Characterization tests of cSTART's beam position monitor

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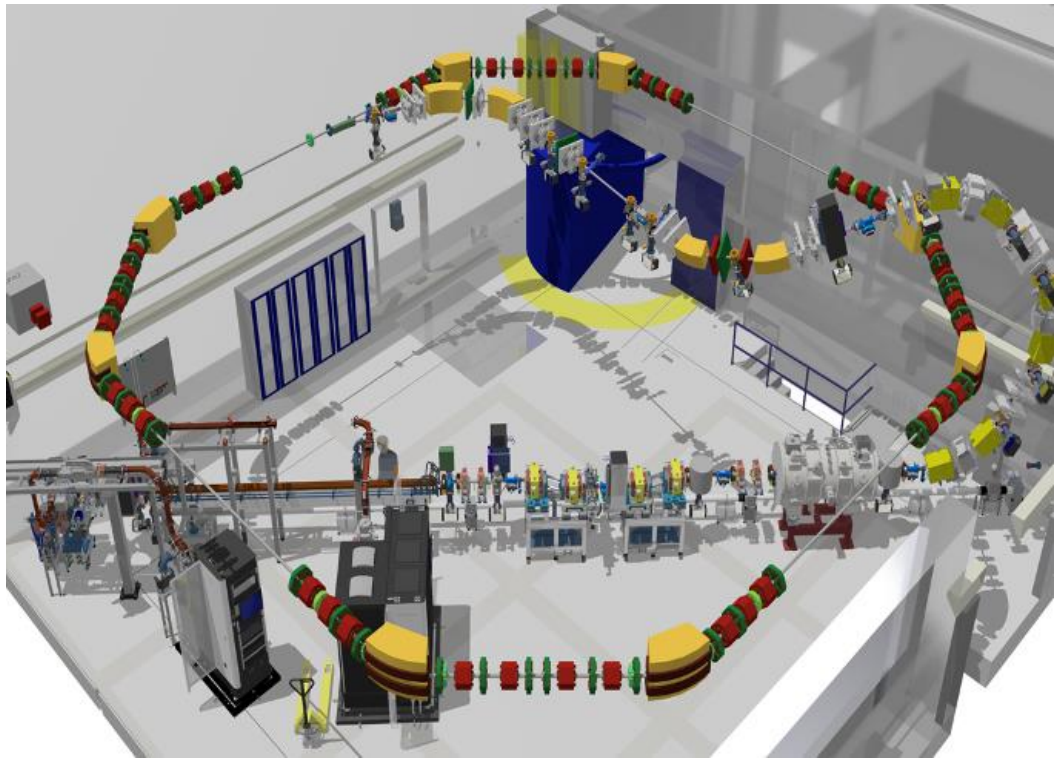
Outline

- cSTART project:
  - Layout and parameters
  - Dynamics and diagnostics
  - Beam position system
- Modified Libera SPARK ERXR
  - Description of the cSTART version
  - Bench tests at KIT using a signal generator (and/or AWG)
  - Tests using FLUTE beam
- Summary and outlook

cSTART goals

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

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

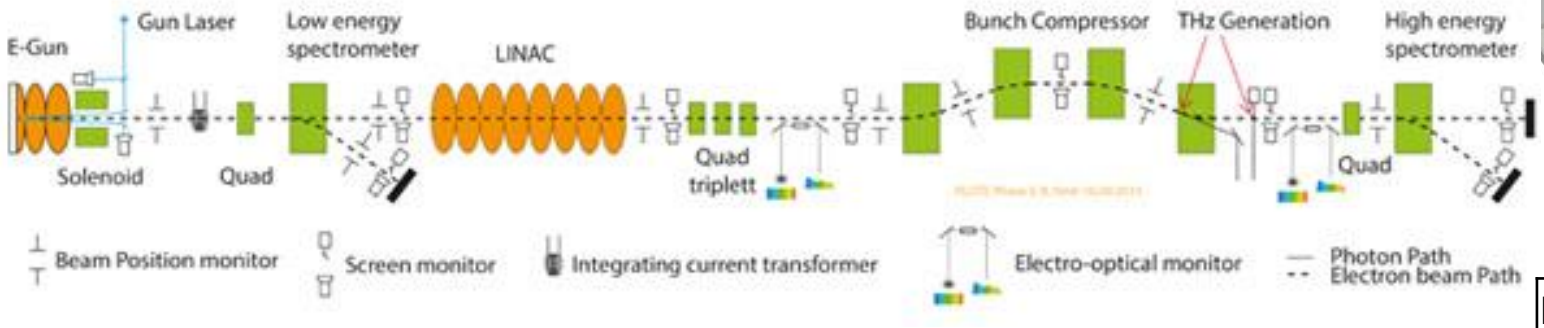


Courtesy Till Borkowski

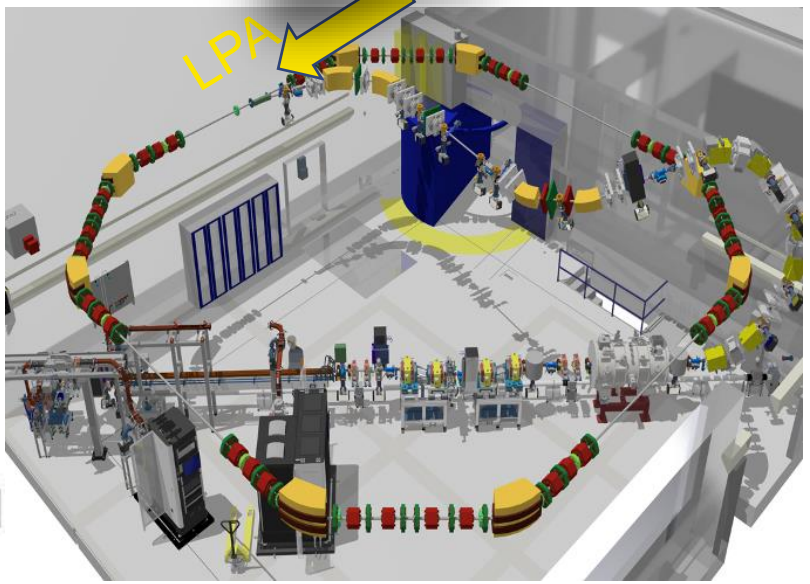
[1] M. Schwarz *et al., Recent developments of the cSTART project, TU4P34, FLS2023,* DOI: 10.18429/JACoW-FLS2023-TU4P34

cSTART injectors

- Two injectors:
  - Phase 1: FLUTE[2] (Ferninfrarot Linac- und Test-Experiment) as a linac-based injector for early phases of the project
  - Phase 2: LPA injectors



FLUTE Linac



FLUTE main parameters

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

[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 parameters

- The project aims to inject and store a single ultra-short electron bunch
- An on-axis injection scheme is planned with a storage period of 100 ms
- Long damping time allows the study of non-equilibrium beam dynamics
- The design of the DBA arcs allows the operation at different momentum compaction factors; low- and ultra-low alpha modes

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	14.8×10^{-3}
Reduced momentum compaction	3.9×10^{-3}

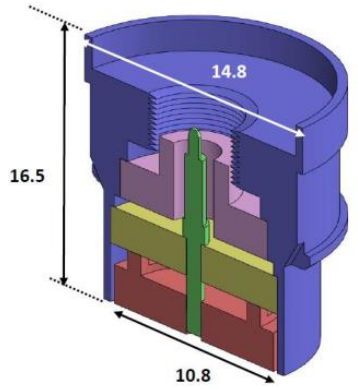
Special features and dynamics

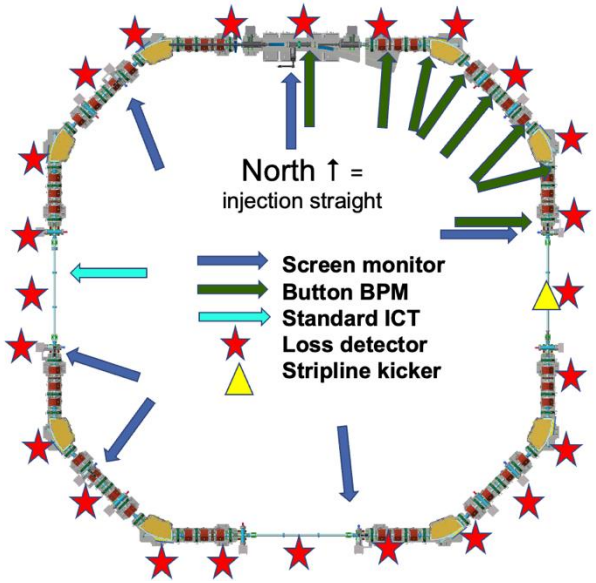
- What makes the dynamics of the cSTART storage ring unique?
  - Low energy beams (long damping periods vs storage time, non-equilibrium beams)
  - Ultra-short bunches
  - Single bunch and high repetition rates
  - Mounted on a height of almost 4 m from the ground (alignment challenges)

- Conditions on beam position measurements:
  - Fast (turn-by-turn @ 6.94 MHz)
  - Resolution of 100 µm @ 100 pC (to avoid severe elongation of the LPA injected beam upon the first turn)

The beam position system

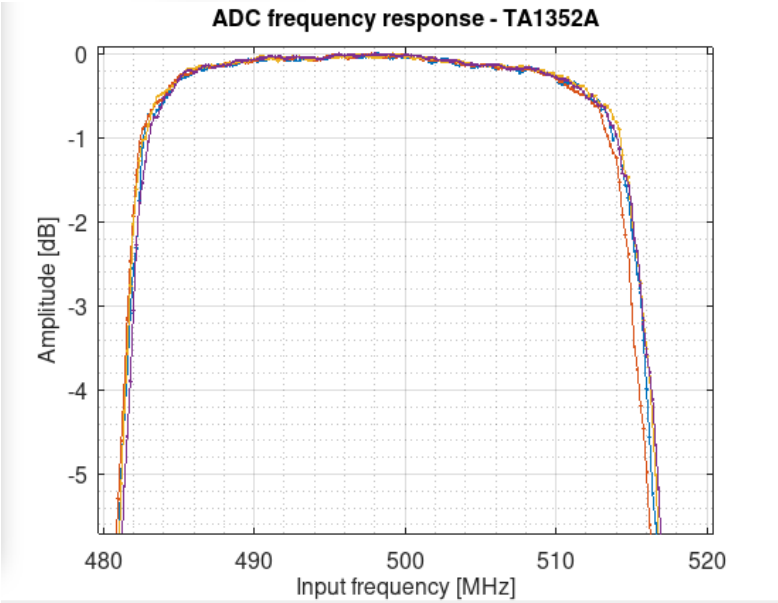
- Each arc will be equipped with 7 B-BPM (7 h/v orbit correctors) + 1 B-BPM in the injection section (29 in total)
- Beam pipe: 28 mm radius
- Design of electrodes:
  - The ESRF design (PMB Alcen)
  - Button radius = 5.4 mm
  - Button thickness = 2.5 mm
  - Button gap = 250 µm





The modified SPARK ERXR

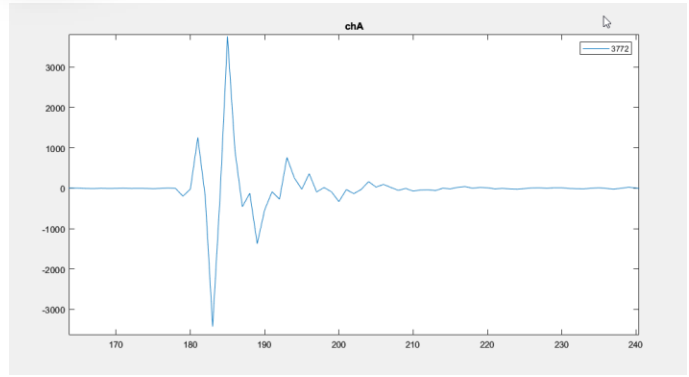
- A customised DEELS Spark ERXR from i-Tech:
  - A different SAW filter (front-end filter) : central frequency 499 MHz and Bandwidth 33 MHz
  - ADC sampling frequency 117.95450 MHz (one turn corresponds to 17 ADC samples)
  - Receives triggers at 6.93850 MHz (revolution frequency) and 1 Hz (injection frequency)
  - Variable attenuation from 0 dB to 31 dB (to be changed manually)
- Why customized?
  - Nearly no overlap between signals of successive turns
  - Turn-by-turn (TBT) resolution of 100 µm @ 100 pC



Courtesy Peter Leban

Tests at i-Tech

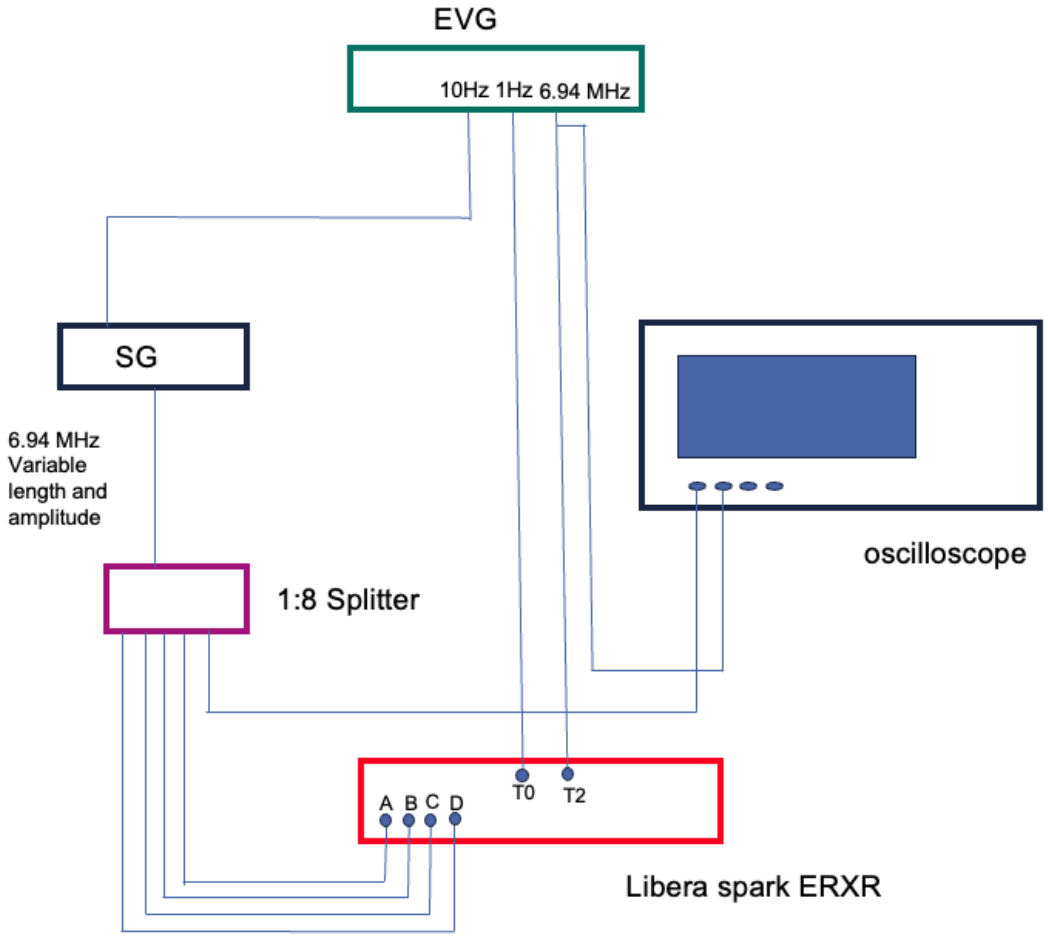
- A prototype of the modified SPARK ERXR was tested at i-Tech
- The tests were performed using a signal generator with fixed pulse length 1 ns, peak 6 V, voltage on button 1.7 V max
  - i-Tech used an external attenuator (60dB) to simulate the signal amplitude in the range of 1 pC to 1 nC
  - TBT resolution was then calculated as the RMS of the measured TBT positions in X and Y

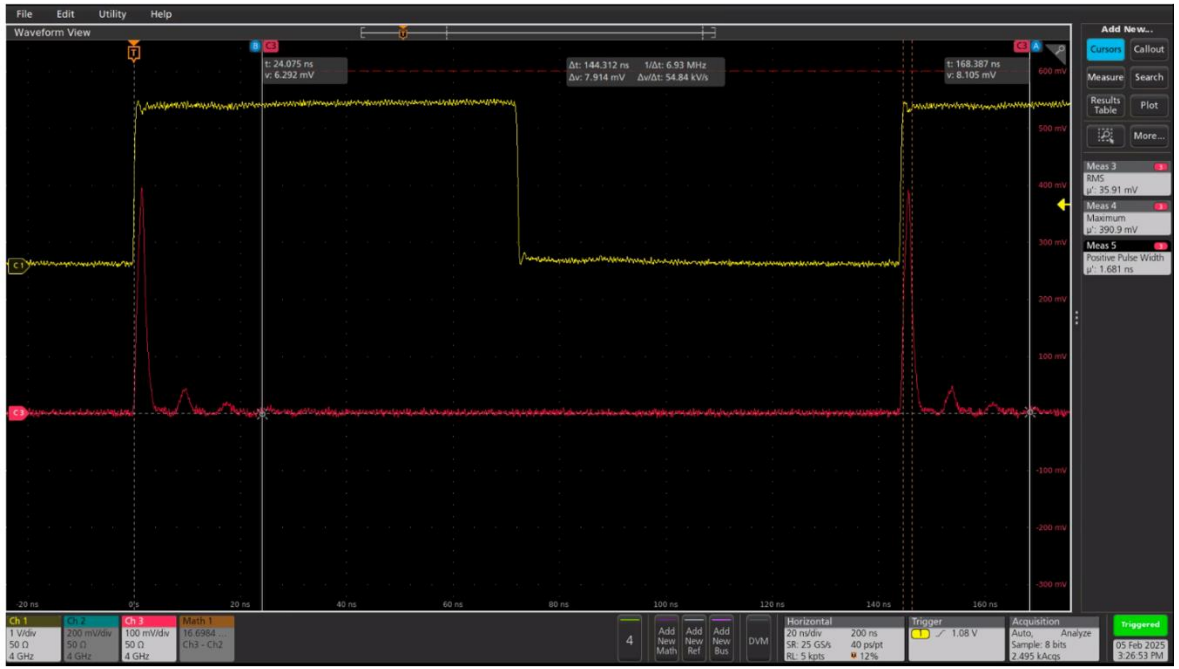


Processed ADC counts are calculated as follows $\sqrt{\sum_{i=1}^{17} x_i^2}$

Courtesy Peter Leban

Tests with signal generators





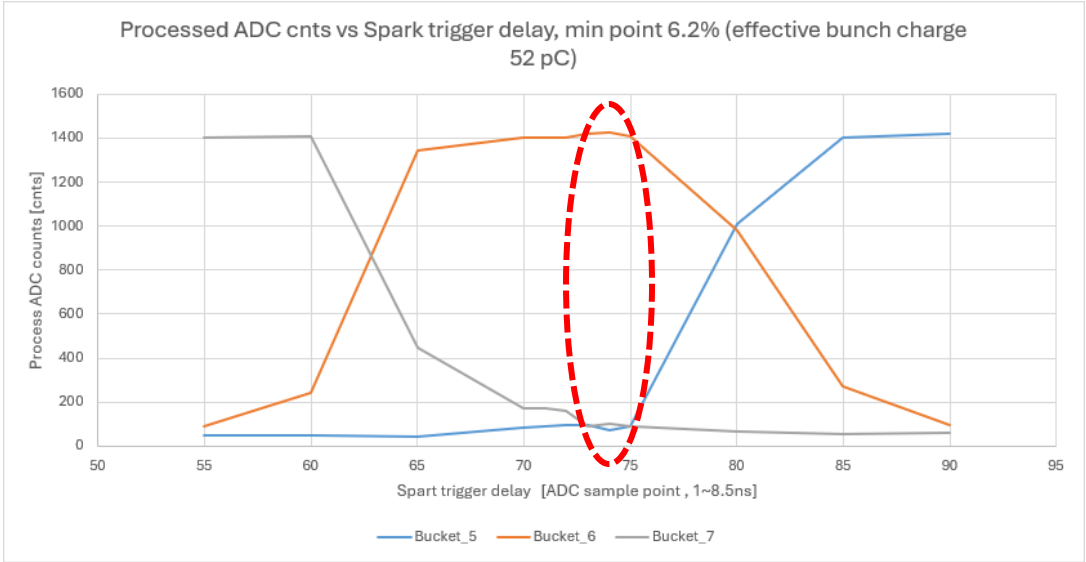
Red: signal generated from signal generator at 6.94 MHz (output from the splitter)

6.94 MHz trigger signal from the EVG

Turn-to-turn overlap: using SPARK trigger delay

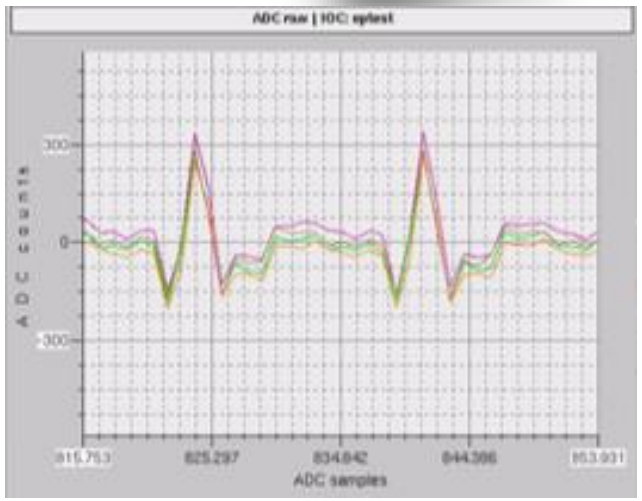
- For this test, the signal generator generated 5 Hz signals
- The delay on the signal generator was set so that the signal appears in the 5th bucket
- A SPARK delay scan over two buckets (34 steps: 1 point=8.5 ns) was performed
- For each step the processed ADC was calculated in buckets 5, 6 and 7
- At the highest processed counts, the leakage of the to the neighbor bucket was estimated to be 6 %

Processed ADC counts are calculated as follows $\sqrt{\sum_{i=1}^{17} x_i^2}$

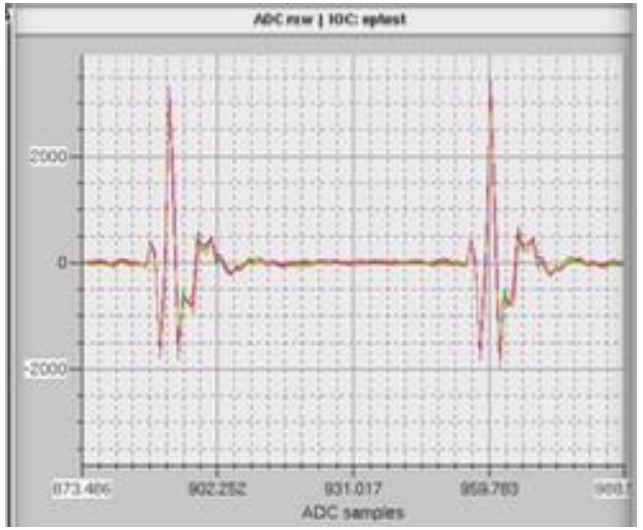


Turn-to-turn overlaps: A second approach

- Generate pulses at 2, 3, 4 etc … times slower pulse frequency than the 6.9 MHz
- Compare the integrated ADC counts for each frequency to the 6.9 MHz (within the same 17 ADC samples)
- An approximate estimation was also in the order of 6%



6.94 MHz

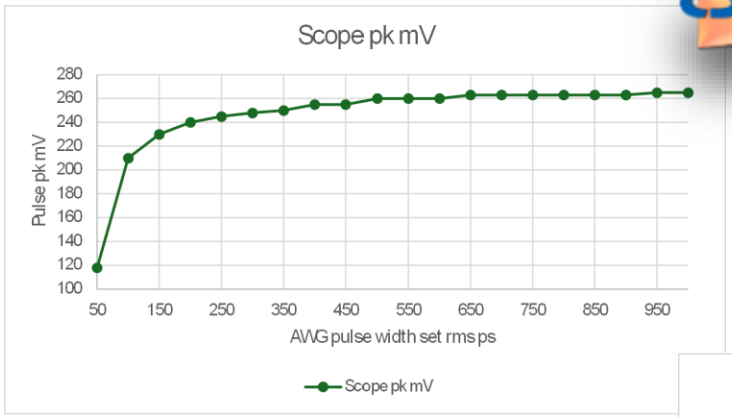


1.725 MHz

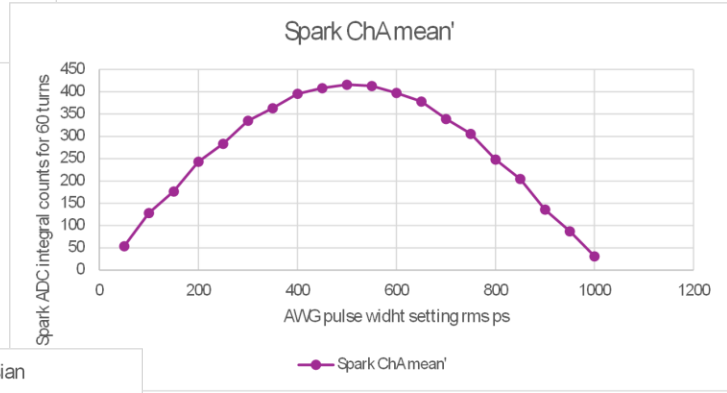
Dependency over pulse length

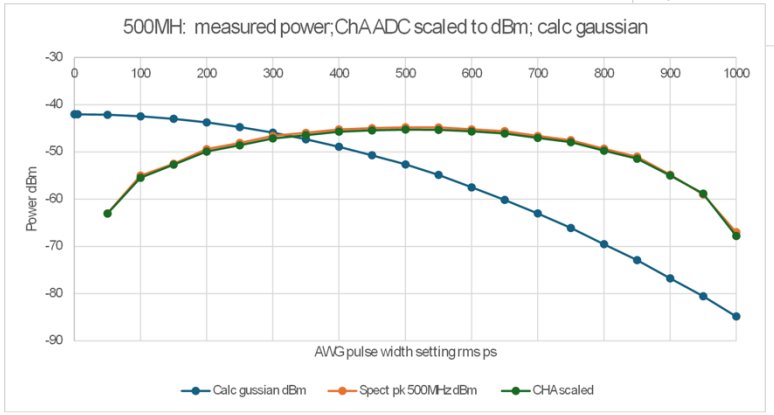
- An AWG from Tektronix (50 GSps) (pulse length down to 50 ps) was used for this test
- Dependency over pulse width?

  - Set of measurements varying bunch length 50 ps to 1 ns (a square signal), the signal peak kept almost constant
  - The output signal from the AWG was also readout on the oscilloscope (extract pulse length and peak value)
  - The AWG output was also connected to the spectrum analyser to measure the power of the 499 MHz component of the generated signal.
  - The scaled integral of the ADC counts follow the profile of the 499 MHz component power
  - Compared to Gaussian signal, we don't expect further reduction of the power from the 499 MHz component

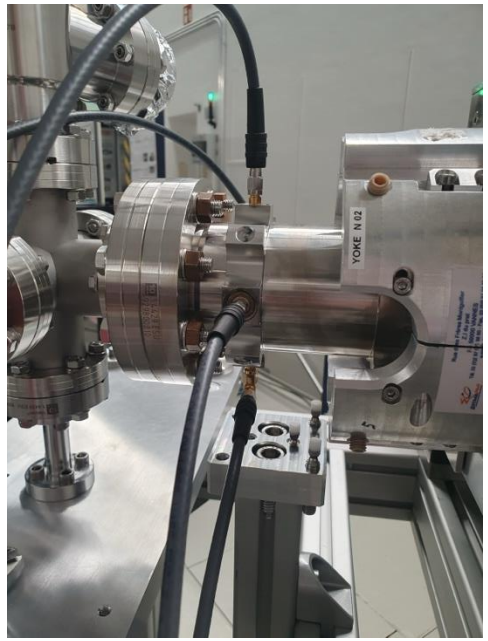


Attenuation set to 0 dB

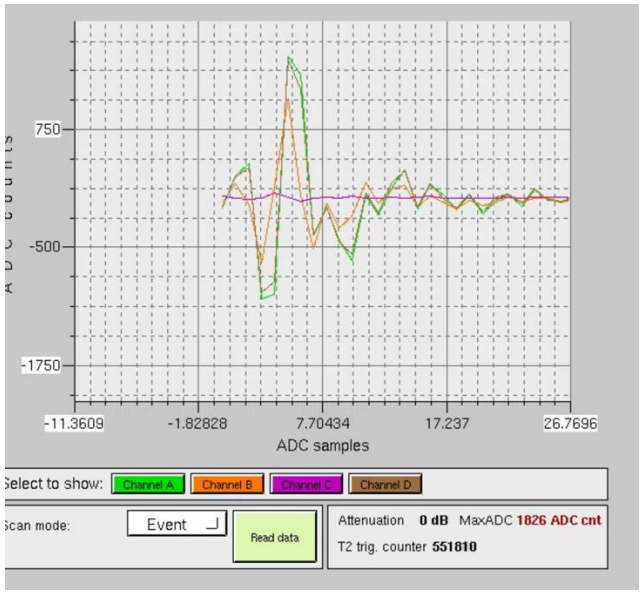




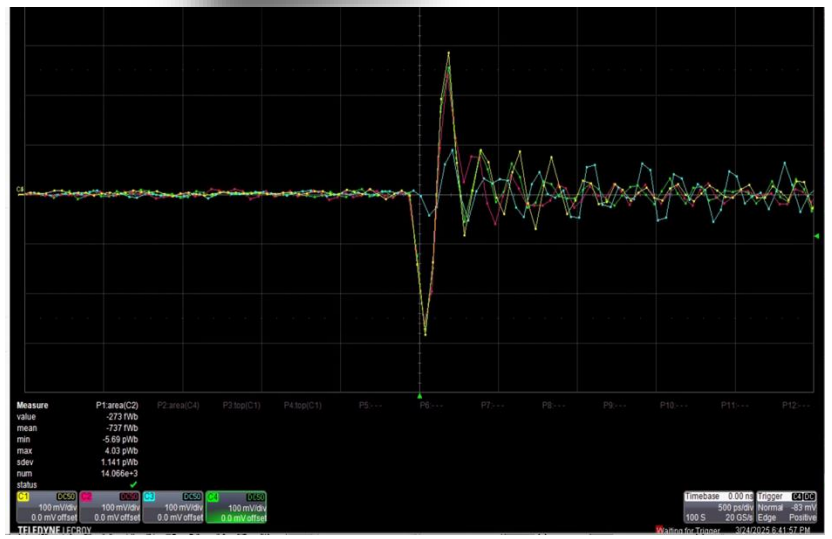
Tests with FLUTE beam



A cSTART prototype button BPM is mounted at the end of FLUTE Linac



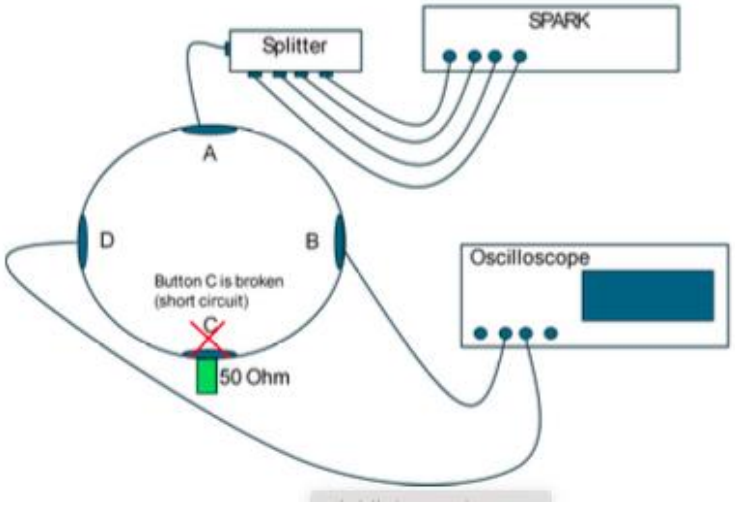
The four buttons connected to the Libera SPARK channels, A, B, C and D.



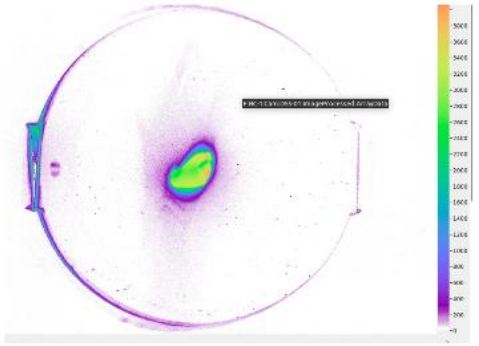
The four buttons connected to an oscilloscope

- One button is broken (channel C, bottom button): tested with a Network Analyser (short circuit)

Making the best out of the bad B-BPM measurements



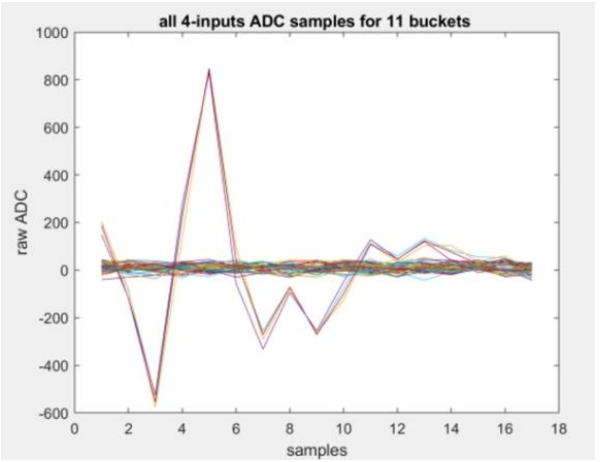
One button is split into four outputs and connected to SPARK



Beam observed on the last screen before the B-BPM block

Oscilloscope measurements

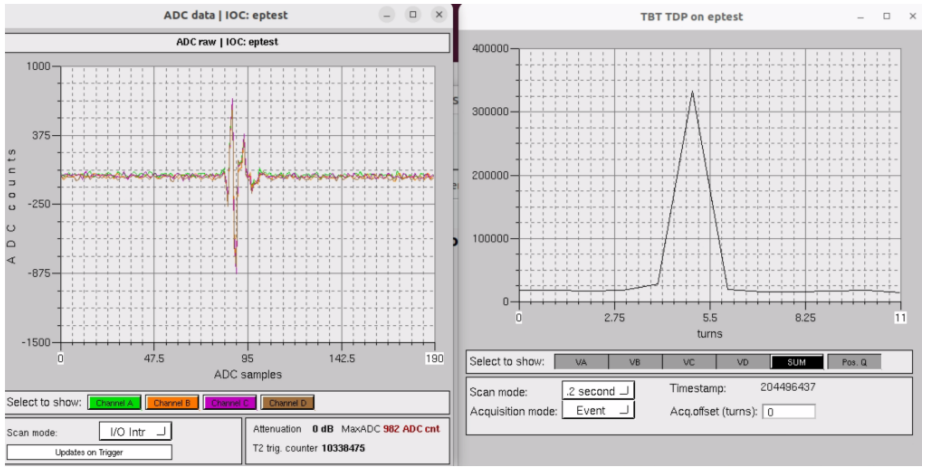
- Note: Physical apertures of the beam pipes don't match Flute beam pipe aperture: 38 mm, B-BPM block: 62 mm (cSTART): wakefields?
- Data analysis:
  - 100 successive injections were analysed
  - For each injection, the bunch occupies the 6th bucket (after the trigger delay was adjusted carefully)



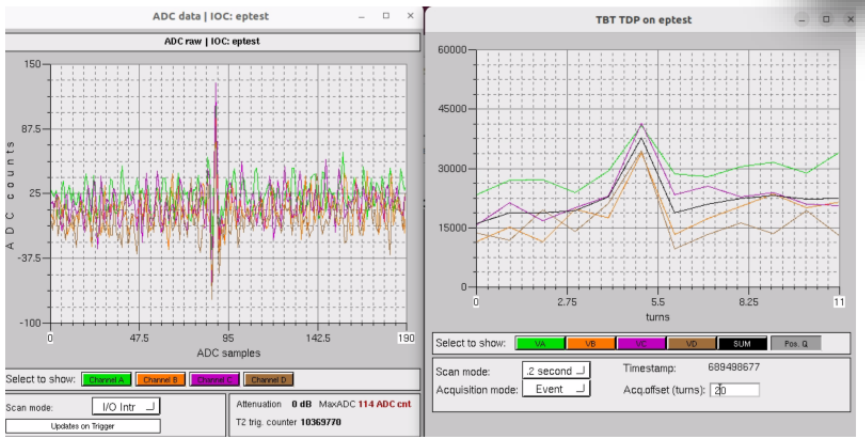
6th bucket

Measurements at different bunch charges

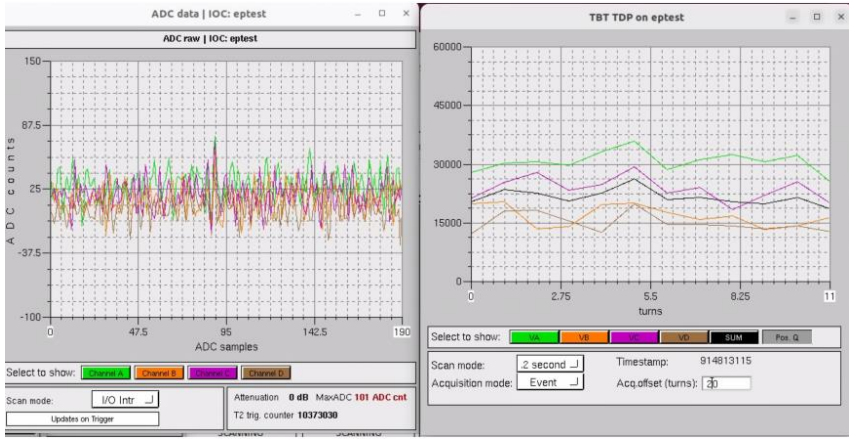
54 pC



5 pC

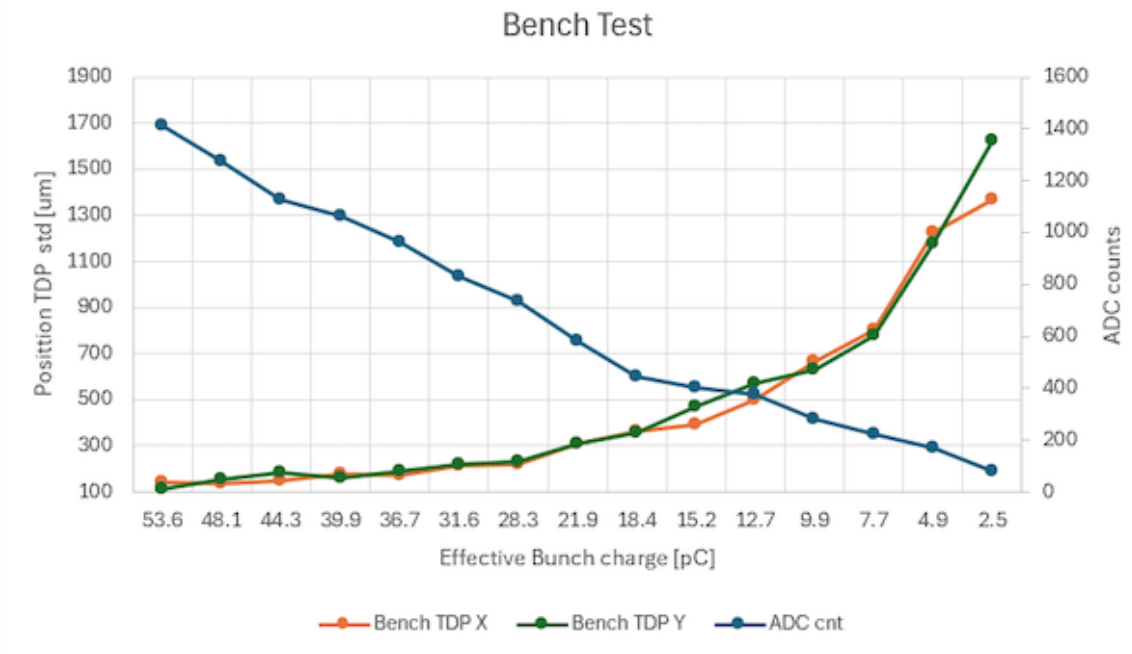


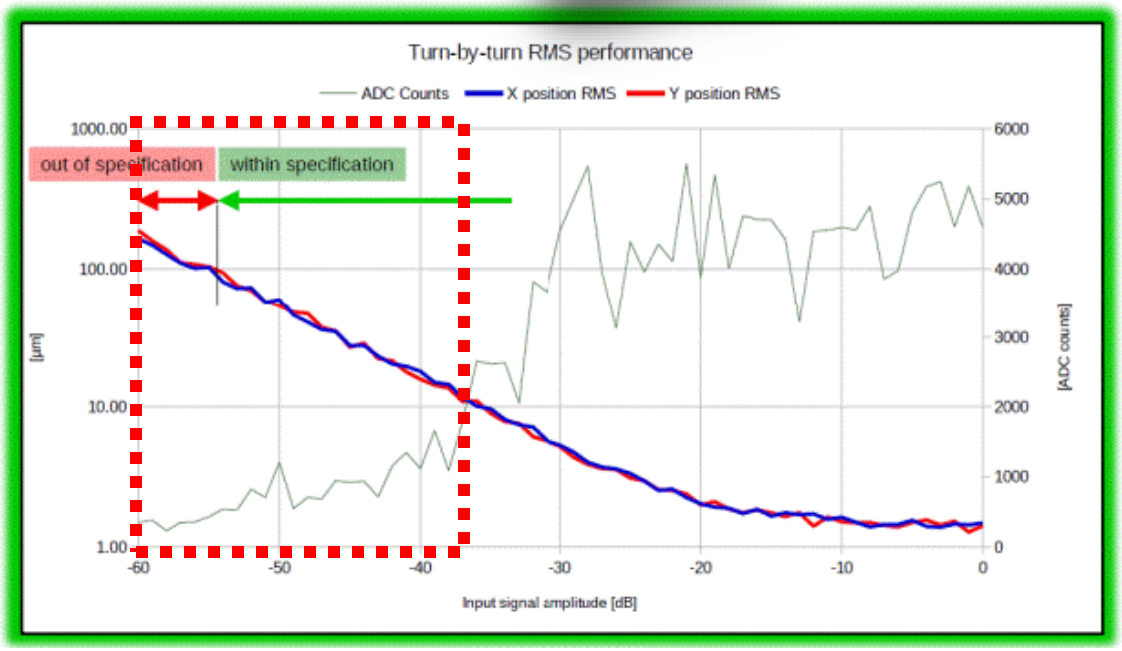
2.5 pC



- The maximum attained bunch charge I_B at FLUTE was 200 pC
- Effective bunch charge is then Q_b divided by four (splitter)
- Processed ADC counts were calculated for different bunch charges $\sqrt{(\sum_{i=1}^{17} x_i^2)}$

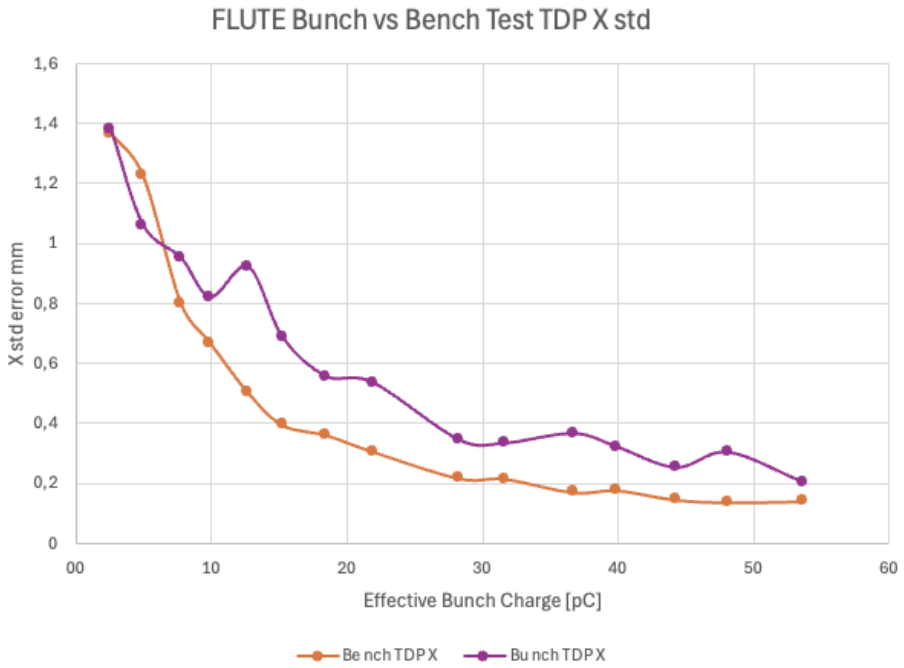
Resolution with signal generator

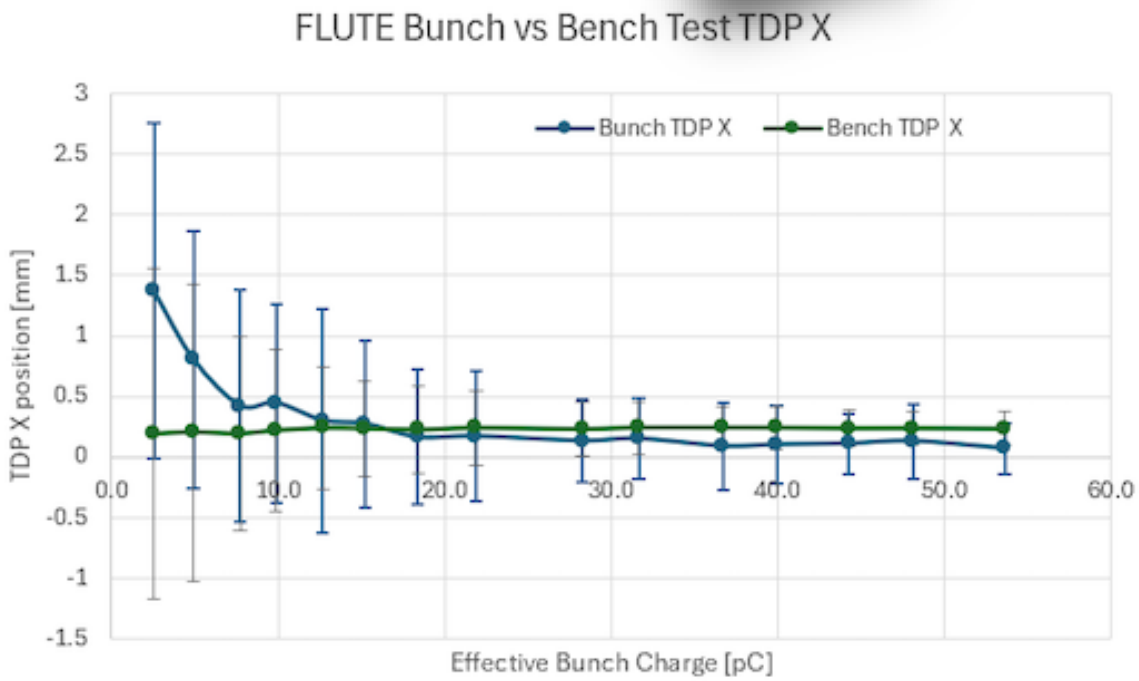




- At 20 pC we are at almost 300 µm resolution
- Considering the option of using amplifiers (low noise RF amplifiers: Gain 30 dB), to be ordered and tested

Resolution with FLUTE bunch





- FLUTE laser was not very stable and jittered pretty much during the tests
- This translates to the std of the turn-by-turn position measurements (are wakefields contributing to the errors as well?)
- The absolute positions between tests performed with the FLUTE bunch and the signal generator agree within error bars

Summary and outlook

- The cSTART project at KIT is in the phase of its final design report
- Few diagnostics and instrumentations are being tested either on the bench or with an electron bunch at FLUTE
- The beam position instrumentation: Libera SPARK ERXR has been modified for the cSTART project
  - A prototype has been delivered to KIT and tested
  - Tests with a signal generator and an AWG revealed **a very small turn-to-turn overlap (6 %)** and the **independency of the Libera readout on the bunch length**
  - Tests with the button BPMs at FLUTE allowed the **reconstruction of the position resolution against bunch charge**
  - **Overall the Libera SPARK seems to be performing well and within specifications down to 50 pC**
- Further tests and analysis are still in progress to identify error sources and try to compensate for them
- RF pre-amplifiers will be ordered and tested at KIT

Acknowledgments:

The cSTART team:

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Thank you very much for your attention

Questions and/or Suggestions??