Status of the FCC Study

Michael Benedikt, Frank Zimmermann (CERN)
Katsunobu Oide (KEK)
on behalf of the FCC global design study team

19 Jan. 2016
Conference, IAS Program on HEP
HKUST, Hong Kong

YEARS / ANS CERN

*Work supported by the **European Commission** under Capacities 7th Framework Programme project EuCARD-2, grant agreement 312453, and the HORIZON 2020 project EuroCirCol, grant agreement 654305*

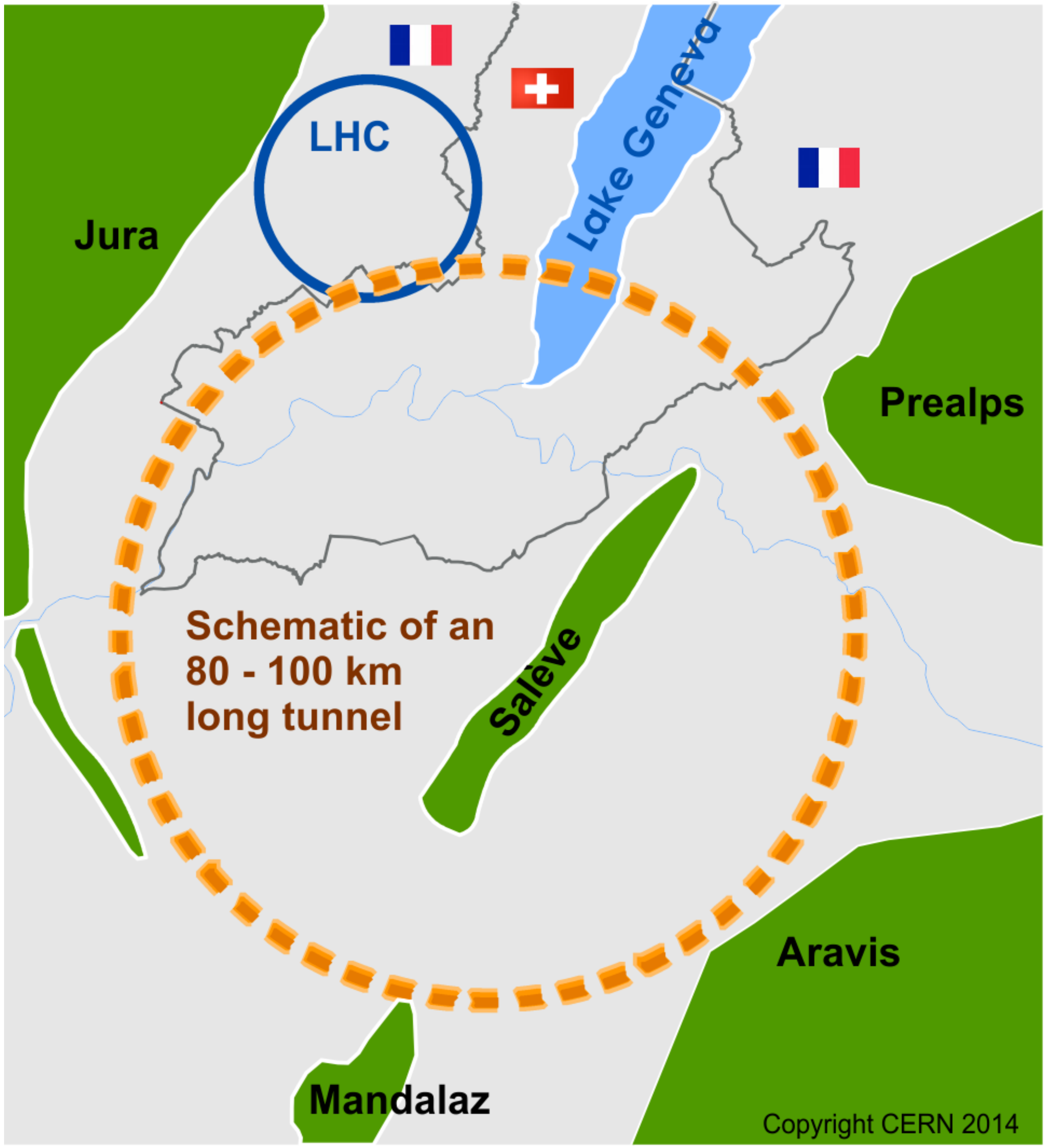
Future Circular Collider Study
GOAL: CDR and cost review for the next ESU (2018)

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

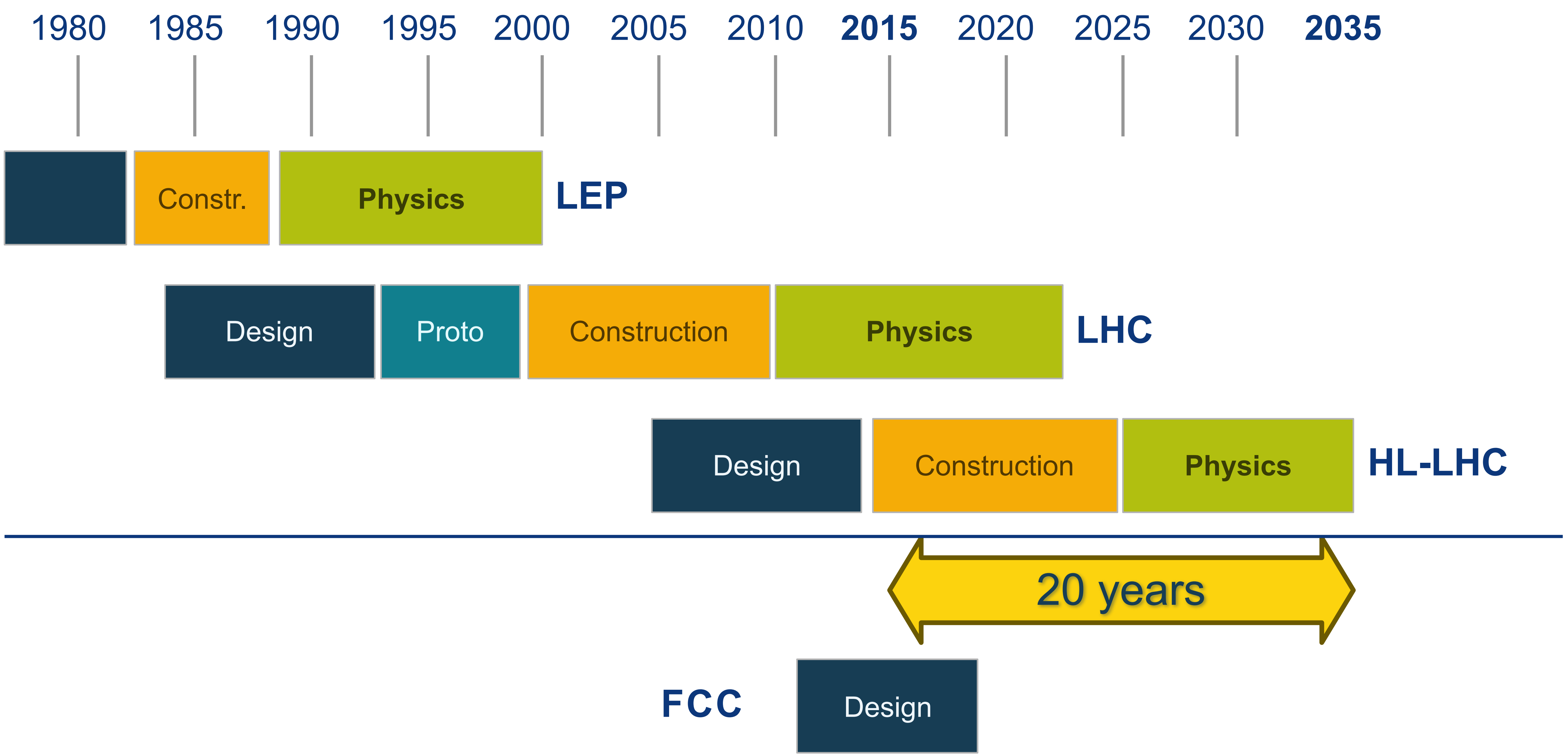
- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km

- **80-100 km tunnel infrastructure** in Geneva area
- ***e*$^+$*e*$^-$ collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**
- **HE-LHC** with *FCC-hh* technology



CERN Circular Colliders and FCC



CDR by end 2018 for next strategy update

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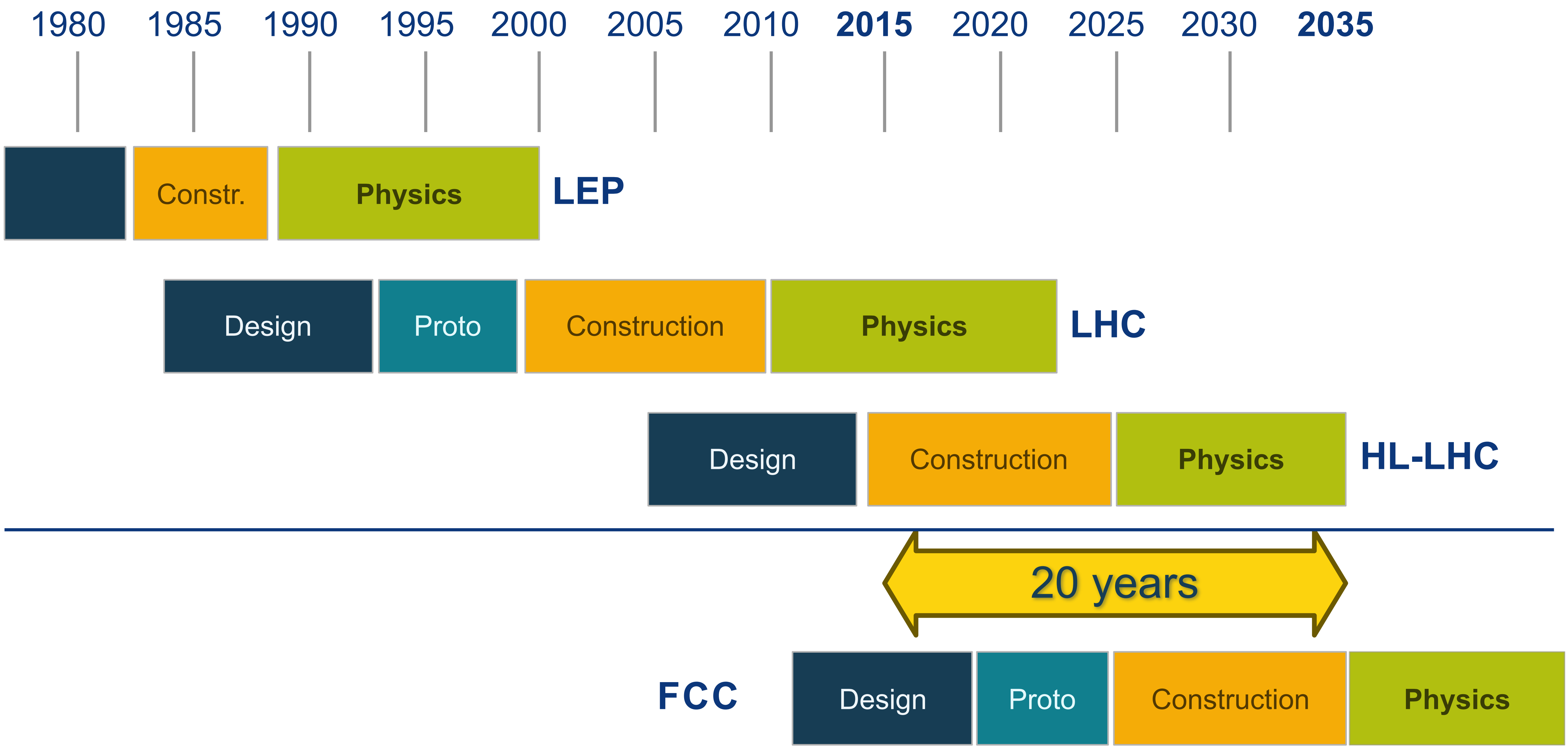


CDR by end 2018 for next strategy update

Progress on site investigations

Alignment | Shaft Tools

Choose alignment option

93km quasi-circular ▾

Tunnel depth at centre: 299mASL

Gradient Parameters

Azimuth (°): -15

Slope Angle x-x(%): .5

Slope Angle y-y(%): 0

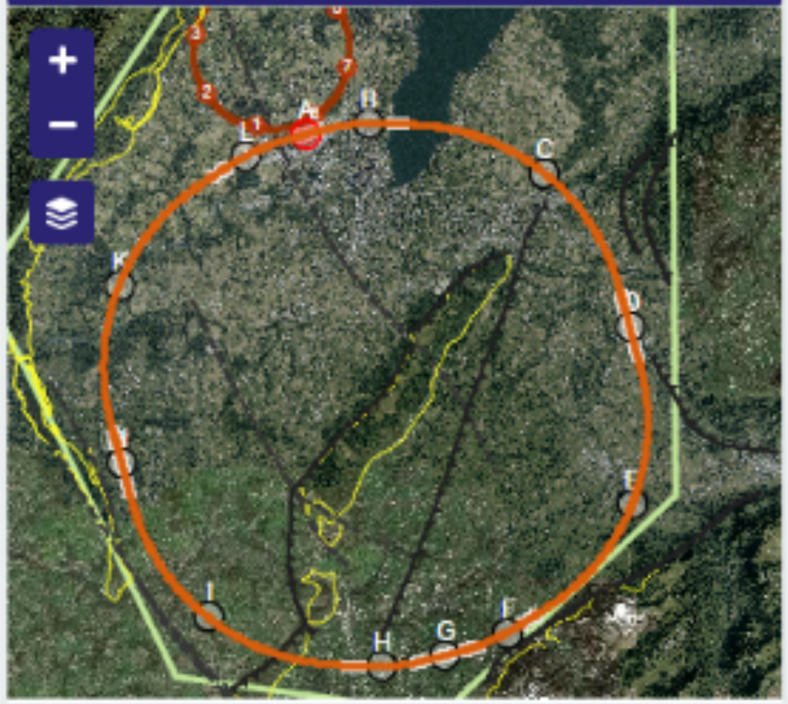
CALCULATE

Alignment centre

X: 2499812 Y: 1106889

LHC Intersection	CP 1	CP 2
Angle		
Depth	589m	589m

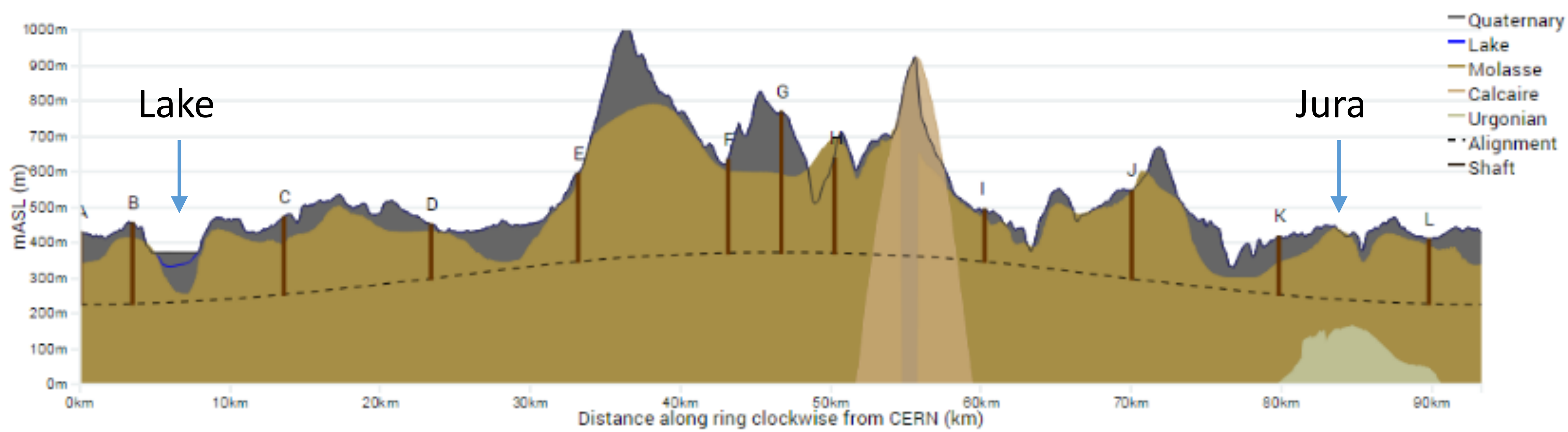
Alignment Location



Geology Intersected by Shafts | Shaft Depths

	Shaft Depth (m)				Geology (m)			
Point	Actual	Min	Mean	Max	Quaternary	Molasse	Urgonian	Calcaire
A	203	200	204	212	93	111	0	0
B	227	219	226	231	41	185	0	0
C	218	208	217	225	75	143	0	0
D	153	150	154	158	19	134	0	0
E	247	233	249	261	24	223	0	0
F	262	251	269	304	32	230	0	0
G	396	392	393	396	177	220	0	0
H	266	231	274	322	0	325	0	0
I	146	141	144	149	26	120	0	0
J	248	247	251	258	6	242	0	0
K	163	153	159	164	76	87	0	0
L	182	182	184	187	17	165	0	0
Total	2711	2607	2724	2867	585	2185	0	0

Alignment Profile



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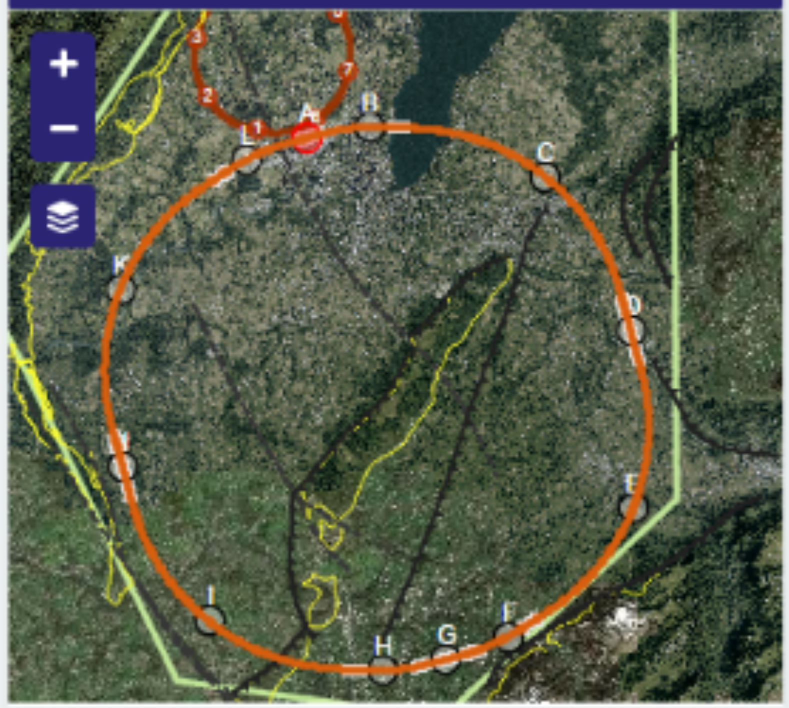

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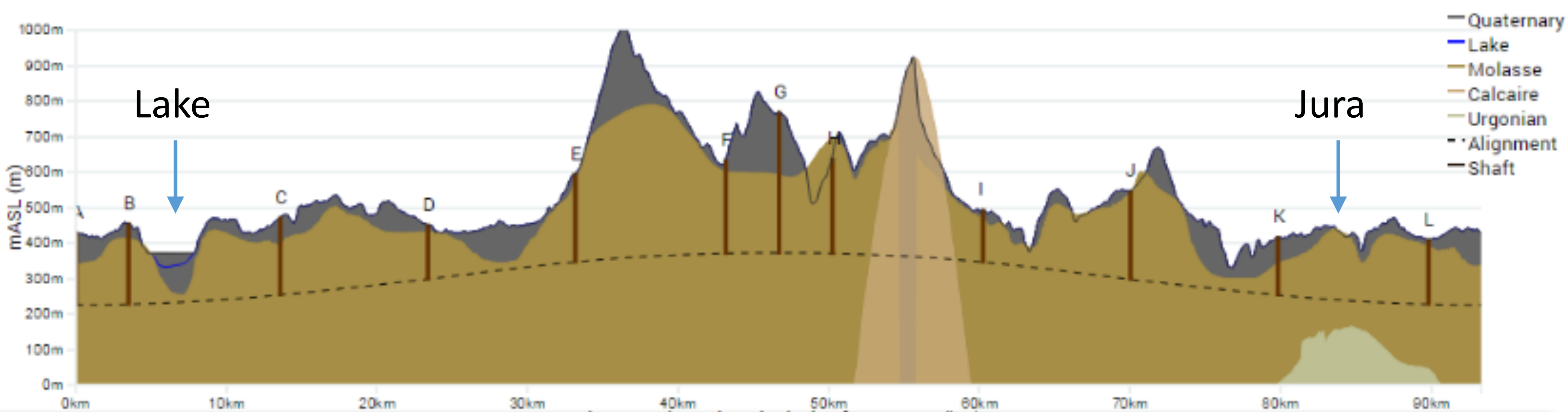
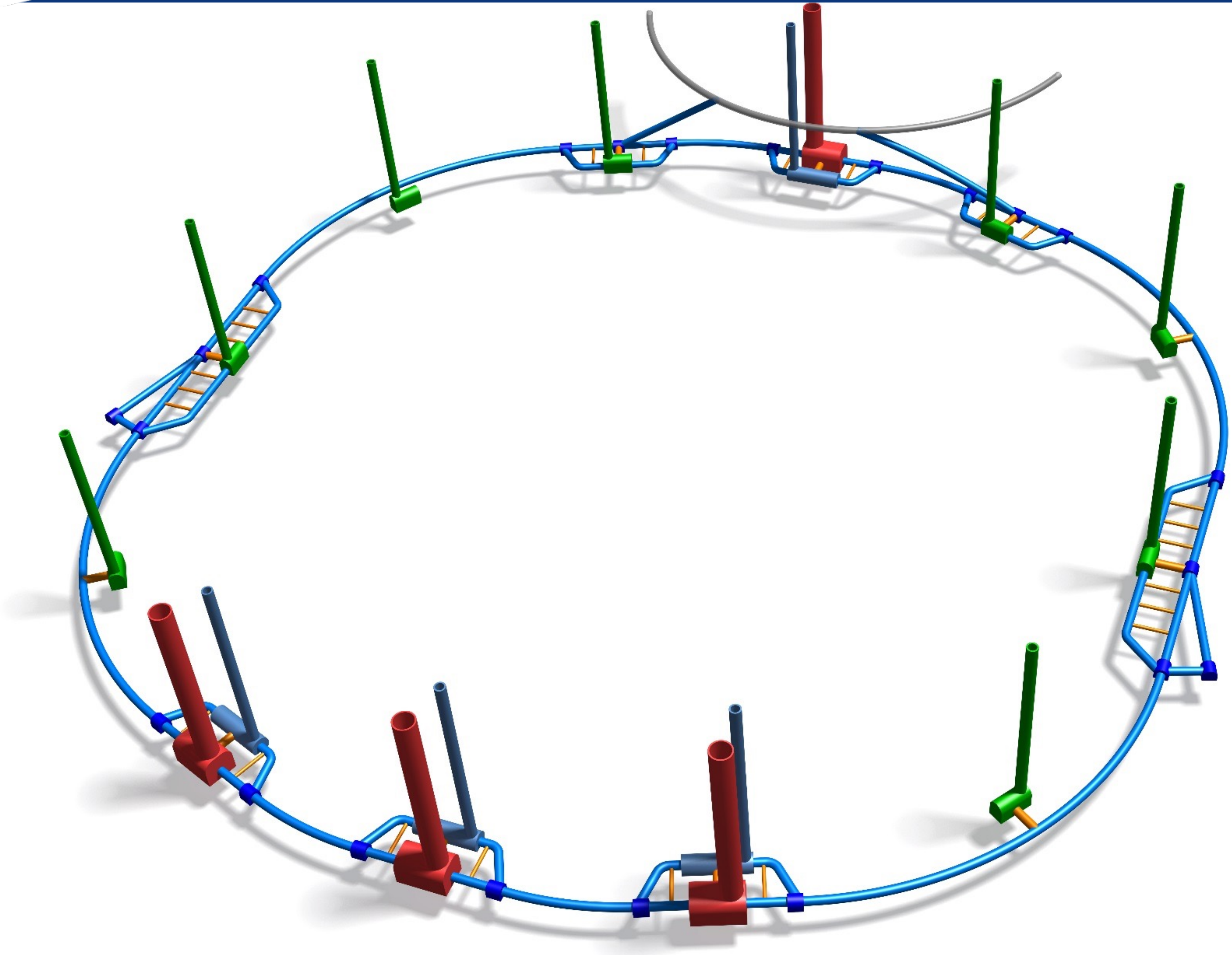


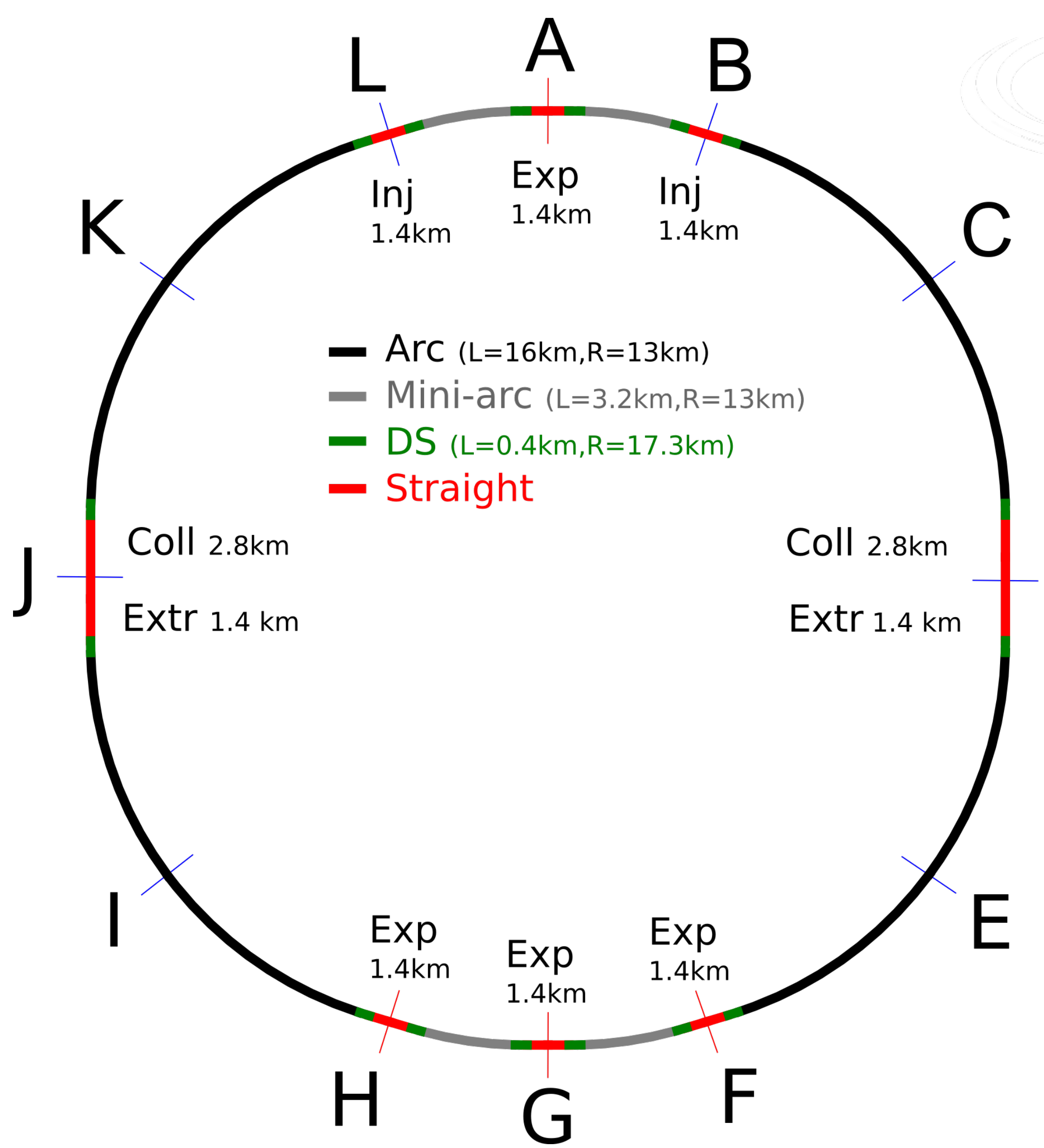
- 90 – 100 km fits geological situation well
- LHC suitable as potential injector

FCC 3D tunnel model

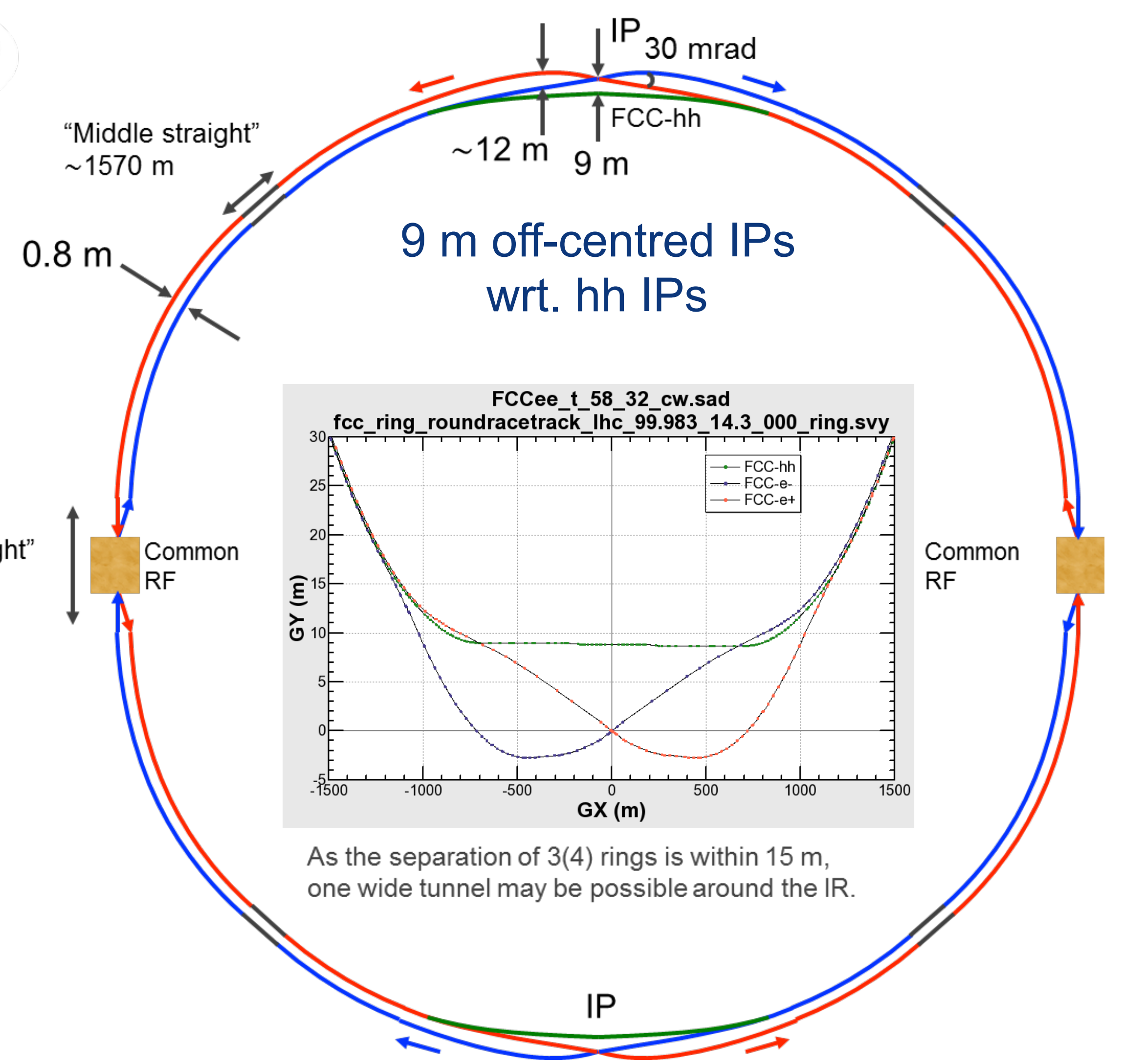


FCC consistent machine layouts

FCC-hh



FCC-ee 1, FCC-ee 2, FCC-ee booster (FCC-hh footprint)



Closed optics solutions for full ring for both machines available

hadron collider parameters

Parameter	FCC-hh		SPPC	LHC	HL LHC
collision energy cms [TeV]	100		71.2	14	
dipole field [T]	16		20	8.3	
# IP	2 main & 2		2	2 main & 2	
bunch intensity [10^{11}]	1	1 (0.2)	2	1.1	2.2
bunch spacing [ns]	25	25 (5)	25	25	25
luminosity/Ip [10^{34} $cm^{-2}s^{-1}$]	5	~25	12	1	5
events/bunch crossing	170	~850 (170)	400	27	135
stored energy/beam [GJ]	8.4		6.6	0.36	0.7
synchrotron radiation [W/m/ aperture]	30		58	0.2	0.35

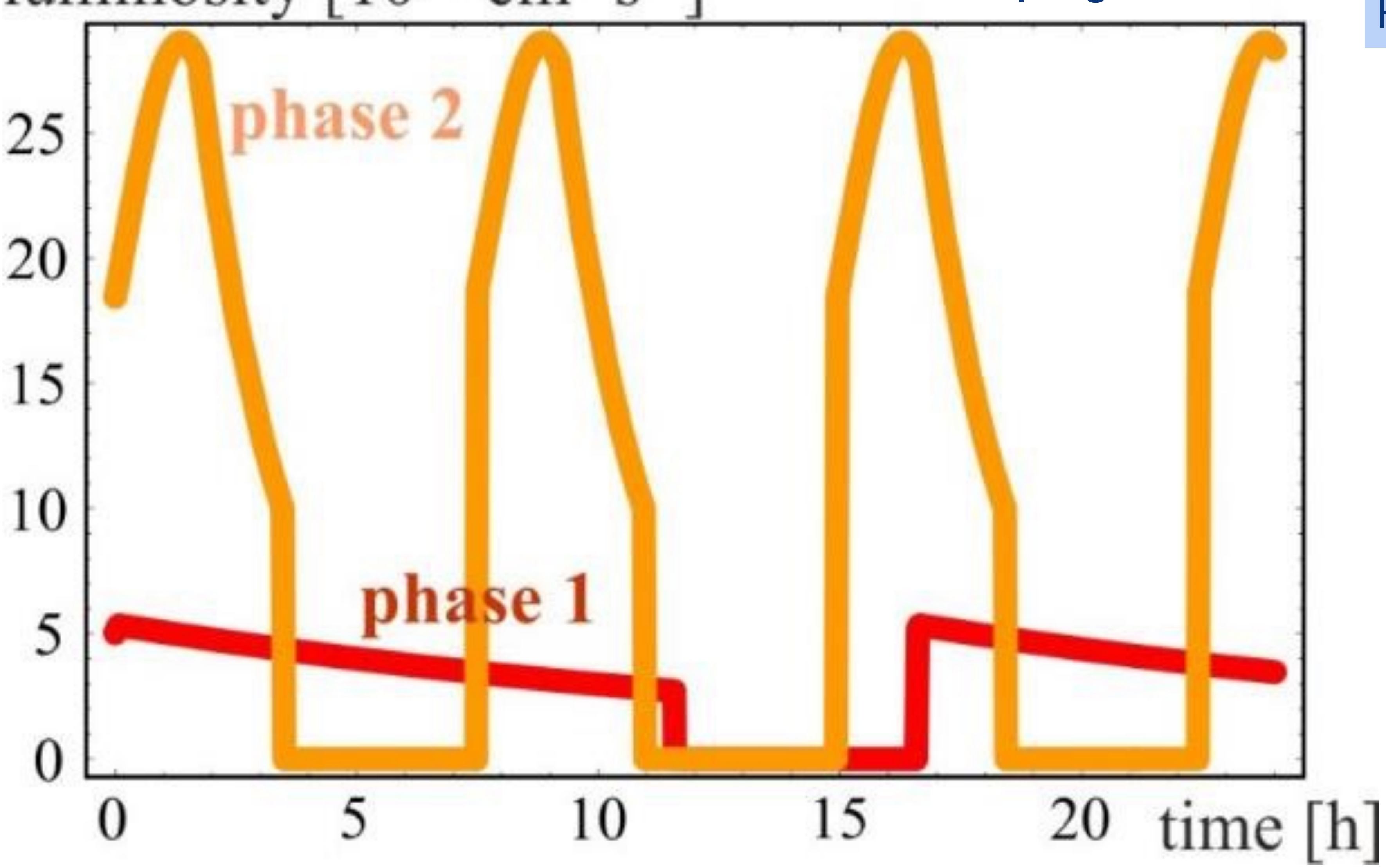
Squeeze β*, reduce emittance

FCC-hh luminosity phases

phase 1: β^*=1.1 m, ΔQ_{tot}=0.01, t_{ta}=5 h, 250 fb^{-1} / year

phase 2: β^*=0.3 m, ΔQ_{tot}=0.03, t_{ta}=4 h, 1 ab^{-1} / year

radiation damping: τ~1 h



PRST-AB 18, 101002 (2015)

for both phases:

beam current 0.5 A

total synchrotron radiation power ~5 MW.

consistent with physics goal: 20 ab^{-1} in total

Luminosity goals for a 100-TeV pp collider

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April 24, 2015

Abstract

We consider diverse examples of science goals that provide a framework to assess luminosity goals for a future 100-TeV proton-proton collider.

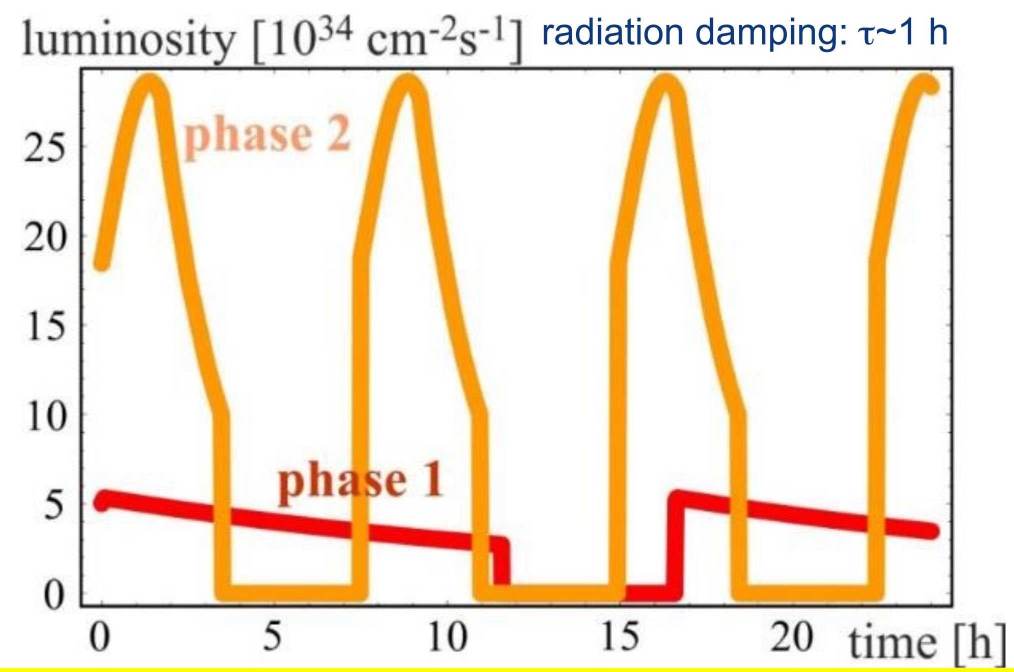
→ physics goal ~ 20 ab^{-1}

OK!

FCC-hh: Key milestones physics studies

2015:

- ✓ Assessment of the requirements for integrated luminosity
- ✓ First definition of benchmarks for detector performance, exploration of detector concepts, development of detector simulation software
- ✓ Workshops (in coordination with FCC-hh) :
  - ✓ Future of HEP (Hong Kong, January)
  - ✓ Physics frontier with Circular Colliders (Aspen, January)
  - ✓ BSM & Higgs @ 100 TeV (CERN, March)
  - ✓ EW Baryogenesis probes at FCC (Amherst, Sept)
  - ✓ Ions at the FCC (CERN, September)
  - ✓ QCD & SM @ 100 TeV (CERN, October)
  - ✓ Dark Matter @ 100 TeV (FNAL, Dec)



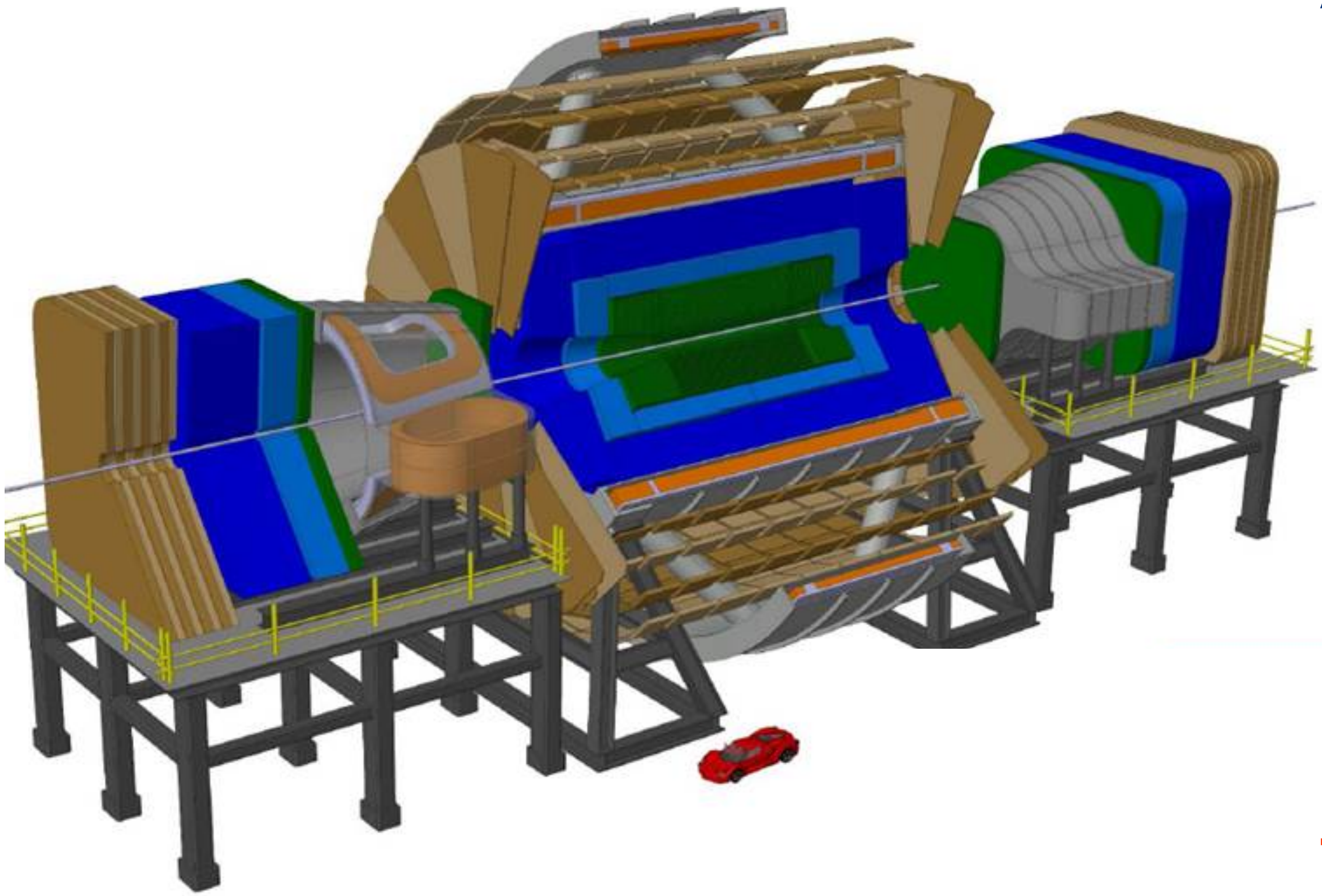
Machine design consistent with preliminary physics goal: ~20 ab^{-1} total

2016:

- ➢ Report on "**Physics at 100 TeV**". Define physics opportunities in the areas of SM, Higgs, BSM, Heavy Ions, injectors => available by Rome FCC week
- ➢ Start integration of physics studies and detector simulation
- ➢ Continue Workshop and WG activities

Detector Concepts for 100TeV pp

Detector concepts using a large B=6T, R=6m solenoid magnet.



A shielding solenoid instead of iron yoke and forward dipole magnets for high η-acceptance.

Highly forward boosted physics objects, radiation levels of >20 x LHC Phase II as well as a pileup of ~1000 pose interesting challenges.

R&D for FCC detectors is a natural continuation of the R&D for LHC Phase II upgrade

key technology R&D - HFM

Conductor R&D

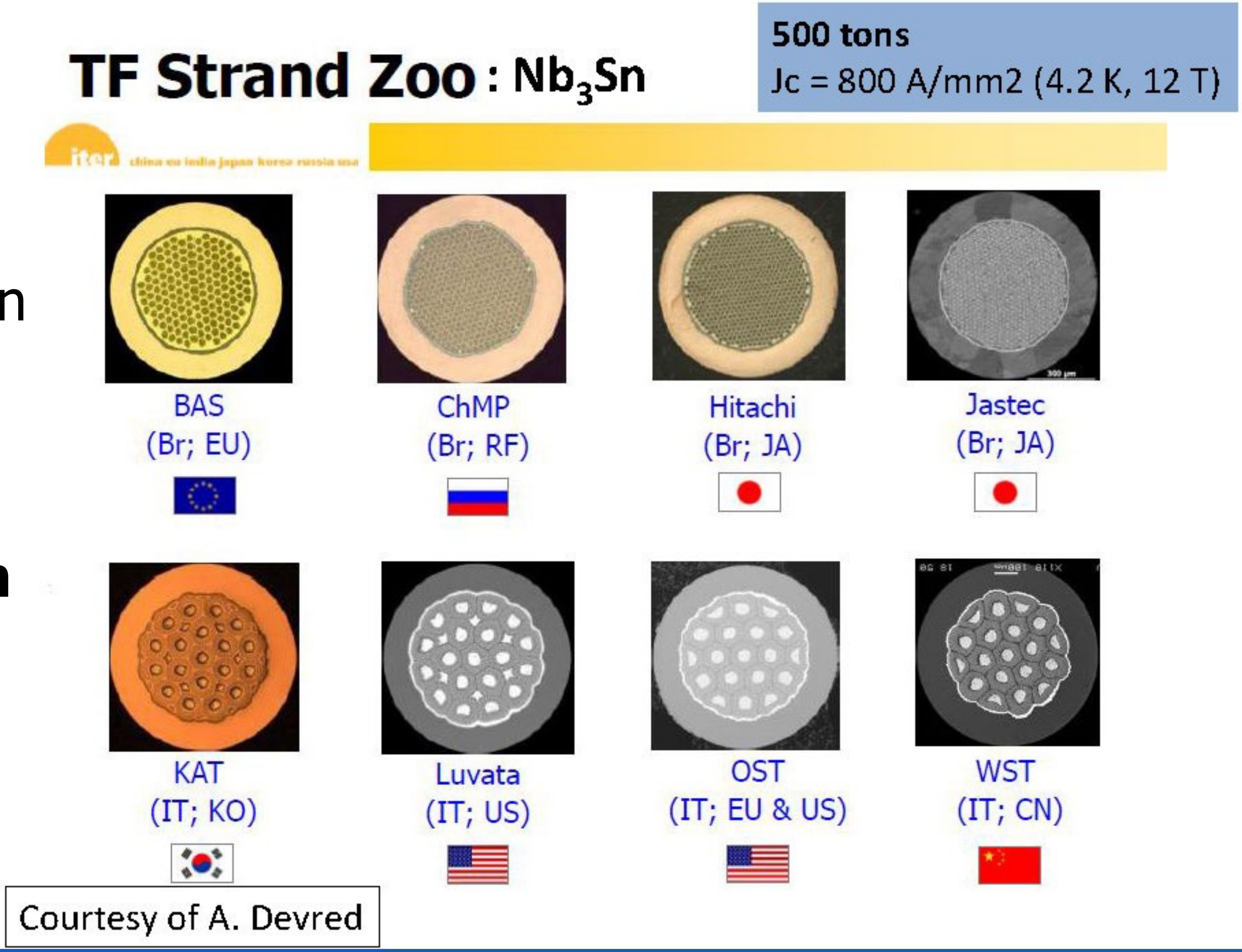
- push critical current density
- material processing
- cost reduction

Magnet Design

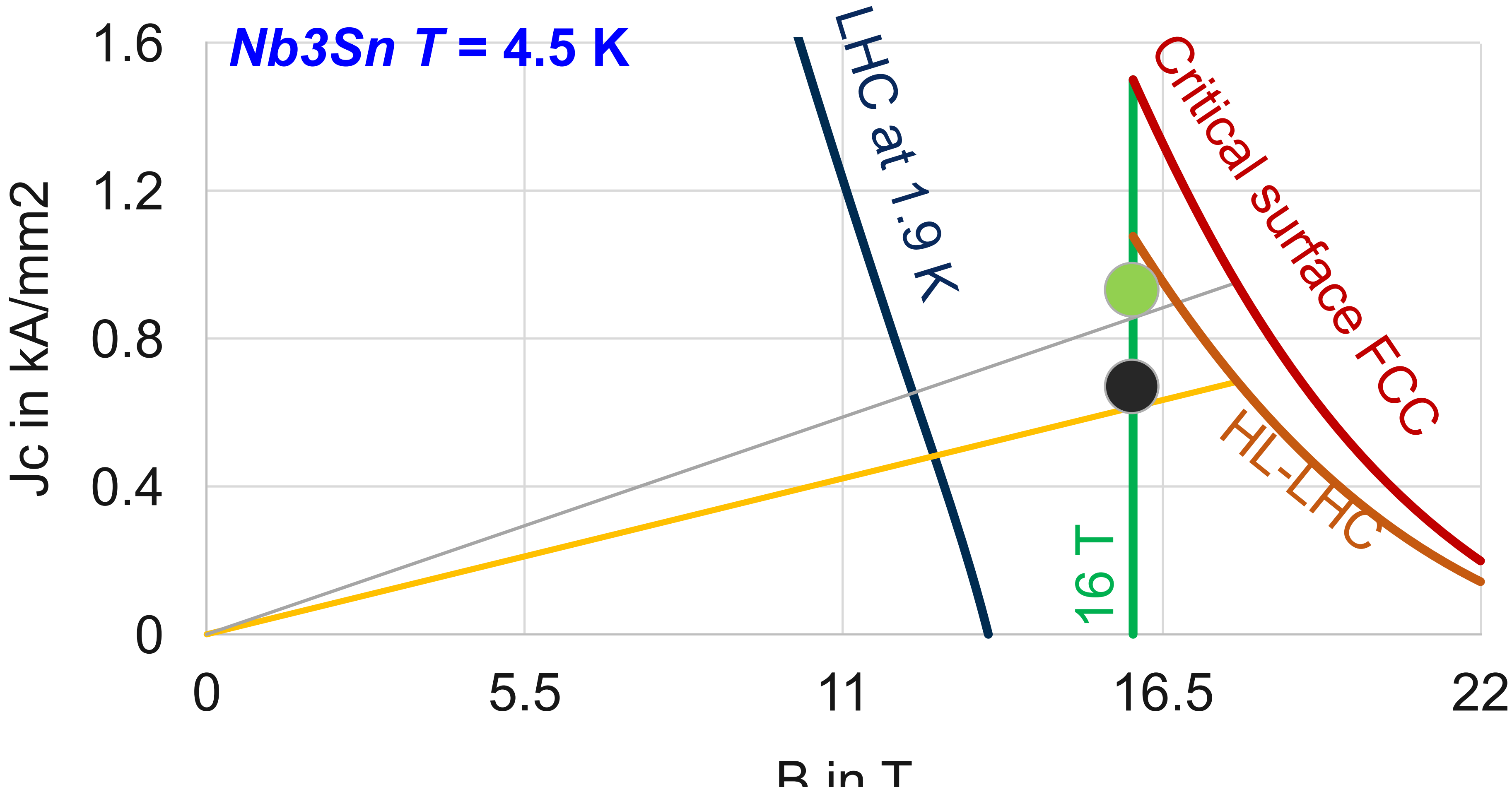
- develop short models
- field quality and aperture
- optimum coil geometry
- manufacturing cost optimisation

Nb_3Sn production for ITER

J_c lower than for FCC, but **large scale production**



superconductor performance

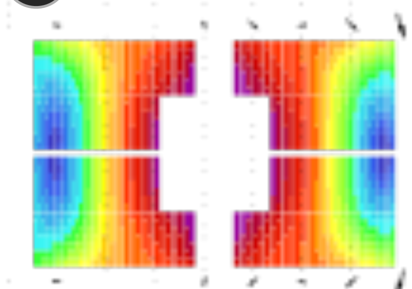


A. Ballarino,
L. Bottura,
D. Schoerling

Nb-Ti
Not possible

Different technology

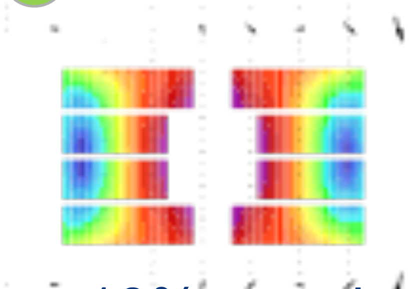
5400 mm^2



~10% margin
HL-LHC

~1.7 times less SC

3150 mm^2

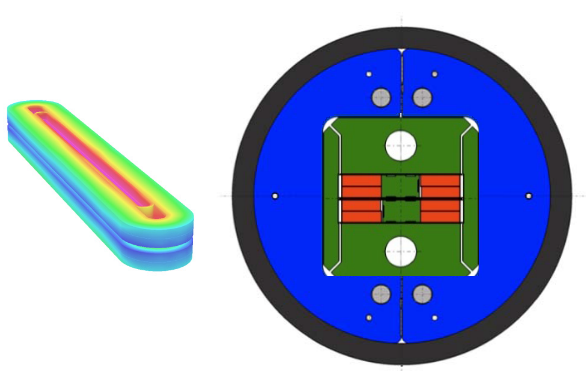


~10% margin
FCC ultimate

CERN – FCC 16T program launched

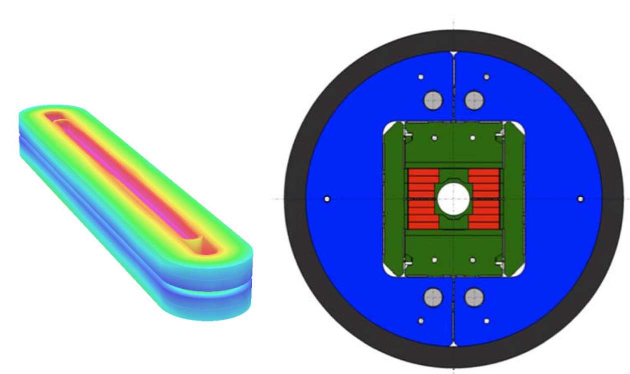
Main Milestones of the FCC Magnets Technologies

Milestone	Description	15	2016	2017	2018	2019	2020	21
M0	High J_c wire development with industry							
M1	Supporting wound conductor test program							
M2	Design & manufacture 16T ERMC with existing wire							
M3	Design & manufacture 16 T RMM with existing wire							
M4	Design & manufacture 16T demonstrator magnet							
M5	Procurement 70 km of enhanced high J_c wire							
M6	EuroCirCol design 16T accelerator quality model							
	Manufacture and test of the 16 T EuroCirCol model							



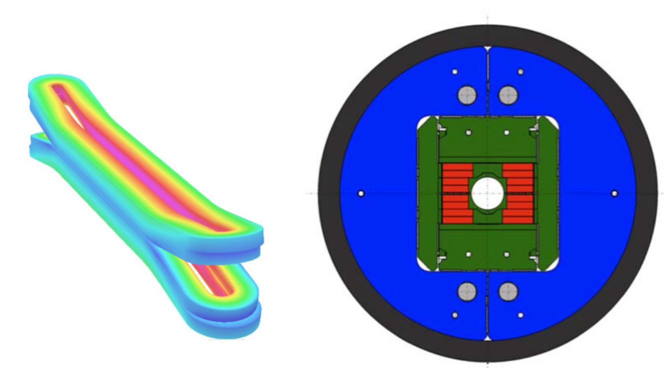
ERMC (16 T mid-plane field)
mid 2017

Enhanced Racetrack Model Coil;
Cables ordered



RMM (16 T in 50 mm cavity)
end 2017

Reduced Model Magnet



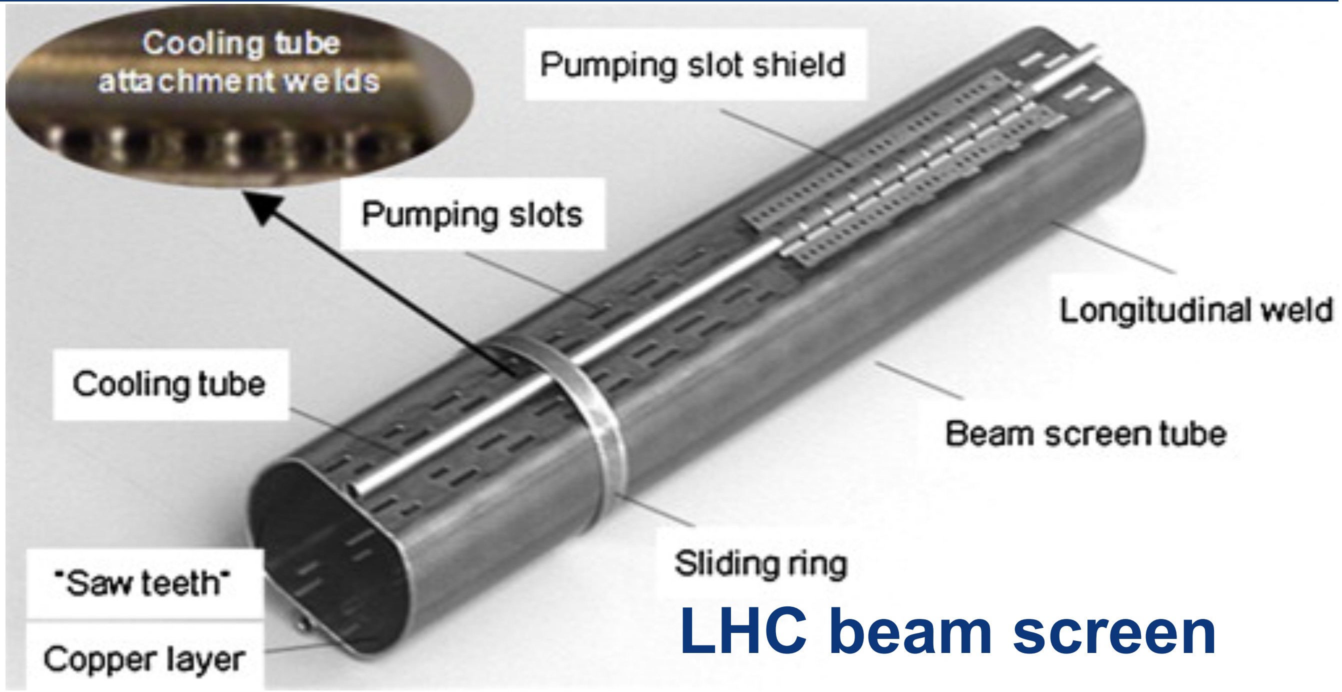
Demonstrator (16 T, 50 mm gap)
end 2018

p synchr. radiation / beam screen

high synchrotron radiation load (SR) of protons @ 50 TeV:

~30 W/m/beam (@16 T)

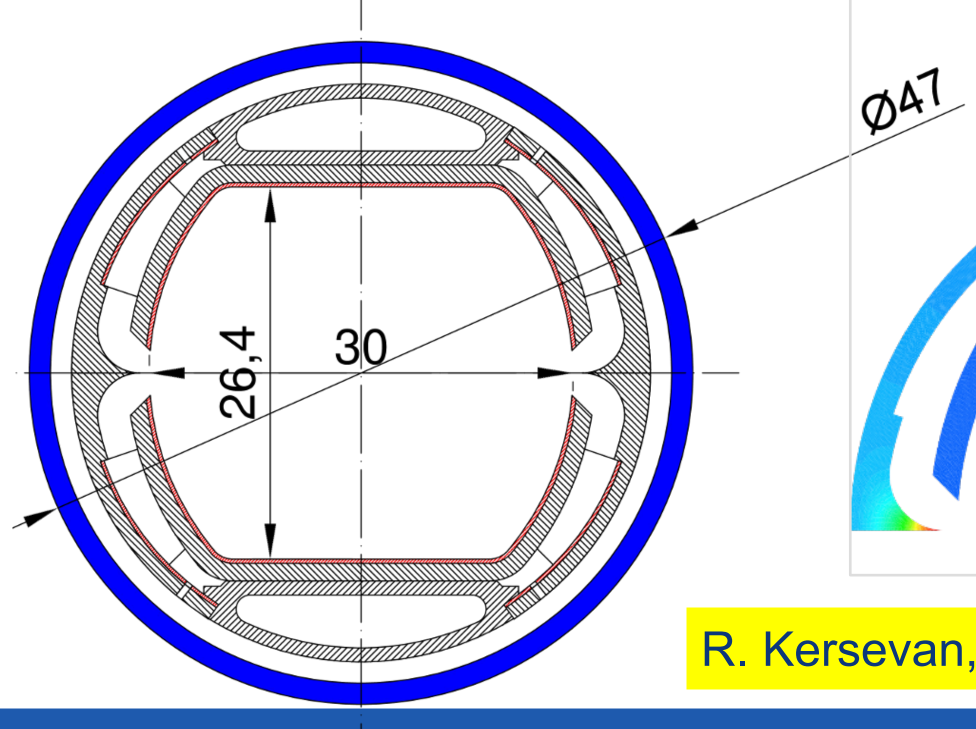
- **5 MW total in arcs** (LHC <0.2 W/m)

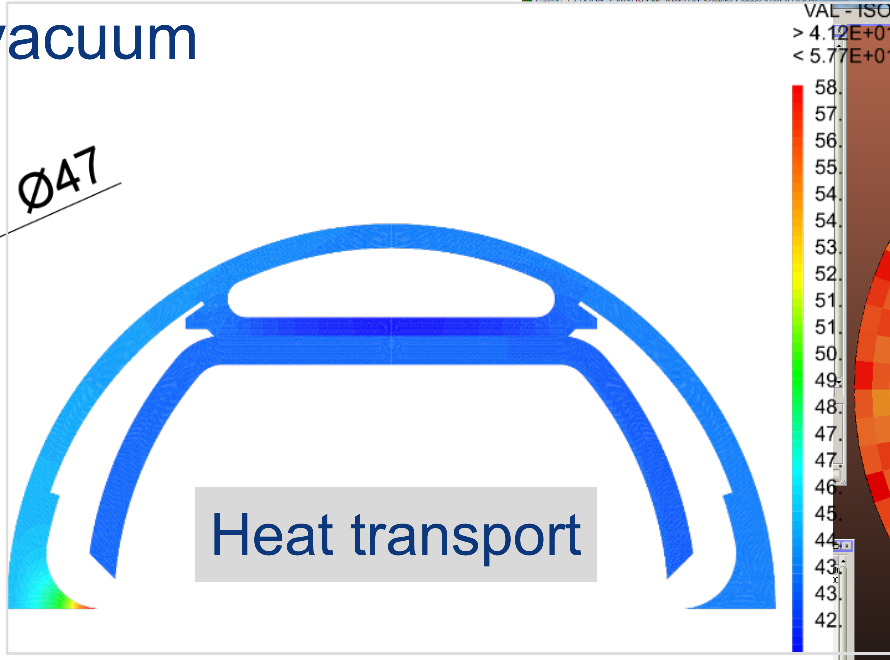


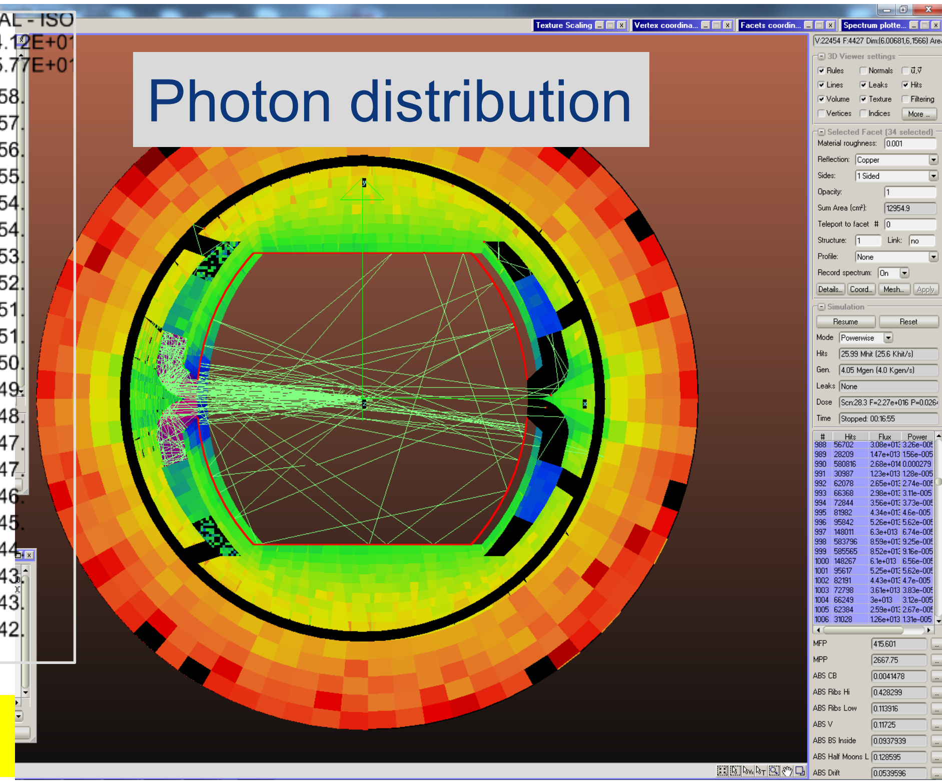
LHC beam screen

new type of ante-chamber

- absorption of synchrotron radiation
- avoids photo-electrons, helps vacuum







R. Kersevan, C. Garion, L. Tavian, et al.

FCC SC RF system

RF frequencies for FCC-hh and FCC-ee: 400 MHz & 2nd harm. 800 MHz

as for LHC and HL-LHC → important synergies

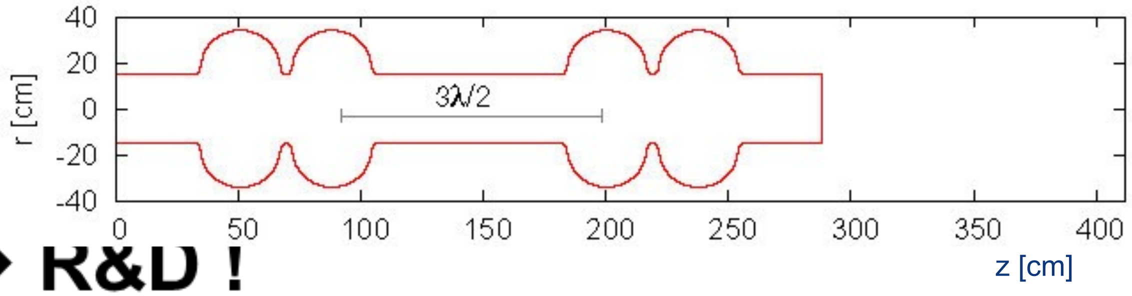
LHC cavities (400 MHz)

RF system requirements for FCC-ee

100 MW synchrotron radiation (power to beam) and characterized by two operation regimes:

- *high gradients* ***for H and $t\bar{t}$ – up to ≈11 GV***
- *high beam loading* ***with currents of ≈1.5 A at the Z pole***

possible FCC-ee cavity layout



Conversion efficiency (wall plug to RF power) … consumption - aiming for 75% or higher → R&D !

- ***important item for FCC-ee power budget, ≈60% achieved for LEP2***
- ***recent breakthrough in klystron efficiency (I. Syratchev)***

New fabrication modes (3-D printing), new materials, better cryogenics

FCC-hh: unprecedented beam power

8 GJ stored energy / beam

- Airbus A380 at 700 km/h
- 24 times larger than in LHC at 14TeV
- can melt 12t of copper
- or drill a 300m long hole

⇒ **machine protection**

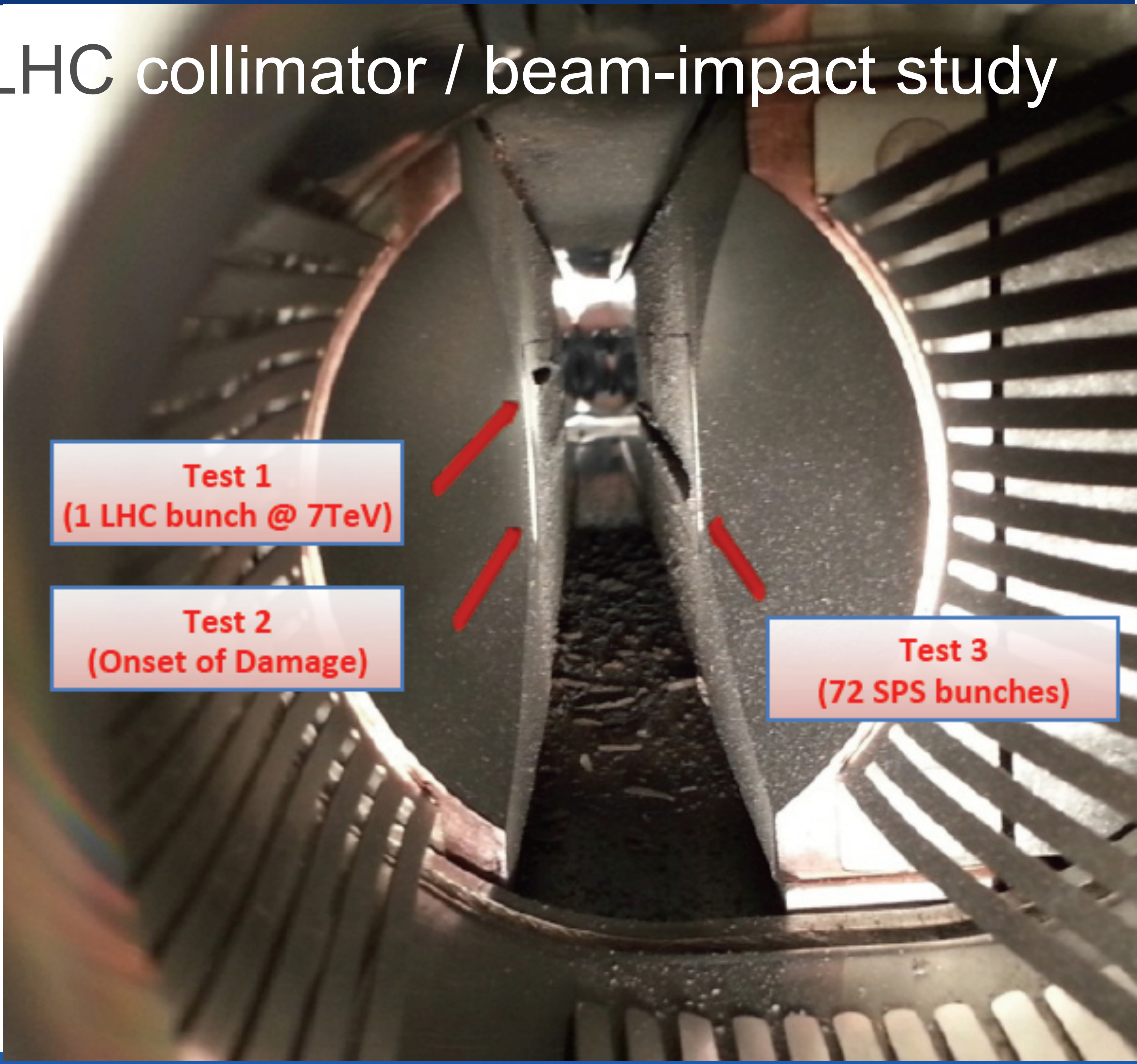
⇒ **beam abort system**

any beam loss important

- e.g. beam-gas scattering, non-linear dynamics
- can quench arc magnets
- background for the experiments
- activation of the machine

⇒ **collimation system**

⇒ **transfer and injection**



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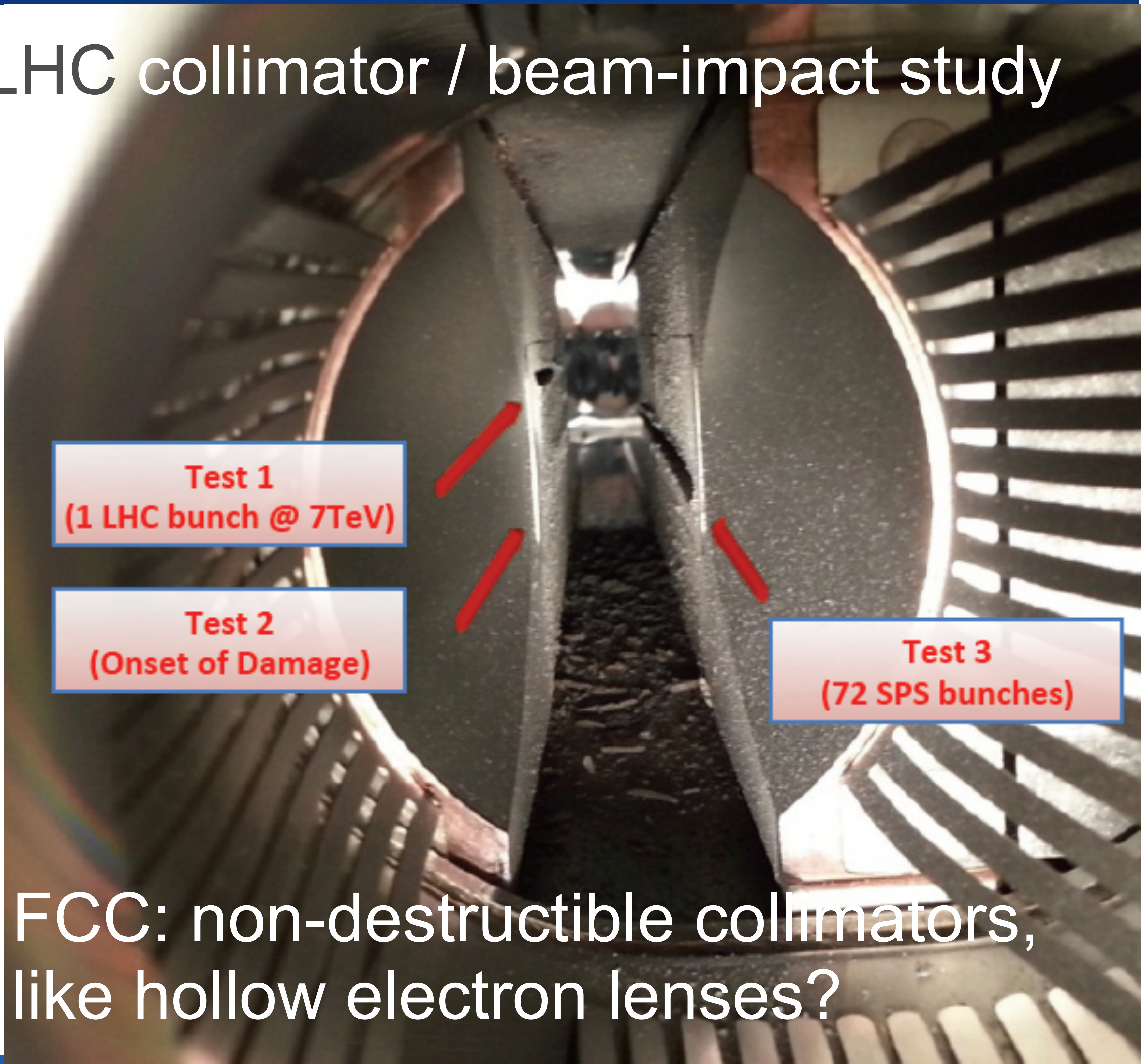
LHC collimator / beam-impact study



FCC: non-destructible collimators, like hollow electron lenses?

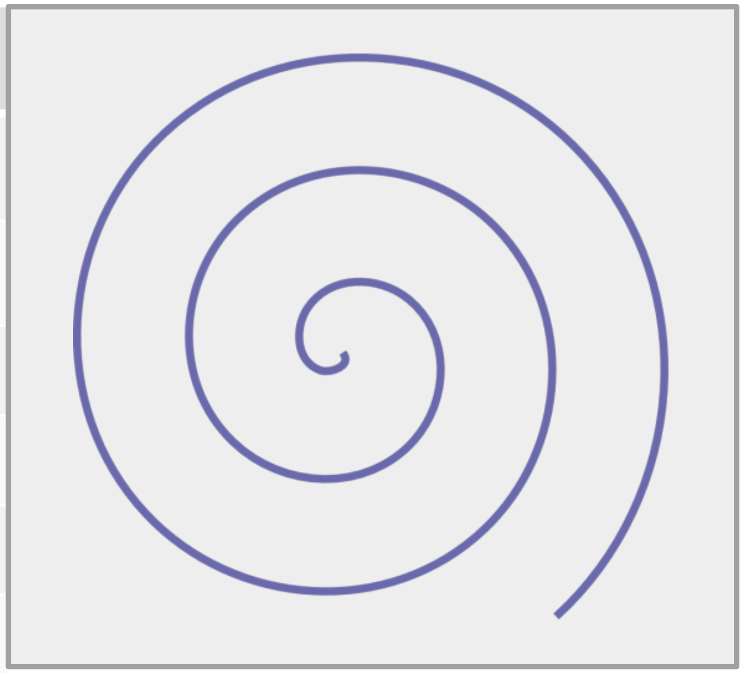
… to FCC beam dump

1.5 km dump line (β~4 km) → 400 μm rms beam size at dump;

for graphite (1.2-1.77 g/cm^3) limit peak temperature to ~1500°C requires minimum of ~1.8 mm separation between successive bunches → minimum linear sweep length ~ 20 m!

even if we increase β to 100 km (2.0 mm rms beam size) we still need ~1.5 mm separation between bunches

	unit	25 ns	5 ns
bunch population		1e11	0.2e11
# bunches		10600	53000
transv. norm. emittance	um	2.2	0.44
rms spot size at dump	mm	0.4 - 1.6	0.2 – 0.7
total beam energy	GJ	8.5	8.5
average power (5 h fills)	kW	500	500



Wolfgang Bartmann

lepton collider physics areas

- highest possible luminosities at all working points
- *beam energy range from 35 GeV to ≈200 GeV*
- **physics programs / energies:**

Z (45.5 GeV) Z pole, 'TeraZ' and high precision M_Z & Γ_Z

W (80 GeV) W pair production threshold, high precision M_W

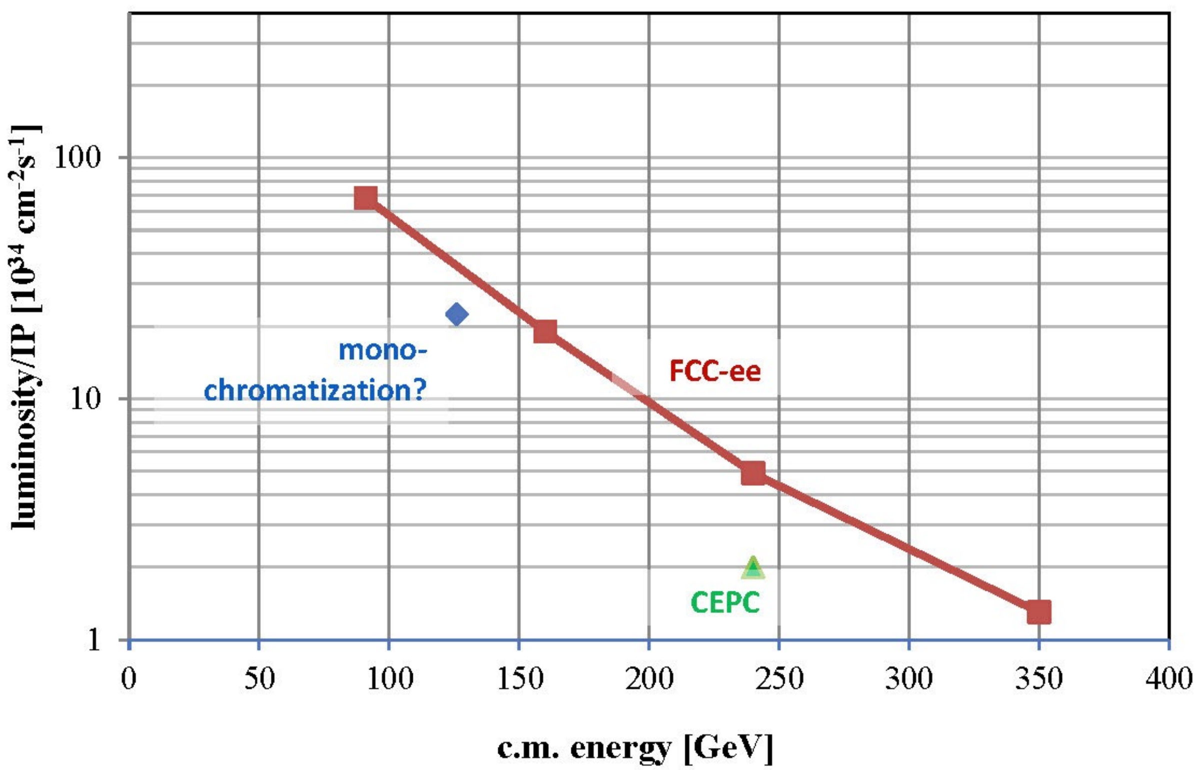
H (120 GeV) ZH production (maximum rate of H's)

t (175 GeV): $t\bar{t}$ threshold, H studies

- some polarization up to ≥80 GeV for beam energy calibration
- machine optimized for operation at 120 GeV?! (2nd priority "*Tera-Z*")

A. Blondel, P. Janot, et al.

FCC-ee : New Physics Discovery via High Precision and Rare Processes



Unequalled luminosity Z, W, H, top factory:
$10^{12\text{-}13}$ **Z**, 10^8 **W**W, 2.10^6 Z**H**, 10^6 **t**$\bar{t}$ events

- ΔE_{CM} < 100 keV
- Comprehensive exploration of EW loops and Higgs sensitivity to new physics up to Multi-TeV scales
- High statistics and clean environment give access to rare processes and decays
- Synergies for physics and detectors with Linear Collider studies

FCC-ee baseline parameters

parameter	FCC-ee			CEPC	LEP2
energy/beam [GeV]	**45**	**120**	**175**	**120**	105
bunches/beam	90000	770	78	50	4
beam current [mA]	1450	30	6.6	16.6	3
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**70**	**5**	**1.3**	**2.0**	0.0012
energy loss/turn [GeV]	0.03	1.67	7.55	3.1	3.34
synchrotron power [MW]	100			103	22
RF voltage [GV]	0.08	3.0	10	6.9	3.5

FCC-ee: 2 separate rings & 2 IPs

CEPC: single beam pipe version

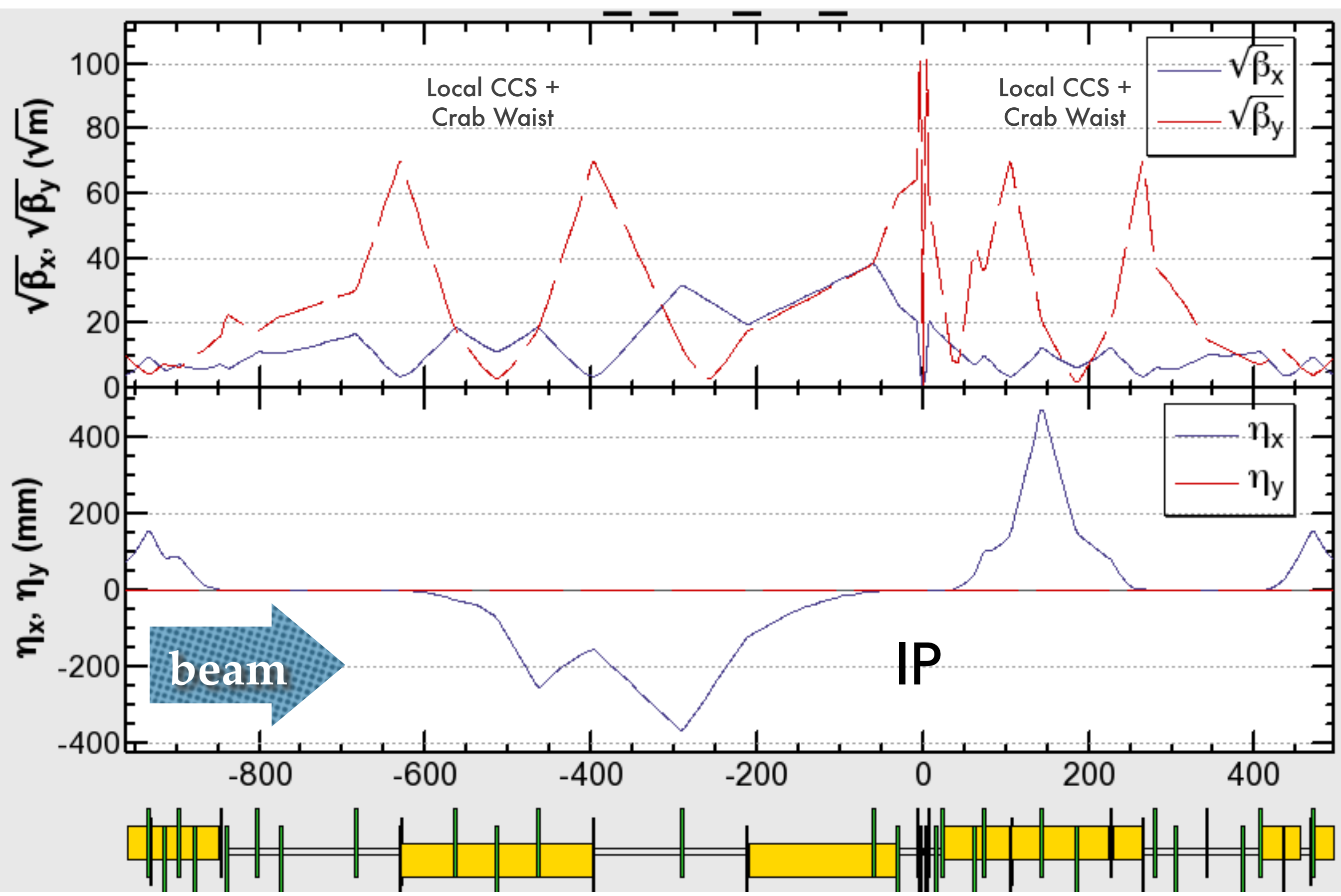
FCC-ee IR optics – two variants

With required momentum acceptance and dynamic aperture

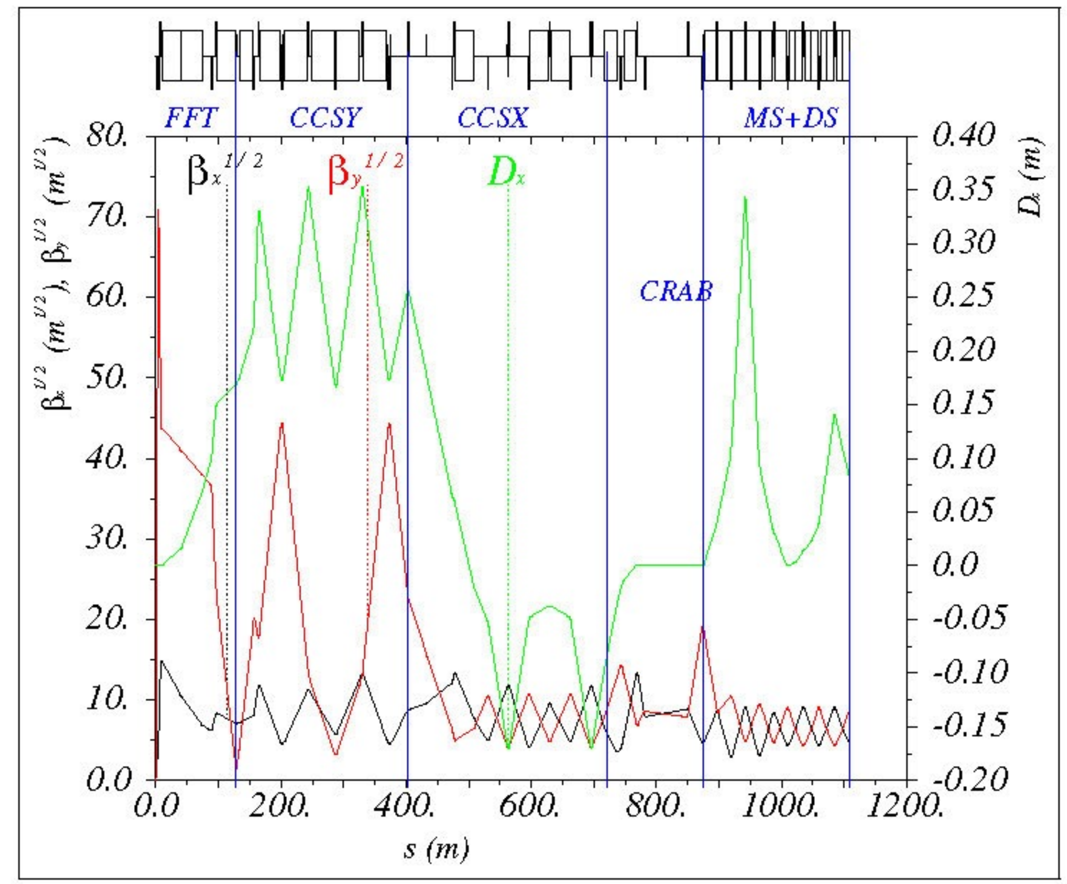
Both feature crab waist optics & local chromatic correction

Interaction Regions: KO 58_32

AB v. 8-1 ($\beta_x^* = 1$ m, $\beta_y^* = 2$ mm)



Synchroton radiation $E_{\gamma,c} \leq 100$ keV



Synchrotron radiation $E_{\gamma,c} \leq 400$ keV

2 IPs		Z 45,5 GeV	W 80 GeV	ZH 120 GeV	tt 175 GeV
Luminosity	10^{34} cm^{-2}s^{-1}	~140	~42	~10	~4

Dynamic Apertures (KO)

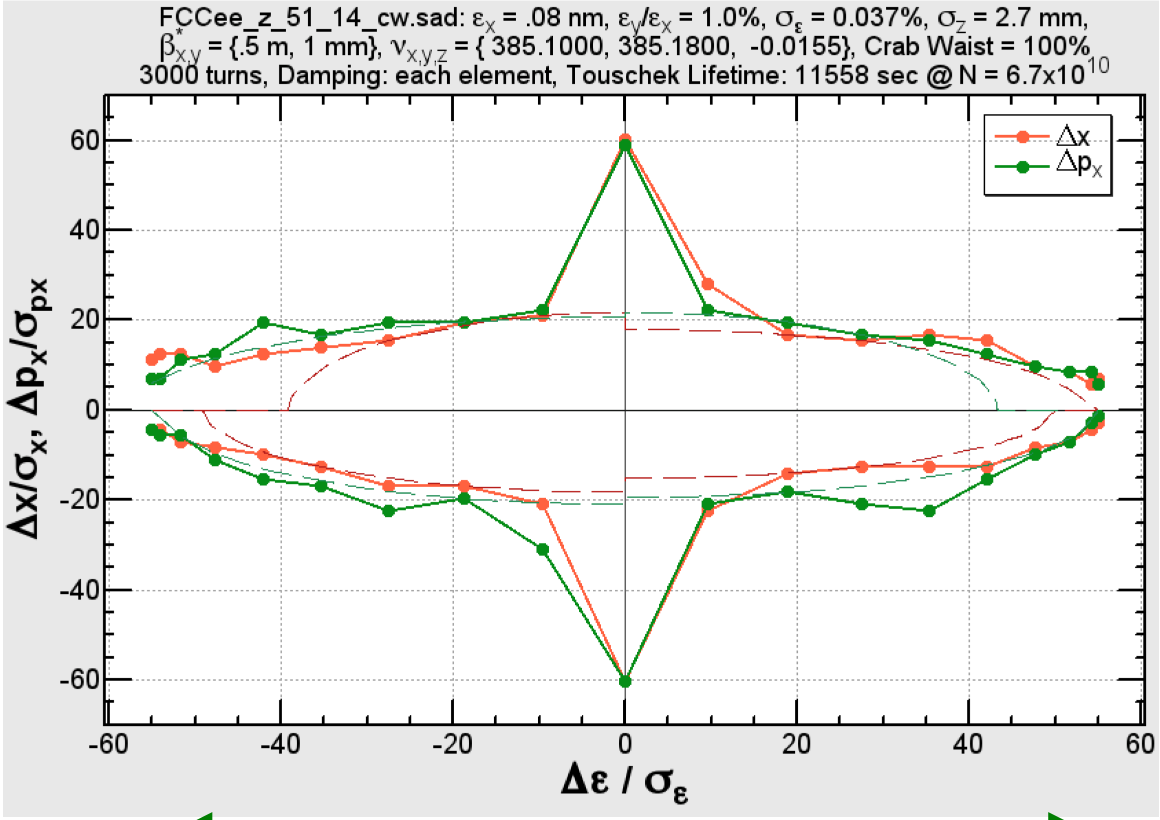
$$\beta^*_{x,y} = (0.5\ \mathrm{m}, 1\ \mathrm{mm})$$

$E_{\mathrm{beam}} = 45.6$ GeV

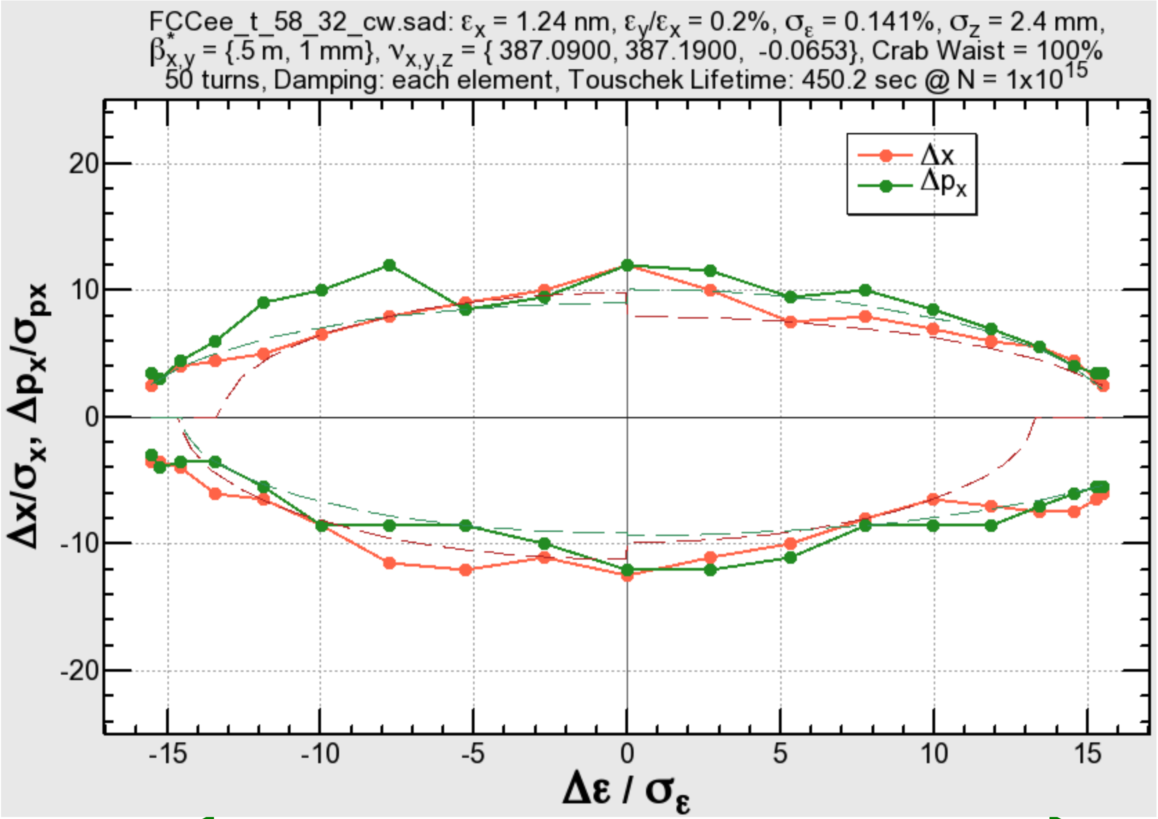
3,000 turns

$E_{\mathrm{beam}} = 175$ GeV

50 turns



$\pm 2\%$



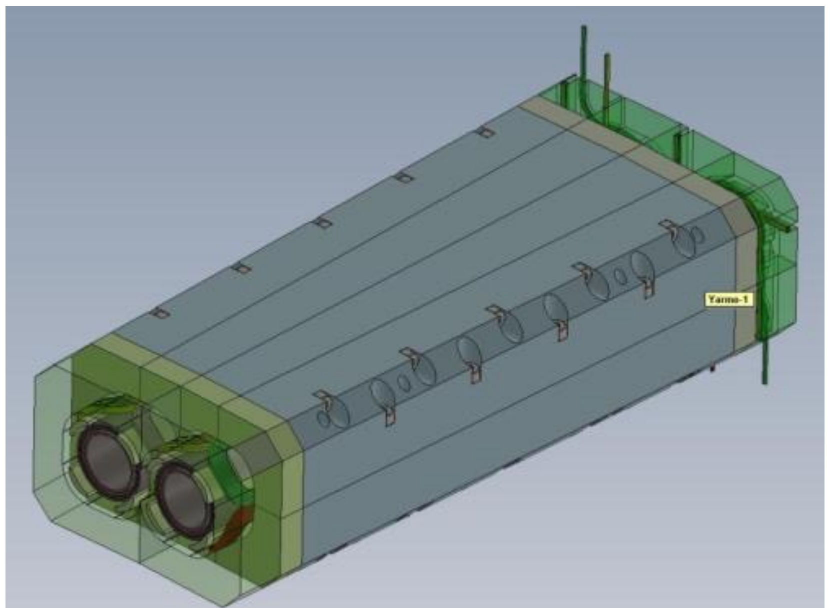
$\pm 2\%$

- Sextupoles must be optimized at each beam energy.
- 3,000 turns are enough to determine the aperture at 45.6 GeV (long. damping = 1,500 turns).
- ±2% acceptance is not necessary for beamstrahlung, but may be useful for synchrotron injection.
- The on-momentum peak of the transverse aperture is recovered due to weaker radiation at 45.6 GeV.

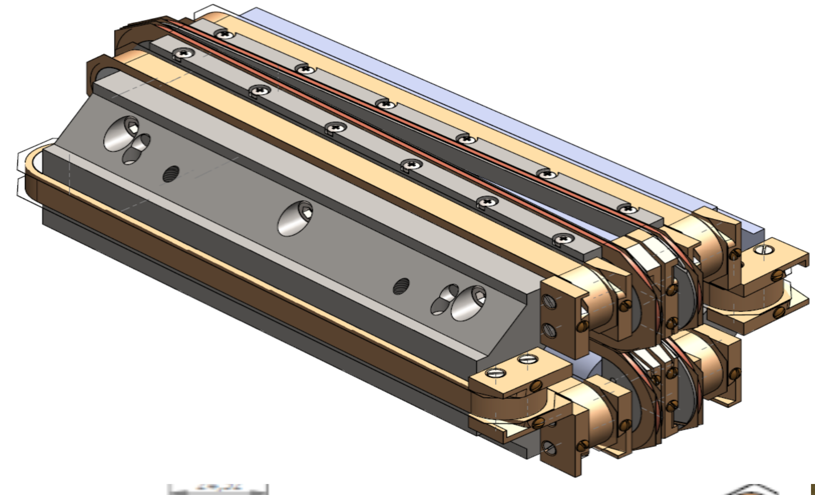
SC final focus quadrupole at BINP

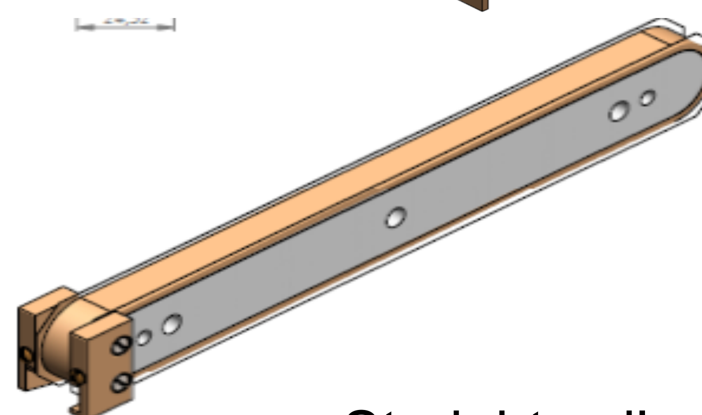
Main contributors are Ivan Okunev and Pavel Vobly

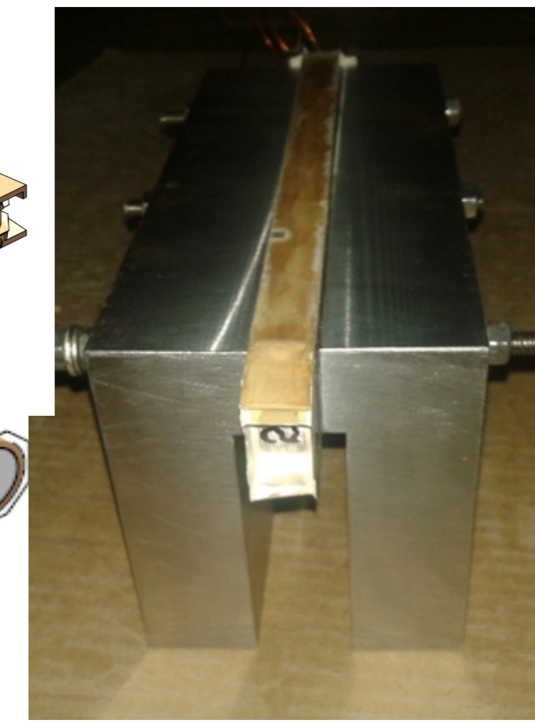
Two versions of the FF twin-aperture iron yoke quad prototype with 2 cm aperture and 100 T/m gradient are in production.



Saddle-shaped coils, complicated in production, the first coil failed. New winding device is in development.







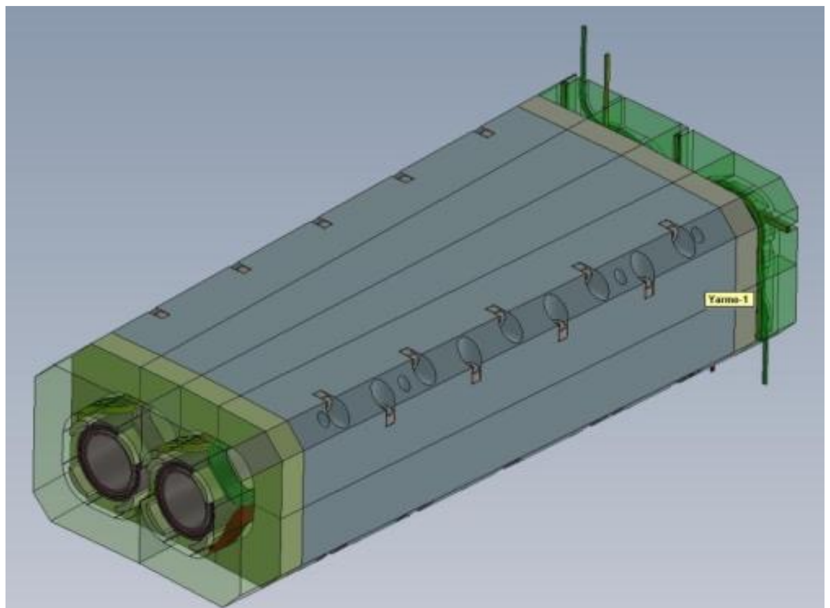
Straight coil, successfully wound and tested (650 A instead of the nominal 400 A)

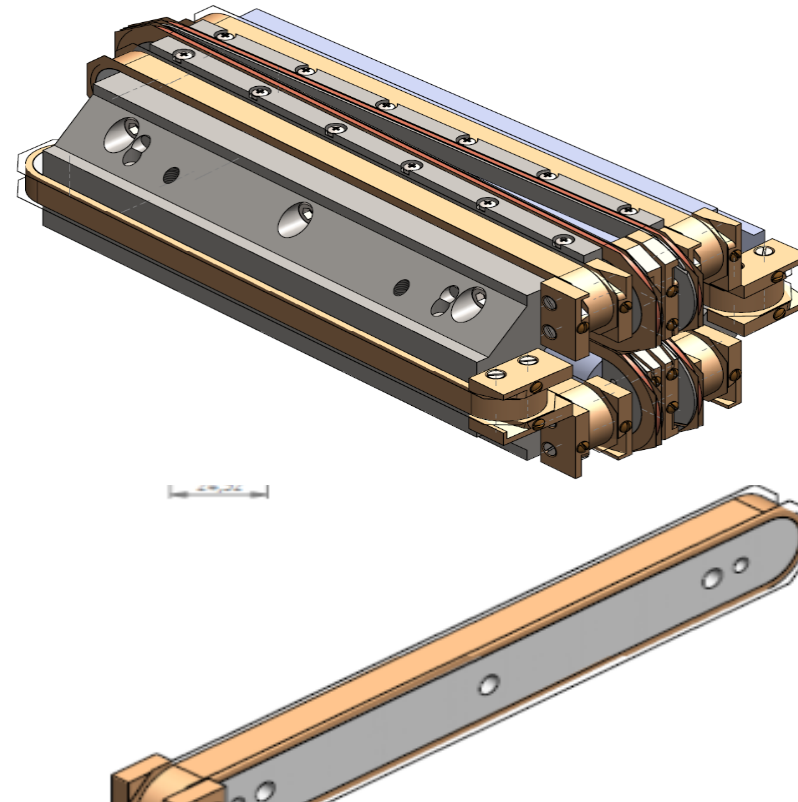
E. Levitchev

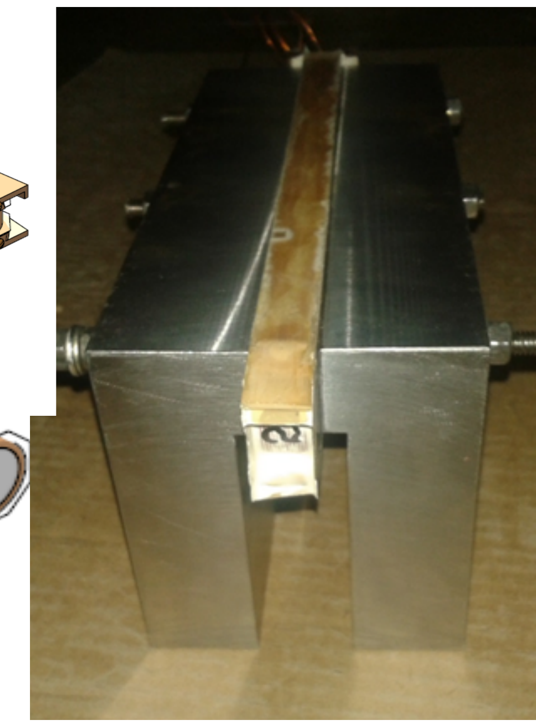
SC final focus quadrupole at BINP

Main contributors are Ivan Okunev and Pavel Vobly

Two versions of the FF twin-aperture iron yoke quad prototype with 2 cm aperture and 100 T/m gradient are in production.







Saddle-shaped coils
con
pro
faile
dev

Also prototyping of CCT quadrupoles has started at CERN (M. Koratzinos, G. Kirby).

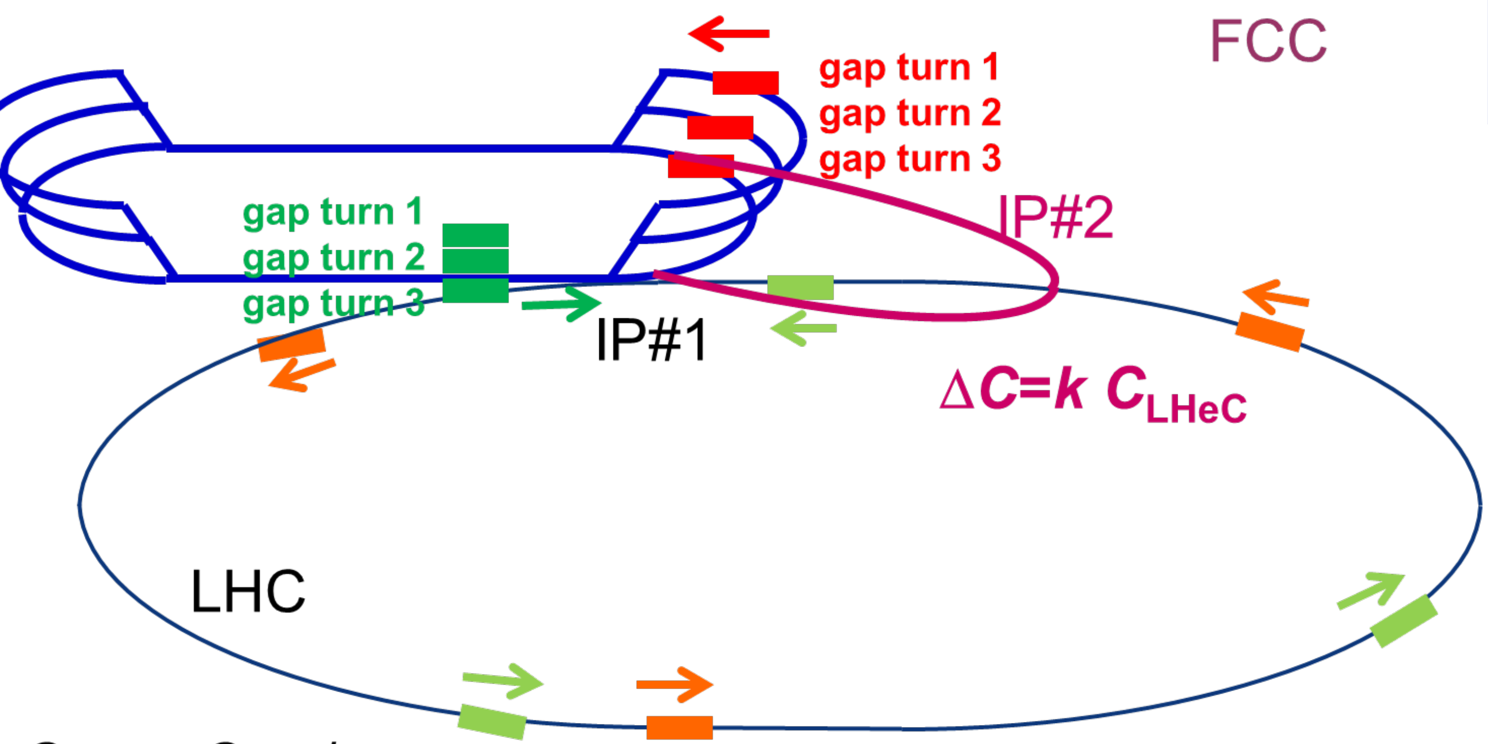
successfully wound
50 A instead of the
A)

E. Levitchev

FCC-he collider

e⁻ from ERL, reusing the "LHeC";

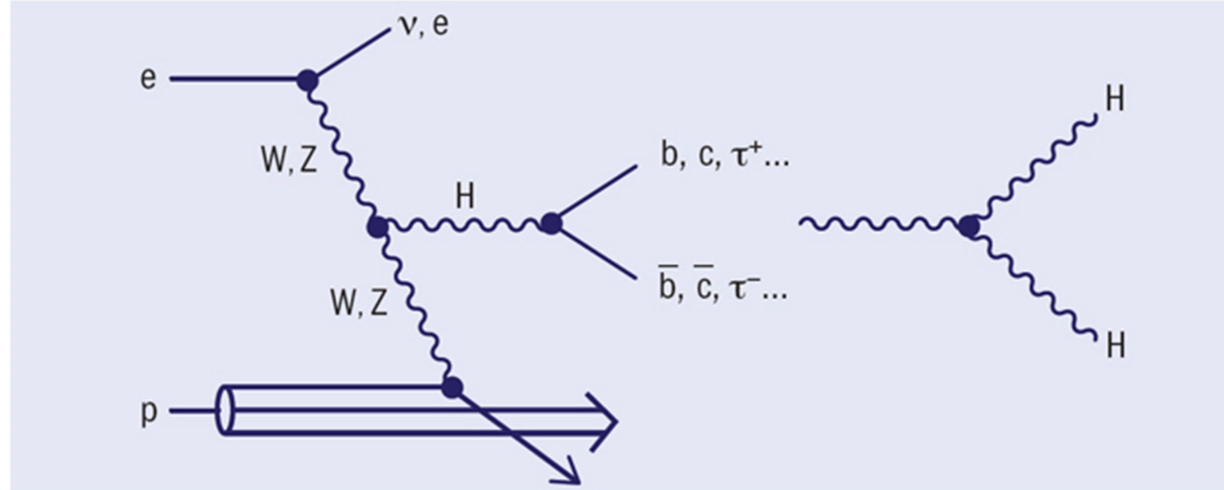
LHeC CDR published in J. Phys. G: Nucl. Part. Phys. 39 075001 (2012)



$C_{LHeC}=C_{LHC}/n$

future: $C_{LHeC}=pC_{FCC}/m$

m, n (=3 or 4), k: integer
p = 1 or 2



- ***h-e*** **Higgs-boson production and decay**
- ***H–bb*** **coupling** in ***WW–H*** **production**;
- **Higgs self-coupling *H–HH*** (<10% precision!? - under study), t
- **lepto-quarks up to ≈4 TeV**
- **Bjorken *x* as low as 10^{-7} - 10^{-8}** [of interest for ultra high energy ν scattering]

I_e~26 mA, $\sigma_{x,y}^*$~2 μm, luminosity/nucleon ~ 3×10^{34} $cm^{-2}s^{-1}$

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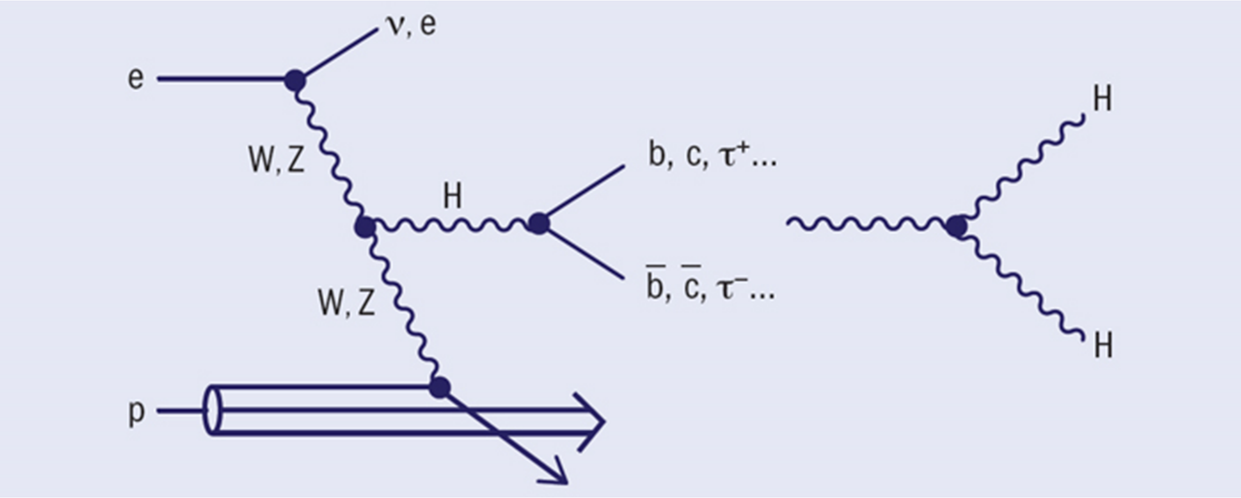
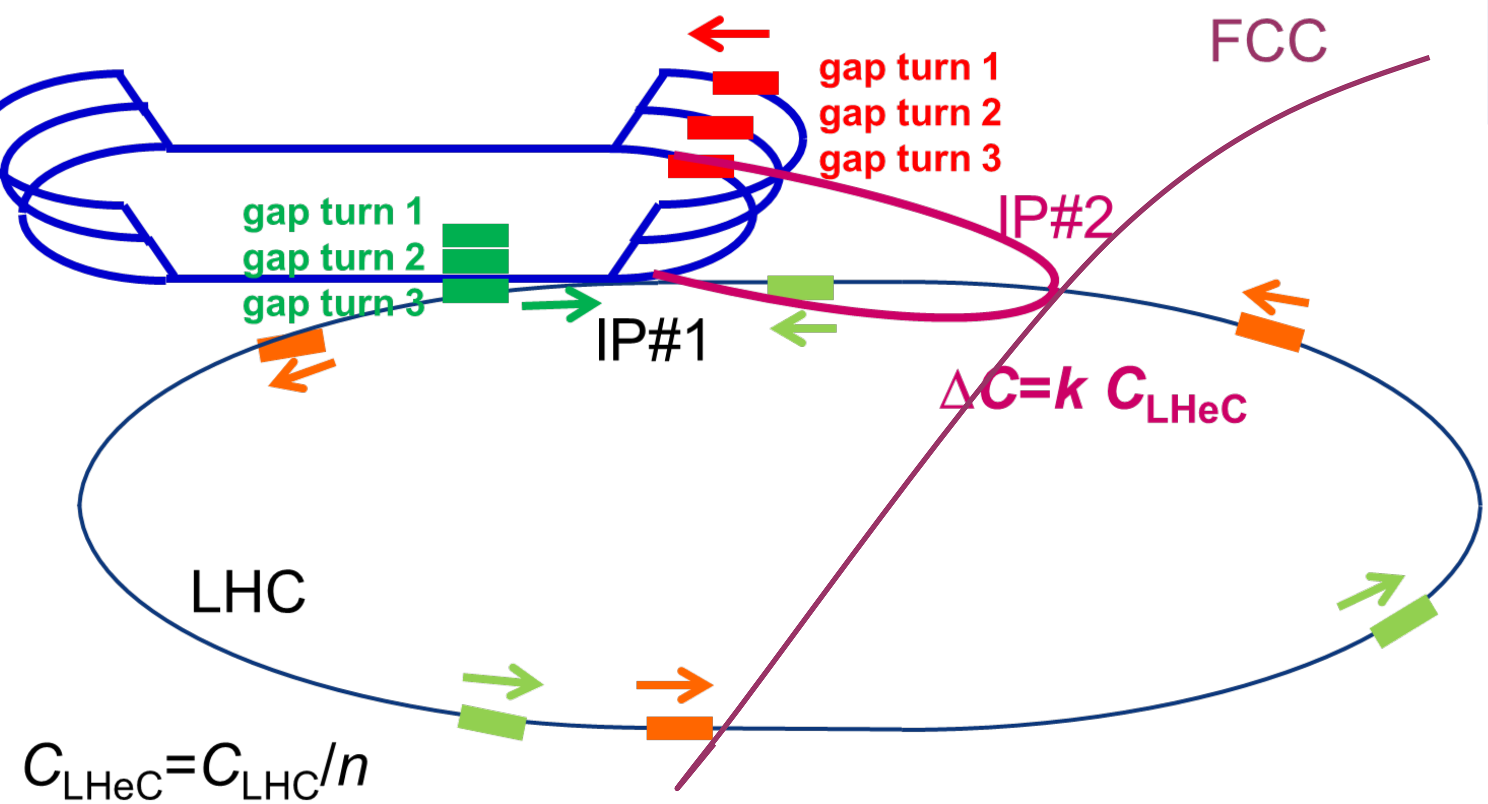
e$^-$ from ERL, reusing the "LHeC";
LHeC CDR published in J. Phys. G: Nucl. Part. Phys. 39 075001 (2012)





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intermediate reviews 2015

11 June 2015, CERN, **Review of FCC Tunnel footprint and Implementation**;
reviewers: Austin Ball, Paul Collier, Massimo Giovannozzi, Philippe Lebrun (chair), Lluis Miralles, Ralf Trant (all CERN)

12 June 2015, CERN, **Review of FCC-ee Crab Waist Option**;
reviewers: A. Blondel (U. Geneva), S. Fartoukh (CERN), J. Jowett (CERN), K. Oide (KEK, chair), P. Raimondi (ESRF)

14 October 2015, CERN, **Review of FCC-ee Optics and Beam Dynamics**;
reviewers: R. Assmann (DESY), A. Blondel (U. Geneva), Y. Cai (SLAC), S. Fartoukh (CERN), J. Jowett (CERN, chair), J.P. Koutchouk (CERN, ret.), V. Lebedev (SLAC), E. Levichev (BINP), P. Raimondi (ESRF)

16 October 2015, CERN, **Review of FCC-hh Injection Energy**;
reviewers: R. Assmann (DESY), O. Bruning (CERN), Y. Cai (SLAC), Antoine Dael (CEA), L. Evans (CERN ret.), W. Fischer (BNL, chair), V. Lebedev (FNAL), A. Yamamoto (KEK)

19-20 November 2015, IPNO Paris, **Review of FCC-hh Optics & Beam Dynamics**;
reviewers: S. Fartoukh, E. Todesco, F. Zimmermann (CERN); O. Napoly (CEA)

FCC International Collaboration

- 70 institutes
- 26 countries + EC

Status: 6 January 2016

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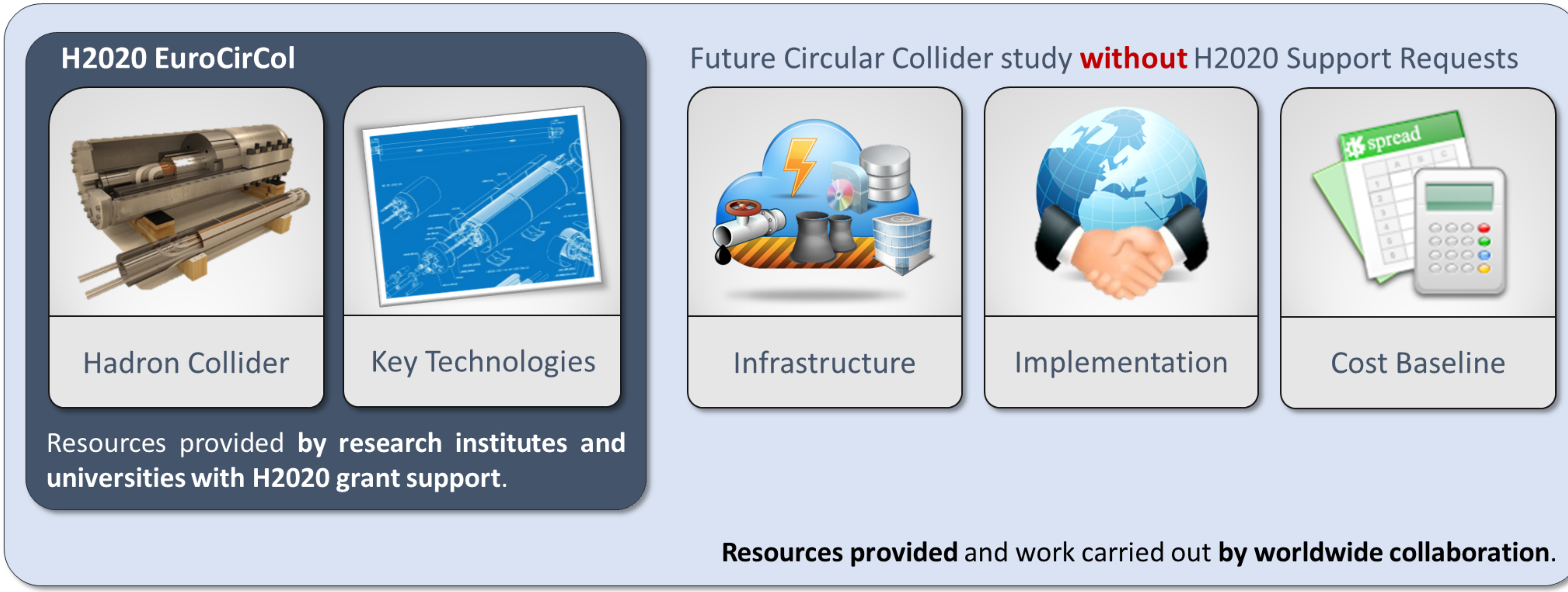
EuroCirCol EU Horizon 2020 Grant

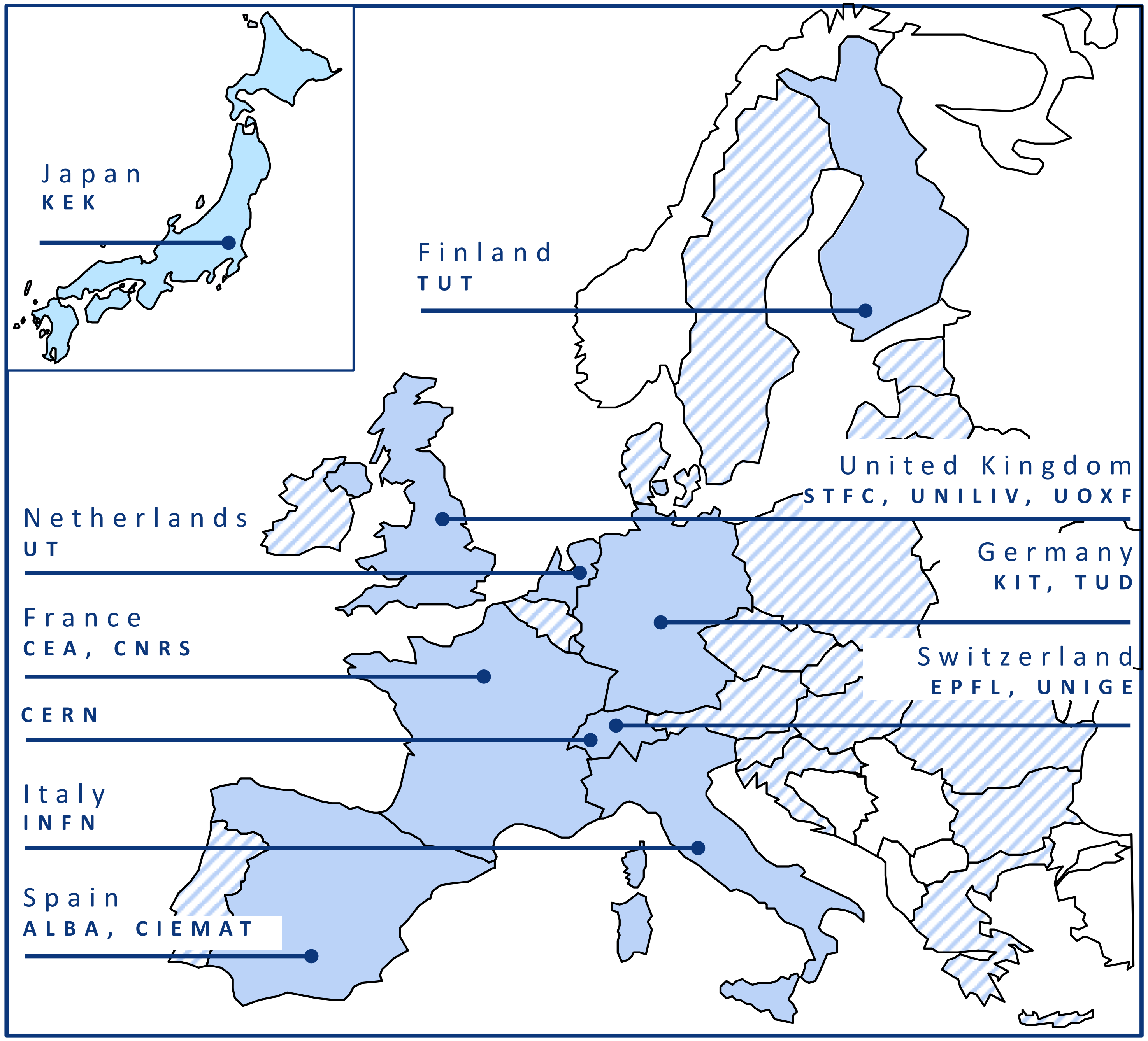
EC contributes with funding to FCC-hh design study



- Core aspects of hadron collider design: **arc & IR optics design, 16 T magnet program, cryogenic beam vacuum system**
- **Recognition of FCC Study by European Commission.**

EuroCirCol Consortium + Associates

CERN	IEIO
TUT	Finland
CEA	France
CNRS	France
KIT	Germany
TUD	Germany
INFN	Italy
UT	Netherlands
ALBA	Spain
CIEMAT	Spain
STFC	United Kingdom
UNILIV	United Kingdom
UOXF	United Kingdom
KEK	Japan
EPFL	Switzerland
UNIGE	Switzerland
NHFML-FSU	USA
BNL	USA
FNAL	USA
LBNL	USA



Consortium Beneficiaries, signing the Grant Agreement

FCC Week 2015

IEEE International Future Circular Collider Conference

March 23 - 27, 2015 | Washington DC, USA

First FCC Week Conference

Washington DC

23-27 March 2015

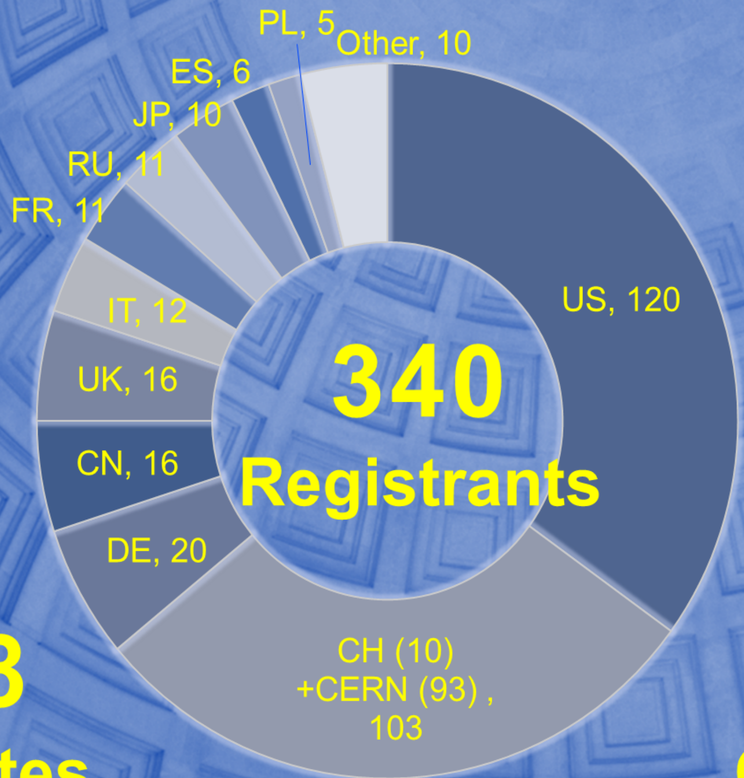
http://cern.ch/fccw2015

Organising & Scientific Program Committee:

G. Apollinari (FNAL)	L.K. Len (DOE)
N. Arkani Hamed (IAS Princeton)	E. Levichev (BINP)
A. Ball (CERN)	J. Lykken (FNAL)
T. Barklow (SLAC)	M. Mangano (CERN)
W. Barletta (MIT)	S. Nagaitsev (FNAL)
M. Benedikt (CERN)	T. Ogitsu (KEK)
A. Blondel (U. Geneva)	K. Oide (KEK)
F. Bordry (CERN)	V. Palmieri (INFN LNL)
L. Bottura (CERN)	A. Patwa (DOE)
O. Bruning (CERN)	F. Perez (ALBA-CELLS)
W. Chou (FNAL,IHEP)	C. Potter (CERN)
P. Collier (CERN)	Q. Qin (IHEP)
E. Delucinge (CERN)	R. Rimmer (JLAB)
M. D'Onofrio (U. Liverpool)	T. Roser (BNL)
J. Ellis (King's College)	L. Rossi (CERN)
F. Gianotti (CERN)	D. Schulte (CERN)
B. Goddard (CERN)	M. Seidel (PSI)
S. Gourlay (LBNL)	A. Seryi (JAI)
[illegible] (CREA)	[illegible] Strauss (DOE)
J. Gutleber (CERN)	S. Strauss
G. Hoffstaetter (Cornell U.)	R. Sundrum (U. Maryland)
J. Incandela (UCSB)	S. Su (U. Arizona)
P. Janot (CERN)	M. Syphers (MSU)
E. Jensen (CERN)	L. Tavian (CERN)
J.M. Jimenez (CERN)	E. Todesco (CERN)
M. Klein (U. Liverpool)	R. Van Kooten (Indiana U.)
M. Klute (MIT)	P. Vedrine (CEA)
[illegible]	J. Wenninger (CERN)
D. Larbalestier (NHFML)	U. Wienands (SLAC)
P. Lebrun (CERN)	F. Zimmermann (CERN)

Further information and registration http://cern.ch/fccw2015

FCC Week 2015 STATISTICS



128 Institutes

21 Countries

FCC International Collaboration

A new era for CERN-US collaboration in particle physics

Posted by Harriet Kim Jarlett on 18 Dec 2015. Last updated 18 Dec 2015, 15.43.
Voir en français

Ambassador Pamela Hamamoto of the United States (left) and CERN Director-General Rolf Heuer (Image: Maximilien Brice/CERN)

…

Today's agreements herald a new era in CERN-US collaboration in particle physics. They confirm the US's commitment to the LHC project, and for the first time, they set down in black and white European participation through CERN in pioneering neutrino research in the US. They are a significant step towards a fully connected trans-Atlantic research programme.

In anticipation of today's agreements, CERN no longer runs its own neutrino beams. Instead, it will serve as a platform for European scientists engaged in neutrino detector R&D who will go on to work at neutrino experiments in the US and elsewhere.

Looking further ahead, today's protocols codify the on-going **collaboration between CERN and the US on future facilities that might succeed the LHC around 2040**.

These protocols are a significant step on the way towards a truly integrated trans-Atlantic research programme in particle physics.

http://home.cern/about/updates/2015/12/new-era-cern-us-collaboration-particle-physics

FCC Week 2016

Rome, 11-15 April 2016

http://cern.ch/fccw2016

IEEE CSC Council on Superconductivity

SAPIENZA UNIVERSITÀ DI ROMA

INFN Istituto Nazionale di Fisica Nucleare Sezione di Roma

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

UNIVERSITA' DEGLI STUDI DI ROMA TorVergata

ROMA TRE UNIVERSITÀ DEGLI STUDI

CERN

Conclusions

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RESERVE SLIDES

FCC Collaboration Status

63 collaboration members & CERN as host institute, 4 November 2015

ALBA/CELLS, Spain
Ankara U., Turkey
U Belgrade, Serbia
U Bern, Switzerland
BINP, Russia
CASE (SUNY/BNL), USA
CBPF, Brazil
CEA Grenoble, France
CEA Saclay, France
CIEMAT, Spain
CNRS, France
Cockcroft Institute, UK
U Colima, Mexico
CSIC/IFIC, Spain
TU Darmstadt, Germany
TU Delft, Netherlands
DESY, Germany
TU Dresden, Germany
Duke U, USA
EPFL, Switzerland
GWNU, Korea

U Geneva, Switzerland
Goethe U Frankfurt, Germany
GSI, Germany
U. Guanajuato, Mexico
Hellenic Open U, Greece
HEPHY, Austria
U Houston, USA
IIT Kanpur, India
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
FZ Jülich, Germany
KAIST, Korea
KEK, Japan
KIAS, Korea

King's College London, UK
KIT Karlsruhe, Germany
Korea U Sejong, Korea
MAX IV, Sweden
MEPhI, Russia
MIT, USA
NBI, Denmark
Northern Illinois U, USA
NC PHEP Minsk, Belarus
U. Liverpool, UK
U Oxford, UK
PSI, Switzerland
U. Rostock, Germany
Sapienza/Roma, Italy
UC Santa Barbara, USA
U Silesia, Poland
TU Tampere, Finland
TOBB, Turkey
U Twente, Netherlands
TU Vienna, Austria
Wroclaw UT, Poland

FCC motivation: pushing the energy frontier

- **A very large circular hadron collider seems the only approach to reach 100 TeV c.m. collision energy in coming decades**
- **Access to new particles (direct production) in the few TeV to 30 TeV mass range, far beyond LHC reach.**
- **Much-increased rates for phenomena in the sub-TeV mass range →increased precision w.r.t. LHC and possibly ILC**

M. Mangano

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M. Mangano

The name of the game of a hadron collider is energy reach

$$\boxed{E \propto B_{dipole} \times \rho_{bending}}$$

Cf. LHC: factor ~4 in radius, factor ~2 in field → O(10) in E_{cms}

FCC Strategic Motivation

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- **European Strategy for Particle Physics 2013:**

  "…to propose an ambitious post-LHC accelerator project….., CERN should undertake design studies for accelerator projects in a global context,…with emphasis on proton-proton and electron-positron high-energy frontier machines..…"

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- **US P5 recommendation 2014:**

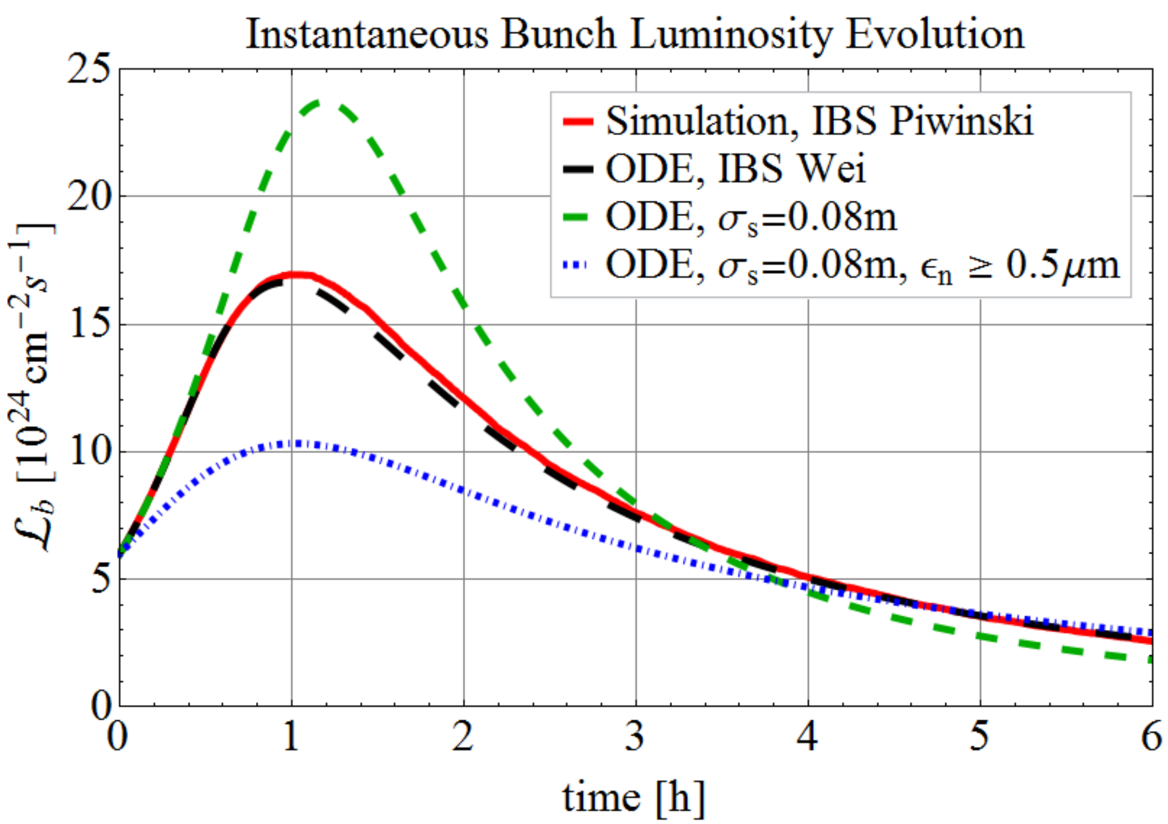
  "….A very high-energy proton-proton collider is the most powerful tool for direct discovery of new particles and interactions under any scenario of physics results that can be acquired in the P5 time window…."

FCC heavy-ion collider (Pb-Pb)

- Synchrotron radiation damping is about *twice as fast*

  $$\alpha_{\varepsilon} \propto \frac{Z^5}{m^4}$$ in the same magnetic field

- *Pb* nuclei are accompanied by intense fluxes of high energy quasi-real photons:
  - Powerful secondary beams
  - Extreme luminosity burn-off
  - Complicated collimator interaction
- Stronger intra-beam scattering ultimately limits emittance



PHYSICAL REVIEW SPECIAL TOPICS—ACCELERATORS AND BEAMS **18,** 091002 (2015)

Potential performance for Pb-Pb, *p*-Pb, and *p*-*p* collisions in a future circular collider

Michaela Schaumann*

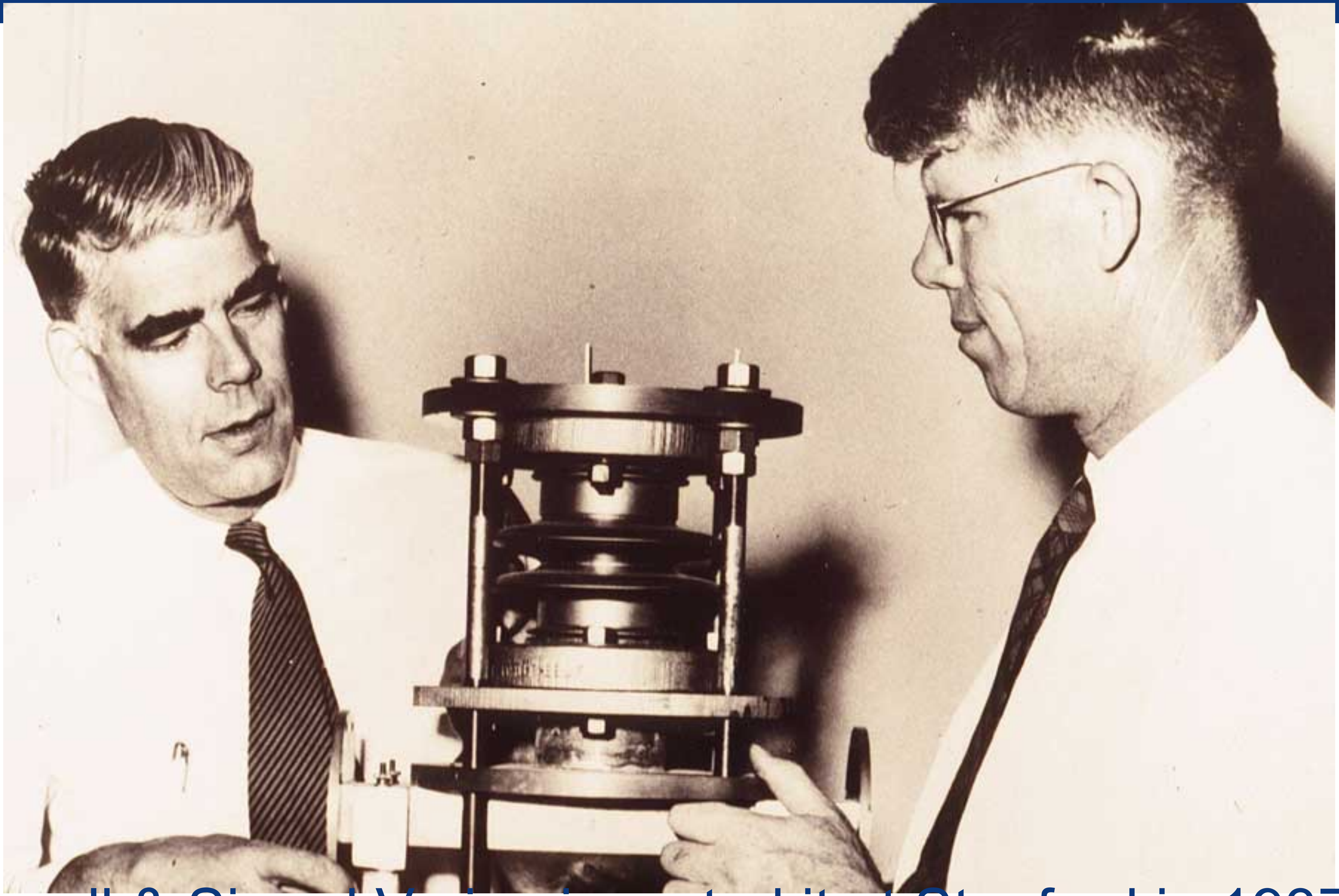
CERN, CH-1211 Geneva 23, Switzerland and III. Physikalisches Institut, RWTH Aachen University, D-52056 Aachen, Germany

(Received 11 December 2014; published 9 September 2015)

J. Jowett, M. Schaumann

PRST-AB 18, 091002 (2015)

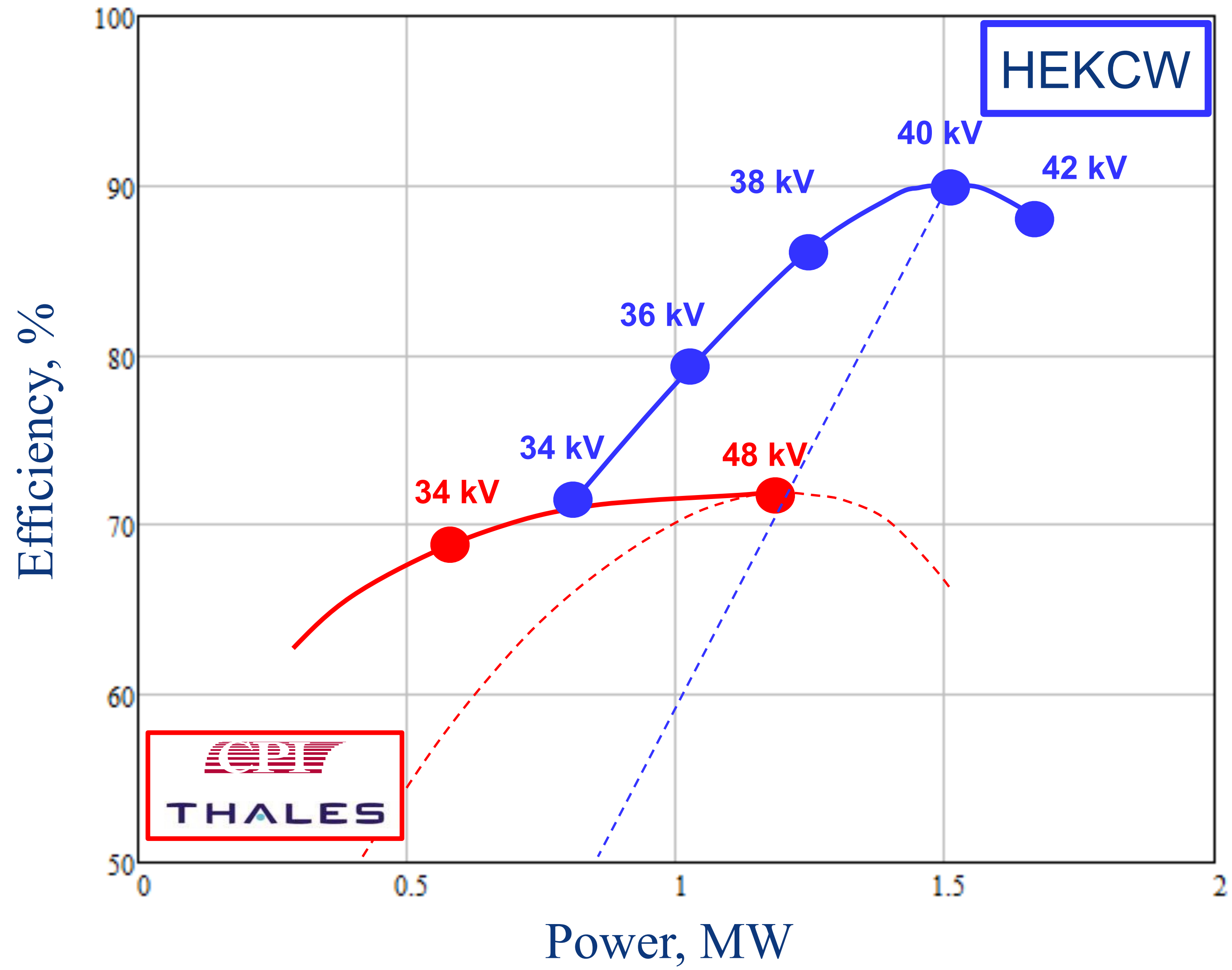
klystron – glorious history



Russell & Sigurd Varian invented it at Stanford in 1937

after 80 years a breakthrough in klystron efficiency!

comparing simulated performances of MBIOT and HEKCW MBK

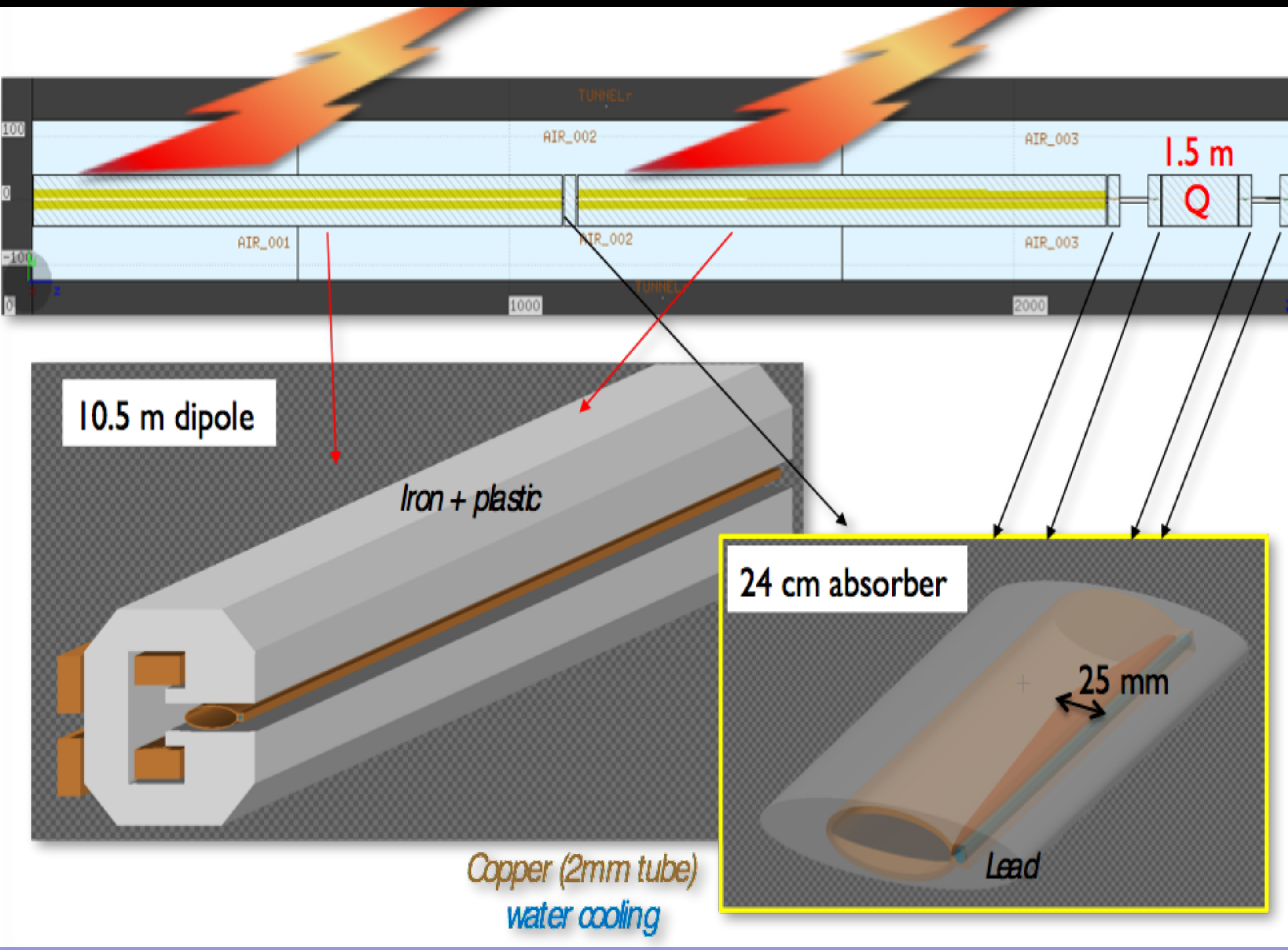


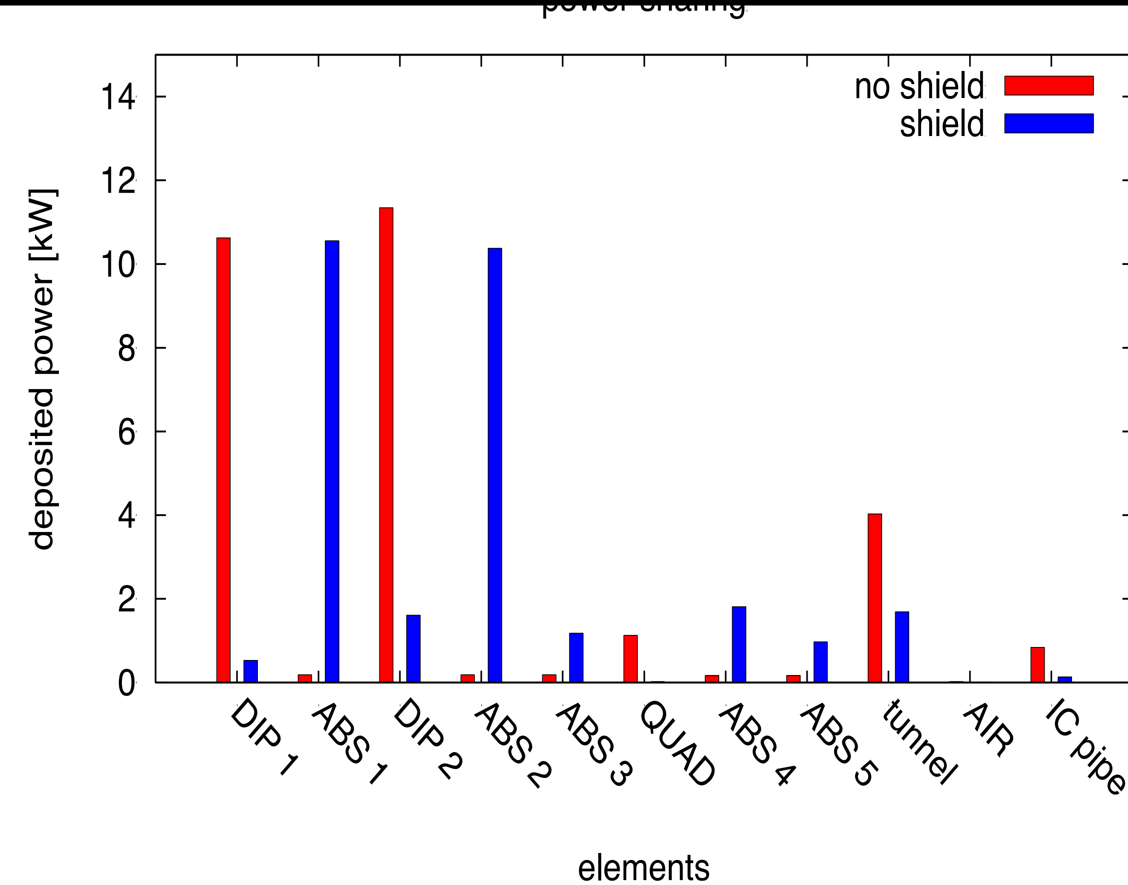
I. Syratchev

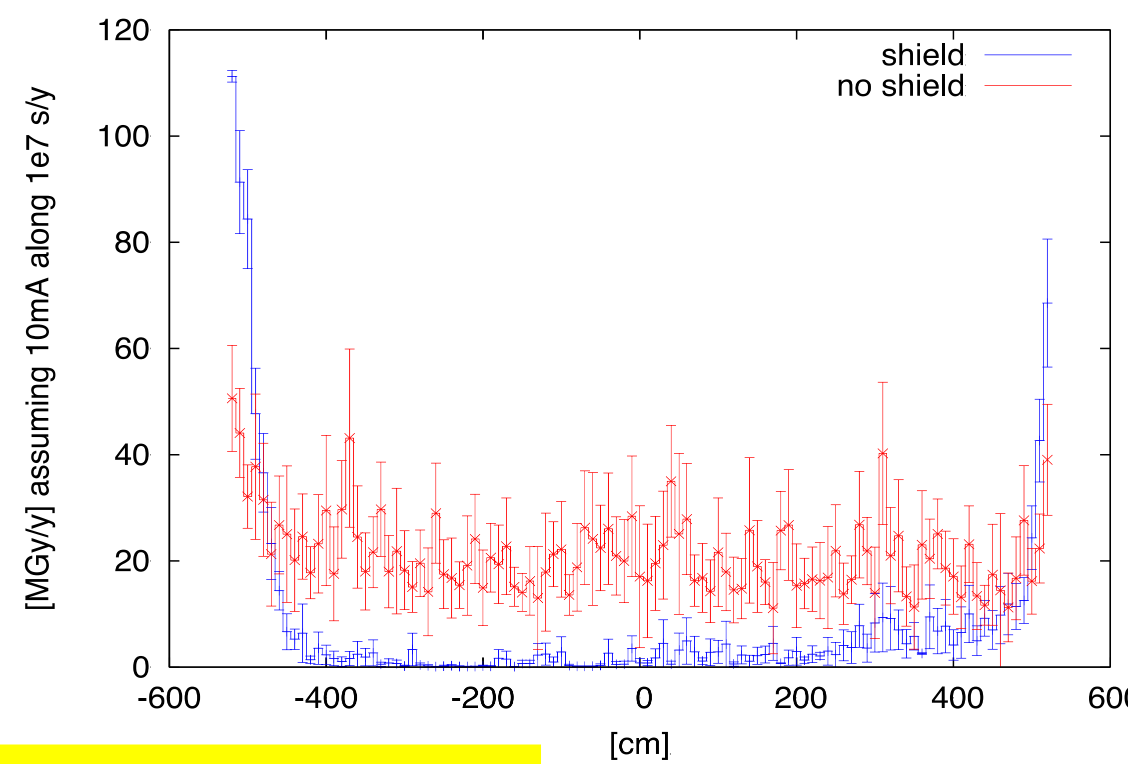
demonstration in Russia this month ?!

Dotted lines – only changing P drive
Solid lines – changing P drive and Voltage

FCC-ee: shielding 100 MW SR with E_c~ 1 MeV







FLUKA geometry layout for half FODO cell, dipole details, preliminary absorber design incl. 5 cm external *Pb* shield

L. Lari, F. Cerutti, A. Ferrari, A. Mereghetti

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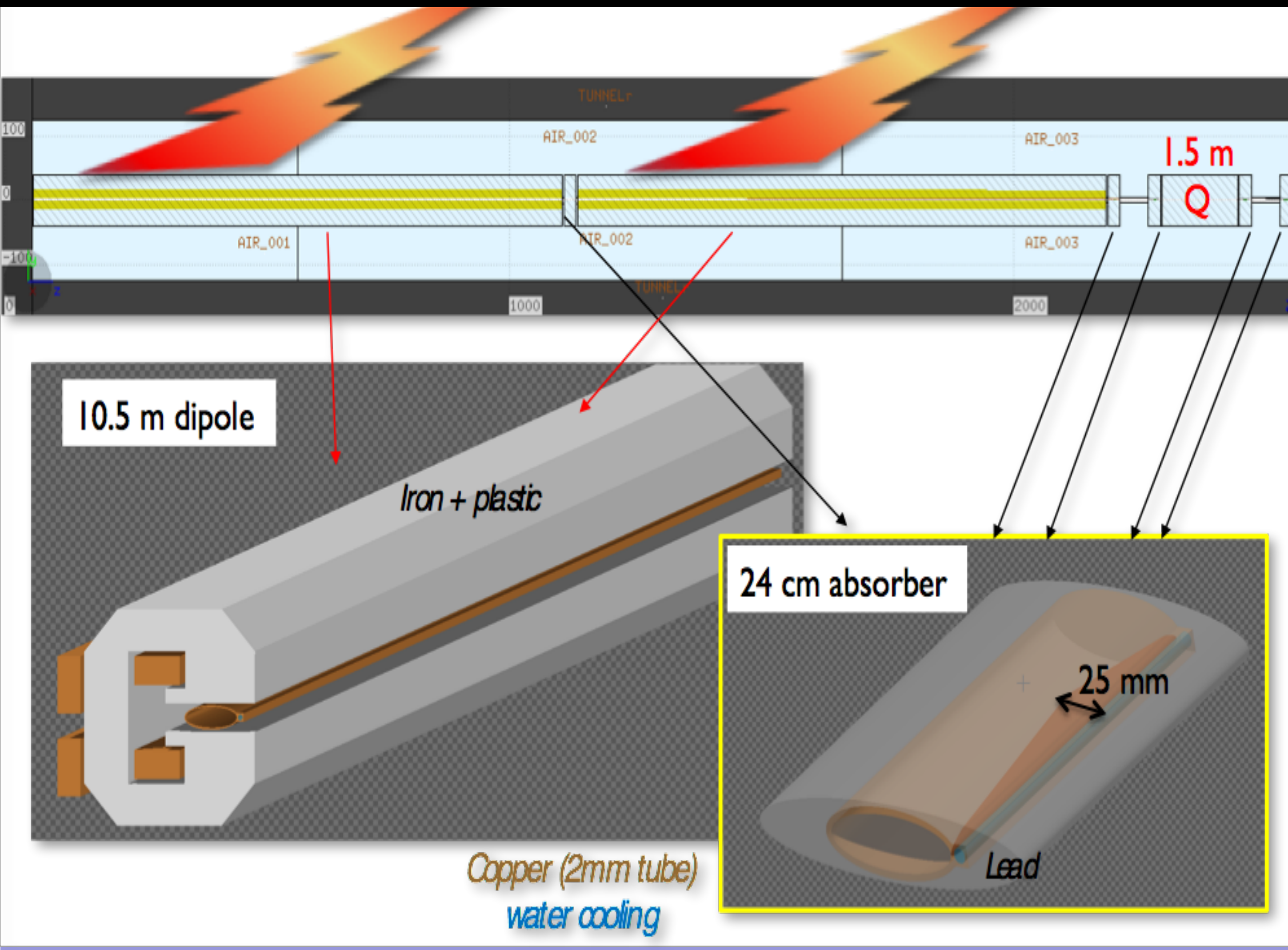

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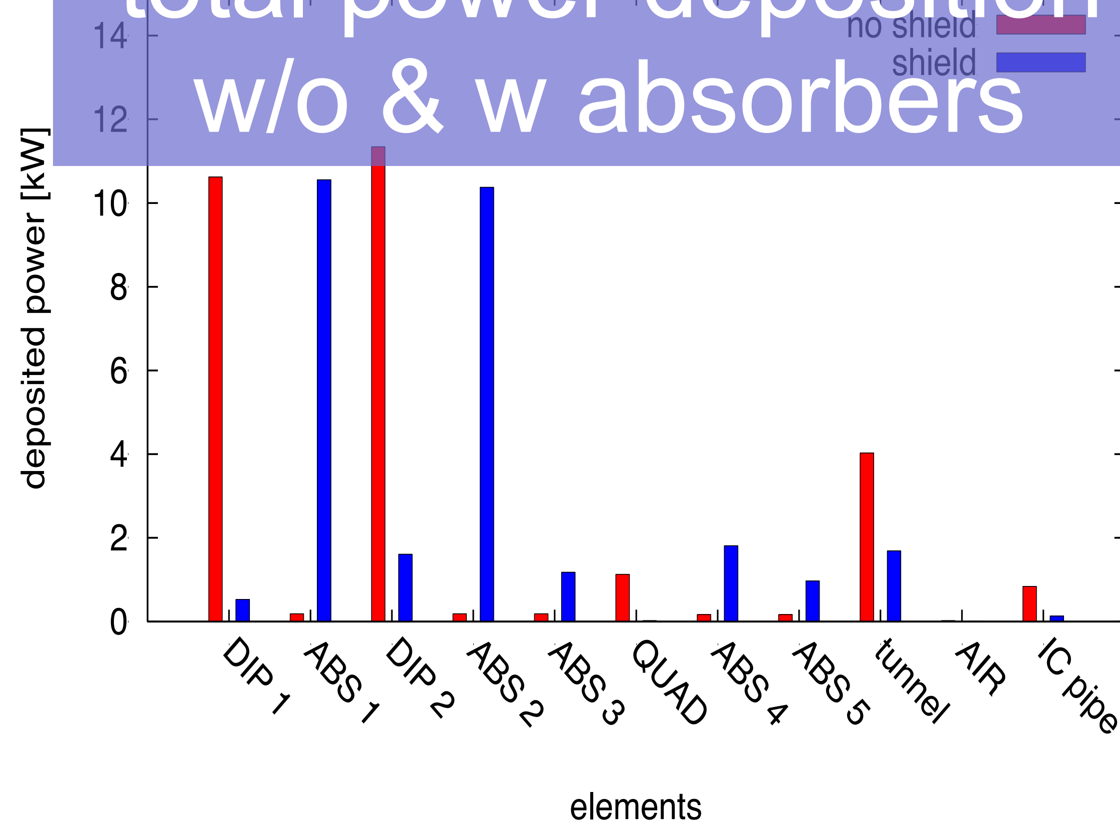

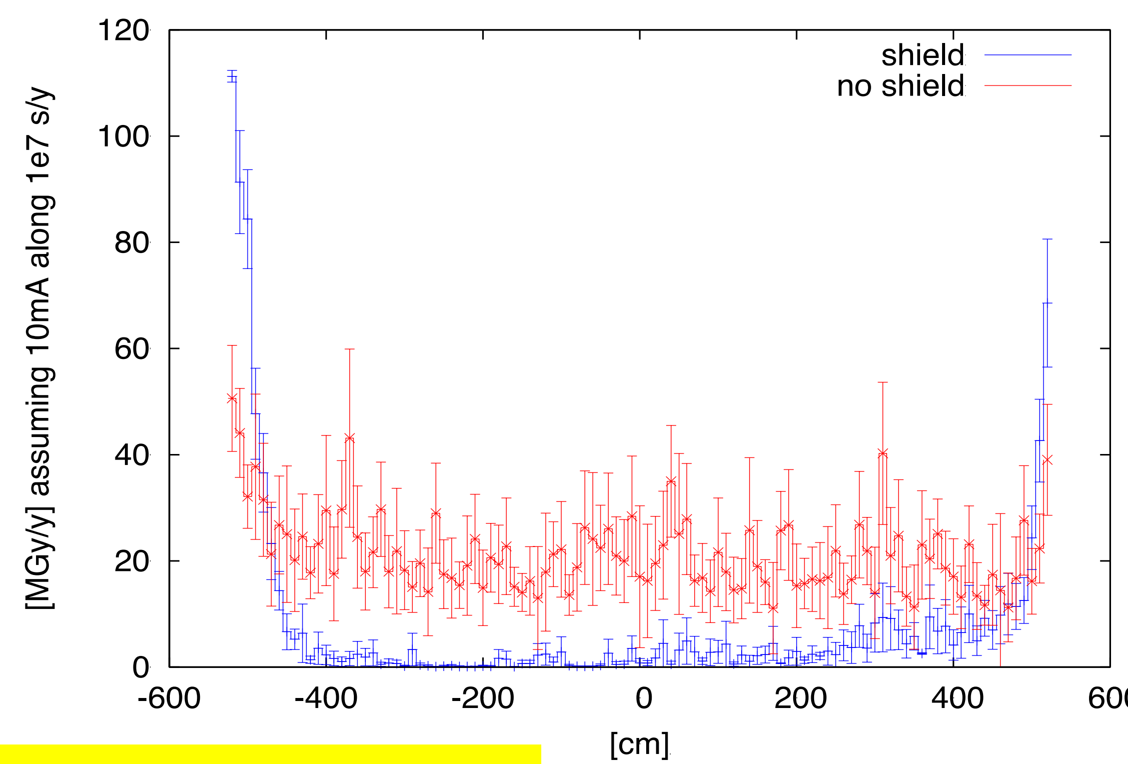

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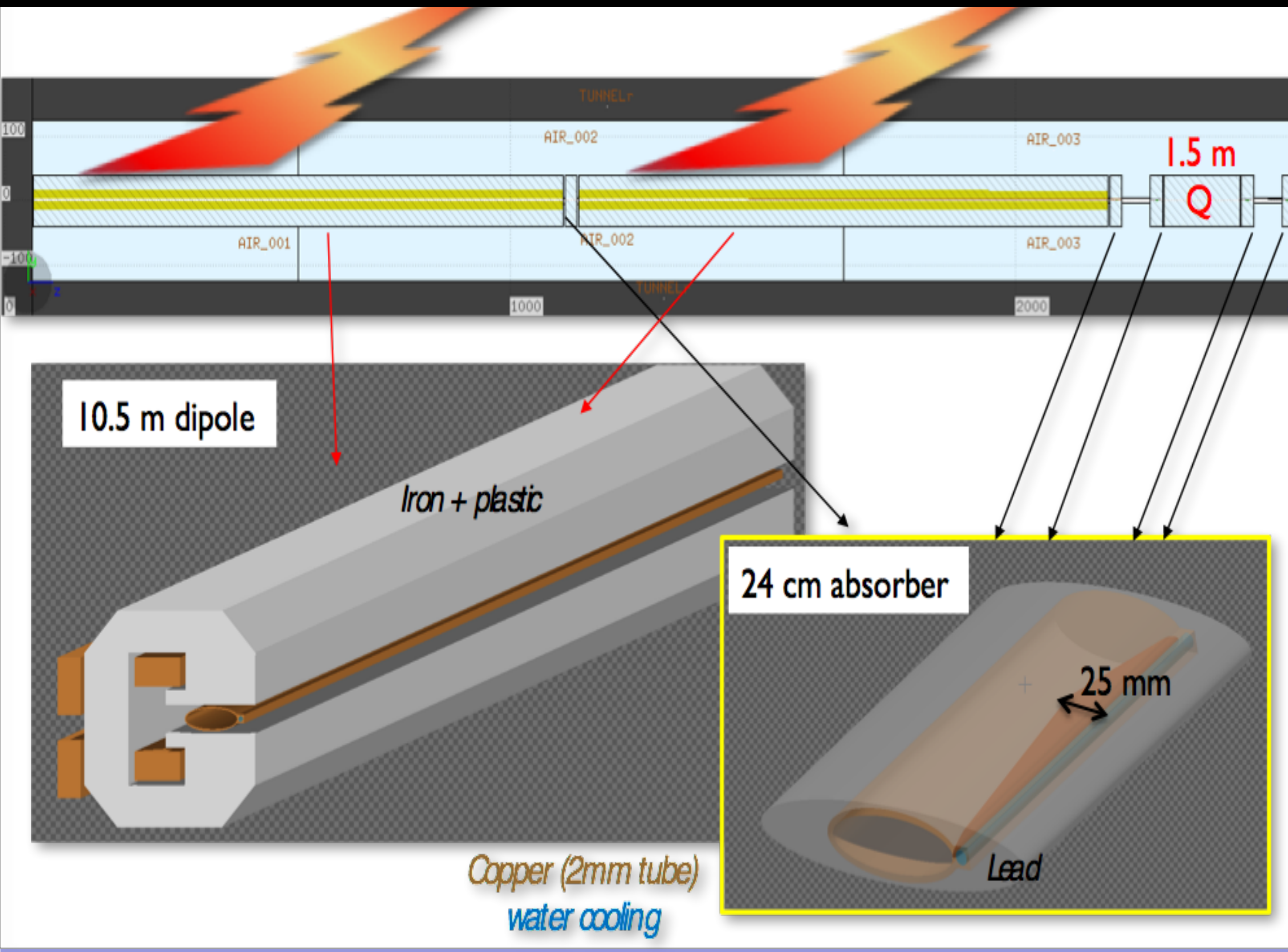

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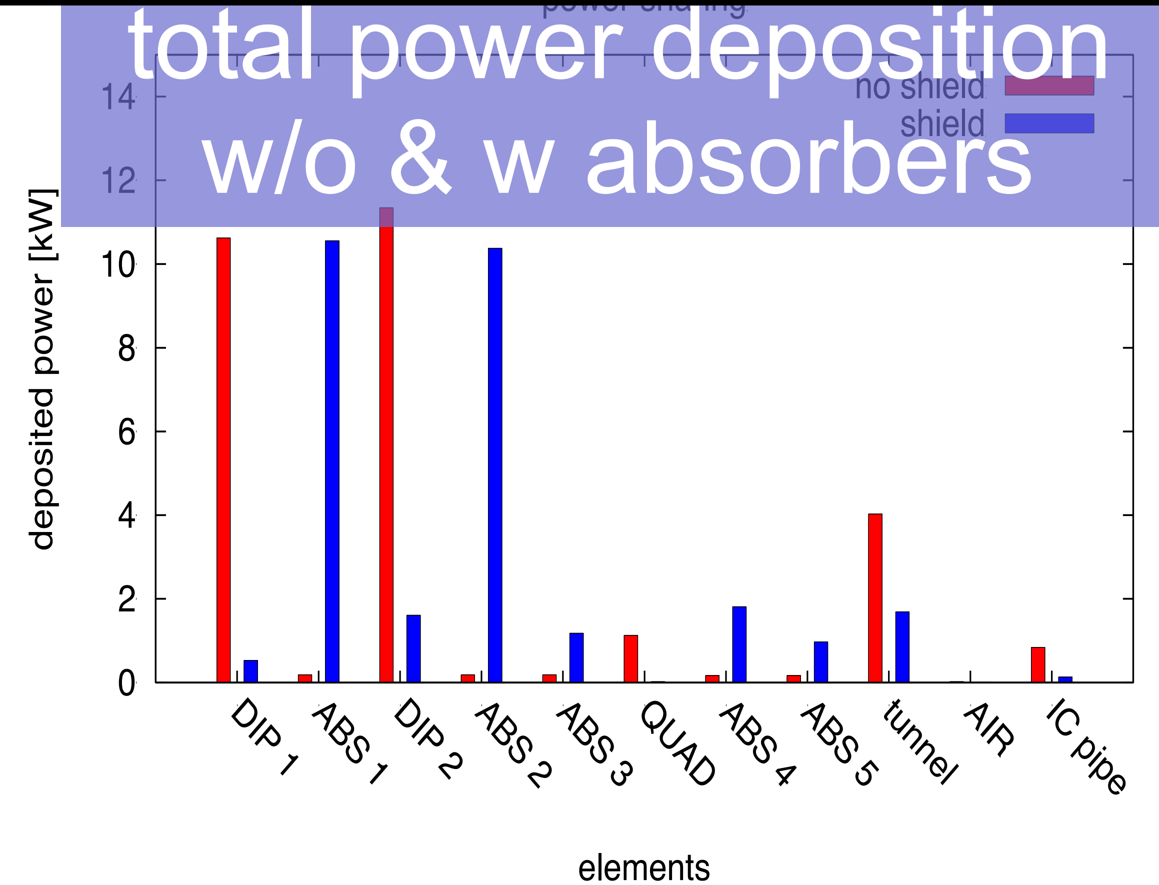
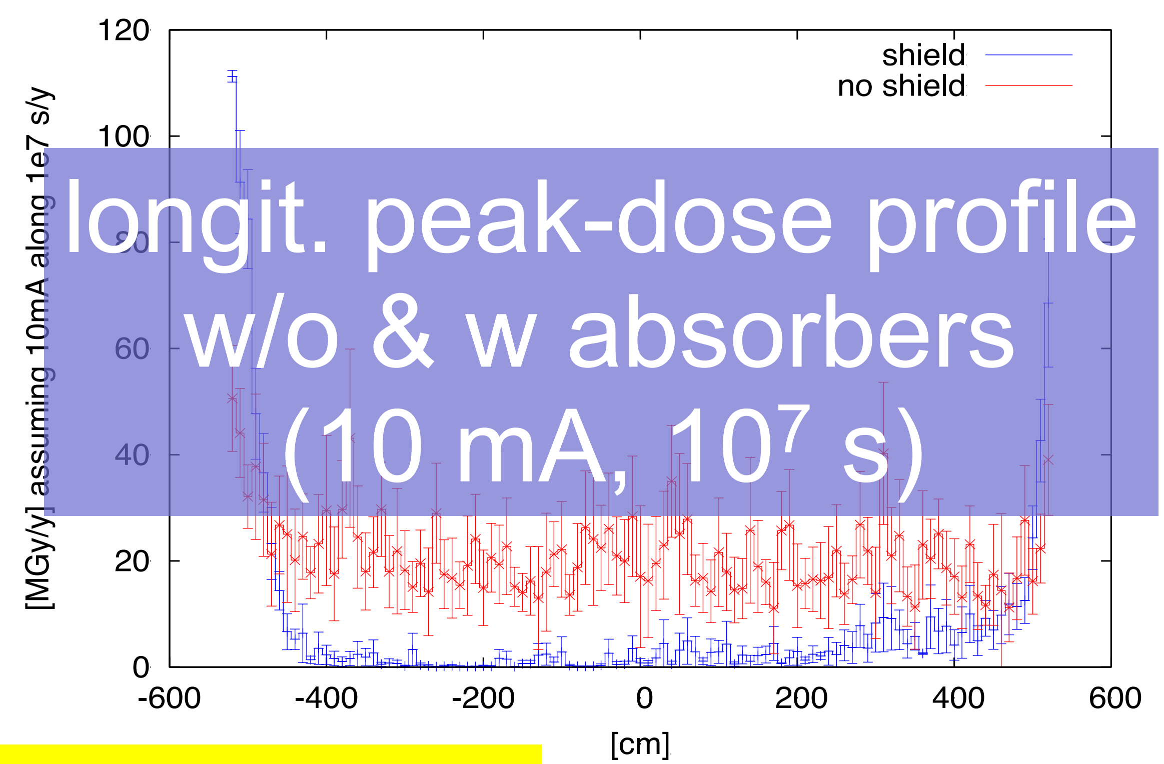
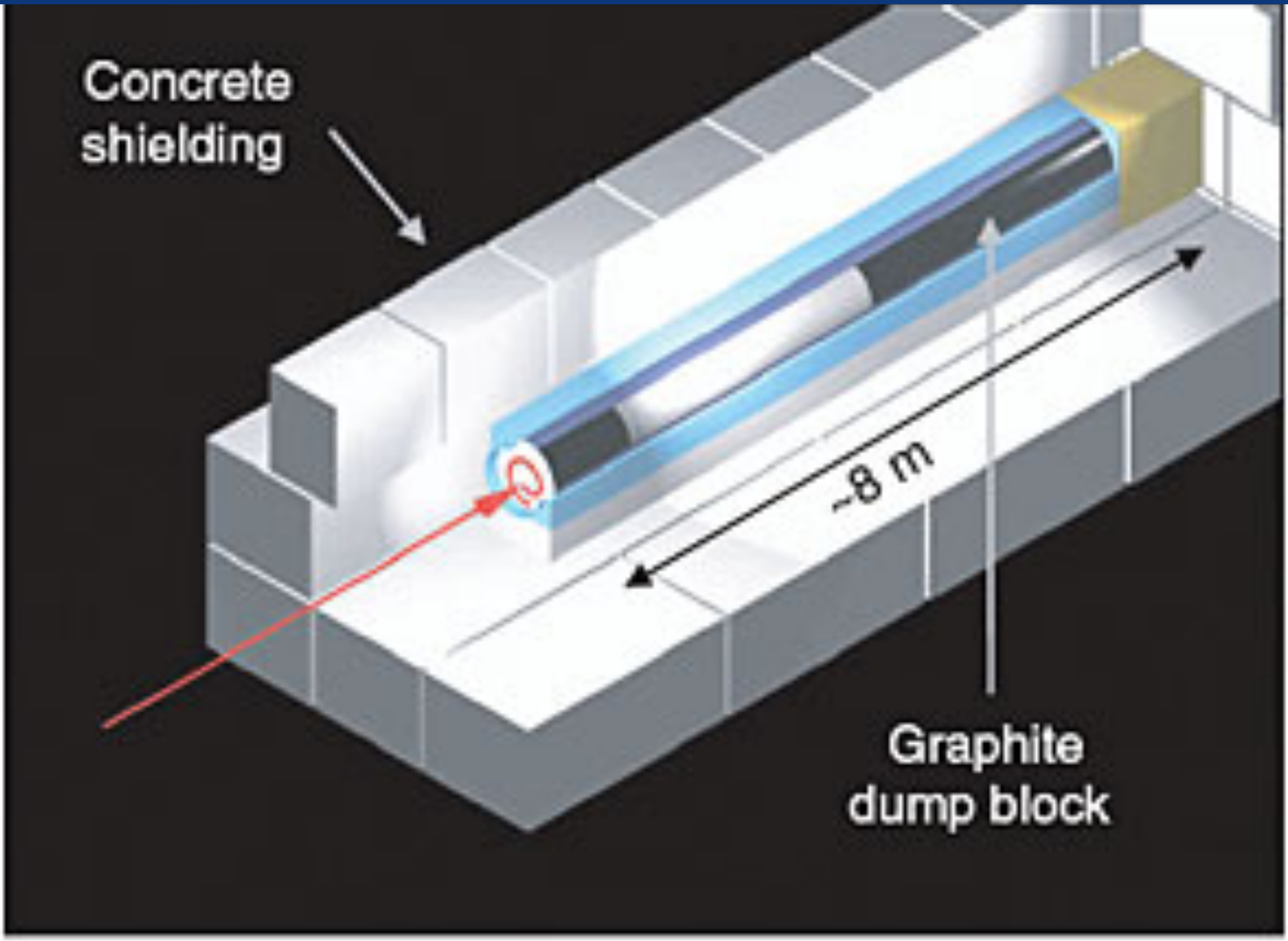


longit. peak-dose profile w/o & w absorbers ($10\ \text{mA}$, $10^7\ \text{s}$)



L. Lari, F. Cerutti, A. Ferrari, A. Mereghetti

from LHC beam dump …

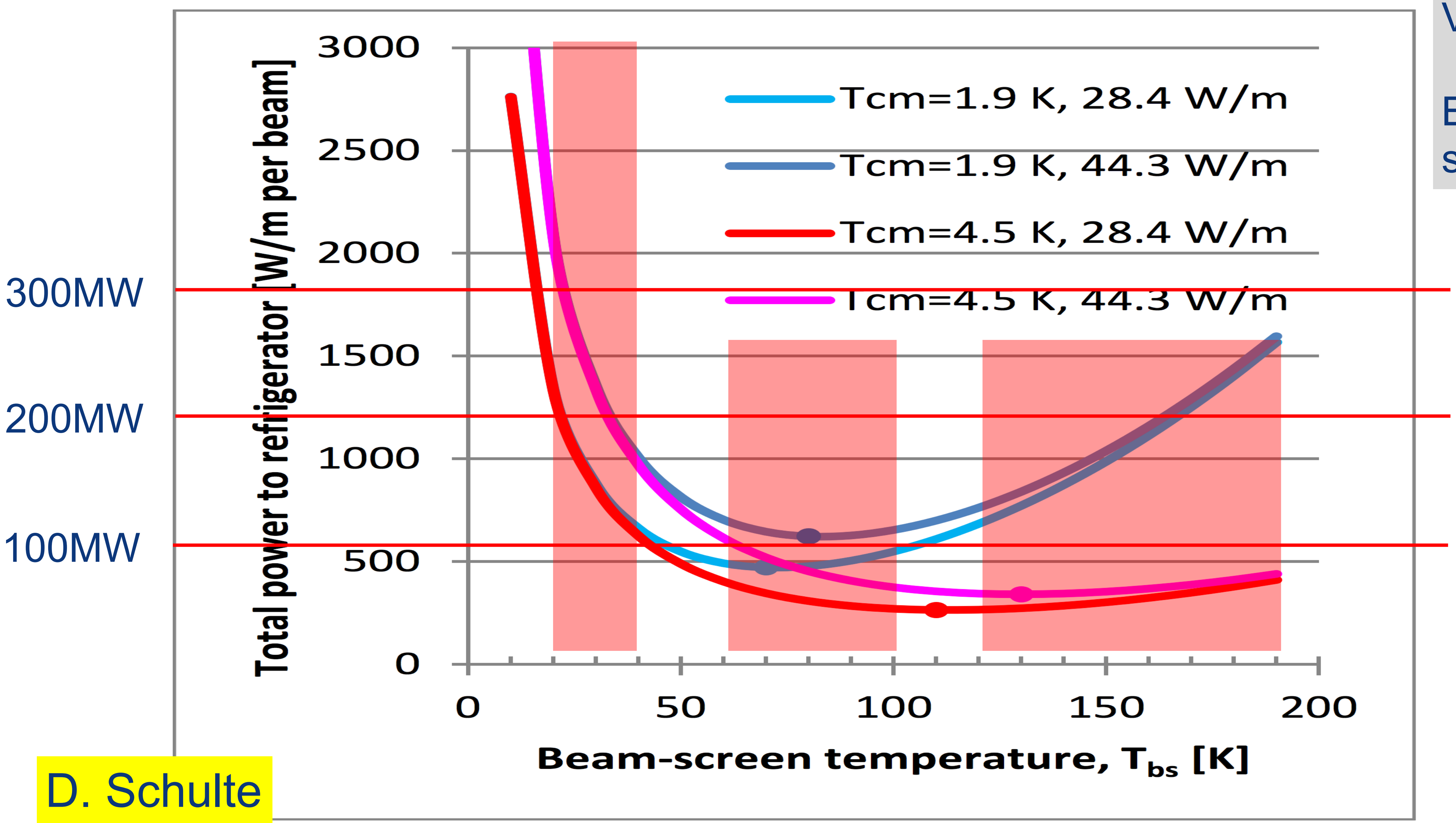


beam-screen temperature

picked 50 K for efficiency and beam stability
but for 4.5 K magnets can also consider 110 K

Ph. Lebrun
L. Tavian
V. Baglin

Based on LHC screen



D. Schulte

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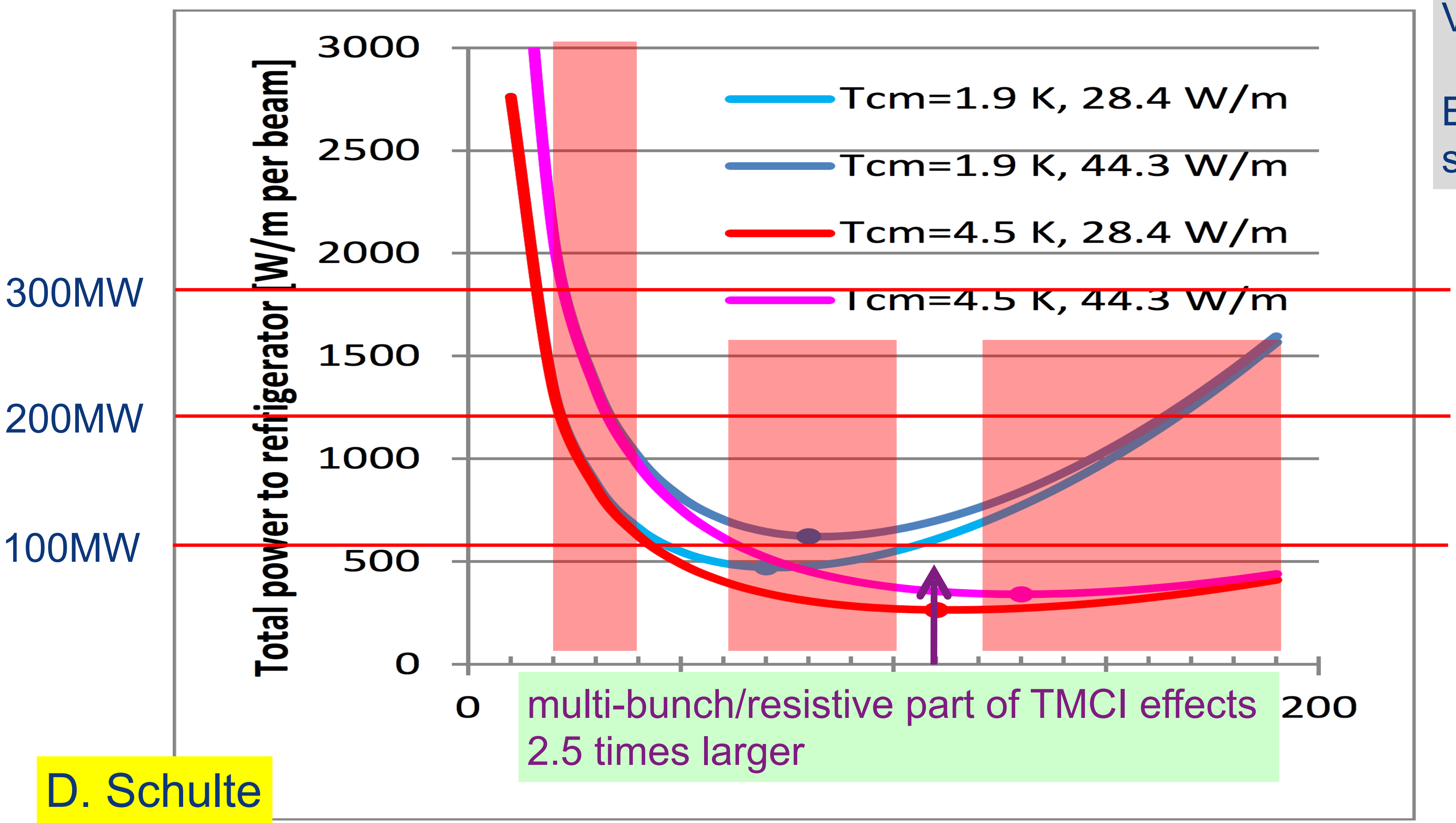


D. Schulte

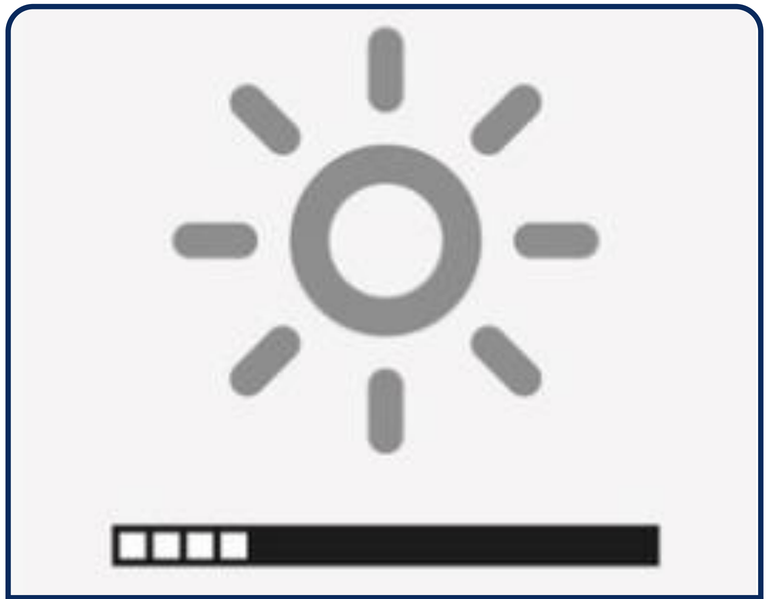
FCC RAMS studies

Milestones:

J. Gutleber

- **Understand and reproduce** current CERN injector and LHC availability with model
- **Identify promising knobs** which significantly impact delivered integrated luminosity
- **Estimate costs** associated with enhancement measures

FCC RAMS studies



How to raise integrated luminosity efficiently?

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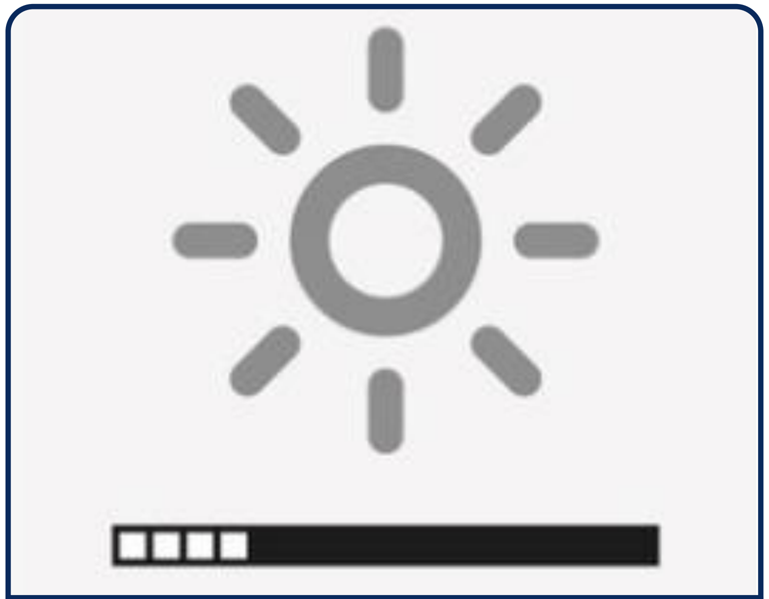
How to raise integrated luminosity efficiently?


What is the price tag for increased luminosity?

J. Gutleber

Milestones:

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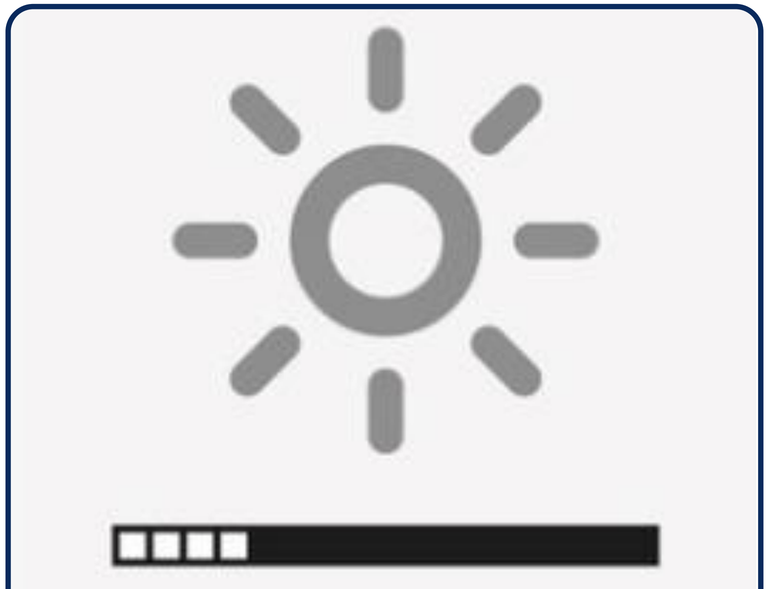
- **Identify promising knobs** which significantly impact delivered integrated luminosity
- **Estimate costs** associated with enhancement measures

FCC RAMS studies



How to raise integrated luminosity efficiently?

What is the price tag for increased luminosity?

How to reduce cost at constant luminosity?

J. Gutleber

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