FCCIS WP2 workshop 29 Nov – 6 Dec 2021 and FCC ABP Day 2 Dec 2021 - *summaries and highlights*

Ilya Agapov, DESY
Michael Hofer, CERN
Tor Raubenheimer, SLAC
Frank Zimmermann, CERN

FCCIS WP2 workshop program – week 1

Monday 29 Nov 2021	Overview, Parameters, Optics and correction¶	Chairs: Angeles Faus-Golfe, Michael Hofer, Frank Zimmermann
9h00-9h25	Welcome, Overview, and FCC-ee Parameter Choices	Frank Zimmermann
9h25-9h30	Workshop information and logistics	Michael Hofer
9h30-10h00	Parameter optimisation at different working point	Dmitry Shatilov
10h15-10h45	Status of the FCC-ee optics and next step	Katsunobu Oide
10h45-11h15	Optics correction	Tessa Charles
Tuesday 30 Nov 2021	**Code development**	**Chairs: Tatiana Pieloni, Gianni Iadarola**
9h00-9h20	Optics repository	Ghislain Roy
9h20-9h40	MAD-X/PTC development and plans	Riccardo De Maria
9h40-10h00	Code comparison and lattice models	Leon van Riesen-Haupt
10h15-10h45	FCC-ee software framework	Felix Carlier
10h45-11h15	XSuite	Gianni Iadarola

Wed 1 Dec 2021	Collimation, Beam-Beam	Chair: Xavier Buffat
9h00-9h30	Layout and optics for a collimation insertion	Michael Hofer
9h30-10h00	Status of collimation simulations for the FCC-ee	Andrey Abramov
10h15-10h45	Beam-beam	Peter Kicsiny
10h45-11h15	Beam-beam studies using Lifetrack	Dmitry Shatilov
11h15-11h45	MAD-NG developments for FCC-ee	Laurent Deniau
Thu 2 Dec 2021	**FCC-ee Accelerators and Beam Physics Day** https://indico.cern.ch/event/1090005/	**Chairs: Edda Gschwendtner, Yannis Papaphilippou**

Friday 3 Dec 2021	MDI	Chair: Manuela Boscolo
9h00-9h20	MDI status and plans	Manuela Boscolo
9h20-9h40	Mechanical Model	Francesco Fransesini
9h40-10h00	CAD integration	Luigi Pellegrino
10h15-10h35	Alignment system in the IR/MDI	Leonard Watrelot
10h35-10h55	Vibration tolerance for IP and arc, feedback performance criteria	Katsunobu Oide
10h55-11h15	MAD-X simulations of vibration in the MDI	Eva Montbarbon
11h15-11h35	Strategy for Vibration suppression:mechanics & control aspects	Laurent Brunetti
13h30-14h00	Low angle radiative Bhaba monitor	Alain Blondel
14h00-14h30	CCT magnet design (followed by CCT Q1 magnet tour)	Mike Koratzinos

FCCIS WP2 workshop program – week 2

Monday 6 Dec 2021	Optics Correction (part 2), and Beam Measurements	Chair: Rogelio Tomas
9h00-9h30	Beam stabilisation and optics correction for PETRA IV	Ilya Agapov
9h30-10h00	Optics corrections & experience at ESRF-EBS	Simone Liuzzo
10h15-10h45	Optics Measurements at SuperKEKB	Jacqueline Keintzel
10h15-10h45	LHC Optics Corrections	Tobias Persson
	Afternoon: SC tours (2 pm and 4 pm)	

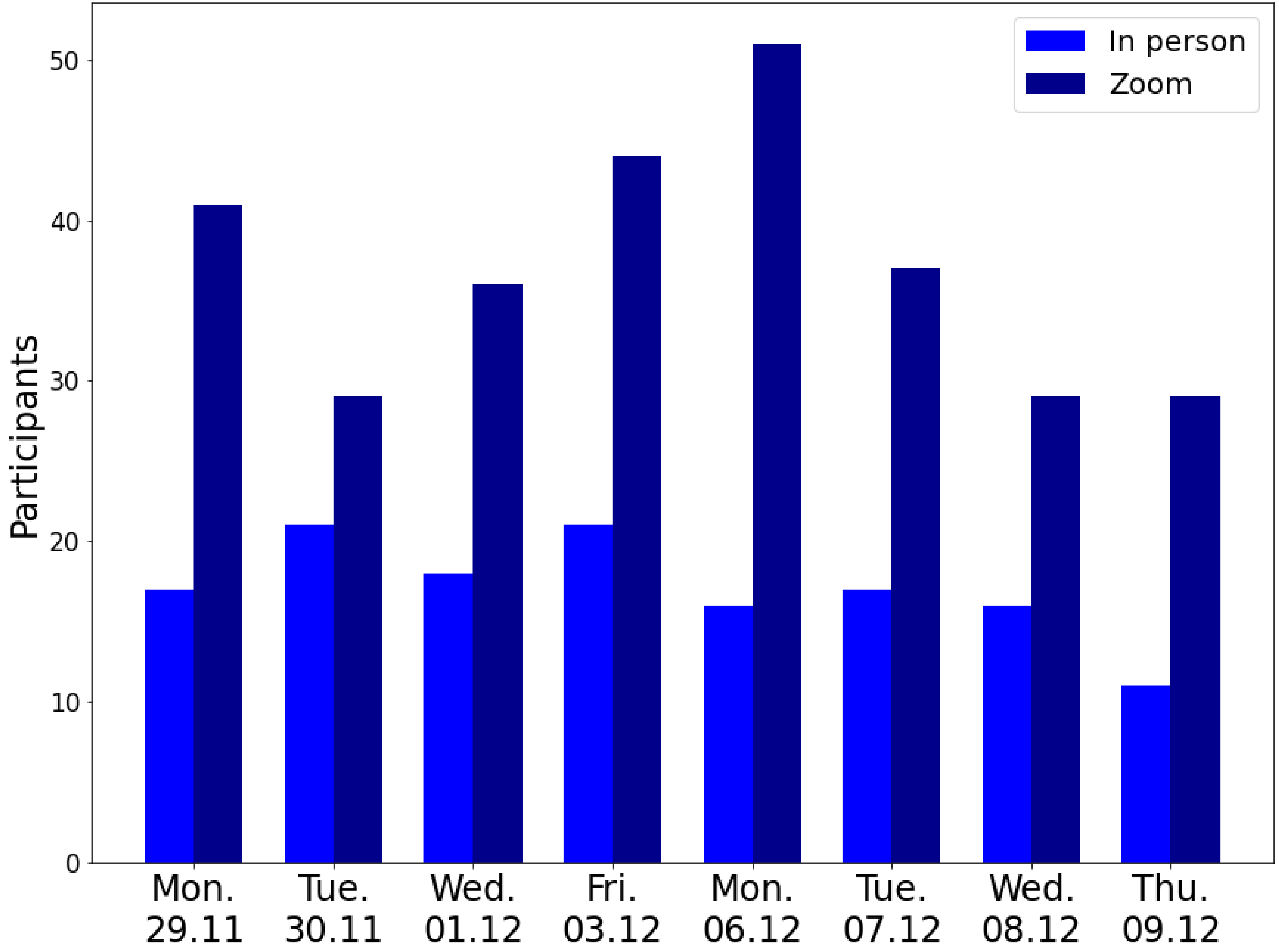
Tuesday 7 Dec 2021	Optics Booster, injection	Chair: Masamitsu Aiba, Michael Hofer
9h00-9h30	Pre-Booster	Ozgur Etisken
9h30-10h00	High-Energy Booster	Antoine Chance, Barbara Dalena, Herve De Grandsaignes
10h15-10h45	Injection and Extraction in the collider	Rebecca Louise Ramjiawan
10h15-10h45	Tracking studies in the collider ring	Patrick Hunchak
10h45-11h05	Design studies for the FCC-ee beam dump	Alexander Krainer

FCCIS WP2 workshop program – week 2 cont'd

Wed 8 Dec 2021	**Collective effects**	**Chair: Mauro Migliorati**
9h00-9h30	Impedance models and single-beam instabilities-Overview	Mauro Migliorati
9h30-10h00	Impedance model & TMCI threshold	Emanuela Carideo
10h30-11h00	Impedance of bellows and flanges	Chiara Antunono
11h00-11h30	Modelling of the FCC resistive wall impedance	Ali Rajabi
15h00-15h30	Electron cloud in the arcs	Fatih Yaman
15h30-16h00	Electron cloud in the arc quadrupoles	Damian Ayim
Thu 9 Dec 2021	**Vacuum, Radiation Environment, Polarisation**	**Chair: Tor Raubenheimer**
9h00-9h30	FCC-ee vacuum system & pressure forecast	Roberto Kersevan
9h30-10h00	Energy deposition & radiation levels in the arcs	Barbara Humann
10h15-10h45	Polarisation and precision energy calibration, overview and plans	Alain Blondel
Fri 10 Dec 2021	**Closing**	**Chair: Ilya Agapov**
9h00-11h00	Summary and close out	Ilya Agapov, Tor Raubenheimer, Frank Zimmermann

56 talks in total

participation per day in person and on zoom



"incredible organization" (I. Agapov)

essential for young researchers

Michael Hofer

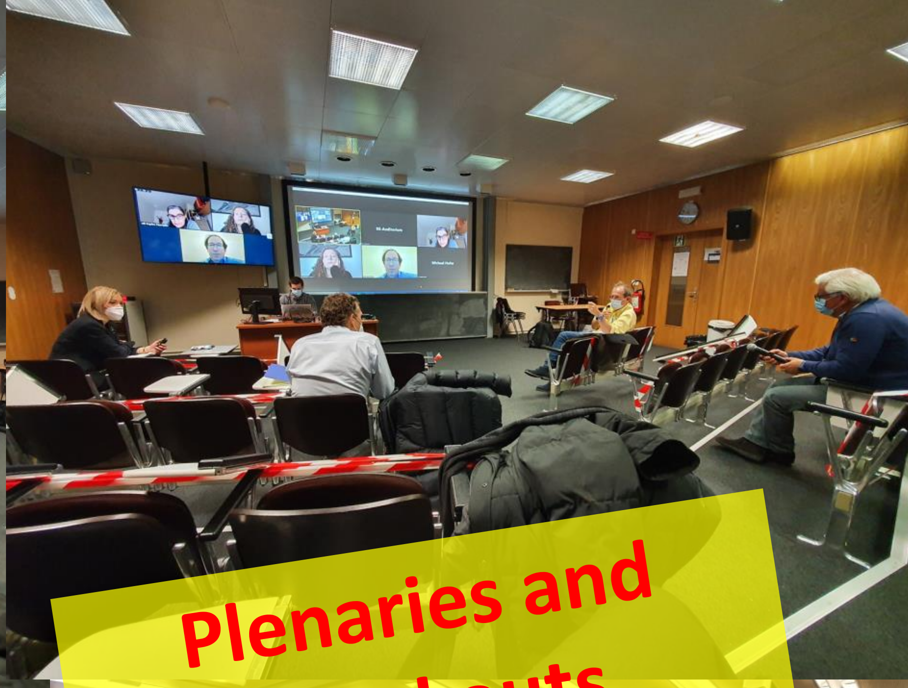
+ many satellite meetings
and follow-up meetings

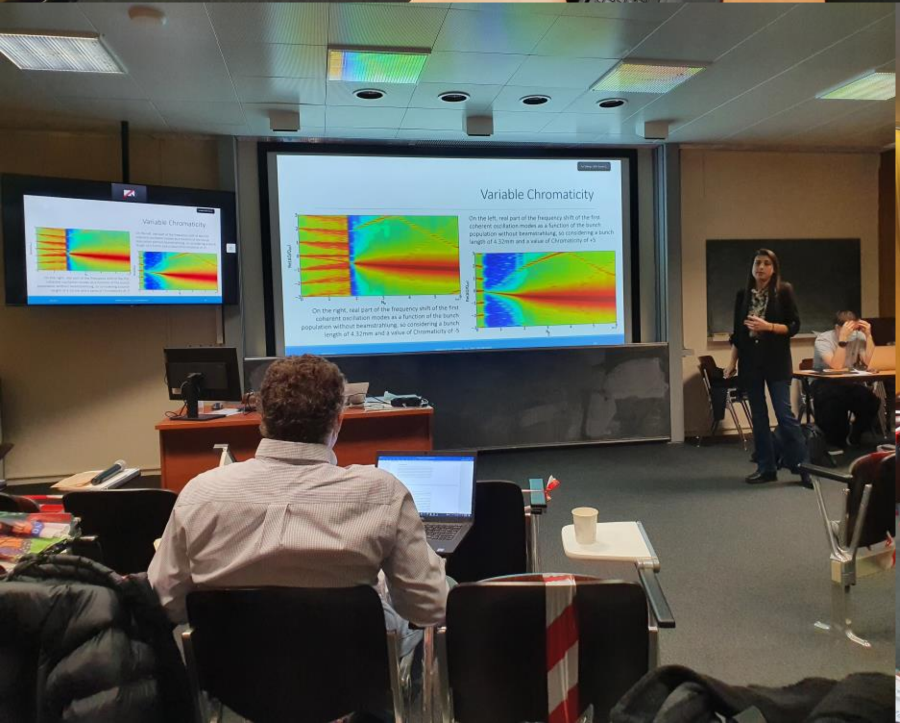

Opening Plenary


Layout in the RF section
Strategy
Step by step approach
Round model
Winglet model
Realistic model
Plenary Sessions

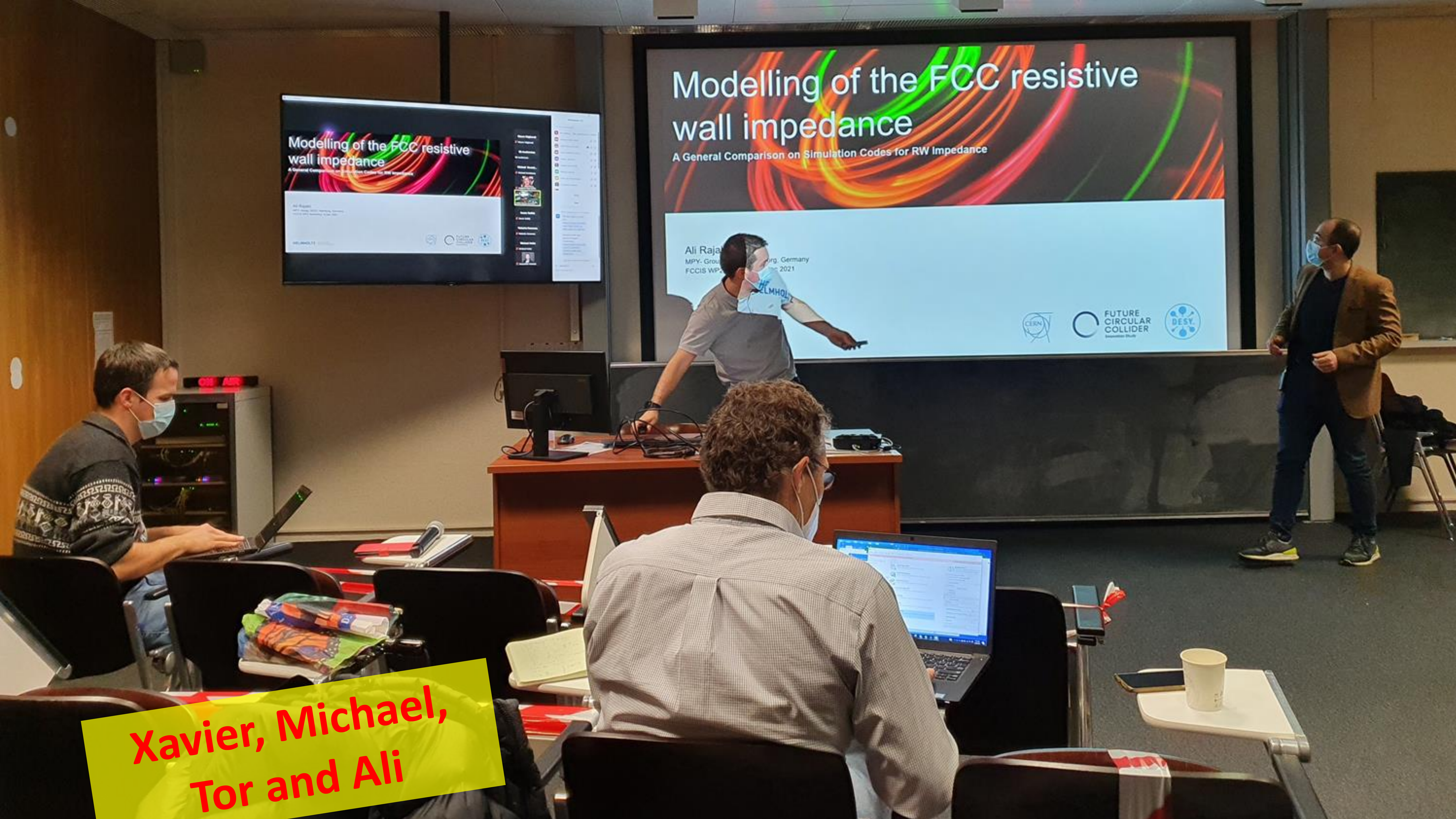

Optics Correction
Session - 2

Plenaries and Breakouts

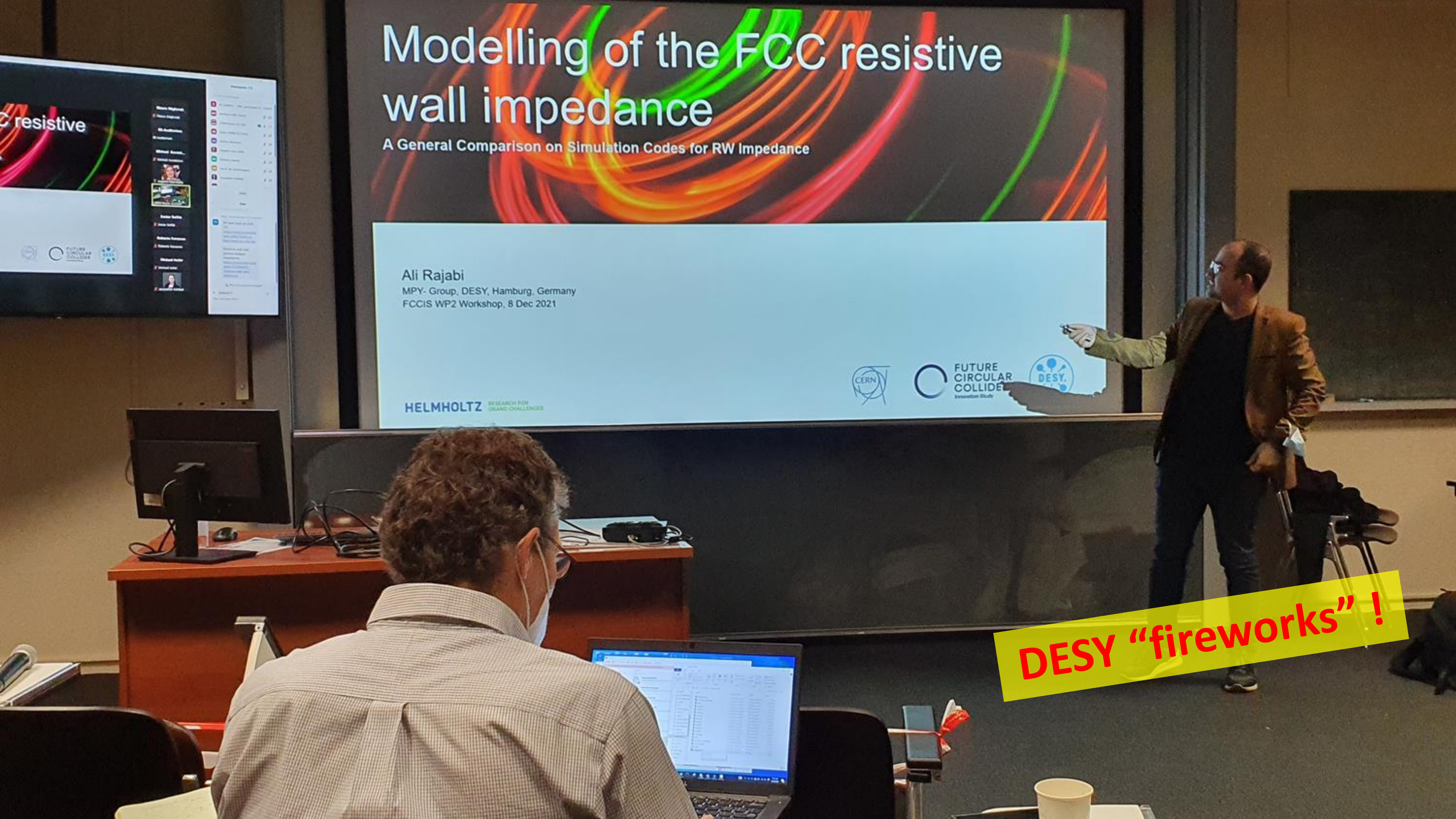





MDI Discussion
AUTODESK VIEWER



Xavier, Michael, Tor and Ali


Modelling of the FCC resistive wall impedance
A General Comparison on Simulation Codes for RW Impedance
Ali Rajabi
MPY- Group, DESY, Hamburg, Germany
FCCIS WP2 Workshop, 8 Dec 2021
HELMHOLTZ
FUTURE CIRCULAR COLLIDER
DESY "fireworks" !


1957
SYNCHROCYCLOTRON
SYNCHROCYCLOTRON
1959
PROTON SYNCHROTRON (PS)
SYNCHROTRON À PROTONS (PS)
1976
1976
SUPER PROTON SYNCHROTRON (SPS)
1983

SC Visit


1959
PROTON SYNCHROTRON (PS)
1976


Booster Discussion


DESY and CERN post-
session strategic planning

Monday
29 Nov 2021

Overview,
Parameters,
and
Optics

08:45 → 12:00 **BE Amphitheatre: Overview, Parameters & Optics** 6/2-024 - BE Auditorium Meyrin

Conveners: Angeles Faus-Golfe (IJClab IN2P3 CNRS-Université Paris-Saclay (FR)), Frank Zimmermann (CERN), Michael Hofer (CERN)

08:45 **Coffee break** 15m

09:00 **Welcome, Overview, and FCC-ee Parameter Choices** 1h

Speaker: Frank Zimmermann (CERN)

Welcome 30m

Speaker: Frank Zimmermann (CERN)

211129_FCCIS-WP2-W... | 211129_FCCIS-WP2-W... | Reminders.pdf | Reminders.pptx

Parameter optimisation at different working points (15' + 15') 30m

Speaker: Dmitry Shatilov (Budker Institute of Nuclear Physics (RU))

FCC_param_opt.pdf

10:00 **Coffee break** 15m

10:15 **Optics and correction** 1h

Status of the FCC-ee optics and next steps (15' + 15') 30m

Speakers: Katsunobu Oide, Katsunobu Oide (High Energy Accelerator Research Organization (JP))

Optics_since_CDR_Oid...

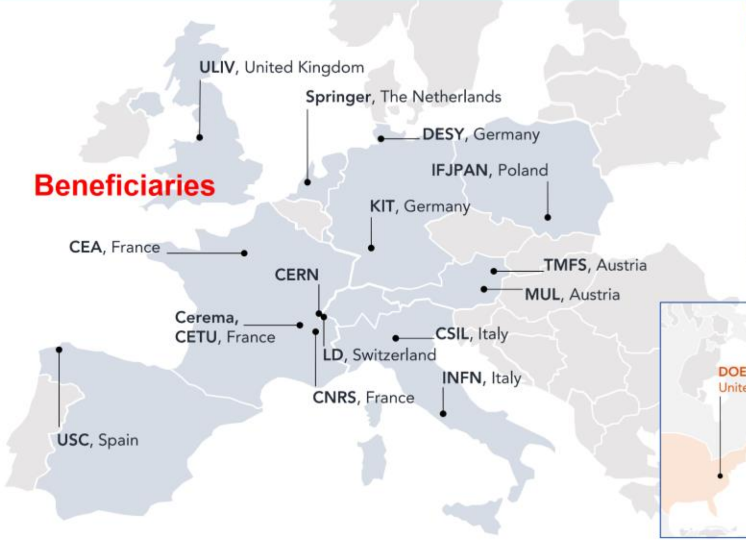
Optics correction (15' + 15') 30m

Speaker: Tessa Charles (University of Liverpool (GB))

FCC_collaboration_Nov...

H2020 DS FCC Innovation Study 2020-24

FUTURE CIRCULAR COLLIDER Innovation Study



Grant Agreement	FCCIS 951754
Duration	48 months
From-to	2 Nov 2020 – 1 Nov 2024
Project cost	7 435 865 €
EU contribution	2 999 850 €
Beneficiaries	16
Partners	6

FCCIS Work Packages

FUTURE CIRCULAR COLLIDER Innovation Study

WP1: study management (CERN)

WP2: collider design (DESY)

Deliver a performance optimised machine design, integrated with the territorial requirements and constraints, considering cost, long-term sustainability, operational efficiency and design for socio-economic impact generation.

WP3: integrate Europe (CERN)

Develop a feasible project scenario compatible with local – territorial constraints while guaranteeing the required physic performance.

WP4: impact & sustainability (CSIL)

Develop the financial roadmap of the infrastructure project, including the analysis of socio-economic impacts.

WP5: leverage & engage (IFJ PAN)

Engage stakeholders in the preparation of a new research infrastructure. Communicate the project rationale, objectives and progress. Create lasting impact by building theoretical and experimental physics communities, creating awareness of the technical feasibility and financial sustainability, forging a project preparation plan with the host states (France, Switzerland).

Welcome & Overview
Frank Zimmermann

WP2 hiring status

FUTURE CIRCULAR COLLIDER

DESY –
- doctoral student **Elaf Musa** (optics correction) started at DESY in June 2021
- postdoc: **Ali Rajabi** (impedance) started at DESY in August 2021
- **doctoral student position (MDI), goal: recruitment by winter 2021/22?**

CEA –
- PhD student for the booster (**Hervé de Grandsaignes**) started from March 2021

INFN –
- **postdoc mechanical engineer Francesco Fransesini (LNF)** started in 4 May 2021; possible first visit to CERN unclear due to pandemic
- postdoc position for impedance & collective effects (Sapienza); candidate could start January 2022
- possibly 2nd postdoc at INFN-LNF ?

KIT -
- doctoral student **Michael Reissig** (beam diagnostics) joined the team from March 2021

LAPP Annecy
- postdoc **Eva Montbarbon**
- **2nd postdoc mech engineer starts on 1 December 2021**

U Oxford –
- CERN doctoral student with Oxford U (IP feedback); candidate might be found in 2022

The Future Circular Collider Innovation Study (FCCIS) receives funding from the European Union's Horizon 2020 research and innovation programme under grant No 951754.
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WP2 formal accomplishments

FUTURE CIRCULAR COLLIDER

- WP2 milestones and deliverables in 2021

M2.1	MS4	Milestone	Product Break- down Structure *Delivered ! Ghislain Roy* Product Breakdown Structure | Zenodo	01/07/2021
D2.1	D4	Deliverable	Collider performance, beam optics and design considerations baseline *Delivered !* Collider performance, beam optics and design considerations baseline | Zenodo	01/11/2021

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Frank Zimmermann

Beamstrahlung

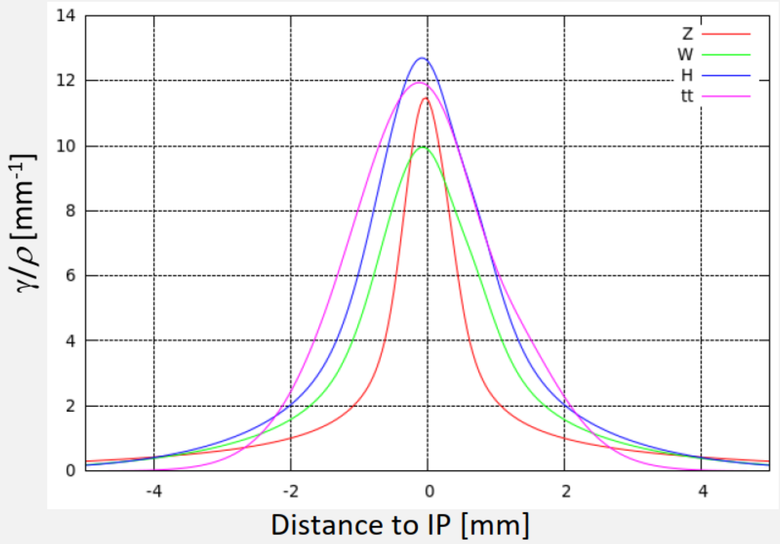
Bending radius in the field of the opposite bunch

surface density

$$\frac{1}{\rho_{\min}} \propto \frac{N_p}{\gamma\sigma_x\sigma_z} \propto \frac{\xi_y}{\sqrt{\beta_x^*\beta_y^*}}\sqrt{\frac{\varepsilon_y}{\varepsilon_x}} \approx 0.002$$

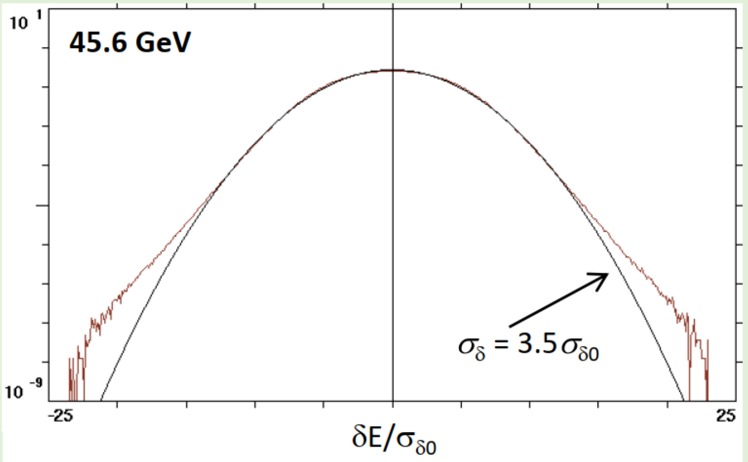
- With increasing energy, beta functions at IP should grow while ξ_y almost does not change => ρ increases.
- Bending radius is not constant along the trajectory, and it depends on the particle coordinates.

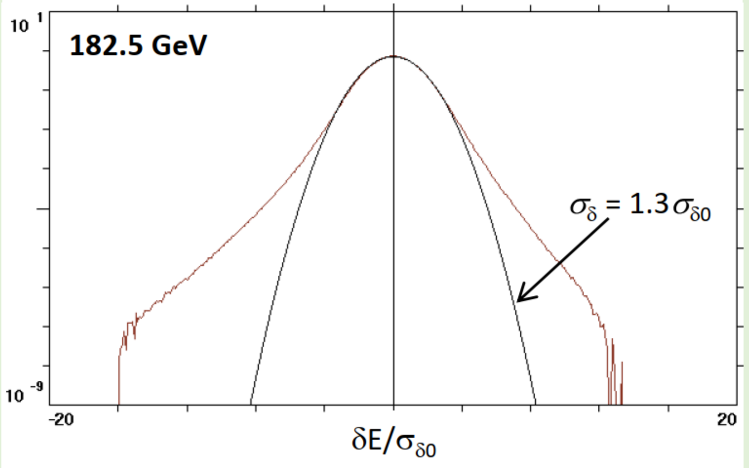
All initial coordinates = 0, except $y_0 = 2\sigma_y$



Parameters for this plot were taken from the CDR table. **At low energy, $\rho_{\min}$ < 8 m.**

Equilibrium energy distribution





- Critical energy of emitted photons: $u_c \propto \gamma^3/\rho$.
- The factor of increasing the energy spread is higher at low energies. The explanation is that it depends on the ratio of the bending radii in the arcs (SR) and in the IPs (BS).
- For low-energy colliders, $\rho_{\min}$ at IP can be even smaller, but the ring radius is <u>much</u> smaller than in FCC, so the effect of BS is negligible.
- At 45.6 GeV, the energy loss due to BS is ~0.31 MeV per IP, compared to ~36 MeV in the arcs due to SR.
- Long tails at ttbar are produced by single emitted BS photons. The ratio u_c/σ_δ is important here, which grows with γ.
- For asymmetry of the tails, an important parameter is the damping factor during the period of synchrotron oscillations. Therefore, asymmetry grows with γ.

Momentum acceptance determines the maximum allowable critical energy for BS photons, which in turn is proportional to ξ_y (and hence luminosity).

Dmitry Shatilov

Parameter Optimization at Z

- Recent simulations (Y. Zhand, M. Zobov) have shown that when impedances are taken into account, coherent beam-beam instability is enhanced. To solve the problem, momentum compaction factor was increased by switching from 60°/60° to 90°/90° long cell optics in arcs (more details in the presentation by K. Oide). This also helps to mitigate collective instabilities.
- The negative consequences of increasing α_p (increase in ε_y and in L_i) are weakened at this energy, but to obtain the "old" luminosity, it is necessary to slightly increase the linear charge density – this will probably be impossible due to other restrictions.
- Low RF frequency (400 MHz) is preferable to mitigate the coherent beam-beam instability (due to smaller ν_z), electron clouds and ion instabilities (due to greater bunch spacing).
- In the "old" optics with 4 IPs, in order to suppress the coherent beam-beam instability, it was required to reduce β_x^* from 15 to 10 cm. As the α_p has increased, this may not be necessary, but should be checked.
- As it is now seen, the main problem is associated with misalignments and errors, which (even after correction) can lead to a significant decrease in the momentum acceptance. An acceptable bunch population and luminosity depend on how successfully we can solve this problem.

Parameter Optimization at WW

Arc optics: 60°/60° => 90°/90°, long cell

At this energy, the 60°/60° optics is optimal, but we decided to switch to 90°/90° long cell – more details in the presentation by K. Oide.

Drawback: peak luminosity drops by about 20%.

Benefits:

- Same arc optics as at Z, simplifies transition from Z to W. The integrated luminosity may not decrease.
- Do not need anymore 60°/60° cell: reduces the number of sextupoles and slightly increases the filling factor.
- Improves overall coherent stability.
- Increases the synchrotron tune (this is important for the energy calibration).

RF options

- For energy calibration by resonant depolarization, the synchrotron modulation index is important:
  $$\zeta = \nu_0 \sigma_\delta / \nu_z$$
- In the CDR, with ν_z = 0.05, we get ζ=2.4, which is too large. And now we have increased σ_δ, since the arc radius has decreased. But increase in α_p helps.
- With U_{RF} = 750 MV and 400 MHz (as in the CDR) we get ν_z = 0.067 and ζ=1.9. With U_{RF} = 1 GV, we get ν_z = 0.08 and ζ=1.57. The optimum RF voltage must be determined by agreement between RF and depolarization requirements.
- Higher RF frequency can be useful. For example, with 600 MHz and 700 MV we get ν_z = 0.079. There should be no obstacles from the side of coherent instability.

Parameter Optimization at ZH

- At this energy, we have to switch to 90°/90° short cell optics to get small emittances.
- Resonant depolarization is not possible here, so we do not need large ν_z.
- Piwinski angle is not very large, so we can choose $\nu_x \approx 0.5 + \phi\nu_z$ and avoid coherent beam-beam instability.
- Change in RF frequency and/or RF voltage will affect ϕ and ν_z to the same extent, therefore will not affect the above condition.
- The only requirement for the RF system is to provide more RF acceptance than the momentum acceptance of nonlinear lattice.
- As for all energies, luminosity depends on momentum acceptance in the presence of misalignments and errors.

Dmitry Shatilov

Parameter Optimization at ttbar

Luminosity is limited by BS lifetime:

$$\tau_{bs} \propto \exp\left(\frac{2\alpha\eta\rho}{3r_e\gamma^2}\right)\cdot\frac{\rho\sqrt{\eta\rho}}{L_i\cdot\gamma^2}$$

α – fine structure constant

η – momentum acceptance

ρ – bending radius of a trajectory at the IP

L_i – length of interaction area

The major tool for increasing the lifetime is making ρ larger. For flat beams, ρ is inversely proportional to the surface charge density:

$$\frac{1}{\rho} \propto \frac{N_p}{\gamma\sigma_x\sigma_z} \propto \frac{\xi_y}{L_i}\sqrt{\frac{\varepsilon_y}{\beta_y^*}} \propto L\sqrt{\frac{\varepsilon_y}{\beta_y^*}}$$

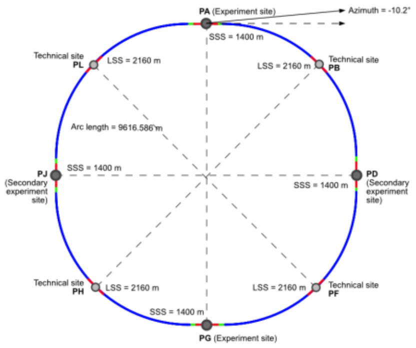
(assuming $L_i \approx \beta_y^*$)

- We need to increase ρ with large luminosity => small emittances (90°/90° short cell optics) and ***increase*** in L_i (i.e. in σ_x) and β_y^*.
- Since ε_x should be small, σ_x is controlled by β_x^* which was increased to 1 m.
- Asymmetrical momentum acceptance to match the actual energy distribution (K. Oide).
- The only requirement for the RF system is to provide more RF acceptance than the momentum acceptance of nonlinear lattice. The bunch length does not matter! But we should keep $N_p \propto \sigma_z$.

The new layout

FUTURE CIRCULAR COLLIDER

- The new layout "31" series has been presented by J. Gutleber in the last optics meeting.
  - 8 surface sites, 4 IP.
  - complete period-4 + mirror symmetries.
- Let us choose "PA31-1.0" for the baseline, for the time being.
  - The adaptation to other variants, if necessary, will be minor.



PA31-1.1 & 1.6 fallback alternatives — J. Gutleber

Scenario	PA31-1.0	PA31-1.1	PA31-1.6
Number of surface sites	8 (potential additional small access shafts at CERN or for ventilation at sites with long access tunnels, e.g. PF)		
Number of arc cells	42		
Arc cell length	213.04636573 m		
SSS@IP (PA, PD, PG, PJ)	1400 m	1400 m	1410 m
LSS@TECH (PB, PF, PH, PL)	2160 m	2100 m	2110 m
Azimuth @ PA (0 = East)	-10.75°	-10.45°	-10.2°
Sum of arc lengths	76 932.686 m		
Total length	91 172.686 m	90 932.686 m	91 052.686 m

Fine adjustment to the layout "PA31-1.0"

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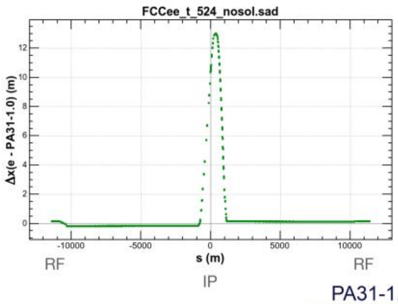
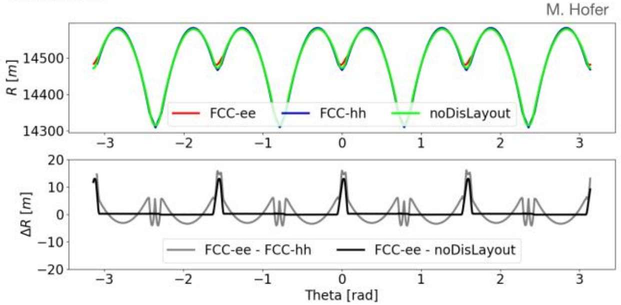
- Now the beam line fits within a few cm from the layout in the arc.
  - The resulting ring circumference is *1.42 m longer* than the layout, due to the IR excursion.
- However, some discrepancy has been found between hh's beam line
  - Investigation is going on by M. Giovannozzi, M. Hofer, T. Risselada





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FCC-hh (Number of arc cells, Arc cell length)

If this number is strictly kept in the design of hh-arc, a discrepancy with the arc may happen?

The arc cell

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- The most preferred phase advances of the FODO in the arc for luminosity: 90/90 @$t\bar{t}$, 60/60 @W, 45/45 (or long 90/90) @Z (D. Shatilov).
  - With 45/45, $\beta_{x,y}$ at SF/SD come close to each other: Long 90/90 is better.
- If we need a lattice structure compatible to all 90/90, 60/60, long 90/90, it will look like (**bold** letters show the sextupole locations. Only showing a half period):

```
          0         1         2         3         4         5         6
 90/90S: FDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFD
 60/60:  FDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFD
 90/90L: F D F D F D F D F D F D F D F D F D F D F D F D F D F D F D F D F D F
```

  - Then 70 FODOs are necessary for the periodicity.
- Instead, if we can eliminate 60/60, the structure is simplified to:

```
          0         1
 90/90S: FDFDFDFDFDFDFDFDFDFD
 90/90L: F D F D F D F D F D
```

- Nevertheless, as the 60/60 is only for W; the loss of luminosity at W can be compensated by:
  - The less tuning time on the transition from 90/90L to 60/60 (more integrated luminosity).
  - Slight increase of luminosity at other energies (D. Shatilov).
    - The filling factor of dipoles: with 60/60: 80.4%, without 60/60: 81.2%.
- **Thus we have chosen to eliminate 60/60, for the time being.**

Katsunobu Oide

The arc cell optics (1 period = 5 FODOs)

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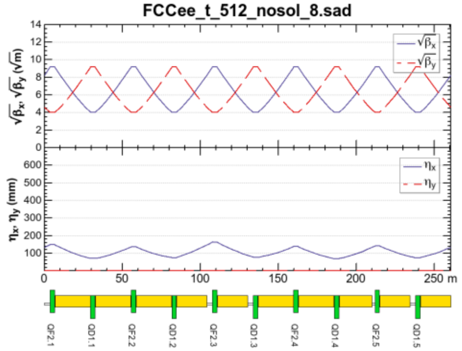
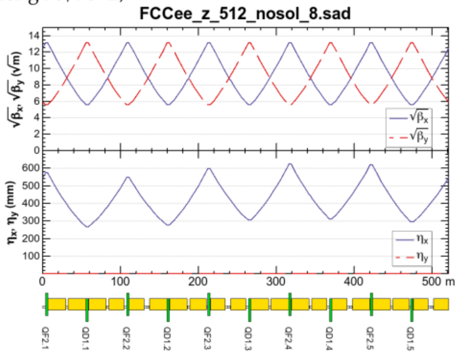
Short 90/90: $t\bar{t}$, Zh



Long 90/90: Z, W



- For long 90/90:
  - The QDs for short 90/90 of the outer ring are turned off.
    - However, their BPMs and correctors are usable for additional orbit/optics correction power.
  - The polarity of QFs for short 90/90 are reversed alternatively to serve as QDs. These should have an easy mechanism in the wiring for switching.
- The arc dipoles should be divided into 3 pieces for installation. Then the field at their connection may matter.

Parameters

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Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	91.174117		91.174107	
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		9600	880	248	36
Bunch population	[10^{11}]	2.53	2.91	2.04	2.64
Horizontal emittance ε_x	[nm]	0.71	2.16	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.32	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	150 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.563 / 53.600		100.565 / 98.595	
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.130	0.069 / 0.154	0.103 / 0.185	0.157 / 0.229
Bunch length (SR/BS) σ_z	[mm]	4.37 / 14.5	3.55 / 8.01	3.34 / 6.00	2.02 / 2.95
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	4.0 / 7.25
Harmonic number for 400 MHz		121648			
RF freuqeuncy (400 MHz)	MHz	399.994581		399.994627	
Synchrotron tune Q_s		0.0370	0.0801	0.0328	0.0826
Long. damping time	[turns]	1168	217	64.5	18.5
RF acceptance	[%]	1.6	3.4	1.9	3.1
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y [a]		0.0040 / 0.152	0.011 / 0.125	0.014 / 0.131	0.096 / 0.151
Luminosity / IP	[$10^{34}/\text{cm}^2\text{s}$]	189	19.4	7.26	1.33
Lifetime (q + BS)	[sec]	–		1065	2405
Lifetime (lum)	[sec]	1089	1070	596	701

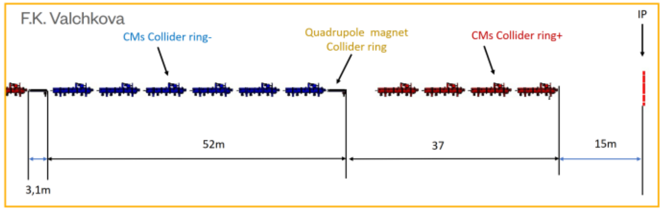
[a] incl. hourglass.

The luminosities and beam-beam related numbers are based on a simple model w/o beam-beam simulations.

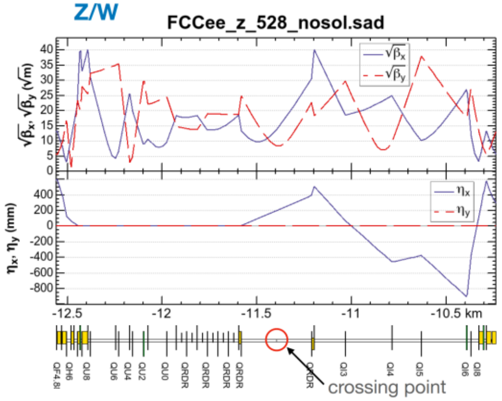
Katsunobu Oide

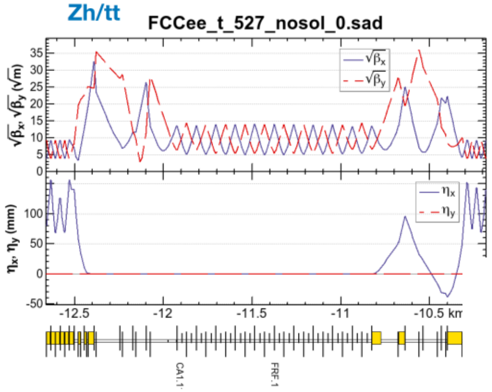
Layout in the RF section ($t\bar{t}$)

- Each space for RF is extended from 40 m to 52 m according to the request by F.K. Valchkova.
- The center of RF ("FRF") section is now shifted from the geometric center of the section to produce $\lambda_{\mathrm{RF400}}/2$ path difference from the IP between $e^{\pm}$, which is the condition of the common RF to ensure the collision at the IP.
  - The harmonic number for 400 MHz is 121648 with $f_{\mathrm{RF}} = 399.994627\,\mathrm{MHz}$ for Zh/tt.



- Designed an RF section for Z/W, which has a crossing point in the middle. The right part of the section is rebuilt at the transition to Zh/tt.





Katsunobu Oide

Optimum RF phase ($t\bar{t}$)

Suggested by T. Raubenheimer, D. Shatilov

If we have two RF frequencies f_1 and f_2 with voltages $V_1$and V_2, the total accelerating voltage $V(z)$ and its potential energy $W(z)$ are written as:

$$V(z) = V_1 \sin(\phi_1 + k_1 z) + V_2 \sin(\phi_2 + k_2 z) - U_0 = -\frac{\partial W(z)}{\partial z}, \quad (1)$$

$$W(z) = -\frac{V_1}{k_1}\cos(\phi_1 + k_1 z) - \frac{V_2}{k_2}\cos(\phi_1 + k_2 z) + U_0 z, \quad (2)$$

where $\phi_{1,2}$ are the RF phases at the equilibrium $z = 0$, and $k_{1,2}$ are the wave numbers, respectively. The energy loss per turn is denoted by U_0. At the equilibrium, $V(z) = 0$, obviously.

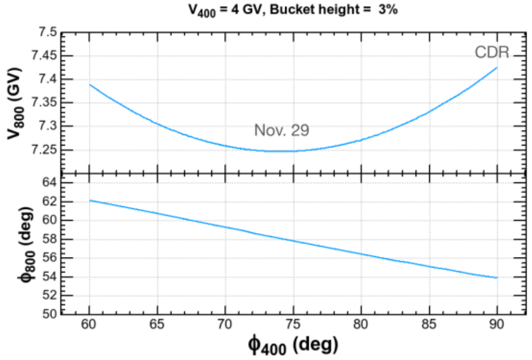
The bucket hight δ is obtained by energy conservation at the unstable fixed point $z_1 > 0$:

$$V(z_1) = 0, \quad (3)$$

$$W(z_1) = -\frac{\alpha C E}{2}\delta^2 + W(0), \quad (4)$$

where α, C, and E are the momentum compaction, circumference, and beam energy, respectively. Note that the kinetic energy term above has negative sign.

Then once ϕ_1 and V_1 are given, we can obtain the solution for ϕ_2, V_2, and z_1 to satisfy the equations above, at least numerically.



I have once obtained the optimum for a given V' or bunch length, but D. Shatilov pointed out that an optimization for a fixed bucket height is suitable for FCC-ee.

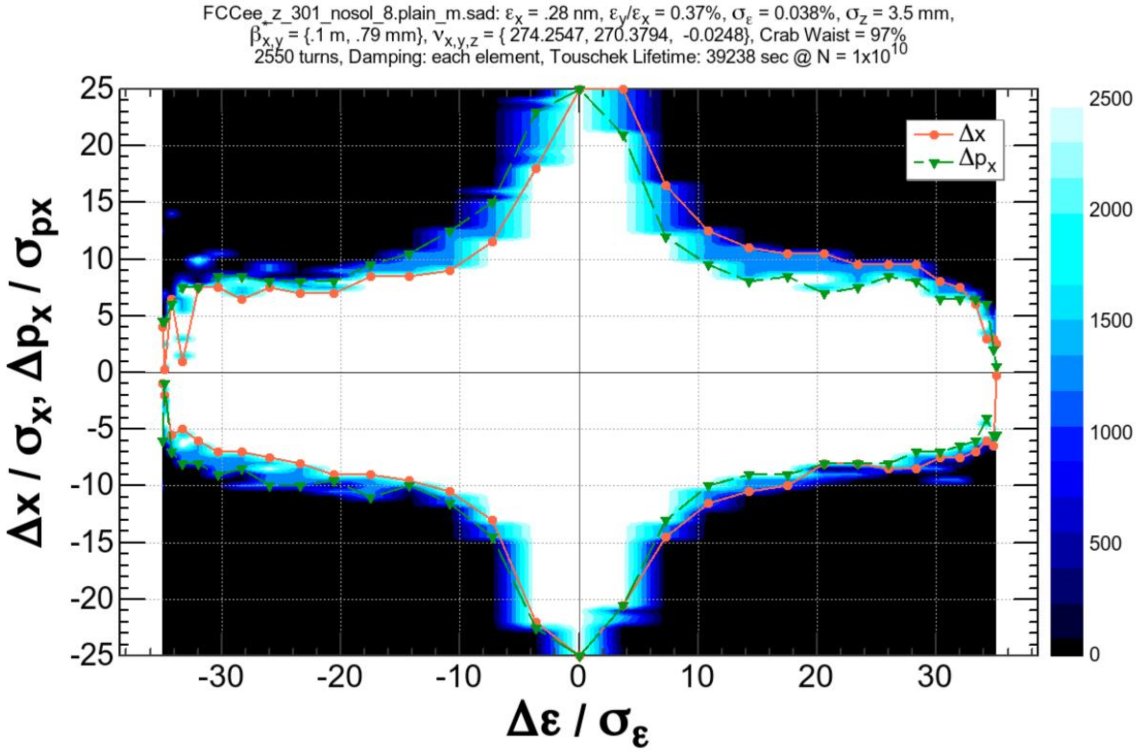
Reduction of DA by errors/corrections

FUTURE CIRCULAR COLLIDER

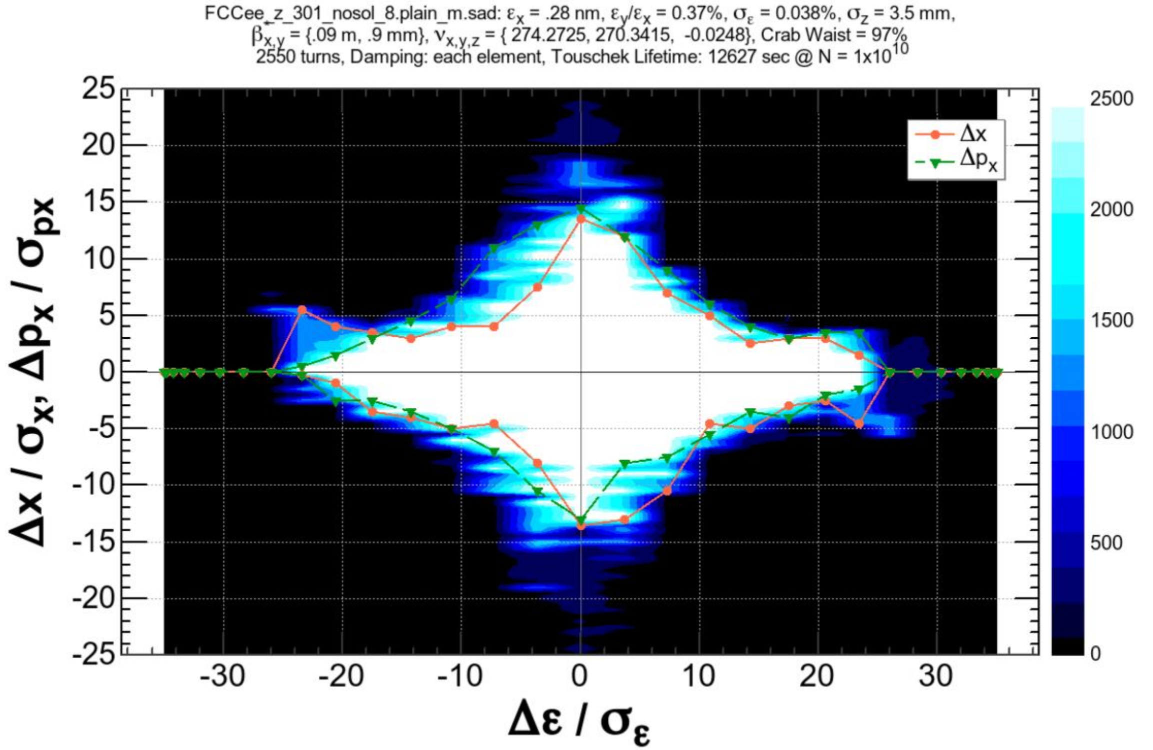
An example of errors and corrections by T. Charles, with an old 4IP lattice.

301_8

No error



Errors + corrections ("seed 1")



- The dynamic aperture shrinks with the errors and corrections ("seed 1") as seen in figures above.
  - The errors/corrections for 301_9 were simply applied on 301_8. The resulting vertical emittance raised to 0.2 pm.
- The corresponding momentum acceptance: ±1.3% (no error) → ±0.8%? (seed_1).
- Further optimization of sexts with errors/corrections may improve the DA

Katsunobu Oide

Tessa Charles

Orbit correction:

- MICADO & SVD from MAD-X
  - Hor. corrector at each QF, Vert. corrector at each QD

    1598 vertical correctors / 1590 horizontal correctors
  - BPM at each quadrupole

    1598 BPMs vertical / 1590 BPMs horizontal

Vertical dispersion and orbit:

- Orbit Dispersion Free Steering (DFS)

$$\begin{pmatrix}(1-\alpha)\vec{y} \\ \alpha\vec{D}_y\end{pmatrix} = \begin{pmatrix}(1-\alpha)\mathbf{A} \\ \alpha\mathbf{B}\end{pmatrix}\vec{\theta}$$

Linear coupling:

- Coupling resonant driving terms (RDT)
  - 1 skew at each sextupole

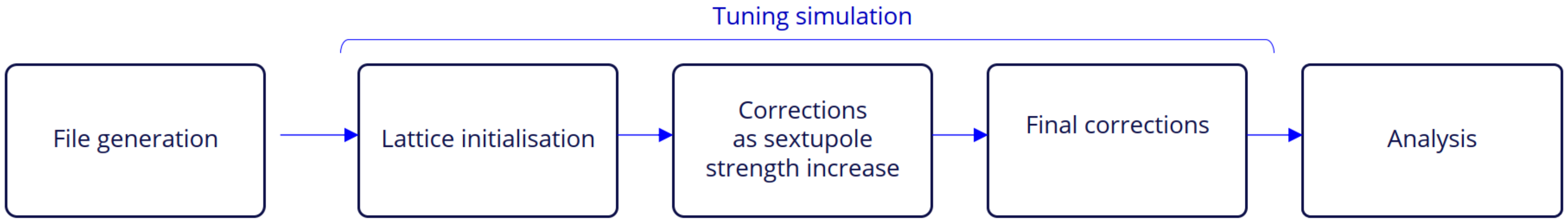
$$\begin{pmatrix}\vec{f}_{1001} \\ \vec{f}_{1010} \\ D_y\end{pmatrix} = -\mathbf{M}\,\vec{\mathbf{J}}$$

Beta beating correction & Horizontal dispersion via Response Matrix:

- Rematching of the phase advance at the BPMs
  - 1 trim quadrupole at each sextupole

$$\begin{pmatrix} f_1\left(\frac{\beta_1-\beta_{y0}}{\beta_{y0}}\right) \\ f_2\left(\frac{\beta_2-\beta_{y0}}{\beta_{y0}}\right) \\ \dots \\ f_m\left(\frac{\beta_m-\beta_{y0}}{\beta_{y0}}\right) \end{pmatrix}_{meas} = \begin{pmatrix} f_1\,(R_{11}, R_{12}, R_{13}, \dots, R_{1n}) \\ f_2\,(R_{21}, R_{22}, R_{23}, \dots, R_{1n}) \\ \dots \\ f_m\,(R_{m1}, R_{m2}, R_{m3}, \dots, R_{mn}) \end{pmatrix} * \begin{pmatrix} k_1 \\ k_2 \\ \dots \\ k_n \end{pmatrix}$$

Tuning simulations



FCC-ee emittance tuning results

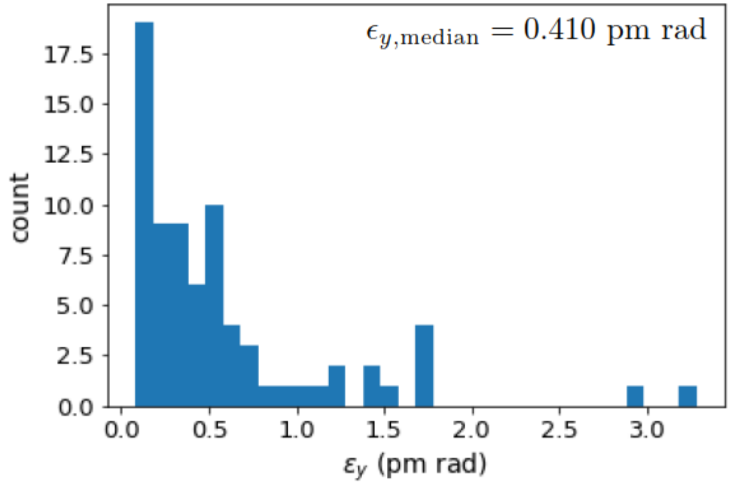
RMS misalignment and field errors tolerances:

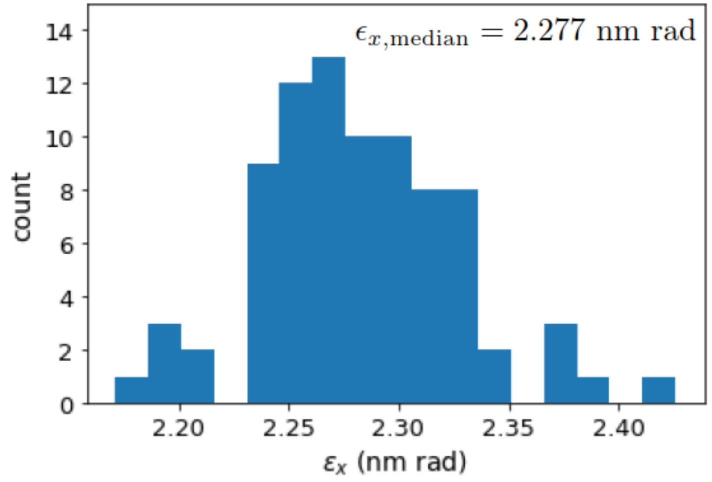
Type	ΔX (μm)	ΔY (μm)	ΔPSI (μrad)	ΔS (μm)	ΔTHETA (μrad)	ΔPHI (μrad)
Arc quadrupole*	50	50	300	150	100	100
Arc sextupoles*	50	50	300	150	100	100
Dipoles	1000	1000	300	1000	-	-
Girders	150	150	-	1000	-	-
IR quadrupole	100	100	250	50	100	100
IR sextupoles	100	100	250	50	100	100
BPM**	-	-	100	-	-	-

* misalignment relative to girder placement
** misalignment relative to quadrupole 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	$\Delta k/k = 2 \times 10^{-4}$

ttbar (182.5 GeV) 4IP lattice,
after correction strategy:





Tessa Charles

Wednesday
1 Dec 2021

Collimation,
Beam-beam,
and
MAD-NG

08:40 → 11:45 **BE Amphitheatre: Collimation, beam-beam**

6/2-024 - BE Auditorium Meyrin | zoom | Join | 6/2-024

Convener: Xavier Buffat (CERN)

08:45 **Coffee break** 15m

09:00 **Collimation** 1h

- Layout and optics for a collimation insertion in FCC-ee (15'+ 15') — 30m
  Speaker: Michael Hofer (CERN)
  FCC_collimation_meeti...
- Status of collimation simulations for the FCC-ee (15'+ 15') — 30m
  Speaker: Andrey Abramov (CERN)
  CollimationSimulations... | CollimationSimulations...

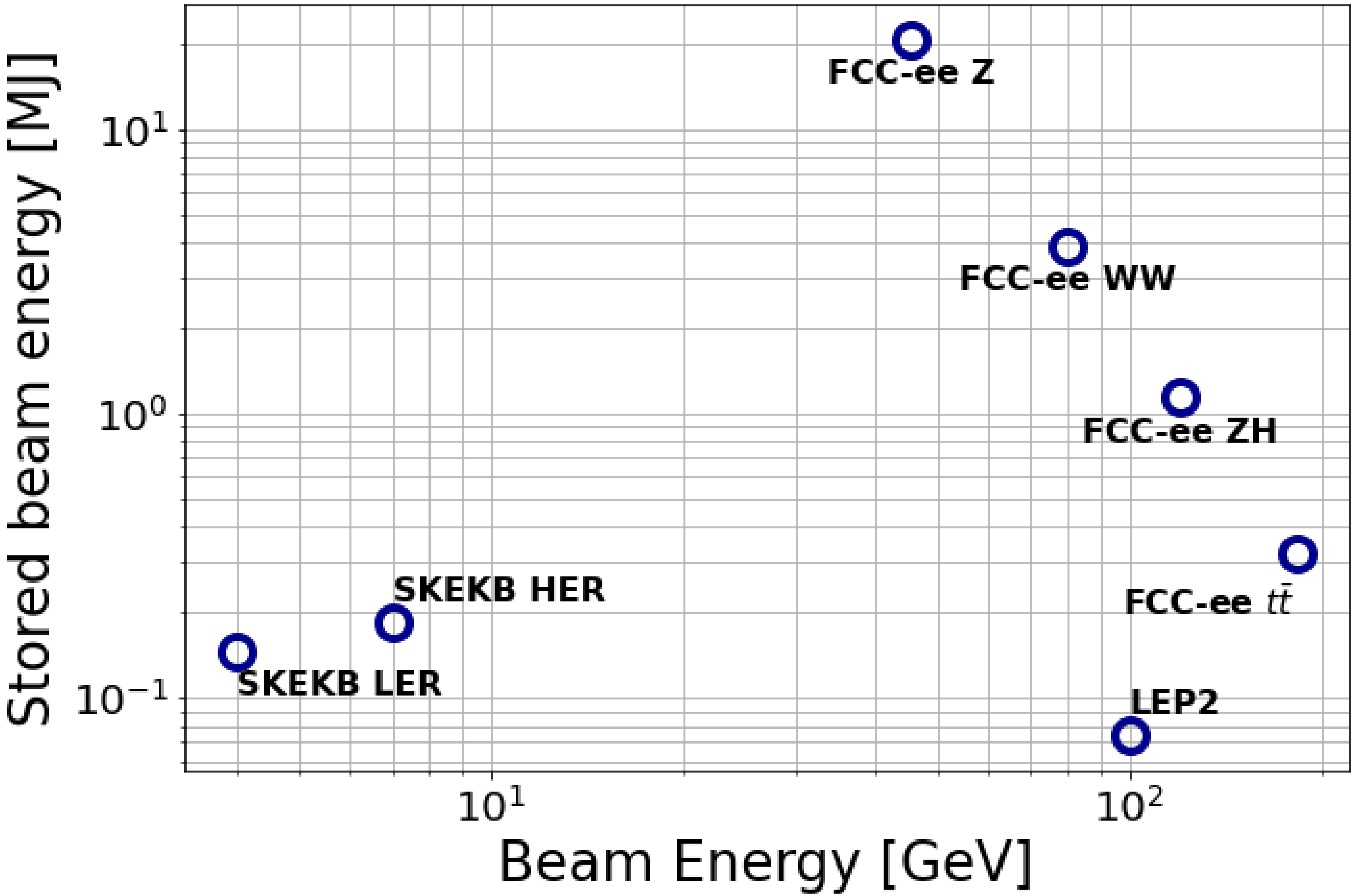
10:00 **Coffee break** 15m

10:15 **Beam-beam** 1h 15m

- Code development (15'+ 15') — 30m
  Speaker: Peter Kicsiny (EPFL)
  pkicsiny_beambeam_6...
- Quasi-strong-strong beam-beam simulations for FCC-ee (15'+ 15') — 30m
  Speaker: Dmitry Shatilov (Budker Institute of Nuclear Physics (RU))
  qss_beam_beam.pdf
- MAD-NG developments for FCC-ee — 30m
  Speaker: Laurent Deniau (CERN)
  ld_2112-mad_fcc_slide...

Collimation and machine protection

Michael Hofer



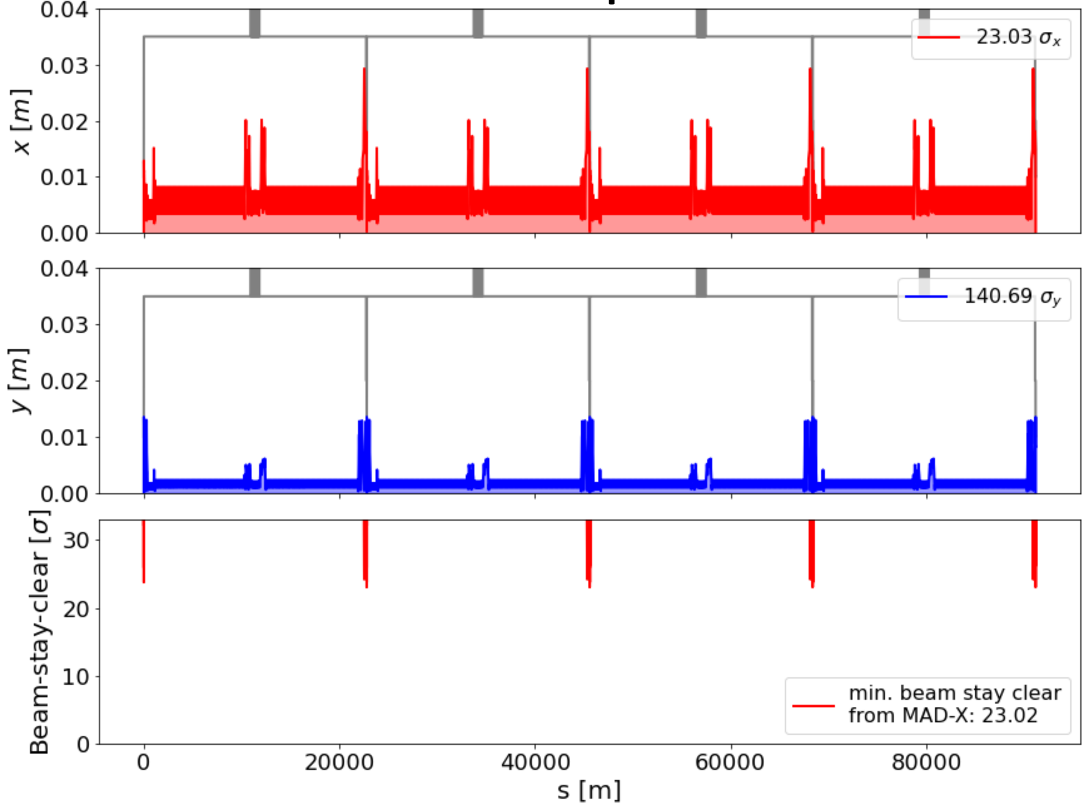
Beam stay clear in new layout

Michael Hofer

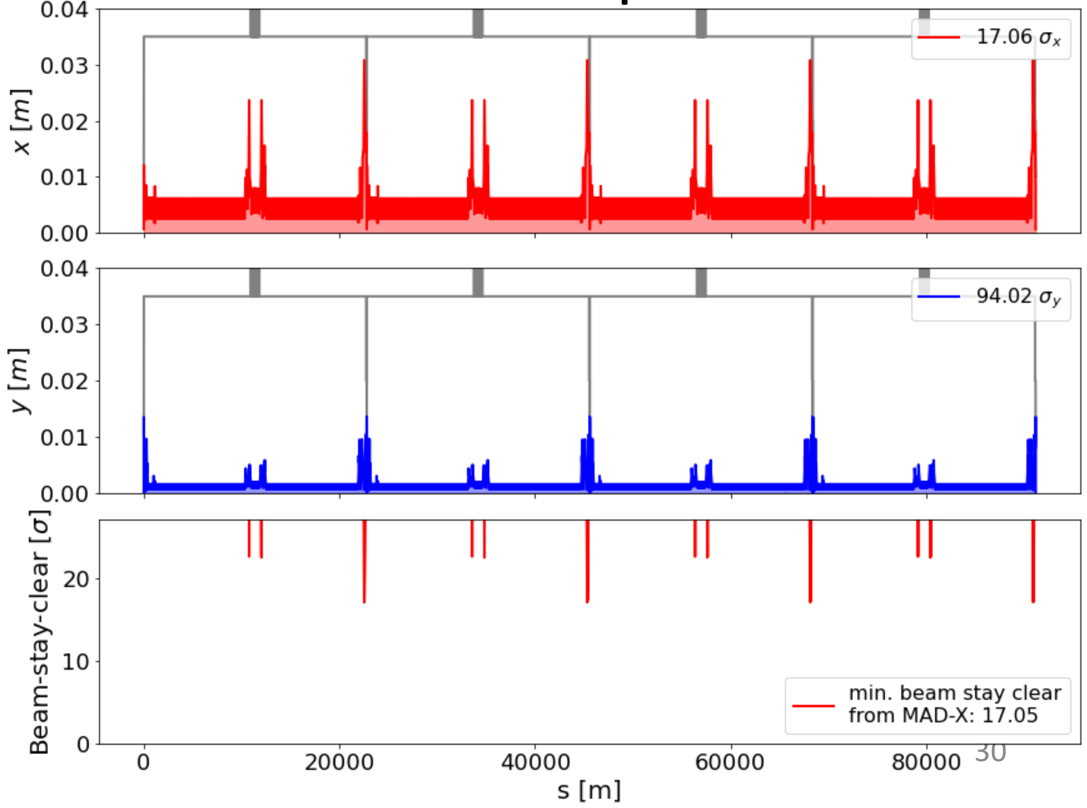
- With new layout, switch to long and short 90/90 optics
  - For Z mode, ε_x increased from 0.27 nm to 0.71 nm
  - Minimum beam stay clear found in new layout: Z : 23 $\boldsymbol{\sigma_x}$ at QC1 (final focus quadrupole)

    $t\bar{t}$: 17 $\boldsymbol{\sigma_x}$ at BWL

Z operation mode

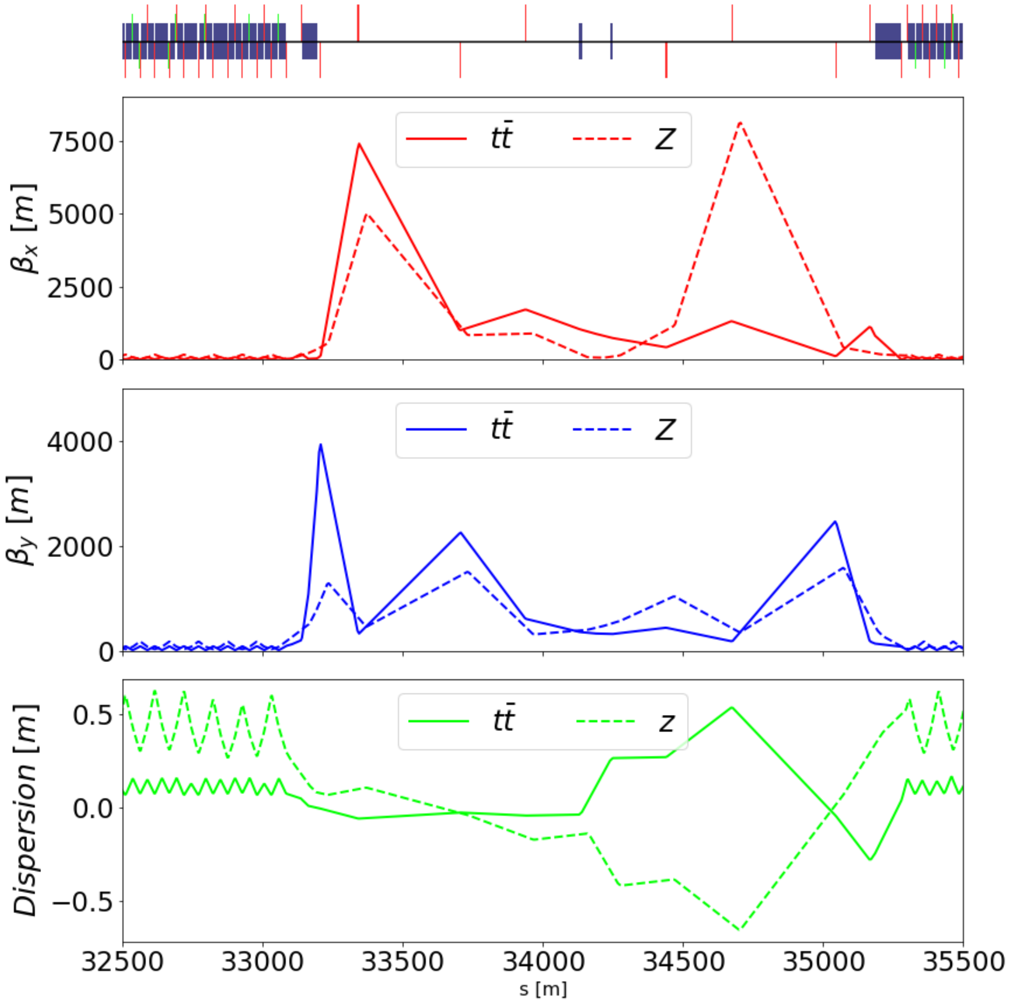


$t\bar{t}$ operation mode



Potential layout and collimation optics for 4IP

- Based on preliminary lattice for new layout,
  a 4IP compatible layout was developed
  - With only one 2.1 km long straight section available, may serve as combined β– and momentum collimation
  - Beam crossing at the center of insertion
  - With different arc optics between Z and $t\bar{t}$ operation modes, no common solution found



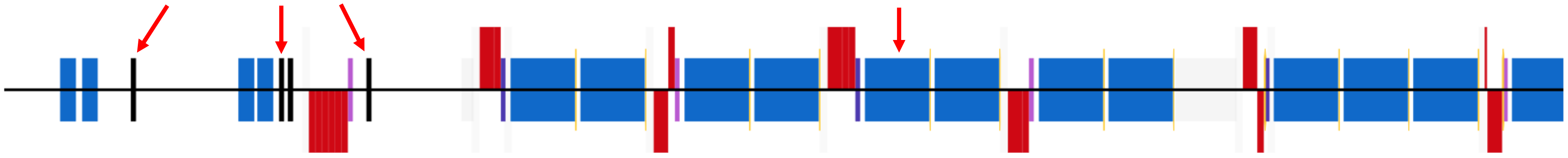
Michael Hofer

Collimation simulations

Andrey Abramov

Code	6D symplectic tracking	Synchrotron radiation	Tapering (lattice)	Geant4 integration	FLUKA integration	Speed	Aperture modelling
MAD-X	Available	Available	Available	Not available	Not available	Partial availability	Available
SixTrack	Available	Not available	Not available	Available	Available	Available	Available
BDSIM	Not available	Available	Not available	Available	Not available	Not available	Available
Merlin++	Available	Available	Not available	Not available	Not available	Available	Available
pyAT	Available	Available	Available	Partial availability ★	Not available	Available	Available
xTrack	Available	Partial availability ★	Not available	Partial availability ★	Not available	Available	Available

Not available | Partial availability | Available | ★ = in development

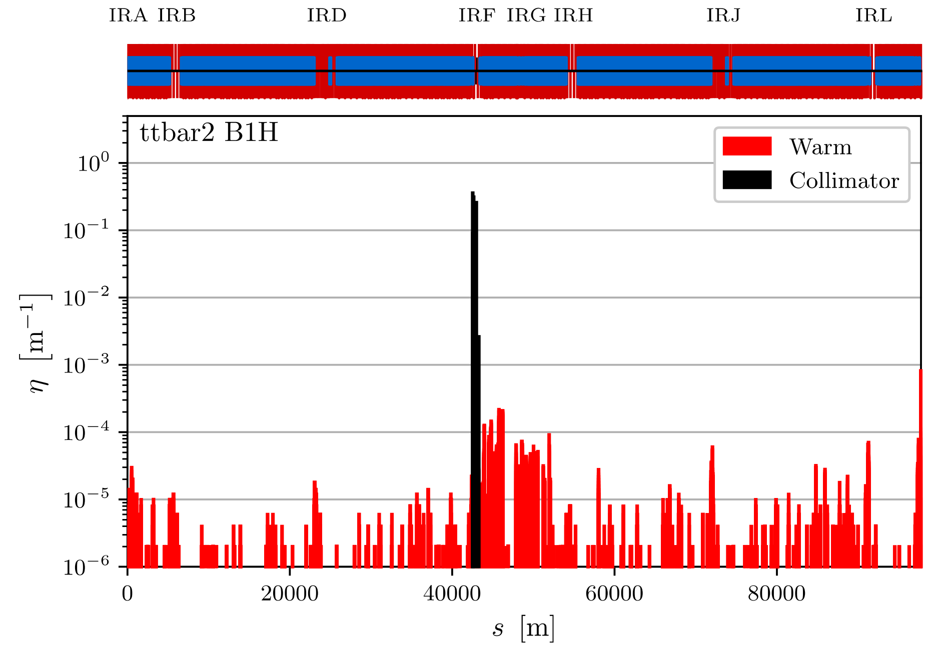


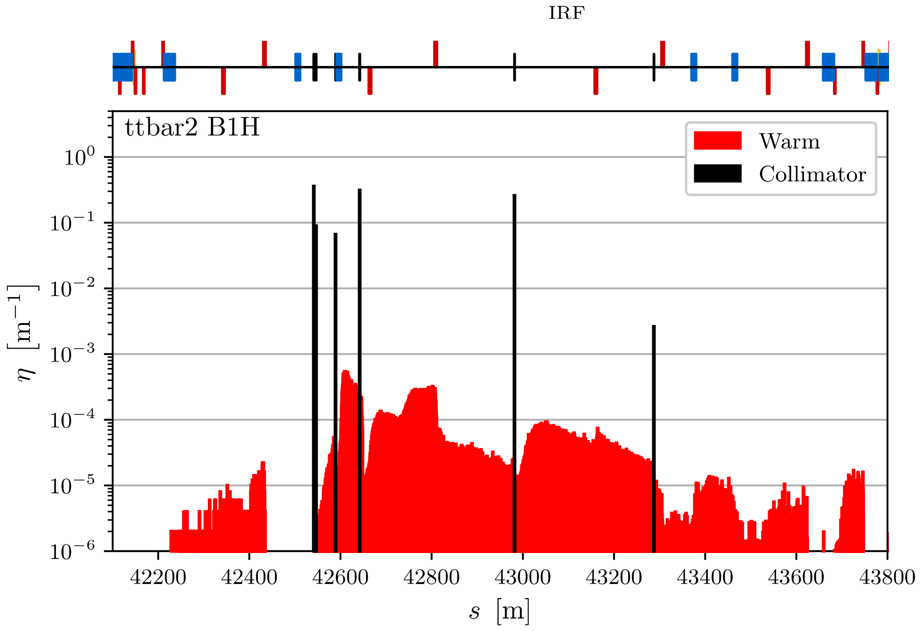
example lattice section

Loss map comparison

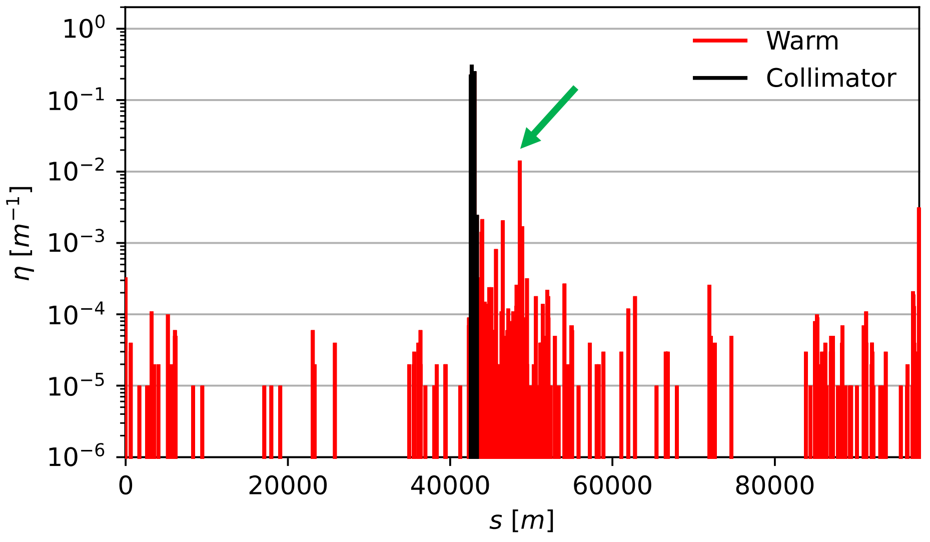
Andrey Abramov

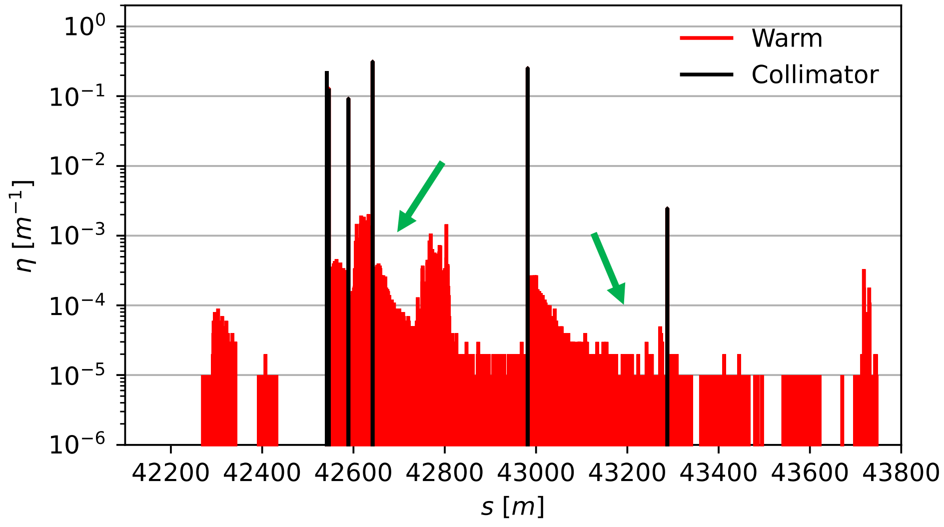
SixTrack-FLUKA





pyAT-Geant4





Xsuite development status for beam-beam studies

Peter Kicsiny

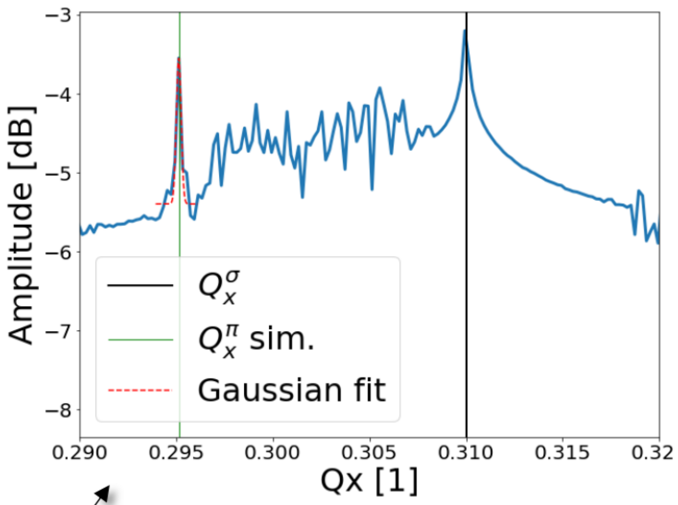
- Implemented:
  - 6D weak-strong model (based on Sixtrack implementation)
  - Tracking through the arcs/injection lines with a simplified map (including linear chromatic effect, without coupling)
  - Element-by-element tracking through the arcs (based on Sixtrack implementation)
  - Transverse and longitudinal wakefields (PyHEADTAIL)
  - 6D strong strong model with soft Gaussian approximation

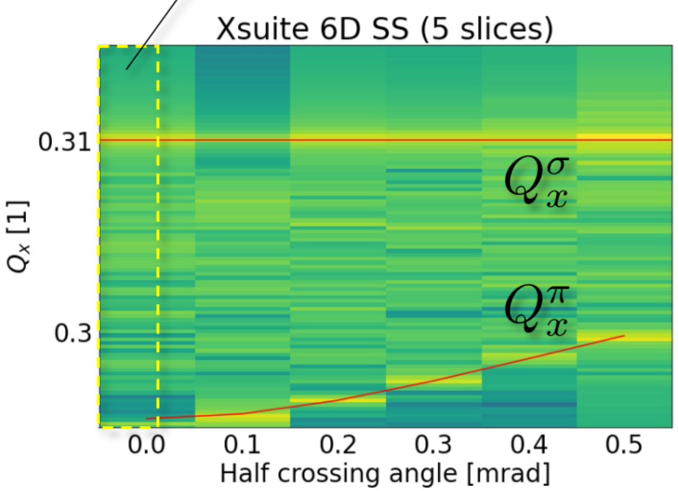
- Ongoing
  - Synchrotron radiation (A. Latina)
  - Beamstrahlung

- Plans
  - 6D strong-strong with field solver and Beamstrahlung (adapting field solvers already implemented in xsuite)
  - Synchro-beam mapping including solenoid field
  - 6D weak-strong model with non-Gaussian distributed charges (crab-waist of the strong beam)
  - Background (Beamstrahlung photons, Bhabha scattering, pair production)
  - GUINEA PIG interface for direct benchmarks

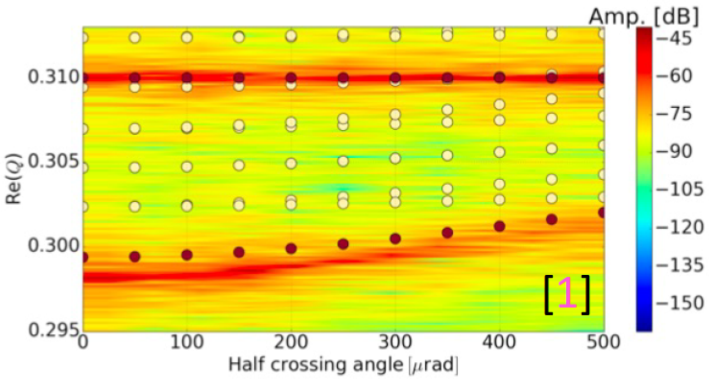
Benchmark studies: effect of crossing angle at HL-LHC

Peter Kicsiny





- First test of 6D strong-strong beam-beam interaction using Xsuite w/o Beamstrahlung and synchrotron radiation
- Collective modes in **soft-Gaussian approximation** are reproduced correctly (Yokoya factor: 1.1)
- Dependence of π mode with crossing angle matches past studies and theory



(a) x-component.

$$Q^\pi_{x,y} = Q^\sigma_{x,y} + Y \cdot \Delta Q_{x,y}$$

$$\Delta Q_{x,y} = \frac{1}{2\pi}\arccos[\cos(2\pi Q^\sigma_{x,y}) - 2\pi\xi_{x,y}\sin(2\pi Q^\sigma_{x,y})] - Q^\sigma_{x,y}$$

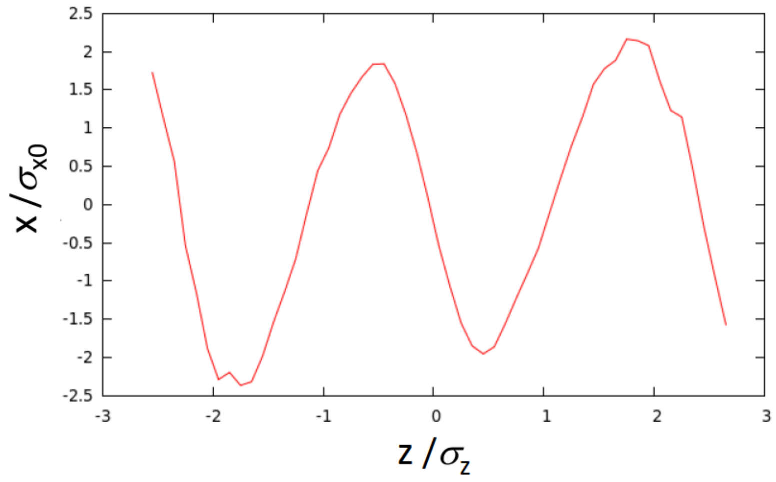
$$\xi_x = \frac{N r_0 \beta_x^*}{2\pi\gamma\sigma_x\sqrt{1+\left(\frac{\sigma_z}{\sigma_x}\mathrm{tg}(\Phi)\right)^2}\left(\sigma_x\sqrt{1+\left(\frac{\sigma_z}{\sigma_x}\mathrm{tg}(\Phi)\right)^2}+\sigma_y\right)}$$

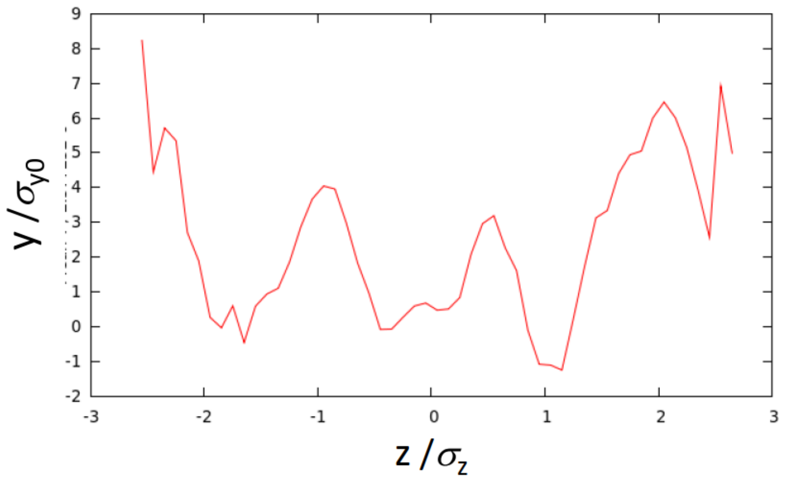
$$\xi_y = \frac{N r_0 \beta_y^*}{2\pi\gamma\sigma_y\left(\sigma_x\sqrt{1+\left(\frac{\sigma_z}{\sigma_x}\mathrm{tg}(\Phi)\right)^2}+\sigma_y\right)}$$

[1] L. Barraud [https://cds.cern.ch/record/2684699/files/CERN-ACC-NOTE-2019-0032.pdf]

Coherent Beam-Beam Instability with Betatron Coupling

One of the turns

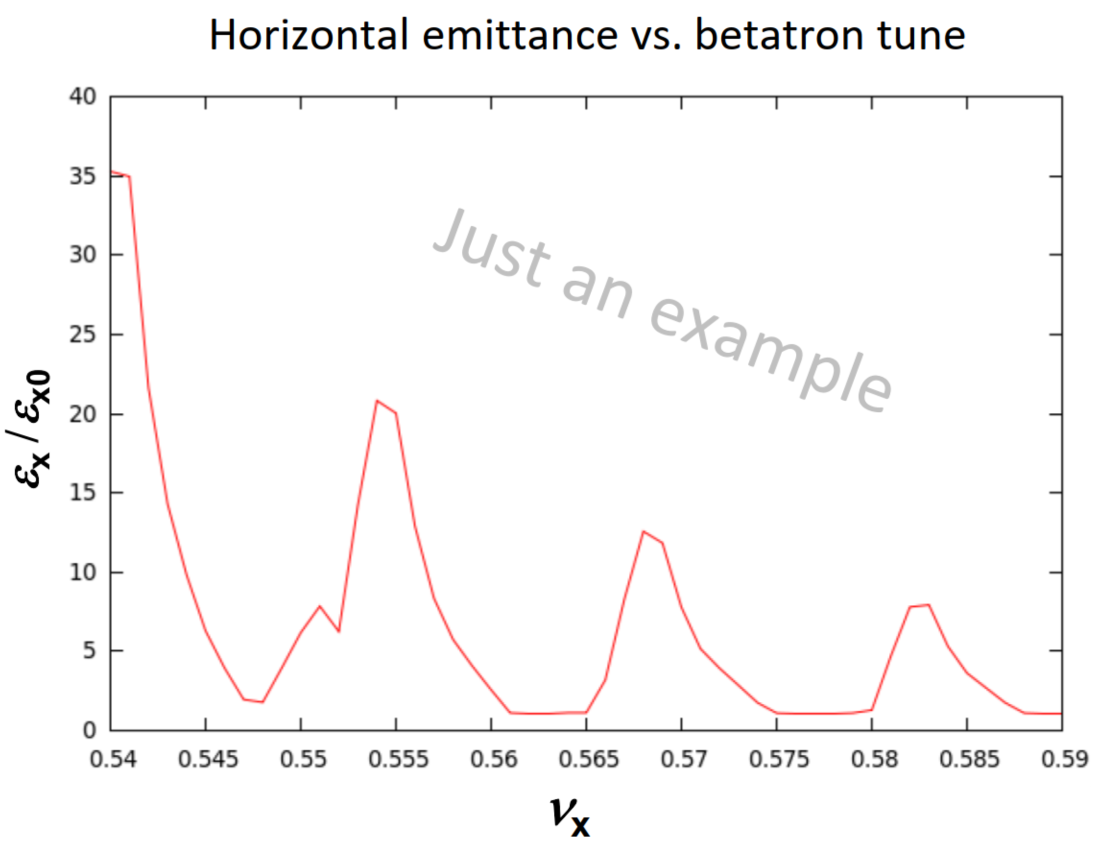




- The bunch shape wriggles in the horizontal plane. Due to betatron coupling, these waves also appear in the vertical plane.
- Dependence of the vertical kick on vertical displacement is much stronger than the dependence of the horizontal kick on horizontal displacement. Wriggles in the vertical plane are amplified by the vertical beam-beam kicks.
- These zigzags are pumped into the vertical emittance more efficiently than into the horizontal one! Possible reasons:
  - Difference between betatron tunes.
  - Large vertical tune spread.
- As a result, the vertical emittance blowup turned out to be much stronger than the horizontal!

Dmitry Shatilov

Coherent Beam-Beam Instability: Tune Scan



Scanning in a model with an explicit betatron coupling is difficult, since for each point one will have to re-select the sextupole offsets in order to obtain the design ε_y, and then get all matrices from SAD.

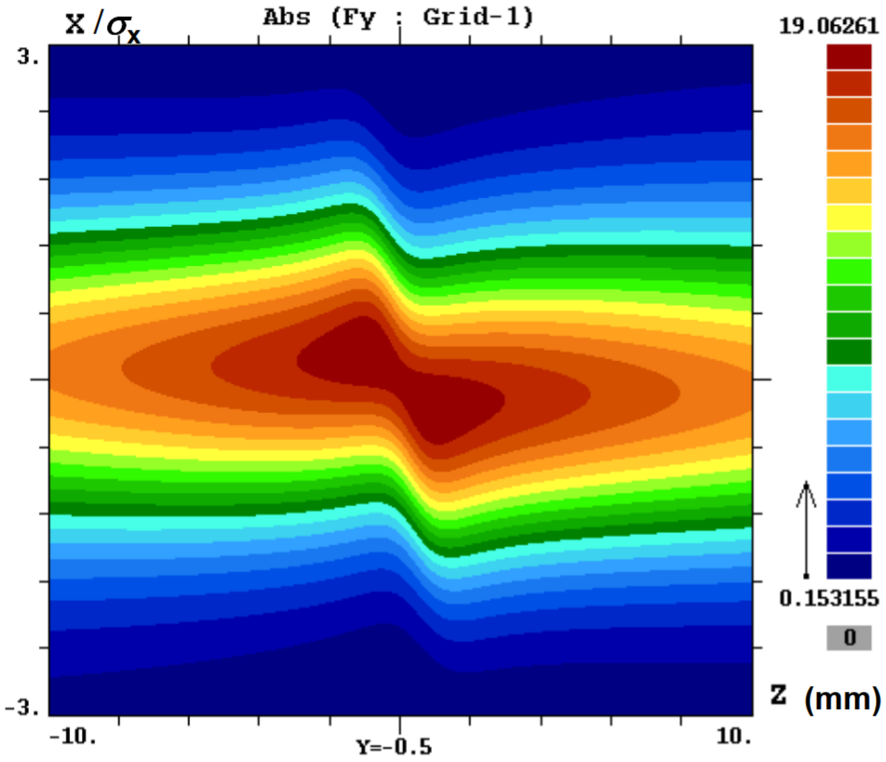
Therefore, a simple model without betatron coupling is used, which provides the correct values for ε_x.

The vertical emittance and luminosity in such a model will be incorrect and do not need to be paid attention to. It is only important for us to identify the areas in which there is no instability.

There are many scans to be performed to optimize the parameters, and there are many points in each scan. And each point is tens of thousands of turns (several damping times). Hence, computation speed matters, which means the advantage of QSS model.

Dmitry Shatilov

Non-Gaussian Strong Bunch



Vertical kick from a crabbed bunch

ICFA BDN 52, p.42 (2010)

So far, we have assumed that the density distribution in the slices is Gaussian. In fact, this is not the case, especially in the crab waist collision scheme.

For an arbitrary distribution, one need to build grids and calculate the kicks by interpolating between nodes. Here different approaches are possible, but they are equally applicable to all beam-beam models: WS, SS and QSS.

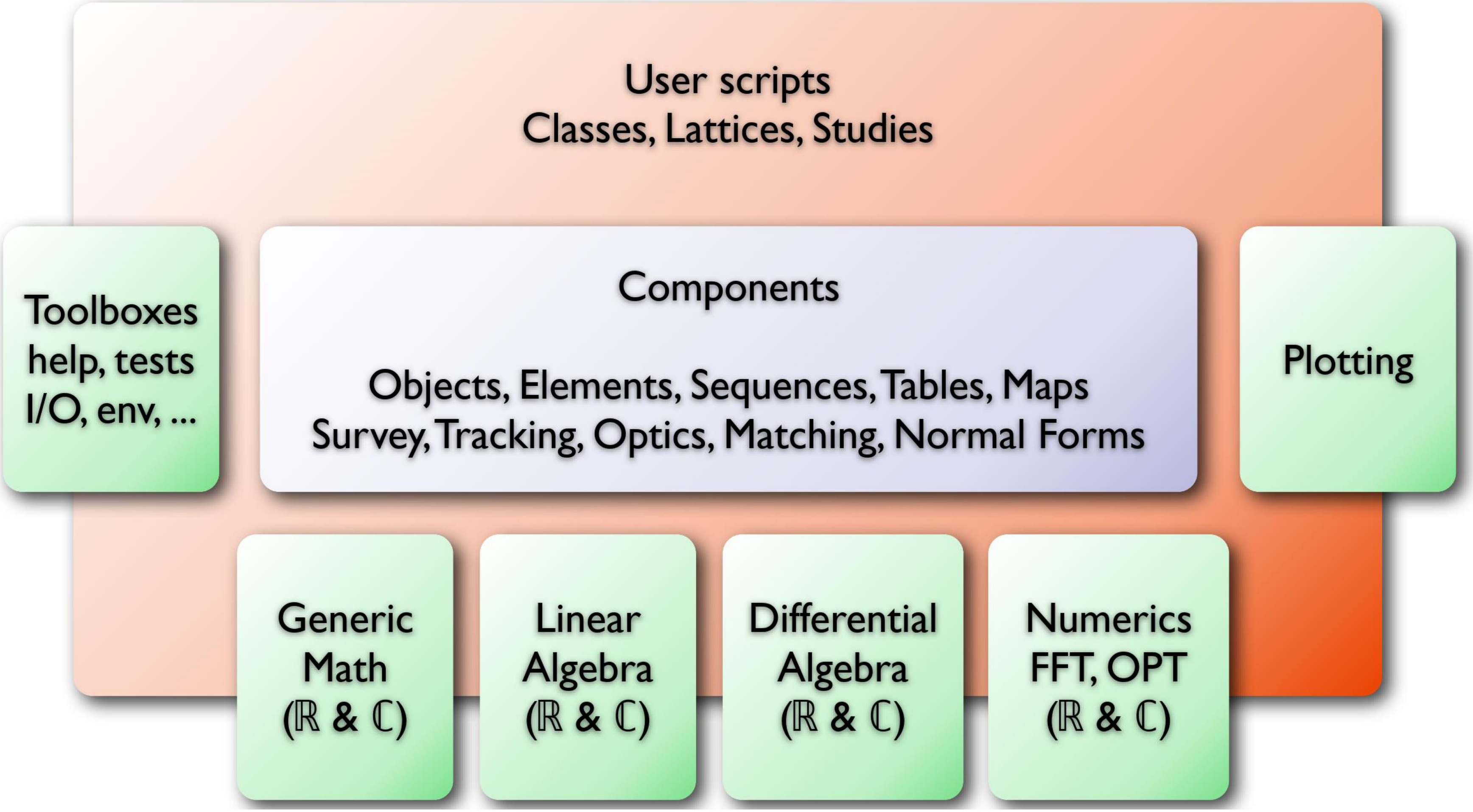
Here is an example of a grid for crabbed bunch. As it turned out, this has a positive effect: the suppression of resonances is slightly improved and the luminosity is slightly increased.

On the other hand, there are many effects that we do not yet take into account, and which *slightly* worsen the situation. So, for simplicity, un-crabbed strong bunches are usually used in simulations.

Dmitry Shatilov

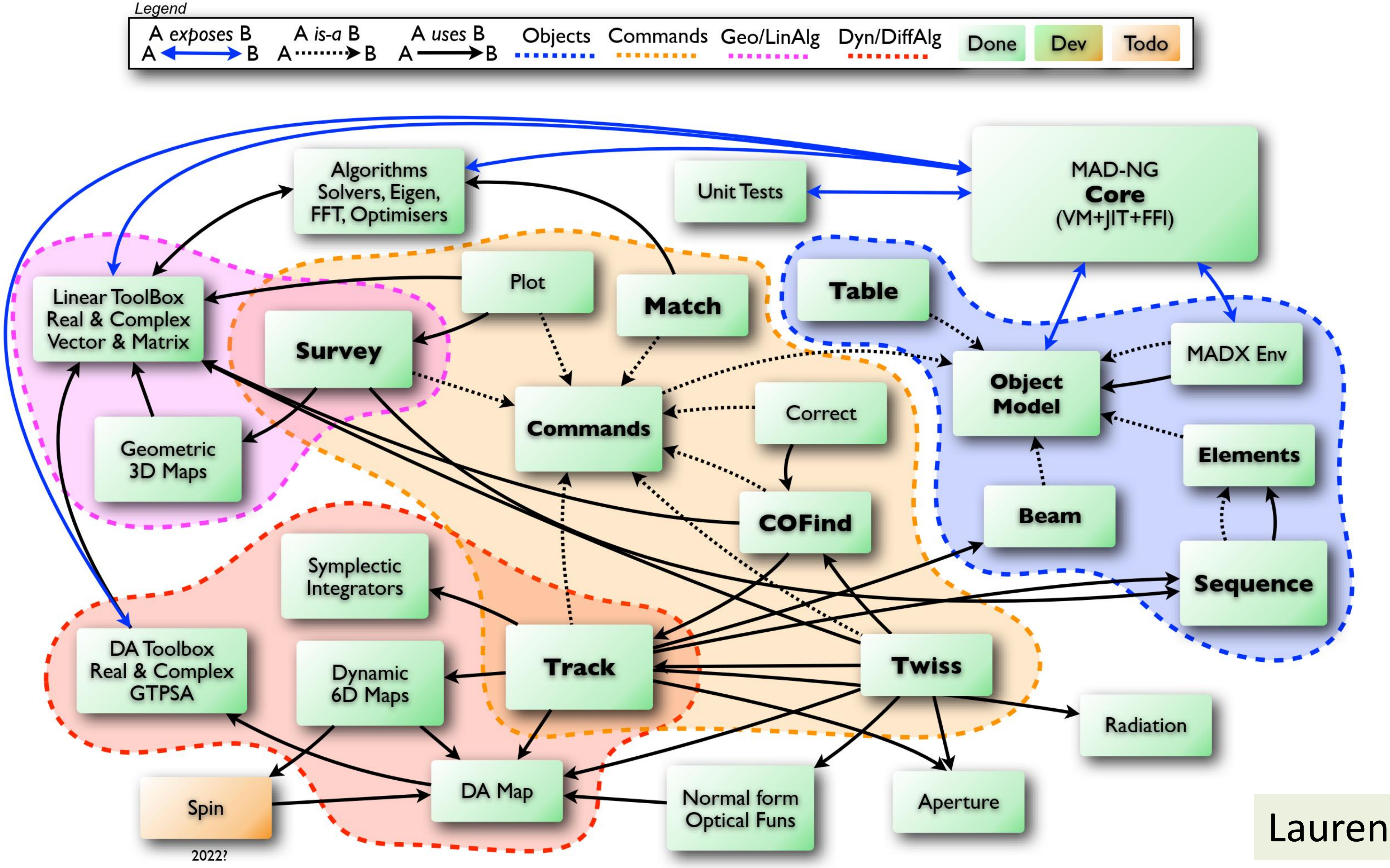
MAD-NG schematic layout

- ***Built from the start as a platform to develop & benchmark physics.***
  - ➡ *Everything is accessible, modifiable and extensible* ***by users from scripts*** *(e.g. even at runtime).*



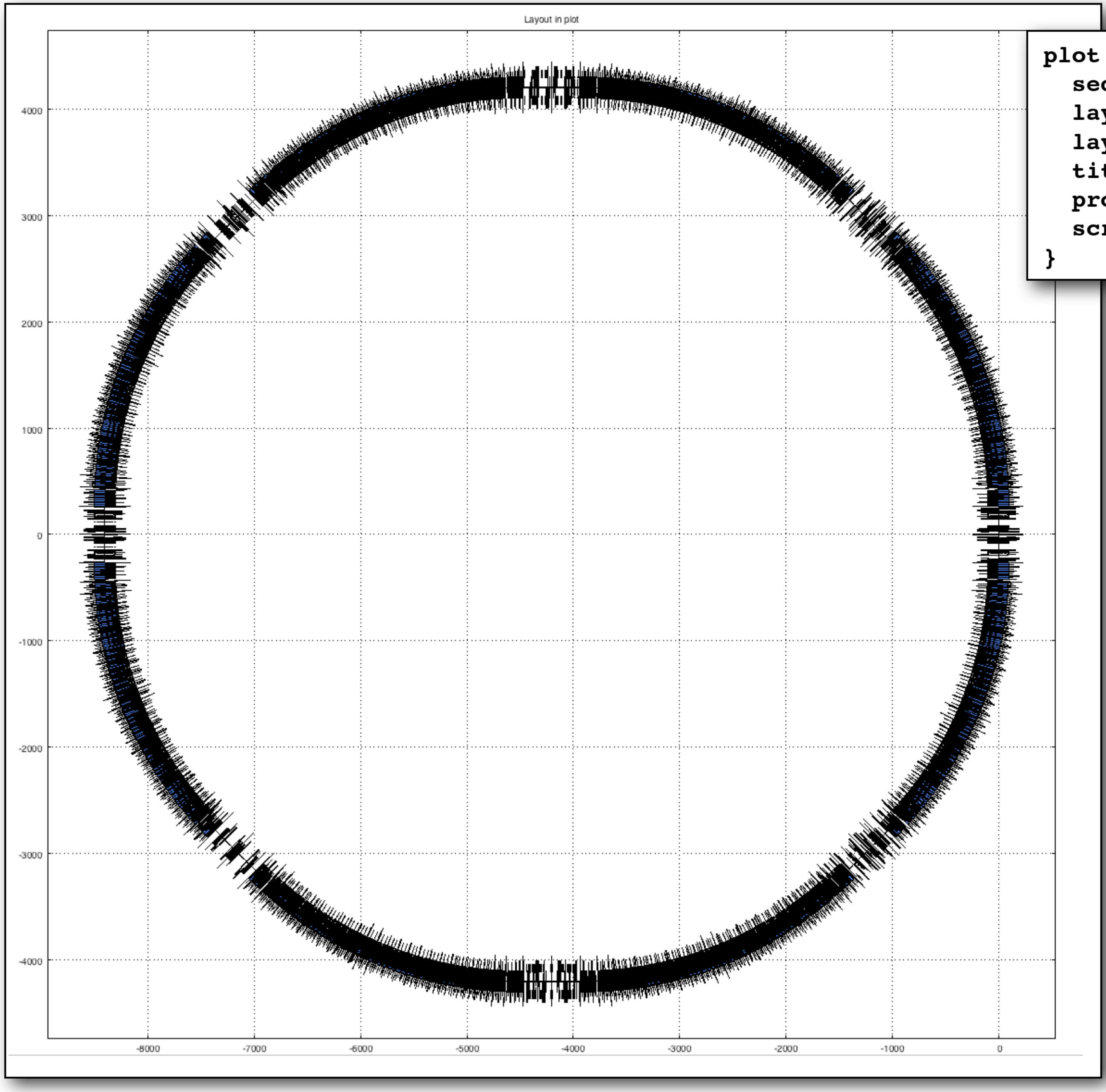
Laurent Deniau

MAD-NG ecosystem



Laurent Deniau

MAD-NG sequence plot (LHC 1 & 2 survey)




```
plot {
  sequence = {lhcb1,lhcb2},
  laypos   = "in",
  layonly  = false,
  title    = "Layout in plot",
  prolog   = 'set size ratio -1',
  scrdump  = "plotlhc.gp",
}
```

MAD-X loads the entire LHC definition in ~1 s. (2 beamlines, ~30000 lines)

MAD-NG loads the entire LHC in MAD-X format and saved it in files in ~1 s.

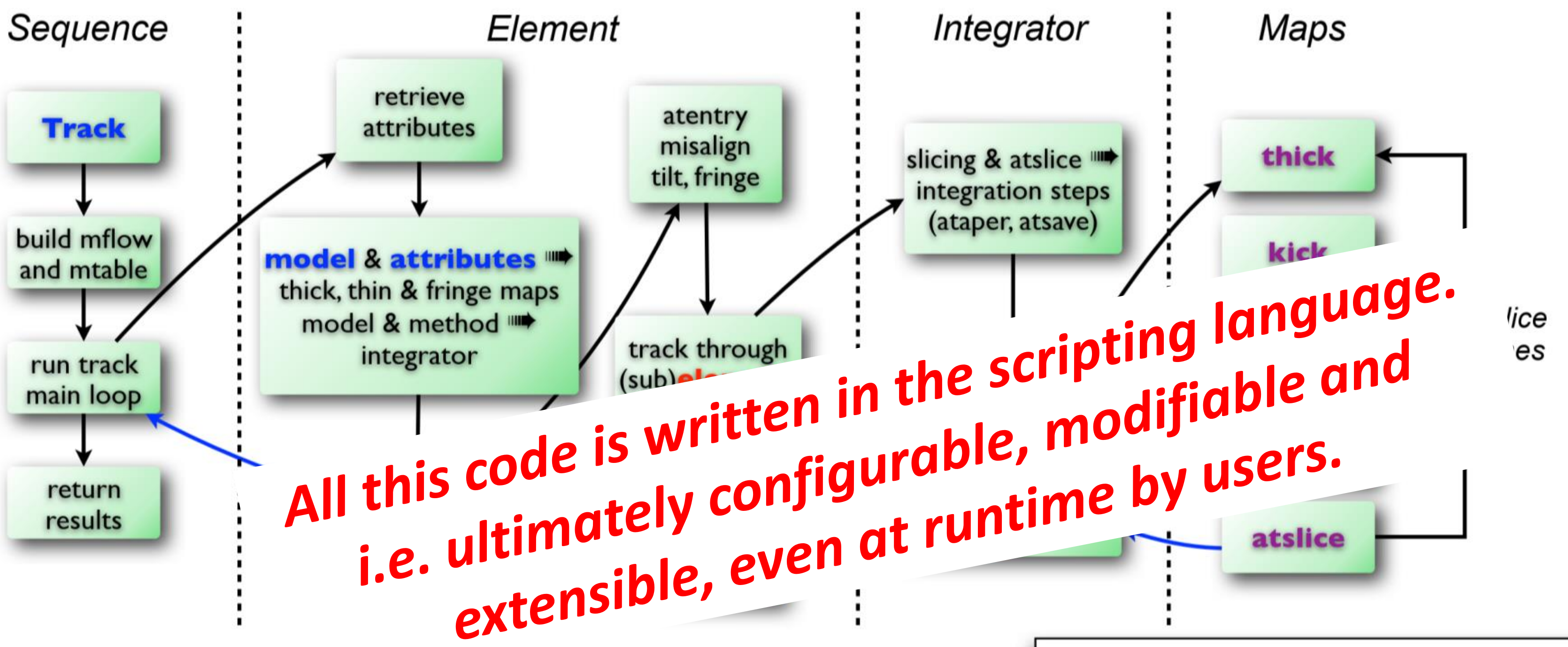
MAD-NG loads the entire LHC from converted files (.mad files) in ~0.2 s.

Gnuplot script (.gp files) size is 5 MB & 125000+ lines and takes ~1 sec to display.

All items are tagged i.e. moving the mouse over show their name and kind

Laurent Deniau

MAD-NG track in “depth”: user-defined extensions



All this code is written in the scripting language. i.e. ultimately configurable, modifiable and extensible, even at runtime by users.

Physics can be parametrised and/or configured by element attributes and commands attributes

Physics can be extended by providing new maps or actions e.g. strong beam-beam (functional approach)

Physics can be extended by creating new element or modifying existing element or subelements track method (object oriented approach)

Physics can be extended by providing extra integration methods e.g. 3D field maps.

Laurent Deniau

MAD-NG status and plan

- MAD-NG is reaching the end of its development process.
- 2022 will focus on participation to real studies and consolidation.
  - bottom-top validation for the physics of real case studies.
  - add missing physics on demand (e.g. tapering, spin, generalised multipoles).
  - complete unit tests & manual.
  - improve performance (room for x3-x5 in speed).
  - simplify some aspects, “simpler is better” (e.g. object model).
- On some aspects, MAD-NG is more mature than MAD-X
  - better code architecture and structure.
  - more flexible and extensible for the physics (new features require day(s)).
  - less surprises when combining features (e.g. misalignments and slicing).
  - main stream programming language for scripting (save user time!) & many toolboxes.
  - mature technologies, syntax error, backtrace, debugger, profiler, JIT (save user time!).
  - some features have been back ported to MAD-X (e.g. permanent misalignment, patches) or will be (fringe fields, combined/overlapping elements).
  - support backtracking, charged particles, parallel sequences, useful for e.g. matching IPs, no need for reverse sequence, etc…

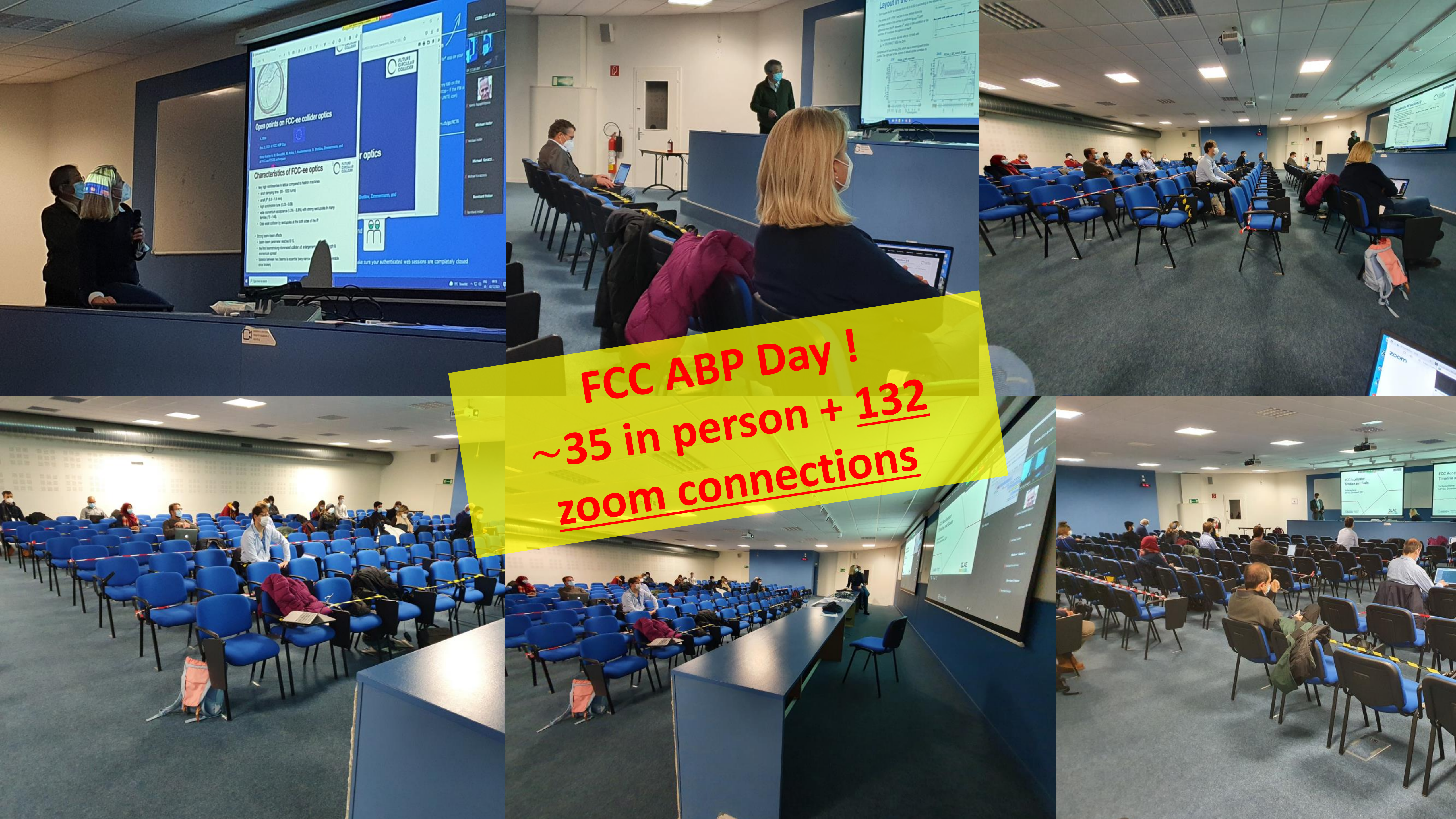
Do not hesitate to ask me some help!

Laurent Deniau

FCCIS ABP Day 2 December 2021

Early morning	**Session 1**	**Chair: Edda Gschwendtner**
8h30-8h40	Welcome and Goals of the ABP Day	Yannis Papaphilippou, Frank Zimmermann
8h40-9h00	FCC Accelerator Pillar - Plan and milestones	Tor Raubenheimer
9h00-9h20	ee Collider Design - Open points	Katsunobu Oide
9h20-9h40	Booster Design - Open points	Antoine Chance, Barbara Dalena
9h40-10h00	FCC-hh Design - Open points	Massimo Giovannozzi
10h00-10h20	Collimation for ee and hh - Open points	Andrey Abramov
10h20-10h40	Collective Effects – Open points	Mauro Migliorati

Late morning	**Session 2**	**Chair: Yannis Papaphilippou**
11h00-11h20	MDI – Open points	Manuela Boscolo
11h20-11h40	Pre-injector Complex – Open points	Mattia Schaer, Paolo Craievich
11h40-12h00	Energy Calibration - Open points	Alain Blondel
12h00-12h20	Code Development	Tatiana Pieloni, Felix Carlier
12h20-12h40	Other open points	Frank Zimmermann
12h40-13h00	FCC FS - Motivations, Goals, Timeline, Organisation, etc.	Michael Benedikt, Frank Zimmermann


FCC ABP Day !
~35 in person + 132
zoom connections

Characteristics of FCC-ee optics

FUTURE CIRCULAR COLLIDER

- Very high nonlinearities in lattice compared to hadron machines
  - short damping time (20 - 1200 turns)
  - small β^* (0.8 - 1.6 mm)
  - high synchrotron tune (0.03 - 0.08)
  - wide momentum acceptance (1.3% - 2.8%) with strong sextupoles in many families (75 - 146).
  - Crab waist collision by sextupoles at the both sides of the IP.

- Strong beam-beam effects
  - beam-beam parameter reaches 0.15.
  - the first beamstralung-dominated collider: x3 enlargements of bunch length & momentum spread
  - balance between two beams is essential (very narrow stable area, unrecoverable once broken).

Katsunobu Oide

Open Issues

FUTURE CIRCULAR COLLIDER

- Dynamic aperture
  - Machine errors and corrections have significant impacts on the dynamic aperture, even the resulting linear optics look OK.
    - how can we recover this?
    - what kind of diagnostics and correctors are required?
    - what about the effects by storing high currents, esp. at Z?
  - Beam-beam performance, estimation with lattice + errors
    - Estimation of beam halo formation is important for collimation strategy.
    - Full simulation of topup injection
  - Possible beam blowup due to lattice nonlinearities (chromatic coupling, synchrobeta emittance)
    - beam-beam can make things worse…
  - estimation of effects due to global deformation of the tunnel and beam line.
- Missing components in the present lattice:
  - Better arc cell structure using combined quad-sext HYS magnets
  - BPMs & correctors, with diagnostics strategy
  - collimation strategy and collimators incl. impedance.
  - injection/extraction scheme, optics, devices, incl. transport lines
  - polarimeters
  - IP solenoid + compensation solenoid with realistic profile
  - realistic length of each magnet, esp. dipoles
  - longitudinal profile of each magnet, effective lengths, interference between magnets
  - technically reasonable spaces between magnets
  - feedback system: bunch-by-bunch + narrow band
- and many more…

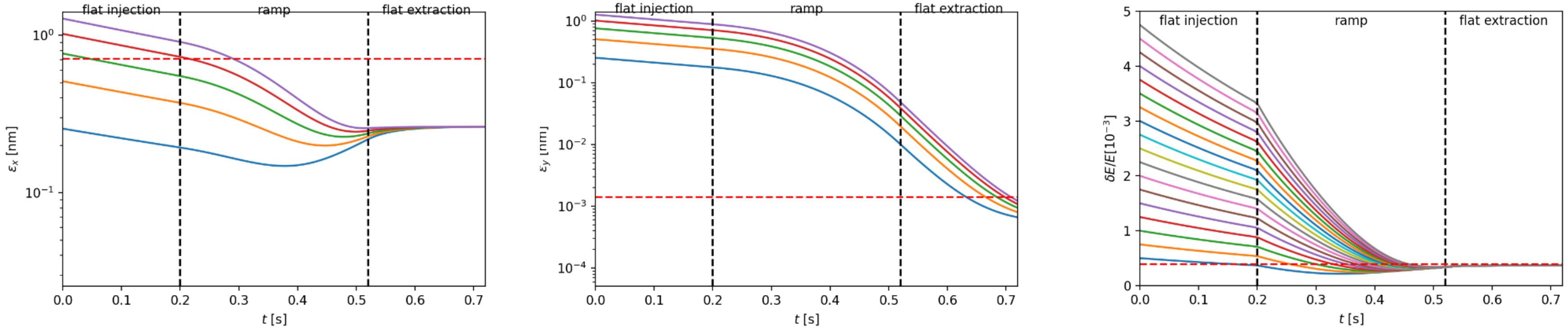
Katsunobu Oide

Z operation with I2 x 8

I2 and I5 are multiplied by 8.

Injection parameters:

- 20 GeV
- Normalized emittance: 10 to 50 µm
- Energy spread: 0.05% to 0.5%



With I_2 and I_5 multiplied by 8, we get values below the target.

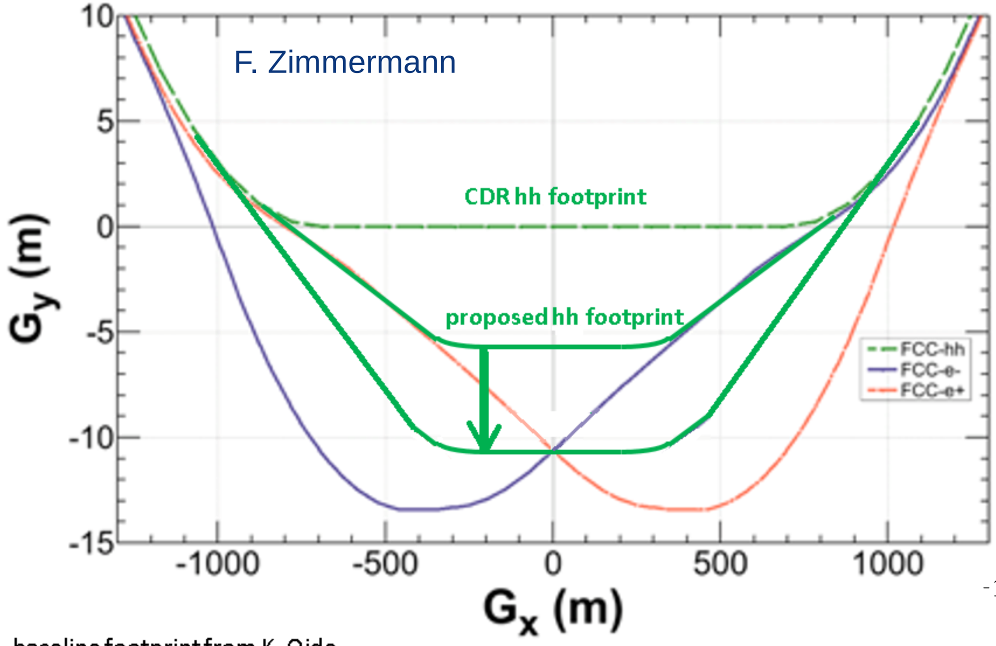
But we increase the radiated power: needs to find a good tradeoff and we have to optimize the cycling time for Z operation.

Antoine Chance
Barbara Dalena
Herve de Grandsaignes

Choice of the injection energy

- Experience from CEPC dipole prototypes shows some discrepancy between simulations and prototypes for the field quality and field reproducibility.
- What is the minimum dipole field to get field reproducibility?
- Impact: dynamic aperture, optics correction.

Layout optimisation of high-luminosity insertions

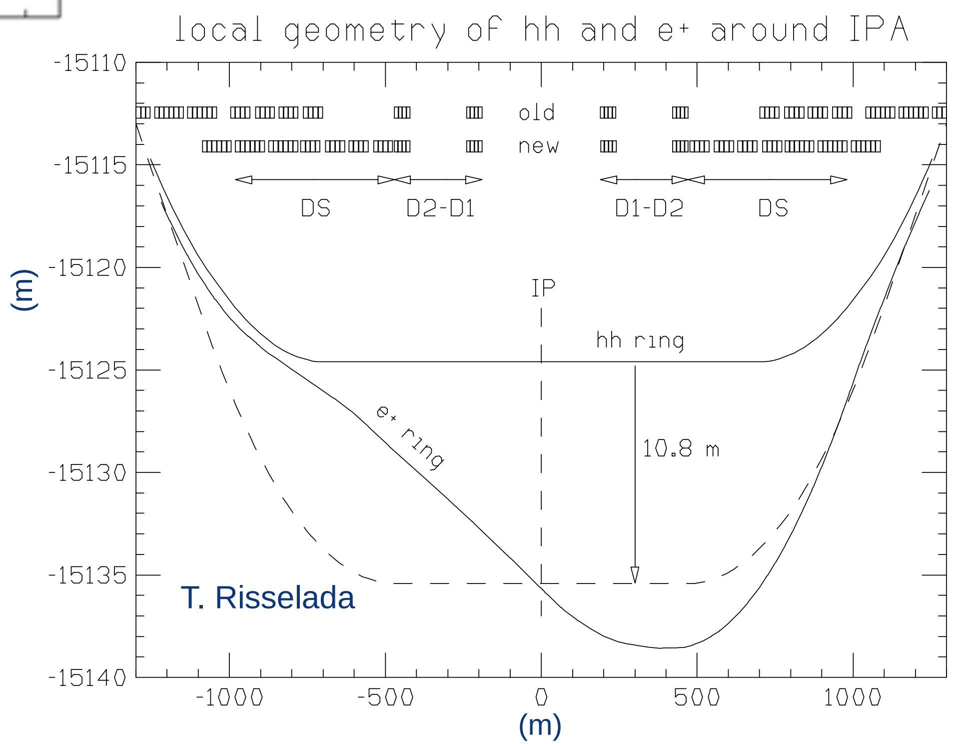


baseline footprint from K. Oide

- CDR
  - FCC-hh footprint compatible with FCC-ee injector

Massimo Giovannozzi

- Implementation of an improved layout with FCC-ee and FCC-hh IPs with same transverse positions
- Advantages
  - Size of detector cavern reduced
  - Possibility to re-use FCC-ee detector for FCC-hh
  - Tunnel width reduced over 2 x 500 m



FCC-hh collimation : future work and open points

Future work on present system design (based on the CDR):

- Refine tolerances for aperture calculations
- Further error studies, including also alignment and magnetic field errors
- Some studies of failure scenarios done (not shown here) – some more might be needed
- Study outgassing and cooling of the most impacted elements in collimation insertion
- Study different materials in cooling pipes to avoid damage
- Consider HiRadMat tests of collimator materials with FCC-equivalent beam impacts if available
- Impedance is on the limit – we might want to improve it
- Pb ion operation
  - Energy deposition studies of collimation insertion and dispersion suppressor, possibly including imperfections
  - Further studies of secondary beams from collision points

Alternative system designs

- Present FCC-hh IRJ has a 2.8km length – requests to shorten insertion to 2.1 km or less
  - Need to re-think the layout – could possibly re-use work for the LHC on a new betatron cleaning optics with higher β-functions, which would require a lower scaling factor of the insertion length
  - Would require redoing most of the studies presented today
- Studies of an optimized dog-leg geometry are ongoing
- Consider novel collimation scenarios – crystal collimation, combining betatron and off-momentum collimation
- Study alternative collimator / jaw designs, which are not based on the LHC design

Andrey Abramov

FCC-ee collimation : future work and open points

Future work on the collimation system design:

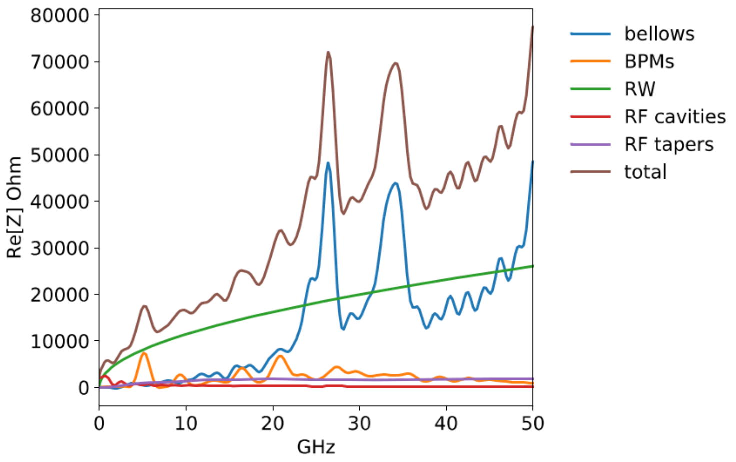
- Define equipment loss tolerances – detectors, superconducting magnets
- Define reference loss scenarios
- Study the failure scenarios
- Refine the optics and the layout of the collimation system
- Adapt to the new layout and optics
- Improve the aperture model and the mechanical and beam tolerances
- Study the mechanical design of collimators the materials, and the impedance
- Develop and validate simulation frameworks for tracking studies
- Perform tracking studies to determine the collimation performance
- Perform energy deposition studies in collaboration with the FLUKA team

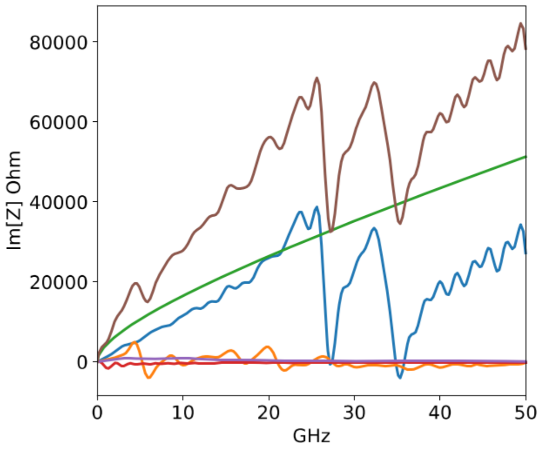
Additional future work

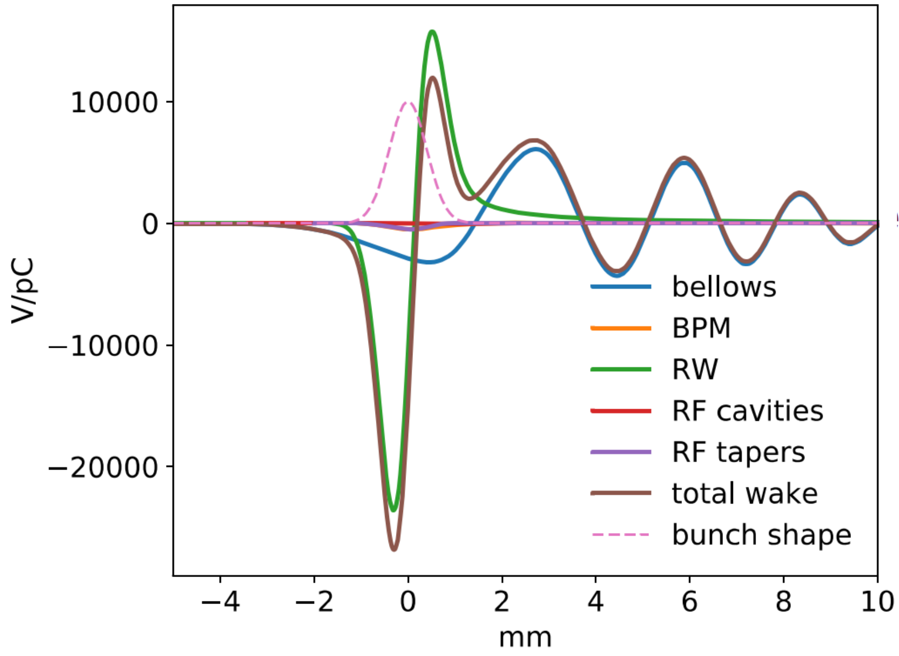
- Study collimation aspects for secondary photon beams from the IPs
- Determine if collimation in the Booster is required
- Perform tracking studies for top-up injection
- Planned work with EPFL to implement new tools on BOINC with GPUs, in the context of machine-learning applied to loss rate modelling for both the FCC-ee and FCC-hh

Andrey Abramov

Total impedance and wake – longitudinal plane

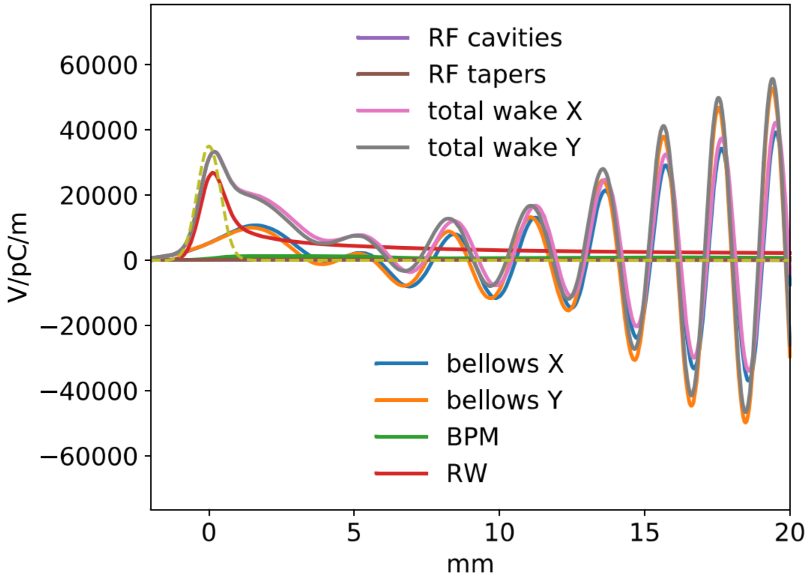






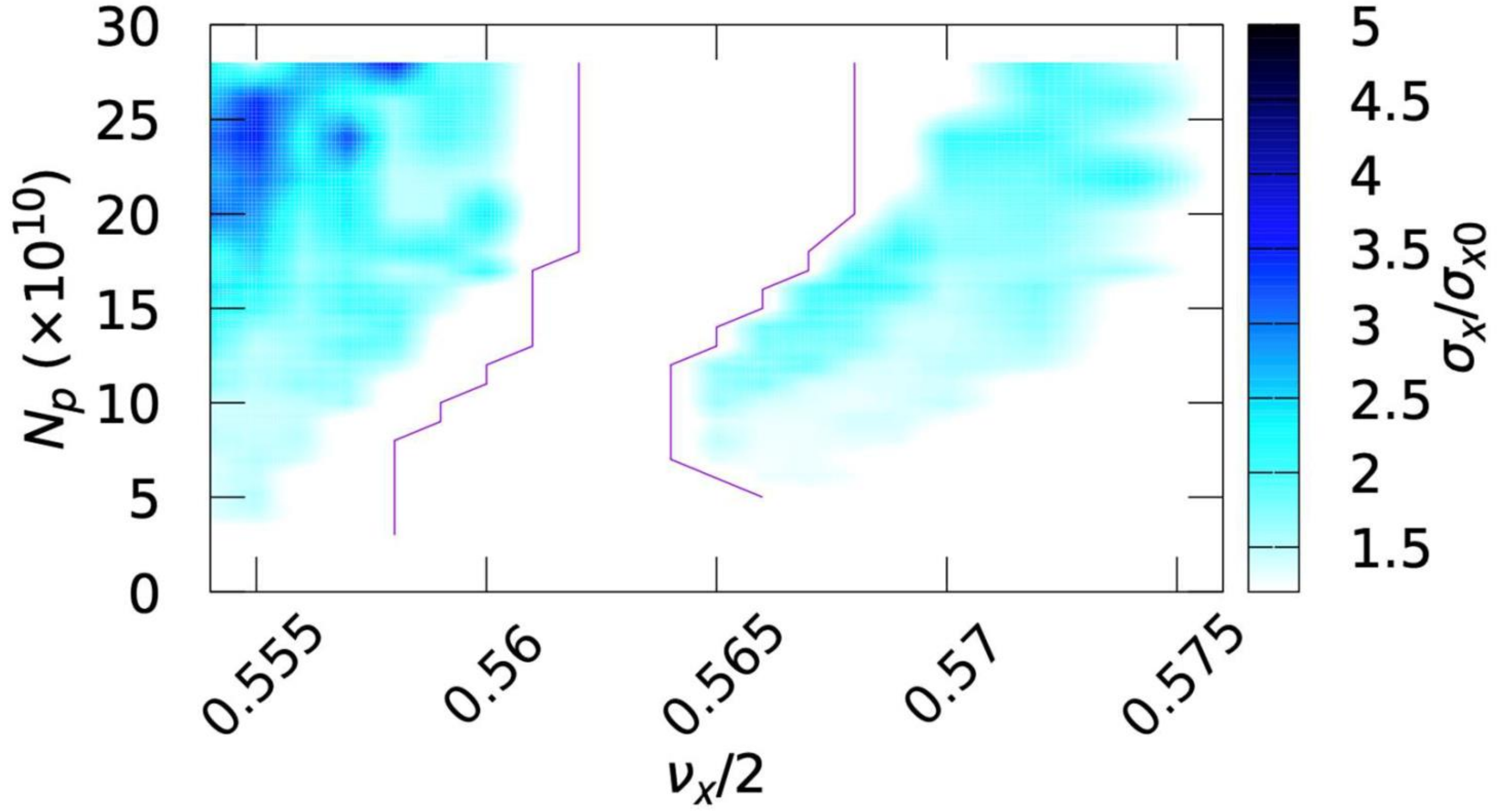
Mauro Migliorati
Emanuela Carideo
Chiara Antuono

and wake – transverse plane



Interplay between beam-beam and longitudinal impedance

Mitigation methods for CDR parameters: higher harmonic cavity, higher momentum compaction factor



Higher momentum compaction factor

Mauro Migliorati
Yuan Zhang

Other topics

- Electron could, including the multi-bunch effects
- Ion instabilities
- Impedance evaluation, repository, and collective effects in the Booster and in the whole injection system
- Longitudinal and transverse feedback system for coupled bunch instabilities (in particular, very important for the transverse plane due to the resistive wall, also in the Booster)
- …

Mauro Migliorati

Open questions for mechanical model

Conceptual design of IR elements/systems:
some are under study, others require optimisation,
others are yet missing

- **Progress with the mechanical assembly** adding all the main components as they will be provided by the experts of the different systems.
- Introduce the weight of the components to design the **supports** and start with the structural studies. This will allow the optimization of the different options of different configurations of supports for **vibration** mitigation, in collaboration with LAPP.
- Space for the **alignment system** to fulfill the stringent requirements.
- **Thermal and mechanical simulations** Just started, with preliminary studies (cooling of central pipe, strength of simplified X pipe to vacuum load at several thicknesses)
- We will define the **strategy for the integration.**

→

Cryostat design
IR beam diagnostic devices
IR corrector magnets
Shielding
Vacuum system
Remote vacuum connection

Vertex detector (& other IP detectors)

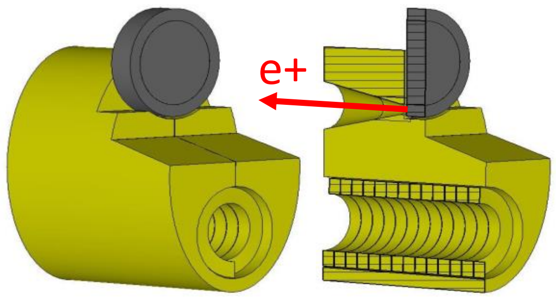
Manuela Boscolo

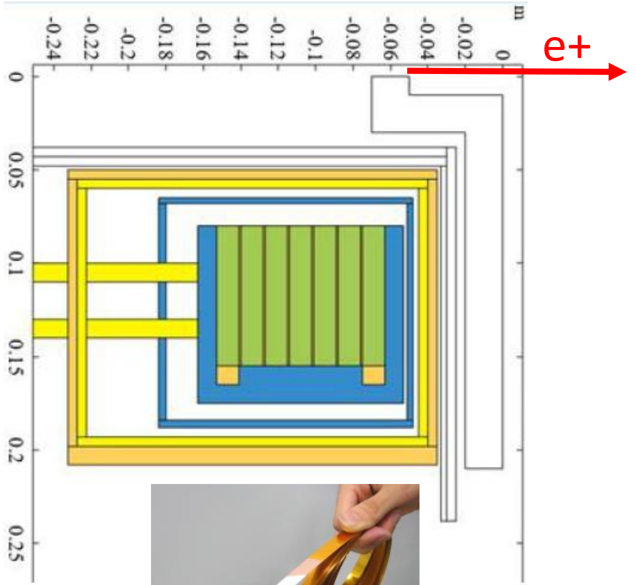
PAUL SCHERRER INSTITUT PSI

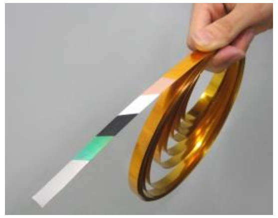
Positron Source (WP3)

Mattia Schaer

FUTURE CIRCULAR COLLIDER







AMD options	AMD profiles	Target exit position w.r.t AMD exit [mm]	B0 @ target exit [T]	Opt. spot size [mm]	Acc. yield	PEDD [J/g]
BINP FC (Pavel)	a = 8 mm	5+18	7	1.5	2.39	29.7
	a = 16 mm	2+18	5	1.4	2.38	31.9
Analytic SC	Optional		5	1.2	3.18	30.6
			6	1.1	3.57	30.9
			7	1.0	3.95	32.1
			8	1.0	4.24	29.9
			9	1.0	4.44	28.6
			10	1.0	4.60	27.6
			11	1.0	4.73	26.8
	Optimised		**12**	**1.0**	**4.88**	**26.0**
			13	1.0	4.92	25.8
PSI HTS (Jaap) Upstream only [Vers.: Sep 2021]	a = 20 mm	18	7	0.5 (fixed)	4.27	< 30
		0	8.7		4.57	
		-5	9.2		4.65	
		-10	9.7		4.71	
		-15	10.2		4.75	
		-20	10.7		4.77	
		-30	**11.8**		**4.79**	
		-40	12.8		4.78	
		-50	13.7		4.69	

Config:
Electron energy: 6 G
Number of bunches: 2 per pulse
Spot size: 0.5 mm
Target profile: conventional, 5 X0 (~18 mm)
Capture linac: CLIC L-band TW, 0.5 T
E&time acceptance: ±3.8%, 9.33 mm (32° @ 2.856 GHz)

From different presentations (I. Chaikovska, Y. Zhao, P. Martyshkin, J. Kosse)

From beam energy to E_{CM}

Alain Blondel

$$\sqrt{s} = 2\sqrt{E_b^+ E_b^-}\cos\alpha/2, \quad \approx E^+_b + E^-_b$$

Energy gain (RF) = losses in the storage ring
Synchrotron radiation (SR)
beamstrahlung (BS)

$$\Delta_{RF} = 2\Delta_{SRi} + 2\Delta_{SRe} + 2\Delta_{BS}$$

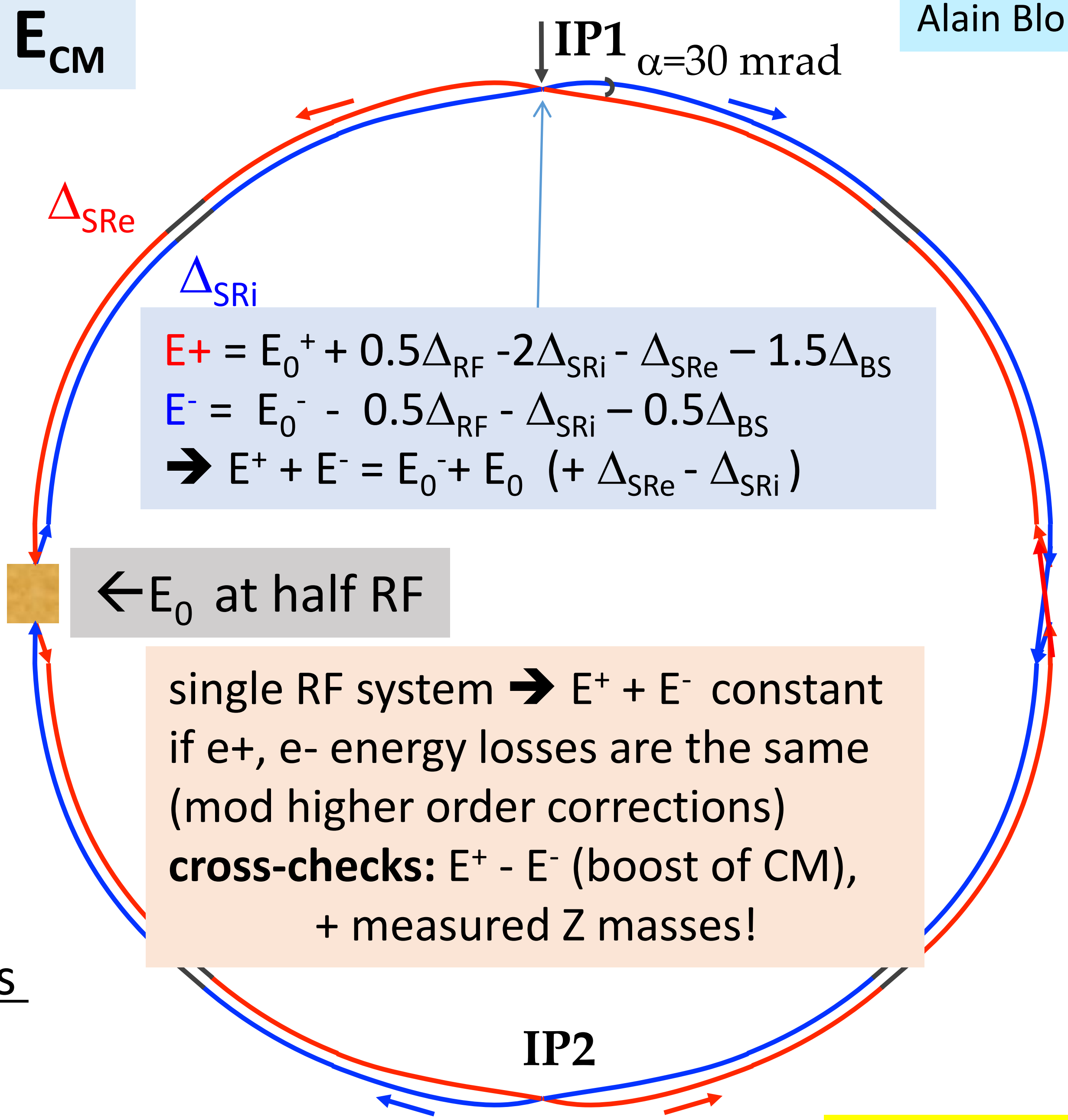
at the Z (O of mag.):

$\Delta_{SR} = 2\Delta_{SRi} + 2\Delta_{SRe}$ =39 MeV

$\Delta_{SRe} - \Delta_{SRi} \approx \alpha/2\pi\ \Delta_{SR}$ = 0.20 MeV

Δ_{BS} = 0 up to 0.62 MeV

the average energies E_0 around the ring
are determined by the magnetic fields
➔ same for colliding or non-colliding beams
-- measured by resonant depolarization
-- can be different for e^+ and e^-



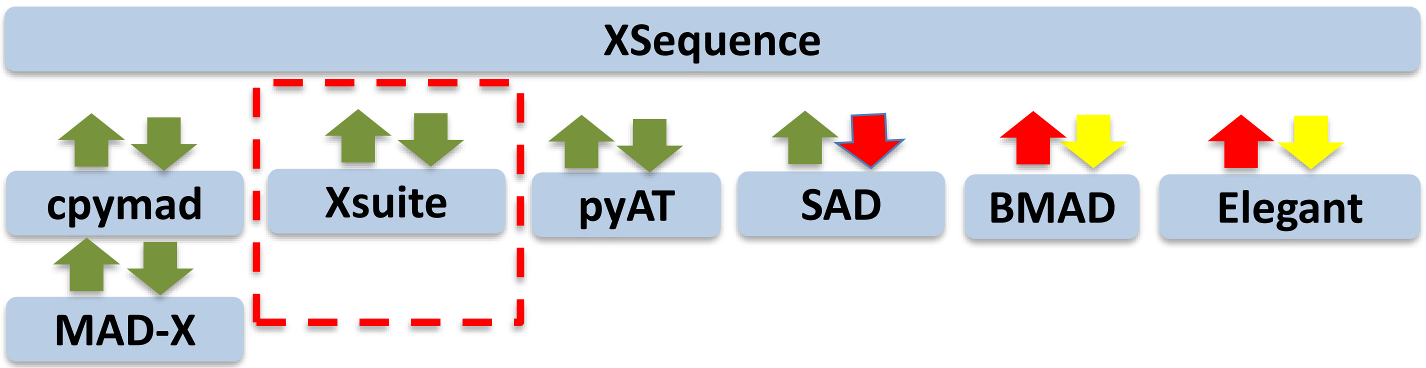
$E+ = E_0^+ + 0.5\Delta_{RF} - 2\Delta_{SRi} - \Delta_{SRe} - 1.5\Delta_{BS}$
$E^- = E_0^- - 0.5\Delta_{RF} - \Delta_{SRi} - 0.5\Delta_{BS}$
➔ $E^+ + E^- = E_0^- + E_0$ $(+ \Delta_{SRe} - \Delta_{SRi})$

single RF system ➔ $E^+ + E^-$ constant
if e+, e- energy losses are the same
(mod higher order corrections)
cross-checks: $E^+ - E^-$ (boost of CM),
+ measured Z masses!

CDR 2-IP scenario

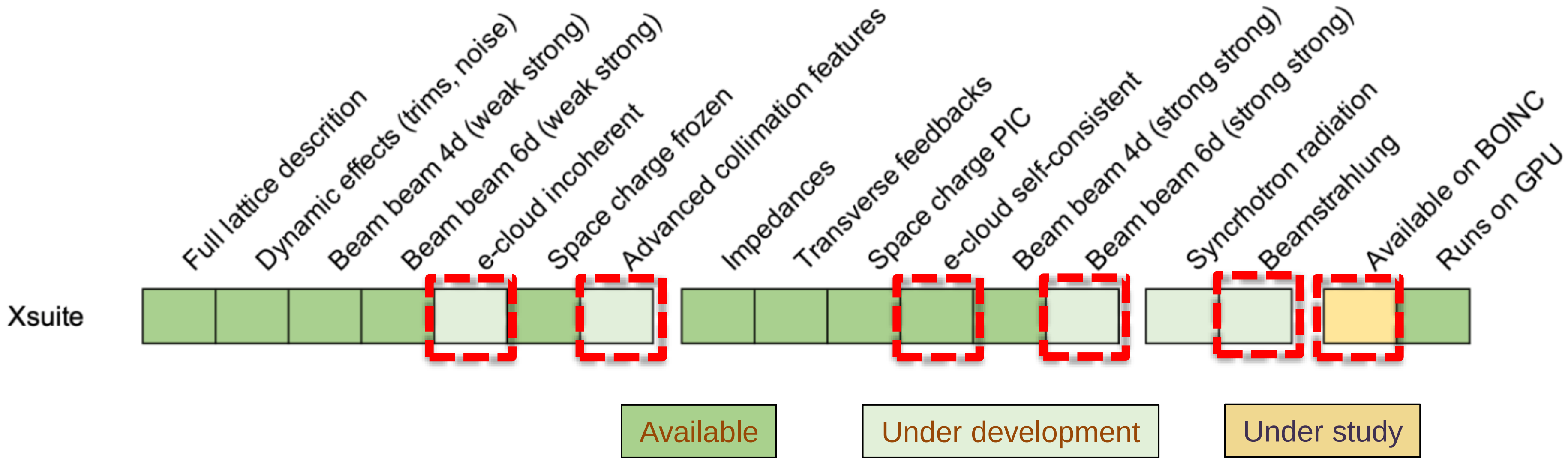
Developments in Xsuite

F. Carlier



- Xsequence is part of a broader effort in code development
- The development of xsequence fits nicely in current efforts of code developments with ABP at CERN in the frame of Xsuite.

Allows to bring current code development efforts for the LHC to the FCC-ee community



Tatiana Pieloni

Tatiana Pieloni

Beam-beam Developments

P. Kicsiny Talk

Overview of existing simulation tools for circular machines

	Weak-strong 6D	Quasi strong-strong 6D	Strong- strong 6D	Beamstrahlung	Transverse wakefields	Longitudinal wakefields	Tracking with simplified maps	Tracking element-by-element	Background generation	Crab waist of the strong beam	Synchro-beam mapping with solenoid field
GUINEA PIG [1]	Available	Not available	Available	Available	Not available	Not available	Not applicable	Not applicable	Available	Not applicable	No info
COMBI [2]	Available	Available	Available	Not available	Available	Not available	Available	Not available	Not available	Not available	Not available
BBWS [3]	Available	Not available	Not available	Available	Available	Available	Available	Available	Not available	Not available	Not available
BBSS [4]	Not available	Not available	Available	Available	Available	Available	Available	Available	Not available	Not applicable	No info
IBB [5]	Not available	Not available	Available	Available	Available	Available	Available	Not available	Not available	No info	Not available
LIFETRAC [6]	Available	Available	Not available	Available	Not available	Not available	Available	Available	Not available	Available	Not available
BeamBeam3D [7]	Available	Not available	Available	Available	Available	Not available	Available	Not available	Not available	Not applicable	Not available

Available | Not available | No info | Not applicable

- Several codes have been used for beam-beam simulations in various colliders
  - They were used for different kinds of studies with different models
  - No cross-framework communication

[1] D. Schulte [https://cds.cern.ch/record/331845/files/shulte.pdf]
[2] T. Pieloni, W. Herr [https://accelconf.web.cern.ch/p05/PAPERS/TPAT078.PDF]
[3] K. Ohmi [https://indico.cern.ch/event/438918/contributions/1085290/attachments/1147002/1644777/BenchBBcodes.pdf]
[4] K. Ohmi [https://oraweb.cern.ch/pls/hhh/code_website.disp_code?code_name=BBSS]
[5] Y. Zhang [https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.23.104402]
[6] D. Shatilov [http://cds.cern.ch/record/1120233/files/p65.pdf]
[7] J. Qiang [https://amac.lbl.gov/~jiqiang/BeamBeam3D/]

- Review of existing Models
- Discussions with Experts to define needs, challenges and strategy
  (Shatilov, Ohmi, Oide, Frank)

Other open points (incomplete list)

Frank Zimmermann

- **Maintaining knowhow** from LEP, PEP-II and (Super-)KEKB and preparing for FCC
- **Injection scheme for booster and pre-booster** - how many wigglers, **how much SR power?**
- **Emittance evolution from source to collider, incl. IBS** in all rings, injection effects, etc.
- **E-cloud** build up and effects, e-cloud plus beam-beam, **ion-driven instability for all rings**
- **Touschek effect,** scattering off thermal photons, **gas scattering in all machines**
- **Modelling of beam tails – collimation and protection systems**
- **Dust effects** in the collider, esp. in the electron ring (quench? background? abort?)
- **Injection energy for the full-energy booster**, field quality, dynamic aperture etc.
- **Damping Ring dynamic aperture and capture efficiency for simulated e+ distributions**
- **Integration of longitudinal dynamics codes** & plasma acceleration codes
- **Optics modelling, esp. IR and the solenoid, fringe fields** – are we there ? Can we learn from other ABP sections (e.g. sources and linacs) ?
- **Alternative emittance calculations**, e.g. Hirata-Ohmi-Oide formalism, … tracking ?….
- Development of **advanced feedback system against low-mode res.-wall. instability**
- **Impedance calculations** - many components to be considered and added
- - **nonlinear wake fields, e.g., at the collimators ; CSR**
- - computing challenges, e.g. those encountered by Sasha Novokhatski