Low emittance rings
Report from WP6 LOWεRING

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Thanks to R. Nagaoka (SOLEIL), M. Boge (PSI), M. Borland (APS), R. Hettel (SLAC)

2nd EuCARD2 Annual Meeting, Barcelona, 21 April 2015

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

Outline

- WP6 description and present status
- Review of activities and summary of R&D challenges

coordination	(**task 6.1**)
low emittance ring design	(**task 6.2**)
collective effects	(**task 6.3**)
technology	(**task 6.4**)

- Conclusions and next steps

WP6 objectives

WP6 aims at fostering links between the communities of

damping rings, light sources and lepton colliders

working on low emittance rings, by establishing and supporting networks through

workshops
support exchange of people and ideas

Many problems and R&D challenges are common
Identify synergies and common R&D programmes

Initiated by CLIC DR + ILC DR + CESR + B-factories + LS (2010-2011)
put on solid feet by EuCARD2

WP6 present status

Workshops:

2013 July – 1st general Workshop - Oxford 81 participants
2014 January – Collective effects (TWIICE) – Paris 75 participants
2014 May – Technology (ALERT) – Valencia 52 participants
2014 September – 2nd general Workshop – Frascati 78 participants

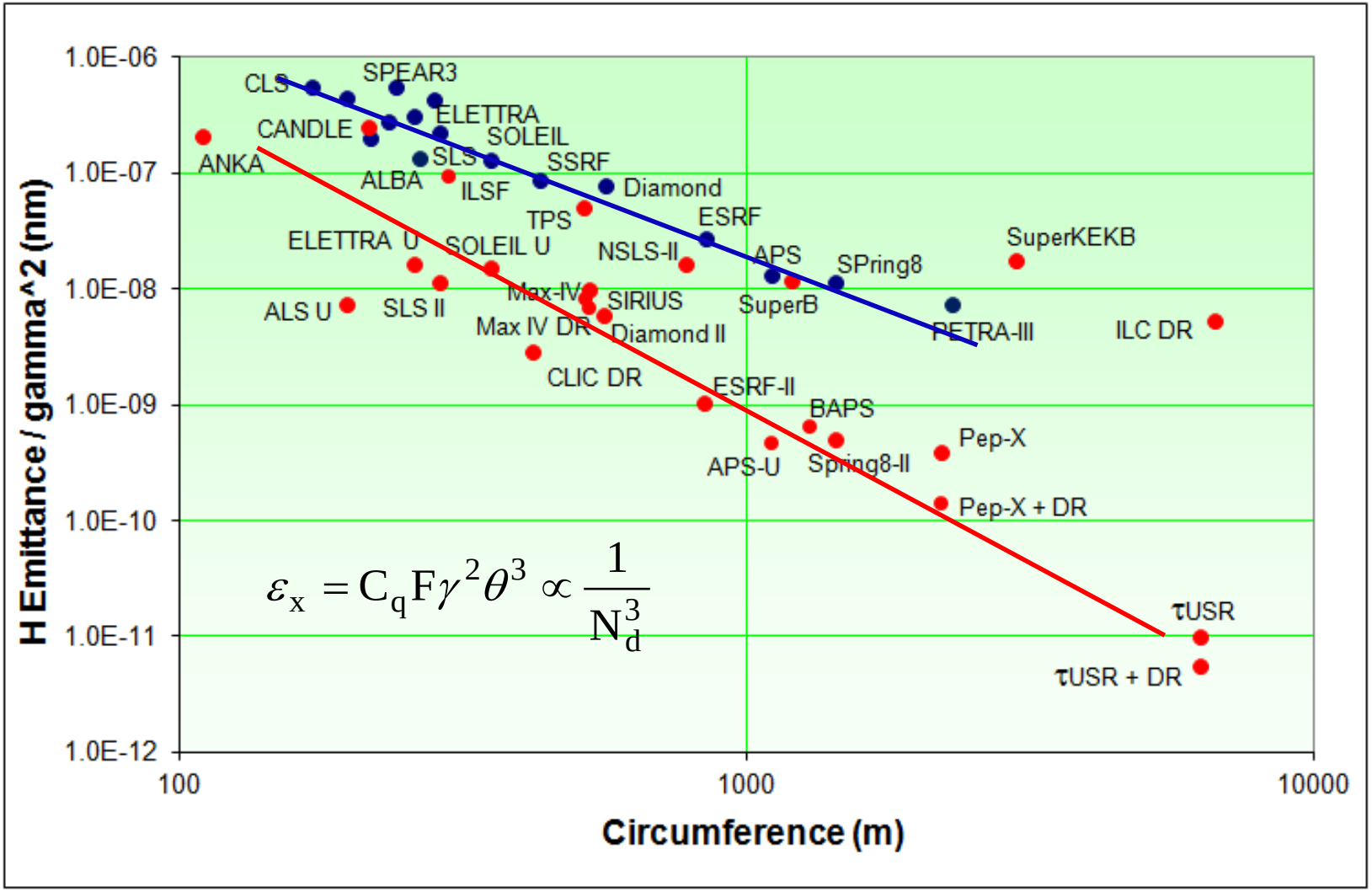
Deliverables: on http://eucard2.web.cern.ch/science/deliverables

EuCARD2- DEL – D6.1: Low emittance ring design - interim report
EuCARD2- DEL – D6.2: Instabilities, impedance, collective effects - interim report
EuCARD2- DEL – D6.3: Low emittance ring technology - interim report

Imminent:

2015 April – Low emittance ring design – Barcelona – 50 registered
2015 September – 3rd general workshop – Grenoble
2016 January – 2nd topical workshop on collective effect workshop

Survey of low emittance rings



New rings and upgrade programmes

MAX-IV	330 pm		3 GeV	7BA	**LER 2010**
Spring-8 II	70 pm	(48)	6 GeV	6BA	
PEP-X	5 pm		6 GeV	7BA	
APS	100 pm	(25)	7 GeV	7BA	**IPAC 11-12**
τUSR	3 pm		9 GeV	7BA	
SIRIUS	280 nm		3 GeV	TBA	**USR Beijing 12**
ESRF II	140 pm	(28)	6 GeV	7BA-hybrid	
Diamond II	140-270 pm	(20-10)	3 GeV	(270 pm DDBA - 140 pm 5BA)	
ALS	100 pm	(20)	2 GeV	9BA	
BAPS	50 pm		5 GeV	10BA	**IPAC13-14**
SOLEIL	430 pm	(10)	2.7 GeV	DB-split	
SLS	250 pm	(20)	2.4 GeV	Longitudinal gradient bend	
ELETTRA	250 pm	(28)	2 GeV	6BA	
ANKA	5000 pm	(18)	2.5 GeV	split-TME	
CLS	800 pm	(22)	2 GeV	7BA	
SPEAR III	750 pm	(13)	3 GeV	DQBA	

Why now?

- Strong push from the light source community (MAX IV, ESRF, SIRIUS...)

  better science enabled by better photon properties

- Growing confidence in “aggressive” low emittance lattice designs **(task 6.2)**

  from DBA to MBA

  injection in smaller apertures (…eventually on axis)

- Excellent control of the beam properties proven at many light sources **(tasks 6.2&6.3)**

  orbit, optics, stability, lifetime, losses, customised optics…

  beam based tuning tools, cures for instabilities

- Key enabling technologies appear to be mature

  no showstoppers in magnets, vacuum, diagnostics, RF, … **(task 6.4)**

Topics/Issues in lattice design (task 6.2)

- Growing confidence in "aggressive" low emittance lattice designs

Lattice design evolution from DBA, TBA to 4BA,…MBA:

Lattice optimisation tools improved (linear and nonlinear dynamics)

Low emittance lattices require small angle bending

$$\varepsilon_x = C_q F \gamma^2 \theta^3 \propto \frac{1}{N_d^3}$$

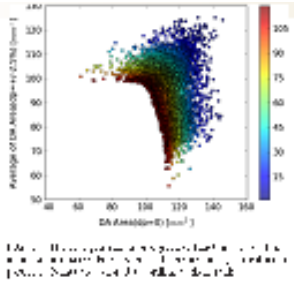
MBA lattices (large rings favoured) but
strong focussing + small dispersion → strong sextupoles

"Novel" concepts put forward

longitudinal varying field dipoles (ESRF, Sirius, …)
antibends for dispersion suppression (SLS)
solenoids for round beams (SOLEIL, …)
Robinson wigglers [see LER 2014 prize talk T. Goetsch 5pm today]

incorporating correction and BBA capabilities from the design

Optimisation of beam dynamics



Symplectic Tracking based methods

DA, MA separated

DA, MA together

SOLEIL SYNCHROTRON

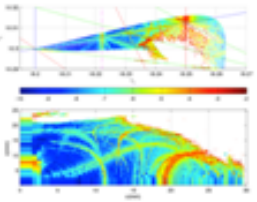
from L. Nadolski, ICFA LowEring, Oxford 7/13

Direct tracking based optimization

GLASS

Analytical based method

Genetic Algorithm
MOGA



Lie Algebra/Differential Algebra

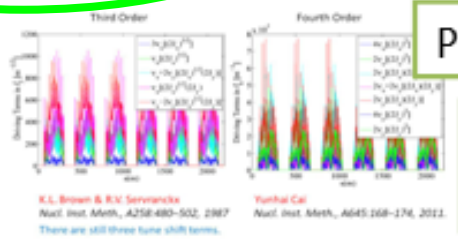
Resonance Driving Terms
RDT minimization

Amplitude Tuneshift
minimization

Frequency Maps
FMA
Diffusion factor

Nonlinea
r "LOCO"

Canceling
Sextupole
Resonances



Phase advances

Interleaved
sextupoles

Resonance identification

Robustness to magnetic, alignment errors

Robustness ID configurations

Tracking codes: PTC MADX TRACY AT LEGO OPA ELEGANT

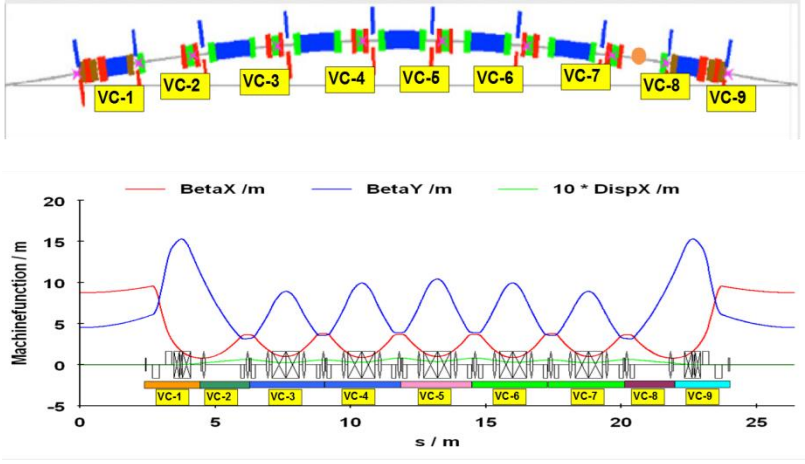
Optimisation of beam dynamics

Deep Blue–Kasparov: 3½–2½

Lattice design

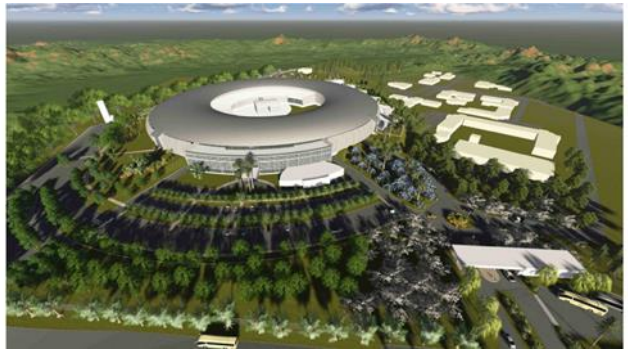
MAX–IV (Sweden) is taking the first pioneering step with 7BA, under construction

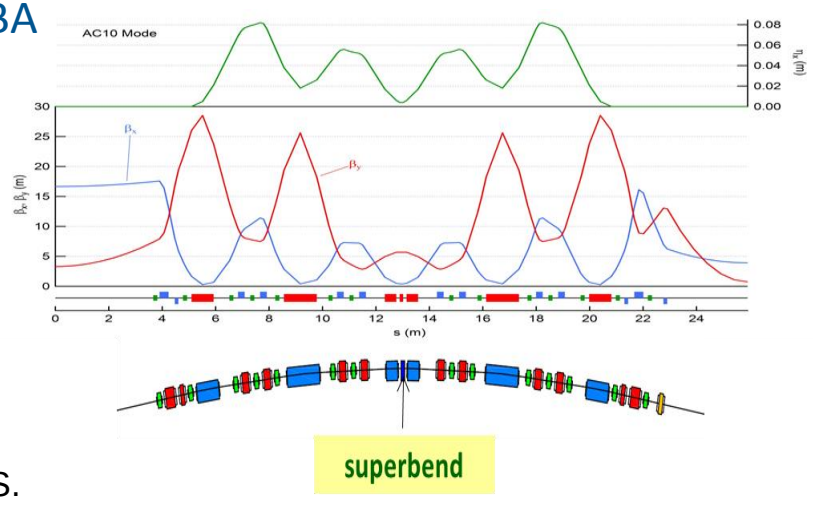
3 GeV, 528 m, 0.25 nm



Sirius (Brazil) just started construction of 5BA with superbend

3 GeV, 518 m, 0.28 nm





L. Liu, LNLS.

Lattice design

ESRF (France)

6 GeV, 844 m, 4 nm → 150 pm

- Dispersion bumps for efficient sextupoles
- Longitudinal gradient dipoles (D1, D2, D6, D7) to further reduce emittance
- Combined dipole-quadrupoles D3-4-5
- 3-pole wiggler as hard X-ray source

APS (US - preliminary)

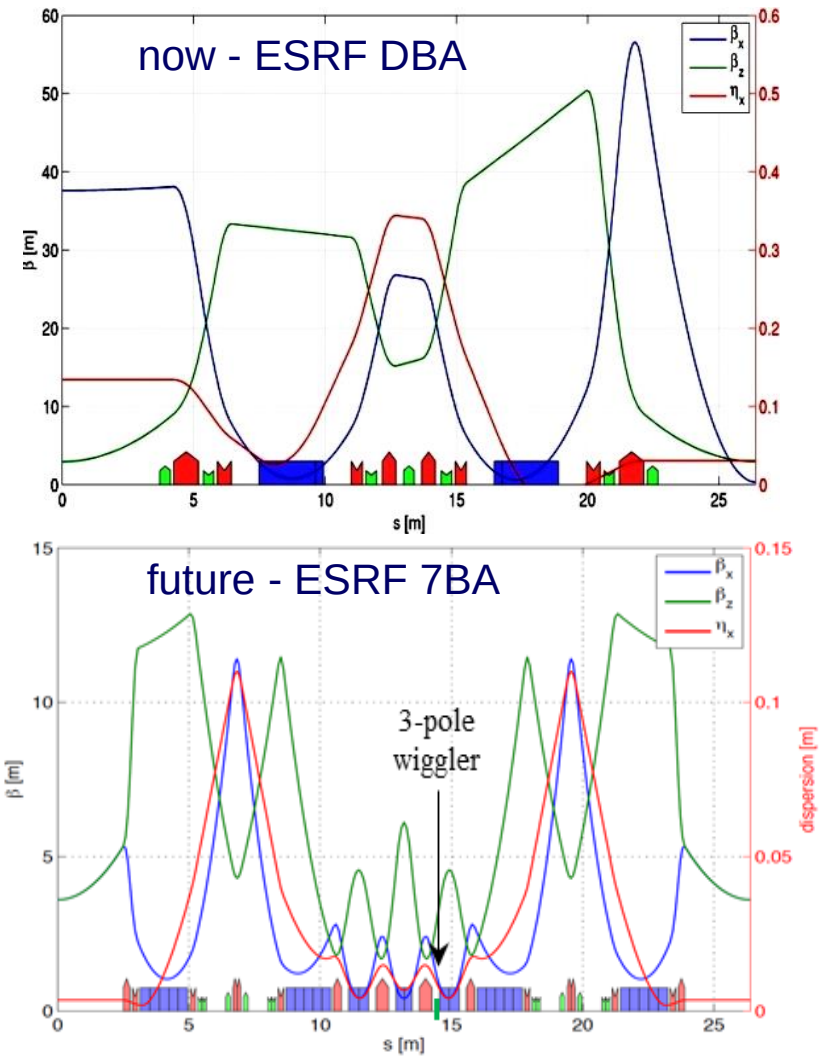
7 → 6 GeV, 1104 m, 3.1 nm → ~65 pm

- ESRF-style lattice, 3-pole wiggler
- Swap-out injection
- Superconducting undulators

SPring-8 (Japan)

8 → 6 GeV, 1436 m, 2.8 nm → <100 pm

- lattice under development

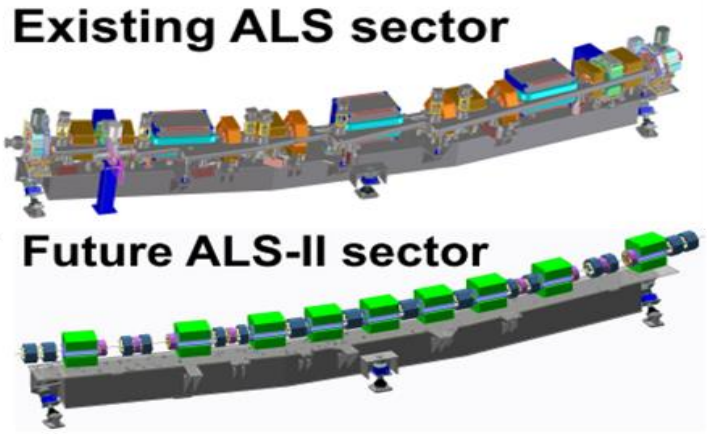


Lattice design

ALS-U (US - LBNL)

1.9 GeV, 200 m, 2 nm → 52x52 pm

- 9BA
- Swap-out injection from accumulator ring
- 3-T PM superbend insertions



Other rings:

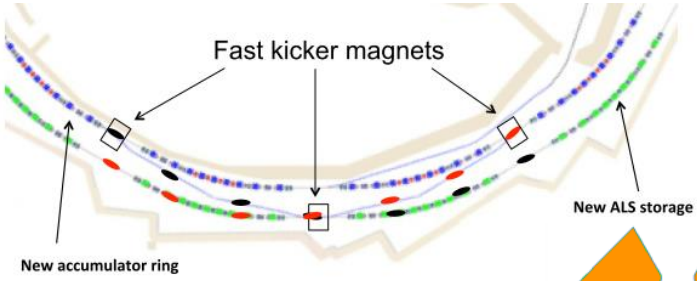
- **SLS** (Switzerland - PSI)

  2.4 GeV, 288 m, 5 nm → 0.25 nm

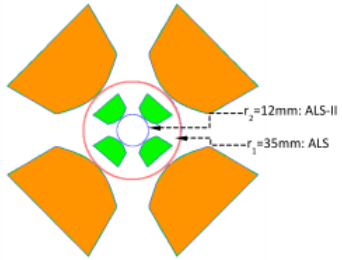
- **Soleil** (France)

  2.75 GeV, 354 m, 3.9 nm → 0.5 nm

…..



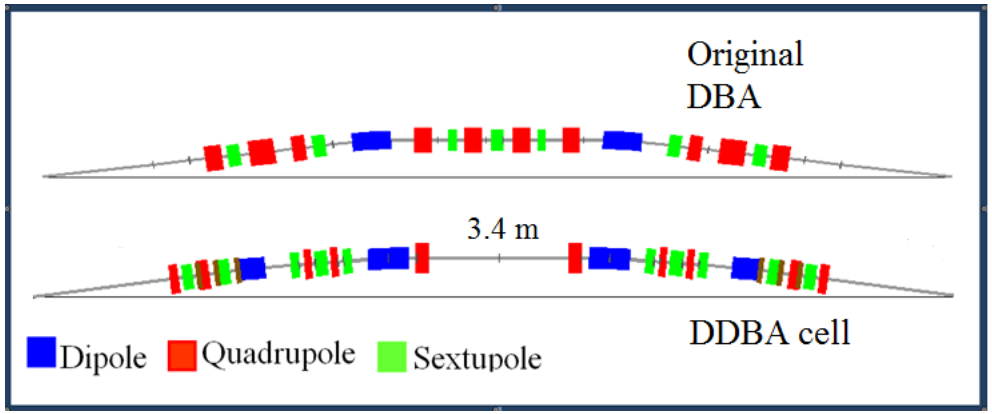
ALS-II swap-out/accumulator

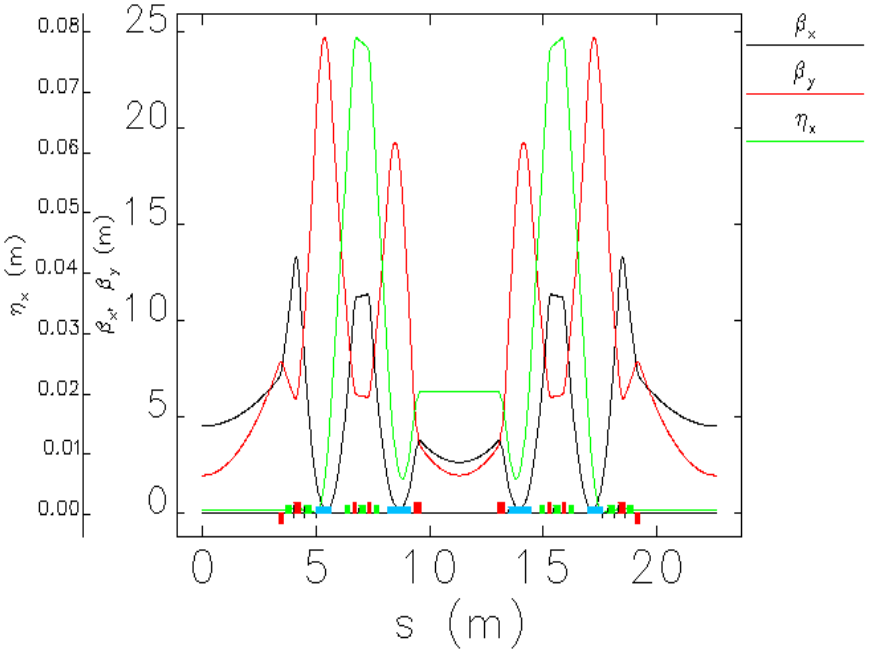


ALS-U 24-mm ID chamber

Lattice design

Diamond II





- Splitting the DBA cell to create an additional straight section (3.4 m)
- Introduce dispersion bump and remove sextupoles in the new straight

This lattice double the ring capacity and
reduces the emittance by a factor 20 (to 270 pm)

Experimental control of beam optics

- Excellent control of the electron optics proven at many light sources

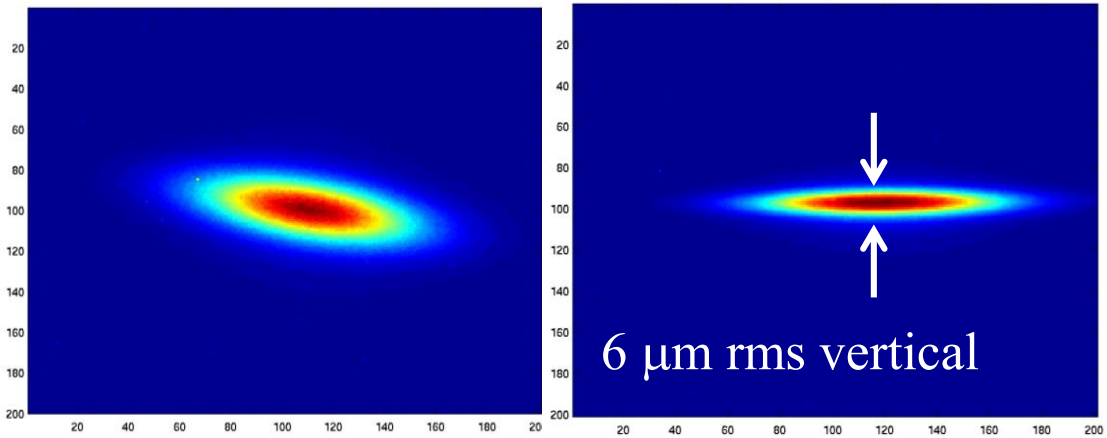
  Proven correction strategies

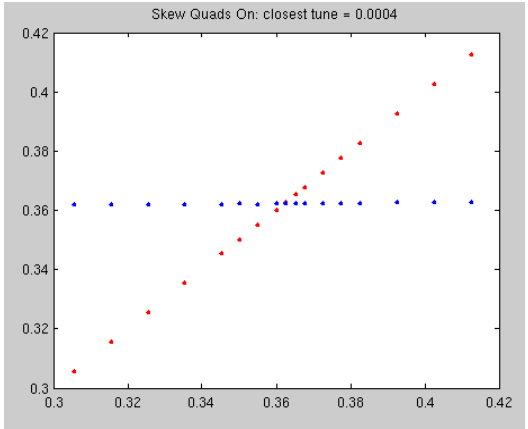
  beam based tuning techniques

  (better instrumentation: diagnostics, power supplies, …)

e.g. Diamond operates with a very good control of the beam optics

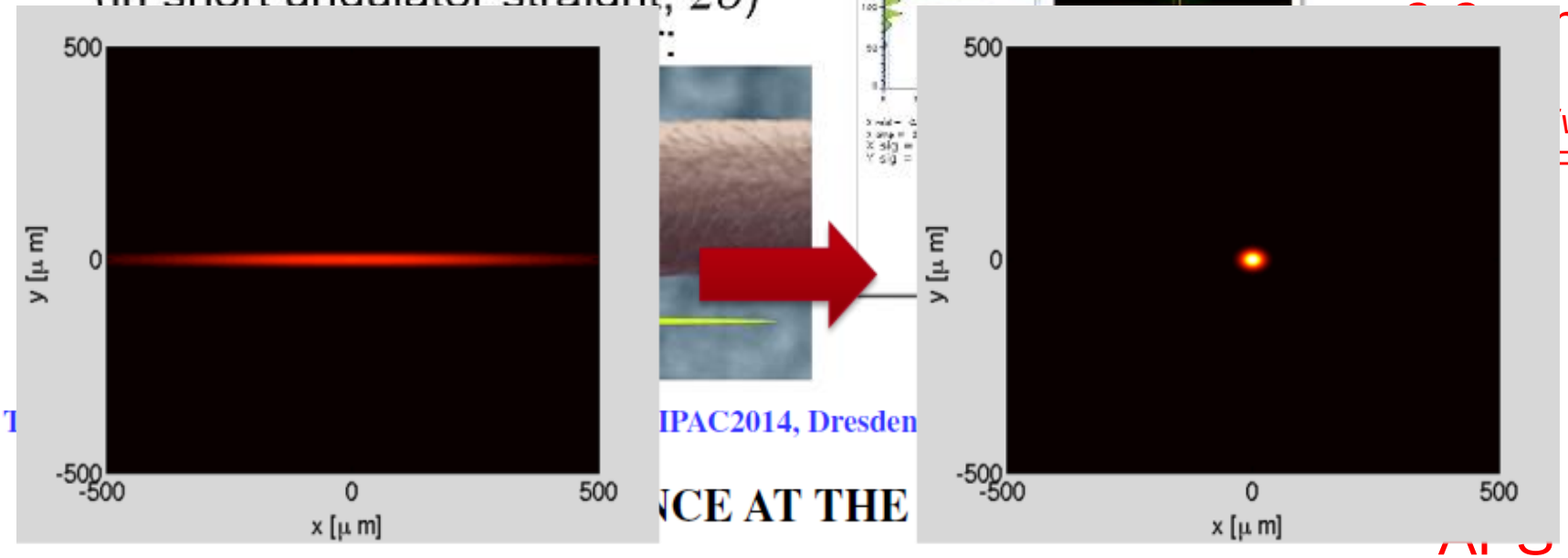
- Optics deviation **(beta-beating) reduced to 1% level** with **LOCO and equivalent ORM based** methods
- Emittance [2.78 - 2.74] (2.75) nm
- Energy spread [1.1e-3 - 1.0-e3] (1.0e-3)
- Emittance coupling ~0.08% achieved → vertical emittance ~ 2.0 pm (2009 WR)





Experimental control of beam optics

- Beam size 3.6 ± 0.6 μm
- Emittance 0.9 ± 0.4 pm
- SLS beam cross section (in short undulator straight, 2σ)



SLS

0.35 pm

IPAC2014, Dresden

NCE AT THE

R. Dowd, Y-R. E. Tan, Australian Synchrotron, Clayton, Australia
K. P. Wootton, University of Melbourne, Parkville, Australia

Running for the "Quantum LOVE prize" at the next general workshop in Grenoble

LOWεRing design (task 6.2)

Issues and topics related to Task 6.2 discussed so far in the general meetings

Topical workshop organised by PSI/ALBA

Next Thursday and Friday

1st Workshop on Low Emittance Lattice Design

23-24 April 2015
Hosted by the ALBA Synchrotron on the Campus of the Autonomous University of Barcelona, Spain
Europe/Zurich timezone

Search

Registration is complete

- Overview
- Programme
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- Uploading presentations
- Facility Visit
- EuCARD-2 Annual Meeting
- Secretariat

The 1st Workshop on Low Emittance Ring Lattice Design will be held from 23-24 April 2015, hosted by the ALBA Synchrotron on the Campus of the Autonomous University of Barcelona.

The workshop will focus on the following topics:

- Design Concepts
- Design Tools / Tools for Non-linear Optimization
- Error Sensitivity / Alignment Strategies / Correction Schemes
- Influence of Collective Effects on Designs

The sessions will start with tutorial like educational talks (* see programme) which prepare the floor for short contributions on particular aspects followed by discussions. All participants are invited to propose contributions to the organizing committee.

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453.

Starts 23 Apr 2015 08:00
Ends 24 Apr 2015 19:50
Europe/Zurich

Hosted by the ALBA Synchrotron on the Campus of the Autonomous University of Barcelona, Spain
Barcelona, Spain

Topics/Issus in collective effects (task 6.3)

High current Instabilities is another fundamental common topic

topical workshops attracted and highlighted synergies with the hardon collider community as well

Instabilities and Impedances in Low Emittance Rings (IILER): *- Numerical (3D) wake field calculations and optimization of vacuum component designs, - Benchmarking of commercially available 3D EM solvers, - Theoretical approach to short-range wakes, - High frequency impedance of metallic coated chamber, - Beam-based and bench measurement of impedance, - Impact of harmonic cavities on collective effects*

Two-Stream Instabilities in Low Emittance Rings (2-SILER): *- Simulation of electron cloud build-up and use of the former in electron cloud instabilities, - Mitigations for the suppression of secondary electron yield, - Measurement of electron cloud in a ring, - Characterization of FBII, - FBII arising from local outgassing*

Particle Scattering in Low Emittance Rings (PASLER): *- Model dependence of IBS effects, - Lattice design that minimizes the IBS, - Discrepancies between models and measurement, - Importance of tail cuts, - Necessity of extending the existing models, - Experimental characterizations of IBS on existing rings*

Coherent Synchrotron Radiation Instabilities (CSRI): *- Advanced single shot measurement using ultra-fast detectors, - Comparison of CSR threshold between measurement and theory, -Extension of the theoretical model from the parallel-plate to rectangular chambers*

Activity report: EuCARD2- DEL – D6.2

Topics/Issus in collective effects (task 6.3)

Topical Workshop on Instabilities, Impedance and Collective Effects (TWIICE) organized at SOLEIL:

More than 70 participants from 26 institutes and universities from around the world (Europe: 19, USA: 5, Asia: 2) :

Altogether 35 talks (among which 7 reviews) in 5 sessions:

Perspectives:

- Large number of studies presented confirms the recognition by the community of the high degree of importance in understanding and mastering the beam collective effects.
- The studies covered in WP6.3 would have an important link to those of WP5 (Extreme Beams: XBEAM). Besides, the link to the two other sub-work packages 6.1 and 6.3 is getting increasingly deepened as the studies advance, both accelerator physics-wise and technology-wise

Next topical workshop on instabilities scheduled for January 2016

Topics/Issues in LER technology (task 6.4)

- Key enabling technologies appears to be mature

Task 6.4 promotes the interaction on the development of enabling technologies relevant for low emittance rings

- Magnets
- Alignment and magnet measurements
- IDs – CPMUs – SCUs
- Vacuum – NEG coating
- Diagnostics (BPMs and orbit feedback)
- Diagnostics (beam properties)
- Multibunch feedback (transverse – longitudinal)
- Kickers and novel injection systems
- RF and harmonic cavities

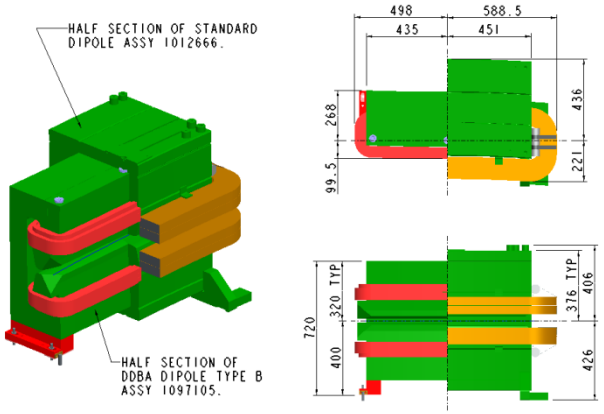
Magnets (task 6.4)

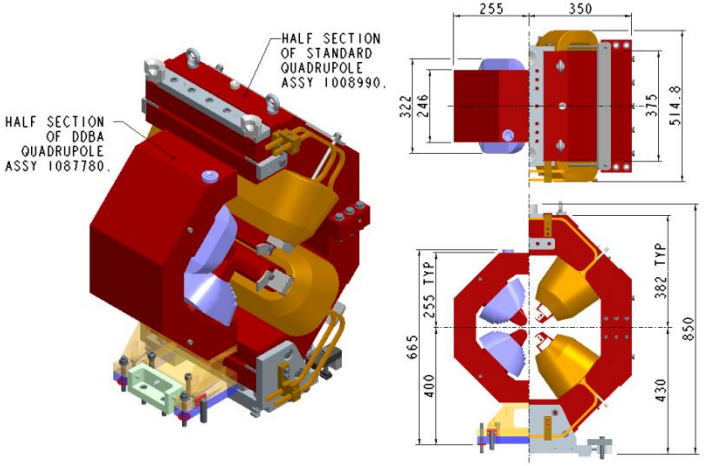
Compact and stronger magnets

- small bore quadrupoles (~30 mm diameter to reach ~70 T/m – up to 100 T/m)
- rather complex dipoles (gradient 0.8 T with 14 T/m – Longitudinal gradient ESRF)

These require

- Precision magnet pole machining for small aperture magnets, combined function magnets, tolerance for magnet crosstalk (e.g. MAX-Lab)





As a consequence vacuum chamber in the arcs have much reduced apertures

e.g. Diamond elliptical 29 mm * 20 mm; it was octagonal 84 mm * 38 mm

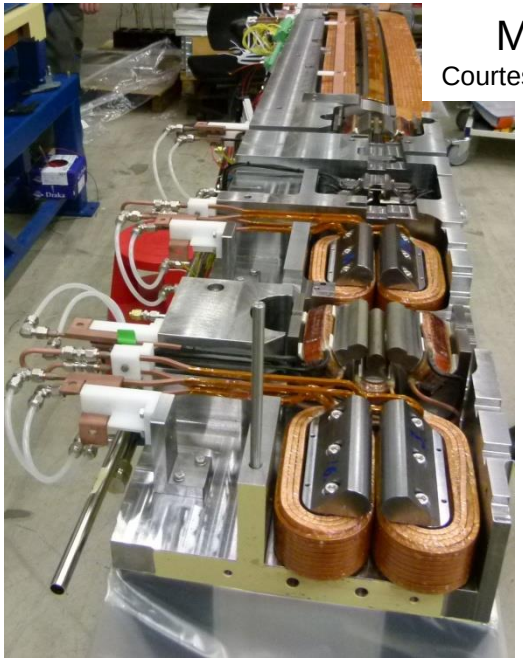
Pumping and radiation absorption become more complicated

Vacuum (task 6.4)

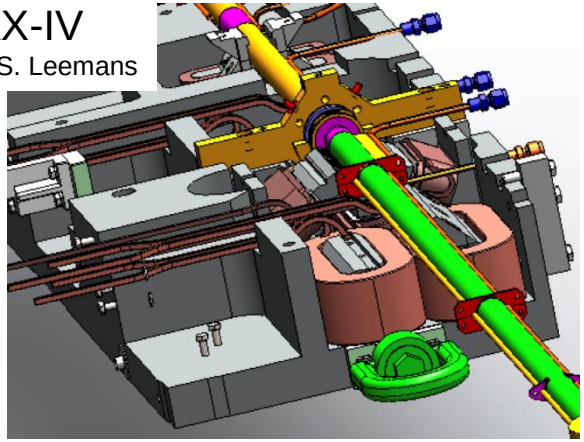
Vacuum technology

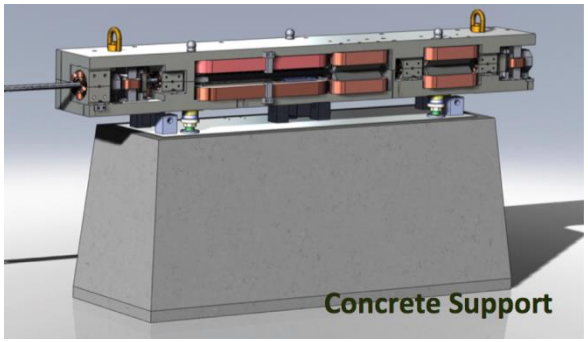
- NEG-coated vacuum chambers enable small apertures to enable high magnet gradients

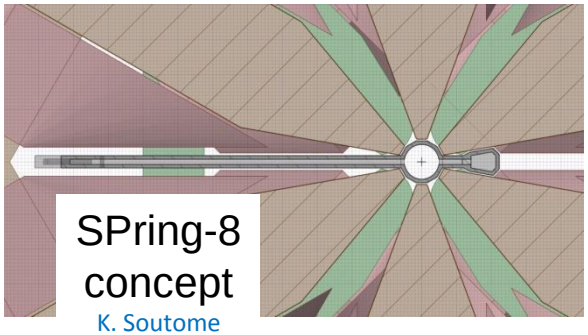
  Pioneered at CERN, used extensively at Soleil, and adopted for MAX-IV and Sirius MBA lattices



MAX-IV
Courtesy S. Leemans







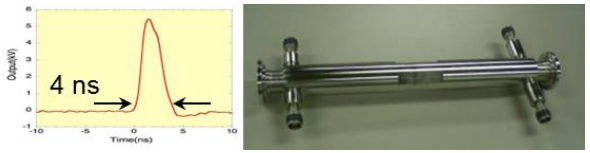
SPring-8
concept
K. Soutome

Not all designs have adopted a full neg-coated chamber approach

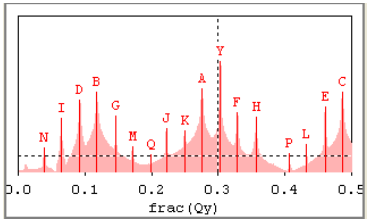
Enabling technologies (task 6.4)

Other advances in low emittance ring technology

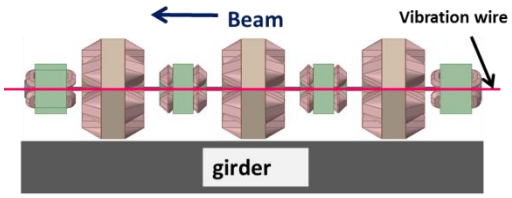
- Fast kickers for on-axis injection
- Sub-micron e- BPMs with micron resolution single pass capability: non-linear lattice tuning
- Accelerator and beam line component mechanical positioning and stabilizing systems
- "In-situ" and beam-based magnet measurement and alignment methods
- Mode-damped RF cavities (fundamental and harmonic)
- Highly stable solid state RF power sources
- High performance IDs (superconducting, Delta, RF, etc.)
- Advances in X-ray optics and detectors
  start-to-end beam line system simulations, SC detectors, cryo-cooled mirrors, etc.



Fast kickers (KEK ATF)

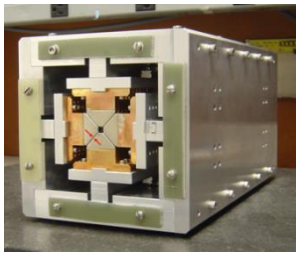


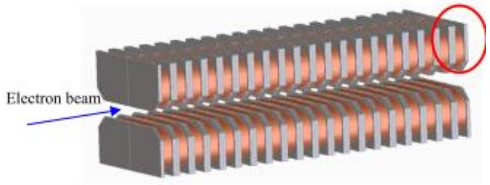
Higher order resonances detected by turn-turn BPMs (A. Franchi)



SPring-8 concept based on NSLS-II vibrating wire method - K. Soutome

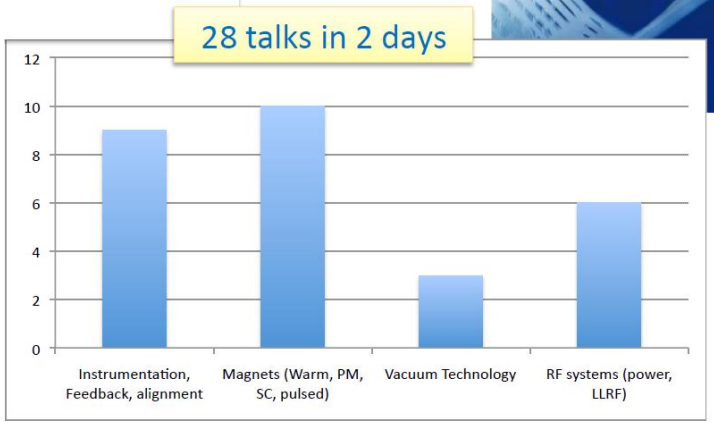
Delta undulator prototype - A. Temnykh





SC undulator development at LBNL (S. Prestemon et al.), APS (E. Gluskin et al.) and elsewhere

Enabling technologies (task 6.4)



- 1st workshop on Technology sponsored by the network
- 52 participants *(Europe: 39, USA: 11, Asia: 2)*

Activity report: EuCARD2- DEL – D6.3

Next topical workshop to be scheduled for 2016

Conclusions and open issues

Damping rings and many light sources aim at operating with low emittance lattices. New light source projects aim at reaching diffraction limited rings in horizontal plane as well: these are based on MBA lattices

Vertical emittance in the 1-2 pm range are no longer uncommon.

DA and Touschek lifetime studies are crucial. Magnets and apertures design will be at the cutting edge of present R&D.

Collective effects (IBS) will limit the stored current to 100-200 mA. They might be mitigated by Harmonic Cavity for bunch lengthening. Round beams could help and more R&D is needed

The emerging consensus is that enabling technologies appear to be within reach and mature in some cases. No showstopper have been yet found.

Conclusion

The development of ultra low emittance rings is now seriously tackled by a large community, including US and Asia. The LOWεRING community sponsored by EuCARD2 is playing a leadership role in fostering these developments

- ICFA Low Emittance Rings Workshops (LowERing)
- XDL 2011 Workshops for ERLs and DLSRs, Cornell, June 2011
- Beijing USR Workshop, Huairou, October 2012
- DLSR Workshop, SPring-8, December 2012
- Low Emittance Ring Workshop, Oxford, July 2013
- SLAC DLSR Workshop, SLAC, December 2013
- Workshop on collective effects (TWIICE), Paris, 2014
- Workshop on Low Emittance Rings Technology (ALERT), Valencia, 2014
- Low Emittance Rings Workshop (LER2014), Frascati, September 2014
- DLSR Workshop, Argonne, November 2014
- Workshop on Low emittance ring design, Barcelona,
- Low Emittance Rings Workshop (LER2015), Grenoble, September 2015