CERN

# Kickers, Septa and Protection Elements

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based on lectures and input from

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# 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

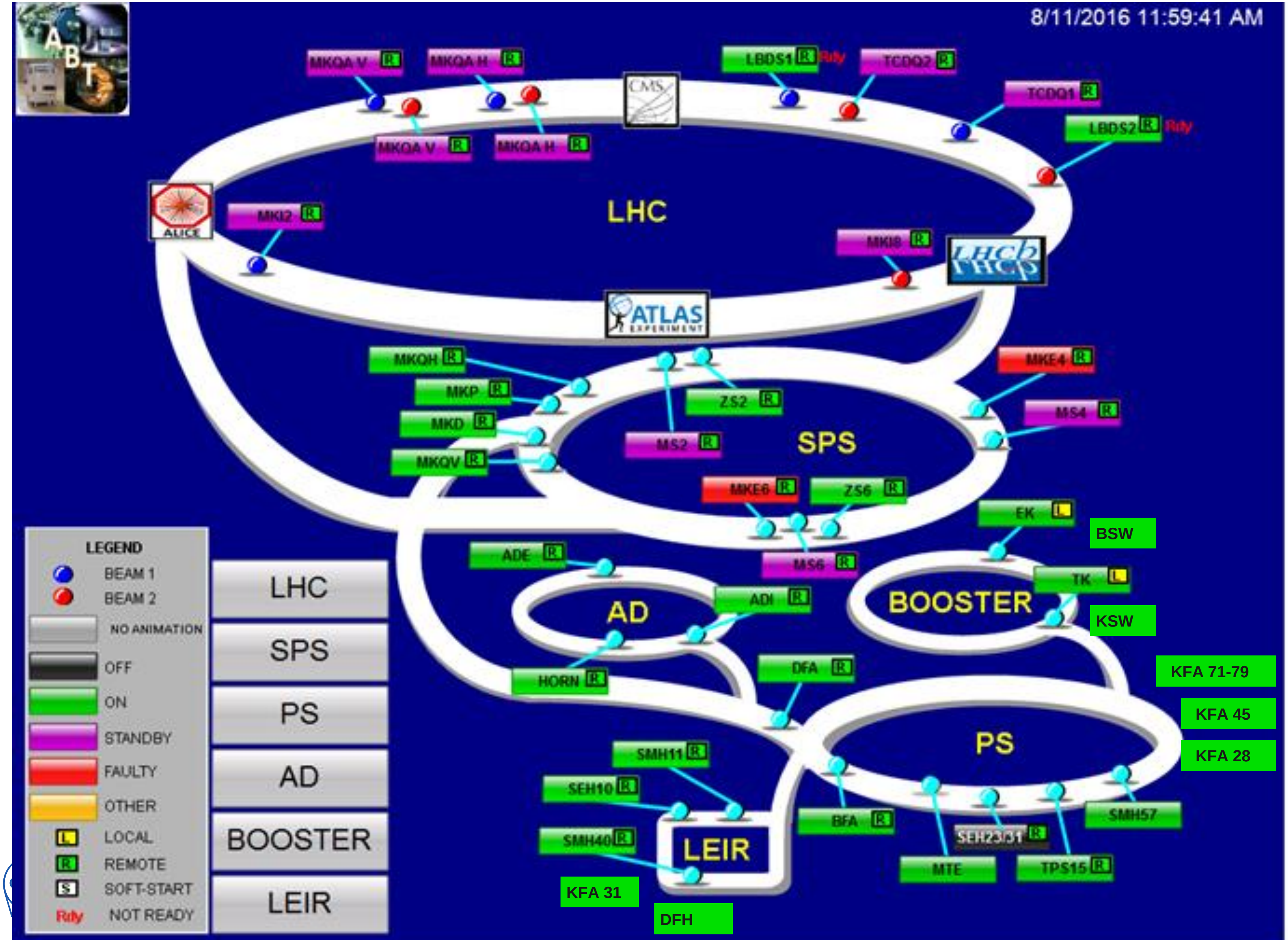
**TE-ABT**

| BTP Beam Transfer Physics | EC Electronics & Controls | FPS Fast Pulsed Systems | SE Septa |
|---|---|---|---|

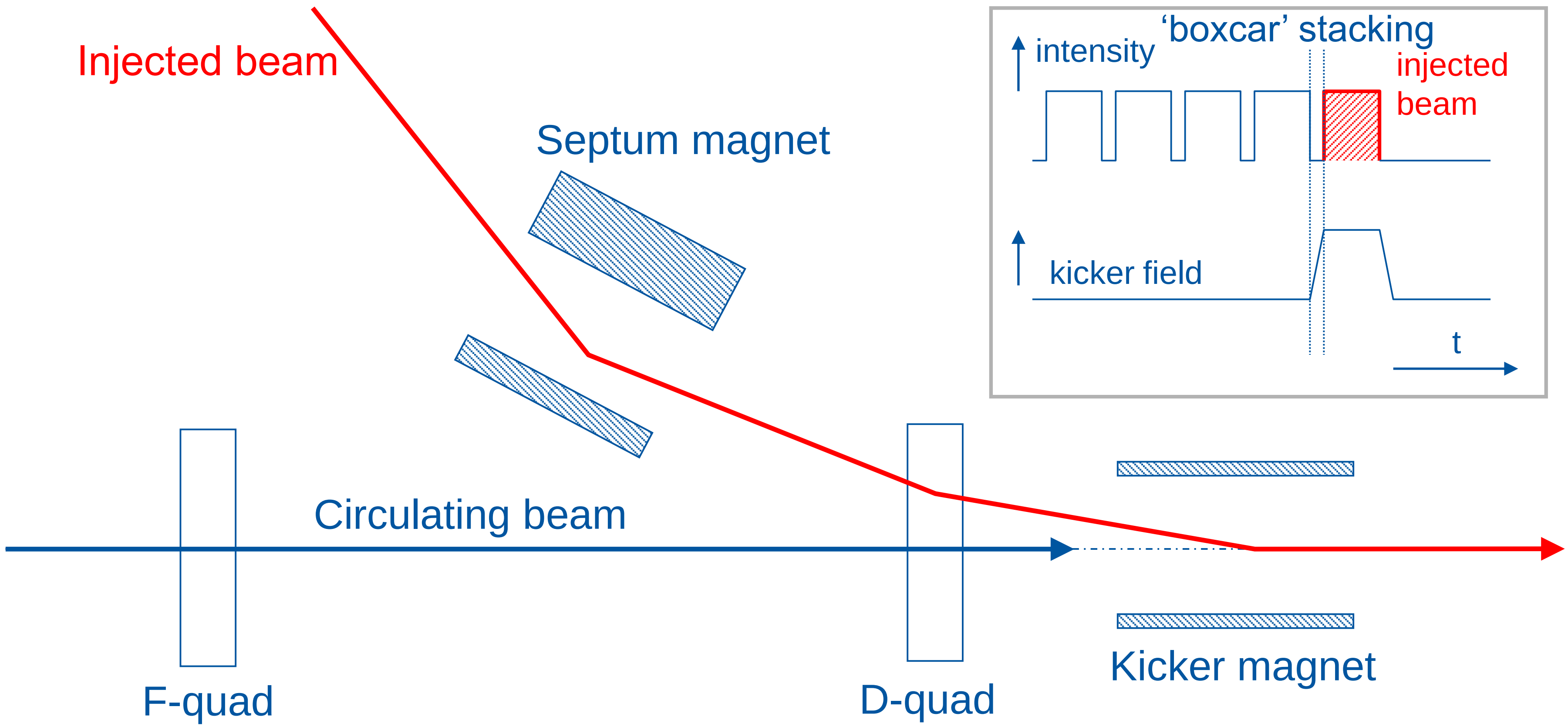
To address operational issues TE-ABT features a Kicker Piquet (72010) outside working hours.

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

# BT systems distributed over the complete CERN accelerator chain:



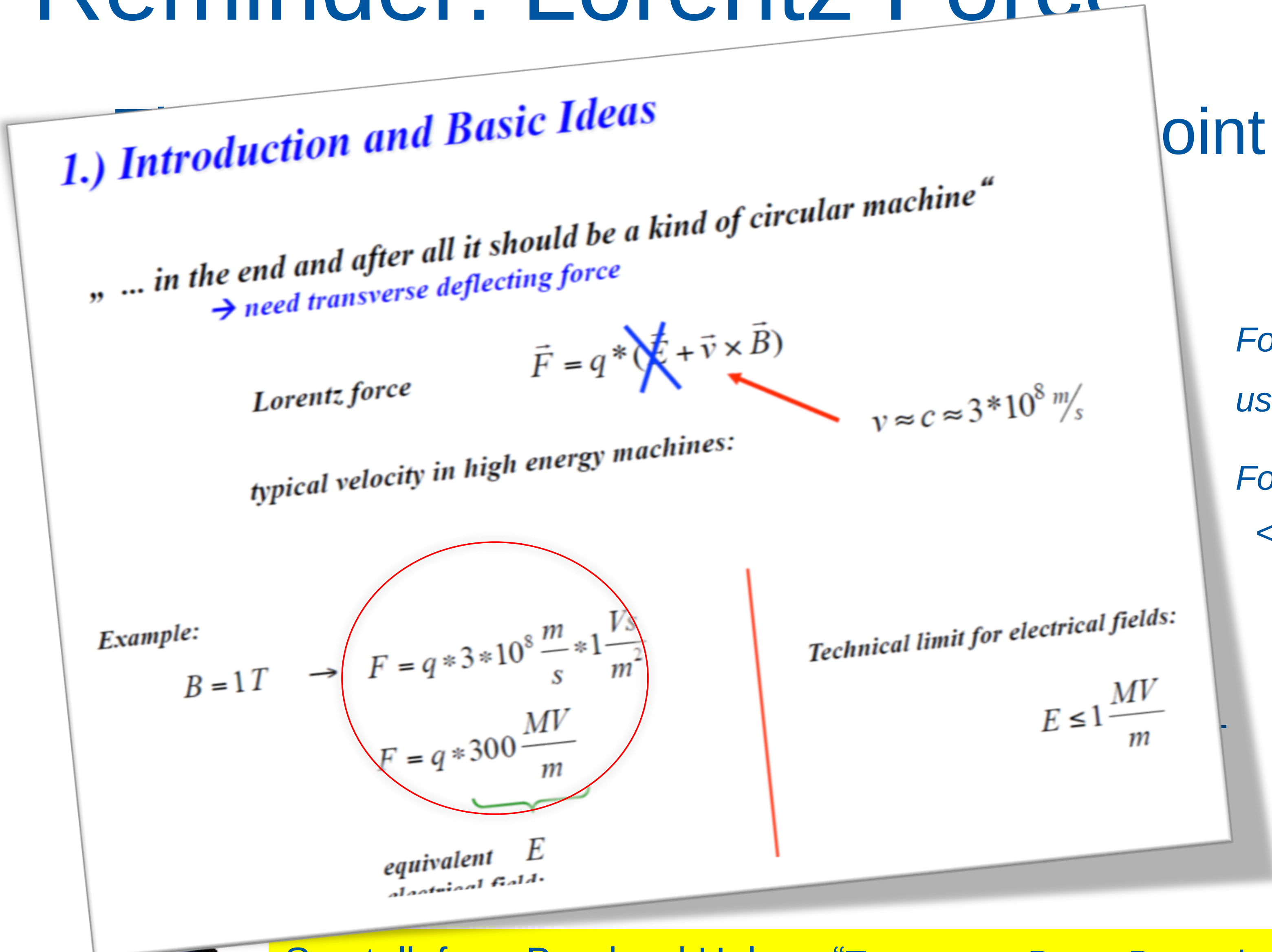
# Reminder: injection, extraction




- **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 J. Schmidt

# Reminder: Lorentz Force




oint

*For Kickers:*

*usually < 0.3T*

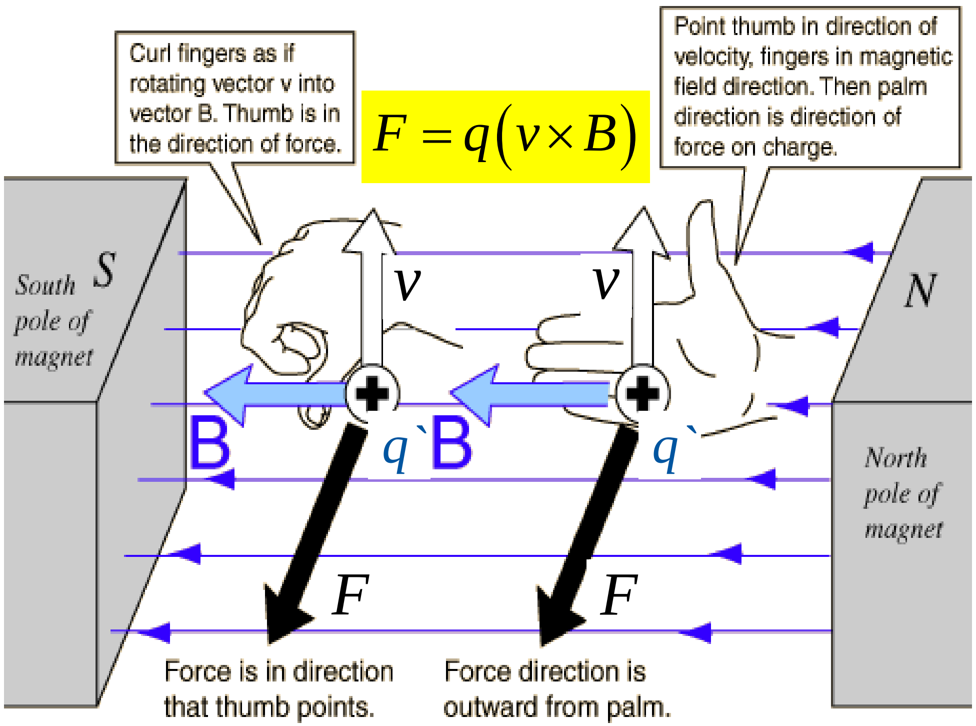
*For Septa:*

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

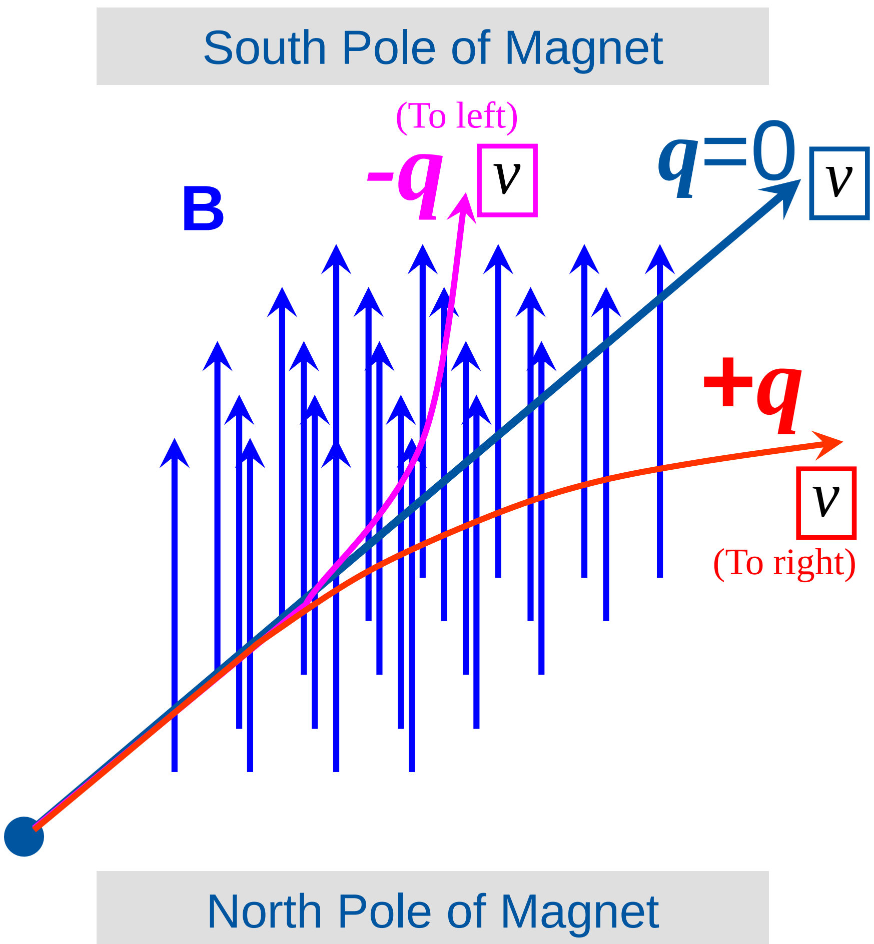
See talk from Bernhard Holzer: "Transverse Beam Dynamics I"

# Reminder: Deflection in a Magnetic Field

## Right-Hand Rule



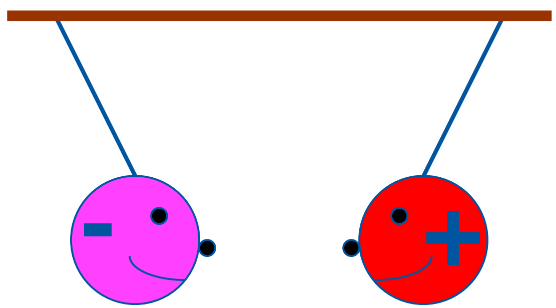

Ref: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magfor.html



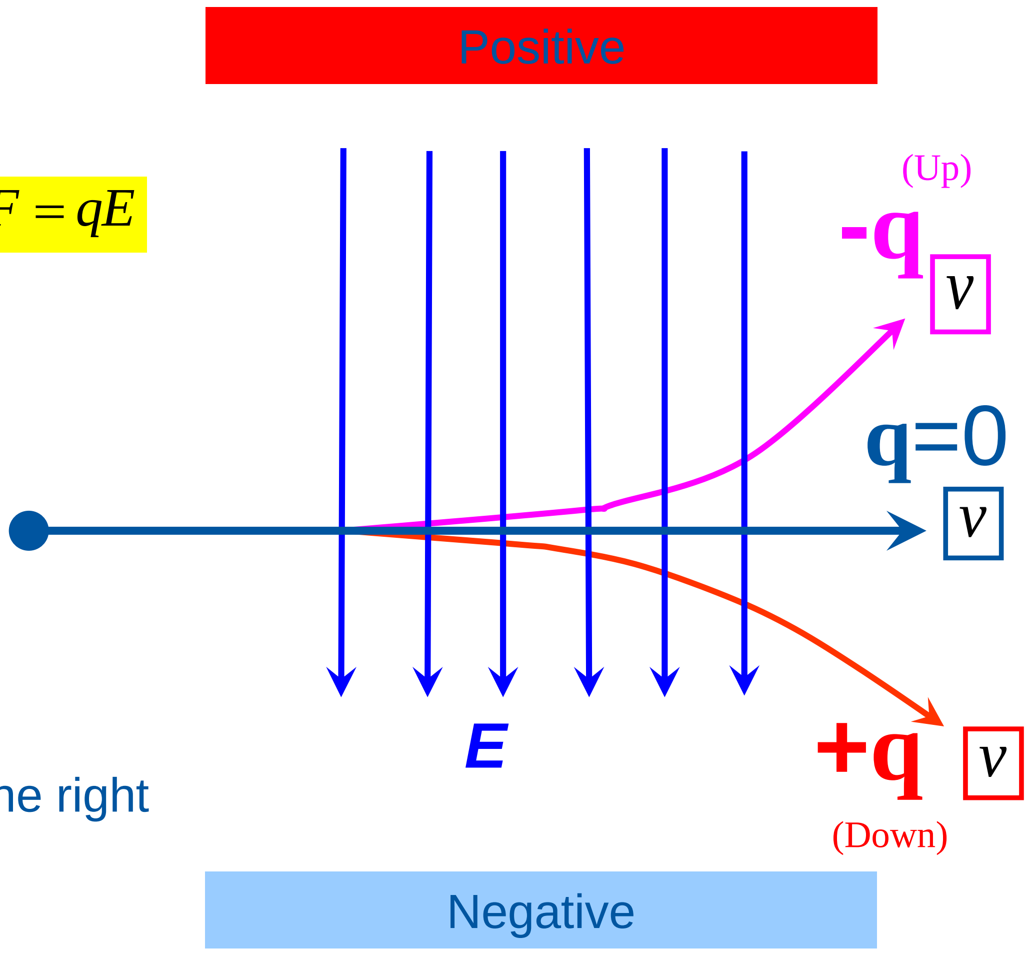

Charge moving into plane of paper

# Reminder: Deflection in an Electric Field

Opposites Attract !



$$F = qE$$




Charge moving from the left to the right

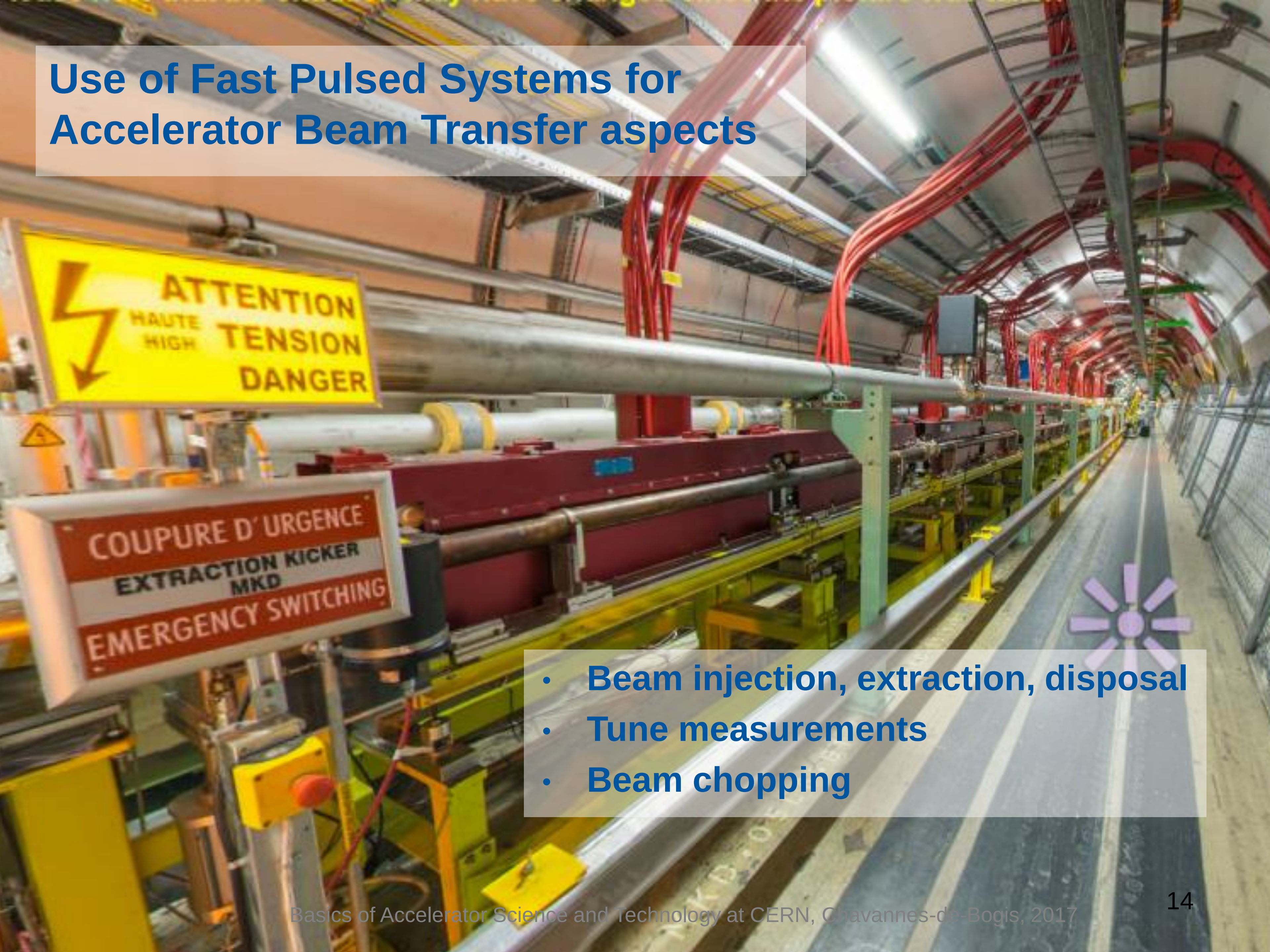
# Kicker's

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

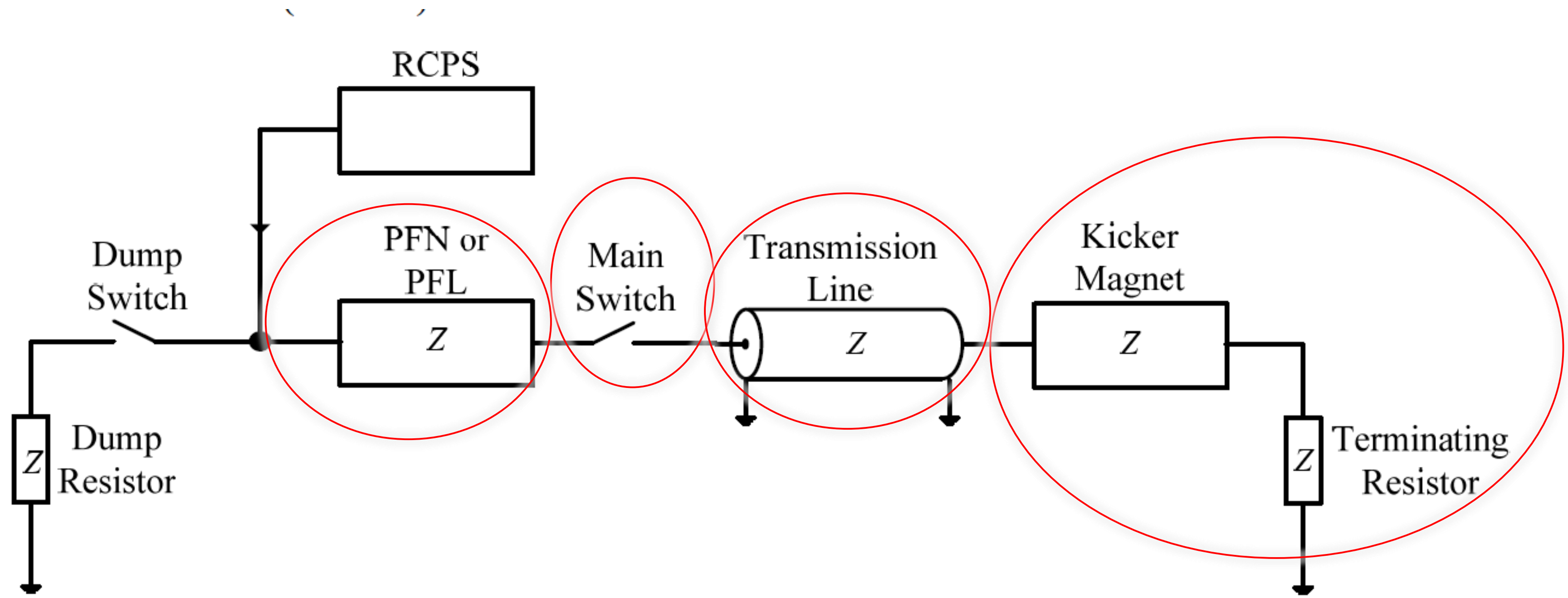



**Fig. 4:** Simplified schematic of a kicker system

# 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

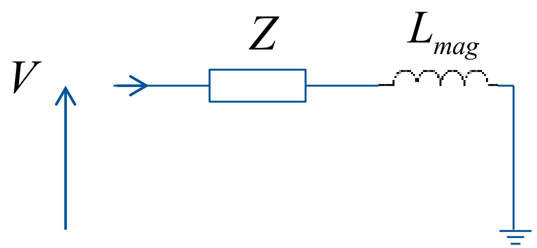
- Outside Vacuum
  - Magnet build around vacuum chamber
  - Magnet easier to build
  - HV insulation can be an issue
  - Complex vacuum chamber necessary
    - keep beam vacuum
    - let transient field pass -> ceramic + metallization
    - consumes aperture!

Magnet in the vacuum tank with ceramic beam pipe

- 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"



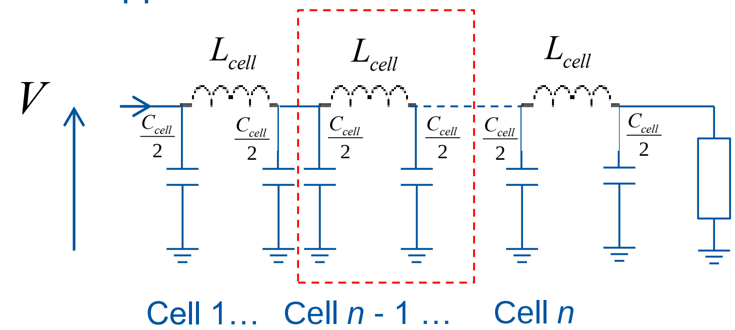

$$I = \frac{V}{Z}(1 - e^{-t/t}) \qquad t = \frac{L_{mag}}{Z}$$

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

- e.g. LHC MKD ~2.8 μs

## "transmission line"

Approx. of matched transmission line




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

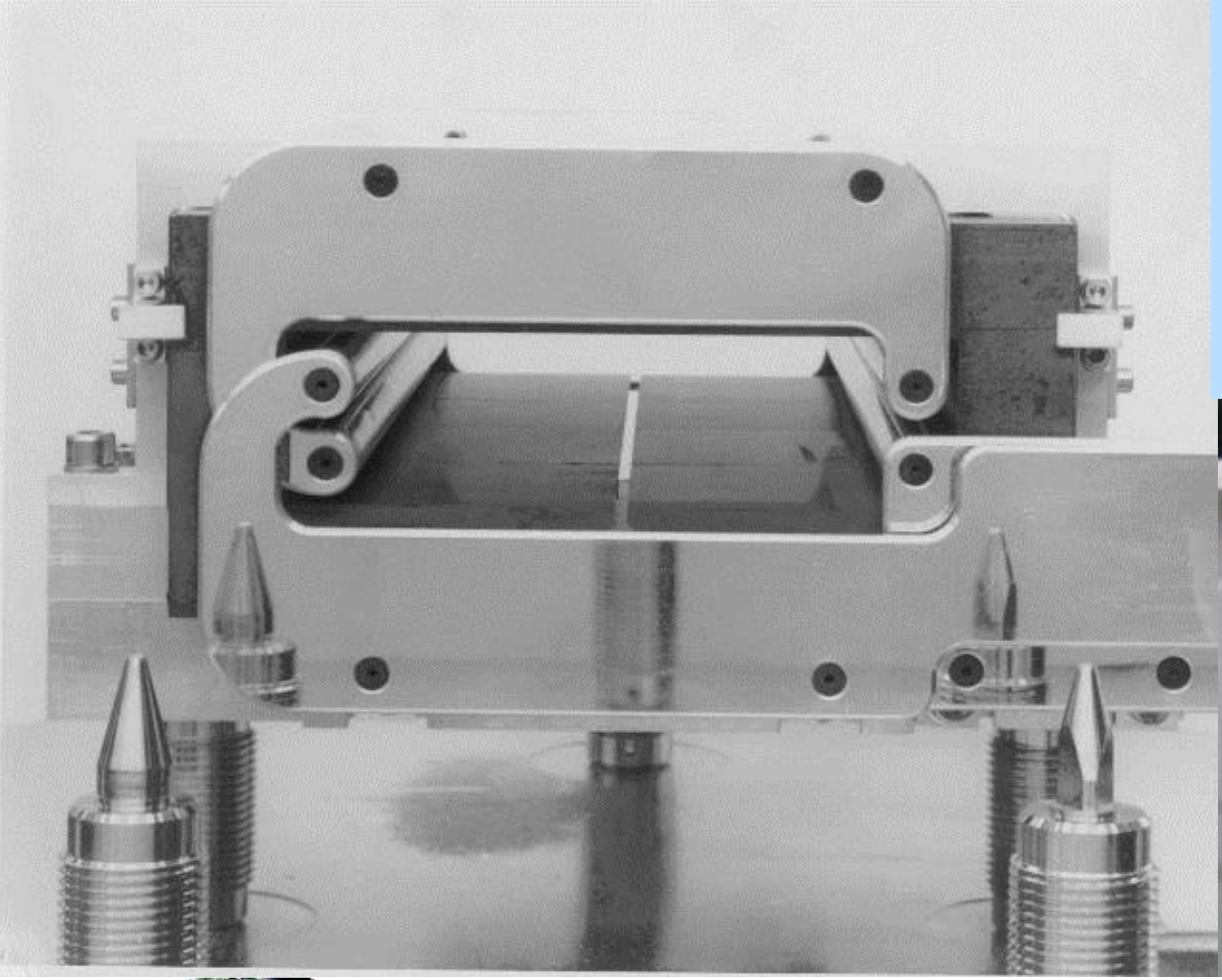
$$Z = \sqrt{\frac{L_{cell}}{C_{cell}}}$$

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

- 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 KFA-45 ~70 ns

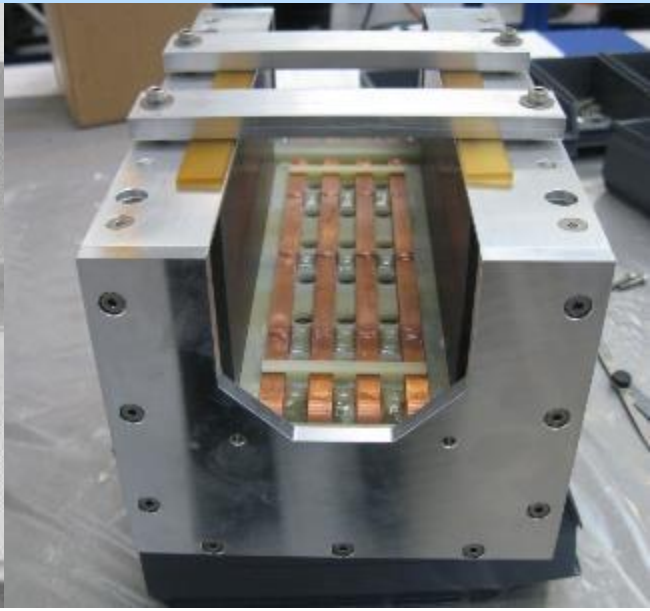
# Lumped Inductance Magnets



- Used for “slower” systems (> 0.4μs range).
- “Simple” and “robust”.

At CERN:

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

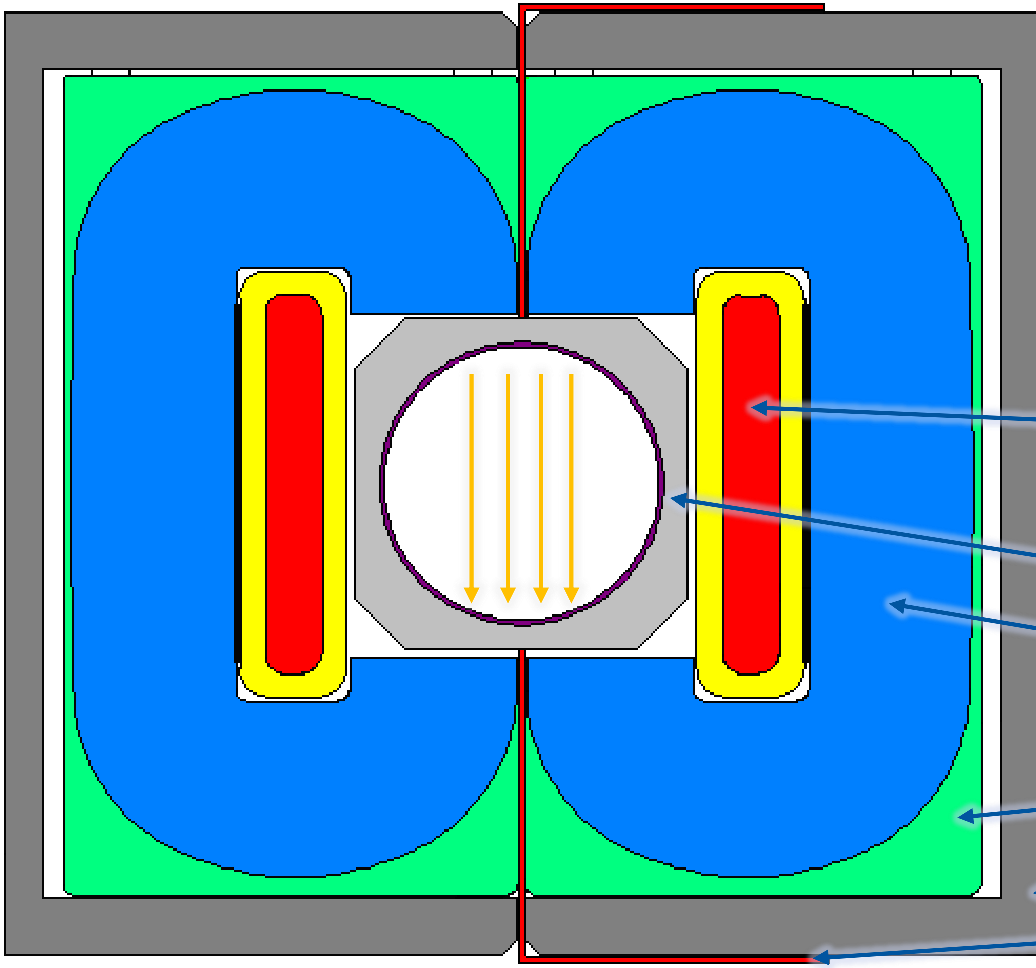


# LHC extraction kickers “MKD”

- **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.**

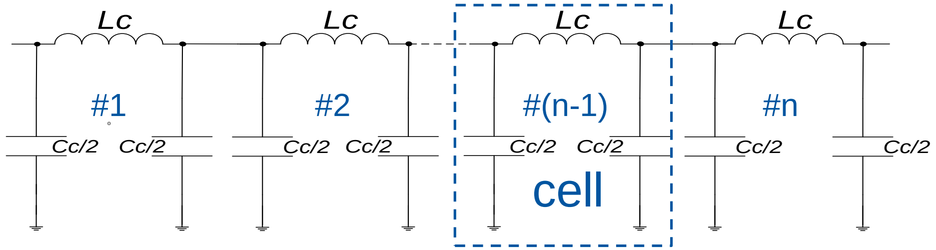
# Extraction kicker magnet - MKD

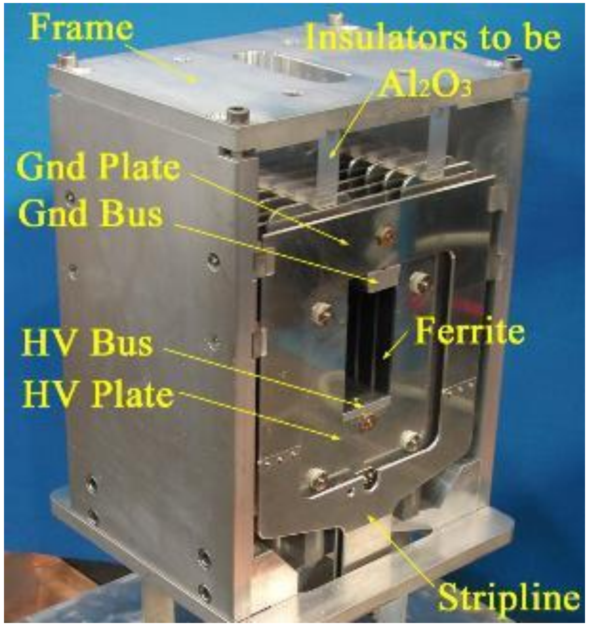
**Magnets are built around a metallized ceramic vacuum chamber**

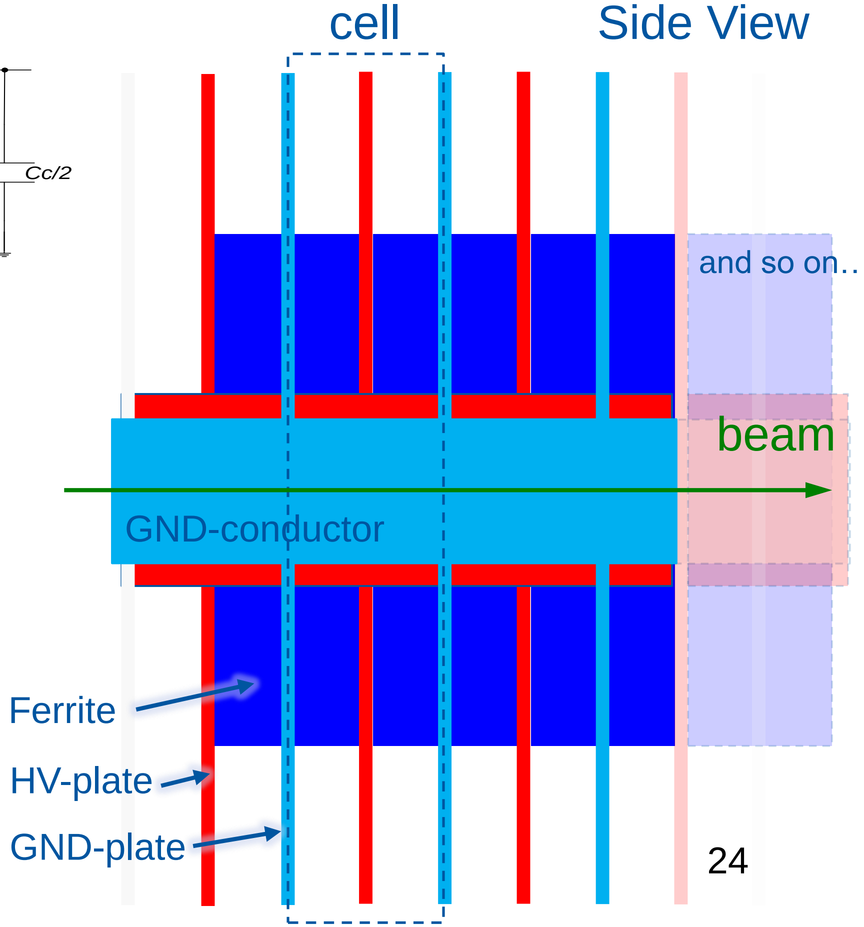


# Magnets – Transmission Line Kicker

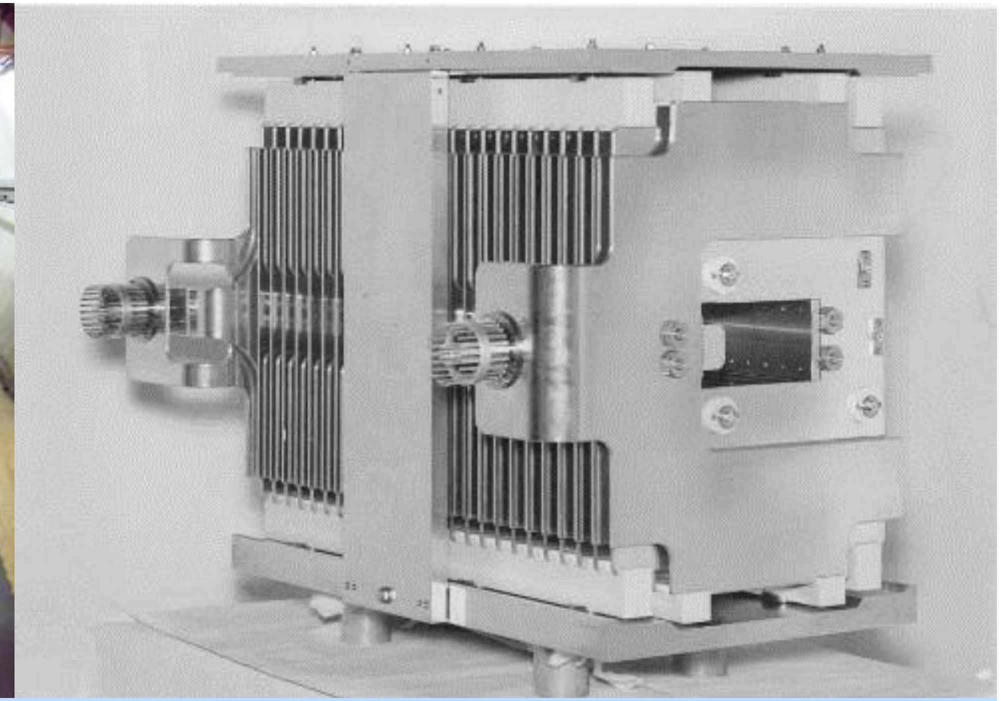
- Fast kicker magnets are generally **ferrite loaded** transmission lines:
  - Kicker magnets consists of many, relatively short, cells to approximate a broadband coaxial cable
  - Ferrite C-cores are sandwiched between HV plates
  - Grounded plates are interleaved to form a capacitor to ground



# Transmission Line Kickers

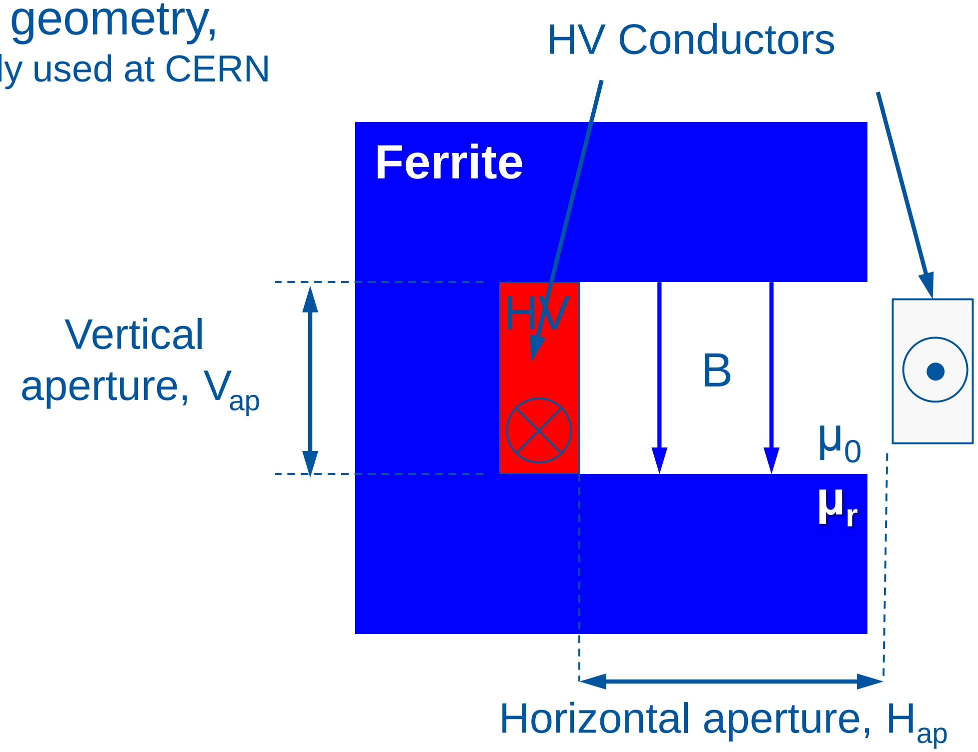



At CERN:

- 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

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

- 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 G.de Rijk

# 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 $C_c = \frac{L_c}{{Z_0}^2}$

Feasible :

- 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.

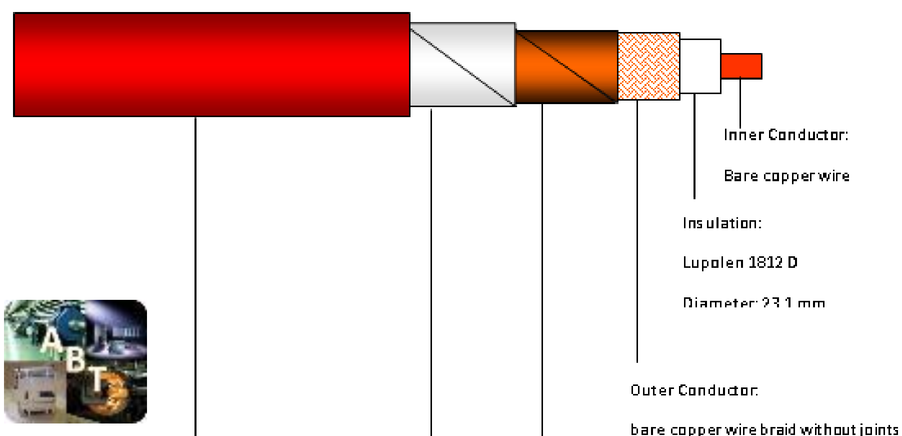
# High Voltage Coaxial Cables for Kicker Systems

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

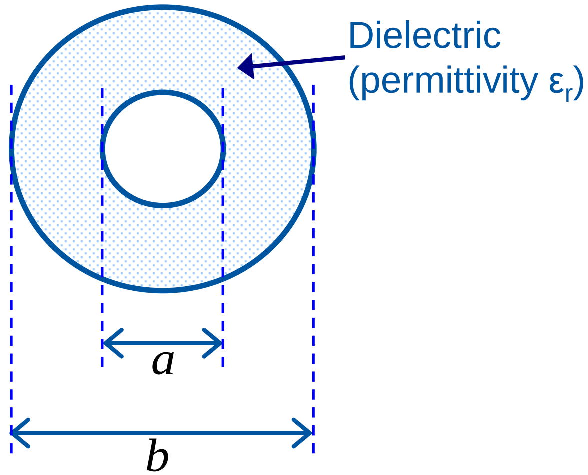
# Coaxial Cables

Coaxial cables play a major role in kicker systems!

- Need to **transmit fast pulses, high currents**.
- Cables an be also used as **pulse forming line (PFL).**
- Should **not attenuated** 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 filled 80 kV)
- Precise **characteristic impedance** over complete length mandatory! Otherwise issues with reflections.
- Needs 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 20 Ω to 50 Ω). $Z_0 = \sqrt{\frac{L}{C}}$

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); |
| $\varepsilon_0$ | is the permittivity of free space ($8.854 \times 10^{-12}$ 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

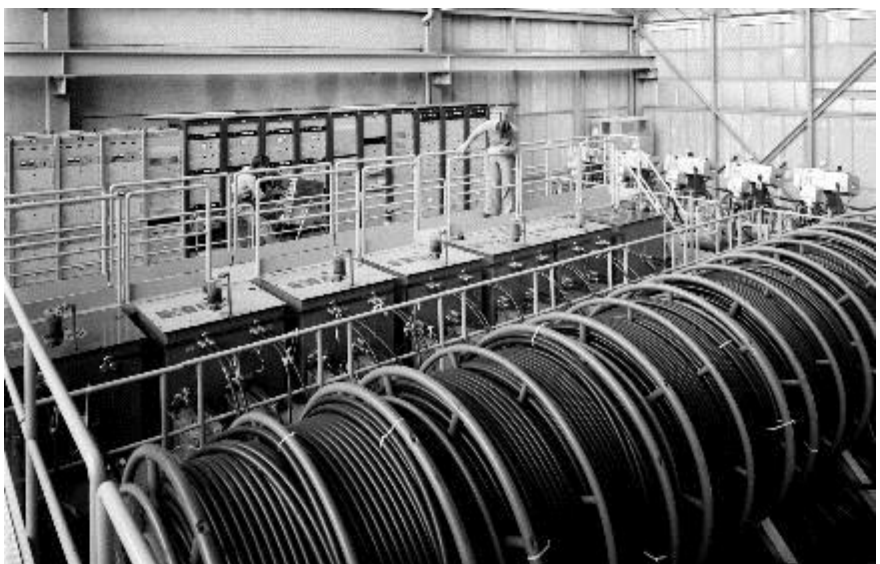
# Pulse Generators

- 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)

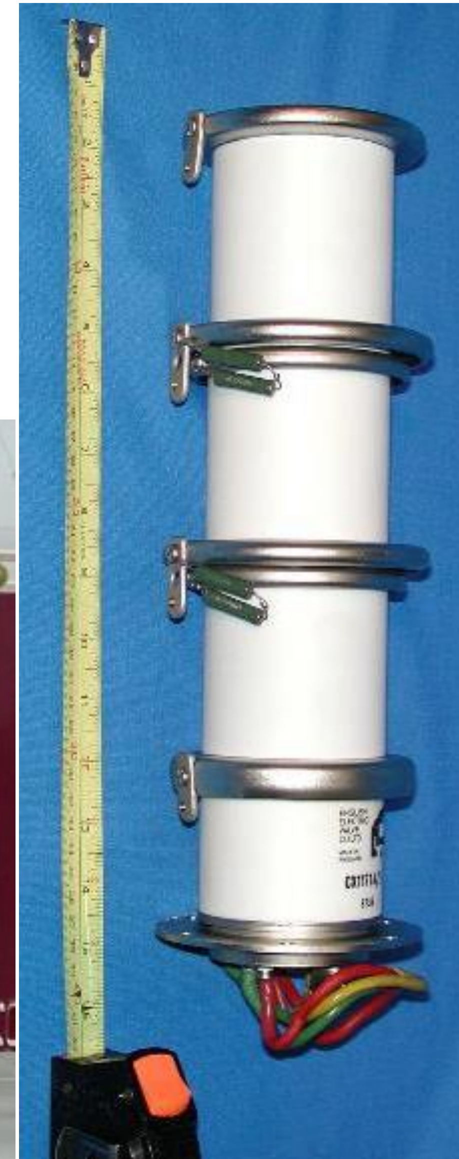
# Switches

## 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.

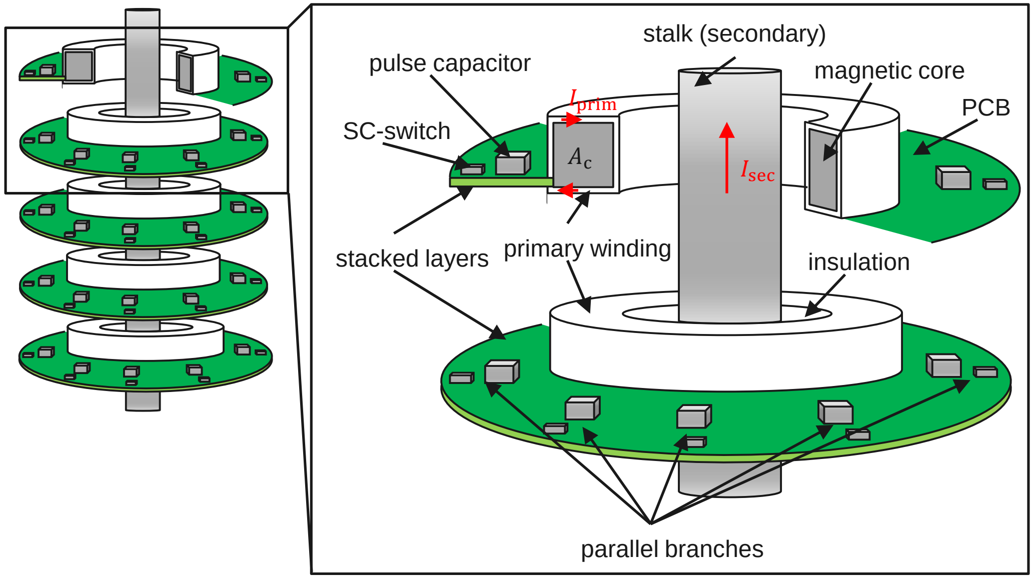
## Power semiconductor switches

- 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 switching > 1 μs (~18kA/μs).

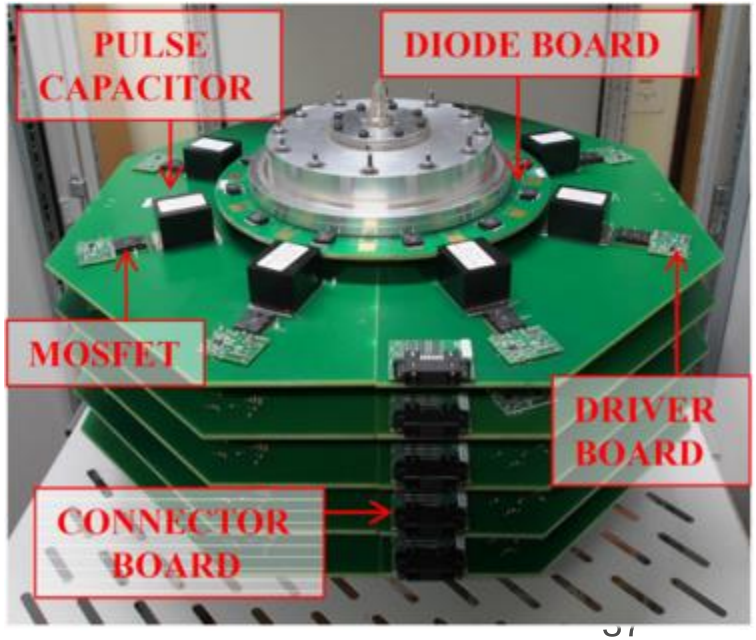


~ 340 mm

# 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.



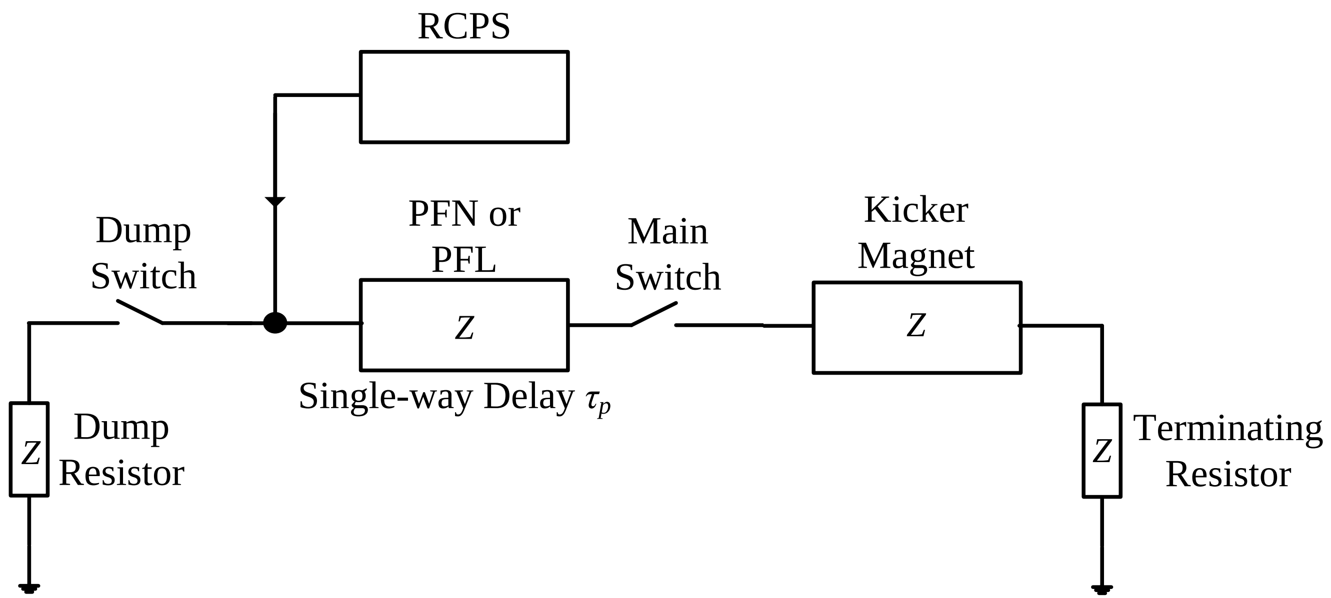

- Advantages:
  - **Modularity:** the same module design can be used for different voltage/current specifications;
  - **Short rise and fall times** can be achieved;
  - Output pulse **voltage can be modulated** -> excellent flat top quality.
  - Switches and control electronics are referenced to ground.
- Disadvantages:
  - Output transformer maximum **pulse length** limited to typically ~3 µs (depends on magnetic core);

Currently being developed for CLIC and FCC.

# Pulse Transmission

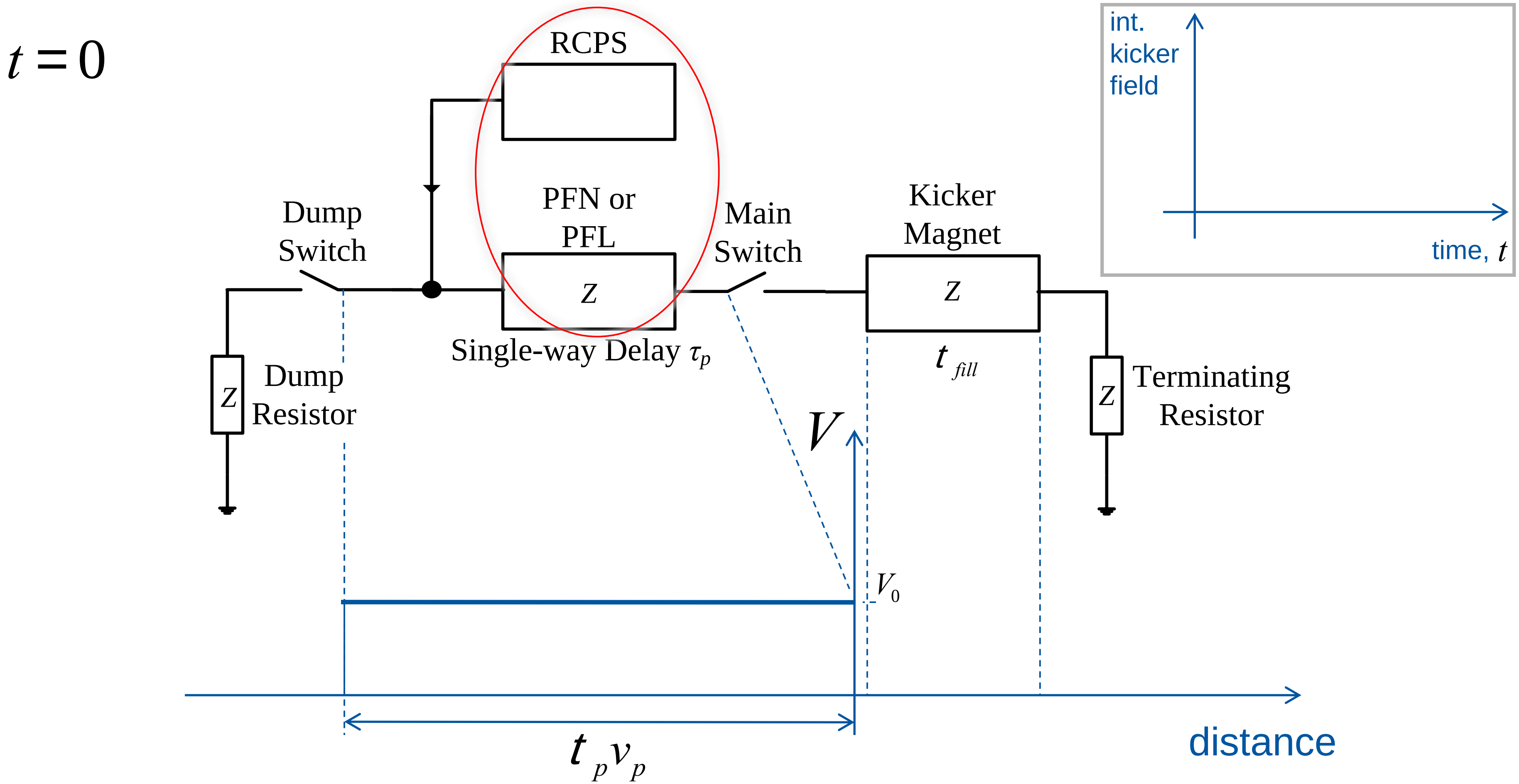
# Pulse Transmission

## Simplified kicker system schematic




Lets see what happens when we pulse the system…

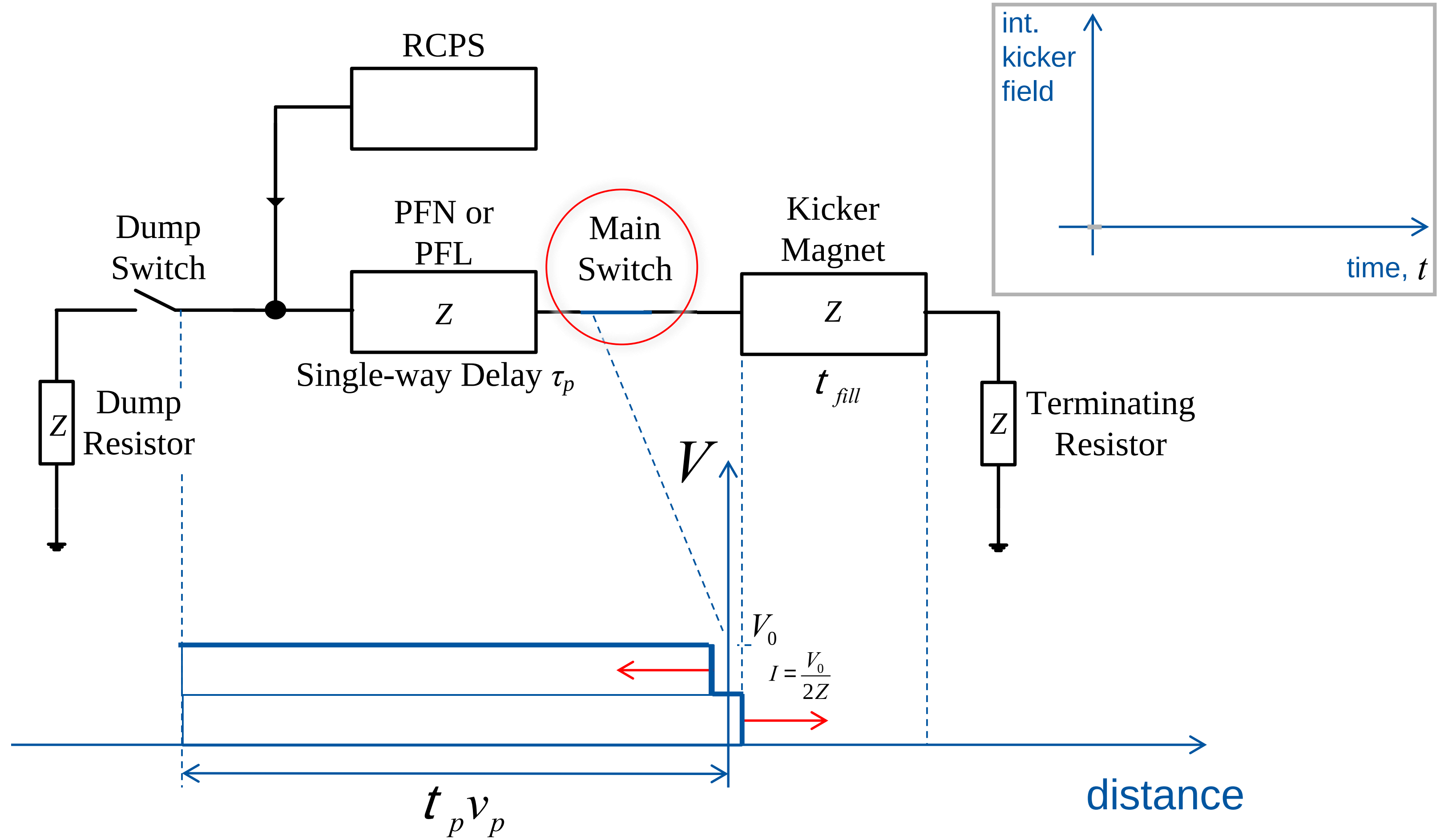
# Simplified kicker system schematic




- 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

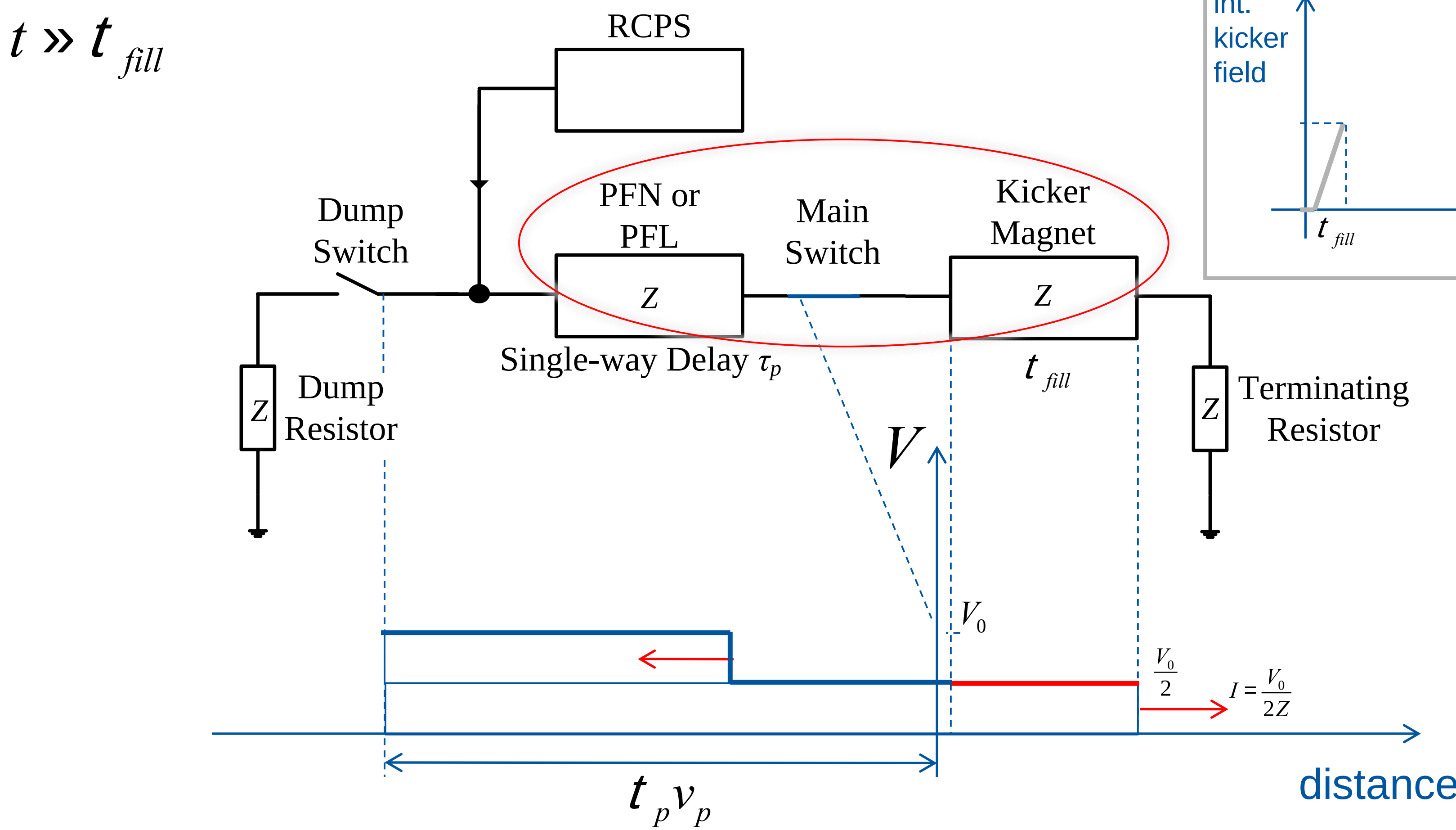
# Simplified kicker system schematic

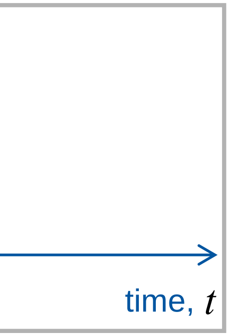
$t » 0$




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

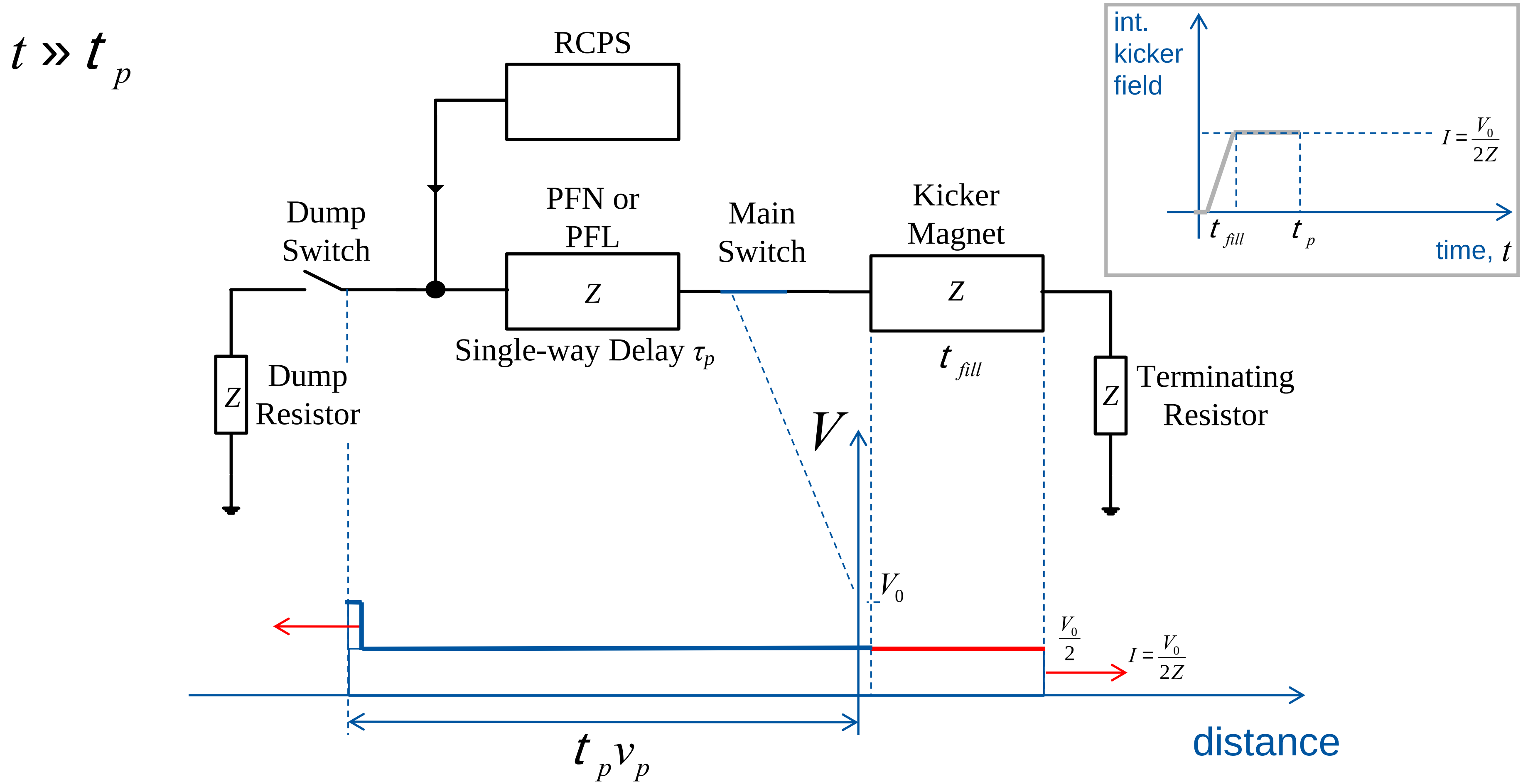
# Simplified kicker system schematic



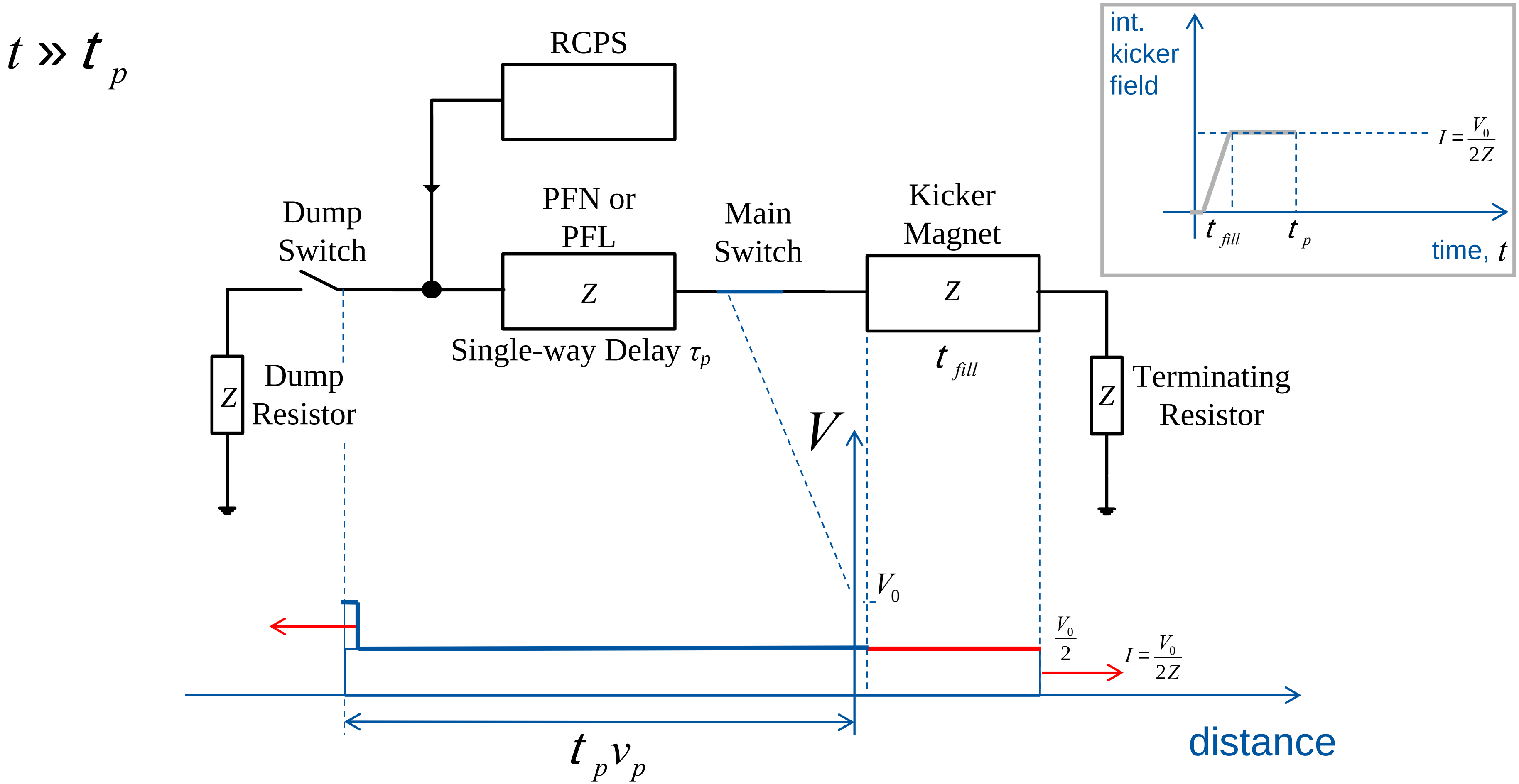

- At t = $\tau_{fill}$, the voltage pulse of magnitude $V_0/2$ has propagated through the kicker and nominal field achieved with a current $V_0/2Z$
  - typically $\tau_p >> \tau_{fill}$ (schematic for illustration purposes)

# Simplified kicker system schematic



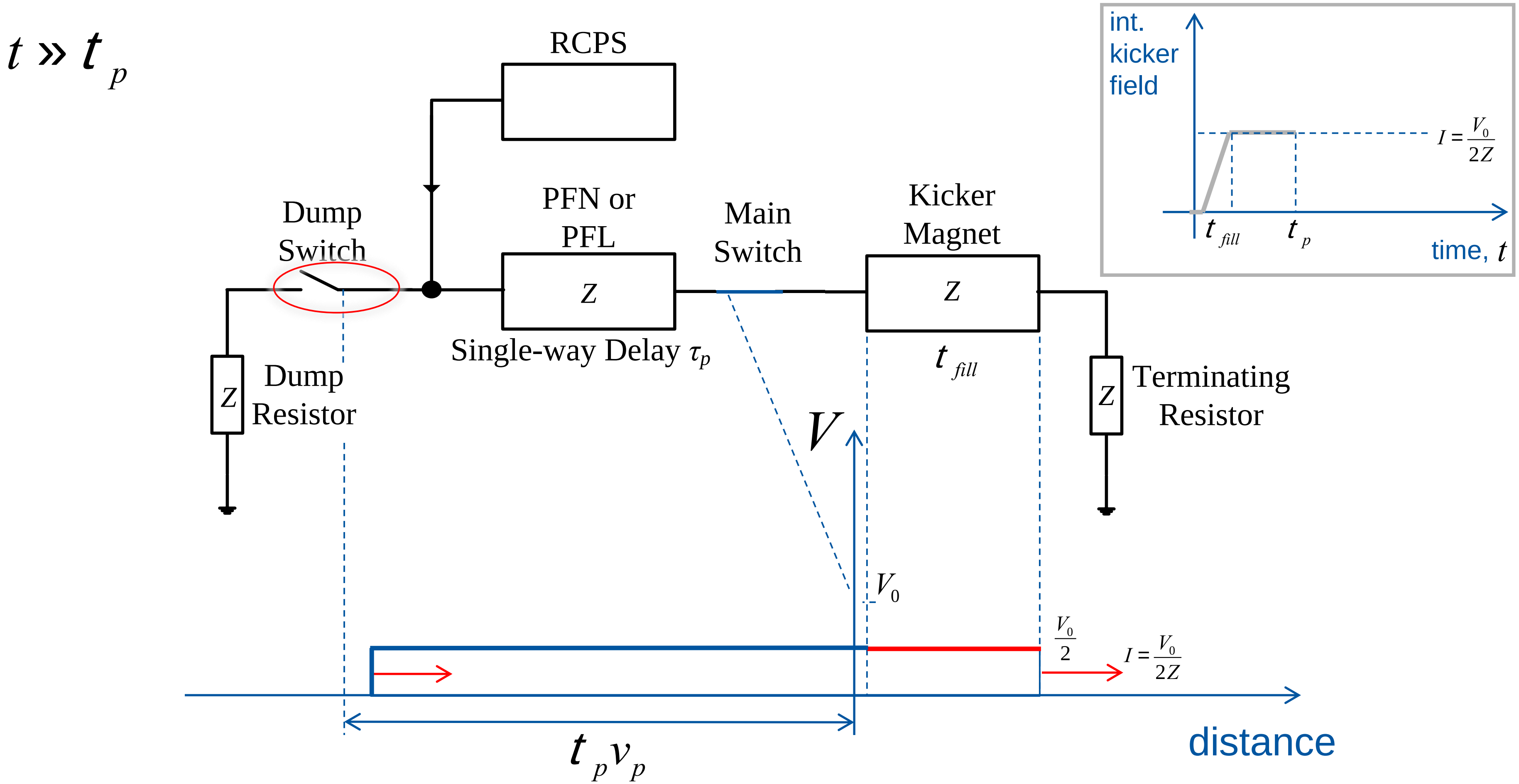

- PFN continues to discharge energy into kicker magnet and matched terminating resistor.

# Simplified kicker system schematic




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

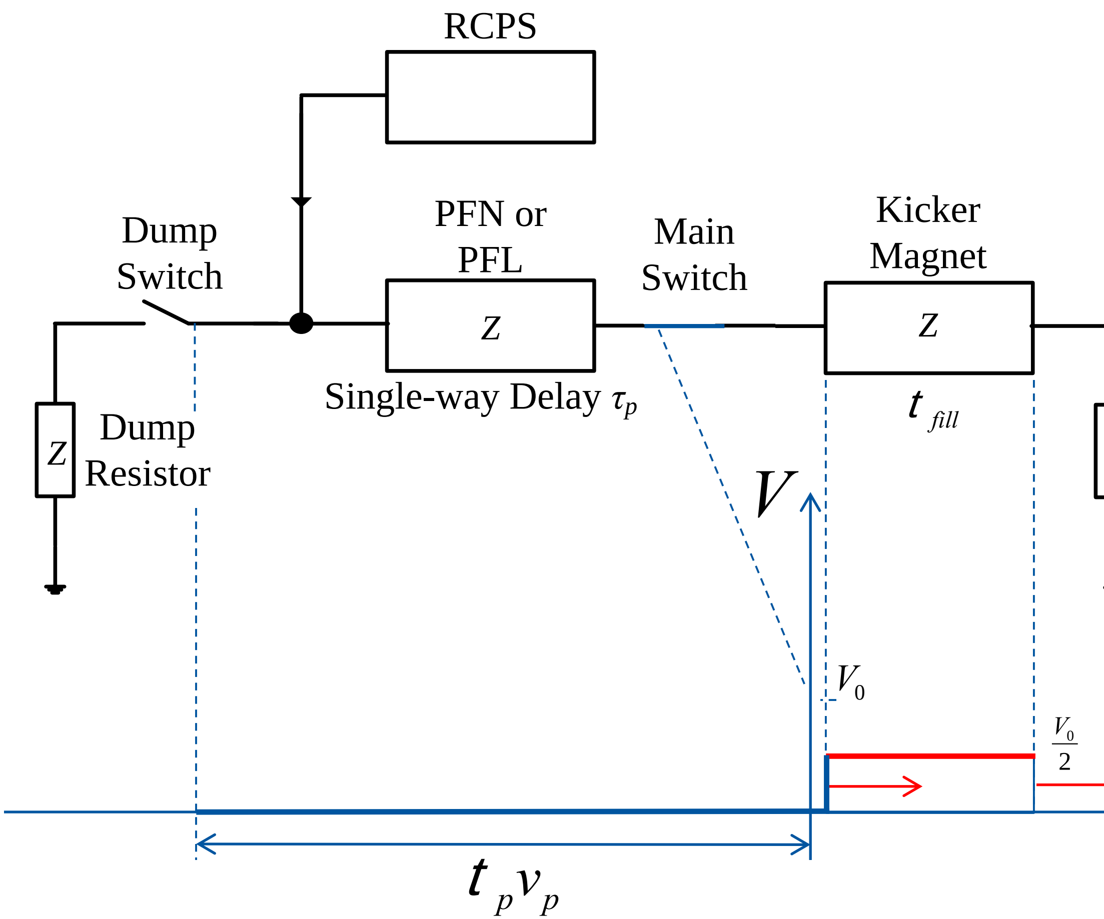
# Simplified kicker system schematic

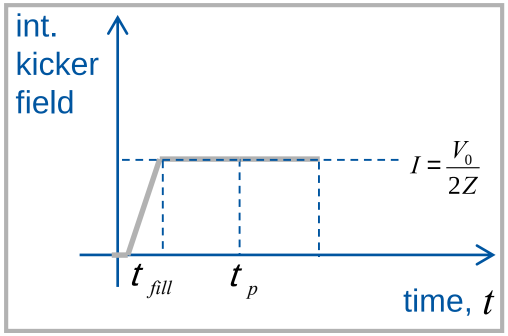



- PFN continues to discharge energy into matched terminating resistor.

# Simplified kicker system schematic

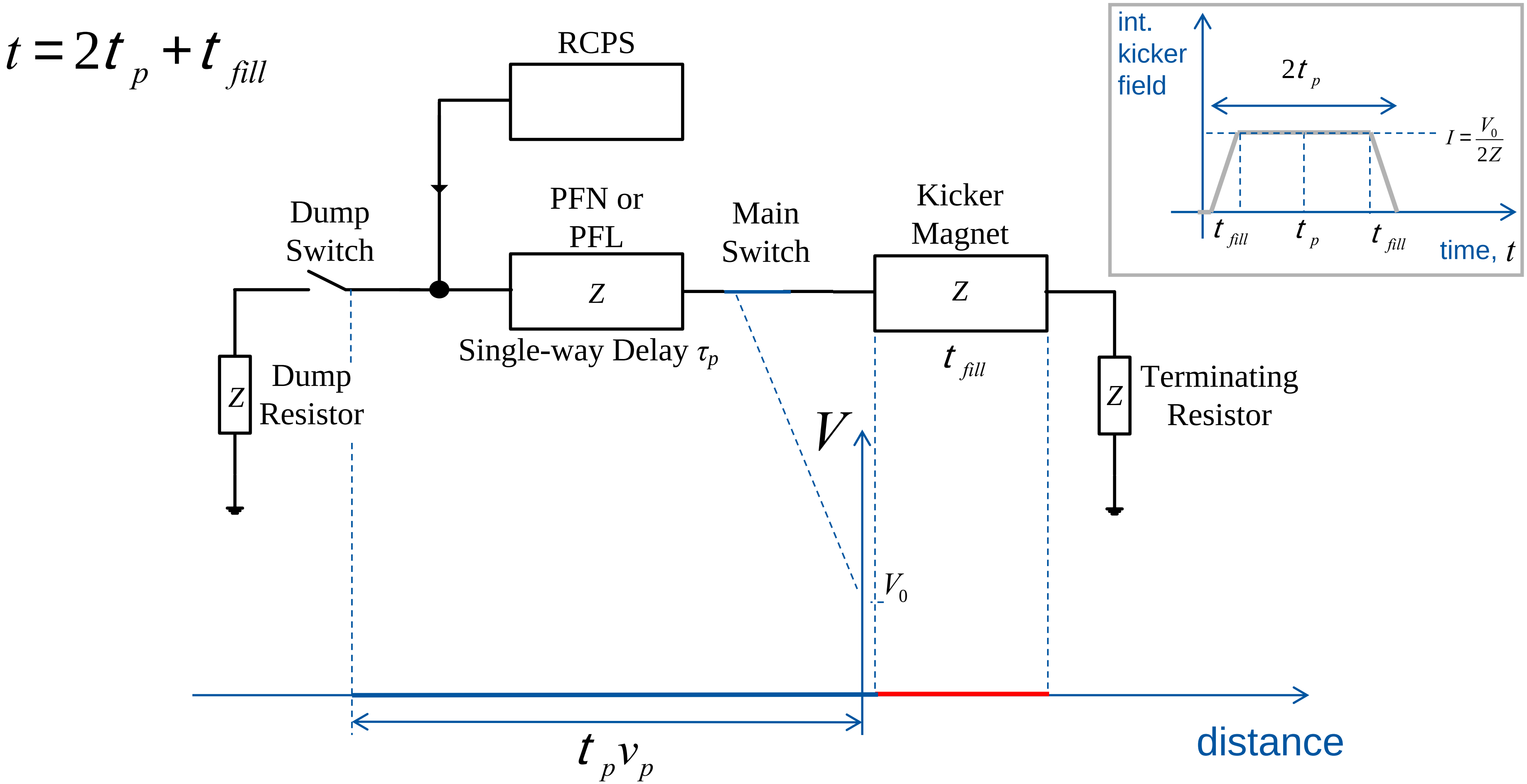
$t \gg 2t_p$




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

# Simplified kicker system schematic




- 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

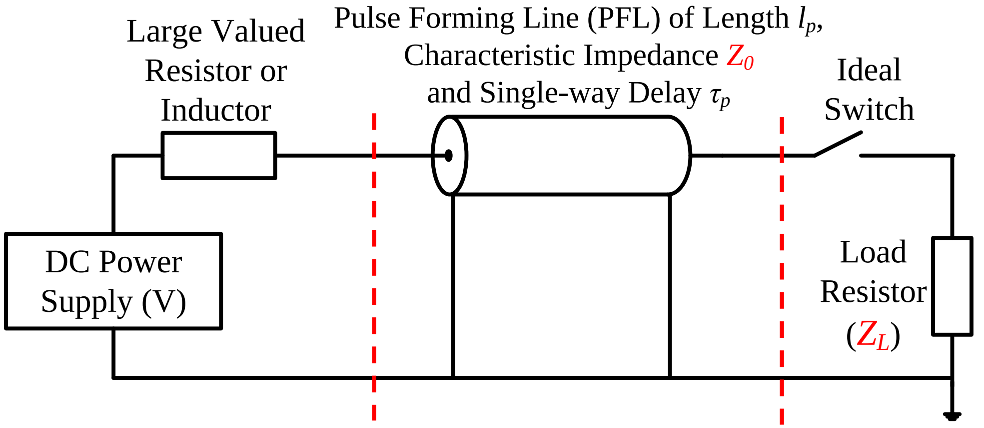
- Reflection coefficient:
  - Ratio of reflected wave to incident wave

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

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

# Reflections

- A simplified pulse forming circuit:




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

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

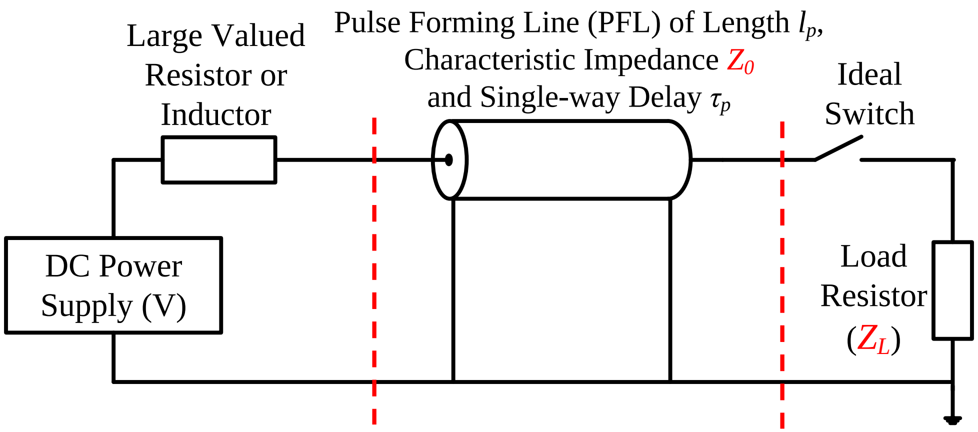
- In the matched case:

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

- Hence PFL charging voltage is twice the required voltage!

# Reflections

- A simplified pulse forming circuit:

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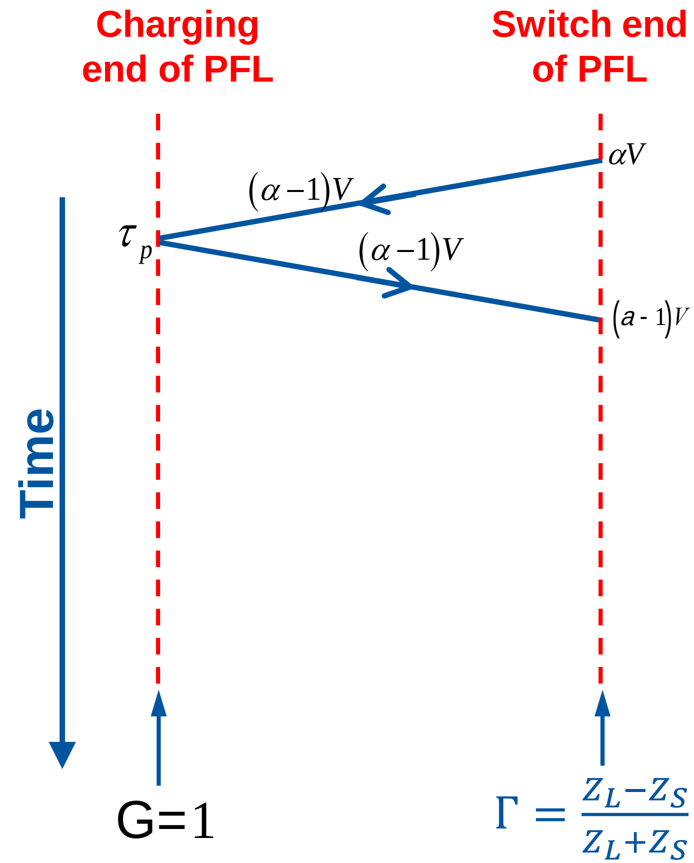


for matched case:

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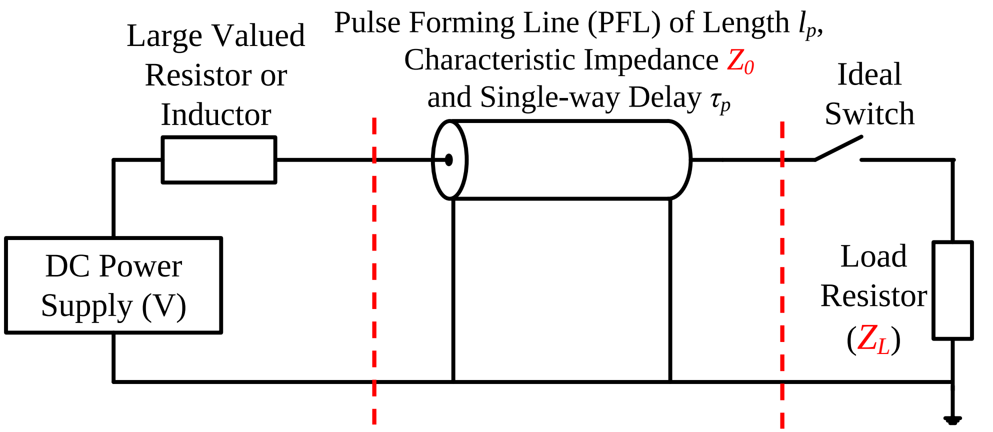
# Reflections

- A simplified pulse forming circuit:



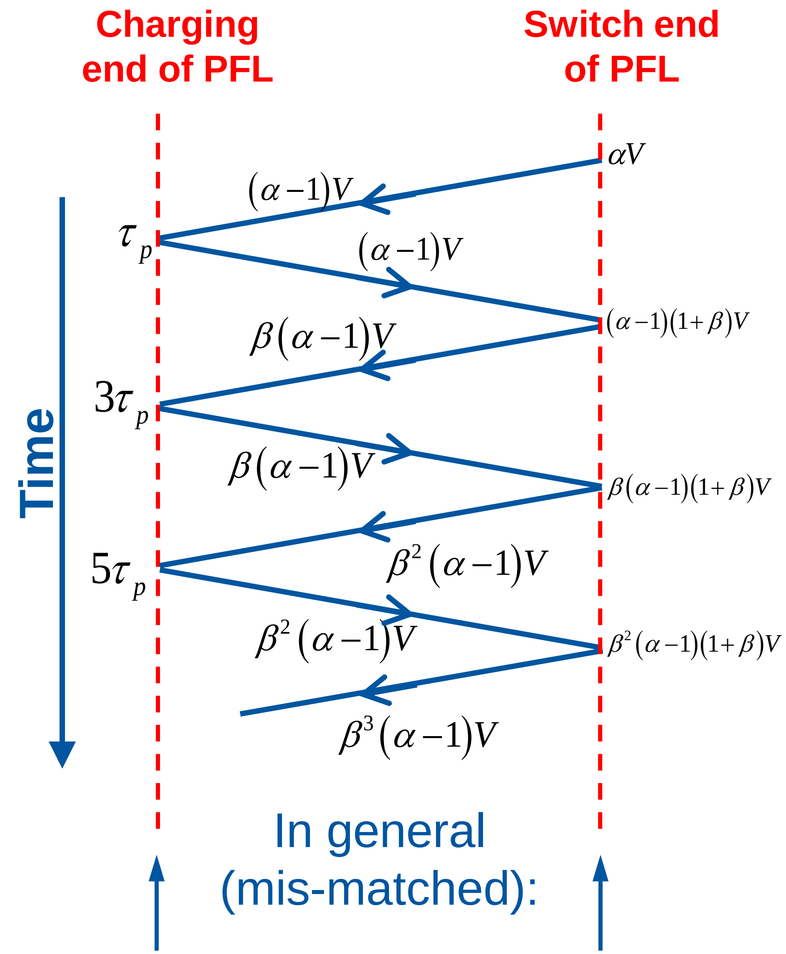

**Match impedances to avoid reflections!**

- 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:

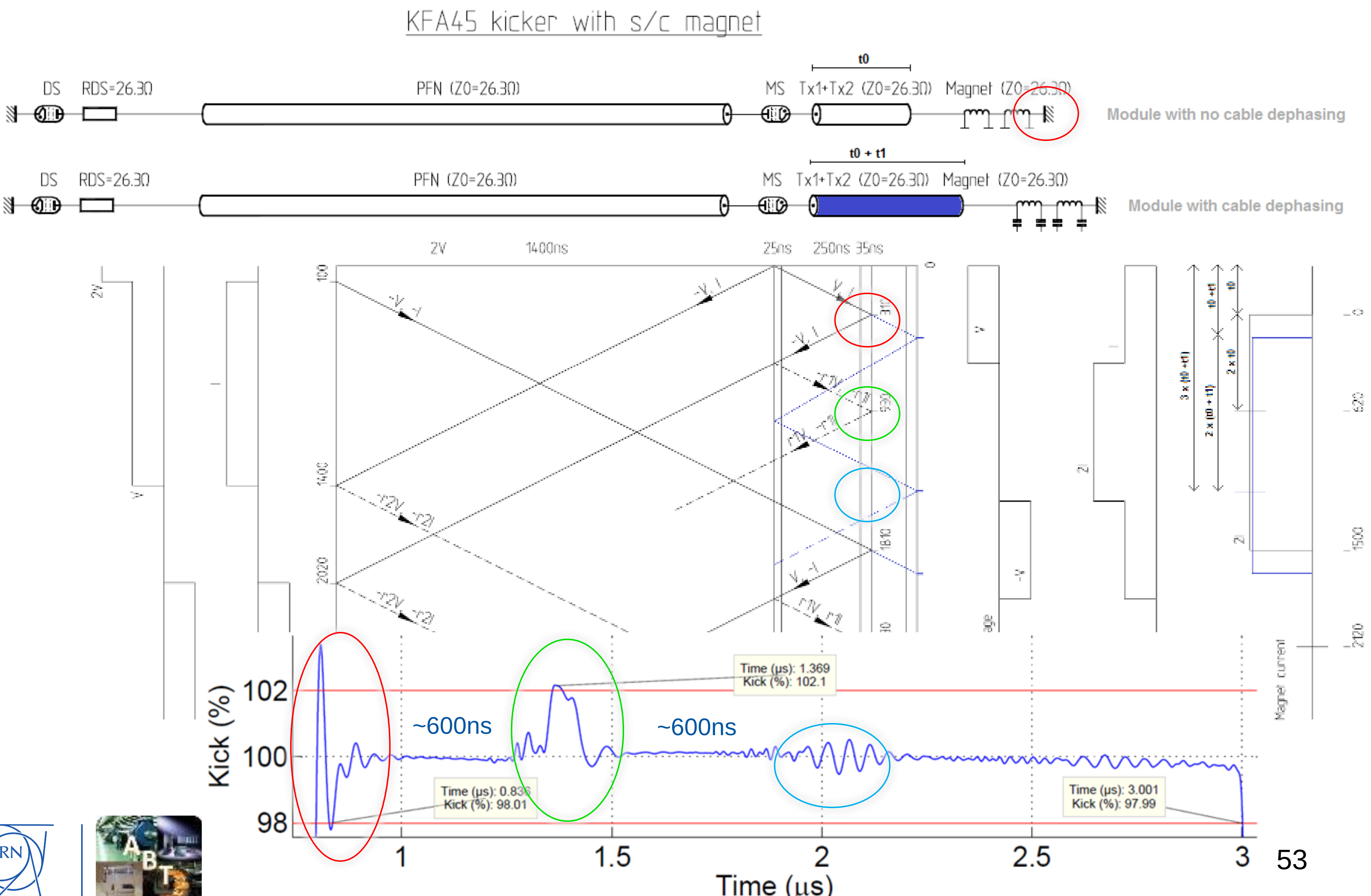
$$Z_0 = Z_L \qquad a = \frac{1}{2}, \ b = 0$$



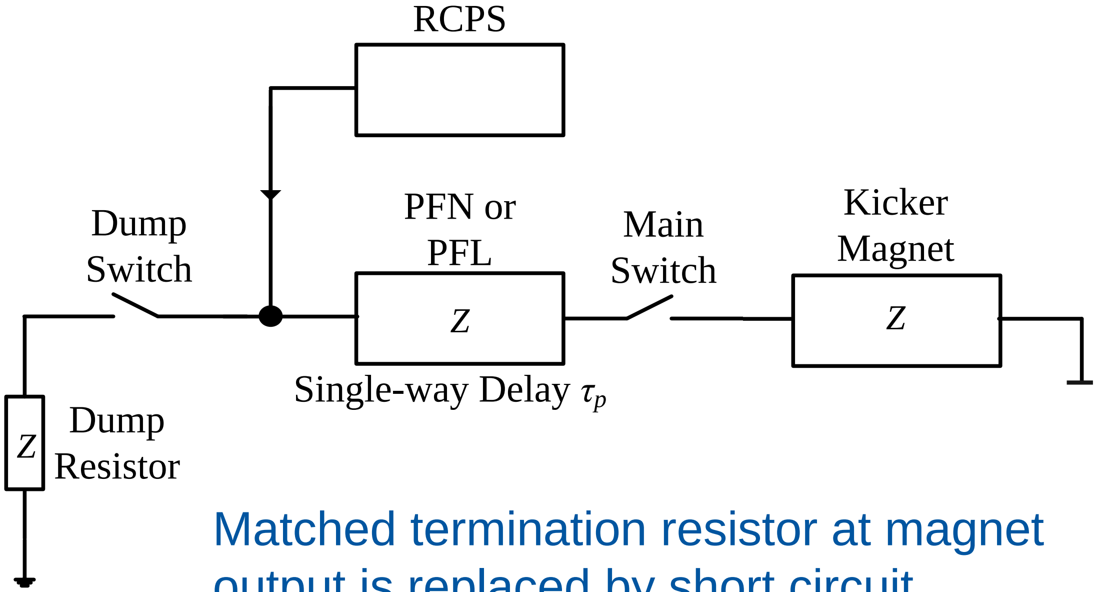

G=1

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

# Reflections: Example KFA-45



# Terminated vs. Short Circuited (SC) mode




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

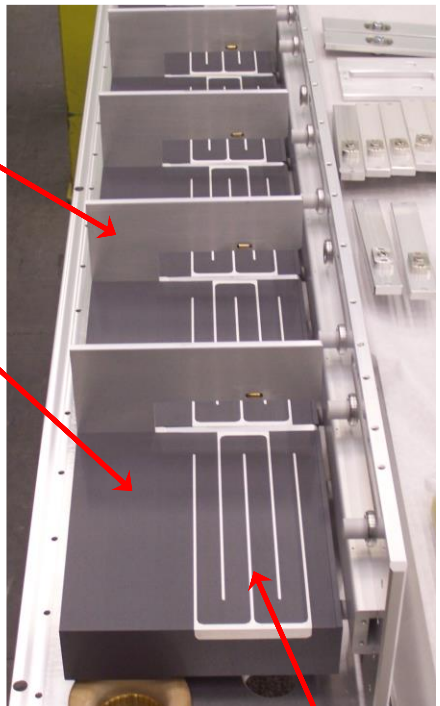
- In SC point:
  - Voltage =0 (incoming and reflected wave cancels)
  - Current doubles $I_{sc} = V\left(\frac{1-\Gamma}{Z}\right)$
- Magnet kick strength doubles but also the reflected wave needs to travel trough the kicker again -> rise time doubles as well.
- Any system mismatch will create reflections!

# Beam Coupling Impedance

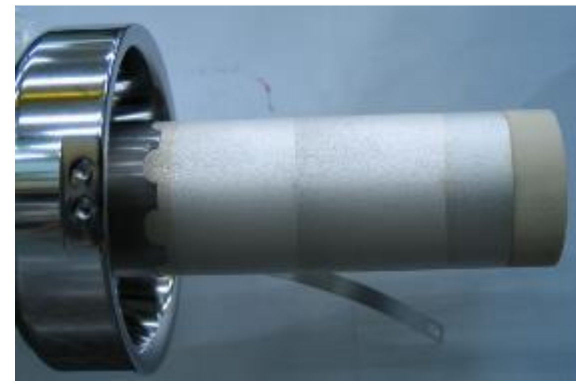
In order to reduce beam coupling impedance the ferrite must be shielded from the beam, by providing <u>a path for beam image current</u>. However the design must ensure that eddy-currents, induced by the fast rising field, do not unduly increase field rise-time.

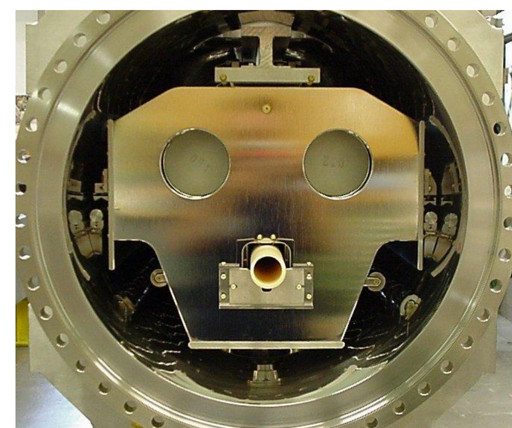
**HV Plate**

**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

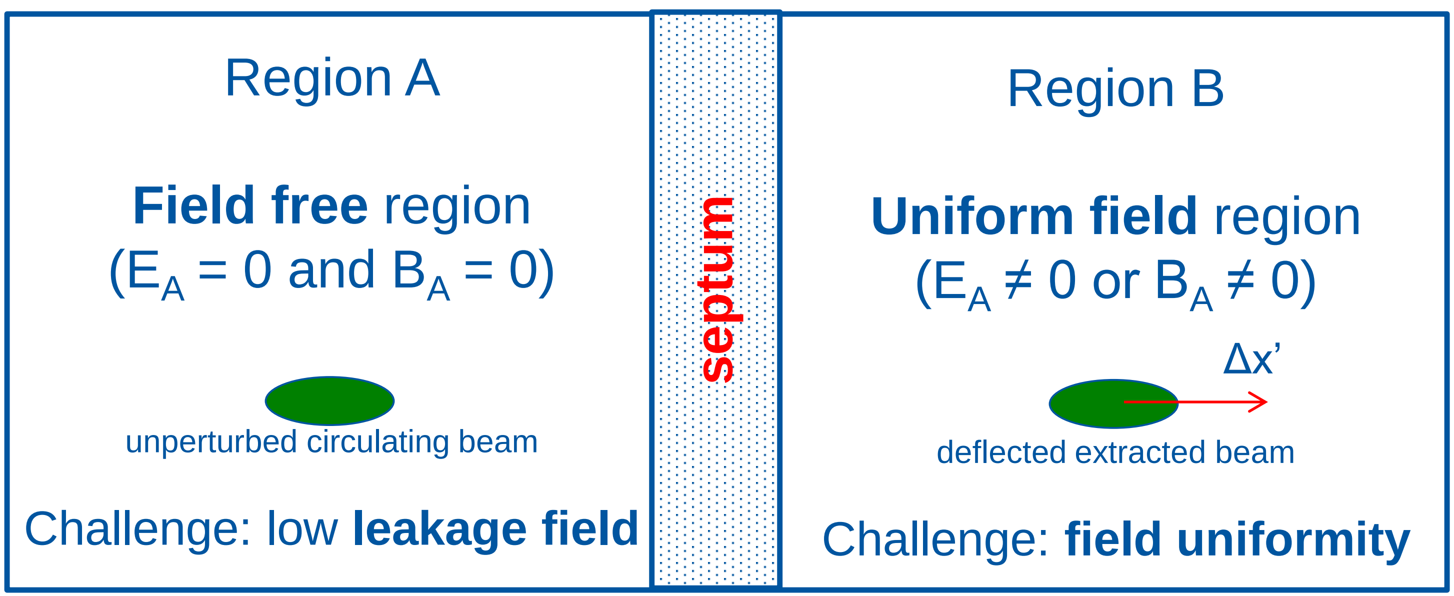
# Septa

- Two main types:
  - **Electrostatic septa (DC)**

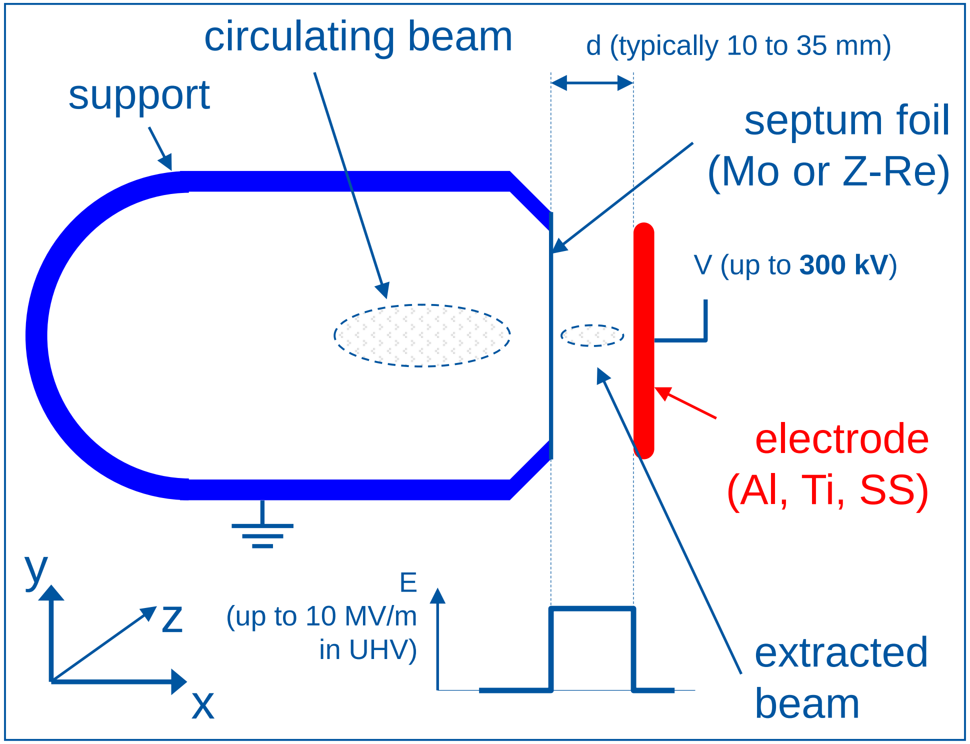
  “weak” field, “thin” septum

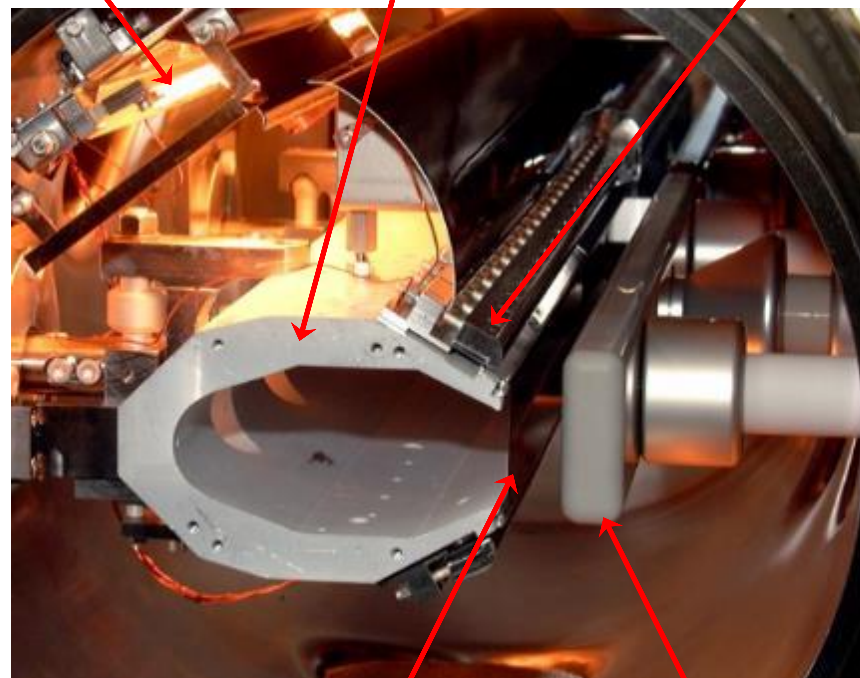
  - **Magnetic septa** (DC and pulsed):
    - Direct drive septum
    - Eddy current septum (pulsed only)
    - Lambertson septum (deflection parallel to septum)

  “strong” field, “thick” septum



# Electrostatic foil septum



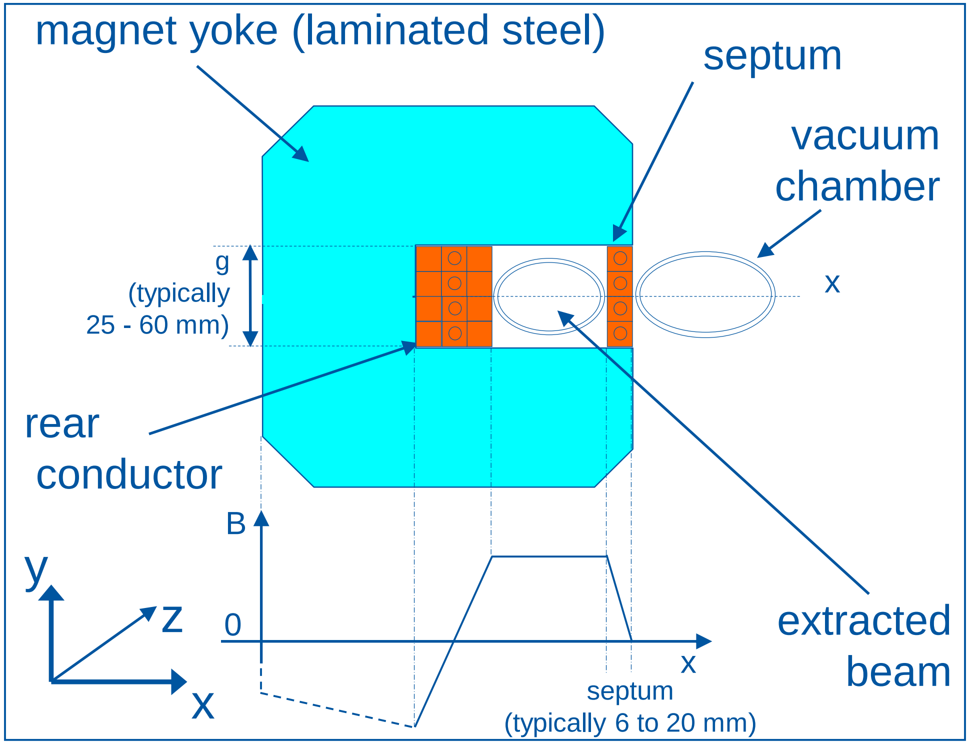

- **Thin septum** ~ 0.1 mm needed for high extraction efficiency:
  - Foils or stretched wire arrays provide thinner septa
- Challenges include **conditioning and preparation of HV surfaces**, vacuum in range of $10^{-9}$ – $10^{-12}$ mbar and **in-vacuum precision position alignment**

# 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!

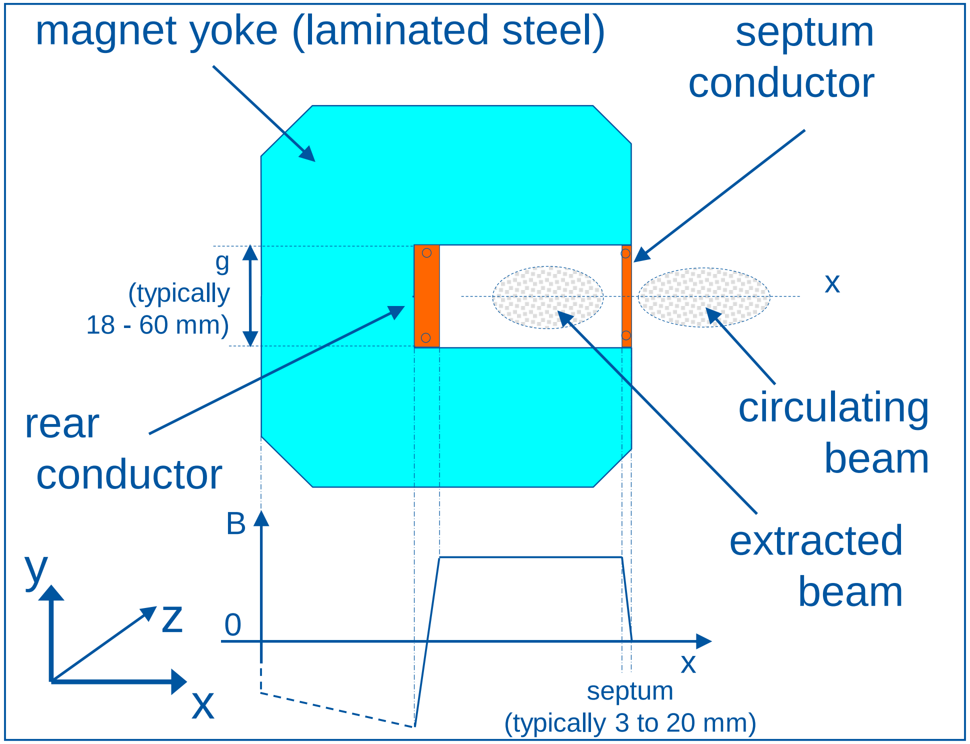
# DC direct drive magnetic septum

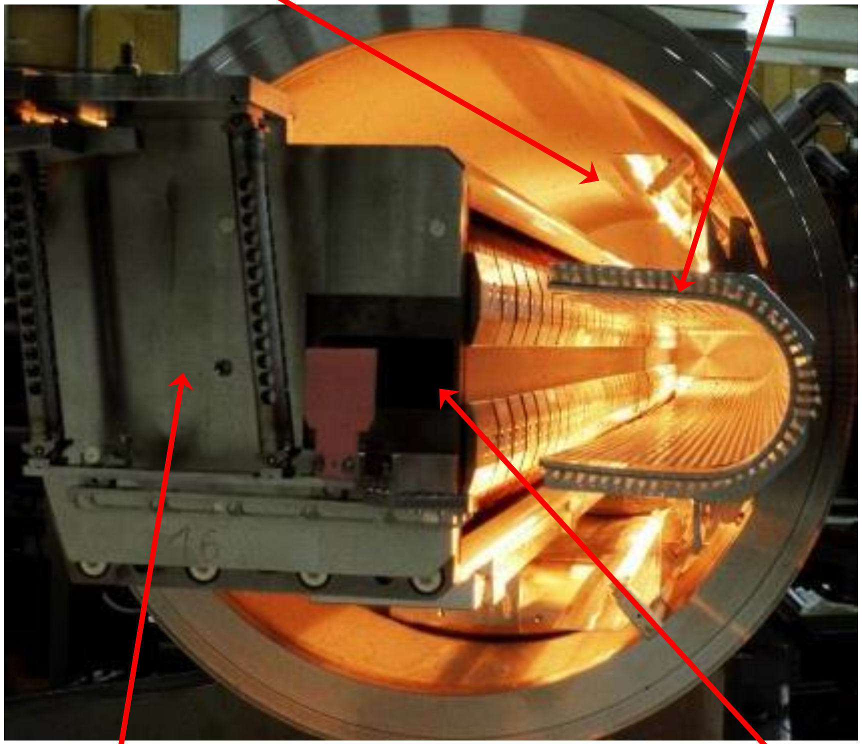




- **Continuously powered, rarely under vacuum**
- Multi-turn coil to reduce current needed but **cooling** still an issue:
  - Cooling water circuits flow rate typically at 12 – 60 l/min
  - Current can range from 0.5 to 4 kA and power consumption up to **100 kW**!

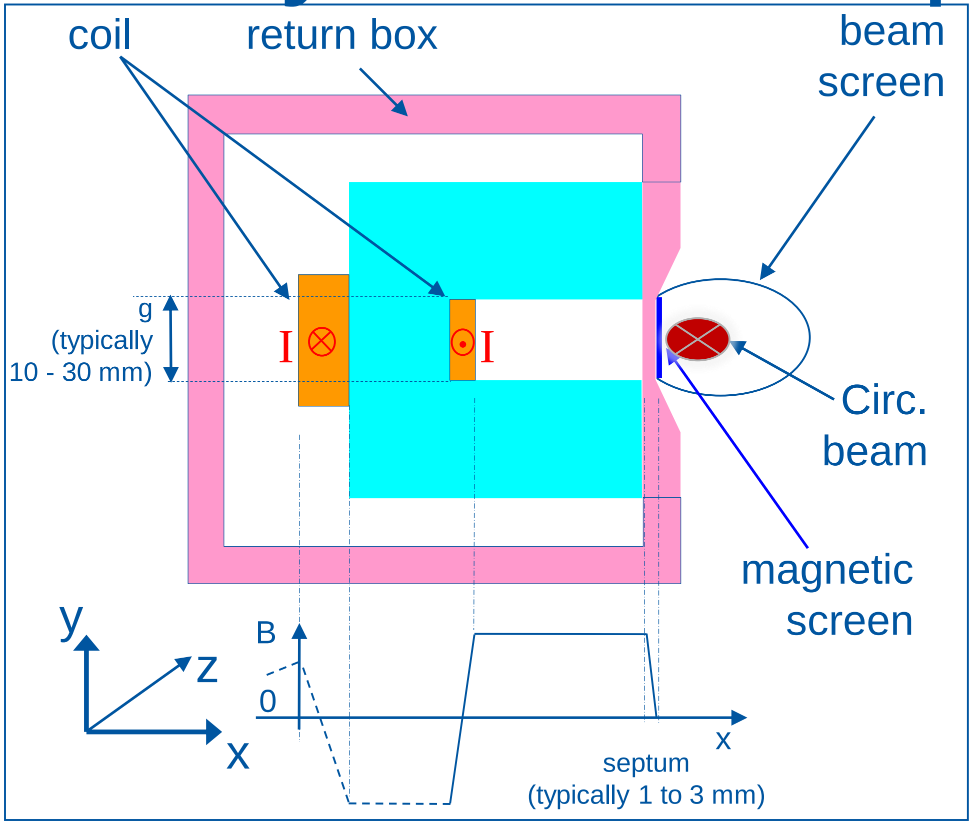
# Direct drive pulsed magnetic septum




- **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

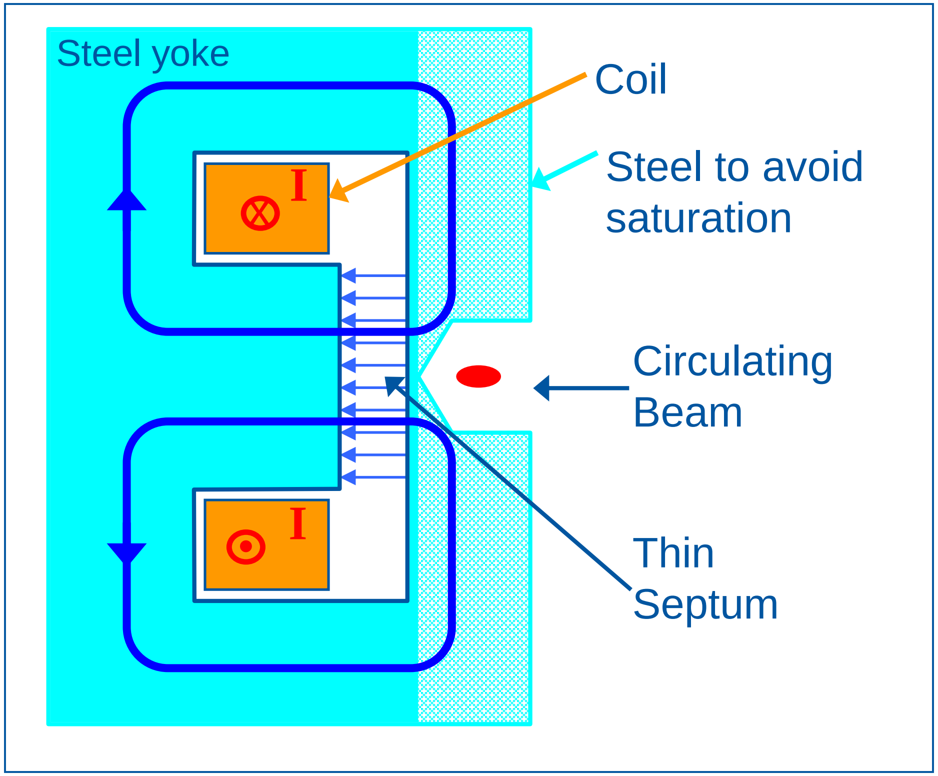
# Eddy current septum




- 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.

# Protection Devices

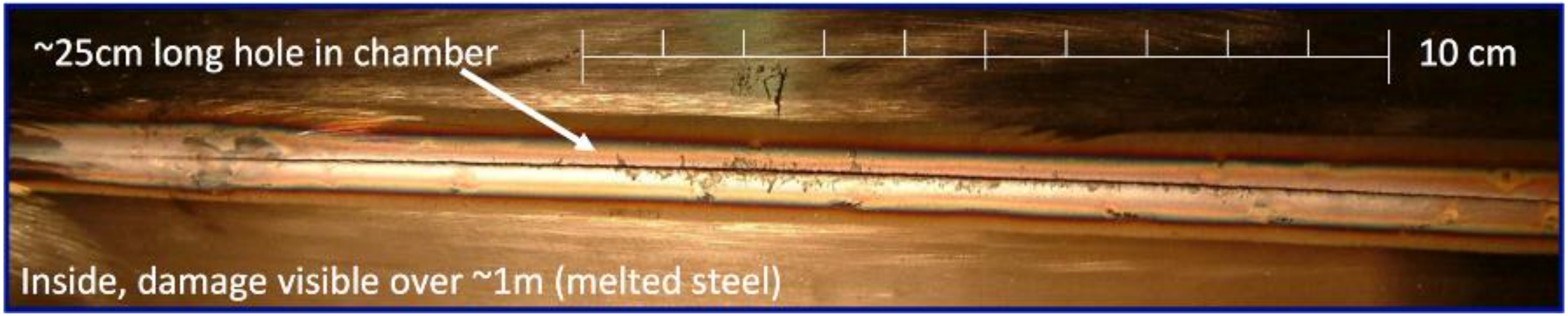
If you google it…

…well you better do this at home.

# Protection devices

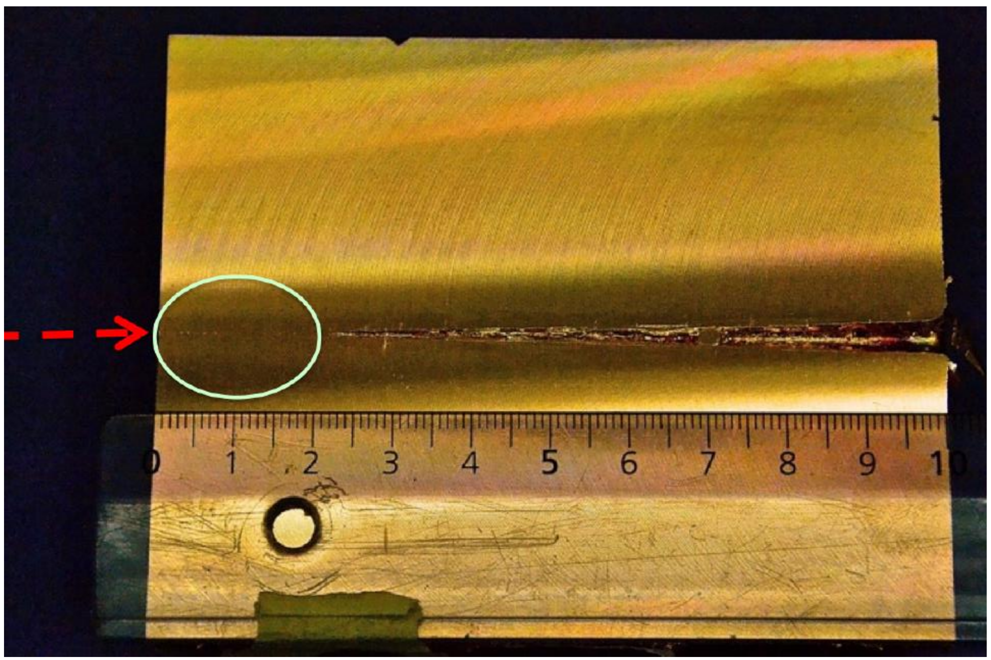
- BT-Protection devices **protect valuable equipment** and also increase machine availability.
- Hasn't been such a concern in the early days. Getting crucial these days already at lower energies due to **record beam intensities and high brightness beams**. Nominal LHC beam can easily penetrated several 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**.

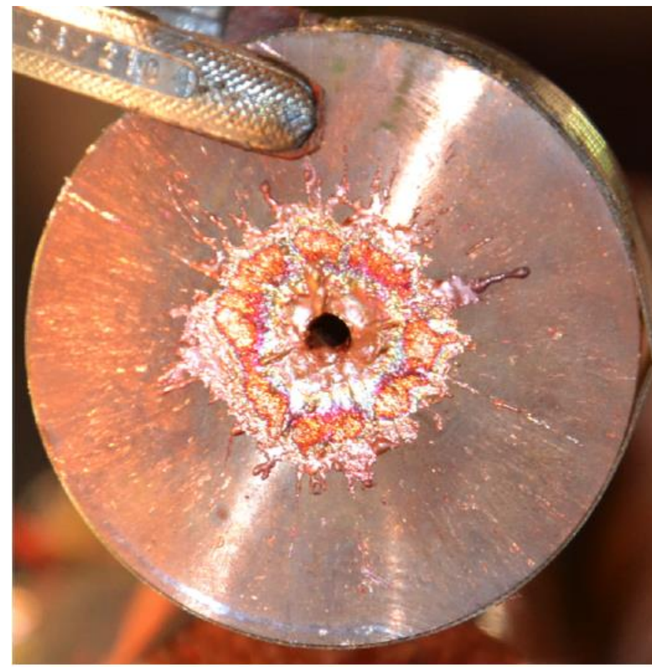
- In 2004 an extr. septum power supply failure directed $3.4 \times 10^{13}$ protons at 450 GeV into the TL vacuum chamber (2.5 MJ beam energy):



# 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

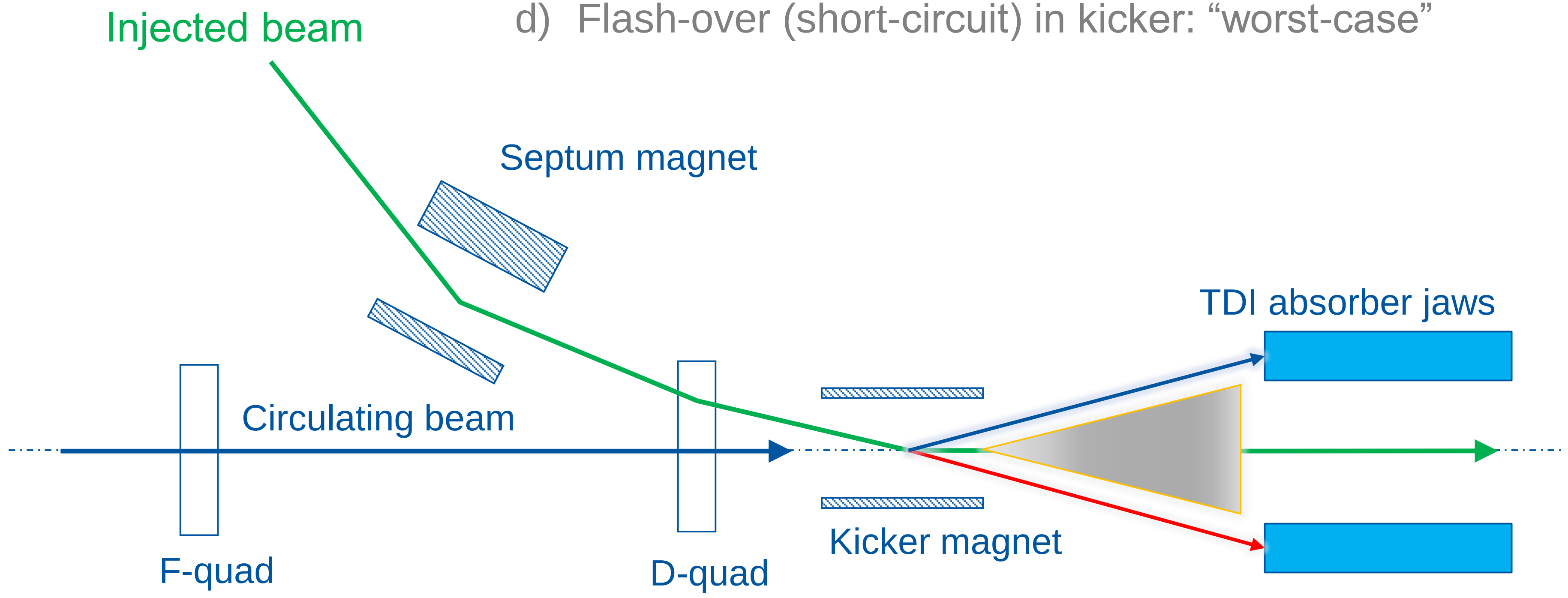
- **Failures** associated with beam transfer equipment are typically **very fast** and difficult to catch, for example:
  - **No turn-on** of kicker: injection protection
  - **Erratic** turn-on of kicker: circulating beam swept over aperture
  - **Flash-over** (short-circuit) in kicker: wrong kick angle
  - **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

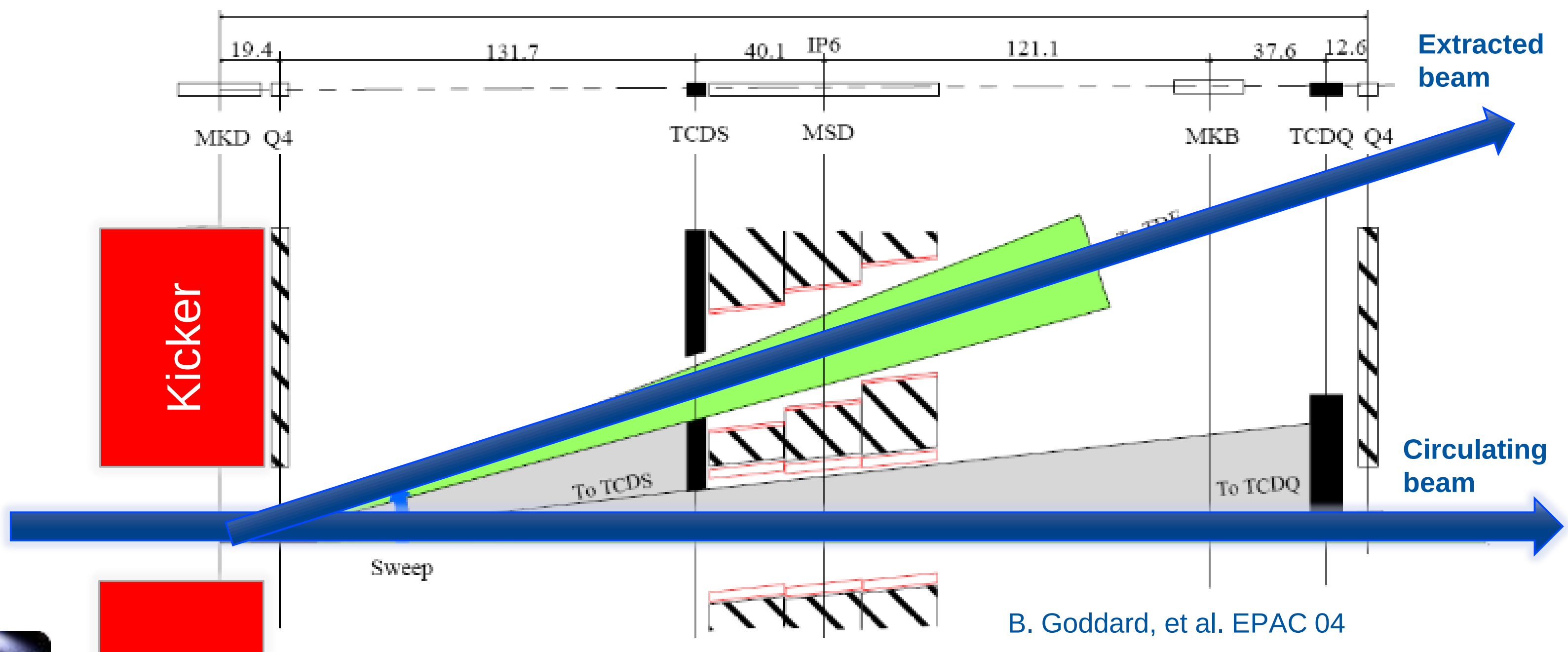
Dedicated injection dump (TDI) to protect against fast failures on the injection kicker system.

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

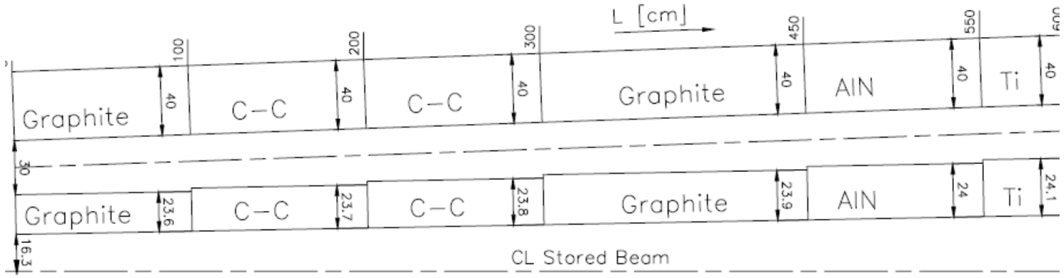
- **360 MJ stored energy** per beam to be safely extracted. **Reliability** and **machine protection** is a major concern.
- **Kickers** are fired in a particle free 3 µs long **abort gap**, next arriving beam is then deflected into the dump line.
- **Absorbers** in front of septa (TCDS) and Q4 (TCDQ).
- **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

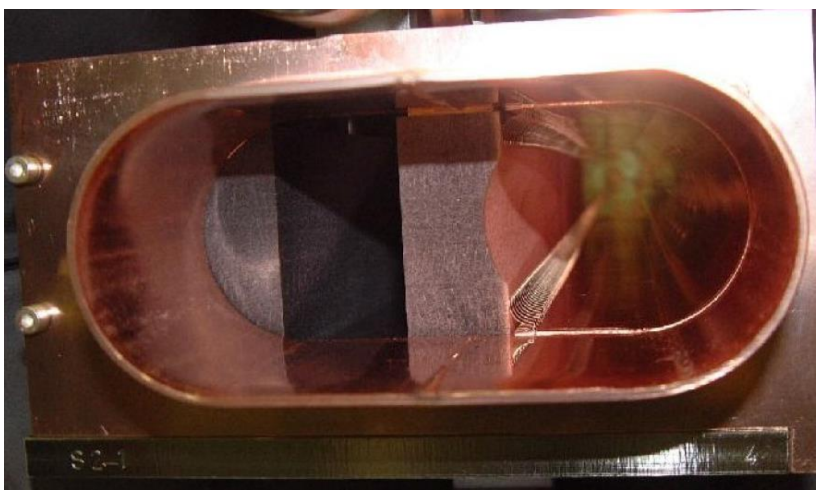
## TCDS

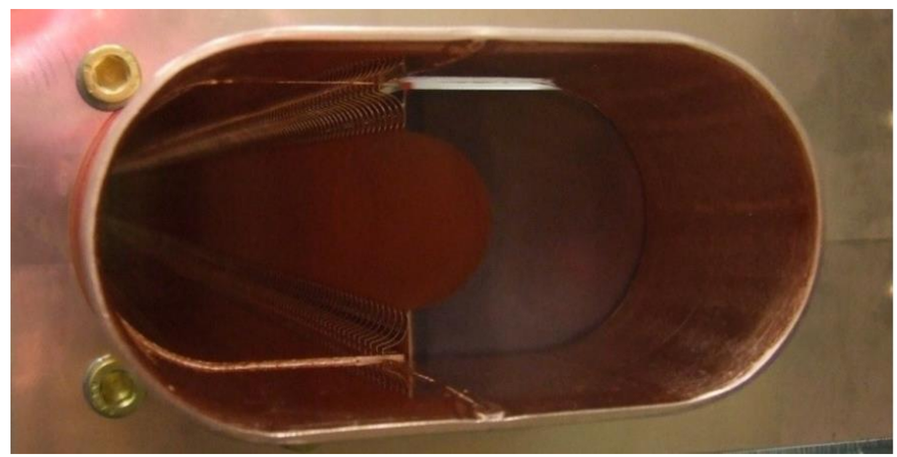



Sandwich construction.

## 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.

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Thanks for your attention!

Questions?

If some appear later on: Feel free to pass by Building 865!

# Example parameters for kickers at CERN

| **Kicker** Location | Beam momentum (GeV/c) | # Magnets | Gap Height [$V_{ap}$] (mm) | Current (kA) | Impedance (Ω) | Rise Time (ns) | Total Deflection (mrad) |
|---|---|---|---|---|---|---|---|
| CTF3 | 0.2 | 4 | 40 | 0.056 | 50 | ~4 | 1.2 |
| PS Inj. | 2.14 | 4 | 53 | 1.52 | 26.3 | 42 | 4.2 |
| SPS Inj. | 13/26 | 16 | 54 to 61 | 1.47/1.96 | 16.67/12.5 | 115/200 | 3.92 |
| SPS Ext. (MKE4) | 450 | 5 | 32 to 35 | 2.56 | 10 | 1100 | 0.48 |
| LHC Inj. | 450 | 4 | 54 | 5.12 | 5 | 900 | 0.82 |
| LHC Abort | 450 to 7000 | 15 | 73 | 1.3 to 18.5 | 1.5 (not T-line) | 2700 | 0.275 |

# Example parameters for septa at CERN

| **Septum** Location | Beam momentum (GeV/c) | Gap Height (mm) | Max. Current (kA) | B (T) | Deflection (mrad) | Septum thickness (mm) |
|---|---|---|---|---|---|---|
| LEIR/AD/CTF (13 systems) | Various | 25 to 55 | 1 DC to 40 pulsed | 0.5 to 1.6 | up to 130 | 1.7 - 19.2 |
| PS Booster (6 systems) | 1.4 | 25 to 60 | 28 pulsed | 0.1 to 0.6 | up to 80 | 1 – 15 |
| PS complex (8 systems) | 26 | 20 to 60 | 2.5 DC to 33 pulsed | 0.2 to 1.2 | up to 55 | 3 - 11.2 |
| SPS Ext. | 450 | 20 | 24 | 1.5 | 2.25 | 4.2 - 17.2 |