GHC VS LCC DESIGN CONCEPTS NEXT STEPS FOR PRE-TDR PHASE

gratefully acknowledging the contributions of MANY colleagues

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Global Hybrid Correction - GHC

GHC Optics is designed by **Katsunobu Oide**, based on immense experience with accelerators, test-beams and in particular SuperKEKB

Four-fold symmetry with four IPs, a 30 mrad crossing angle, and strong doublets for final focusing, with crab-waist scheme using the IR chromaticity sextupoles (virtual CW).
Chromaticity is corrected both locally and globally with only one Chromatic Correction Section in the vertical plane on either side of the IP; horizontal chromaticity is mostly corrected with sextupoles in the arcs.
Many arc sextupole families, assembled in –I pairs, allow the tuning of geometric and chromatic aberrations through a **global optimisation**.
Extensively studied and the baseline for the FSR

Local Chromaticity Correction - LCC

LCC Optics is initially designed by **Pantaleo Raimondi**, based on very extensive experience with accelerators, test-beams and light sources.
With contributions from **S. Liuzzo, S. White, M. Hofer** et al.

Four-fold symmetry with four IPs, a 30 mrad crossing angle, and strong doublets for final focusing, with crab-waist scheme using dedicated sextupoles.
Chromaticity and other aberrations are corrected locally with two Chromatic Correction Sections on either side of the IP, plus a few octupoles and decapoles.
Transparency conditions allow matching section by section and stitching of the full lattice.
Few arc sextupole families nested in pairs allow the **achromatic and aberration-free transport** of the beams between insertion regions.
Developed since 2022, and achieved good performance in 2024

Arcs

GHC

FODO cells with varying lengths: 104 m at Z and W, 52 m at ZH and t-tbar. Change of configuration

-I transform between pairs of sextupoles.

Repeating pattern every five cells with 2 sext. pairs

Each pair of sextupoles is independent.
Sextupoles can be strong and are doubled at high energy (2 x 1.3 m)

Positron and electron optics assembled for QF/QD coincidence for optimal double-aperture quadrupoles

LCC

FODO cells with a change of phase advance between lower and higher energies. No change of configuration.

Nested pairs of sextupoles

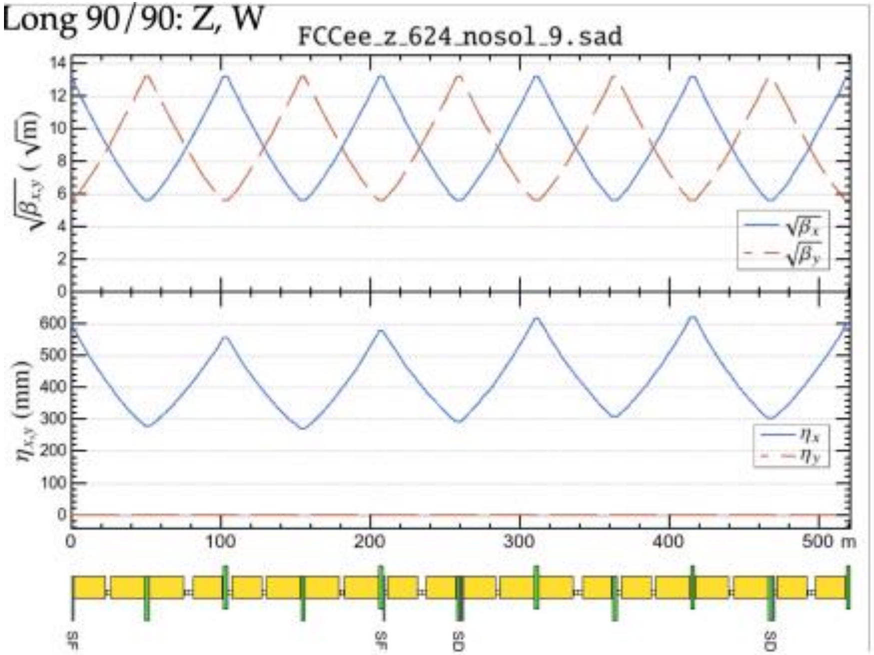
Repeating pattern over five cells with 4 sext. pairs

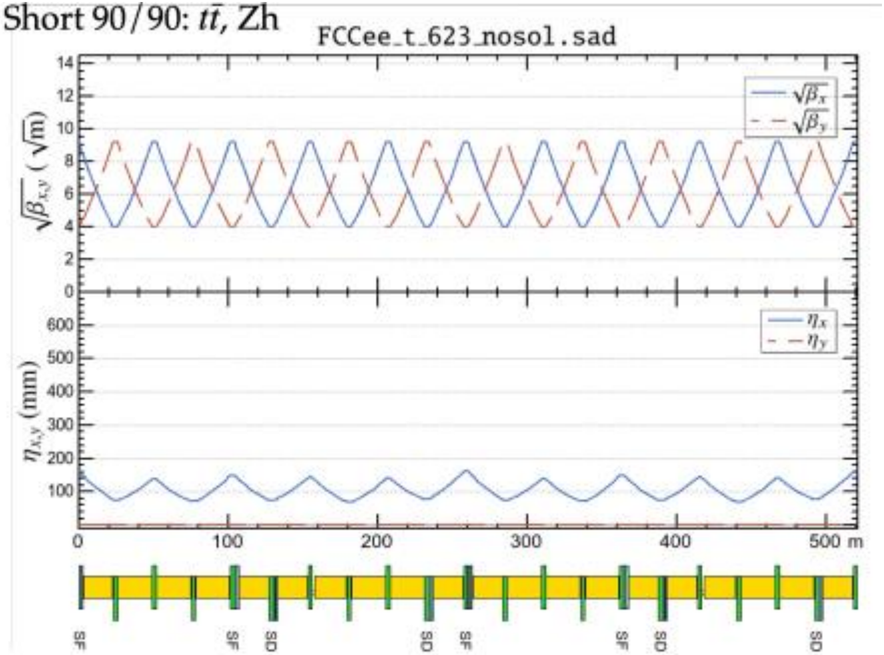
Four sextupole families per arc.

Sextupoles are short; 0.3 to 0.5 m

QF and QD have unequal lengths, and optics is assembled for QD/QD and QF/QF.

GHC Arcs



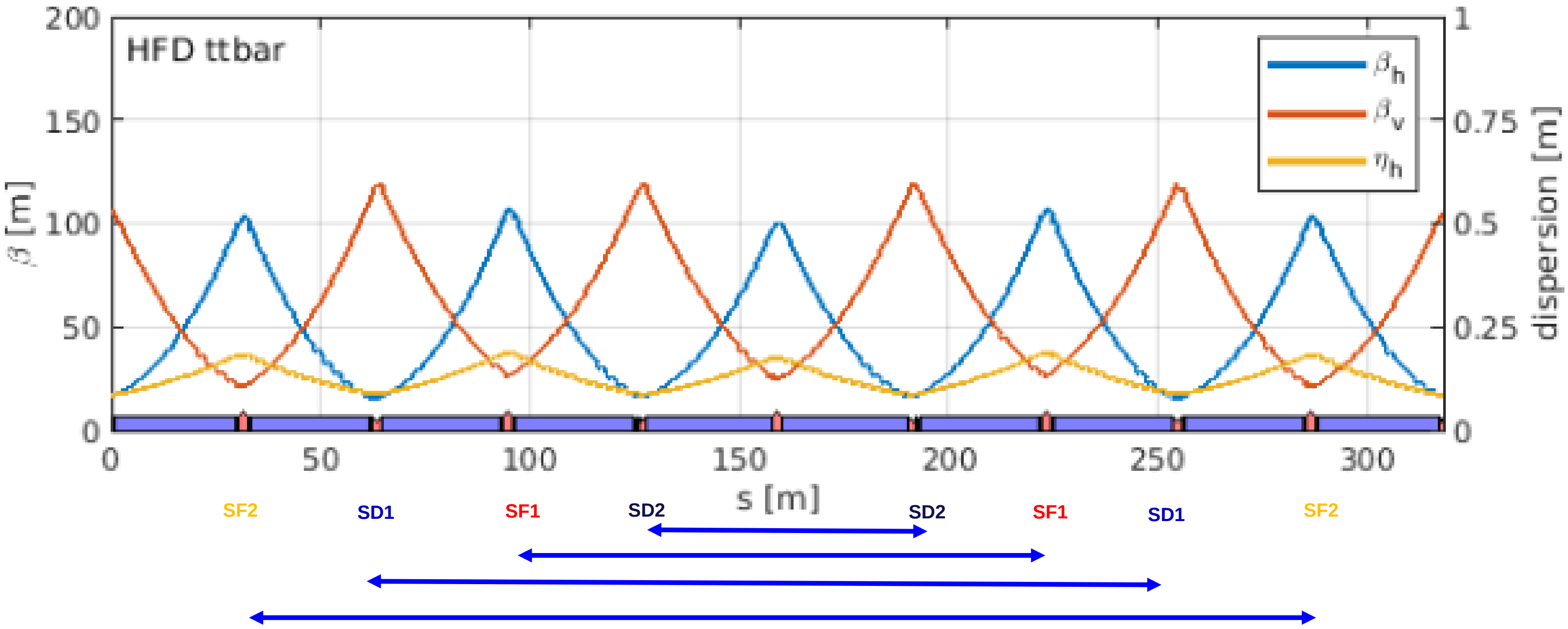


PRAB **19**, 111005 (2016)

K. Oide

Full installation of Quadrupoles and Sextupoles;
powering scheme for switching between Z or W and Zh
Many more BPMs at Z and W; Orbit correctors?

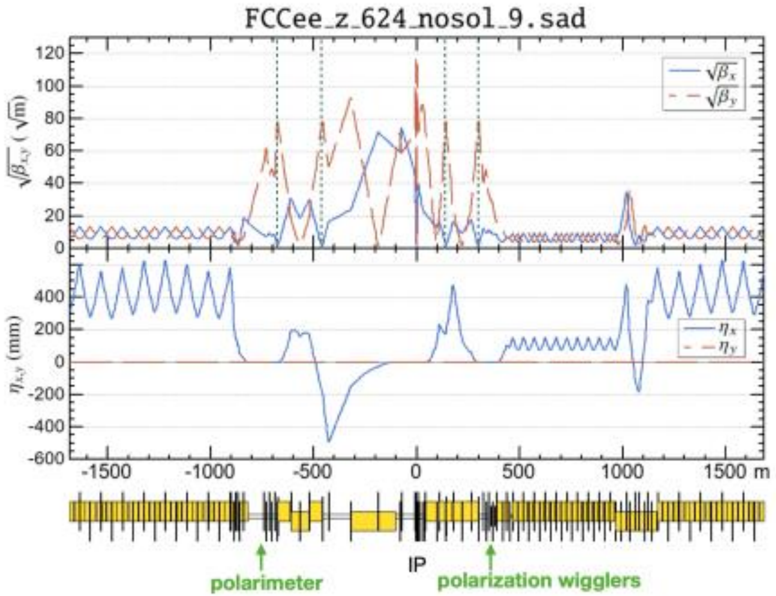
LCC Arcs



PRAB **28**, 021002 (2025)

P. Raimondi,` S. Liuzzo, S. White, M. Hofer, et al.

Experimental Insertions : GHC



- One Chromatic correction section per side of each IP
- Asymmetric dispersion at the sextupoles of each pair
- Zero-dispersion sextupole used as CWS
- Short "return arc" on the outgoing side
- Weak bends for SR sweeping away from the detector
- Well developed and actively tuned

PRAB **19**, 111005 (2016)

K. Oide

Experimental Insertions

PRAB **28**, 021002 (2025)

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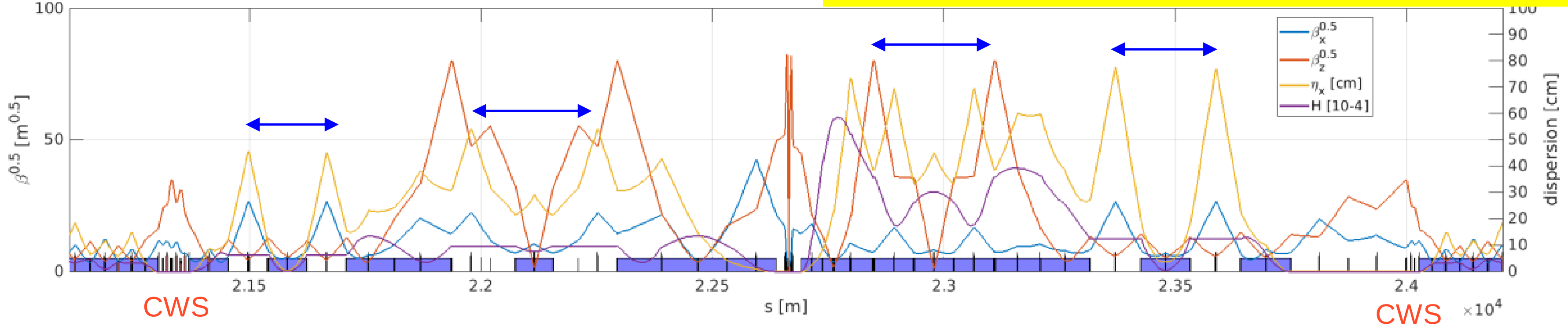


- Two Chromatic correction sections per side of each IP, one H and one V, with symmetric dispersion
- Dedicated Crab-Waist Sextupoles at entrance and exit
- Weak bends for SR sweeping away from the detector

Technical Insertions

GHC

Universal insertion to fulfill the requirements for:

- Injection from Booster and Dump
- Collimation, in transverse and momentum space
- RF

Cannot maintain the universal insertion at Zh and ttbar, given the need for a very long FODO section for RF and the change from horizontal crossing and vertical separation to horizontal EM separators

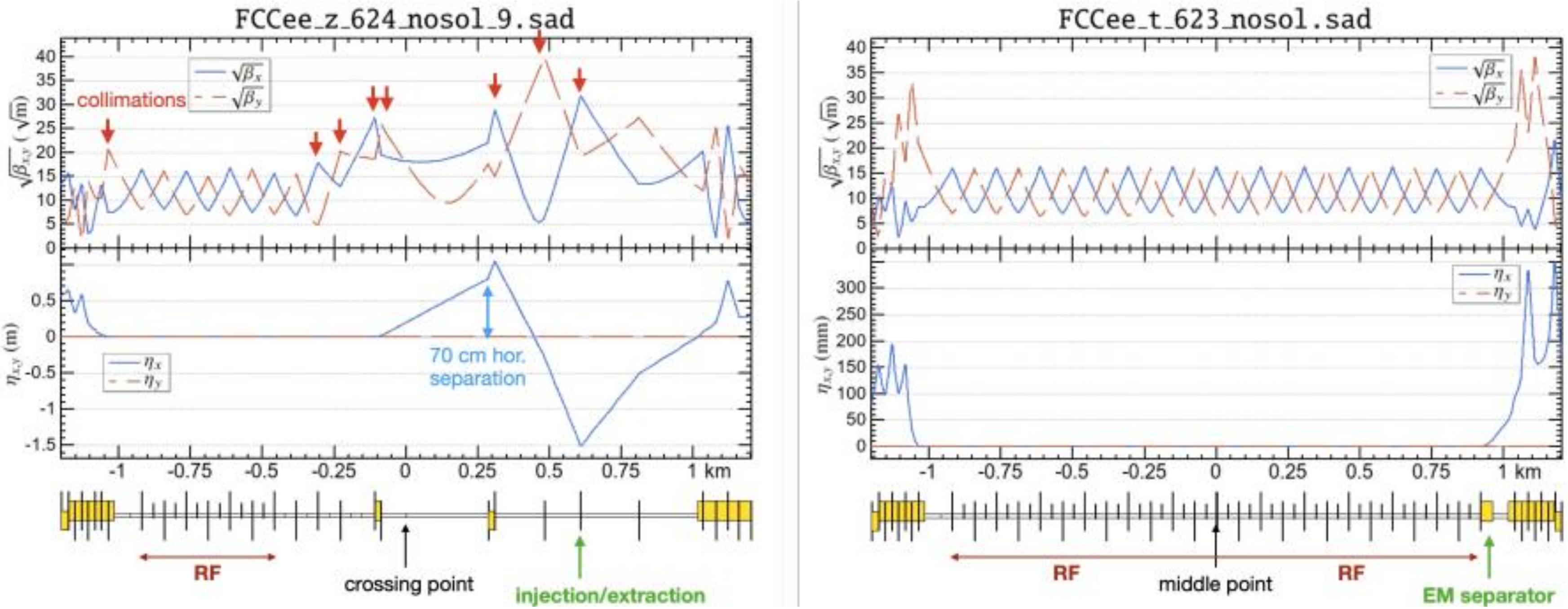
LCC

Still very basic insertion matched for RF, with no dispersion and FODO with rather low beta.

Sextupoles in the matching section between the arcs and the FODO cells are used to cancel chromaticity and other aberrations (transparency)

Will match the universal insertion from GHC, with horizontal crossing and vertical separation, into the LCC, as a first step for comparison.

Technical Insertions : GHC



PRAB **19**, 111005 (2016)

K. Oide

Optics variants (apply to both GHC and LCC)

Ballistic Optics

- Final quadrupole doublets are turned off
- Solenoids and compensations are turned off

➢ Allows measurement of a straight trajectory across the detector region to determine the BPM offsets

➢ Final quadrupole doublets are the main source of natural chromaticity;
the sextupoles can be much reduced or off;
the optics is easier to correct and tune.
Good optics for a fresh startup.

Higher beta* optics

- Cromaticity and aberrations scale with 1/beta*

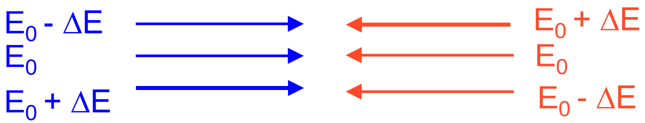
➢ beta at the final quadrupole doublets is reduced;
the natural chromaticity is reduced;
the sextupoles can be reduced;
the optics is easier to correct and tune

➢ The solenoids can be turned on and we can deliver luminosity

➢ Perfect for gradual tuning of the collider with increasing performance

Optics variants: Monochromatization

- See the poster of Anna Korsun et al.
  “Updated monochromatization Interaction Region optics design for FCC-ee GHC lattice”
- Opposite sign dispersion at the IP for the two beams creates opposite correlation between position and energy to reduce the spread of the CM energy of the collisions
- Necessary for direct H production at a collision energy of 125 GeV.
  See presentation of Marumi Kado at the plenary session on Monday, 19th.



Optics variants (could apply to both GHC and LCC arcs?)

HTS Optics

- See the presentation on HTS4 development by M. Koratzinos on Thursday 22nd May, 10:30

- Solution for nesting short quadrupole and sextupole plus corrector magnets in a compact package.
- Increased packing factor allows for weaker bends and less synchrotron radiation power
- We can increase the beam current and the luminosity, for a given radiated power, or save on operating costs and energy footprint

- Technological readiness is not met yet.

- Could be an add-on to the design of the arcs of both the GHC and LCC optics.

Nested Magnets

- See the presentation of Cristobal Garcia later this morning

Optics Comparison: Why?

“Behold, I set before you this day, a blessing and a curse.” Deut. 11:26

GHC and LCC are based on different principles and require different hardware.

Many equipment groups need to focus on one solution and cannot do their R&D for several options!

We can only compare optics that have the same level of performance. **Reached in 2024**
Feasibility Study Report is based on GHC Optics, listing LCC optics as an option.
Going from Conceptual to Technical Design requires detailed hardware studies;

Our curse is that we have to choose **now.**

Comparison Criteria: Performance

Performance in the context of the FCC:
maximum integrated luminosity for a given time and for a given cost (CAPEX+OPEX)

Best average luminosity vs. maximum instantaneous luminosity

Top-up injection allows continuous operation until a fault occurs that dumps the beams.

Maximum production requires careful optimisation of the running sequence
as much as the ultimate luminosity that can be reached.

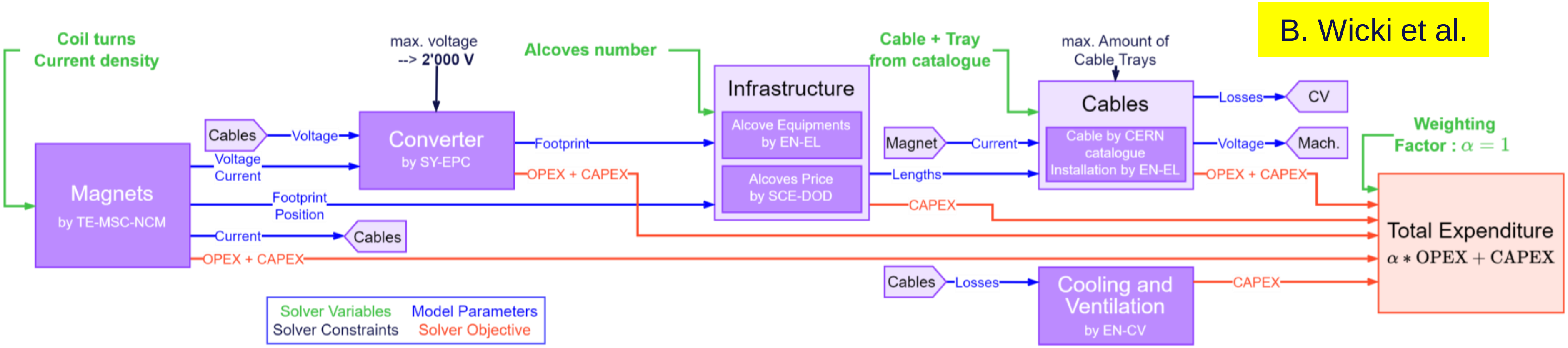
Comparison Criteria: Tuning and Operation

Tolerances: alignment, vibrations, magnetic imperfections, power converter ripple, tapering granularity, differences in bunch intensities, etc…

Tuning: path to bootstrap the collider in terms of optics (ballistic, relaxed…) and running sequences (change of energies), beam-based alignment, etc.

Operation: tuning knobs (orbit, dispersion, tunes, beta-beating, coupling, chromaticity, amplitude detuning, path length, etc.) and their range. IP-tuning observables. Polarisation (depol. time) and Resonant Depolarisation, Injection, Collimation, Beam-beam…

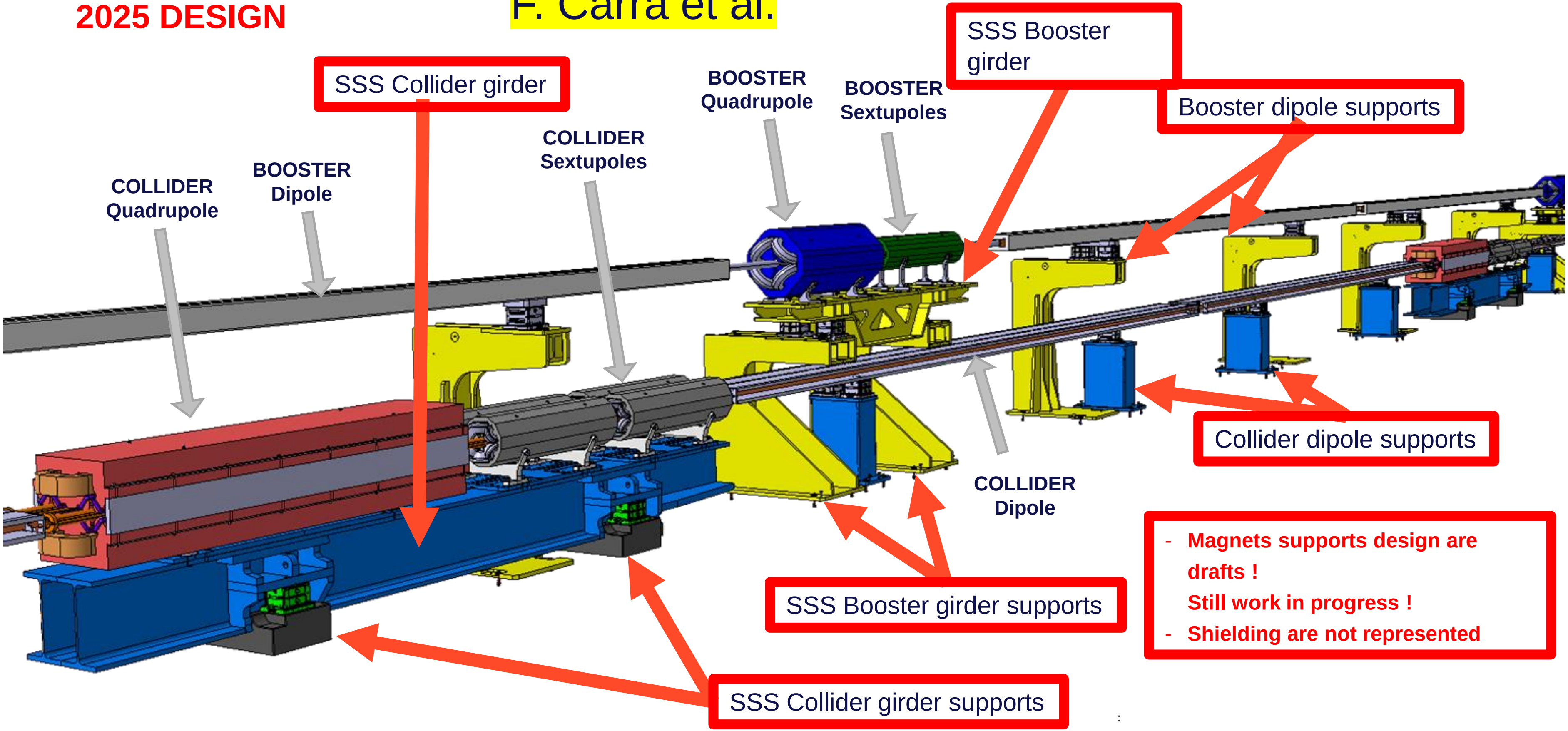
Comparison Criteria: Hardware



- Magnets, Power Converters, Cables, Cooling and Ventilation, Civil Engineering…
- RF, injection, dumps, collimators, beam instrumentation

2025 DESIGN

F. Carra et al.



- Magnets supports design are drafts ! Still work in progress !
- Shielding are not represented

Data Collection

- Data will be sparse
  - Many studies done with GHC optics – at various stages v22, v23, v24…
  - Much less has been done with LCC optics
- Integrate the universal technical insertions in LCC optics for comparative studies
- We cannot compare two fully optimised optics
  - Compare like-for-like configurations as best as we can
  - Interpolate where needed

Decision Process

The choice of a new baseline optics will be based on a very wide array of comparison criteria and will require expertise to evaluate the data.

The choice should be made by a group/body in a management role in the Study.

A group of experts could evaluate and review the data and make a recommendation.
open for discussion…

Timeline and Outcome

- **Summer 2025**: Repository reorganised and ready; Optics layout; naming conventions
- **September 2025**: Optics with technical insertions and complete layouts
- **December 2025**:
  - **Optics Comparison Report;**
  - Optics in Layout Database;
  - Geometry frozen for Civil Engineering
- ***March 2026: Decision on Optics***
- **FCC Week 2026: First Technical Design of Optics**

Conclusion

Comparing the two optics is a pre-requisite for efficient work for a pre-TDR

It is a delicate and daunting task, with a very aggressive schedule

A “FCC-ee Layout and Optics Design working group” is active and tasked with this comparison and the preparation of the work in view of the pre-TDR.

Very positive reception and participation! Thanks to all!
We look forward to active and focused participation.

Thank you for your attention.