FCC–hh: Extraction and Dilution Kicker

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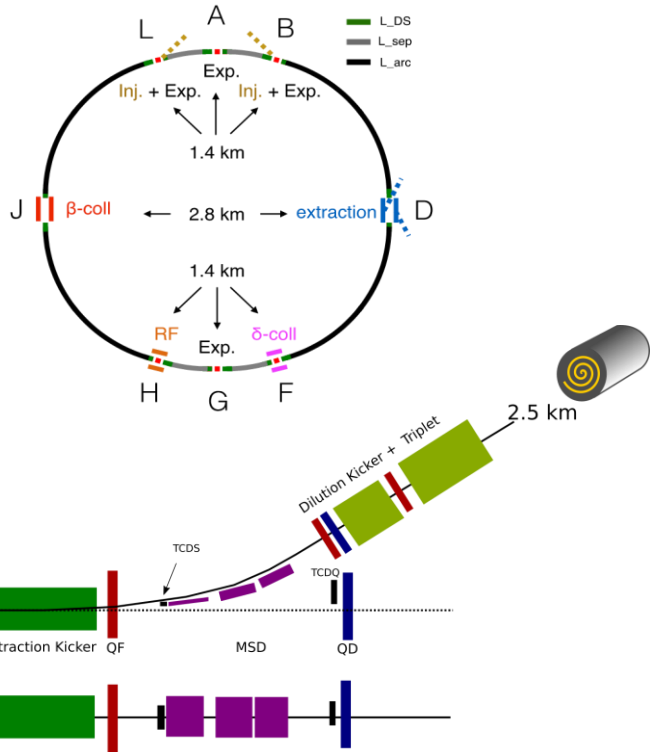
Outline

- Beam dump system layout
- Motivation for design strategy and implications for hardware systems
- Extraction Kicker System
- Dilution Kicker System
- Summary and next steps

Extraction - Layout

- IPD, 2.8 km for extraction of beam 1 and 2
- 2.5 km dumpline with dilution kicker system to create sweep pattern at graphite beam dump
- Design mainly driven by machine protection
  - Safely extract 8.5 GJ beam
  - Reduce failure probabilities
  - Avoid downtime in case of failure



Extraction – Requirements

Constraints for…

0. Enable/survive a nominal dump

1. Safely extract the beam – always guarantee kicker triggering

2. Survive asynchronous dump
   - Energy deposition studies at protection absorber and beam dump

3. Avoid asynchronous dumps
   - Reduce probability of pre-firing kicker
   - in case of single pre-firing extraction kicker no asynchronous dump
     - ► Dump with next abort gap
     - ► 1 turn with 1.5 sigma oscillation of miskicked bunches (part of the beam)

4. Avoid other failures with damage potential/ avoid failures req. immediate repair

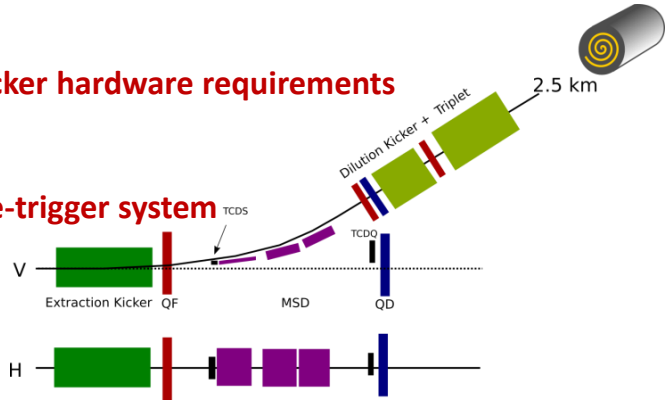
… dilution system (sweep-pattern: amplitude/frequency)
… extraction kicker (kick strength)

… redundancy/trigger system

…extraction kicker (rise-time)
…dilution system (sweep-pattern: amplitude/frequency)

…relaxing kicker hardware requirements

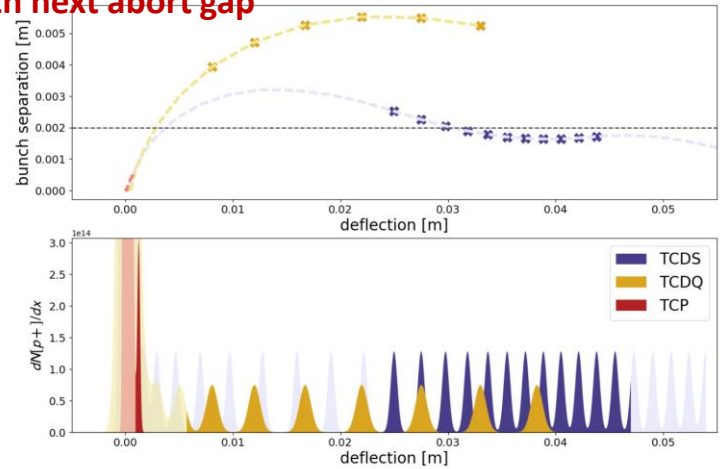
… trigger / re-trigger system



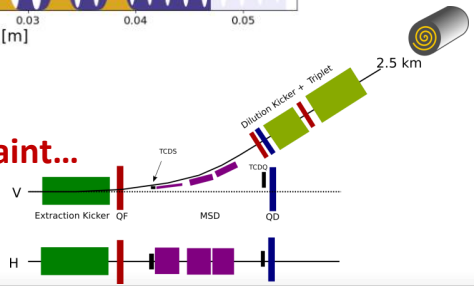
Extraction Kicker Requirement

Extraction Kicker	Unit	Parameter
System Length	m	120
Number of Modules		150
BdL [top]	Tm	7.5
Deflection	mrad	0.045
Aperture height [horiz]	mm	50
Aperture width [vert]	mm	40
module length	m	0.6
Inductance	nH	700
Current	kA	3.3
required risetime [0-100%]	us	1
Voltage	kV	<6

reduce prob. for asynch. dump, relax requirements + synch. dump with next abort gap



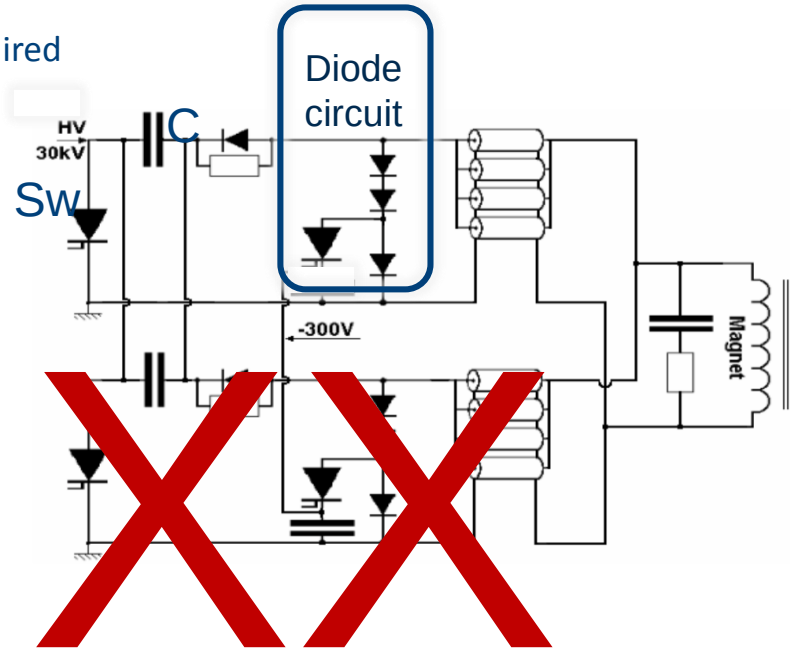
survive asynch. dump: hard constraint…
… otherwise sacrificial absorber necessary → beyond CDR



Extraction System - Circuit

Basic idea based on LHC dump kicker but with significant modifications:

- Lumped inductance magnet as per LHC
- Only one branch per generator – parallel generators not required

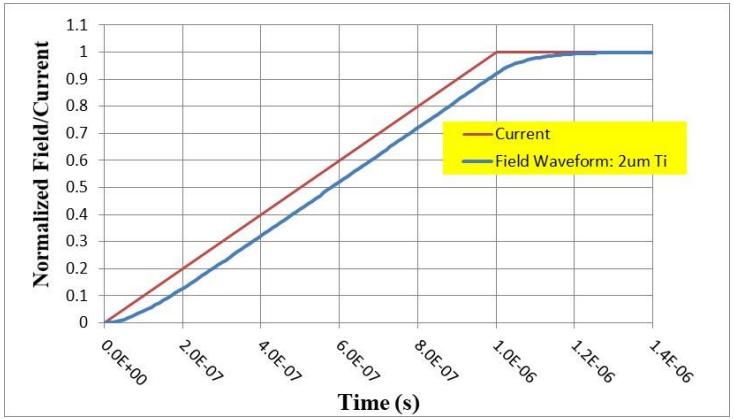


- **Significantly reduced peak voltage and current**
  - <6 kV c.f. 30 kV for LHC
  - 3.3 kA c.f. 20 kA for LHC
- Pre-charged capacitor (C), together with a turn-on switch (Sw), to create the first quarter of a sine-wave
- Once the current starts to reduce in magnitude, a “diode circuit” allows the magnet current to free-wheel (flattop length >326us)

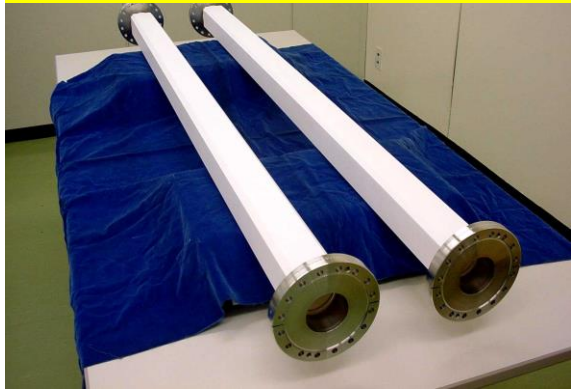
Extraction System – Beam Coupling Impedance

An uniform resistive layer is the easiest way to provide beam screening

- However a ceramic chamber or plates are required on which to apply the layer, which requires an increase in the aperture of the magnet
- However eddy currents induced in the coating increase the field rise-time



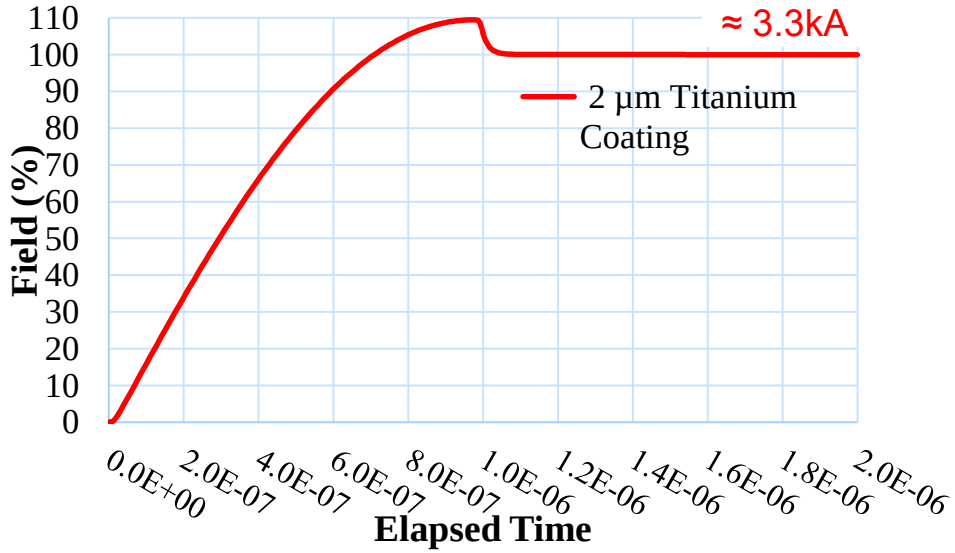
LHC beam dump extraction kicker MKD



Magnetron sputtering

Extraction System – Field Rise Time

- A ~500 nF storage capacitor gives the required field rise time
- Without a 2µm Ti coating, the storage capacitor is charged to ~4600 V for 50 TeV
- With a 2µm Ti coating, the storage capacitor is charged to ~5000 V for 50 TeV



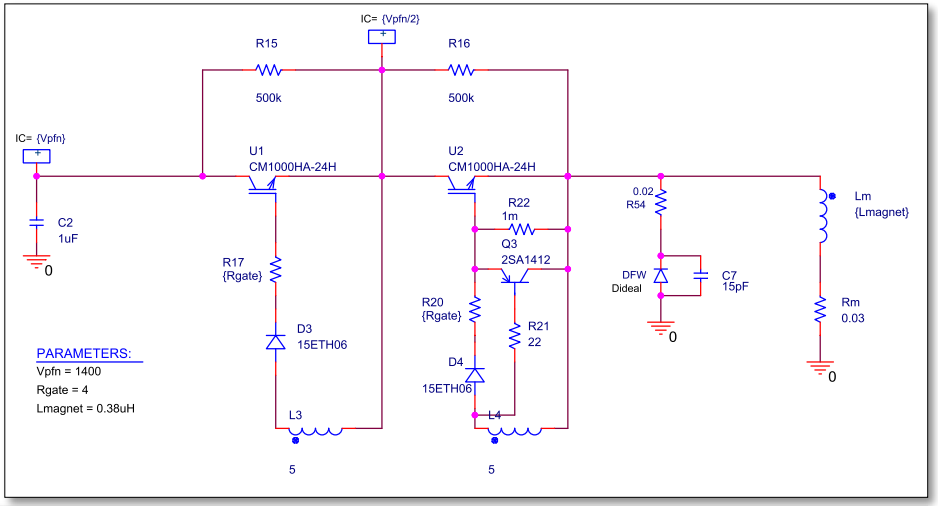
- The field overshoot is ~10%
- The capacitor voltage and field overshoot can be reduced by mounting the generators under the magnet, rather than in a parallel gallery:
  - ⇨ Rad-hard components, including power semi-conductors, would be required.

Outlook: Alternative Switch Topologies

- **Alternative (double) switch topologies can limit the current in the kicker magnet in case of an erratic with the aim to reduce or eradicate the impact of an erratic trigger on the beam**

- Two alternative generator topologies:
  - **Series connection of two switches** to inhibit current through magnet in case of single self-trigger (simulation: reduction of pulse strength to ~1%)
  - **Shorting crowbar switches**

Concept to prove



Above: PSpice Model for Series Switch Architecture, P. Van Trappen: Further information: New design concepts for suppressing erratic triggering of solid state switch stacks (P. Van Trappen et al, FCCWeek 2017)

Outlook: Alternative Switch Topologies ctd.

- **no asynch dump in case of pre-firing kicker. If probability for asynch. dump due to other failures low enough:**
  - No high segmentation (150 MKDs) required for concept of '1sig osc.' as impact of erratic switch is mitigated by second switch
  - Option: LHC like system, but with second switch, ~30 modules.

MKD: 2nd switch / reduced seg.	Unit	Parameter
System Length	m	120
Deflection	mrad/Tm	0.045/7.5
Number of Modules		30
module length	m	1.5
Current	kA	6kA
required risetime [0-100%]	us	5
Voltage	kV	<6

However...

⇨ IGBT switch should be operated at low blocking voltage to limit transient amplitude if one switch has an erratic

⇨ To relax hardware requirements: Increase risetime ~5us

- Extraction protection / primary would be damaged → sacrificial absorbers
- Probability of an asynch. dump (due to e.g. both switches failing/synchronization errors) should be minimized

Not baseline, completely different strategy

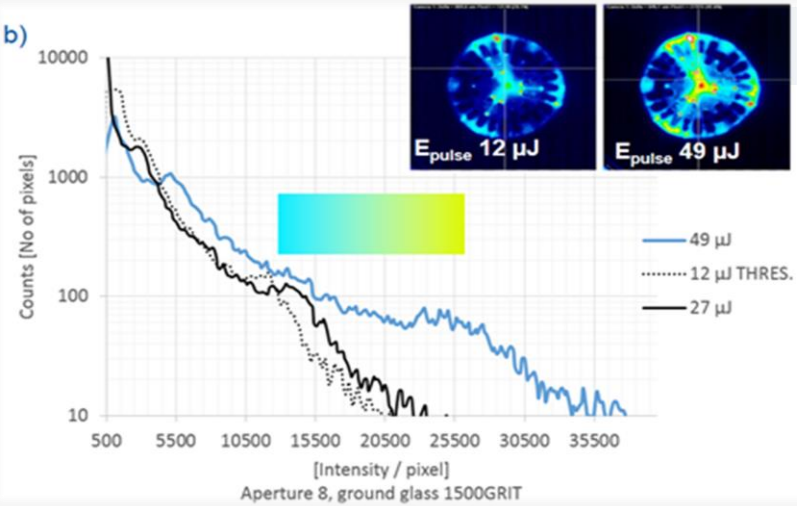
Outlook: Triggering and Retriggering

- The probability of multiple erratics, due to common mode failures such as electromagnet coupling needs to be kept as low as possible;
- Optically triggered thyristors potentially avoids false triggering by electromagnetic coupling of noise into cables.

a)

(a) Anode and cathode sides of a thyristor wafer that has been etched

b)



(b) CCD camera images and histograms of the optical interface output light projected on the thyristor wafer.

N. Magnin, Laser triggering of thyristor swiches, **Wed. 1050**

Dilution Kicker Requirement

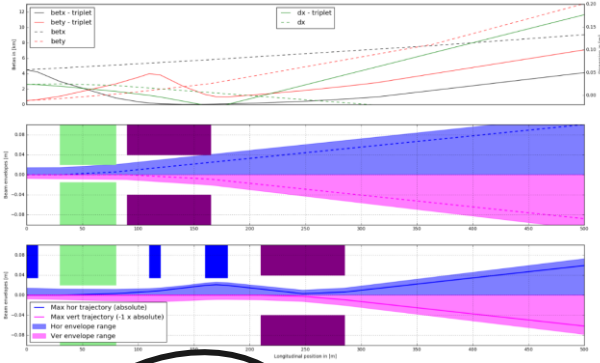
50 kHz; constant frequency to meet dilution requirements

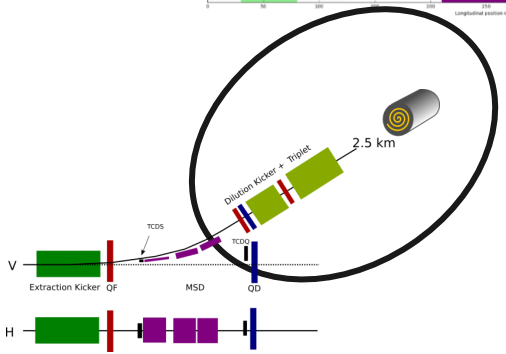
~30 horizontal, 55 vertical kicker

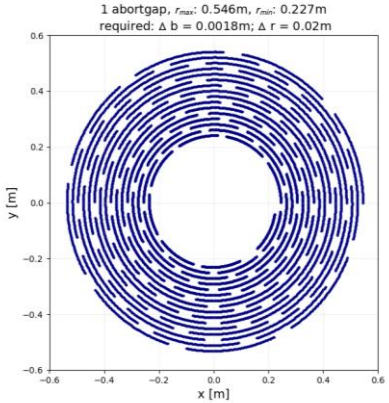
vertical system more challenging due to large aperture → improved by focusing triplet structure in dumpline

Dilution system (V):

- Aperture width = 40 mm
- Aperture height = 46 mm
- 55 V magnets and generators:
  - ~2200 nH per magnet
  - 15.9 kA magnet current







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	triplet		w.o triplet	
	MKBH	MKBV	MKBH	MKBV
frequency [kHz]	50	50	50	50
risetime [us]	5	5	5	5
Installed L [m]	60	110	100	110
Gap field [T]	0.5	0.5	0.5	0
Modules	30	55	50	50
BdL [Tm]	22	42	38	39
gap height [m]	0.03	0.046	0.026	0.046
gap width [m]	0.03	0.04	0.046	0.086
Current [kA]	12	16	10	34
Voltage [kV]	8	12	12	12

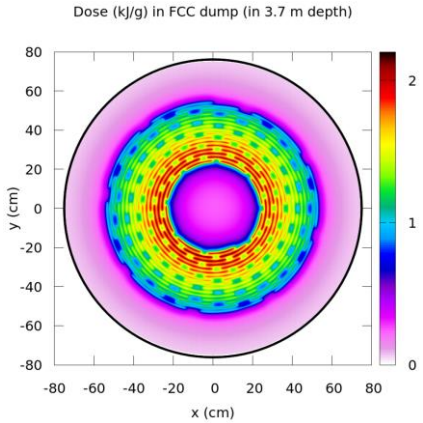
Dilution System

Very technologically challenging.

Basic idea based on LHC dilution system but with significant modifications:

- Lumped inductance magnet, each ~1.5m long to give a reasonable inductance (~2µH)
- Oscillation frequency of ~50kHz (14.2kHz for LHC), for a damped sine (H) / cosine (V) wave
- No beam screening required

The design of the generators and kicker magnets still need to be studied in detail.



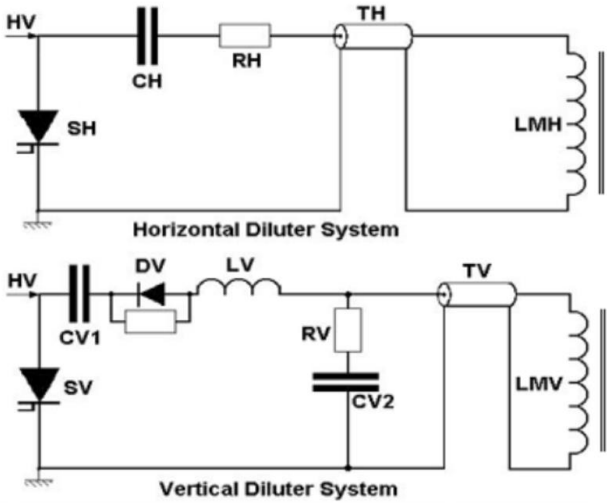
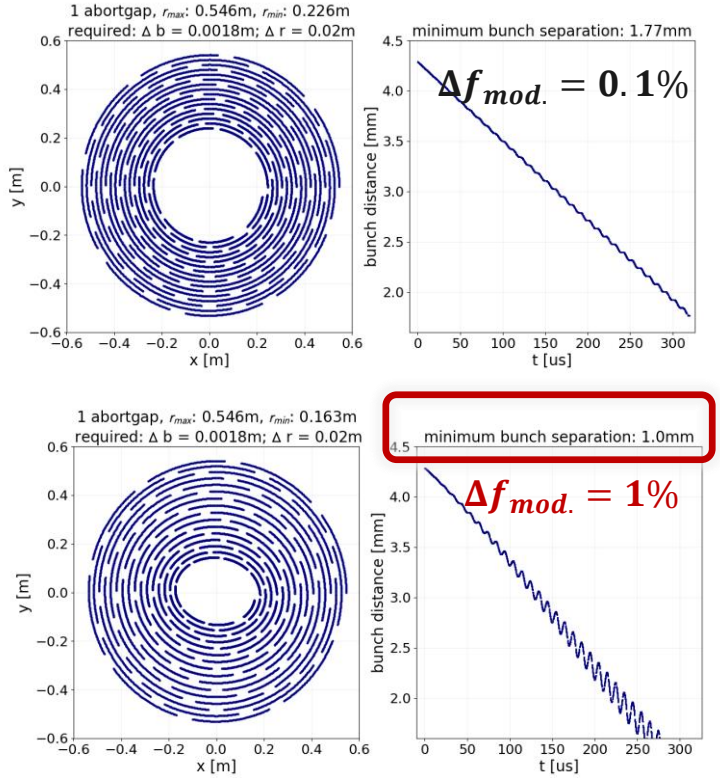
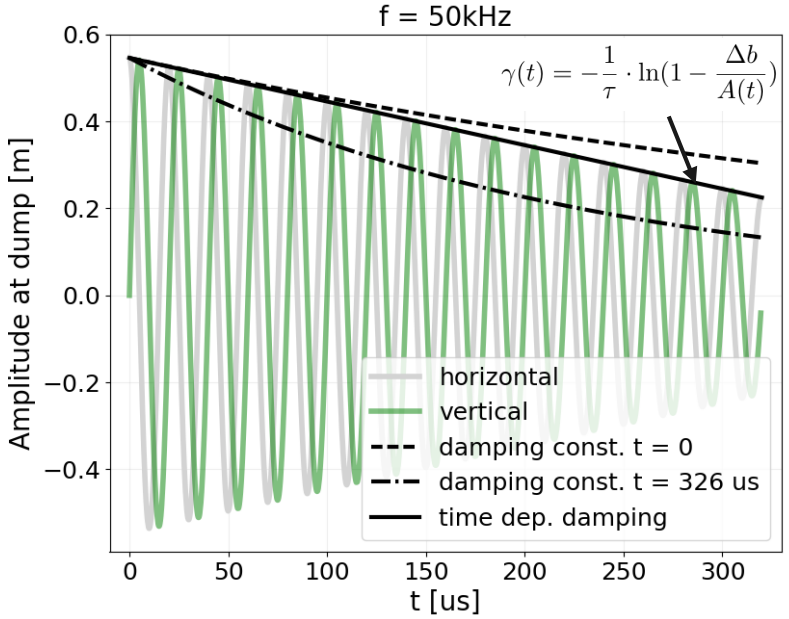


Figure courtesy: A. Lechner

Dilution System - Challenges





Conclusion

- Highly segmented extraction (150) and dilution kicker (30h/55v) system proposed – relaxed hardware parameters for single segment

- **Extraction kicker:** Lumped inductance magnets with Ti coating for impedance shielding and pre-charged capacitor (<6kV) to create risetime of 1us (10% overshoot)

  → IGBT switch development necessary to make use of single sw/generator possible, otherwise 2sw.

- **Dilution System:** Lumped inductance magnet, 1.5m. vertical system more challenging due to larger aperture: 15kV/12kA

  → Challenge for dilution system: very well matched frequencies (0.2-0.5%), decreasing damping constant,… → to be studied beyond the CDR