THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY
HKUST JOCKEY CLUB INSTITUTE FOR ADVANCED STUDY
IAS PROGRAM
Online Program
High Energy Physics
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FCC-ee & hh R&D issues and status

Frank Zimmermann, CERN

HKUST IAS HEP, 19 January 2021

FUTURE CIRCULAR COLLIDER

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European Commission | Horizon 2020 European Union funding for Research & Innovation

photo: J. Wenninger

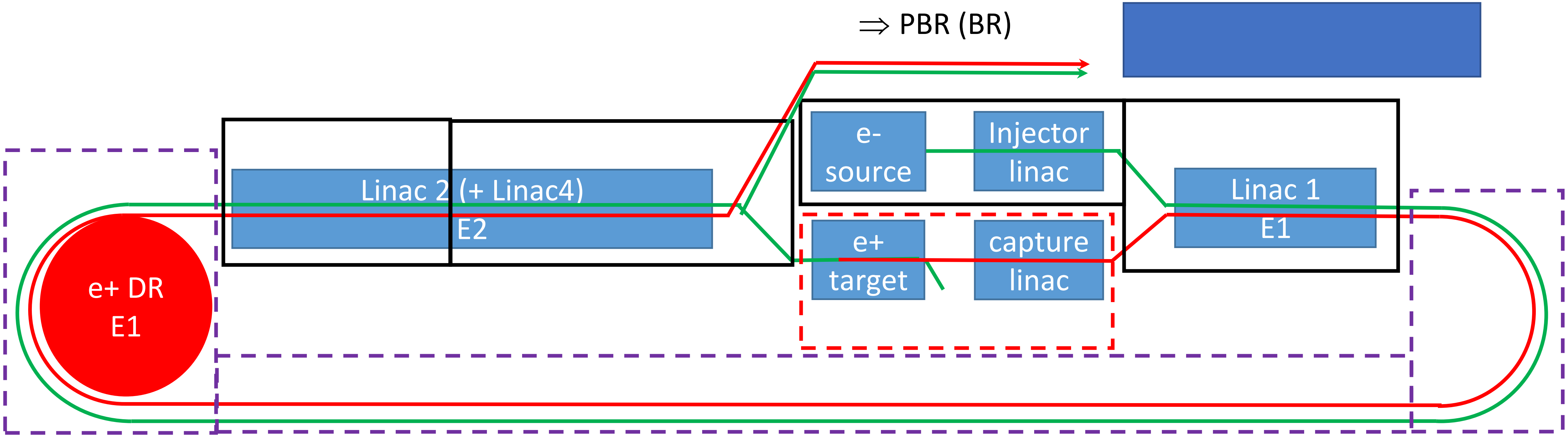
FCC-ee issues requiring further studies (Z, W, H factory)

1. Design for **maximum energy efficiency.**
2. **Attainable vertical emittance** in presence of various errors and with colliding beams, and further luminosity optimization. **Alignment tolerances** and alignment system.
3. Complete **impedance model**, with an evaluation of transverse multibunch resistive-wall instability and single-bunch longitudinal microwave instability. **Ion and electron-cloud instabilities** with mitigation measures. Design and performance of a **bunch-by-bunch feedback system. Interplay of impedance and beam-beam effects**.
4. **Finalisation & completion of beam optics**, incl. collimation, tuning flexibility, injection & extraction systems. Design for **different # of collision points**. **Dynamic aperture optimizing.**
5. **Software tool for e^+e^- optics** with IR crossing angle, **SR, beam-beam** & **beamstrahlung.**
6. **Collimation system ; collimation / masking and machine protection strategy.**
7. **Specification of beam instrumentation and required measurement precision/accuracy.**
8. **Optimization of the injector complex** (higher-energy linac versus pre-booster, linac pulse)

layout of the FCC-ee injector 6 GeV (20 GeV)

25-162.5 GeV plasma e^+/e^- linac could replace PBR & FEB !

CEPC, Z. Y. Xu et al., PRAB **23**, 091301 (2020)



Alexej Grudiev, Paolo Craievich, Hans Braun, et al.

FCC-ee issues requiring further studies (top factory)

1. **Interaction region optimization and shielding of the hard synchrotron radiation** including radiation from the final quadrupoles.
2. **Beam-tail collimation** for background control.
3. Further **off-momentum dynamic aperture optimisation** to maximize beamstrahlung lifetime.
4. **Operational scenarios supporting higher luminosity and shorter beam lifetimes** with more frequent injections.
5. **Single-bunch beam instabilities with highest bunch charge.**
6. **RF system changes for collider and booster, with associated modified optics configuration.**
7. Maximum **energy efficiency.**
8. **Machine protection and radioprotection**.

beam lifetime in collision versus collimator settings in LEP

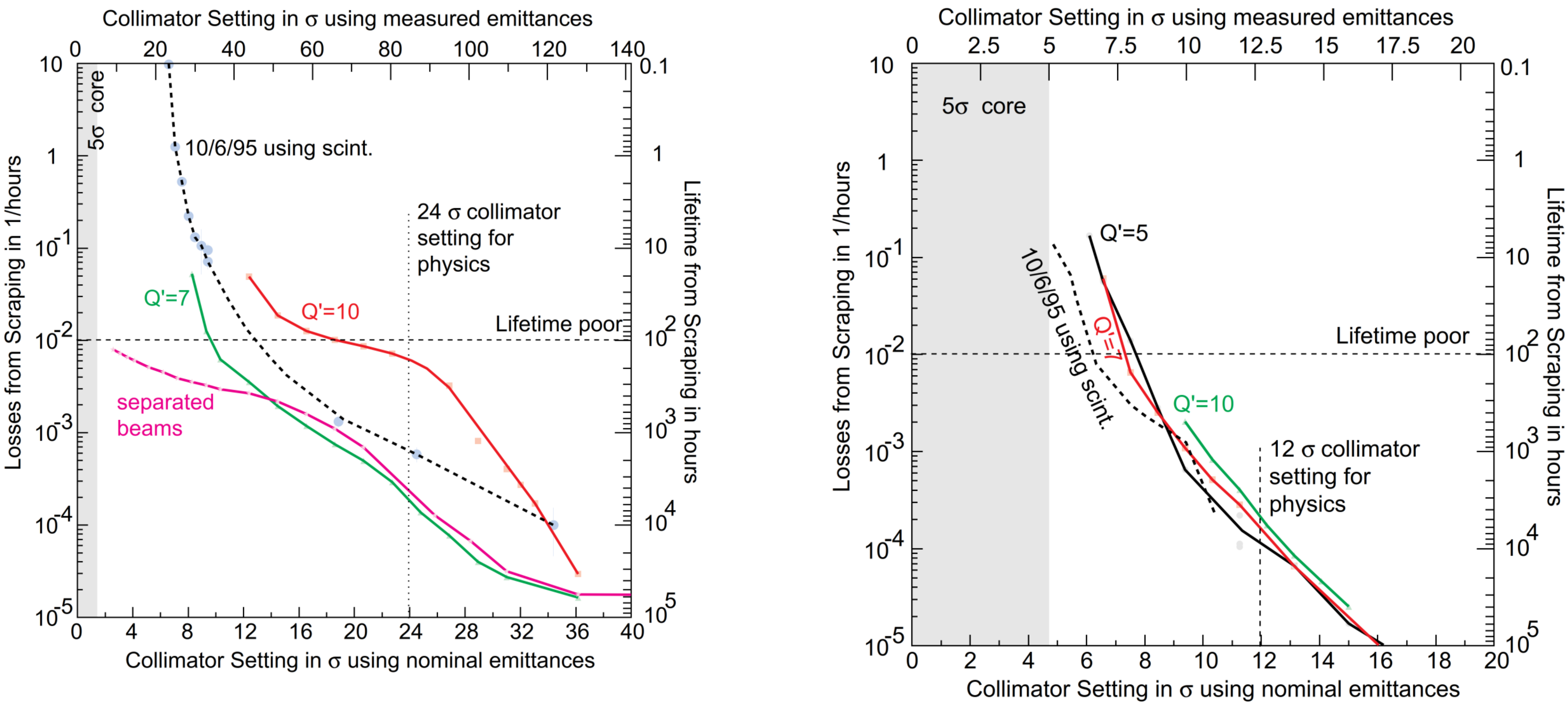


Figure 4: Measured beam tails in the vertical plane.

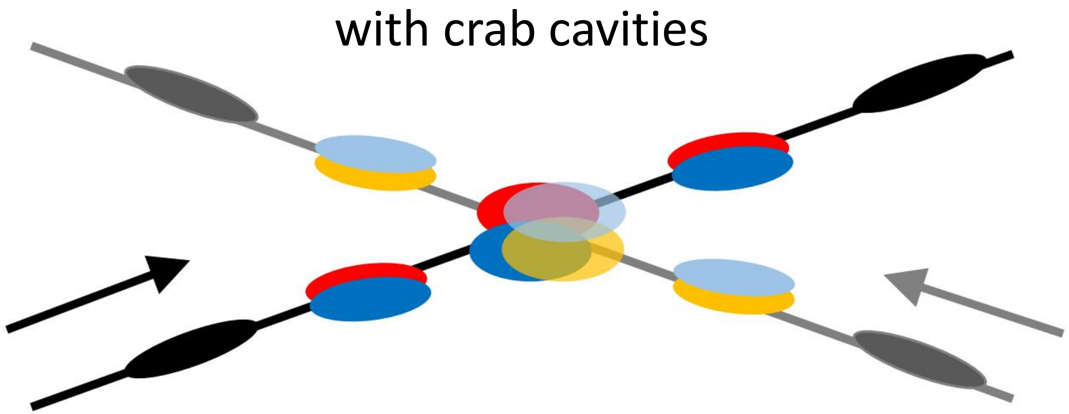
Figure 5: Measured beam tails in the horizontal plane.

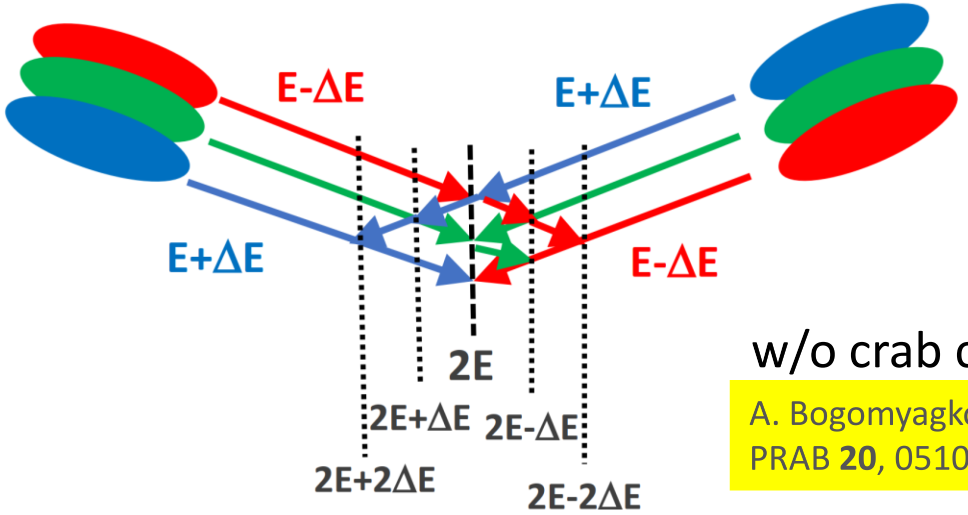
H. Burkhardt, 1995

FCC-ee issues requiring further studies (energy calibration)

1. Develop & integrate **tools for simulating orbit + optics correction processes plus simultaneous optimization of luminosity and polarization**, including spin matching. Essential for confirming feasibility and operability of proposed data taking scheme.
2. Design of **diagnostics allowing control of beam-beam offsets and measurement of IP residual dispersion**. This diagnostics will help reduce centre-of-mass energy shifts; it should also benefit luminosity optimization.
3. **Explore resonant depolarization process**s and its sensitivity to energy spread and synchrotron tune to optimize procedures and machine settings.
4. **Detailed design of polarisation wigglers** including proper management of the radiation.
5. Scrutinize and integrate the **polarimeter design**. Explore its use for **Compton-backscattering based measurements** precision & stability of momentum measurement.
6. Thoroughly assess and possible further reduce **energy-point-to-energy-point systematic uncertainties.** This involves, amongst others, development of energy model and thorough design of monitoring devices.

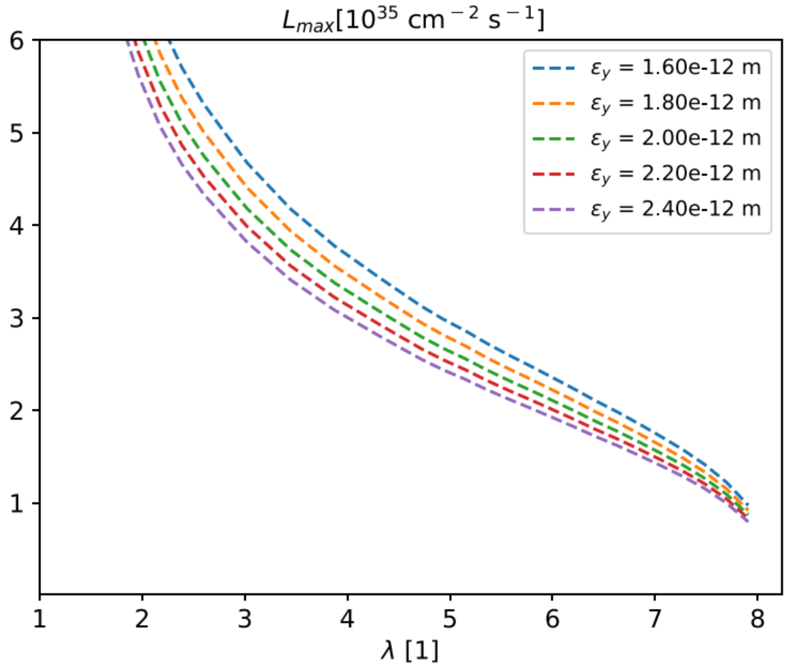
monochromatization scenarios for *s*-channel H production





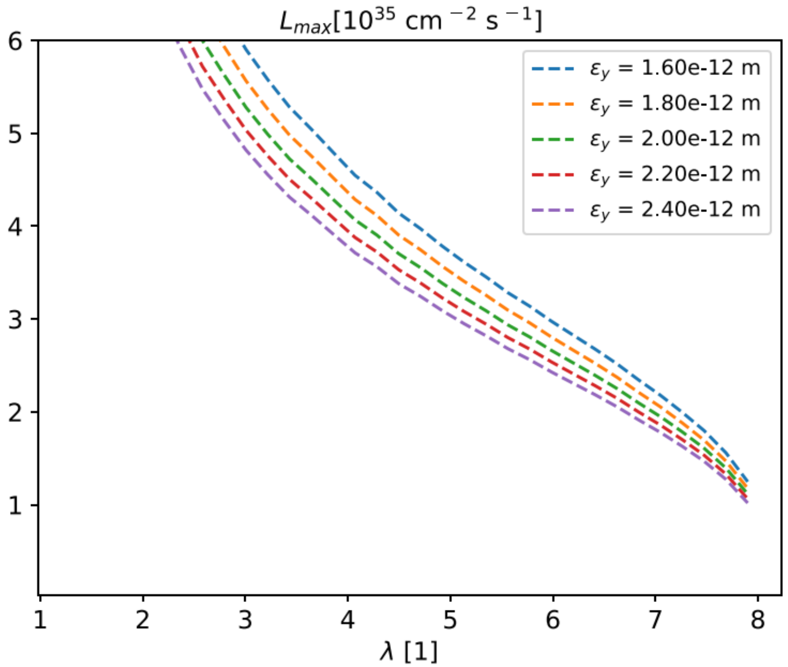
w/o crab cavities

A. Bogomyagkov, E. Levichev
PRAB **20**, 051001 (2017)



for either m-c scenario:
L=2.5 × 10^{35} cm^{-2} s^{-1}
w. σ_W ~13 MeV
cf: w/o monochromatization:
L= 8 ×10^{35} cm^{-2}s^{-1} w. σ_W ≈ 115 MeV
narrow width of Higgs Γ_H ≈ 4.2 MeV
→ monochromatization yields 3x more Higgs bosons + improved signal / background

M.A. Valdivia, F.Z., 2020



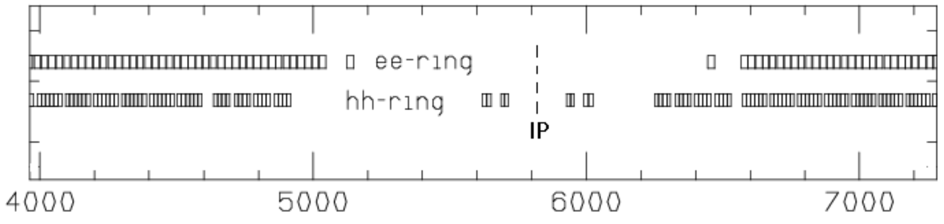
FCC-ee issues requiring further studies (monochromatization)

1. **Elaborate optimum set of IP parameters and optimum choice of monochromatization scheme** – compare proposals with and crab cavities etc.
2. **Develop optical lattices producing required large D_x^***, along with target values for β_x^* and β_y^*.
3. **Devise running mode, including the continuous monitoring of the collision energy and of its spread,** at the 10^{-5} level, the operation procedures, and the diagnostics, provided both by the accelerator instrumentation and by the particle physics detectors.
4. Further **improve data analyses for s-channel Higgs event selection** and background reduction, as well as for few-MeV Higgs mass precision required beforehand.

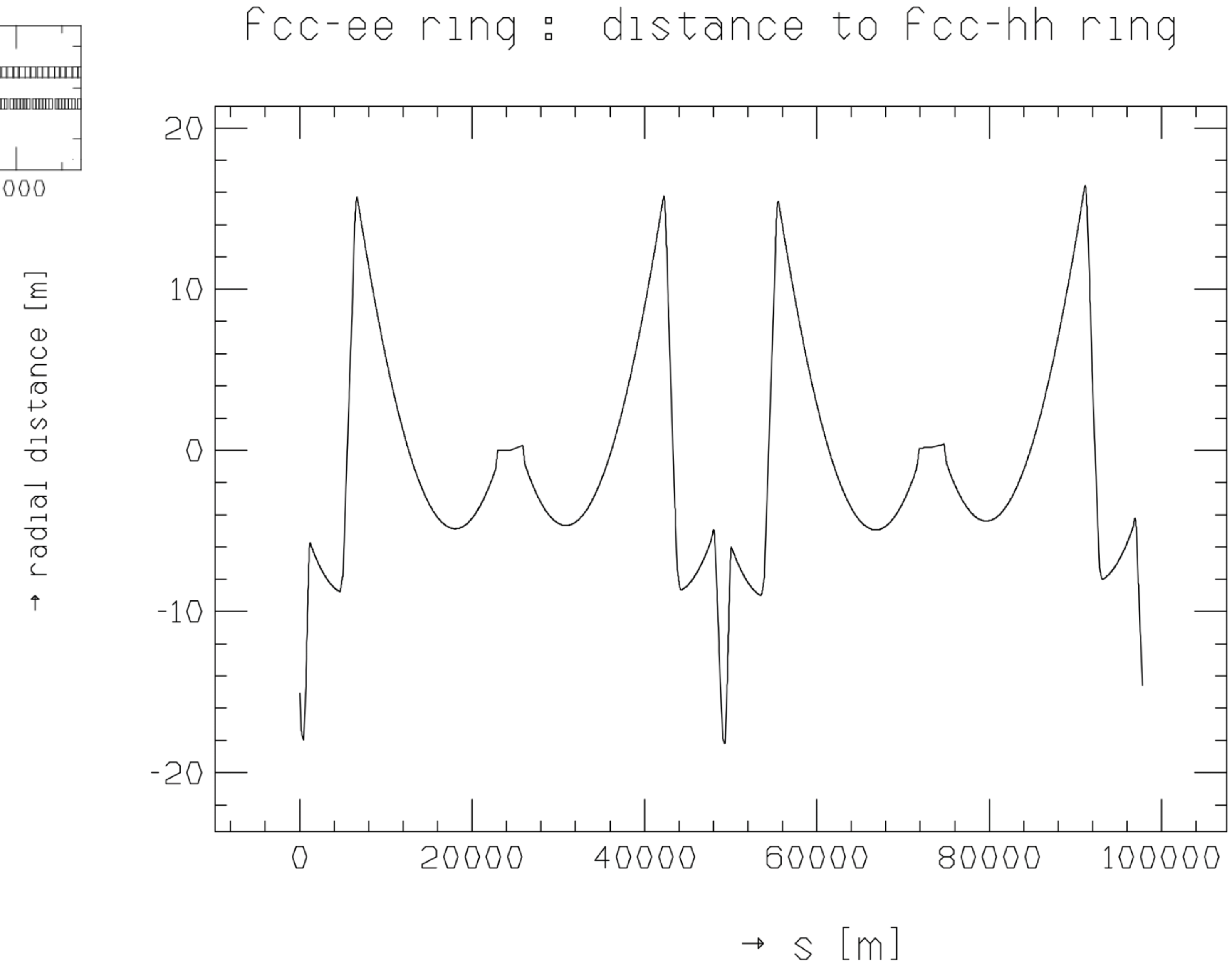
FCC-hh issues requiring further studies and accelerator optimization

1. **Shortening the length of the betatron collimation system** (presently 2.8 km). In parallel also the beam extraction section should be shortened (e.g. by installing a longer extraction septum, and more extraction kickers).
2. Layout/geometry modifications to **reduce transverse distance between the FCC-hh and FCC-ee collision points**; studies of the **importance of mirror symmetry or super-periodicity and the associated tolerances.**
3. Development of **cost-efficient 16 T dipole magnets with acceptable field errors**.
4. Studies and developments of **alternative injector scenarios,** e.g. injection from a superconducting SPS and elaboration of all the implications. Optimization and review of the injector complex.
5. **Machine protection and radiation issues** (further optimisation of the interaction region; shortening of extraction section; failure scenarios; etc.)
6. Further **RF system design** and development of **FCC-hh crab cavities.**
7. Design for **maximum energy efficiency.**

FCC-ee offset from FCC-hh at present



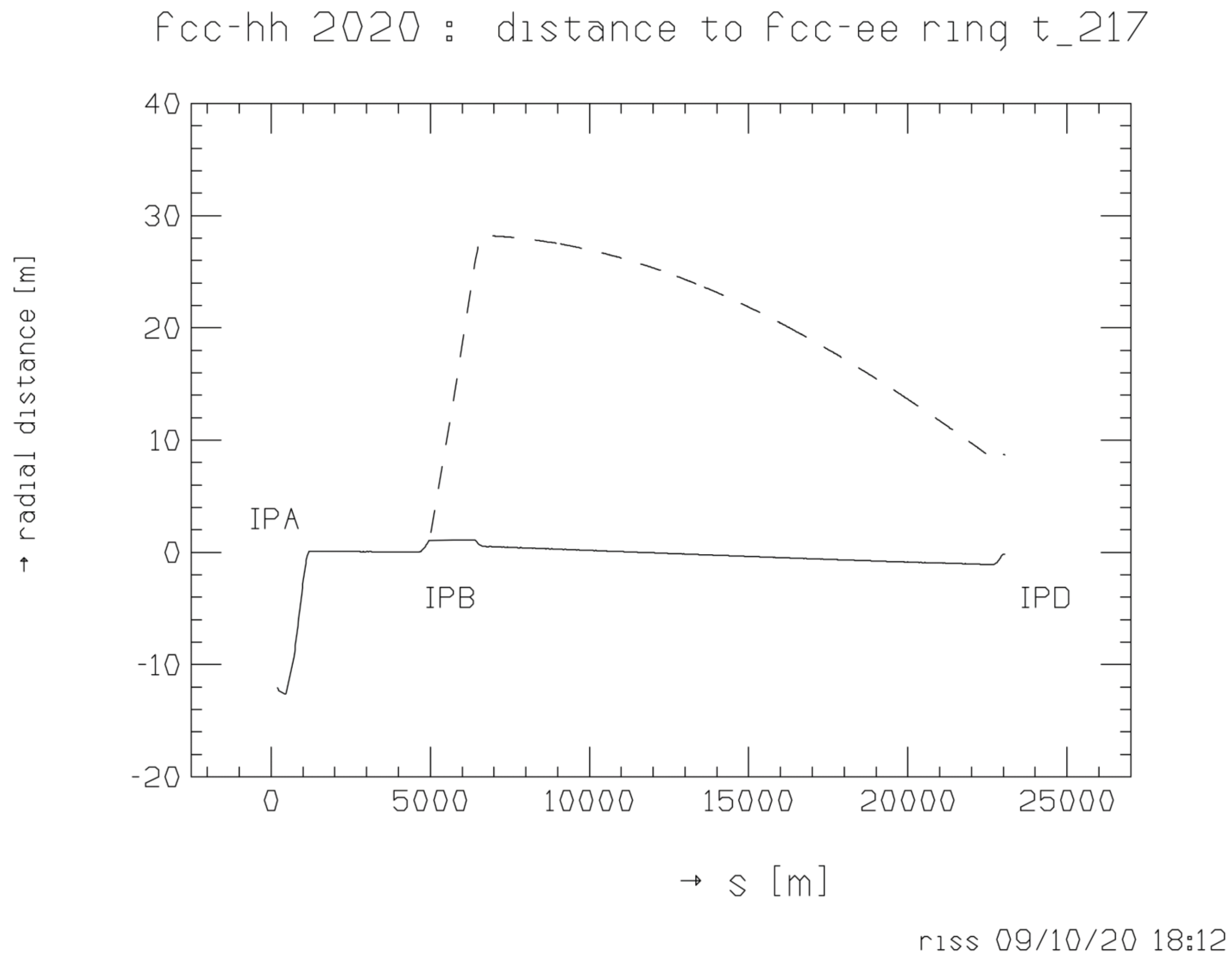
displacement in points B & L



Thys Risselada,
M. Giovannozzi,

work in progress

FCC-ee footprint rematched to new FCC-hh footprint

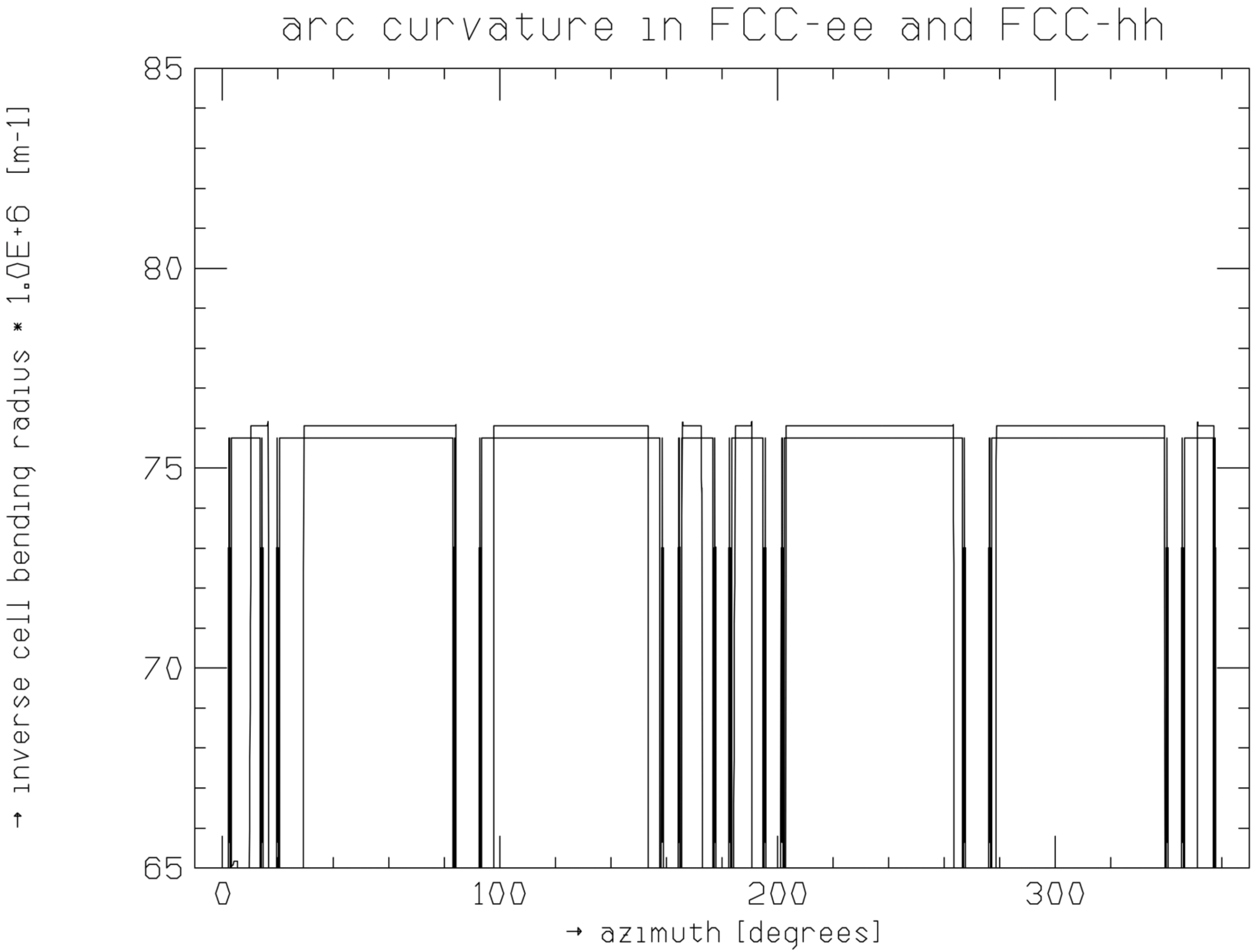


“hacked”

offset only around IP

Thys Risselada, M. Giovannozzi, work in progress

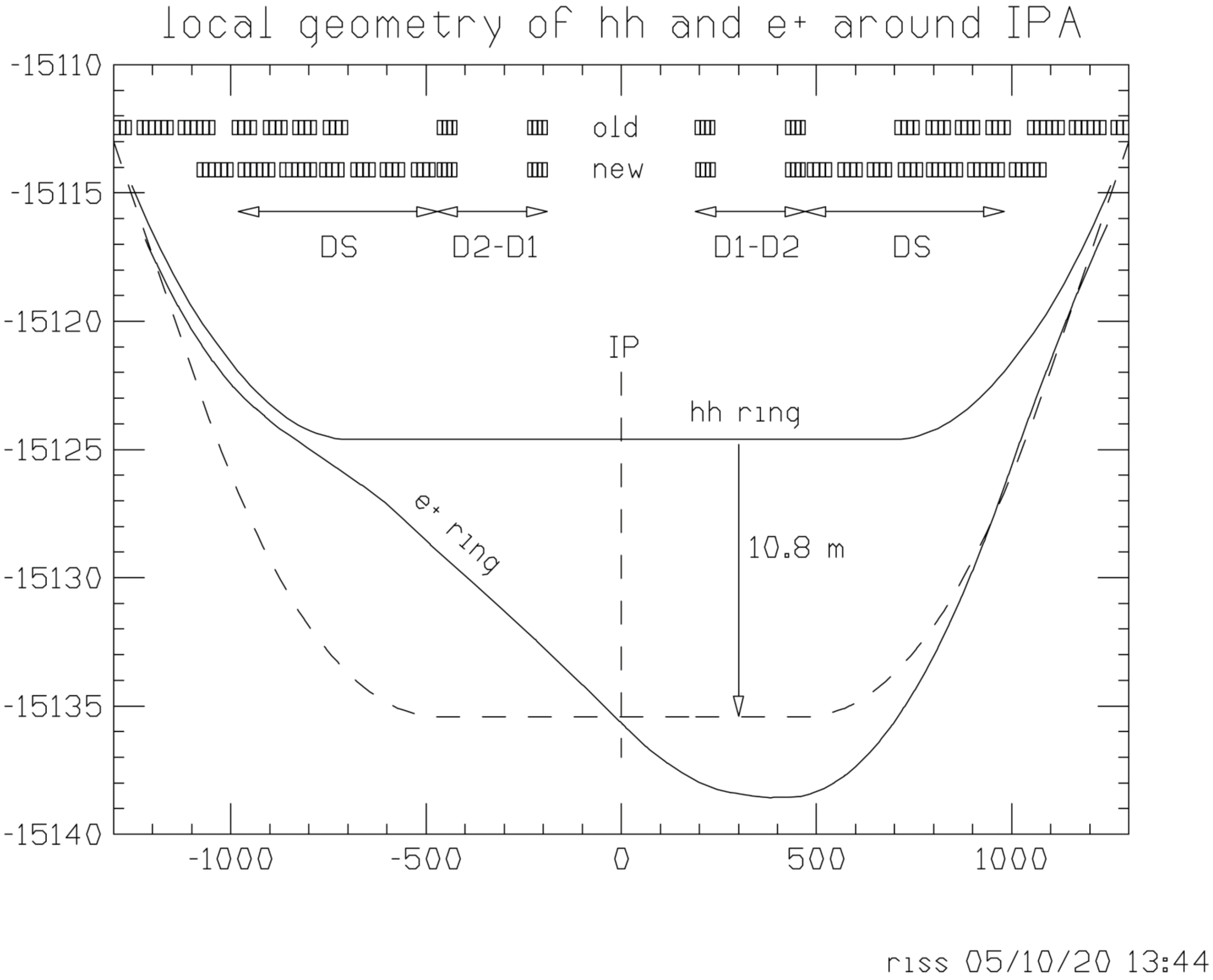
FCC-hh and FCC-ee arc curvatures



The bending radius of the hh ring is slightly larger than in the ee ring; the inverse bending radii are 75.75E-6/m and 76.06E-6/m respectively.

Thys Risselada,
M. Giovannozzi

FCC-hh IR geometry with IP at same location as FCC-ee's



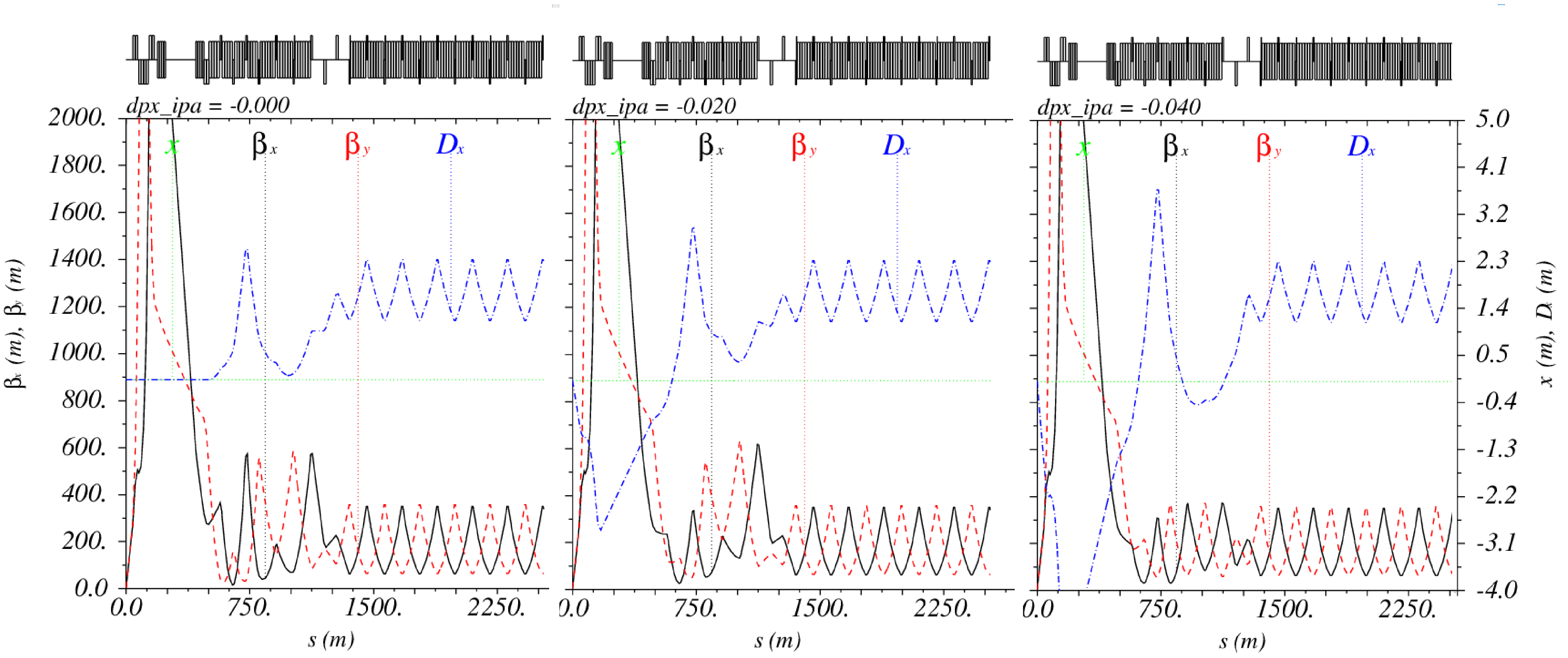
Adjusted bend strengths in the hh ring.; to compensate I decided to lower by 7 % the bending angles in the hh DS.

Working on a machine containing only bends and drifts, pushed the magnets around in order to move the hh IP towards the ee IP.

Moving all 4-bend groups of the DS, plus the adjacent 3 groups of 6-bend half cells, as close as possible to the D2 magnet, brings together the IPs of hh and ee.

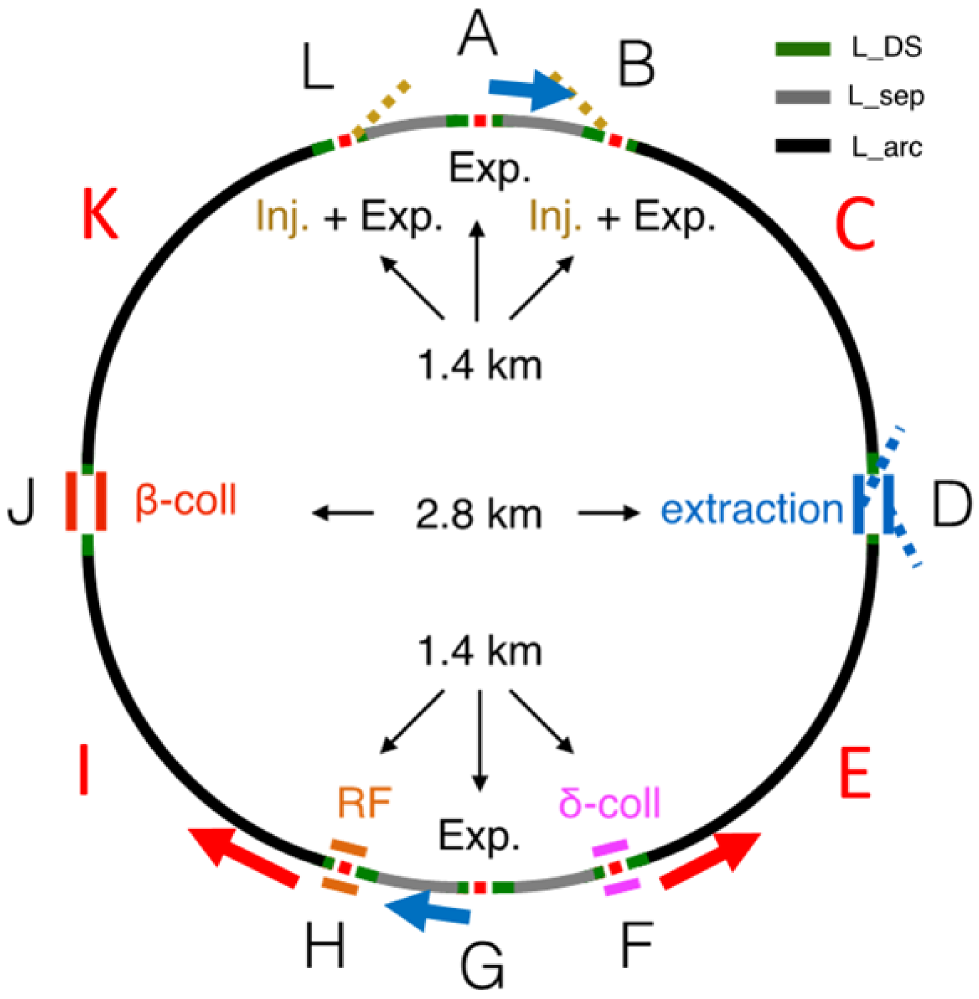
Thys Risselada,
M. Giovannozzi,
work in progress

FCC-hh IR optics with IP at FCC-ee location



Thys Risselada, M. Giovannozzi, work in progress

site optimization proceeding in parallel and might further change layout and footprint(s)



superperiodicity

- probably important for FCC-ee but not relevant for FCC-hh
  - no merit for hadrons ?

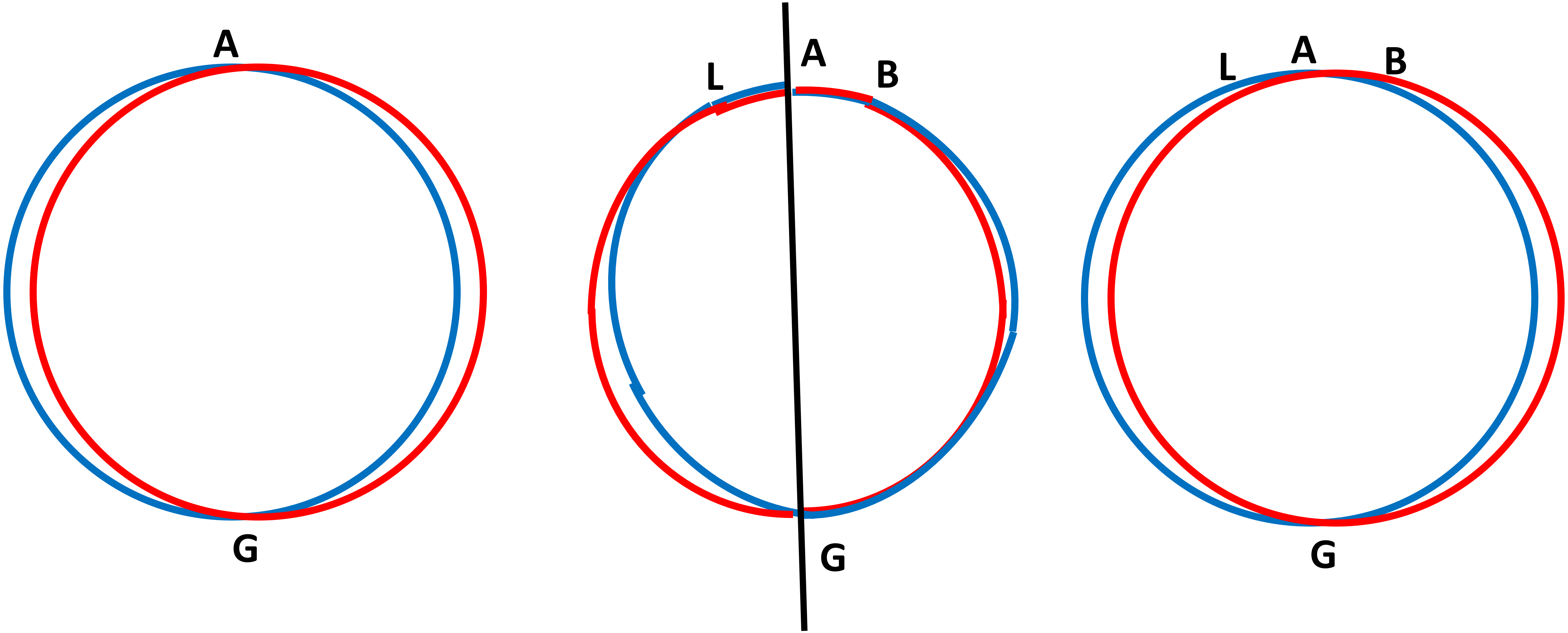
mirror symmetry

- ensures equal circumference for beam 1 and beam 2 , but beams could stay in the same aperture on both sides of points L and B (parasitic crossing?)
- might potentially help for FCC-ee if choosing 4 IPs

V. Mertens, D. Schulte, K. Oide, J. Gutleber

question of mirror symmetry

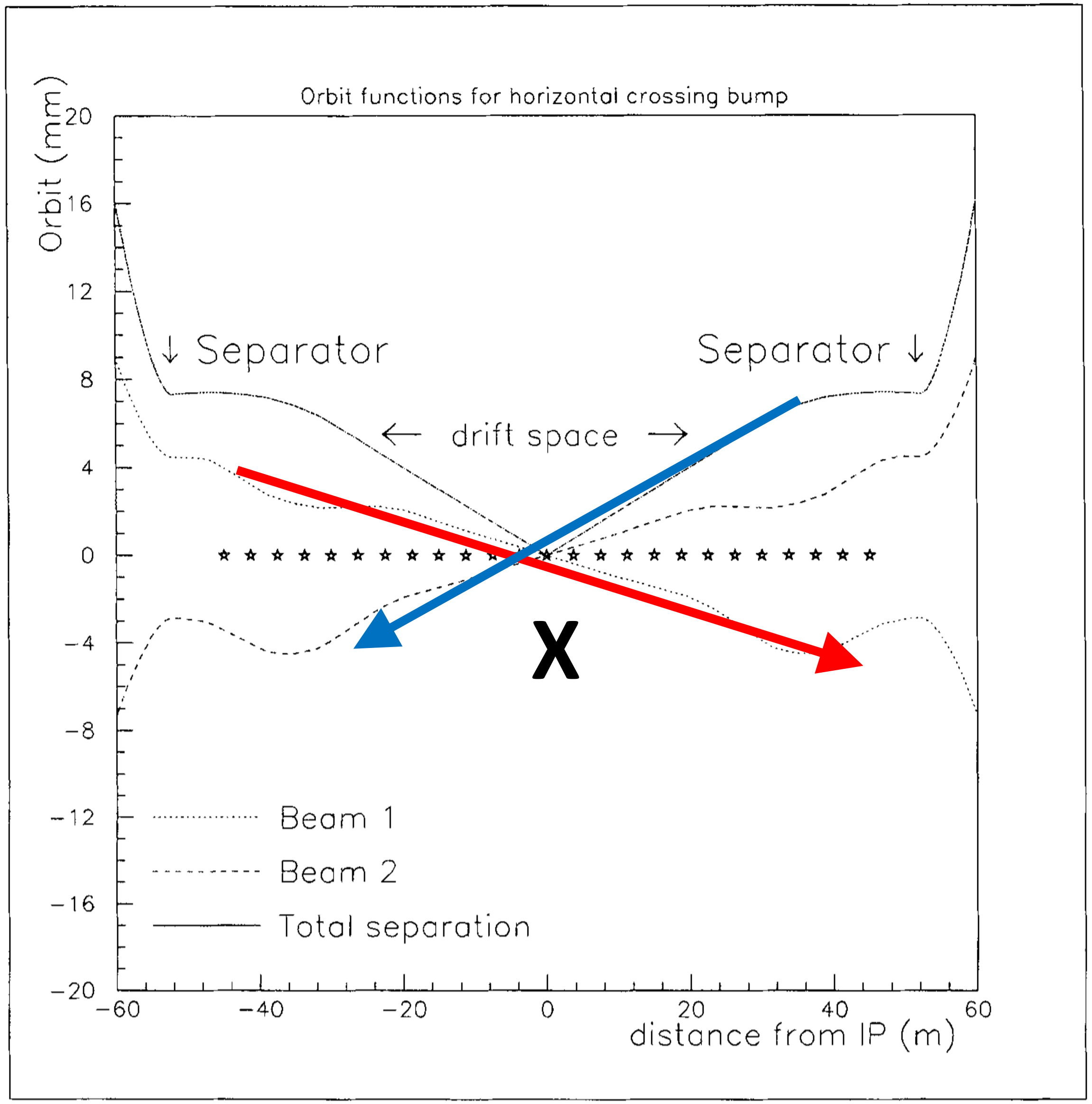
beam 1 and **beam 2** should each spend half circumference in outer and inner aperture



OK for 2 IPs, OK for 4 IPs with mirror symmetry also OK for 4 IPs if no change aperture in L & B standard x crossing

no problem for vertical crossing (e.g. point B)

issue is secondary IP with horizontal crossing (i.e. point L)

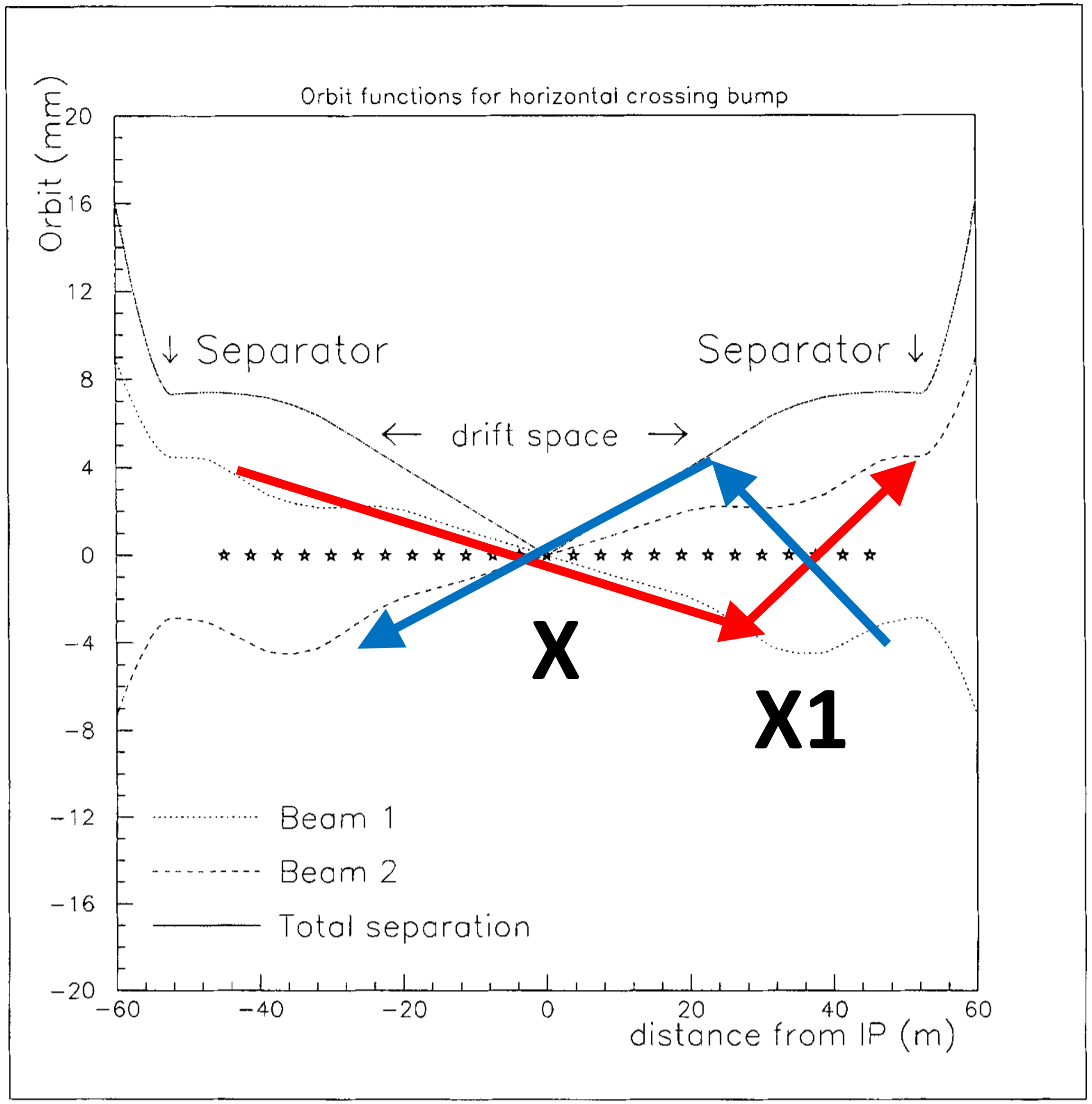


W. Herr, 1995

same aperture x crossing (concept)

no problem for vertical crossing (e.g. point B)

issue is secondary IP with horizontal crossing (i.e. point L)

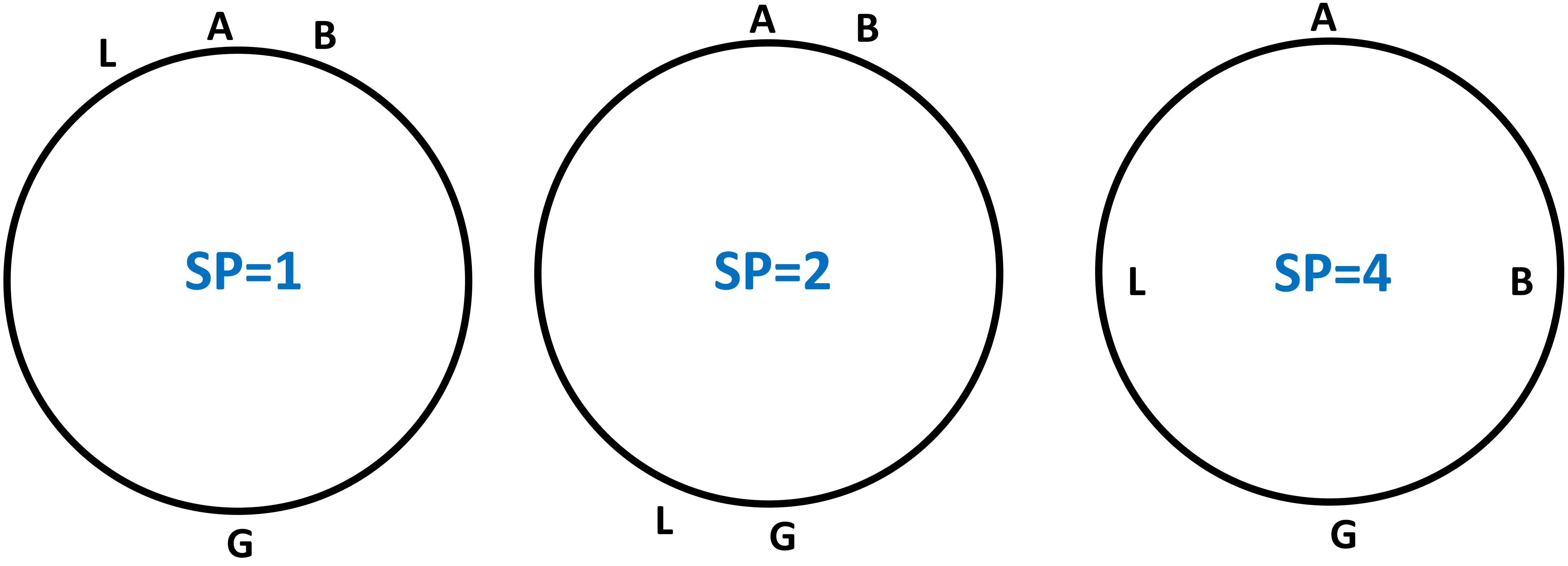


→ **avoid collision at X1 (separation in vertical direction)** important for e^+e^-

question of superperiodicity

example 4 IPs

K. Oide



$mQ_x + nQ_y = p$ $\qquad$ $mQ_x + nQ_y = 2p$ $\qquad$ $mQ_x + nQ_y = 4p$

resonance condition for lattice errors (DA) and for beam-beam

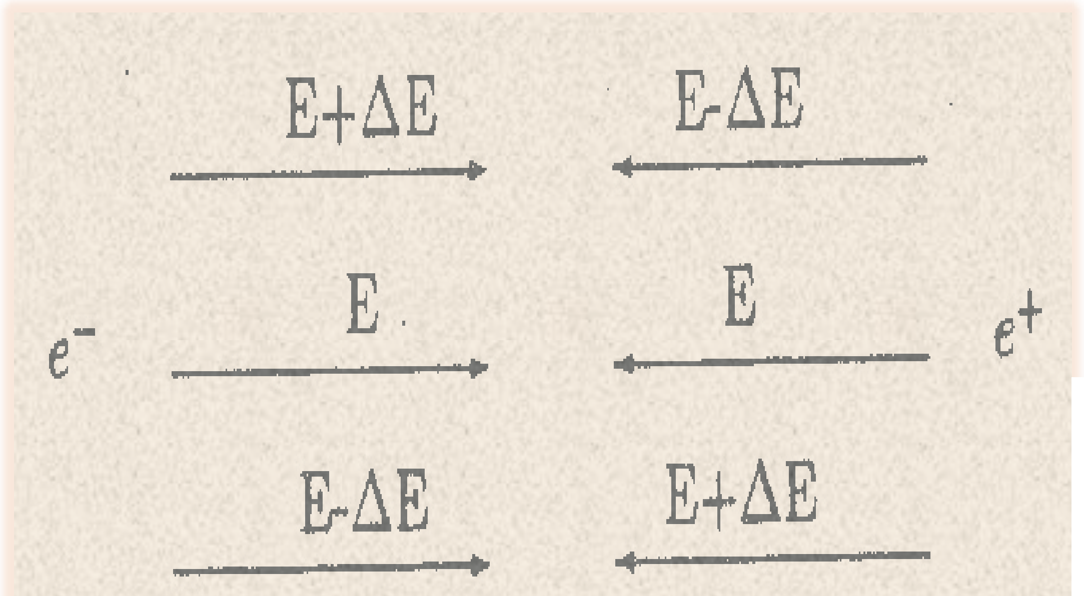
conclusions

several tantalizing questions
lots of work still ahead of us
excellent synergies between CEPC and FCC studies

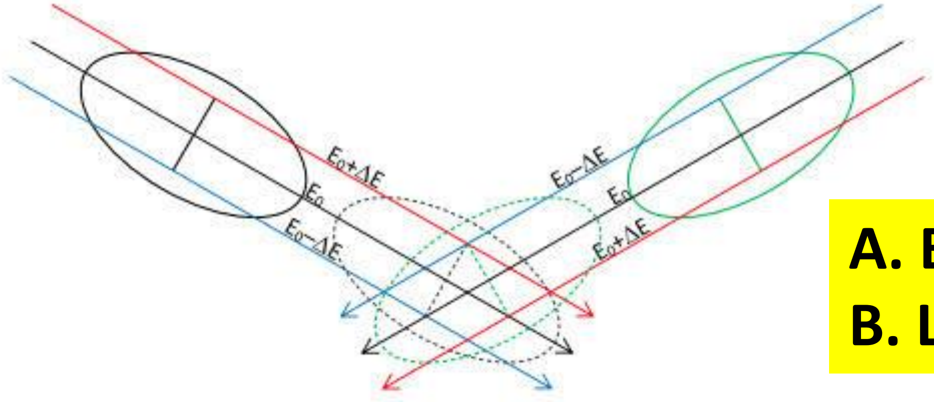
relevant Snowmass 2021 LOIs:
FCC-ee as Z, W and H factory, LOI #146
FCC-ee upgrade to top factory, LOI #147
Precision Energy Calibration for a Future Circular Electron-Positron Collider, LOI #148
Monochromatized direct s-channel Higgs production in e+e - at $\sqrt{s}$=125 GeV, LOI #149
Optimizing the FCC-hh Hadron Collider, LOI #153

spare slides

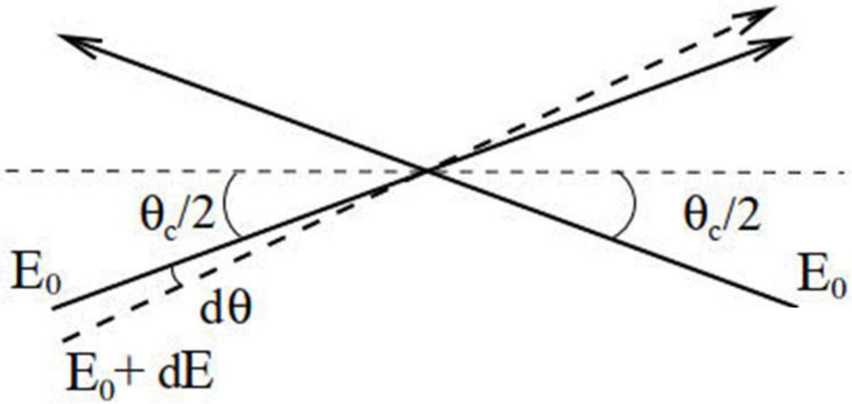
monochromatization for s-channel H production



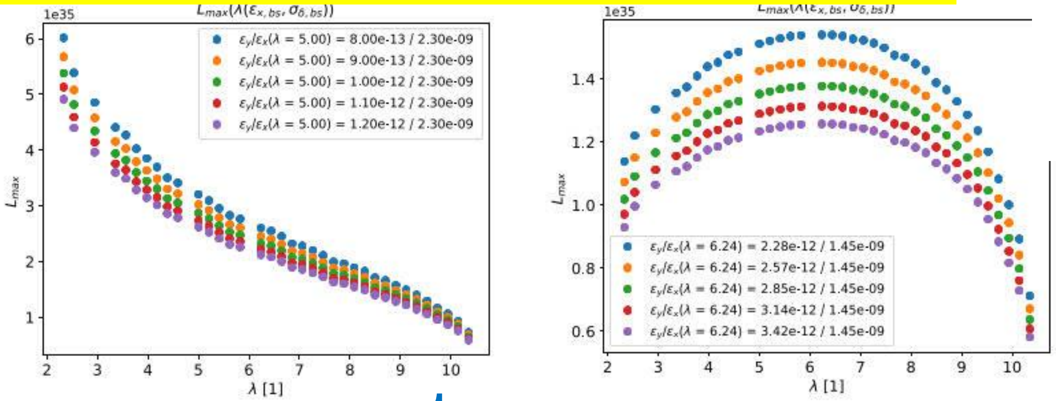
A. Renieri, 1975; A. Faus-Golfe, 1996



A. Bogomyagkov, B. Levichev, 2017



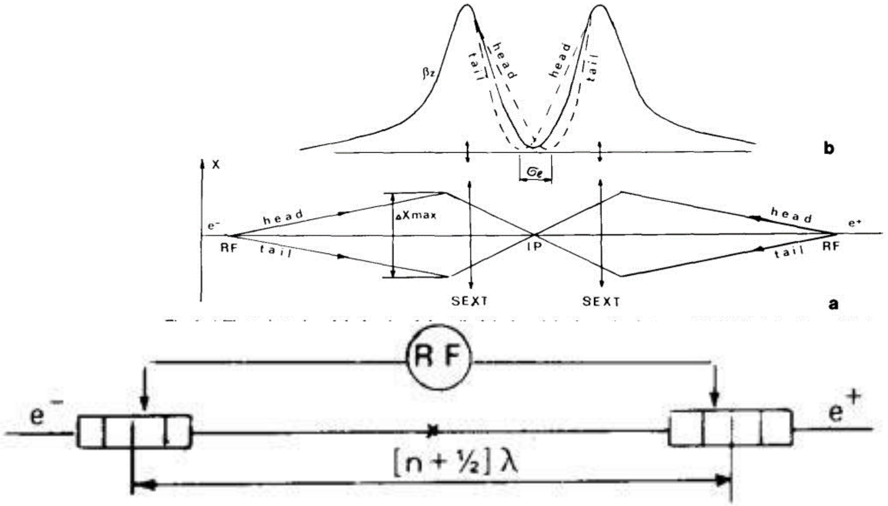
V. Telnov, 2020



$\varepsilon_y = \text{const.}$

$\varepsilon_y = \kappa_\varepsilon \varepsilon_x$

M.A. Valdivia, F.Z., 2019



A. Zholents, 1988