Challenges of the beam diagnostic system for cSTART

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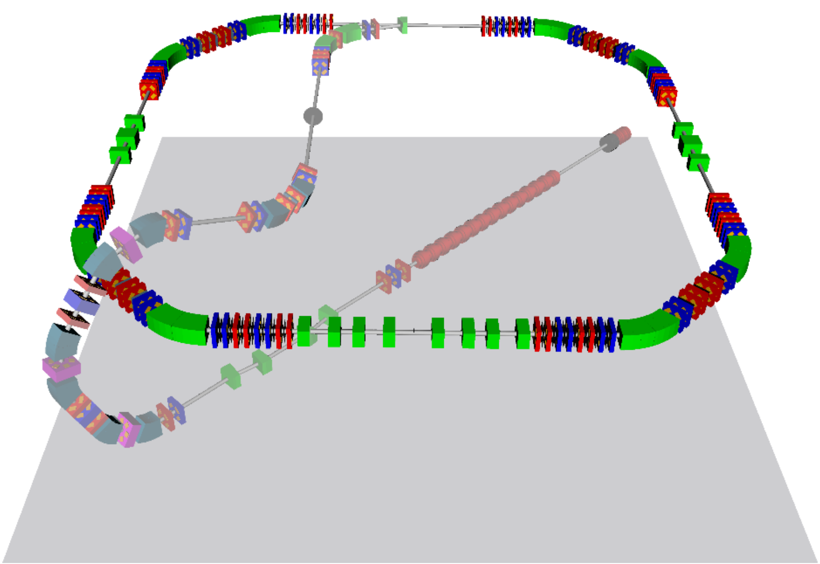
KIT, Laboratory for Applications of Synchrotron Radiation (LAS)



Outline

- Overview of the cSTART project
- Design and parameters of the electron storage ring
- Beam position monitors
- Longitudinal profile monitors
- Beam loss monitors
- Current monitor
- KARA booster as a model of cSTART
- Summary
- Comments or further suggestions ?

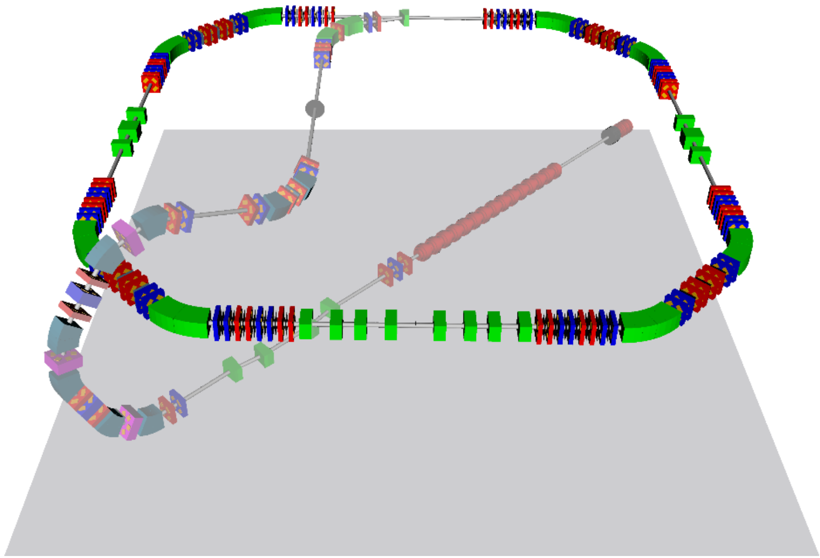
The cSTART project

- ✓ Goal: demonstration and examination of the injection and the storage of a laser wakefield accelerated (LWFA) electron beam

- ✓ The Very Large Acceptance compact Storage Ring (VLA-cSR) for accelerator research and technology will be built by KIT at campus north within the cSTART project [1-3]

- ✓ Injector for commissioning: FLUTE [4] (Ferninfrarot Linac- und Test-Experiment) photo-injector will deliver a LWFA-like electron beam at 50 MeV, 1 -10 Hz

- ✓ A transfer line [5] (arc and dogleg) will transport the electron beam from FLUTE to VLA-cSR ring at 3 m in the same hall

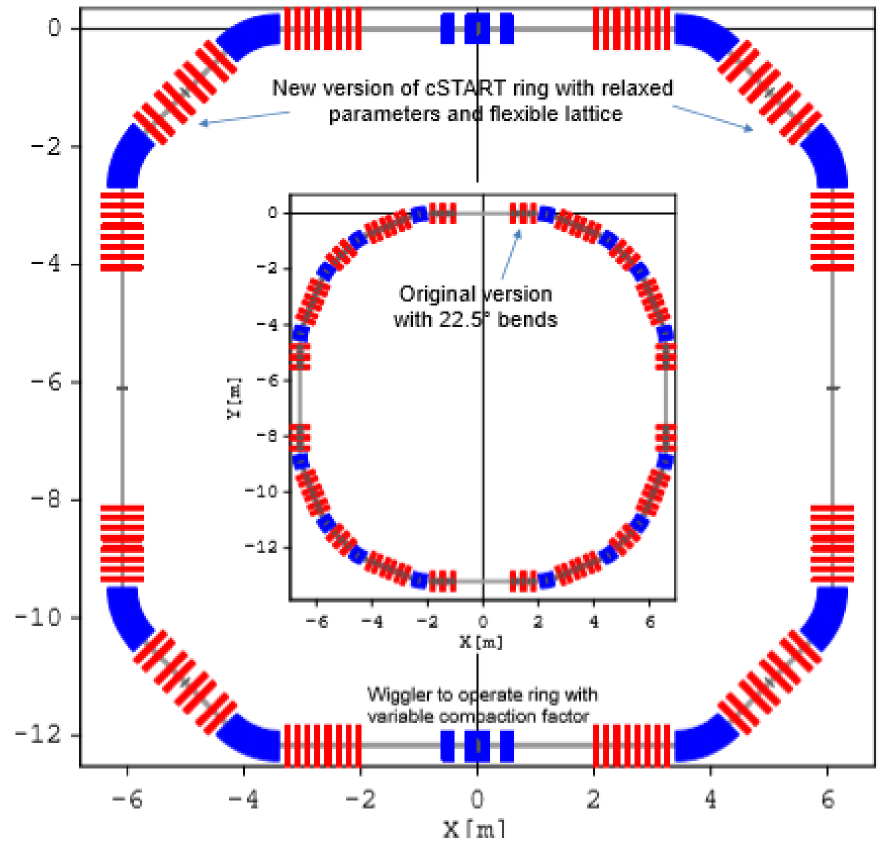


Courtesy: J. Schäfer

[1] B. Haerer et al., proceedings of IPAC2019, TUPGW020
[2] A. Papash et al., proceedings of IPAC2018, THPMF071
[3] A. Papash et al., proceedings of IPAC2017, TUPAB037
[4] https://www.ibpt.kit.edu/flute.php
[5] J. Schäfer, Master thesis, "Lattice design of a transfer line for ultra-short bunches from FLUTE to cSTART"

Design and Parameters-I

- ✓ The provisional design of the VLA-cSR lattice is a Double Bend Achromat, Focusing Defocusing Focusing (DBA-FDF).
- ✓ The magnet design may adopt the MAX-IV design[6], where all magnet elements of one cell are realised as one mechanical unit
- ✓ At least one of the four drifts will be dedicated for beam diagnostics
- ✓ Beam diagnostics to be placed in the arc will be restricted by the very short distances between magnetic elements



Courtesy: A. Papash

[6] MAX-IV Detailed Design Report (DDR)

Design and Parameters-II

Circumference (m)	44.112
Energy (MeV)	50 (– 500)
Filling pattern	single bunch
Revolution frequency (MHz)	6.8
Bunch charge	20 – 200 pC up to 1 nC
Bunch length	down to 20 fs

→ Given the small circumference of the ring, the revolution frequency of single bunches is very high (6.8 MHz)

→ Furthermore, repetition rates of the cSTART diagnostics will be very high and thus require very fast electronics

→ To measure signals from low bunch currents, very sensitive beam diagnostics and with high dynamic range are required

Beam position monitors (BPM)

- ✓ During the first operation phase of VLA-cSR, the aim is to store the ultra short bunch delivered by the transfer line, for few turns in the storage ring

- ✓ A resolution of 100 μm minimum is required for orbit corrections

- ✓ Possibility of using existing technologies at the accelerator facilities at KIT:

Accelerator	KARA @ low alpha operation	FLUTE
BPM type	Button	Cavity (PSI)
Bunch length	1 ps	1 to 300 fs
Bunch current	1 mA	1 pA to 300 pA
Repetition rate	2.74 MHz	1 to 10 Hz

KARA: Karlsruhe Research Accelerator, the storage ring of the KIT synchrotron light source and a KIT accelerator test facility

- ✓ Given the very short bunches (20 fs), button BPMs are not suitable as they will deliver a very low and deformed signal

- ✓ Cavity BPMs are maybe able to perform well with the given rep rates, however the installation might be problematic in the arcs

- ✓ A hybrid BPM system could be considered, with cavity BPMs installed in the drifts

Beam position monitors (BPM) -II

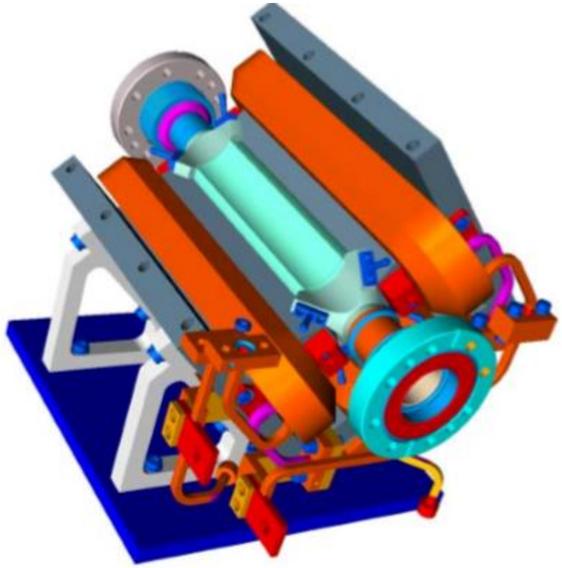
✓ Stripline BPM is another good choice to measure positions of very short bunches, given its design takes signal propagation into account.

✓ Preliminary estimations:

1) Striplines to be considered should have an optimal length of 11 cm

2) To cope with the low bunch current, striplines should get closer to the beam (conideration of impedance issues, simulations and calculations are required)

3) Given the tight spaces between elements and the negligible synchrotron losses per turn (< 1eV @ 50 MeV and 4 keV at 500 MeV), a possibility of mounting striplines inside quadrupoles might be considered [7]



Stripline inside a quadrupole at TTF2

[7] D. Noelle et al., proceedings of LINAC 2004, TUP69

Longitudinal profile monitors

Karlsruher Institut für Technologie

→ Given the fs bunch length, very good time resolution (1 to 5 fs) is needed for the measurement of the bunch profile

→ At KARA, we use a streak camera[8] (visible light) and EOSD (Electro-Optical Spectral Decoding) [9]

→ At FLUTE, we will use SRR (Split Ring Resonator)[10] and EOSD

→ At cSTART, a streak camera is a potential candidate in case we aim at relative bunch profile measurement, and is a practical tool for measuring different physics phenomena (head-tail instability, micro-bunching instability, etc..)

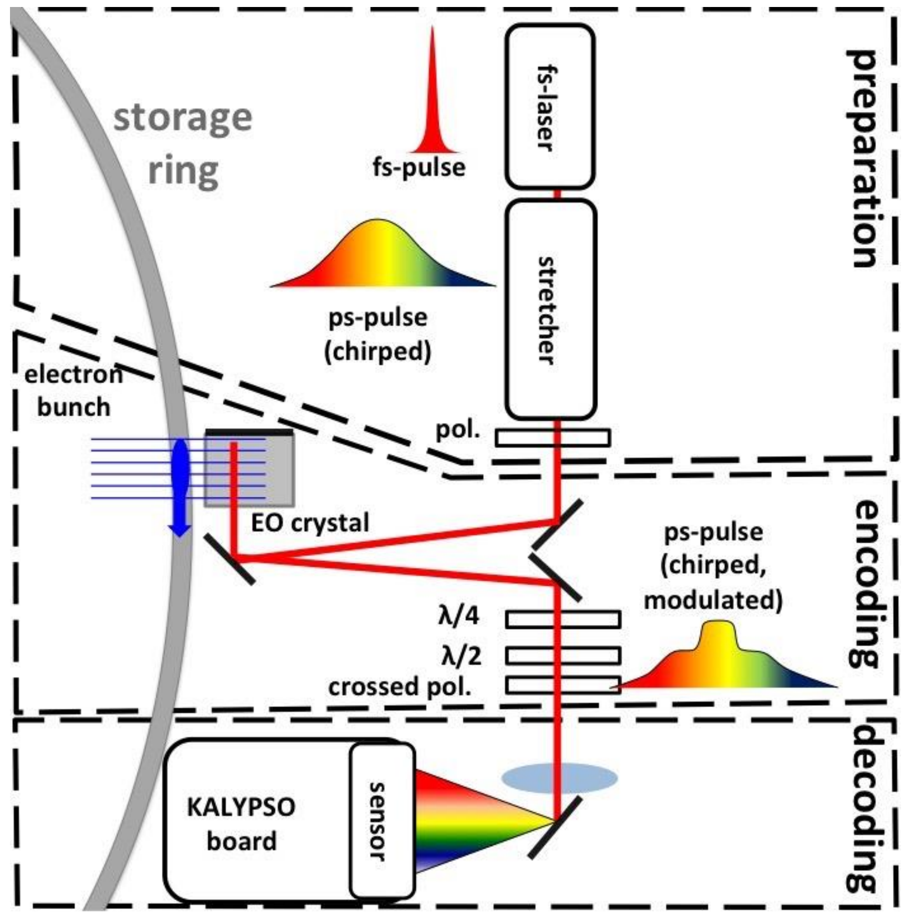
→ The EOSD successfully operated/installed at KARA is a promising method and thus is another good candidate

→ The SRR method is a destructive method and thus inadequate for cSTART bunch profile measurements

[8] B. Kehrer et al., proceedings of IPAC 2015, MOPHA037
[9] S. Funkner et al, arXiv:1912.01323v1
[10] V. Schlott et al, proceeding of IBIC2017, TUPCC16

EOSD at KARA

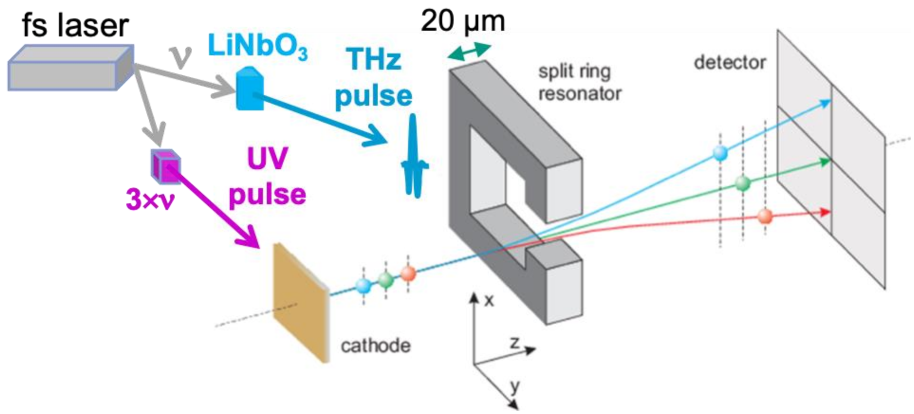
- → EOSD: EO Spectral Decoding for single shot measurements, using chirped laser pulses
- → Chirped laser pulse is sent on the EO crystal synchronised with the electron bunch
- → The modulated pulse will be read out by a fast detector KALYPSO[11] after passing through a crossed polarizer
- → KALYPSO reads data at a frame-rate of 2.7 MHz (rev. freq at KARA)
- → Measure bunch length at KARA in the order of 50 ps down to 1 ps
- → Development of the whole system along with the detector promises with higher repetition rates and temporal resolution measurements
- → Far field EOSD is also under preparation and test at the IR beamline at KARA



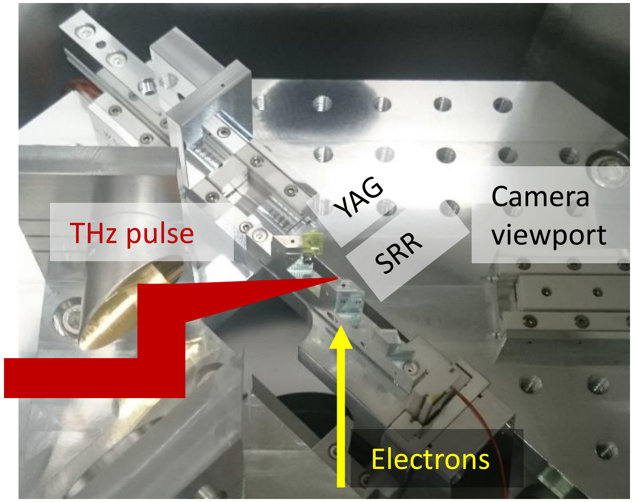
Courtesy: G. Niehues

[11] L. Rota et al., NIMA, https://doi.org/10.1016/j.nima.2018.10.093

Split Ring Resonator (SRR) at FLUTE

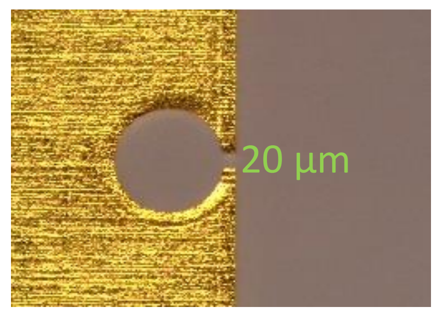


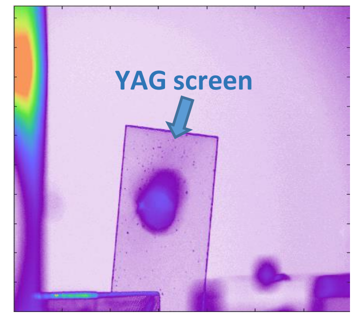
J. Fabiańska et. al., Sci. Rep. 4, 5645 (2015)

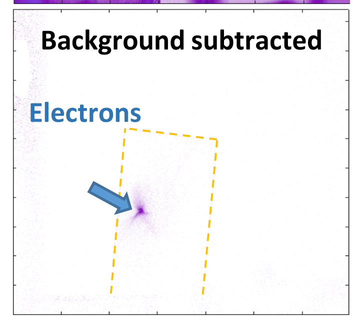


- → THz streaking with SRR promises ultra-high (sub-femtosecond) temporal resolution even for relativistic electron bunches
- → SRR is still under preparation and test at FLUTE
- → The expected temporal resolution is in the order of ≤ 20 fs

Courtesy: M. J. Nasse







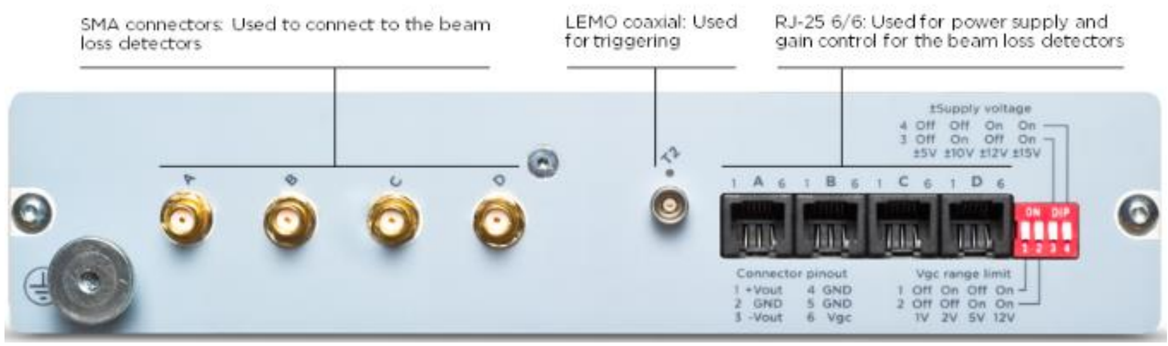
Beam Loss Monitors (BLM)

- ✓ The first challenge concerning BLMs is the excess of material in the arc and the low bunch current, which may result in very low signals

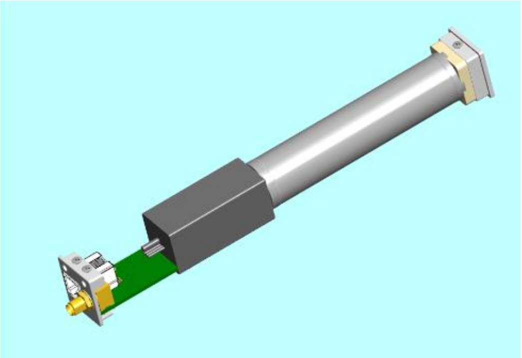
- ✓ The option of having in-vacuum BLMs might not be considered given the challenging mechanical design in the arcs

- ✓ We think of using the same BLM system used at the EBS-ESRF [12] (Extremely Brilliant Source):

a) Detectors: Hamamatsu H10721-110 PMT, scintillator EJ-200
b) Electronics: Libera BLM (14 bit, 125 MHz ADC)



Libera BLM



PMT

[12] L. Torino et al, proceedings of IBIC 2018

BLMs - II

→ Steps to do:

1) Detailed simulation of beam losses through studying particle material interaction with GEANT4 for example

2) Choosing the best candidate positions for BLM in the ring

→ At KARA, samples of the before-mentioned BLMs have been tested and used to help figure out some issues with the machine

→ After a shut down period at KARA, it was very difficult to store the beam for one full turn

→ BLMs helped figure out the position of the beam loss through scanning the losses outside the vacuum chamber of one of the insertion devices

Current monitors

→ Integratred Current Transformers (ICT), are the best choice for current monitors given the ultra short bunches

→ At FLUTE, two Turbo-ICTs (from Bergoz) are foreseen to measure the bunch current of 1 fs – 200 fs bunch length

→ For cSTART, we will adopt the same system as at FLUTE, Turbo-ICT and BCM-RF [13] (RF beam charge monitor)

→ The noise RMS is 10 fC for single bunch operation (bunch charge at cSTART is 20 pC to 1 nC)

→ The mounting of such a device is directly on the beampipe, thus two of these monitors would be mounted in the drift spaces

Turbo-ICT & BCM-RF

[13] https://www.bergoz.com/en/turbo-ict-bcm-rf-0

KARA booster as a model of cSTART

Accelerator	KARA booster
Circumference	26.4 m
Energy (GeV)	53 to 500 MeV
RF frequency	499.7212 ± 0.01 MHz
Revolution frequency	11.36 MHz
Filling pattern	Up to 44 bunches
Beam current	5 mA

WHAT ELSE?

→ KARA boo… ents a first role model of cSTART and could serve as test bench for …

→ An upgra… bera brilliance units with Libera Spark

→ A streak camera is also foreseen at one of the two light ports of the booster for longitudinal profile measurements

→ Possibility of beam loss measurements using PMT and Libera BLM is also under discussion and a study plan in under consideration

Summary

→ An overview of the future cSTART project was presented

→ The design and the list of important parameters were highlighted

→ The choice of BPMs is restricted by space and by the ultra short bunch length, striplines mounted inside quadrupoles might be an option (cavity BPMs in the drifts)

→ EOSD under development and test at KARA will be a choice along with a streak camera for longitudinal profile measurements

→ BLMs choice will depend on results from particle-material interaction, as very low signals are predicted

→ Turbo-ICTs are the best choice for current monitors, to be installed in the drifts

→ KARA booster as a test bench of beam diagnostics for cSTART

→ More detailed studies and research are required for such a challenging case at cSTART

Suggestions and/or comments

Your comments and further suggestions are very welcomed.

The study is still in its early phase and your help is very much appreciated.

Thank you for your attention