FCC-EE OPTICS AND INTEGRATION OF POLARIMETER AND WIGGLERS

A. Blondel, M. Hofer, K. Oide, J. Wenninger, F. Zimmermann
and gratefully acknowledging contributions from many colleagues in the FCC collaboration

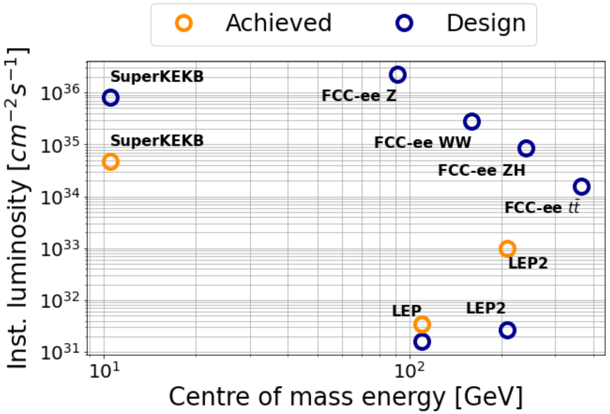
FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754

Motivation

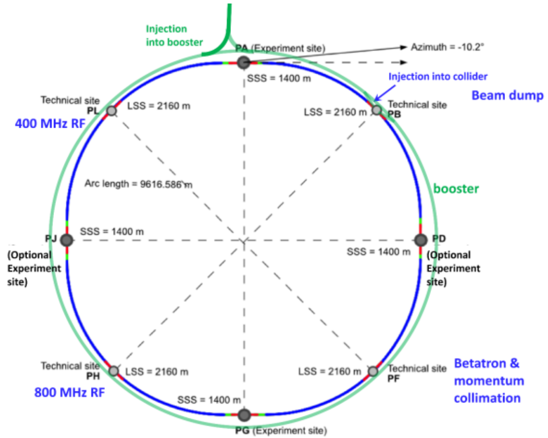
- Design of a highest-luminosity, energy frontier e^+e^- collider, optimized to study Z, W, Higgs, and top particles

- Brings several challenges for optics design, such as
  - Double ring e^+e^- collider with a circumference of 91 km, following the layout of a potential succeeding proton-collider
  - Minimal changes between four different operation modes
  - SR power limited to 50 MW/beam at all energies
  - Other "goodies": Tapering, top-up injection, crab waist collision scheme, $E_{critical}$ below $100\ keV$ for the last dipoles upstream of IP

- Relying also on input from EPOL studies in guiding decisions



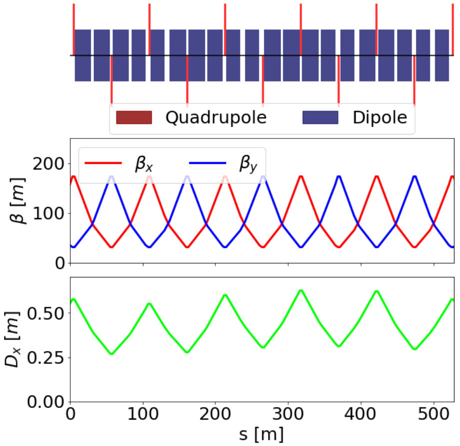
Sources: 1,2,3,4



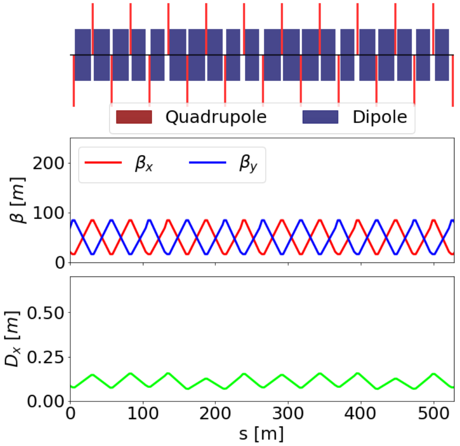
Arc cell considerations

- FODO cell is used in the arcs due to high packing factor
  - Large momentum compaction at Z and W required for mitigation of collective instabilities and low emittance for H and $t\bar{t}$ operation
  - In current lattice, variable cell length implemented
    - For Z and W, cell length of ~100m
    - Reduce cell length for H and $t\bar{t}$ to 50m by installing quadrupoles in the gaps between dipoles
  - Tapering of magnets along the ring to compensate for sawtooth effect
  - For testing and optimizing fabrication, integration, and transport, a mock-up of an arc half-cell is in planning

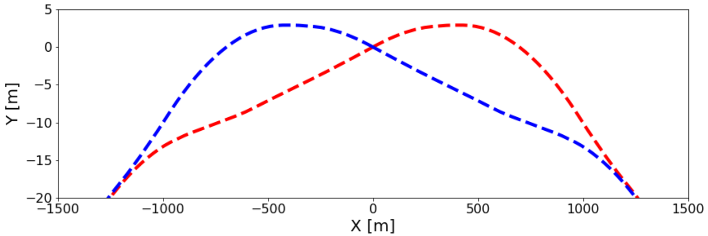
Z



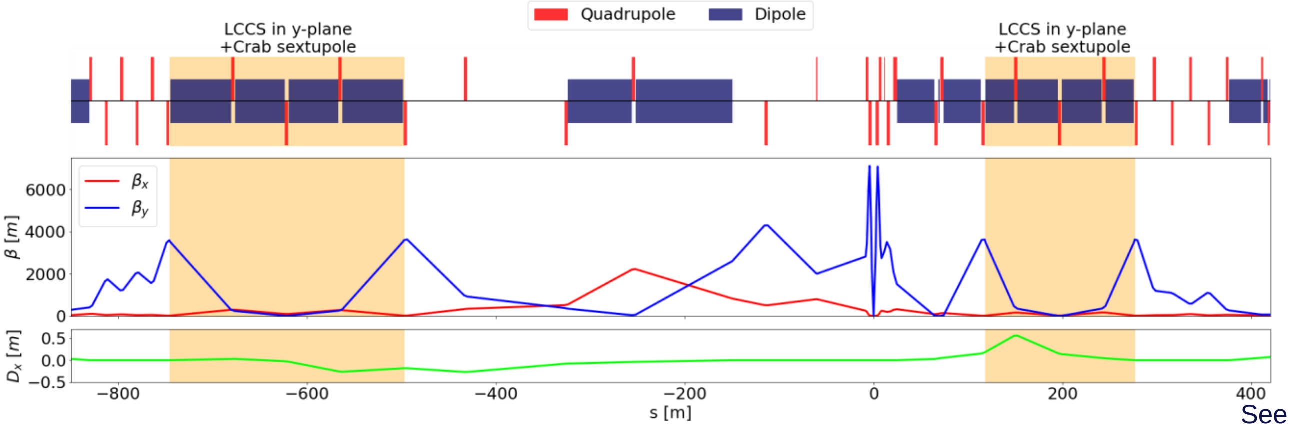
$t\bar{t}$



Experimental IR



- Common IR layout for all working points
  - L* of 2.2 m and horizontal crossing angle of 30 mrad
  - Use of superconducting final focus quadrupoles
  - Asymmetric layout with weak bending of dipoles upstream of IP to keep SR E_{crit} < 100 keV
  - Detector solenoid with 2 T locally compensated by anti-solenoids
  - Local chromaticity correction in vertical plane, combined with crab sextupoles

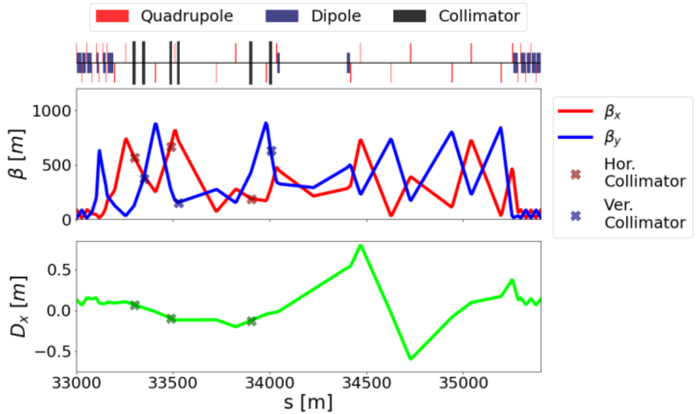


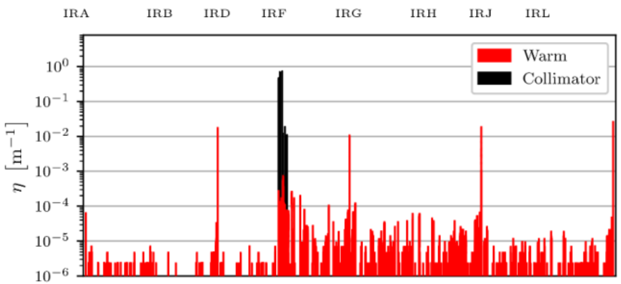
Operation mode	β_x^* [mm]	β_y^* [mm]
Z	100	0.8
W	200	1
H	300	1
$t\bar{t}$	1000	1.6

See K. Oide, PRAB **19**, 111005, Nov. 2016

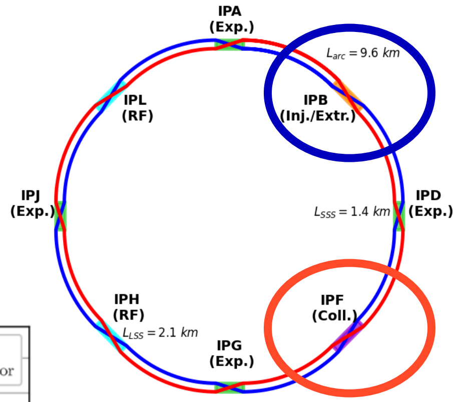
Integration of auxiliary insertions

- In 4-IP layout, beam crossing in every straight section required
- First design of a collimation insertion under study
  - Betatron and momentum collimation in point F

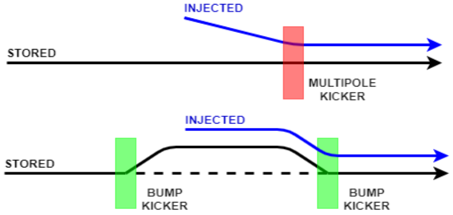




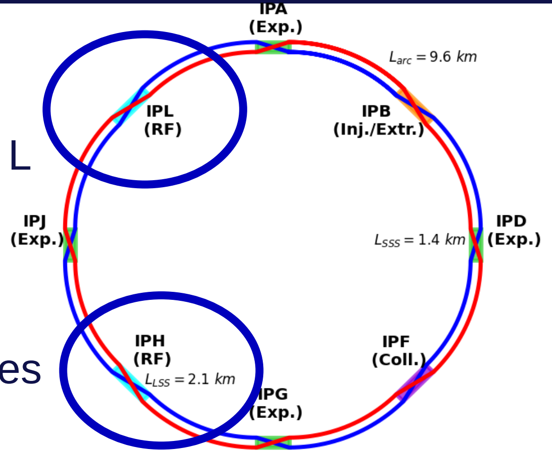
A. Abramov et al.



- Top-up injection and extraction located in point B, combined insertion and compatibility with different injection schemes to be studied
  - Feasible injection schemes identified, using either nonlinear kicker or one turn closed orbit bump

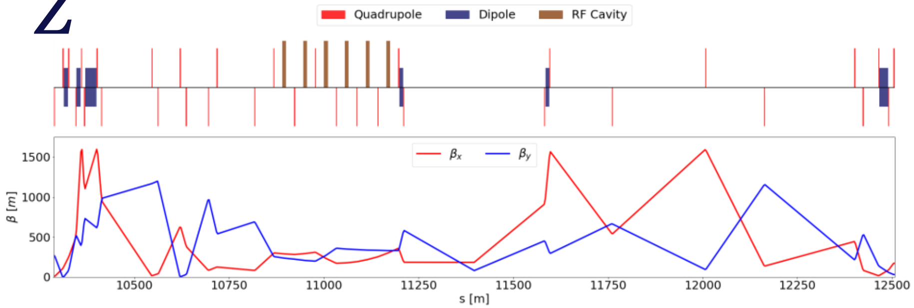


RF insertions

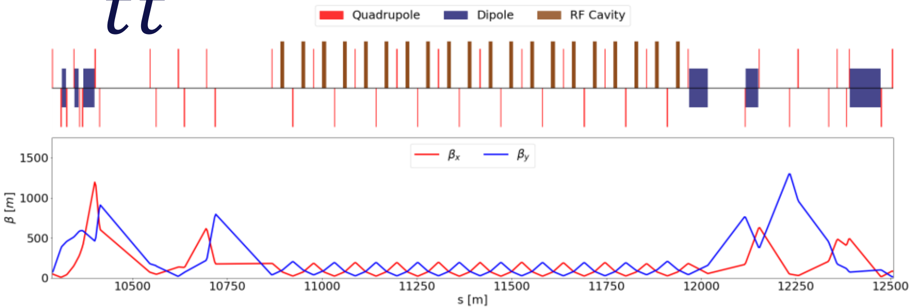


- After preliminary survey of surface sites, RF placed in points H and L
  - To reduce the uncertainty on center-of-mass energy, RF located in a single place for Z and W operation
- In $t\bar{t}$ operation, RF cavities distributed between points H and L
  - Different RF settings and their impact on center-of-mass energies under study (see talk by J. Keintzel)
- Insertion layout modified between operation modes
  - At Z and W, separate RF for each beam with beam crossing in the middle of the insertion
  - Common RF for H and $t\bar{t}$ operation modes

Z



$t\bar{t}$

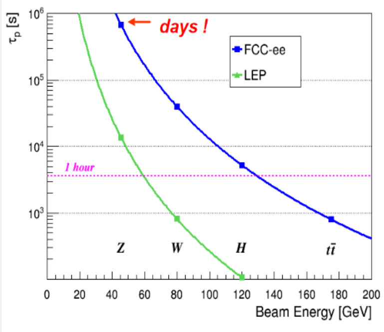


INTEGRATION OF WIGGLER AND POLARIMETER

EPOL operation scenario and Hardware

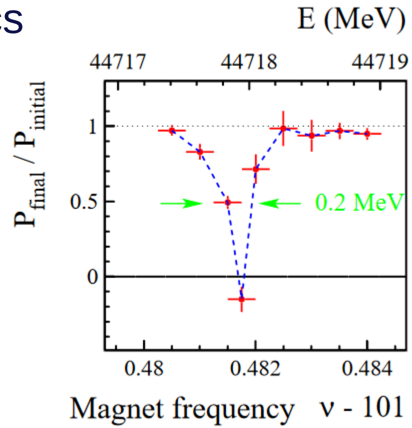
- “Natural” polarization rise time τ_p in FCC-ee at Z above 250h ($\frac{1}{\tau_p} \propto \frac{E^5}{\rho^3}$)
  - Operation scenario foreseen:
    1. Inject ~200 pilot bunches
    2. Use **wigglers (ρ ↓)** to achieve desired level of polarization (< ~5%) in reasonable amount of time
    3. Turn wiggler off and fill up machine for physics
    4. Use **polarimeter** to measure polarization of pilot bunches while frequency sweep of **RF-magnet**

See arXiv:1909.12245 for more detail



Polarization risetimes for LEP and FCC-ee

J. Wenninger, “Polarised Electron Beams/Energy Calibration”, CAS 2018



Example RDP measurement at LEP, see https://doi.org/10.1007/BF01496579

Wiggler design

- Wiggler design for FCC-ee follows 3 three block LEP design

  J. Jowett and T. Taylor, "Wigglers for control of beam characteristics in LEP"

  - Length, field, and number of wigglers free parameters, but $\left(\frac{\sigma_E}{E}\right)^2 \propto \frac{E^4}{\gamma^3 \tau_p \Delta E_{loss}}$, (see **PRAB** 19, 101005, 2016)
  - Asymmetry parameter $r = \frac{B_+}{B_-} = \frac{L_-}{L_+}$
  - Length of one unit $(L_- + L_+)$ = 3.5m , put together in packages of 3 units with L = 12 m (including extra 0.5m on each side to adjacent element)

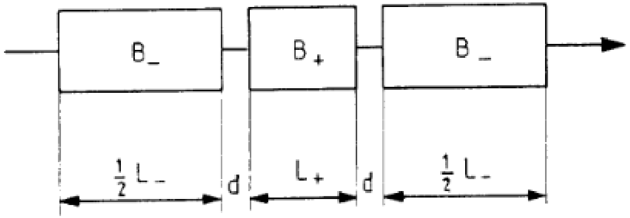


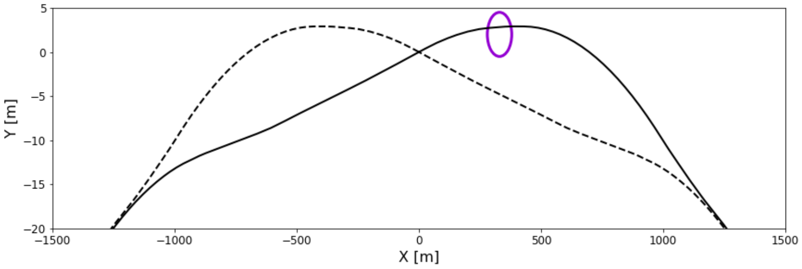
Fig. 1 Model used for calculations.

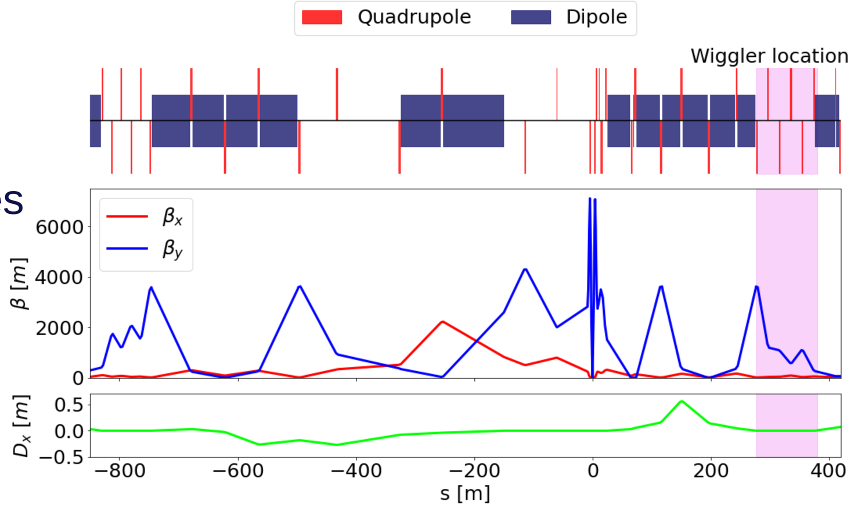
Parameter	w/ wiggler	w/o wiggler
Energy spread [MeV]	64	17
τ_∞ [h]	12	248
ΔE_{loss} [MeV]	51.4	35.8
ΔL [mm]	0.0135	

Parameter	FCC-ee	LEP
Number of units per beam	24	8
B_+ [T]	0.7	1.0
L_+ [mm]	430	760
r	6	2.5
d [mm]	250	200
Crit. Energy of SR photons [keV]	968	1350

Wiggler Location

- Should be installed in dispersion free section and ideally small β_x to limit impact on aperture
- Wigglers foreseen to be installed in 16m long drift space downstream of the interaction point
- Tracking studies show impact of wigglers on beam lifetime (see K.Oide, FCC-Week 2022)
  - Partially mitigated by turning off crab sextupoles

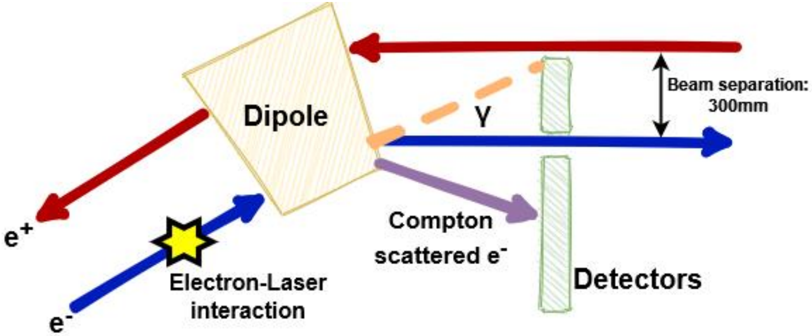




Polarimeter working principle

- Measure polarization based on spin-dependent Compton scattering of circularly polarized laser with $e^{\pm}$-beam
  - Detection not only of photons but also scattered electron

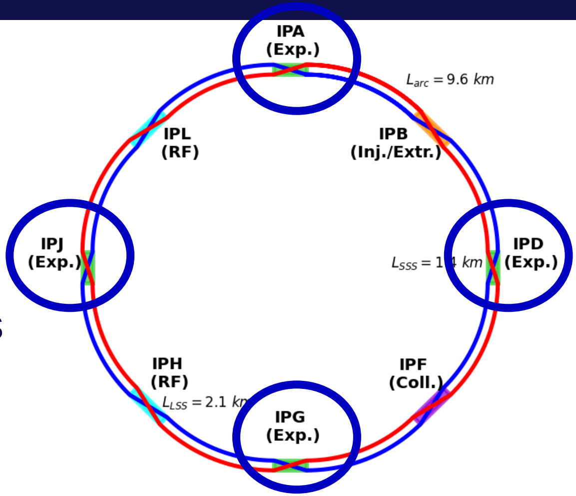
- Baseline: One polarimeter per beam
- Requirements:
  - Dipole magnet with high precision field map ($\theta_{dipole} = 2\,mrad$)
  - Field free region ($L_{drift} = 100m$) after dipole to separate scattered $e^{\pm}$ and γ from main beam
  - Si-Detector for scattered e^{+}/e^{-}, roughly 400mm wide [ref] (cf. to beam separation of 300mm)

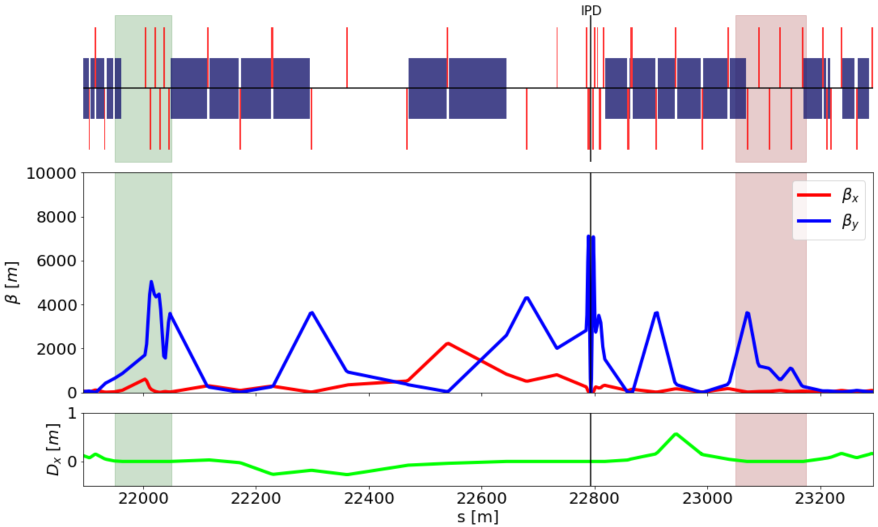


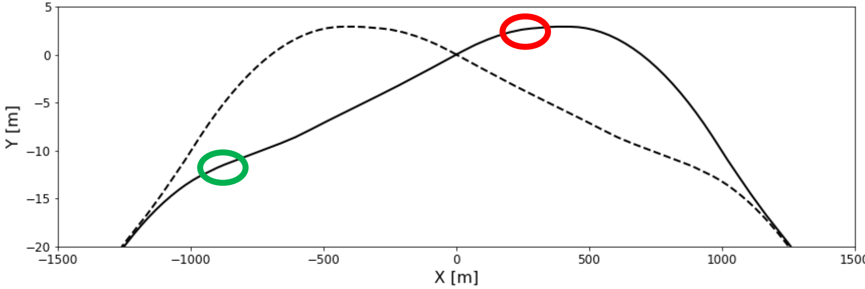
- Two options under study, either upstream of IP, or in RF-section

Polarimeter upstream of IP

- Preferred option to install polarimeter on inside beam to provide space for e^+/e^- detector
  - In current 4-IP layout, only the case upstream of experiments
  - Option downstream discarded due to interference with crab sextupole

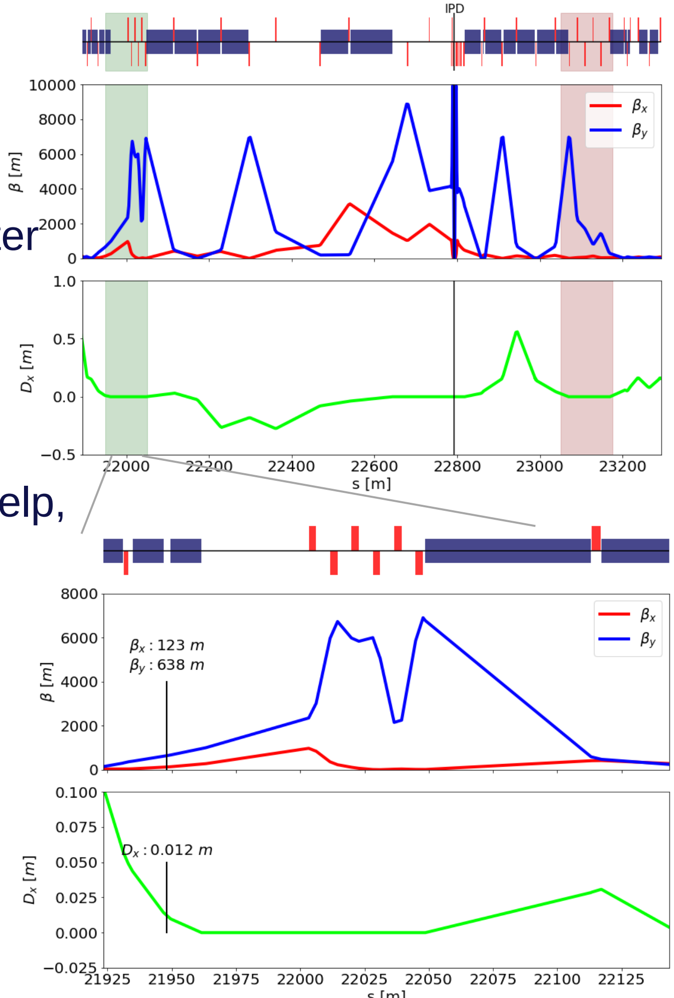


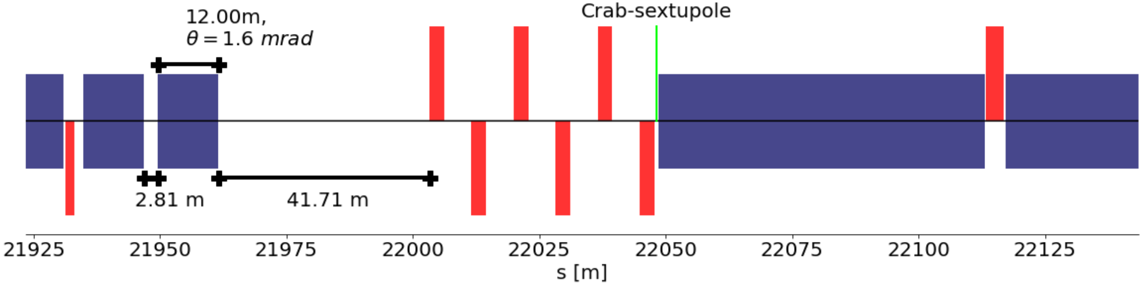




Polarimeter upstream of IP

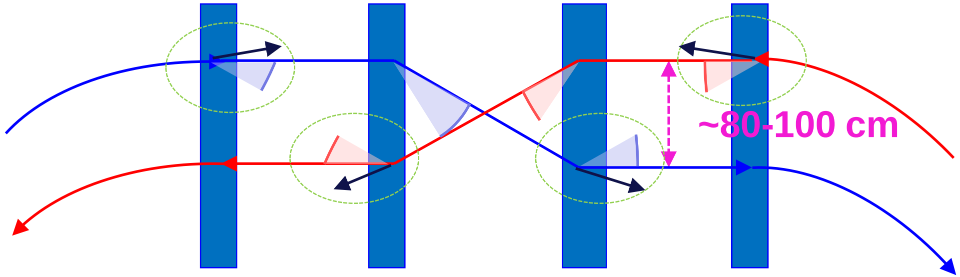
- Modified layout provides sufficient space for detectors, compatible with all operation modes and multiple polarimeter
  - Drift space to detector less than half of targeted length
  - Could be compensated by change of laser wavelength or detector [ref]
  - Moving dipoles and crab sextupoles closer to IP may help, but could have implication on DA, SR background, ..



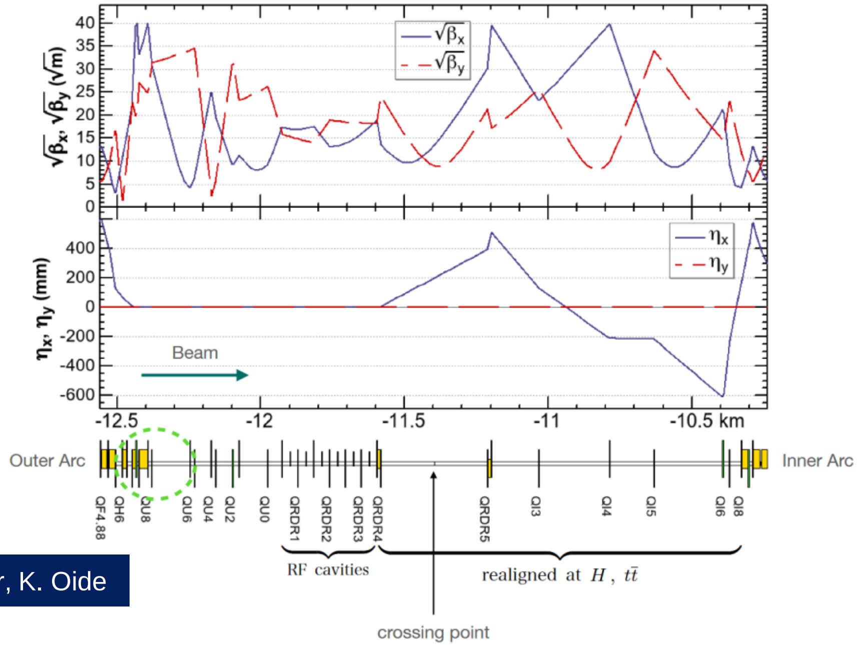


Polarimeter upstream of RF

- Alternative proposal to increase beam separation of non-IP straight to accommodate detector between beams
  - During Z operation, cavities installed only in one RF section, polarimeter used in “empty” insertion

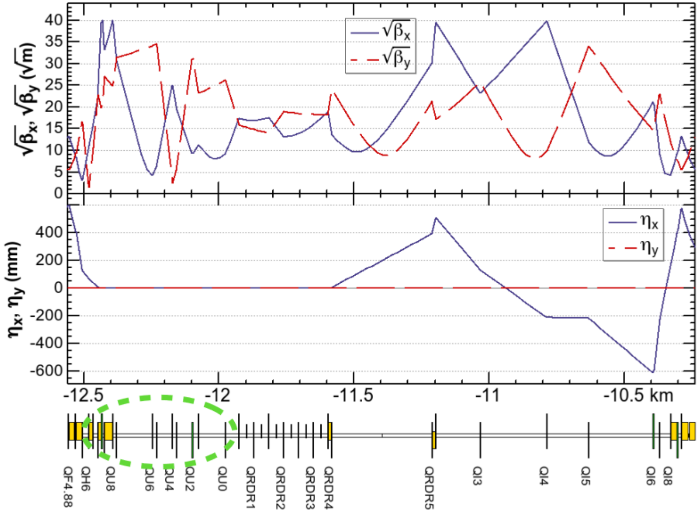


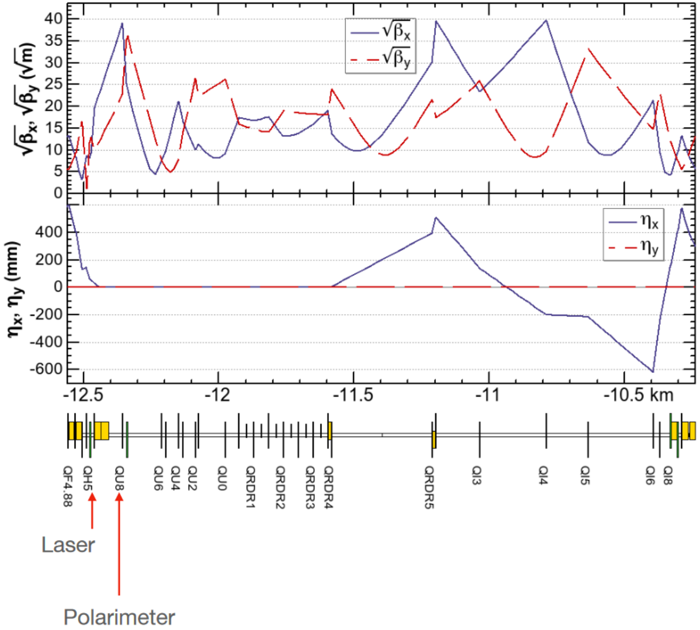
J. Wenninger, K. Oide



Polarimeter upstream of RF

- Rearranging some quadrupoles and splitting last dipole of the dispersion suppressor allows to meet requirements

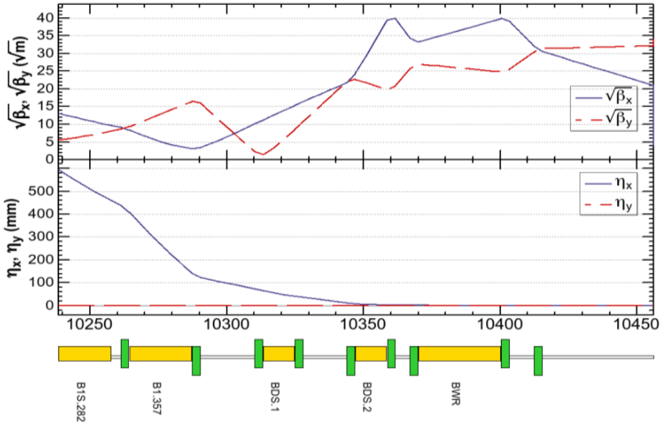


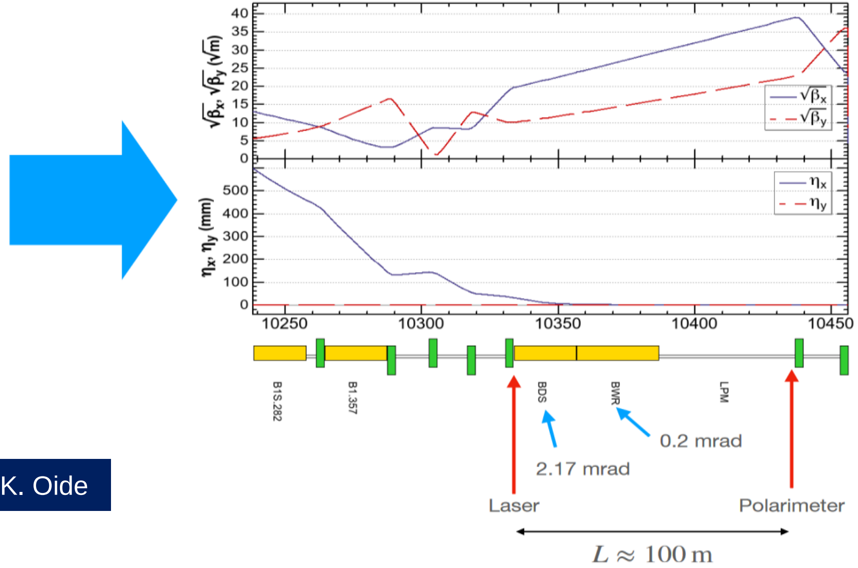


J. Wenninger, K. Oide

Polarimeter upstream of RF

- Rearranging some quadrupoles and splitting last dipole of the dispersion suppressor allows to meet requirements
  - Design consistent with RF layout for $H/t\bar{t}$ operation
  - Common design for both RF straight, with weak bending dipole (BWR) to avoid SR on cavities





J. Wenninger, K. Oide

Conclusions and next steps

- FCC-ee aims at e^+e^- collision with unprecedented energies and record luminosity
  - Sheer size and ambitious parameter set to provide interesting (optics-)challenges

- Baseline optics design for collider ring established,
  continuous development to provide consistent design for Feasibility Study Report in 2025

- Despite enormous size of FCC-ee, some challenge to find optimal location for hardware for polarization measurements
  - Wigglers located downstream of each IP
  - Two options for Polarimeter under study
    - Location in an RF straight with larger beam separation
    - Upstream of IP compatible with multiple polarimeters in the ring,
      but may require changes in laser or detector
  - RF-kickers not discussed yet
    - Working assumption: system similar to LHC TFB sufficient ($L_{total} \approx 6\,m$),
      potential to install in RF-straight

Thanks for your attention!