Ultra-low emittance rings: report for WP7

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

WP7: Ultra-low Emittance Rings

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

Actually 10 years of LER workshops

1th Low Emittance Rings Workshop, 12-15 January 2010 CERN – participants 70
https://ler2010.web.cern.ch/
2th Low Emittance Rings Workshop, 3-5 October 2011 Heraklion, Crete
https://lowering2011.web.cern.ch/
3th Low Emittance Rings Workshop 8-10 July 2013 Oxford University
https://indico.cern.ch/event/247069/overview (EuCARD-2) – participants 80
4th Low Emittance Rings Workshop, 17-19 September 2014, INFN-LNF Frascati
https://agenda.infn.it/event/7766/ (EuCARD-2) – participants 67
5th Low Emittance Rings Workshop, 15-17 September 2015 ESRF, Grenoble
https://indico.cern.ch/event/395487/overview (EuCARD-2)
6th Low Emittance Rings Workshop, 26-28 October 2016 • Synchrotron SOLEIL
https://www.synchrotron-soleil.fr/en/events/low-emittance-rings-workshop-2016 (EuCARD-2)
7th LER Workshop, 15-17 January 2018 CERN (ARIES)
https://indico.cern.ch/event/671745/
8th LER Workshop 26-30 October 2020 INFN-LNF Frascati (**held remotely**) (ARIES)
https://agenda.infn.it/event/20813/overview – participants 160

Courtesy S. Guiducci

Topical workshop

Many topical workshops:

Low emittance ring technology

- ALERT 14 Valencia
- ALERT 16 Trieste
- ALERT 19 Ioannina (ARIES)

Collective effects

- TWIICE 2014 Soleil
- TWIICE 2016 Diamond

Diagnostics

- DULER Diamond 2018 (ARIES)

Injection

- TWIIS-1 BESSY 2017 (ARIES)
- TWIIS-2 PSI 2019 (ARIES)

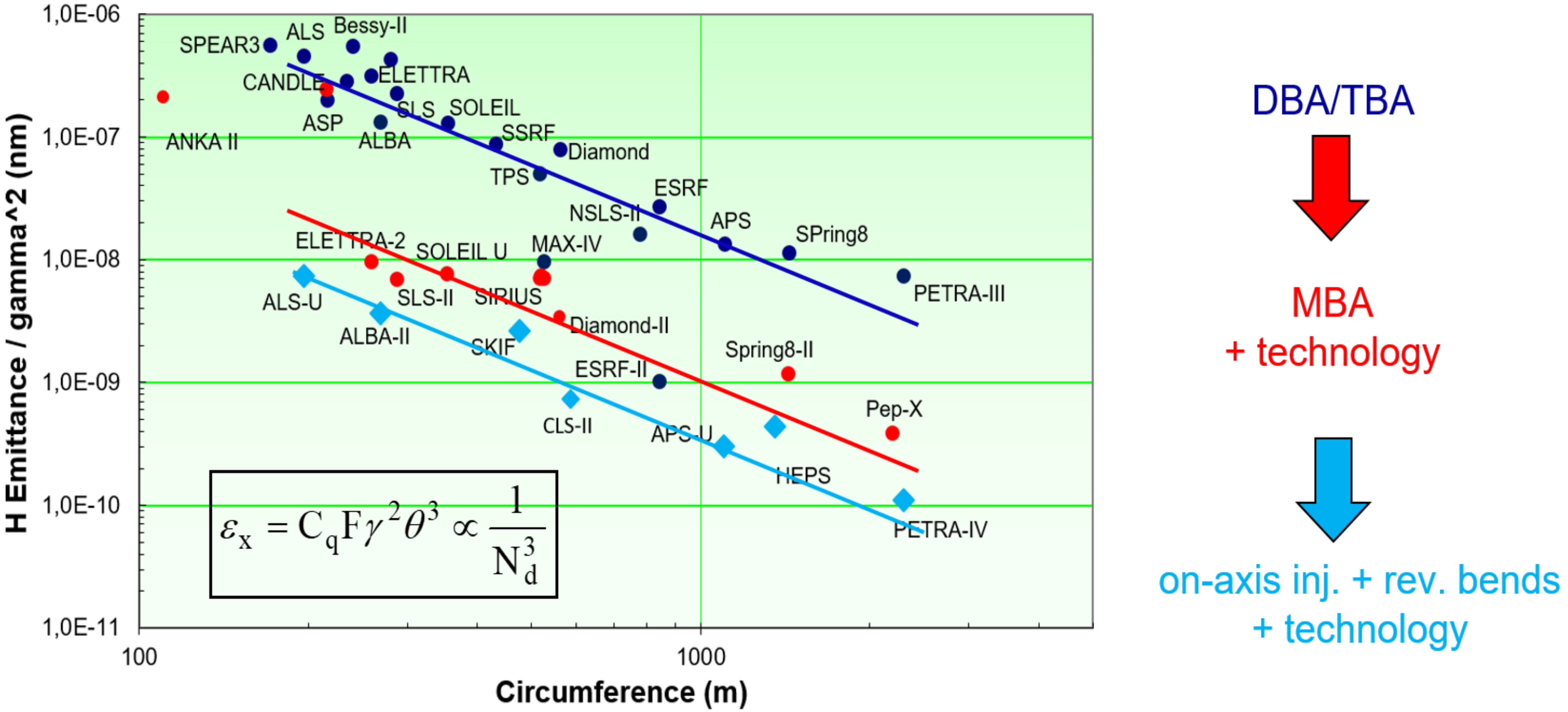
Commissioning

- KIT 2019 (ARIES)

2010-2020

Low emittance rings landscape

Community based in majority on light sources



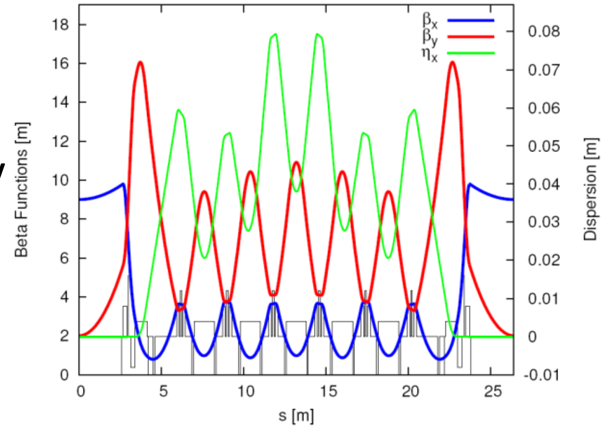
Multibend achromat (MBA) technology underpins the development of diffraction limited light sources

HEPS <60 nm; APS-U 42 nm; PETRA IV 20 pm;

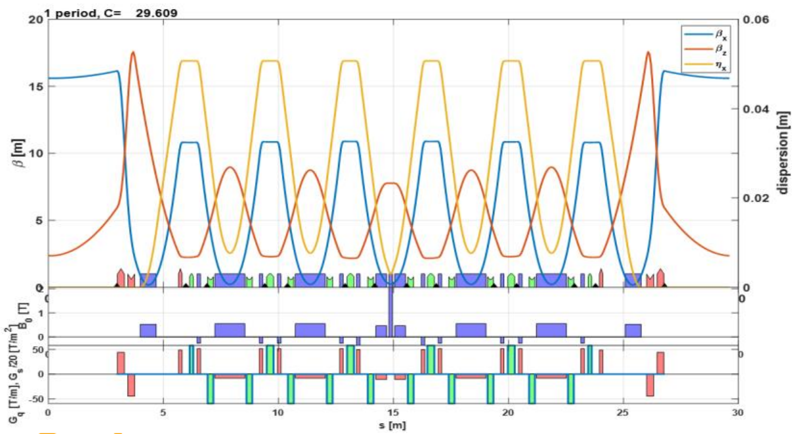
Examples of implementation

The classical **Multibend Achromat:** the MAX IV- type cell is implemented in different forms (sextupoles distribution) in SIRIUS, SLS-II, SKIF, ELETTRA2.0 (possibly with reverse bends)

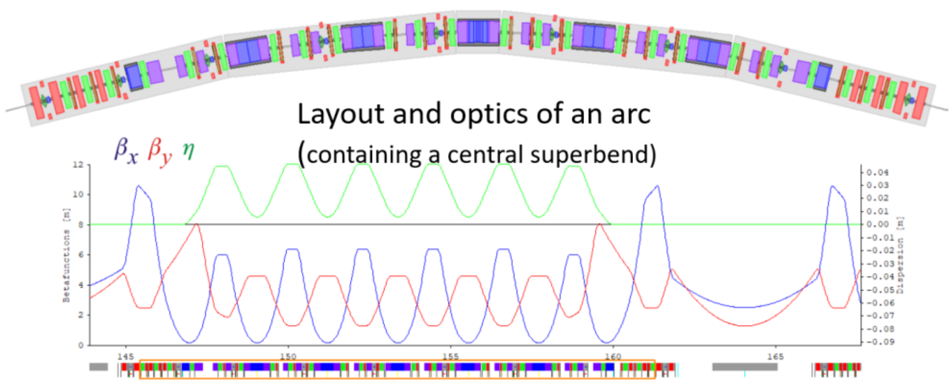
MAX IV – **7BA**
330 pm at 3 GeV



SKIF (Novosibirsk) - **7BA** 75 pm at 3 GeV



modified-TME cells flanked by matching cells

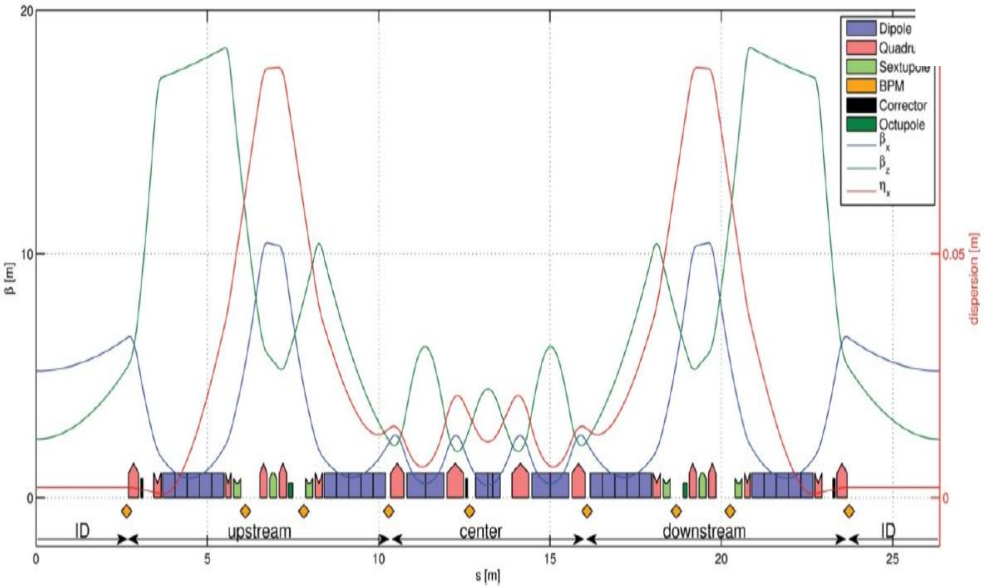


SLS-II (PSI) – **7BA** with superbend
157 pm at 2.7 GeV

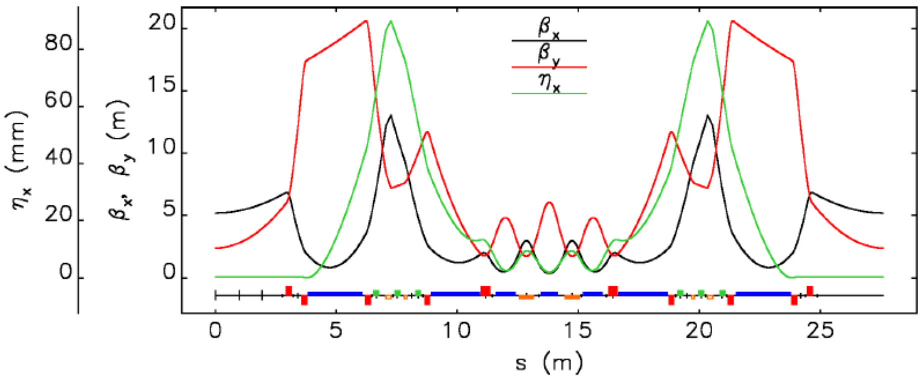
Examples of implementation

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

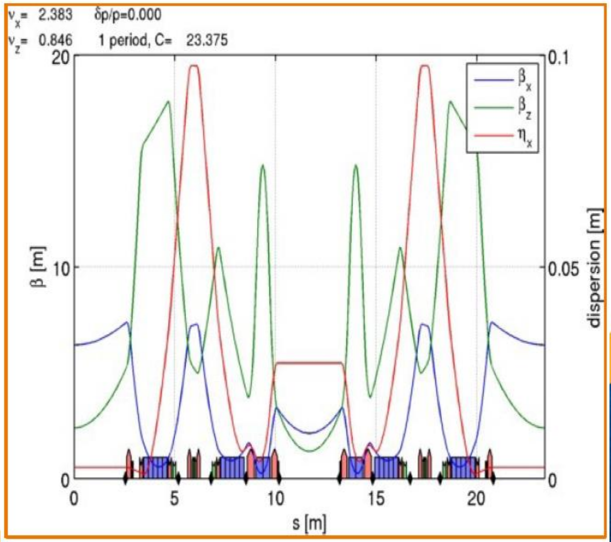
ESRF-EBS Hybrid 7BA cell:
135 pm 6 GeV



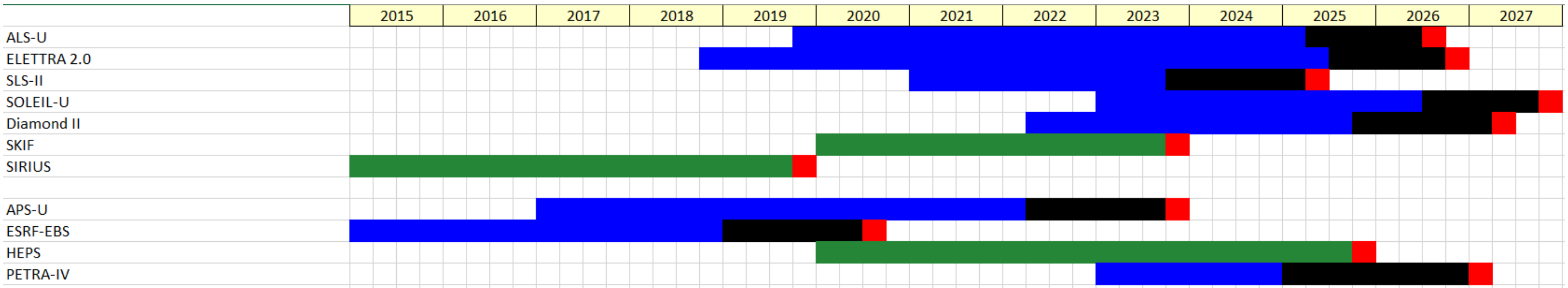
APS-U Hybrid 7BA cell: 42 pm 6 GeV
(HEPS 36 pm - PETRA IV 20 pm)



Diamond-II cell: 135 pm 3.5 GeV
modified ESRF-EBS cell



The field is thriving (and competition is high)



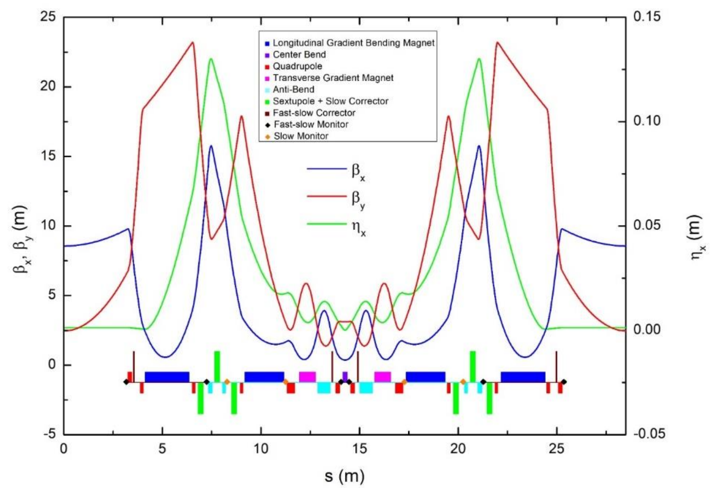
Green bars: green field projects
Black bars: dark period
Red bar: restart of user mode (friendly users in many cases)

Timeline since official project approval
In some cases (APS-U) procurement started before official approval

Congestion of programmes in 2024-2025 will potentially create procurement risks to all projects

… 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)

ARIES

Summary of ring parameters

	energy (Gev)	emittance (pm)	ener. spr. (1e-4)	β_x, β_y (m) @ source point	DA (mm), β (m) @ inj. point	LMA (%) TL (h)	reverse bends
ALS-U	2.0	108	9.8	2.0, 2.8	1.0 @ 2.0	2.5, (1.0)	yes
ELETTRA 2	2.4	212	9.3	5.7, 1.6	6.0 @ 5.7	4.0, (6.2)	yes
SLS-II	2.7	157	12.0	2.5,1.3	7.0 @ 22.0	4.0, (6.3)	yes
SOLEIL-U	2.75	81	9.0	1.3, 1.3	5.0 @ 11.0	3.5, (3.3)	yes
Diamond II	3.5	136	9.0	6.0, 2.5	5.0 @ 6.0	1.6, (4.0)	yes
SIRIUS	3	250	8.5	1.5, 1.5	10.0 @ 17.0	3.7, (3.9)	no
APS-U	6	42	13.5	4.9,1.9	2.2 @ 5.2	2.1, (4.0)	yes
ESRF-EBS	6	135	9.3	6.9, 2.6	8.0 @ 18.6	3.4, (20)	no
HEPS	6	<60 (35)	10	2.6, 2.3	1.0 @ 2.6	1.5, (1.0)	yes
PETRA IV	6	20	11.2	4.0, 2.0	3.6 @ 21.7	2.0, (1.2)	tbd

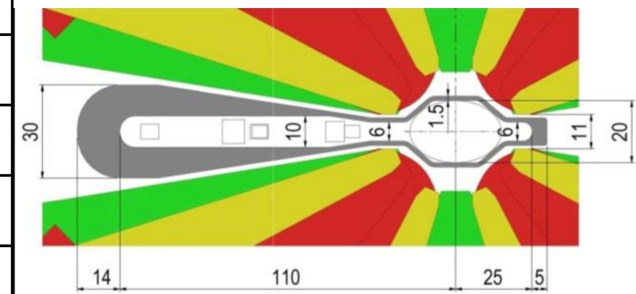
Black classical MBA - Blue HMBA or variations

High gradient magnets and small chambers are used

	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	92	6400	330000	12.5

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)

Alignment tolerances

Low emittance ring sensitiveness to alignment errors requires a careful study of the alignment tolerances. **Beam based methods** are commonly exploited and in the recent years the so-called **commissioning simulations** have been used in defining the acceptable limits for magnet and girder alignments

	emittance (pm)	magnet-to girder offset (μm)	girder-to-girder offset (μm)	girder-to-girder roll (μrad)
ALS-U	108	20	50	100
ELETTRA 2	212	20	50	100
SLS-II	157	30	60	100
Diamond II	136	30	100	200
SIRIUS	250	40	80	300
APS-U	42	30	100	400 (magnets)
ESRF-EBS	135	60	ESRF measured	200 (magnets)
PETRA IV	20	30	50-100	100
3GLS	**few*1000**	**30**	**100**	**200**

Such tolerances demand careful design of

Magnet supports: shimming or adjustable support or gluing

Girder and supports: manual or motorized movers (remotely controlled)

Commissioning simulations

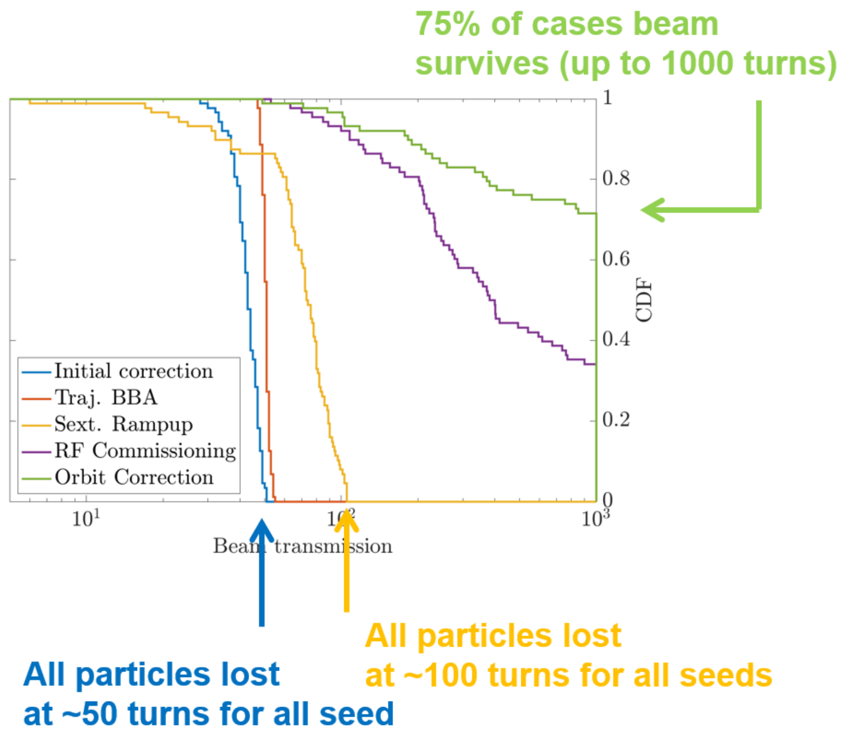
Detailed simulations of the commissioning process are carried out by all major projects see e.g. Sajaev PRAB, 2019
Liuzzo, Virtual commissioning | ESRF

- threading beam for first turn
- switching on sextupoles and RF
- achieving stored beam (many thousands turn tracking)
- orbit corrections
- beam based alignment
- optic corrections (LOCO)

Machine models include realistic errors from magnetic measurements and alignment

Possible real life scenarios are extensively simulated years before the start of he commissioning! (ESRF-EBS, APS-U, ALS-U,...)

Example of commissioning simulations developed for PIV



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

High Energy Physics to Photon Science

In the last 10 years we 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 2010:

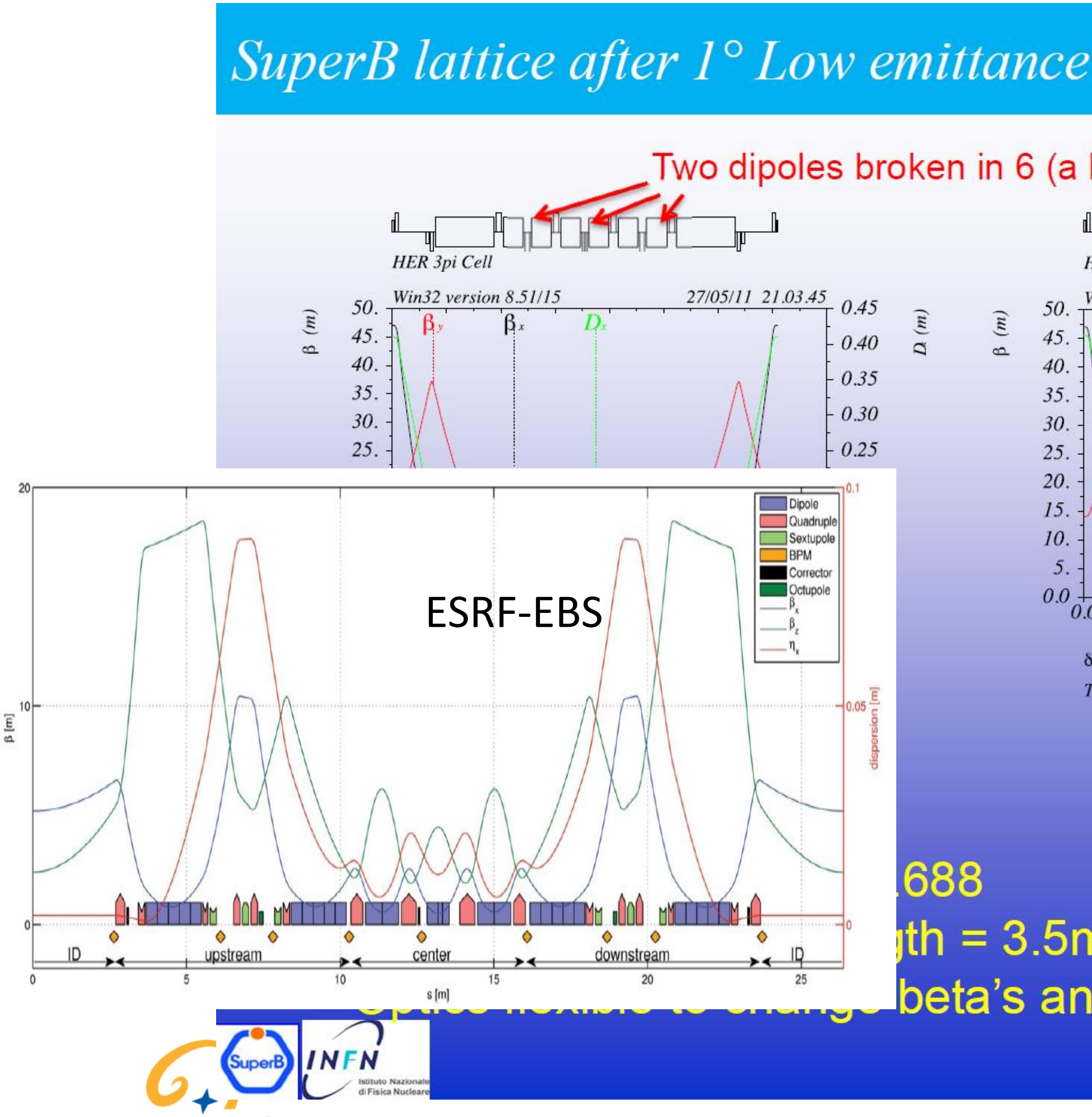
- Fast HV Kickers (ILC)
- Low emittance operation in the V plane (Quantum LOVE prize)

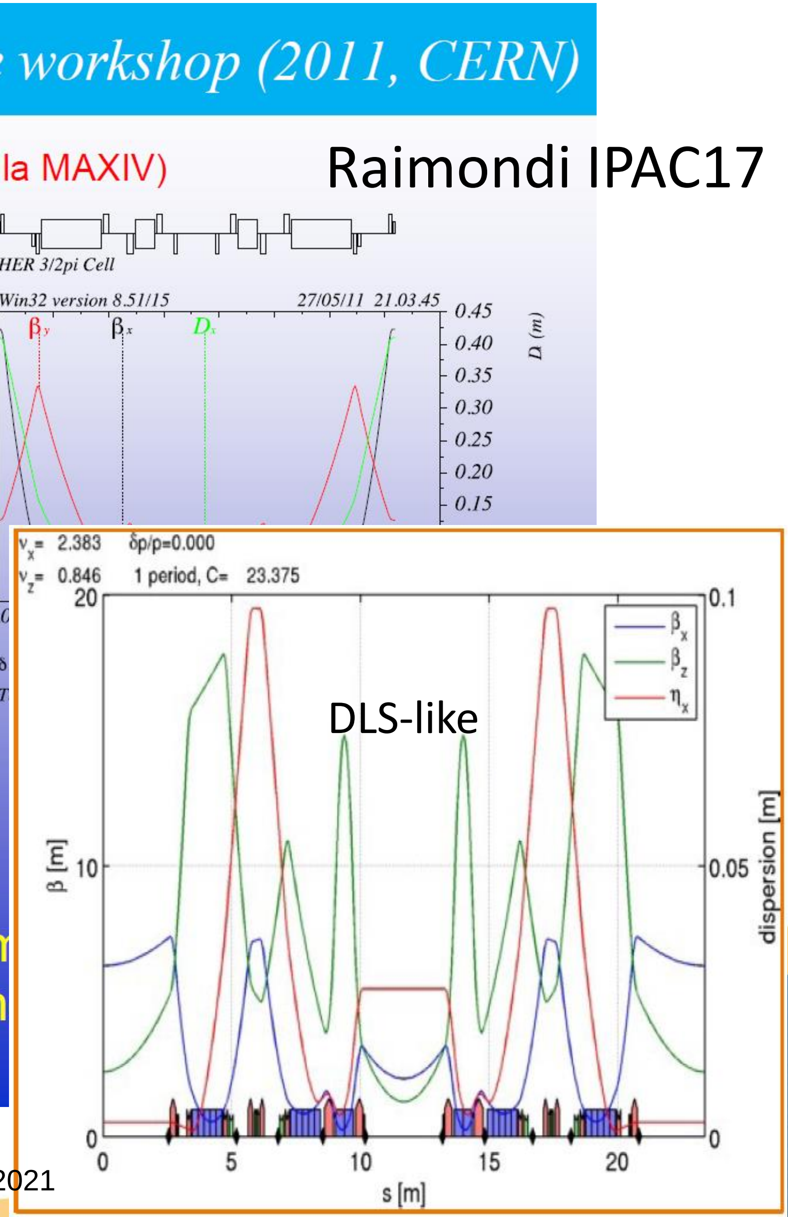
Light source were used as "examples" by damping rings for low emittance tuning

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)

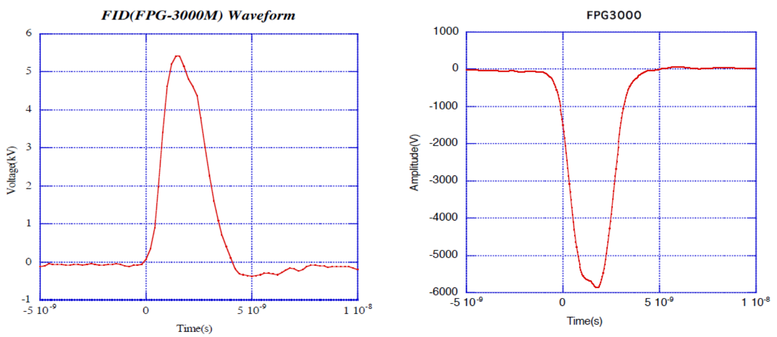
Cross-fertilisation





Cross-fertilisation

Pulse power supply (FID FPG5-3000M)



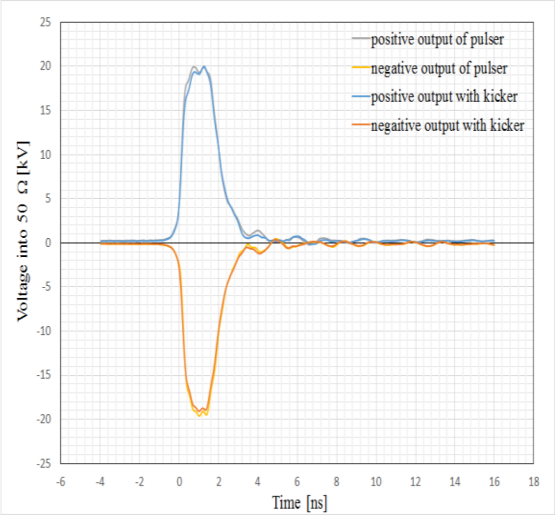
Pulse width(FWHM) = 2ns
Pulse height = 5.8kV
Rise time = ~1.5ns(5%~95%)
Time jitter = ~29ps
Amplitude Jitter = 0.72%
(limited by the scope resolution)

10.1.14 7

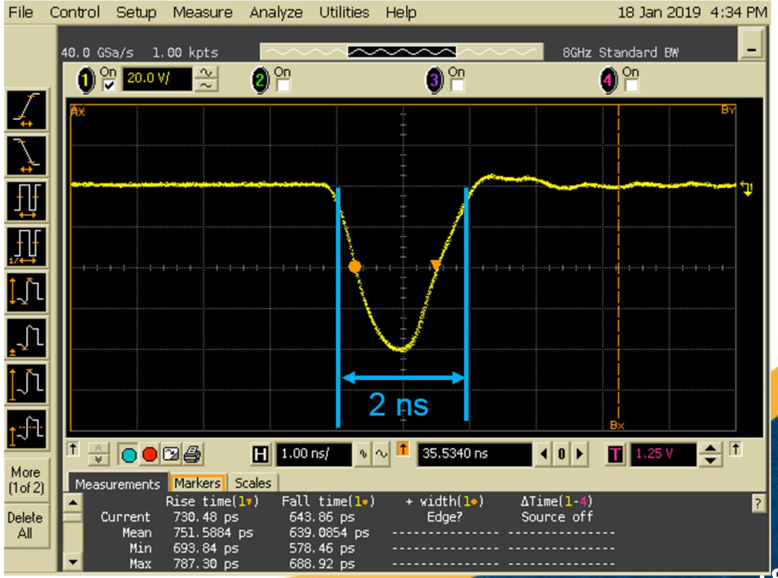
Naito KEK @ LER 2010

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



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	1st General WS						2nd General WS				M		D
2	Injection systems for ultra-low emittance ring	1st Injection WS			M	2nd Injection WS			M	D							
3	Beam dynamics and technology for low-emittance rings	Diagnostics WS				M			Technology WS	M			D				
4	Beam tests and commissioning of low emittance rings		Beam test WS					D commissioning WS									

The general workshop October 2020 was the last of this funding cycle with ARIES

The next project I-FAST (Innovation Fostering in Accelerators Science and Technology) has the kick-off meeting in May 2021

IFAST WP7 task 7.2: Networking

Networking on low emittance ring will continue in I-FAST
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

Conclusions

- Experience gathered show that ultra low emittance lattices based on MBA concept is feasible

- Confidence that design and technological challenges can be met

- Community is vast: while competition is fierce strong networks are in place
  I-FAST (ARIES, EuCARD2, …), LEAPS

- More R&D needed in improving
  sustainability (e.g. extensive use of permanent magnets to reduce power consumption)
  further lowering the emittance both in modest size machines ~300 m and large rings
  larger current operation – impedance IBS controls, bunch lengthening

- Many projects are receiving funds and will come on line by the end of the decade