
CERN

Kickers, Septa and Protection Elements

Thomas KRAMER TE-ABT

based on lectures and input from

M.J. Barnes, W. Bartmann, F. Burkart, J. Borburgh, L. Ducimetiere,
A. Ferrero, T. Fowler, M. Fraser, B. Goddard, J. Holma, V. Kain,
M. Meddahi, L. Sermeus, D. Woog

Content

- Introduction and Reminder
- Beam Transfer Hardware
  - Kickers
  - Septa
  - Protection Devices

Introduction and Reminder

Over **100 operational kicker and septa** modules at CERN

designed, built and operated by

Accelerator Beam Transfer Group

TE-ABT

BTP
Beam Transfer Physics

EC
Electronics & Controls

EDS
Engineering Design&Supply

PPE
Pulsed Power Engineering

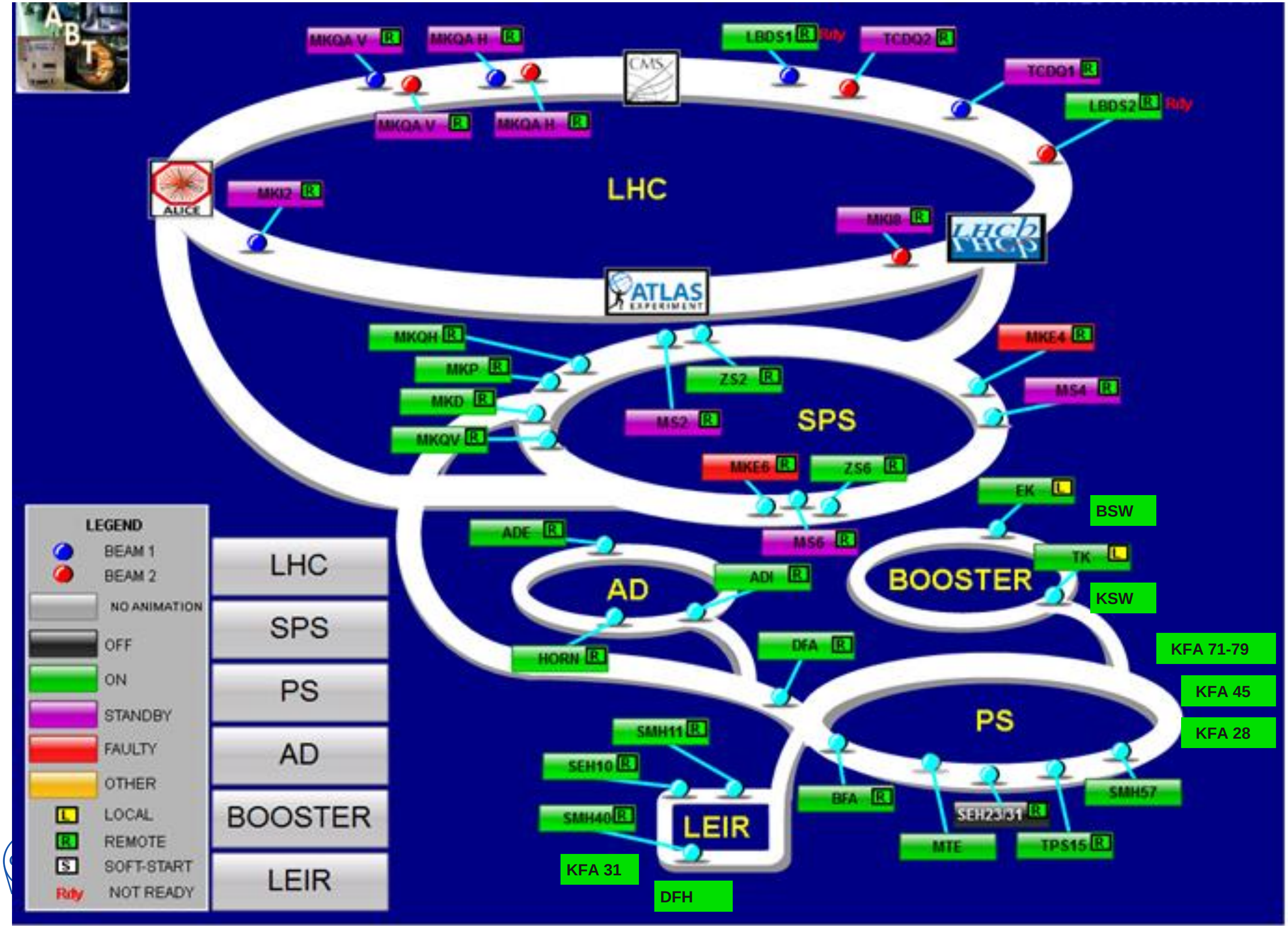
KSC
Kicker System Construction

SE
Septa

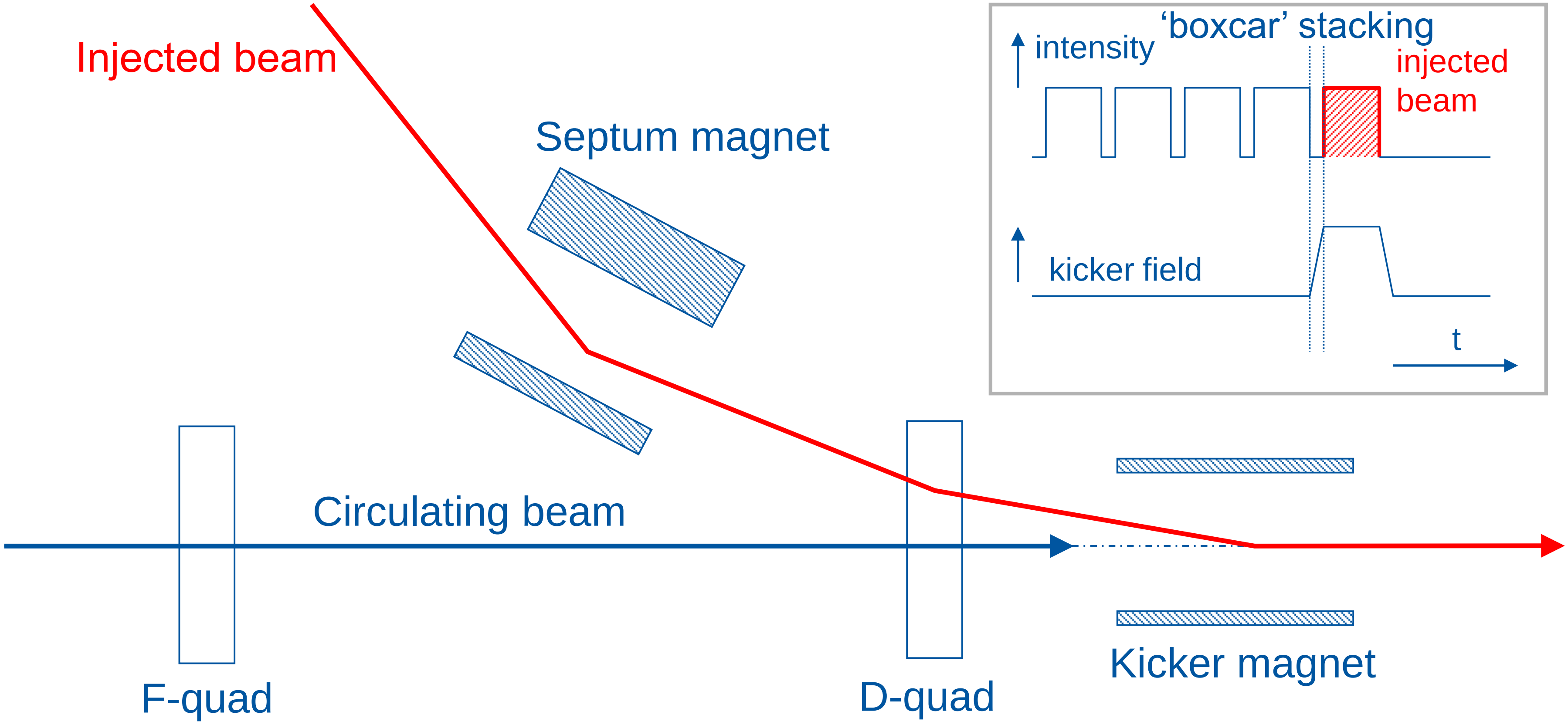
To address operational issues TE-ABT features a Kicker Piquet (72010) outside working hours.

http://te-dep.web.cern.ch/content/accelerator-beam-transfer-group-abt

BT systems distributed over the complete CERN accelerator chain:



Reminder: injection, extraction

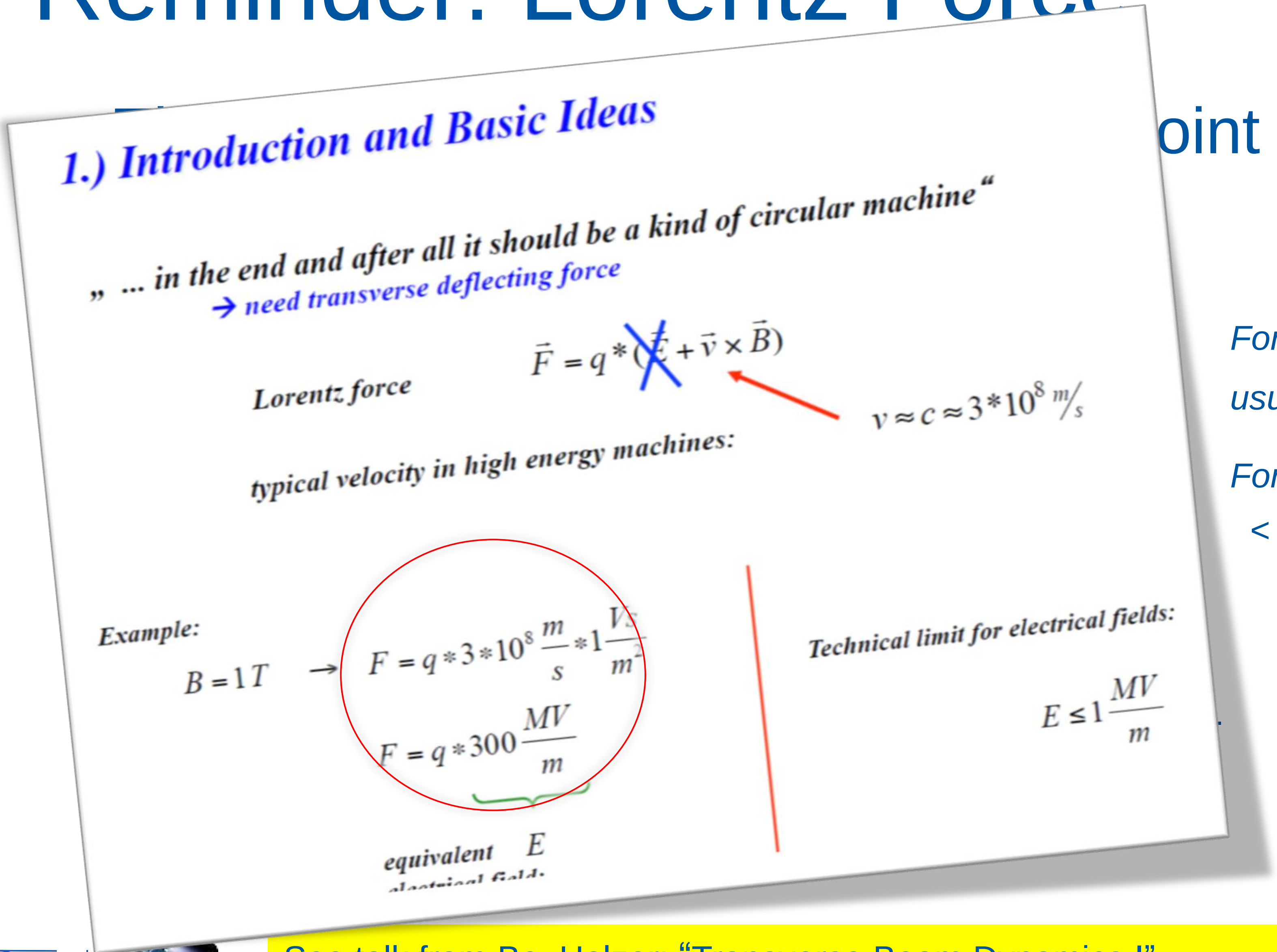


- **Septa** bring the inj. beam close to the circulating orbit (to reduce required kick strength).
- **Kickers** produce fast pulses kick the injected beam finally into the circ. orbit.

For more details see lecture on "Injection and Extraction" from V. Forte

Reminder: Lorentz Force

oint



1.) Introduction and Basic Ideas

„ ... in the end and after all it should be a kind of circular machine"

→ need transverse deflecting force

Lorentz force $\vec{F} = q*(\cancel{\vec{E}} + \vec{v}\times\vec{B})$

typical velocity in high energy machines: $v \approx c \approx 3*10^8\ ^{m}/_{s}$

Example: $B = 1T \rightarrow F = q*3*10^8\frac{m}{s}*1\frac{Vs}{m^2}$

$$F = q*\underbrace{300\frac{MV}{m}}_{E}$$

equivalent electrical field:

Technical limit for electrical fields:

$$E \le 1\frac{MV}{m}$$

For Kickers:

usually < 0.3T

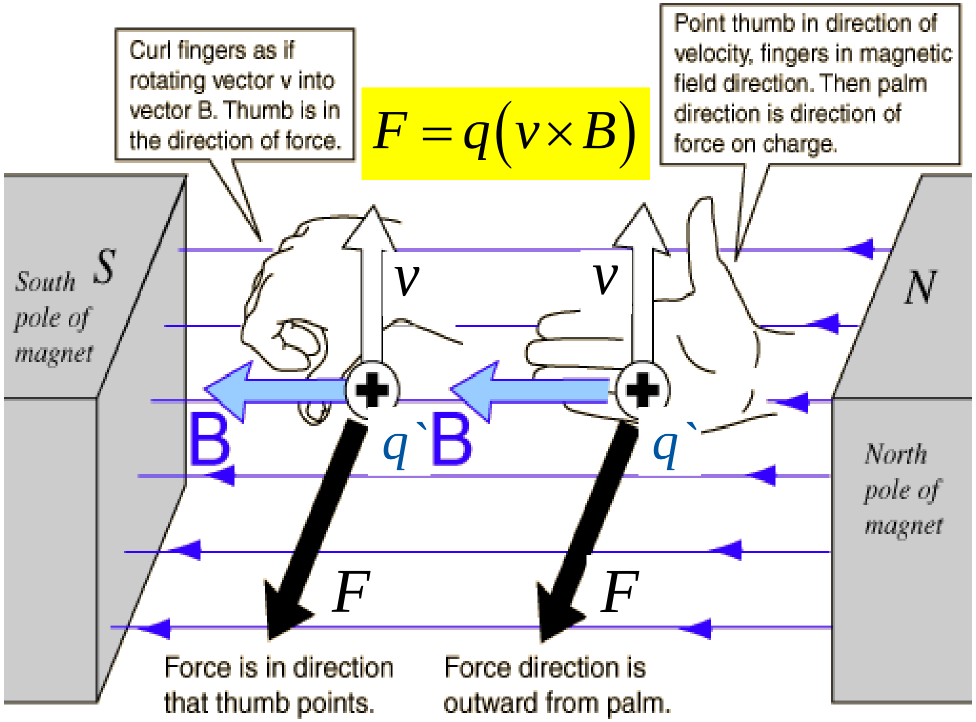
For Septa:

< 1.6T, $< 15\frac{MV}{m}$

See talk from Be. Holzer: "Transverse Beam Dynamics I"

Reminder: Deflection in a Magnetic Field

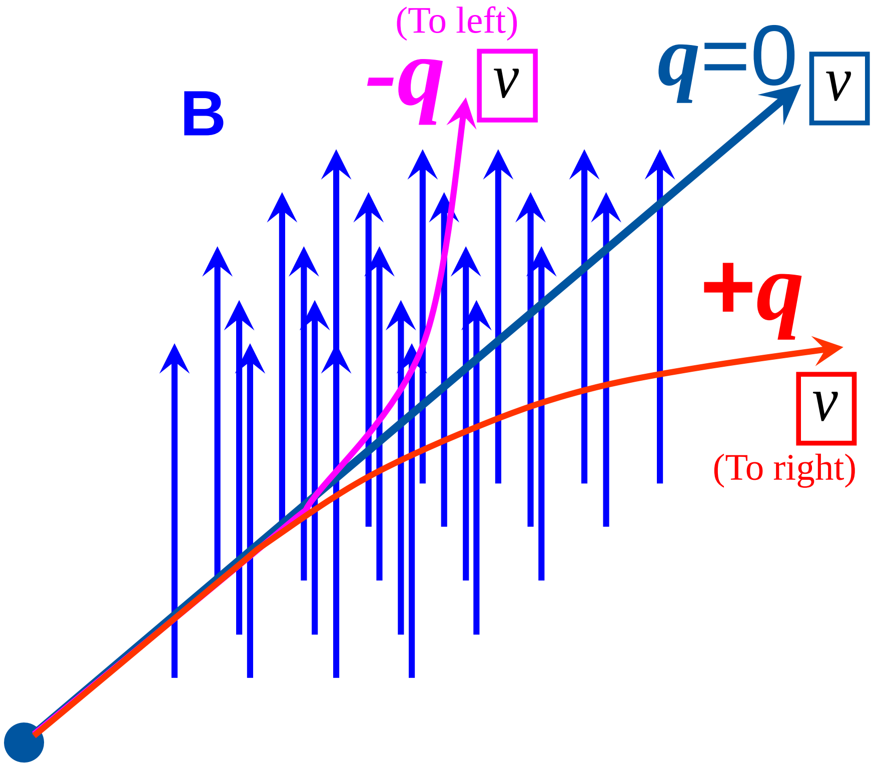
Right-Hand Rule



$$F = q(v \times B)$$

Ref: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magfor.html

South Pole of Magnet



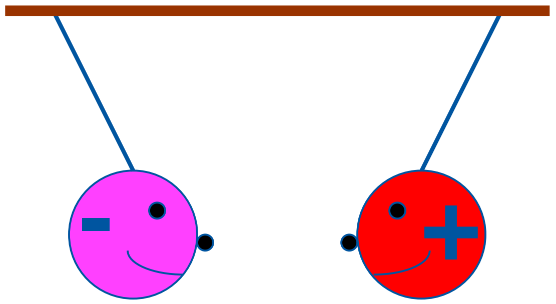
Charge moving into plane of paper

North Pole of Magnet

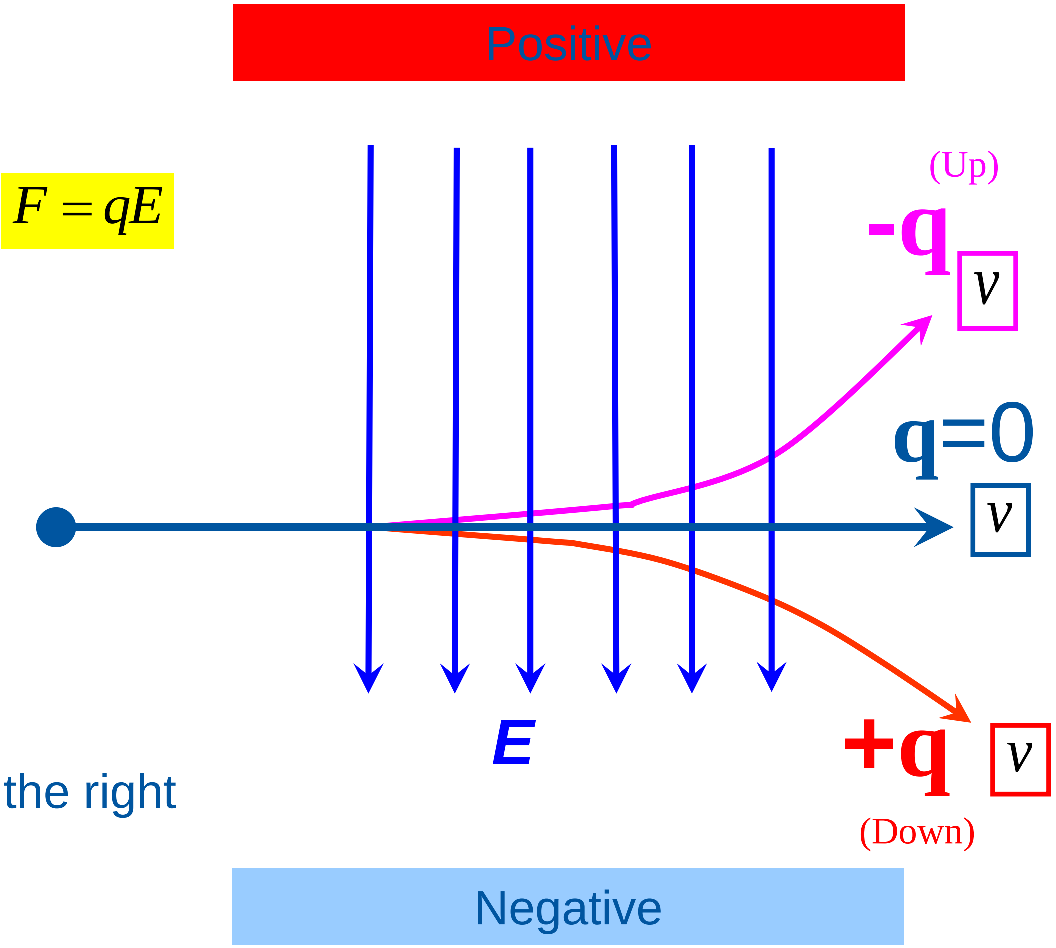
See talk from T. Zickler: “Normal-conducting & Permanent Magnets”

Reminder: Deflection in an Electric Field

Opposites Attract !



$F = qE$



Charge moving from the left to the right

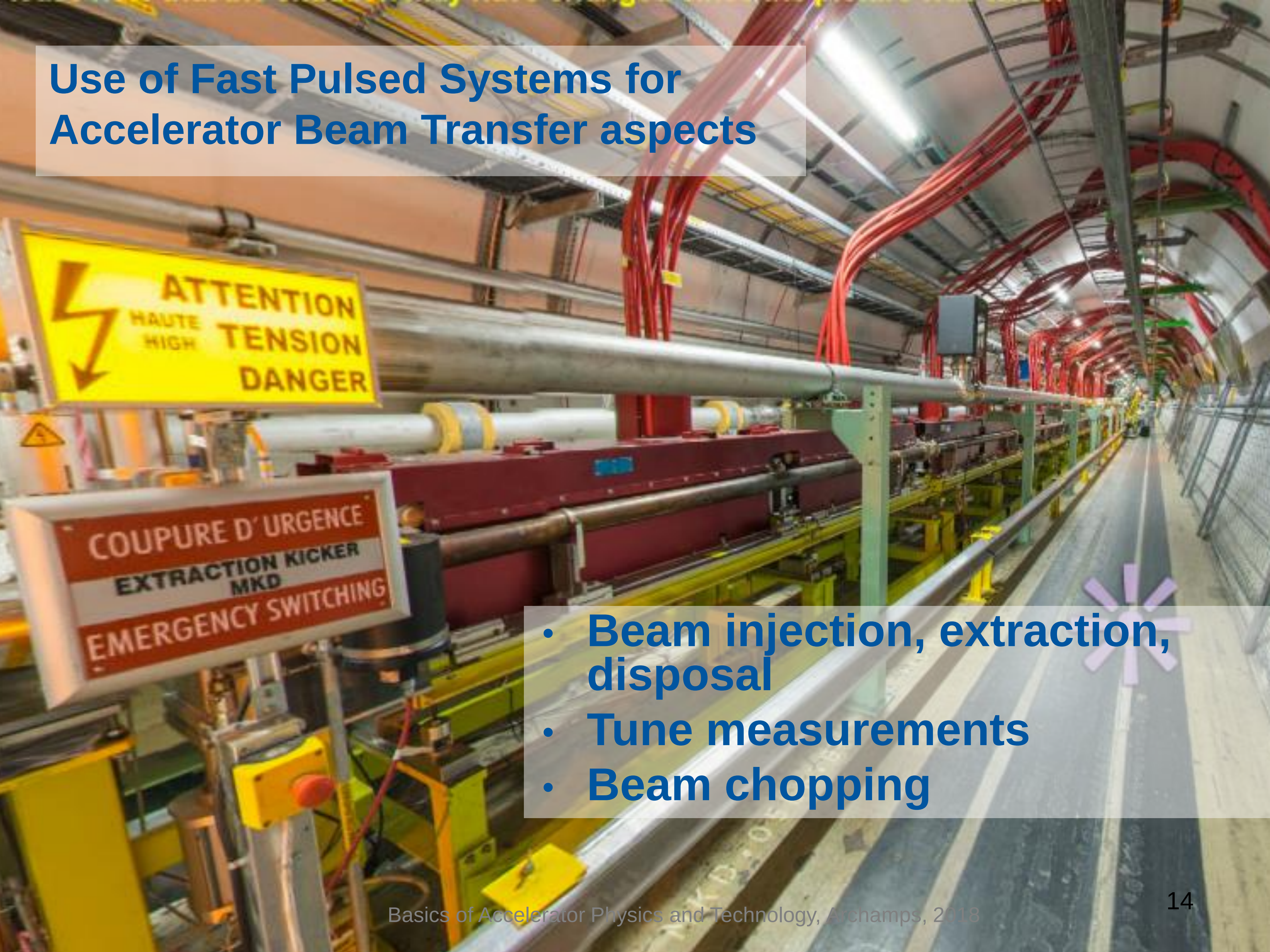
Kicker's

What's a kicker?

If you google it…

…so we also call them **"Fast Pulsed Magnets"**

Use of Fast Pulsed Systems for Accelerator Beam Transfer aspects



- **Beam injection, extraction, disposal**
- **Tune measurements**
- **Beam chopping**

Usual Kicker System Topology

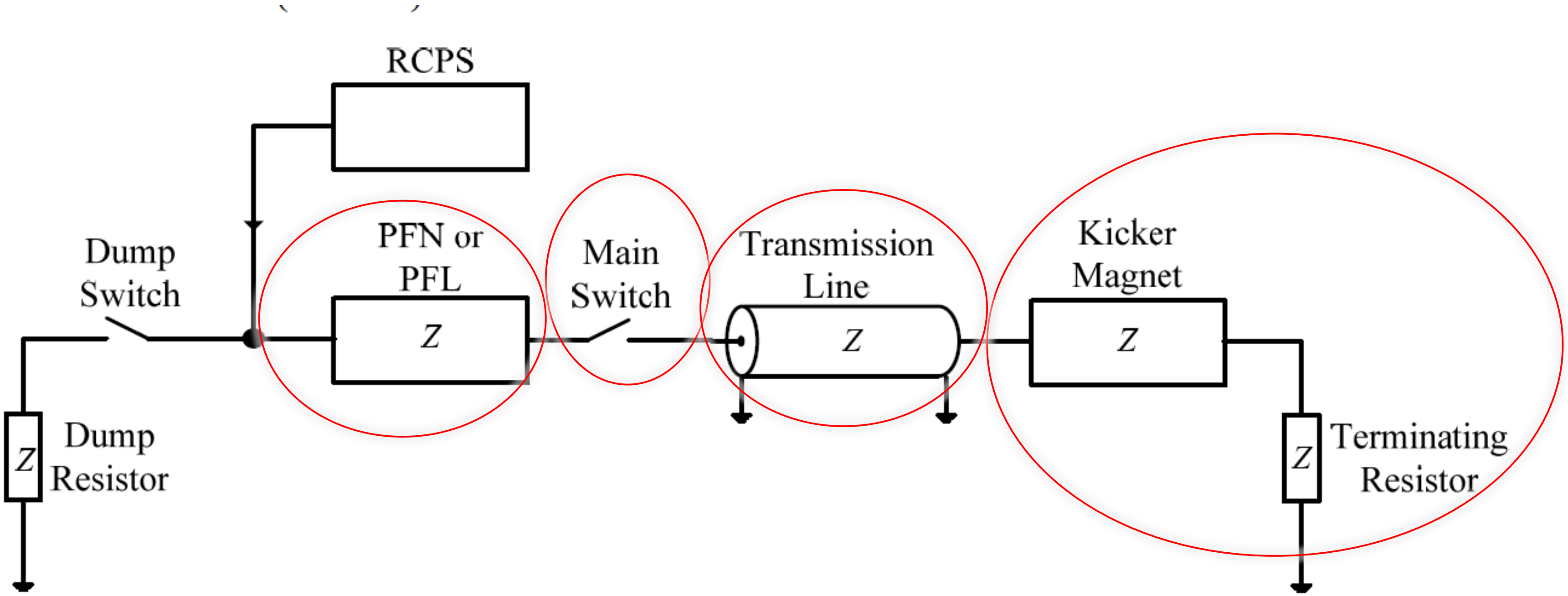


Fig. 4: Simplified schematic of a kicker system

Kicker Magnets

Kicker Magnet Types

- *Basic Concepts*
    - In vacuum magnet
    - Outside vacuum magnet
    - Lumped inductance kicker
    - Transmission line kicker

- *Operational modes*
    - Terminated
    - Short circuited

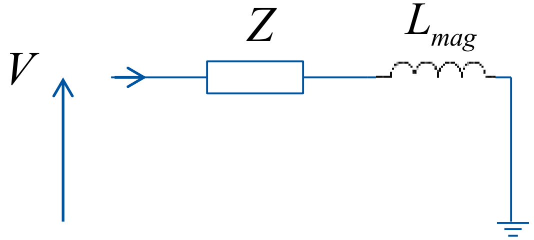
Inside vs. outside Vacuum

- Outside Vacuum
  - Magnet build around vacuum chamber
  - Magnet easier to build
  - HV insulation can be an issue
  - Complex vacuum chamber necessary
    - keep beam vacuum
    - let transient field pass -> ceramic + metallization
    - consumes aperture!

- Inside Vacuum
  - Magnet inside vacuum tank
  - Feedtroughs for all services necessary (HV, cooling, signals)
  - Materials need to be vacuum compatible
    - “Bakeable” design
  - Vacuum also improves HV insulation

Lumped Inductance vs. Transmission Line Kicker

“lumped inductance”



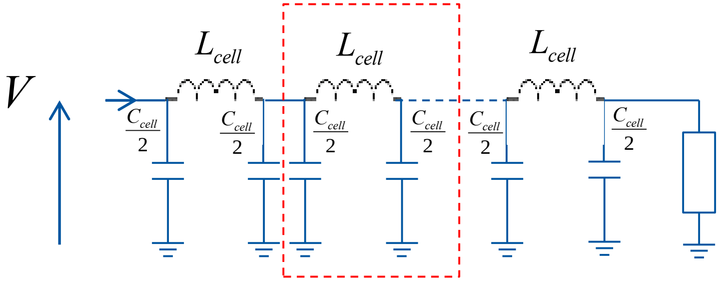
$$I = \frac{V}{Z}(1 - e^{-t/t}) \qquad t = \frac{L_{mag}}{Z}$$

- simple magnet design
- magnet must be nearby the generator to minimize inductance
- slow: rise-times usually >1 μs

- e.g. LHC MKD ~2.8 μs

“transmission line”

Approx. of matched transmission line



Cell 1… Cell *n* - 1 … Cell *n*

$$L_{mag} = nL_{cell}$$

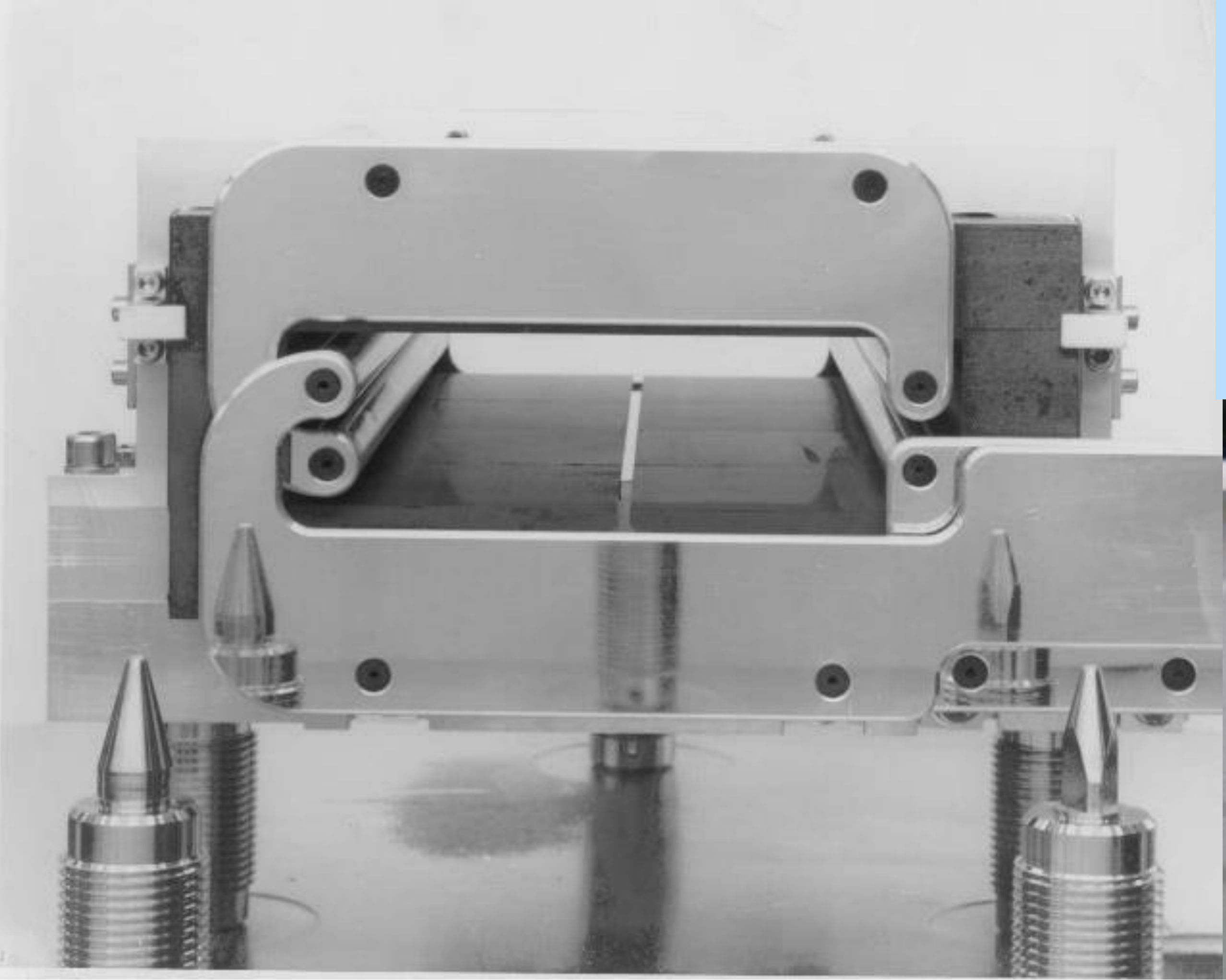
$$Z = \sqrt{\frac{L_{cell}}{C_{cell}}}$$

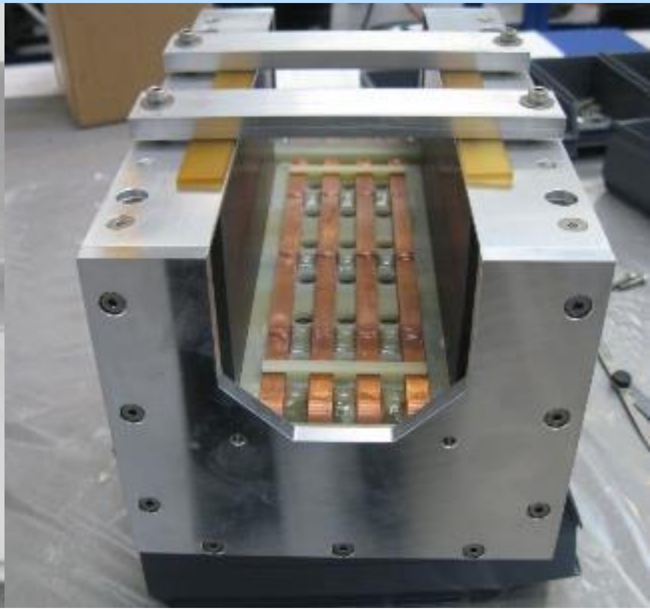
$$t = n\sqrt{L_{cell} \times C_{cell}} = n\frac{L_{cell}}{Z} = \frac{L_{mag}}{Z}$$

- complicated magnet design
- impedance matching important
- field rise-time depends on propagation time of pulse through magnet
- fast: rise-times << 1 μs possible

- e.g. PS KFAs ~100 ns

Lumped Inductance Magnets





- Used for "slower" systems
- "Simple" and "robust"

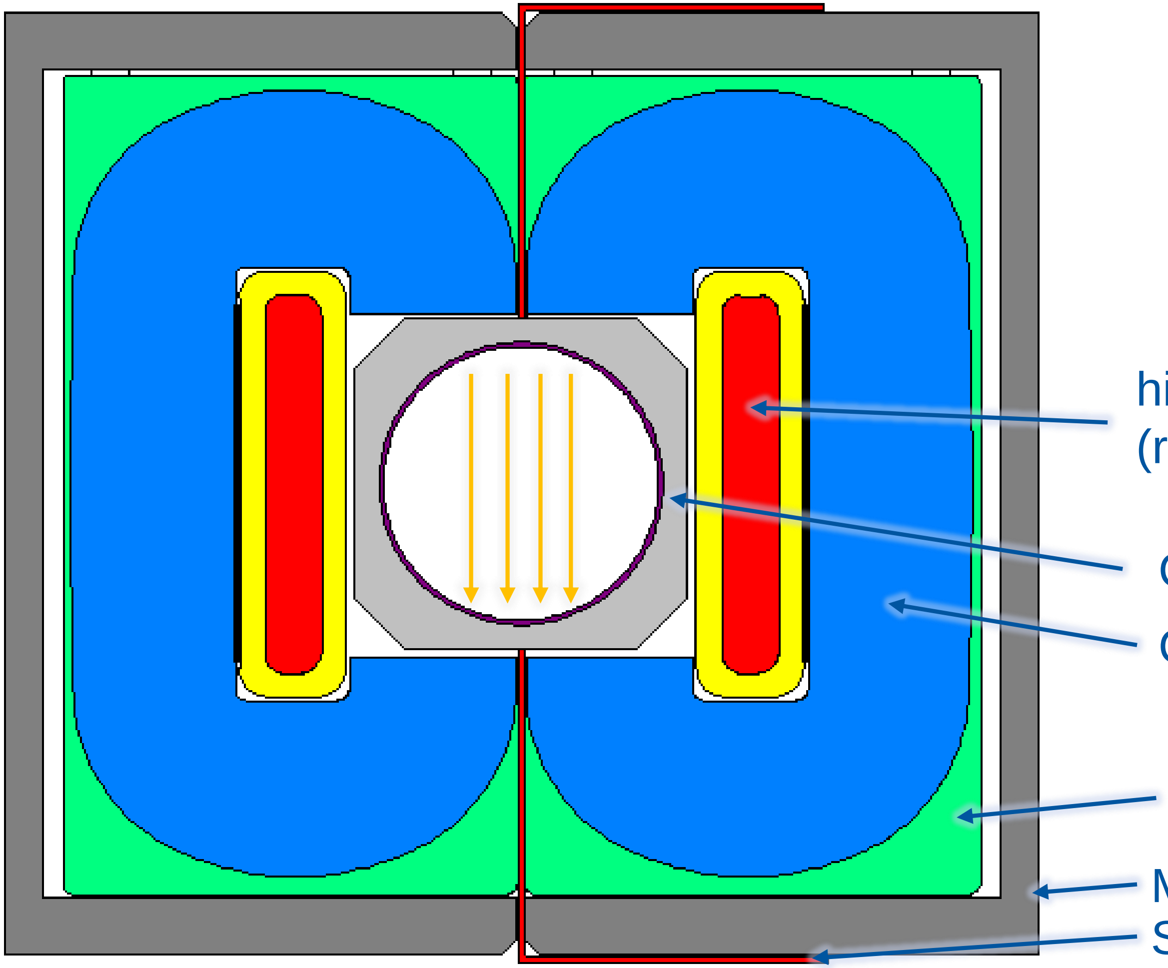
At CERN:

- Currents up to 18.5 kA
- Voltages up to 40 kV

LHC extraction kickers “MKD”

- **15 magnets provide a total horizontal deflection of 0.28 mrad (0.3 T peak field)**
- **Operated at 18.5 kA / 30 kV**
- **Safety and reliability was a major system design factor.**

Extraction kicker magnet - MKD



Magnets are built around a metallized ceramic vacuum chamber

high voltage coil
(red: conductor, yellow: insulation)

Ceramic vacuum chamber

C-core (Si-Fe tape)

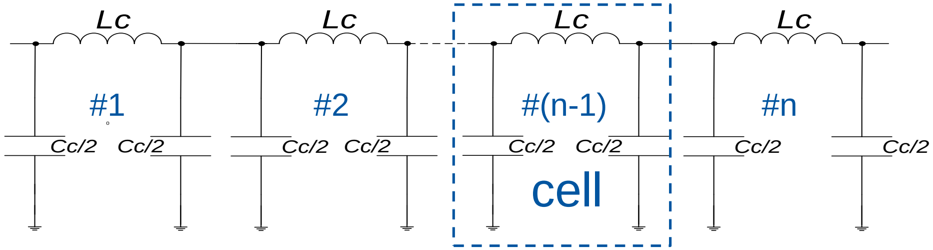
Epoxy moulding

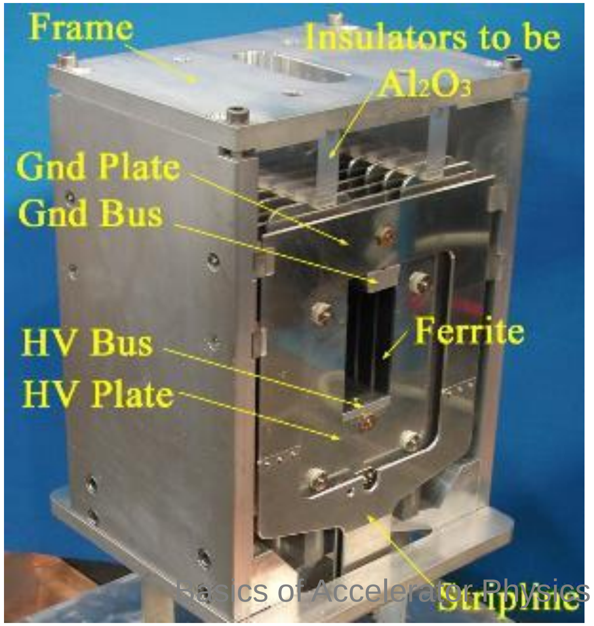
Mechanical frame

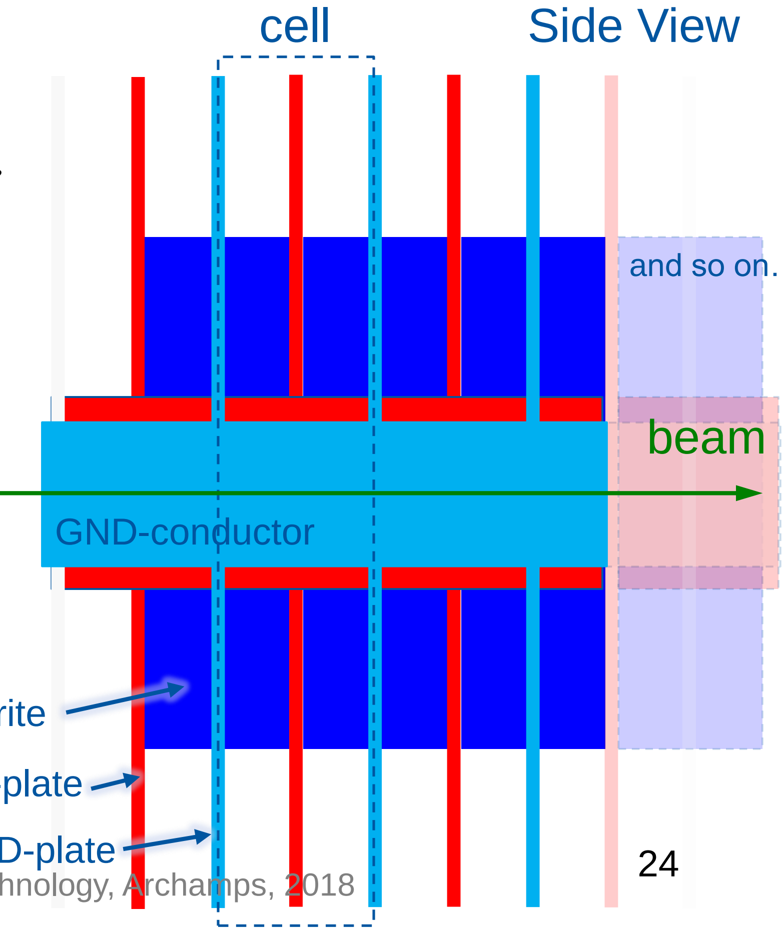
Screen

Magnets – Transmission Line Kicker

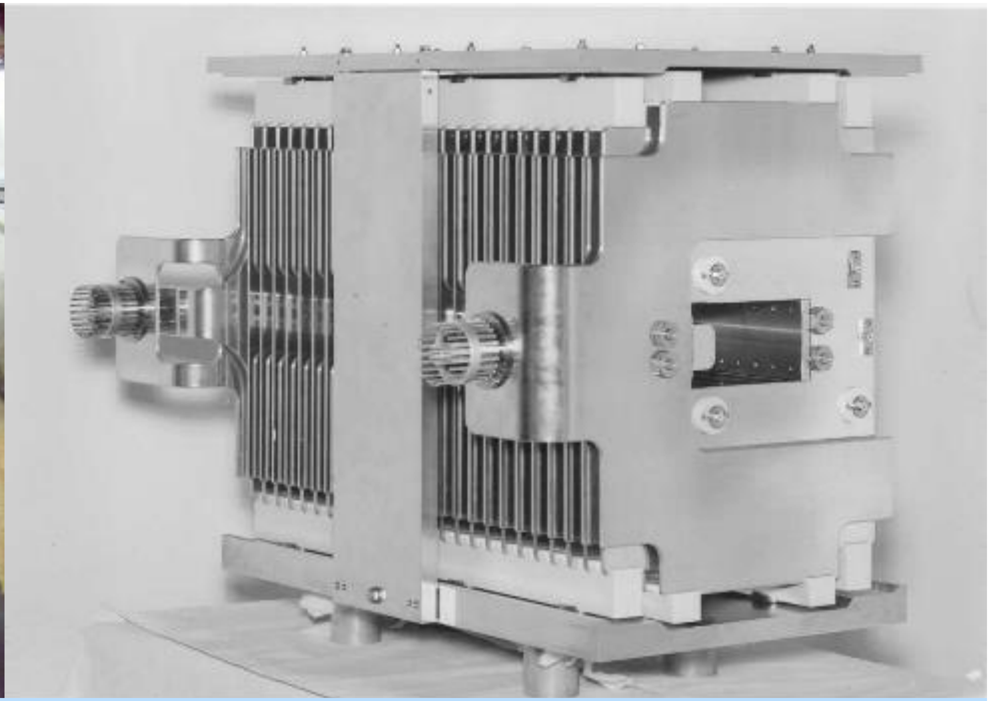
- Fast kicker magnets are generally **ferrite loaded** transmission lines:
  - Kicker magnets consist of many, relatively short, cells to approximate a “broadband” coaxial cable
  - Ferrite C-cores are sandwiched between HV plates
  - Grounded plates are interleaved to form a capacitor to ground







Transmission Line Kickers

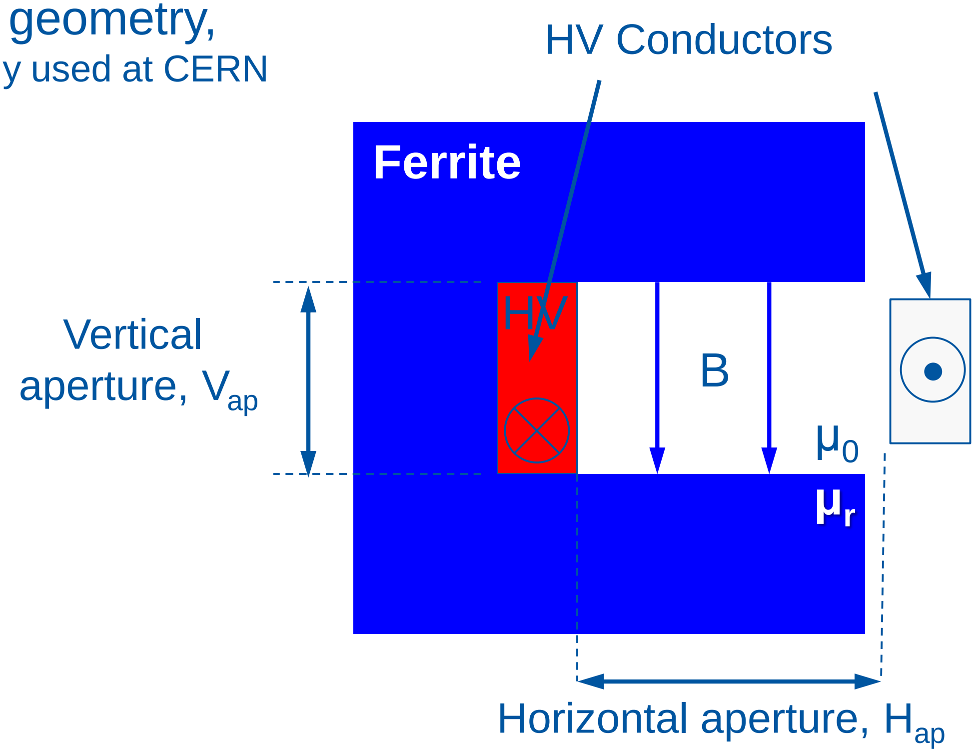


At CERN:

- Used for “faster” systems (30ns-700ns range)
- Currents up to 5 kA
- Voltages up to 80 kV

Basic Magnetic Circuit Parameters

C-core geometry,
commonly used at CERN



Magnetic field

$$B_y \cong \mu_0 \left(\frac{N \cdot I}{V_{ap}} \right)$$

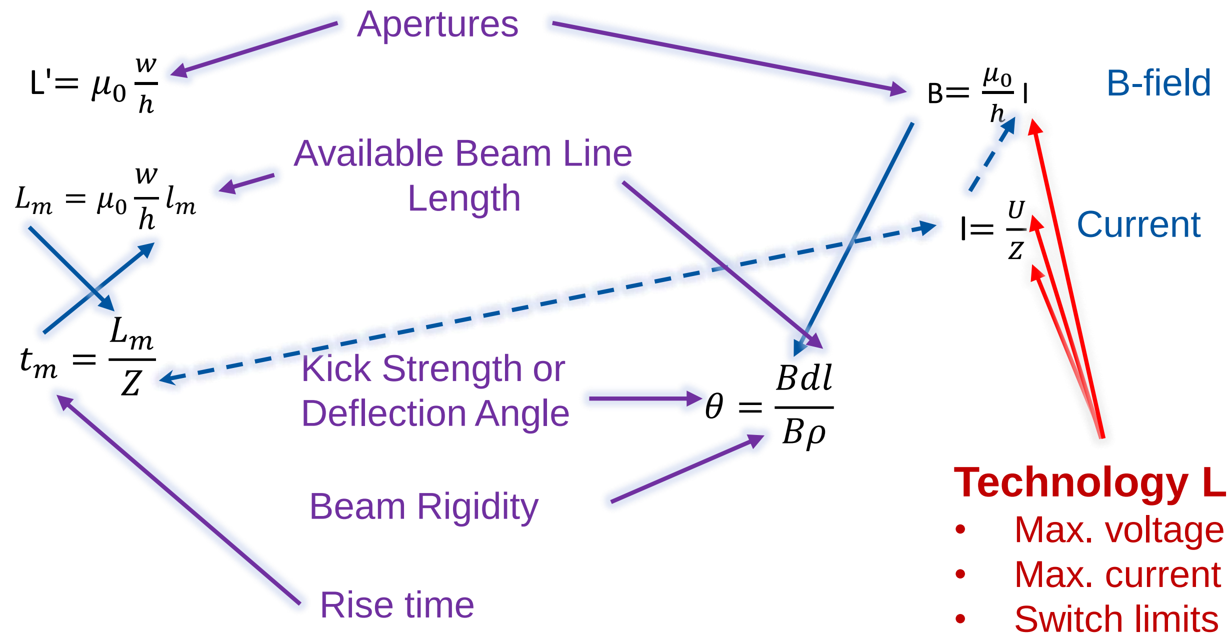
Magnet inductance

$$L_{mag/\mathrm{m}} \cong \mu_0 \left(\frac{N^2 \cdot H_{ap}}{V_{ap}} \right)$$

- Dimensions $\mathbf{H_{ap}}$ and $\mathbf{V_{ap}}$ basically specified by beam parameters at kicker location.
- Ferrite ($\mu_r \approx 1000$) reinforces magnetic circuit and uniformity of the field in the gap.
- For fast rise-times the inductance must be minimised:
  - typically the number of turns, $N = 1$.
  - Kicker systems are often split into several short units.

Find more on magnetic circuits in the “Magnets” lecture from T. Zickler

Simplified Kicker Design Process



“Given” Design Parameters

Magnet / Module design:

Apertures

Unit length Inductance $L' = \mu_0 \frac{w}{h}$

B-field $B = \frac{\mu_0}{h} I$

Available Beam Line Length

Magnet Inductance $L_m = \mu_0 \frac{w}{h} l_m$

Current $I = \frac{U}{Z}$

Split “Magnet” into modules?

Filling time $t_m = \frac{L_m}{Z}$

Kick Strength or Deflection Angle $\theta = \frac{Bdl}{B\rho}$

Beam Rigidity

Rise time

Technology Limits:

- Max. voltage hold off
- Max. current
- Switch limits
- Cables
- etc.

Cell design:

Cell Inductance $L_c = \frac{L_m}{n_c}$ no. of cells

Cell Capacitance $C_c = \frac{L_c}{{Z_0}^2}$

Feasibility aspect:

- Capacitance
- Mech. Apertures
- Voltage hold off

Cell Cut Off Freq. $\omega_{0c} = \frac{2}{\sqrt{L_c C_c}}$

Needs to be high enough to not attenuate the rising or falling edges too much.

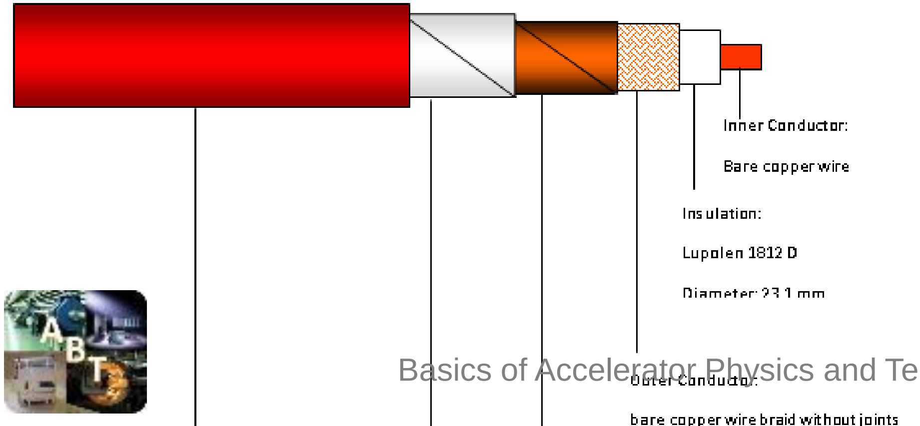
High Voltage Coaxial Cables for Kicker Systems

Transition from SF6 gas filled coaxial cables to RG220 (PS KFA-79)

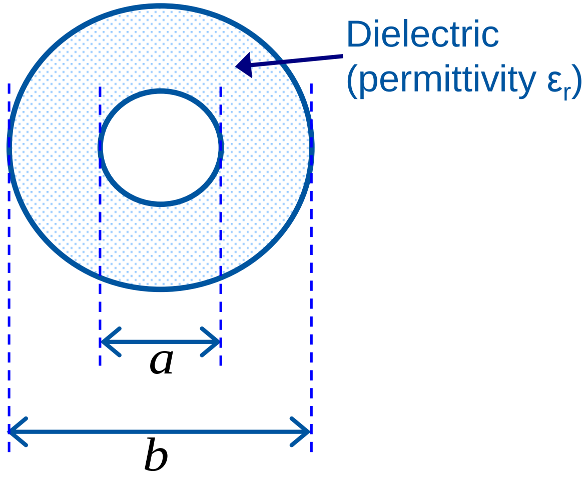
Coaxial Cables

Coaxial cables play a major role in kicker systems!

- Need to **transmit fast pulses, high currents**.
- Cables an be also used as **pulse forming lines (PFL).**
- Should **not attenuate** or distort the pulse (attenuation < ~5.7dB/km for RG220 and <3dB/km for SF6 filled - both at 10 MHz).
- Need to **insulate high voltage** (conventional 40kV, SF6 80 kV)
- Precise **characteristic impedance** over complete length mandatory! Otherwise issues with reflections.
- Need to be **radiation and fire resistant**, acceptable bending radius etc.



Coaxial Cables



Cross-section of coaxial cable

(b-a) needs to withstand U_{nom}

Capacitance per metre length (F/m): $C = \left(\frac{2\pi\varepsilon_0\varepsilon_r}{ln\left(b/a\right)} \right)$

Inductance per metre length (H/m): $L = 2 \cdot 10^{-7} \cdot ln\left(\frac{b}{a}\right)$

Characteristic Impedance (Ω):
(typically 15Ω to 50Ω).

$$Z_0 = \sqrt{\frac{L}{C}}$$

Delay per metre length:
(~5ns/m for suitable coax cable).

$$\tau = \sqrt{L \cdot C}$$

Where:

a	is the outer diameter of the inner conductor (m);
b	is the inner diameter of the outer conductor (m);
ε_0	is the permittivity of free space (8.854×10^{-12} F/m).

Pulse Generators

FHCT stack with trigger transformer

MKD:
15 Pulse generators in gallery parallel to LHC tunnel.
Connected to the magnets via ~30 m of 8 parallel transmission cables.

Pulse Generators

- For **energy storage** and pulse shaping pulse forming lines (**PFL**) or artificial pulse forming networks (**PFN**) can be used.

- A **power switch** is needed to switch the charged "energy storage" to the load. Spark gaps (not anymore at CERN), Thyratrons, Ignitrons, Solid state switches etc. are frequently used.

- The pulse generator is surrounded by loads of other important equipment (e.g. slow controls, timing, cooling etc.) -> not further outlined in this talk.

PFL/PFN

Pulse Forming Line (PFL)

- Low-loss coaxial cable
- Fast and ripple-free pulses
- Attenuation & droop becomes problematic for pulses > 3 μs
- Above 40 kV SF6 pressurized PE tape cables are used at CERN
- Bulky: 3 μs pulse ~ 300 m of cable

Reels of PFL used at the PS complex (as old as the photograph!)

Pulse Forming Network (PFN)

- Artificial coaxial cable made of lumped elements
- For low droop and long pulses > 3 μs
- Each cell individually adjustable: adjustment of pulse flat-top difficult and time consuming.

SPS extraction kicker (MKE) PFN (17 cells)

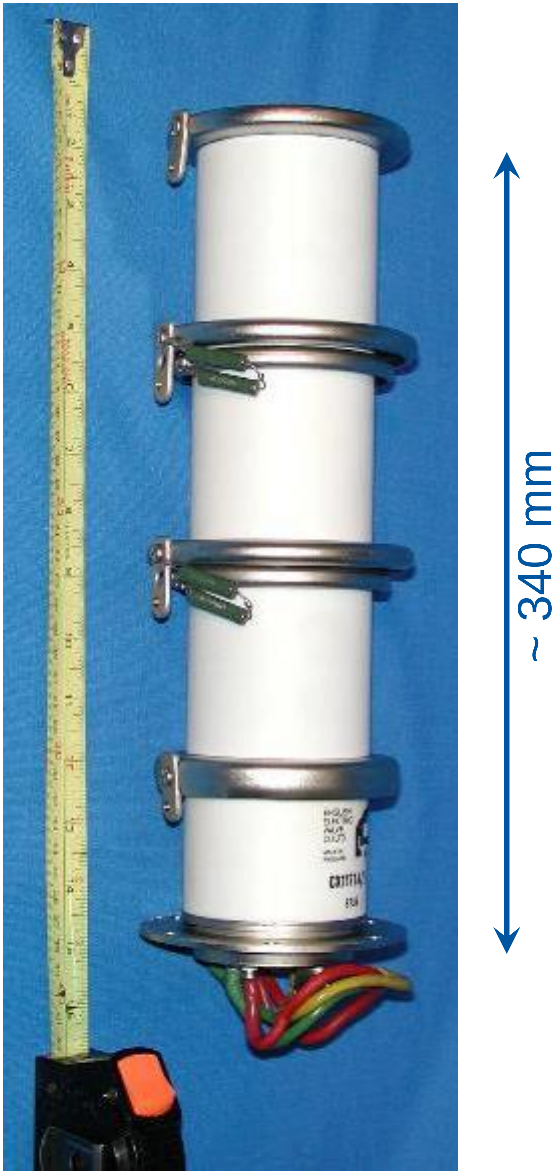
Switches

Thyratrons

- Deuterium gas thyratrons are still commonly used.
- Hold off >80 kV and switch up to 6 kA.
- Fast switching ~ 30 ns (~150 kA/µs).
- Erratic turn-on: use with RCPS to reduce hold-off time.

Power semiconductor switches

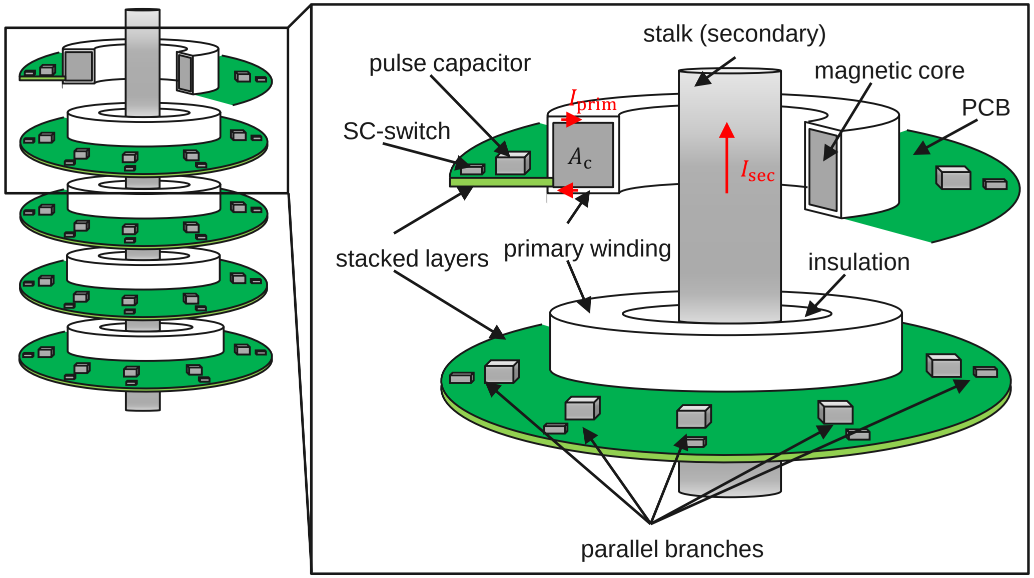
- Various types (MOSFET, IGBT, GTO's…) used at CERN.
- Suitable for scenarios where erratic turn-on is not allowed:
  - LHC beam dump kickers held at nominal voltage throughout operation (>10h) ready to fire and safely abort at any moment.
- Series/parallel "stacking" possible.
- Hold off up to 30 kV and switch up to 18 kA (LHC MKD).
- Slower >1 µs (~18kA/µs).



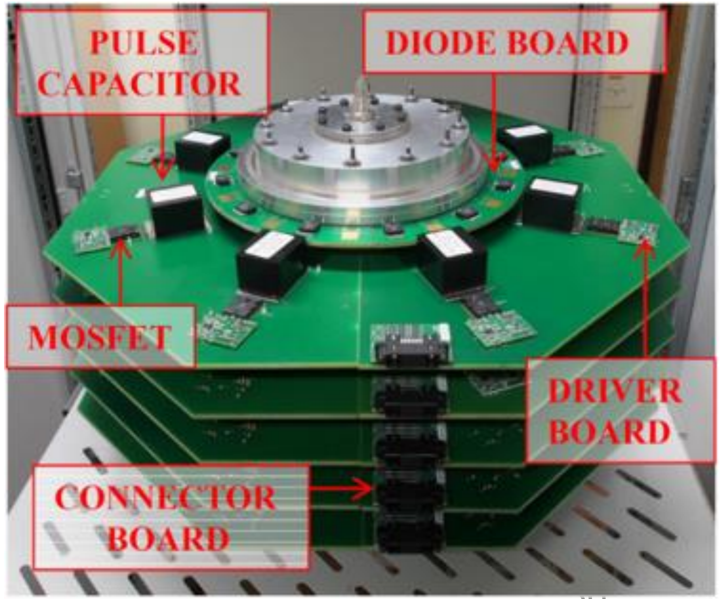
Thyratron

Inductive Adder

- Different pulse generator concept.
- Energy stored in distributed capacitors.
- Capacitors are partially discharged via SiC MOSFET switches in parallel branches.
- Several layers add up to the required output voltage.



- Advantages:
  - **Modularity:** the same module design can be used for different voltage/current specifications;
  - **Short rise and fall times** can be achieved;
  - Output pulse **voltage can be modulated** -> excellent flat top quality.
  - Switches and control electronics are referenced to ground.
- Disadvantages:
  - Output transformer maximum **pulse length** limited by magnetic core (several µs);

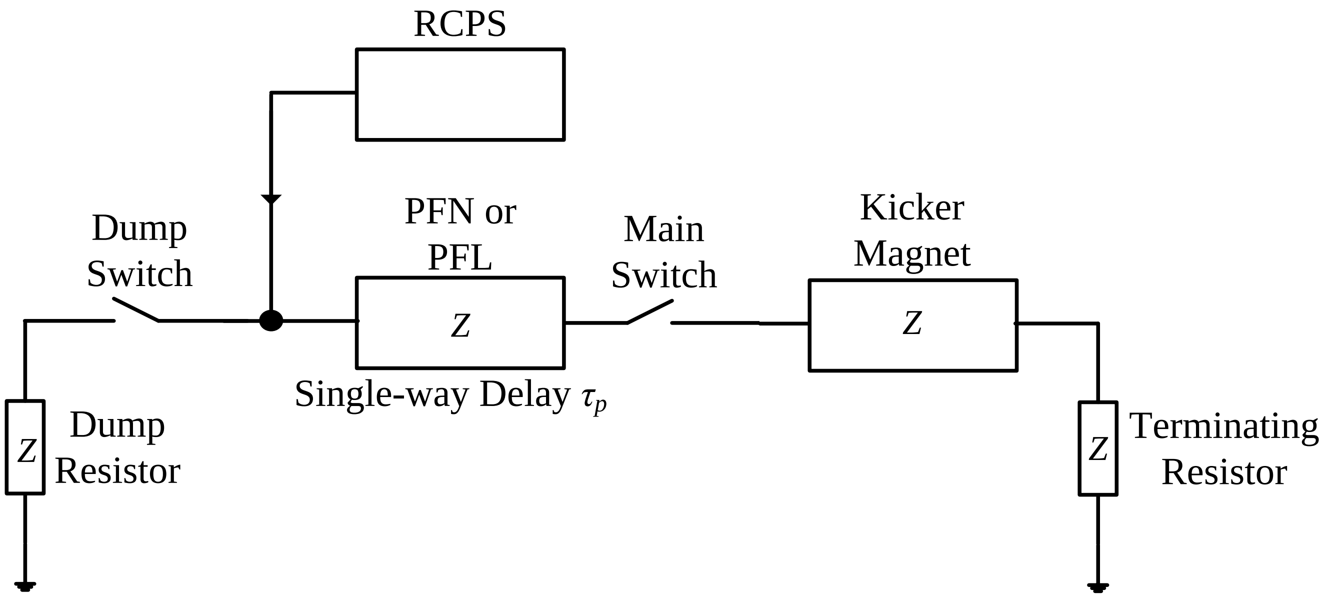


Currently being developed for CLIC and FCC.

Pulse Transmission

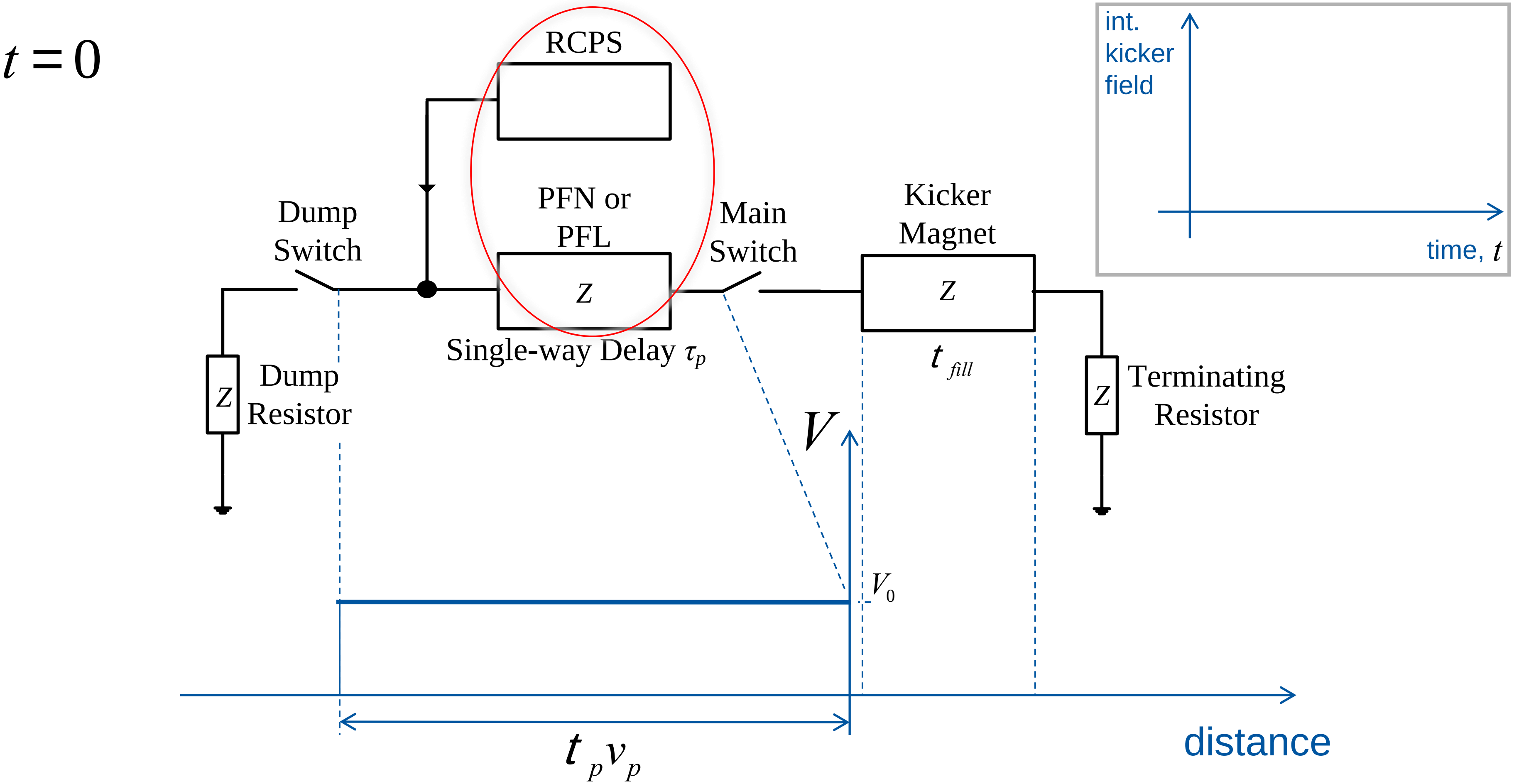
Pulse Transmission

Simplified kicker system schematic



Lets see what happens when we pulse the system…

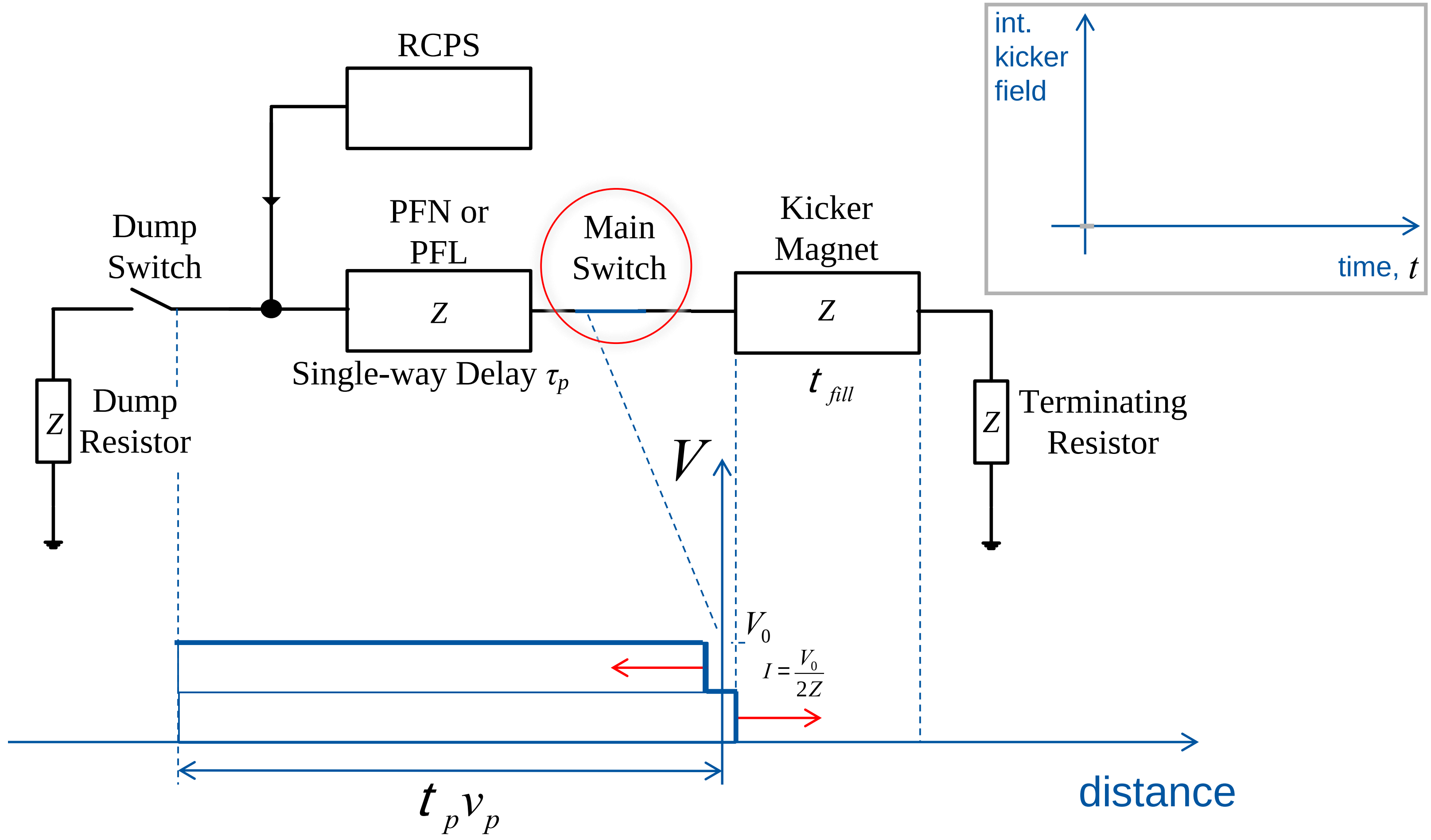
Simplified kicker system schematic



- Pulse forming network or line (PFL/PFN) charged to voltage V_0 by the resonant charging power supply (RCPS)
  - RCPS is de-coupled from the system through a diode stack

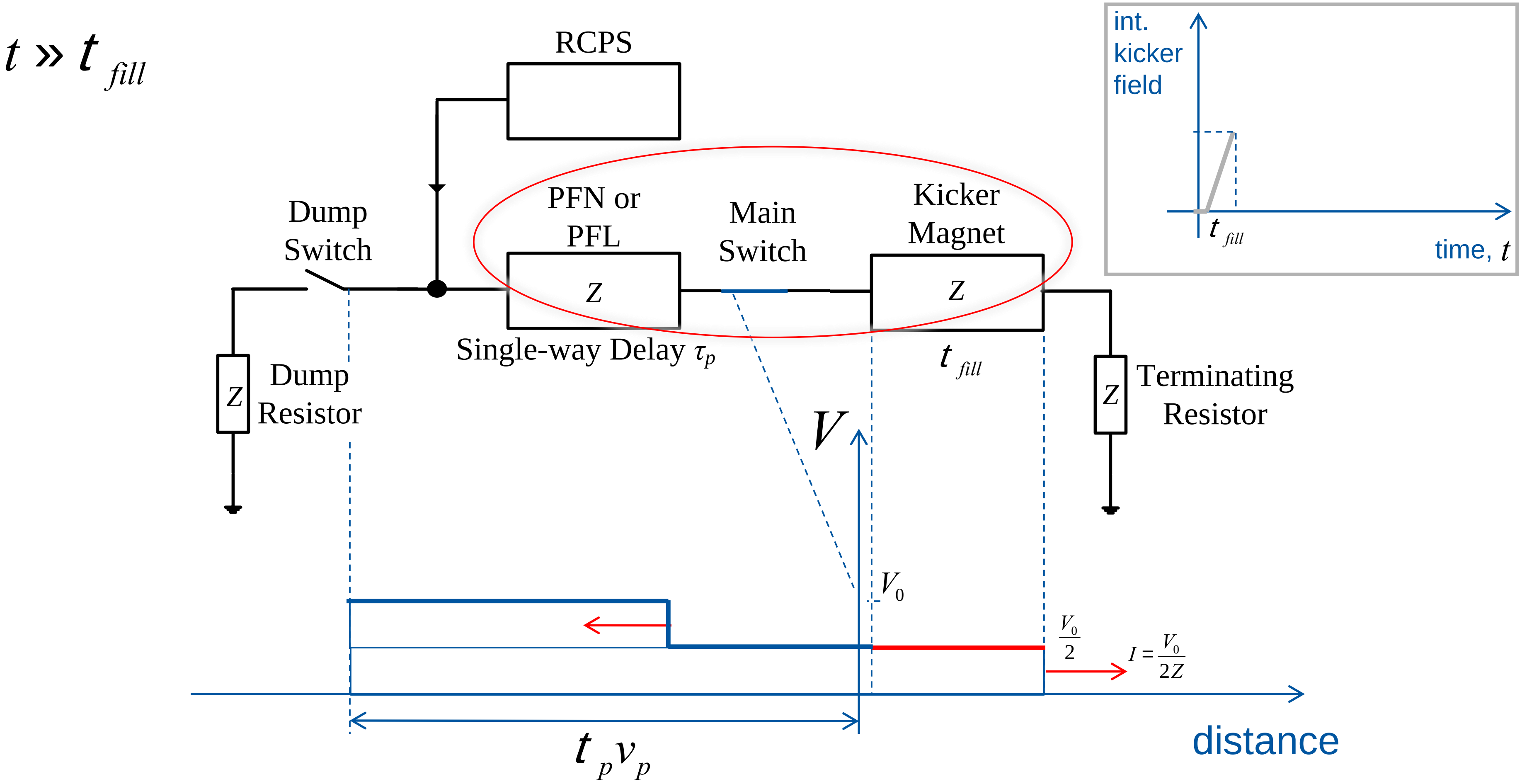
Simplified kicker system schematic

t » 0



- At t = 0, main switch is closed and current starts to flow into the kicker

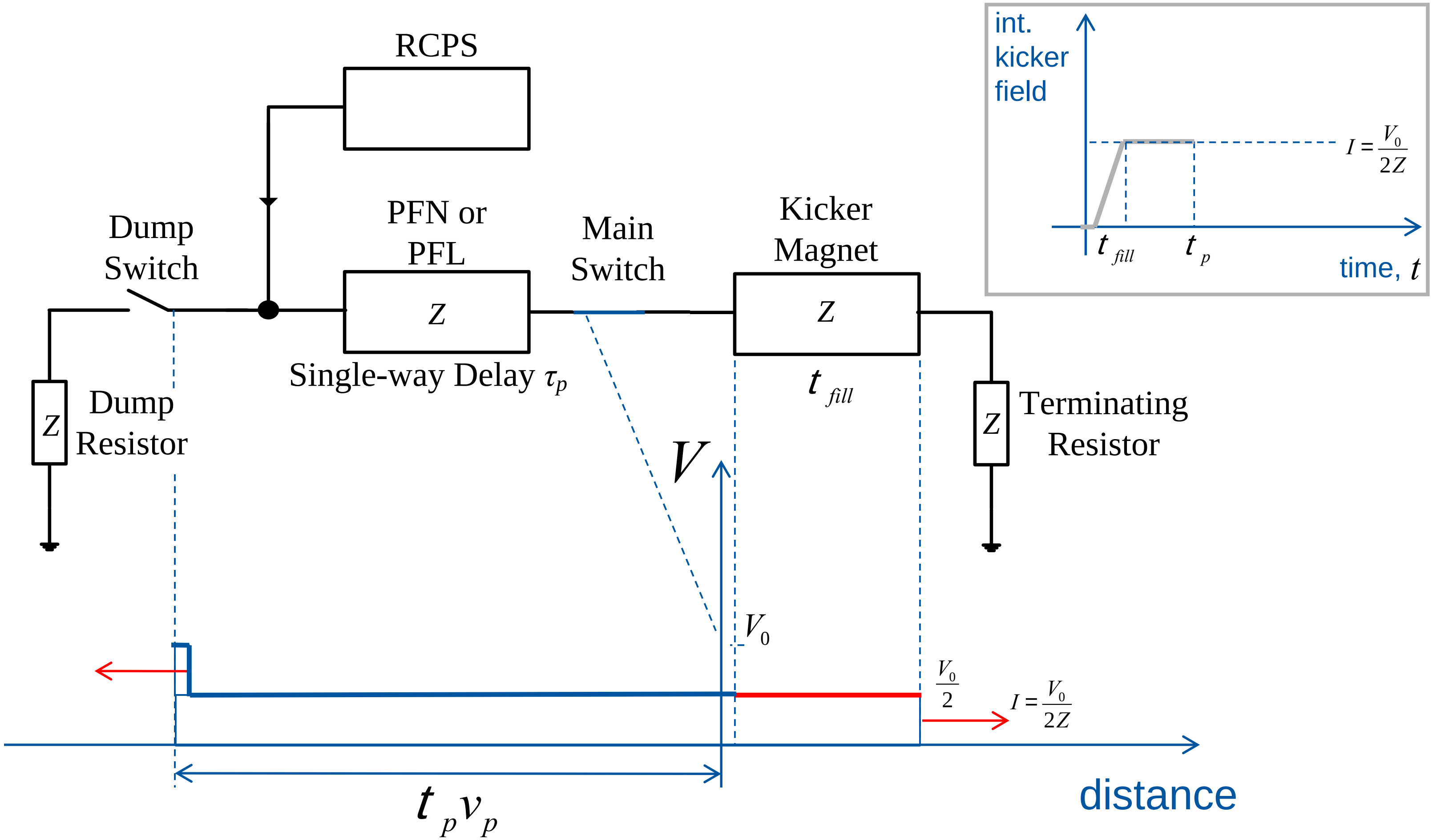
Simplified kicker system schematic



- At t = τ_{fill}, the voltage pulse of magnitude $V_0/2$ has propagated through the kicker and nominal field achieved with a current $V_0/2Z$
  - typically $\tau_p >> \tau_{fill}$ (schematic for illustration purposes)

Simplified kicker system schematic

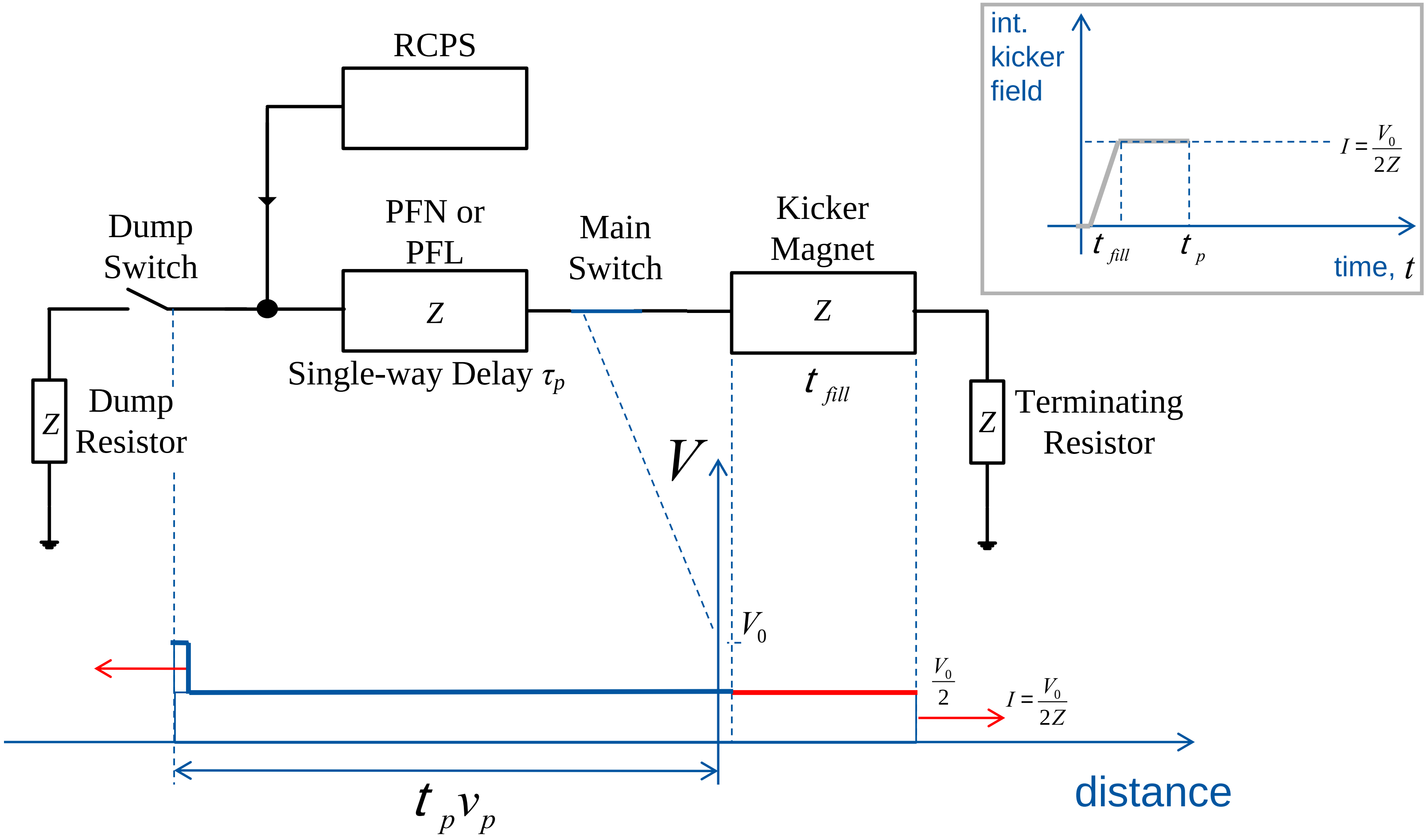
$t \gg t_p$



- PFN continues to discharge energy into kicker magnet and matched terminating resistor.

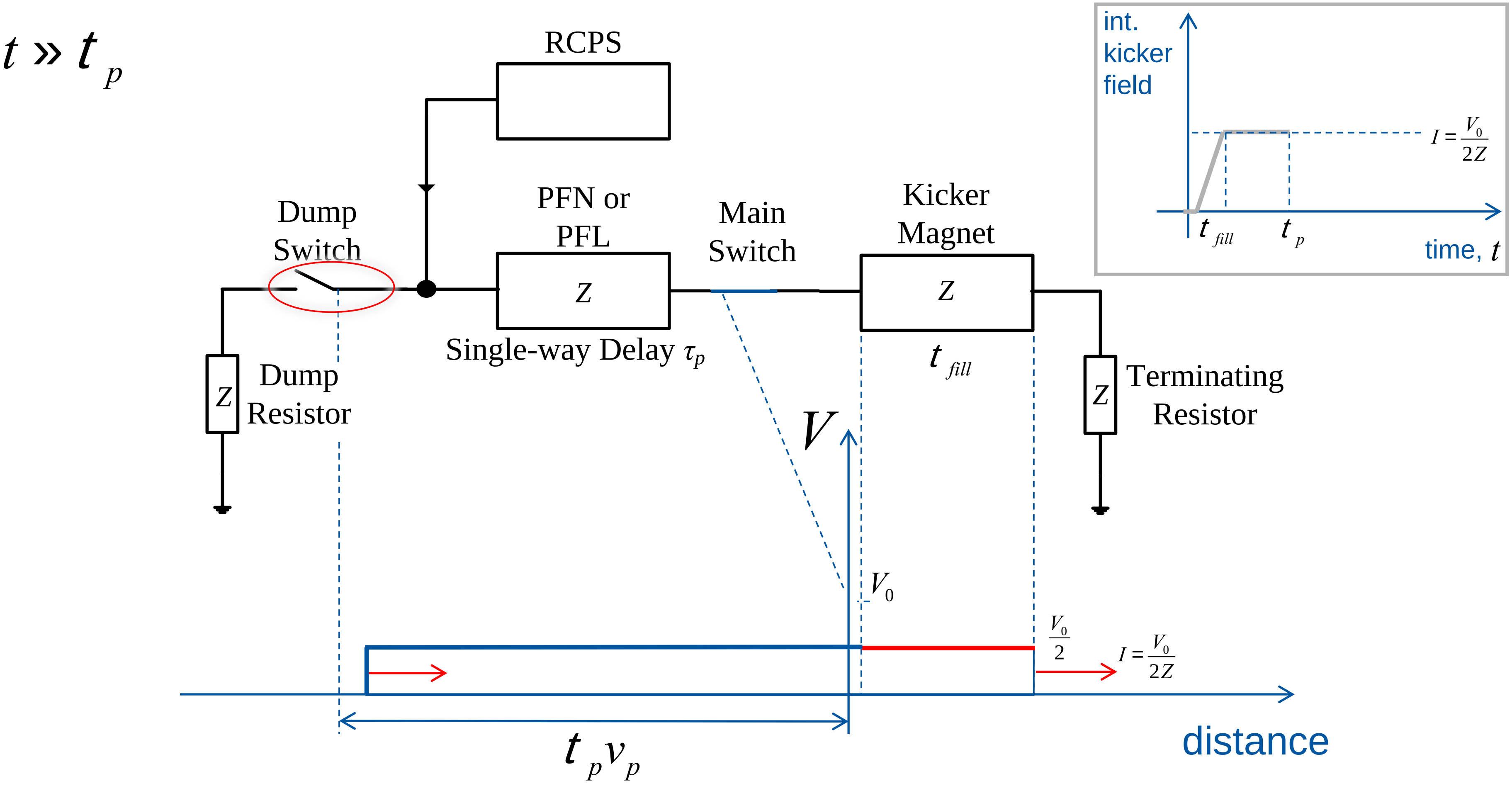
Simplified kicker system schematic

$t \gg t_p$



- PFN continues to discharge energy into kicker magnet and matched terminating resistor
- At t ≈ τ_p the negative pulse reflects off the open end of the circuit (dump switch) and back towards the kicker

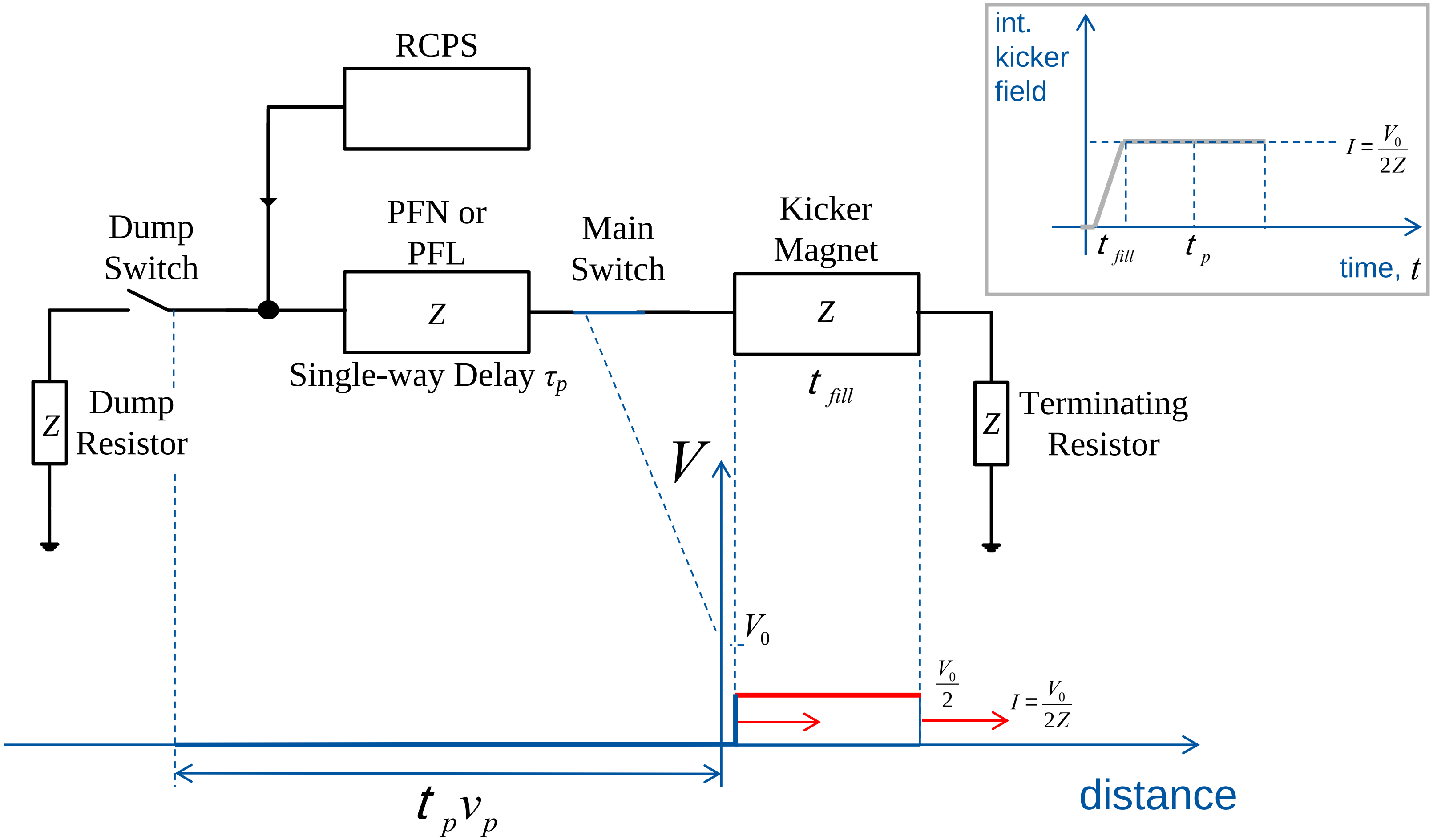
Simplified kicker system schematic



- PFN continues to discharge energy into matched terminating resistor.

Simplified kicker system schematic

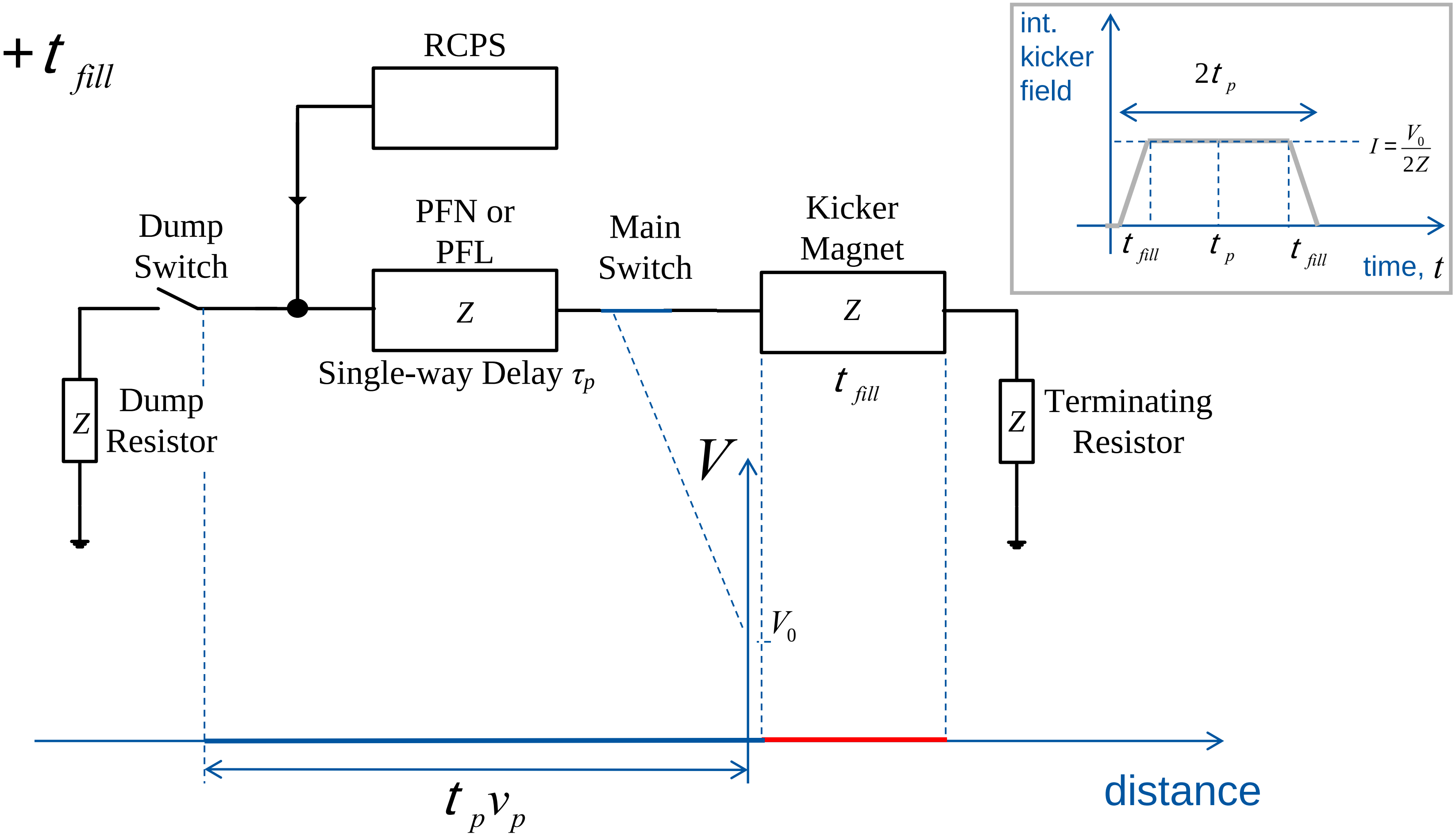
$t \gg 2t_p$



- At t ≈ $2\tau_p$ the pulse arrives at the kicker and field starts to decay.

Simplified kicker system schematic

$$t = 2t_p + t_{fill}$$



- Pulse decayed. All energy has been emptied.
- Kicker pulse length can be changed by adjusting the relative timing of dump and main switches. e.g. if the dump and main switches are fired simultaneously the pulse length will be halved and energy shared on dump and terminating resistors.

Pulse Transmission: Reflections

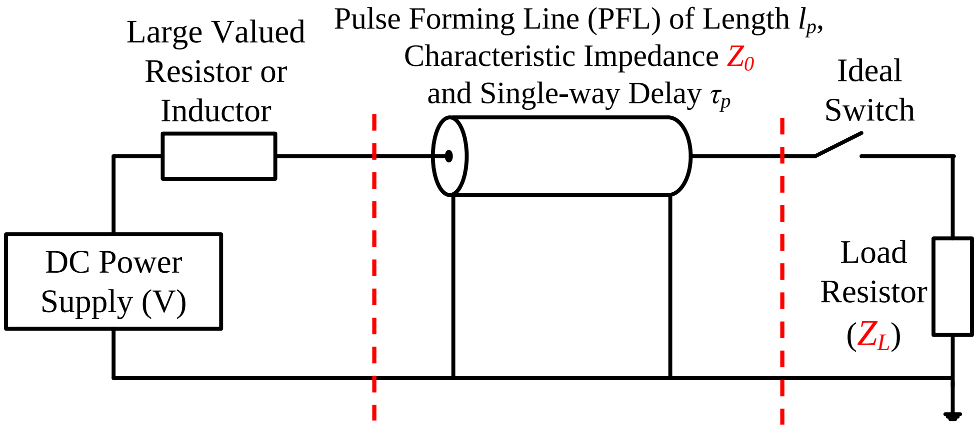
- Reflection coefficient:
  - Ratio of reflected wave to incident wave

$$\Gamma = \frac{E^-}{E^+} \quad \rightarrow \quad \Gamma = \frac{Z_{Load} - Z_{Source}}{Z_L + Z_S}$$

  - Terminated 50 Ω $\qquad \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} = \frac{50-50}{50+50} = 0$
  - SC $\qquad \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} = \frac{0-Z_S}{0+Z_S} = -1$
  - Open line $\qquad \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} = \frac{\infty-Z_S}{\infty+Z_S} = 1$

Reflections

- A simplified pulse forming circuit:



  - When the switch is fired the voltage is divided as:

$$V_L = V \cdot \left(\frac{Z_L}{Z_0 + Z_L} \right) = \alpha V$$

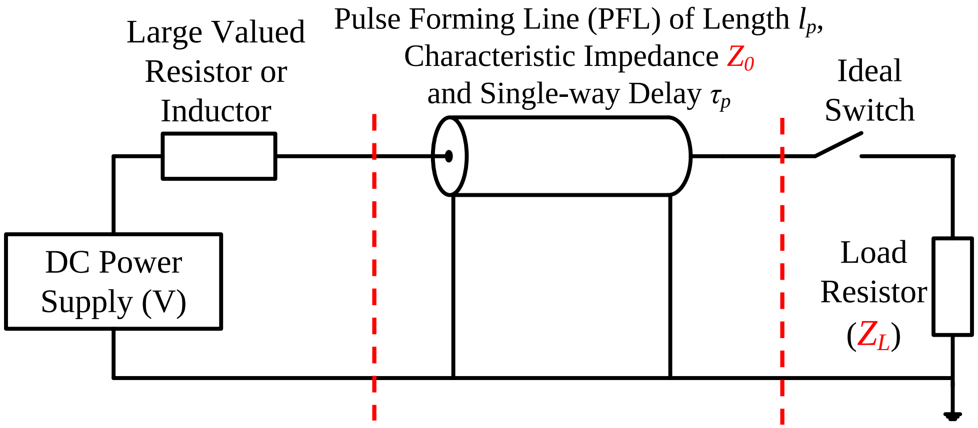
  - In the matched case:

$$Z_0 = Z_L \qquad\qquad a = \frac{1}{2},\ b = 0$$

  - Hence PFL charging voltage is twice the required voltage!

Reflections

- A simplified pulse forming circuit:

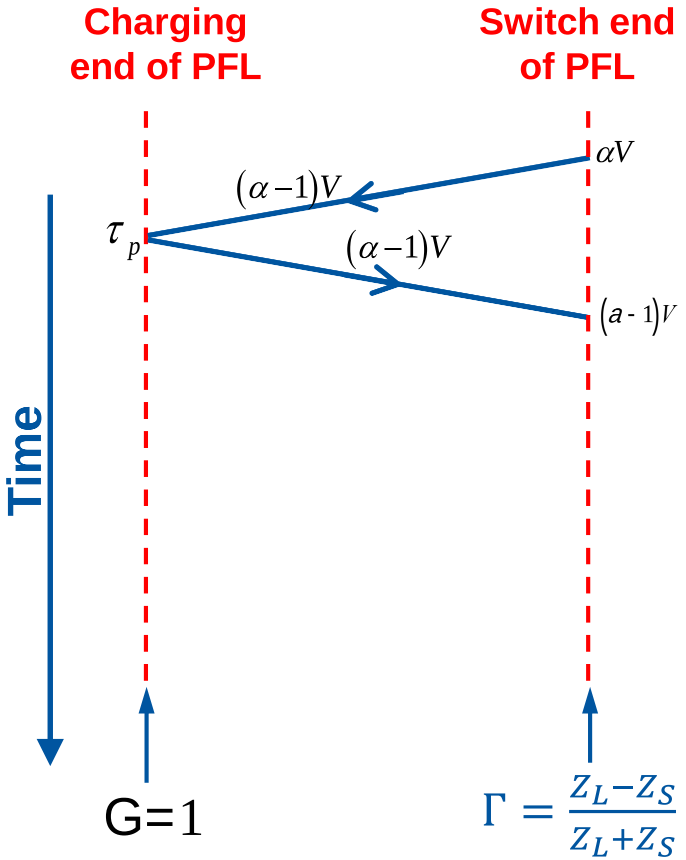


- When the switch is fired the voltage is divided as:

$$V_L = V \cdot \left(\frac{Z_L}{Z_0 + Z_L} \right) = \alpha V$$

- In the matched case:

$$Z_0 = Z_L \qquad a = \frac{1}{2},\ b = 0$$



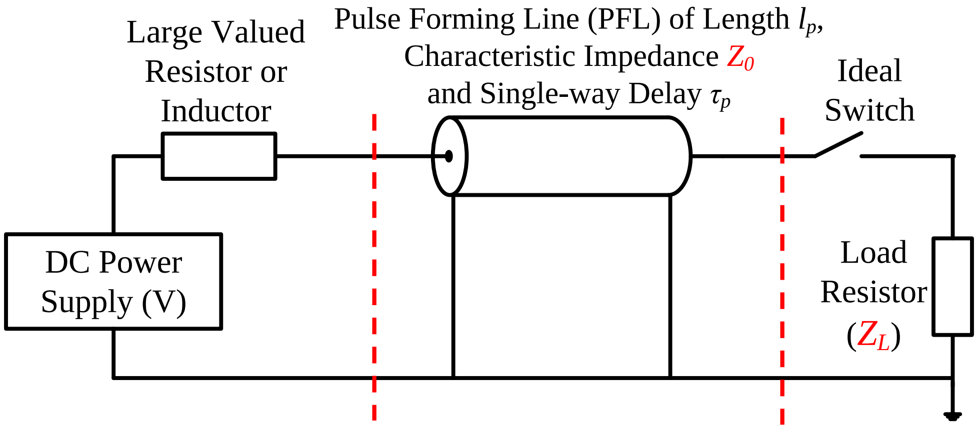
$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

for matched case:

$$\Gamma = 0$$

Reflections

- A simplified pulse forming circuit:



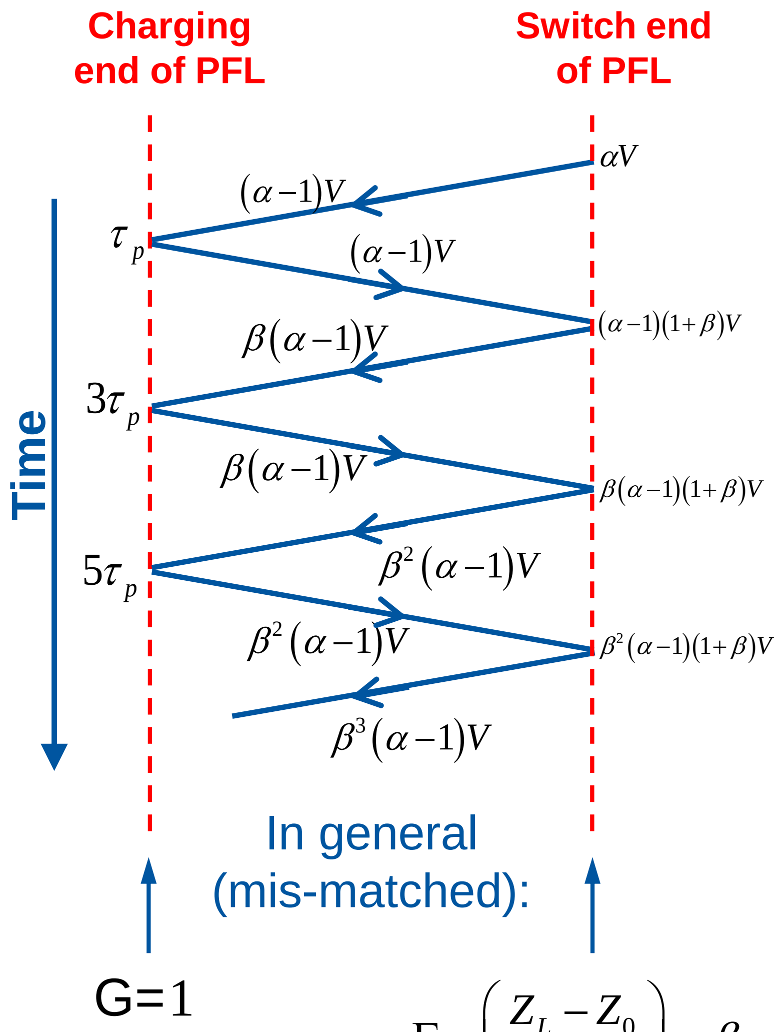
Match impedances to avoid reflections!

- When the switch is fired the voltage is divided as:

$$V_L = V \cdot \left(\frac{Z_L}{Z_0 + Z_L} \right) = \alpha V$$

- In the matched case:

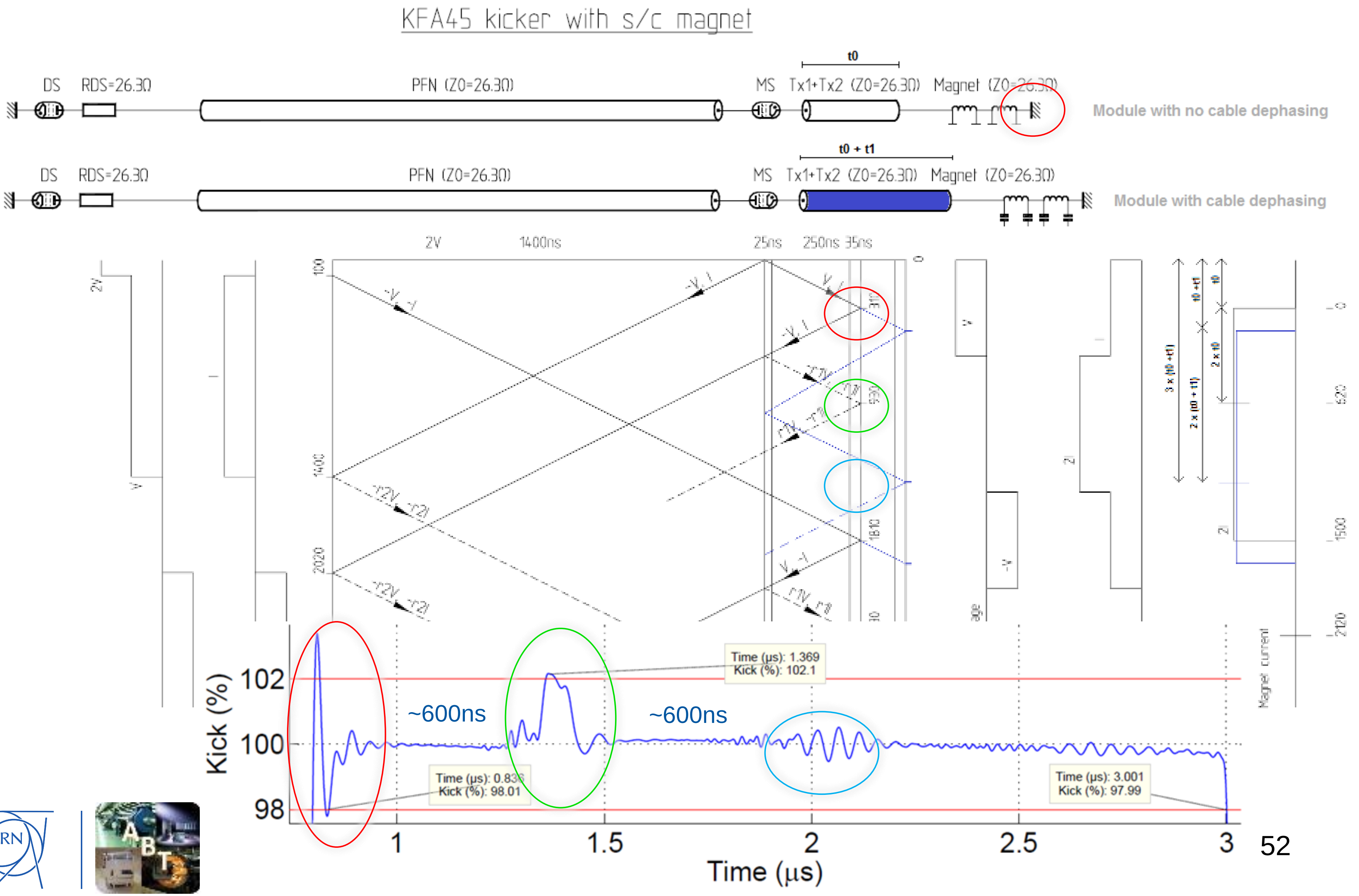
$$Z_0 = Z_L \qquad a = \frac{1}{2},\ b = 0$$



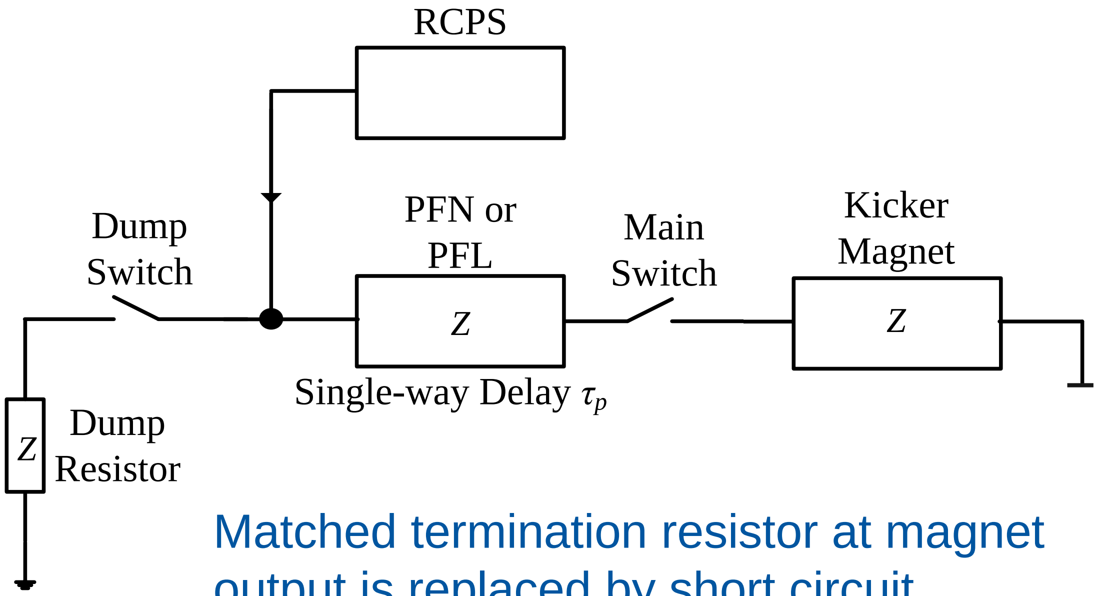
In general (mis-matched):

$$\Gamma = \left(\frac{Z_L - Z_0}{Z_L + Z_0} \right) = \beta$$

Reflections: Example KFA-45



Terminated vs. Short Circuited (SC) mode

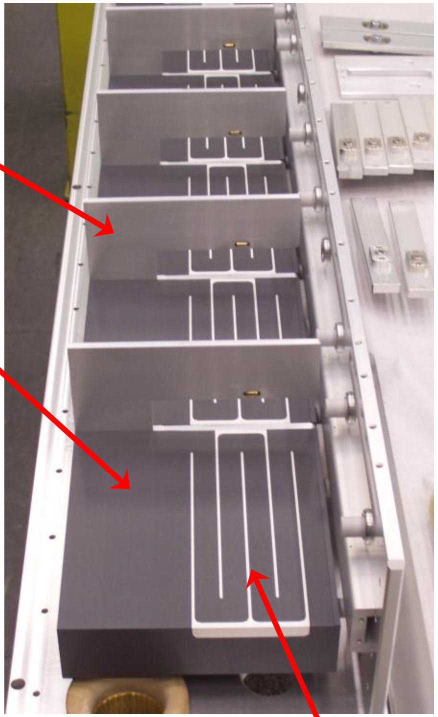


Matched termination resistor at magnet output is replaced by short circuit.

- In SC point:
  - Voltage =0 (incoming and reflected wave cancels)
  - Current doubles $I_{sc} = V\left(\frac{1-\Gamma}{Z}\right)$
- Magnet kick strength doubles but also the reflected wave needs to travel trough the kicker again -> rise time doubles as well.
- Any system mismatch will create reflections!

Beam Coupling Impedance

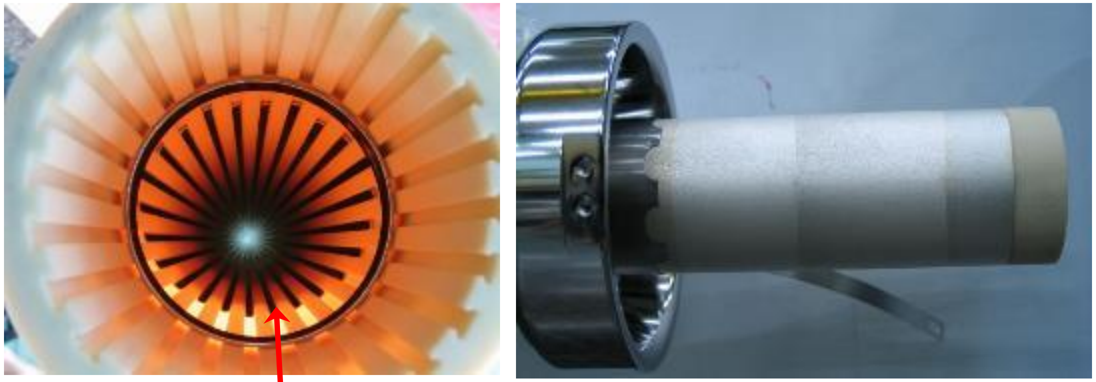
In order to reduce beam coupling impedance the ferrite must be shielded from the beam, by providing a path for beam image current. However the design must ensure that eddy-currents, induced by the fast rising field, do not unduly increase field rise-time.

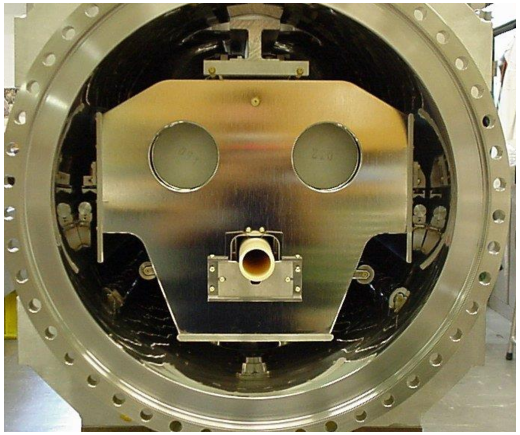


HV Plate

Ferrite

MKE Kicker: serigraphy on ferrite





LHC Injection Kicker: ceramic tube with "beam-screen" conductors in slots

Septa

What is a septum?

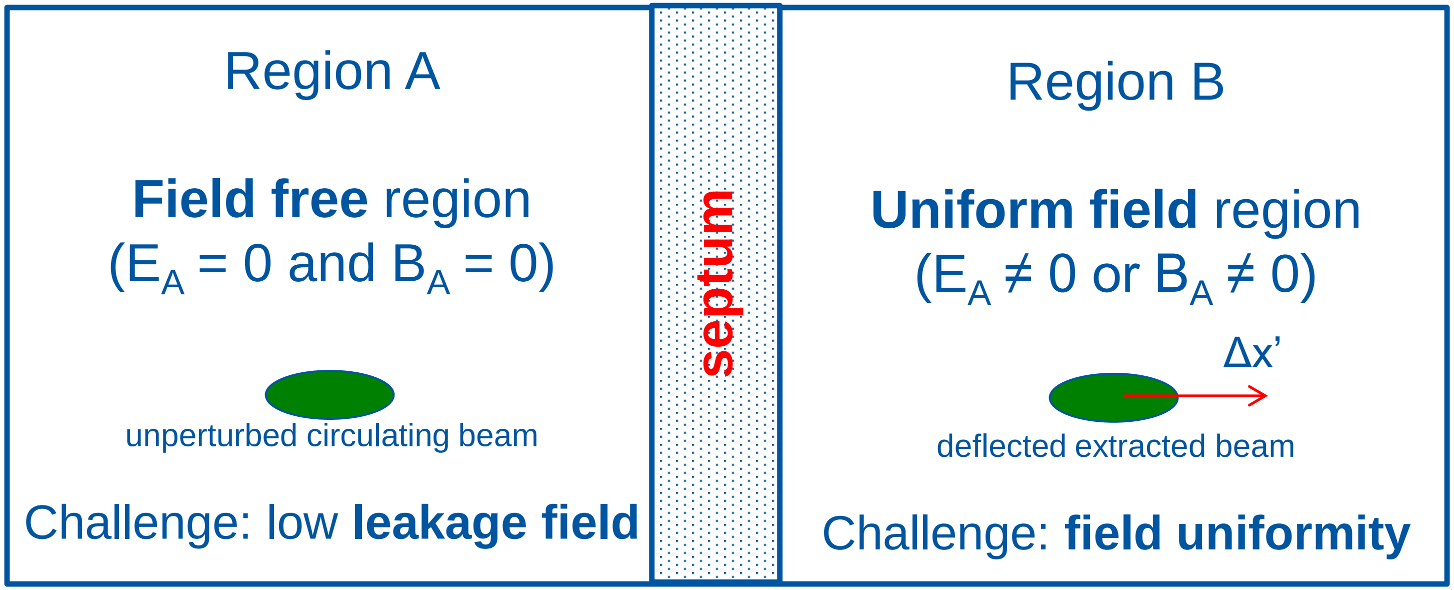
Lets google again…

Septa

LHC beam dump septa (MSD)

Septa

- Two main types:
  - **Electrostatic septa (DC)** → “weak” field, “thin” septum
  - **Magnetic septa** (DC and pulsed): → “strong” field, “thick” septum
    - Direct drive septum
    - Eddy current septum (pulsed only)
    - Lambertson septum (deflection parallel to septum)



Region A

Field free region

($E_A = 0$ and $B_A = 0$)

unperturbed circulating beam

Challenge: low **leakage field**

septum

Region B

Uniform field region

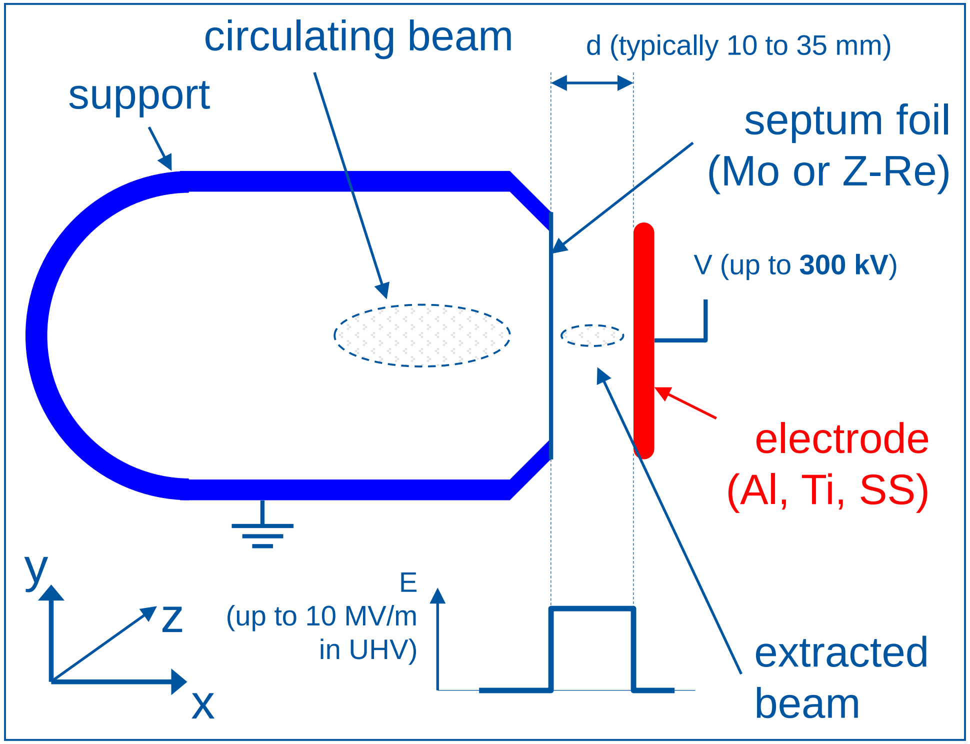
($E_A \neq 0$ or $B_A \neq 0$)

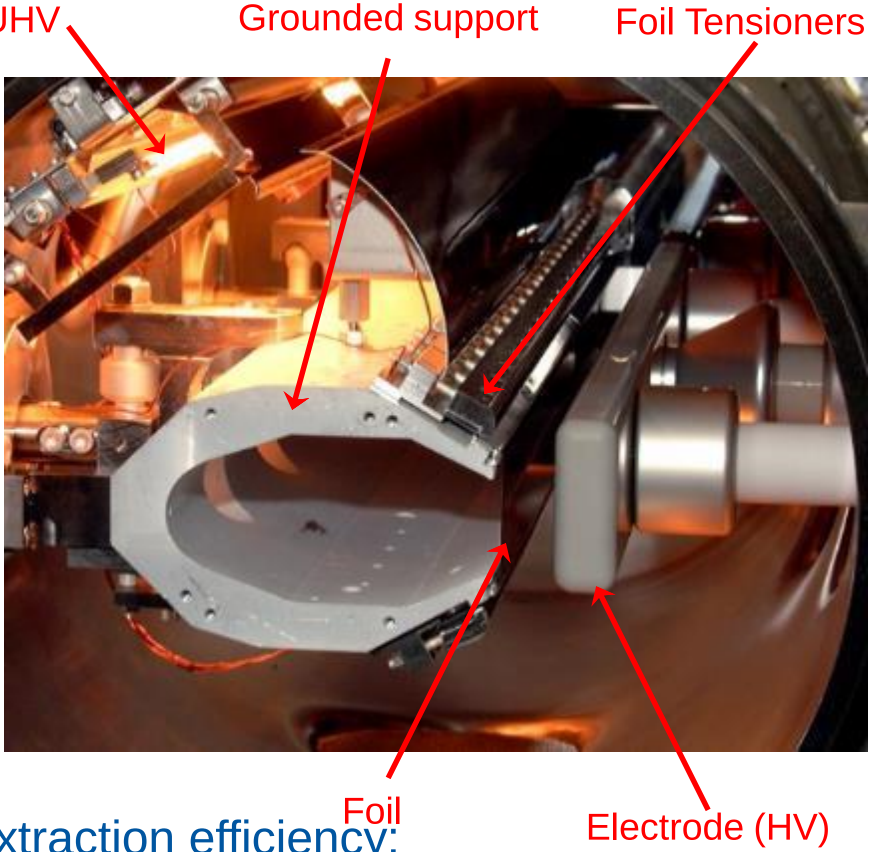
$\Delta x'$

deflected extracted beam

Challenge: **field uniformity**

Electrostatic foil septum





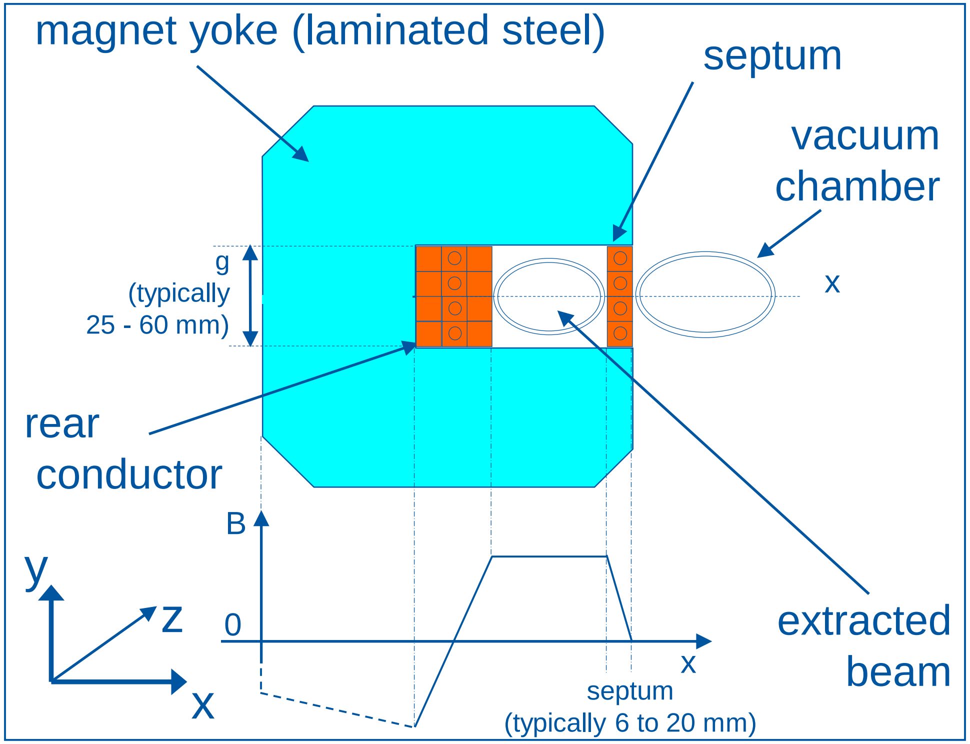
- **Thin septum** ~ 0.1 mm needed for high extraction efficiency:
  - Foils or stretched wire arrays provide thinner septa
- Challenges include **conditioning and preparation of HV surfaces**, vacuum in range of 10^{-9} – 10^{-12} mbar and **in-vacuum precision position alignment**

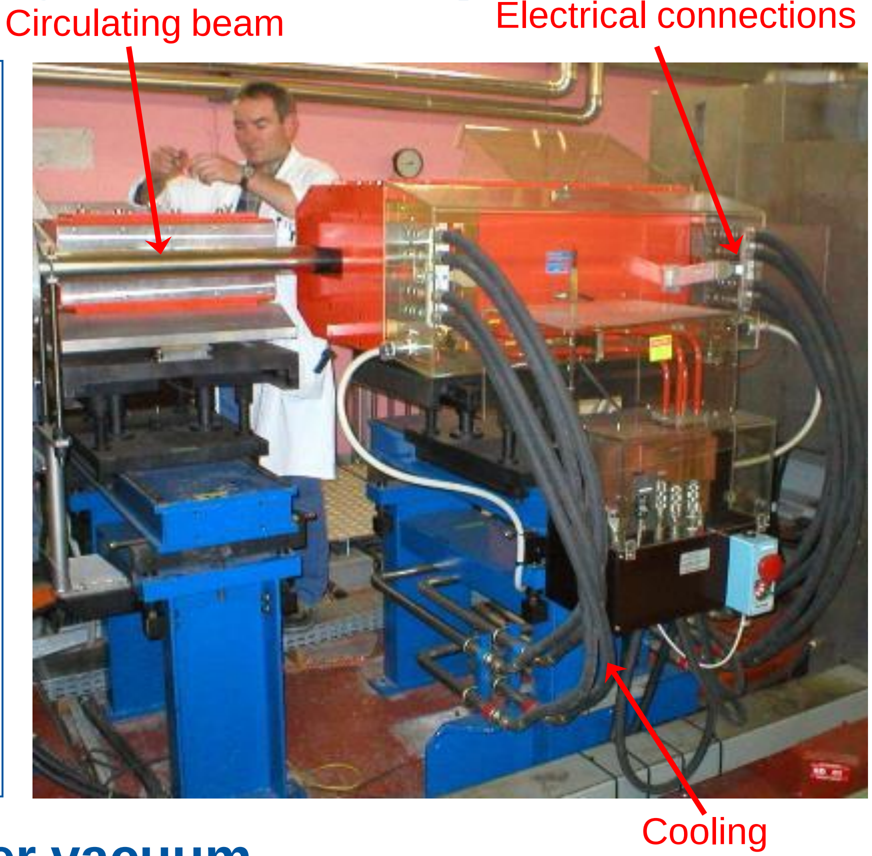
Electrostatic wire septum

At **SPS LSS2** we slow-extract 400 GeV protons using approximately **15 m of septum** split into 5 separate vacuum tanks each over 3 m long.

Alignment of the 60 - 100 μm wire array over 15 m is challenging!

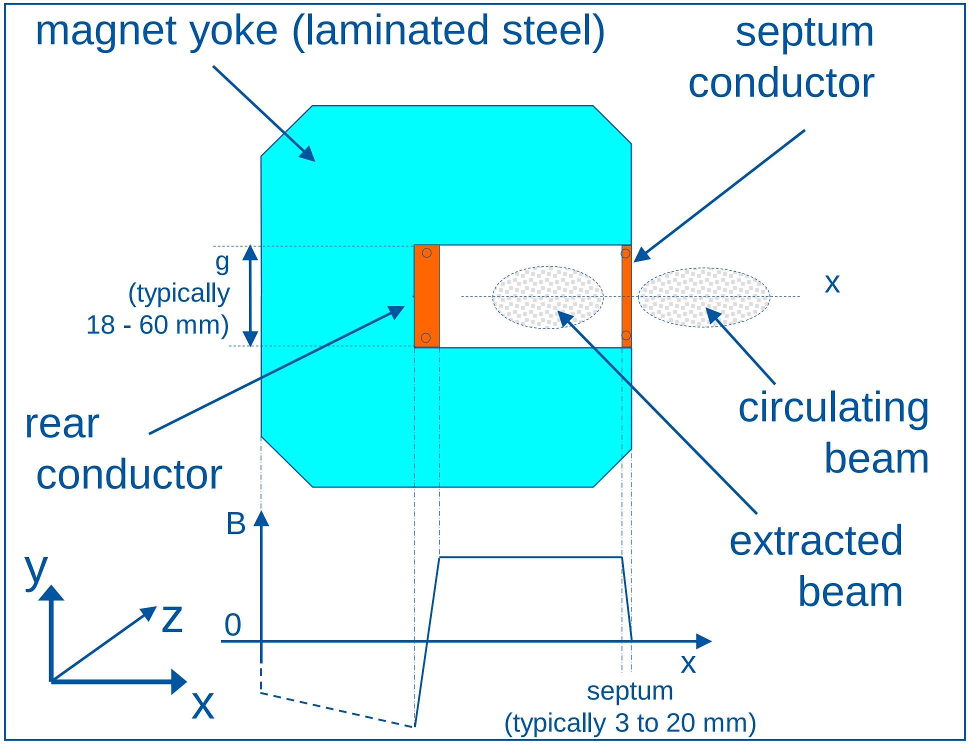
DC direct drive magnetic septum

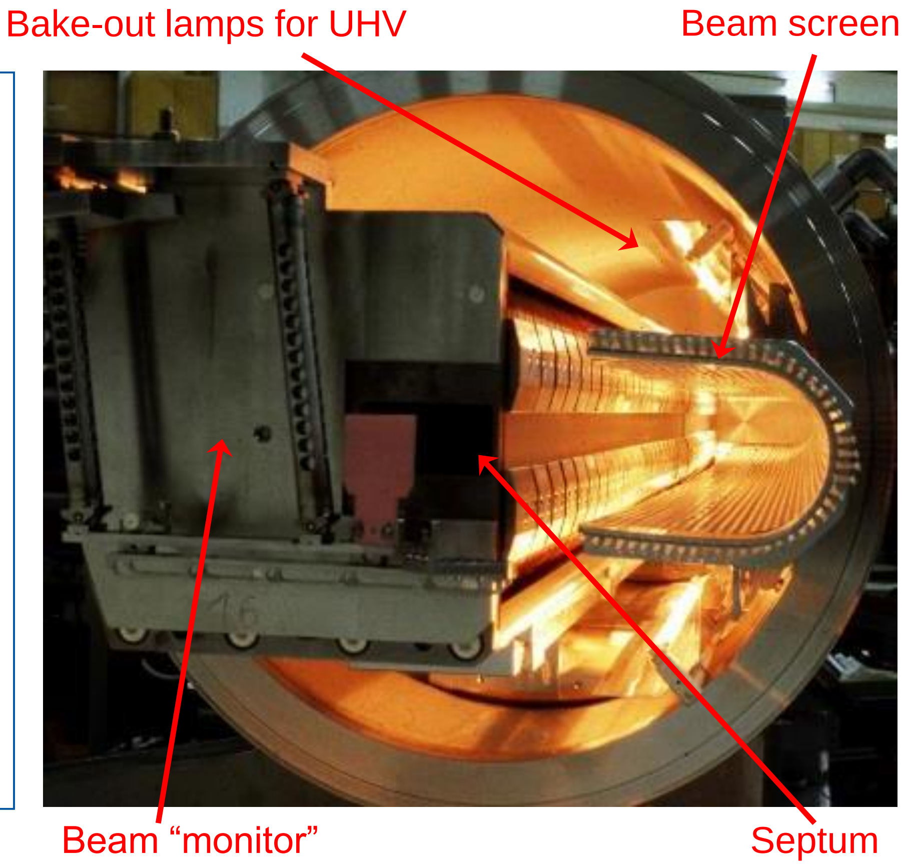




- **Continuously powered, rarely under vacuum**
- Multi-turn coil to reduce current needed but **cooling** still an issue:
  - Cooling water circuits flow rate typically at 12 – 60 l/min
  - Current can range from 0.5 to 4 kA and power consumption up to **100 kW**!

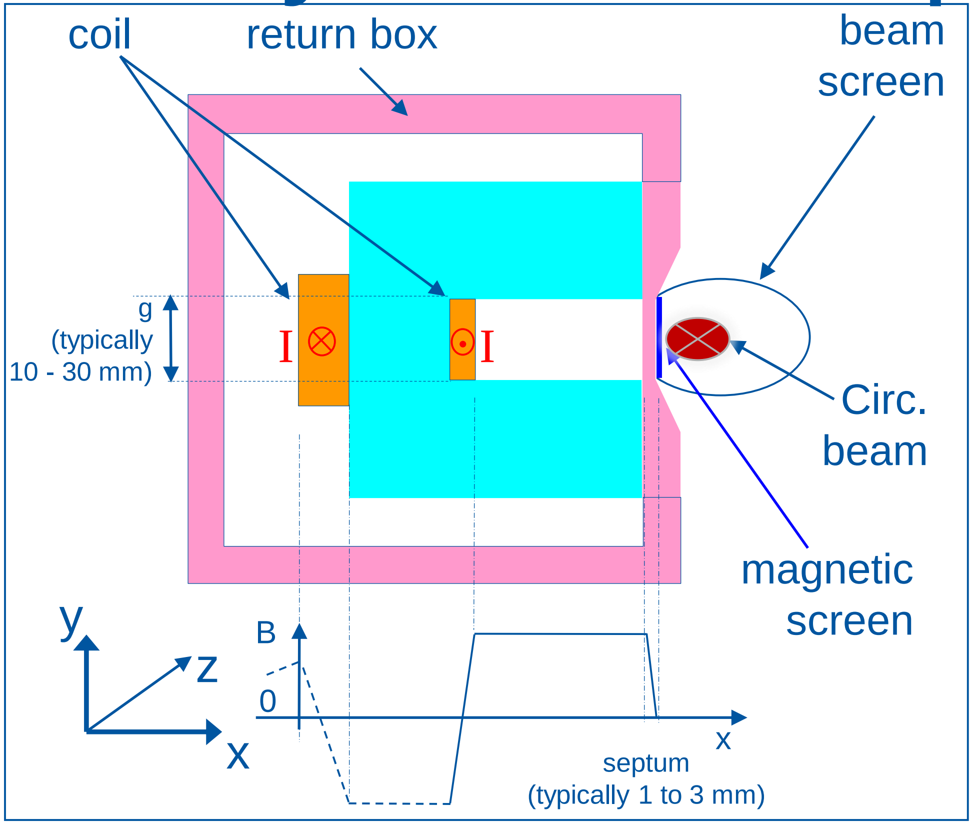
Direct drive pulsed magnetic septum





- **Pulsed current** allows for **thinner septum**
- Usually in vacuum, to minimise distance between circulated and extracted beam even more
- **Single-turn coil** to minimise inductance, bake-out up to 200 °C (~10^{-9} mbar)
- **Pulsed by capacitor discharge** (7 – 40 kA), Cooling water flow rate from 1 – 80 l/min

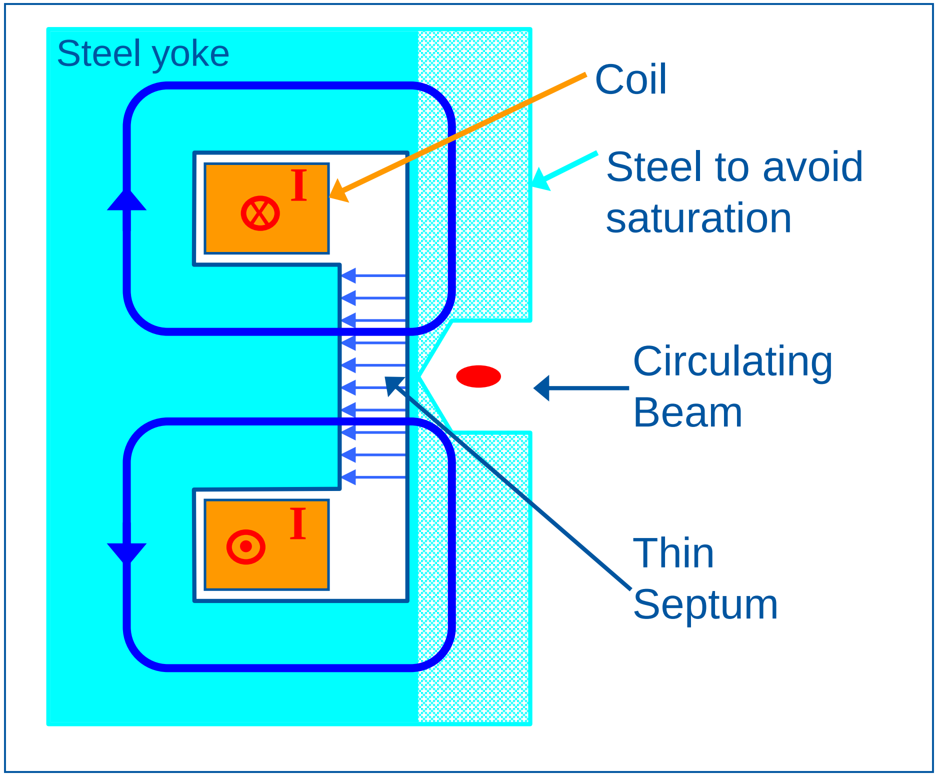
Eddy current septum



- Coil removed from septum and placed behind C-core yoke:
  - Coil dimension **not critical**
  - **Very thin septum blade**
- Magnetic field **pulse induces eddy currents** in septum blade
- Eddy currents **shield** the circulating beam from magnetic field
- Return box and **magnetic screen reduce fringe field** seen by circulating beam

- In or out of vacuum, single-turn coil
- Pulsed by capacitor discharge (~10 kA fast pulsed with ~ 50 μs oscillation period)
  - Cooling water flow rate from 1 – 10 l/min

Lambertson septum



- Magnetic **field in gap orthogonal** to previous examples of septa:
  - Lambertson deflects beam orthogonal to kicker: dual plane injection/extraction
- Rugged design: **conductors safely hidden** away from the beam
- Thin steel yoke between aperture and circulating beam – however extra steel required to avoid saturation, magnetic shielding often added

Summary Septa

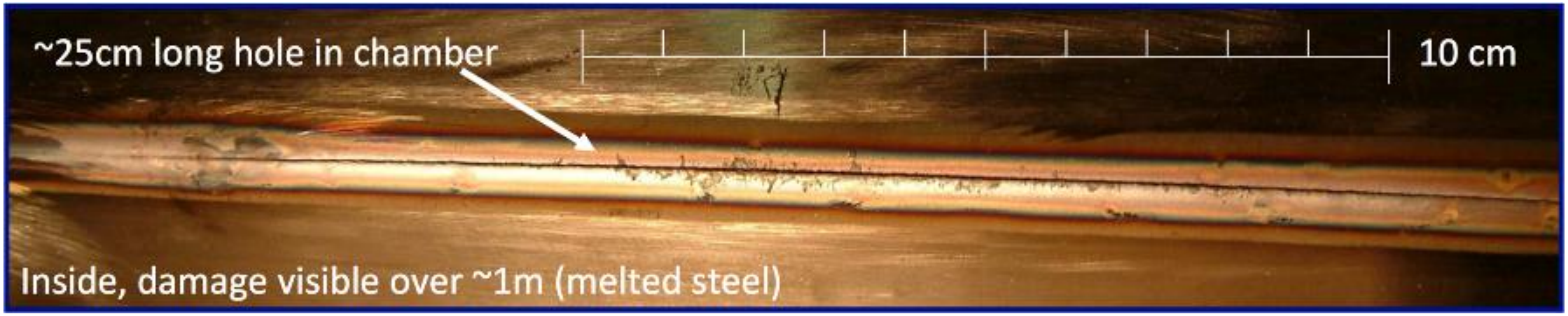
- **Specialized asymmetric devices** to deflect injected and extracted batches in close vicinity of the circulating beam.
- **Electrostatic** and **magnetic** variants.
- Usually **normal conducting** (at least at CERN) but superconducting septa exist as well.
- **Challenging** in terms of **mechanical** and **electrical engineering** as well as during maintenance due to **UHV** and **radiation** environment.

Beam Transfer Protection Devices

Protection devices

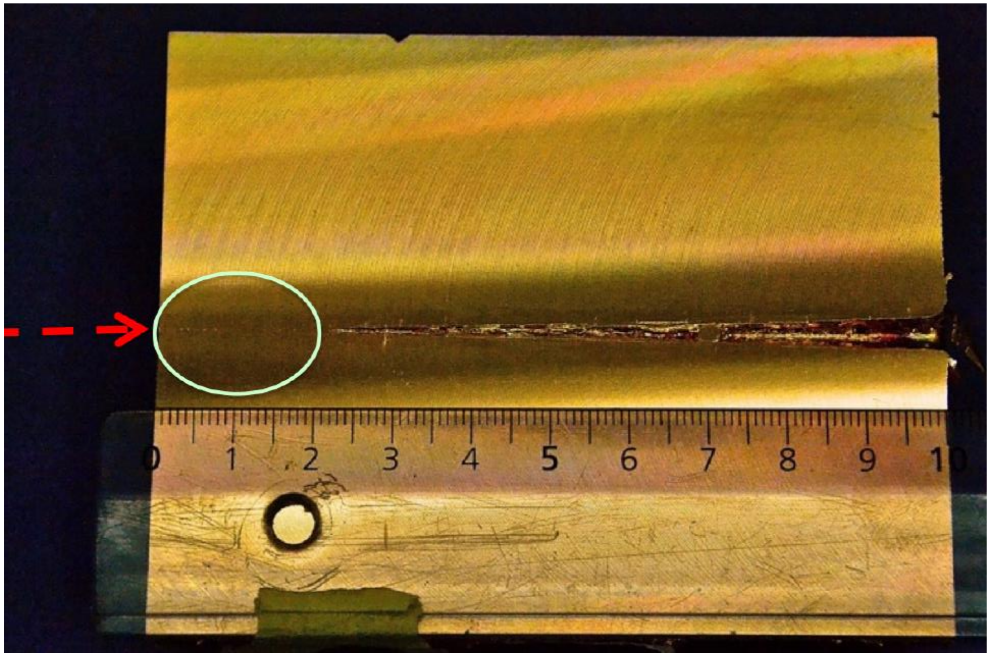
- BT-Protection devices **protect valuable equipment** and also increase machine availability.
- Hasn't been such a concern in the early days. Getting crucial these days already at lower energies due to **record beam intensities and high brightness beams**. Nominal LHC beam can easily penetrated several meters of massive copper.
- **Active and passive protection devices** needed (e.g. BIS and absorbers).
- BT-Absorbers and dumps (with associated beam instrumentation) are also convenient for **commissioning** and (low intensity) beam **set up** and need in any case **validation**.

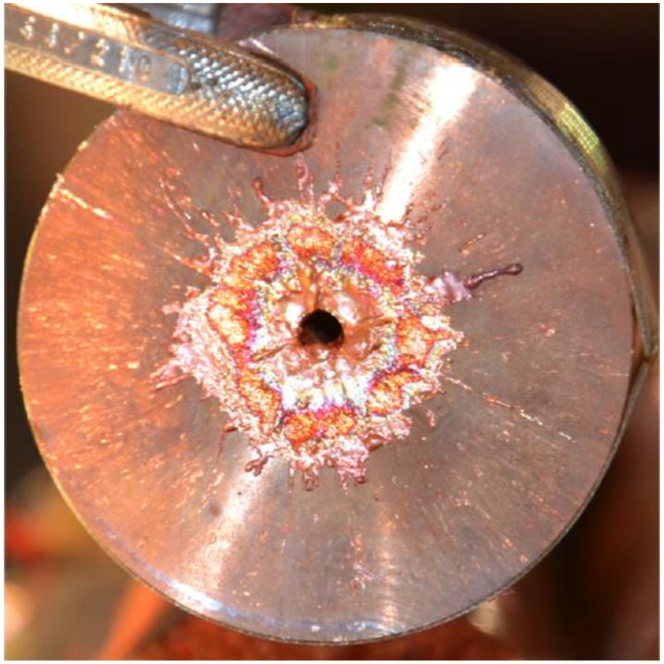
- In 2004 an extr. septum power supply failure directed 3.4x10^{13} protons at 450 GeV into the TL vacuum chamber (2.5 MJ beam energy):



Damage Studies

- Important to understand all mechanisms and material properties (**damage limits**).
- Simulation of **failure scenarios** (MAD-X) and **impact** (FLUKA).
- Validation of simulations by experiments e.g. at CERN's HiRadMat facility.





http://www.cern.ch/hiradmat/

Protection devices

- When beam **parameters exceed damage limit**: critical beam transfer systems need redundancy and multiple layers of protection:
  - **“Fail-Safe” design**
  - **Active protection** systems (e.g. BIS, not covered in this talk)
  - **Passive protection** devices form the last layer of security
    - Passive protection devices are **designed to dilute and absorb beam energy** safely

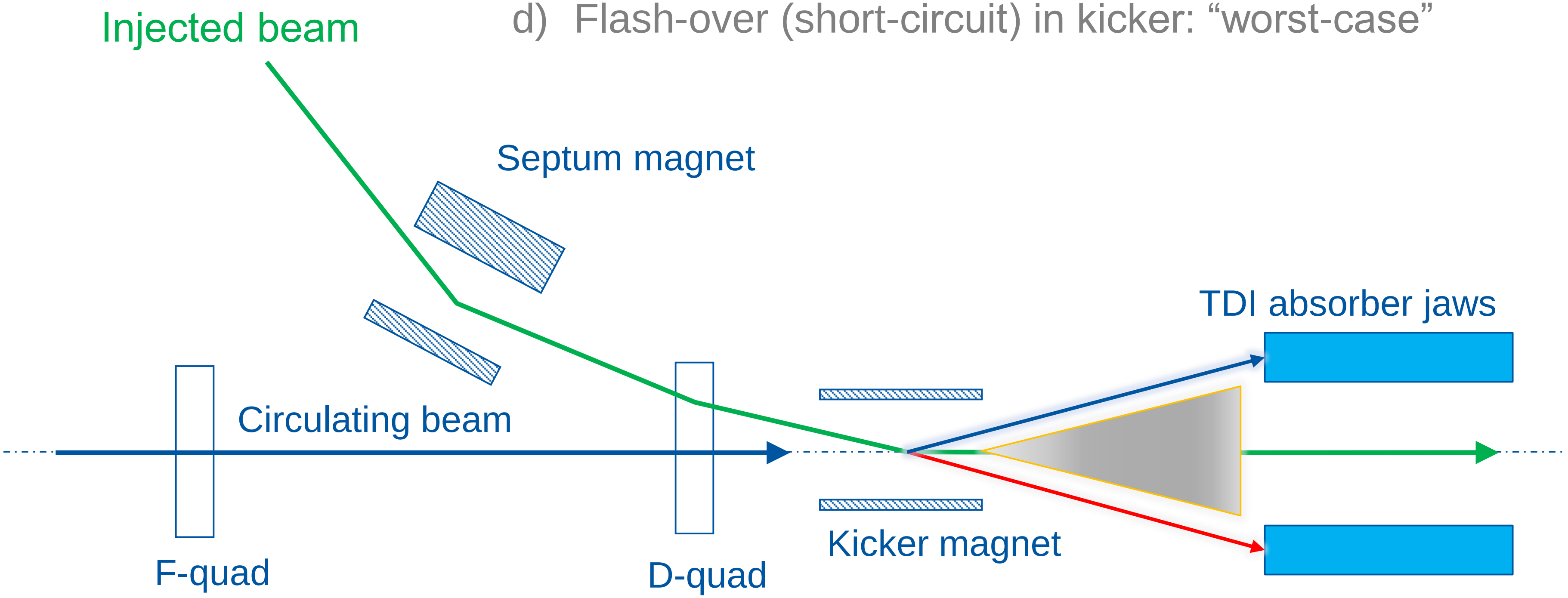
- **Failures** associated with beam transfer equipment are typically **very fast** and difficult to catch, for example:
  - **No turn-on** of kicker: injection protection
  - **Erratic** turn-on of kicker: circulating beam swept over aperture
  - **Flash-over** (short-circuit) in kicker: wrong kick angle
  - **Wrong timing** or particles in abort gap
  - **Transfer line failure:** steering beam into aperture limitation of downstream machine

See talk from Markus Zerlauth: “Machine Protection”

Example: Injection protection

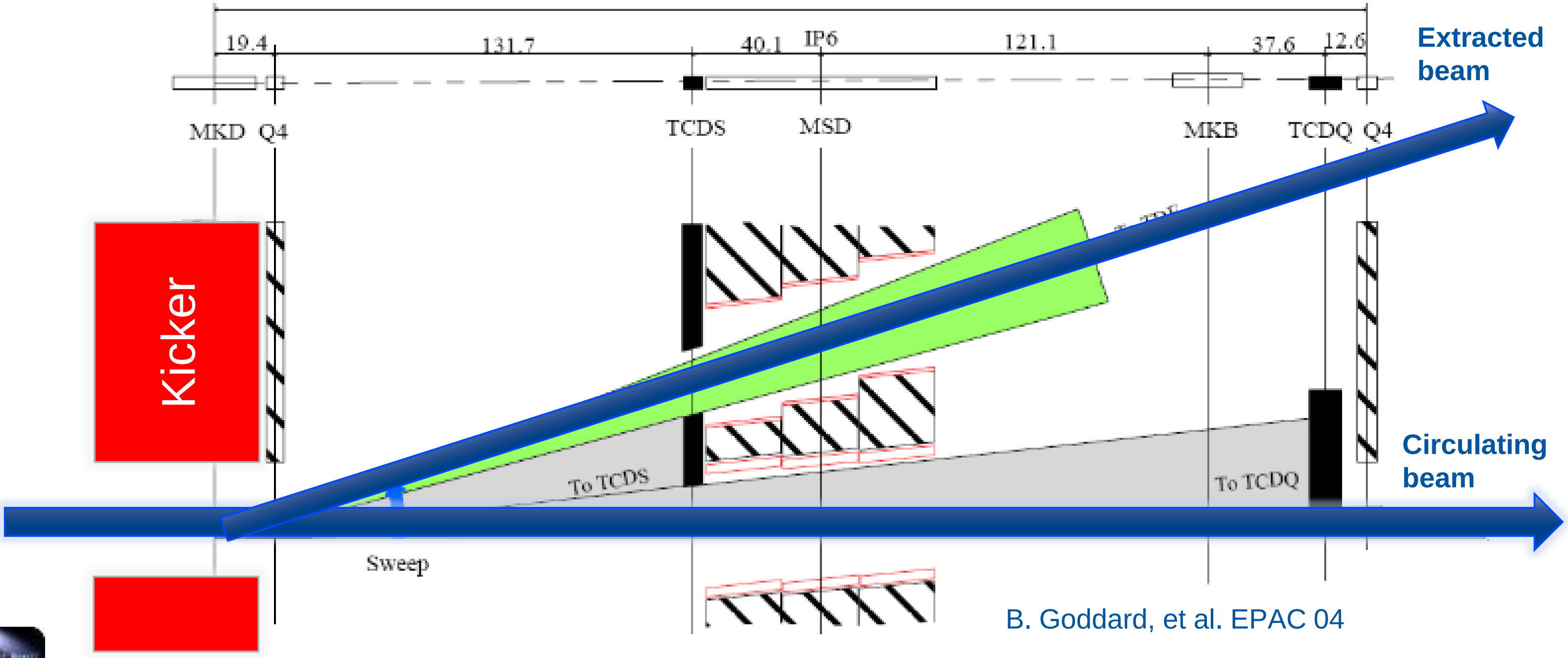
Dedicated injection dump (TDI) to protect against fast failures on the injection kicker system.

a) Normal injection process
b) No turn-on: beam steered onto absorber
c) Erratic turn-on: circulating beam steered onto absorber
d) Flash-over (short-circuit) in kicker: “worst-case”



Example: LHC Extraction protection

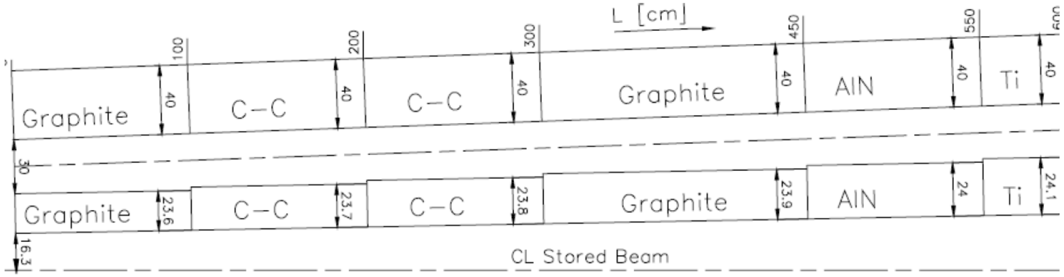
- **360 MJ stored energy** per beam to be safely extracted. **Reliability** and **machine protection** is a major concern.
- **Kickers** are fired in a particle free 3 µs long **abort gap**, next arriving beam is then deflected into the dump line.
- **Absorbers** in front of septa (TCDS) and Q4 (TCDQ).
- **Abort Gap Keeper** and **Abort Gap Cleaning**.
- Sophisticated **Beam Interlock System**. (e.g. Surveillance of orbit, BLMs, MB current, Septa, Kicker, Access etc. over 10.000 devices connected)



B. Goddard, et al. EPAC 04

LHC Extraction: Passive Protection Devices

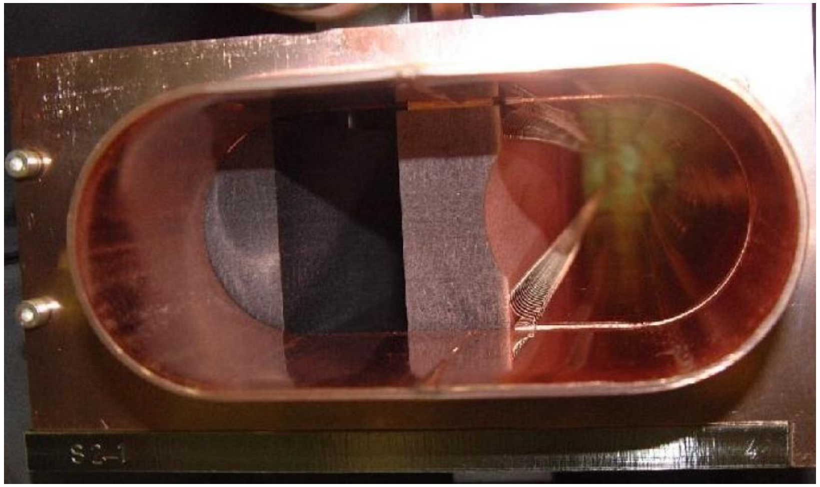
TCDS

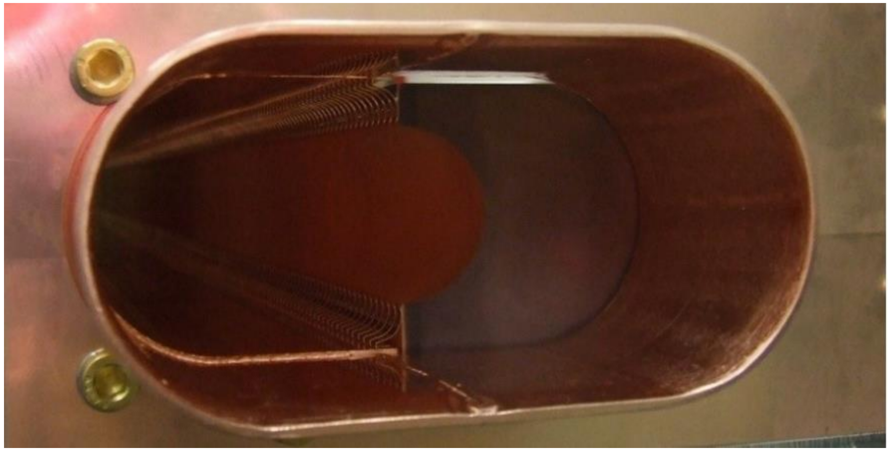


Sandwich construction.

TCDQ

Movable (follows beam energy).





Summary BT-Protection Devices

- **Dedicated absorbers** for TL, injection and extraction protection are used **when beam parameters exceed damage limit**.

- Designed to **dilute and absorb beam energy** safely.

- Premise is however to **reduce critical failure** cases already **by design**.

Bibliography for Septa

- M.J. Barnes, J. Borburgh, B. Goddard, M. Hourican, “**Injection and Extraction Magnets: Septa**”, CERN Accelerator School CAS 2009: Specialised Course on Magnets, Bruges, 16-25 June 2009, arXiv:1103.1062 [physics.acc-ph].
- J. Borburgh, M. Crescenti, M. Hourican, T. Masson, “**Design and Construction of the LEIR Extraction Septum**”, IEEE Trans. on Applied Superconductivity, Vol. 16, No. 2, June 2006, pp289-292.
- M.J. Barnes, B. Balhan, J. Borburgh, T. Fowler, B. Goddard, W.J.M. Weterings, A. Ueda, “**Development of an Eddy Current Septum for LINAC4**”, EPAC 2008.
- J. Borburgh, B. Balhan, T. Fowler, M. Hourican, W.J.M. Weterings, “**Septa and Distributor Developments for H- Injection into the Booster from Linac**4”, EPAC 2008.
- S.Bidon, D.Gerard, R.Guinand, M.Gyr, M.Sassowsky, E.Weisse, W.Weterings, A.Abramov, A.Ivanenko, E.Kolatcheva, O.Lapyguina, E.Ludmirsky, N.Mishina, P.Podlesny, A.Riabov, N.Tyurin, “**Steel Septum Magnets for the LHC Beam Injection and Extraction**”, Proc. of EPAC 2002, Paris.
- J.M. Cravero & J.P. Royer, “**The New Pulsed Power Converter for the Septum Magnet in the PS Straight Section 42**”, CERN PS/PO/ Note 97-03, 1997.
- J.P. Royer, “**High Current with Precision Flat-Top Capacitor Discharge Power Converters for Pulsed Septum Magnets**”, CERN/PS 95-13 (PO), 1995.

Bibliography for Kickers

- M.J. Barnes, L. Ducimetiére, T. Fowler, V. Senaj, L. Sermeus, "**Injection and extraction magnets: kicker magnets**", CERN Accelerator School CAS 2009: Specialised Course on Magnets, Bruges, 16-25 June 2009, arXiv:1103.1583 [physics.acc-ph].
- D. Fiander, K.D. Metzmacher, P.D. Pearce, "**Kickers and Septa at the PS complex**, CERN", Prepared for KAON PDS Magnet Design Workshop, Vancouver, Canada, 3-5 Oct 1988, pp71-79.
- M.J. Barnes, G.D. Wait, I.M. Wilson, "**Comparison of Field Quality in Lumped Inductance versus Transmission Line Kicker Magnets**", EPAC 1994, pp2547-2549.
- G. Kotzian, M. Barnes, L. Ducimetière, B. Goddard, W. Höfle, "**Emittance Growth at LHC Injection from SPS and LHC**", LHC Project Report 1116.
- J. N. Weaver et al., "**Design, Analysis and Measurement of Very Fast Kicker Magnets at SLAC**," Proc of 1989 PAC, Chicago, pp. 411–413.
- L. Ducimetière, N. Garrel, M.J. Barnes, G.D. Wait, "**The LHC Injection Kicker Magnet**", Proc. of PAC 2003, Portland, USA, pp1162-1164.
- L. Ducimetière, "**Advances of Transmission Line Kicker Magnets**", Proc. of 2005 PAC, Knoxville, pp235-239.
- W. Zhang, J. Sandberg, J. Tuozzolo, R. Cassel, L. Ducimetière, C. Jensen, M.J. Barnes, G.D. Wait, J. Wang, "**An Overview of High Voltage Dielectric Material for Travelling Wave Kicker Magnet Application**", proc. of 25th International Power Modulator Conference and High Voltage Workshop, California, June 30-July 3, 2002, pp674-678.
- J. Bonthond, J.H. Dieperink, L. Ducimetikrre, U. Jansson, E. Vossenberg, "**Dual Branch High Voltage Pulse Generator for the Beam Extraction of the Large Hadron Collider**", 2002 Power Modulator Symposium, Hollywood, USA, 30 June-3 July 2002, pp114-117.
- Pulsed Power Workshop 2018 https://indico.cern.ch/event/682148/

Thanks for your attention!

Questions?

If some appear later on: Feel free to ask them by email!