MDI MAGNETS AND IR LAYOUT

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Istituto Nazionale di Fisica Nucleare

MDI Topical Meeting
23 October 2025

Introduction

- **4 April 2022**: Pre-engineering design review and roadmap discussion for FCC-ee IR magnets
  Chaired by John Seeman https://indico.cern.ch/event/1139384/

- **22 November 2024**: MDI mini-workshop on IR, MDI, Magnets, Cryostats
  Chaired by John Seeman https://indico.cern.ch/event/1477819/

- **14 May 2025:** Meeting on detector magnet specs for screening solenoid design
  IDEA detector: https://arxiv.org/abs/2502.21223

- **Today objectives**: restart the discussion to continue the activity for the pre-TDR phase
  - New clearances at QC1 thanks to larger L* (2.4 m instead of 2.2) → impact to cryostat dimensioning
  - Updated GHC/LCC IR optics
  - Local and non-local compensating solenoids
  - IR correctors for IP tuning

Agenda

MDI topical meeting on FCC-ee IR magnet design

Thursday 23 Oct 2025, 16:30 → 17:40 Europe/Rome

Description https://cern.zoom.us/j/8782092936?pwd=VC9ybEZYSmIrTmRQTXZWdDJ2dkU5QT09

16:30 → 16:40 **Introduction** 10m

Speakers: John Seeman (SLAC), Manuela Boscolo (Istituto Nazionale di Fisica Nucleare)

Seeman MDI Goals ...

16:40 → 17:00 **IR optics** 20m

Speakers: Helmut Burkhardt (CERN), Katsunobu Oide, Pantaleo Raimondi

IR_GHC_Oide_2510...

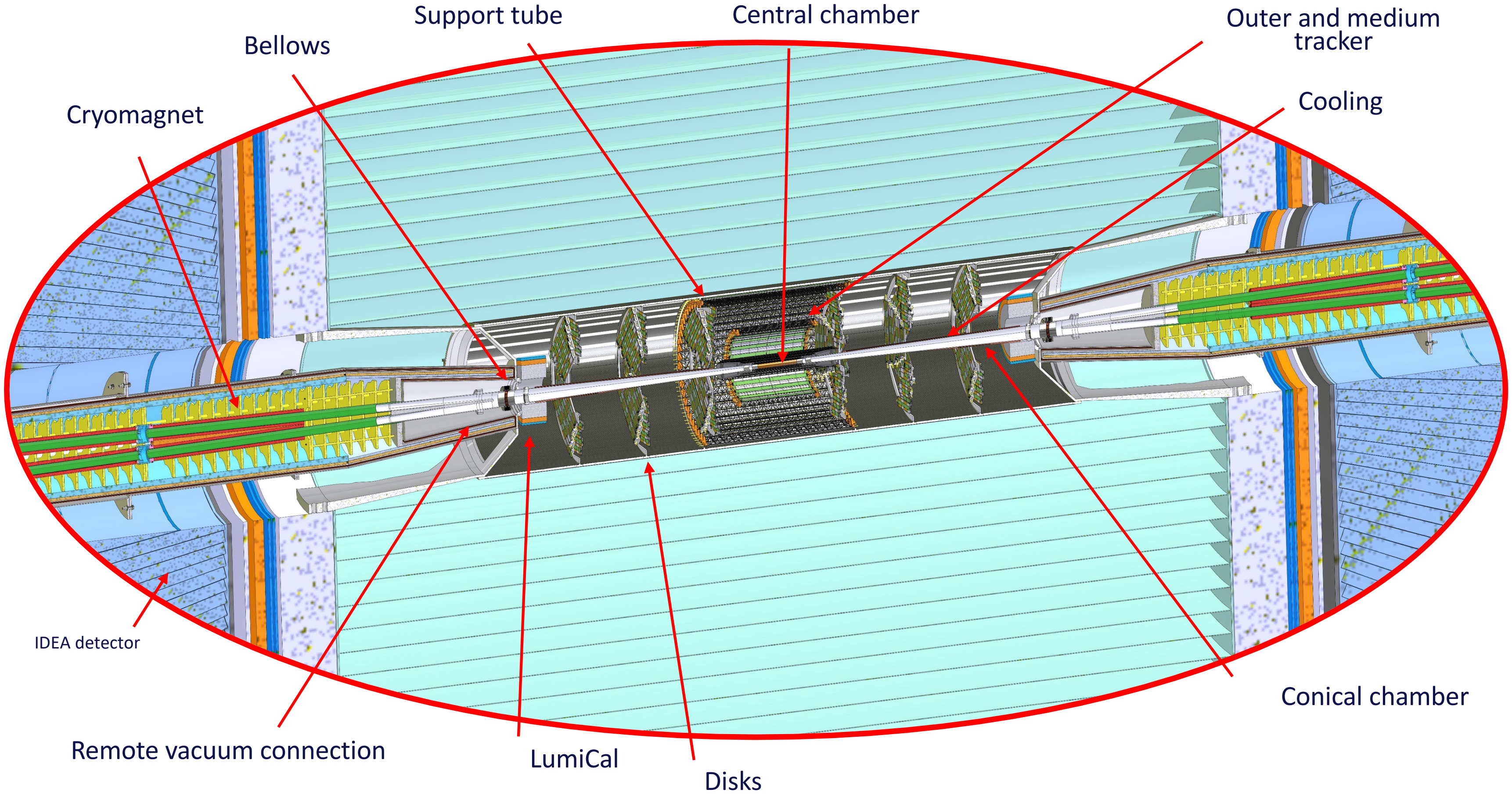
17:00 → 17:20 **IR magnet system requirements & questions** 20m

Speakers: Brett Parker (Brookhaven National Laboratory), John Seeman (SLAC), Mike Koratzinos (CERN), Vikas Teotia (BNL)

17:20 → 17:35 **Discussion** 15m

Speakers: Brett Parker (Brookhaven National Laboratory), Helmut Burkhardt (CERN), John Seeman (SLAC), Katsunobu Oide, Manuela Boscolo (Istituto Nazionale di Fisica Nucleare), Mike Koratzinos (CERN), Pantaleo Raimondi

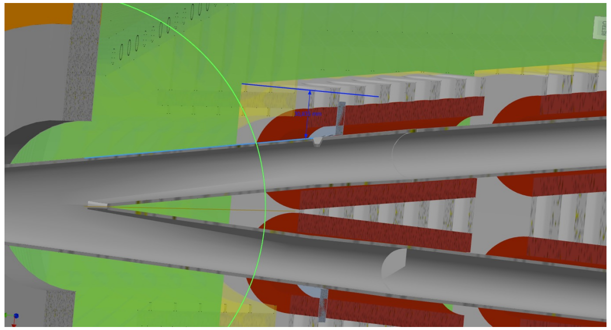
FCC-ee engineered Interaction Region



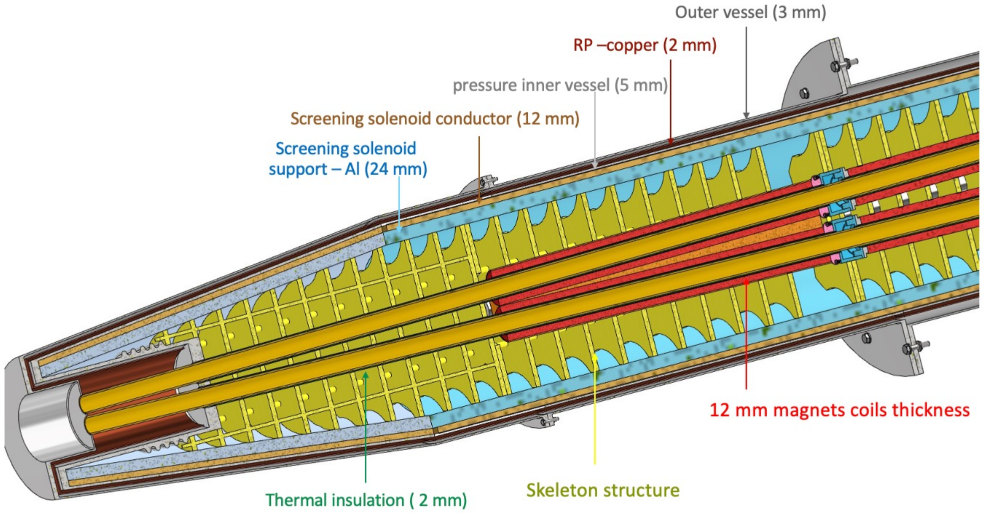
On the final focus quadrupoles design

M. Koratzinos

- Small distance of coils at first segment of QC1L1
- Need space for skew correctors winding to be added around QC1
- Need to allow few per cents of different strength of the FFQ
- Cryostat has to fit in the crowded MDI region



minimum distance between the magnetic centers of e+/e- for QC1L1 is (only) 66 mm

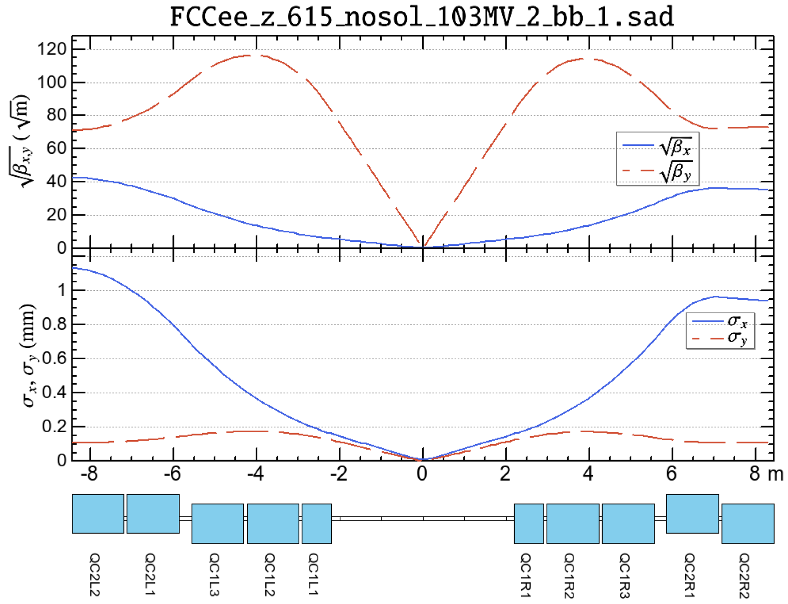


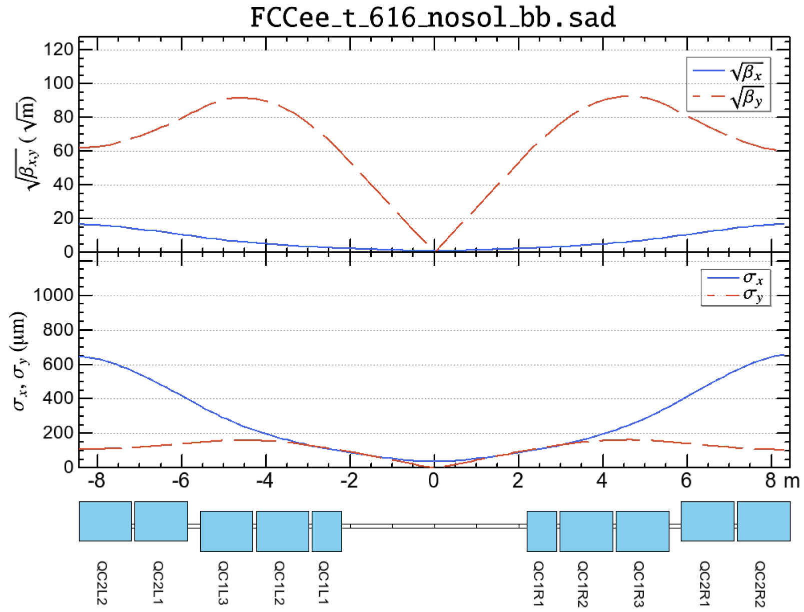
Need a firm mount of:
- cold mass containment shell
- heat shields
- internal support structure
- outer cryostat shell

 Manuela Boscolo

FCC-ee IR optics design

Flexible design with final focus doublet
in slices to adapt for the different beam energies





GHC K. Oide

(see later for the most updated plots)

Inner radius apertures:

15 mm for QC1

20 mm for QC2 → 25 mm normal conducting option possible for LCC

Compensating solenoids

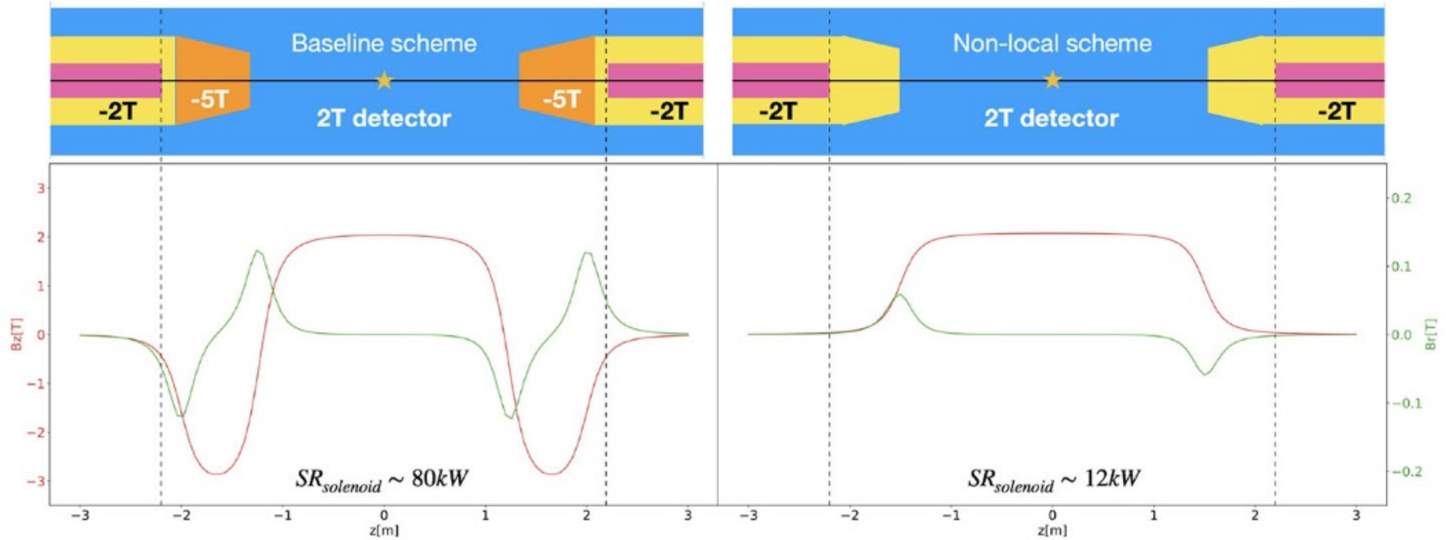


Figure 2 Conceptual sketch of the IR, ±3 m from the IP, with the 2 T detector field in blue, FFQ in pink, compensating solenoid in orange, and -2 T screening solenoid in yellow, for the baseline (*local-scheme*) (top left) and for the *non-local-scheme* (top right). In the bottom plots are the corresponding longitudinal (red) and radial (green) magnetic field profiles along the 15 mrad axis in the IR

https://doi.org/10.1140/epjti/s40485-025-00117-3

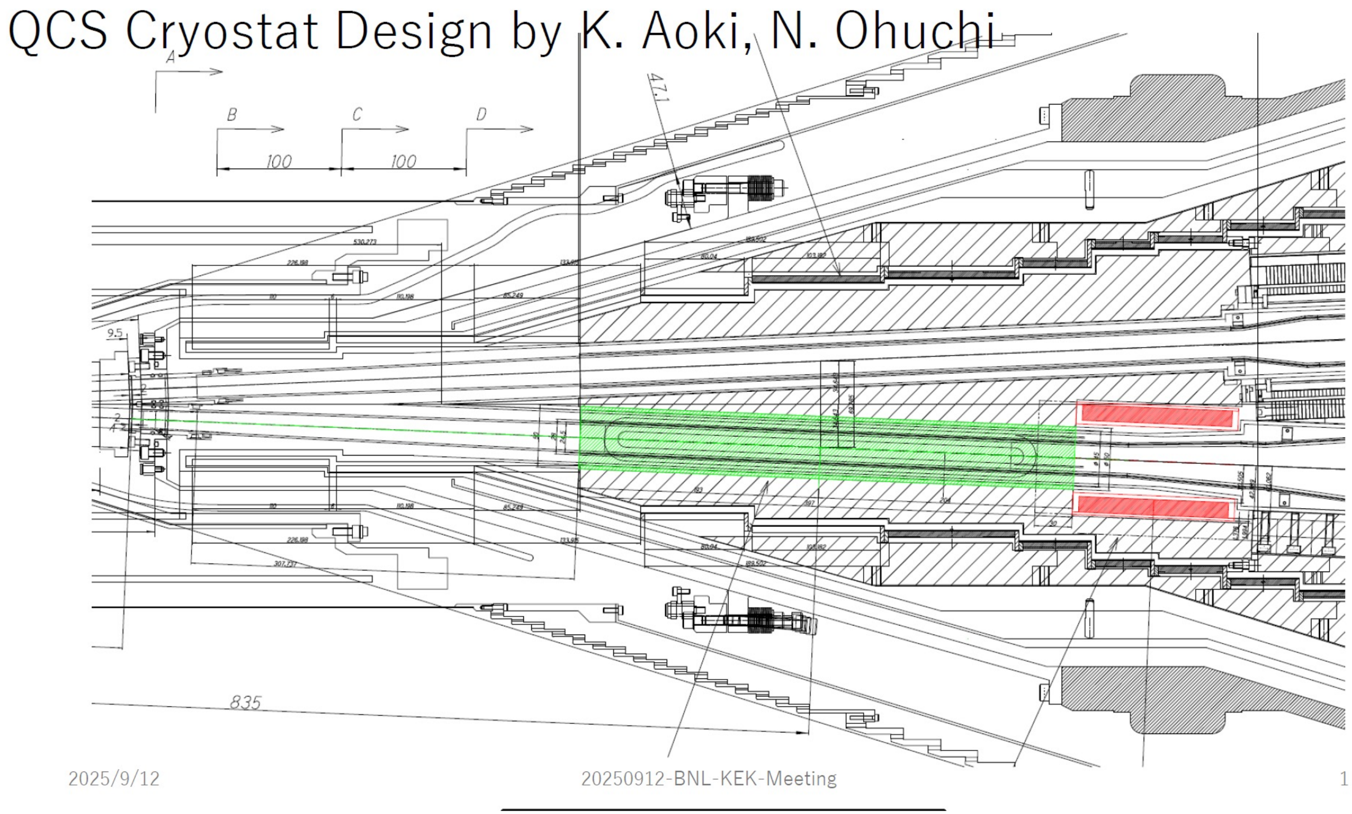
Backup material

Screening solenoid design

Brett Parker

- Critical IR cryostat driver, as it defines the basic outer envelope of the cryostat
- But back to the FCC-ee anti-solenoid…. we can “soften” (spread out longitudinally) the Bz transition from the full detector field to the fully compensated field overlapping the IR quads if that would be helpful and thereby alter the radial fields that beams go though due to the crossing angle; this should (we believe) have some impact on the emittance hit due to the detector solenoid which we would hope to minimize.
- My hope, especially if we can settle on the non-local compensation scheme, is that we can free up critical space in the “nose region” of the cryostat for necessary mechanical structure without intruding into the experimental acceptance (too much…).

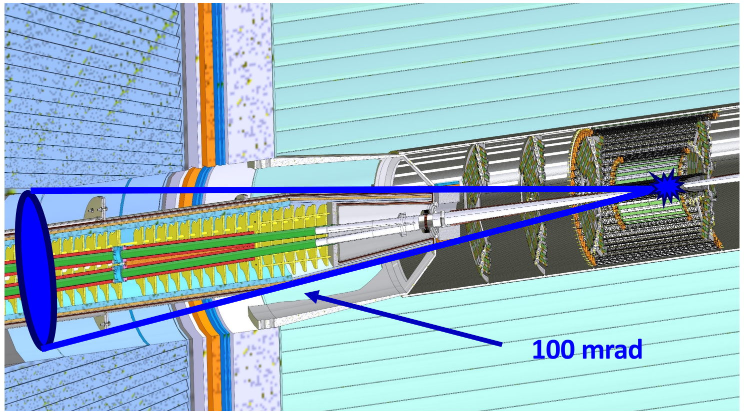
anti-solenoid



The green highlighted region is a new Nb2Sn quadrupole KEK is collaborating with Fermilab on.

Red highlighted region: where BNL must fit all the new Direct Wind correctors in the interconnect region between the IR quadrupole doublet elements (e.g. b1, a1, a2, a3 and b4 coils).

Detector and machine constraints on cryostat



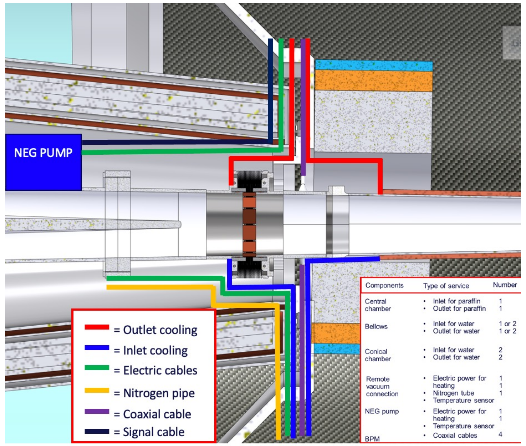
The main parameters for the IR cryo-magnet system are:

- **<100 mrad cone**
  This requirement was set at the CDR, need to be reconfirmed by physics
- **Vertex and detector acceptance |cosθ <0.992| might be an upper boundary (120 mrad)**
  100-110 mrad debatable
  not more than 120 mrad

- **z (cryostat) >1.2 m (need to be checked with services)**
- **Crossing angle 30 mrad**
  Value set at the CDR

- **Beam pipe diameter at QC1 30 mm**

- **L* = 2.2 m → 2.4 m new!**

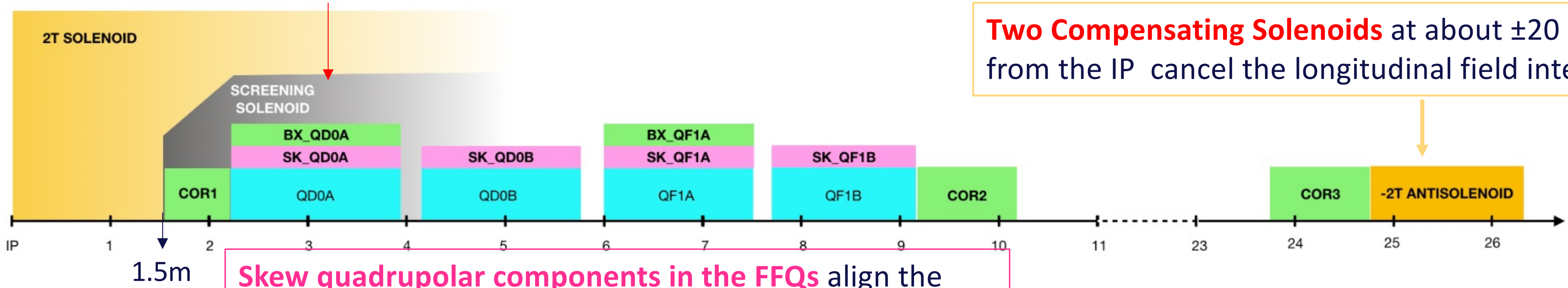


Nonlocal Solenoid Compensation Scheme

Details in: IPAC2024- TUPC68, “Alternative Solenoid Compensation Scheme for the FCC-ee Interaction region”, A. Ciarma, M.B., H. Burkhardt, P. Raimondi: link

A **Screening Solenoid** shields the Final Focus Quads

Two Compensating Solenoids at about ±20 m from the IP cancel the longitudinal field integral



Skew quadrupolar components in the FFQs align the magnet axis to the rotated reference frame of the beam

Dipole Correctors right after the beam pipe separation and around the FFQs compensate the orbit distortion generated by the horizontal crossing angle in the detector field

- **This solution is optics independent.**
- **The tuning knobs -correctors and skews- are needed for orbit and coupling correction for all optics.**

Nonlocal scheme: table of correctors and skew quads

NAME	KEYWORD	S_FROM_IP	L	VKICK	HKICK	K1L	K1SL		delta Y	notes
		[m]	[m]	[rad]	[rad]	[m-1]	[m-1]		[m]	BRHO = 152
SQY2L	MULTIPOLE	-728.50365	0	0	0	0	2.04E-05			
QSI2L	MULTIPOLE	-549.72564	0	0	0	0	-1.31E-06			
SQY1L	MULTIPOLE	-370.94763	0	0	0	0	-2.04E-05			
QSI1L	MULTIPOLE	-195.2548	0	0	0	0	1.31E-06			
BX3ML	KICKER	-23.75	1	0	1.92E-07	0	0			
BX2ML	KICKER	-9.15	1	4.83E-05	-1.83E-06	0	0			
QF1BL	QUADRUPOLE	-7.65	1.5	0	0	0	0		0	HKICK FROM FEED-DOWN IN MADX
QF1AL	QUADRUPOLE	-6	1.5	0	8.89E-05	0.11847695	-0.002337		7.50E-04	HKICK FROM FEED-DOWN IN MADX
QD0BL	QUADRUPOLE	-4.1	1.75	0	0.00E+00	0.22726574	-0.004483		0	HKICK FROM FEED-DOWN IN MADX
QD0AL	QUADRUPOLE	-2.2	1.75	0	1.89E-04	-0.6314718	0.01245625		-3.00E-04	HKICK FROM FEED-DOWN IN MADX
BX1ML	KICKER	-1.50016	0.7	3.05E-04	-5.01E-06	0	0			70 SLICES IN MADX, HERE ALREADY MULTIPLIED
IPD	MARKER	0	0	0	0	0	0			
BX1MR	KICKER	1.50017	0.7	3.13E-04	5.28E-06	0	0			70 SLICES IN MADX, HERE ALREADY MULTIPLIED
QD0AR	QUADRUPOLE	3.95	1.75	0	1.92E-04	-0.6392698	-0.0126101		-3.00E-04	HKICK FROM FEED-DOWN IN MADX
QD0BR	QUADRUPOLE	5.85	1.75	0	0.00E+00	0.22704913	0.00447871		0	HKICK FROM FEED-DOWN IN MADX
QF1AR	QUADRUPOLE	7.5	1.5	0	1.01E-04	0.13422389	0.00264767		7.50E-04	HKICK FROM FEED-DOWN IN MADX
QF1BR	QUADRUPOLE	9.15	1.5	0	0	0	0		0	HKICK FROM FEED-DOWN IN MADX
BX2MR	KICKER	10.15	1	5.42E-05	1.95E-06	0	0			
BX3MR	KICKER	24.75	1	0	-1.92E-07	0	0			
QSI1R	MULTIPOLE	96.38432	0	0	0	0	1.49E-06			
SQY1R	MULTIPOLE	182.97156	0	0	0	0	-1.08E-05			
QSI2R	MULTIPOLE	313.51187	0	0	0	0	-1.49E-06			
SQY2R	MULTIPOLE	444.05218	0	0	0	0	1.08E-05			

A. Ciarma

IR beam pipe

P = 160 W

T_{max} (chamber) = 50°C

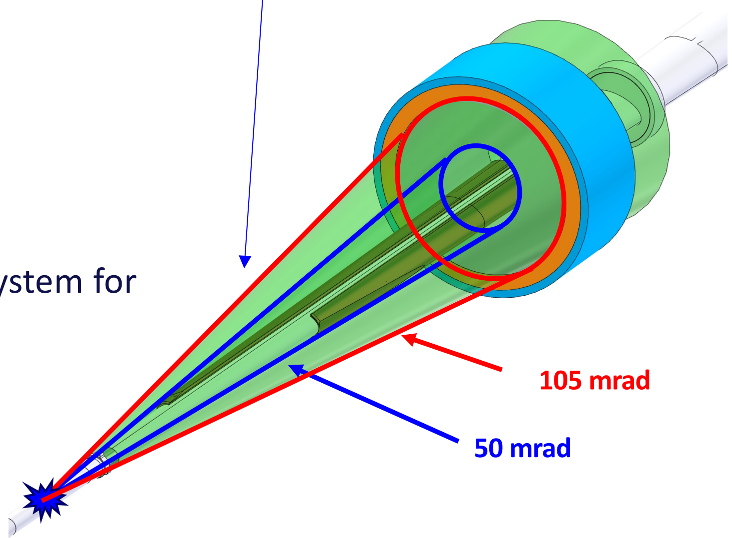
T_{max} (water) = 18°C

P = 54 W

T_{max} (chamber) = 29°C

T_{max} (paraffin) = 20°C

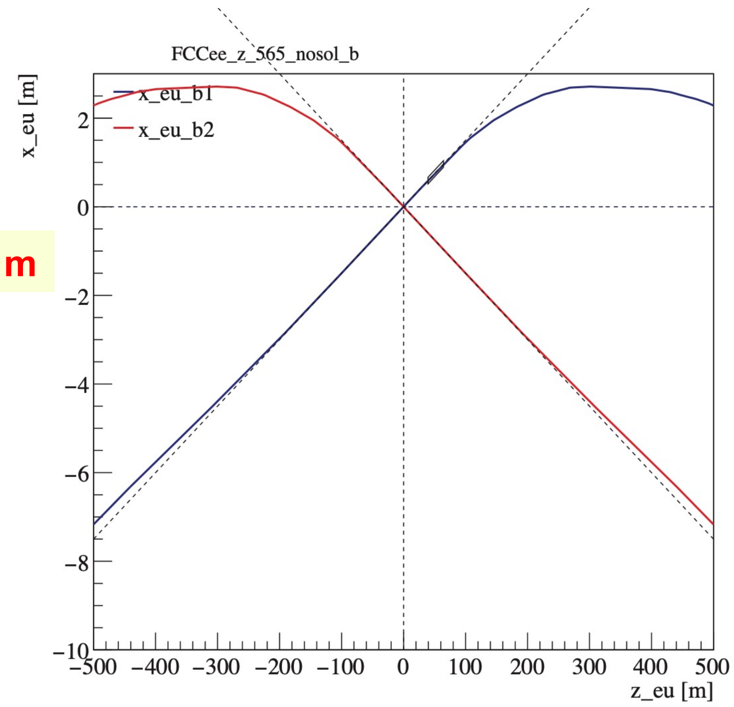
Clearance: Asymmetric cooling system for the lumical acceptance window



Courtesy by H. Burkhardt

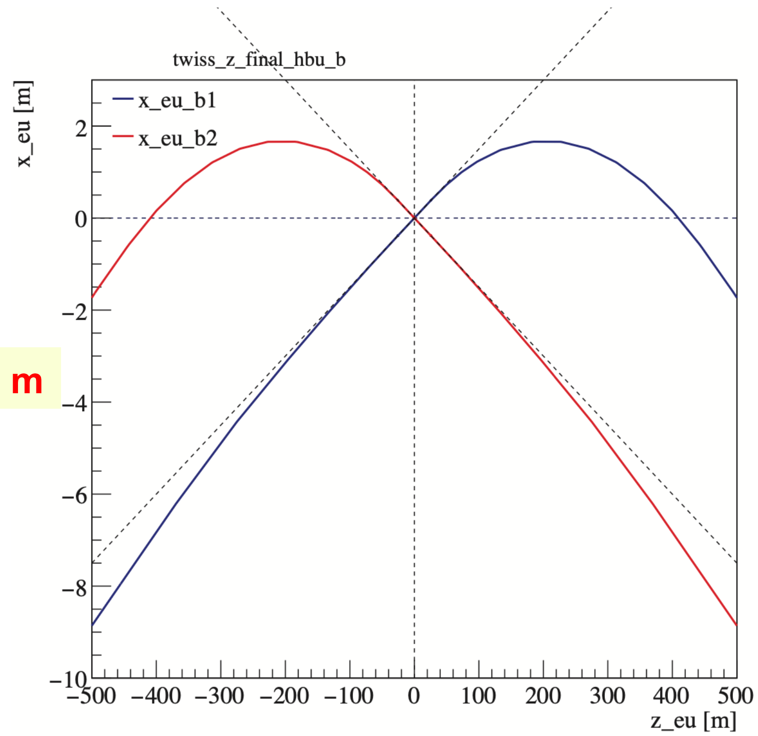
Survey

~9.5 m



Local – K. Oide

~7 m



Nonlocal – LCCO

SC Final Focus quadrupole QC1

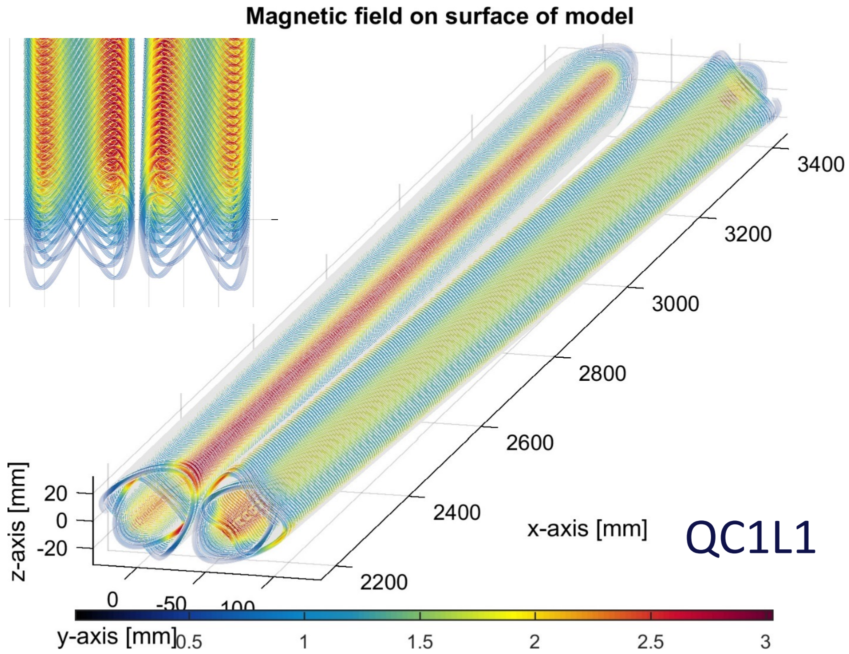
M. Koratzinos

Canted Cosine theta (CCT) design

Quadrupole with embedded local edges correction and crosstalk correction

Pros:

- Excellent field quality
- The design can have embedded correctors



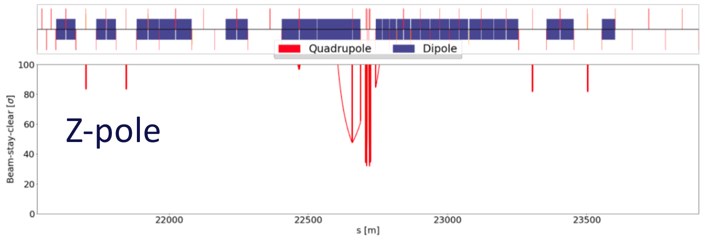
NbTi, radius aperture 20 mm

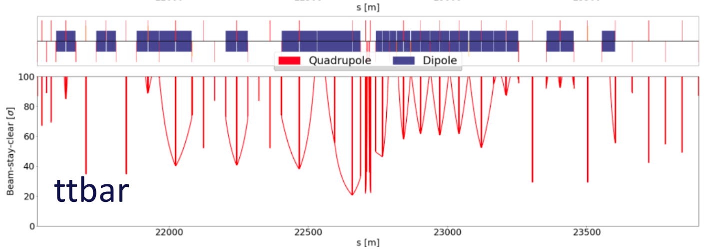
Some of the open questions related to the IR magnets design:
Required field stability, field quality, cross-talk compensation, required IR correction coils required shielding for magnet protection and for beam losses, magnet and vacuum chamber supports.
List of requirements for the overall IR magnets will help to move to the next level of design.

LCCO Final Focus - Impact to IR design

- The Final Focus is optimized to have the **largest possible beam stay clear (BSC) and minimum losses** in the final focus system and all the way through the IR

Beam Stay Clear



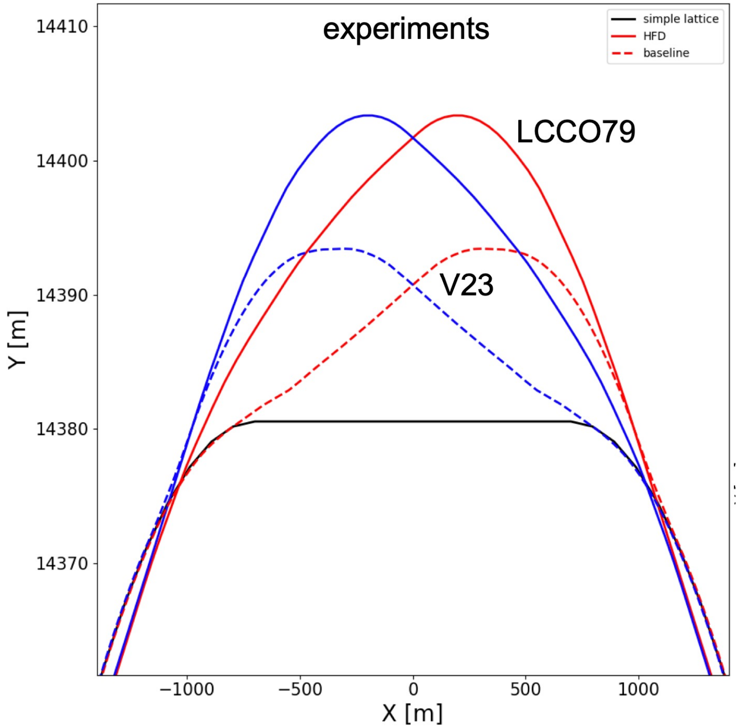


Preliminary aperture model same as baseline,
r=35 mm everywhere, but: r=15 mm at QC1; r=20 mm at QC2
Bottlenecks:

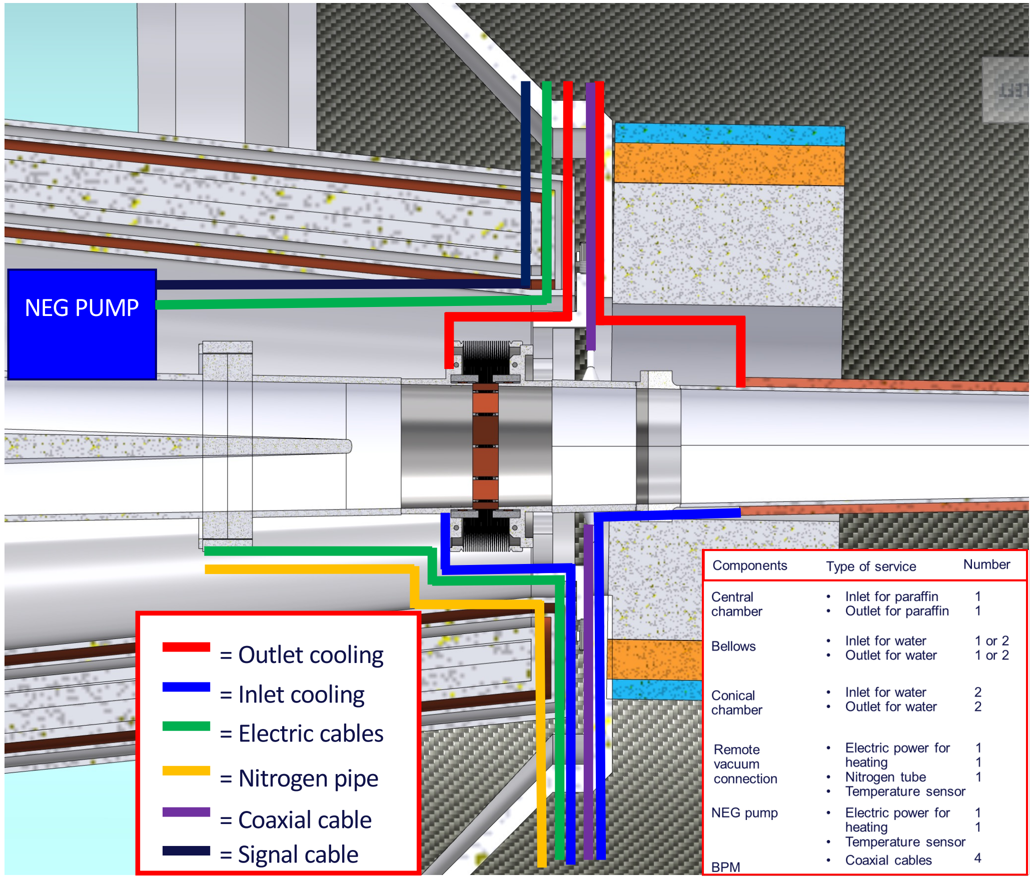
- **baseline Z: 14.5 σ_x / tt_{bar}: 14.4 σ_x**
- **LCCO Z: 31 σ_x / tt_{bar}: 20 σ_x**

M. Hofer, link
173rd Optics meeting

Survey Layout



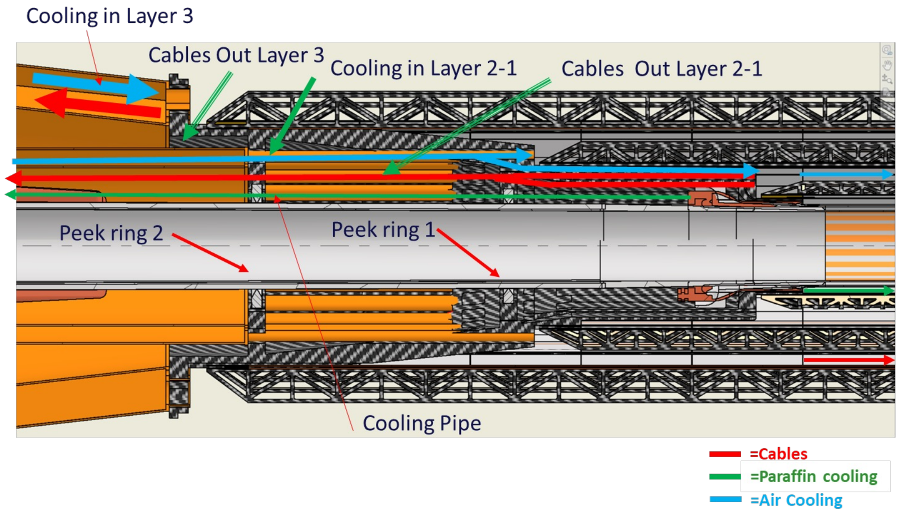
Services integration challenges



Components	Type of service	Number
Central chamber	• Inlet for paraffin • Outlet for paraffin	1 1
Bellows	• Inlet for water • Outlet for water	1 or 2 1 or 2
Conical chamber	• Inlet for water • Outlet for water	2 2
Remote vacuum connection	• Electric power for heating • Nitrogen tube • Temperature sensor	1 1 1
NEG pump	• Electric power for heating • Temperature sensor	1 1
BPM	• Coaxial cables	4

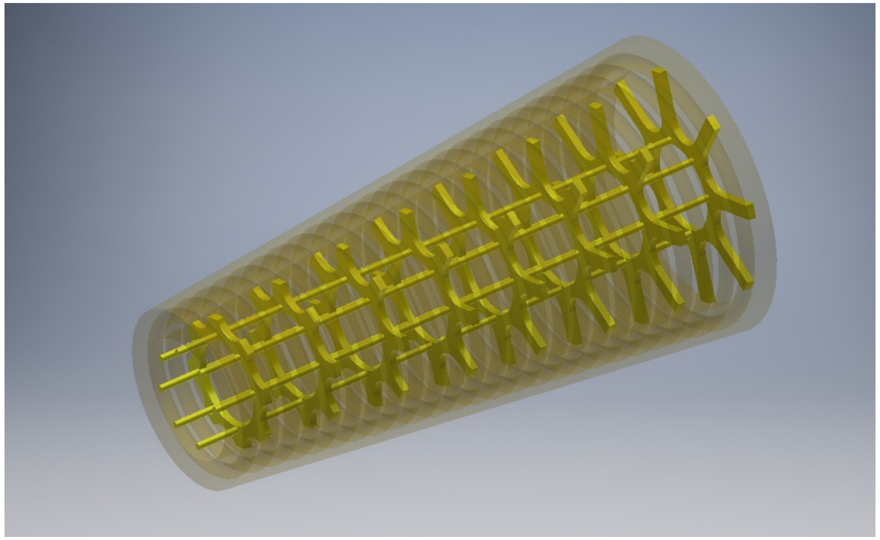
There are two problematic areas for the services integration:

- Interface with the cryomagnetic system.
- Interface between the vacuum chamber and the vertex detector.

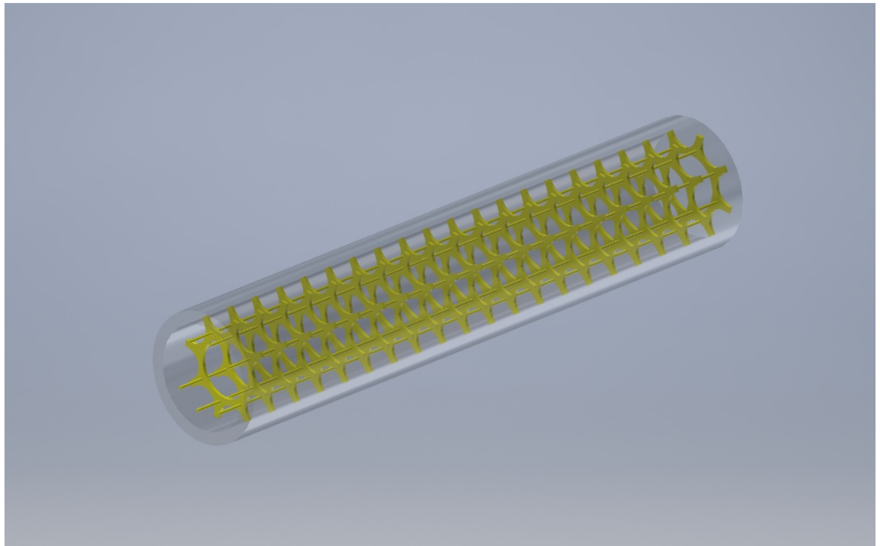


FCC-ee Cryostat sketch concept

M. Koratzinos



compensating solenoid



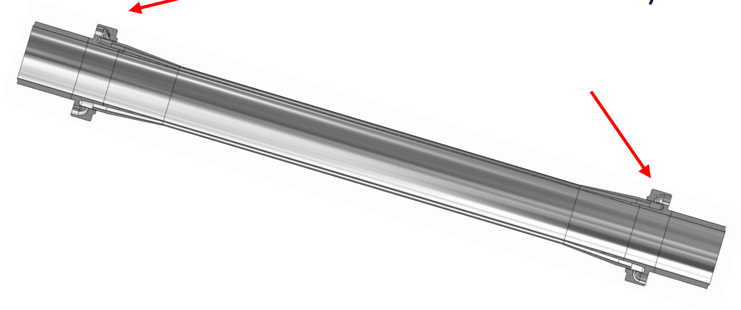
screening solenoid

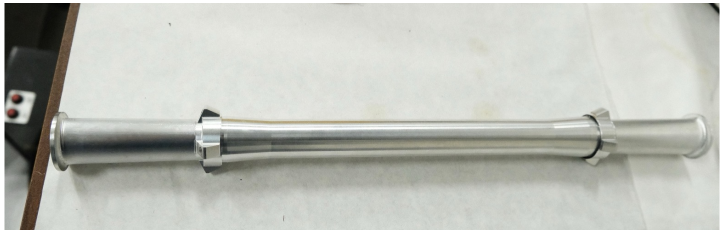
The idea is to use a stiff skeleton which will replace the very heavy cryostat.
All load bearing capability will rely on this skeleton

This is what is presently implemented in the CAD for the cryostat

Central beam pipe

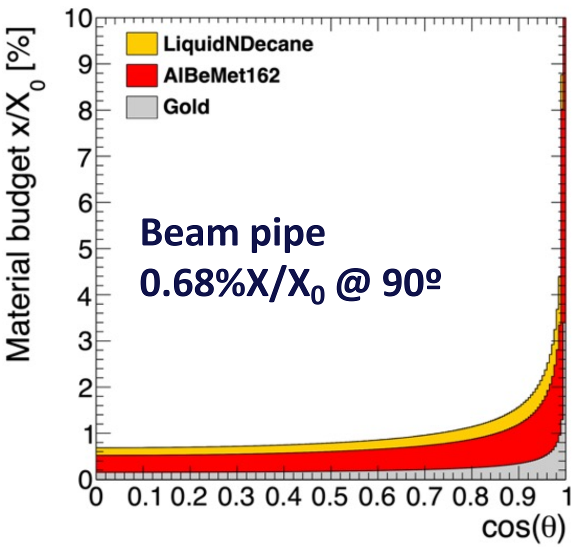
Inlets/outlets for the paraffin cooling circuit housed in a double layer





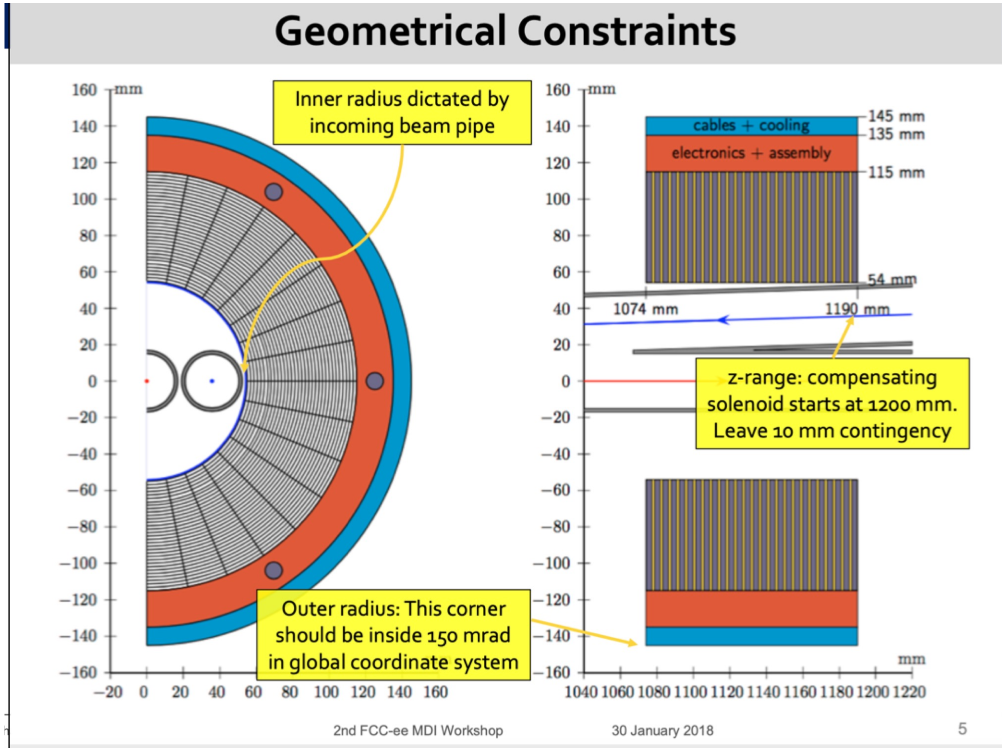
Inner radius 10 mm

Material	thickness
AlBeMet162 (62% Be and 38% Al alloy)	0.35 mm
Paraffin (PF200)	1 mm
AlBeMet162	0.3 mm
Au	5 μm



Beam pipe
0.68%X/X_0 @ 90º

Luminosity calorimeter



LumiCal Design

- W+Si sandwich: 3.5 mm W + Si sensors in 1 mm gaps
  - Effective Moliere radius: ~15 mm
- 25 layers total: 25 X_0
- Cylindrical detector dimensions:
  - Radius: $54 < r < 145$ mm
  - Along outgoing beam line: $1074 < z < 1190$ mm
- Sensitive region:
  - $55 < r < 115$ mm;
- Detectors centered on and perpendicular to outgoing beam line
- Angular coverage (>1 Moliere radius from edge):
  - Wide acceptance: 62-88 mrad
  - Narrow acceptance: 64-86 mrad
  - Bhabha cross section @ 91.2 GeV: 14 nb
- Region $115 < r < 145$ mm reserved for services:
  - Red: Mechanical assembly, **read-out electronics**, cooling, equipment for alignment
  - Blue: Cabling of signals from front-end electronics to digitizers (behind LumiCals?)