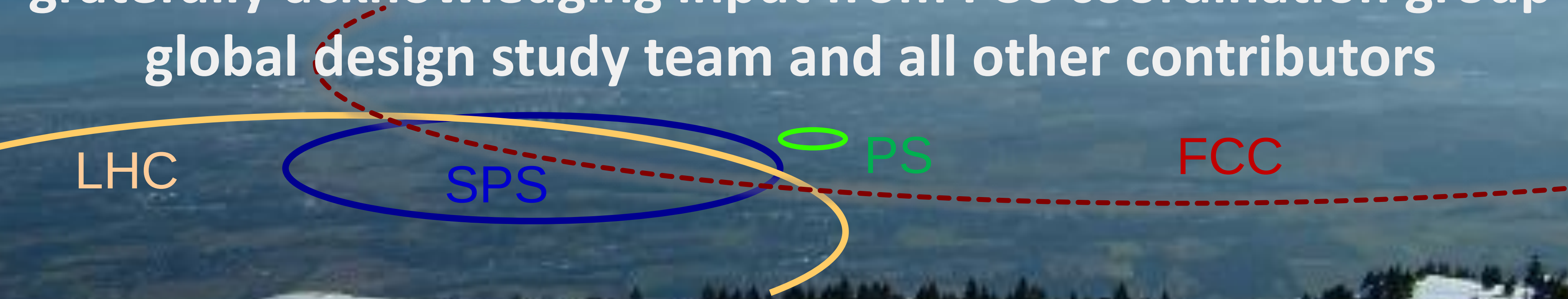
Future Circular Collider Study

Status and Progress

M. Benedikt, F. Zimmermann

gratefully acknowledging input from FCC coordination group global design study team and all other contributors



http://cern.ch/fcc

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

Outline

- FCC Study Scope & Time Line
- Machine Design
- Technologies
- FCC Organisation & Collaboration

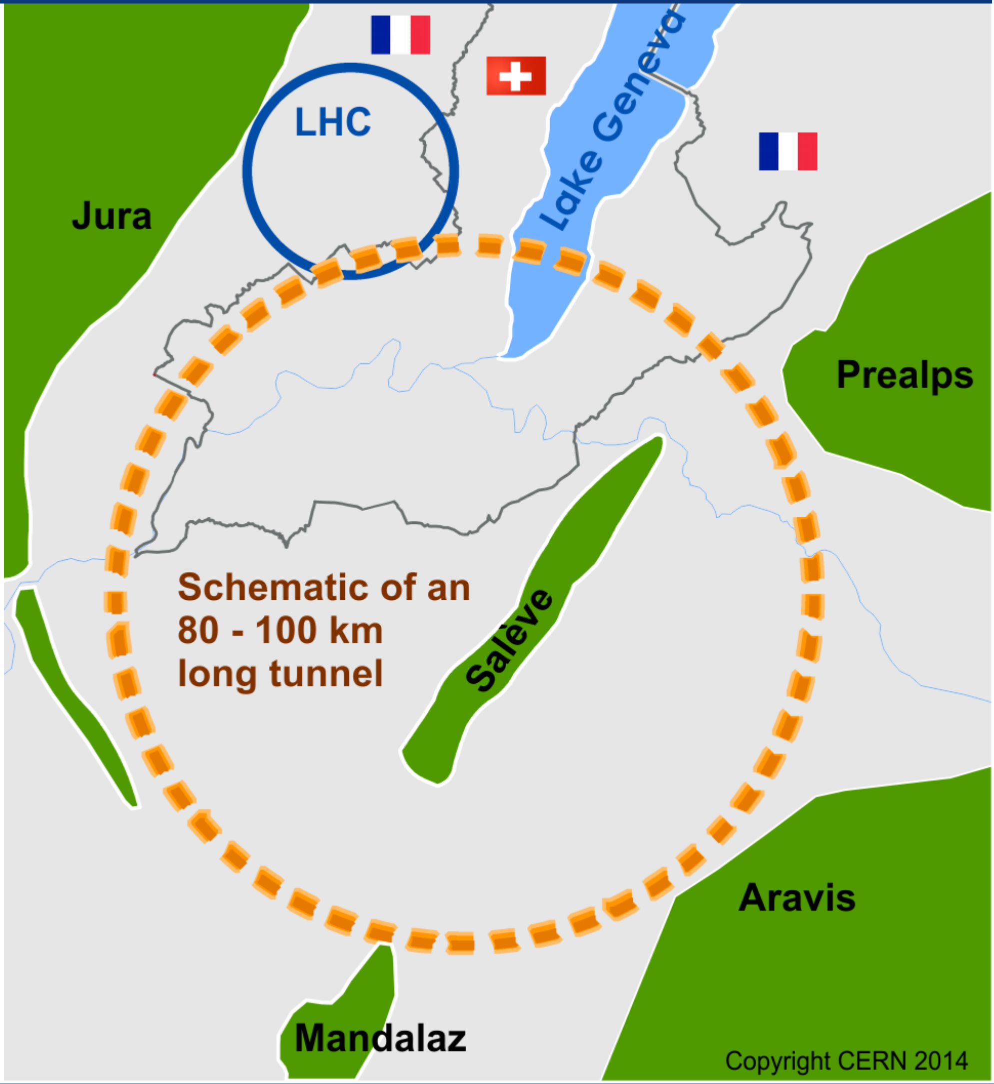
Future Circular Collider Study
Goal: CDR for European Strategy Update 2018/19

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

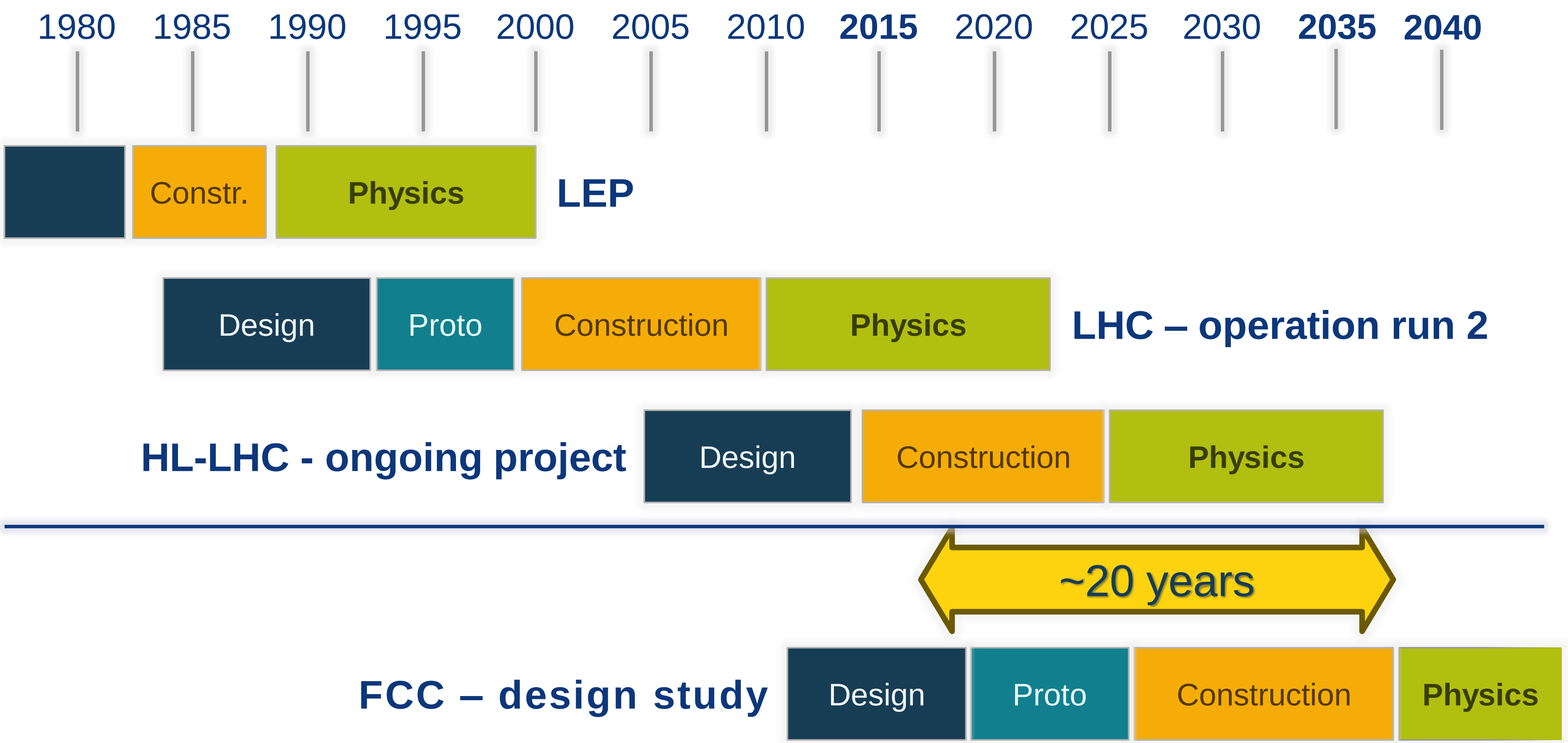
- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km

- **80-100 km tunnel infrastructure** in Geneva area, site specific
- ***e⁺e⁻* collider (*FCC-ee*),** as potential first step
- ***p-e* (*FCC-he*) option,** integration one IP, FCC-hh & ERL
- **HE-LHC** with *FCC-hh* technology



CERN Circular Colliders & FCC



Must advance fast now to be ready for the period 2035 – 2040

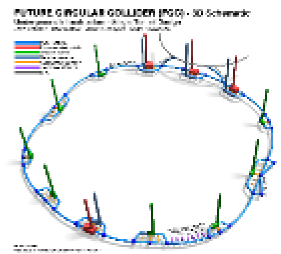
Goal of phase 1: CDR by end 2018 for next update of European Strategy

progress - civil engineering studies

Review panel – Decision to **focus on 100 km tunnel**

FCC week 2016 in Rome:
- **Single and double** tunnel
- **Inclined** access tunnels
- **hh** and **ee** requirements

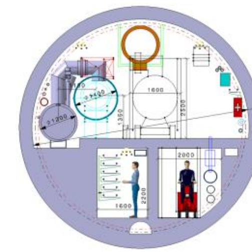
- **Revised layout** for realisation studies
- **Naming** convention



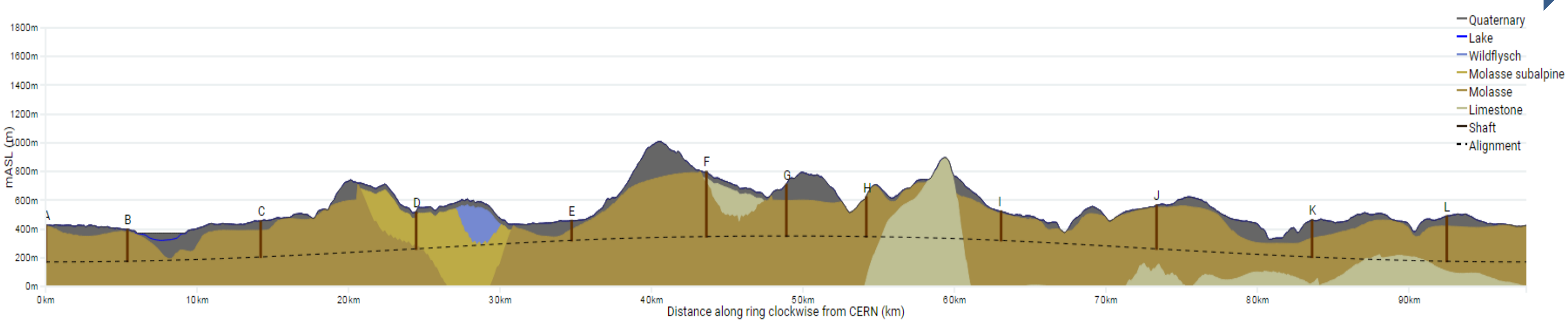
Cost and schedule study ongoing with 2 consultants

ILF CONSULTING ENGINEERS
GC GEOCONSULT
synaxis

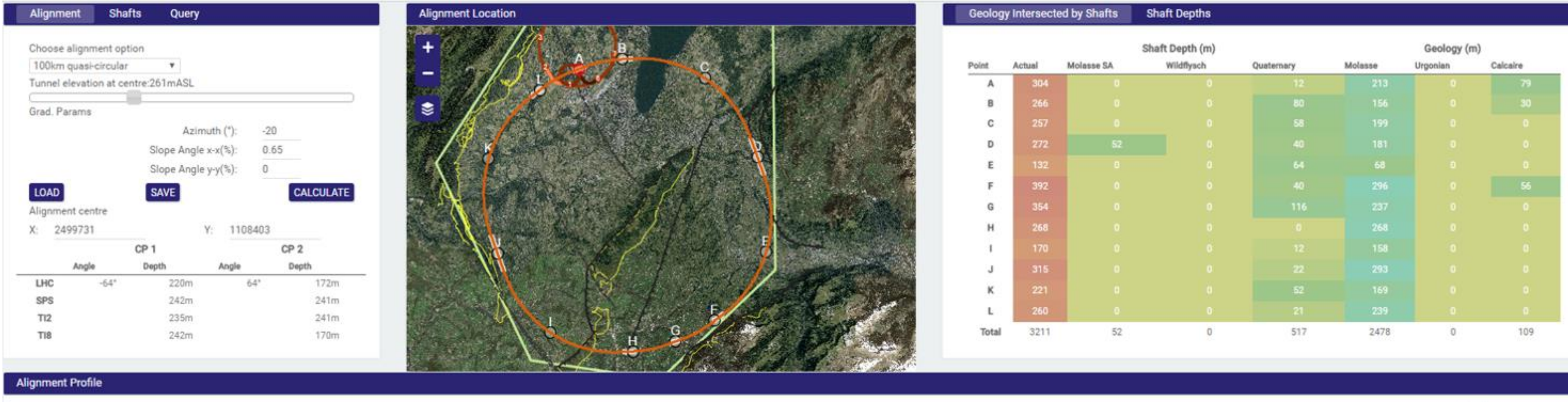
- Cost & schedule **estimates**
- **Inclined** access shafts **assessment**
- Tunnel and shaft **cross-section designs**



Nov. 2015 | Apr. 2016 | Aug. 2016 | Sept. 2016 | Dec. 2016



Progress on site investigations



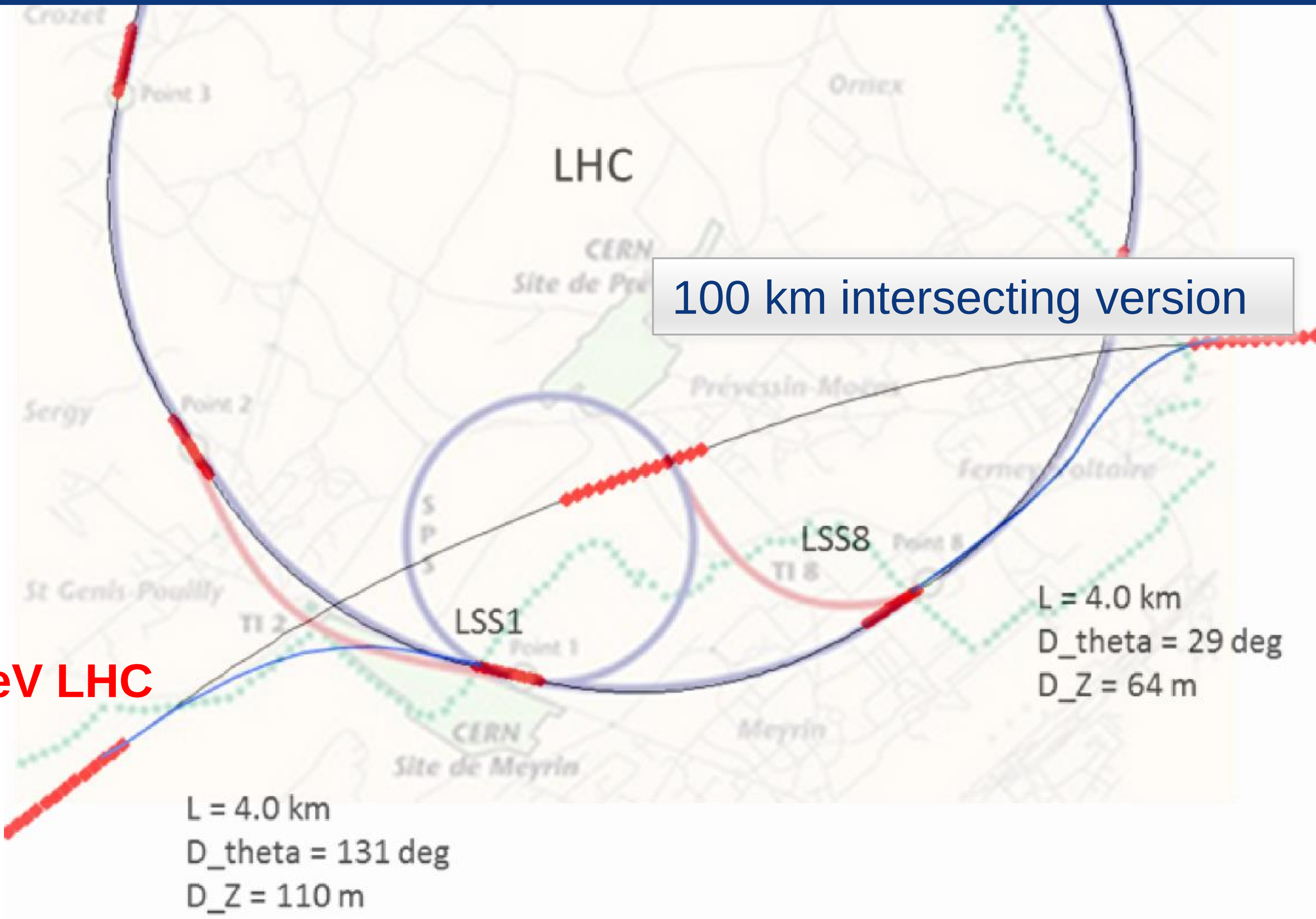
Point	Shaft Depth (m) Actual	Molasse SA	Wildflysch	Quaternary	Geology (m) Molasse	Urgonian	Calcaire
A	304	0	0	12	213	0	79
B	266	0	0	80	156	0	30
C	257	0	0	58	199	0	0
D	272	52	0	40	181	0	0
E	132	0	0	64	68	0	0
F	392	0	0	40	296	0	56
G	354	0	0	116	237	0	0
H	268	0	0	0	268	0	0
I	170	0	0	12	158	0	0
J	315	0	0	22	293	0	0
K	221	0	0	52	169	0	0
L	260	0	0	21	239	0	0
Total	3211	52	0	517	2478	0	109

- 90 – 100 km fits geological situation well
- LHC suitable as potential injector
- The 97.75 km version, tangent to LHC, is now being studied in more detail

FCC-hh injector studies

Injector options:

- SPS → LHC → FCC
- SPS/$SPS_{upgrade}$ → FCC



Current baseline:

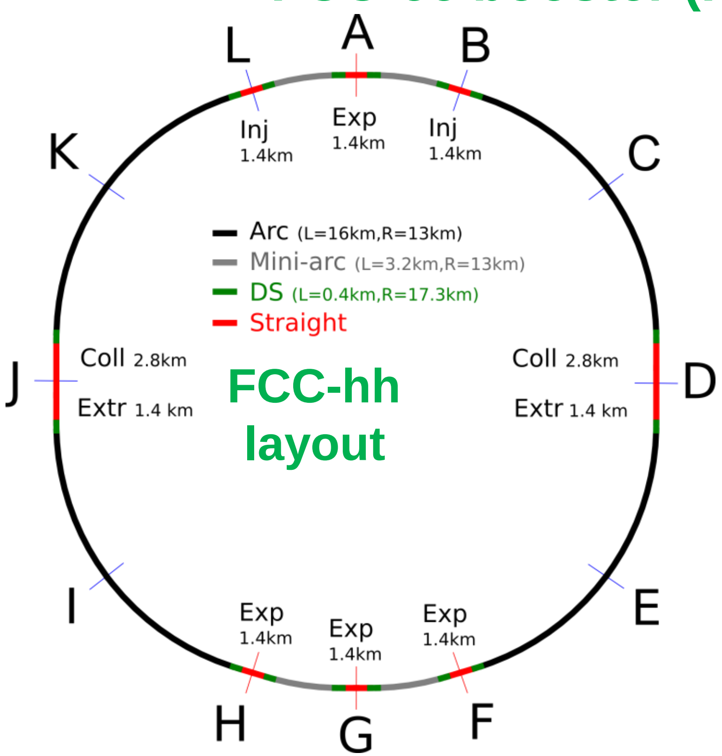
- Injection energy 3.3 TeV LHC

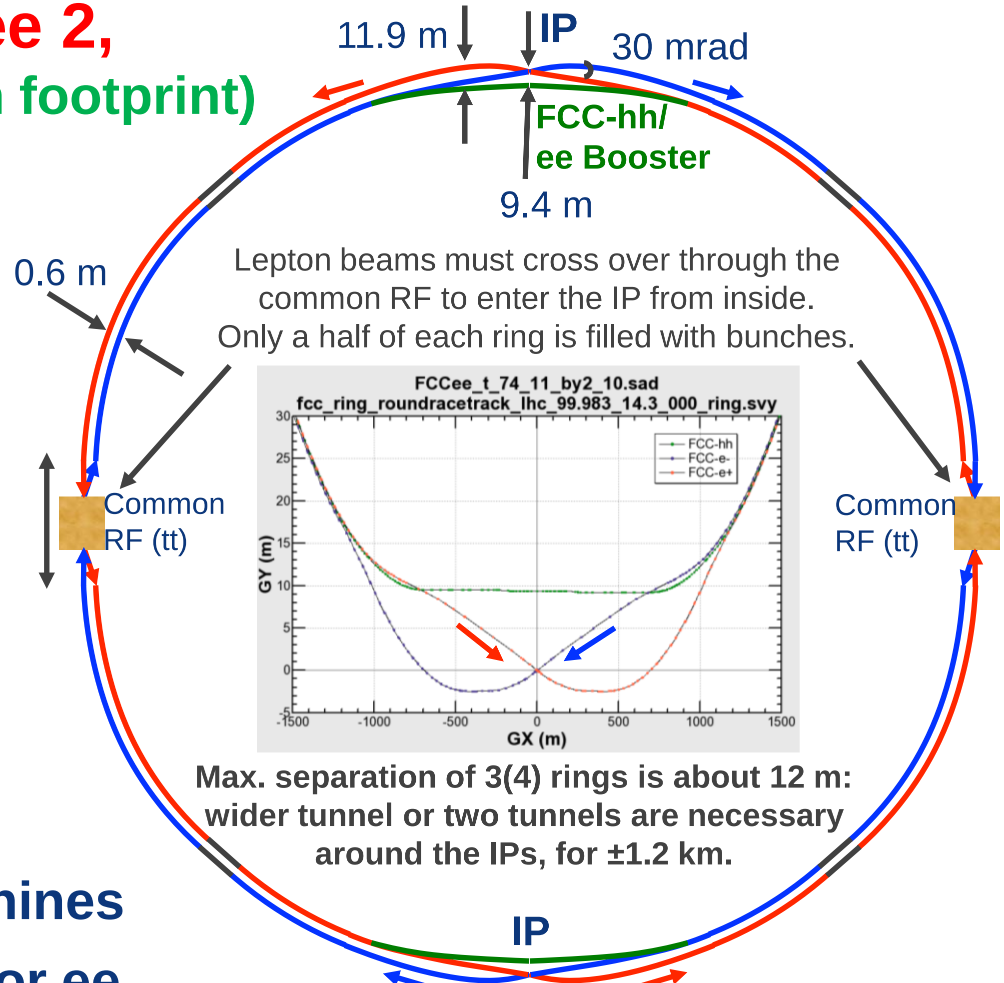
Alternative option:

- Injection around 1.5 TeV
- $SPS_{upgrade}$ could be based on fast-cycling SC magnets, 6-7T, ~ 1T/s ramp

Common layouts for hh & ee

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



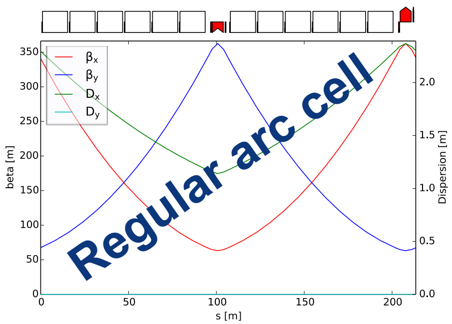


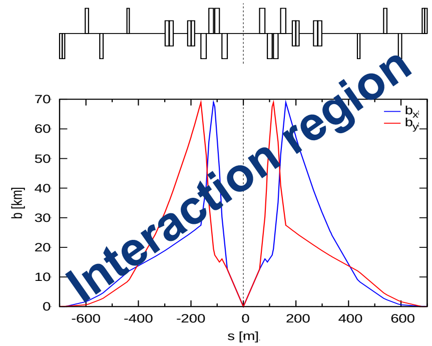
- **2 main IPs in A, G for both machines**
- **asymmetric IR optic/geometry for ee to limit synchrotron radiation to detector**

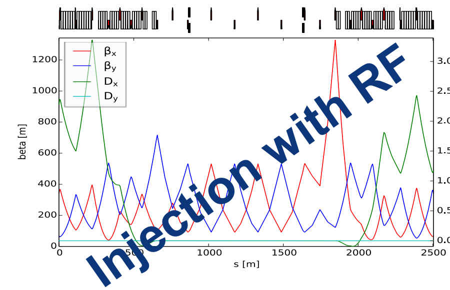
Hadron collider parameters

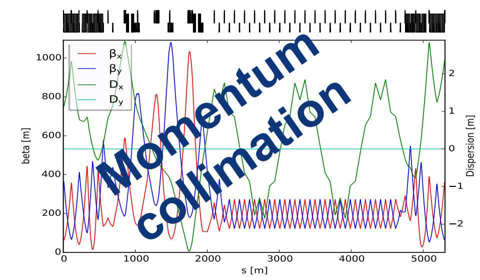
parameter	FCC-hh		HE-LHC* *tentative	(HL) LHC
collision energy cms [TeV]	100		>25	14
dipole field [T]	16		16	8.3
circumference [km]	100		27	27
# IP	2 main & 2		2 & 2	2 & 2
beam current [A]	0.5		1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25	25
beta* [m]	1.1	0.3	0.25	(0.15) 0.55
luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	5	20 - 30	>25	(5) 1
events/bunch crossing	170	<1020 (204)	850	(135) 27
stored energy/beam [GJ]	8.4		1.2	(0.7) 0.36
synchrotr. rad. [W/m/beam]	30		3.6	(0.35) 0.18

FCC-hh optics & layout



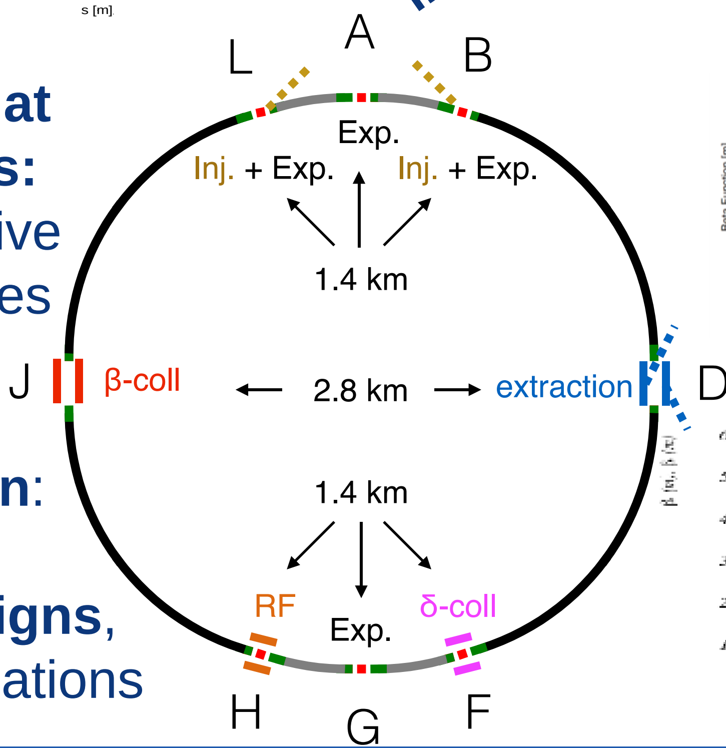


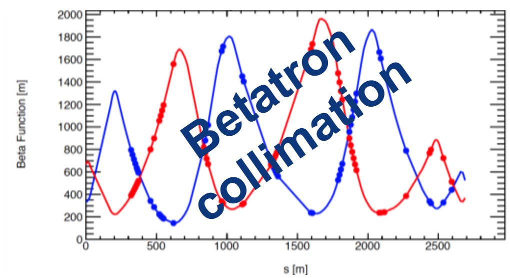




Contributions from teams **at CERN and other institutes:**

- Complete optics, collective effects, collimation studies



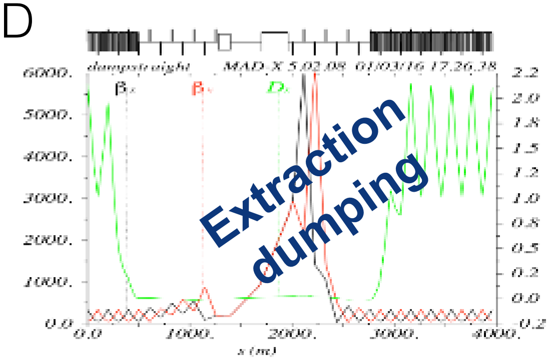


NEW LAYOUT NOV. 2016

Basis for **design evaluation**:

- Beam dynamics, losses

Feedback to element designs, e.g. magnet quality specifications



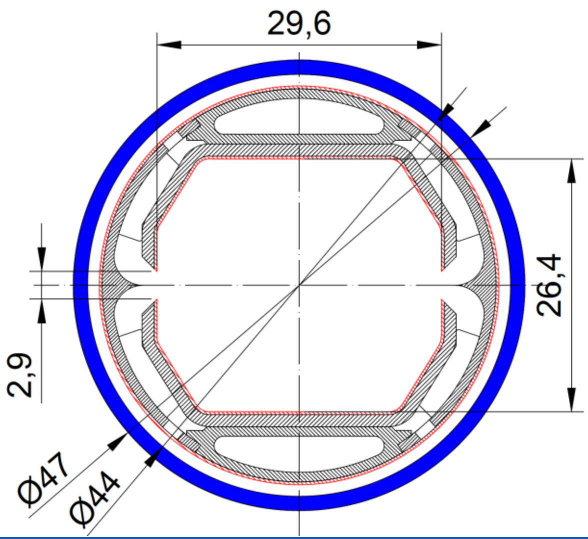
Synchrotron radiation beam screen prototype

High synchrotron radiation load of proton beams @ 50 TeV:

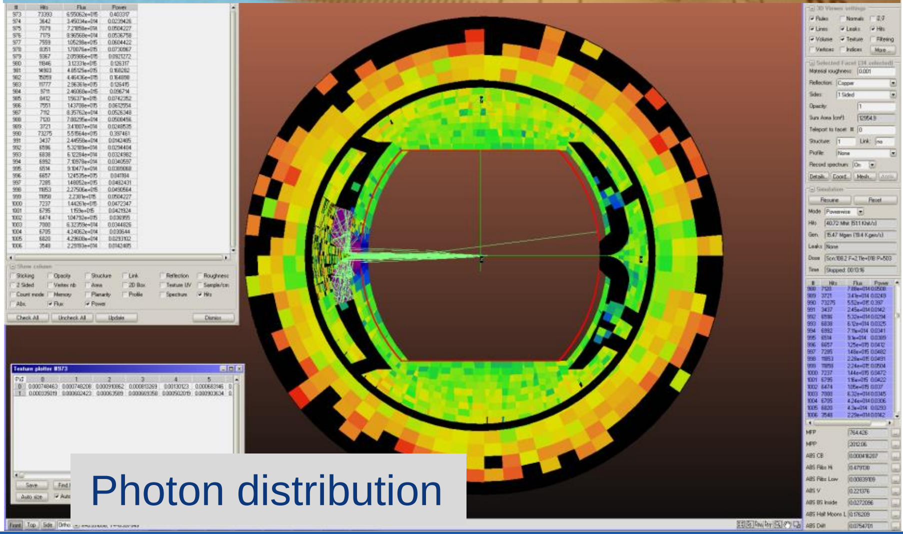
- **~30 W/m/beam (@16 T)** (LHC <0.2W/m)
- **5 MW total in arcs (@1.9 K!!!)**

New Beam screen with ante-chamber

- absorption of synchrotron radiation at 50 K to reduce cryogenic power by a factor 50 to 100 MW total

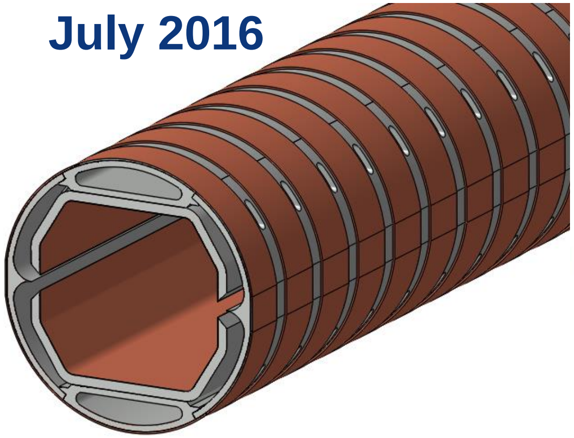


First FCC-hh beam screen prototype
Testing 2017 in ANKA within EuroCirCol

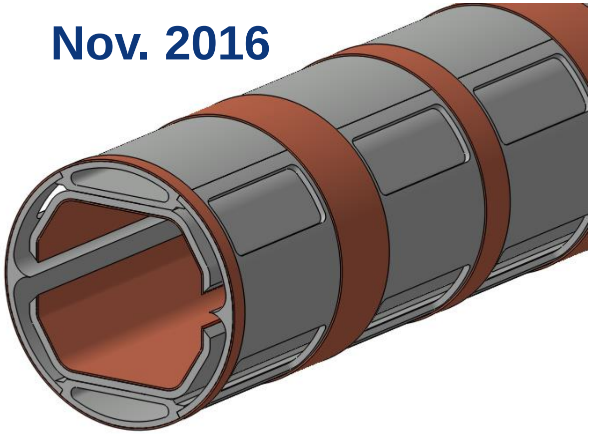


evolution of beam screen design

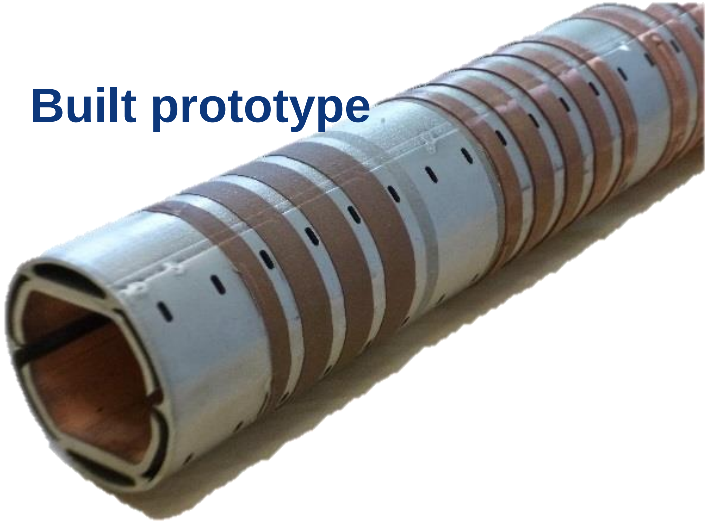
July 2016



Nov. 2016

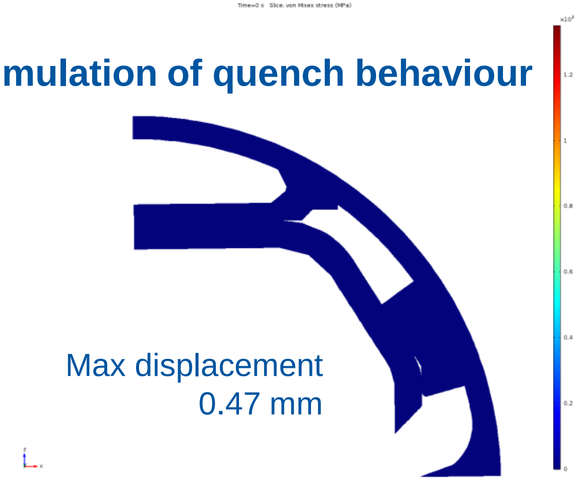


Built prototype



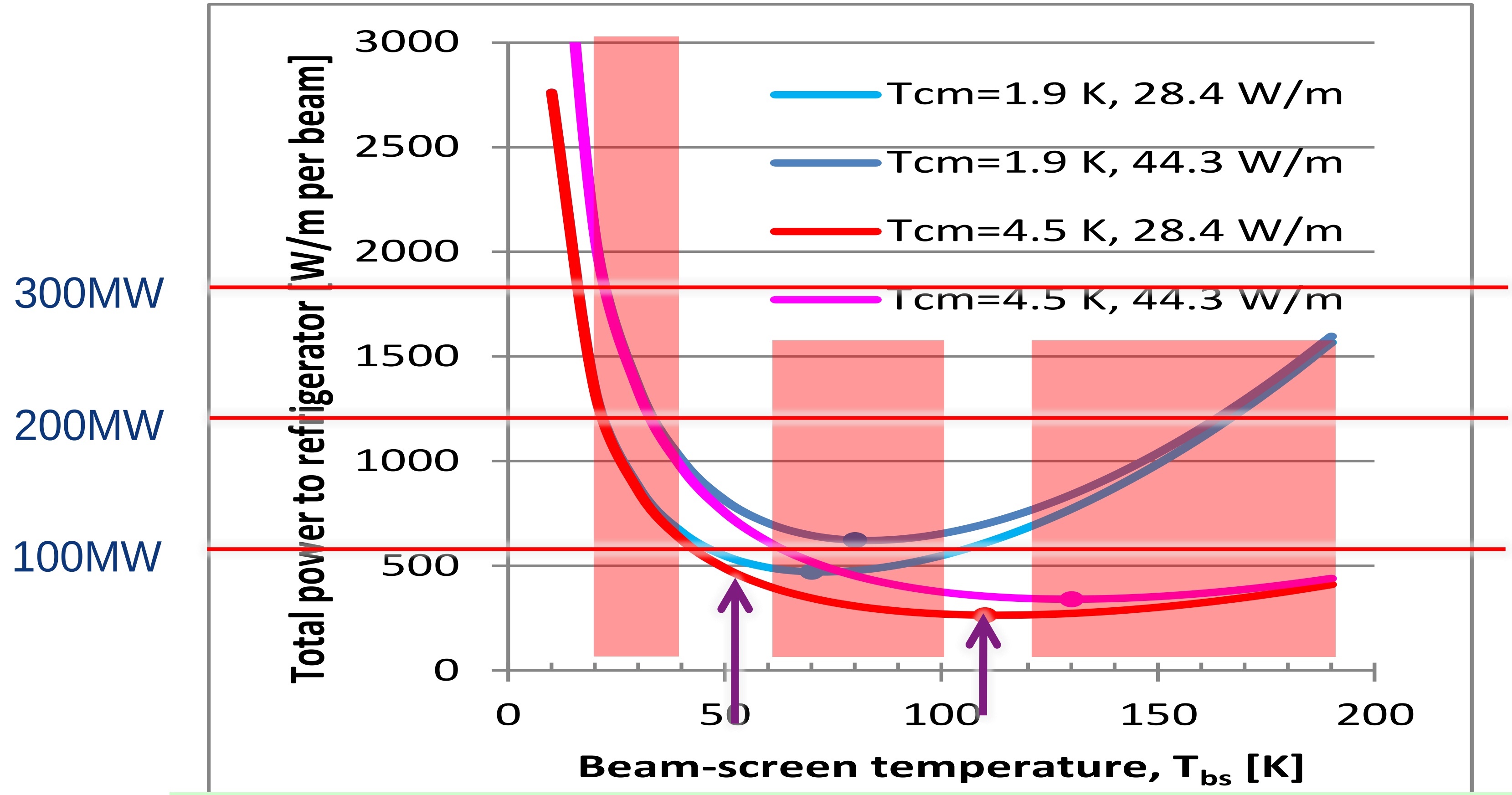
Ready for test @ ANKA in 2017

Progress on
- Geometry design and beam screen support
- Prototype construction
- Thermal load to cold bore reduction
- Synchrotron Radiation absorber
- Pumping speed optimisation
- Pumping holes optimisation
- Misalignment effects



Cryo power for cooling of SR heat

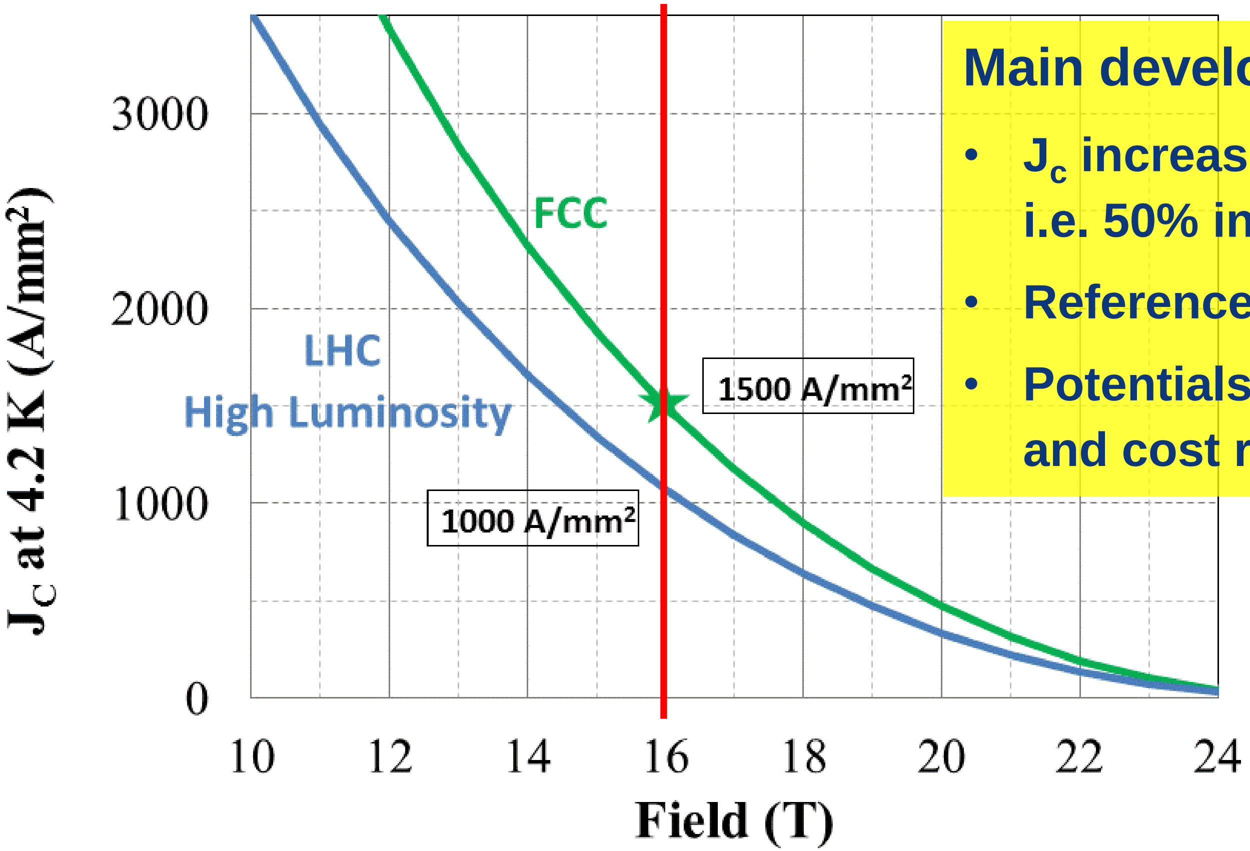
Overall optimisation of cryo-power, vacuum and impedance
Termperature ranges: <20, 40K-60K, 100K-120K



Multi-bunch instability growth time: 25 turns 9 turns (ΔQ=0.5)

Nb_3Sn conductor program

Nb_3Sn is one of the major cost & performance factors for FCC-hh and requires highest attention



Main development goals until 2020:

- J_c increase (16T, 4.2K) > 1500 A/mm² i.e. 50% increase wrt HL-LHC wire
- Reference wire diameter 1 mm
- Potentials for large scale production and cost reduction

Collaborations FCC Nb_3Sn program

Procurement of state-of-the-art conductor for protoyping:

- **Bruker**– **European,**
- **OST** – **US**

Stimulate conductor development with regional industry:

- **CERN/KEK** – **Japanese** contribution. Japanese **industry** (JASTEC, Furukawa, SH Copper) and laboratories (Tohoku Univ. and NIMS).
- **CERN/Bochvar High-technology Research Inst.** – **Russian** contribution. Russian **industry** (TVEL) and laboratories
- **CERN/KAT** – **Korean** **industrial** contribution
- **CERN/Bruker**– **European** **industrial** contribution

Characterisation of conductor & research with universities:

- **Europe: Technical Univ. Vienna, Geneva University, University of Twente**
- **Applied Superconductivity Centre** at Florida State University

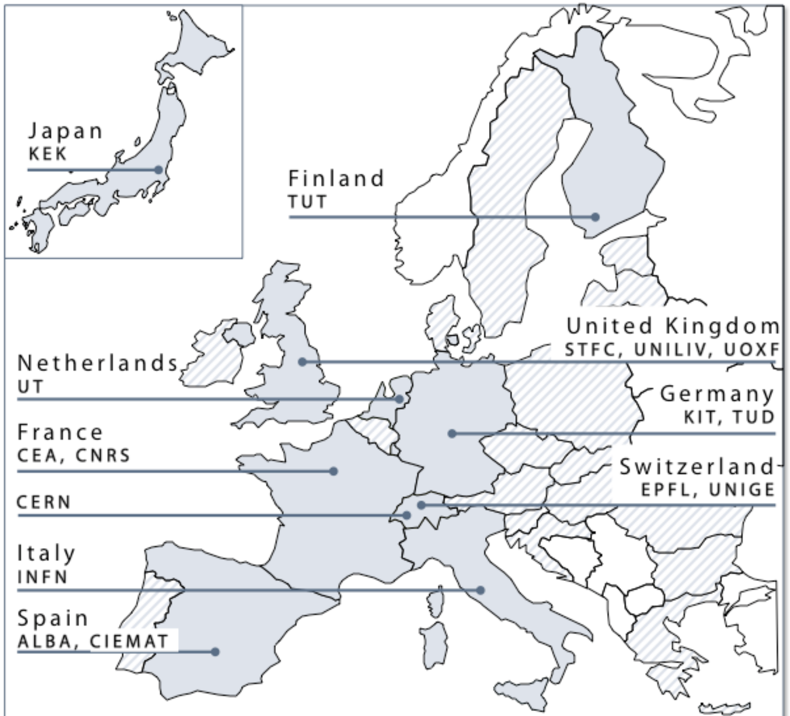
New US DOE MDP effort – **US** activity with **industry** (OST) and labs

CERN-EU program 'EuroCirCol' on 16 T dipole design

UNIVERSITY OF TWENTE. INFN TAMPERE UNIVERSITY OF TECHNOLOGY

cea

cnrs dépasser les frontières



EuroCirCol consortium, federating 16 partners, 1 from Japan and 1 IEIO

CERN

UNIVERSITY OF OXFORD

TECHNISCHE UNIVERSITÄT DARMSTADT

KIT Karlsruher Institut für Technologie

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

UNIVERSITÉ DE GENÈVE

ALBA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

MANCHESTER 1824

European Union Horizon 2020 program

- Support for FCC study
- Grant agreement 654305
- 3 MEURO co-funding

Scope:

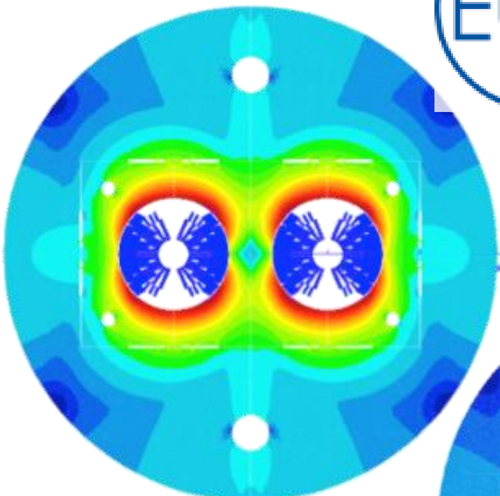
FCC hadron collider

- Optics Design
- Cryo vacuum design
- 16 T dipole design, construction folder for demonstrator magnets

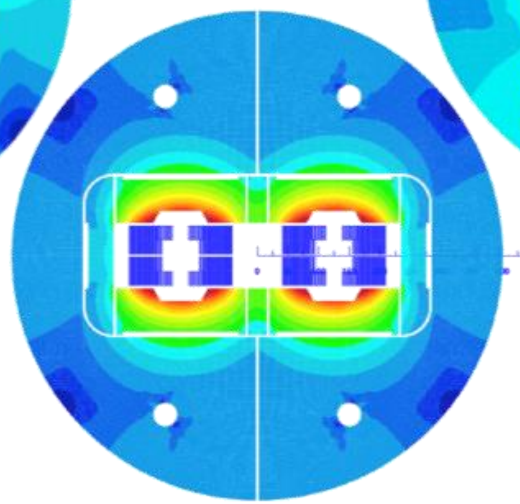
16 T dipole options and plans

EuroCirCol
A key to New Physics

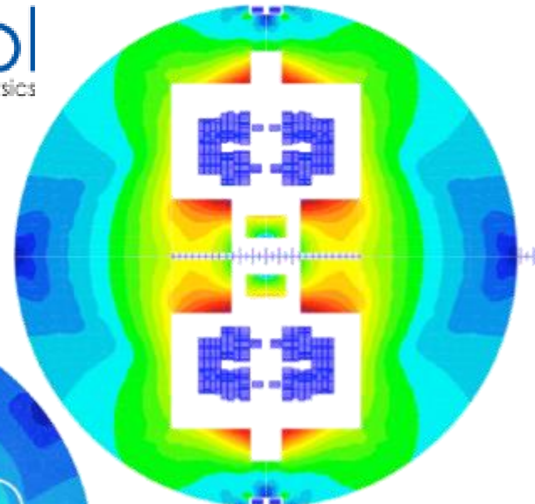
Cos-theta



Blocks

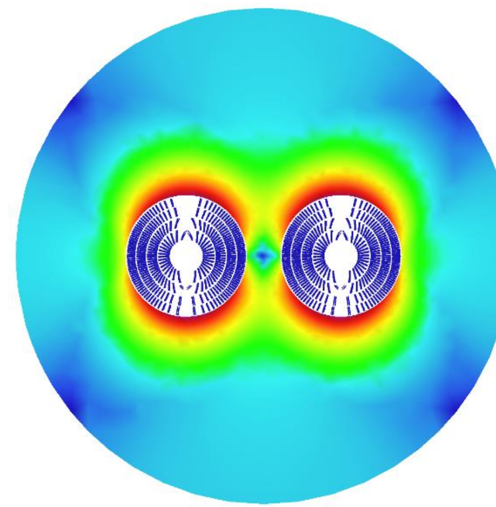


Common coils



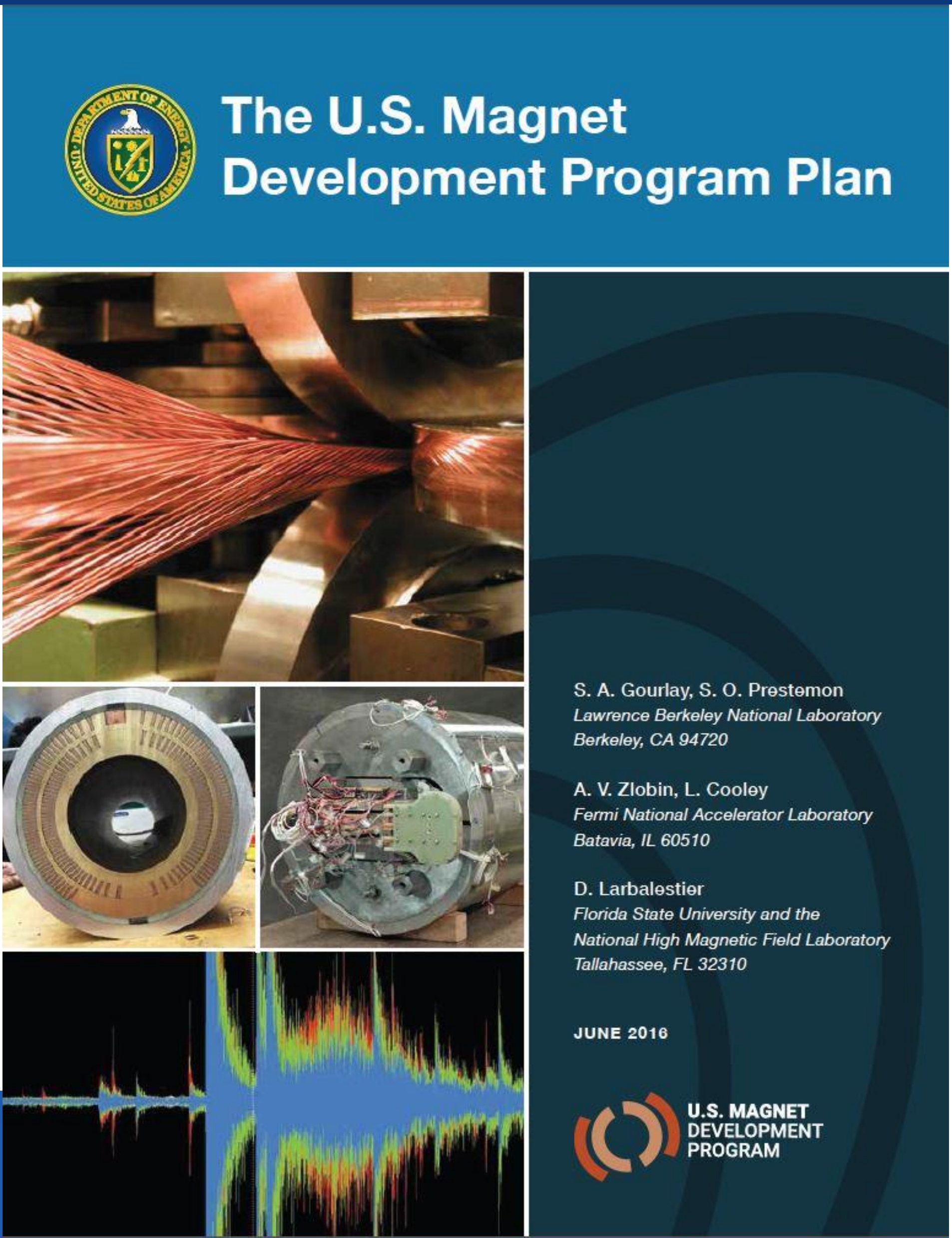
Swiss contribution
via PSI

Canted
Cos-theta



- **Down-selection of options mid 2017 for detailed design work**
- **Model production 2018 - 2022**
- **Prototype production 2023 - 2025**

US Magnet Development Program


The U.S. Magnet Development Program Plan

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JUNE 2016

U.S. MAGNET DEVELOPMENT PROGRAM

Program (MDP) Goals:

GOAL 1:

Explore the performance limits of Nb_3Sn accelerator magnets with a focus on minimizing the required operating margin and significantly reducing or eliminating training.

GOAL 2:

Develop and demonstrate an HTS accelerator magnet with a self-field of 5 T or greater compatible with operation in a hybrid LTS/HTS magnet for fields beyond 16 T.

GOAL 3:

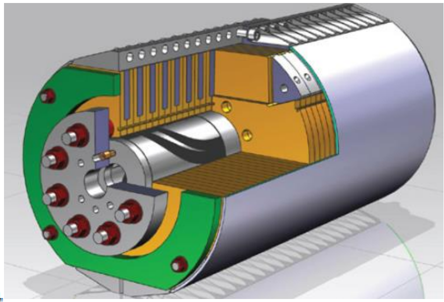
Investigate fundamental aspects of magnet design and technology that can lead to substantial performance improvements and magnet cost reduction.

GOAL 4:

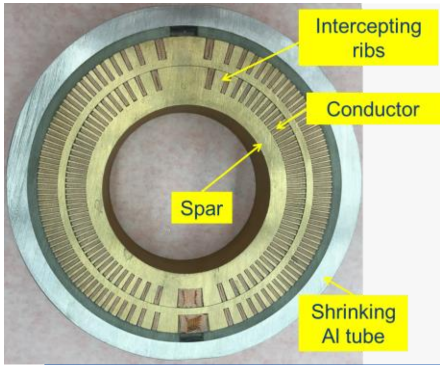
Pursue Nb_3Sn and HTS conductor R&D with clear targets to increase performance and reduce the cost of accelerator magnets.

Under Goal 1:

16 T cos theta dipole design



16 T canted cos theta (CCT) design



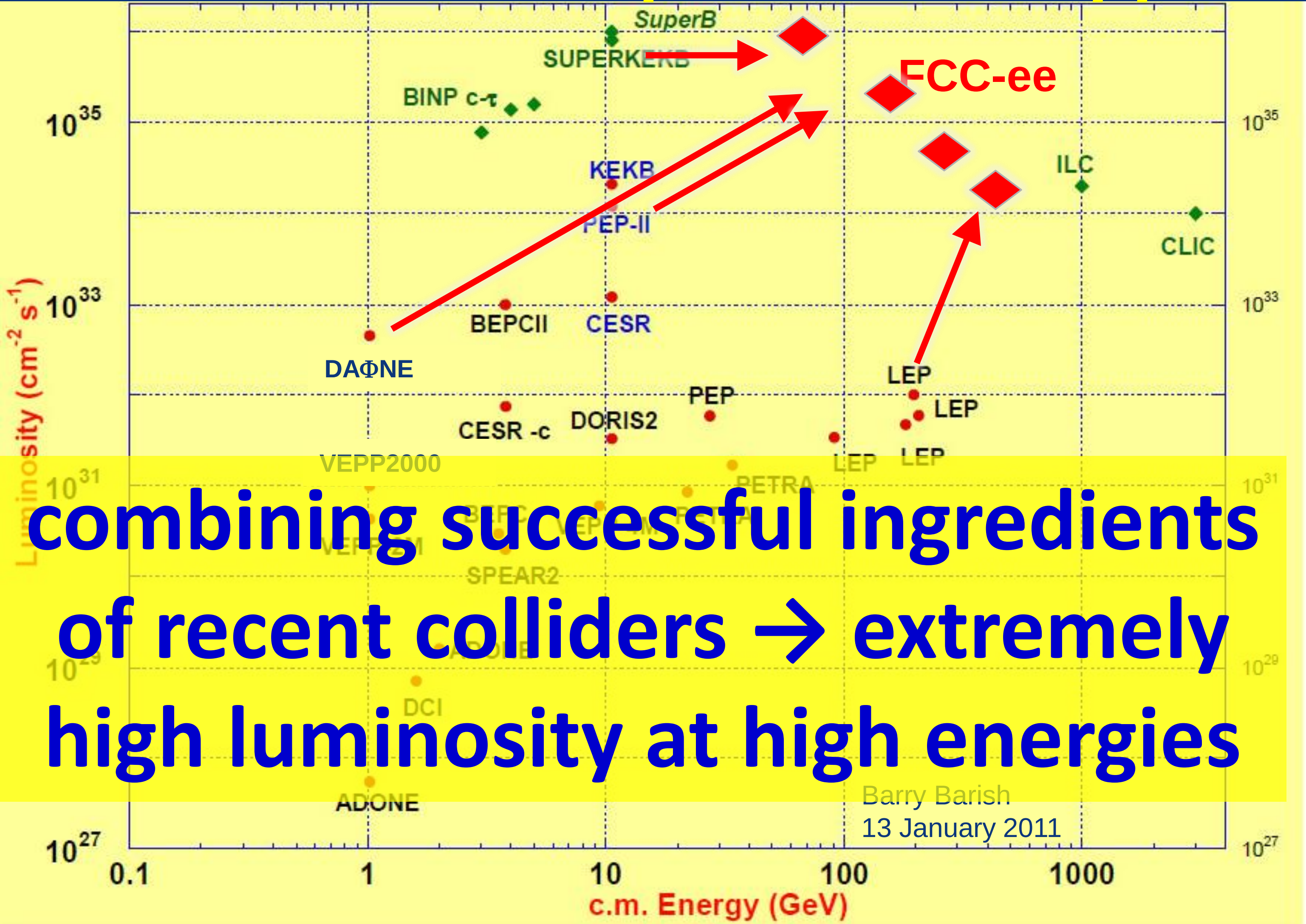
lepton collider parameters

parameter	FCC-ee (400 MHz)					LEP2
Physics working point	**Z**		**WW**	**ZH**	**tt_{bar}**	
energy/beam [GeV]	**45.6**		**80**	**120**	**175**	105
bunches/beam	30180	**91500**	**5260**	**780**	**81**	4
bunch spacing [ns]	7.5	**2.5**	**50**	**400**	**4000**	22000
bunch population [10^{11}]	1.0	**0.33**	**0.6**	**0.8**	**1.7**	4.2
beam current [mA]	1450	**1450**	**152**	**30**	**6.6**	3
luminosity/IP x $10^{34}cm^{-2}s^{-1}$	210	**90**	**19**	**5.1**	**1.3**	0.0012
energy loss/turn [GeV]	0.03	**0.03**	**0.33**	**1.67**	**7.55**	3.34
synchrotron power [MW]	**100**					22
RF voltage [GV]	0.4	**0.2**	**0.8**	**3.0**	**10**	3.5

identical FCC-ee baseline optics for all energies

FCC-ee: 2 separate rings, LEP: single beam pipe

FCC-ee exploits lessons & recipes from past e^+e^- and *pp* colliders



combining successful ingredients of recent colliders → extremely high luminosity at high energies

LEP:
- high energy
- SR effects

B-factories:

KEKB & PEP-II:
- high beam currents
- top-up injection

DAFNE: crab waist

Super B-factories

S-KEKB: low β_y*

KEKB: e^+ source

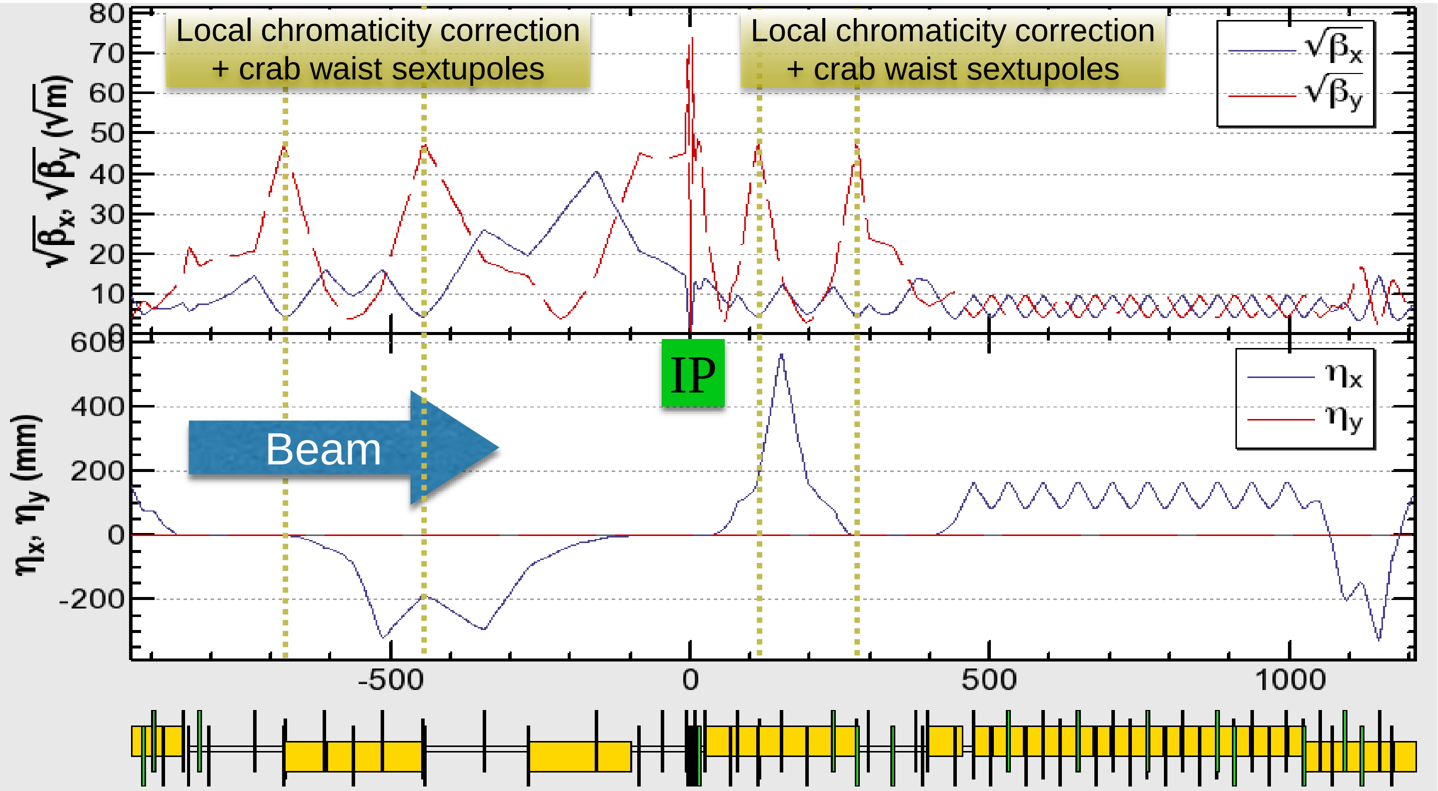
HERA, LEP, RHIC:
- spin gymnastics

FCC-ee optics design

Optics design for all working points achieving baseline performance

Interaction region: asymmetric optics design

- Synchrotron radiation from upstream dipoles <100 keV up to 450 m from IP
- Dynamic aperture & momentum acceptance requirements fulfilled at all WPs



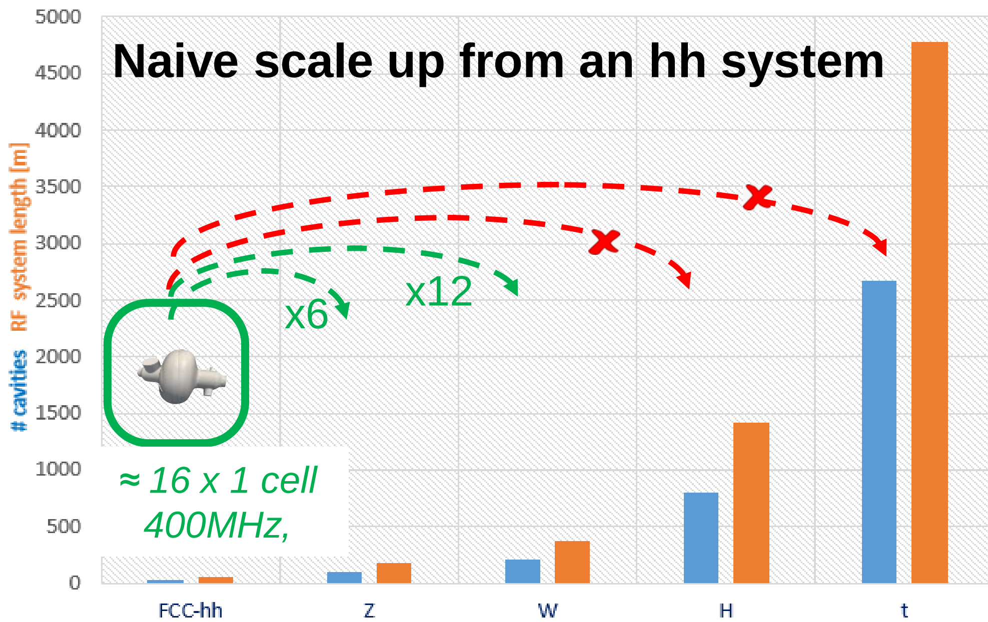
RF system requirements

Very large range of operation parameters

"Ampere-class" machines

	V_{total} GV	$n_{bunches}$	I_{beam} mA	ΔE/turn GeV
hh	0.032		**500**	
Z	0.4/0.2	30000/90000	**1450**	0.034
W	0.8	5162	152	0.33
H	**5.5**	770	30	1.67
t	**10**	78	6.6	7.55

"high gradient" machines

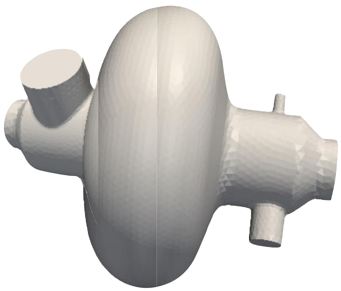


- **Voltage and beam current ranges span more than factor > 10^2**
- **No well-adapted single RF system solution satisfying requirements**

RF system R&D lines

400 MHz single-cell cavities preferred for hh and ee-Z (few MeV/m)

- Baseline Nb/Cu @4.5 K, development with synergies to HL-LHC, HE-LHC
- R&D: power coupling 1 MW/cell, HOM power handling (damper, cryomodule)



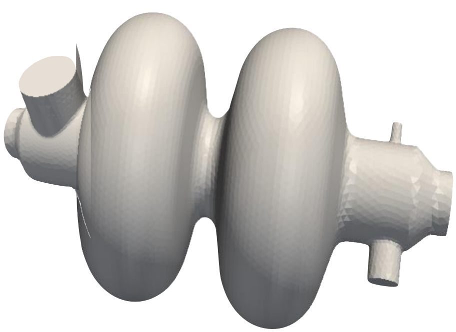
hh: ≈ 16 cells per beam

Z: ≈ 100 per beam (+ 100 for booster ring)

(W: ≈ 210 per beam (+ 210 for booster ring))

400 or 800 MHz multi-cell cavities preferred for ee-ZH, ee-tt and ee-WW

- Baseline options 400 MHz Nb/Cu @4.5 K, ◄━► 800 MHz bulk Nb system @2K
- R&D: High Q_0 cavities, coating, long-term: Nb_3Sn like components

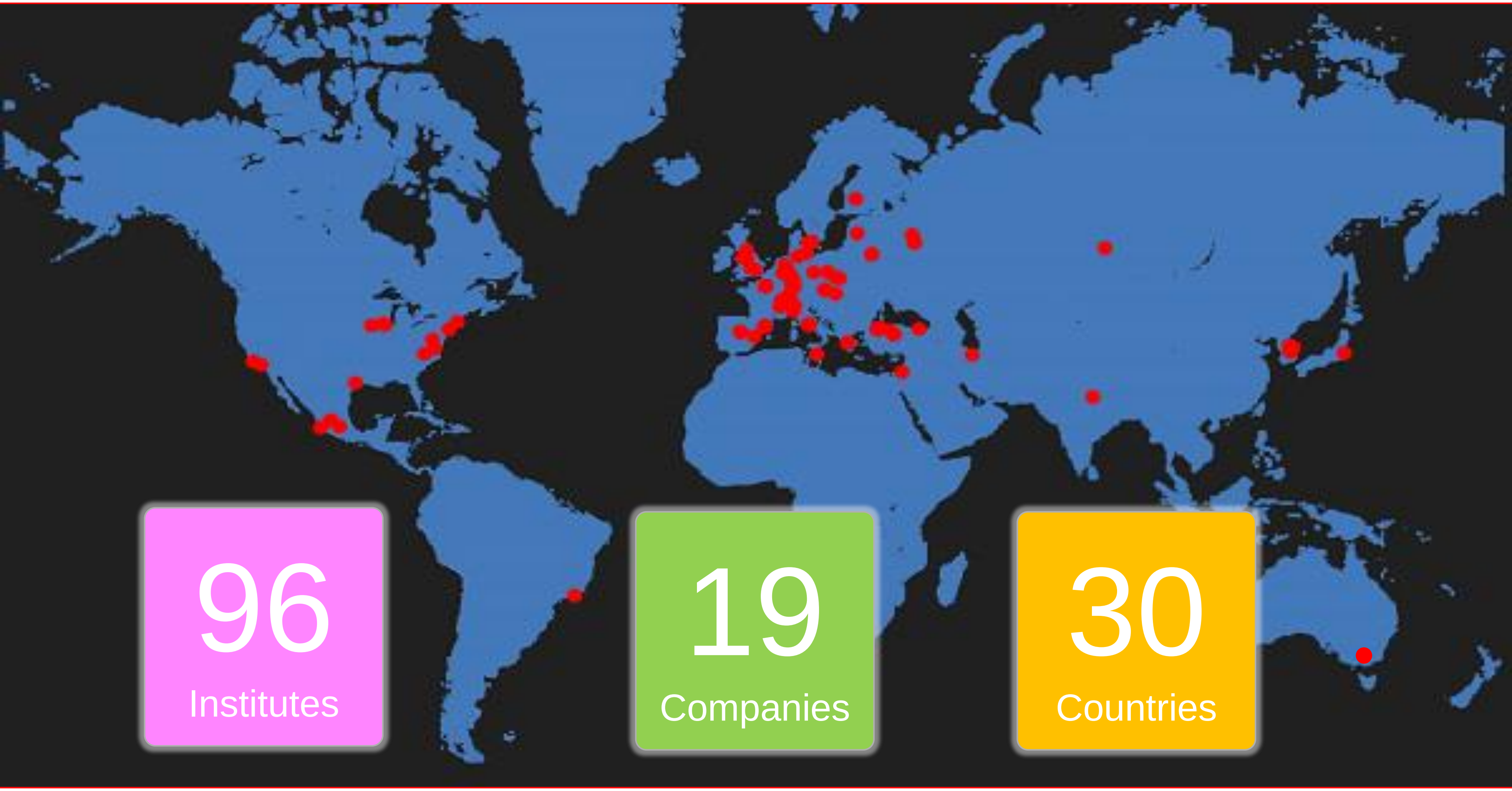


W: ≈ 200 per beam (+ 200 for booster)

H: ≈ 800 per beam (+ 800 for booster)

t: ≈ common 2600 cells for both beams (+ 2600 for booster)

collaboration & industry relations



FCCWEEK 2016

International Future Circular Collider Conference

ROME 11-15 APRIL

fccw2016.web.cern.ch

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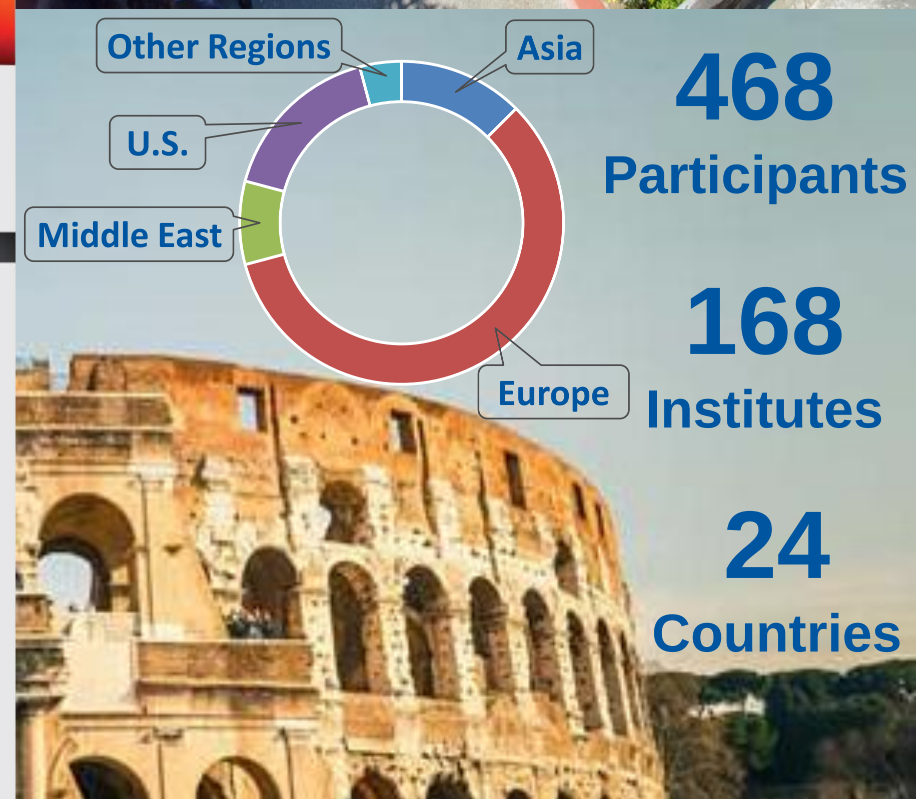

Summary

- FCC study is advancing well towards the CDR for end 2018
- Consolidated parameter sets exists for FCC-hh and FCC-ee machines with complete baseline optics design and beam dynamics compatible with parameter requirements
- First round of geology, civil engineering & infrastructure studies completed
- Superconductivity is the key enabling technology for FCC. The Nb3Sn program towards 16 T model magnets is of prime importance for FCC-hh and so is the development of high-efficiency SRF systems for FCC-ee.
- **International collaboration is essential to advance on all challenging subjects to prepare a solid and convincing case for the next European Strategy update.**


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