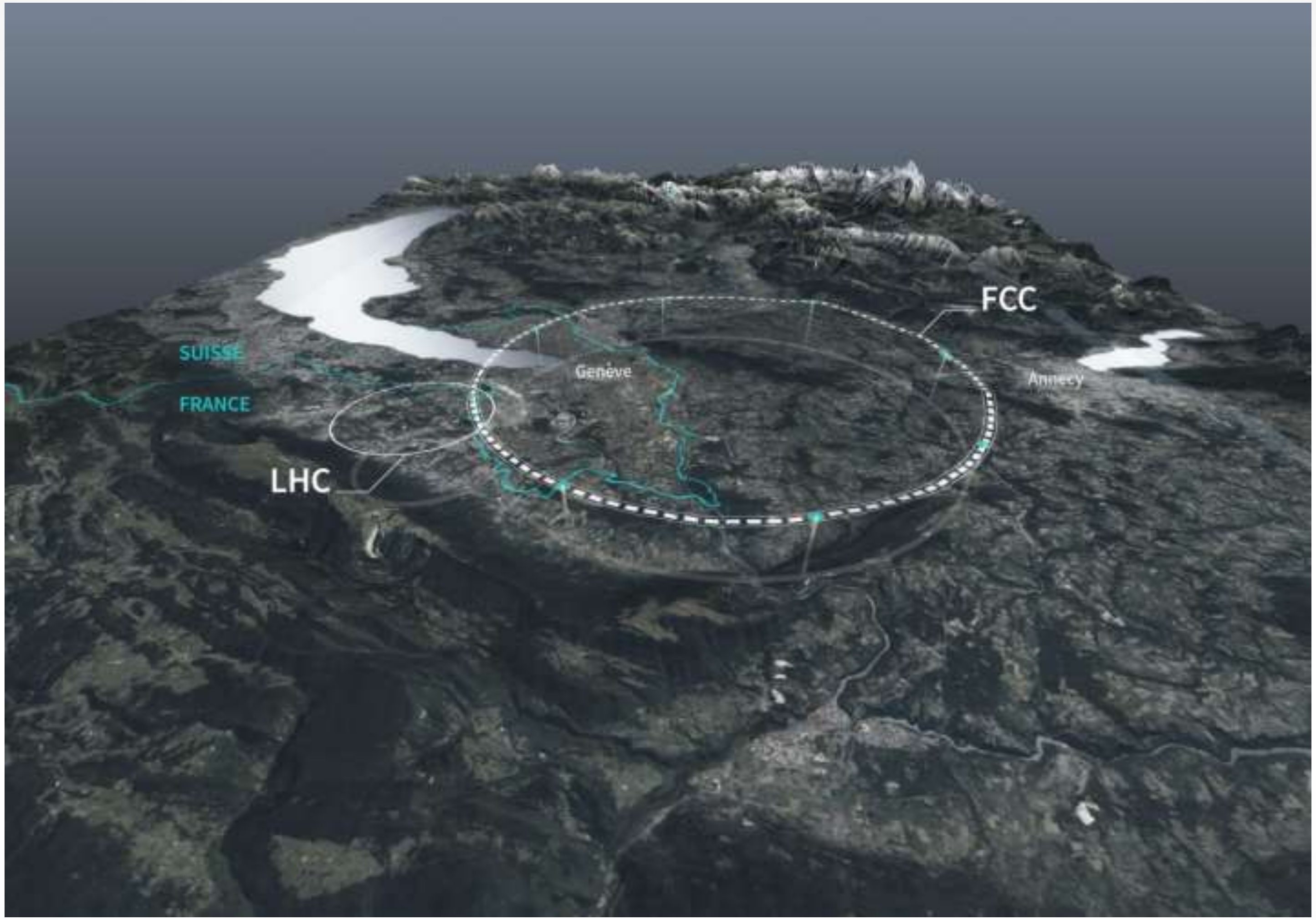


FCCee Design Work

In Europe and in the US

Vladimir SHILTSEV (NIU)

with contributions from:
E.Gianfelice-Wendt,
X.Huang, J.Qiang,
P.Raimondi, J.Seeman,
I.Agapov, F.Zimmermann,
A.Novokhatski, et al

The 2nd US FCC Workshop, ***MIT, 03/26/24***

- **Goal: FCCee Design Report 11/01/24**
- FCC Innovation Study (FCCIS) ongoing
- 5 tasks = many topics including (WG2):
  - collider performance and beam lifetime,
  - mechanical alignment tolerances,
  - misalignment models,
  - trim coil baseline and beam-based alignment,
  - collider and booster optics,
  - vibration and ripple tolerances plus mitigations,
  - booster vacuum,
  - booster impedance, and
  - electron cloud

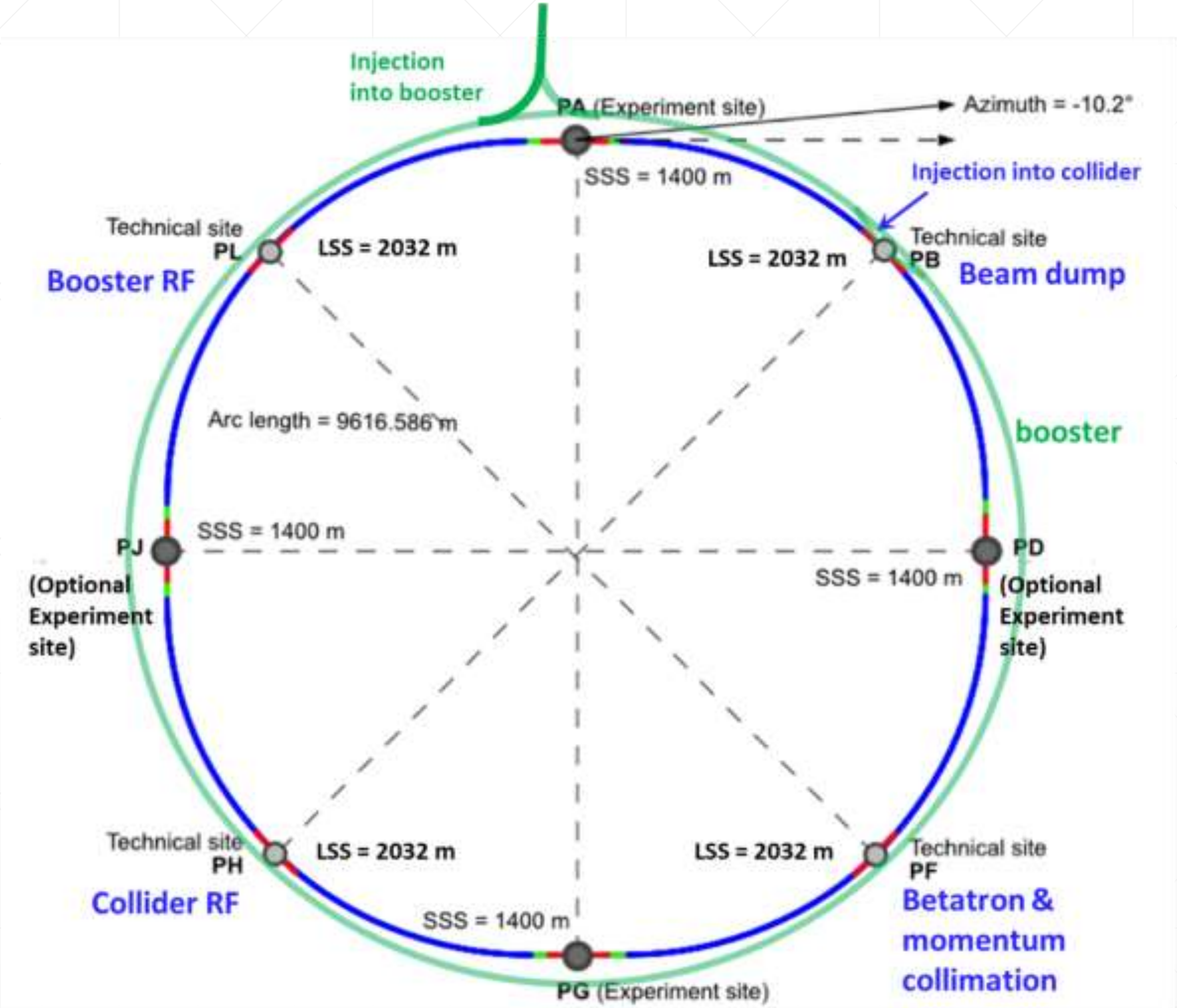
Europe:
CERN, DESY, INFN, CEA, KIT, CNRS, PSI, …

US:
SLAC, BNL, FNAL, MIT, Cornell, …

Japan:
KEK

FCCIS WP2 Task 2.2 Collider Design: baseline established

- **Baseline optics adjusted to the latest layout** and further improved, tentative parameter table established.
- At the same time, significant work on a **lattice alternative (HFD/LCCO**, which holds a promise of better tolerances to alignment errors. **Investigations of lattice performance** taking into account more detailed beam optics models (synchrotron radiation, crab waist) are ongoing.
- **Dynamic aperture reduction due to various ingredients in HFD/LCCO** observed and ways to mitigate such reduction are under study.



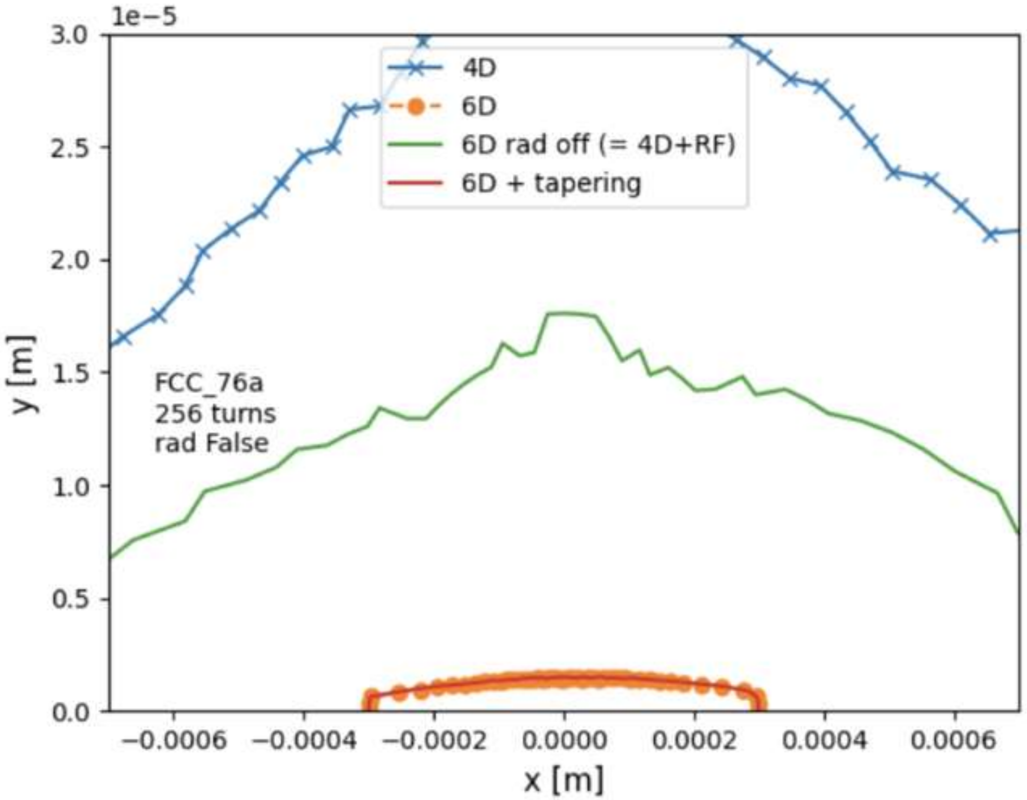
Optimised FCC-ee collider layout with 4 interaction points

I.Agapov/F.Zimmermann

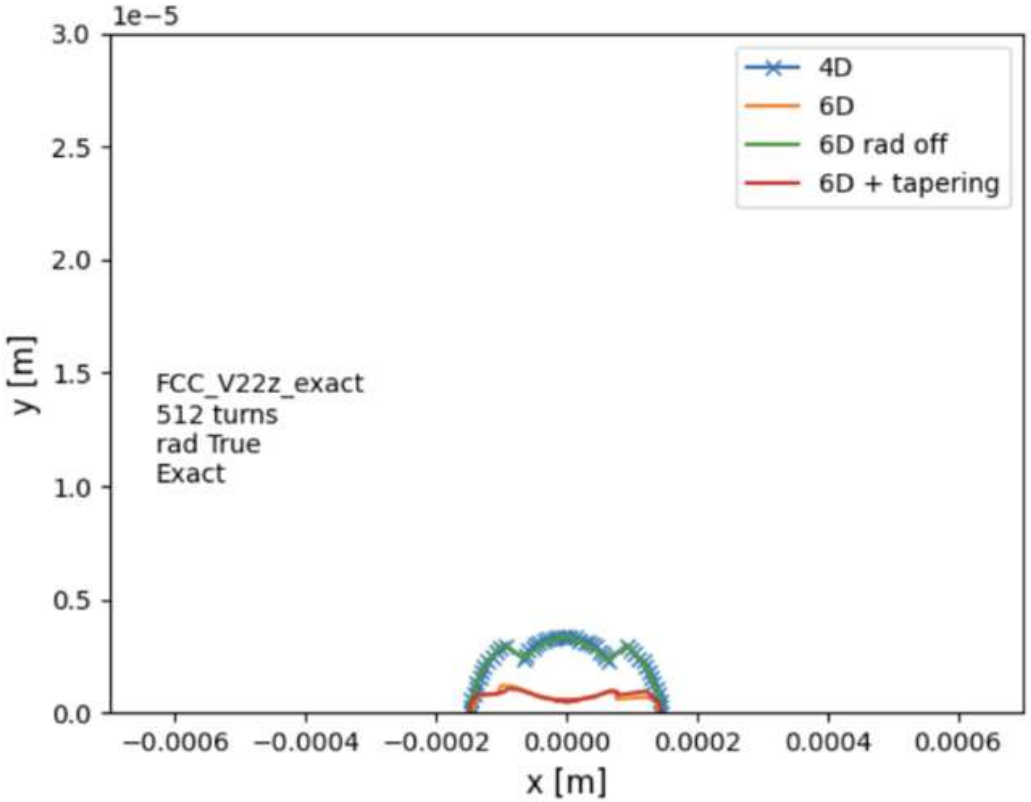
FCCIS WP2 Task 2.2 Collider Design: performance evaluated

see follow-up talk by P.Raimondi

LCCO



BASELINE



- Comparison of Dynamic Apertures of the baseline V22 (right) and alternative HFD/LCCO lattice still without crab waist (left).
- Significant effect of SR on HFD/LCCO performance

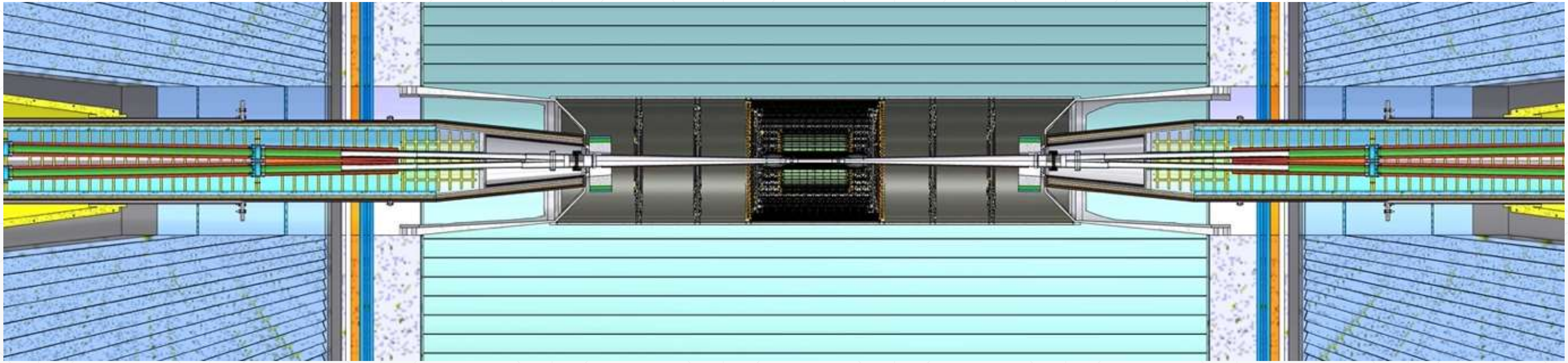
I.Agapov/F.Zimmermann

FCCIS WP2 Task 2.3 Interaction Region & MDI Design

Significant progress on the IR mechanical design

see follow-up talk by M.Boscolo

- Vacuum chamber design and its cooling system,
- Lumical integration
- Bellows design
- Vertex design and integration
- Lightweight carbon support tube for the central vacuum chamber and the inner and outer vertex detectors

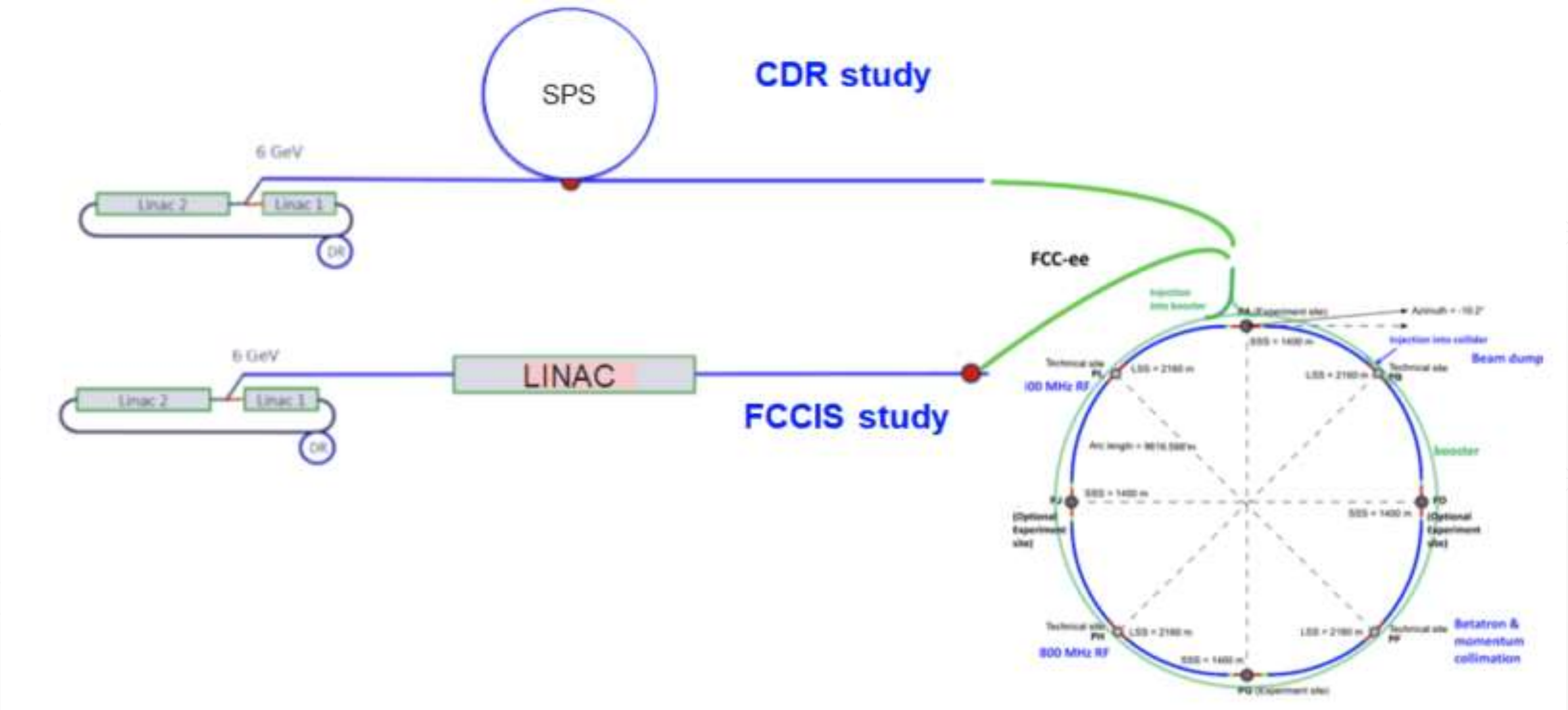


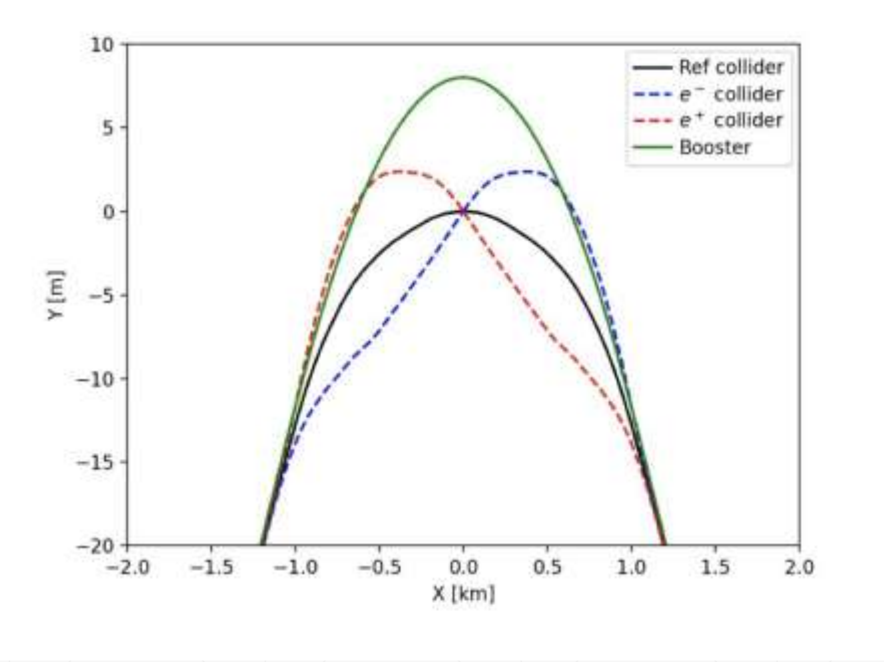
Interaction region mechanical layout

I.Agapov/F.Zimmermann

WP2 Task 2.4 Full energy booster & top-up injection design

- **Booster optics updated** to comply with the constraints from civil engineering and collider. The circumference has been adjusted.
- The layout of the booster is now significantly different to obtain a **transverse offset of 8 m from the collision point** and to avoid any perturbation of the experiment by the synchrotron radiation emitted from the booster.





I.Agapov/F.Zimmermann

Proposed US Contributions (pre-P5)

1. Interaction region design, and integrated machine design
   - Modeling/simulations: crab waist and beam-beam/beamstrahlung, DA, chromatic compensation and optics correction schemes
2. Losses, collimation and background
   - Modeling/simul: codes on halo formation, background in detectors, efficient collimation system(elens/NLO/CS), detector background masking, TMCI, build collimation system for 4 IRs and rings
3. Polarization (esp. at 45 GeV and 80 GeV beam energies):
   - Modeling/simulations: 45-80 GeV energy calibration, error analysis, design and build wigglers, polarimeters, polarized sources
4. Instrumentation:
   - Design and prototyping, then build, IR BPMs and lumi monitors, TMCI feedback systems, emittance and halo monitors, Low Level RF

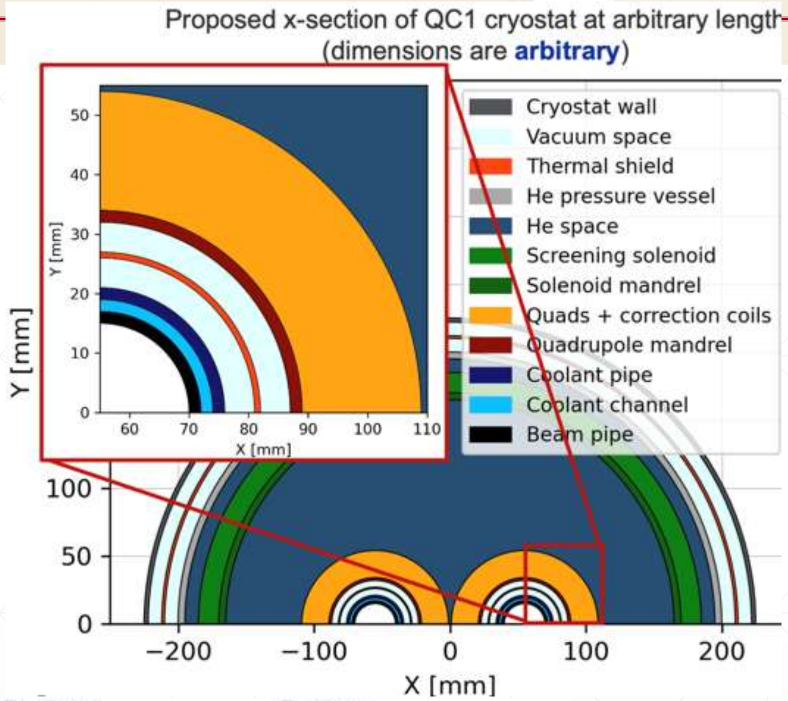
Work started in the US:

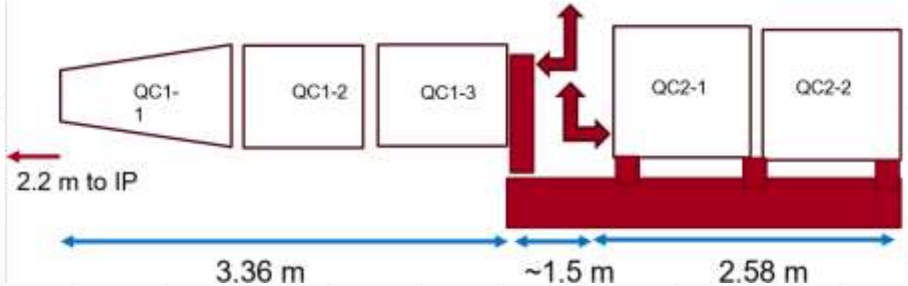
- IR Design/MDI – SLAC, BNL (J.Seeman, B.Parker, A.Novokhatsky, T.Raubenheimer, M.Sullivan)
- Beam-Based Alignment strategy – SLAC (X.Huang)
- Beam-Beam Simulations – LBNL (J.Qiang)
- Polarization – FNAL & Cornell (E.Gianfelice-Wend, and D.Sagan)

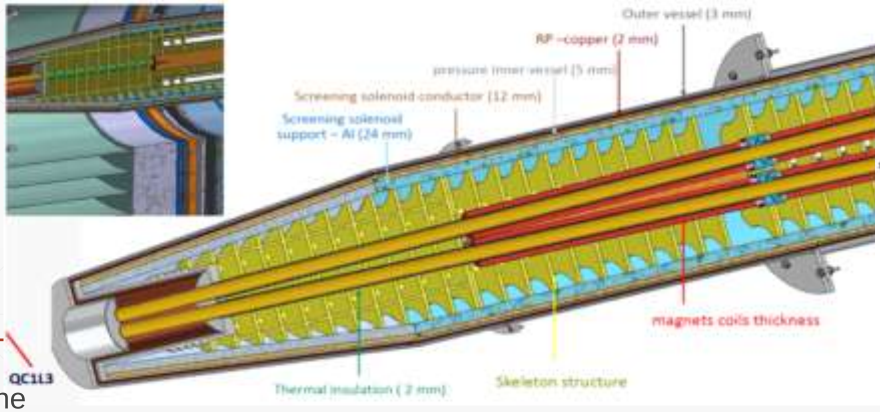
SLAC Work on IR Magnets and Cryostats

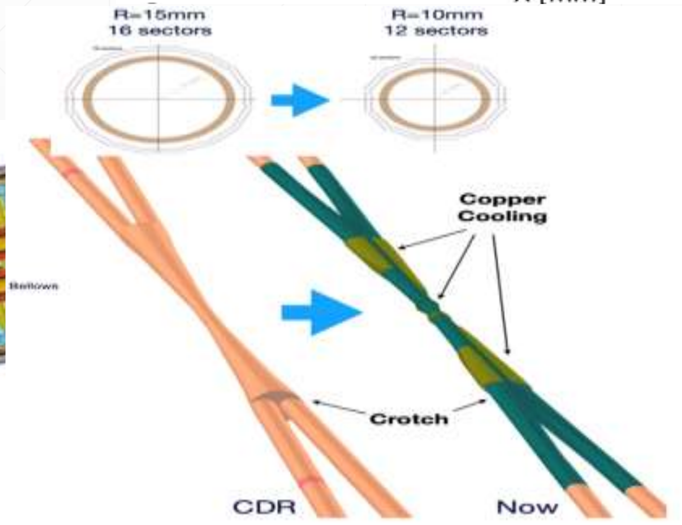
(J. Seeman, T.Raubenheimer, …)

- SC magnet specifications, trim coils
- Magnet dimensions, layout, tolerances
- Cryostat, cryogenics, instrumentation
- Supports, expansion, power leads









M. Boscolo, M. Koratzinos, B. Parker, P. Borges de Sousa, F. Fransesini, …

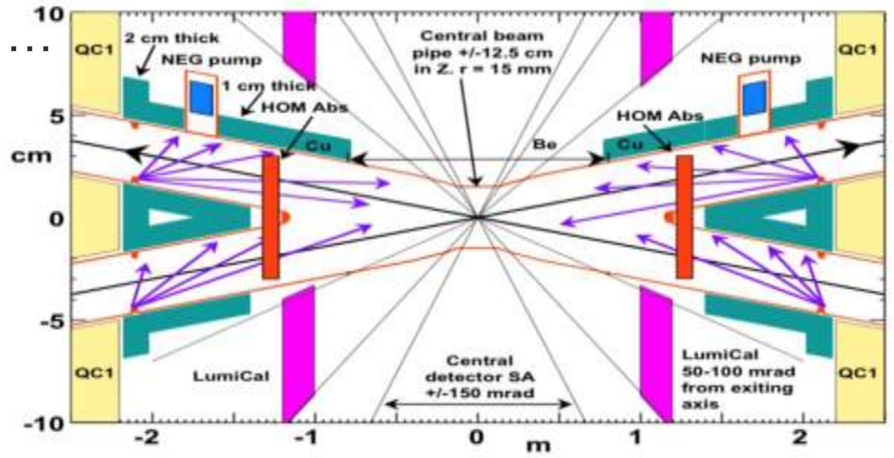
J.Seeman

SLAC Work: Machine Detector Interface

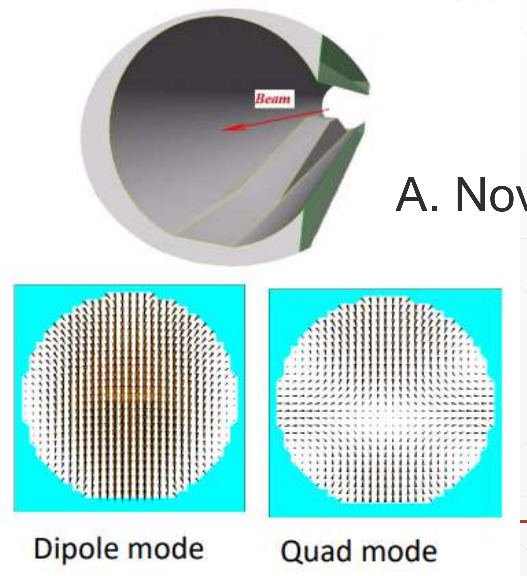
(A. Novokhatski, J. Seeman, M. Sullivan, …)

- MDI overall with detector components
- IP vacuum chamber designs, layout
- HOM calculations, mitigations (next slide)
- Detector stay clears, cone angle
- Lumi-Cal layout, location, masking
- Background calculations, loss mitigation
- Beam loses, power deposition, damage

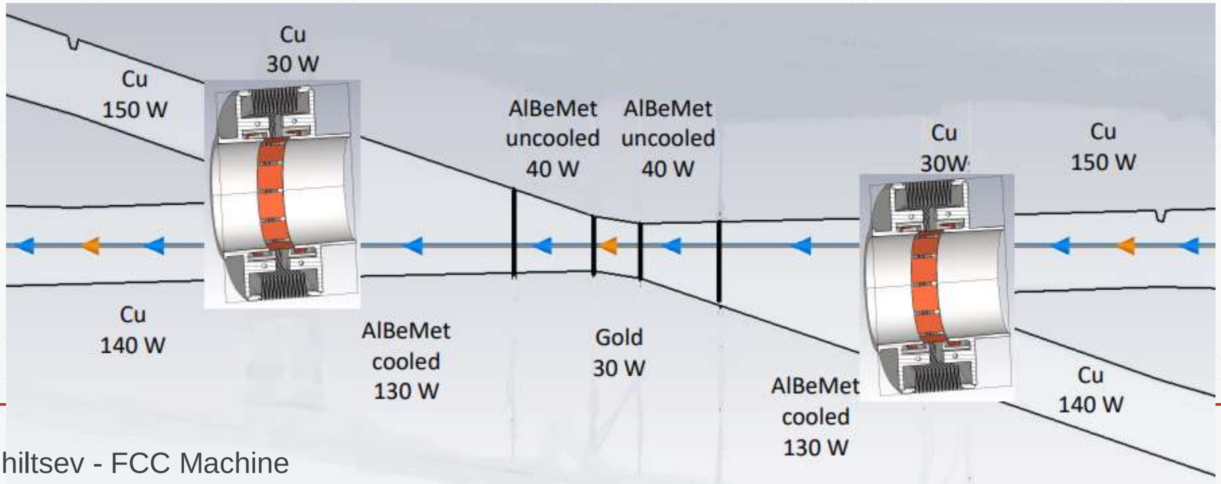
M. Sullivan …



3D sketch of key IR systems over first 3 m from IP



A. Novokhatski …

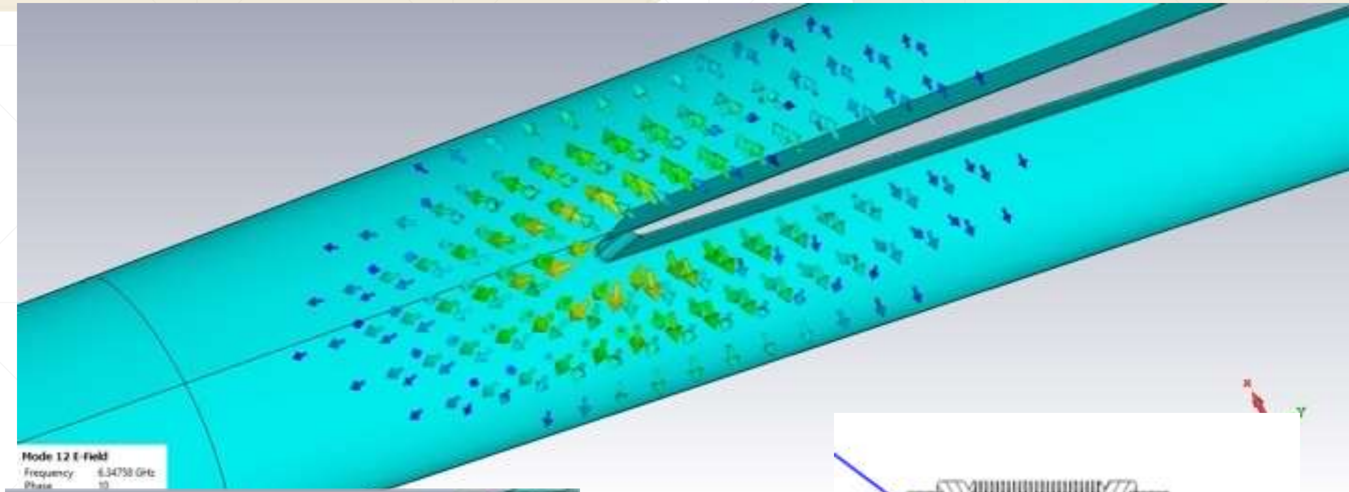


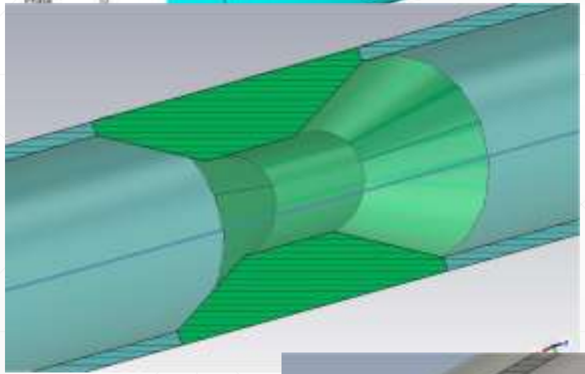
J.Seeman

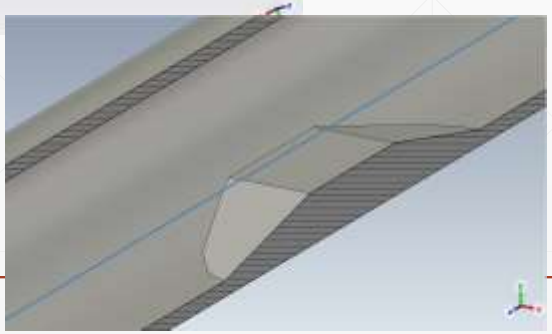
SLAC Work: FCC-ee Interaction region beam pipe design

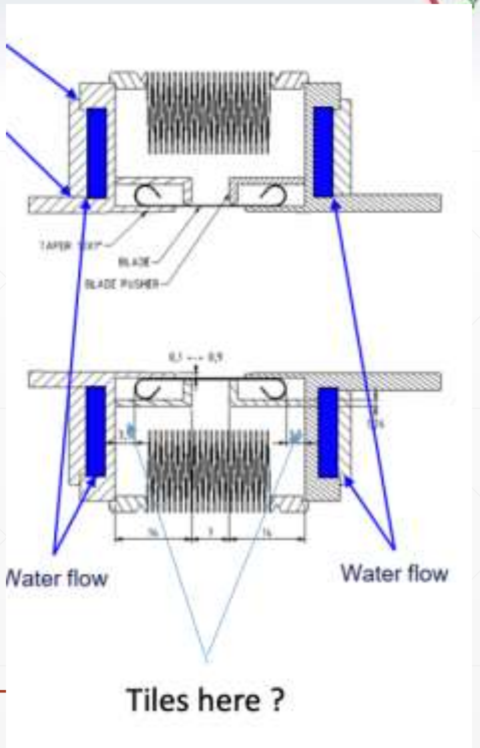
(A. Novokhatski, …)

- The design of the FCC IR beam pipe is based on the optimization study of the wake field losses of the colliding beams.
- We developed a special beam pipe shape, which have minimum impedance and only one unavoidable trapped mode
- Calculate power heat load distribution for the design of the cooling system
- Continue analyses and optimization of the synchrotron radiation masks, BPMS and design of the HOMs absorbing bellows







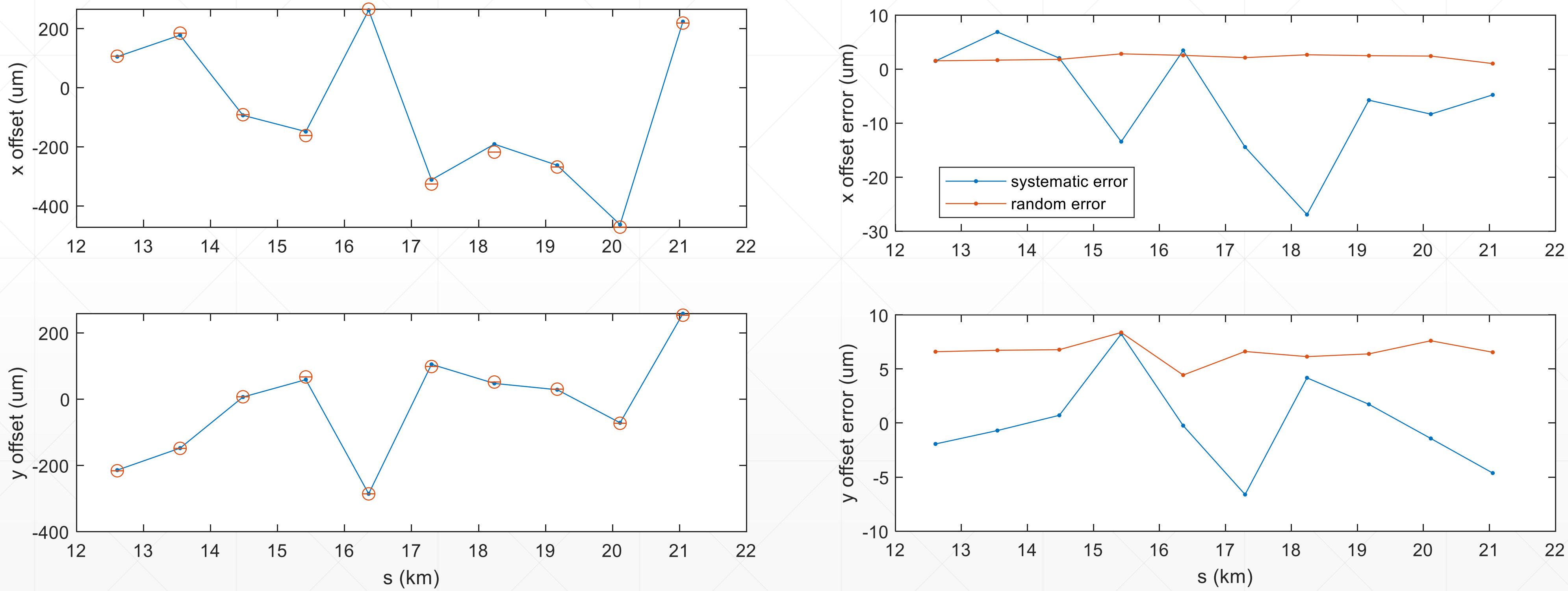


A.Novokhatski

Parallel beam-based alignment for FCC-ee

X. Huang, Phys. Rev. Accel. Beams 25, 052802 (2022)

- **Parallel BBA** finds the magnet centers of a group of quadrupoles simultaneously by correcting the induced orbit shifts (i.e., orbit shift due to modulation of magnet strengths)
- This improved method has been demonstrated for FCC-ee in simulation



Finding centers of 10 quadrupoles in the same time, with high accuracy (Error bar < 10 um for BPM error $\sigma = 1$ um)

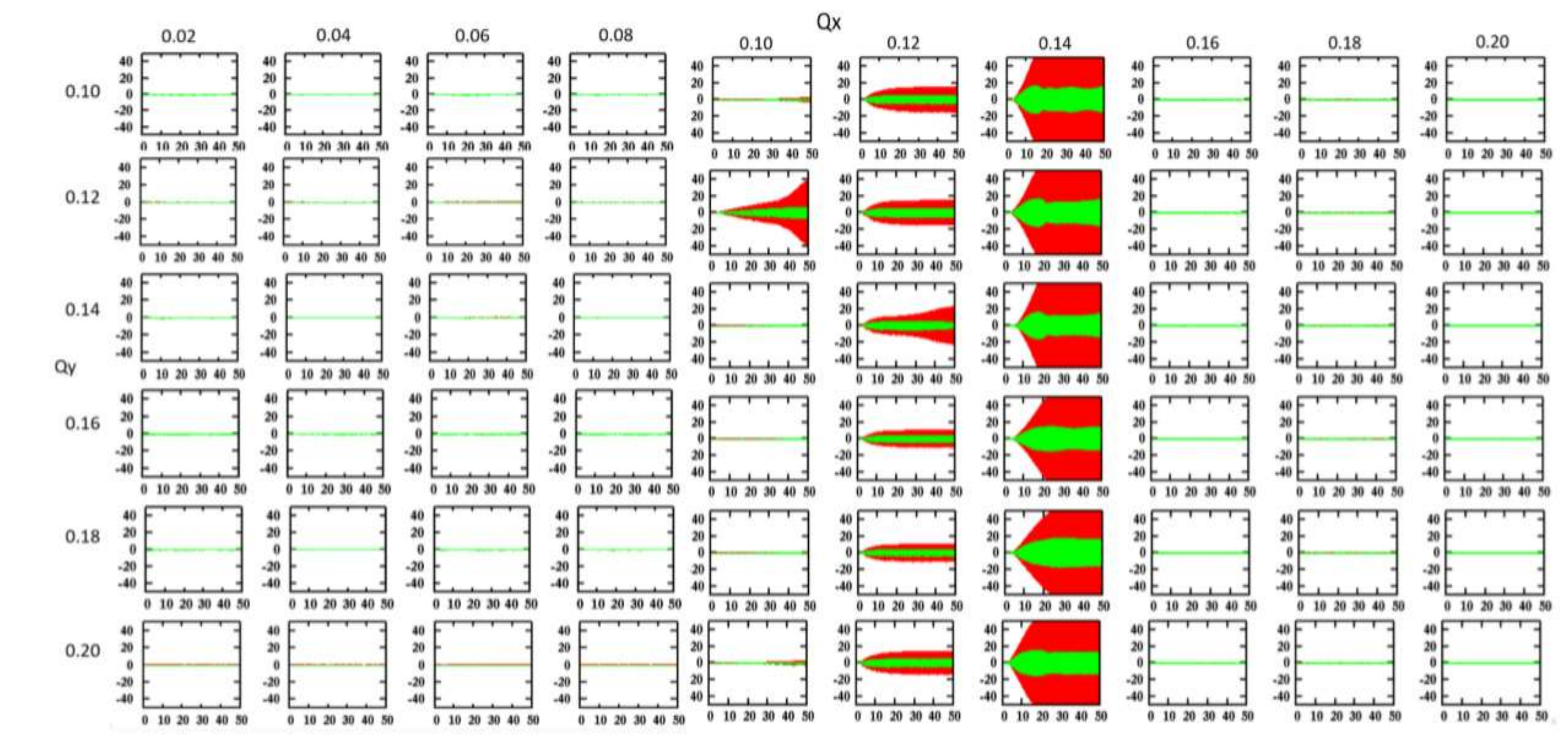
Method has been extended to sextupoles by minimizing induced orbit shift with optimizer

X.Huang

Working Point Optimization Needed to Avoid Coherent Beam-Beam Instability (plan, J.Qiang)

<Xp> and <Xe> in electron tune scan

Simulated with **BeamBeam3D**

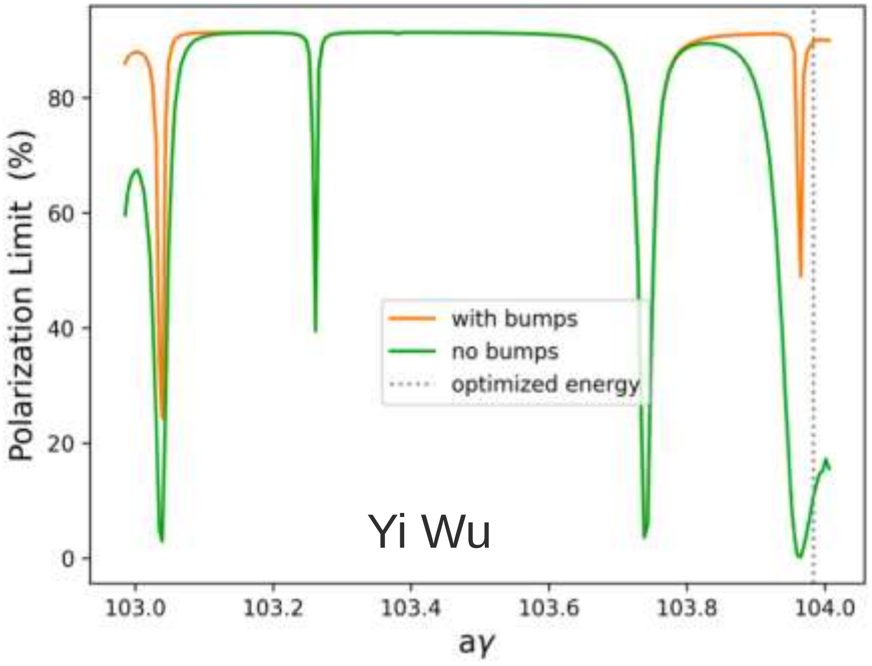


J. Qiang et al., in Proc. IPAC2022, WEPOPT041, p. 1942, 2022.

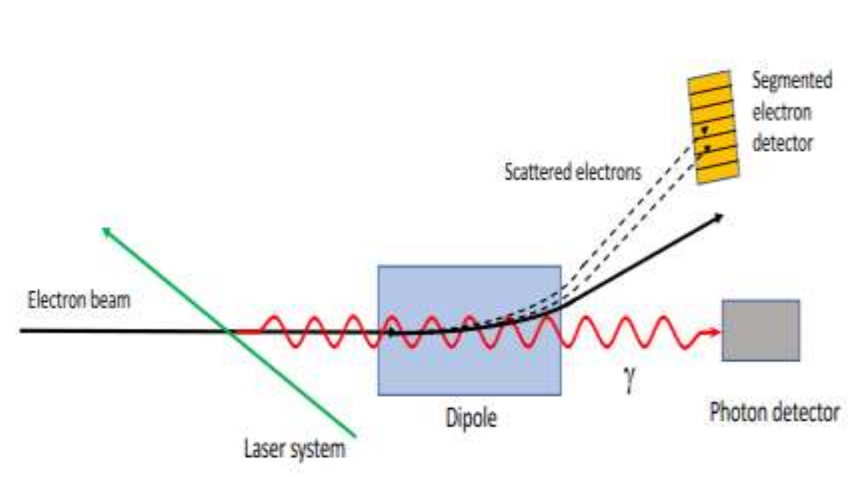
J.Qiang

Polarization and energy-calibration

- Design requirement – unique energy resolutions:
  - 4keV at 45GeV → 78 m of wigglers to polarize 5-10%
  - 250 keV at 80 GeV
- Initial work at FNAL by Eliana Gianfelice-Wendt
  - Simulations for EIC and FCCee
  - Control beam orbit ~20 um
  - Transferred knowledge to Yi Wu (PhD work at EPFL)
- Other expertise (potentially available):
  - Cornell – M.Signorelli and D.Sagan (Bmad code)
  - EIC team (V.Ptitsyn, V.Ranjbar)
- Substantial progress in Europe:
  - Beam tests at KIT/KARA in 2023 – RDP observed through change in Touschek lifetime - addressed systematic effects of RDP measurements, incl. beam optics measurements and RDP scans at various beam intensities, scanning velocities and directions.



First order energy scan with and without harmonic bumps optimized at 45.82 GeV (aγ = 103.983) using the Rossmanith-Schmidt scheme in V22 lattice



Initial work by E.Gianfelice-Wendt

Summary

- FCC Machine Design studies progress
  - aim for Nov 1, 2024 for completion
- Strong and active international team
  - Over many topics, well organized
- Activities in the US spread over several labs/universities:
  - Unique expertise is (potentially) available
  - IR design, MDI, alignment control, polarization, beam-beam, etc
  - While important for the FCC Design, the studies in the US are of limited scope:
    - funding streams/ plans not established yet

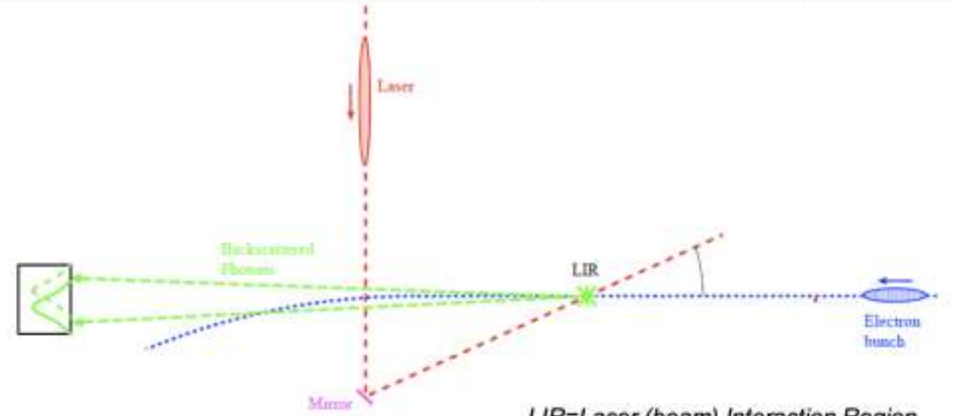
FCCIS WP2 Task 2.5 Polarisation and energy calibration

- A transverse-field kicker (RF-kicker) excites one pilot bunch via a TEM-wave travelling towards the beam with a varying frequency.
- The proposed variation rate is equivalent to about 1 keV/s of beam energy change and the kick is approximately 1 μrad per turn.
- A **stripline kicker d**esign with 1 m longitudinal length, magnetic and electric fields of 75 μT and 225 V/m respectively, would meet the aforementioned performance parameters at the Z-pole.
- Additionally, **residual longitudinal polarization in colliding bunches must be controlled below 10^{-5}**, demanding a selective RF-kicker to distinguish between pilot and colliding bunches. Such an exciter could also be combined with a transverse feedback system, which could be investigated in future studies.

I.Agapov/F.Zimmermann

FCCIS WP2 Task 2.5 Polarisation and energy calibration

- Measurement done **with polarimeter** + **spectrometer**
- Either a **Q-switched Nd:YAG 532 nm, few-nsec pulse-duration laser or a mode-locked Ytterbium 515 nm laser**, allowing operation with pulses of 10 psec to a few ns. The photons interact with the bunch via inverse Compton scattering. Silicon pixel detectors record the back-scattered photons and the scattered e- about 100 m downstream, to determine the 3D polarization vector.
- **Precise models for relating measurements to the ECMs at the IPs are then needed** to account for **SR losses**, **beamstrahlung losses, wakefields**, **opposite-sign vertical dispersion** (OSVD) in combination with a transverse collision offset at the IP.
- In addition to four baseline beam energies, operation with beams of 62.5 GeV is being studied, corresponding to the peak of Higgs production. Due to the narrow resonance width of 4.2 MeV monochromatization, reducing the spread of the ECM, is required. This could be achieved, e.g., by intentionally introducing opposite-sign dispersion at the IP, accounting for beamstrahlung effects.



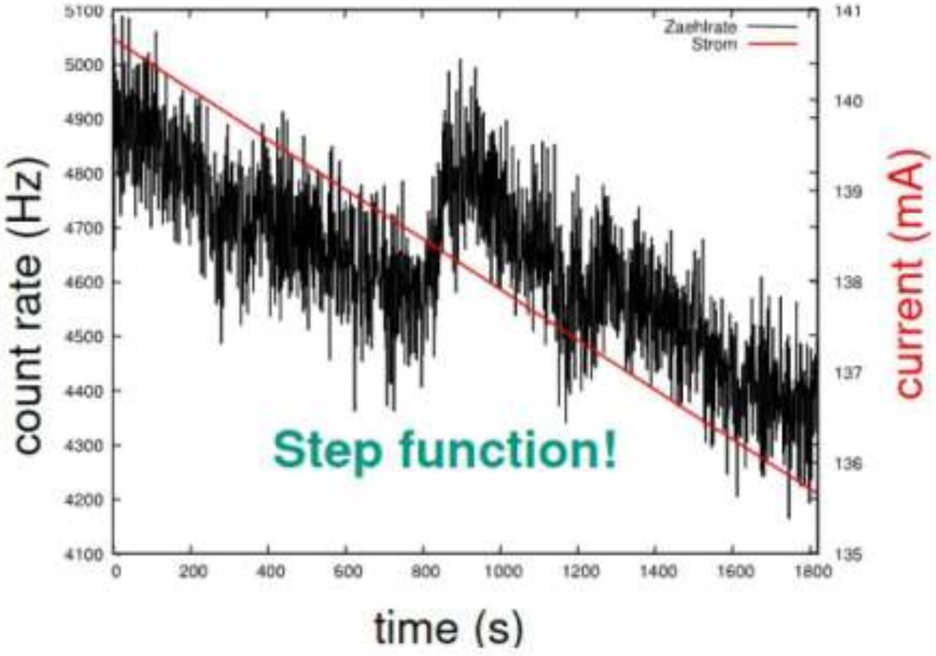
LIR=Laser (beam) Interaction Region

I.Agapov/F.Zimmermann

FCCIS WP2 Task 2.5 Polarisation and energy calibration tests

Beam tests at KIT/KARA in 2023 addressed systematic effects of RDP measurements, incl. beam optics measurements and RDP scans at various beam intensities, scanning velocities and directions. A detailed analysis is currently ongoing.

No Compton polarimeter, but RDP observable through change in Touschek lifetime.

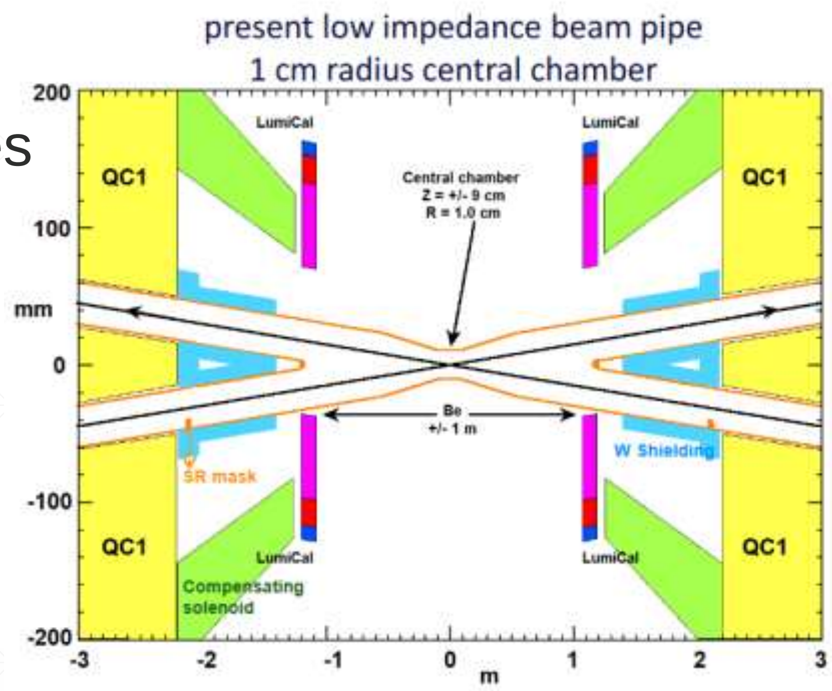


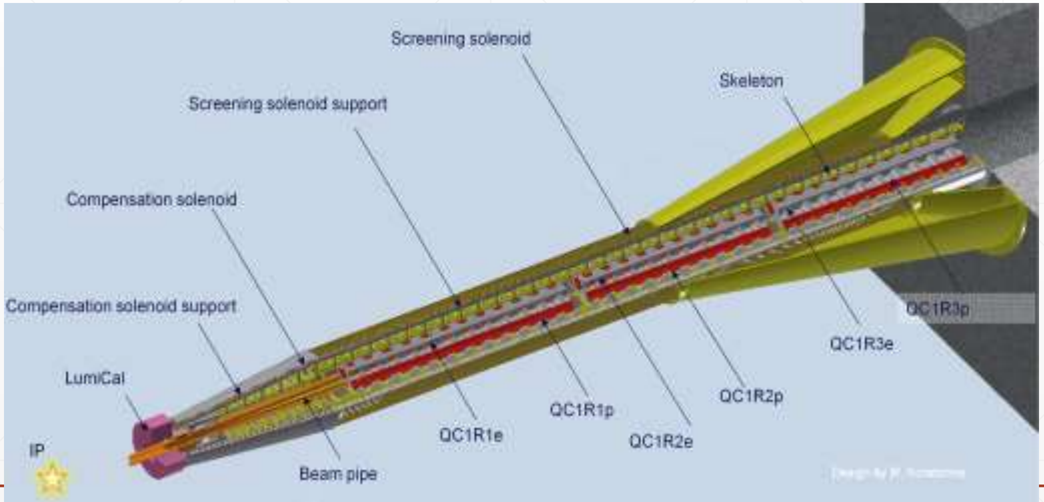
Very short polarisation times (~10 minutes), so many measurements possible.

I.Agapov/F.Zimmermann

Topic 1: Accelerator MDI and IR Magnets

- Manuela Boscolo – FCCee IRs:
  - 4 hi-lumi IPs/CrabWaist, challenges
  - Now 2 cm dia central chamber
  - Control/dump ~400kW s.radiation
  - Full IR mock up in Frascati
- Brett Parker
  - Complex set of magnets
  - 30 tons of pull on anti-solenoid
- John Seeman
  Angelika Drees
  - Tons of relevant experience from PEP-II (199-2008) and EIC (now)





Comparisons of IR features for FCCee, CEPC, ILC, SuperKEKB
(J. Seeman, SLAC)

SLAC

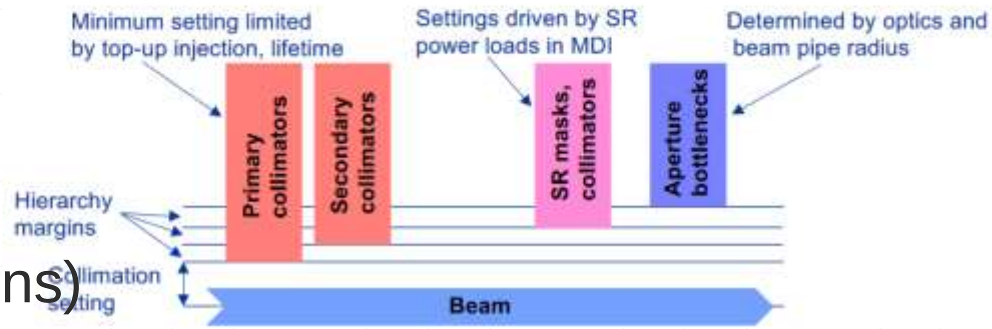
Machine		FCCee	CEPC	ILC	SuperKEKB
Crossing-angle	mrad	30	33	14	83
L*	m	2.2	1.9	3.5	0.935
Vertical β_y* at IP	mm	0.7-1.6	0.9-2.7	0.4	0.3
Detector sol'n field	T	2/3	3	3.5/5	1.5
Detector stay clear	mrad	100	118/141	90	350/436
Two beam ΔX at L*	mm	66	62.7	49	77.6
He temperature	K	1.9	4.2	4.5	4.5

+ significant circulating beam current/power/losses/SR/heating

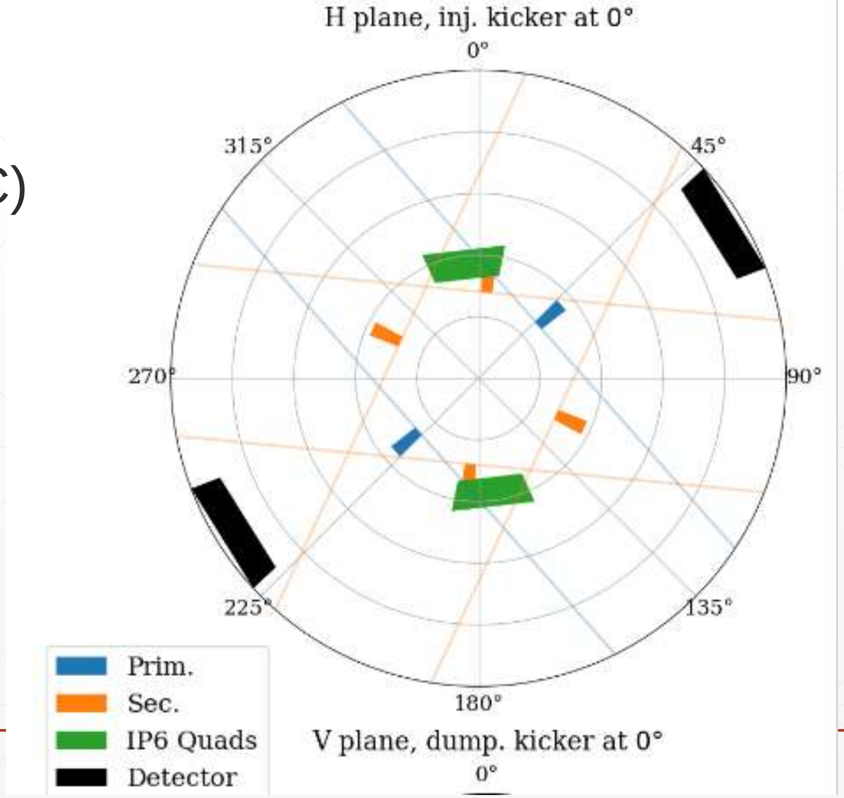
J.Seeman

Topic 2: Collimation and Protection

- Andrey Abramov – current FCCee scheme:
  - 18 MJ at 45 GeV (LHC ions)
  - IRs and arcs
  - Source of instabilities
  - S-KEKB damage (80% in 2 turns)
  - Alternatives:
    - hollow laser Compton (J.Byrd)
    - hollow e-beam (as in Tevatron, RHIC)

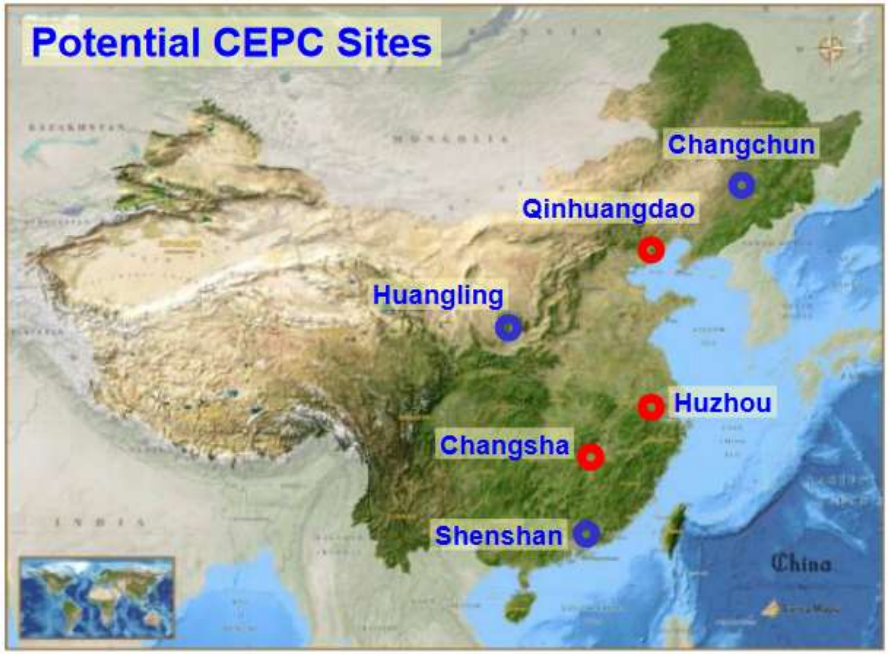


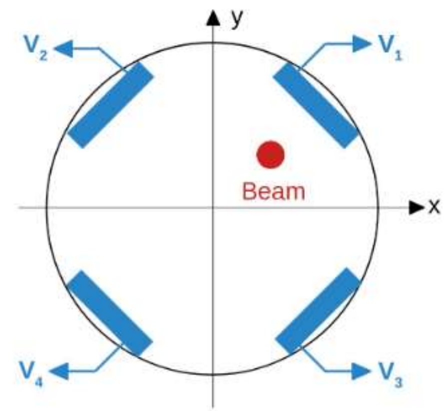
- Matthew Valette – EIC collimation
  - 18 GeV e-
  - 18 cm long collimators
  - Conceptually similar to FCCee

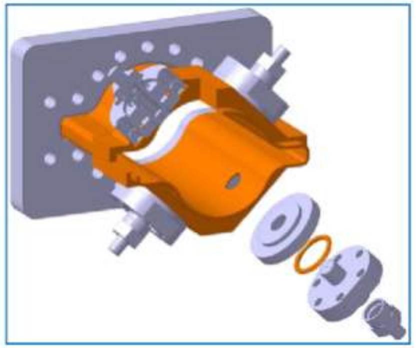


Topic 4: Joint with Detectors

- Jianchung Wang– CEPC:
  - Raised P=30→50MW
  - TDR later this yr, 36B RMB
  - A lot of progress
  - **If** in the 15th 5-yr plan – civil ‘26
  - 1st beam 2036
- Jacqueline Keintzel – IR diagn.:
  - 1um BPMs
  - Polarimeters
  - SR dumps
  - Wigglers
  - How do we support central part of the detector, etc

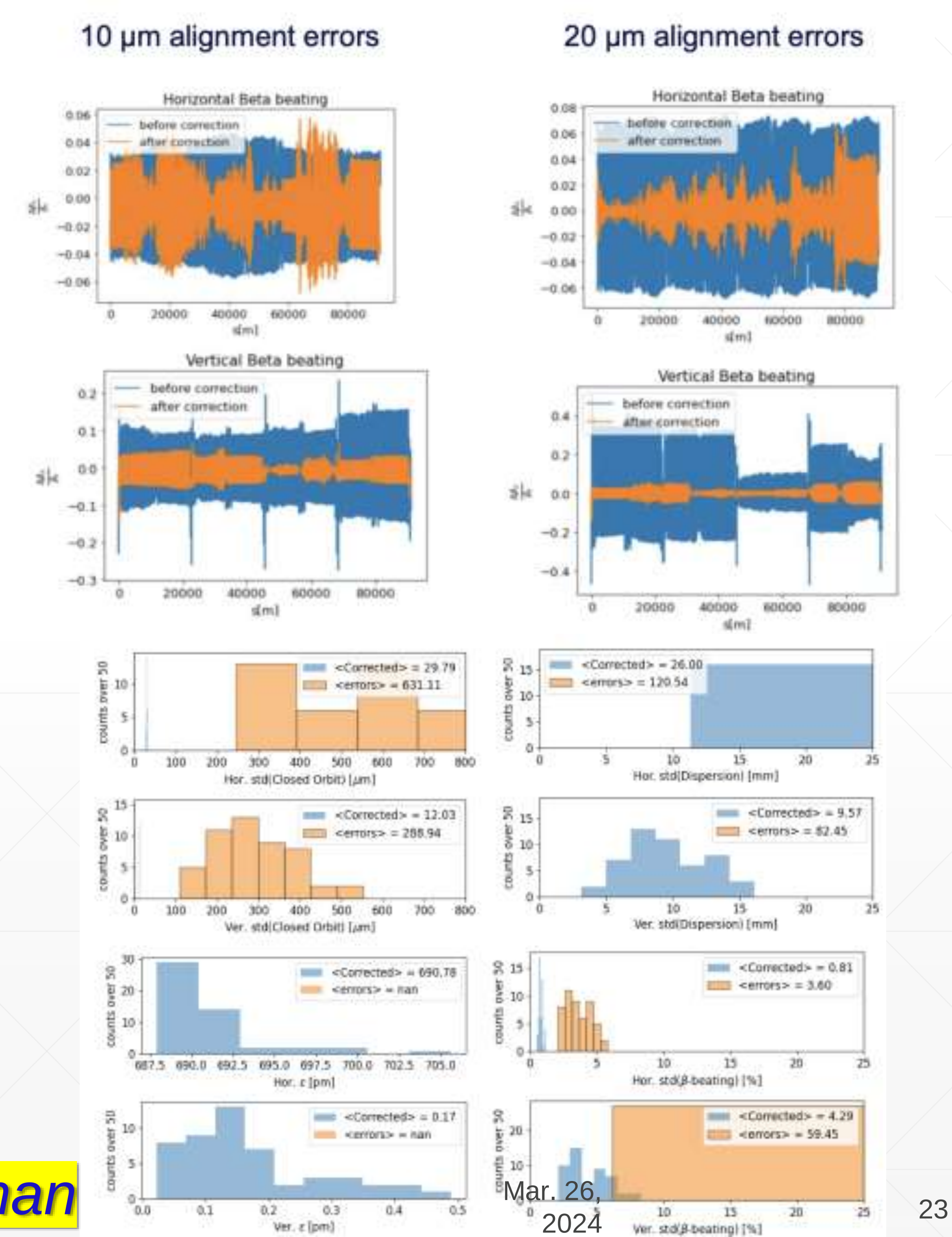






FCCIS WP2 Task 2.2 Collider Design: tuning challenges addressed

- **Optics correction and emittance tuning** chain further improved and benchmarked.
- Feasibility of orbit and beta-beat correction in the arcs has been firmly established.
- **Correction tools have been experimentally tested at synchrotron light sources such as ESRF-EBS and PETRA III.**
- Coupling correction to achieve vertical emittances below ca. 0.7 pm rad without collision is required to avoid inacceptable vertical emittance blow-up and the resulting luminosity reduction due to beam-beam interaction.
- **Improving coupling correction, as well as establishing procedures for the final focus alignment are the next important steps** towards firmly establishing the feasibility of optics correction and emittance tuning procedures.



I.Agapov/F.Zimmerman