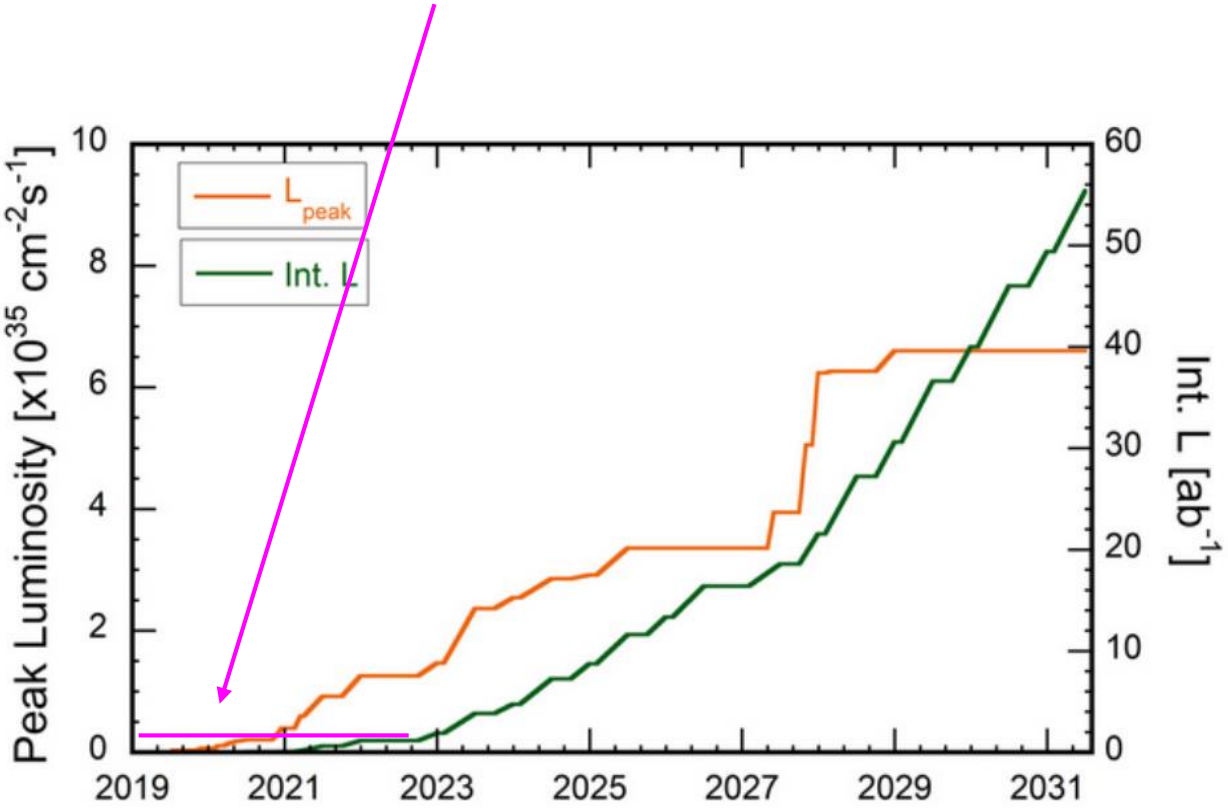
FCC-ee optics tuning The Challenge

R. Tomas for the FCC-ee tuning team

SuperKEKB luminosity record 3.9x10^{34} cm^2/s @ β*=1mm

Previous projection:

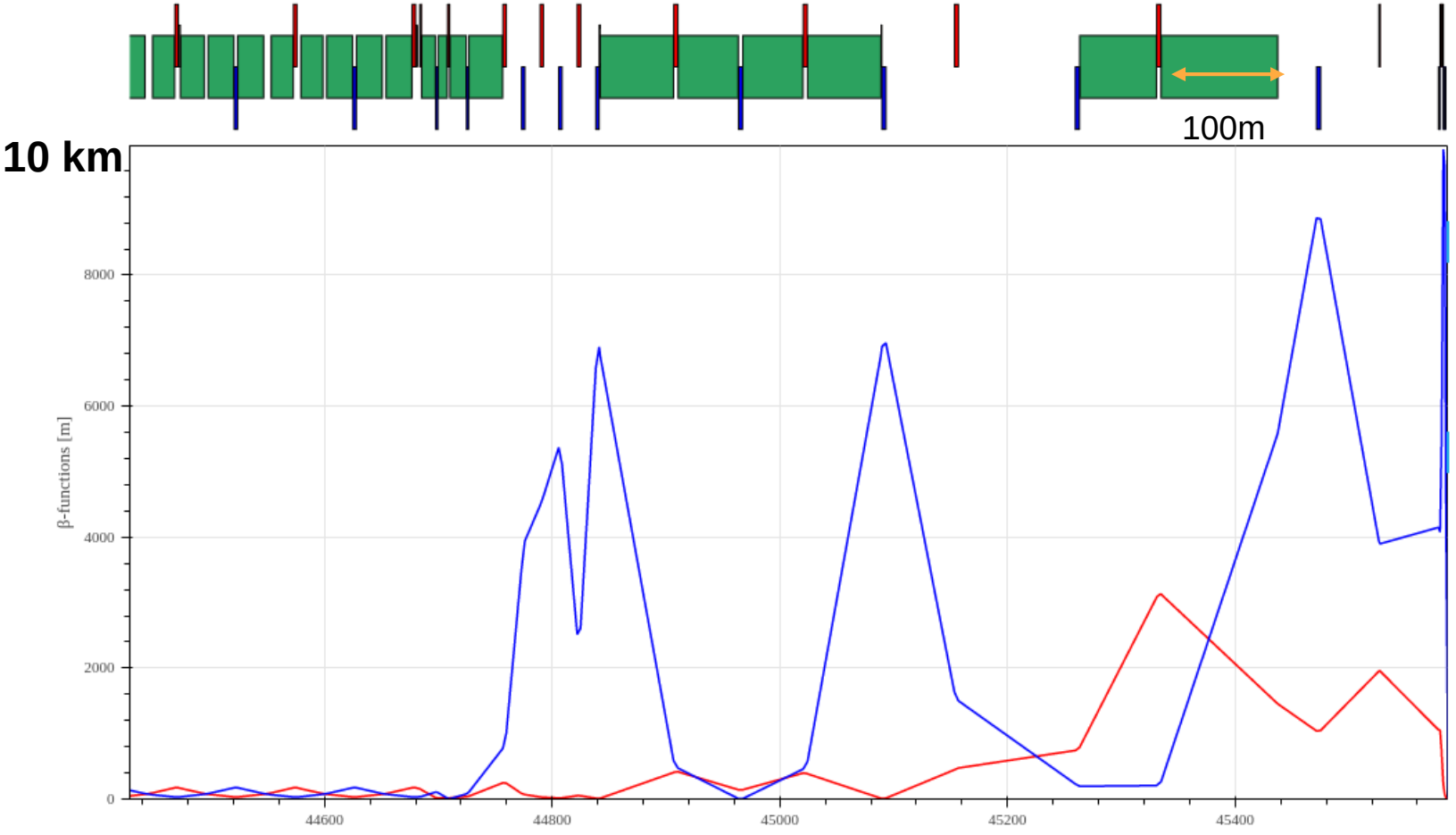


FCC-ee tuning team

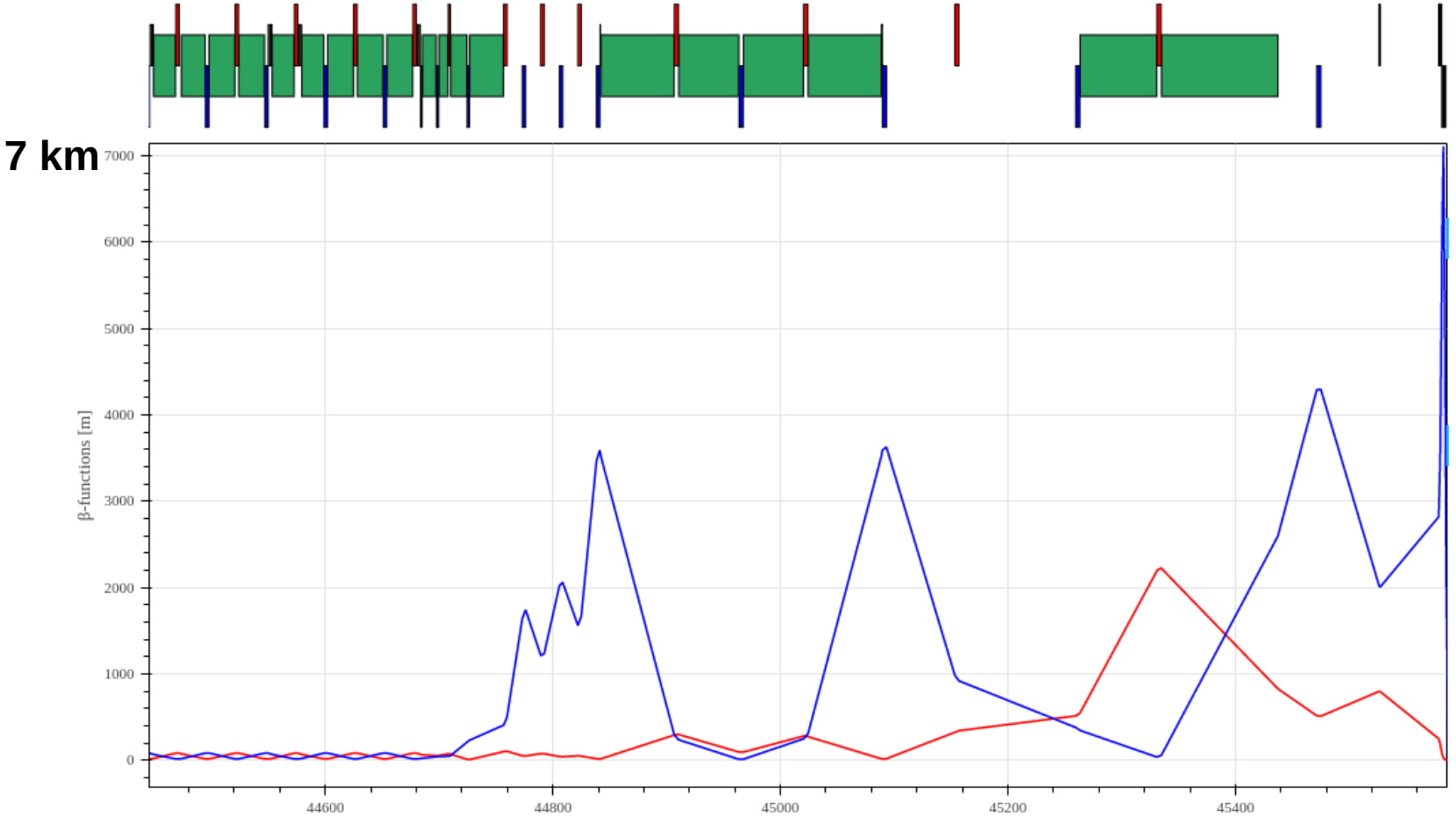
CERN e-group FCCee_tuning-team: Ilya AGAPOV, Esmaeil AHMADI, Felix CARLIER, Antoine CHANCE, Tessa CHARLES, Barbara DALENA, Riccardo DE MARIA, Andrea FRANCHI, Cristobal GARCIA, Michael HOFER, Patrick HUNCHAK, Jacqueline KEINTZEL, Simone LIUZZO, Lukas MALINA, Katsunobu OIDE, Tobias PERSSON, Tatiana PIELONI, Tor RAUBENHEIMER, Guillaume SIMON, Rogelio TOMAS, Fani VALCHKOVA-GEORGIEVA, Leon VAN RIESEN-HAUPT, Simon WHITE, Yi WU, Frank ZIMMERMANN + *Anyone is welcome!*

Meetings so far: 22 Apr, 22 Mar, 17 Mar, 10 Feb, 17 Nov and 10 Nov.

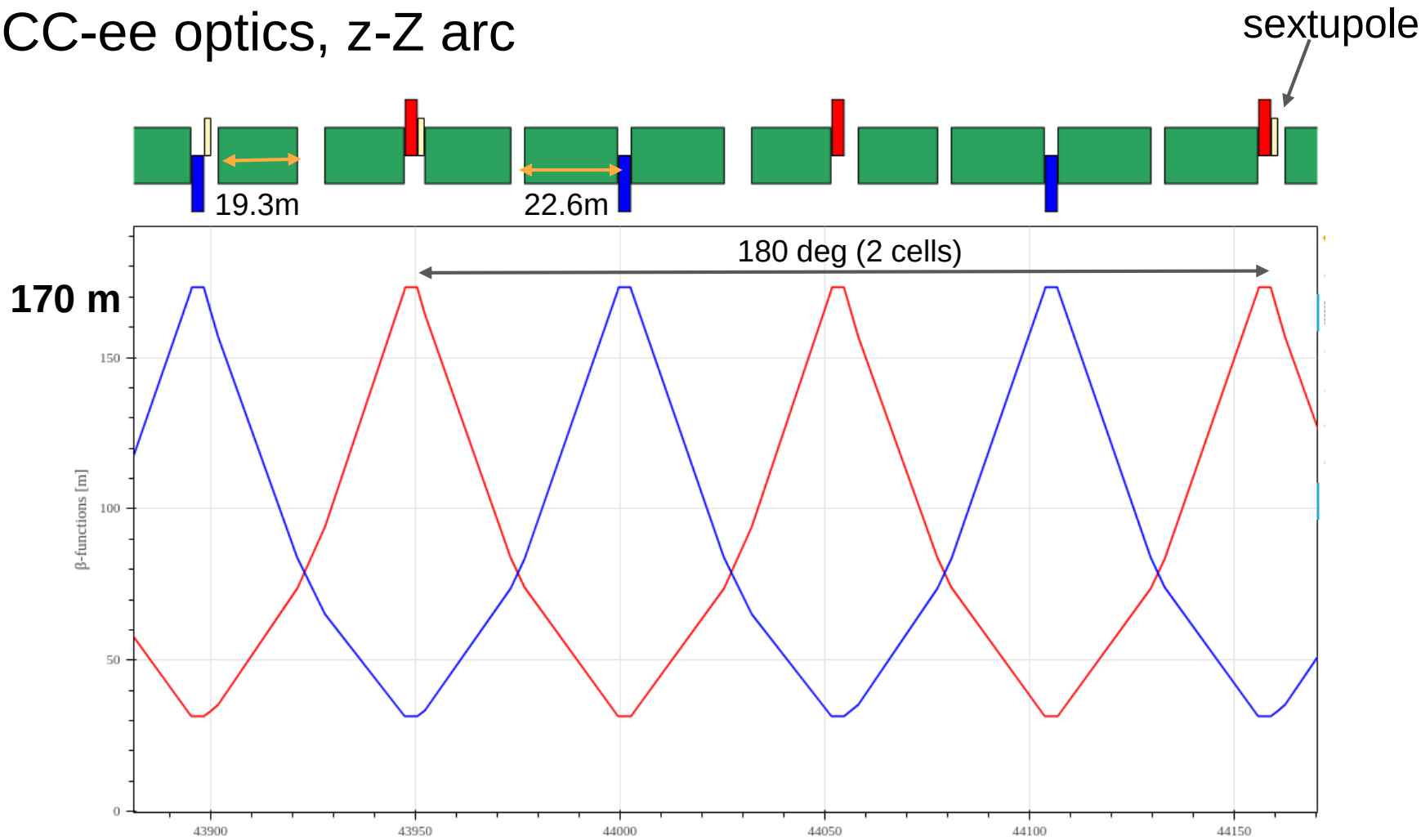
FCC-ee optics (repository V22, *thanks Michael!*), z-Z 45.6 GeV



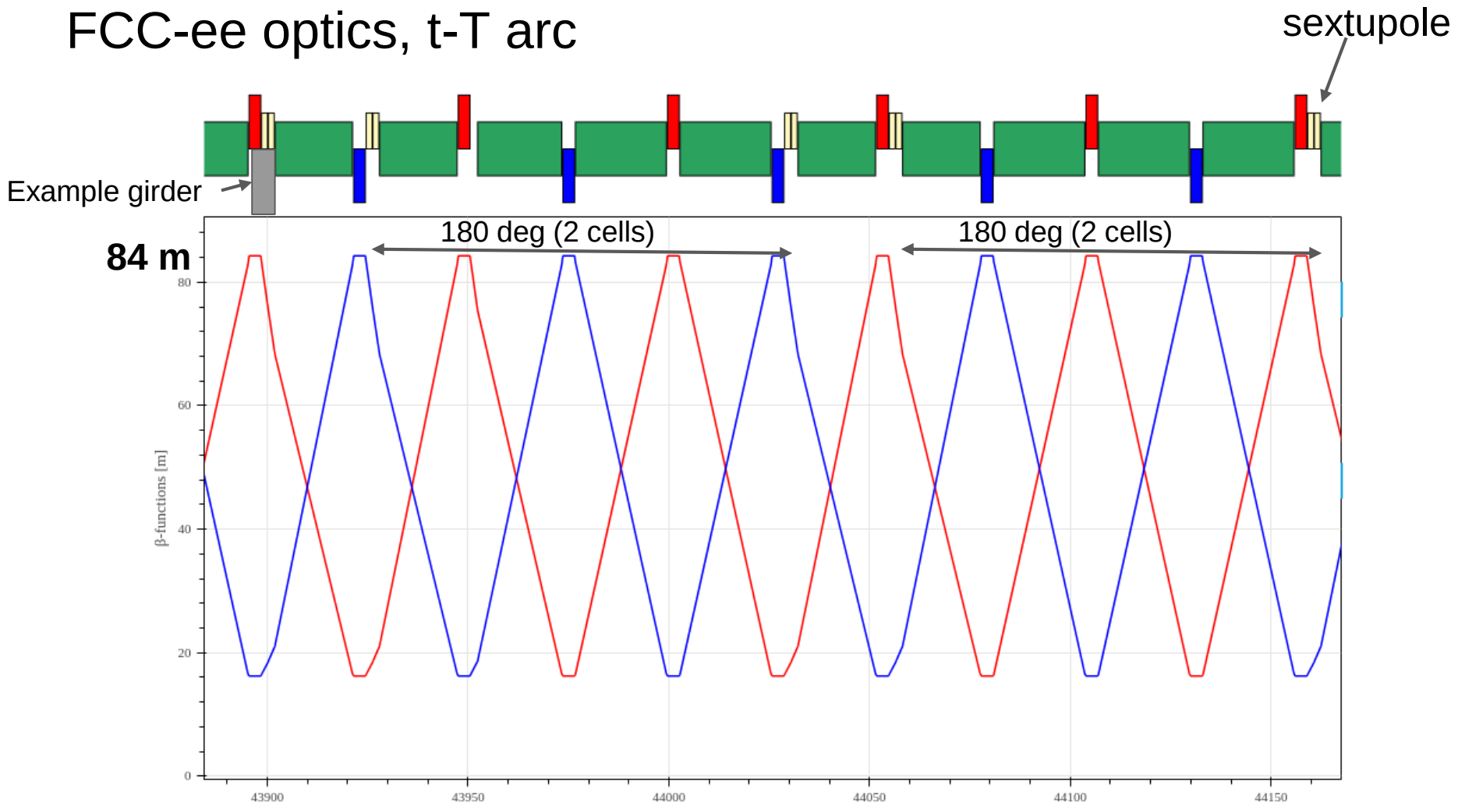
FCC-ee optics, t-top 182.5 GeV



FCC-ee optics, z-Z arc



FCC-ee optics, t-T arc



T. Charles,
March 2022

H. Mainaud, 10 Feb:
"The actual value of tolerances will not be the cost driver."

RMS misalignment and field errors tolerances:

Type	ΔX (μm)	ΔY (μm)	ΔPSI (μrad)	ΔS (μm)	ΔTHETA (μrad)	ΔPHI (μrad)
Arc quadrupole*	50	50	300	150	70	70
Arc sextupoles*	50	50	300	150	70	70
Dipoles	1000	1000	300	1000		
Girders	150	150	-	1000		
IR quadrupole	100	100	250	200	70	70
IR sextupoles	100	100	250	200	70	70

* misalignments relative to girder placement

Factor 2 lower tolerances might be considered if needed.

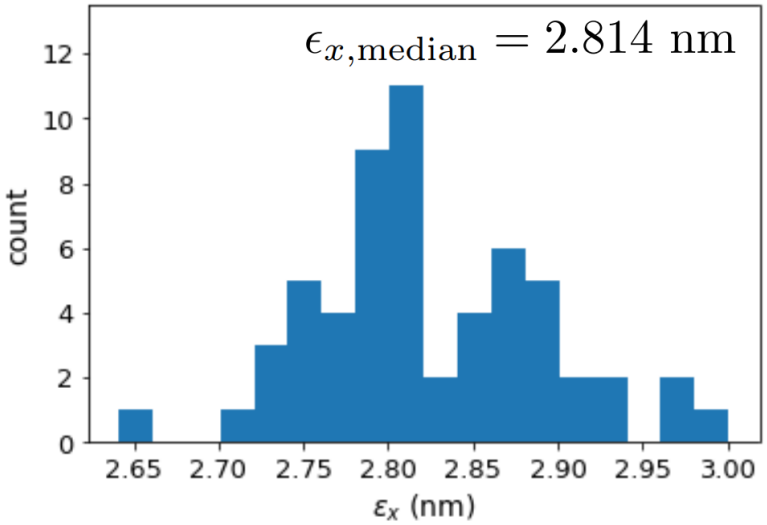
Type	Field Errors
Arc quadrupole*	$\Delta k/k = 2 \times 10^{-4}$
Arc sextupoles*	$\Delta k/k = 2 \times 10^{-4}$
Dipoles	$\Delta B/B = 1 \times 10^{-4}$
Girders	-
IR quadrupole	$\Delta k/k = 2 \times 10^{-4}$
IR sextupoles	$\Delta k/k = 2 \times 10^{-4}$

Only non-linear error so far is arc sextupole strengths.

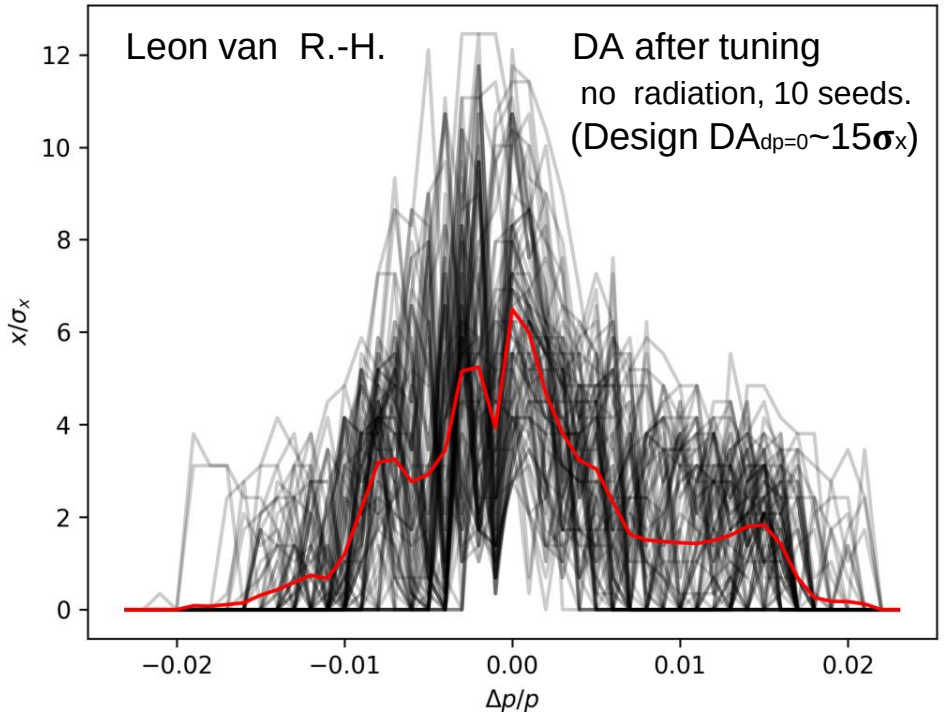
Note: BPM errors not included

Status of optics tuning, tt lattice

T. Charles has demonstrated good linear optics corrections, however:



Design ϵ_x= 1.45 nm

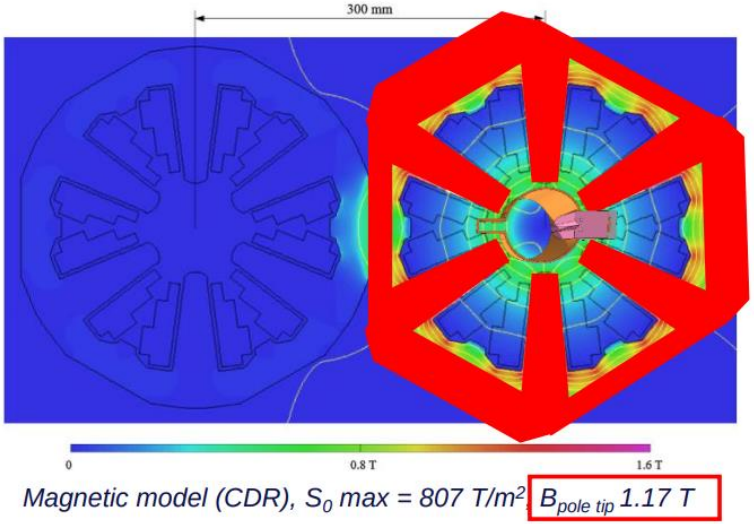


Horizontal emittance factor 2 larger than design.

D. Shatilov also experiences poor DA for tuned lattices.

Realistic tuning: Realistic lattice and magnets

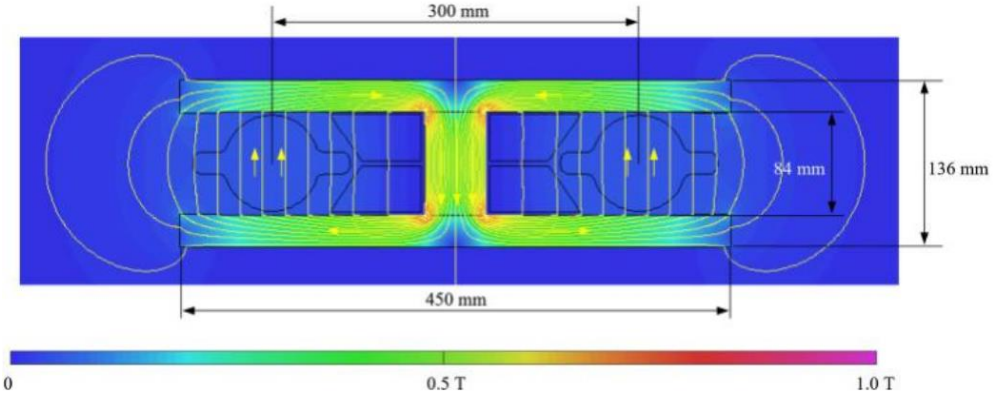
- Need to split dipoles to keep a maximum length of about 12m (gap of 30cm). See Leon’s presentation.
- Need space for orbit and skew quadrupole correctors:
  - Many locations without sextupoles
  - Sextupole design is at the edge:
  - Need longer sext. if combined with quad. and dip.



Jeremie Bauche, March 17th

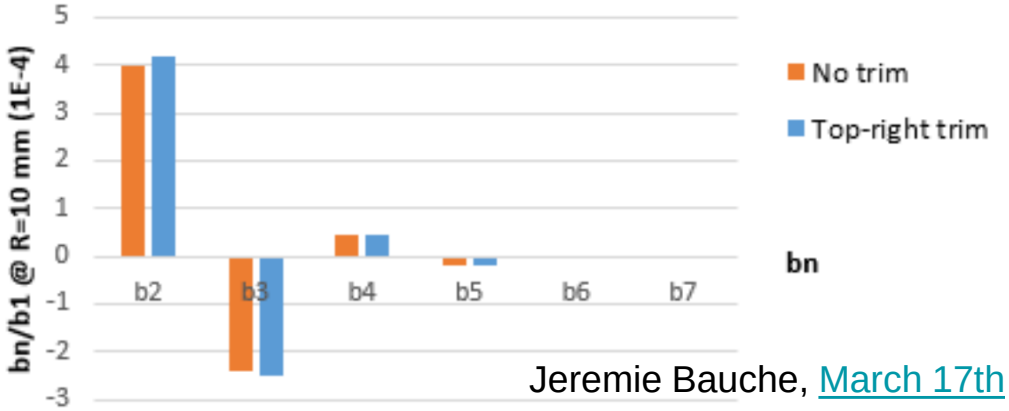
Dipoles

- Need to converge on tapering design (trim coils? How many FODO per tapering unit?)
- Need to consider b2 of 4 units. Compensation in main quads?
- b3 of 2 units: Impact on DA and tuning? Compensation with arc sextupoles not obvious.



Magnetic model cross-section (CDR), B_0 *max = 57 mT*

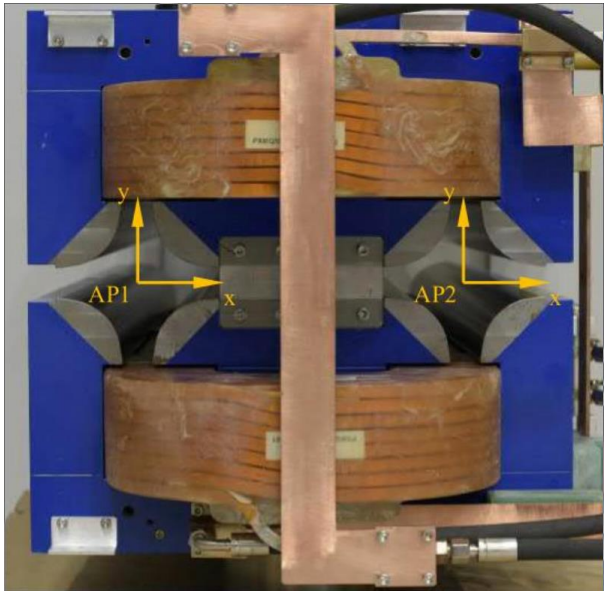
Strength, 45.6 GeV–182.5 GeV	mT	14.1–56.6
Magnetic length	m	21.94/23.94
Number of units per ring		2900
Aperture (horizontal × vertical)	mm	130 × 84
Good field region (GFR) in horizontal plane	mm	±10
Field quality in GFR (not counting quadrupole term)	10^{-4}	≈1



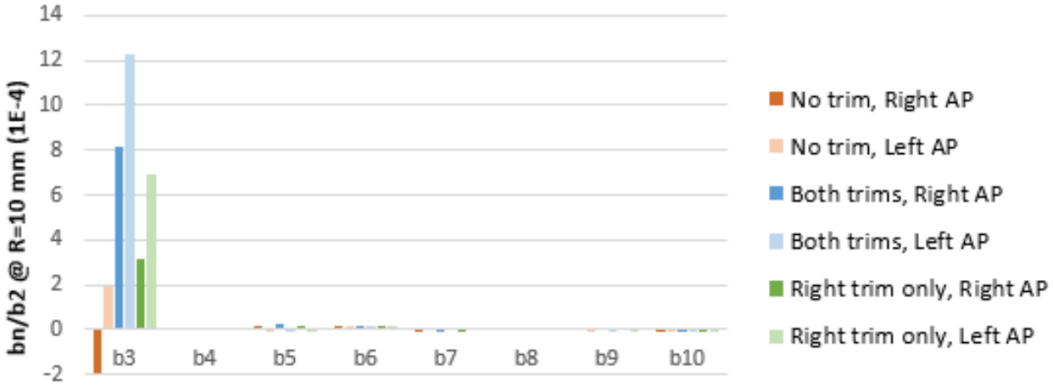
Jeremie Bauche, March 17th

Quadrupole

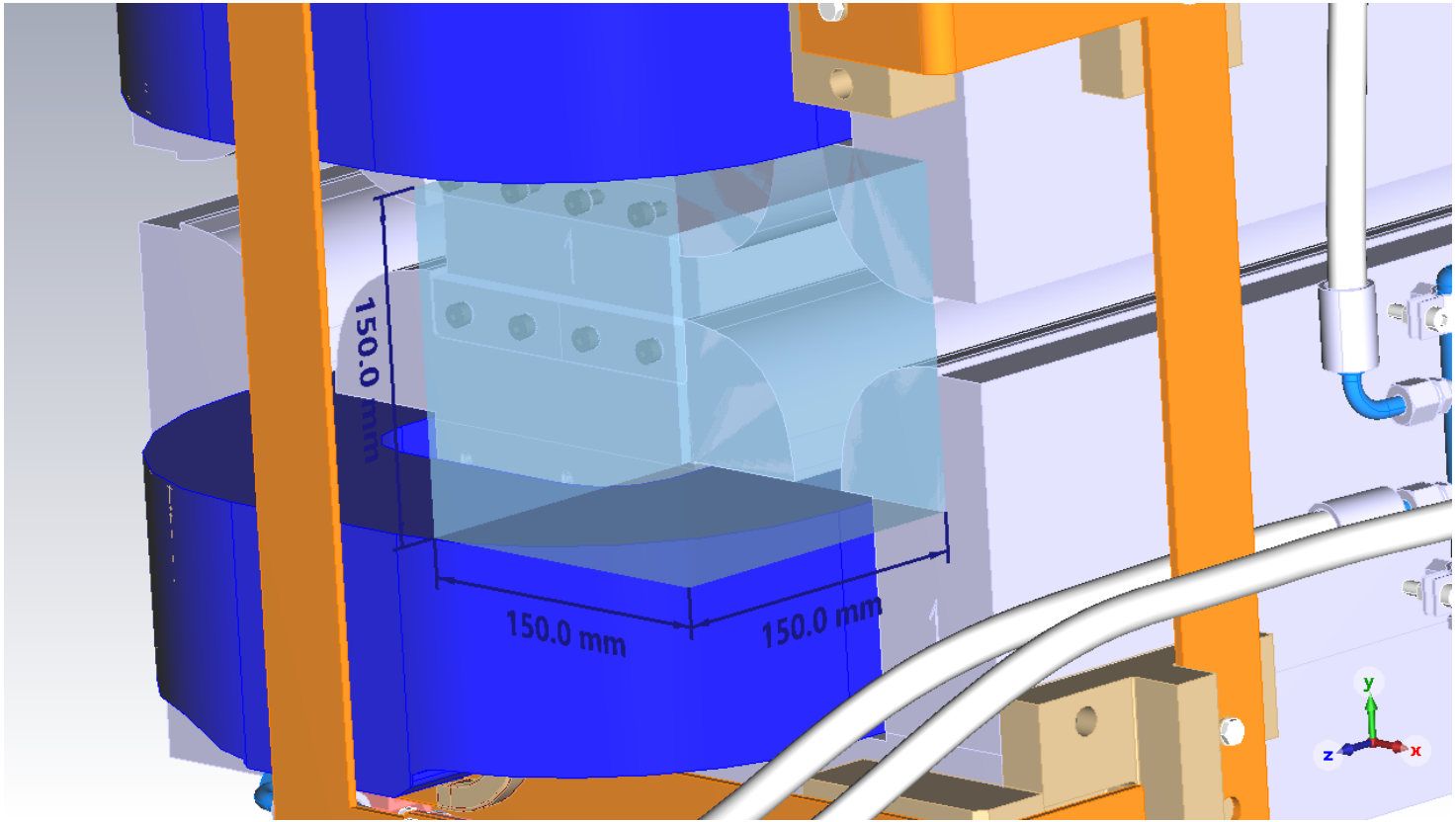
- Shift of quadrupole centers outwards by 0.4 between Z and T operation
- Independent powering of apertures (for tapering or tuning) challenging: induced quadrupole offsets (0.2mm) and large b3 (10 units) →design under investigation
- Tolerance studies needed, considering compensating quad center shift with dipoles/correctors and quad b3 with sextupoles



Jeremie Bauche, March 17th

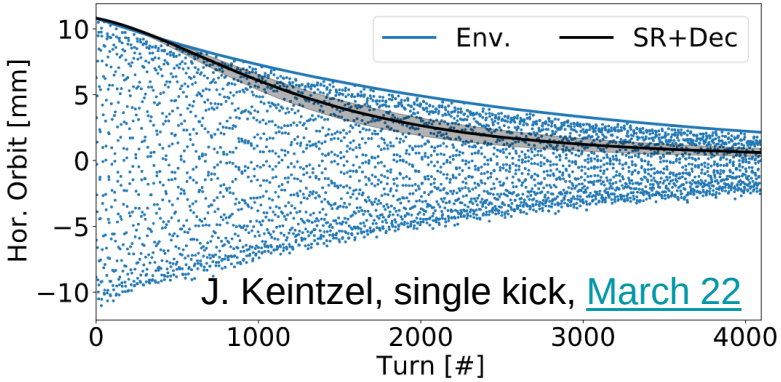


BPMs fit in the quadrupoles (M. Wendt, April 22)

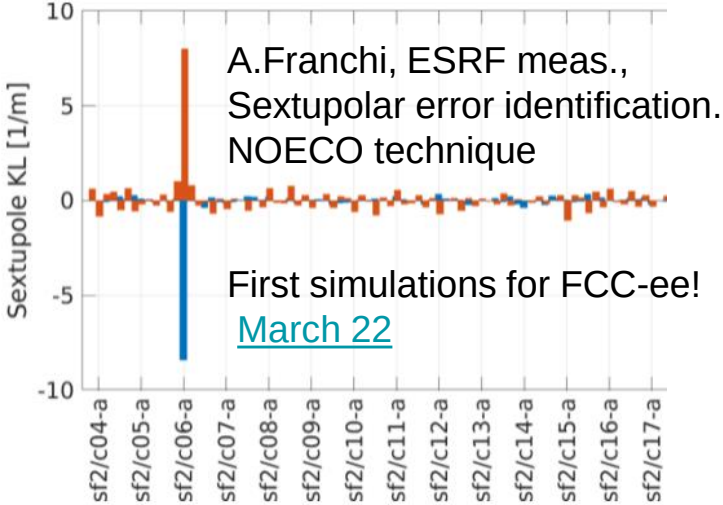


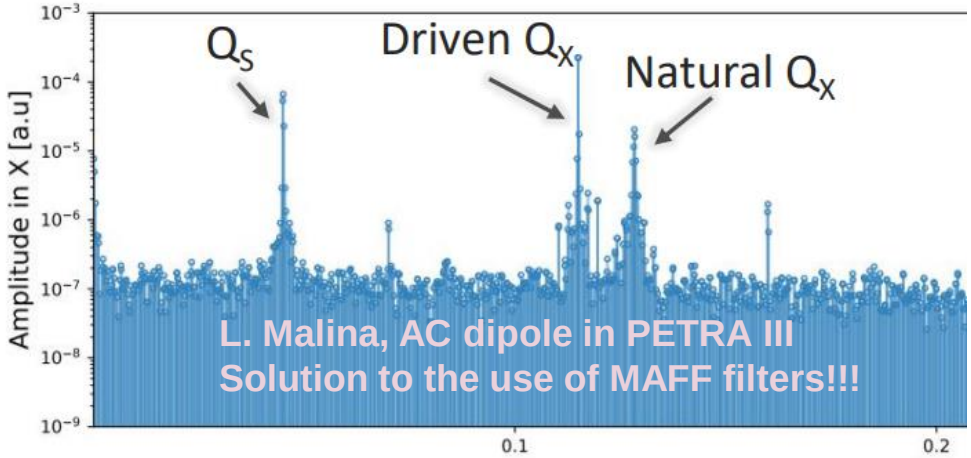
Optics measurements in FCC-ee

- Current tuning simulations assume ideal optics measurements
- Large energy loss in FCC-ee, fast damping or chromaticity may induce systematic errors in all techniques: single kick, AC dipole, NOECO and LOCO-like



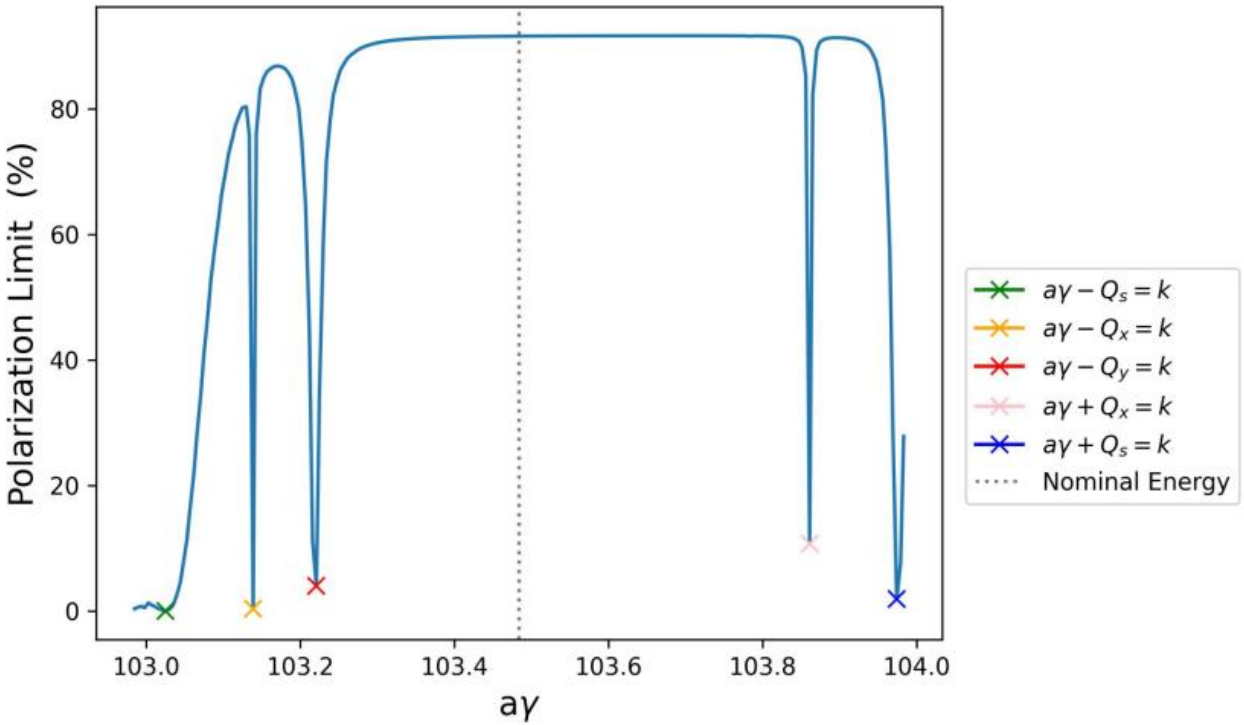
For LOCO-like: see S. Liuzzo's presentation today





Effective models with errors for pol./luminosity studies?

Yi Wu, Félix Carlier, Tatiana Pieloni (EPFL), Feb. 10



Imperfections and corrections will drive machine design and performance!

Various attempts to provide ‘effective models’, however these models need validation…

Further studies needed!

(see D. Shatilov next)

Codes

- Codes are critical for these studies and we are far from ‘unificiation’
- Tuning codes:
  - Tessa’s tuning: Python + MADX
  - ESRF: MATLAB
  - DESY + ESRF: Migrate AT to pyAT ?
- Beam dynamics codes (with popular uses):
  - SAD: Lattice design, tracking, emit, DA, etc.
  - MADX & MADX-PTC: Tracking, errors, DA, tapering, emit, Normal Form, basic polarization calculation
  - BMAD and SITROS: Polarization, etc.
  - Xsuite: Tracking, collimation, etc.
  - MAD-NG: Coming-up with a fast Normal Form
  - (Main efforts: CERN: MAD-X/NG & Xsuite, EPFL: Xsuite)
  - ELEGANT might be used by IPM (Iranian light source) colleagues

Contributions to codes are also extremely welcome and important (very few volunteers so far…)

Missing studies

- Massive amount of tuning studies with alternative configurations and improved lattice realism needed (lengths, tapering schemes, multipoles, BPM errors, ground motion, solenoid imperfections, etc.).
- Improvements to tuning speed / efficiency (both in code and machine)
- Studies for all lattices: Z, W, H, t
- Measurements simulations (single kick, AC dipole, (AC-)ORM or LOCO, K-mod, etc.)
- Local corrections of IR parameters (IP knobs, K-mod, waist-shift, etc.)
- Tolerance on multipoles / offsets with dedicated correction approaches.
- Calculation of DA and MA after tuning (and polarization eventually)
- Sextupole knobs or schemes for DA / MA optimization
- Effective models
- Repository for tuned lattices / tuning codes inputs / effective models
- Spin tuning
- Commissioning process (beta* squeeze, etc…)
- …

Summary & outlook

Time is now, people are here!!!