FIRST PROTOTYPE OF THE CLIC DRs STRIPLINE KICKER

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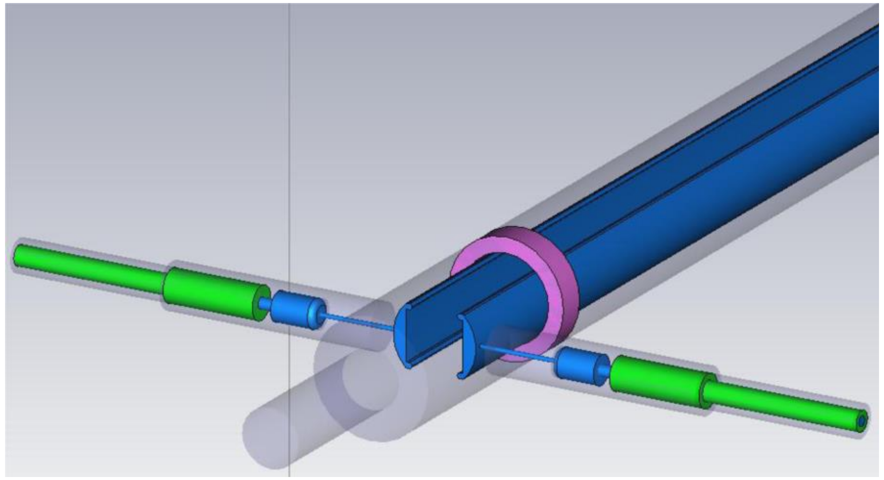
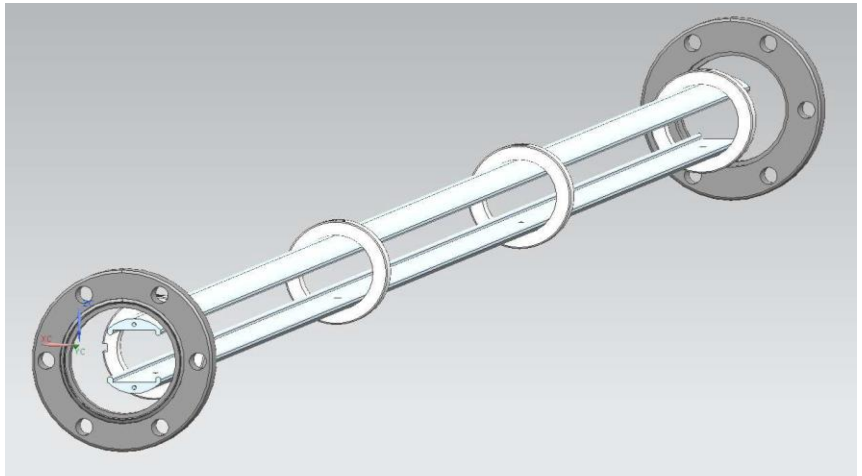
Acknowledgment to M.J. Barnes (CERN) and M. Pont (ALBA)

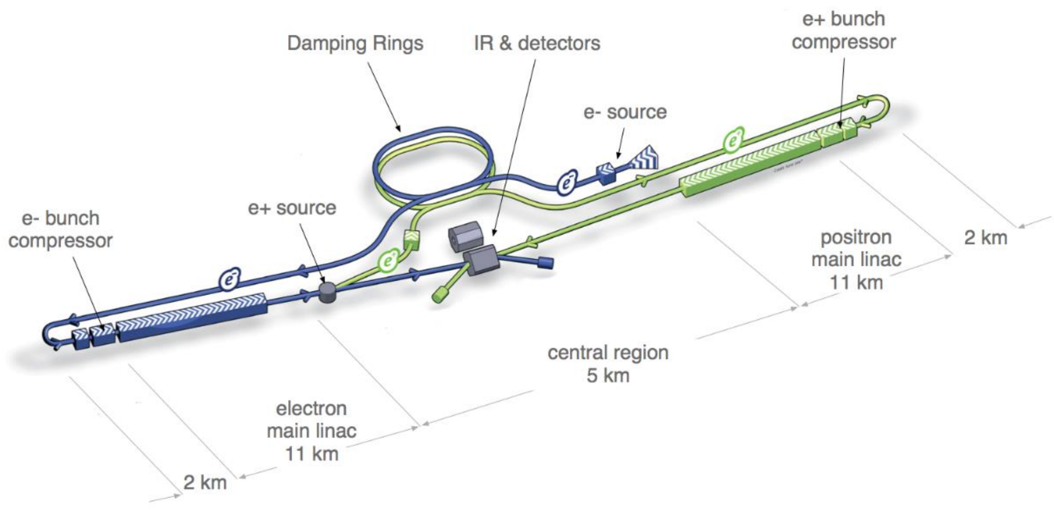
Outline

1) Possible future Linear Colliders: ILC and CLIC
2) Damping Rings for CLIC
3) CLIC DR Extraction Kickers
   - Concept and Manufacturing
   - Characterization
4) Goals for Measurements
   - Beam Coupling Impedance
   - Transverse Field Homogeneity
   - Field Flat-top Stability, Pulse-to-Pulse Repeatability
5) Measurements on Prototype Stripline Kicker at Alba
   - Installation
   - Issues with Macor Rings
   - Proposals for Revision of Macor Rings
6) Conclusions and Future Work



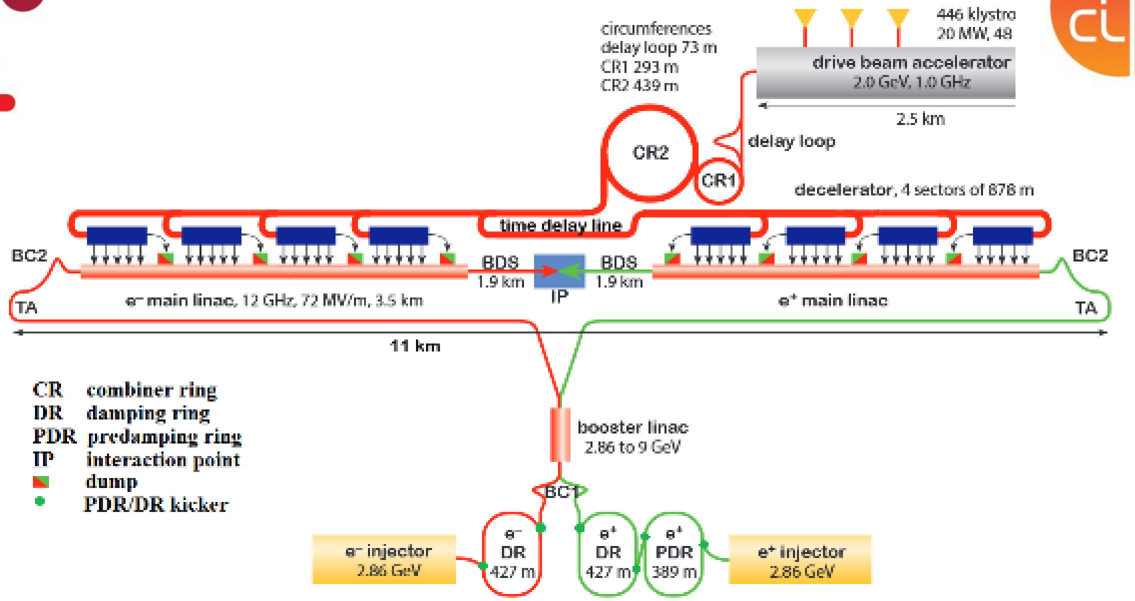


1. The Future Linear Colliders



Superconducting RF technology.

Bunch by bunch injection and extraction systems → very fast kickers (T_p< 10 ns) with tight pulse-to-pulse stability (±7x10^{-4}), not a flat-top pulse.

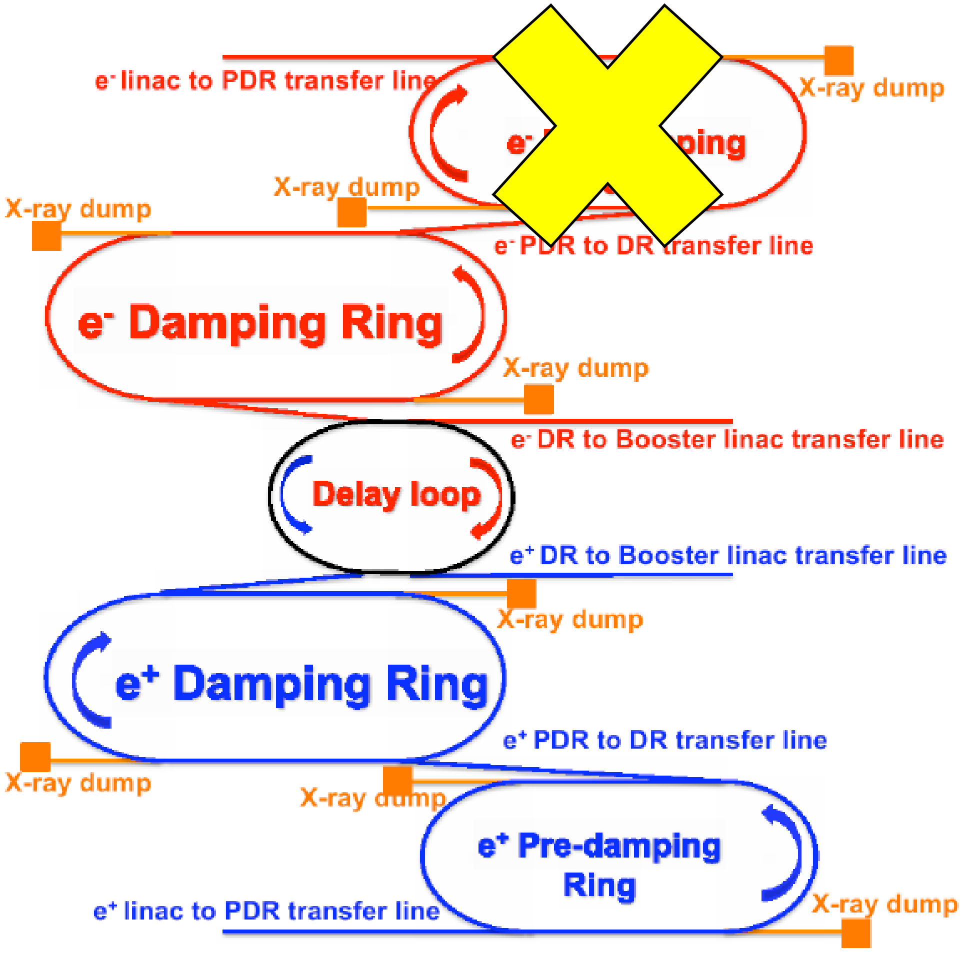


Normal conducting RF technology.

Injection and extraction of a **whole train of bunches** (312 bunches) → very stable flat-top pulse (±2x10^{-4}) over 160 ns, rise time 0.1…1 µs.

2. Damping Rings for CLIC

$L_{CLIC} = 6x\ L_{LHC} \rightarrow$ very low emittance beams

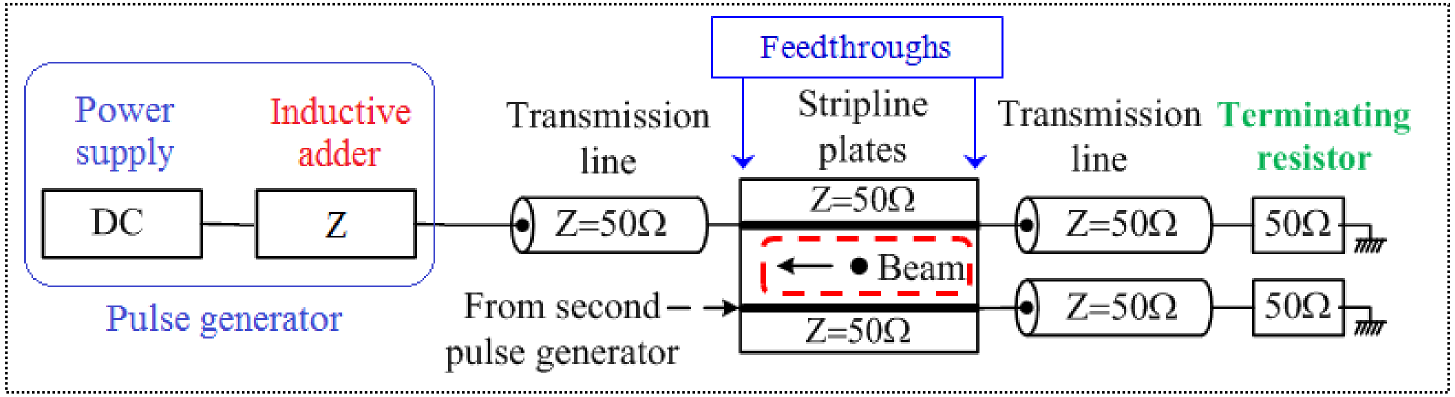


Electron beam parameters	CLIC DR (2 GHz)
Beam energy	2.86 GeV
Circumference	427.15 m
Bunch population	4.1×10^9
Extracted normalized horizontal emittance	0.5 µm
Extracted normalized vertical emittance (geometrical emittance)	**5 nm** **(< 1 pm)**
Number of bunches	312
Bunch spacing	0.5 ns
Bunch length	1.8 mm

1 pm in ASP and SLS

3. Technological Choice of the Extraction Kicker for CLIC DRs

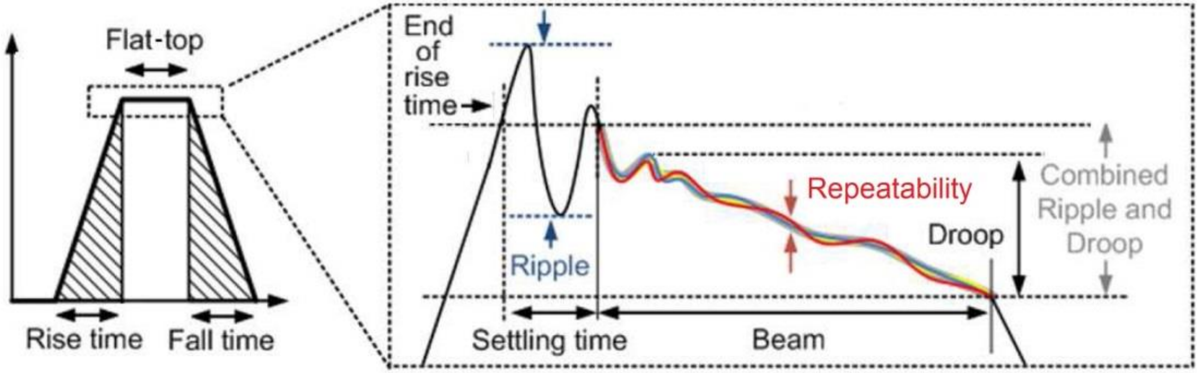
Inductive Adders: Talk by J. Holma



Simplified schematic of a kicker system (Courtesy of J. Holma)

Main challenges:

- Extremely tight requirements for field flat-top stability and repeatability:
  - Field flat-top repeatability: ±0.01 %.
  - Field flat-top stability [droop + ripple] (at extraction): ±0.02 %
- Rise/fall times ≤ 100 ns desired.



CLIC DR kicker pulse definition

3. Technological Choice of the Extraction Kicker for CLIC DRs

Striplines

Main challenges:

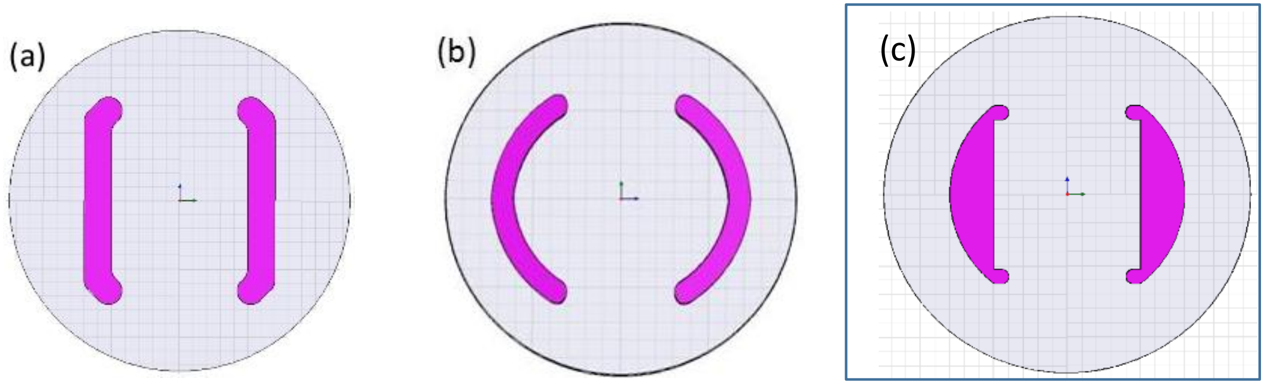
- Excellent **field homogeneity**: ± 0.01% over 1 mm radius.
- Good **power transmission**: $S_{11} < 0.1$ up to 10 MHz.
- Very low **beam coupling impedance**: 0.05 Ω/n in the longitudinal plane and 200 kΩ/m in the transverse plane.

Previous studies of the injection and extraction kickers for the ILC DRs and the CLIC CR, have demonstrated that the stripline kicker is the most suitable technology.

- ILC DR injection kicker (DAΦNE): higher field inhomogeneity than is permissible in CLIC.
- ILC DR extraction kicker (ATF): short striplines (≈ 30 cm); field inhomogeneity above CLIC specifications.
- CLIC CR extraction kicker (CIEMAT): higher field homogeneity, same effective length (1.7 m). This geometry was studied initially.

What did we do?

1) **Design of the striplines.**
   - Analytical studies and numerical simulations with Quickfield (2D), HFSS and CST.
   - Consideration of the two operation modes of the striplines: odd mode (seen by the kicked beam) and even mode (seen by the circulating beam).
   - Proposal of a new electrode shape: half-moon electrodes.



- Better impedance matching

$Z_{even} = 50\ \Omega;\ Z_{odd} = 40.5\ \Omega$

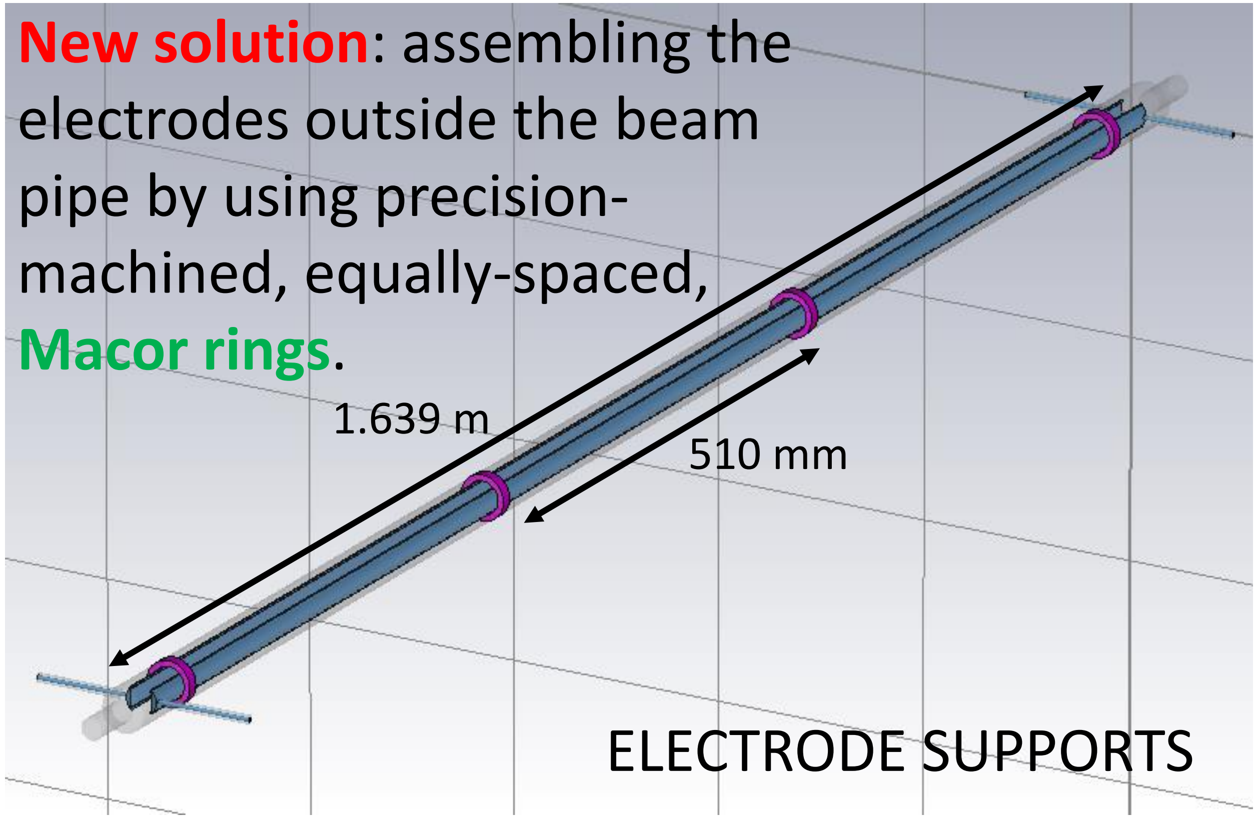
- Excellent field homogeneity

2) **Study of the components: feedthroughs and electrode supports.**
3) **Manufacturing of the prototype striplines by Vacuum Projects S.L., in Spain**
4) **Laboratory tests and measurements at CERN.**

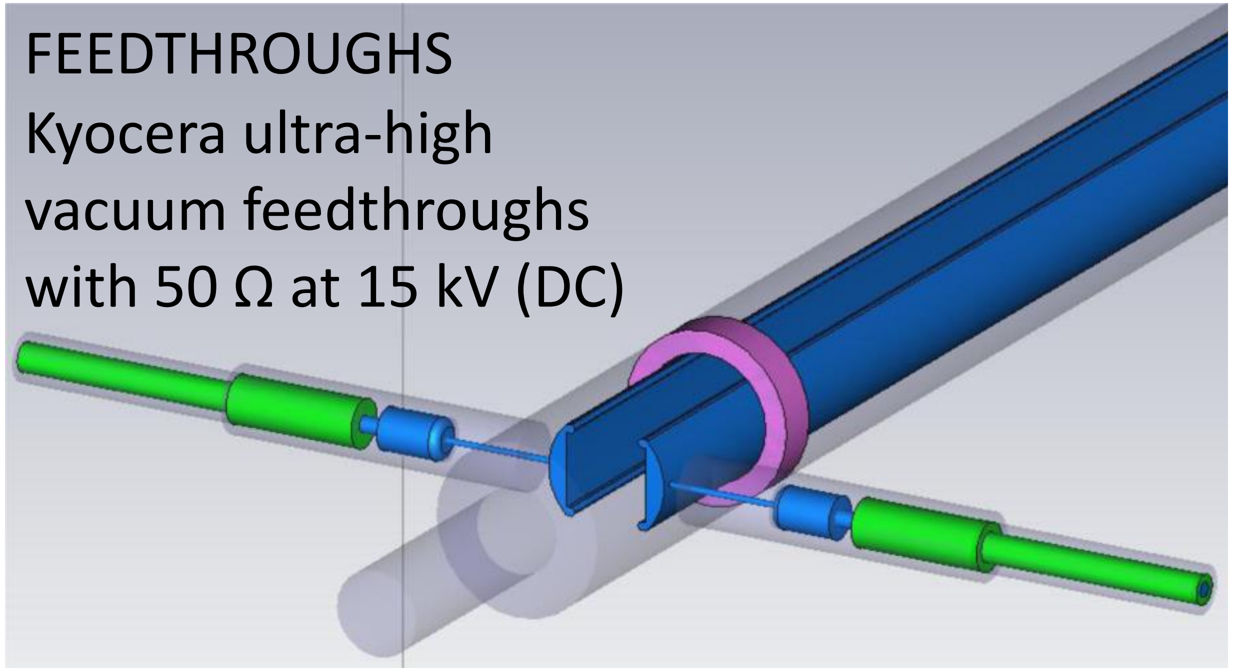
4. Components Study of the Striplines and Manufacturing

Two components may introduce additional impedance mismatch in the striplines: **electrode supports** and **feedthroughs**.

New solution: assembling the electrodes outside the beam pipe by using precision-machined, equally-spaced, **Macor rings**.

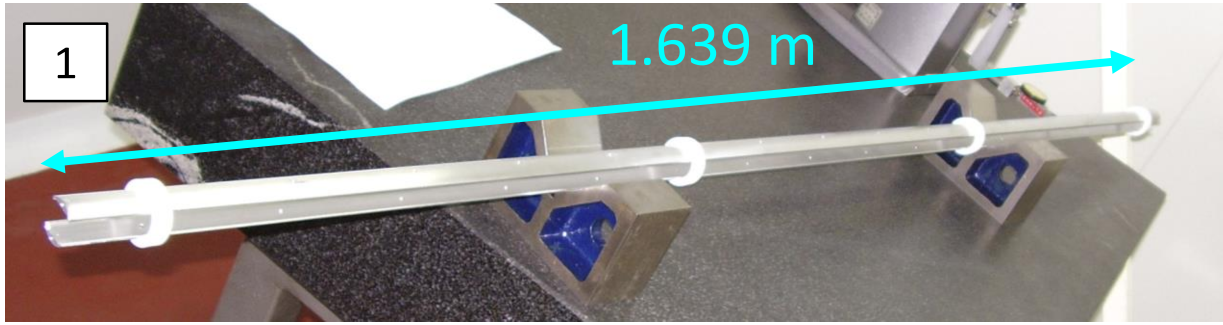


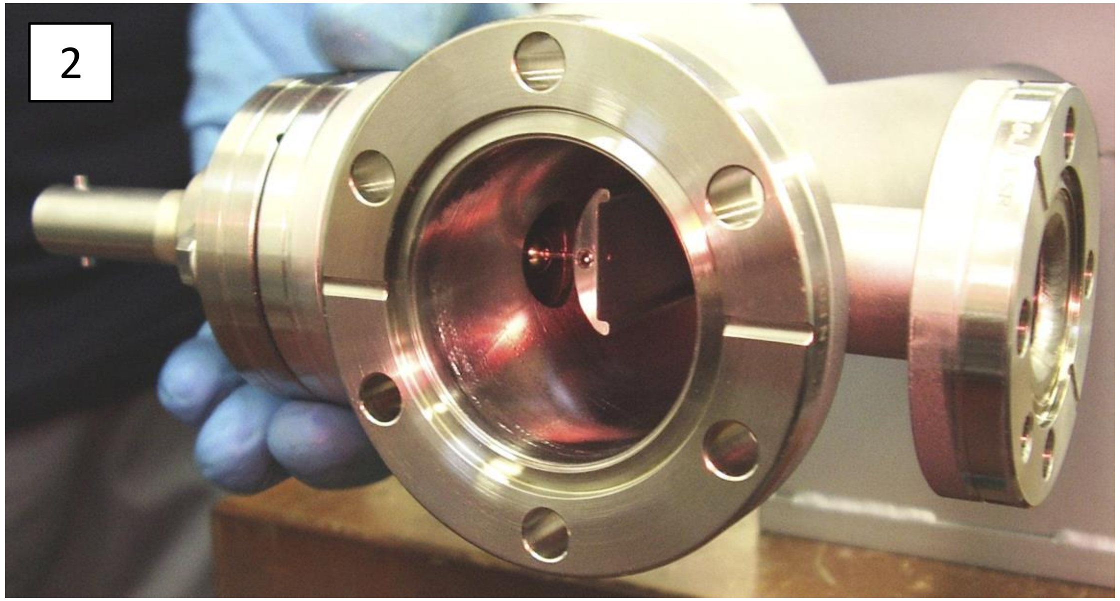
FEEDTHROUGHS
Kyocera ultra-high vacuum feedthroughs with 50 Ω at 15 kV (DC)



CST Microwave Studio (MWS) and CST Particle Studio (PS) have been used in order to study the effect of these components upon the **S_{11} parameter** and the **beam coupling impedance**.

4. Components Study of the Striplines and Manufacturing





1 The electrodes and the electrode supports are assembled outside the beam pipe. In current design, Macor rings are equally spaced (not optimum).

2 Once the electrodes position, separation and parallelism is verified, the assembly is introduced into the beam pipe.

5. Stripline Characterization Studies

Parameter	Analytical	Numerical	Measurement
Odd mode characteristic impedance	✓	✓	
Even mode characteristic impedance	✓	✓	
Field homogeneity		✓	
Reflection and transmission parameters		✓	✓
Beam coupling impedance	✓	✓	✓
HV DC breakdown test / conditioning			✓

NEXT STEP

Measurements with beam at ALBA:

- Striplines: beam coupling impedance.
- Striplines + HV DC power supplies: transverse field homogeneity.
- Striplines + inductive adders (talk by J. Holma): field flat-top stability, pulse-to-pulse repeatability.

8. What do we want to measure at ALBA?

1) Beam coupling impedance

- Beam coupling impedance is one of the most demanding requirements for the CLIC DR striplines: it has been analytically estimated, numerically calculated and measured in laboratory, but it is very important to fully characterize it with beam.

- Results from the lab measurements did not originally agree with analytical and numerical results for the transverse beam coupling impedance:
  - Latest measurements and their interpretations are now in agreement with the analytical and numerical predictions[1];
  - beam based measurements at ALBA are expected to confirm and complete this study.

- Neither HV DC power supplies nor inductive adders required.

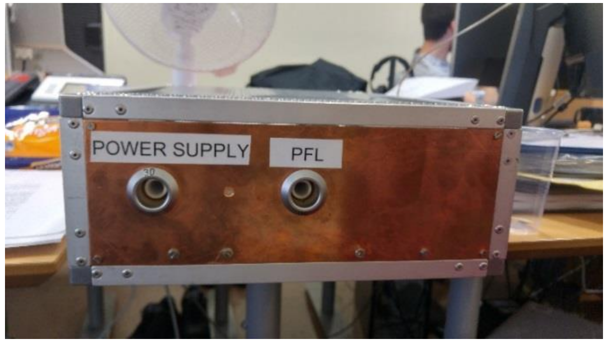
[1]This study has been published in the Proceedings of the IPAC 2017: C. Belver-Aguilar, M.J. Barnes, “Review of Stripline Beam Impedance: Application to the Extraction Kicker for the CLIC Damping Rings”.

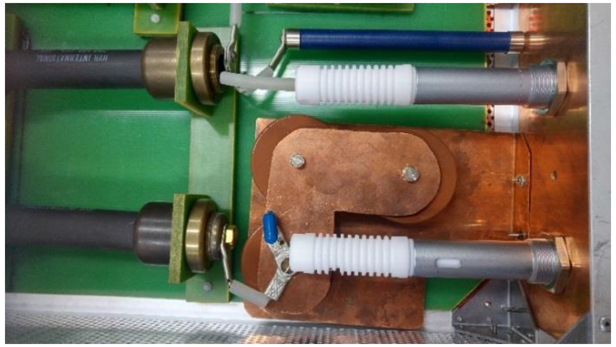
8. What do we want to measure at ALBA?

2) Transverse field homogeneity

- Field homogeneity is one of the most demanding requirements for the CLIC DR striplines: it has only numerically calculated (in 2D[2]), and it is very important to fully characterize it. The electric field will be characterized with beam at ALBA.
- HV DC power supplies required (provided by ALBA).
  - Influence of the beam: the breakdown voltage will probably be lower than in lab.
- A low-pass filter could also be required, to protect the power supplies from the voltage (estimated to be 45 – 60 V for a beam of 150 mA) produced by the image currents – presently being considered.
- For reliable results, issues with the Macor rings have to be solved (explained in following slides).

[2]Studies of field homogeneity in 3D using Opera have commenced, to take into account the end effects.

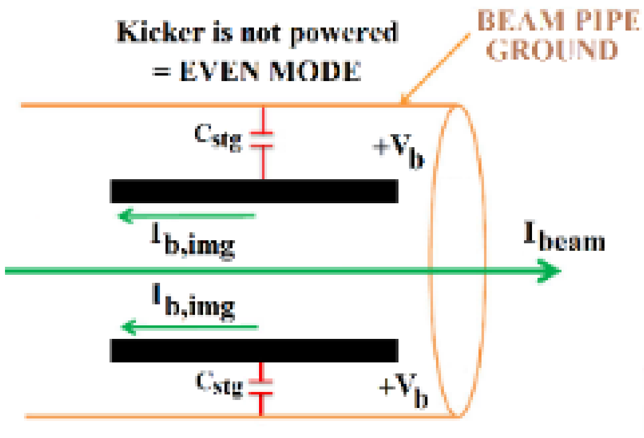




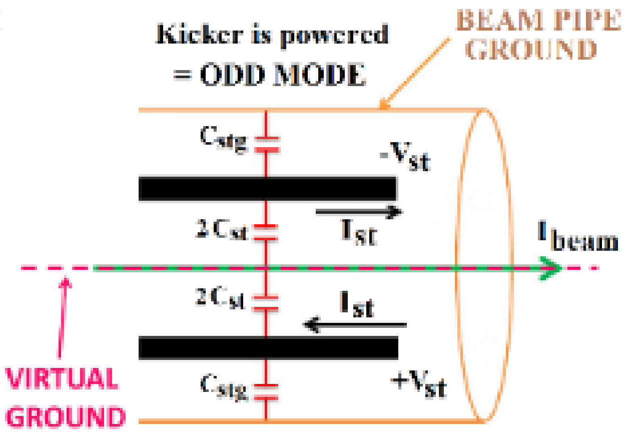
Example of a low-pass filter box used in CERN HV installations

3) Field flat-top stability and pulse-to-pulse repeatability, with inductive adders

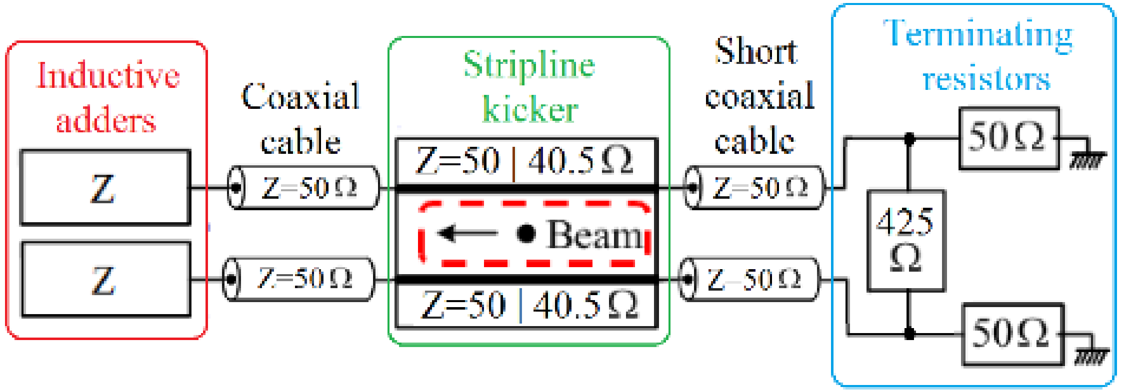
- Two inductive adders (Talk by J. Holma) are expected to be supplied by CERN to ALBA at the end of 2017.
- Impedance mismatching in the odd mode (kick mode) produces a lower magnetic contribution to the kick angle[3]. A special matching network will be implemented.



Z = 50 *Ω*



Z = 40.5 *Ω*



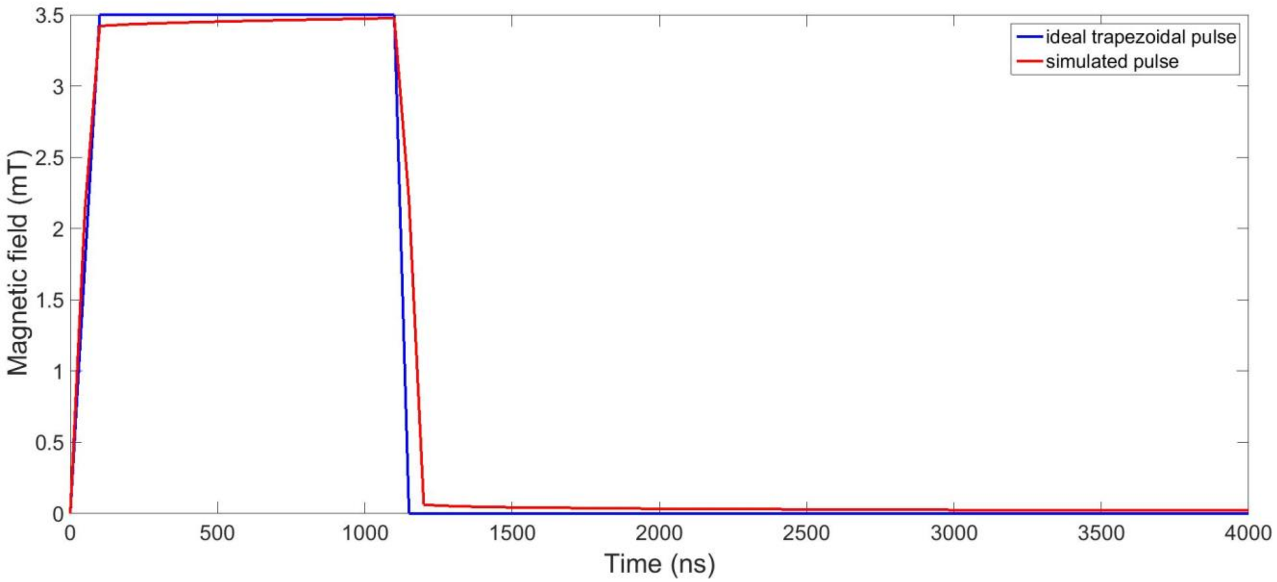
Z_{Term} = 50 | 40.5 *Ω*

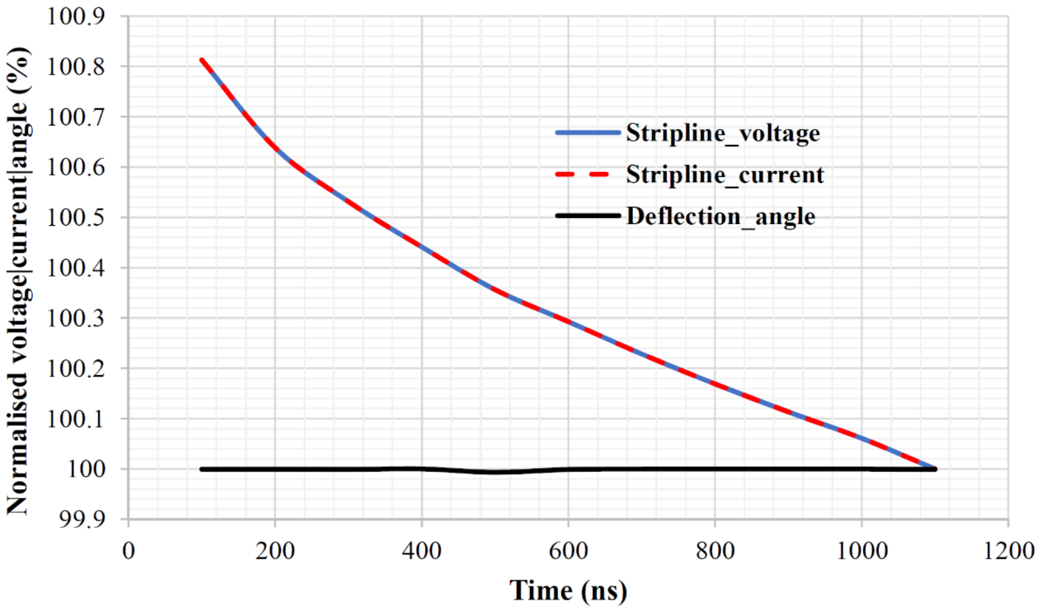
[3]Proceedings of the IPAC 2016: C. Belver-Aguilar, M.J. Barnes, L. Ducimitière, “Review on the Effects of Characteristic Impedance Mismatching in a Stripline Kicker”.

8. What do we want to measure at ALBA?

3) Field flat-top stability and pulse-to-pulse repeatability, with inductive adders

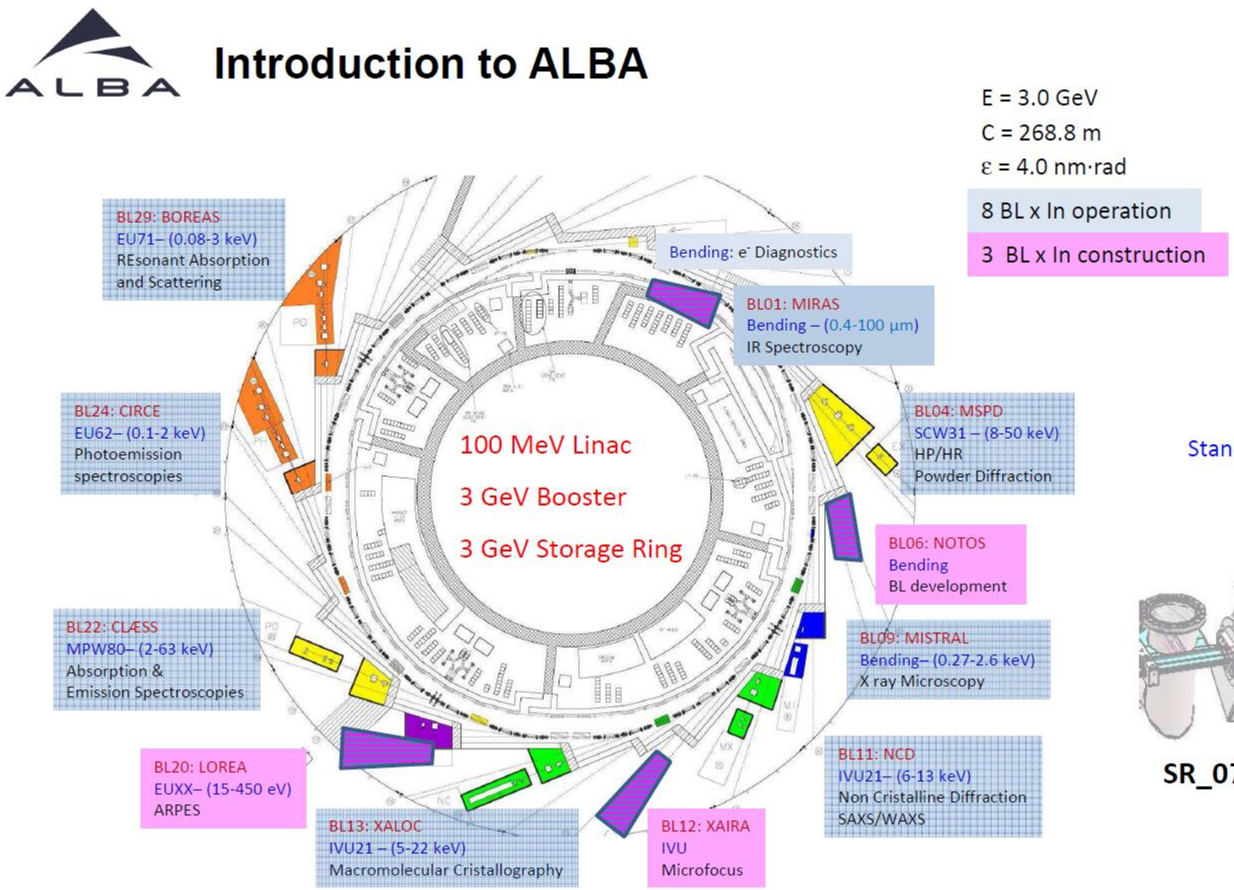
- Transient studies of the magnetic field have been completed:
  - A new waveform has been calculated, to improve the flatness of the magnitude of the magnetic field throughout the flat-top of the pulse[4]. For the optimum total deflecting electric and magnetic field, the voltage and current pulses for the striplines are “controlled decay waveforms”.



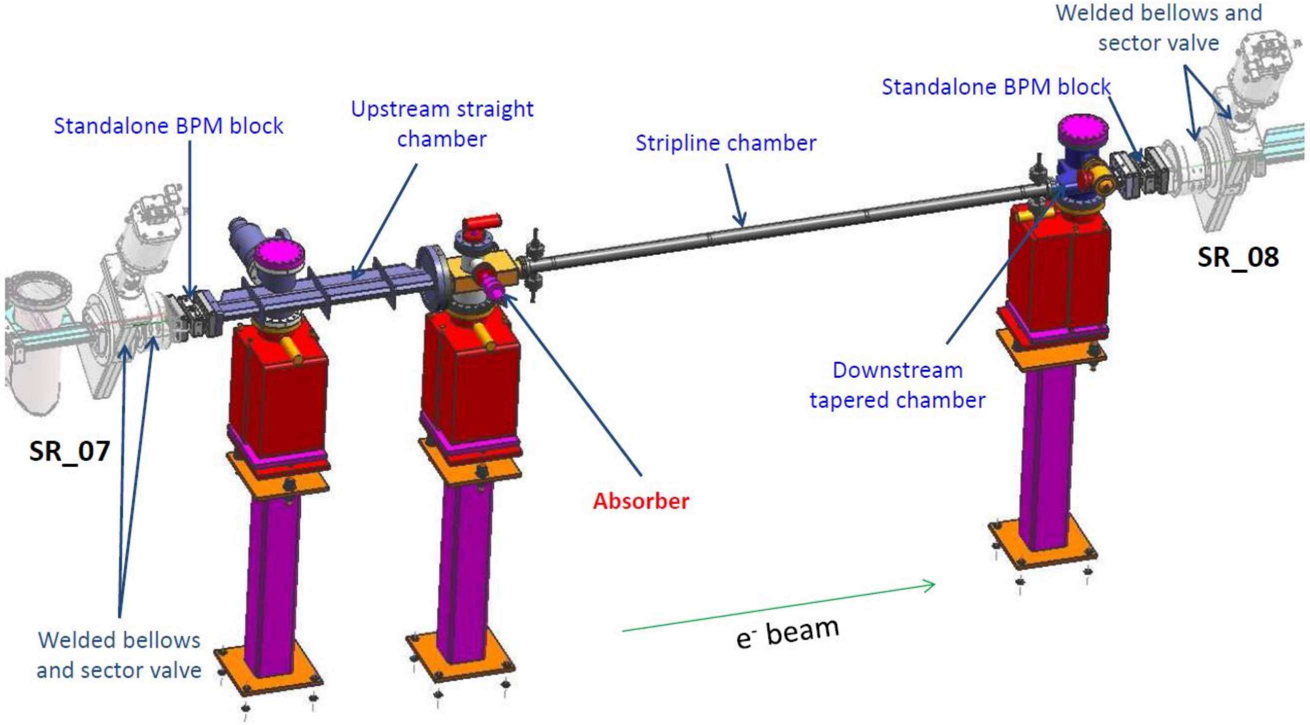


[4]Proceedings of the IBIC 2016: C. Belver-Aguilar, M.J. Barnes, “Transient Studies of the Stripline Kicker for Beam Extraction from CLIC Damping Rings”.

6. Striplines Installation at ALBA

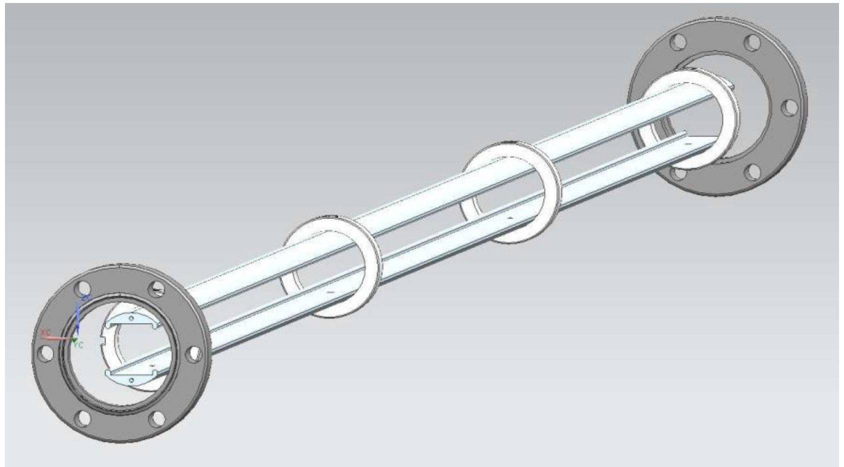


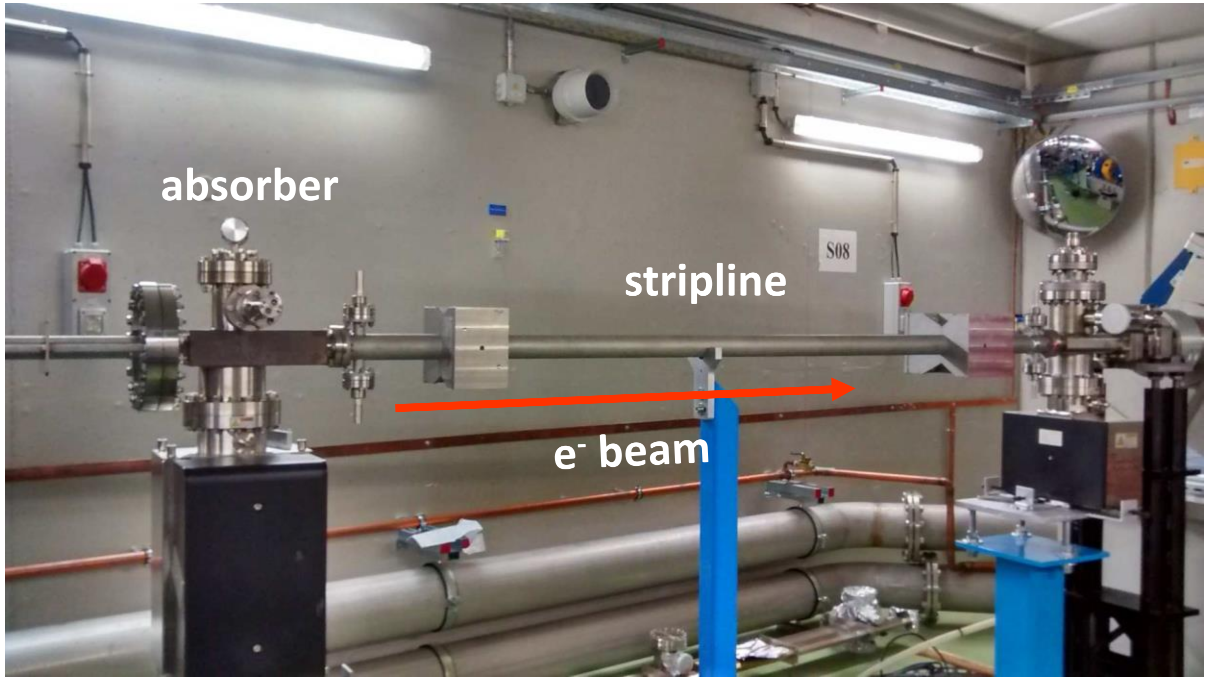
Where the striplines will be placed for testing? In a medium straight section of the storage ring.



6. Striplines Installation at ALBA

- Absorber design is critical:
  - Should protect the stripline from synchrotron radiation (SR).
  - Should not limit the horizontal aperture of the storage ring.
  - ✓ Proposed solution: rotate the stripline by 90° c.f. design: deflection would be in vertical direction.





First installation: January 2017

- The striplines were not terminated.
  - terminating resistors were not available.
- Estimated temperature at the electrodes could reach 80 °C, which seemed acceptable…

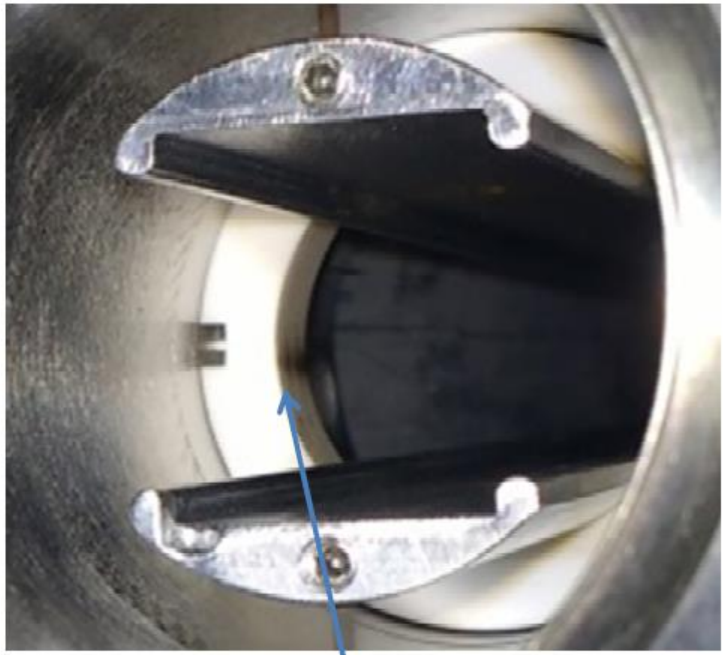
6. Striplines Installation at ALBA

… however, during conditioning with the beam,

For I > 110 mA, the pressure started to increase.

- Residual gas analyser (RGA, 10 m) showed a clean spectrum.

Zoom in at stripline exit, last MACOR ring



SR hitting the MACOR rings

<u>Sources of pressure increase inside the stripline</u>:

- Photo desorption due to SR on the absorber? No
- SR impinging on the MACOR rings?
- Thermal desorption?

Since the striplines were limiting nominal beam conditions for users (I = 150 mA), the stripline was replaced by a spare chamber.

6. Striplines Installation at ALBA

Second installation: March 2017

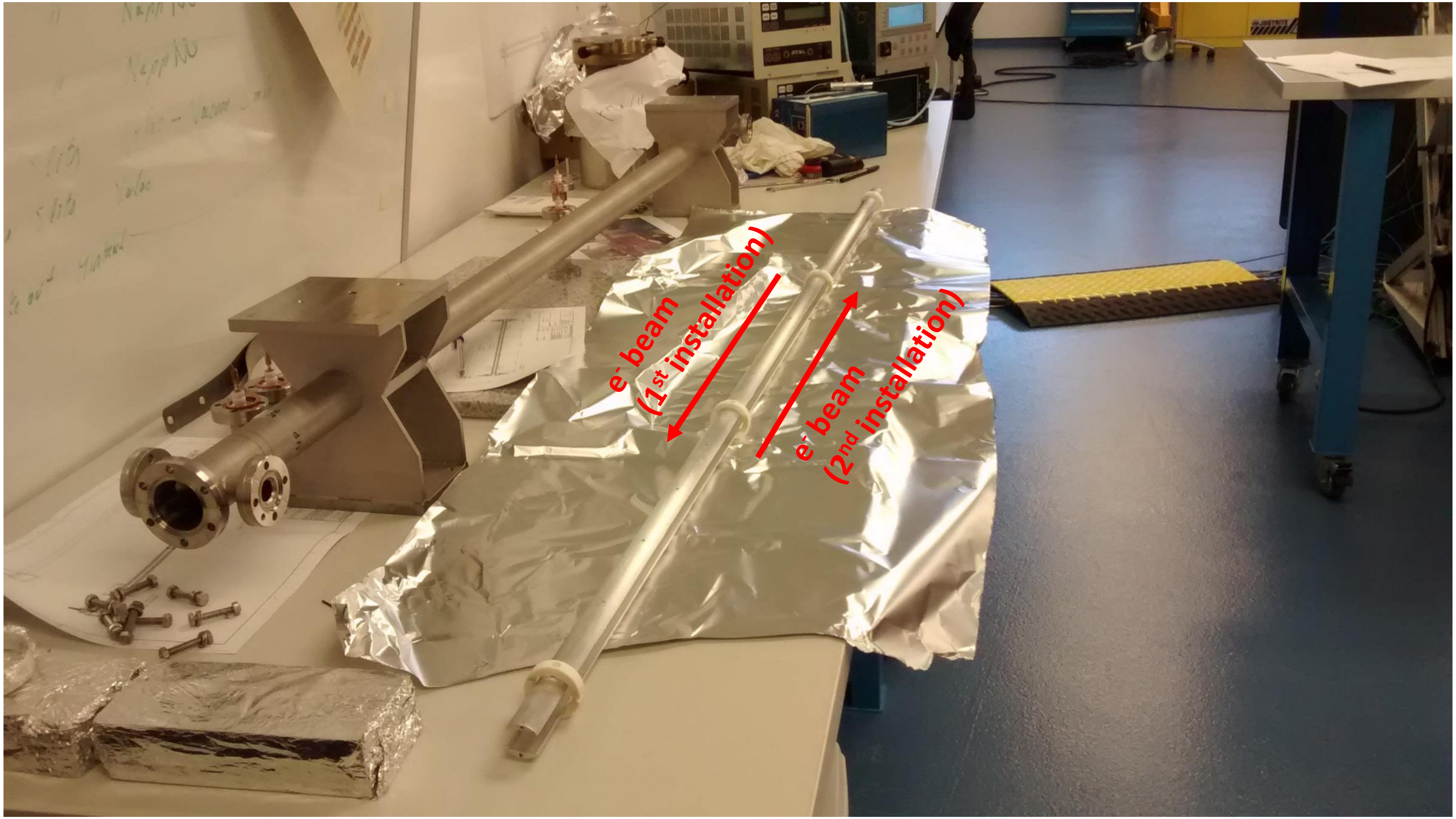
- The striplines were turned 180° regarding the beam direction, and re-aligned.
- The feedthroughs were connected via HV cables to terminating resistors.
- RGA installed next to the stripline.

For I > 135 mA, the pressure started to increase.

- Thermal desorption? No
- Macor degradation?

The stripline was replaced by a spare chamber and disassembled to analyse the Macor rings.

7. Macor Rings Studies



7. Macor Rings Studies

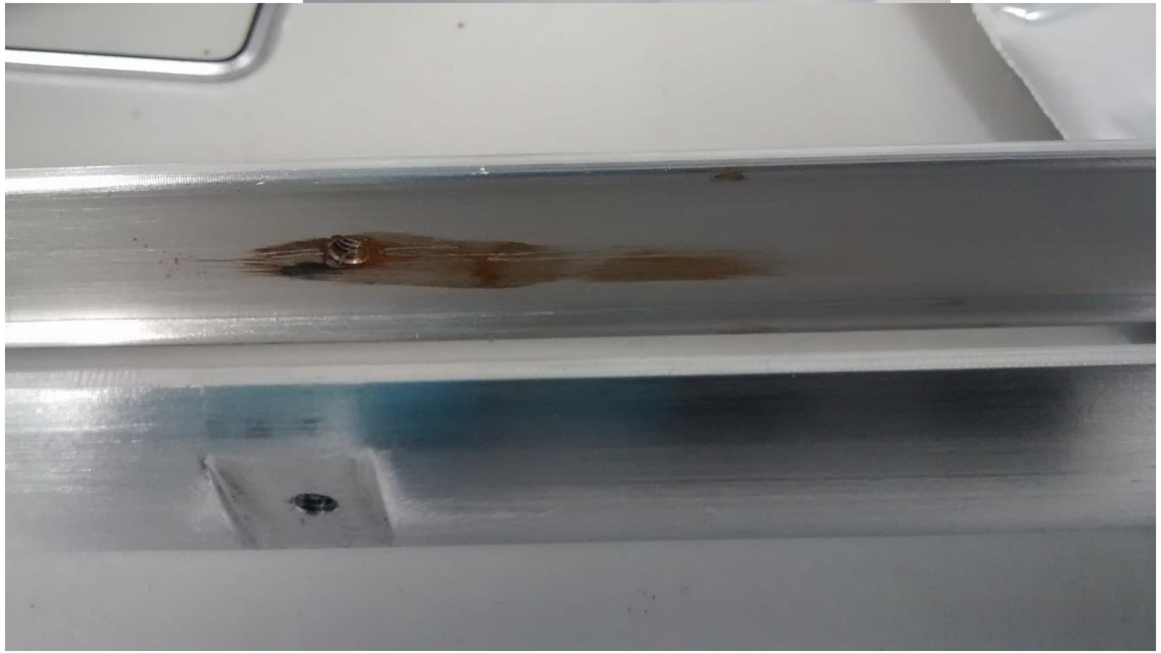
SR Marks on the Macor Rings

1st installation

2nd installation

Another issues:

- 4th ring (of the 1st installation) was chipped.
- The striplines have been screwed to the Macor rings but, in addition, Loctite was mistakenly used.
- Loctite has been used in all the screws, and can be seen as a yellow mark on the inner part of the electrodes.
    - It was cleaned up with acetone.



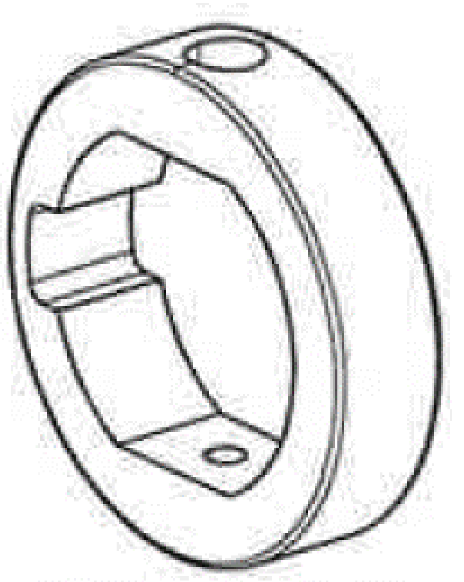
7. Macor Rings Studies

Analysis of Macor Ring at The Catalan Institute of Nanoscience and Nanotechnology (ICN2) using Scanning Electron Microscope (SEM) + Energy Dispersive X-Ray (EDX)

1) Small chipped piece, white, no signs of degradation. Detection of elements of Macor only (O, Si, Mg, Al, K and F).
2) Shallow marks coming from low energy photons and/or scattered photons. Yellowish decolouration.
   - Black spots, mostly made of C. Are they coming from the Loctite or from Macor degradation?
3) Black marks where SR has impacted:
   - Black spots, mostly made of C.
   - Bright areas, mostly made of metals, like Fe and/or Ag. Are they coming from silver plated screws?

7. Macor Rings Studies

Proposed Solutions



1) Increase the aperture for the SR, to avoid as much as possible SR impact. If required, another ring can be placed at a certain distance apart from this one – the distance should be optimized by SR conditions.
2) If the problem persists, fabrication of new rings with another material which ALBA has already experience with.
   - Al_2O_3 was proposed but dismissed for manufacturing reasons.
   - Other materials are under consideration.
3) If necessary, removal both the upstream ring (the most affected low energy or scattered photons) and the downstream ring (the most affected by SR): the two ends of the electrodes would be held by the feedthroughs only
   - But the rings are the only guarantee we have about the distance and parallelism of the electrodes: the transverse field homogeneity may no longer be correct.

9. Conclusions and Future Work

- The development of the extraction kicker system for the CLIC DRs has been divided in two parts: the striplines development and the inductive adder development.
- The striplines have been already designed, manufactured and tested in laboratory. To complete the study, beam based measurements at ALBA are required.
- Installation and conditioning of the striplines at ALBA presents some unexpected issues, mostly related with SR hitting the Macor rings. Newly shaped Macor rings are being manufactured. Next installation (October 2017).
- For the striplines, the most demanding requirements are the beam coupling impedance and the field homogeneity, which are planned to be measured at ALBA in the next months.
- The complete extraction kicker system (striplines + inductive adders) will be tested in laboratory.
- Can the design parameters of the complete extraction kicker system be verified with measurement at Alba, during 2018?