Remaining issues on the design of beam optics for the FCC-ee collider rings

K. Oide
Nov. 10, 2020 @ FCC November Week 2020

Many thanks to J. Bauche, M. Benedickt, A. Blondel, M. Boscolo, T. Charles, J. Gutleber, M. Koratzinos, V. Mertens, T. Risselada, D. Shatilov, F. Zimmermann, and all FCC-ee collaborators

The Future Circular Collider Innovation Study (FCCIS) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 951754.

Issues beyond the CDR

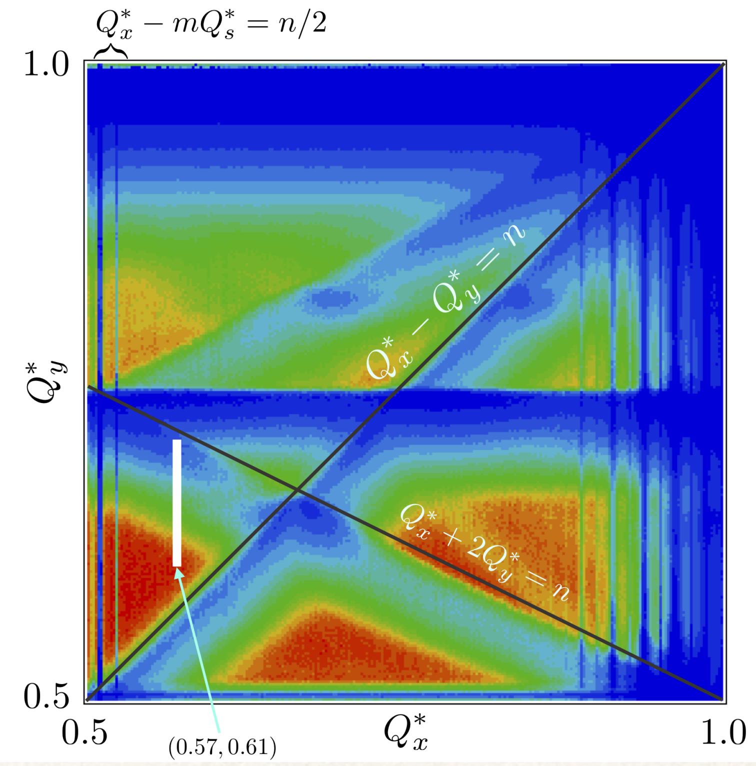
- 4 IP or not?
- Layouts:
  - Tunnel placement
  - Around the IP
  - Consistency with hh & the main booster
- Straight sections:
  - Injection & beam dump
  - RF for all energies
  - Polarimeters, polarization wigglers
- MDI-related issues:
  - IR optics
    - Inclusion of solenoids
    - Final quads with inevitable multipoles
    - Local chromatic/crab sextupoles
  - Collimators: how many and where?
- More details:
  - Separation between magnets
  - Additional correctors, BPMs
  - Dividing very long dipoles in the interaction region as well as arcs into realistic lengths.
  - Inclusion of field characteristics of actual magnets (effective length, fringes, multipoles).
  - and more…

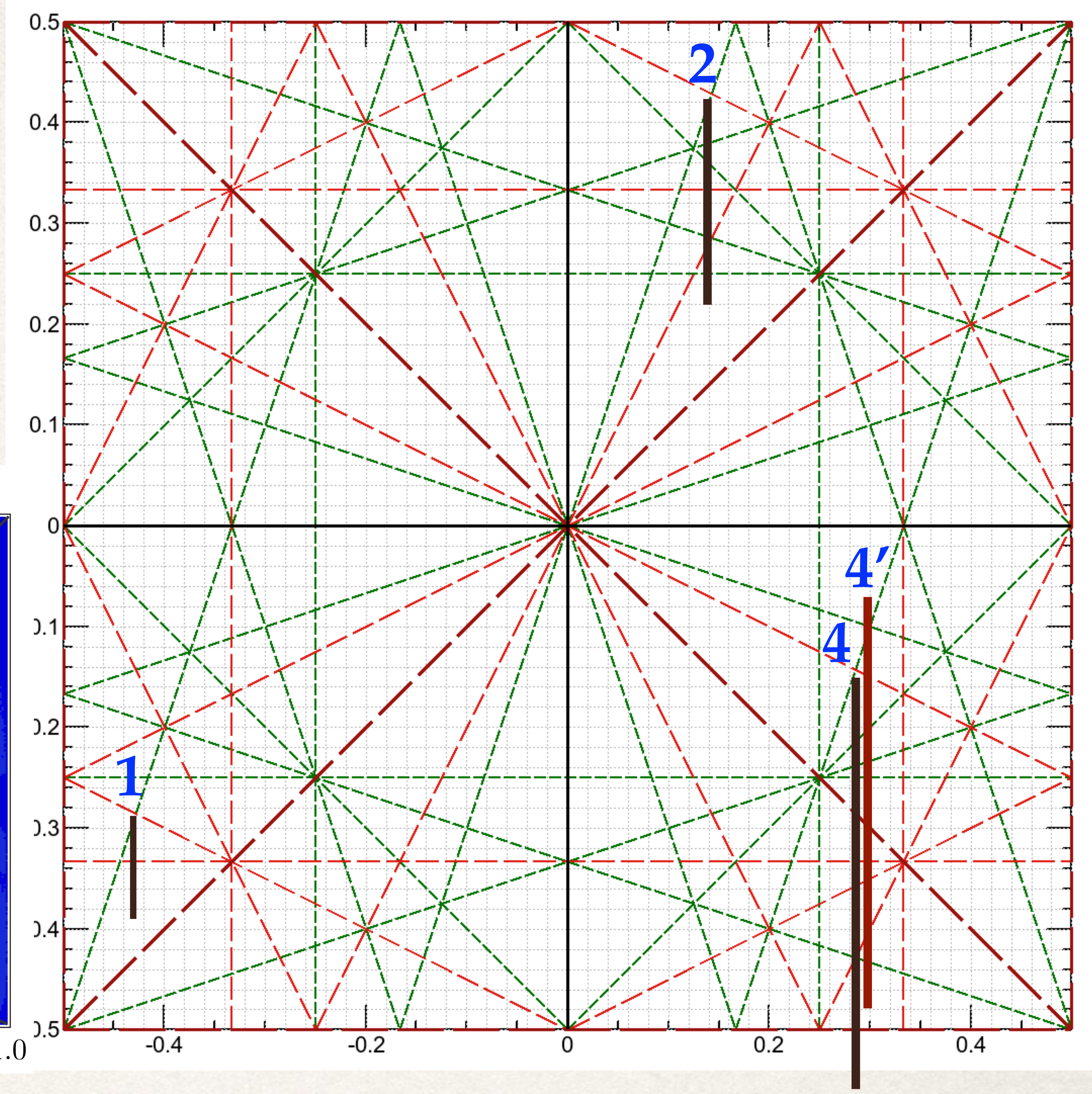
4 IP or not?

- As pointed out by D. Shatilov, the expected beam-beam footprint crosses a number of resonance lines including the half integer ($\nu_y = N$) and sum resonance ($\nu_x + \nu_y = N$).
- The harmfulness of these resonances depends on the machine errors and corrections.

Beam-beam footprint at Z

CDR ("1 IP")

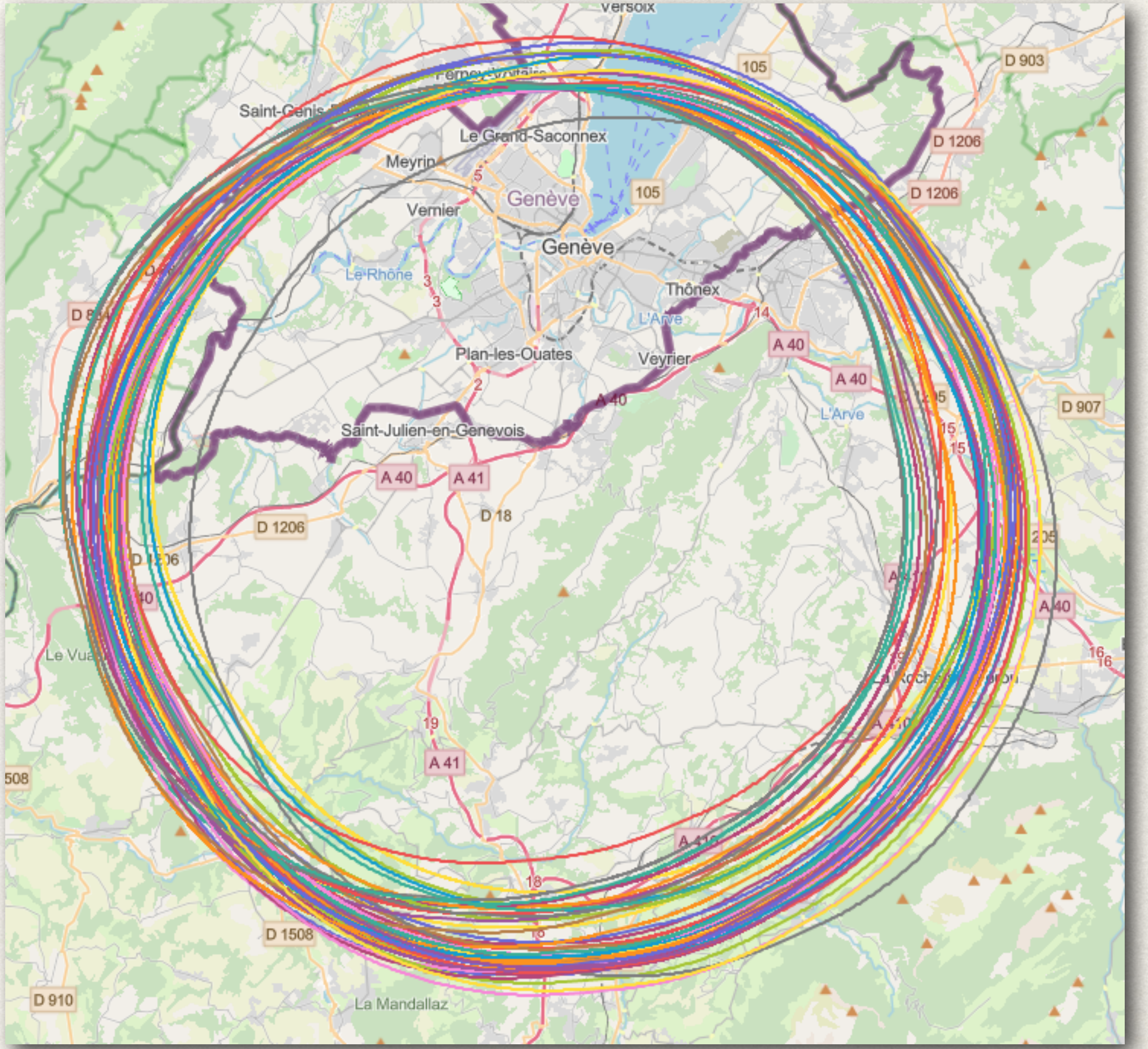




- The achievable β-beats after misalignments & corrections may be still within the allowable level (T. Charles), but…
- Beam-beam simulation with lattice errors must be done for the decision (D. Shatilov).

Layouts

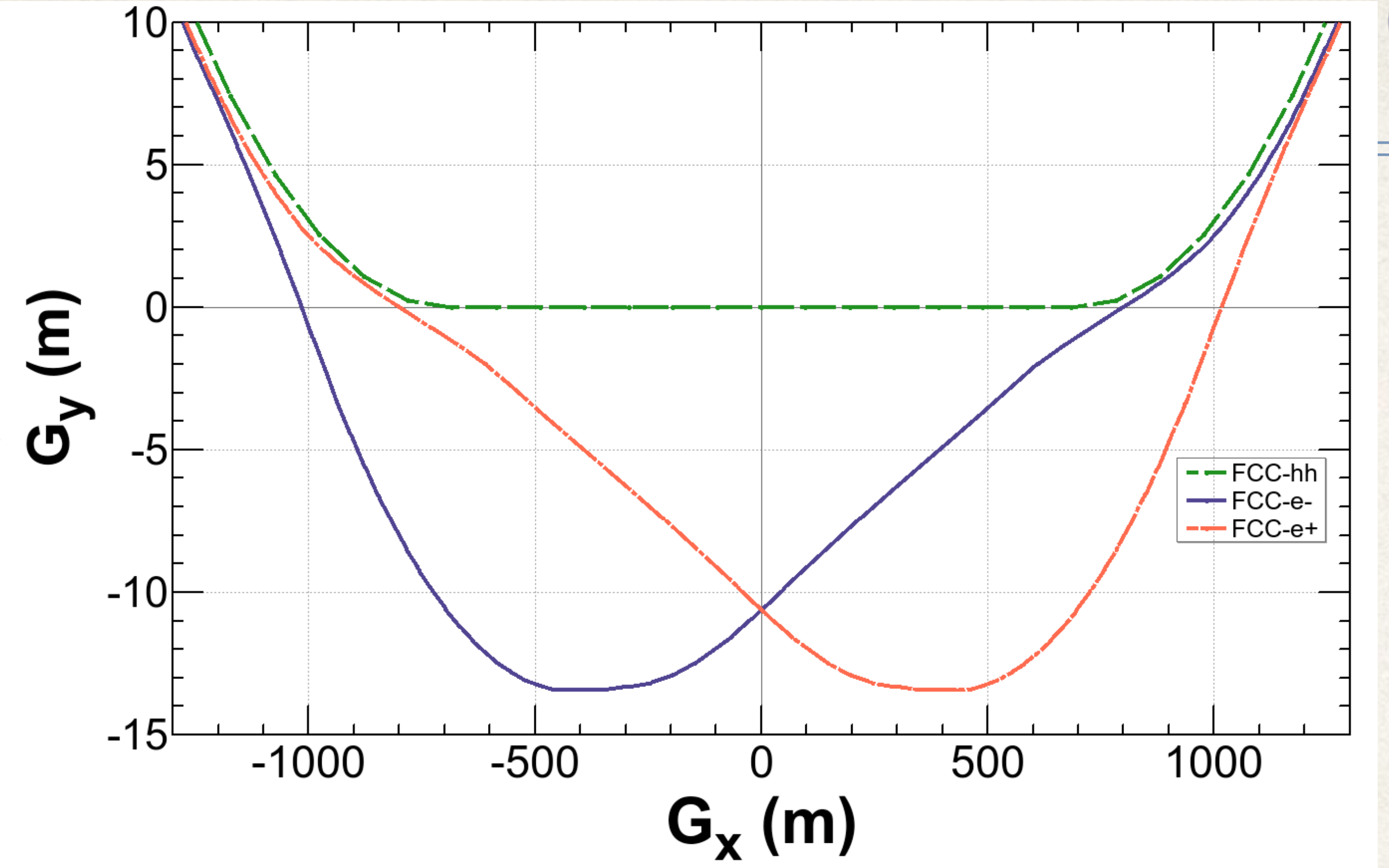
- 45 scenarios out of hundreds were individually looked at and retained for further optimisation at micro-level (J. Gutleber, V. Mertens, A-L. Verdier).
- The beam optics will be redone after the global layout is fixed.
- There will be no fatal impact, but may affect the performance such as the luminosity by a small amount.



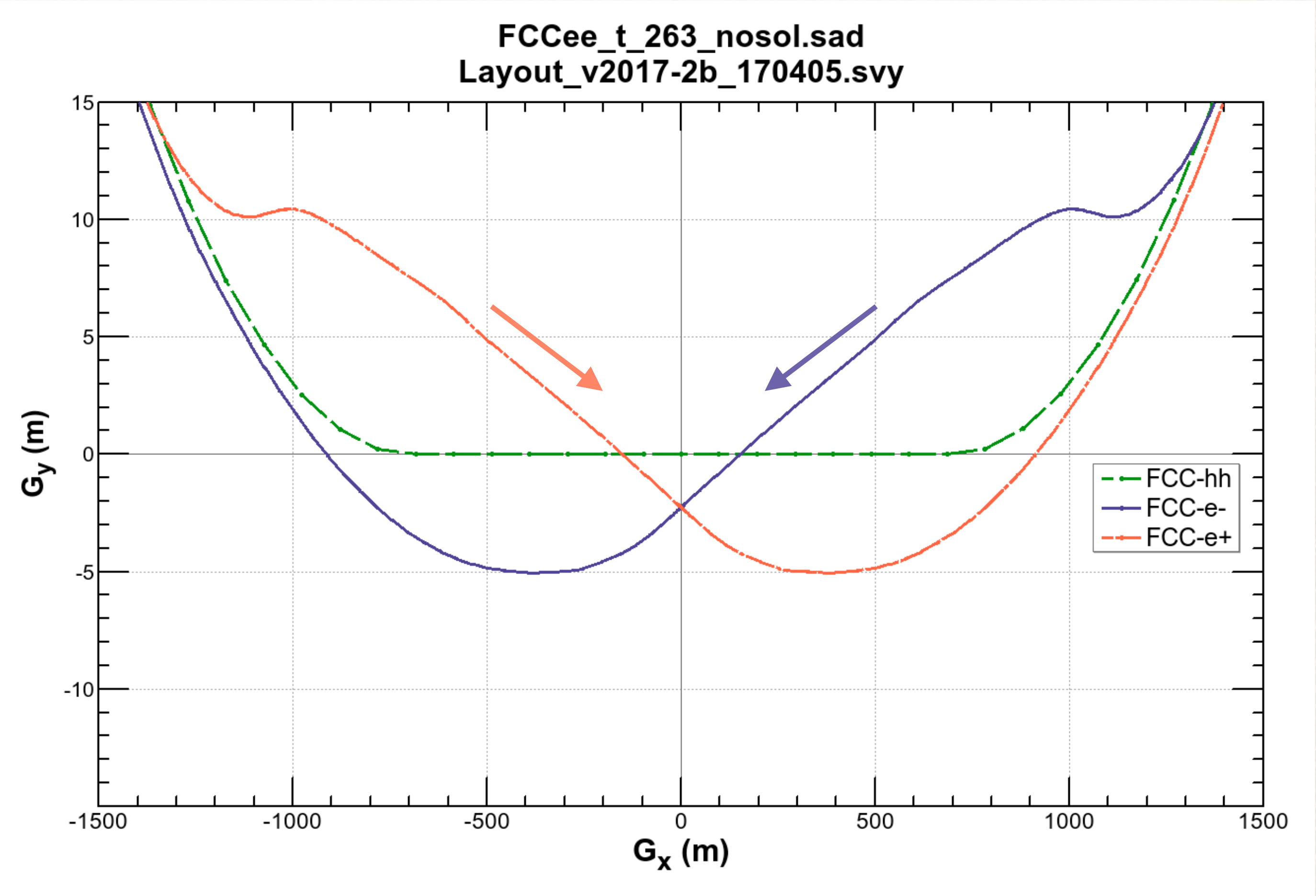
- J. Gutleber, V. Mertens, A-L. Verdier

Layout around the IP

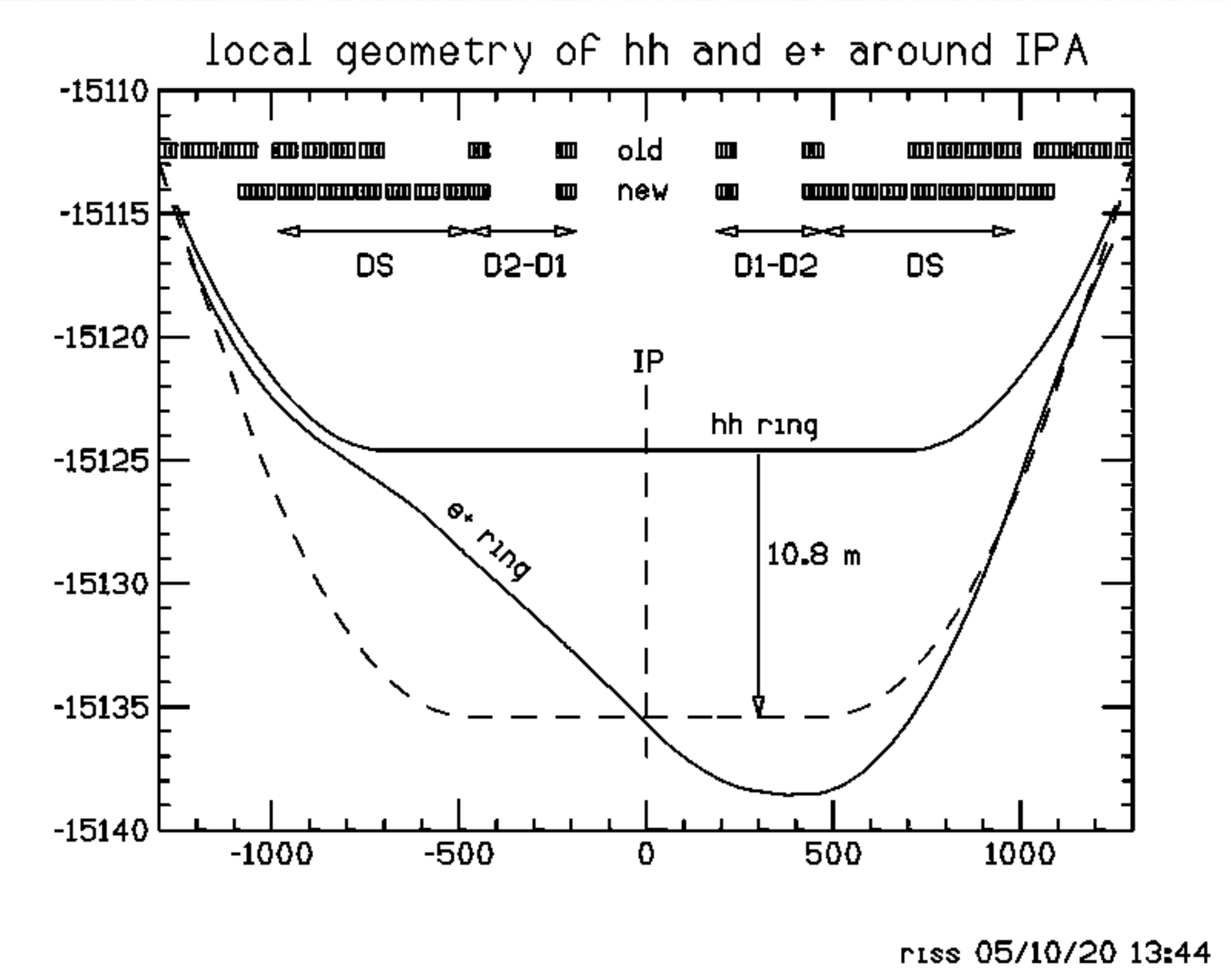
- The layout around the IP on the CDR needs a large space for the tunnels of ee, booster and hh.

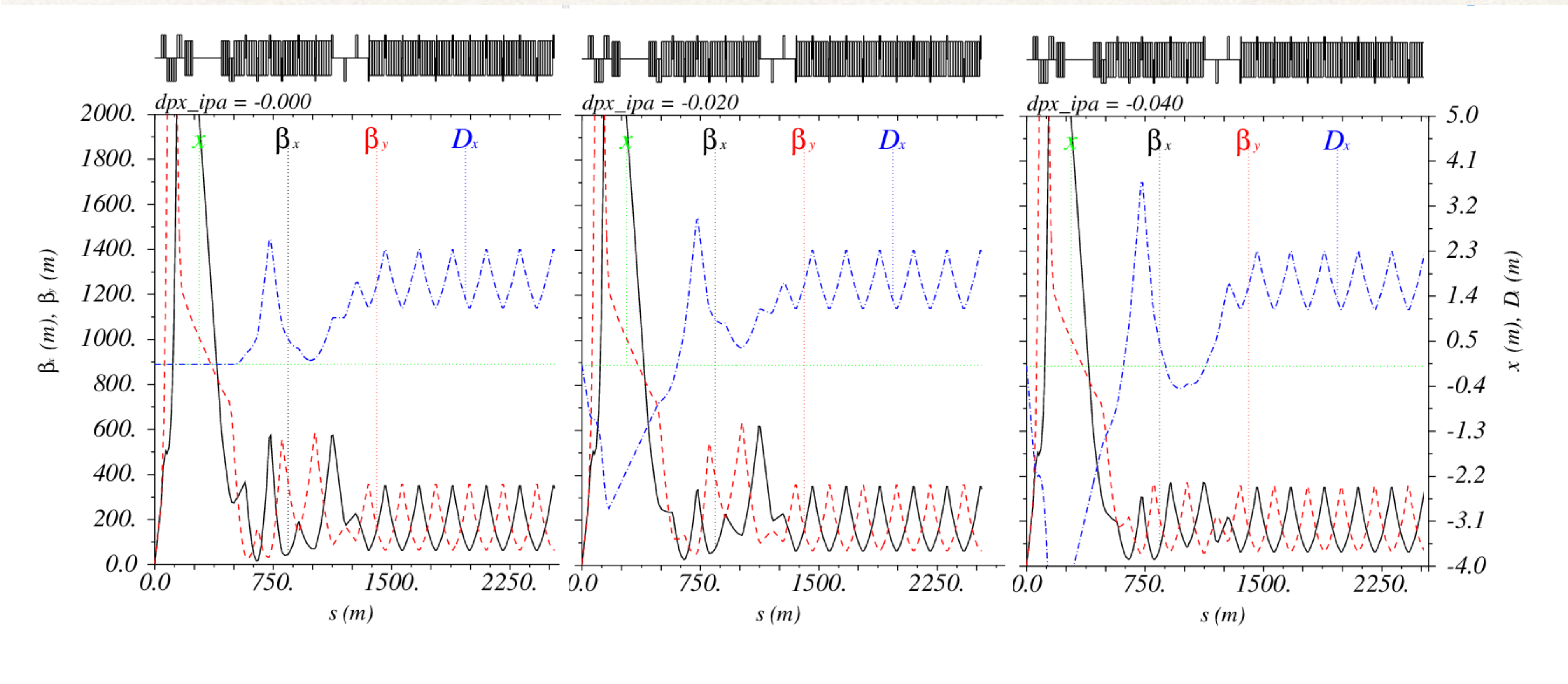


- The size of cavern for two detectors also matter.
- It is possible to modify the ee-rings, but still needs a large space for tunnels.



- A possible solution is to make the hh ring to follow the outer footprint of ee, as investigated by T. Risselada (preliminary):





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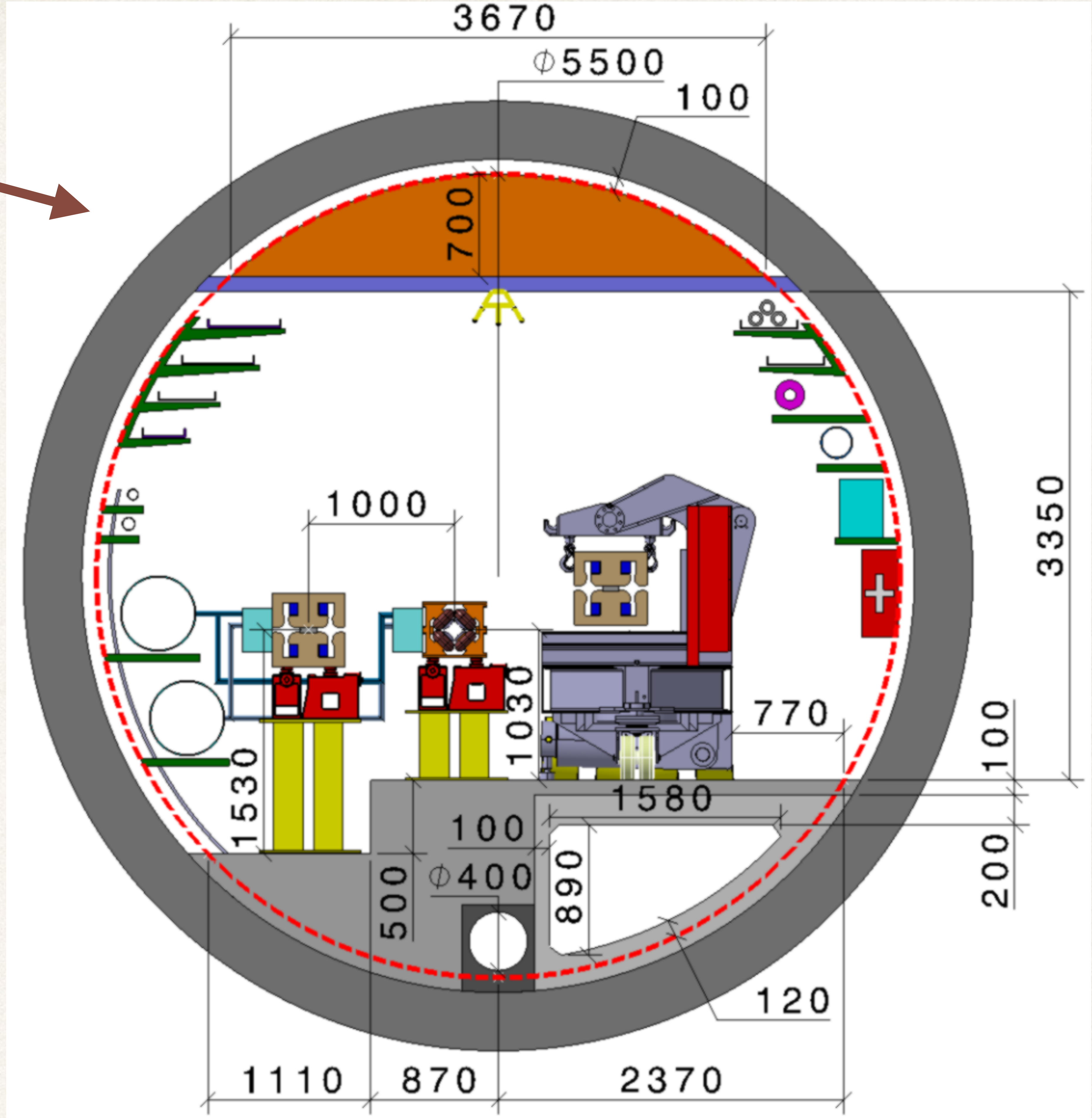
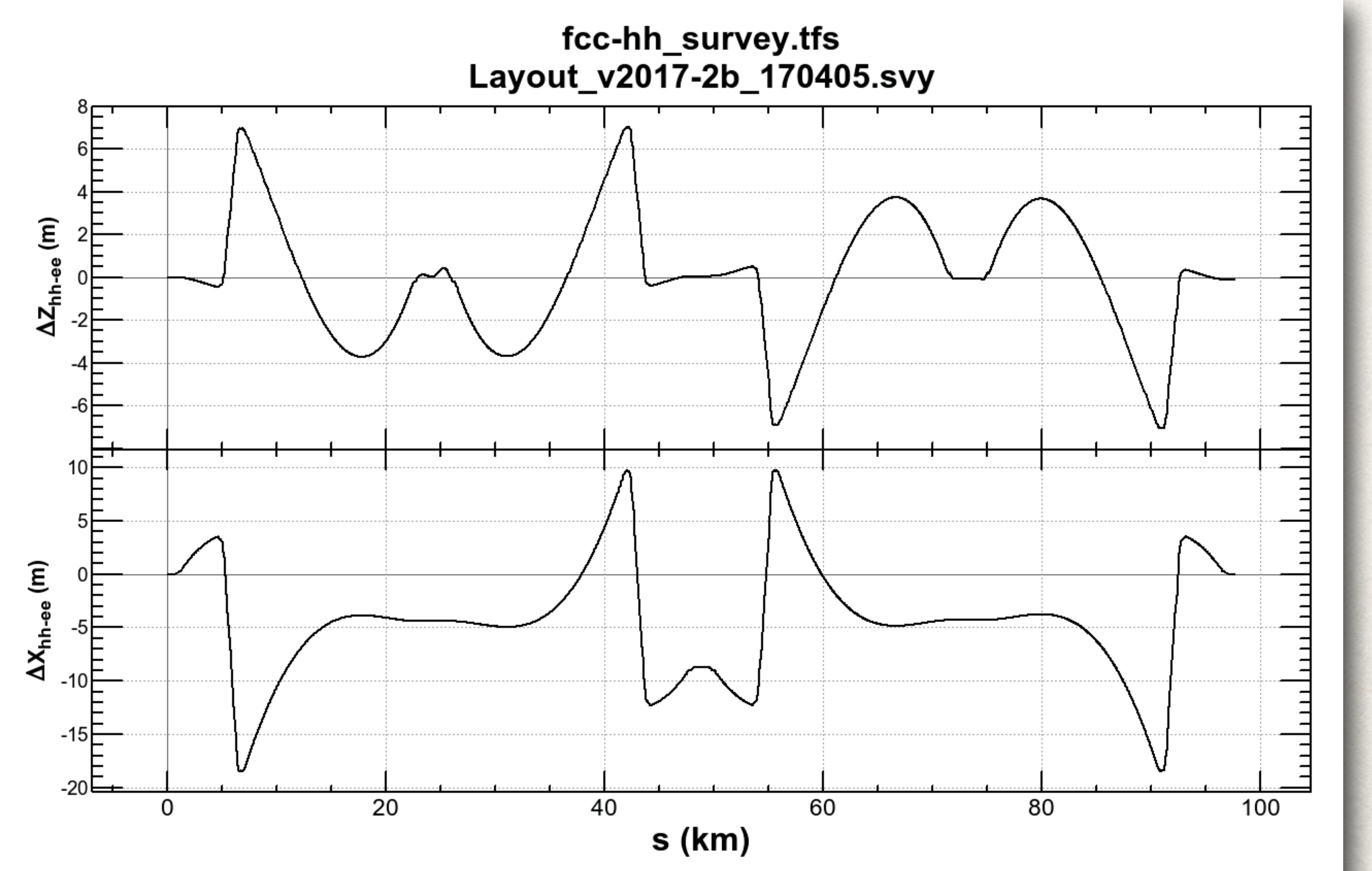
Consistency of the layout with FCC-hh & Booster

- The Main Booster may be elevated for a better arrangement and easier injection to the collider, access from the both sides of the rings, etc.:
    - The circumference of the booster must be adjusted, to use the common RF freq. as the collider.
- Currently there is some discrepancy in the layouts between ee & hh. Should be solved on either side:



V. Mertens



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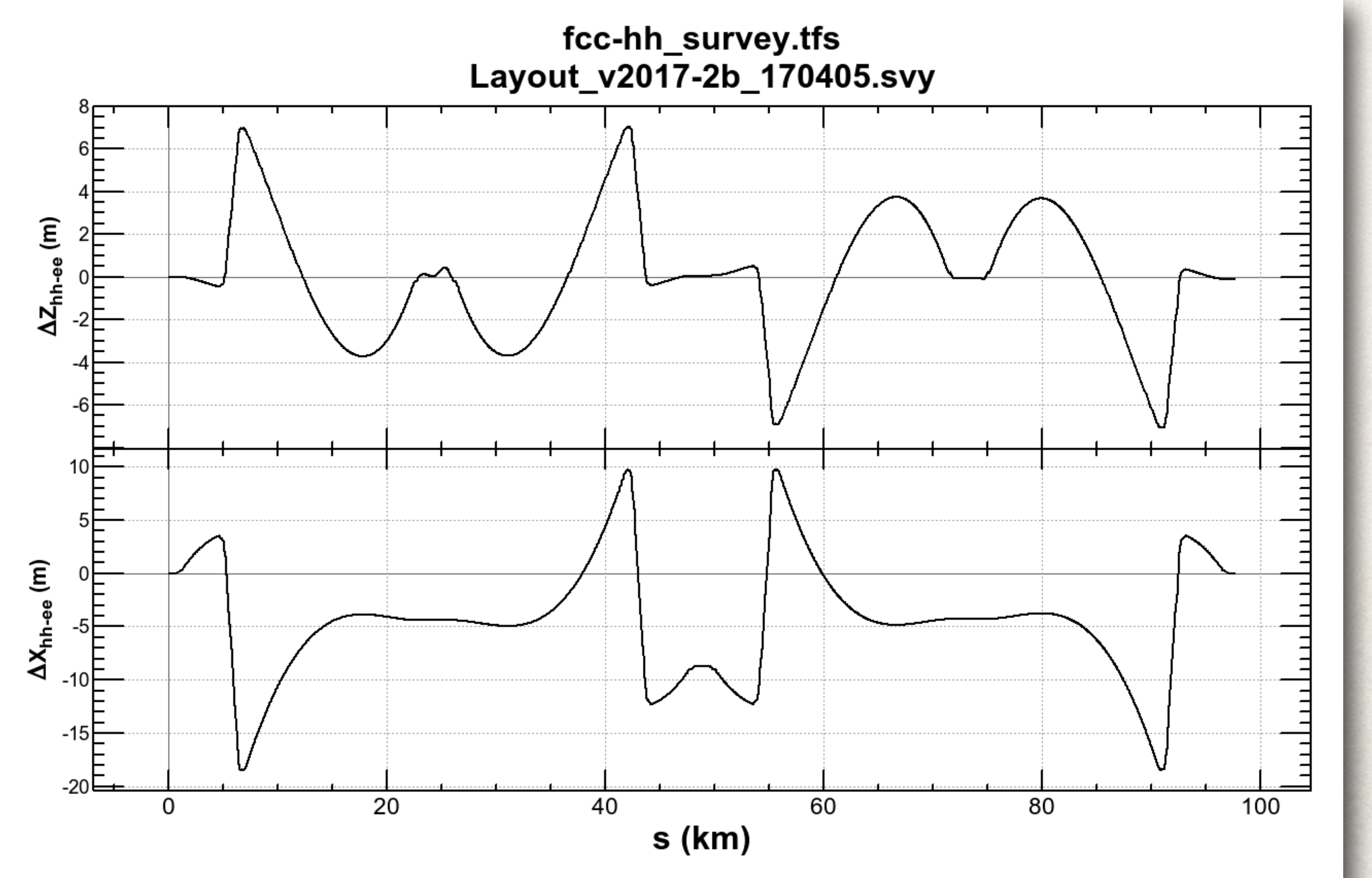
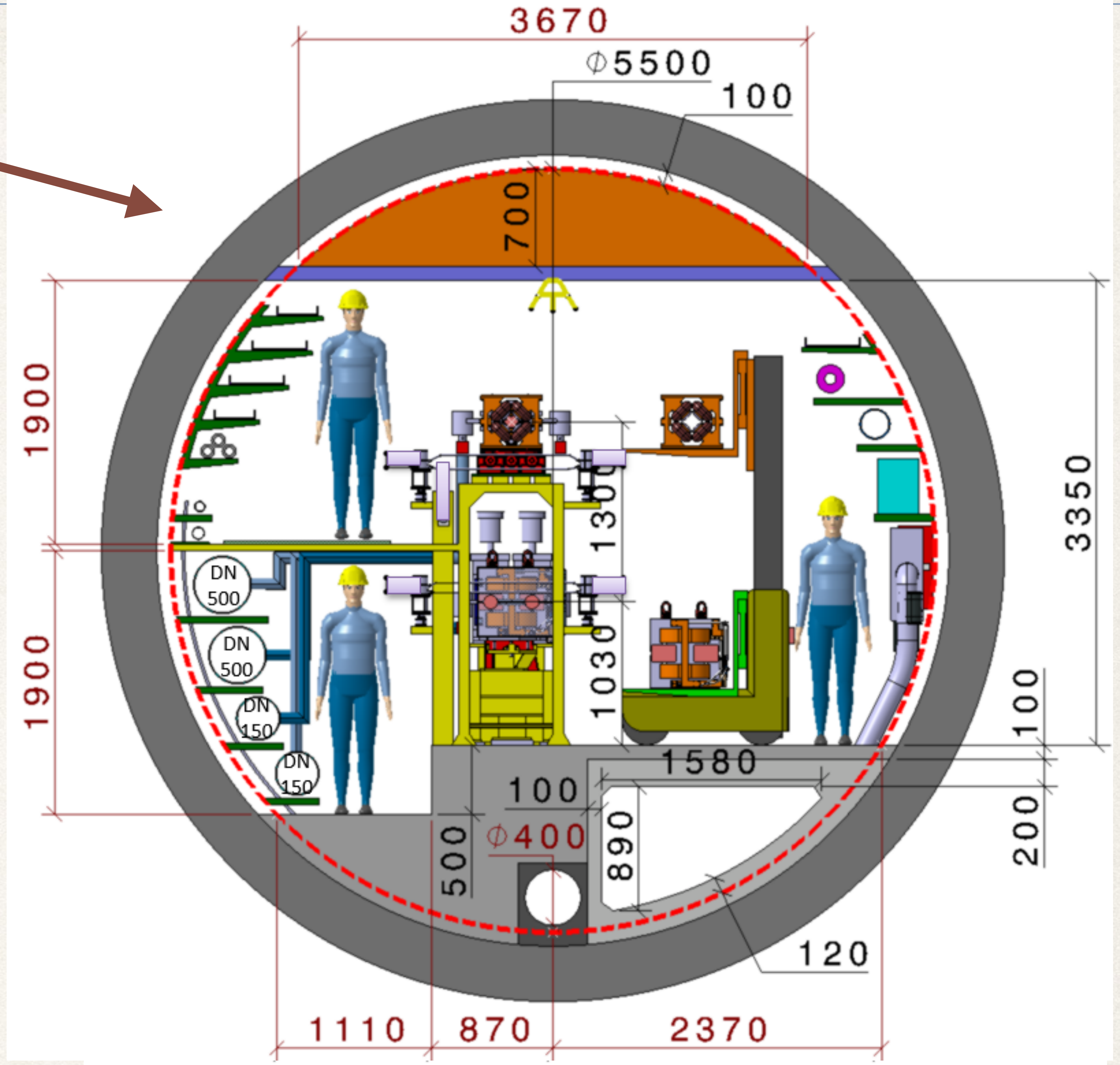




V. Mertens

Injection & beam dump

- The injection & beam dump optics must be refined, esp. for synchrotron injection.
    - The transport line, including a vertical translation must be designed.
    - The usable straight section must be identified.
    - For 4 IP, the injection will be done in the same section as the RF.

M. Aiba
CDR

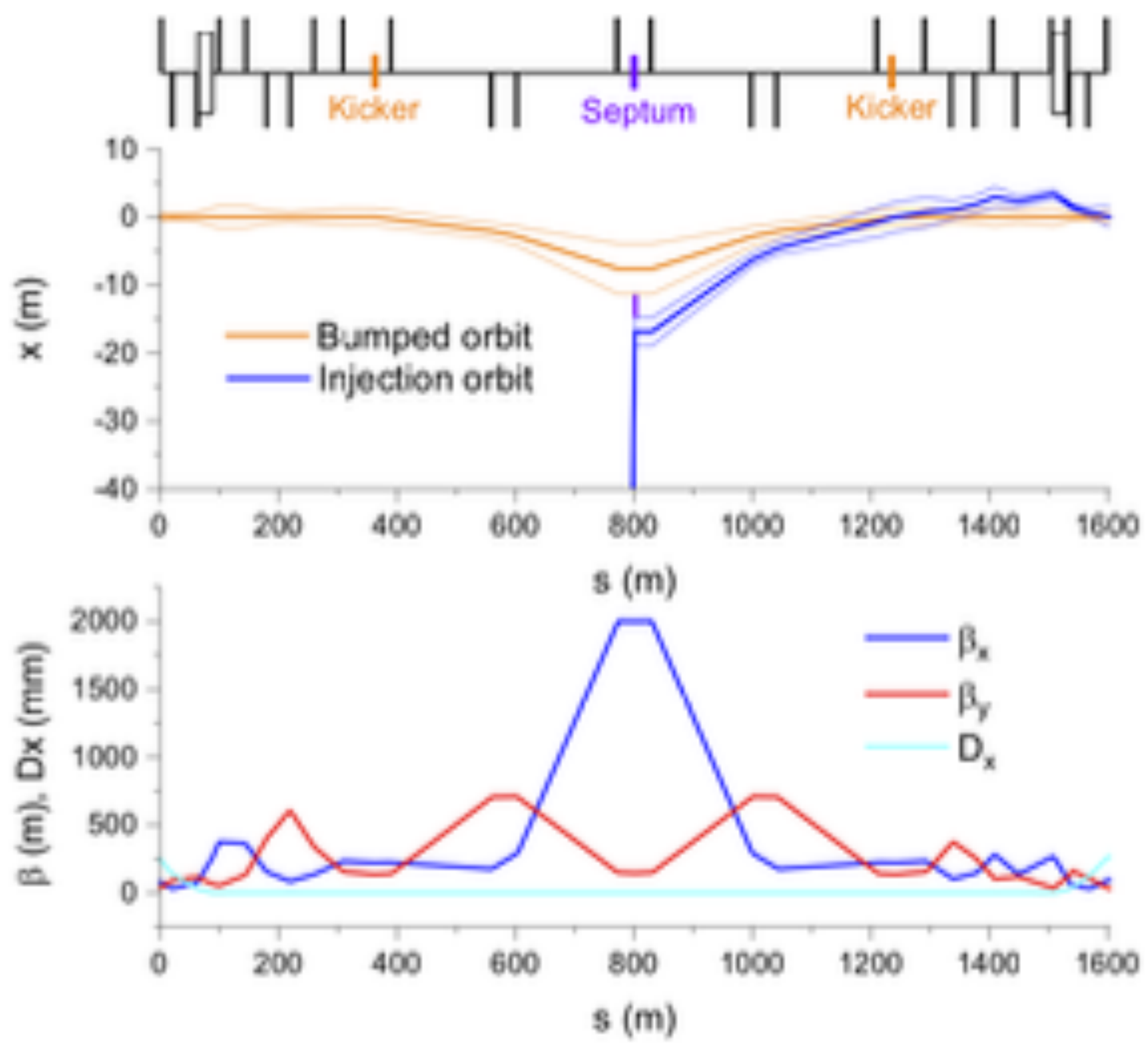
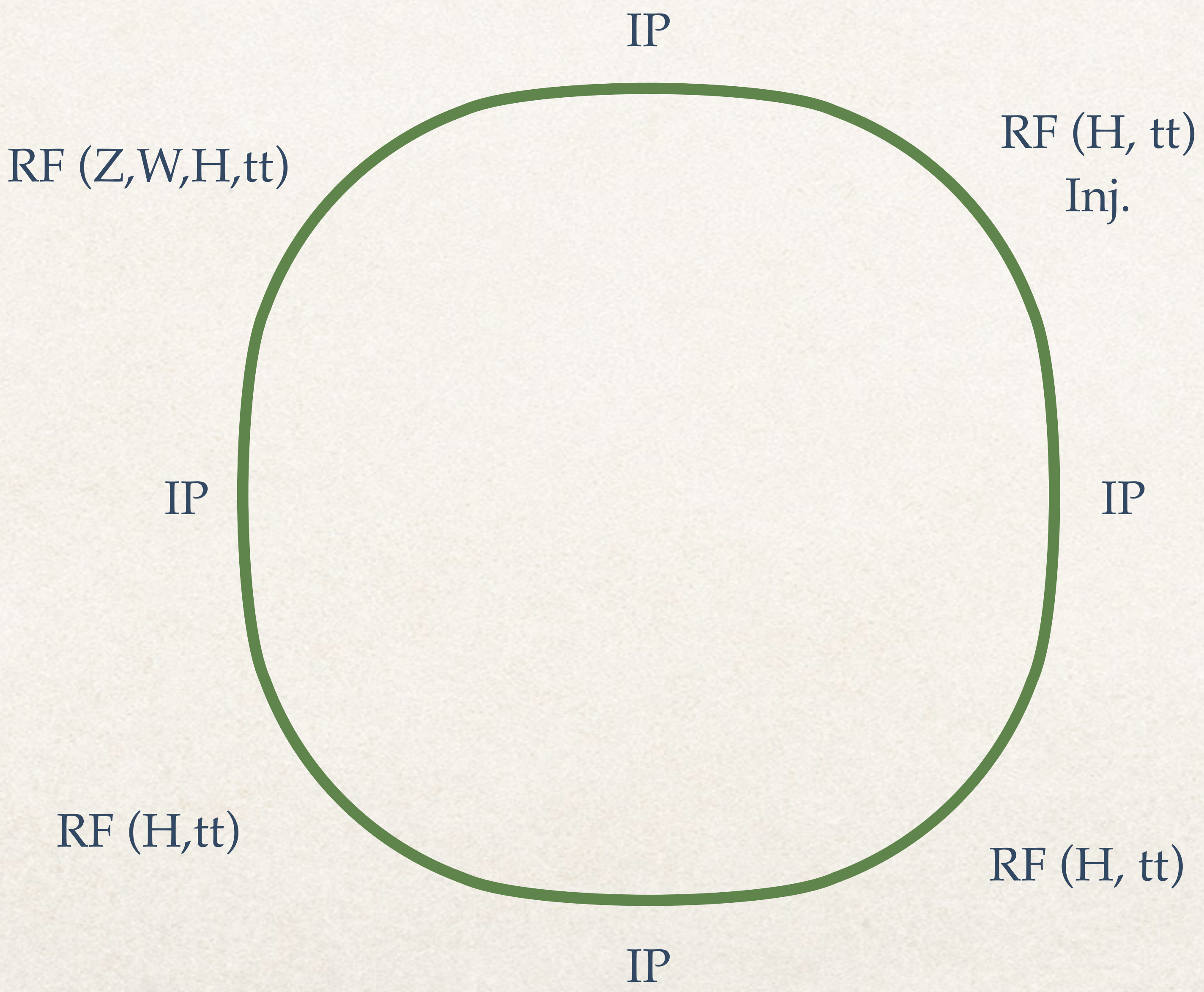


Figure 2.39: Injection straight section layout (top), optical functions (middle) and beam orbits (bottom) together with 5σ envelopes.



RF for all energies

- As for the RF section, so far a toy optics for $t\bar{t}$ (common RF) has been designed in the CDR.
  - As the necessary RF cavities will change according to the staging scenario, the beam optics must be designed for each energy.
  - Lower energies need a separated RF, beam lines with an additional crossing.
  - Sharing common cryostats for the booster with the collider at high energies may be thinkable.
- In the case of common RF, the path length from the IP to RF must be adjusted.
  - The polarization wigglers can be used for path-length adjuster?

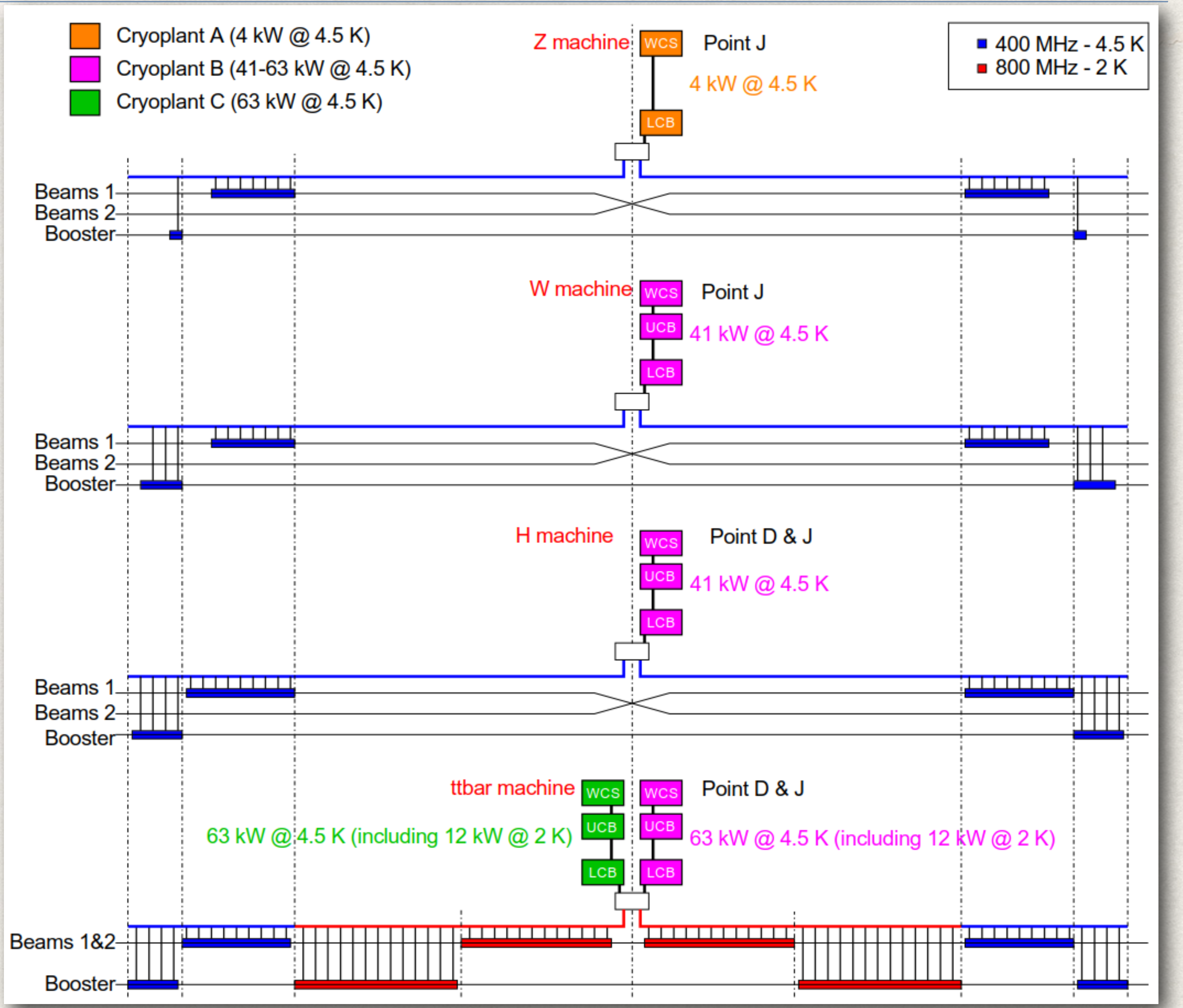


Figure 5.13: Cryogenic plant architecture.

RF staging scenario in the CDR

MDI-related issues: solenoids at the IP

- Currently solenoids have *not* been included in the official lattice.
  - Its effect on the dynamic aperture, etc., has been evaluated in SAD.
  - There remain small discrepancies in the optics between MAD-X and SAD with a tilted solenoid.
  - Once included, the closed orbit depends on the energy due to the crossing angle. So a correction scheme is necessary.
  - The overlapping quads and their higher multipoles should be included, too.
  - Correction windings on the final quads must be included in the lattice.

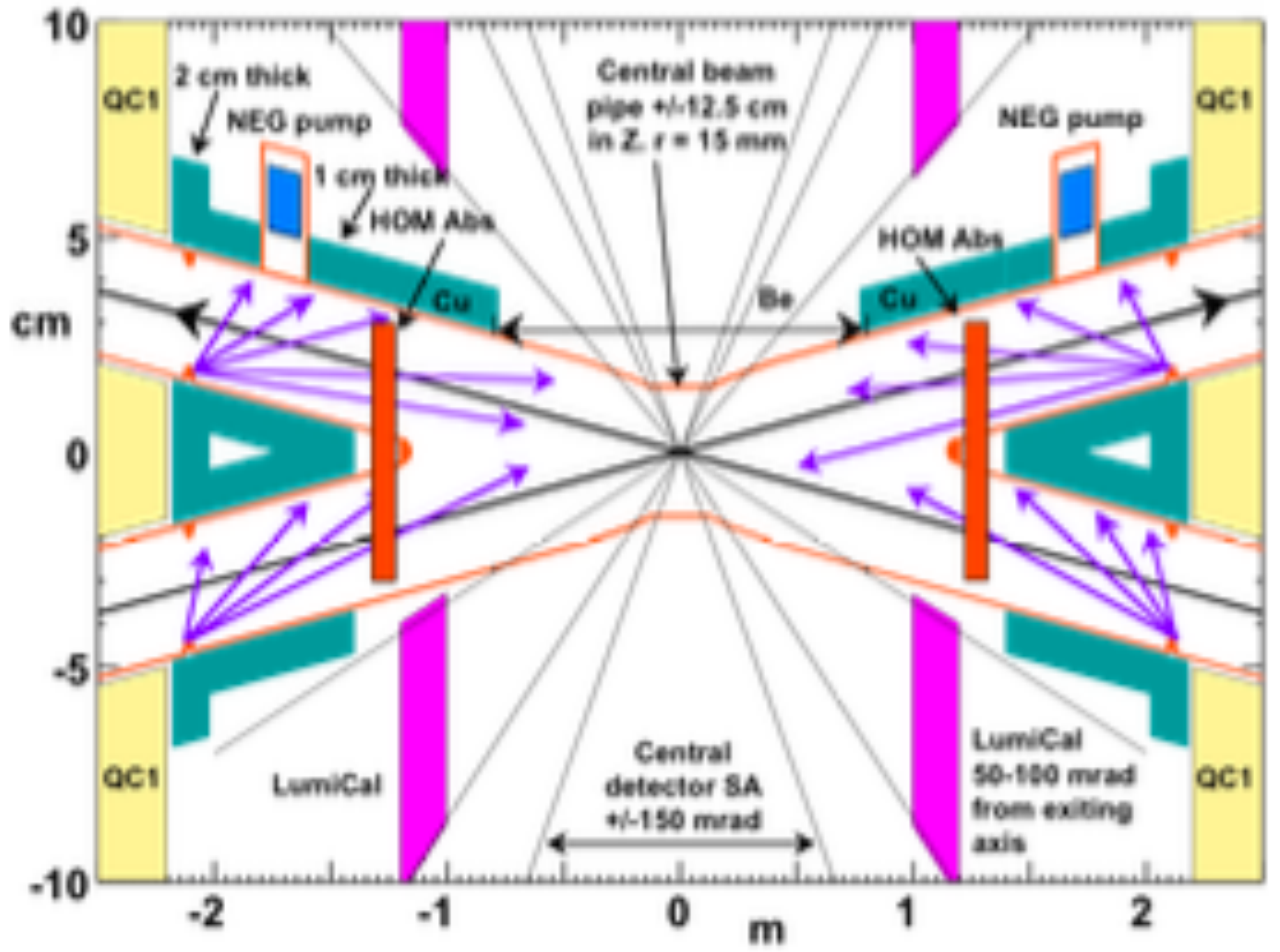


Figure 2.16: An x–z view of the FCC-ee IR layout for ± 2.5 m from the IP. Note the expanded ve
scale.

MDI-related issues: quads and sexts

- The strengths of final quads must be weaken at lower energies to reduce the effects of synchrotron radiation fluctuation.
- The design of the sextupoles for the local chromaticity correction and crab waist must be finalized. They are very strong, esp. at $t\bar{t}$.
    - If necessary they should be lengthened.

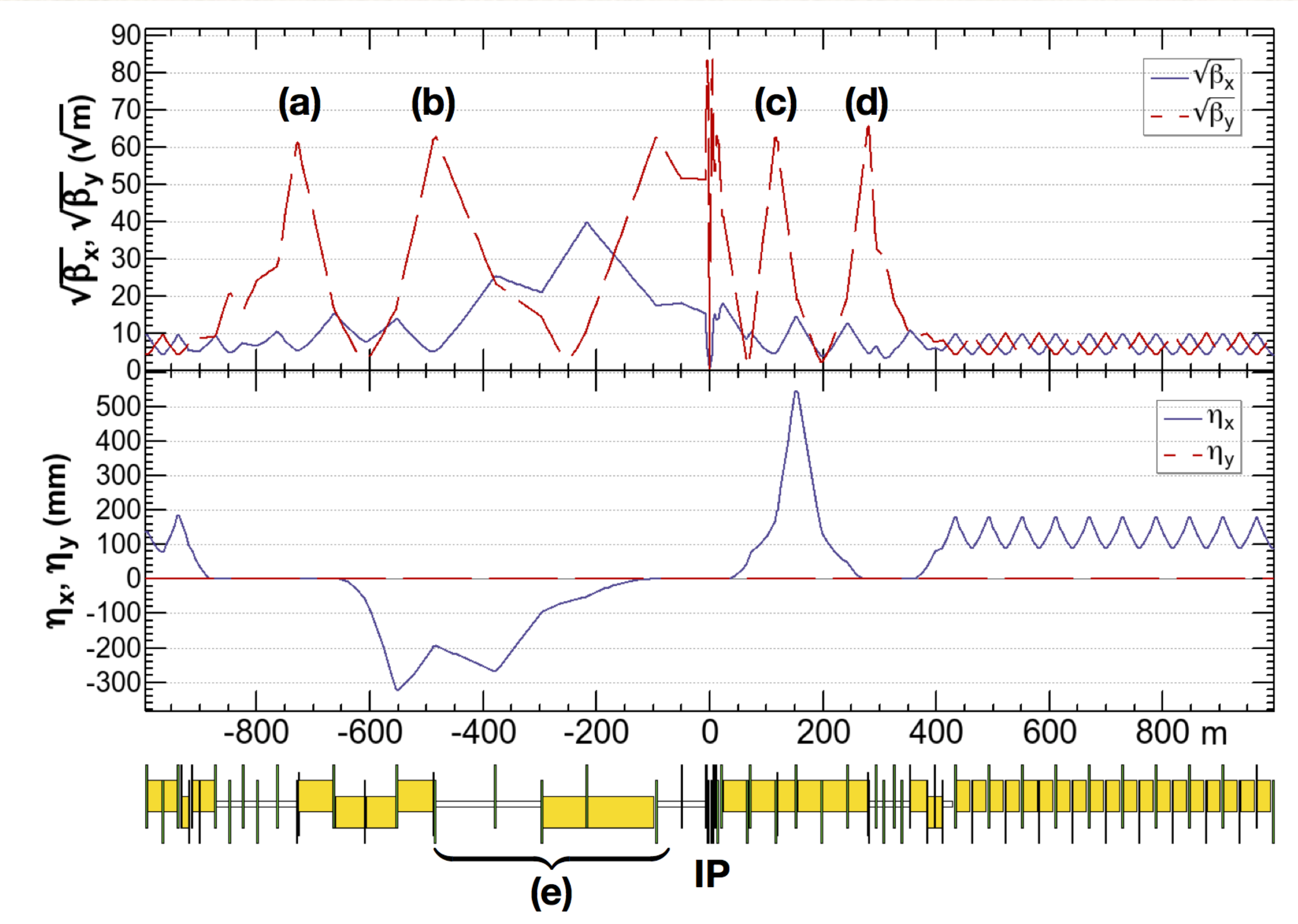


Figure 2.6: The beam optics of the FCC-ee IR for $t\bar{t}$. Upper and lower rows show $\sqrt{\beta_{x,y}}$ and dispersions, respectively. The beam passes from the left to the right. The optics is asymmetric to suppress the synchrotron radiation toward the IP. Dipoles are indicated by yellow boxes; those in region (e) have a critical energy of the SR photon below 100 keV at the $t\bar{t}$. Sextupoles for the LCCS are located at (a–d), and sextupoles at (a,d) play the role of crab sextupoles.

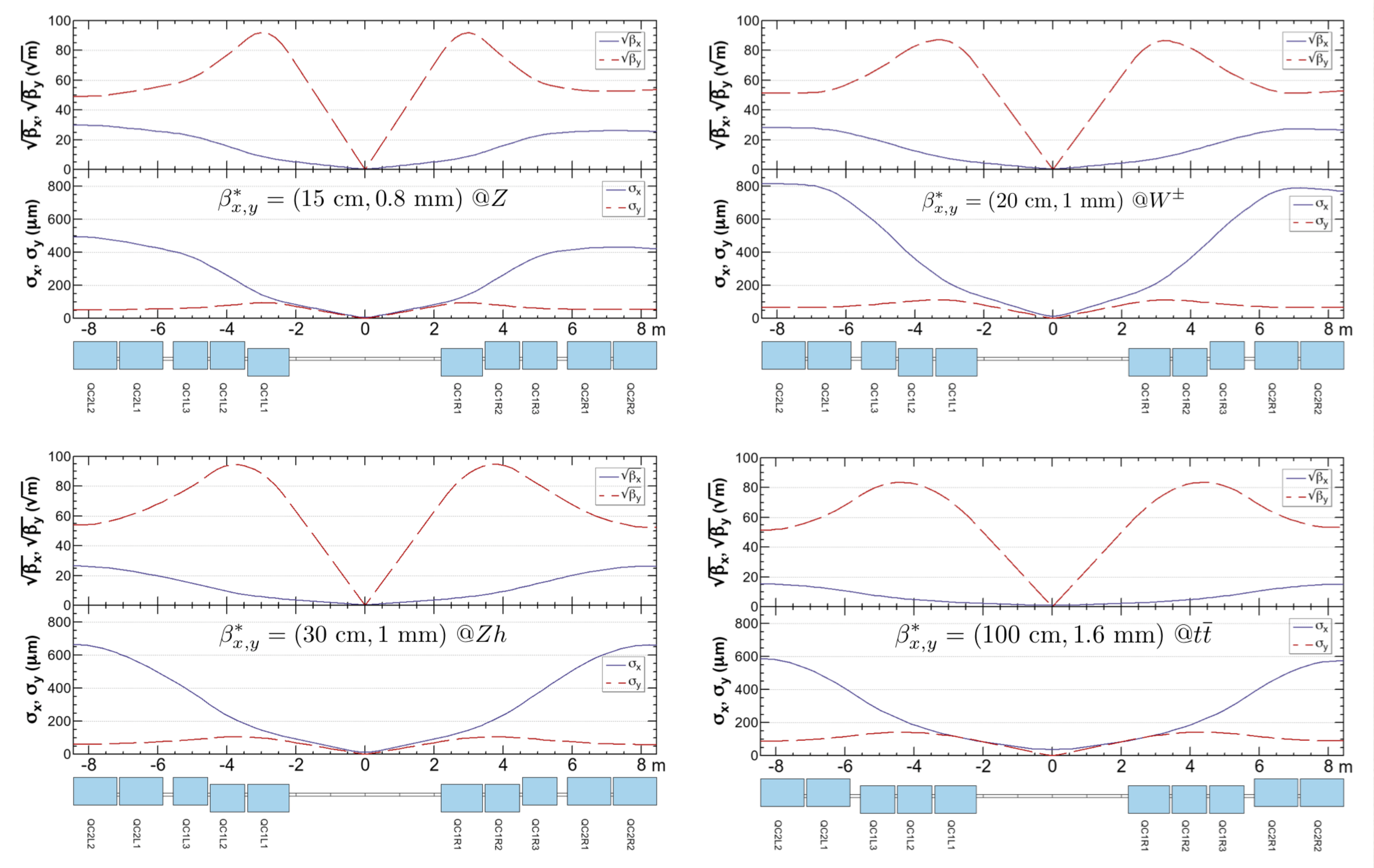
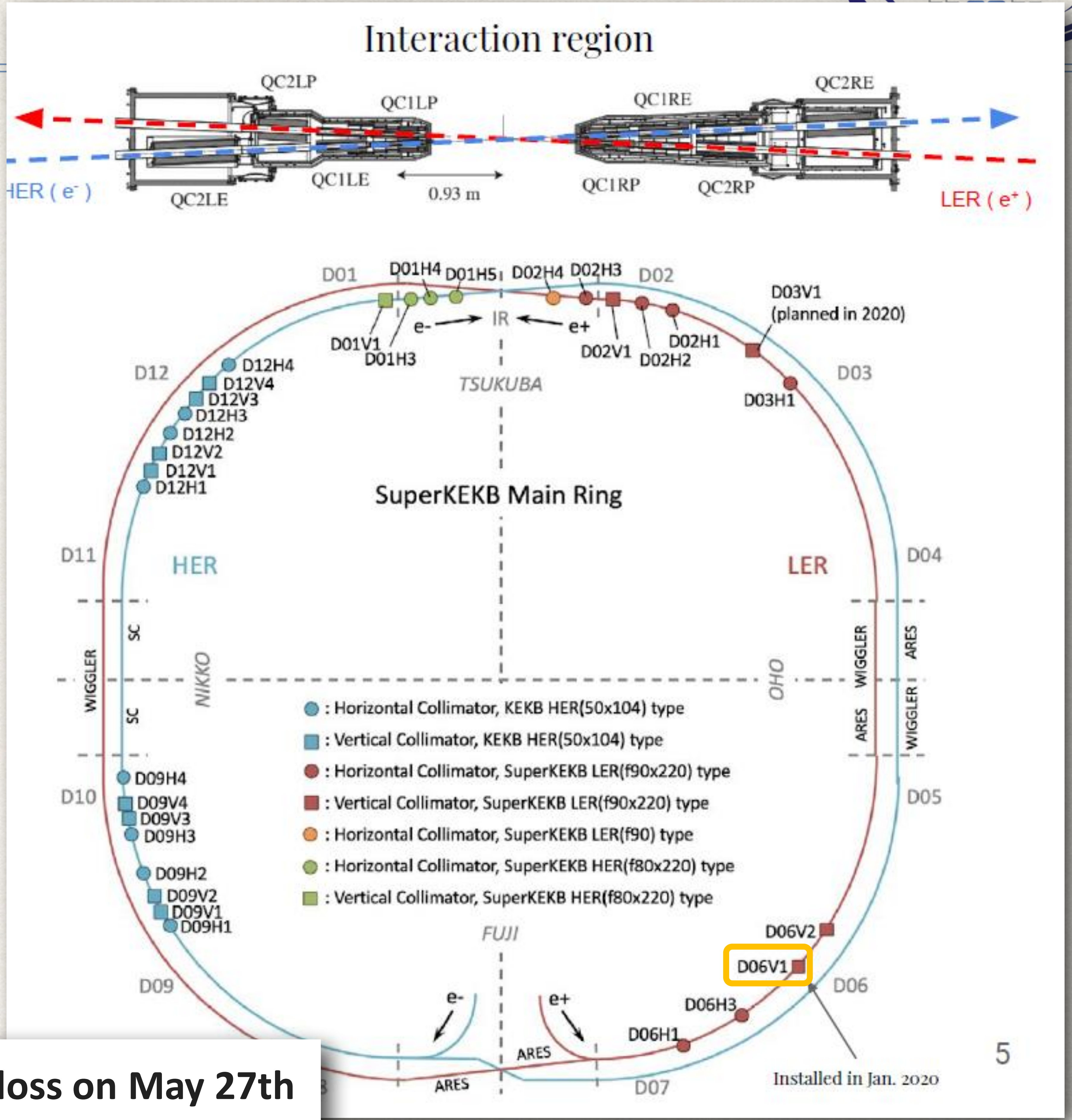
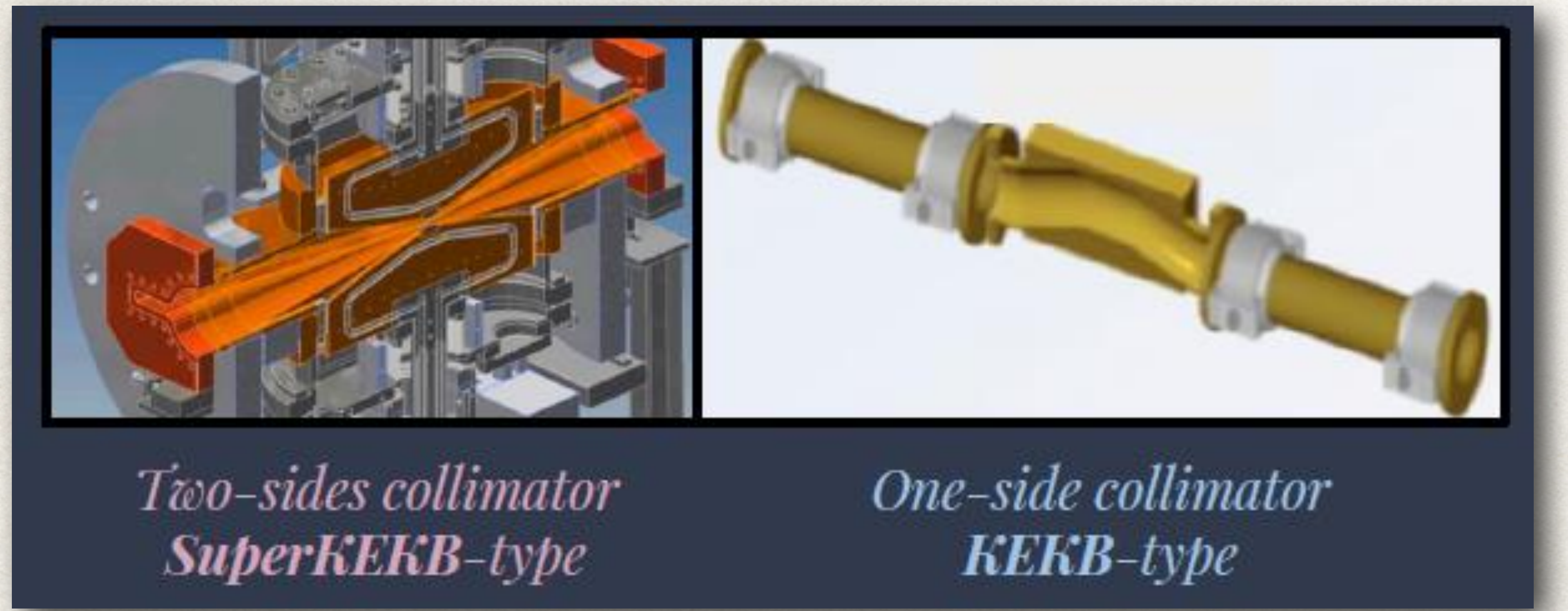


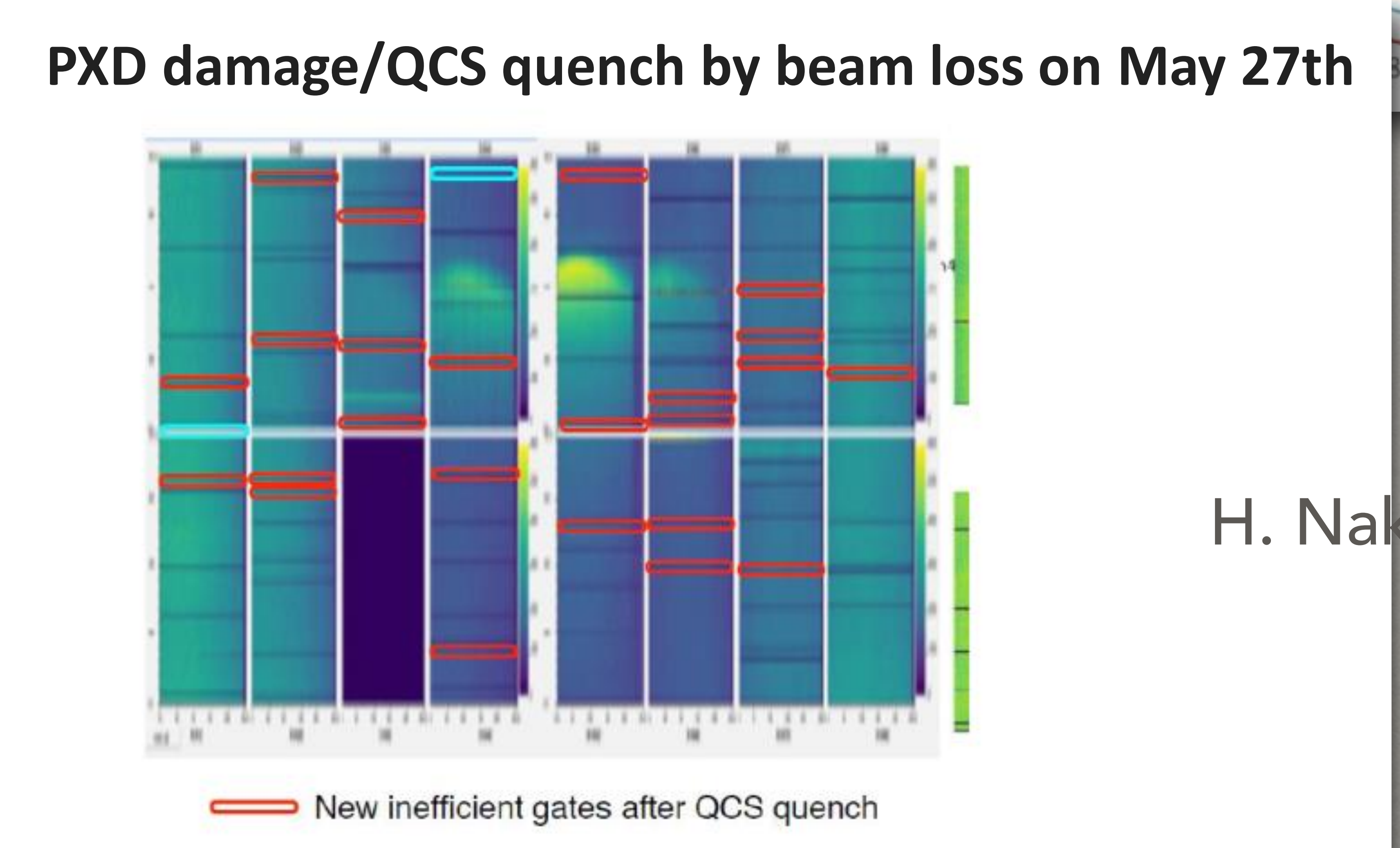
Figure 2.7: The $\sqrt{\beta_{x,y}}$ and beam sizes around the IP at Z (upper left), WW (upper right), ZH (lower left), and $t\bar{t}$ (lower right). The beam sizes assume the equilibrium emittances listed in Table 2.1. The final quadrupoles QC1(L/R) are longitudinally split into three slices. While all slices of QC1 are vertically focussing at $t\bar{t}$, only the first ones are at Z. Note that the inner radius of the beam pipe through these quadrupoles is larger than 15 mm.

MDI-related issues: collimators

- Where and how many collimators do we need?
  - Both for stored & injected beams.
  - SR and particle losses, beam-beam effects must be taken into account.
  - It is not easy to install a collimator in the middle of arc.
- Technical design of the collimators are necessary considering:
  - Roles (spoiler vs. absorber)
  - Material, shape, impedance, …







SuperKEKB
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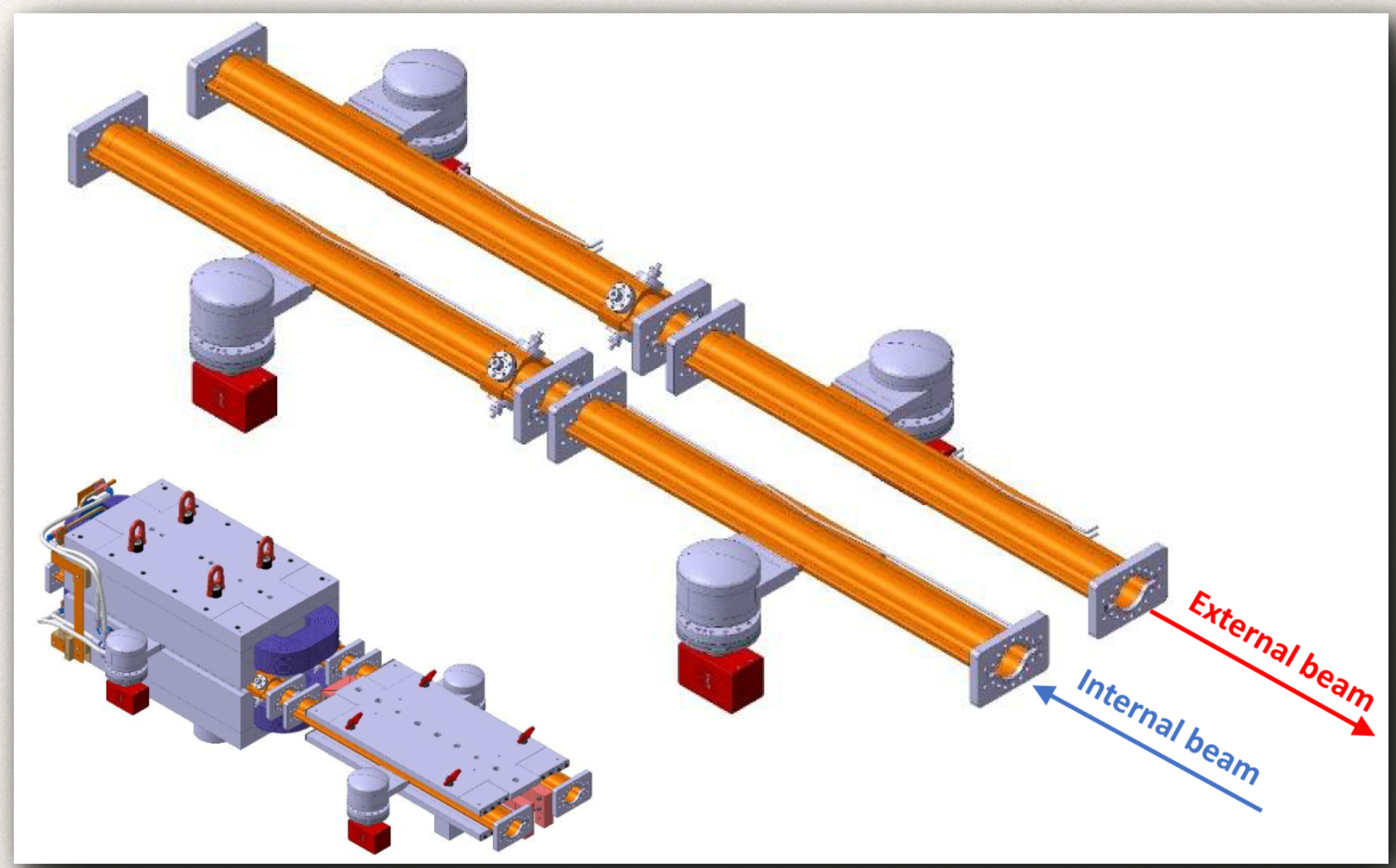
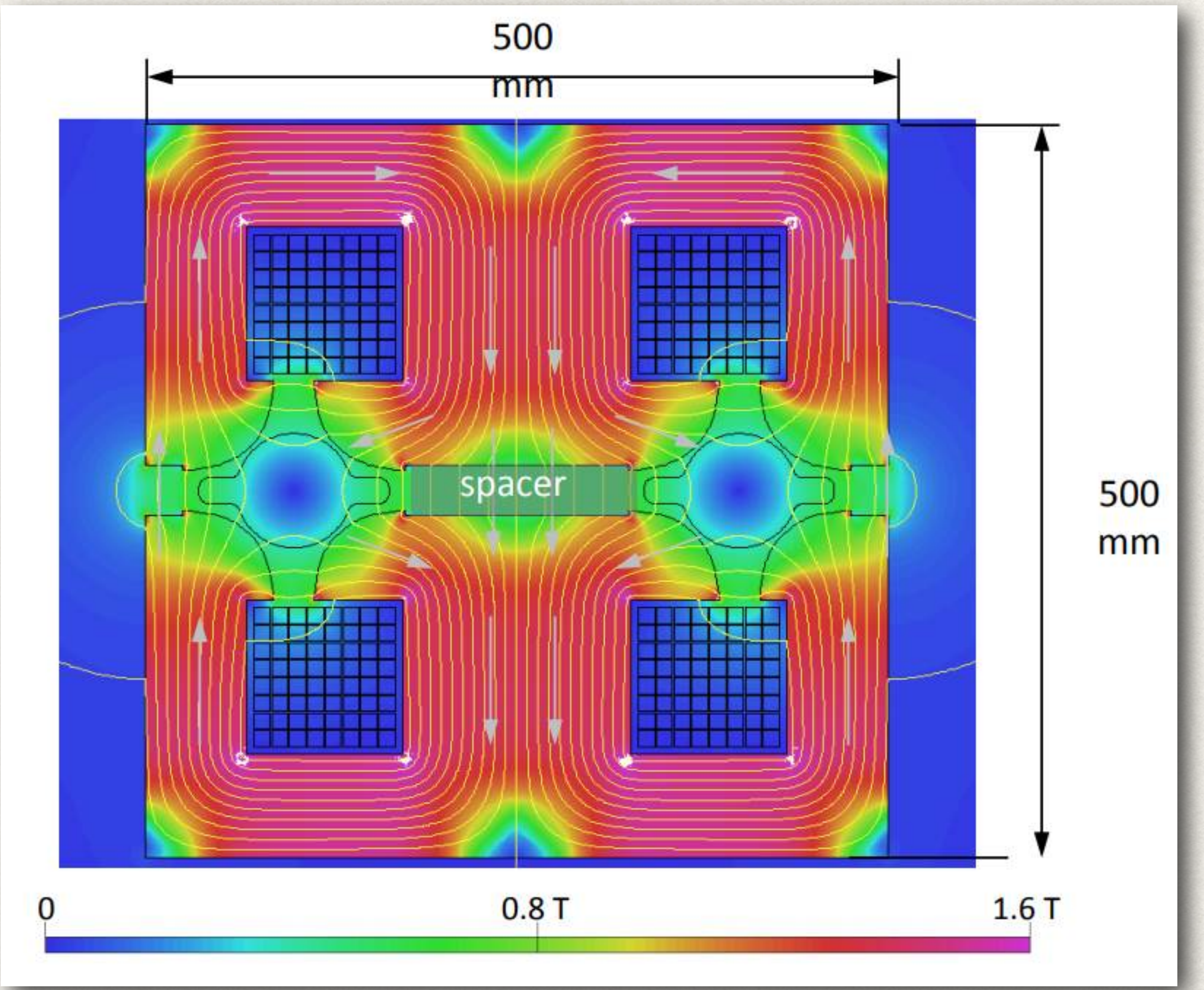
Details:

- The current design in the CDR squeezes the space between components to almost minimum (10-30 cm).
- Thus if more spaces are needed for cabling, pumps, photon absorbers, additional correctors, BPMs, etc., the lattice must be modified.
  - It will affect the luminosity performance by a small amount.
- The CDR lattice has a very long (25-100 m) dipoles. They must be divided into shorter ones with realistic lengths.
- The arc does not have dedicated vertical orbit correctors. Only trim windings on sextupoles are supposed to use.
- Prototyping is necessary.



Details (2)

- The magnetic characteristics of all magnets must be included, by field calculation and measurements:
    - effective length
    - fringe profile
    - multipoles
- The issue of cross-talk and shift of field center of twin-aperture quads observed at CEPC must be addressed.



J.Bauche

Details (3)

- BPMs must be included in the lattice adjacent to all quads.
- Horizontal & vertical orbit correctors must be added in the straight sections.
- In many places including the arc, the trim windings of dipoles, which are necessary for tapering, can be used for horizontal orbit correctors.

Thank you!

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