



A new frontier: Ring with Ultra Low Emittance (WP7)

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Outline

- Ring with Ultra-Low Emittance: context and aims
- The Low Emittance Ring community
- Work packages and technical challenges
- Ongoing activity and conclusion

Low emittance rings

Light sources \rightarrow brilliance = $\frac{\text{flux}}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}} \propto \frac{I_{\text{beam}}}{\epsilon_x \epsilon_y}$

diffraction limited operation at 0.1nm requires 10's pm $\epsilon < \frac{\lambda}{2\pi}$

Colliders (e.g. FCC, CEPC) \rightarrow luminosity = $\frac{n_b f_{\text{rev}} N_1 N_2}{4\pi \sigma_x \sigma_y} S = \frac{n_b f_{\text{rev}} N_1 N_2}{4\pi \epsilon_x k\beta^*} S$

requires few nm (5nm for superKEKB)
as present state-of-the-art light sources

Damping rings \rightarrow decreasing equil. emittance $\epsilon(t) = \epsilon_f + (\epsilon_i - \epsilon_f) e^{-\frac{t}{2\tau_{x,y}}}$

500 pm H and 2 pm V (specs for ILC-DR)
<100 pm H and 5 pm V (specs for CLIC-DR)

Aims

RULE aims at establishing and supporting networking activities between the three accelerator communities involved in R&D in low emittance ring

- synchrotron light sources
- damping rings
- colliders

mostly based on

- workshops organization
- fostering collaborations and exchange of ideas
- defining and carrying out common R&D programmes
- supporting visit/exchanges/experiments
- support for students

Milestones: workshops – Deliverables: activity reports



The low emittance ring community (I)

Before EuCARD2

First LER-type workshop in Geneva January 2010

driven by damping ring and colliders

ILC, CLIC and SuperB

networking activity driven by Y. Papahilippou, M. Palmer, S. Guiducci

only few light sources

NO upgrades

Light source only there because of small V emittance

QLOVE – adjudicated(?) to ASP in 2014....

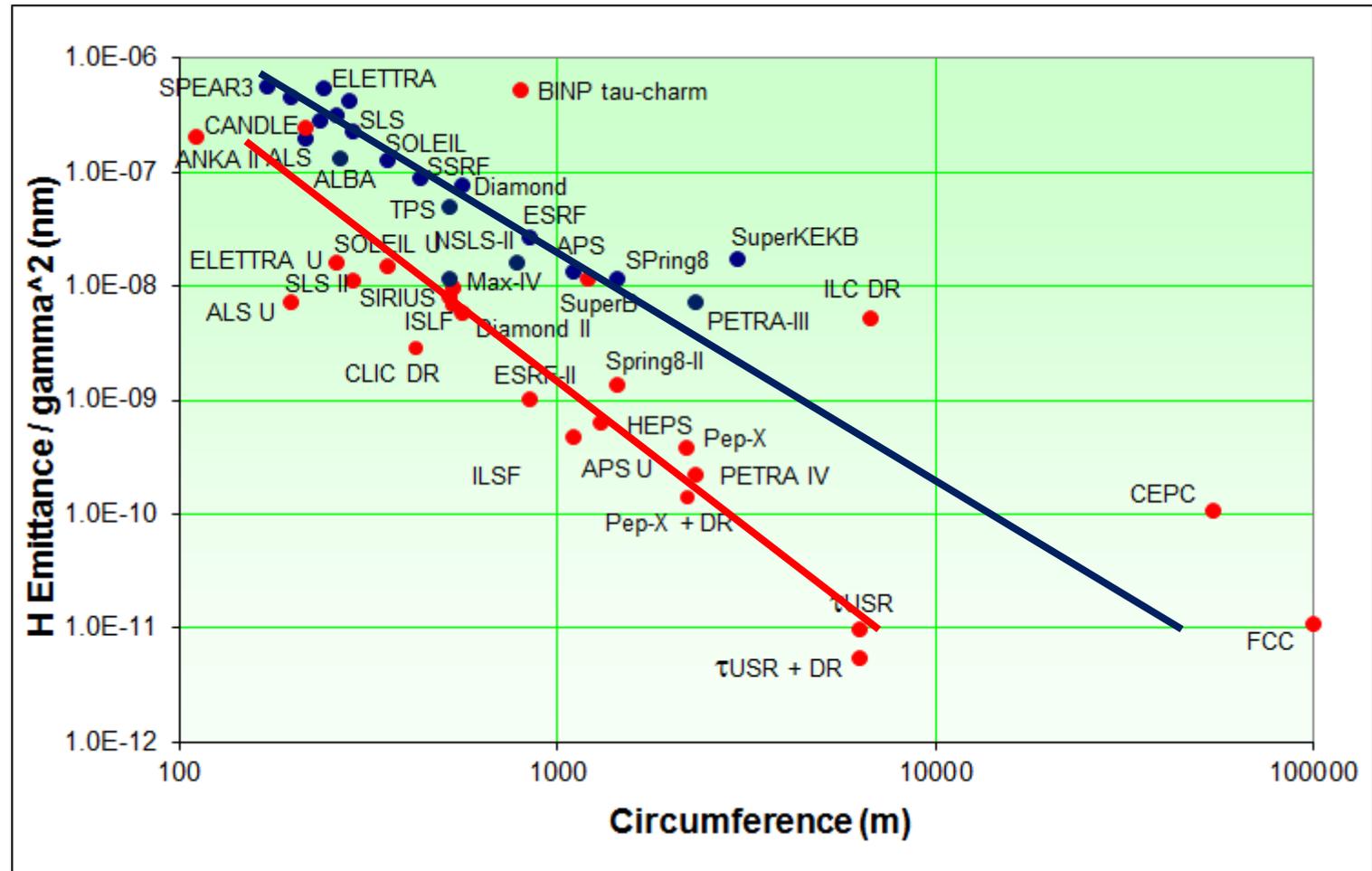
MAX IV funded in end 2009

Community shift 2010-2017

IPAC 14-16 have seen ~15 light source upgrade projects/studies

- MAX IV was commissioned in 2016
- ESRF-EBS placing contracts
magnets placed, large scale proc. mid 16; back in op. 2020
- Sirius under construction
- APS-U has passed CD1
- ALS-U has passed CD0, BAPS got money for R&D programmes
- SLS-II and Diamond II
advanced consultation with user community in view of CDR
- many labs are investigating options (SOLEIL, ELETTRA, Petra IV, ...)

Rings with Low Emittance



The low emittance ring community (II)

- **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**
- 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 (2015)**
- **Low Emittance Rings Workshop (LER2015), Grenoble, September 2015**
- **Workshop on collective effects (TWIICE-2), Abingdon (UK), 2016**
- DLSR workshop, Hamburg, (2016)
- **Workshop on Low Emittance Rings Technology (ALERT-2), Trieste, 2016**
- **Low Emittance Rings Workshop (LER2016), SOLEIL, October 2016**
- **Workshop on lattice design (LERD-II), Lund, Sweden, 2016**
- High Brightness Synchrotron Light Source Workshop, Brookhaven, 2017



- **WP6: low emittance rings**
- **Y. Papahilippou (CERN)**
- **S. Guiducci (INFN)**
- **R. Bartolini (JAI/DLS)**

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



WP7 Overview

- Task 7.1. Coordination and Communication
 - Lead University of Oxford (R. Bartolini)
- Task 7.2. Injection Systems for ultra-low emittance rings
 - Co-lead: PSI (M. Boege) and University of Oxford (R. Bartolini)
- Task 7.3. Beam dynamics and technology for ultra-low emittance rings
 - Co-lead: CERN (Y. Papaphilippou), INFN (M. Biagini), SOLEIL (R. Nagaoka)
- Task 7.4. Beam tests and commissioning of ultra-low emittance rings
 - Lead KIT (A.S. Mueller)

WP7 Task 1

- Task 7.1. Coordination and Communication

- Lead University of Oxford (R. Bartolini)

- Coordinate the tasks 7.2, 7.3 and 7.4
- Monitor progress and timely achievement of milestones/deliverables
- Representing the community of ultra-low emittance rings
- Organise the general workshops and other relevant networking activities
- Foster collaboration with industrial partners

WP7 Task 2

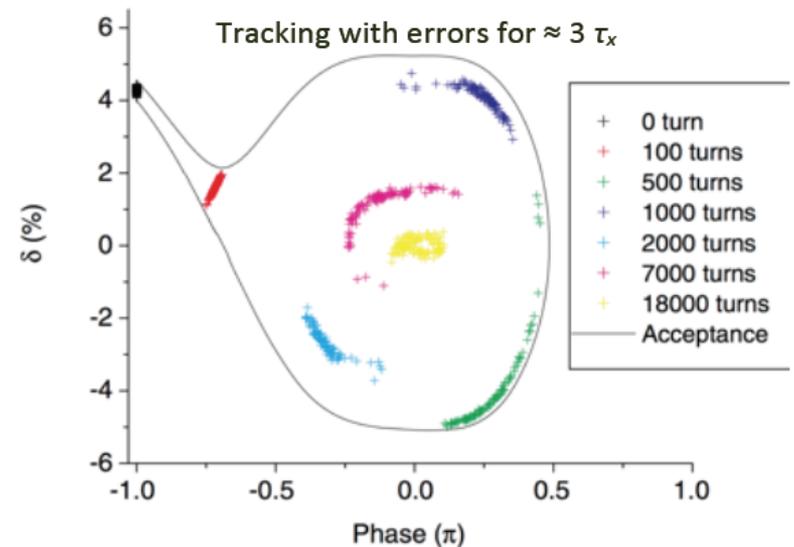
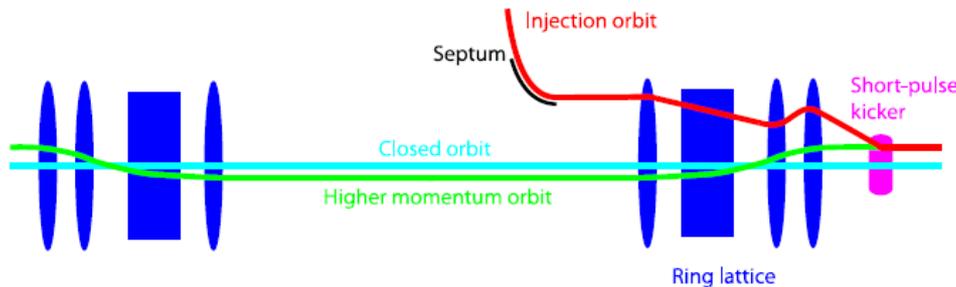
- Task 7.2. Injection Systems for ultra-low emittance rings
 - Co-lead: PSI (M. Boege) and University of Oxford (R. Bartolini)
- Exchange scientific information and share experience on the **technology of injection systems, including septa, kickers and pulsers**
- Explore the impact of injection system parameters in the optimisation of the rings dynamic aperture and the **design of the injectors**

Novel injection schemes

A wide variety of injection schemes has been put forward or re-discovered

- Single kicker (S. Leemann, NIMA 693, 117 (2012))
- Nonlinear multipole kicker (Bessy II, SOLEIL, MAX IV, ALS, HEPS)
- Off energy injection (M. Aiba, PRSTAB, 18, 020701, (2015))
- Off phase injection (HEPS)
- Antiseptum (SLS)
- Swap out injection (APS-U, ALS-U)

e.g. injected beam separated in longitudinal phase space from the stored beam and kicked on axis with a fast kicker



Development of kickers

On axis swap out injection underpinned by R&D on stripline kickers and PFN or inductive adders with fast rise time < 10 ns

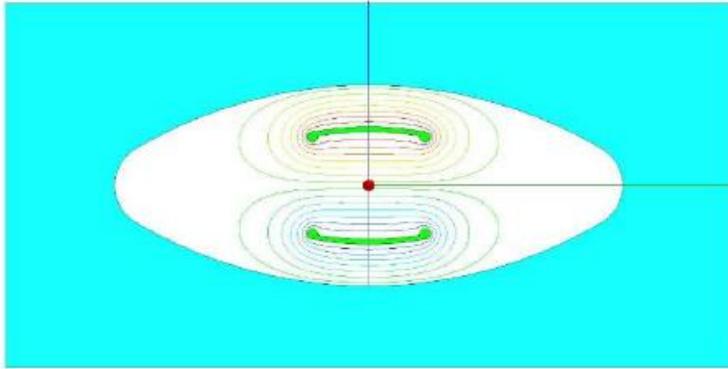


Figure 2. Cross section of ALS prototype magnet.

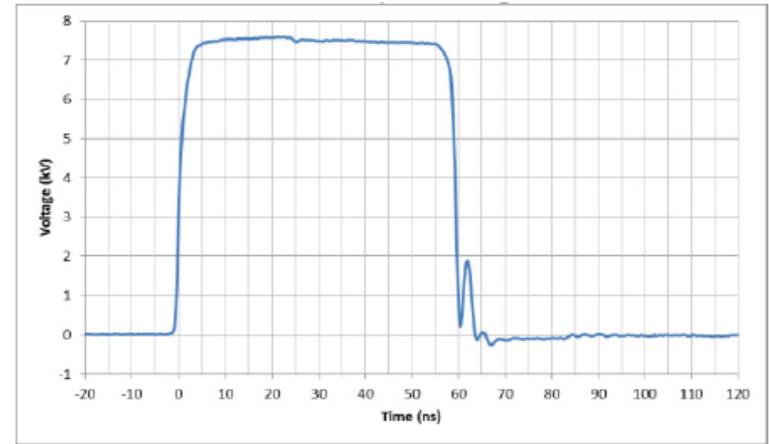
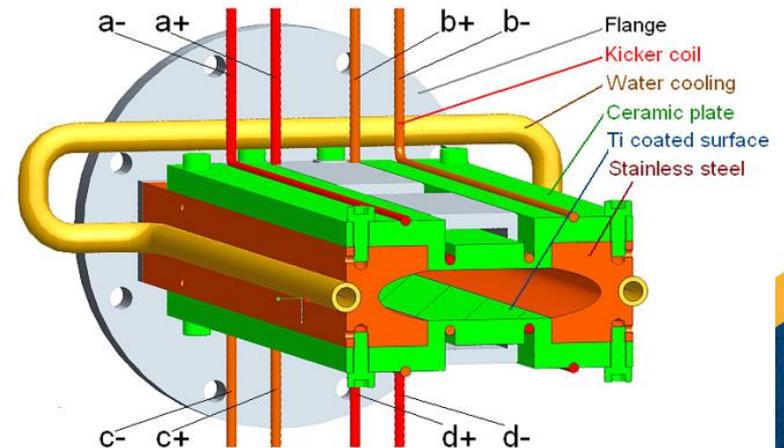
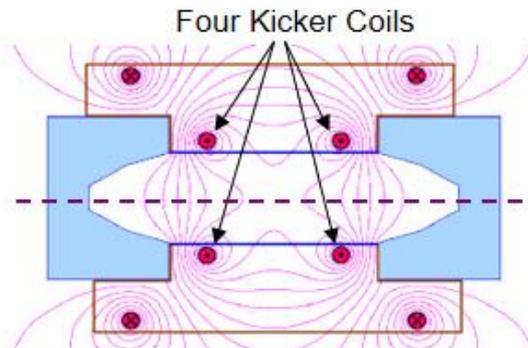


Figure 8. Output pulse from a FID pulser.

NLK for transparent injection in small DA

2D Magnet Model

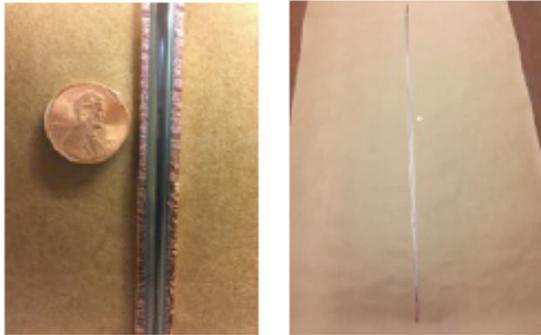


WP7 Task 3

- Task 7.3. Beam dynamics and technology for ultra-low emittance rings
 - Co-lead: CERN (Y. Papaphilippou), INFN (M. Biagini), SOLEIL (R. Nagaoka)
- Promote scientific interaction involving the technology and design of **innovative magnets** and the impact to beam dynamics and the machine model
- Exchange ideas on the impact of two-stream instabilities on beam dynamics and the **design of vacuum systems including mitigation techniques**
- Coordinate design efforts and experimental tests of main and harmonic **RF systems** for various bunch structures, with high currents

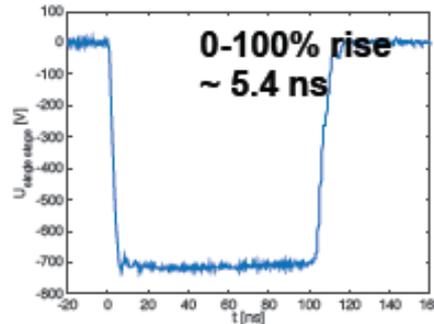
Summary (e.g. ALS-U R&D programme)

Very small NEG coated vacuum chambers



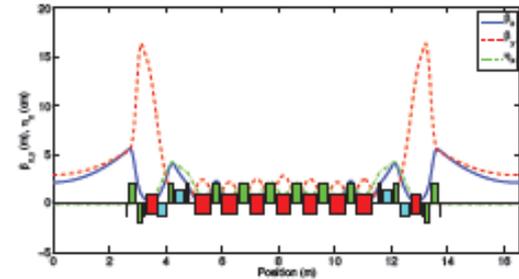
Coated 6 mm chamber (world record)

On-axis Injection – Fast pulsed magnets



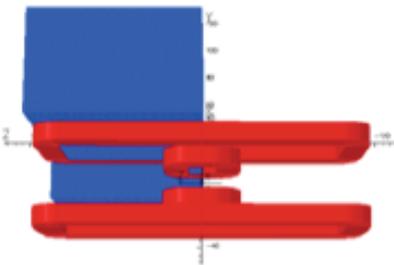
Adder achieves 5 ns rise (7 ns needed)

Optimization of Physics Design



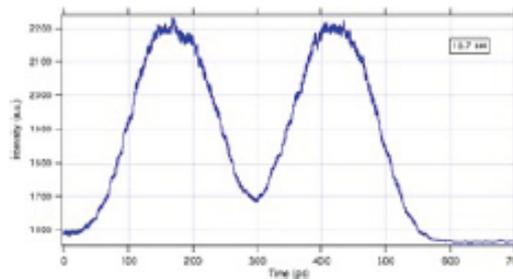
Released Baseline Lattice

Magnets – SR Production



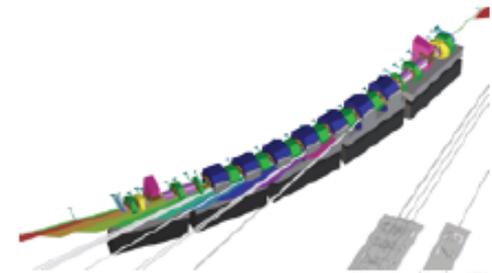
Evaluated Superbend options

Harmonic Cavities - Transients



Achieved needed bunch lengthening with ALS-U bunch trains in ALS (3HC)

Engineering



Automated iteration between physics and CAD model

WP7 Task 4

- Task 7.4. Beam tests and commissioning of ultra-low emittance rings
 - Lead KIT (A.S. Mueller)
- Support exchange and collaboration between low emittance rings for beam tests covering beam dynamics and technology issues, including **measurements and diagnostic techniques**
- Support efforts in the **new rings commissioning** but also new operating modes of existing rings

Support for ESRF-EBS Commissioning

Continue the activity developed in Eucard2

- Low Emittance Tuning (beam based) tests at Diamond + PSI + ESRF
- Collective effects studies Diamond, ALBA, PSI, SOLEIL, MAX IV
- Hardware test

Examples: beam tests of hardware in EuCARD2

- High-field ($\sim 3\text{T}$), low period ($\sim 5\text{cm}$) **superconducting 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 **pulsar**
 - Stripline produced by Spanish industry, under laboratory tests at CERN, to be measured with beam at ALBA SR
 - Inductive adder achieving pulse jitter tolerances $\sim 10^{-4}$ 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 $\sim 1\mu\text{m}$)
 - Novel measurement methods using vertical undulator at the Australian Light Source (reaching the **quantum limit** of vertical emittance $\sim 0.4\text{pm}\cdot\text{rad}$)

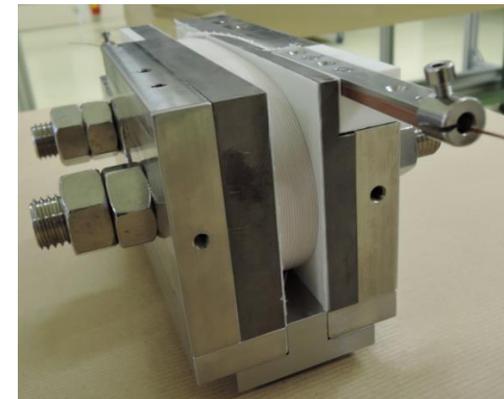
Prototype
inductive adder



NbTi wiggler lowered in the ANKA SR



Nb₃Sn short
model winding



Milestone and deliverables

Task	Description	Year 1				Year 2				Year 3				Year 4				
		Q1	Q2	Q3	Q4													
1	Coordination and Communication			M				M					M				M	D
2	Injection systems for ultra-low emittance ring			M				M		D								
3	Beam dynamics and technology for low-emittance rings			M						M				D				
4	Beam tests and commissioning of low emittance rings								M					M				D

Deliverables are the final reports on the task activity
 Milestones are workshops or mini-workshop

Upcoming activities

First topical workshop on Injection and Injection Systems
(Bessy II Berlin, 28-30 August 2017)

Topical Workshop on Injection and Injection Systems

28-30 August 2017
Bessy II Berlin
Europe/Zurich timezone

Overview
Timetable
Participant List

We are pleased to announce that the first Topical Workshop on Injection and Injection systems will be organized by BESSY II on the 28th-30th August 2017 as a sub-series of **Ring for Low Emittance (RULE)** workshops within the newly EU funded **ARIES** programme (Accelerator Research and Innovation for European Science and Society).

The aim of the workshop is to bring together experts from the scientific community working on Injection and Injections Systems for ultra-low emittance machines, including light source storage rings, damping rings, and future e+/e- circular colliders.

A strong R&D effort has been ongoing in the optimisation of the beam dynamics of such accelerators and devising novel injection scheme to refine and improve the injection process. New schemes for off axis injection and on axis injection with and without

50 participants

~20 labs (D, US, France, China, UK, Japan, Italy, Spain)

1 from industry



Upcoming activities

Networking: support visits/exchange of staff (WP1)
and experiments at facilities (WP4)

examples (personal view)

NLK

Call a meeting with interested parties to discuss progress and further routes to improve NLK (ALBA, Diamond, ILSF, ...)

Compensation kicker

Contact with Diamond and Spring-8

Next workshop on injection to be held at PSI

7th Low emittance ring workshop (CERN, January 2018 TBC)

Next topical workshop to be decided

Thanks to Bessy

