Karlsruhe Institute of Technology

The cSTART project: A unique storage ring with challenging beam diagnostics requirements

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Outline

- General description of the cSTART project
  - Goals
  - Layout and parameters
  - Preliminary schedule

- Beam diagnostic systems
  - Beam position monitors
  - Screen monitors
  - Charge monitors
  - Beam loss monitors

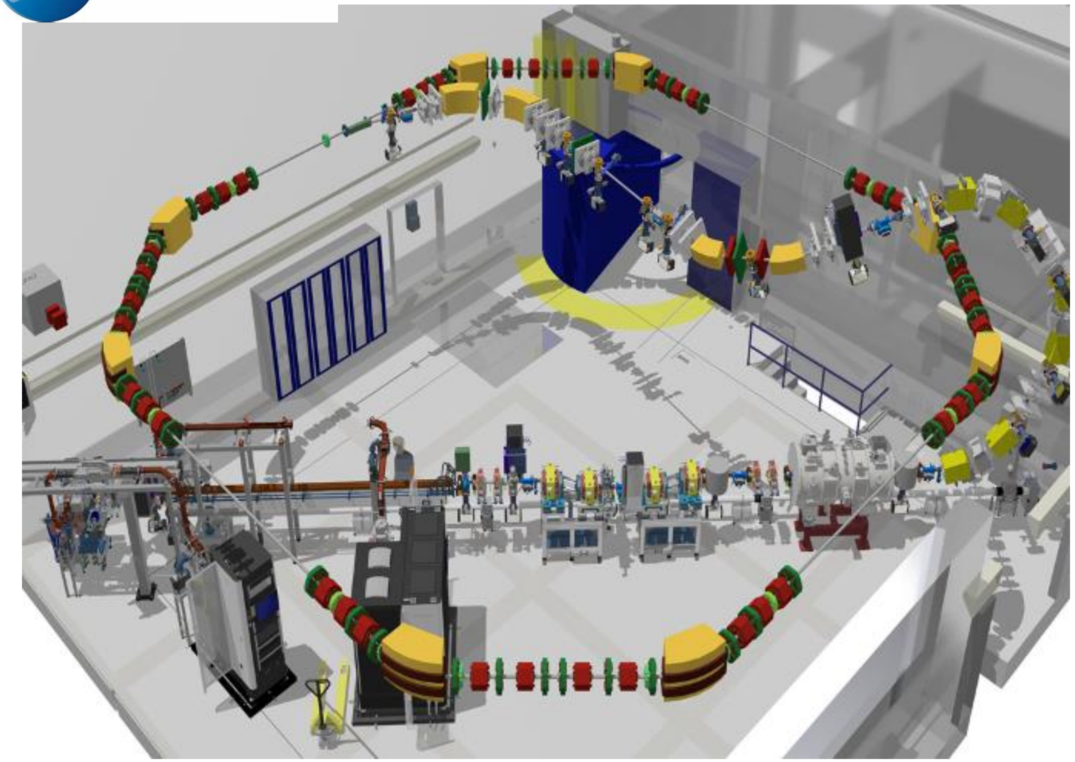
- Diagnostic experiences at KIT accelerators

- Summary

cSTART goals

- cSTART[1]: compact STorage ring for Accelerator Research and Technology

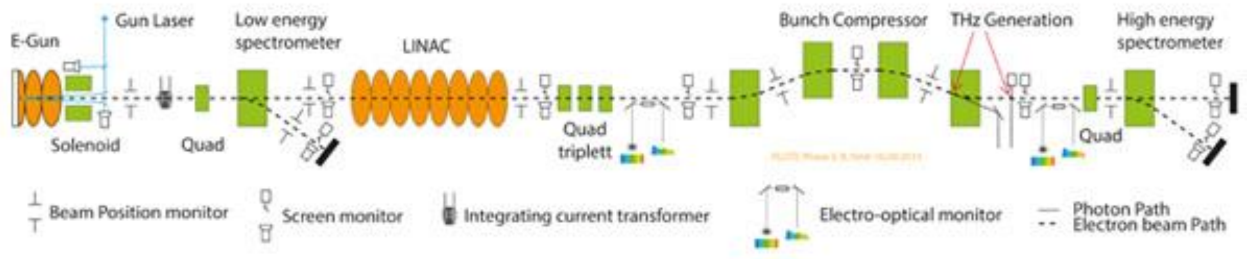
- Goals:
  - Demonstration of the injection of electron beams from LPA (Laser Plasma Accelerator)
  - Storage of sub-ps bunches in very large acceptance storage ring
  - Study of non-equilibrium beam physics



[1] M. Schwarz *et al., Recent developments of the cSTART project, TU4P34, FLS2023,* DOI: 10.18429/JACoW-FLS2023-TU4P34

cSTART layout

- Two injectors:
  - FLUTE[2] (Ferninfrarot Linac- und Test-Experiment) as a linac-based injector for early phases of the project
  - Injector(s) based on Laser Plasma Accelerators (LPA)
- Aim: demonstration of compact accelerators: transfer-line from FLUTE up to VLA-cSR
- Injection into the Very Large Acceptance - compact Storage Ring (VLA-cSR)



FLUTE Linac, courtesy T. Borkowski

FLUTE main parameters

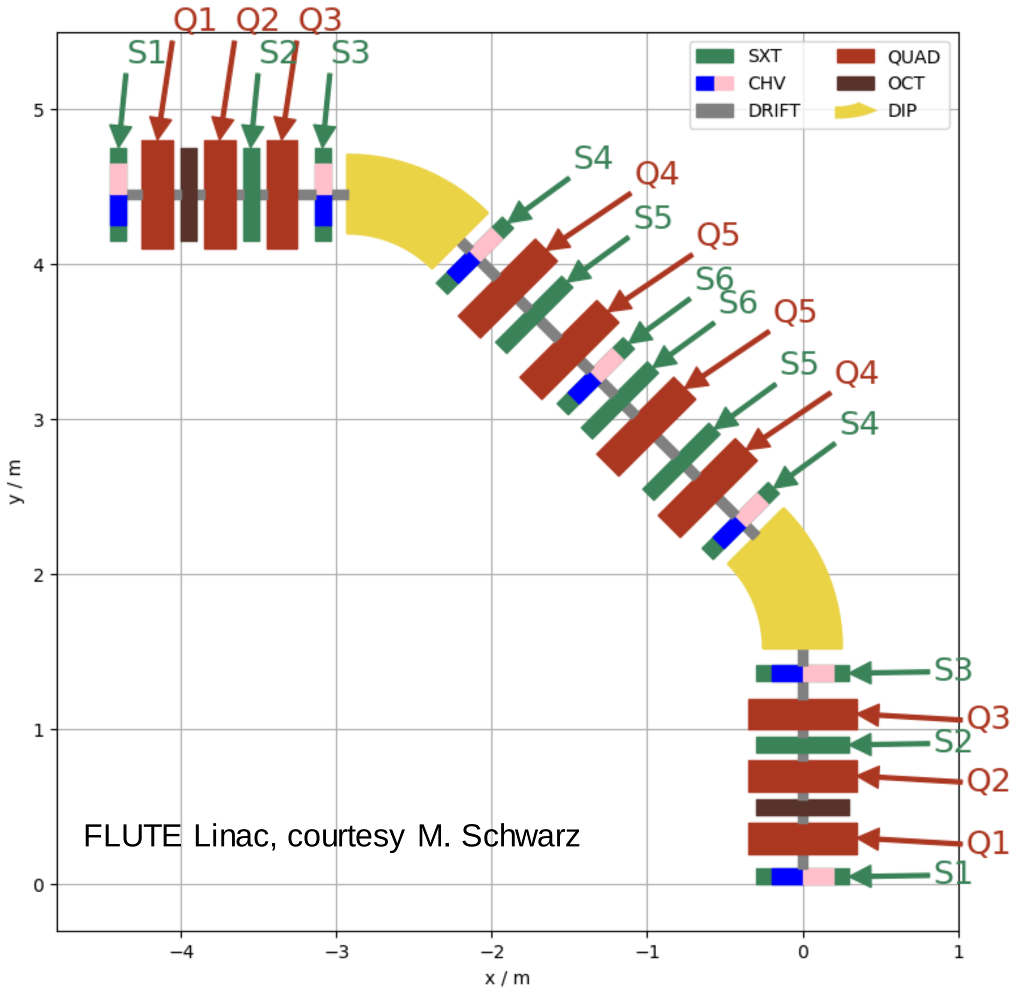
Energy	40-50 MeV
Repetition Rate	1 Hz to 10 Hz
Electron Bunch Charge	1 pC to 1nC
Electron Bunch Length	1 fs to 300 fs
Spectral Band Coverage	up to 30 THz
THz E-field strength	up to 1 GV/m

[2] Nasse MJ *et al*., FLUTE: a versatile linac-based THz source. Rev Sci Instrum. 2013 Feb;84(2):022705. doi: 10.1063/1.4790431. PMID: 23464187.

VLA-cSR layout

- A very compact DBA (double bend achromat) arc section filled with
  - One family of bending magnets (dipoles)
  - Five families of quadrupoles
  - Six families of sextupoles (chromaticity correction, corrector magnets including coils for orbit correction)
  - One family of octupoles
  - Diagnostics

- Four straight sections hosting
  - Injection and extraction (septa and kickers)
  - RF cavity
  - Future experiments
  - Diagnostics



VLA-cSR parameters

- The project aims to inject and store a single electron bunch
- An on-axis injection scheme, extraction of the circulating bunch after e.g. 100 ms and on-axis injection of a new electron bunch
- Long damping time allows the study of non-equilibrium beam dynamics
- The design of the DBA arcs allows the operation at different momentum compaction

Circumference of the storage ring	43.2 m
Operation mode	single bunch
Energy range	40 to 90 MeV
Energy spread	~2%
Bunch charge	1 pC to 1 nC
Bunch length within one turn	~10 fs up to~10 ps
Injection rate	1 to 10 Hz
Revolution/repetition frequency	6.94 MHz (144 ns)
Damping time (h /v/ l) (50 MeV)	29.5, 26.5, 12.6 s
Nominal momentum compaction	14.8 x 10^{-3}
Reduced momentum compaction	3.9 x 10^{-3}

Preliminary schedule of cSTART project

- Technical Design Report, TDR (September 2024)
- Final Design Report, FDR (spring 2025)
- Construction of the accelerator system (winter 2026)
- Final alignment end of 2026
- Site Acceptance Test SAT and first beam commissioning (beginning of 2027)
- The whole project is split over several workpackages, e.g.
  - Vacuum
  - Magnets
  - Injection/extraction
  - RF system
  - **Beam diagnostics**
  - Transferline
  - Control system and timing, etc.

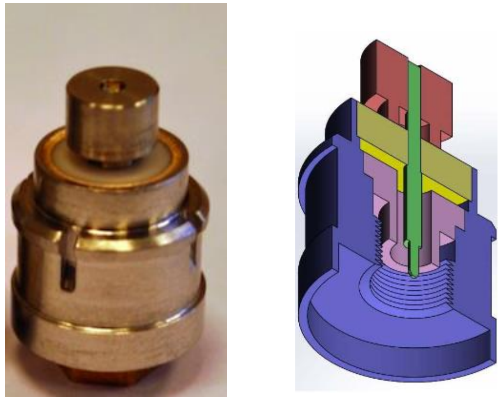
Beam diagnostics for the cSTART project

- For the commissioning and operation of cSTART, the following beam diagnostics tools are defined:
  - Beam position monitors
  - Screen monitors
  - Charge monitors
  - Beam loss monitors
- Requirements on beam diagnostics:
  - To provide turn-by-turn measurements (6.94 MHz = 144 ns)
  - Measurement at wide range of bunch charge (1 pC up to 1 nC)
  - Measurement at wide range of bunch length (10 fs up to 10 ps) within one turn

Options for Beam Position Monitors (BPMs)

- Requirements:
  - Measure position on **turn-by-turn basis**
  - Provide a **resolution ≤ 100 µm at 20 pC** bunch charge

BPM type	Pros	Cons
button BPMs	• **cheap** • **small**	• **low resolution at low bunch charges (100 µm @ 56 pC)**
Striplines	• **higher resolution than button BPMs** • **avoid signal deformation for short bunches (10 fs)**	• **need space** • **expensive and integration inside quads require a complicated design and fabrication**
cavity BPMs	• **high linearity and fast signal (high rep. rates)** • **high resolution (order of few µm) at low bunch charges** • **big dynamic range**	• **have effect on the beam through wakefields** • **need space**



B.K. Scheidt, TUPF14, proc. Of IBIC2014
https://ebs.esrf.fr/2015/11/26/ebs-button/

B. Keil et al., TUPC25, proc. Of IBIC2013

Specifications/Characterisation of BPMs

BPM quantity	FLUTE	Transfer-line	VLA-cSR	LPA
button BPMs	no	2	~28	no
cavity BPMs	8	4	no	2

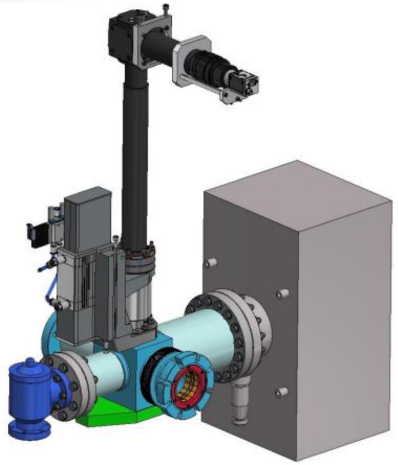
- Cavity BPMs: (PSI design)
  - Length: 15 cm
  - Frequency: 3.3 GHz
  - Aperture: 38 mm
  - Resolution: ~10 µm for a bunch charge range of 10 – 200 pC
  - Readout electronics: DBPM3 hosts 4 cavity BPMs

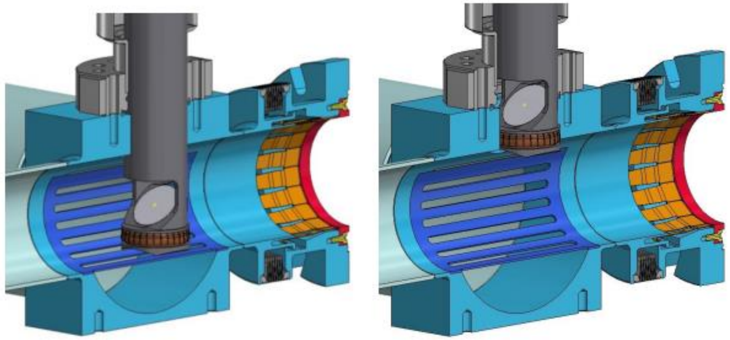
- Button BPMs (ESRF design)
  - Button diameter: 10.8 mm
  - Electrode thickness: 2.5 mm
  - Pre-amps will be connected to the buttons to improve the signal
  - Readout electronics: Libera SPARK ERXR
  - *Question: Any buttons (≤ 15 mm) able to provide a higher resolution?*

Screen Monitors

- Screen monitors are essential in the very first stages of commissioning to get the beam injected and completed a single turn.
- YAG screens (circular) are chosen for their high photon yield pictured by CCD cameras.
- Screen monitors are mainly installed at the entrance and in the middle of each arc section.
- Screens are mounted on pump ports.
- KIT plan five pneumatic screens mounted in the vertical plane and one motorized screen in the horizontal plane in the injection straight.
- Screen holder and camera share the same port for the pneumatic screens.
- The motorized screen moves with steps of 100 microns, placed in the middle of the injection line, to see the injected and stored beam simultaneously.

research instruments





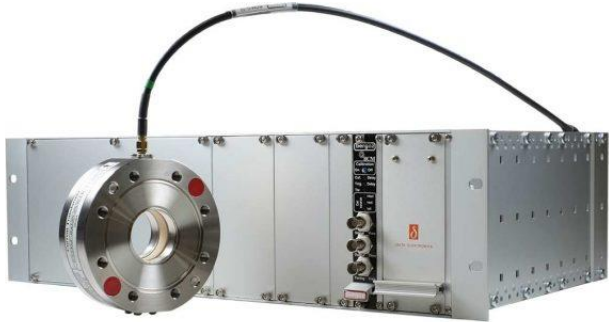
Charge monitors (CM)

- Requirements:
  - Bunch charge measurements at every stage (injector, transfer-line, storage ring) is required
  - In the storage ring: a turn-by-turn charge measurement is required, measure charges down to 1 pC

- Turbo-ICTs from Bergoz are the best-known CMs for low bunch charge measurements **but cannot provide turn-by-turn measurements**

Integrated Charge Transformer (ICT)

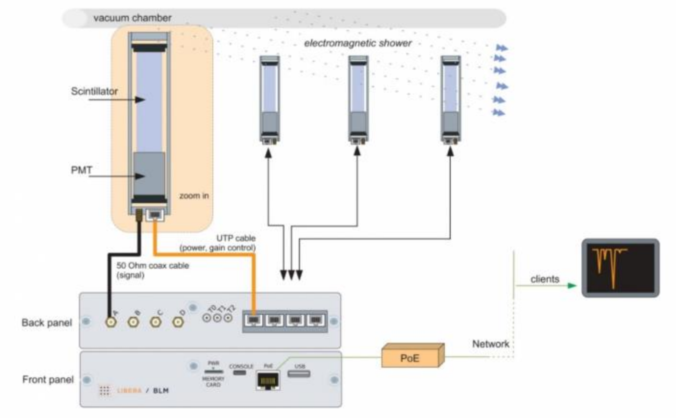
	Turbo-ICT (FLUTE + transfer-line)	Standard ICT (VLA-cSR)
charge resolution and noise	• **10 fC rms or 1%** of a single pulse charge	• **0.55 pC noise** on a single bunch
readout electronics	• BCM-RF-E (Analog, an option to connect it to an ADC unit) • **not possible to be read out by another electronics**	• BCM-IHR-E (Very slow for cSTART, trigger at 20 kHz) • **faster readout electronics is recommended (Digit-500)**
repetition rate	**≤ 2 MHz** (too slow, cannot provide turn by turn charge measurements)	possible to provide **turn-by-turn measurements**



Turbo-ICT & BCM-RF-E(up), ICT and BCM-IHR-E (below)
https://www.bergoz.com/products/

Beam Loss Detectors (BLDs)

- Beam loss measurements are crucial during the commissioning phase where too many uncertainties exist
- Essential to protect the accelerator tools and electronics during operation from radiation damage
- Scintillation based BLDs connected to photomultipliers and readout by Libera BLM units form i-Tech
- Dimensions: 22 x 2.5 x 2.5 cm, lead shielding (against synchrotron radiation)
- Scintillation rod is : EJ-200, peak wavelength= 425 nm, sensitive to X-rays and gammas.
- BLDs are mounted on mechanical support outside the vaccuum chamber, calibrated by radioactive sources or LED
- BLDs will be distributed around the transferline at potential loss locations and around the VLA-cSR at high despersion positions next to sextupoles

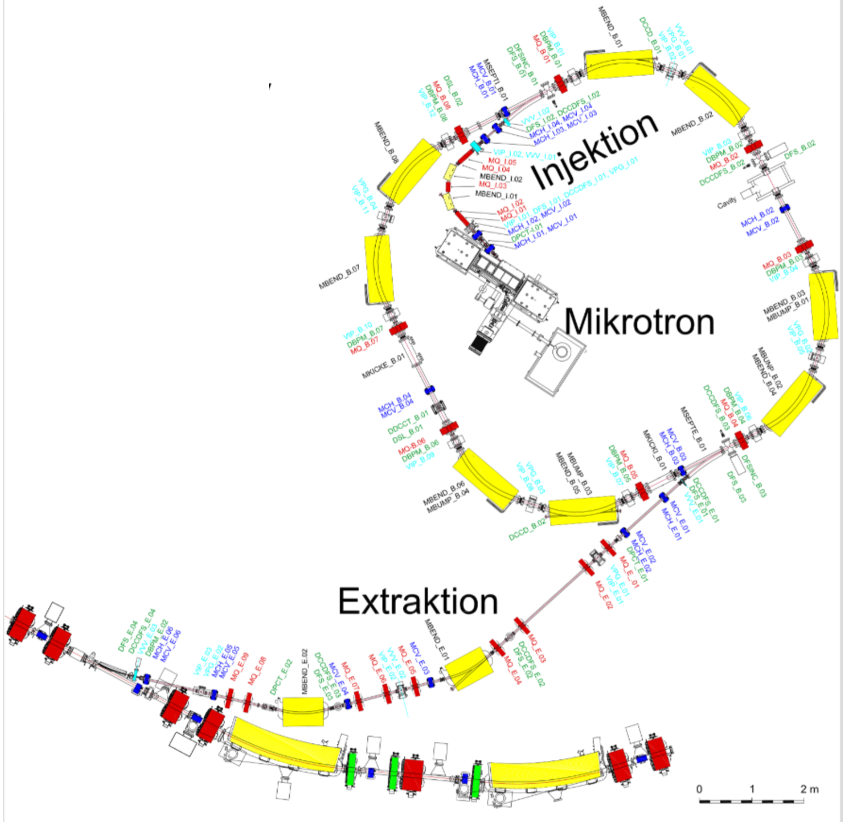


https://www.i-tech.si/products/libera-blm/

KIT accelerators

- KARA: KArlsruhe Research Accelerator

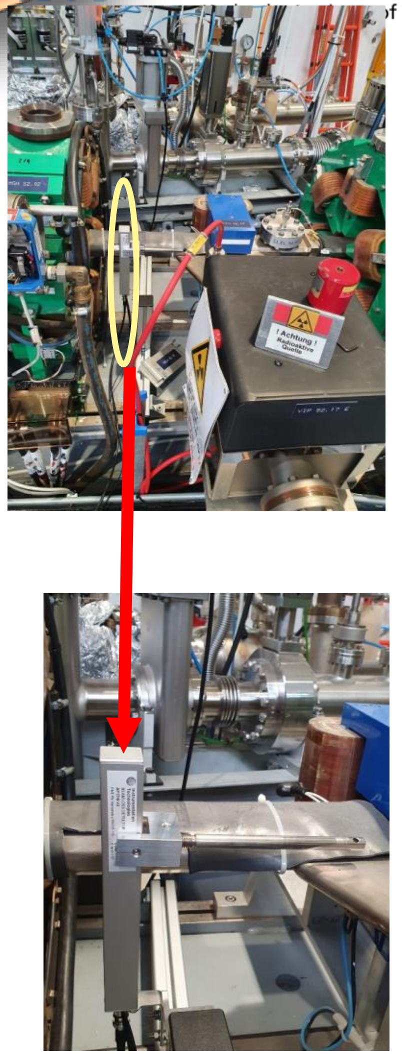
Accelerator	KARA	KARA booster
Circumference	110 m	26.4 m
Energy (GeV)	From 500 MeV to 2.5 GeV	53 to 500 MeV
RF frequency	500 MHz	500MHz
Revolution frequency	2.74 MHz	11.36 MHz
Filling pattern	Single bunch up to 184 bunches	Up to 44 bunches
Beam current	1 mA to 200 mA	5 mA



courtesy U. Herberger

Experiences at KARA/Booster and FLUTE

- Experiences with button BPMs and Libera SPARK readout units (reading out, data storage, trigger, synchronisation to the machine)
- Experiences with screen monitors and CCD camera (calibration, timing and synchronisation, aquisition, etc.)
- Experiences with Turbo-ICTs and cavity BPMs at FLUTE (calibration and measurements)
- Experiences with calibration of Scintillation BLDs using a radioactive source



courtesy D. El Khechen

Summary and Outlook

- cSTART project aims at the injection of LPA electron beam and storage of very short bunches
- Currently the project is in the TDR phase and the first beam is planned in 2027
- A beam diagnostics system is defined for commissioning and operation of cSTART
- At KIT accelerators, we are developing our expertise on the chosen beam diagnostic tools as preparation for cSTART
- Future diagnostics for ARD like EO[3] (Electro-optical) and special diagnostics for non-equilibrium beam physics are under development: high resolution, covering wide range of parameters and very fast

[3] M. Reissig et al., "First two-bunch measurements using the electro-optical near-field monitor at KARA", in Proc. IPAC'23, Venice, Italy, May 2023, pp. 4756-4759. doi:10.18429/JACoW-IPAC2023-THPL121

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Thank you very much for your attention

Questions?? Suggestions??