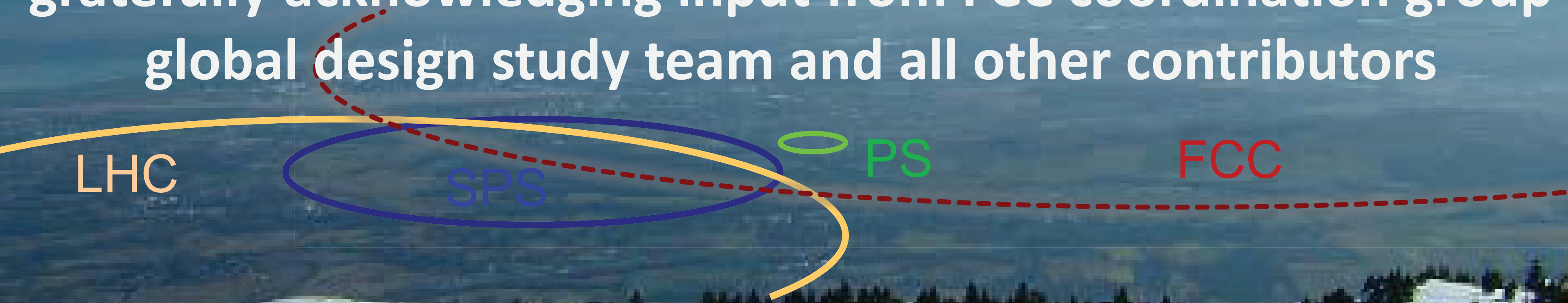
Future Circular Collider Study

Status and Progress

M. Benedikt

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 & Parameters
- Technologies
- FCC Organisation & Collaboration

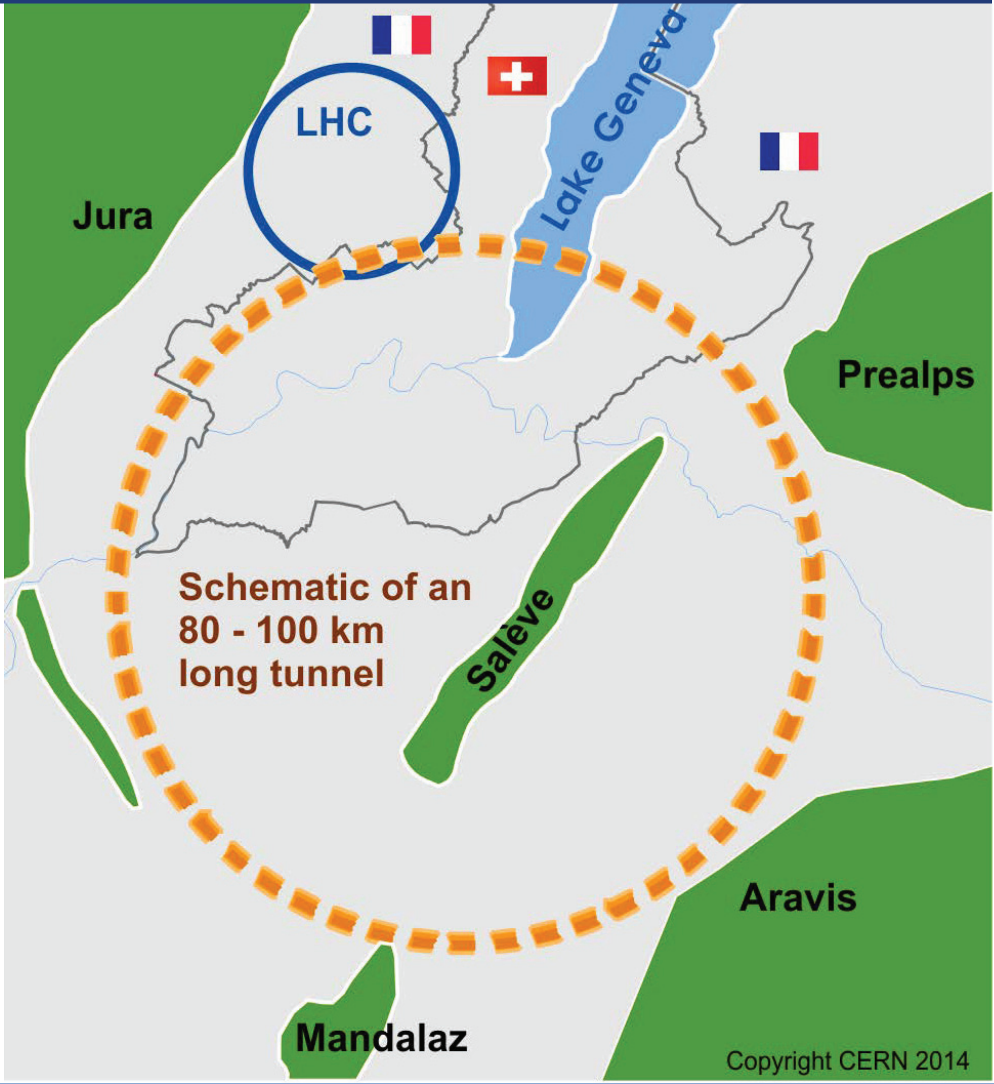
Future Circular Collider Study
Goal: CDR for European Strategy Update 2018/19

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

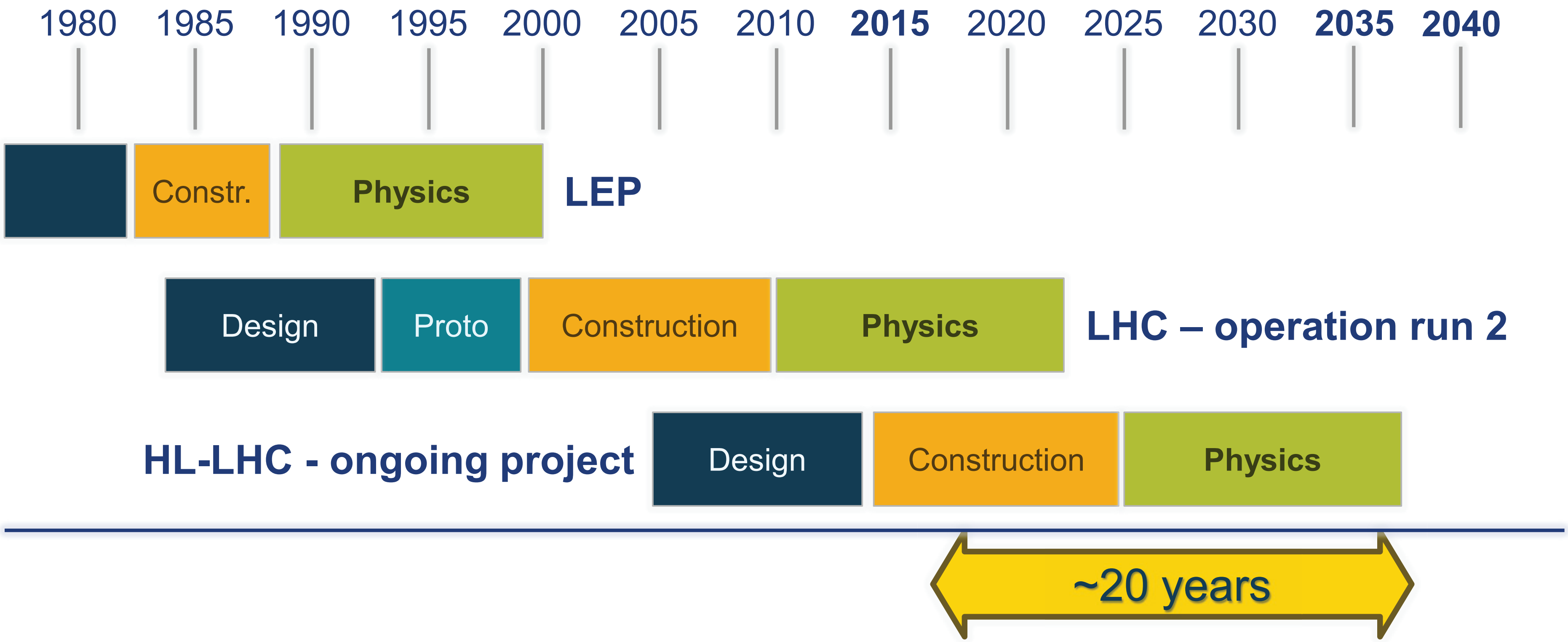
- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

  ~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



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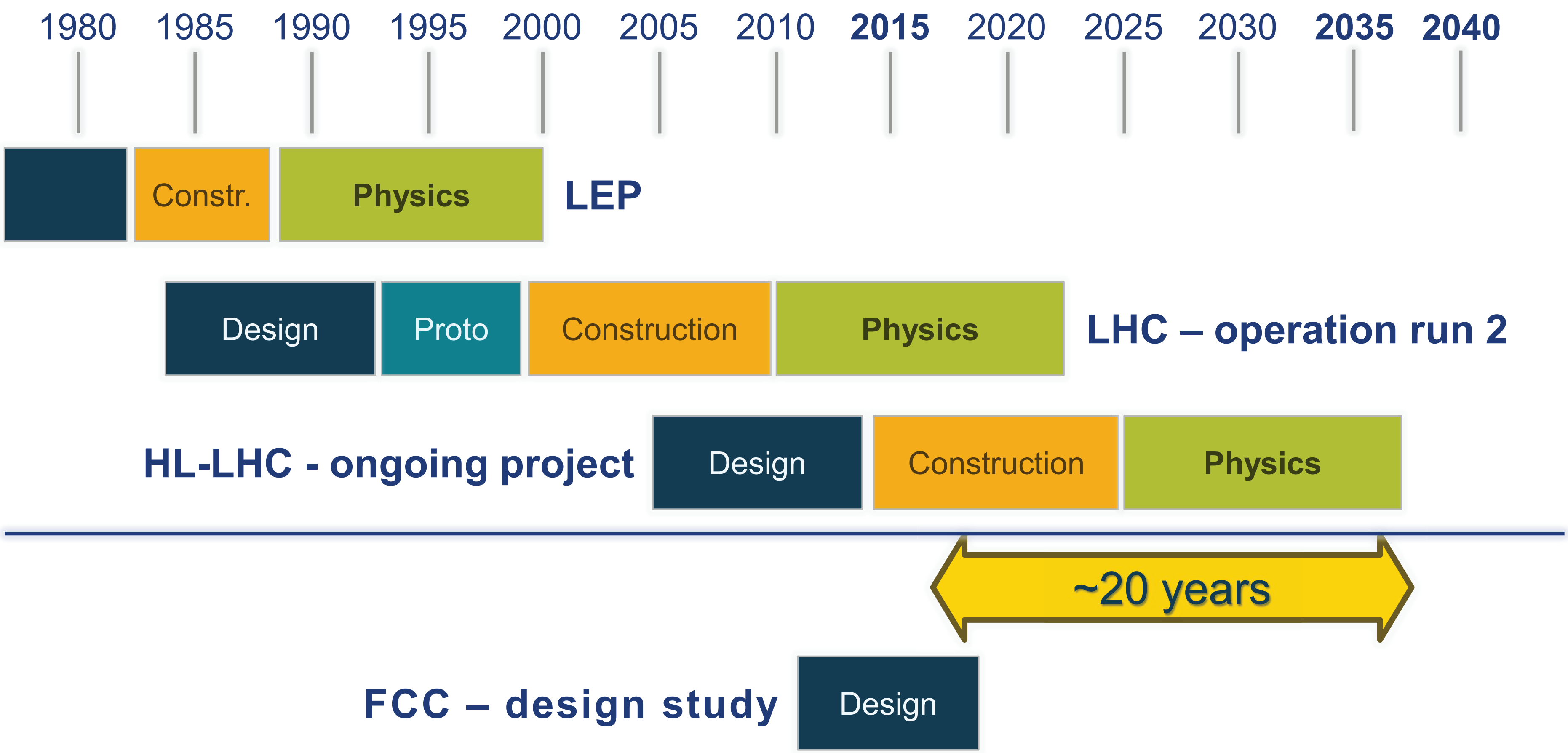

Must advance fast now to be ready for the period 2035 – 2040

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

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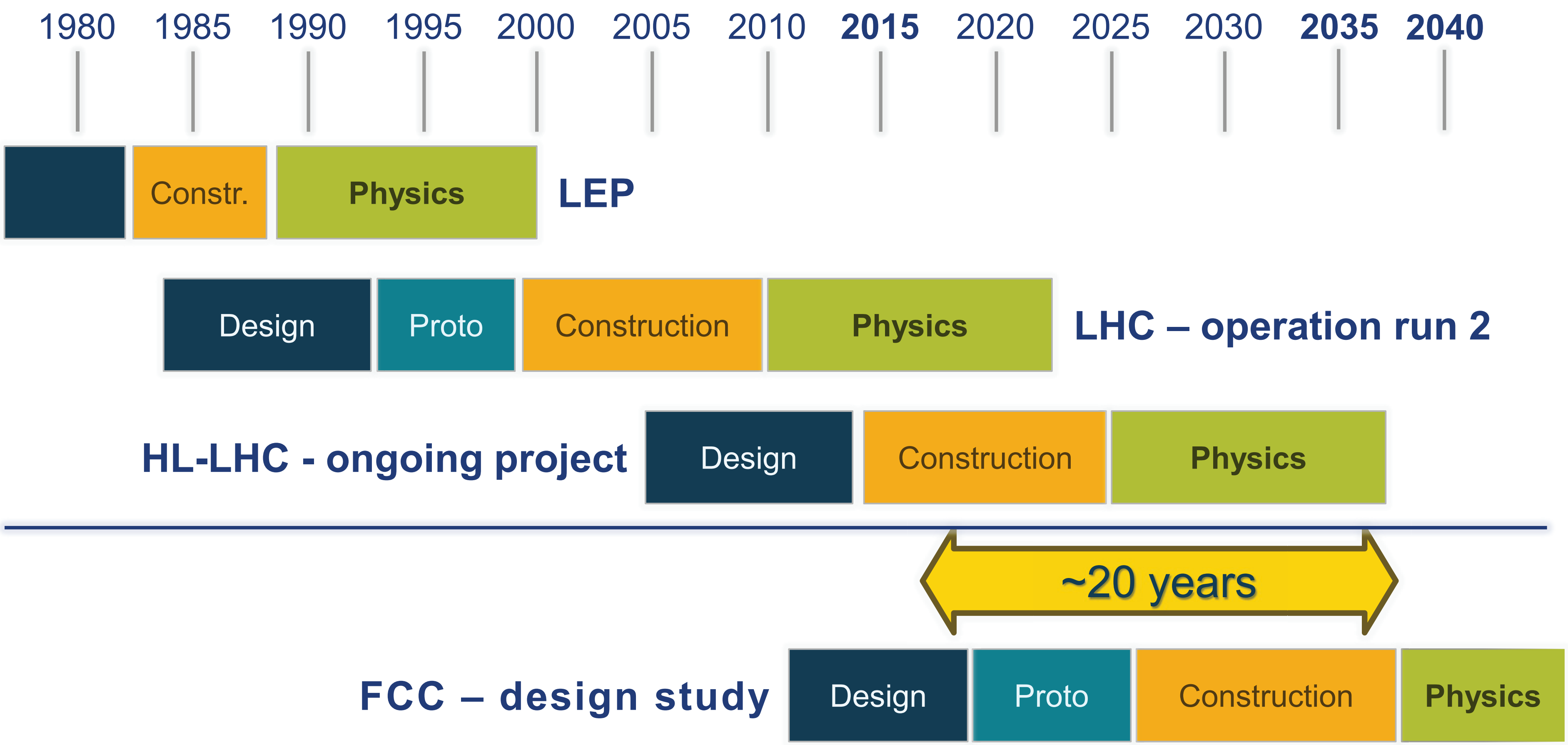

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Progress on site investigations

Alignment | Shafts | Query

Choose alignment option: 100km quasi-circular

Tunnel elevation at centre: 261mASL

Grad. Params

Azimuth (°): -20

Slope Angle x-x(%): 0.65

Slope Angle y-y(%): 0

LOAD | SAVE | CALCULATE

Alignment centre

X: 2499731 Y: 1108403

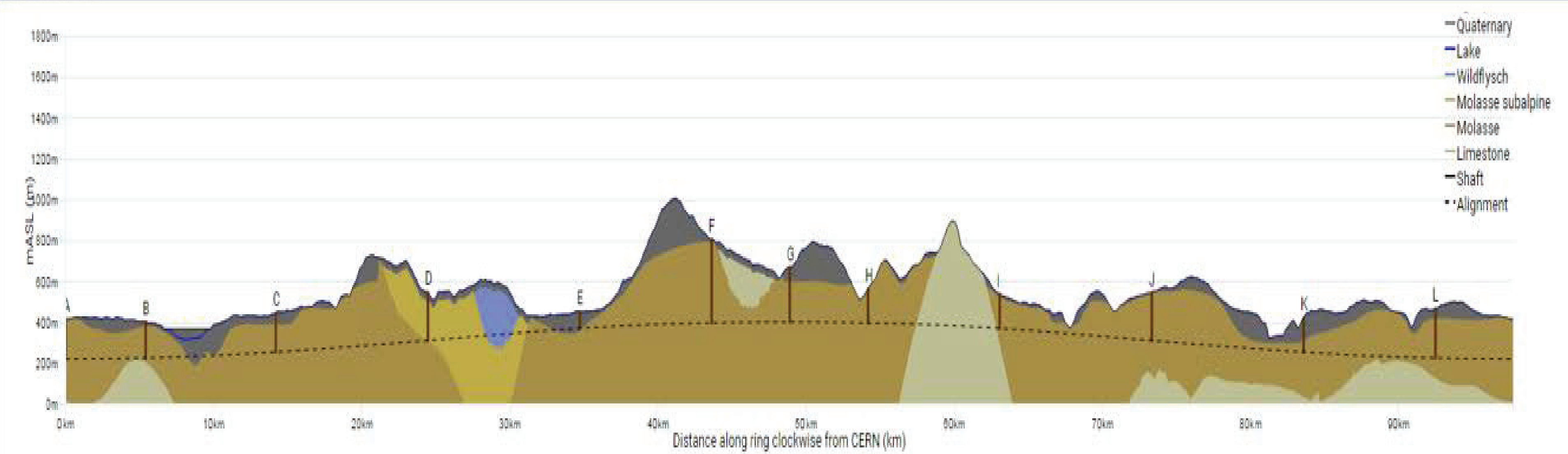
	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	-64°	220m	64°	172m
SPS		242m		241m
TI2		235m		241m
TI8		242m		170m

Alignment Location

Geology Intersected by Shafts | Shaft Depths

	Shaft Depth (m)				Geology (m)		
Point	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Calcaire
A	304	0	0	13	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

Alignment Profile



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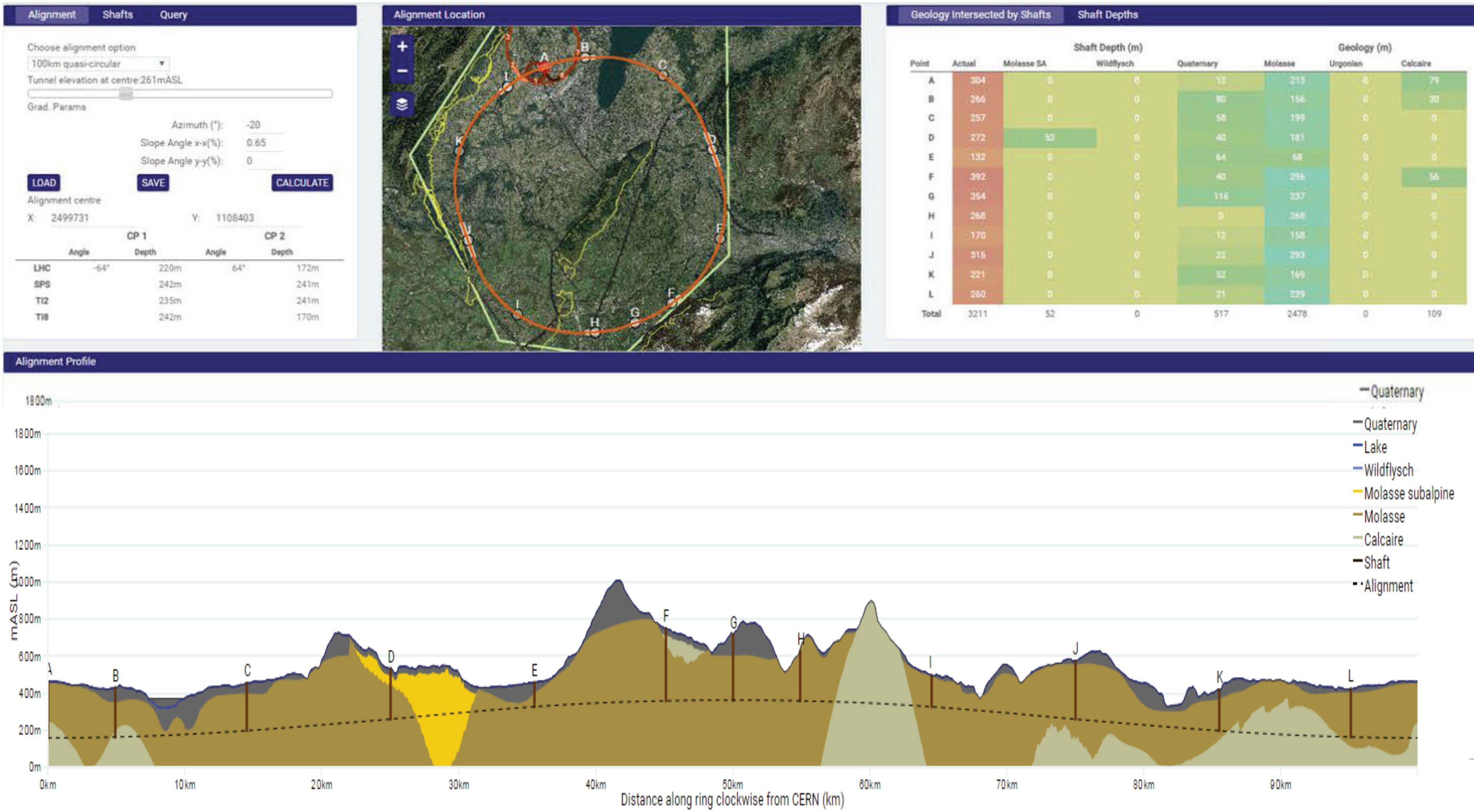

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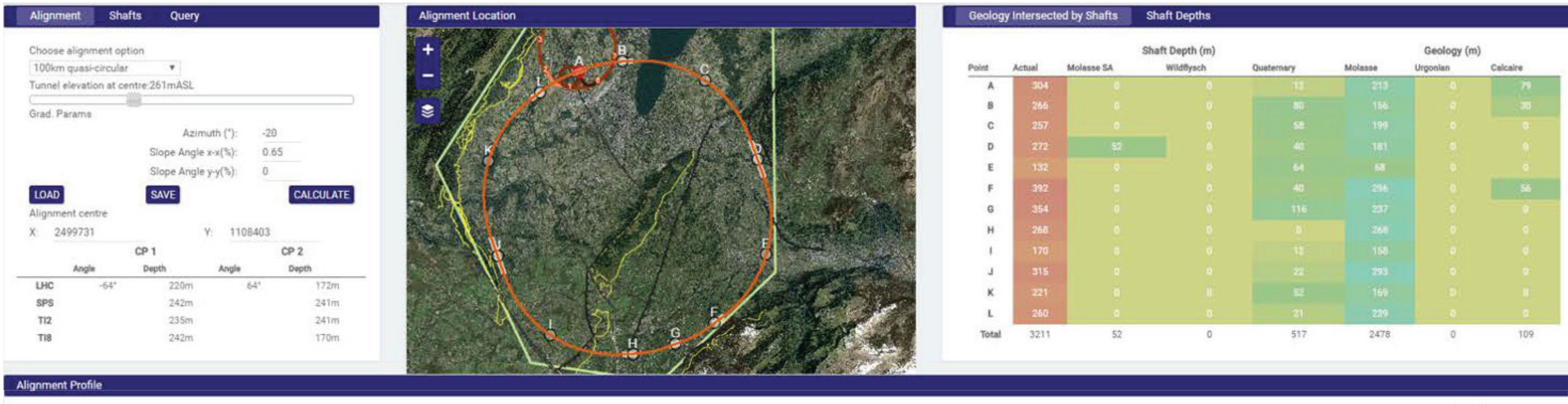
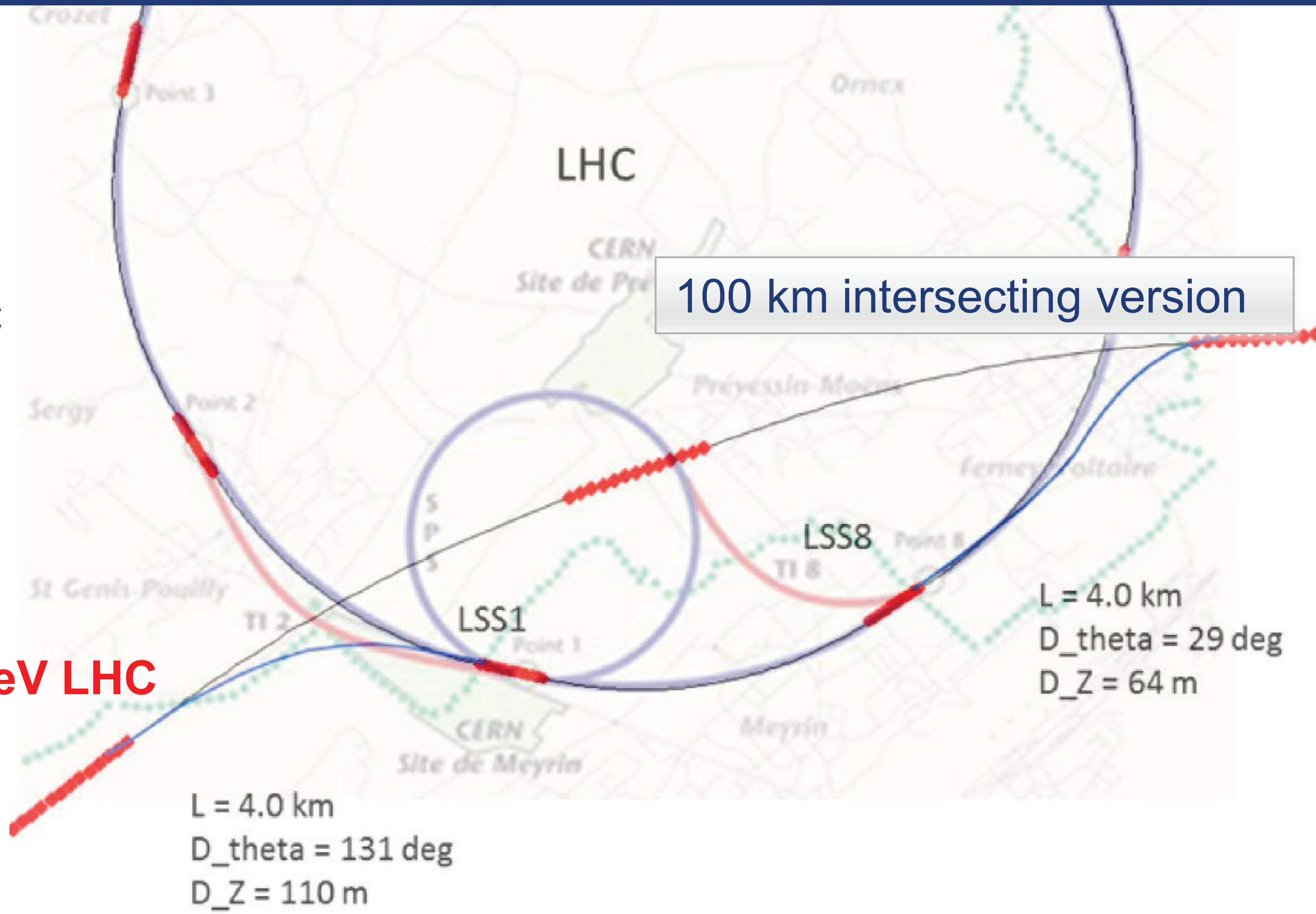


- 90 – 100 km fits geological situation well
- LHC suitable as potential injector
- The 100 km version, intersecting LHC, is now being studied in more detail

FCC-hh injector studies

Injector options:

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



Current baseline:

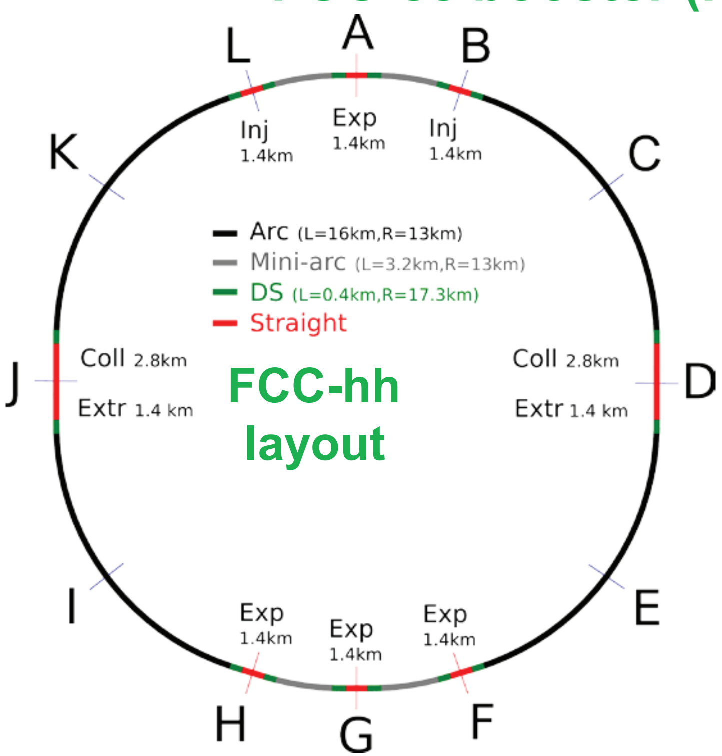
- **Injection energy 3.3 TeV LHC**

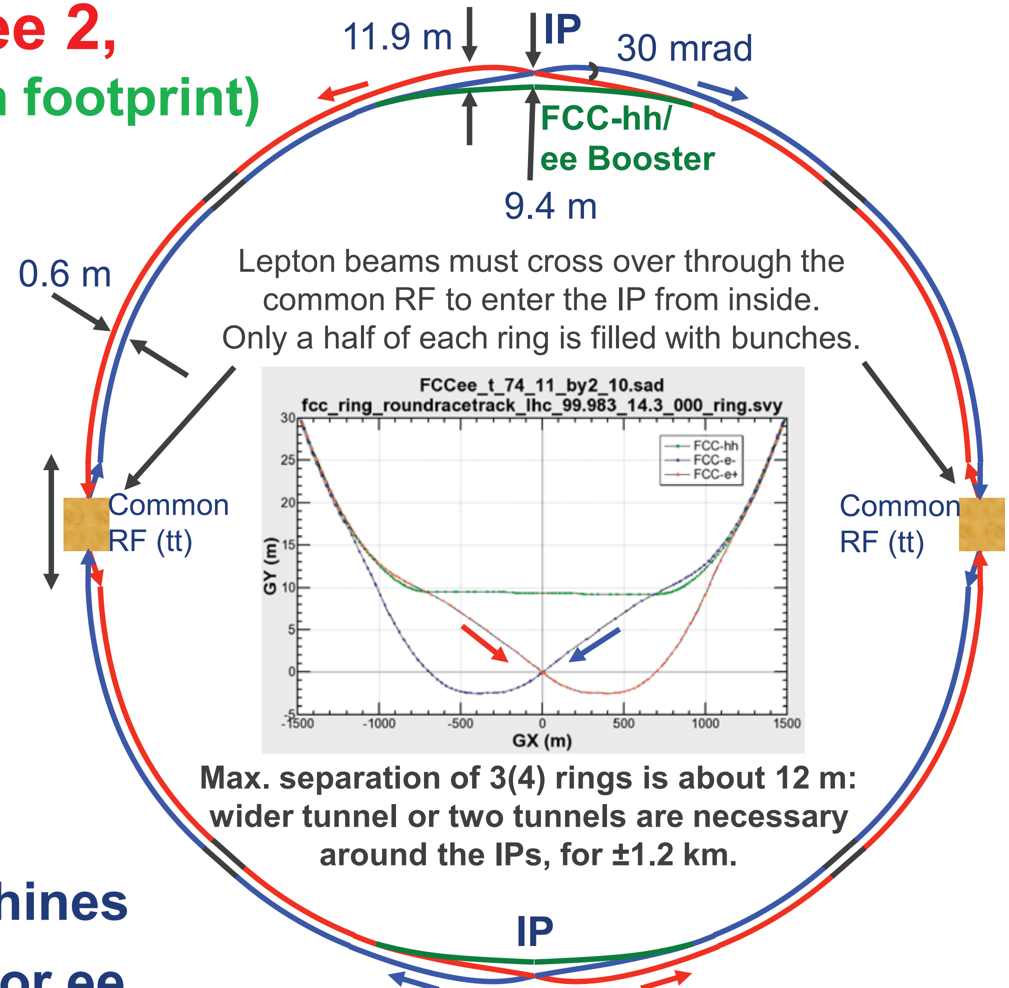
Alternative option:

- **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

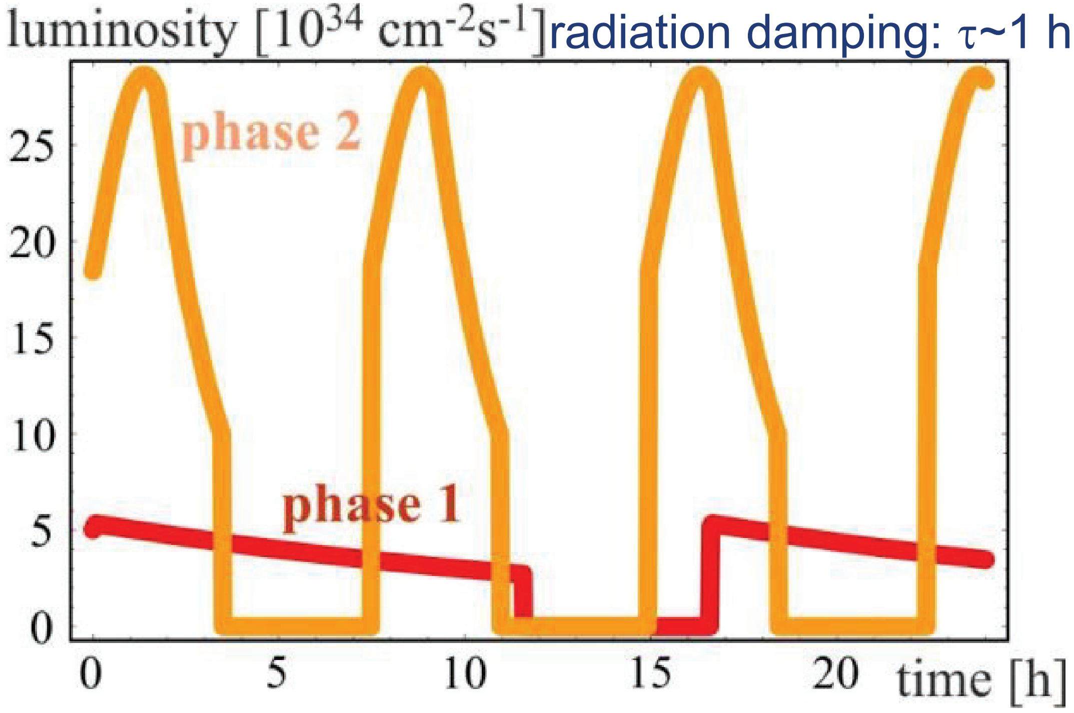
parameter	FCC-hh		HE-LHC* *tentative	(HL) LHC
collision energy cms [TeV]	100		>25	14
dipole field [T]	16		16	8.3
circumference [km]	100		27	27
# IP	2 main & 2		2 & 2	2 & 2
beam current [A]	0.5		1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25	25
beta* [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 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

Transition via operational experience, no HW modification



Total integrated luminosity over 25 years operation:

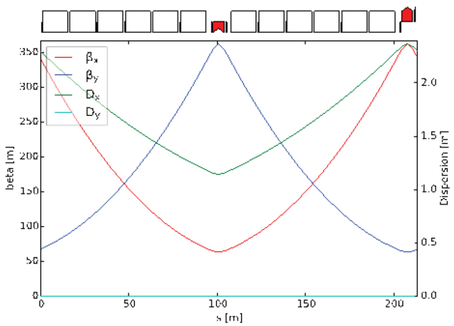
O(20) ab^{-1}/experiment

consistent with physics goals

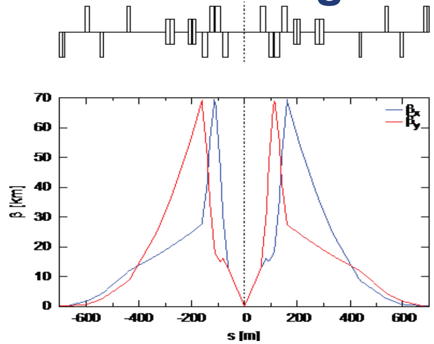
PRST-AB 18, 101002 (2015)

FCC-hh full-ring optics design

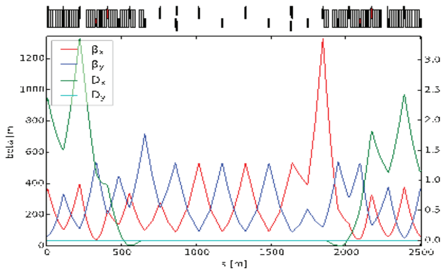
Regular arc cell



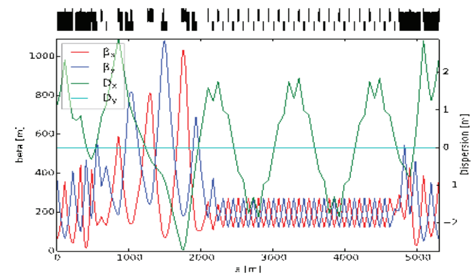
Interaction region

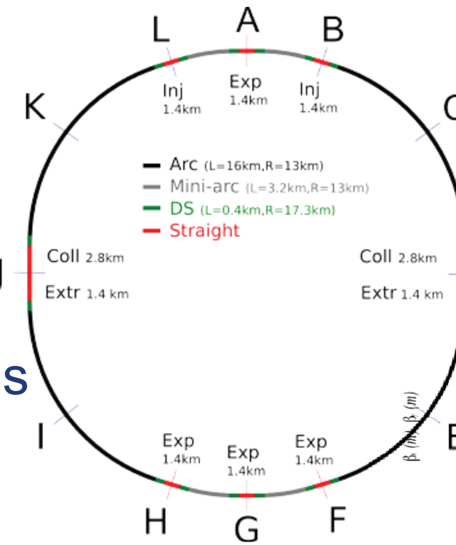


Injection with RF

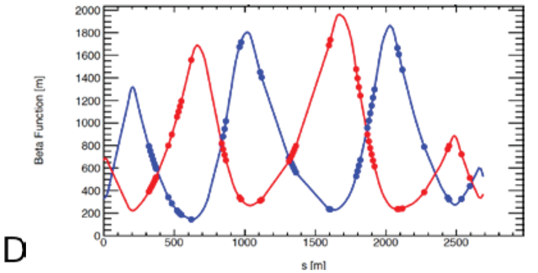


Momentum collim.

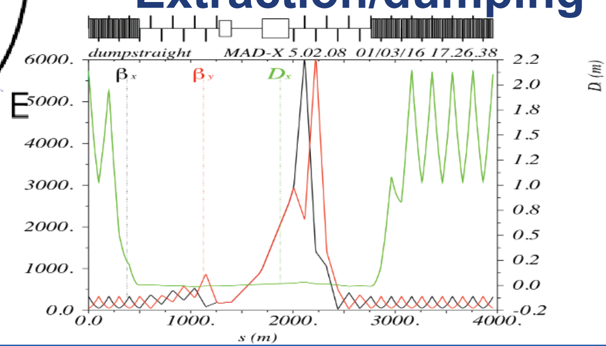




Betatron collimation



Extraction/dumping



Full ring optics design available as basis for:

- beam dynamics studies
- optimisation of each insertion
- definition of system specifications (apertures, etc.)
- improvement of baseline optics and layout
- collimation efficiency study & optimisation

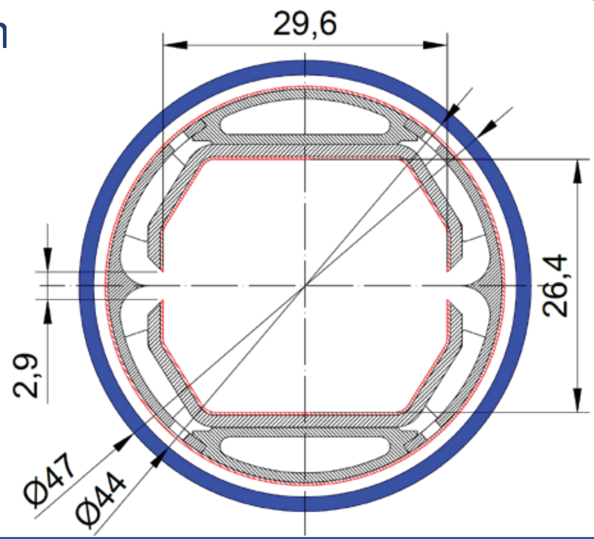
Synchrotron radiation beam screen prototype

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!!!)**

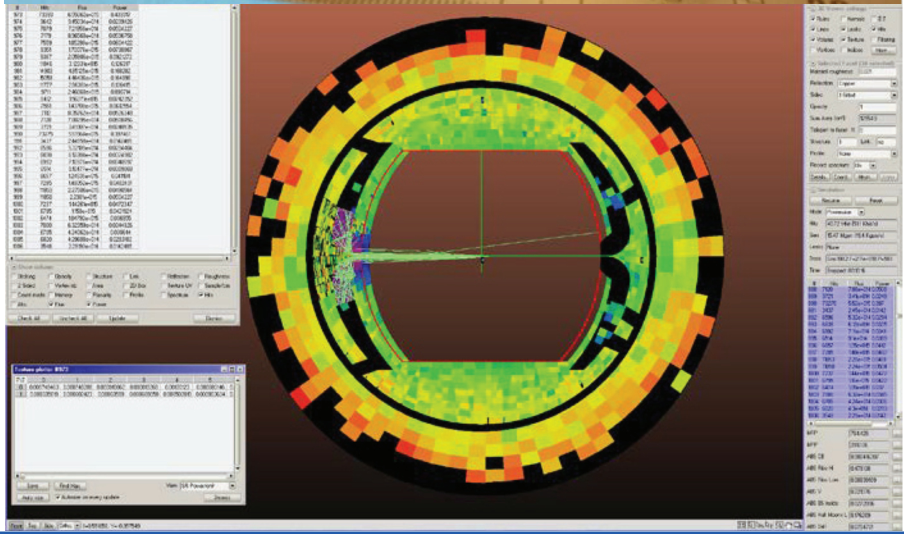
New Beam screen with ante-chamber

- absorption of synchrotron radiation at 50 K to reduce cryogenic power
- factor 50! reduction of power for cryo system



First FCC-hh beam screen prototype

Testing 2017 in ANKA within EuroCirCol



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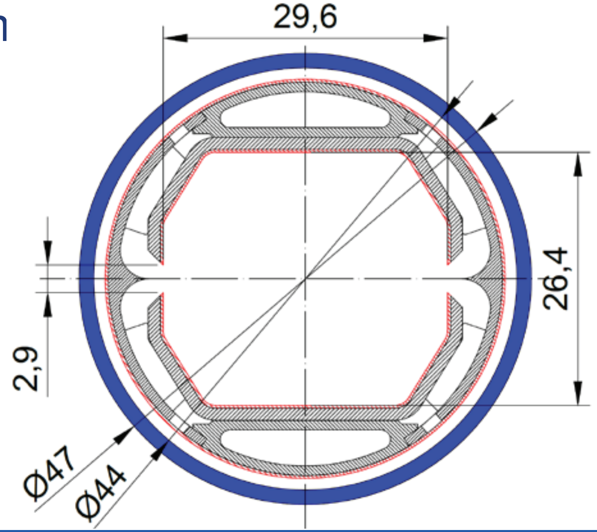

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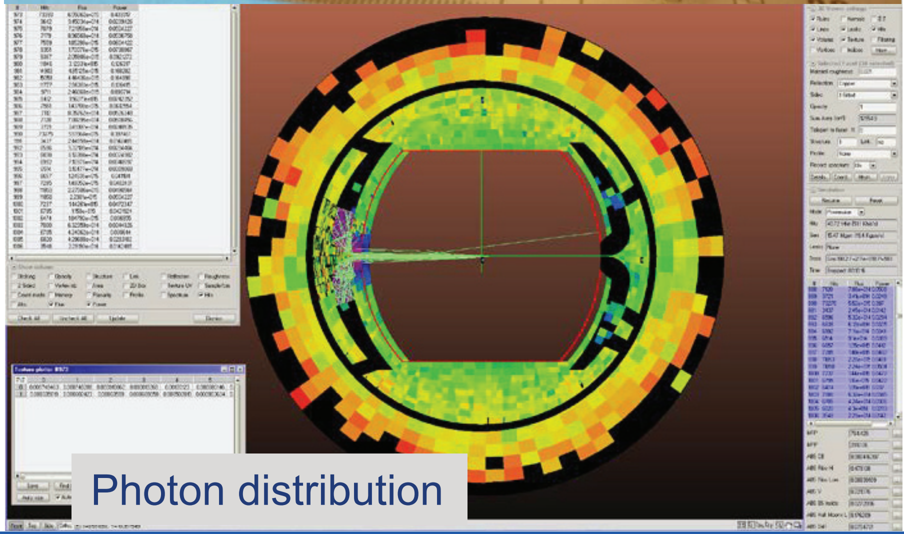
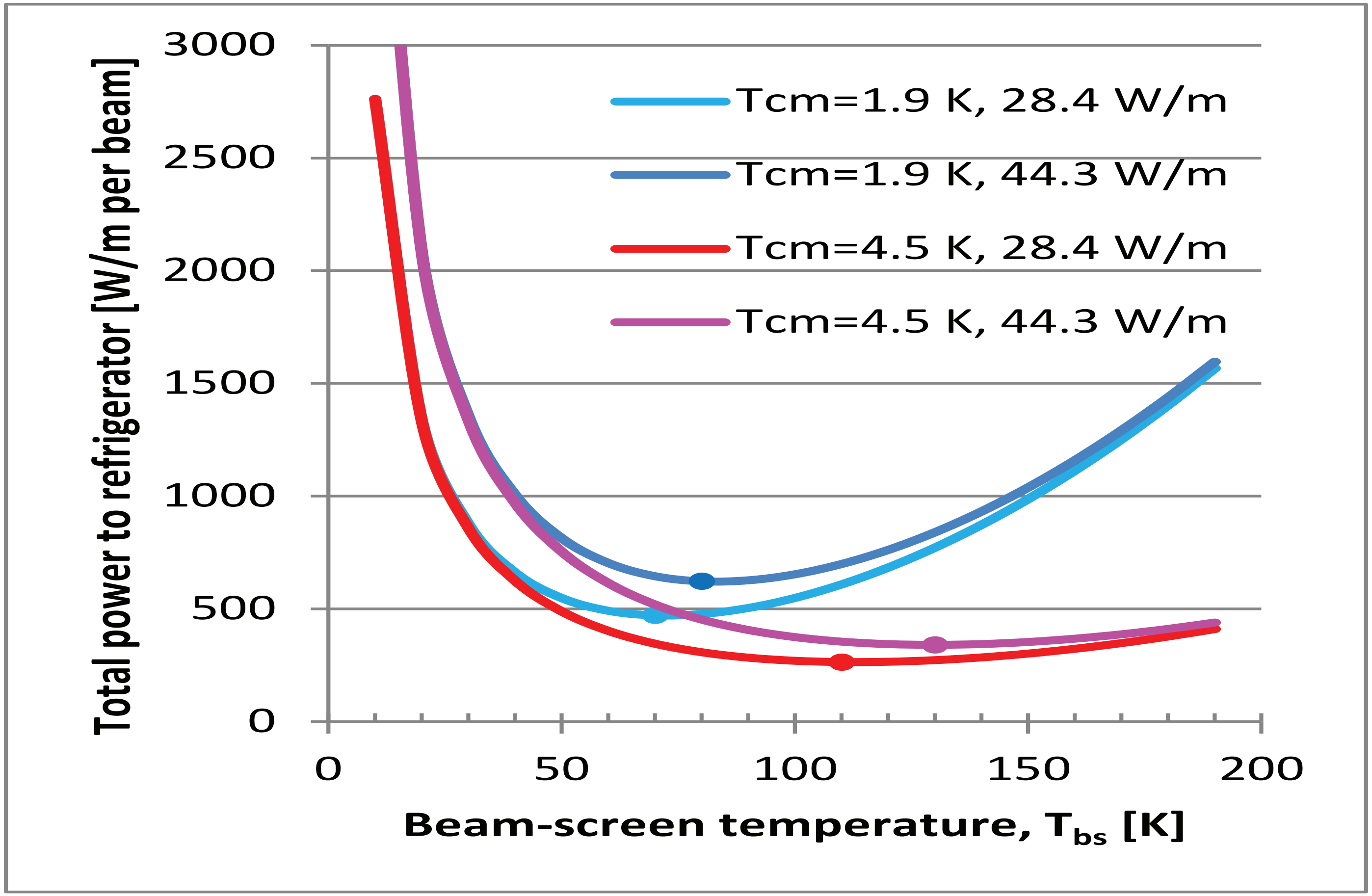


Photon distribution

Cryo power for cooling of SR heat

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



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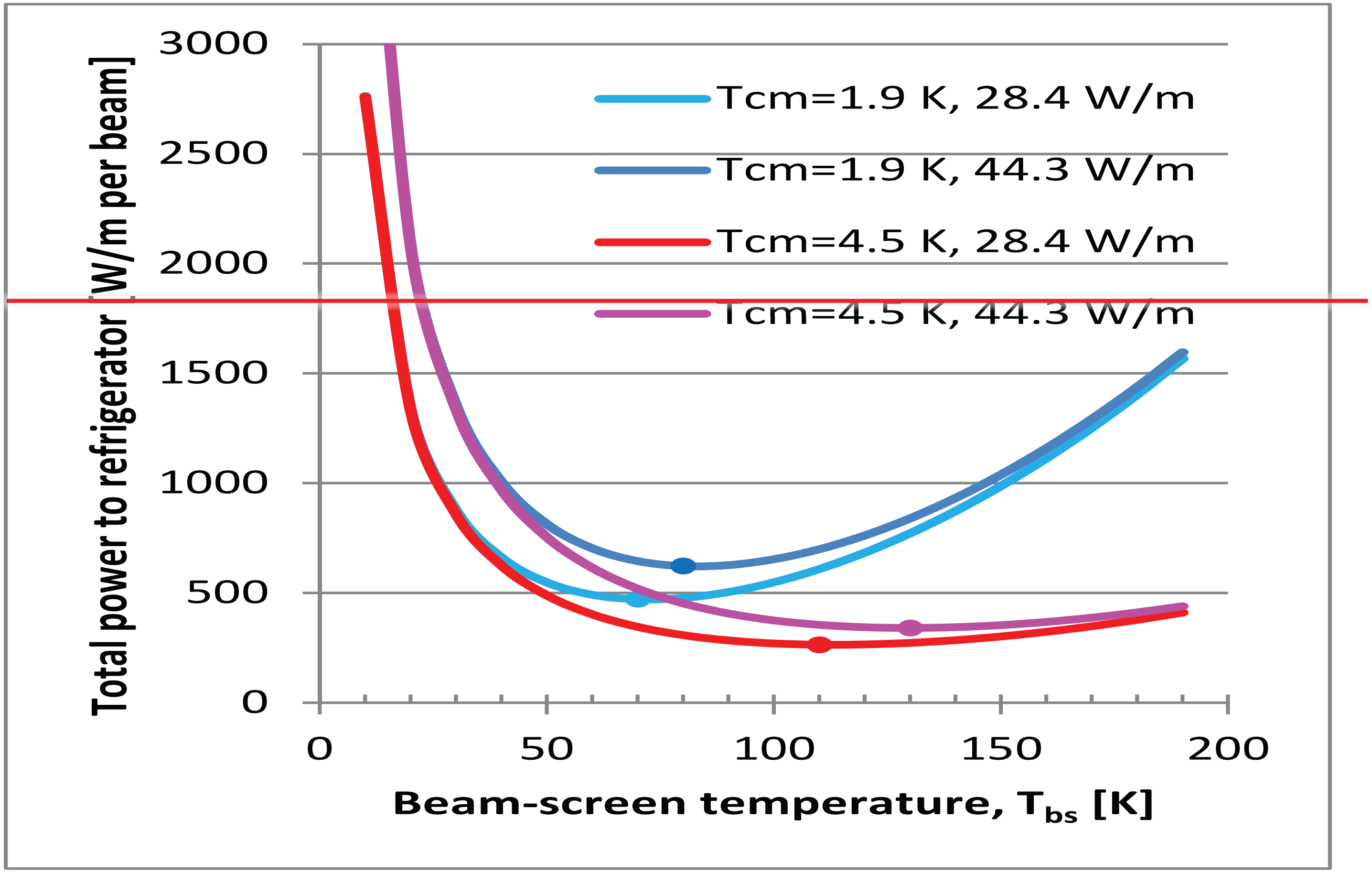

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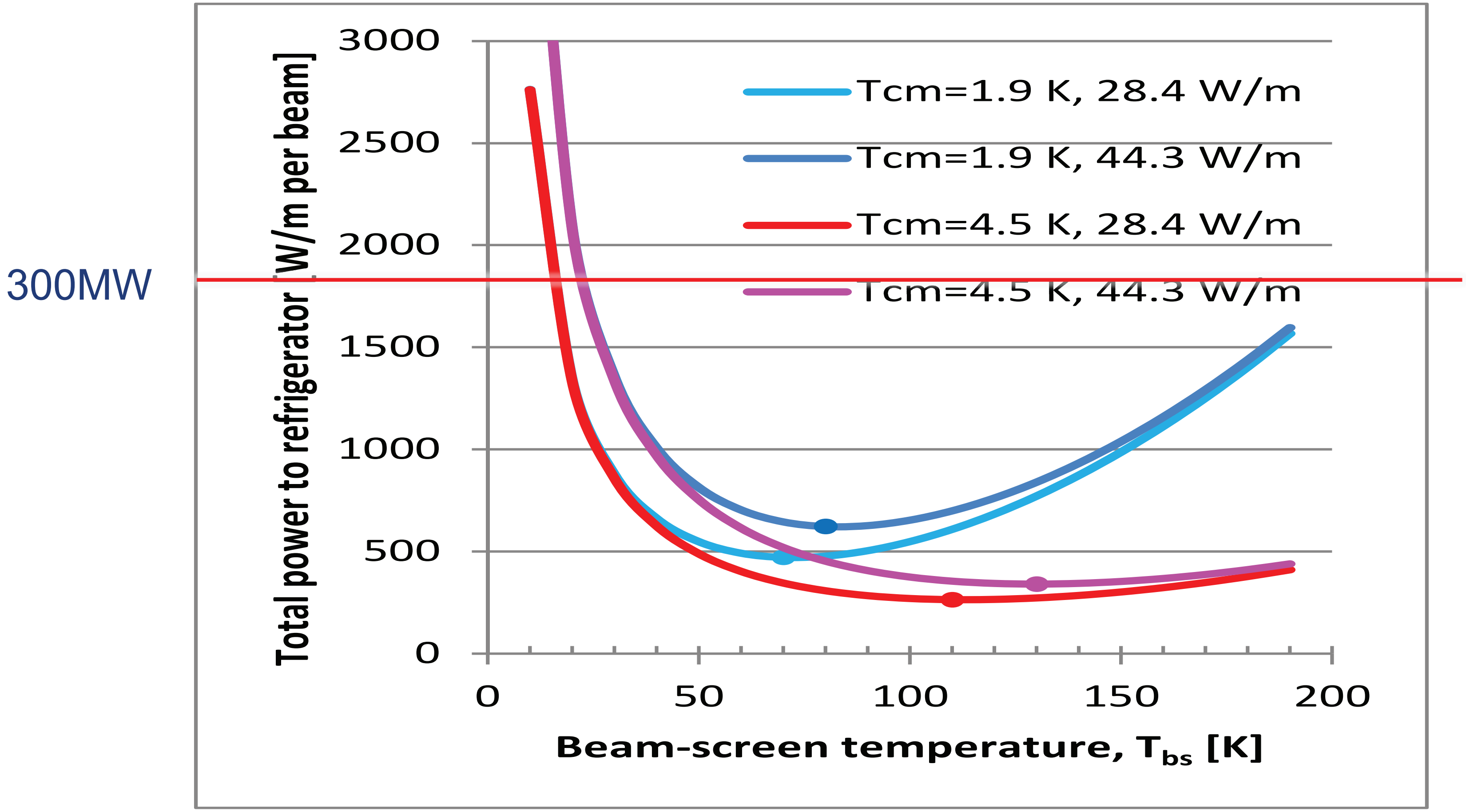

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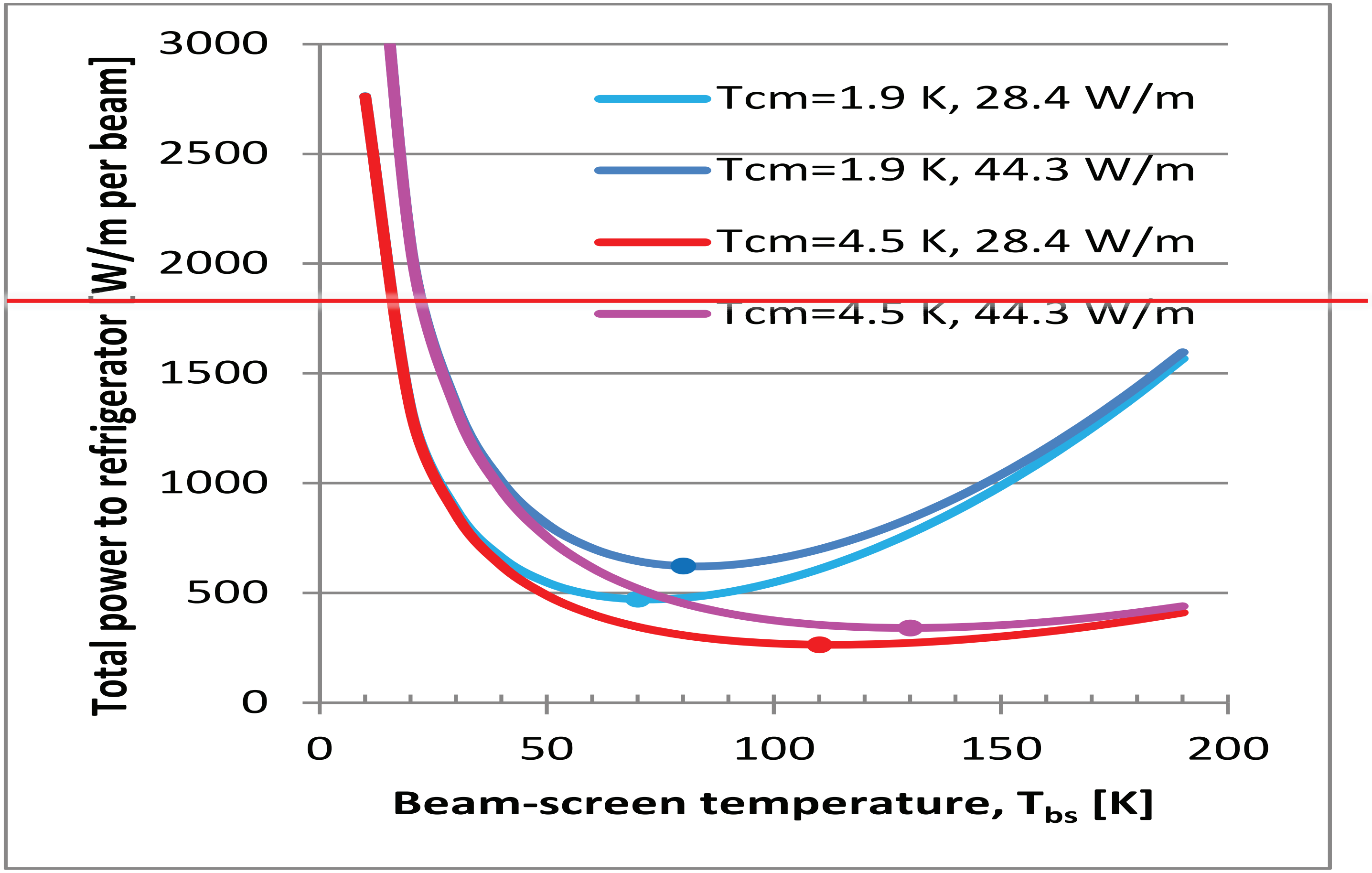
300MW

200MW



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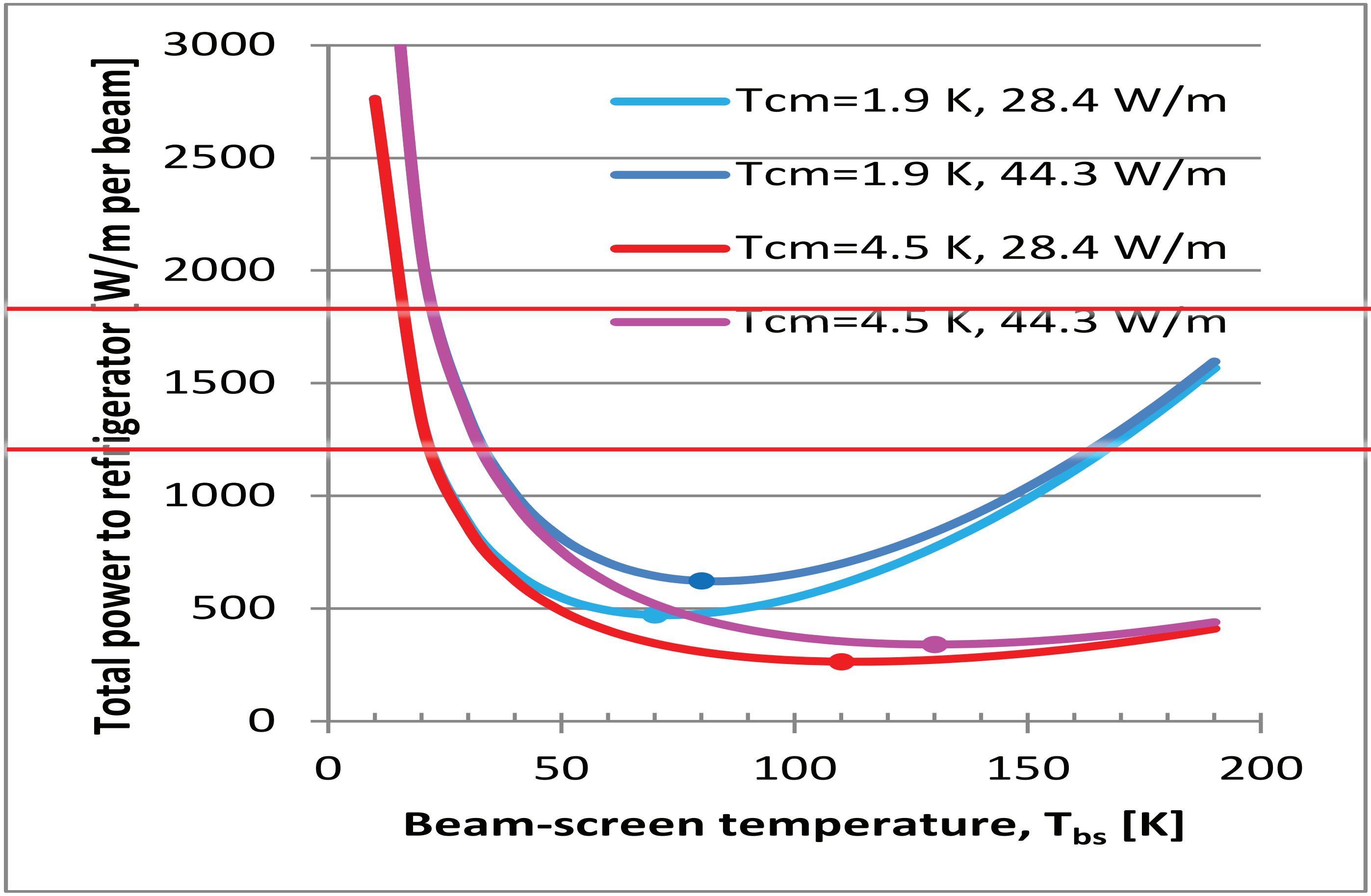

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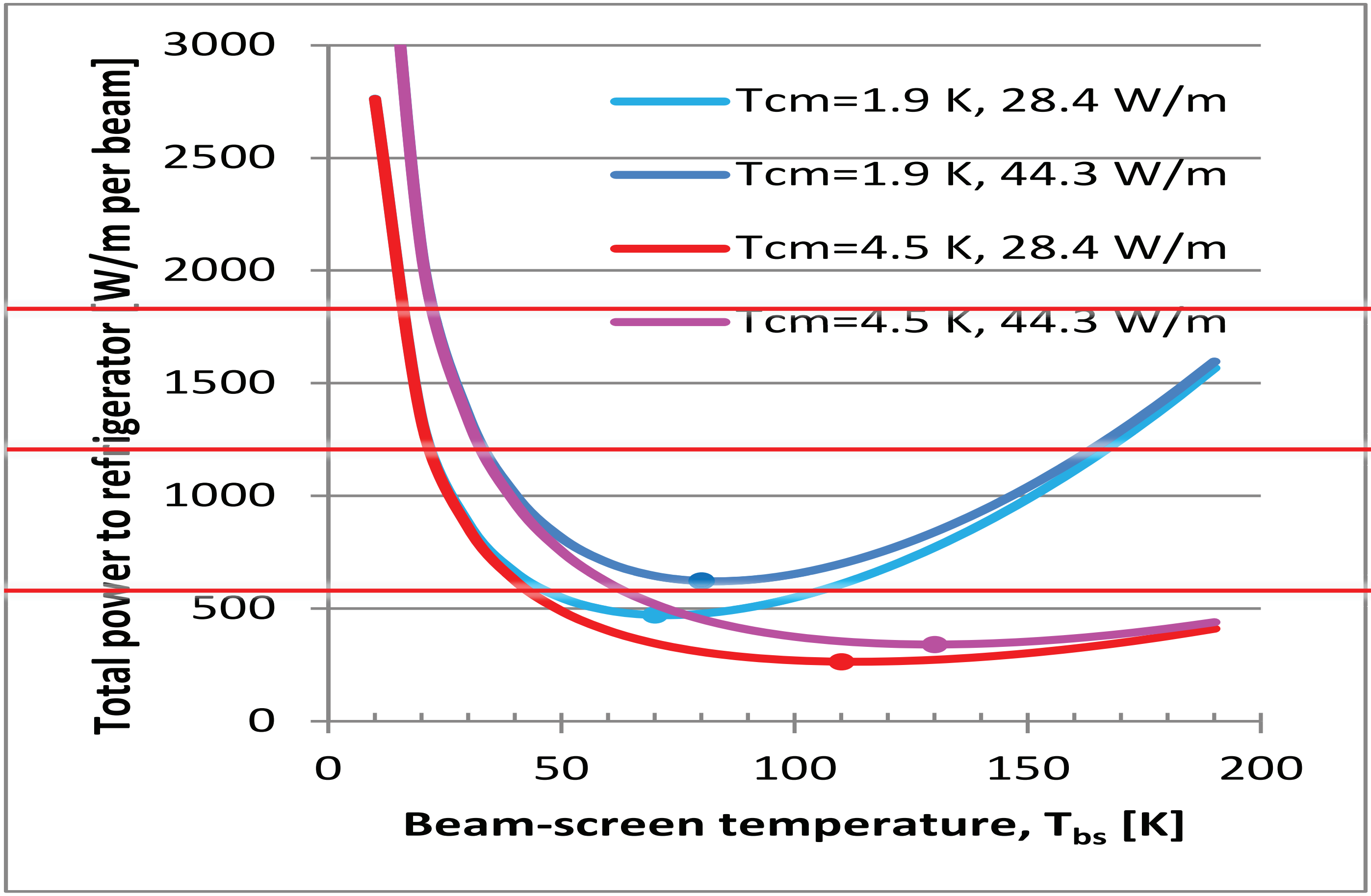

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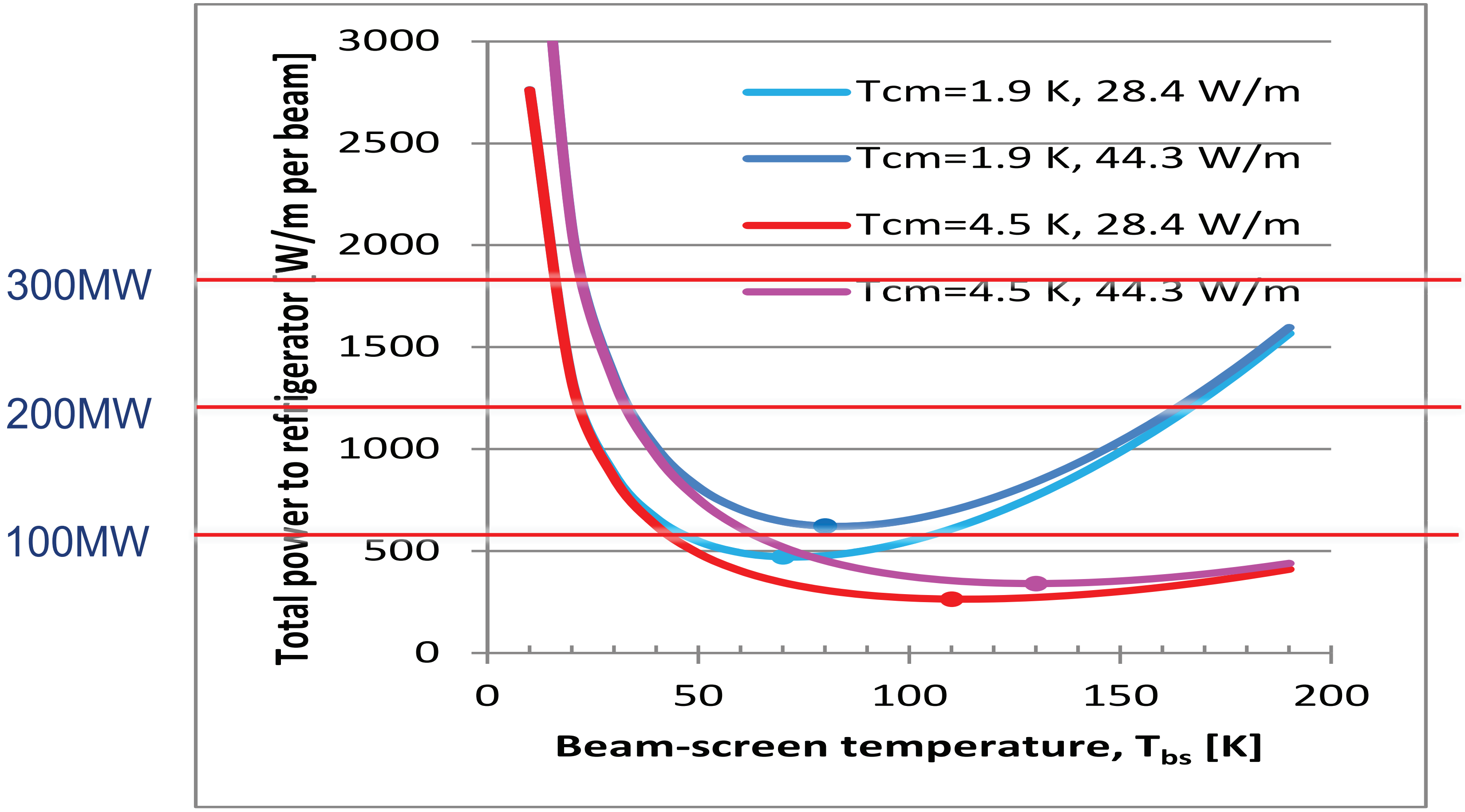

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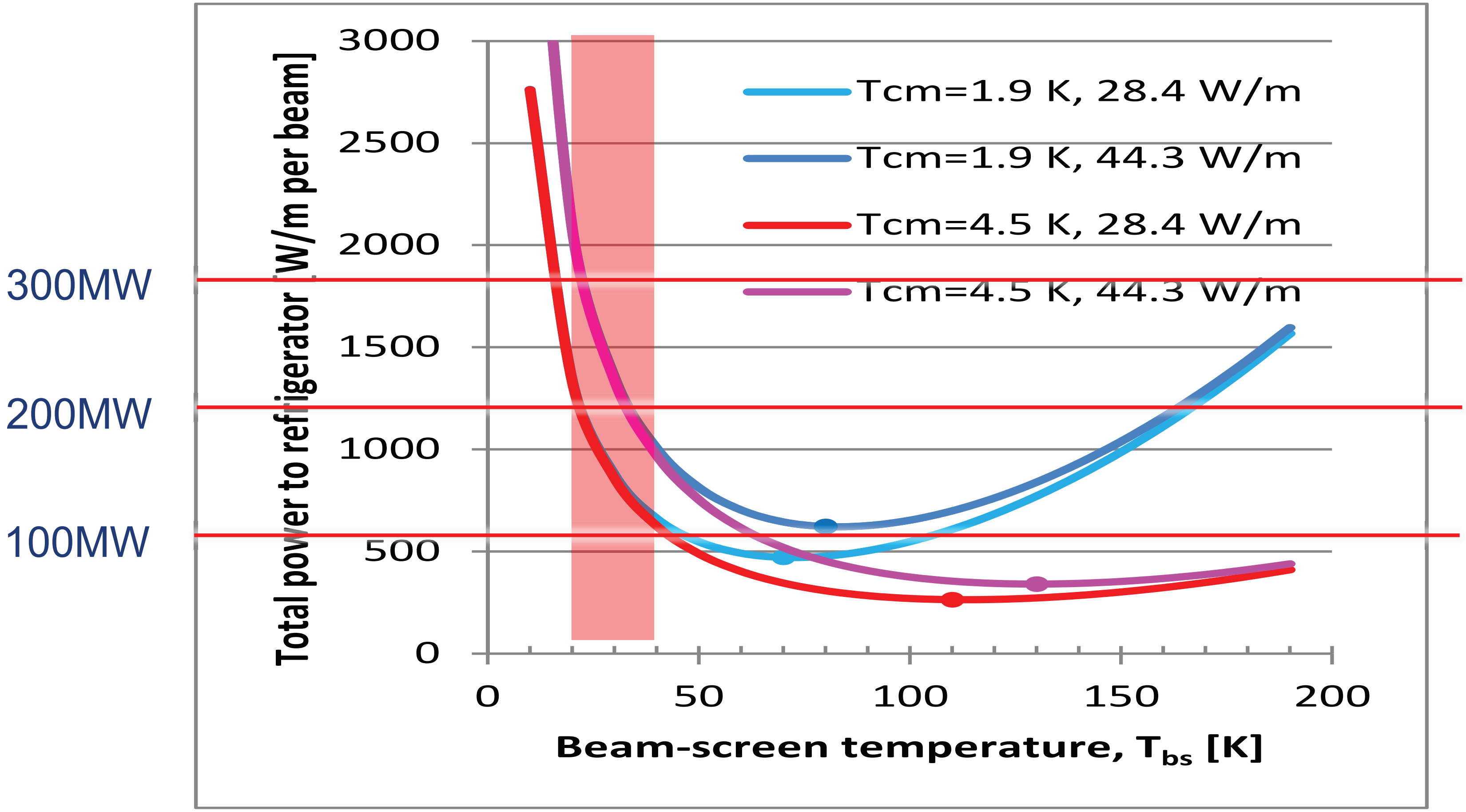

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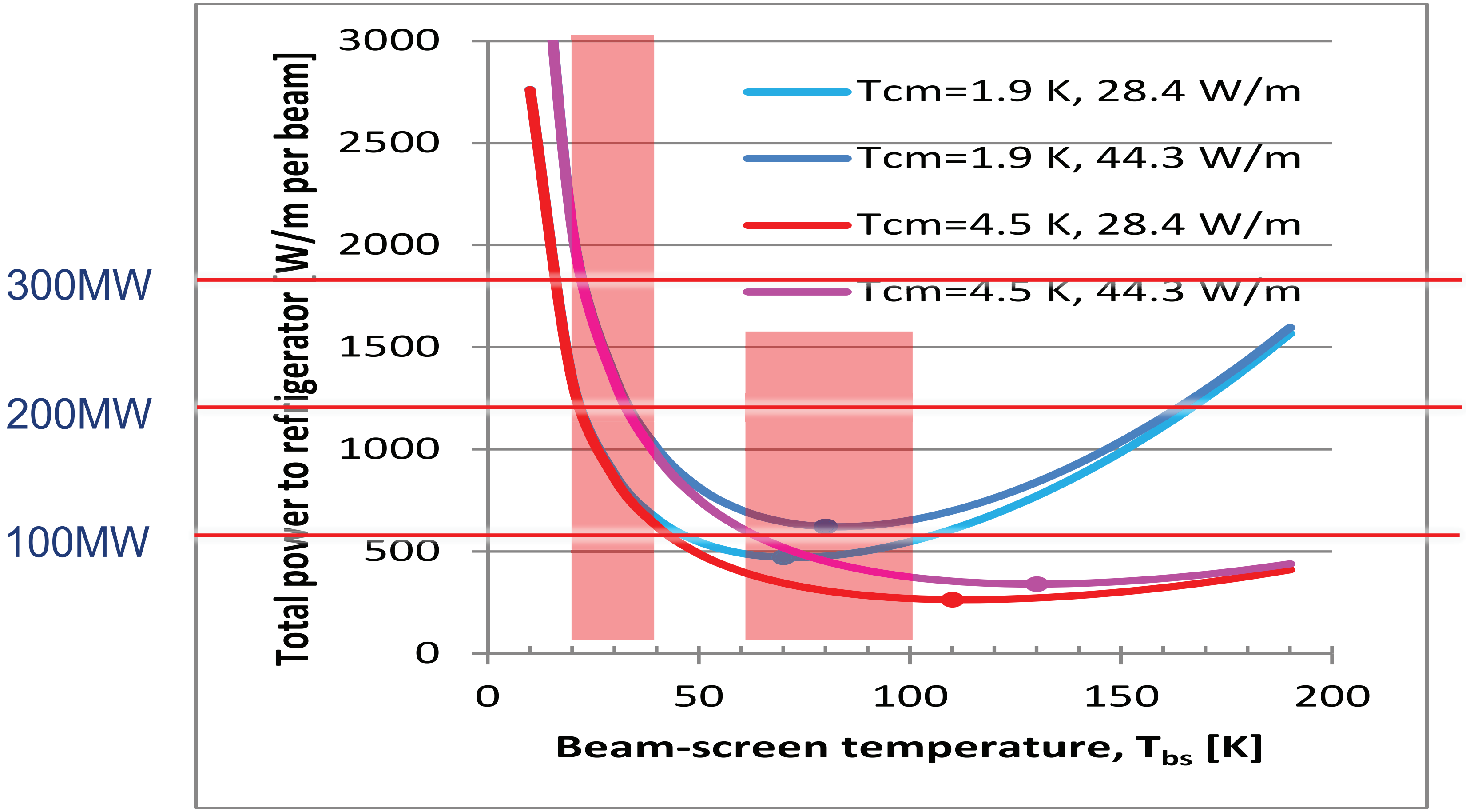

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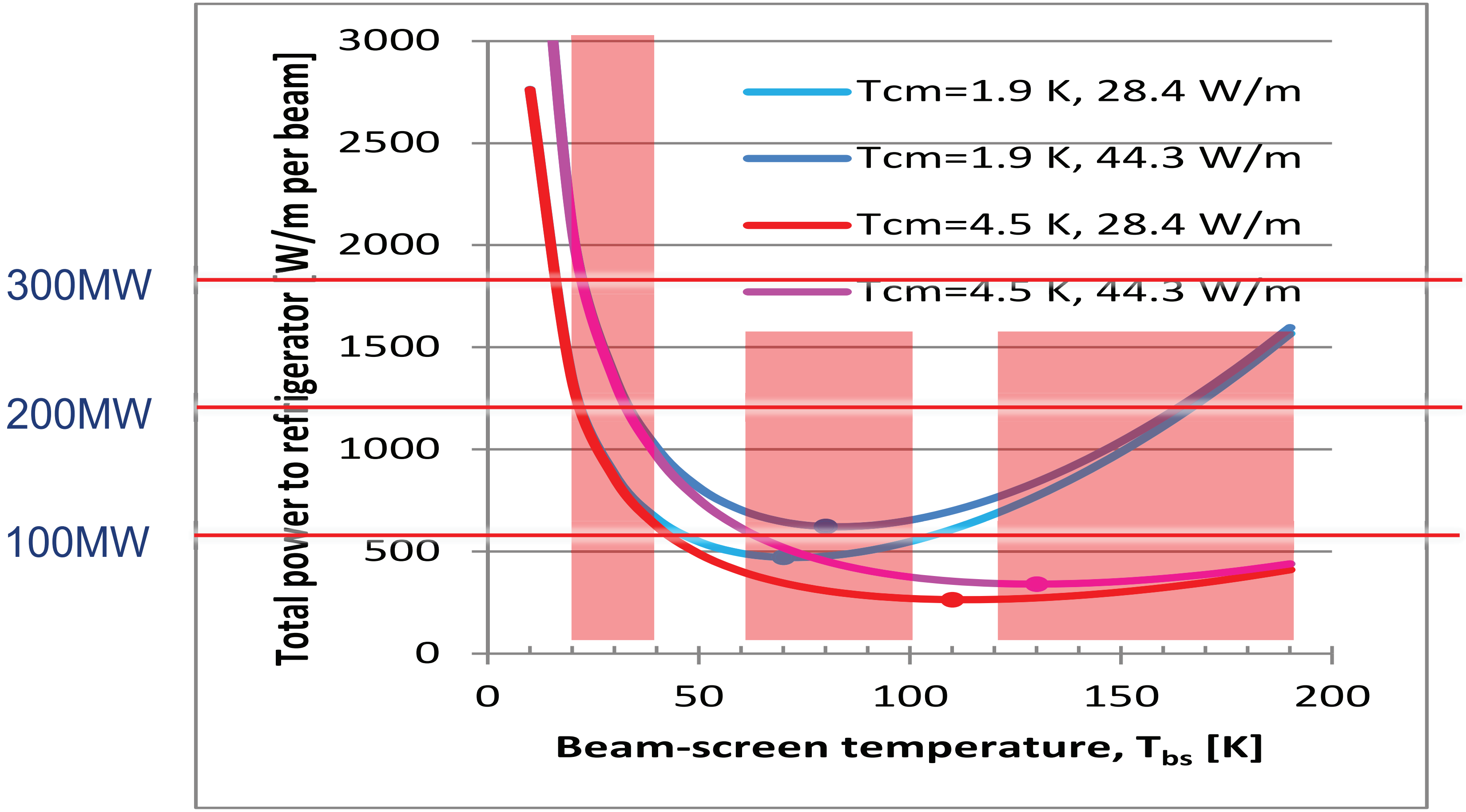

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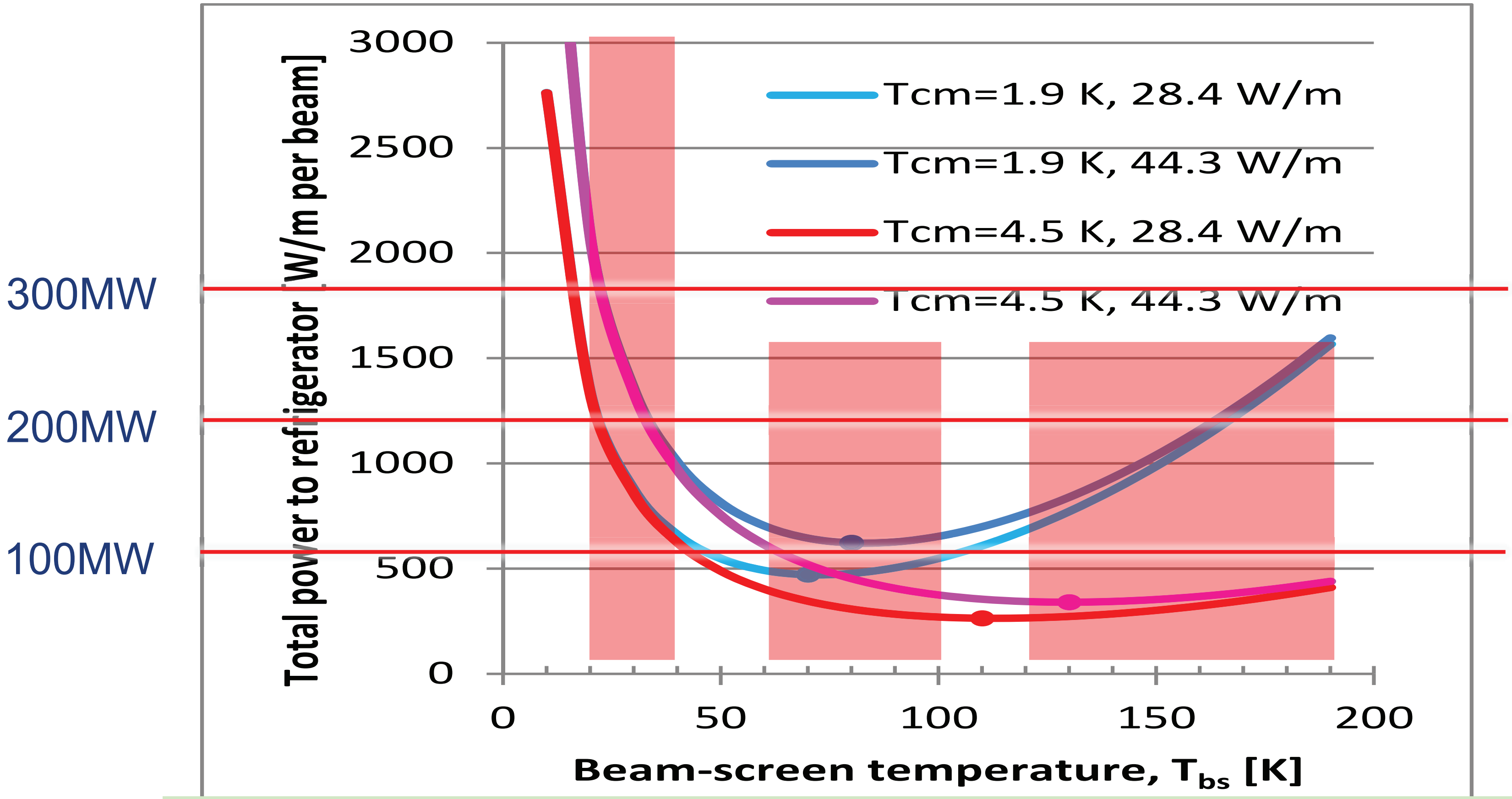

Multi-bunch instability growth time: 25 turns 9 turns (ΔQ=0.5)

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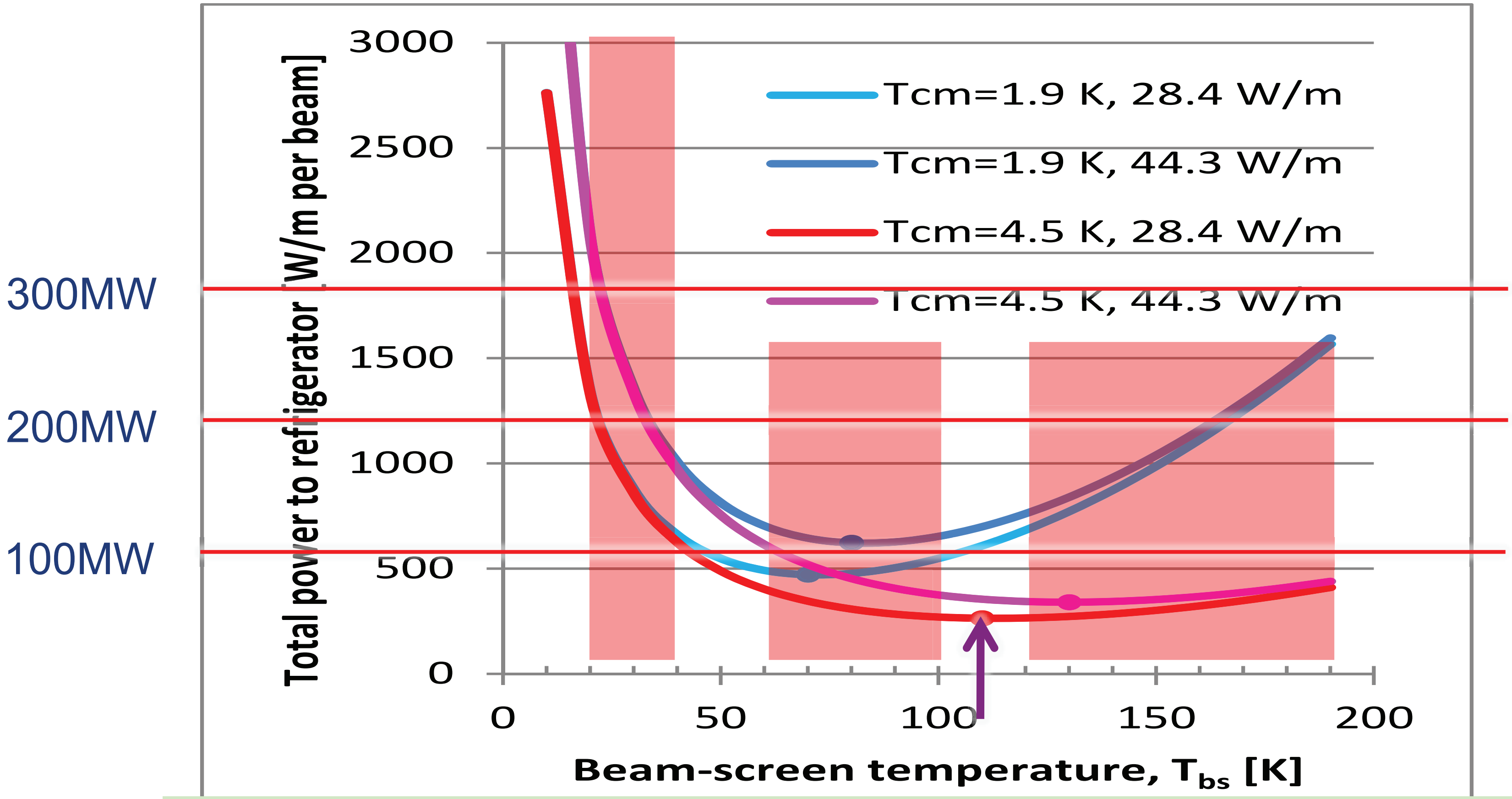

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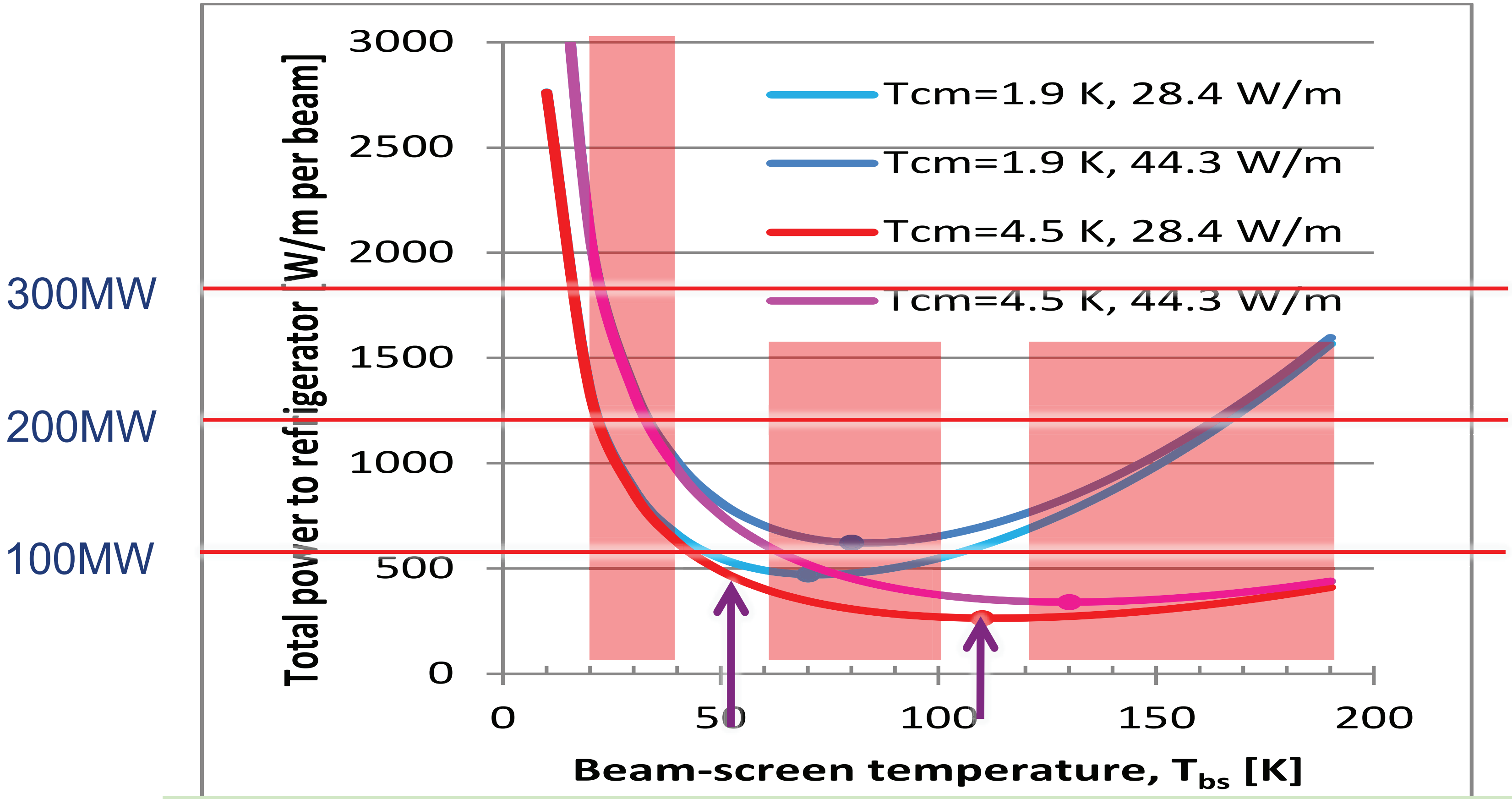

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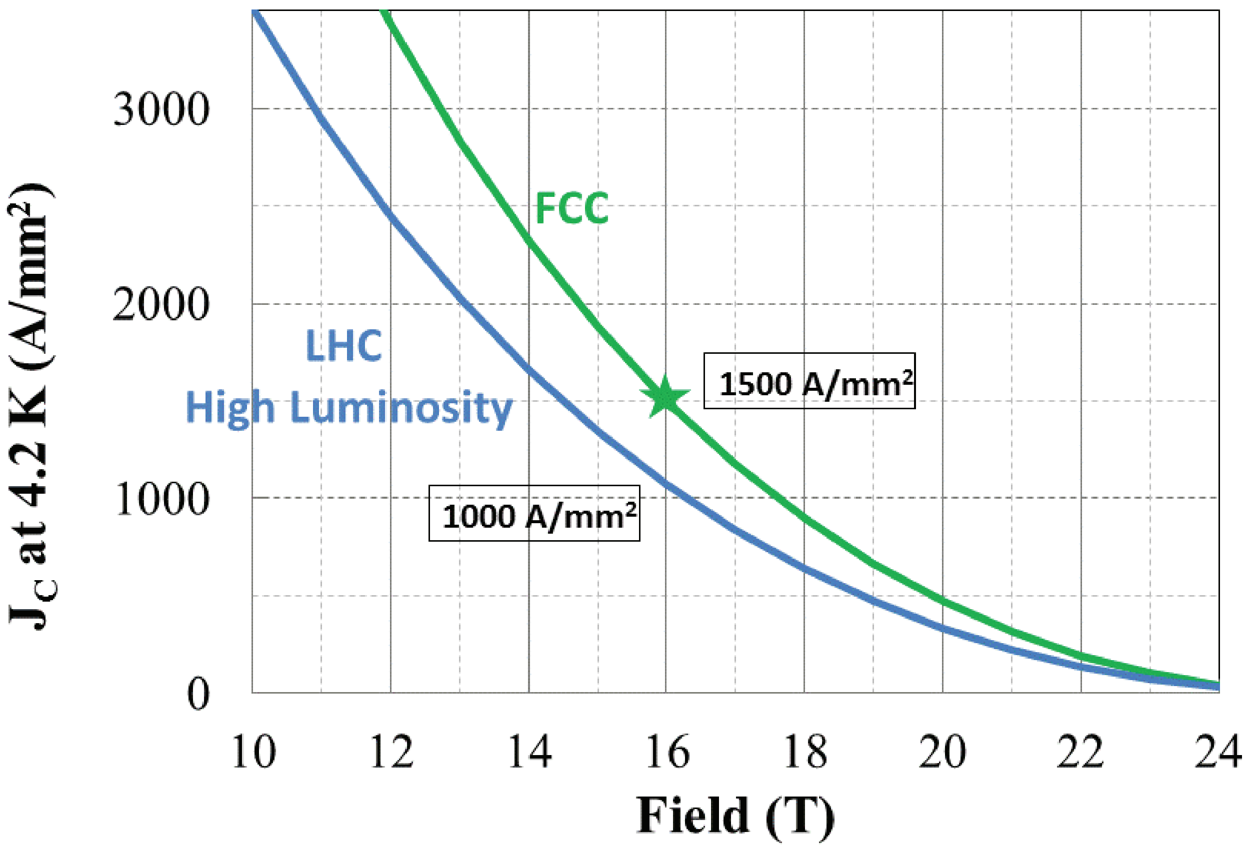
Nb_3Sn conductor program

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



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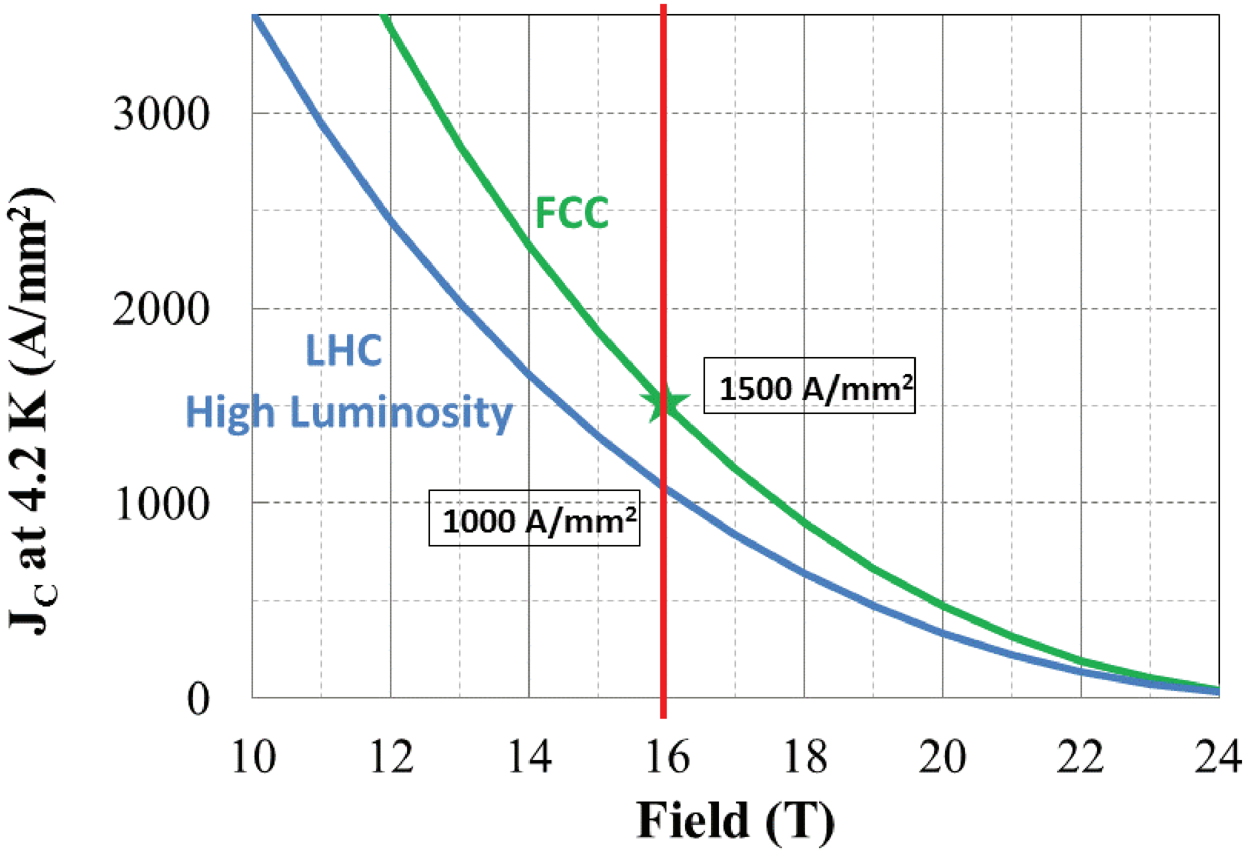

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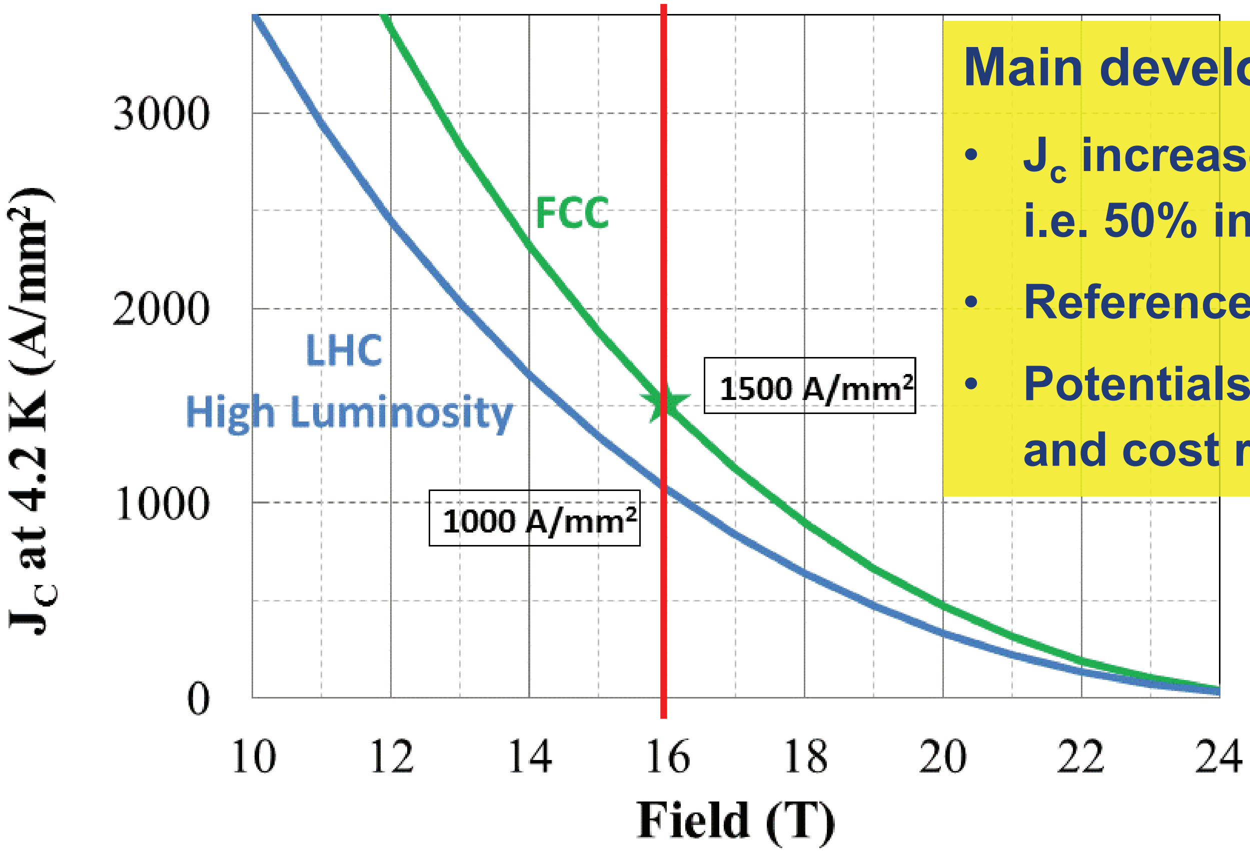


Main development goals until 2020:

- 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

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

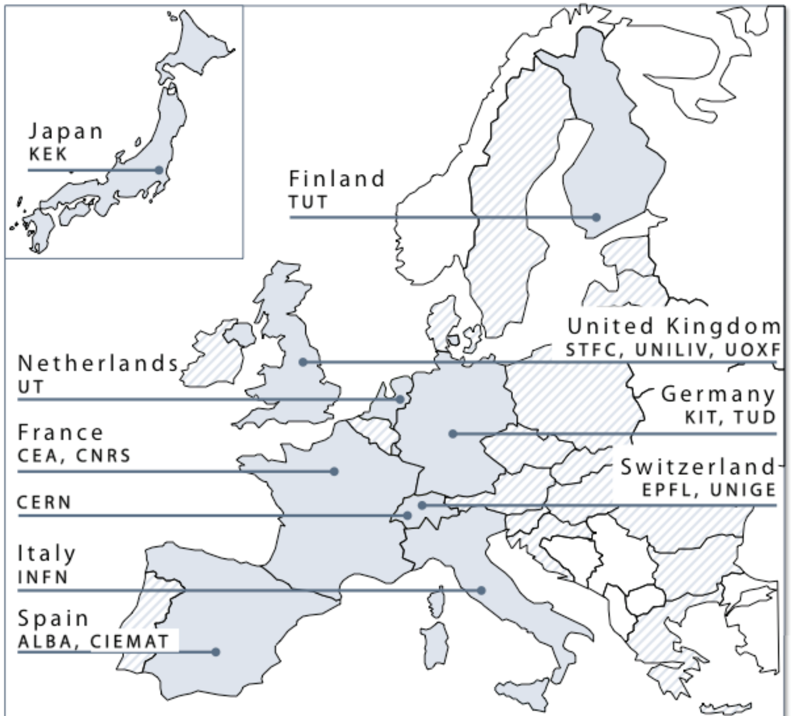
Characterisation of conductor & research with universities:

- **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



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

TECHNISCHE UNIVERSITÄT DARMSTADT

KIT Karlsruher Institut für Technologie

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

UNIVERSITÉ DE GENÈVE

cea

cnrs dépasser les frontières

CERN

UNIVERSITY OF OXFORD

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

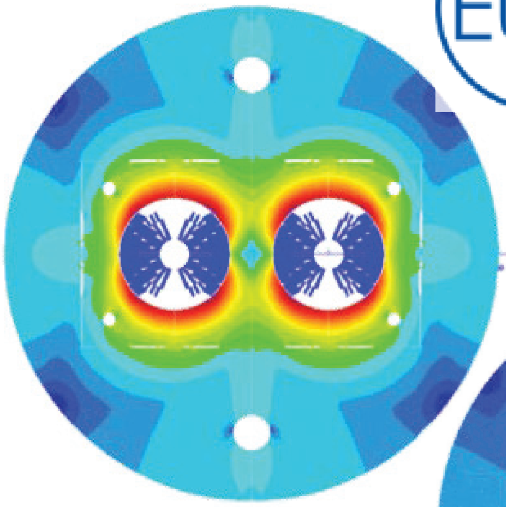
Scope:

FCC hadron collider

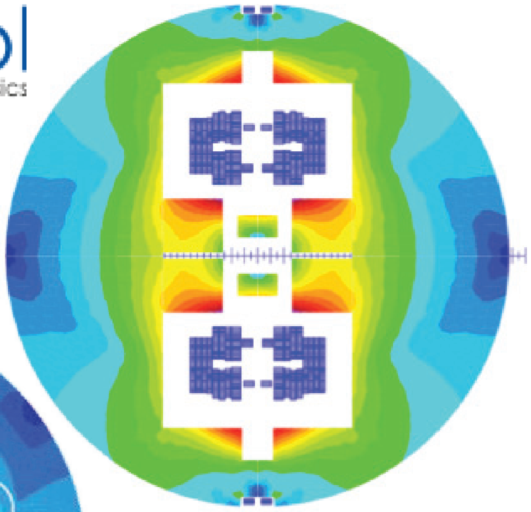
- Optics Design
- Cryo vacuum design
- 16 T dipole design, construction folder for demonstrator magnets

16 T dipole options and plans

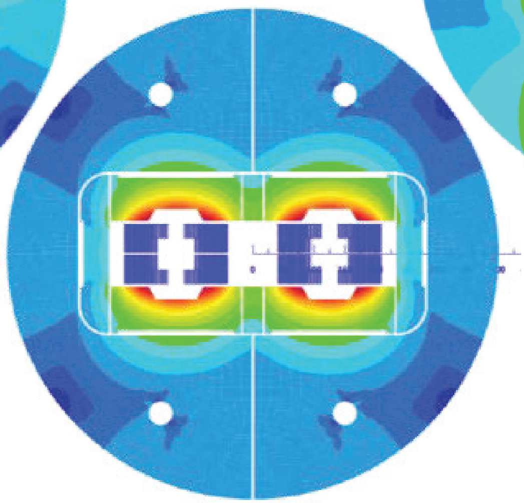
Cos-theta



Common coils

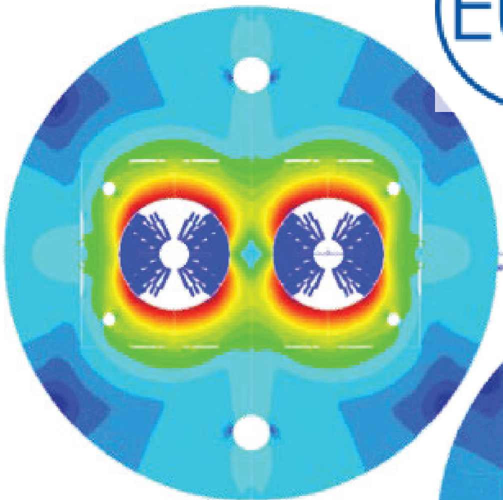


Blocks



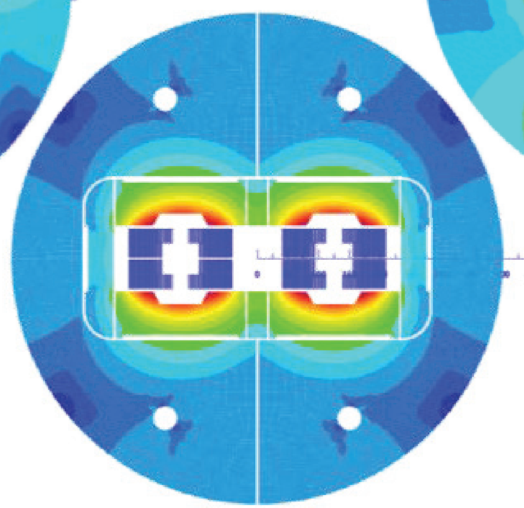
16 T dipole options and plans

Cos-theta

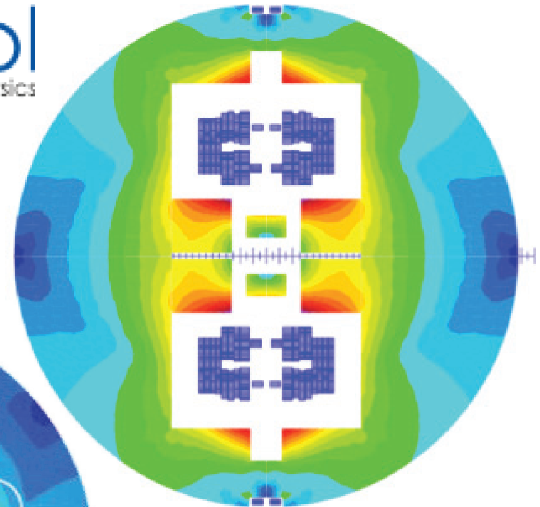


EuroCirCol
A key to New Physics

Blocks



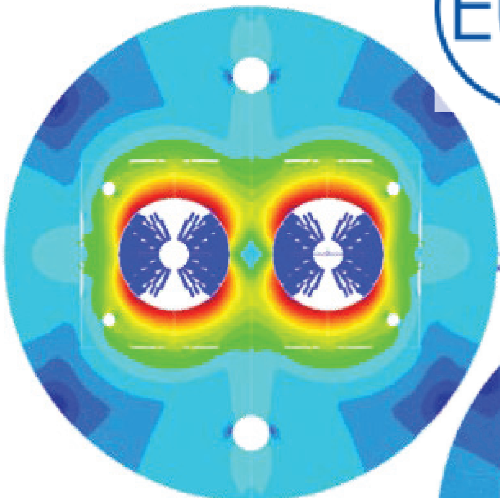
Common coils



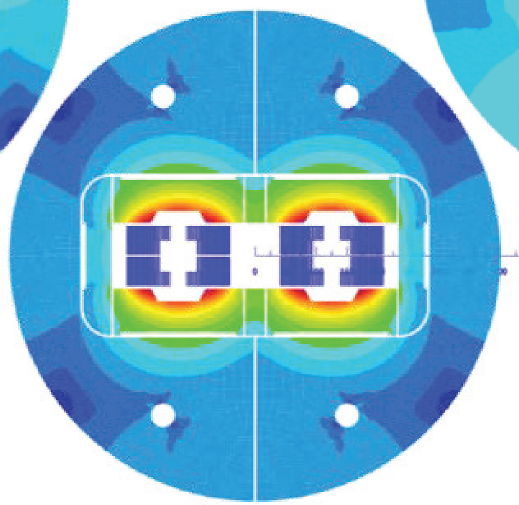
Swiss contribution
via PSI

16 T dipole options and plans

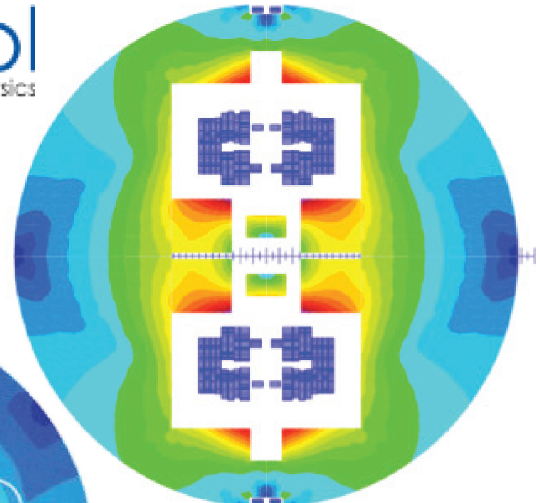
Cos-theta



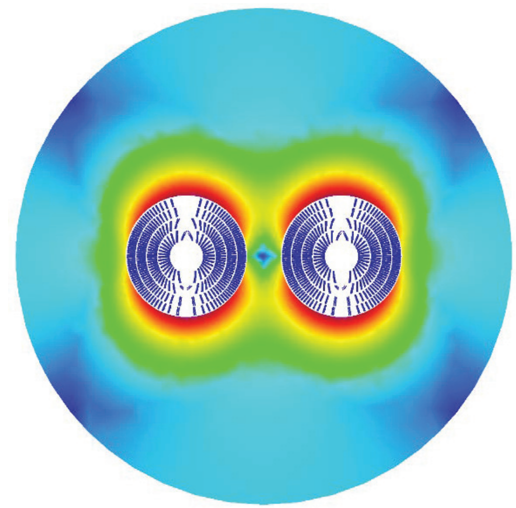
Blocks



Common coils



Swiss contribution
via PSI



16 T dipole options and plans

EuroCirCol
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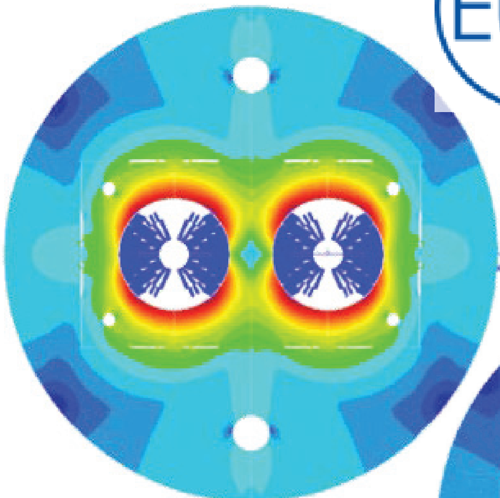
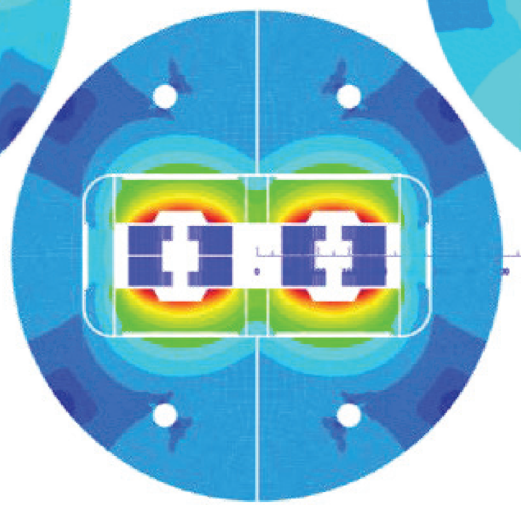
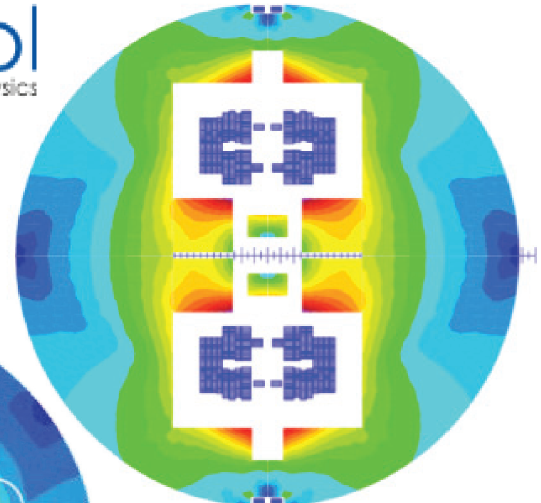
Cos-theta



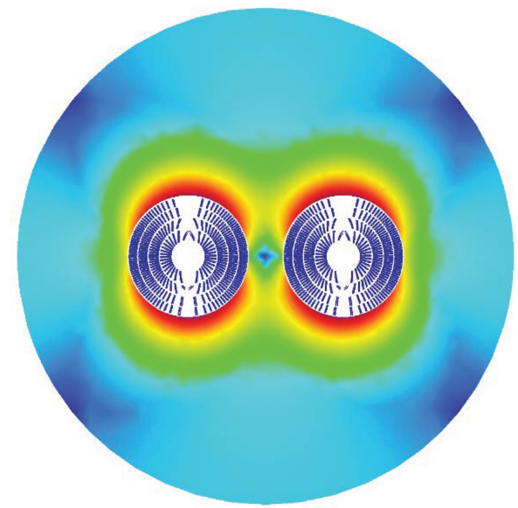
Blocks



Common coils

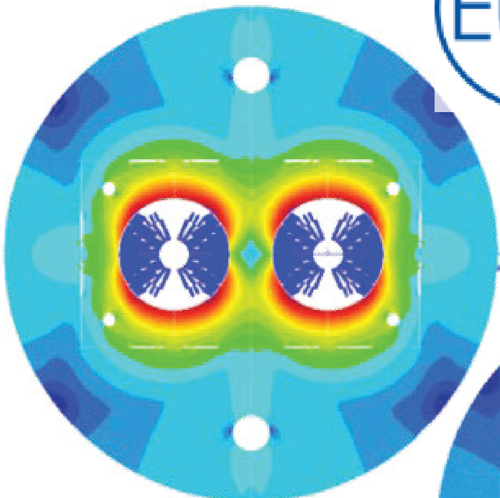


Swiss contribution
via PSI



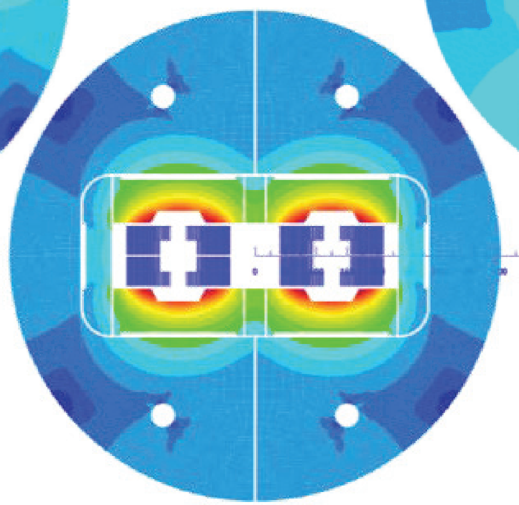
16 T dipole options and plans

Cos-theta

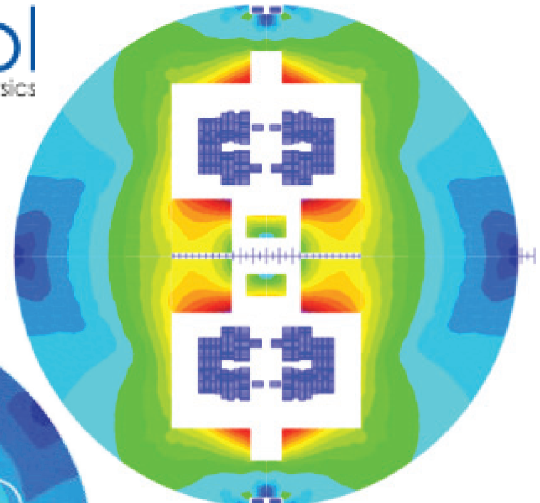


EuroCirCol
A key to New Physics

Blocks

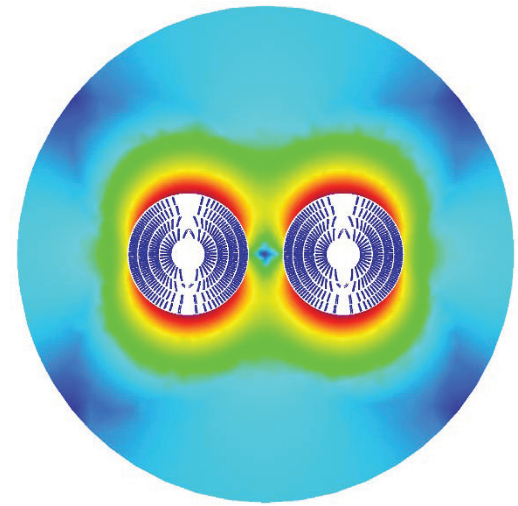


Common coils



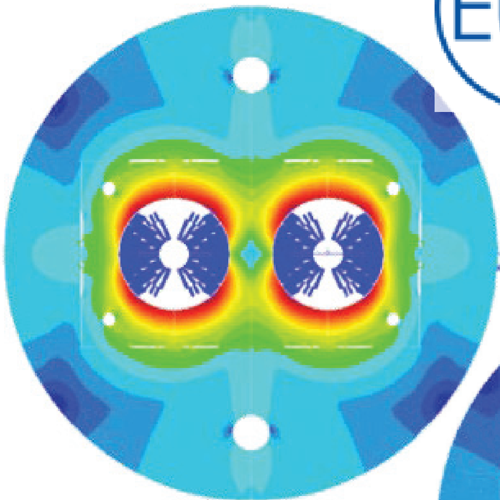
Swiss contribution
via PSI

Canted
Cos-theta



16 T dipole options and plans

Cos-theta



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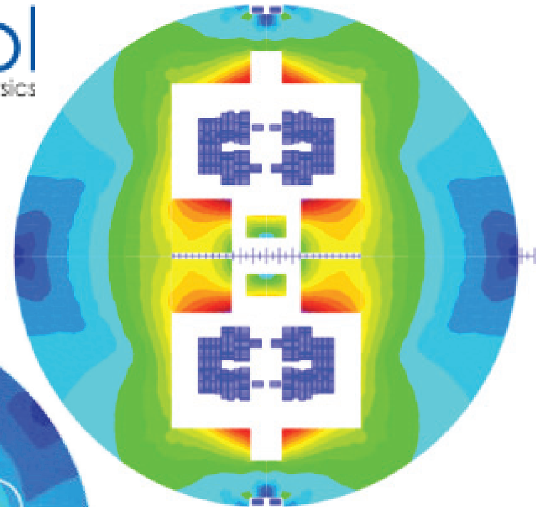

Swiss contribution
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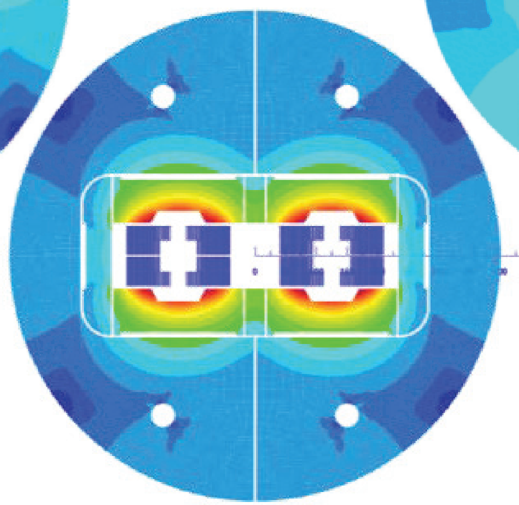
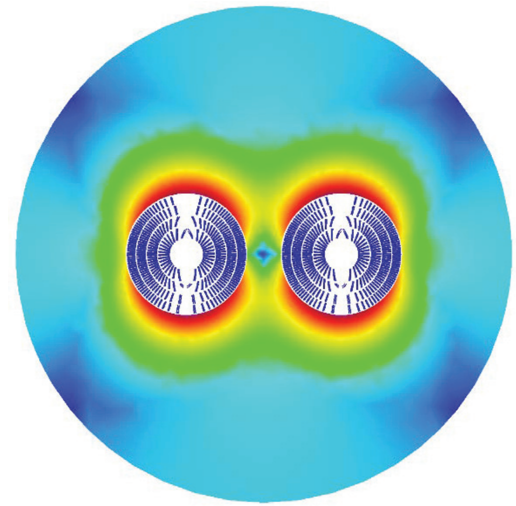
Blocks

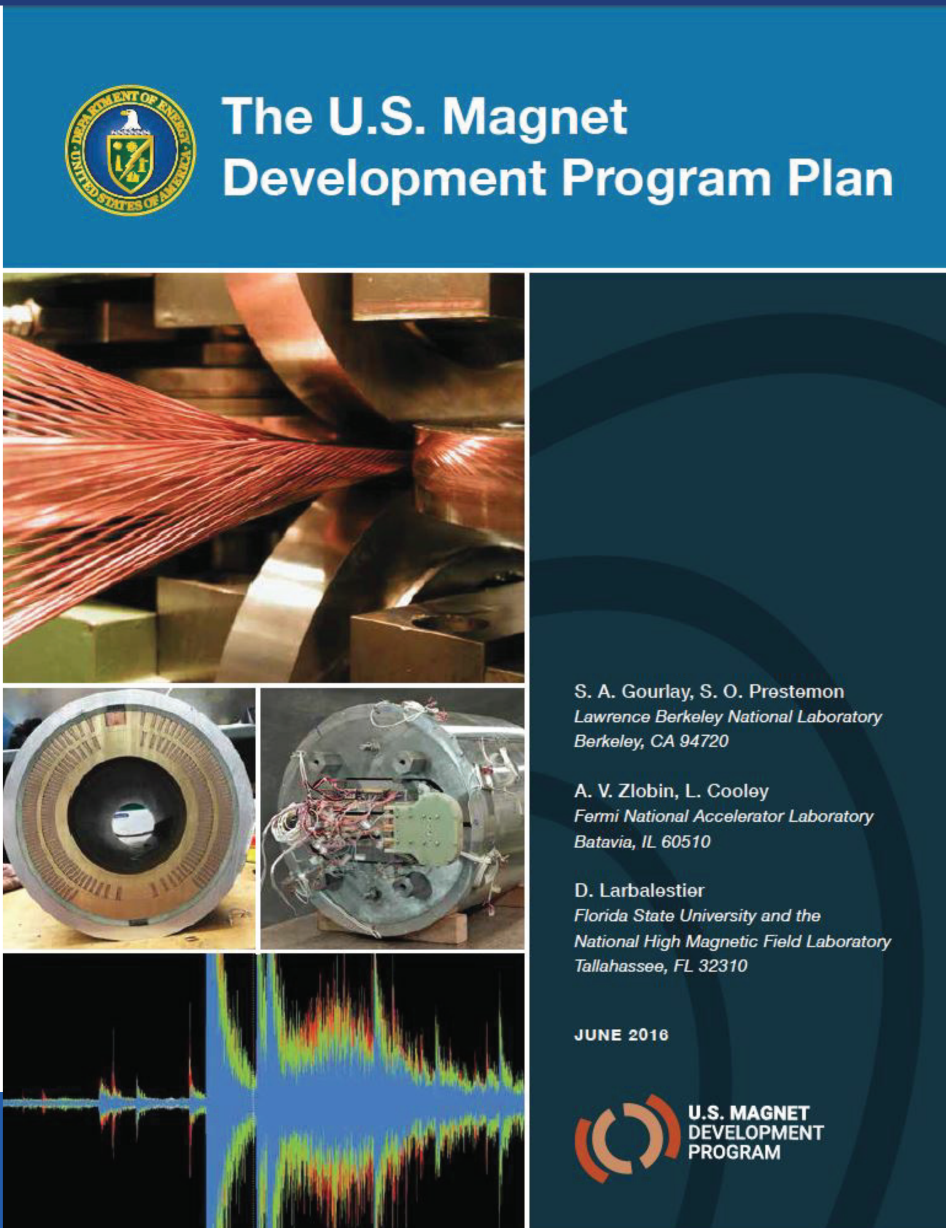


Canted Cos-theta



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

US Magnet Development Program



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:

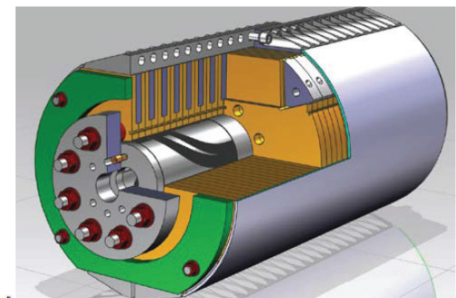
Investigate fundamental aspects of magnet design and technology that can lead to substantial performance improvements and magnet cost reduction.

GOAL 4:

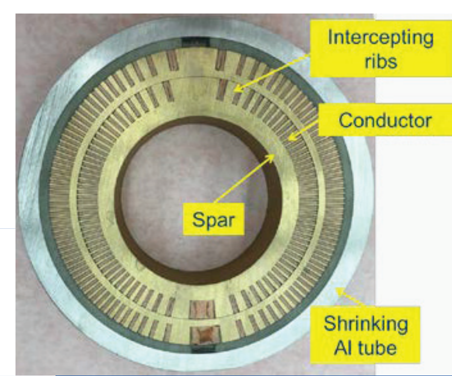
Pursue Nb_3Sn and HTS conductor R&D with clear targets to increase performance and reduce the cost of accelerator magnets.

Under Goal 1:

16 T cos theta dipole design



16 T canted cos theta (CCT) design



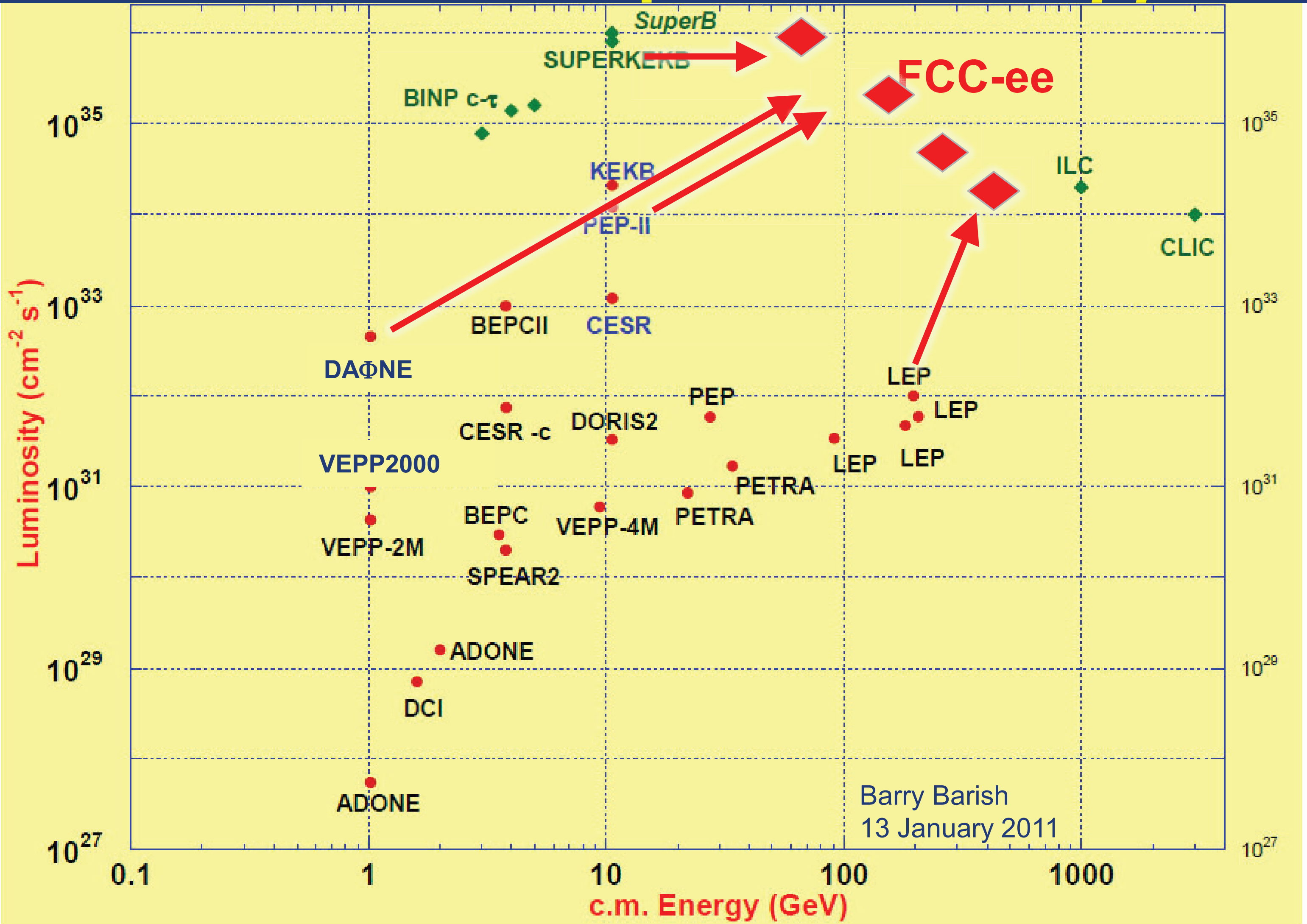
lepton collider parameters

parameter	FCC-ee (400 MHz)					LEP2
Physics working point	Z		WW	ZH	$t\bar{t}$ / 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



LEP:
high energy
SR effects

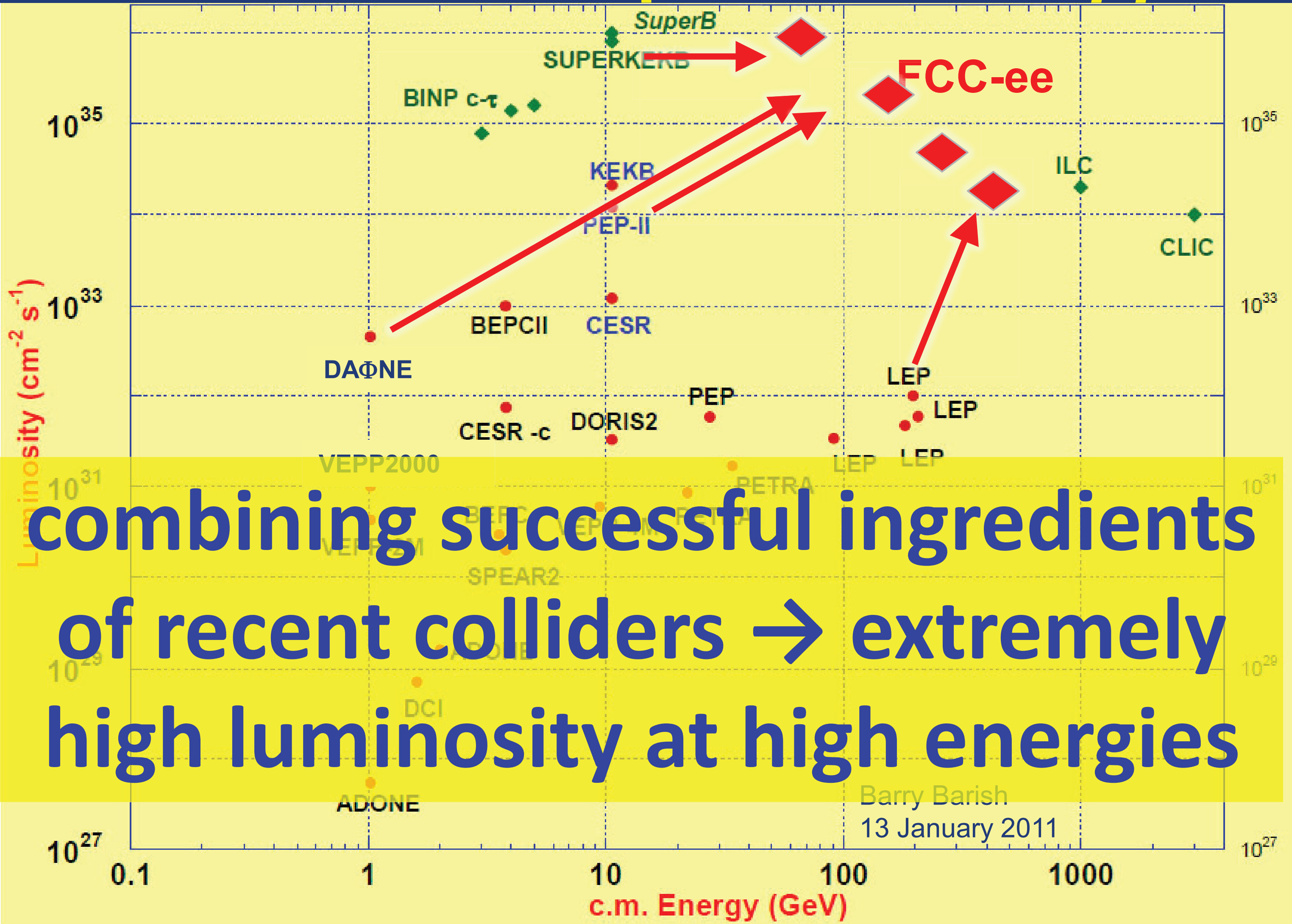
B-factories:
KEKB & PEP-II:
high beam currents
top-up injection
DAFNE: crab waist

Super B-factories
S-KEKB: low β_y*

KEKB: e^+ source

HERA, LEP, RHIC:
spin gymnastics

FCC-ee 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

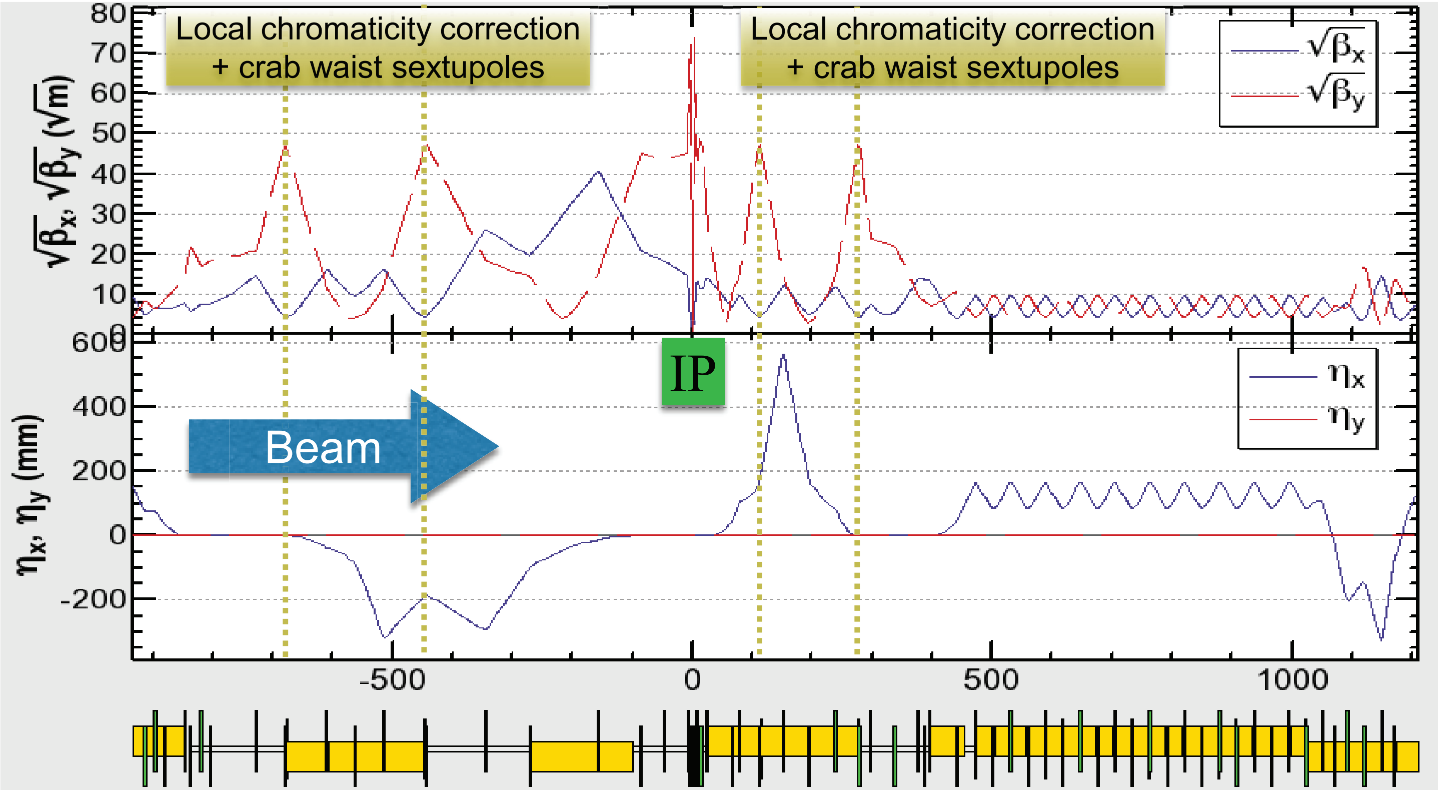
HERA, LEP, RHIC:
- spin gymnastics

FCC-ee optics design

Optics design for all working points achieving baseline performance

Interaction region: asymmetric optics design

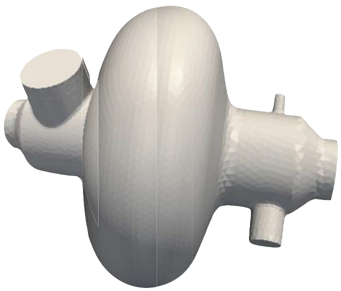
- Synchrotron radiation from upstream dipoles <100 keV up to 450 m from IP
- Dynamic aperture & momentum acceptance requirements fulfilled at all WPs



RF system 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))

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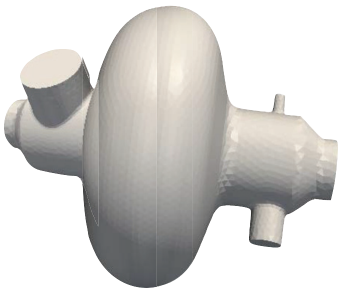

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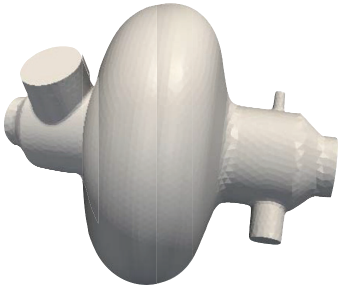

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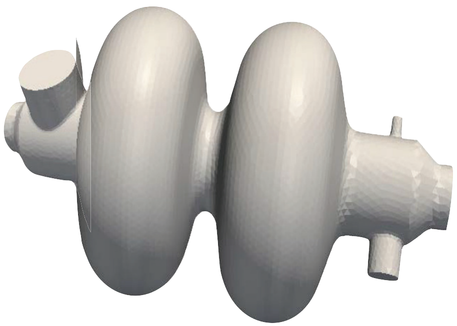

W
≈ 200 per beam
(+ 200 for booster)

H
≈ 800 per beam
(+ 800 for booster)

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

FCC International Collaboration

- 89 institutes
- 28 countries + EC

Status: August, 2016

FCC Collaboration Status

88 collaboration members + EC + CERN as host

ALBA/CELLS, Spain
Ankara U., Turkey
Aydin U, Istanbul, Turkey
U Belgrade, Serbia
U Bern, Switzerland
BINP, Russia
CASE (SUNY/BNL), USA
CBPF, Brazil
CEA Grenoble, France
CEA Saclay, France
CIEMAT, Spain
Cinvestav, Mexico
CNRS, France
CNR-SPIN, Italy
Cockcroft Institute, UK
U Colima, Mexico
UCPH Copenhagen, Denmark
CSIC/IFIC, Spain
TU Darmstadt, Germany
TU Delft, Netherlands
DESY, Germany
DOE, Washington, USA
TU Dresden, Germany
Duke U, USA
EPFL, Switzerland
UT Enschede, Netherlands
ESS, Sweden
U Geneva, Switzerland
Giresun U. Turkey
Goethe U Frankfurt, Germany

GSI, Germany
GWNU, Korea
U. Guanajuato, Mexico
Hellenic Open U, Greece
HEPHY, Austria
U Houston, USA
ISMAB-CSIC, Spain
IFAE, Spain
IFIC-CSIC, Spain
IIT Kanpur, India
IFJ PAN Krakow, Poland
INFN, Italy
INP Minsk, Belarus
U Iowa, USA
IPM, Iran
UC Irvine, USA
Isik U., Turkey
Istanbul University, Turkey
JAI, UK
JINR Dubna, Russia
Jefferson LAB, USA
FZ Jülich, Germany
KAIST, Korea
KEK, Japan
KIAS, Korea
King’s College London, UK
KIT Karlsruhe, Germany
KU, Seoul, Korea
Korea U Sejong, Korea

U Liverpool, UK
U Lund, Sweden
U Malta, Malta
MAX IV, Sweden
MEPhI, Russia
UNIMI, Milan, Italy
MISiS Moscow
MIT, USA
Northern Illinois U, USA
NC PHEP Minsk, Belarus
OIU, Turkey
Okan U, Turkey
U Oxford, UK
PSI, Switzerland
U. Rostock, Germany
RTU, Riga, Latvia
UC Santa Barbara, USA
Sapienza/Roma, Italy
U Siegen, Germany
U Silesia, Poland
Stanford U, USA
U Stuttgart, Germany
TAU, Israel
TU Tampere, Finland
TOBB, Turkey
U Twente, Netherlands
TU Vienna, Austria
Wigner RCP, Budapest, Hungary
Wroclaw UT, Poland


FCCWEEK 2016
International Future Circular Collider Conference
ROME 11-15 APRIL
fccw2016.web.cern.ch
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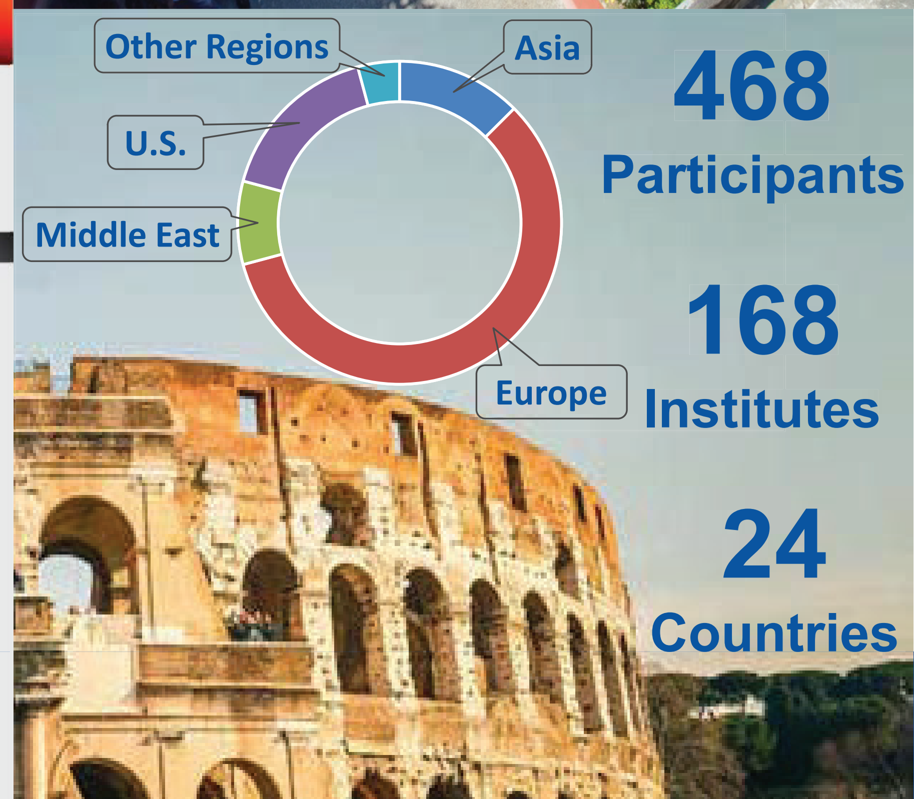
Other Regions
Asia
U.S.
Middle East
Europe
468
Participants
168
Institutes
24
Countries

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 the development of high-efficiency SRF systems is critical for FCC-ee.
- **International collaboration is essential to advance on all challenging subjects and the community is warmly invited to join the FCC efforts.**


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DPG
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29 MAY - 02 JUNE
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