FCC-ee accelerator summary

FCC Week 2023, 9 June 2023

Ilya Agapov/DESY, Tor Raubenheiner/SLAC, Frank Zimmermann/CERN
on behalf of FCC collaboration & FCCIS DS team

http://cern.ch/fcc

photo: J. Wenninger

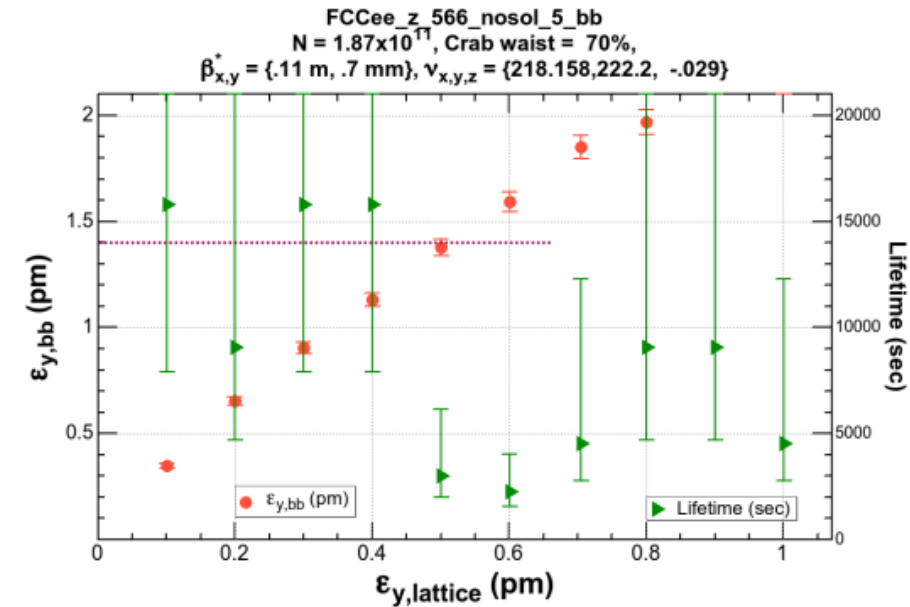| Monday	Wednesday - Optics correction & tuning, chair: S. Boogert	Thursday – code development, chair: T. Pieloni
FCC accelerator, Tor Raubenheimer/SLAC	**Beam instrumentation for FCC-ee**, T. Lefevre	**Code development status**, L. van Riesen Haupt/EPFL
Tuesday – baseline design, chair: A. Faus-Golfe	**Tolerances & BBA strategy,** T. Raubenheimer	**Accelerating beam dynamics simulations**, D. Di Croce/EPFL
Layout, optics, parameters, Katsunobu Oide/U Geneva	**Status of the FCC-ee optics tuning studies**, R. Tomas	**Beam-beam code progress**, P. Kisciny/EPFL
Top-up injection baseline scenario, Yann Dutheil/CERN	**Optics measurements & BB alignment**, J. Keintzel	**Review of MAD-X for FCC-ee studies**, G. Simon/U Paris-Saclay
Beam lifetime due to radiative Bhabha scattering, Krzysztof Piotrzkowski, AGH	**Simulations of IR tuning,** L. Van Riesen Haupt	**E-cloud studies for FCC**, F. Yaman, Izmir IT
Tuesday - collimation & collective effects, chair: T. Raubenheimer		**Thursday – alternative FCC-ee Optics development, chair: M. Boland**
FCC-ee collimation, Andrey Abramov/CERN		**Alternative HFD/DFD Optics**, P. Raimondi
Technical challenges and required studies for FCC-ee BIDS, A. Perillo Marcone/CERN	*21+1 talks*	**Dynamic aperture and momentum acceptance for alternative optics**, M. Hofer
Collective Effects, Mauro Migliorati/Sapienza		**Combined function lattice with constant partition numbers for FCC-ee**, C. Garcia
Electron-Cloud Studies, Luca Sabato/EPFL		**Synchrotron radiation background for an alternative FCC-ee optics**, K. Andre

If we push the luminosity further ($@Z$)…

FCCee_z_566_nosol_4_bb
N = 1.51x10^{11}, Crab waist = 70%,
$\beta^*_{x,y}$ = {.11 m, .7 mm}, $\nu_{x,y,z}$ = {218.158,222.2, -.029}
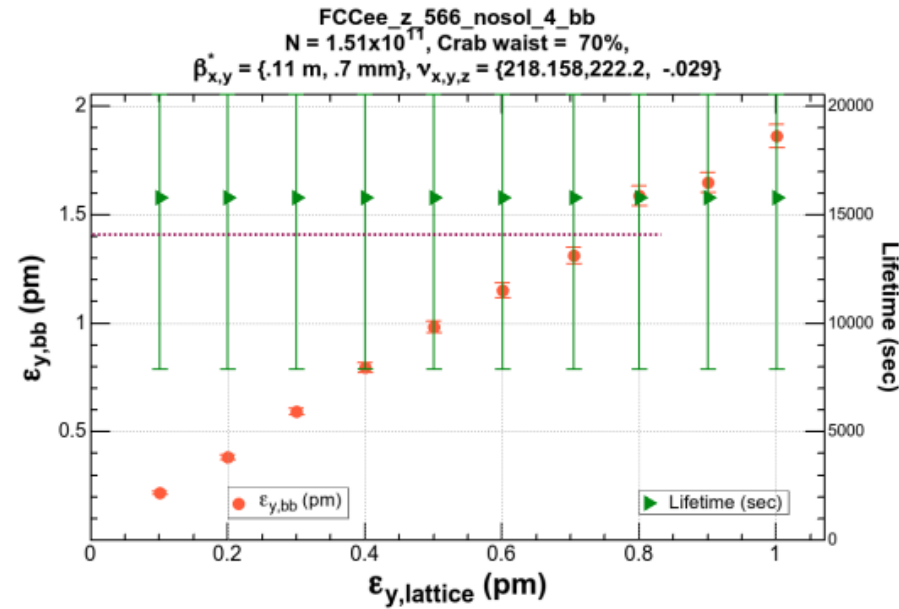
$$\mathscr{L}/\text{IP} = 140 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$$
$$N = 1.51 \times 10^{11}$$
$$\tau \gtrsim 15000\,\text{s}$$
$$\varepsilon_{y,\text{lattice}} = 0.75\,\text{pm}$$

FCCee_z_566_nosol_5_bb
N = 1.87x10^{11}, Crab waist = 70%,
$\beta^*_{x,y}$ = {.11 m, .7 mm}, $\nu_{x,y,z}$ = {218.158,222.2, -.029}

$$\mathscr{L}/\text{IP} = 154 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$$
$$N = 1.87 \times 10^{11}$$
$$\tau \sim 3000\,\text{s}$$
$$\varepsilon_{y,\text{lattice}} = 0.52\,\text{pm}$$

- If we push the luminosity further by increasing the bunch charge (right plot),
  - Indeed, the luminosity gets higher by 10%, but
  - lifetime drops to 1/5 (~3000 s),
  - the required lattice vertical emittance reduces from 0.75 pm to 0.52 pm.
  - note that these have not taken the errors/corrections into account yet…

K. Oide

SuperKEKB LER tune survey

$$\varepsilon_{y0}/\varepsilon_y$$
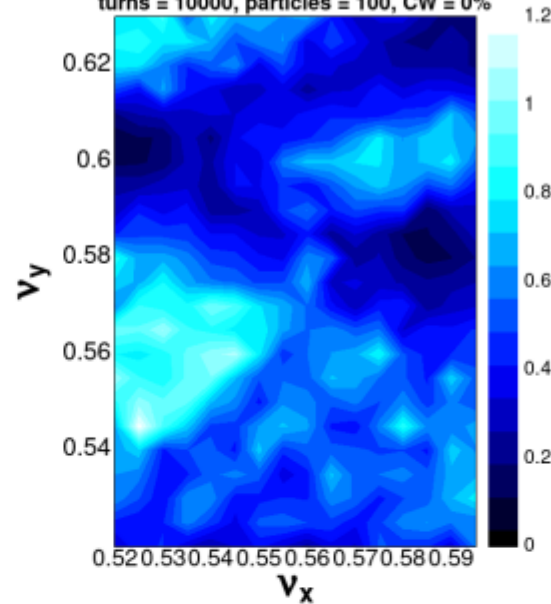

Original (SK2=0)
sler_1704_80_A_YO1_cw1_40_4_bb.sad
turns = 10000, particles = 100, CW = 0%

Chromatic coupling corr.
sler_1704_80_A_YO1_cw1_40_4_bb_cc.sad
turns = 10000, particles = 100, CW = 0%

No solenoid lattice
sler_1705_80_1-nosol_1_bb_cw_ts.sad
turns = 10000, particles = 100, CW = 0%

CW = 0%

sler_1704_80_A_YO1_cw1_40_4_bb.sad
turns = 10000, particles = 100, CW = 100%

sler_1704_80_A_YO1_cw1_40_4_bb_cc.sad
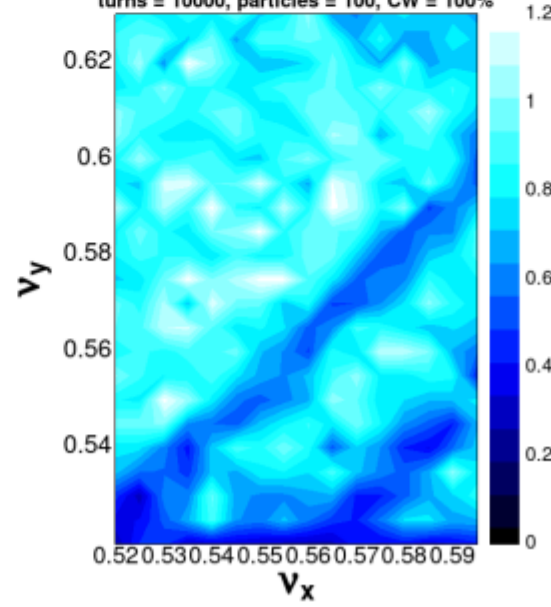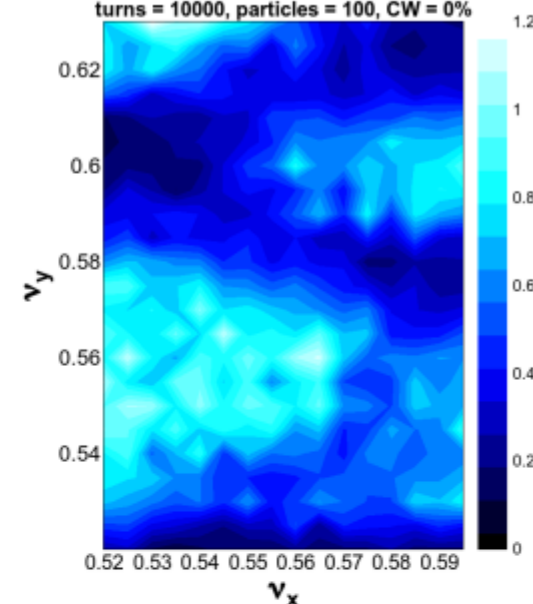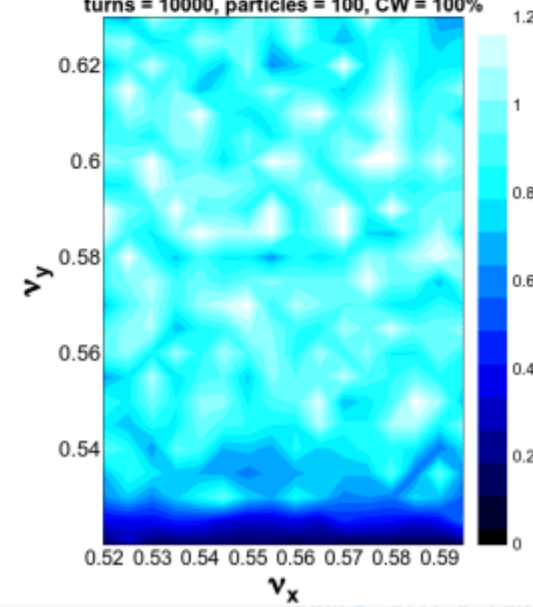turns = 10000, particles = 100, CW = 100%

sler_1705_80_1-nosol_1_bb_cw_ts.sad
turns = 10000, particles = 100, CW = 100%

CW = 100%

- A perfect compensation of the solenoid field is essential to suppress the beam-beam blowup in the case of SuperKEKB.

- In this plot, sextupoles are not re-optimized at each tune.

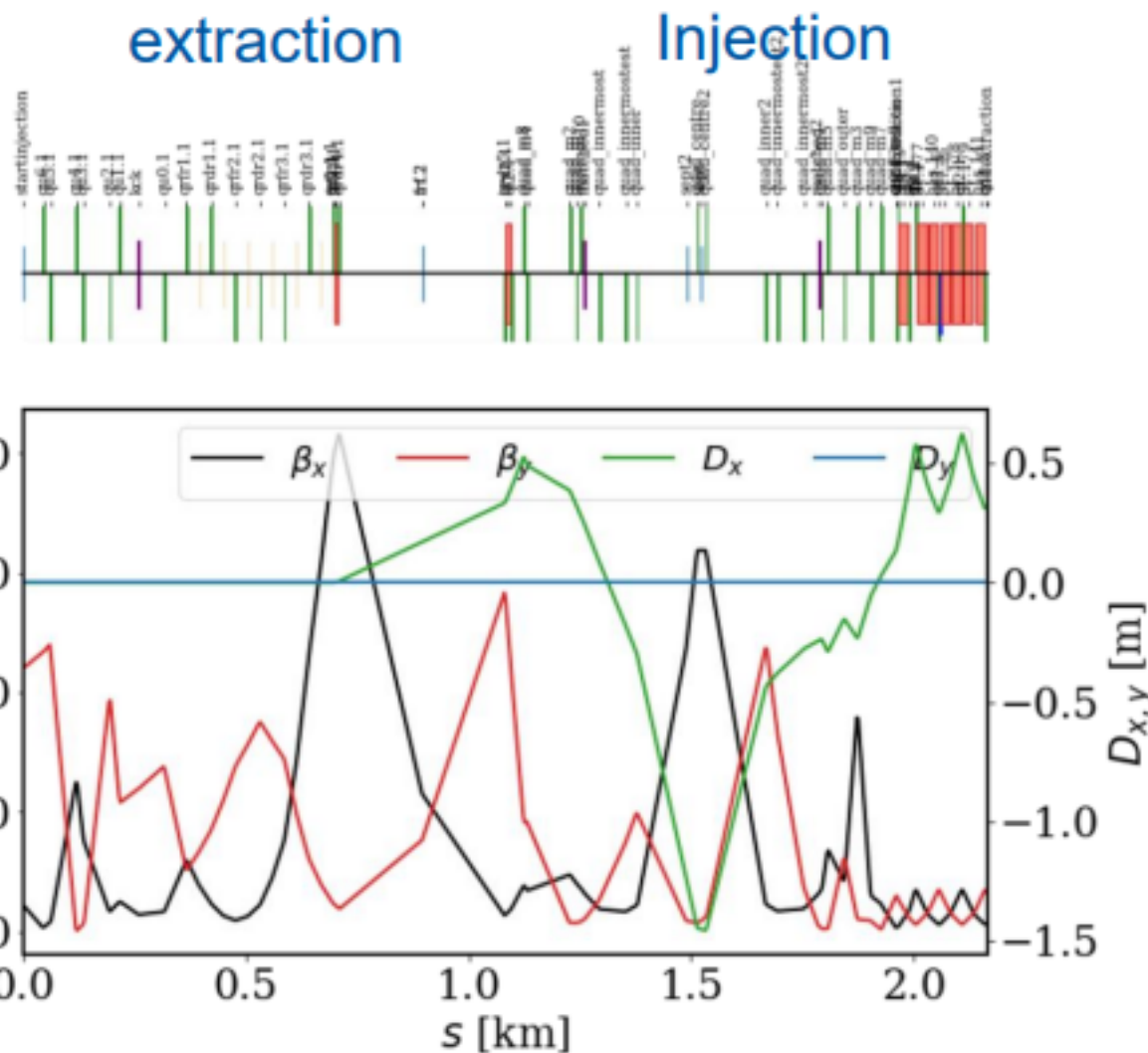K. Oide

Injection optics and combined integration

Geometrical baseline scenario for injection and extraction layout.
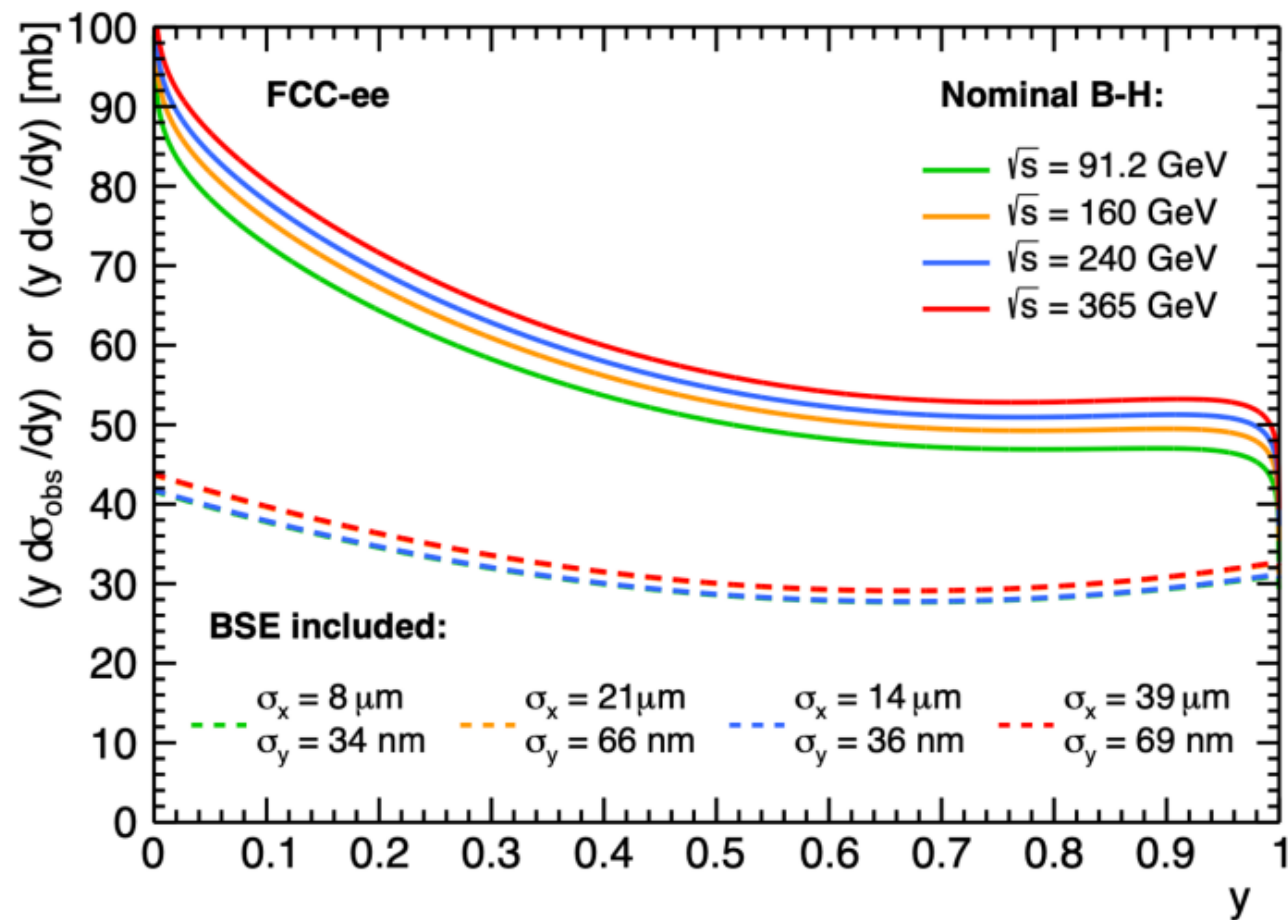Position of the booster ring and relative planes between rings is indicative only.
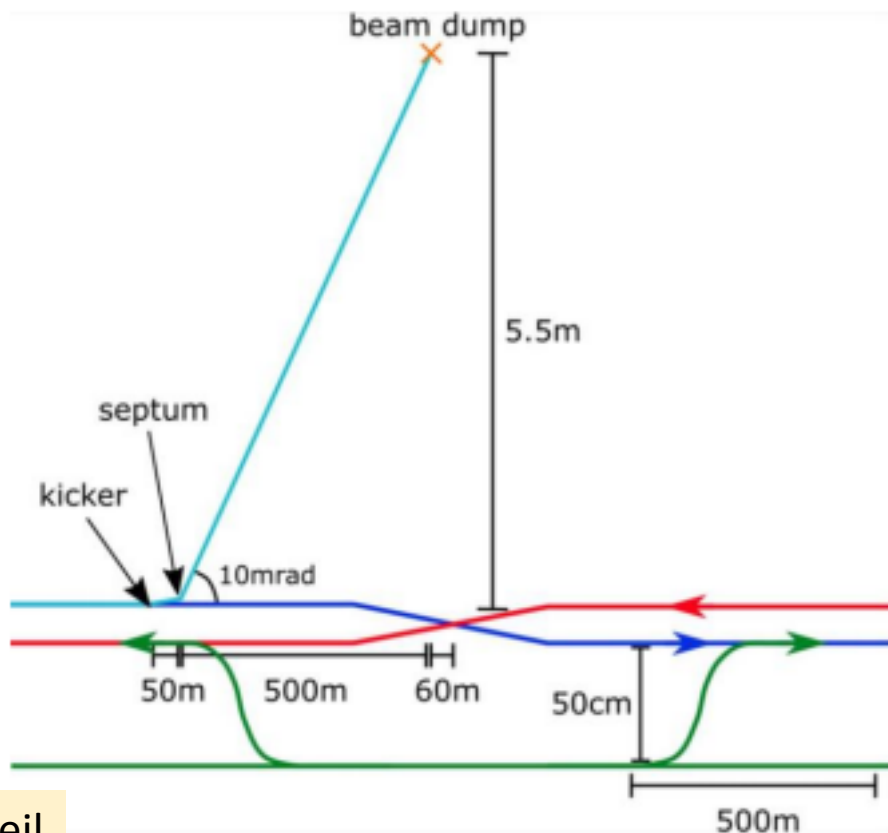
First combined injection extraction optics, with dispersion.

Y. Dutheil

Bremsstrahlung spectra @ FCC-ee

Figure 2. Bremsstrahlung spectra at the $\sqrt{s} = 91.2$ GeV, 160 GeV, 240 GeV and 365 GeV FCC-ee – solid lines $y \, d\sigma/dy$ are for the Bethe-Heitler nominal case and dashed ones $y \, d\sigma_{obs}/dy$ when the BSE is included. Note that the spectra with the BSE included overlap due to similar σ_y: those at $\sqrt{s} = 160$ GeV and 365 GeV, as well as those at $\sqrt{s} = 91.2$ GeV and 240 GeV.

Strong distortions of whole bremsstrahlung spectra, where $y = E_\gamma / E_e$

arXiv:2305.12033

K. Piotrzkowski

Beam halo losses for the Z mode

- The *Z* mode is the current focus (Beam 1, 45.6 GeV, e⁺), **17.8 MJ** stored beam energy

- The **5 minute** beam lifetime → total loss power **59.2 kW**

- Radiation and tapering included

- 3 cases consiered:

  - **Horizontal betatron losses (B1H)**

  - **Vertical betatron losses (B1V)**

  - **Off-momentum losses $\delta < 0$ (B1-dp)**

- For the off-momentum case, using a tilted collimator, aligned to the beam divergence

beam envelope
beam centroid
collimator jaws
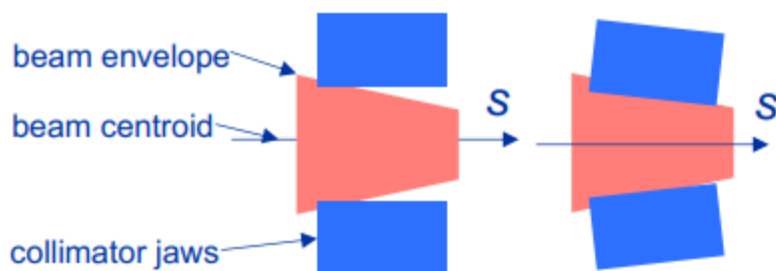
Parallel jaw and tilted collimator schematic

Type	Plane	Material	Length [m]	Gap [σ]
β prim.	H	MoGr	0.4	11.0
β sec.	H	Mo	0.3	13.0
β prim.	V	MoGr	0.4	65.0
β sec.	V	Mo	0.3	75.5
δ prim.	H	MoGr	0.4	29.0
δ sec.	H	Mo	0.3	32.0
SR BWL	H	W	0.1	18.6
SR QC3	H	W	0.1	16.7
SR QT1	H	W	0.1	14.6
SR QT1	V	W	0.1	196.4
SR QC2	H	W	0.1	14.2
SR QC2	V	W	0.1	154.2

Collimator parameter and settings for the Z mode

Total loss power: **59.2 kW**

aperture bottlenecks:
final focus
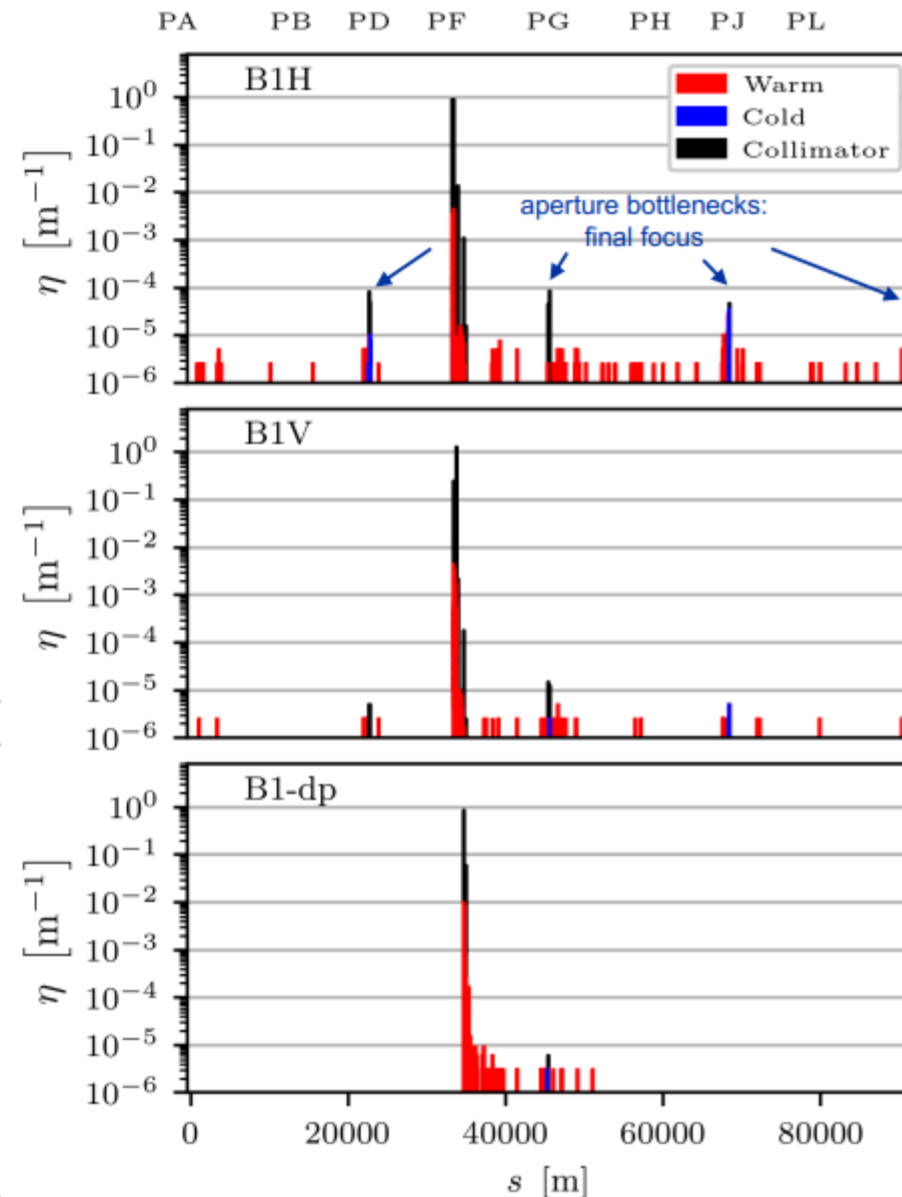
Z-mode betatron halo loss maps

Failure beam loss scenarios

- **Fast beam losses due to failures are important for the design of the collimation system**

  - SuperKEKB has experiences sudden beam loss, up to 80% intensity loss over 2 turns (T. Ishibashi, talk)

  - Such events have damaged collimators, and the cause is not well understood

- **Fast beam losses in the FCC-ee:**

  - Accidental beam loss scenarios and their likelihood must be studied in detail to devise a protection strategy

    - Injection failures and asynchronous beam dumps are likely failures that must be modelled in detail

  - The set of failure modes to protect against could drive significant changes in the collimation design

    - Special solutions may be required to handle such losses

    - As a worst-case, sacrificial collimators can be considered
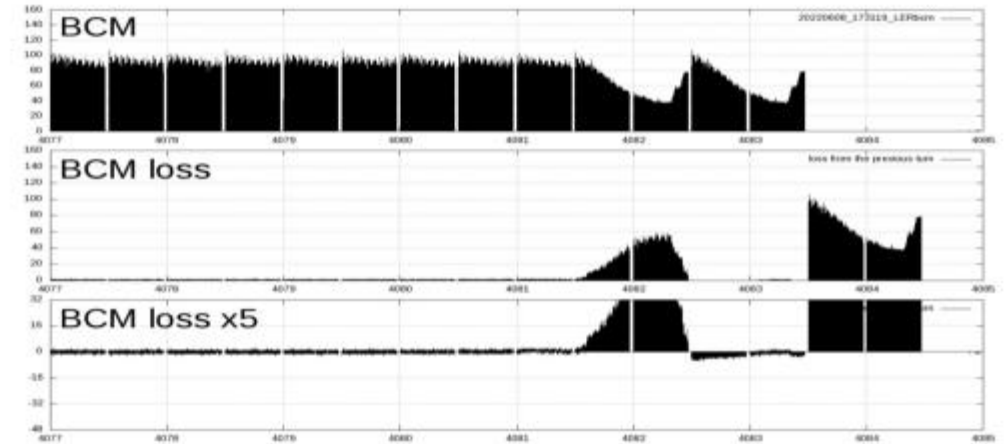
Beam current during a sudden beam loss in the SuperKEKB – T. Ishibashi (talk)
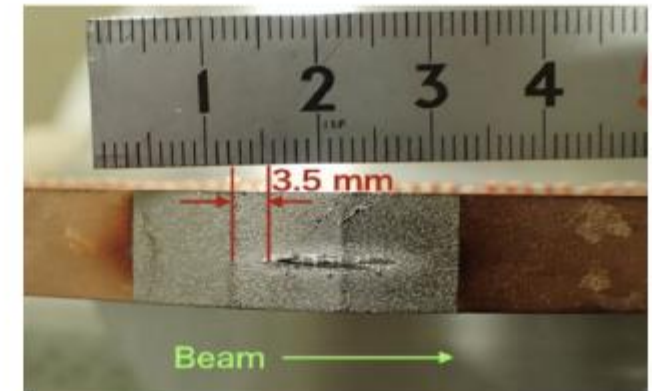
Collimator damage in SuperKEKB
https://doi.org/10.1103/PhysRevAccelBeams.23.053501

FUTURE

A. Abramov

Known Beam Intercepting Devices (BID) for FCC-ee (excluding injectors and booster)

1. **Positron Source**

2. **Extraction dump + spoilers (colliders)**

3. **Beamstrahlung dump**

4. **Betatron and momentum collimators**

5. **SR collimators**

6. **IR masks**

7. **Injection protection devices (TDIS-type)**

8. **Extraction protection devices (TCDQ/TCDS type)**
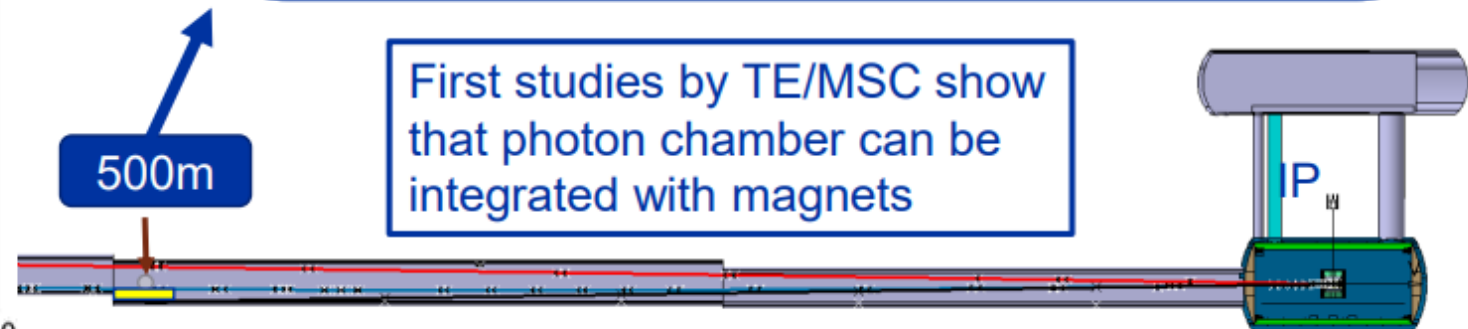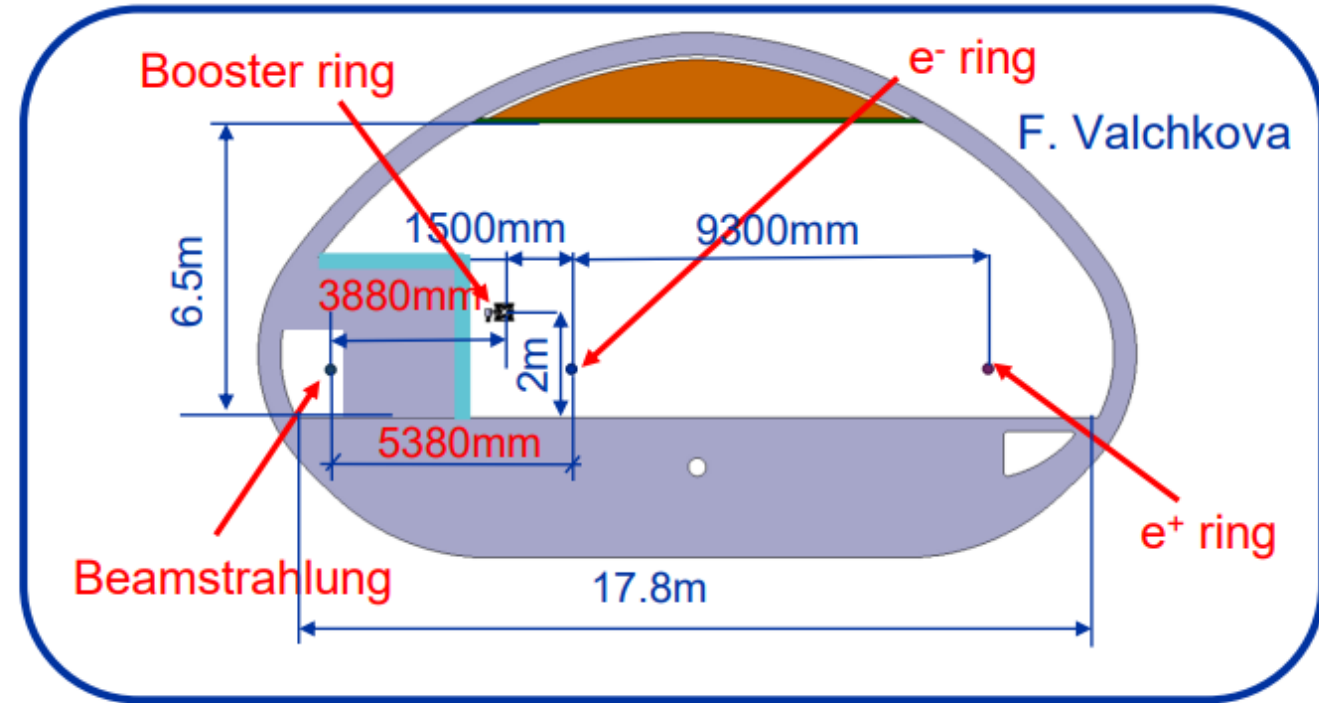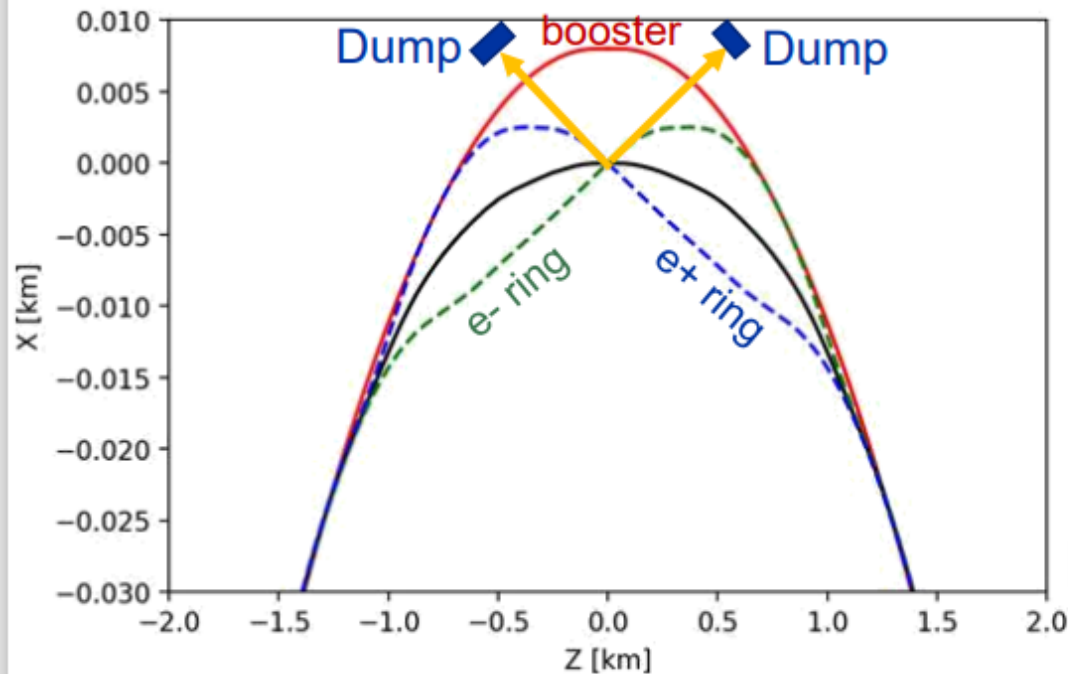

A. Perillo Marcone
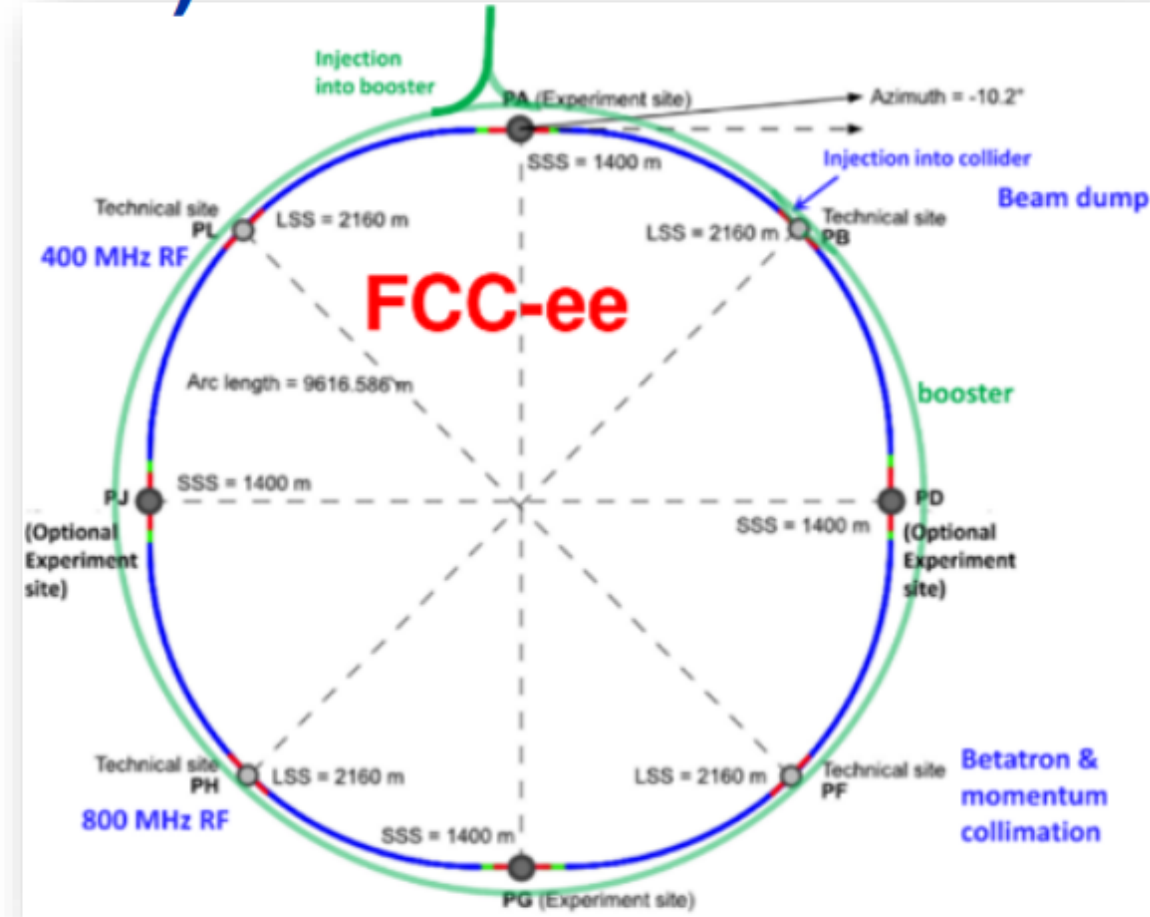
Challenges related to collimators materials

- Carbon most promising material in case of beam trajectory failure.

- However, all carbon/graphite grades have low electrical conductivity

- High-conductivity 3D CfC could be feasible (to be investigated)

- Prototype and testing would be required to study new materials

- Robust coatings (if applicable)

Long experience with LHC collimators in term of complexity and required R&D

A. Perillo Marcone

Beamstrahlung dumps location

- Internal high-power dump on beamline has many disadvantages
- External dump preferred → in order to have enough separation between dump and collider+booster, **need 500 m extraction line**

Booster ring

e⁻ ring

F. Valchkova

6.5m

1500mm

9300mm

3880mm

2m

5380mm

17.8m

e⁺ ring

Beamstrahlung

First studies by TE/MSC show that photon chamber can be integrated with magnets

500m

IP

Dump · booster · Dump

e- ring e+ ring

A. Perillo Marcone

Transverse coupled bunch instability and feedback system

- To suppress the TCBI, a bunch-by-bunch feedback system is necessary.

- The damping time in the transverse plane should be of the order of 2 ms, similar to the damping time of SuperKEKB, for example (about 1 ms).

- However, 2 ms in FCC-ee corresponds to 6-7 turns. We must pay attention to the design of such a feedback system.

- The bunch-by-bunch feedback system is also useful to suppress the single bunch TMCI, even if it can excite the '-1 mode' instability.

- The good news is that its threshold has an intensity higher than that corresponding to the TMCI without the feedback.
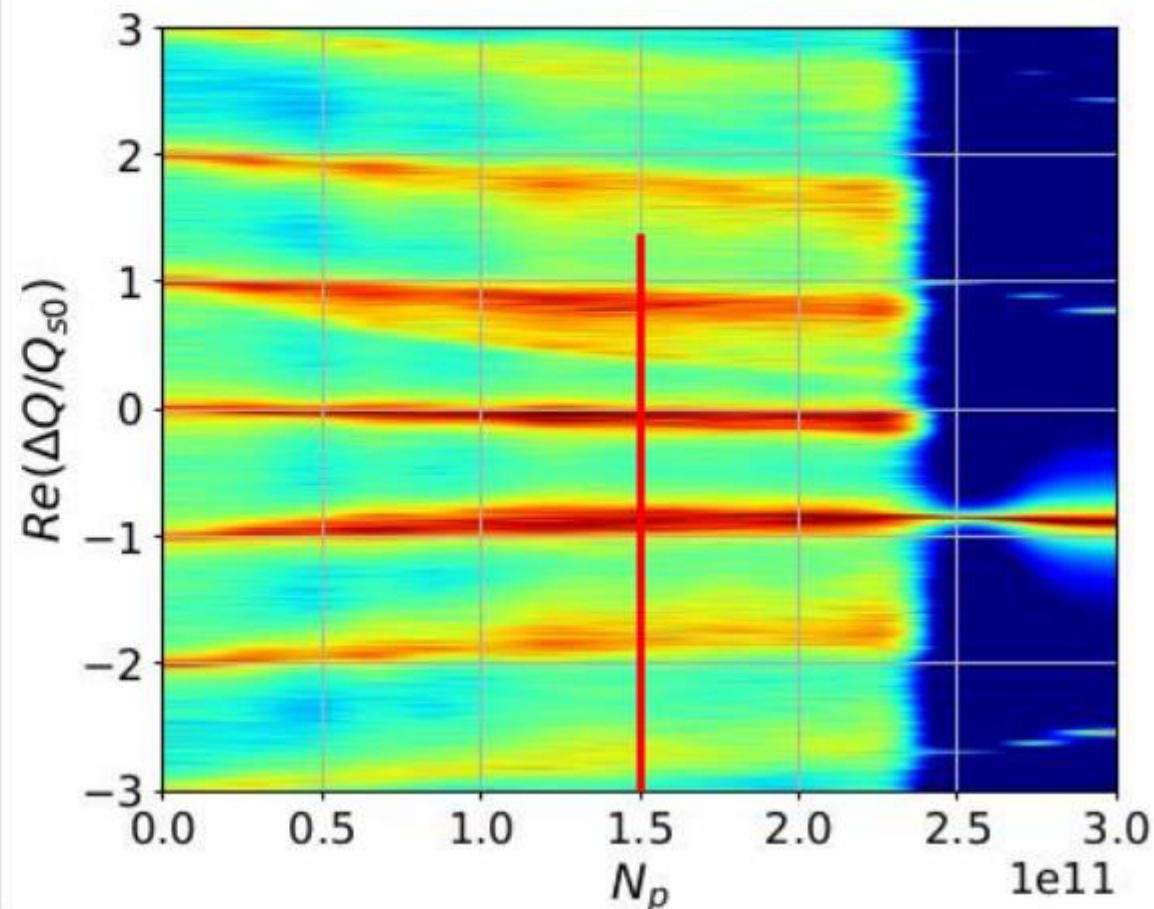

M. Migliorati
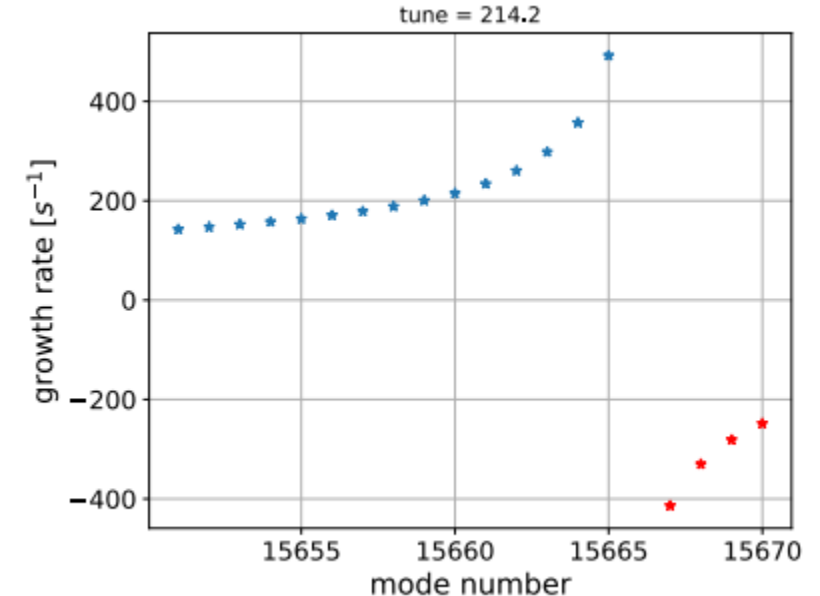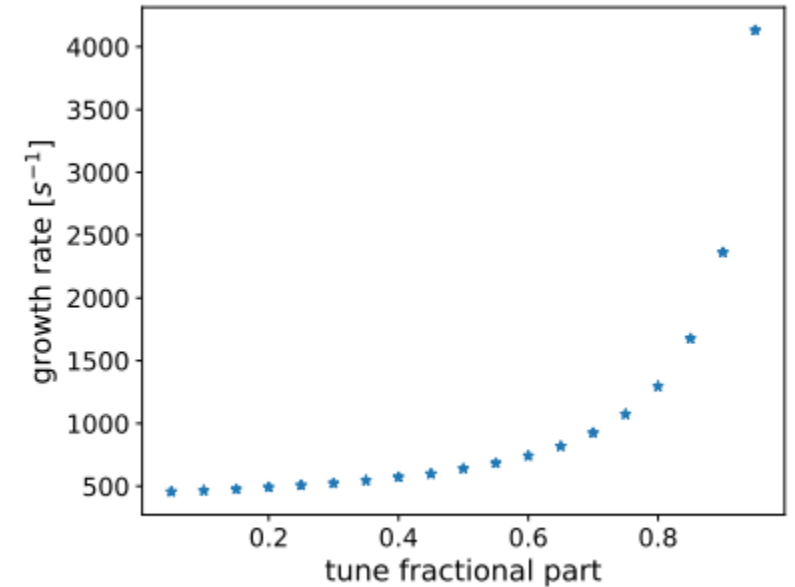
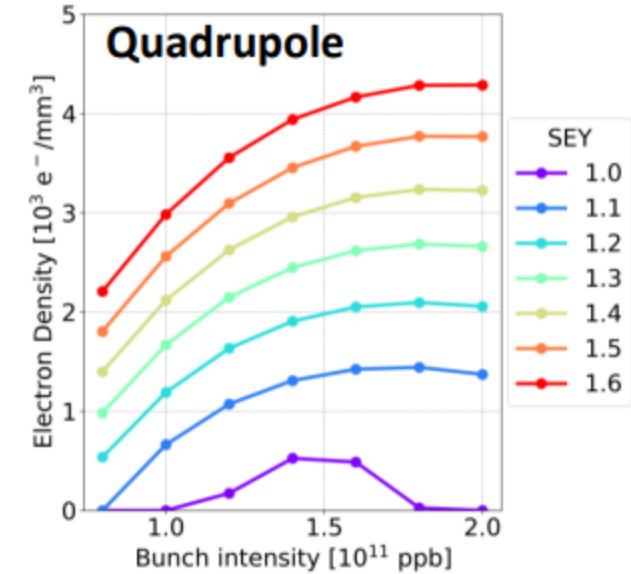# Single bunch collective effects in the transverse plane: new parameters and reduced beam pipe (from 35 mm to 30 mm of radius)
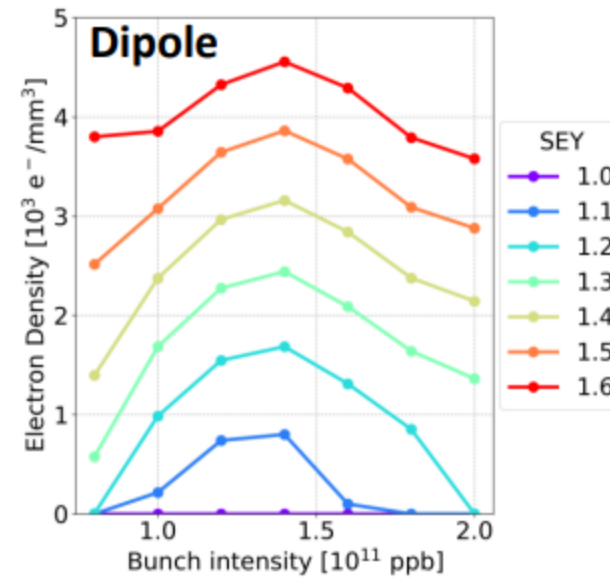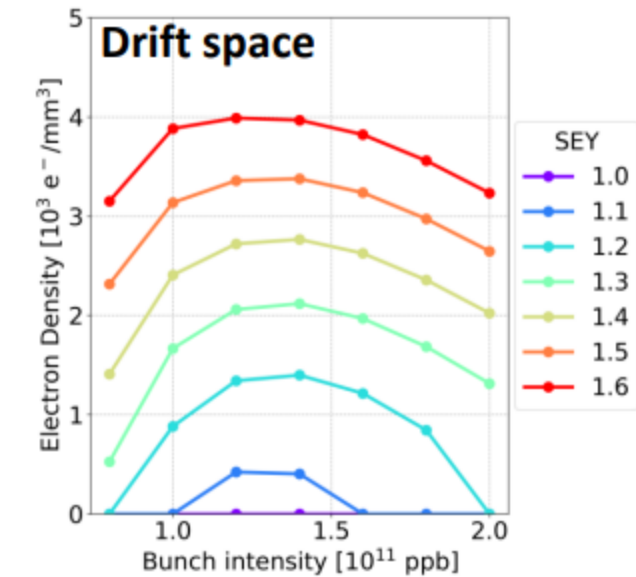
no feedback
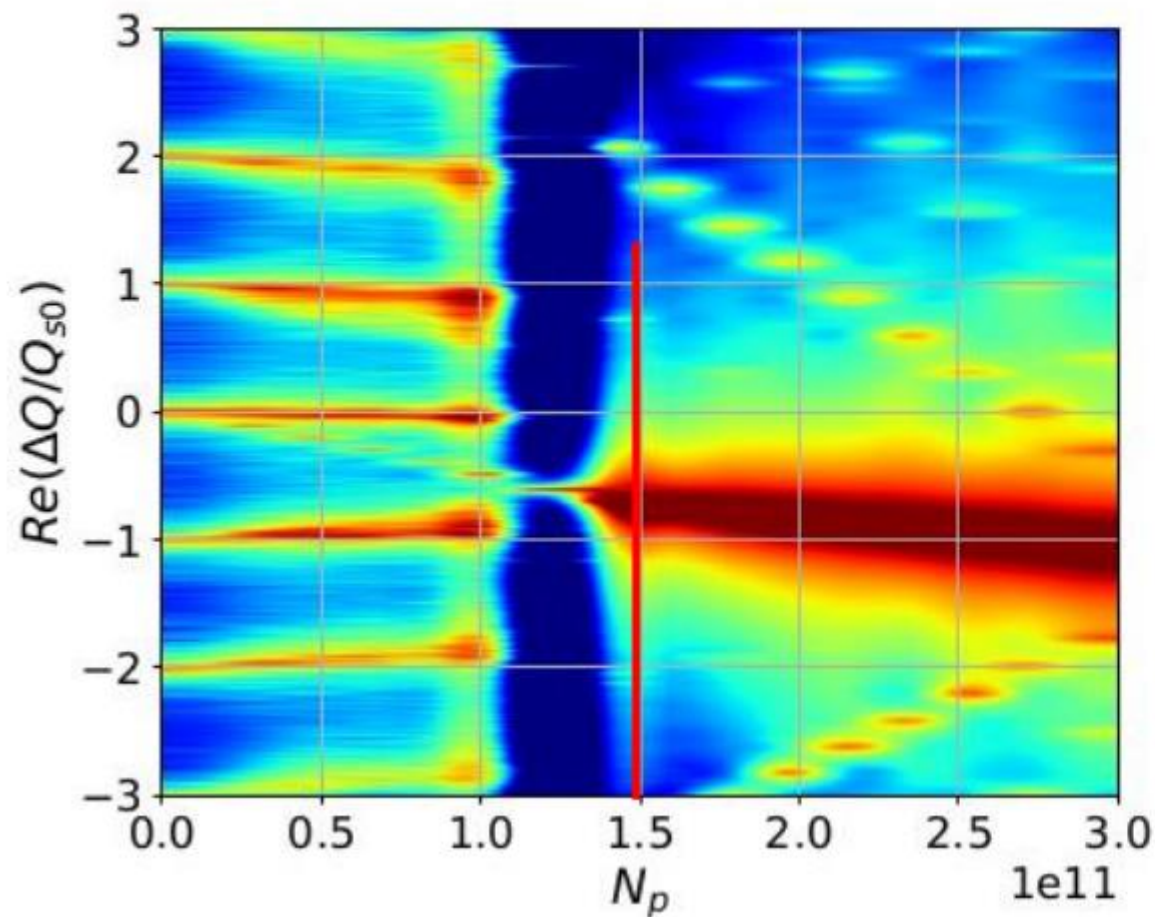
with feedback

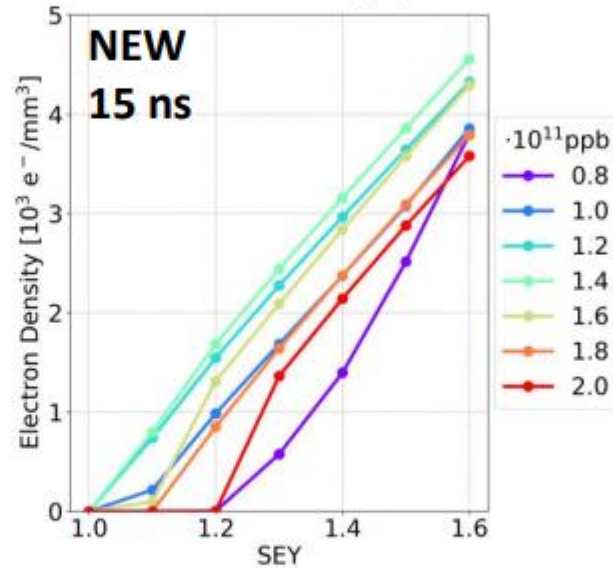# e-cloud build up simulation

- In the drift space, the dependence on the bunch intensity is non-monotonic
- In the dipole, the electron density has a similar behaviour with respect to the bunch intensity
- In the quadrupole, the bunch intensity has a non-negligible effect on the electron density

L. Sabato

Comparison: New vs Old Parameters

- With the new parameters the max bunch spacing reachable becomes 18.9 ns (16,000 bunches) instead of 32.9 ns (9,200 bunches)
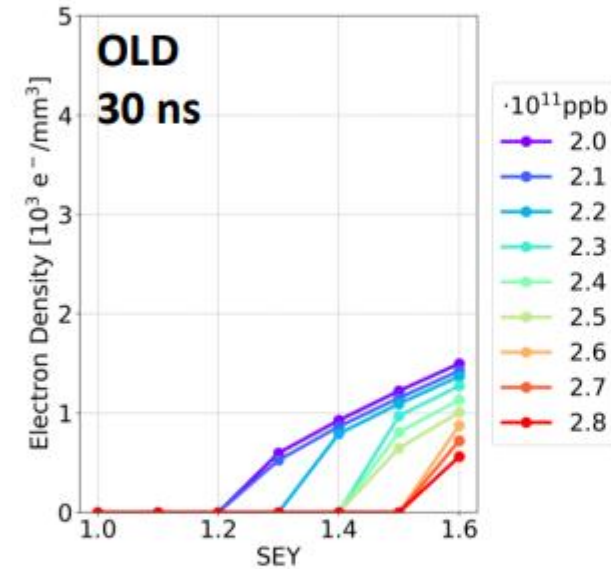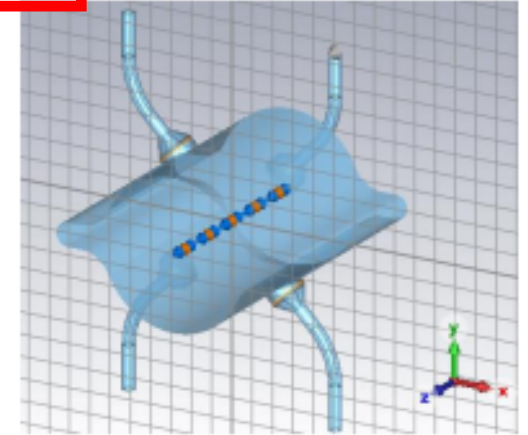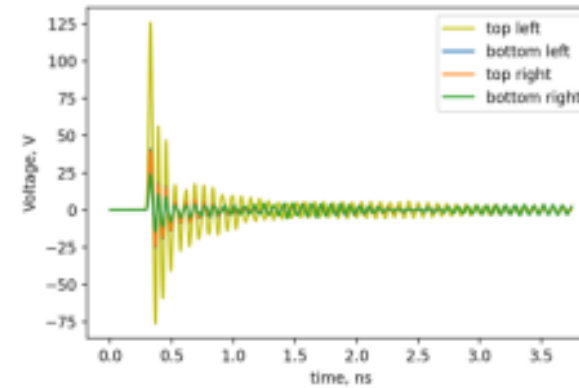

- Comparing the new configuration and the old configuration with the max bunch spacing reachable there is a clear difference both in the range of multipacting threshold and in the e-cloud density

→E-cloud build-up can only be suppressed with SEY < 1.0

→Impact of higher electron density to be determined by stability simulations

L. Sabato

New Workforce on FCC-ee BPM R&D
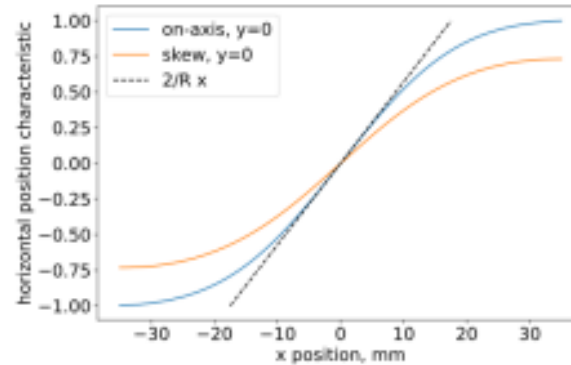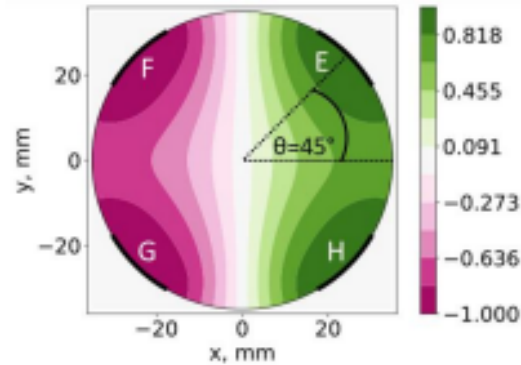
- **New BI Doctoral Student, *Emily Howling*, University of Oxford**
  - *Started in April 2023, 3-years PhD on FCC-ee BPMs, located at CERN*

  - *Focus on MR arc BPM pickups, low beam-coupling impedance, prototyping, lab characterization, beam studies at CLEAR*

T. Lefevre

BLM R&D

Dedicated FCC-ee BLM R&D has not started, but...

- **Optical BLM system based on *Cherenkov* fibers offers**
  - **High directivity**
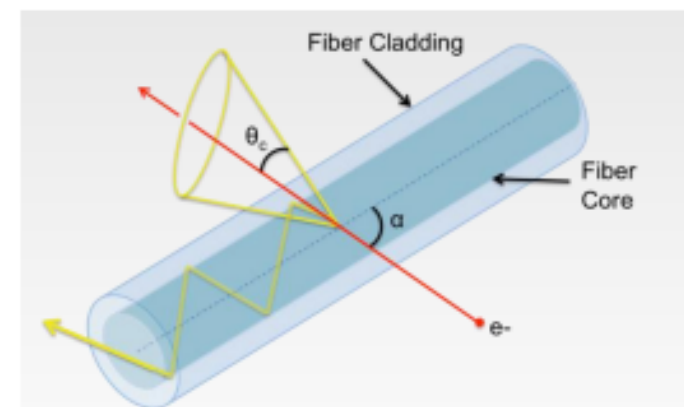 - **Only measures charged particles – insensitive to X-rays**

- **Building on existing studies initiated for Linear Collider or SPS slow extraction**
  - *Development of Cherenkov BLM at CLEAR -* S. Benitez et al., IPAC, Campinas, SP, Brasil (2021) pp. 2640
  - **Position resolution of a distributed oBLM system:** *E. Nebot del busto et al,, IBIC, Melbourne, Australia (2015) pp. 580,* S.Benitez et al. , IPAC 2022, Bangkok, Thailand (2022) pp. 351
  - **Crosstalk between beam losses from CLIC Drive and Main beams:** *M. Kastriotou et al, IBIC, Melbourne, Australia (2015) pp. 148*
  - **RF studies (Breakdown and Dark current):** *M. Kastriotou et al., IPAC, Busan, Korea, 2016, pp. 286*

T. Lefevre

Beam Size Measurement

- **Use of synchrotron radiation at high beam energies** suffer from diffraction effects !

FCC-ee: SR Photon Spectra

E_{crit} (keV)
19.545
105.540
356.200
1104.750
1252.963

F' (ph/s/m)
7.030E+17
1.348E+17
4.0466E+16
1.314E+16
1.157E+16

Linear Power Density: ~ 743 (W/m) (50 MW total by design)
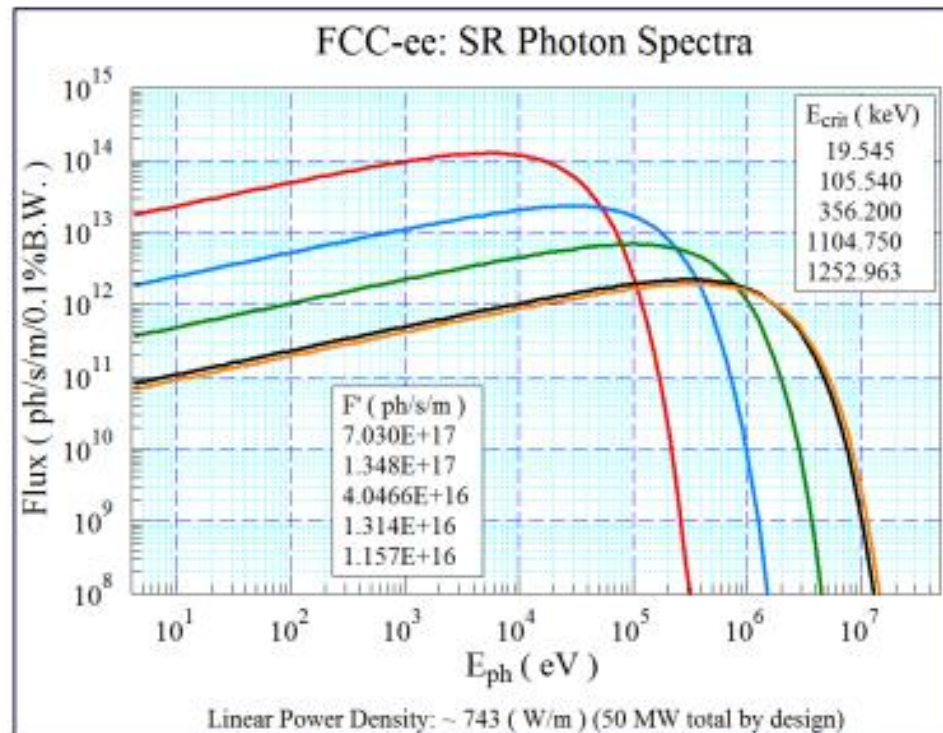
$$\sigma_{diff} = \frac{1.22\lambda}{4\sigma_y'} \approx 0.43\gamma\lambda$$

Diffraction limit:
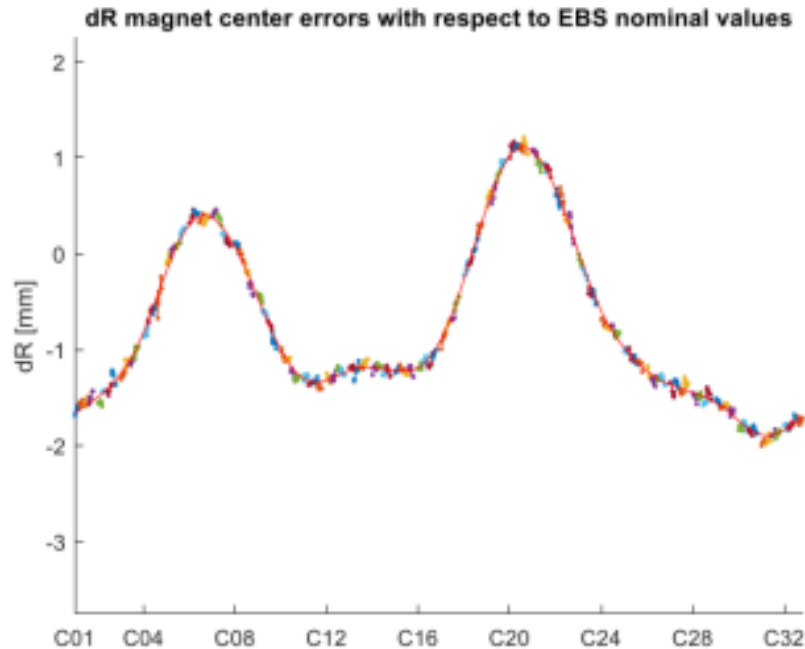**~15 µm @ 0.1 nm (182.5 GeV)**

FCC-ee challenge:

- **Large arc radius requires very long, extended SR extraction lines**
  - *Need for detailed numerical simulations*

T. Lefevre

Alignment Length scales – Example from ESRF

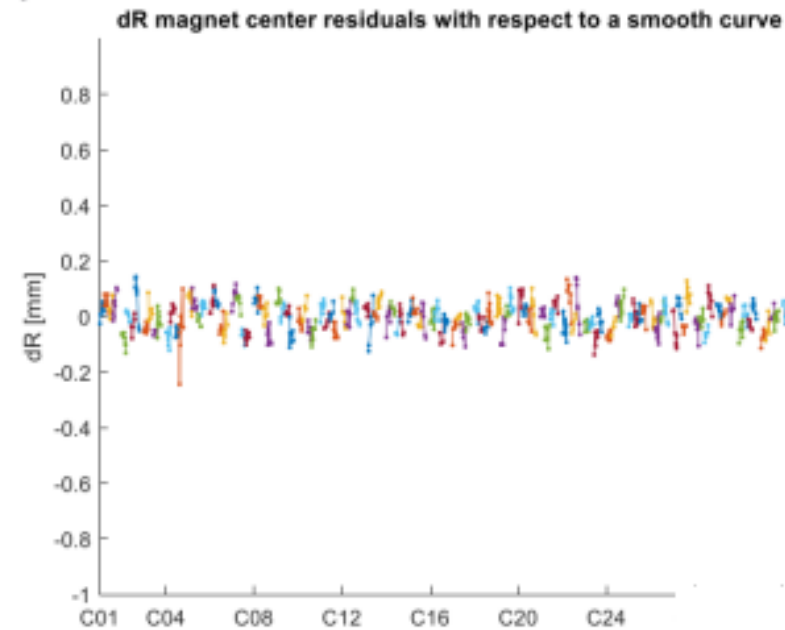- **ESRF achieved excellent performance**
  - Long wavelength misalignments have minimal effect

NOVEMBER 2019 – AFTER FINAL ALIG

dR magnet center errors with respect to EBS nominal values

NOVEMBER 2019 – AFTER FINAL ALIG

dR magnet center residuals with respect to a smooth curve

ESRF upgrade
Circ ~ 850 meters
X tunes ~ 70

D. Martin on behalf of the
ESRF Survey and Alignment Group

T. Raubenheimer

Proposed Alignment and Ground Motion model II

- ## Dynamic variation
  - **Some combination of incoherent waves, plane waves, systematic variation, and ATL-type diffusion**
  - **Verify feedback, feed-forward, and BBA timescales**

Timescale	tolerance	Correlation		https://cds.cern.ch/record/554622/files/woab009.pdf
f > 100 Hz	1 nm	none		https://www.slac.stanford.edu/cgi-bin/getdoc/slac-pub-8595.pdf
100 > f > 10 Hz	5 nm	none		
10 > f > 1 Hz	20 nm	none		
1 > f > 0.01	100 nm	none		
1 > f > 0.01	1 um	10 km		
tidal	1 mm	1000 km		systematic horizontal motion across the ring
diurnal	??			
Seasonal	100 um	around lake region		systematic vertical deformation
ATL		1x10-5 um^2/m/s		PRL 104 238501 (2010)

T. Raubenheimer

Expectation for BBA

BBA alignment requirements		
Length scale	tolerance	
6	10 um	BBA alignment of quadrupole to sextupole to bpm How do we reference long girder to BPM?
50	20 um	BBA alignment of quadrupoles to BPM using dither and smoothing with steering
200	20 um	
1000	100 um	BBA alignment of trajectory
10000	1 mm	BBA alignment from circumference and trajectory

Requirements

- **0.1 um BPM resolution at high current for stored multi-bunch beam**
- **Trims on quadrupoles and sextupoles without coupling to magnetic center**
- **Clarification on location of dipole and skew correctors is required**
- **Correctors or movers to implement corrections (dipoles for quads and maybe quad/skew quad trims on the sextupoles)**
- **Timescale for correction faster than degradation**

T. Raubenheimer

https://indico.cern.ch/event/1242395/

FUTURE CIRCULAR COLLIDER

Optics Tuning and Corrections for Future colliders workshop

26–28 Jun 2023
CERN
Europe/Zurich timezone

Come join us!

Enter your search term

More than 45 participants already registered from more than 20 labs.

- Overview
- Timetable
- Contribution List
- Registration
- Participant List
- Program committee
- Accommodation
- CERN lightweight account application

The workshop will bring together experts from the circular and linear collider community and the high brightness synchrotron radiation sources to discuss the tuning and correction of beam optics.
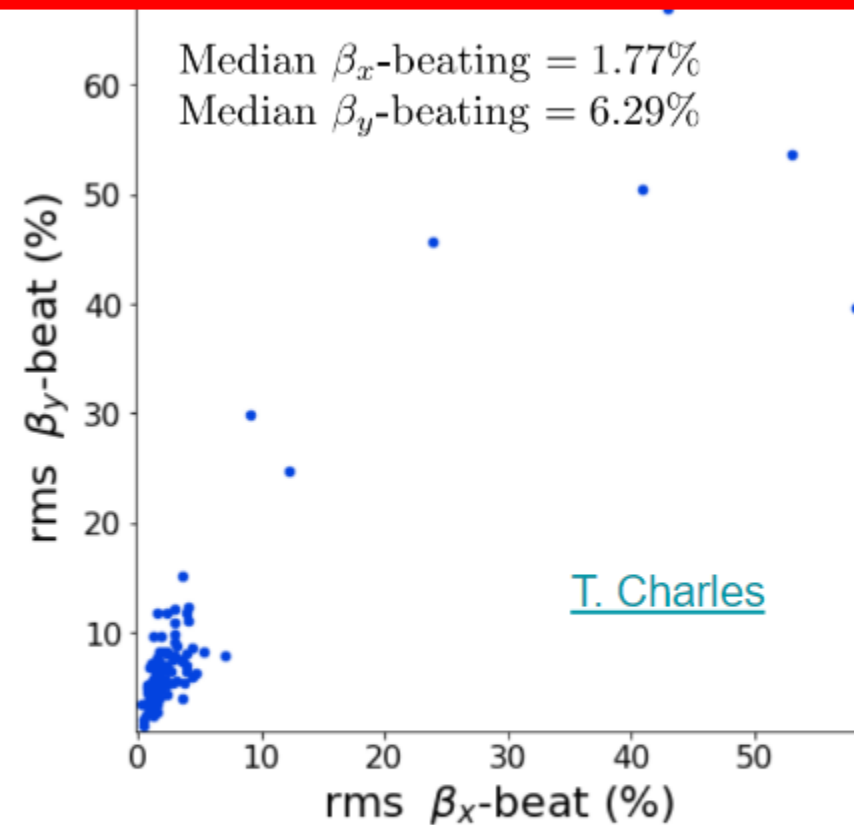
Topics to be covered are:

- correction of linear and nonlinear beam optics through the accelerator;
- sensitivity and optimization of dynamic aperture;
- impact of collective effects on the beam optics;
- component errors, drifts, and correlations;
- transport and preservation of polarization;
- modeling tools and optimization techniques.

The workshop plans to be in-person and will support some virtual participation.

R. Tomas

Assumption: 10 µm after beam-based alignment

| 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 possibly with movers+BPMs+displacement sensors (**design concept needed to reach 10 µm and better**).

Median β_x-beating = 1.77%
Median β_y-beating = 6.29%

rms β_y-beat (%)

rms β_x-beat (%)

T. Charles

Very promising improvement in the tuning of the FCC-ee linear optics, including chromaticity correction. To-do: include BPM alignment errors, IP tuning, DA & lifetime optimization. Yet, need to monitor IR sextupole drifts at 1µm level.
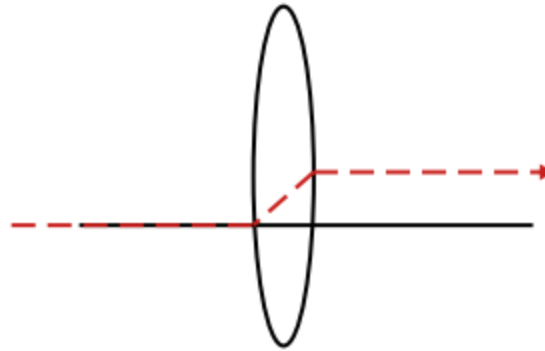
R. Tomas

Principle of Beam Based Alignment

- **Goal for FCC-ee: 10 μm residual alignment for arc quadrupoles and sextupoles**

- Example: quadrupole with transverse offset
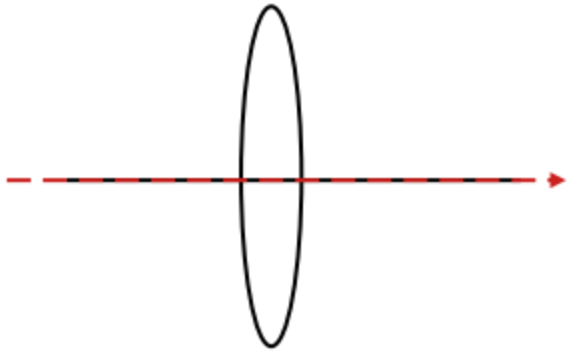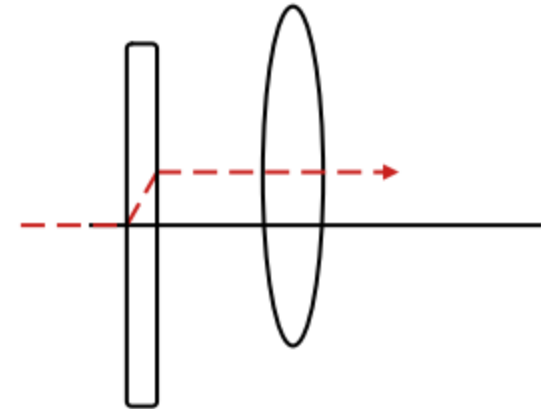
Aligned quadrupole
Beam passed through center

Quadrupole modulation does not change orbit

Misaligned quadrupole
- Beam does not pass through center
- Leads to dipole kick due to feed-down
- Orbit offset propagates to other elements

Quadrupole modulation changes orbit

**Misaligned quadrupole
and adjusted orbit kicker**
- Beam passes through center again
- No feed-down from this quadrupole
- Orbit offset propagestes to other elements

Quadrupole modulation does not change orbit

J. Keintzel

Knobs via SVD

L. Van Riesen Haupt

- **Effective** for creating knobs where linear fitting fails
  - β_w **control**
    - Still not very linear but better than fit
  - **Vertical β waist shift**
- Seems to be **more effective** than linear fit
- Allows to gain **insights** in the behaviour of the machine
  - Also useful for **alignment tolerances**
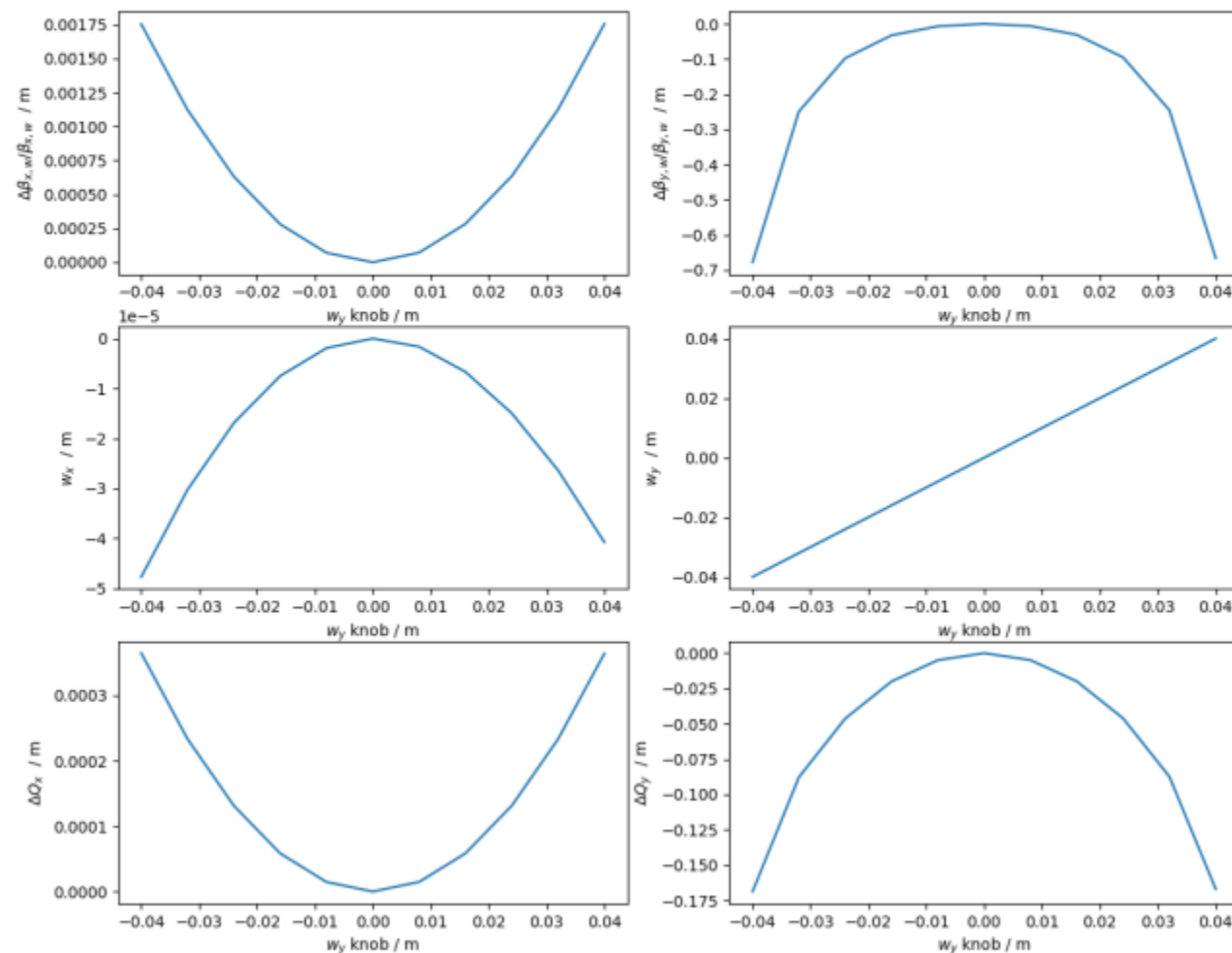
Synergies and New Developments
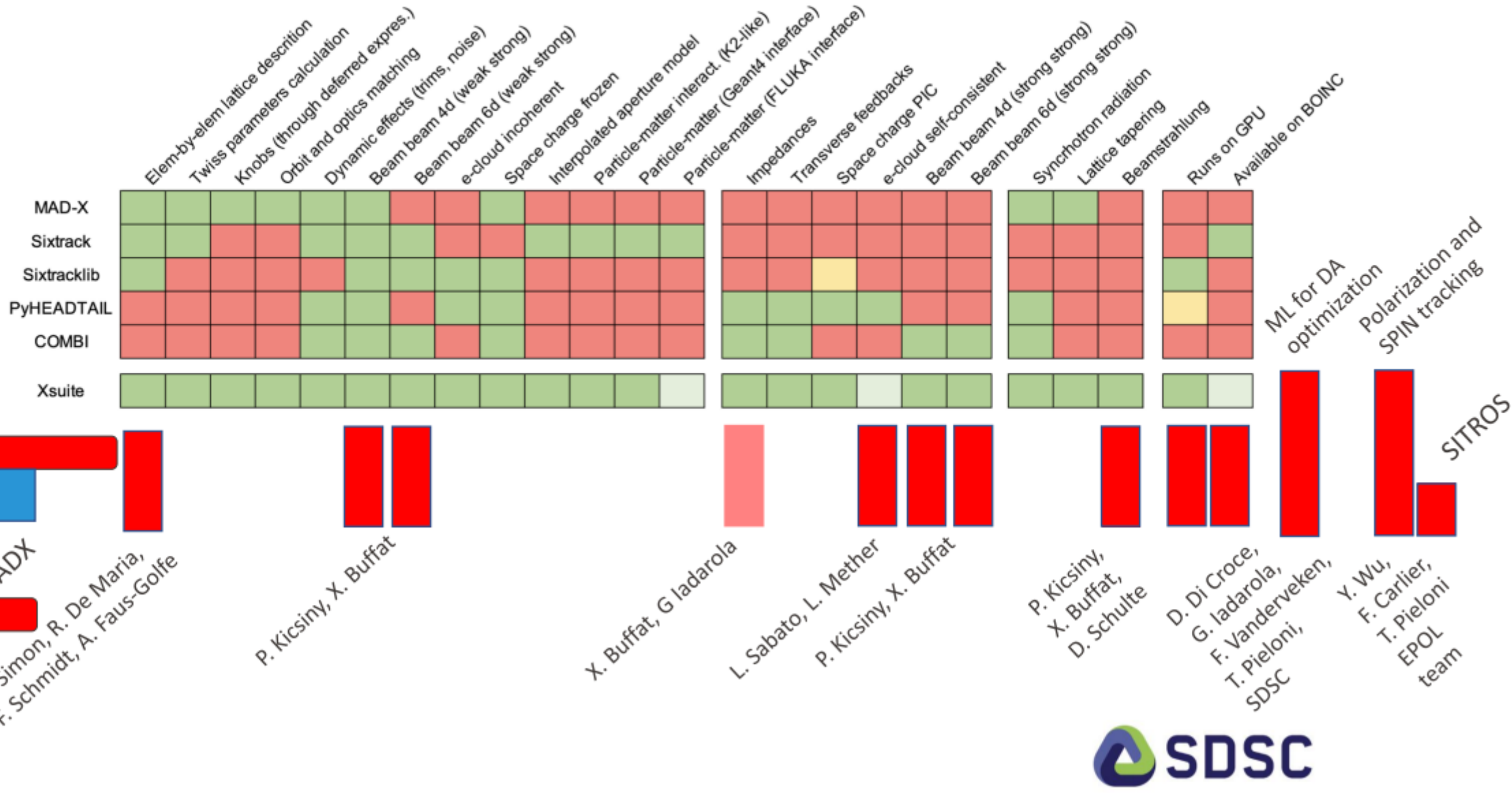
L. Van Riesen Haupt

Consistency - Benchmarking

L. Van Riesen Haupt

- Important to **benchmark** new tools with existing codes
  - Simple examples before studying **multiple effects**
  - **Understand** sources of possible inconsistencies
- Extensive study benchmarking **xsuite** since this is a primary tool
  - **Optics** with radiation and tapering compared to optics codes (MADX,SAD)
  - **Dynamic** aperture with and without radiation (MADX, SAD, MADX-PTC)
  - **Emittance** from tracking
    - Compared to other **tracking** codes
    - Compared to matrix **methods**
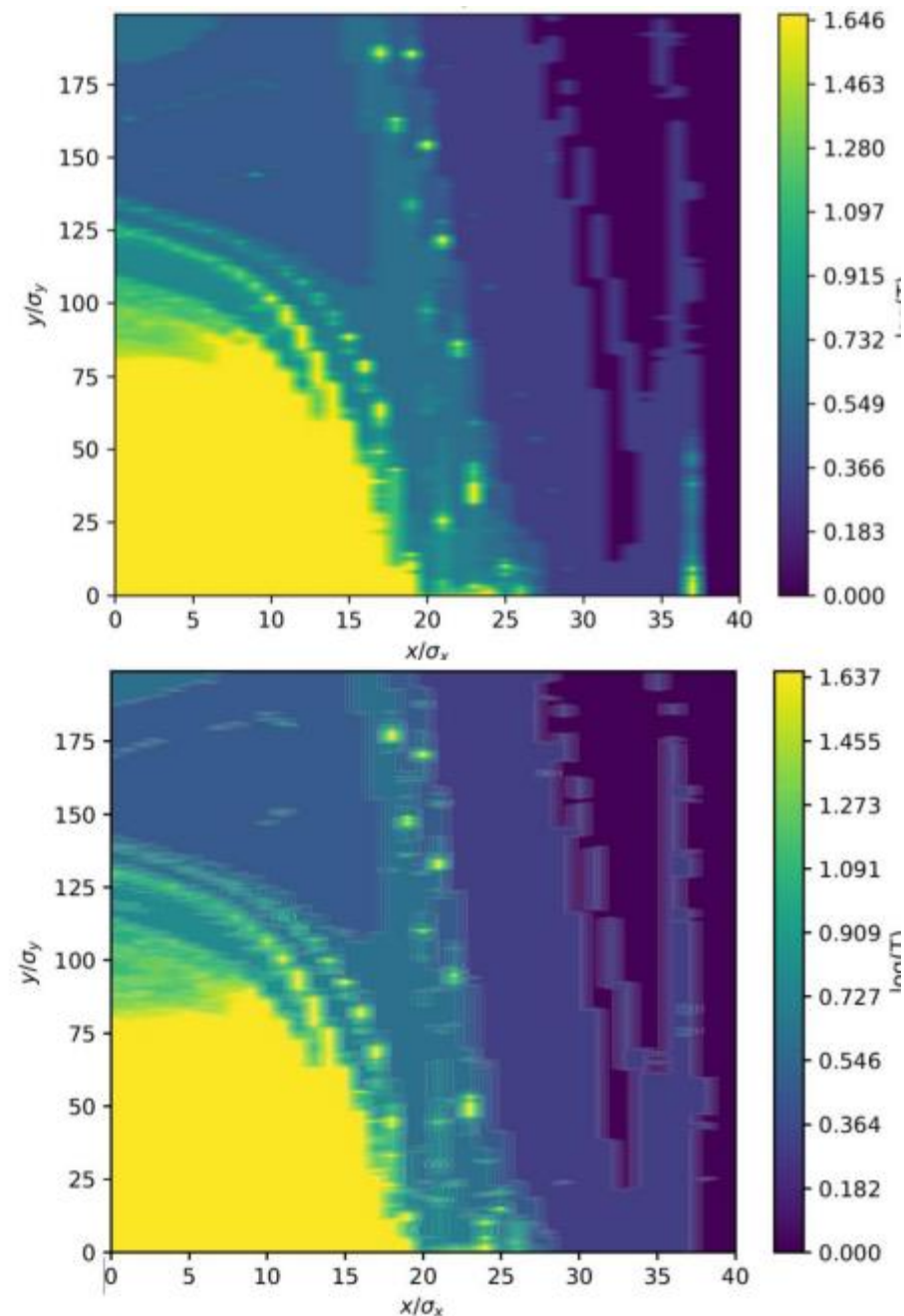
FCC-ee survival plot with radiation using SAD (top) and Xtrack (bottom)

MACHINE LEARNING 4 FUTURE CIRCULAR COLLIDER

- The ML4FCC project (epf.ch/labs/lpap/machine-learning-applied-to-accelerators) is a collaboration between EPFL, CERN, and SDSC. We are working towards implementing an Active Deep Learning framework that provides an FCC model and tuning knobs for machine design and optimization based on particle tracking simulations.

- Currently, we have developed a first Active Learning framework that incorporates machine learning tools to accelerate DA simulation using HL-LHC data (presently available). This framework includes smart sampling of machine parameters and particle phase-space for specific machine configurations, as well as the implementation of a Deep Neural Network for DA regression.

- Check the poster on Active Learning for DA simulations later today!
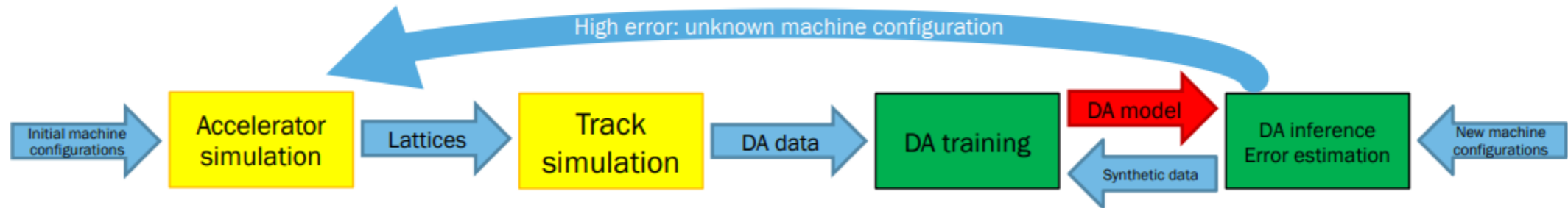
- To keep the active framework functional, we continuously submit tracking simulations to generate new data for the ML model.

D. Di Croce

D. Di Croce

Performance of the Xsuite beam-beam models

Time 1 collision on CPU
(AMD EPYC 3 GHz, single core)

FCC-ee Z
$N_{particles}$ = 1e6
N_{slices} = 100

Model	WS	QSS	SS
Runtime [s]	~40	~90	~110

Only 1 beam tracked

Number of calls to the 3 main operations
over a single collision

Beam-beam with N_s slices	WS	QSS	SS
Assign slices	0	1	$2N_s - 1$
Compute stat. moments	0	1	$2N_s - 1$
Synchrobeam kick	1	$2N_s - 1$	$2N_s - 1$

Scaling on GPU
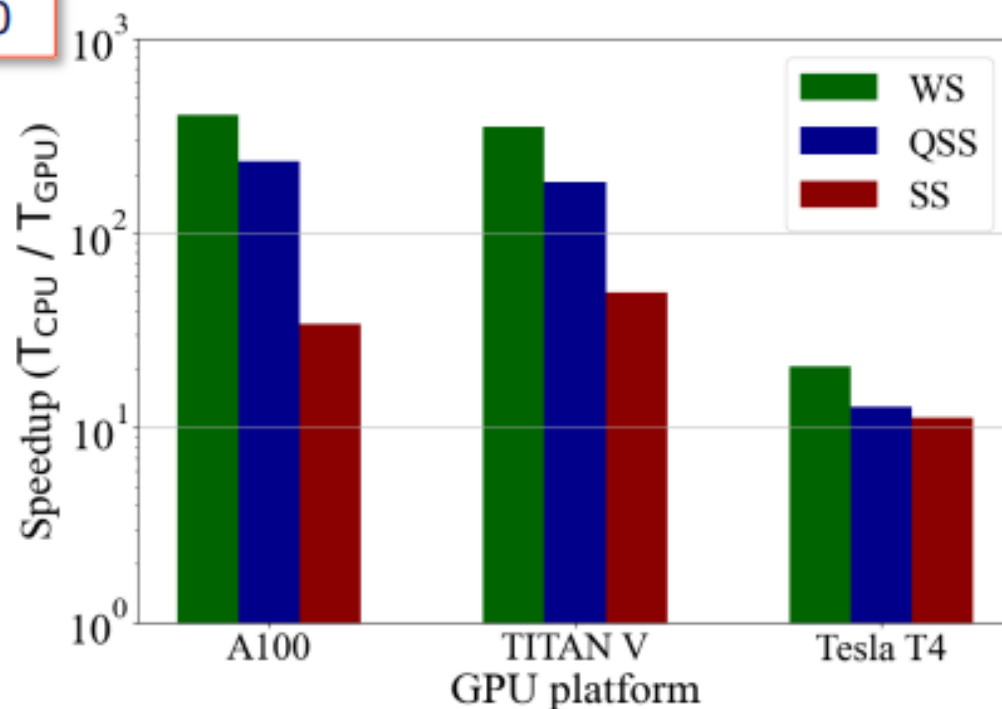
- Before: typical setup with single CPU (~ 1 week)
- GPU significantly reduces computational cost (< 1 day)

P. Kisciny

x-z instability

- x-z instability regions reproduced in QSS simulation
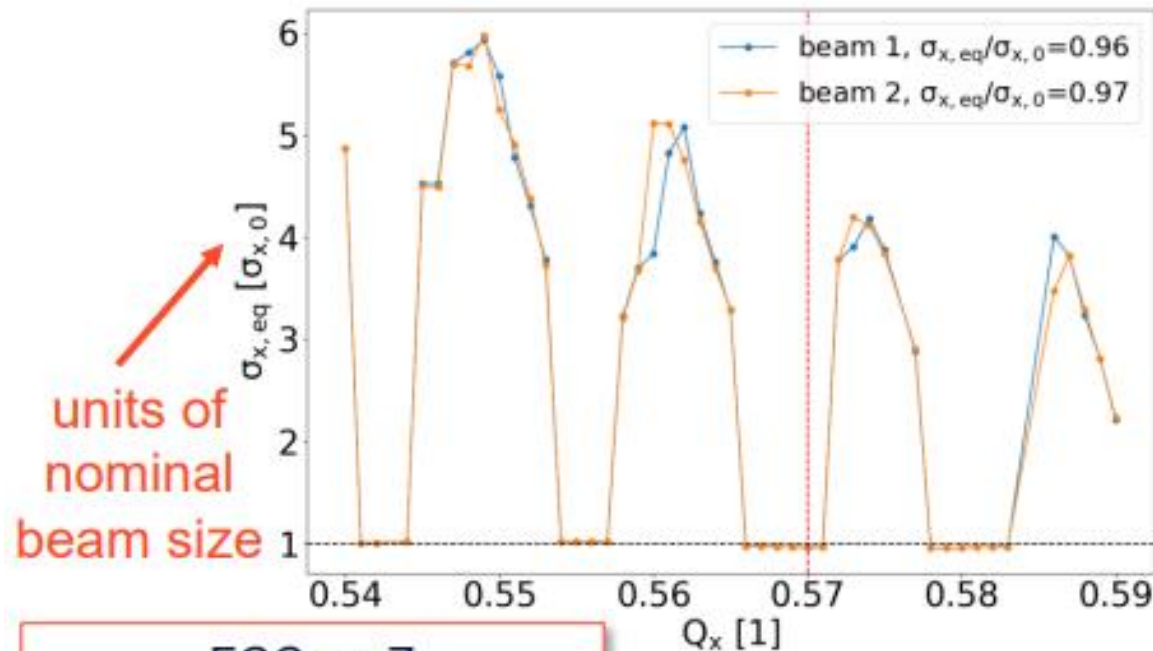
FCC-ee Z
Quasi strong-strong (f=1)
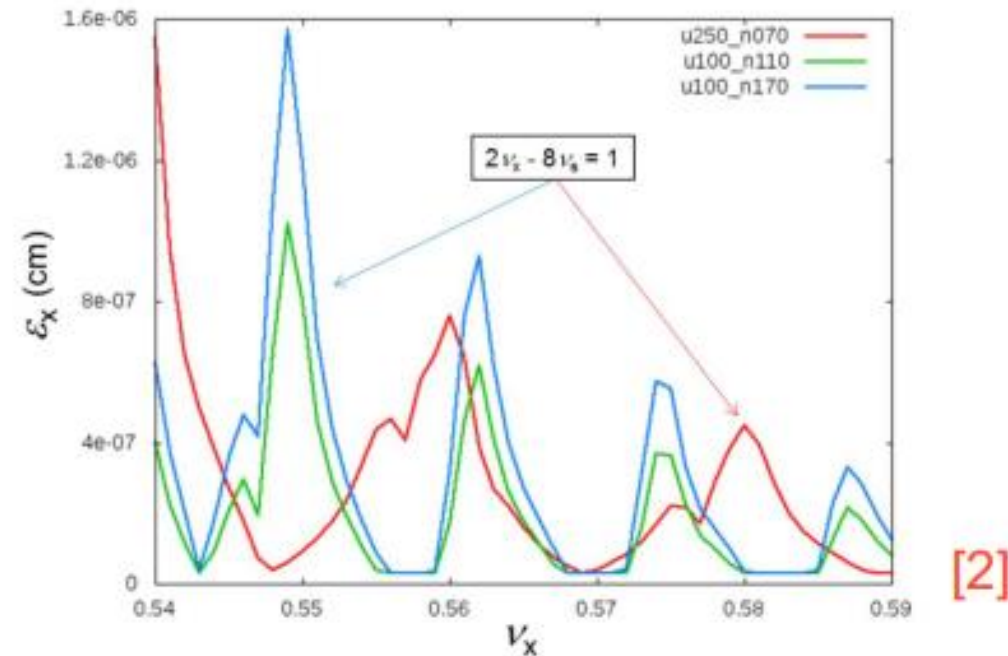N_{coll} = 1e4
$N_{particles}$ = 1e6
N_{slices} = 300

units of nominal beam size

[2]

Figure 7: Growth of ε_x due to coherent X-Z instability, as a function of ν_x. Red line corresponds to U_{RF} = 250 MV, N_p = 7·10[10], green and blue lines – U_{RF} = 100 MV, N_p = 1.1·10[11] and 1.7·10[11].

P. Kisciny

Summary

Progress so far
- ➢ Development progress in the Xsuite beam-beam model (https://github.com/xsuite)
  - ➢ Beamstrahlung, Bhabha scattering, luminosity (soft-Gaussian)
- ➢ Successful benchmark of all approximations (WS, QSS, SS)
  - ➢ FMA, x-z instability, 3D flip-flop (including validation of Khoi's model)

Ongoing work
- ➢ Combination of beam-beam + full lattice
- ➢ Beam lifetime studies

Thank you!

Next steps
- ➢ Simulations with updated FCC-ee parameters (4 IPs)
- ➢ Impact of lattice imperfections (misalignment, orbit and optics corrections)
- ➢ Top-up injection
- ➢ Benchmark at SuperKEKB

P. Kisciny

MAD-X TWISS and TRACK use two separate numerical methods that are not necessarily connected.

MAD-X TWISS computes transfer matrices using second order expanded maps from the origin. This introduces small inaccuracy that are relevant for the FCC lattices when tapering is used.

MAD-X tapering in V5.07 was fine-tuned on the TWISS calculation, giving consistent results at the expenses of the tracking model.

MAD-X tapering in V5.08 and V5.09 introduce a more coherent tapering method, giving better result in tracking, but exposing the inaccuracies of TWISS.

We are in the process of making the TWISS more accurate, using the exact option.

Tunes results in MAD-X

| TWISS	No tapering	Tapering w/o EXACT	Tapering + EXACT
5.07.00	0.2240 0.3600	0.2240 0.3593	x
5.08.01	0.2240 0.3600	0.2153 0.3509	0.2168 0.3523
5.09.00	0.2240 0.3600	0.2153 0.3509	0.2168 0.3523
PR1163	0.2240 0.3600	0.2153 0.3509	0.2171 0.3526
EMIT	No tapering	Tapering w/o EXACT	Tapering + EXACT
5.07.00	0.2240 0.3600 0.101	0.2240 0.3600 0.0815	x
5.08.01	0.2240 0.3600 0.101	0.2153 0.3515 0.0815	0.2168 0.3530 0.0815
5.09.00	0.2240 0.3600 0.101	0.2153 0.3515 0.0815	0.2168 0.3530 0.0815
PR1163	0.2240 0.3600 0.101	0.2153 0.3515 0.0815	0.2171 0.3533 0.0815
TRACK	No tapering	Tapering w/o EXACT	Tapering + EXACT
5.07.00	0.2240 0.3600 0.101	0.1797 0.3942 0.0833	x
5.08.01	0.2240 0.3600 0.101	0.2236 0.3588 0.0815	0.2236 0.3588 0.0815
5.09.00	0.2240 0.3600 0.101	0.2236 0.3588 0.0815	0.2236 0.3588 0.0815
PR1163	0.2240 0.3600 0.101	0.2236 0.3588 0.0815	0.2236 0.3588 0.0815

G. Simon

$n'_{(\gamma)}$: 1e-3 m^{-1} $n'_{(\gamma)}$: 1e-4 m^{-1} $n'_{(\gamma)}$: 1e-5 m^{-1} min

Dipole, ECLOUD SEY

Dipole Region, Furman-Pivi SEY Model
bunch spacing: 15 ns , SEY=1.4

photoelectron generation rate [m^{-1}]
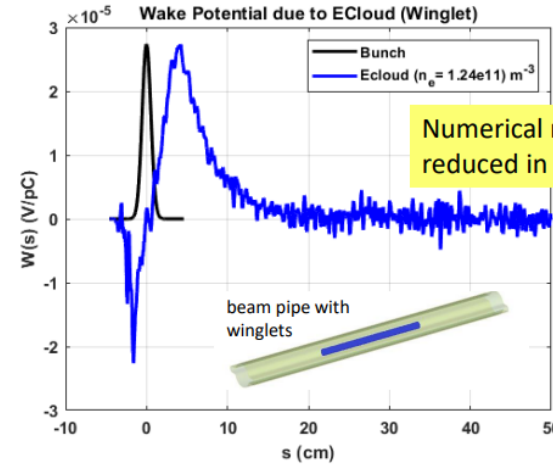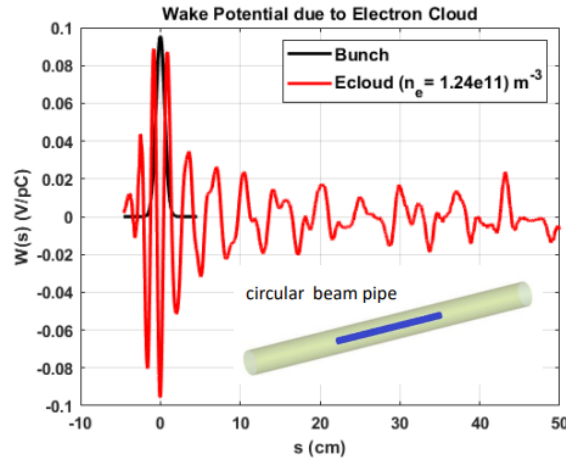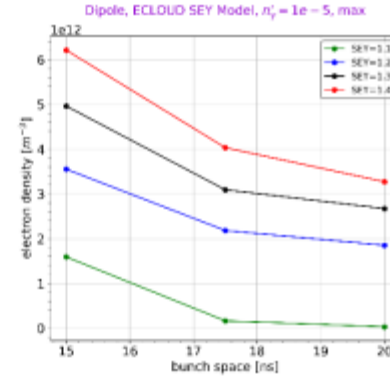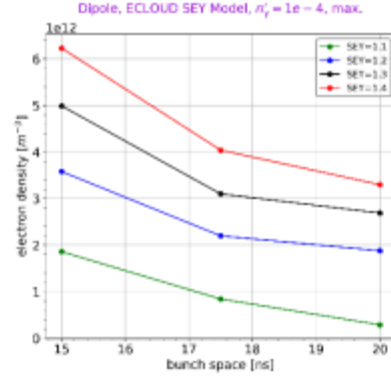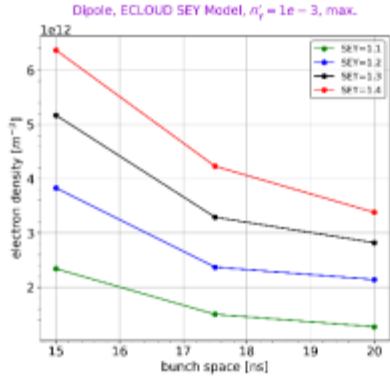
Numerical noise should be reduced in the computations
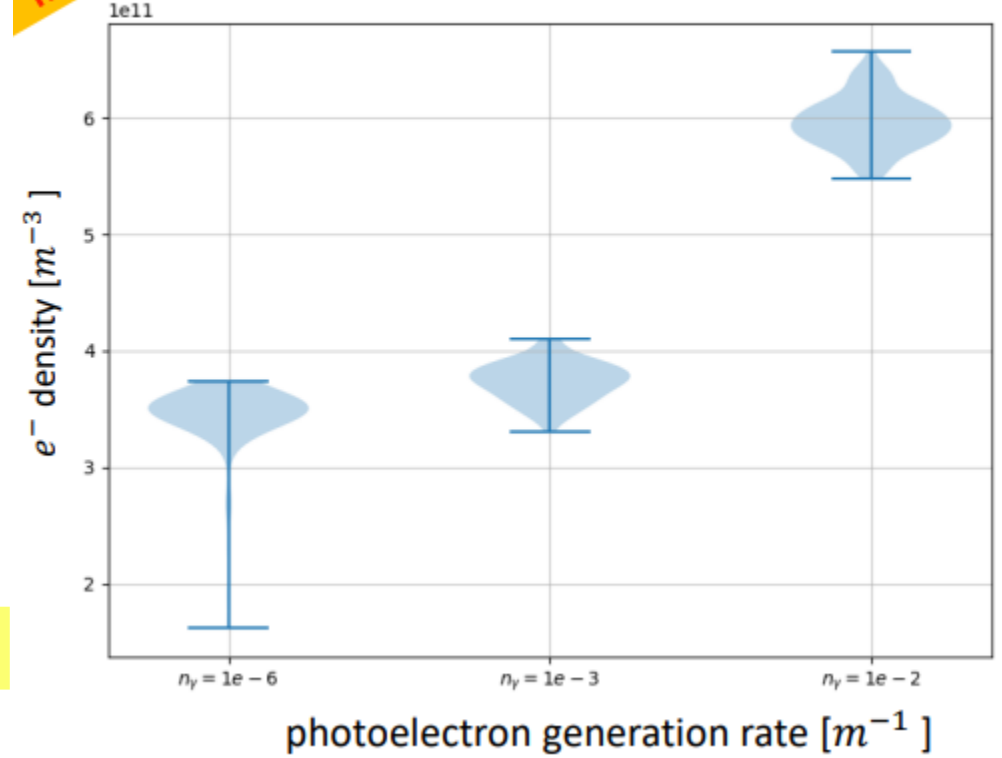
- According to initial results, winglets significantly decrease the magnitude of the wakes due to Ecloud

- Higher computational power needs for the accurate wake and impedance calculations
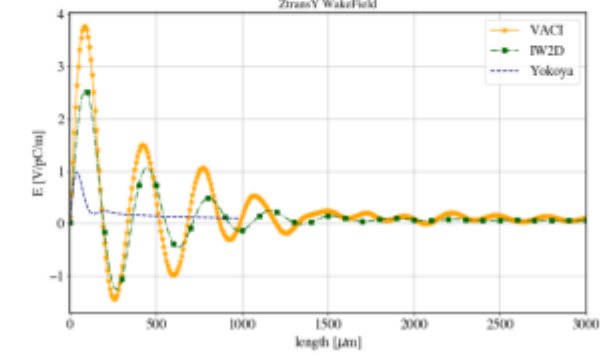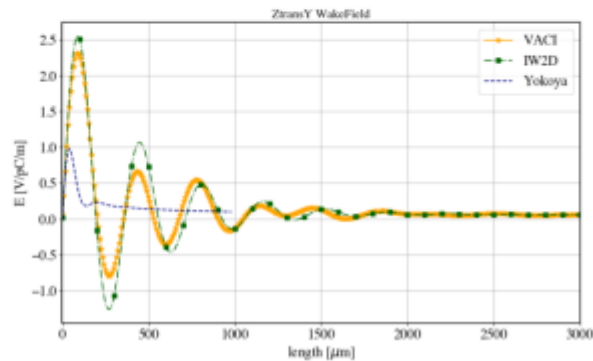
F. Yaman
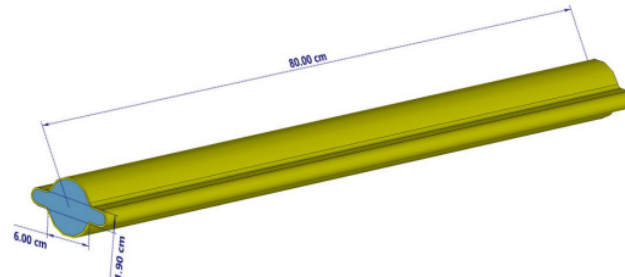
Possibility of reducing the radius of the FCC main ring chamber
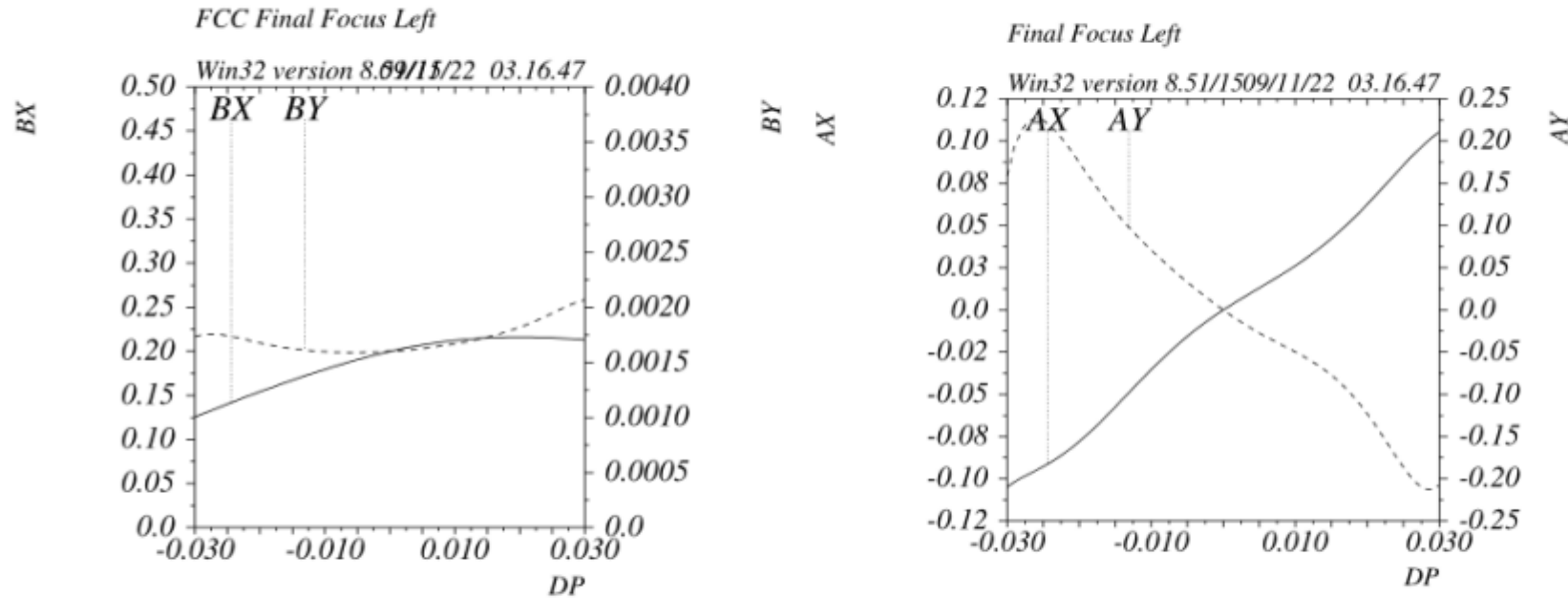
35 mm → 30 mm

1. As a reference, IW2D simulations were conducted for a pipe with an R of 35 mm in both cases.
2. Yokoya's code result is for a single layer round pipe with R=35 mm.
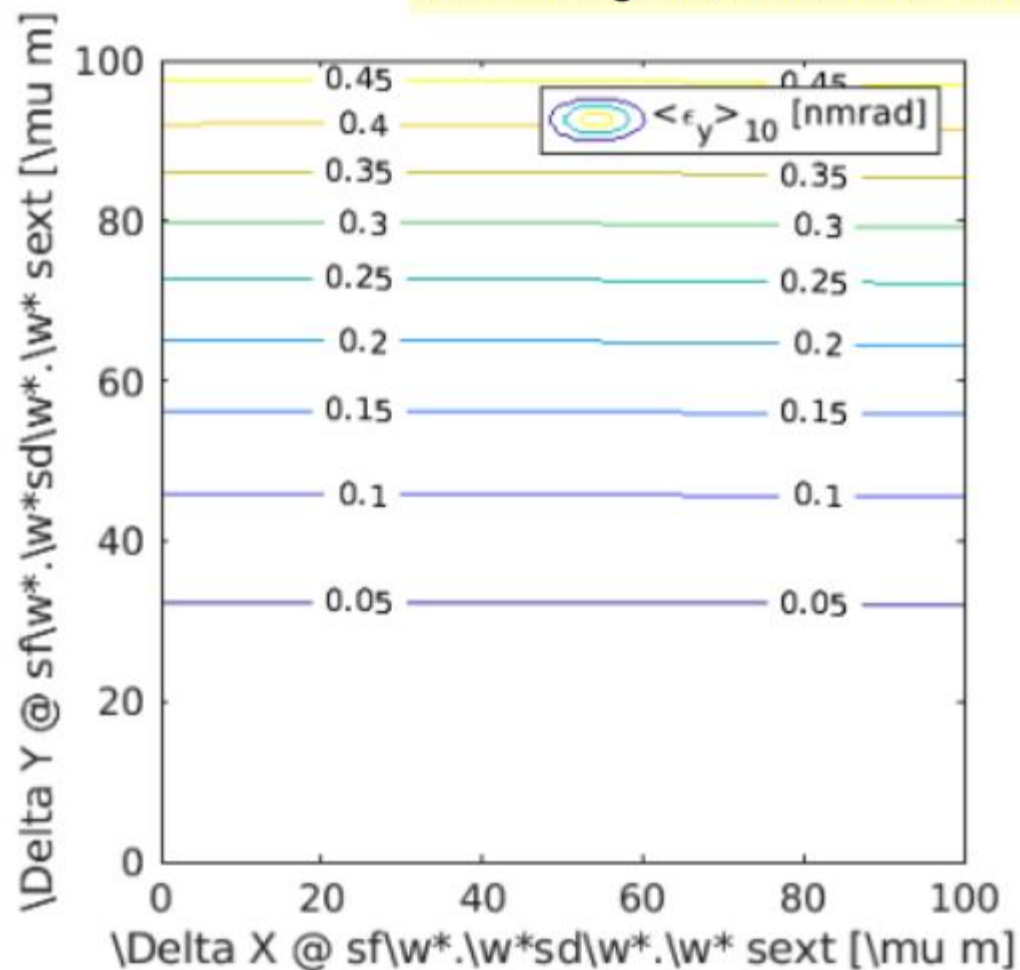

35 mm → 30 mm

A. Rajabi
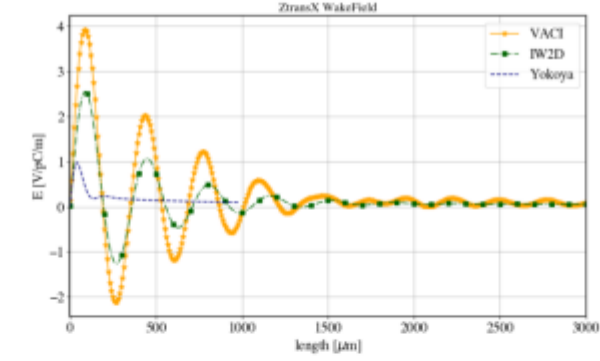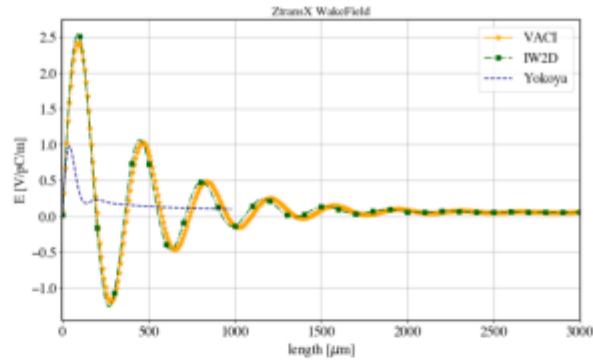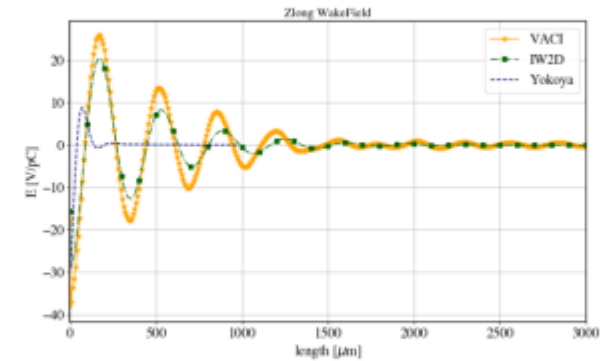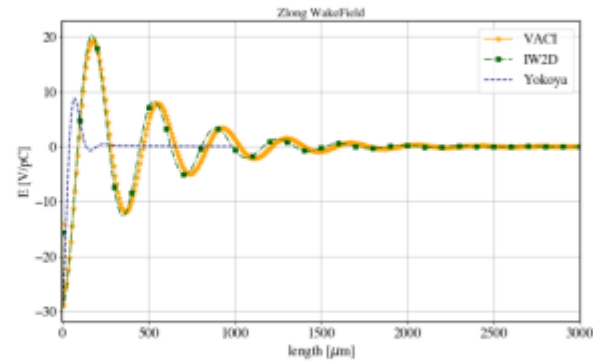
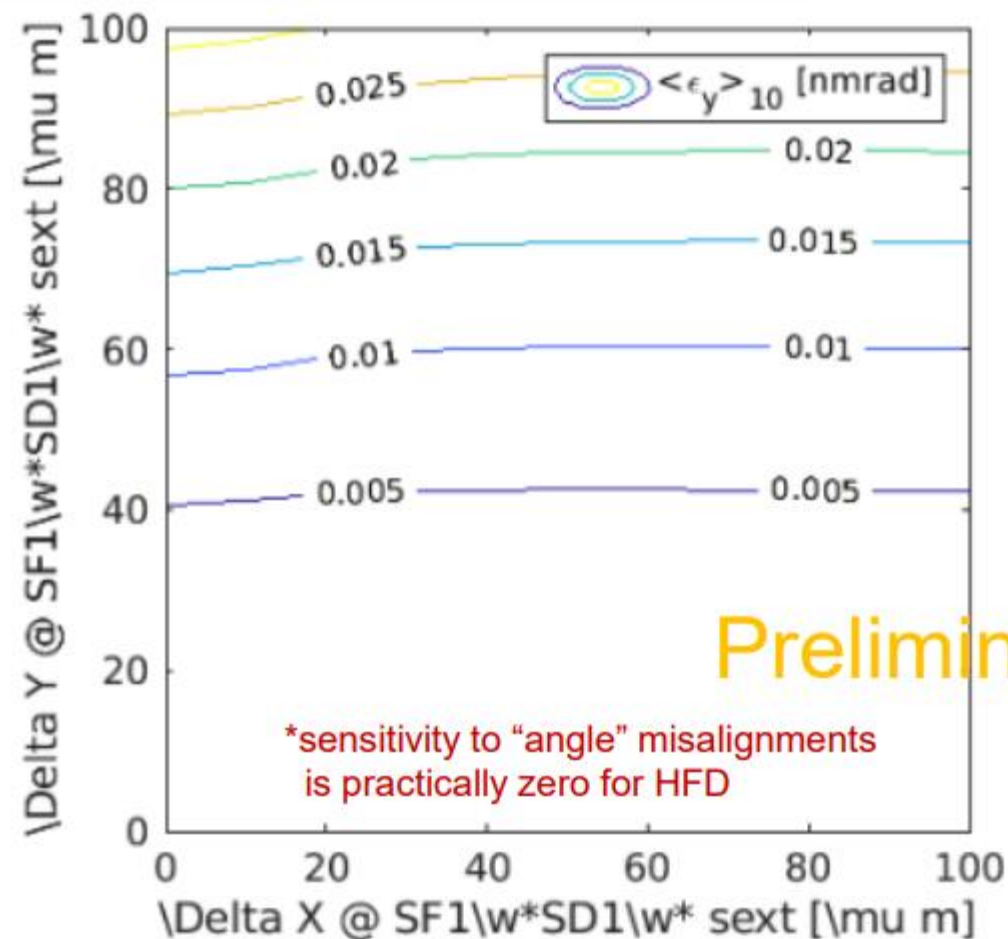# Final Focus with up to Fifth Order Chromatic Correction v_23c

A (DECy K4L~300 in MADX units) decapole at the same location of the SDM can cancel the fifth order chromaticity very effectively

Achieving small vertical emittance is easier with lower sensitivity to errors

Baseline Z Optic

HFD Z Optic with Local Chromatic Correction

*sensitivity to "angle" misalignments is practically zero for HFD

Preliminary

P. Raimondi

Comparison to Pantaleo's new lattice proposal (S. Liuzzo)

criteria	$\Delta\beta/\beta$		$\Delta\eta$		$\Delta\epsilon$	Tunes
	H	V	H	V	V	
	1 %	1 %	1 mm	0.05 mm	1‰ϵ_h	
arc sextupoles tolerances [μm]						
V22@Z	19	10	4	30	40	(0.26, 0.38)
HFD51@Z	59	45	8	>100	»100	(0.22, 0.32)
V22@t	10	8	8	85	15	(0.26, 0.38)
HFD51@t	19	10	10	»100	32	(0.24, 0.31)

At Z, Pantaelo's lattice features arc sextupole alignment tolerances larger by a factor 2 at least.
Nevertheless, at tt the gain seems to be lower, below a factor 2.

R. Tomas

Full ring general parameters

Z lattice:	ttbar lattice:	Z lattice:	ttbar lattice:
Ex = 0.528nm	Ex = 2.03nm	Ex = 0.343nm	Ex = 2.03nm
Jx = 1.00	Jx = 1.00	Jx = 1.54	Jx = 1.00
Alphac = 2.37e-5	Alphac = 0.901e-5	Alphac = 2.37e-5	Alphac = 0.901e-5
U0 = 34.38MeV	U0 = 8.78GeV	U0 = 33.06MeV	U0 = 8.46GeV
Sig_E = 3.82e-4	Sig_E = 1.50e-3	Sig_E = 4.29e-4	Sig_E = 1.45e-3
Betay*= 0.8mm	Betay*= 1.6mm	Betay*= 0.8mm	Betay*= 1.6mm
Betax*= 0.15m	Betax*= 1.0m	Betax*= 0.15m	Betax*= 1.0m

Machine parameters consistent with baseline for all modes

With offset quads (Z lattice, 3rd column)

With HTS U0 is further reduced by ~3%

With offset quads (ttbar lattice, 4th column)

P. Raimondi
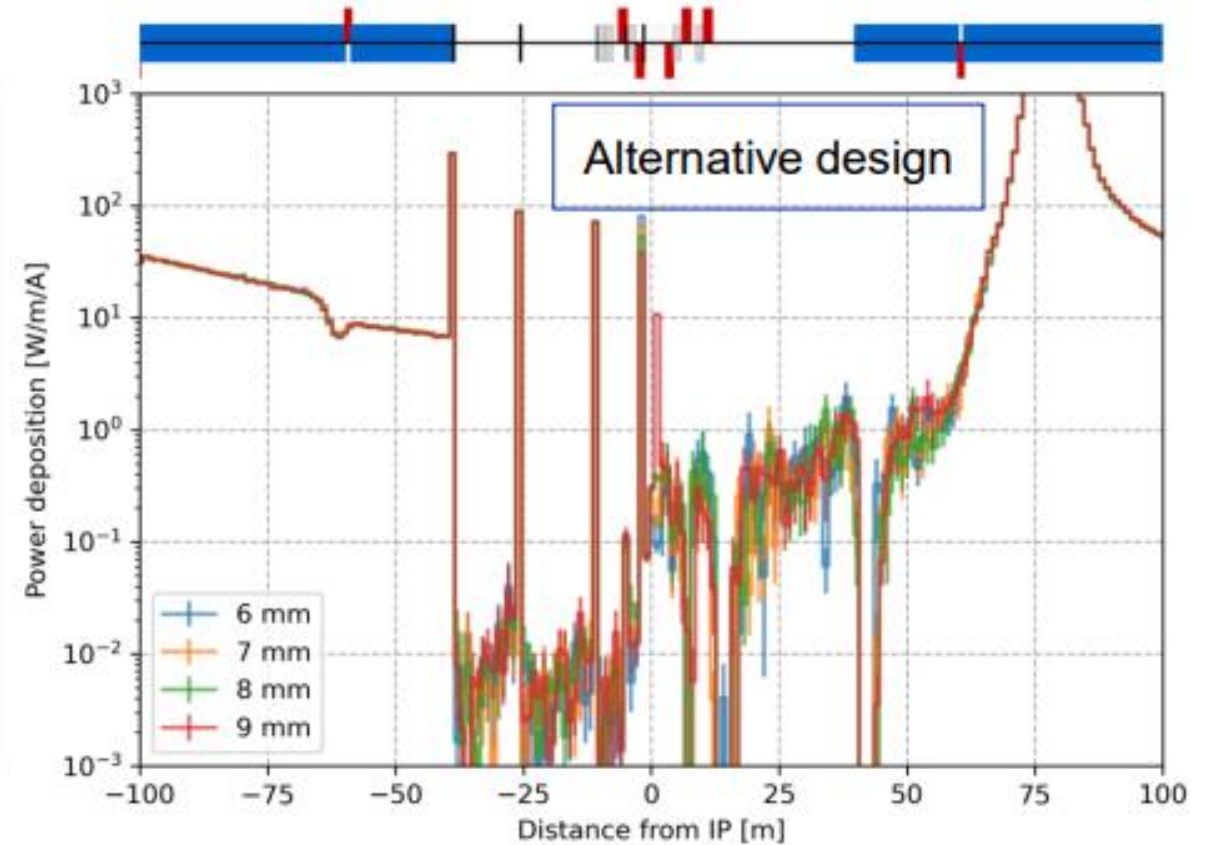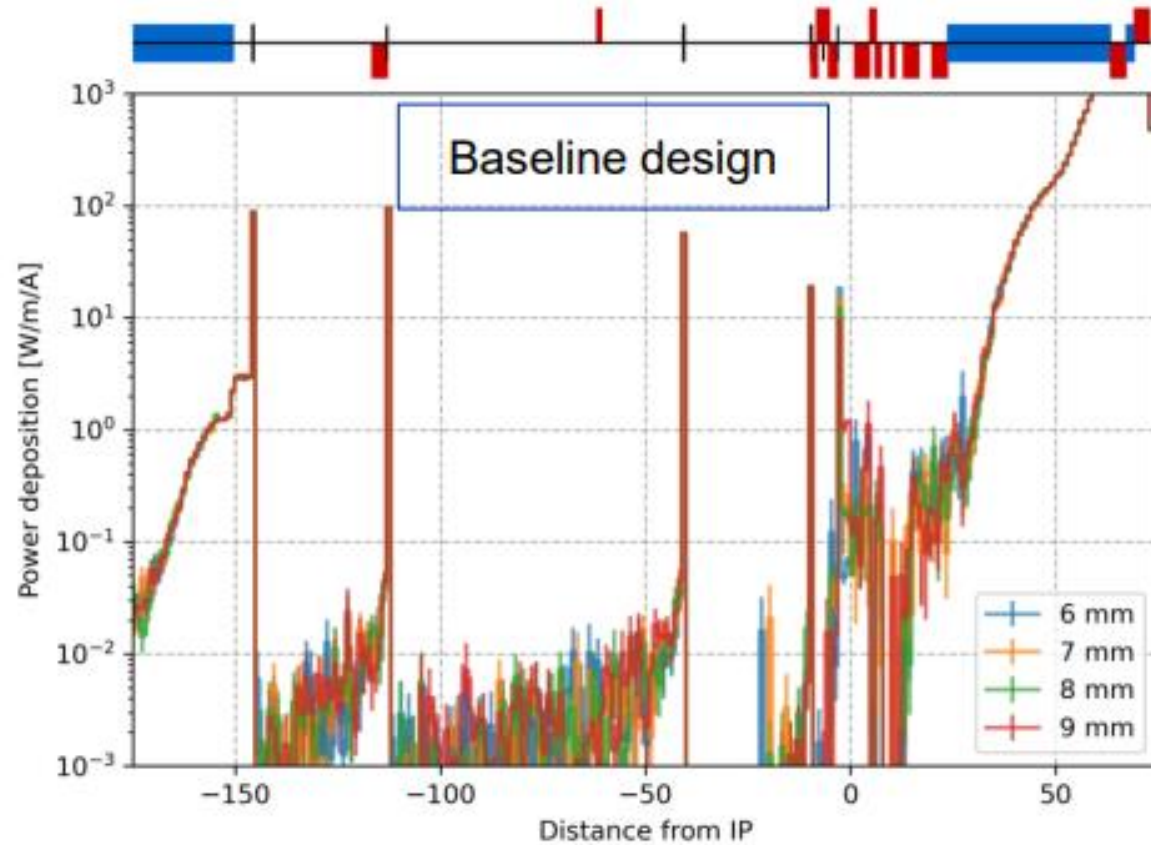
Dynamic aperture with radiation

- Tracking studies repeated with SR emission in all elements and with tapered lattice

- Slightly more pronounced reduction of DA at $t\bar{t}$ operation mode, minor differences at Z
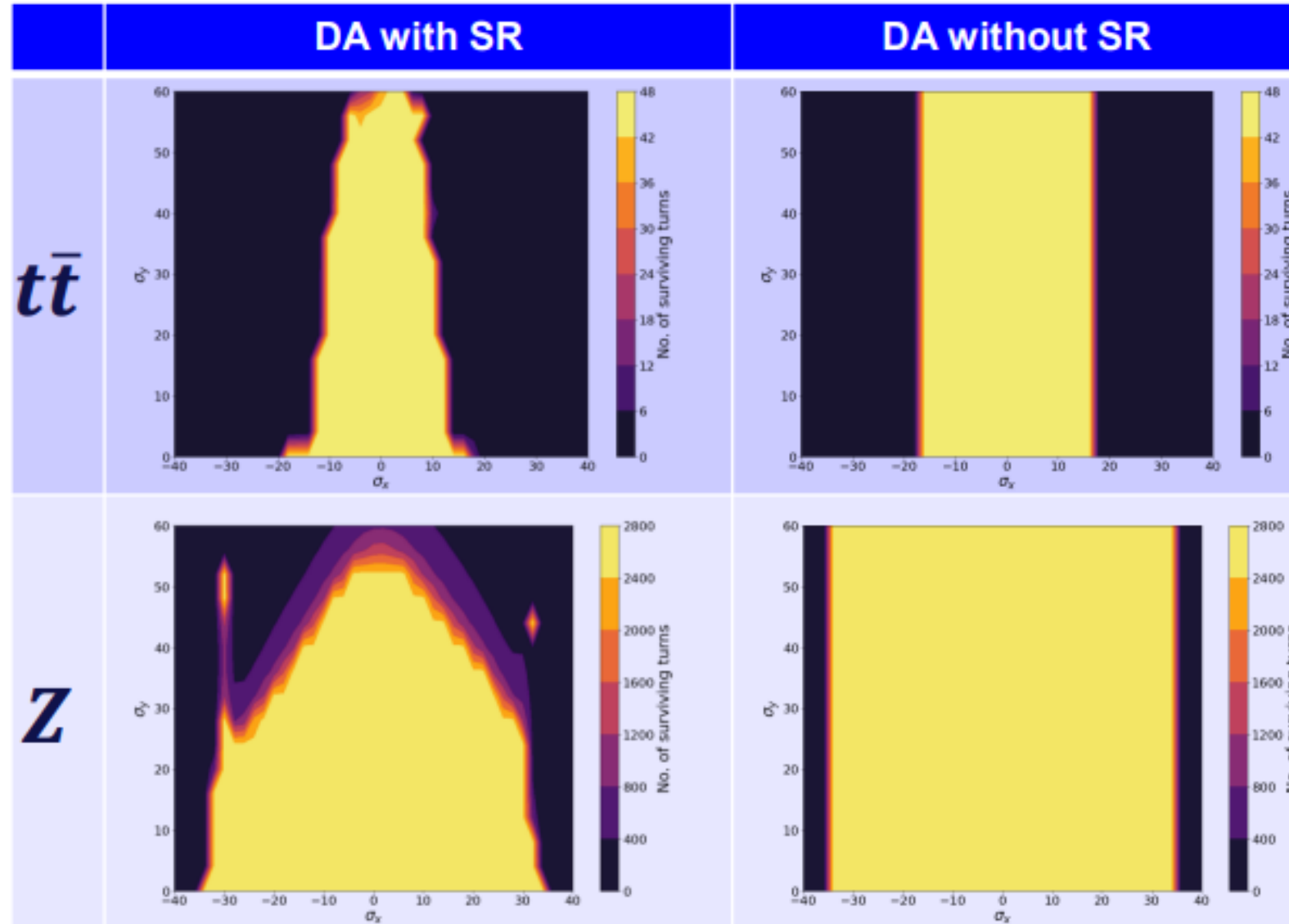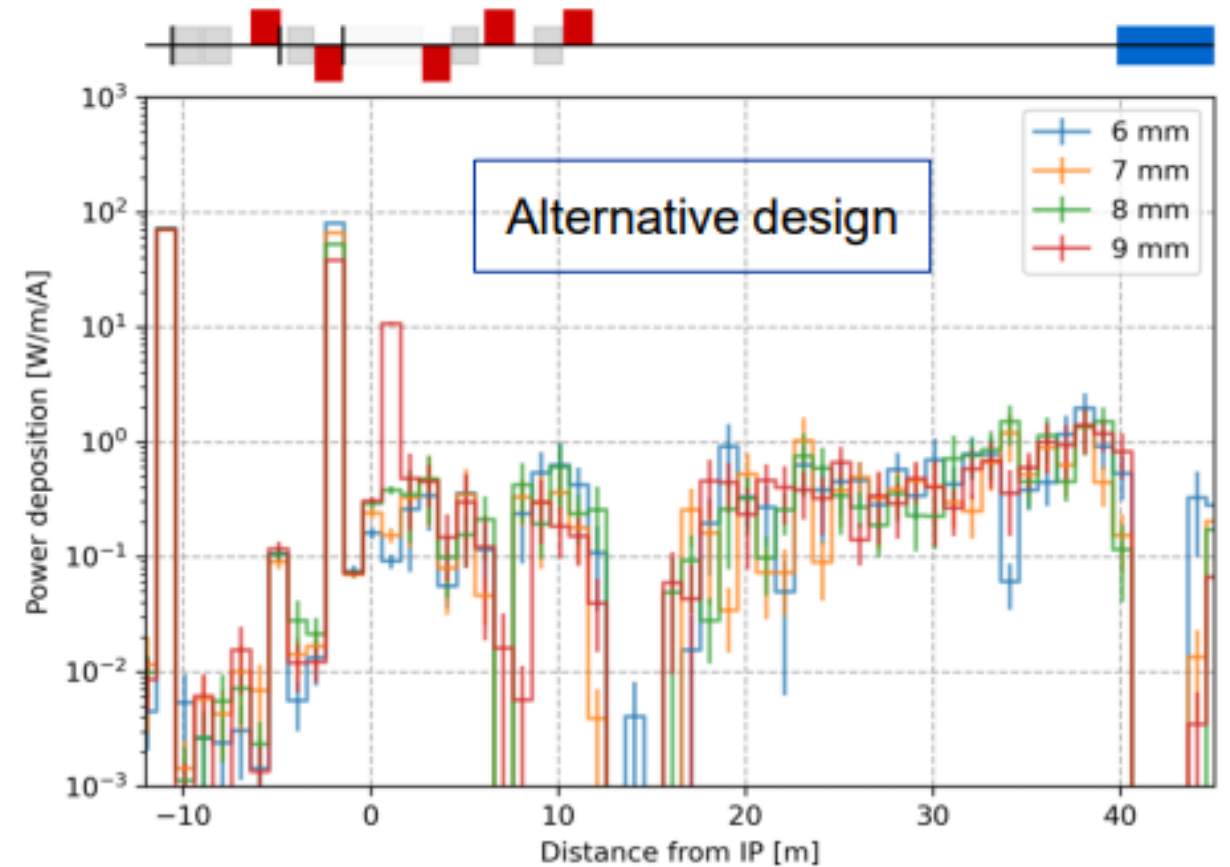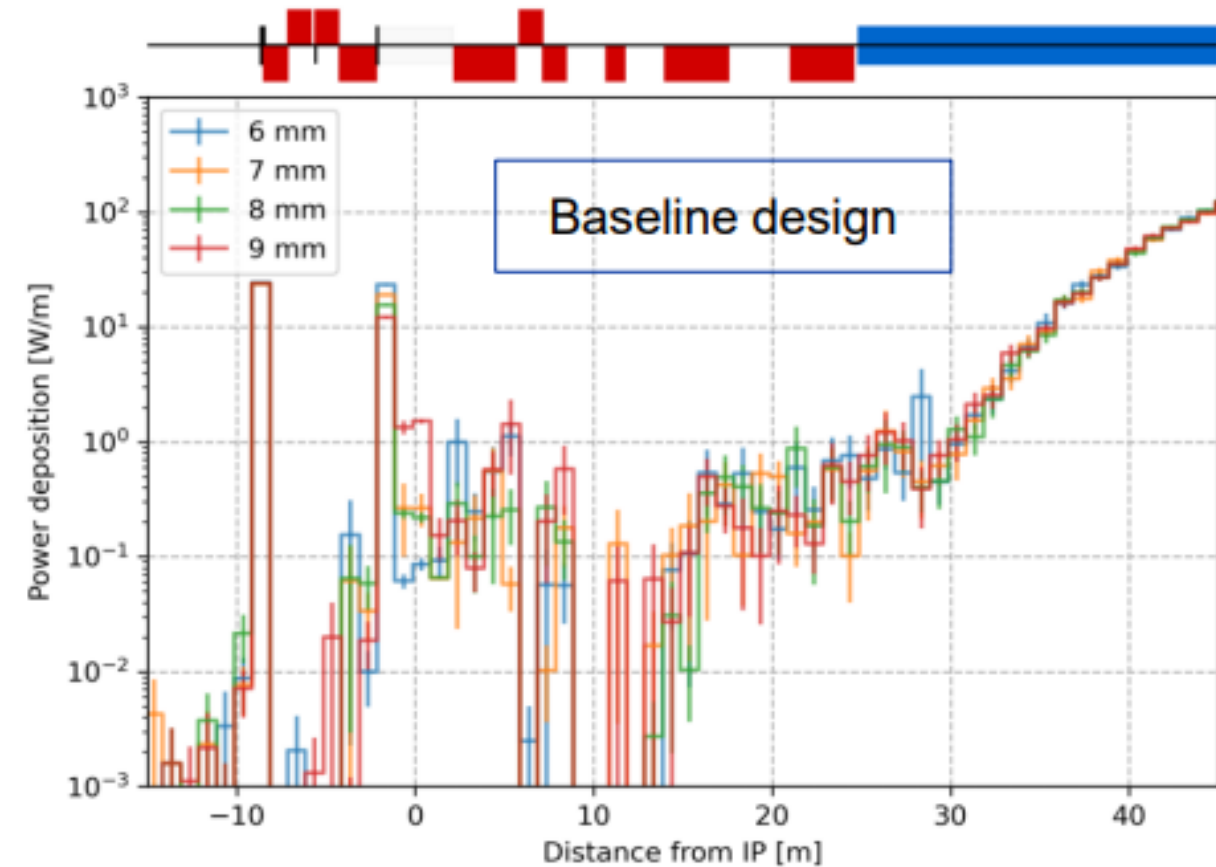
Comparison with the baseline design

10 seeds of 100000 primaries total of 1M primaries (*i.e.* positrons)

K. Andre

Comparison with the baseline design - Zoom

10 seeds of 100000 primaries total of 1M primaries (*i.e.* positrons)

K. Andre

CFM FODO cell design: equilibrium emittance behaviour

The total bending angle over a FODO in the Z-mode baseline(Oide-san solution) corresponds to the sum of the four dipoles (B1)
We **distributed among four dipoles** and two CFMs containing quadrupolar components **plus bending angle (θQF and θQD).**
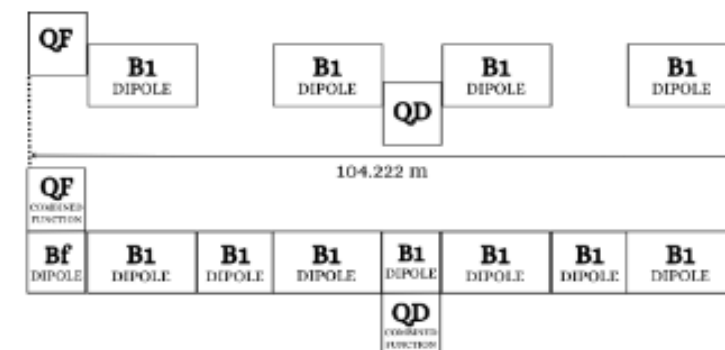
An equal dipolar magnetic field in the **CFM quadrupoles** leads to an unstable lattice due to the **change in the Damping Partition Numbers**.

We need to look for a solution

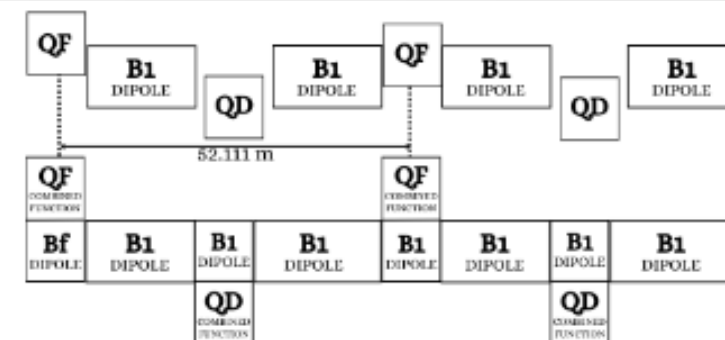The design should be compatible to the tt-mode

C. Garcia-Jaimes

Great progress everywhere !

Challenges:
optics evolution, parameter evolution, beam-based alignment, feedback,….

A wonderful energetic & competent team and getting younger

Lots of praise including from the FCC SAC

FCCWeek2023 Best Poster Awards

Prize Committee: Freya Blekman / DESY, Angeles Faus-Golfe / CNRS, Michiko Minty / BNL, Frank Zimmermann / CERN
Online survey, trophy & certificate: David Goldsworthy, Jeanette Kotzian, Panos Charitos

Vasiliki Batsari , the FCC-ee HTS4 Project

Mostafa Behtouei, Wakefields of the FCC-ee Collimation System