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Futurs grands projets d'accélérateurs à la frontière des hautes énergies

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Ecole des Accélérateurs - Bénodet 6 Février 2014

Plan

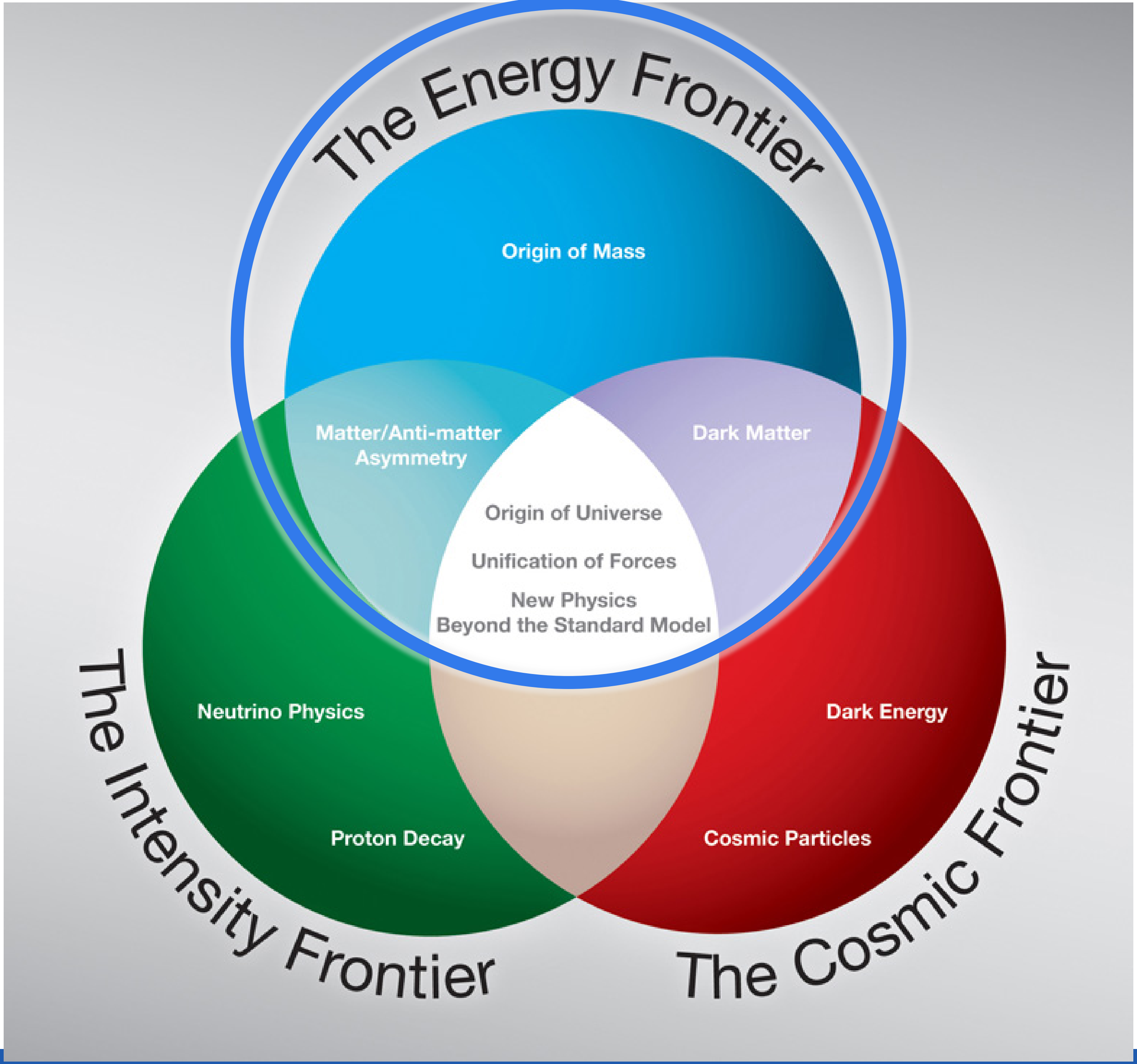
Le LHC: présent et futur

- **LHC rappel et Run 1**
- **LS1 status**
- **Run 2 (de LS1 à LS2)** $\Rightarrow$ ***13-14 TeV***
- **LS2 et Run 3** $\Rightarrow$ **300 fb^{-1}**
- **"High Luminosity LHC project"** $\Rightarrow$ **3'000 fb^{-1}**

Post-LHC machines:

- **Collisionneurs linéaires: ILC, CLIC** $\Rightarrow$ ***0.25-3 TeV***
- **Collisionneurs circulaires: FCC,** $\Rightarrow$ ***100 TeV***

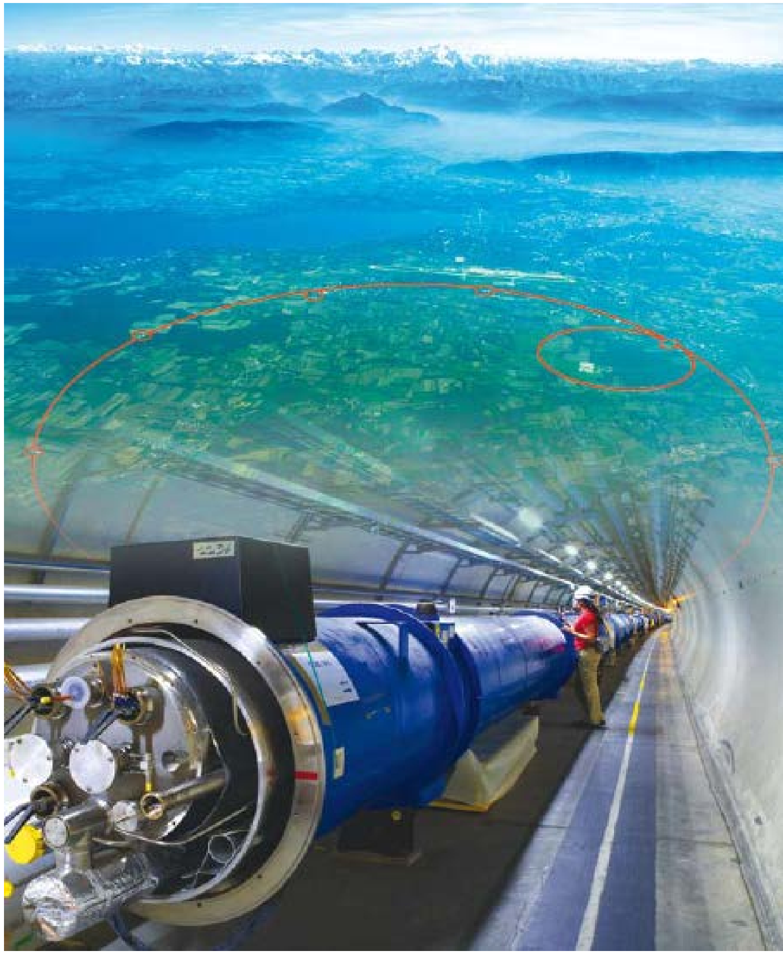
- **Conclusion**


The Energy Frontier
Origin of Mass
Matter/Anti-matter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Proton Decay
Dark Energy
Cosmic Particles
The Intensity Frontier
The Cosmic Frontier

LHC (Large Hadron Collider)

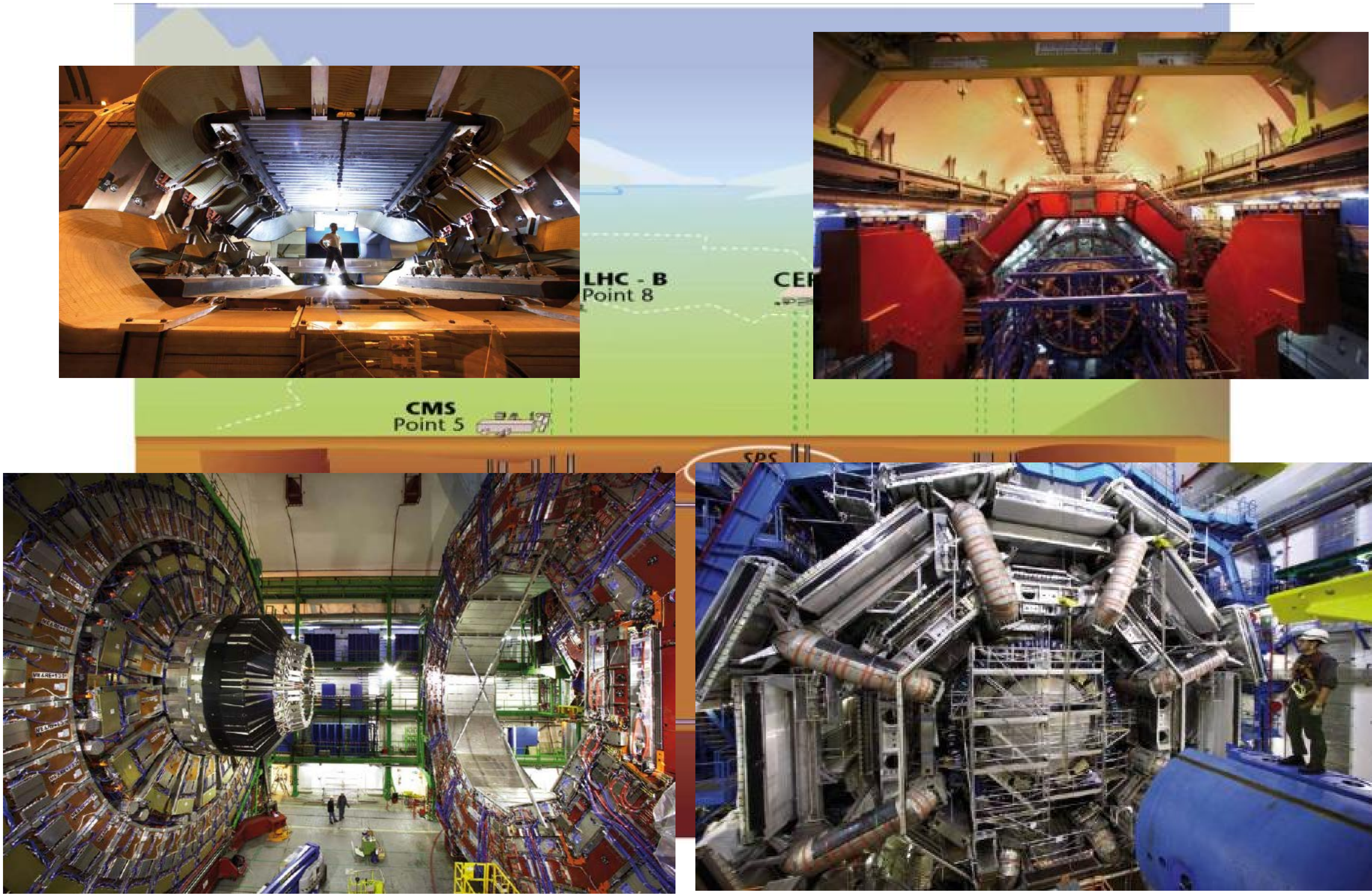
14 TeV proton-proton accelerator-collider built in the LEP tunnel

Lead-Lead (Lead-proton) collisions



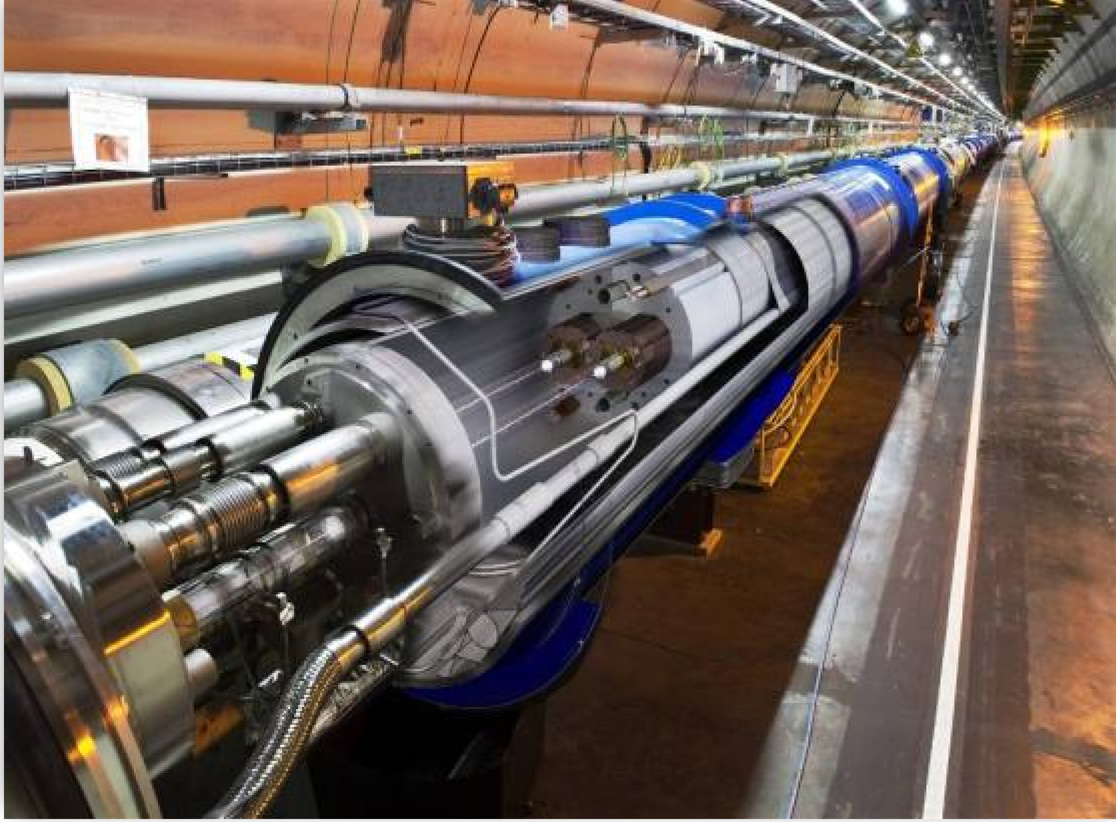
1983 : First studies for the LHC project
1988 : First magnet model (feasibility)
1994 : Approval of the LHC by the CERN Council
1996-1999 : Series production industrialisation
1998 : Declaration of Public Utility & Start of civil engineering
1998-2000: Placement of the main production contracts
2004 : Start of the LHC installation
2005-2007: Magnets Installation in the tunnel
2006-2008: Hardware commissioning
2008-2009: Beam commissioning and repair
2009-2030: Physics exploitation

Overall layout of LHC
Four large experiments



Les grands défis technologiques

Les spécifications de nombreux systèmes dépassaient le plus souvent l'état de l'art.
Il a fallu mener de longs programmes de R&D avec de nombreux instituts et industries du monde entier.



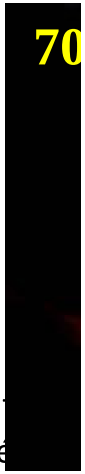
- **Aimants supraconducteurs à champ élevé: 8.3 T** (1232 aimants dipolaires de 15 m)
- **Le plus grand système d'aimant supraconducteurs** (~8000 aimants)
- **La plus grande installation cryogénique 1.9 K** (hélium superfluide, 150 tonnes de Lhe pour refroidir 37'000 tonnes)
- **Ultra-vide cryogénique pour les faisceaux de particules** (10^{-13} atm, 10 fois plus faible que sur la lune)
- **Des forts courants électriques contrôlés avec une grande précision** (jusqu'à 13 kA)
- **Une très grande précision pour les convertisseurs de puissance** (niveau du ppm)
- **Un système de protection ultra-fiable pour les aimants et les équipements** (énergies stockées: magnétique > 10 GJ, dans les faisceaux >700 MJ)

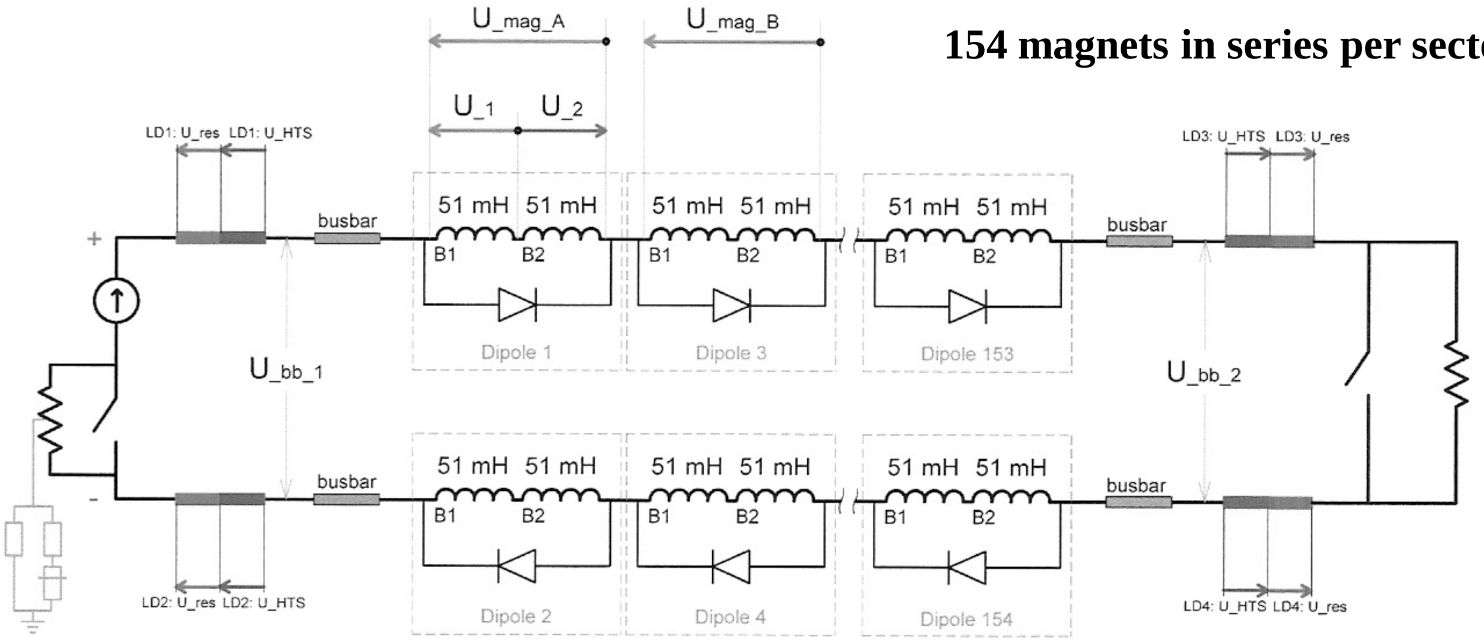
Energy management challenges

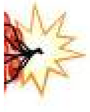
Energy stored in the magnet system: 11.3 GJoule

Ener

154 magnets in series per sector (x8)







Fu

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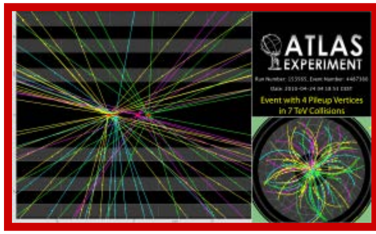
Ecole des

LHC, the construction timeline:
Nb-Ti magnet maturation



9 T - 1 m single bore

10 T-1m Nb3Sn dipole

9 T -10 m long protoype

9 T-15 m final protoype

Last LHC dipole

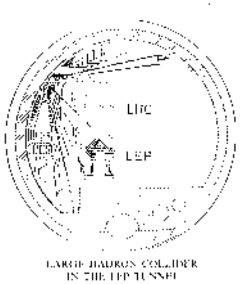
1985 1987 1990 1994 2000 2006 2010

LHC study

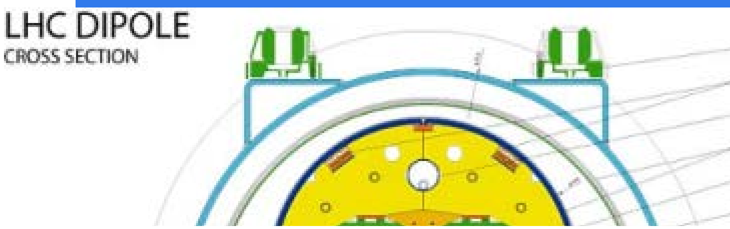
Decision for Nb-Ti

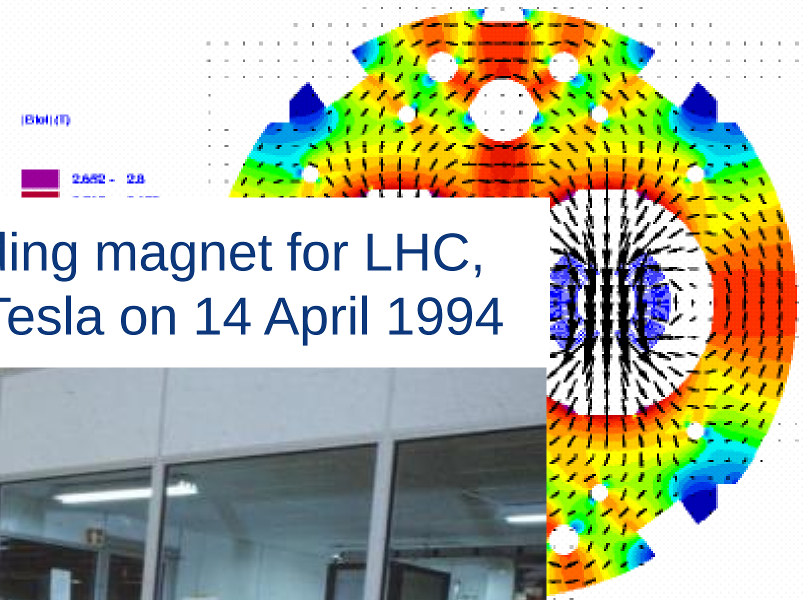
Industry contracts Nb-Ti

LHC start-up

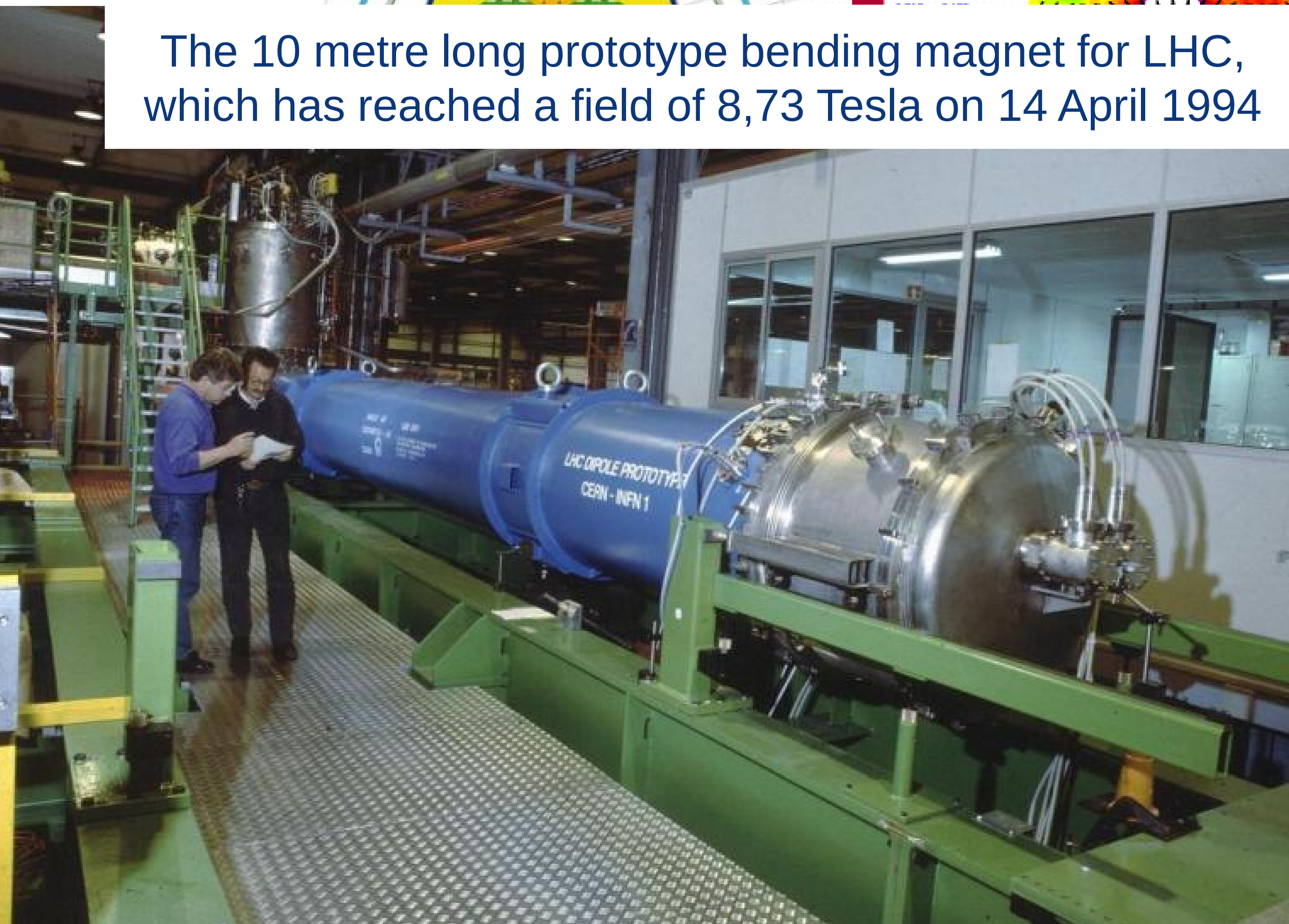


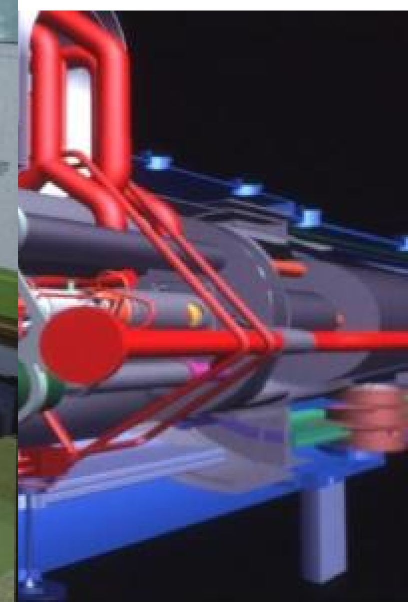
Prototype and industrialisation



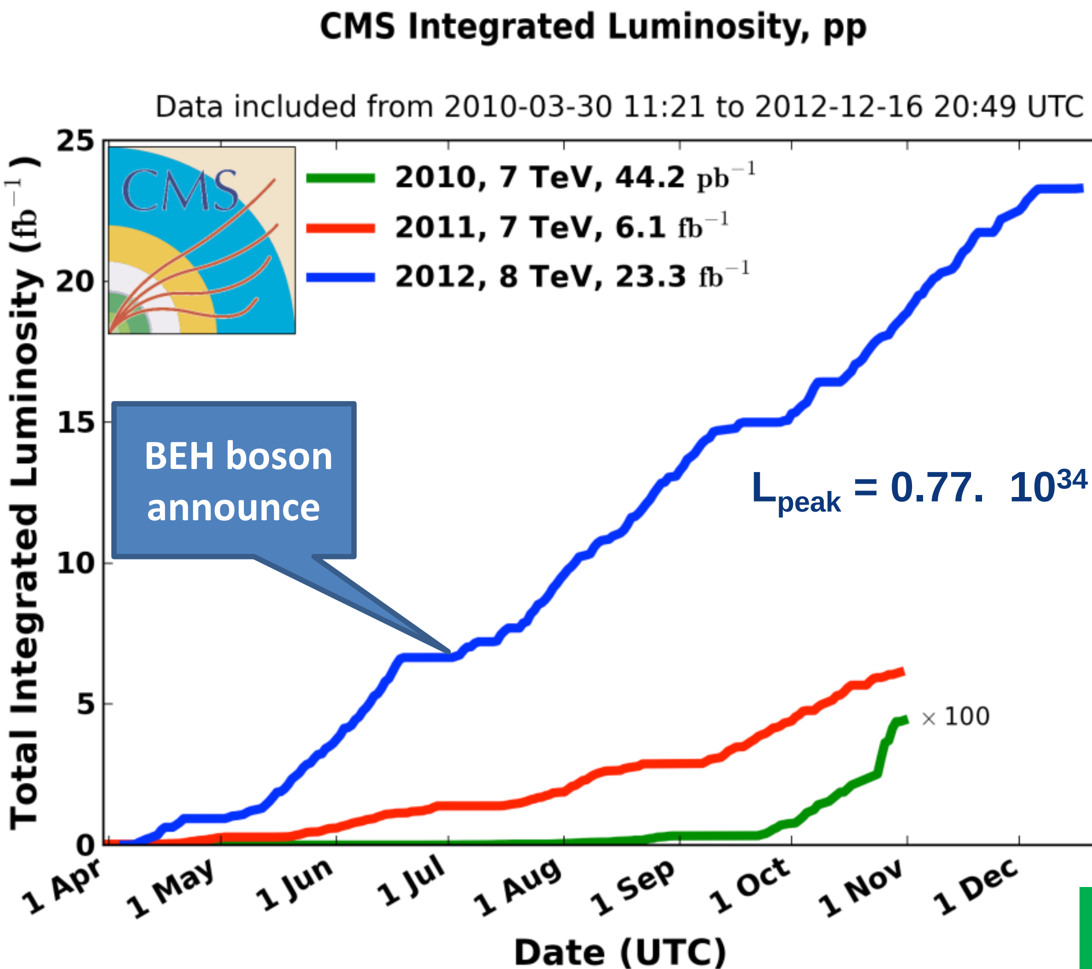


The 10 metre long prototype bending magnet for LHC, which has reached a field of 8,73 Tesla on 14 April 1994





2010-2012: LHC integrated luminosity



2010: **0.04 fb^{-1}**
7 TeV CoM
Commissioning

2011: **6.1 fb^{-1}**
7 TeV CoM
… exploring limits

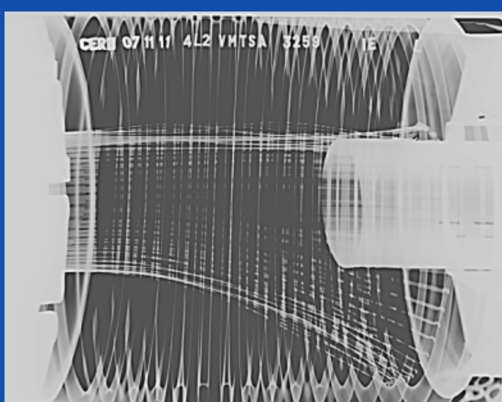
2012: **23.3 fb^{-1}**
8 TeV CoM
… production

3.5 TeV and 4 TeV in 2012
Up to 1380 bunches
with1.5 10^{11} protons

Some Limitations: cont'd

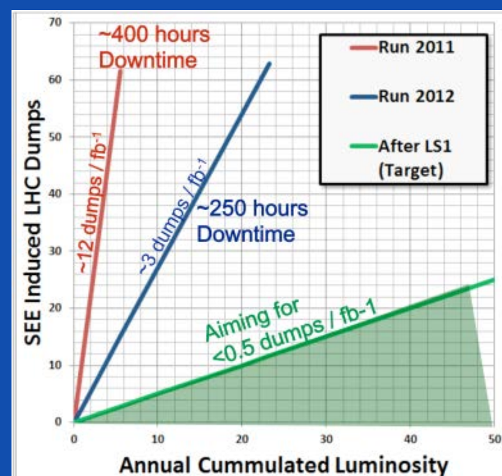
Beam induced heating

- Local non-conformities (design, installation)
  - Injection protection devices
  - Sync. Light mirrors
  - Vacuum assemblies



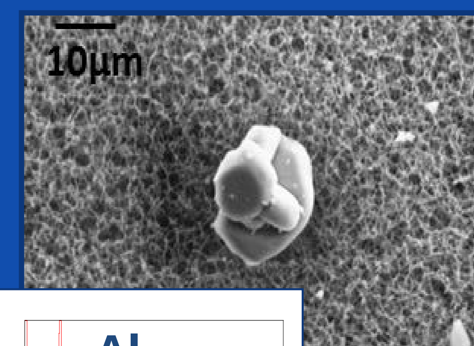
Radiation to electronics

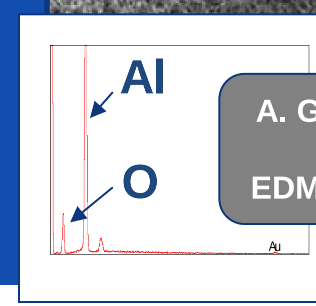
- Concerted program of mitigation measures (shielding, relocation…)
- Premature dump rate down from $12/fb^{-1}$ in 2011 to $3/fb^{-1}$ in 2012



UFOs

- 20 dumps in 2012
- Timescale 50-200 µs
- Conditioning observed
- Worry about 6.5 TeV

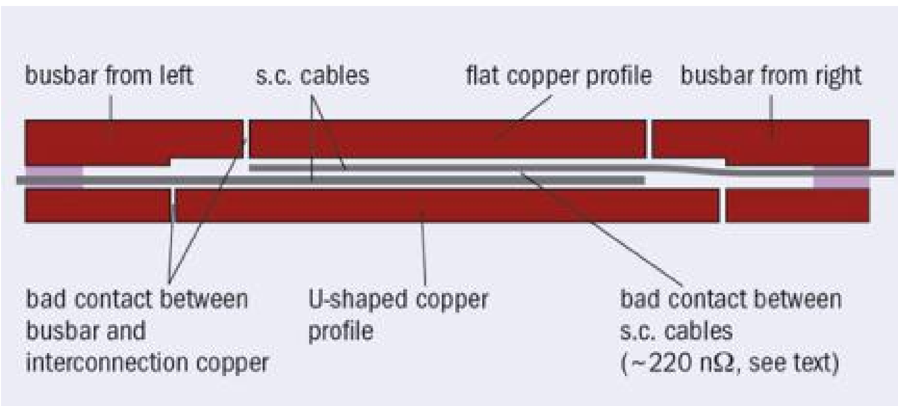




A. Gerardin, N. Garrel
EDMS: 1162034

Long Shutdown 1

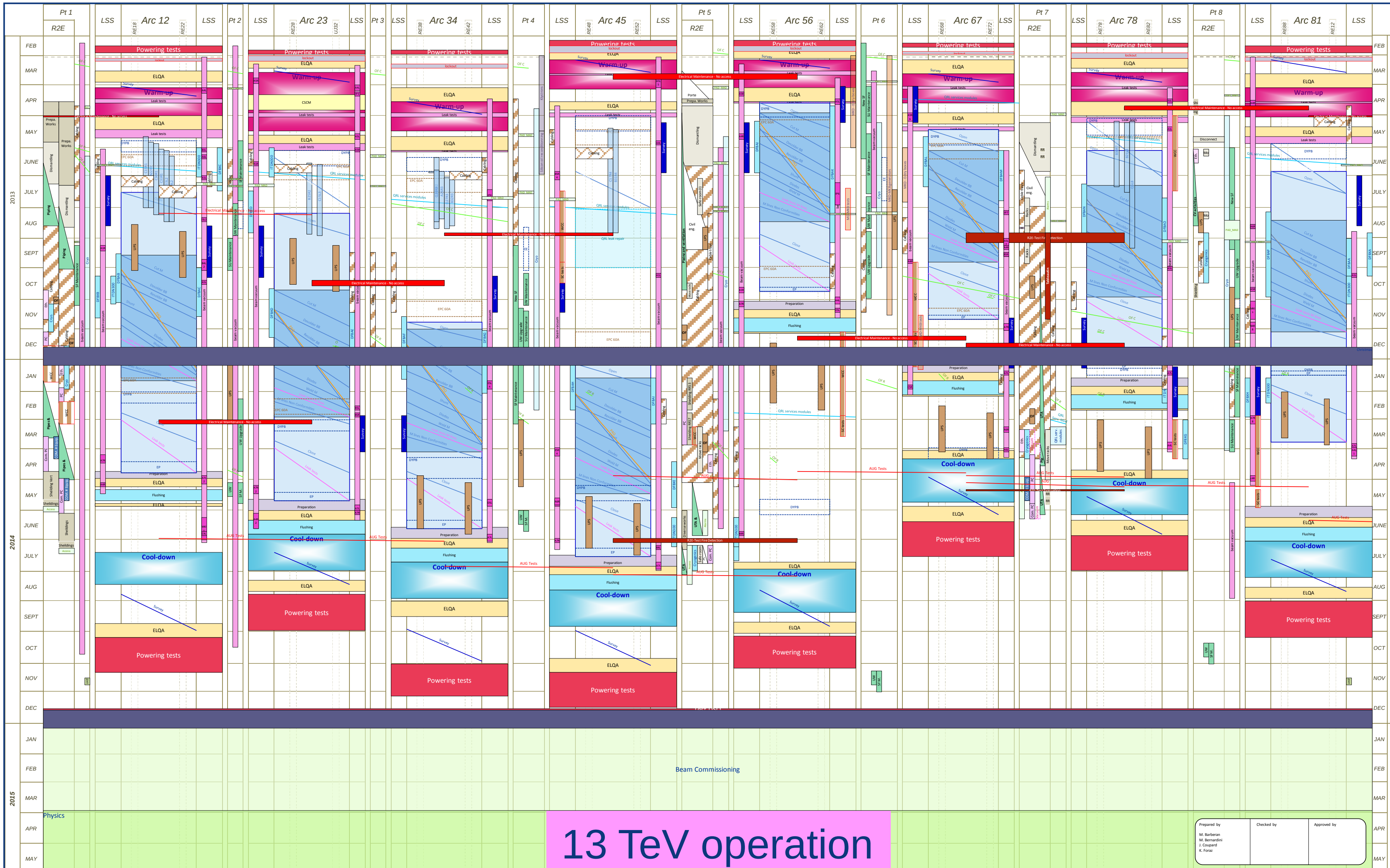
LS1 starts as the shutdown to repair the magnet interconnects to allow nominal current in the dipole and lattice quadrupole circuits of the LHC.



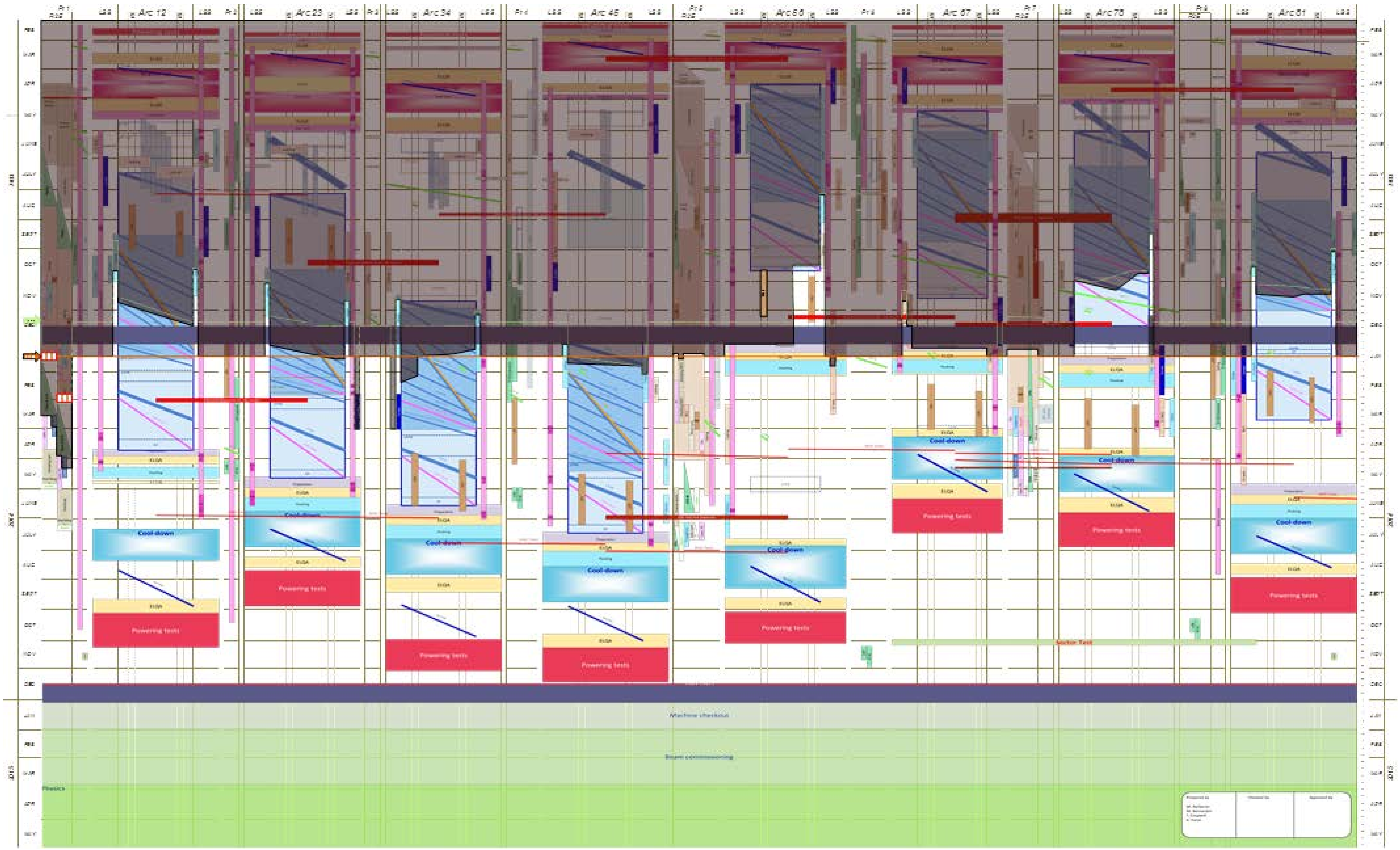
or shutdown which, in ... repairs, maintenance, ... nd cabling across the ... x and the associated experimental facilities.

All this in the shadow ... interconnects.

LS1: LHC schedule



So far, LS1 is on schedule for beams in January 2015 for LHC



http://cern.ch/ls1dashboard

The main 2013-14 LHC consolidations

Openings: 100 %

1695 Openings and final reclosures of the interconnections

Complete reconstruction of ~~1500~~ 3000 of these splices

80 % done

Consolidation of the 10170 13kA splices, installing 27 000 shunts

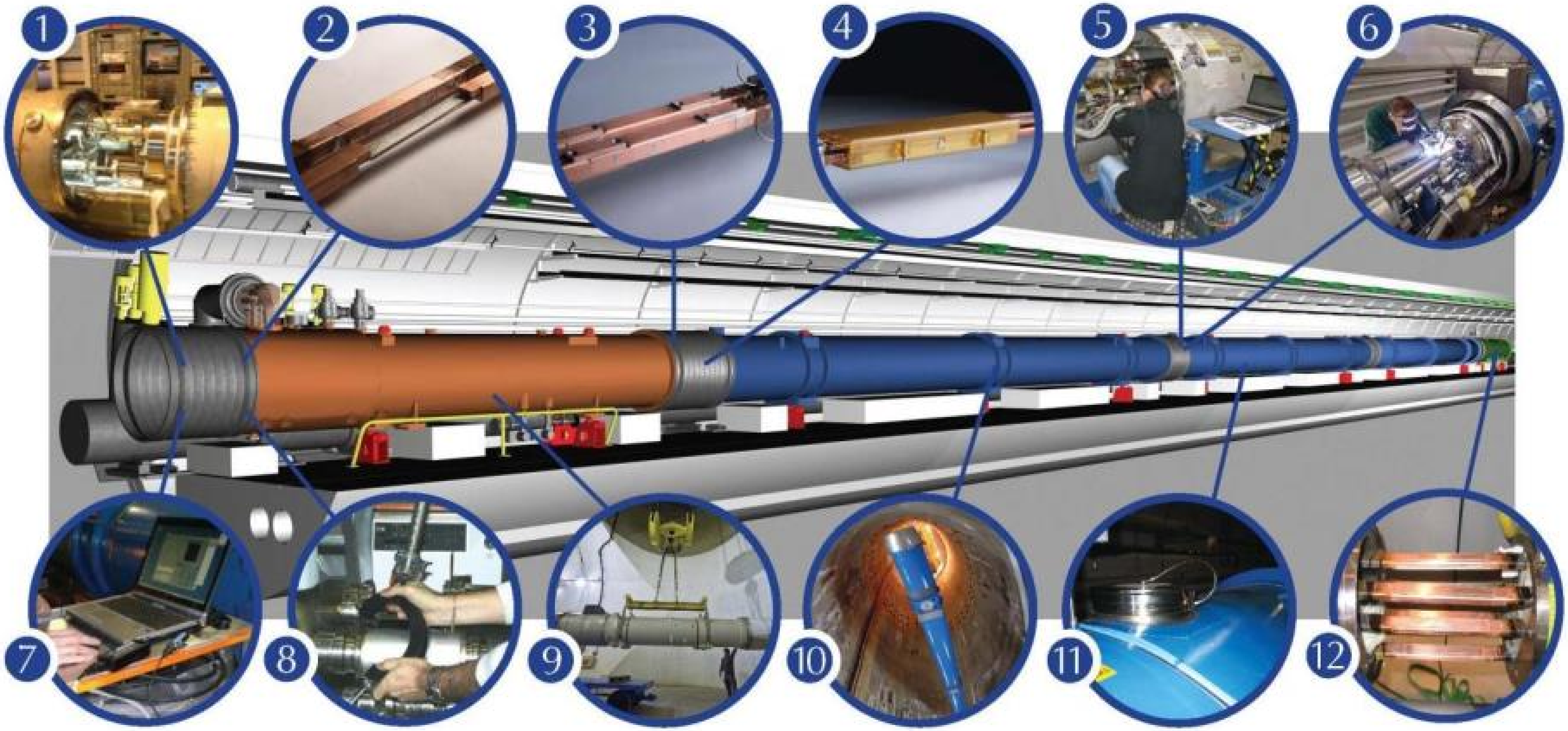
70 % done

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

50 % done

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

3 quadrupole magnets to be replaced

Done

15 dipole magnets to be replaced

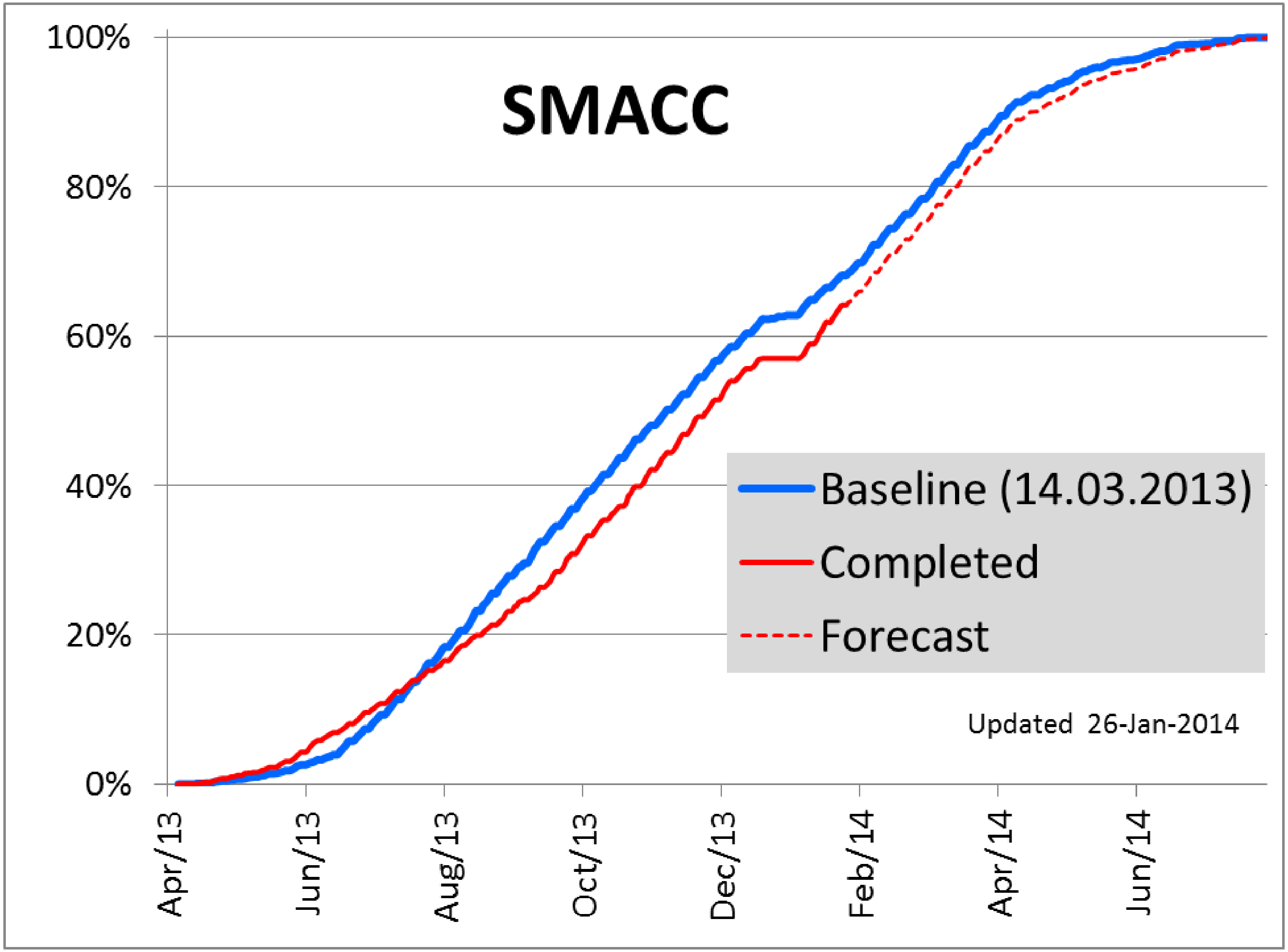
Done

Installation of 612 pressure relief devices to bring the total to 1344

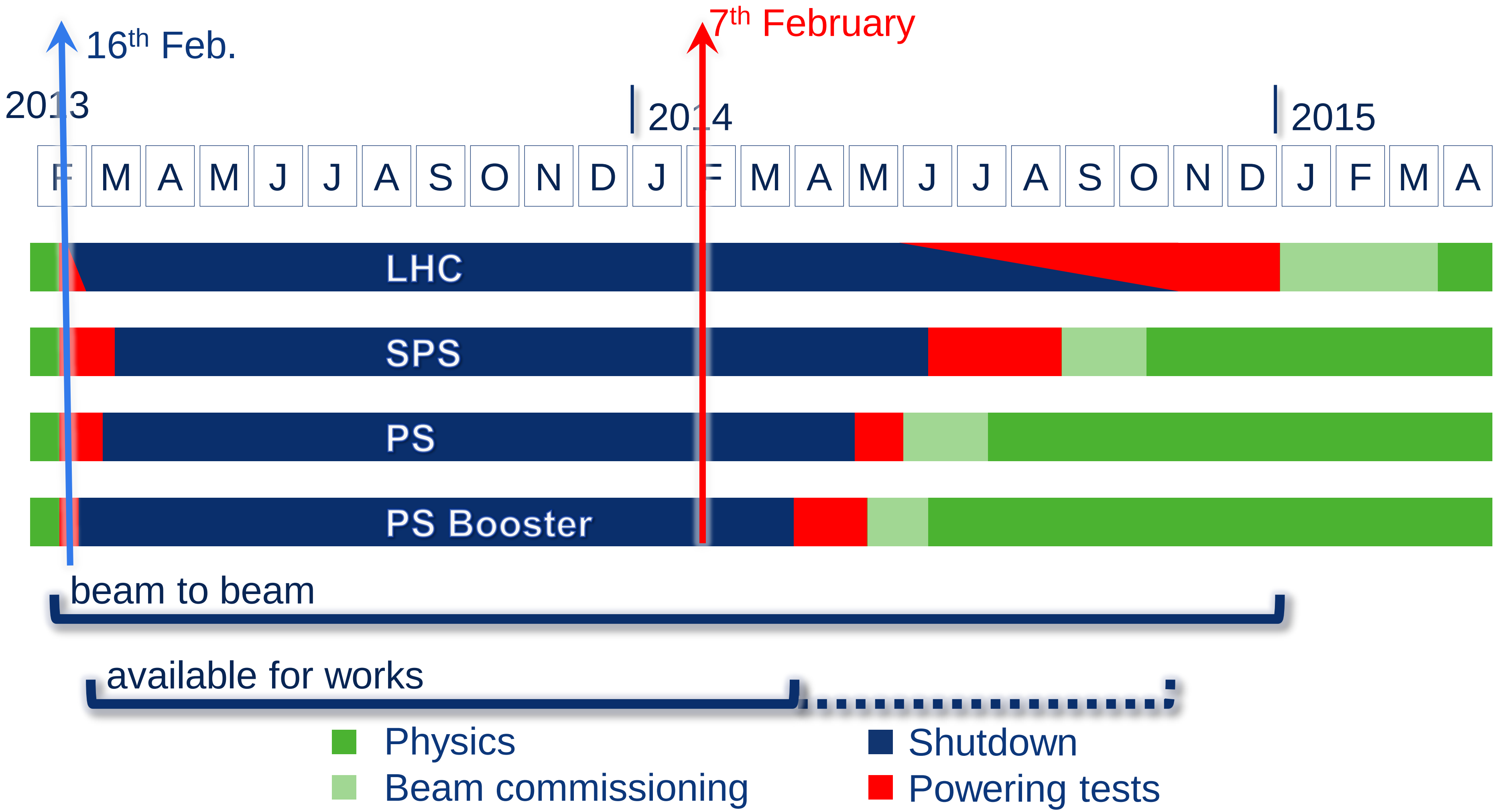
Done

Consolidation of the 13 kA circuits in the 16 main electrical feedboxes

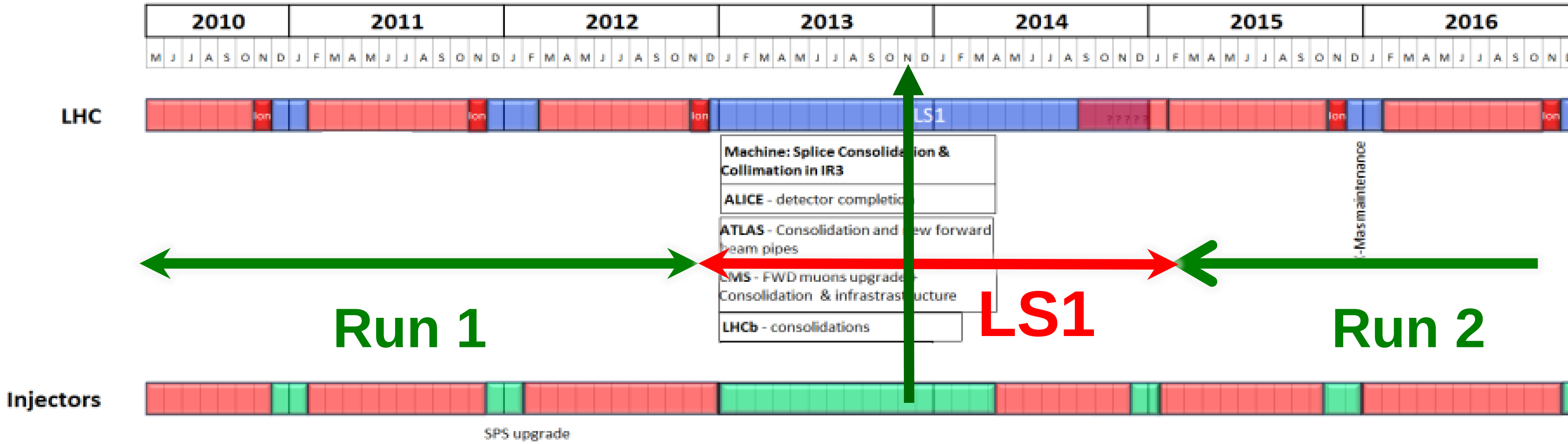
SMACC Dashboards

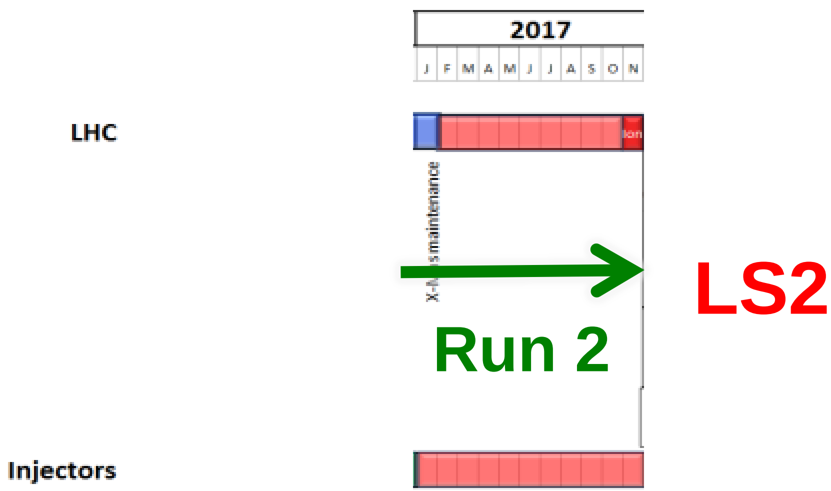


LS 1 from 16th Feb. 2013 to Dec. 2014



Run2: 3 years Operation Run after LS1





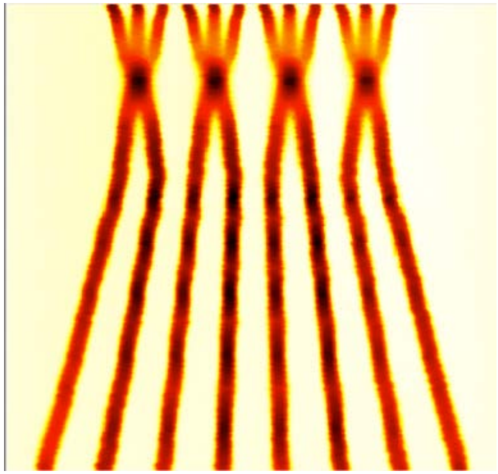
Run 2:
Start with 6.5 TeV and later decision towards 7 TeV according to magnet training

Expectations after Long Shutdown 1 (2015)

- Collisions at least at **13 TeV** c.m.
- **25 ns** bunch spacing

  Using new injector beam production scheme (BCMS), resulting in brighter beams.

Batch Compression and Merging and splitting (BCMS)

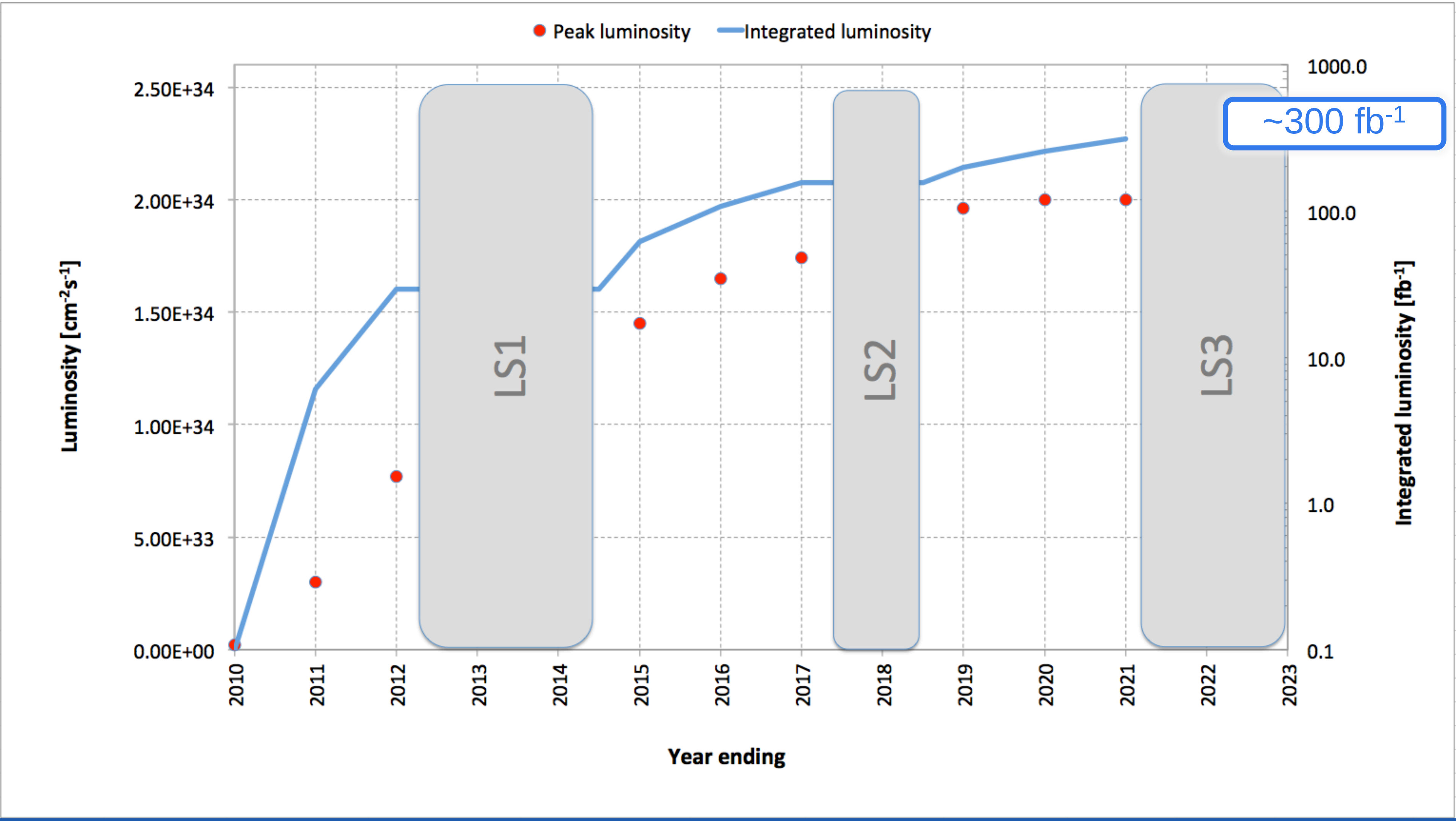


Courtesy of the LIU-PS project team

- **β^* ≤ 0.5m** (was 0.6 m in 2012)
- Other conditions:
  - Similar turn around time
  - Similar machine availability
- Expected maximum luminosity: **1.6×10^{34} cm^{-2} s^{-1}** ± 20%
  - Limited by inner triplet heat load limit, due to collisions debris

	Number of bunches	Intensity per bunch	Transverse emittance	Peak luminosity	Pile up	Int. yearly luminosity
25 ns BCMS	2508	1.15×10^{11}	1.9 µm	1.6×10^{34} cm^{-2}s^{-1}	~43	~42 fb^{-1}

“Baseline” luminosity (up to Nov. 2013)



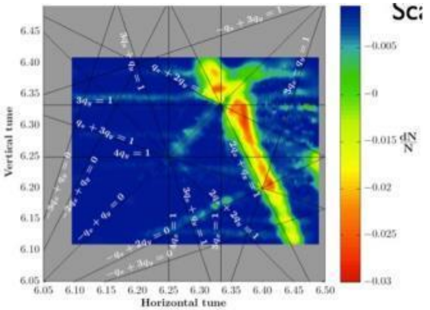
LS2 : (2018), LHC Injector Upgrades (LIU)

LINAC4 – PS Booster:

- H^- injection and increase of PSB injection energy from 50 MeV to 160 MeV, to increase PSB space charge threshold
- New RF cavity system, new main power converters
- Increase of extraction energy from 1.4 GeV to 2 GeV

PS:

- Increase of injection energy from 1.4 GeV to 2 GeV to increase PS space charge threshold
- Transverse resonance compensation
- New RF Longitudinal feedback system
- New RF beam manipulation scheme to increase beam brightness



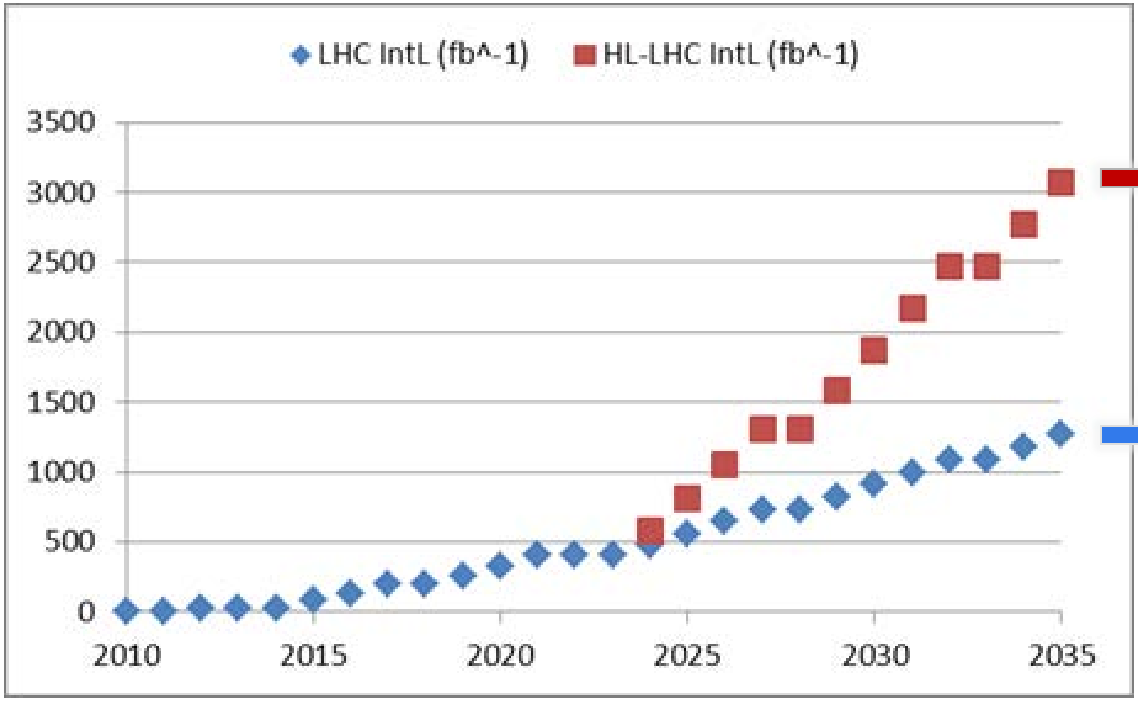
SPS

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

These are only the main modifications and this list is far from exhaustive

Project leadership: R. Garoby and M. Meddahi

Why High-Luminosity LHC ? (LS3)



By implementing HL-LHC

Almost a factor 3

By continuous performance improvement and consolidation

Around 300 fb^{-1} the present Inner Triplet magnets reach the end of their useful life (due to radiation damage) and must be replaced.

Goal of HL-LHC project:

- 250 – 300 fb^{-1} per year
- **3000 fb^{-1} in about 10 years**

The European Strategy for Particle Physics
Update 2013

c) *Europe's top priority should be the **exploitation of the full potential of the LHC**, including the high-luminosity upgrade of the machine and detectors with a view to collecting **ten times more data than in the initial design, by around 2030**. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

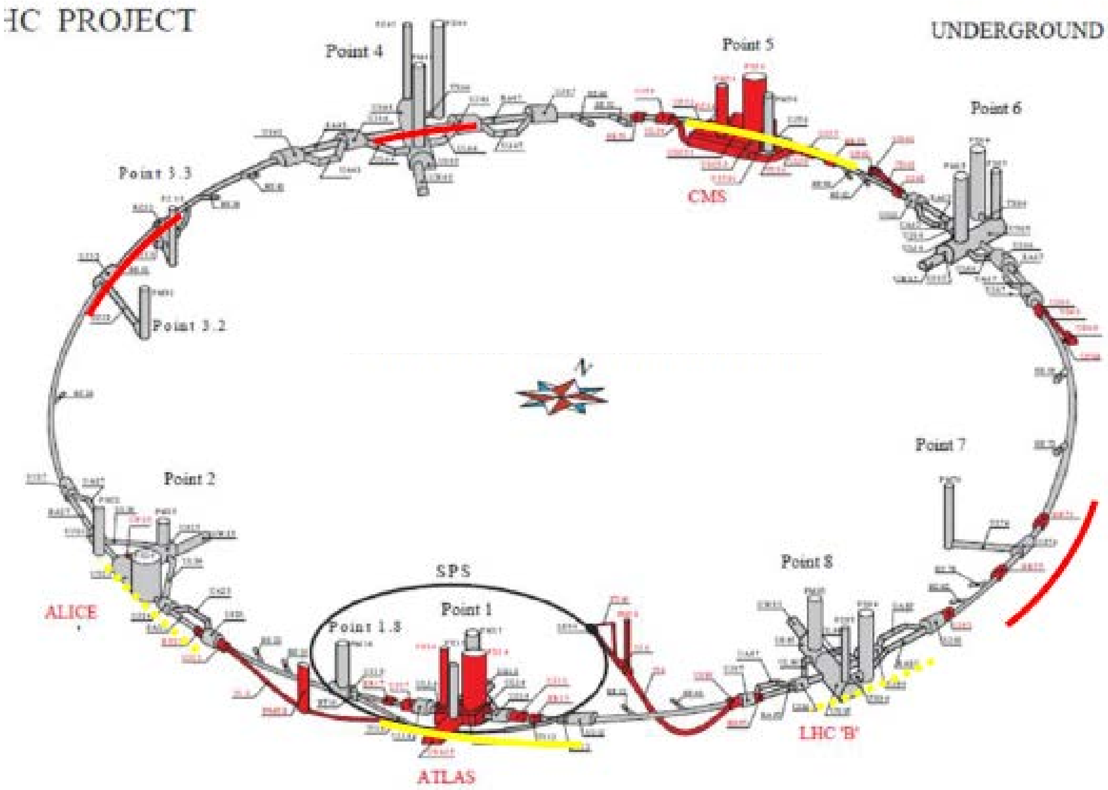
HL-LHC from a study to a PROJECT

$300\ fb^{-1} \rightarrow 3000\ fb^{-1}$

including LHC injectors upgrade **LIU**

(Linac 4, Booster 2GeV, PS and SPS upgrade)

The HL-LHC Project



- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- …

Major intervention on more than 1.2 km of the LHC

Project leadership: L. Rossi and O. Brüning

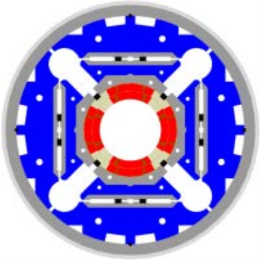
Squeezing the beams: High Field SC Magnets

Quads for the inner triplet

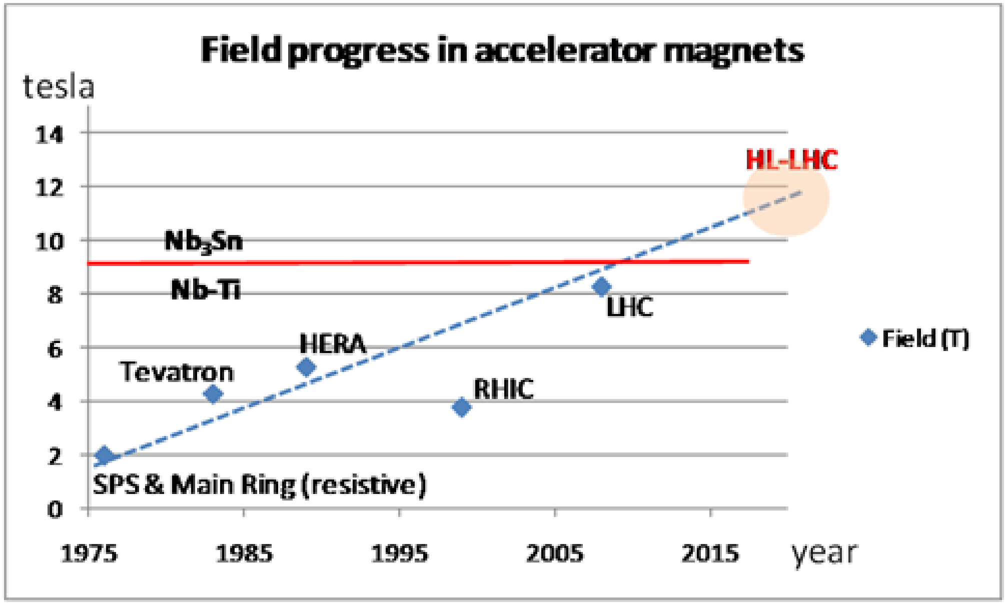
Decision 2012 for low-β quads

Aperture ∅ 150 mm – 140 T/m

(B_{peak} ≈12.3 T)



(LHC: 8 T, 70 mm)



More focus strength,

β* as low as 15 cm (55 cm in LHC)

thanks to ATS** (Achromatic Telescopic Squeeze) **optics

In some scheme even β down to 7.5 cm are considered*

- Dipoles for beam recombination/separation capable of 6-8 T with 150-180 mm aperture (LHC: 1.8 T, 70 mm)
- Dipoles 11 T for LS2 (see later)

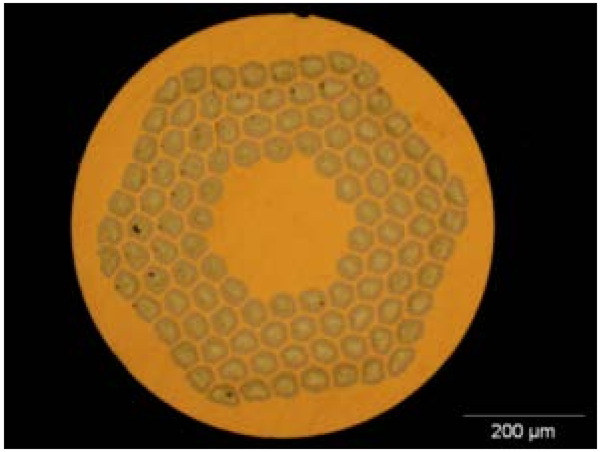
Courtesy Lucio Rossi

The « new » material : Nb_3Sn

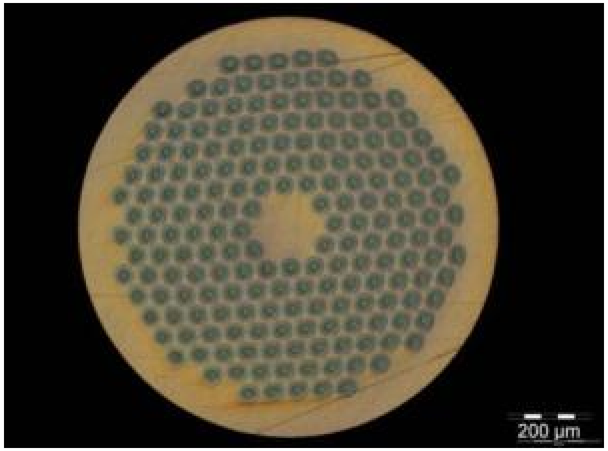
- Recent 23.4 T (1 GHz) NMR Magnet for spectroscopy in Nb_3Sn (and Nb-Ti).
- 15-20 tons/year for NMR and HF solenoids. Experimental MRI is taking off
- ITER: 500 tons in 2010-2015!

  It is comparable to LHC *(1200 tons of Nb-Ti but HL-LHC will require only 20 tons of* Nb_3Sn *)*

- HEP ITD (Internal Tin Diffusion):
  - High Jc., 3xJc ITER
  - Large filament (50 µm), large coupling current...
  - Cost is 5 times LHC Nb-Ti

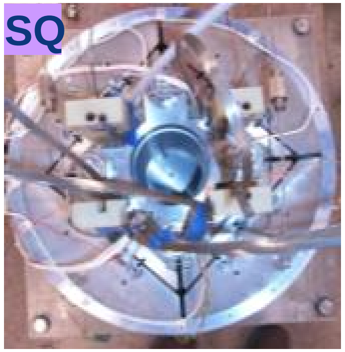


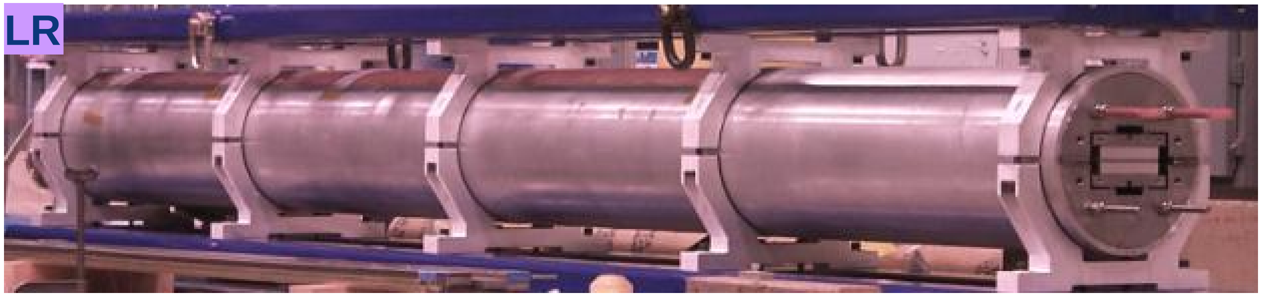
0.7 mm, 108/127 stack RRP from **Oxford OST**

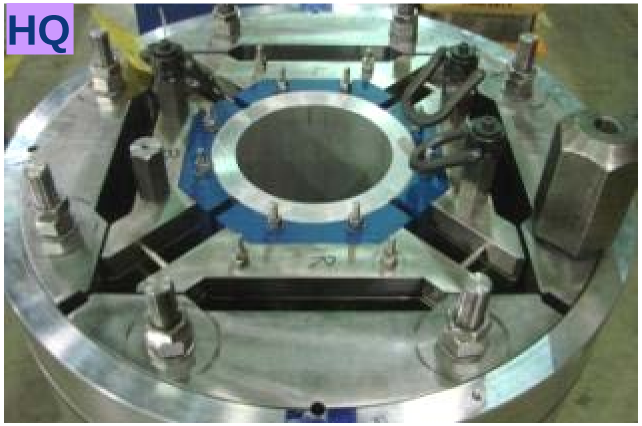


1 mm, 192 tubes PIT from **Bruker EAS**

LARP (US LHC program) Magnets



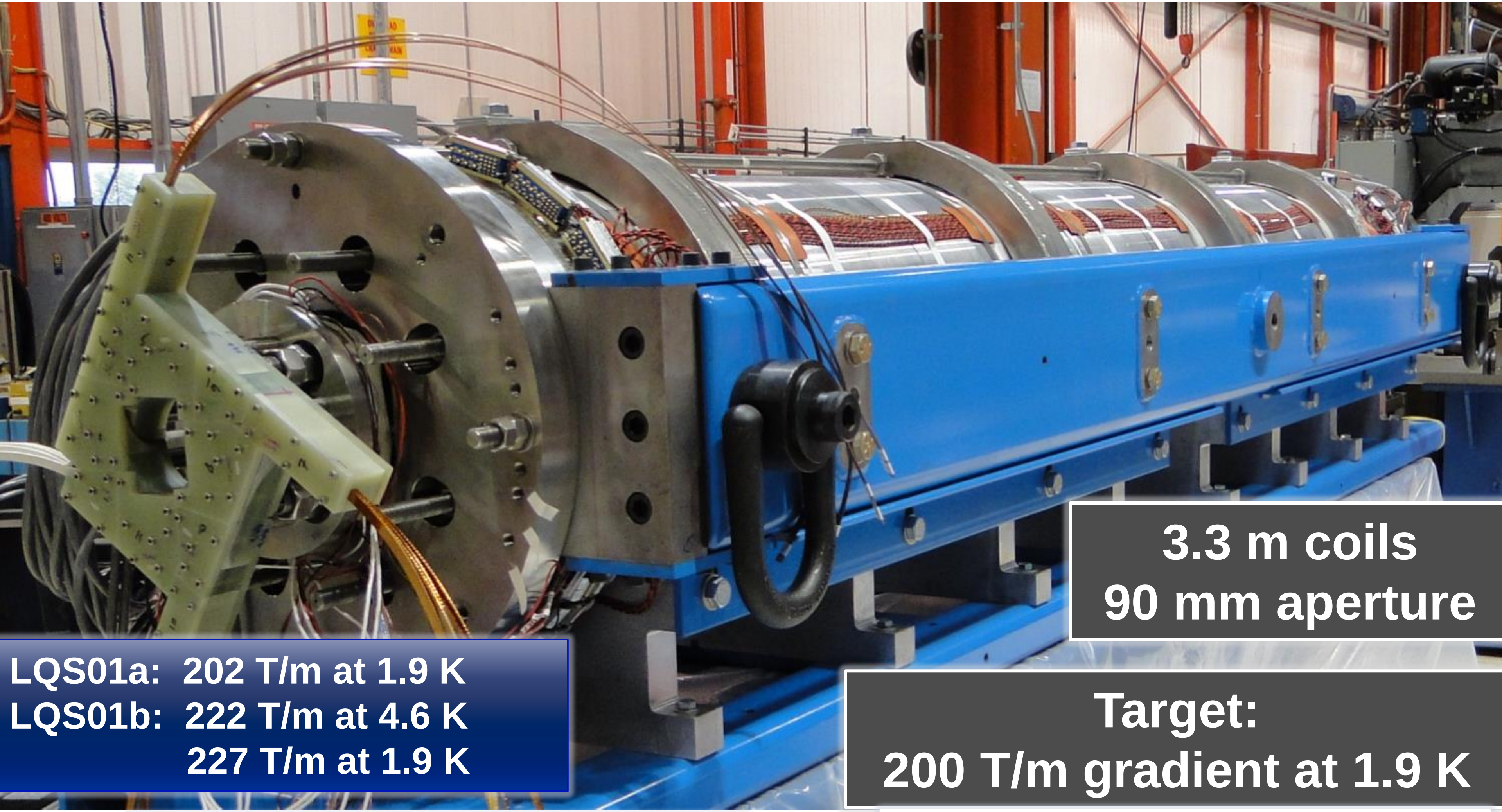




LQS of LARP

Courtesy: G. Ambrosio FNAL and G. Sabbi , LBNL

LARP



3.3 m coils
90 mm aperture

LQS01a: 202 T/m at 1.9 K
LQS01b: 222 T/m at 4.6 K
227 T/m at 1.9 K

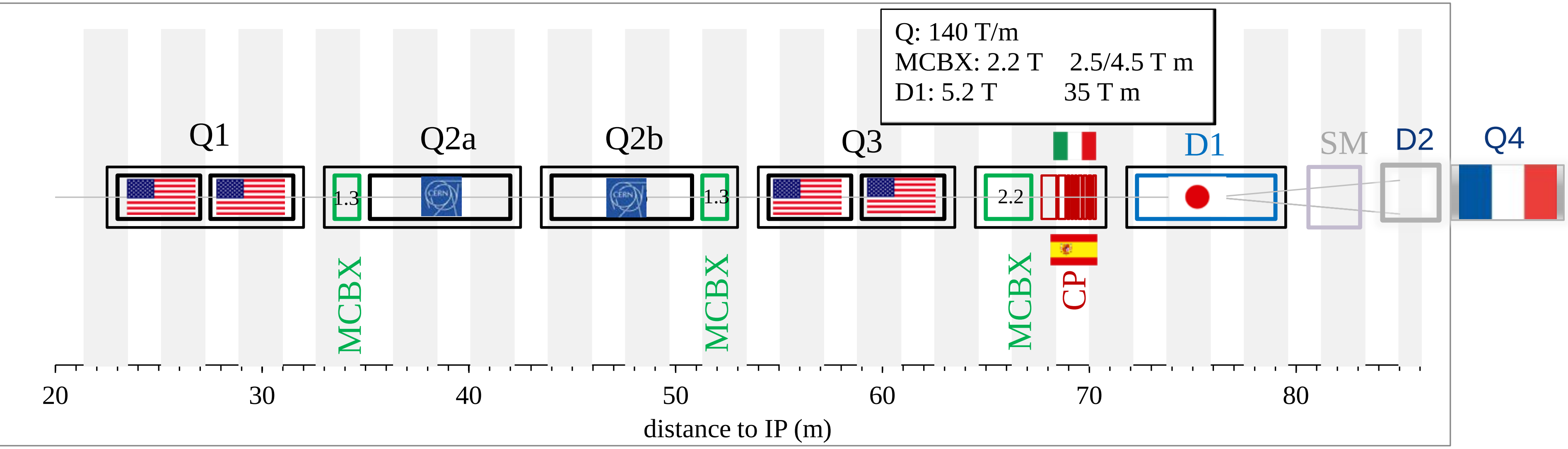
Target:
200 T/m gradient at 1.9 K

LQS02: 198 T/m at 4.6 K 150 A/s
208 T/m at 1.9 K 150 A/s
limited by one coil

LQS03: 208 T/m at 4.6 K
210 T/m at 1.9 K
1^{st} quench: 86% s.s. limit

Setting up International collaboration

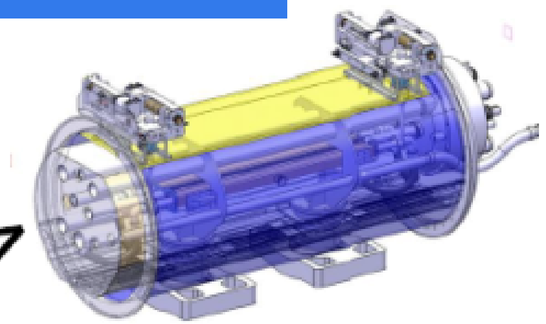
Baseline layout of HL-LHC IR region

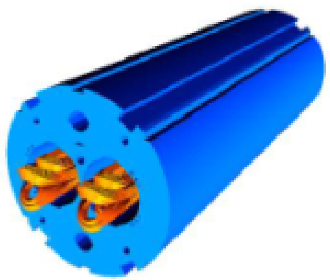


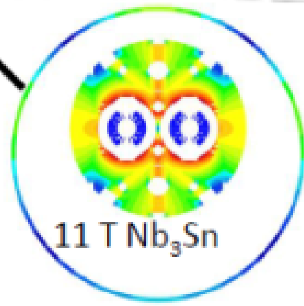
with national laboratories **but also involving industrial firms**

LS2 : collimators and 11T Dipole

- LS2 2017-18: Point-X,7 & IR-2
- LS3 2020+: IR1,5 as part of HL-LHC







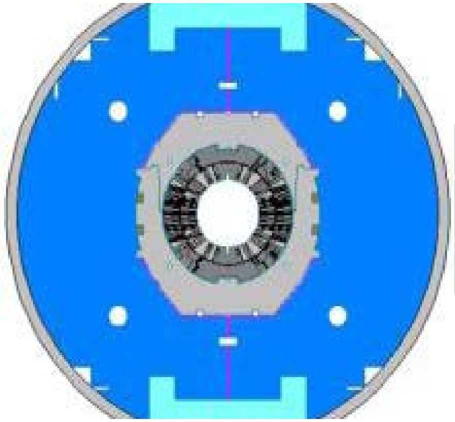
$\int BdL$ = 119.2 Tm @ I_{nom} = 11.85 kA
in series with MB with 20 % margin

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

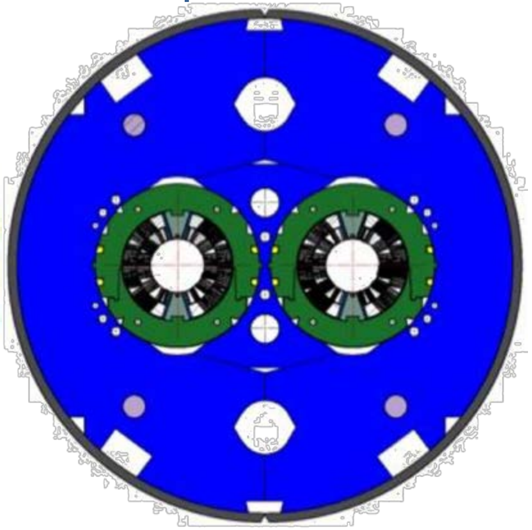
LS2: 24 coldmass + 4 spares = 28 CM
LS3: 16 coldmass + 4 spares = 20 CM
Total 48 CM

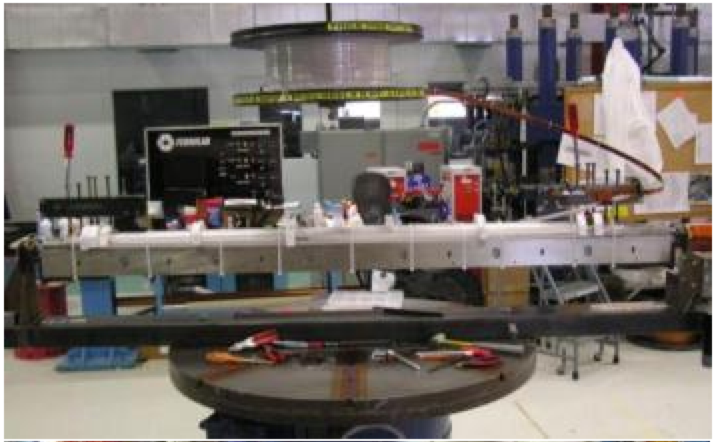
Nb_3Sn 11T Dipole R&D

Single aperture model



Twin aperture model

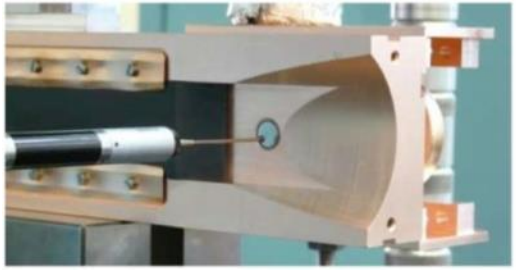




IR Collimation Upgrade

Update of present collimation system during LS1:

- Replace existing collimators
- Reduce setup time (gain of factor ~100)
- Improved monitoring



For HL-LHC add dispersion suppressor collimation

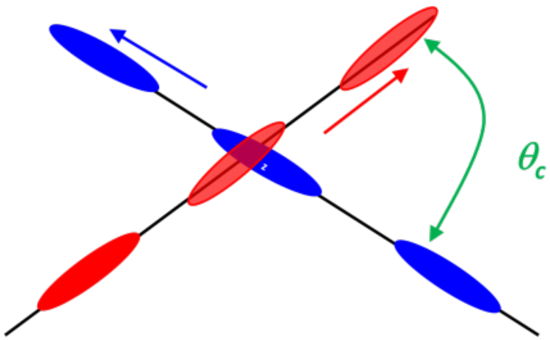
- Eliminate off-momentum particles in a region with high dispersion
- Technology of choice for the DS collimators is warm with by-pass cryostat
- **low impedance collimators: coating with Molybdenum**
- Design completed with 4.5 m integration length.
- Prototyping on-going

Crab Cavities, Increase “Head on”

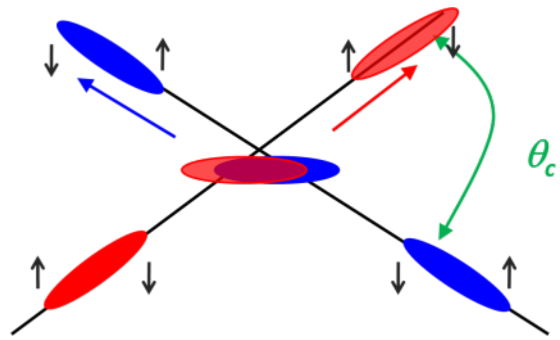
Aim: reduce the effect of the crossing angle

RF-Dipole Nb prototype

Without crabbing

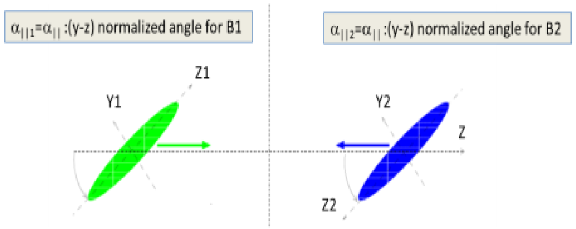


Without crabbing

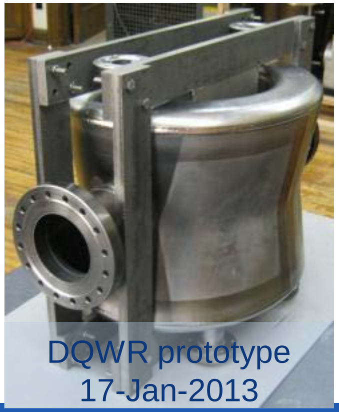


4-rod in SM18 for RF measurements

New crossing strategy under study to soften the pile-up density:
some new schemas have interesting potential as “crab-kissing”, to be discussed with all experiments
(“Pile-up at HL-LHC and possible mitigation” Stephane Fartoukh)



- 3 proto types available
- Cavity tests are on-going
- Test with beam in SPS foreseen in 2015-2016
- Beam test in LHC foreseen in 2017



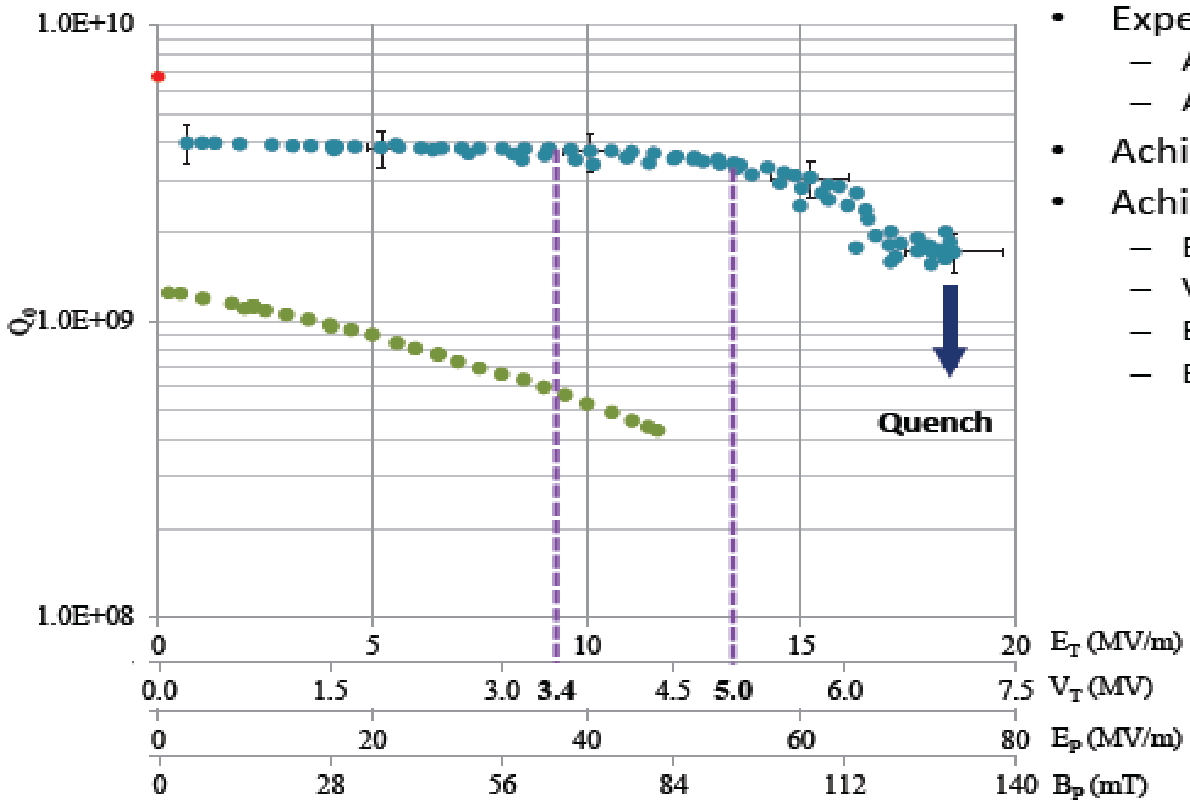
DQWR prototype
17-Jan-2013

First test of RF dipole (April 2013) (ODU-SLAC at J-LAB)

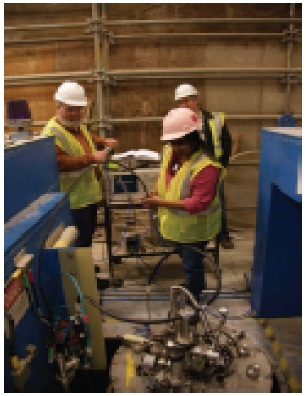
LARP

PoP RF Dipole 4.2 K and 2 K Test Results

High Luminosity LHC



- Expected $Q_0 = 6.7\times10^9$
  - At $R_S = 22\ n\Omega$
  - And $R_{res} = 20\ n\Omega$
- Achieved $Q_0 = 4.0\times10^9$
- Achieved fields
  - $E_T = 18.6$ MV/m
  - $V_T = 7.0$ MV
  - $E_P = 75$ MV/m
  - $B_P = 131$ mT



Jefferson Lab

Old Dominion University

Courtesy A. Ratti, LBL

Thinking to cryomodule…

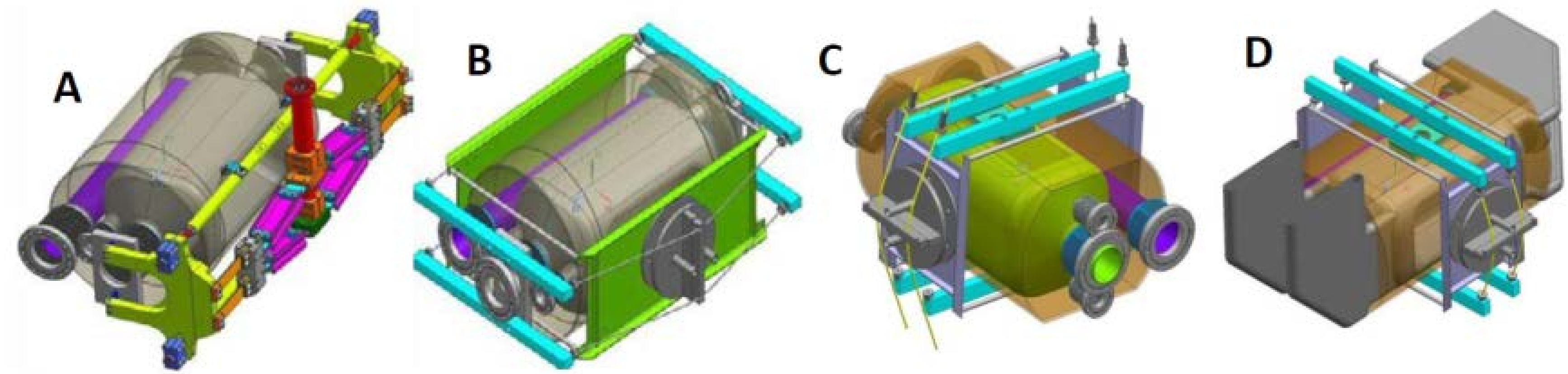
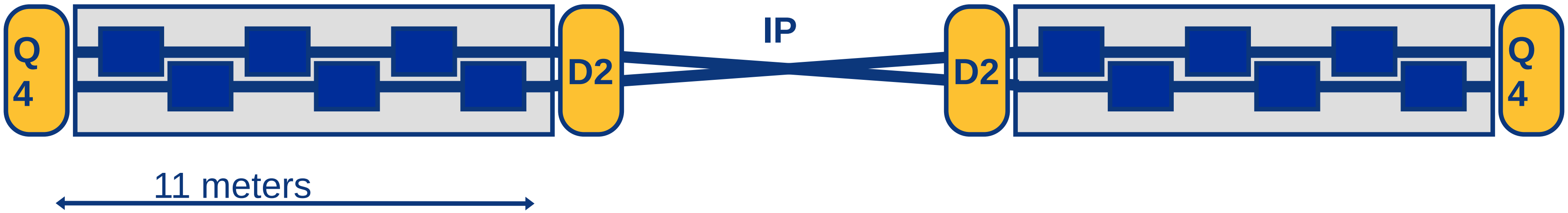
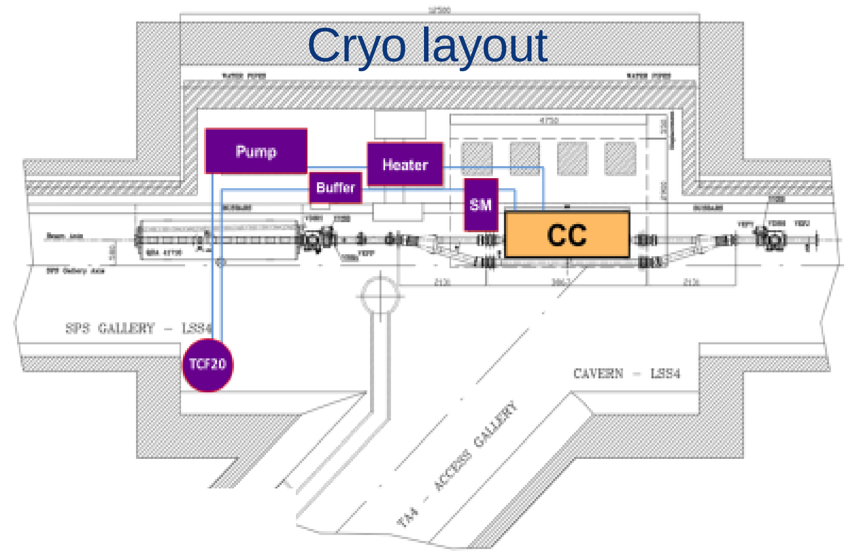


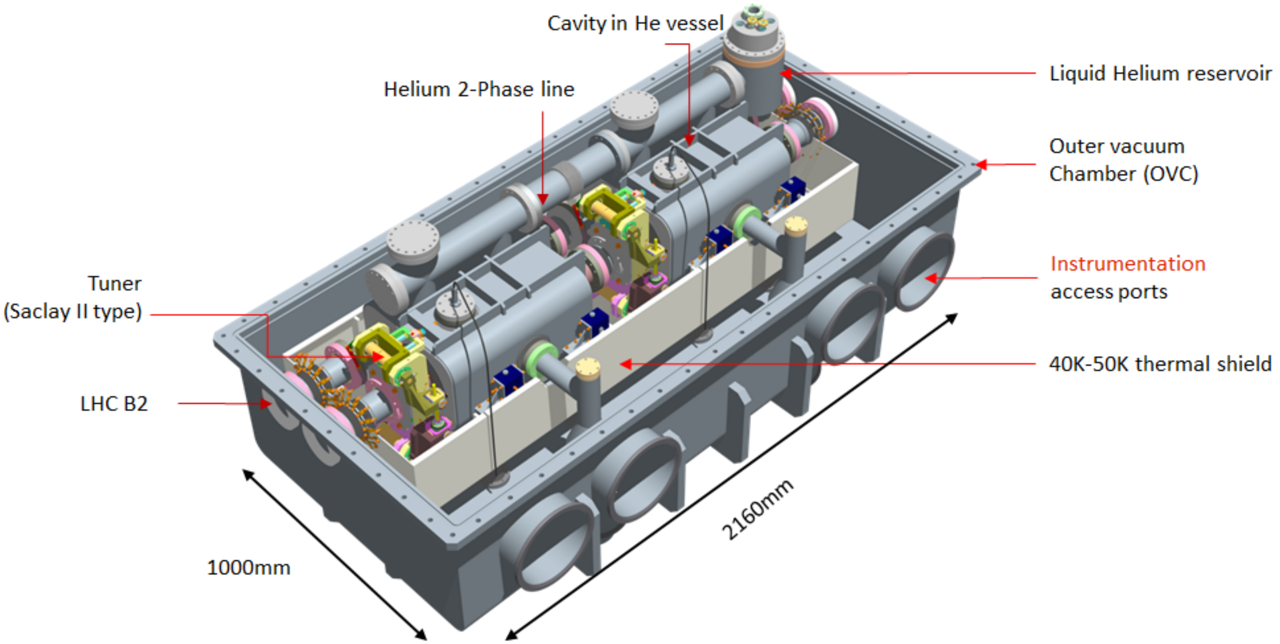
Figure 1: LHC crab cavity cryostat concept – A) JLab design, B) ANL design (helium pressure actuates bellows), C) ANL design (tuner deforms cavity outer surfaces), D) Waveguide



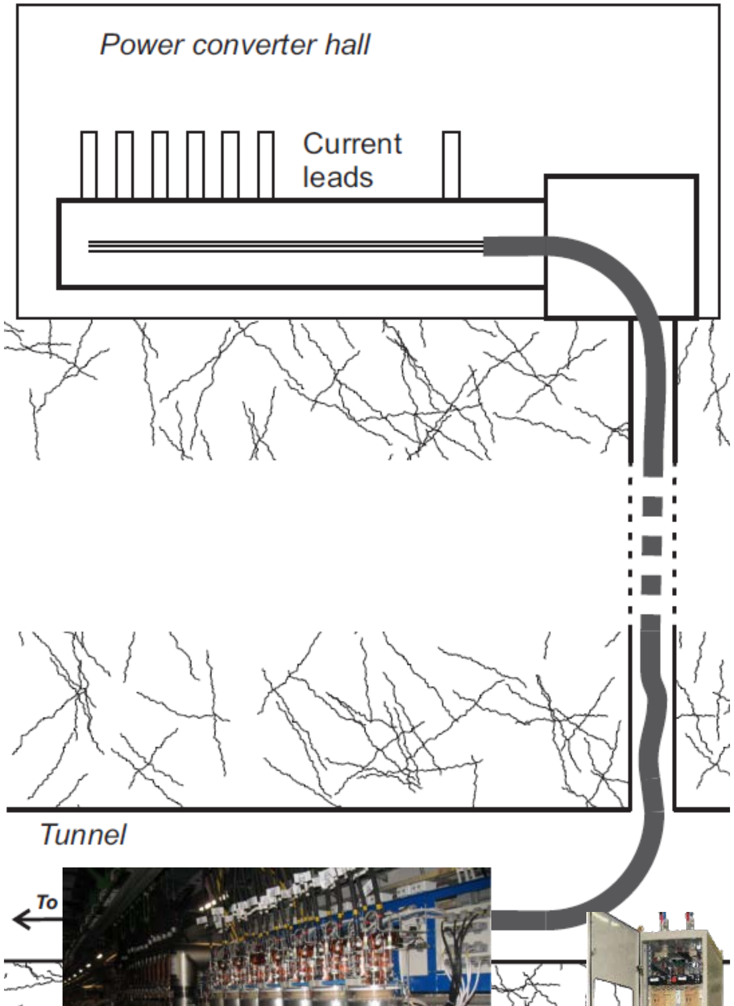
Courtesy Lucio Rossi

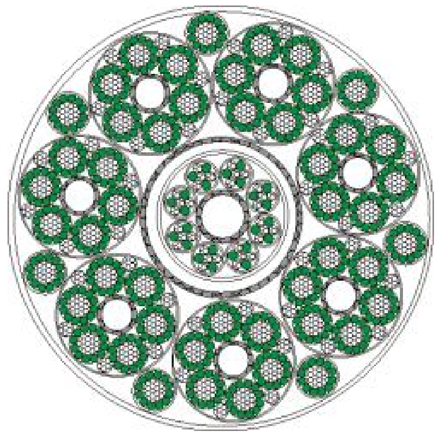
…and to test with beam in the CERN SPS (2016-2017)





R2E: Removal of Power Converter (200kA-5 kV SC cable, 100 m height)





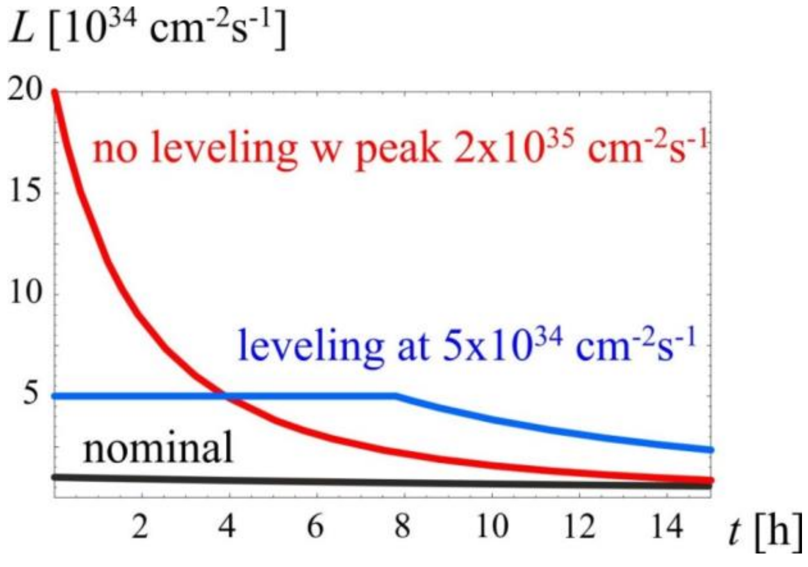
Φ = 62 mm

MgB_2
(or other HTS)

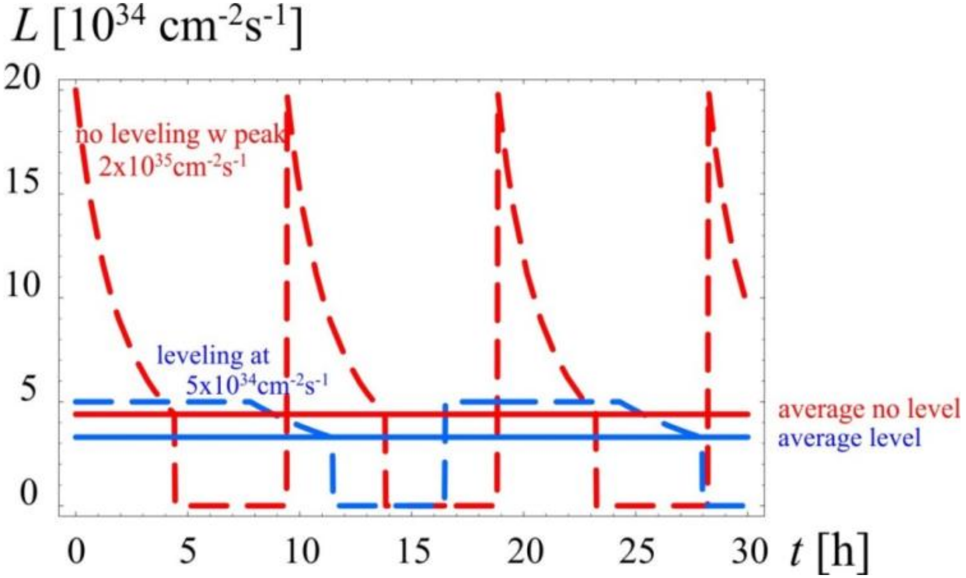
7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables – Itot~120 kA @ 30 K

Also DFBs (current lead boxes) removed to surface
Final solution to R2E problem – in some points
Make room for shielding un-movable electronics
Make the maintenance and application of ALARA principle much easier and effective

Luminosity Levelling, a key to success

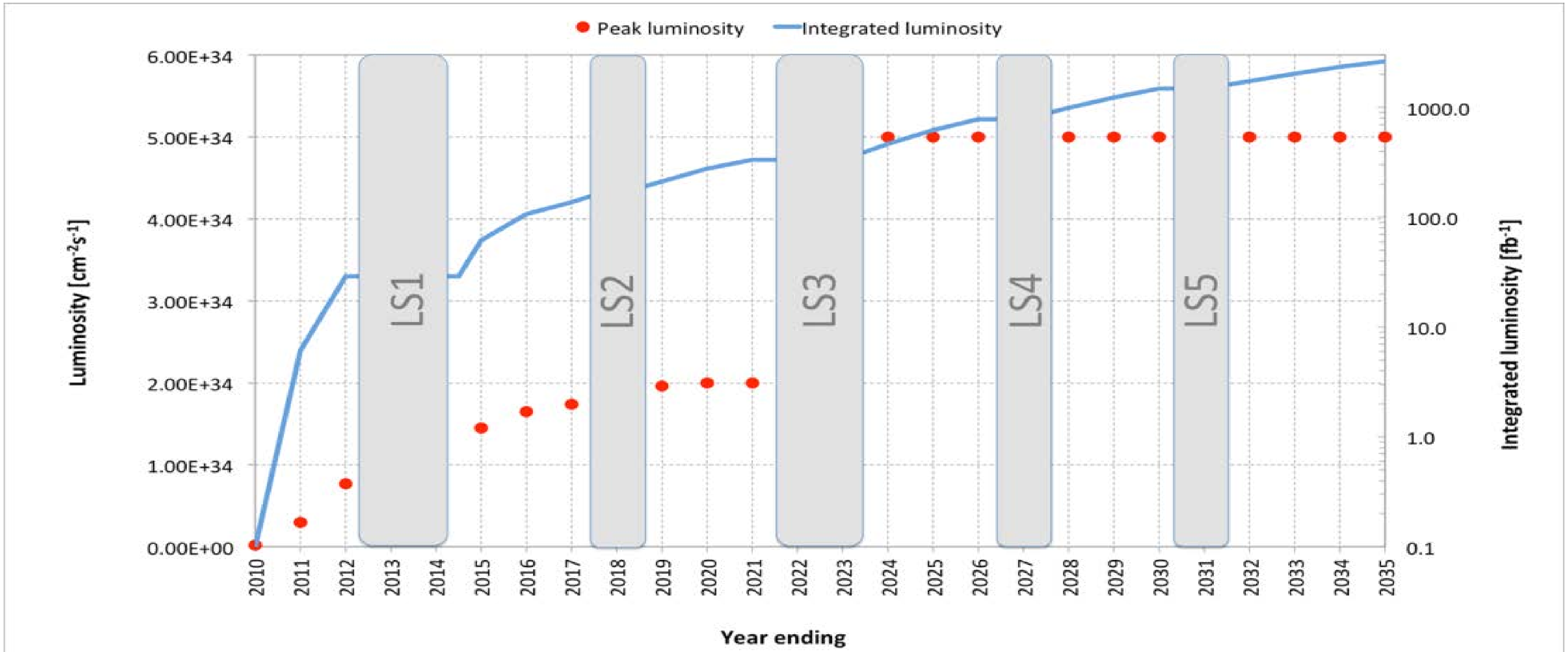


- High peak luminosity
- Minimize pile-up in experiments and provide "constant" luminosity



- Obtain about 3 - 4 fb^{-1}/day (40% stable beams)
- About 250 to 300 fb^{-1}/year

The plan of HL-LHC (baseline)

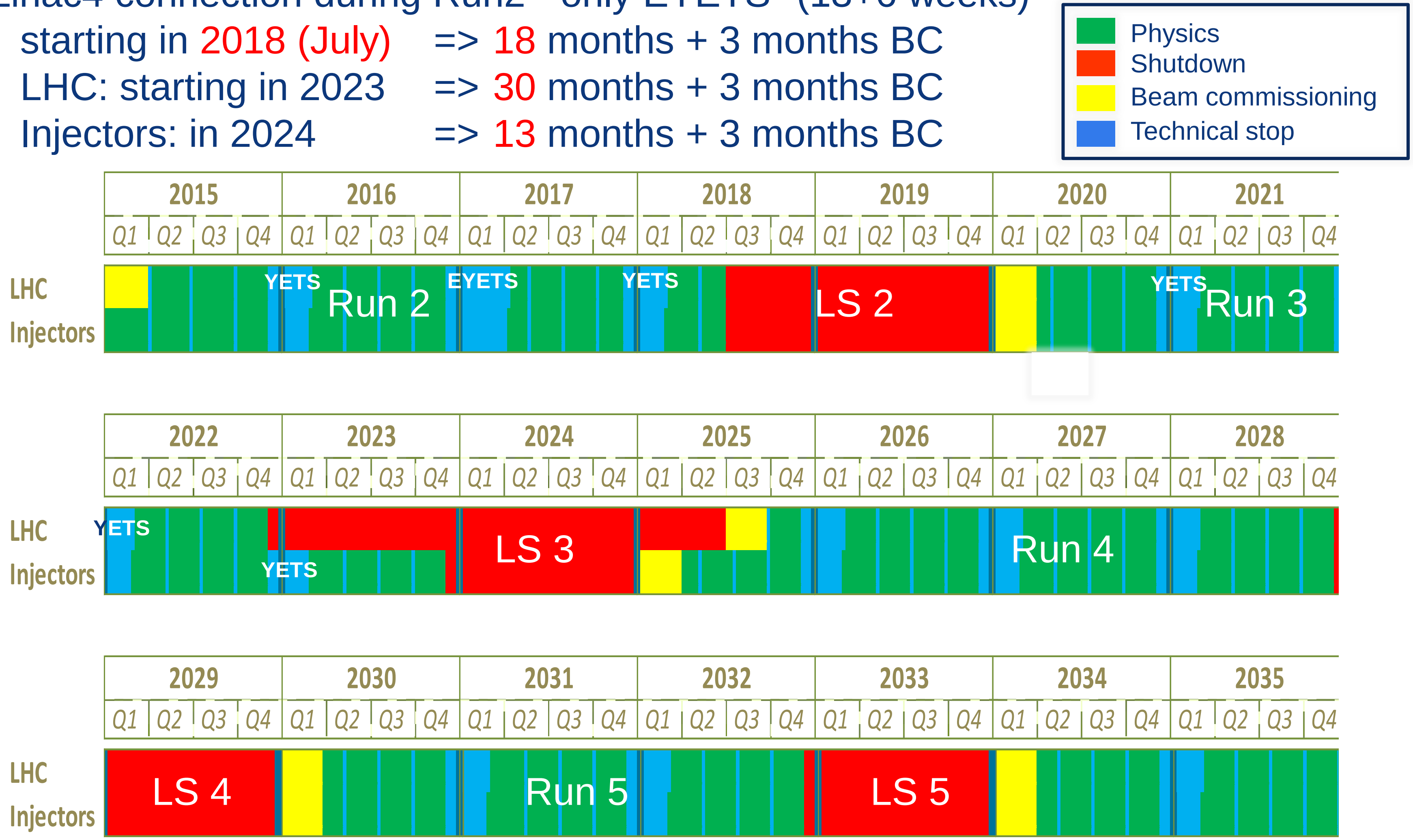


Levelling at 5 10^{34} cm^{-2} s^{-1}: 140 events/crossing in average, at 25 ns; several scenarios under study to limit to 1.0 → 1.3 event/mm

Total integrated luminosity of 3000 fb^{-1} for p-p by 2035, with LSs taken into account and 1 month for ion physics per year.

LHC schedule beyond LS1

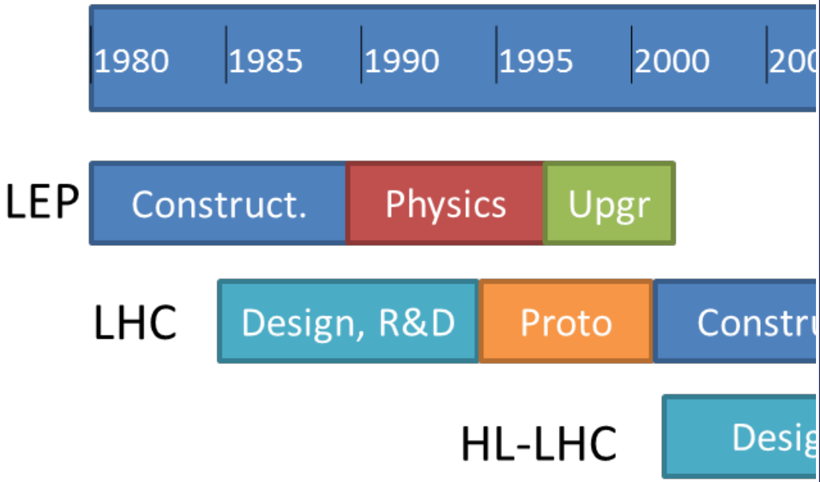
No Linac4 connection during Run2 - only EYETS* (13+6 weeks)
LS2 starting in 2018 (July) => 18 months + 3 months BC
LS3 LHC: starting in 2023 => 30 months + 3 months BC
Injectors: in 2024 => 13 months + 3 months BC



*) Extended Year End Technical Stop

LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

"…exploitation of the full pote
high-luminosity upgrade of th
=> High Lumi

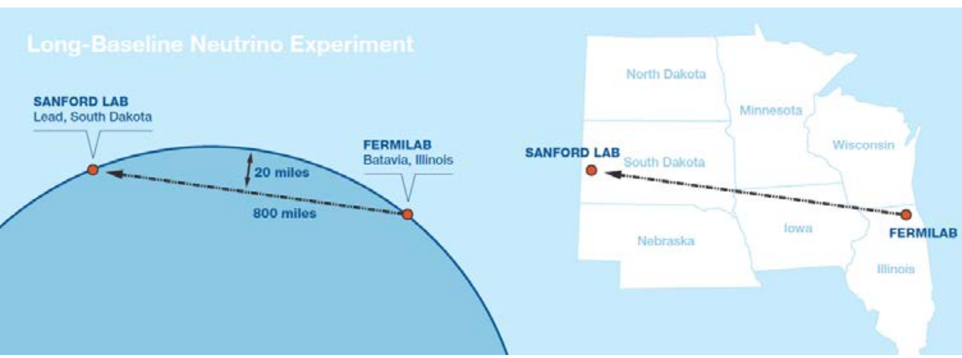


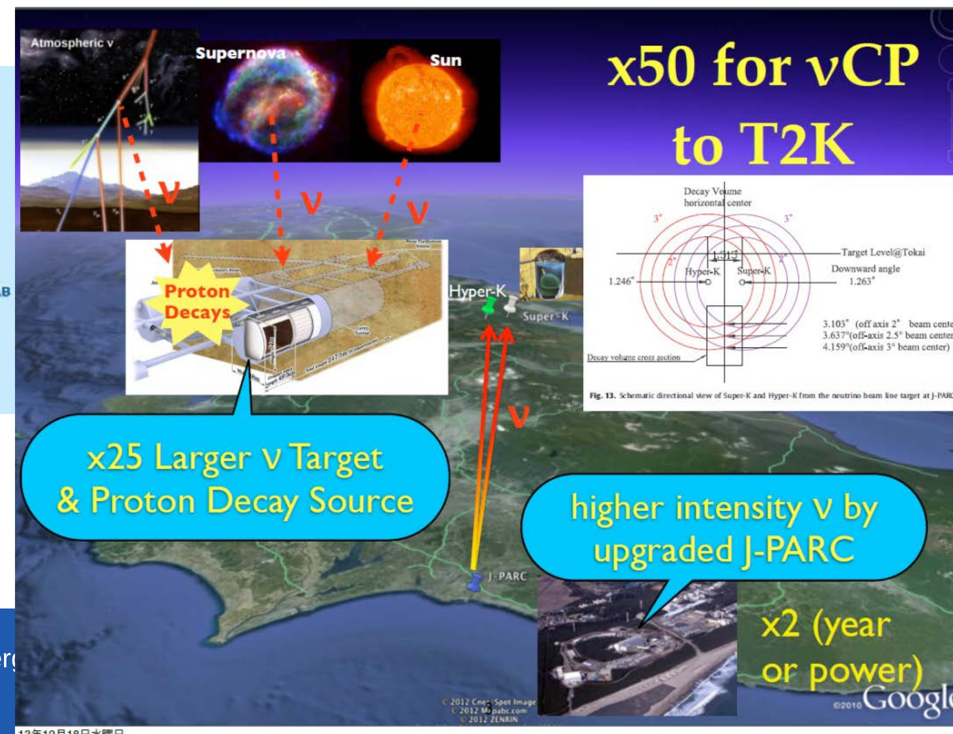
Kick-off meeting: 11th Nov. 2013 (Daresbury)

http://cern.ch/hilumilhc

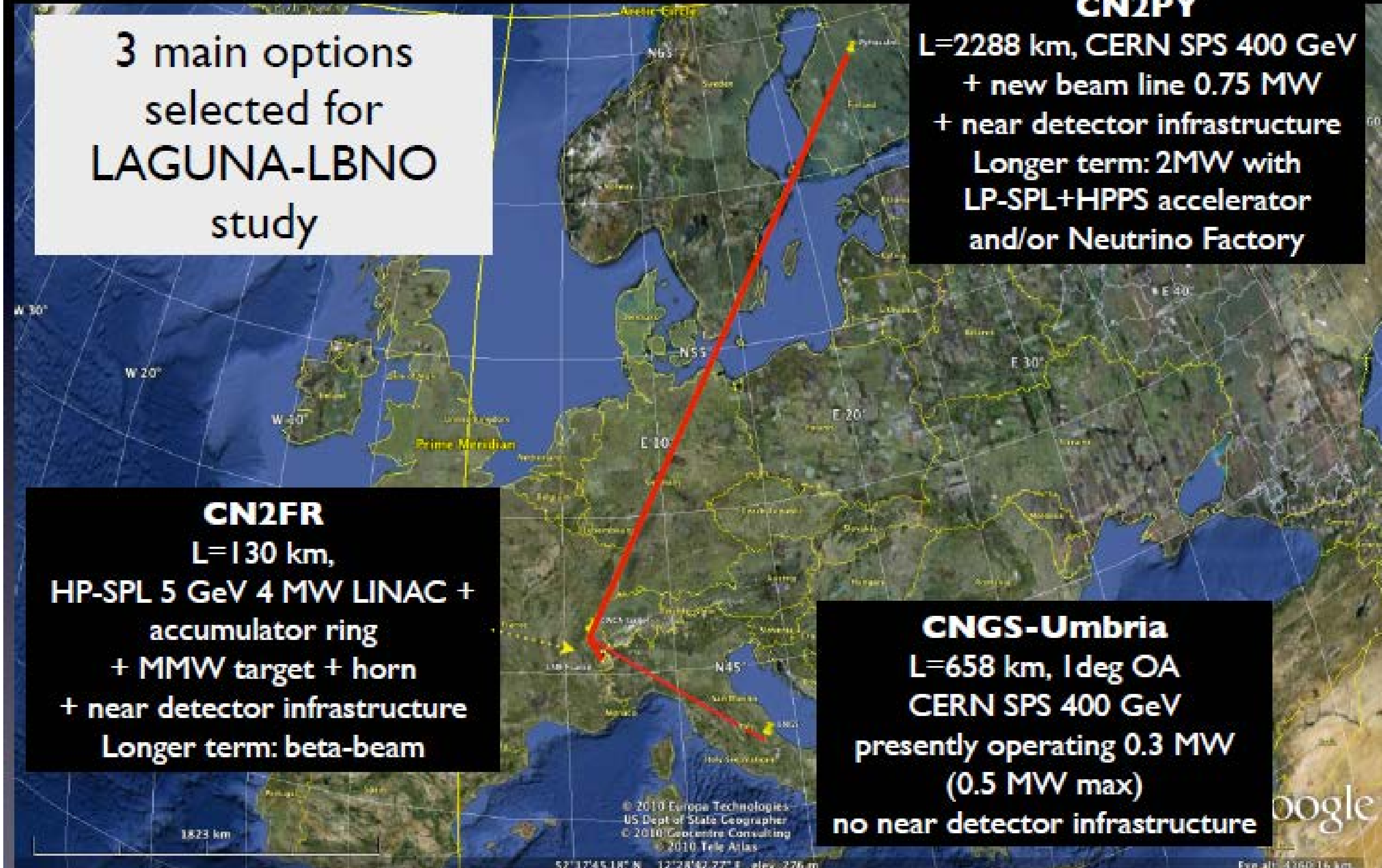
The European Strategy for Particle Physics Update 2013

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*

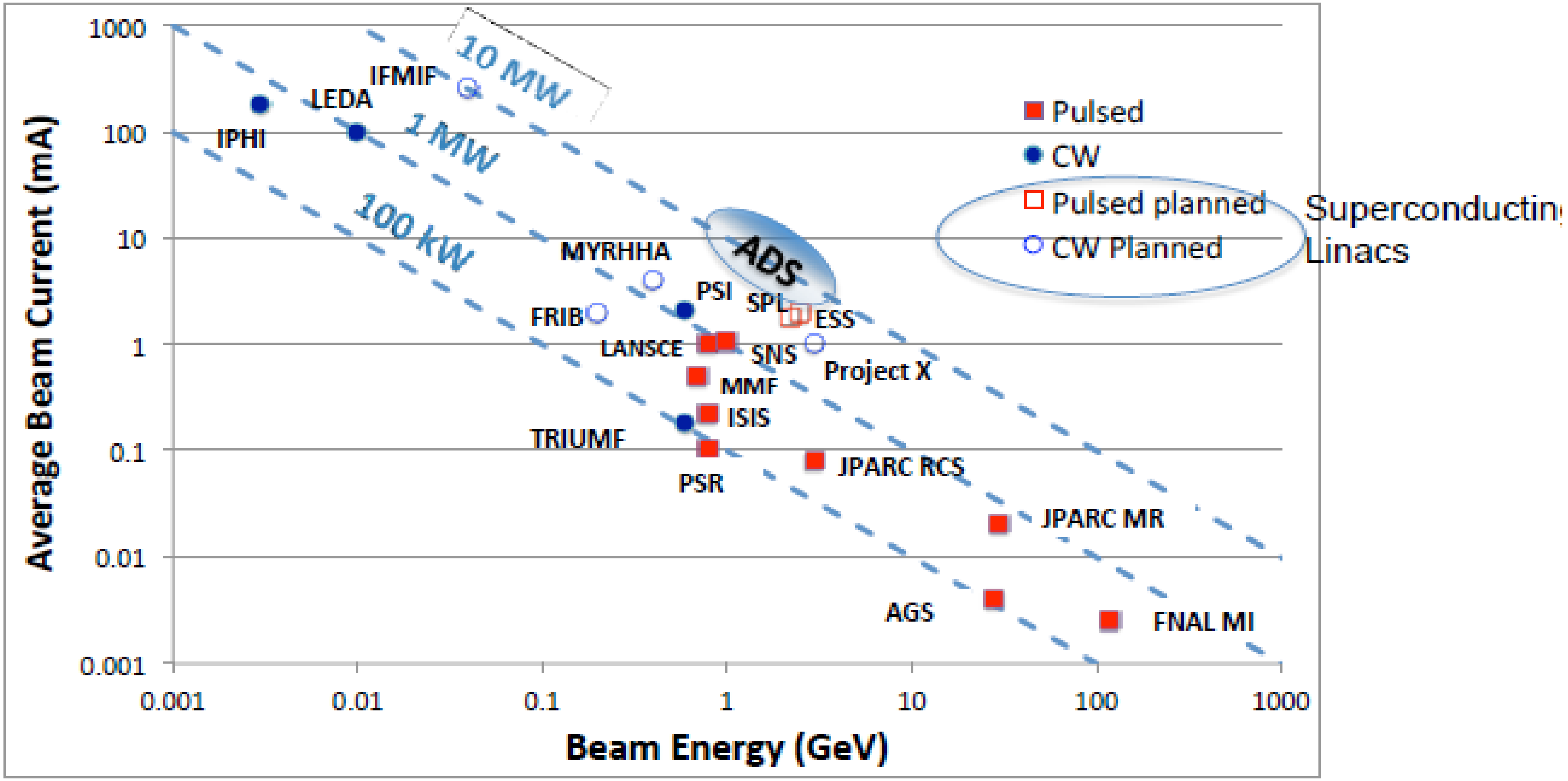




LAGUNA-LBNO study cases



High Power Accelerator History



- Relevant accelerators with ~ MW beam experience
  - PSI: 600 MeV cyclotron, 1.3 MW
  - SNS 925 MeV superconducting linac , 1 MW

The European Strategy for Particle Physics Update 2013

e) There is a strong scientific case for an **electron-positron collider**, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded.

The **Technical Design Report of the International Linear Collider (ILC)** has been completed, with large European participation. **The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate.**

Europe looks forward to a proposal from Japan to discuss a possible participation.

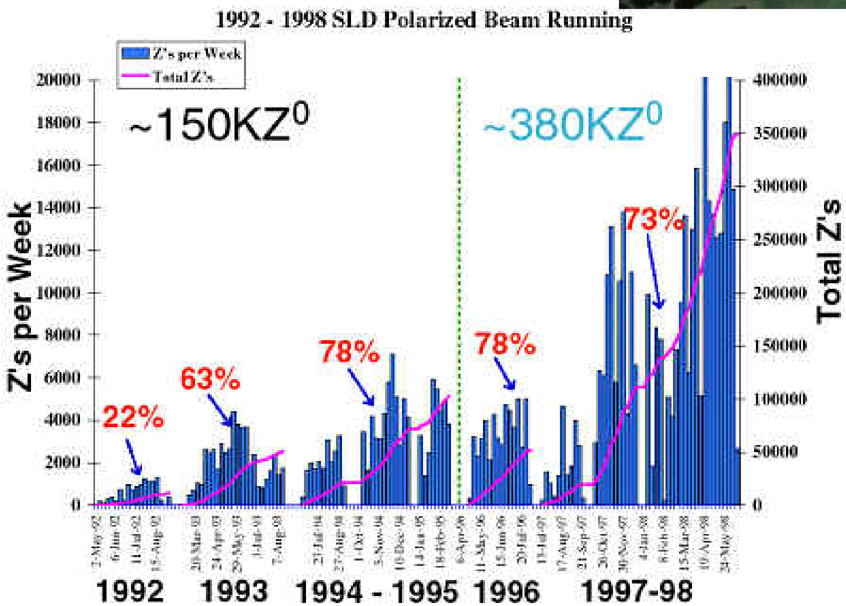
The real Beginning was *at SLAC*

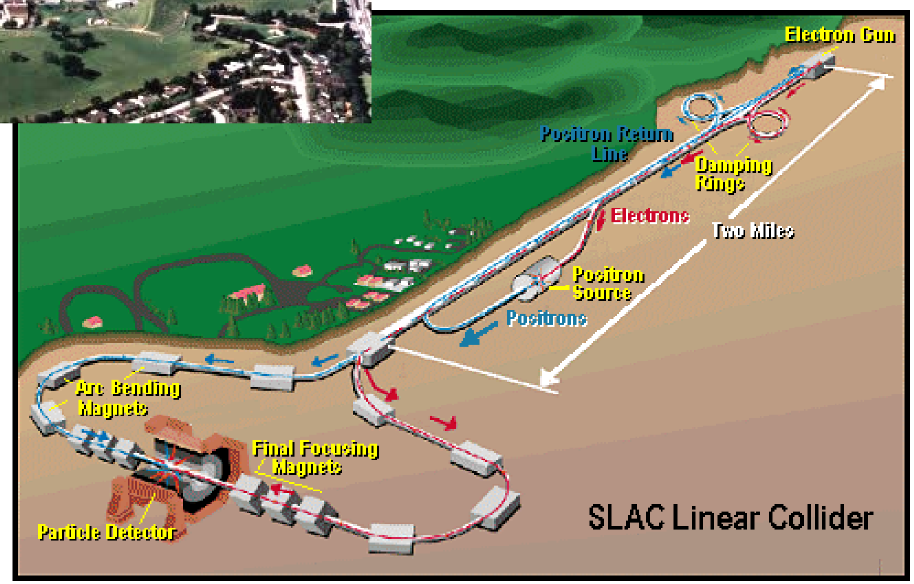
Burt Richter

SLAC Linear Collider (SLC)

1988-1998

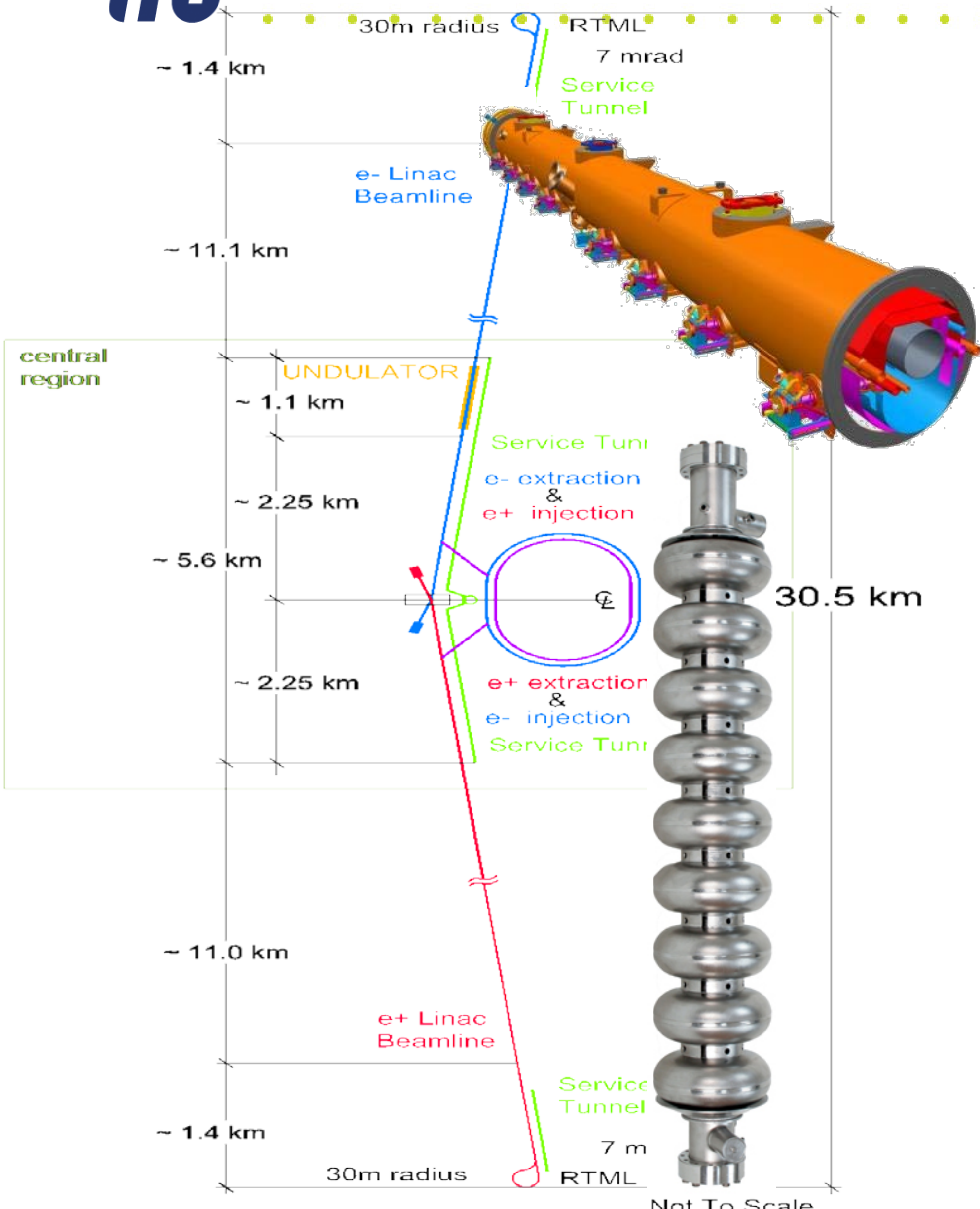
A proof of principle



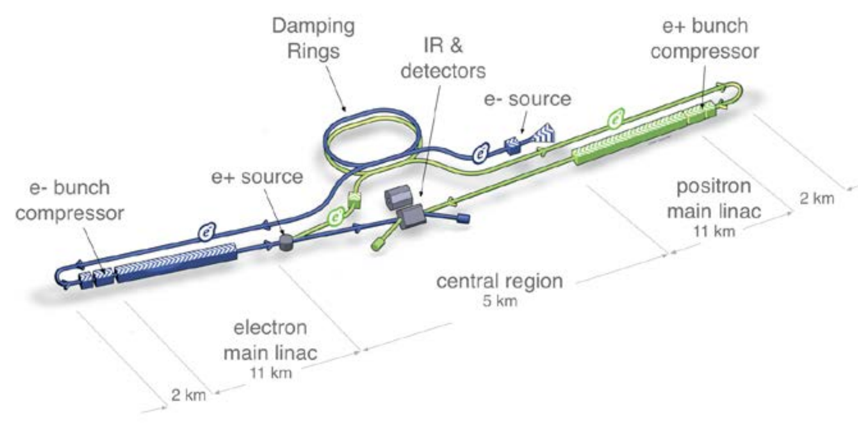


Achieved $\sigma^x \times \sigma^y$ = 1/3 of design

ILC in a Nutshell



- 200-500 GeV E_{cm} e^+e^- collider
  L ~2×10^{34} $cm^{-2}s^{-1}$
  - upgrade: ~1 TeV
- SCRF Technology
  - 1.3GHz SCRF with 31.5 MV/m
  - 17,000 cavities
  - 1,700 cryomodules
  - 2×11 km linacs



500 GeV Parameters

Physics

Max. E_{cm}	500 GeV
Luminosity	1.8×10^{34} $cm^{-2}s^{-1}$
Polarisation (e-/e+)	80% / 30%
δ_{BS}	4.5%

Beam (interaction point)

tiny emittances
nano-beams at IP
strong beam-beam

σ_x / σ_y	574 nm / 6 nm
σ_z	300 μm
$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$	10 μm / 35 nm
β_x / β_y	11 mm / 0.48 mm
bunch charge	2×10^{10}

...tructure)

High-power high-current
beams. Long bunch trains.
→ SCRF

Number of bunches / pulse	1312
Bunch spacing	554 ns
Pulse current	5.8 mA
Beam pulse length	727 μs
Pulse repetition rate	5 Hz

Accelerator (general)

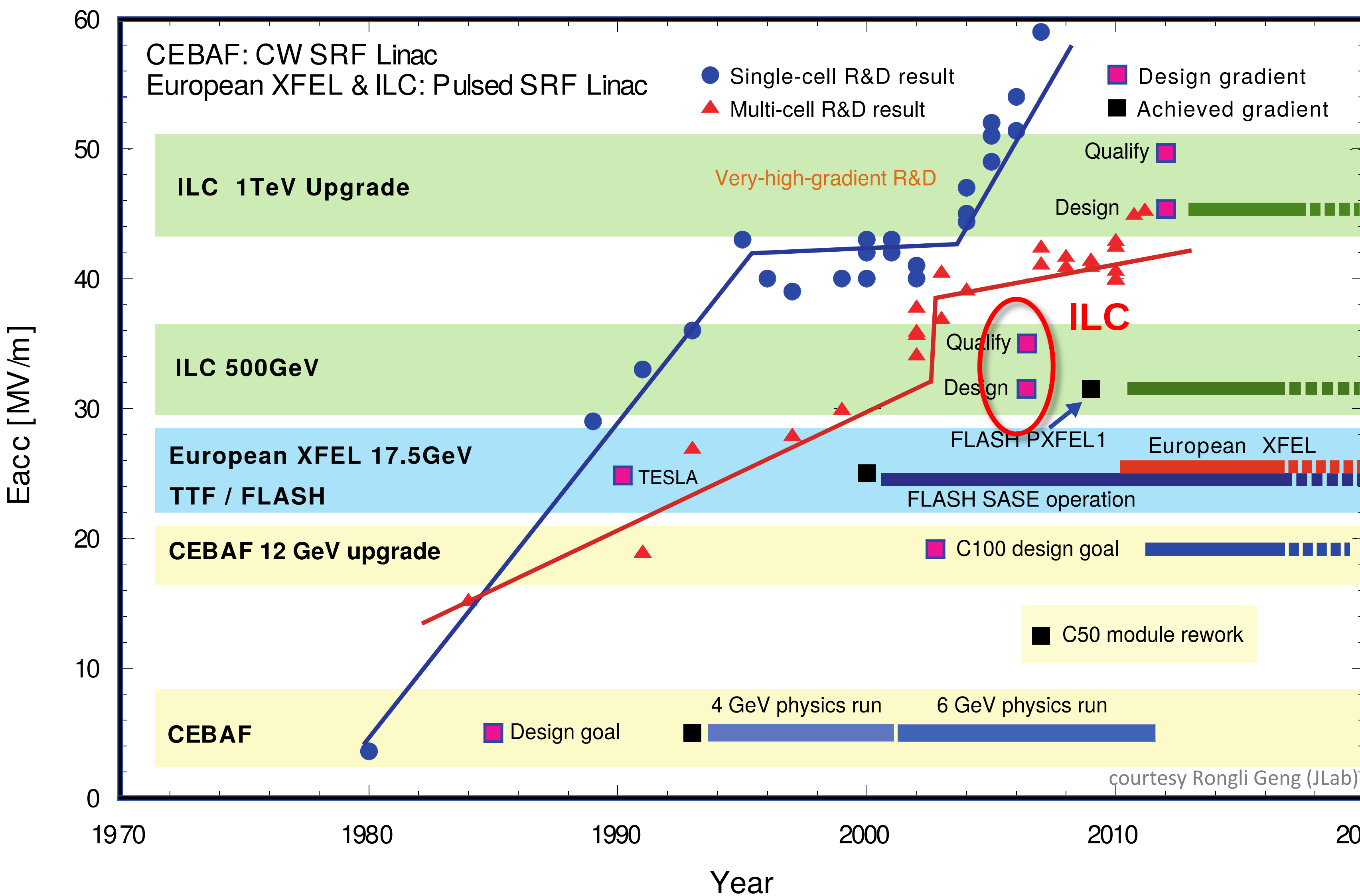
Average beam power	10.5 MW (total)
Total AC power	163 MW
(linacs AC power	107 MW)

1.3 GHz Superconducting RF Cavity

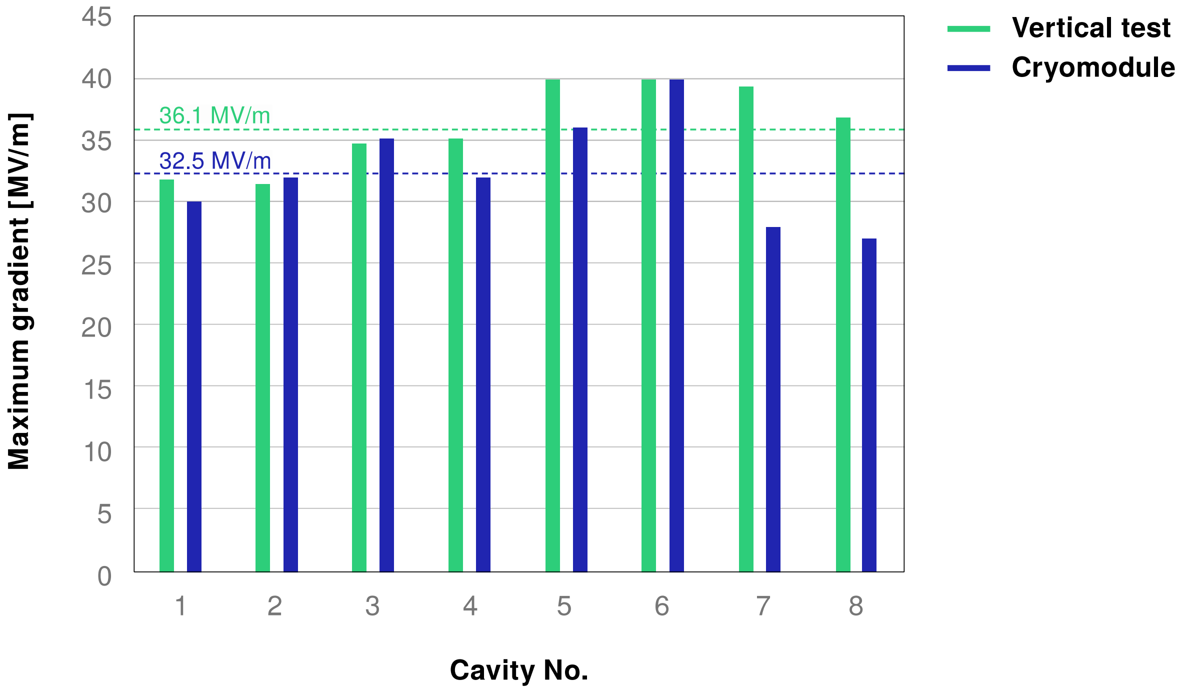
- solid niobium
- standing wave
- 9 cells
- operated at 2K (LHe)

- 35 MV/m
- $Q_0 \geq 10^{10}$

The Quest for High Gradient

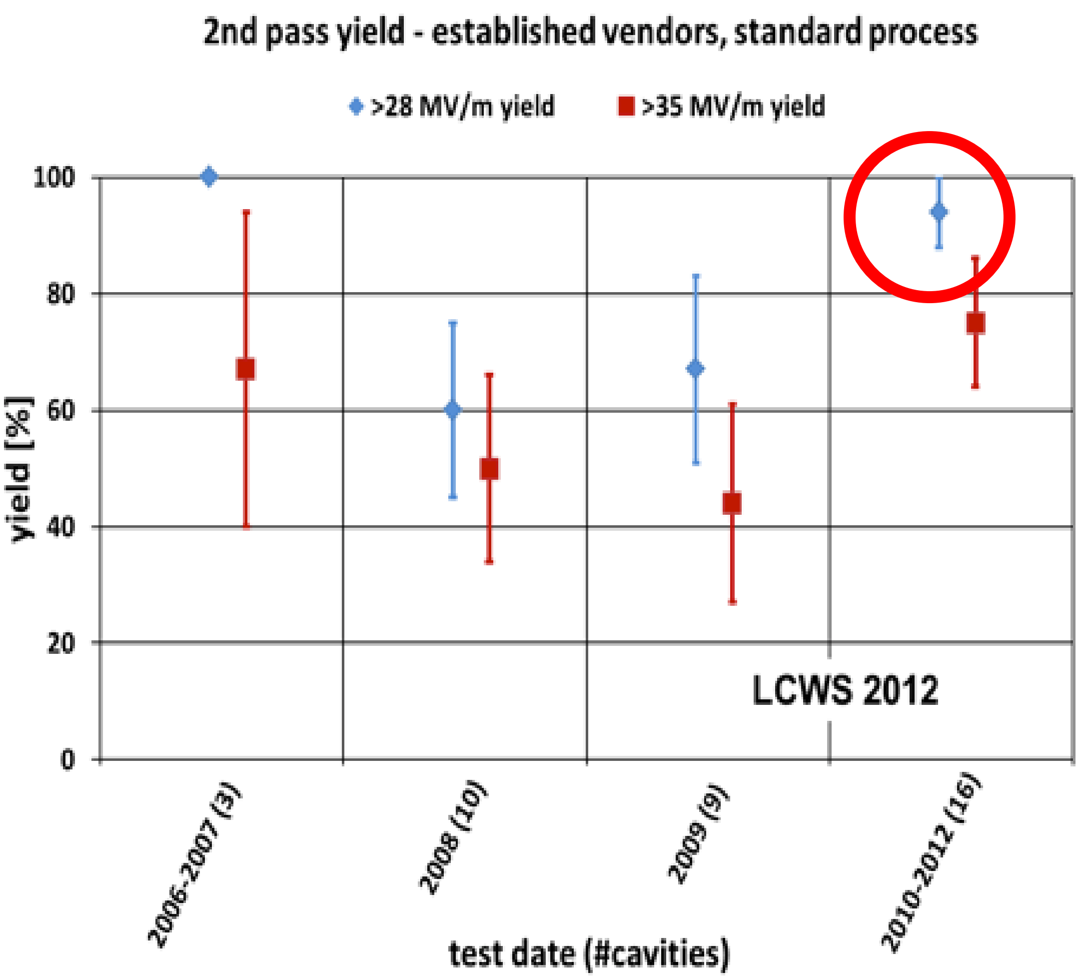


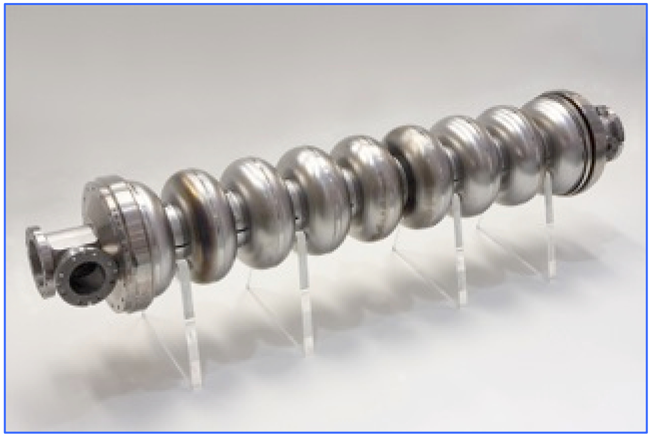
Worldwide Cryomodule Development



PXFEL 1 installed at FLASH, DESY, Hamburg

Progress in SCRF Cavity Gradient





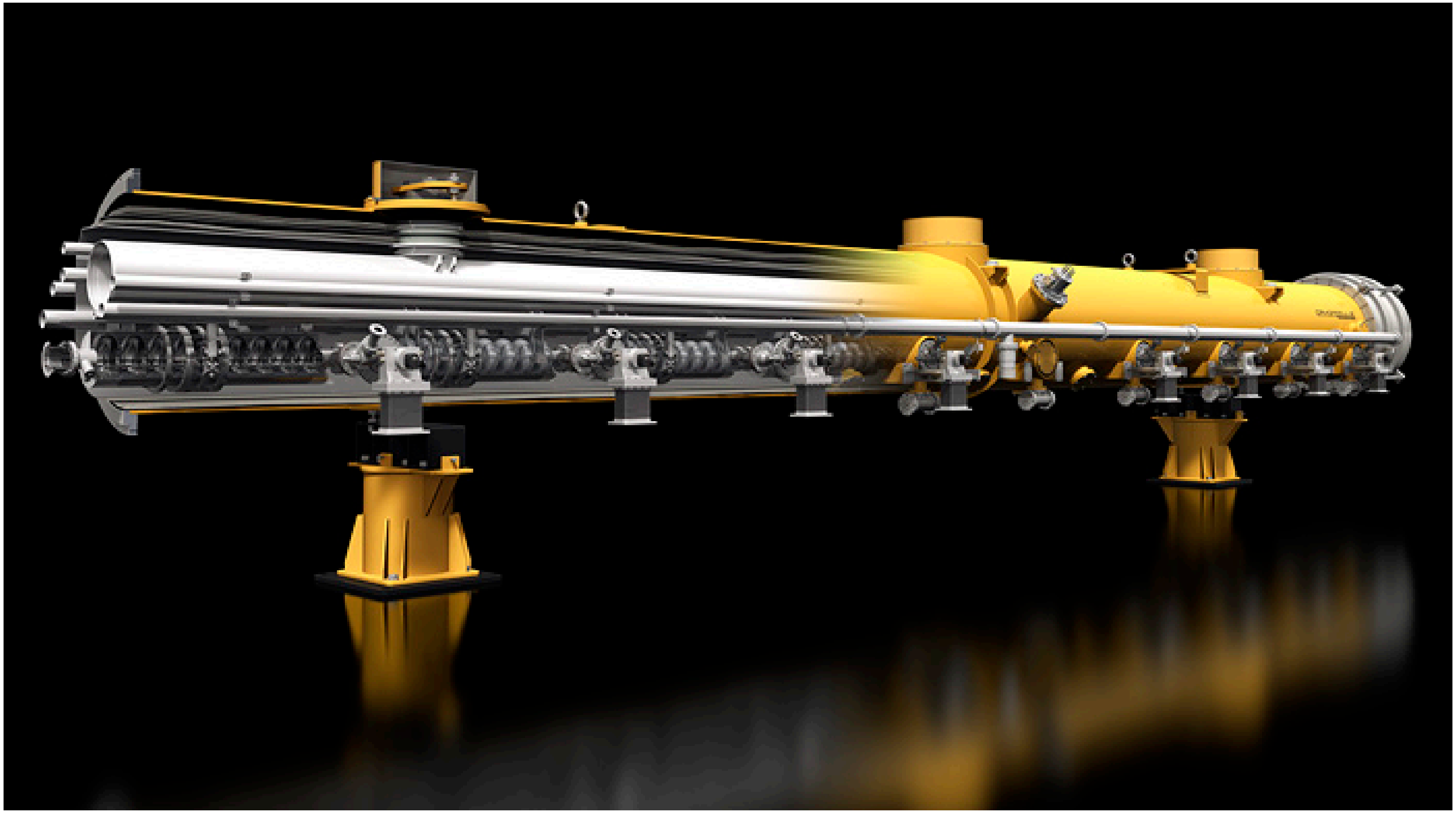
Production yield:
94 % at > 28 MV/m,

Average gradient:
37.1 MV/m

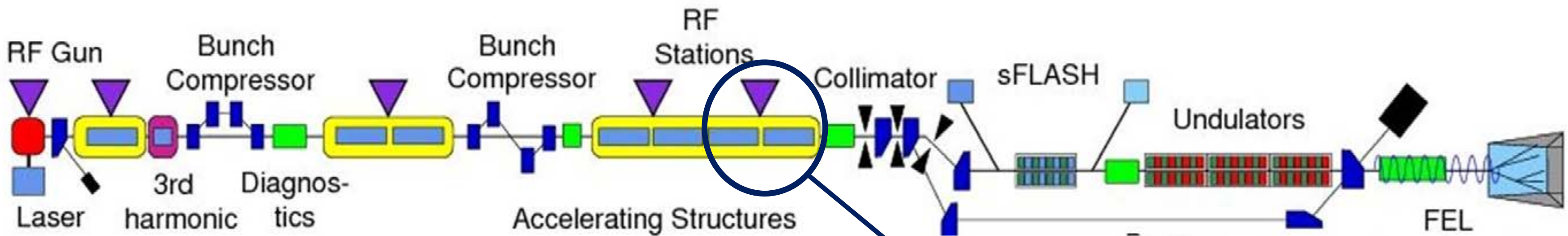
reached in 2012

ILC Cryomodule

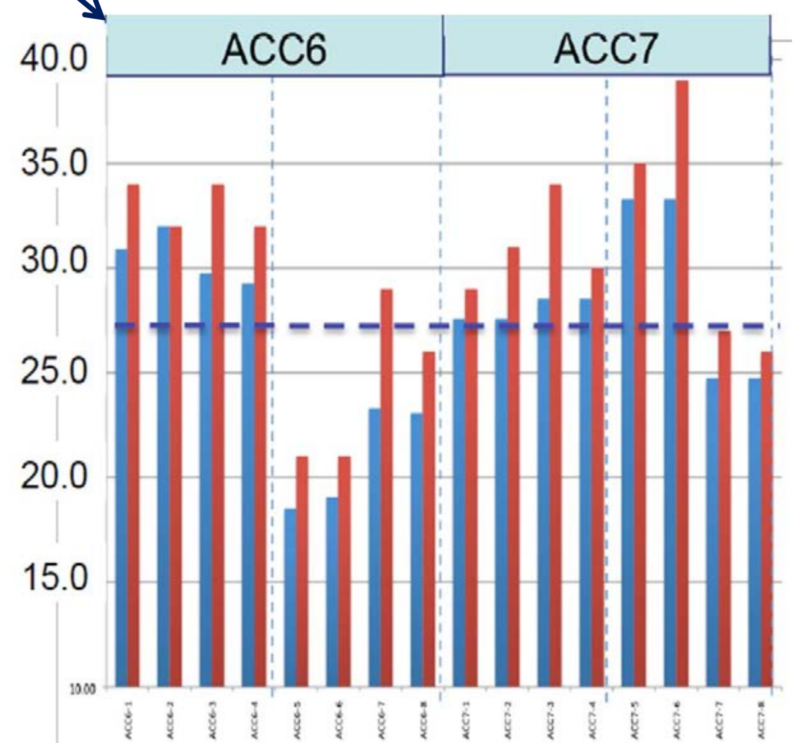
- **12.6 m long; 1 m diameter**
  - (Similar to LHC dipole)
  - 8 cavities w / SC quad magnet in middle



FLASH@DESY 9mA Experiment



		XFEL	ILC (upg.)	FLASH design	9mA studies
Bunch charge	nC	1	3.2	1	3
# bunches		3250	2625	7200*	2400
Pulse length	µs	650	970	800	800
Current	mA	5	9	9	9



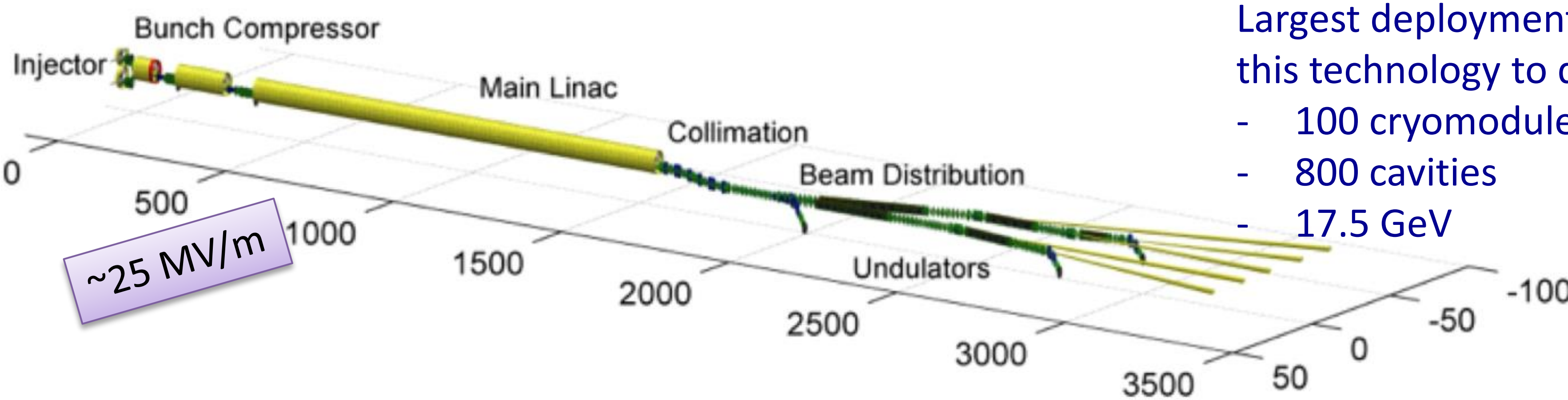
Many basic demonstrations:

- heavy beam loading with long bunch trains
- operation close to quench limits
- klystron overhead etc.

Development (LLRF & controls):

- tuning algorithms
- automation
- quench protection etc.

European XFEL @ DESY

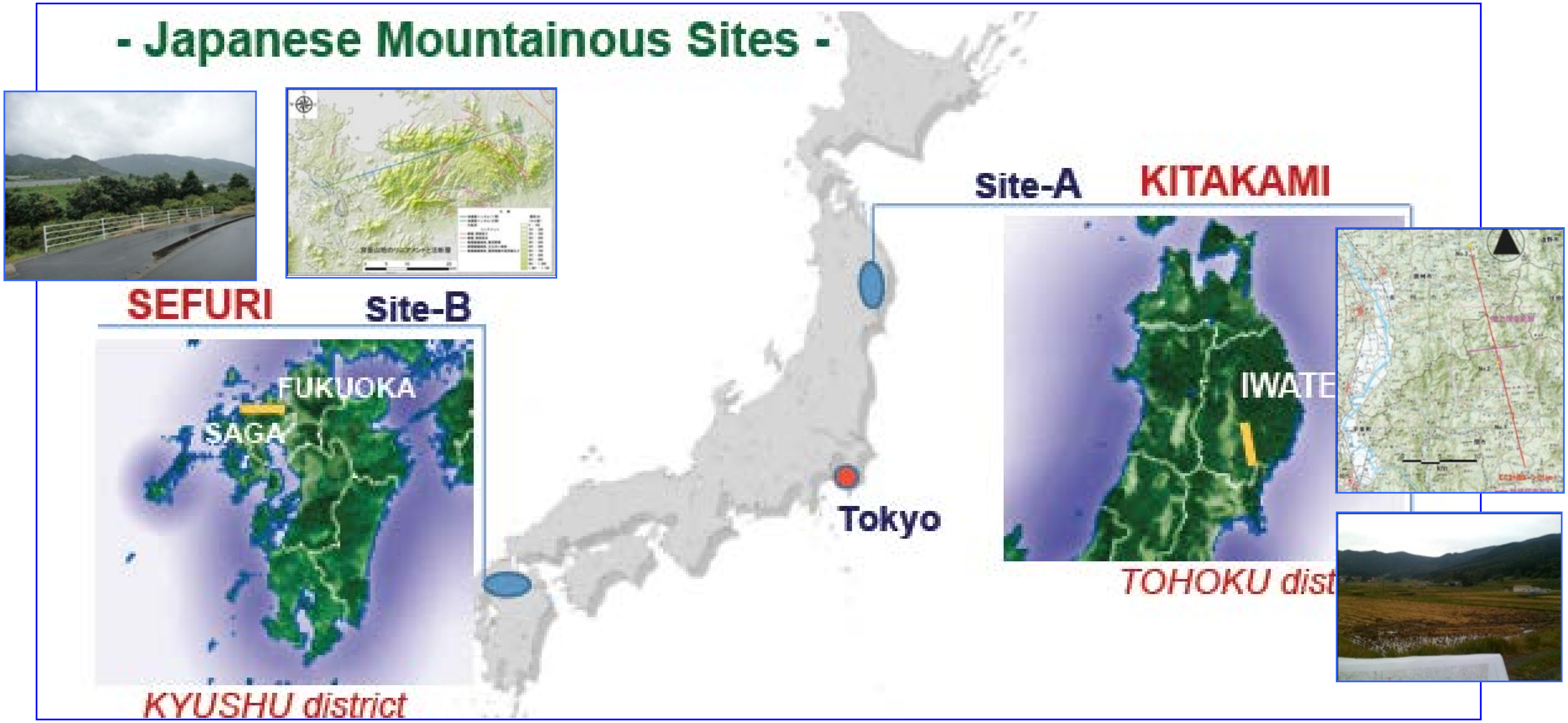


Largest deployment of this technology to date
- 100 cryomodules
- 800 cavities
- 17.5 GeV

Institute	Component Task
CEA Saclay / IRFU, France	Cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold-vacuum system; integration of superconducting magnets; cold beam-position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher-order-mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IFJ PAN Cracow, Poland	RF cavity and cryomodule testing
BINP, Russia	Cold vacuum components

The ultimate 'integrated systems test' for ILC. Commissioning with beam 2nd half 2015

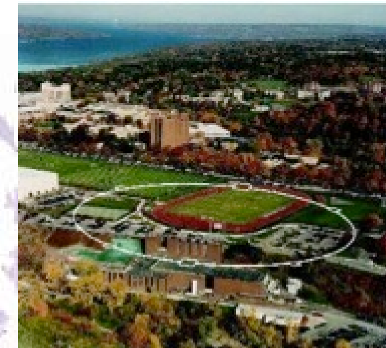
Looking towards the East



Global Cooperation for ILC Accelerator Beam Demonstration

TTF/FLASH (DESY) ~1 GeV
ILC-like beam ILC RF unit
(* lower gradient)

STF (KEK) operation/construction
ILC Cryomodule test : S1-Global
Quantum Beam experiment



CesrTA (Cornell)
electron cloud
low emittance

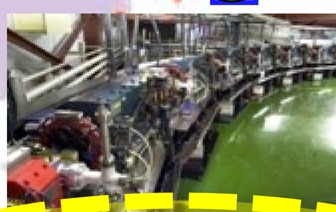
DESY

INFN Frascati

KEK, Japan

FNAL

Cornell



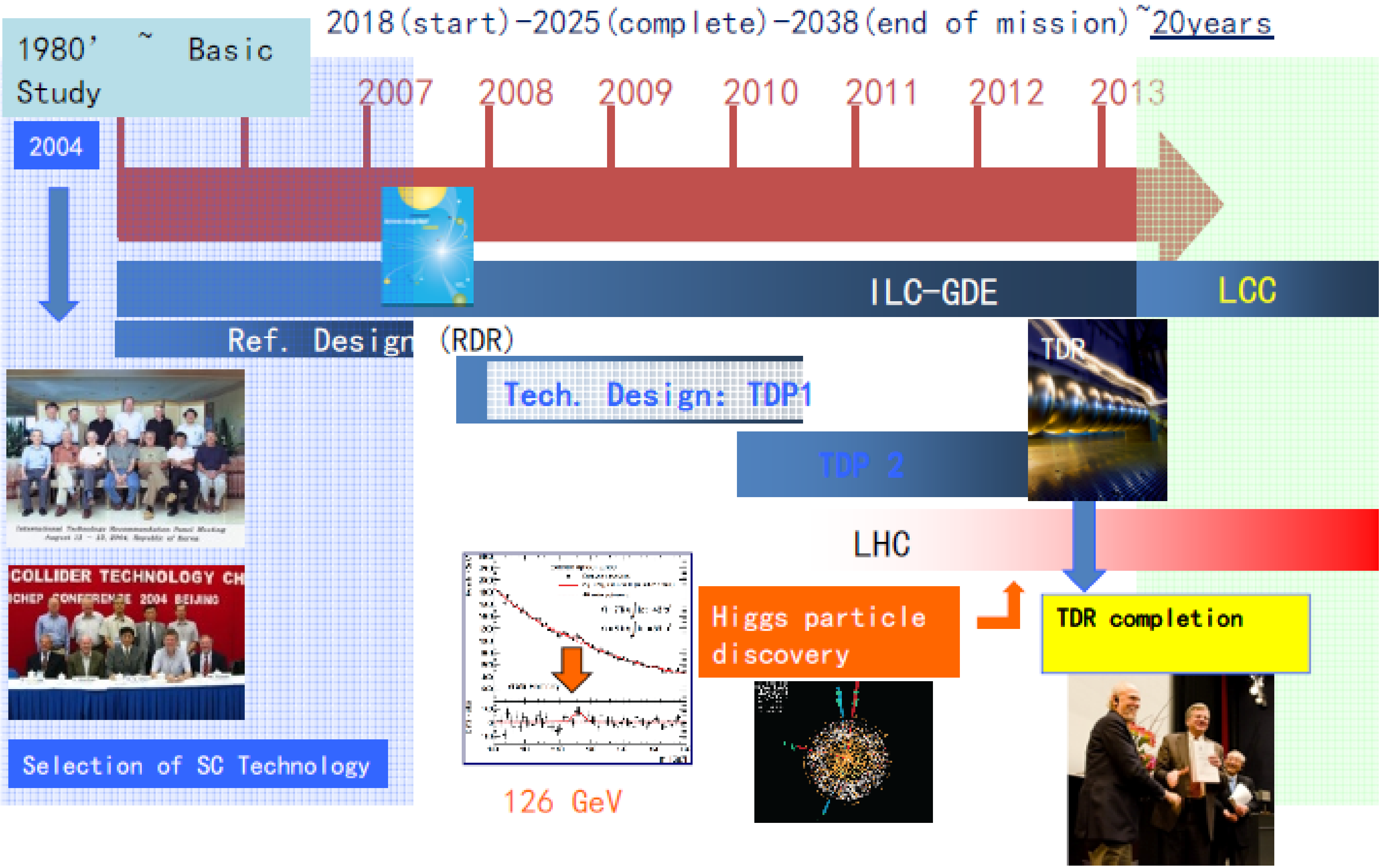
NML facility ILC RF unit test
Under construction

DA^{f}NE (INFN Frascati)
kicker development
electron cloud

ATF & ATF2 (KEK)
ultra-low emittance
Final Focus optics
KEKB electron-cloud

Large research facilities takes long time

ILC Time Line



Technical Design Report Completed

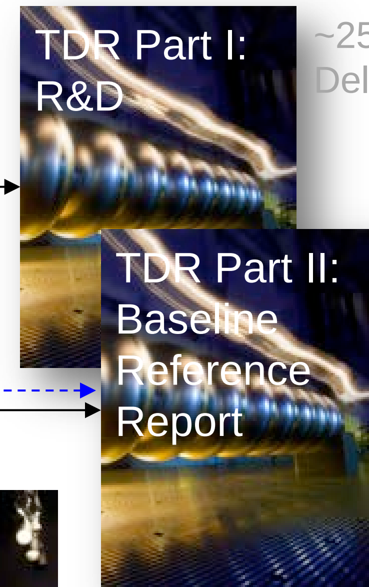
2007

2011

2013*

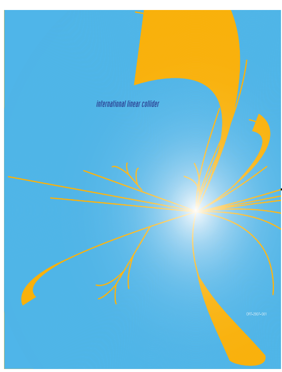
ILC Technical Progress Report ("*interim report*")

AD&I



~250 pages Deliverable 2

~300 pages Deliverables 1,3 and 4



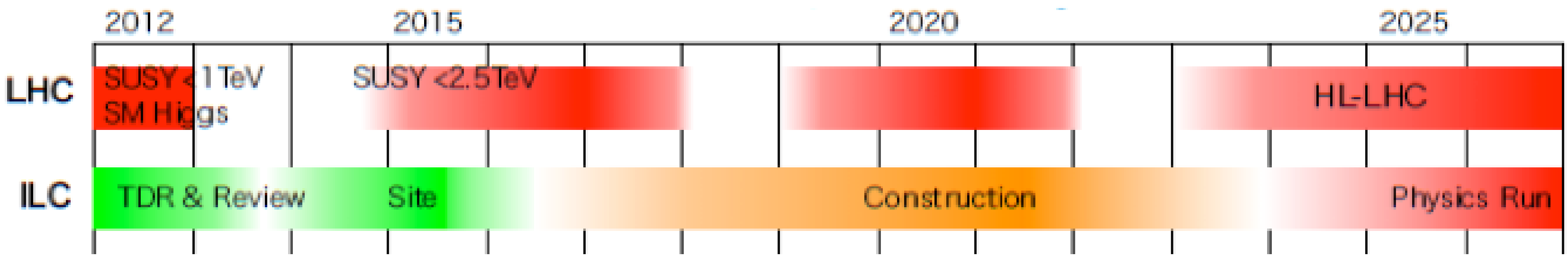
Reference Design Report

Technical Design Report

* end of 2012 – formal publication early 2013

Timeline

Atsuto Suzuki @ the P5 meeting in Chicago



LCC working timeline

ILC Timeline

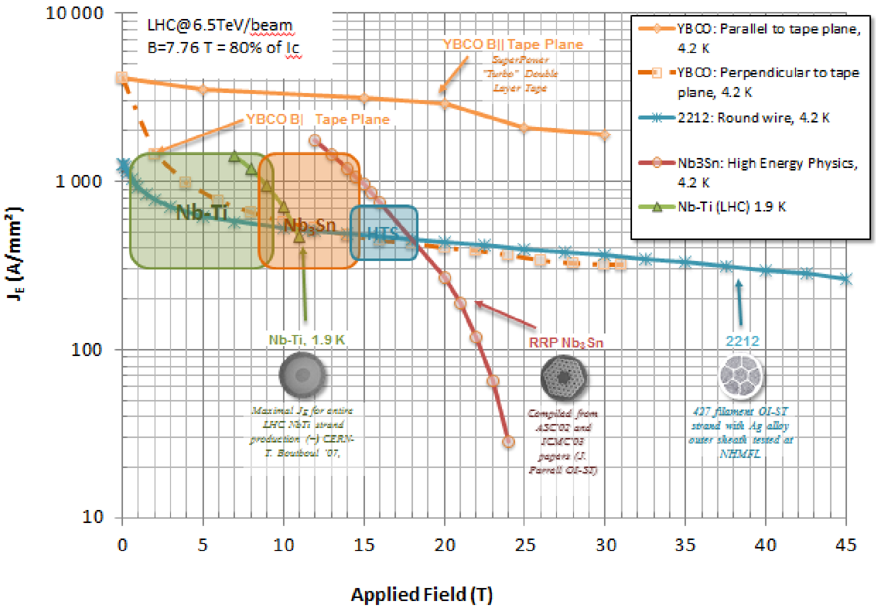
Proposed by LCC

- 2013 - 2016
  - Negotiations among governments
  - Accelerator detailed design, R&Ds for cost-effective production, site study, CFS designs etc.
  - Prepare for the international lab.
- 2016 – 2018
  - 'Green-sign' for the ILC construction to be given (in early 2016)
  - International agreement reached to go ahead with the ILC
  - Formation of the ILC lab.
  - Preparation for biddings etc.
- 2018
  - Construction start (9 yrs)
- 2027
  - Construction (500 GeV) complete, (and commissioning start) (250 GeV is slightly shorter)

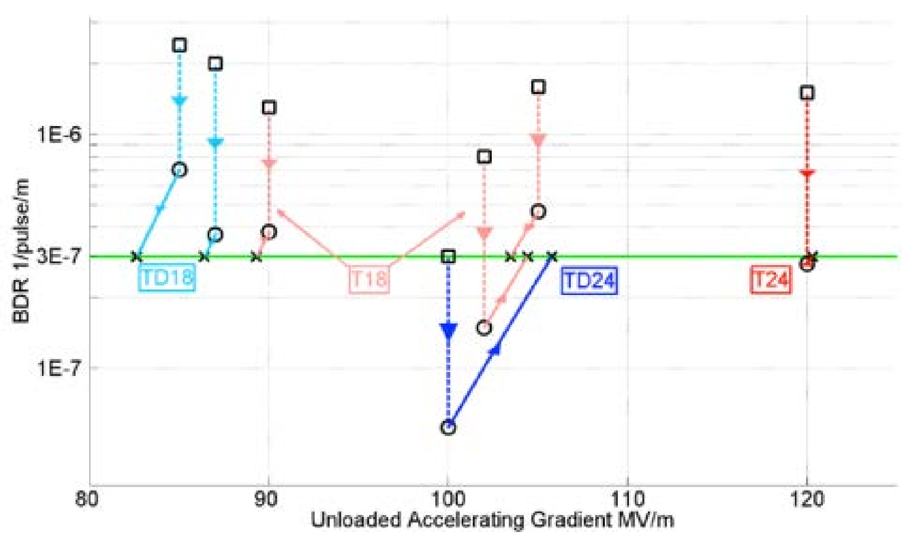
"to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update"

d) *CERN should undertake design studies for accelerator projects in a global context,* *with emphasis on* ***proton-proton and electron-positron high-energy frontier machines****. These design studies should be coupled to a vigorous accelerator* ***R&D programme****, including* ***high-field magnets*** ***and*** ***high-gradient accelerating structures****,* ***in collaboration with national institutes, laboratories and universities worldwide.***

HFM



HGA



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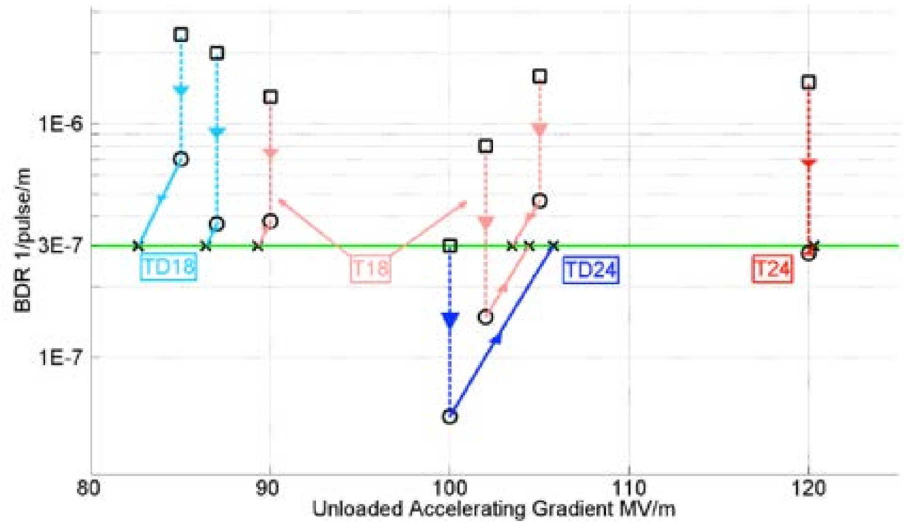
HGA

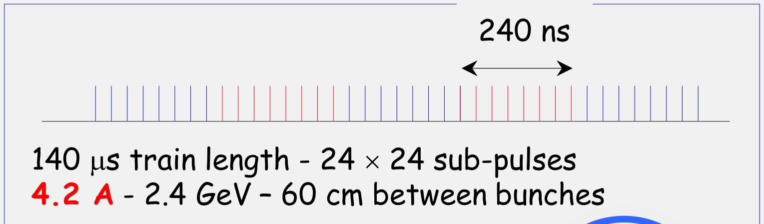


And also R&D on Proton-Driven Plasma Wakefield Acceleration (AWAKE Expt at CERN)

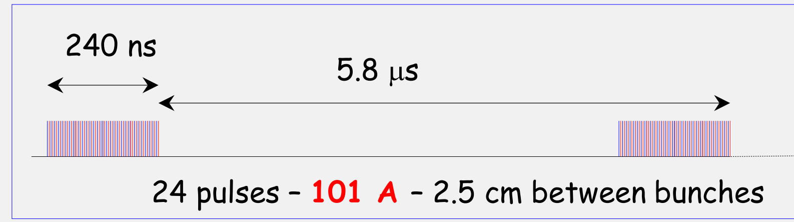
CLIC Layout at 3 TeV

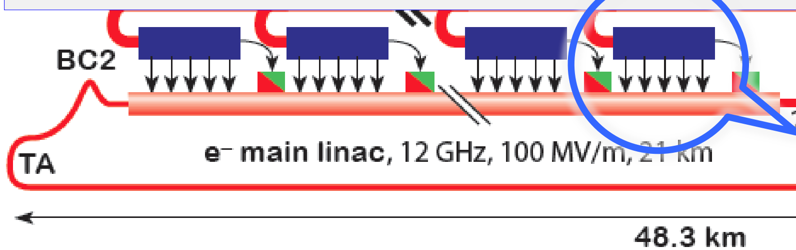
Drive Beam Generation

Drive beam time structure - initial



Drive beam time structure - final





- CR combiner ring
- TA turnaround
- DR damping ring
- PDR predamping ring
- BC bunch compressor
- BDS beam delivery system
- IP interaction point
- dump

e⁻ injector, 2.86 GeV

Main Beam Generation Complex

Possible CLIC stages studied

Table 1: Parameters for the CLIC energy stages of scenario A.

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		354	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	80	80/100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	2.3	3.2	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	1.4	1.3	2
Main tunnel length		km	13.2	27.2	48.3
Charge per bunch	N	10^9	6.8	3.7	3.7
Bunch length	σ_z	μm	72	44	44
IP beam size	σ_x/σ_y	nm	200/2.6	~ 60/1.5	~ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	2350/20	660/20	660/20
Normalised emittance (IP)	$\varepsilon_x/\varepsilon_y$	nm	2400/25	—	—
Estimated power consumption	P_{wall}	MW	272	364	589

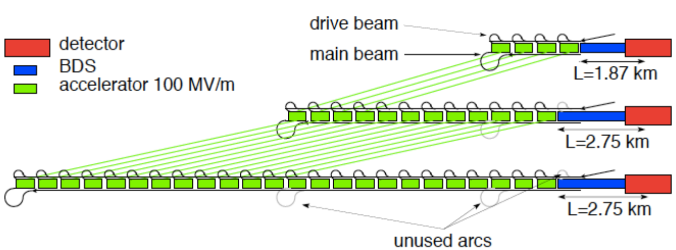


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

Table 2: Parameters for the CLIC energy stages of scenario B.

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		312	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	100	100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.3	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.7	1.4	2
Main tunnel length		km	11.4	27.2	48.3
Charge per bunch	N	10^9	3.7	3.7	3.7
Bunch length	σ_z	μm	44	44	44
IP beam size	σ_x/σ_y	nm	100/2.6	~ 60/1.5	~ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	—	660/20	660/20
Normalised emittance	$\varepsilon_x/\varepsilon_y$	nm	660/25	—	—
Estimated power consumption	P_{wall}	MW	235	364	589

Key features:

- High gradient (energy/length)
- Small beams (luminosity)
- Repetition rates and bunch spacing (experimental conditions)

The CLIC CDR documents

Vol 1: The CLIC accelerator and site facilities

- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- https://edms.cern.ch/document/1234244/

Vol 2: Physics and detectors at CLIC

- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- http://arxiv.org/pdf/1202.5940v1

Vol 3: "CLIC study summary"

- Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)
- http://arxiv.org/pdf/1209.2543v1

In addition a shorter overview document was submitted as input to the European Strategy update, available at: http://arxiv.org/pdf/1208.1402v1

An input document to Snowmass 2013 has also been submitted: http://arxiv.org/abs/1305.5766

“CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and ***electron- positron high-energy frontier machines.****”*

Context of CERN’s LC studies

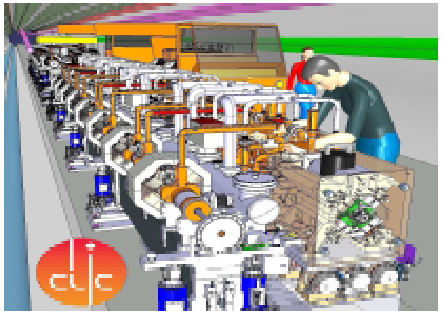
- Highest possible energy e+e- with CLIC (CDR 2012)
- ILC in Japan, a possibility for exploring the Higgs in detail, starting at 250 GeV

In accordance with this, pursue three connected activities in the period towards 2017-18 (when LHC results at nominal energy are becoming mature):

- CLIC as option for the energy frontier
- ILC project development contributions using common activities wherever possible
- Detector and Physics studies for future LCs

SLAC-R-985
KEK Report 2012-1
PSI-12-01
JAI-2012-001
CERN-2012-007
12 October 2012

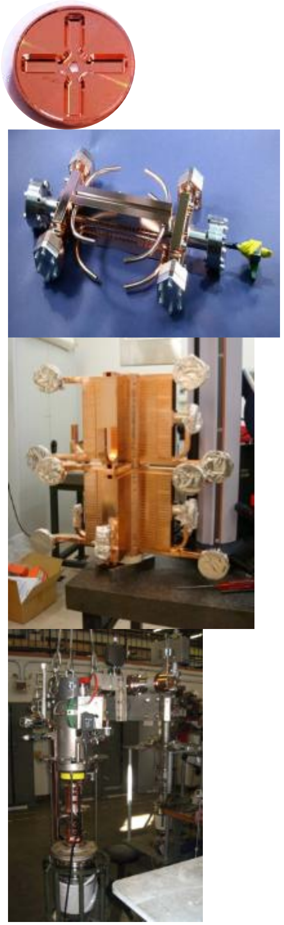
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



A MULTI-TEV LINEAR COLLIDER
BASED ON CLIC TECHNOLOGY
CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012

CLIC Accelerator Activities 2012-18



Re-baselining studies ongoing (375 GeV, ~1.5 TeV, 3 TeV) – including more work on a klystron based initial phase

- Overall design and system optimisation, technical parameters for all systems
- Overall performance, reliability and risk studies
- Cost, power/energy optimisation, scheduling, site, etc

Develop the technical design basis. i.e. move toward **a technical design for crucial items** of the machine; X-band as well as all other parts.

- Priorities are module/structure development including significantly more testing facilities, complete modules for lab and CTF3, modulators/klystrons, alignment/stability/magnet studies and instrumentation
- Purpose: Technical developments, industrial developments, cost and power optimisation, and components as needed for systemtests

System tests and programs to address the key performance and operation goals

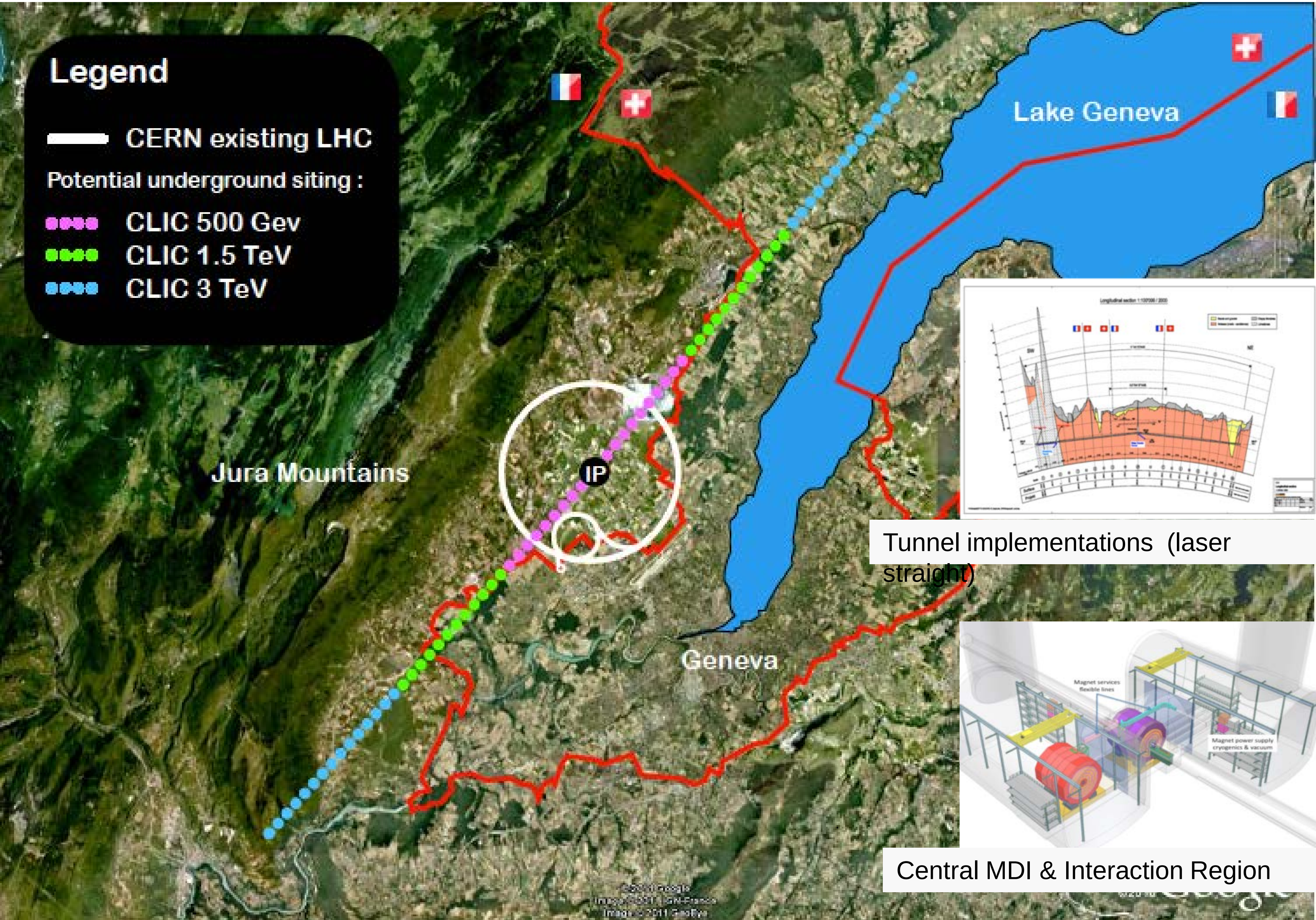
- CTF3+ and drive beam front end
- ATF, FACET and various other smaller programmes for specific studies
- Purpose: Studies of drive-beam stability and RF units, beam-loading experiments, deceleration, RF power generation and two beam acceleration with complete modules, as well as beam based alignment/beam delivery system/final focus studies

Various RF elements of a complete module, X-band test stand

Prototyping of magnets, support/alignment systems and module instrumentation

Courtesy of Steinar Stapnes

CLIC near CERN



Tunnel implementations (laser straight)

Central MDI & Interaction Region

Summary Linear Colliders

- Major milestones achieved for CLIC (CDR 2012) and ILC (TDR 2013)
- The Higgs discovery – and future measurements – set up a clear scenario for linear colliders (maybe more to come from LHC – BSM?)
- European Strategy positive with respect to both projects discussed, with different main goals and timescales

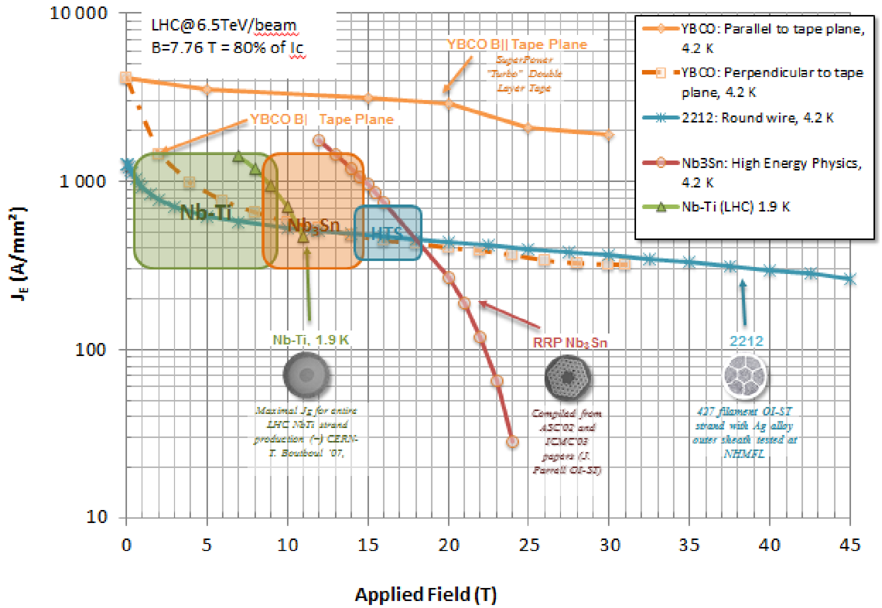
- CLIC programme for 2018 defined (being revised now after the Strategy document), collaboration based developments of key aspects of the technology

- ILC might enter construction (or preparation for construction) in Japan
  - Site choice done, Involvement by other regions a key
  - Europe well prepared to contribute (technically) – finances another challenge

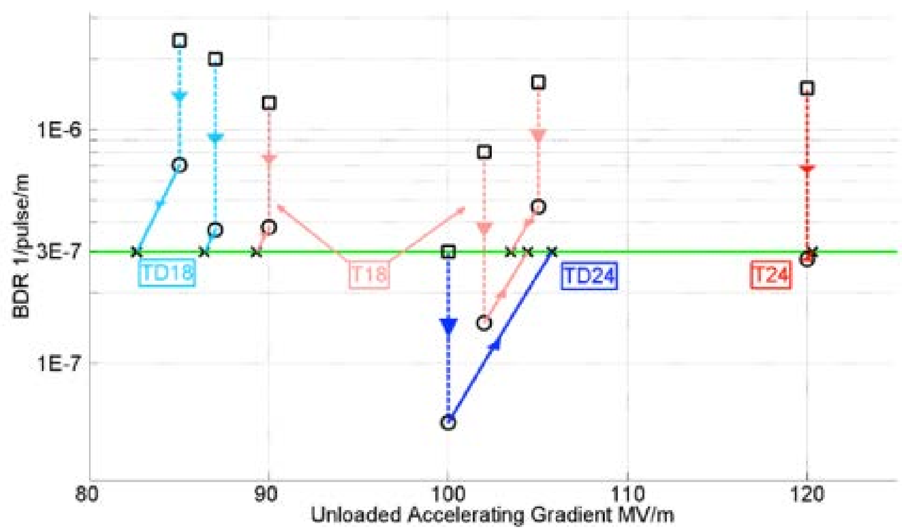
“to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update”

d) *CERN should undertake design studies for accelerator projects in a global context,* *with emphasis on* ***proton-proton and electron-positron high-energy frontier machines****. These design studies should be coupled to a vigorous accelerator* ***R&D programme****, including* ***high-field magnets*** *and* ***high-gradient accelerating structures****,* ***in collaboration with national institutes, laboratories and universities worldwide.***

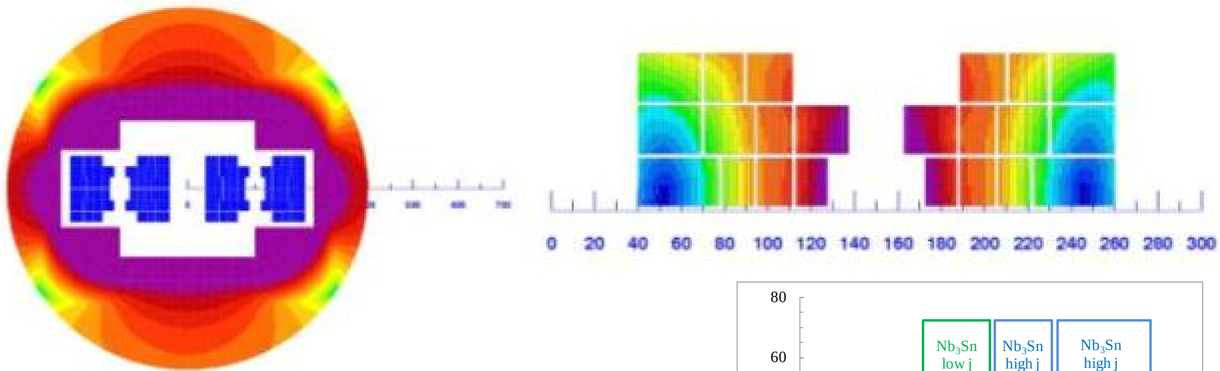
HFM



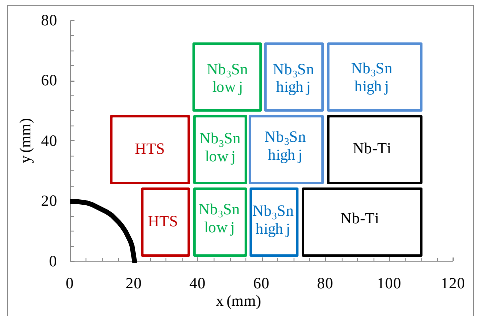
HGA

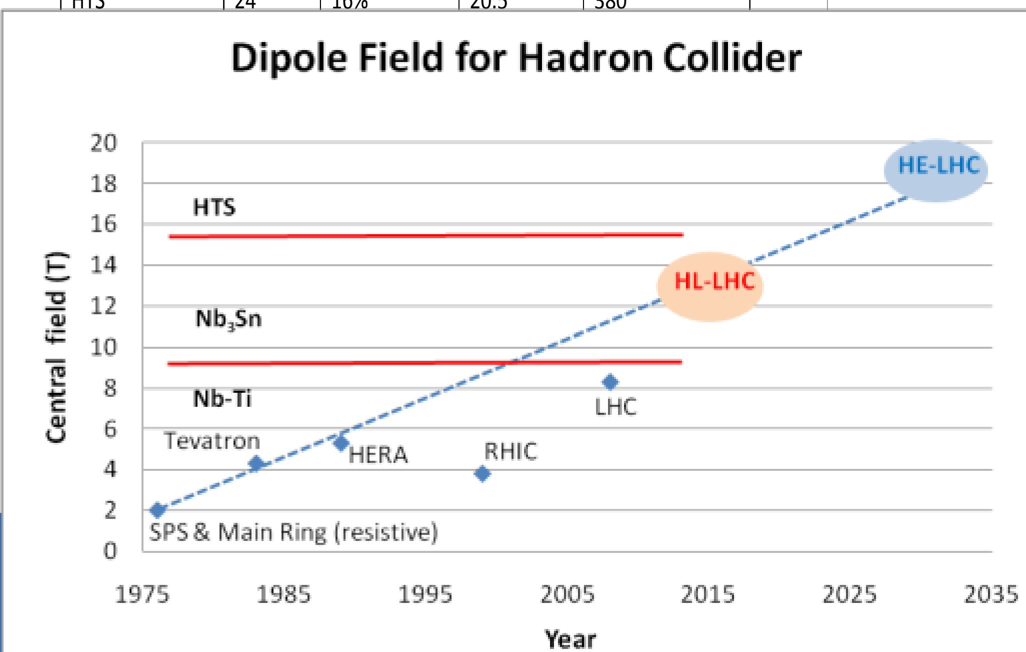


Malta Workshop: **HE-LHC @ 33 TeV c.o.m.**
14-16 October 2010



Material	N. turns	Coil fraction	Peak field	$J_{overall}$ (A/mm^2)
Nb-Ti	41	27%	8	380
Nb3Sn (high Jc)	55	37%	13	380
Nb3Sn (Low Jc)	30	20%	15	190
HTS	24	16%	20.5	380





Magnet design (20 T): very challenging but not impossible.

300 mm inter-beam

Multiple powering in the same magnet (and more sectioning for energy)

Work for 4 years to assess HTS for 2X20T to open the way to 16.5 T/beam .

Otherwise limit field to 15.5 T for 2x13 TeV

Higher INJ energy is desirable (2xSPS)

ng the beam screen at 60 K.

ks to dumping time.

IC. Reaching 2x10^{34} appears reasonable.

s beam handling for INJ & beam dump:

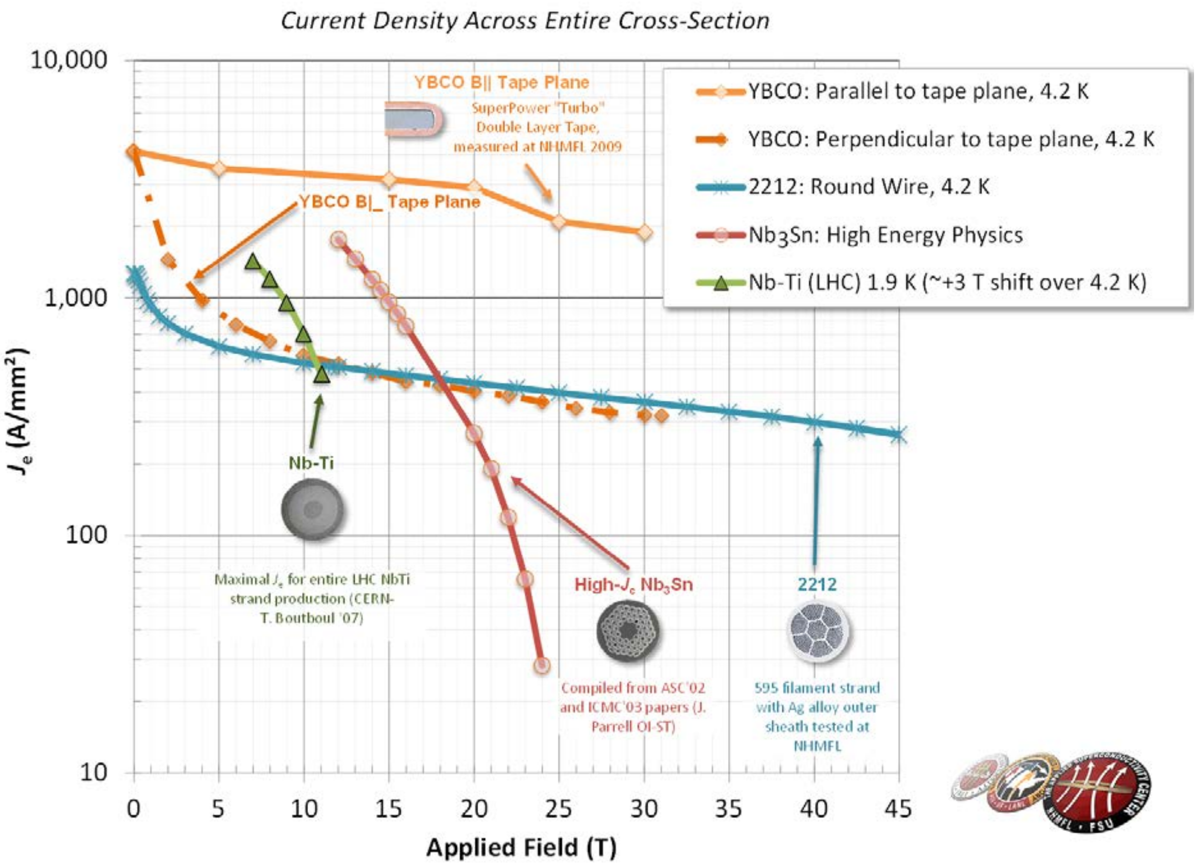
nake twice more room for LHC kickers.

HE-LHC main parameters

parameter	LHC	HL-LHC	HE-LHC
c.m. energy [TeV]	14		33
circumference C [km]	26.7		26.7
dipole field [T]	8.33		20
dipole coil aperture [mm]	56		40
beam half aperture [cm]	~2		1.3
injection energy [TeV]	0.45		>1.0
no. of bunches	2808		2808
bunch population N_b [10^{11}]	1.15	2.2	0.94
init. tr. norm. emittance [μm]	3.75	2.5	1.38
init. longit. emittance [eVs]	2.5		3.8
no. IPs contributing to ΔQ	3	2	2
max. total b-b tune shift ΔQ	0.01	0.015	0.01
beam current [A]	0.584	1.12	0.478
rms bunch length [cm]	7.55		7.55
IP beta function [m]	0.55	0.15	0.35
rms IP spot size [μm]	16.7	7.1 (min.)	5.2

O. Dominguez, L. Rossi, F. Zimmermann

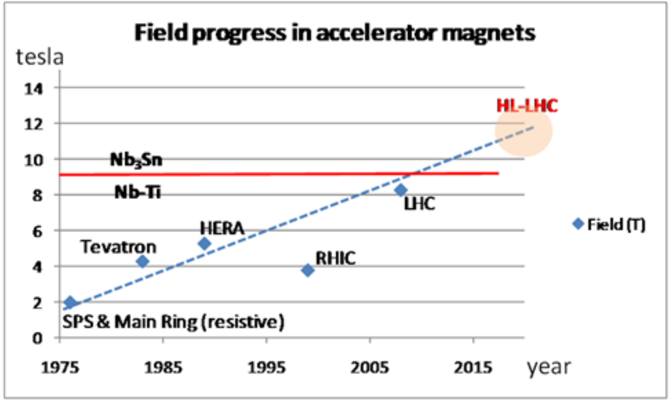
Superconductors: from materials to applications



Superconductors as seen by the eye of an engineer

The grand challenge of today is to develop the technology of **high-field superconductors** **(field quality,…)**

LTS (NbTi ; Nb_3Sn)



NbTi mature but limited to 9T

Is Nb_3Sn mature ? Yes, and no

performance of Nb_3Sn wires has seen a great boost in the past decade (factor 3 in J_C w/r to ITER)

However, Nb_3Sn magnets were never built nor operated in accelerators. Manufacturing, quench, training, protection, strain tolerance, field quality are the focus today to make this new technology a reality

Solid and aggressive R&D in HFM (High Field Magnet) for accelerators must be intensified

HTS

Can HTS displace LTS ? Not today

Much needs to be done to bring this technology to a point where it can be sold as “mature”

Materials have potential that can be exploited

- OPHT for BSCCO-2212
- Thicker layer for YBCO tapes
- The Holy Grail of a round YBCO wire

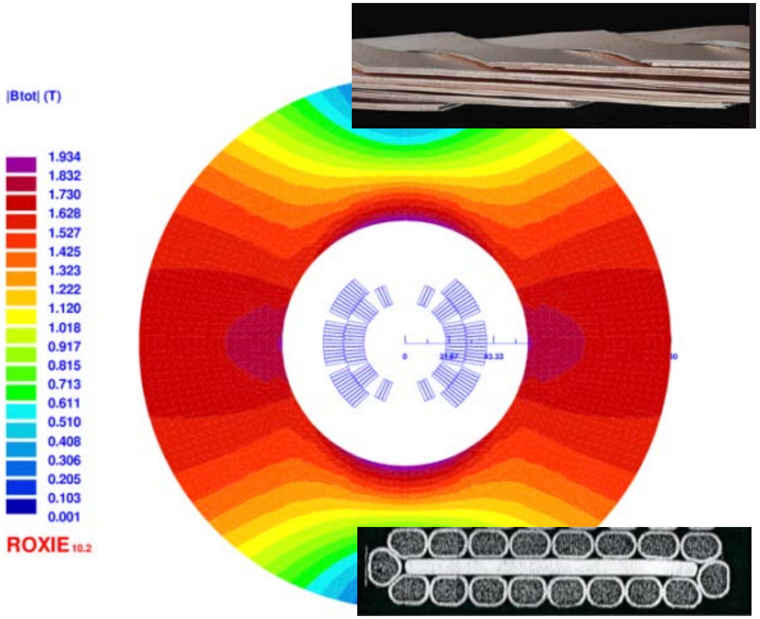
Production quantities, homogeneity and cost need to evolve

Step-up application demands, from self-field (SC-link is an ideal test-bed) to high-field accelerator magnets (feasibility)

From Luca B

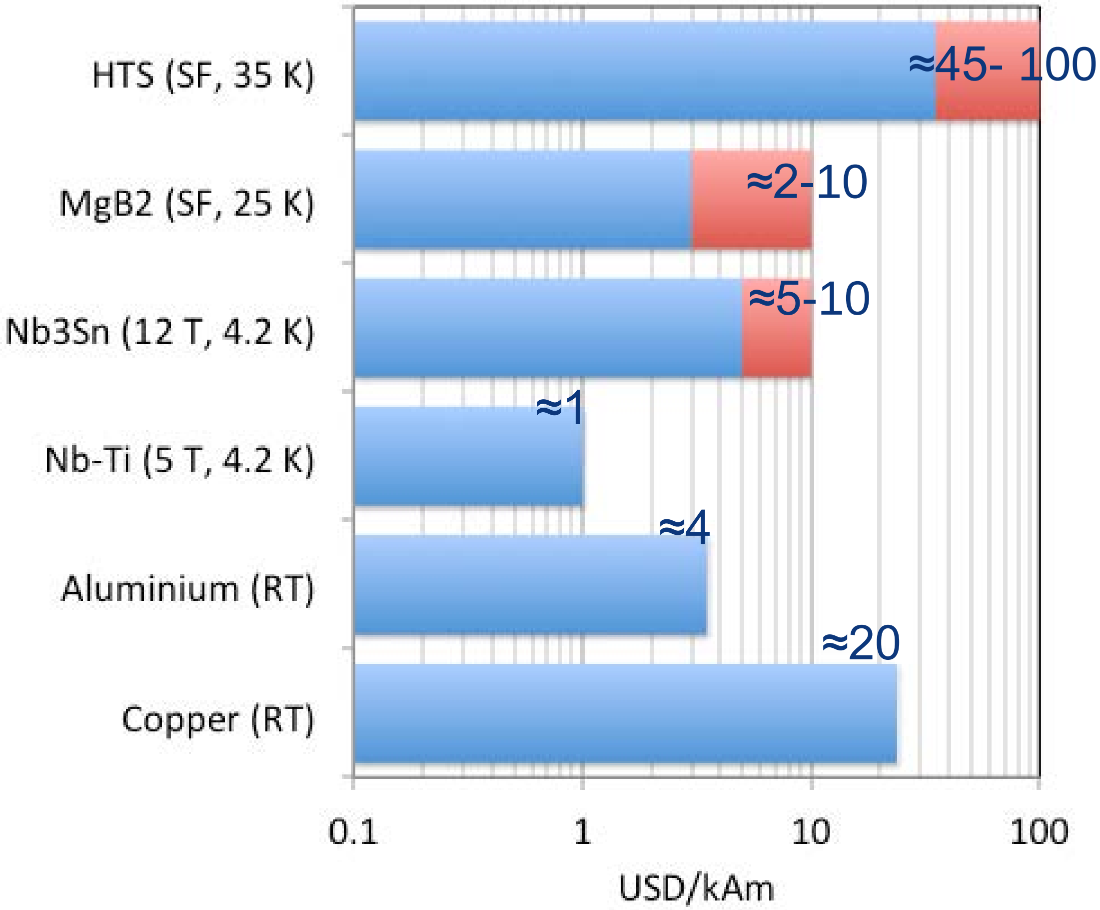
Program Eucard2 on HTS

EuCARD2: Develop 10 kA class HTS accelerator cable using Bi-2212 and YBCO. Test stability, magnetization, and strain tolerance



WP10: a 5 T, 40 mm bore HTS dipole

From materials to applications



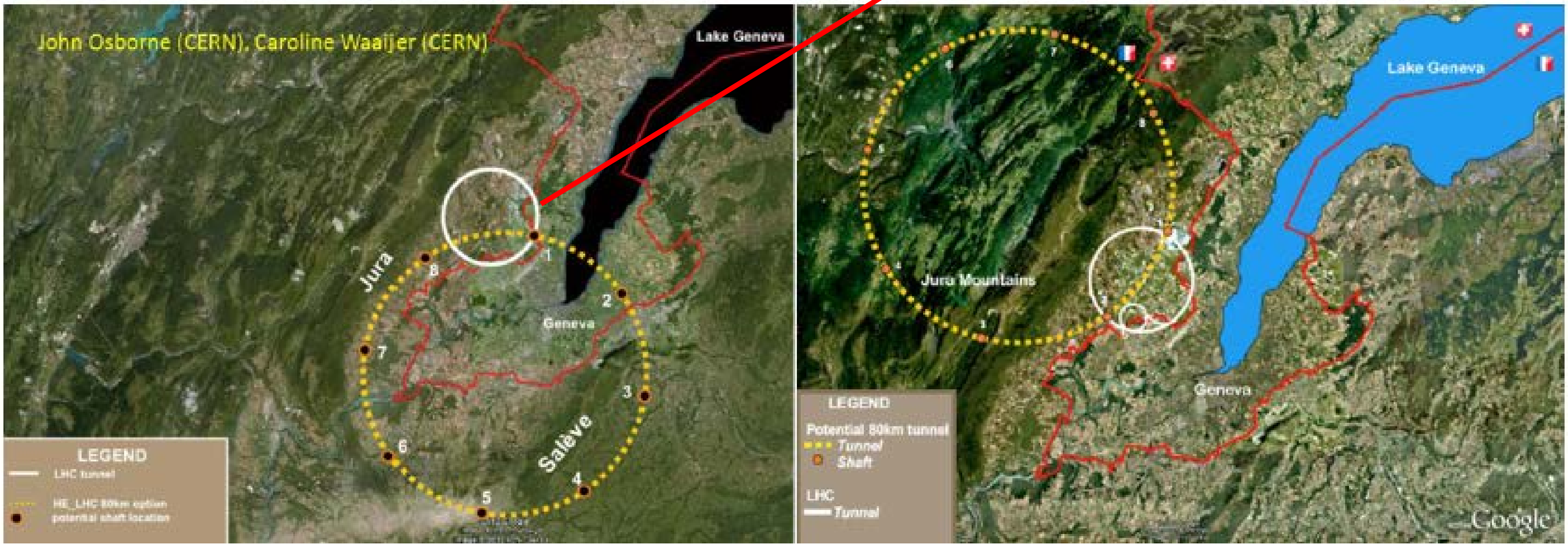
Superconductors as seen by the eye of a manager
The grand challenge of today is availability of **long lengths of reasonably priced commercial materials**

"Very High Energy LHC"

First studies on a new 80 km tunnel in the Geneva area

- **42 TeV with 8.3 T using present LHC dipoles**
- **80 TeV with 16 T based on Nb_3Sn dipoles**
- **100 TeV with 20 T based on HTS dipoles**

HE-LHC :33 TeV with 20T magnets

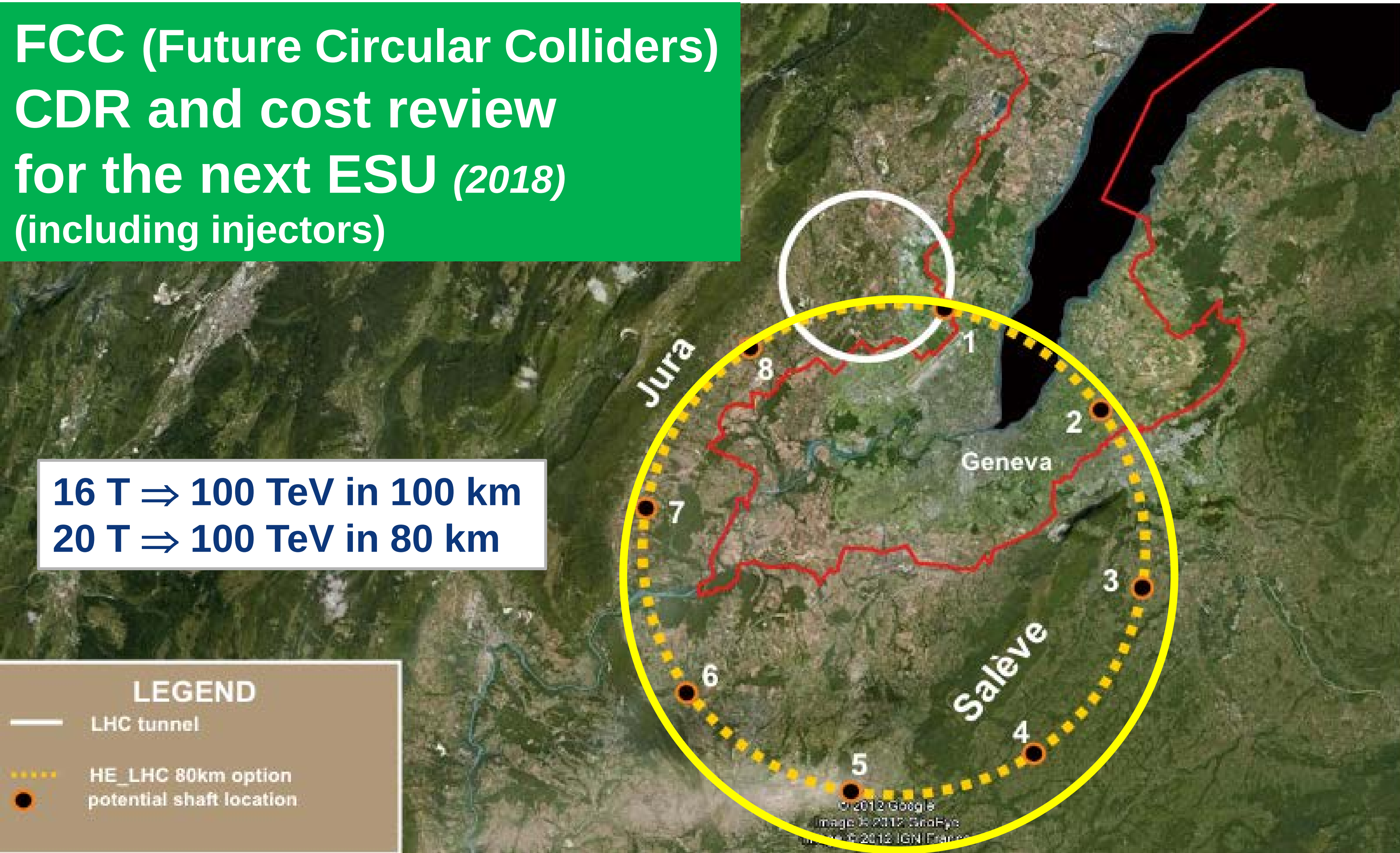


80-100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements

with possibility of e+-e- (TLEP) and p-e (VLHeC)

FCC (Future Circular Colliders)
CDR and cost review
for the next ESU *(2018)*
(including injectors)

16 T ⇒ 100 TeV in 100 km
20 T ⇒ 100 TeV in 80 km



FCC Study Scope and Structure

Future Circular Colliders -
for next European St

Infrast

tunnels, surface buildings, transport (a
ventilation, electricity, cryogenics,
installation processes, maintenance,

Hadron injectors	**Hadron**
Beam optics and dynamics	Optics and be
Functional specs	Functional s
Performance specs	Performa
Critical technical systems	Critical techn
Operation concept	Related R+
	HE-LHC c
	Operatio
	Detecto
	Physics re
	e- p option:

Main parameters for FHC *(hh)*

- **energy = 100 TeV c.m.**
- **dipole field = 16 T (baseline)**
  [20 T option] (design limit)
- **circumference ~100 km**
- **#IPs = 2**
- total beam-beam tune shift = 0.01
- bunch spacing = 25 ns [10 …5 ns option]
- **peak luminosity = 5×10^{34} $cm^{-2}s^{-1}$**
- β^* = 1.1 m *[2 m conservative option]* linked to total beam current (~0.5-1 A)

From M. Benedikt and F. Zimmermann

Main parameters for FEC *(ee)*

- **energy =** 91-Z, 160-W, **240-H,** 350-t **GeV c.m.** (energy upgrade 500-ZHH/ttH)
- **circumference ~100 km**
- **total SR power ≤ 100 MW** (design limit)
- **#IPs = 2 or 4**
- beam-beam tune shift / IP scaled from LEP
- **peak luminosity / IP = 5×10^{34} $cm^{-2}s^{-1}$ at Higgs**
- top-up injection
- $\beta_y^* = 1$ mm ~ σ_z

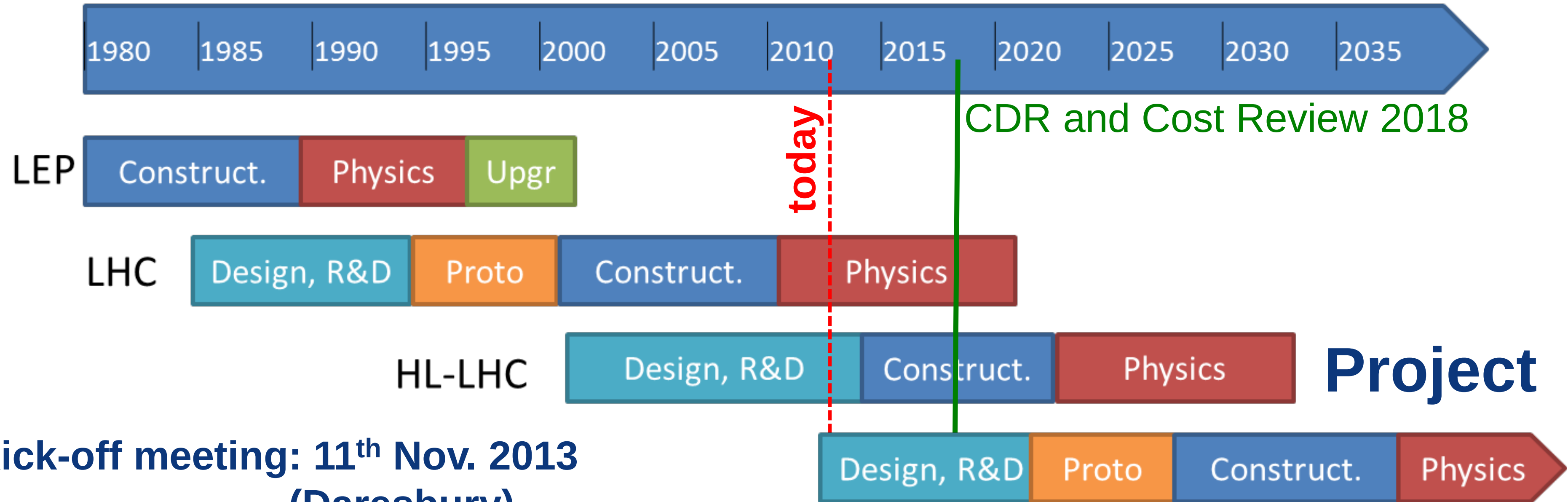
From M. Benedikt and F. Zimmermann

Main parameters FHEC *(he)*

- ***e-* energy = 60, 120, 250 GeV**
- ***p* energy = 50 TeV**
- spot size determined by p
- e^- current from FLC (SR power ≤ 50 MW)
- **#IPs = 1 or 2**

From M. Benedikt and F. Zimmermann

“CERN should undertake design studies for accelerator projects in a global context, with emphasis on ***proton-proton*** *and electron- positron* ***high-energy frontier machines.****”*

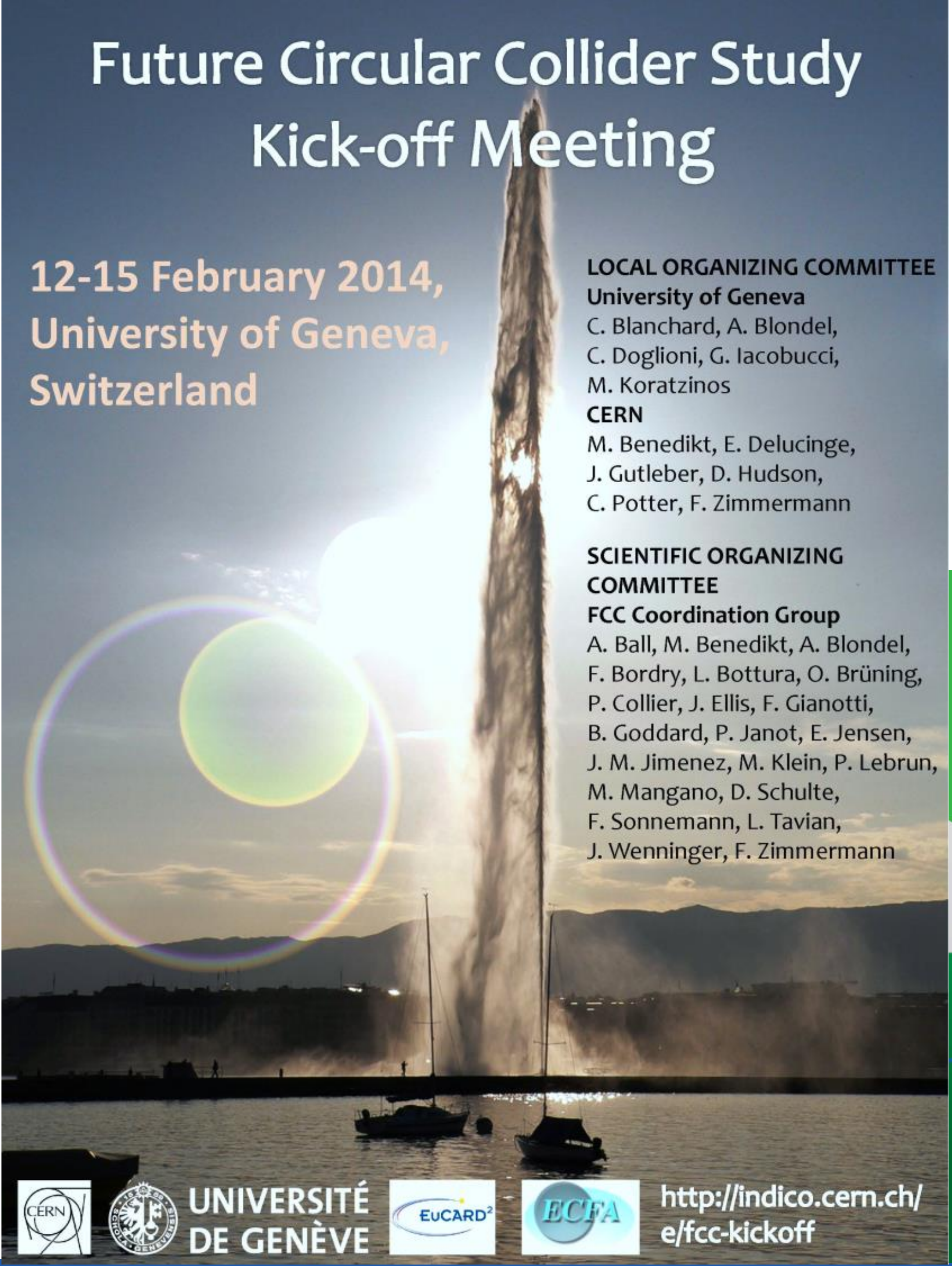


Kick-off meeting: 11th Nov. 2013 (Daresbury)

FCC Study : p-p towards 100 TeV

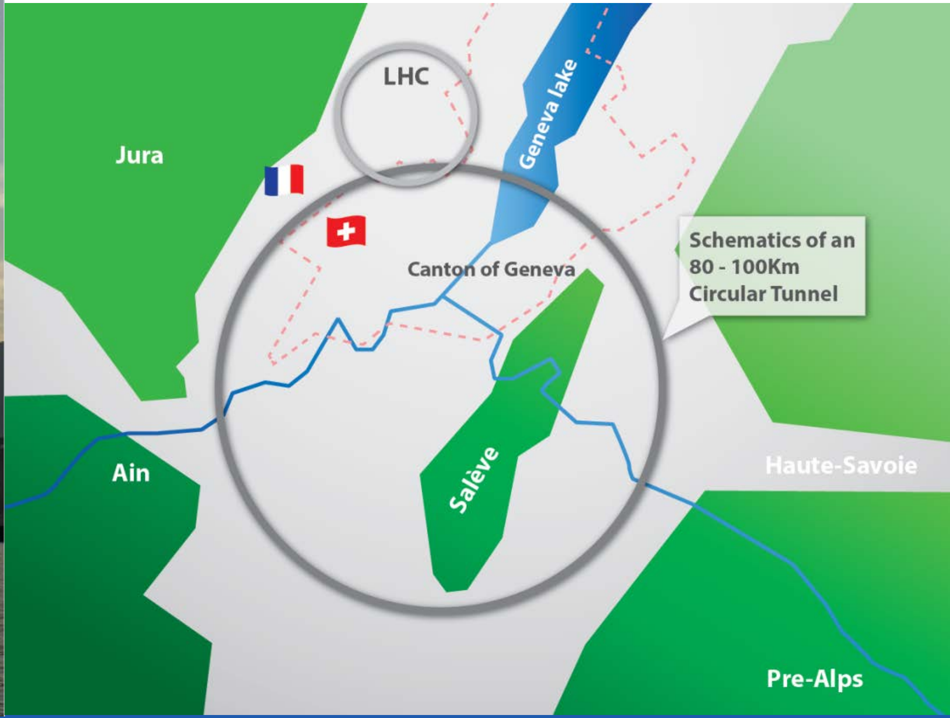
Kick-off meeting: 12th-14th Feb. 2014

FCC: Future Circular Colliders

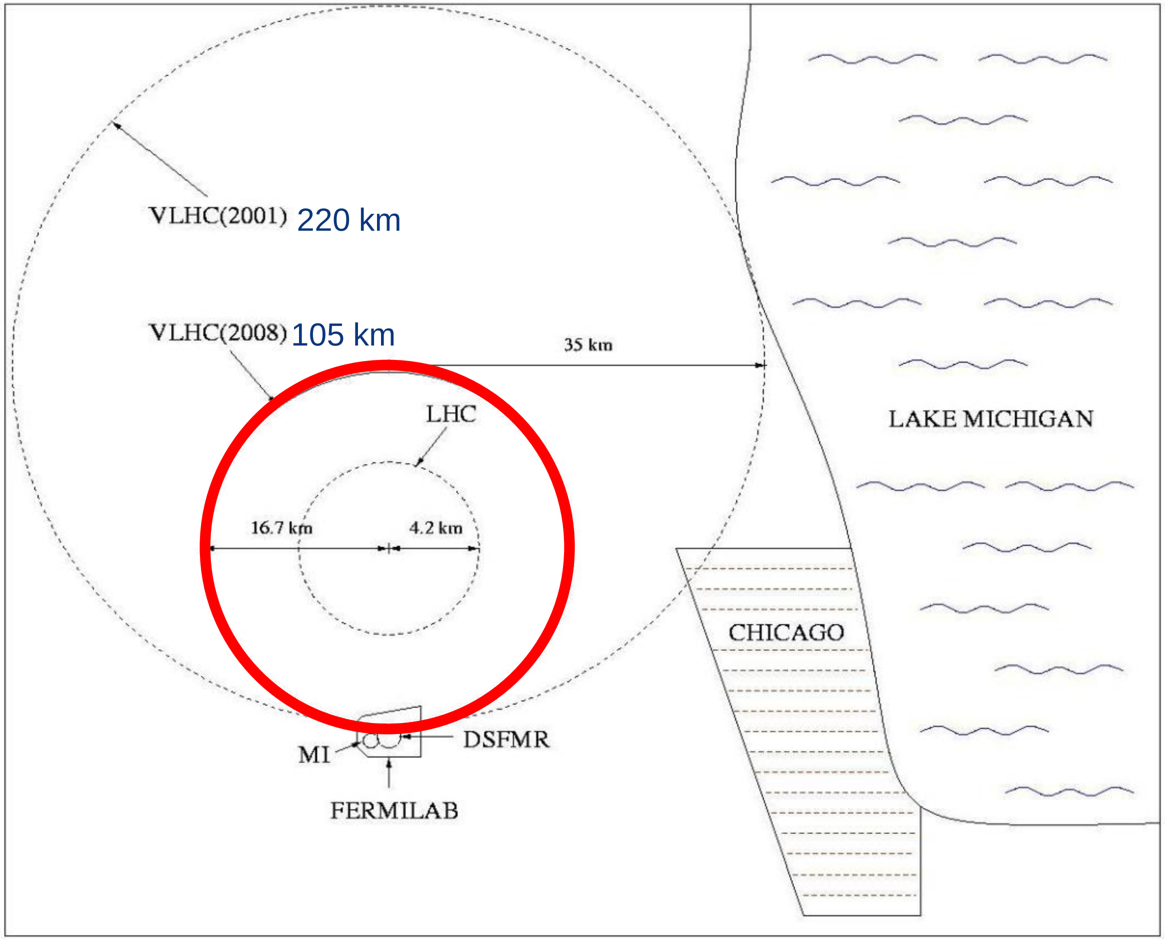


FCC Kick-off Meeting in Geneva next week

http://indico.cern.ch/e/fcc-kickoff



105 km tunnel near FNAL

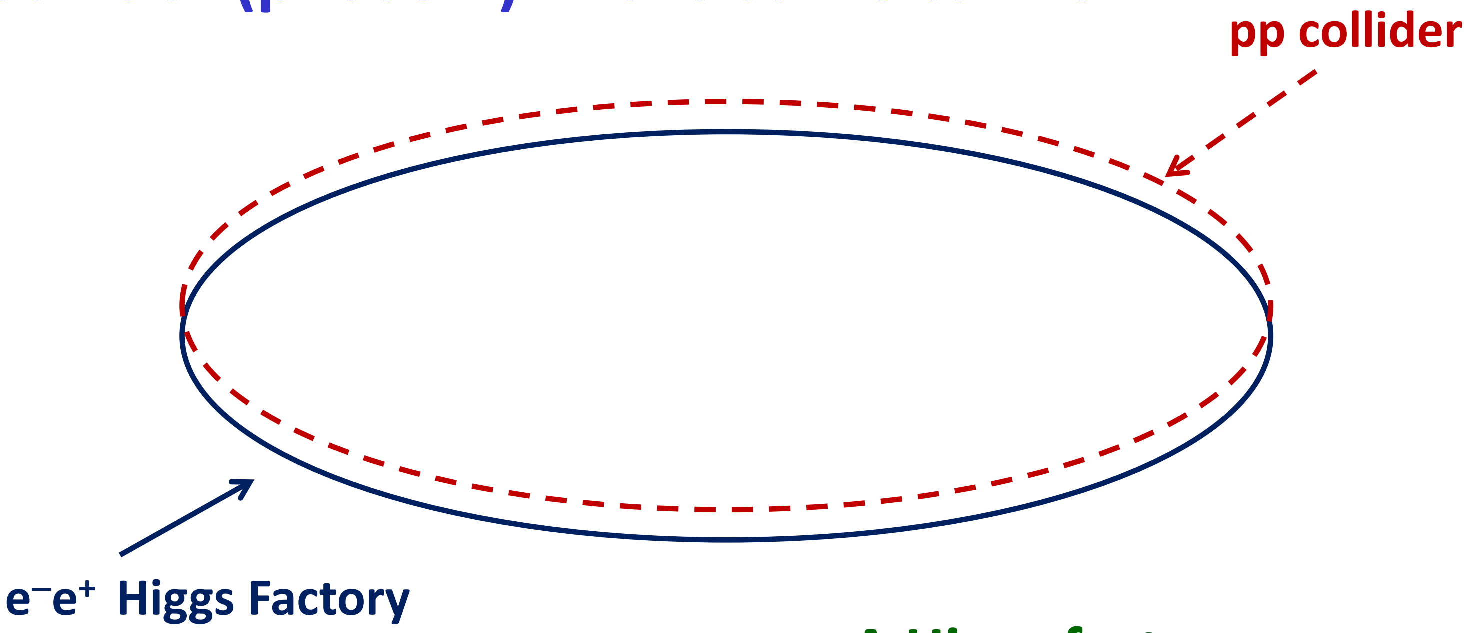


H. Piekarz, "… and … path to the future of high energy particle physics," JINST 4, P08007 (2009)


80 km ring in KEK area
12.7 km
KEK
Mt Tsukuba
筑波山
Miyawaki
宮脇
Tsutsujigaoka
つつじヶ丘
Mt Fuji
富士山
Ishioka
City Office
Makabe Branch
City Office
Chiyoda Branch
市役所千代田庁舎
City Office
Niihari Branch
Toyosato
Hospital
千代田PA
Map data ©2012 Google, ZENRIN

Introduction — What is a (CEPC + SppC) ?

- Circular Electron Positron Collider (phase I) + super pp Collider (phase II) in the same tunnel



A Higgs factory +
A machine of discovery

CEPC basic parameter:

- Beam energy ~120 GeV.
- Synchrotron radiation power ~50 MW.
- 50/70 km in circumference.

SppC basic parameter:

- Beam energy ~50-70 TeV.
- 50/70 km in circumference.
- Needs B_{max} ~20T.

The circumference of CEPC is determined by that of the SppC, which is determined by the final energy of proton beam and the achievable dipole field strength.

2013-10-18 6th TLEP workshop

中國科學院高能物理研究所
Institute of High Energy Physics 4

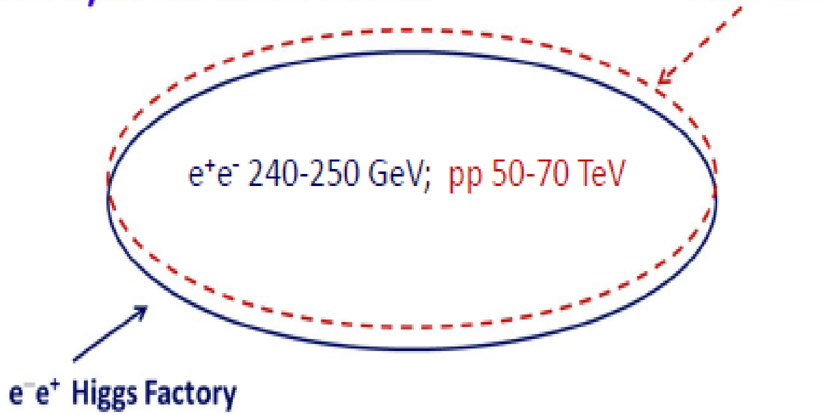
Main parameters for 70km CEPC

Parameter	Unit	Value	Parameter	Unit	Value
Energy	GeV	120	Circumference	km	70
Number of IP		1	SR loss	(GeV/turn)	2.35
N_e/bunch	1E11	4.43	N_b/beam		70
Beam current	mA	21.3	SR power/beam	MW	50
Partition Je		2	Long. damp. time	ms	12
Dipole field	Tesla	0.051	Bending radius	km	7.8
Emittance (x/y)	nm	8.42/0.042	β_{IP} (x/y)	mm	200/1
Trans. size (x/y)	μm	41.0/0.21	Mom. compaction	1E-4	0.45
$\xi_{x,y}$ /IP		0.1/0.1	Bunch length	mm	2.9

CEPC+SppC

- We are looking for a machine after BEPCII
- A circular Higgs factory fits our strategic needs in terms of timing, science goal, technological & economical scale, manpower reality, etc.
- Its life can be extended to a pp collider: great for the future

- Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel



- Circular Higgs factory is complementary to ILC
  - Push-pull option
  - Low energy vs high energy

We hope to collaborate with anyone who is willing to host this machine. Even if the machine is not built in China, the process will help us to build the HEP in China

Courtesy of Prof. Yifang Wang (IHEP)

CEPC+SppC

Where(if in China):
For example, Qin-Huang-Dao

CEPC+SppC

When(**dream**):

- CPEC
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15
    - R&D: 2015-2020
    - Engineering Design: 2015-2020
  - **Construction: 2021-2027**
  - **Data taking: 2028-2035**
- SPPC
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - **Construction: 2035-2042**
  - **Data taking: 2042 -**

International Workshop on Future High Energy Circular Colliders (December 2013) (IHEP, Beijing)

Courtesy of Prof. Yifang Wang (IHEP)

European Strategy for Particle Physics
approved May 2013 by the CERN Council

- **Strategy of Europe for Particle Physics**

- Strategy in a global context
- Strategy developed with international input

- CERN is essential in executing this strategy in and for Europe

European Strategy for Particle Physics
approved May 2013 by the CERN Council

Organisational Issues

Future major facilities in Europe and elsewhere require collaboration on a global scale.

CERN should be the framework within which to organise a global particle physics accelerator project in Europe, and should also be the <u>leading European partner in global particle physics accelerator projects elsewhere</u>. Possible additional contributions to such projects from CERN's Member and Associate Member States in Europe should be coordinated with CERN.

Strategy comprises **four high priority items** for large-scale scientific activities which could/should be organised as international projects

Conclusion: "Exploitation of the full potential of the LHC"

- LS1 [2013-2014] : 1st beams in 2015
- Run 2 : 13 TeV – 25 ns – up to 1.7 10^{34} $cm^{-2}.s^{-1}$, 40-45 fb^{-1} per year
- LS2 (higher intensity - LIU) [2018 or 2019]
- Run 3 (up to ~2.0 10^{34} $cm^{-2}.s^{-1}$)

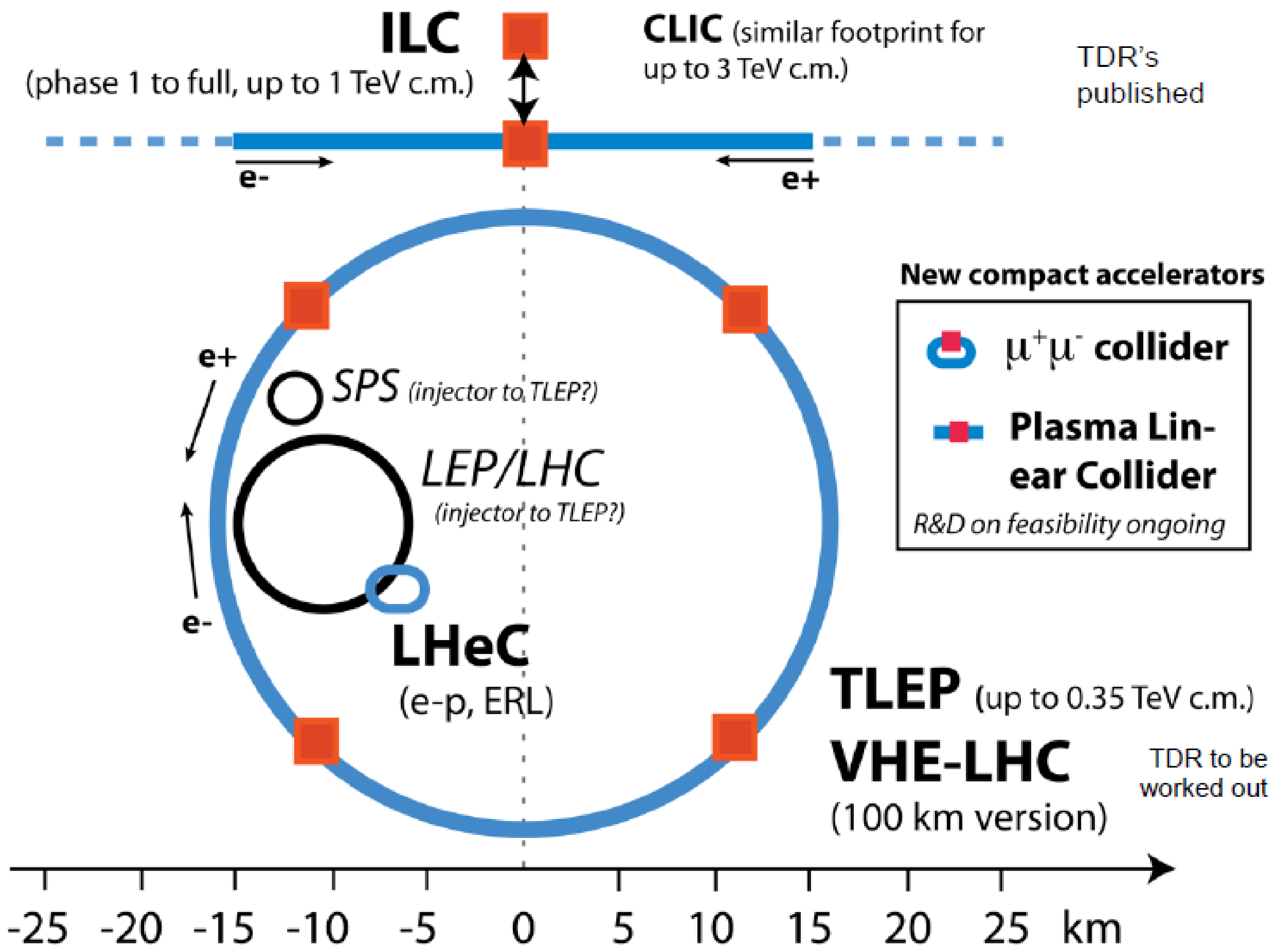
300 fb^{-1} before LS3

- HL-LHC : R&D => now an approved project with a kick-off meeting on 11th Nov. 2013

  A lot of technical and operation challenges :
  - Nb3Sn magnets (accelerator field quality) (HFM roadmap)
  - Collimators
  - Superconducting links
  - Crab cavities
  - Increased availability (machine protection,…)
  - …

  Accelerator-experiment interface are central:
  - Bunch spacing, pile-up density, crossing schemas, background, forward detectors, collimation,…

3000 fb^{-1} before 2035


ILC
(phase 1 to full, up to 1 TeV c.m.)
CLIC (similar footprint for up to 3 TeV c.m.)
TDR's published
e-
e+
New compact accelerators
μ+μ- collider
Plasma Linear Collider
R&D on feasibility ongoing
e+
SPS (injector to TLEP?)
LEP/LHC
(injector to TLEP?)
e-
LHeC
(e-p, ERL)
TLEP (up to 0.35 TeV c.m.)
VHE-LHC
(100 km version)
TDR to be worked out
-25 -20 -15 -10 -5 0 5 10 15 20 25 km

CERN

www.cern.ch