Superconducting magnets of the final focus

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T. Rybitskaya, K. Ryabchenko, S. Sinyatkin (BINP)

Final focus requirements

- Due to the small vertical beta function in IP, the final lenses should be placed as close as possible to IP (in our case L * = 900 mm) inside the detector.
- Strong focusing requires a large lens gradient (up to 100 T / m),
- The entire system, including the cryostat, must be very compact.
- Two independent lenses are required for independent beam tuning.
- A full intersection angle of 60 mrad gives a horizontal separation of 54 mm orbits at the beginning of the first lens.
- It is necessary to compensate the longitudinal field of the detector and to shield from the detector field the lenses of the final focus,
- Due to the large beta functions, small errors in the magnetic field of the lenses (edge fields, inaccuracies in manufacturing and installation, etc.) strongly affect the dynamics.
- It is necessary to provide for the appropriate correction elements - linear and non-linear.

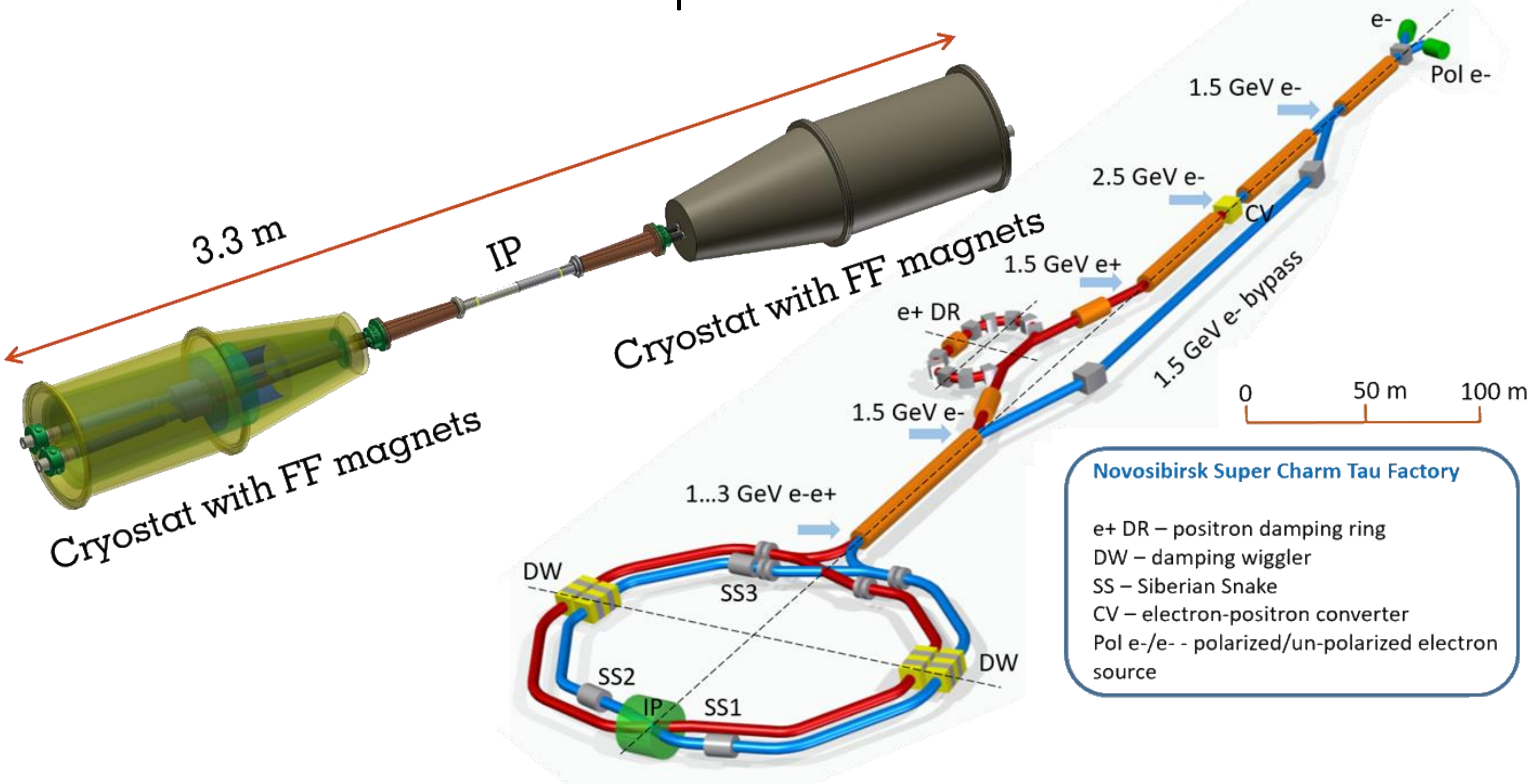
The final focus is …

The final focus is not only a set of individual magnets.

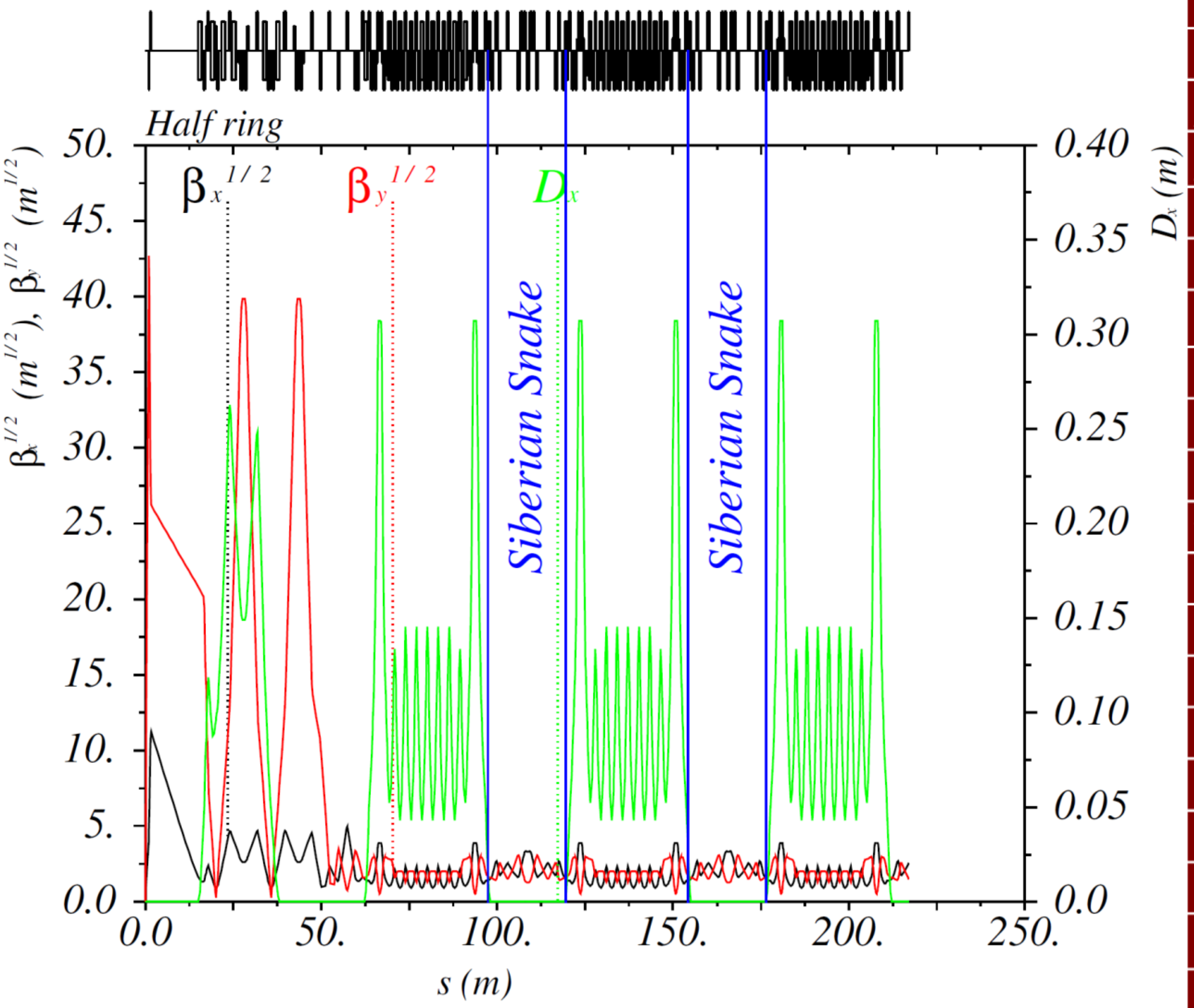
The final focus is a ystem providing

- focusing of a charged particle beam,
- detector field compensation and screening of the FF quadrupoles,
- mechanical alignment and stability of the elements axis,
- linear and non linear correction
- vacuum, cooling and diagnostic.

Novosibirsk Super Charm Tau Factory



SCTF Lattice and parameters



E(MeV)	1000*	1000	1500	2000	3000
Π(m)	478.092				
F_{RF}(MHz)	349.9				
q	558				
2θ(mrad)	60				
κ (%)	0.5				
β_x^*(mm)	50				
β_y^*(mm)	0.5				
$\alpha \times 10^4$	9.77				
I(A)	1	1	2.2	2.2	2
$N_{e/bunch} \times 10^{-10}$	2.1	2.1	4.5	5.2	7
N_b	500	500	490	420	290
U_0(keV)	11.7	11.7	59.3	187.4	948
V_{RF}(kV)	1000	1000	600	1000	2000
ν_s	0.0093	0.0093	0.0059	0.0065	0.0072
δ_{RF}(%)	3.4	3.4	2	2	1.7
$\sigma_e \times 10^3$	1	1.2	0.9	0.8	9.6
σ_s(mm)	7.9	9.5	11	8.8	10
ε_x(nm)	11.3	16.3	8.8	7	10.9
$L_{HG} \times 10^{-35} (cm^{-2}s^{-1})$	0.21	0.14	0.8	1.3	1.1
HG (%)	76	72	79	82	77
ξ_x	0.0042	0.0029	0.0031	0.0042	0.003
ξ_y	0.06	0.04	0.07	0.085	0.054
φ	10	10	16	14	13
τ_L (s)	3245	4968	1803	1080	1197

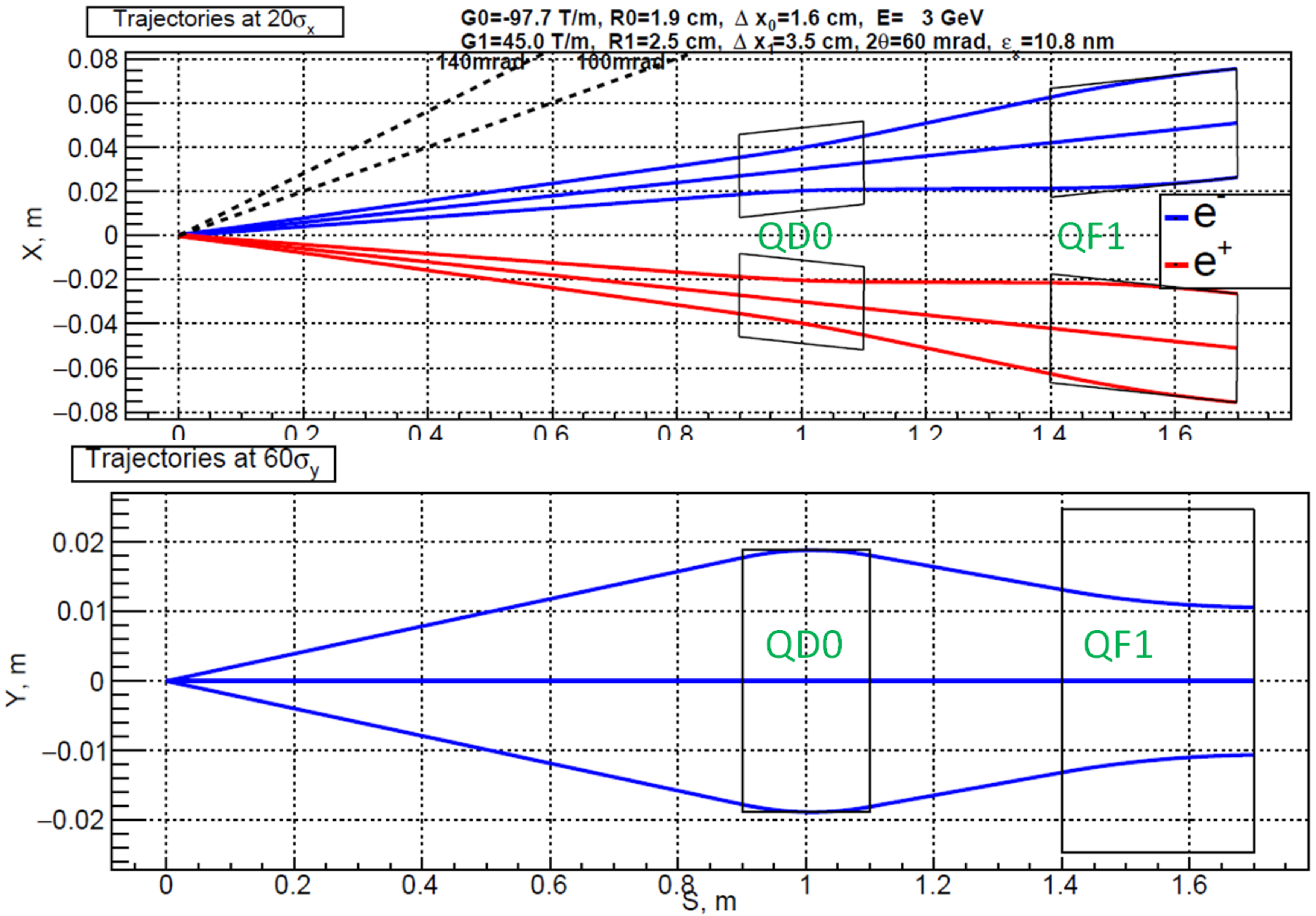
SCTF Beam parameters at the meeting point

E, GeV	1	1.5	2	3
β_x^*/β_y^*, mm	50/0.5			
ε_x, nm	15	9.5	7	11
ε_y, nm	82	50	35	55
σ_x^*, µm	27	22	19	23
σ_y^*, nm	202	158	132	166

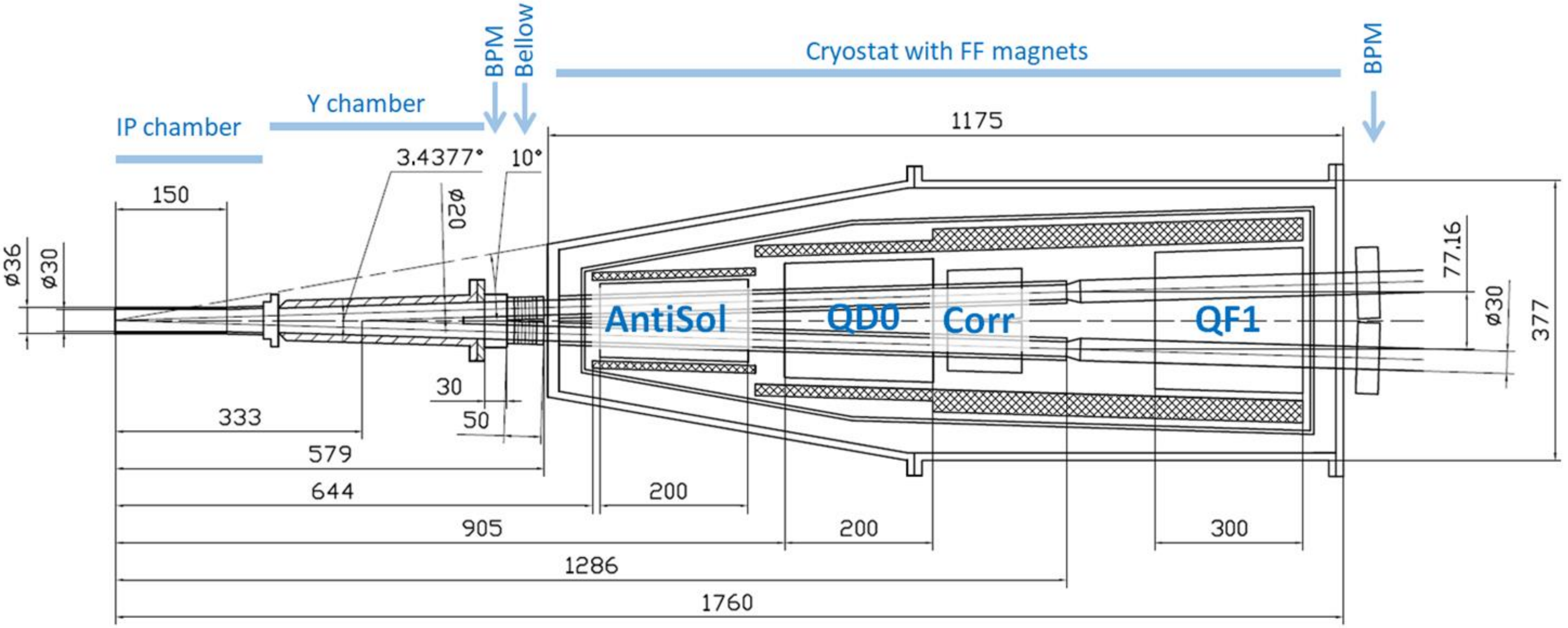
	L*, mm	L, mm	G_0, T/m	$\varnothing_{beam}$, mm
QD0	900	200	−97.7	38
QF1	1400	300	45.0	50

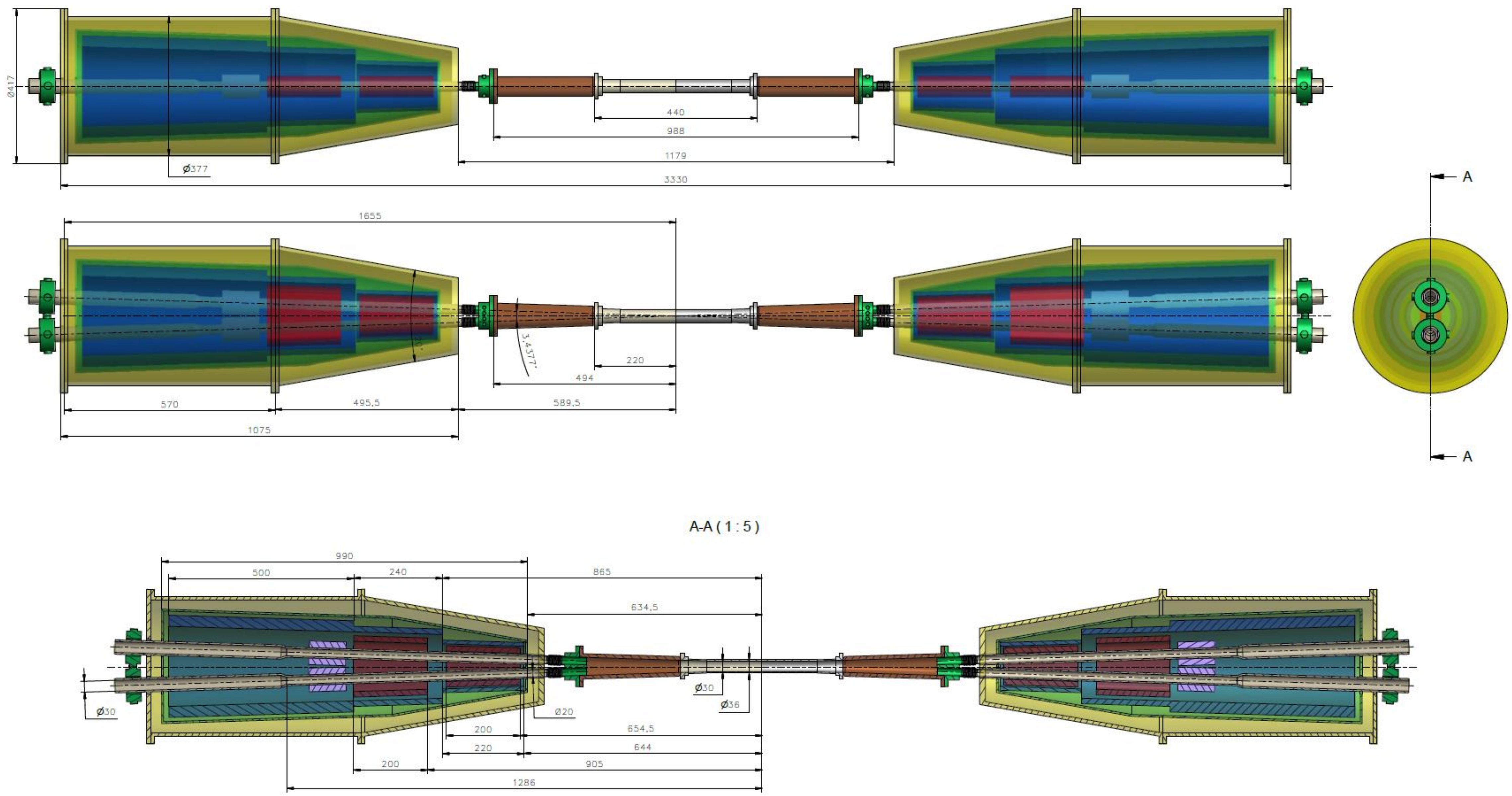
SCTF FF trajectories

The figure schematically shows the placement of the doublet of the final focus lenses and the envelope of the incoming and outgoing beams. Horizontal trajectories are limited by a deviation of $\pm 20\sigma_x$, vertical $\pm 60\sigma_y$



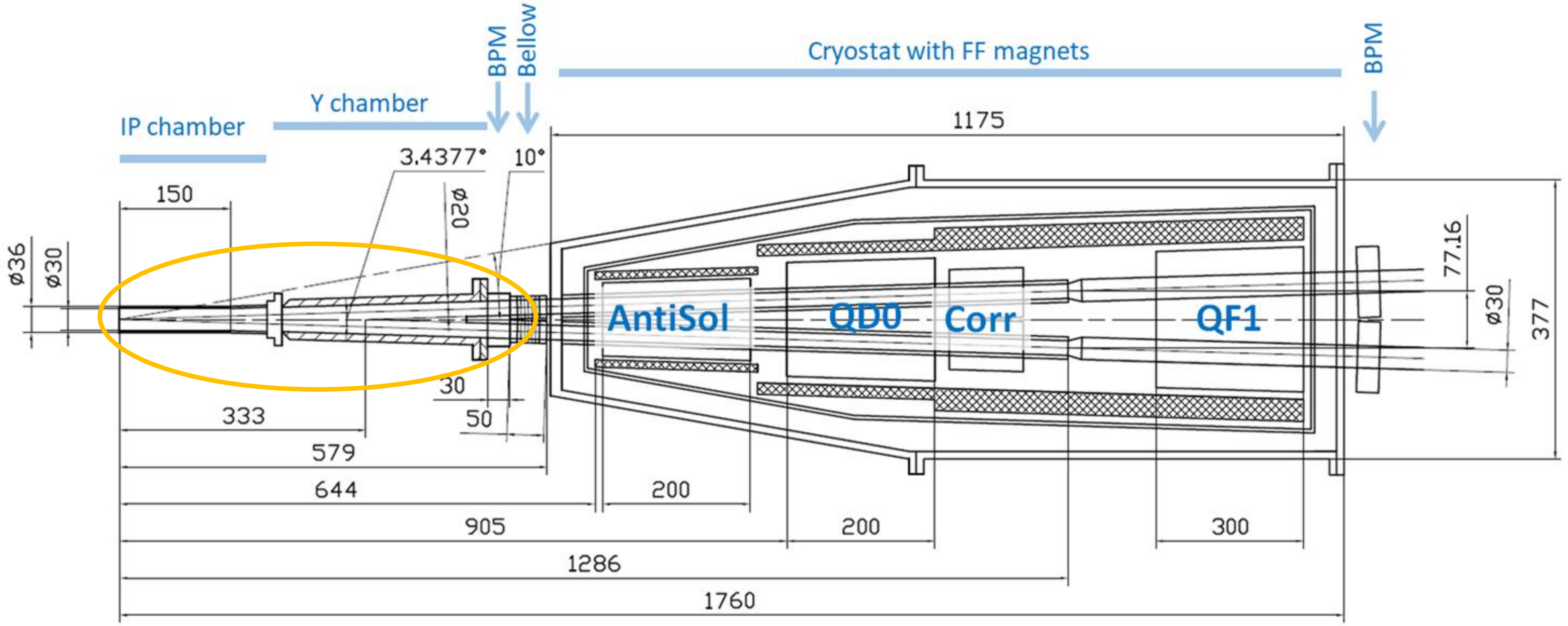
Layout of the final focus area for SCTF





Ø417
Ø377
440
988
1179
3330
1655
3,4377°
220
494
570
495,5
589,5
1075
A
A
A-A (1 : 5)
990
500
240
865
634,5
Ø30
Ø36
Ø20
Ø30
200
654,5
220
644
200
905
1286

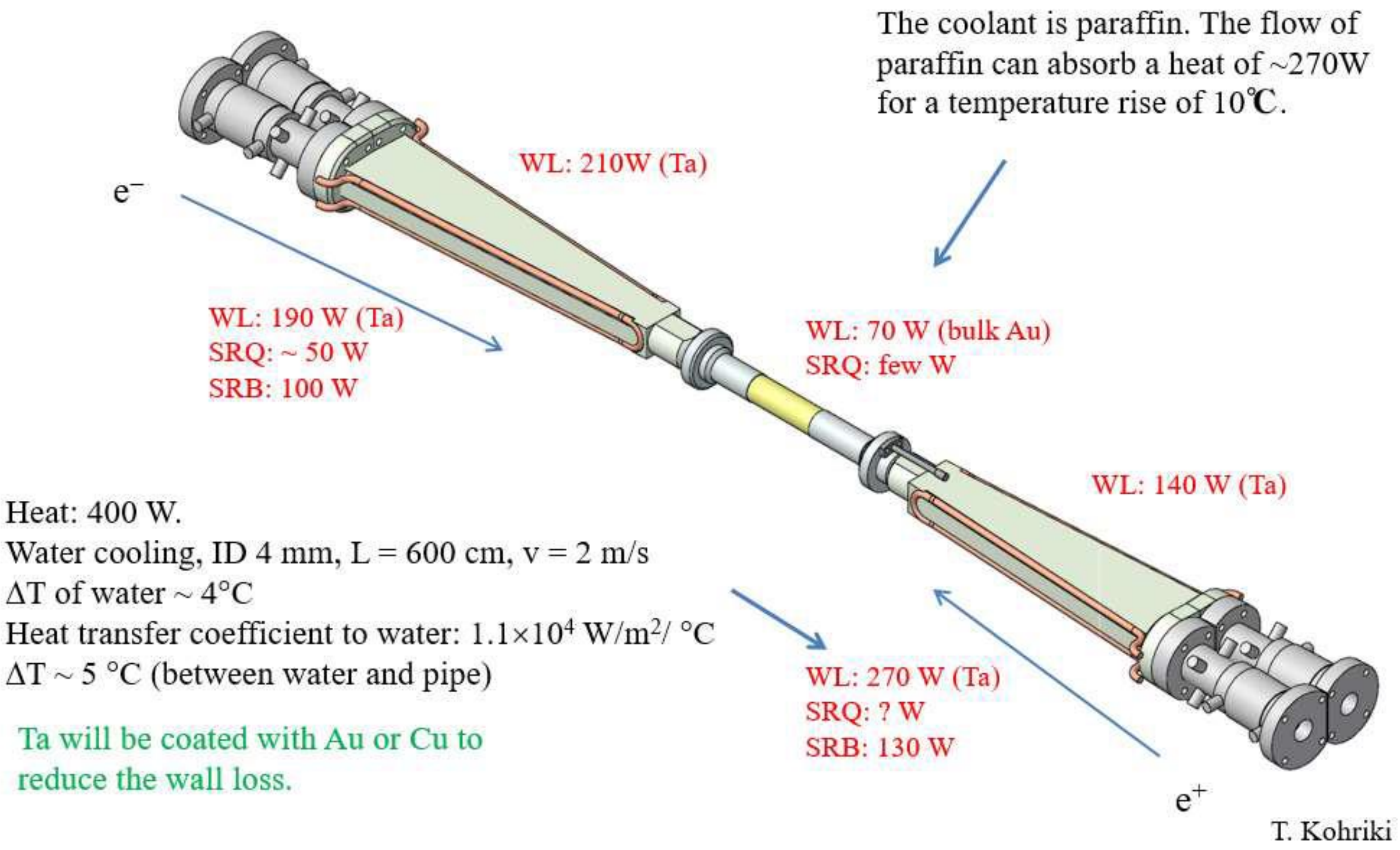
IP camera



Cryostat with FF magnets
BPM
Bellow
BPM
Y chamber
IP chamber
1175
3.4377°
10°
150
ø20
ø36
ø30
AntiSol
QD0
Corr
QF1
77.16
ø30
377
30
333
50
579
644
200
905
200
300
1286
1760

IP camera

The transverse dimensions of the cameras for SuperKEKB, FCC-ee and Super C-τ about the same – we try to use KEK solutions

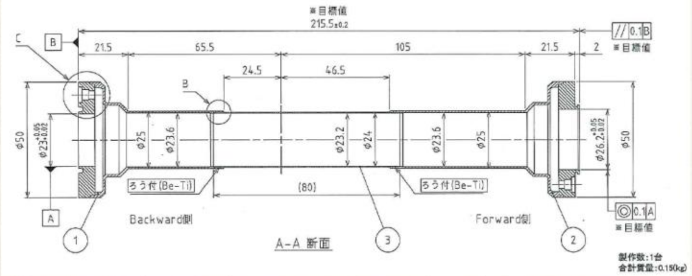


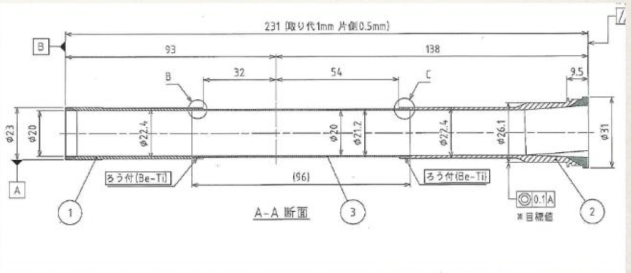
SuperKEKB (Be beam pipe)

Be beam pipe at IP for SuperKEKB

Outer pipe

Inner pipe





- The beam pipe at the IP of SuperKEKB is a double pipe, each consists of middle (Be) and side (Ti) parts, brazed to each other.

	Outer	Inner
Thickness (Be) [mm]	0.4	0.6
Thickness (Ti) [mm]	0.7	1.2

- The inside of inner pipe is Au coated (10 μm thick via 0.3 μm Ti), by magnetron-sputtering.

MTC Metal Technology Co.Ltd.

K. Kanazawa (KEK)

Paraffin for the cooling media

- Normal 10-decan ($C_{10}H_{22}$).
- N=10 is chosen to avoid freezing due to an additional He-gas cooling.
- Higher N is usable otherwise for higher flash point.

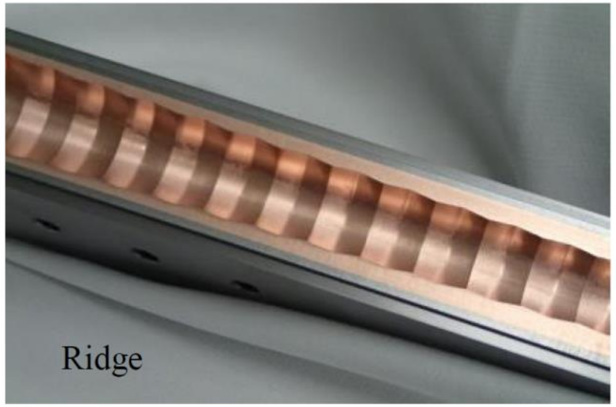
N	10	11	12
Melting point (°C)	-30	-25	-7.5
Flash point(°C)	46	68	85

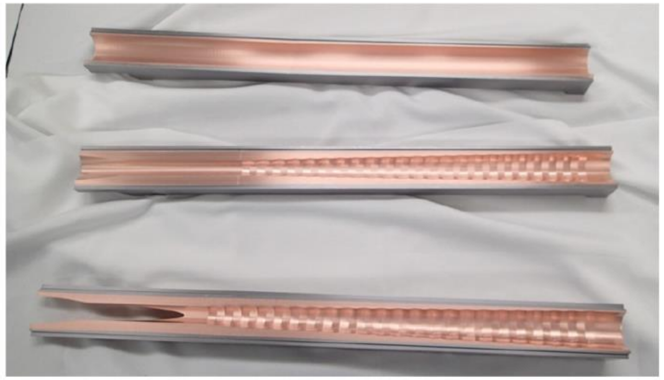
H. Nakayama (KEK, Belle II)

https://indico.cern.ch/event/803859/contributions/3343825/attachments/1807047/2949675/Bepipe_190307_Oide.pdf

SuperKEKB

IP chamber (Ta part manufacturing)

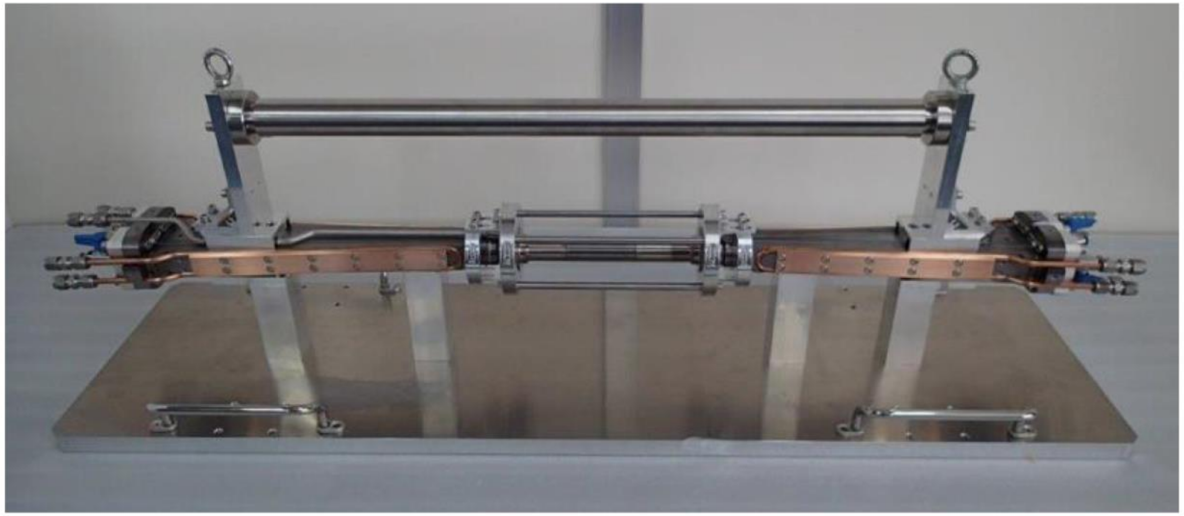




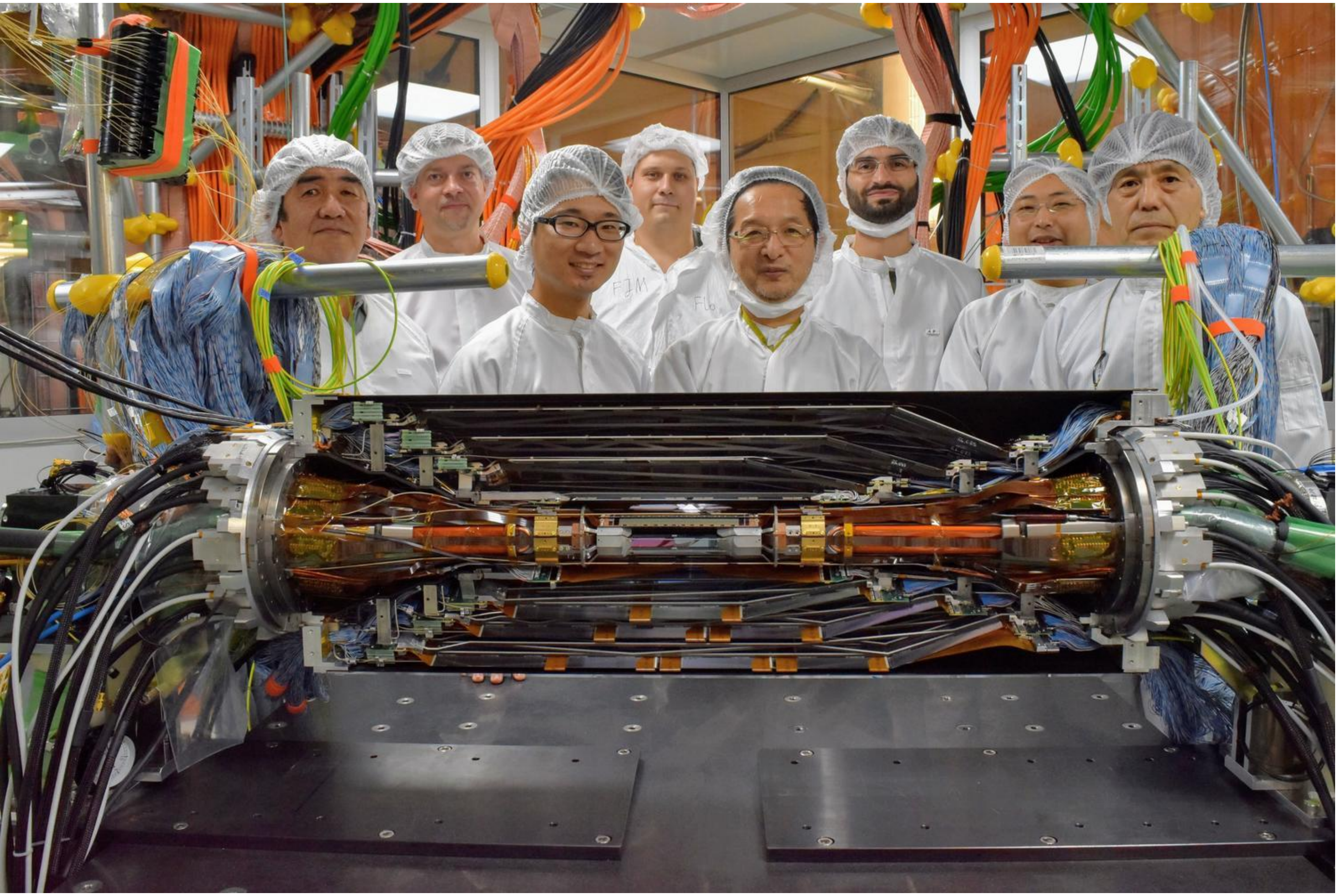
End flange

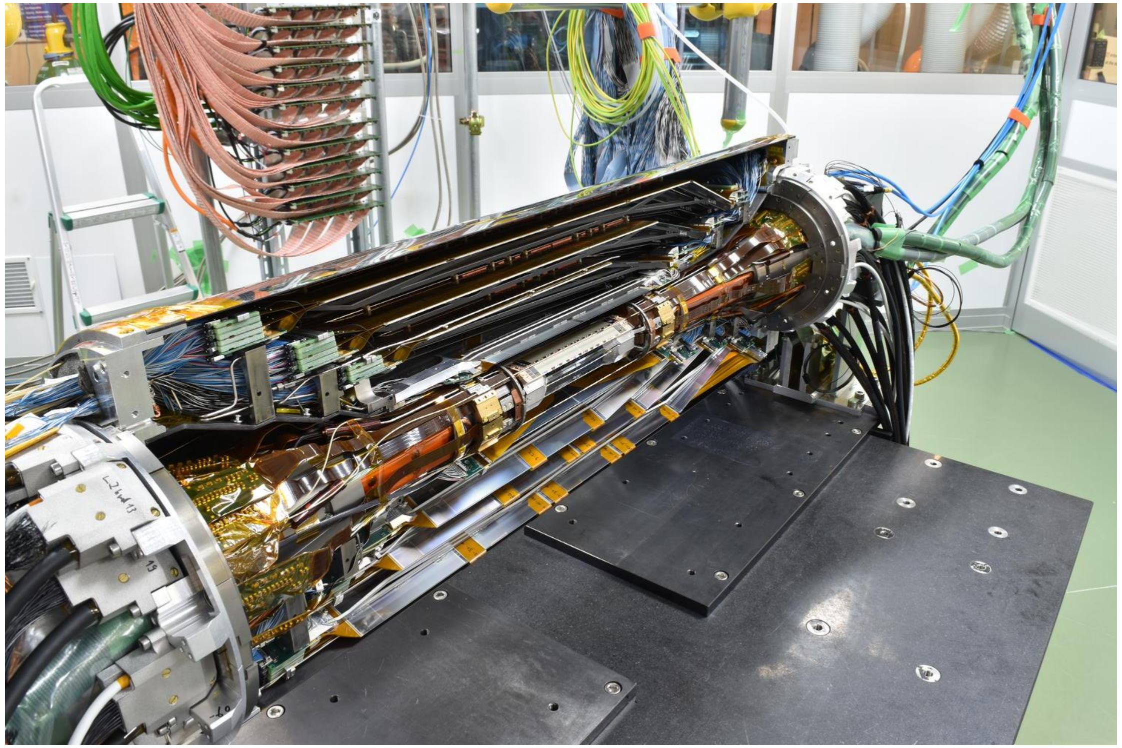
Metal Technology Co., Ltd

IP chamber with a handling tool

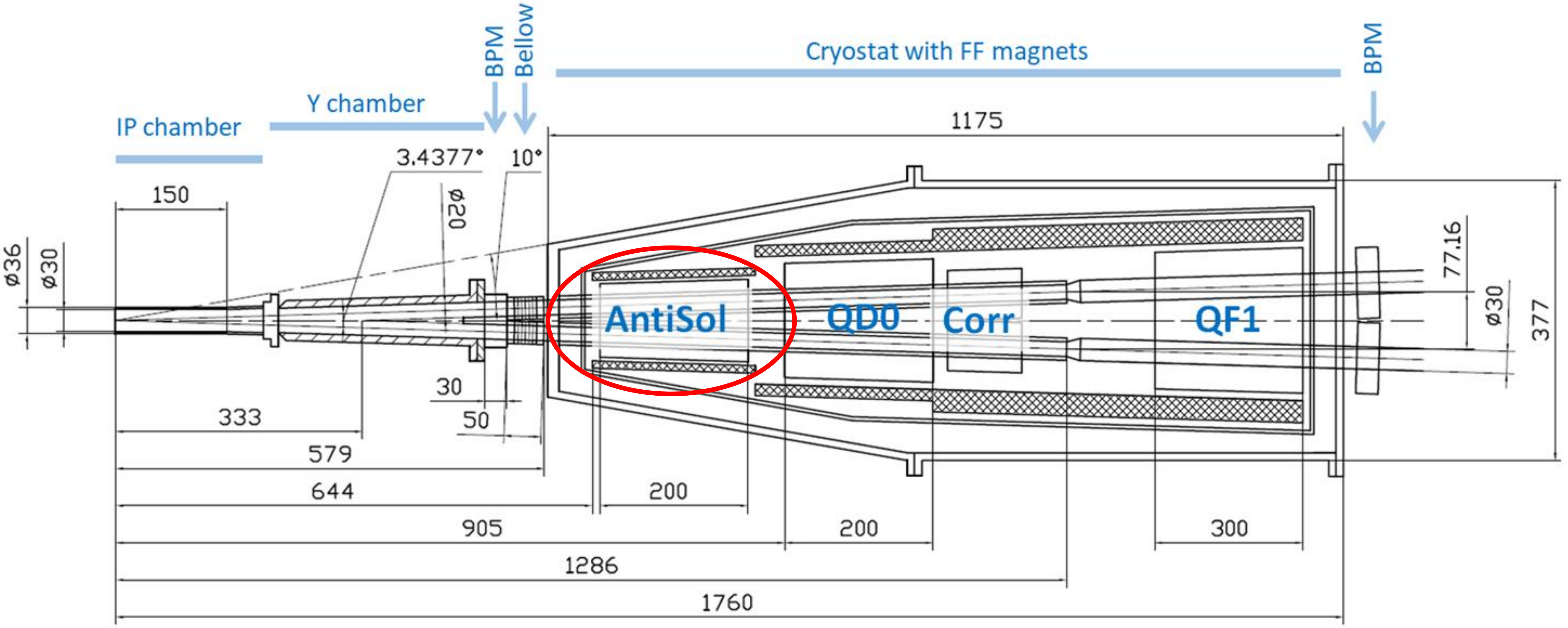


Construction of the Vertex Detector Belle II

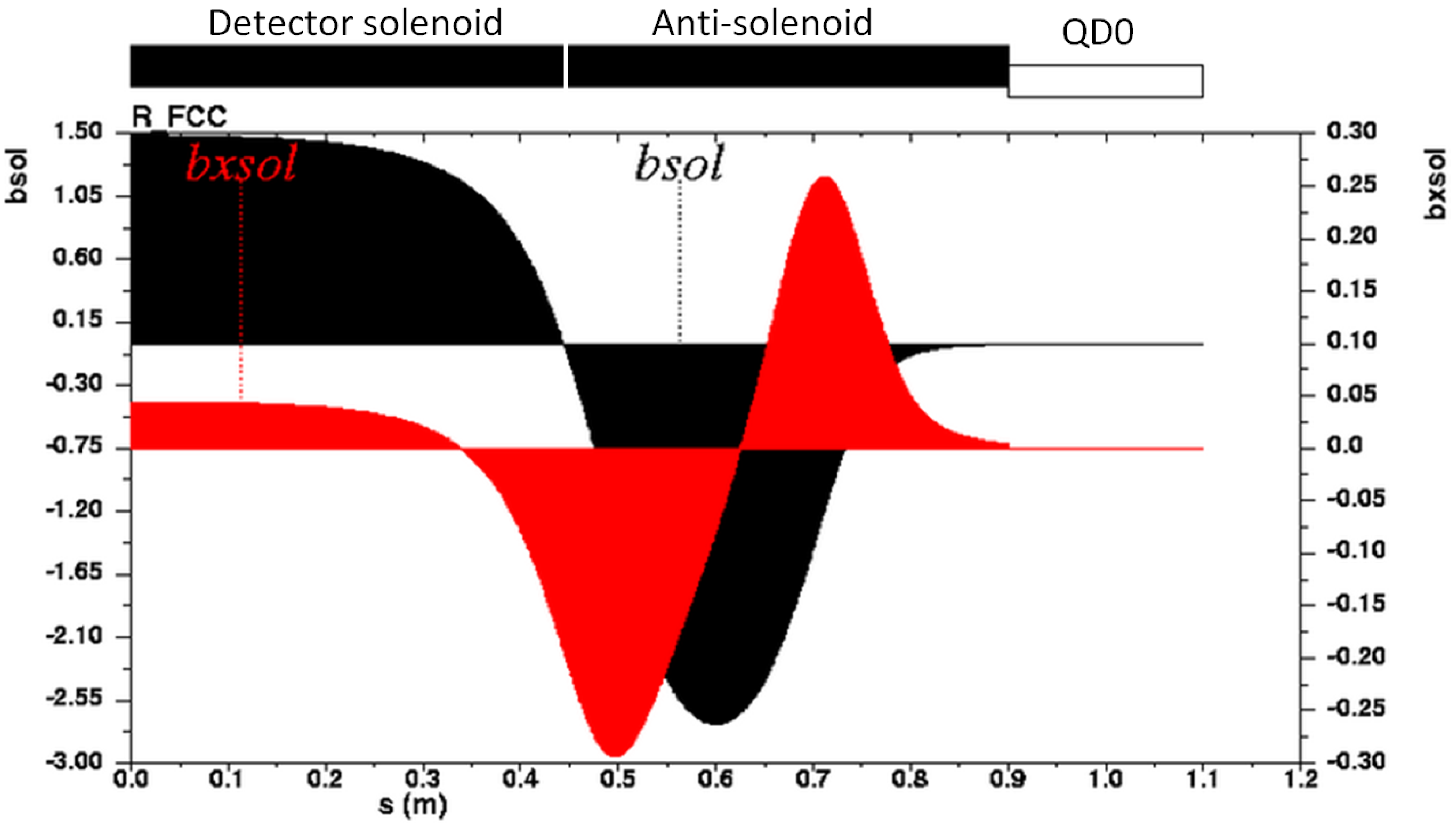




Solenoidal field on the beam path

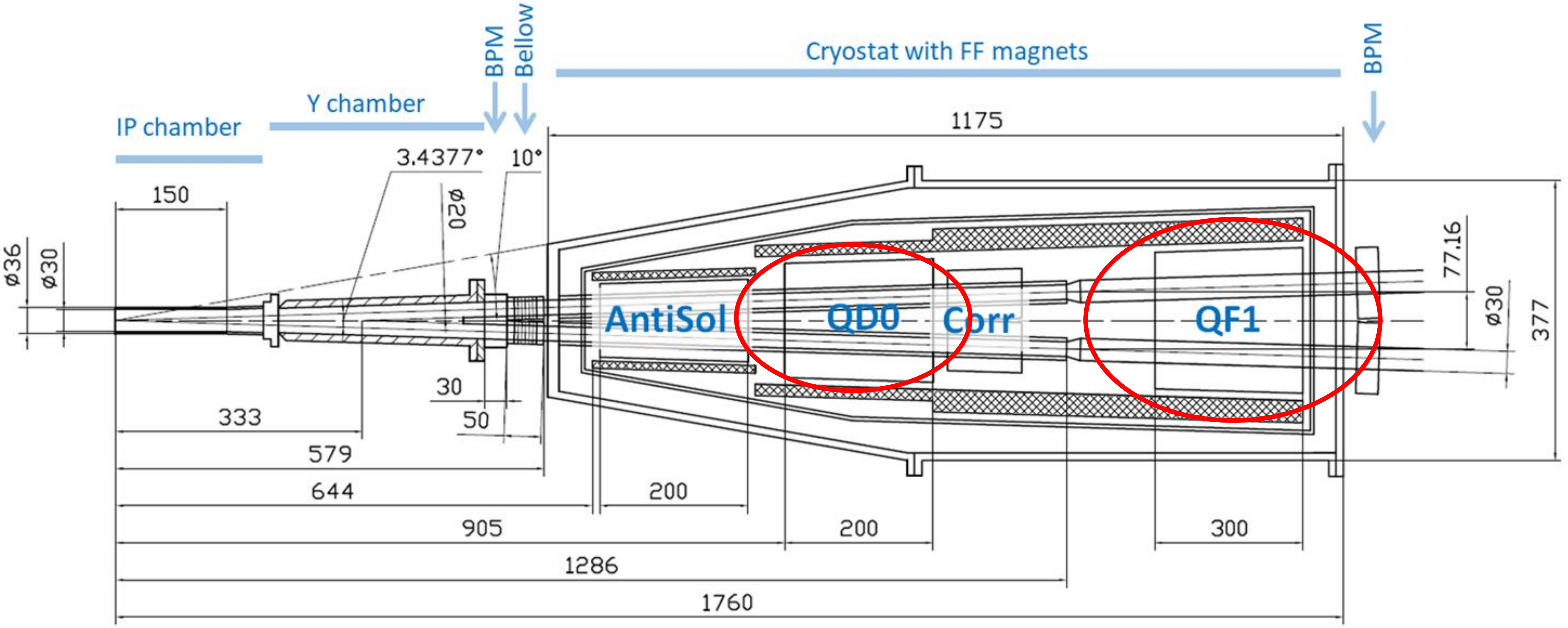


Solenoidal field on the beam path

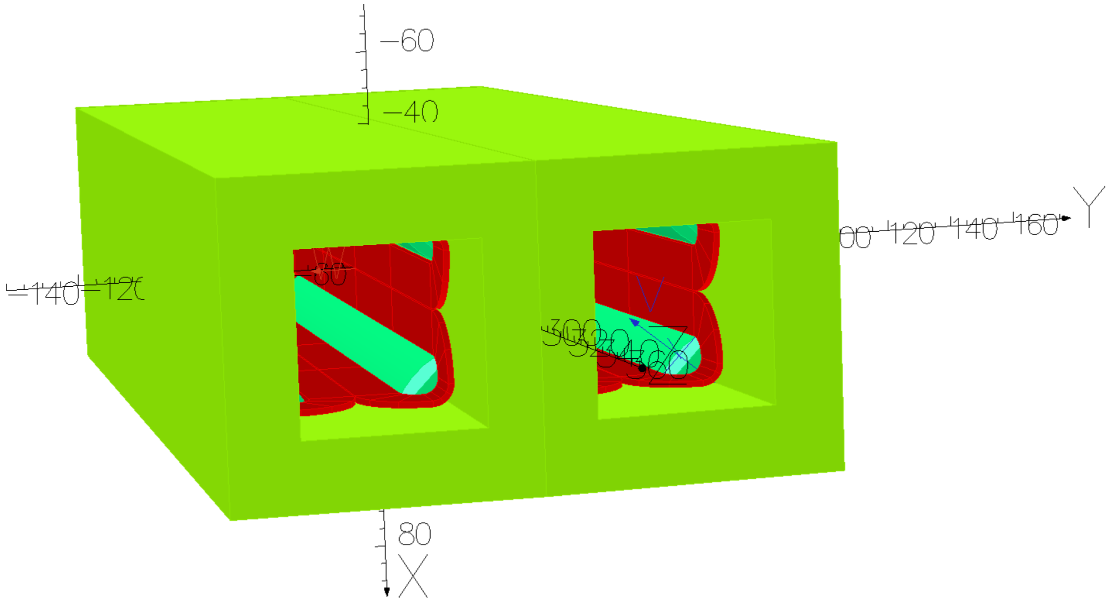


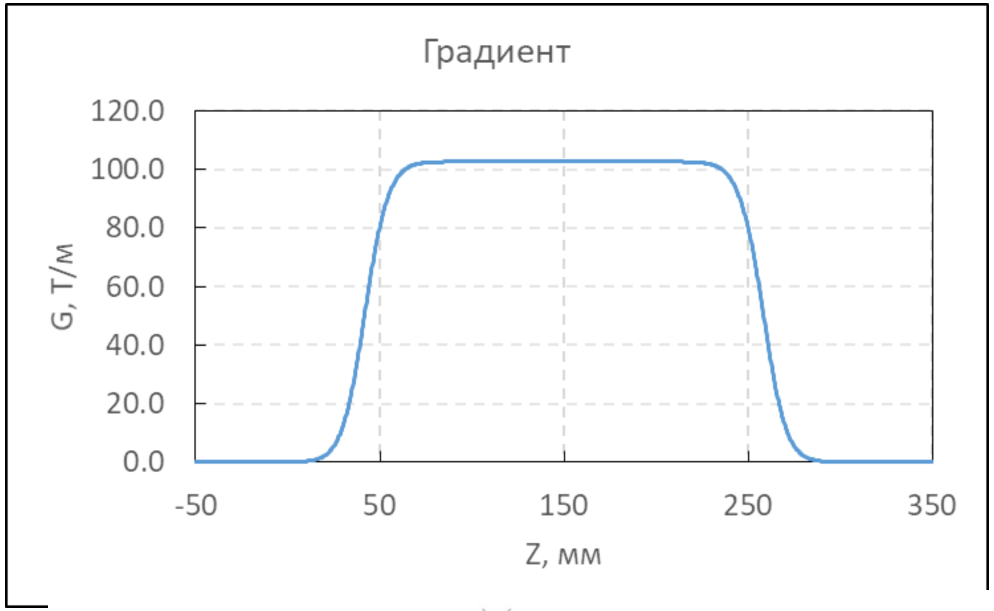
Profile of the solenoidal field along the beam path (shown in black).
The horizontal field on the axis of the beam (in red).

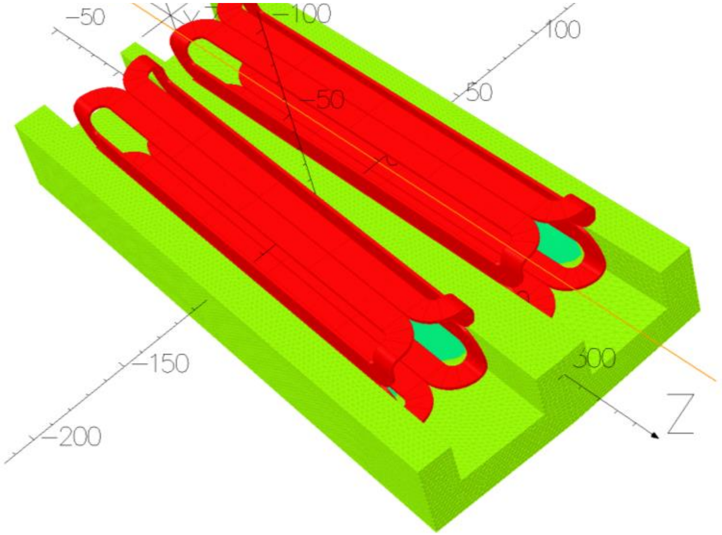
Twin-aperture SC quadrupole

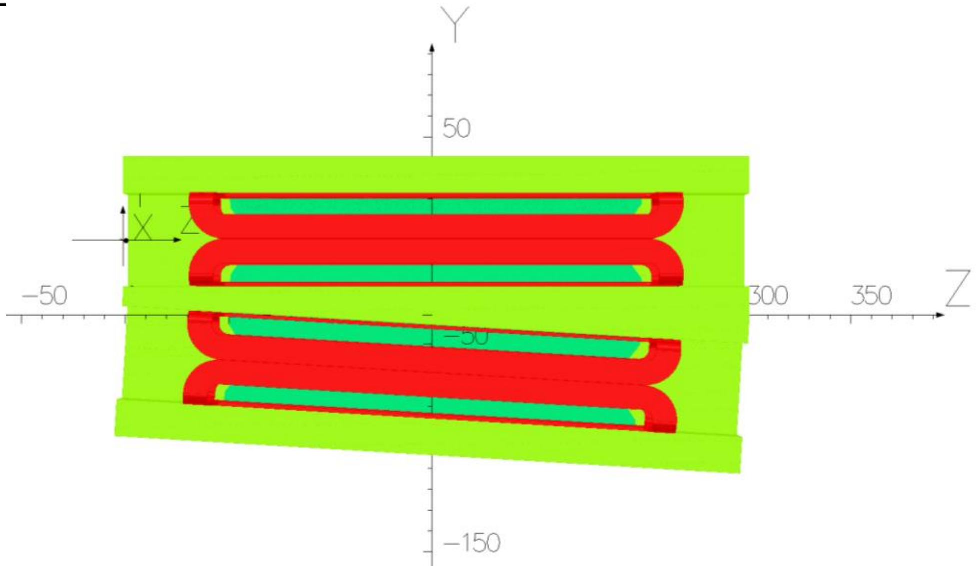


Iron yoke twin-aperture SC quadrupole



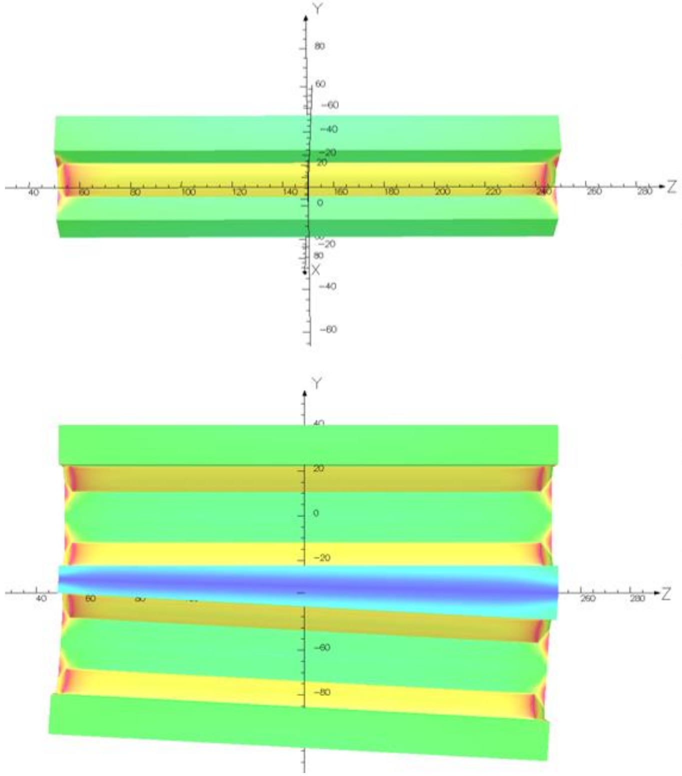


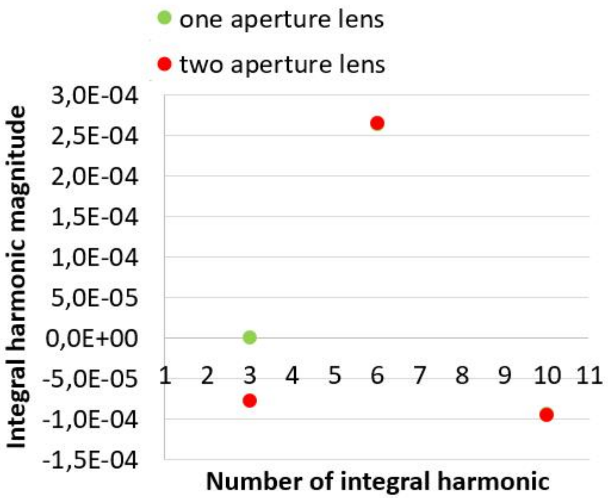


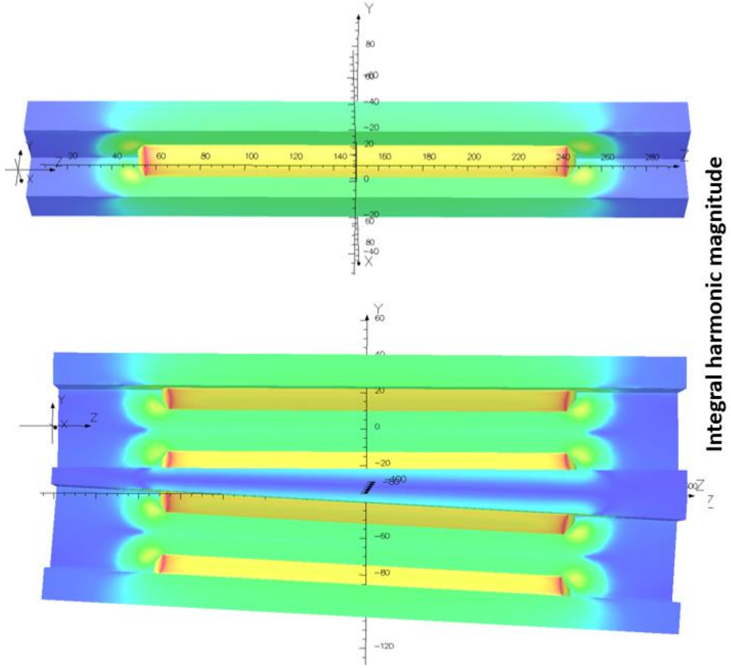


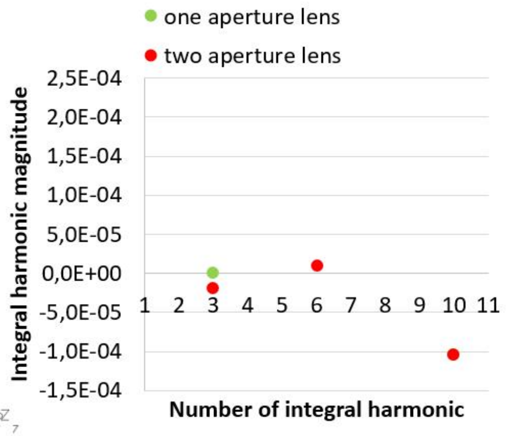
Iron yoke twin-aperture SC quadrupole

Yoke extension reduces the third integral (skew sextupole) harmonic from -8×10^{-5} to -2×10^{-5}. End pole chamfers reduce the sixth harmonic from 2.7×10^{-4} to 1.8×10^{-5}.



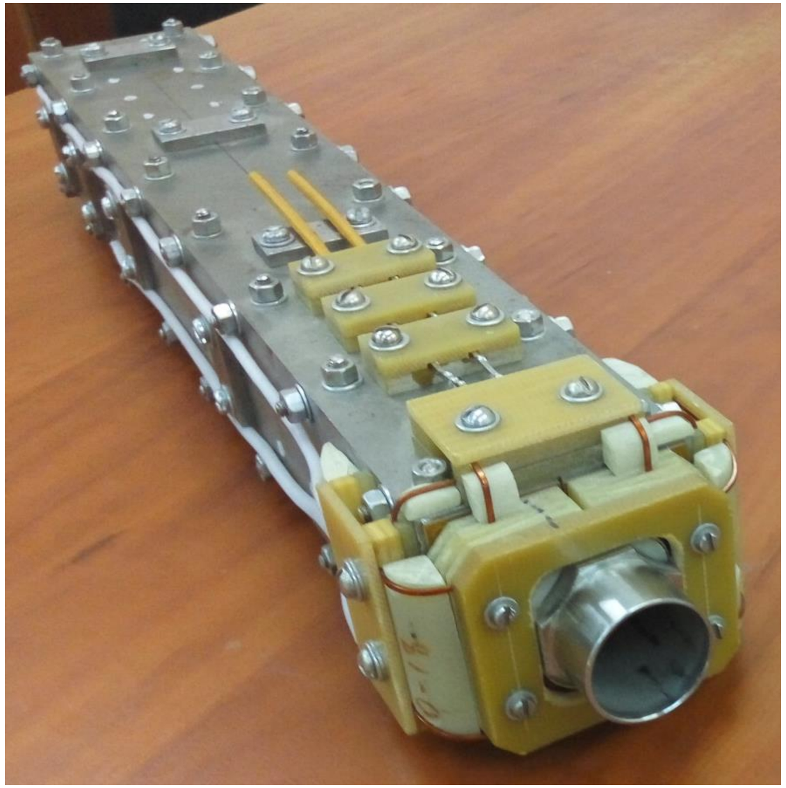




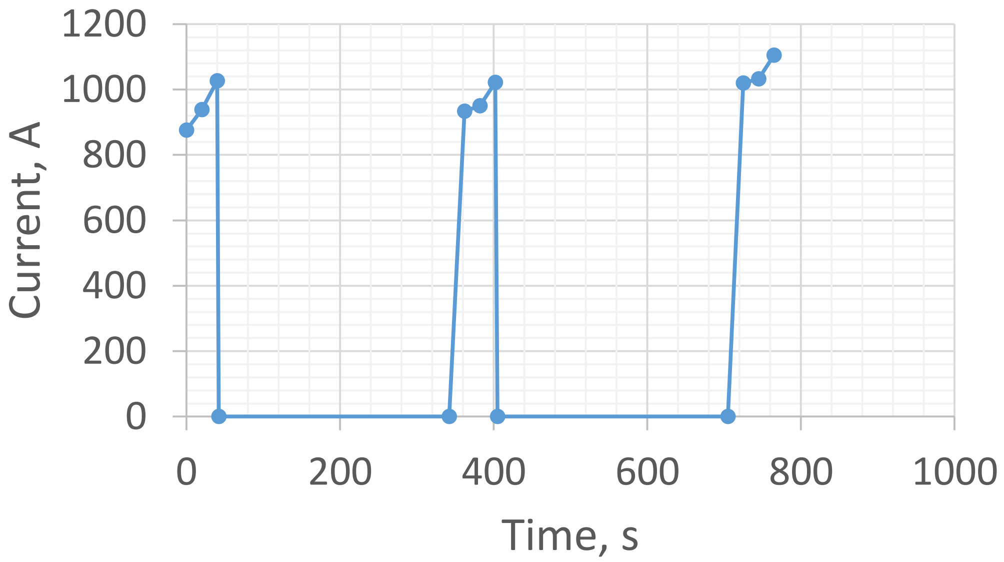


We started detailed manufacturing design of the twin-aperture quadrupole and the Hall probe magnetic measurement equipment for a full scale magnetic measurement.

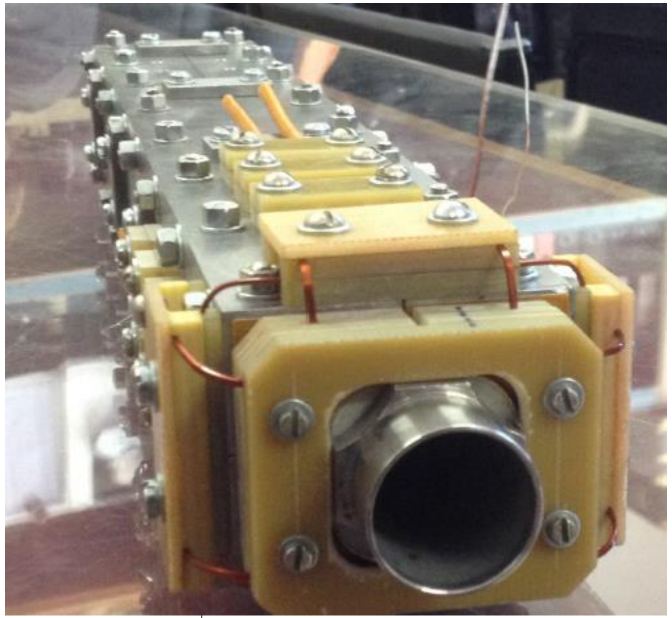
Iron yoke twin-aperture SC quadrupole

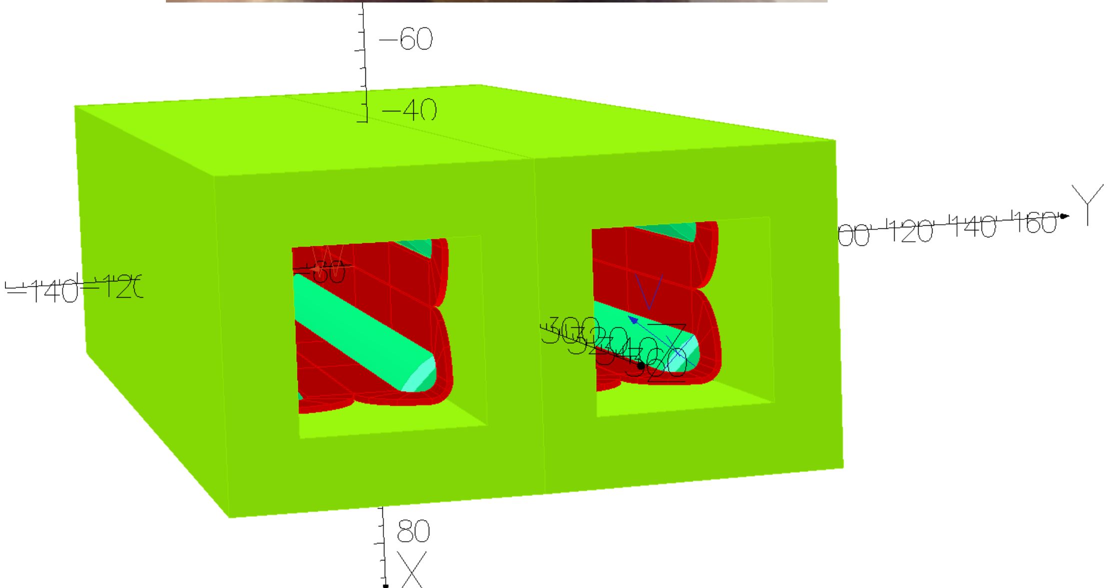


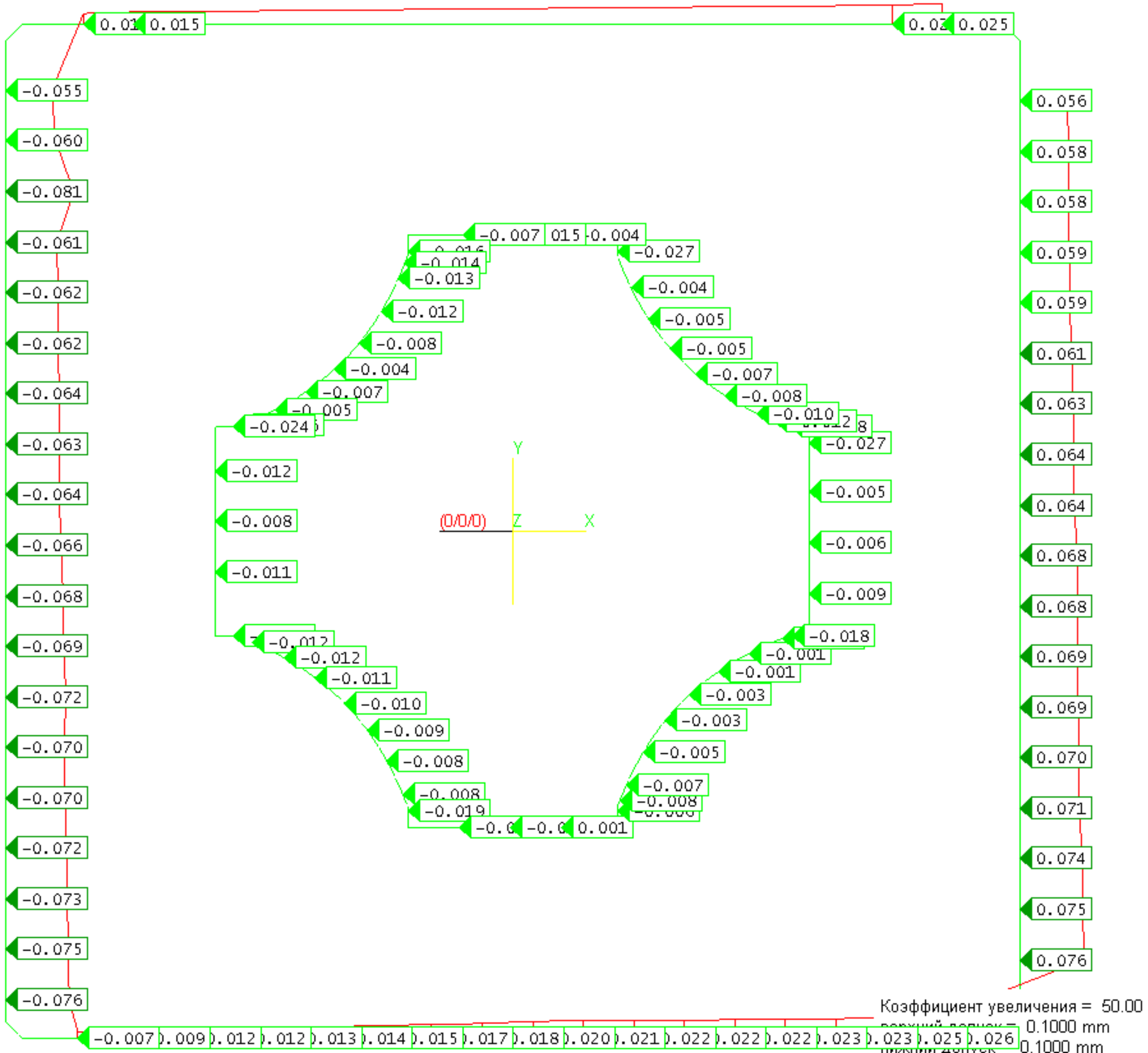
Cu/Sc Ratio (nom)	Bare Size (mm)	Ins. Size (mm)	RRR	Ic Amps (min)	Length (m)	Spool ID
1.35:1	1.20x0.75	1.28x0.83	>70	510@7T	2,730	917



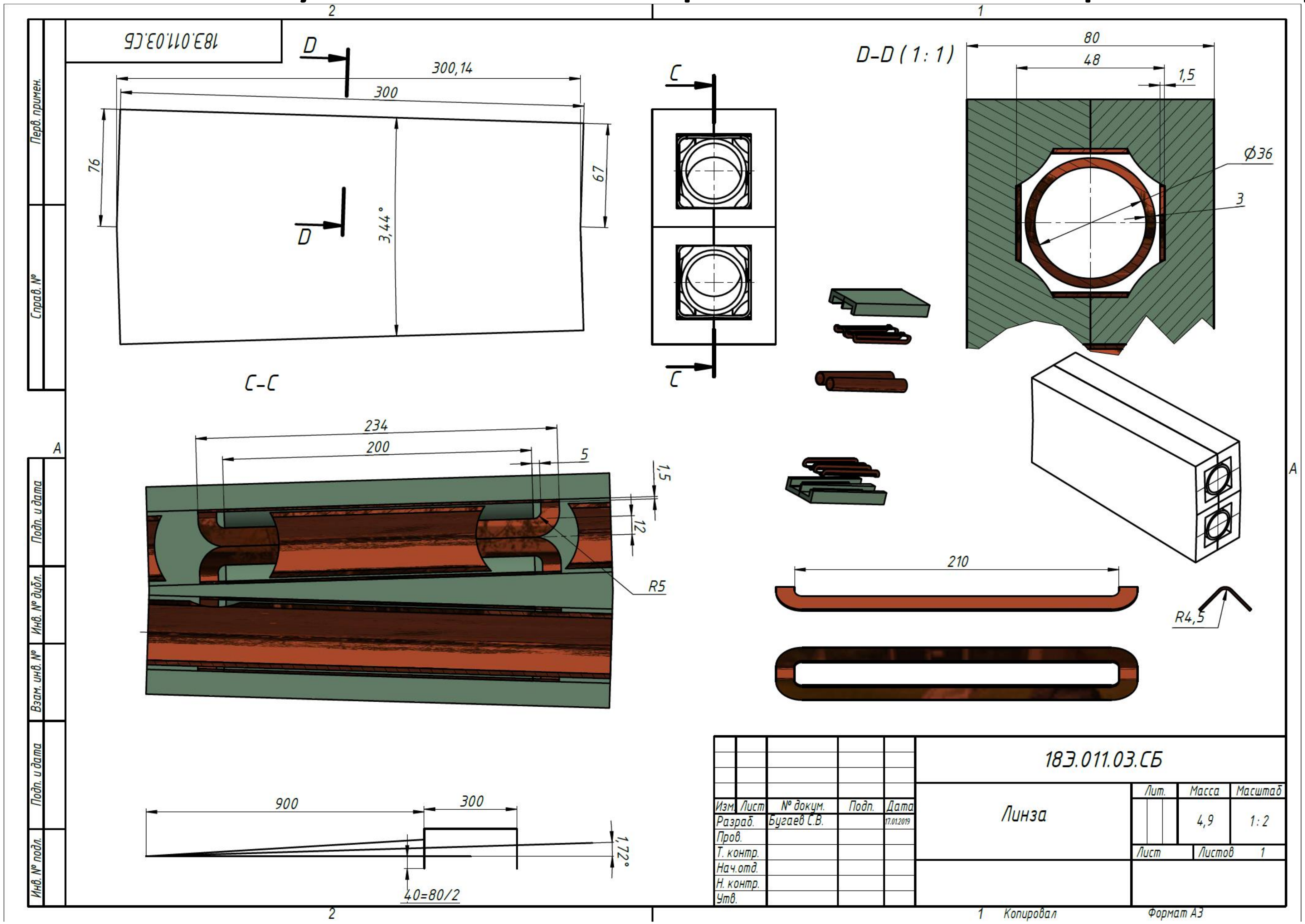
Iron yoke twin-aperture SC quadrupole





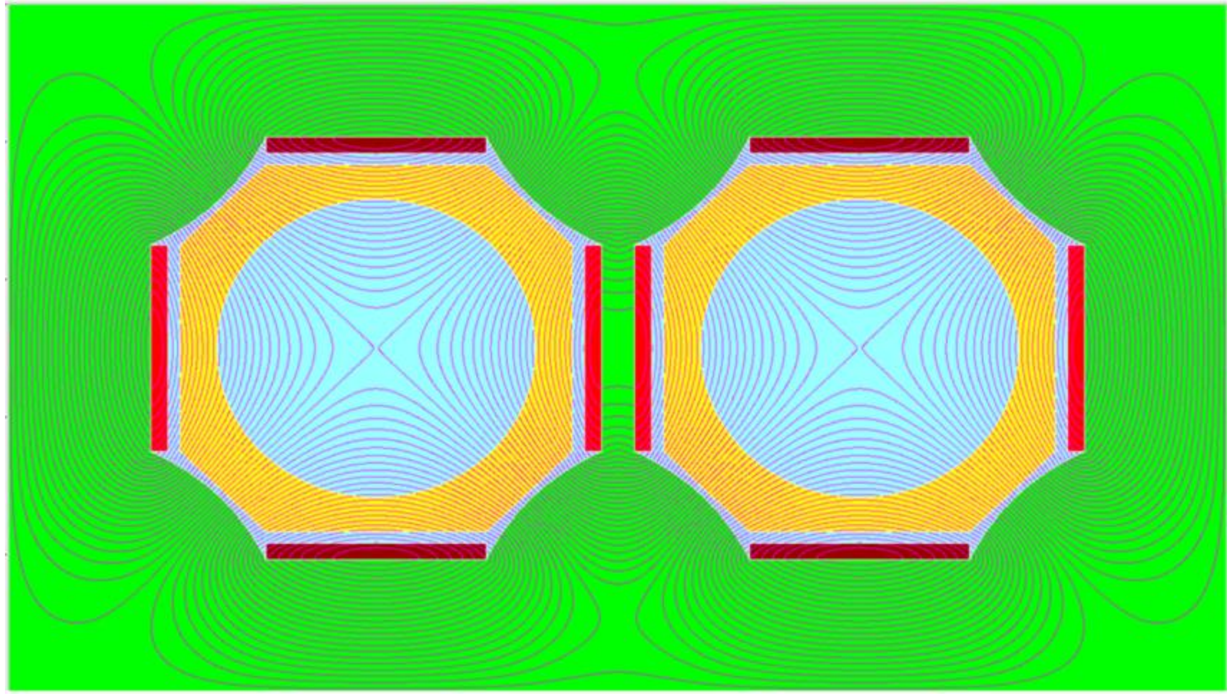


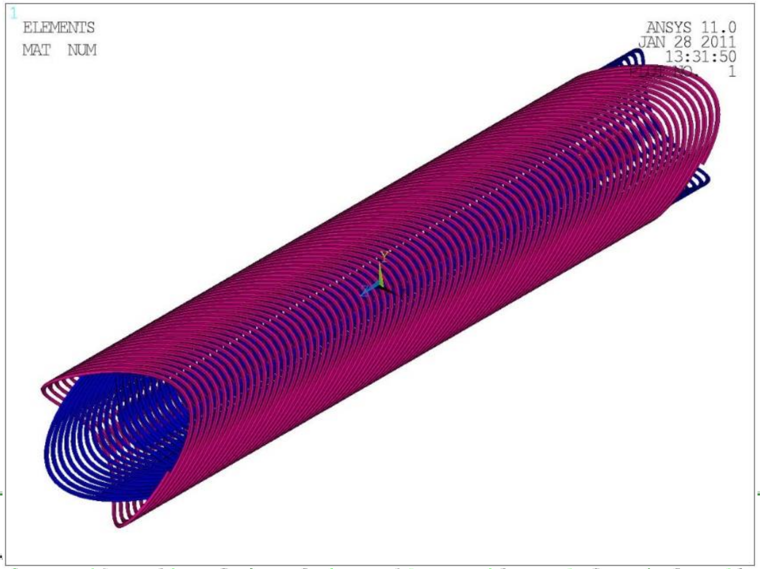
Iron yoke twin-aperture SC quadrupole

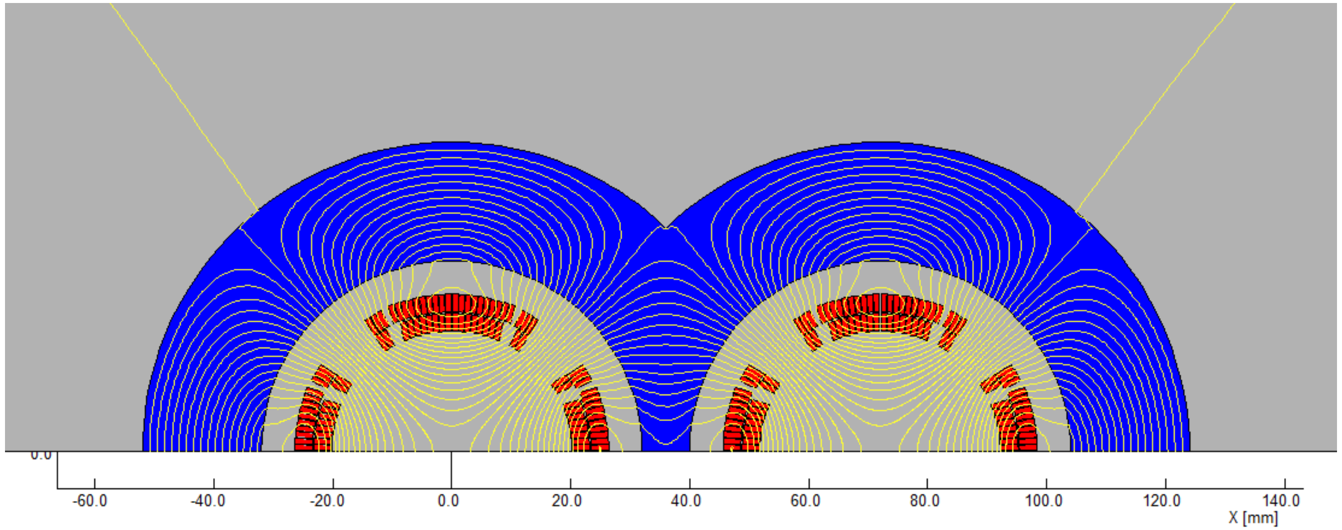


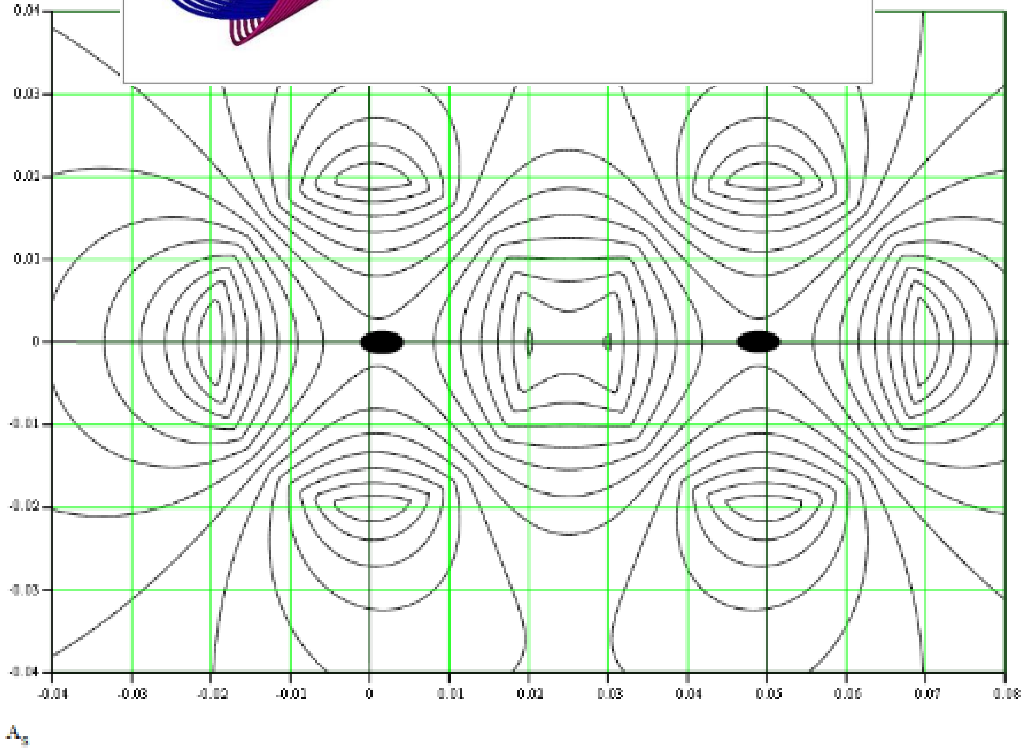
General view drawing of the iron yoke quadrupole. Technical design is in progress.

Features of different types of two aperture lenses









The Canted Cosine Theta (CCT) technology

CCT design has excellent field quality

- there are small edge effects have been corrected locally using
- a novel technique based on the addition of multipole components directly in the CCT-quadrupole coil geometry
- cross talk between the two quadrupoles has been corrected.

The result is a quadrupole magnet with integrated multipole components of less than 10^{-5}

These multipole values do not take into account the effect of imperfections like misalignments and mechanical tolerances. It is, therefore, assumed that cross talk and edge effects are perfectly compensated. The final field quality will be dominated by mechanical tolerances and misalignments.

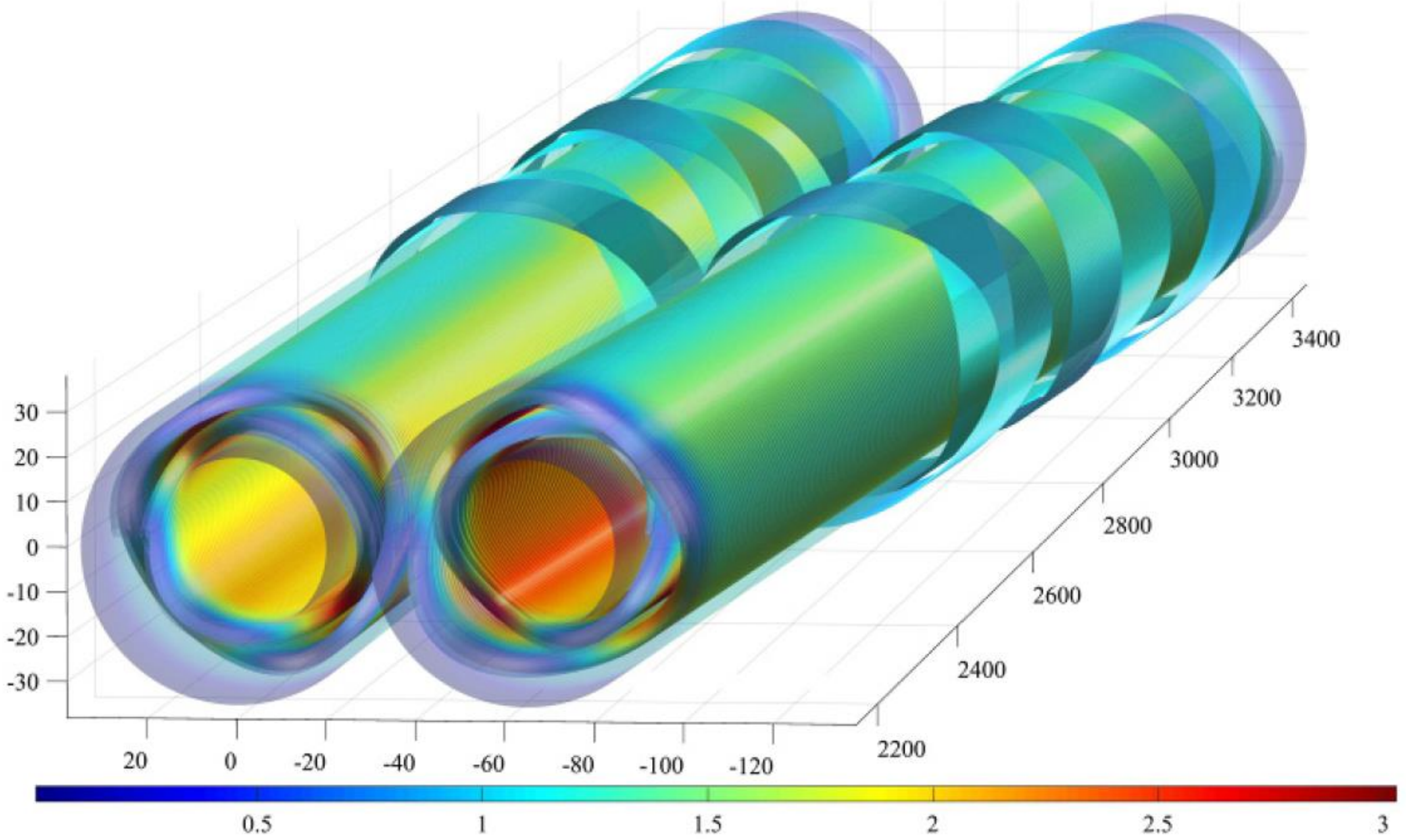


Fig. 3.7. The position of the two quadrupole magnets near the IP (QC1L1P on the left and QC1L1E on the right). The horizontal and vertical orbit correctors are shown along with the skew quadrupole corrector, fitted as extra rings on top of the QC1L1 magnets. The colours correspond to the magnitude of the magnetic field at the surface. A horizontal angle of 30 mrad separates the two beam pipes. The tips of the quadrupoles are 2.2 m from the IP. The axes are in mm and follow the positron beamline; the IP is at the origin (0,0,0).

CEPC (IPAC19)

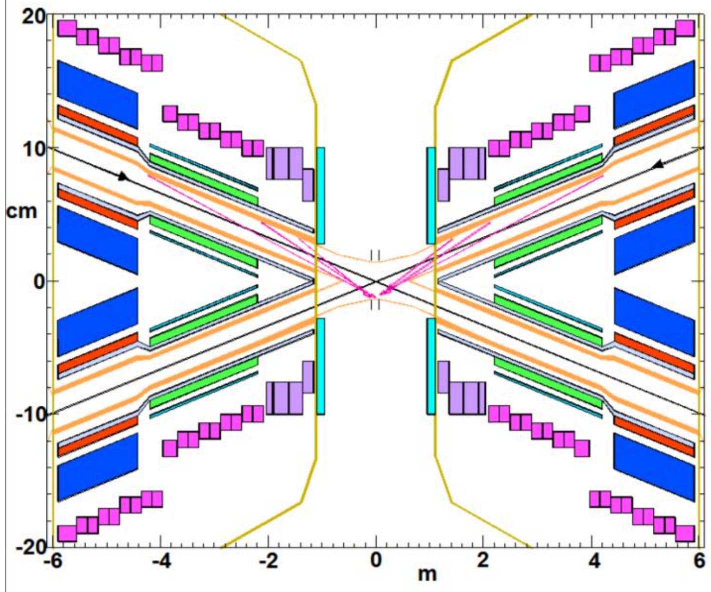
Beam performance of CEPC collider ring

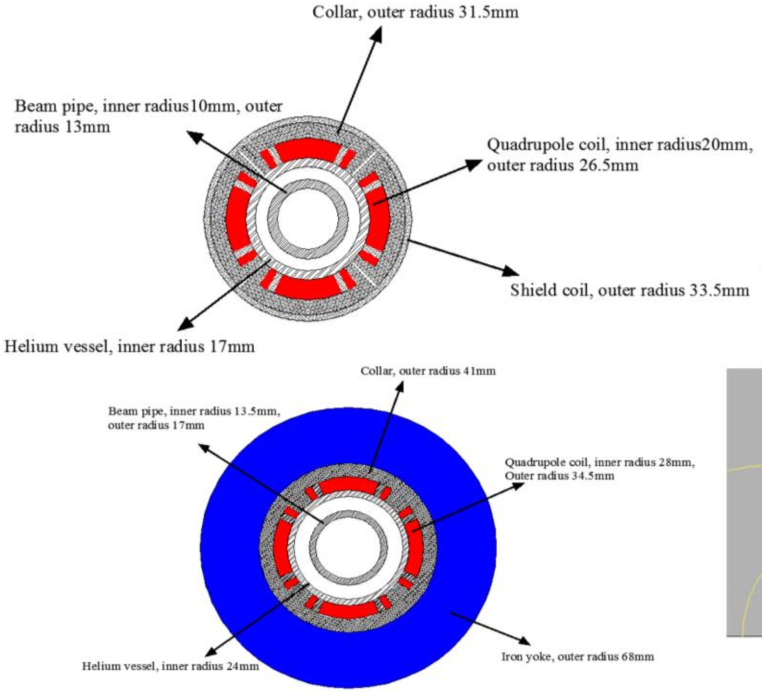
Interaction region

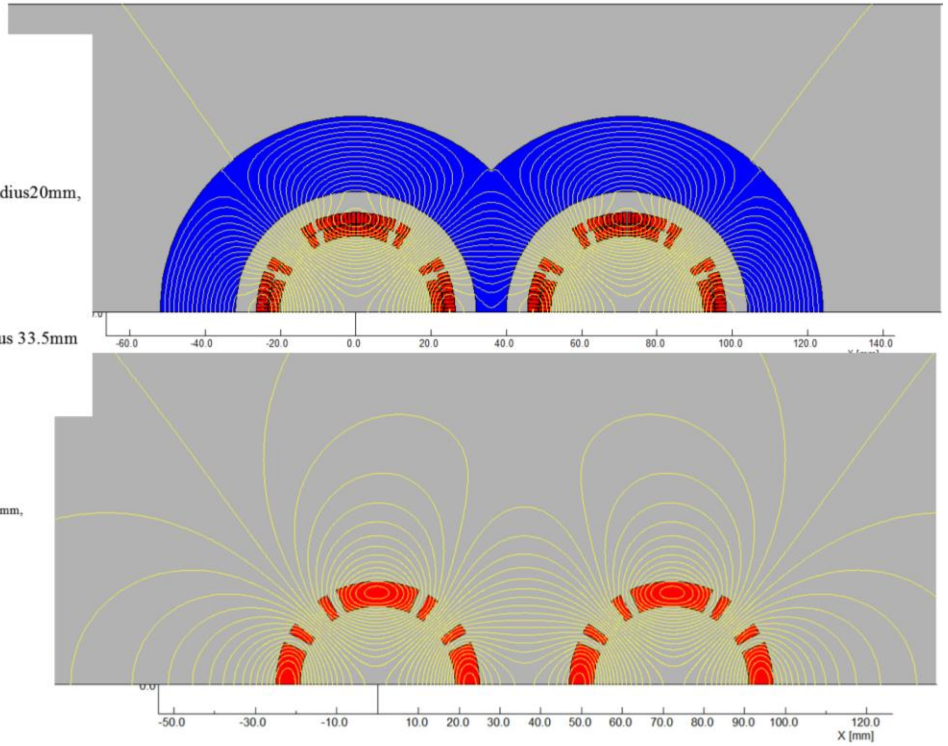
✓ **L*=2.2m, θc=33mrad, βx*=0.36m, βy*=1.5mm, Detector solenoid=3.0T**

– Lower strength requirements of anti-solenoids **(B_z~7.2T)**

– Enough space for the SC quadrupole coils in two-in-one type (Peak field 3.8T & 136T/m) with room temperature vacuum chamber.

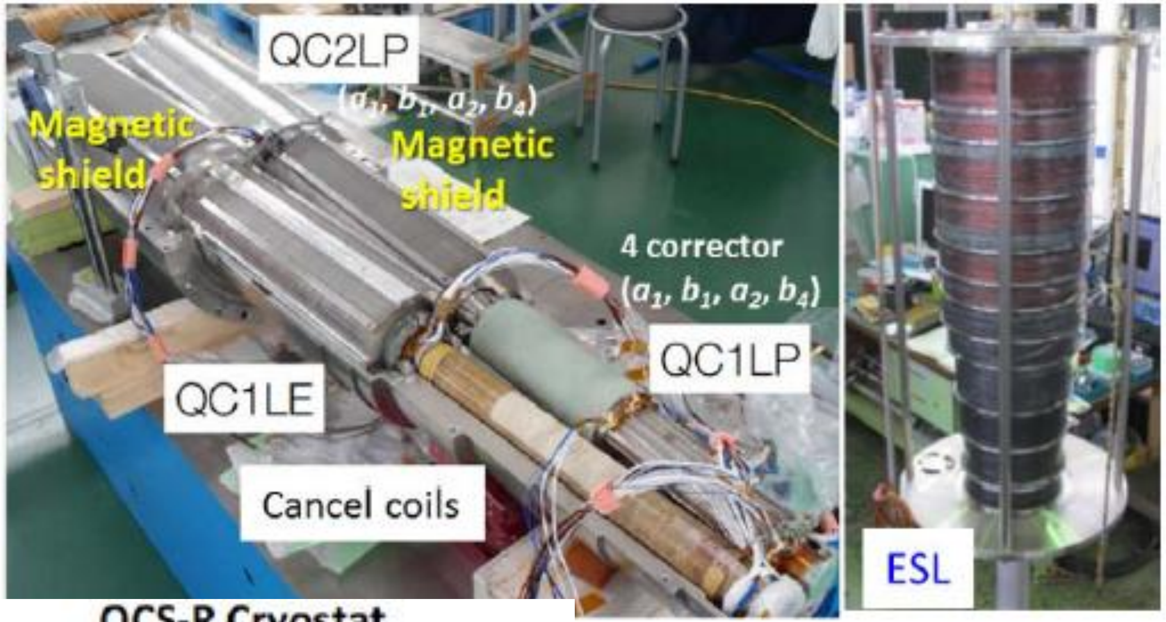


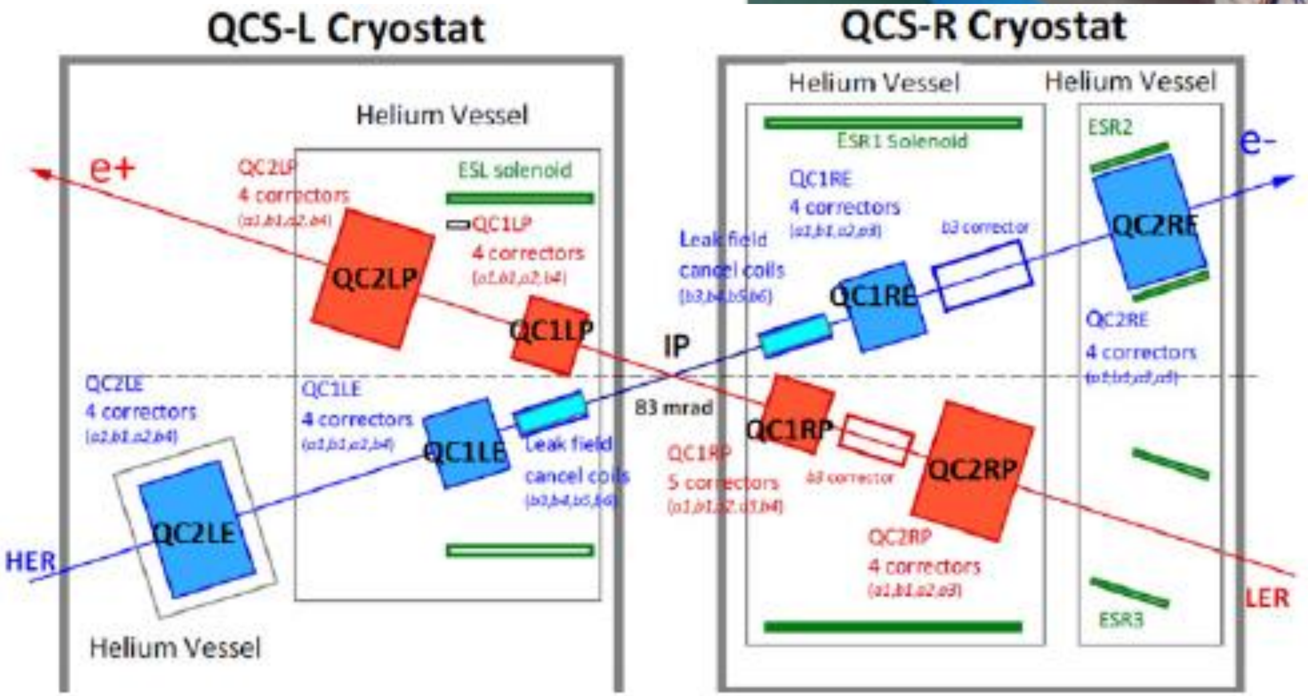




SuperKEKB IR design

IR superconducting magnets





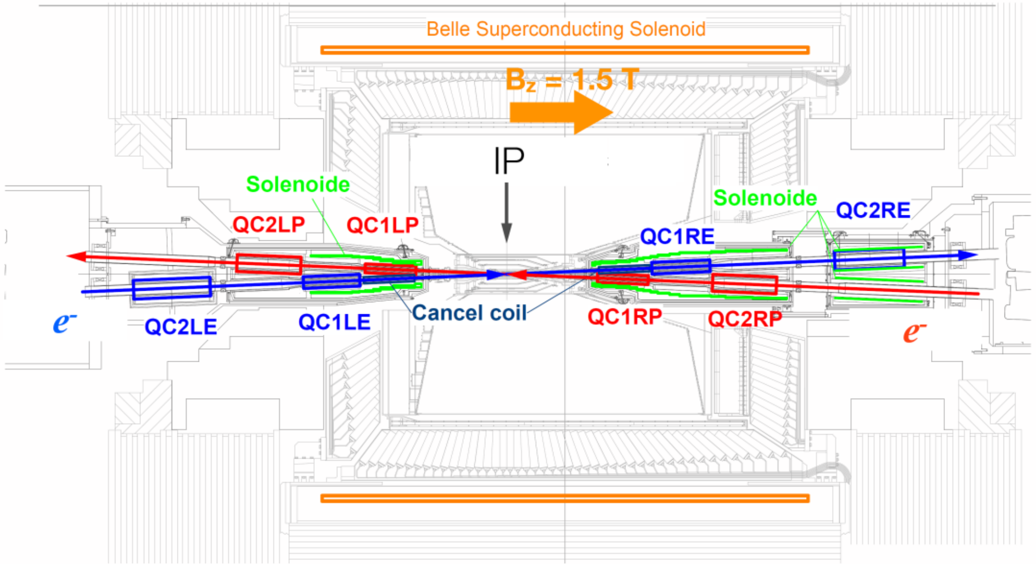
Layout of Final Focus superconducting magnets

SUPER KEKB

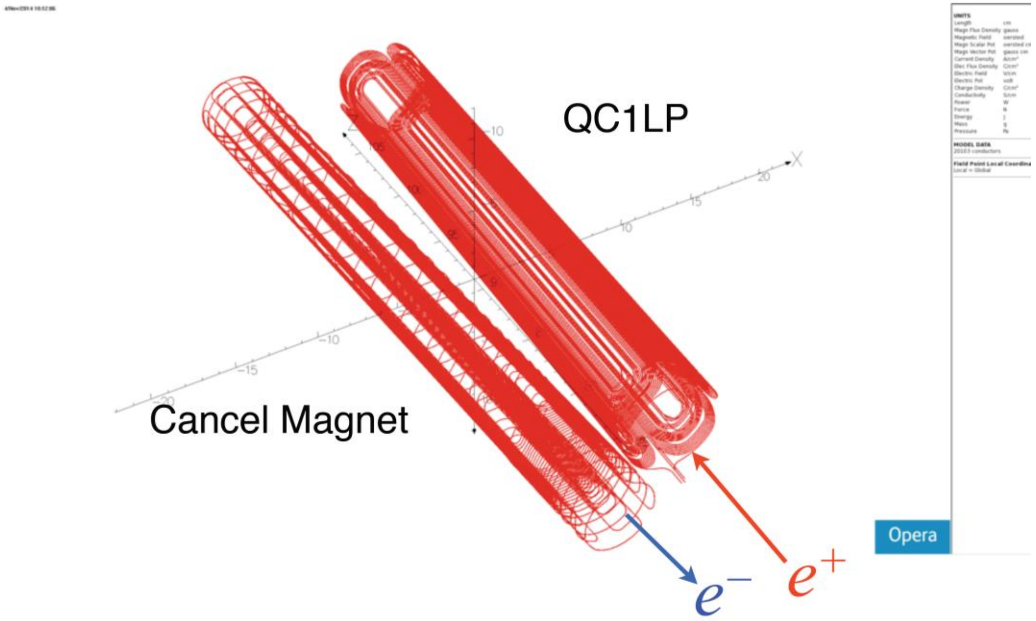
Final focus system at SuperKEKB

Y. Arimoto
The Workshop on Circular Electron Positron Colliders, Rome
24th May 2018

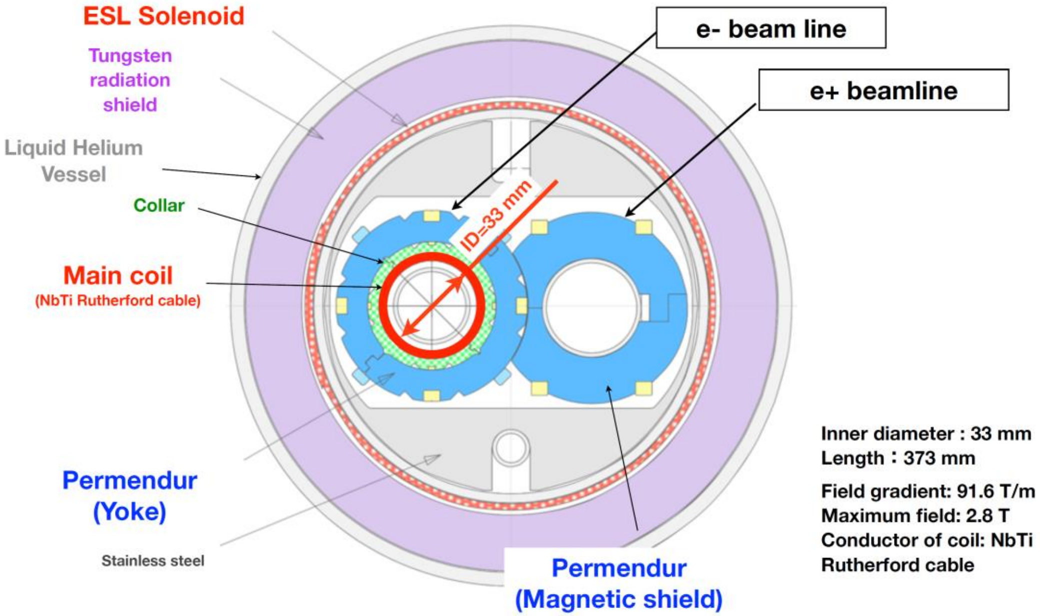
Belle II and QCS



Layout of cancel magnets



Cross section of QC1LE with Lq. Helium Vessel



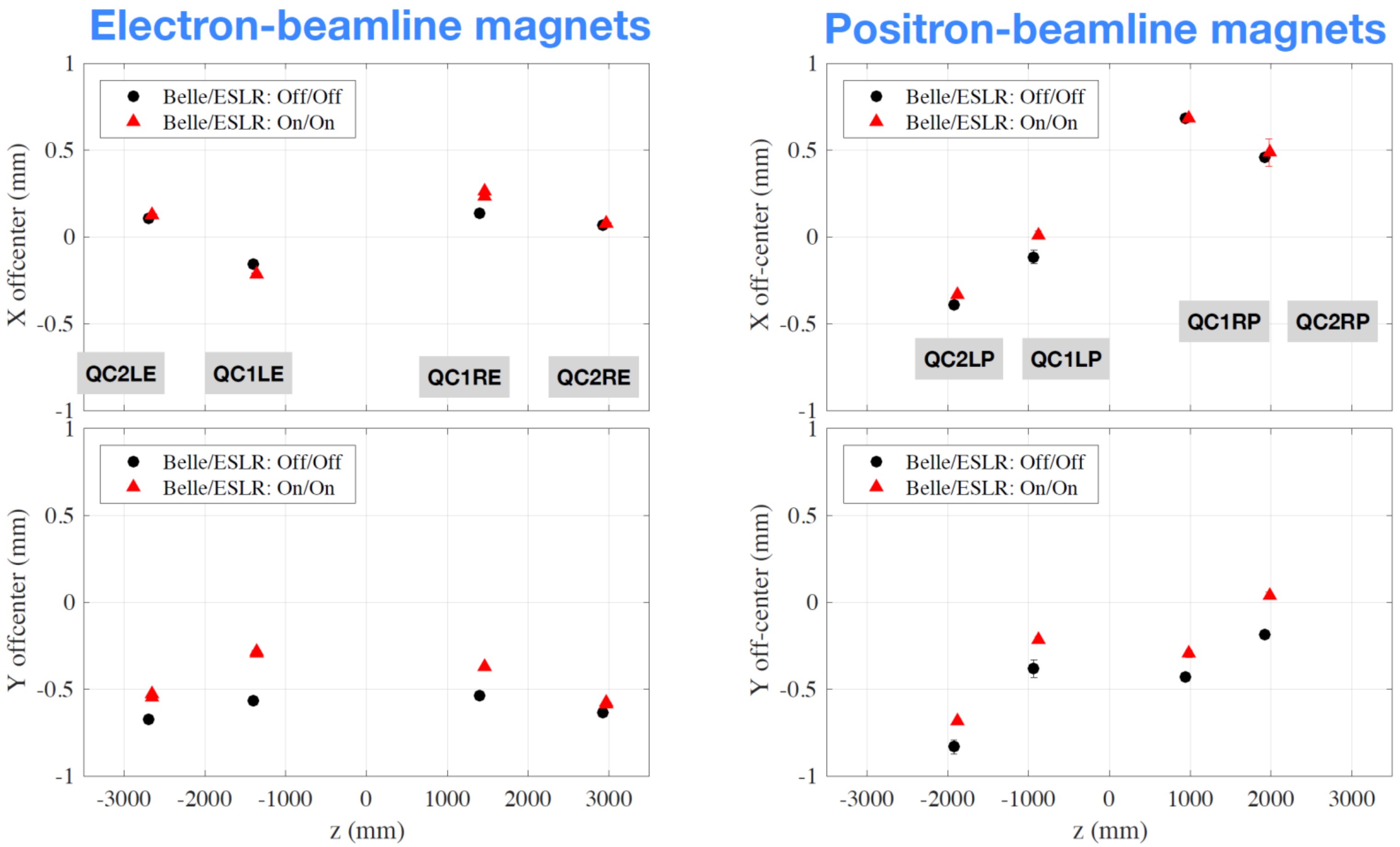
Inner diameter : 33 mm
Length：373 mm

Field gradient: 91.6 T/m
Maximum field: 2.8 T
Conductor of coil: NbTi Rutherford cable

Magnet center for each magnet wrt beamline

Final focus system at SuperKEKB

Y. Arimoto
The Workshop on Circular Electron Positron Colliders, Rome
24th May 2018



Magnet positions are varied with solenoid field turned on/off.

dx ~ 0.1 mm, dy~0.3 mm

The maximum offset from beam line are 0.7 mm for QC1RP in x-direction.
The maximum offset from beam line are -0.6 mm for QC2LP in y-direction.
These offset can be corrected with dipole correctors.

Iron yoke twin-aperture SC quadrupole

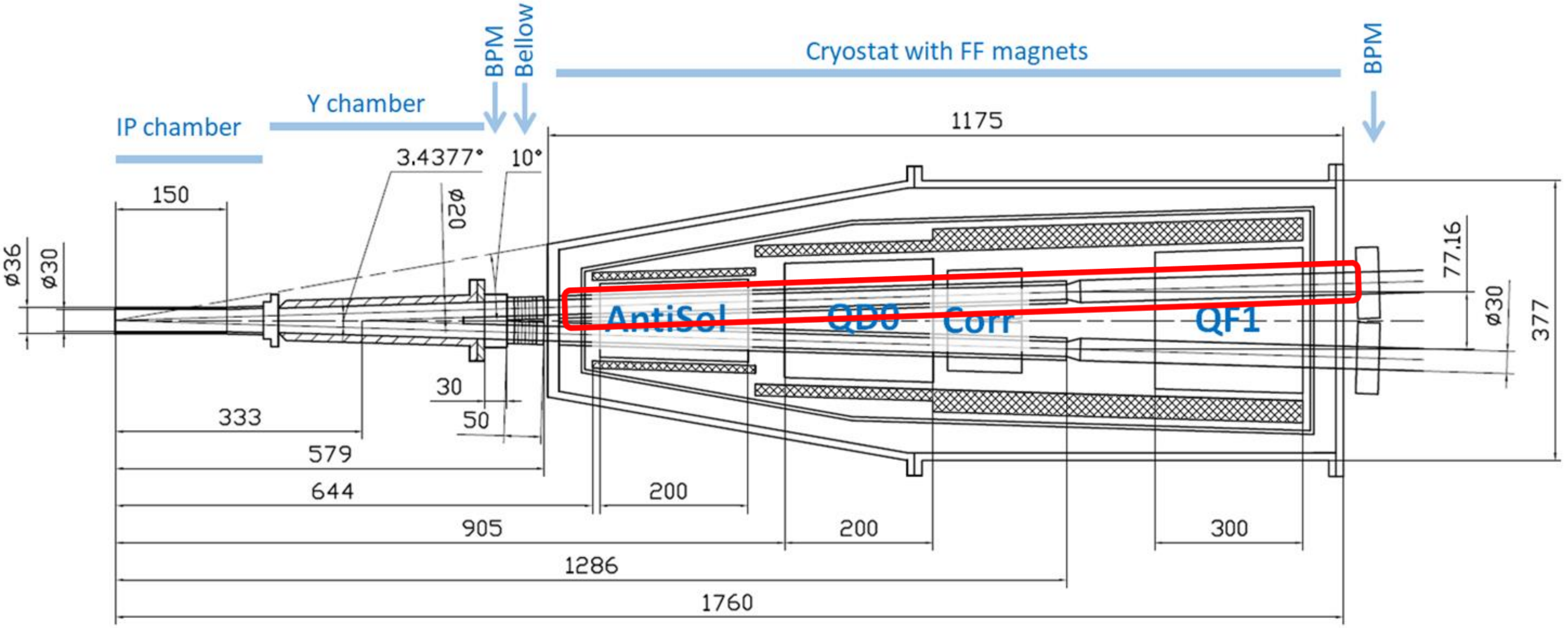
- BINP: iron yoke twin-aperture SC FF quadrupole (Pavel Vobly)
- FCC-ee: CCT technology (Eugenio Paoloni/Mike Koratzinos)
- CEPC: cosine-theta regular technology

Advantages of our design (our vision):

- Iron yoke prevents field cross-talk between apertures
- High field quality (both local and integral) can be achieved
- Relative position of the apertures is of high precision
- Quadrupoles block is rigid and can be easily aligned
- Well proven technology
- Simple and cheap

- Disadvantage: no additional coils can be inserted; separate correctors are needed before/after the quad (not a big problem)

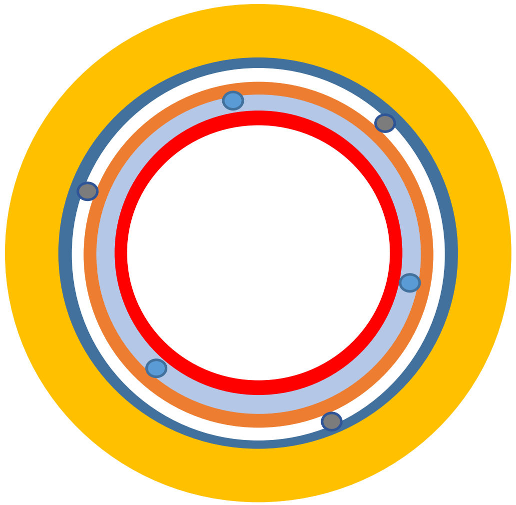
Vacuum chamber inside the cryostat



Vacuum chamber inside the cryostat

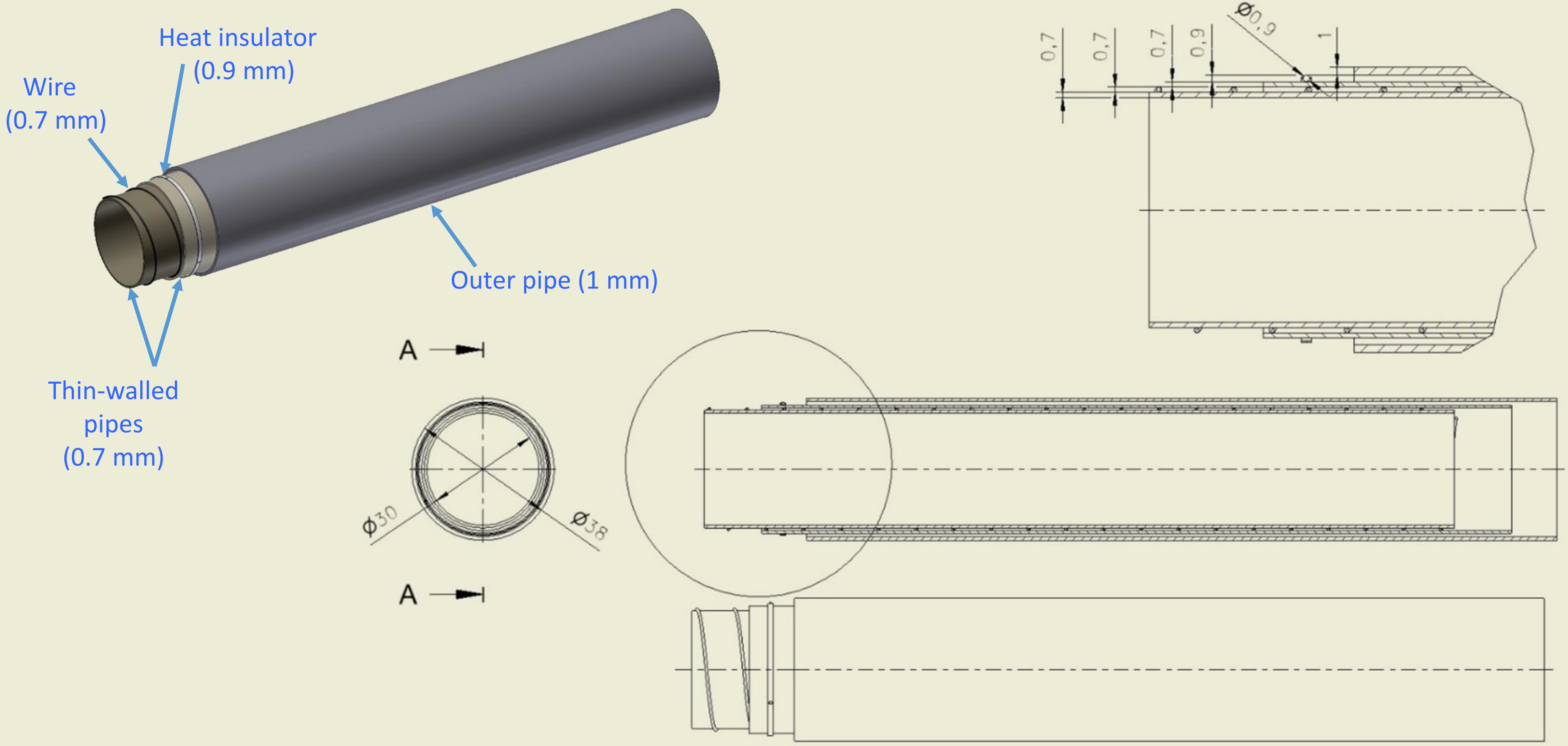
By the analogy with BELLE II, we have room temperature in the beam chamber inside the cryogenic magnetic elements. This minimizes the number of bellows assemblies, high-frequency contacts, eliminates cold-warm transitions and simplifies the task of removing heat load from the beam chamber.

- The thermal load on the camera due to the presence of specular current and high-frequency electromagnetic radiation is 100 W / m
- Objective: To minimize technological gaps in the multilayer chamber, without exceeding the permissible level of heat inflow to the cryogenic system



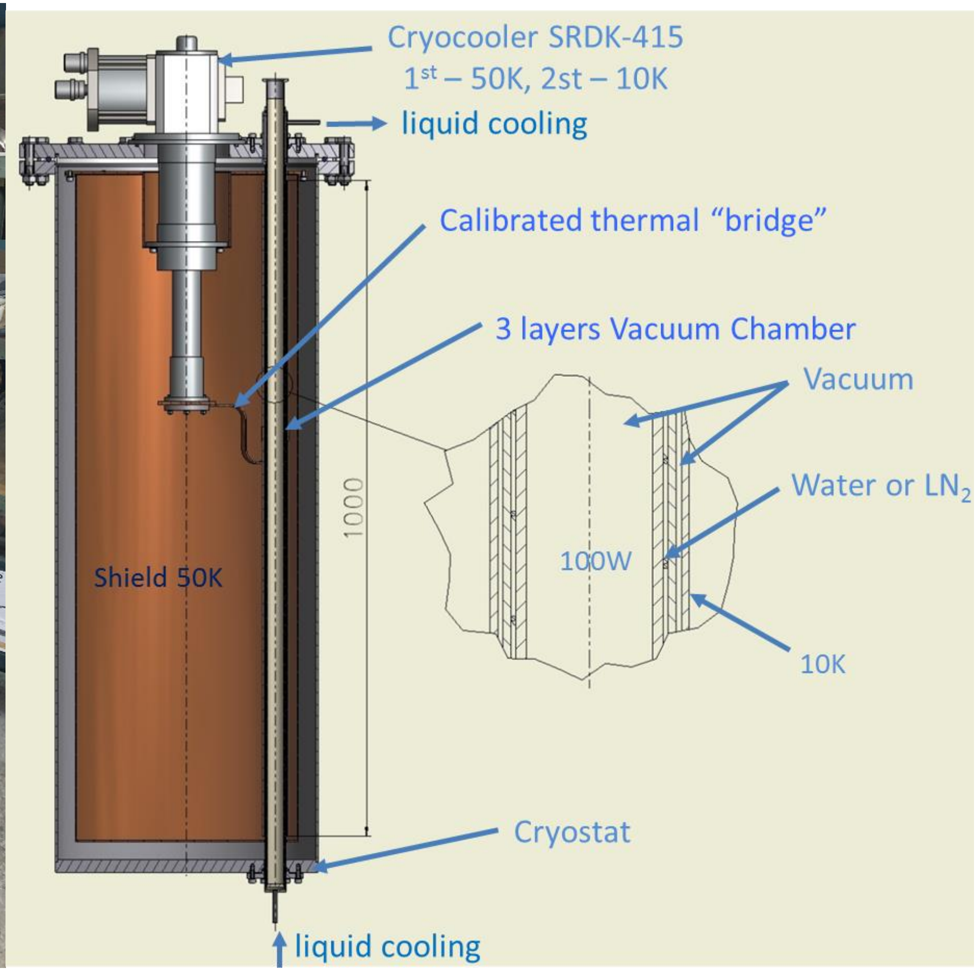
- 0.7 mm thick copper coated inner chamber, T = 300K
- 0.7 mm clearance with water flow to relieve heat load from HOM & IC
- 0.7 mm thick pipe with mirror coating Cu or Au, T = 300K
- Vacuum clearance 0.9 mm with distance heat insulators
- External pipe 1 mm thick, with inner coating Cu, T = 4.2K
- Superconducting coil

Three-layer beam chamber design



Vacuum chamber prototype

Stand for measuring heat gain in a three-layer vacuum chamber



The thermal load on the cryogenic system will be determined in two ways: by changing the temperature of the liquid coolant and by the temperature difference on the thermal bridge between the cryo-cooler and the vacuum chamber.

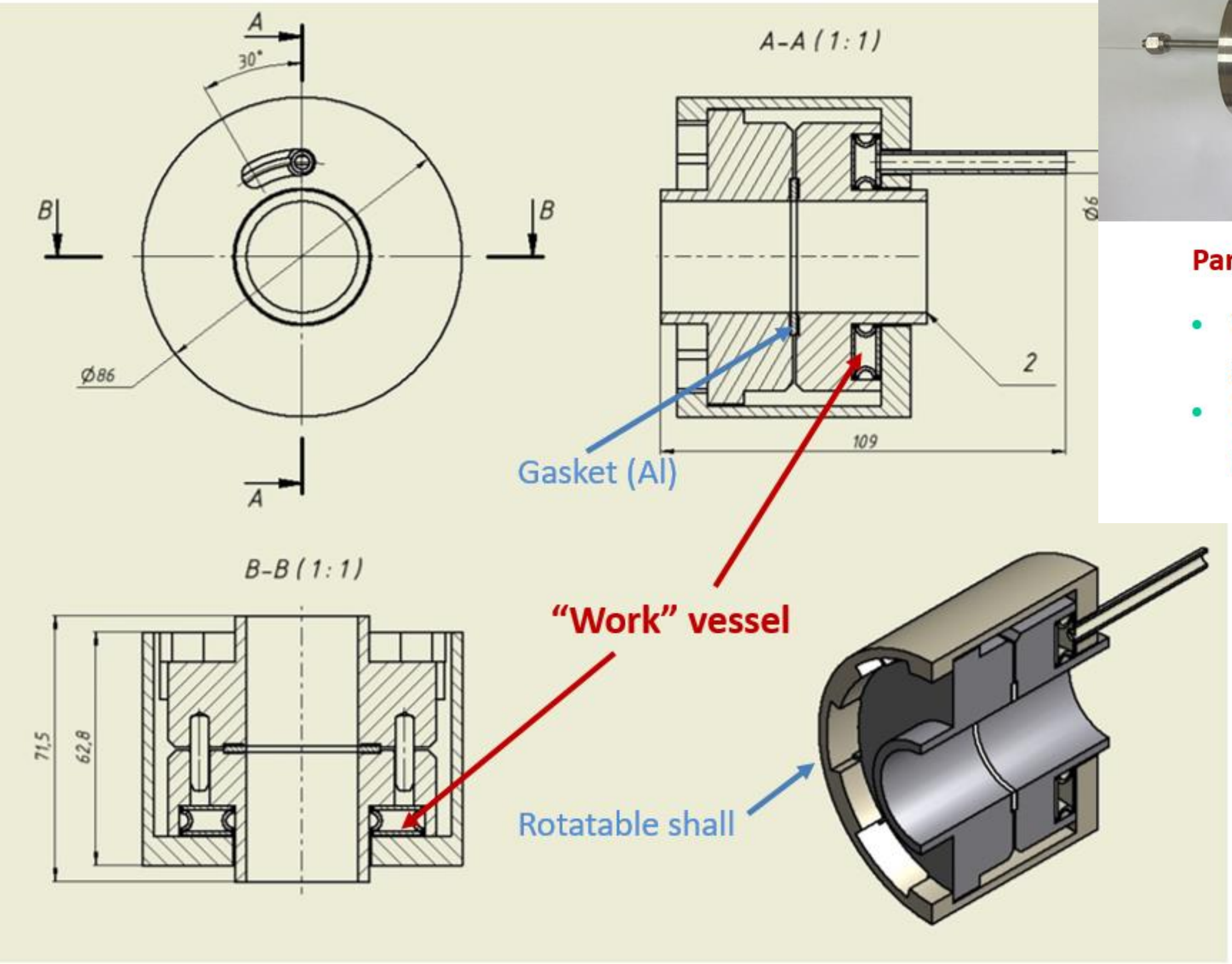
Further goals and plans

- Create a model of our own IP camera
- Develop HOM absorber(?)
- Develop the stabilization and alignment system for the cryostat inside the detector
- Start designing the entire final focus as a single system

- Develop a system of magnetic measurements allowing to measure the magnetic field map inside the vacuum chamber of the cryostat in three planes

Thanks for your attention

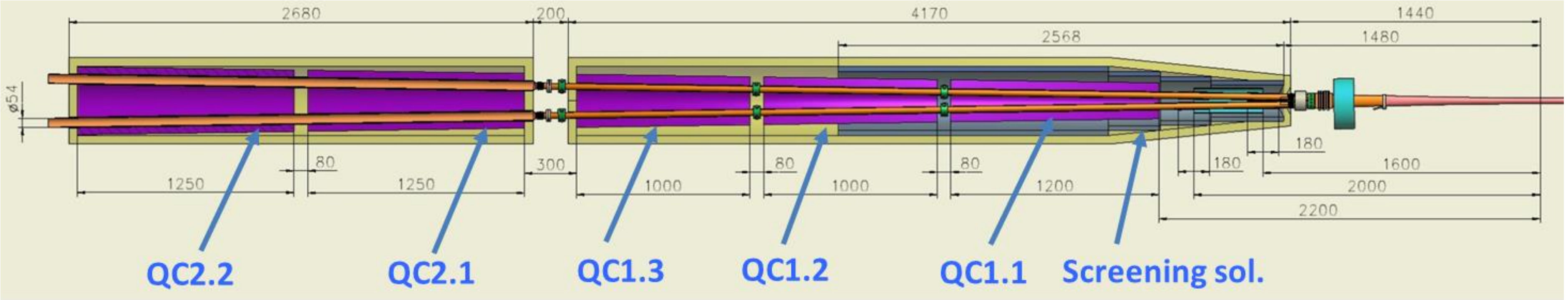
BINP remote flange

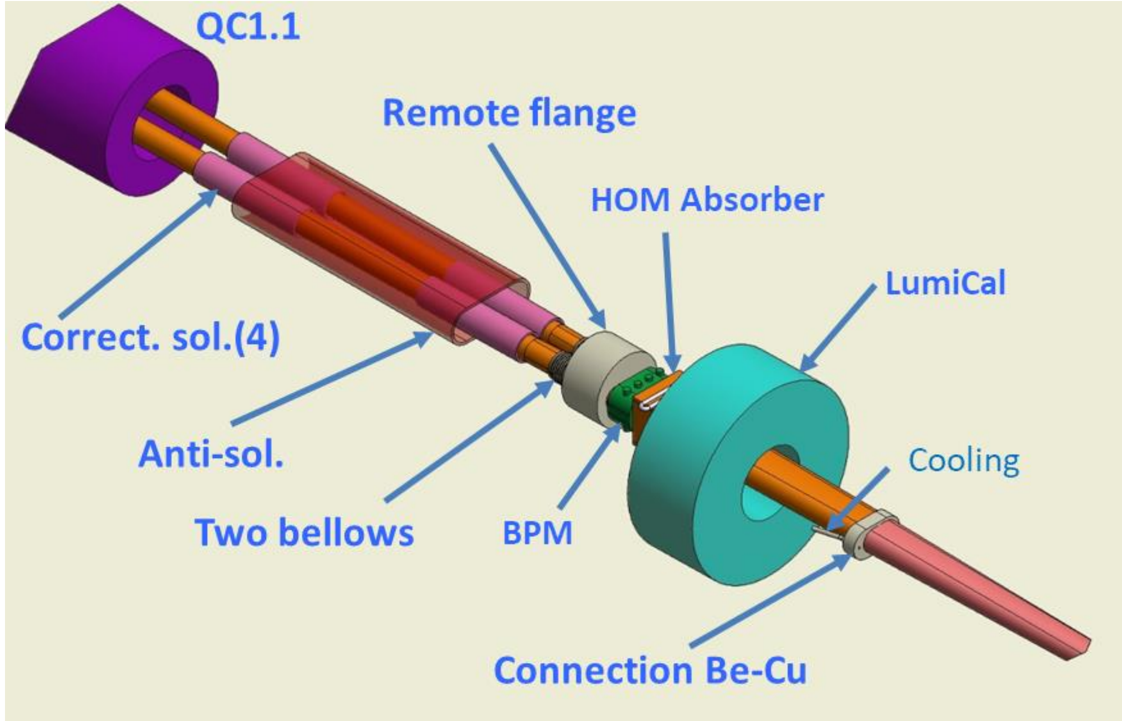


Parts of the flange connection **Assembled connection**

- We've got successful result with Cu and Al gaskets at pressure 150 atmosphere. Leak rate is less than 1E-10 mbar*L/s.
- Note, the connection keeps smoothness of internal surface along beam propagation

Single aperture design works.





Cryostat "walls" thickness.

Outer SS wall 10 mm

10 mm vacuumn

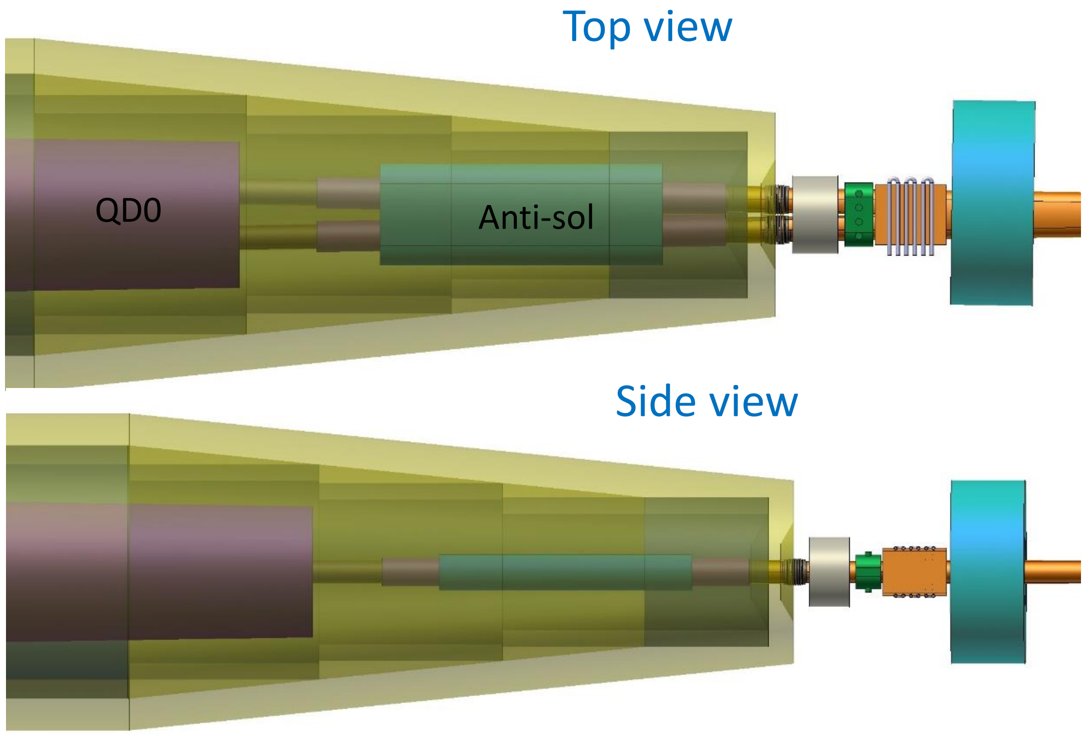
Thermal shield 3 mm

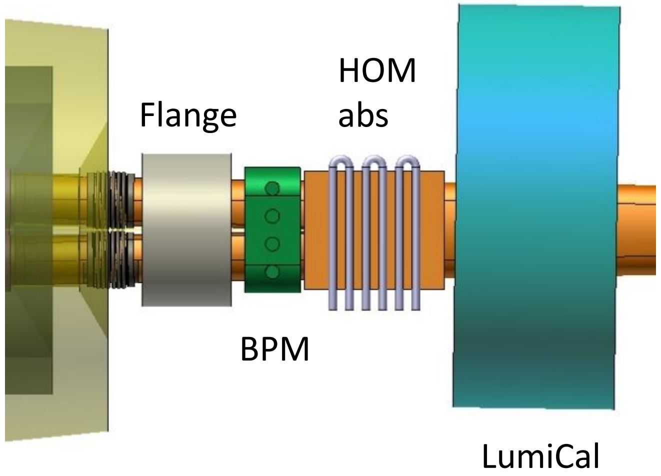
10 mm vacuum

Inner wall 6 mm

In total: ~40…45 mm

BINP alternative

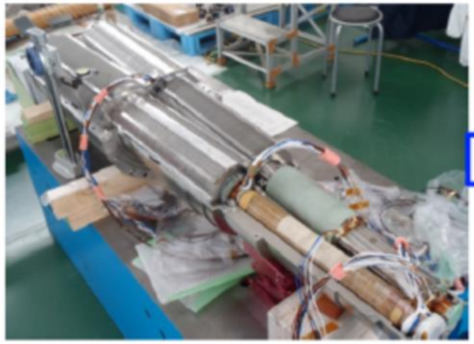


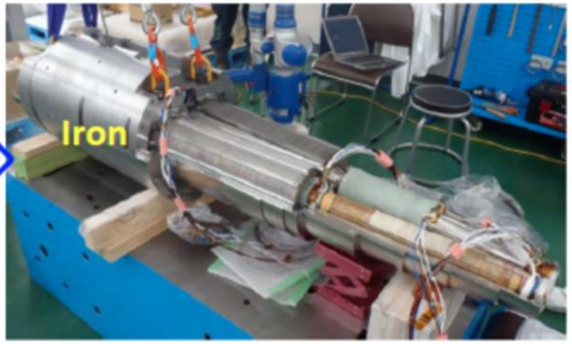


Final focus system at SuperKEKB

Y. Arimoto
The Workshop on Circular Electron Positron Colliders, Rome
24th May 2018

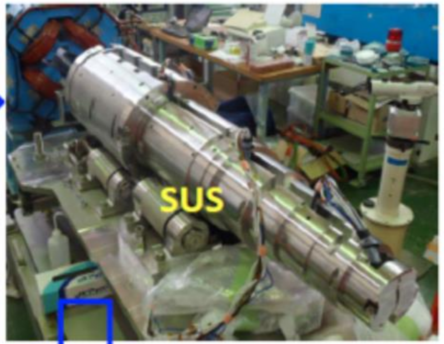
Assembly of the front cold mass of QCSL



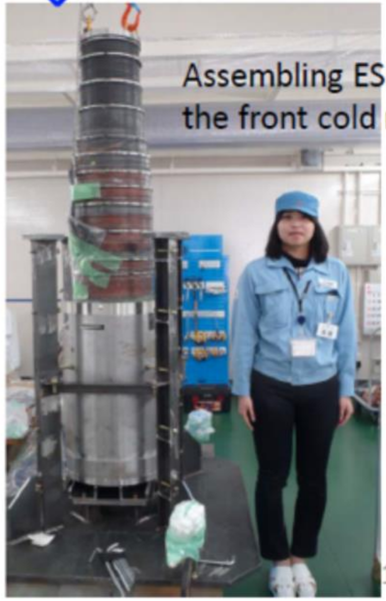


Fixing the magnets with the support components

Measurement of quadrupole alignment in the cold mass with the stationary harmonic coil at room temperature



Assembling ESL on the front cold mass



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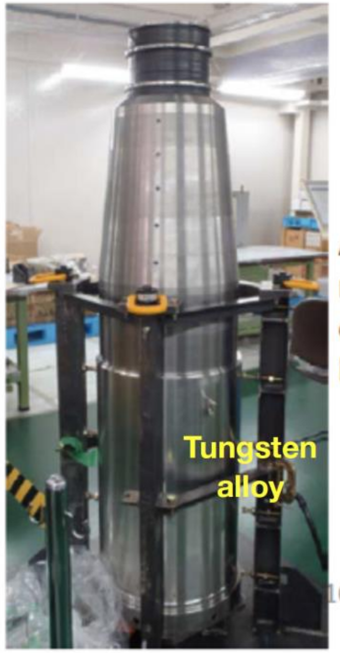
Assembling the radiation shield of W alloy on ESL



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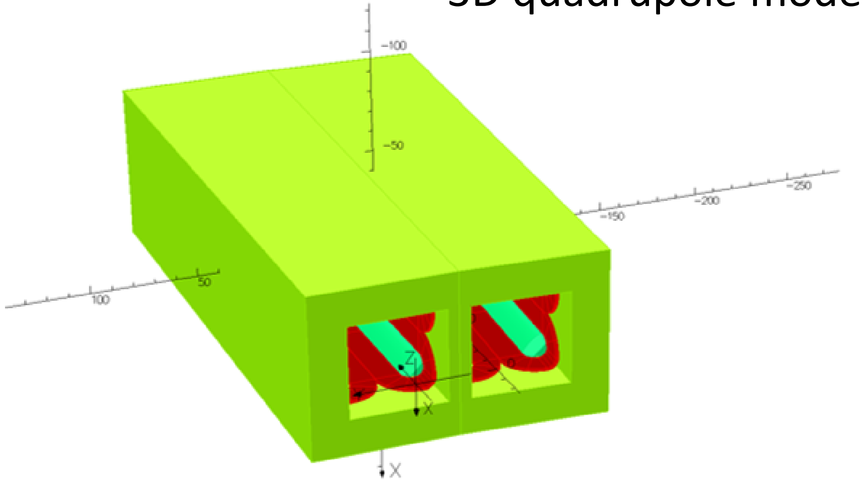
Covering the cold mass with the helium vessel and welding the vessels

N. Ohuchi

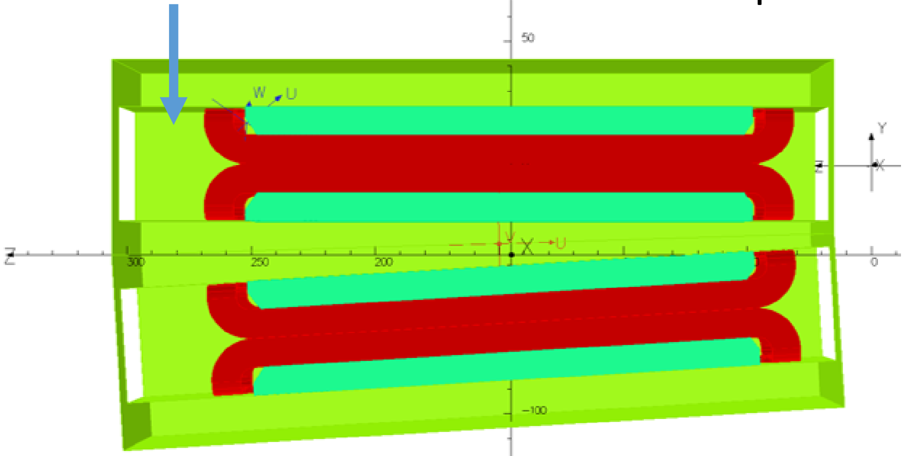
Iron yoke twin-aperture SC quadrupole

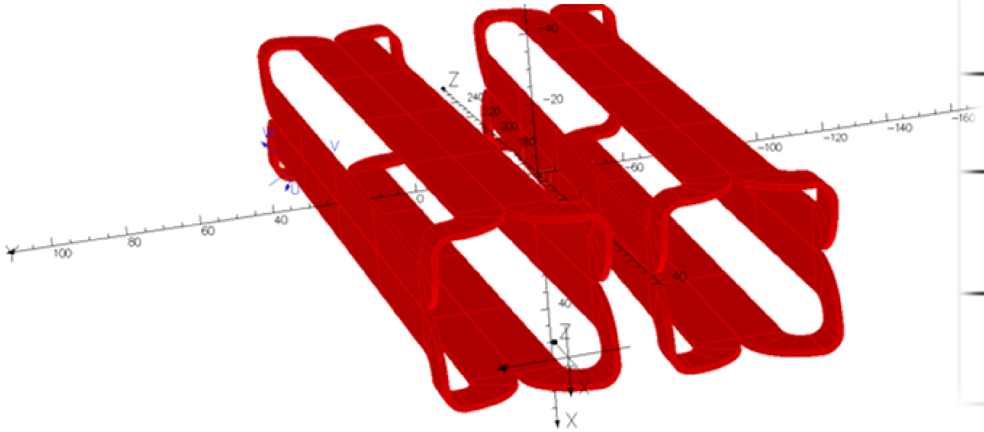
Intensive simulation of the twin-aperture magnetic field is underway (field distribution, field quality, influence of manufacture and assembly tolerance, etc.)

3D quadrupole model



Yoke extension to reduce the apertures cross-talk





Aperture radius, mm	23
Gradient, T/m	100
Gradient integral, T	22
Current, kAmper turn	21.5