The cSTART project at KIT: status and preparations

Dima El Khechen on behalf of the cSTART team, LAS and IBPT, 03 July 2025

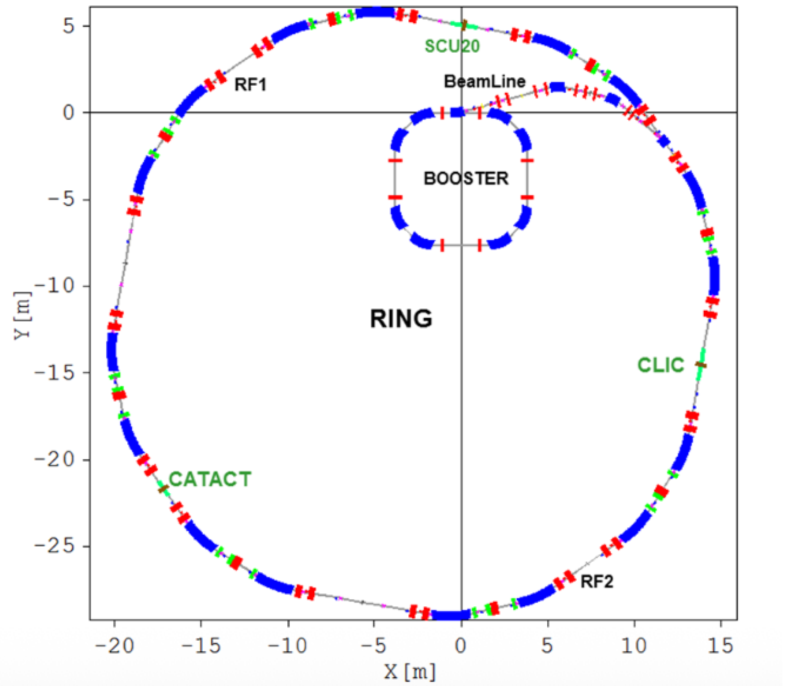
Outline

1. KIT accelerator infrastructures
2. Overview of the cSTART project
   - Description and main goals
   - Layout and parameters
   - Timeline and status
3. Beam diagnostics and Instrumentation
   - Overview of all sub-systems
   - Beam position system and tests
   - Charge measurements and tests
   - Tune measurements
4. Summary

KIT accelerator infrastructure
KARA

- **KARA (KArlsruhe Research Accelerator)**: Synchrotron light source (from 0.5 to 2.5 GeV), user operation and machine physics

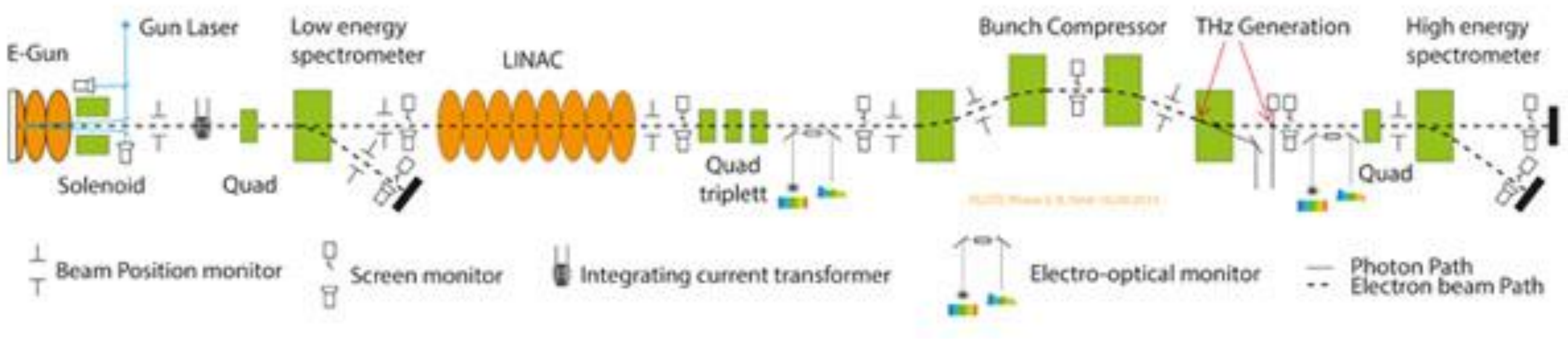
Accelerator	KARA	KARA booster
Circumference	110 m	26.4 m
Energy (GeV)	From 500 MeV to 2.5 GeV	53 to 500 MeV
RF frequency	500 MHz	500MHz
Revolution frequency	2.74 MHz	11.36 MHz
Filling pattern	Single bunch up to 184 bunches	Up to 44 bunches
Beam current	1 mA to 200 mA	5 mA



Courtesy Alexander Papash

KIT accelerator infrastructure
FLUTE

- **FLUTE (Far infrared Linac and Test Experiment):** RF photoinjector (up to 90 MeV) to generate THz radiation



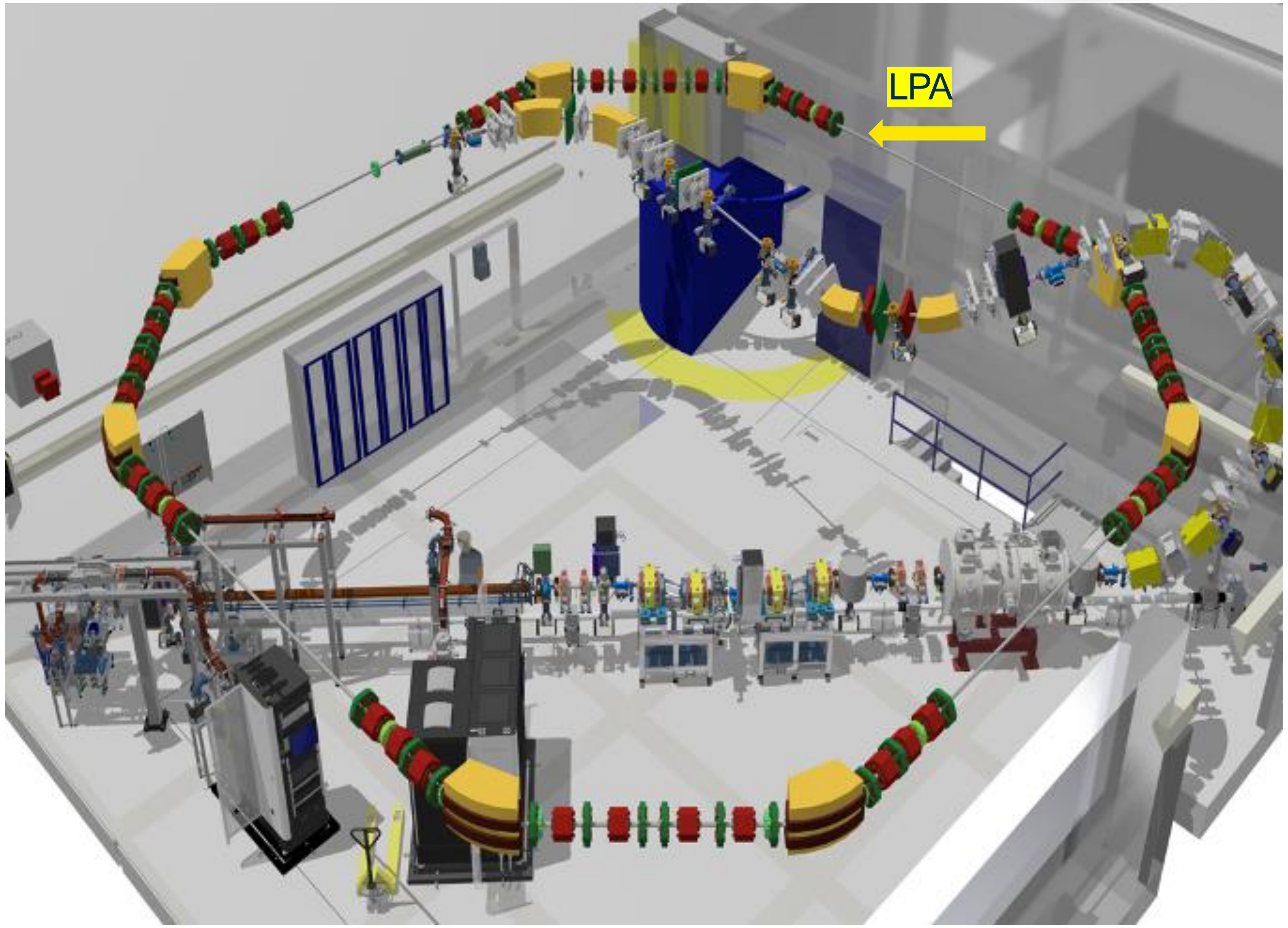
Energy	few MeV up to 90 MeV
Repetition Rate	up to 50 Hz
Electron Bunch Charge	up to 1nC
Electron Bunch Length	down to 1 fs
Spectral Band Coverage	up to 30 THz
THz E-field strength	up to 1 GV/m

The cSTART project
Description and main goals

- **cSTART** (compact STorage ring for Accelerator Research and Technology) will be installed and operated at KIT

- Main goals

1. Demonstration of the injection of beam like / from a Laser Plasma Accelerator (LPA)
   - Two injectors (FLUTE and LPA)
   - IL (Injection Line)t o inject into the storage ring (at 4m height)
2. Storage of sub-ps bunches in a VLA-cSR (Very Large Acceptance compact Storage Ring)
3. Study and understand non-equilibrium beam physics



Courtesy Till Borkowski

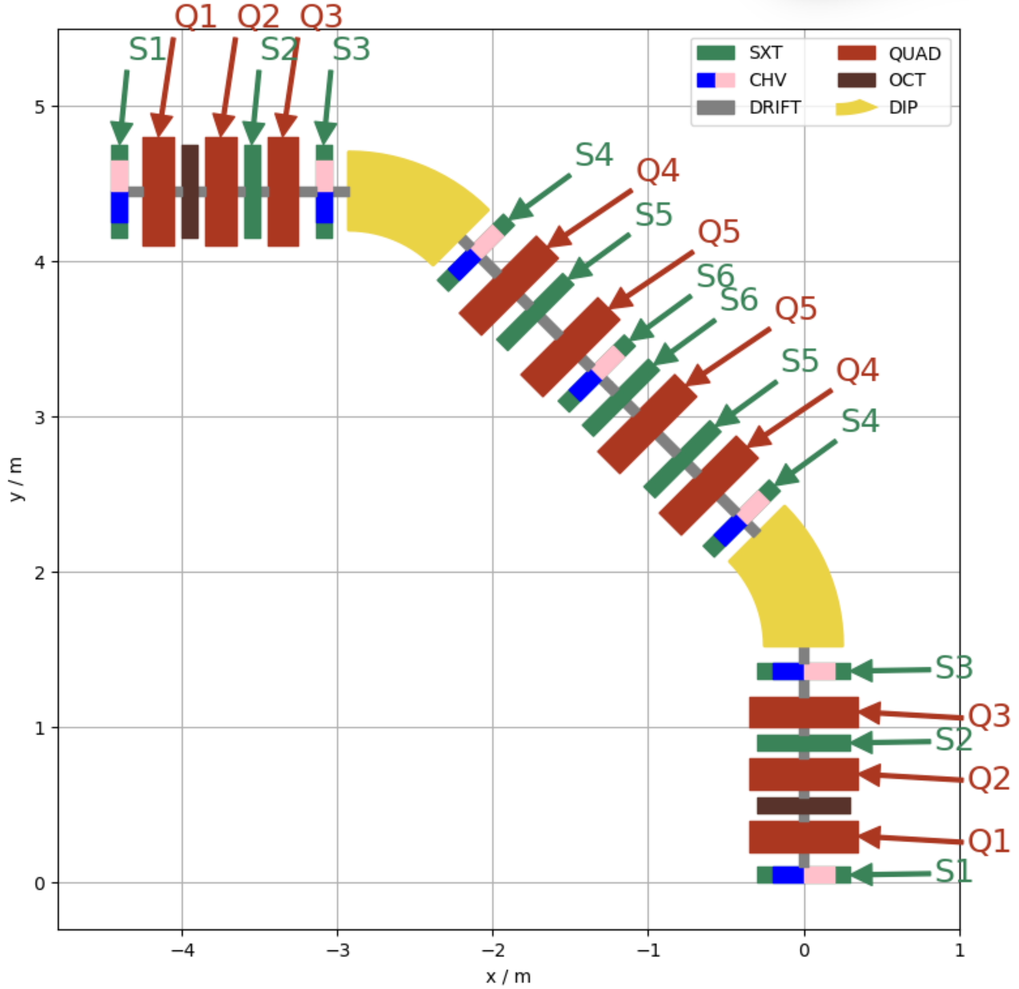
DBA arc section

- A very compact DBA (double bend achromat) arc section filled with

1. One family of dipoles
2. Five families of quadrupoles
3. Six families of sextupoles (chromaticity correction, coils for orbit correction)
4. One family of octupoles
5. Diagnostics

- Four straight sections hosting

1. Injection and extraction (septa and kickers)
2. RF cavity
3. Future experiments
4. Diagnostics (stripline kicker for tune measurements, Electro-optical setup)



Courtesy Markus Schwarz

The cSTART project
Main parameters of the VLA-cSR

- The injection scheme is designed to inject on-axis a single bunch at rates up to 10 Hz
- The storage of the beam in the VLA-cSR will be for only 100 ms
- The long damping periods compared to the storage time allows the study on non-equilibrium beam physics
- The design and the flexibility of the DBA arc allow the operation at different momentum compaction regimes (short and ultra-short bunches)

Circumference of the storage ring	43.2 m
Operation mode	single bunch
Energy range	40 to 90 MeV
Momentum acceptance	$\pm 4\%$
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	14.8×10^{-3}
Reduced momentum compaction	3.9×10^{-3}

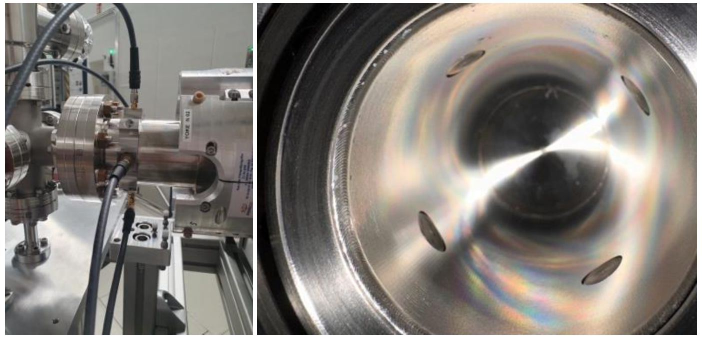
Status and Timeline

- cSTART work split takes place between KIT and Research Instruments (RI) as a main contractor
- Technical Design Report (TDR) phase is complete, and the FDR (Final) is due by the end of 2025
- Main systems like vacuum including light ports, girders, magnets, injection system, beam diagnostics etc. are all ordered and in production phase, few items arrived already
- The assembly and adjustments of the cSTART components will start in January 2026
- Commissioning of cSTART is planned in the last quarter of 2027
- Construction of the LPA already started, several tests and experiments are taking place

Beam diagnostics and Instrumentation at cSTART

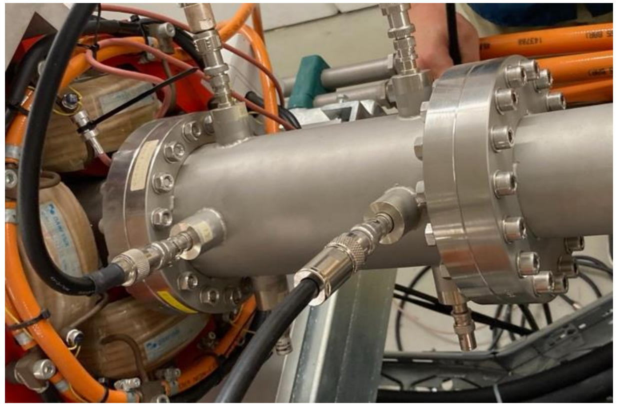
- Beam diagnostics are mainly taken care of by KIT (IL and VLA-cSR)

1. BPM (Beam position monitors)
2. Charge monitors
3. Beam loss detectors
4. Screen monitors (RI)
5. Tune measurements

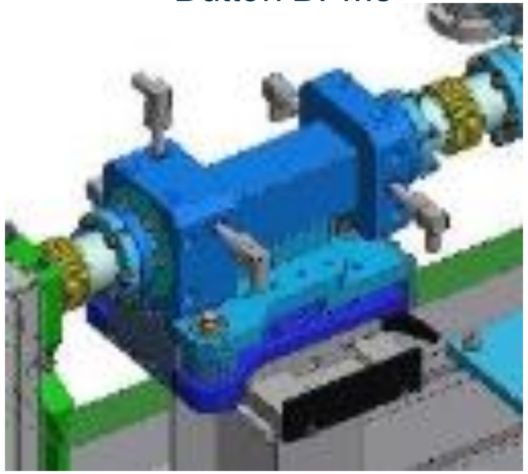


Button BPMs

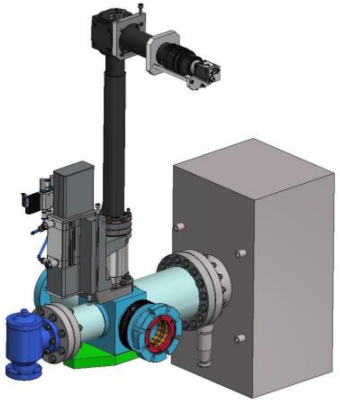
Charge monitor (Bergoz)



Stripline kicker for tune measurements



cavity BPM (PSI)



Screen monitor

Beam loss detector (i-Tech)

research instruments

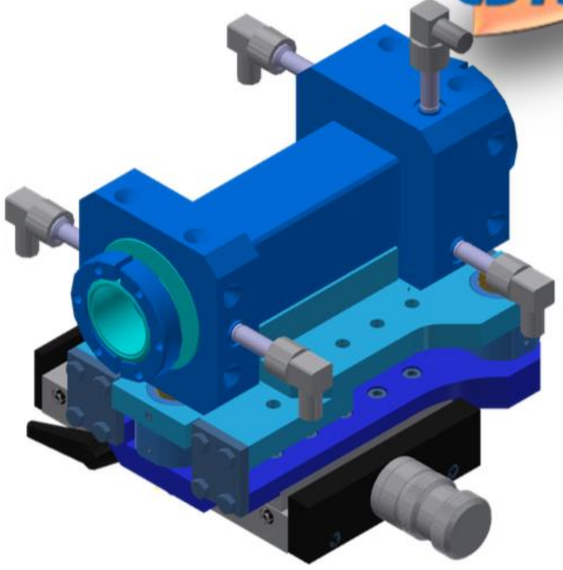
General requirements and specifications

- The VLA-cSR is a storage ring with special features:
  - Single bunch at 6.94 MHz repetition rate
  - Ultra-short bunches
  - Mounted at 4 meters (alignment challanges)
  - Long damping periods compared to storage (non-equilibrium beams)

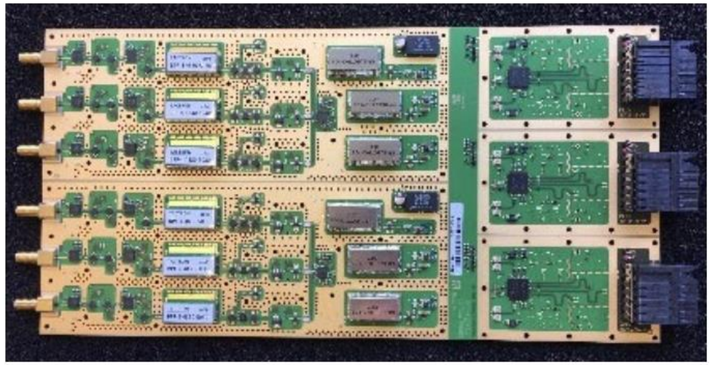
- Specifications on beam diagnostics:
  - Fast (turn-by-turn)
    - Modification on off-shelf diagnostics
  - High resolution for beam based alignment and to avoid severe elongations of the LPA injected beams

Beam position diagnostics
Injection line

- Four cavity BPMs (like at FLUTE) from PSI (Paul Scherrer Institute): Measures position and charge
- Technical Specifications:
    - 255 mm length.
    - 38 mm inner aperture.
    - 3.3 GHz working frequency
    - Loaded quality factor >100



Readout electronics:
DBPM3 readout boxes: Single bunch RMS noise < 10 µm
Each BPBM3 hosts four RF Front End card (RFFE)



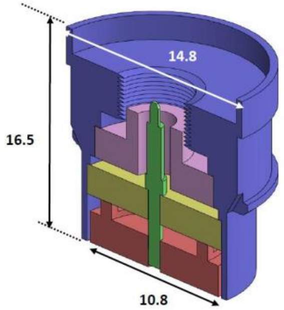
RFFE

Synchronization to the injection trigger

Beam position diagnostics
VLA-cSR

- 29 B-BPMs distributed mainly in the arc sections (seven per arc) and one in the injection section (beampipe diameter 56 mm)

- Technical specifications:
  - ESRF B-BPM design:
    - Button radius = 5.4 mm
    - Button thickness = 2.5 mm
    - Button gap = 250 µm

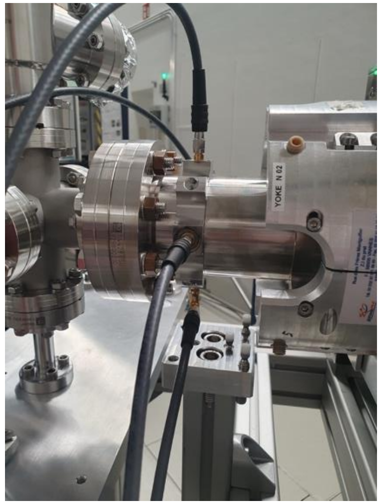


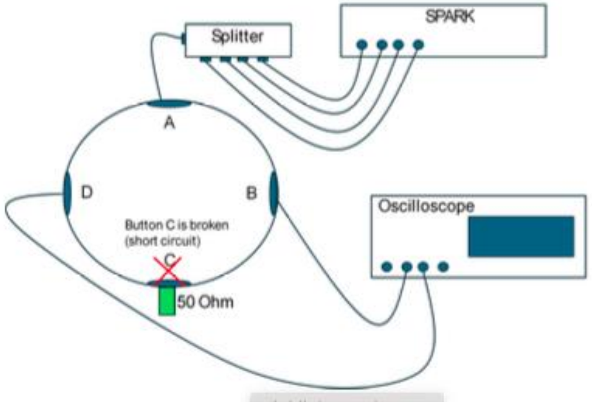
- **Readout electronics**:
  - Libera SPARK ERXR from i-Tech (used at KARA booster):
    - Four channels (four buttons)
    - Injection trigger (1 to10 Hz) and revolution trigger (6.94 MHz)
  - For cSTART, few modifications on Front-End electronics:
    - A new SAW filter:
      - Same central frequency (500 MHz)
      - A larger bandwidth 33 MHz (standard 15 MHz)
    - A sampling frequency of 117.95450 MHZ (t turn corresponds to 17 ADC)

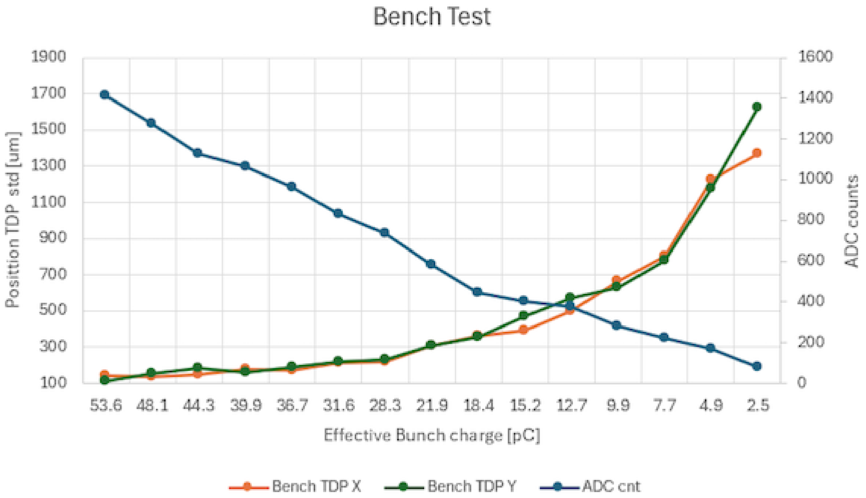
Characterisation tests of the modified prototype

IPAC 2025, THPS094

- Purpose of characterisation:
  - Ensure the specified resolution (100 µm at 100 pC)
  - Ensure no significant overlap between successive turns
- Tests were performed with:
  - Signal generator and Arbitrary wave generator (AWG from Tektronix) (no dependence on bunch length)
  - Electron bunch at FLUTE
- Results:
  - Overlap between the turns in the order of 6%
  - Resolution ligning up with specification
  - Bad resolution at charges down to 10 pC (low noise RF filters to be tested)







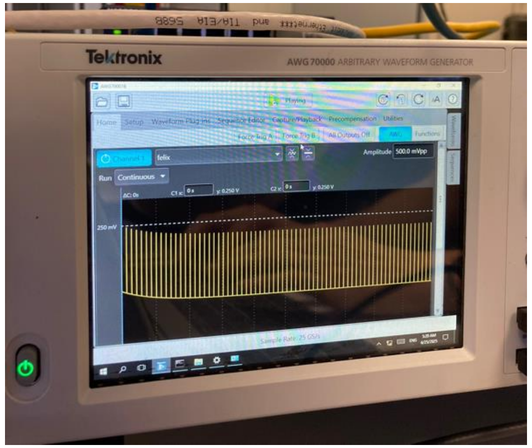
Charge monitors

- Injection line : **Two Turbo-ICT** (Integrating current transformer) with its readout electronics from Bergoz
  - Used for charge measurements at FLUTE
  - Charge resolution down to 10 fC RMS
  - Only limited to repetition rates up to 2 MHz

Turbo-ICT and BCM-RF-E

ICT at the end od FLUTE

- VLA-cSR: one modified ICT from Bergoz and Libera Digit 500 from iTech:
  - Decrease the output pulse length from 70 ns to 28 ns for cSTART
  - Bergoz electronics are slow (few KHz) and not suitable for TBT
  - Characterisation tests of charge calculation with the Libera Digit 500 (bachelor thesis):
    - Using signal generators and AWG (Tektronix)
    - With the electron bunch at FLUTE



Emulation of the droop of the ICT signal with AWG

Beam loss detectors

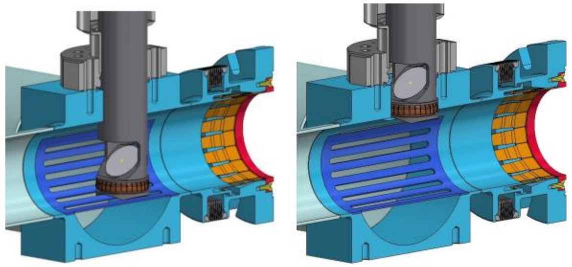
- Based on plastic scnitillators (Hamamatsu EJ200) and a photomultiplier (PMT):
  - Compact (22 x 2.5 x 2.5 cm) with lead shield for shielding scynchrotron radiation
  - Sensitive to gammas and x-rays mainly
  - Readout electronics Libera BLM (Beam loss Monitor) hosts four BLDs
  - Measures slow losses (Touscheck, beam-gas bremstrahlung, ..) and fast losses (injection losses)
  - PMT should be calibrated with either a radioactive source or an LED light
  - Measures TBT

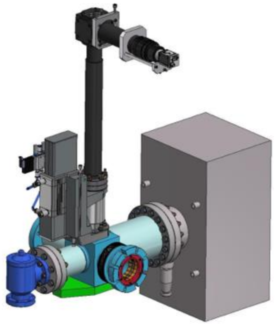
Libera BLD and BLM from iTech

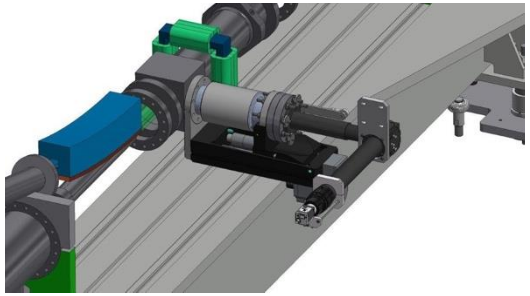
Calibration tests at KARA with a Beryllium source

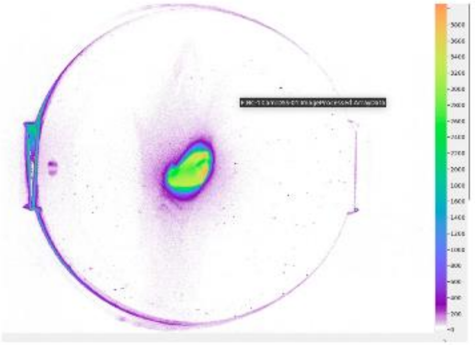
Screen monitors

- Screen monitors will be the fastest and easiest diagnostic tool during commissioning
- 6 screens in the Injection line and 6 screens in the VLA-cSR
- Vertically mounted and pneumatically driven
- One horizontally mounted and motorized (steps 0.1 mm) in the injection straight section
- Screens are round YAG screens and images are taken by CCD cameras





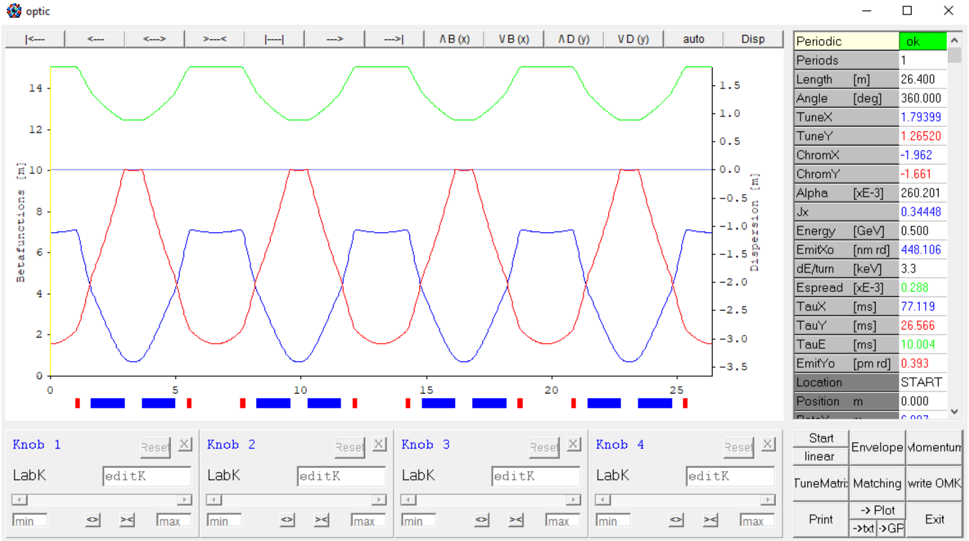




Electron bunch at FLUTE as seen on a YAG screen

Tune measurements
Planned IBIC contribution

- How to measure the tune of a single bunch at 50 MeV in cSTART ?
- The booster at KARA represents the closest approach:
  - A stripline kicker (15 cm) driven by bunch-by-bunch feedback system (BBB)
  - Fast Fourier Transform of turn-by-turn of the beam position data (Libera SPARK ERXR)
- Horizontal tunes were successfully measured
- Vertical tunes are more difficult to measure:
  - Kick the beam only vertically?
  - Drive the stripline with a noise signal?



Summary

- cSTART is a unique KIT project currently in the final design report phase
- Main systems (vacuum, magnets, girders, beam diagnostcs) are ordered and in production phase
- Beam diagnosics system is partially delivered and few instrumentation were characterised and tested
- Longitudinal and transverse profile meaasurements are also being considered for later stages
- Installation and cabling strategies and plans are under preparation
- Making use of experiences with systems and operations of existing KIT accelerators (KARA and FLUTE)

Acknowledgments

The cSTART team:

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THANK
YOU
FOR
YOUR
ATTENTION