PULPOKS

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Ultra Fast Kicker Strip-line

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Prototype for the new EBS kicker magnet

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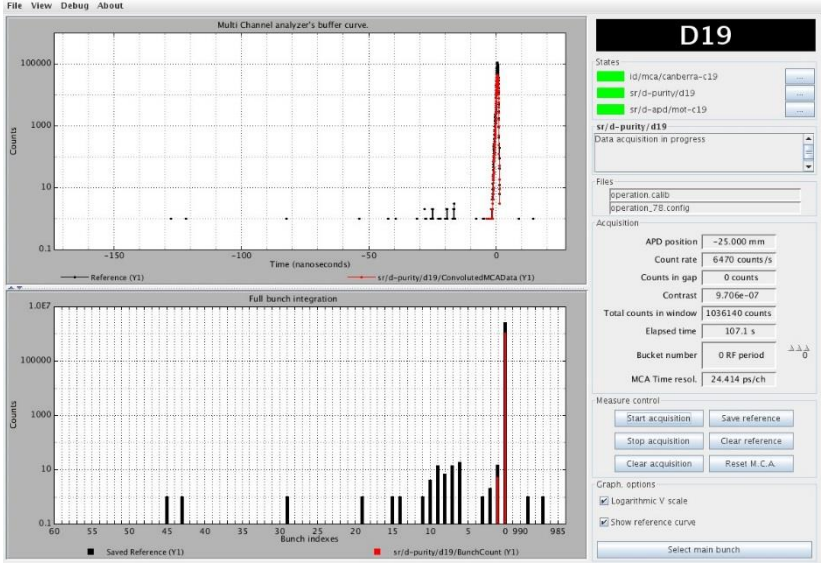
ESRF | The European Synchrotron

Ultra Fast Kicker Strip-line:

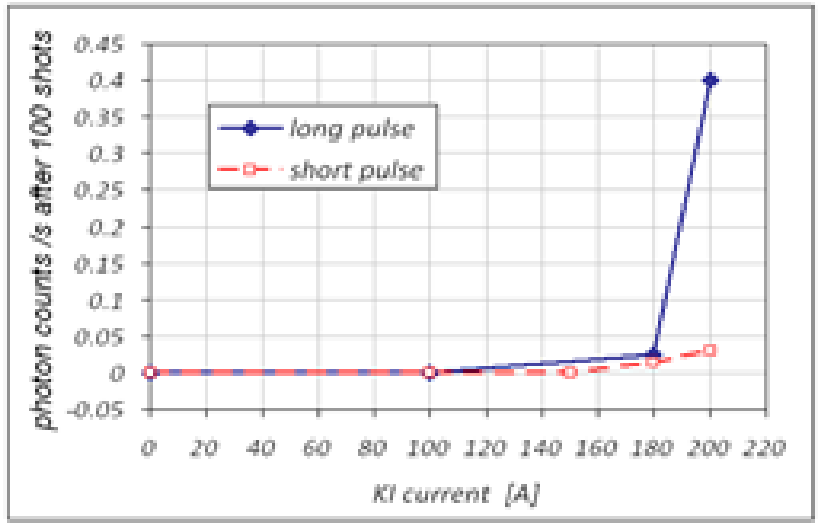


- Goal:
  - ESRF Top up mode need to clean the beam before the Injection in the Storage Ring, so we decide a 3 years ago, to work in 2 directions.
    - Beam cleaning in the Booster: (Diagnostic group).
      - A system already exists using resonant excitation of the impurities by a strip-line kicker. The excitation drops to 0 at the passage of the main bunches via a phase inversion of the excitation signal. This system did not give satistactory results as shot to shot reproducibility of the tunes is not stable enough while the excitation frequency is fixed. A feedback system will be implemented using precise measurement of the booster magnet current to drive the excitation frequency.
    - Add a new Kicker to inject only one pure “bunch” coming from the Linac, without cleaning: (RFgroup).
      - Three competences were in charge of this study:
        - Beam dynamic
        - Strip-line design
        - HV Power supply and installation.

Some Considerations:

- It ‘s a test device, installed in our Booster,
  localized just after the actual Injection kicker Ki.

- Preliminary tests were done to see at which level of current on Ki,
  we obtain no dark current coming from the Linac. (100A).

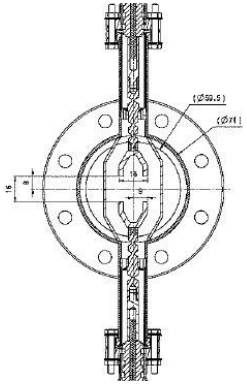


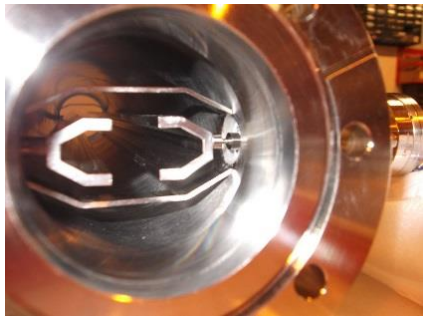
- Time between two bunches: 2.8ns

- With Ki and Strip-line pulsed, we can adjust their setting current to have the nominal deflection.

- Difference between Ki and Strip-line:
  - Ki open a gate of 1us for all coming from Linac,…….. beam and impurities.
  - Strip-line open only 4ns gate, and with our timing system (11 ps step) you can synchronise the field with the beam.

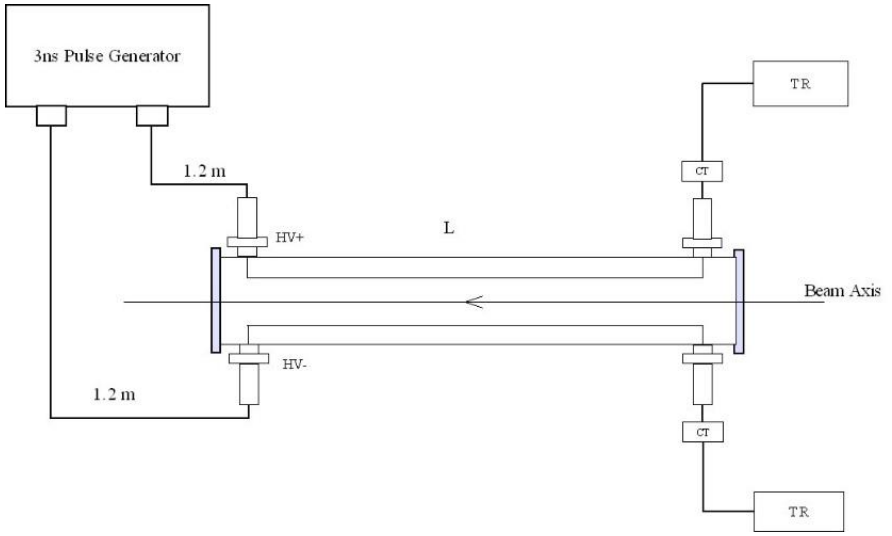
Overview:



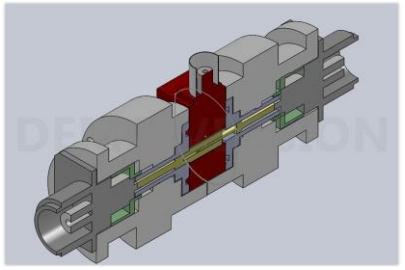


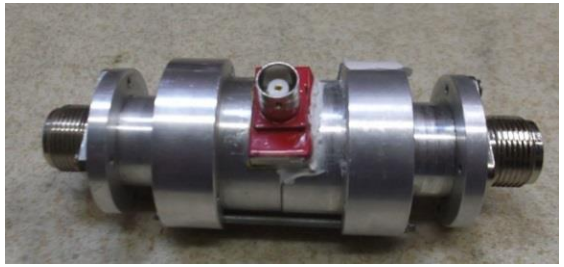
- Mechanical :
  - L= 480 mm
  - Aperture: 30mm x 16mm

- Electrical :
  - Due to goal (only validation of the process) we decided to buy a commercial pulse generator (No time for R&D)
  - FID:
    - 2 outputs (+ and -)….(HV range from 10 to 15KV)
    - Rise time: 1ns - No flat top - Fall time: 1.4ns

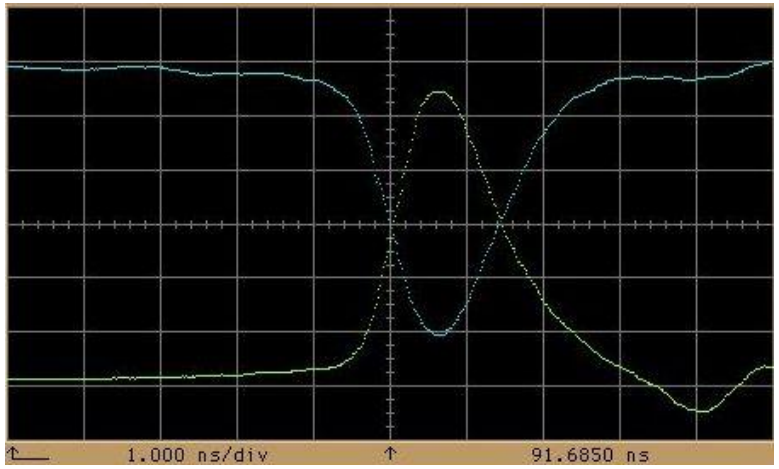


  - Fast “Bergoz” CT are used and integrated in a special HV 50 Ohms house.
  - Terminating resistors from Dicomex (18KV, 50 Ohms)
  - HV Feedthrough: Kyocera



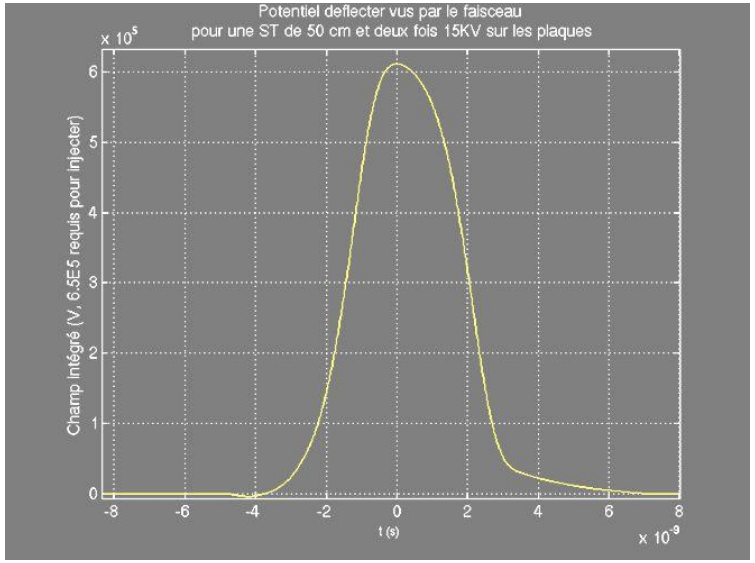


FID Waveforms:



- Positive:
  - Delay between Trig and Pulse output is stable at a fix voltage setting and similar to FID documentation…but we only test it during few hours
  - Delay between the 2 outputs .OK
  - Amplitude stability: Not easy to measure with our fast CT…but with beam, the strip-line do the job.

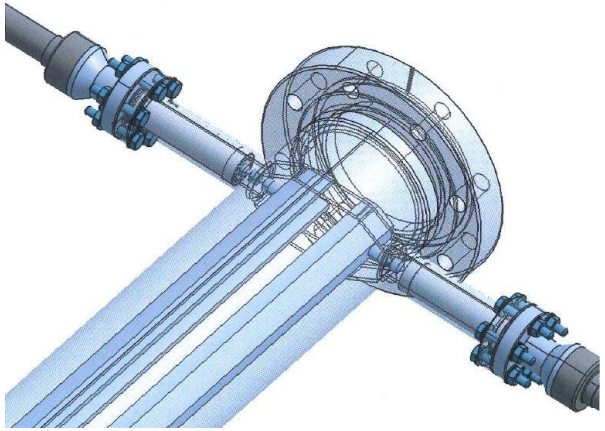
- Negative:
  - FID sensitive to impedance mismatch
  - Delay between Trig and HV pulse change with HV setting.
  - No technical information from FID after breakdown.
  - We dídn’t do long time measurements.



Results and problems:

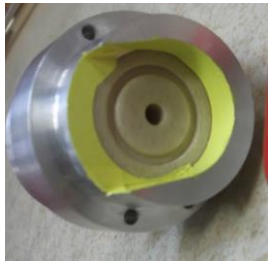
- Success:
  - After some timing adjustment, it's work…we begun with Ki at low level (100A) and FID at 10 KV. After we tried with only the FID at 14KV, and we can inject one bunch with nominal intensity.
- Problems:
  - After 5 hours of test, No HV pulses in the strip-line, No HV pulses coming out from FID… return to FID company.
  - New tests, same punition ..after some HV shots.?? Is FID sensitive?
  - Disassembly and verification of our system (CT, Resistors, cables, connectors, Strip-line)……and we find 3 problems
    - HV Connectors: On SHV 20KV Plug….Bad crimping on FID Cables.
    - Feedthrough: HV breakdown……. even if we well conditioned the strip-line (DC and Pulse)
    - CT house: HV OK, Build for 50 Ohms but at more than 35Mhz…Impedance begin to decrease
    - HV Resistors: Nominal value: 50 Ohms but only 15 Ohms at 1Ghz…..more than 80% pulse reflection
- Limitation of our test:
  - We can inject only one bunch per cycle…….No burst mode on FID.
  - It's a new time domain…ns pulse, we must mixed HV and HF.

Technical Solutions:



- On HV feedthroughs:
  - New long HV Screen, made with Vespel.

  (before we have a small ring of Macor)
- Fast CT :
  - Isolating tape and silicon gel around multi-contact connection.



- Terminating resistors:
  - Decision must be done.

    Commercial parts from other companies (FID, Barth) is too expensive (15KEuros).

    Home made, how we can do better than today ??
- Conclusion:

This device will be reinstall in our Booster ring, to have a spare system for the cleaning.

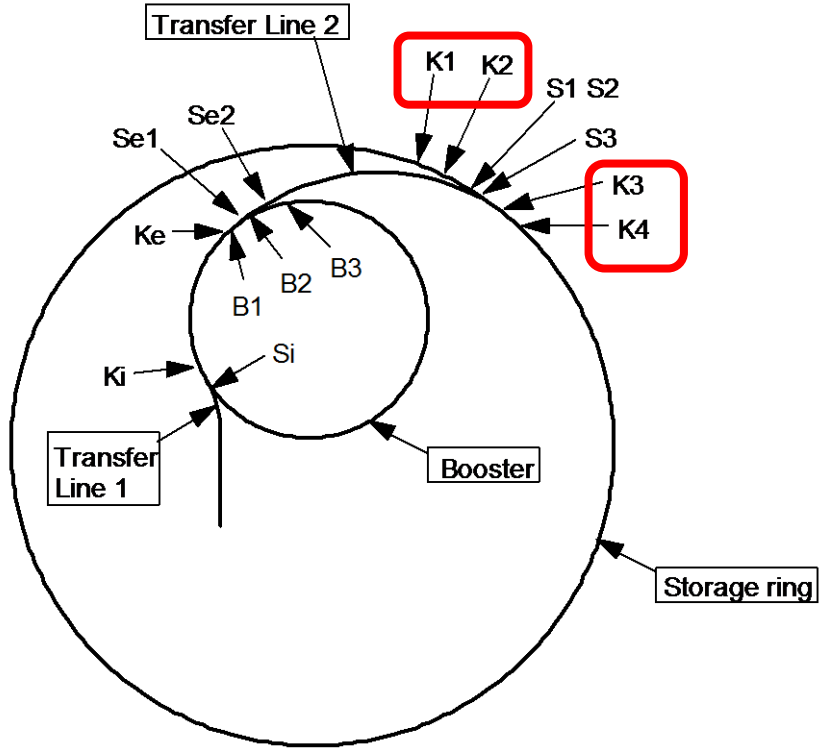
- Limitation of our test:
  - We can inject only one bunch per cycle…….No burst mode on FID.
  - It's a new time domain (ns pulse) …,we must mixed HV and High Frequency.

Prototype for the new EBS kicker magnet

Introduction

New EBS project requires stronger constraints on kicker K1-K4 power supply:

- Increase of current level
  - Current range 2kA to 2.2kA (actual 1.5kA to 2kA)
- Required peak current precision
  - ± 0.05%
- Current difference between Kickers during rise-time and fall-time
  - ± 0.05%



Booster injection: Ki, Si.

Booster extraction: Ke, Se1, Se2, B1, B2, B3.

Storage ring injection: K1, K2, K3, K4, S12, S3.

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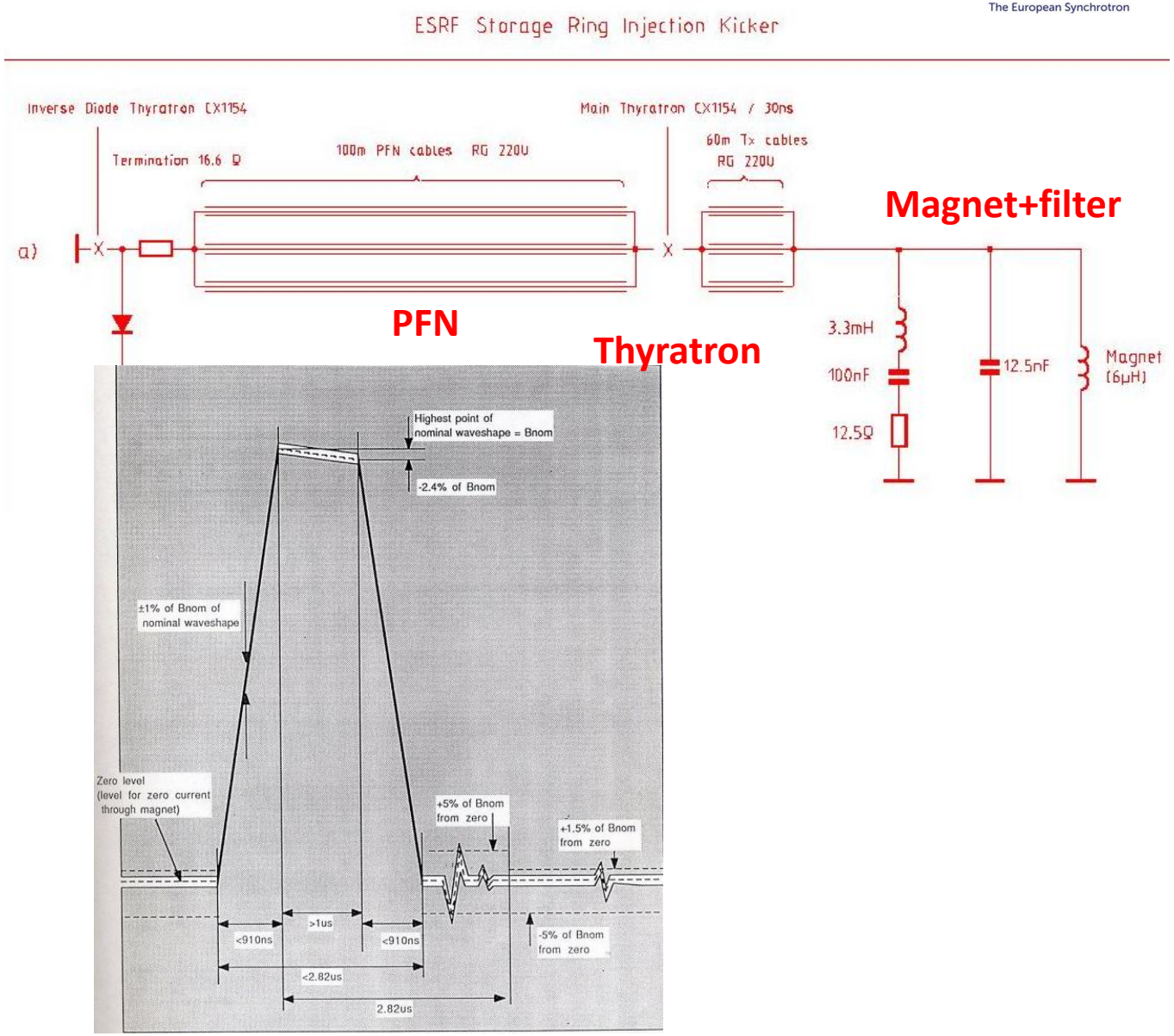
Actual kicker power supply (CERN design):

- Thyratron technology (EEV CX1154)
- 160m(100+60) RG220 PFN up to -35kV charge

Magnet current spec.

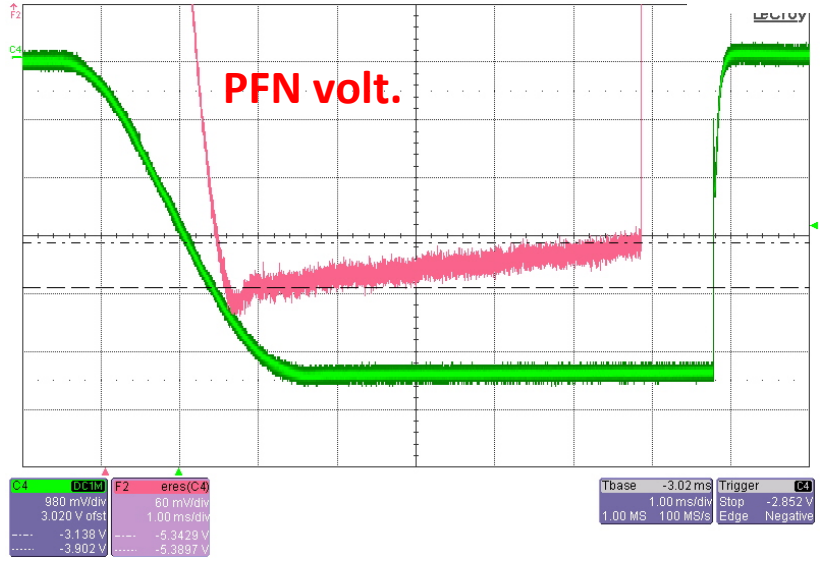
- Rise-time <910ns
- Flat-top >1µs (2.4% of In)
- Fall-time <910ns

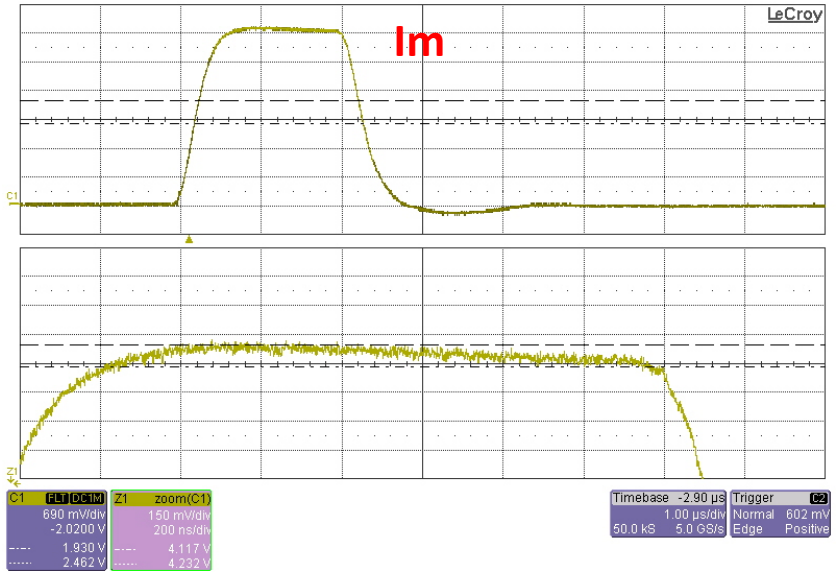


Prototype for the new EBS kicker magnet

Measurements on actual kicker (K1) power supply:

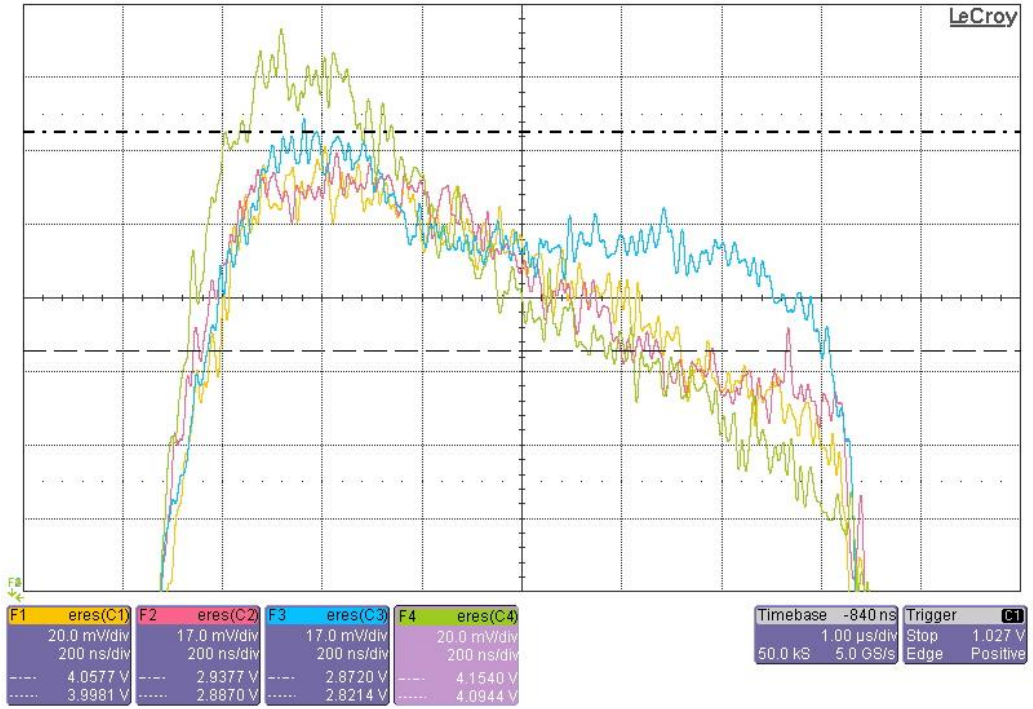
- Im nominal: 1550 A
- Flat-top slope: 2.6% of Im nominal
- Rise time: 455 ns
- Fall-time: 800ns
- Repetition amplitude: +/- 0.19 %
  ….equivalent to +/- 3A





Prototype for the new EBS kicker magnet

	Flat top range of In	Rise time
K1	2.6%	455ns
K2	2.7%	485ns
K3	1.77%	484ns
K4	2.9%	457ns



⇒ Actual spec. are meet for actual machine but….

⇒ Power supplies do not meet the new spec. (precision, repetition)

⇒ New topology is investigated to meet these requirements

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Proposed strategy:

- Beam impact strategy: increase both rise time and fall time validated with beam dynamics Group
  - Rise time: ~50µs
  - Fall-time: 2µs or less

- New power supply impact:
  - Low voltage DC charger (<1kV) with good precision (<0.05%) to achieve stable and precise 2kA peak current
  - Semiconductor technology solution
  - Current differences between kickers (K1-K4) can be accurately adjusted through timing, turn on/off trigger of semiconductors plus matching passive components (R, L, C values)

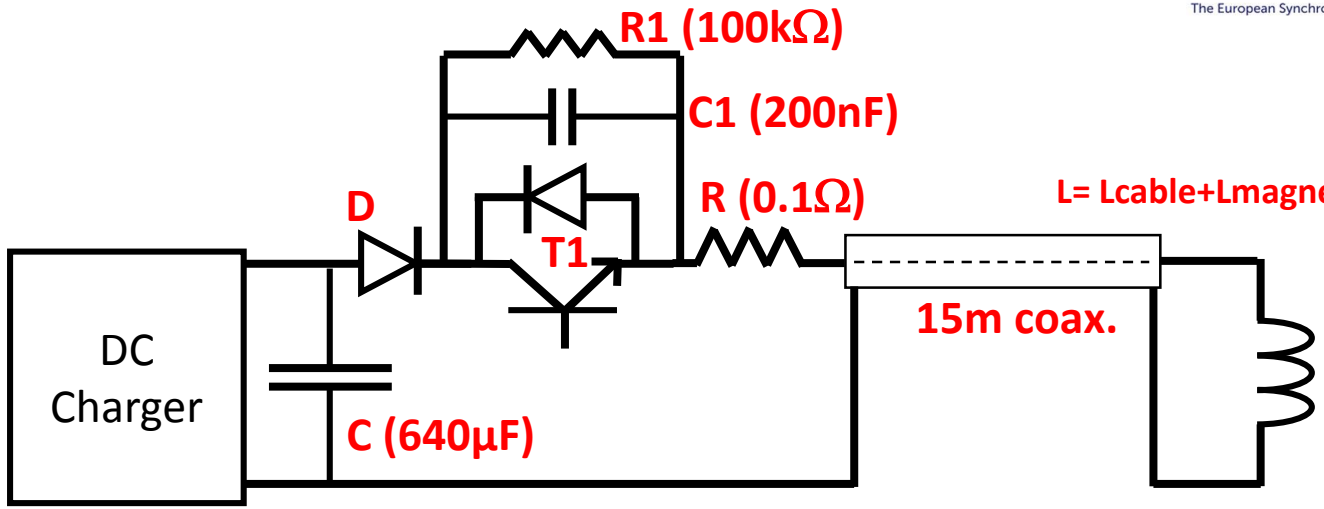
Prototype for the new EBS kicker magnet

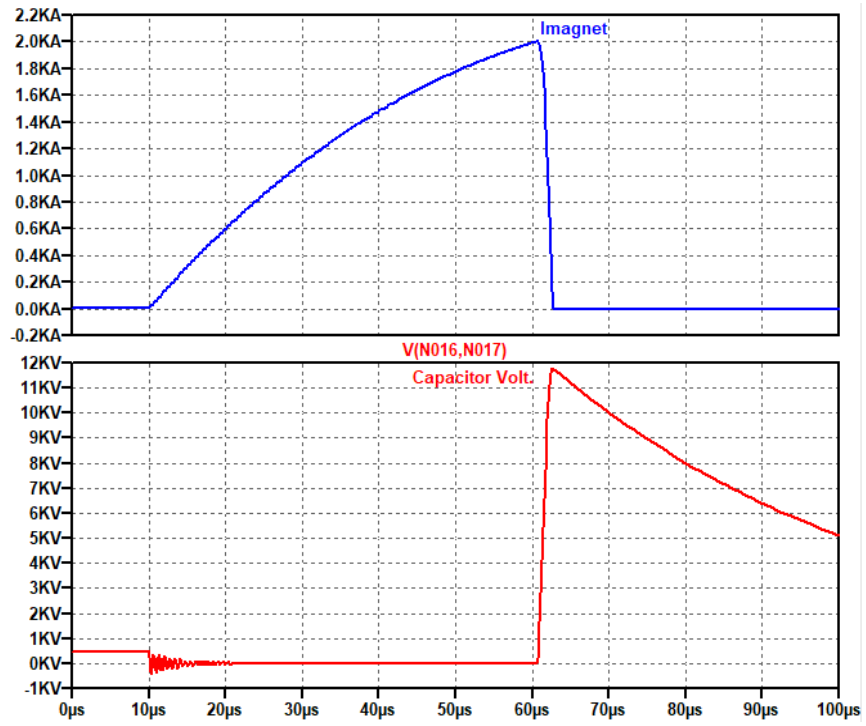
New power supply topology for kickers

- Low voltage DC charger
- Series switch turn on/off capability
- capacitor in // for energy absorption during turn off

Setting parameters:

- Rise time set by RLC
- Fall time set by C1 value and circuit inductance (=> 12kV cap. volt. for 2µs fall-time)
- Peak current adjusted by DC charger value (~500V for 2kA)





Prototype for the new EBS kicker magnet

Choosing switch technology ?

	Supplier	Advantages	disadvantages
All in one High voltage switch	Behlke (15kV/3600A SiC IGBT)	- 1 unique module - Optimize cabling inductance - Simplified ctrl command	- No guaranty on performances (no datasheet) - Availability for 20 yrs ? - Cost
Discrete series/parallel switch	In house or specific lab/supplier	- Low cost IGBTs	- Complex design structure - Ctrl synchronization
Series industrial switch	Dynex, Infineon, ABB…	- 3.3kV to 6.5kV modules - High current capability	- Cabling inductance - Isolated gate driver

$\Rightarrow$ Solution with series industrial switch is investigated for testing prototype

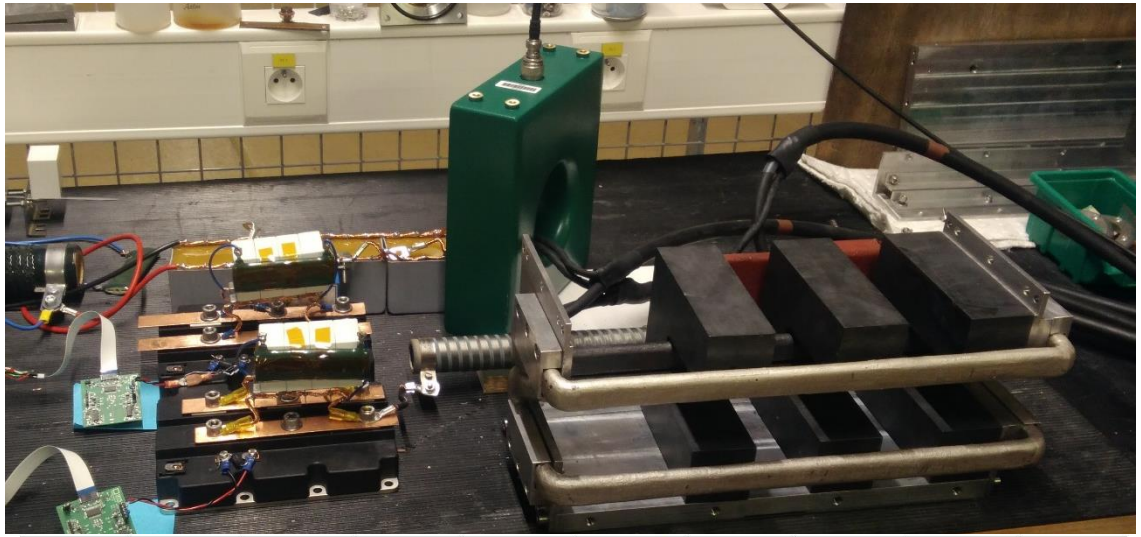
Prototype for the new EBS kicker magnet

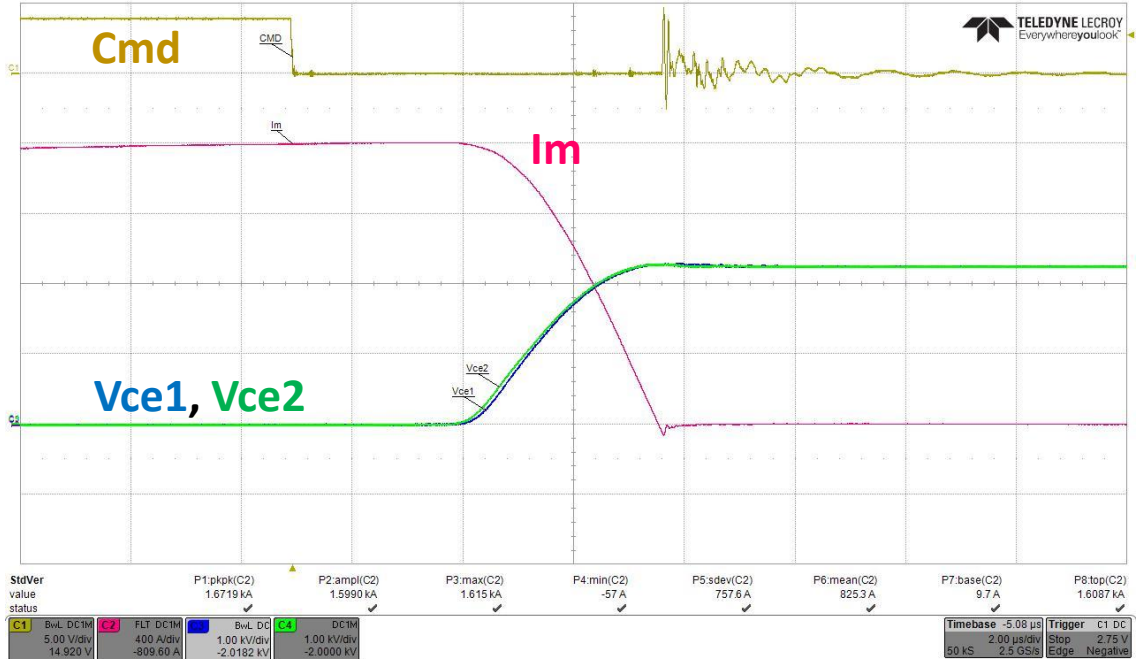
Small scale testing prototype

- IGBT module (3.3kV/3kA peak)
- 2 x IGBT in series (2x3kV charging capacitor during fall time)
- 2 x 20ohm coax. cable in // (20m each)
- Kicker magnet load adjusted for the EBS project (4µH)

Actual results

- 1.6kA (limited by 2 x IGBT in series and Behlke diode rating)
- Fall-time: 3.5µs (expected 2µs with 4 x IGBT and optimize cabling inductance)
- Equal voltage sharing during fall time by setting the turn-off time command of the IGBTs





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Next steps

- Finish prototype with 4 x IGBT module (3.3kV/3kA)
- Optimization of coax. cable selection to minimize calbe inductance (test with low cable impedance => ~5 ohm)
- Reach 2µs min. fall-time to meet specification
- Continue investigation on IGBT switches
  - 4.5kV, 6.5kV IGBT modules/press-pack => increase voltage capacitor and reduce fall-time
  - evaluation of other switches solutions (all in one or discrete assembly)

Thank you for your attention

Questions ?