FCC Accelerator Overview

FCC Week Workshop

June 5, 2023

Tor Raubenheimer
on behalf of FCC collaboration & FCCIS DS team

Particular thanks to Andrey Abramov, Wolfgang Bartmann, Jeremie Bauche, Michael Benedikt, Manuela Boscolo, Olivier Brunner, Federico Carra, Antoine Chance, Paolo Craievich, Barbara Dalena, Massimo Giovannozzi, Michael Hofer, Jacqueline Keintzel, Fani Kuncheva-Valchkova, Anton Lechner, Mauro Migliorati, Katsunobu Oide, Vittorio Parma, Franck Peauger, Dmitry Shatilov, Rogelio Thomas, Frank Zimmermann

Outline

- Siting and Parameters
- Main Rings
  - Optics and correction
  - Collimation and Tuning
  - Arc cell Integration
  - SRF
- Booster ring
- Transport line and Pre-Injector
- FCC-hh

Will focus on the Baseline which is being developed for the Mid-Term Review. Alternatives are being developed in some cases to improve performance or reduce costs.

Lots of progress over the last two years! Convey the depth of the design work and level of detail supporting the Mid-Term Review.

FUTURE CIRCULAR COLLIDER

FCC-ee layout

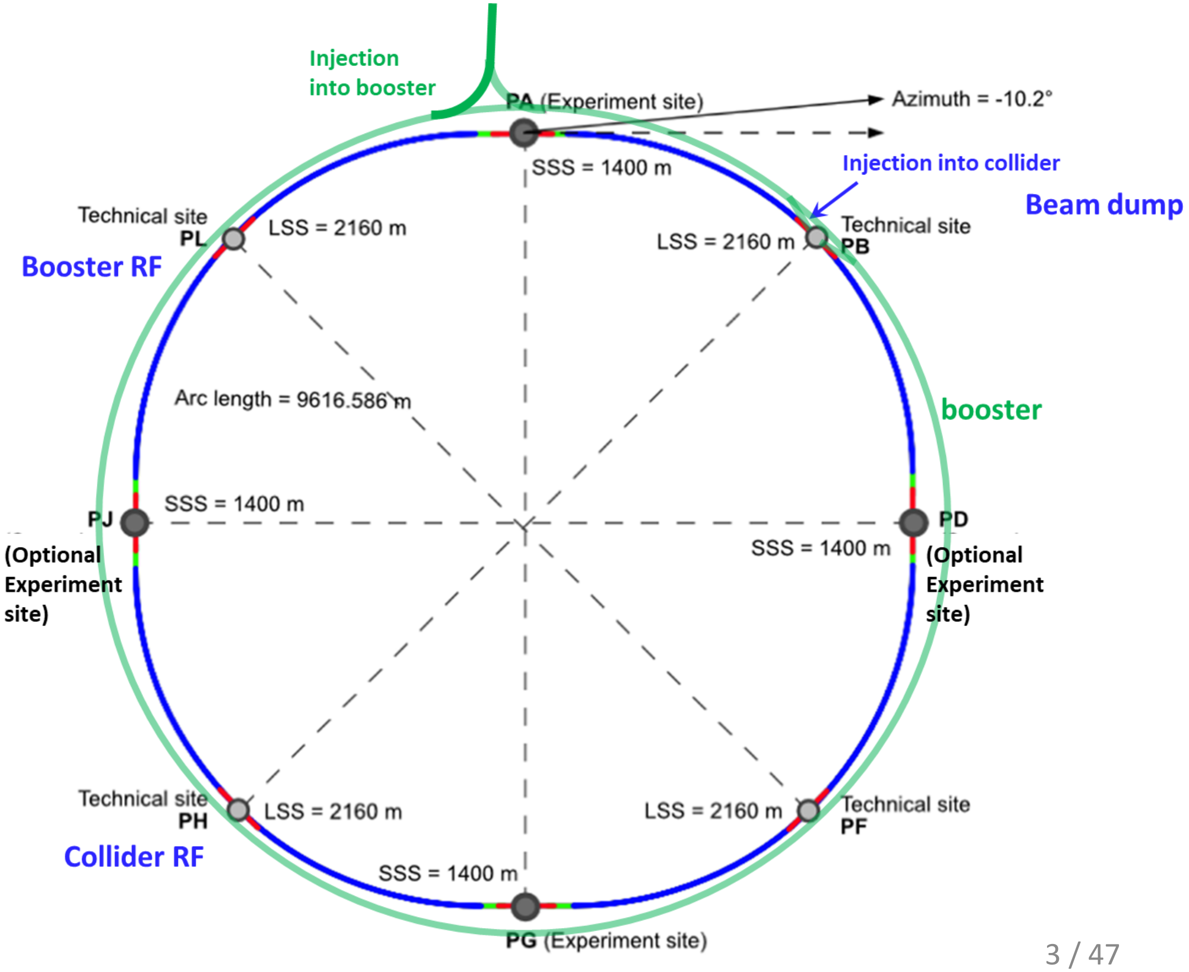
Double ring e+e- collider with 91 km circ.

Common footprint with FCC-hh, except around IPs

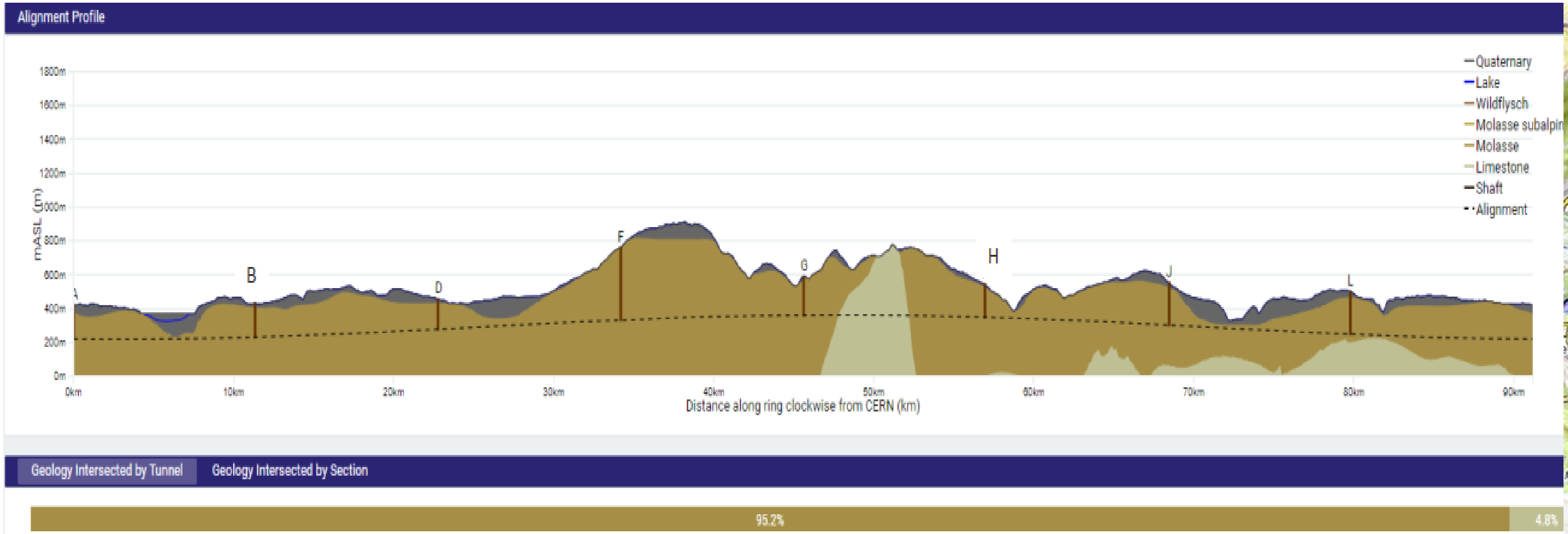
Perfect 4-fold super-periodicity allowing 2 or 4 IPs; large horizontal crossing angle **30 mrad, crab-waist collision optics**

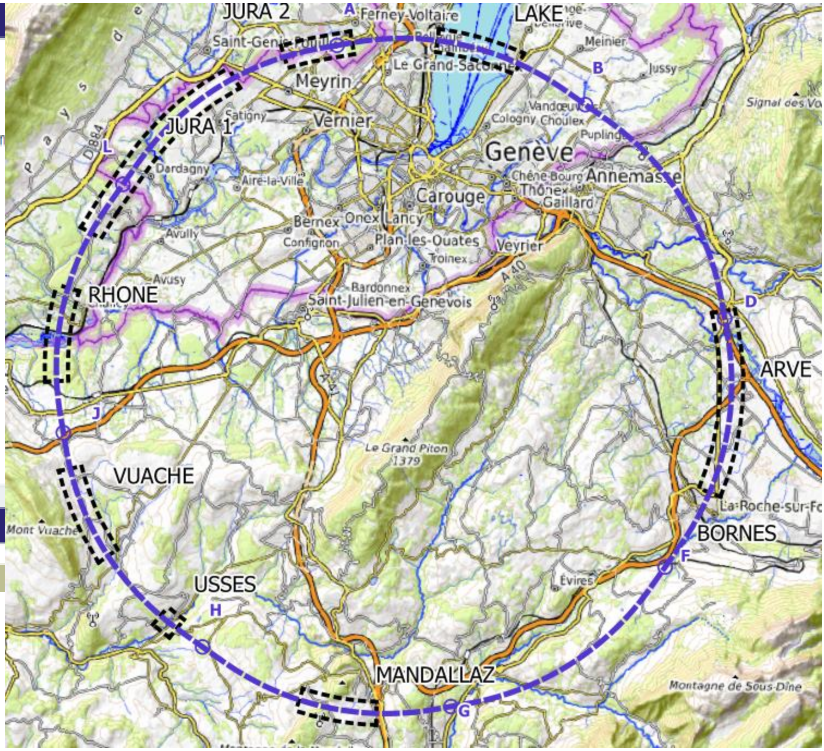
Synchrotron radiation power 50 MW/beam at all beam energies

Top-up injection scheme for high luminosity Requires **booster synchrotron in collider tunnel and 20 GeV e+/e- source and linac**



Optimized placement and layout





present baseline implementation

- Layout chosen out of ~ 50 initial variants
- 95% in molasse geology for minimising tunnel construction risk
- Well matched to existing electrical power distribution
- <4 km of new roads in total to connect the surface sites to existing roads and other networks

site investigations planned for 2024 and 2025 to verify geological conditions:

- limestone-molasse border, karstification, water pressure, moraine properties, etc.
- ~40-50 drillings, 100 km of seismic lines

FCC-ee: main machine parameters and run plan

FUTURE CIRCULAR COLLIDER

Running mode	Z		W	ZH	$t\bar{t}$
Number of IPs	2	4	4	4	4
Beam energy (GeV)	45.6		80	120	182.5
Bunches/beam	12000	15880	688	260	40
Beam current [mA]	1270	1270	134	26.7	4.94
Luminosity/IP [10^{34} cm^{-2} s^{-1}]	180	140	21.4	6.9	1.2
Energy loss / turn [GeV]	0.039	0.039	0.37	1.89	10.1
Synchr. Rad. Power [MW]			100		
RF Voltage 400/800 MHz [GV]	0.08/0	0.08/0	1.0/0	2.1/0	2.1/9.4
Rms bunch length (SR) [mm]	5.60	5.60	3.55	2.50	1.67
Rms bunch length (+BS) [mm]	13.1	12.7	7.02	4.45	2.54
Rms hor. emittance $\varepsilon_{x,y}$ [nm]	0.71	0.71	2.16	0.67	1.55
Rms vert. emittance $\varepsilon_{x,y}$ [pm]	1.42	1.42	4.32	1.34	3.10
Longit. damping time [turns]	1158	1158	215	64	18
Horizontal IP beta β^*_x [mm]	110	110	200	300	1000
Vertical IP beta β^*_y [mm]	0.7	0.7	1.0	1.0	1.6
Beam lifetime (q+BS+lattice) [min.]	50	250	—	<28	<70
Beam lifetime (lum.) [min.]	35	22	16	10	13
	4 years 5 x 10^{12} Z LEP x 10^5		2 years >2x10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

- Very high luminosity at Z, W, and Higgs
- Accumulate > luminosity in 1st 10 years at Higgs, W, and Z than ILC at Higgs
- Accommodates up to 4 experiments → robustness, statistics, specialized detectors, engage community
- Run plan naturally starts at low energy with the Z and ramps but could be adjusted using an RF Bypass to start at Higgs

Accelerator Design

Well developed layout that will deliver (extremely) high luminosity Z → t-tbar

Design benefits from LEP, LHC, DAFNE, and B-factory experience as well as LC, EIC and CEPC development

Have detailed lattices for collider rings and booster
Full simulations of beam-beam effects
Working on alignment and correction strategies

The accelerator has highly repetitive Arcs with challenging IRs
- **→ Develop prototype of half arc-cell**
- **→ Develop IR mock-up**

Most R&D is focused on optimizing systems for power efficiency & cost

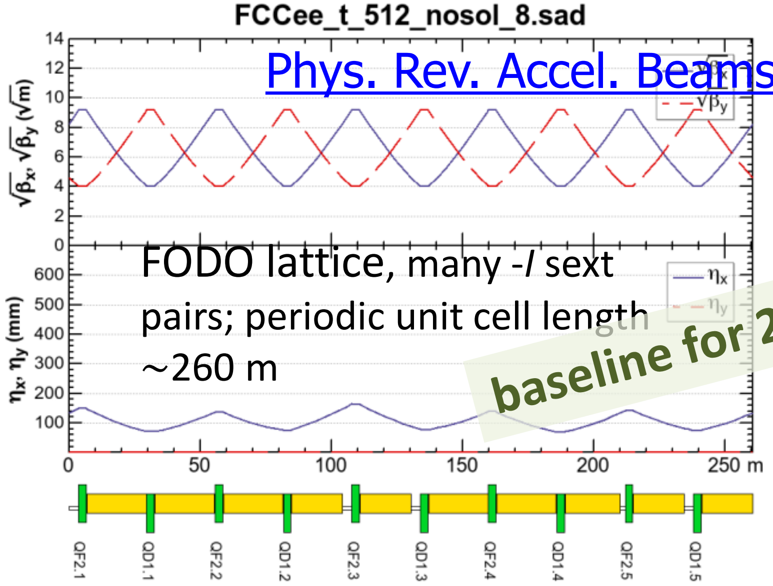
FCC-ee collider optics development: 2 options

FUTURE CIRCULAR COLLIDER

arc

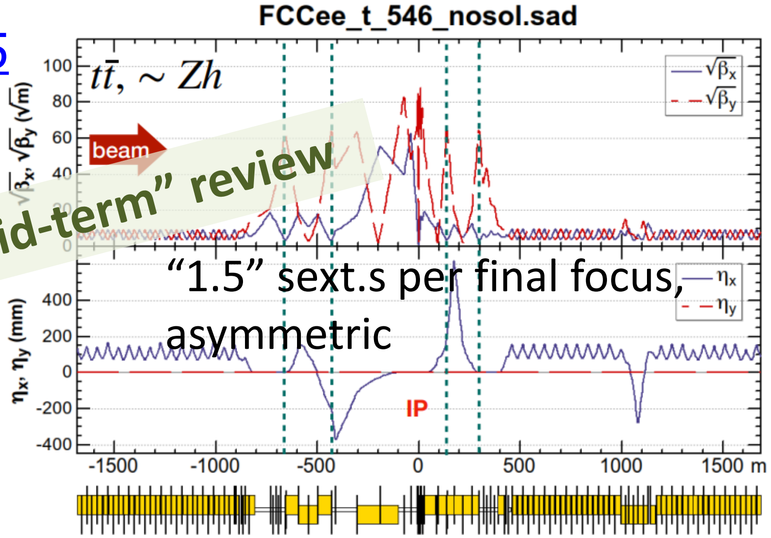
interaction region

Short 90/90: $t\bar{t}$, Zh



[Phys. Rev. Accel. Beams **19**, 111005]

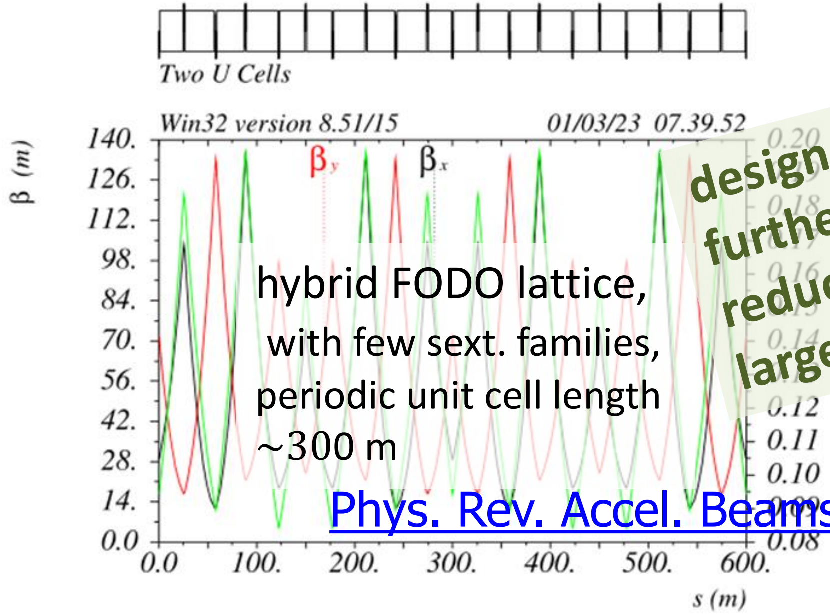
FODO lattice, many -*I* sext pairs; periodic unit cell length ~260 m



"1.5" sext.s per final focus, asymmetric

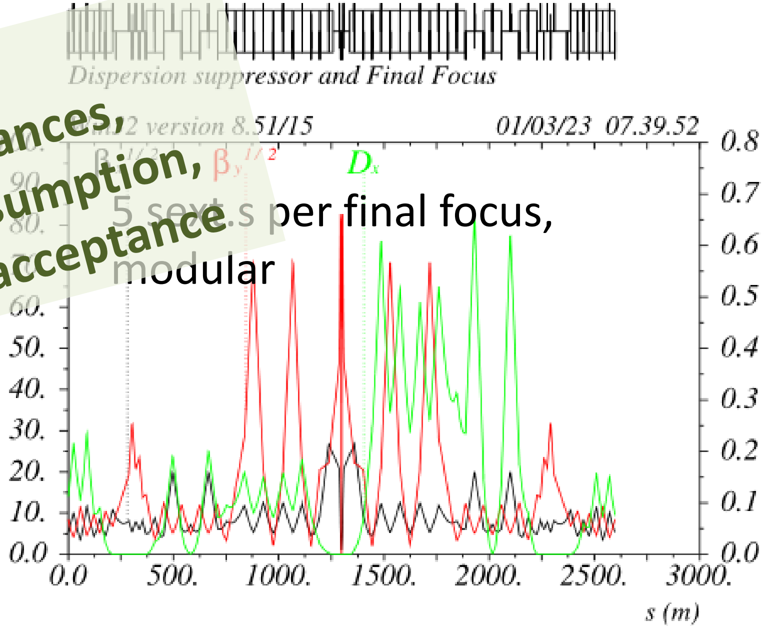
baseline for 2023 FCC "mid-term" review

K. Oide, 2023 EPS
Rolf Wideroe award winner



hybrid FODO lattice, with few sext. families, periodic unit cell length ~300 m

[Phys. Rev. Accel. Beams **26**, 021601]



5 sext.s per final focus, modular

design in progress - further relaxed tolerances, reduced power consumption, larger momentum acceptance

P. Raimondi, 2017 EPS
Gersh Budker award winner

FUTURE CIRCULAR COLLIDER

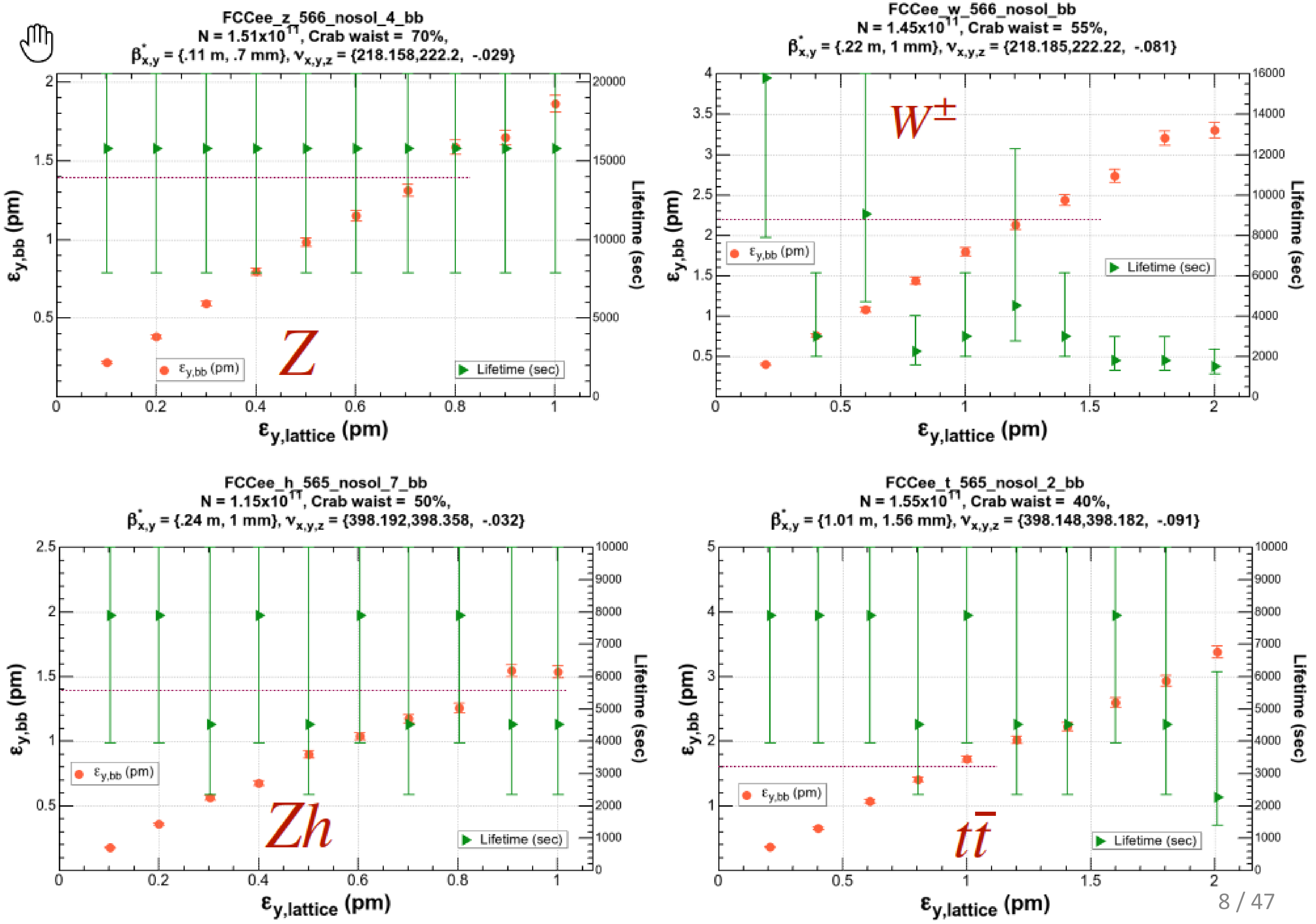
Lifetime and Dynamic Aperture

K. Oide

Excellent progress over last 6 months

Tuning beam optics and chromatic correction while optimizing for both 4 and 2 IPs

Established configurations for all four working points with lifetime >> than minimum reqs.

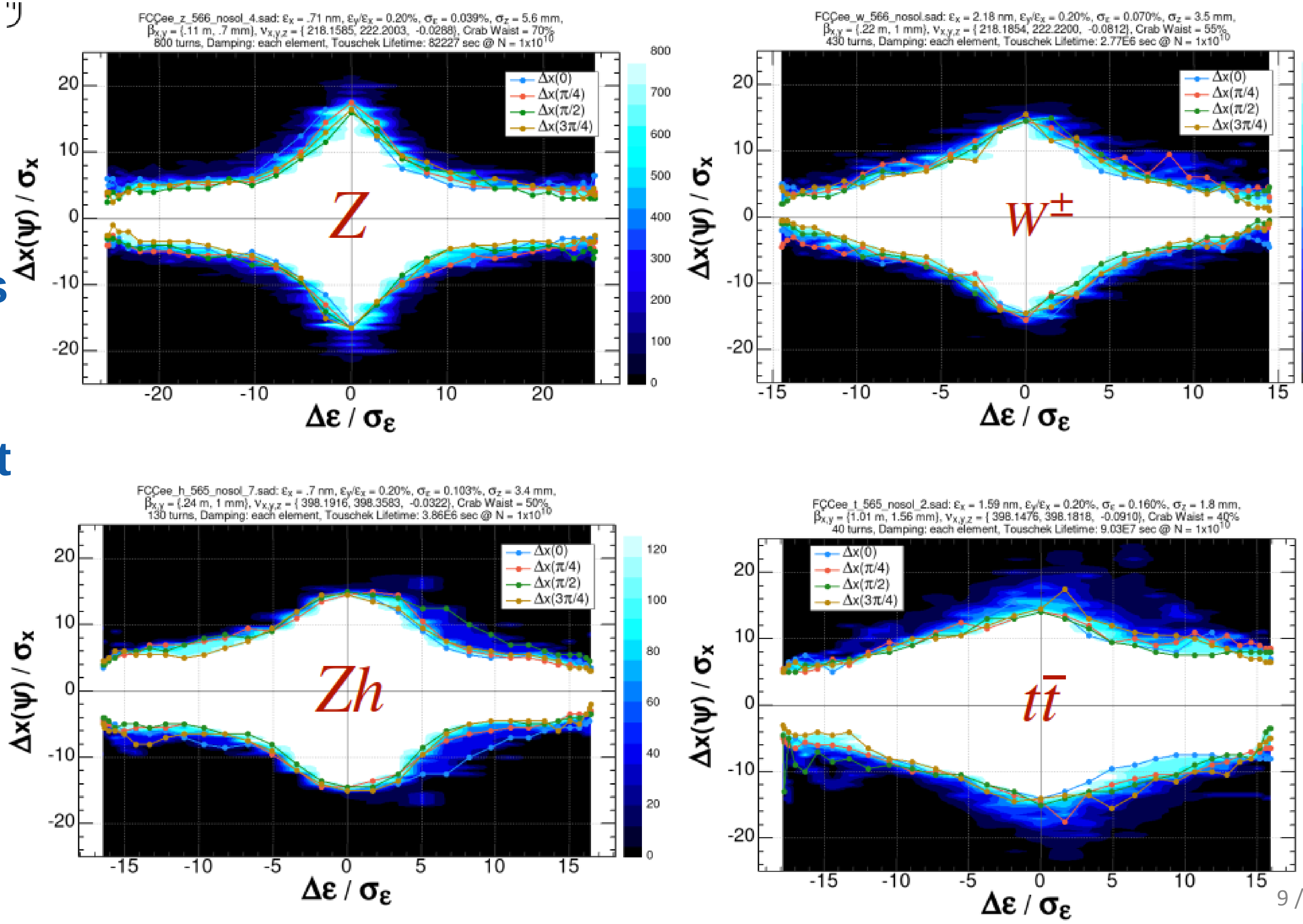


Lifetime and Dynamic Aperture

K. Oide

Dynamic aperture exceeds requirements at all four working points

Impact of errors is being evaluated but tolerances will be tight for DA as well as the optics



Alignment Correction and Tuning

R. Thomas

Alignment is a serious challenge for the main rings and Booster

Have developed an algorithm to correct using an iterative approach based in MADX but need better performance

Planning to start from 'realistic' mechanical alignment and iterate with Beam-Based Alignment techniques to achieve ~10 um effective alignment.

Working to develop tuning knobs to tune the IP parameters after main alignment procedures

Length	Mech. align.	Comment
6 m	20 - 50 um	Pre-align on girder
50 m	200 um	Structured laser tracker or analogous
200 m	500 um	Structured laser tracker or analogous
1000 m	2 mm	Smoothed alignment from local and surface
10000 m	5 mm	Surface alignment → tunnel

FUTURE CIRCULAR COLLIDER

Alignment Correction and Tuning

R. Thomas
J. Keintzel

Collaborating with modern synchrotron light sources to develop alignment algorithms and linear colliders on IP tuning knobs

Will also need to develop and model feedback to maintain the rings

FUTURE CIRCULAR COLLIDER

Optics Tuning and Corrections for Future colliders workshop

26–28 Jun 2023
CERN
Europe/Zurich timezone

Enter your search term

- Overview
- Timetable
- Contribution List
- Registration
- Participant List
- Program committee
- Accommodation

The workshop will bring together experts from the circular and linear collider community and the high brightness synchrotron radiation sources to discuss the tuning and correction of beam optics.

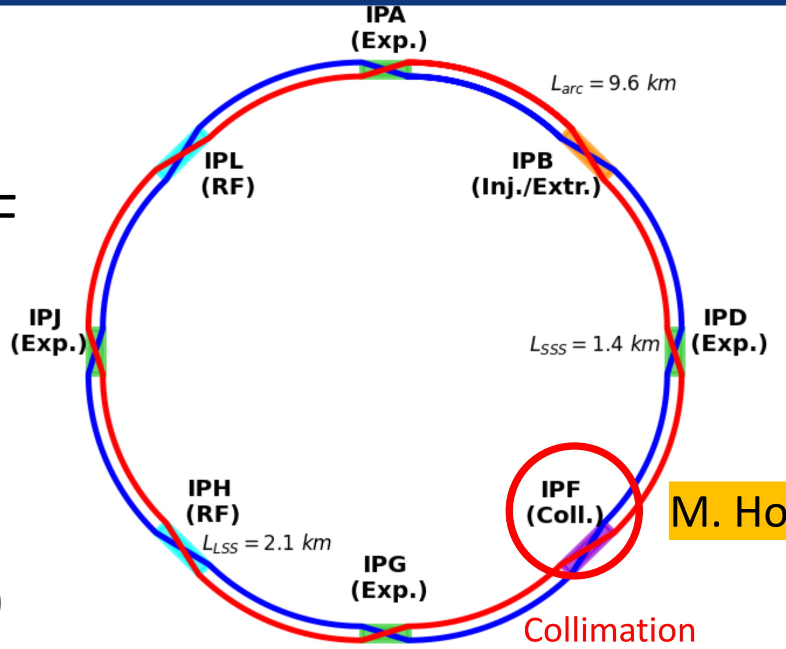
Topics to be covered are:

- correction of linear and nonlinear beam optics through the accelerator;
- sensitivity and optimization of dynamic aperture;
- impact of collective effects on the beam optics;
- component errors, drifts, and correlations;
- transport and preservation of polarization;
- modeling tools and optimization techniques.

Main Ring Collimation

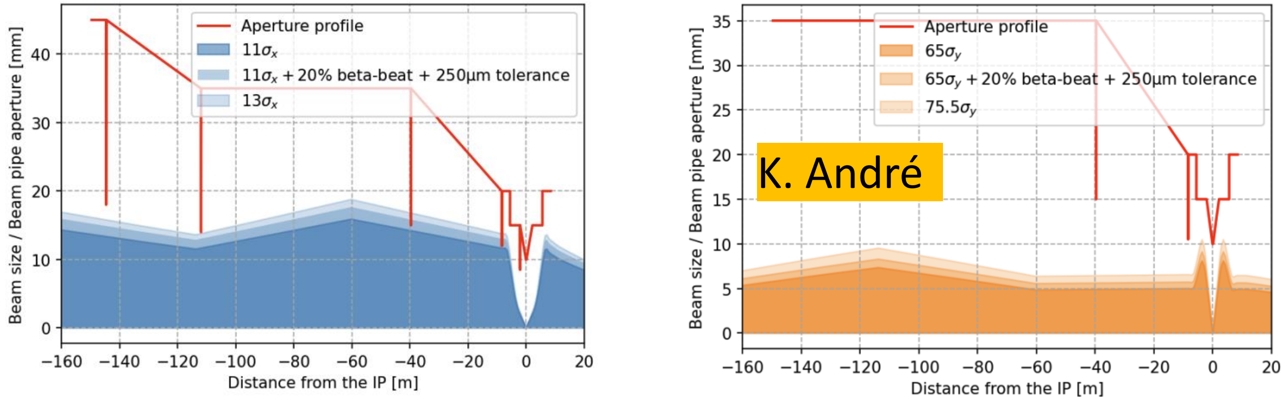
A. Abramov

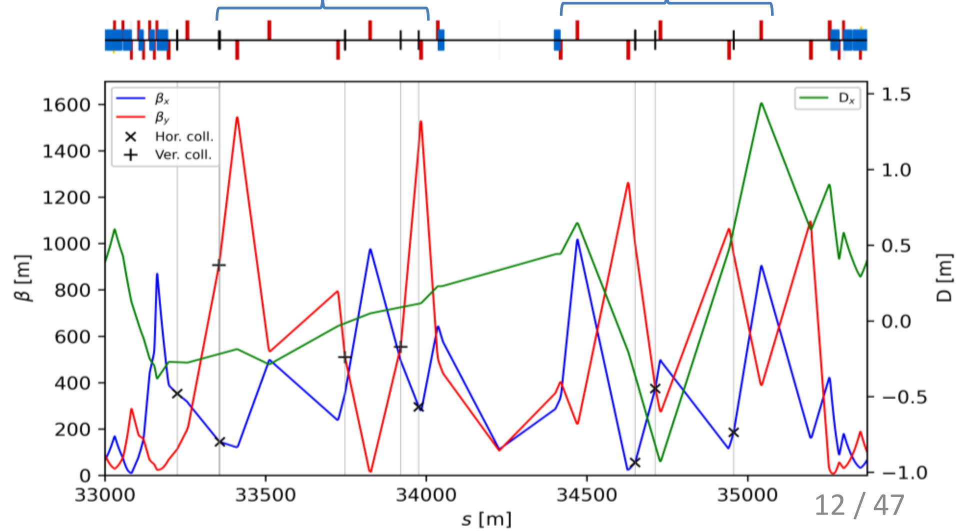
- **Dedicated halo collimation system in PF**
  - Two-stage betatron and off-momentum collimation in PF
  - Defines the global aperture bottleneck
  - First collimator design (G. Broggi)
- **Synchrotron radiation collimators around the IPs**
  - 6 collimators and 2 masks upstream of the IPs (K. André)
  - Designed to reduce detector backgrounds and power loads in the inner beampipe due to photon losses



M. Hofer

Collimation insertion

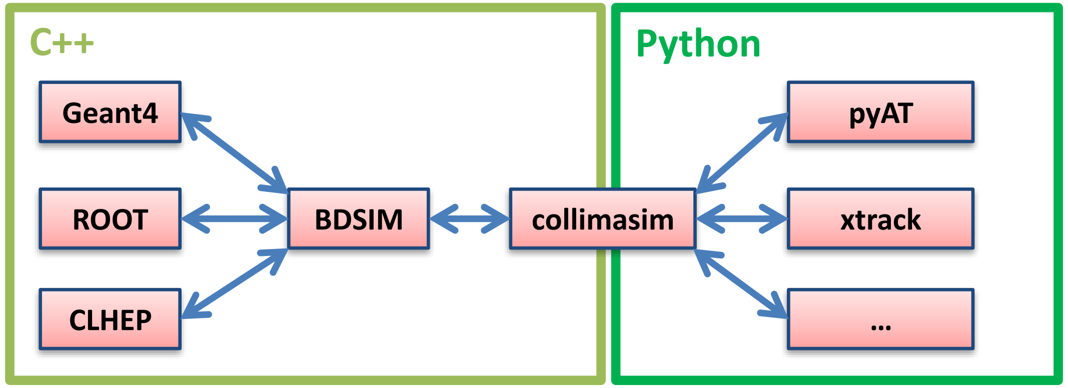




Main Ring Collimation

A. Abramov

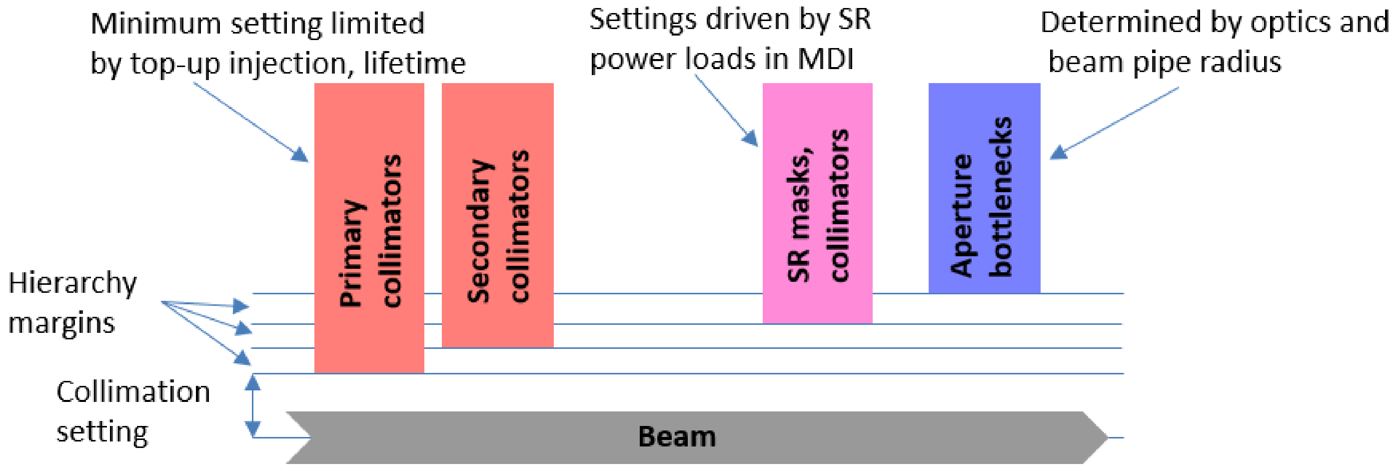
Complete simulation package for modeling performance in FCC-ee and FCC-hh (these tools are now being used at EIC as well)



Three layered collimation system has excellent performance

With a pessimistic 5-minute lifetime at Z → 59.2 kW absorbed in PF while < 2 W reach experimental IRs

Super KEKB observations of 'fast beam loss' needs to be understood as it would be hard to protect against



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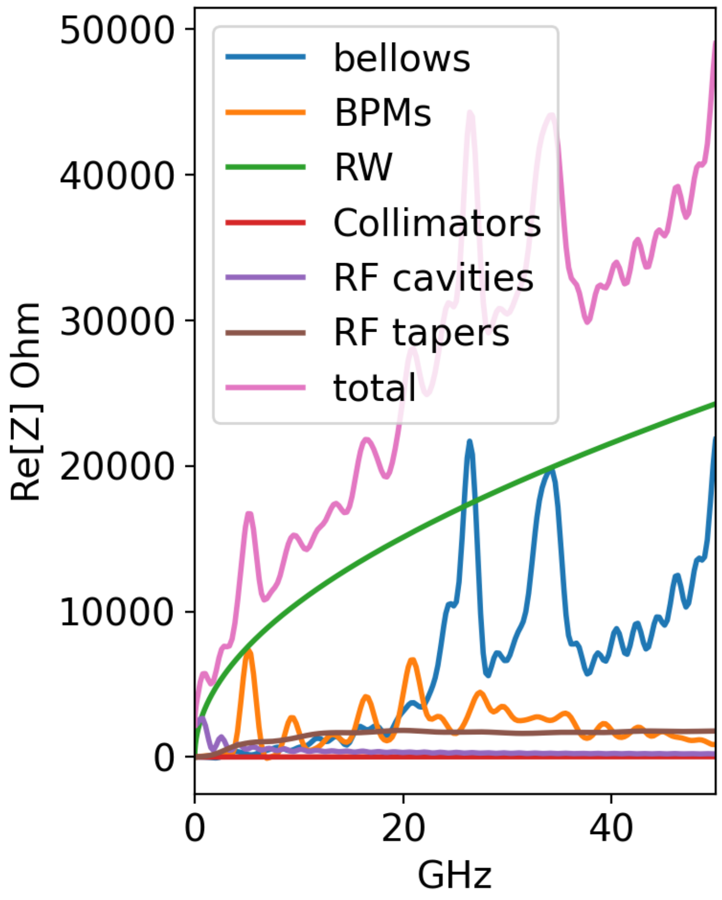
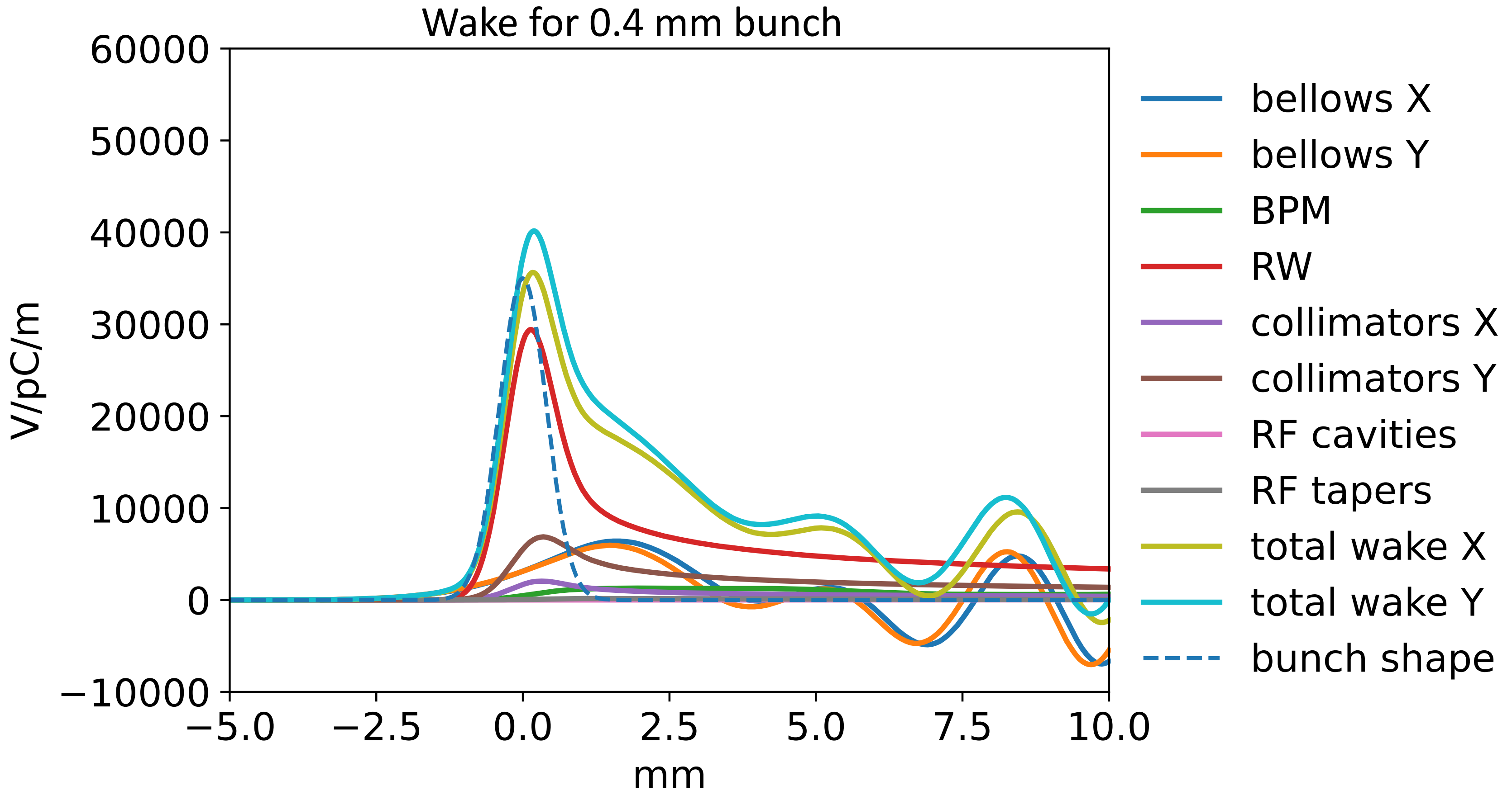
Main Ring Collective Effects

M. Migliorati

Building models for transverse and longitudinal impedance

Resistive wall dominates but collimators, tapers, bellows, … are all important





Main Ring Collective Effects

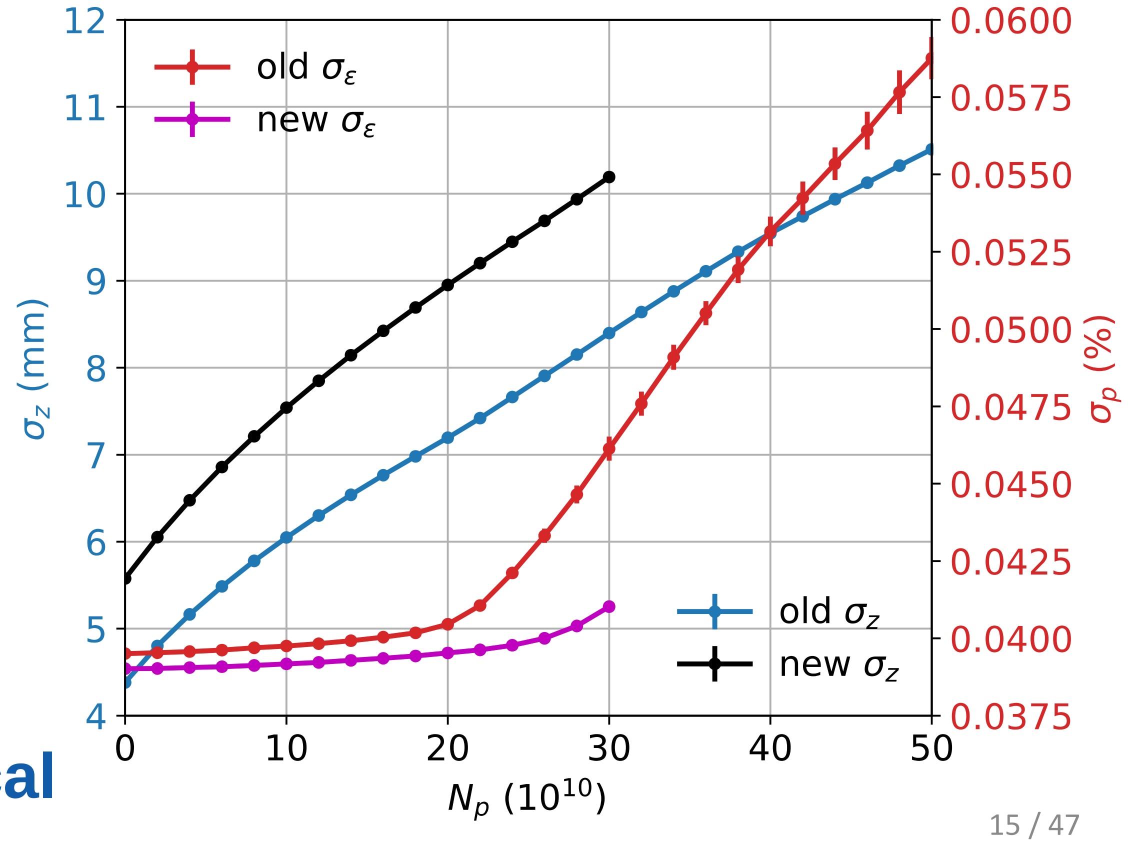
M. Migliorati

Impedance has some impact on the longitudinal distribution

Transverse beam is unstable → bunch-by-bunch feedback similar to Super KEKB with 2 ms damping time but many fewer turns

Collimators are a significant source of transverse impedance and working to balance the geometric and resistive contributions

There is a strong interplay between the longitudinal and transverse wakefields, beam-beam, and feedback systems. Must study all effects together
→ simulation and modeling tools are critical

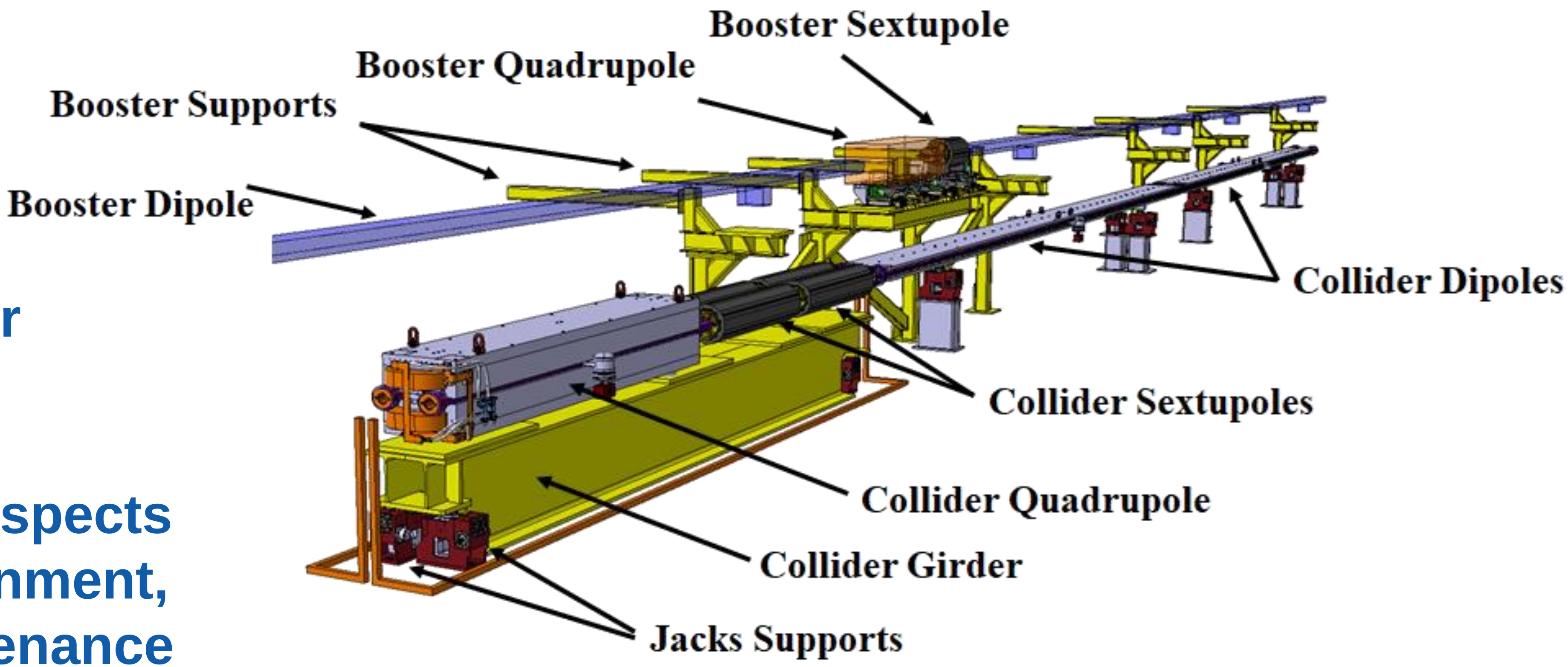


Arc Cell Integration

F. Carra
L. Baudin

Arc cells are repeated 1500 times → optimize the layout for performance, cost, installation, maintenance, …

Arc half-cell team developed detailed layout for the repeating structure of Booster and Main Rings

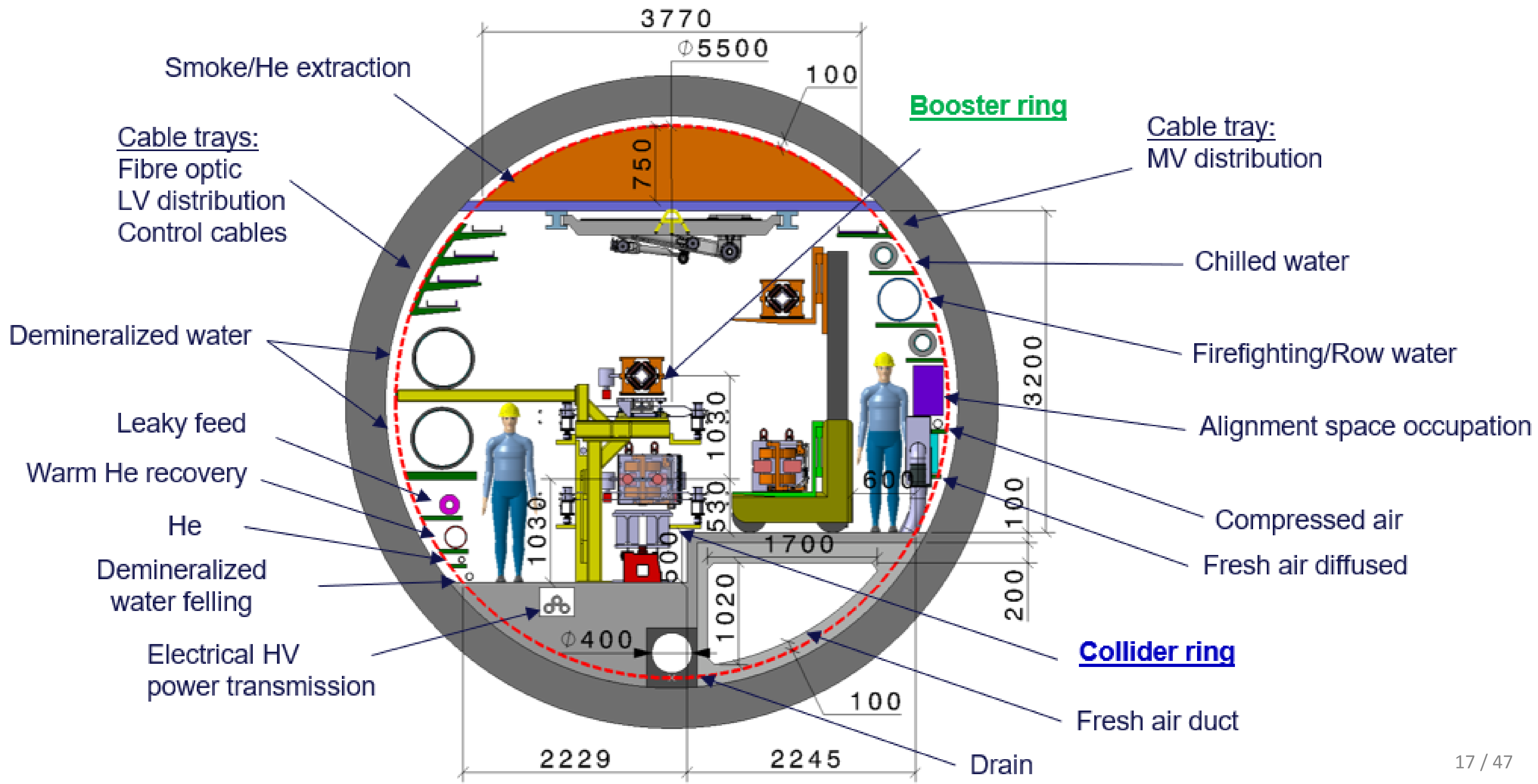


Considered many aspects including cost, alignment, stability, and maintenance

Fully documented and starting phase-II with detailed engineering of a mockup

Arc Cell Integration

F. Kuncheva-Valchkova



Arc Cell Radiation Protection

A. Lechner

Main challenge: cumulative ionizing dose (@ttbar) much higher than in LEP and HL-LHC arcs (over an arc length of > 70 km!)

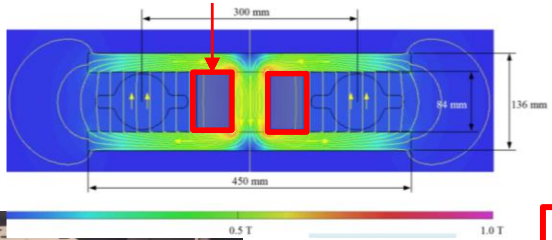
	LEP (100GeV, 15A*h)	HL-LHC (per year)	FCC-ee (182.5GeV, 15A*h)
2)	2.25kGy	1.4Gy	600kGy
5)	50.3kGy		350kGy
6)	4.5kGy		150kGy

Per year @ttbar (w/o booster contribution)

Cable insulation

Magnet insulation

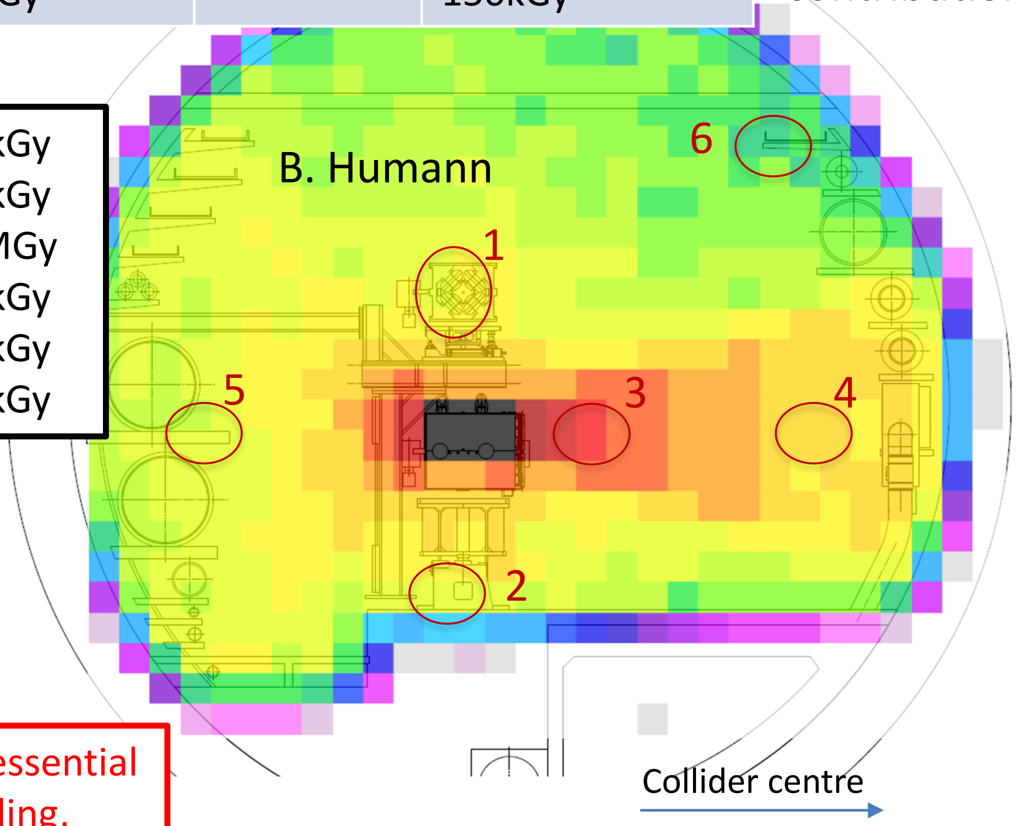
O(MGy) can damage insulation



Electronics

Designing a system with commercial-off-the-shelf electronics (with some level of complexity) considered as unfeasible for a dose above 1 kGy

1) 400kGy
2) 600kGy
3) 1.5MGy
4) 700kGy
5) 350kGy
6) 150kGy



Radiation to materials and electronics are an essential aspect - solutions still to be developed! (shielding, rad-hard by design, …)

Superconducting RF Systems

F. Peauger and O. Brunner

SRF systems replenish the energy lost to synchrotron radiation in the main ring and accelerate the beam in the Booster

Main Ring RF is very high power while the Booster has low duty cycle and low current. Voltages are similar in both rings: 100 MV (Z), 1 GV (W), 2 GV (Higgs), 11 GV (t-tbar)

For Z thru Higgs, Main Ring RF is based 400 MHz Nb coated Cu cavities operating at 4.5K while the Booster uses 800 MHz solid Nb at 2K

For t-tbar both rings would be upgraded with high-Q 800 MHz cavities operating at 2K

Mode	Point H		Point L	
	400 MHz CMs	800 MHz CMs	400 MHz CMs	800 MHz CMs
Z	4.5K	NO CMs	NO CMs	2K
W	4.5K			2K
Higgs	4.5K			2K
ttbar	4.5K	2K		2K

FUTURE CIRCULAR COLLIDER

Superconducting RF Systems

F. Peauger and O. Brunner

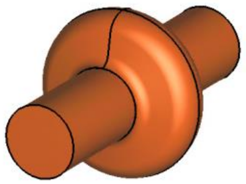
12-May-23	Z		W		H		ttbar2		
	per beam	booster	per beam	booster	2 beams	booster	2 beams	2 beams	booster
RF Frequency [MHz]	400	800	400	800	400	800	400	800	800
RF voltage [MV]	120	140	1050	1050	2100	2100	2100	9200	11300
Eacc [MV/m]	5.72	6.23	10.61	20.01	10.61	20.76	10.61	20.12	20.10
# cell / cav	1	5	2	5	2	5	2	5	5
Vcavity [MV]	2.14	5.83	7.95	18.75	7.95	19.44	7.95	18.85	18.83
#cells	56	120	264	280	528	540	528	2440	3000
# cavities	56	24	132	56	264	108	264	488	600
# CM	14	6	33	14	66	27	66	122	150
+ #CM	14	6	33	8	0	13	0	122	123
- #CM	-		14				-	-	-
T operation [K]	4.5	2	4.5	2	4.5	2	4.5	2	2
dyn losses/cav * [W]	19	0.3	129	3	129	4	129	23	3
stat losses/cav * [W]	8	8	8	8	8	8	8	8	8
Qext	5.8E+04	3.1E+05	9.2E+05	7.6E+06	9.1E+05	1.6E+07	4.5E+06	4.2E+06	8.1E+07
Detuning [kHz]	9.885	4.385	0.575	0.140	0.106	0.012	0.009	0.056	0.002
Pcav [kW]	901	210	378	89	382	47	78	163	8
energy loss / turn ** [MV]	39.40	39.40	370.00	370.00	1890.00	1890.00	10100.00		10100.00
cos phi	0.33	0.28	0.35	0.35	0.90	0.90	0.98	0.86	0.89
Beam current [A]	1.280	0.128	0.135	0.0135	0.0534	0.003	0.010	0.010	0.0005
Lacc [m]	0.375	0.937	0.749	0.937	0.749	0.937	0.749	0.937	0.937
#cav/CM	4	4	4	4	4	4	4	4	4
R/Q [ohm]	87.6	521	181.1	521	181.1	521	181.1	521	521
G [ohm]	238.50	272.90	234.70	272.90	234.70	272.90	234.70	272.90	272.90
Q0	2.7E+09	3.0E+10	2.7E+09	3.0E+10	2.7E+09	3.0E+10	2.7E+09	3.0E+10	3.0E+10
Ep/Eacc	2.20	2.05	2.00	2.05	2.00	2.05	2.00	2.05	2.05
Bp/Eacc	5.36	4.33	5.33	4.33	5.33	4.33	5.33	4.33	4.33
Ep [MV/m]	12.58	12.76	21.23	41.03	21.23	42.55	21.23	41.25	41.21
Bp [mT]	30.65	26.96	56.57	86.66	56.57	89.87	56.57	87.13	87.05
Cavity design	QUASI-LHC	UROS5	2CELLV2	UROS5	2CELLV2	UROS5	2CELLV2	UROS5	UROS5
Prf no beam [kW]	225.14	52.53	94.60	22.30	95.57	11.68	19.49	40.68	2.10

FCC-ee SRF Technology

FUTURE CIRCULAR COLLIDER

Z

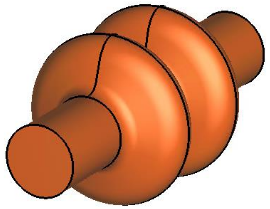
1-cell
400 MHz,
Nb/Cu



low R/Q, HOM damping, powered by 1 MW RF coupler and high efficiency klystron

W, H

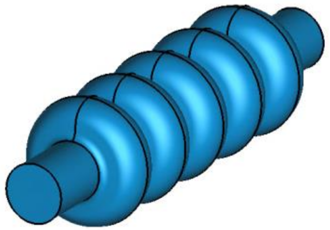
2-cell
400 MHz,
Nb/Cu



moderate gradient and HOM damping requirements; 500 kW / cavity, allowing reuse of klystrons already installed for Z

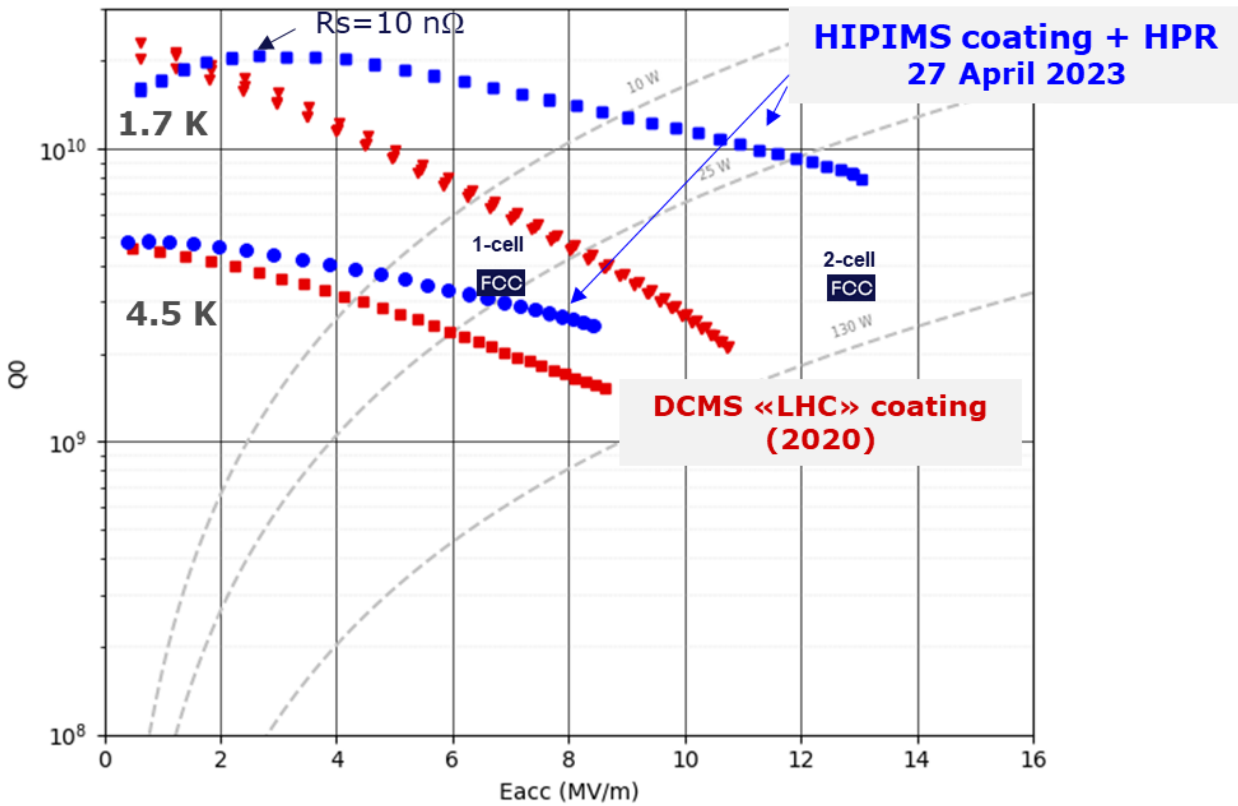
ttbar, booster

5-cell
800 MHz,
bulk Nb



high RF voltage and limited footprint thanks to multicell cavities and higher RF frequency; 200 kW/ cavity

Broad R&D collaborations on SRF



First attempt of HiPIMS* niobium coating on a 400 MHz Cu cavity

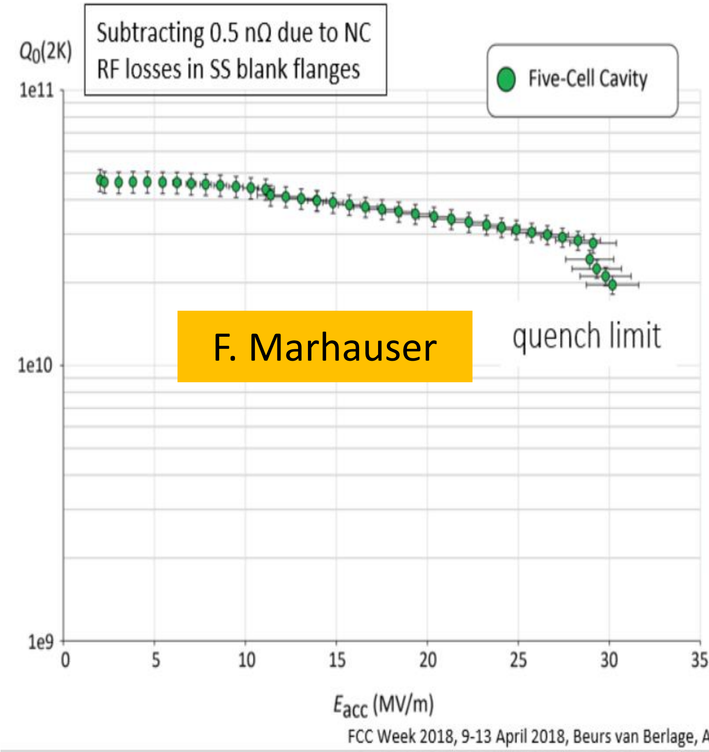
*High-power impulse magnetron sputtering

F. Peauger, O. Brunner

FCC-ee SRF Tech.

Broad R&D collaborations on SRF

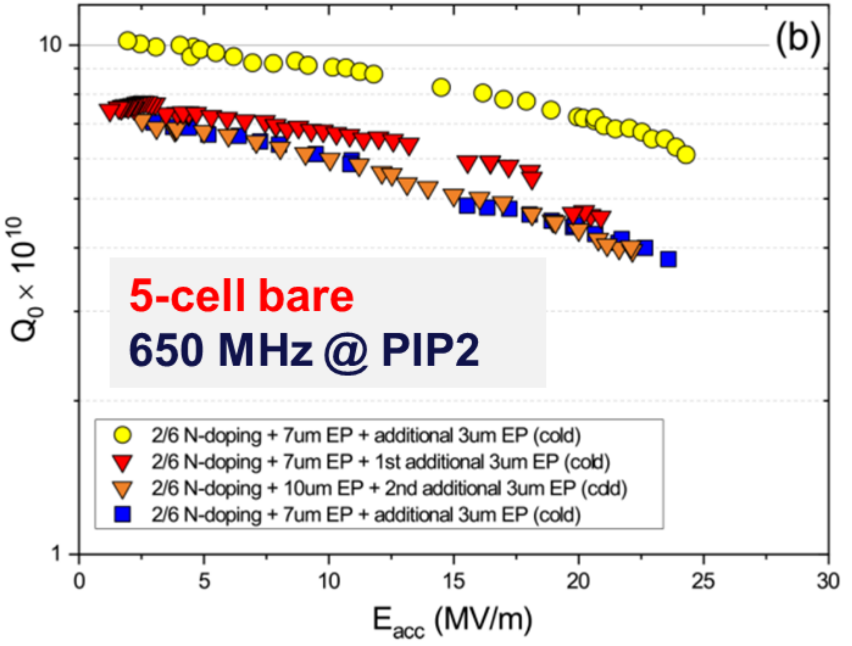
5-cell bare cavity development (2018), successful collaboration with JLAB



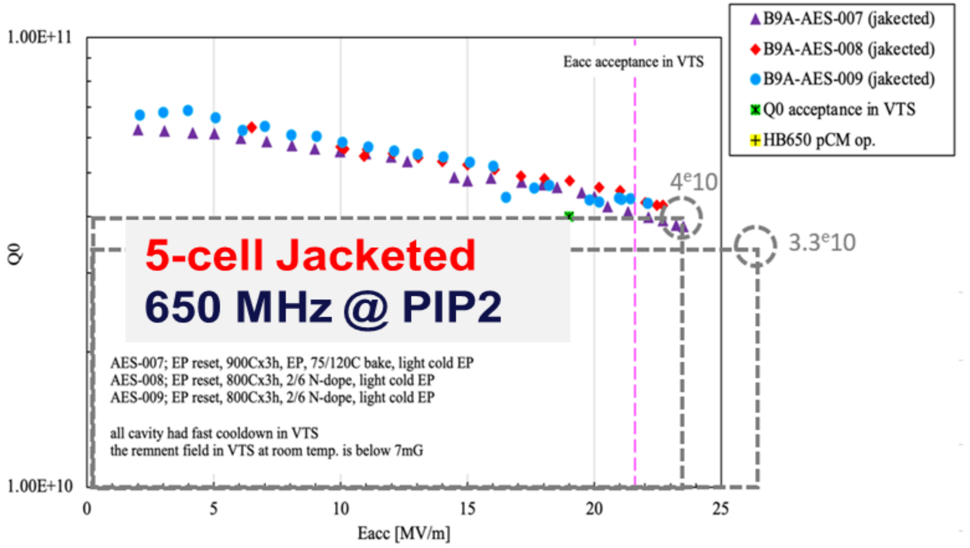
Main post-processing steps

	Unit	CRN5
Bulk BCP	µm	216
High-T heat treatment	°C, hrs.	800, 3
Final EP	µm	30
HPR cycles		4
Low-T bake-out	°C, hrs.	120, 12

Promising R&D towards ultra-high Q_0. Collaboration with FNAL



Q0 = 6e10 @ 25 MV/m
with 2/6 N-doping + EP + cold EP



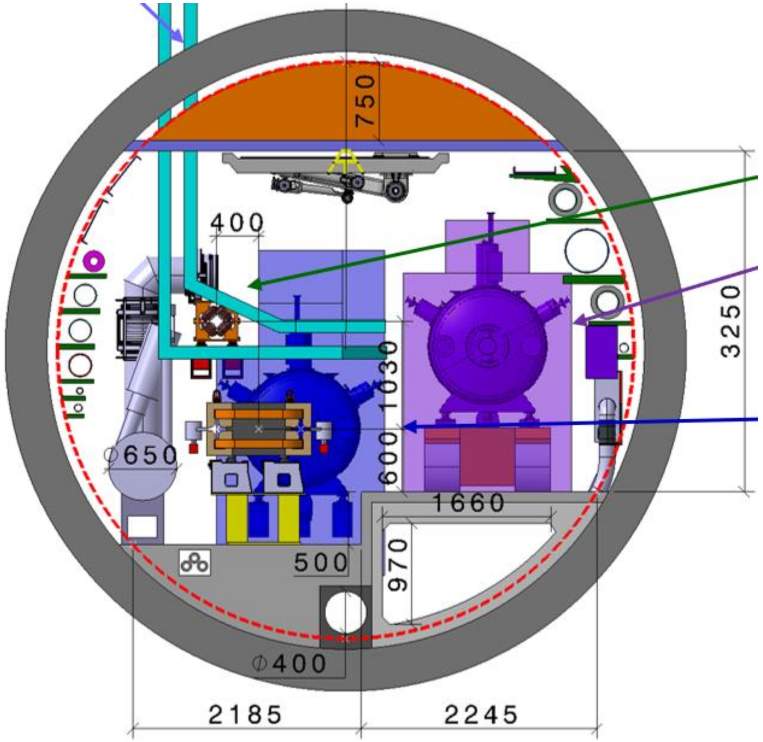
Q0 = 3.5e10 @ 25 MV/m
with 2/6 N-doping or midT bake + EP

F. Peauger, O. Brunner

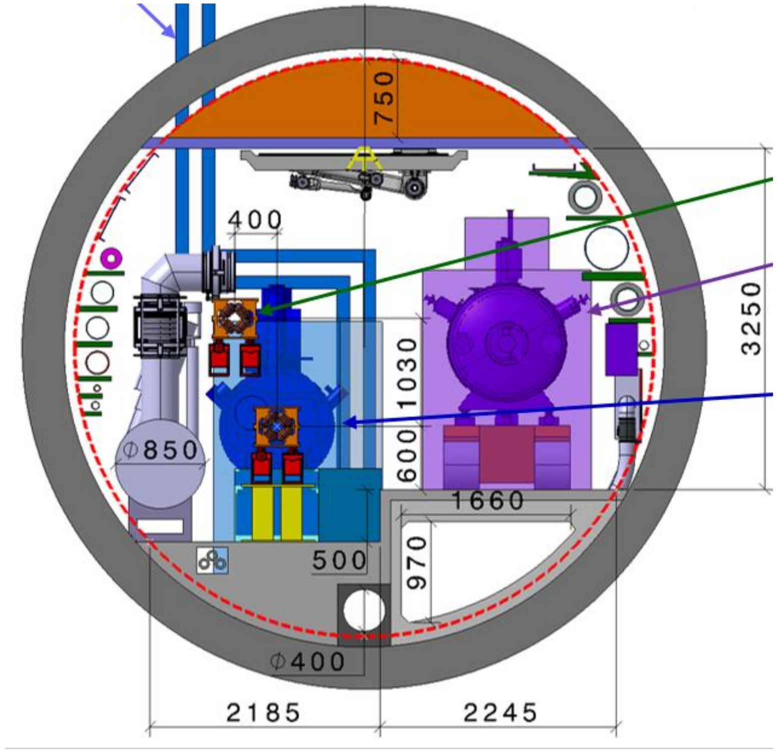
FCC-ee SRF Tunnel Cross-sections

Collider

400 MHz (5.5 m tunnel)

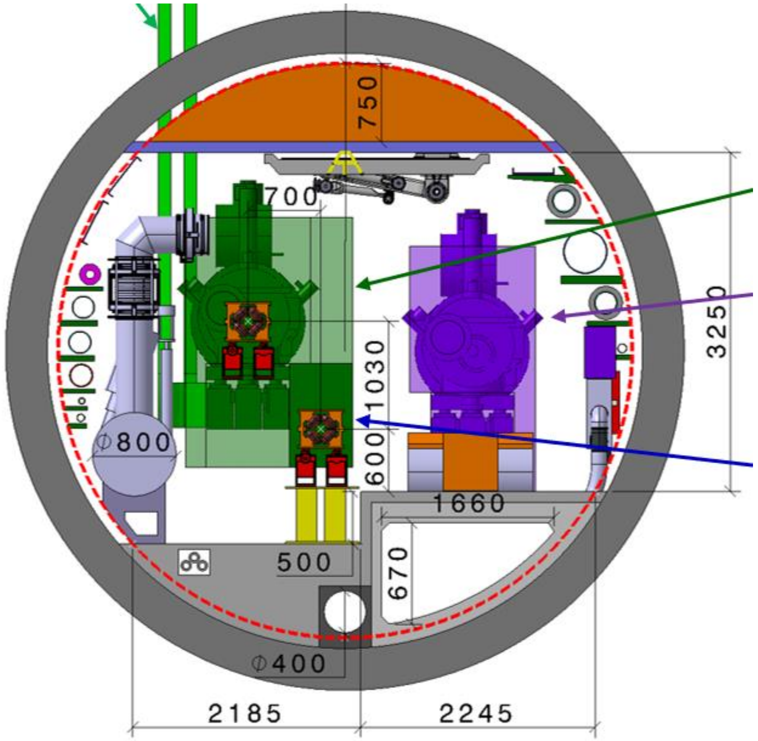


800 MHz (5.5 m tunnel)



Booster

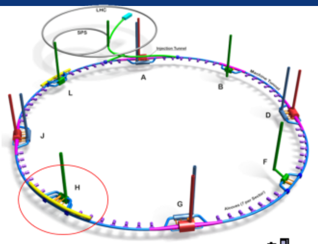
800 MHz (5.5 m tunnel)



FCC-ee SRF Layout

F. Valchkova-Georgieva

- Distance between e^+e^- quadrupoles 52 m, length 3.1 m.
- Distance between booster quadrupoles 52 m, length 1.5 m.

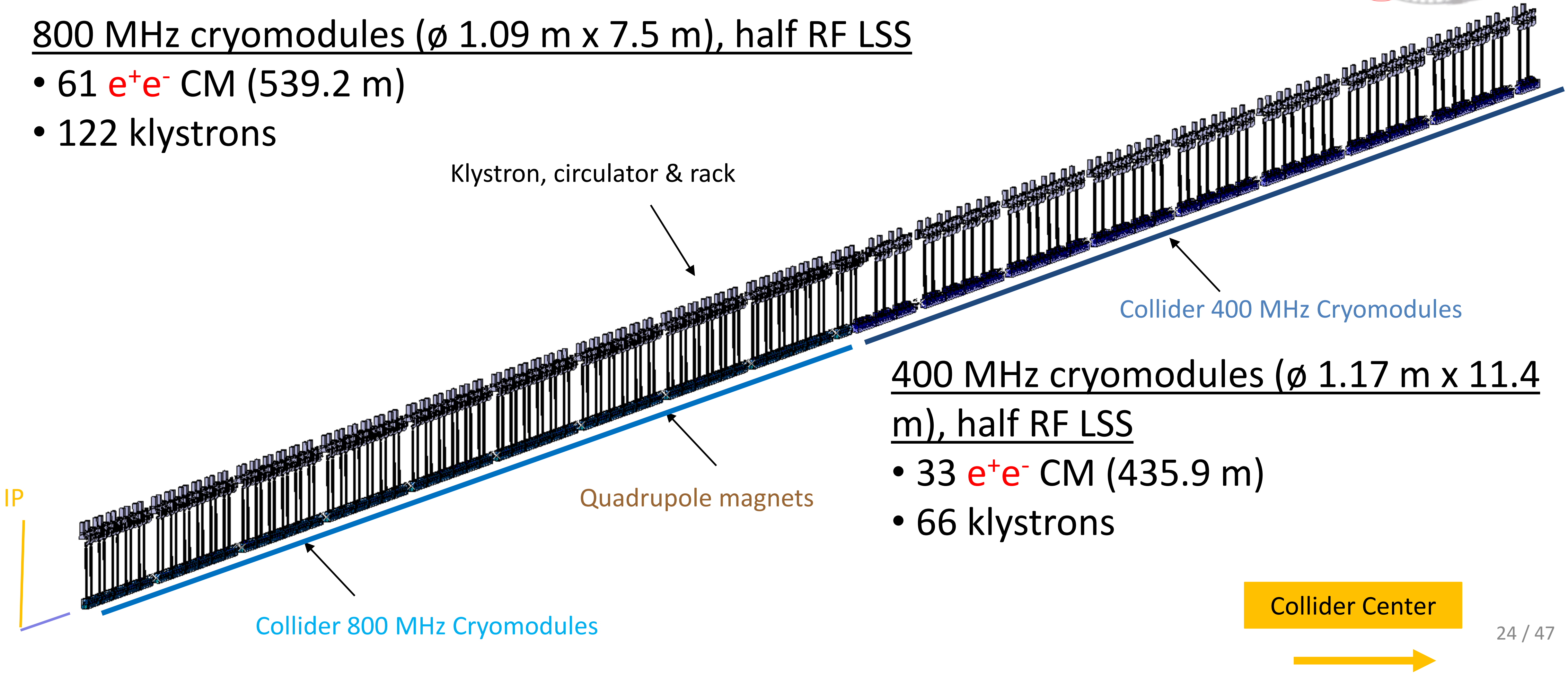


<u>800 MHz cryomodules (ø 1.09 m x 7.5 m), half RF LSS</u>

- 61 e^+e^- CM (539.2 m)
- 122 klystrons

<u>400 MHz cryomodules (ø 1.17 m x 11.4 m), half RF LSS</u>

- 33 e^+e^- CM (435.9 m)
- 66 klystrons



FCC-ee SRF Cryomodules

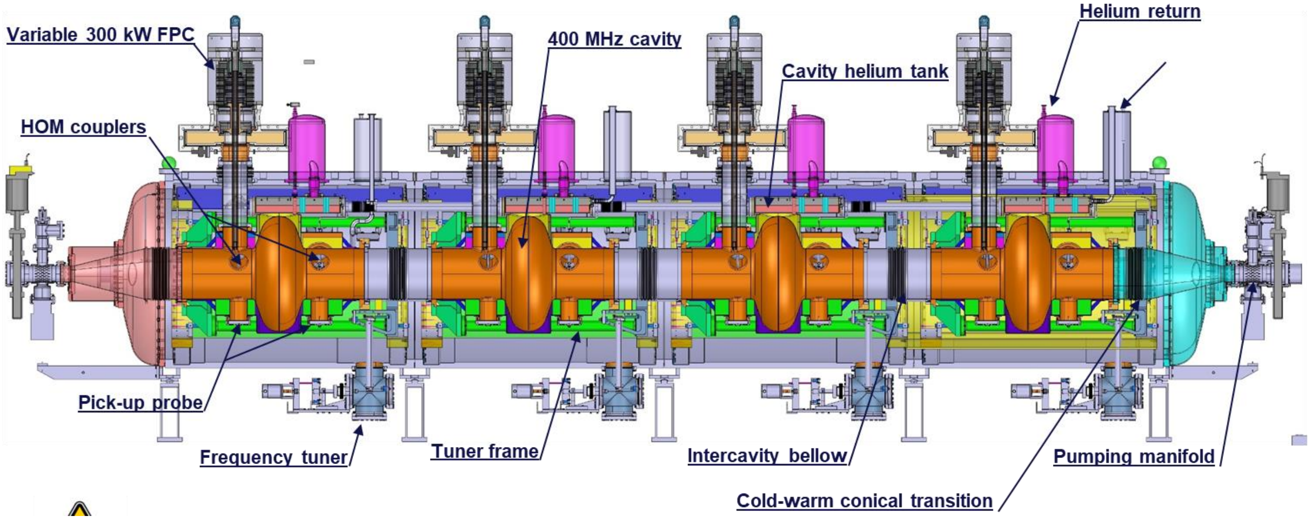
V. Parma

Cryomodule engineering just starting. Baseline assumptions start from existing CERN cryomodules. Collaborations beginning with FNAL, INFN, ….

1-cell 400 MHz	10 m
2-cell 400 MHz	10 m
5-cell 800 MHz	7.2 m

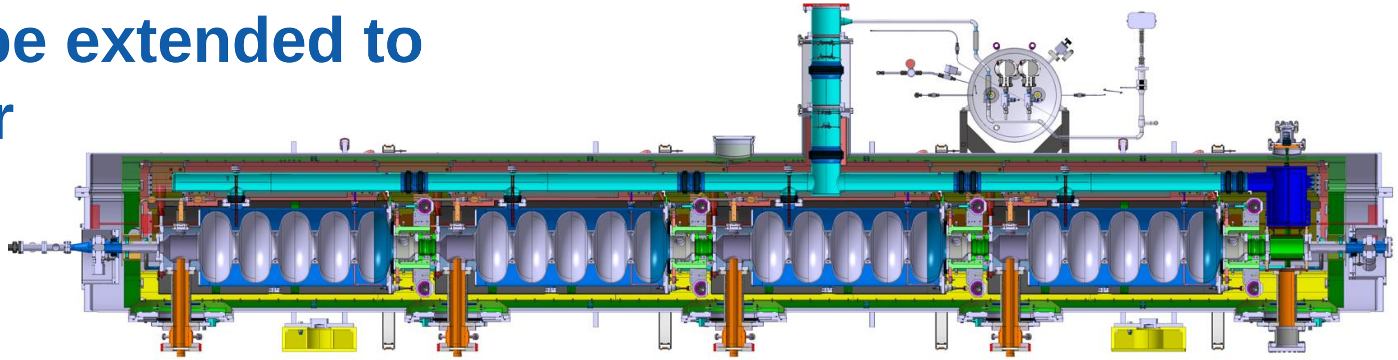
400 MHz with 4 cavities

Example of the LHC cryomodule
(400 MHz, 4.5 K)



800 MHz with 4 cavities but may be extended to 6 or more to optimize filling factor

Example of the SPL cryomodule
(704 MHz, 2 K)



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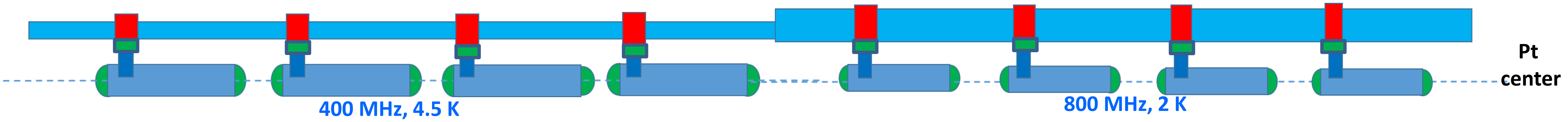
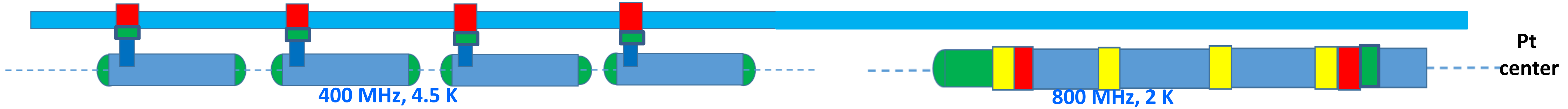
FCC-ee SRF Cryodistribution Options

V. Parma

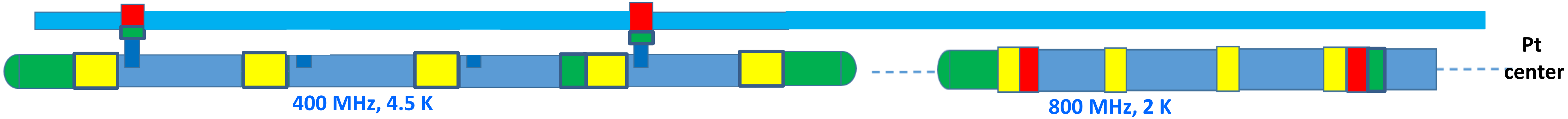
- **A1 (baseline)**: fully segmented with separate cryo line



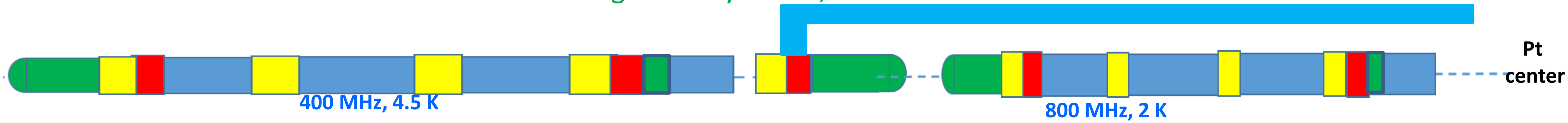
- **AC2**: 800 MHz cont. with integr. cryo lines



- **AC3**: 400 MHz vac. cont. with separate cryo line; 800 MHz cont. with integr. cryo lines.



- **AC4**: 400 MHz and 800 MHz cont. with integrated cryo lines;



End Cap module | CM interconnection | Service Module | Vac.Barr. | Jumper

(quads not shown)

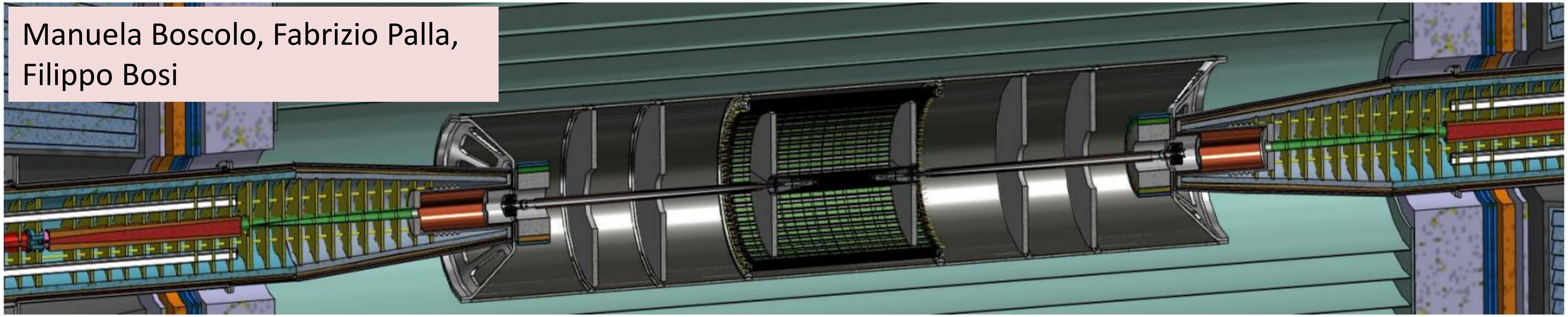
FCC-ee Machine-Detector Interface

M. Boscolo

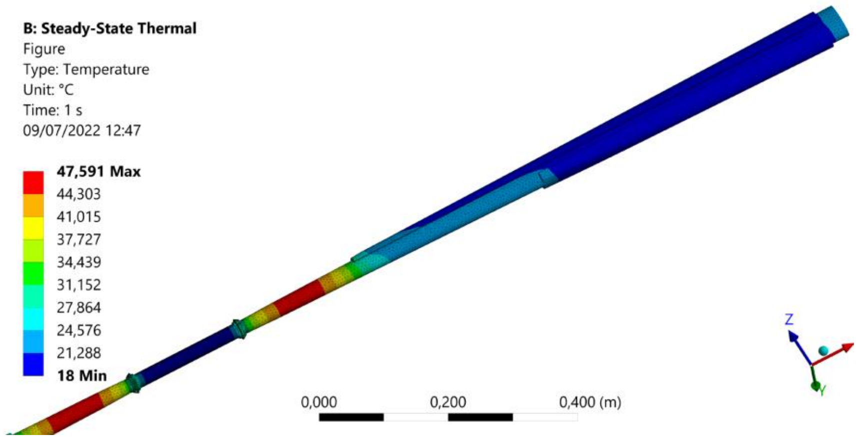
- **Mechanical model:**
  - **engineered IR beam pipe** with cooling system and support
  - **vertex detector** designed, integrated in MDI, modeled with **Key4HEP**
  - integration of the **lumical**
- **Backgrounds** simulations:
  - **beam losses** in the MDI: halo collimation and loss maps in the MDI
  - **synchrotron radiation** in the MDI with SR collimators and masking
  - **Detector backgrounds** simulations with refined and more realistic software model
- **Beamstrahlung** Photon dump:
  - optimal location at 500 m from IP, study on the magnet aperture yoke to allow an extraction line
  - started radiation studies with Fluka

Novel outer support tube for central beam pipe and vertex

Manuela Boscolo, Fabrizio Palla, Filippo Bosi

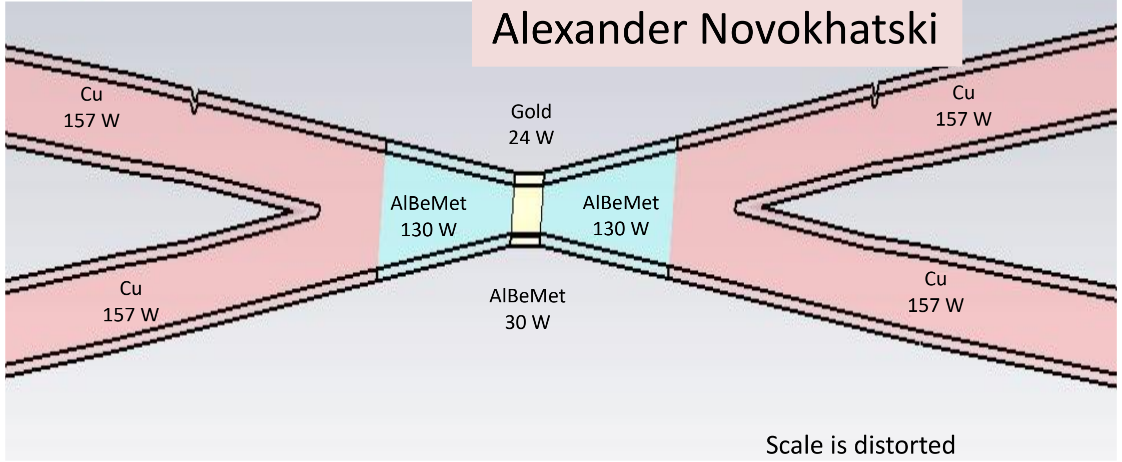


- Inside the same volume of the support tube that holds also the LumiCal
  - Vertex detector supported by the beam pipe
  - Outer Tracker (1 barrel and 6 disks) fixed to the support tube



IR heat load distribution

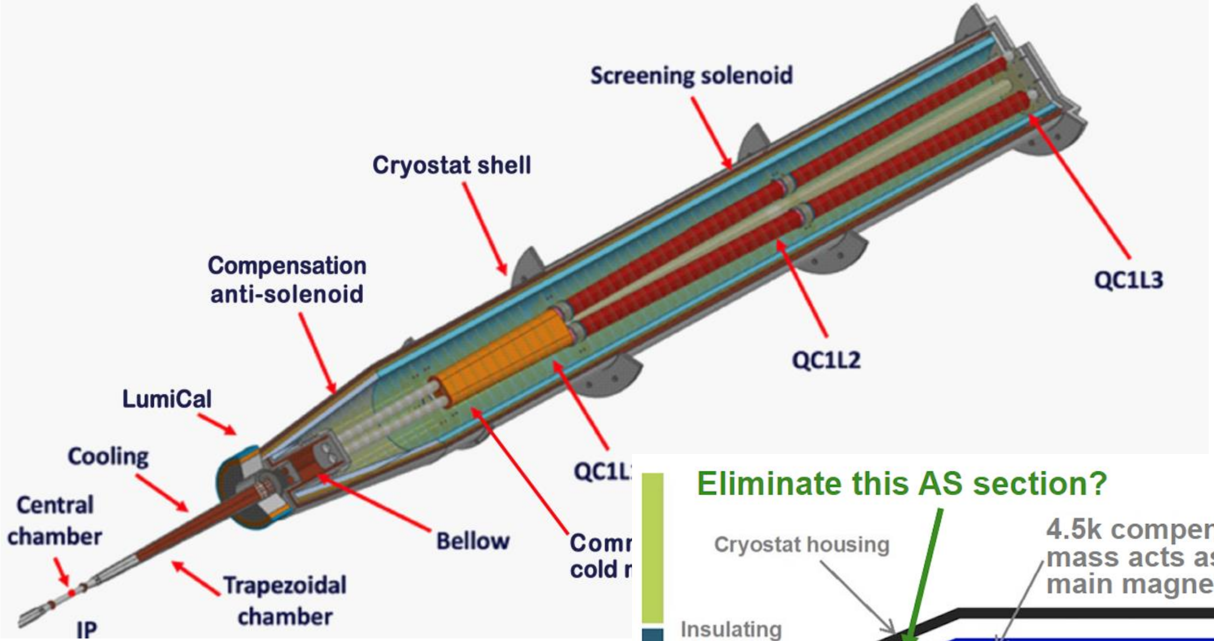
Alexander Novokhatski



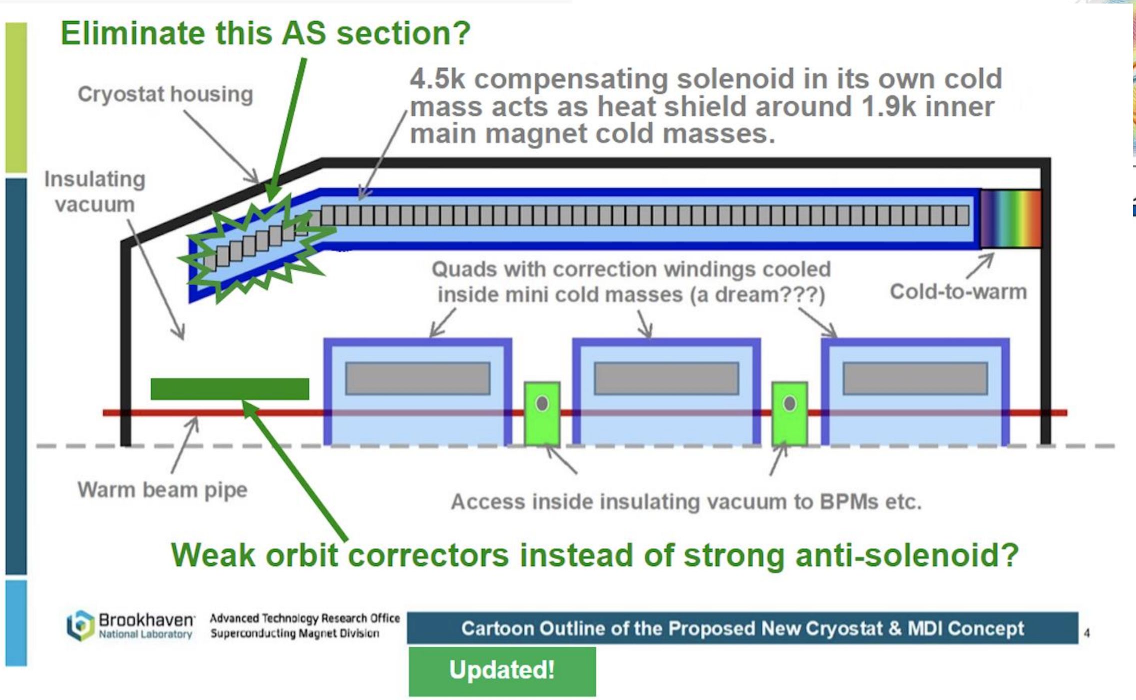
FCC-ee IR Magnets

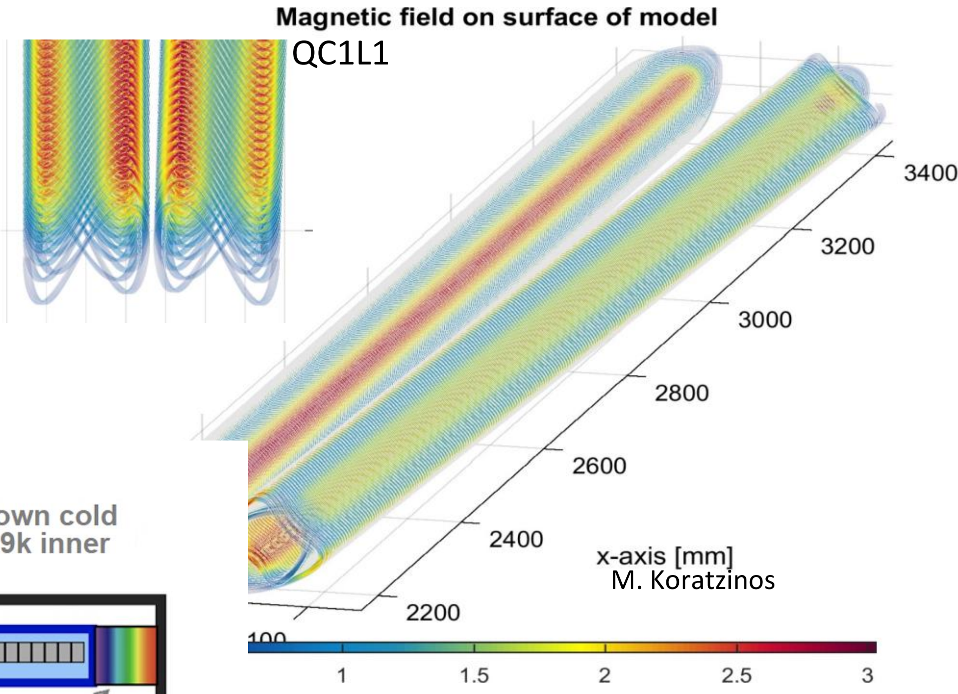
B. Parker, M. Boscolo

Ongoing work to develop IR quadrupoles with ~100 T/m



Magnets have 2cm radius. More like LC final quads than LHC. Ongoing collaboration with BNL on direct-wind tech.





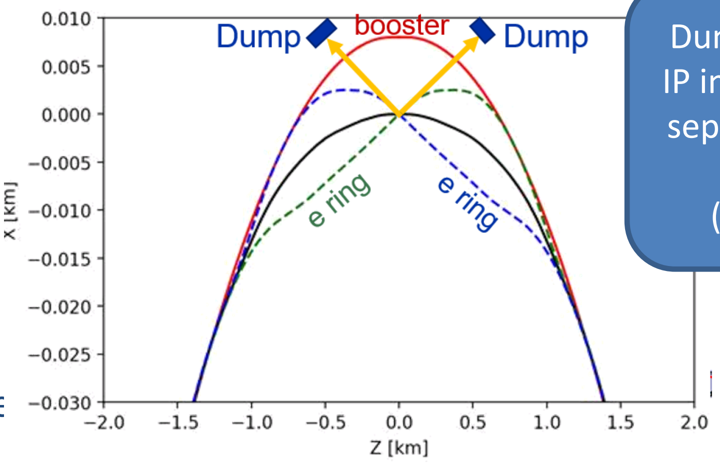
Integration of complete cryostat with magnets, correctors, and diagnostics is required.

Beamstrahlung Dumps

A. Lechner

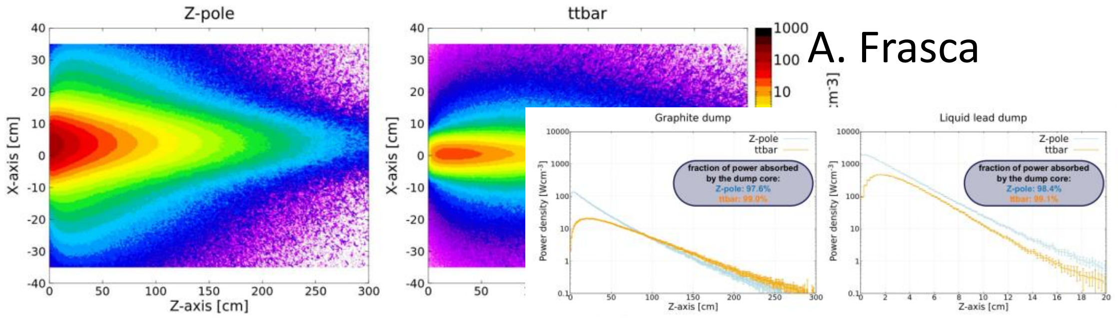
Two 400 kW dumps are needed at each IP to accommodate the high power beamstrahlung

- **High-power dumps needed to safely dispose of the high photon flux from IP**
- **Challenges for the dump design:**
  - High-power density (MeV photons) → challenging for absorber material and windows
  - Activation (through photo-nuclear interactions)!
  - Radiation environment around dump (ionizing dose to equipme radiation to electronics)



Dump placed 500 m from IP in order to have enough separation from booster / collider (space for shielding)

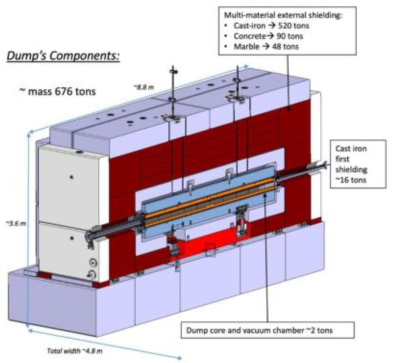
First considerations on radiation fields/power deposition, but more studies and R&D needed to develop a conceptual dump design and shielding – liquid metal considered as core material



A. Frasca

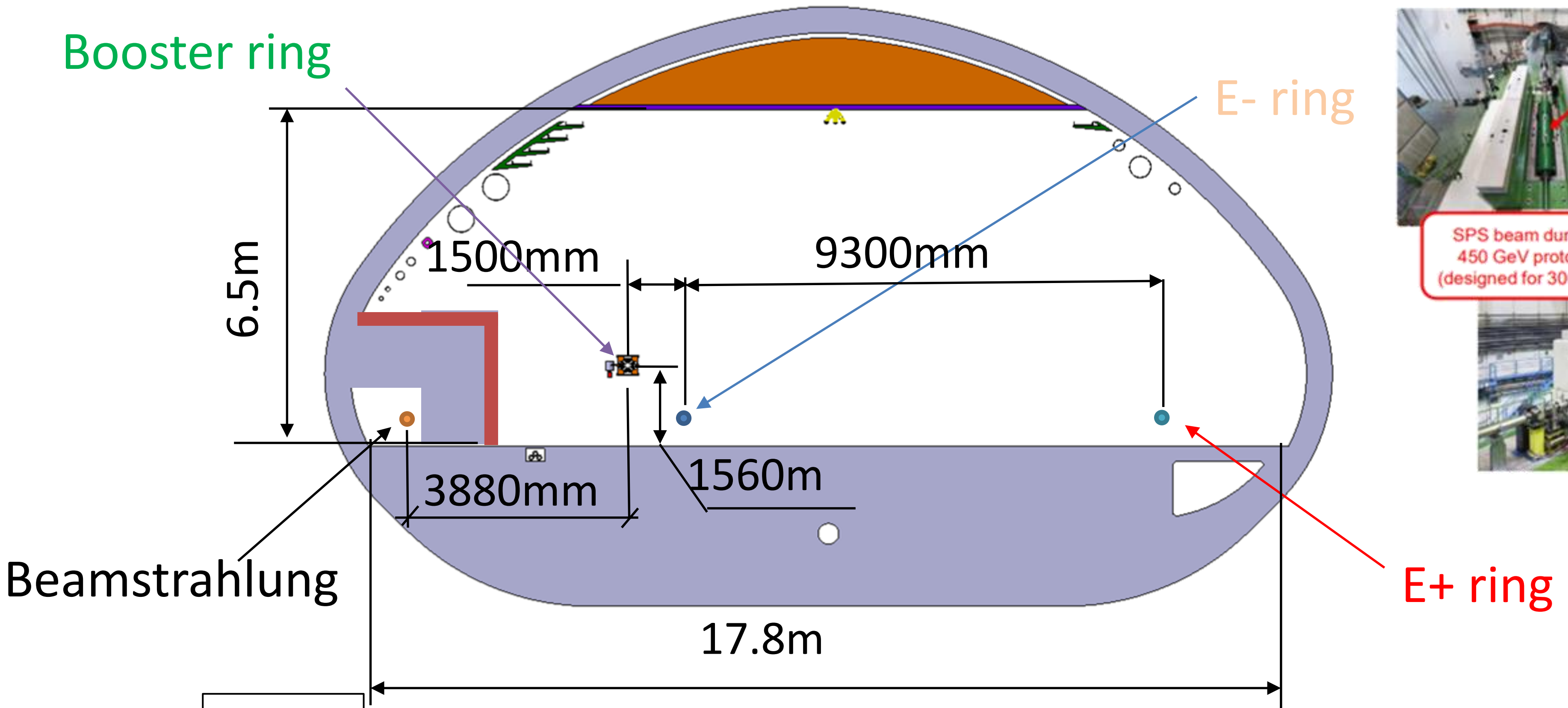
High-power beam dumps - example

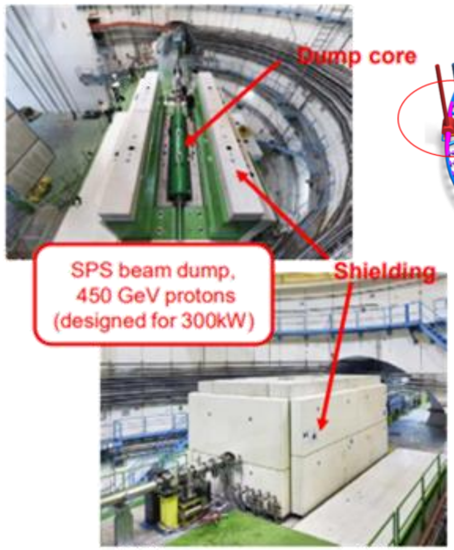
SPS beam dump, designed for 300 kW in the most demanding scenario

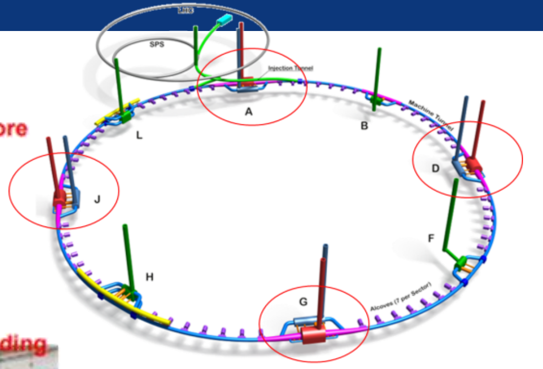


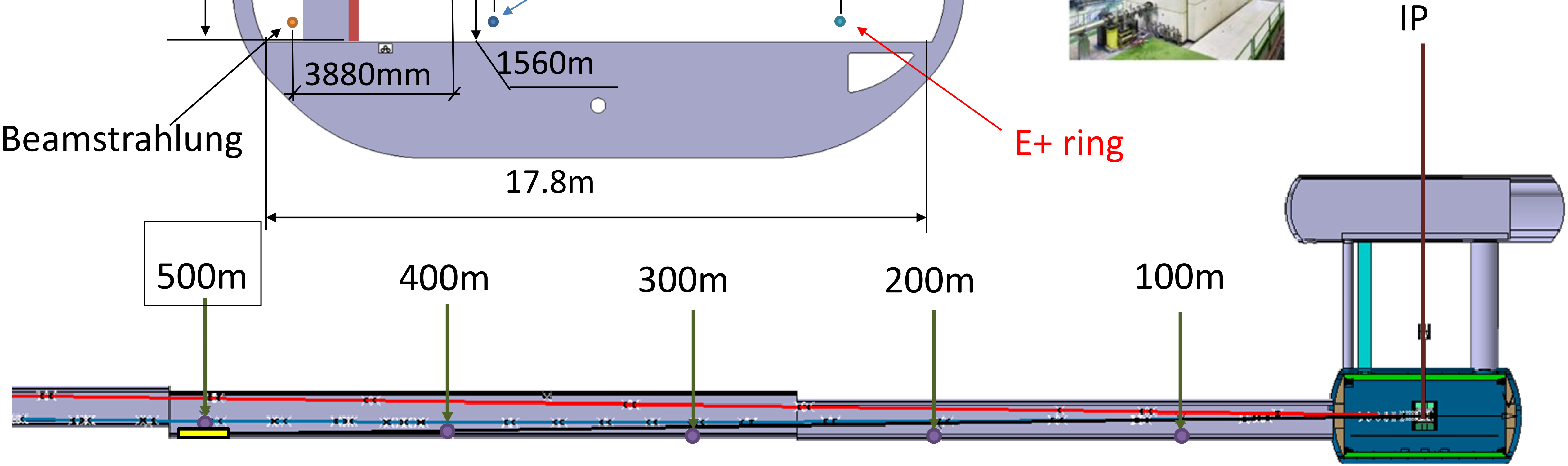
Beamstrahlung Dumps

F. Valchkova-Georgieva









FCC-US Workshop

Home | Registration | Agenda | Abstract Submission | Logistics | Join Remotely | Contact Us

Motivation

This workshop aims to better organize the FCC-ee community within the US and identify the most important and feasible areas of research to enable optimal FCC-ee accelerator, detectors and physics output by leveraging our domestic expertise. We will discuss the most needed elements

Important Dates

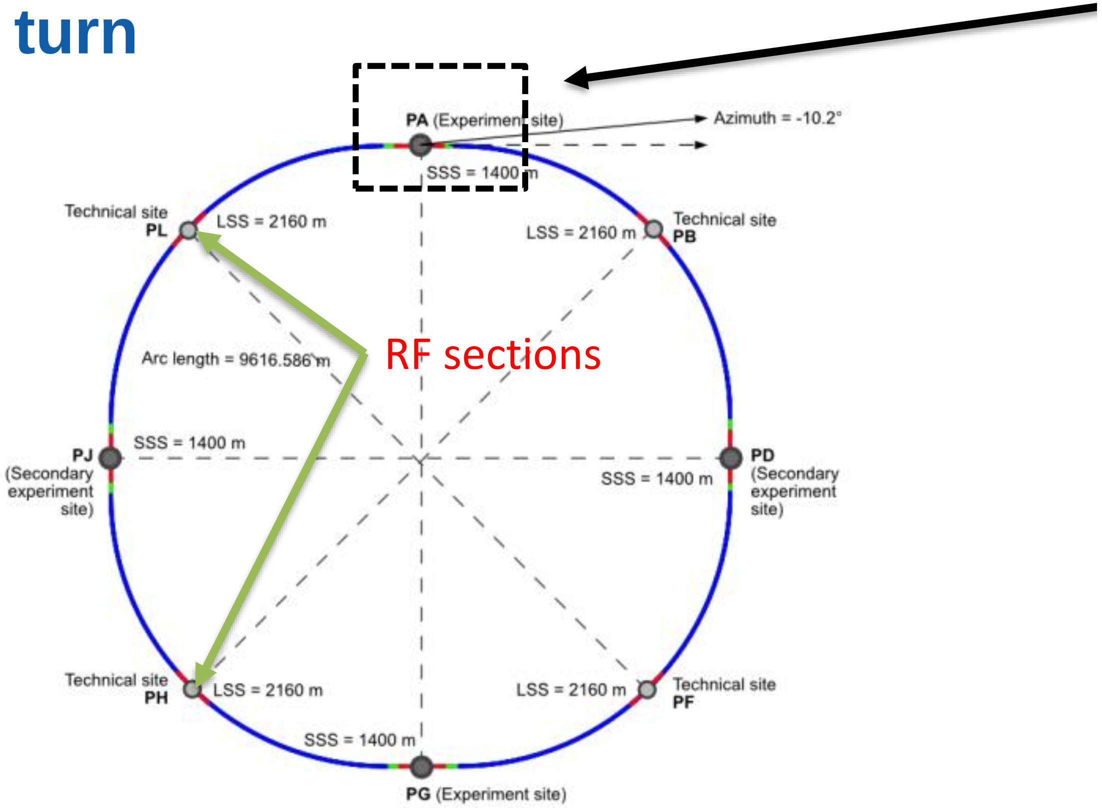
February 7, 2023	General registration opens
March 23, 2023	General registration closes

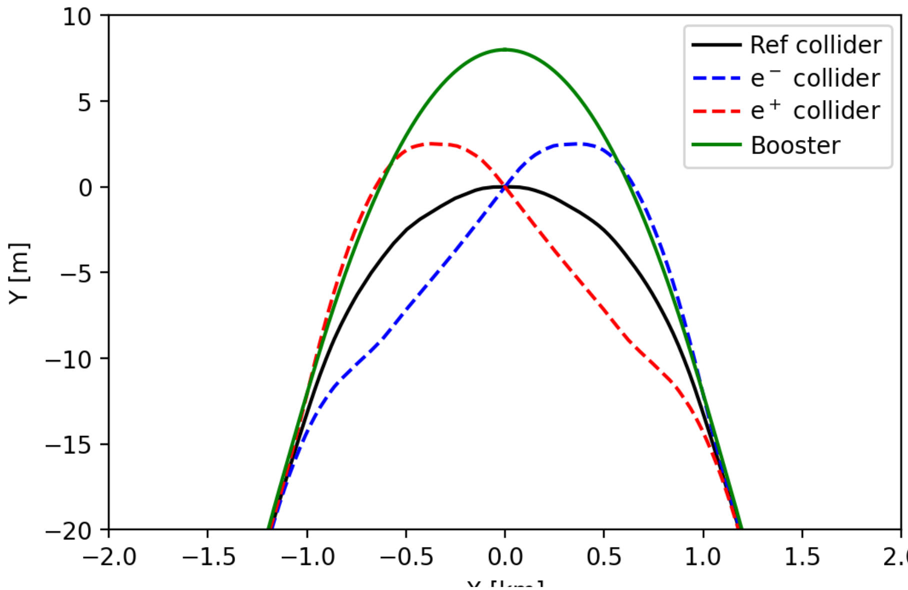
Focused on US activities aimed at IR design and magnets, MDI, Collimation, etc

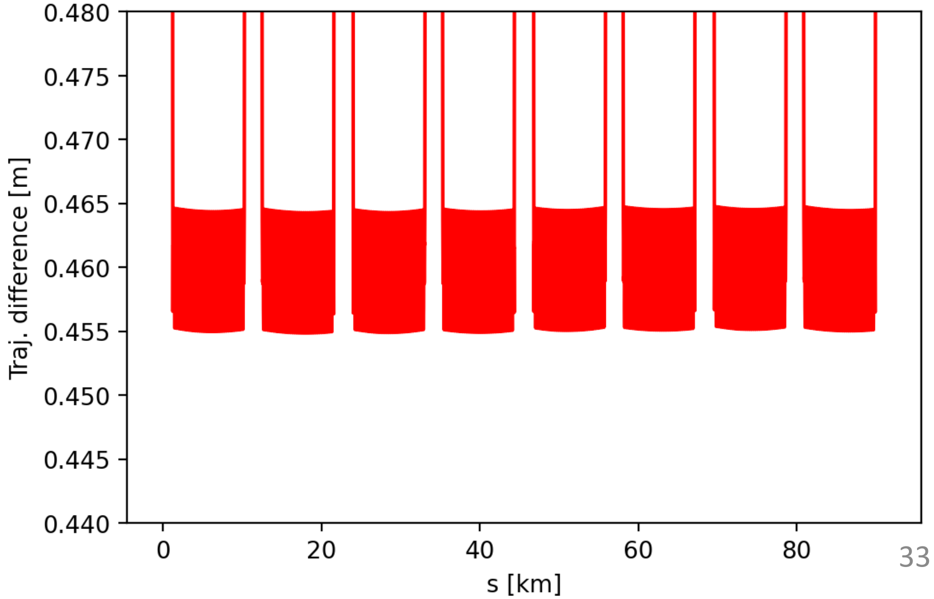
Booster Ring

A. Chance, B. Dalena

Booster is placed above main rings
Detailed layout is ongoing
Operates with roughly 10% Main Ring current. Bunches are accumulated from Pre-Injector at 400 Hz and extracted in single turn







Booster Ring Collective Effects

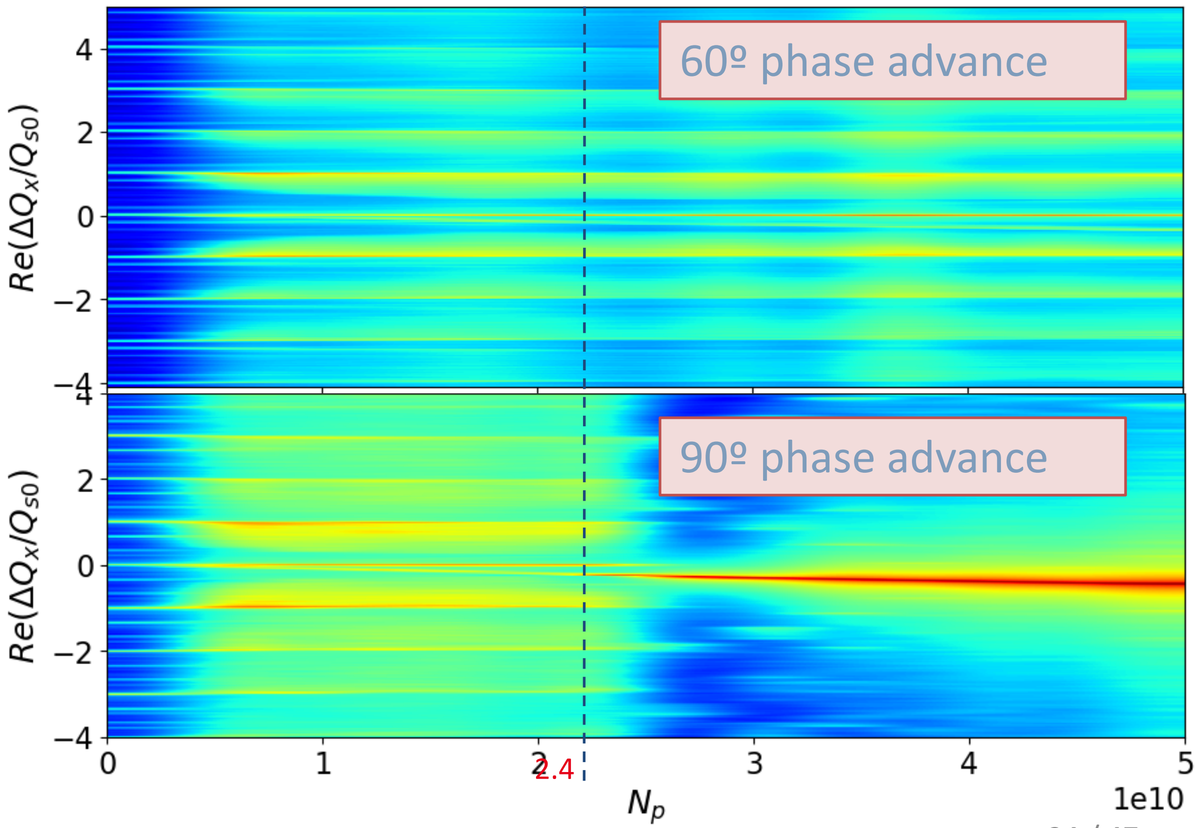
A. Chance, B. Dalena

Booster is ramped from 20 GeV to Main Ring energy. Two phase advance options: 60° for Z and W and 90° for Higgs and t-tbar.

Beam current is roughly 10% of Main Ring but stainless-steel vacuum chamber and 800 MHz RF have larger impedance.

Intra-Beam Scattering is an impact at 20 GeV → damp for ~1s at top energy.

TMCI study requires both longitudinal and transverse impedance leads to threshold close to nominal bunch. Work is ongoing.

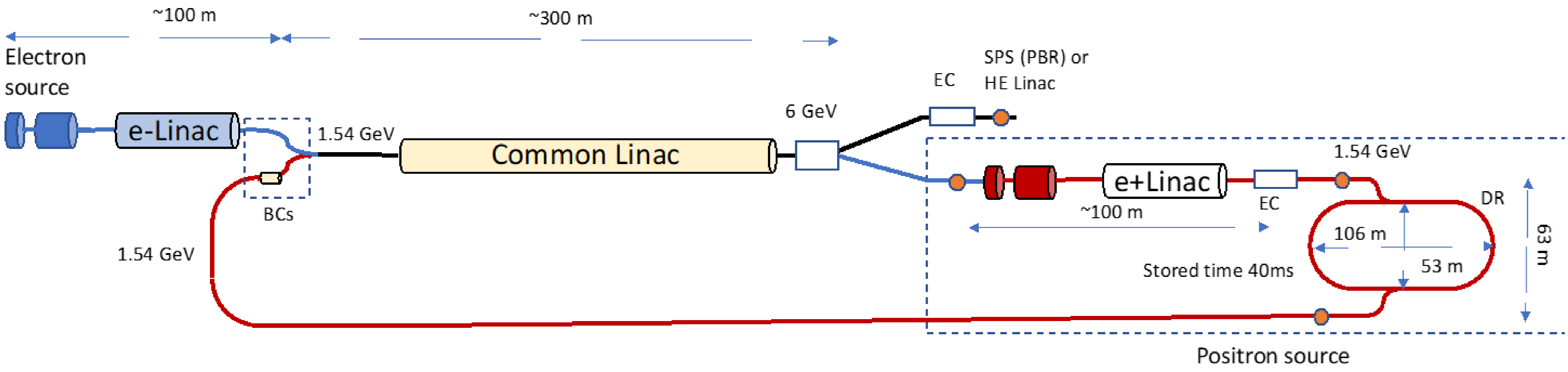


FCC-ee Pre-Injector

Pre-Injector generates e+ and e- bunches at 400 Hz (2x200Hz)
Supplies Booster ring with full bunch train at 20 GeV and roughly 10% current

P. Craievich, I. Chaikovska, A. Grudiev, C. Milardi, et al.

FCC-ee pre-injector layout



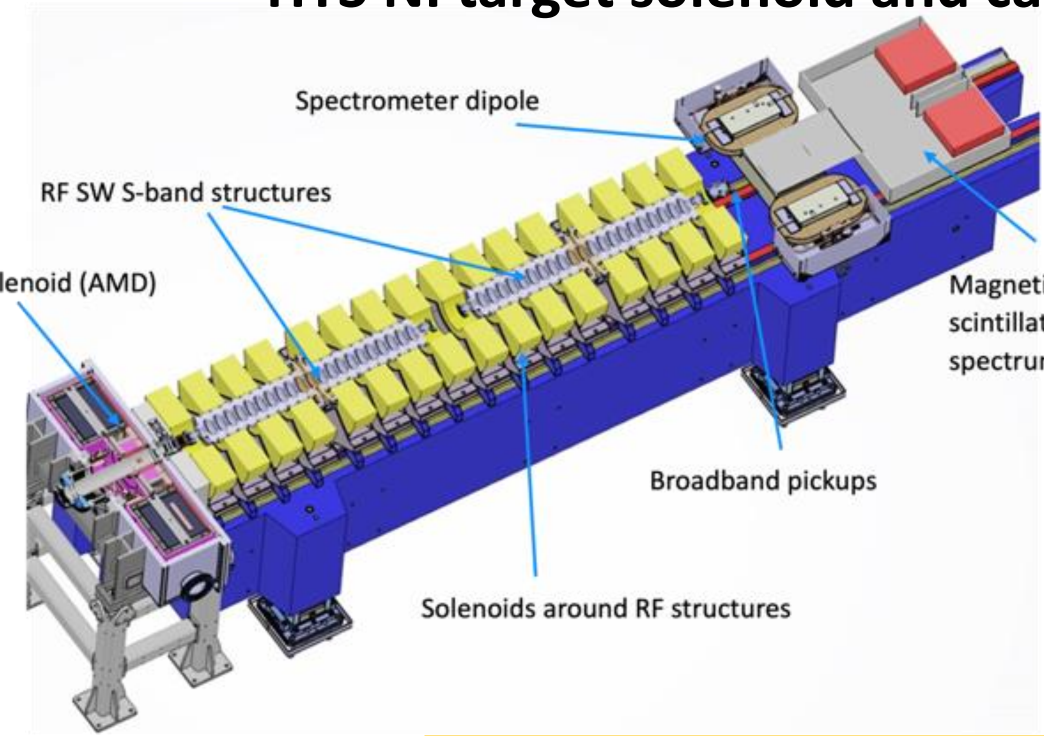
Baseline Pre-Injector uses HE linac to accelerate from 6 GeV to 20 GeV Booster. SPS is also possible to use with slightly longer cycle time.

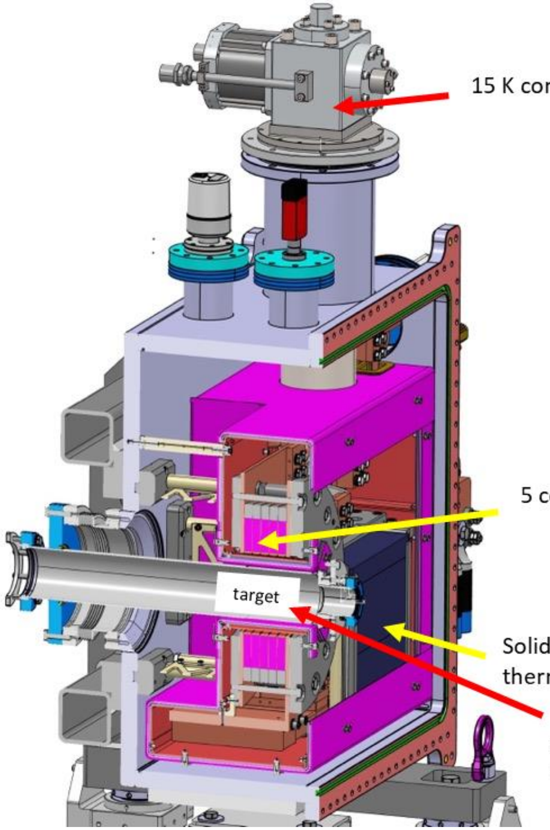
Pre-Injector Positron Source R&D

PAUL SCHERRER INSTITUT PSI
CHART Swiss Accelerator Research and Technology
cea
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis
INFN LNF Istituto Nazionale di Fisica Nucleare
KEK High Energy Accelerator Research Organization
INFN FERRARA Istituto Nazionale di Fisica Nucleare Sezione di Ferrara

Pre-Injector generates e+ and e- bunches at 400 Hz (2x200Hz) Positron target at 6 GeV. E+ rate is within a factor of 2x shown by the SLC at SLAC and is an order of magnitude lower than typical for LC designs. Experiment planned at PSI to demonstrate target and capture

HTS NI target solenoid and capture





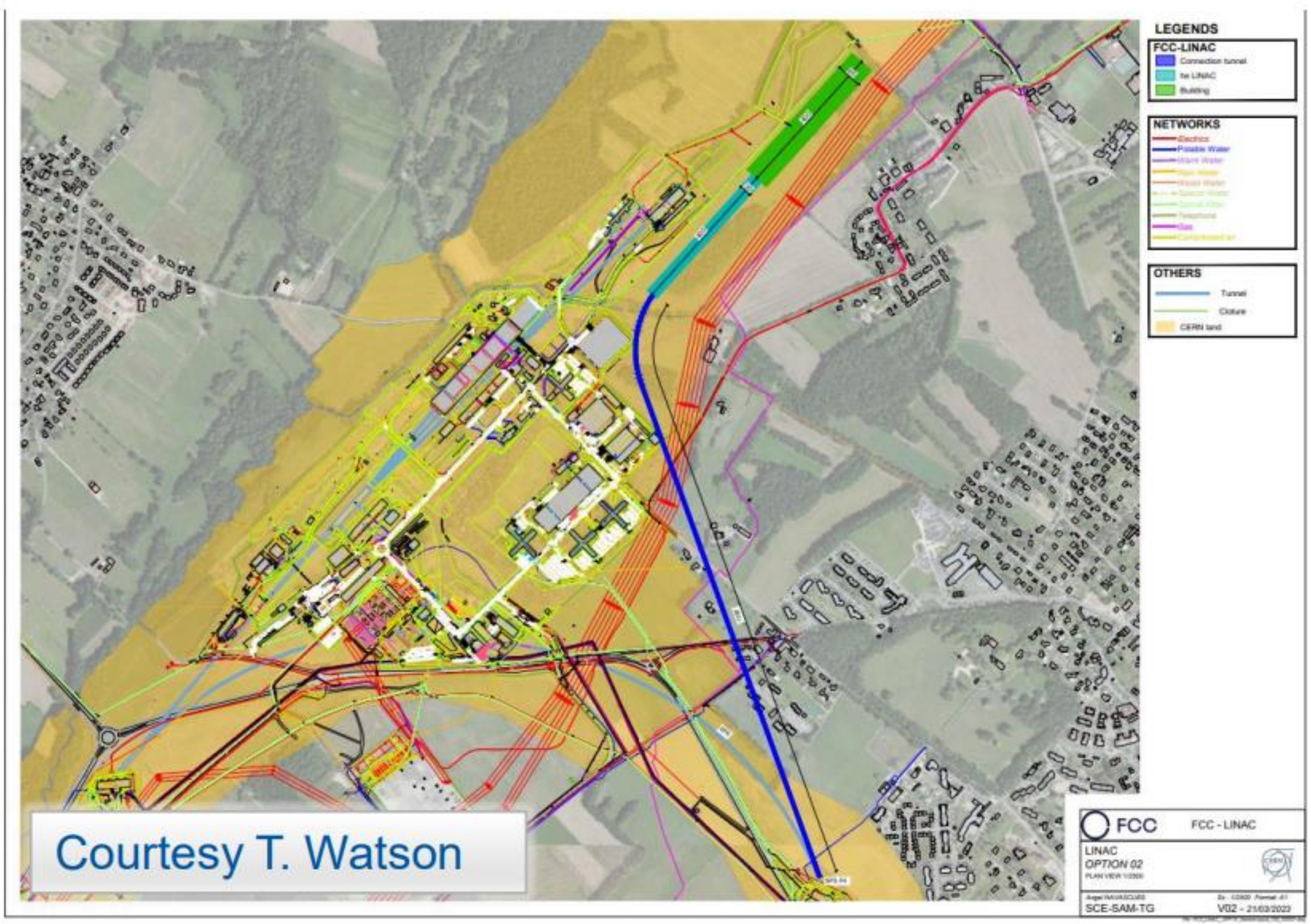
P. Craievich, J. Kosse, T. Michlmayr, H. Rodrigues

FCC-ee Transport Lines

W. Bartmann

Pre-injector located on Prevessin site with transport lines down to SPS and then down to FCC-ee

Layout is consistent with 20 GeV linac



FCC-ee Transport Lines

W. Bartmann

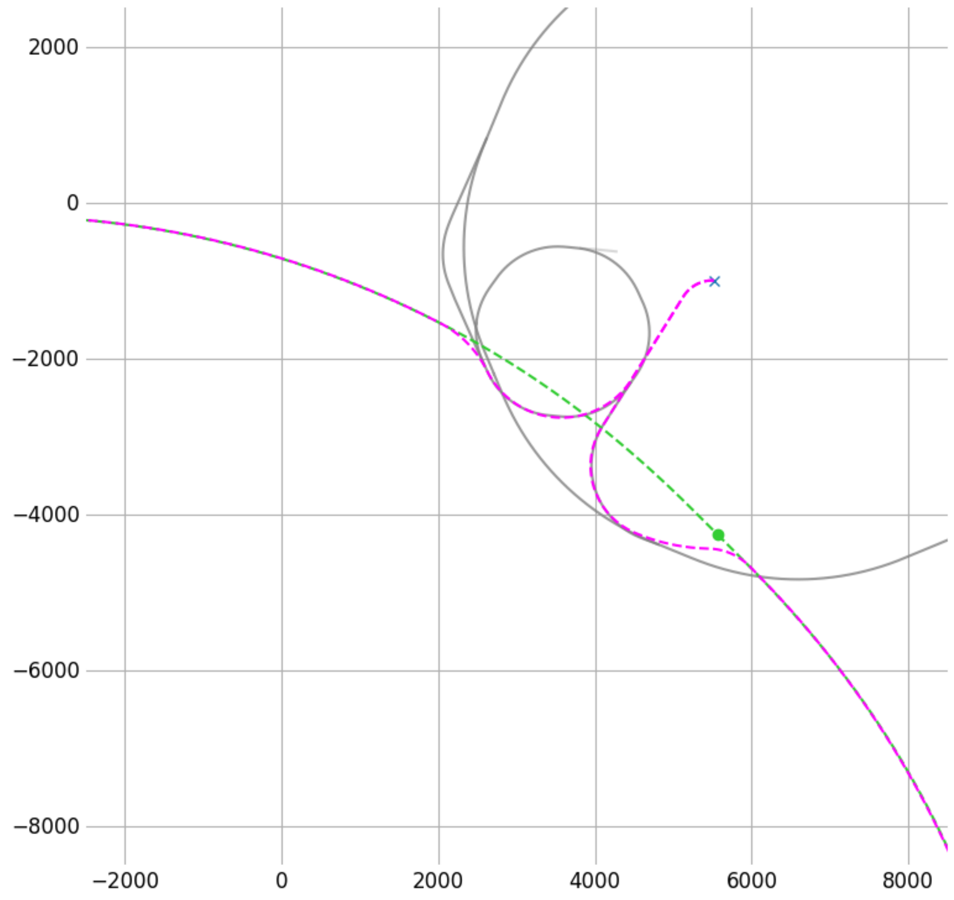
Pre-injector located on Prevessin site with transport lines down to SPS and then down to FCC-ee

Configuration allows use for SPS-SC or LHC for FCC-hh.

Initial transport line would be electro-magnets and would need to be switched while final lines of the SPS could be permanent magnets

Working to clarify requirements

Transport lines for FCC-hh from SPS-SC

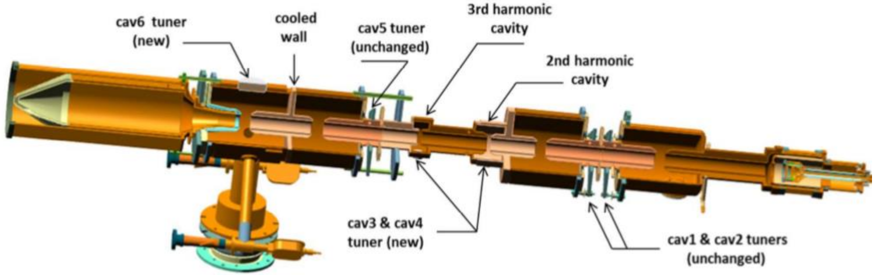


FUTURE CIRCULAR COLLIDER

FCC-ee R&D Examples

efficient RF power sources (400 & 800 MHz)

I. Syratchev

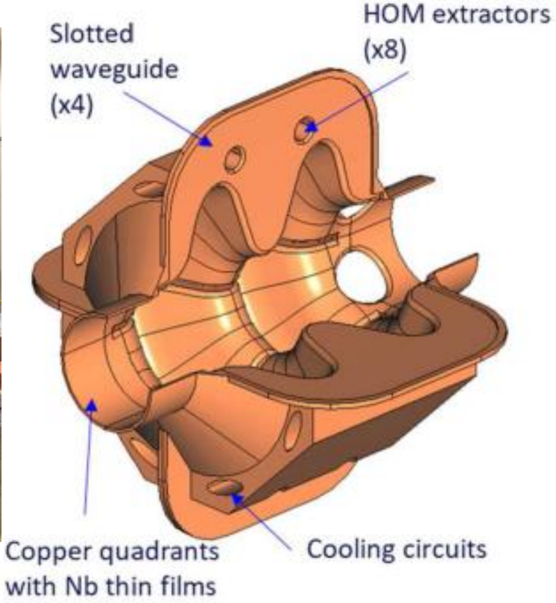


high efficiency klystrons
& scalable solid-state amplifiers

FPC & HOM coupler, cryomodule, thin-film coatings

efficient high-Q SC cavities

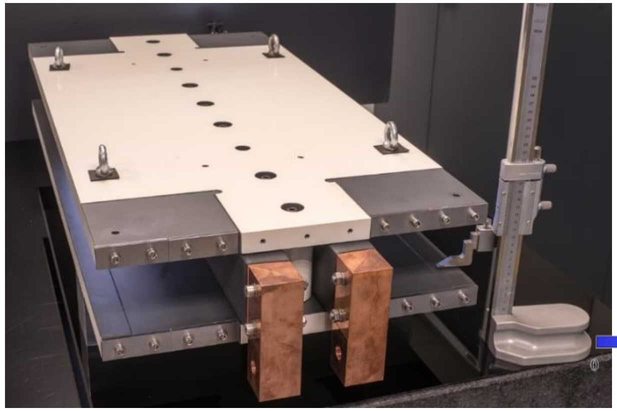
400 MHz 1- & 2-cell Nb/Cu, 4.5 K

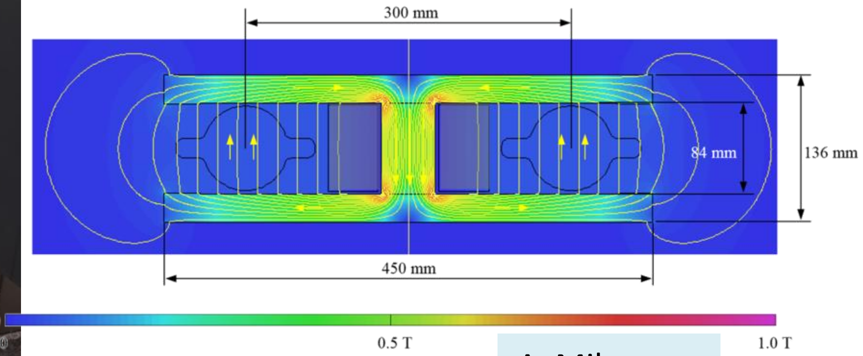


Slotted Waveguide Elliptical cavity (SWELL) for high beam current & for high gradient, seamless by nature – links to past work at ANL (Liu & Nassiri, PRAB 13, 012001)

I. Syratchev

energy **efficient** twin aperture **arc dipoles**





A. Milanese

under study: **CCT HTS quad's & sext's for arcs**

- **reduce energy consumption** by O(50 MW)

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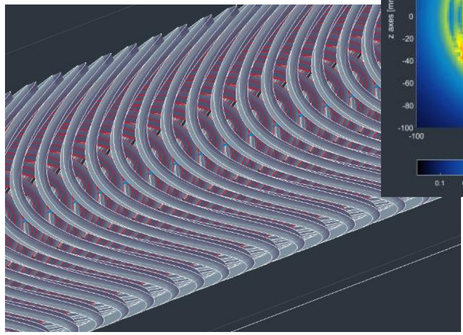
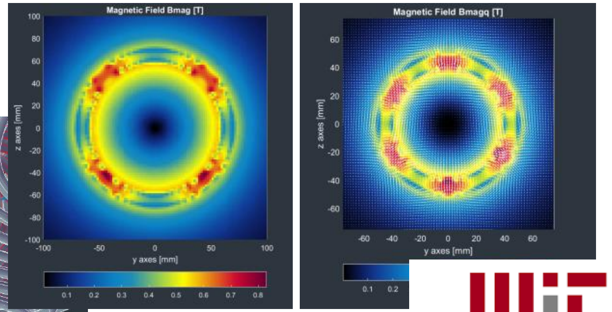


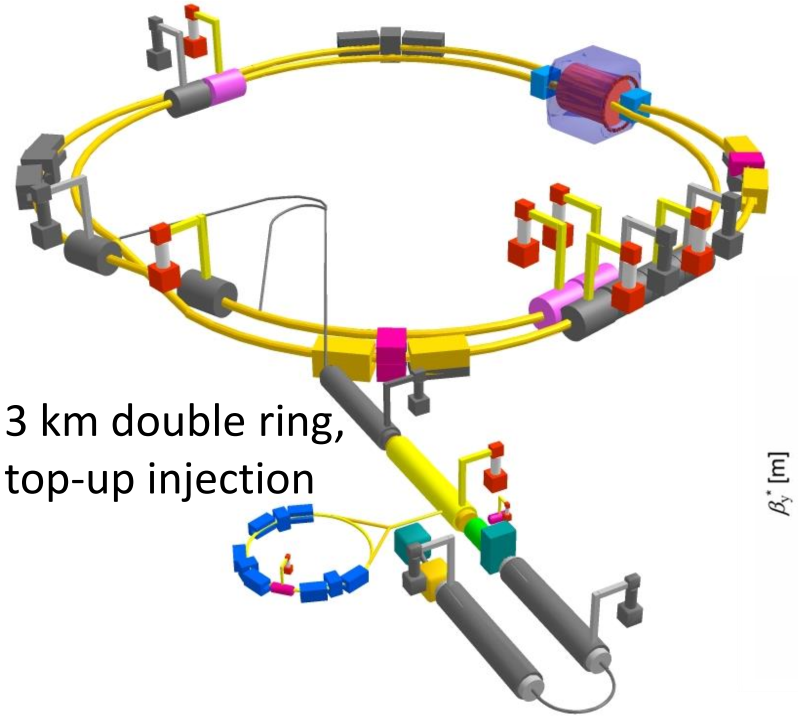


M. Koratzinos, B. Auchmann

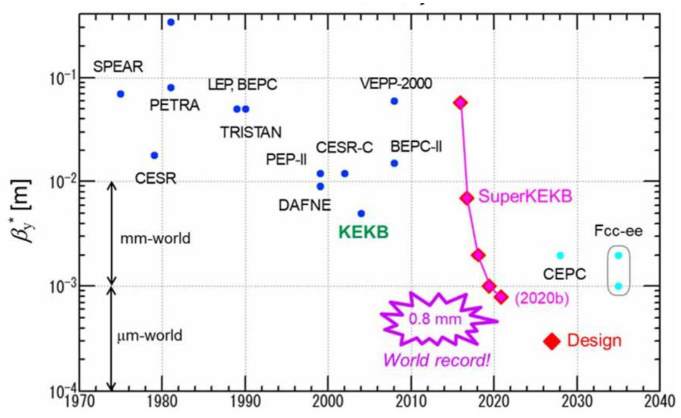
Massachusetts Institute of Technology

SuperKEKB*

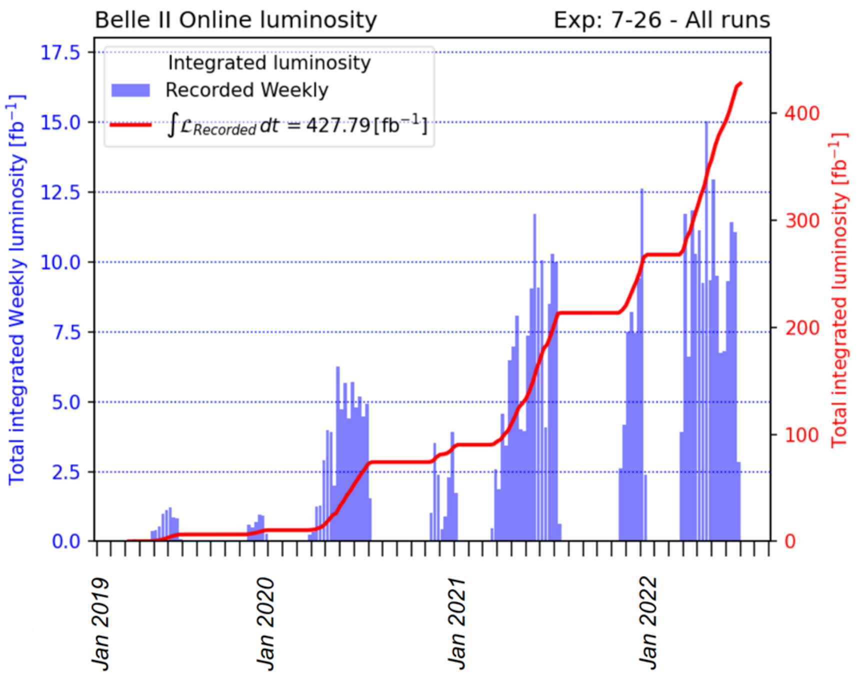
world's highest luminosity & lowest β^* e^+e^- collider

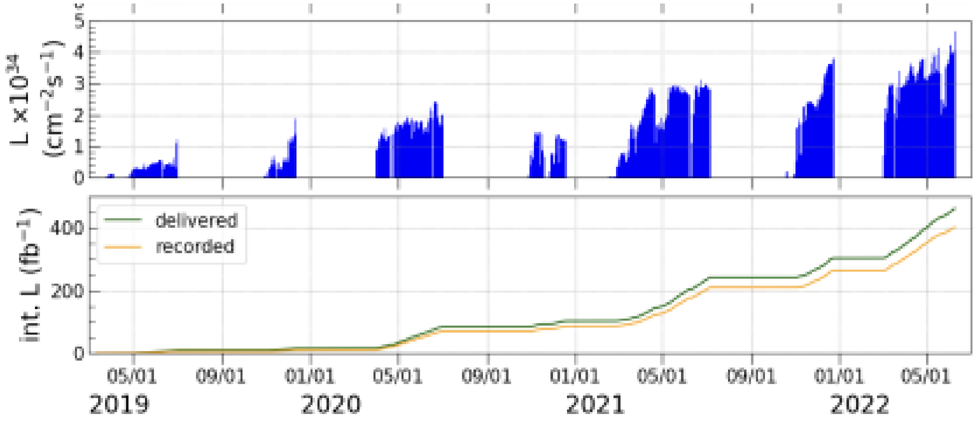


3 km double ring, top-up injection



total integrated luminosity so far ~430 fb^{-1} over ~3 years





world record luminosity of 4.7x10^{34} cm^{-2}s^{-1},
β_y^* = 1.0 mm (= FCC), also β_y^* = 0.8 mm shown – with "virtual" crab-waist collision scheme originally developed for FCC-ee (K. Oide)

DAFNE and SuperKEKB have demonstrated the crab-waist optics

Critical to understand (not necessarily fix) Super KEKB luminosity versus current and 'fast beam loss' challenges!

US Electron Ion Collider (EIC)

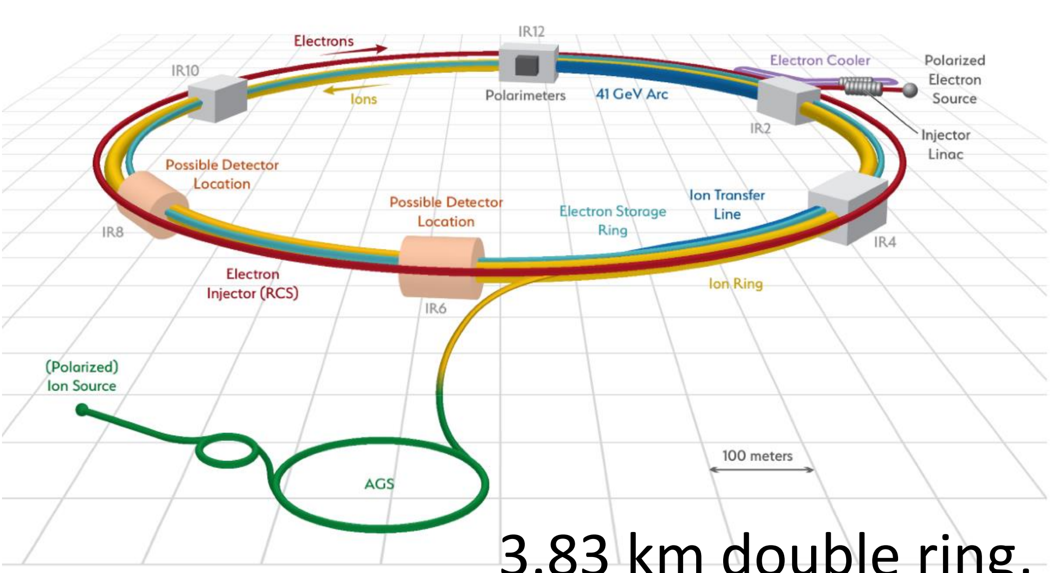
US EIC Electron Storage Ring similar to, but more challenging than, FCC-ee

beam parameters almost identical, but twice the maximum electron beam current, or half the bunch spacing, and lower beam energy

>10 areas of common interest identified by the FCC and EIC design teams, addressed through **joint EIC-FCC working groups**, still evolving

EIC will start beam operation about a decade prior to FCC-ee

The EIC will provide an invaluable opportunity to train next generation of accelerator physicists on an operating collider as well as testing hardware prototypes, beam control schemes, etc.



3.83 km double ring, full-energy e^-injection, injection rate 1 Hz, every 2 min into same bucket

	EIC	FCC-ee-Z
Beam energy [GeV]	10 (18)	45.6 (80)
Bunch population [10^{11}]	1.7	1.7
Bunch spacing [ns]	10	15, 17.5 or 20
Beam current [A]	2.5 (0.27)	1.39
SR power / beam /meter [W/m]	7000	600
Critical photon energy [keV]	9 (54)	19 (100)

FCC – EIC Collaboration

Multiple FCC-EIC workshops held over last year

FCC-EIC EPOL Workshop September 2022, FCC-EIC MDI Workshop October 2022, FCC-US Workshop April 2023

Focus on Machine-Detector Interface (MDI) and Beam Physics

Developing common tools, e.g. the Collimation simulation and Polarization packages, and comparing hardware implementation for diagnostics, collimators, vacuum, SRF, ….

event

FCC-EIC Joint & MDI Workshop 2022

17–28 Oct 2022
CERN
Europe/Zurich timezone

This extended two week working meeting combines the 1st FCC-EIC Joint Workshop and the 4th FCC-ee MDI Workshop. The event will take place at CERN, from 17 to 28 October 2022 in a hybrid in-person and online participation format. The working meeting will start on Monday 17 October after lunch and will end on Friday 28 October. It will be organized with presentations in the afternoon, followed by discussions on various topics.

Overview
Timetable
Contribution List
My Conference

FCC-hh Design Status

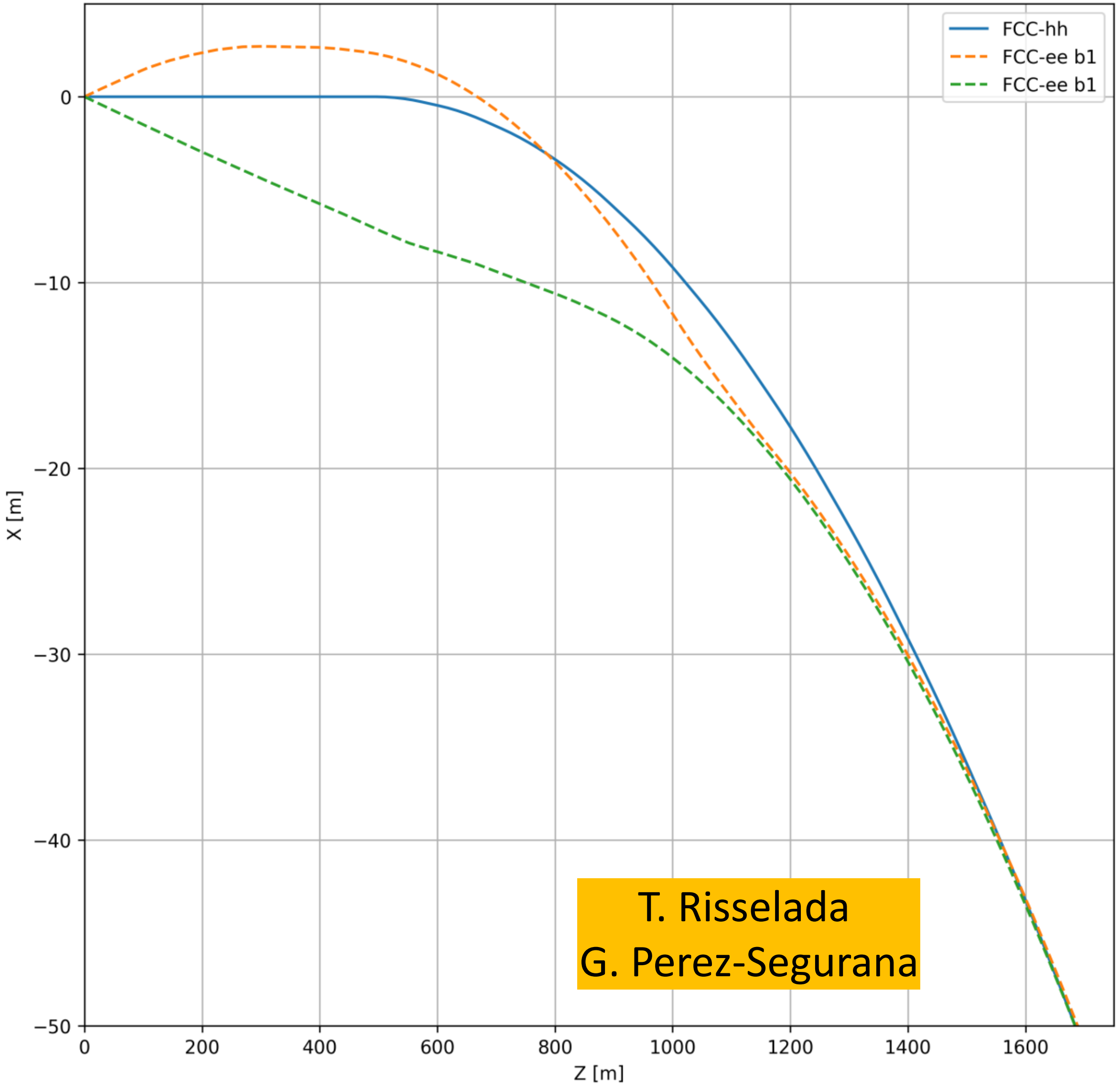
M. Giovannozzi

- **The FCC-hh layout has been updated to match the new placement**

- **Optimization of the Arc Cells improves the filling factor and alignment with FCC-ee**

- **Updated parameters for different magnets technology options and AC power constraints**

- **Work ongoing to evaluate the collimation, injection/extraction straight sections, and align the transport lines with SPS-SC or LHC**

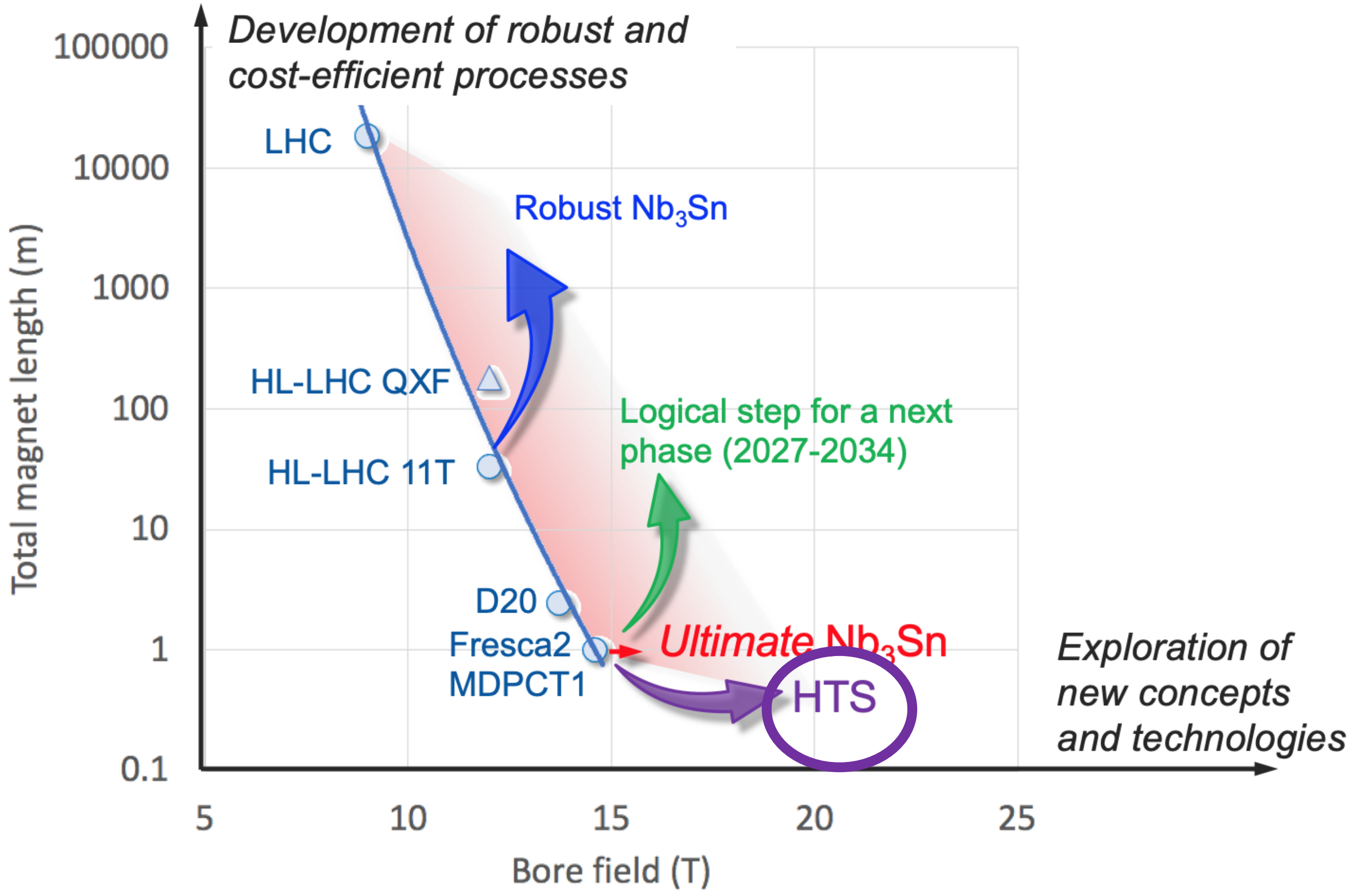


T. Risselada
G. Perez-Segurana

HFM: preparing for FCC stage 2 (FCC-hh)

FUTURE CIRCULAR COLLIDER

In parallel to FCC studies, CERN High Field Magnet development program as long-term separate R&D project working with European, US and Asian efforts



CERN budget for high-field magnets doubled in 2020 Medium-Term Plan (~ 200 MCHF over ten years)

Main R&D activities:

- ❑ materials: goal is ~16 T for Nb_3Sn, at least ~20 T for HTS inserts
- ❑ magnet technology: engineering, mechanical robustness, insulating materials, field quality
- ❑ production of models and prototypes: to demonstrate material, design and engineering choices, industrialisation and costs
- ❑ infrastructure and test stations: for tests up to ~ 20 T and 20-50 kA

Detailed deliverables and timescale being defined through Accelerator R&D roadmap under development

L. Bottura, F. Gianotti, A. Siemko

FCC-hh Accelerator Parameters

Parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	80-116		14	14
dipole field [T]	14 (Nb_3Sn) – 20 (HTS/Hybrid)		8.33	8.33
circumference [km]	90.7		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	2700		7.3	3.6
SR power / length [W/m/ap.]	32.1		0.33	0.17
long. emit. damping time [h]	0.45		12.9	12.9
beta* [m]	1.1	0.3	0.15 (min.)	0.55
normalized emittance [μm]	2.2		2.5	3.75
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	5 (lev.)	1
events/bunch crossing	170	1000	132	27
stored energy/beam [GJ]	7.8		0.7	0.36

Mid-Term Review & Cost Review, autumn '23

Mid-term review report, supported by additional documentation on each deliverable, will be submitted to review committees and to Council and its subordinate bodies, as input for the review.

Results of both general mid-term review and the cost review should indicate the main directions and areas of attention for the second part of the Feasibility Study

Infrastructure & placement

- Preferred placement and progress with host states (territorial matters, initial states, dialogue, etc.)
- Updated civil engineering design (layout, cost, excavation)
- Preparations for site investigations

Technical Infrastructure

- Requirements on large technical infrastructure systems
- System designs, layouts, resource needs, cost estimates

Accelerator design FCC-ee and FCC-hh

- FCC-ee overall layout with injector
- Impact of operation sequence: Z, W, ZH, $t\bar{t}$ vs start at ZH
- Comparison of the SPS as pre-booster with a 10-20 GeV linac
- Key technologies and status of technology R&D program
- FCC-hh overall layout & injection lines from LHC and SC-SPS

Physics, experiments, detectors:

- Documentation of FCC-ee and FCC-hh physics cases
- Plans for improved theoretical calculations to reduce theoretical uncertainties towards matching FCC-ee statistical precision for the most important measurements.
- First documentation of main detector requirements to fully exploit the FCC-ee physics opportunities

Organisation and financing:

- Overall cost estimate & spending profile for stage 1 project

Environmental impact, socio-economic impact:

- Initial state analysis, carbon footprint, management of excavated materials, etc.
- Socio-economic impact and sustainability studies

FUTURE CIRCULAR COLLIDER

Summary

- **FCC-ee has highest luminosity at Z, W and H@240 GeV of all proposed factories**
- **Feasibility Study is preparing for Mid-Term review with a ‘complete’ design**
    - Beam optics and beam physics, inc. collective effects, addressing major challenges
    - Describe high-cost technical systems, e.g. SRF, arc magnets, vacuum, …
    - Layout identified to ensure complete civil / infrastructure cost estimates
    - Alternative options and R&D identified to further improve performance / cost
- **Based on 60 years of experience with circular e^+e^- colliders, some of which currently in operation, hence no need for a large demonstrator facility**
    - Super KEKB and EIC will provide important information
    - R&D on components focused on improved performance, increased efficiency, industrialization, cost aspects, sustainability and minimizing environmental impact
    - R&D timelines are consistent with construction in 2030’s
- **Very significant progress over the last two years!**

Version: 0.28 Date: 26.05.2023

thank you !

Day	Sunday	Monday	Tuesday					Wednesday					Thursday					Friday	Day
Time	Registration desk	Plenary	Parallel 1	Parallel 2	Parallel 3	Parallel 4	Governance	Parallel 1	Parallel 2	Parallel 3	Parallel 4	Governance	Parallel 1	Parallel 2	Parallel 3	Parallel 4	Governance	Plenary: **Summaries**	Time
Room	Santosa Suite	Orchard Suite	Orchard Suite	Cromwell 1+2	Cromwell 3+4	Kensington Suite	Cromwell 6	Orchard Suite	Cromwell 1+2	Cromwell 3+4	Kensington Suite	Cromwell 6	Orchard Suite	Cromwell 1+2	Cromwell 3+4	Kensington Suite	Cromwell 6	Orchard Suite	
08:30-09:00		Opening	Baseline design	Physics Case + Theoretical calculations (I)	FCCIS WP3 Integrate Europe (I)	UK industrial event		Optics correction	Detector requirements from Physics (I)	Technologies	Communicating Large-Scale Research Infrastructures		Injector (II)	EPOL (II)	Electricity and Energy Management	SRF Technology (I)		Civil Engineering Technical Infrastructures	08:30-09:00
09:00-09:30		CERN Council expectations for FCC FS																FCC-ee	09:00-09:30
09:30-10:00		Key note: Physics perspectives										Governance						FCC-ee injector FCC-hh & magnet	09:30-10:00
10:00-10:30			Coffee Break (Santosa Suite)					Coffee Break (Santosa Suite)					Coffee Break (Santosa Suite)						10:00-10:30
10:30-11:00		Coffee Break (Santosa Suite)	Collimation & collective effects	Physics Case + Theoretical calculations (II)	FCCIS WP3 Integrate Europe (II)	UK industrial event		Injector (I)	Detector requirements from Physics (III)	Future magnet developments	Communicating Large-Scale Research Infrastructures		FCC-hh	Detectors (I)	Safety, Transport & Survey	SRF Technology (II)		Coffee Break	10:30-11:00
11:00-11:30		FCC Feasibility Study status																MDI and EPOL	11:00-11:30
11:30-12:00		Baseline Scenario & Host States																PED	11:30-12:00
12:00-12:30		Civil Engineering	Lunch break (Santosa Suite)				Scientific Advisory Committee in Bromton room	Lunch break (Santosa Suite)					Lunch break (Santosa Suite)					Closing remarks	12:00-12:30
12:30-13:00		Lunch break (Santosa Suite)																END	12:30-13:00
13:00-13:30																			13:00-13:30
13:30-14:00			Machine Detector Interface (I)	RF Points for FCC-ee	FCCIS WP4 Impact & Sustainability (I)			EPOL (I)	Civil Engineering	Directions for R&D	Machine Detector Interface (III)	Scientific writing	Code development	Software and Computing / Detectors	Technologies	FCC-eh	Scientific Advisory Committee		13:30-14:00
14:00-14:30		FCC Accelerator					FS Steering Committee												14:00-14:30
14:30-15:00																			14:30-15:00
15:00-15:30	Registration + as from 07:30am on Monday 5 June	Technical Infrastructure	Coffee Break (Santosa Suite)					Coffee Break (Santosa Suite)					Coffee Break (Santosa Suite)						15:00-15:30
15:30-16:00		Coffee Break (Santosa Suite)	Machine Detector Interface (II)	Integration and Cooling	FCCIS WP4 Impact & Sustainability (I)			Plenary: **UK Session**					Alternative FCC-ee Optics Development	Detectors (II)	Technologies	Early Career Researchers			15:30-16:00
16:00-16:30		PED plenary: i) Physics case, ii) Theoretical calculation strategy, iii) Detector requirements from physics																	16:00-16:30
16:30-17:00																			16:30-17:00
17:00-17:30																			17:00-17:30