Summary of LER2018

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John Adams Institute
for Accelerator Science

LER - CERN
17th January 2018

diamond

Low Emittance Ring 2018

81 delegates – 40 talks – 4 main sessions

Ring design – injection – optimization

Ring operation – performance – tuning – experiments

Collective effects

LER technology

https://indico.cern.ch/event/671745/overview

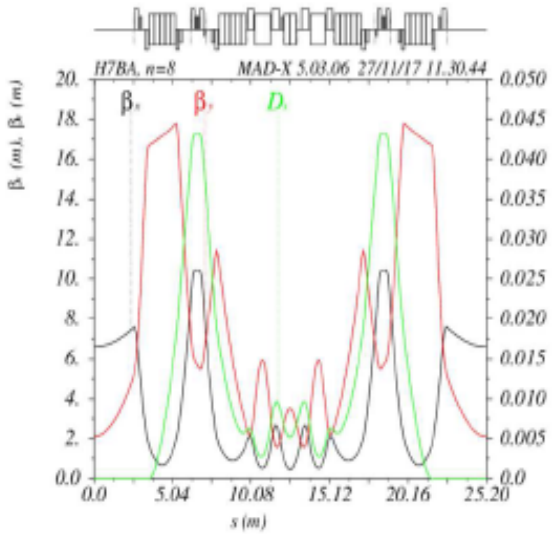
Ring design – injection - optimisation

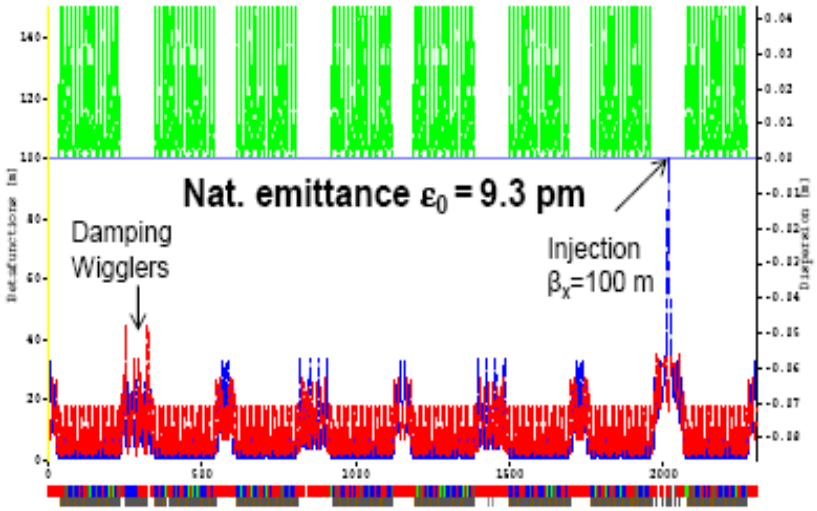
Petra IV (R. Wanzenberg)
APS-U upgrade (V. Sajaev)
The SEEIST initiative (D. Einfeld)

SOLEIL upgrade (A. Nadji)
Elettra II (E. Karantsoulis)
SLRI upgrade (T. Pulampong)

Petra IV

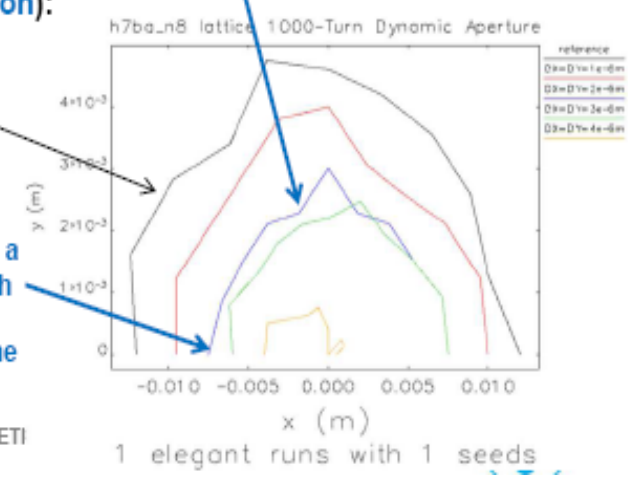
ESRF EBS lattice scaled





- RF: 500 MHz, 6 MV, bucket height=3.3%
- A_x = 1.35 mm·mrad Dynamic acceptance
- A_y = 1.24 mm·mrad (6 D tracking, no errors)

sensitivity to errors (2 µm rms, all magnets, no correction):



The DA is reduced by a factor 2 with respect to the ideal one

- an on axis injection seems to be required for a safe injection (with errors)

Petra IV

Interaction with photon scientist

Joint meeting: photon science and accelerator physics

PETRA IV Workshop in Jesteburg, July 12-13, 2017

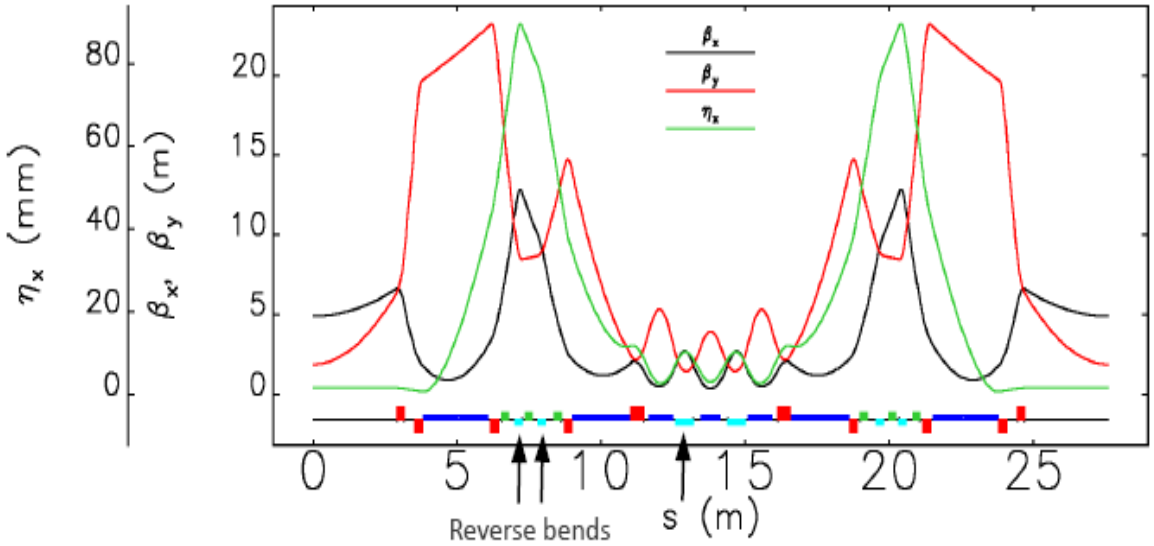
Sessions:

- Science Case and Lattice Design Status
- Brilliance and Flux
- Design and Technical Implications (Accelerator)
- Design and Technical Implications (Photon Beamlines)

APS U

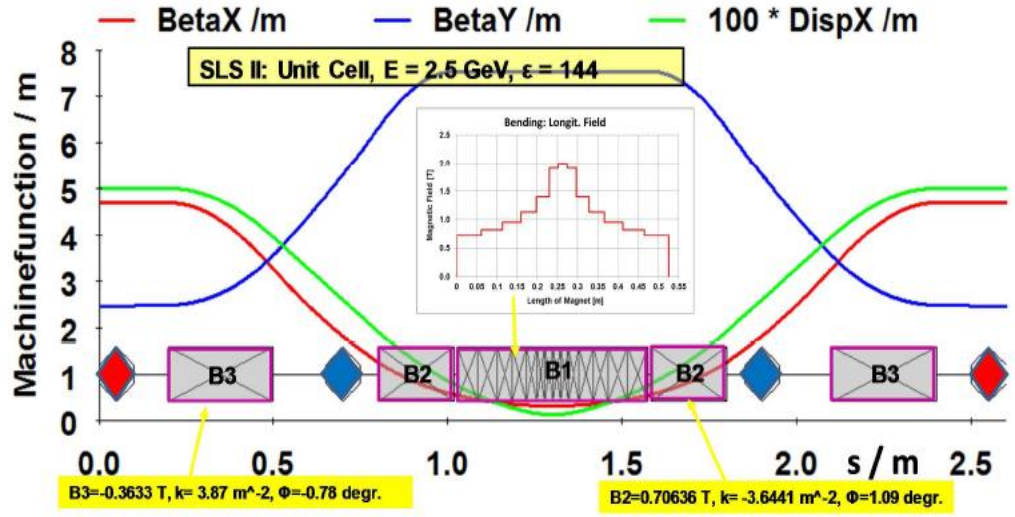
ESRF EBS – antibend – 42 pm – on axis injection

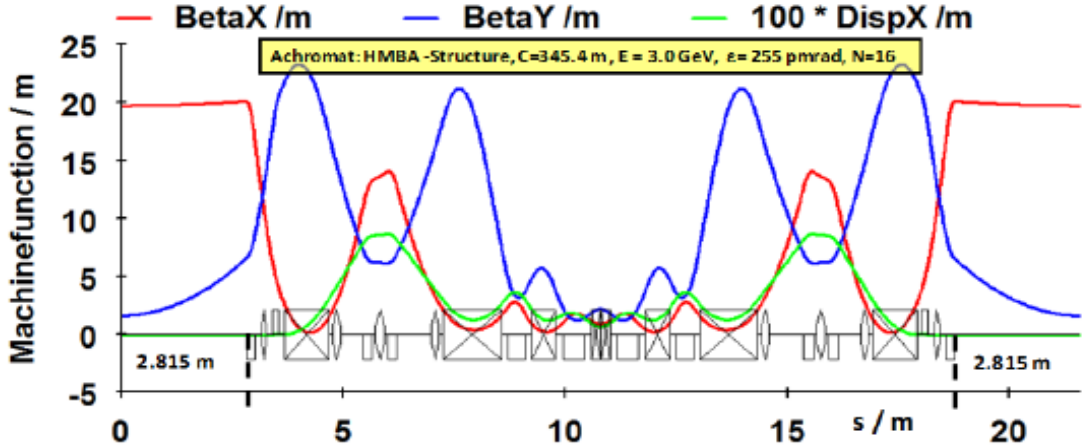
- After extensive study, chosen hybrid 7-bend achromat with 4 longitudinal-gradient dipoles and 3 transverse-gradient dipoles[1]
  - It provides for two locations with larger dispersion that can be used for chromaticity correction
  - Phase separation between sextupole triplets is ≈3π in X and ≈π in Y
- Sextupoles have 20-fold symmetry to allow for more knobs
- Introduction of reverse bends allowed us to further reduce emittance[2]



Highlights: RF stayed at 352 MHz, booster improved, long lead procurement started, commissioning simulations

SEEIST initiative





Many lattices compared

The dynamic aperture is pretty good, but has still to be optimized. Roughly 26 % of the circumference are devoted to straights. With an energy of 2.5 GEV the emittance comes down to 177 pmrad

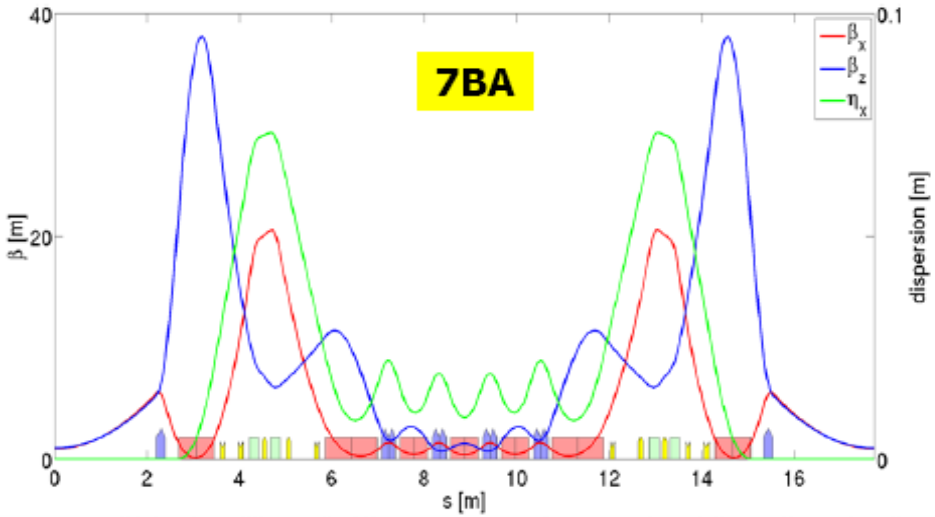
SOLEIL plan (A. Nadji)

Executive decision to move from (7BA/6BA) to new lattice – no constraints on symmetry and beamline position

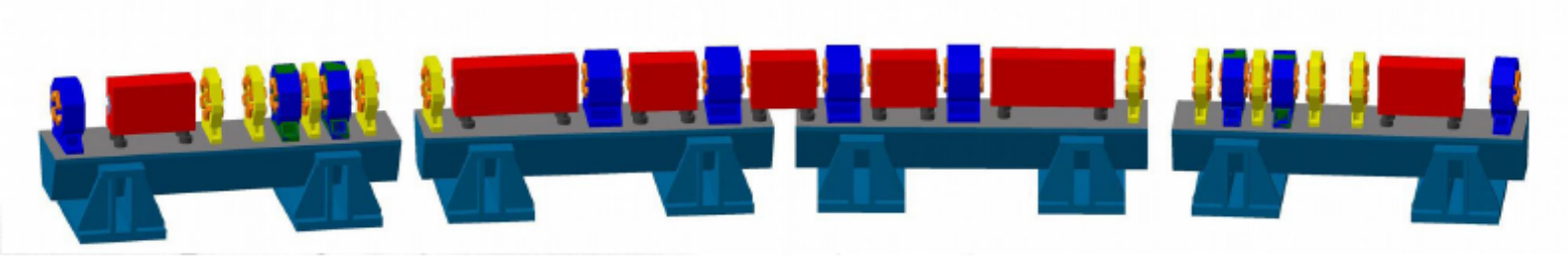
SOLEIL SYNCHROTRON

New baseline Storage Ring Lattice – November 2017

ε_x = 72 pm.rad 20 identical cells – 20 straight sections L_{ss} = 4.4 m **$\beta_x = \beta_z$ = 1 m!**



Circumference	C (m)	354.7
Energy	E (GeV)	2.75
Working point	ν_x, ν_z	55.20 , 18.20
Natural Chromaticities	ζ_x, ζ_z	-134, -125
Momentum compaction	α_1	1.5 10^{-4}
Natural emittance	ε_0 (pm.rad)	72
Energy spread	$\sigma_{\Delta E}$	8.6 10^{-4}
Energy loss per turn	ΔE_{rad} [keV]	310
Damping times	$\tau_{x,z,s}$ [ms]	10, 21, 24



– Sextupole < 2000 T/m^2 – Quadrupole < 100 T/m – Dipole ~ 0.6 T & 40 T/m
– Without longitudinal gradient in bending magnets.

Strategy and guideline for a new baseline lattice

- **Push further the reduction of the emittance in order to maximize the intensity of coherent photon flux arriving at the beamlines especially in the soft to tender X-rays photon energy range up to 3 keV.**

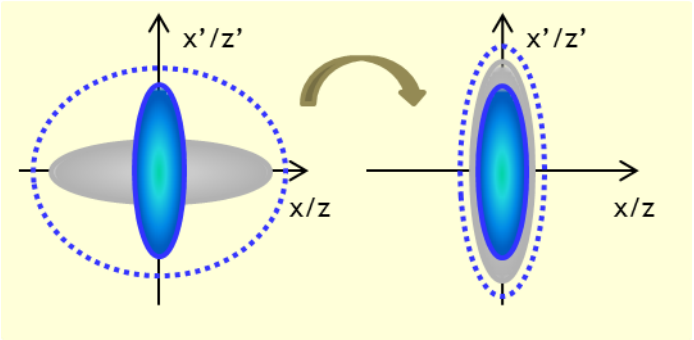
- **To achieve this goal two objectives are the key guiding principle for the optimization of the new lattice.**

  ✓ **the electron beam emittances in both horizontal and vertical planes must be close to the single-electron photon beam emittance in this energy range.**

$$B_n(\lambda) = \frac{F_n(\lambda)}{4\pi^2(\varepsilon_x \otimes \varepsilon_R(\lambda))(\varepsilon_z \otimes \varepsilon_R(\lambda))}$$

$$f_c(\lambda) = f_{cx}(\lambda)\, f_{cz}(\lambda) = \frac{\varepsilon_R(\lambda)}{\varepsilon_R(\lambda) \otimes \varepsilon_x(e^-)} \frac{\varepsilon_R(\lambda)}{\varepsilon_R(\lambda) \otimes \varepsilon_z(e^-)}$$

  ✓ **the orientation of the phase space ellipse of the electron beam should match the one of the photon beam.**



$\sigma'_R \approx \sqrt{\lambda/2L}$ $\quad \sigma_R \approx \sqrt{2\lambda L}/2\pi$ $\quad \varepsilon_R = \sigma_R \sigma'_R = \lambda/2\pi$ $\quad \beta_R = \sigma_R/\sigma'_R = L/\pi$

A. Nadji, Soleil

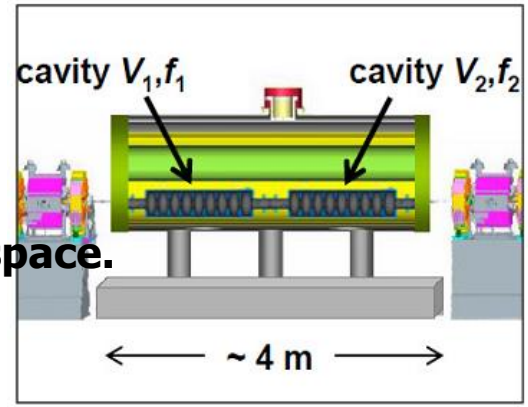
TEMPORAL STRUCTURE and SHORT PULSE

❑ Temporal structure:

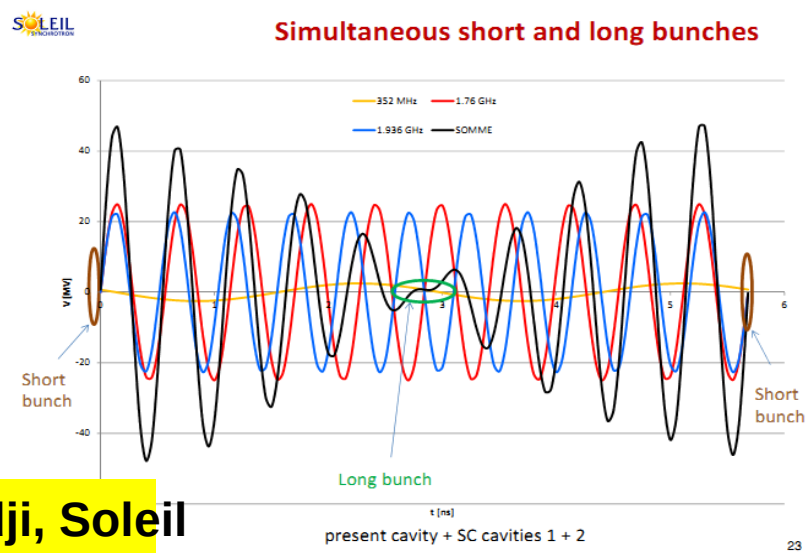
- Hybrid/camshaft mode, 1 bunch, 8/16 bunches.
- Possibility of Pseudo Single Bunch with the camshaft mode.
- *Bunch length ~ 24 ps - 120 ps FWHM.*

❑ Short pulse option:

- Use higher emittance ~ 600 pm.rad (compensate for IBS and reduced beam lifetime).
- Use of two harmonic cavities with two different frequencies "à la BESSY VSR", in order to shape the longitudinal phase space. Short and long bunch alternate.



SOLEIL	f_{RF} (GHz)	V_{RF} (MV)	V'_{RF} (MV. GHz)
Nominal RF SC cavity	0.352	1	2π 0.35
First harmonic SC cavity (n=5)	1.760	10	2π 17.6
Snd harmonic SC cavity (n=5+1/2)	1.936	9.1	2π 17.6
Even fixed points			2π 35
Gain			35/0.35 = 100
Theoretical bunch length reduction			$\sqrt{100} = 10$



A. Nadji, Soleil

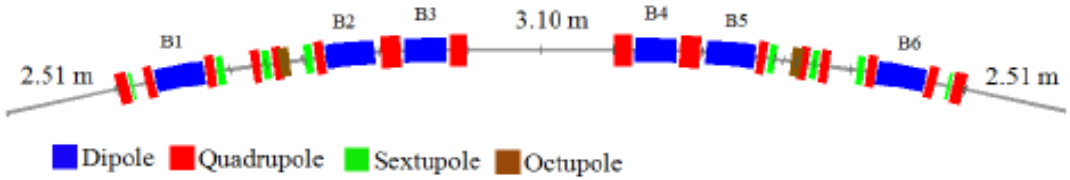
ELETTRA 2.0 status

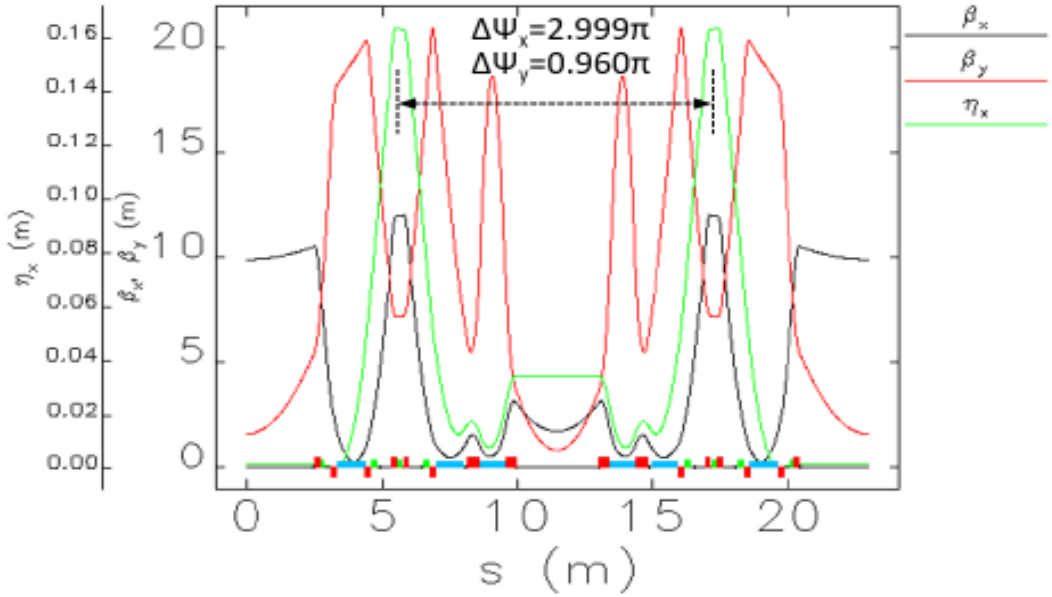
- For Elettra 2.0 our S6BA optics is chosen as the closest to the various requirments (up to now)
- The optics is very flexible and can accommodate a number of super-bends.
- Installation of insertion devices also possible in the middle of the arc. For the moment the space available there, is 1.6 m.
- The 1.0 version of the Elettra 2.0 conceptual design report is available.
- Other types of MBAs are also under evaluation
- ***Project approved by the Italian Government!!!***

SLRI upgrade

Original Diamond upgrade study

DTBA (Double triple bend achromat)





Local Dispersion bump and chromaticity correction

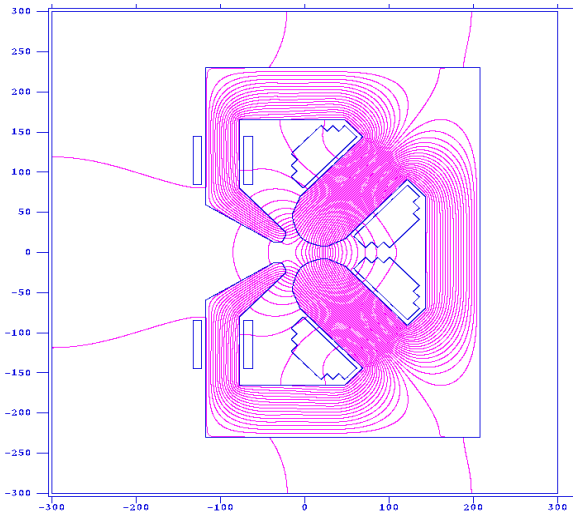
Odd-pi phase advance trick

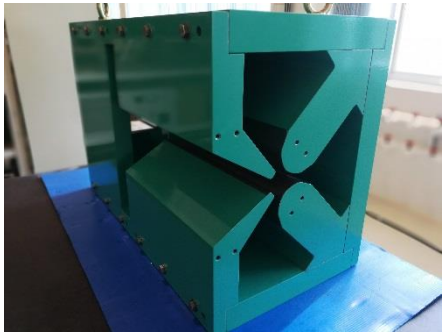
14 Cell -> RING

28 straights in total

SLRI R&D

magnets





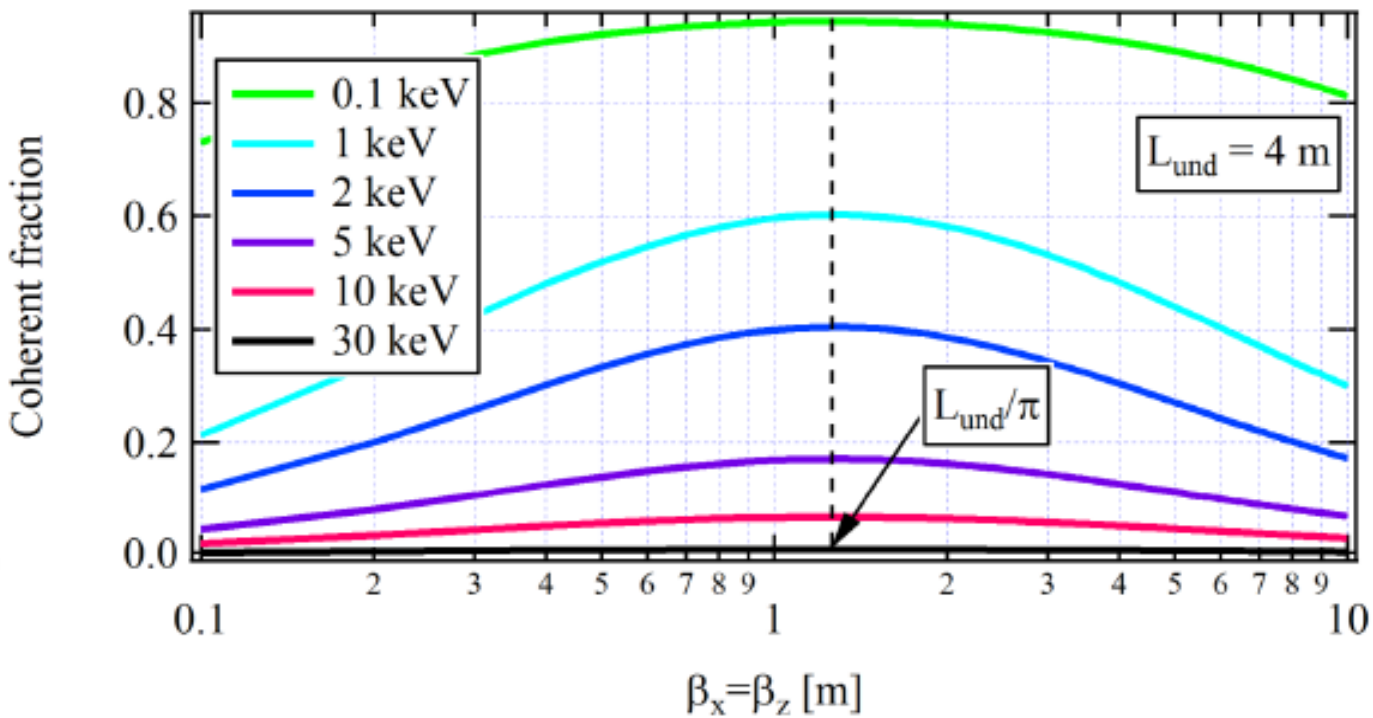
vacuum

Twisted Wire Target (Ti, Zr and V)

Open issues?

Lattice design? HMBA or TME + LGB + RB
Analytical vs numerical optimisation tools
On axis / off axis?
$\varepsilon = \lambda/2/pi$ and $\beta = L/\pi$

Phase space matching: Optimum β function



Further common issues to upgrade

- Beam energy variable or fixed (Elettra)?
- Number of beamlines/IDs reduced when upgrading with same footprint?
- Dark period: shutdown for users about 18 months → how to optimize?
- Dynamic Aperture for off-axis injection
- Short pulse operation
- Coherence
- Bunch lengthening for longer lifetime and lesser IBS
- Fancy multi-functions magnets
- NEG coating
- Free space available

Collective effects

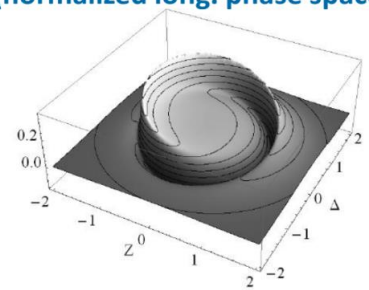
TMCI with HC (M. Venturini)
Ion trapping (A. Gamelin)
Collective effect at MAX IV (F. Cullinan)
Collective effect at APSU (R. Lindberg)
Self-consistent simulation code (G. Bassi)
Collective effects at NSLS-II (A. Blednykh)
High frequency impedance measurements (A. Passarelli)
Resistivity measurement of coated surfaces (E. Plouviez)

There were six contributions in the Collective Effects Session:

1) A theory for TMCI in the presence of Harmonic Cavities and RW (Marco Venturini, ALS)

- **A long standing question of the impact of bunch lengthening harmonic cavities on TMCI was addressed theoretically by assuming RW as the impedance.**
- **The linearized Vlasov equation (Sacherer's equation) was used by properly introducing the longitudinal amplitude-dependent tune shift term, treating the resultant numerical singularity by writing the equation into a dispersion relation and numerically solving a discretized equation.**
- **It was discovered that the beam is unstable from zero current as the mode coupling between the modes 0 and -1 occurs already partially due to tune shifts. The growth rate in this (low-current) regime was found to depend on the current as I^6 and the threshold deduced via equilibrium to radiation damping turned out to be nearly a factor 2 below the TMCI threshold without HCs for ALS-U.**

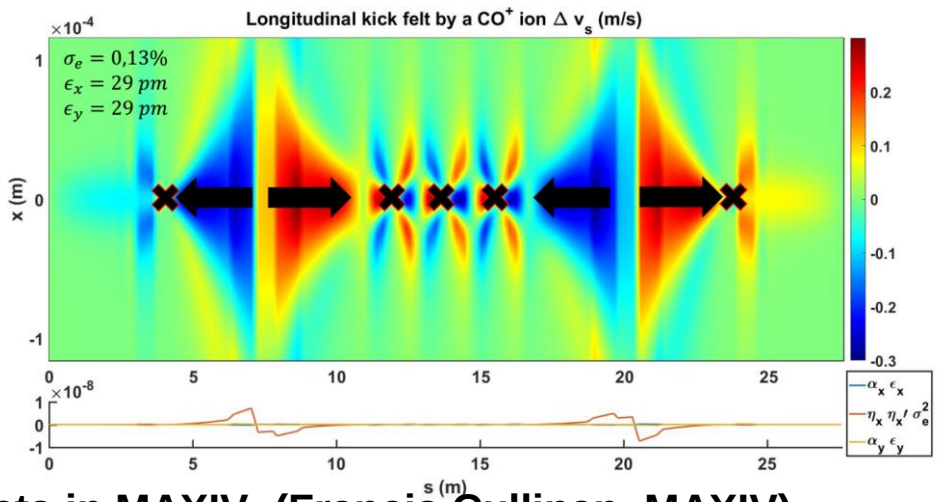
Density plot of unstable perturbation (normalized long. phase space)



2) Ion-trapping in electron storage rings (Alexis Gamelin, LAL)

- **Ion-trapping in electron storage rings was studied by developing a numerical code (*NUAGE*) that follows the ion motions again rigid Gaussian electron bunches and taking into account magnetic lattice and in particular dipole fields that bring about longitudinal ion motions.**

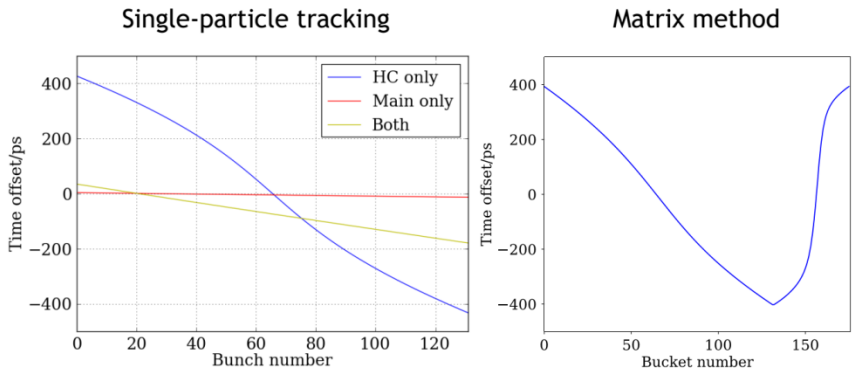
- **The studied effectively confirmed that low-emittance light source rings such as SOLEIL and APS-U treated do not suffer from ion trapping and in one case there was even an self-cleaning mechanism.**
- **For ThomX, some ion accumulation points were identified in the lattice, where introduction of ion clearing electrodes generating longitudinal expulsing field appeared effective to chase them away → To be demonstrated in reality**



Self-cleaning mechanism found for APS-U

<u>3) Collective effects in MAXIV (Francis Cullinan, MAXIV)</u>

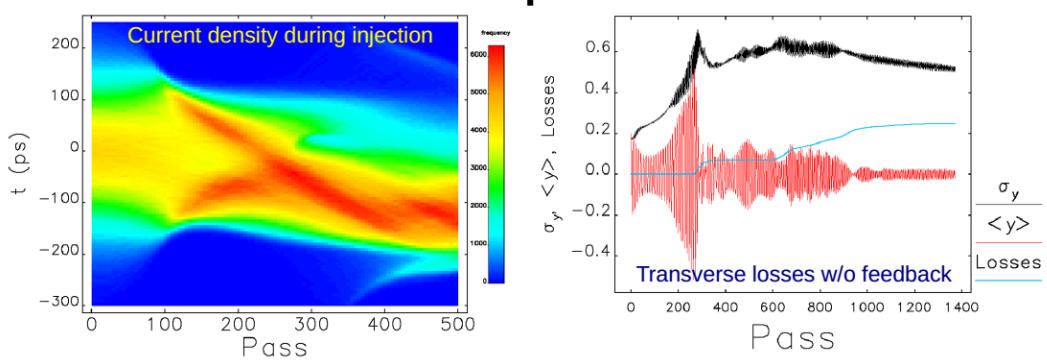
- **Broadband impedance was measured with beam longitudinally and transversely and compared with predictions → It turned out that the measured impedance was significantly larger (by factor of ~10 in *L* and 3 in *V*). However, these large impedances have no harmful effects on operation.**
- **Cavity-induced HOMs are the biggest obstacle in raising the beam current. The cavity kicker installed help suppressing the longitudinal coupled-bunch modes via bunch-by-bunch feedback.**
- **Transient beam loading induced by passive HCs are studied by deriving an analytical phaser-based equation which is solved by matrix inversion → Comparisons are to be made with tracking and beam-based measurement**



Comparison of the developed matrix method to tracking for the harmonic cavities-induced transient beam loading

4) Collective effects in APS-U (Ryan Lindberg, APS)

- **The successful modelling of the present APS ring was applied to APS-U. → No critical issues found in single bunch instabilities both longitudinally and transversely.**
- **Transient transverse instabilities occur at injection due to longitudinal phase space mismatch, but can be cured with transverse bunch-by-feedback**
- **Cavity-induced HOMs cause more problems for APS-U than the current ring as radiation damping is weaker for the former → Can be controlled with a combination of temperature tuning, better HOM dampers, and a suitable longitudinal feedback system**
- **Ion trapping studied systematically by computing expected vacuum pressure profiles using SynRad+ and MolFlow+. It could be a problem in the 324 bunch mode, but several mitigation methods developed;- Decrease emittance ratio, - Employ ion clearing gaps, and - Use NEG in the multiplets**



Longitudinal phase-space mismatch of injected and stored beam results in longitudinal oscillations/structure which can generate large transverse wakefields, which can drive oscillations, emittance growth, and particle losses

Collective effects (contd)

1. G. Bassi: Simulation code for self-consistent modelling…

   Tracking code SPACE that can simulate 15M particles using 1000 processors in CORI at NERSC. The idea is to treat simultaneously short (single bunch) and long (multi bunch) range wakes in a 6D space for a fully coupled system. Showed effect of treating together head tail and coupled bunch modes.

   Applied his code to study the effects of the passive HC of MAX IV and the microwave instability in NSLS-II without however comparison with measurements

2. A. Blednykh: Summary of studies …NSLS-II

   The machine achieved 400 mA and for users operates at 350 mA. He has shown a series of interesting effects like tune shift with current different for open and closed ids explaining that it is due to in-vacuum IDs at high betas. Showed measurements of bunch length with current in the contest of microwave instability study, an intrigued result that provoked lots of discussion due to the fact that the beam size did not follow a curve but showed local minima and maxima. Simulations with SPACE showed the same behavior. Tried to give an explanation of this by arguing a combined LMI and TMCI effect that did not convince.

   Went on with TMCI indicating the threshold at 0.6 mA for +2/+2 chromaticity. Showed the longitudinal impedance budget indicating as the biggest contributor the rf-shielded flanges (about 800) due to some bad contacts solved by replacing the springs of the contacts. Finally he presented and tried to explain some overheating problem in the metalized ceramic chamber.

Collective effects (contd)

A. Passarelli: High Frequency impedance measurements of coated wave-guides

To avoid secondary electron emission and formation of electron cloud in very high frequency wave guides amorphous Carbon coating that reduces the emission is studied in two configurations of a rhomboidal guide with a 1.27 mm side. One configuration is coating all sides of the rhomboidal tube while the other is coating a copper plate placed in the middle along the smaller diagonal of the rhombus. Measurements performed via a TERA K15 time domain THz spectrometer evaluating the power attenuation. Results showed that the copper coated plate gives better results. Continue studies with NEG coating that seems to give similar results and there was again audience interest on NEG coating and its impedance

E. Plouviez: Comments on resistivity measurements of coated surfaces: Presented measurements of transmission and reflection coefficients of NEG coating on capton foil using a simple device and a power meter performed in 2004 and 2016 getting for 0.6 micron NEG Z=16.5Ohm and for 2 micron Z=5 Ohm. However later measurements elsewhere showed a factor 10 difference in conductivity showed that maybe roughness and other factors are important. Hot topic

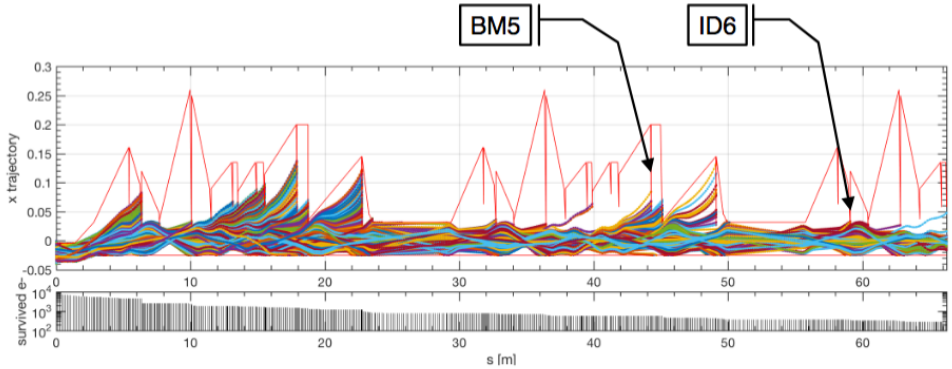
Operation and beam dynamics

MAX IV (P. Tavares)
Review of injection schemes (P. Kuske)
BESSY-VSR (A. Jankowiak)
Tracking studies for Top-Up ESRF (S. Liuzzo)
First turn around HEPS (Y. Zhap)
Nonlinear dynamics of CLIC damping ring (H. Ghasem)
Beam halo formation at KEK (R. Yang)

Recent measurement of linear and nonlinear optics at ESRF (A. Franchi)
Precise optics measurement on storage ring (L. Malina)
Experimental studies of high field wiggler at KIT (P. Zisopoulos)
Analytical N-BPM method for optics measurement (A. Wegscheider)
BPM calibration (A. Garcia Tabares)

Top-Up safety simulations

FORWARD TRACKING



Forward tracking of 10000 particles filling the injection straight section

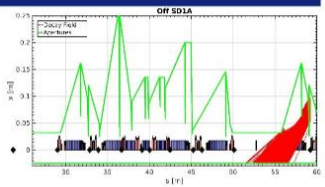
Particles may be lost on the crotch absorber of BM5 and ID6. Can they enter the beam port ?

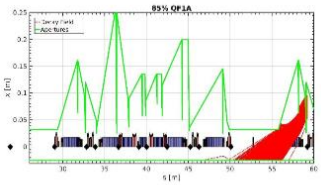
ID FRONT-END, SUMMARY

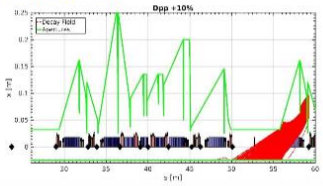
The same have been reproduced for degraded working conditions still allowing stored beam:

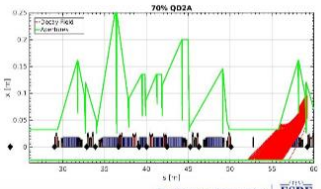
- **SD1A off**
- **QD3 at 50%**
- **QD2 at 70%**
- **QF1 at 85%**
- **Injected beam off-momentum by 10%**

In all cases, the backtracking shows no particle reaching the injection section







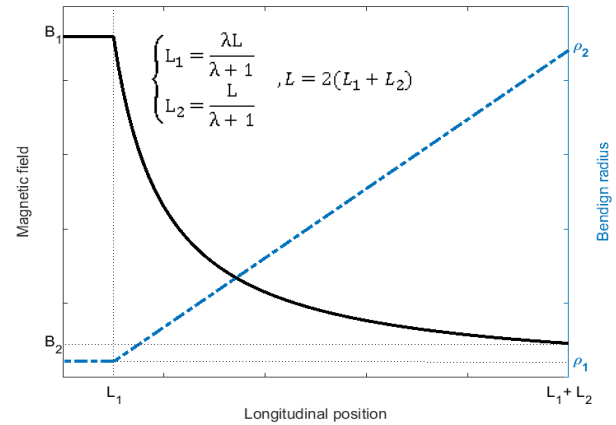


Nonlinear dynamics of CLIC damping rings

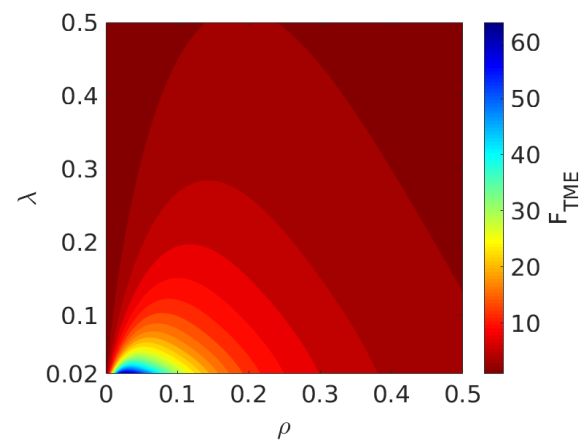
- **The horizontal emittance can be further reduced below the TME limit by considering dipole magnets with longitudinal variable bending field.**
- **Regarding the analytical studies, the trapezium field profile dipole provides the minimum horizontal emittance.**

$$\begin{cases} \rho_1 \; (0 < s < L_1) \\ \rho_1 \left[1 + \frac{\lambda+1}{L} \left(\frac{1-\rho}{\rho} \right) \left(s - \frac{\lambda L}{\lambda+1} \right) \right] \; (L_1 < s < L_1 + L_2) \end{cases}$$

$$\begin{cases} B_1 \; (0 < s < L_1) \\ B_1 \left[1 + \frac{\lambda+1}{L} \left(\frac{1-\rho}{\rho} \right) \left(s - \frac{\lambda L}{\lambda+1} \right) \right]^{-1} \; (L_1 < s < L_1 + L_2) \end{cases}$$



- **The longitudinal variable bend can be generally characterized by defining the length and bending radius ratios as λ = L1/L2 and ρ = ρ1/ρ2.**

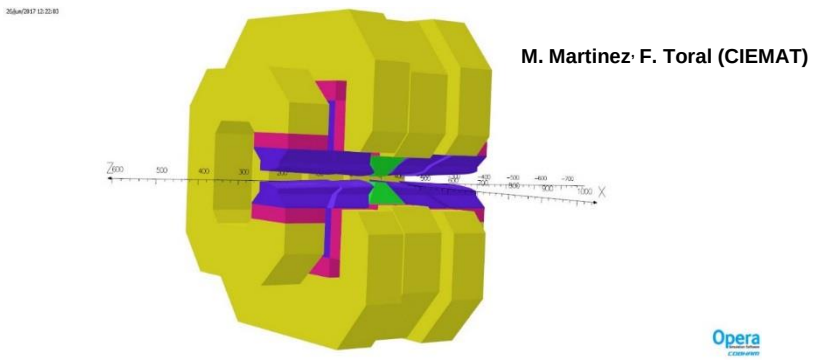


- **The emittance reduction factor of TME cell (F_{TME}) is the ratio of the absolute minimum emittances of a uniform with respect to a variable field dipole.**

S. Papadopoulou, F. Antoniou and Y. Papaphilippou, *Emittance reduction with variable bending magnet strengths: Analytical optics considerations*, preprint (2017).

- **The Trapezium field dipole is selected for application in CLIC DR.**

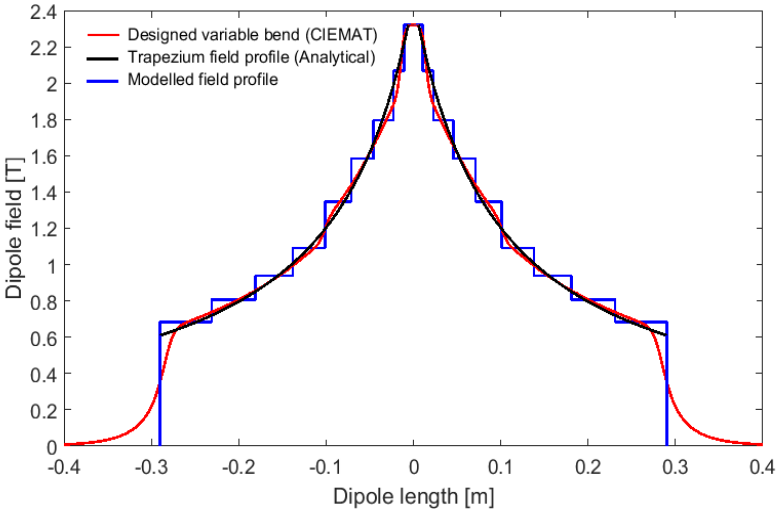
- **For the CLIC DR application and from the magnet design and technology point of views, the achieved λ and ρ are 0.04 and 0.29 respectively which correspond to F_{TME}=7.**



M. Martinez, F. Toral (CIEMAT)

- **The designed dipole has the total length of 58 cm and bends the beam by 4 degrees.**

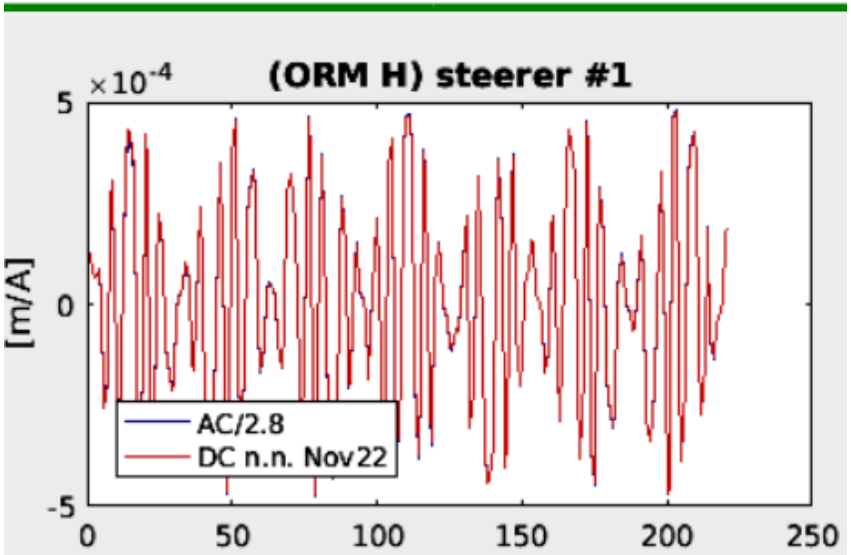
- **The blue step line represents the modelled dipole field profile by MADX and ELEGANT codes based on using separated rectangular shape dipole sections.**



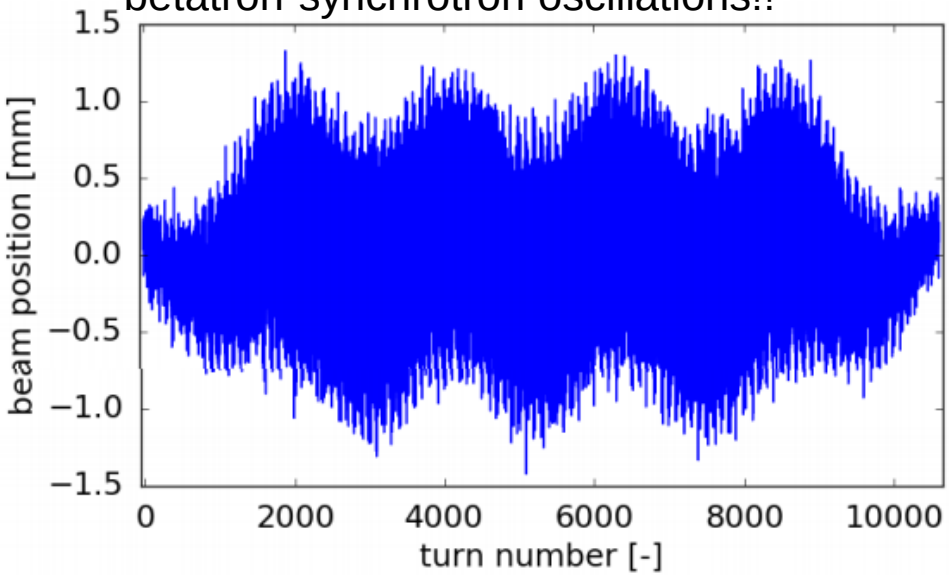
Parameters	Highest field section	Lowest field section
Length (cm)	2.143	5.900
Field (T)	2.321	0.685
Radius (m)	4.111	13.937
Def. angle (Deg.)	0.299	0.243
K (m^{-2})	-1.100	-1.100

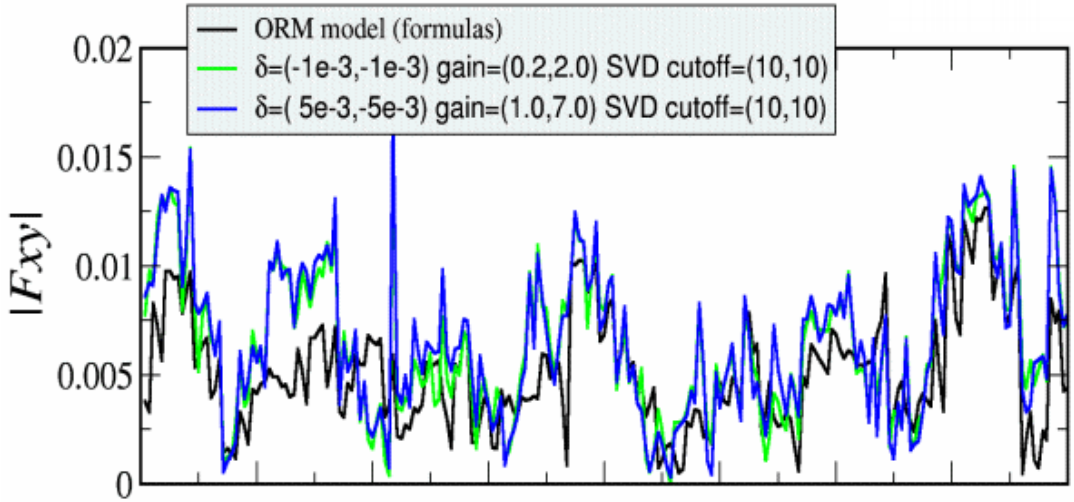
Optics Control goes **AC**

ORM diagonal block line AC Vs DC



L. Malina, LHC, 3D driven betatron-synchrotron oscillations!!





A. Franchi, ESRF:

*ORM in 34 seconds!!! (also in Diamond, NSLSII and ALBA)

*AC dipole Turn-by-turn coupling measurement at low chroma.

Optics control goes **Analytical**

$$D'_x(j) = -2D_x(j) + \frac{\sqrt{\beta_{j,x}}}{\sin(\pi Q_x)} \sum_{m=1}^{M} \left[K_{m,1} - \frac{1}{2} K_{m,2} D_{m,x} \right] D_{m,x} \sqrt{\beta_{m,x}} \cos\left(\Delta\phi_{x,mj} - \pi Q_x\right)$$

$$\begin{pmatrix} \delta\vec{O}^{(xx)} \\ \delta\vec{O}^{(yy)} \\ \delta\vec{D}_x \end{pmatrix} = \mathbf{N} \begin{pmatrix} \delta\vec{K}_1 \\ \delta\vec{K}_0 \end{pmatrix}$$

$$\begin{pmatrix} \delta\vec{O}^{(xy)} \\ \delta\vec{O}^{(yx)} \\ \delta\vec{D}_y \end{pmatrix} = \mathbf{S} \begin{pmatrix} \vec{J}_1 \\ \vec{J}_0 \end{pmatrix} .$$

A. Franchi, ESRF: Fully analytical ORM matrix derivative generation

$$Q' = \frac{Q_s}{\sigma_\delta} \sqrt{\frac{A_1 + A_{-1}}{A_0}}$$

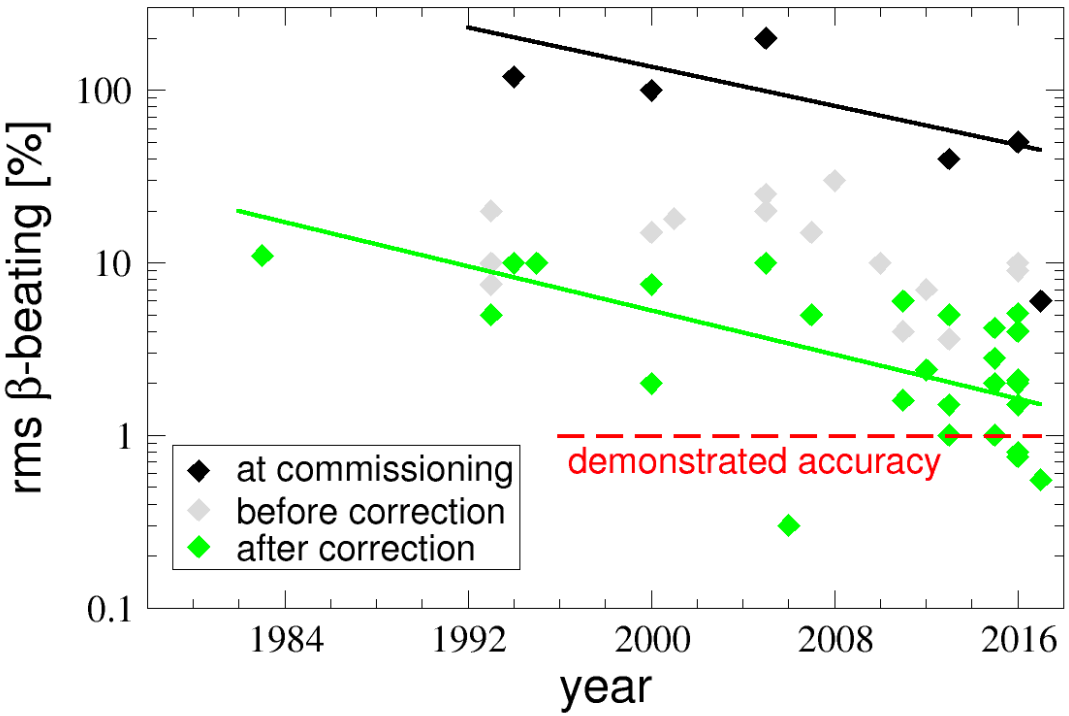
P. Zisopoulos, chroma or energy spread measurements from turn-by-turn data

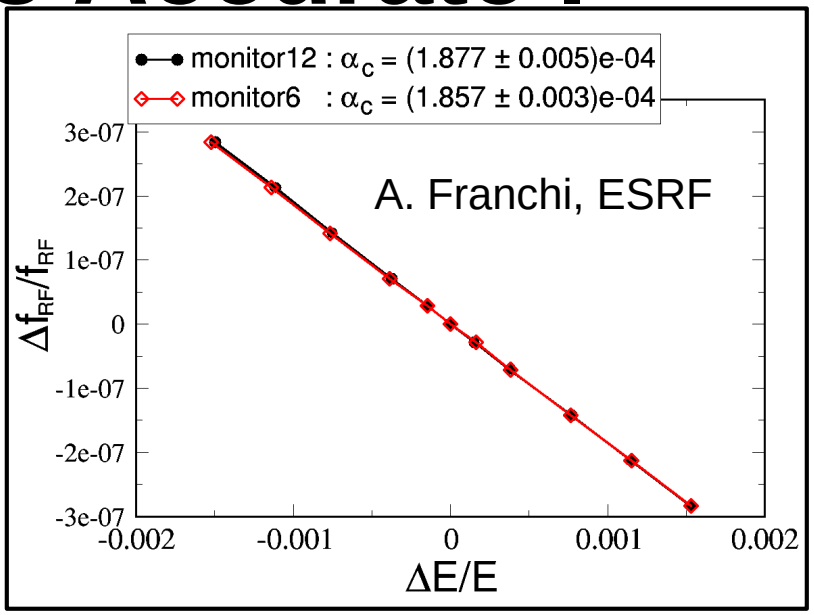
$$\beta_l(s_i) \approx \frac{\cot\phi_{ij_l} - \cot\phi_{ik_l}}{\cot\phi^m_{ij_l} - \cot\phi^m_{ik_l} + g_{ij_l} - g_{ik_l}} \left[\beta^m(s_i) - 2\alpha^m(s_i)\delta s_i\right]$$

A. Wegscheider, LHC, Analytical N-BPM method for beta-from-phase

Challenges pending: Correction of AC dipole effects with chromaticity, etc.

Optics control goes **Accurate I**



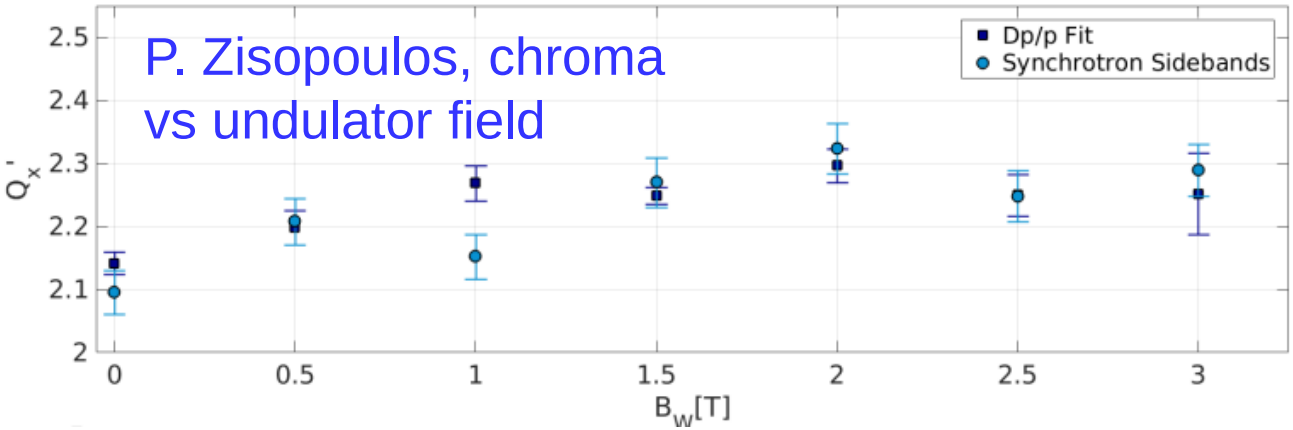


	α_c value (10^{-4})
Ideal model	1.7795
Model with errors	1.827 ±0.004 (*)
ID 20	1.76 ±0.14
ID 21	1.87 ± 0.11
hard x-ray monitor	1.867 ± 0.004(^)

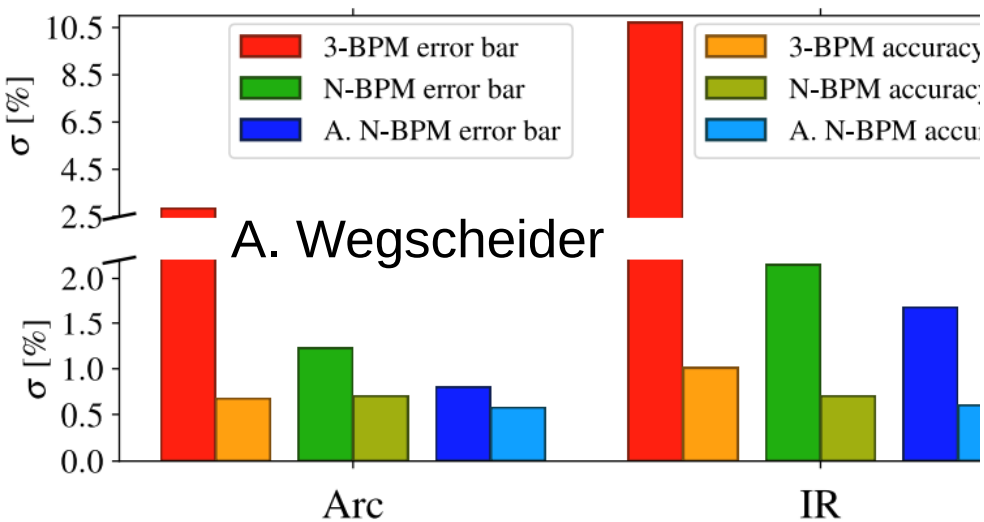
β-function measurements precision pushed down to 4 ‰ and sub-% accuracy was demonstrated ESRF

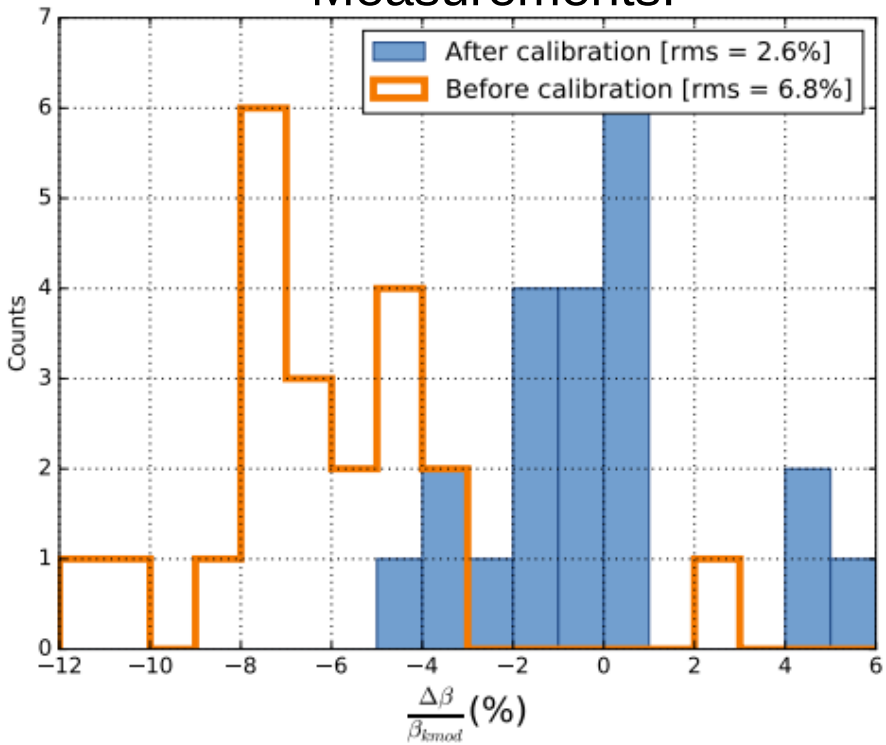
L. Malina

Optics control goes **Accurate** II



A. Garcia Tabares, BPM calibration with optics Measurements:





LER technology

FCCee Vacuum (R. Kersevan)
NEG coating (O. Malyshev)
Cherenkov radiation detector at Cornell (T. Lefevre)
Ideal orbit feedback in LER (G. Rehm)

High efficiency klystrons (I. Syratchev)
Design and test of extraction kickers (C. Belver-Aguilar)
Summary of SCUs activity at APS (Y. Ivanyuschenkov)

See P. Kuske summary

Conclusions

Many excellent talks (cannot fit in this short summary)

MAX IV well in operation

ESRF-EBS and SIRIUS being built

Other slowly but steadily gaining approval

APS–U CD1 February 16; ALS–U CD0 September 16

Many projects in design phase. Common theme in light sources colliders and damping rings is the ever aggressive lattice design and technological choices

Community always large (80 delegates!)

Next RULE workshop

https://indico.cern.ch/event/682952/overview

Topical Workshop on Diagn...

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Europe/Zurich English Login

Topical Workshop on Diagnostics for Ultra-Low Emittance Rings

19-20 April 2018
Diamond Light Source
Europe/Zurich timezone

Search...

- Overview
- Timetable
- Participant List

The workshop puts together the experience of the Diagnostics Groups and parts of the Beam Dynamics Groups of the accelerator communities working on ultra low emittance lattices for damping rings, colliders and light sources.

Starts 19 Apr 2018, 13:00
Ends 20 Apr 2018, 18:00
Europe/Zurich

Diamond Light Source
G59
Diamond House, Harwell Campus, Didcot, OX11 0DE, United Kingdom

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Abingdon 19-20 April 2018