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SI LAB
Silizium Labor Bonn

BELLE II GERMANY MEETING - AUGUST 2025

PXD EMERGENCY SHUTDOWN INVESTIGATION

paula.scholz@uni-bonn.de

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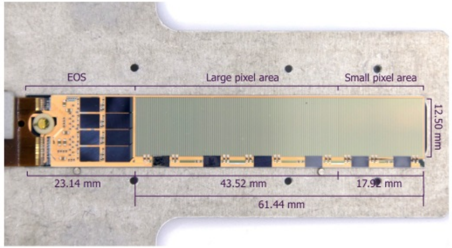
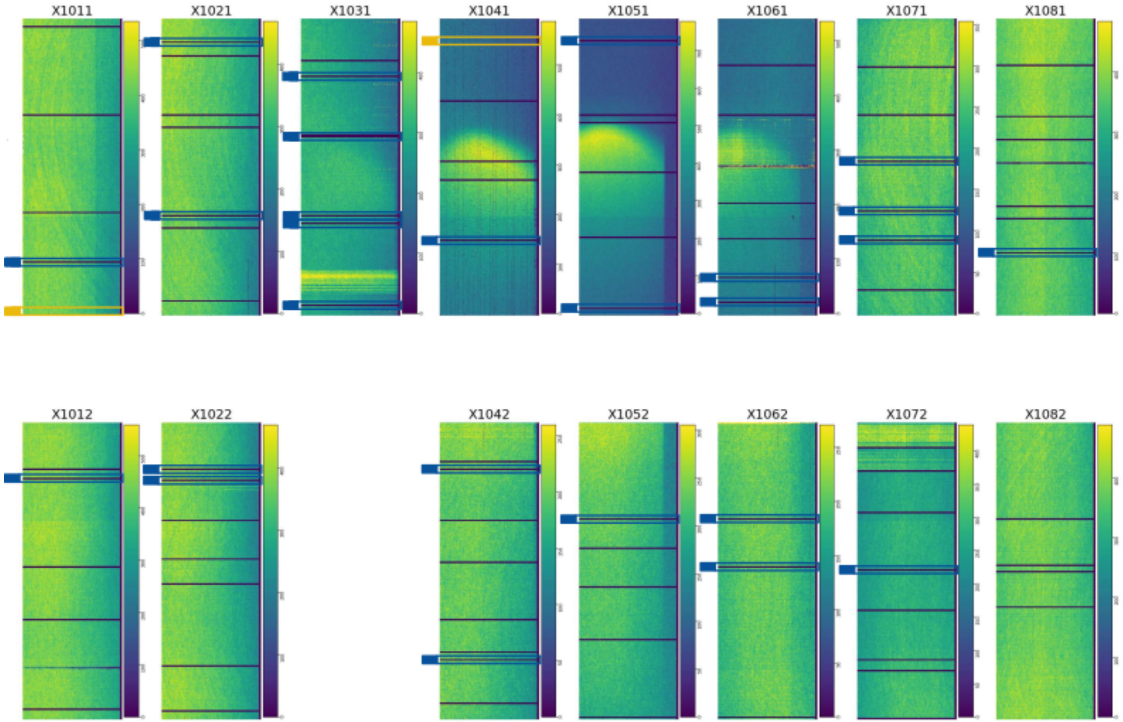
MOTIVATION

[3]



- Switchers **vulnerable** to large radiation
- Example: Beam loss event in 2020
  - Estimated dose: 500 rad for PXD1 in 40 µs
  - Increased number of **inefficient rows**
    - In total 89 inefficient rows ➔ efficiency drop of 3%
    - blue flags: freshly emerged inefficient rows
- Damage can be prevented when Switchers are turned off

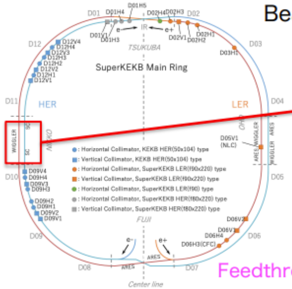
➔ Shutdown as fast and safe as possible



[4]

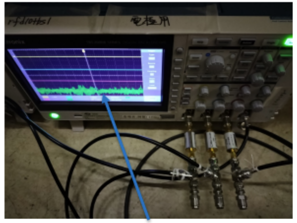
BEAM LOSS DETECTION

- New sensors, improved signal transmission
  → Faster and earlier detection of SBLs
- Plan : Include signals into PXD interlock
  → Lower threshold to put PXD into safe OFF state
- Candidate : Signal in clearing electrode
- Signal detected close to area where pressure burst occurred
- Strong correlation with SBLs
- Cable routing started (amplification and integration still TBD)
- To benefit from faster detection, we must minimise PXD shutdown delay



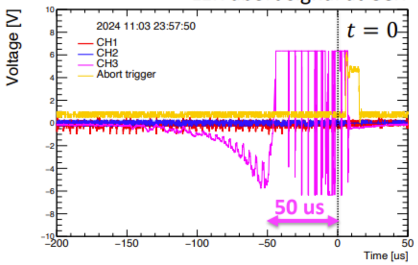
Beam pipe with clearing electrode

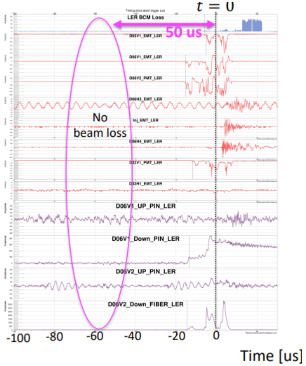
Feedthrough for clearing electrode



Monitor the signal from the feedthrough

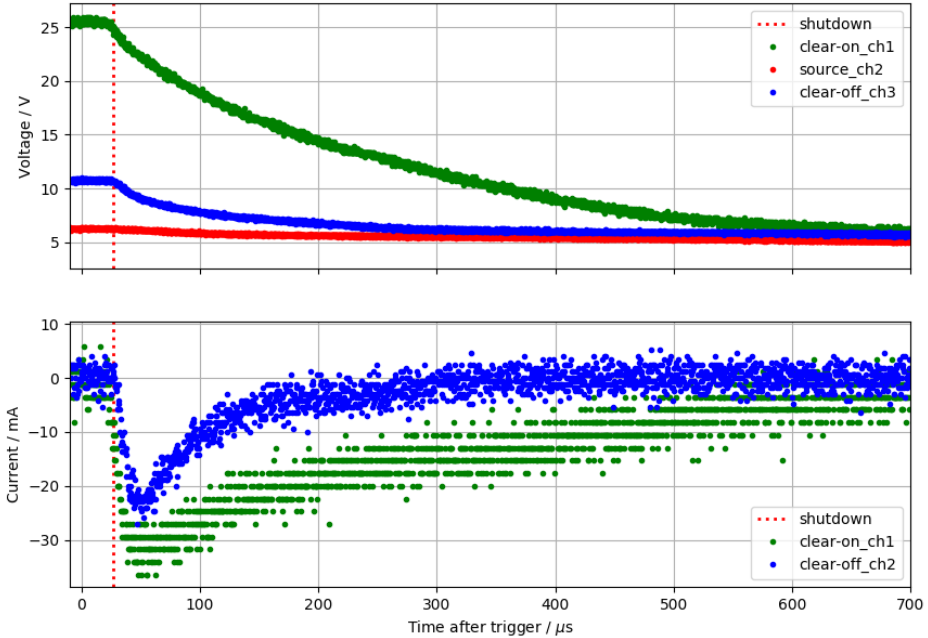
LER abort signal at CCR





REGULAR SHUTDOWN

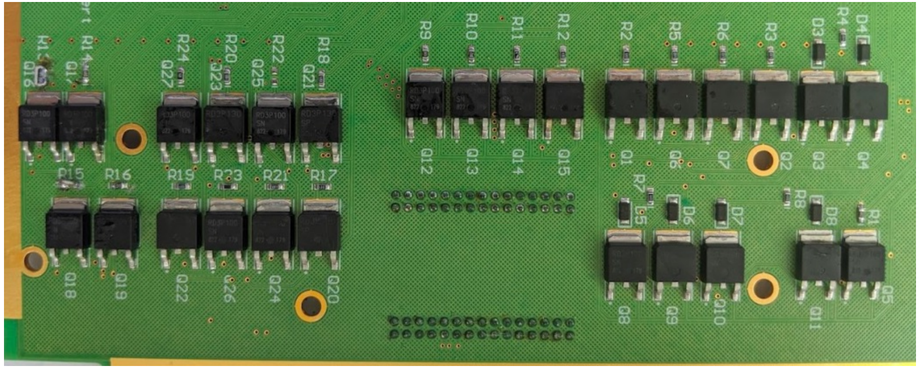
- Regular shutdown applied at PXD1:
  - Switch off power
- Example: Shutdown of Switcher voltages
- **Long discharge time** due to capacitors
  - Shutdown time in ms-range



[4]

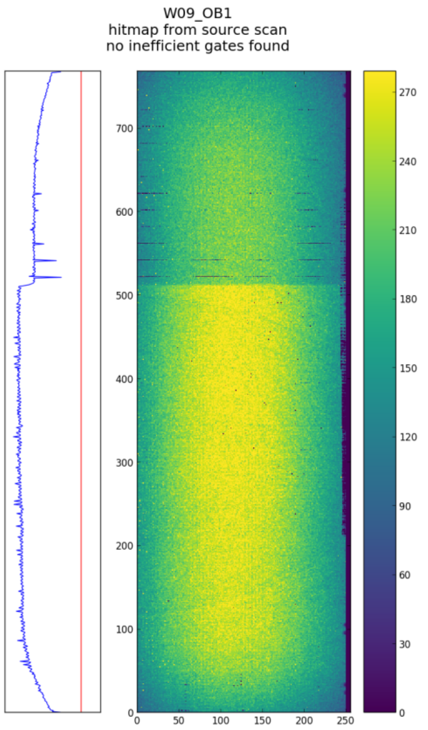
FAST SHUTDOWN BOARD

- Idea:
  - Short all channels with FET (Field Effect Transistor) to respective ground
    - ➔ **Active pull-down**
  - Add resistor to influence pull-down time
- Problem:
  - Required resistor values unclear yet

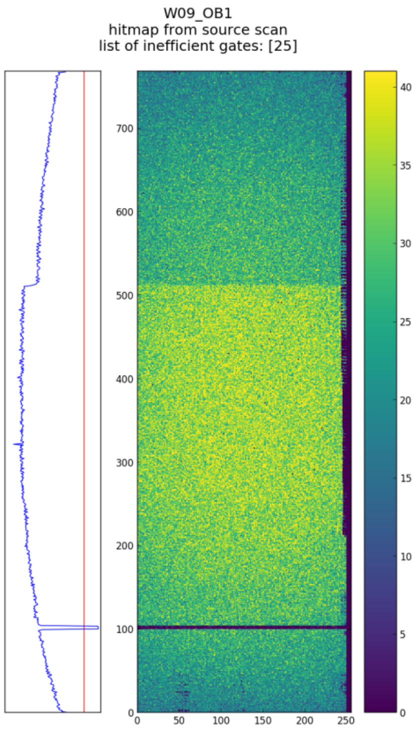


RESULTS FROM FAST SHUTDOWN

- Testing of **fast shutdown** board resulted in high Switcher currents
- Example:
  - Compare hitmaps before and after using fast shutdown board
  - Detected **inefficient rows**
- If done wrongly:
  - Fast shutdown has **same effects** as a beam loss event



Before fast shutdown

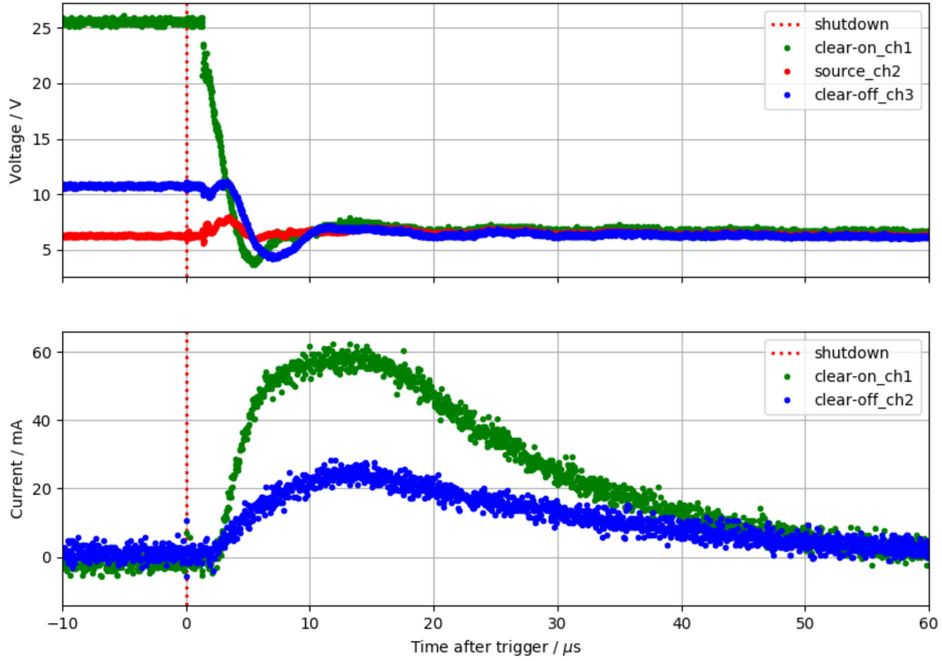


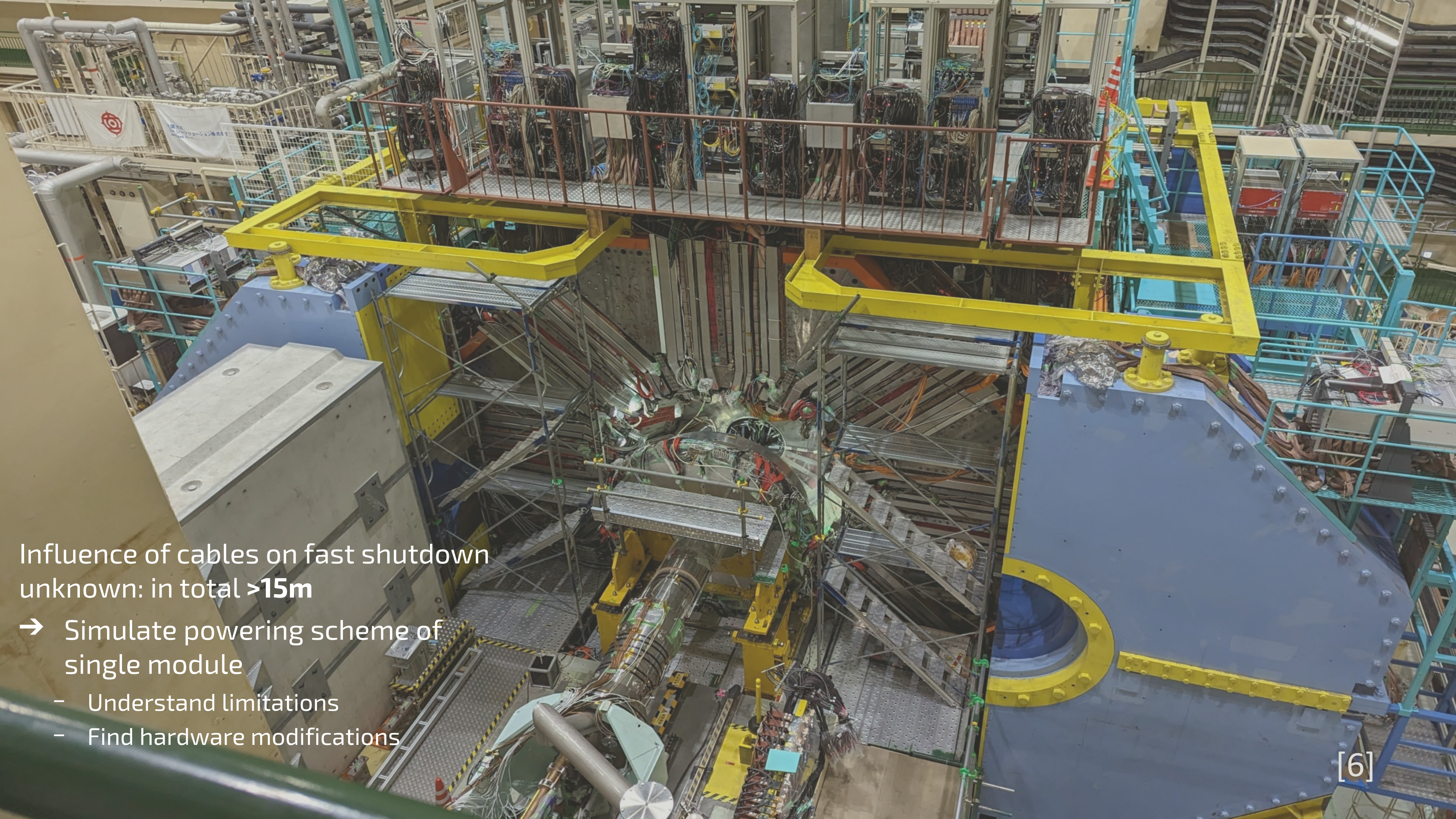
After fast shutdown

[5]

FAST SHUTDOWN MEASUREMENT

- Example: Shutdown of Switcher voltages (Clear On/ Clear Off), **measured at Power Supply level**
- $R_{ClearOn} = 0\,\Omega$, $R_{ClearOff} = 0\,\Omega$
- $V_{ClearOn}$ drops below $V_{ClearOff}$ ➔ violation of shutdown sequence
- Testing on module is harmful



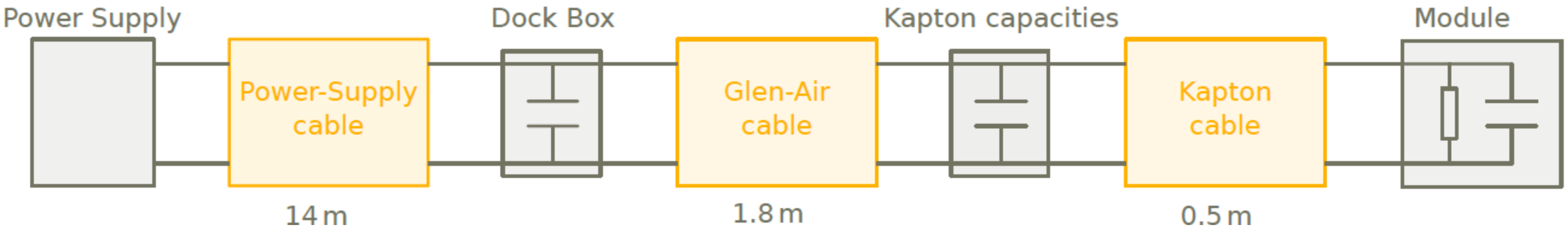


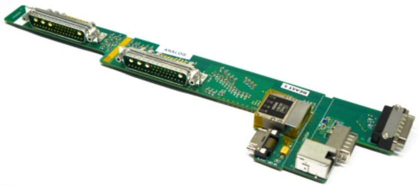
Influence of cables on fast shutdown unknown: in total **>15m**

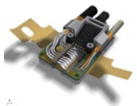
➔ Simulate powering scheme of single module
- Understand limitations
- Find hardware modifications

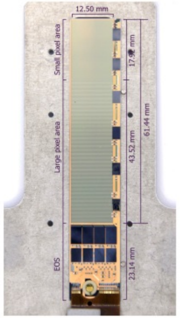
[6]

SIGNAL PATH









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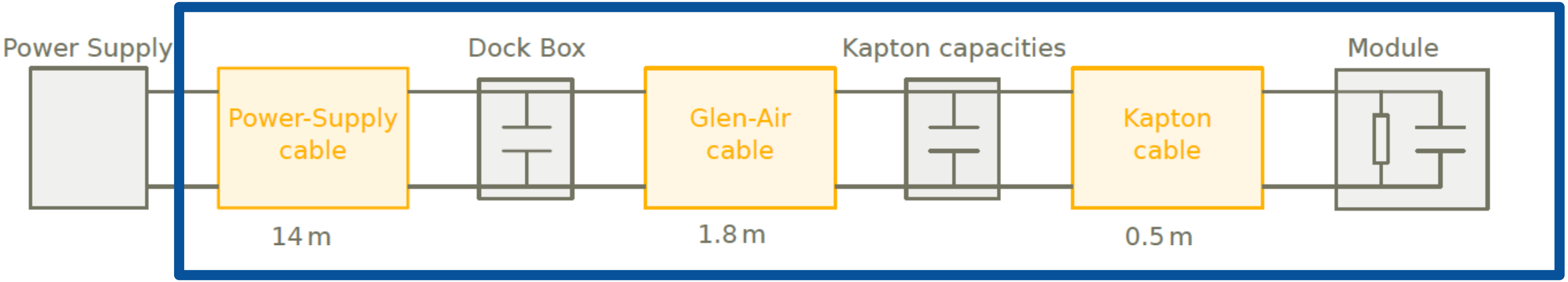
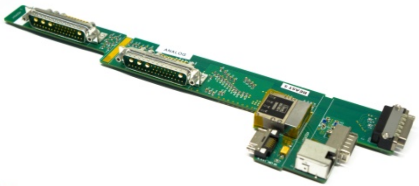
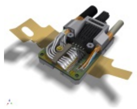
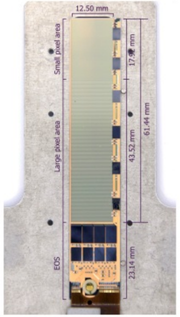
SIGNAL PATH





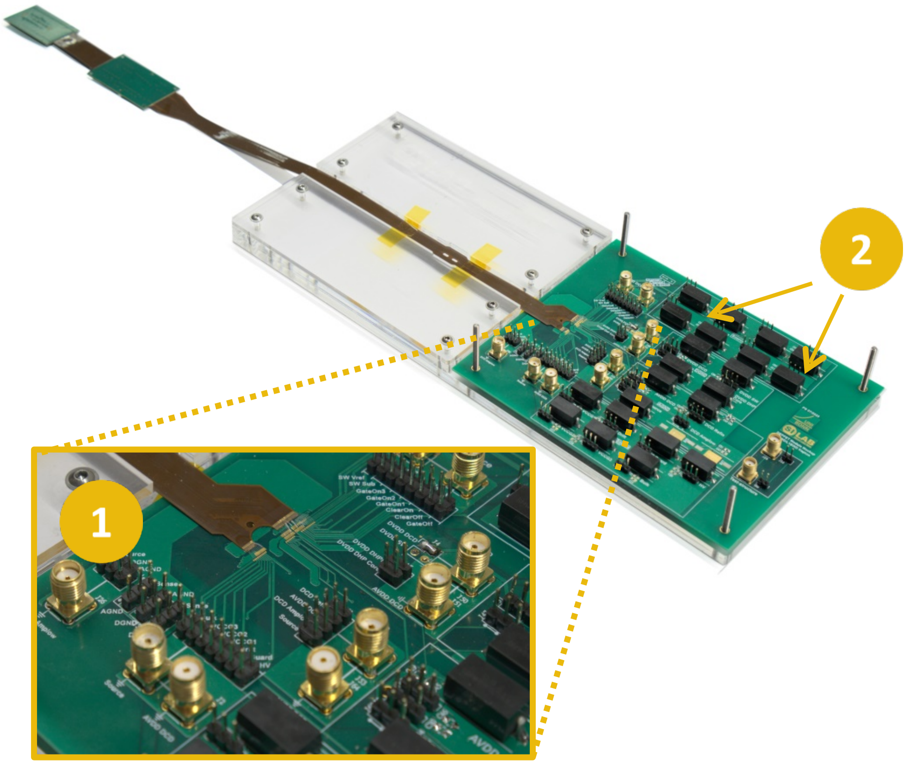




[1]

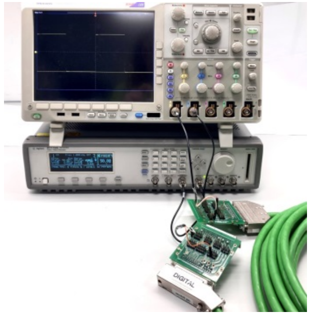
MODULE MOCKUP

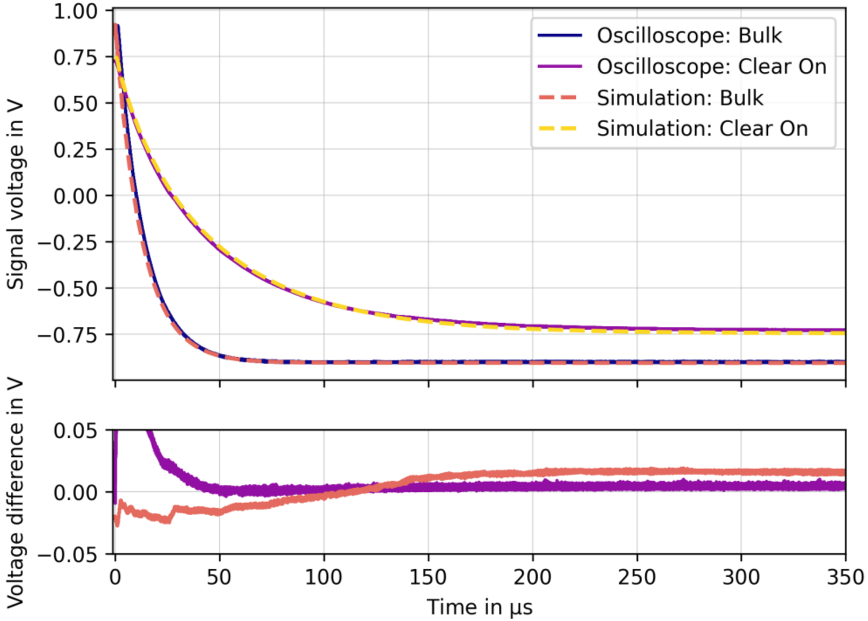
- Verification of simulation: **Module mockup PCB**
  - Connection to all of the lines of Kapton 1
    - Wire bonding necessary
  - Module mockup 2
    - Resistors and capacitors mimic module properties after the Kapton connection



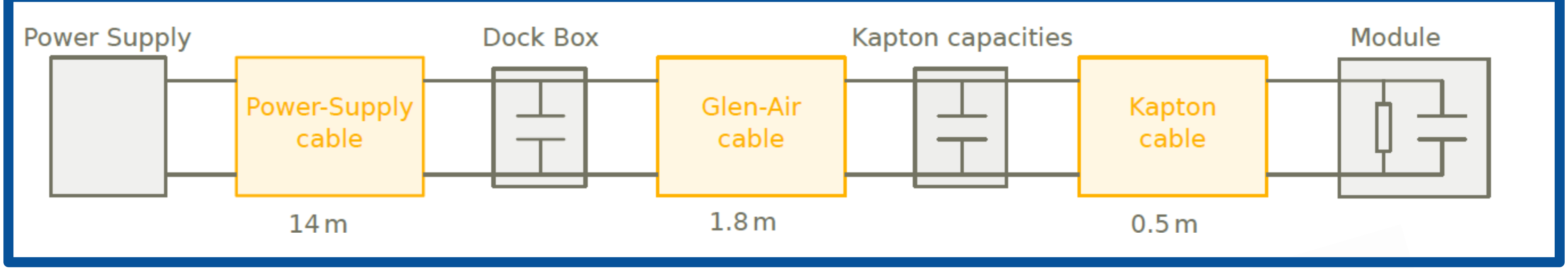
FULL CABLE PATH: POWERING OF TWO LINES

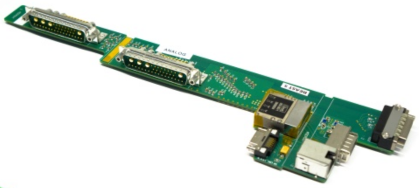
- Simulated with HyperLynx
- PXD PS is not simulated
- Not only powered lines need to be simulated because of **capacitive coupling**
- Replication of load with custom made PCB
- Compared to reference measurement
- Average voltage deviation:
  - Bulk line.: 8.7 mV
  - Clear On line: 13.26 mV

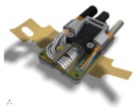


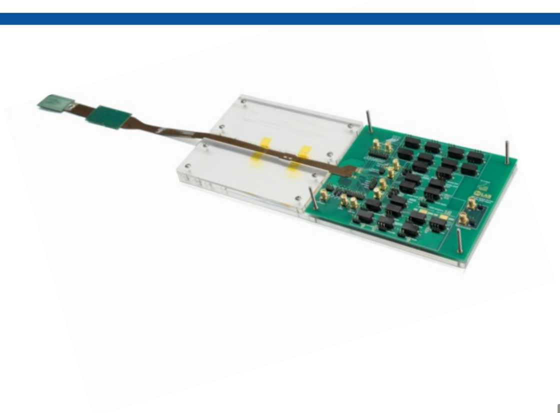


SIGNAL PATH









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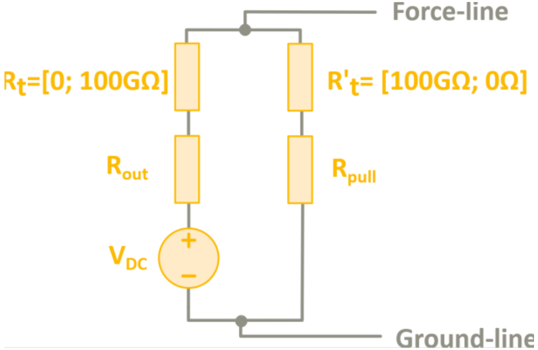
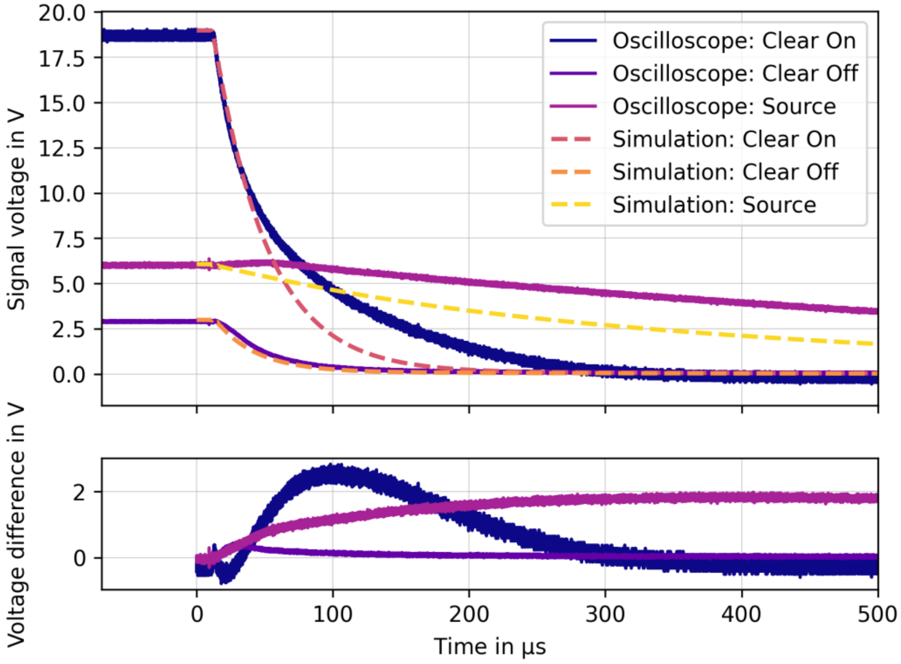
SHUTDOWN PROCEDURE

ACTIVE SHUTDOWN

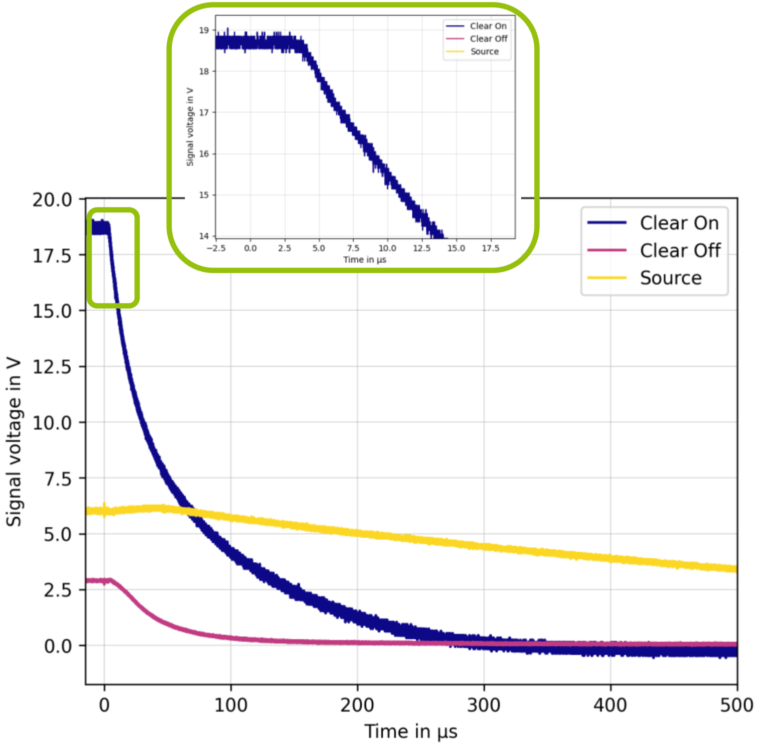
- Active shutdown → **short** force and ground line
- Simulate by **time dependent resistor** which switches from 100 GΩ to 0 Ω





ACCELERATION OF FAST SHUTDOWN

- Two areas for improvement:
  - Clear-On signal only drops slowly
    → generate steeper curve
  - Signal starts dropping ~4us after the shutdown-signal was sent
    → decrease reaction time



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TRANSMISSION OF SHUTDOWN SIGNAL

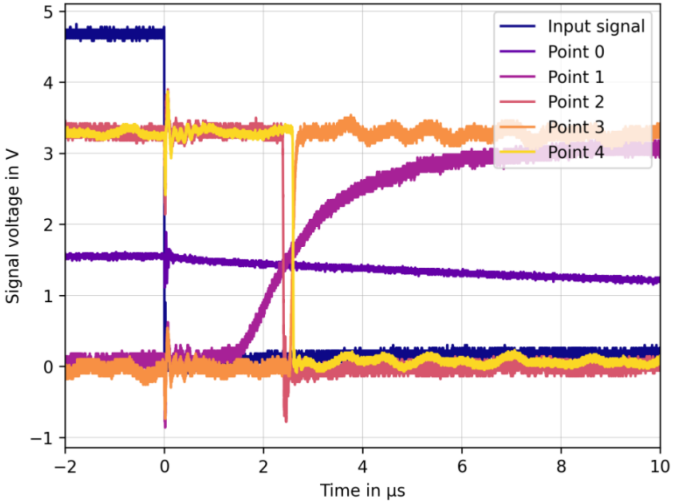
0 after R27

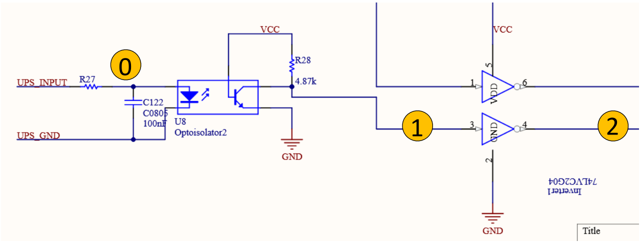
1 after optocoupler (PS8101-F3-A)

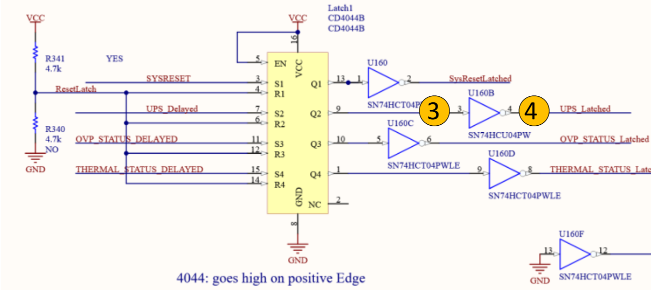
2 after inverter (74LVC2G04)

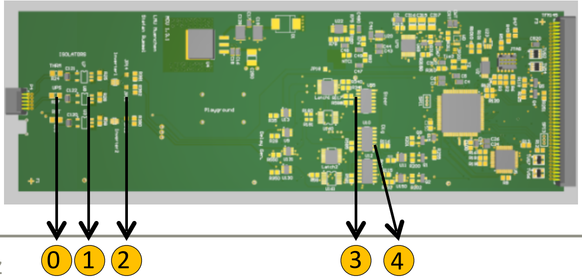
3 after NAND latch (CD4044B)

4 after inverter (SN74HCU04PW)









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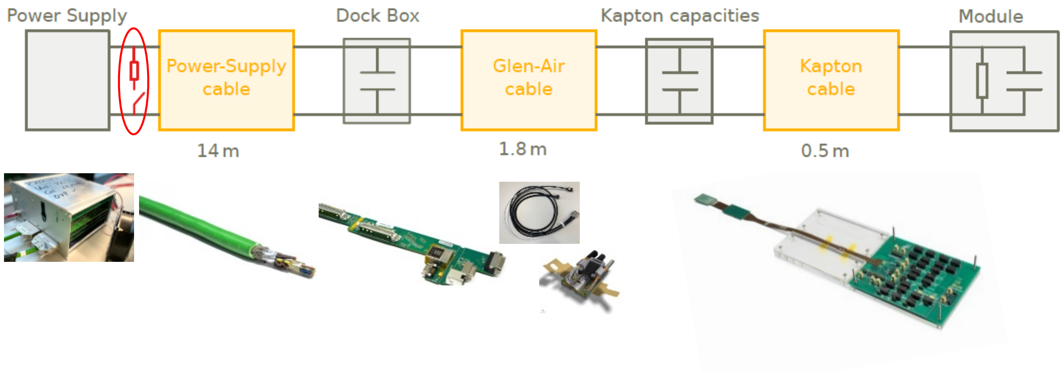
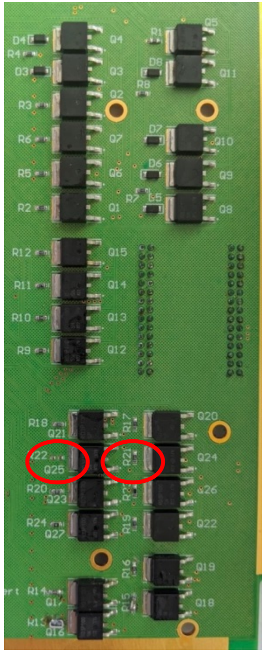
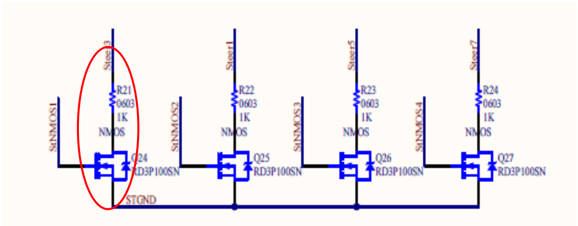
SETUP



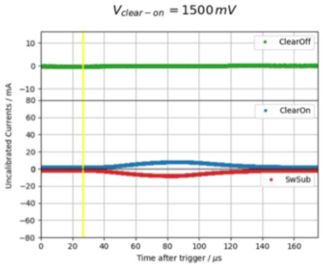
- **How can the shutdown-time be influenced?**
- PS + Full cable path + Module Mockup
- External signal supplies fast shutdown signal
- Oscilloscope + active probes
- Measure Clear On and Clear Off voltage during fast shutdown with varying resistor values R_{on} and R_{off}

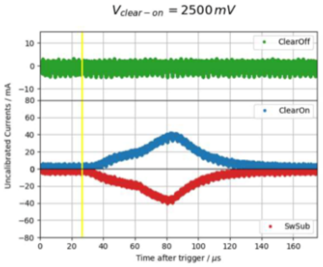


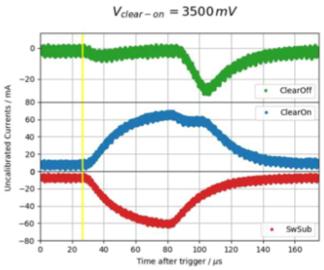


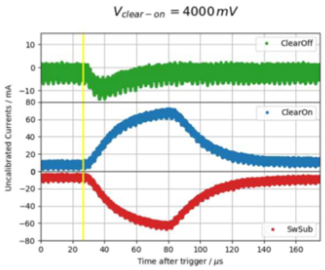
3V-LIMIT

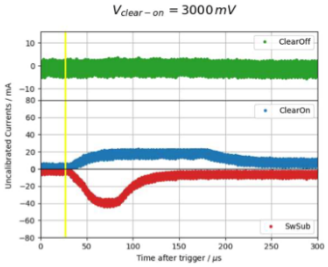
- Measured current in switcher (Clear On, Clear Off) for varying applied Clear On voltages
- Below V_{on}= 3V: no current flow between Clear On and Clear Off → switcher is deemed ‘safe’

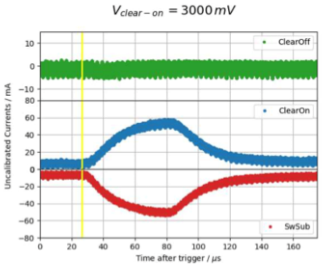






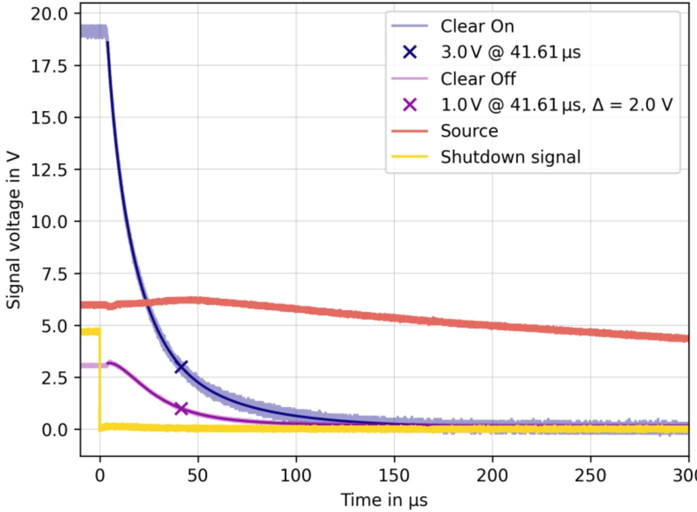






EXEMPLARY MEASUREMENT

- R_{on} = 2 Ω, R_{off} = 5Ω
- 3V-limit
  - Showed earlier: starting at V_{on} = 3V, the modules seemed safe from irradiation
  - Time, at which Clear On voltage drops below 3V
  - Voltage of Clear Off at that time + voltage difference Δ
- Fast-Shutdown board only pulls down Clear voltages -> Source voltage drops much slower



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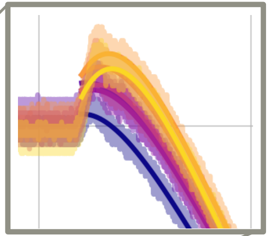
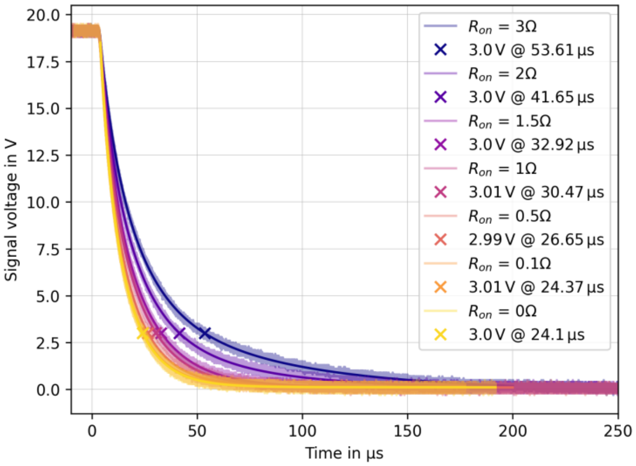
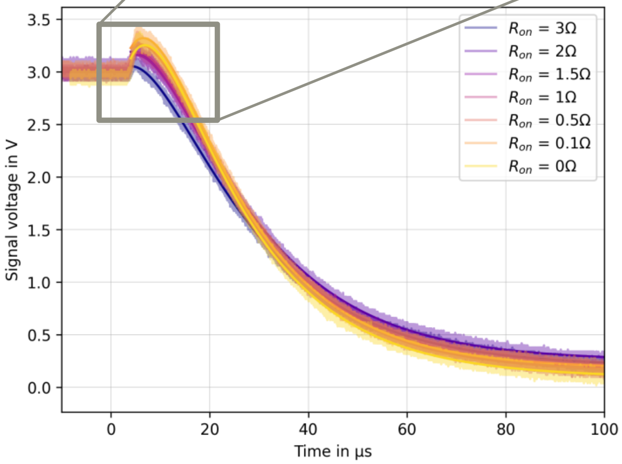
INFLUENCE OF R_{ON}



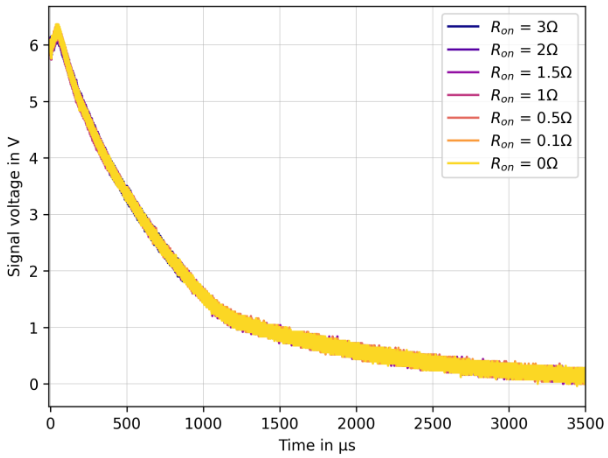
Clear On voltages during Fast shutdown, $R_{off} = 5\,\Omega$



Clear Off voltages during Fast shutdown, $R_{off} = 5\,\Omega$



Source voltage during Fast Shutdown, $R_{off} = 5\Omega$

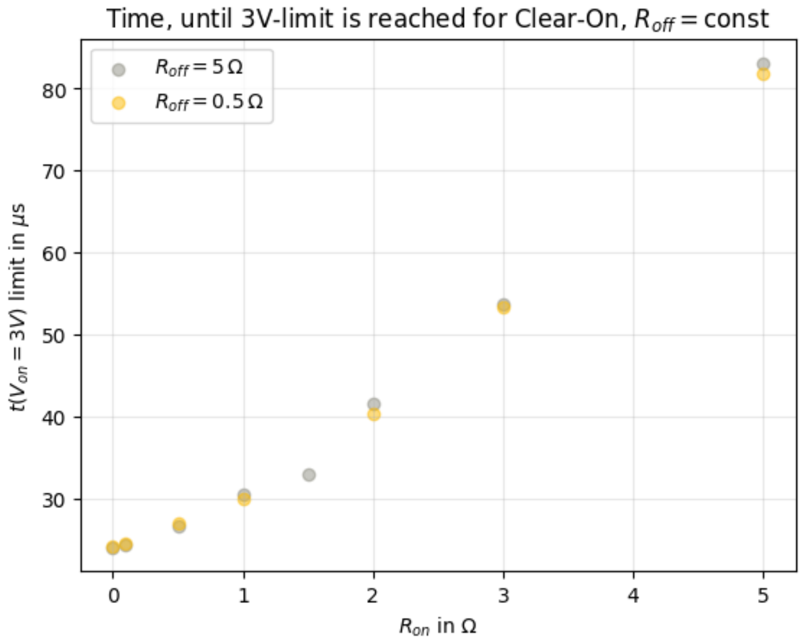


DECAY TIME DEPENDENCE

- 3V-limit for different R_{on} values (R_{off} = 5Ω or R_{off} = 0.5Ω fixed)
- Would expect linear behaviour?

$$U = U_0 * \exp(-\frac{t}{RC}) \rightarrow \boxed{R = -\ln\left(\frac{3}{19}\right) * \frac{1}{C} * t}$$

  - Influence of regulator circuit in PS?



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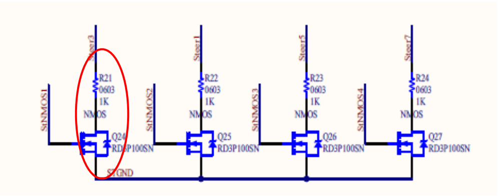
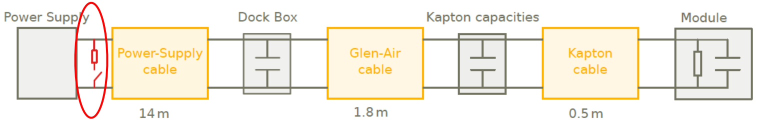
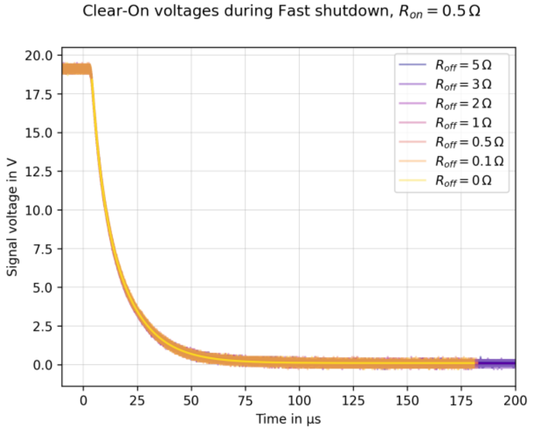
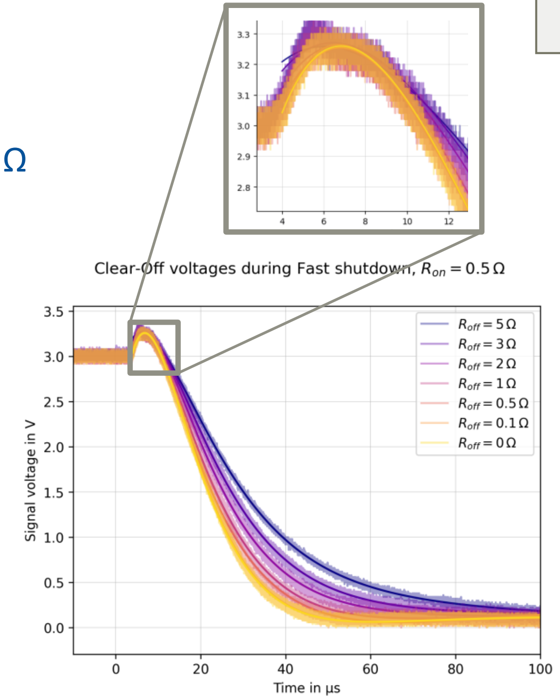
INFLUENCE OF R_{OFF}

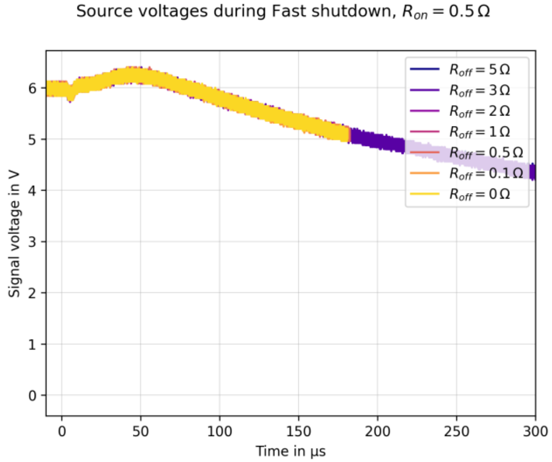




- Pull-Down Resistor studies
- Finished measurements with different R_{on} and R_{off} values
- Here: impact of R_{off}; R_{on} = 0.5 Ω

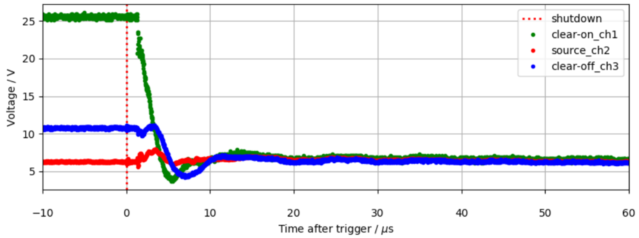




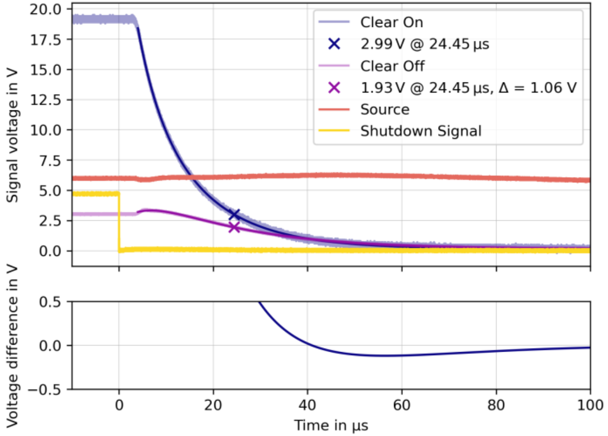


$V_{ON} < V_{OFF}$?!

- Asic requirement: Clear On voltage should never drop below Clear Off voltage
- Could be observed in the past for $R_{on} = R_{off} = 0\Omega$
  - Measured on Hybrid5 (full system demonstrator)
  - Not full cable path included → less realistic
- So far: observed with $R_{off} = 5\Omega$ & $R_{on} < 0.5\Omega$
  - Not as severe as before

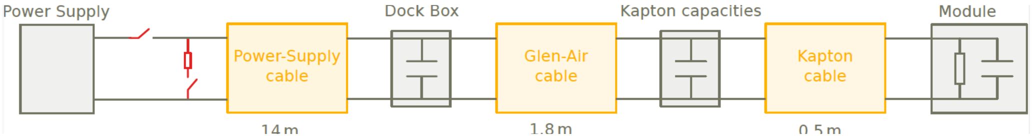


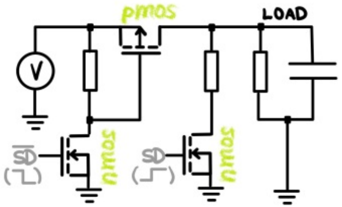
R-test: FAST shutdown | w/ probes ($R_{on} = 0.1\,\Omega$, $R_{off} = 5\,\Omega$); AGND grounded

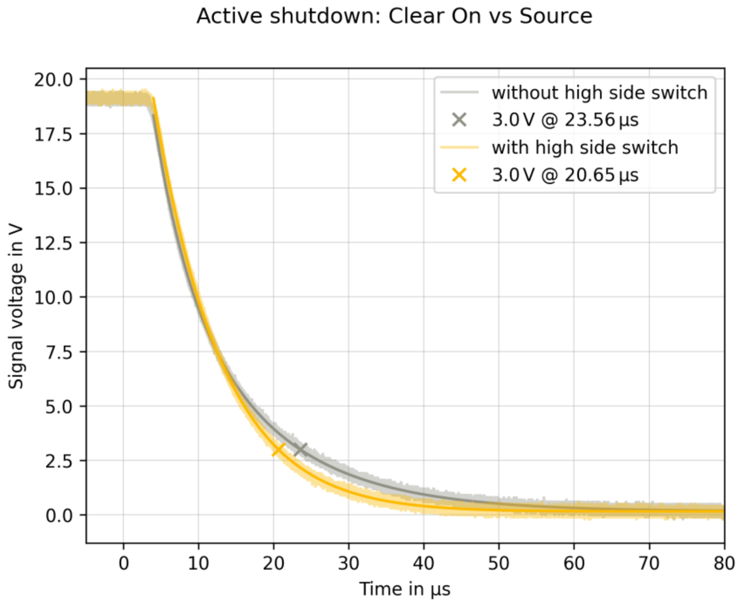


NEW IDEA: HIGH SIDE SWITCH

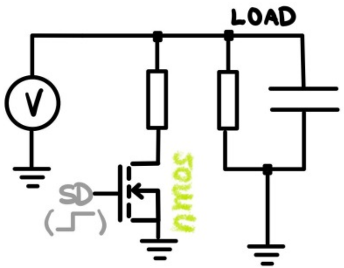
- Separate PS from load by implementing a switch in series
- Reduce influence of regulator inside of PS
- Shown design only works for positive, high enough voltages
- Pmos steered via nmos
- Faster shutdown of Clear-On voltage due to high side switch?



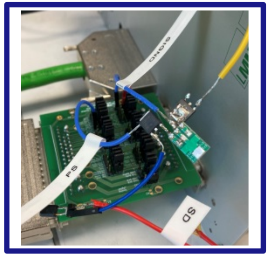




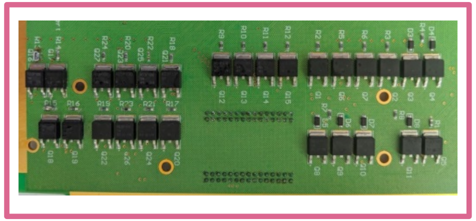
INFLUENCE OF FRONT PCB

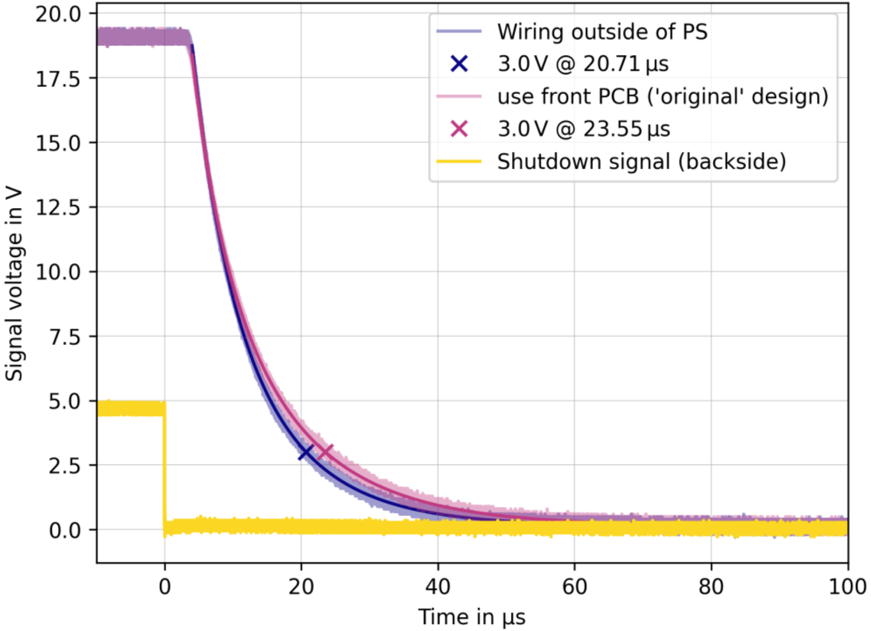


- Sped up fast shutdown seems to come from ***not using front PCB***, not from opening the force line
- Assumptions:
  - Resistance of traces on front PCB?
  - Inductance of traces on front PCB?



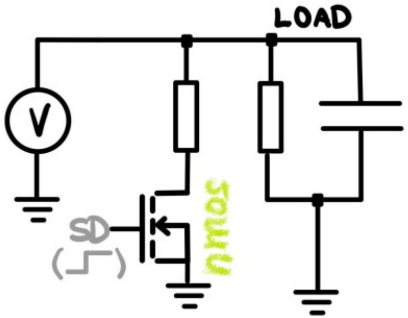
VS

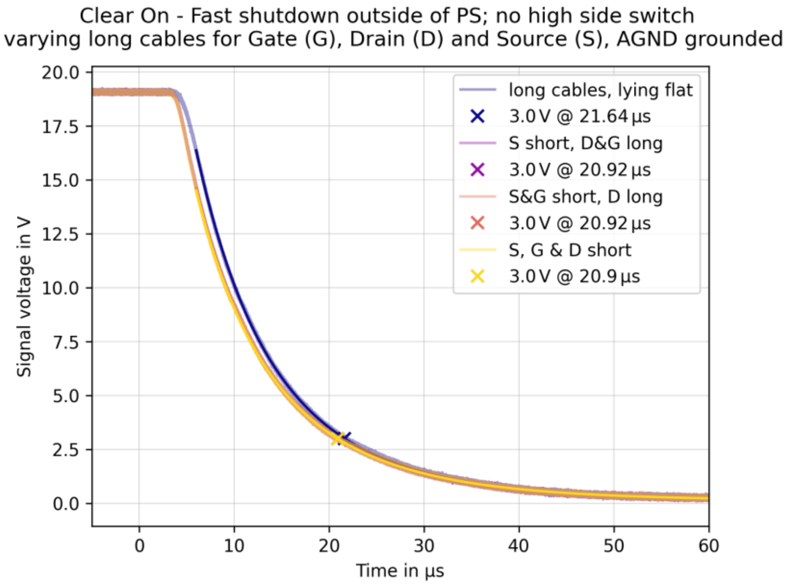




INFLUENCE OF CABLE PARAMETERS

- Test fast shutdown of Clear On with different cable lengths for drain, gate and source of nmos
- Fast shutdown implemented outside of PS, not on fast shutdown board
- Cable length (resistance?) plays a role
- Inductance plays a role, measurements still ongoing





SUMMARY AND CONCLUSION

- Fast shutdown → avoid PXD damage due to beam loss events
- Simulation of PXD powering net
- Descrepancies between simulation and measurement for **Power Supply**
- **Lab-tests**:
  - Varying combinations of pull-down resistors
  - Faster transmission of shutdown signal within Power Supply

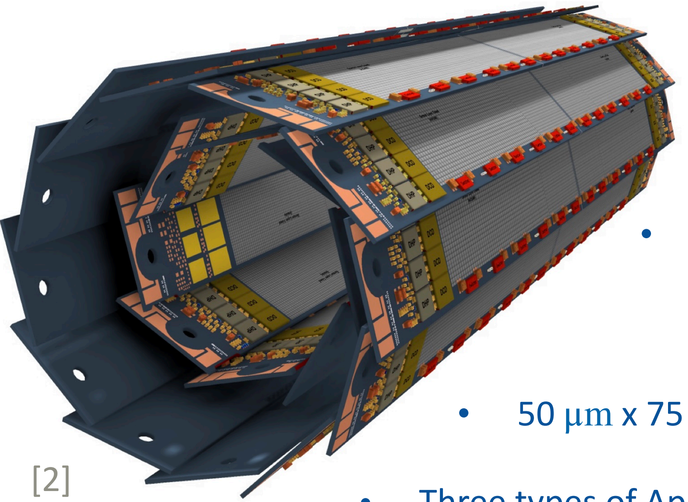
→ Test Beam Campaign at MAMI in October 2025?

→ Production of new Fast Shutdown boards

→ Installation at KEK (summer 2026?)

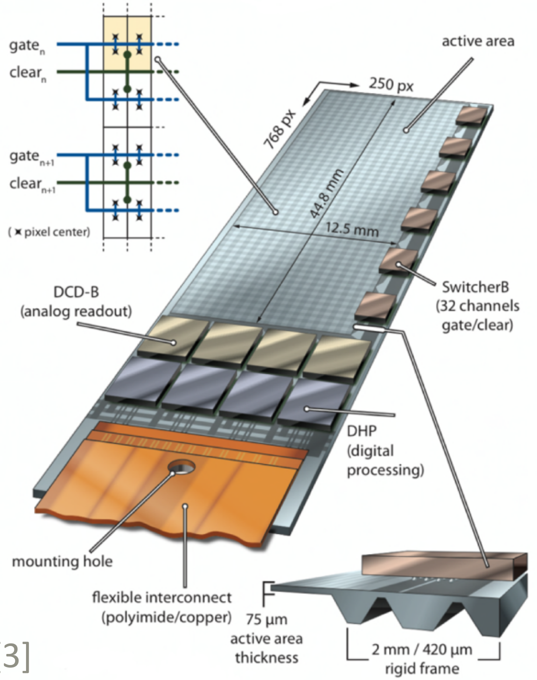
THANK YOU!

BELLE II PIXEL DETECTOR (PXD)



[2]

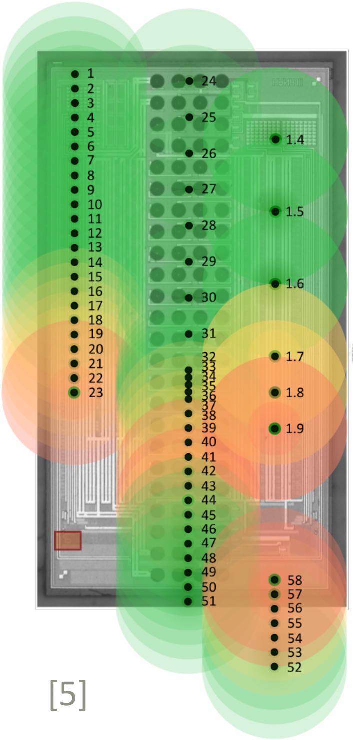
- PXD: two layers of DEPFET (Depleted Field Effect Transistor) modules at radii of 14 mm and 22 mm
- 50 μm x 75 μm pixels thinned to 75 μm
- Three types of Application Specific Integrated Circuits (ASICs) are responsible for readout:
  - DCD, DHP, **Switchers**



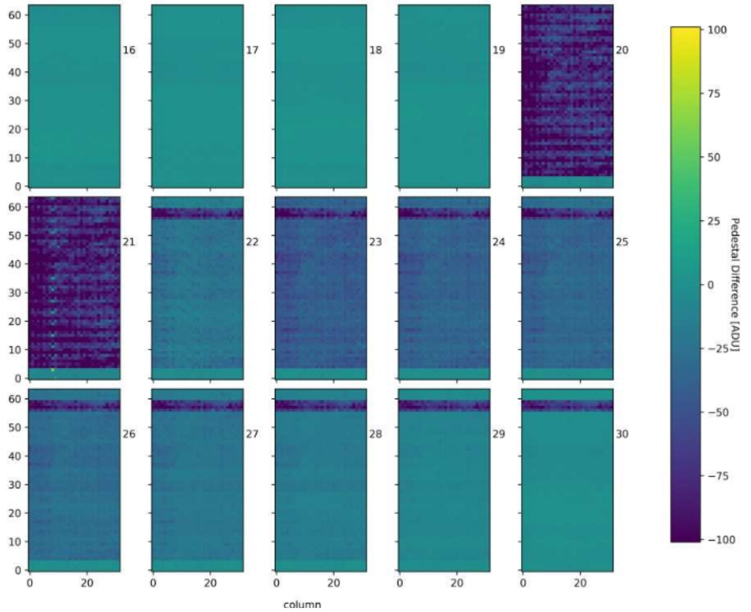
[3]

CONFIRMATION OF RESULTS

- Irradiation with electron beam
- Fine scan of ASIC area
  - July 2020 with H5029
  - Colour coded measurement points
  - red => permanent damage
- Raw data difference of 15 raw frames during injection
  - Second to last Switcher channel is damaged permanently
- Switcher only vulnerable when turned on



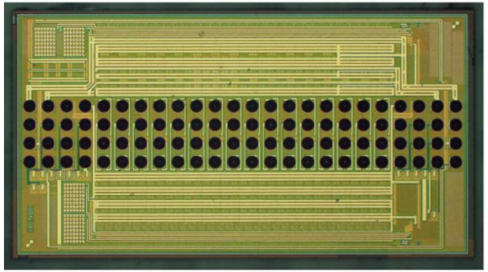
[5]



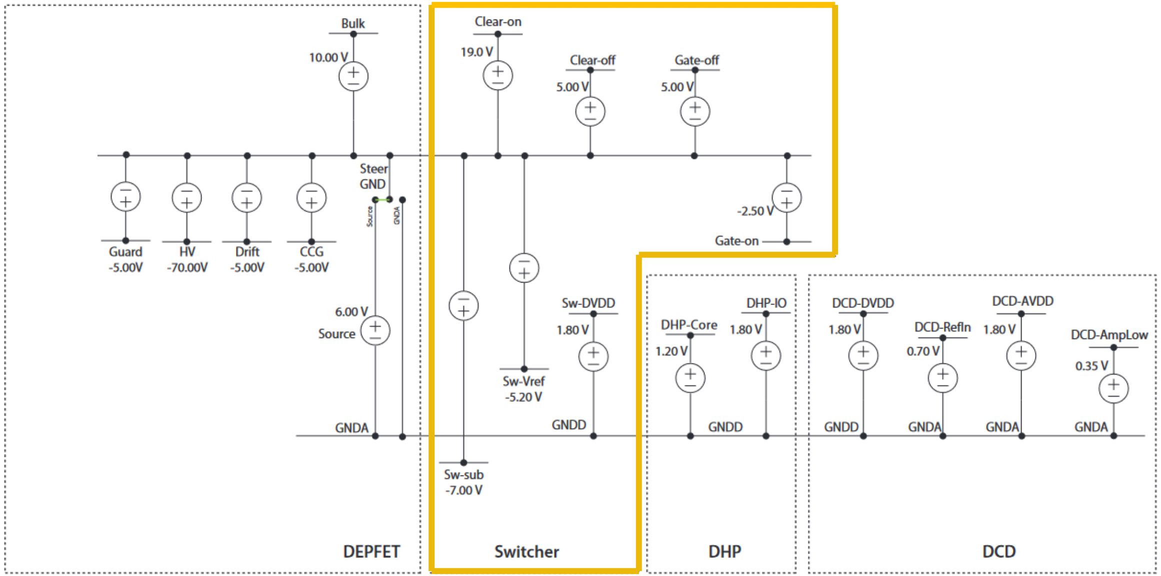
[6]

POWERING SCHEME

- Dedicated power-up and power-down sequence
- Range between +19V and -7V
- Switcher switches between high voltages



[7]

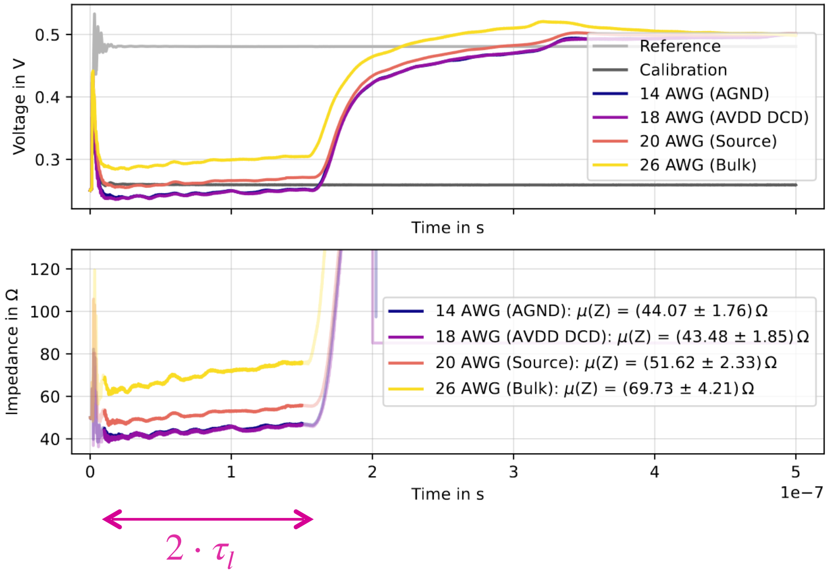


[8]

UNIVERSITÄT BONN

DELAY TIME AND IMPEDANCE

- Needed for Simple Line model (HyperLynx)
- **Impedance profile**: view cable as cascade of cable segments
  - Reflection at cable connection
  - Average over cable length
  - Rise in impedance due to DC-resistance
- **Delay time**: $\tau_l = \left(75.5 \pm 0.5\right)\ \mathrm{ns}$



Simple Line

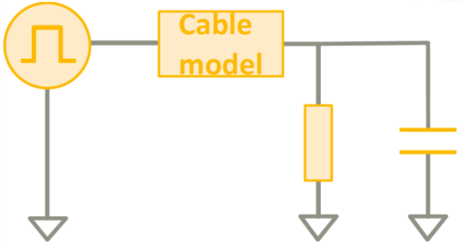
→ HyperLynx

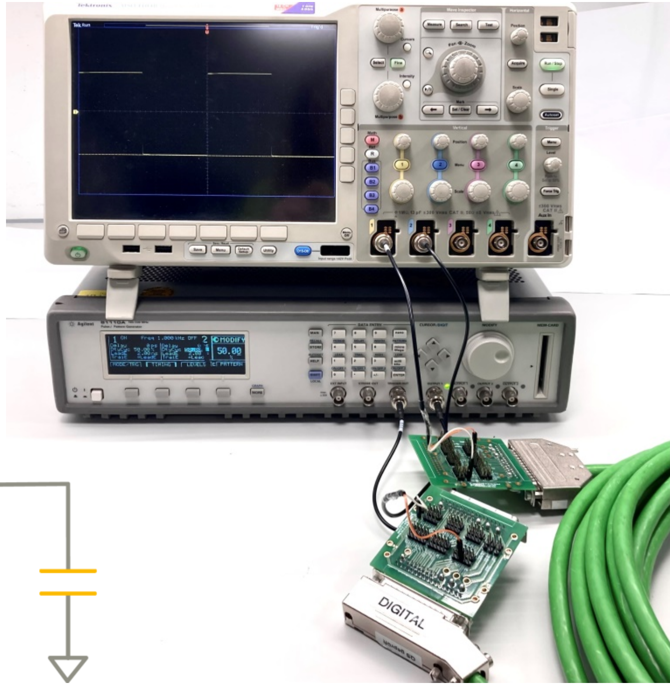
- Impedance
- Delay time
- DC-Resistance

UNIVERSITÄT BONN

REFERENCE MEASUREMENT

- **Measurement** to compare against simulation
  - **Falling edge** of a squared pulse
  - View transmitted signal on oscilloscope
- Verify each cable segment **individually**
- For quantification:
  - Compute **difference in voltage** between simulation and measurement data





SHUTDOWN PROCEDURE

PASSIVE SHUTDOWN

- Passive shutdown → **separate** force line from power supply
- Simulate by **time dependent resistor** which switches from 0 Ω to 100 GΩ
- Time constant in simulation too big