Low Emittance Rings - report from WP6

Y. Papaphilippou, CERN,

R. Bartolini, Un. Oxford - DIAMOND, S. Guiduci, INFN-LNF

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WP6 - Low Emittance Rings: 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 working group on damping rings…
- ...and overtaken by the light source community towards diffraction limited storage rings

- 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

Objectives and Results

- Coordinators:
  - R. Bartolini (UOXF)
  - S. Guiducci (INFN-LNF)
  - Y. Papaphilippou (CERN)

  } Each one representing community of X-ray storage rings of e+/e- colliders and damping rings

- Form a **coordination board**, representing the Low Emittance Rings community (including non-EU members)
  - B. Hettel (SLAC)
  - Q. Qin (IHEP)
  - D. Rubin (Cornell)
  - J. Urakawa (KEK)

  } Representing "Ultimate-storage ring" community and damping ring test facilities

  - Task coordinators: M. Böge (PSI), R. Nagaoka (Soleil), H. Schmickler (CERN)
- Organize Low Emittance Rings' general and topical workshops

WP6 present status

Workshops (milestones):

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
2015 April – Low emittance ring design – Barcelona, 50 participants
2015 September– 3rd general Workshop – Grenoble, 67 participants
2016 February – Collective effects (TWIICE-II) – Oxford, 61 participants
2016 September – Technology (ALERT) – Trieste, 75 participants
2016 October – 4th general Workshop – Paris, 75 participants
2016 December – Low emittance ring design – Lund, 32 participants

Deliverables:

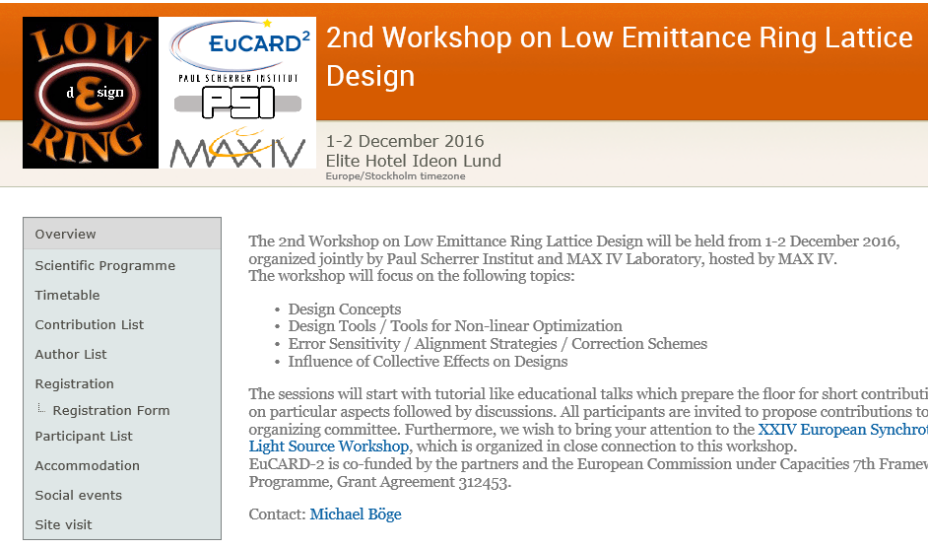
EuCARD2- DEL – D6.1-4: Low emittance ring design
EuCARD2- DEL – D6.2-5: Instabilities, impedance, collective effects
EuCARD2- DEL – D6.3-6: Low emittance ring technology

6.2. Low Emittance Ring Design (LERD)
Objectives and Results

Enable evaluation of methods, approaches and numerical tools for designing ultra-low emittance optics

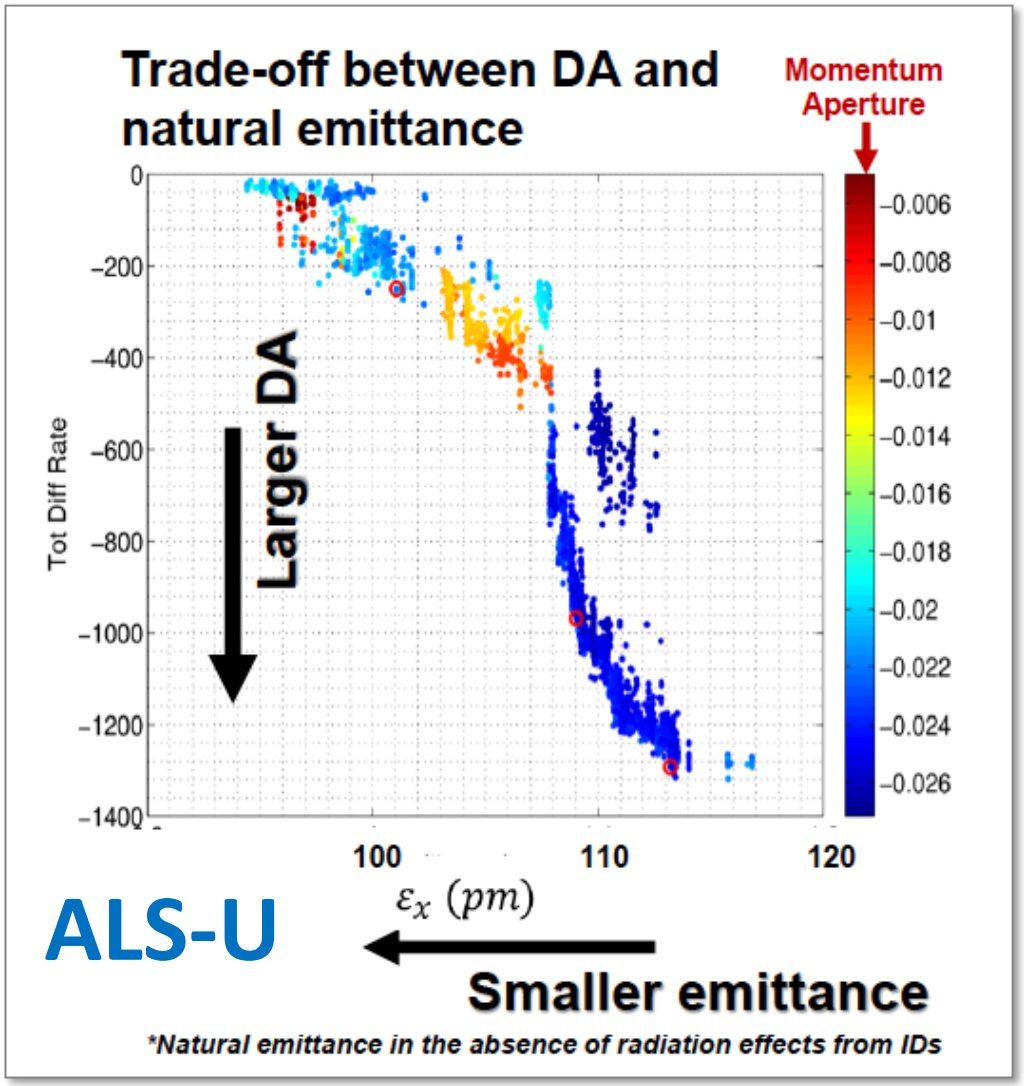
Integrate studies and measurements of sub-picometer vertical emittances with high-intensity beams

LOWεRing design (task 6.2)



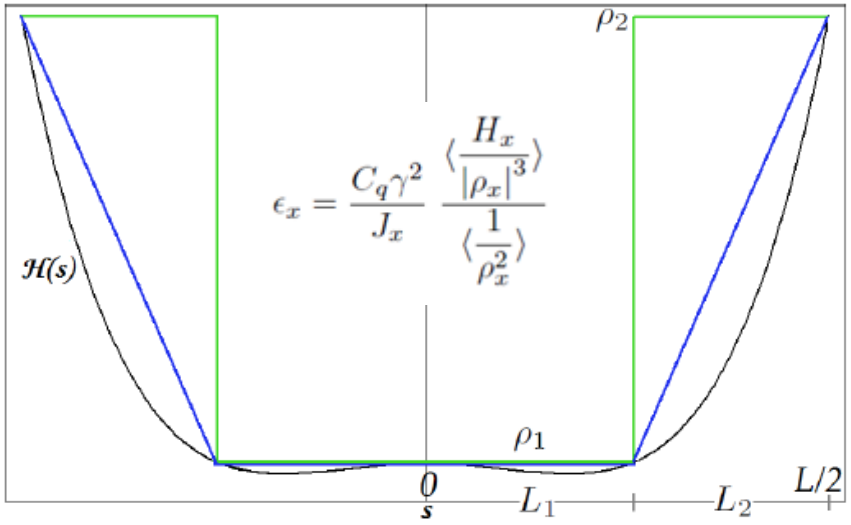
- Issues and topics related to Task 6.2 discussed in the general meetings and two topical meetings
  - ALBA, April 2015
  - MAXIV, December 2016

Example of Optimisation of beam dynamics - MOGA



- Pioneered by M. Borland et al.
- Objectives: simultaneous optimization of multiple objectives, particularly where objectives are conflicting
- Suitable for large dimension parameter spaces ensuring the search of global minimum
- Results: indicates the best trade-off between objectives
- Parallel implementation may be necessary

Longitudinally variable bends[1]



$$\rho_{st}(s) = \begin{cases} \rho_1, & 0 < s < L_1 \\ \rho_2, & L_1 < s < L_1 + L_2 \end{cases}$$

$$\rho_{tr}(s) = \begin{cases} \rho_1, & 0 < s < L_1 \\ \rho_1 + \dfrac{(L_1 - s)(\rho_1 - \rho_2)}{L_2}, & L_1 < s < L_1 + L_2 \end{cases}$$

S.Papadopoulou et al.

Bending radii ratio

$$\rho = \frac{\rho_1}{\rho_2}$$

Lengths ratio

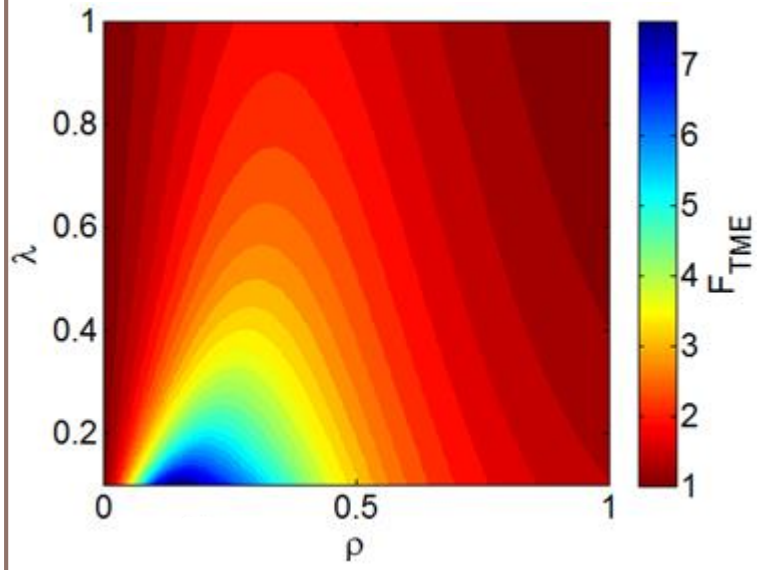
$$\lambda = \frac{L_1}{L_2}$$

Emittance reduction factor

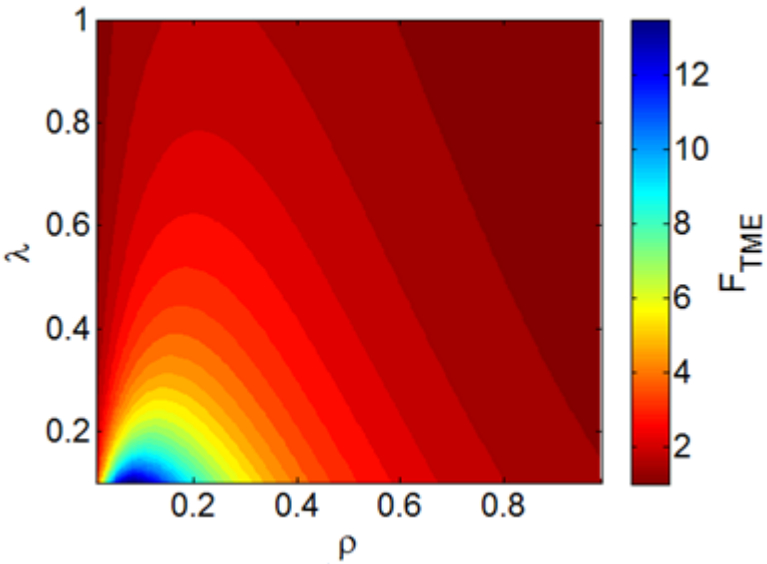
$$F_{TME} = \frac{\epsilon_{TME_{uni}}}{\epsilon_{TME_{var}}}$$

$$F_{TME} > 1$$

Step profile



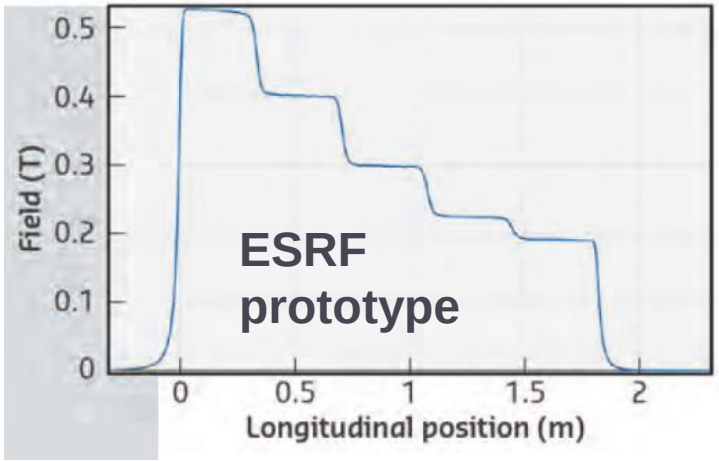
Trapezium profile

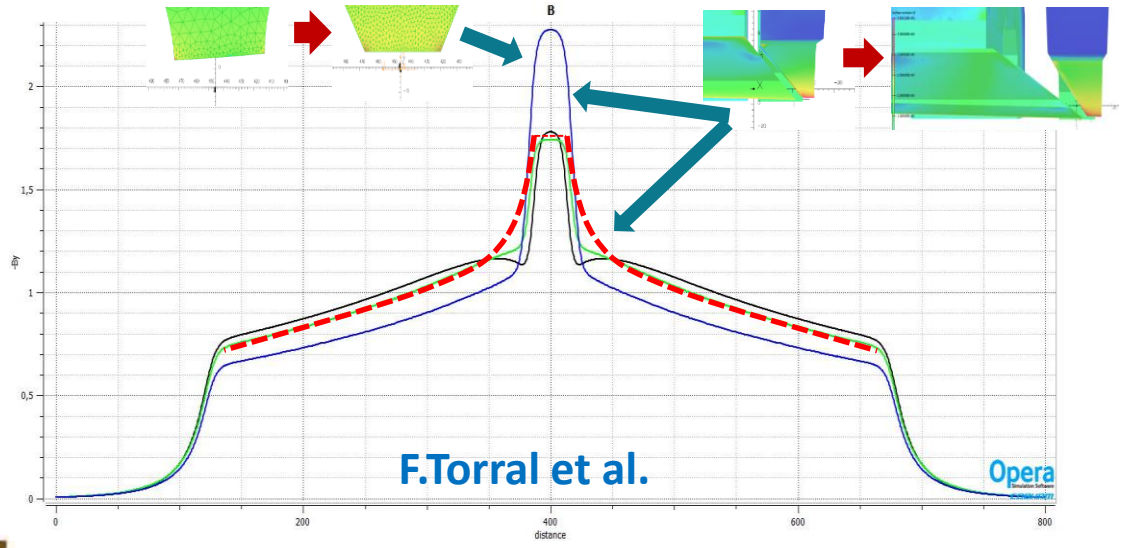


The parameterization of the emittance reduction factor F_{TME} with the bending radii ratio ρ and the lengths ratio λ, always for λ>0.1.

Varying Dipoles with gradient for ESRF and CLIC DR

Design @ CIEMAT with ~2.3 T peek field !!!





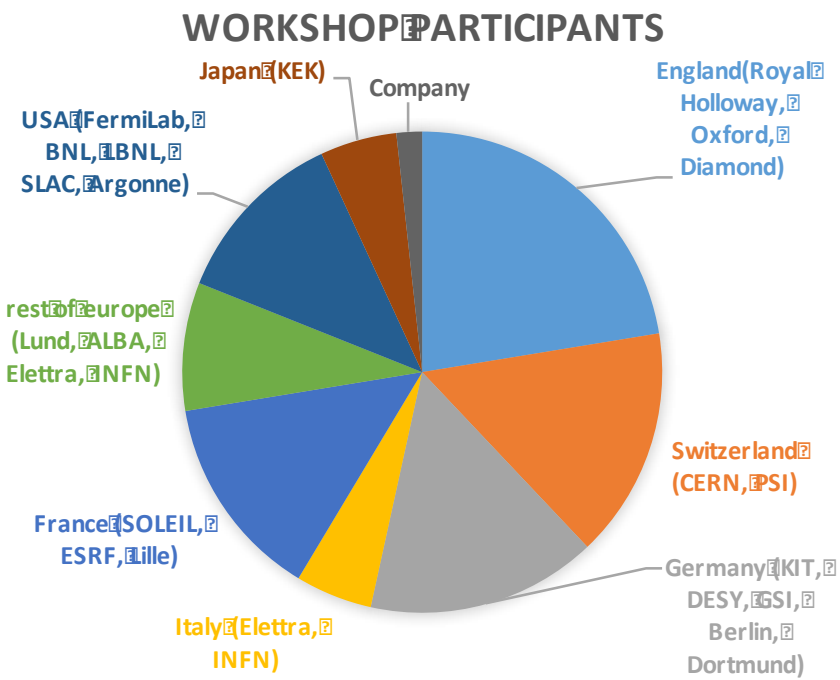
Normalized multipoles	
b1	10000.00
b2	-536.37
b3	-1.28
b4	3.11
b5	-0.54
b6	-0.29
b7	-0.16
b8	0.09
b9	-0.18
b10	0.13

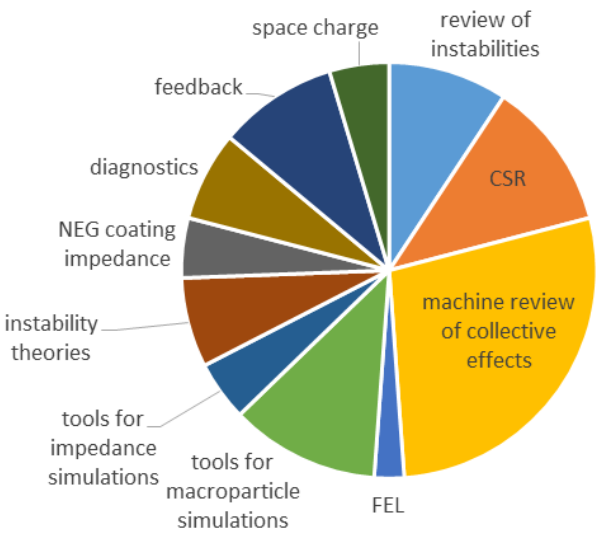
6.3. Instabilities, Impedances and Collective Effects (IICE)
Objectives and Results

- Focus on methods to evaluate impact of impedances and instabilities in LER
- Promote methods to estimate impact of two-stream instabilities and techniques to cure them
- Enable Intrabeam Scattering community to improve theory and simulations through experimentation
- Provide a forum to help achieve Coherent Synchrotron Radiation, avoiding micro-bunching instabilities

Topics/Issues in collective effects (task 6.3)

2nd Topical Workshop on Instabilities, Impedance and Collective Effects (TWIICE -II) organized at Oxford:





Agenda in https://indico.cern.ch/event/459623/

3 days, 61 delegates, 41 talks + 2 introductions and 5 summaries

Topics/Issus in collective effects (task 6.3)

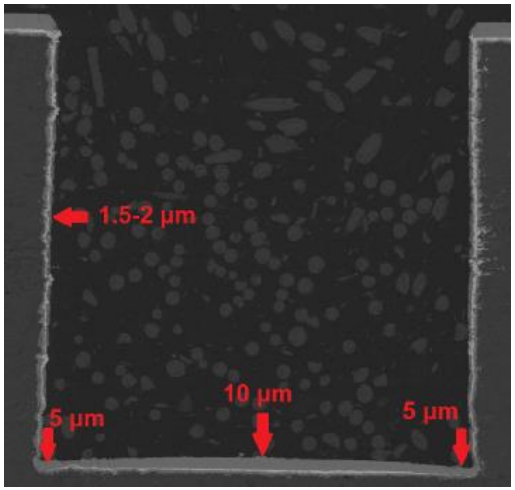
2nd Topical Workshop on Instabilities, Impedance and Collective Effects (TWIICE -II) organized at Oxford:

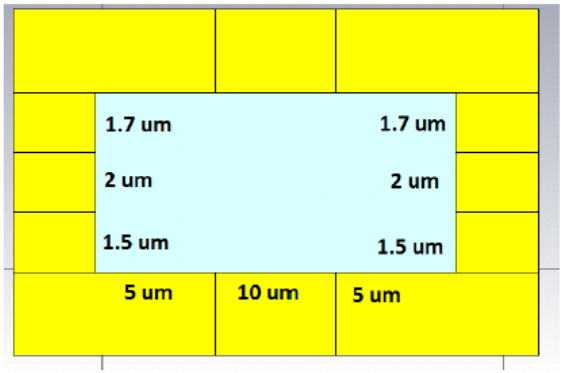
A large number of contributions went **beyond** the strict problematic of low emittance rings

- Intense effort in all machines to identify **impedance sources**, minimize them and build an impedance model
- **Benchmark codes** with measurements of beam observables (collaboration among different laboratories)

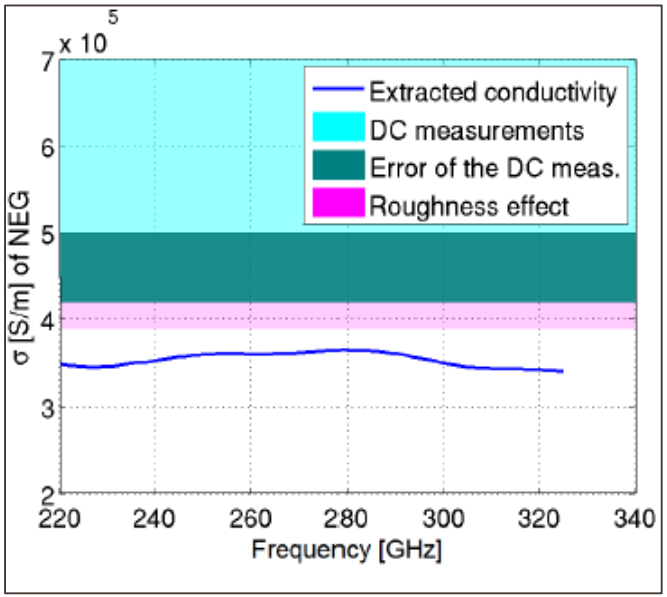
Effects of coating on impedance: NEG characterization in high frequency

- Waveguide method used for measuring NEG conductivity
  - In different frequency ranges (~10 GHz, 220 – 330 GHz, 500 – 750 GHz)
  - A few interesting observations
    - Non-uniformity of the NEG coating is an essential ingredient to extrapolate correctly the conductivity values in the different energy ranges





E.Koukovini et al.

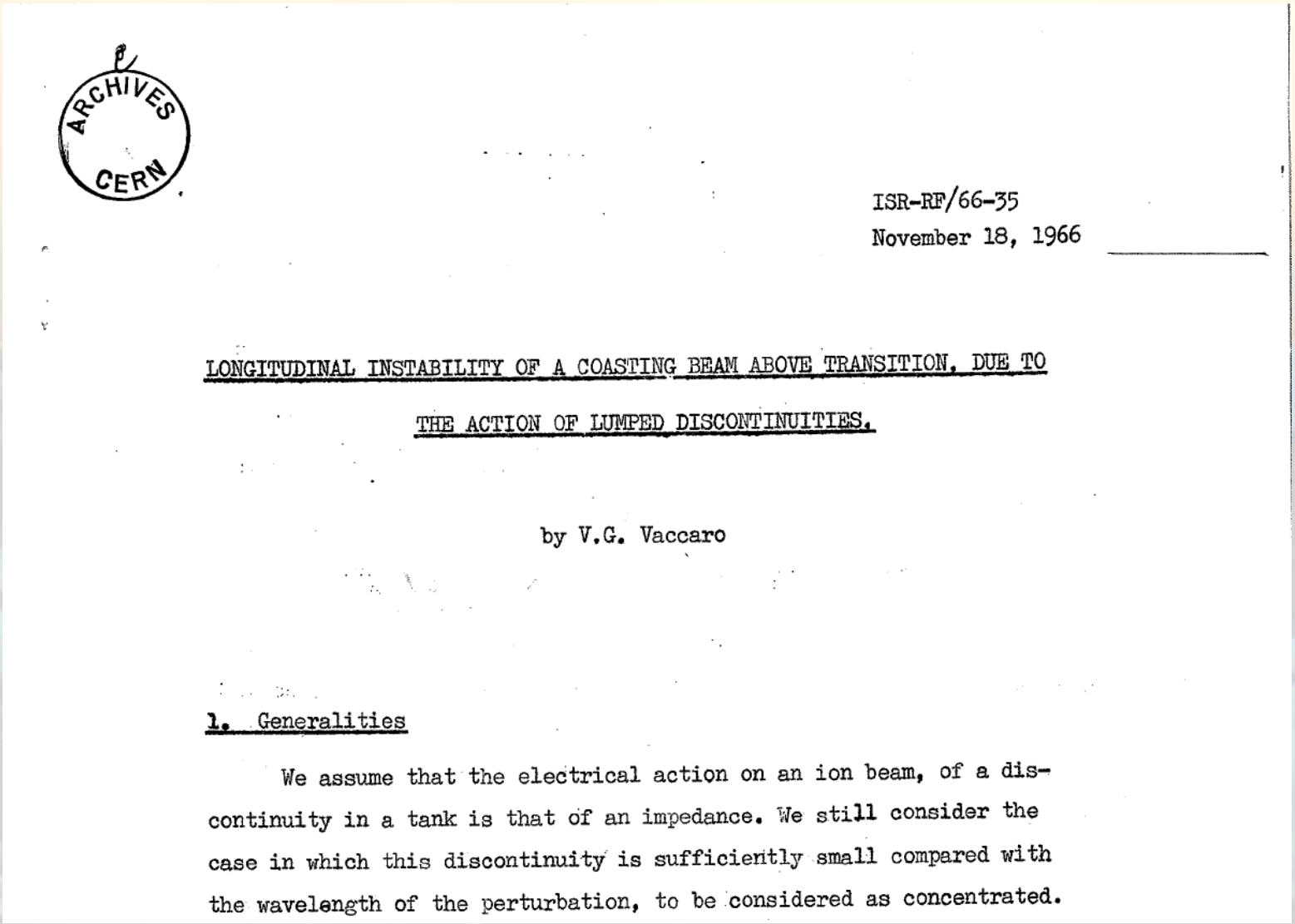


Shortly it will be fifty, but it does not look like it

Vittorio G. Vaccaro

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II
and INFN- SEZ. DI NAPOLI

- Andy Sessler proposed that I could write a paper concerning the cases we have already discussed…



ISR-RF/66-35
November 18, 1966

LONGITUDINAL INSTABILITY OF A COASTING BEAM ABOVE TRANSITION, DUE TO THE ACTION OF LUMPED DISCONTINUITIES.

by V.G. Vaccaro

1. Generalities

We assume that the electrical action on an ion beam, of a discontinuity in a tank is that of an impedance. We still consider the case in which this discontinuity is sufficiently small compared with the wavelength of the perturbation, to be considered as concentrated.

Sophie Marceau

La Boom - The Party – Il tempo delle mele (1980)

Shortly she will be fifty, but she does not look it

6.4. Low Emittance Rings Technology (LERT)
Objectives and Results

Promote interactions concerning insertion devices, magnets and alignment in low emittance rings
Establish contacts within low emittance rings diagnostics specialists for common studies
Exchange experiences of low impedance strip-line kickers and high voltage pulsers
Coordinate design efforts and experimental tests in RF cavity design for various bunch structures

- Key enabling technologies appears to be mature

Enabling technologies (task 6.4)

- Two topical workshops organised
  - IFIC Valencia, May 2014
  - Trieste, September 2016
  - Organised session involving **industry** in collaboration with WP2 (See highlight talk of **R.Geometrante**)

Advanced Low Emittance Rings Technology (ALERT) 2014 Workshop

5-6 May 2014
IFIC
Etc/GMT+1 timezone

Overview
Timetable
Contribution List
Author List
Registration
Participant List
Accommodation
Venue

Valencia | 5-6 May 2014

Advanced Low Emittance Rings Technology (ALERT) 2016 Workshop

14-16 September 2016
Trieste, Italy
Europe/Rome timezone

Overview
Scientific Programme
Timetable
Contribution List
Registration
Participant List
Venue
Accommodation

Trieste | 14-16 September 2016

ALERT 2016 TRIESTE

RF systems

MAXIV: 100 MHz with Rohde & Schwarz 60 kW CW solid state liquid cooled amplifiers based on two 30 kW transmitters / amplifiers with additional power combiner

CLIC DR	1 GHz	2 GHz, **no train interleaving after DR**
Classical RF system based on the NC ARES-type cavities	Baseline P_{RF} = 3.8 MW; L = 32 m; Cavity design: OK	Alternative 2.0 P_{RF} = 5.9 MW; L = 48 m; Cavity design: ok?
Classical RF system based on the SCC cavities	Alternative 1.1 P_{RF} = **0.6** MW; L = 108 m; Cavity design: **ok?**	Alternative 2.1 P_{RF} = **0.6** MW; L = **800** m; Cavity design: **NOT OK**
RF system with RF frequency mismatch	Alternative 1.2 P_{RF} = **1.3** MW; L = **16** m; Cavity design: **OK**	Alternative 2.2 P_{RF} = 2.1 MW; L = 24 m; Cavity design: OK
"A-la-linac" RF system with strong input power modulations	Alternative 1.3 P_{RF} = 3.3 MW; L = **8** m; Cavity design: **OK**	Alternative 2.3 P_{RF} = 5.8 MW; L = **12** m; Cavity design: **OK**

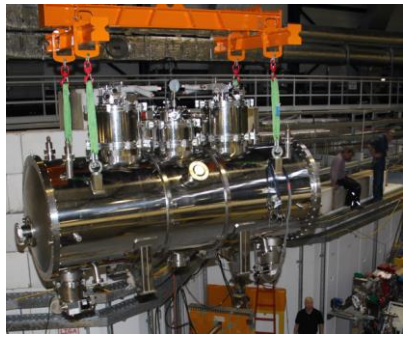
Solid state amplifiers at **SOLEIL**: High efficiency (65%), redundancy, modularity, low phase noise,
MTBF > 1y

Collaboration between colliders and light sources

- High-field (~3T), low period (~5cm) **super-conducting** NbTi **damping wiggler** (BINP-KIT/ANKA –CERN)
  - Prototype installed at ANKA SR for heat-load (cooling concept) and beam dynamics measurements
  - Ultimately serve the SR user community
- Low-impedance, stringent field homogeneity **stripline kicker** and ultra-stable **pulser**
  - Stripline produced by Spanish industry, under laboratory tests at CERN, to be measured with beam at ALBA SR
  - Inductive adder achieving pulse jitter tolerances ~10^{-4} to be tested with the prototype stripline and beam (ALBA)
- Correction **methods** and beam **instrumentation** for achieving and measuring **ultra-low emittances** (beam size of ~1µm)
  - Novel measurement methods using vertical undulator at the Australian Light Source (reaching the **quantum limit** of vertical emittance ~0.4pm.rad)

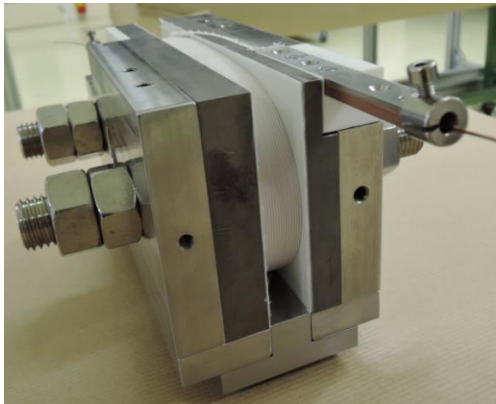
Prototype inductive adder

NbTi wiggler lowered in the ANKA SR



Stripline licker laboratory tests

Nb_3Sn short model winding



EuCARD² Student prize

- Sponsor trip to a major accelerator conference for presenting work related to low emittance rings
- Selection procedure: Poster presentations in general Low-ε-ring workshops
- And the winners are…
  - LOWERING2013 workshop: **Eirini Koukovini Platia** (CERN/EPFL), **Simone Liuzzo** (ESRF/Un. Of Rome)
  - LOWERING2014 workshop: **Tobias Goetsch** (HZ Berlin)
  - LOWERING2015 workshop: **Panos Zisopoulos** (CERN/Un. of Uppsala) and **Stefania Papadopoulou** (CERN/Un. of Creta)
  - LOWERING2016 workshop: **Alexis Gamelin** (LAL-SOLEIL) and **Michele Carla** (CELLS/ALBA)

Pr. Dieter Einfeld

- During the General Low-ε-Ring workshop 2016, honoring **Pr. Dieter Einfeld**, the person who popularized the Multi-Bend Achromat lattice approach

Deliverables

- Three interim and final reports (one per task)
  - Five achieved on time, one imminent

Delive-rable Number [61]	Deliverable Title	Lead benefi-ciary number	Estimated indicative person-months	Nature [62]	Dissemi-nation level [63]	Delivery date [64]	Achieved month
D6.1	Low Emittance Ring Design interim report	19	2.00	R	PU	18	18
D6.2	Instabilities, Impedances and Collective Effects interim report	9	2.00	R	PU	18	18
D6.3	Low Emittance Ring Technology interim report	1	2.00	R	PU	18	19
D6.4	Low Emittance Ring Design final report	30	3.00	R	PU	46	46
D6.5	Instabilities, Impedances and Collective Effects final report	9	3.00	R	PU	46	46
D6.6	Low Emittance Ring Technology final report	1	3.00	R	PU	46	Imminent

Milestones

- 3 topical and 3 general workshops (dates slightly advanced-delayed)
- A 4th general workshop organized (October 2016, SOLEIL, Paris)

Milestone number [59]	Milestone name	Lead benefi-ciary number	Delivery date from Annex I [60]	Achieved month
MS41	First workshop of Collective effects in Low Emittance Rings	9	6	12
MS42	First workshop of Low Emittance Rings Technology	1	9	15
MS43	Annual LOW-e-RING workshop, first year	40	12	6
MS44	First workshop of Low Emittance lattice design	30	18	24
MS45	Annual LOW-e-RING workshop, second year.	40	24	18
MS46	Second workshop of Collective effects in Low Emittance Rings	9	30	36
MS47	Second workshop of Low Emittance Rings Technology	1	33	45
MS48	Annual LOW-e-RING workshop, third year.	40	36	35
MS49	Second workshop of Low Emittance lattice design	30	36	45

Leadership

The LOWεRING community sponsored by EuCARD2 played a **leadership** role in fostering the world-wide development of low emittance rings

- ICFA Low Emittance Rings Workshops (LowERing, 2010, 2011)
- 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 (LowERing2014), Frascati, September 2014
- DLSR Workshop, Argonne, November 2014
- Workshop on Low emittance ring design, Barcelona, April 2015
- Low Emittance Rings Workshop (LowERing2015), Grenoble, September 2015
- 2nd Workshop on Instabilities, Impedance and Collective Effects (TWIICE -II), Abington, February 2016
- DLSR Workshop, DESY, March 2016
- 2nd Workshop on Low Emittance Rings Technology (ALERT), Trieste, September 2016
- Low Emittance Rings Workshop (LowERing2015), SOLEIL, October 2016
- 2nd Workshop on Low emittance ring design, Lund, Dexember 2016

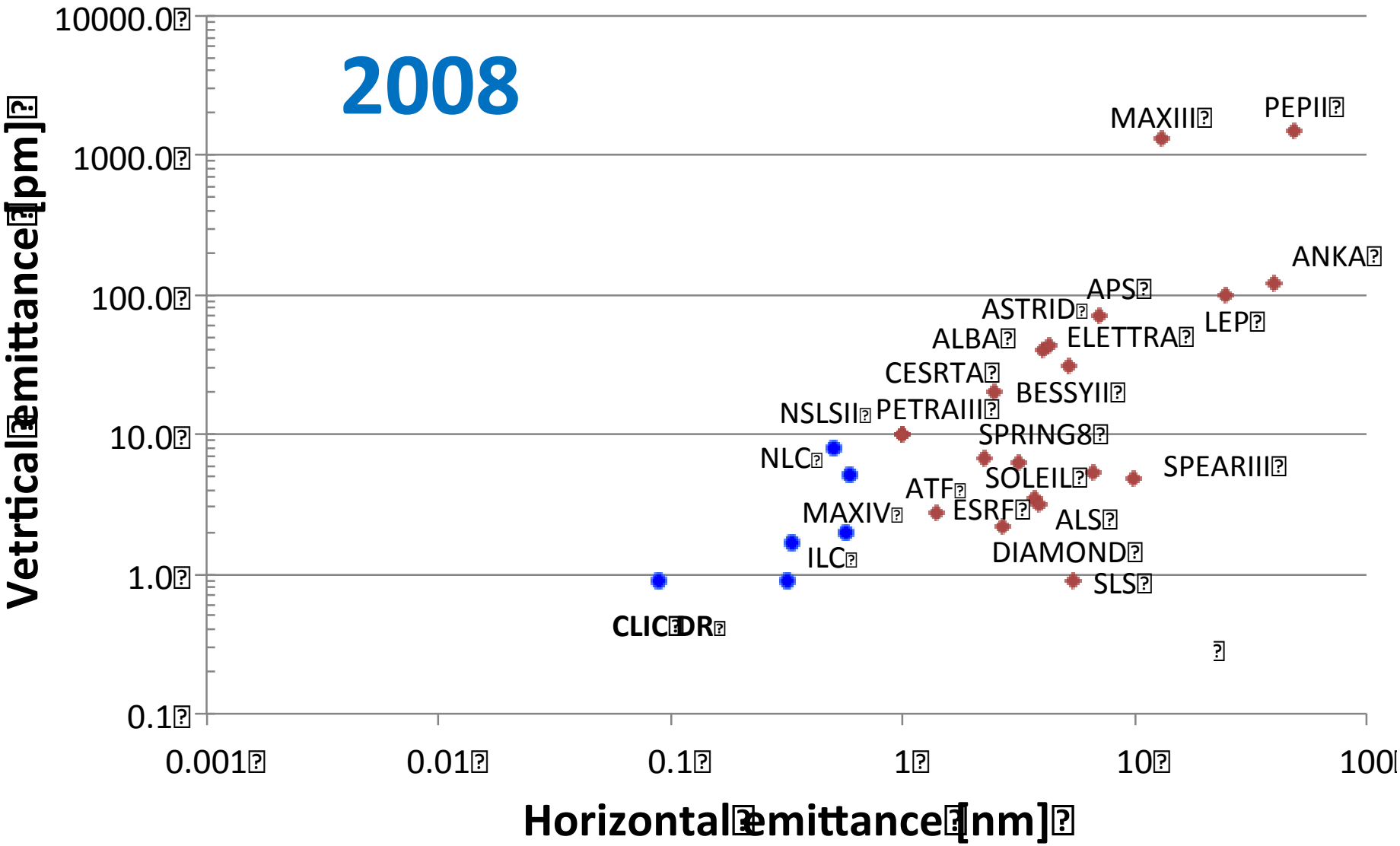
LOWεRING 2016 SOLEIL, Paris

LOWεRING 2015 ESRF Grenoble

Low Emittance Rings Community evolution

- First LER-type workshop (before EUCARD2) in Geneva January 2010, driven by damping ring and colliders
  - ILC in full swing, CLIC CDR in preparation, SuperB in good shape
- Idea of the first organizers (Y. Papaphilippou, M. Palmer, S. Guiducci) to involve light sources
  - No upgrades yet foreseen
  - Few light sources interested mainly to small vertical emittance (< 1 pm in SLS and ASP)
  - Max IV funded in end 2009
- Low-ε-Ring proposal came out of these initial discussions

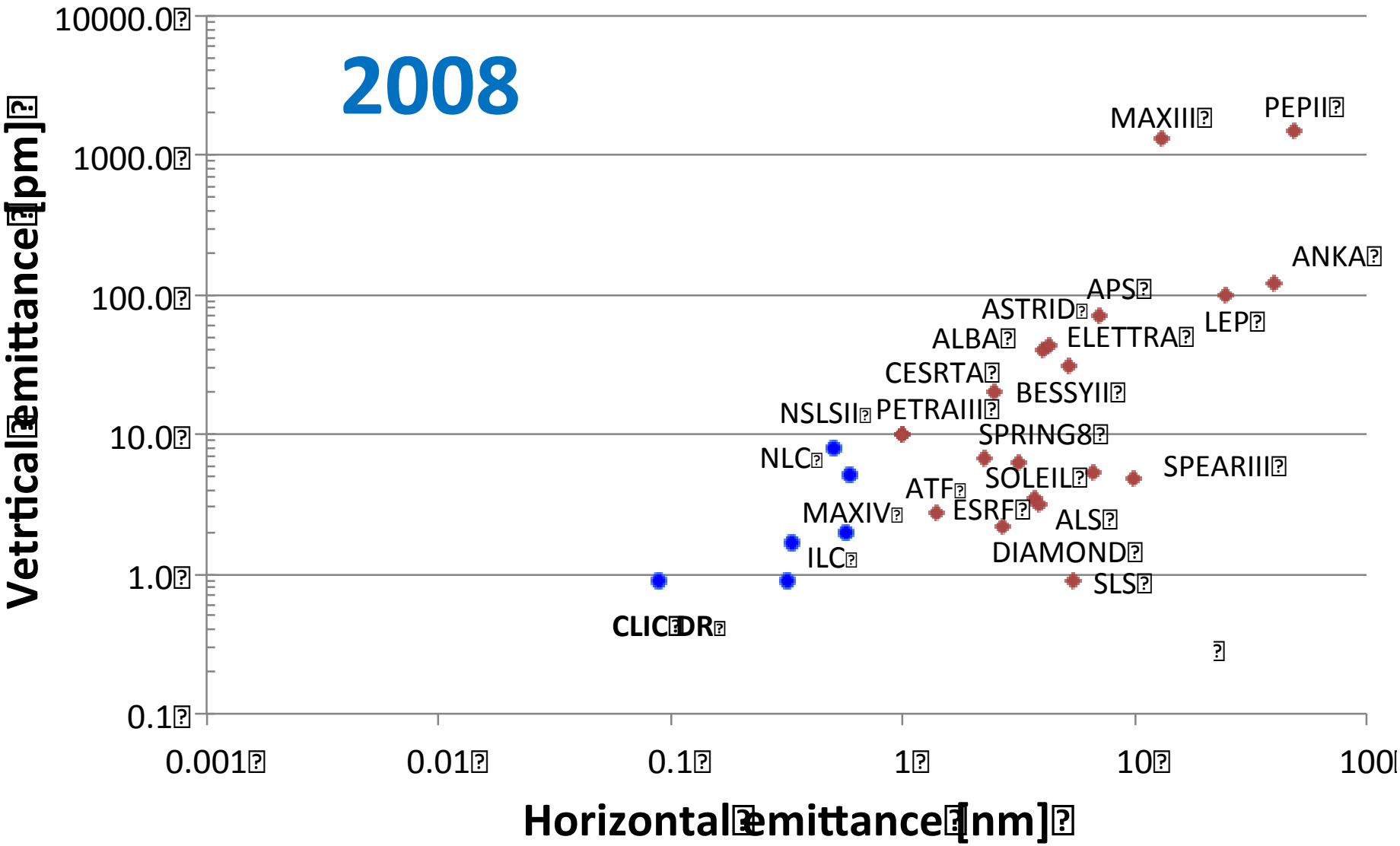
Emittance targets



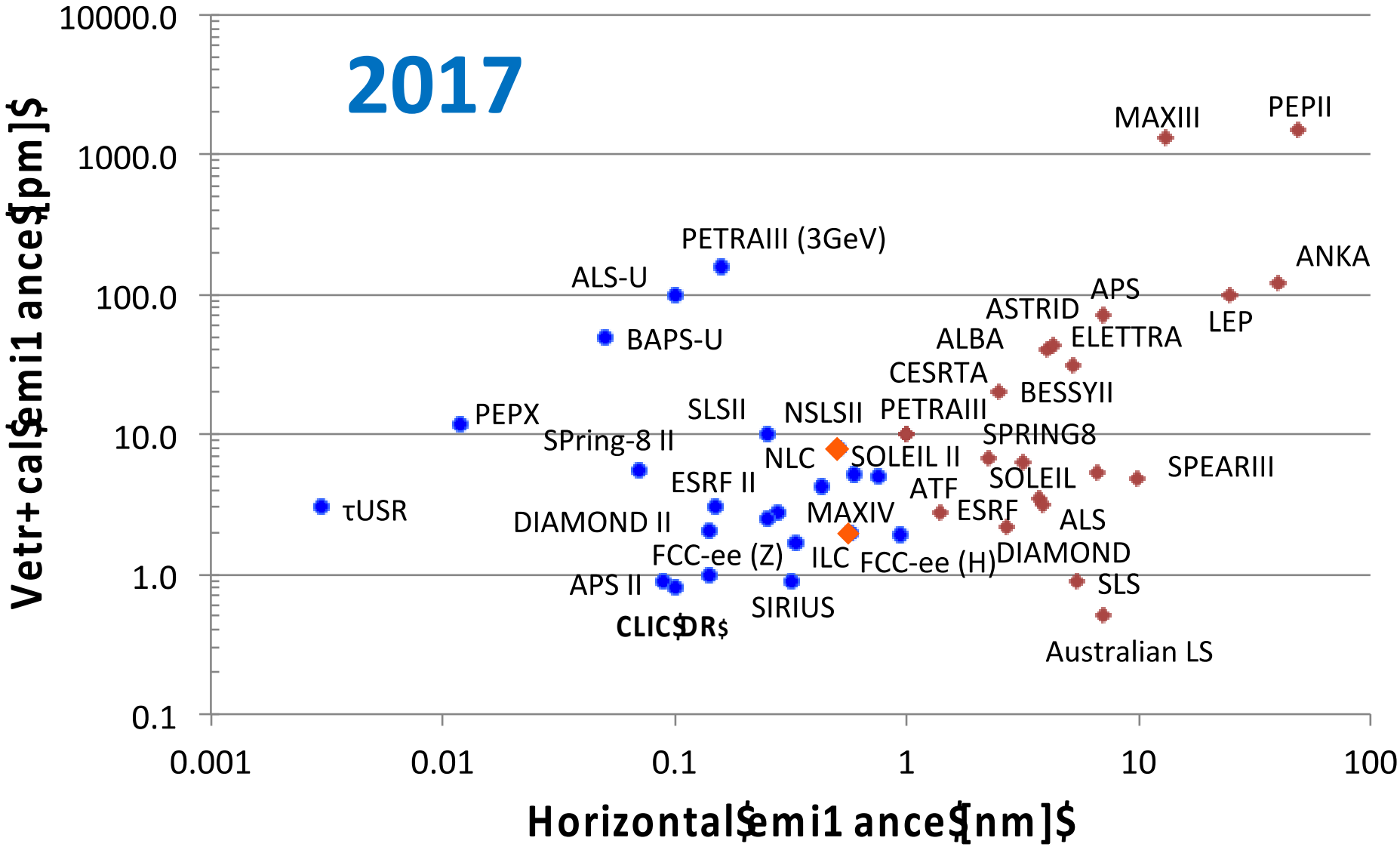
Low Emittance Rings Community evolution

- Since 2014, > 13 upgrade studies for light sources can be testified from IPAC publications
  - MAX IV under commissioning
  - ESRF-EBS in procurement
  - SIRIUS under construction
  - APS-U CD1
  - ALS-U CD0
  - Spring-8
  - HEPS
  - SLS-II
  - Diamond II
  - PETRA IV
  - SOLEIL, ILSF, ANKA, SPEAR III, …

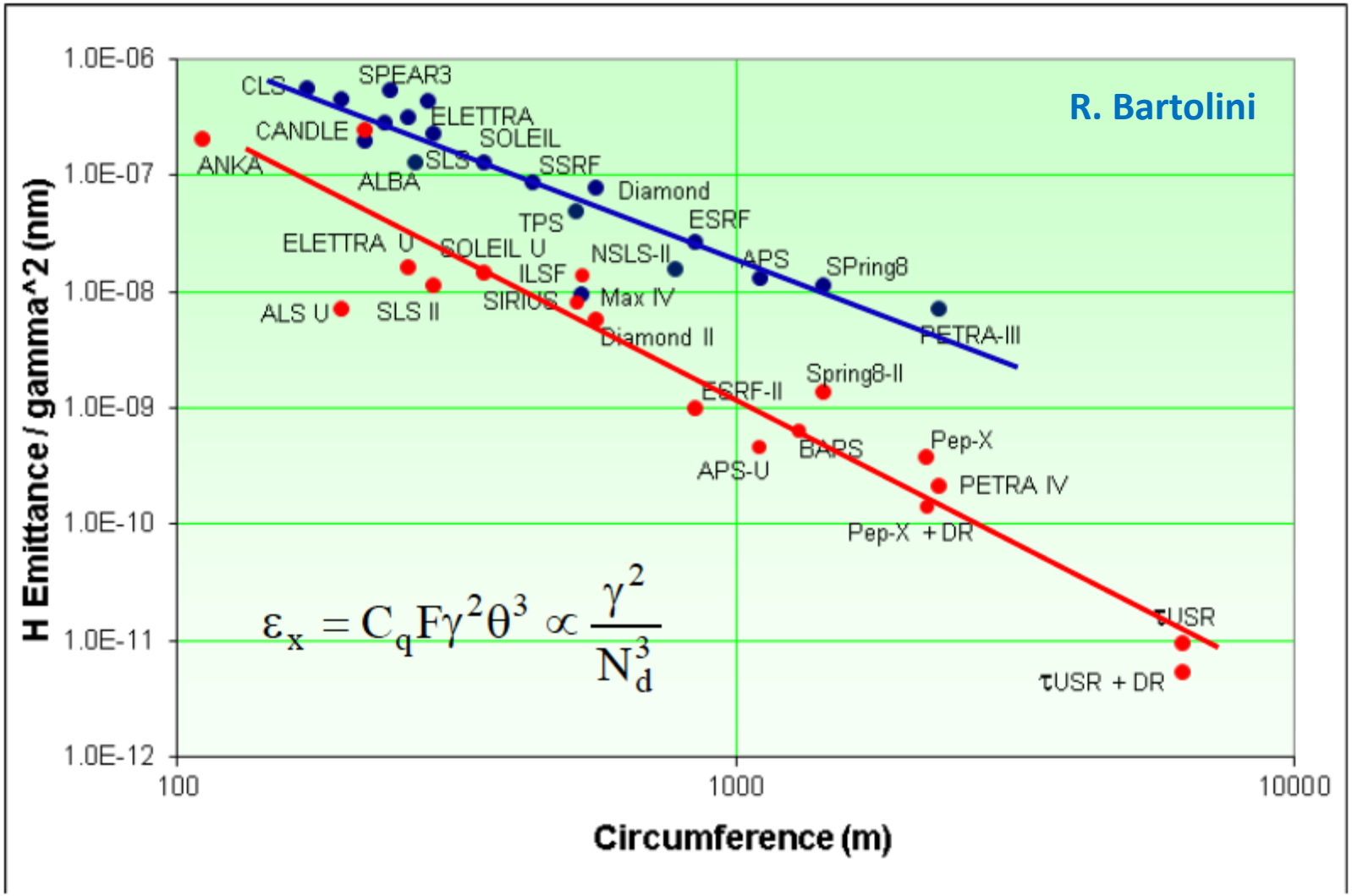
Emittance targets



Emittance targets



Survey of low emittance rings



EuCARD²

ARIES

RuL

Rings with Ultra-Low Emittance

THANKS to all involved partners
for the **great work**