



Summary of the 4th Low Emittance Rings Workshop LCWS2014 6 Oct. 2014, Belgrade



S. Guiducci (INFN-LNF)

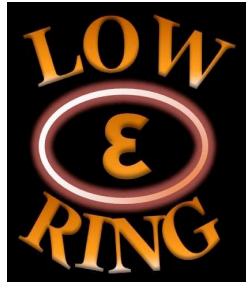


EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453



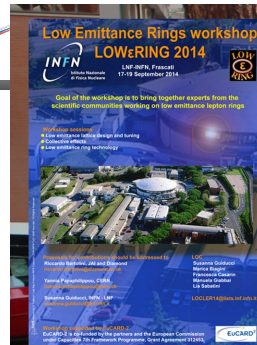
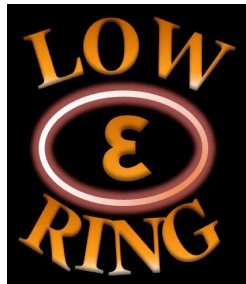
WP6 - Low Emittance Rings Network: scope and background

- Bring together scientific communities of **synchrotron light sources' storage rings, damping rings** and **e⁺/e⁻ ring colliders** in order to communicate, identify and promote common work on topics affecting the design of **low emittance electron and positron rings**
- Initiated by the CLIC-ILC collaboration on damping rings (by Yannis Papaphilippou and Mark Palmer)
- State of the art in design of accelerator systems especially in **X-ray storage rings** approaches the **goals of damping rings** for linear colliders and **future e⁺/e⁻ ring collider** projects
- Network coordinators: Riccardo Bartolini (JAI, Diamond), Yannis Papaphilippou (CERN), Susanna Guiducci (LNF)



- **LER2010** CERN
- 12-15 January 2010 <http://ler2010.web.cern.ch/ler2010/>
70 participants, 56 talks in 3.5 days
- **LER2011** Crete, 3-5 October 2011, 46 talks in 3 days
<http://lowering2011.web.cern.ch/lowering2011/>
- **LER2013** Oxford, 8-10 July 2013, first one supported by Eucard-2 Network
87 participants, 41 talks in 3 days
<http://www.physics.ox.ac.uk/lowemittance13/participants.asp>

EuCARD² 4th Low Emittance Rings' workshop



Low Emittance Rings workshop LOWεRING 2014



- 2nd workshop sponsored by network: Frascati, September 2014
- 78 participants (*Europe: 47, USA: 17, Asia: 14*)
- 2nd Student prize



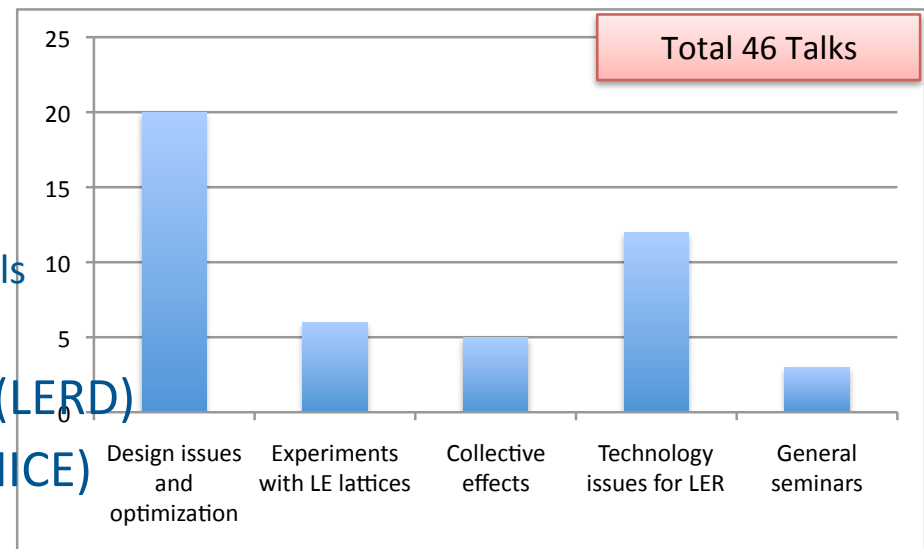
4th Low Emittance Rings workshop

INFN – LNF, Frascati

17-19 September 2014

Workshop sessions:

- Low Emittance optics design (LERD)
 - New proposals and upgrades
 - nonlinear beam dynamics and optimisation tools
 - novel injection schemes
- Experiments with low emittance lattices (LERD)
- Collective Effects and beam instabilities (IICE)
 - intrabeam scattering
 - electron cloud
 - machine impedance
- Low Emittance Ring Technology (LERT)
 - IDs and magnets
 - Kickers
 - RF design
 - vacuum





Workshop Program

- Design issues and optimization (LERD) (20 talks)
 - Introduction to design issues and optimisation of low emittance rings, Yunhai Cai (SLAC)
 - 8 talks on proposals of new generation machines or upgrades of present ones toward very low emittances
- Experiments with low emittance lattices (LERD) (6 talks)
 - Review of experiments with low emittance lattices, James Safranek (SLAC)
- Collective effects (IICE) (5 talks)
 - Review of Instabilities issues for low emittance rings and Summary of TWIICE workshop, Ryutaro Nagaoka (Soleil)
- Technology issues for lowerings (LERT) (12 talks)
 - Review of technology issue for lowerings and summary of ALERT workshop, John Byrd (LBNL)
- *All the talks in plenary sessions*
- *Each session has an opening review talk on the main issues*
- *A fraction of time is used for discussion (in parallel) and summaries in preparation of the network interim reports*

- Next Generation X-ray Analyses and the ESRF Upgrade Programme, Francesco Sette (ESRF)
 - A reduction of a factor ~ 30 in emittance allows to increase x-ray brilliance by 2 orders of magnitude, and transverse coherence by factor 30-40. A new page in X-ray science: intense – stable – coherent X-ray nano-beams to unveil the mysteries of materials and living matter in the lengthscale gap between optical and electron microscopies: 1-1000 nanometers
- Challenges of Low Emittance Rings, Yannis Papaphilippou (CERN)
 - A review of beam physics and technical challenges facing x-ray light sources, damping rings and storage ring colliders aiming at ultra low emittances
- Beijing Higgs Factory, Qing QIN (IHEP)
 - A ring-based Higgs factory, CEPC, is under study at IHEP and R&D will be proposed in the near future.

Colliders
(and their
injectors)

- Luminosity or brightness

$$\mathcal{L} = \frac{N_1 N_2 f n_b}{4\pi \sigma_x \sigma_y}$$

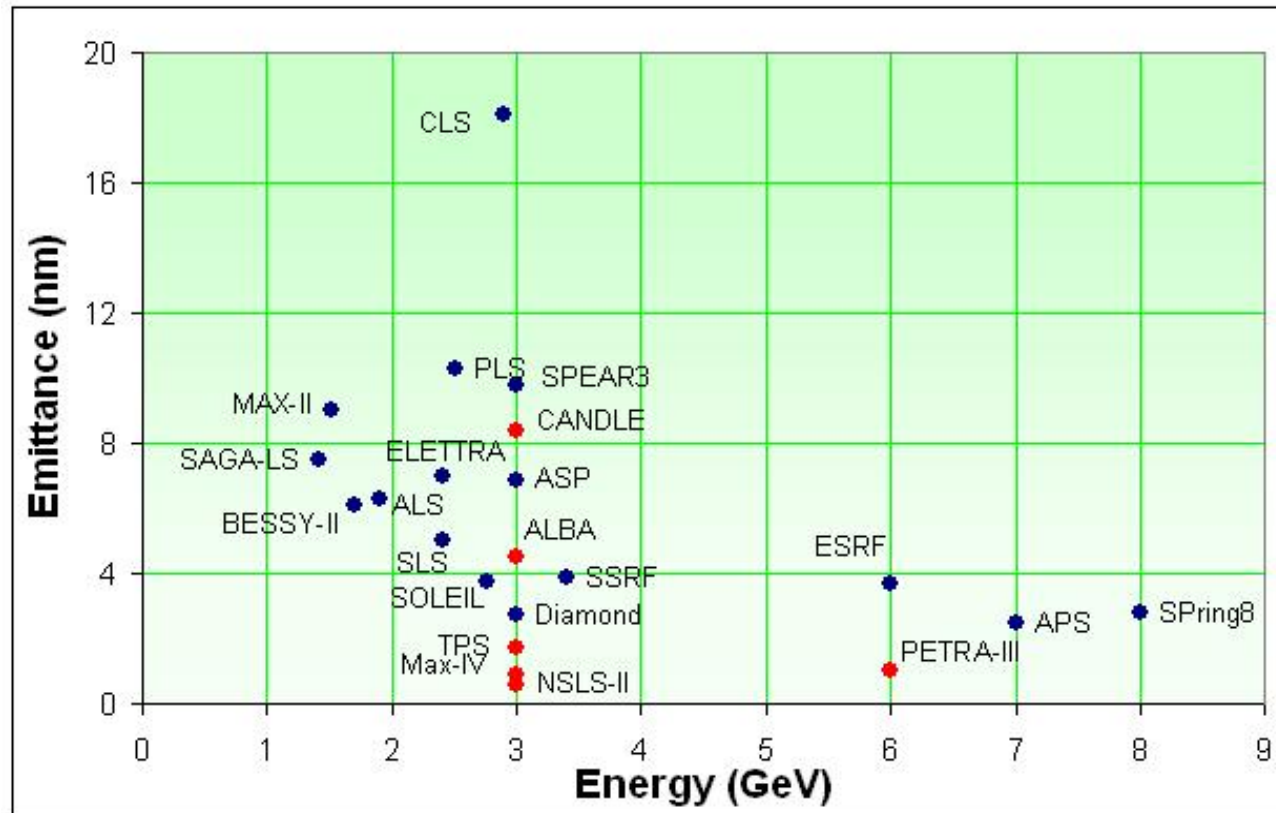
X-ray
storage
rings

- Photon brilliance

$$B = \frac{N_p}{4\pi^2 \bar{\epsilon}_x \bar{\epsilon}_y}$$

- Extreme intensity within ultra-low beam dimensions
 - Lattice design, Collective effects, Associated technology

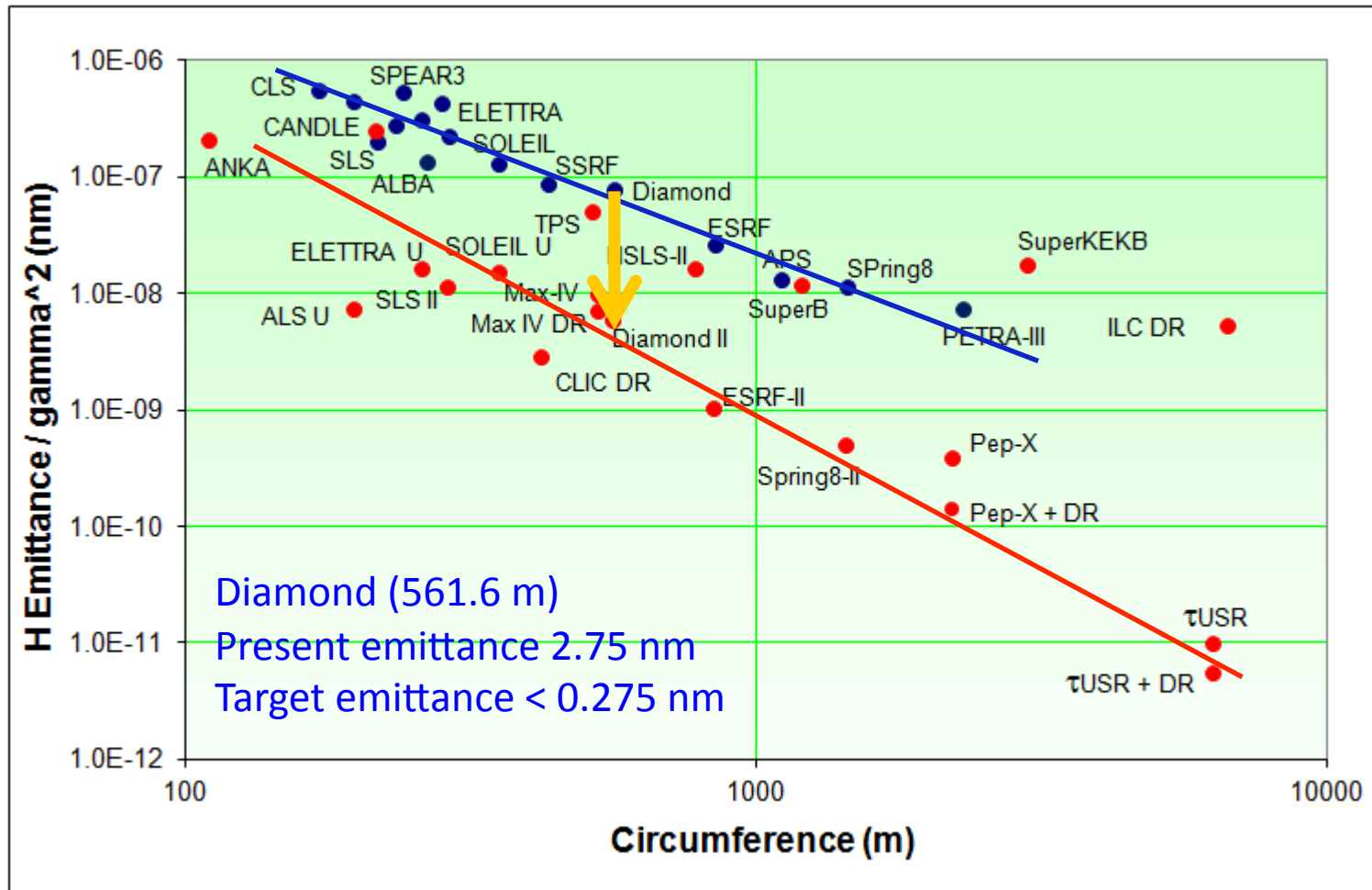
Storage Ring Light Sources



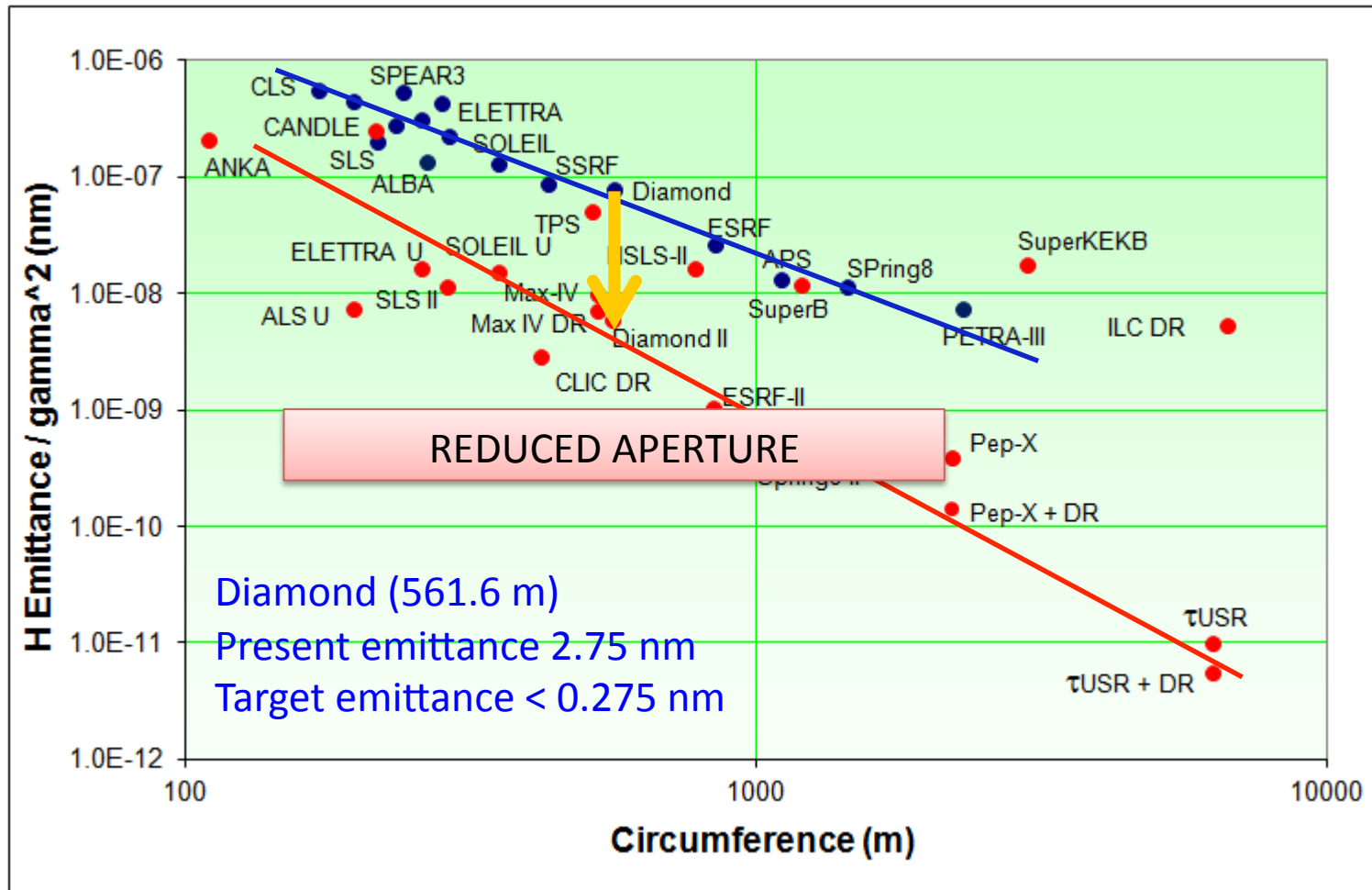
Courtesy of R. Bartolini, Low Emittance Rings Workshop, 2010, CERN

Frontier is at 100 pm emittance. Challenge is to lower it even more down to 10 pm without increase of ring size.

Survey of low emittance lattices



Survey of low emittance lattices



Design Issues

- Lower emittance
 - DBA, TBA, ..., MBA cells, more dipoles and smaller dispersion
 - Stronger focusing, more quadrupoles
 - Reasonable cost, size, or complexity
- Stronger sextupoles
 - Mitigation of structure resonances
 - Compensation of chromatic aberration
 - Mechanical and electrical design, alignment tolerance, correction scheme
 - Alternative injection scheme
- Collective effects
 - Intra-beam scattering and Touschek lifetime
 - Resistive-wall impedance and multi-bunch feedback system
 - Coherent synchrotron radiation
 - Electron cloud (only for positron rings)

Diffraction limited light sources: beyond the nm.rad frontier



- 2010 Petra-III was commissioned → 1 nm H emittance
- 2011-12 SLS and ASP ~1 pm V emittance (best achieved)
- 2012 ESRF et al. operate with 8pm V emittance
- 2013 ALS upgraded to a 2 nm H emittance lattice
- 2014 NSLS-II started operation → 0.5 nm H emittance
- 2014 ASP claimed the quantum limit V emittance 0.35 pm
- 2014 Petra III has tested a 160 pm lattice at 3GeV
- 2016 MAX IV 300 pm H emittance lattice
- 2016 SIRIUS 280 pm H emittance lattice
- 2019 ESRF II 150 pm H emittance lattice

Diffraction limited light sources: beyond the nm.rad frontier

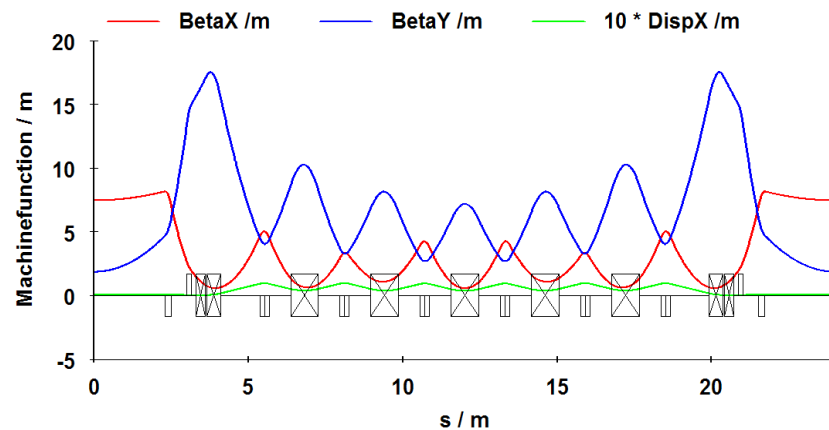
- 2010 Petra-III was commissioned → 1 nm H emittance
- 2011-12 SLS and ASP ~1 pm V emittance (best achieved)
- 2012 ESRF et al. operate with 8pm V emittance
- 2013 ALS upgraded to a 2 nm H emittance lattice
- 2014 NSLS-II started operation → 0.5 nm H emittance
- 2014 ASP claimed the quantum limit V emittance 0.35 pm
- 2014 Petra III has tested a 160 pm lattice at 3GeV
- 2016 MAX IV 300 pm H emittance lattice
- 2016 SIRIUS 280 pm H emittance
- 2019 ESRF II 150 pm H emittance

Damping Rings specifications

ILC DR	0.5 nm H emittance
	2 pm V emittance
CLIC DR	<100 pm H emittance
	5 pm V emittance

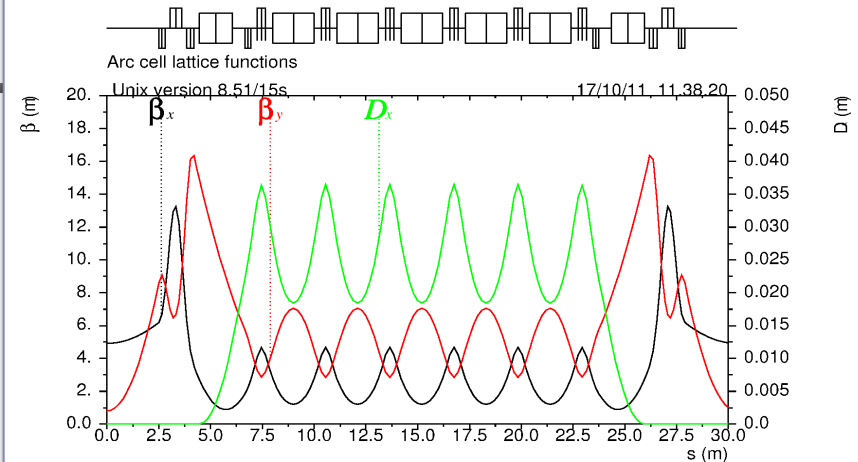
MAX-IV Light Source

7 Bend Achromat, at 3 GeV



Cancellation of Geometric 3rd and 4th Resonances

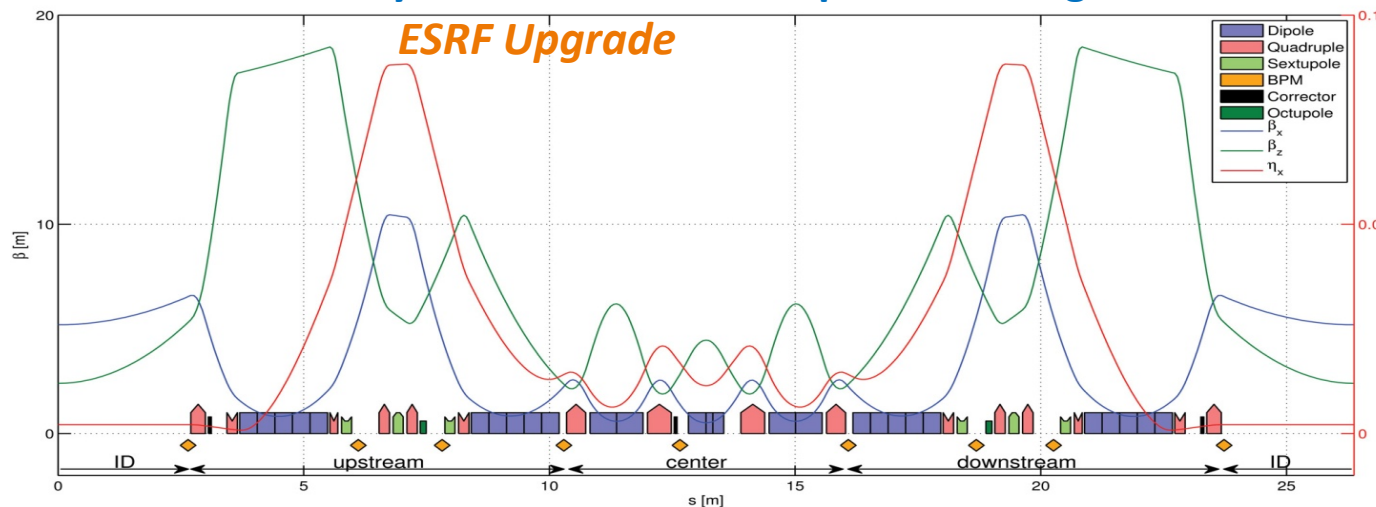
PEP-X 7 Bend Achromat



Cell phase advances:

$$\mu_x = (2 + 1/8) \times 360^\circ, \mu_y = (1 + 1/8) \times 360^\circ.$$

7 bends hybrid achromats to replace existing DBA



3 high-gradient bending magnets

2 longitudinally varying field dipoles

- “Vertical Emittance at the Quantum Limit”, Rohan Dowd, Australian Synchrotron
- NSLSII commissioning: up to 50 mA and interesting measurements on IBS and Collective Effects in a short time
- New machines or upgrades proposals aiming at very low emittances have been presented: ESRF, APS, BAPS, Diamond, SLS, Elettra, ANKA
- Proposals for alternatively generate round beams: horizontal field wigglers (BINP)
- Local round beam optics: test proposed at SOLEIL

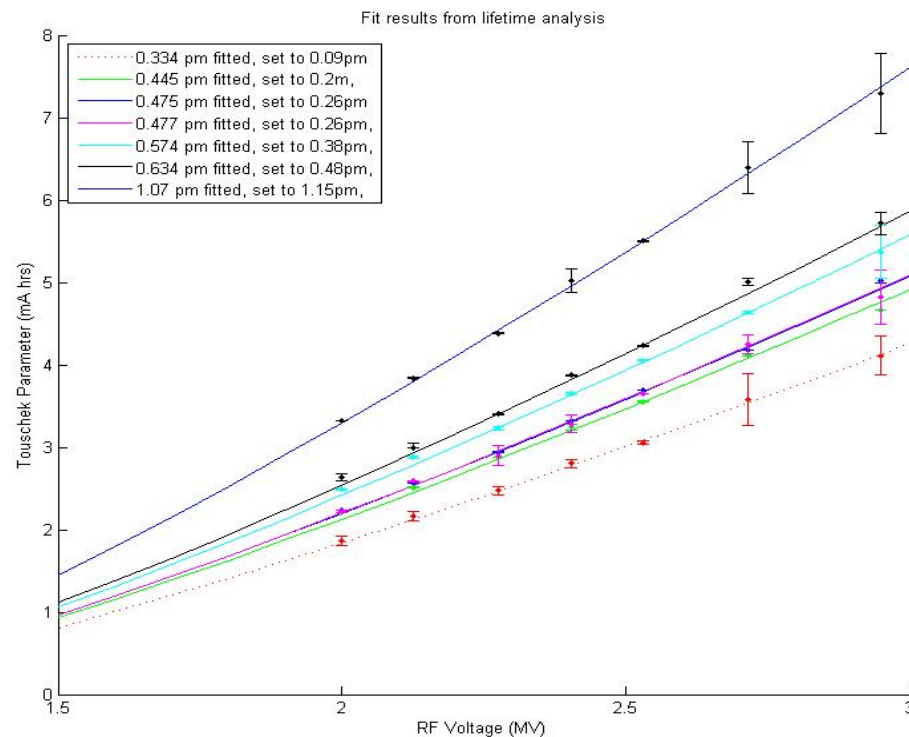
- New injection schemes with small transverse aperture
 - Pulsed multipole kicker injection, successfully tested at Bessy-II
 - Swap-out injection
 - Longitudinal injection between buckets
- Powerful optimization algorithms for linear and nonlinear dynamics: MOGA, MOPS
 - Multi Objective Genetic Algorithms: more and more used as a second step for optimization of lattices
 - Multi Objective Swarm Optimization used both online/offline
- Experimental Turn-by-Turn measurement progress:
 - Very encouraging results at ESRF measuring sextupolar, octupolar Resonant Driving Terms with TbT data
- Low emittance studies at 3 GeV at PETRA III



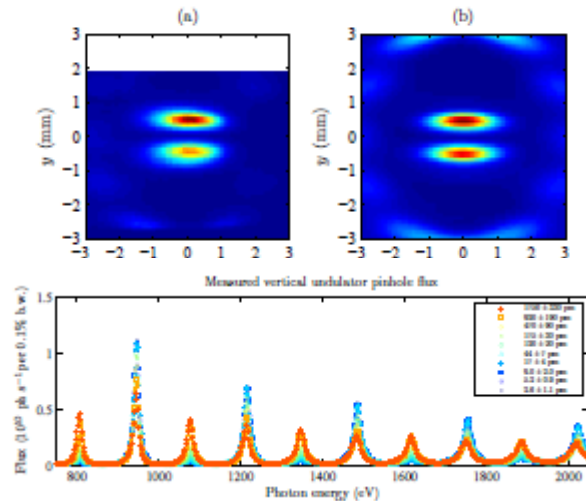
Vertical Emittance at the Quantum Limit

Very precise tuning of the ring and nice measurements

Indirect measurement of
vertical beam size through
Touschek lifetime



R. Dowd, Australian synchrotron



Direct beam emittance measurements
with vertical undulator down to $\sim 1\mu\text{m}$

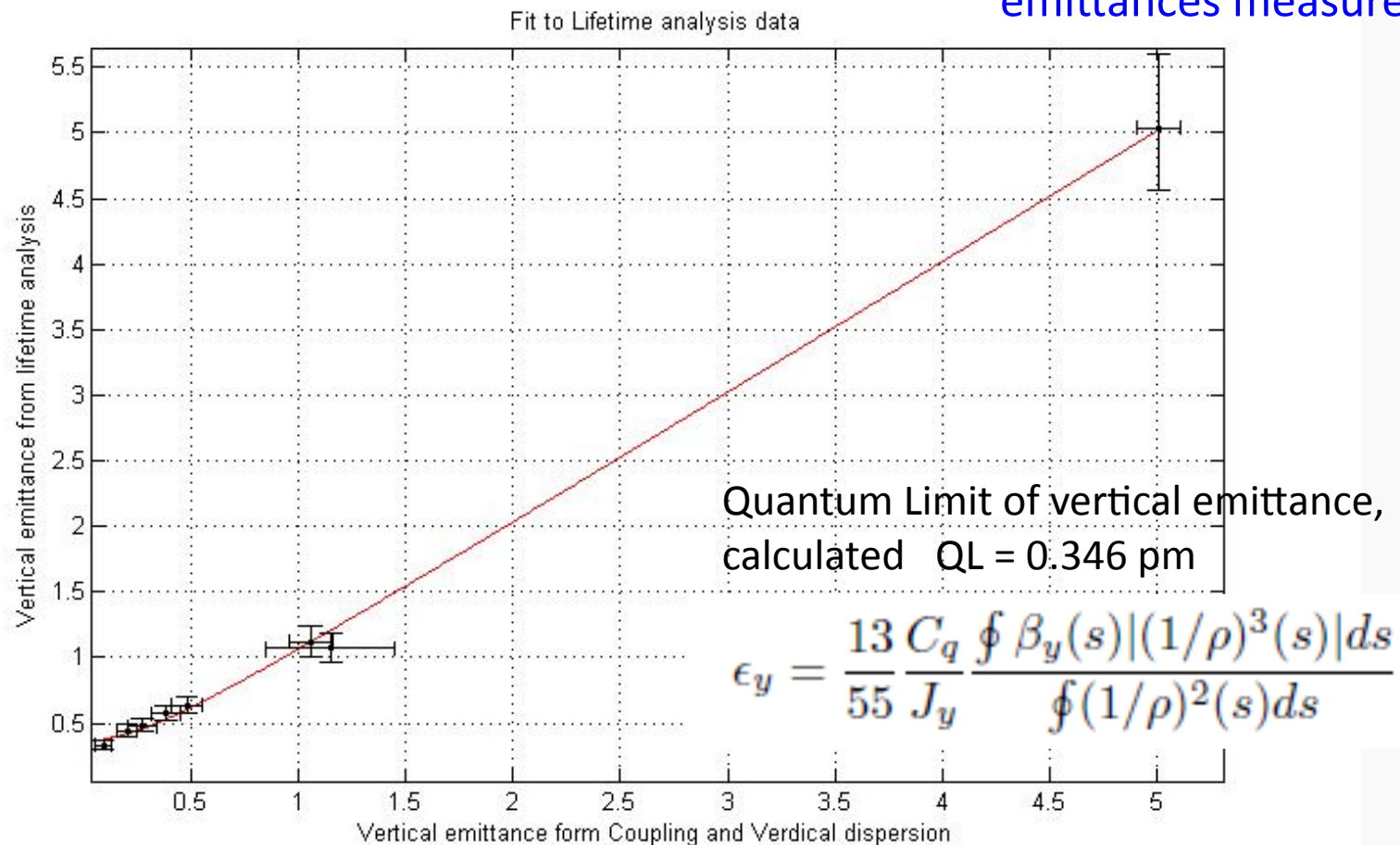
Photon flux ratios between odd and
even harmonics can be used to
determine vertical spatial coherence
and therefore emittance.

Reference: K. Wootton, *et al*, Submitted to PRST:AB
Thesis 18 K. Wootton at <http://hdl.handle.net/11343/39616>

Experimental determination of Quantum Limit

Fit using $y = \sqrt{QL^2 + x^2}$.

Sub-picometer
emittances measured

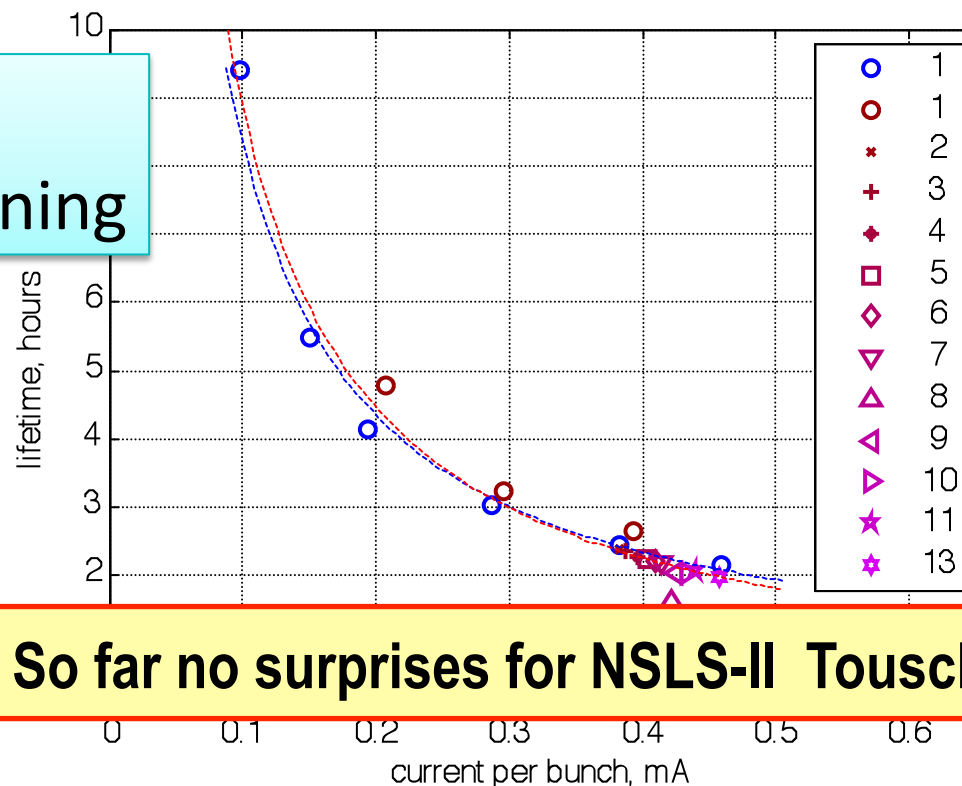


Result: Experimental $QL = 0.37 \pm 0.06 \text{ pm}$,

Later Example of Touschek Lifetime Results

- July 13, SC cavity voltage $V=1.2$ MV, RF acceptance=1.8%
- 1-15 ~uniform bunch trains fills at various total currents

NSLSII
Commissioning



- $\epsilon_x = 2.1$ nm
- $\kappa = 0.4\%$
- $\epsilon_{acc} = 1.8\%$

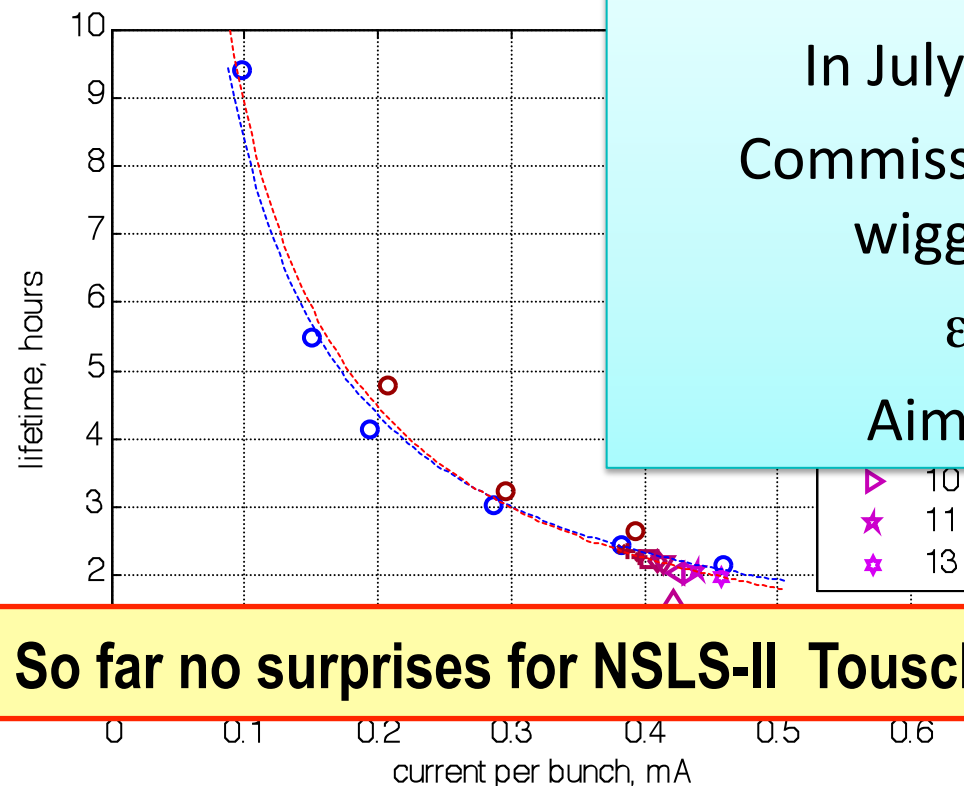
So far no surprises for NSLS-II Touschek lifetime

- Measurements (@ 0.5 mA / bunch): $\tau_{tous} = 2.1$ hours (+/-10%, gas > 50 hours)
- Expectation (@ 0.5 mA / bunch): $\tau_{tous} = 2.1$ hours

Boris Podobedov

Later Example of Touschek Lifetime Results

- July 13, SC cavity voltage $V=1.2$ MV, RF acceptance=1.8%
- 1-15 ~uniform bunch trains fills at va



Commissioning started March 26

In July reached 50 mA

Commissioning lattice with
wigglers gap open

$$\varepsilon_x = 2.1 \text{ nm}$$

Aiming at 0.5 nm

So far no surprises for NSLS-II Touschek lifetime

- Measurements (@ 0.5 mA / bunch): $\tau_{\text{tous}} = 2.1$ hours (+/-10%, gas > 50 hours)
- Expectation (@ 0.5 mA / bunch): $\tau_{\text{tous}} = 2.1$ hours

Boris Podobedov

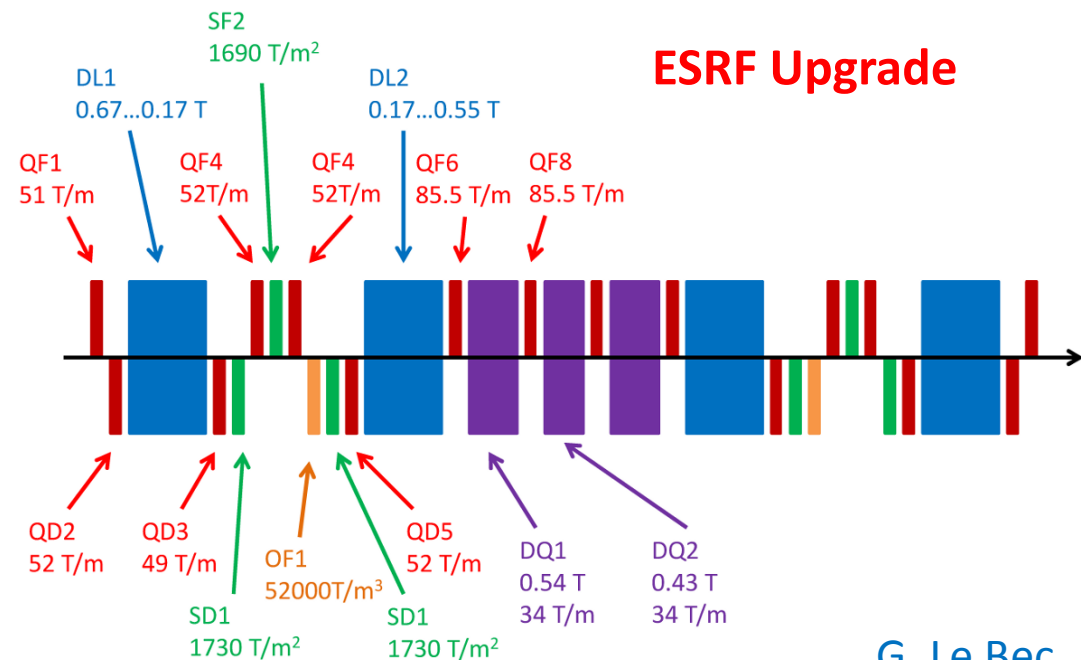


Highlights on technology

- **Magnets**
 - DDBA upgrade of DIAMOND
 - ESRF upgrade dipoles and quadrupoles
 - CLIC wigglers: NbTi (3T, ~5cm period) and Nb₃Sn (>3.5T, period < 4.8cm)
- **Kickers**
 - DAΦNE injection kicker tested with very short pulse duration ~10ns
 - Laboratory measurements of CLIC stripline kicker in progress
- **RF design**
 - Concepts for high frequency RF system (1-2GHz) with tight phase jitter tolerances and large transient beam loading have been developed
- **Vacuum**
 - Impedance behaviour of NEG films in some special cases (thickness changes, high frequency, roughness effects) need to be considered carefully in the design. High frequency measurement preparation is promising.

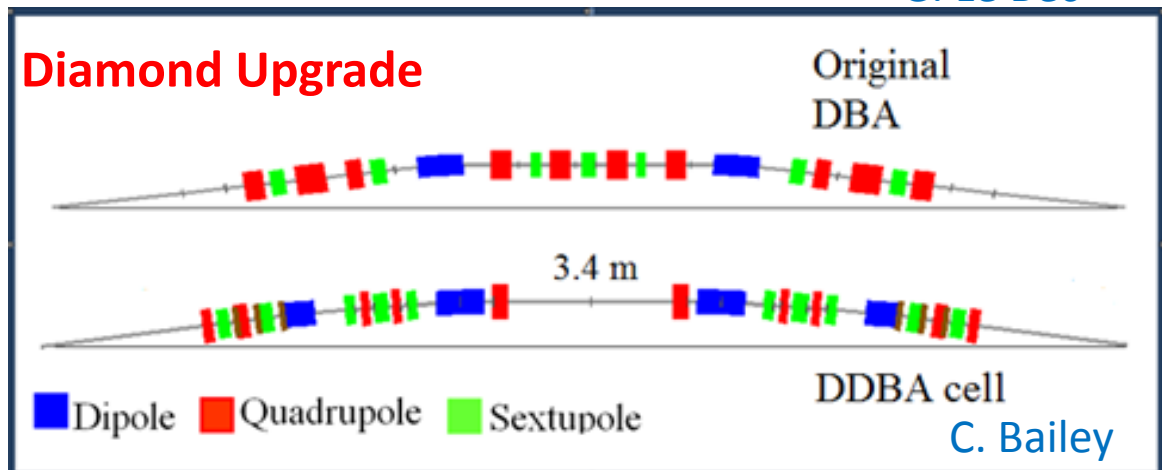
Challenges

- High gradients
- Combined magnets
- Small bore radius
- Tight tolerances
- No space longitudinally
- More than 1000 magnets



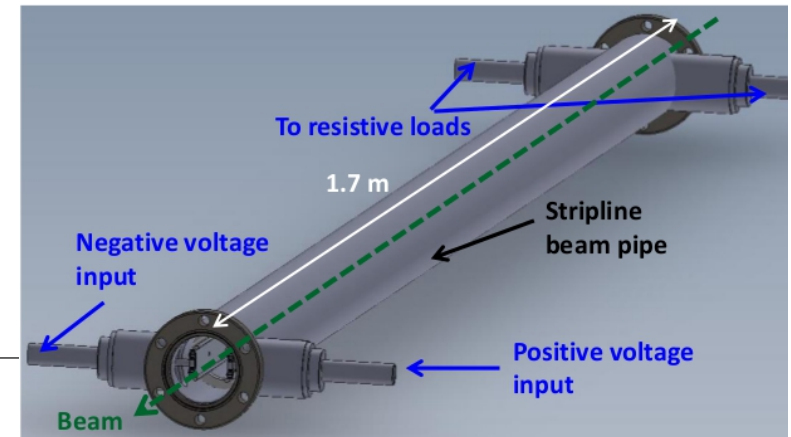
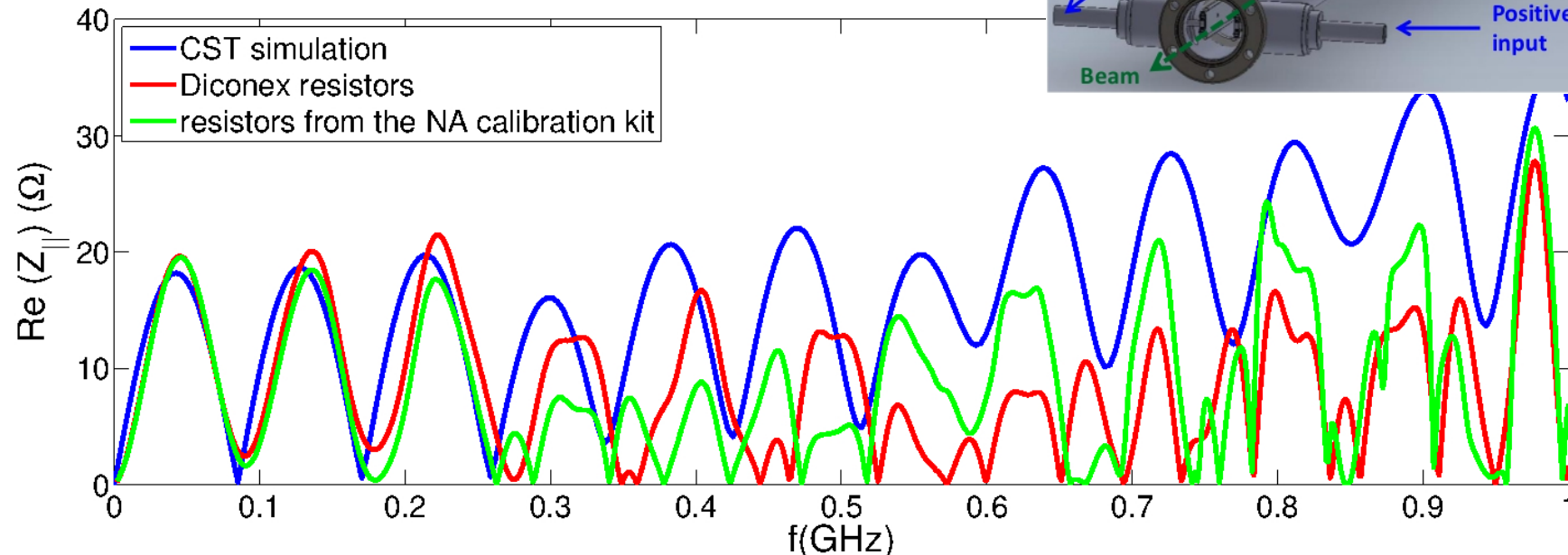
G. Le Bec

Dipole	Quadrupole
0.67 and 0.965 m	0.25 m
14.385 Tm ⁻¹	70 Tm ⁻¹
0.8 T Central	
	Sextupole
	0.175 m
	2000 Tm ⁻²



C. Bailey

CLIC DR Kicker longitudinal coupling impedance

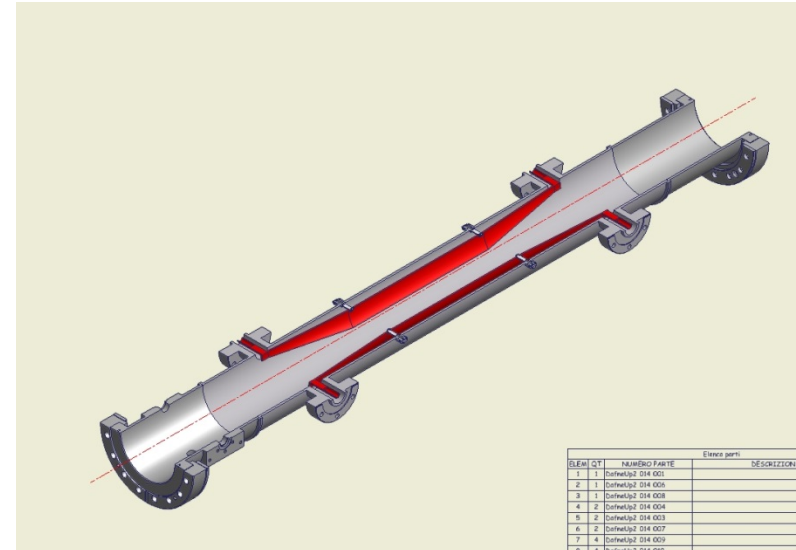
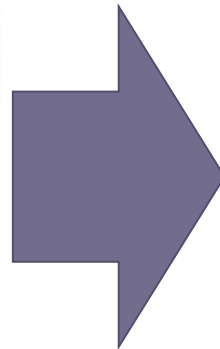
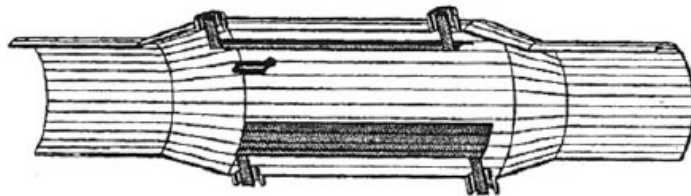


- The resistively matched measurements generally gives good results below a few hundred MHz but the residual mismatch in the system can cause large oscillations which mask the true impedance.
- The longitudinal beam coupling impedance measurements have been repeated, using the [resonant method](#). Results are being analyzed.

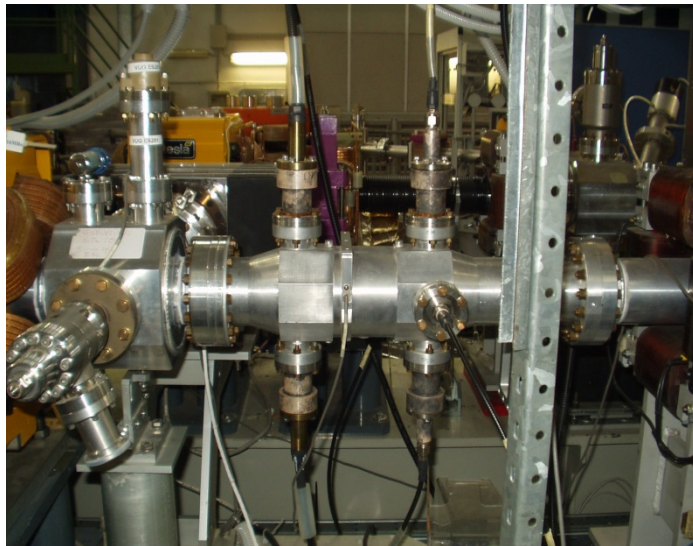
OTHER APPLICATIONS: NEW TAPERED KICKER FOR THE DAΦNE TRANSVERSE FEEDBACK

The new DAΦNE kickers of the horizontal feedback system have been designed using the same “philosophy” of tapered striplines.

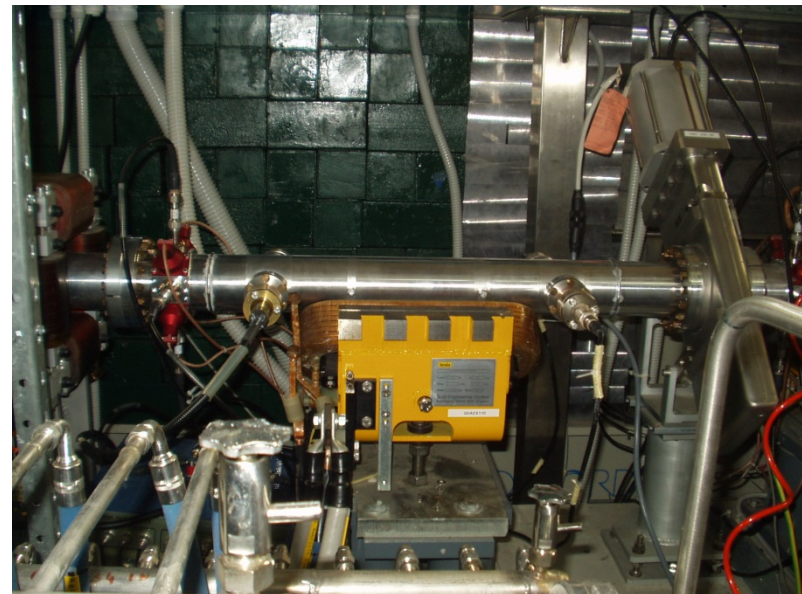
We increased the performances of the feedback system by a factor 5.



REF. CT	NUMERO PARTE	Elenco parti	DESCRIZIONE
1	1	Stripline 20 cm	
2	1	Stripline 20 cm	
3	1	Stripline 20 cm	
4	2	Stripline 20 cm	
5	2	Stripline 20 cm	
6	2	Stripline 20 cm	
7	4	Stripline 20 cm	
8	4	Stripline 20 cm	



20 cm striplines



22 cm+ 2*12 cm tapers

D. Alesini

Studies of Collective Effects in MAXIV

Multi-bunch: resistive wall

For RW *mbtrack* uses the eff. radius b_{eff}

- With passive HC the threshold is at ~ 40 mA

cavity tuning for optimal bunch lengthening is needed

- Further investigation with ideal cavity potential (cross check with passive HC)

➤ geometric impedance improves the threshold

suggests the head-tail damping

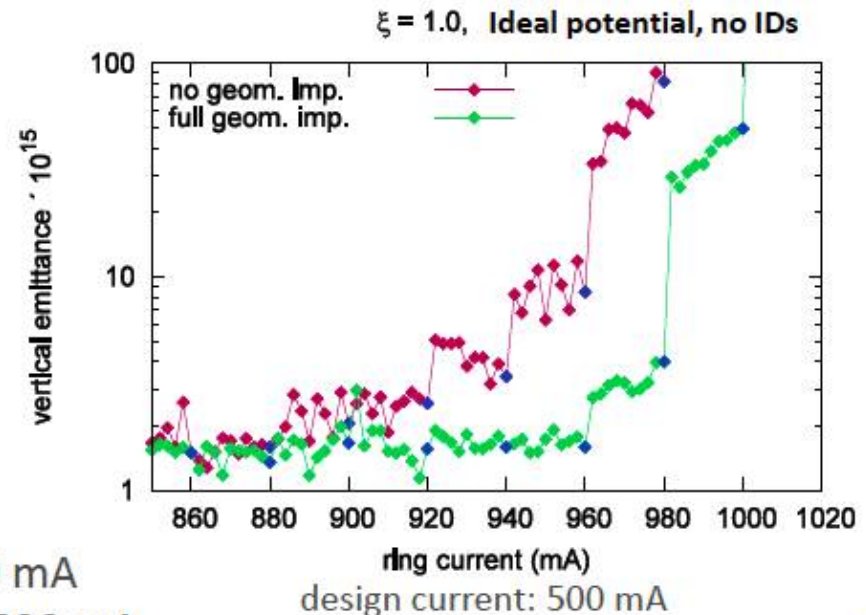
- RW scales as $I \cdot b_{\text{eff}}^3$

➤ I_{th} with 5 planned IDs ($\xi=1$): 380 mA

➤ I_{th} with 5 planned IDs ($\xi=1.2$): >500 mA

$\xi > \xi_{\text{design}}$ allows to achieve design current

Optics design has been made to provide ξ up to +4





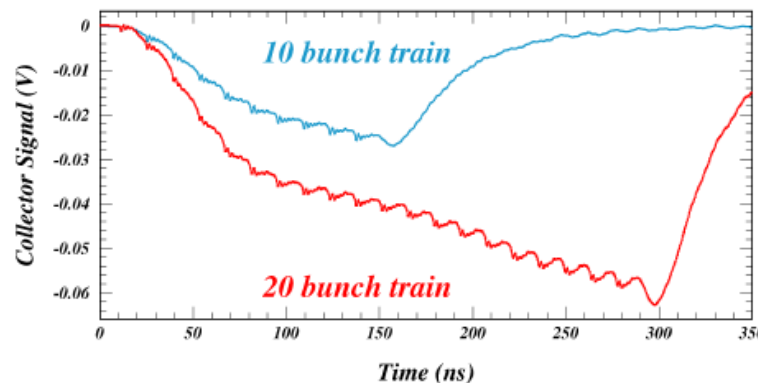
Measurement of electron cloud trapping in CESR



Cornell Laboratory for
Accelerator-based Sciences and Education (CLASSE)

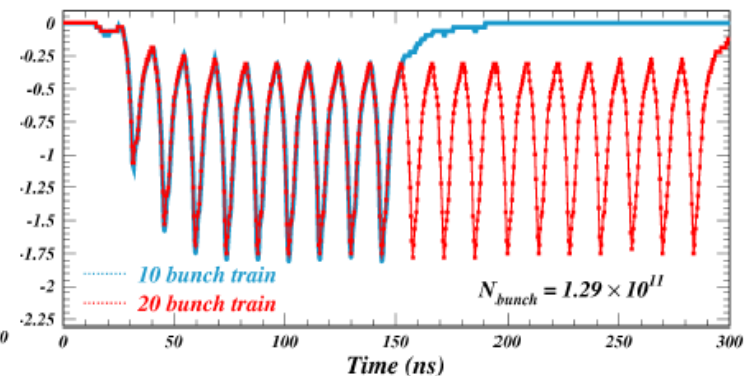
Discovery of electron trapping
June 2013

Shielded stripline signals
for 10- and 20-bunch trains
of 5.3 GeV positrons
in the 7 T/m quadrupole magnet



Observation of Electron Trapping in a Positron Storage Ring,
M.G. Billing et al, arXiv 1309.2625

Shielded button electrode signals
recorded simultaneously
in a field-free region
of the CESR ring

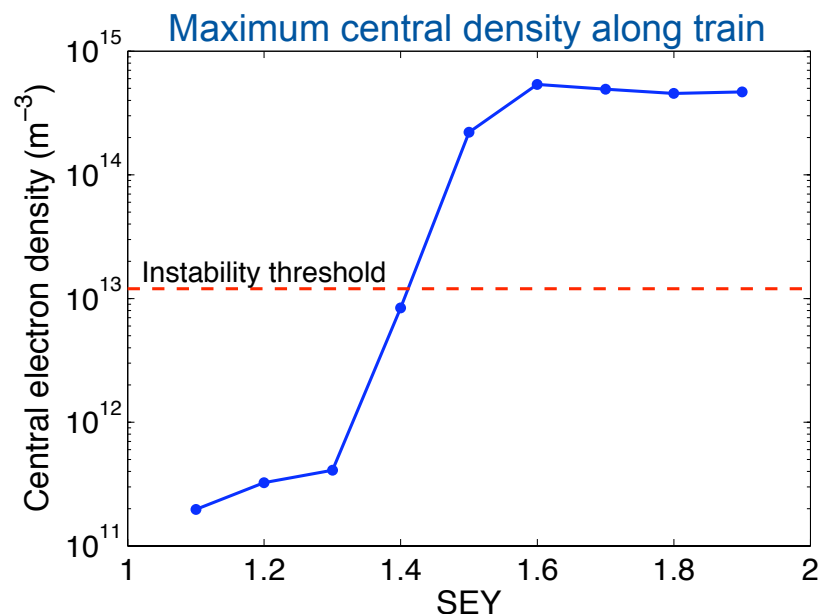
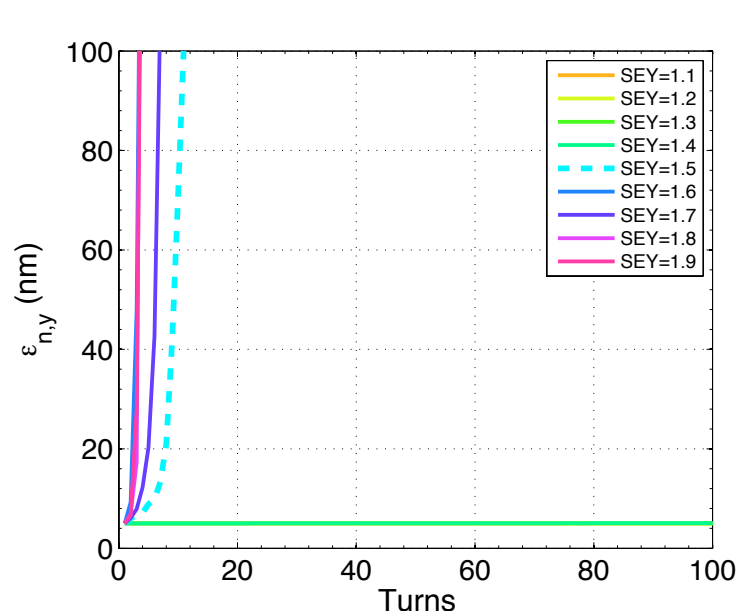


Shielded Button Electrodes for Time-resolved Measurements of Electron Cloud Buildup
JAC et al, Nucl. Instrum. Meth. A749, 42 (2014)

How do the first ten bunches know that ten more are coming?

Electron cloud which can contribute to the signal is trapped during the 2.3 μ s interval between trains.
The change in slope indicates that six bunches suffice to clear this signal-producing trapped cloud.

Low- ϵ example: CLIC-DR, Wigglers



- Instability simulations with initial densities given by PyECLOUD
 - Build-up mildly dependent on ϵ , instability strongly dependent
- Beam is unstable for all SEY values above build-up threshold!

Electron cloud suppression crucial!

Review of Instabilities Issues for Low Emittance Rings ...

3. Conclusions

- Efforts to lower the beam emittance generally tend to enhance beam instability and collective effects, both in terms of impedance and beam sensitivity.
- Therefore, if the beam intensity is to be used as a knob to attain higher brilliance in future low emittance rings, the coupling impedance, as well as all concerned beam instabilities and collective effects must be well studied and mastered in advance.
- The high quantity and quality of studies presented at TWIICE workshop demonstrate the enormous efforts actively being made by the colleagues in the low emittance ring community (and also of hadron ring community) in all directions.
- For more details of the presentations made at TWIICE, please visit the workshop site at <http://www.synchrotron-soleil.fr/Workshops/2014/TWIICE> where all the contributions are accessible. The 2nd TWIICE is to be organized in 2016.



Thank you for
the attention!

Low Emittance Rings workshop LOWεRING 2014



Istituto Nazionale
di Fisica Nucleare

LNF-INFN, Frascati
17-19 September 2014



Goal of the workshop is to bring together experts from the
scientific communities working on low emittance lepton rings

Workshop sessions

- Low emittance lattice design and tuning
- Collective effects
- Low emittance ring technology

