FCC-ee optics tuning Working Group

J. Keintzel and R. Tomas
for the FCC-ee optics tuning team

FCC-ee tuning team & WG meetings

New members

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

Meetings so far: 22 Sept, 25 Aug, 21 July, 14 Jul, 30 Jun, 9 Jun, 22 Apr, 22 Mar, 17 Mar, 10 Feb, 17 Nov and 10 Nov.

Last tuning team report in the 157th FCC-ee Optics Design

FCC-ee tuning team & WG meetings

CERN e-group FCCee_tuning-team:

Iranian Light Source Facility

UNIVERSITY OF LIVERPOOL

Laboratoire d'Annecy de Physique des Particules

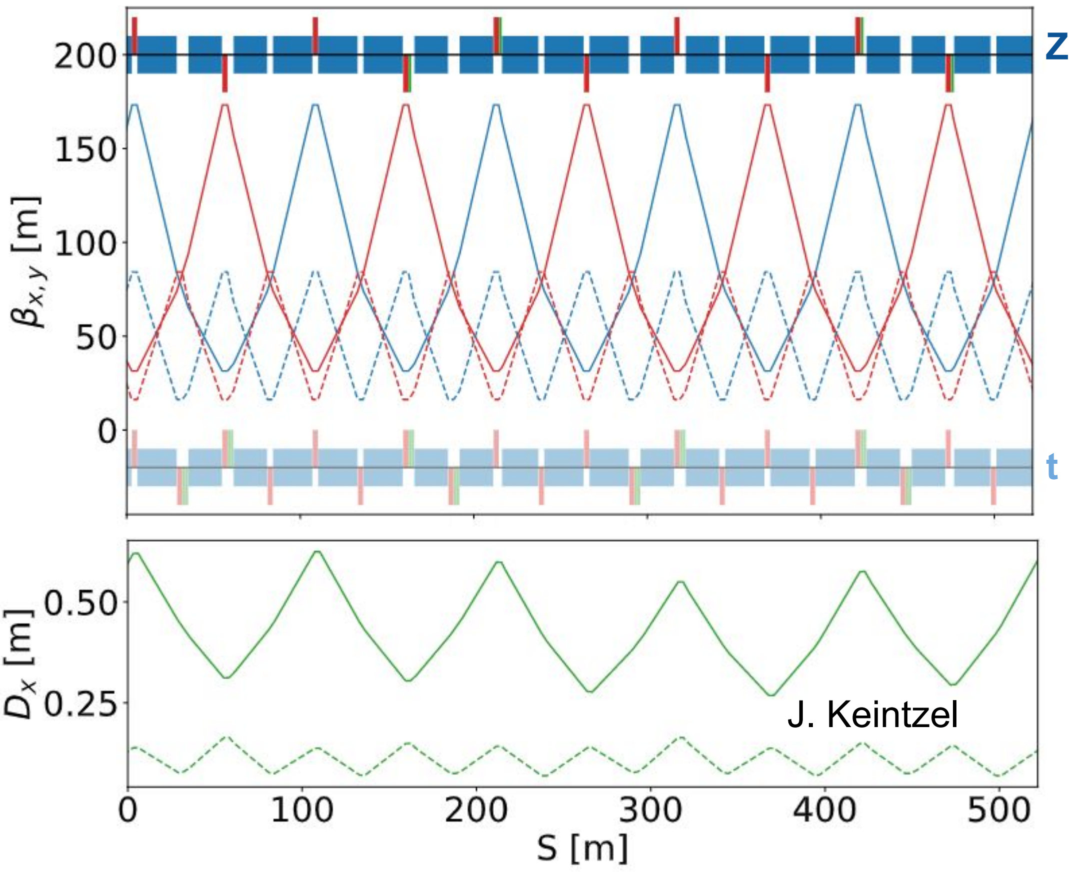
UNIVERSITÉ DE GENÈVE

+ Anyone is welcome!

Meetings so far: 22 Sept, 25 Aug, 21 July, 14 Jul, 30 Jun, 9 Jun, 22 Apr, 22 Mar, 17 Mar, 10 Feb, 17 Nov and 10 Nov.

Last tuning team report in the 157th FCC-ee Optics Design

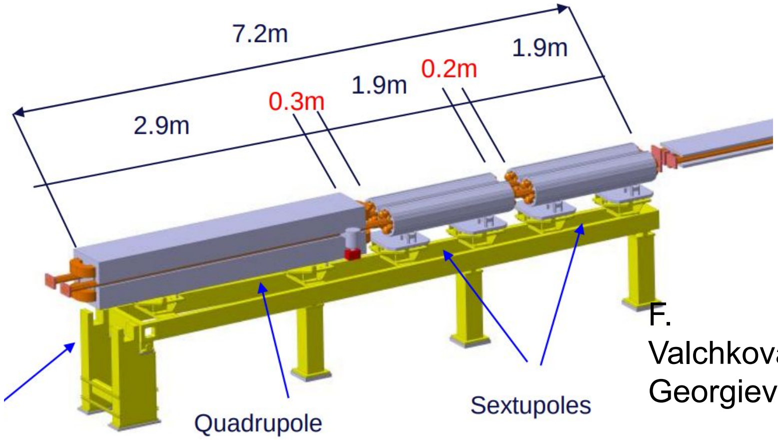
FCC-ee FODO super-cell and correctors at t and Z



Orbit correctors and skew quadrupoles are assumed to be placed at sextupoles (with extra coils).

At **t** only 2 over 5 quads have sextupoles attached (at most 1 over 2 if **Z** sexts are kept).

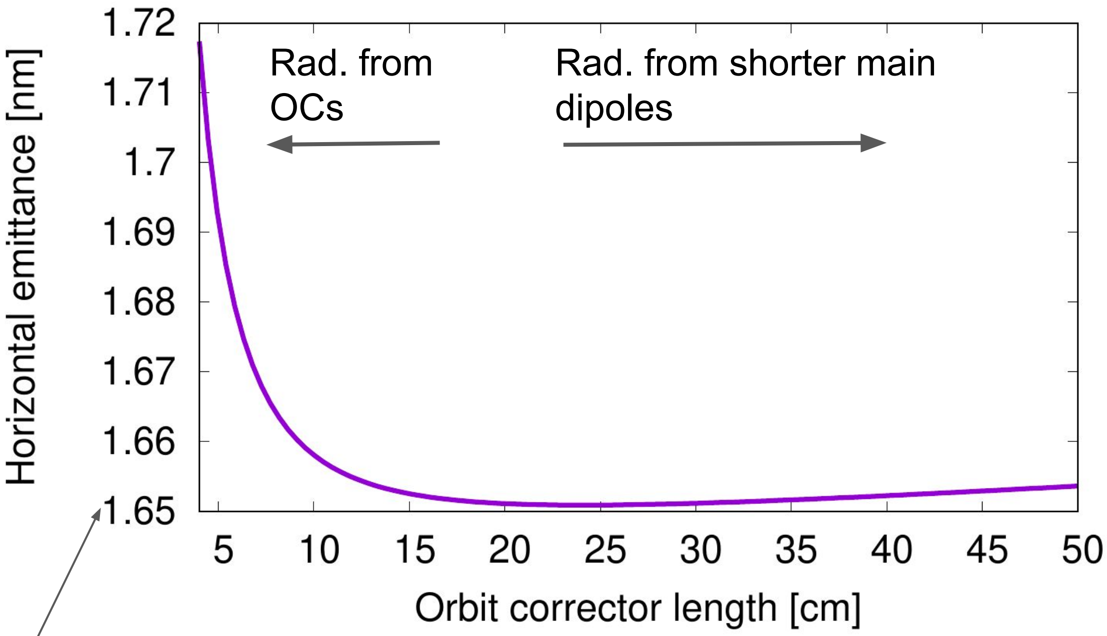
Current tuning simulations assume one orbit corrector at every quadrupole.



F. Valchkova-Georgieva

Orbit corrector length

Optimum corrector length is 25cm (10cm maybe still OK). Further studies needed.



Actual value of emittance not representative as it is just for one tuned seed.

How does CEPC reach successful tuning results for linear optics and DA?

[Yiewi Wang's slides](#) [Tessa Charles's slides](#)

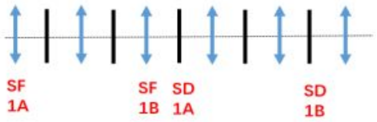
	CEPC	FCC-ee
Number of IPs	2	4
Sextupole rms misalignment [μm]	100→10	140
Arc quad. rms misalignment [μm]	100	170
IR quads. and sexts. strength errors	No	Yes
Arc chromaticity correction	8SF-8SD	2SF-2SD

Note the 10 μm specification for sextupole misalignment of CEPC is assumed after beam-based alignment.

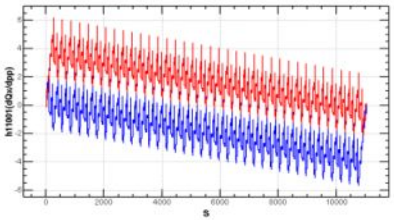
8SF-8SD Vs 2SF-2SD in CEPC

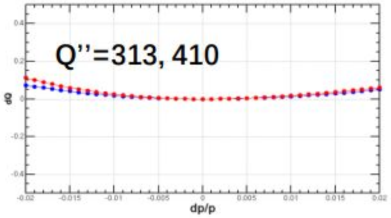
[Yiewi Wang's slides]

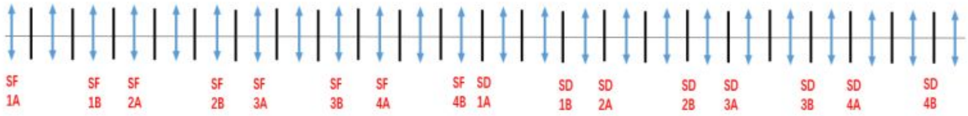
- A lattice with **8-repeated sextupoles scheme** for Higgs & ttbar modes
  - much less 2nd order chromaticity for the horizontal plane
  - The distribution of sextupoles for Higgs & ttbar modes (90 deg cell) allowed to select –I sextupole pairs for W &Z modes (60 deg cell) .

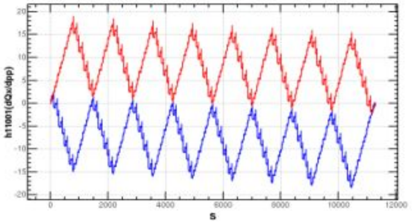


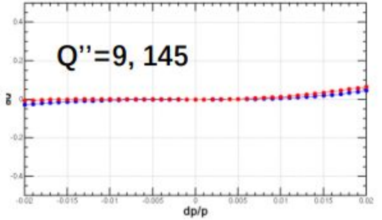
Scheme with **2 repeated sextupoles**
Proposed by K. Oide











Scheme with **8 repeated sextupoles**
Proposed by Tianjian Bian

News from SuperKEKB

Y. Ohnishi's slides

- Between 10% and 20% of operational time is devoted to optics tuning!
- Optics tuning can only be done at low beam intensity -> Effects from high intensity are unprobed (e.g. resistive wall, SR heating, etc.).
- Currently β^* = 1 mm
- Optics and injection efficiency deteriorate from sextupole displacements (probably caused by SR heating)
- IR sextupole shift by 20 μm changes tune by 0.01 -> Target control = 10 μm
- Dedicated orbit bumps at IR sextupoles improve injection efficiency (sextupole movers not functional).
- **Future**: gated turn-by-turn BPM measurements can allow to perform optics measurements at high beam intensity,

Extrapolating from SuperKEKB HER to FCC-ee?

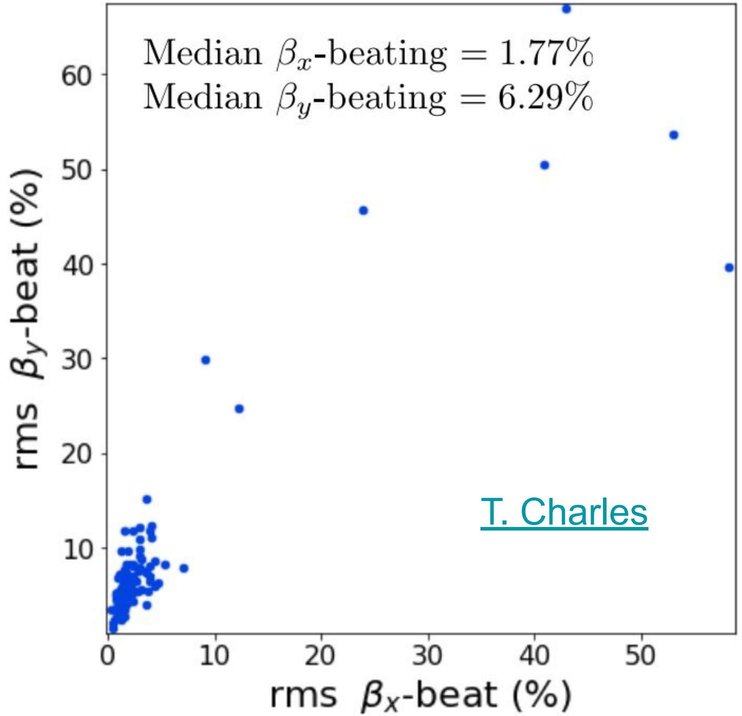
	SKEKB, HER	**FCC-ee, Z**
Number of IPs	1	4
IR sext. offset for DQy=0.005 [μm]	10	3
Target orbit control [μm] (at IR sextupoles)	10	$3/\sqrt{4}$ = **1.5 ?**
Number of IR sextupoles	4	16
β^* **[mm]**	1	0.8
ARC sext. offset for DQy=0.005 [μm]	200	250
Number of ARC sextupoles	100	832
Target orbit control [μm] (at ARC sextupoles)	-	$250/\sqrt{832}$ = **10 ?**

1.5 μm seems too large as the corresponding beta-beating from one IR sext. is 10%

Using the 10 μm beam-based alignment in FCC-ee

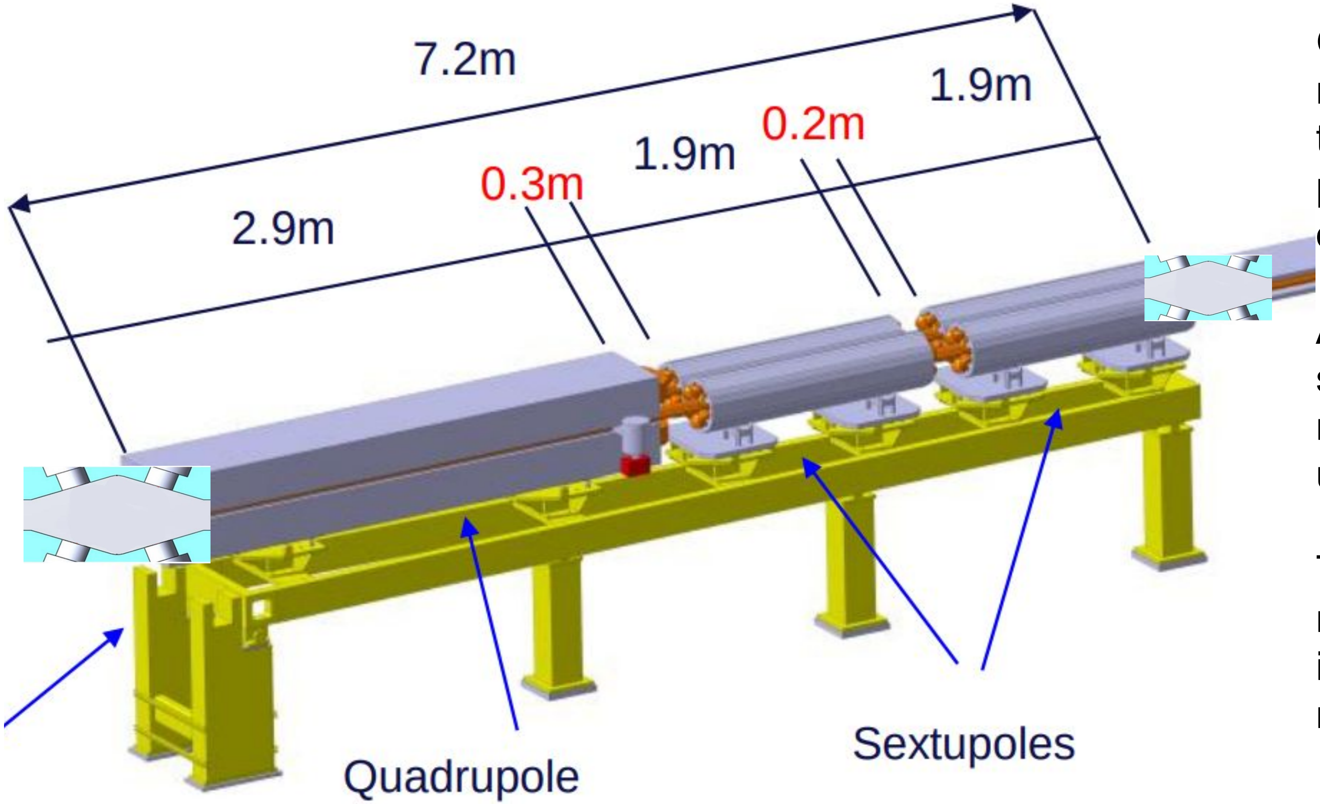
Type	ΔX (μm)	ΔY (μm)
Arc quadrupole*	50	50
Arc sextupoles*	10	10
Dipoles	1000	1000
Girders	150	150
IR quadrupole	100	100
IR sextupoles	10	10

Assuming beam-based alignment and possibly movers+BPMs (design concept needed to reach 10 μm).



Very promising improvement in the tuning of the FCC-ee linear optics, including chromaticity correction. To-do: include BPM alignment errors and DA calculation and optimization

How to reach 10 μm sextupole-to-beam offset in physics

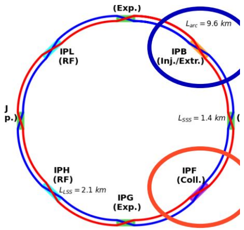


Girder and magnets will likely move by 10s of μms due to temperature changes between pilot and high intensity operation.

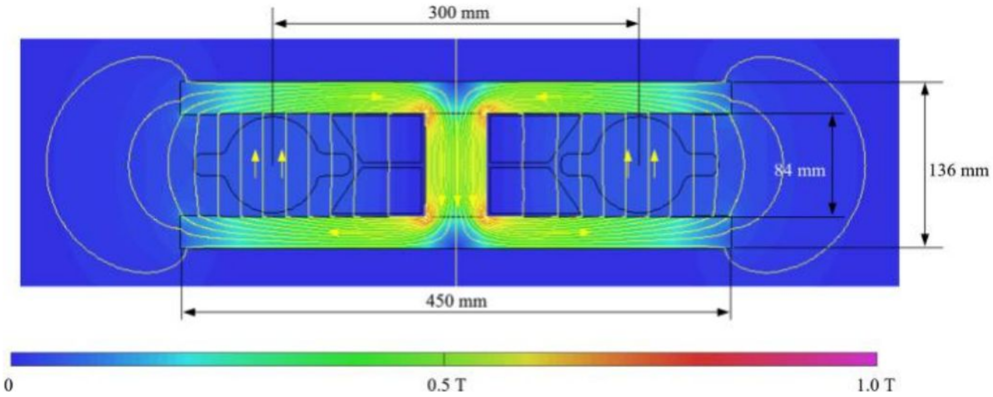
Attaching BPMs to quads and sexts could determine magnet-to-beam offsets. Then use movers?

Turn-by-turn optics measurements at high intensity could relax the 10 μm requirement.

Dipoles

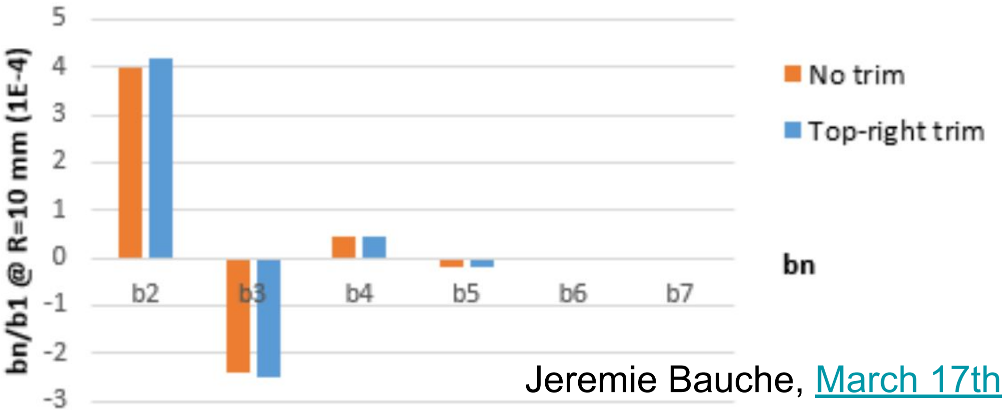


- Need to converge on tapering design (how many FODO per tapering unit?)
- Need to consider **b2 of 4 units** (sign changing arc-by-arc). Compensation in main quads? (see next slide)
- **b3 of 2 units**: Causes <u>10 units of chroma</u>. At 2.5mm b3 gives <u>another b2 unit</u>. Impact on DA and tuning? 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]

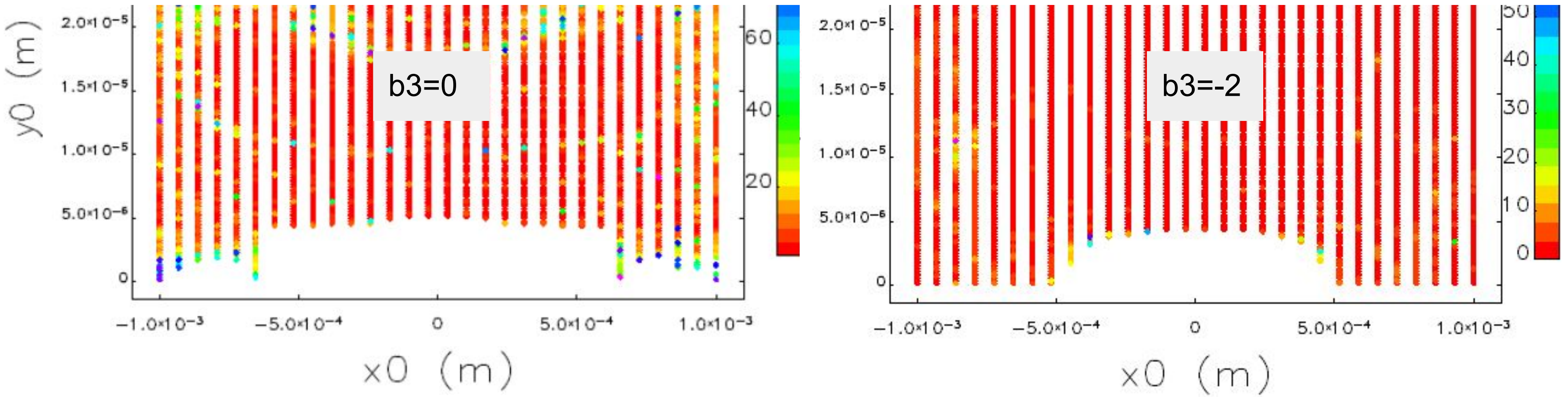
Dipole b2 errors

Tessa's slides: Systematic b2 and b3 dipoles do not affect resulting emittance after tuning (no chroma. corr.) but need more iterations (19 seeds did not converge for lack of CPU time). DA not checked.

Cristobal's slides: b2=4 units seems too much as it generates above 2% beta-beating. 1.6 units to get 1% beta-beating. Alternatively arc/IR optics rematching including b2 errors has already been demonstrated in the design. DA to be checked.

Dipole b3 errors

Esmaeil's slides: b3=-2×10^{-4} causes chroma changes by ∓10 units. News on DA:



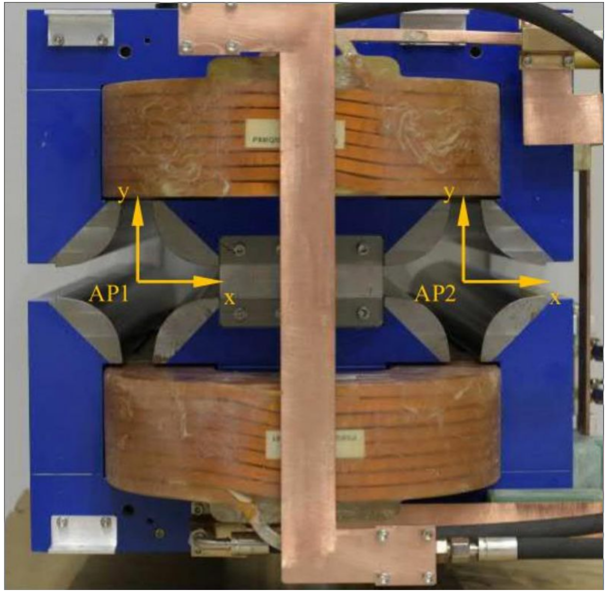
Clear reduction on DA from dipole b3 error of -2×10^{-4}. First attempts of chromaticity correction do not improve DA but need further exploration.

Esmaeil will present further news on Nov 3rd FCC-ee tuning WG meeting.

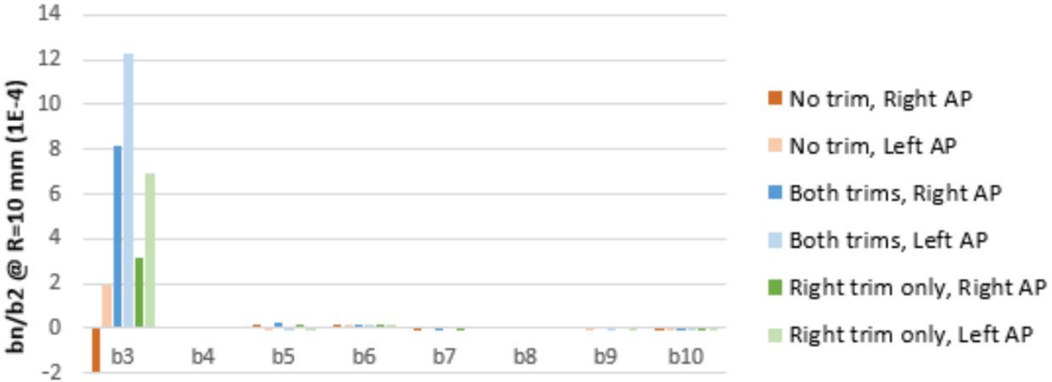
Can dipole b3 be reduced to 1 unit? Will we need small sextupoles to correct it?

Quadrupole

- Measured shift of quadrupole centers separation by **0.4mm** between **Z** and **t** operation. This is not seen in simulations.
- Independent powering of apertures (for tapering or tuning) challenging: induced quadrupole offsets (**0.2mm**) and large **b3 (10 units).** As expected from simulations.

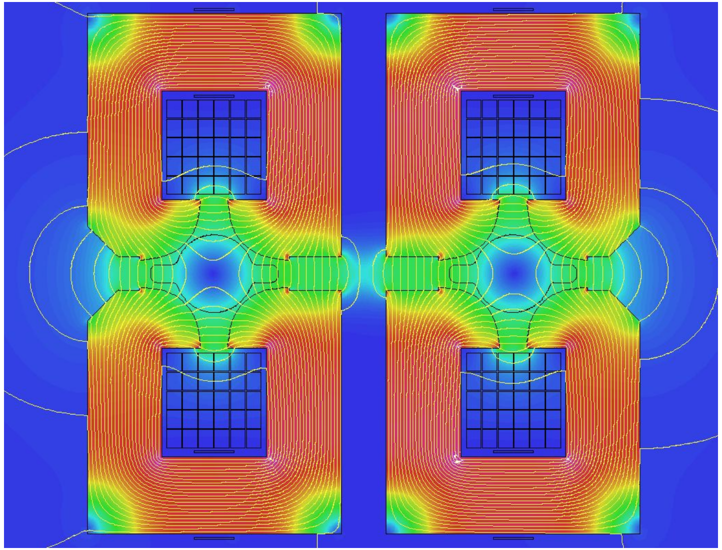


Jeremie Bauche, [March 17th]



New quadrupole design

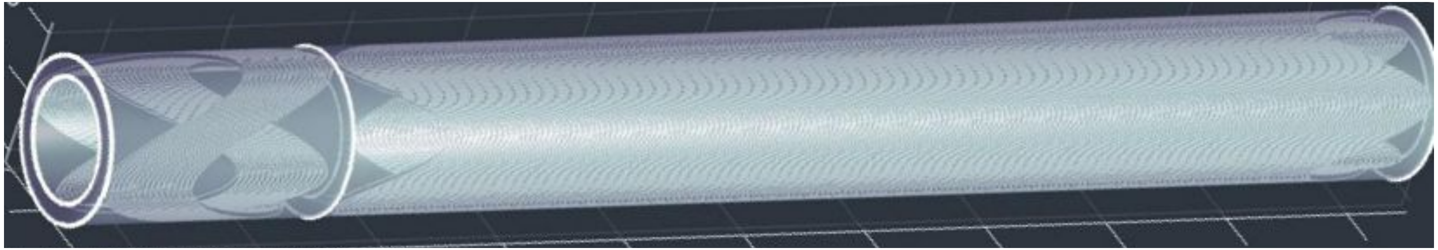
- Prototype not yet manufactured. Aperture separations between **Z** and **t** for new design unknown.
- Independent powering of apertures (for tapering or tuning): induced quadrupole offsets reduced (**0.03mm**), as well as **b3 (2 units)**
- Jeremie will request an increase of beams separation from 300mm to 350mm on Nov 3rd FCC-ee design meeting, that should reduce aperture cross talk and improve field quality.



Jeremie Bauche, FCC week 2022

Superconducting Short Straight Section

Mike's slides



- Possibility to put 2 or 3 layers of SC magnets to include: Dipole, Quad, sextupoles and correctors.
- This reduces SR power and horizontal emittance → First lattice design by Cristobal in EPFL-LPAP activity meeting
- No space limitations for correctors.
- Magnetic field quality to be assessed.

Measurement and correction approaches

- Original LOCO requires huge amount of CPU time and memory for FCC-ee (see Simone's slides and E. Musa's slides)
- Modified LOCO, or optics parameter fitting techniques with reduced number of correctors, COD, is used in SuperKEKB.
- Tessa is assuming optics measurements at BPMs, as in the LHC, along with a response matrix approach on existing corrector magnets. These could come from COD or turn-by-turn BPM data analysis.
- All measurement approaches are challenged by the FCC-ee energy loss, damping, non-linear dynamics and size. Therefore requiring careful design and simulations (see J. Keintzel's slides).

Next FCC-ee tuning WG meeting in November 3rd

- ARCs and SSs beam dynamics analysis/optimization (Pantaleo)
- Impact of dipole b3 on DA (Esmaeil)

https://indico.cern.ch/event/1213879/

Back-up slides

T. Charles, March 2022

H. Mainaud, 10 Feb: *"The actual value of tolerances will not be the cost driver, being 'size' the main driver."*

Factor 2 lower tolerances should be considered (at least).

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

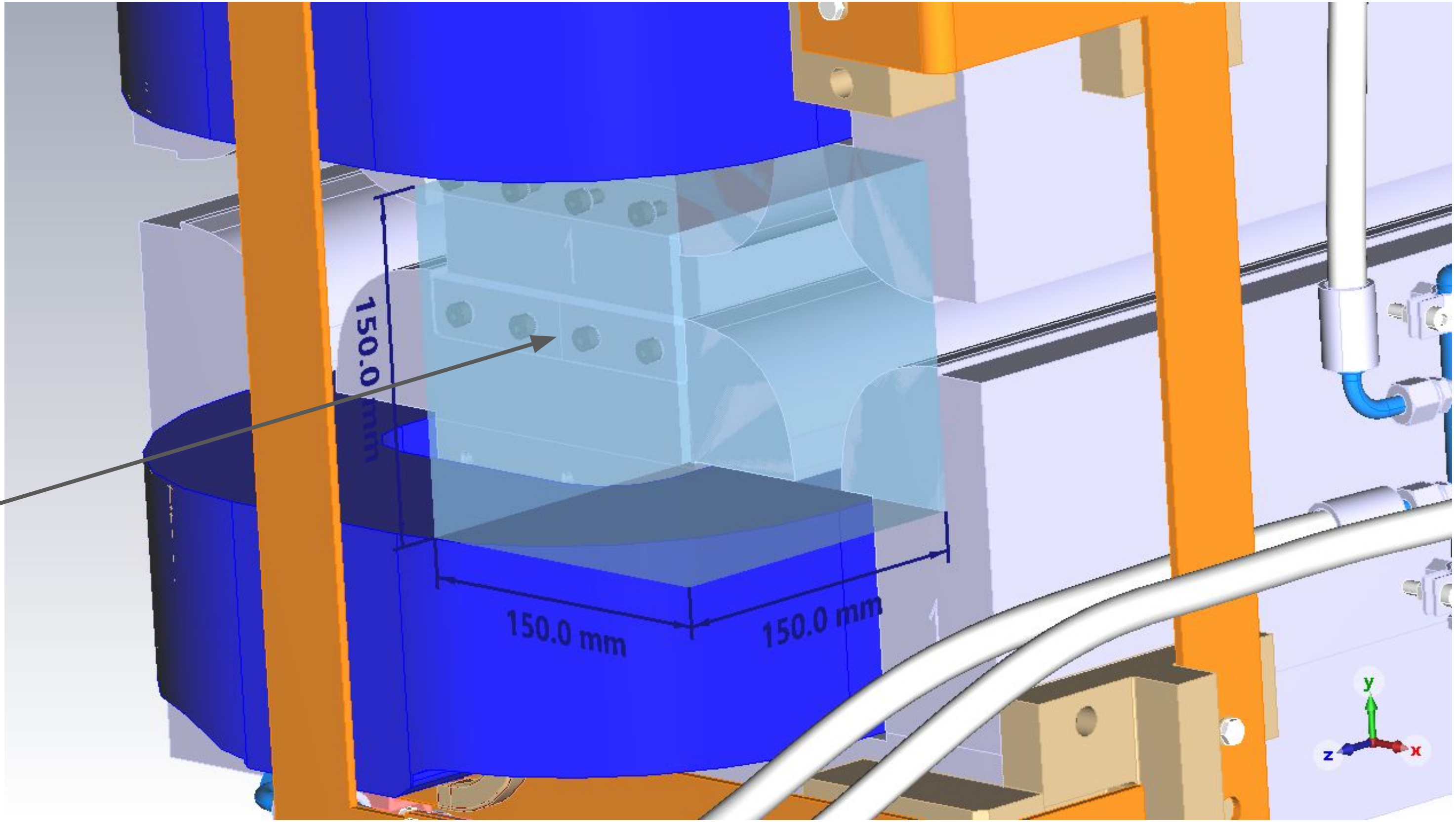
* misalignments relative to girder placement

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

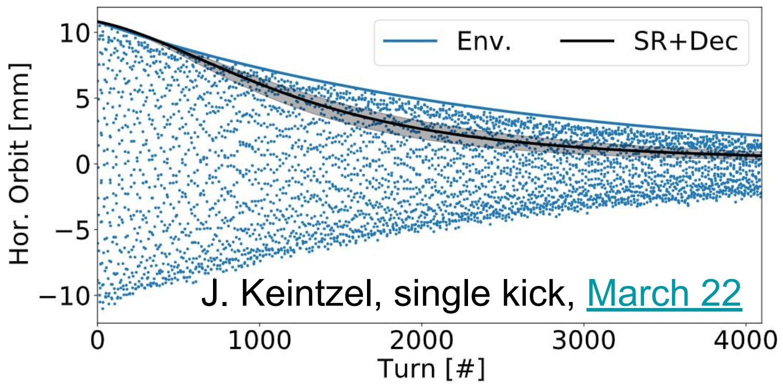
BPMs fit in the quadrupoles (M. Wendt, [April 22])



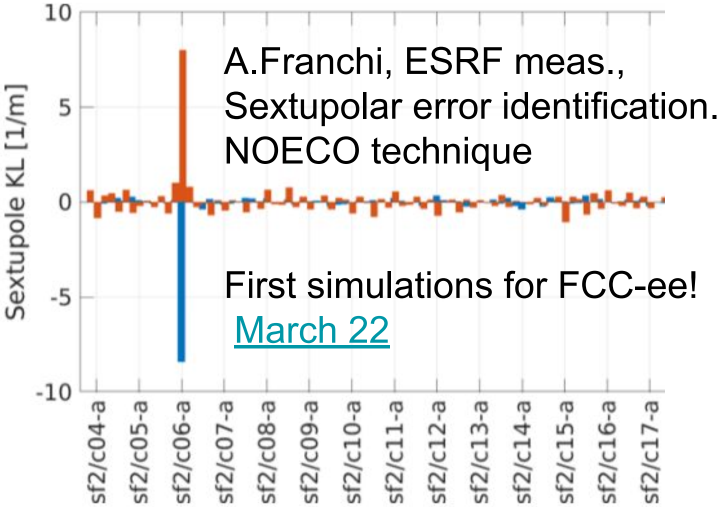
BPM fits in
this blue box

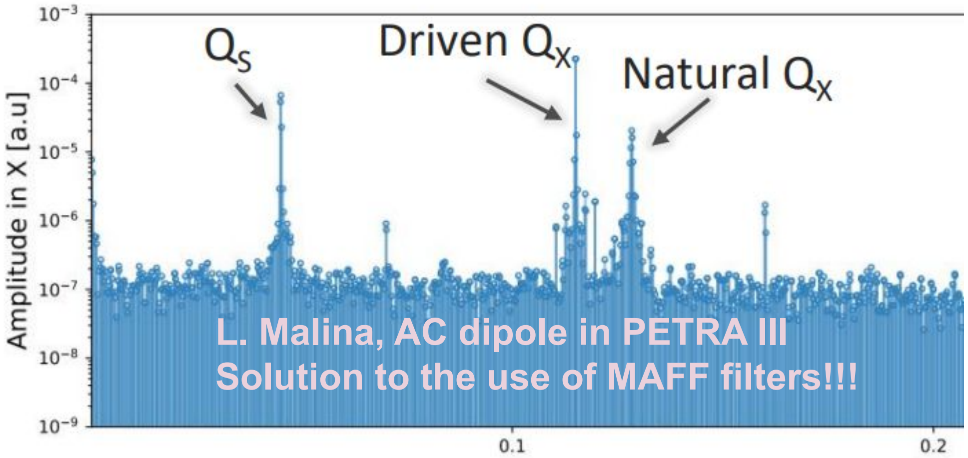
Optics measurements in FCC-ee

- 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





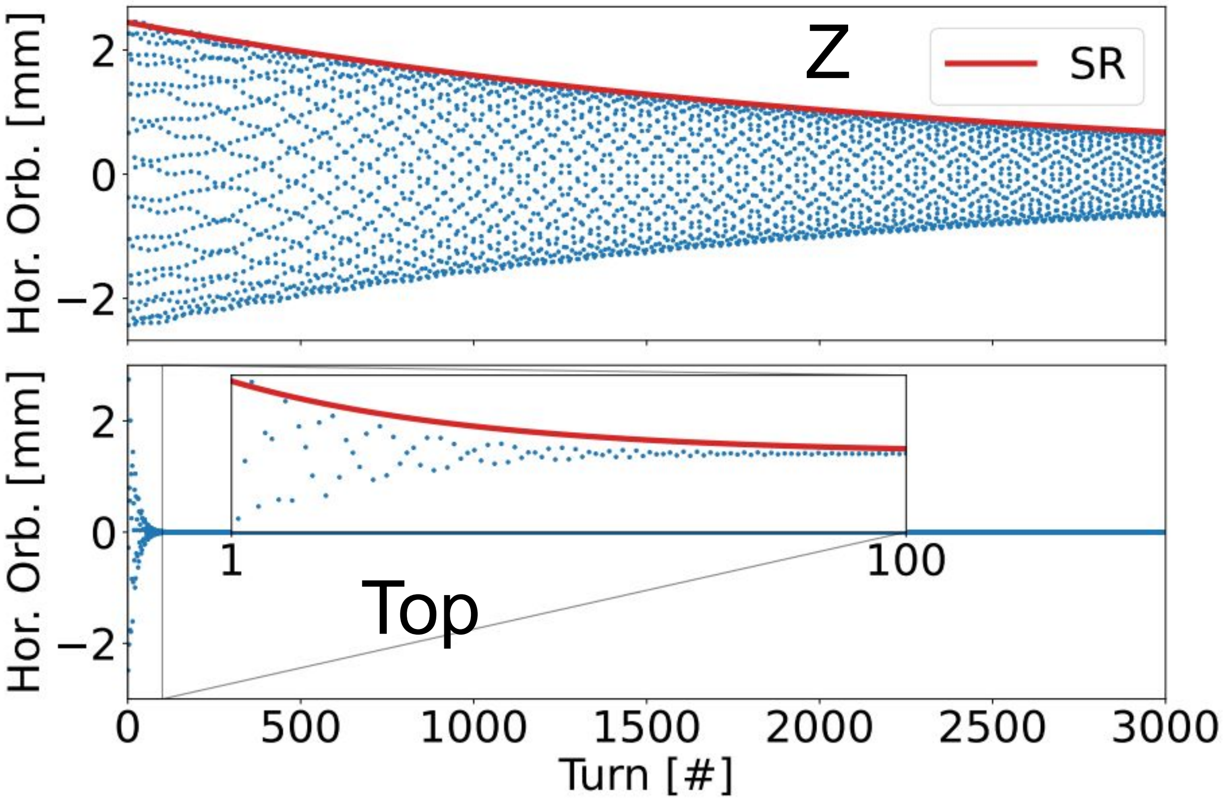
Single kick feasibility at Z and Top

J. Keintzel's poster

While the single kick technique is appropriate for the Z energy it is not feasible at the Top for the too fast damping.

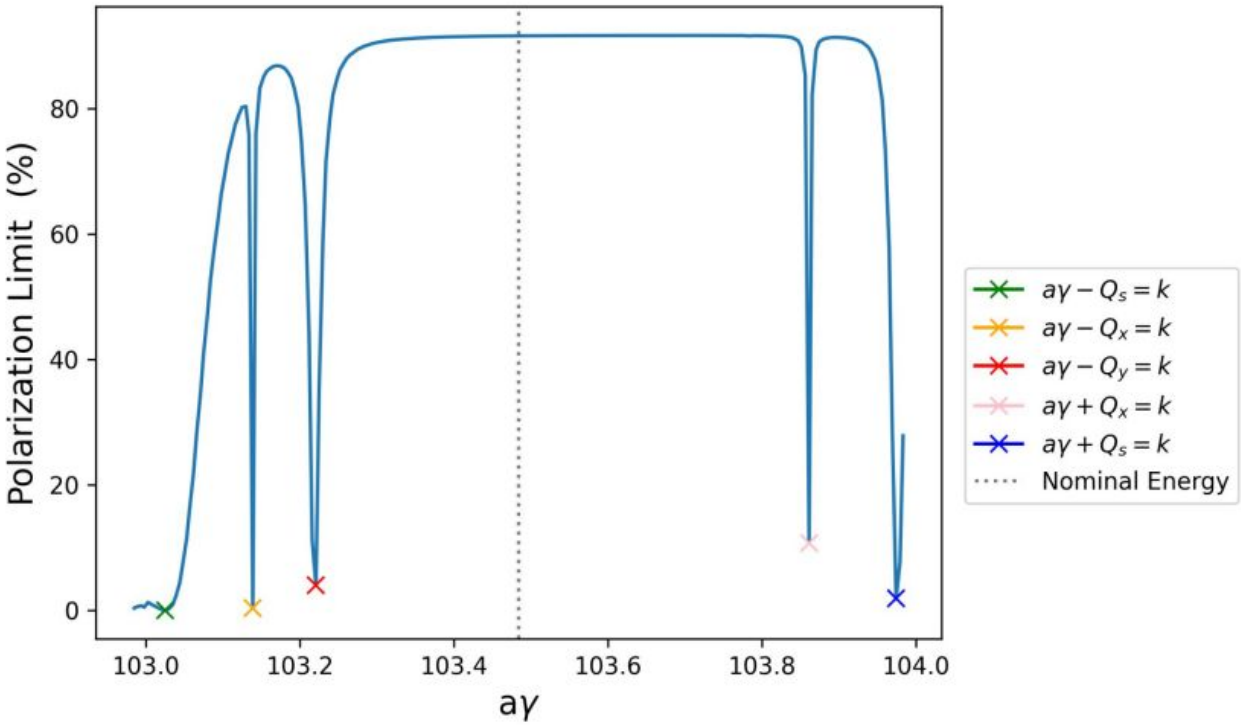
Need to study AC dipole and ORM or LOCO at the Top energy!

(teams at DESY, ESRF & CERN already at it!)



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!

Codes (see dedicated session at 16:00)

- 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
  - 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: Orbit, tracking, IPM (Iranian light source)

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