Experimental tests for the CLIC extraction kicker system at ALBA

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on behalf of the ALBA and CERN team

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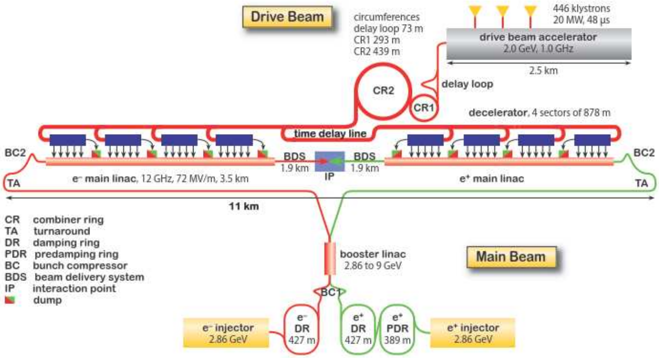
- Introduction:
  - CLIC damping ring extraction
  - Stripline kicker
  - Inductive adder
- Experimental set-up at ALBA
- Stripline installation issues
- Transverse homogeneity - High Voltage DC
- Pulse flatness - Inductive adder

Introduction: CLIC damping ring beam extraction

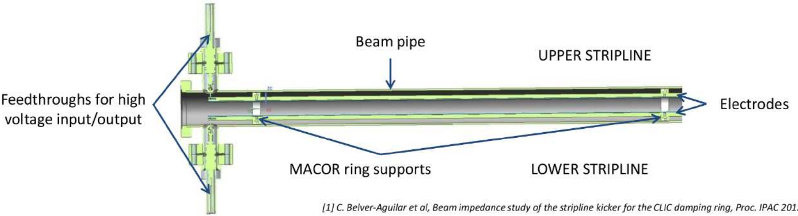
- Damping ring beam extraction affects directly collider luminosity
- To ensure a repeatable extraction process a special stripline kicker and pulser unit was developed
- ALBA signed an agreement signed with CERN to characterize the stripline with beam at ALBA Storage Ring



Stripline design and requirements

- Beam pipe ID: 40.50mm
- Total length: 1.7m
- Electrodes hold by MACOR rings
- Electrode-to-electrode gap: 20mm

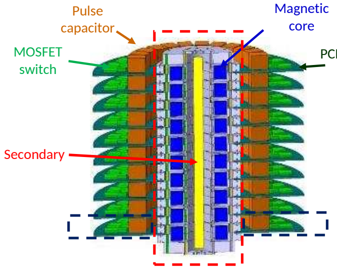
CLIC Stripline parameters	
Kick angle, mrad	1.5
Effective length, m	1.7
Good Field Region, mm	±1
Field homogeneity	$\pm 2 \cdot 10^{-4}$
Flat top reproducibility	$\pm 1 \cdot 10^{-4}$
Pulse rise & fall time, ns	100
Pulse flat top, ns	160 - 900

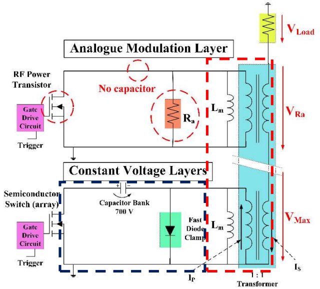


[1] C. Belver-Aguilar et al, Beam impedance study of the stripline kicker for the CLIC damping ring, Proc. IPAC 2012

Extremely flat pulse modulator: Inductive adder

- A high voltage pulse is buildup by magnetically adding the discharge of many capacitors
- Each capacitor is discharged independently by a MOSFET into a single-turn coil
- The coil serves as the primary winding of a transformer
- The transformers secondaries are stacked in series to provide a high voltage pulse
- In some of the discharge circuit the capacitor is replaced by a resistive element to provide some degree of modulation of the pulse shape

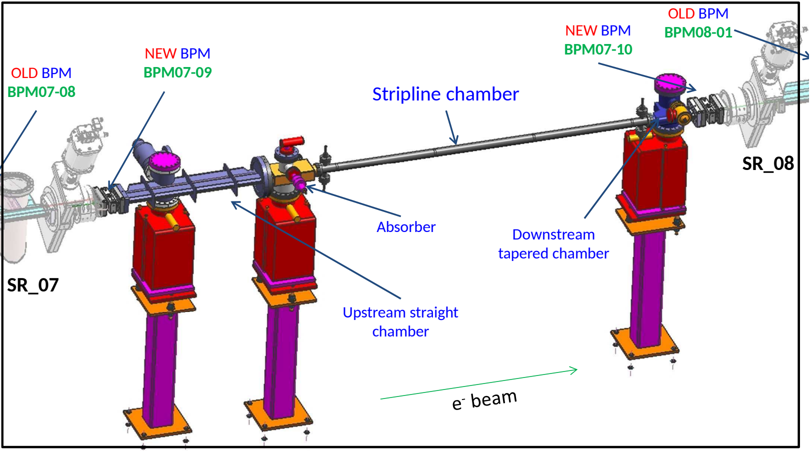




"A Pulse Power Modulator with Extremely Flat-top Output Pulses for the Compact Linear Collider at CERN"
J. Holma, PhD Thesis, Aalto University, Helsinki 2015.

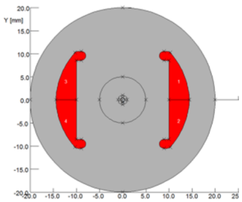
Experimental set-up at ALBA

- The stripline was housed in an ALBA 4m medium straight section
- 2 more BPMs were installed to easy the characterization process
- New vacuum pumps, radiation absorber and beam-pipe transitions were also required

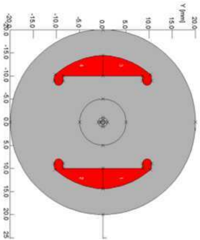


Stripline installation in ALBA

- The stripline is designed for horizontal beam extraction
- To avoid horizontal aperture limits was rotated by 90 degree when installed in ALBA



CLIC configuation

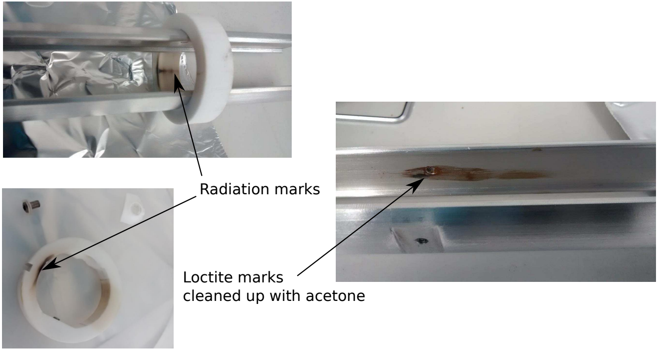


ALBA configuration

Stripline installation in ALBA

Issues...

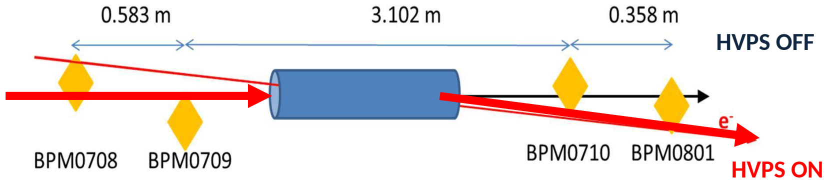
- Despite a long conditioning, vacuum issues were observed
- Standard machine operation (180mA) was not possible. After inspection, the cause was identified:
  - MACOR rings used to support the electrodes
  - LOCTITE 406 used to lock the threads



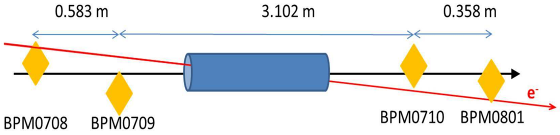
- Reworking the rings geometry and cleanup did not solved the issue
- It was decided to install the stripline solely during measurements

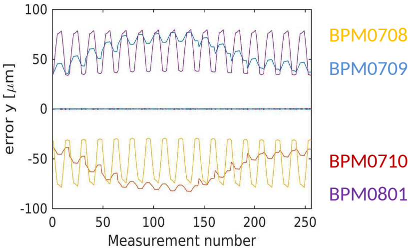
DC transverse homogeneity test

- Stripline powered in DC: 2 days to reach ±10KV and 13mA beam
- Beam deflection measured locally with 4 BPMs, no optics in-between
- 2 BPMs measure beam angle before and 2 after the stripline



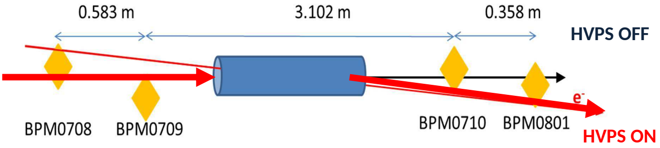
To avoid systematic errors BPM calibration is required

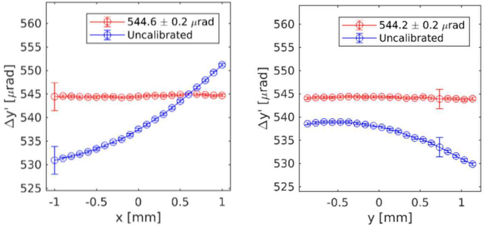




- Stripline is switched off $\rightarrow$ beam moves straight through the BPMs
- Transverse beam position is scanned ($\pm$1mm bumps) and the BPMs gain, offsets and rolls fitted from the measured positions

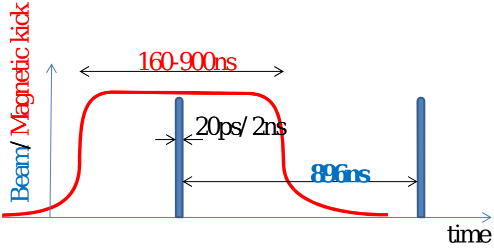
DC transverse homogeneity results





- Stripline powered in DC at ±10KV, beam position ±1mm
- Measured kick: 544.4±0.2 urad, (560 urad expected)
- Homogeneity: $3.7 \cdot 10^{-4} \pm 5.3 \cdot 10^{-4}$ (CLIC requirements: $< 2 \cdot 10^{-4}$)

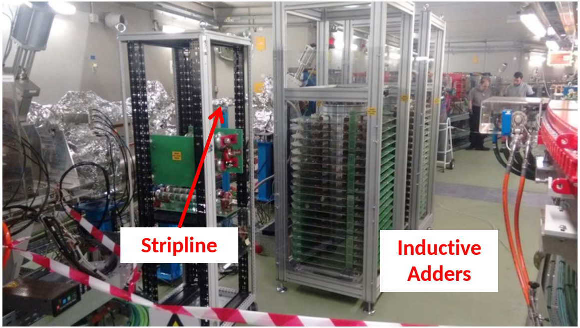
Longitudinal homogeneity: field flat-top flatness



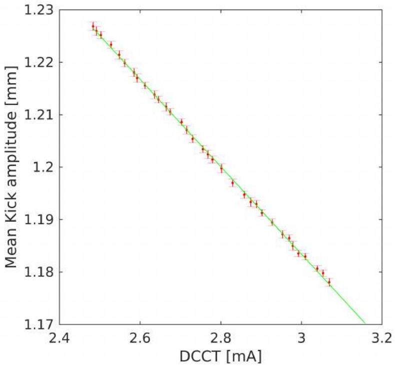
- Single bunch operation ($\sim$2/3mA)
- Stripline pulse delay is scanned to inspect the flat-top (50 steps)
- Kick amplitude is inferred from 120 turn-by-turn BPMs, 500 turns averaging over 50 shots

Longitudinal field homogeneity with inductive adders

- Inductive adder installed in the tunnel to avoid long cables
- 2 Inductive Adders: one for electrodes
- Pulse length 160 $\rightarrow$ 900ns at $\pm$5KV (10KV electrode-to-electrode)

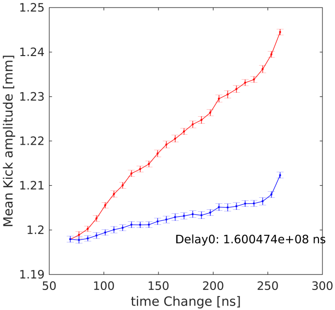


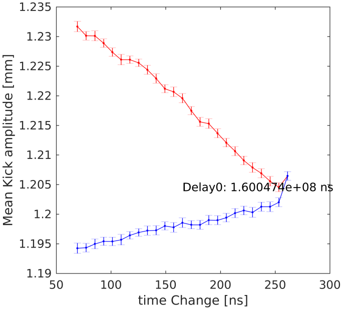
Effect of current decay on BPMs signal

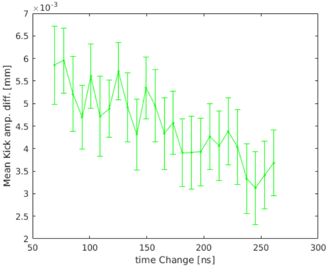


- Measurements extend over a long time (~1h)
- Current drop is not negligible (operating in single bunch)
- The change in current affect BPMs measurements in several ways (decoherence, tune-shift, BPM gain...)
- To mitigate the problem the BPMs response was characterized at different current settings

BPM current decay compensation

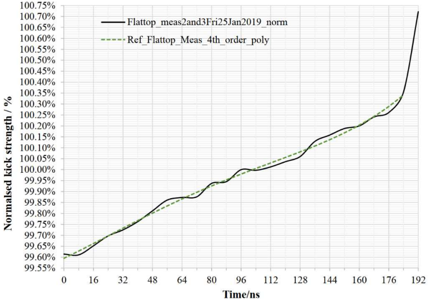




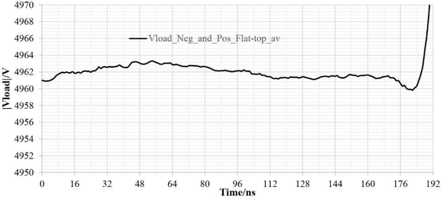


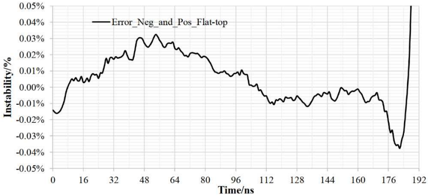
- Measurements are repeated 2 times: scanning the pulse profile back and forth
- Data are corrected for current dependency
- Difference between the 2 corrected scans should be zero

Longitudinal field homogeneity with inductive adders

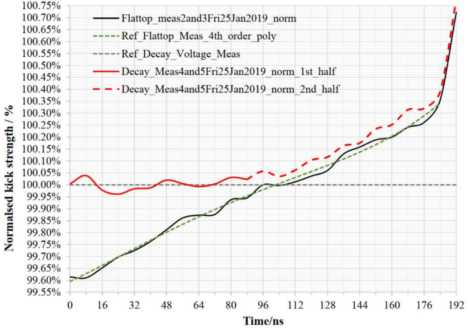


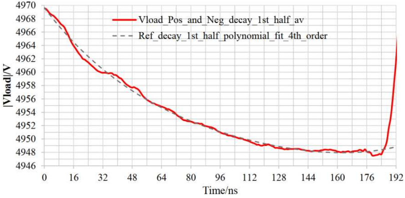
- First beam-based measurement (top)
- flat-top was optimized looking at the dummy-load voltage (bottom)
- The slope observed in the beam-based measurement is expected
- Voltage flatness at the dummy-load <0.03% (bottom right)
- The analog modulation layers will be tuned to compensate the slope





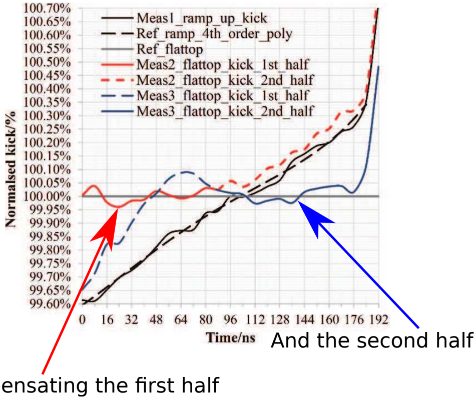
Partial flat-top compensation with analog modulation layers





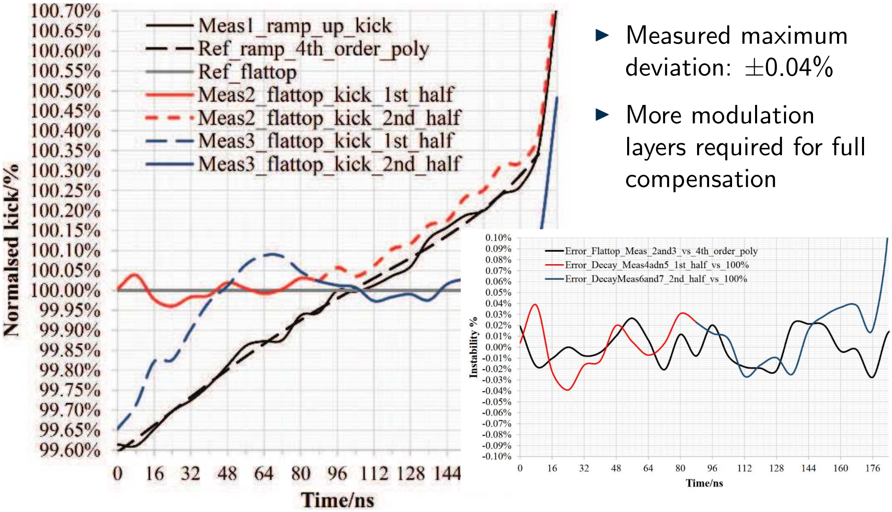
- Analog compensation layers are tuned to flatten the kick
- Lack of dynamic range does not allow to compensate the whole flat-top
- Only the first 88ns are flattened

Compensating the second half of the kick



- The flat-top from 88 to 176 ns is now correctly compensated
- Resulting in a bad compensation of the first half (0 to 88 ns)

Longitudinal field homogeneity with inductive adders



- Measured maximum deviation: $\pm 0.04\%$
- More modulation layers required for full compensation

Conclusions

- A full-scale prototype of the CLIC extraction kicker, including the stripline and two inductive adders, has been tested in the ALBA storage ring.
- Some design ingenuity have been highlighted:
  - MACOR exposed to beam radiation $\rightarrow$ not vacuum compatible
  - Different geometry or material should be used
- Degassing and arching have been the biggest limiting factor during tests:
  - The stripline could not be installed permanently in ALBA
  - Limited time for the actual measurements $\rightarrow$ tight schedule!
- The stripline voltage was limited by degassing and was not the optimal for the inductive adder operations
- Therefore a full compensation of the flat-top slope was not possible
- Nevertheless the results from beam-based measurements are fully consistent with the one obtained with electrical measurements
- No major limitation was highlighted: CLIC specifications should be completely within reach with the actual set-up