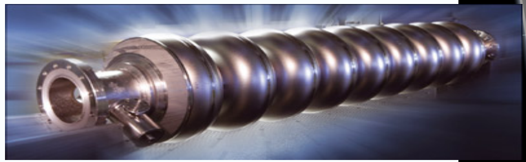
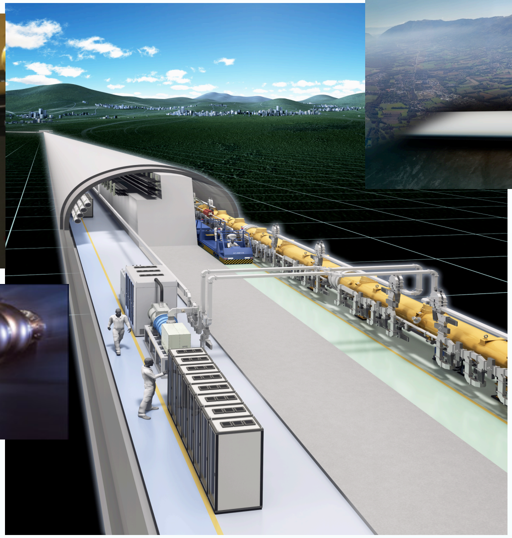
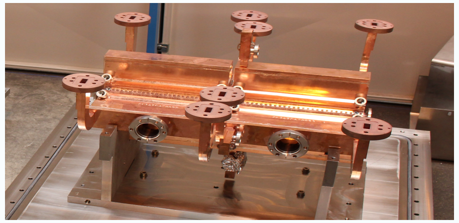




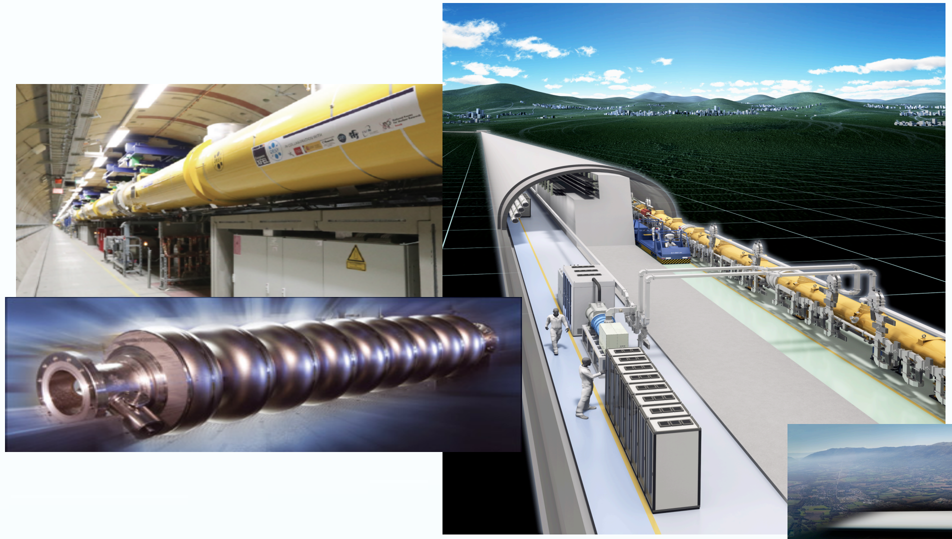


Large Accelerator Projects: Present and Future

A. Faus-Golfe

Present and Future Accelerator perspectives

An uncompleted view …



In operation
In construction
Under study

International Large Scale Projects

2017
LHC
ATF2
Super B
XFEL
…

2019
ESS
SC linac

2020
EU Strategy:
FCC/CLIC, ILC
LBNF…

2025
HL-LHC
11T Nb_3Tn
FAIR

2026
LBNF/
DUNE

2028
CepC
ILC
1.3GHz SC
nano-beam/
stabilization

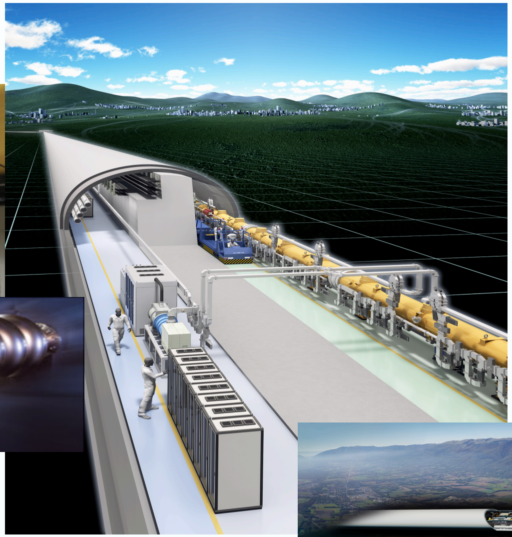
PLC

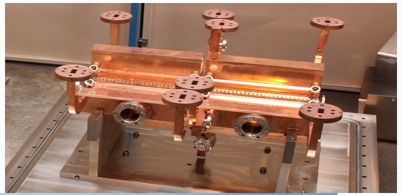
CLIC
12 GHz two-beam
nano-beam/
stabilization

2040
HE-LHC
16T $Nb_3Tn/NbTn$
FCC pp
16T $Nb_3Tn/NbTn$
FCC ee
High current Z-pole
CppC

Present and Future Accelerator perspectives

An uncompleted view …





In operation
In construction
Under study

International Large Scale Projects

2017 · 2019 · 2020 · 2025 · 2026 · 2028 · 2040

2017
LHC
ATF2
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…

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2040
HE-LHC
16T Nb_3Tn/NbTn
FCC pp
16T Nb_3Tn/NbTn
FCC ee
High current Z-pole
CppC

Outline

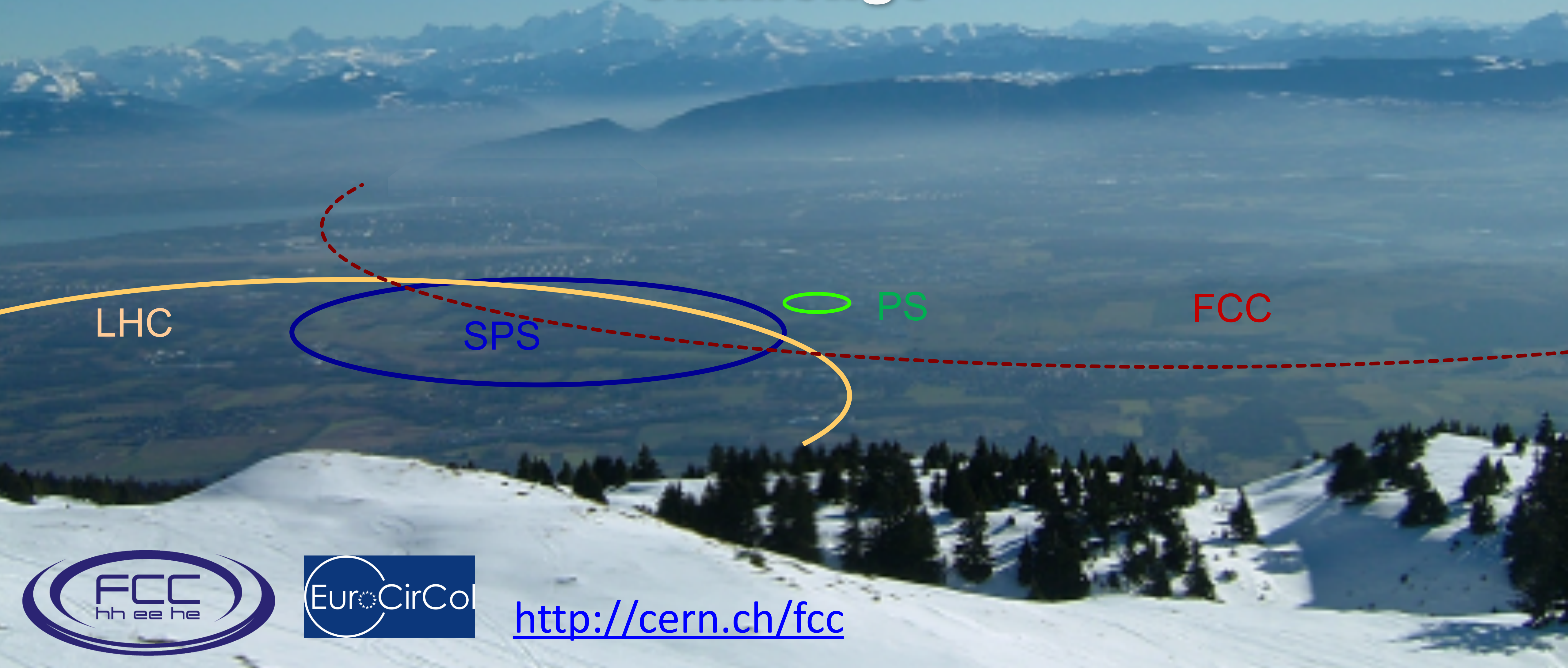
- **The FCC project:** FCC-hh, HE-LHC, FCC-ee, FCC-eh

  - Scope and Parameters
  - FCC-hh: layout, optics: collimation system, implementation and integration, SC magnets and special technologies
  - HE-LHC: optics and integration
  - FCC-ee: optics, magnets, MDI, SRF, Klystrons
  - FCC-eh: parameters, ERL, SRF and cryo
  - Summary and outlook

- **The LC projects:** ILC, CLIC

  - ILC accelerator: status and optimization
  - CLIC accelerator: status and rebaselining
  - Summary and outlook

Future Circular Collider: the next BIG accelerator challenge



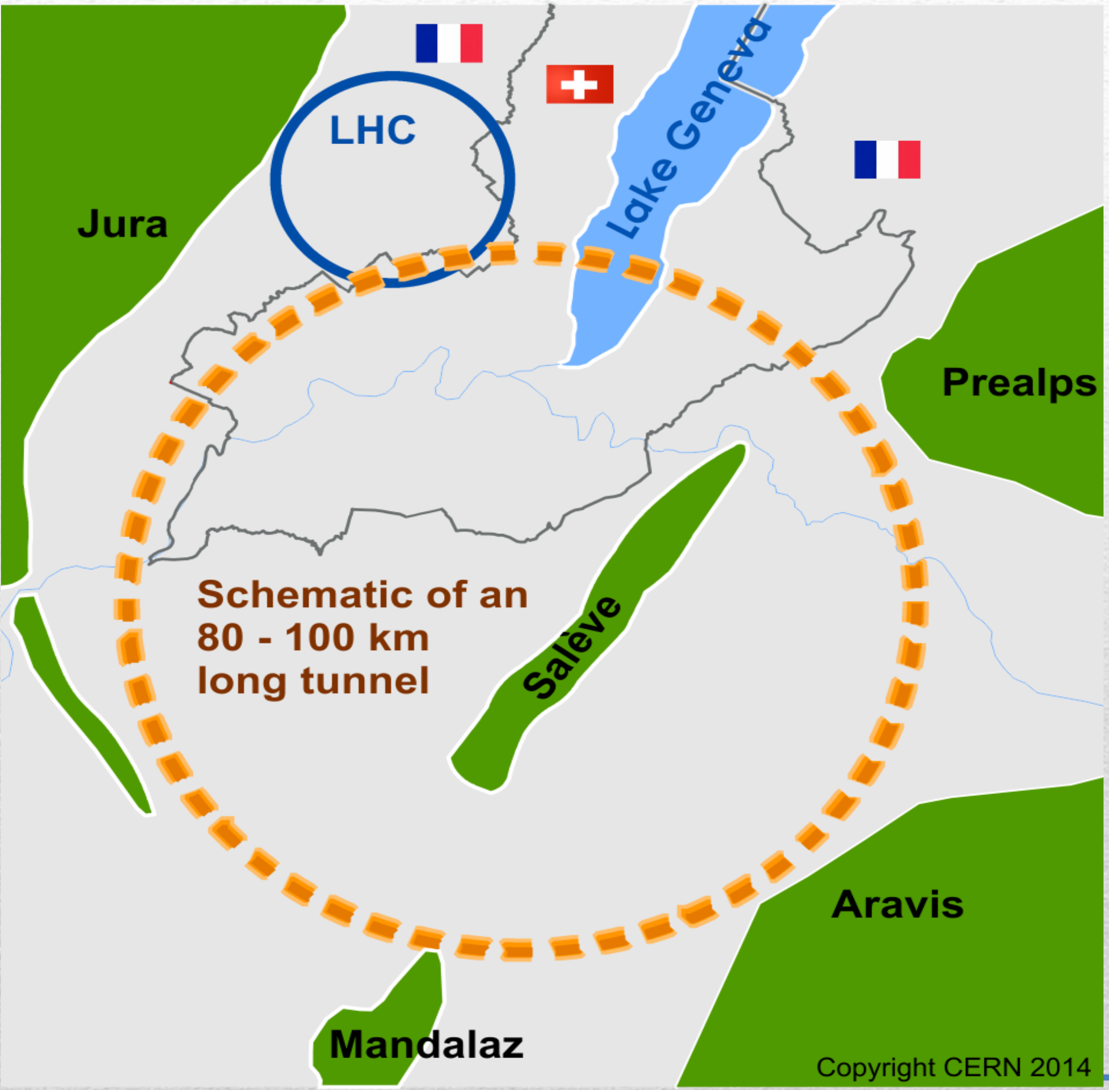
FCC hh ee he

EuroCirCol

http://cern.ch/fcc

*Work supported by the **European Commission** under the HORIZON 2020 project EuroCirCol, grant agreement 654305*

Scope of FCC Study



~16 T ⇒ 100 TeV *pp* in 100 km

International FCC collaboration (CERN as host lab) to study:

- ***pp*-collider (*FCC-hh*)** main emphasis, defining infrastructure requirements
- **~100 km tunnel infrastructure** in Geneva area, site specific
- **e^+e^- collider (*FCC-ee*),** as potential first step
- ***p-e* (*FCC-he*) option,** integration one IP, e from ERL
- **HE-LHC** with *FCC-hh* technology
- **CDR for end 2018**

FCC-pp collider parameters

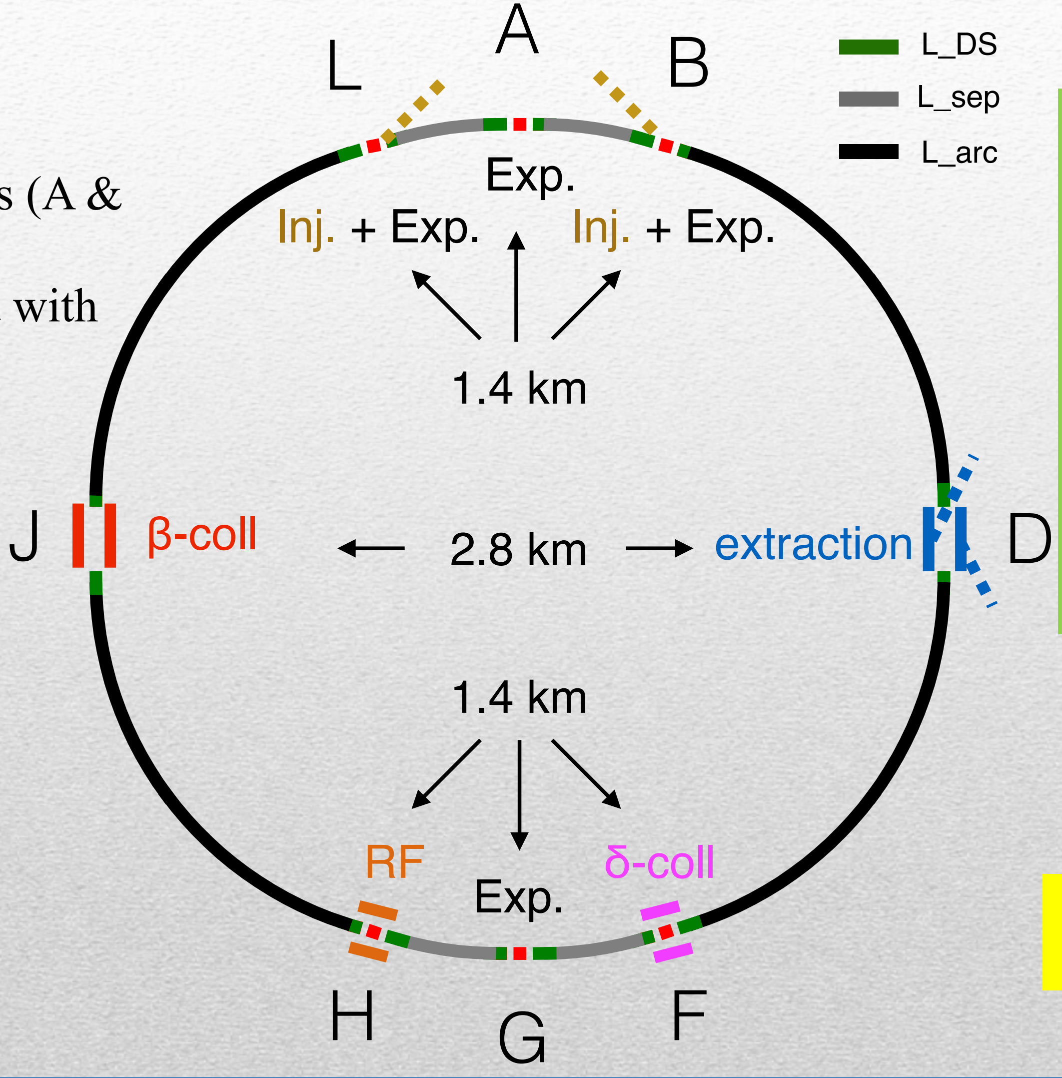
parameter	FCC-hh		HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		27	14	14
dipole field [T]	16		16	8.33	8.33
circumference [km]	97.75		26.7	26.7	26.7
beam current [A]	0.5		1.12	1.12	0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2 (0.44)	2.2	1.15
bunch spacing [ns]	25	25 (5)	25 (5)	25	25
synchr. rad. power / ring [kW]	2400		101	7.3	3.6
SR power / length [W/m/ap.]	28.4		4.6	0.33	0.17
long. emit. damping time [h]	0.54		1.8	12.9	12.9
beta* [m]	1.1	0.3	0.25	0.20	0.55
normalized emittance [μm]	2.2 (0.4)		2.5 (0.5)	2.5	3.75
peak luminosity [10^{34} cm^{-2}s^{-1}]	5	30	25	5	1
events/bunch crossing	170	1k (200)	~800 (160)	135	27
stored energy/beam [GJ]	8.4		1.3	0.7	0.36

FCC-ee collider parameters

parameter	Z	W	H (ZH)	ttbar
cm collision energy [GeV]	91	160	240	350
beam current [mA]	1400	147	29	6.4
no. bunches	71000	7500	740	62
bunch intensity [10^{11}]	0.4	0.4	0.8	2.1
bunch spacing [ns]	2.5 / 5.0	40	400	5000
SR energy loss / turn [GeV]	0.036	0.34	1.71	7.72
total RF voltage [GV]	0.25	0.8	3.0	9.5
long. damping time [turns]	1280	235	70	23
horizontal beta* [m]	0.15	1	1	1
vertical beta* [mm]	1	2	2	2
horiz. geometric emittance [nm]	0.27	0.26	0.61	1.33
vert. geom. emittance [pm]	1.0	1.0	1.2	2.66
bunch length with SR & BS [mm]	4.1	2.3	2.2	2.9
luminosity [10^{34} $cm^{-2}s^{-1}$]	130	16	5	1.4

FCC-hh new layout

- **Two high-luminosity** experiments (A & G)
- **Two other** experiments combined with **injection** (L & B)
- **Two collimation** insertions
  - Betatron cleaning (J)
  - Momentum cleaning (F)
- **Extraction insertion** (D)
- **Clean insertion with RF** (H)
- **Compatible** with **LHC** or **SPS** as **injector**



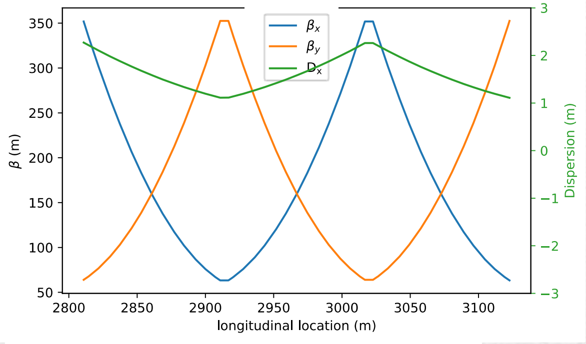
New features:

- **Overall length 97.75 km**
- **Economy length 2.25 km**
- Injections upstream side of experiments
- **Avoids mixing of extraction region and high-radiation collimation areas**

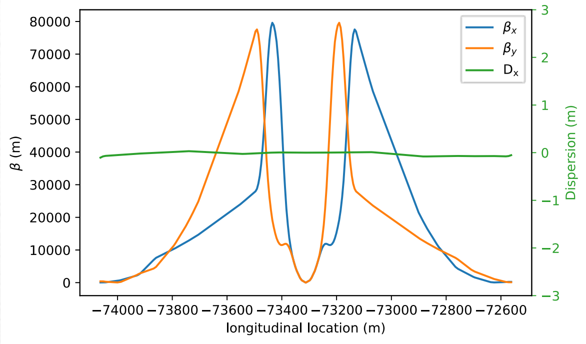
Taking this layout as fixed
(for CDR preparation)

Integrated FCC-hh lattice design

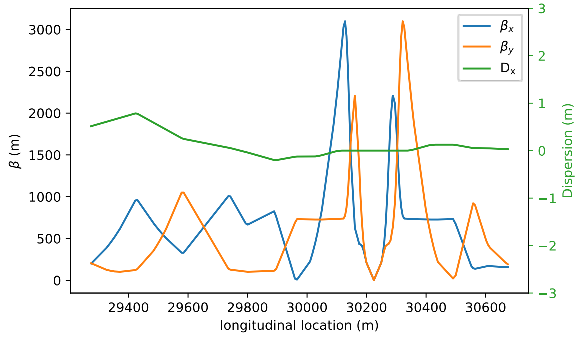
Arc



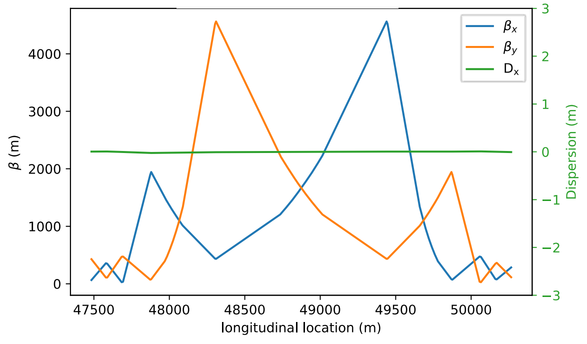
Main experiments



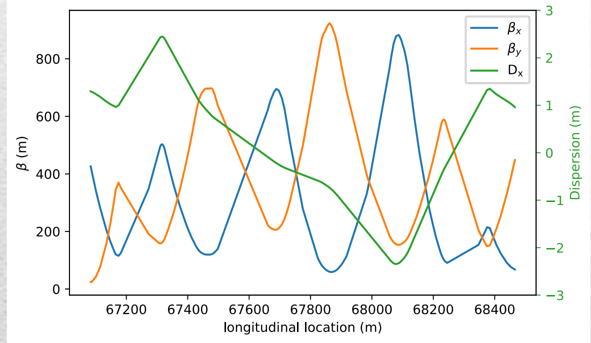
Special experiments



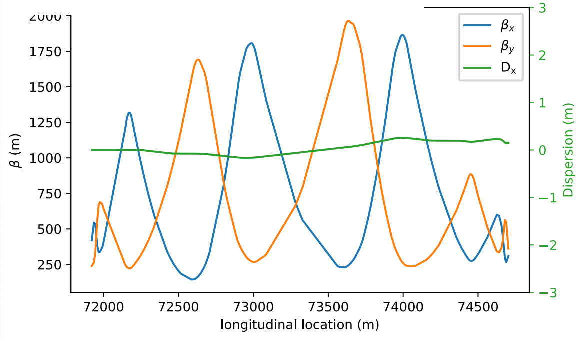
Extraction



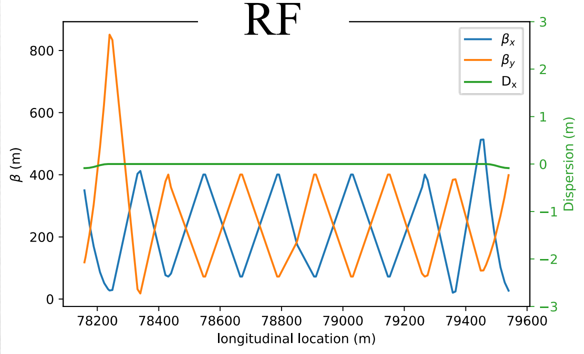
Momentum collimation



Betatron collimation



RF



Full integrated lattice exists

- Lattice imperfection studies ongoing, injection dynamic aperture OK, @collision ongoing
- Dynamic aperture optimization in iteration with magnet design (balancing errors at injection/collision)
- Tentative specifications for magnets correctors and alignment tolerances

Implementation - new footprint baseline

Alignment | Shafts | Query

Choose alignment option

V4variation_v2017-2

Tunnel elevation at centre:322mASL

Grad. Params

Azimuth (°): -23.5

Slope Angle x-x(%): 0.3

Slope Angle y-y(%): 0.08

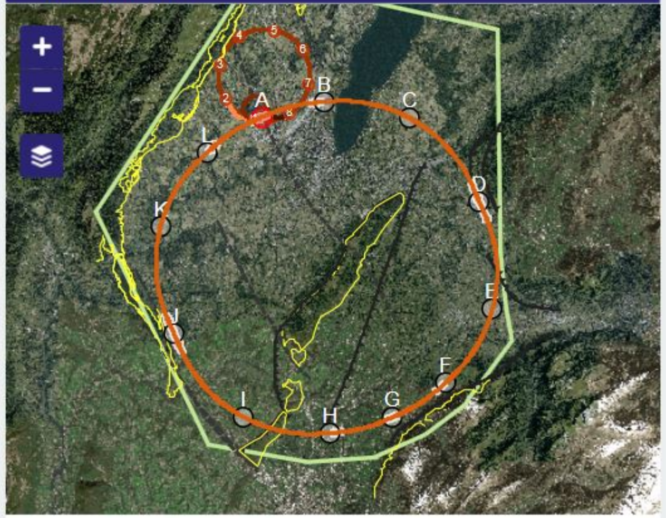
LOAD SAVE CALCULATE

Alignment centre

X: 2499941 Y: 1107760

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	37°	49m	-40°	83m
SPS		121m		126m
TI2		121m		126m
TI8		51m		118m

Alignment Location



Geology Intersected by Shafts | Shaft Depths

Point	Shaft Depth (m) Actual	Molasse SA	Wildflysch	Quaternary	Geology (m) Molasse	Urgonian	Limest
A	152	0	0	0	152	0	
B	121	0	0	26	95	0	
C	127	0	0	44	83	0	
D	205	66	0	40	100	0	
E	89	0	0	89	0	0	
F	476	0	0	49	427	0	
G	307	0	0	73	234	0	
H	266	0	0	0	266	0	
I	198	0	0	11	187	0	
J	248	0	0	1	247	0	
K	88	0	0	70	18	0	
L	172	0	0	89	83	0	
Total	2449	66	0	492	1892	0	

Optimisation in view of accessibility surface points, tunnelling rock type, shaft depth, etc.

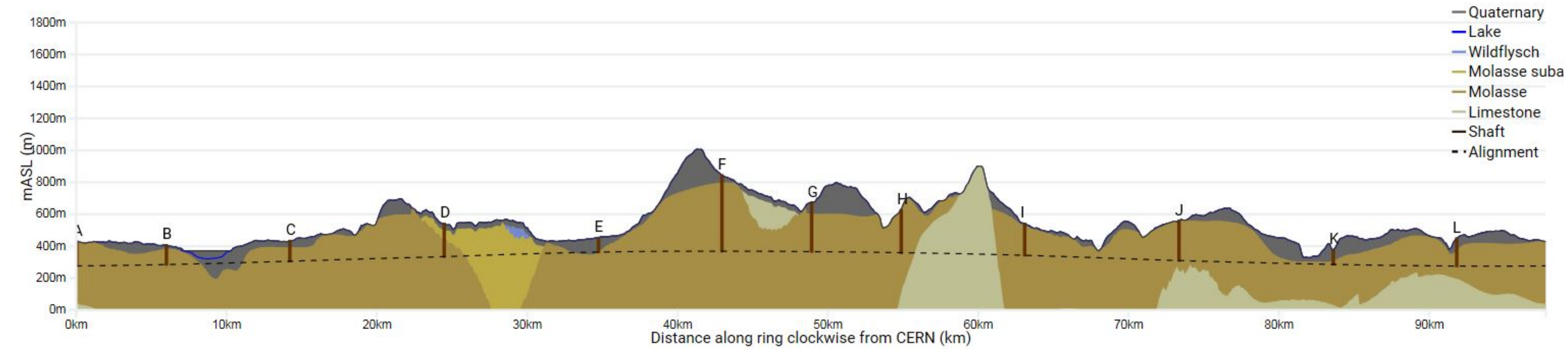
Tunneling

- Molasse 90%, Limestone 5%, Moraines 5%

Shallow implementation

- ~ 30 m below lakebed
- Reduction of shaft length and technical installations
- One very deep shaft **F** (RF or collimation), alternatives being studied, e.g. inclined access

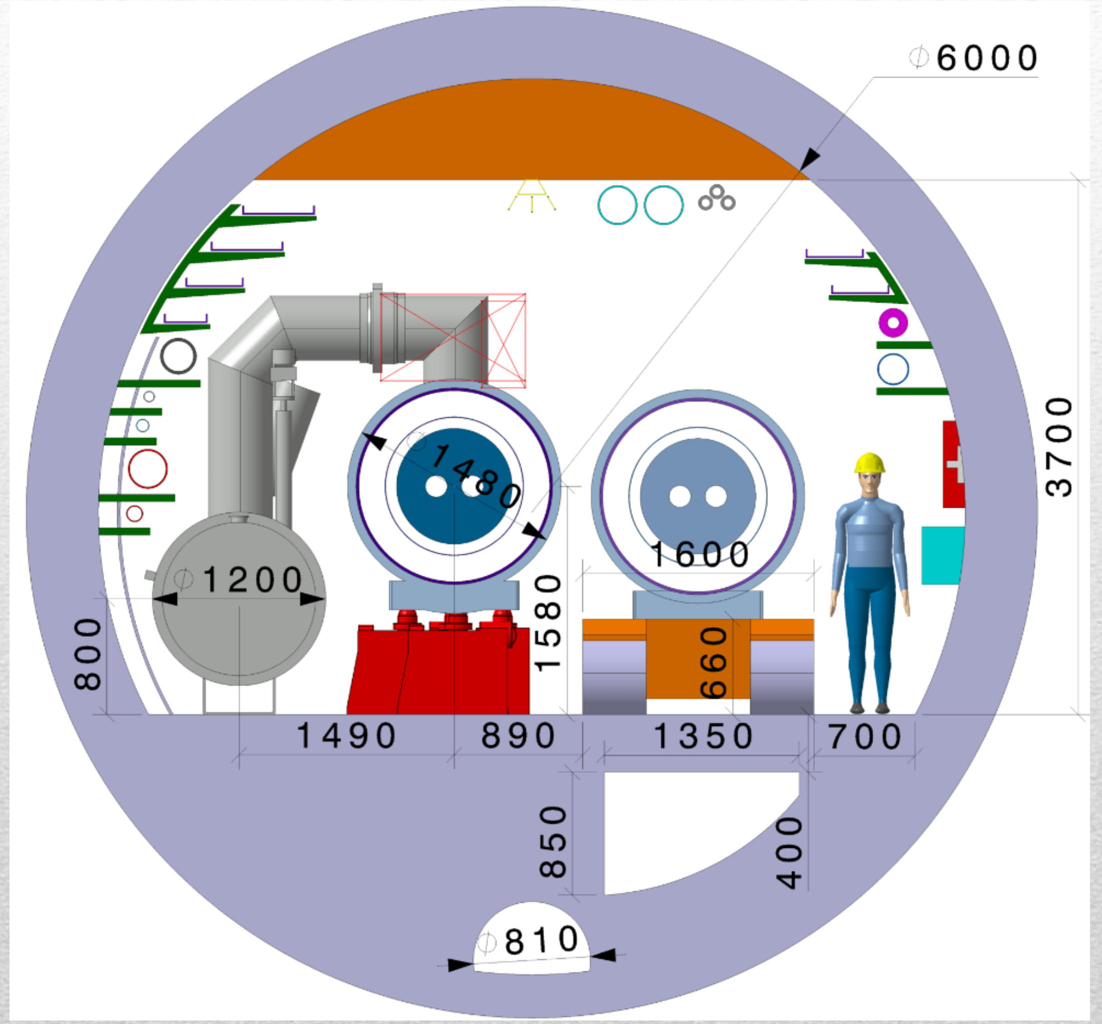
Alignment Profile



Geology Intersected by Tunnel | Geology Intersected by Section

84.6% | 5.2% | 5.5% | 4.7%

FCC-hh integration



Basic layout following LHC concept

- **6 m inner tunnel diameter**
- Main space allocation:
  - 1200 mm cryo distribution line (QRL)
  - 1480 mm installed cryomagnet
  - 1600 cryomagnet magnet transport
  - >700 mm free passage.

The SC Magnets

16 T magnets target:

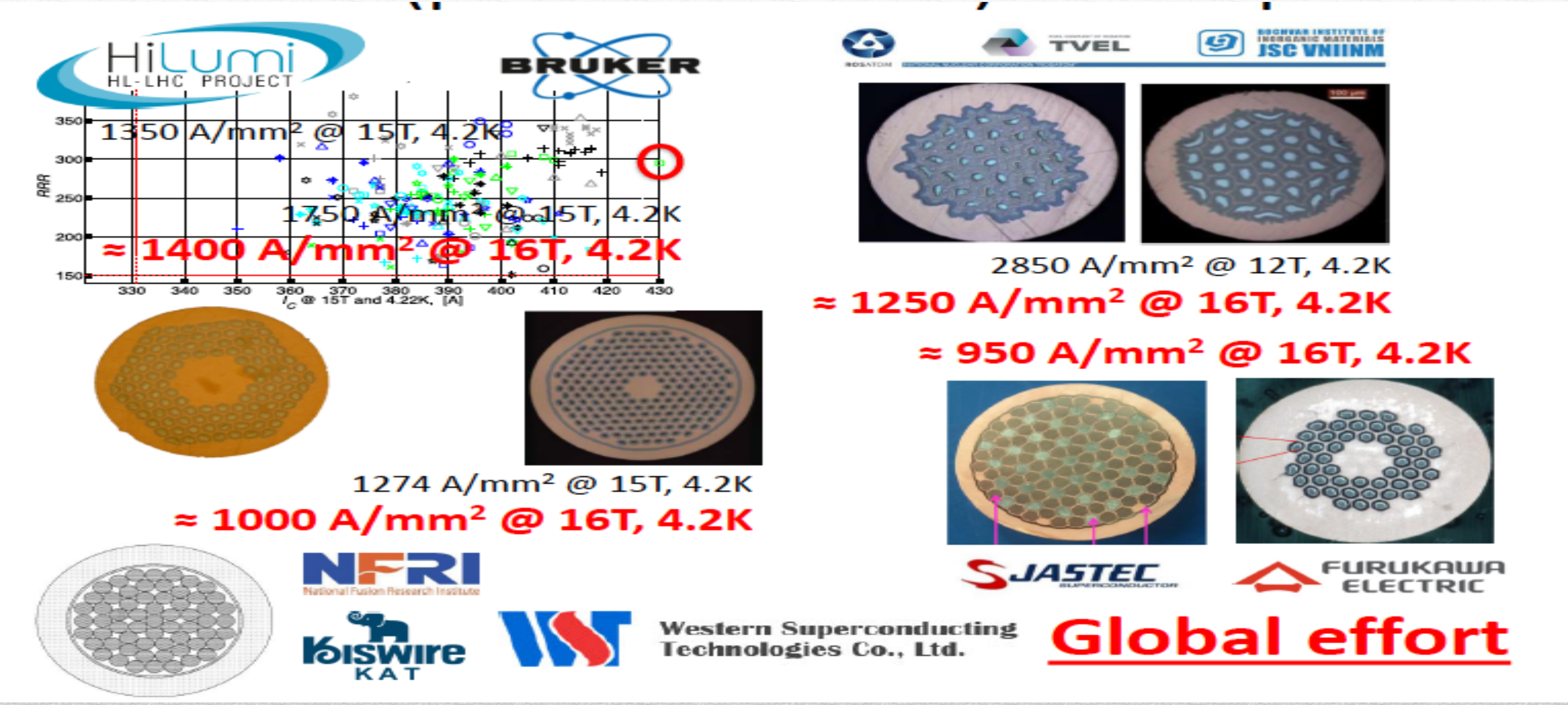
- **a reference design** for the 16 T dipoles, including integration in **cryostat**;
- a **concept** for the magnet and **circuit protection**;
- an estimate of the **cost** for the series production;

But many unknowns:

- **conductor cost**
- achievable **conductor performance**, no enhancements expected within 2018
- **electromechanical performance** of conductor and cable not yet fully characterized
- achievable **magnet performance** (required margin) has a major impact on cost
- **No** Nb_3Sn **magnet operating** in a particle accelerator in 2018

The SC Magnets

The Conductor (Nb_3Sn) Development Global Program:



16 T cryo-dipole integration approach

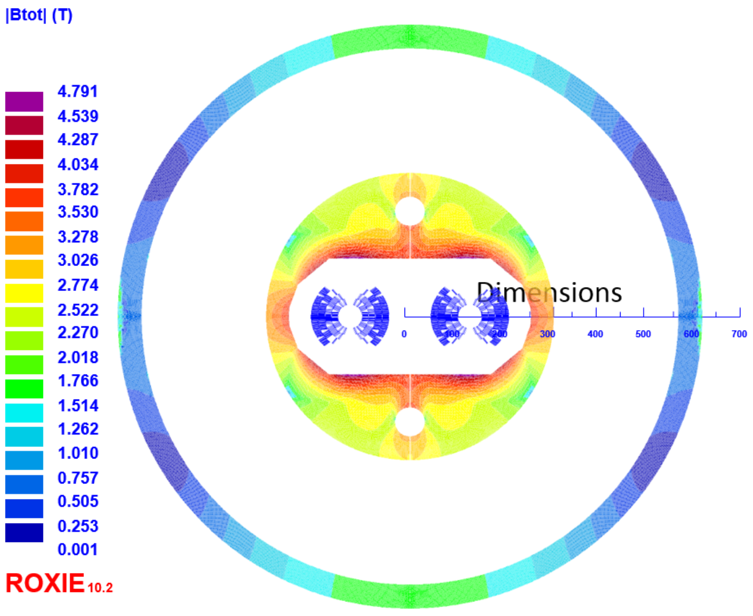
Design strategy: develop a single 16 T magnet, compatible with both HE LHC and FCC-hh requirements:

- Goal is reduction of external diameter to ~1200 mm
- Options und consideration:
  - Allow stray-field and/or cryostat as (partial) return-yoke
  - Active compensation with (simple) shielding coils
  - Optimization of inter-beam distance (compactness of coils)
  - *(QRL integrated in magnets, → negative impact on integral field because of longitudinal space required for service module (5%))*

→ **Smaller diam. also relevant for FCC-hh cost optimization**

→ **Design optimization for specific project after decision**

Example magnetic cryostat coldmass 40t, total mass 62t

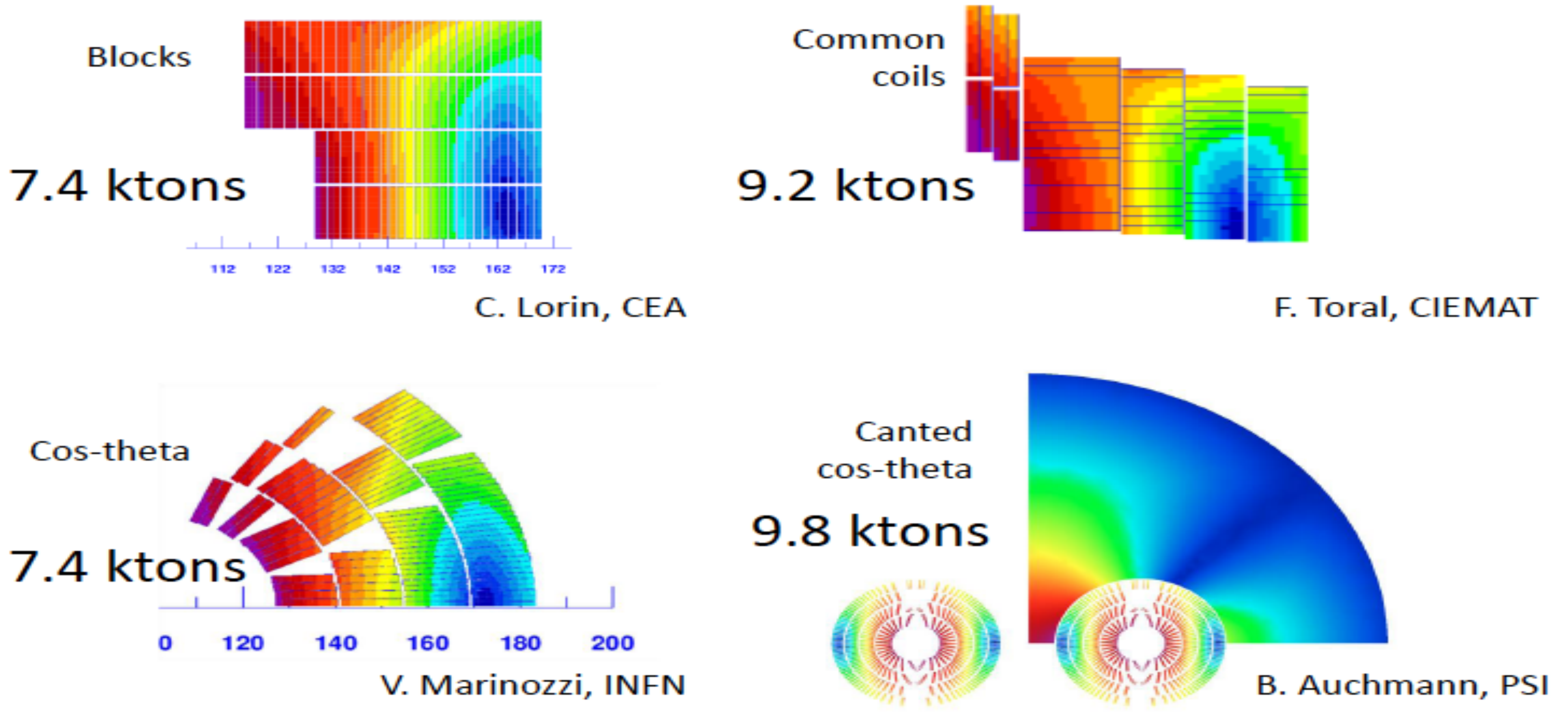


Only magnetic elements shown

Description	ID in mm	OD in mm
Iron yoke	-	600
Aluminium shrinking cylinder	600	740
Stainless steel He tight shell	740	760
Al radiation shield	934	940
Vacuum vessel (magnetic steel)	1120	1220

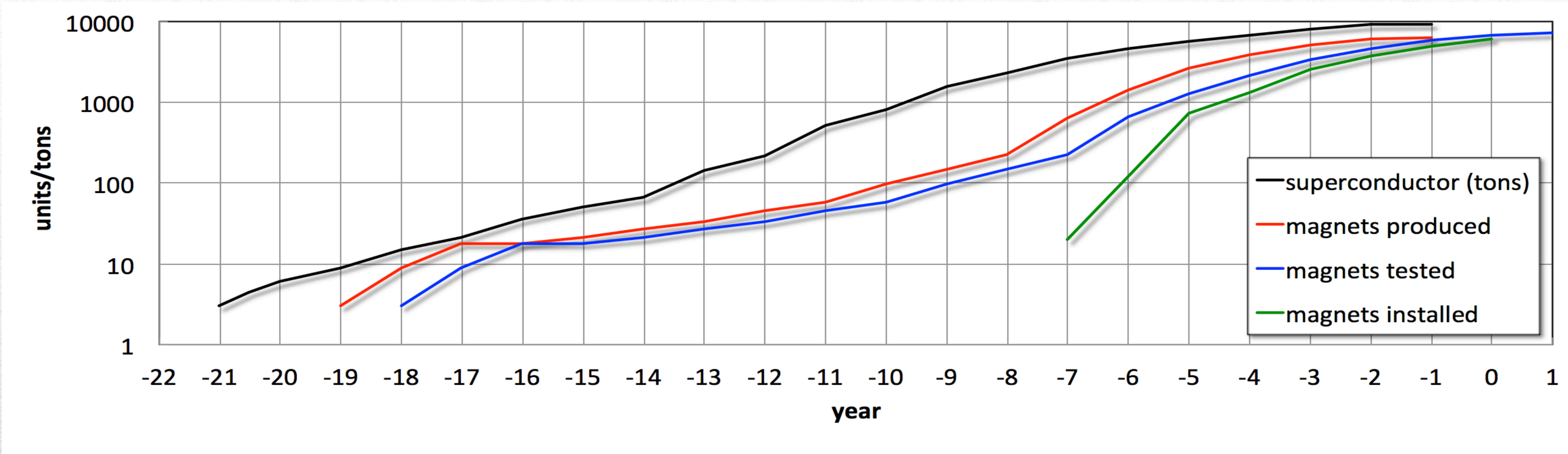
The SC Magnets

The evolution of the dipole designs:



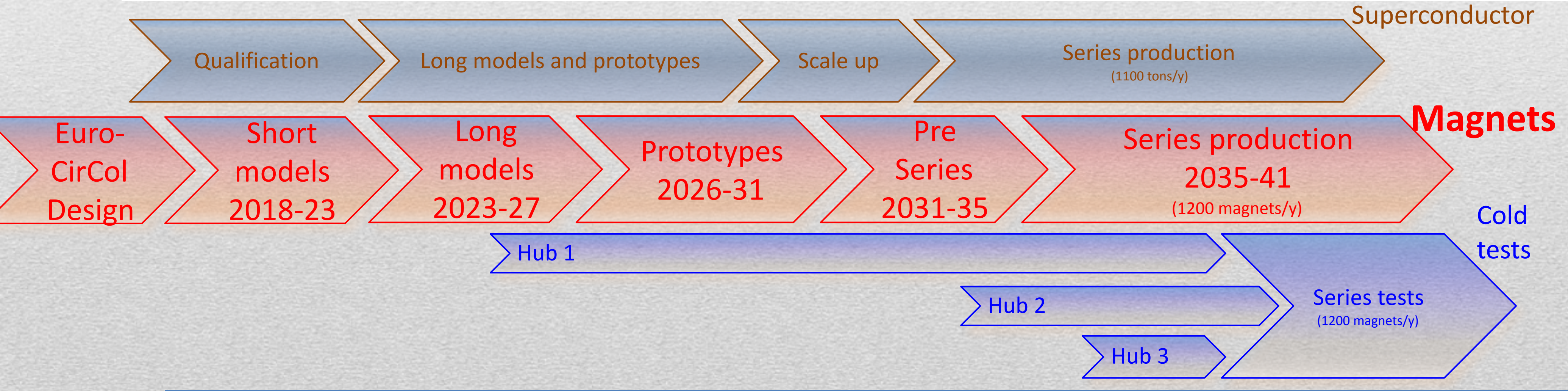
All designs stable and optimized (recall initial estimate of 9000 tons)

16 T magnet R&D schedule



Total duration of magnet program:

~20 years



Would follow on HL-LHC Nb3Sn program with long models with industry from 2023/24

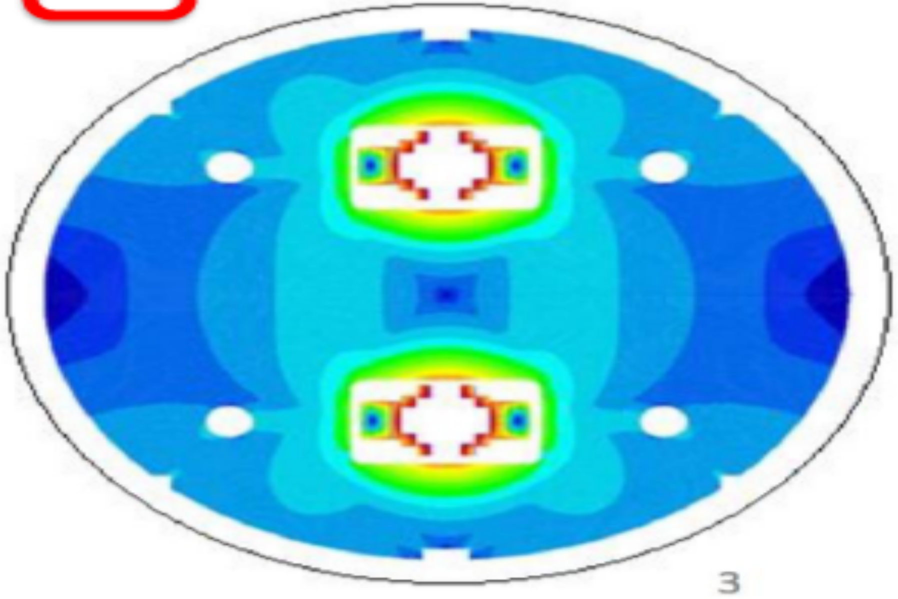
The SC Magnets

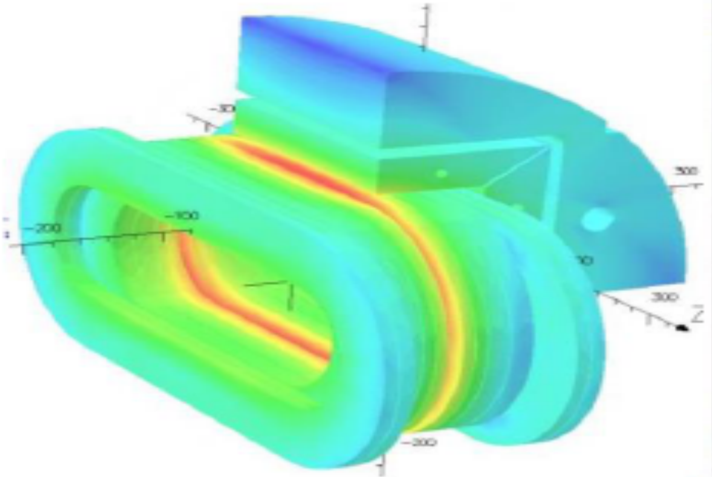
The companions in this effort:

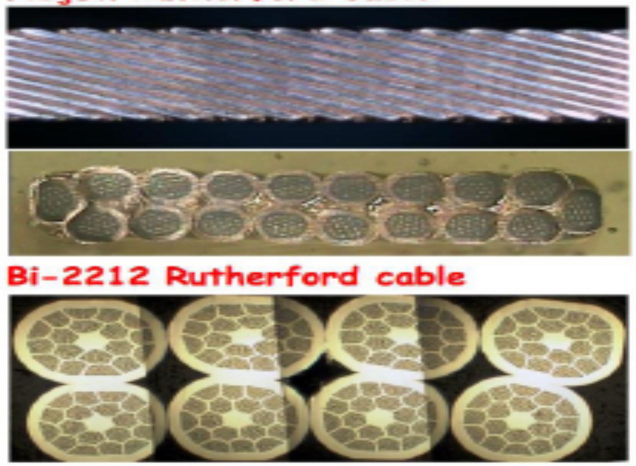
The SC Magnets

The companions in this effort: CN

Conceptual design of the SPPC 12-T magnet
with IBS and common coil configuration



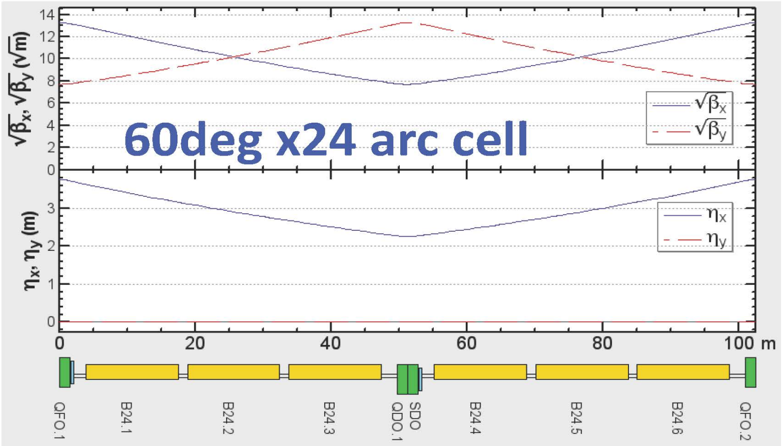


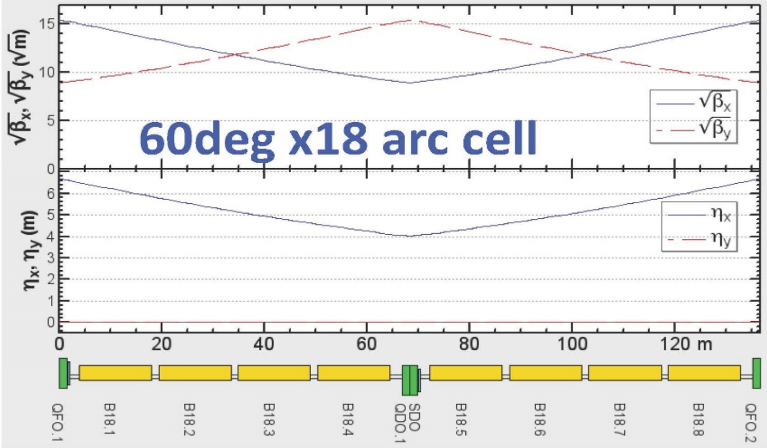


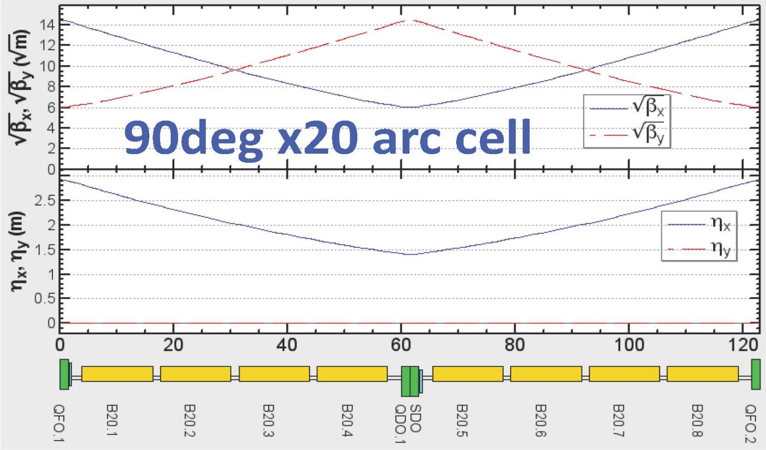
Significant engagement
in HFM technology

Q. Xu, IHEP

HE-LHC optics design work







Studying various arc-cell options, optimizing dipole field, quadr. & sext. strengths, geometry & dynamic aperture, aperture requirements, injection energy, etc.

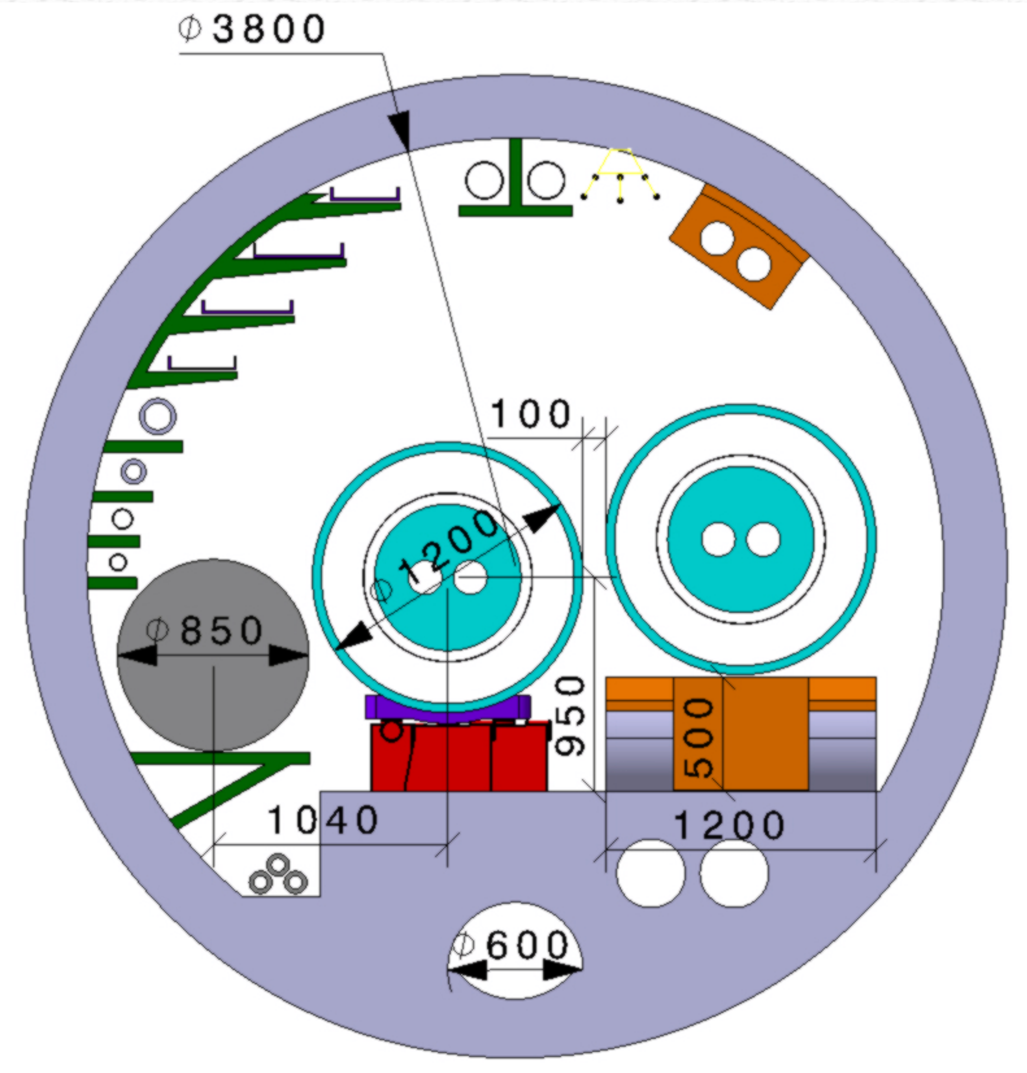
	24 x 60 deg	18 x 60 deg	20 x 90 deg
dipole length, m	**13.56**	**14.1**	**12.39**
number of dipoles	**1280**	**1280**	**1424**
dipole field, T	**16.3**	**15.68**	**16.04**
cell quad gradient, T/m	**289.5**	**215.9**	**340.0**

HE-LHC integration aspects

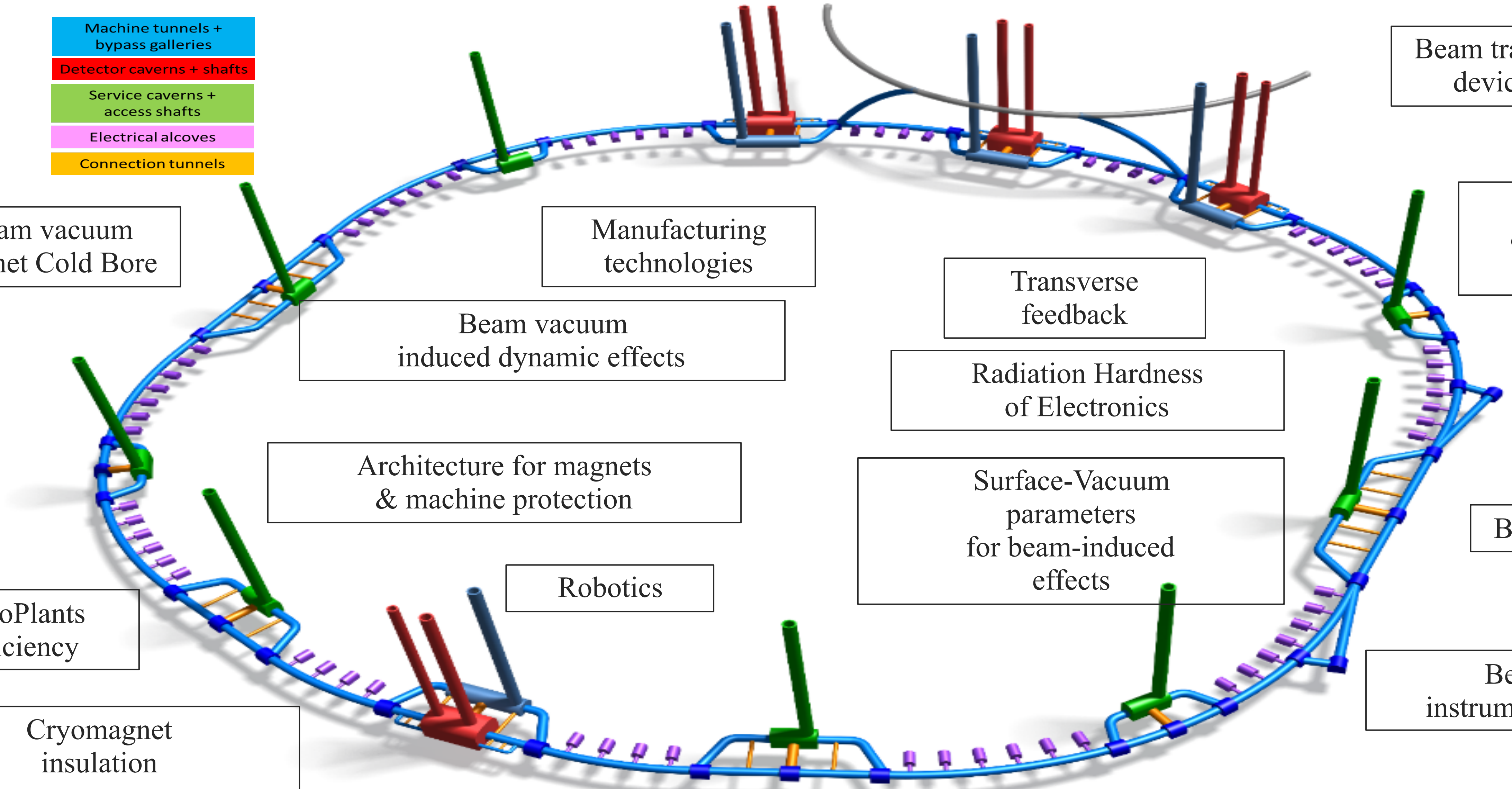
Present working hypothesis for HE LHC design:

No major CE modification on machine tunnel and caverns

- Similar geometry and layout as LHC machine and experiments
- Due to 16 T dipole field and increased cryogenic load, magnet cryostat and cryo distribution line (QRL) larger than for LHC.
- Challenges for tunnel integration and QRL & 16 T cryostat design.
- **Maximum magnet cryostat external diameter compatible with LHC tunnel: 1200 -1250 mm**
- **Classical 16 T cryostat design based on LHC approach gives ~1500 mm diameter!**



The special technologies



Beam vacuum Magnet Cold Bore

Manufacturing technologies

Beam vacuum induced dynamic effects

Architecture for magnets & machine protection

Robotics

CryoPlants efficiency

Cryomagnet insulation vacuum

Beam transfer devices

Normal conducting magnets

Transverse feedback

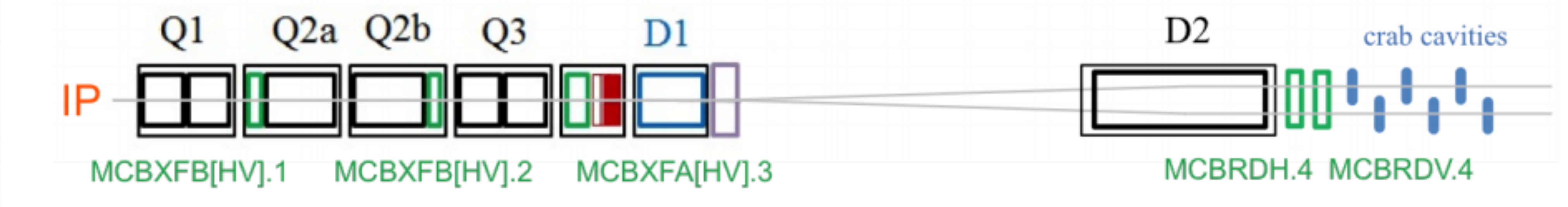
Radiation Hardness of Electronics

Surface-Vacuum parameters for beam-induced effects

Beam dumps

Beam instrumentation

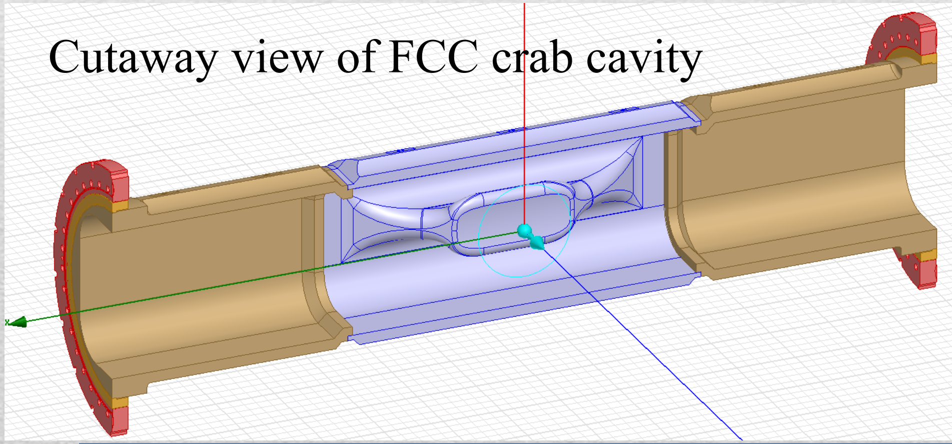
Nb/Cu crab cavity for FCC-hh / HE-LHC



Schematic layout:
E. Cruz-Alaniz,
Nov. 2016, Barcelona

- **Performance of both HE-LHC and FCC-hh phase 2 based on crab cavities!**
  - **Development of compact Nb/Cu SC crab cavity based on ridged waveguide resonator**
  - **Low longitudinal and transverse impedances, provides natural damping for HOMs**
  - **Compatible with 200 mm inter-beam distance**

Cutaway view of FCC crab cavity



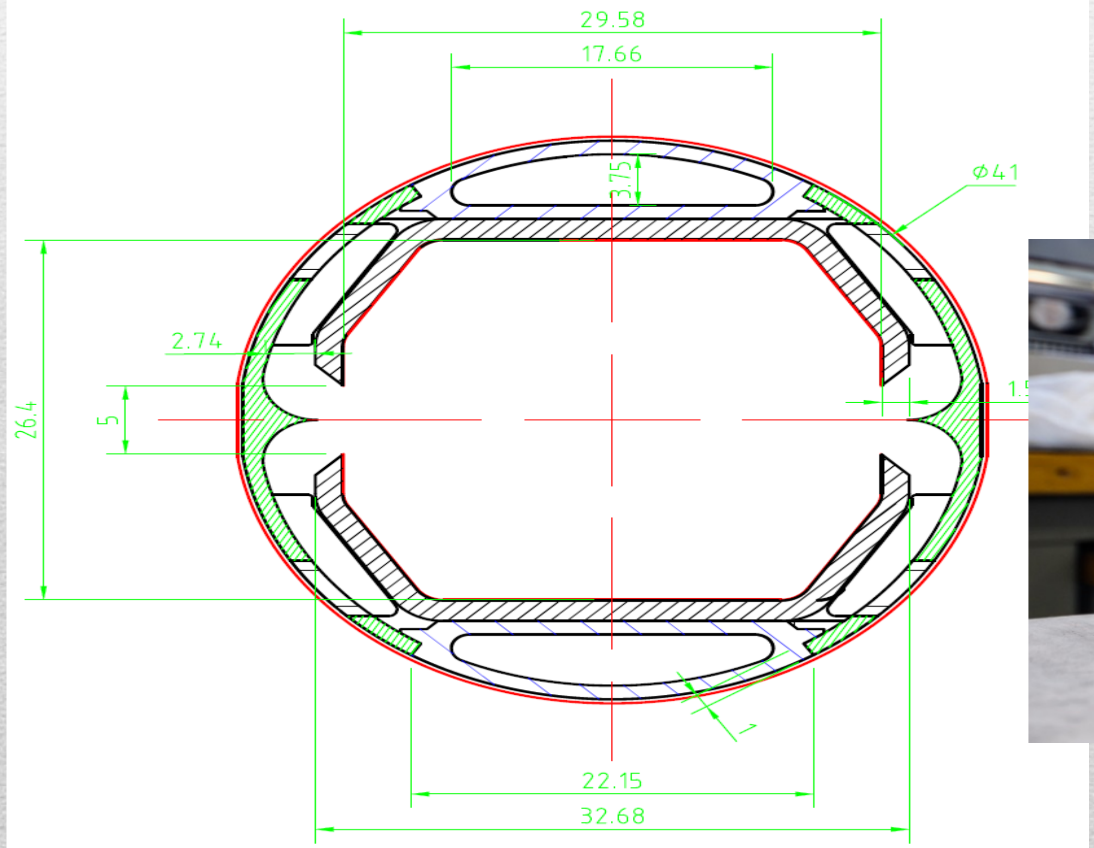
Wide
Open
Waveguide

	FCC-hh
RF frequency [MHz]	400
Total voltage V [MV]	18 (uncertainty ±20%)
Available length [m]	20
Beam separation [mm]	250 (maybe 204 soon)
Average beta in the ring [m]	(339+67)/2 = 203
Beta* [m]	0.3
Crossing angle [urad]	89
Beta at CC location [m]	10100 ÷ 10900

The beam vacuum

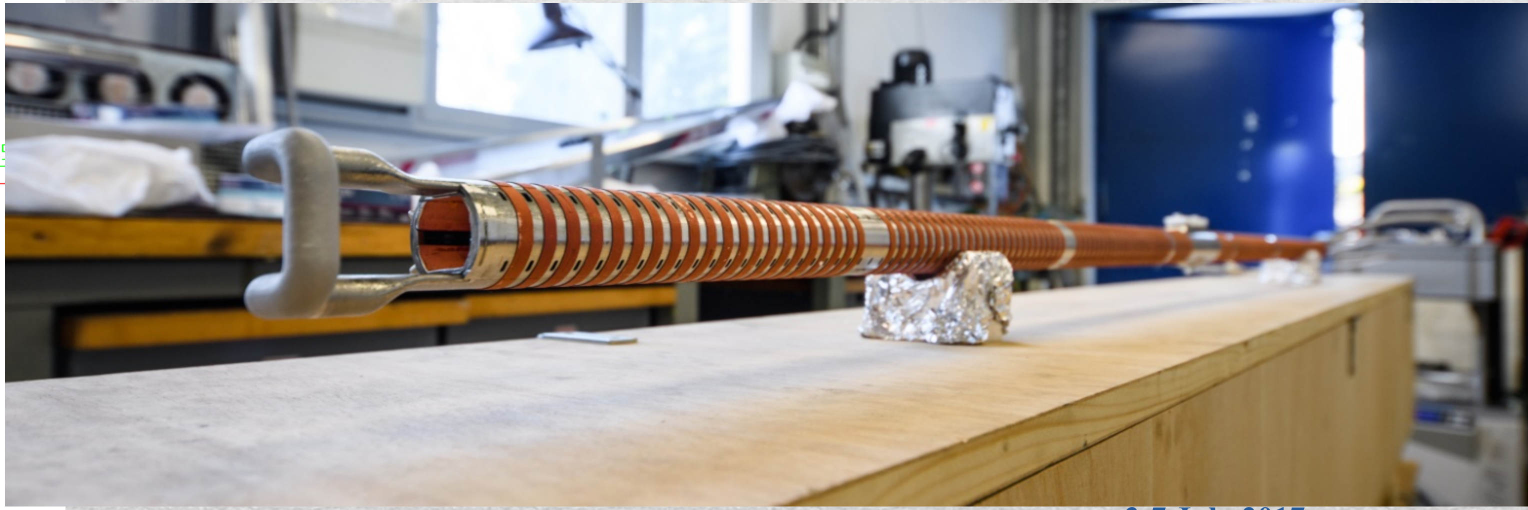
Beam Vacuum:

- One of the most critical elements for FCC-hh
- Absorption of synchrotron radiation at ~50 K for cryogenic efficiency (5 MW total power)
- Provision of beam vacuum, suppression of photo-electrons, electron cloud effect, impedance, etc.



FCC Beamscreen prototype for test at ANKA:

External copper rings for heat transfer to cooling tubes



The beam instrumentation

Beam Instrumentation:

- **BPMs:**

Electronics prototype in order to measure the **resolution for turn by turn** measurements (single bunch) for signals levels corresponding to 5×10^{8} protons measured with a 30 mm button.
Paper study for a BPM with 4+N sensors for interlocked BPMs.

- **Transverse profiles:**

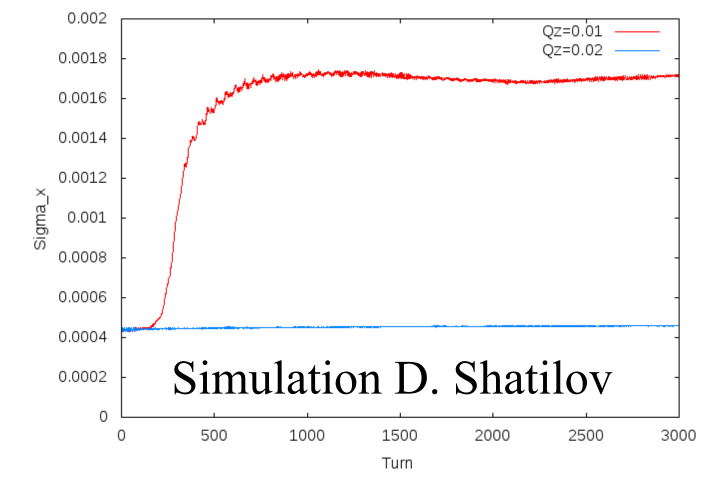
Development from a gas-jet sheet monitor to a **gas-jet scanner**. Simulations and construction of a prototype.
Theoretical & experimental studies to improve halo diagnostics from a contrast ratio 10^{-4} to 10^{-6} including apodization and a semitransparent cover for the central beam. Studies of parasitic light sources and their mitigation.
X-ray interferometry for proton profile evaluations

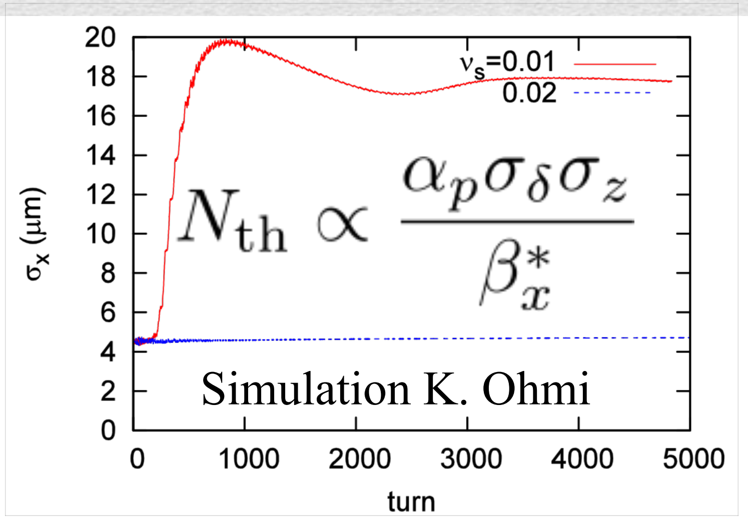
- **Versatile communication link (rad-hard) based on HEP chips and fibre optics**

FCC-ee new optics baseline

Motivations for optics changes since Rome:

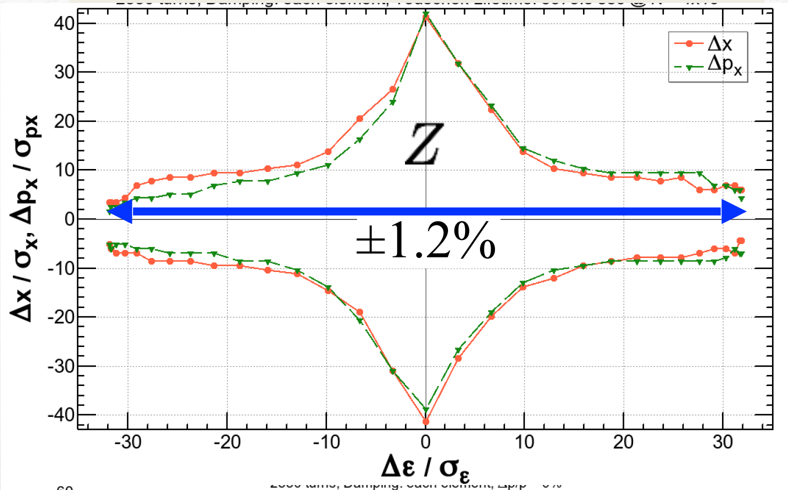
- Mitigation coherent beam-beam instability at Z working point
  - Smaller βx*
  - 60°/60° cell in the arc (larger emittance and momentum compaction), also mitigates microwave instability
- Fitting ee layout to the footprint of the new FCC-hh layout
- Adapt optics for the "Twin Aperture Quadrupole" scheme for arc quadrupoles

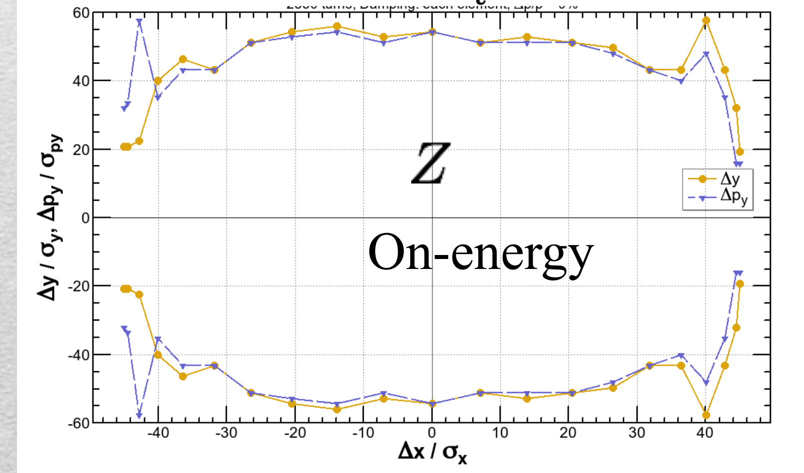




Dynamic aperture studies

45.6 GeV, $\beta^*_{x,y}$ = (0.15 m, 1 mm)

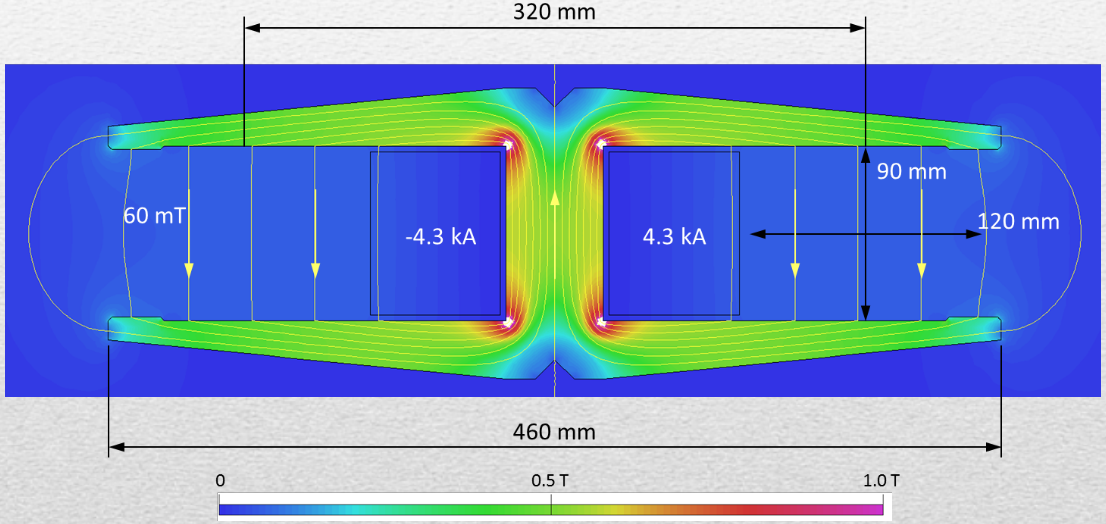




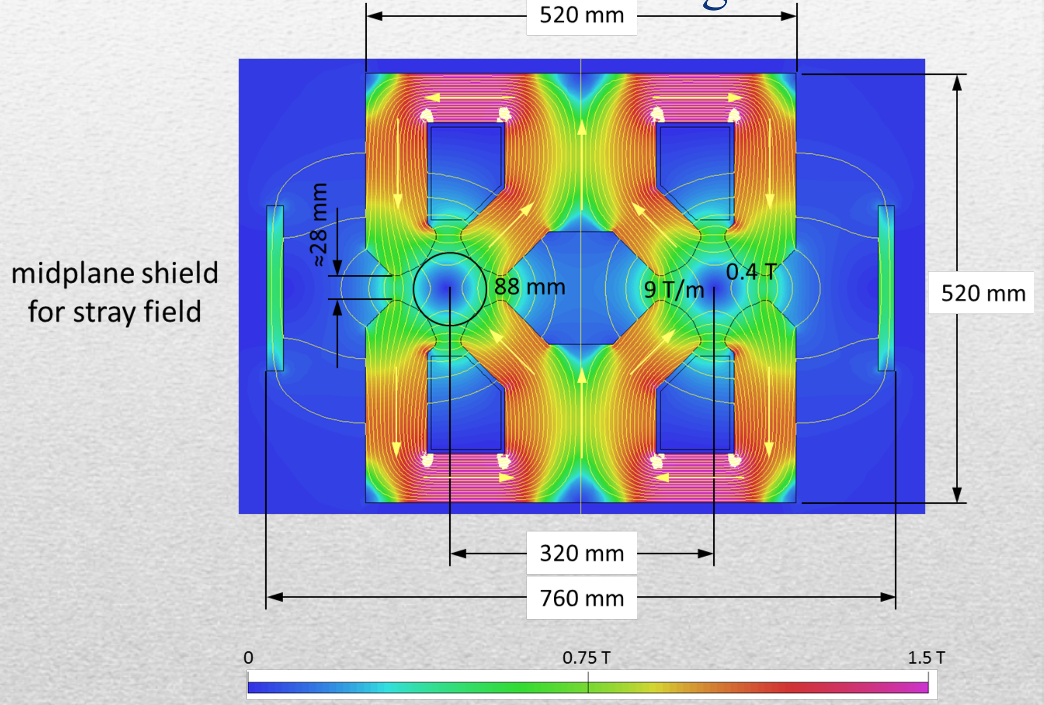
FCC-ee dual aperture main magnets

Prototyping launched of main dipole and quadrupole magnets (~1 m units)

Dipole:
twin aperture yoke, single busbars as coils



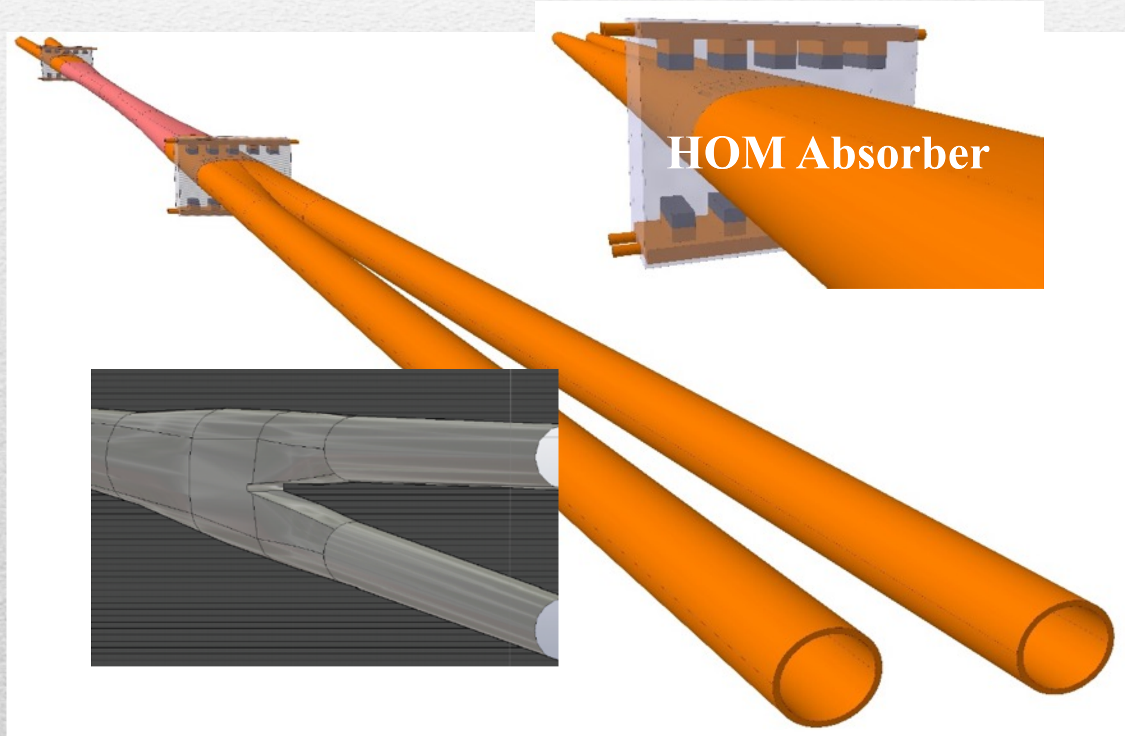
Quadrupole:
twin 2-in-1 design

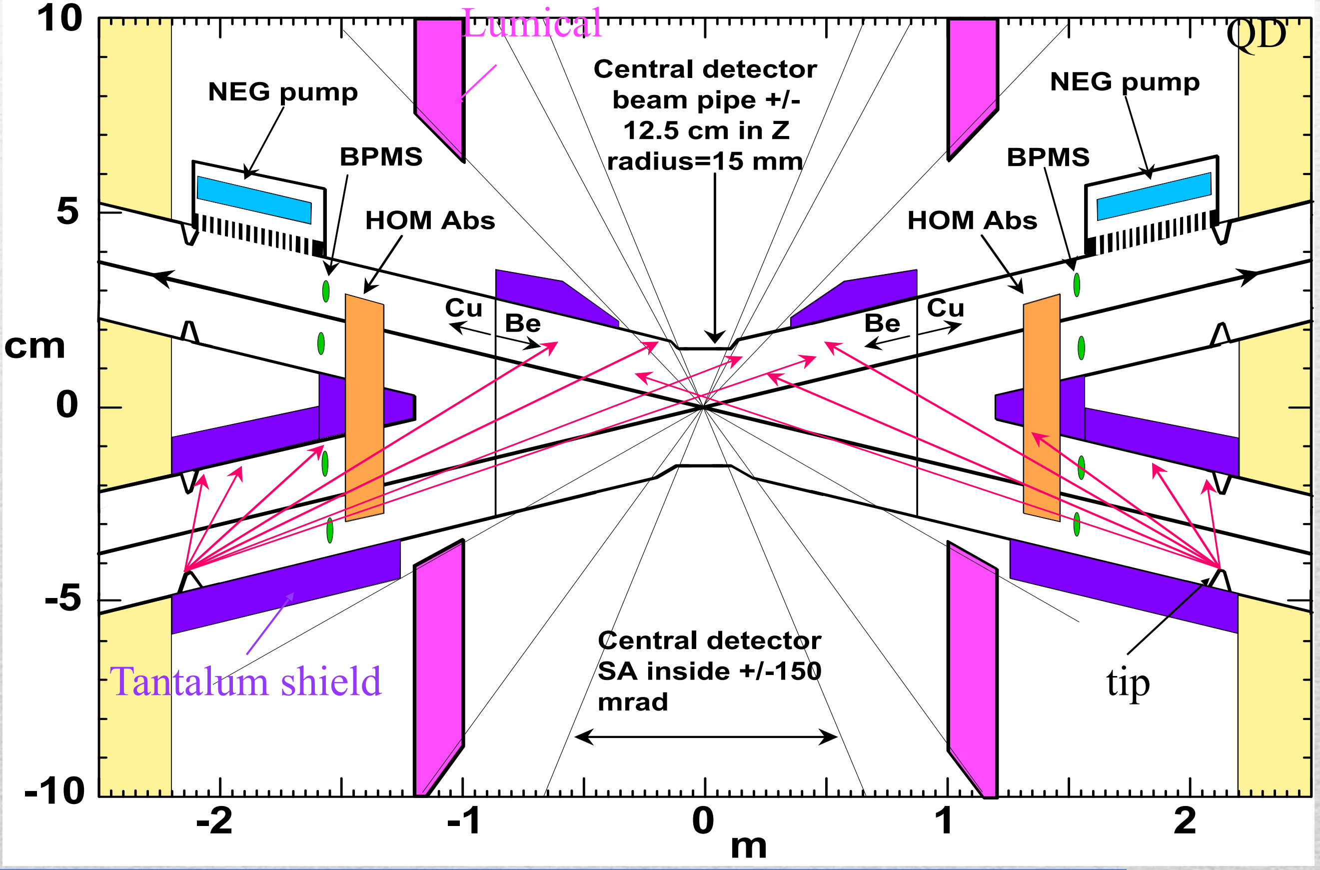


- **Considerable savings in Ampere-turns and power consumption by novel dual aperture designs**
- **Power consumption twin quad: 22 MW at 175 GeV with Cu coil (half of single-aperture quads) and power consumption twin dipole: = 17 MW at 175 GeV with Al bus bar**

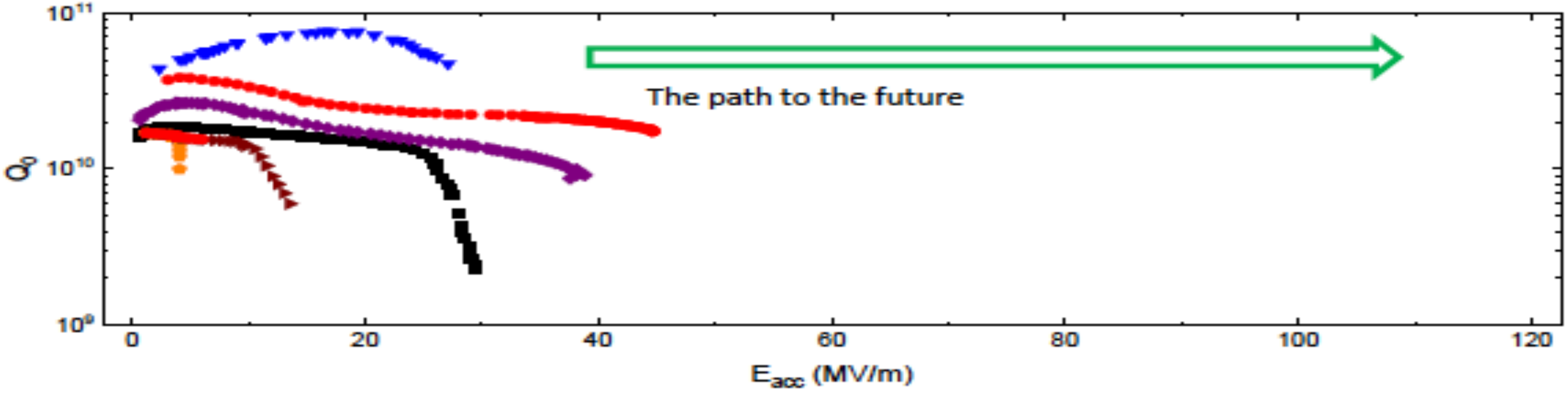
FCC-ee MDI optimisation

- Detailed IR design, beam pipe diameter 3 cm throughout, symmetric final focus, L* = 2.2 m
- Ta shield 1 cm, SR mask tips, 5μm Au in central section to cope with SR at high energy
- Design of HOM absorber to avoid trapped modes in central chamber

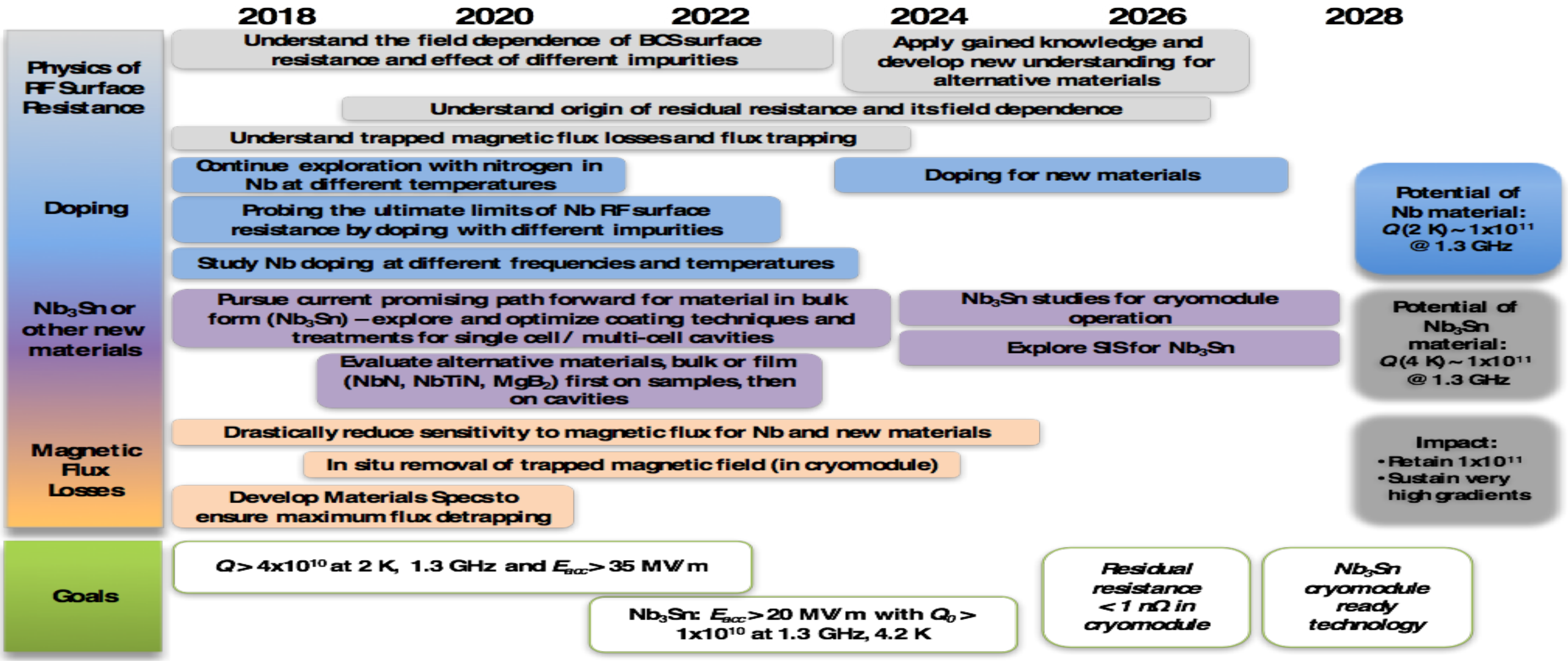




The SRF Roadmap "evolution":

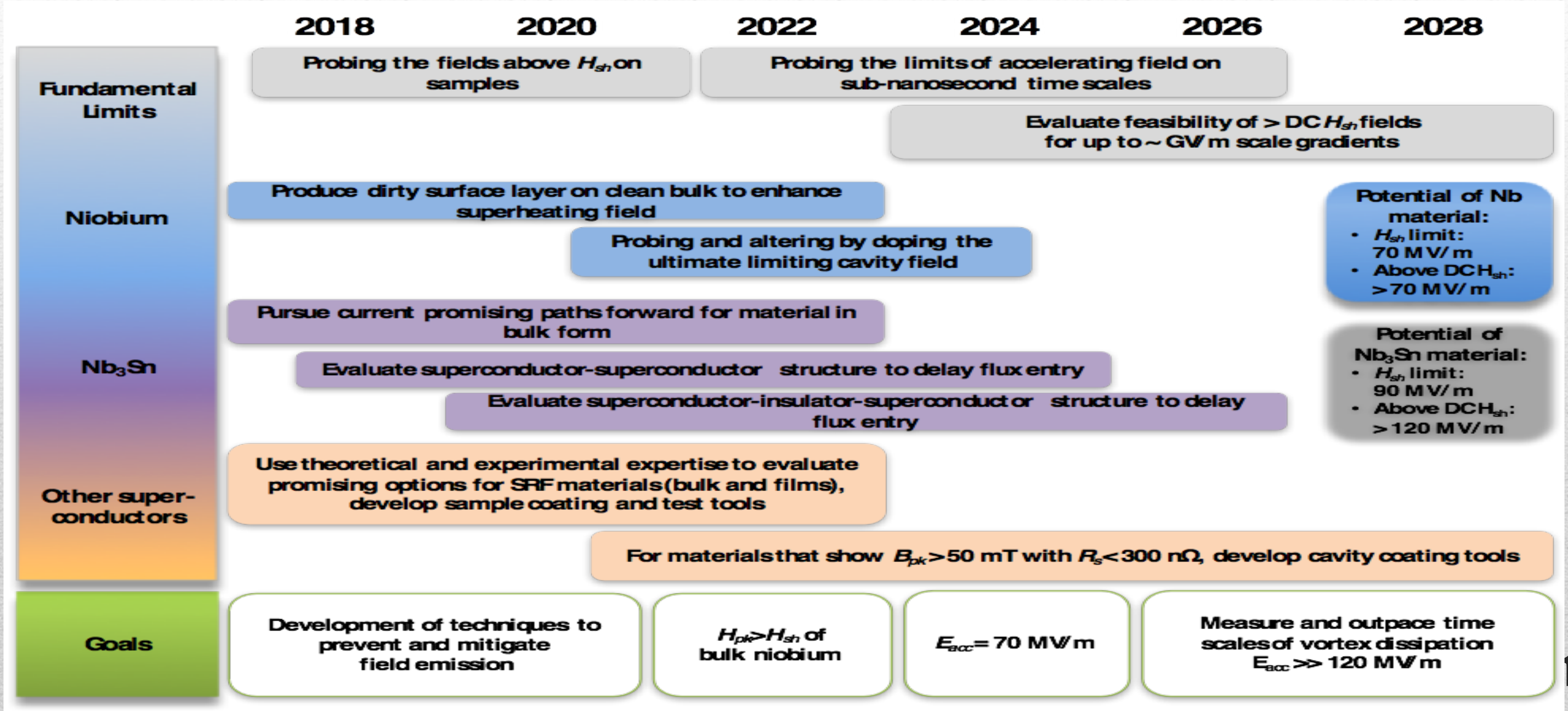


The SRF High-Q Roadmap:



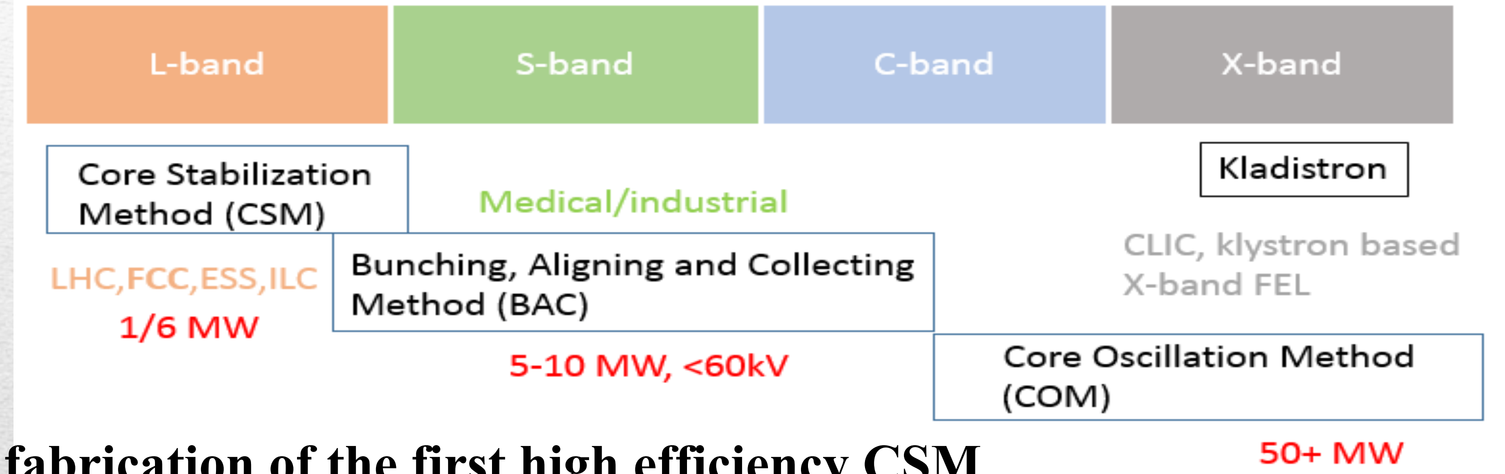
The SRF

The SRF High-Gradient Roadmap:



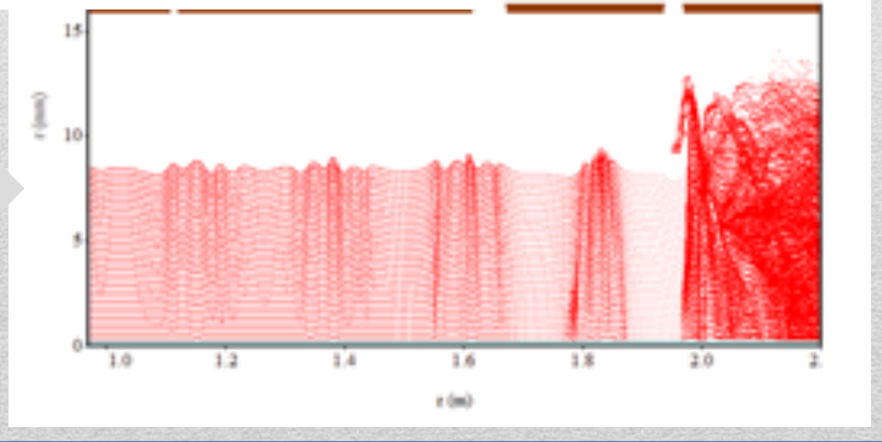
Efficient klystron technology

- **Development of new klystron bunching technologies to increase RF power production efficiency to almost 90%, was initiated at CERN in 2013 (HEIKA), essential for FCC-ee**

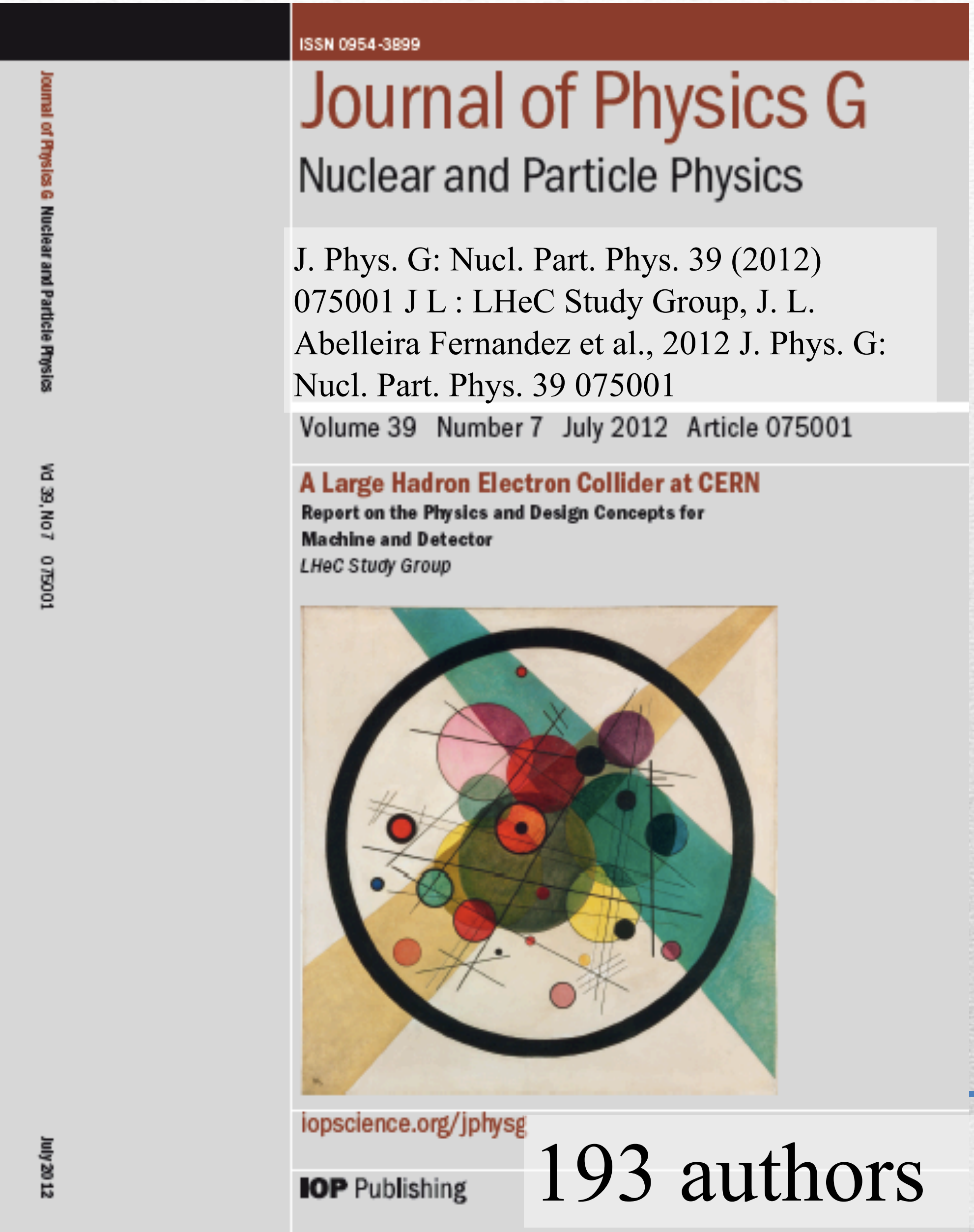


- **Towards fabrication of the first high efficiency CSM tube**
- **Presently negotiations with industry for protoype production for end 2018**
- **Single beam, 1.4 MW, 0.8 GHz, 134 kV, 12.55 A**

85.7% efficiency in simulations



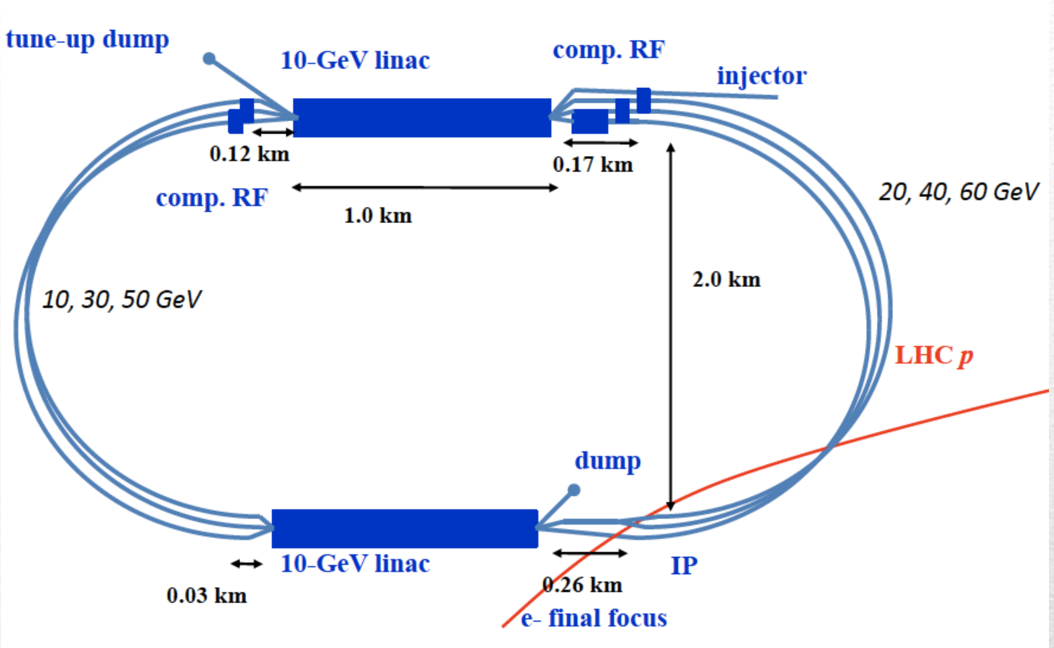
LHeC CDR - published in 2012



J. Phys. G: Nucl. Part. Phys. 39 (2012) 075001 J L : LHeC Study Group, J. L. Abelleira Fernandez et al., 2012 J. Phys. G: Nucl. Part. Phys. 39 075001

193 authors

after CDR completion ERL option selected



key numbers:

- operation in parallel with LHC

TeV scale collision energy ➔ 50-150 GeV beam energy

-power consumption < 100 MW ➔ 60 GeV beam energy

-int. luminosity > 100 * HERA

-peak luminosity > 10^{33} $cm^{-2}s^{-1}$

FCC-eh & HE-LHeC *ep* baselines

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	12.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.5	1
$\gamma\epsilon_p$ [μm]	3.7	2	2.5	2.2
electrons per bunch [10^9]	1	2.3	3.0	3.0
electron current [mA]	6.4	15	20	20
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor H_{geom}	0.9	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3	1.3
proton filling H_{coll}	0.8	0.8	0.8	0.8
luminosity [10^{33}cm^{-2}s^{-1}]	1	8	12	15

EDMS 17979910 FCC-ACC-RPT-0012 V1.0, 6 April, 2017,
"A Baseline for the FCC-he"

PERLE – ERL test facility

PERLE CDR
accepted for publication in J. Phys. G.

PERLE

Powerful Energy Recovery Linac for Experiments

Conceptual Design Report

proposed construction at LAL-Orsay

CELIA Bordeaux, MIT Boston, CERN, Cockcroft and Astec Daresbury, TU Darmstadt, U Liverpool, Jefferson Lab Newport News, BINP Novosibirsk, IPNO and LAL Orsay

http://arxiv.org/abs/1705.08783

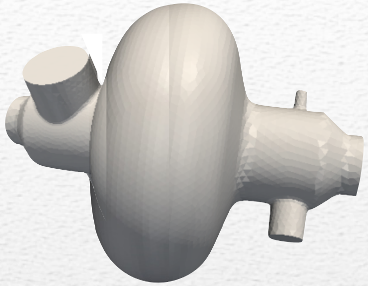
February 6^{th}, 2017

key purposes:

- demonstrate and investigate **multi-turn, high current energy recovery** in a racetrack electron linac – the basis of FCC-eh, HE-LHeC, and LHeC

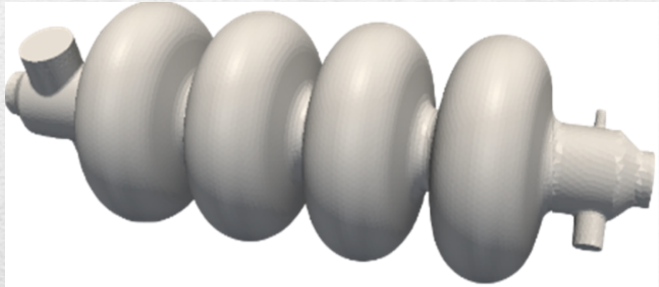
- **high current load tests of SRF cavities**
  - e.g. testing FCC prototype cavities at 800 and 400 MHz

LHeC/FCC-eh/FCC RF system

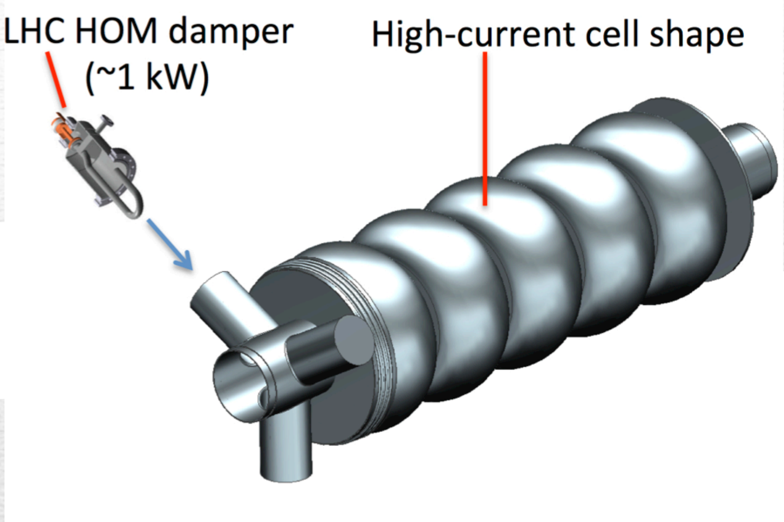


400MHz,

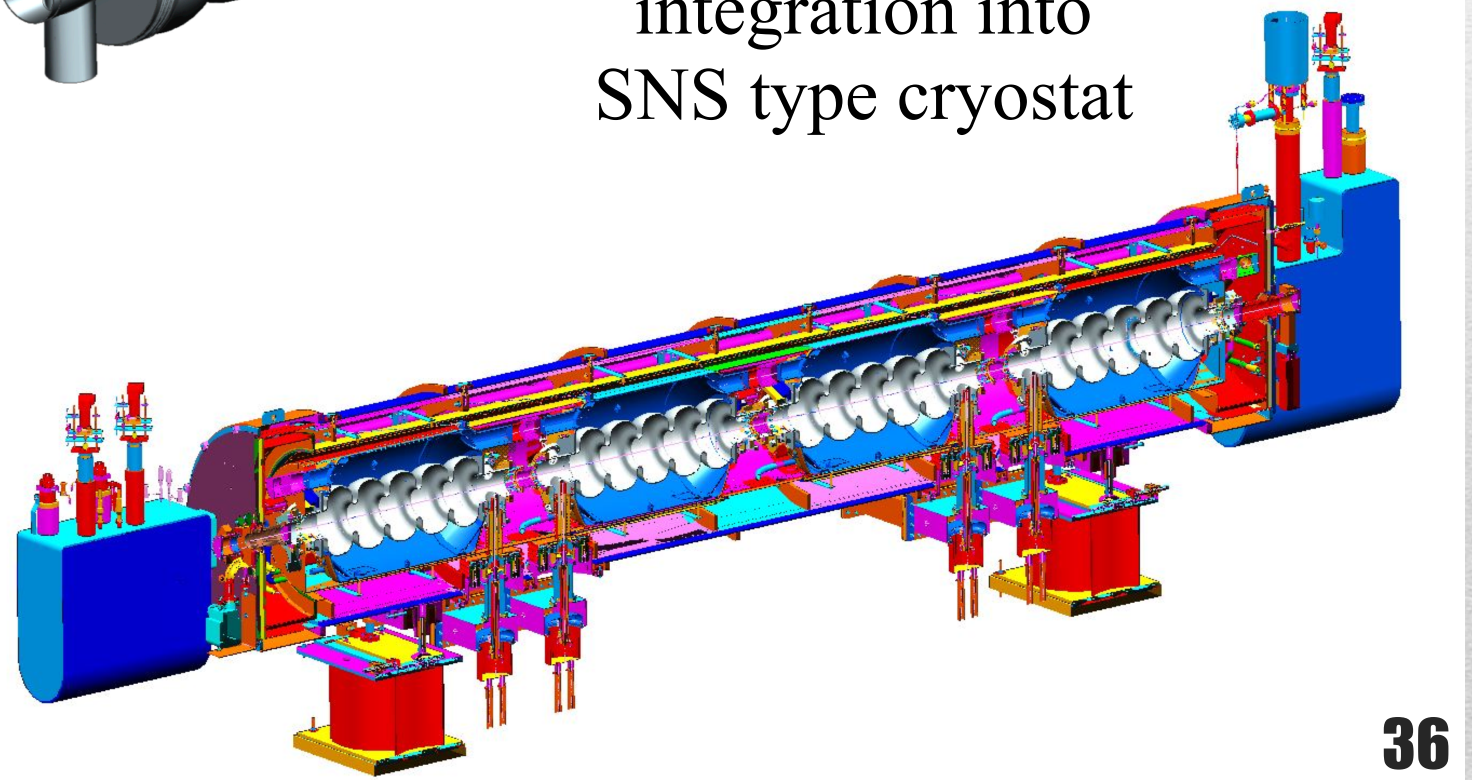
1 cell, Nb/ Cu



400/800 MHz, multi-cells, Nb/Cu

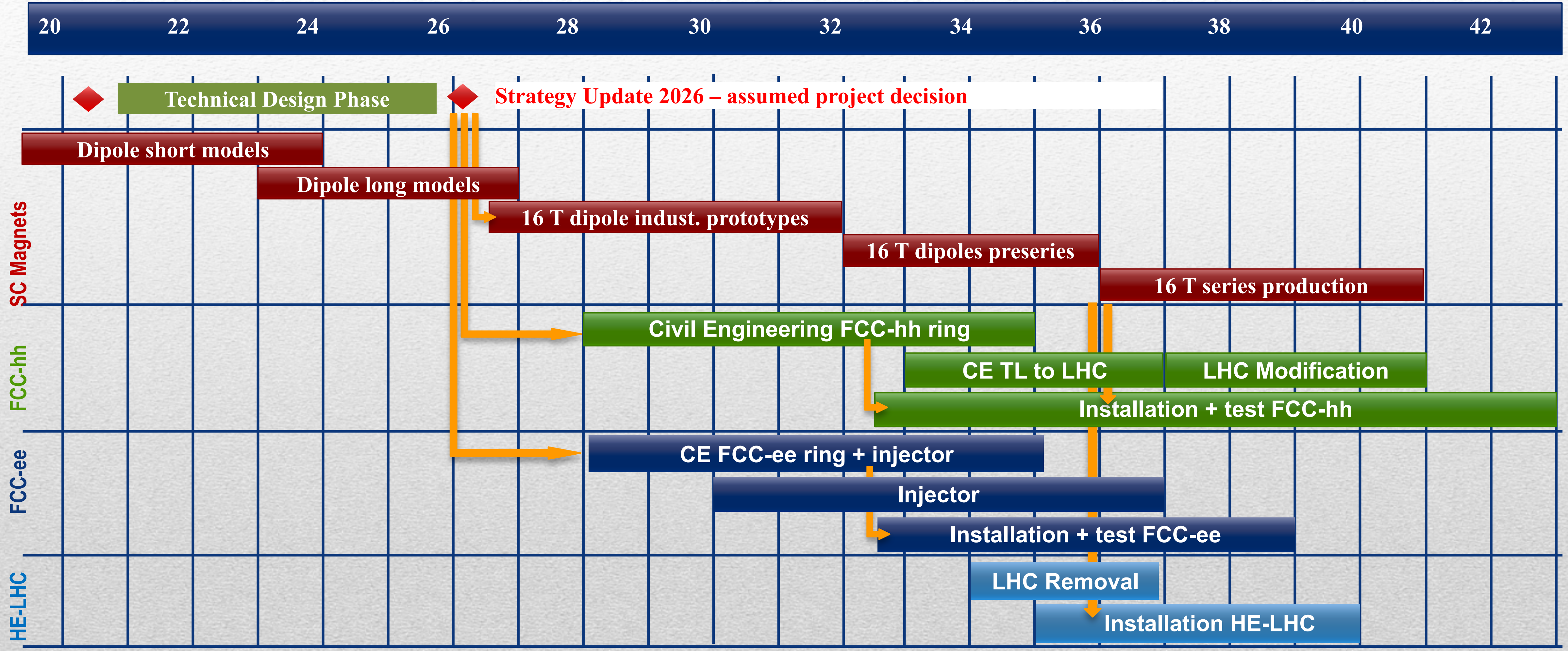


straightforward integration into SNS type cryostat

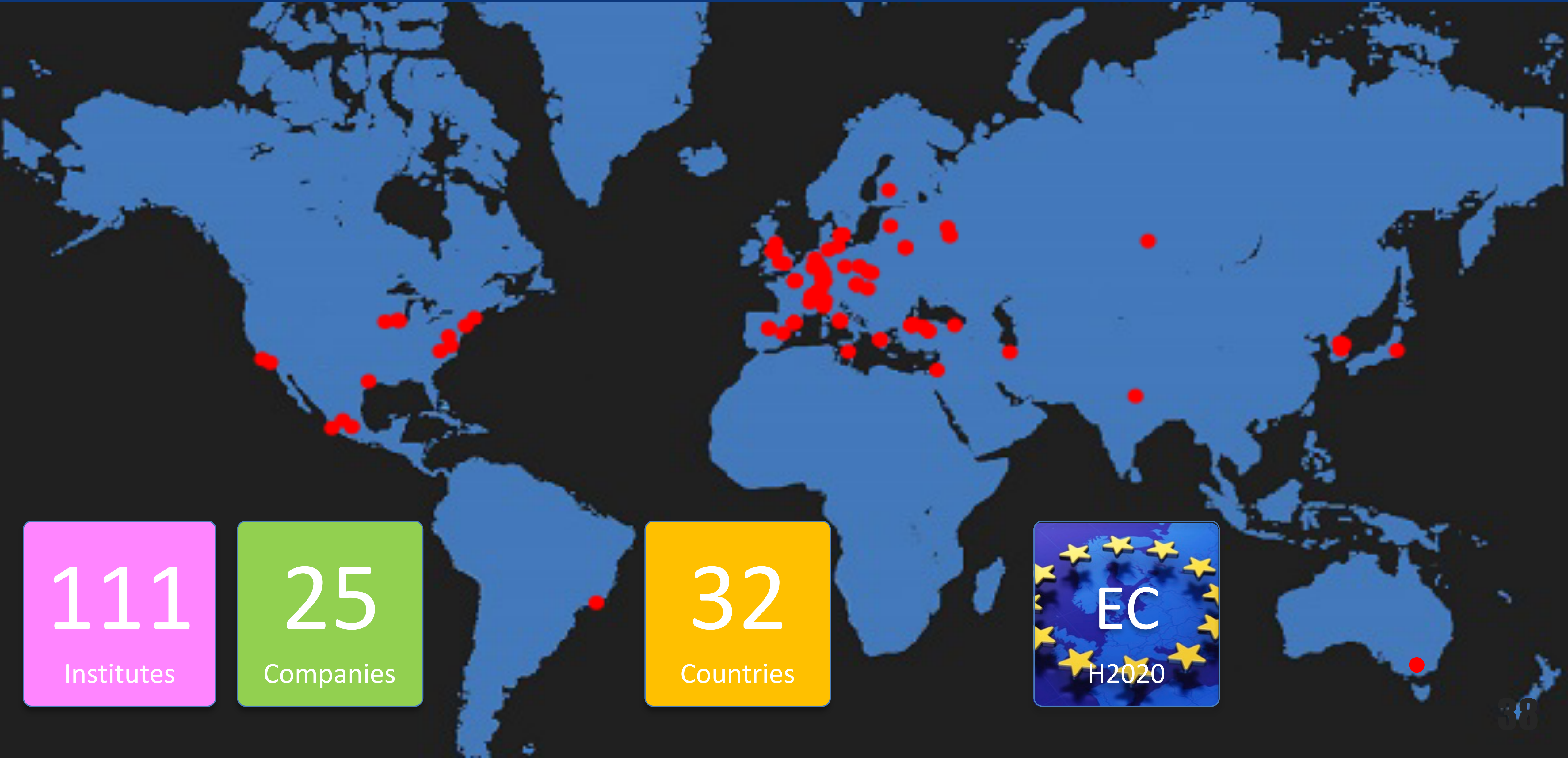


June Workshop on the LHeC/FCCeh and PERLE at LAL/IPN Orsay
https://indico.cern.ch/event/698368/

Draft Schedule Considerations



Collaboration & Industry Relations



111 Institutes

25 Companies

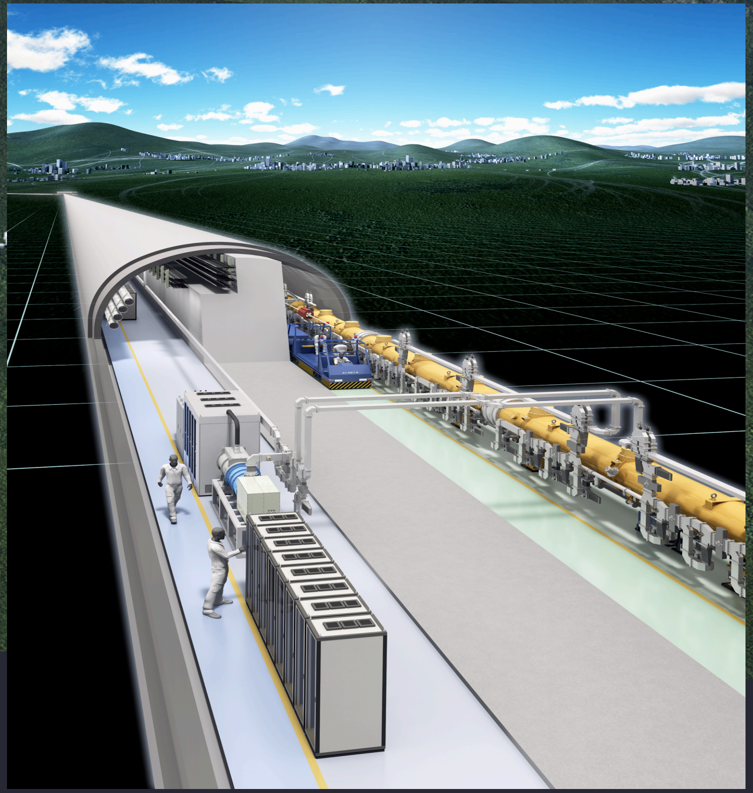
32 Countries

EC H2020

Summary and outlook 2017/18

- Consolidate design baselines for FCC-hh, FCC-ee, HE-LHC
- Comprehensive parameter document for FCC-eh was recently published
- 2018 FCC physics workshop: 15-19 Jan. 2018, CERN (FCC physics WS in Jan. 2017 (>200 participants)).
- Advance further on HW developments (magnets, SRF, special technologies)
- Develop implementation scenarios, schedules and cost estimates
- Define author/contributor teams for CDR core parts
- Prepare, assemble and edit CDR contributions
- FCC Week in 2018 9-13 April in Amsterdam CDR draft contents reviewed
- Presentation of printed CDR at the end of 2018
- Next FCC Week in Spring 2019 at CERN

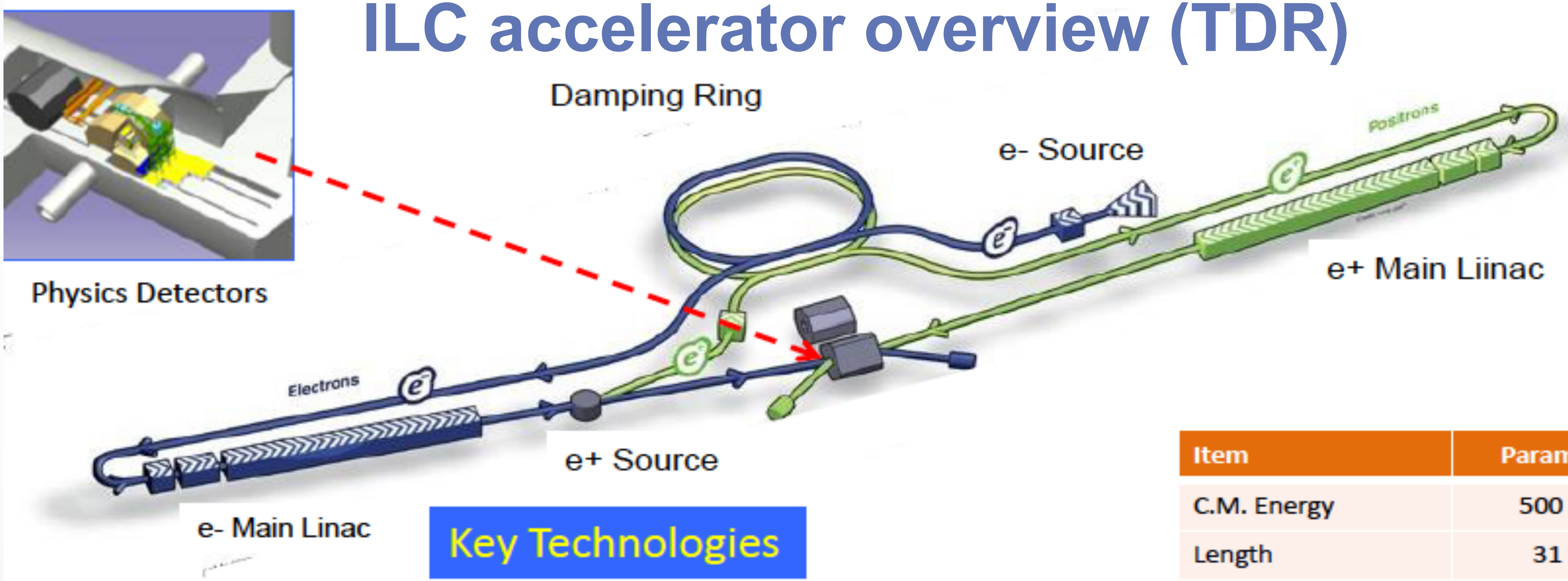
ILC accelerator: status and optimizitation



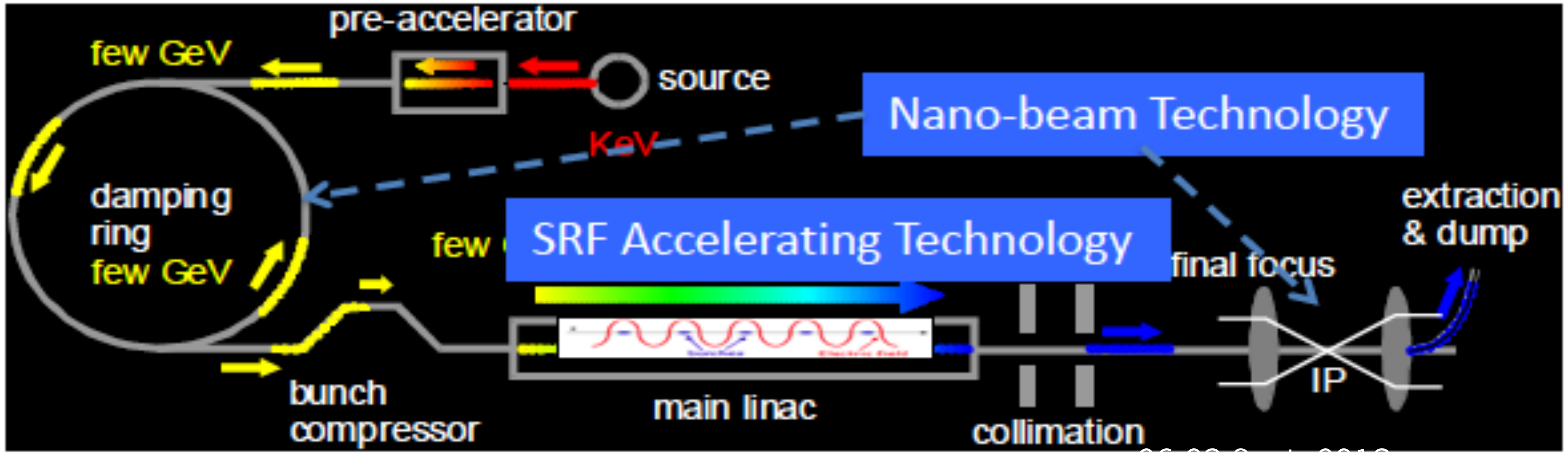
http://www.linearcollider.org/

26-28 Sept. 2018

ILC accelerator overview (TDR)

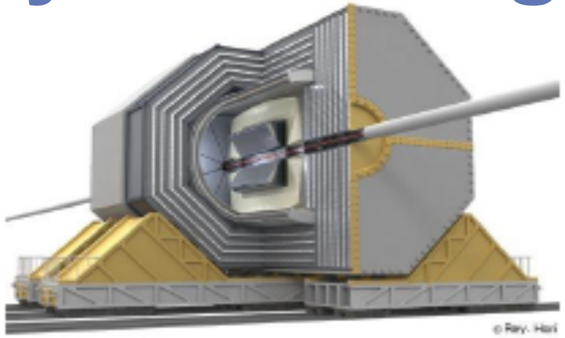


Key Technologies

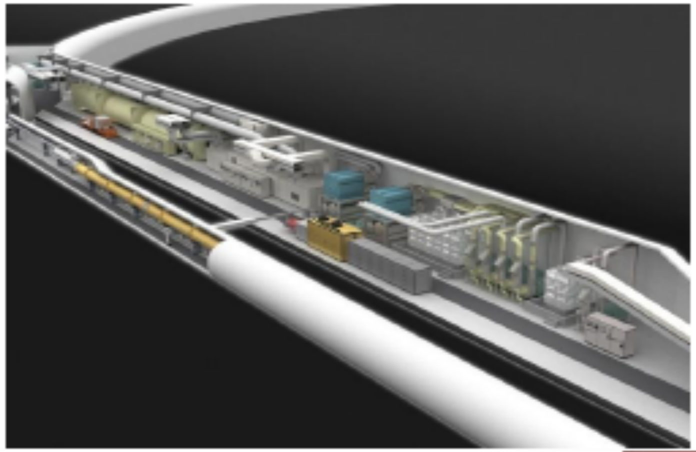


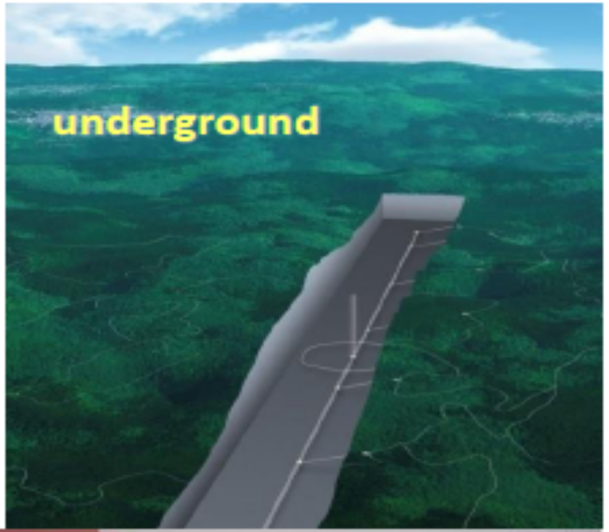
Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} cm^{-2}s^{-1}
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	5.9 nm
SRF Cavity G. Q_0	31.5 MV/m Q_0 = 1x10^{10}

The key technologies

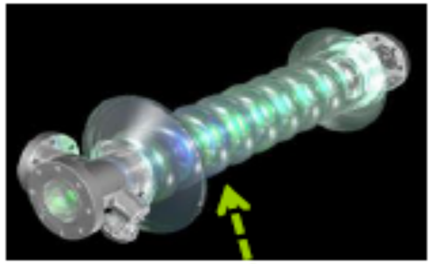


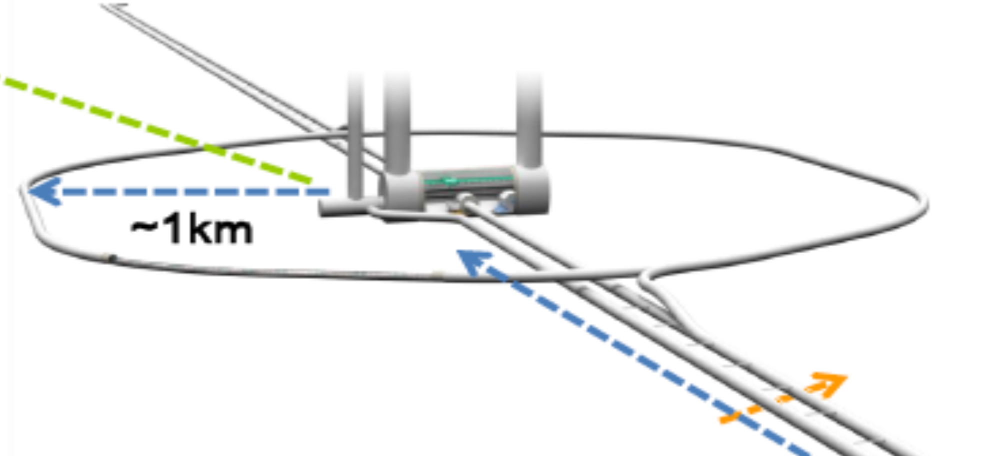
Detector

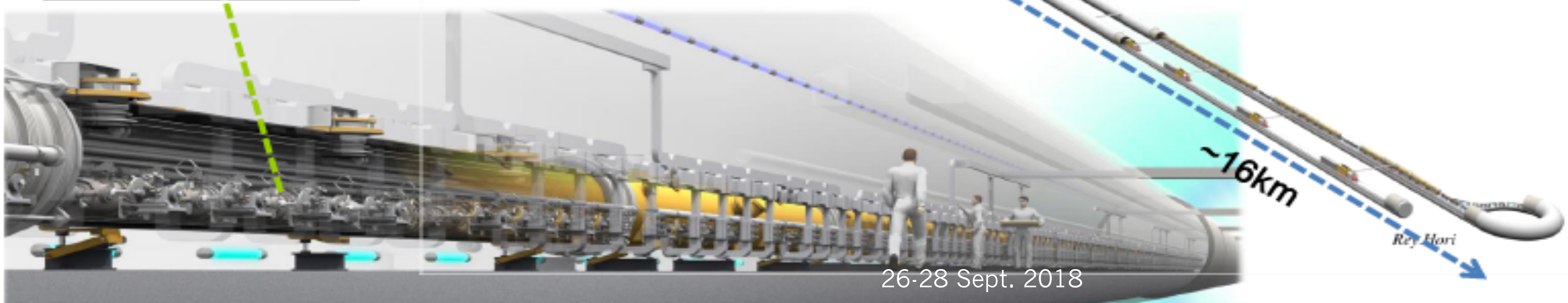




Superconducting cavity







ILC500 (TDR) →ILC250

Item	Parameters
C.M. Energy	250 GeV
Length	20.5 km
Luminosity	1.35 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm
SRF Cavity G. Q_0	31.5~35 MV/m Q_0 = 1 ~1.6x10^{10}

ILC 500GeV

~31km

ILC 250GeV

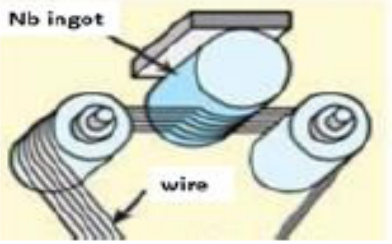
→ Cost reduction

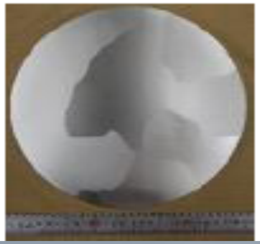
~20km

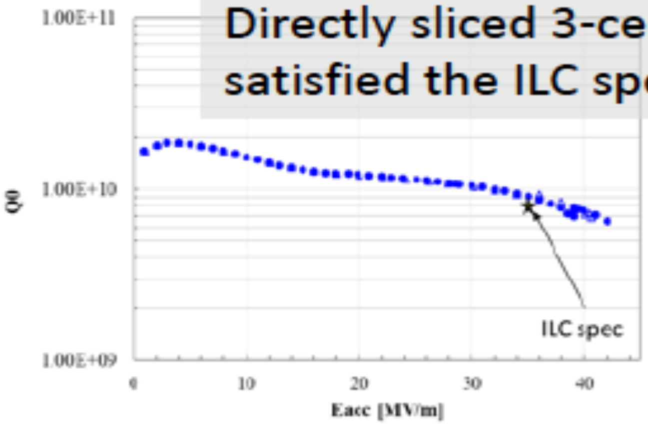
SRF Cost-reduction R&D

Cost reduction by techn. innovation

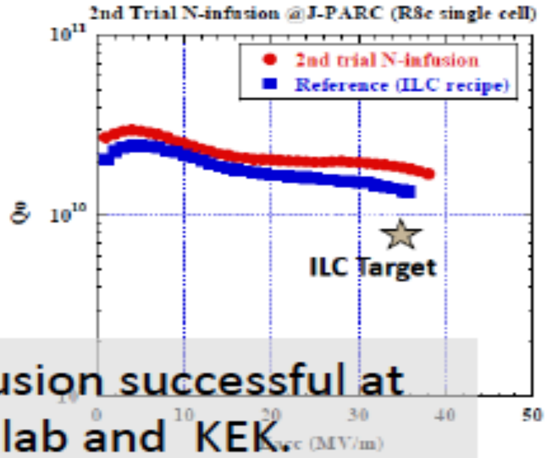
- *Nb material process → reduce material cost*
- *Cavity Surface process with N-infusion (High-G and –Q): reduce # cavities and cost*







Directly sliced 3-cell cavity satisfied the ILC spec.



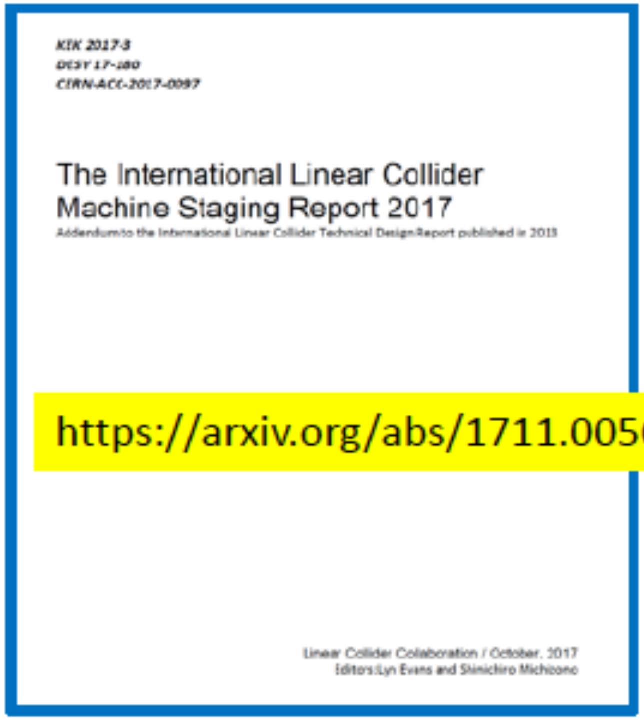
N-infusion successful at Fermilab and KEK.

ILC-500 (TDR) → ILC250

TDR update:

Options A, A': 250 GeV

	Collision E. [GeV]	Tunnel Space [GeV]	Value Total (MILCU in 2012)	Reduction [%]
TDR	250/250	500	7,980	0
TDR update	250/250	500	7,950	-0.4
Option A	125/125	250	5,260	-34
Option A' (w/ R&D)	125/125	250	4,780 w/ R&D success	-40

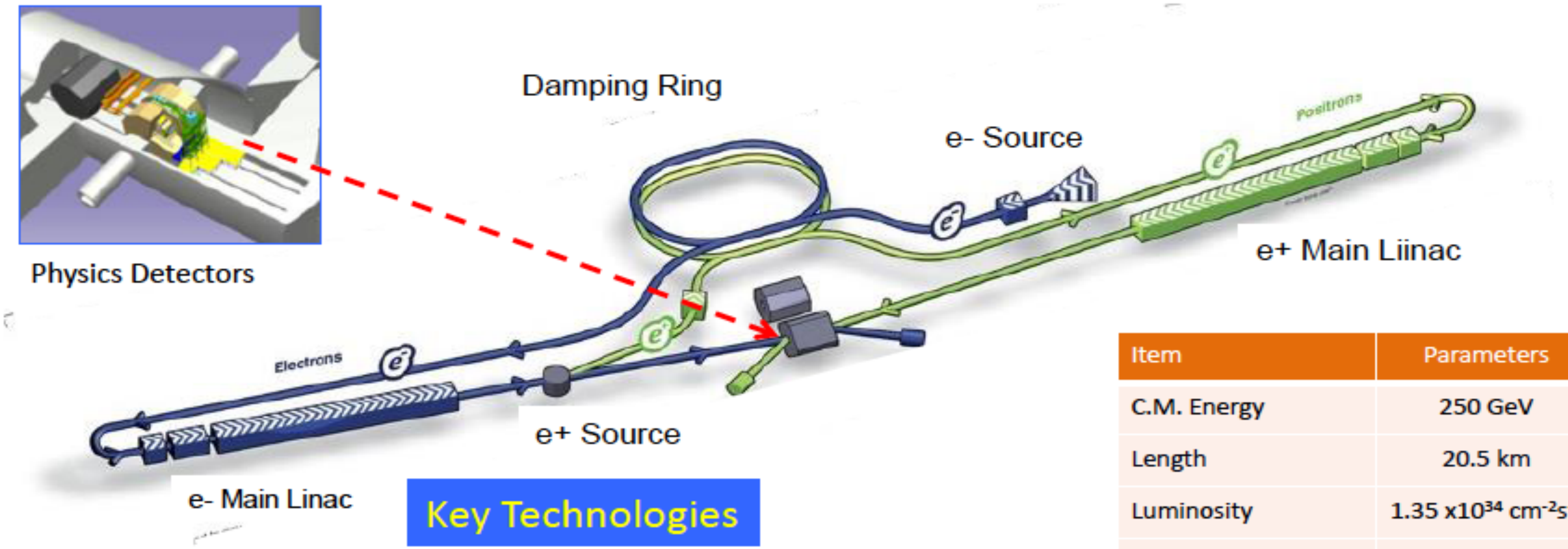

KEK 2017-3
DESY 17-180
CERN-ACC-2017-0097

The International Linear Collider
Machine Staging Report 2017

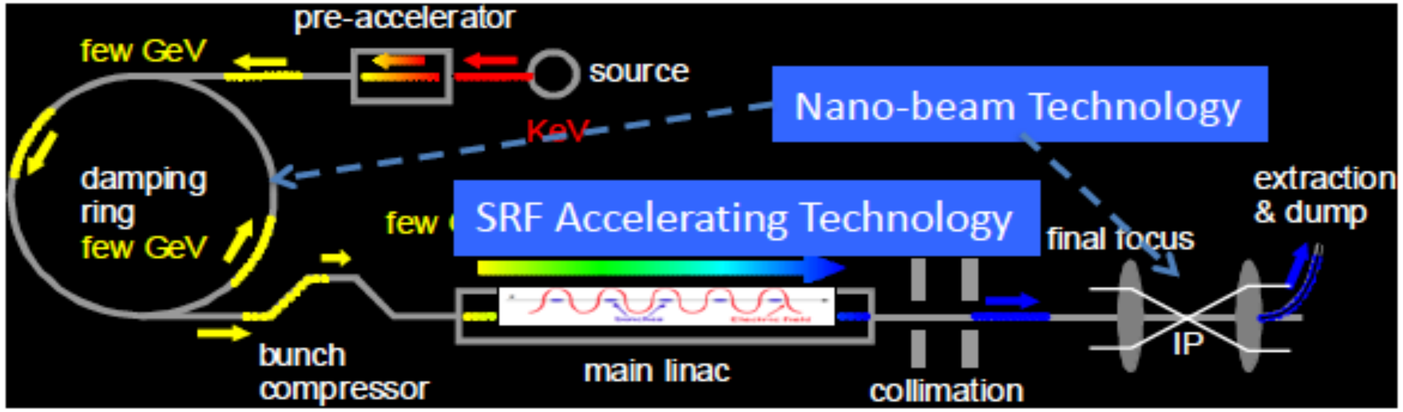
Linear Collider Collaboration / October, 2017

https://arxiv.org/abs/1711.00568

ILC250 Acc. Design Overview



Key Technologies



Item	Parameters
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Beam size (y) at FF	7.7 nm
SRF Cavity G. Q_0	31.5~35 MV/m Q_0 = 1 ~1.6x10 ^{10}

Technical Status in 2018

•***Key Technologies advanced!***

- Nano-beam Technology :

  KEK-ATF2: FF **beam size (v)**: 41 nm at 1.3 GeV (equiv. to 7 nm at ILC)

- SRF Technology :

  European XFEL completed: <G = ~ 30 MV/m> achieved with 800 cavities and accelerator commissioning/operation reaching > 90 % design energy.

  LCLS-II: construction in progress

  H-FEL (Shinghai): construction approved

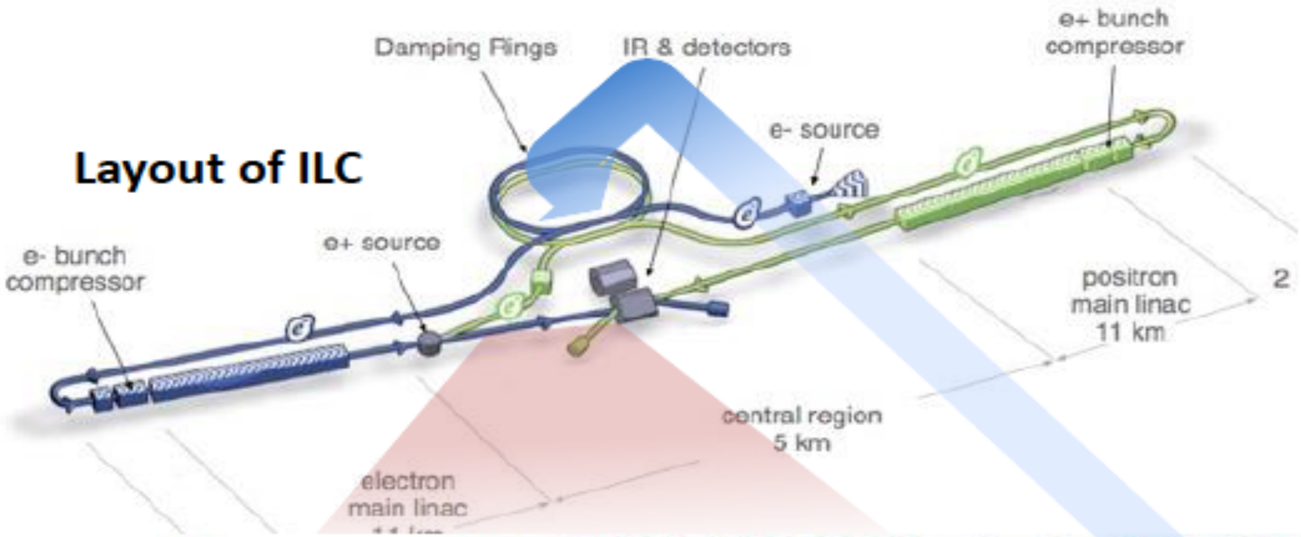
  US-Japan: Cost Reduction R&Ds in progress, focusing on "**N Infusion**" **process** demonstrated, at Fermilab, **for High-Q and High-G**

General design updated:

– **ILC** 250 GeV proposal has been authorized by ICFA/LCB

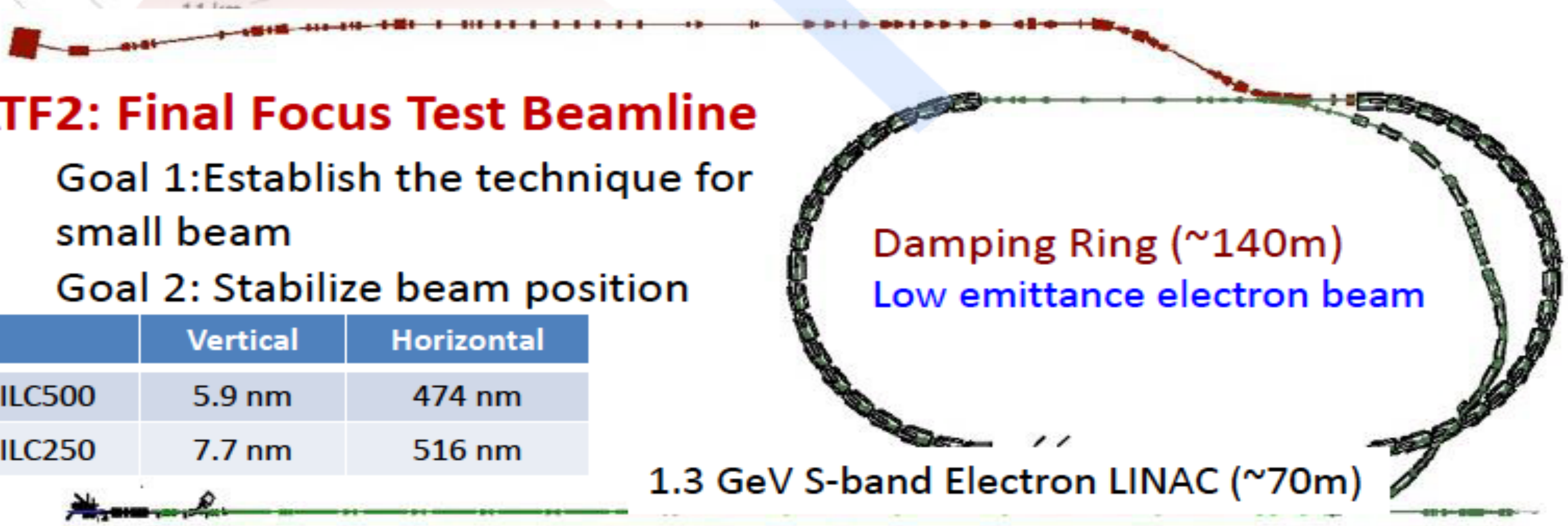
ATF/ATF2: Accelerator Test Facility

Layout of ILC



Develop the nanometer beam technologies for ILC

- Key of the luminosity maintenance
- 7.7 nm beam at IP (ILC250)



ATF2: Final Focus Test Beamline

Goal 1:Establish the technique for small beam

Goal 2: Stabilize beam position

	Vertical	Horizontal
ILC500	5.9 nm	474 nm
ILC250	7.7 nm	516 nm

Progress in FF Beam Size and Stability at ATF2

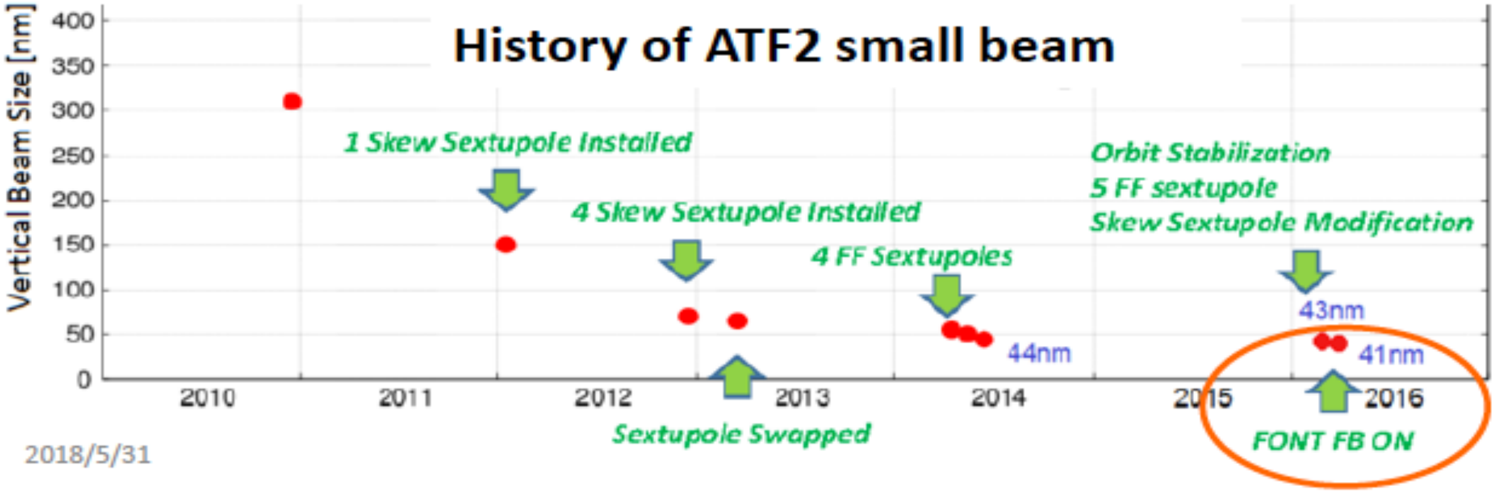
Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances

- ATF2 Goal : 37 nm → 6nm @ILC500GeV
  7.7nm@ILC250GeV
  - Achieved 41 nm (2016)

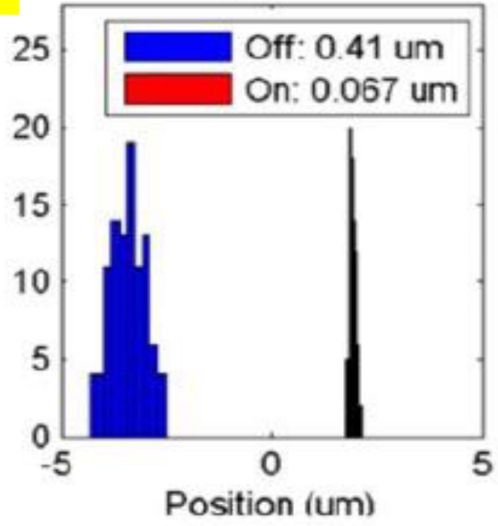
Goal 2: Develop a few nm position stabilization for the ILC collision

- FB latency **133** nsec achieved
  (target: < 300 nsec)
- positon jitter at IP: 410 → 67 nm (2015) (limited by the BPM resolution)

We continue efforts to achieve goal 1 and goal 2.



Nano-meter stabilization at IP



2018/5/31

Progress in Positron Source Study

A comprehensive Study Report Published

http://lcdev.kek.jp/~yokoya/temp/PositronReport/v7.zip

Report on the ILC Positron Source

Positron Working Group

May 23, 2018

Summary

The present report have described the present status and scope of the two schemes of positron production, putting emphasis on the contraversy and/or urgent issues.

The technology status of the undulator and e-driven schemes were summarized in the AWLC2017 at SLAC[63]. It was a result of the discussion within the positron working group. The present status is essentially the same as at AWLC2017. Here, the summary table is reproduced (Table 6.1) with a few updates. (See the reference for the details of the individual components.)

Table 6.1: Summary of the technology status of the two schemes

	Undulator Scheme		e-Driven Scheme	
Target	Further consideration on wheel design, cooling calculation, mechanical performance (magnetic bearing), and Ti-Cu contact needed. Prototype shoud be built.	C	Further test of vacuum seal needed. W-Cu contact must be studied.	B
Matching device	FC has the problems of time-dependent field and PEDD.	D	Improvement from superKEKB and BINP. Design of cooling needed.	B
	QWT: yield marginal. Hardware design still required.	B		
Capture cavity	TDR design almost sufficient	A	Further consideration on thermal deformation and cavity cooling design needed	B
Beam dump	Photon dump still requires detailed design.	C	Beam dump is not an issue but radiation shielding must be studied instead.	B

B Basic partial tests done or known to work. No whole prototype.

C Calculation study only. But no show stopper seen yet.

D Break through needed.

E There is a fatal problem.

A few comments on this table:

- Here, driver beam, booster linac and yield simulation are omitted. These are more or less in the state B or better for both schemes.
- The flux concentrator for the undulator scheme is assigned D. However, as explained in Sec.2.1, the positron yield with QWT is nearly enough, though marginal. Thus, we can eliminate the row for FC of undulator scheme.

Note, however, this table does not mean that every member agrees on the status evaluation of individual items. Some of them suggest to assign severer scores for some items. Re-evaluation of the table is inevitable in the near future by the time to down-select the scheme. But it is more important to make a complete "ToDoList" for each item as stated above.
As shown in the previous section

- The cost of the accelerator components for the two schemes are almost the same.
- The CFS cost of the undulator scheme is higher due to the tunnel longer by ~2 km.
- The power consumption of the e-driven scheme is larger by ~4 MW.

But these are not a decisive factor in the choice.

As the table shows, the technology for neither scheme is ready now. Among the two the e-driven scheme seems to be closer to realization, judging from the present status of prototype development. On the otherhand, the baseline scheme, i.e., the undulator scheme, if feasible, has an advantage of the positron polarization. Therefore, the primary question for the choice of the scheme is

- Is the undulator scheme feasible?
- If so, can the feasibility be firmly verified by the time of design finalization?

We do not know clearly when is the deadline for the decision, but it is not too far, within a couple of years. In this respect of the project schedule we need a guidance from TCMB or LCC.
The working group hope that this report gives useful information for the decision in the near future.

Progress in Positron Source Study

A comprehensive Study Report Published

http://lcdev.kek.jp/~yokoya/temp/PositronReport/v7.zip

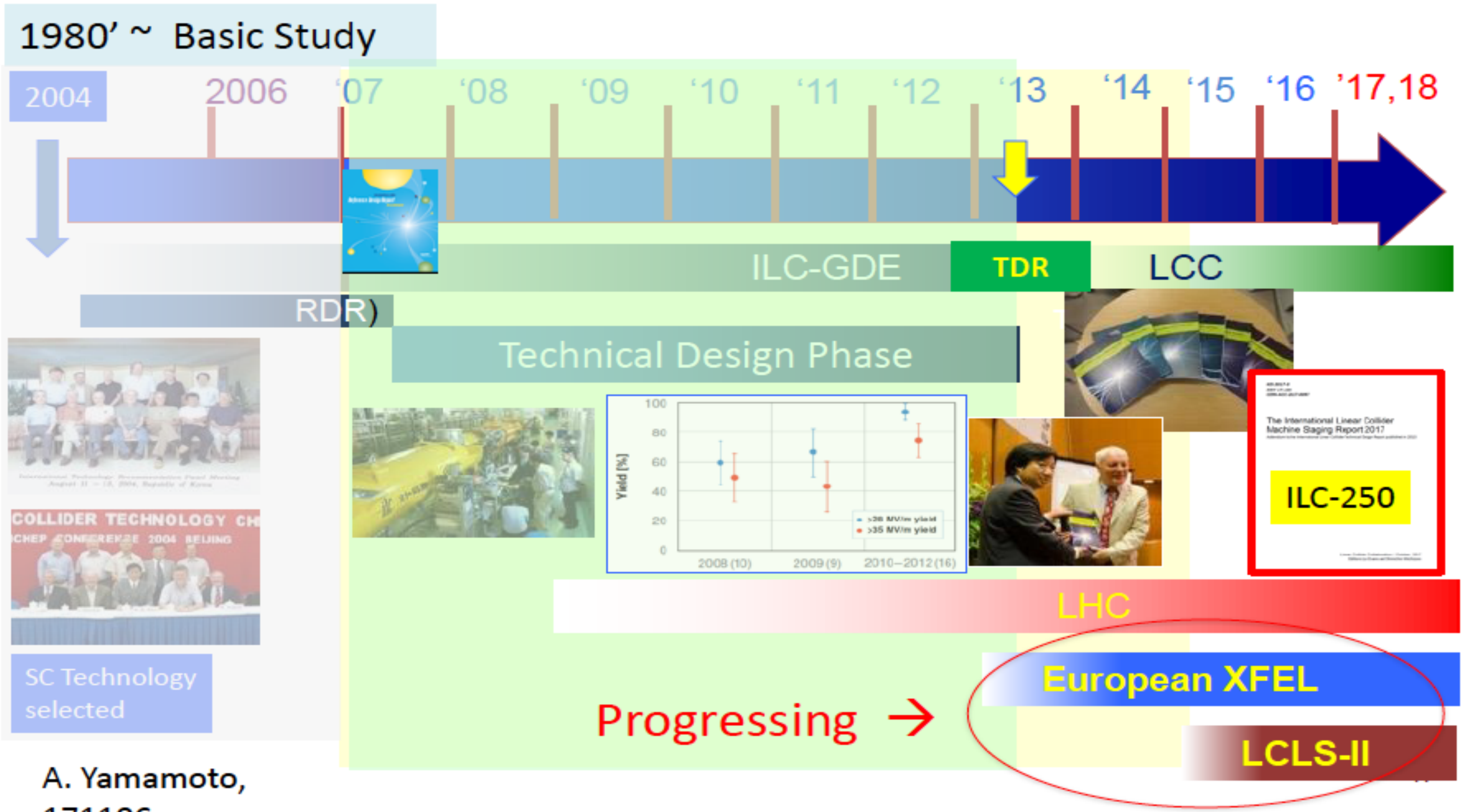
Report on the ILC Positron Source

Positron Working Group

Summary

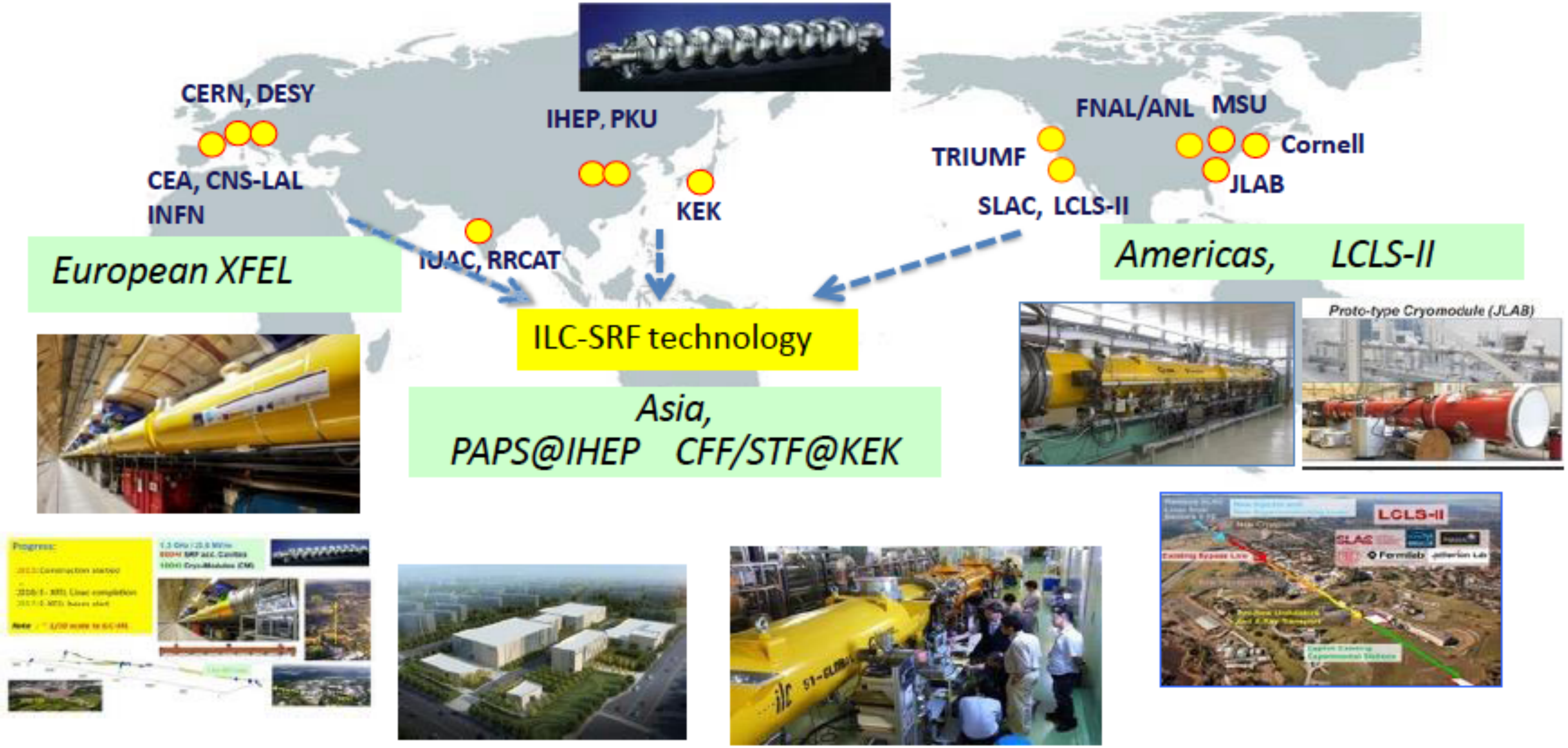
- The choice, undulator or e-driven, is very important but the deadline is not now. A couple of years later.
- Before this choice we need CFS studies in somewhat in detail. Should be done in parallel.
- Must think of the scenario
  - undulator only, or
  - e-driven → undulator
- The former is simple, but many questions must be answered for the latter
- Laser-straight issue can be managed anyway

ILC-GDE to LCC



A. Yamamoto, 171106

SRF Progress with Worldwide Collaboration



Courtesy, H. Weise

European XFEL, SRF Linac Completed

Progress:

2013: Construction started

...

2016: E- XFEL Linac completion

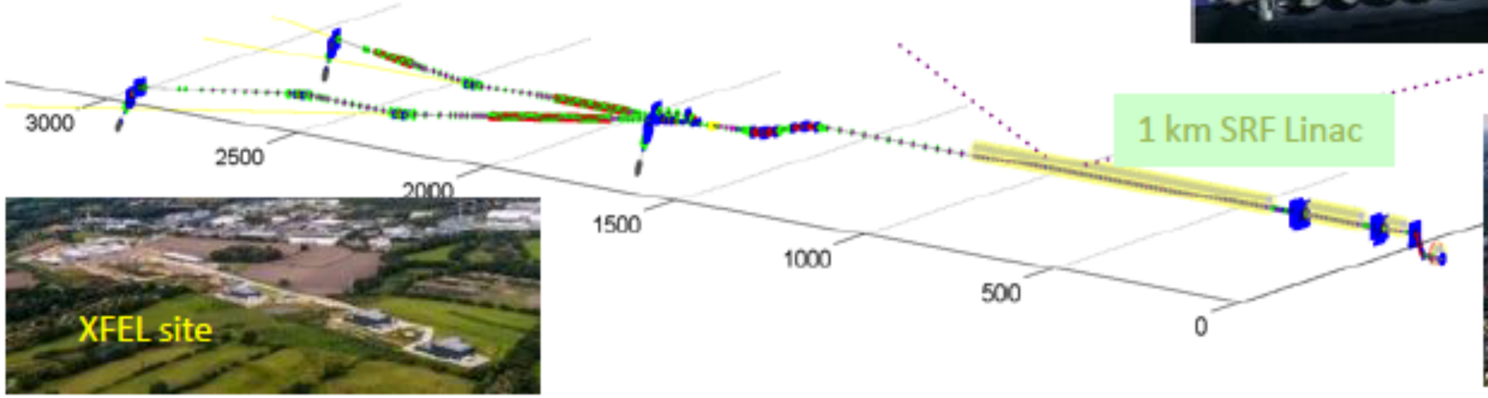
2017: E-XFEL beam start

1.3 GHz / 23.6 MV/m

800+4 SRF acc. Cavities

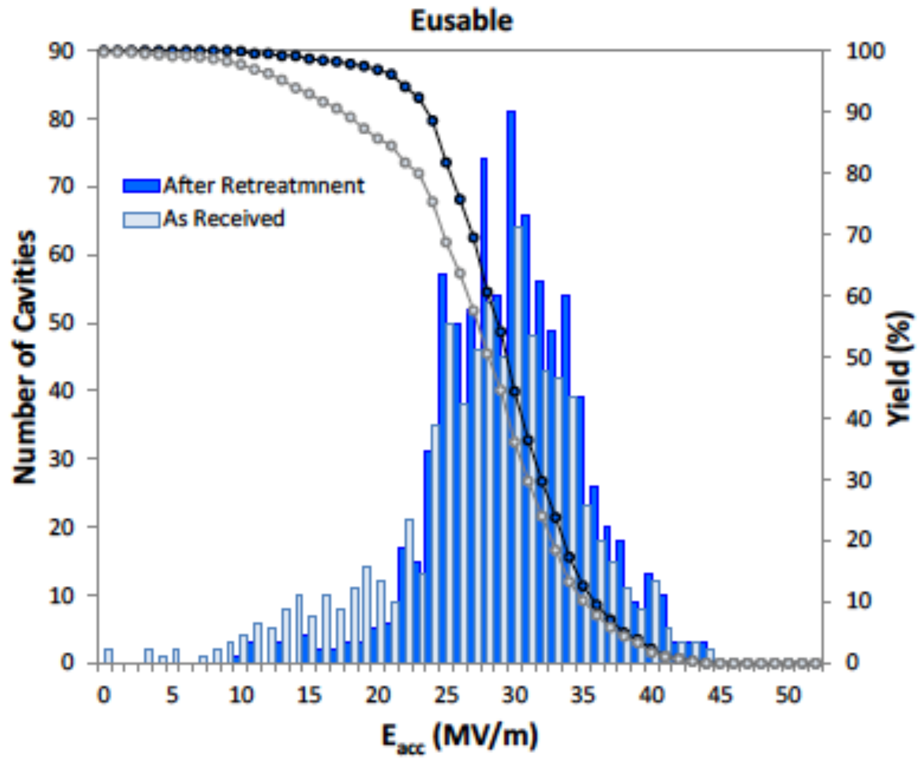
100+3 Cryo-Modules (CM)

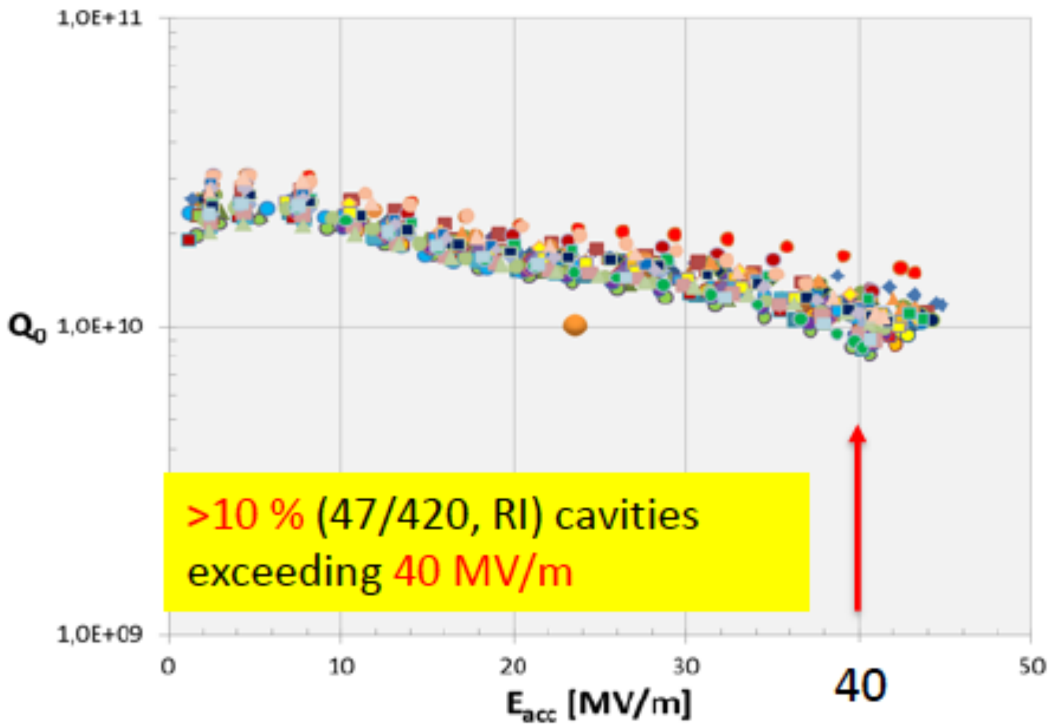
: ~ 1/10 scale to ILC-ML



Courtesy, D. Reschke , N. Walker, C. Pagani

European XFEL: SRF Cavity Performance



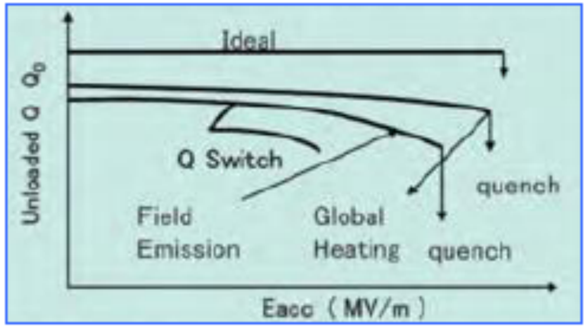


After Retreatment:

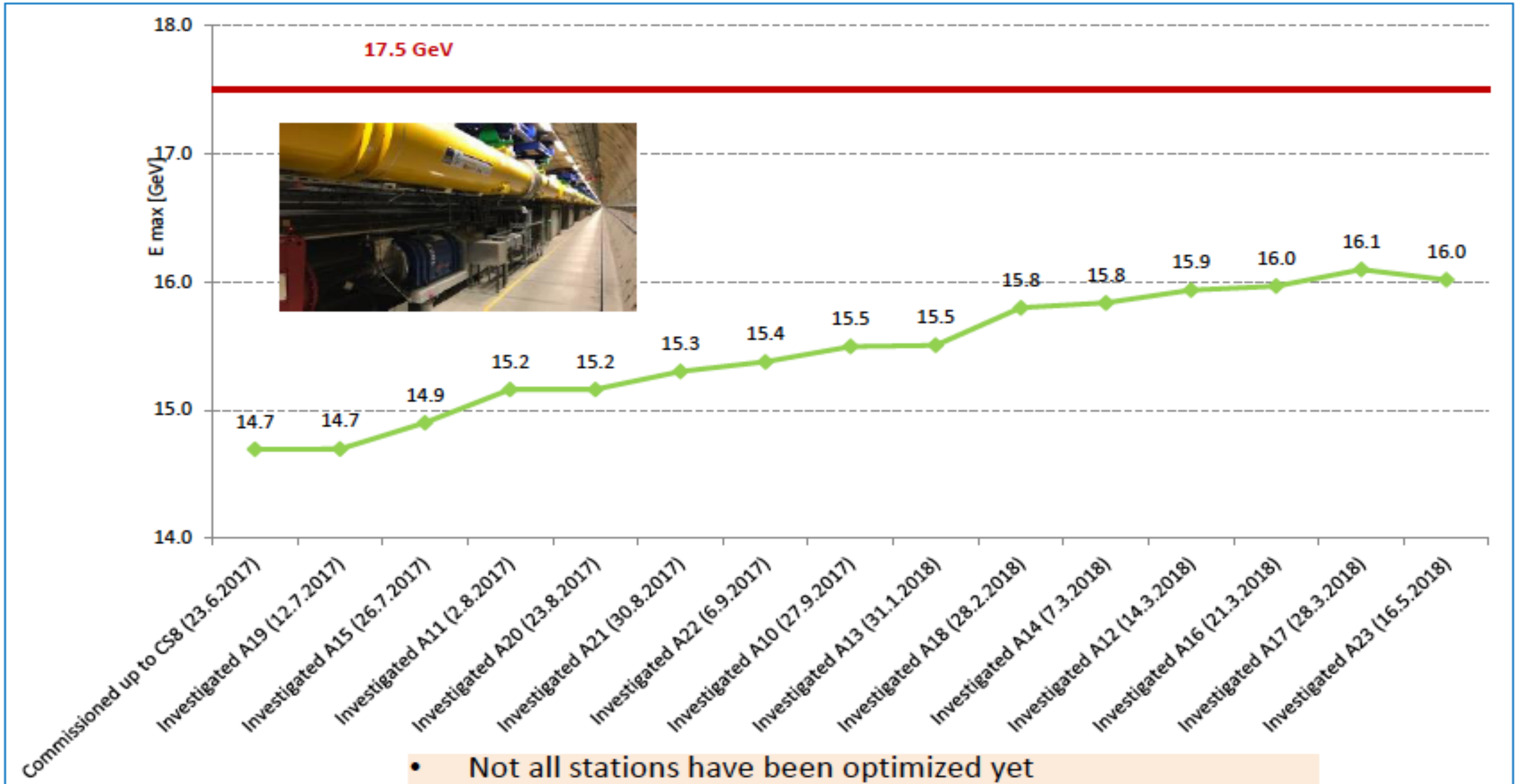
E-usable: 29.8 ± 5.1 [MV/m]

(RI): E usable 31.2 ± 5.2 [MV/m]), w/ 2nd EP

(EZ): E usable 28.6 ± 4.8 [MV/m]) , w/ BCP (instead of 2nd EP)



European XFEL: Emax Development as of 16th of May 2018



- Not all stations have been optimized yet
- CS9 commissioning nearly done
  – 1.3 GeV additional energy gain expected
- Continued effort necessary to reach and exceed 17.5 GeV
  – Expected latest by end of summer 2018

Courtesy, M. Ross

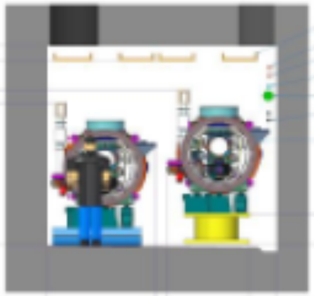
LCLS-II Concept

Use 1st km of SLAC Linac for CW SCRF Linac

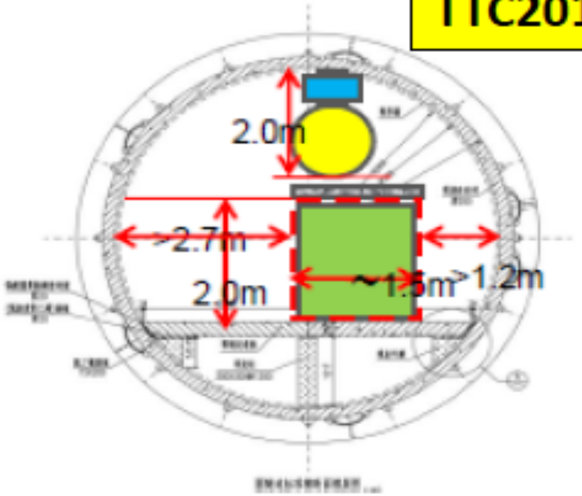
EXFEL，LCLS-II(HE) and Shanghai XFEL

TTC2018 D.Wang

European XFEL



LCLS-II



	EuropeanXFEL	LCLS-II（HE）	Shanghai XFEL
RF mode	Pulsed	CW	CW
Power source	Klystron	SSA	SSA
Install	Single ac Tunnel	Tunnel + Gallery	Single ac Tunnel
2K heat load/CM	~20w/CM	~80w/CM	~80w/CM
Tunnel slope	~	0.5%	~
N of modules	~100	~35（+19）	~75
2K capability	~3kW	~ 2 x 4kw	~ 3x4 or 4x3 kw

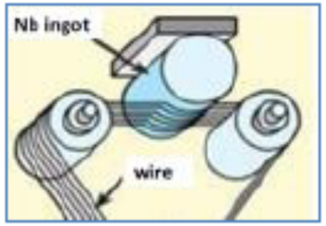
S. Michizono, S. Belomestnykh

ILC Cost-Reduction R&D in US-Japan Cooperation on SRF Technology, for ~3 years

Based on recent advances in technologies;

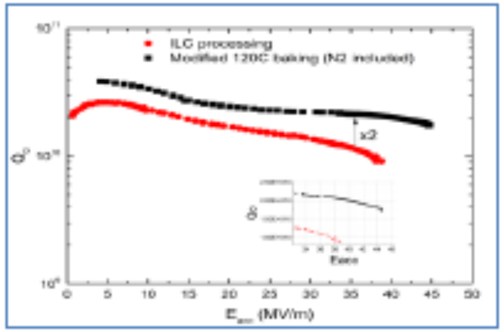
– Nb materia/sheet preparation

- w/ optimum RRR and clean surface



– SRF cavity fabrication for high-Q and high-G

-w/ a new “N Infusion” recipe demonstrated by **Fermilab**



– Power input coupler fabrication

- w/ new (low Second. e- emission) ceramic without TiN coating

– Cavity chemical process

- w/ vertical EP and new chemical (non HF) solution

– Others

US-Japan cost reduction R&D

Evaluate the cavity performance from vertical test to horizontal test

Cavity fabrication

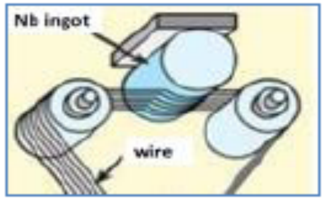
Heat treatment

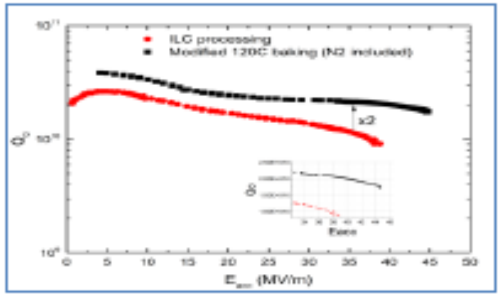
Vertical test

	Standard Fabrication/Process
Fabrication	Nb-sheet purchasing
	Component Fabrication
	Cavity assembly with EBW
Surface Process	EP-1 (~150um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at ~~> 600 C~~ → 800 C
	Field flatness tuning
	~~EP-2 (~20um)~~
	~~Ultrasonic degreasing or ethanol~~ ~~(or EP 5 um with fresh acid)~~
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C (+ N2 infusion)
Cold Test (vertical test)	Performance Test with temperature and mode measurement
Cryomodule	Installation to the cryomodule

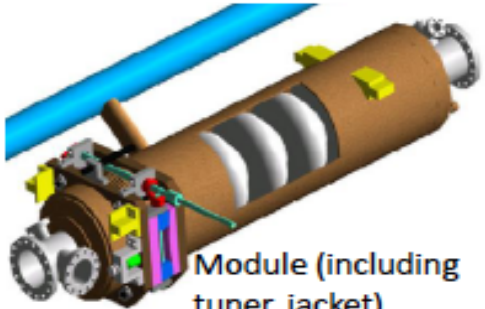
N-Infusion

New Nb material/process





Degradation-free environment



Module (including tuner, jacket)

Stand-alone horizontal test

Horizontal test

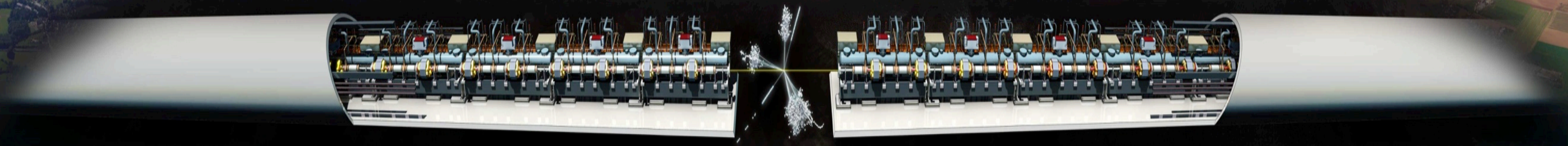
Module test at stF-2

Summary

- ILC collision energy, 250 GeV, for starting well established. The accelerator construction cost well estimated with a meaning cost reduction,
- Key technologies of “Nano-beam” and “SRF” matured. Thanks for worldwide efforts for SRT technology, with European XFEL, LILS-II, and further.
- Positron source study reached a comprehensive report, to be prepared for timely decision after a green-light given.
- The US-Japan, SRF cost-reduction R&D program in progress with encouraging results.
- Our best effort has been made to provide comprehensive information to official WGs and IAP at MEXT is reaching a very critical stage to evaluate the ILC 250 GeV proposal.

All ILC
Global Design Effort
Physics and Detectors
Map
Asia
Atlantic Ocean
Africa
South America
Pacific Ocean
Indian Ocean
Australia
Australia
Pacific Ocean
Google
Terms of Use

CLIC accelerator: status and rebaselining



http://clic-study.web.cern.ch/

Compact Linear Collider

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

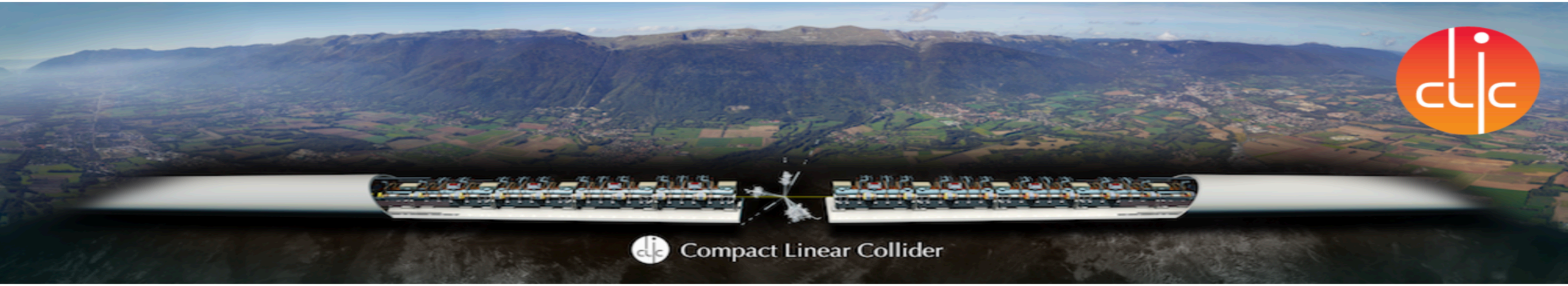
Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion



CLIC Review Key recommendations

CLIC Accelerator Study – Review of objectives for the MTP 2016-2019

March 1st, 2016

Report from the Review Panel

Members: O. Brüning; P. Collier, J.M. Jimenez, R. Losito; R. Saban, R. Schmidt; F. Sonnemann; M. Vretenar (Chair).

Introduction and general remarks

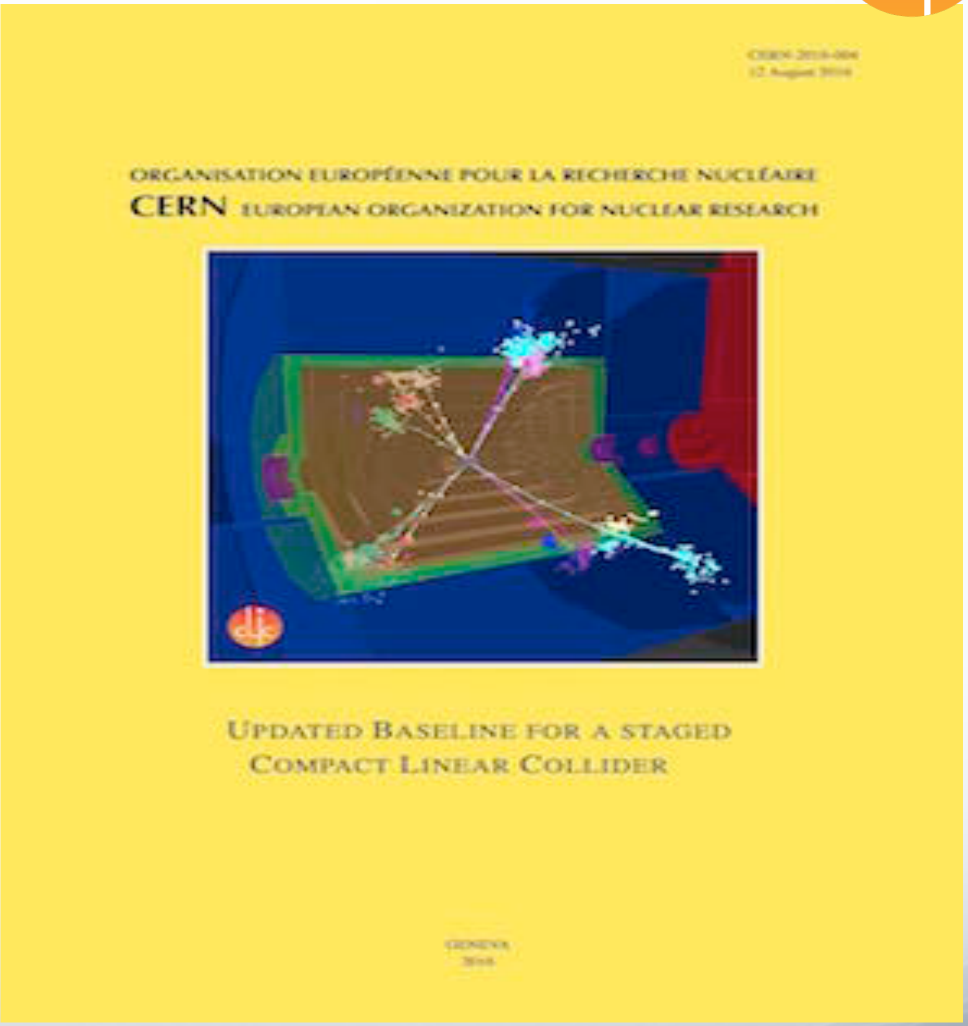
The Panel was very impressed by the enormous amount of work that was presented, by the enthusiasm of the CLIC team and by the wealth of knowledge accumulated by the CLIC study. The CLIC accelerator study has reached a high level of maturity and has been able to establish a large community consisting in about 50 collaborating laboratories and universities, working together on a number of technical challenges

After the publication of the Conceptual Design report in 2012, the CLIC Study is presently in the Development Phase, to prepare a more detailed design and an implementation plan for the next European Strategy Upgrade in 2018-19. This phase is expected to be followed by a Preparation Phase covering the period 2019-25; in case of a positive decision, a construction

- **Produce optimized, staged design:**
  380 GeV (optimised for Higgs + top physics)
  → 1.5 TeV → 3 TeV
- **Optimize cost and power consumption**
- **Support efforts to develop high-efficiency klystrons**
- **Develop 380 GeV klystron-only version as alternative**
- **Consolidate high-gradient structure test results**
- **Develop plans for 2020-25 (‘preparation phase’), with possibility of physics no later than 2035**
- **Continue and enhance participation in KEK/ATF2**

Rebaselining doc

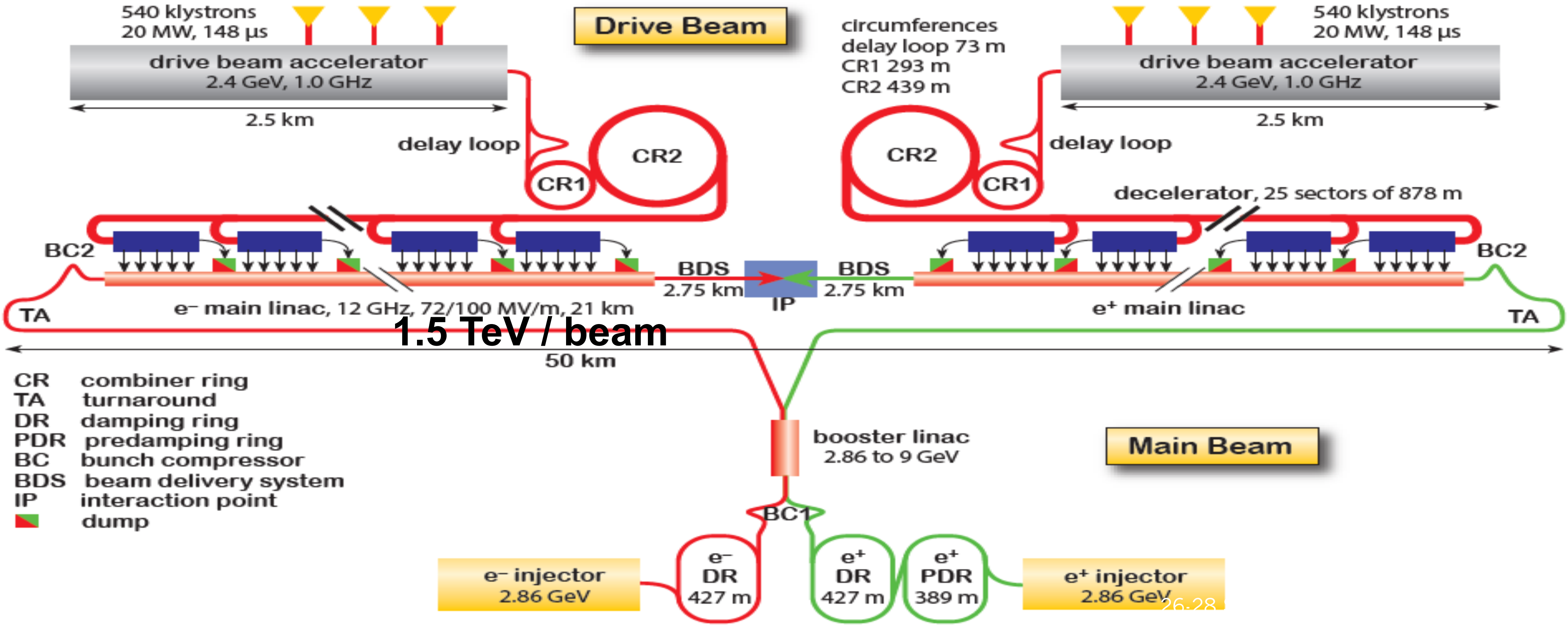
- **Optimize machine design w.r.t. cost and power for a staged approach to reach multi-TeV scales: 380 / 1500 / 3000 GeV**
- **Adapting appropriately to LHC and other physics findings**
- **Possibility for first physics no later than 2035**
- **Project Plan to include accelerator, detector, physics**



CERN-2016-004

arXiv:1608.07537

CLIC at 3 TeV



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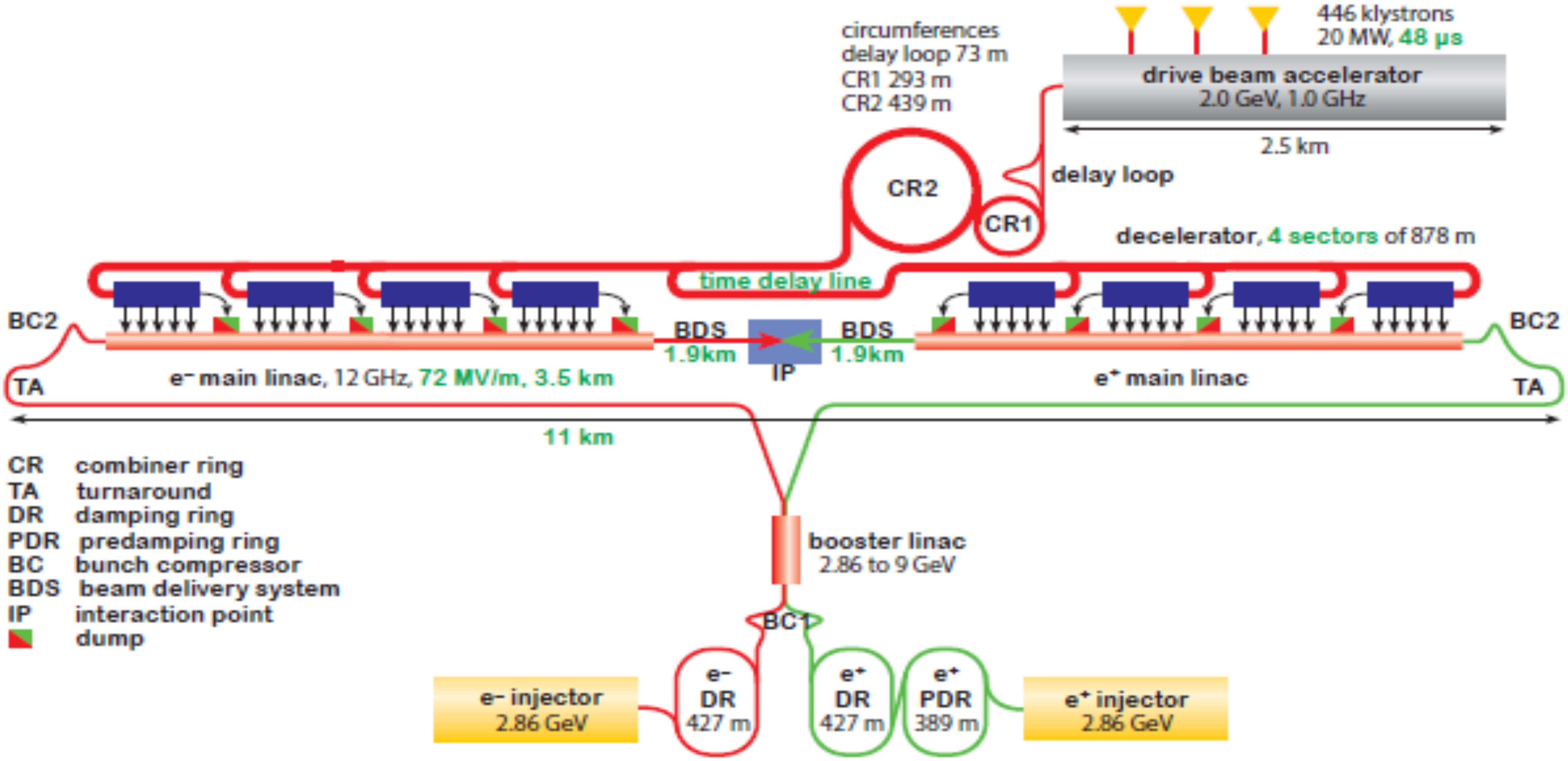
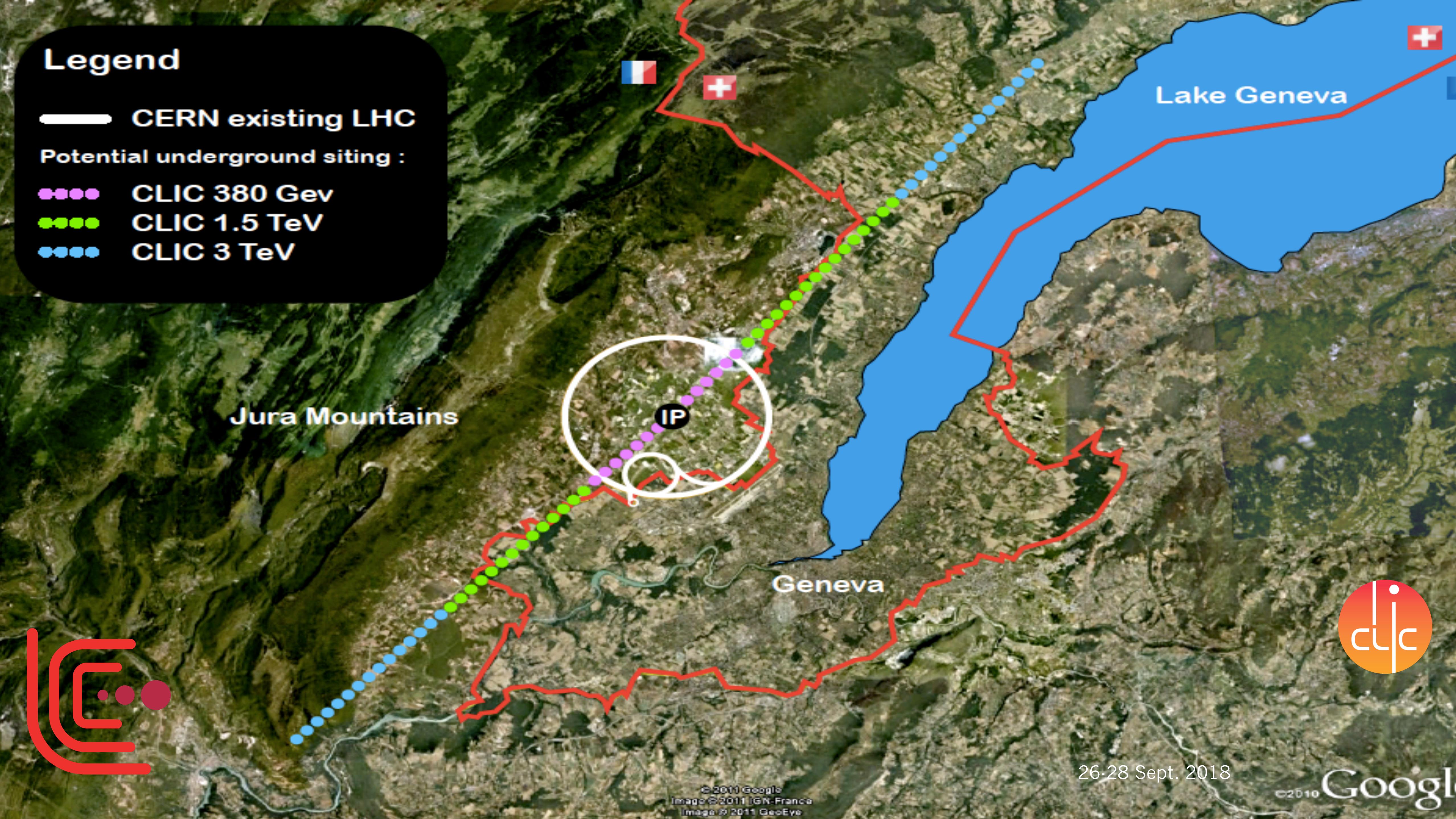
CLIC at 380 GeV

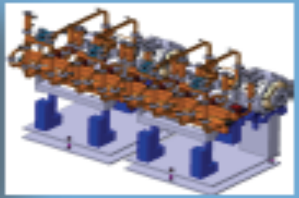
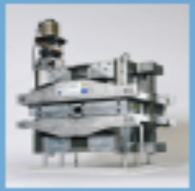
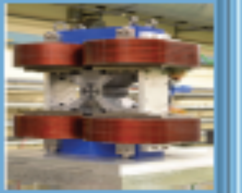



Legend
CERN existing LHC
Potential underground siting :
CLIC 380 Gev
CLIC 1.5 TeV
CLIC 3 TeV
Lake Geneva
Jura Mountains
IP
Geneva
© 2011 Google
Image © 2011 IGN-France
Image © 2011 GeoEye
©2010 Google

Rebaselining: first stage energy ~ 380 GeV

Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of √s	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100
Site length	km	11	50

Technical developments

Modules (drive-beam, klystron type)	  	Final modules, from revised designs to industrial modules
Optimized structures	  	Use existing test-stands for testing, increase manufacturability, brazed, halves, conditioning
Klystrons and Modulators	  	Efficiency and costs, significant gains possible for efficiency, industrial cost-models and optimisation
Magnets	   	Permanent magnets, industrial capabilities
Civil engineering, infrastructure	  	Detailed site layout and CE/ infrastructure designs

Industrialization examples

Bodycote (FR)
Reuter (DE)
TMD (UK)

SWISSto12 (CH)
3T RPD (UK)
Concept Laser (DE)
INITIAL (FR)
Protoshop (DE)

VDL (NL)
LT-Ultra (DE)
Yvon Boyer (FR)
DMP (ES)
Morikawa (JP)
KERN (DE))

Thermocompact (FR)
BACMI (FR)
Multivalent (NL)

CINEL (IT)
VDL (NL)
BACMI (FR)
CECOM(IT)
Reuter (DE)
Nihon (JP)
COMEB (IT)
Viztrotech (KR)

Thales (FR)
CPI(US)
Toshiba (JP)

Scandinova (SE)
Jema (ES)
Picatron (CH)

Needed by the time of the TDR:
Qualified companies, technical and commercial documentation, reliable costs (i.e. not first prototype), ideally (small) part of larger marked

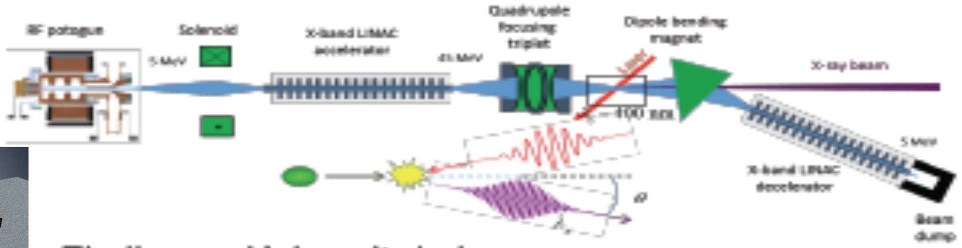
Resources and Collaboration

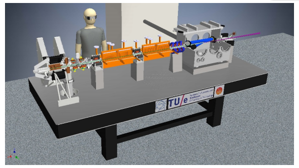
- So all this is possible – what is the problem ?
  Resources: A total of ~30 MCHF/ year foreseen in the CERN MTP (Medium Term Plan) 2020 onwards for energy frontier developments

- What is (part of) the solution ?
  Collaboration and increasing use of X-band technologies in other projects

  Additionally: Medical applications (proton and very high energy electron therapy)

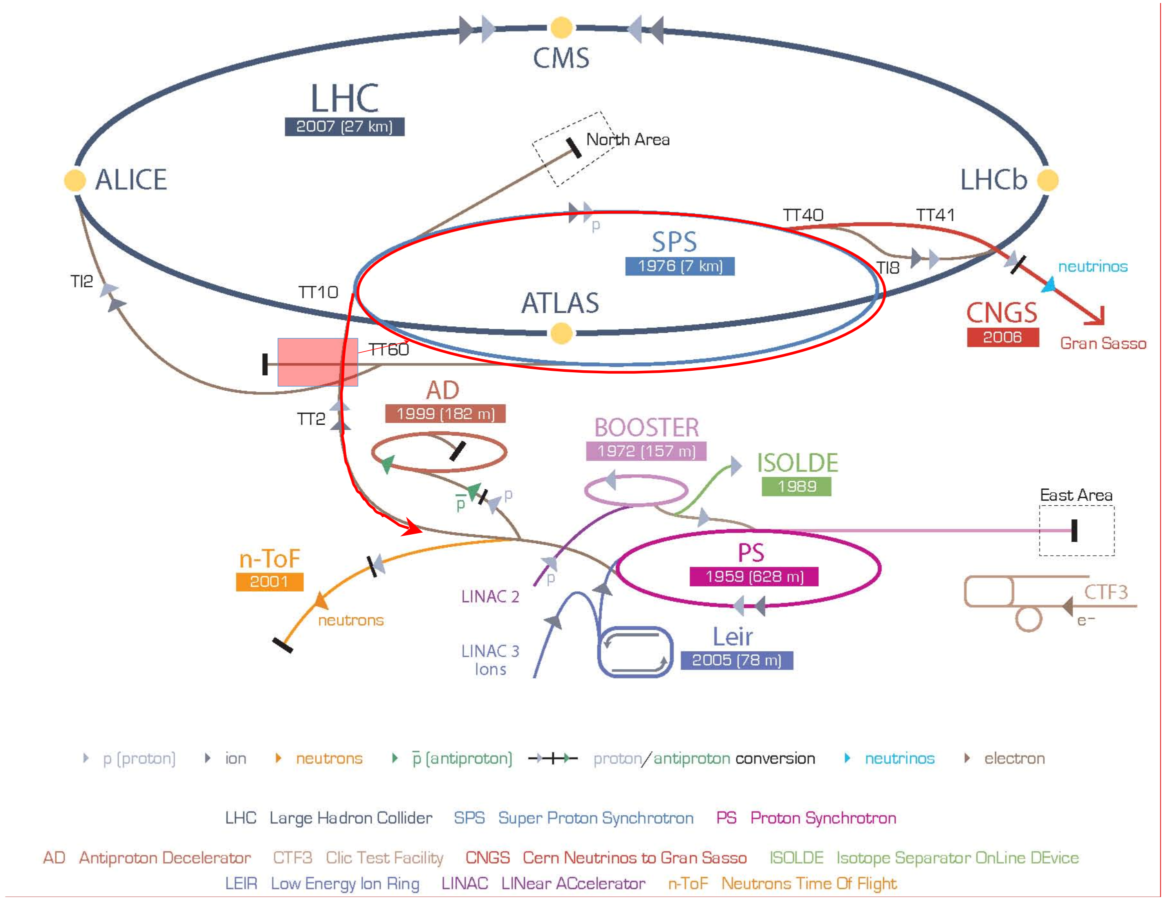
INFN Frascati advanced acceleration facility
EuPARXIA@SPARC_LAB





Eindhoven University led
SMART*LIGHT Compton Source

An e-beam facility at CERN



Accelerator implementation at CERN of LDMX type of beam

X-band based 60m LINAC to 3 GeV in TT4-5.

- Fill the SPS in 2s (bunches 5ns apart) via TT60
- Accelerate to ~10 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle
- Experiment(s) considered in UA2 area or – better - bring beam back on Meyrin site using TT10

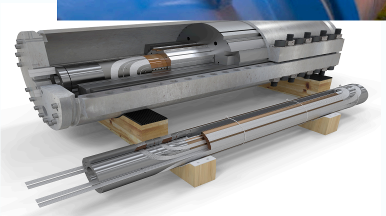
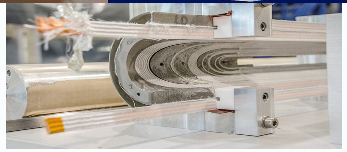
Beyond LDMX type of beam:
Other physics experiments can be considered (for example heavy photon searches)
Several other possible uses of linac and SPS beams for R&D

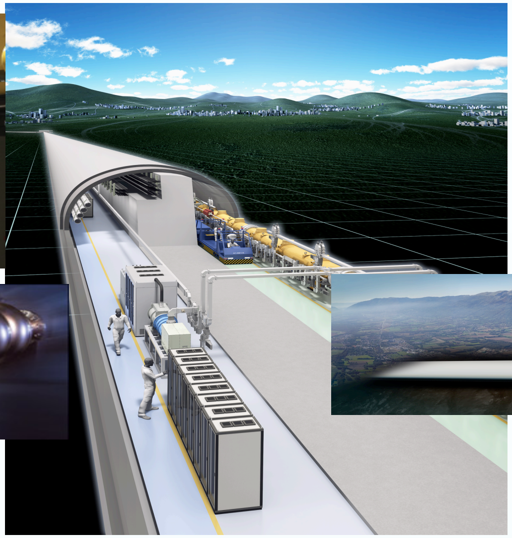
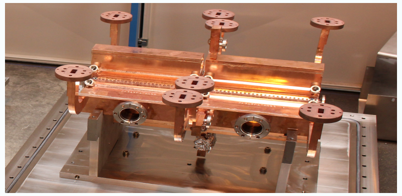
Summary

- The CLIC programme in the Preparation Phase 2020-25 is quite straight-forward but detailed work needed to make coherent with "related" projects and studies
  - Resources available a serious constraint
  - Collaboration partners outside CERN – with the significant X-band projects now happening – can cover important parts of work needed
  - Our goal is to present a complete overview for next phase by end 2018

- A 3 GeV linac for non-collider e-beams at CERN will cover a significant part of what is needed for a CLIC TDR phase – plus interesting physics (the main motivation) and accelerator R&D

- LHC physics developments can have large impact
- ILC moving ahead will change the next phase programme


Thanks for your attention

The collimation system

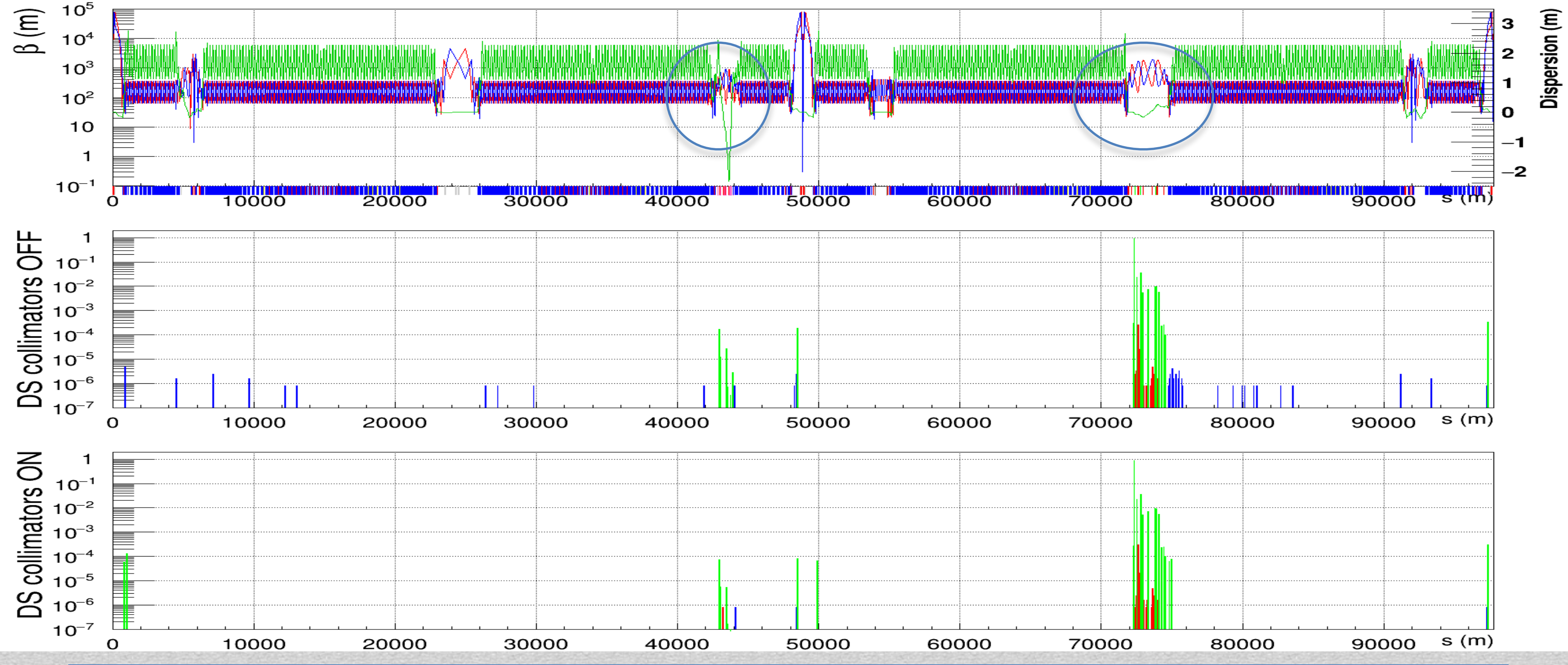
- **Halo cleaning** versus quench limits (for SC machines)
- Passive **machine protection**
  First line of defence in case of accidental failures
- **Reduction of total doses** on accelerator equipment
  Provide local protection to equipment exposed to high doses
- **Cleaning of physics debris** (collision products)
  Avoid SC magnet quenches close to the high-lumi experiments
- **Concentration of losses/activation** in controlled areas
  Avoid many loss locations around the 100-km tunnel
- **Optimize background** in the experiments
  Minimize impact of halo losses on quality of experimental data

The collimation system

Full ring loss map V8 on-momentum

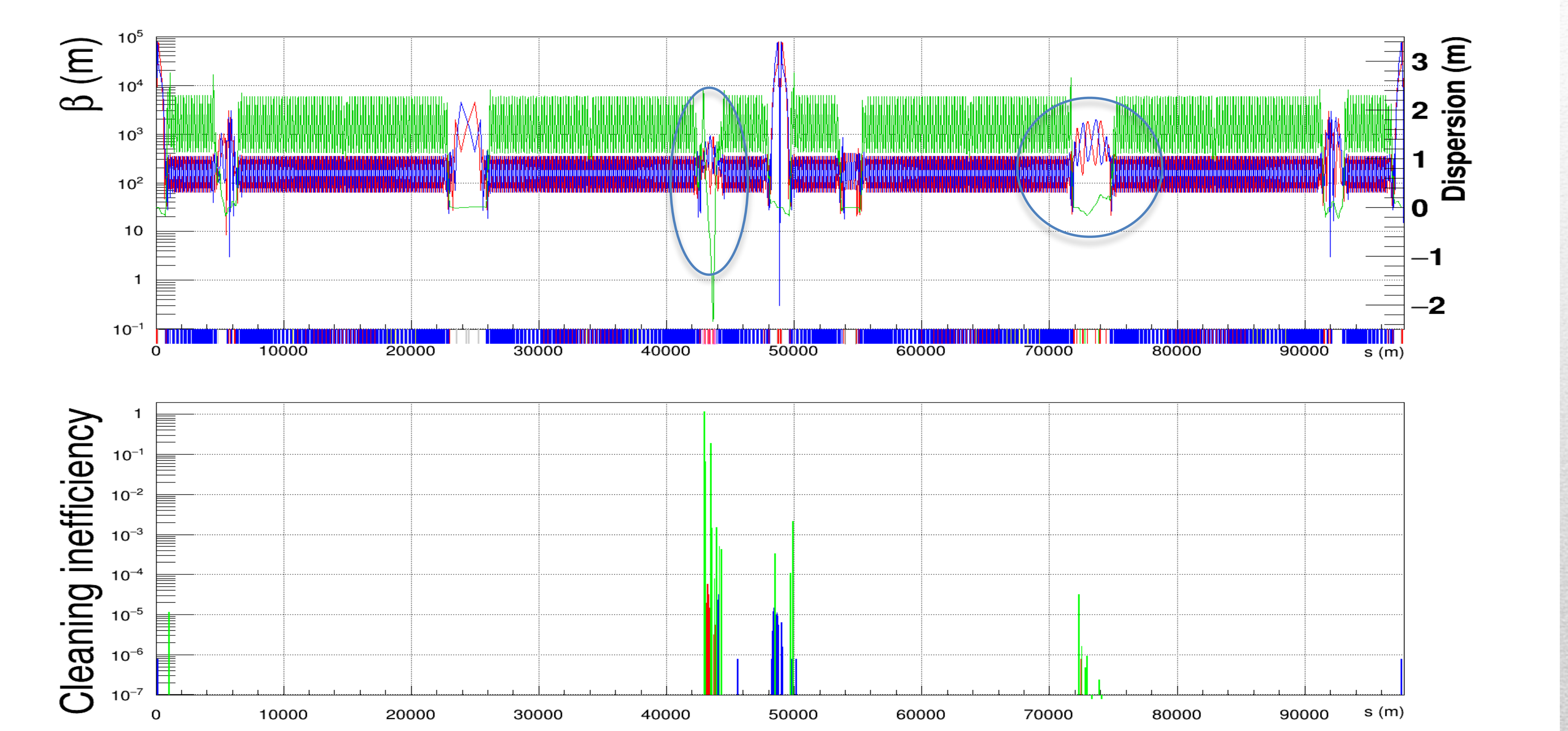
The collimation system

Full ring loss map V8 on-momentum wo/w DS collimators



The collimation system

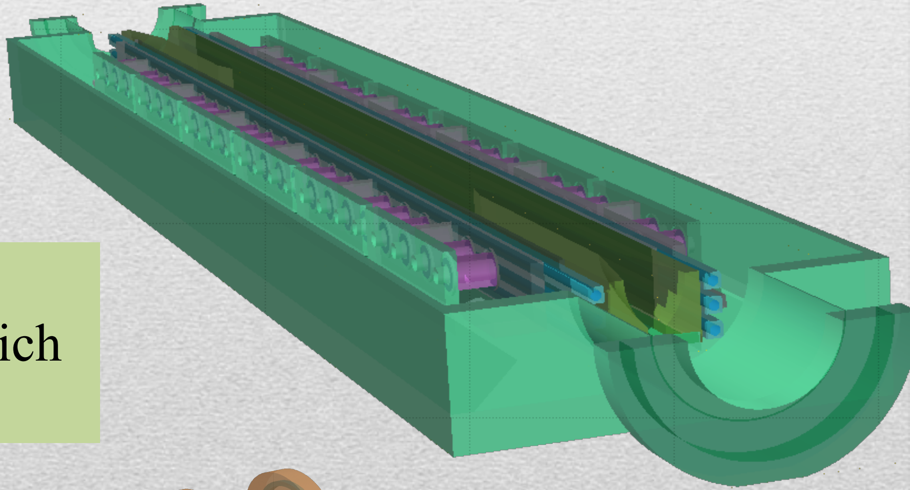
Full ring loss map V8 off-momentum



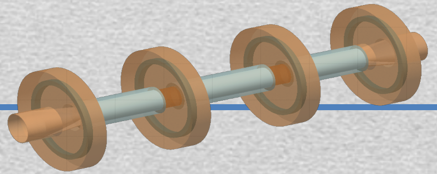
The collimation system

Same collimators and absorbers as in LHC:

- **Primary collimators**: 7.6 σ, 0.6 m long carbon based collimators
- **Secondary collimators**: 8.8 σ, 1 m long carbon based collimators
- **Active absorbers**: 12.6 σ, 1 m long, tungsten based collimators
- **Passive absorbers:** in front of the magnets, 0.4m to 1.5m long



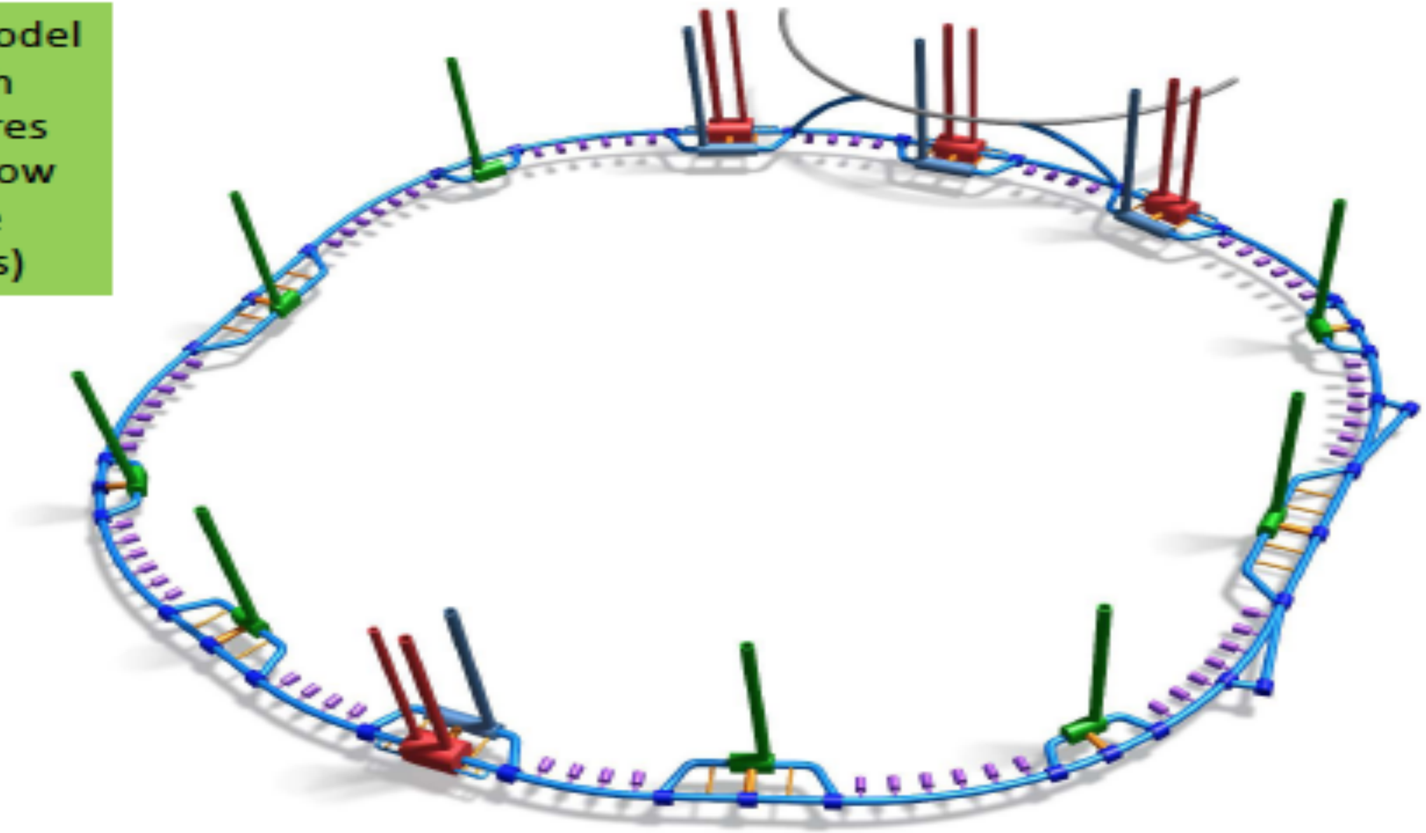
- CFC collimators consume significant portion of the impedance budget
- Investigate alternative materials, e.g. Molybdenum Graphite (MoGr) which is foreseen for HL-LHC



Civil engineering and Infrastructure

Overall Schematic 3D view:

Single tunnel model updated with all main features known up to now (w/o FCC-ee enlargements)

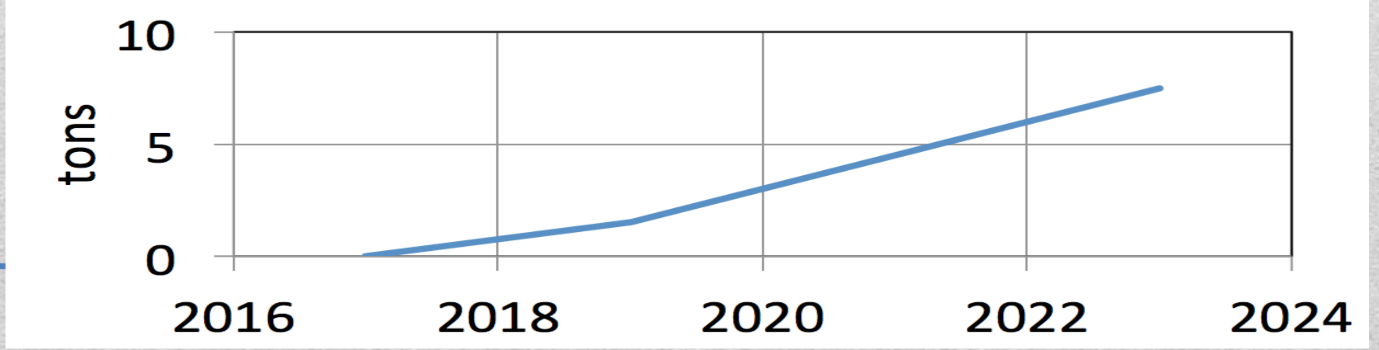


Colour code:

- Machine tunnels + bypass galleries
- Detector caverns + shafts
- Service caverns + access shafts
- Electrical alcoves
- Connection tunnels

What do we expect next ?

- Understand limits of Nb_3Sn while moving towards the first performance targets (Jc current density, RRR residual resistance ratio)
    - Allowable engineering limits (stress, strain)
    - Grain formation and grain refinement physics
- Evaluate the potential and opportunity for alternative superconductors (MgB_2, Bi-2212, REBCO, Fe-based)
- Procure the first large lengths of superconducting wire to feed the technology and model program
    - 1.5 tons by 2019
    - 6 tons by 2023



FCC-ee RF staging scenario

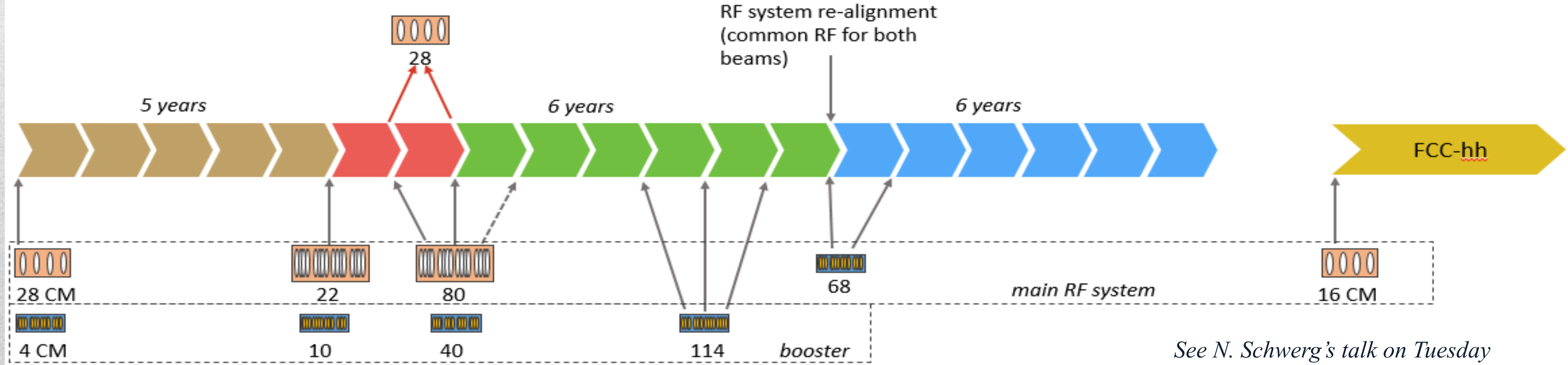
"Ampere-class" machine

	V_tot (GV)	n_bunch	I_beam (mA)
Z	0.2	91500	1450
W	0.8	5260	152
H	3	780	30
t	10	81	6.6

"high gradient" machine

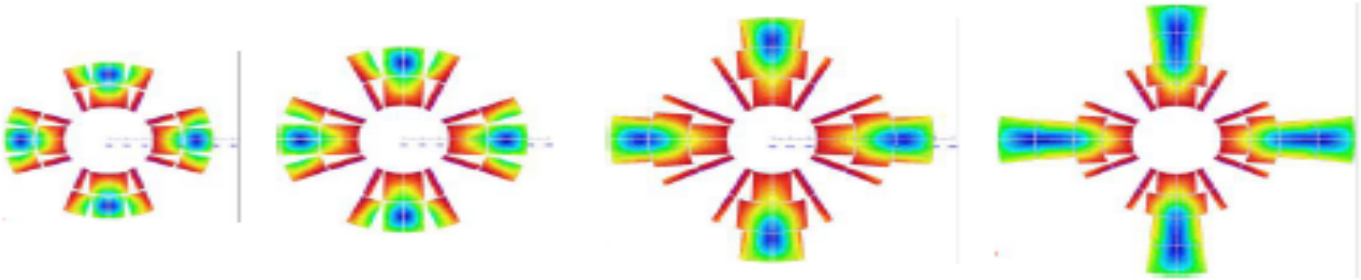
Three sets of RF cavities to cover all options FCCee & Booster:

- **Installation sequence comparable to LEP (≈30 CM/shutdown)**
- **high intensity (Z, FCC-hh): 400 MHz mono-cell cav, ≈ 1MW source**
- **high energy (H, t): 400 MHz four-cell cavities, also for W machine**
- **booster and t machine complement: 800 MHz four-cell cavities**
- **Adaptable 100MW, 400MHz RF power distribution system**

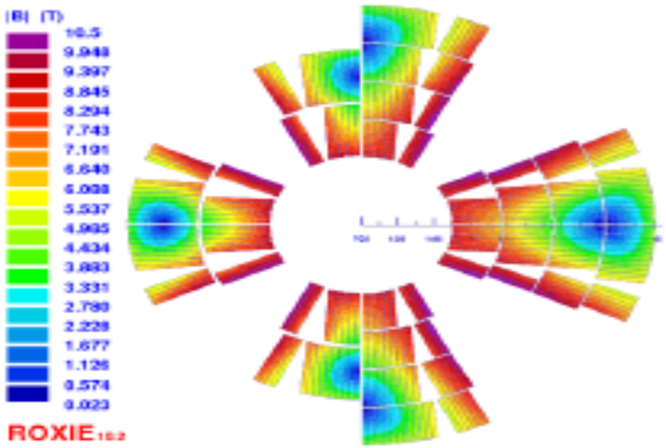


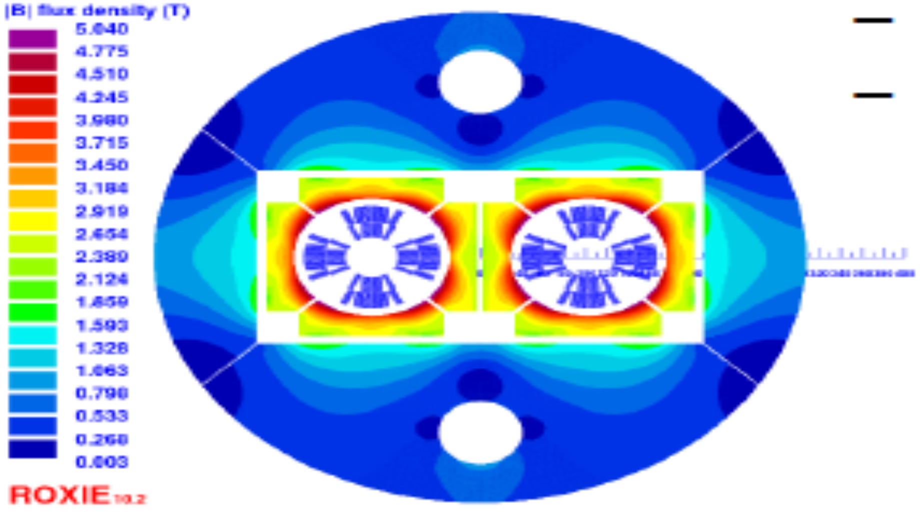
See N. Schwerg's talk on Tuesday

The main Quadrupole design:



365 T/m 390 T/m 413 T/m 392 T/m





360 T/m 400 T/m

It seems that to reach

- $G > 400$ T/m
  - 4 layers → complexity
- 370 T/m < G < 390 T/m
  - 2 layers → $I_{op} > 25$ kA
- $G < 360$ T/m
  - 2 layers, $I_{op} \sim 20$ kA
  - More room for support in case of inter-aperture reduction

Conceptual Design Report

1 – PHYSICS Physics opportunities across all scenarios	2 Hadron Collider Summary	3 – Hadron Collider Comprehensive: Accelerator, Injectors, Technologies, Infrastructure, Operation, Experiment, eh
	4 Lepton Collider Summary	5 – Lepton Collider Comprehensive: Accelerator, Injectors, Technologies, Infrastructure, Operation, Experiment
	6 High Energy LHC Summary	7 – High Energy LHC Comprehensive: Accelerator, Injectors, Infrastructure *Refs to FCC-hh, HL-LHC, LHeC*

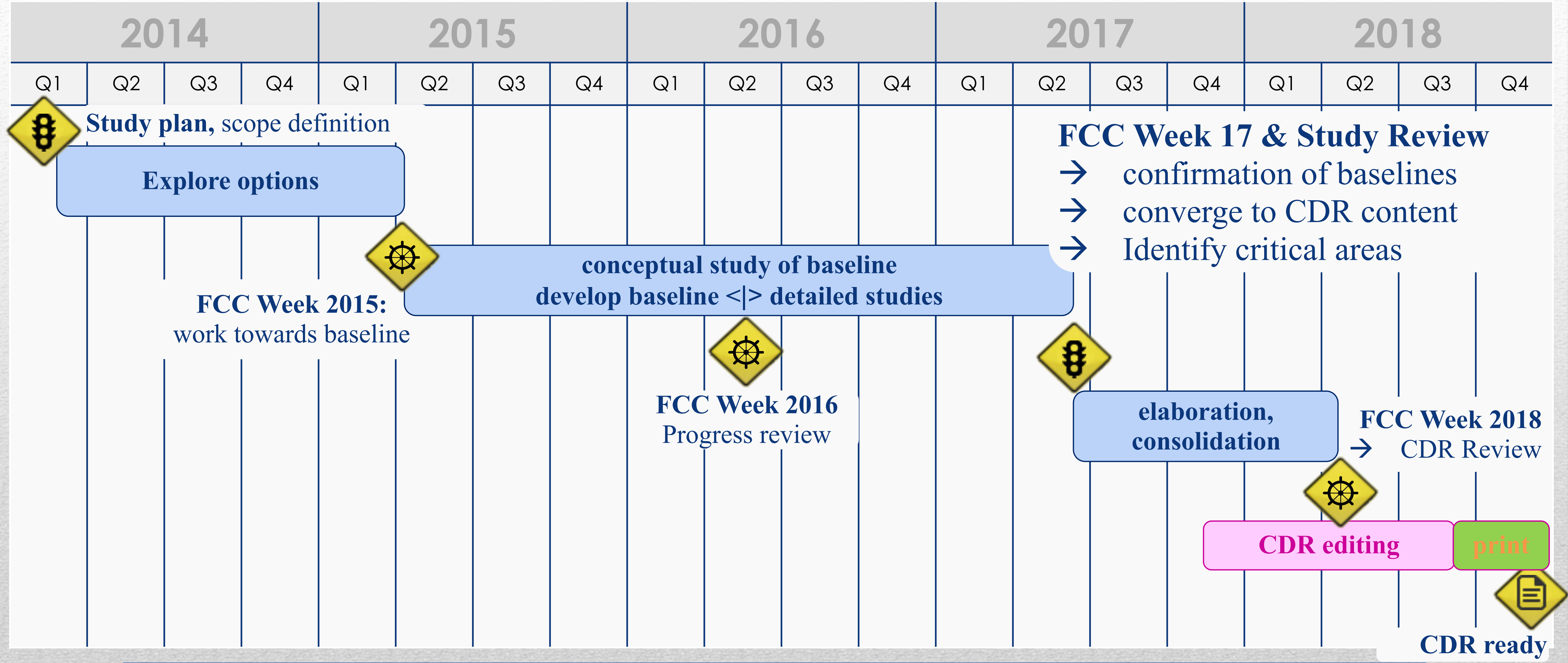
- **Required for end 2018, as input for European Strategy Update**
- **Common physics summary volume**
- **Three detailed volumes FCChh, FCCee, HE-LHC**
- **Three summary volumes FCChh, FCCee, HE-LHC**

CDR planning

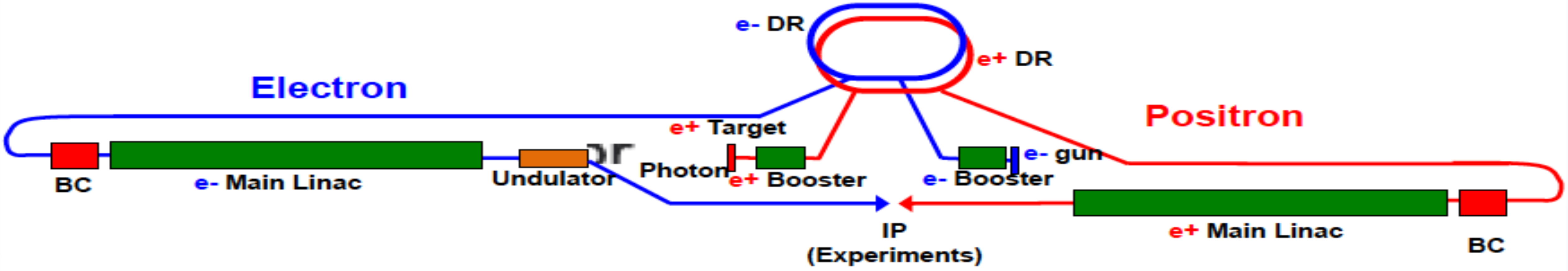
2017	Jun	▲ToC & Volume layout definition | Jun
	Jul	
	Aug	
	Sep	▲Guidelines, tools ready, editorial teams operational | Sep
	Oct	▲VOLUME EDIT STARTS | Oct
	Nov	
	Dec	
2018	Jan	
	Feb	
	Mar	
	Apr	▲Contents review by IAC (FCCWeek) | Apr 9-13
	May	Review session with IAC | May 15
	Jun	▲END OF VOLUME EDIT | June 30
	Jul	Overall editing: Proofread, homogenization, cross-referencing, polishing
	Aug	▲END of Final edit | Aug 31
	Sep	
	Oct	▲ PRINT FINISHED | Oct 26

- **Editing package "Overleaf"**
- **During summer nomination of editors and author groups**
- **FCC CDR available for publication in November 2018.**

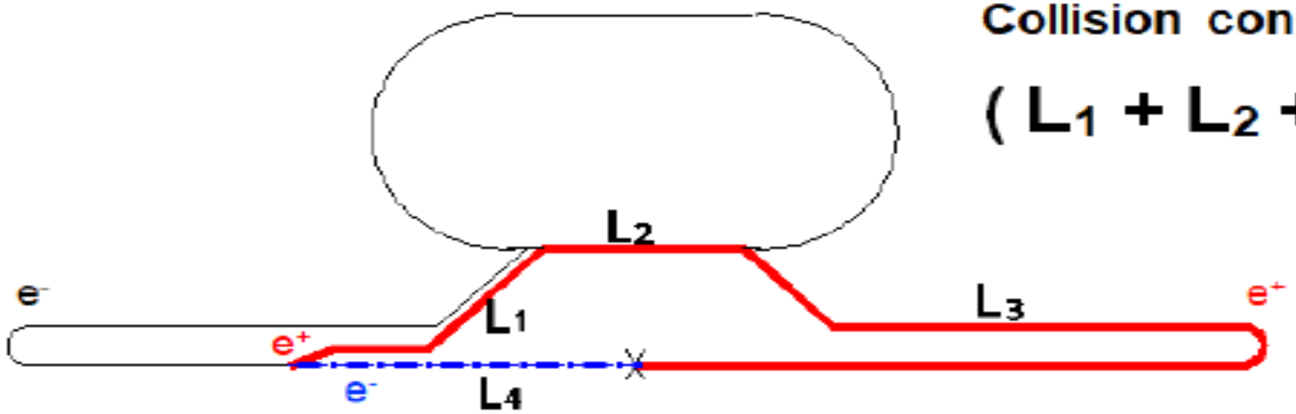
CDR Study Timeline



Positron sources: undulator-based e+ source



- Positrons can be generated by increasing the undulator length from 147 m to 231 m.
- This longer undulator source of positrons is the new baseline for the ILC250GeV staging.
- Electrons lose ~3 GeV in the undulator and this is compensated by the main electron linac.
- Collision condition constraint should be satisfied at Undulator source.



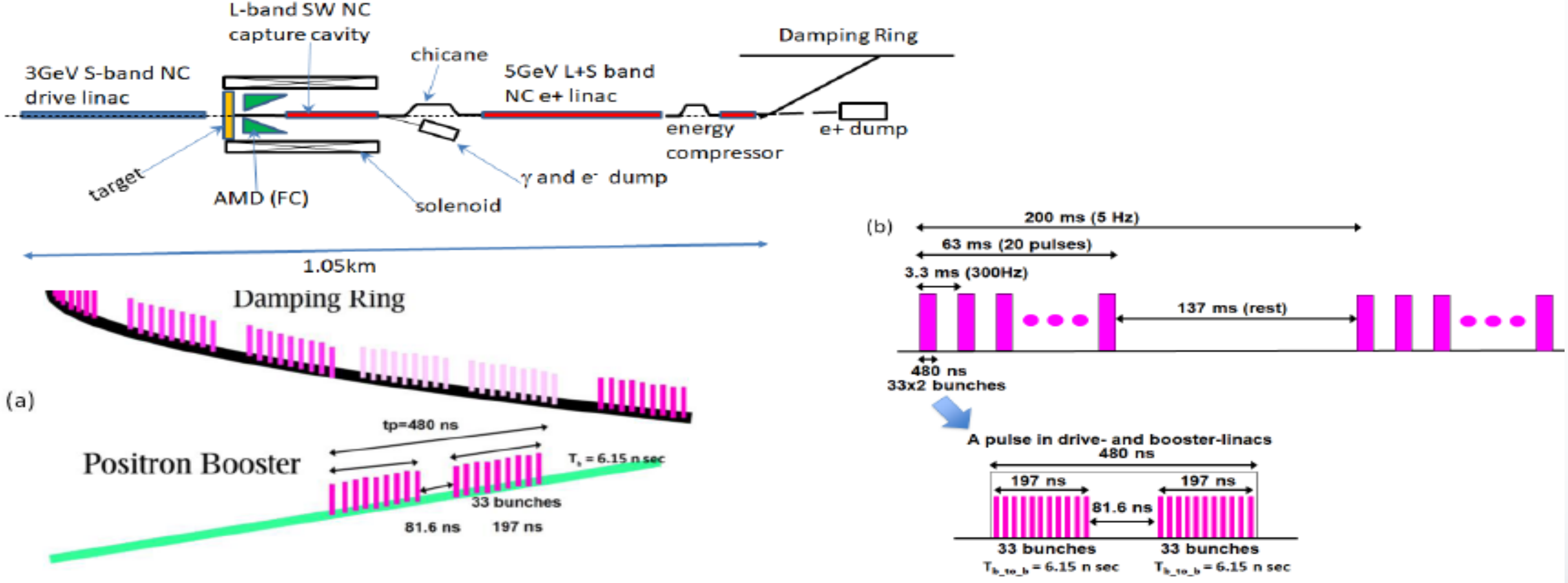
Collision condition

$$(L_1 + L_2 + L_3) - L_4 = n \times C_{DR}$$

n = integer

L_3 (e^+ ML/RTML) has to be adjusted.

Positron sources: e^- -driven e^+ source



-Different electron bunch patterns will be used (from undulator system).
-Beam pulses with ~480 ns duration (including ~66 bunches) will be accelerated in the normal conducting linacs.
-The linacs will operate at 20 pulses every 200 ms, with inter-pulse intervals of 3.3 ms.
-The remaining 137 ms will be reserved for damping of positrons in the damping ring.

Positron sources: cost comparison and luminosity upgrade

-No cost difference between accelerator components for the undulator and e-driven.
-Some cost reduction (of the order of a few ten's of MILCU*) associated with the e-driven system is expected, if the space for the timing constraint in the undualtor scheme is omitted.
-The undulator source will still be considered as the baseline source of positrons.
-However, an e-driven source of positrons can be adopted initially for ILC250 GeV and be replaced by undulator in future upgrades, depending on the technical maturity, because the e-driven source is safer for achieving design luminosity at low electron energies (~125 GeV) and has the big advantage that positron beam commissioning can be done without needing the full electron linac and damping ring.

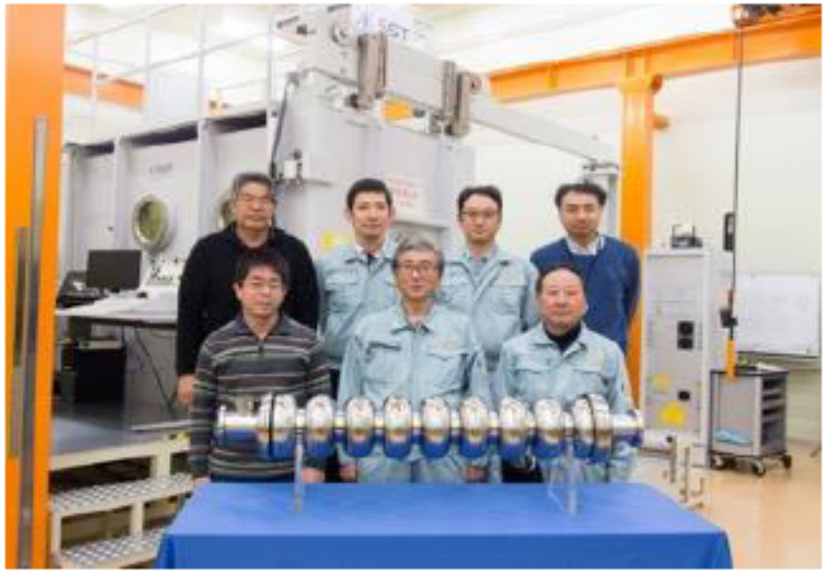
-The basic change in the luminosity upgrade is the increase in the number of bunches from 1,312 to 2,625.
-In the case of the e-driven, one more positron damping ring is required because beam-loading compensation is difficult to realize with a 3-ns-wide bunch spacing.
-The driving beam linac should be extended from 3 GeV to 4.8 GeV and the modulators of the driving linac and booster should be reinforced owing to longer beam pulse durations.

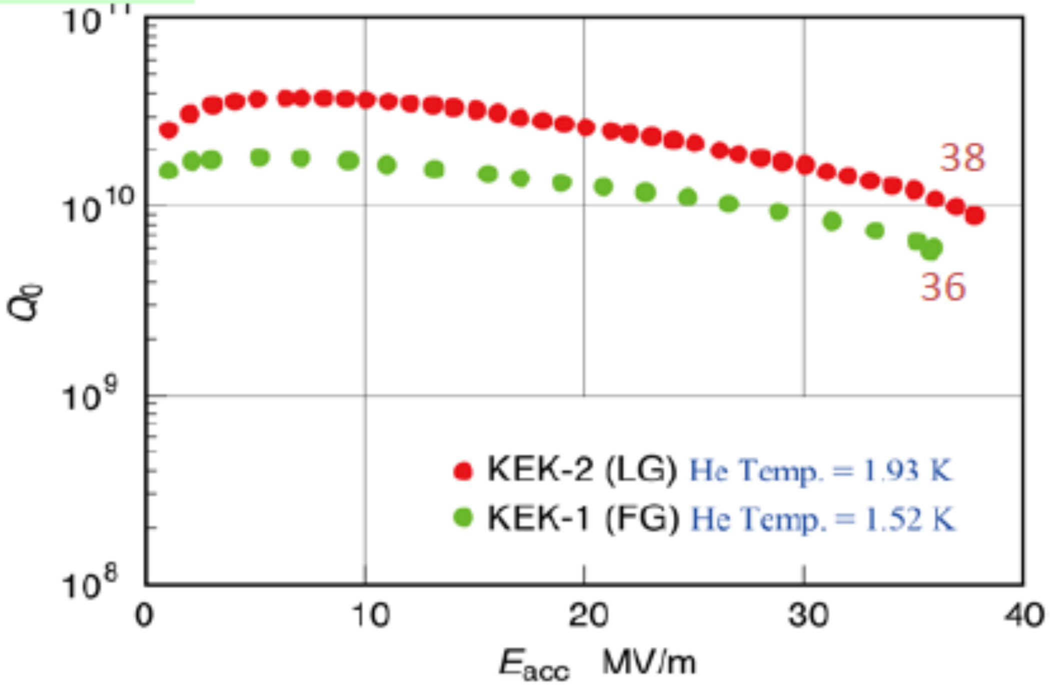
*The reference currency (the "ILCU") is the United States dollar (USD) as of January, 2012.

Nb-ingot sliced, LG Cavity at KEK

Ingot sliced Niobium (**Tokyo Denkai**)
(Dia : 260 mm)

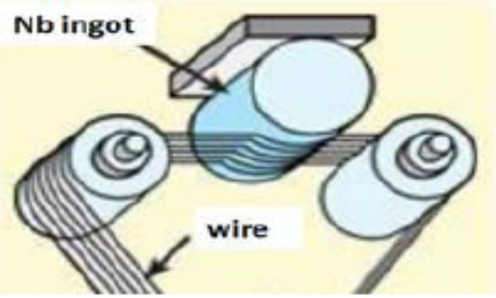
1.3 GHz TESLA-like SRF cavity, using Nb directly sliced demonstrated:

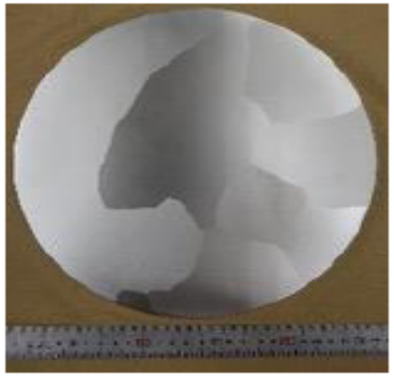




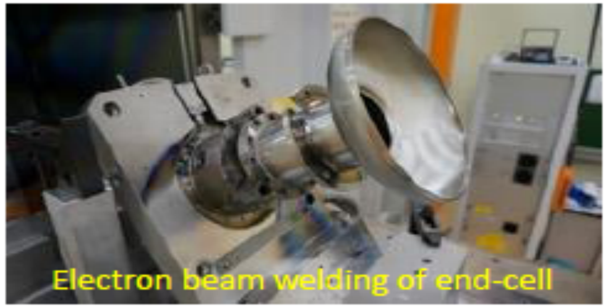
Direct sliced Nb material performance

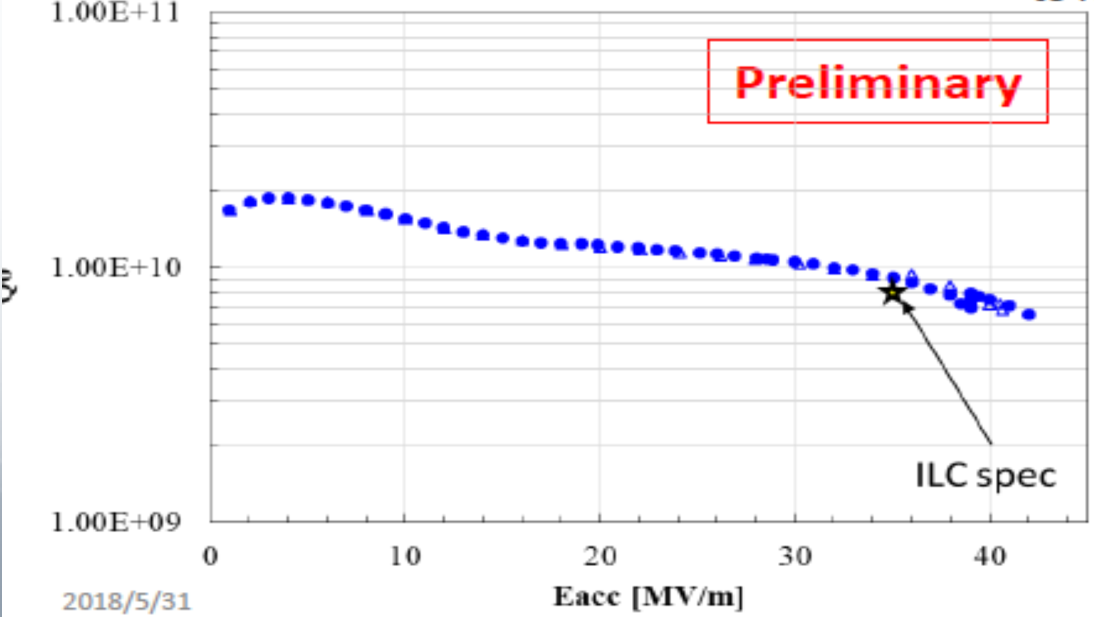
Made from large grain Nb disks;
medium RRR Nb with high Ta content (**CBMM**)





Annealed for
800°C × 3hrs
to remove stresses.





- The 3-cell cavity achieved very high gradient **(> 40 MV/m)** and satisfies ILC spec.

Standard Procedure Established

	Standard Fabrication/Process
Fabrication	Nb-sheet purchasing
	Component Fabrication
	Cavity assembly with EBW
Process	EP-1 (~150um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 800 C
	Field flatness tuning
	EP-2 (~20um)
	Ultrasonic degreasing or ethanol (or EP 5 um with fresh acid)
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C
Cold Test (vertical test)	Performance Test with temperature and mode measurement

Key Process

Fabrication

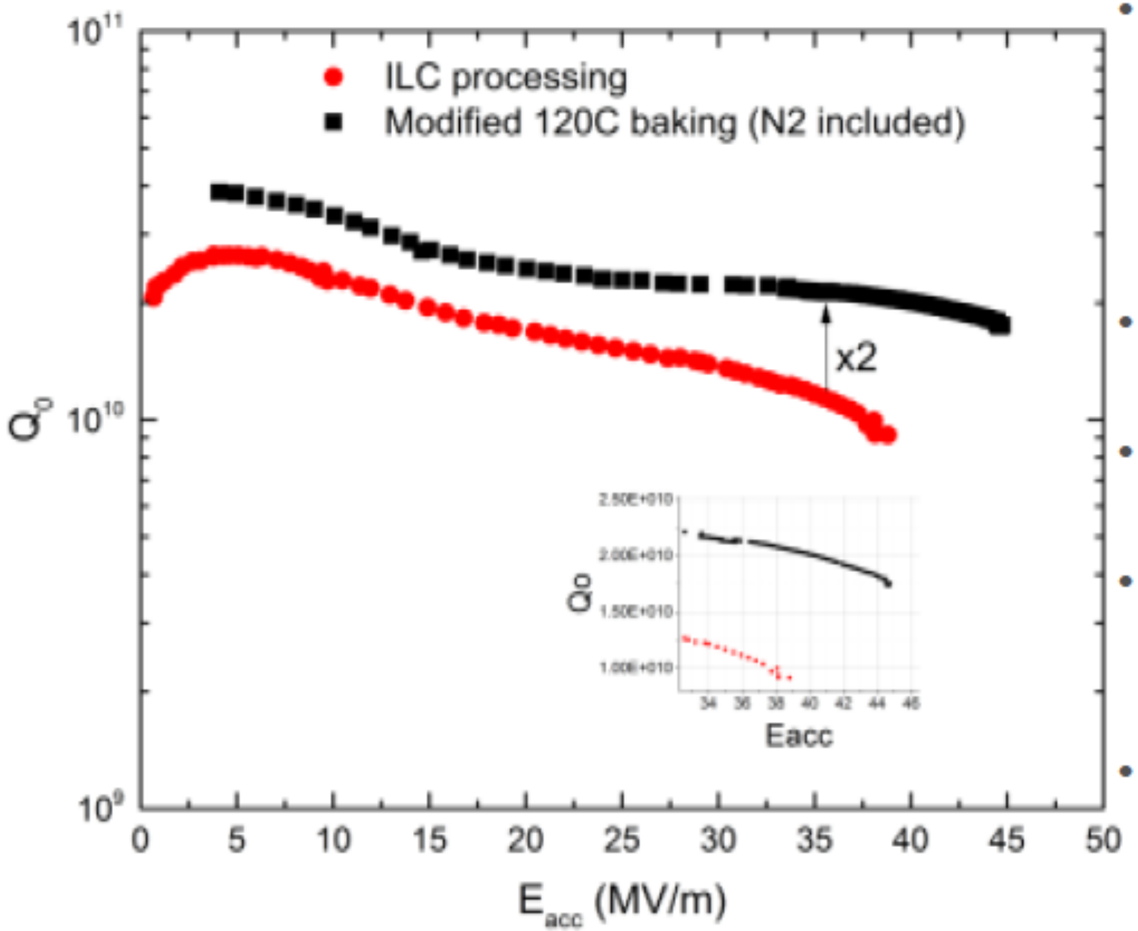
- Material
- EBW
- Shape

Process

- Electro-Polishing
- Ethanol Rinsing or
- Ultra sonic. + Detergent Rins.
- High Pr. Pure Water cleaning

Cavity performance progress at FNAL: "standard" vs "N infused" cavity surface treatment

A. Grassellino



Increase in Q by > a factor of two
Increase in gradient ~15%

- FNAL recently demonstrated a new treatment, which utilizes "nitrogen infusion", achieving
  - 45.6 MV/m → 194 mT
  - with Q ~ 2×10^{10}
- Systematic effect observed on several single cell cavities
- FNAL has now successfully applied it on three nine cell cavities
- Jlab, KEK have reproduced similar results on single cell cavities with Q >2e10 at 35 MV/m
- R&D work towards:
  - Best recipe for higher Q at high gradient
  - Robustness of process

A Grassellino *et al* 2017 *Supercond. Sci. Technol.* 30 094004

Fermilab

Cavity performance progress at FNAL: "standard" vs "N infused" cavity surface treatment

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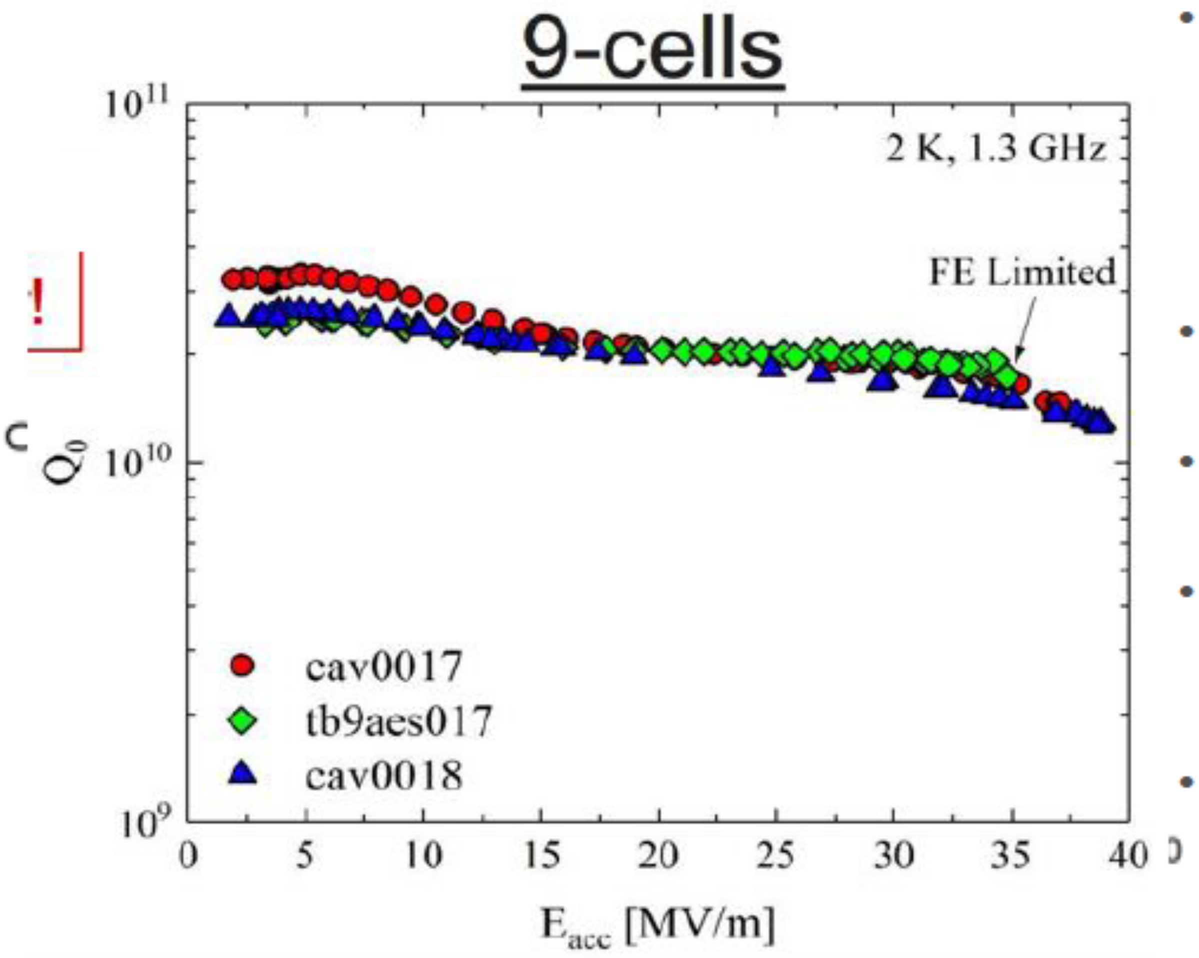

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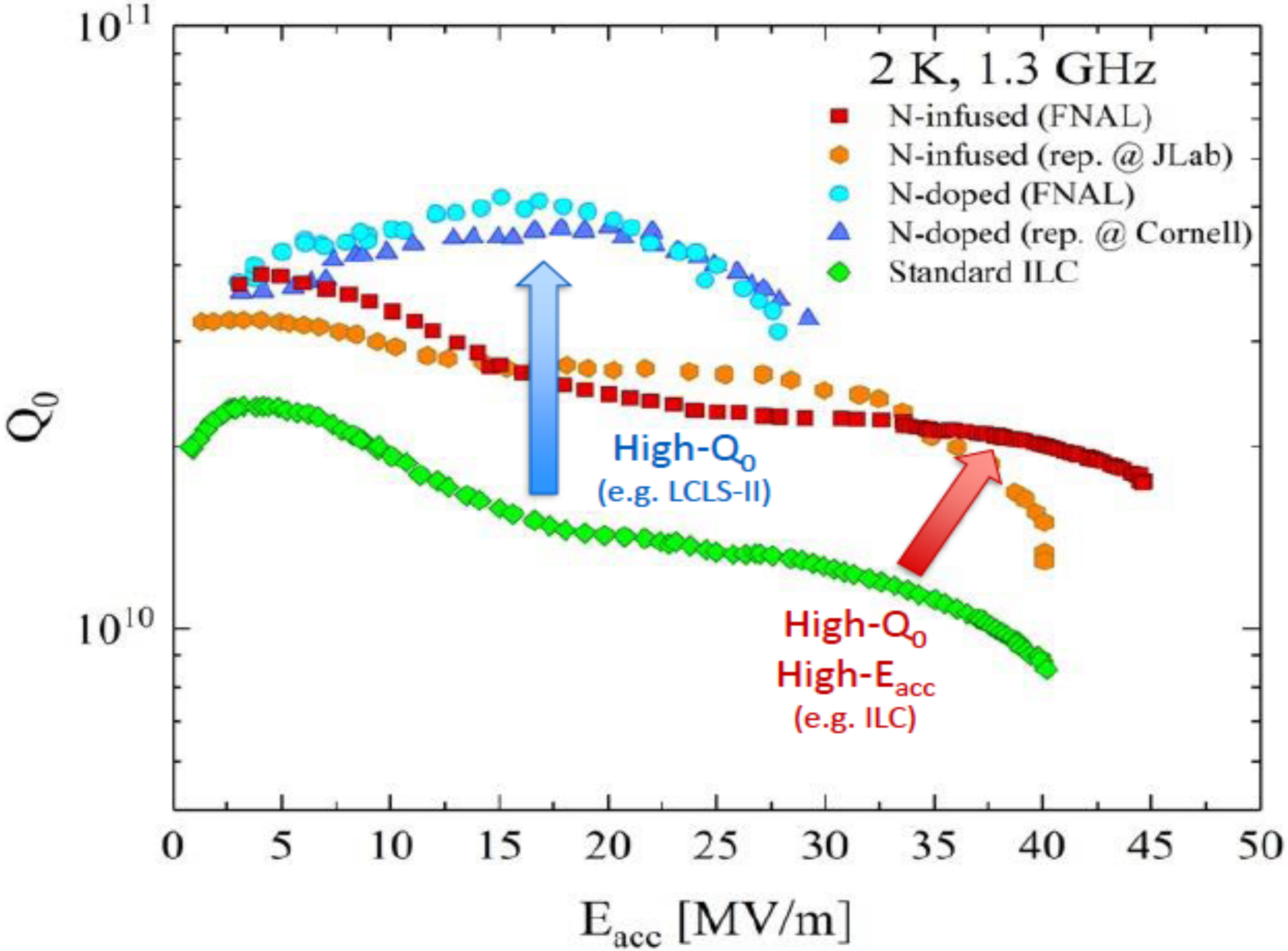
A. Grassellino

Potential for very high Q at very high gradients

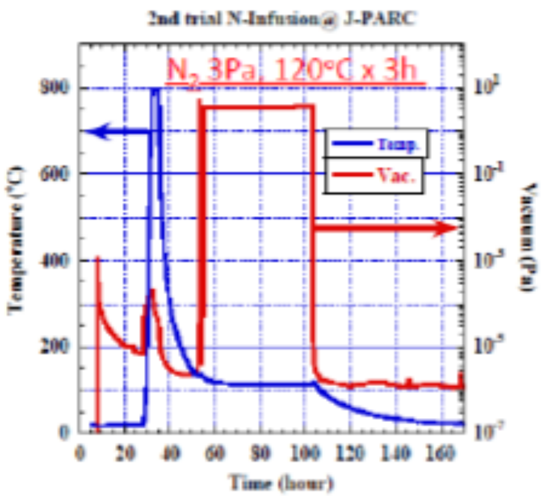


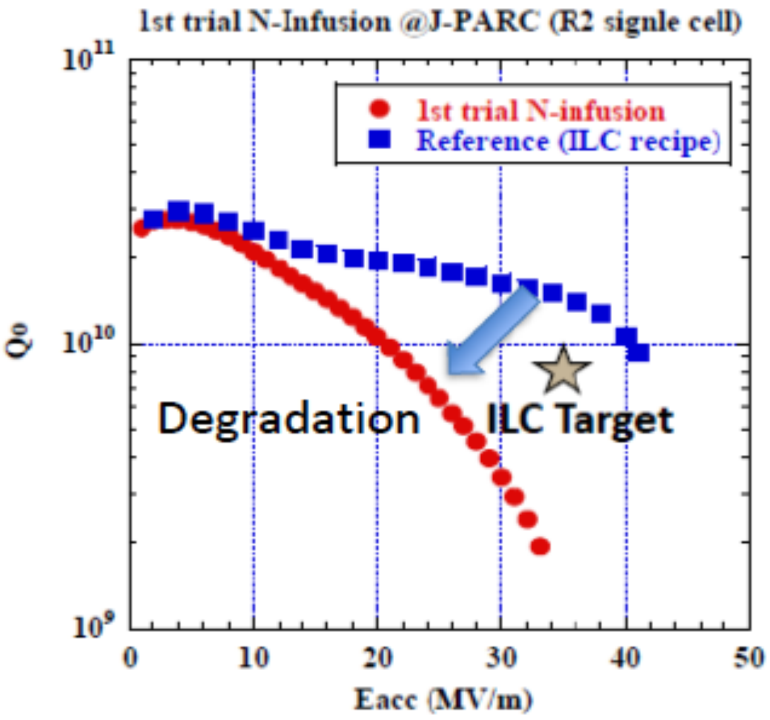
ILC Cost Reduction R&D global effort will explore doping parameter space to extend high Q at the highest gradients

Currently working on this R&D direction: FNAL, KEK, Jlab, Cornell, DESY

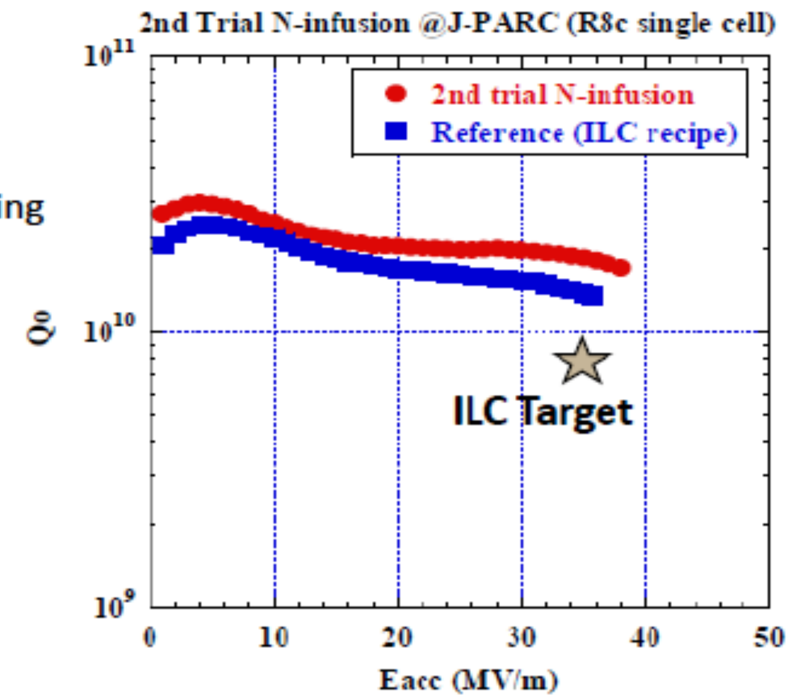
Recent N-Infusion result at KEK

- First trial of N-infusion showed degradation occurred at >5MV/m.
- Degradation seems to come from background vacuum during 120deg. N-Infusion.
- Background vacuum during N-Infusion was improved from 1.7e-2Pa to 1e-5Pa using larger turbo-molecular pump with reduced rotation speed.
- Second trial of N-Infusion was done with improved background vacuum during N-Infusion (120 deg.)
- It showed successful N-Infusion result (Q value +35**%** gradient +5%).





After the vacuum pumping system improvement



X-band Technology

CERN	XBox-1 test stand	50 MW	Operational, connection to CLEAR planned
	Xbox-2 test stand	50 MW	Operational
	XBox-3 test stand	4x6 MW	Operational
Trieste	Linearizer for Fermi	50 MW	Operational
PSI	Linearizer for SwissFEL	50 MW	Operational
	Deflector for SwissFEL	50 MW	Design and procurement
DESY	Deflector for FLASHforward	6 MW	Design and procurement
	Deflector for FLASH2	6 MW	Design and procurement
	Deflector for Sinbad	tbd	Planning
Tsinghua	Deflector for Compton source	50 MW	Commissioning
	Linearizer for Compton source	6 MW	Planning
SINAP	Linearizer for soft X-ray FEL	6 MW	Operational
	Deflectors for soft X-ray FEL	3x50 MW	Procurement

Australia	Test stand	2x6 MW	Proposal submission
Eindhoven	Compact Compton source, 100 MeV	6 MW	Design and procurement
Valencia	S-band test stand	2x10 MW	Installation and commissioning
KEK	NEXTEF test stand	2x50 MW	Operational
SLAC	Design of high-efficiency X-band klystron	60 MW	In progress
Daresbury	Linearizer	6 MW	Design and procurement
	Deflector	tbd	Planning
	Accelerator	tbd	Planning
Frascati	XFEL,plasma accelerator, 1 GeV	4(8)x50 MW	CDR
	Test stand	50 MW	Design and procurement
Groningen	1.4 GEV XFEL Accelerator, 1.4 GeV	tbd	NL roadmap, CDR

Above: EU Design Study for X-Band FELs 2018-2020: http://compact-light.web.cern.ch

Beyond being a collaboration for CLIC, many groups have their own X-band facilities and components (see overview on the left)

In the CLIC preparation phase:
Take advantage of the widespread use of electron linacs, and rapidly increasing use of X-band → increase collaboration

Preparation phase planning

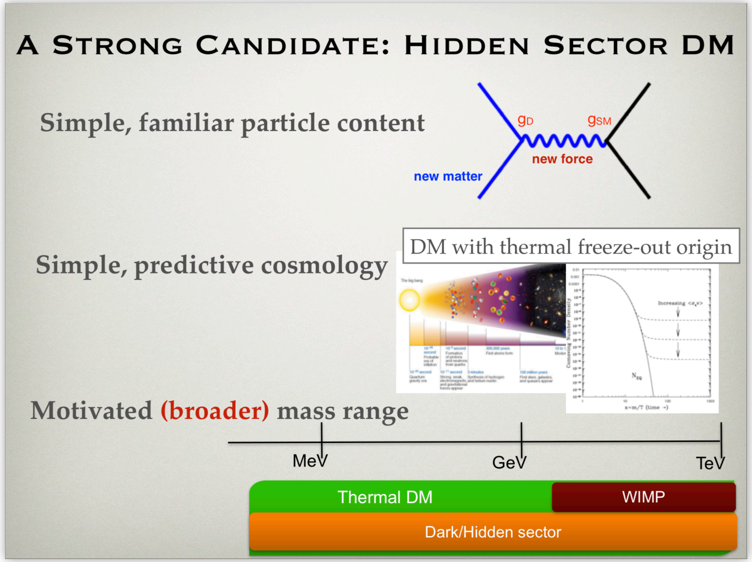
- The main activities needed for a TDR are quite clear, keywords: costs/power R&D, industrial activities, final parameters, site preparation, detector and physics studies
  - Concerns: Drive-beam facility, ATF2 or similar, resources
  - The way forward depends very strongly on the collaboration – for each item/study needed for the TDR: Combine CERN resources, collaboration activities, industrial interests and educational programmes

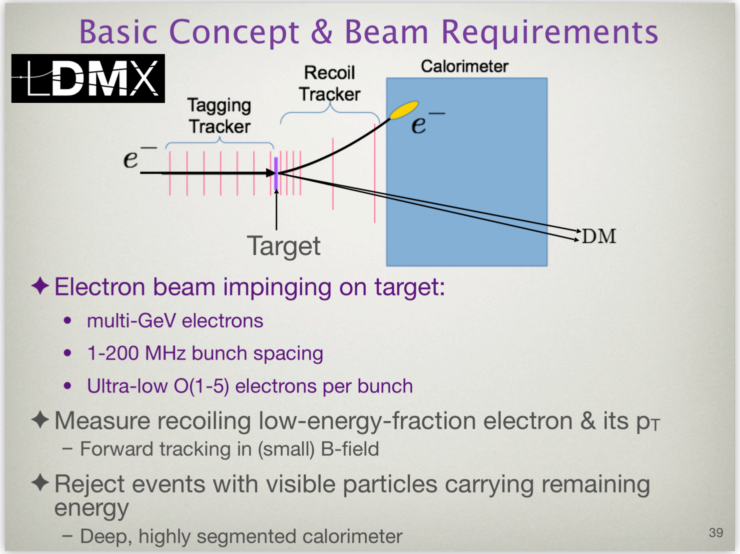
- Examples:
  - Klystron modules – if done for FEL projects outside CERN the CERN efforts can be less
  - Permanent magnets – if industry interested (for use outside CLIC), or other projects for use on a short timescale, we need to participate and not carry such a programme
  - If a country would like to establish a training or exchange programme with CERN for electron linacs/X-band we will pu into the planning matching funds
  - Network of X-band testing facilities – rely strongly on activities outside CERN
    - need to be creative -

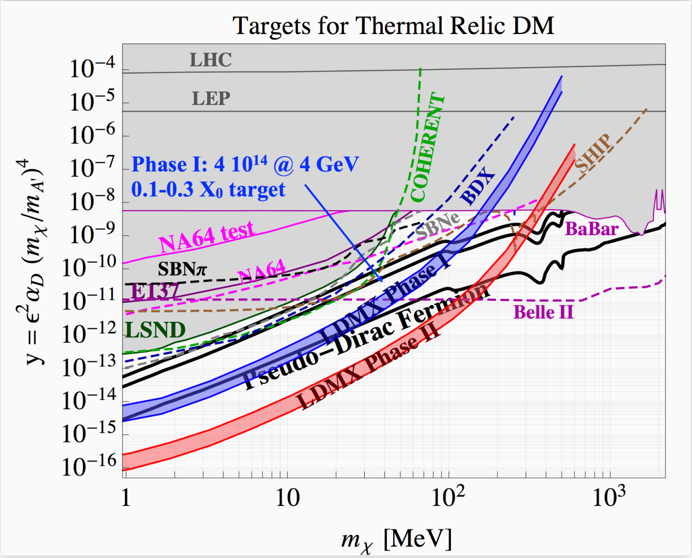
The CLIC studies are CERN hosted

Also relevant for the CLIC preparation phase: Potential use of CLIC technology for e-beams as part of non-collider physics programme at CERN – use of ~3 GeV e-linac

Physics with e-beams, example LDMX





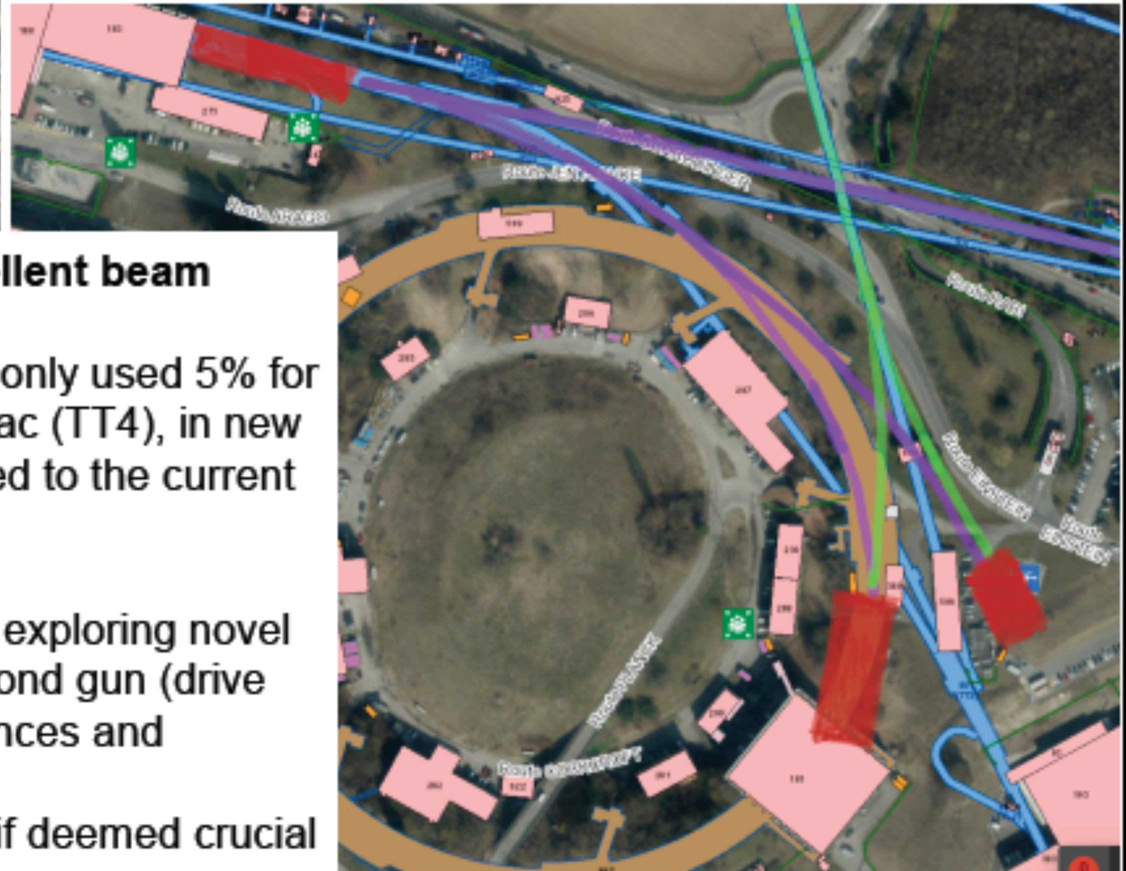


Talk by P. Schuster
“Physics Beyond Colliders”
Nov 21, 2017

GREEN: ~10+ GeV electron beam in SPS

Acc. in SPS, can also be a damped small emittance beam. Long bunches.

- Extracted to Meyrin side for LDMX like experiment.
- Can also – possibly – be guided to AWAKE.
- Other uses, either extracted or circulating to be worked out.



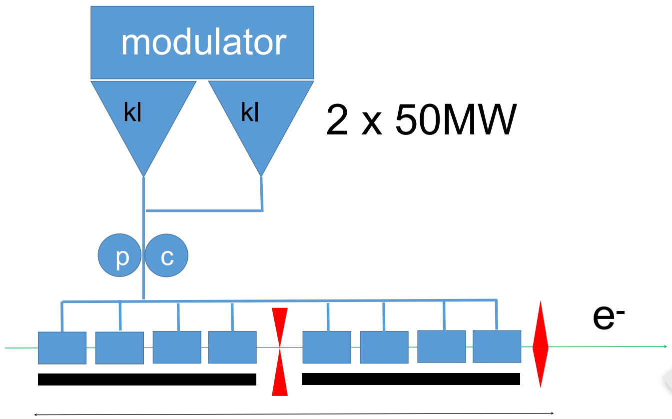
PURPLE: 3 GeV x-band linac with excellent beam quality

Short bunch electrons from X-band linac, only used 5% for filling the SPS. Can be used right after linac (TT4), in new experimental area, and/or possibly directed to the current AWAKE area.

- CLEAR type of research progamme.
- Electrons for drive and/or probe beam exploring novel accelerating techniques, including second gun (drive and probe bunches with variable distances and charges).
- Longer term possibilities for positrons if deemed crucial

X-band linac layout

Make use of study recently made for LNF ~1.0 GeV X-band linac
“CLIC-like” RF unit: 2*(klystron+modulator) + pulse compressor + 8 accelerating structures

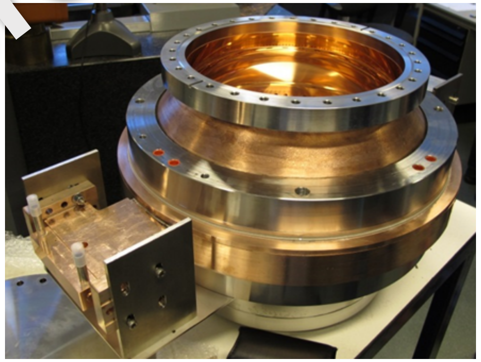


Klystron

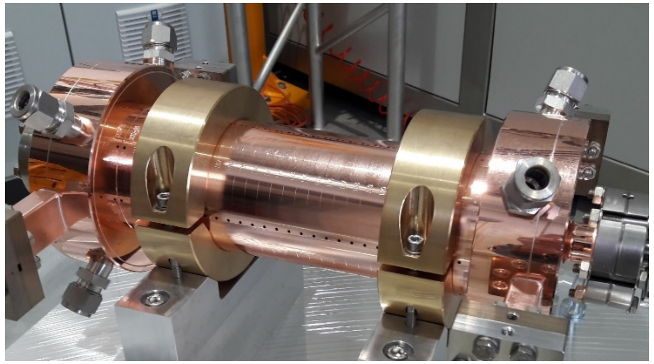
Modulator

- One “CLIC-like” type RF unit accelerates 200ns bunch train up to 264 MeV*
- 11 RF units to get to 2.9 GeV in ~60 m

Pulse compressor



Accelerating structure



* (lower than for Frascati single bunch operation: 336 MeV/unit)

Obvious interesting link with a CLIC preparation phase

Main known unknowns

- New physics
  - CLIC have energy flexibility (reach) to ~3 TeV
  - Working Group on New Accelerator Technology set up
  - Low energy studies – a CLIC type short linac can open opportunities

- ILC moves ahead
  - Two e+e- machines for SM/Higgs precision physics not reasonable
  - High gradient (in a wide sense) R&D will still be a priority

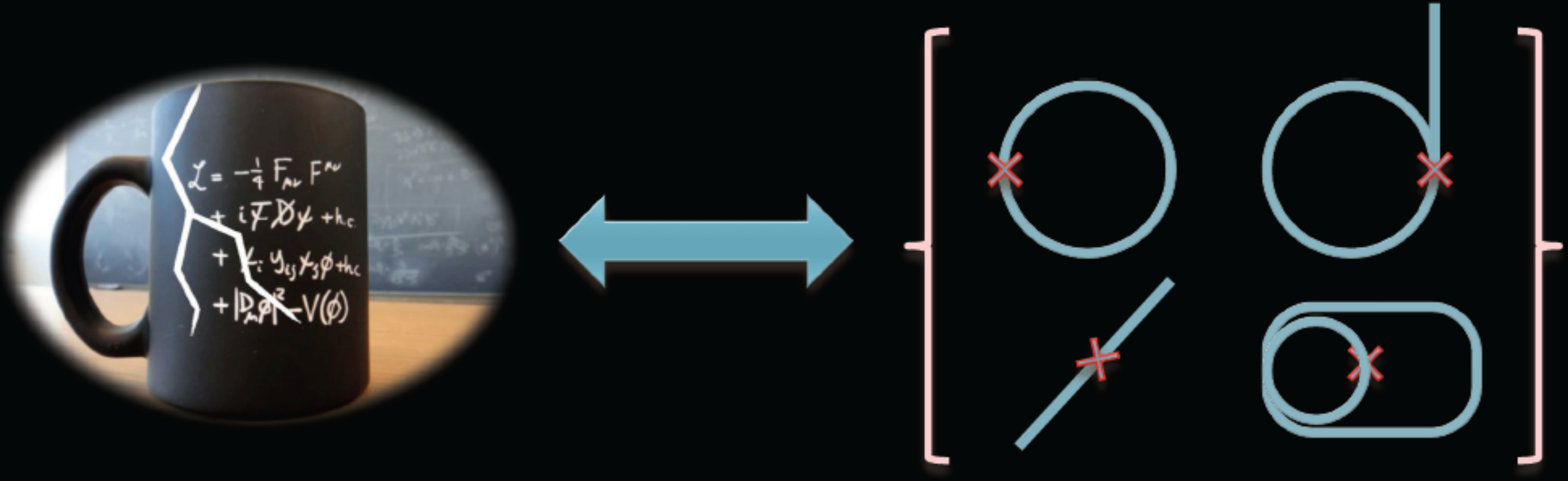
Large Accelerator Projects Key technologies:

Components			SCRF				NCRF	HLRF	SC Mag.		NC Mag.	Vac.	Optics	Others
Techniques			HG	HQ	CRYO	CRAB		HE-Klys	Nb_3Tn	CRYO				
PROJECTS	FCC	FCC-hh			X	X			X	X		X		
		HE-LHC			X	X			X	X			Coll	Integr.
		FCC-eh/ LHeC			X									
		FCC-ee	X	X	X			X			X		IRs	Integr.
	LC	ILC	X	X									IRs	e+
		CLIC					X	X			X		IRs	

Large Accelerator Projects Expertise Key technologies at IPNO-LAL-CSNSM-IMNC-LPT:

Components			SCRF				NCRF	HLRF	SC Mag.		NC Mag.	Vac.	Optics	Others
Techniques			HG	HQ	CRYO	CRAB		HE-Klys	Nb_3Tn	CRYO				
PROJECTS	FCC	FCC-hh			X	X			X	X		X		
		HE-LHC			X	X			X	X			Coll	Integr.
		FCC-eh/ LHeC			X									
		FCC-ee	X	X	X			X			X		IRs	Integr.
	LC	ILC	X	X									IRs	e+
		CLIC					X	X			X		IRs	

If these (non-collider) experiments would provide hints where to look for new physics, it would be interesting if we can address these with current and future colliders



<u>In general</u>: explore the synergies of the physics potential of non-collider and collider experiments

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