Ultra-low emittance rings: report for WP7

R. Bartolini (DESY), M. Biagini (INFN), M. Böge (PSI),
R. Nagaoka (SOLEIL), A-S Müller (KIT), Y. Papahilippou (CERN)

- ARIES WP7 mission and activities
- ultra low emittance rings - examples
- (some) technological challenges and contributions of ARIES WP7
- Conclusions and future work with I-FAST

WP7: Rings with Ultra-Low Emittance (RULε)

Mission of the network

Fostering networking activities, **exchange of ideas and staff** in the accelerator community involved in design, construction and operation of ultra-low emittance rings
(**light sources, HEP: damping rings and colliders**)

via

General Workshops
Topical workshops
Student support (and student prizes)
Supporting staff for joint experiments
engagement with industrial partners

WP7: Tasks description

WP7 addressed key design and technology challenges in the development of ultra-low emittance rings and tests of key aspects of the beam dynamics

- Task 7.1. Coordination and Communication (R. Bartolini, UOXF)
- Task 7.2. Injection Systems for U-LER (M. Boege, PSI)
- Task 7.3. Technology for ultra low emittance rings
  (Y. Papaphilippou, CERN, M. Biagini, INFN, R. Nagaoka, SOLEIL)
- Task 7.4. Beam tests and commissioning of U-LER (A.S. Mueller, KIT-ANKA)

WP7: milestones and deliverables

Milestones: General and Topical workshops

MS33	First general workshop of the RULE network (Task 7.1)	WP7	41 - UOXF	9	Agendas, attendance lists on Indico
MS34	First topical meeting of the RULE network: injector (Task 7.2)	WP7	41 - UOXF	12	Agenda, attendance lists on Indico
MS35	First topical meeting of the RULE network: technology (Task 7.3)	WP7	1 - CERN	15	Agenda, attendance lists on Indico
MS36	Second topical meeting of the RULE network: injector (Task 7.2)	WP7	41 - UOXF	24	Agenda, attendance lists on Indico
MS37	Second topical meeting of the RULE network: technology (Task 7.3)	WP7	1 - CERN	27	Agenda, attendance lists on Indico
MS38	Second general workshop of the RULE network (Task 7.1)	WP7	41 - UOXF	33	Agenda, attendance lists on Indico

Deliverables: summary report on workshops and beam tests

D7.1	First beam tests for low emittance rings	WP7	41 - UOXF	Report	Public	18
D7.2	Final report on injection schemes and injector studies	WP7	41 - UOXF	Report	Public	27
D7.3	Final report on technology for low emittance rings	WP7	1 - CERN	Report	Public	36
D7.4	Final report on the Rings with Ultra-Low Emittance network	WP7	17 - KIT	Report	Public	46

ARIES WP7 RULε: milestones and deliverables

		Year 1				Year 2				Year 3				Year 4			
Task	Description	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Coordination and Communication			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			M		D				
4	Beam tests and commissioning of low emittance rings							D									

1st General WS

2nd General WS

1st Injection WS

2nd Injection WS

Diagnostics WS

Technology WS

Beam test WS

commissioning WS

All milestones and deliverable reached in year 4

General and Topical workshops

General workshop (continuing the tradition of the LER workshops)

7th LER Workshop, 15-17 January 2018 CERN
https://indico.cern.ch/event/671745/

8th LER Workshop 26-30 October 2020 INFN-LNF Frascati (**held remotely)**
https://agenda.infn.it/event/20813/overview – ***participants 160***

Low emittance ring technology
- ALERT 19 Ioannina

Diagnostics
- DULER Diamond 2018

Injection
- TWIIS-1 BESSY 2017
- TWIIS-2 PSI 2019

Commissioning
- KIT 2019

High Energy Physics to Photon Science

In the last 10 years EUCARD2 and ARIES have seen a shift from a community driven in majority by HEP projects, network and R&D to a community based in majority on light sources

Evolution of the field (personal, i.e. limited view)

Hot topics in 2011:

- Fast HV Kickers (ILC)
- Low emittance operation in the V plane (Quantum LOVE prize)

Light source were used as “examples” by damping rings for low emittance tuning

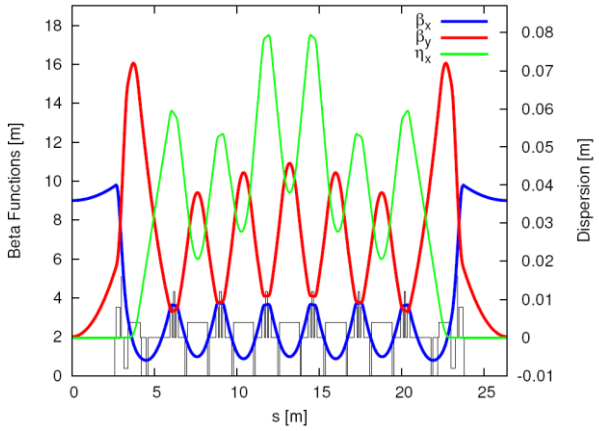
Upgrade projects based on MBA (2012 - today)

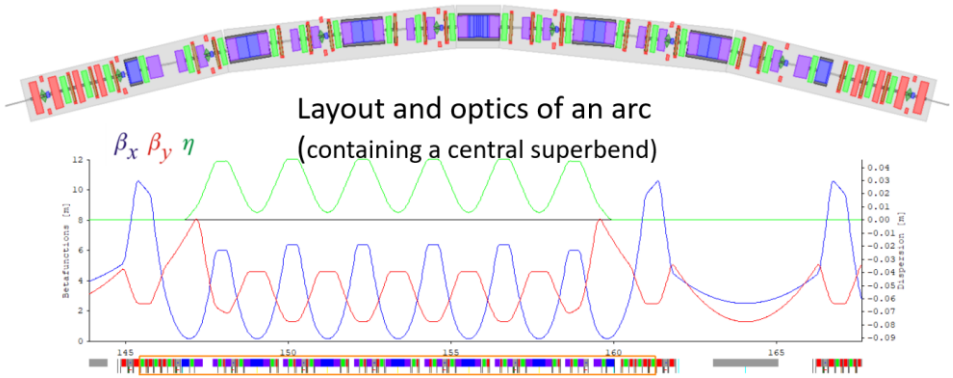
- Design concepts: MBA, HMBA (merging design concepts of HEP and light sources), novel injection schemes, magnet and vacuum technology, optimisation tools (DA/MA and commissioning)

Low emittance lattice types

The classical **Multibend Achromat:** the MAX IV-type cell is implemented in SIRIUS, SLS-II, SKIF, ELETTRA2.0

MAX IV – **7BA**
330 pm at 3 GeV

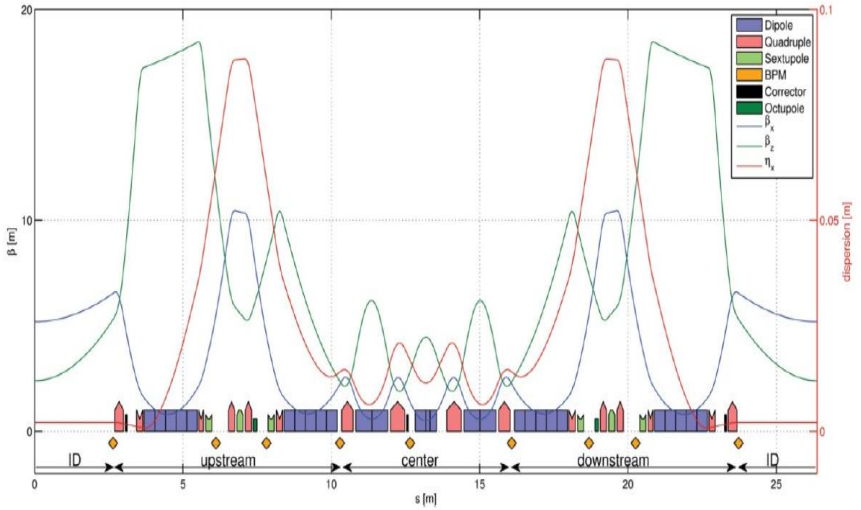




SLS-II (PSI) – **7BA** with superbend
157 pm at 2.7 GeV

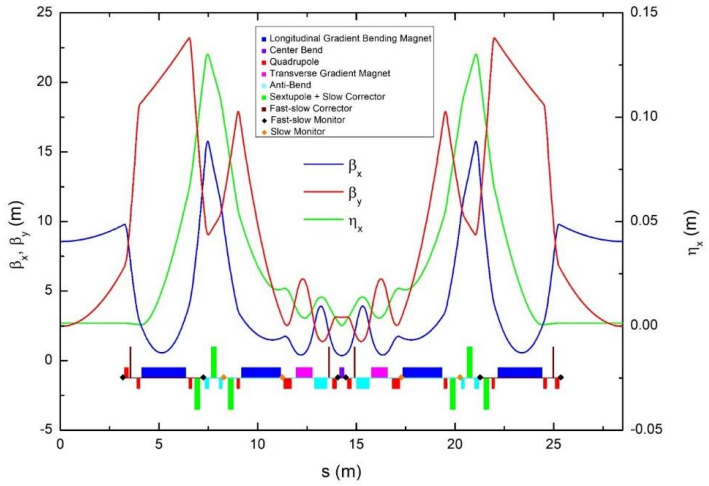
Hybrid Multibend Achromat (Raimondi) based on longitudinal gradient dipoles and cancellation of nonlinear aberration by sextupole pairing

ESRF-EBS Hybrid 7BA cell:
135 pm 6 GeV



… and more new projects

4GSR
Pohang Accelerator Laboratory, Korea



General Parameter	
Energy / GeV	4.0
Symmetry / Sub-Symmetry	28
Straight Sections: No & Length / m	28 / 6.5
Ring Circumference / m	798.8
# Dipole Magnets	28 * 7 = 196
Nat. Emittance / prad m	58
regular hor/ver @ coupling	55 / 6 @ 10 %
Diffraction limited source for	λ > 1.7 / 0.365 nm
Energy spread	1.20E-3
Bunch Length σ_t / ps	10.68 (without HC) / 53.40 (with HC)

BESSYIII – Helmholtz Zentrum Berlin

- Energy = 2.5 GeV
- Emittance ~ 100 pm rad
- I ~ 300 mA
- 16 straights
- 5.6 m straight length (max. 5 m useable length)
- Circumference max. 320 m

- **MBA with**
  High coherence fraction from 100 eV to 2.5 keV
  Flexible repetition rates: TRIBs

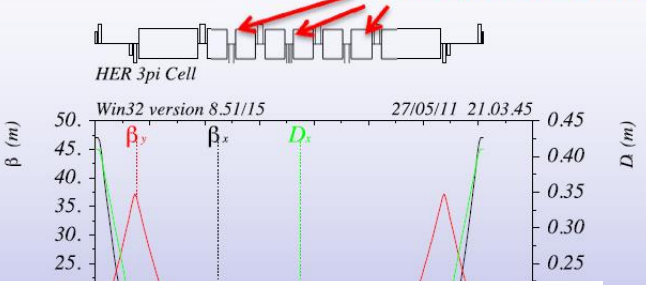
- TopUp full-energy injection
  (low emittance combined function booster, 1 Hz, in the same tunnel with 100 – 150 MeV linac injector)

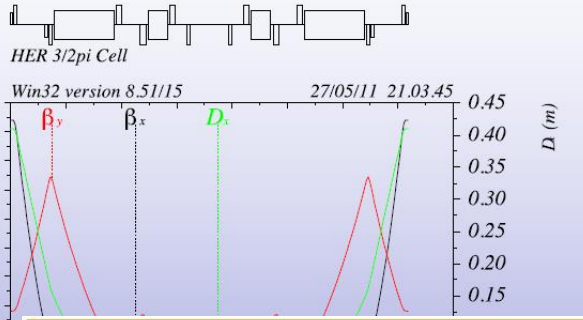
Cross-fertilisation SR-HEP

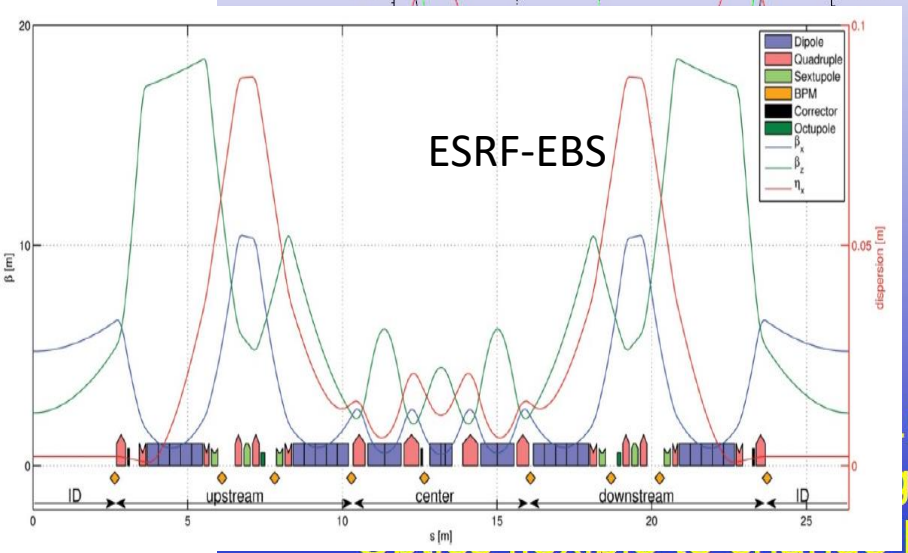
SuperB lattice after 1° Low emittance workshop (2011, CERN)

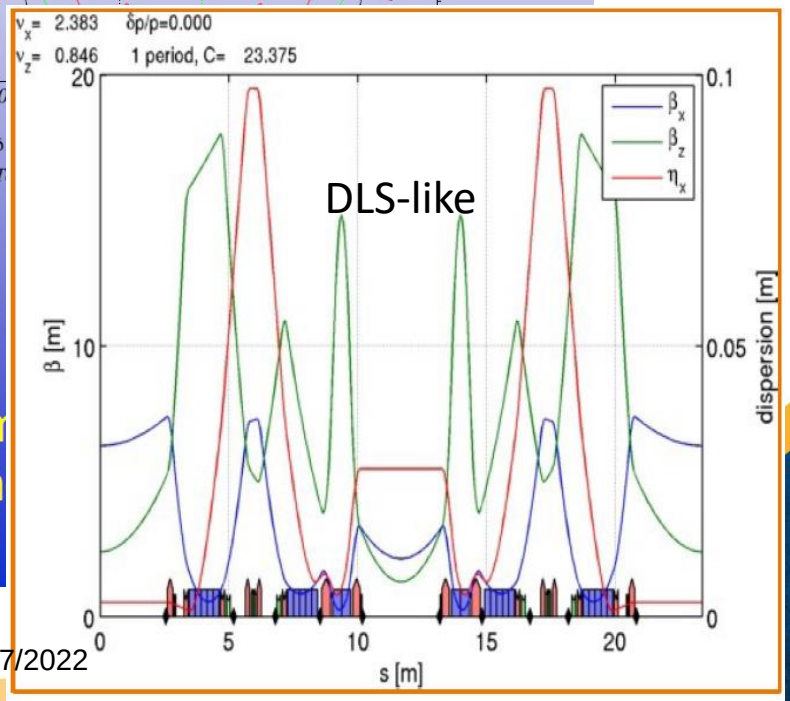
Two dipoles broken in 6 (a la MAXIV)

Raimondi IPAC17









688

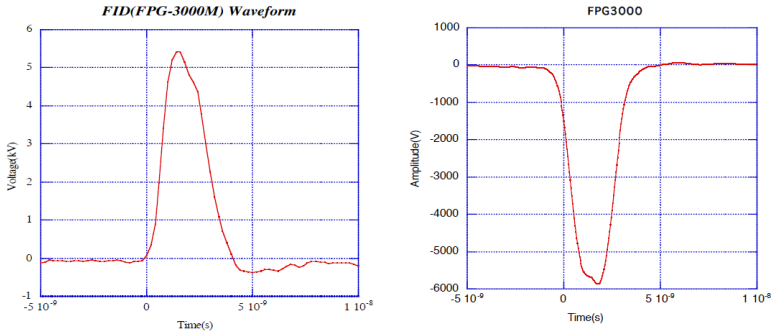
th = 3.5m

beta's an

Cross-fertilisation SR-HEP

The technology of fast (~ns) high voltage (tens of kV) kickers originally devised for HEP damping rings has found crucial applications in novel injection schemes for ultralow emittance light sources

Pulse power supply (FID FPG5-3000M)



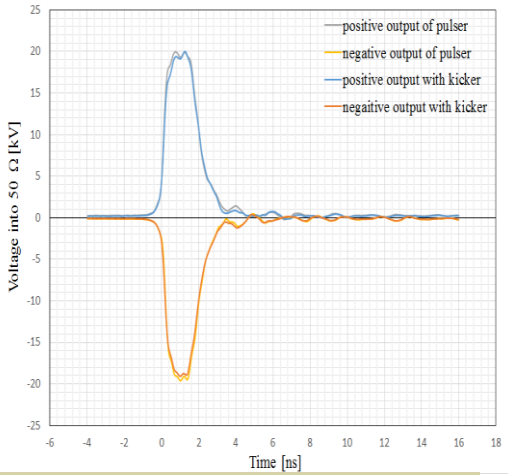
Pulse width(FWHM) = 2ns
Pulse height = 5.8kV
Rise time = ~1.5ns(5%~95%)
Time jitter = ~29ps
Amplitude Jitter = 0.72%
(limited by the scope resolution)

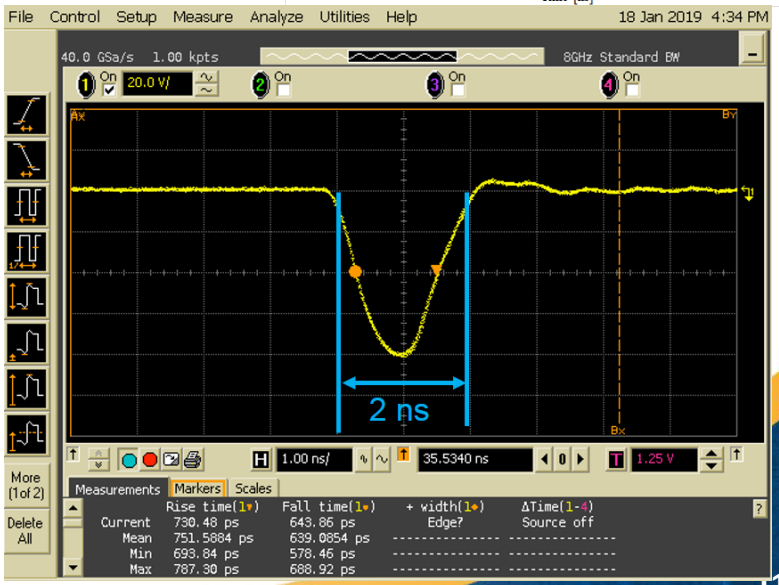
10.1.14 7

Naito KEK @ LER 2010

HEPS - 2018

300mm long kicker:
Pulse voltage: ±20kV into 50Ω
Tr(10%-90%)=670.7ps
Tf(90%-10%)=1.4ns
FWHM=1.9ns





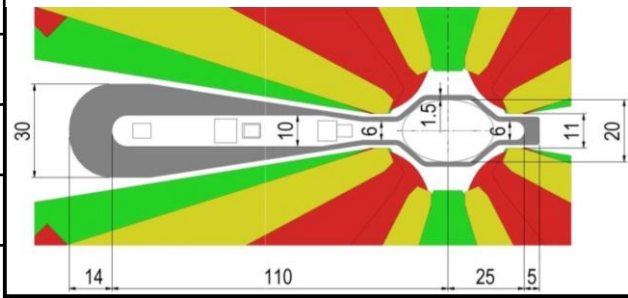
Kentech/Sydor
2ns – 3 kV

WP7.3: High gradient magnets and small chambers issues

	energy (Gev)	MAX b' T/m	MAX b'' T/m^2	MAX b''' T/m^3	min. bore radius (mm)
ALS-U	2.0	105	10500	n/a	12.0
ELETTRA 2	2.4	50	4000	45000	13.0
SLS-II	2.7	97	8000	270000	10.5
SOLEIL-U	2.75	<110	16000	1500000	8.0
Diamond II	3.5	85	7700	660000	12.0
SIRIUS	3	45	2400	n/a	14.0
APS-U	6	86	6300	n/a	13.0
ESRF-EBS	6	90	3200	37000	12.8
HEPS	6	80	7500	670000	12.5
PETRA IV	6	115	4000	150000	11.0

High gradients require

- small bore radius
- difficult vacuum system design (e.g. NEG, extraction of photons)

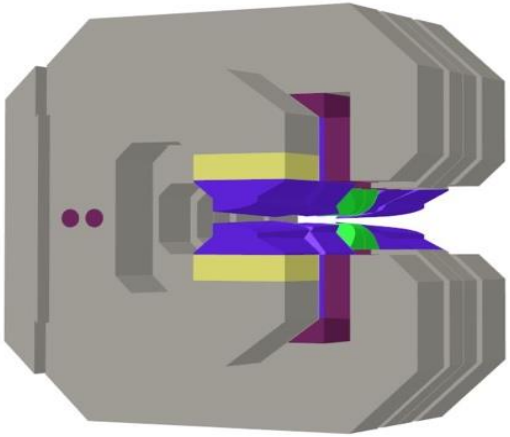


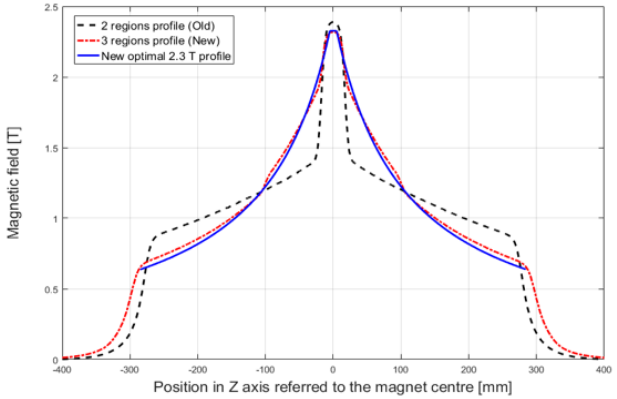
Vanadium Permendur (e.g. Vacoflux) poles increasingly used

Design optimised for efficiency (e.g. including PM and minimisation of power consumption in cables)

WP7.3: Novel magnet designs were extensively discussed

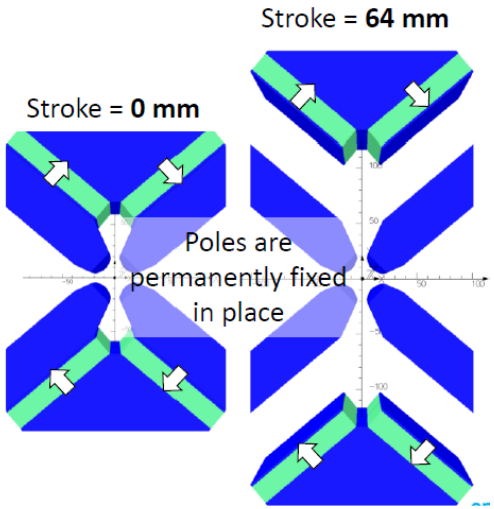
Longitudinally variable dipole are used in many light sources (ESRF-EBS, PETRA IV, SLS-II) Example with transverse gradient developed for the CLIC damping ring

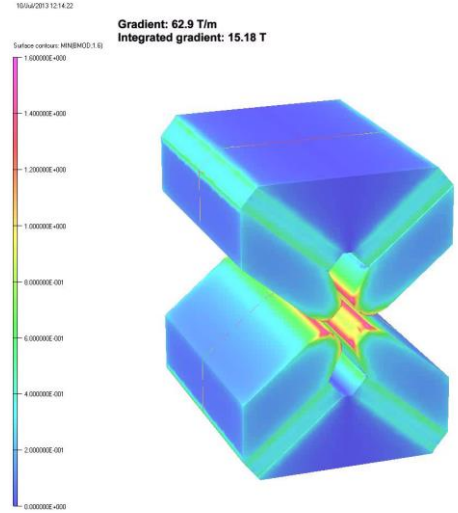




Courtesy
Y. Papaphilippou
(CERN)

Permanent magnet based quadrupoles: tuneable ZEPTO for the CLIC damping rings

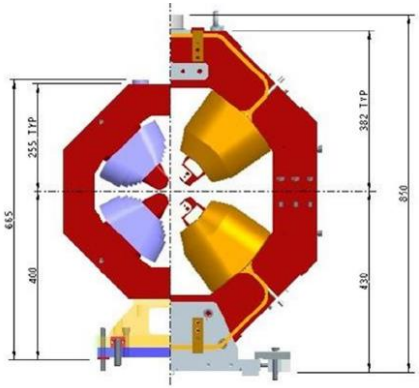


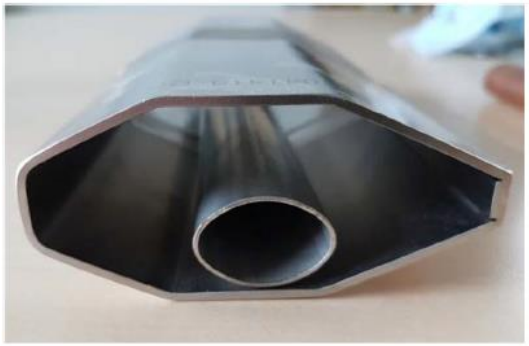


Courtesy
B. Shepherd
(STFC)

WP7.3: NEG coating in small size vacuum chamber

Small bore radius magnet imply the use f small aperture vacuum chamber. Effective vacuum can be achieve with extensive use of NEG coating

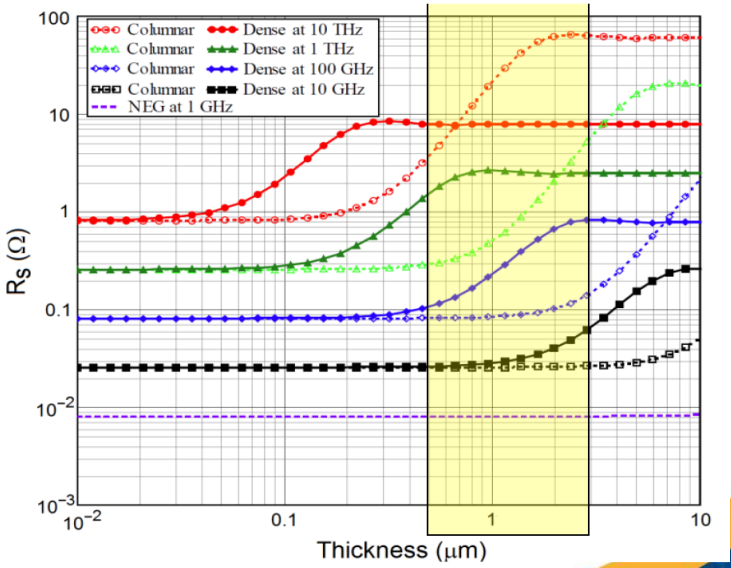




- Thickness and uniformity requirements on the coating to achieve pumping
- impedance effect of the coating
- logistic in the activation procedure (e.g. in-situ vs ex-situ activation, # cycles)

Resistivity as a function of the NEG thickness for different frequencies and different morphology.

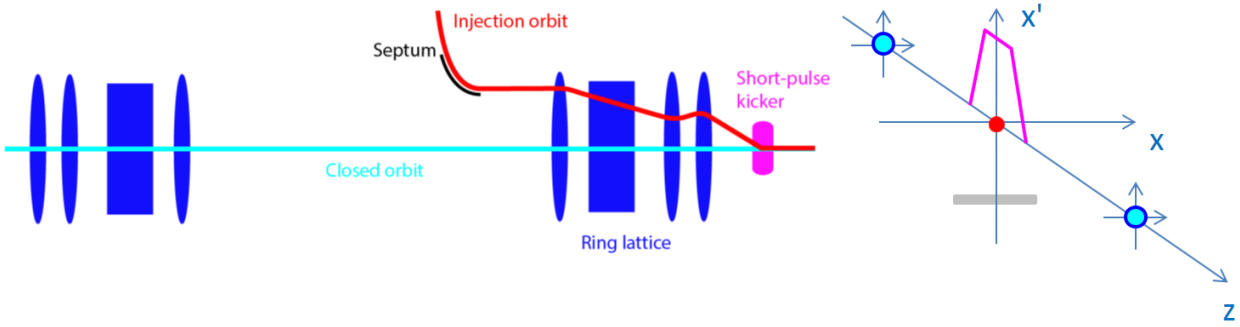
The yellow band indicates the typical values chosen in accelerators.



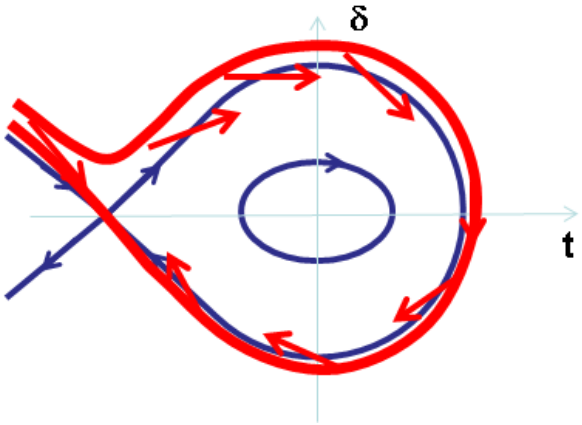
Courtesy O. Malyshev (STFC)

WP7.4: Novel injection scheme were tested

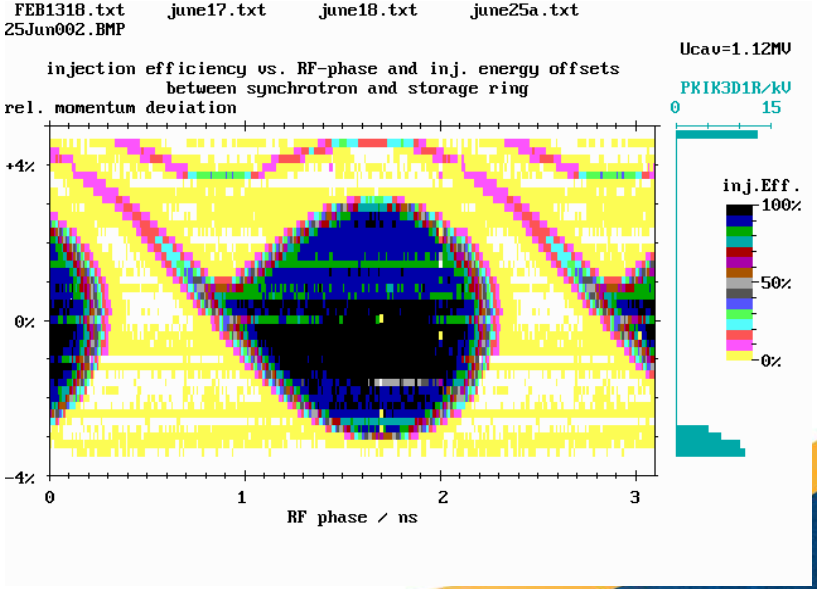
Longitudinally off-energy injection concepts were tested at BESSY-II



Injection efficiency for off-phase off-energy injected beam were measured at BESSY
Showing the feasibility of capture and possibly accumulation



Courtesy M. Aiba (PSI) P. Kuske (BESSY)



Extremely quick commissioning of ESRF-EBS

ESRF-EBS (140 pm – 6 GeV) has achieved the nominal operational parameters ahead of schedule

28/11/2019: start of commissioning (3 turns)

06/12/2019: first stored beam

15/12/2019: first accumulation

14/3/2020: 200 mA

P. Raimondi in http://agenda.infn.it/event/20813

The networking activities will continue in IFAST WP7 task 7.2

Networking activities on low emittance ring will continue in I-FAST in **WP7: High brightness accelerator for light sources**

Task 7.2: Led by KIT

Continuation of the network activity on the themes of

Machine design
Low emittance ring technology
Collective effects
Injection systems
Commissioning strategies

Acknowledgments

Thanks the ARIES project and the EU for supporting the RULε network