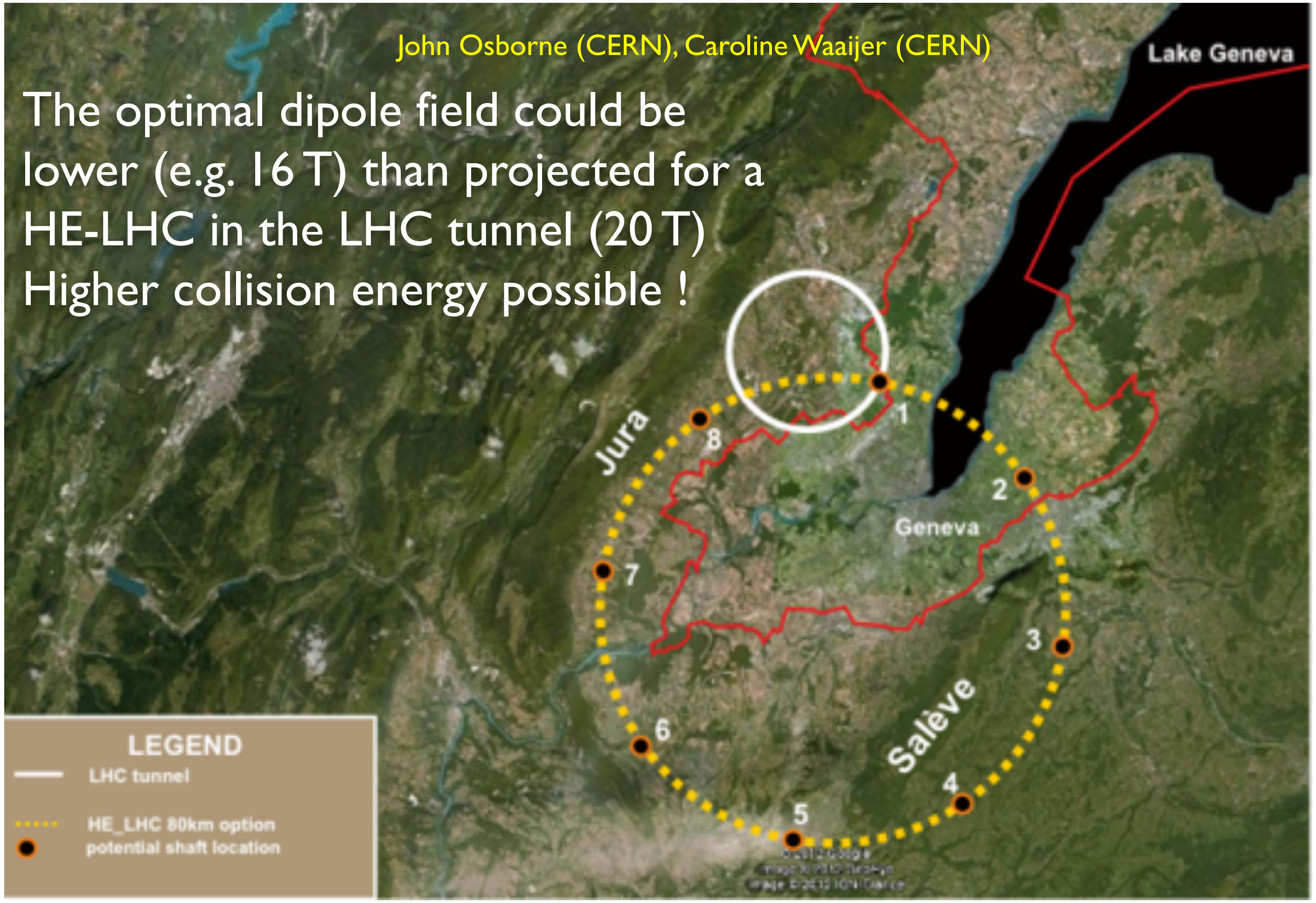






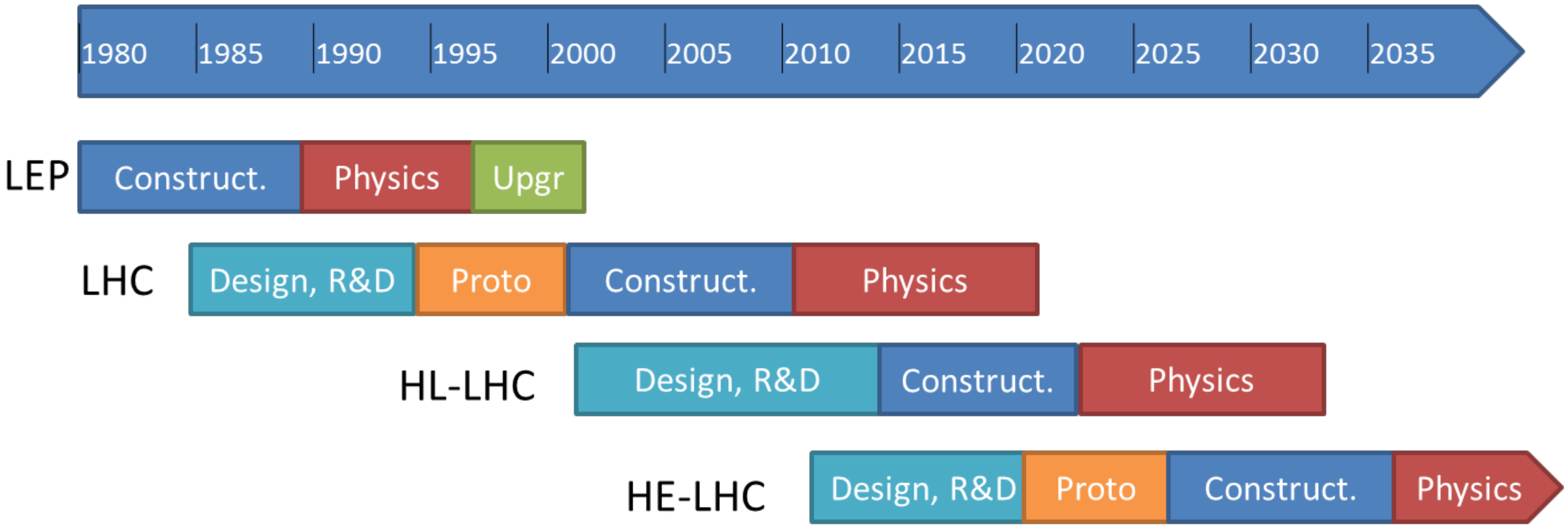
By courtesy of E. Todesco

The big leap: a new tunnel !



Whichever the optimal solution,
a vigorous high field magnet R&D should start today

Timeline



- It seems awfully early to talk about the next machine, and yet we are already late if we wish to have continuity !

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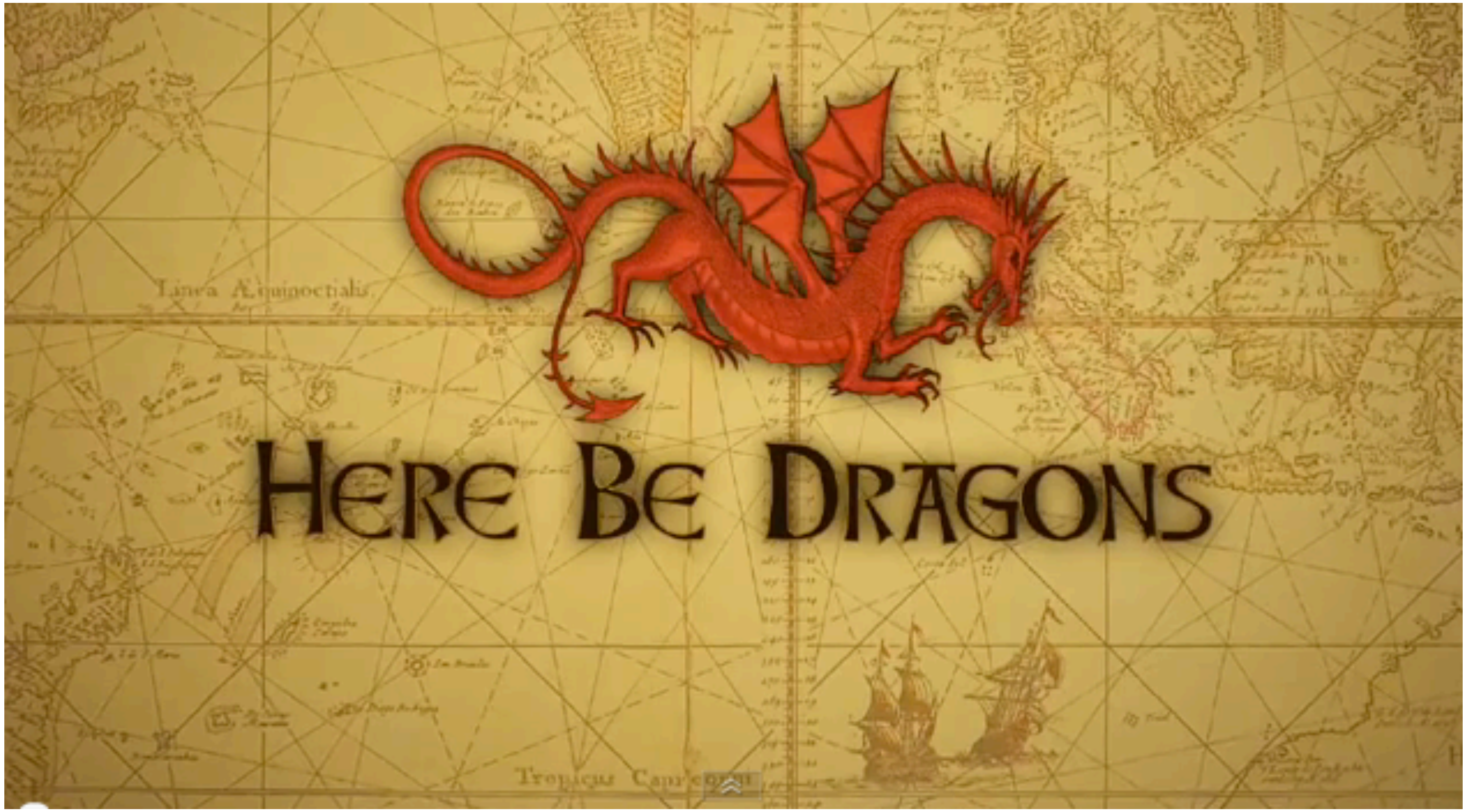
Drawing the line, today

- The production of physics material at the LHC proceeds very well, and the physics case for a HL-LHC is strong
- The ensuing demands for technology R&D are many, intellectually interesting, technically challenging, and *urgent*
  - Just on magnets (my toy) we are looking at new materials (Nb_3Sn, HTS), need a technology proof by 2015, production by 2020
  - This will open a new portfolio of applications (laboratory, energy, medical)
- HEP, and the LHC as its latest creation, is an ideal herald of innovation and advancement whose stewardship has an unbeatable record

Have no fear in the future of HEP…



… and thank you for your attention !