SUMMARY OF ACCELERATORS TECHNICAL DESIGN AND SRF TECHNOLOGIES

JP. Burnet,
M. Morrone, I. Karpov, S. Mazzoni
Presented by: T. Raubenheimer

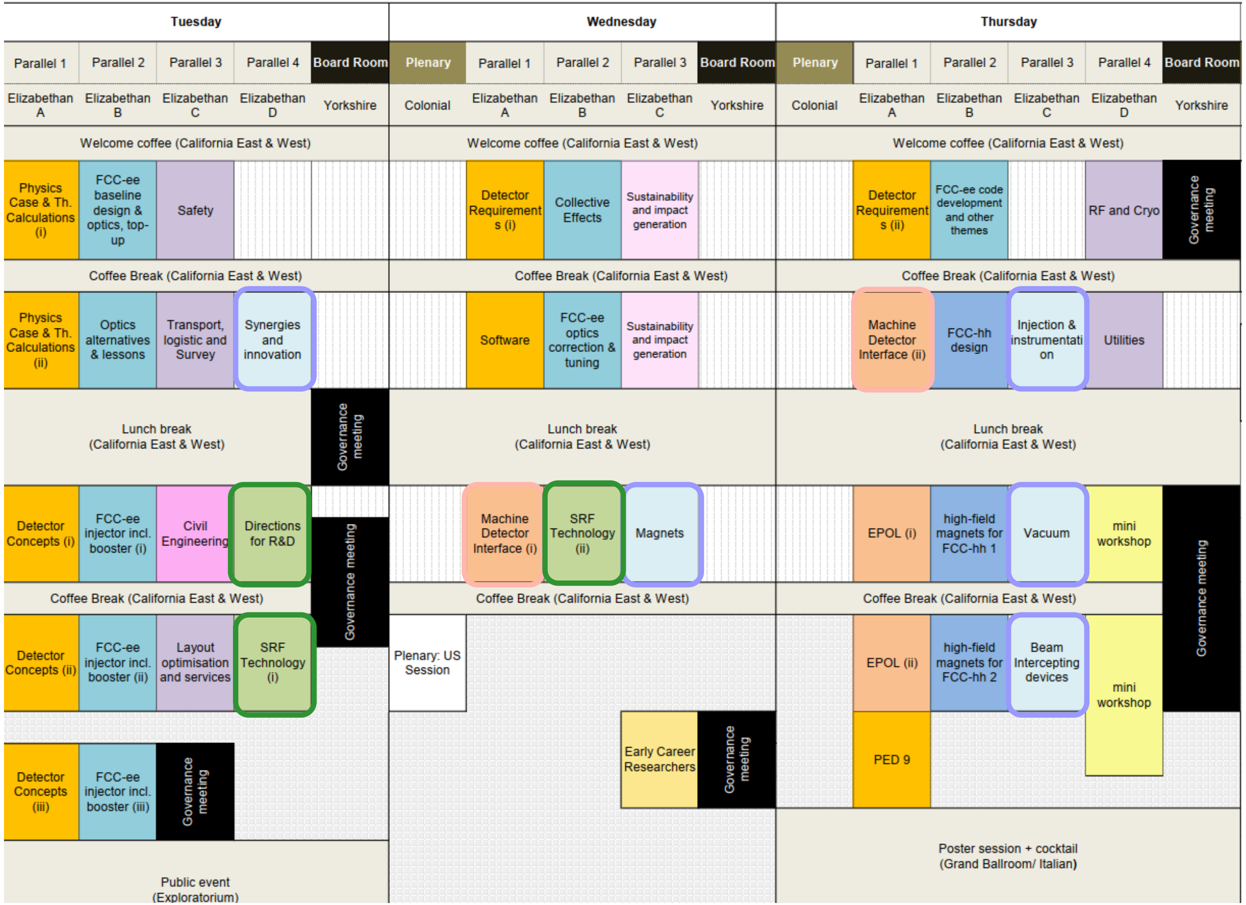
FCC Week 2024

June 14, 2024

5 sessions on
Accelerator Technical Design

5 sessions on
Technical Infrastructures

3 sessions on SRF technology



Tuesday					Wednesday					Thursday					
Parallel 1	Parallel 2	Parallel 3	Parallel 4	Board Room	Plenary	Parallel 1	Parallel 2	Parallel 3	Board Room	Plenary	Parallel 1	Parallel 2	Parallel 3	Parallel 4	Board Room
Elizabethan A	Elizabethan B	Elizabethan C	Elizabethan D	Yorkshire	Colonial	Elizabethan A	Elizabethan B	Elizabethan C	Yorkshire	Colonial	Elizabethan A	Elizabethan B	Elizabethan C	Elizabethan D	Yorkshire
Welcome coffee (California East & West)					Welcome coffee (California East & West)					Welcome coffee (California East & West)					
Physics Case & Th. Calculations (i)	FCC-ee baseline design & optics, top-up	Safety				Detector Requirements (i)	Collective Effects	Sustainability and impact generation			Detector Requirements (ii)	FCC-ee code development and other themes		RF and Cryo	Governance meeting
Coffee Break (California East & West)					Coffee Break (California East & West)					Coffee Break (California East & West)					
Physics Case & Th. Calculations (ii)	Optics alternatives & lessons	Transport, logistic and Survey	Synergies and innovation			Software	FCC-ee optics correction & tuning	Sustainability and impact generation			Machine Detector Interface (ii)	FCC-hh design	Injection & instrumentation	Utilities	
Lunch break (California East & West)				Governance meeting	Lunch break (California East & West)					Lunch break (California East & West)					
Detector Concepts (i)	FCC-ee injector incl. booster (i)	Civil Engineering	Directions for R&D	Governance meeting		Machine Detector Interface (i)	SRF Technology (ii)	Magnets			EPOL (i)	high-field magnets for FCC-hh 1	Vacuum	mini workshop	Governance meeting
Coffee Break (California East & West)					Coffee Break (California East & West)					Coffee Break (California East & West)					
Detector Concepts (ii)	FCC-ee injector incl. booster (ii)	Layout optimisation and services	SRF Technology (i)		Plenary: US Session						EPOL (ii)	high-field magnets for FCC-hh 2	Beam Intercepting devices	mini workshop	
Detector Concepts (iii)	FCC-ee injector incl. booster (iii)	Governance meeting						Early Career Researchers	Governance meeting		PED 9				
Public event (Exploratorium)										Poster session + cocktail (Grand Ballroom/ Italian)					

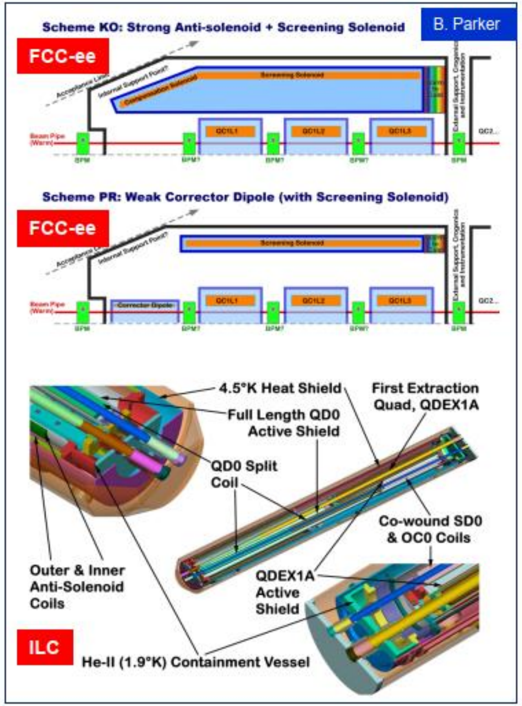
Accelerator Technical Design

SRF technology

Accelerators Technical Design Session 1 : Synergies & innovation

FCC-ee / ILC / EIC Synergies: Machine Detector Interface (MDI)

Presented by M. Minty, BNL



Physics requirements

- detector stay clear (L* and forward angle)
- interplay with accelerator performance optimization

Mechanical engineering requirements

- beam pipe design (warm/cold transitions)
- cryostat support (from detector or external)
- detector installation and access requirements
- utility interfaces (cryogenics, leads etc.)

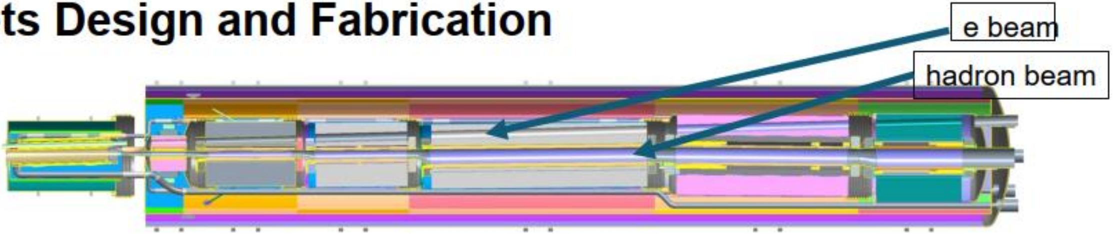
Overlapping requirements

- vibration mitigation (including interactions with beam-based trajectory feedback systems)
- instrumentation (luminosity and beam position monitors)
- radiation shielding (beamstrahlung and radiative Bhabhas)
- space constraints

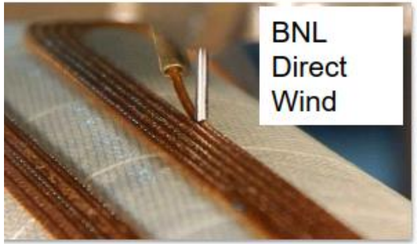
Brookhaven National Laboratory

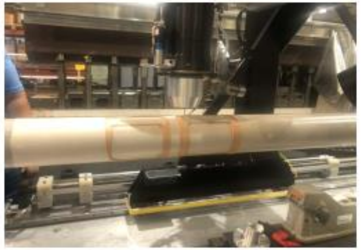
Collective experience in past and future colliders is critical in advancing MDI optimization.

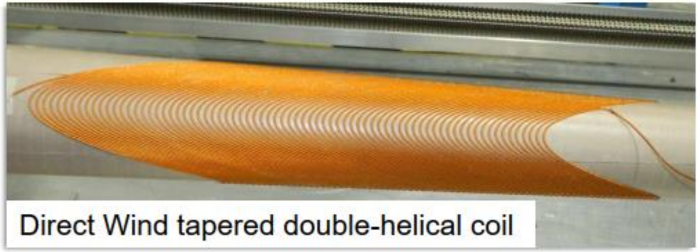
IR Magnets Design and Fabrication



- Direct Wind magnet technology (adapts to compact spaces, CCT-like local field adjustment)
- Collared magnet technology (warm e-beampipe, field crosstalk low)
- Complex magnet systems (integrate: 4.5K, 1.9K and warm systems, BPMs, current leads, low vibration supports)
- Development, prototyping, manufacturing, quench protection, testing






Direct Wind tapered double-helical coil

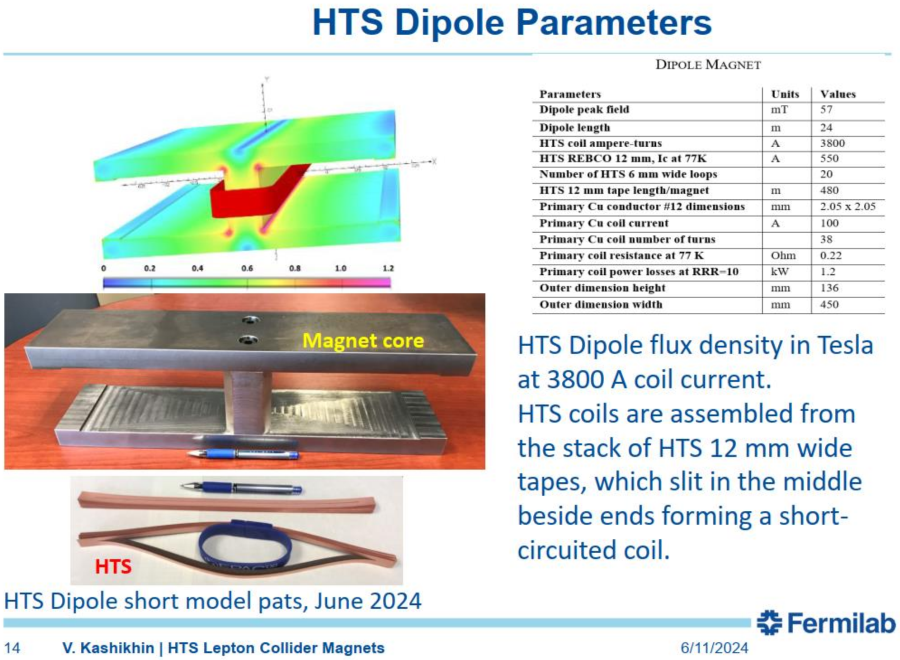
Brookhaven National Laboratory

M. Minty – FCC Week, 10-14 June 2024

Presented by M. Minty, BNL

Proposal of HTS coils for dipole with permanent current

Presented by V. Kashikhin, FNAL



HTS Dipole Parameters

DIPOLE MAGNET

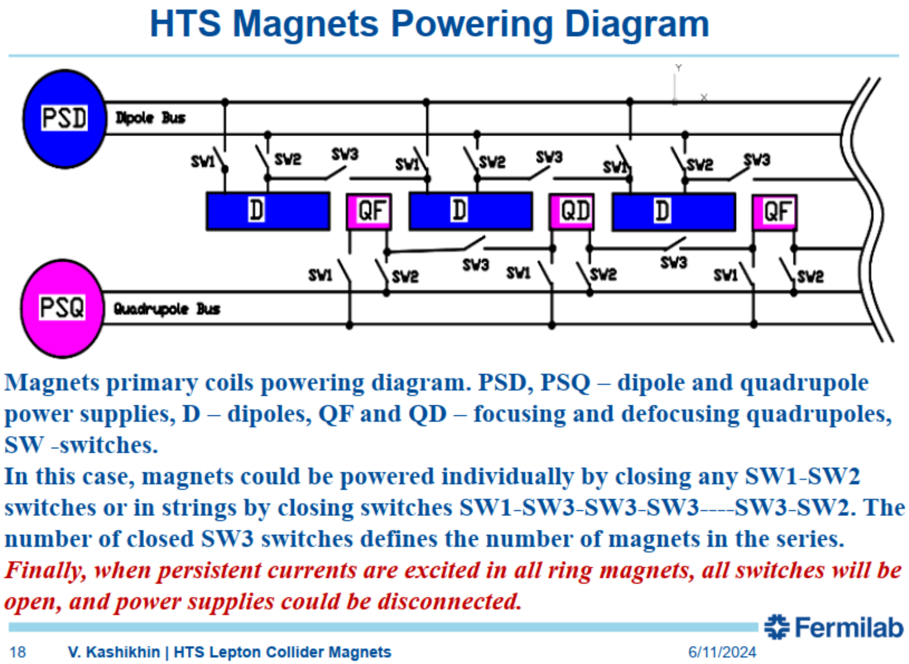
Parameters	Units	Values
Dipole peak field	mT	57
Dipole length	m	24
HTS coil ampere-turns	A	3800
HTS REBCO 12 mm, Ic at 77K	A	550
Number of HTS 6 mm wide loops		20
HTS 12 mm tape length/magnet	m	480
Primary Cu conductor #12 dimensions	mm	2.05 x 2.05
Primary Cu coil current	A	100
Primary Cu coil number of turns		38
Primary coil resistance at 77 K	Ohm	0.22
Primary coil power losses at RRR=10	kW	1.2
Outer dimension height	mm	136
Outer dimension width	mm	450

HTS Dipole flux density in Tesla at 3800 A coil current.
HTS coils are assembled from the stack of HTS 12 mm wide tapes, which slit in the middle beside ends forming a short-circuited coil.

HTS Dipole short model pats, June 2024

Fermilab

14 V. Kashikhin | HTS Lepton Collider Magnets 6/11/2024



HTS Magnets Powering Diagram

Magnets primary coils powering diagram. PSD, PSQ – dipole and quadrupole power supplies, D – dipoles, QF and QD – focusing and defocusing quadrupoles, SW -switches.
In this case, magnets could be powered individually by closing any SW1-SW2 switches or in strings by closing switches SW1-SW3-SW3-SW3----SW3-SW2. The number of closed SW3 switches defines the number of magnets in the series.
Finally, when persistent currents are excited in all ring magnets, all switches will be open, and power supplies could be disconnected.

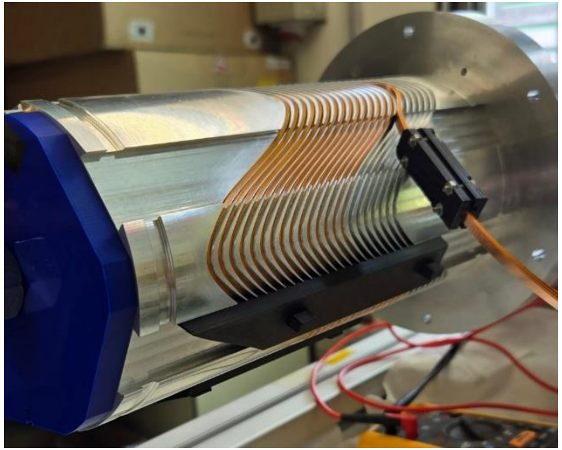
Fermilab

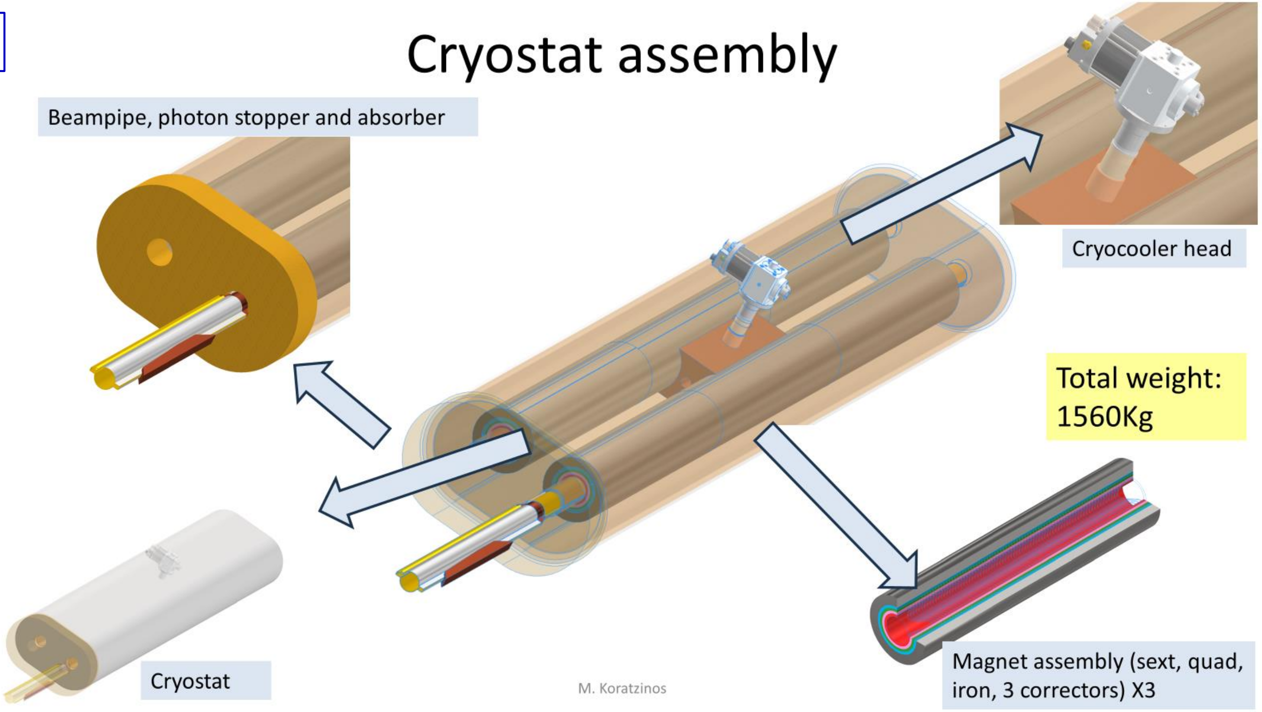
18 V. Kashikhin | HTS Lepton Collider Magnets 6/11/2024

Proposal of HTS quadrupole/sextupole magnets

Swiss Accelerator
Research and
Technology

Presented by M. Koratzinos, PSI





Cryostat assembly

Beampipe, photon stopper and absorber

Cryocooler head

Total weight: 1560Kg

Cryostat

Magnet assembly (sext, quad, iron, 3 correctors) X3

M. Koratzinos

Advantages of C^3 Technology for the Injector Linacs

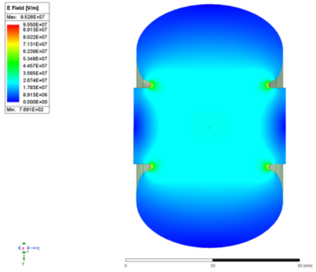
Presented by Emilio Nanni, SLAC

Possible Synergies with FCC-ee

FCC-ee High Energy Linac

- Injector linac operates with closely spaced bunches – up to 5.5 nC
- Initial study with a/wl = 0.125 (conservative, average for HE linac concept is 0.12)
- Gradient 22.5 MeV/m
- **Baseline: 6 MW/m, 3 microsecond**

Linac Properties	
Charge (nC)	0-5.5 nC
Number Bunches	1-4
Bunch Spacing	25 ns spacing
Initial Energy	6 GeV
Final Energy	20 GeV



SLAC

Ansys

Shunt impedance 300 K (77 K): 58.5 MΩ/m (146-158 MΩ/m)
a/wl = 0.125
Emax/Ea = 4.35
Sc max = 242mW/um^2
Period: 53.5 mm
Aperture: 13.4 mm
Nose Cone Gap: 41.1 mm
Height: 42.9 mm
R/Q: 3.04
Q: 19250 (300 K)
Power Dissipated @ 21.9MeV/m = 440 kW

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Accelerators Technical Design Session 2 : magnets

Collider Dipole parameters

Presented by J. Bauche, C. Eriksson, CERN

- Main changes: **aluminium busbar** at **higher current density**
- Power dissipation is ~80% larger than 2023 Cu BB design, but the increased OPEX is far outweighted by the **reduced CAPEX,** with an **overall lower TOTEX*** over the lifetime!
- Busbar geometry adjusted to make more room for trim coils (adjusted current density) and match cooling requirements
- Total circuit voltage stays < 1kV

**see presentations B. Wicki on Tuesday 16:14 and Wednesday 14:06*

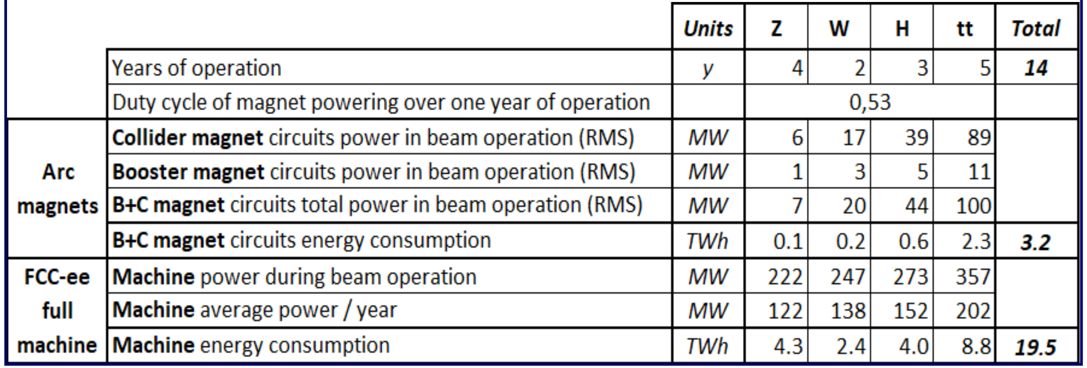
Cheaper with aluminum but more losses

Parameter	Unit	Value 2023	Value 2024
Max strength	mT	61	61
Magnetic length (average)	m	21.15	21.15
Busbar material		Copper	**Aluminium**
Max current in busbars	A	3628	3665
Conductor dimensions	mm^2	66 x 55	**62 x 33**
Cooling diameter	mm	7	8.1
Current density	A/mm^2	1.01	**1.85**
Voltage drop per magnet	V	1.2	2.2
Resistance per magnet	mΩ	0.34	0.62
Power per magnet	kW	4,4	**8.2**
Number of water circuits	-	1	1
Water temperature rise	°C	11.2	14.2
Cooling water speed	m/s	2.4	2.7
Pressure drop	bar	5	5
Reynolds no.	-	23745	30380

Magnet circuits power consumption

Presented by J. Bauche, C. Eriksson, CERN

Magnet circuits vs. FCC-ee full machine (mid-term report)



		Units	**Z**	**W**	**H**	**tt**	***Total***
	Years of operation	*y*	4	2	3	5	***14***
	Duty cycle of magnet powering over one year of operation		0,53				
Arc magnets	**Collider magnet** circuits power in beam operation (RMS)	*MW*	6	17	39	89	
	Booster magnet circuits power in beam operation (RMS)	*MW*	1	3	5	11	
	B+C magnet circuits total power in beam operation (RMS)	*MW*	7	20	44	100	
	B+C magnet circuits energy consumption	*TWh*	0.1	0.2	0.6	2.3	***3.2***
FCC-ee full machine	**Machine** power during beam operation	*MW*	222	247	273	357	
	Machine average power / year	*MW*	122	138	152	202	
	Machine energy consumption	*TWh*	4.3	2.4	4.0	8.8	***19.5***

- **Power** of the FCC-ee magnets at tt$_{bar}$ is **comparable to the CERN SPS main dipoles** (~90 MW peak)
- The **arc magnet circuit integrated power consumption** over the **project lifetime** is **3,2 TWh**
  - **This is only 17%** of the **full FCC-ee machine** (booster + collider)
  - **70%** of this consumption is for the **tt$_{bar}$ phase only**

Courtesy ***J.P. Burnet***

With the **set of parameter presented today**:

- **RMS power** of **collider magnets** would scale up by **+33%** (119 MW @ ttbar)
  - **3.2 TWh → 4.3 TWh** of total magnet integrated power consumption
  - **17% → 22%** of FCC-ee full machine integrated power consumption
- Magnet circuit **TOTEX** would scale down by **-15%**

Short prototype magnet production & test plan

Presented by H. Deveci, L. von Freeden, CERN

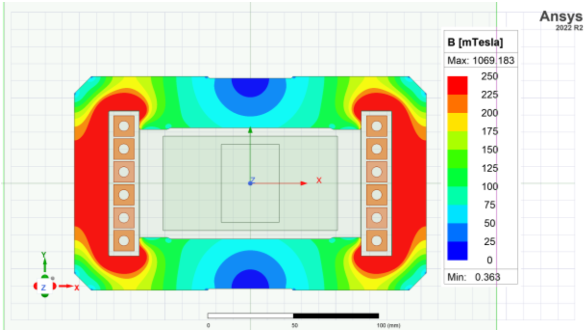
The number of turns is increased in the model magnet for convenience

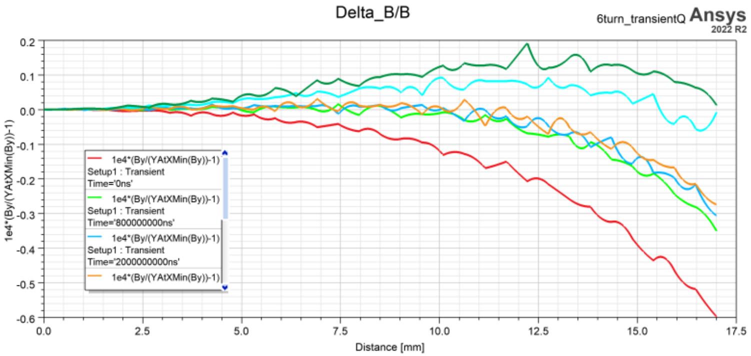
The length of the model magnet is determined as 500 mm

Valid representation of the baseline dipole

M270-50A steel coils are provided

Yoke is optimised for the entire tt_ cycle to minimize the distortions in the field quality caused by the hysteretic effect

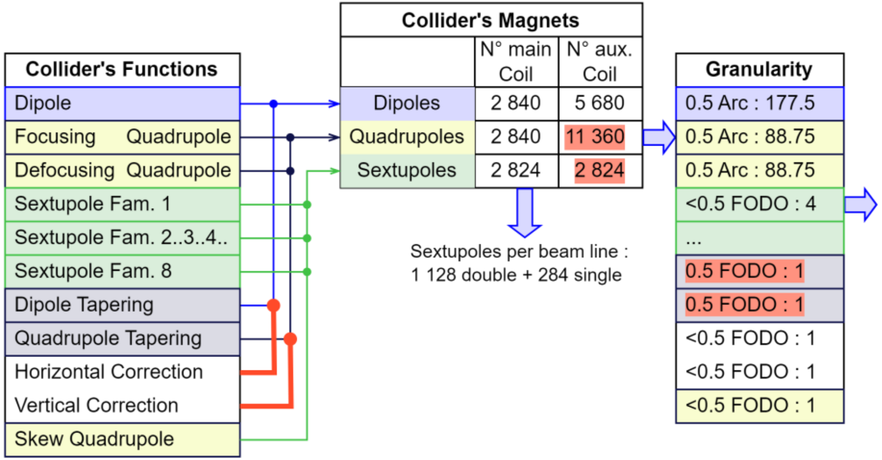




Number of Circuit – Collider’s Alternative

Presented by B. Wicki, CERN

Horizontal Correction with Dipole's Auxiliary Coil
Vertical Correction with Quadrupole's Auxiliary Coil



Collider's Functions
Dipole
Focusing Quadrupole
Defocusing Quadrupole
Sextupole Fam. 1
Sextupole Fam. 2..3..4..
Sextupole Fam. 8
Dipole Tapering
Quadrupole Tapering
Horizontal Correction
Vertical Correction
Skew Quadrupole

Collider's Magnets		
	N° main Coil	N° aux. Coil
Dipoles	2 840	5 680
Quadrupoles	2 840	11 360
Sextupoles	2 824	2 824

Sextupoles per beam line :
1 128 double + 284 single

Granularity
0.5 Arc : 177.5
0.5 Arc : 88.75
0.5 Arc : 88.75
<0.5 FODO : 4
...
0.5 FODO : 1
0.5 FODO : 1
<0.5 FODO : 1
<0.5 FODO : 1
<0.5 FODO : 1

Even More overall Number of Circuits
Smaller Granularity for Dipole and Quadrupole Tapering
Even More space for main coil in Sextupole

CAPEX ↑
CAPEX ↓ OPEX ↘

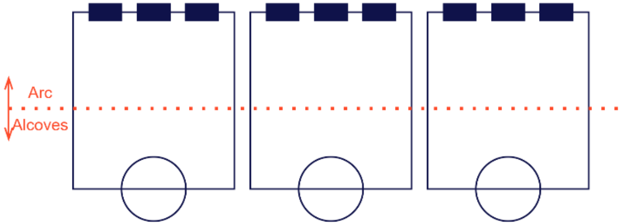
Collider Magnets	**N° Magnets**	**N° Circuits**
Dipole	2'840	16
Quadrupole	2'840	32
Sextupole	5'080	706
Sub-Total	10'760	754
Dipole Tapering	Achieved with Horizontal Corrector	
Quadrupole Tapering	Achieved with Vertical Corrector	
Sub-Total	0	0
Horizontal Corrector	5'680	5'680
Vertical Corrector	11'360	11'360
Quadrupole Corrector	----	----
Skew Quadrupole	2'824	2'824
Sub-Total	19'864	19'864
Straight Section	?	?
Total	**30'624**	**20'618**

Controllability

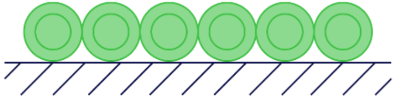
Presented by B. Wicki, CERN

Controllability : -100% to +100%

Polarity of group can be reversed during run



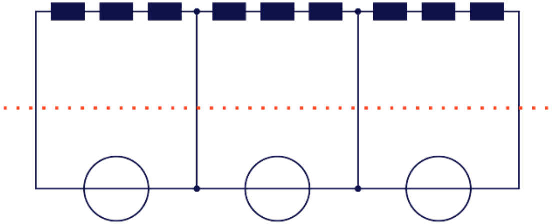
$$N_{cable} = 2N_{circ}$$



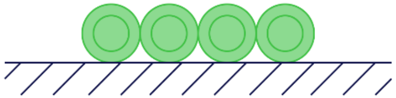
Power converters are too big to be put in the arcs.

Controllability : 0% to +100%

Polarity of group not reversed during run



$$N_{cable} = N_{circ} + 1$$

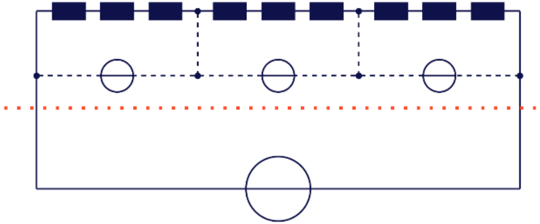


Close to half the space by using cable sharing.

CAPEX ↘
OPEX ↘

Controllability : 0% to +10%

Polarity of group not reversed during run
+ lower change percentage



$$N_{cable} = 2 \qquad +(N_{circ} + 1)$$

Only one converter in the alcoves.

The trimmers + cabling in the arc section, closest to magnets.

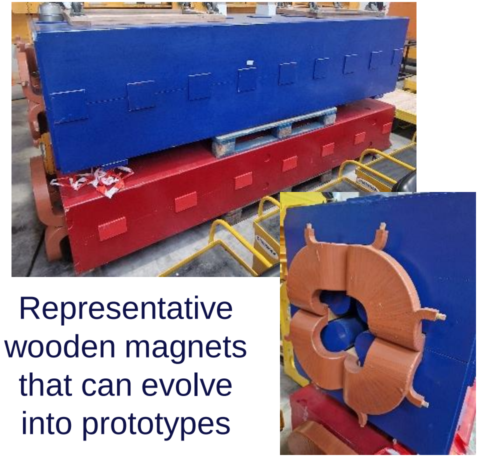
But need of Radiation hard trimmers

CAPEX ?
OPEX ↘

What will be installed in the 1:1 Mock-up?

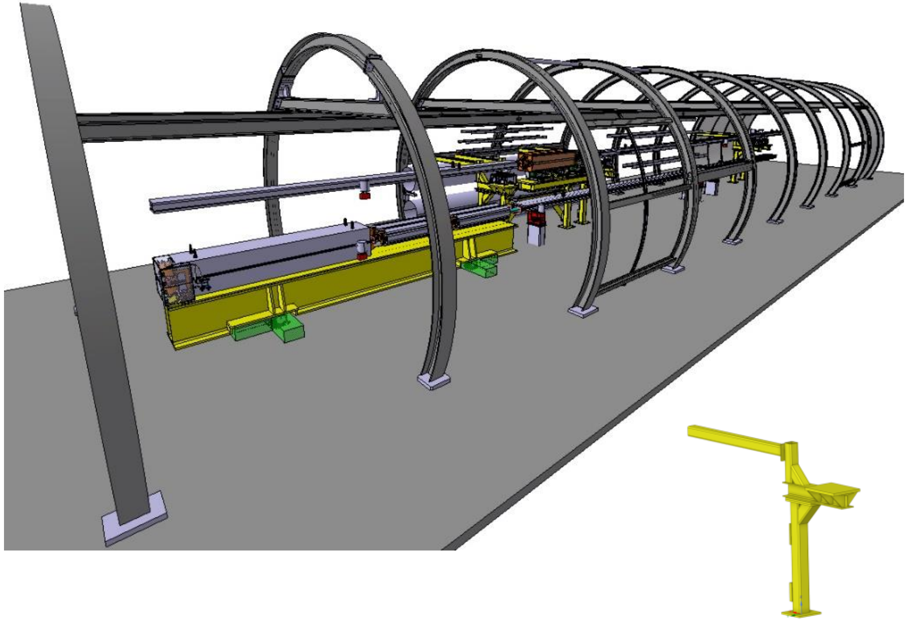
Presented by A. Piccini, CERN

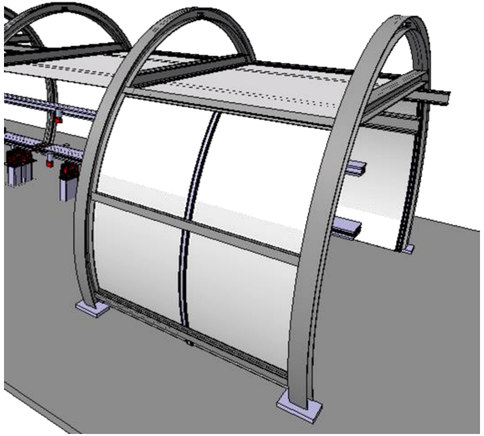
The envelope will consist of arches reinforced by beams and closed by plates/sheets

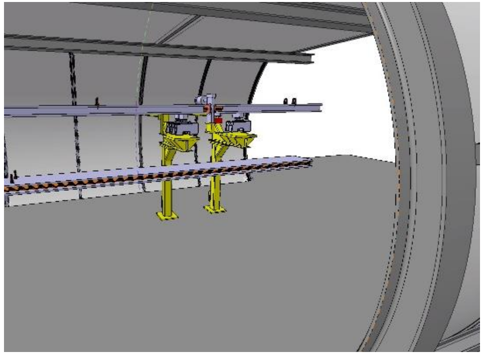


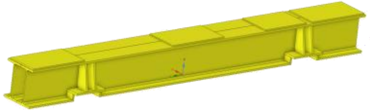
Representative wooden magnets that can evolve into prototypes

(example SPS wooden magnets)









Girder = PAEC collaboration

Install real structures for booster and collider supports

Courtesy M. Rouchouse

Test of final focus quadrupole prototype

Presented by M. Koratzinos, PSI

Testing at cold at SM18 (CERN)

- Cryostat supporting 1.9K superfluid helium
- Training campaign
- Measurement of splice resistance
- Measurement of quenchback
- Measurement of RRR

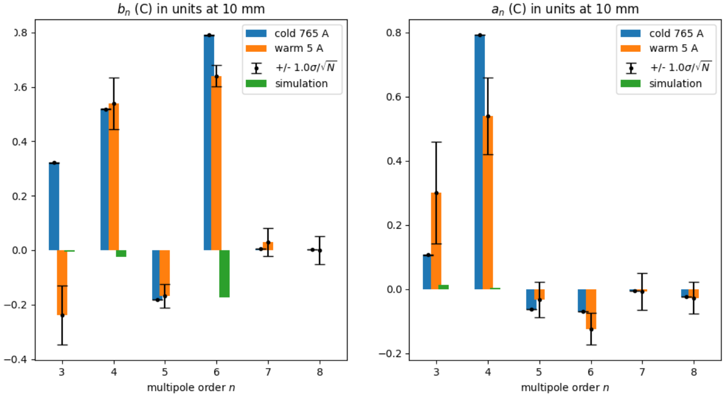
CHART
Swiss Accelerator
Research and
Technology

THE FIRST SUPERCONDUCTING FINAL FOCUS QUADRUPOLE PROTOTYPE OF THE FCC-ee STUDY

A. Thabuis, M. Koratzinos, G. Kirby, M. Liebsch, C. Petrone
European Organization for Nuclear Research (CERN), Geneva, Switzerland

https://arxiv.org/abs/2405.20105

Field quality - cold

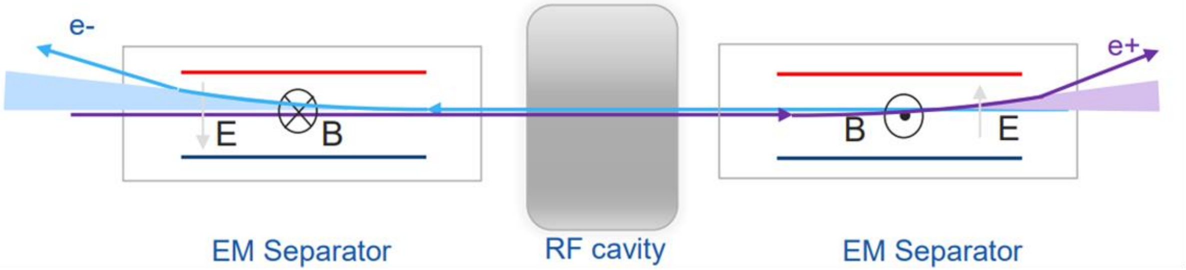


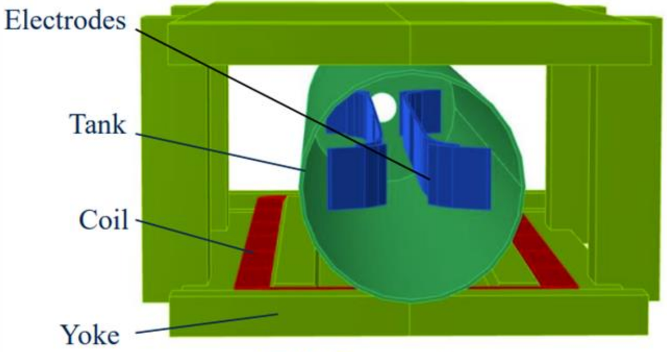
Accelerators Technical Design Session 3 : Injection & Instrumentation

Booster and Collider challenges for septa and separators

Presented by J. . Borburgh, CERN

- Update on tech choice and topology for septa for Booster and Collider injection, extraction and dump and EM separator for ttbar.
- Septum tech at forefront of technology but **no showstoppers**. Present baseline mature enough for implementation in FCC
- EM separator for ttbar needed to ensure beams pass in the centre of RF cavity with no synchrotron light hitting the cavity. Based on longitudinal matching of B and E field for cancellation on incoming beam only. **Several challenges: heat deposition, impedance budget, field matching tolerance unknown at present.** Studies needed



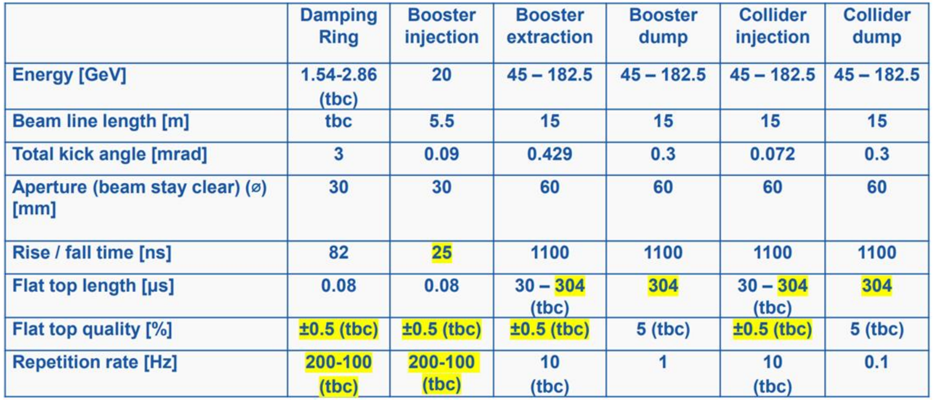


EM Separator

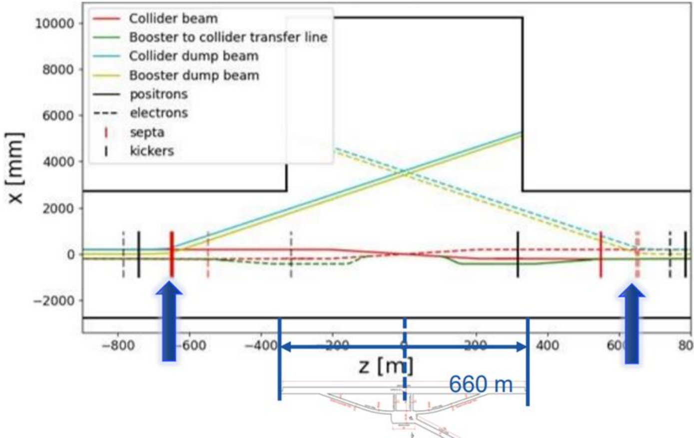
Overview and challenges for fast pulsed beam transfer system

Presented by G. Favia, CERN

- Tech for **magnet and generator** for damping inj + extr, booster inj+extr+ dump, collider inj+dump studied. Optimal choice identified for all cases
- **No showstoppers** but challenges identified (highlighted in table)
- Point B (booster to collide extraction, booster and collider dump) would require **additional service area** to keep cable length short (blue arrows). Booster injection integration to be verified as well.



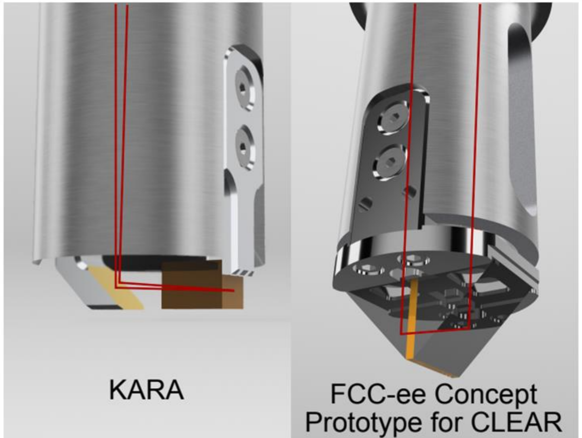
	Damping Ring	Booster injection	Booster extraction	Booster dump	Collider injection	Collider dump
Energy [GeV]	1.54-2.86 (tbc)	20	45 – 182.5	45 – 182.5	45 – 182.5	45 – 182.5
Beam line length [m]	tbc	5.5	15	15	15	15
Total kick angle [mrad]	3	0.09	0.429	0.3	0.072	0.3
Aperture (beam stay clear) (⌀) [mm]	30	30	60	60	60	60
Rise / fall time [ns]	82	25	1100	1100	1100	1100
Flat top length [μs]	0.08	0.08	30 – 304 (tbc)	304	30 – 304 (tbc)	304
Flat top quality [%]	±0.5 (tbc)	±0.5 (tbc)	±0.5 (tbc)	5 (tbc)	±0.5 (tbc)	5 (tbc)
Repetition rate [Hz]	200-100 (tbc)	200-100 (tbc)	10 (tbc)	1	10 (tbc)	0.1



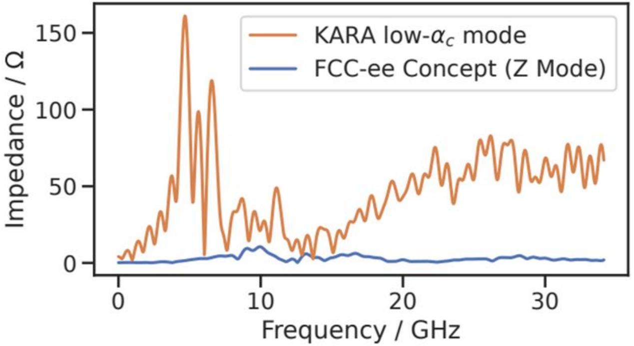
Studies on an electro-optical longitudinal bunch profile monitor

Presented by M. Reissig, KIT

- FCC-ee required bunch by bunch, < 100 fs resolution, non-interceptive bunch length measurement. Electro-optic spectral decoding method fulfils requirements.
- E-O detector installed and operational in Karlruhe Research Accelerator**. New design for FCC being developed**. Prototype is under test, positive first validation in tests at CERN.
- Preliminary impedance check of protruding crystal for Z mode OK. Many studies needed: **heat load and radiation resistance of crystal, integration in FCCee**


KARA

FCC-ee Concept Prototype for CLEAR

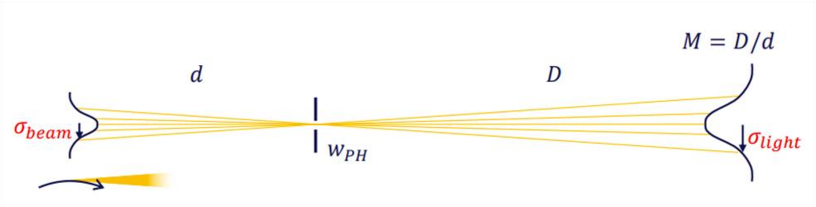


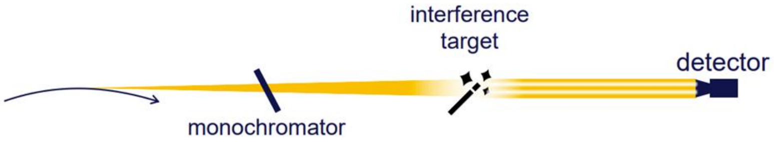
Impedance at KARA vs. FCC-ee concept

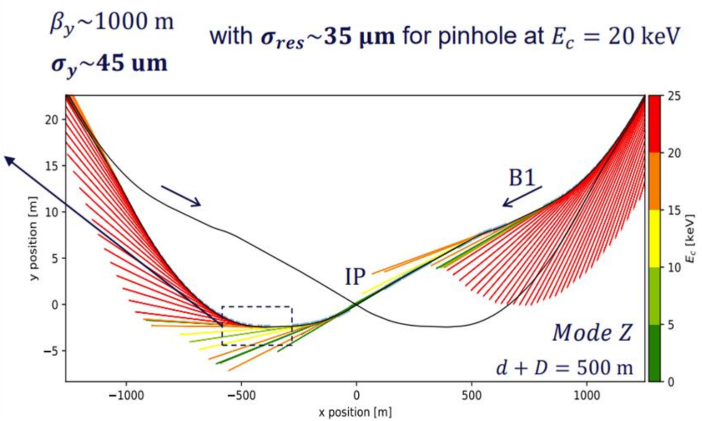
Transverse beam size monitoring

Presented by D. Butti, CERN

- Combination of synchrotron radiation-based techniques likely to fulfil FCCee requirements (high precision bunch by bunch, occasional high accuracy)
- **Pinhole** lines (robust, few % precision, OK for RMS size > 50 um) combined with **interferometric** techniques (few um RMS size) use similar infrastructure: possibility to have both in same extraction line. Studies ongoing at ALBA light source
- **Integration** in FCC-ee ongoing: dedicated wiggler (nice to have), dipoles downstream of interaction points







BPM design studies

Presented by E. Howling, U. Oxford and CERN

- Arc button BPMs shall provide measurement with 0.1 um (orbit) / 10 um (turn by turn) resolution**.** Challenges are **impedance** (10000 BPMs!), **rad tolerance, alignment and stability.**
- Simulations and experimental validation ongoing at CERN for choice of optimal button **size** and **gap.** 8 mm radius current compromise between signal and wakeloss . Work ongoing.
- IR BPMs must have **1 um** single pass resolution. At present, integration of BPMs in IR is very challenging (space reservation, presence of BPMs between segmented quads)

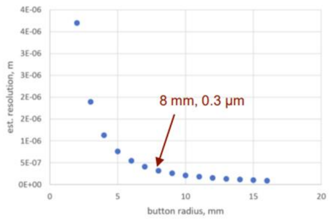


Fig 15: Resolution as a function of button radius.

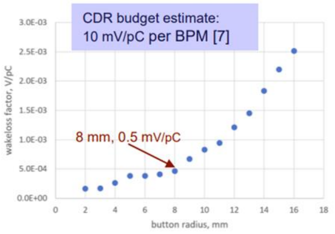
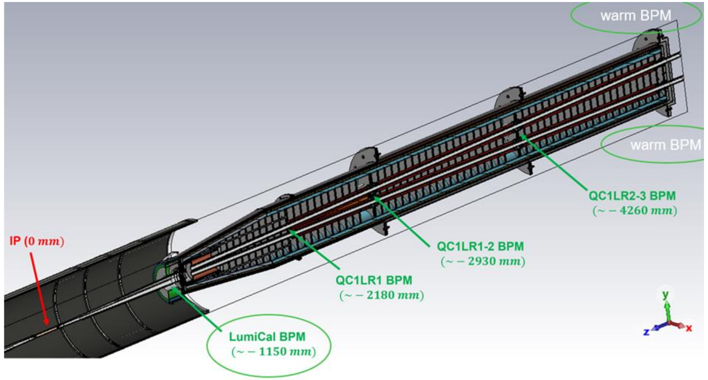


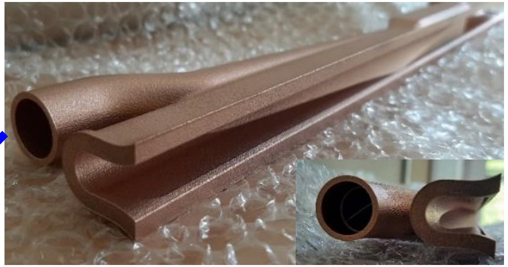
Fig 16: Wakeloss factor as a function of button radius.



Accelerators Technical Design Session 4 : Vacuum & Radiation

FCC-ee vacuum design status

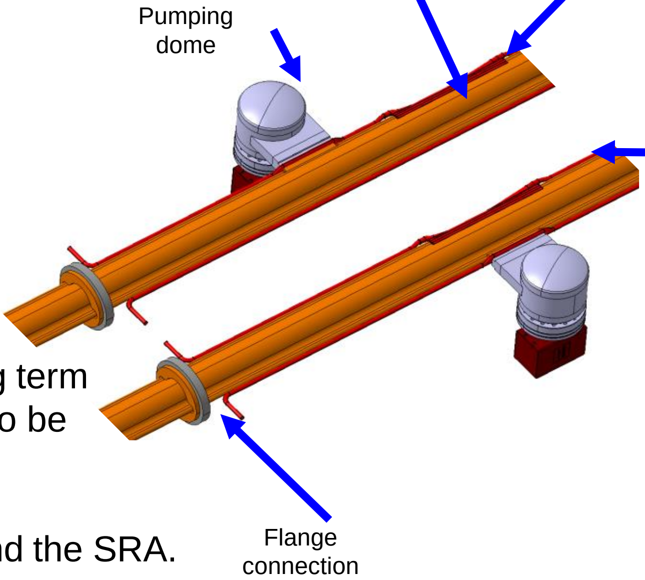
Presented by C.Garion, CERN

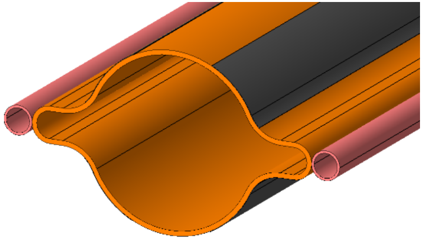


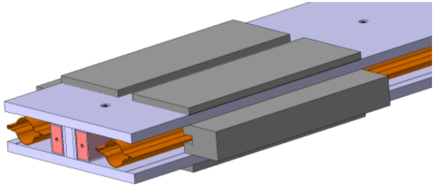
3D printed synchrotron radiation absorber

The chamber design is based on an extruded profile equipped with:

- Synchrotron radiation absorbers, 3D printed, laser welded
- Cooling circuit, laser welded,
- Flanges, FSW welded,
- Bake out system, thermal sprayed
- Thermal insulation,
- Dismountable SMART connections
- Pumping dome, if any.







3D printed synchrotron radiation absorber

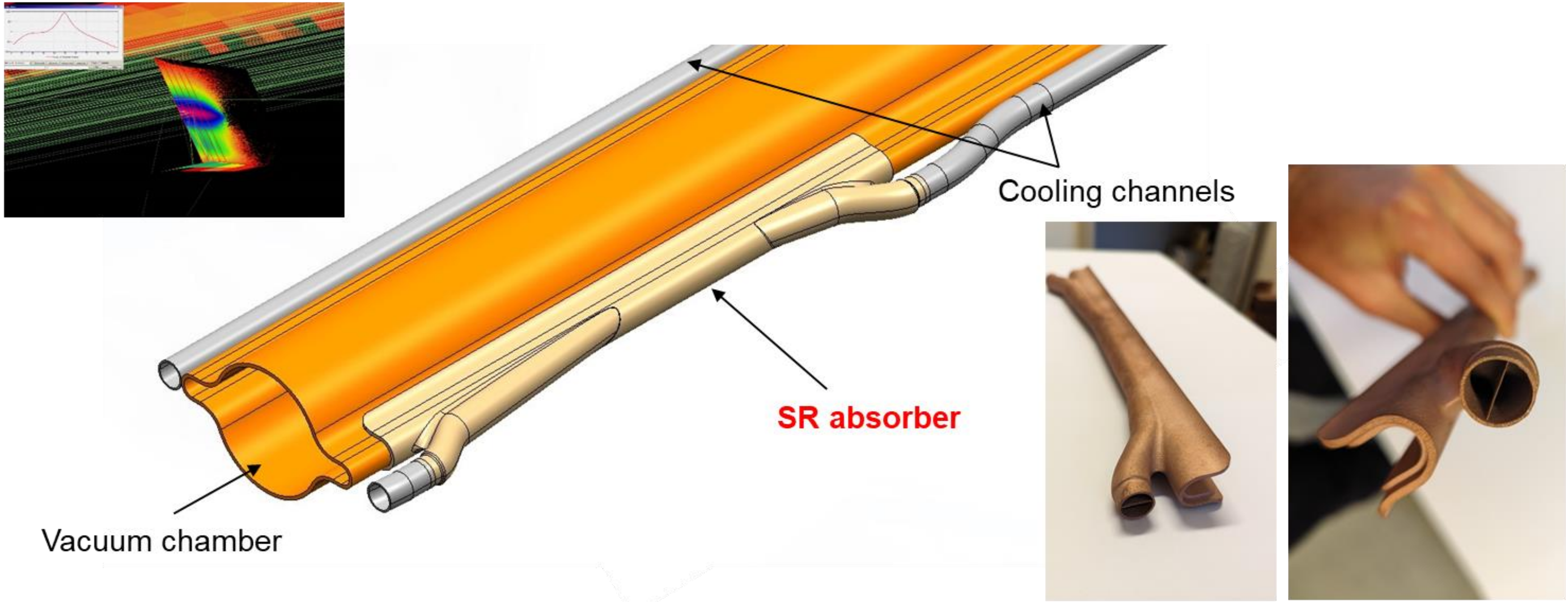
Vacuum chamber is NEG coated. Long term performance of thin NEG coating has to be assessed.

Additional shielding is integrated around the SRA.

Synchrotron radiation absorber design

Presented by M. Moorone, CERN

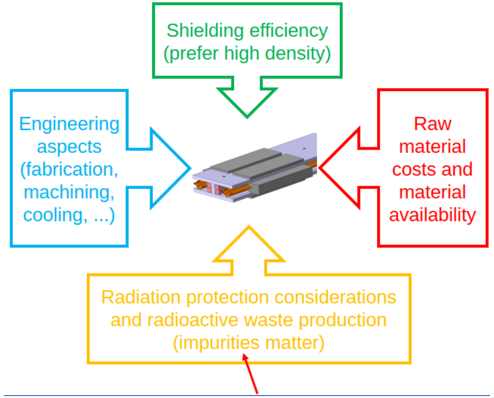
The SR absorber is a complex 3D-printed copper-alloy component welded into a dedicated aperture of the vacuum chamber and connected to the cooling channels running on the chamber’s winglets.



Radiation and shielding in the FCC-ee arcs

Presented by A. Lechner, CERN

Material selection is a trade-off between:

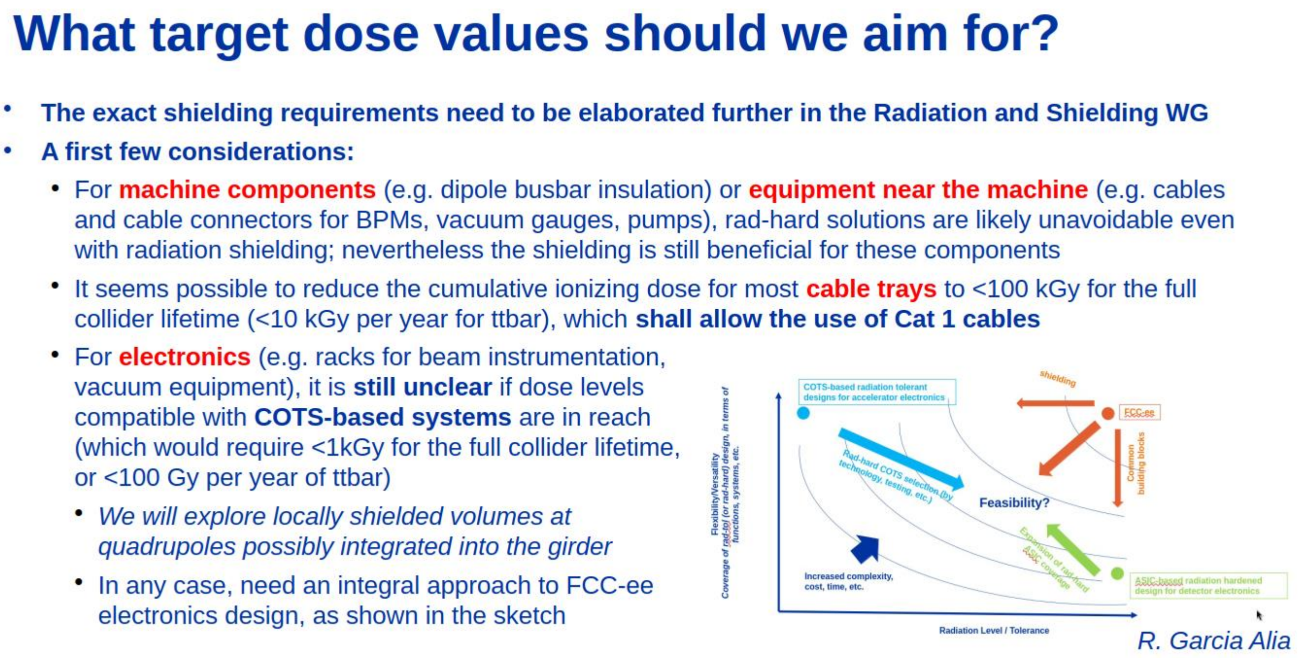


Shielding efficiency (prefer high density)

Engineering aspects (fabrication, machining, cooling, ...)

Raw material costs and material availability

Radiation protection considerations and radioactive waste production (impurities matter)



What target dose values should we aim for?

- **The exact shielding requirements need to be elaborated further in the Radiation and Shielding WG**
- **A first few considerations:**
  - For **machine components** (e.g. dipole busbar insulation) or **equipment near the machine** (e.g. cables and cable connectors for BPMs, vacuum gauges, pumps), rad-hard solutions are likely unavoidable even with radiation shielding; nevertheless the shielding is still beneficial for these components
  - It seems possible to reduce the cumulative ionizing dose for most **cable trays** to <100 kGy for the full collider lifetime (<10 kGy per year for ttbar), which **shall allow the use of Cat 1 cables**
  - For **electronics** (e.g. racks for beam instrumentation, vacuum equipment), it is **still unclear** if dose levels compatible with **COTS-based systems** are in reach (which would require <1kGy for the full collider lifetime, or <100 Gy per year of ttbar)
    - *We will explore locally shielded volumes at quadrupoles possibly integrated into the girder*
    - In any case, need an integral approach to FCC-ee electronics design, as shown in the sketch

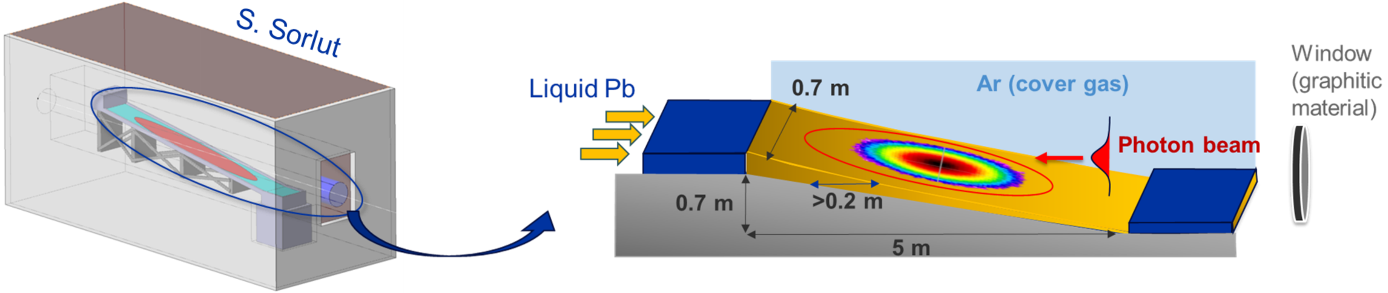
R. Garcia Alia

Accelerators Technical Design Session 4 : Beam Intercepting Devices

Beamstrahlung dump concepts, design, considerations & R&D roadmap

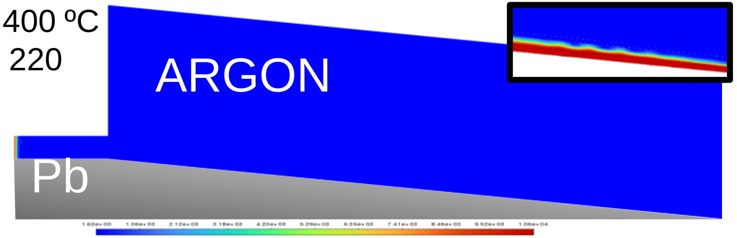
Presented by M. Calviani, CERN

Proposal of a pure liquid Pb absorber



2D CFD calculation
- Multiphase: VoF (+Level-Set)
- Turbulence: k-omega sst
- Transient [0, 2.823]s
- Explicit VoF (CFL 1)
- Inlet Height 0.3 m
- Inlet Flow rate 220 kg/s

T_i = 400 ºC
Q_i = 220 kg/s



Lead flow driven by:

Instabilities
- Kelvin-Helmholtz
- Roll waves
- Turbulence

Forces:
- Gravity
- Friction
- Surface tension
- Viscosity

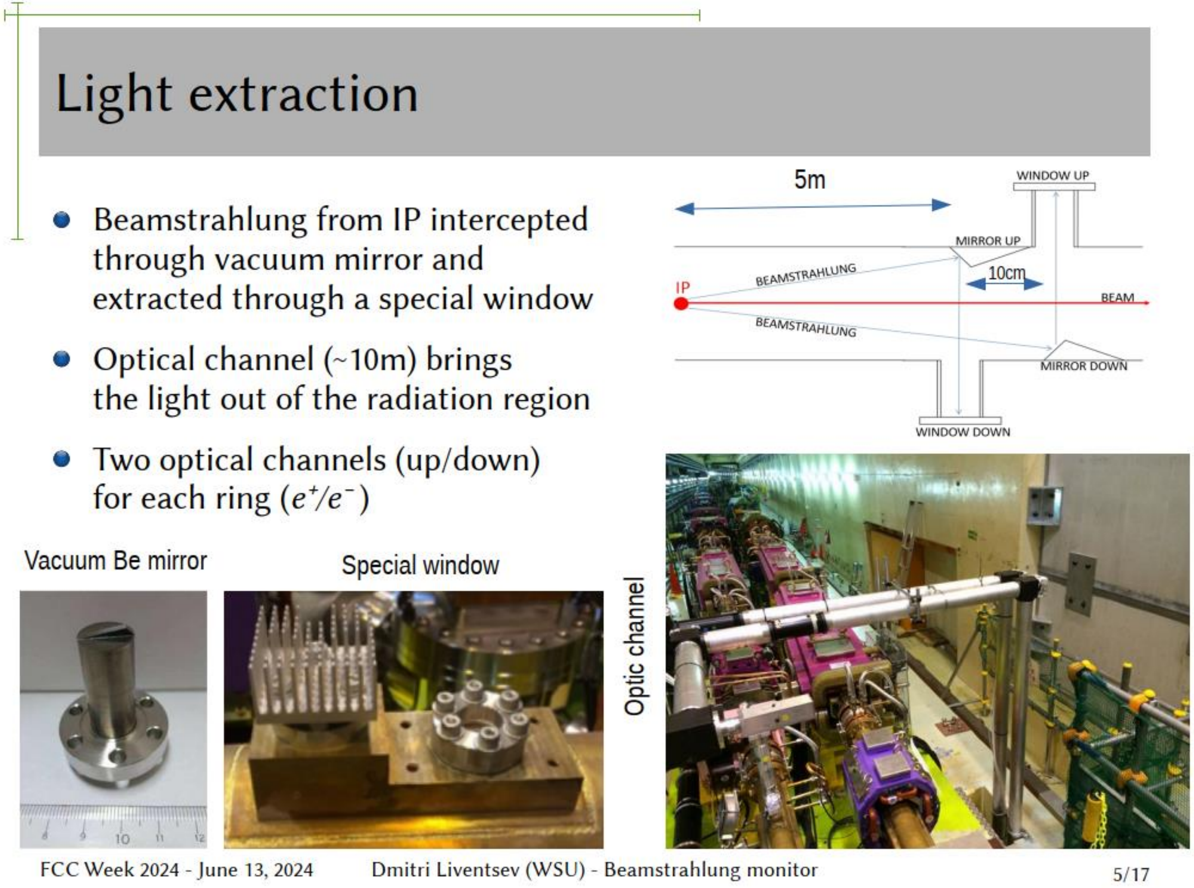
Geometry

Beamstrahlung monitor

Presented by Dmitri Liventsev, Wayne State

Monitor developed for SuperKEKB

Applicable for FCC?



Light extraction

- Beamstrahlung from IP intercepted through vacuum mirror and extracted through a special window
- Optical channel (~10m) brings the light out of the radiation region
- Two optical channels (up/down) for each ring (e^+/e^-)

Vacuum Be mirror

Special window

Optic channel

FCC Week 2024 - June 13, 2024 Dmitri Liventsev (WSU) - Beamstrahlung monitor 5/17

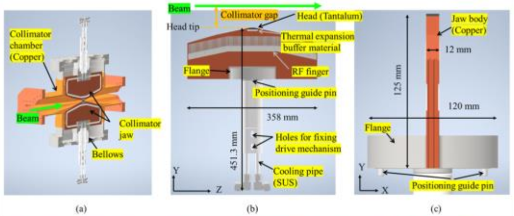
Requirements for Collimation System and R&D paths

Presented by A. Perillo-Marcone, CERN

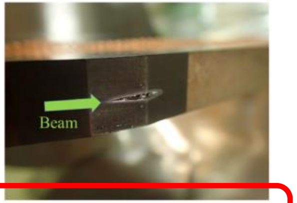
SuperKEKB Collimators

Main features

- Short jaws
- Geometry “optimised” for SuperKEKB
- Openable/repairable (jaws can be replaced)
- Other absorbing material options being assessed
- High Z metals are good in terms of impedance and cleaning efficiency but are destroyed in case of accidental scenarios(*)



Terui *et al.* (https://doi.org/10.1016/j.nima.2023.168971)



(*) ~100 times less beam stored energy than FCC

Design Features

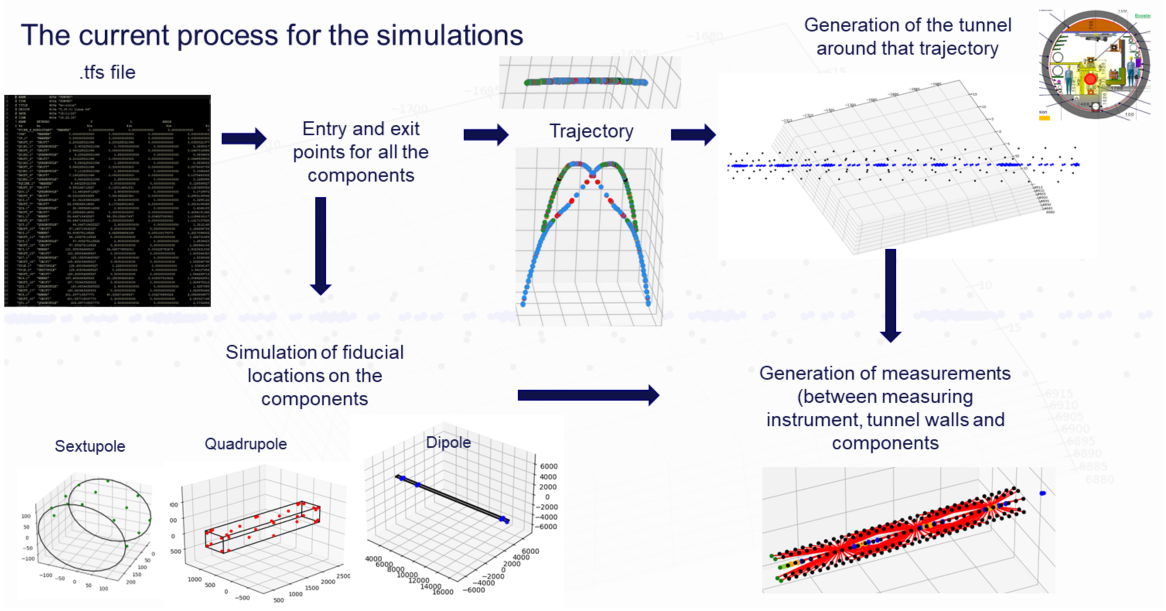
- **Robust/reliable design**
- **Openable tank, fully dismountable**
  - Jaws shall be replaceable
  - Repairs
- **Efficient thermal management**
  - Diffusion-bonded interfaces may be required
- **Flexible elements (bellows) in the direction of movement (more reliable in the long term)**
- **Removable bellow (as opposed to welded to the tank)**

Overview of the FCC-ee alignment and monitoring study

Presented by Léonard WATRELOT, CERN

First goal is to study the alignment error propagation as it impacts :

- Marking
- Initial installation
- Monitoring
- Adjustment
- Resources
- Cost
- Time spent



The current process for the simulations

.tfs file

Entry and exit points for all the components

Trajectory

Generation of the tunnel around that trajectory

Simulation of fiducial locations on the components

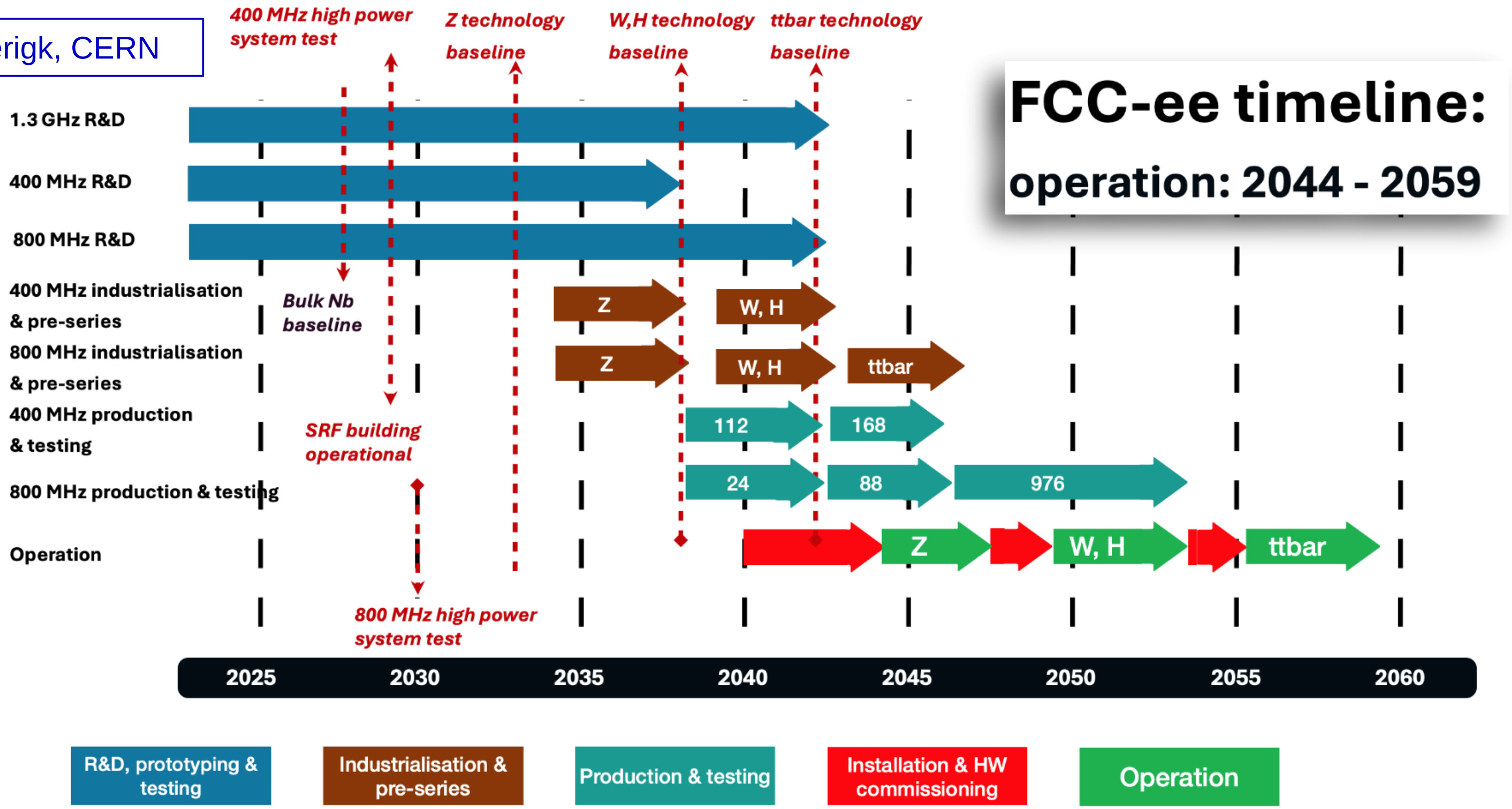
Generation of measurements (between measuring instrument, tunnel walls and components

SRF technology

Presented by F. Gerigk, CERN

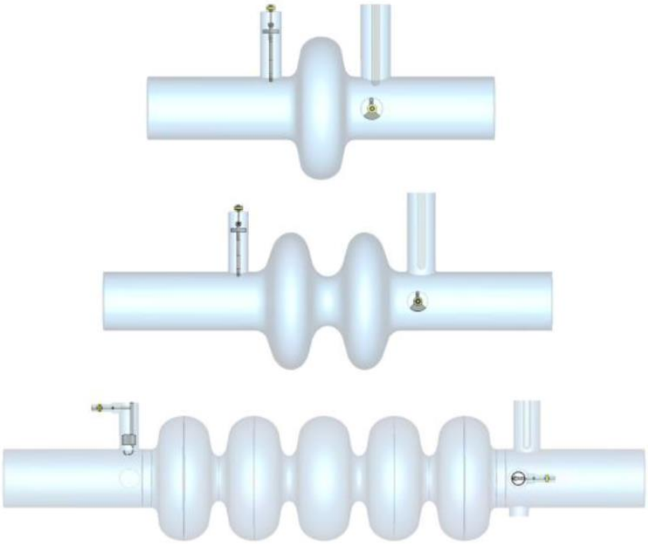
FCC-ee timeline:

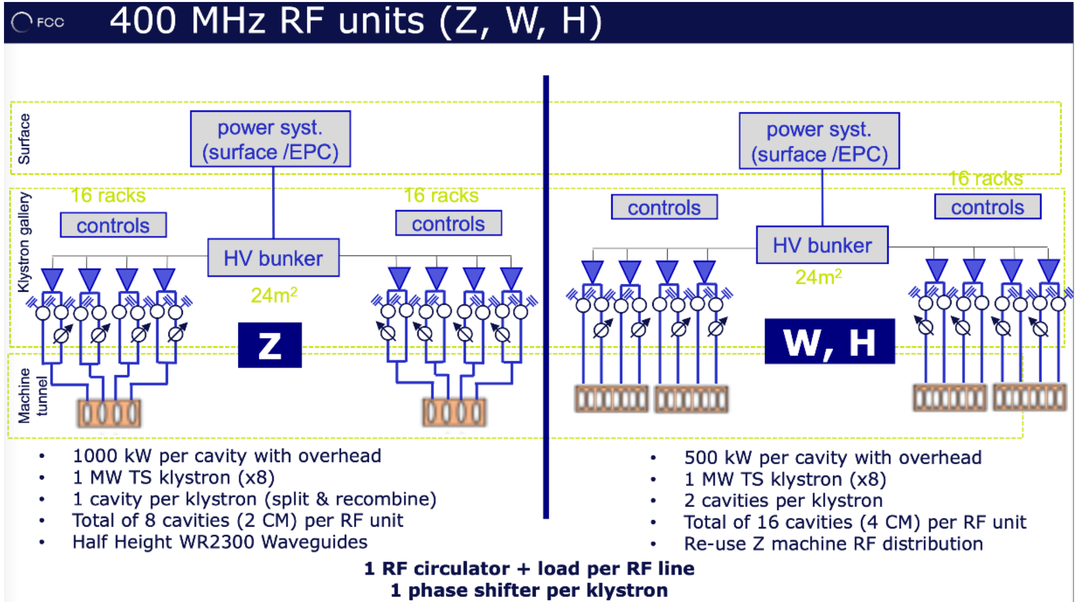
operation: 2044 - 2059



CERN is making a strategic investment in a dedicated new SRF facility, in fundamental SRF R&D, in prototyping and in the development of high-efficiency RF sources.

Presented by F. Peauger, CERN





400 MHz RF units (Z, W, H)

- 1000 kW per cavity with overhead
- 1 MW TS klystron (x8)
- 1 cavity per klystron (split & recombine)
- Total of 8 cavities (2 CM) per RF unit
- Half Height WR2300 Waveguides

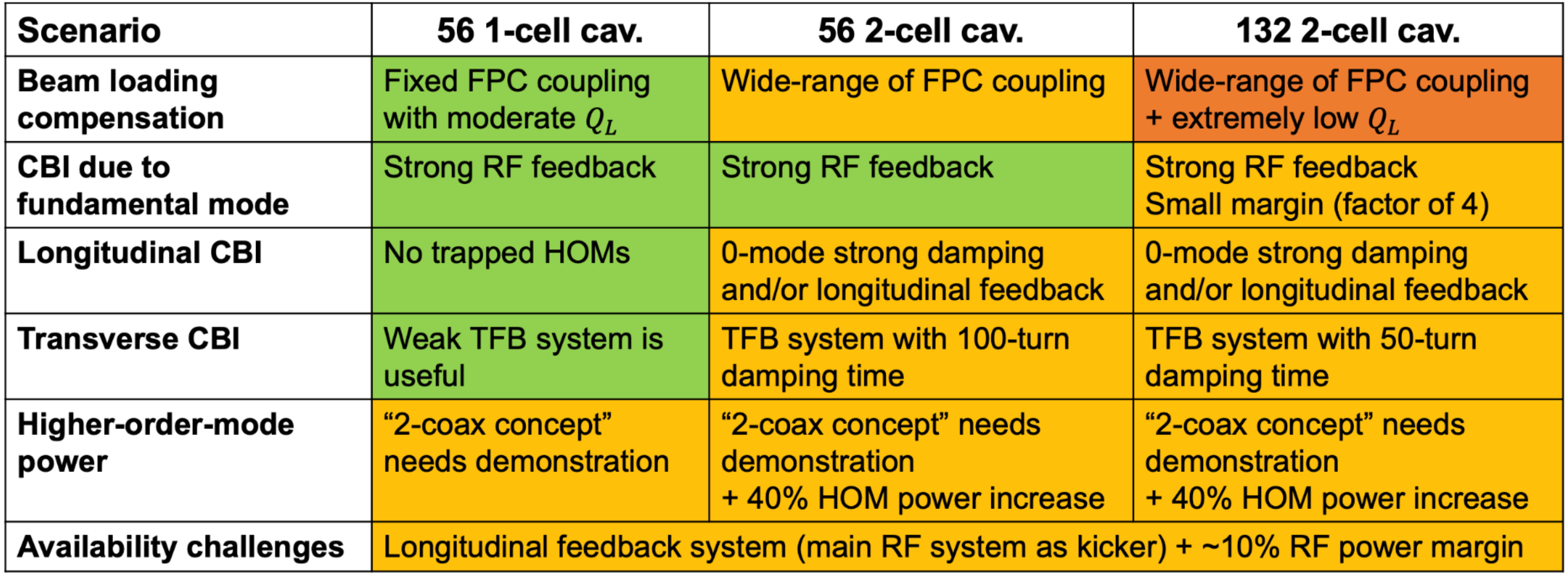
- 500 kW per cavity with overhead
- 1 MW TS klystron (x8)
- 2 cavities per klystron
- Total of 16 cavities (4 CM) per RF unit
- Re-use Z machine RF distribution

1 RF circulator + load per RF line
1 phase shifter per klystron

Unchanged RF design of the three cavity types. HOM power extraction scheme proposed for the module. Mechanical design can start.

Types of RF power sources identified, with novel approach for high efficiency klystron at ~MW level.

Presented by I. Karpov, CERN



Scenario	56 1-cell cav.	56 2-cell cav.	132 2-cell cav.
Beam loading compensation	Fixed FPC coupling with moderate Q_L	Wide-range of FPC coupling	Wide-range of FPC coupling + extremely low Q_L
CBI due to fundamental mode	Strong RF feedback	Strong RF feedback	Strong RF feedback Small margin (factor of 4)
Longitudinal CBI	No trapped HOMs	0-mode strong damping and/or longitudinal feedback	0-mode strong damping and/or longitudinal feedback
Transverse CBI	Weak TFB system is useful	TFB system with 100-turn damping time	TFB system with 50-turn damping time
Higher-order-mode power	"2-coax concept" needs demonstration	"2-coax concept" needs demonstration + 40% HOM power increase	"2-coax concept" needs demonstration + 40% HOM power increase
Availability challenges	Longitudinal feedback system (main RF system as kicker) + ~10% RF power margin		

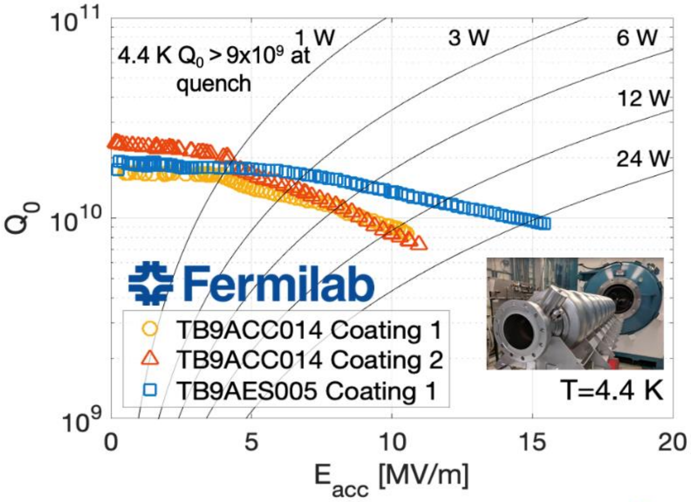
The 2-cell design seems feasible for the nominal current at Z, but challenging

Reverse phase operation mode is in the air

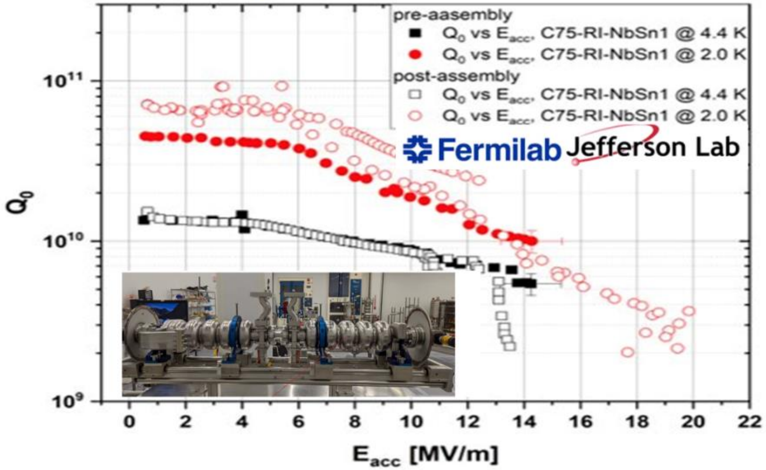
Presented by M. Liepe, Cornell

Towards Applications: Practical Nb_3Sn Cavities

Fermilab: 9-cell 1.3 GHz cavities



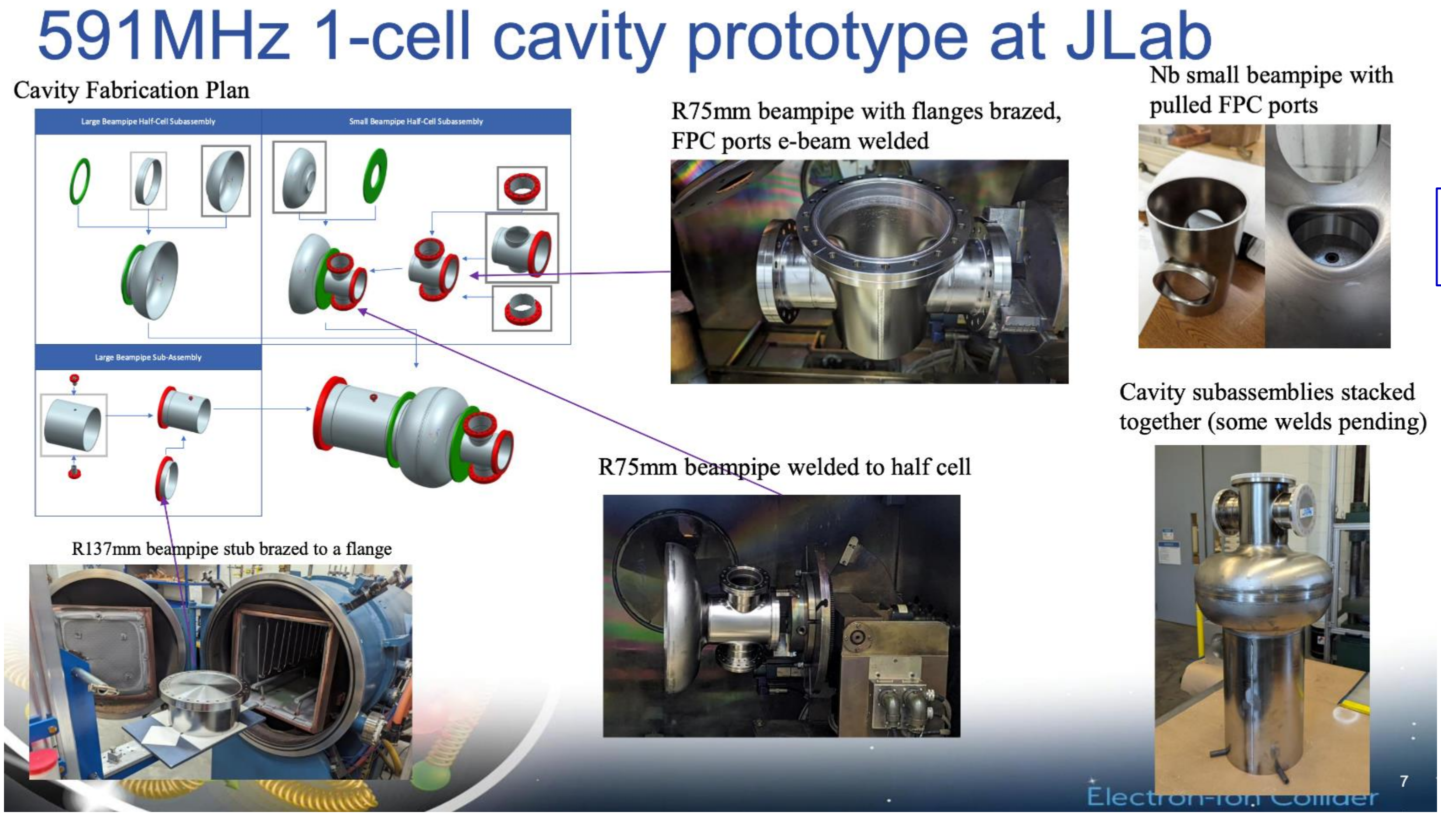
CEBAF-style quarter module using Nb_3Sn 5-cell cavities



>15 MV/m with Q_0~10^{10} at ~4K on accelerator structures!

=> Becoming an option for first accelerator projects!

Transfer of performance from single-cell to full-scale cavities is well underway.



591MHz 1-cell cavity prototype at JLab

Cavity Fabrication Plan

R75mm beampipe with flanges brazed, FPC ports e-beam welded

Nb small beampipe with pulled FPC ports

Cavity subassemblies stacked together (some welds pending)

R75mm beampipe welded to half cell

R137mm beampipe stub brazed to a flange

7

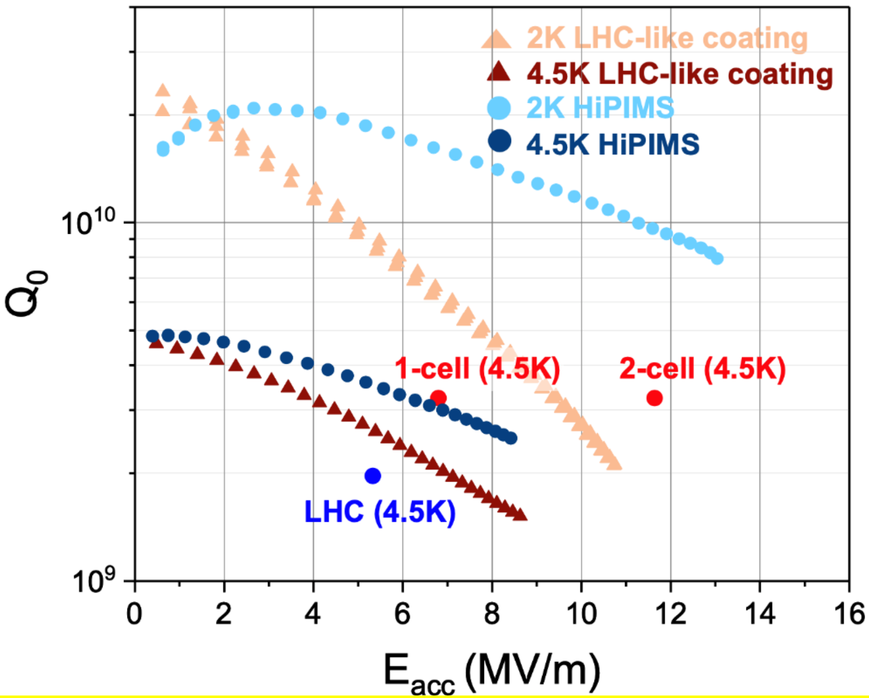
Electron-Ion Collider

Presented by J. Guo, Jlab

The ESR 1-cell prototype cavity is close to complete, with vertical testing expected in a few months. The first article cryomodule is funded and scheduled to complete is about 2 years.

400 MHz HiPIMS: results

Presented by C. Pereira Carlos, Univ. Geneva



Very promising result:

- PC04 is not a seamless substrate
- Treated by SUBU instead of EP.
- Coating done with Bipolar HiPIMS (HiPIMS + PP, DC biasing was not yet possible)
- HiPIMS coating validated, yet to be optimized (power supply limitation)

Continue fundamental study on samples and 1.3 GHz cavities to optimize coating recipe -> Prioritize coatings and RF measurements of 400 MHz cavities

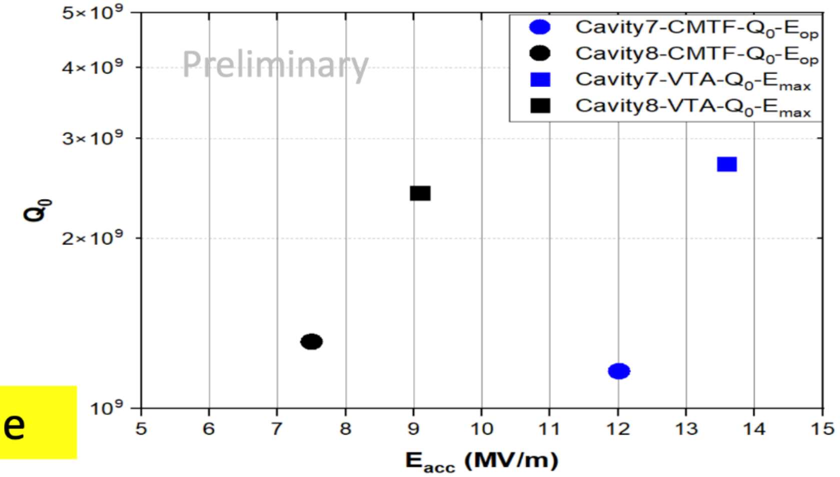
QCM Preliminary Qualification Test Results

Presented by A.-M. Valente-Feliciano, Jlab

Cavity	CMTF f(MHz) @ 4 K	CMTF f(MHz) @ 2 K	VTA Emax (MV/m) @ 4 K	CMTF Emax (MV/m) @ 4 K	Eop (MV/m) 1 h run @ 4 K FE-free	VTA Emax (MV/m) @ 2 K	CMTF Emax (MV/m) @ 2 K	Eop (MV/m) 1 h run @ 2 K FE-free
5C75-RI-NbSn01	**1496.56**	**1496.59**	**13.6**	**13.3**	**12.6**	**18.5**	**13.2**	**12.4**
5C75-RI-04	**1496.41**	**1496.44**	**9.0**	**7.9**	**7.5**	**9.2**	**8.7**	**8.5**

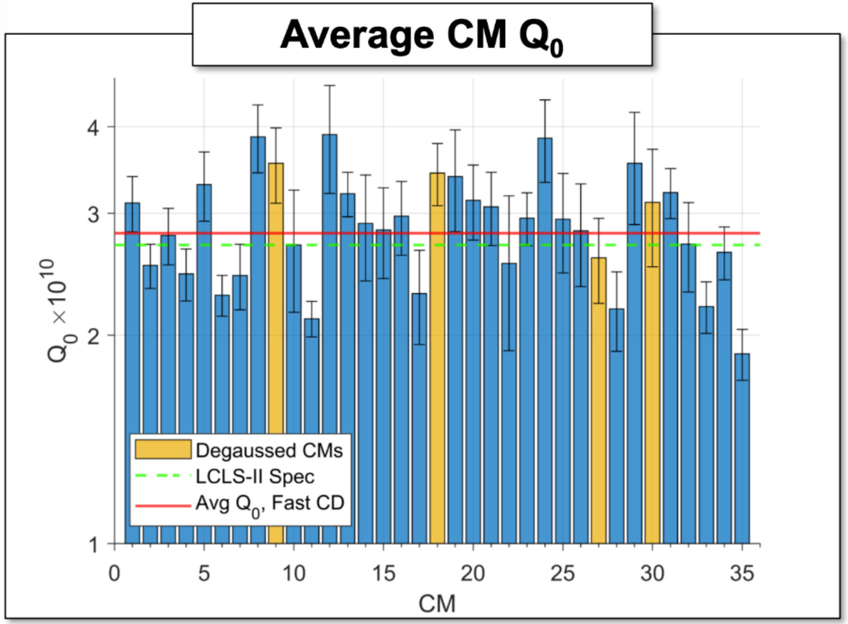
- Accelerating gradients close to vertical test at 4 K
- Frequency difference between two cavities ~150 kHz
- Second cavity tuned to match the first one at 2 K– no degradation

First demonstration of >10 MeV Nb_3Sn cryomodule



Presented by D. Gonnella, SLAC

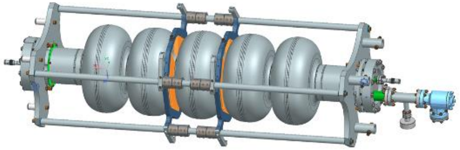
Q_0 in the Linac



- Due to the strong coupling in the CM, Q_0 is measured cryogenically
- Full CM average Q_0 results look promising
- Across the linac an **average of 2.8×10^{10}** has been observed, **exceeding the spec** of 2.7×10^{10}
- Low performers can likely be improved by additional CM degaussing

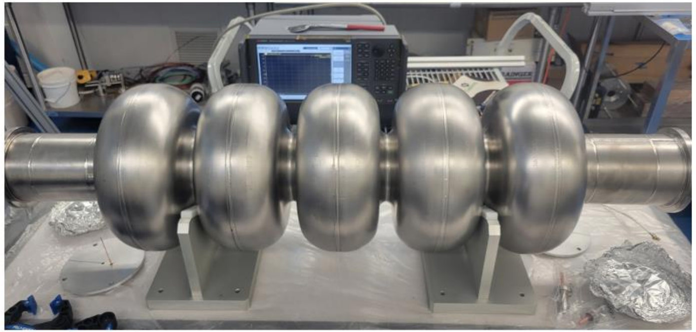
Demonstrates High Q_0 in an installed linac for the first time

800 MHz 5-cell cavity



Presented by K. McGee, FNAL

- Fabricated at JLab, currently at FNAL
- High-power RF cold-test plan (Spring 2024):
  1. Baseline cold-test (EP, last tested 2018, see Figure 4)
  2. First mid-T (300-350C) baking treatment (High-Q development)



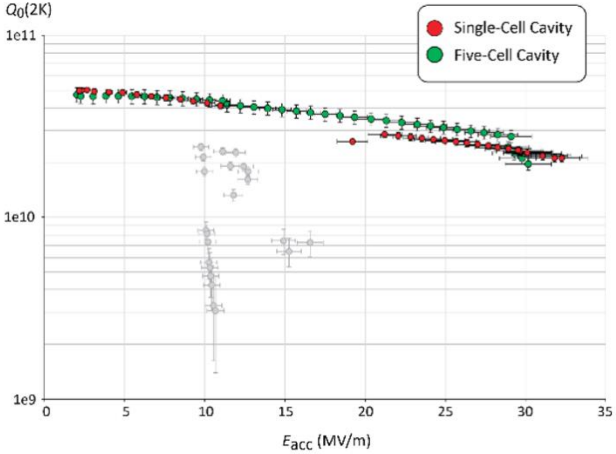
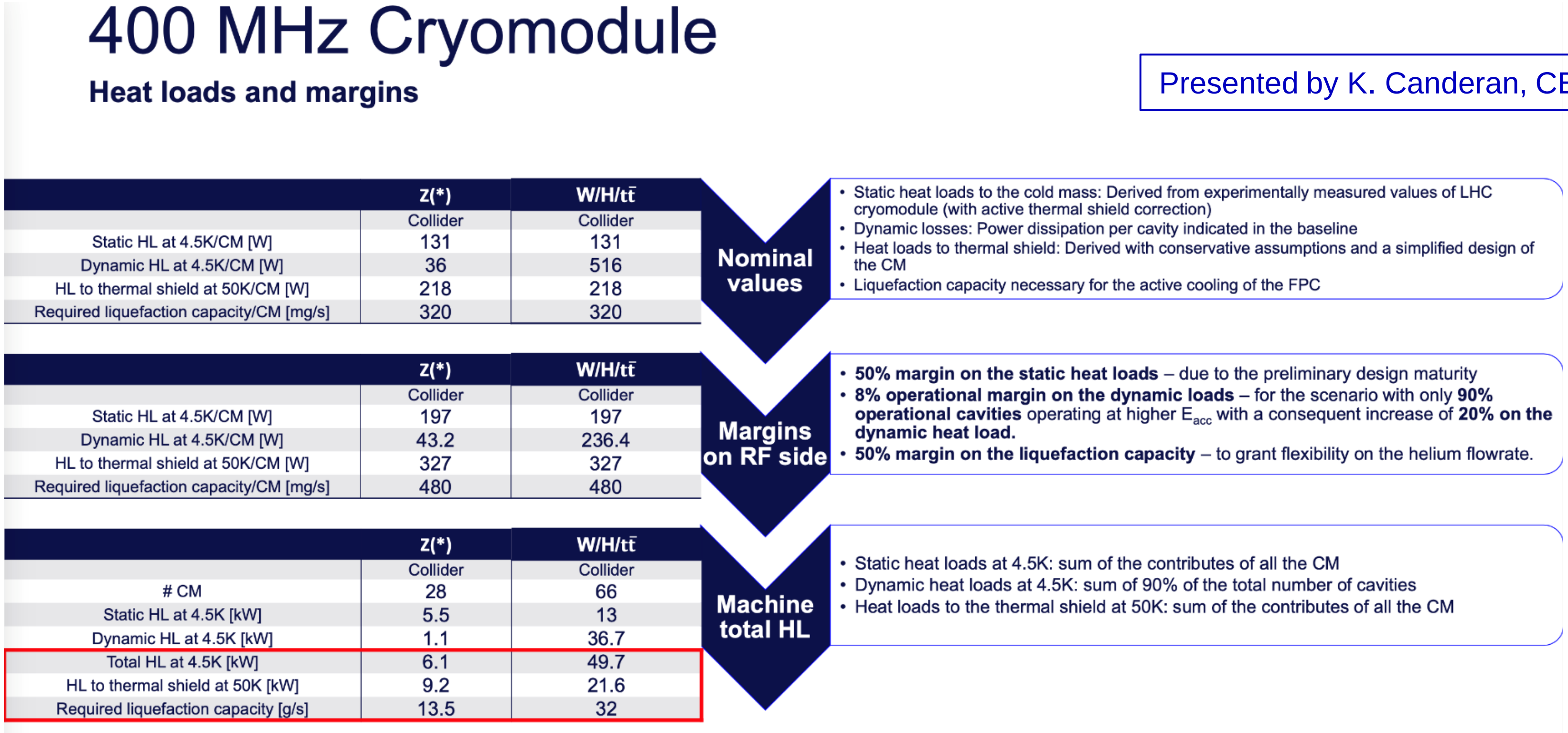


Figure 4: Combined VTA results for the five-cell and single-cell cavity as measured at 2 Kelvin.

F. Marhauser et al. 802 MHz ERL Cavity Design and Development (cern.ch) IPAC 2018 **THPAL146**



400 MHz Cryomodule

Heat loads and margins

Presented by K. Canderan, CERN

	Z(*)	W/H/$t\bar{t}$
	Collider	Collider
Static HL at 4.5K/CM [W]	131	131
Dynamic HL at 4.5K/CM [W]	36	516
HL to thermal shield at 50K/CM [W]	218	218
Required liquefaction capacity/CM [mg/s]	320	320

Nominal values

- Static heat loads to the cold mass: Derived from experimentally measured values of LHC cryomodule (with active thermal shield correction)
- Dynamic losses: Power dissipation per cavity indicated in the baseline
- Heat loads to thermal shield: Derived with conservative assumptions and a simplified design of the CM
- Liquefaction capacity necessary for the active cooling of the FPC

	Z(*)	W/H/$t\bar{t}$
	Collider	Collider
Static HL at 4.5K/CM [W]	197	197
Dynamic HL at 4.5K/CM [W]	43.2	236.4
HL to thermal shield at 50K/CM [W]	327	327
Required liquefaction capacity/CM [mg/s]	480	480

Margins on RF side

- **50% margin on the static heat loads** – due to the preliminary design maturity
- **8% operational margin on the dynamic loads** – for the scenario with only **90% operational cavities** operating at higher E_{acc} with a consequent increase of **20% on the dynamic heat load.**
- **50% margin on the liquefaction capacity** – to grant flexibility on the helium flowrate.

	Z(*)	W/H/$t\bar{t}$
	Collider	Collider
# CM	28	66
Static HL at 4.5K [kW]	5.5	13
Dynamic HL at 4.5K [kW]	1.1	36.7
Total HL at 4.5K [kW]	6.1	49.7
HL to thermal shield at 50K [kW]	9.2	21.6
Required liquefaction capacity [g/s]	13.5	32

Machine total HL

- Static heat loads at 4.5K: sum of the contributes of all the CM
- Dynamic heat loads at 4.5K: sum of 90% of the total number of cavities
- Heat loads to the thermal shield at 50K: sum of the contributes of all the CM

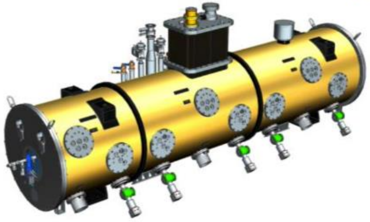
Definition of a heat loads budget and margins for the cryogenic system + a preliminary cryogenic scheme for 400 MHz & 800 MHz

Preliminary design of FCC 800MHz Cryomodule

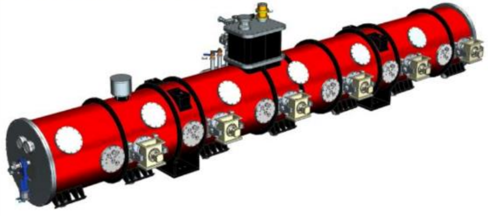
Presented by D. Passarelli, FNAL

- The FCC 800 MHz CM design is based on SSR2 and HB650 PIP-II CMs with the following main differences:
  - Heat exchangers and valves are integrated into the Cryogenic Distribution System (CDS).
  - A “Jumper” will be used to interface with CDS through welded connection into the tunnel (no u-tubes).
  - Couplers are actively cooled with helium.

FCC 800 MHz cryomodule



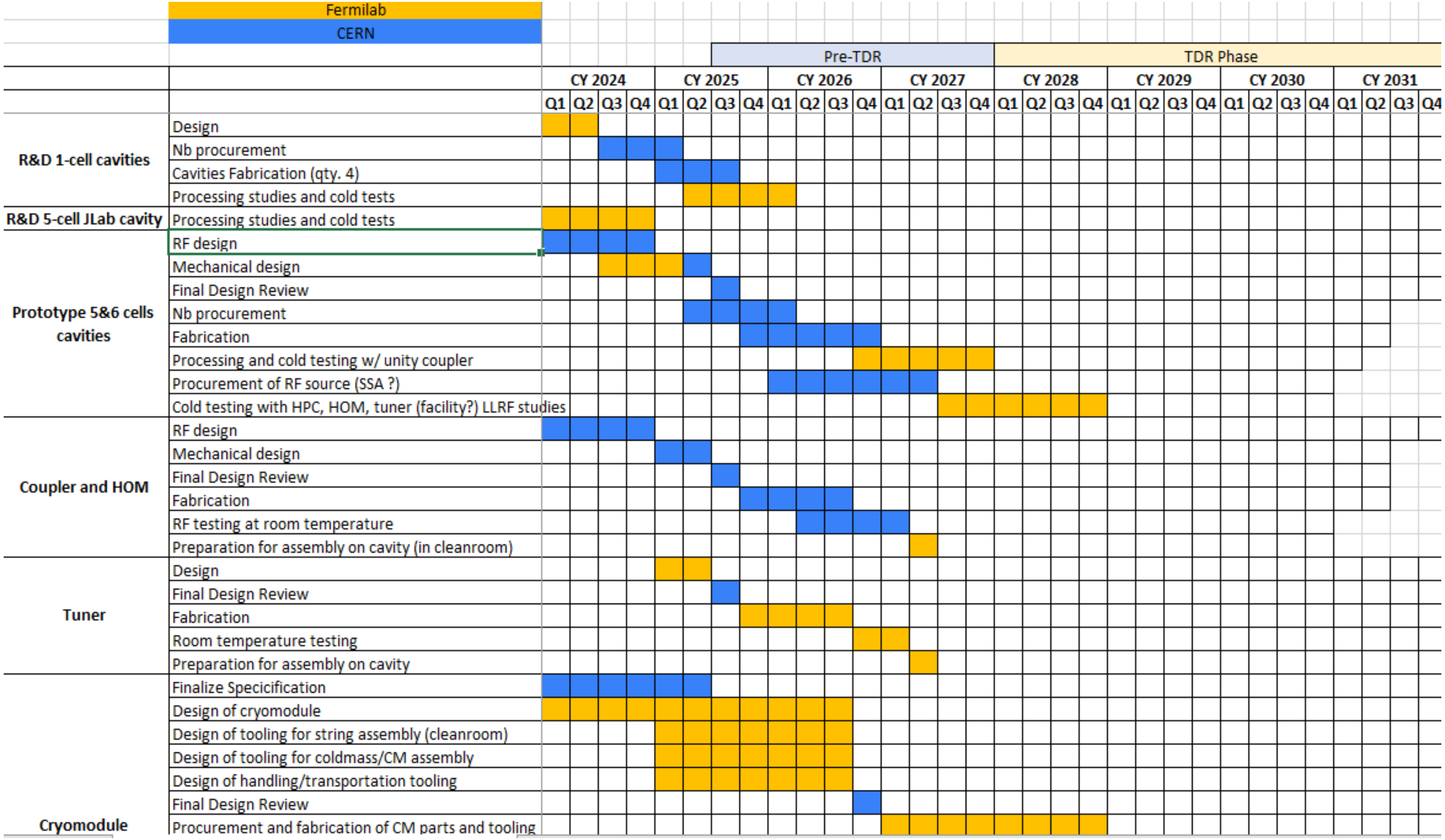
PIP-II SSR2 cryomodule



PIP-II HB650 cryomodule

“Final Design of the Pre-Production SSR2 Cryomodule for PIP-II Project at Fermilab”, V. Roger et al., Proceedings of LINAC 2022
“Design of the 650 MHz High Beta Prototype Cryomodule for PIP-II at Fermilab”, V. Roger et al., Proceedings of SRF 2021

The experience gained in designing, assembling, and testing PIP-II cryomodules has substantially expedited the design phase of the 800 MHz cryomodule.



🟨 Fermilab
🟦 CERN

								Pre-TDR										TDR Phase															
		CY 2024				CY 2025				CY 2026				CY 2027				CY 2028				CY 2029				CY 2030				CY 2031			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
R&D 1-cell cavities	Design	🟨	🟨																														
	Nb procurement			🟦	🟦	🟦																											
	Cavities Fabrication (qty. 4)					🟦	🟦	🟦																									
	Processing studies and cold tests						🟨	🟨	🟨	🟨																							
R&D 5-cell JLab cavity	Processing studies and cold tests	🟨	🟨	🟨	🟨																												
Prototype 5&6 cells cavities	RF design	🟦	🟦	🟦	🟦																												
	Mechanical design			🟨	🟨	🟨	🟦																										
	Final Design Review							🟦																									
	Nb procurement						🟦	🟦	🟦	🟦																							
	Fabrication								🟦	🟦	🟦	🟦	🟦																				
	Processing and cold testing w/ unity coupler												🟨	🟨	🟨	🟨	🟨																
	Procurement of RF source (SSA ?)									🟦	🟦	🟦	🟦	🟦	🟦																		
	Cold testing with HPC, HOM, tuner (facility?) LLRF studies															🟨	🟨	🟨	🟨	🟨	🟨												
Coupler and HOM	RF design	🟦	🟦	🟦	🟦																												
	Mechanical design					🟦	🟦																										
	Final Design Review							🟦																									
	Fabrication								🟦	🟦	🟦	🟦																					
	RF testing at room temperature										🟦	🟦	🟦	🟦																			
	Preparation for assembly on cavity (in cleanroom)														🟨																		
Tuner	Design					🟨	🟨																										
	Final Design Review							🟦																									
	Fabrication								🟨	🟨	🟨	🟨																					
	Room temperature testing												🟨	🟨																			
	Preparation for assembly on cavity														🟨																		
Cryomodule	Finalize Specicification	🟦	🟦	🟦	🟦	🟦	🟦																										
	Design of cryomodule	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																					
	Design of tooling for string assembly (cleanroom)					🟨	🟨	🟨	🟨	🟨	🟨	🟨																					
	Design of tooling for coldmass/CM assembly					🟨	🟨	🟨	🟨	🟨	🟨	🟨																					
	Design of handling/transportation tooling					🟨	🟨	🟨	🟨	🟨	🟨	🟨																					
	Final Design Review												🟦																				
	Procurement and fabrication of CM parts and tooling													🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨												

Preliminary ideas for joint Fermilab-CERN collaboration on 800 MHz RF

Many thanks to all the speakers

Yes we can!

Many thanks to all chairpersons