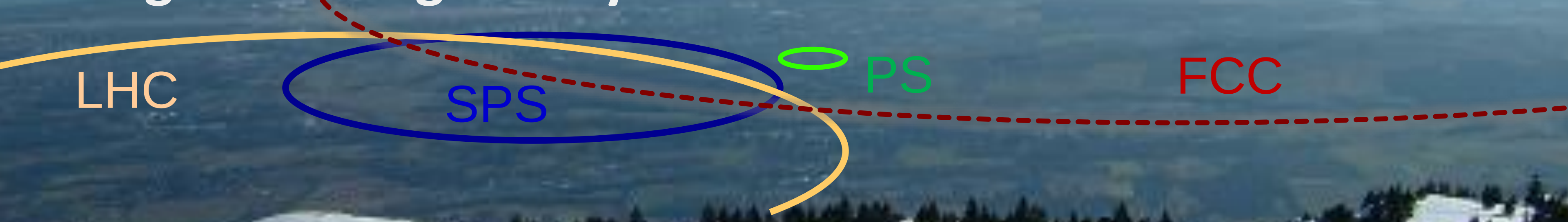
Future Circular Collider Study

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

- Motivation for Future Circular Colliders
- FCC Study Scope & Time Line
- Machine Design
- Detectors & Machine Detector Interface
- Technologies
- FCC Organisation & Collaboration

FCC strategic motivation

- **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….coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures,…."

- **U.S. strategy and 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…."

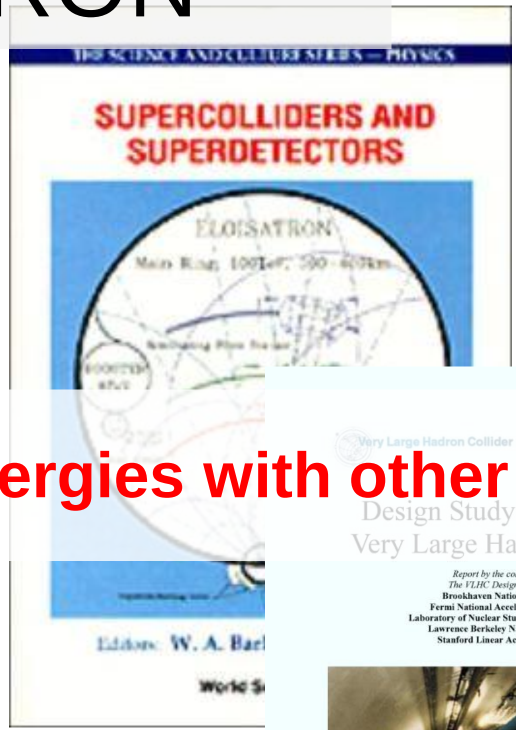
- **International Committee on Future Accelrators statement 2014:**

  "…. ICFA supports studies of energy frontier circular colliders and encourages global coordination….."

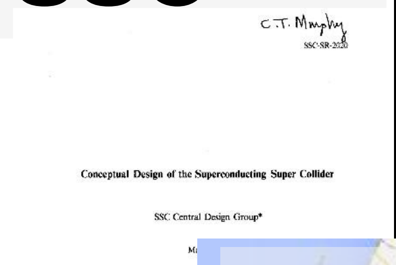
Previous studies in Italy (ELOISATRON 300km), USA (SSC 87km, VLHC 233km), Japan (TRISTAN-II 94km)

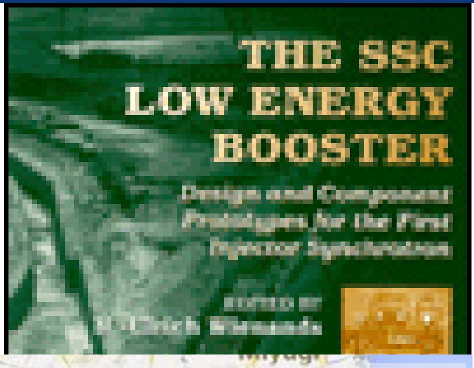
ELOISATRON

Supercolliders Superdetectors: Proceedings of the 19th and 25th Workshops of the INFN Eloisatron Project



SSC





SSC C

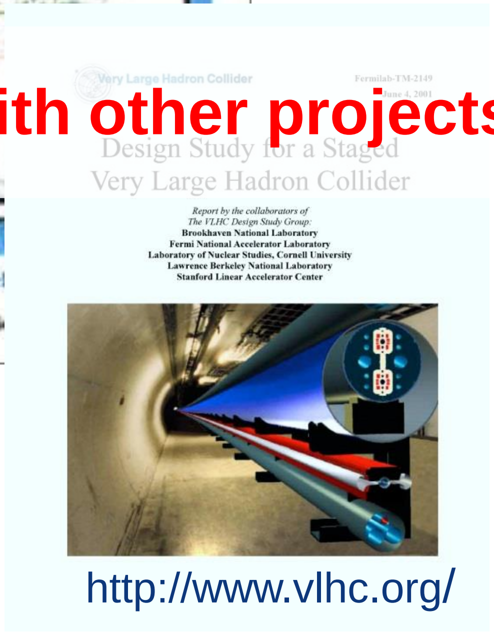
TRISTAN II

F. Takasaki

→ Exploit synergies with other projects and prev. studies

VLHC

VLHC Design Study Group Collaboration
June 2001. 271 pp.
SLAC-R-591, SLAC-R-0591, SLAC-591, SLAC-0591, FERMILAB-TM-2149



http://www.vlhc.org/

CepC/SppC study (CAS-IHEP) 54 km (baseline)
e^+e^- collisions ~2028; *pp* collisions ~2042

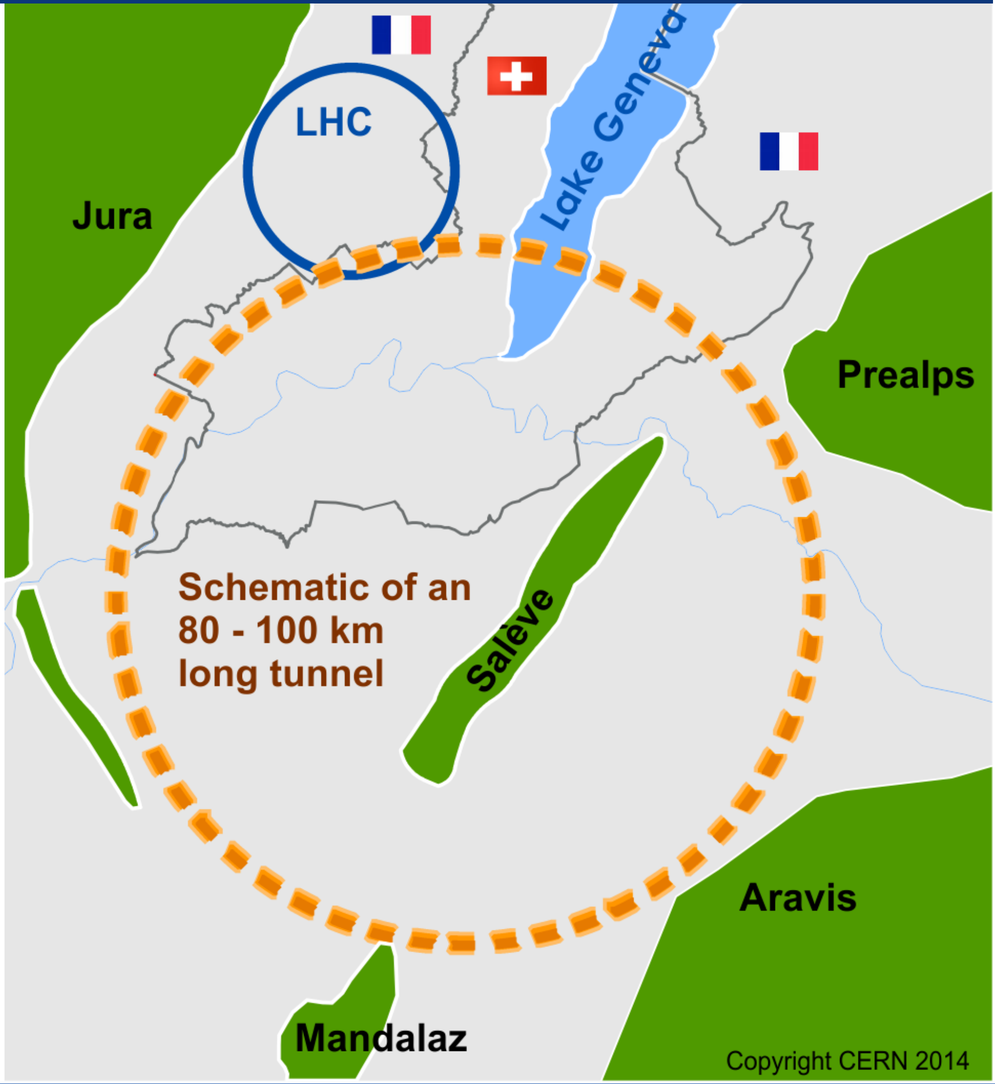
Future Circular Collider Study
Goal: CDR for European Strategy Update 2018/19

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

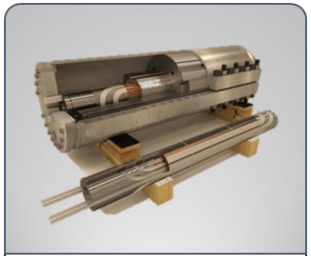
- **80-100 km tunnel infrastructure** in Geneva area, site specific
- ***e*⁺*e*⁻ collider (*FCC-ee*),** as potential first step
- ***p-e* (*FCC-he*) option,** integration one IP, FCC-hh & ERL
- **HE-LHC** with *FCC-hh* technology



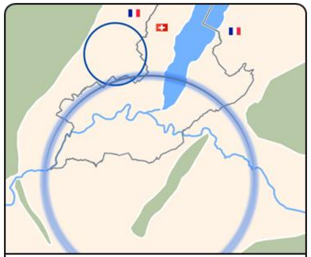
FCC Scope: Accelerator and Infrastructure

Collider Designs

FCC-hh: **100 TeV pp collider as long-term goal**
→ defines infrastructure needs
FCC-ee: **e^+e^- collider**, potential intermediate step
HE-LHC: **based on FCC-hh technology**

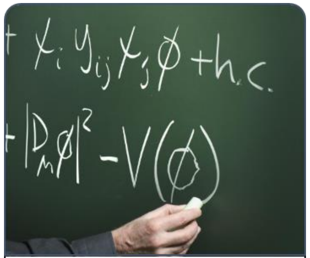

R&D Programs

Launch R&D on key enabling technologies
in dedicated R&D programmes, e.g.
16 Tesla magnet program, cryogenics,
SRF technologies and RF power sources


Infrastructures

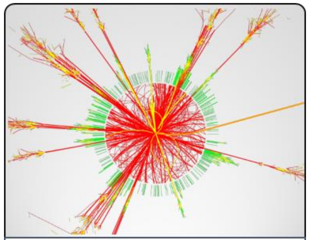
Tunnel infrastructure in Geneva area, linked to CERN accelerator complex;
site-specific, as requested by European strategy

FCC Scope:
Physics & Experiments



Physics Cases

Elaborate and document
- **Physics opportunities**
- **Discovery potentials**



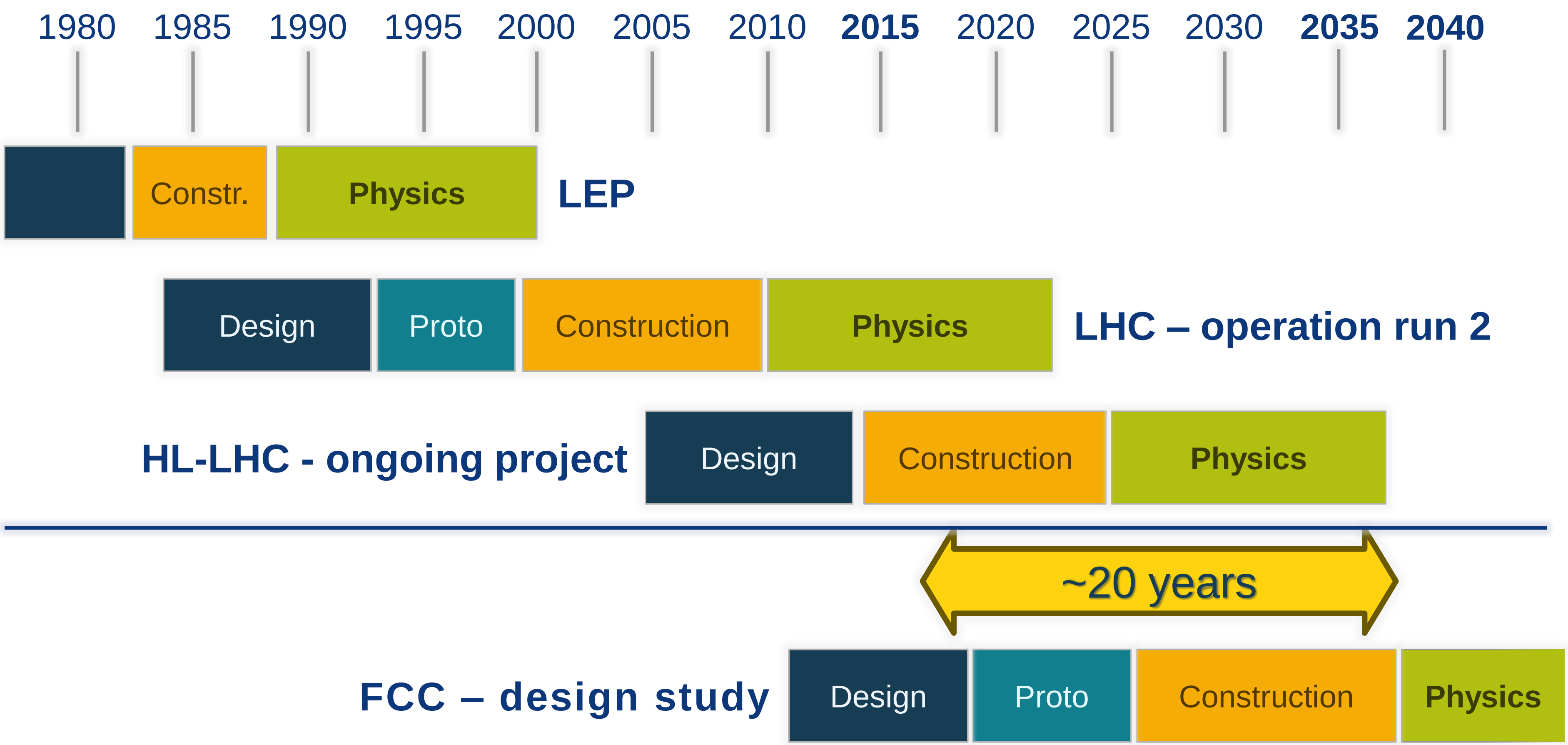
Experiments

Experiment concepts for hh, ee and he
Machine Detector Interface studies
R&D needs for **detector technologies**

Cost Estimates

Overall **cost model for collider scenarios** including infrastructure and injectors
Develop **realization concepts**
Forge **partnerships with industry**

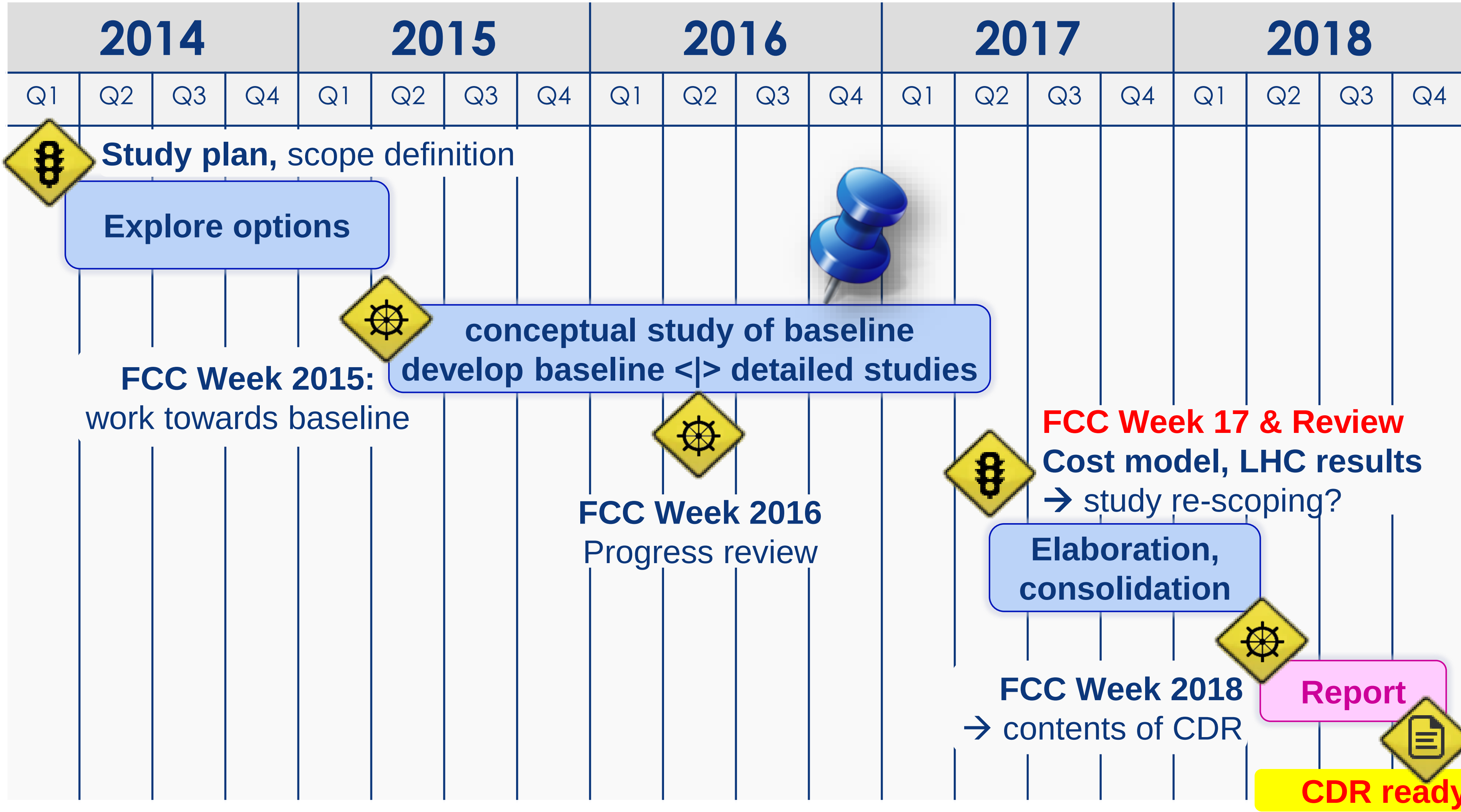
CERN Circular Colliders & FCC



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

FCC CDR Study Timeline



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

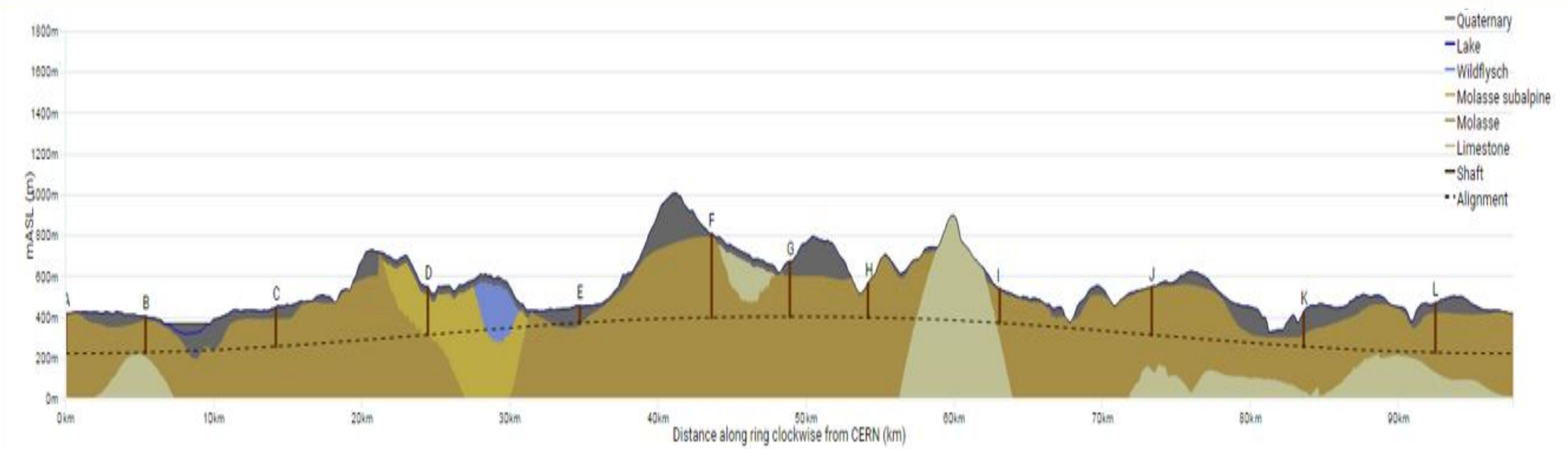
	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	-64°	220m	64°	172m
SPS		242m		241m
TI2		235m		241m
TI8		242m		170m

Alignment Location

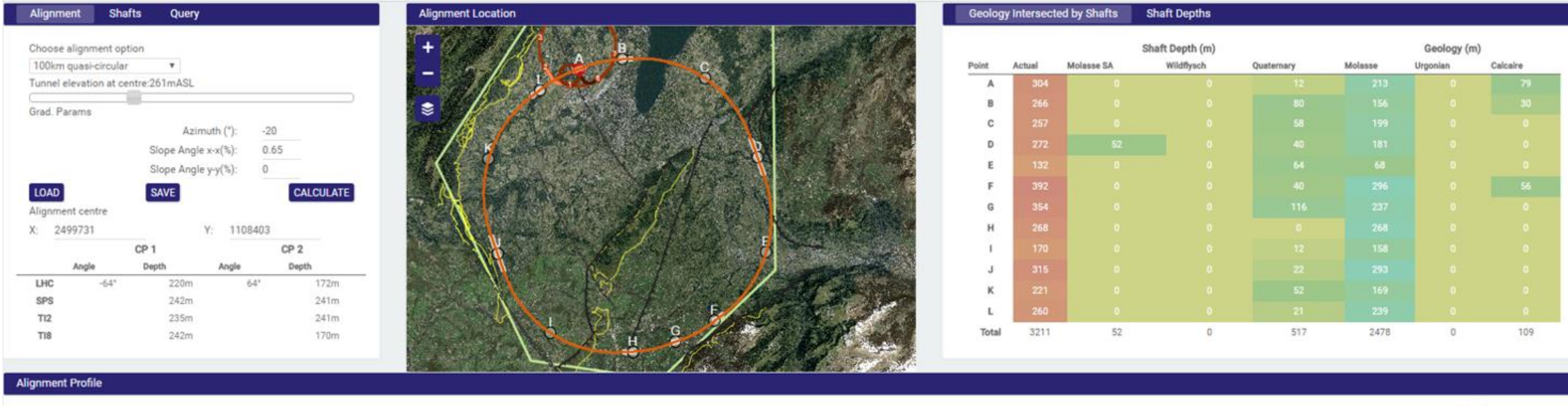
Geology Intersected by Shafts | Shaft Depths

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

Alignment Profile



Progress on site investigations

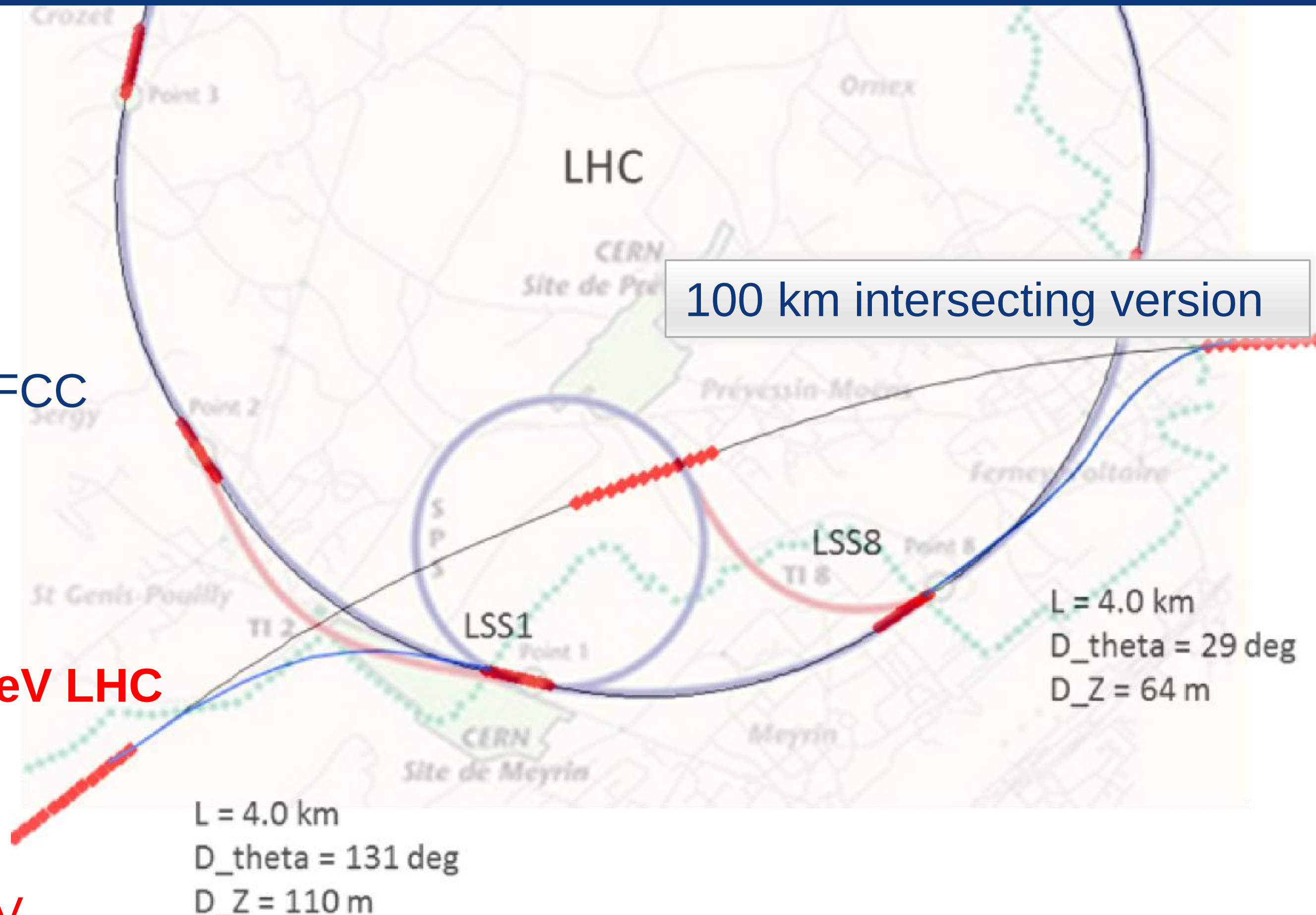


- 90 – 100 km fits geological situation well
- LHC suitable as potential injector
- The 100 km version, intersecting LHC, is now being studied in more detail

FCC-hh injector studies

Injector options:

- **SPS → LHC → FCC**
- SPS/$SPS_{upgrade}$ → FCC
- SPS -> FCC booster → FCC



Current baseline:

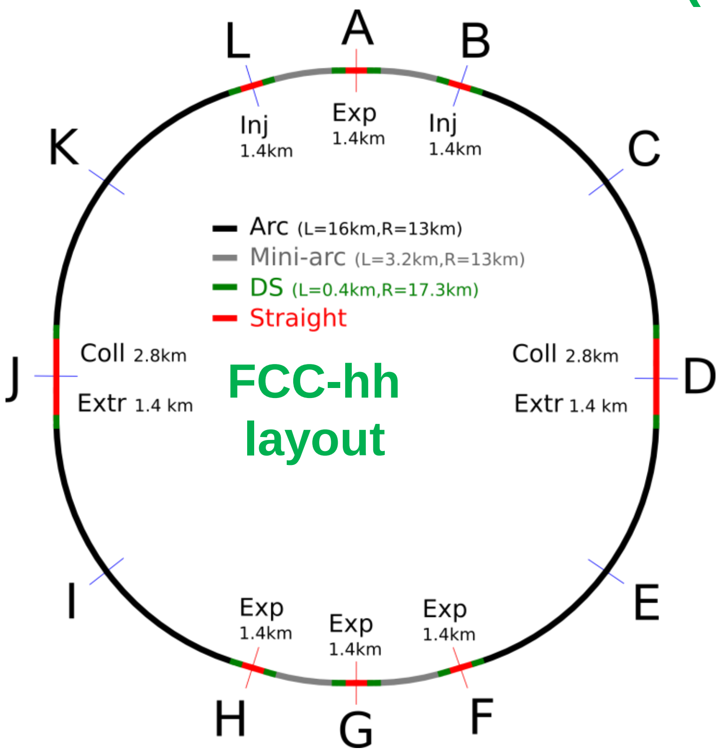
- **injection energy 3.3 TeV LHC**

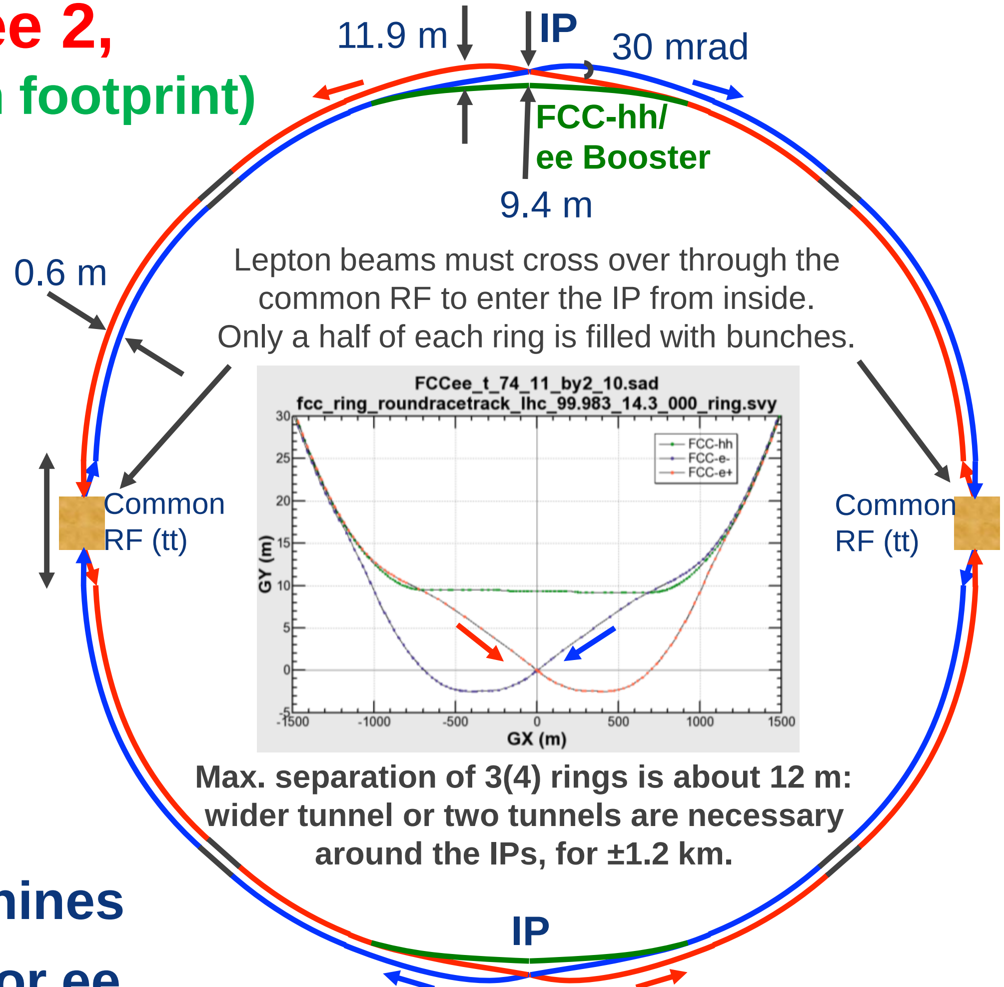
Alternative options:

- Injection around 1.5 TeV
- **compatible with: $SPS_{upgrade}$, LHC, FCC booster**
- **$SPS_{upgrade}$ 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

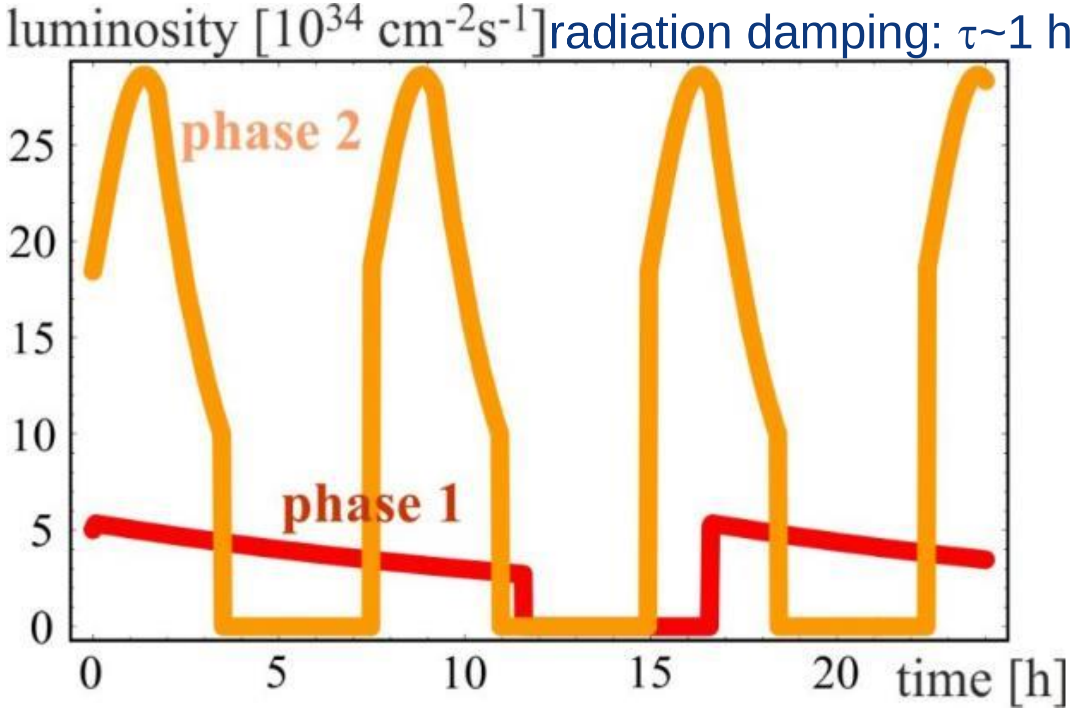
parameter	FCC-hh		SPPC	HE-LHC* *tentative	(HL) LHC
collision energy cms [TeV]	100		71.2	>25	14
dipole field [T]	16		20	16	8.3
circumference [km]	100		54	27	27
# IP	2 main & 2		2	2 & 2	2 & 2
beam current [A]	0.5		1.0	1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2	2.2	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25	25	25
beta* [m]	1.1	0.3	0.75	0.25	(0.15) 0.55
luminosity/IP [10^{34} cm^{-2}s^{-1}]	5	20 - 30	12	>25	(5) 1
events/bunch crossing	170	<1020 (204)	400	850	(135) 27
stored energy/beam [GJ]	8.4		6.6	1.2	(0.7) 0.36
synchrotr. rad. [W/m/beam]	30		58	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)

Physics prospects

Physics at the FCC-hh

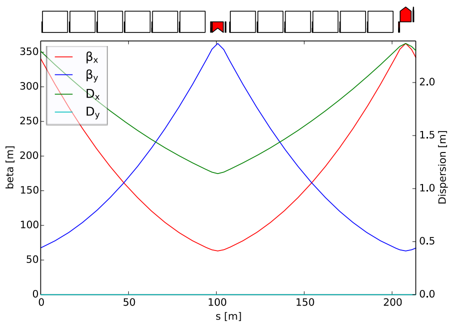
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/FutureHadroncollider

- **Volume 1: SM processes** (238 pages)
- **Volume 2: Higgs and EW symmetry breaking studies** (175 pages)
- **Volume 3: beyond the Standard Model phenomena** (189 pages)
- **Volume 4: physics with heavy ions** (56 pages)
- **Volume 5: physics opportunities with the FCC-hh injectors** (14 pages)

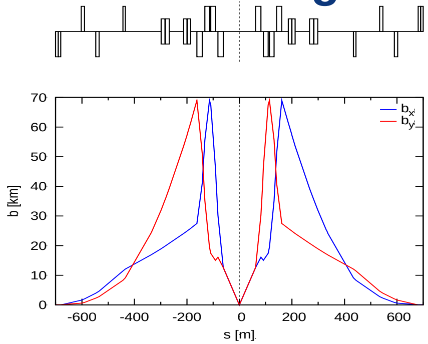
- **Being published as CERN yellow report**

FCC-hh full-ring optics design

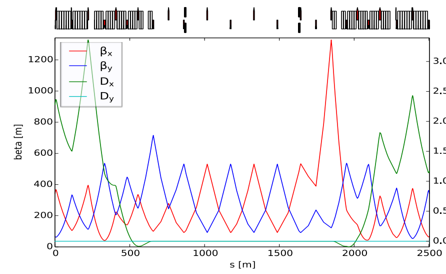
Regular arc cell



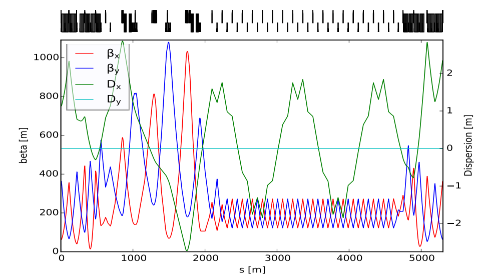
Interaction region



Injection with RF

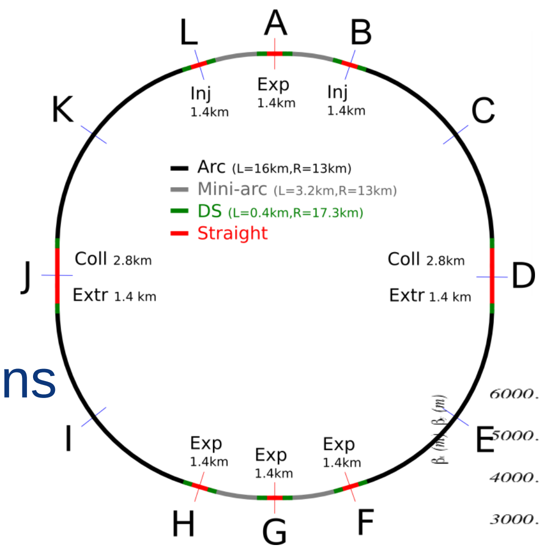


Momentum collim.

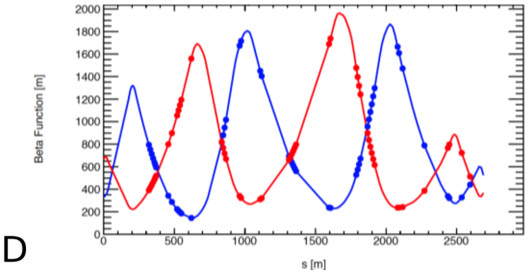


Full ring optics design available as basis for:

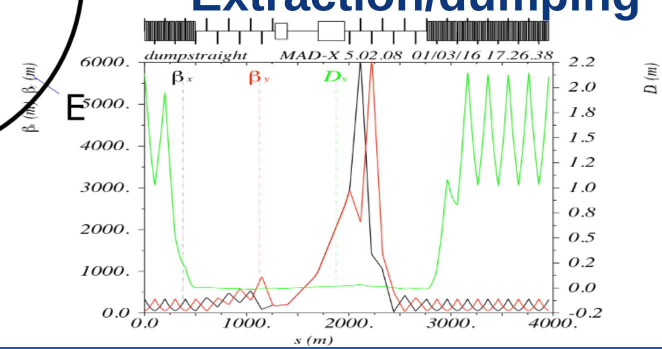
- beam dynamics studies
- optimisation of each insertion
- definition of system specifications (apertures, etc.)
- improvement of baseline optics and layout
- collimation efficiency study & optimisation



Betatron collimation



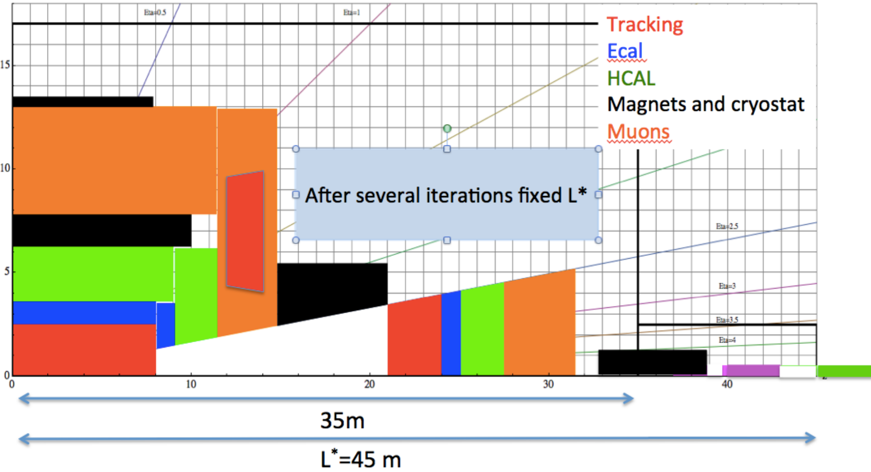
Extraction/dumping

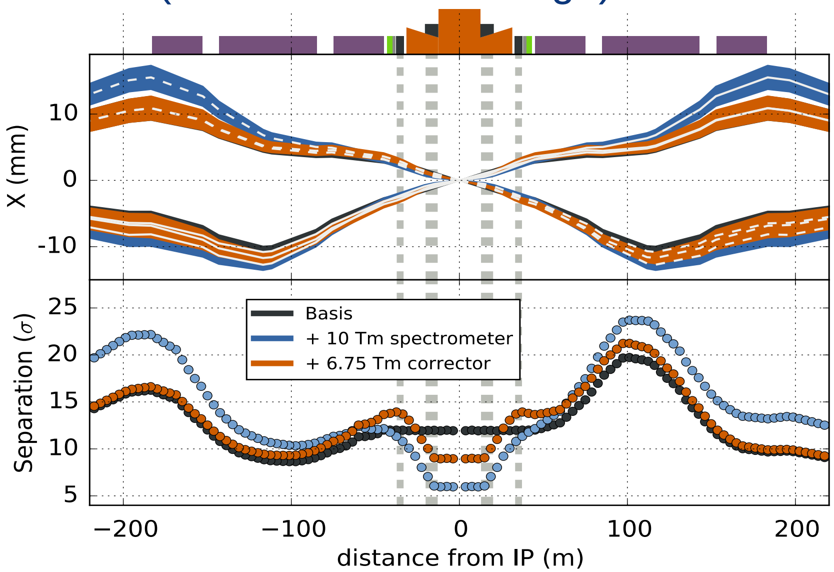


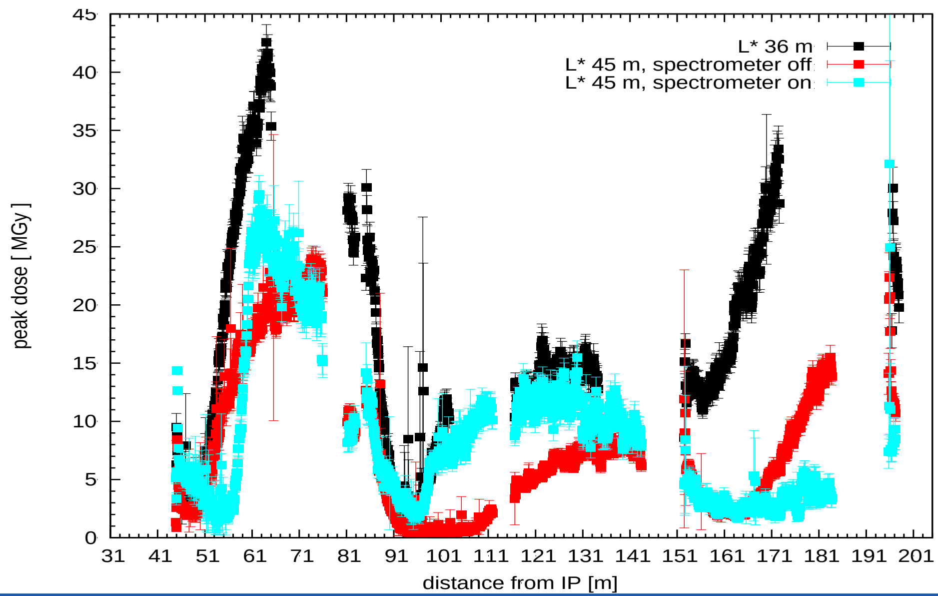
FCC-hh MDI status

Design of interaction region

- Distance from IP to first machine quadrupole L^*=45 m.
- Integrated spectrometers and compensation dipoles.
- Optics and magnet optimization for beam stay clear and collision debris.
  - ✓ Magnet lifetime should be ≥ 3 years (from radiation damage).

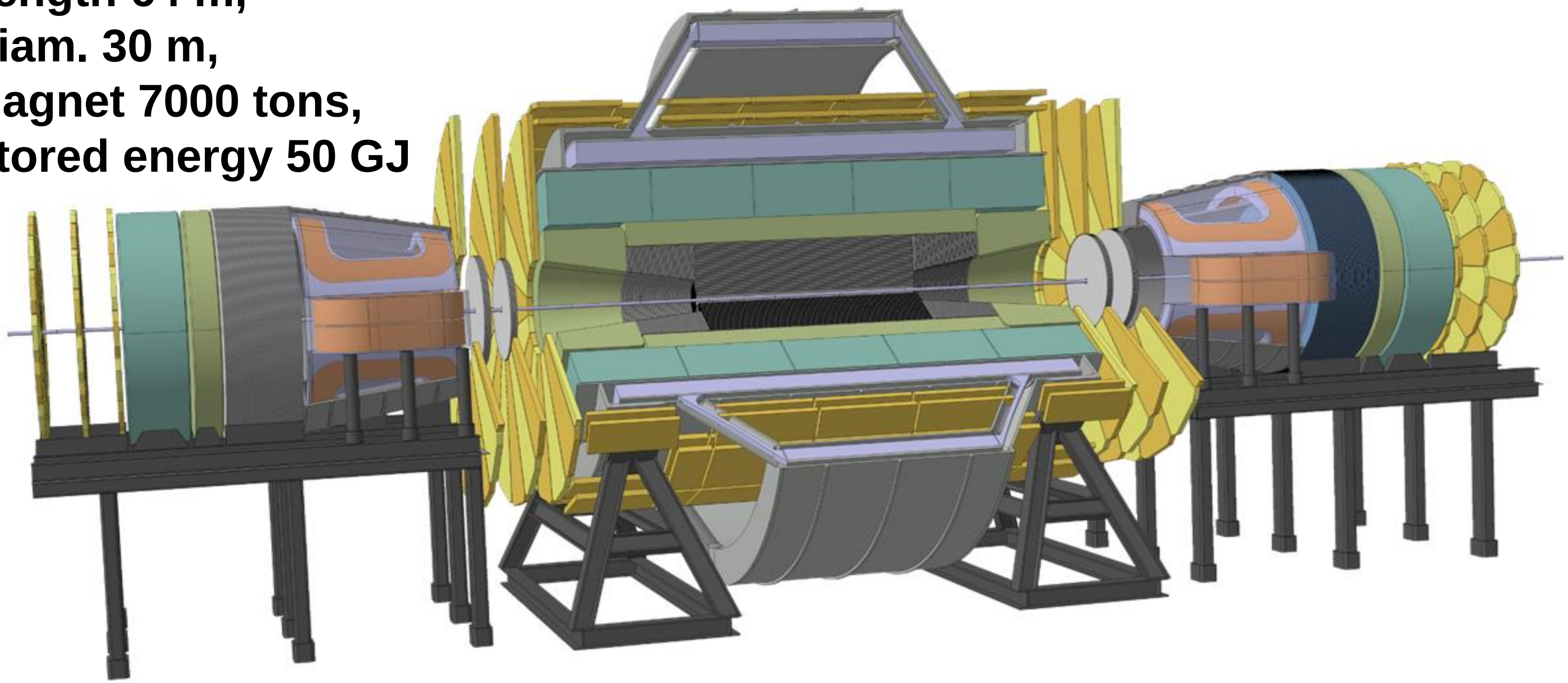






Detector concepts for 100 TeV pp

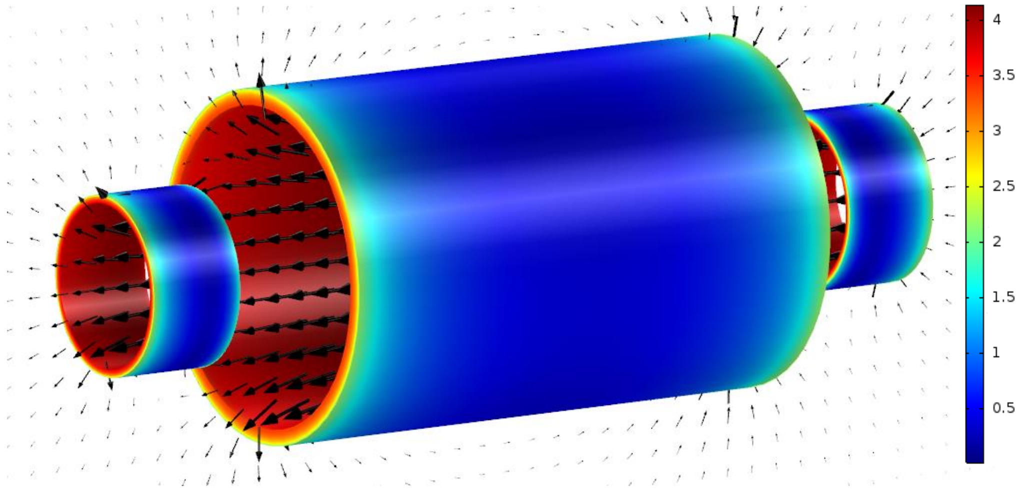
- **A B=6 T, R=6 m solenoid with shielding coil and 2 dipoles has been engineered in detail. Alternative magnet systems are being studied**
  - **Length 64 m,**
  - **Diam. 30 m,**
  - **Magnet 7000 tons,**
  - **Stored energy 50 GJ**



R&D for FCC detectors will be a natural continuation of LHC Phase II upgrade

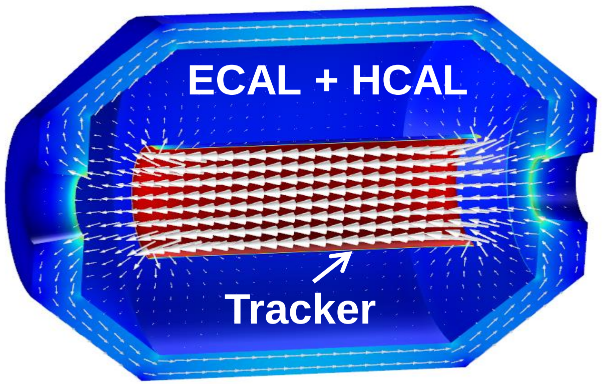
Detector Magnet Studies

Designs for physics-performing and cost-efficient magnet systems



Today's baseline:

4T/10m bore 20m long Main Solenoid
4T Side Solenoids – all unshielded
14 GJ stored energy, 30 kA and
2200 tons system weight



Alternative challenging design:

4T/4m Ultra-thin, high-strength Main Solenoid
allowing positioning inside the e-calorimeter,
280 MPa conductor (side solenoids not shown)
0.9 GJ stored energy, elegant, 25 t only,
but needs R&D!

Beam power and machine protection

Stored energy 8.4 GJ per beam

– At least one order of magnitude higher than for LHC, equivalent to A380 (560 t) at nominal speed (850 km/h).

– **Collimation, control of beam losses and radiation effects (shielding) are of prime importance.**

– **Injection, beam transfer and beam dump all critical.**

Damage of a beam with an energy of 2 MJ

All machine protection issues to be addressed early on!

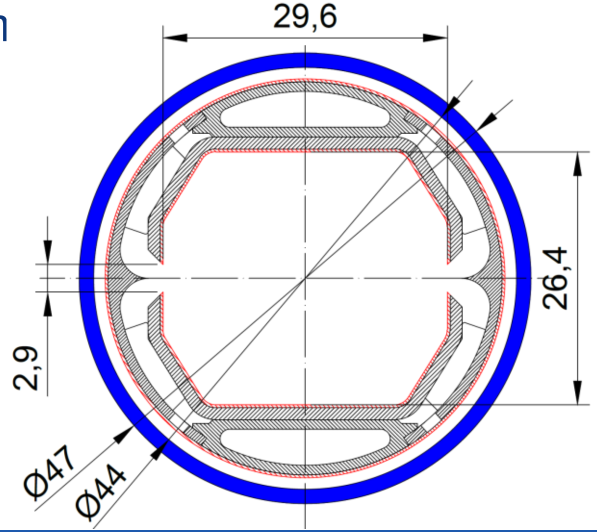
Synchrotron radiation beam screen prototype

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!!!)**

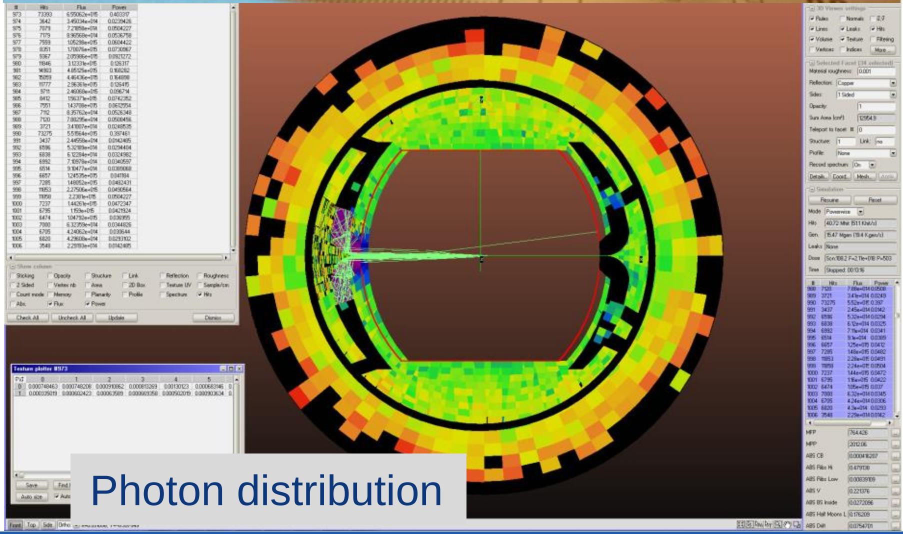
New Beam screen with ante-chamber

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



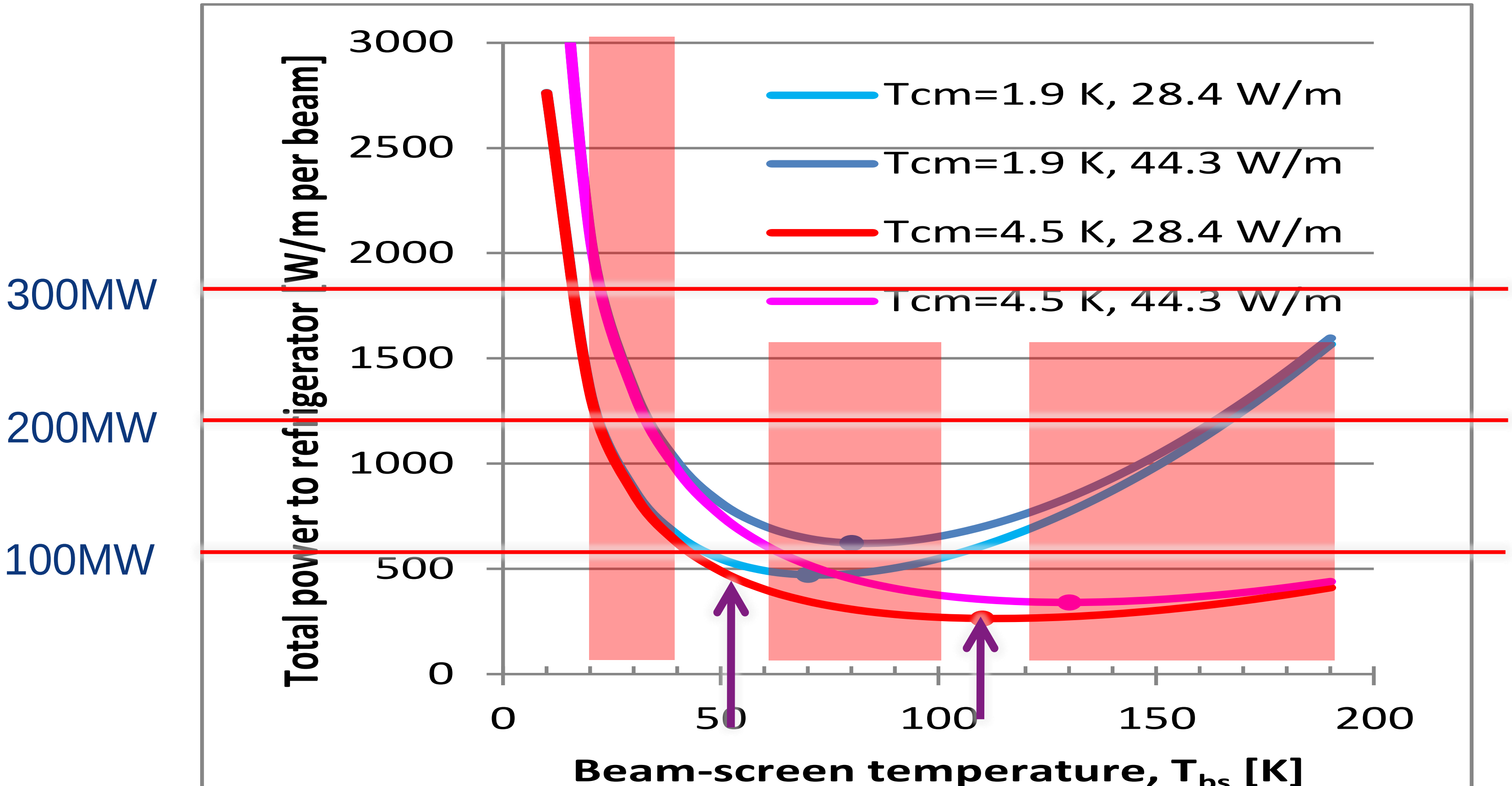
First FCC-hh beam screen prototype

Testing 2017 in ANKA within EuroCirCol



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 ($\Delta Q=0.5$)

Main SC Magnet system FCC (16 T) vs LHC (8.3 T)

FCC

Bore diameter: 50 mm

Dipoles: $4578\ units, 14.3\ m\ long, 16\ T \Leftrightarrow \int Bdl{\sim}1\ MTm$

$\text{Stored energy} \sim 200\ \text{GJ (GigaJoule)} \sim 44\ \text{MJ/unit}$

Quads: $762\ magnets,\ \ 6.6\ m\ long, 375\ T/m$

LHC

Bore diameter: 56 mm

Dipoles: $1232\ units, 14.3\ m\ long, 8.3\ T \Leftrightarrow \int Bdl{\sim}0.15\ MTm$

$\text{Stored energy} \sim 9\ \text{GJ (GigaJoule)} \sim 7\ \text{MJ/unit}$

Quads: $392\ units,\ \ 3.15\ m\ long, 233\ T/m$

FCC Technology program 2016-2020

FCC-ST-0001

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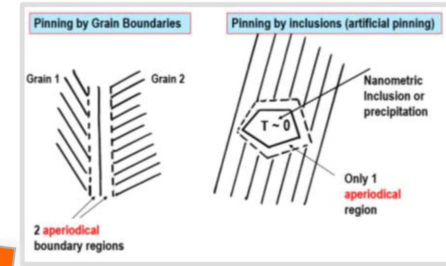
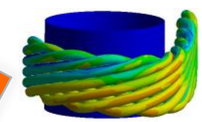
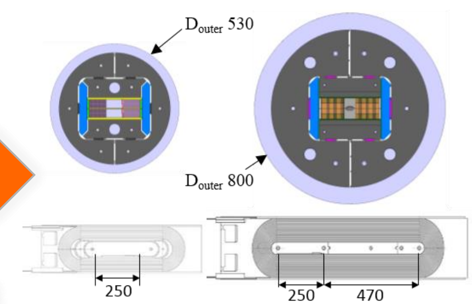
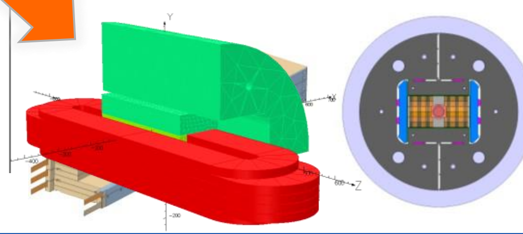




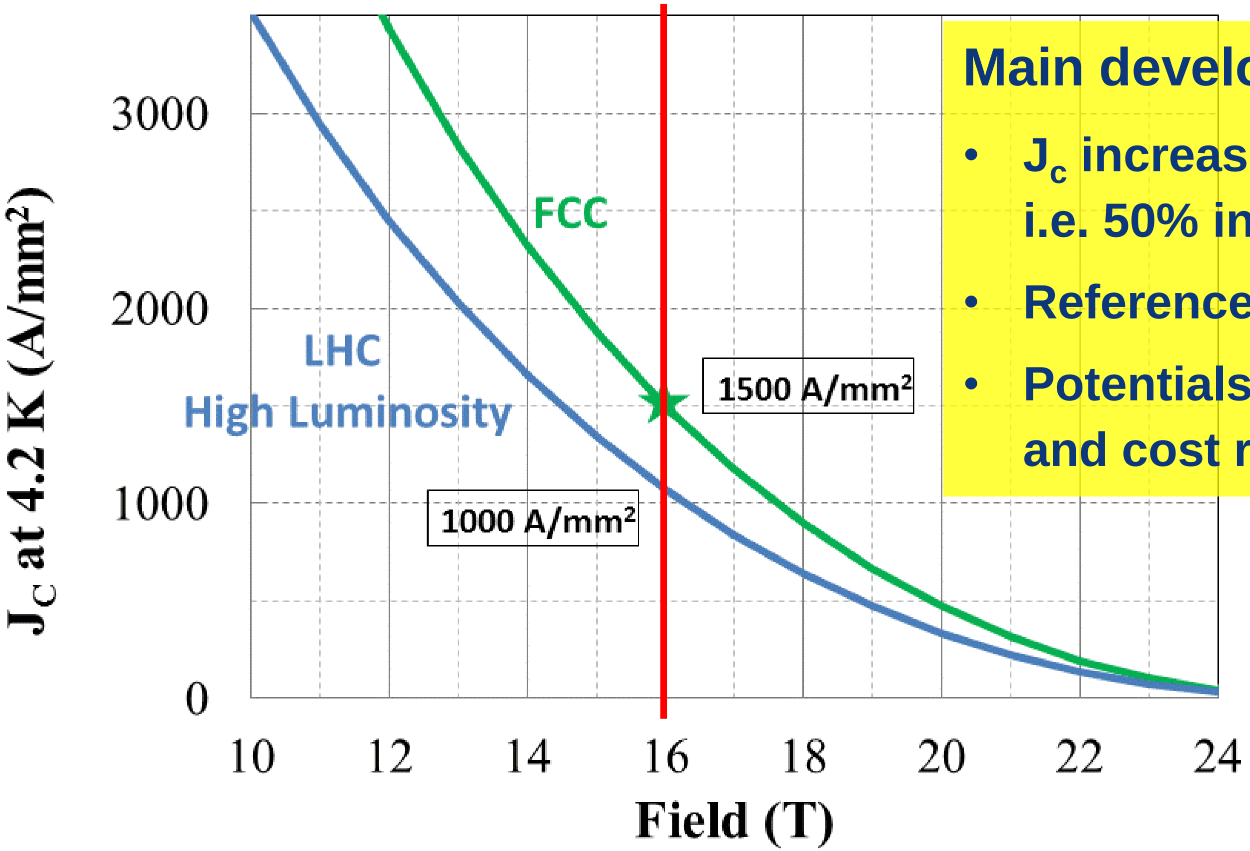




15 MCHF material over 4 years (8 MCHF on conductor R&D)

Nb_3Sn conductor program

Nb_3Sn is one of the major cost & performance factors for FCC-hh and must be given 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:

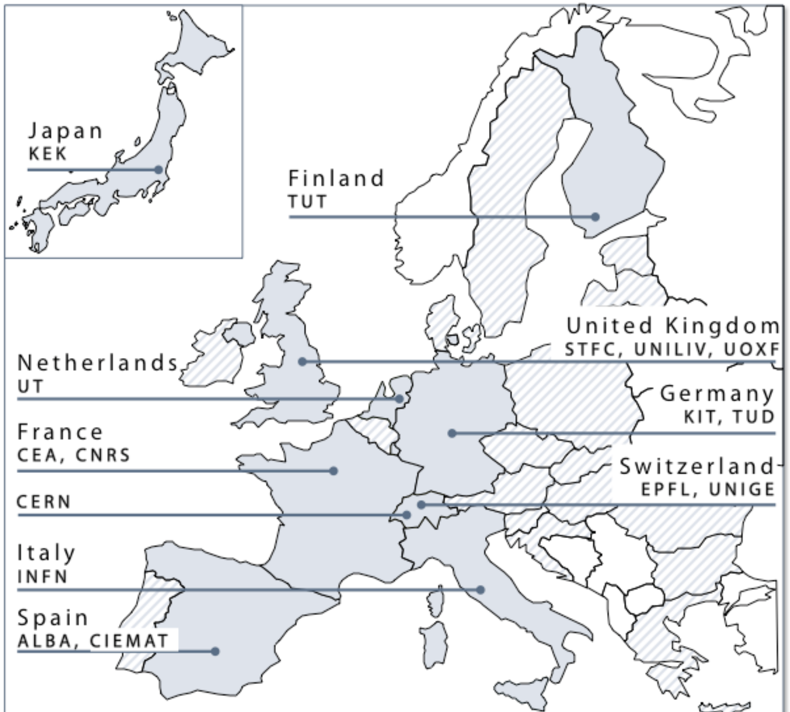
- **CERN/KEK** – **Japanese** contribution. Japanese **industry** (JASTEC, Furukawa, SH Copper) and laboratories (Tohoku Univ. and NIMS).
- **CERN/Bochvar High-technology Research Inst.** – **Russian** contribution. Russian **industry** (TVEL) and laboratories
- **CERN/KAT** – **Korean** **industrial**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



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

European Union Horizon 2020 program

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

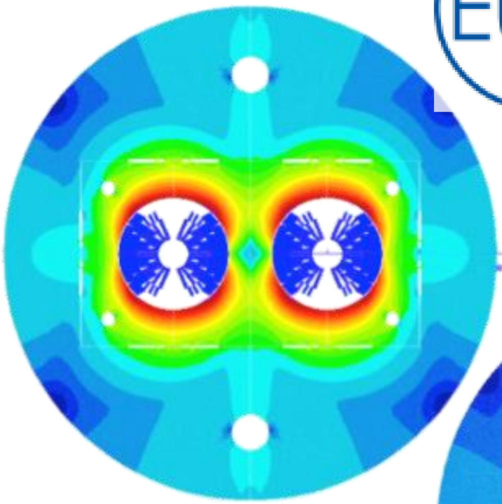
Scope:

FCC hadron collider

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

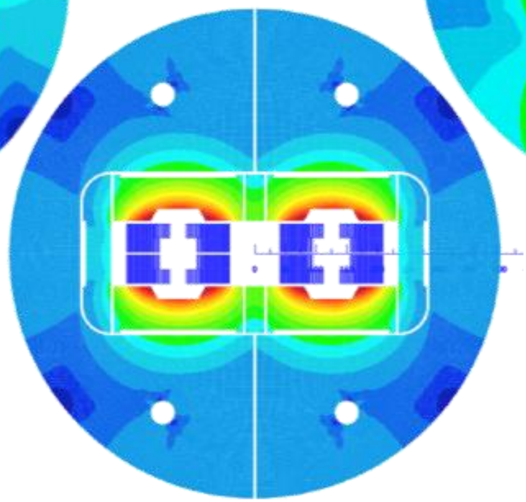
16 T dipole options and plans

Cos-theta

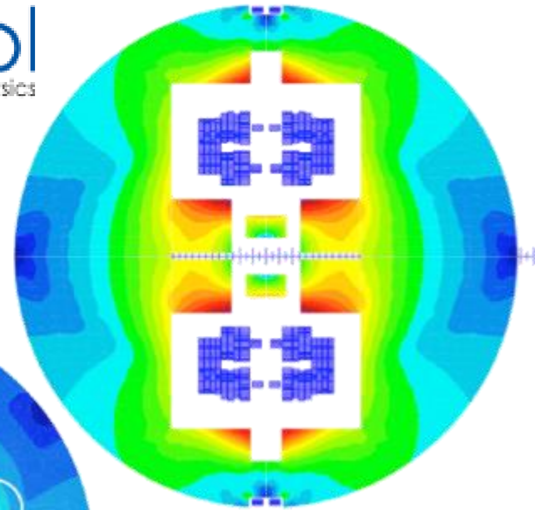


EuroCirCol
A key to New Physics

Blocks

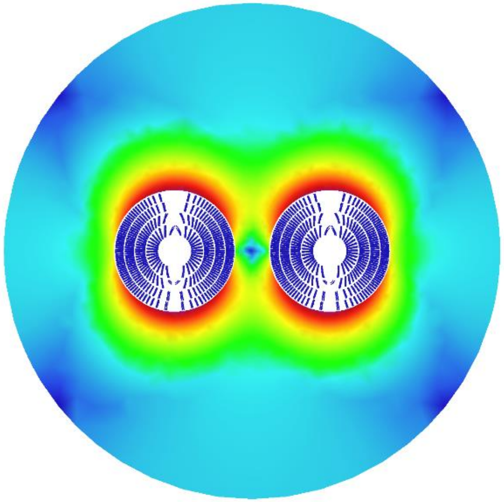


Common coils



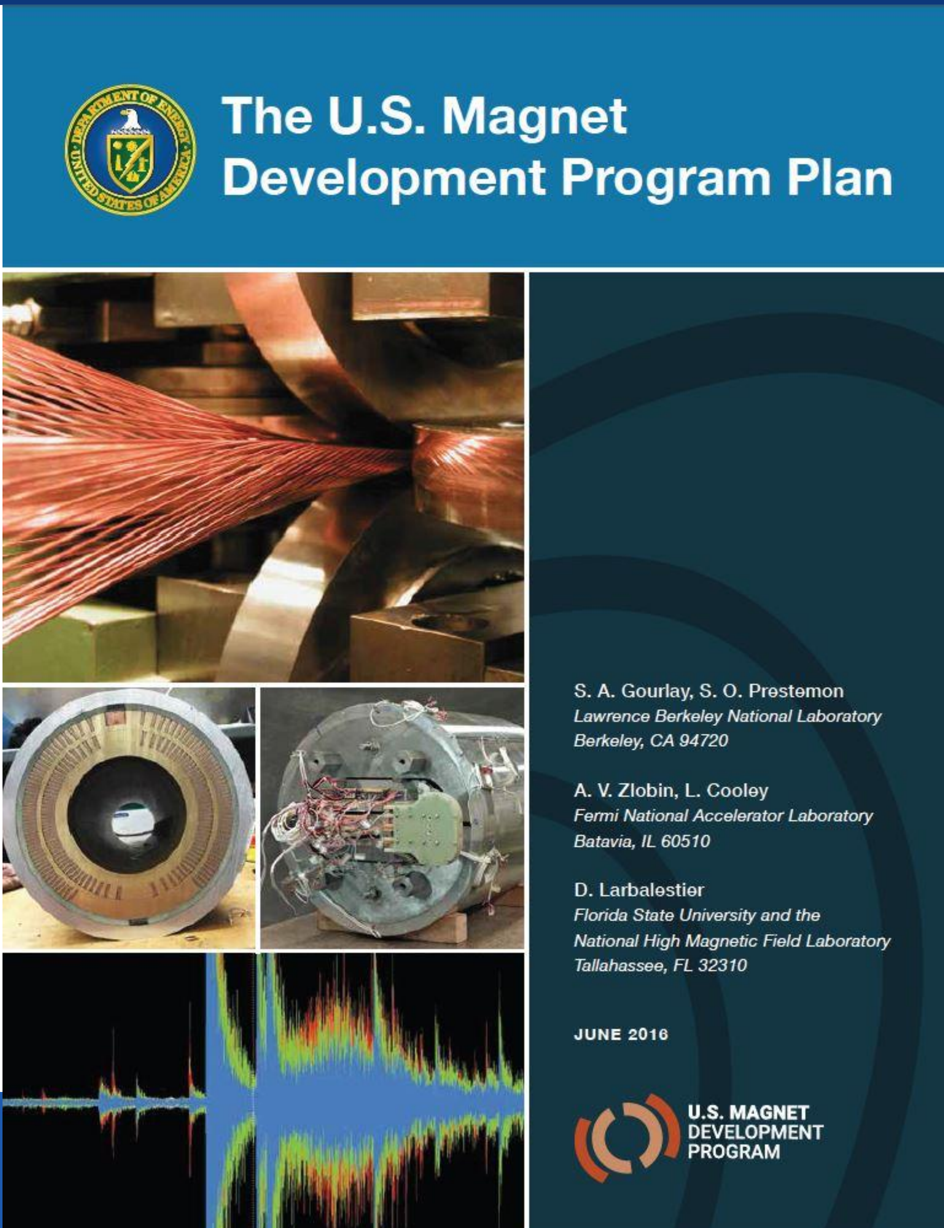
Swiss contribution
via PSI

Canted
Cos-theta



- **Down-selection of options end 2016 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:

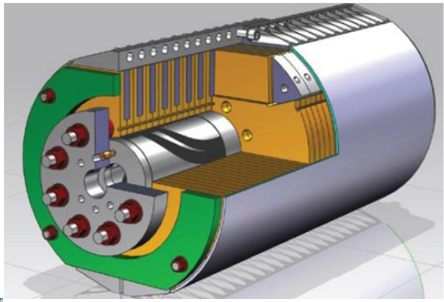
Investigate fundamental aspects of magnet design and technology that can lead to substantial performance improvements and magnet cost reduction.

GOAL 4:

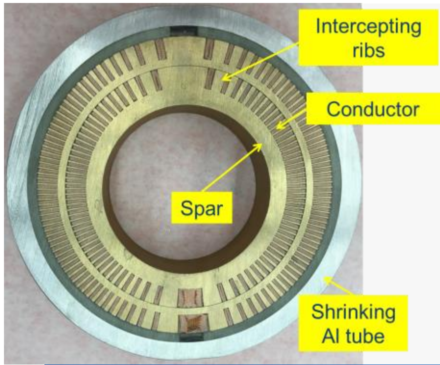
Pursue Nb_3Sn and HTS conductor R&D with clear targets to increase performance and reduce the cost of accelerator magnets.

Under Goal 1:

16 T cos theta dipole design



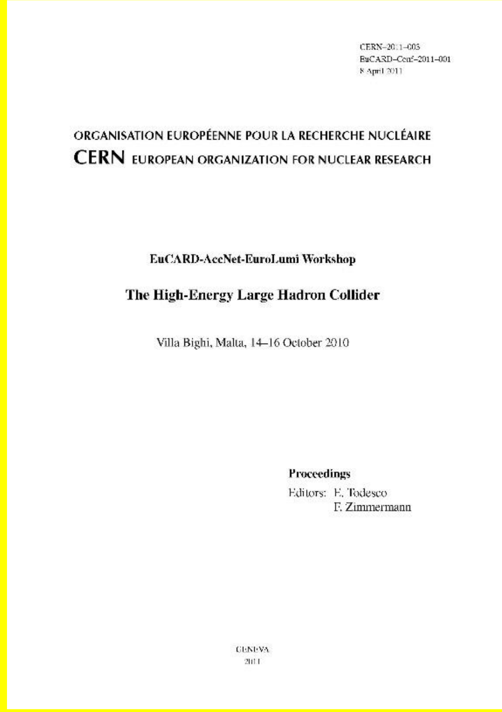
16 T canted cos theta (CCT) design



High-Energy LHC

FCC study continues effort on **high-field collider in LHC tunnel**

2010 EuCARD Workshop Malta;
Yellow Report CERN-2011-1


CERN–2011–003
EuCARD–Conf–2011–001
8 April 2011

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

EuCARD-AccNet-EuroLumi Workshop

The High-Energy Large Hadron Collider

Villa Bighi, Malta, 14–16 October 2010

Proceedings
Editors: E. Todesco
F. Zimmermann

GENEVA
2011

EuCARD-AccNet-EuroLumi Workshop: The High-Energy Large Hadron Collider - HE-LHC10, E. Todesco and F. Zimmermann (eds.), EuCARD-CON-2011-001; arXiv:1111.7188; CERN-2011-003 (2011)

- based on 16-T dipoles developed for FCC-hh
- extrapolation from (HL-)LHC and from FCC developments
- **Present focus: optics scaling, infrastructure requirements & integration**

FCC–ee physics requirements

- **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*
- **beam energy range from 35 GeV to ≈200 GeV**
- **highest possible luminosities** *at all working points*
- **some polarization up to ≥80 GeV** for beam energy calibration

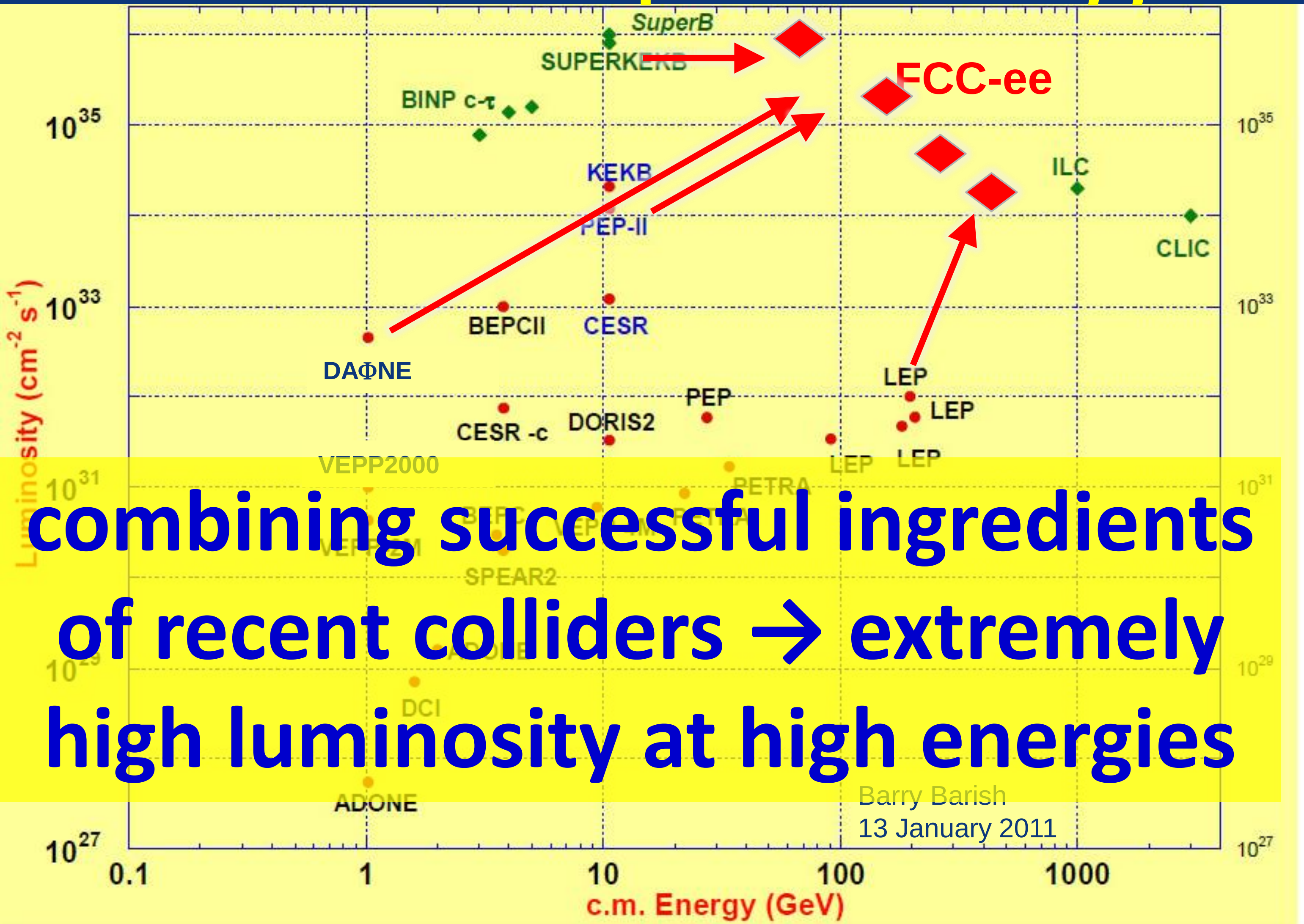
lepton collider parameters

parameter	FCC-ee (400 MHz)					CEPC	LEP2
Physics working point	Z		WW	ZH	tt_{bar}	H	
energy/beam [GeV]	45.6		80	120	175	120	105
bunches/beam	30180	91500	5260	780	81	50	4
bunch spacing [ns]	7.5	2.5	50	400	4000	3600	22000
bunch population [10^{11}]	1.0	0.33	0.6	0.8	1.7	3.8	4.2
beam current [mA]	1450	1450	152	30	6.6	16.6	3
luminosity/IP x $10^{34}cm^{-2}s^{-1}$	210	90	19	5.1	1.3	2.0	0.0012
energy loss/turn [GeV]	0.03	0.03	0.33	1.67	7.55	3.1	3.34
synchrotron power [MW]	100					103	22
RF voltage [GV]	0.4	0.2	0.8	3.0	10	6.9	3.5

identical FCC-ee baseline optics for all energies

FCC-ee: 2 separate rings CEPC, 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

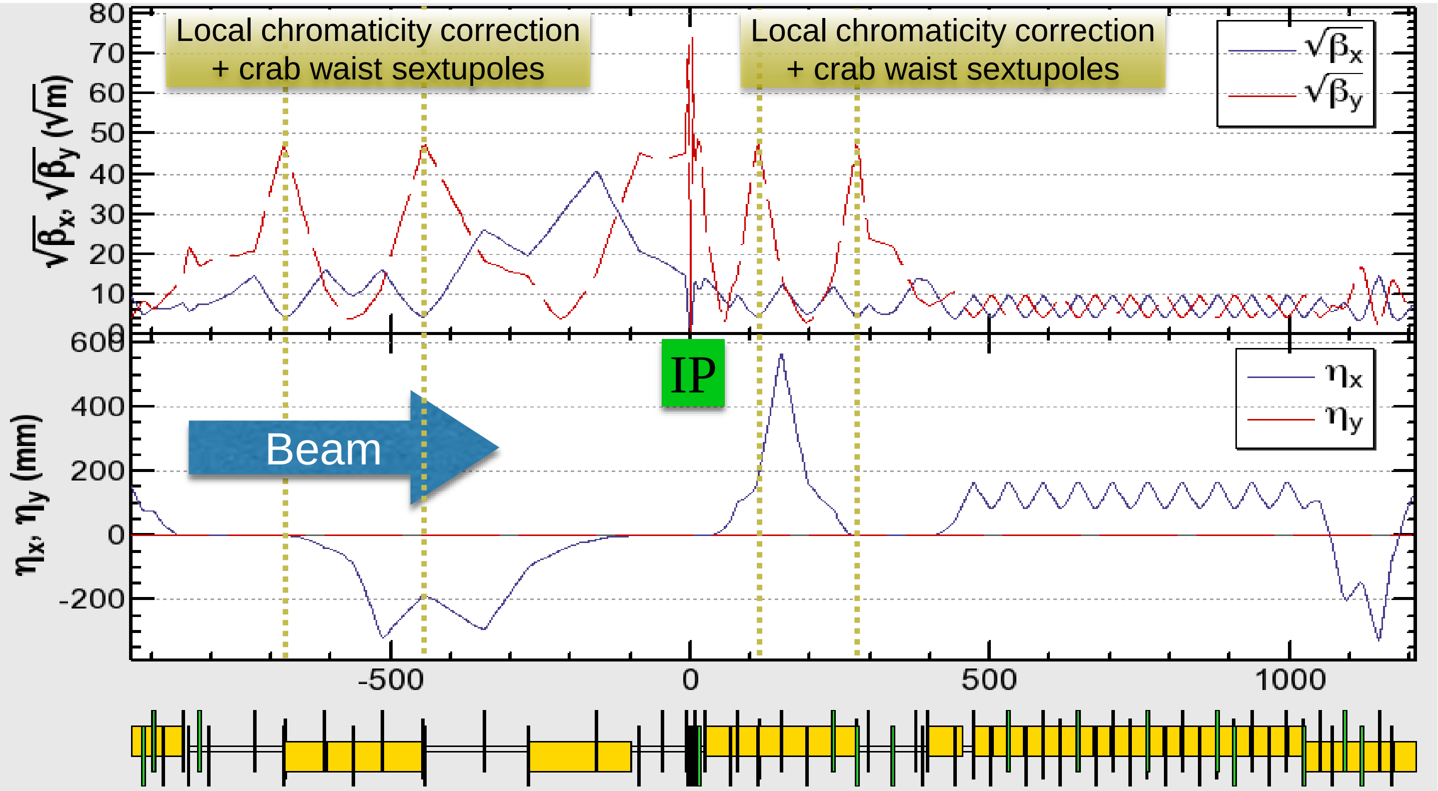
HERA, LEP, RHIC:
- spin gymnastics

FCC-ee optics design

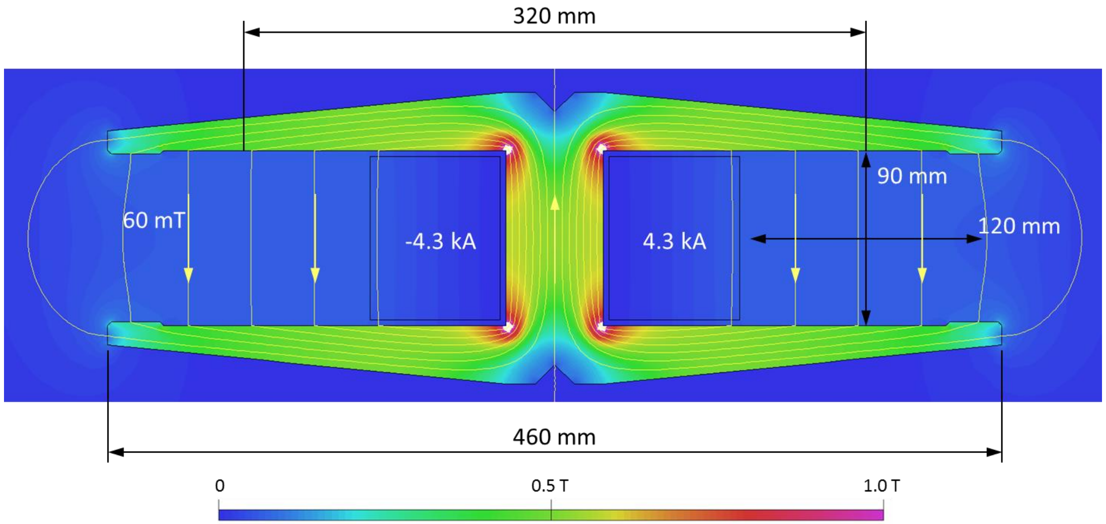
Optics design for all working points achieving baseline performance

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

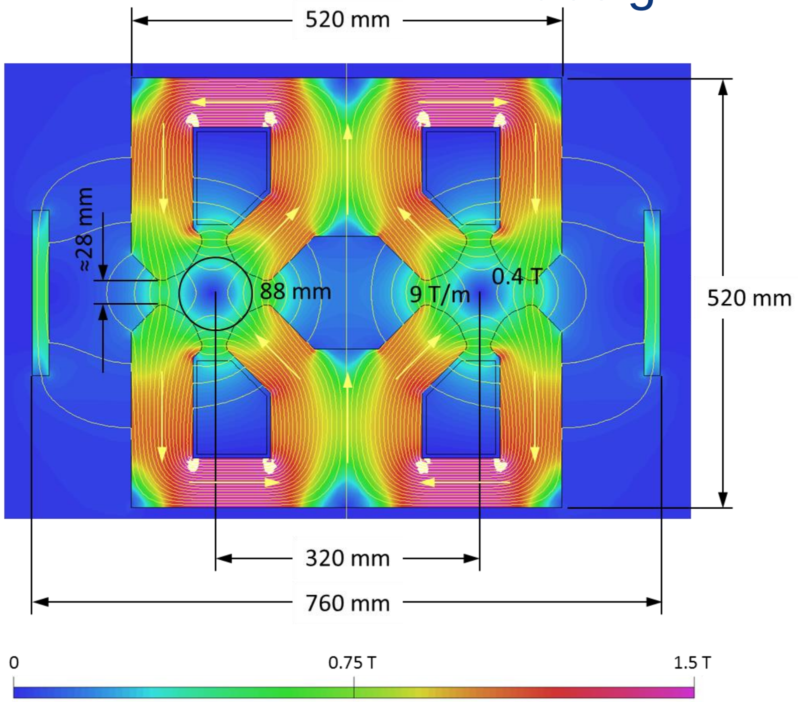


Efficient 2-in-1 FCC-ee arc magnets



Dipole:
twin aperture yoke
single busbars as coils

Quadrupole:
twin 2-in-1 design



midplane shield
for stray field

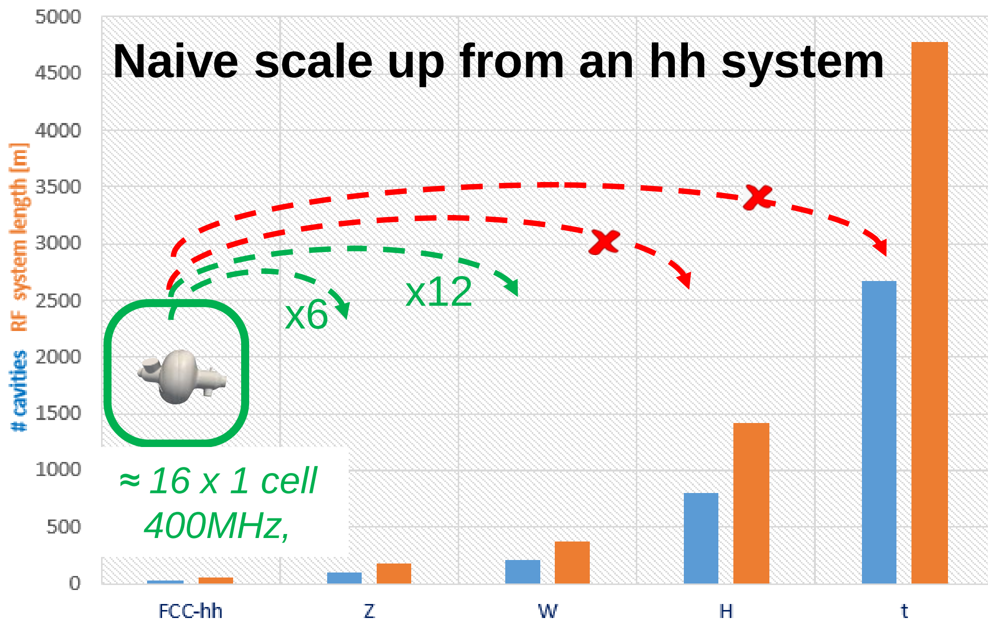
- **Novel arrangements allow for considerable savings in Ampere-turns and power consumption**
- **Less units to manufacture, transport, install, align, remove,…**

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

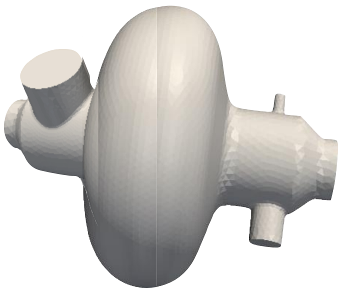


- **Voltage and beam current ranges span more than factor > 10^2**
- **No well-adapted single RF system solution satisfying requirements**

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)



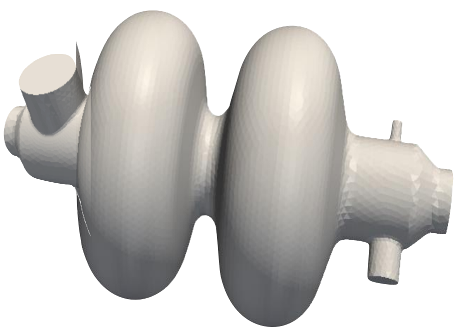
hh — ≈ 16 cells per beam

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-H, ee-tt and ee-W

- 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)

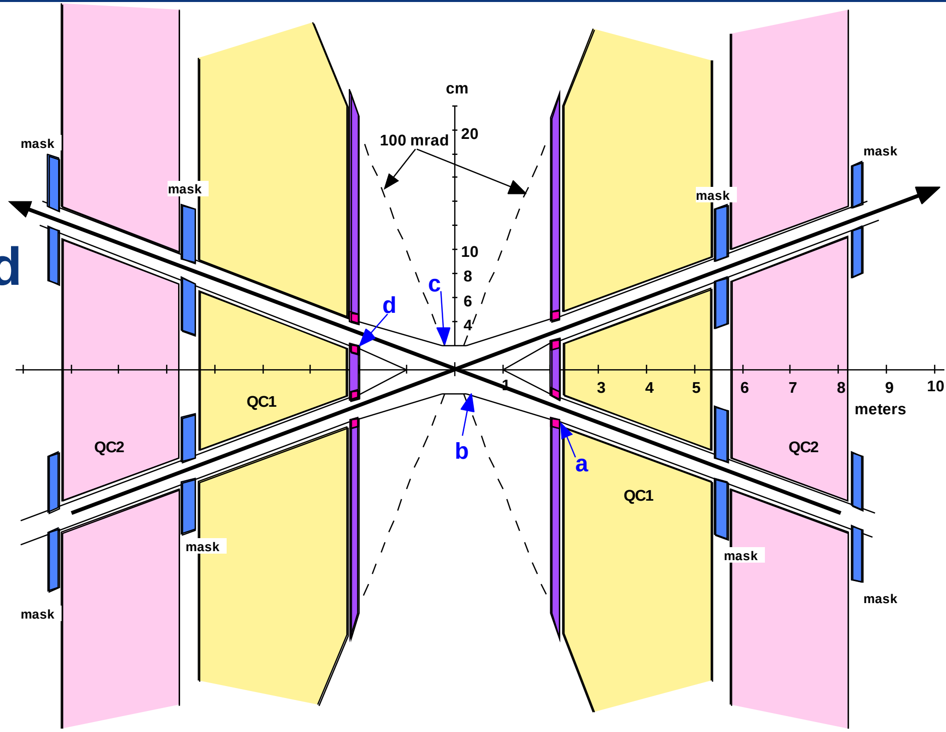
H — ≈ 800 per beam (+ 800 for booster)

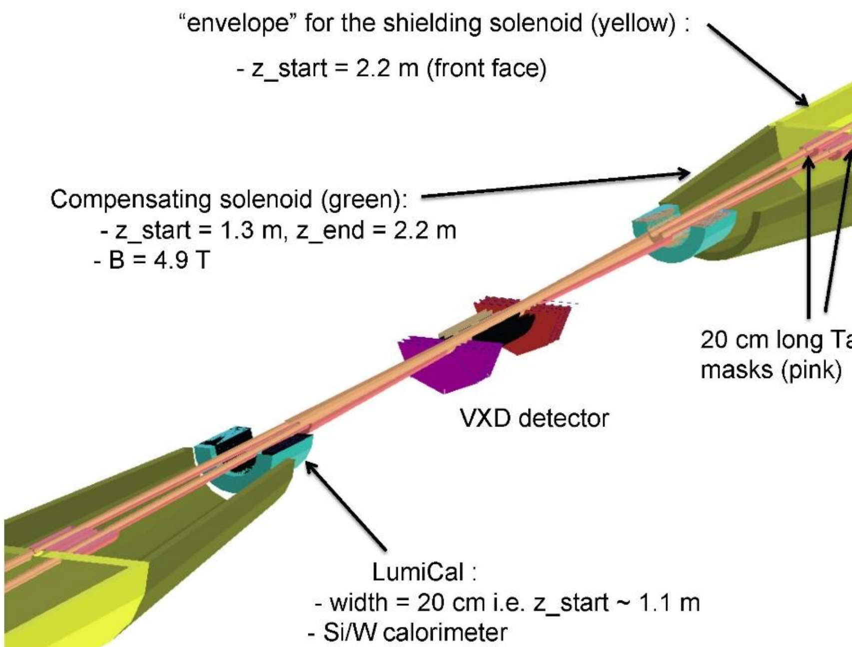
t — ≈ common 2600 cells for both beams (+ 2600 for booster)

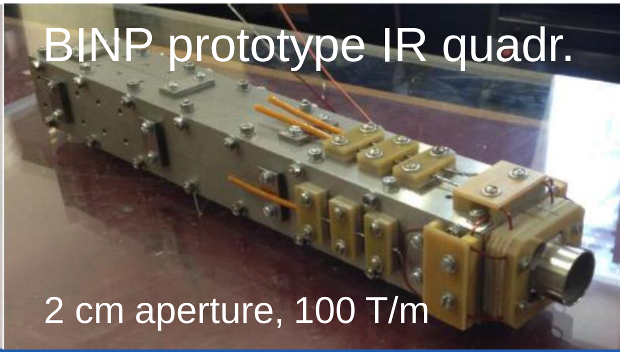
FCC-ee MDI optimisation

MDI work started with optimization of

- ***l****, **IR quadrupole design**
- **compensation & shielding solenoid**
- **SR masking and chamber layout**







FCC International Collaboration

- 88 institutes
- 28 countries + EC

Status: August, 2016

FCC Collaboration Status

87 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
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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International Future Circular Collider Conference
ROME 11-15 APRIL
fccw2016.web.cern.ch
http://cern.ch/fccw2016
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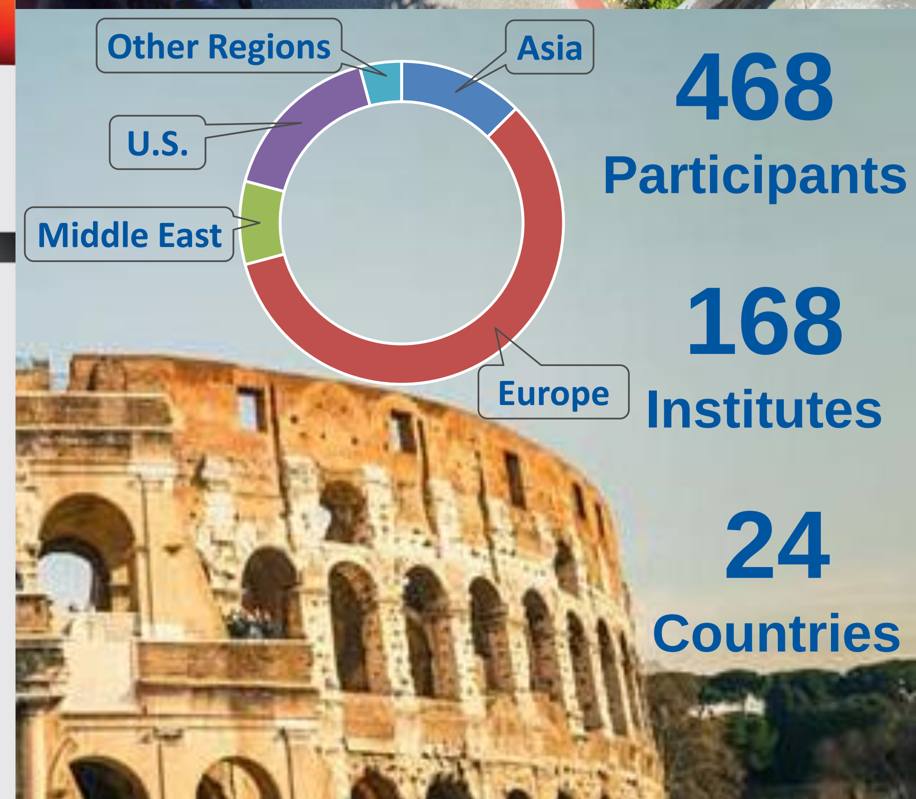
Other Regions
Asia
U.S.
Middle East
Europe
468
Participants
168
Institutes
24
Countries

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
- Major activities for next months concern collimation system (layout, materials), machine protection and beam dumping, machine impedance budget and MDI optimisation, injectors.
- Superconductivity is the key enabling technology for FCC-hh and the Nb3Sn program towards 16 T model magnets is of prime importance.
- Development of high efficiency RF systems is critical for FCC-ee.
- Next milestone is a study review at FCC Week 2017, to confirm baseline and define contents of the Conceptual Design Report.
- **International collaboration is essential to advance on all challenging subjects and the community is warmly invited to join the FCC efforts.**


FCCWEEK2017
Future Circular Collider Conference
BERLIN, GERMANY
29 MAY - 02 JUNE
fccw2017.web.cern.ch