Summary of FCCee IR Magnet Review April 4-5, 2022

John Seeman (SLAC) (Chair)

FCC Week Paris

June 2, 2022

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Review Committee and Observers

- Committee:
- Bernhard Auchmann (PSI/CERN), Stefania Farinon (INFN-GE), Patrick Janot (CERN), GianLuca Sabbi (LBNL), John Seeman, Chair (SLAC), Massimo Sorbi (MI.INFN), Holger Witte (BNL), Akira Yamamoto (KEK)

- Observers:
- Laurent Brunetti (CNRS LAPP), Angeles Faus-Golfe (CNRS), Roberto Losito (CERN), Vittorio Parma (CERN), Luigi Pellegrino (INFN), Manfred Wendt (CERN)

FCCee IR Magnet Review Agenda (April 4)

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14:00 **Introduction, high-level requirements and detector needs**

Speakers: Manuela Boscolo (INFN e Laboratori Nazionali di Frascati (IT)), Michael Kenneth Sullivan (SLAC National Accelerator Laboratory (US))

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14:30 **Requirements from Optics, fields, l*, and vibration tolerances**

Speakers: Katsunobu Oide (High Energy Accelerator Research Organization (JP)), Katsunobu Oide

IR_Optics_Oide_22...

15:00 **CCT final quadrupole design, prototype and proposed cryostat, quench performance**

Speaker: m Koratzinos (Massachusetts Inst. of Technology (US))

IR_review.pdf IR_review.pptx

15:40 **Break**

16:00 **Experience with IR magnets from SuperKEKB**

Speakers: Norihito Ohuchi (KEK), norihito ohuchi

FCCee-IR-Review-S...

16:30 **EIC IR magnet design**

Speaker: Holger Witte (Brookhaven National Laboratory)

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17:00 **IR alignment requirements and strategy**

Speaker: Leonard Watrelot (CNAM - Conservatoire National des Arts et Métiers (FR))

IR alignment, requir...

Charge Question #1:

The review should evaluate the requirements of the IR quadrupoles and compensating solenoids.

- The review should include the overall dimensions, angular stay-clear, magnetic fields including correction coils with frequency response, quadrupole/solenoid technology, operation temperature, apertures, alignment and stability, heat loads, and availability.

Charge Question #2:

Concepts and initial engineering considerations would also be discussed for implementation of the magnets and cryostat.

- The review will include concepts for the windings, correction coils, beampipe, supports, cryostat and feedthroughs, alignment, stabilization, cooling, and access and maintenance.

High Level Requirements and Detector Needs (M. Boscolo, INFN Frascati)

FCC-ee basic design choices

Double ring e+ e- collider

Common footprint with FCC-hh, except around IPs

Asymmetric IR layout and optics to limit synchrotron radiation towards the detector

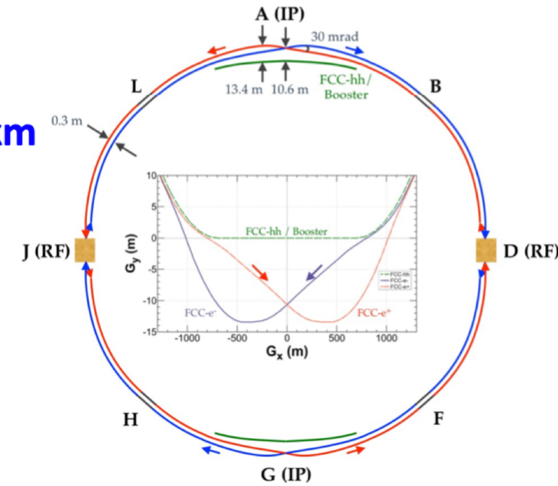
2 IPs (or 4IPs) large horizontal crossing angle 30 mrad, **crab-waist** collision optics

Synchrotron radiation power **50 MW/beam** at all beam energies

Top-up injection scheme for high luminosity requires booster synchrotron in collider tunnel

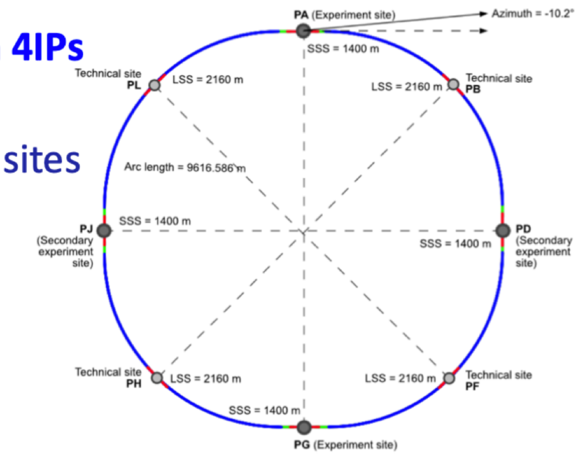
"Tapering" of magnets along the ring to compensate the sawtooth effect

CDR
C=97 km



evolution 4IPs
C=91 km

8 surface sites



FCC-ee Interaction Region

Crab-waist scheme, based on two ingredients:
- concept of **nano-beam scheme** (vertical squeeze of the beam at IP and horizontal crossing angle increased, reducing the instantanous overlap area, allowing for a lower β_y*)
- **crab-waist sextupoles**

Smaller beams at IP → higher luminosity & higher backgrounds
(IP bkgs and beam losses in the final focus quads due to the very high β-function)

- Squeezed beams at IP, tens of nm in σ_y* (vertical emittance ε_y =1 pm at 45.6 GeV)
- This scheme, with the goal luminosity of $10^{36}cm^{-2}s^{-1}$ at 45 GeV sets the constraint to:
  - L* (distance between IP and first quad)
  - the strength of the final focus doublet
  - the solenoidal detector field (e.g. $\varepsilon_y \propto B_z^{\,5}$)

L*=2.2 m
B(detector) = 2 T

⬇

Tight and packed interaction region with first final focus quadrupole QC1 inside detector, different QC1 for each beam, and two anti-solenoids inside the detector, as well.

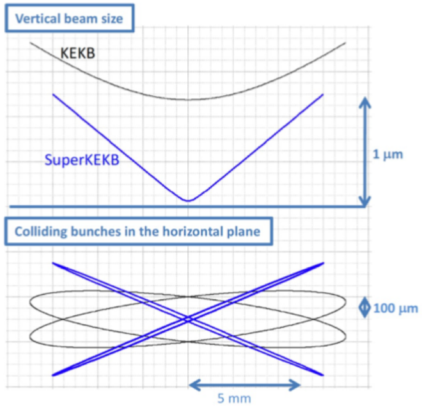


Figure 2: Schematic view of the nanobeam collision scheme.

https://arxiv.org/pdf/1809.01958.pdf

Committee: High Level Recommendations for FCCee Requirements

- Carry out an optimization study to establish (or document an already existing study) whether L* could be increased or decreased without affecting substantially the performance.

- Provide a complete analysis of tolerance requirements and specifications of the various IR subsystems.

- Proceed with the mechanical analysis of the detector solenoid to be coupled with the magnetic and mechanical analysis of the IR magnet system.

Requirements: Optics, Fields, L*, Vibration (K. Oide, CERN)

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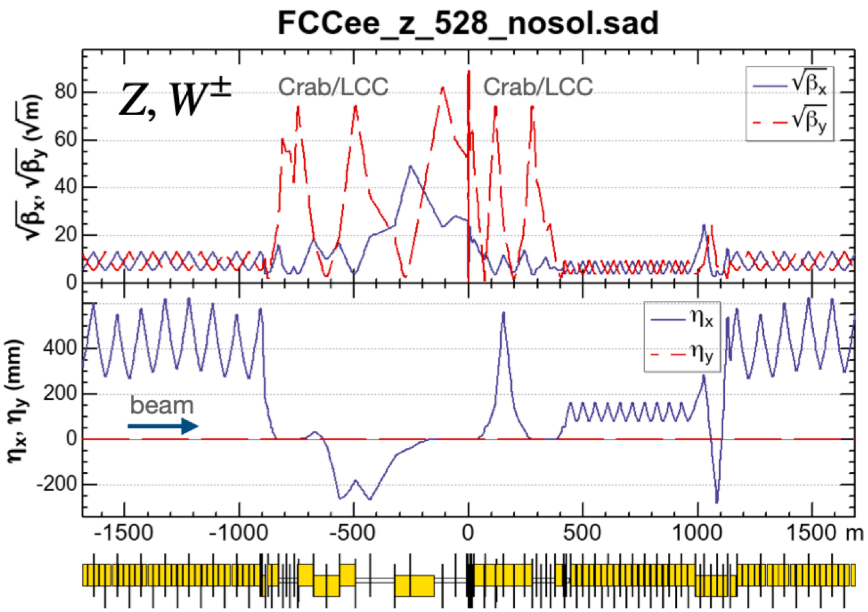

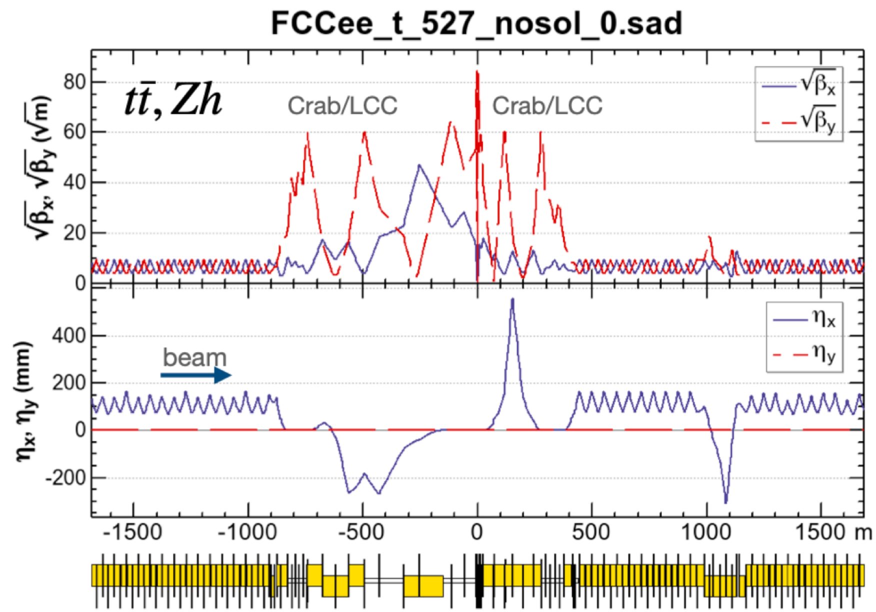

- The IR optics are very asymmetric to reduce the upstream SR toward the IP $\left(u_c \leq 100\,\mathrm{keV}\,@\,t\bar{t}\right)$.
- A sextupole pair on each side of the IP dedicates to the crab waist and the local chromaticity correction.
- The arcs are different between Z/W (long 90/90) and Zh/$t\bar{t}$ (90/90).

K. Oide, Apr. 4, 2022

Committee: High Level Recommendations for FCCee Optics

SLAC

- The design parameters of the all the magnets should be made clearer. The magnets should not only be studied in the standalone configuration, but the complete assembly of the magnetic system should also be given.

- The actual 3D magnetic field maps of the measured IR magnets should be passed to the beam dynamics studies.

- Include axial and radial coupling of individual magnets in terms of cross-talk, load line, mechanics, and protection concept.

Final focus quadrupoles

- Two main units on each side of the IP and for each beam, e^+ (P)and e^-(E): QC1LE, QC2LE, QC1RE,QC2RE, QC1LP, QC2LP, QC1RP,QC2RP
- QC1 is inside the detector and itself comprises three units per side per beam: QC1L1P, QC1L2P,QC1L3P, QC1L1P, QC1L2P,QC1L3P, QC1L1E, QC1L2E,QC1L3E, QC1L1E, QC1L2E,QC1L3E
- There are 5X2X2=20 single aperture units in total

From the FCC CDR update 13/12/2019, Katsunobu Oide

	Start position (m)	Length (m)	B' @Z (T/m)	B' @W (T/m)	B' @ H (T/m)	B' @ tt (T/m)
QC2L2	-8.44	1.25	25.05	43.82	61.30	69.50
QC2L1	-7.11	1.25	-0.18	0.00	7.32	56.85
QC1L3	-5.56	1.25	-19.35	-34.38	-53.08	-99.98
QC1L2	-4.23	1.25	-18.57	-32.94	-53.07	-99.98
QC1L1.1	-2.9	0.7	-40.95	-70.00	-99.71	-95.39
QC1L1.2	2.2	0.7	-40.95	-70.00	-99.71	-95.39
QC1R2	2.98	1.25	-25.44	-37.25	-51.94	-100.00
QC1R3	4.31	1.25	-19.54	-39.51	-53.65	-91.87
QC2R1	5.86	1.25	14.64	16.85	-2.65	37.19
QC2R2	7.19	1.25	19.50	44.32	67.52	94.43

M. Koratzinos

- Optics design is such that E and P quads have the same strength
- Maximum strength is 100T/m
- The most difficult element is QC1L1, the closest to the beam and where the E and P quads are closer together

The updated parameters are rather different for QC1L1: its length is now 70cm from 120cm

Committee: High Level Recommendations for FCCee Magnets

- Ascertain whether additional SC corrector circuits are required in order to correct for the various sources of field distortions.
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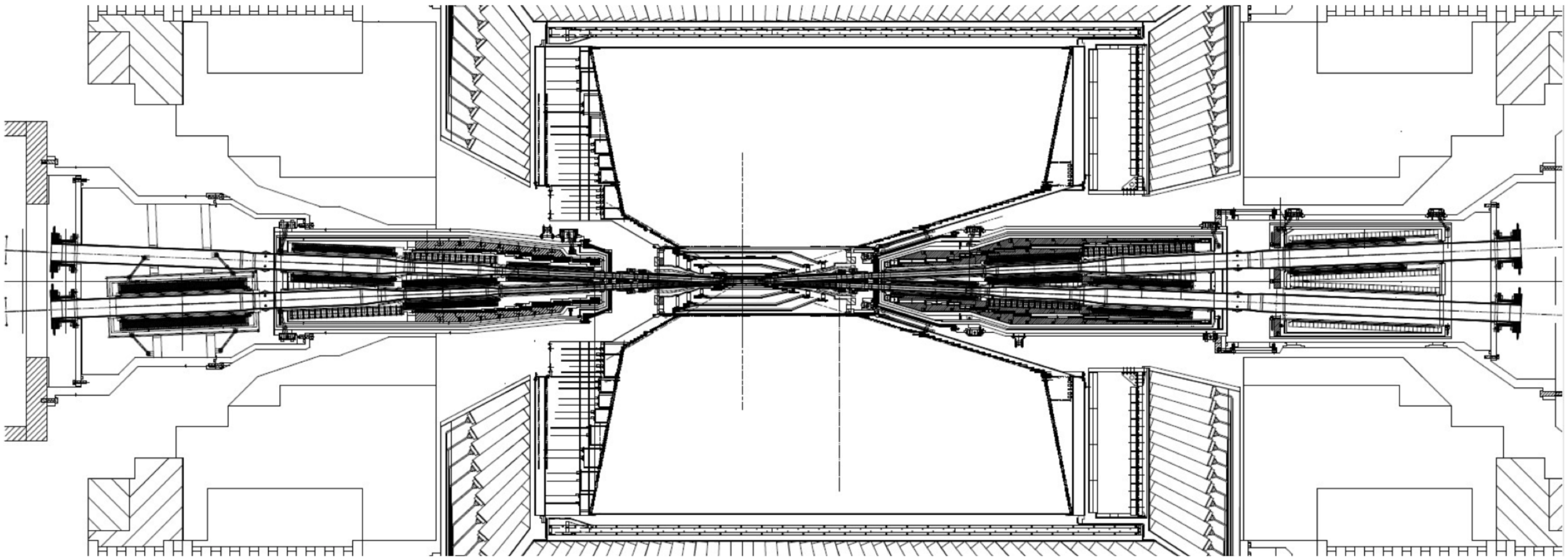
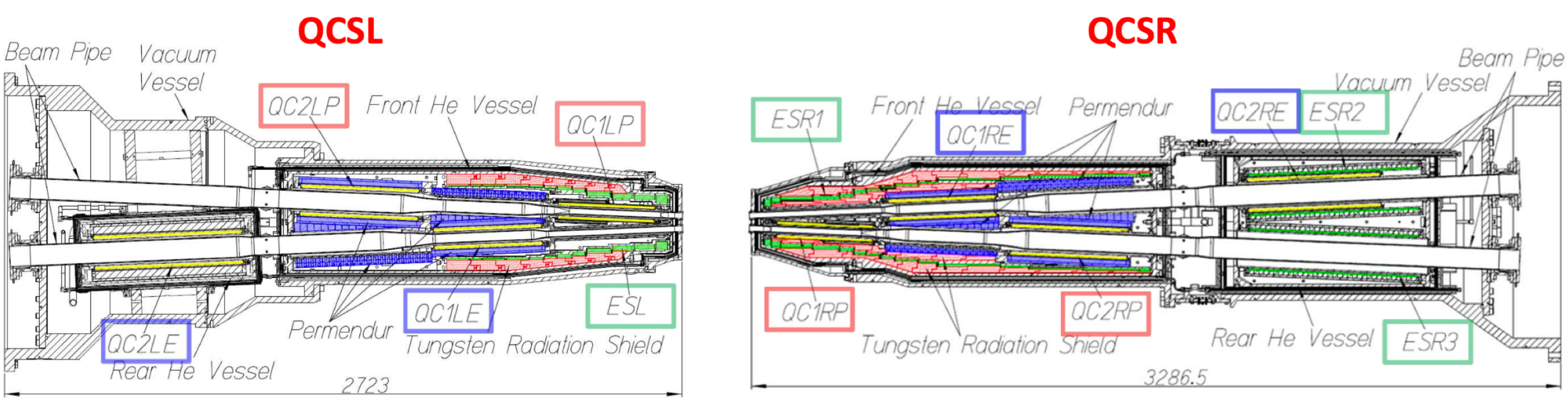
- Study whether there can be a redesign of the compensation solenoid (smaller OD compensation solenoid) that leaves more room for engineering of heat shields, cryostat, etc.

- Make a preliminary assessment of the direct coil winding method (BNL), with pros and cons compared to the CCT technique.

- Derive a worst-case for the cryogenic system from the individual sources of heat loads in different operational scenarios.

SuperKEKB IR Magnet System (Norihito Ohuchi, KEK)



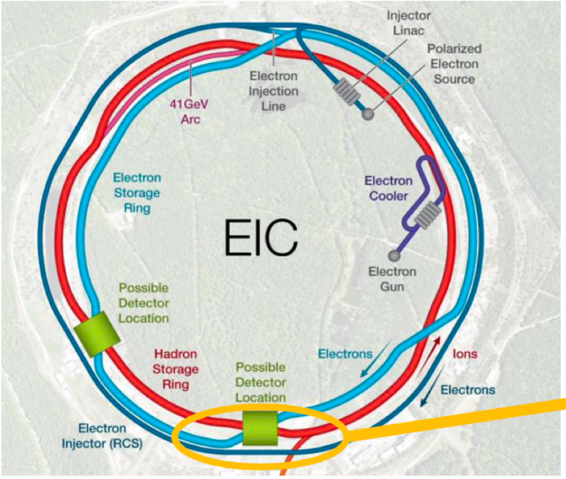


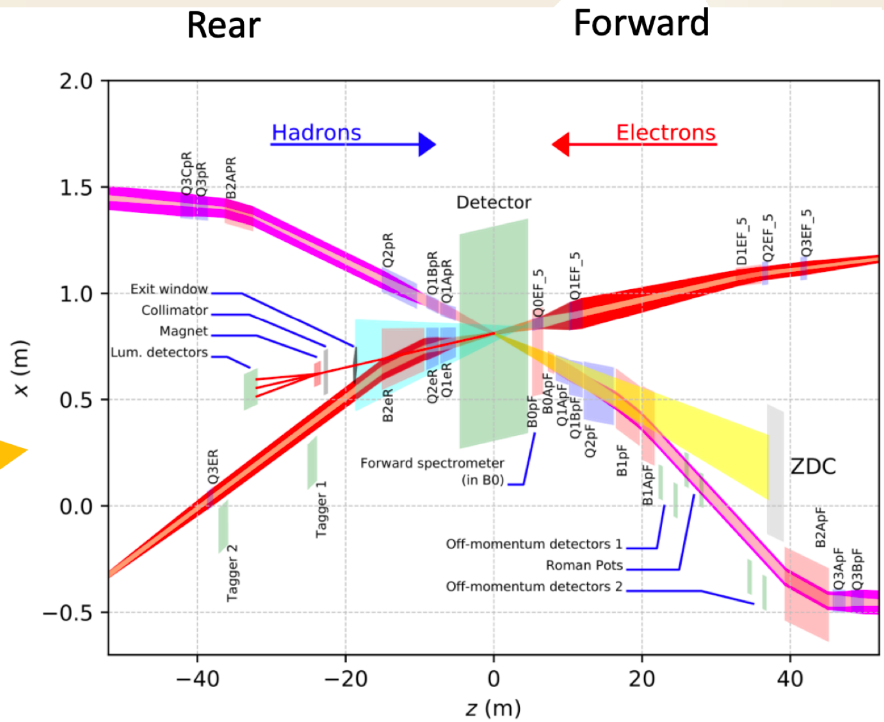
High Level Recommendations from SuperKEKB for FCCee

- Document the constraints on the IR magnets coming from the 100 mrad cone requirement, and solutions to satisfy them (or lack thereof).

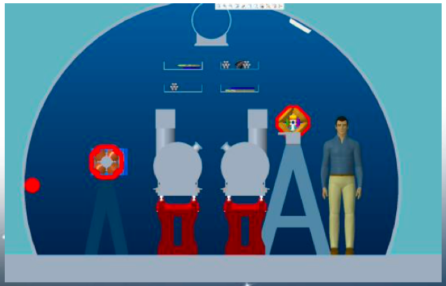
- Document all heat sources that affect the beam pipe magnet system in a systematic manner, in order to accurately evaluate the total (normal and cryogenic) heat loads including radiative Bhabha scattering.

EIC IR Magnet Design (Holger Witte, BNL)





- Use key RHIC infrastructure
  - Addition: ESR and RCS
- On-Project IR:
  - Detector at RHIC IP6
- IR Region: ±130m around IP6
  - Inner/near IR: ±30m
- New magnets: mostly inner IR
  - Also: matching dipoles
  - Spin rotator solenoids



Electron-Ion Collider

High Level Recommendations for FCCee from EIC

- Determine if the designs of the IR magnets need to incorporate the potential of up to a 1.5% difference in the two beam energies (depending on the IP and on the center-of-mass energy).

- Include in the FCC-ee baseline design all fundamental aspects of system integration in relation to magnetic analysis (operational margins, field quality); mechanical analysis (forces, mechanical support); quench protection and failure modes.

- Check whether the magnet field stability criteria can be relaxed given operational experience at SuperKEKB and RHIC.

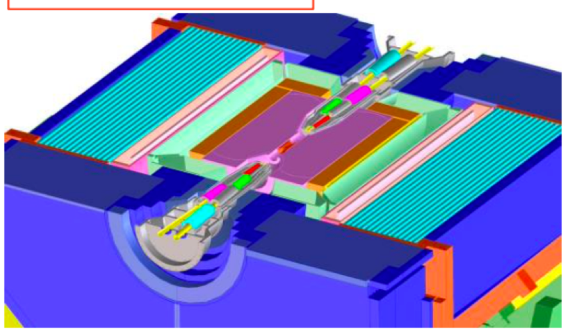
Alignment (L. Watrelot, CNAM)

Alignment strategy

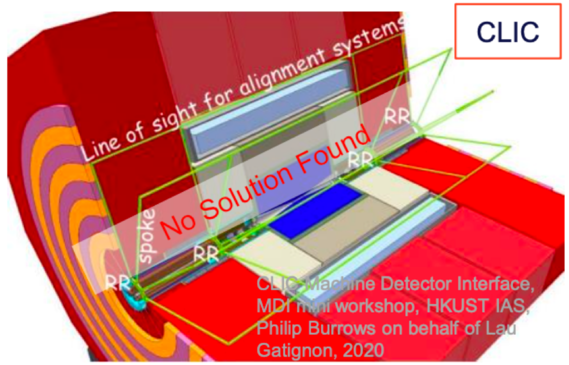
Alignment	Alignment + monitoring	Pre-alignment + monitoring + re-adjustment

DAFNE/KLOE

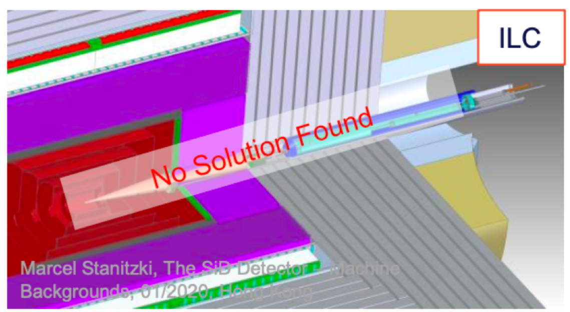
SuperKEKB/Belle II



CLIC



ILC

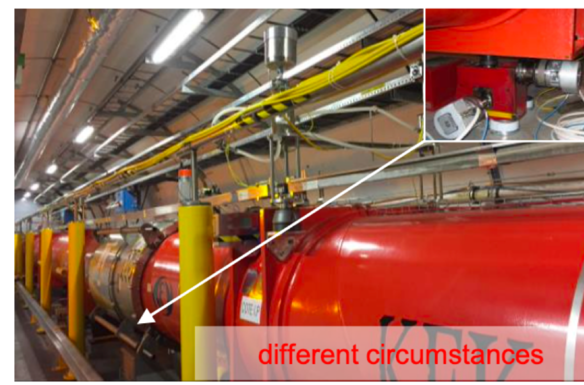


~ LHC/ATLAS and CMS

(monitoring of the cryostat without knowing the position of the cold masses inside)

HL-LHC/ATLAS and CMS

(monitoring of the cold masses)



High Level Recommendations for FCCee Alignment

- Specify the boundary conditions about couplings (mechanical, magnetic, ...) between detector and IR magnet systems.

- Establish if beam tuning or corrections can be used to relax some of the interaction region tolerances.

- Develop a strategy for and study the feasibility of suspending (with wires) the compensating solenoid and connecting the two halves of the beam pipe.

Summary of FCCee IR Magnet Review

- The review committee wishes to thank the FCCee project and presenters for interesting and informative discussions.
- Review general overall highlights:
- The cone angle between accelerator and detector of 100 mrad should be optimized given all the constraints on both sides.
- All the mechanical, electrical, and field tolerances should be studied as an integrated group and loosened as much as is possible.
- All the various magnetic fields and SC correctors in the cryostat need to be studied together along with the main coils for field quality, compatibility, and constructability.
- The mechanical and heat designs of the cryostats should be taken to the next level.