Accelerators at the high-energy frontier: CERN plans, projects and future studies

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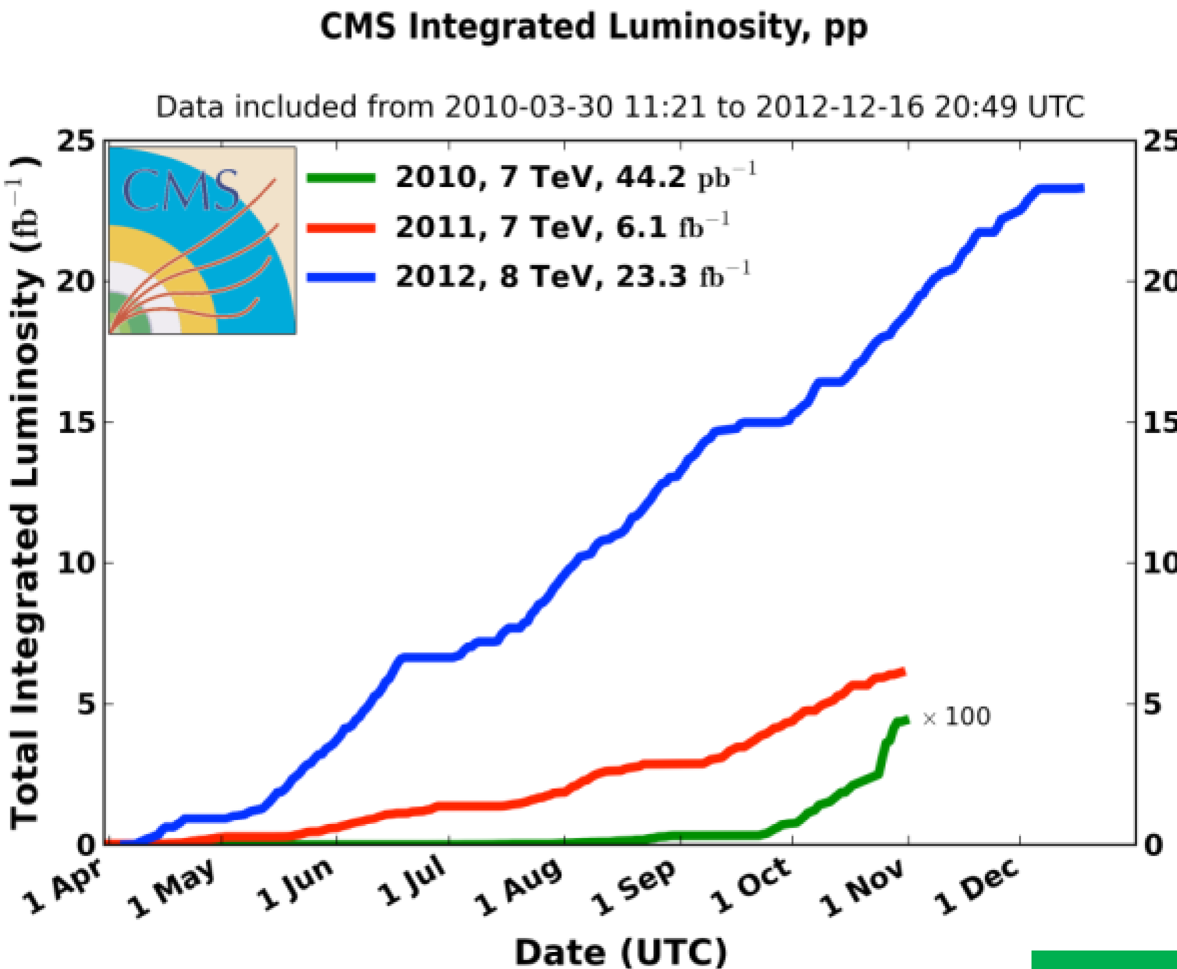
- LHC plans for runs 2 and 3
- The High-Luminosity LHC project
- The CLIC study
- The FCC study

LHC Run 1 (2010-2012)
A rich harvest



$\Sigma \sim 30\ \text{fb}^{-1}$

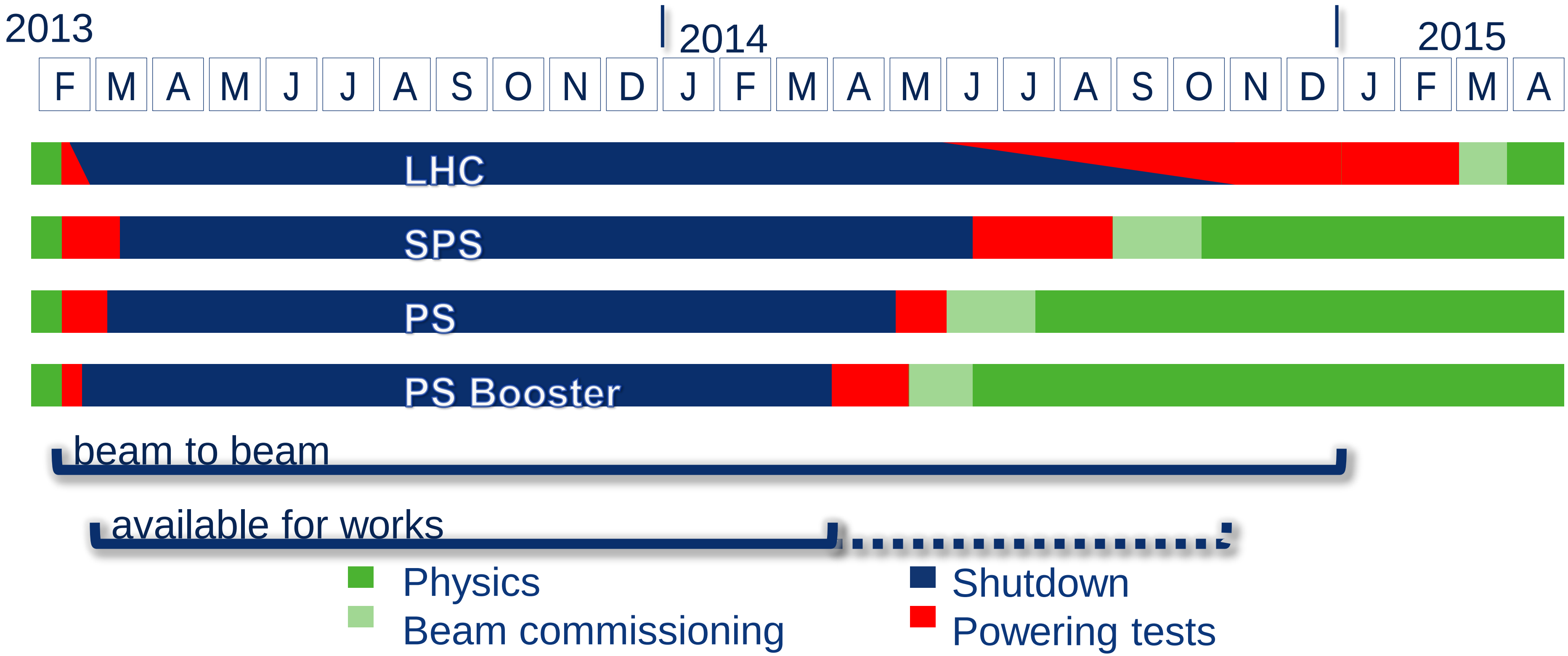
2010: **$0.04\ \text{fb}^{-1}$**
7 TeV CoM
Commissioning

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

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

7 TeV and 8 TeV in 2012

LS1 from February 2013 to December 2014



LHC consolidation during LS1

1695 Openings and final reclosures of the interconnections

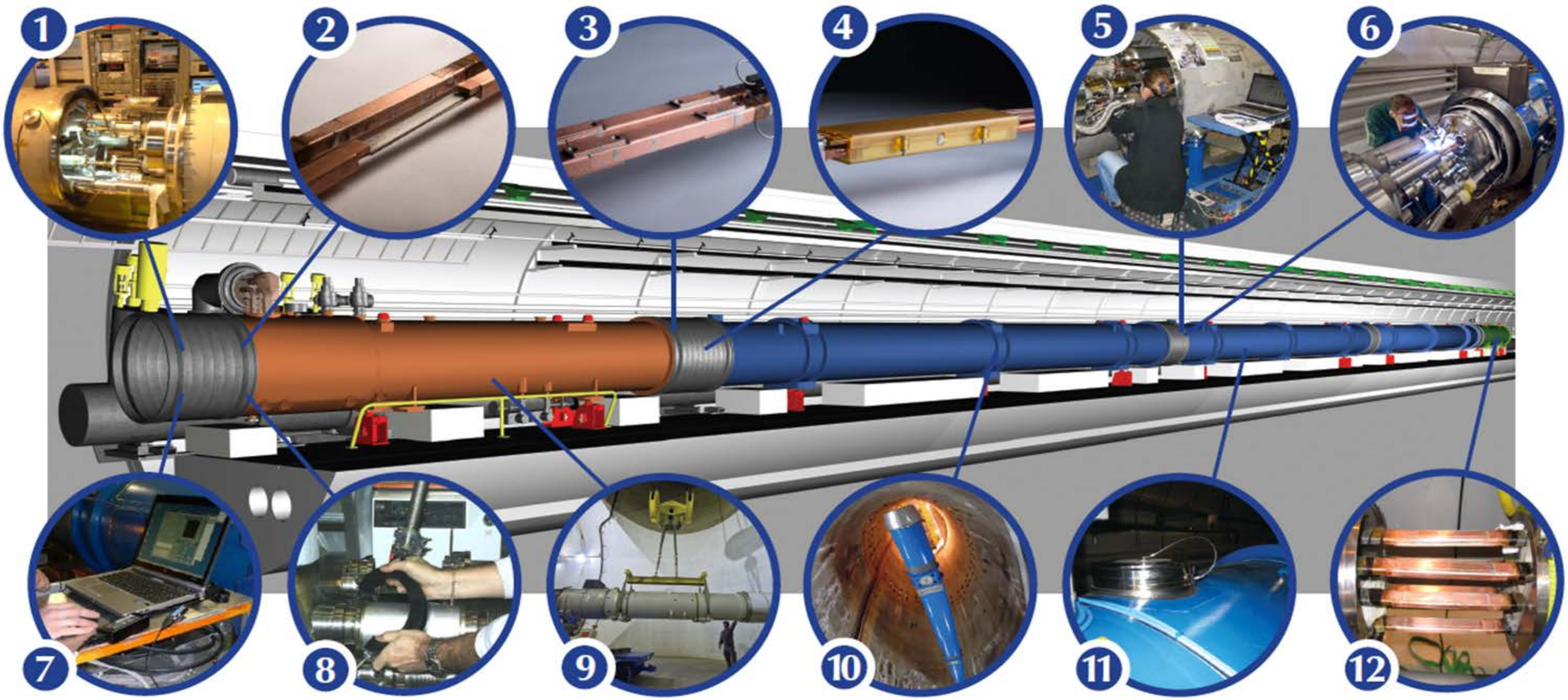
Complete reconstruction of 3000 of these splices

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

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

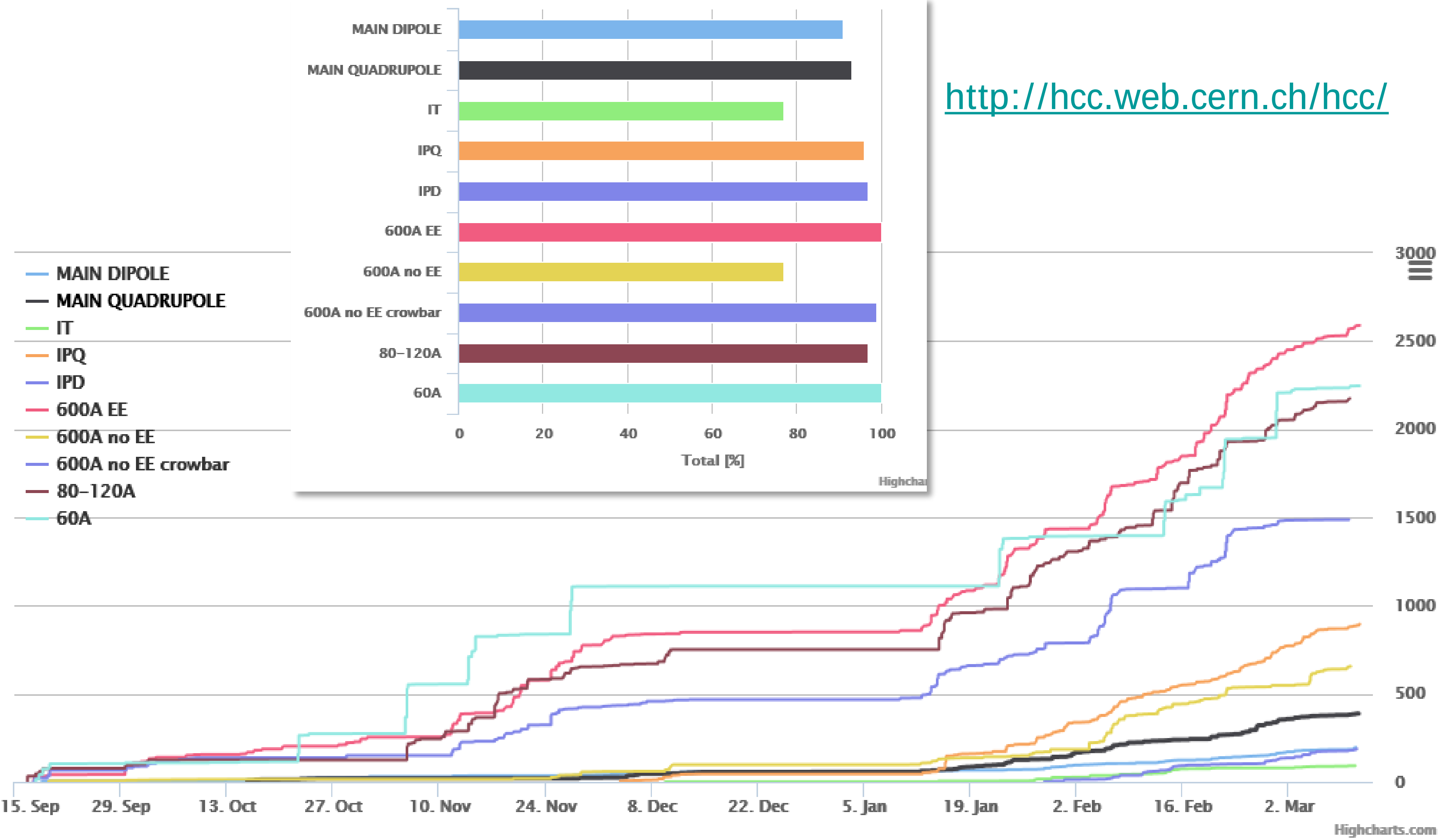
3 quadrupole magnets to be replaced

15 dipole magnets to be replaced

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

Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes

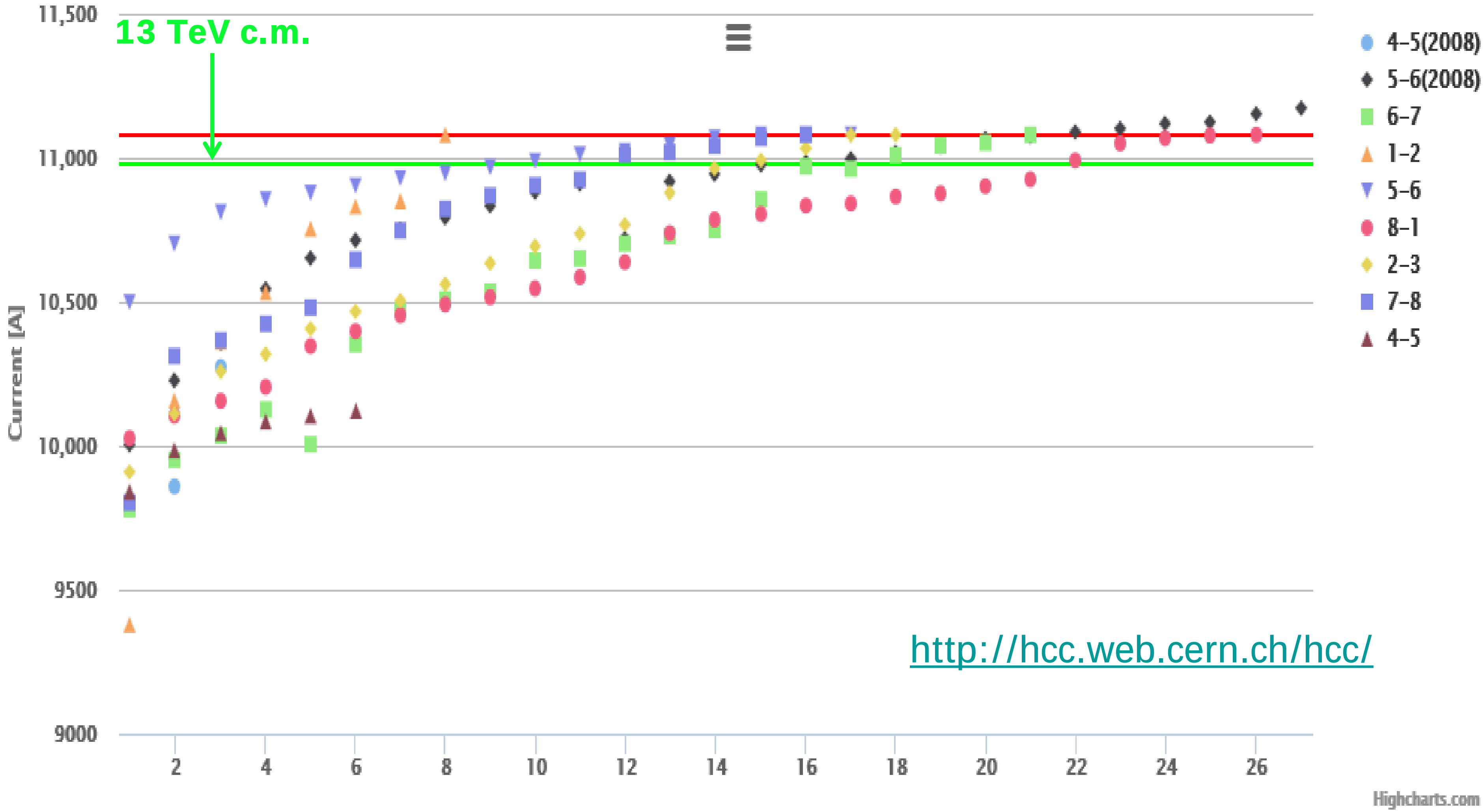
LHC restart
Power tests on magnet circuits



http://hcc.web.cern.ch/hcc/

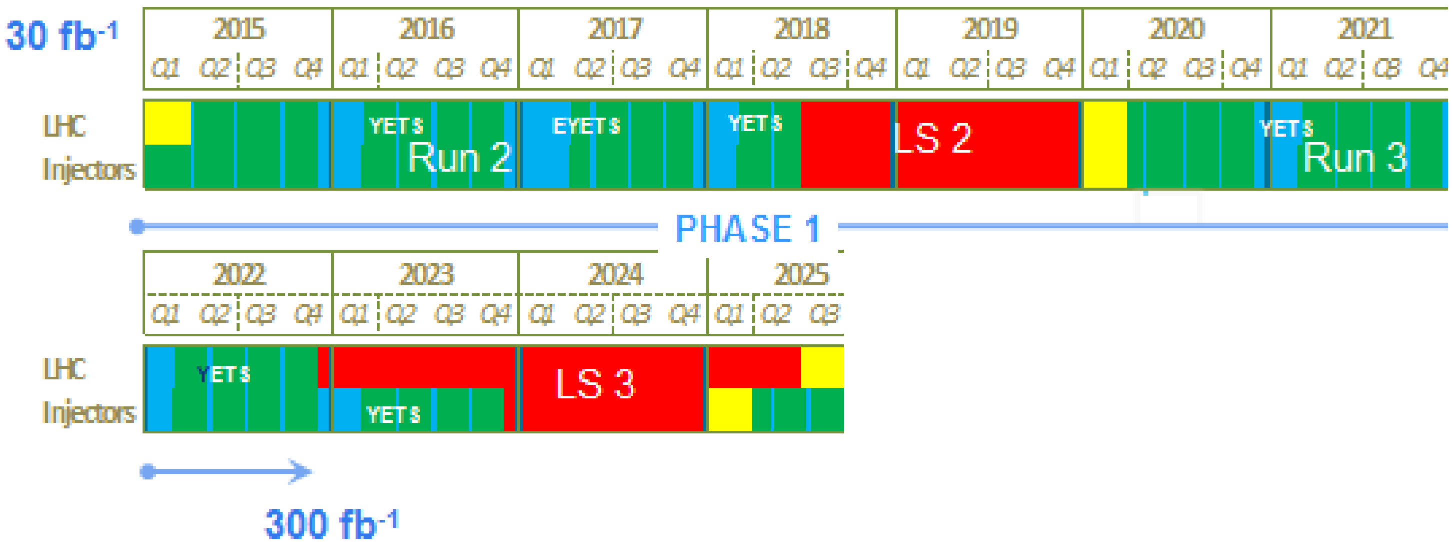
LHC restart

Dipole re-training, by sector



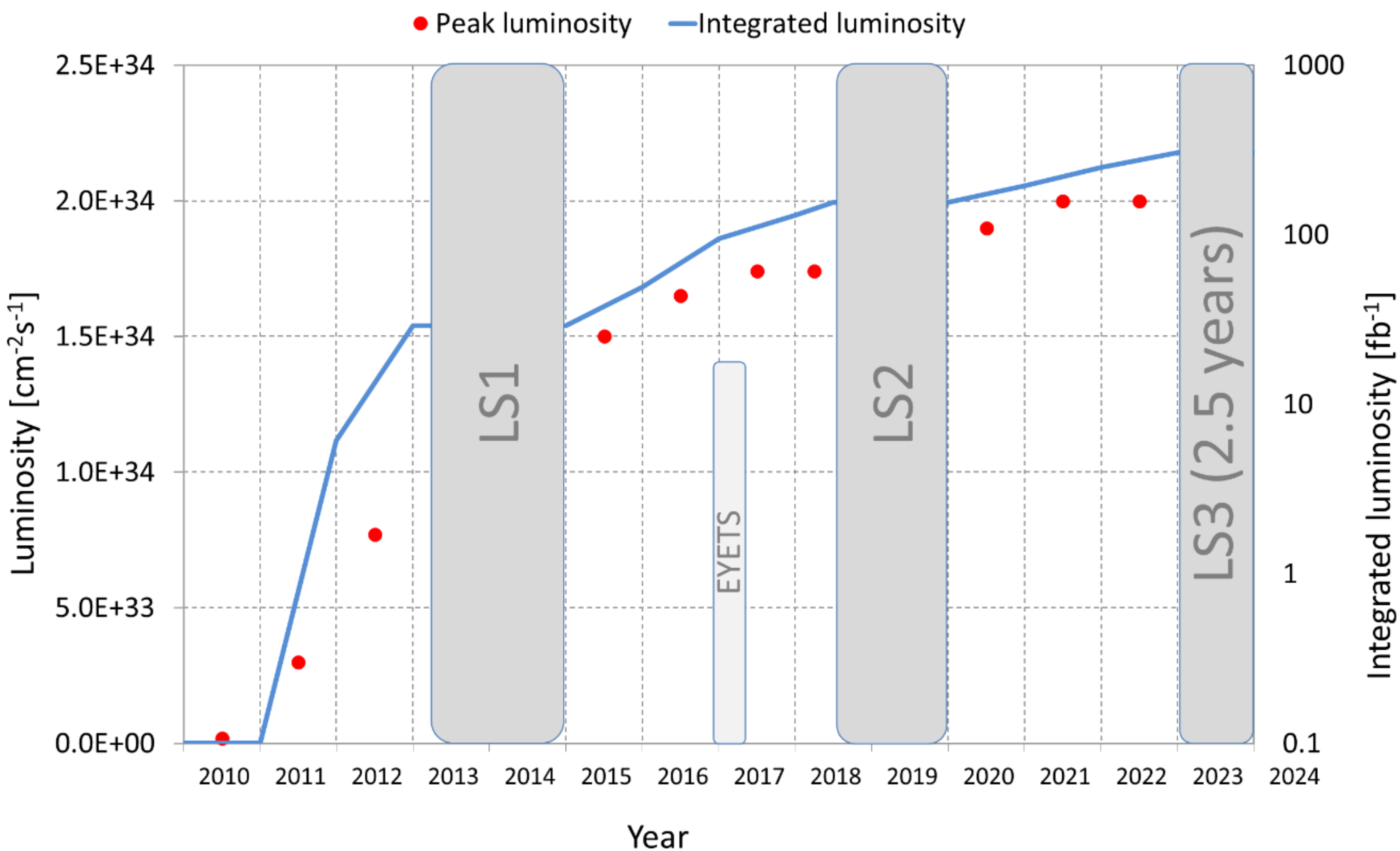
http://hcc.web.cern.ch/hcc/

Plans for LHC runs 2 and 3



- **Run 2**
  - Luminosity goal 1.3 x 10^{34} cm^{-2} s^{-1}, operation with 25 ns bunch spacing (2800 bunches), giving an estimated pile-up of 40 events per bunch Xing
  - Integrated luminosity goal ~100-120 fb^{-1} (better estimate by end 2015)
  - Priorities for 2015
    - p-p: 13 TeV c.m., integrated luminosity ~10 fb^{-1}, 25 ns bunch spacing
    - Pb-Pb: one month towards end of year
- **Runs 2 and 3**: aim at 300 fb^{-1} before LS3

LHC luminosity plan for Runs 2 and 3



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European Strategy Update 2013
Top-priority large-scale scientific activities

- To **measure Higgs properties** with highest possible precision and search for **new physics at the energy frontier**
  - 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 of collecting ten times more data than the original design, by around 2030

- To propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy Update
  - 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.

- http://cds.cern.ch/record/1567258/files/esc-e-106.pdf

CERN medium- & long-term plans

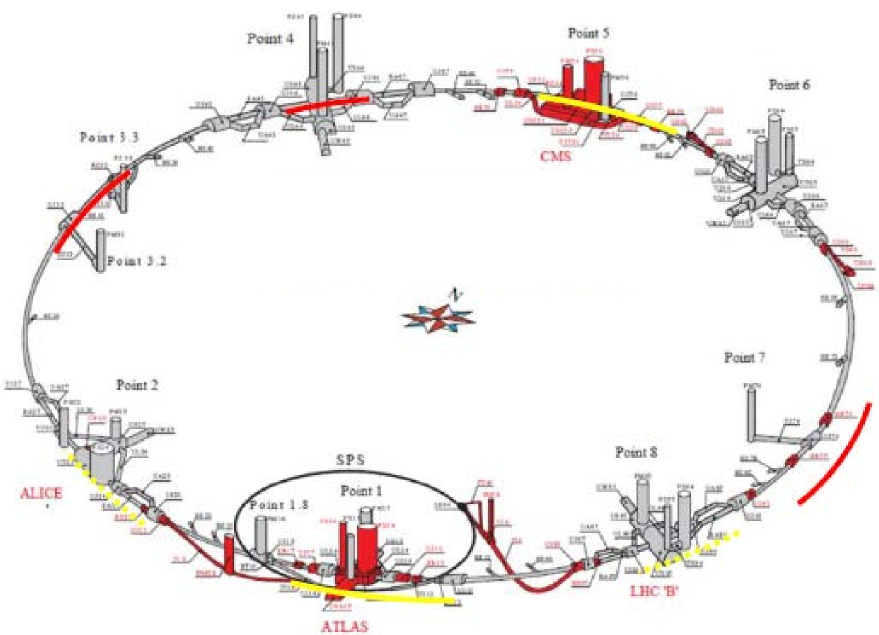
The **CERN Medium-Term Plan** approved by the Council in June 2014 implements the European Strategy including a long-term outlook

The scientific programme is concentrated around four priorities:

1. **Full LHC exploitation** – the highest priority – including the construction of the High-Luminosity Upgrade until 2025
2. **High-Energy Frontier** – CERN's role and preparation for the next large scale facility
3. **Neutrino Platform** – contribute to a future long baseline facility in the US and allow for detector R&D for neutrino experiments
4. **Fixed-target programme** – maintain the diversity of the field and honour ongoing obligations by exploiting the unique facilities at CERN

The HL-LHC project
Objectives and contents

- Determine a **hardware configuration** and a set of **beam parameters** that will allow the LHC to reach the following targets:
  - enable a total integrated luminosity of 3000 fb^{-1}
  - enable an integrated luminosity of 250-300 fb^{-1} per year
  - design for $\mu \sim 140$ (~ 200) (peak luminosity of 5 (7) 10^{34} cm^{-2} s^{-1})
  - design equipment for ‘ultimate’ performance of 7.5 10^{34} cm^{-2} s^{-1} and 4000 fb^{-1}



Major intervention on 1.2 km of LHC ring

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

Paths to high luminosity

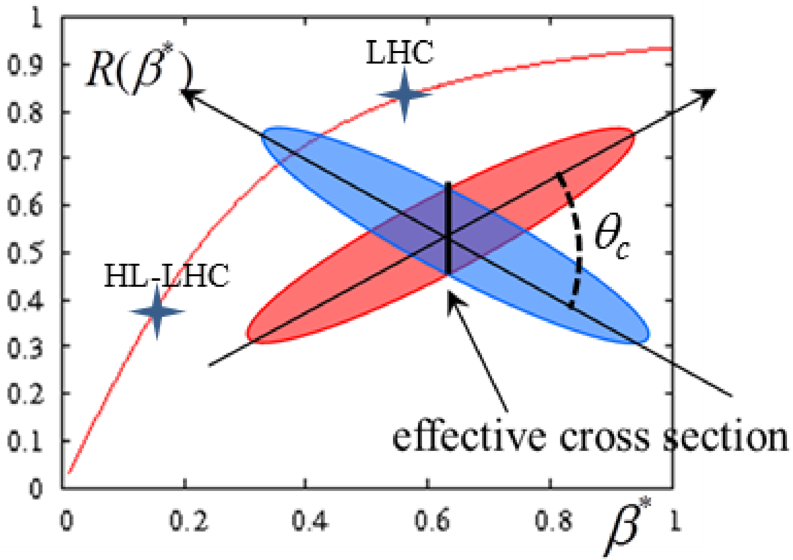
Increase bunch population

Increase R = reduce crossing angle?

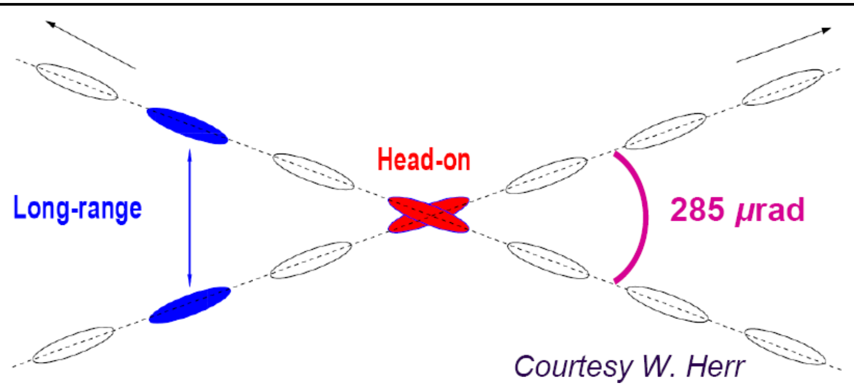
$$L = \gamma \frac{n_b N^2 f_{rev}}{4\pi\, \beta^*\, \varepsilon_n} R; \qquad R = 1/\sqrt{1 + \frac{\theta_c\, \sigma_z}{2\sigma}}$$

Reduce beta at collision

Reduce emittance



Beam-beam effect precludes too low crossing angle



The HL-LHC project
From accelerator physics to technology

Accelerator physics

- Reduce emittance → Increase intensity & brightness of injectors: the LIU project
- Increase bunch population → Increase intensity & brightness of injectors: the LIU project; → More powerful cryogenics, Improved collimation, Improved machine protection, Stronger R to E → relocation
- Reduce beta at collision → New low-beta quadrupoles
- Limit beam-beam effect → "Crab" cavities
- Reduce crossing angle → "Crab" cavities

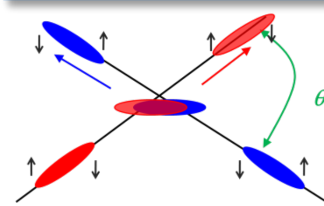
Increase intensity & brightness of injectors: the LIU project

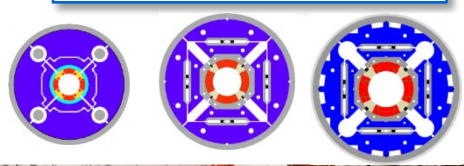
More powerful cryogenics
Improved collimation
Improved machine protection
Stronger R to E → relocation

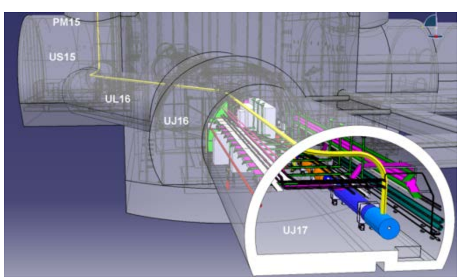
New low-beta quadrupoles

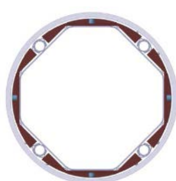
“Crab” cavities

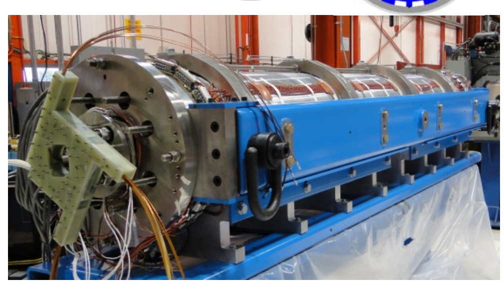
Accelerator technology

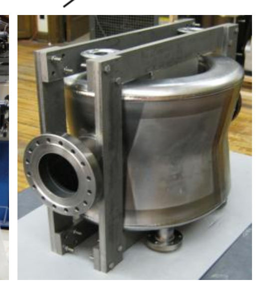






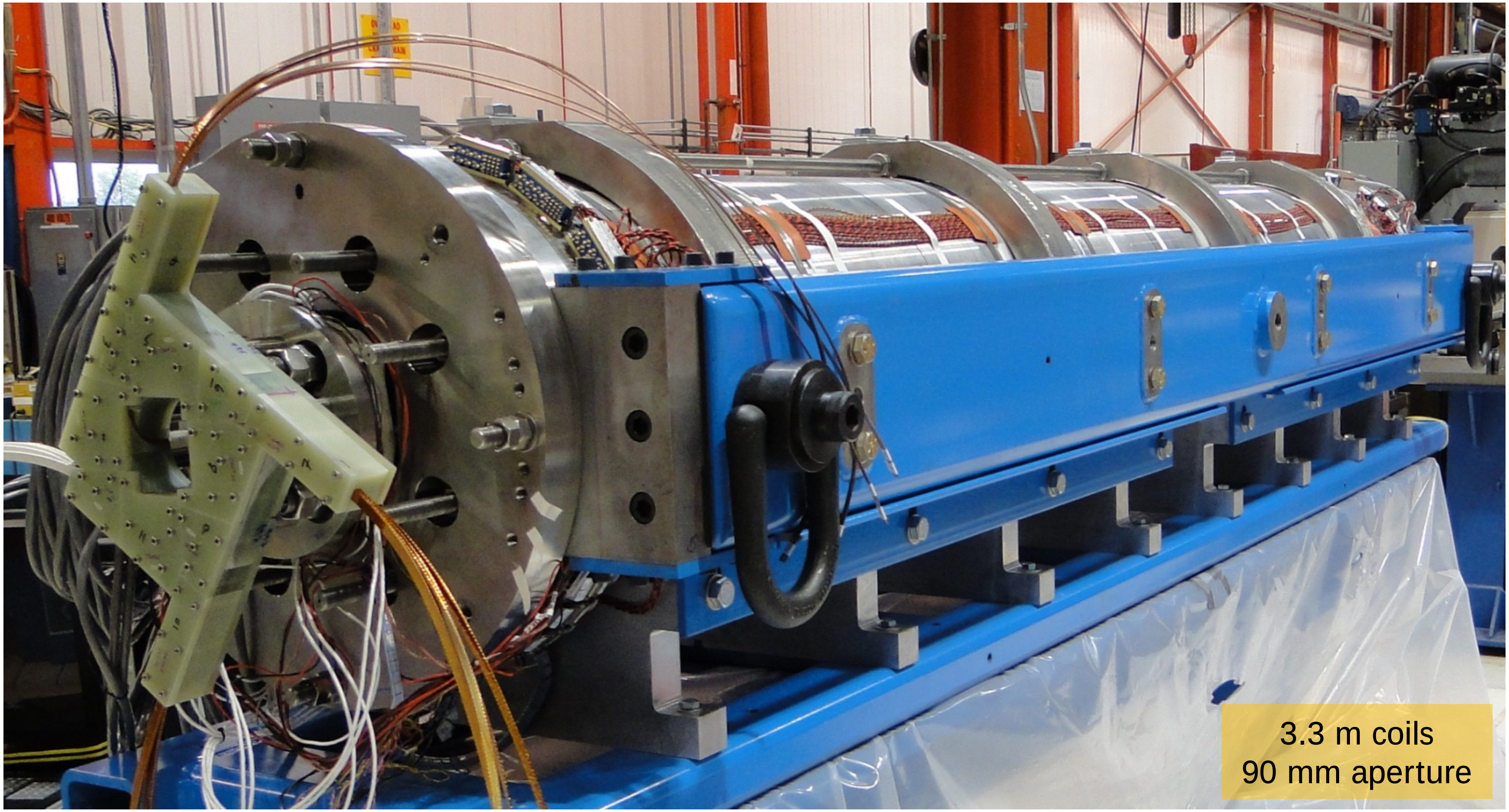






Development of high-field magnets

LARP long Nb_3Sn quadrupole

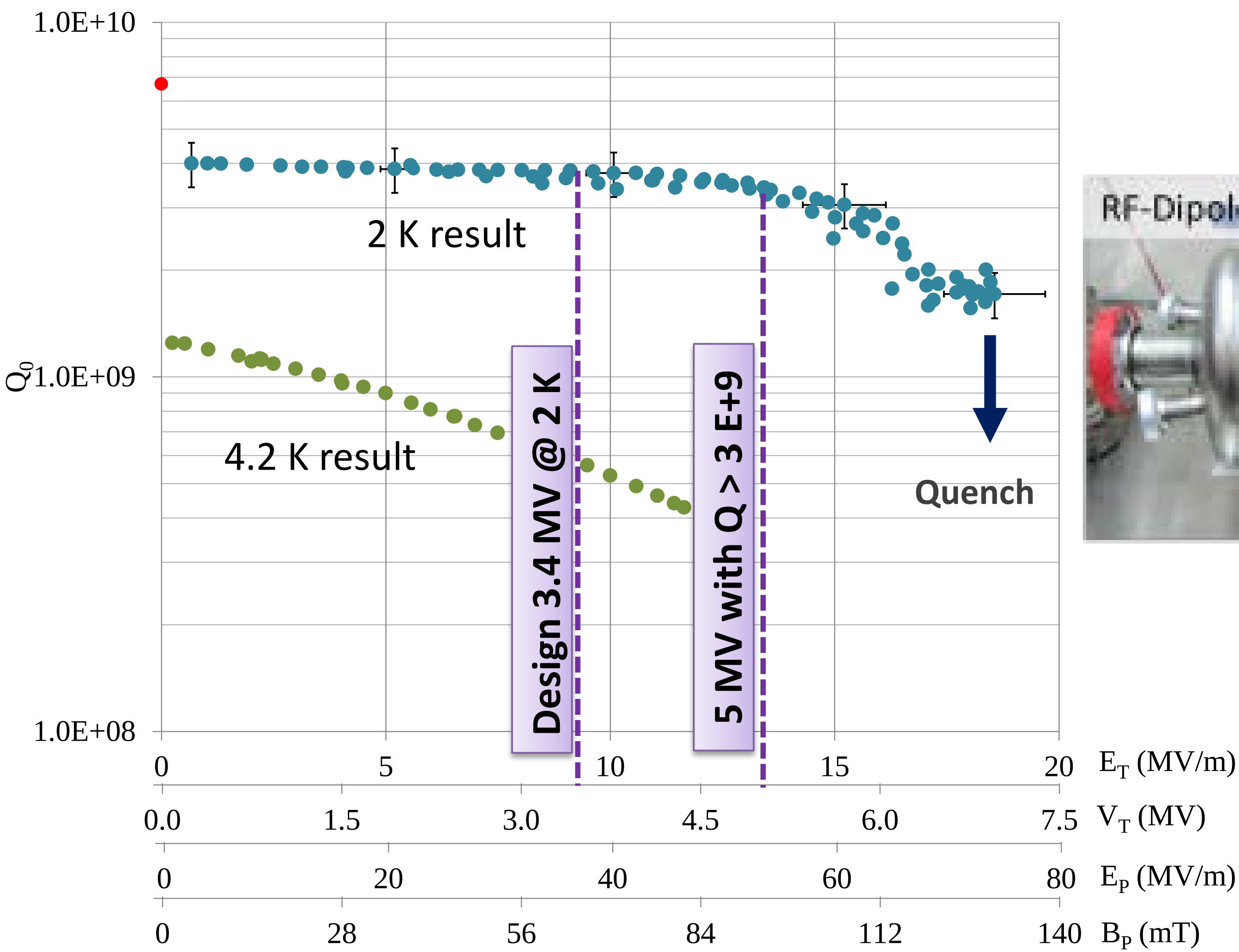


3.3 m coils
90 mm aperture

Target:
200 T/m gradient at 1.9 K

Reached:
208 T/m at 4.6 K
210 T/m at 1.9 K

Prototype “crab” cavities
Excellent test results



OLD DOMINION UNIVERSITY

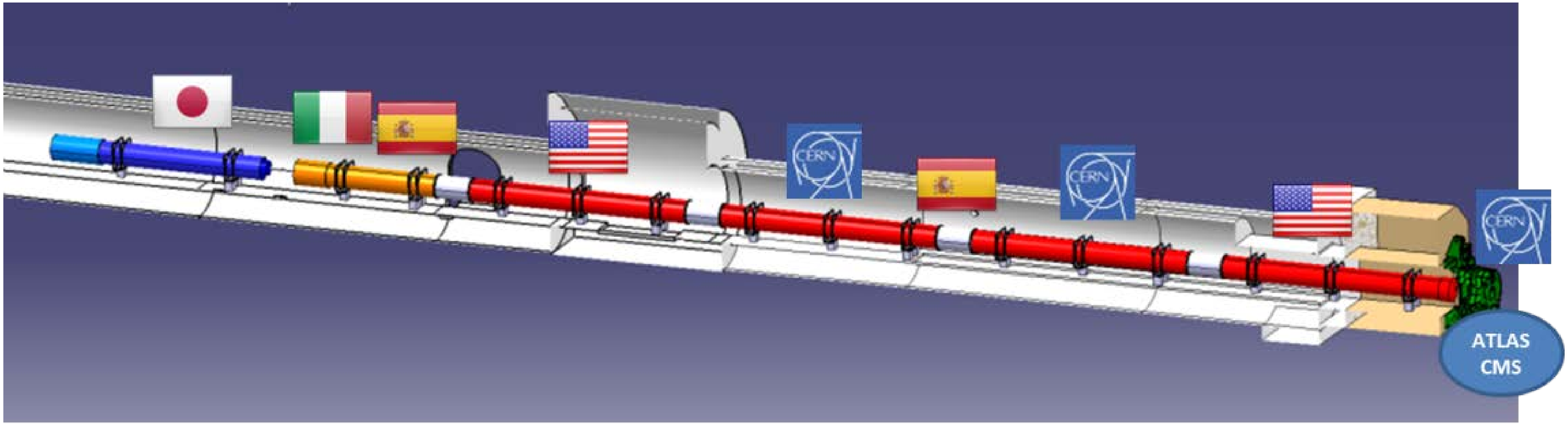
LARP

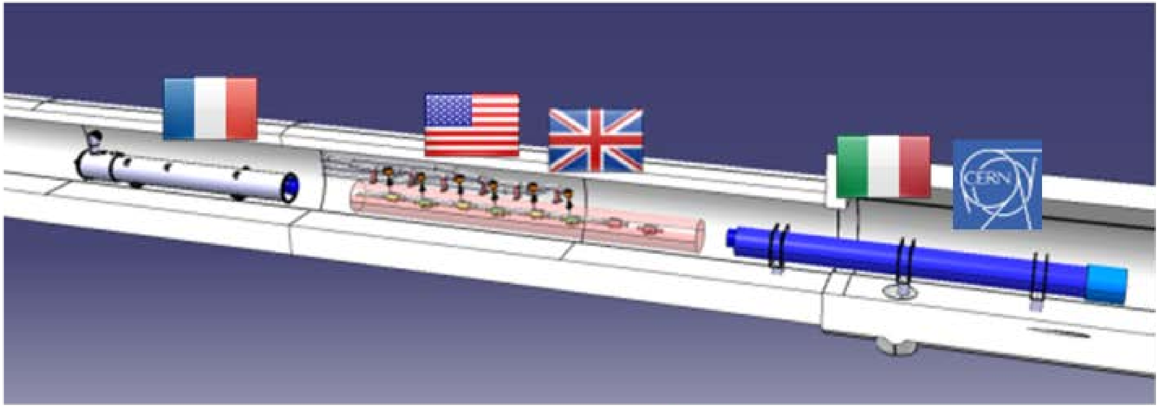
J. Delayen

The HL-LHC collaboration

L. Rossi

HL-LHC collaboration workpackages



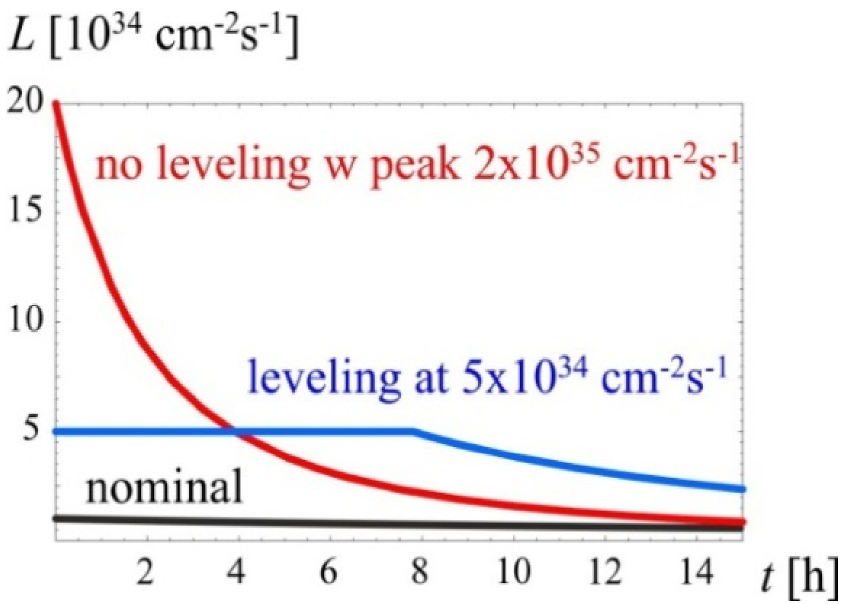


Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

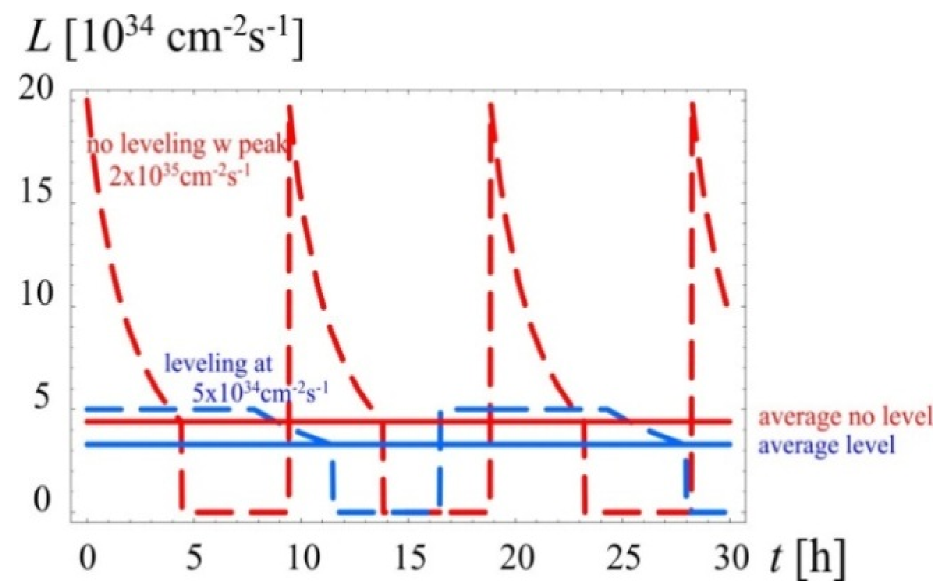
CC : R&D and Design **UK**

Luminosity leveling

Maximize integrated luminosity, limit pile-up & radiation dose



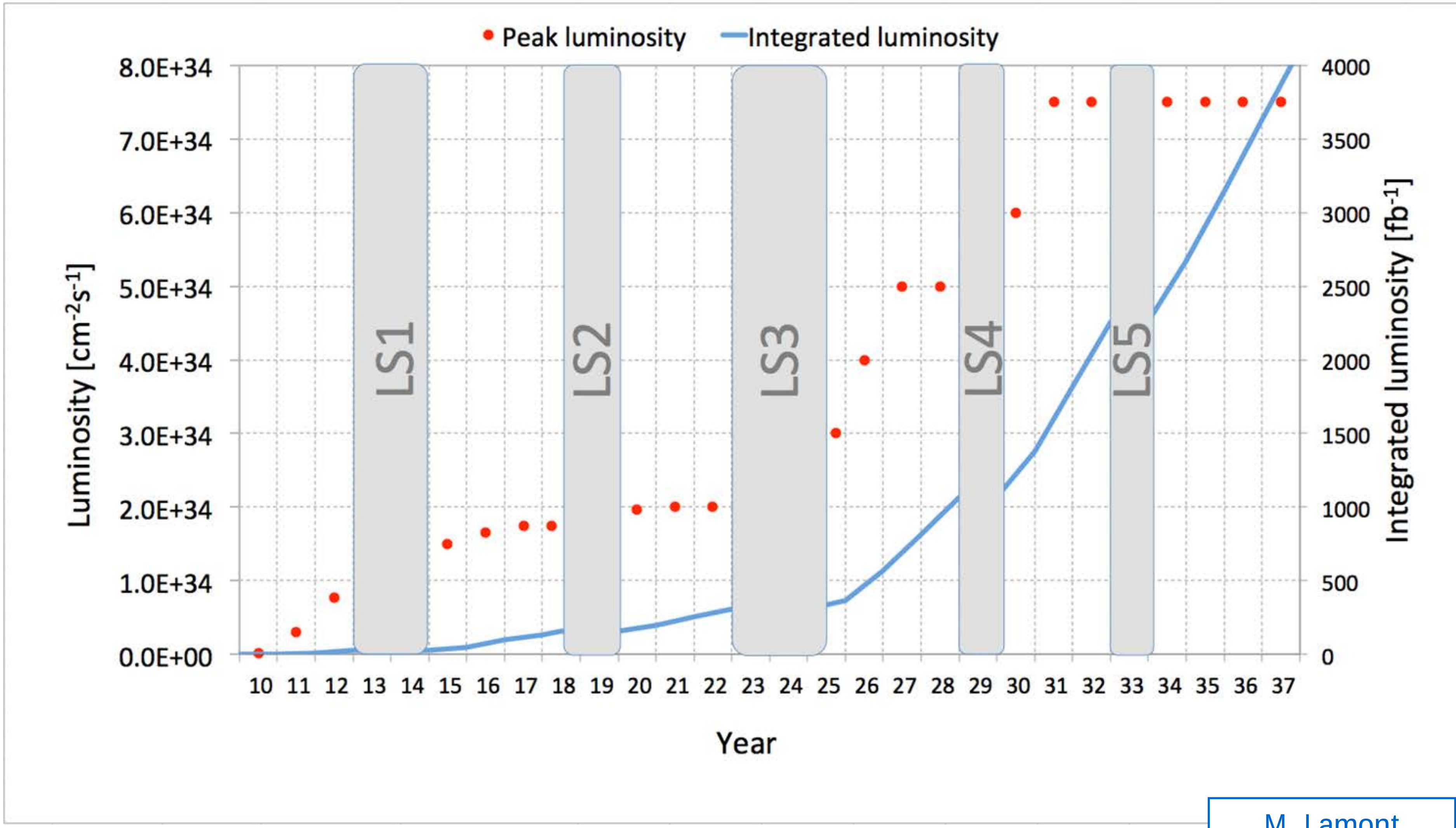
Evolution of luminosity during single long fill
- Nominal LHC
- HL-LHC, no levelling
- HL-LHC, with levelling



Luminosity profiles with optimized run time
- HL-LHC, no levelling
- HL-LHC, with levelling

O. Brüning

HL-LHC luminosity forecast



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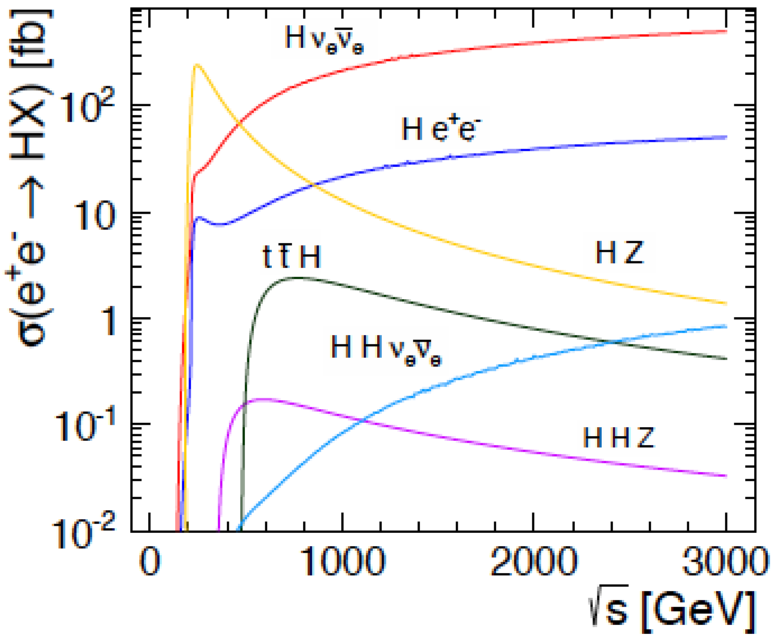
Scope of the CLIC study

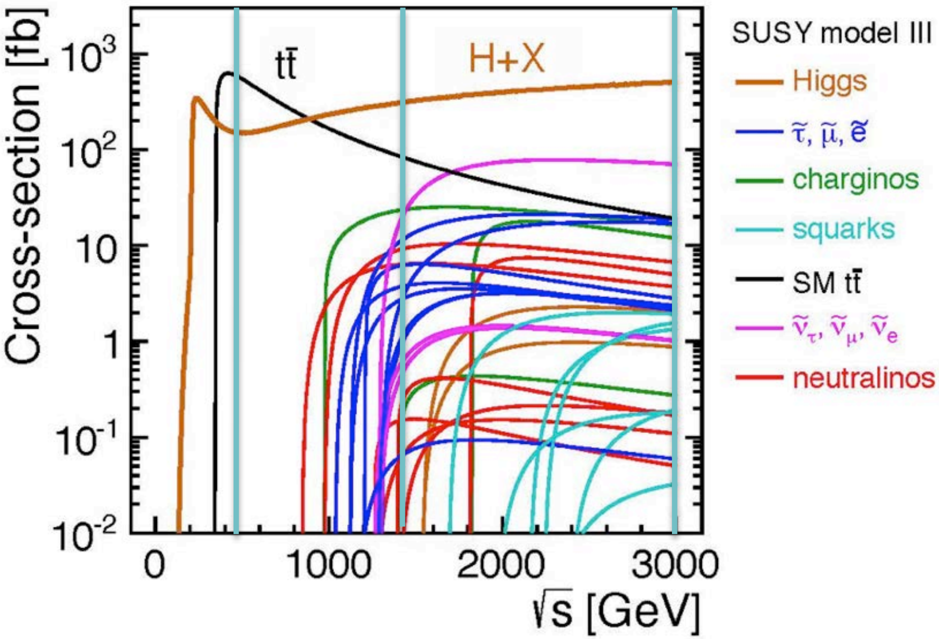
- The Compact Linear Collider (CLIC) is a high-energy linear e+ e- collider with the potential to operate at centre-of-mass energies ranging from few hundred GeV up to 3 TeV, and with luminosities of a few 10^{34} $cm^{-2}.s^{-1}$
- CLIC will allow for the exploration of Standard Model physics, such as precise measurements of the Higgs, top and gauge sectors, as well as for a multitude of searches for new physics, either through direct discovery or indirectly, via high-precision observables
- CLIC is based on a novel two-beam acceleration technique providing acceleration gradients at the level of 100 MV/m in normal-conducting structures
- The high luminosity is achieved by the very small beam emittances, ensured by appropriate design of the beam lines and tuning techniques, as well as by a precision pre-alignment system and an active stabilisation system
- The conceptual study covers the the main linacs and their detectors, as well as the drive beam and main beam injector complexes
- The study includes power, energy and industrialisation aspects and provides staged implementation scenarios, including schedule and cost estimates

Precision SM physics



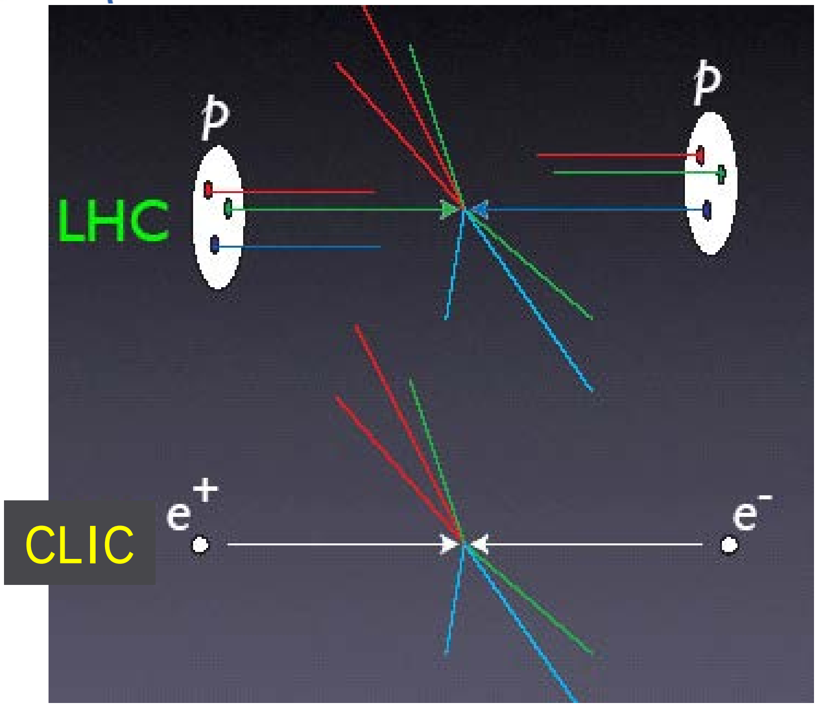
Cross-sections
for different production mechanisms
for a 125 GeV Higgs boson

New physics



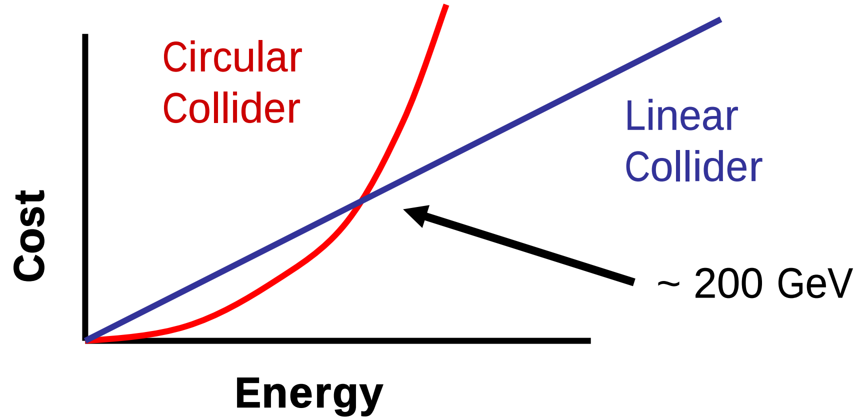
Cross-sections
for pairs of superpartners in SUSY *Model III*
(the H+X cross-section is for a 125 GeV SM
Higgs boson)

Why electrons?



- Electrons are elementary particles, protons are composite
- Well defined initial state in energy and angular momentum
- Permits precision studies
- All center-of-mass energy is used in the collision

Why linear?



- Parasitic synchrotron radiation
  - scales with E^4/m^4 and with 1/R
  - strong limitation of electron machines at high energy
- Different scaling of investment cost w r to beam energy
- BUT, single-pass machine
  - Lower efficiency
  - Need low-emittance, high-brightness beams
  - Contain emittance growth
  - Squeeze the beams as small as possible at collision point

The luminosity challenge of linear colliders

- Lower-energy regime (small beamstrahlung)

$$\mathcal{L} \sim \frac{1}{\sqrt{\beta_y \varepsilon_y}} \eta \frac{P}{E}$$

Grid power

Beam energy

Grid-to-beam efficiency

Vertical beta at collision

Vertical emittance

- High-energy regime (large beamstrahlung)

$$\mathcal{L} \sim \frac{1}{\sqrt{\sigma_z}} \frac{1}{\sqrt{\varepsilon_y}} \eta \frac{P}{E}$$

Bunch length

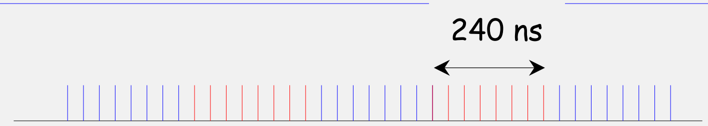
CLIC

Particles per bunch	3.7×10^9	bunches per pulse	312
bunch spacing	$15\,cm$	bunch length	$44\,\mu m$
initial r.m.s. energy spread	$\leq 2\,\%$	final r.m.s. energy spread	$0.35\,\%$
initial horizontal emittance	$\leq 600\,nm$	final horizontal emittance	$\leq 660\,nm$
initial vertical emittance	$\leq 10\,nm$	final vertical emittance	$\leq 20\,nm$

CLIC layout at 3 TeV

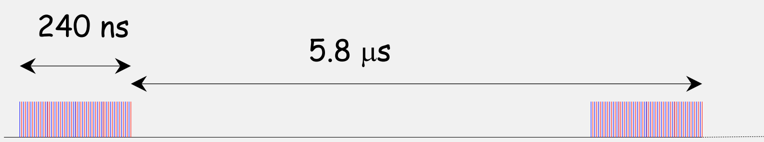
Drive Beam

Drive beam time structure - initial

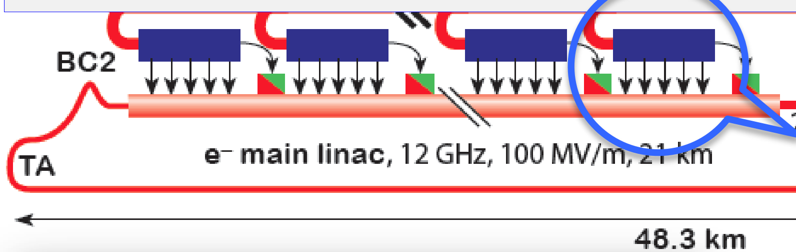


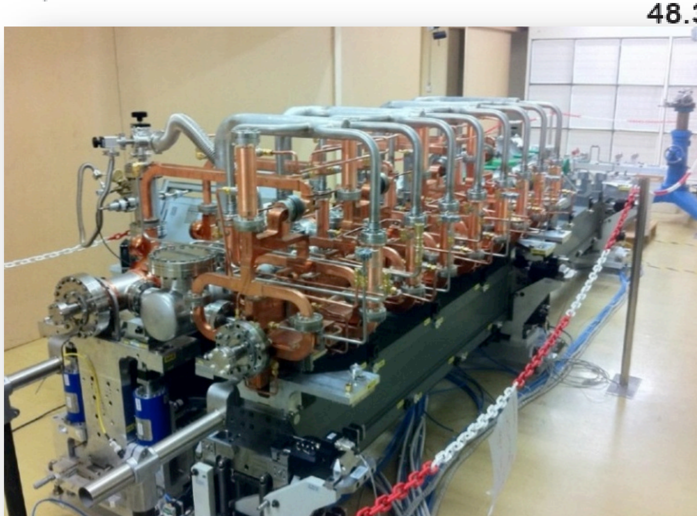
140 μs train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

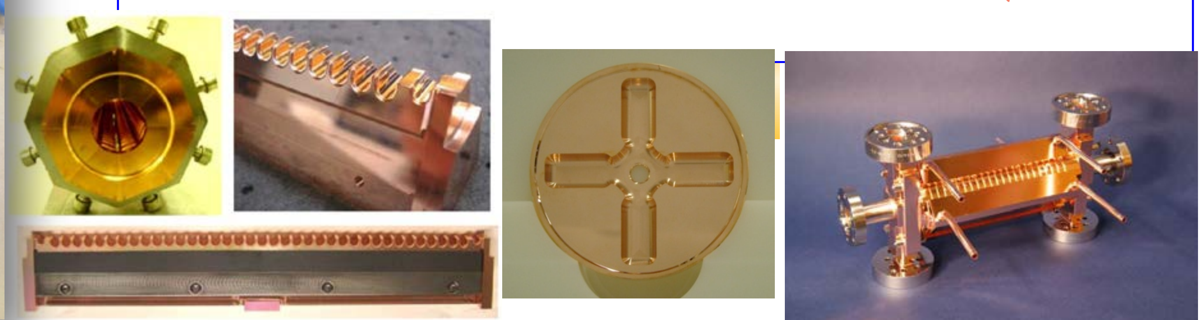
Drive beam time structure - final



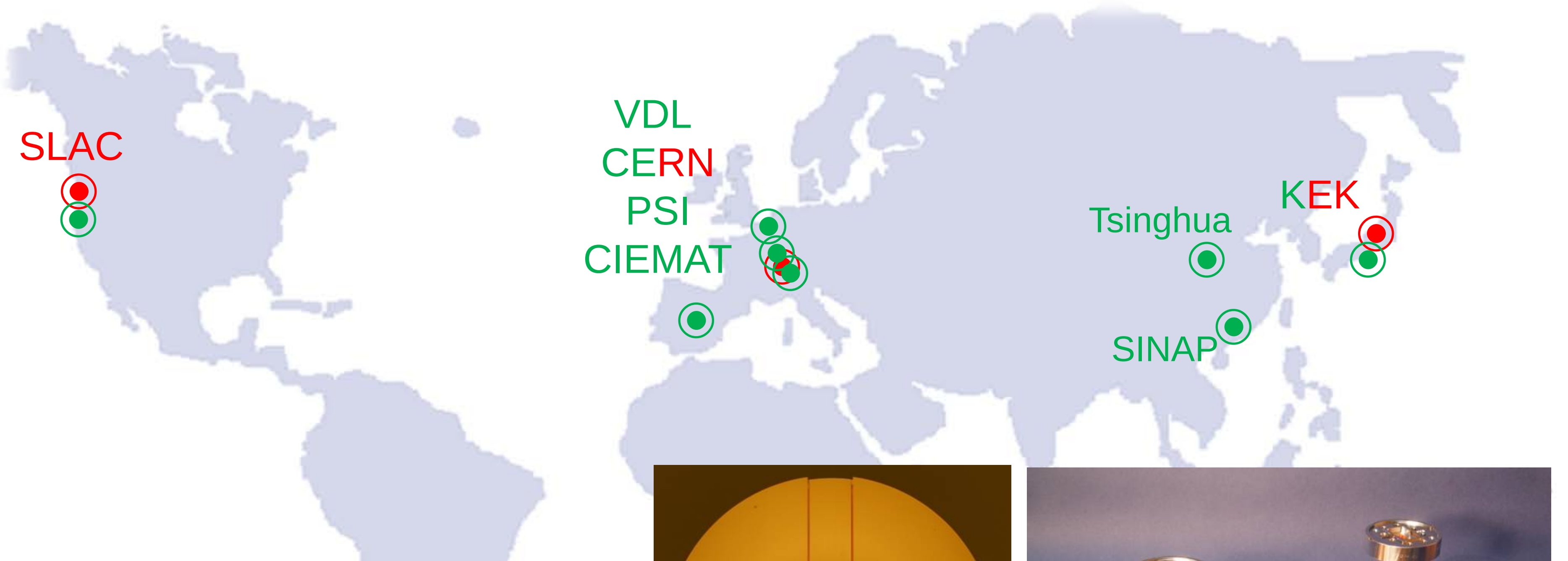
24 pulses – 101 A – 2.5 cm between bunches



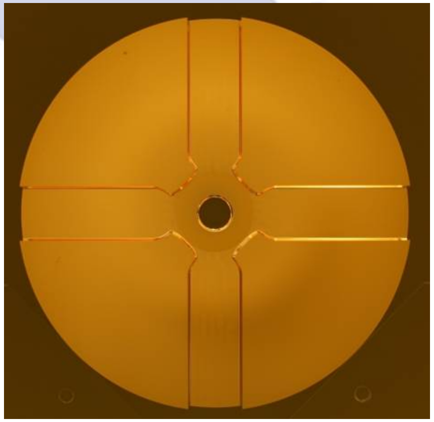


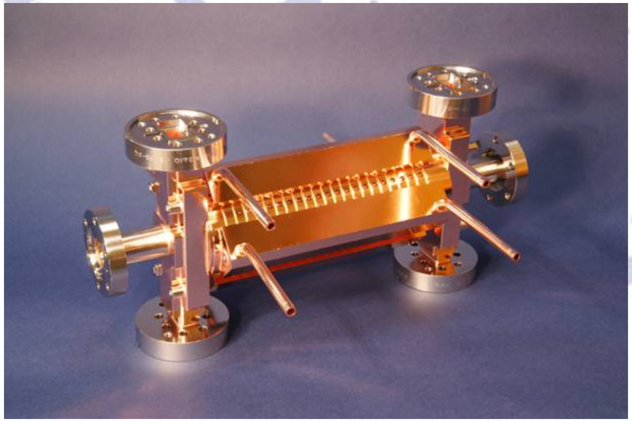


Development and testing of X-band structures



- High gradient structures and high efficiency RF (structure prod. in green)
- X-band High power Testing Facilities (in red)

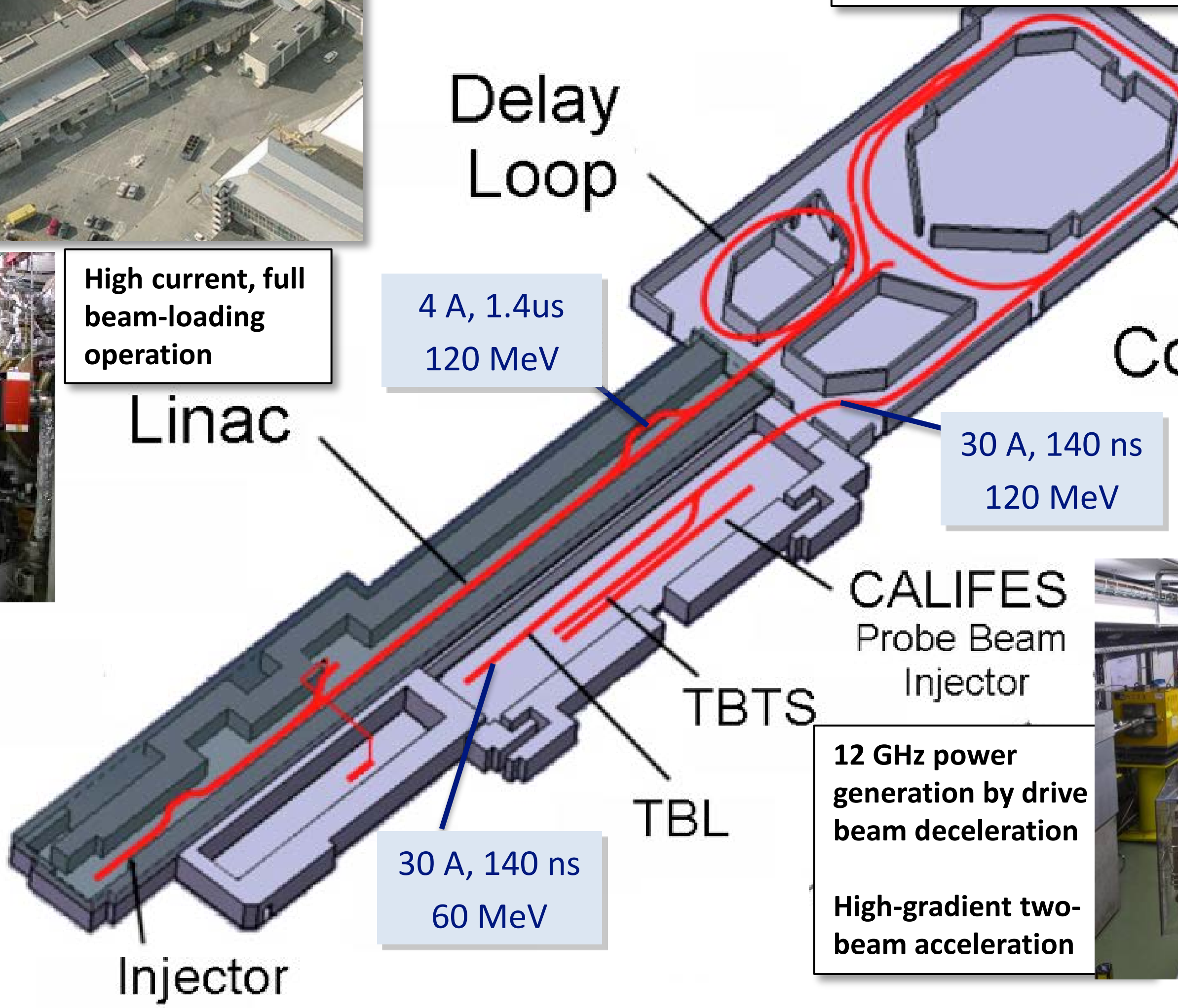




CLIC Test Facility (CTF3)

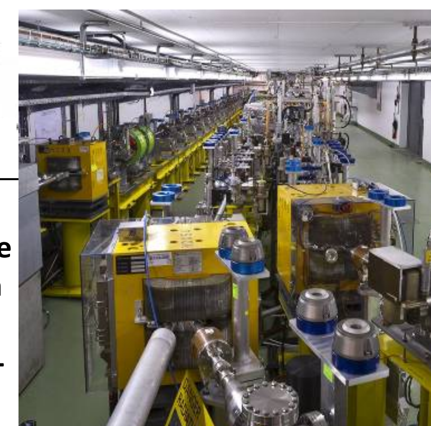
High current, full beam-loading operation

Beam recombination and current multiplication by RF deflectors

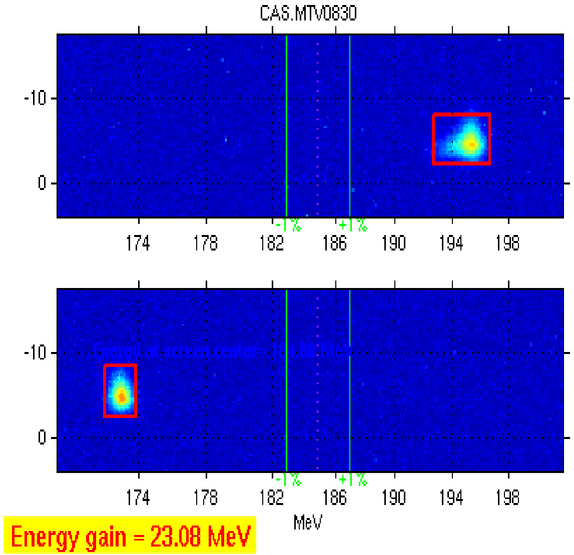


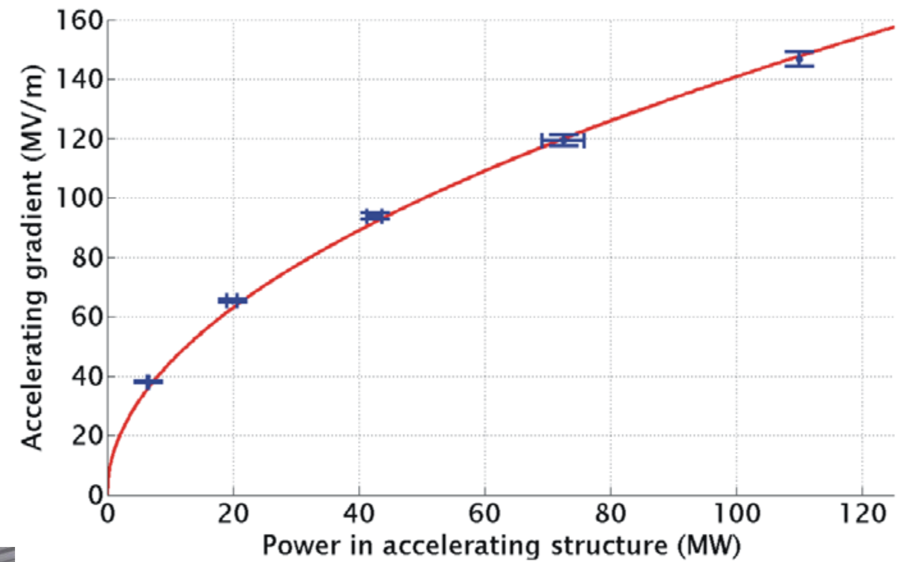
12 GHz power generation by drive beam deceleration

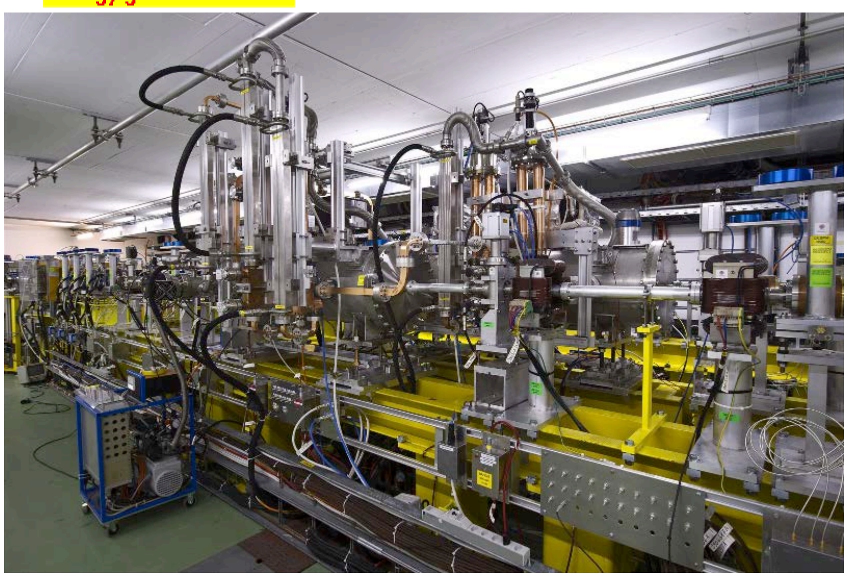
High-gradient two-beam acceleration



Two-beam acceleration demonstrated





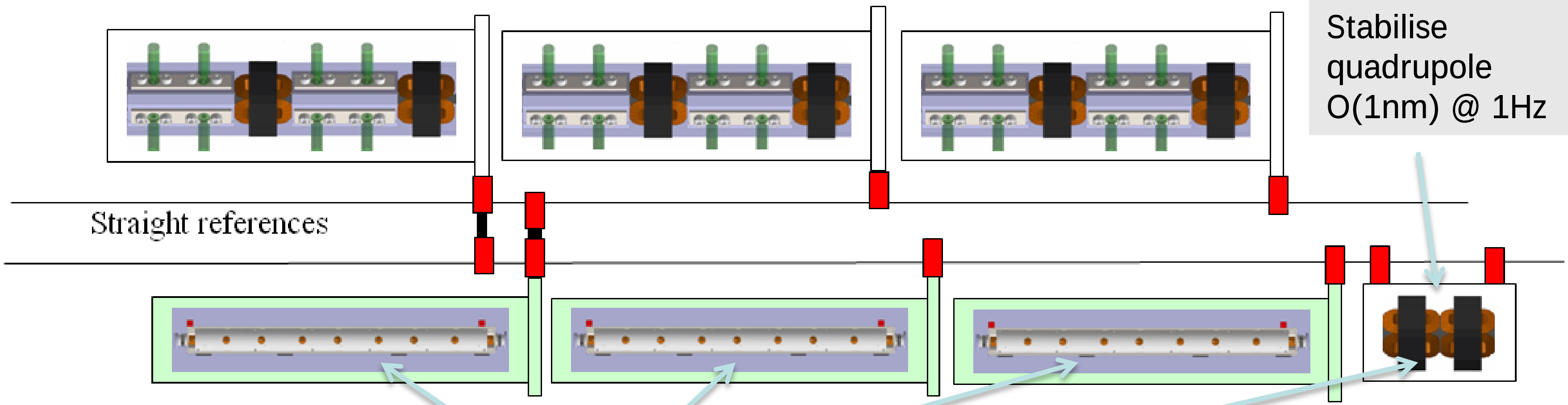


Maximum gradient 145 MV/m

Consistency between
- produced power
- drive beam current
- test beam acceleration

Alignment of main linacs

Stabilise quadrupole O(1nm) @ 1Hz



1) Pre-align BPMs+quads accuracy O(10μm) over about 200m

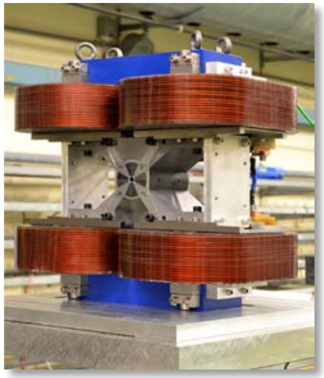
2) Beam-based alignment

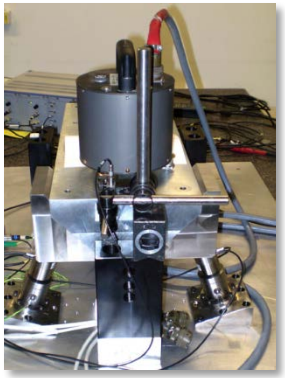
3) Use wake-field monitors accuracy O(3.5μm)

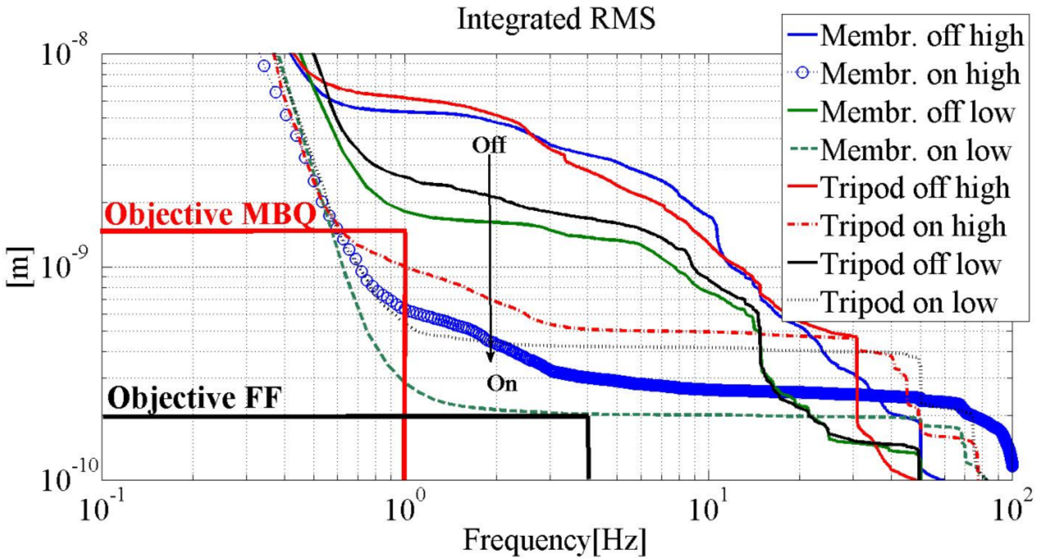
Test of prototype shows
- vertical RMS error of 11μm
- i.e. accuracy is approx. 13.5μm

Active stabilization of quadrupoles

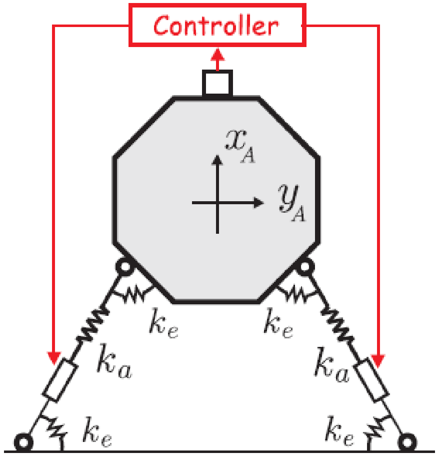
Typical quadrupole jitter tolerance
O(1nm) in main linac and
O(0.1nm) in final doublet

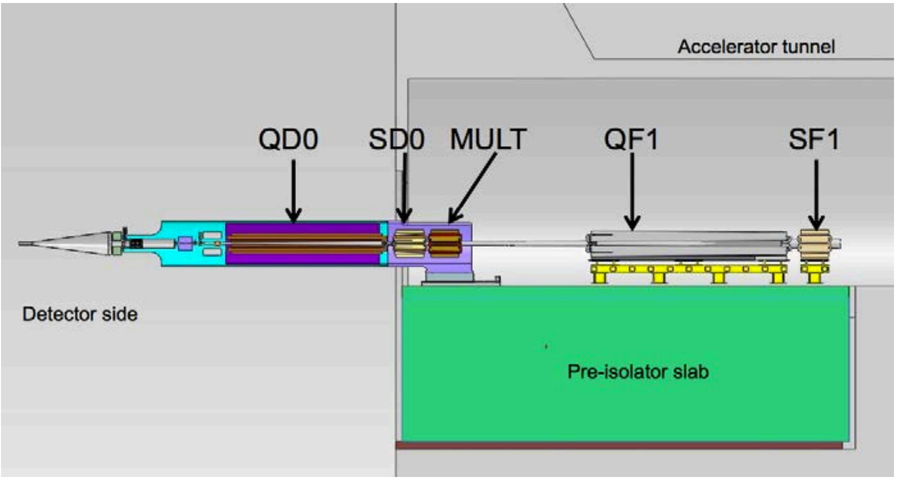




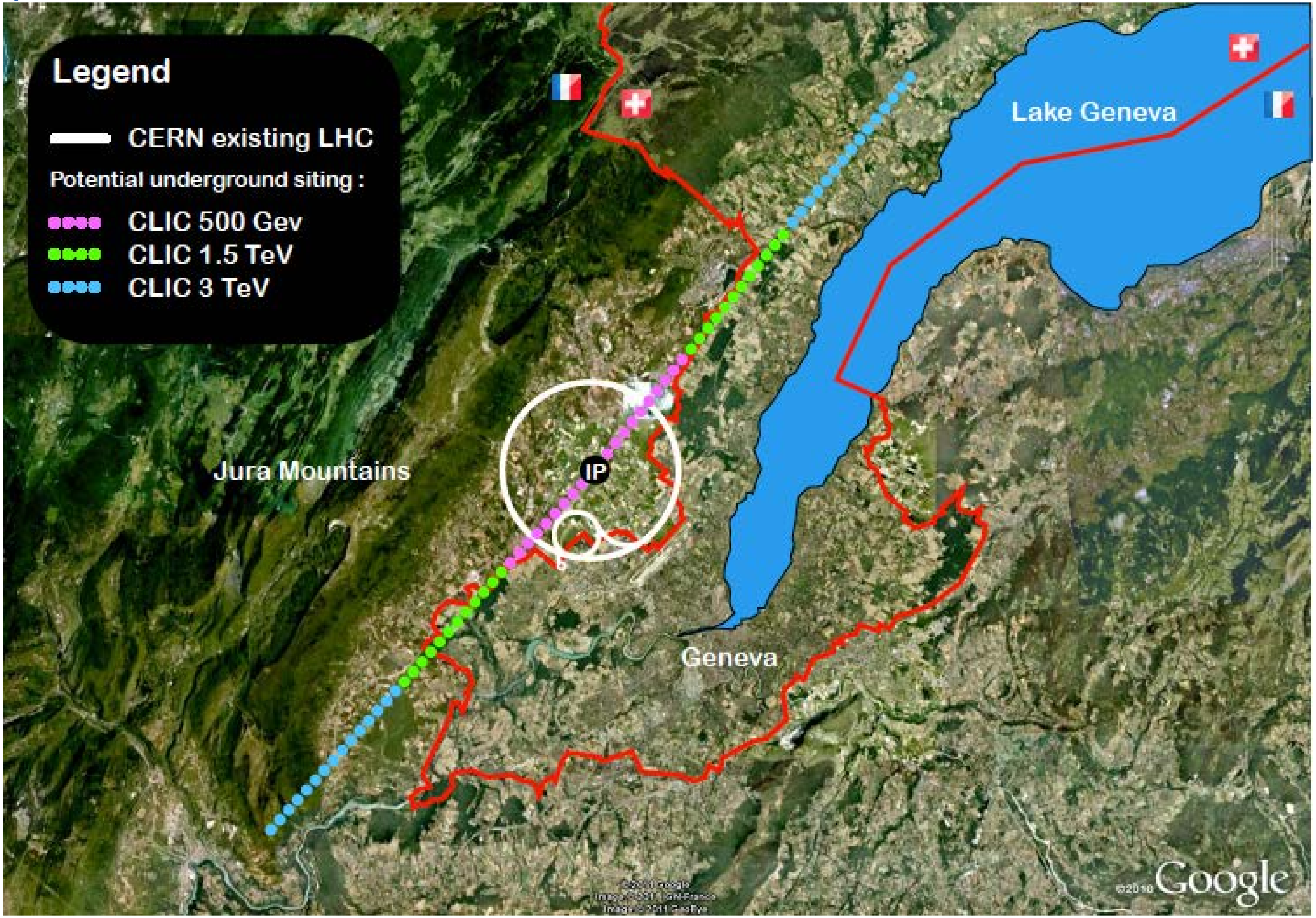


Final Focus QD0 Prototype

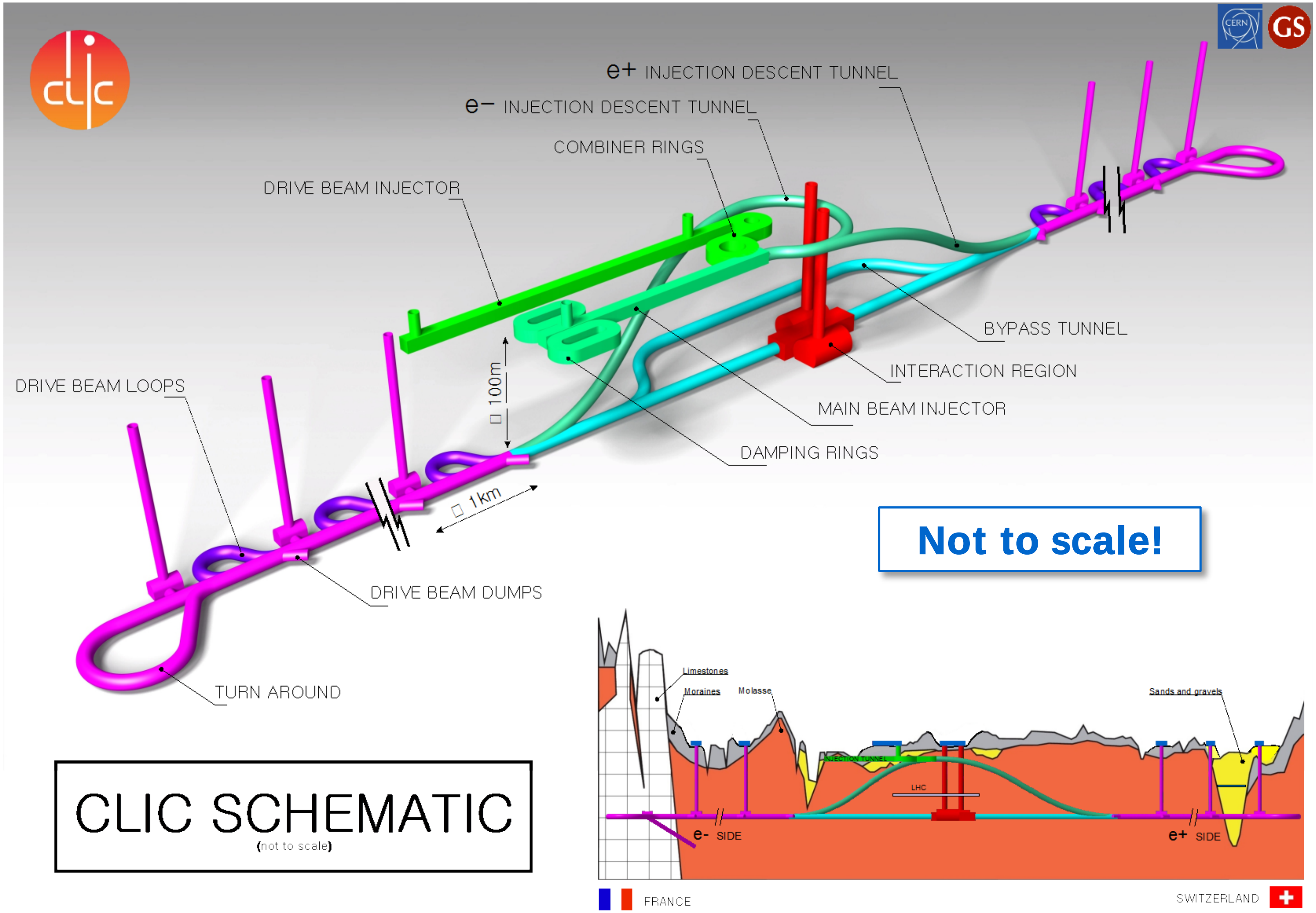




Possible siting and staging of CLIC

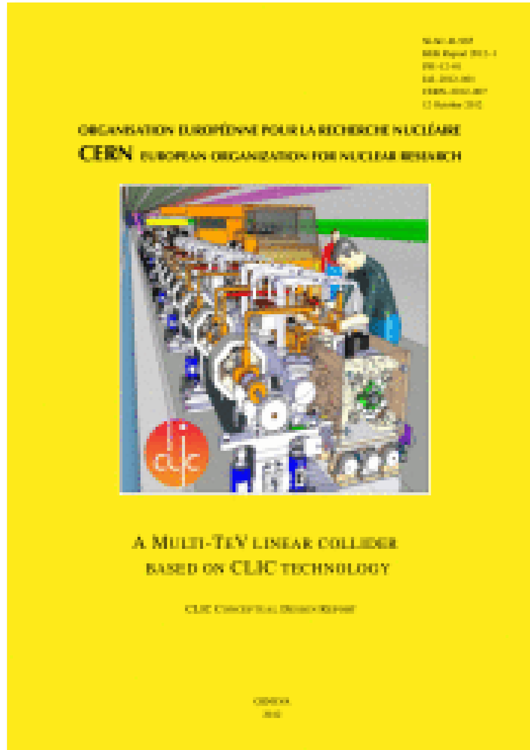


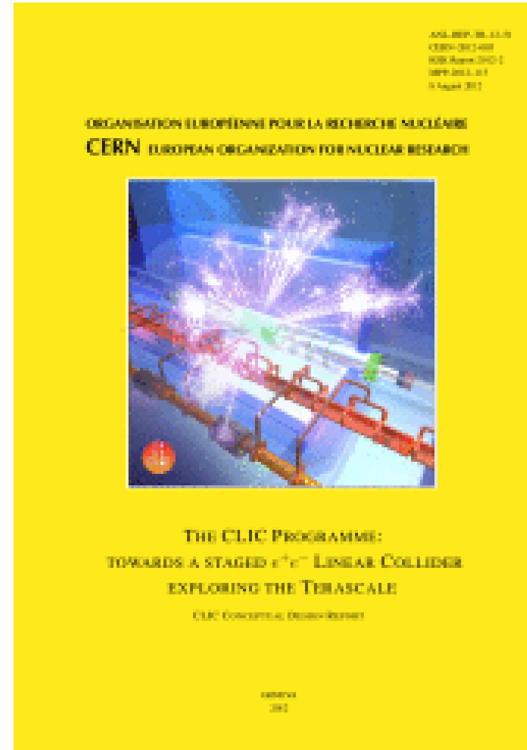
CLIC schematic implantation



The CLIC collaboration
More than 50 institutes world wide

CLIC Conceptual Design Report (2012)





- 3 volumes
  - physics & detectors,
  - accelerator complex,
  - strategy, cost & schedule
- Collaborative effort: > 50 institutes worldwide

CLIC possible roadmap

2013-18 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.

4-5 year Preparation Phase

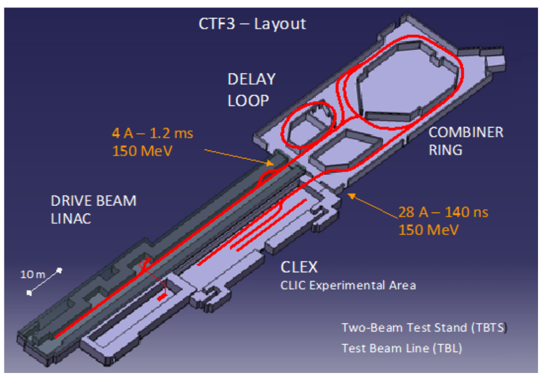
Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

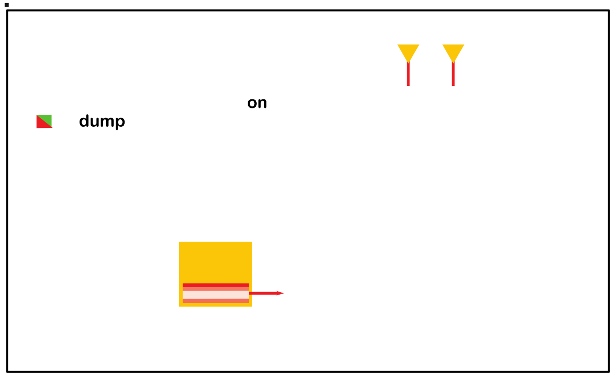
Prepare detailed Technical Proposals for the detector-systems.

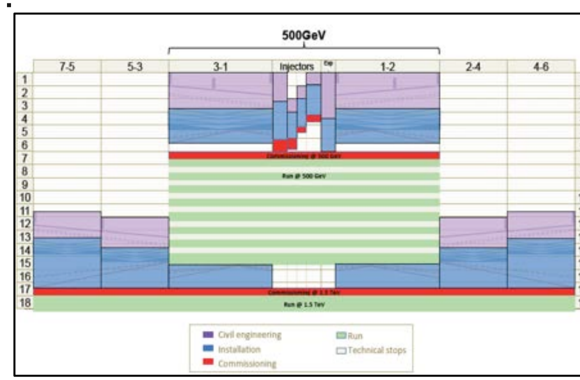
Construction Phase

Stage 1 construction of CLIC, in parallel with detector construction.

Preparation for implementation of further stages.







2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects as FCC), take decisions about next project(s) at the Energy Frontier.

2024-25 Construction Start

Ready for full construction and main tunnel excavation.

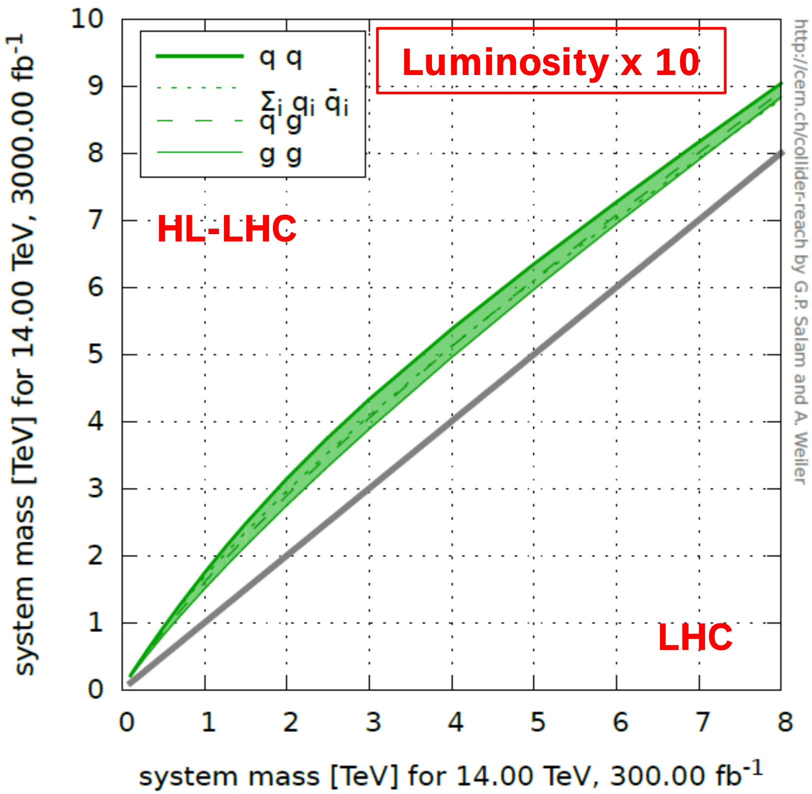
Commissioning

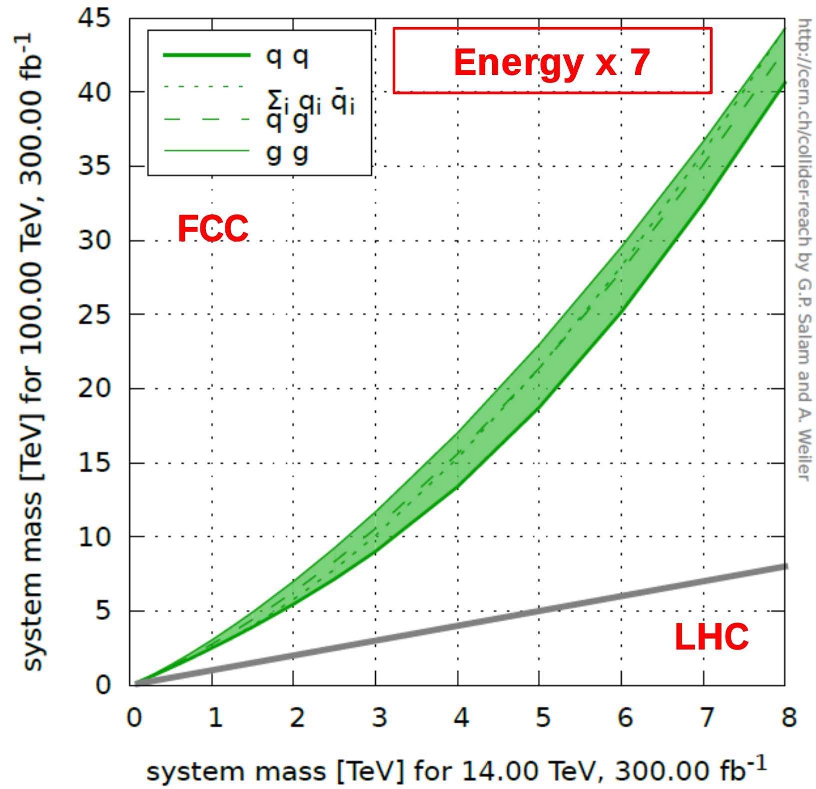
Becoming ready for data-taking as the LHC programme reaches completion.

Scope of FCC study

- The main emphasis of the conceptual design study shall be the long-term goal of a hadron collider with a centre-of-mass energy of the order of 100 TeV in a new tunnel of 80 - 100 km circumference for the purpose of studying physics at the highest energies.
- The conceptual design study shall also include a lepton collider and its detectors, as a potential intermediate step towards realization of the hadron facility. Potential synergies with linear collider detector designs should be considered.
- Options for e-p scenarios and their impact on the infrastructure shall be examined at conceptual level.
- The study shall include cost and energy optimisation, industrialisation aspects and provide implementation scenarios, including schedule and cost profiles

A crude estimate of energy vs luminosity gains
Collider Reach by G. Salam & A. Weiler

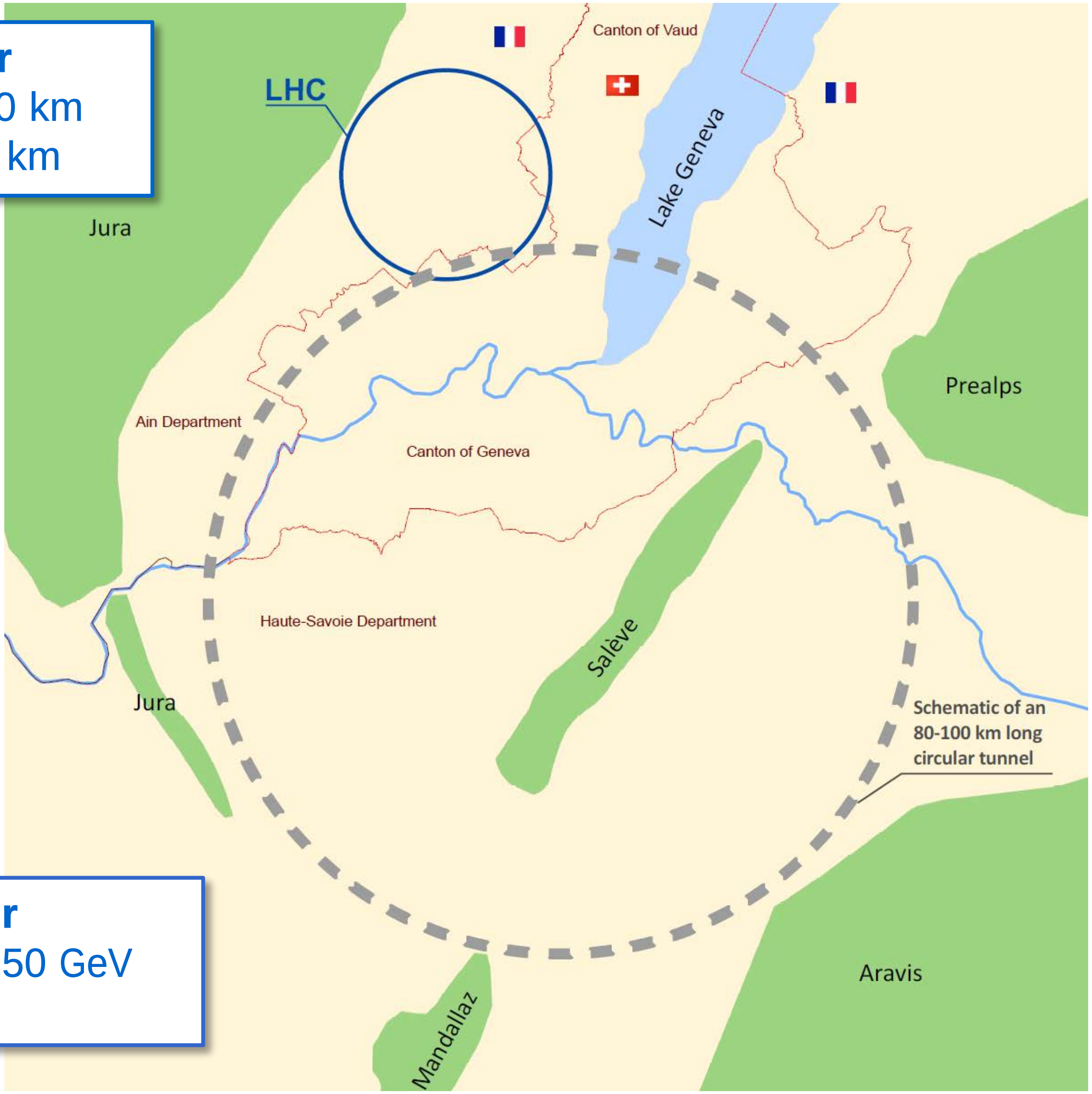




- The *Collider Reach* tool gives an estimate of the system mass that can be probed in BSM searches at one collider setup given an established system mass reach of some other collider setup, assuming that cross sections scale with the inverse squared system mass and with partonic luminosities
- http://collider-reach.web.cern.ch/collider-reach/

Study of Future Circular Colliders
Quasi-circular tunnel of 80 to 100 km perimeter

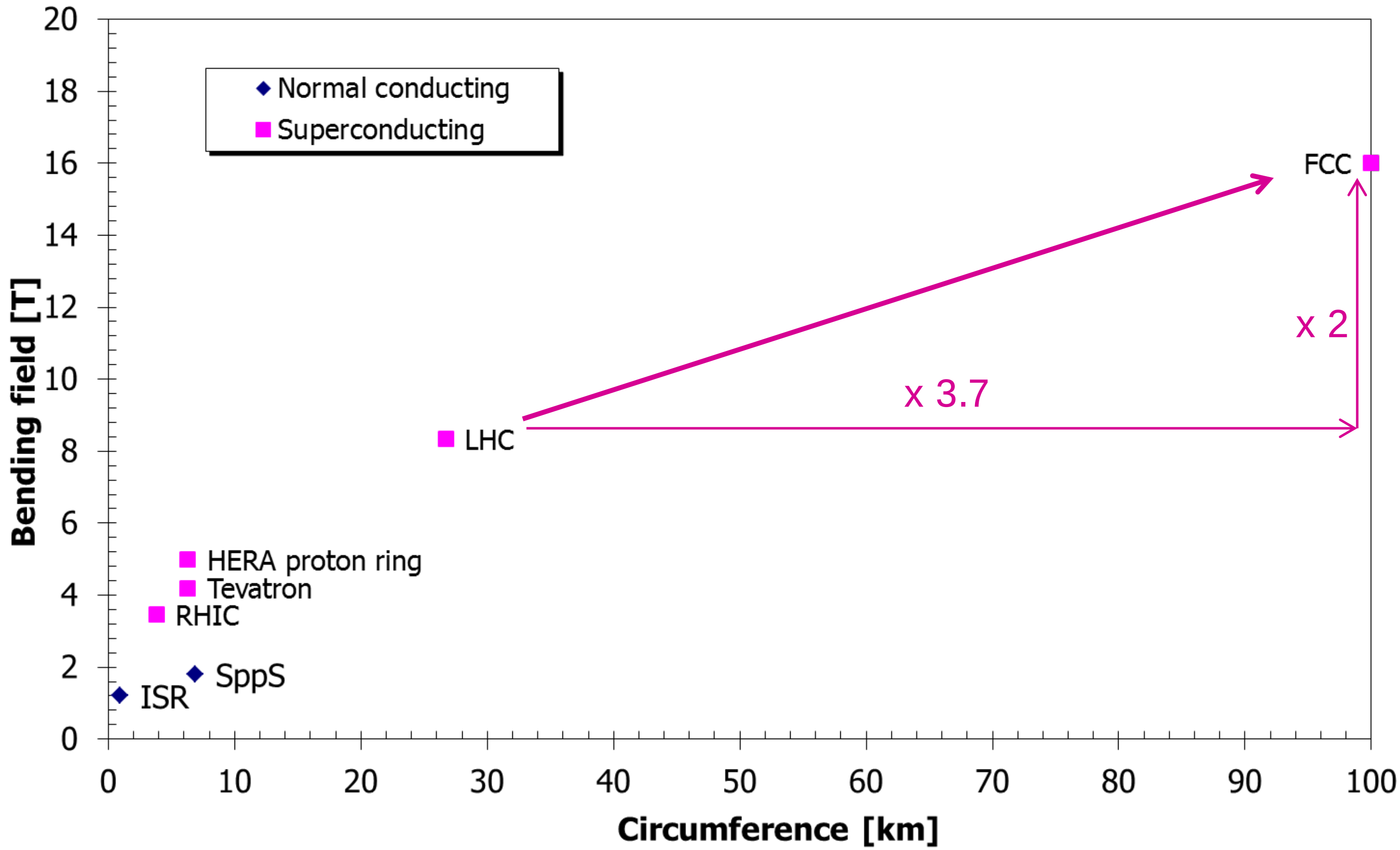
Hadron collider
16 T $\Rightarrow$ 100 TeV for 100 km
20 T $\Rightarrow$ 100 TeV for 80 km



e+ e- collider
Collision energy 90 to 350 GeV
Very high luminosity

FCC-hh design targets

- Pushing the energy frontier by maximizing the energy reach
- Hadron collider only option for exploring energy scale at tens of TeV



FCC-hh baseline parameters

parameter	LHC	HL-LHC	FCC-hh
c.m. energy [TeV]	14		100
dipole magnet field [T]	8.33		16 (20)
circumference [km]	36.7		100 (83)
luminosity [10^{34} $cm^{-2}s^{-1}$]	1	5	5 [→20?]
bunch spacing [ns]	25		25 {5}
events / bunch crossing	**27**	**135**	**170 {34}**
bunch population [10^{11}]	1.15	2.2	1 {0.2}
norm. transverse emitt. [μm]	3.75	2.5	2.2 {0.44}
IP beta-function [m]	0.55	0.15	1.1
IP beam size [μm]	16.7	7.1	6.8 {3}
synchrotron rad. [W/m/aperture]	0.17	0.33	28 (44)
critical energy [keV]	0.044		4.3 (5.5)
total syn.rad. power [MW]	**0.0072**	**0.0146**	**4.8 (5.8)**
longitudinal damping time [h]	**12.9**		**0.54 (0.32)**

FCC-ee design targets

- Aiming for very high luminosity: high beam current, small beam size
- Luminosity at each energy limited by synchrotron radiation from the beams, limit 50 MW per beam
- highest possible luminosity for a wide physics program ranging from the Z pole to the $t\bar{t}$ production threshold
  - *beam energy range from 45 GeV to 175 GeV*
- main physics programs / energies:
  - *Z (45.5 GeV): Z pole, 'TeraZ' and high precision M_Z & G_Z,*
  - *W (80 GeV): W pair production threshold,*
  - *H (120 GeV): ZH production (maximum rate of H's),*
  - *t (175 GeV): $t\bar{t}$ threshold*
- some polarization up to ≥80 GeV for beam energy calibration
- optimized for operation at 120 GeV

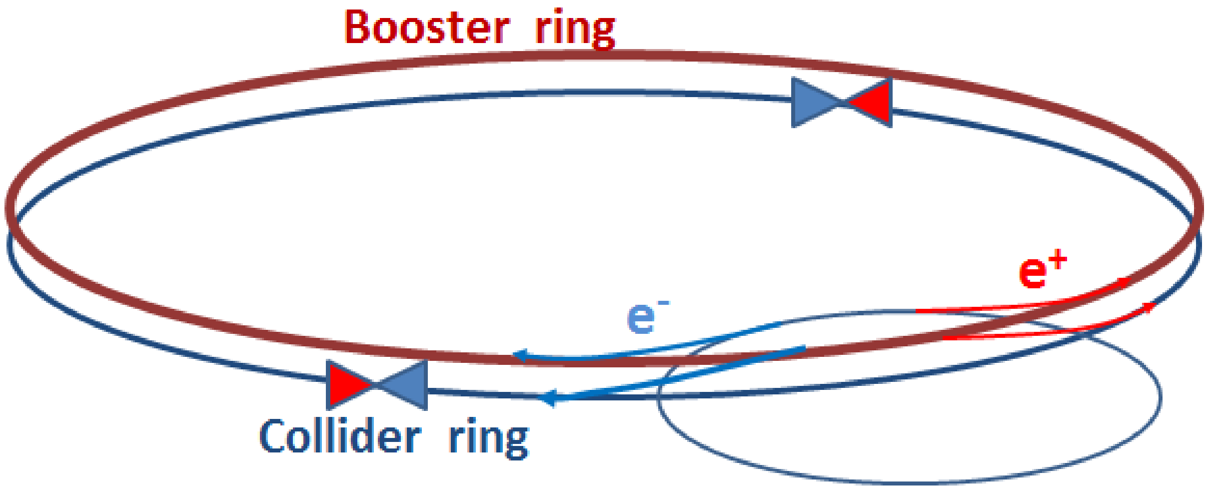
FCC-ee baseline parameters

parameter	LEP2	FCC-ee				
		Z	Z (c.w.)	W	H	t
E_{beam} [GeV]	104	45	45	80	120	175
circumference [km]	26.7	100	100	100	100	100
current [mA]	3.0	1450	1431	152	30	6.6
$P_{SR,tot}$ [MW]	22	100	100	100	100	100
no. bunches	4	16700	29791	4490	1360	98
N_b [10^{11}]	4.2	1.8	1.0	0.7	0.46	1.4
ε_x [nm]	22	29	0.14	3.3	0.94	2
ε_y [pm]	250	60	1	1	2	2
β^*_x [m]	1.2	0.5	0.5	0.5	0.5	1.0
β^*_y [mm]	50	1	1	1	1	1
σ^*_y [nm]	3500	250	32	84	44	45
$\sigma_{z,SR}$ [mm]	11.5	1.64	2.7	1.01	0.81	1.16
$\sigma_{z,tot}$ [mm] (w beamstr.)	11.5	2.56	5.9	1.49	1.17	1.49
hourglass factor F_{hg}	0.99	0.64	0.94	0.79	0.80	0.73
L/IP [10^{34} cm^{-2}s^{-1}]	0.01	28	212	12	6	1.7
τ_{beam} [min]	434	298	39	73	29	21

crab waist

FCC-ee top-up injection

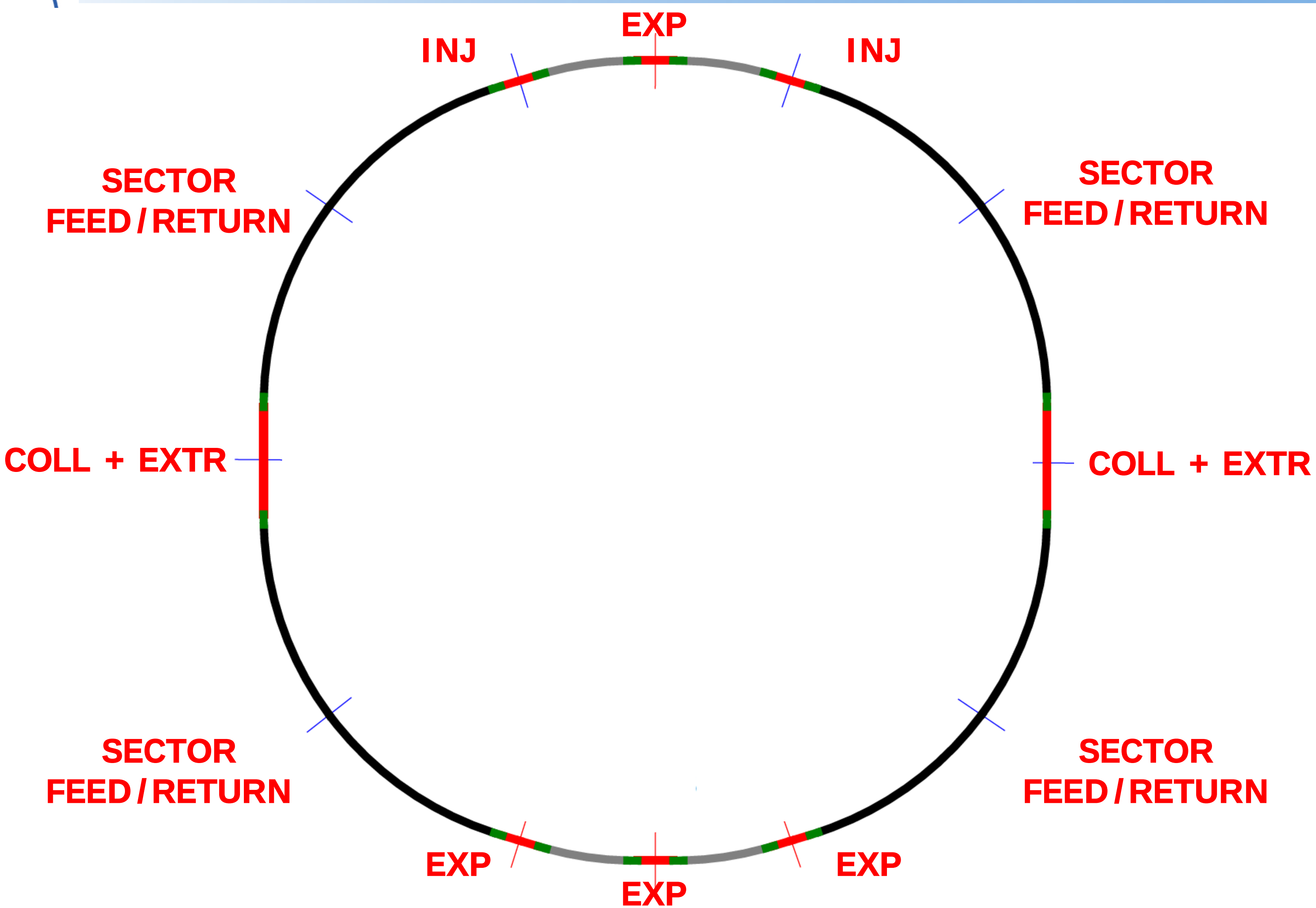
- In view of the low luminosity lifetime, a booster of the same size (same tunnel) as the collider ring(s) must provide beams for top-up injection
  - same RF voltage, but low power (~ MW)
  - top up frequency ~ 0.1 Hz
  - booster injection energy ~5-20 GeV
  - bypass around the experiments



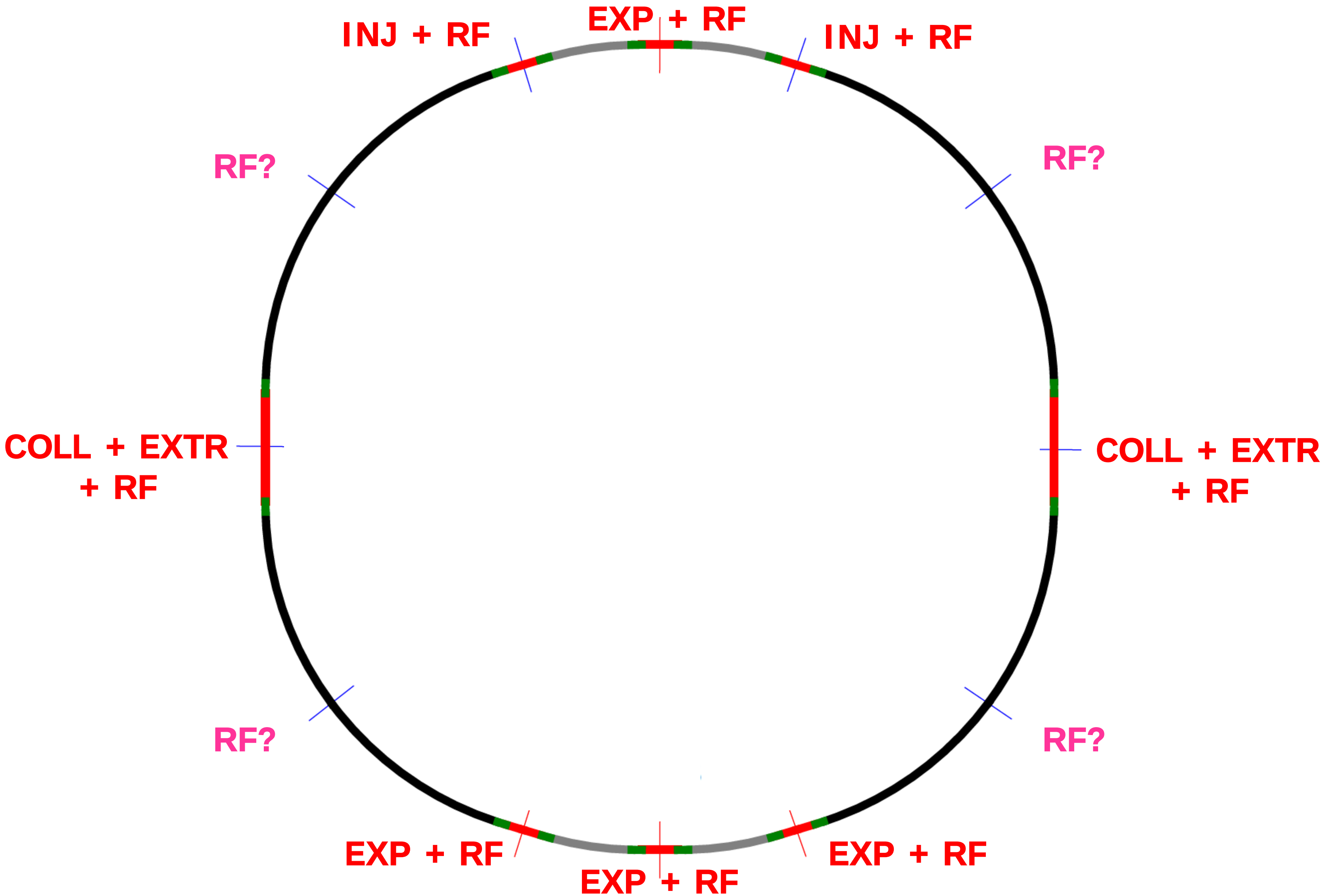
Tunnel footprint

- 4 values of perimeter considered, rational multiples of LHC taken as high-energy booster for FCC-hh
  - 80.0 km
  - 86.6 km
  - 93.3 km
  - 100.0 km
- Arc radius of curvature maximized
  - FCC-hh: to reach maximum beam energy at achievable magnetic field
  - FCC-ee: to reach maximum luminosity at 50 MW/beam synchrotron power
- Geometry
  - Experimental areas “clustered” and separated by short arcs, away from injection and collimation regions
  - Long straight sections for IRs and RF
  - Distribute RF in LSS to limit energy sawtoothing (FCC-ee)
  - Extended short straight sections for FCC-hh collimation and extraction
  - Dispersion suppressors on either side of LSS and ESS
  - Very short technical straight sections between long arcs (FCC-hh)

Allocation of Straight Sections FCC-hh



Allocation of Straight Sections FCC-ee



Siting study 93 km perimeter

PRELIMINARY

Alignment | **Shaft Tools**

Choose alignment option

93km quasi-circular ▼

Tunnel depth at centre: 286mASL

Gradient Parameters

Azimuth (°): -15

Slope Angle x-x(%): .3

Slope Angle y-y(%): 0

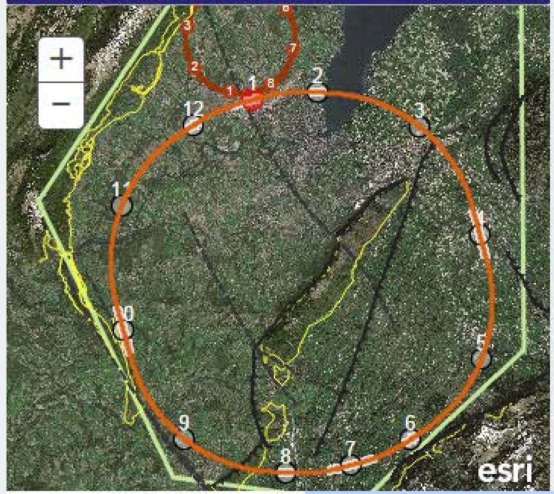
CALCULATE

Alignment centre

X: 2498923 Y: 1106695

LHC Intersection	IP 1	IP 2
Angle	1°	-1°
Depth	542m	542m

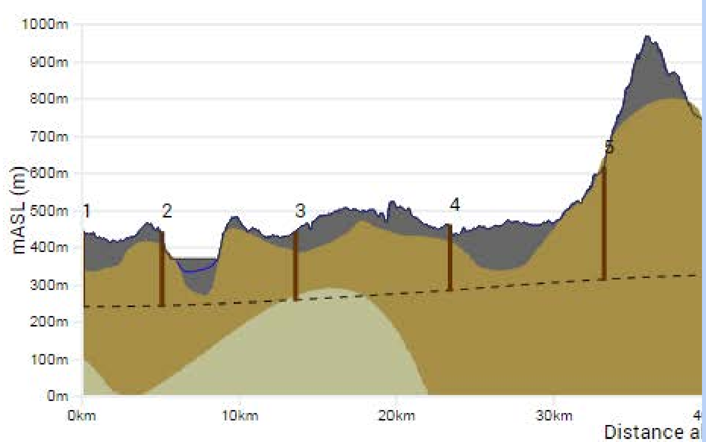
Alignment Location



Geology Intersected by Shafts | **Shaft Depths**

	Shaft Depth (m)				Geology (m)		
Shaft	Actual	Min	Mean	Max	Moraine	Molasse	Calcaire
1	200	195	197	200	92	108	0
2	196	143	181	211	34	162	0
3	183	175	184	194	53	121	9
4	174	146	166	178	44	130	0
5	299	286	311	350	0	325	0
6	336	325	339	350	35	302	0
7	374	349	377	412	119	256	0
8	337	318	341	366	44	56	237
9	155	131	145	167	94	61	0
10	315	305	320	336	46	269	0
11	203	199	202	204	122	81	0
12	239	229	238	243	58	181	0
Total	3014	2801	3001	3211	741	2052	247

Alignment Profile

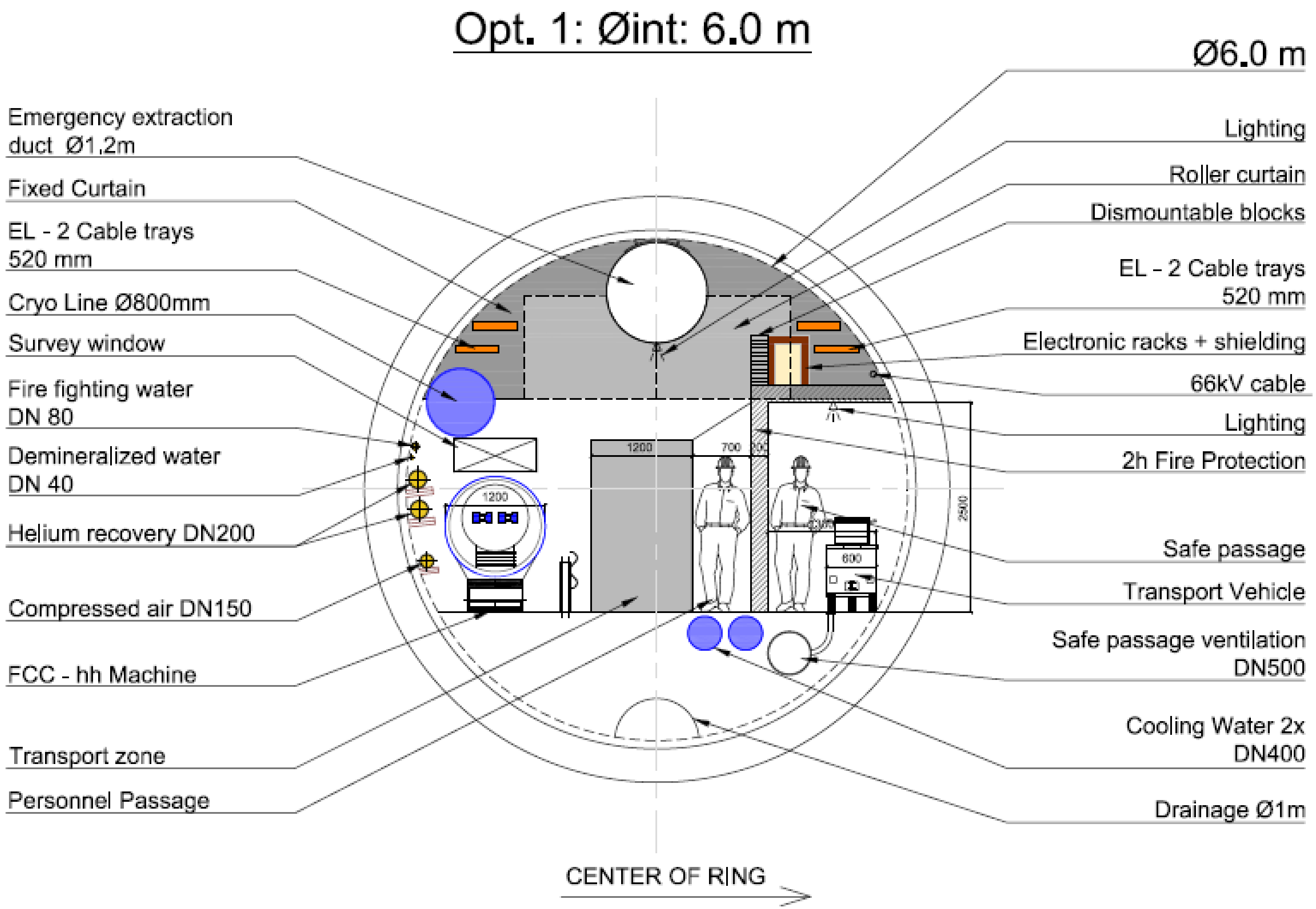


Preliminary conclusions:

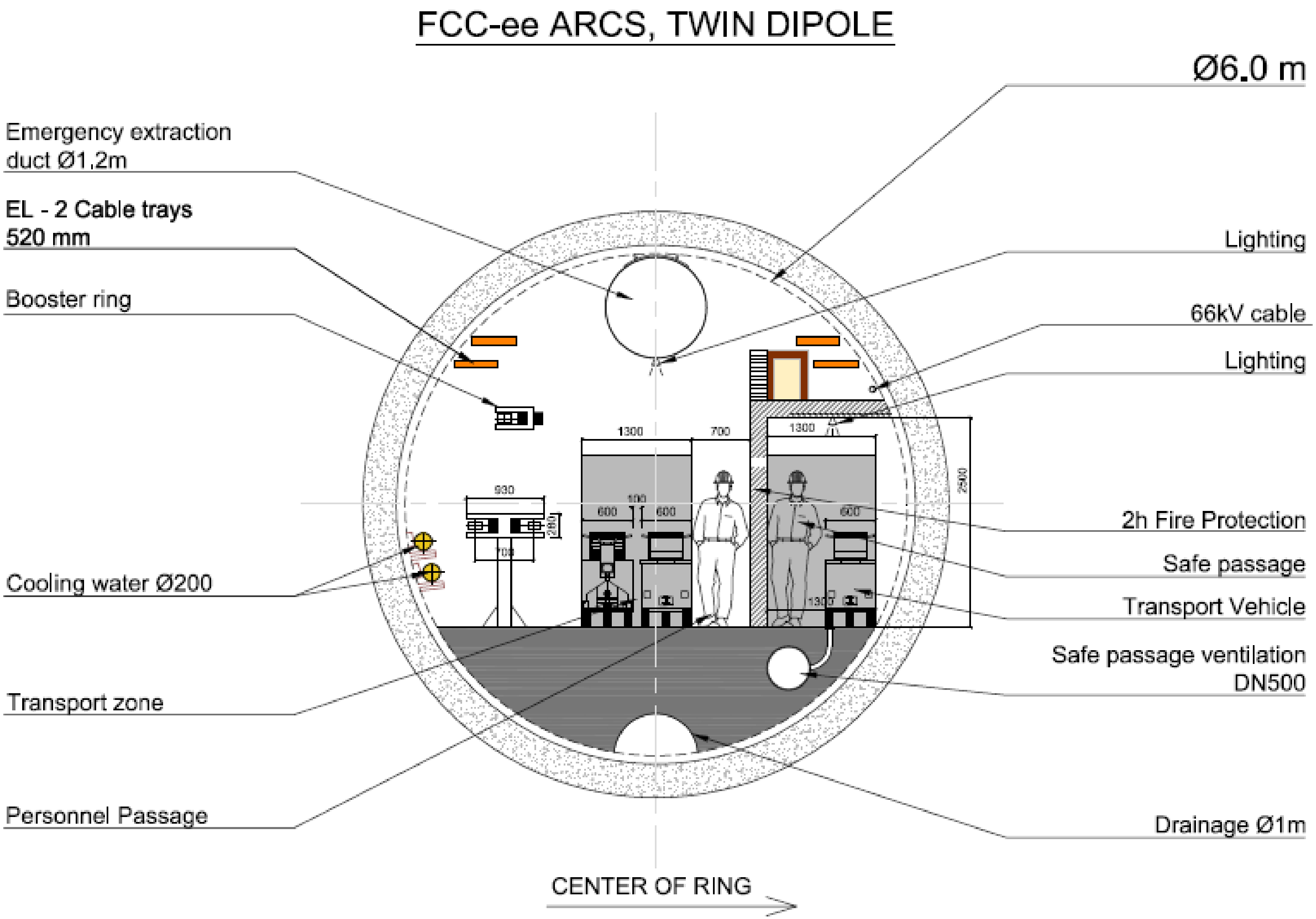
- 93 km tunnel fits geological situation well
- 100 km tunnel seems also compatible with geological considerations
- The LHC could be used as an injector

J. Osborne & C. Cook

FCC-hh arcs
Single tunnel

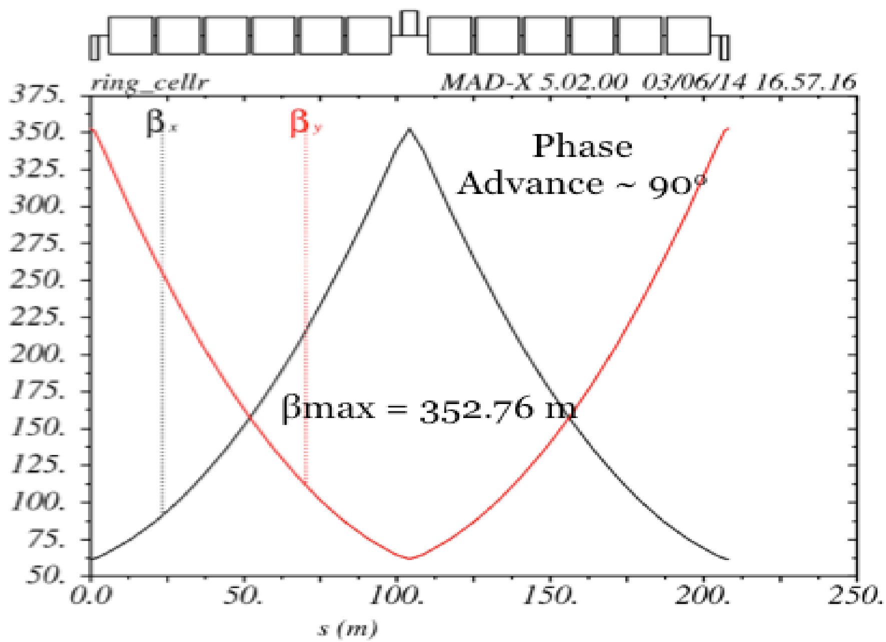


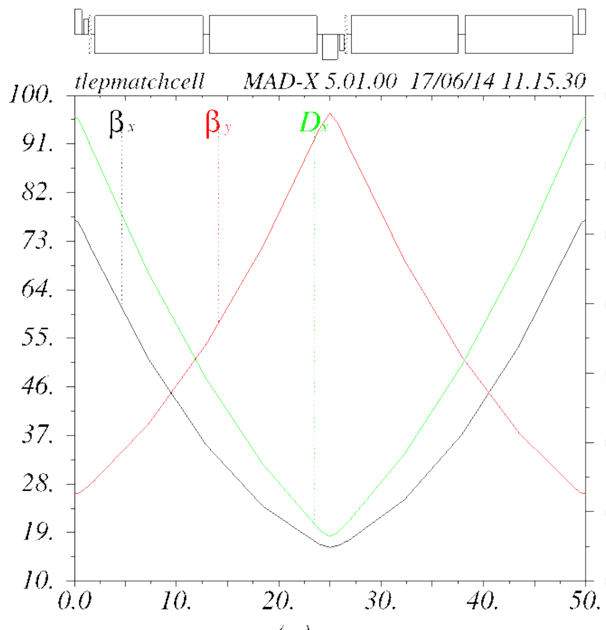
FCC-ee arcs
Single tunnel



Lattice

- FCC-hh
  - Cell length ~ 200 m
  - Short TSS between LARCs
- FCC-ee
  - Cell lengths from ~50 m to ~300 m, depending on the energy & phase advance
  - No TSS unless one needs to add RF stations between LARCS



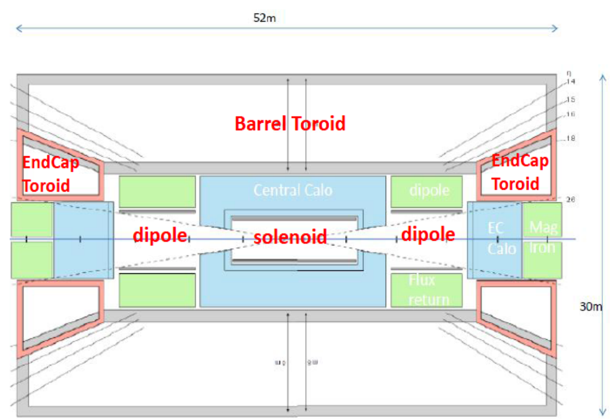


B. Holzer

Experiments

- FCC-hh
  - Very large detectors (L>50 m, D~30 m) using 5 T solenoids
  - Sets the size of caverns and installation shafts
- FCC-ee
  - No preliminary design available
  - ILC-type detectors would be much smaller than FCC-hh detectors
  - Unconventional ideas of detectors making use of large cavern volume of FCC-hh

2. Option 3: Toroids + Solenoid + Dipoles (ATLAS +)



- ❖ 1 Air core Barrel Toroid with 7 x muon bending power B_zL^2.
- ❖ 2 End Cap Toroids to cover medium angle forward direction.
- ❖ 2 Dipoles to cover low-angle forward direction.
- ❖ Overall dimensions: 30 m diameter x 51 m length (36,000 m^3).

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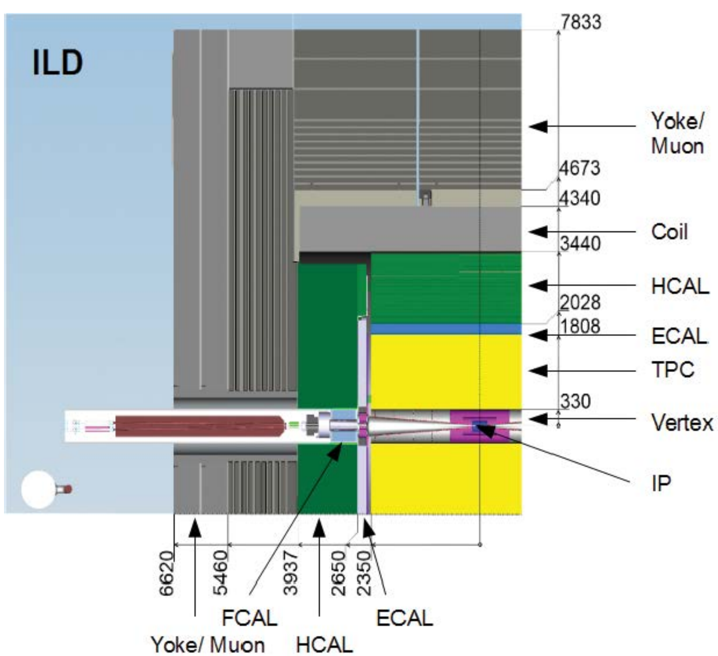
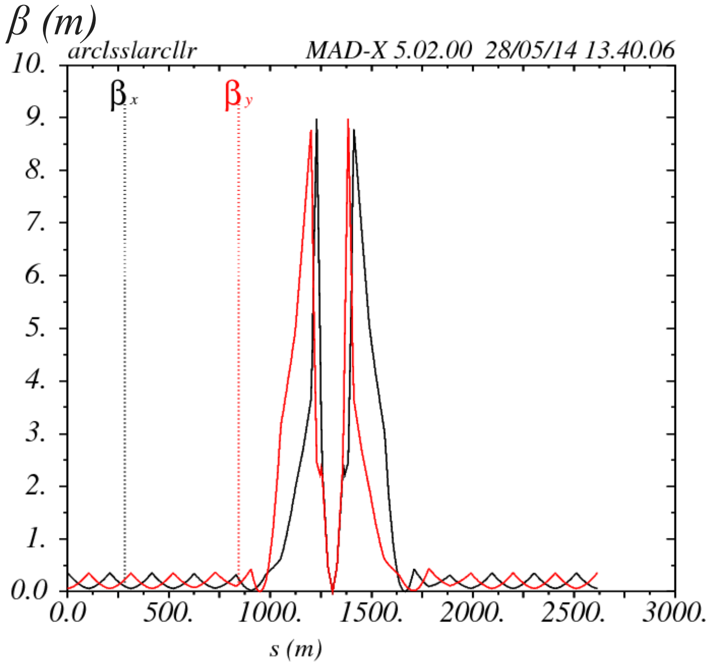
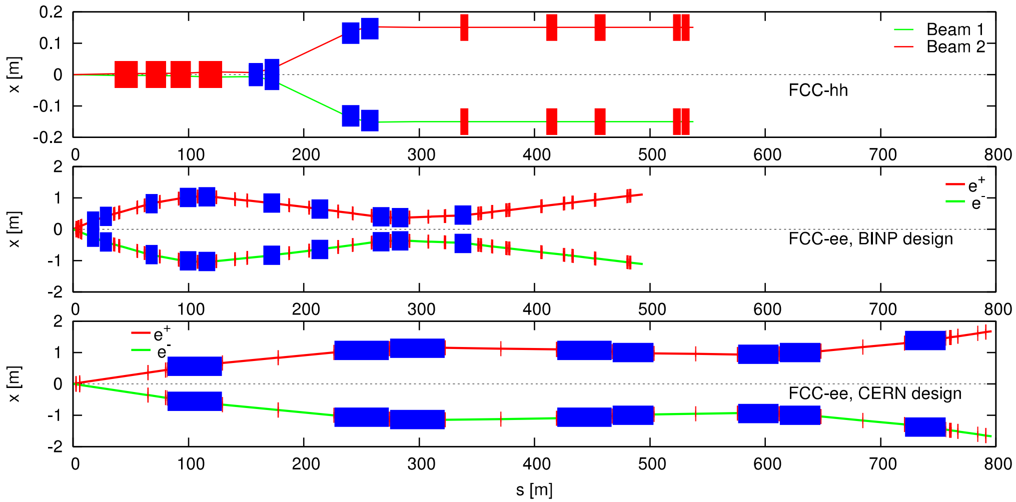


Interaction regions

- FCC-hh
  - Small crossing angle 11 μrad
  - Moderate β* = 1.1 m
  - Very large detectors ⇒ L* = 46 m
  - Length of IR ~1 km ⇒ LSS = 1.4 km
- FCC-ee
  - Large crossing angle 30 mrad
  - Small β* = 1 mm
  - Small L* = 2 m
  - Length of IR may require LSS > 1.4 km

⇒ work in progress



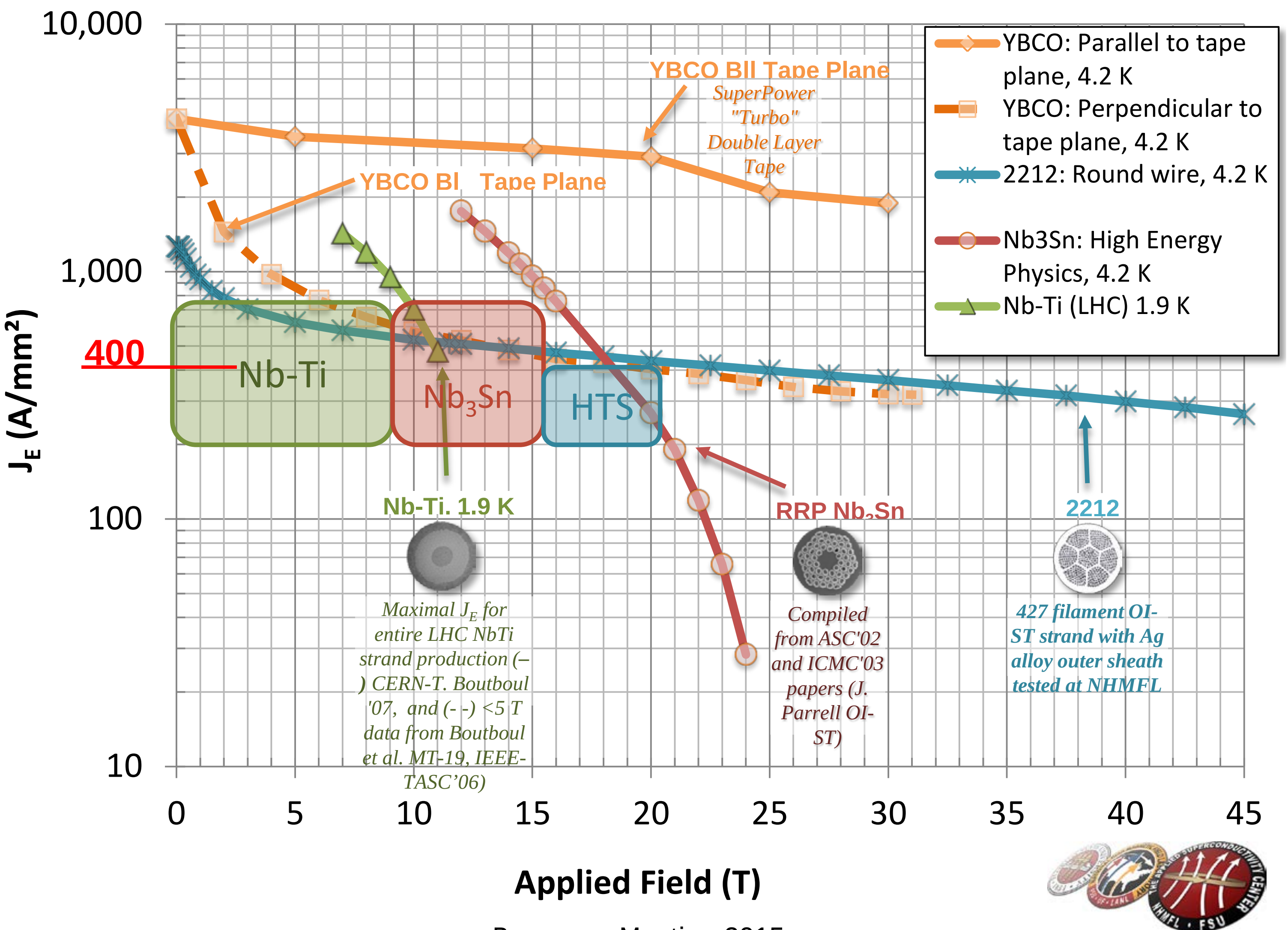


J. Wenninger

FCC-hh key technology
High-field superconducting magnets

- **Baseline**: 16 T for 100 TeV in 100 km with Nb-Ti + Nb_3Sn
  - Conductor development
  - Short models with aperture 40-50 mm and accelerator features (margin, field quality, protectability, cycled operation)
  - **R&D goal**: 16T short dipole models by 2018/19 (America, Asia, Europe)
- In parallel, **long-term development** targeting 20 T with Nb-Ti + Nb_3Sn + HTS
  - 5 T insert (EuCARD2), ~40 mm aperture and accelerator features
  - Outsert of large aperture ~100 mm, (FRESCA2 or other)
  - **R&D goal**: demonstrate HTS/LTS 20 T dipole technology

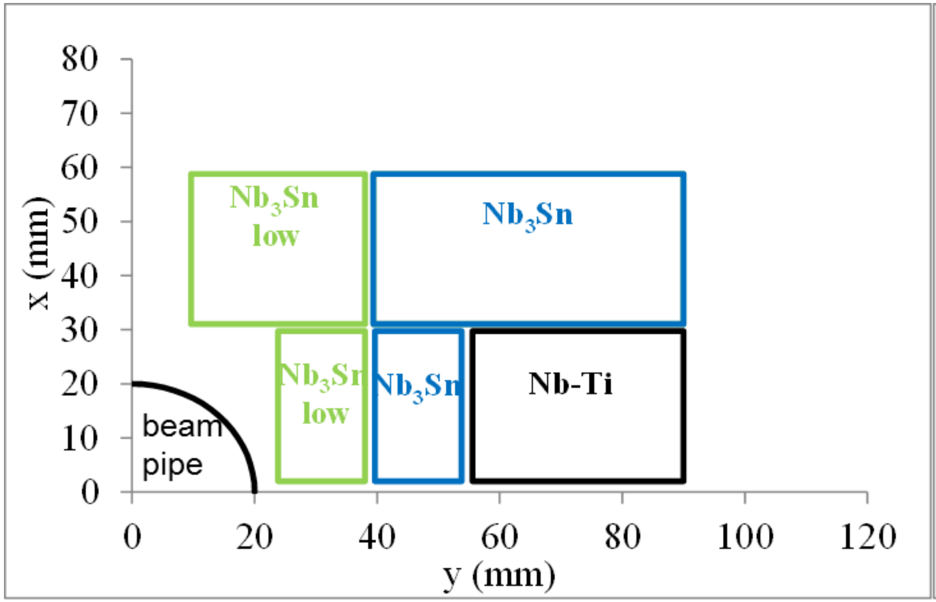
Advanced superconductors to reach high fields



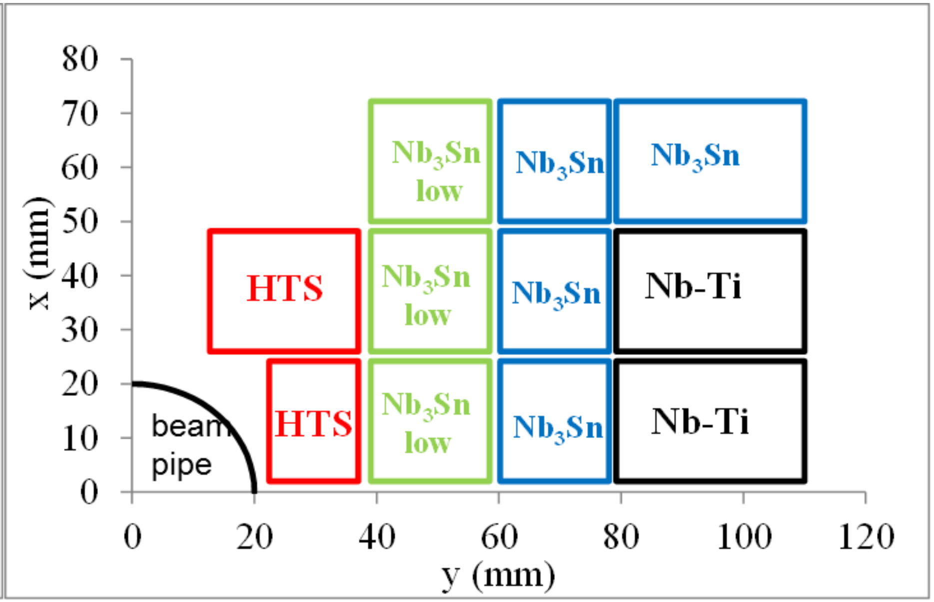
Nested coils using multiple superconductors for technically optimized, cost-effective design

- Arc magnet system will be the major cost driver of FCC-hh
- Cross-section examples of nested, hybrid block coils (1/4 shown)

16 T



20 T



L. Rossi, E. Todesco

FCC-hh challenges
Stored beam energy

- Stored energy 8 GJ per beam, 16 GJ total
  - 20 times higher than LHC
  - Equivalent to A380 (560 t) at nominal speed (850 km/h)

- Collimation, control of beam losses and radiation effects very important
- Injection, beam transfer and dump very critical
- Machine protection issues to be addressed early on!

FCC study
Status

- Study launched at FCC kick-off meeting in February 2014
- Presently forming a global collaboration based on general MoUs between CERN and individual partners + specific addenda for each participant
- First International Collaboration Board meeting on 9-10 September 2014 at CERN, chaired by Prof. L. Rivkin (PSI/EPFL)
- Design study proposal for EU support in the Horizon 2020 program submitted, evaluation expected in January 2015
- First FCC Week workshop from 23 to 27 March 2015 in Washington DC

FCC study
MoU status on 21 January 2015

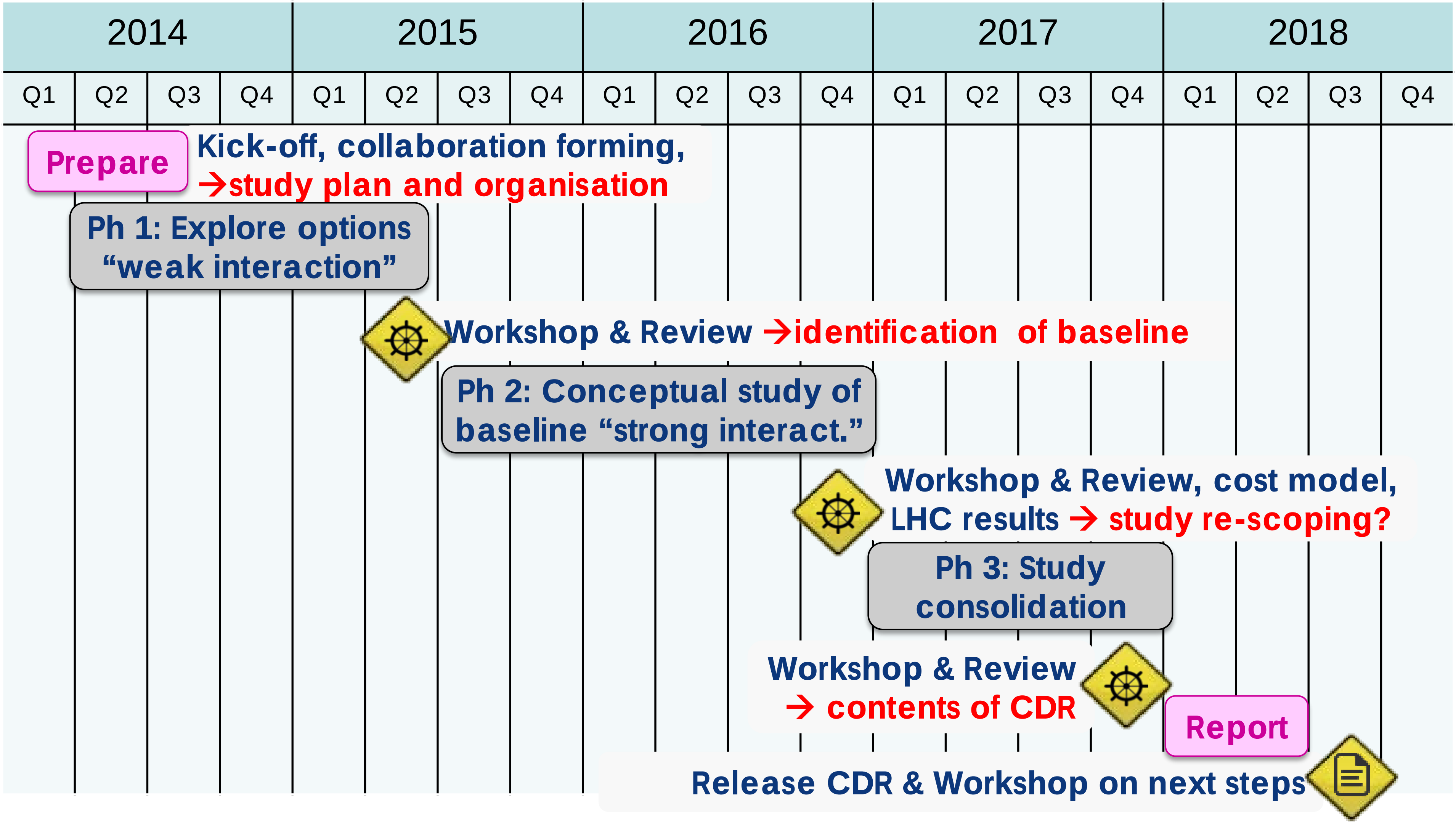
43 collaboration members

ALBA/CELLS, Spain
U Bern, Switzerland
BINP, Russia
CASE (SUNY/BNL), USA
CBPF, Brazil
CEA Grenoble, France
CIEMAT, Spain
CNRS, France
Cockcroft Institute, UK
U Colima, Mexico
CSIC/IFIC, Spain
TU Darmstadt, Germany
DESY, Germany
TU Dresden, Germany
Duke U, USA

EPFL, Switzerland
Gangneung-Wonju Nat. U., Korea
U Geneva, Switzerland
Goethe U Frankfurt, Germany
GSI, Germany
Hellenic Open U, Greece
HEPHY, Austria
IFJ PAN Krakow, Poland
INFN, Italy
INP Minsk, Belarus
U Iowa, USA
IPM, Iran
UC Irvine, USA
Istanbul Aydin U., Turkey

JAI/Oxford, UK
JINR Dubna, Russia
KEK, Japan
KIAS, Korea
King's College London, UK
Korea U Sejong, Korea
MEPhI, Russia
Northern Illinois U., USA
NC PHEP Minsk, Belarus
PSI, Switzerland
Sapienza/Roma, Italy
UC Santa Barbara, USA
U Silesia, Poland
TU Tampere, Finland

FCC study
Work plan



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