Development of Fast Kicker Prototype for SLS 2.0 Advanced Injection Schemes

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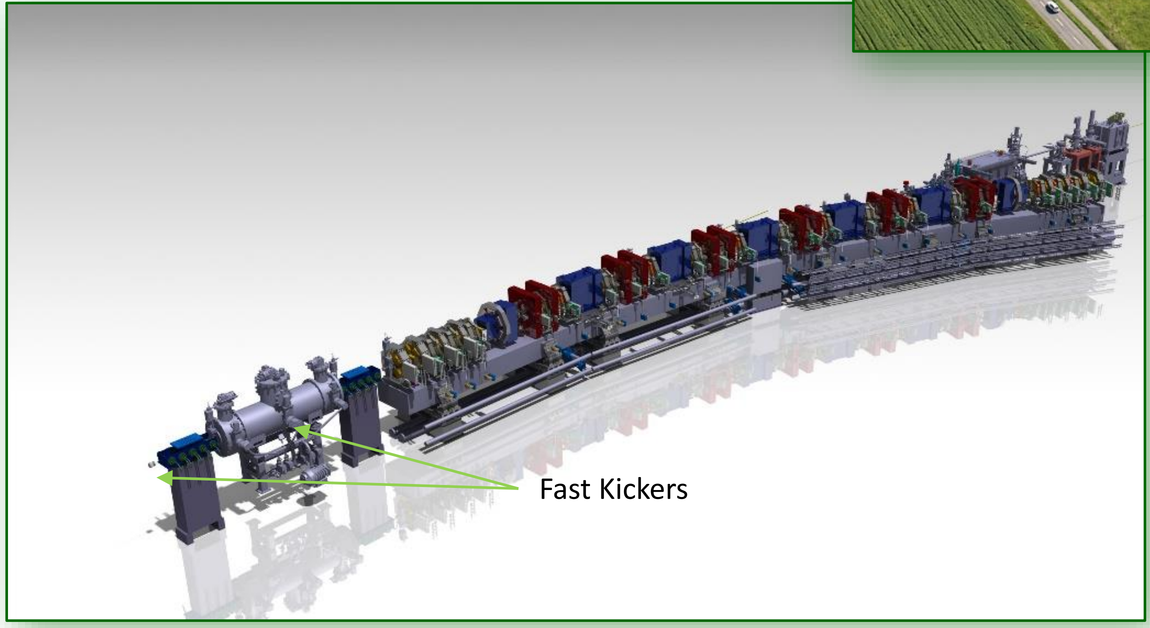
The "Fast" injection scheme should be able to ensure single-bunch off-axis top-up injection affecting only 10 to 15 SR bunches that are 2 ns apart.

The "Super fast" one should bring the perturbed bunches down to only one.

In "on-axis" mode it should be able to inject a top up bunch between two SR bunches with minimum disturbance of the adjacent ones. To do this a combination of special beam injection schemes and an extremely fast (ns) kicker system is required.

Swiss Light Source (SLS) part of Paul Scherrer Institute, Switzerland



3D model of the upgraded SLS 2.0 electron storage ring starting with straight section 2

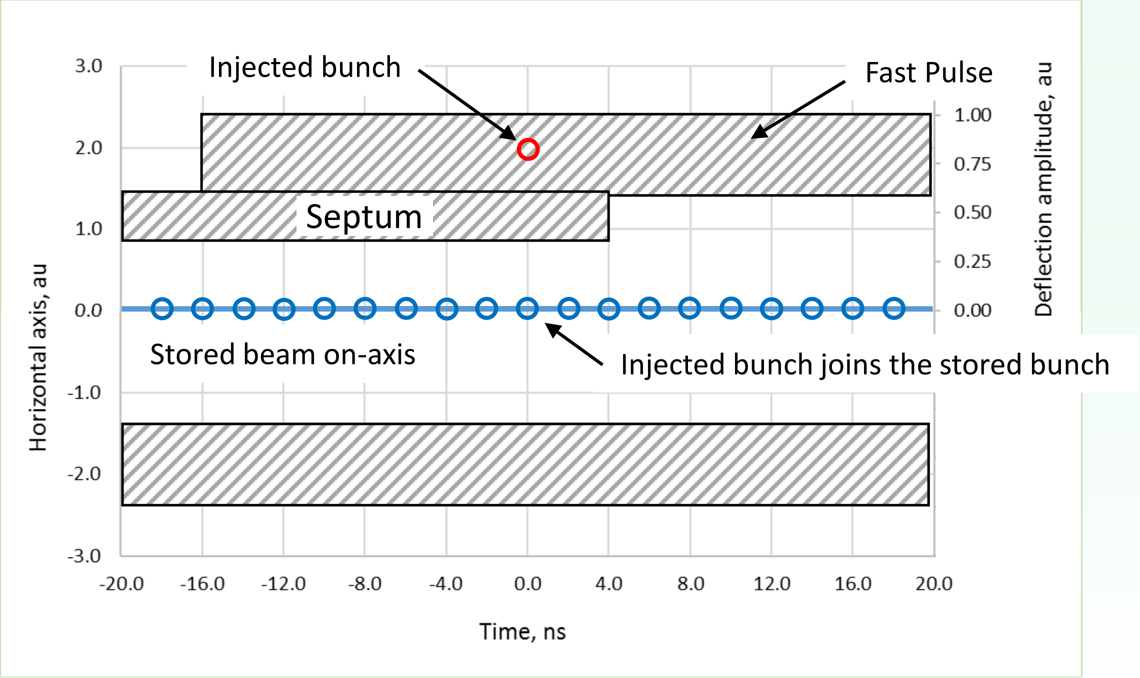
SLS 2.0 Advanced Injection Schemes

"Fast" injection scheme, aperture sharing

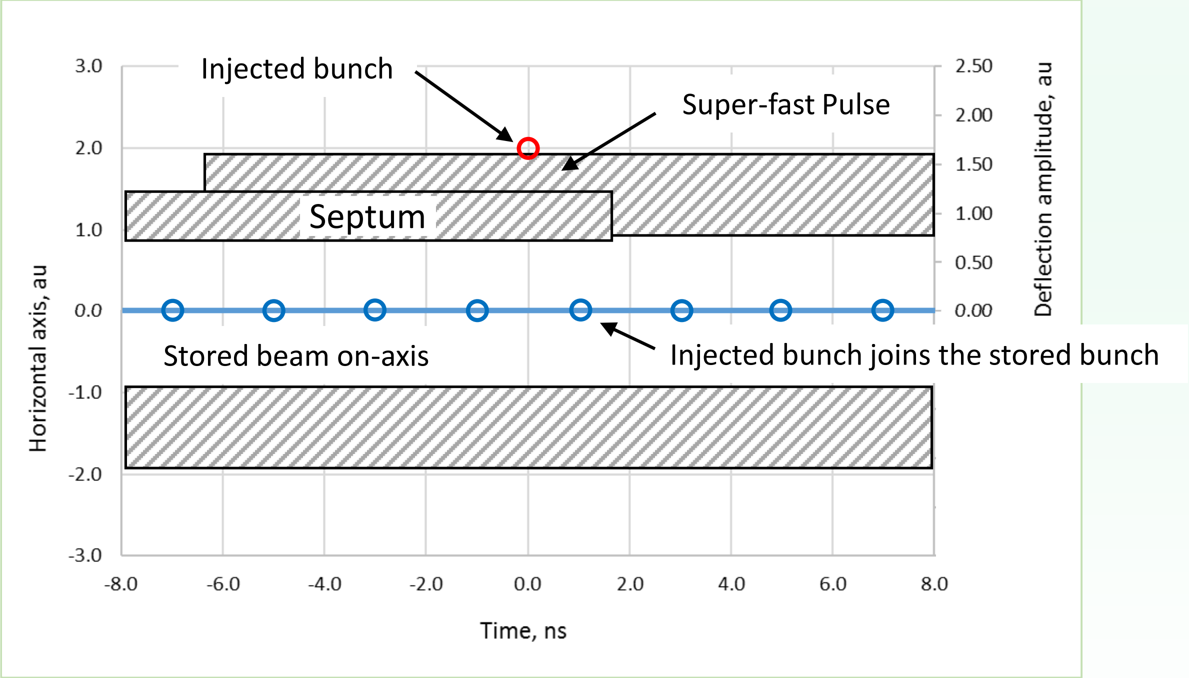
A portion of the stored beam (15 bunches in the illustration) and the *injected* bunch are deflected with a short kicker pulse (20..30 ns) to fit in the machine aperture. With decaying ***Betatron oscillation*** they come back on axis.

"Super-fast" injection scheme, on-axis

A very short kicker pulse (<2 ns) puts the injected bunch on-axis *without significantly disturbing* the adjacent stored bunches. With decaying ***Synchrotron oscillation*** the injected bunch joins a stored one.



Simplified illustration of "Fast" injection scheme with aperture sharing (off-axis injection)

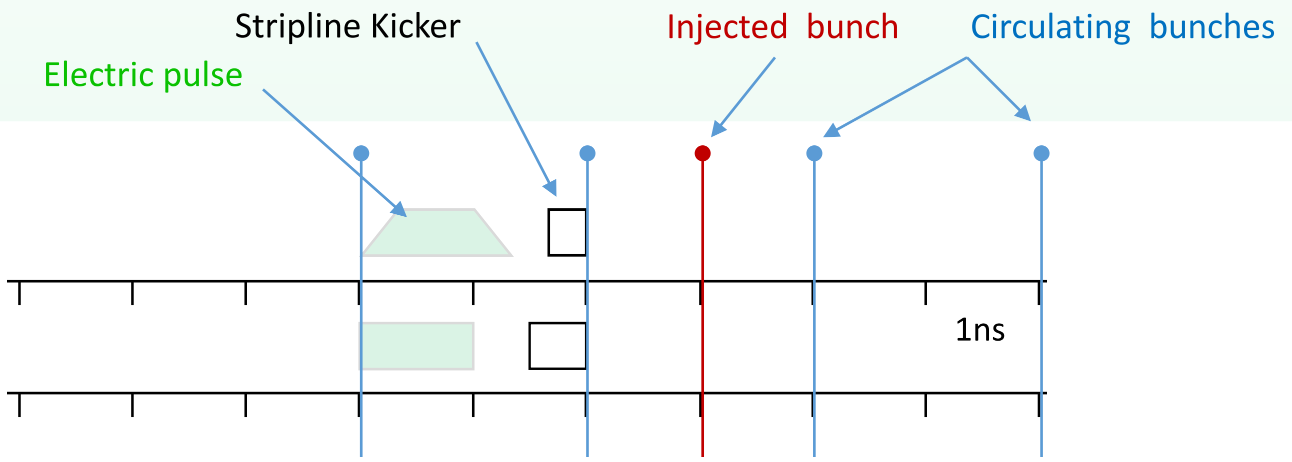


Simplified illustration of "Super-fast" on-axis injection scheme

Anatomy of the deflection with stripline kickers

- Nanosecond-long deflections require stripline (TEM) kickers -> Small deflection angles

- In order to add magnetic and electric deflection the electric pulses and the particle beam should **counterpropagate** (down-steam excitation).



0.66/1.32 ns pulse,
0.33 ns kicker (10 cm)

1.0 ns pulse,
0.5 ns kicker (15 cm)

Time representation of a rectangular and trapezoidal pulse to inject between two bunches in 500 MHz storage ring.

Conditions for an efficient use the kicker and not disturbing adjacent bunches:

1. Pulse full-amplitude length ≥ 2x Kicker electrical length
2. Pulse total length + 2x Kicker electrical length ≤ bunches separation

Ideal: a rectangular pulse, 1 ns long and TEM kicker with 0.5 ns electrical length.

SLS 2.0 Fast Kicker requirements and single section prototype construction

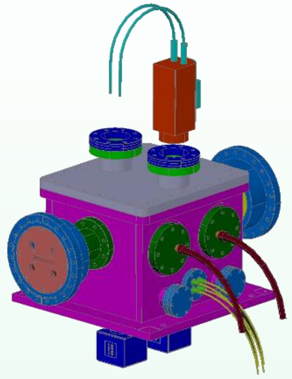
Given and machine related

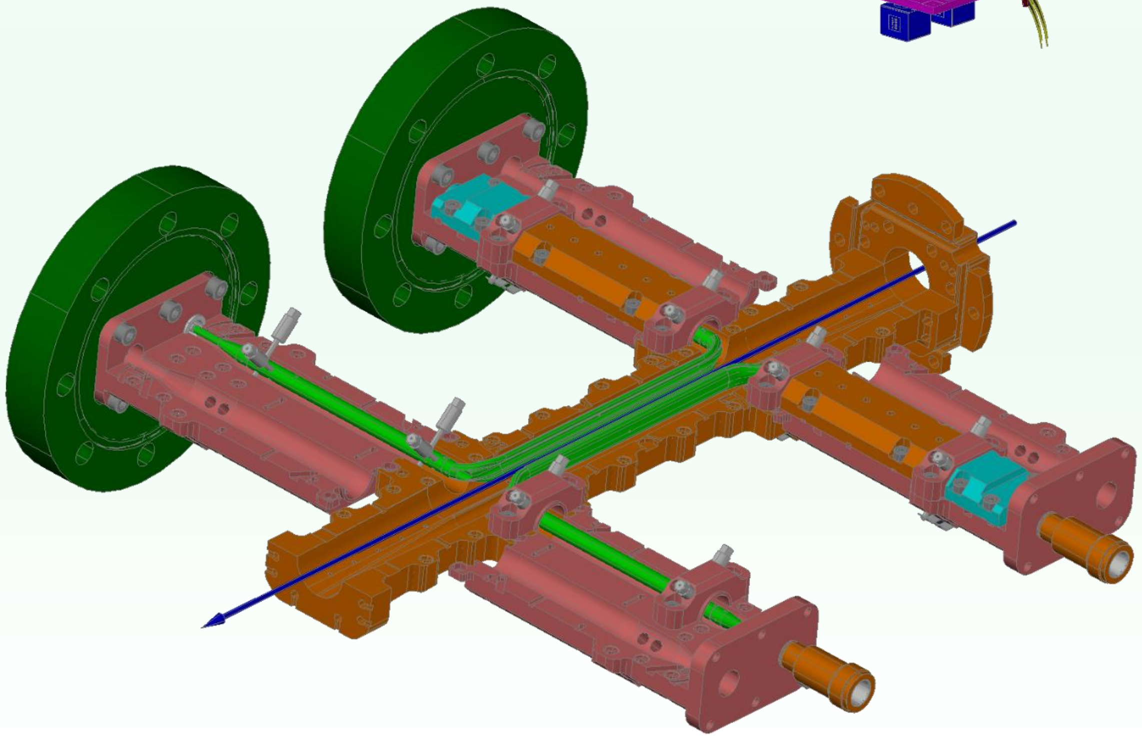
Parameter	Fast	Super-fast
Beam momentum	2.7 GeV/c	
SR bunch spacing	2 ns	
Injection repetition rate	3 Hz	
Injection type	Horizontal	
Number of defl. SR bunches (off-axis)	<15	1..3
Number of defl. SR bunches (on-axis)	NA	0..2
Deflection angle (off-axis)	>0.35 mrad	
Deflection angle (on-axis)	NA	1.0 mrad
Horizontal aperture on axis	±5 mm	
Active kicker length	800 mm	

Derived and chosen kicker parameters

Parameter	Fast	Super-fast
Deflection type	Electromagnetic (TEM)	
Kicker type	Stripline (vacuum)	
Kicker section length	100 mm	
Number of sections	8	
Maximum deflection	0.5 mrad	1.0 mrad
Magnetic field	2.8 mT	5.7 mT
Electric field	0.9 MV/m	1.7 MV/m
Electrode voltage	±4.3 kV	±8.5 kV
Electrode current	±85 A	±170 A
Excitation pulse length	<30 ns	~2 ns
Odd / Even el. impedance	2x 50.0 Ω / 2x 56.0 Ω	

Kicker prototype in the vacuum chamber



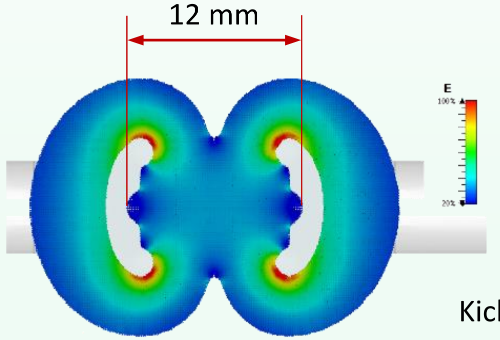


Kicker prototype interior

SLS 2.0 Fast Kicker prototype – Electrical Characteristics

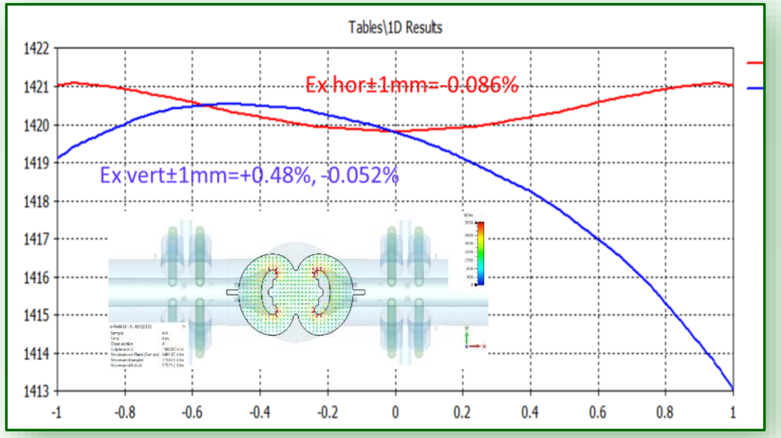
Blades

The kicker electrodes were optimized to provide the necessary field and electrical impedance maximizing the clear aperture on axis. Care was taken to avoid excessive surface electric field.

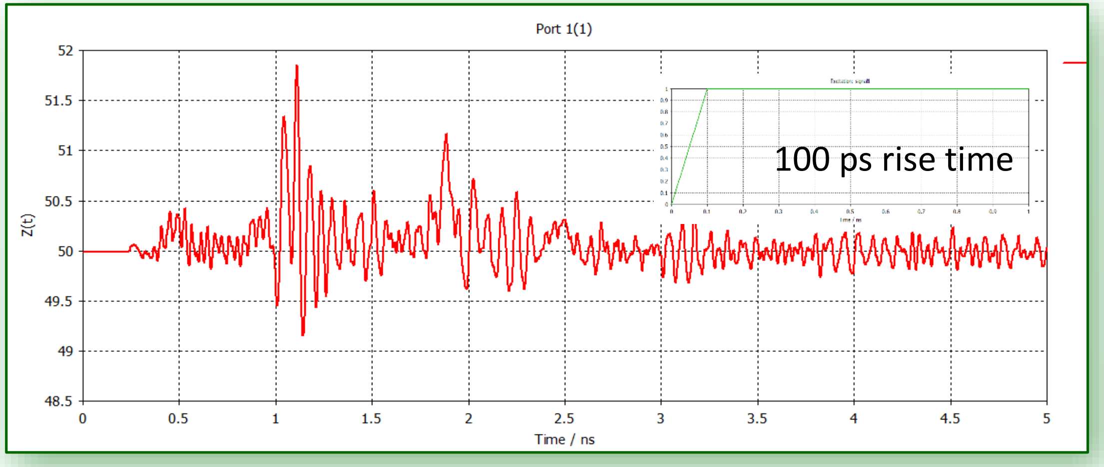


Kicker blades' cross section

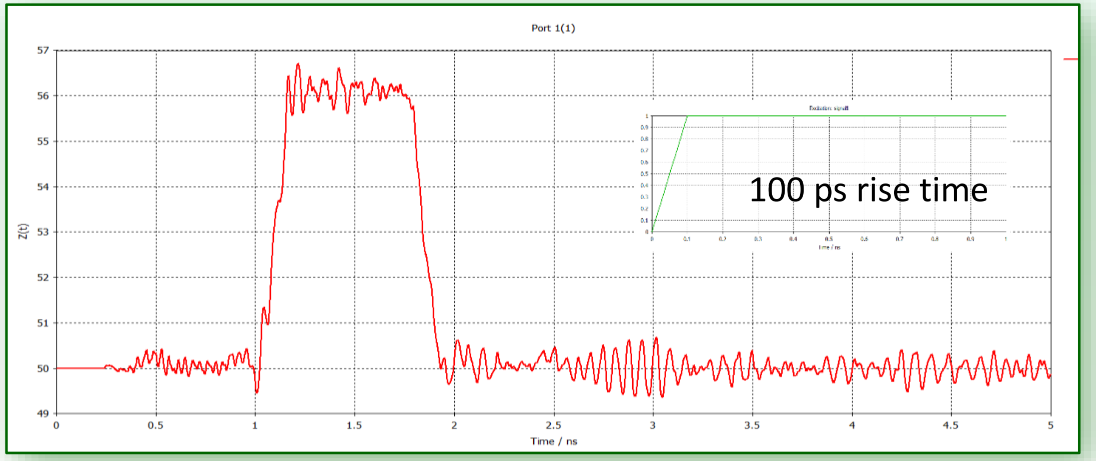
Matched blades with increased beam space at the center



Differential mode 100.14 Ω (Odd impedance 50.07 Ω)



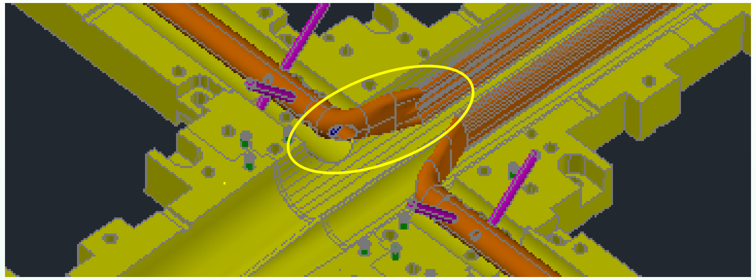
Common mode 28.0 Ω (Even impedance 56.0 Ω)

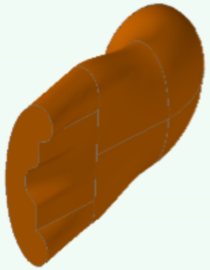


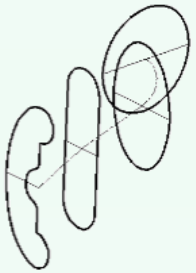
SLS 2.0 Fast Kicker prototype – Electrical Characteristics

Coaxial line to blades transition

The transition from the stripline structure to the feeding coaxial transmission lines is carefully designed to minimize impedance mismatch. This part of the geometry defines as well the amplitude of the beam-induced pulses.



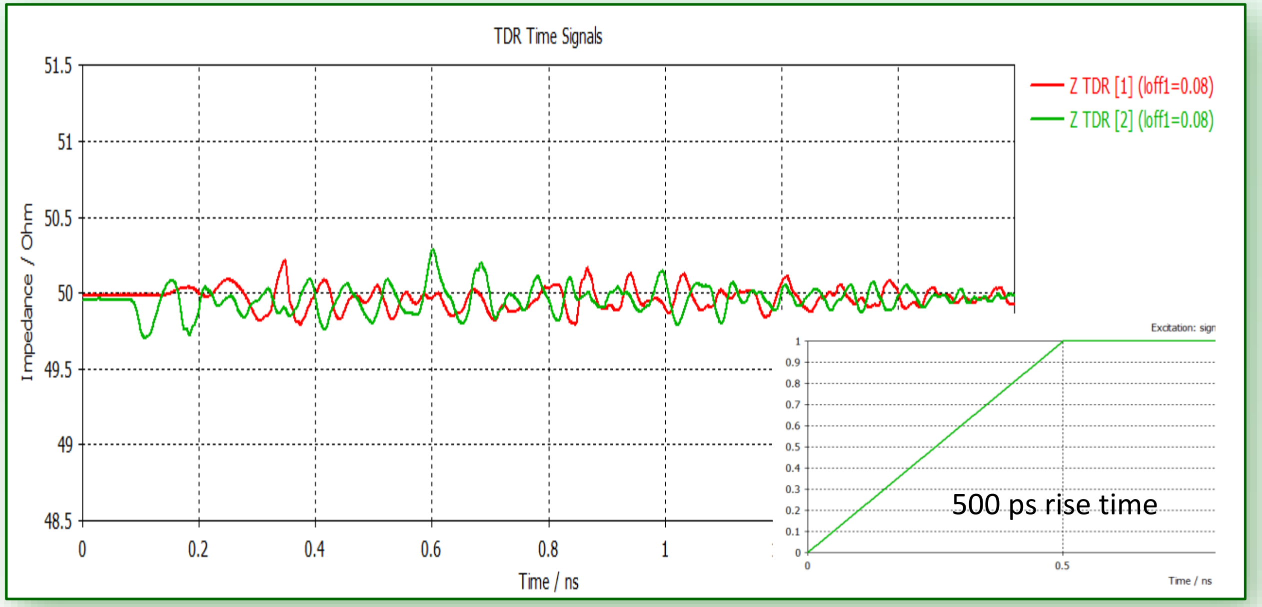




Step by step cross section evolution of the transition

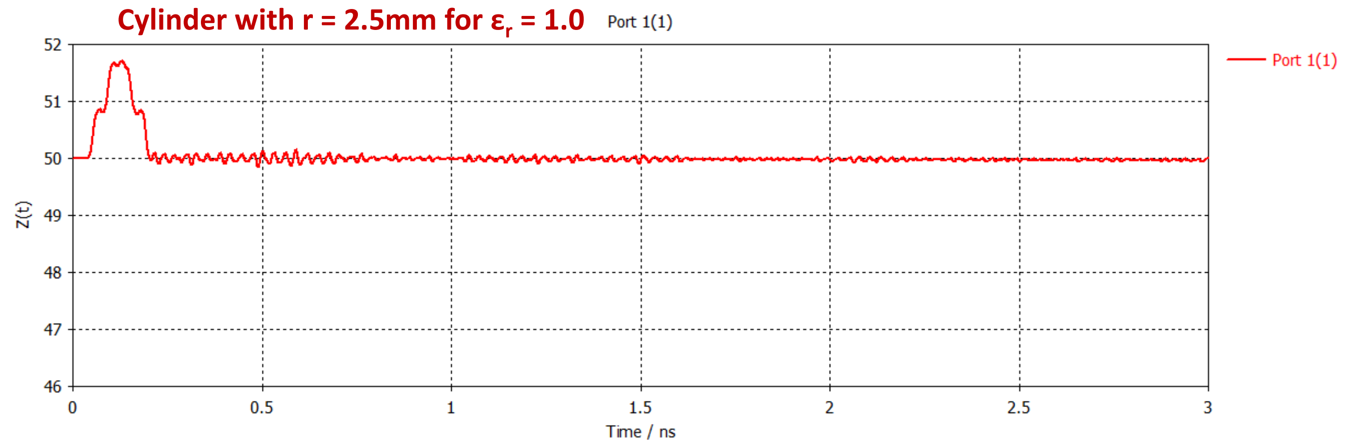
Blade-to-transmission line transition side view

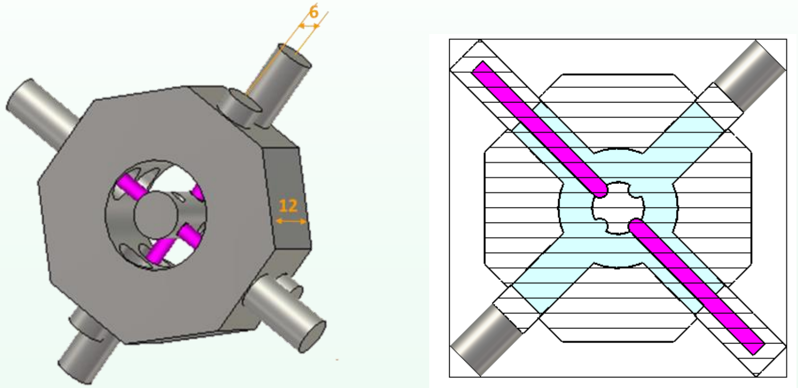
Simulated time domain reflectometry of blade-to-coaxial line transition



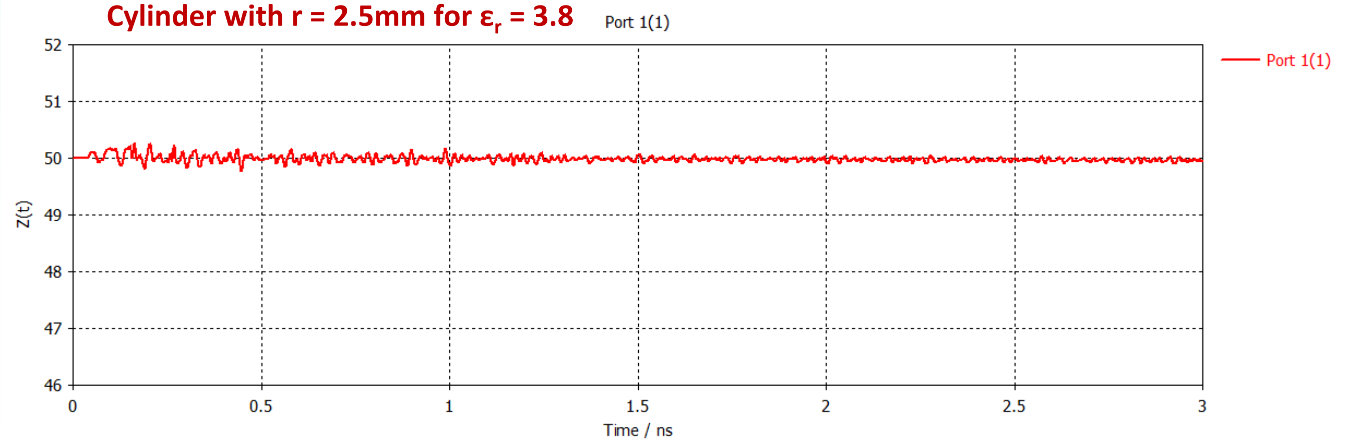
SLS 2.0 Fast Kicker Prototype – Electrical Characteristics

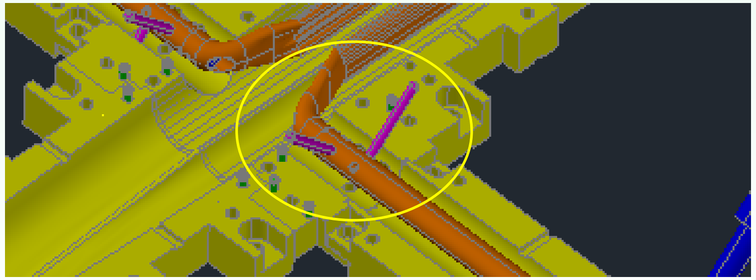
Support and adjustment section





3D model of the support.





Simulated time domain reflectometry

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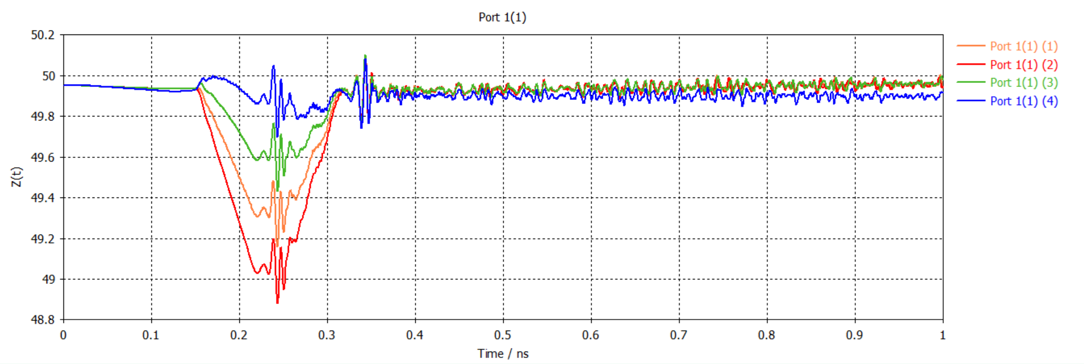
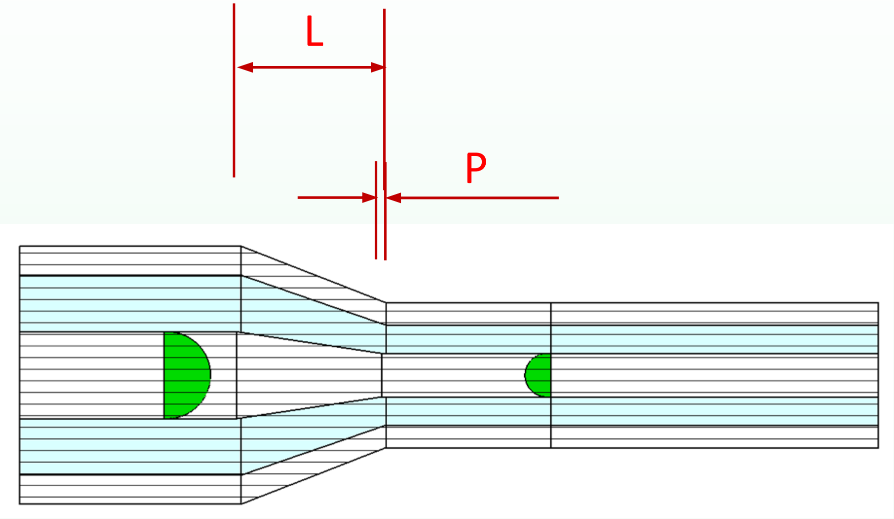
SLS 2.0 Fast Kicker Prototype – Electrical Characteristics

50 Ω to 50 Ω transition

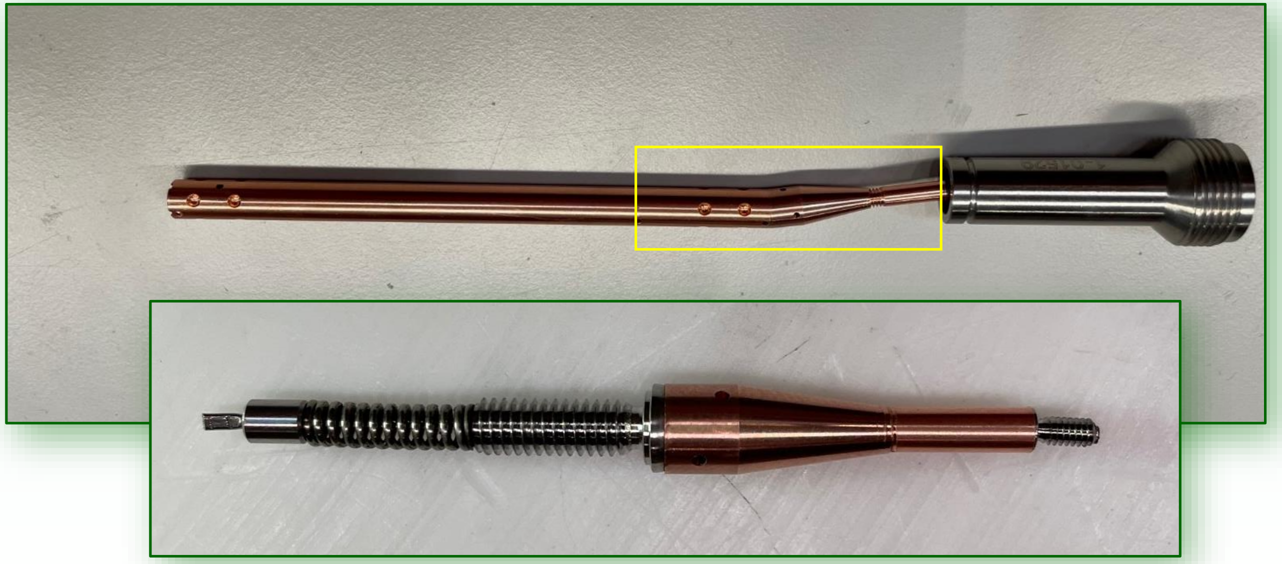


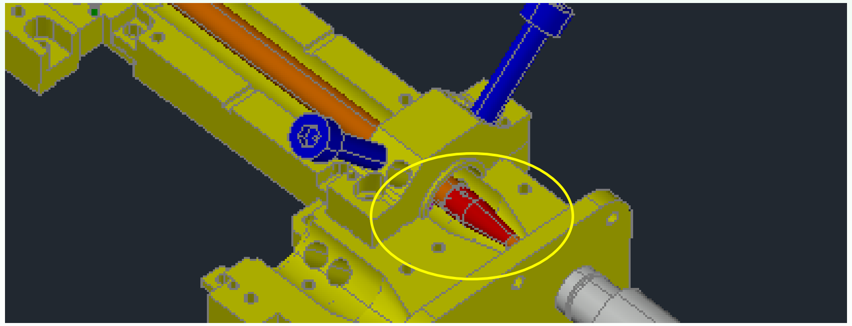
Simulated time domain reflectometry of the conical transition

P = 0 mm
P = 0.1 mm
P = 0.2 mm
P = 0.3 mm



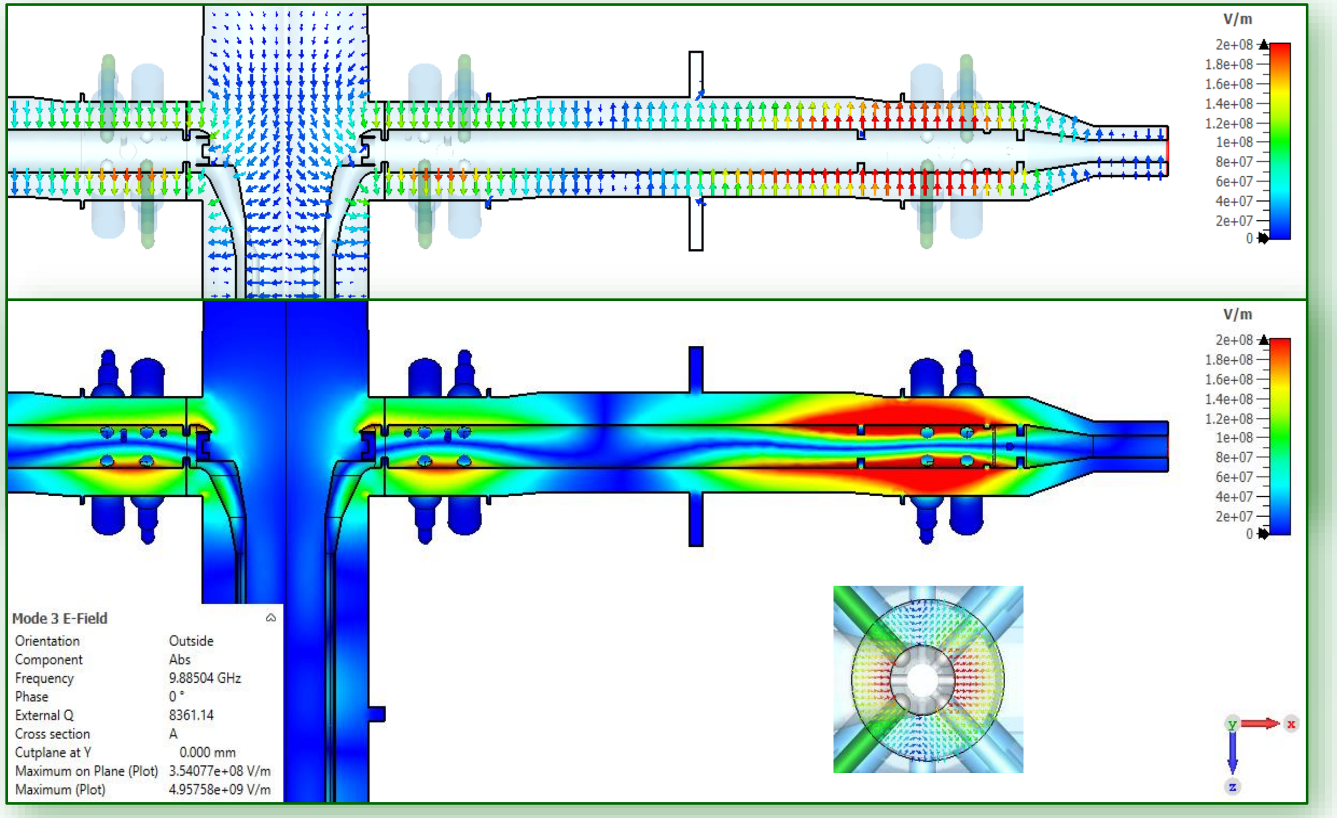
3D model of the conical transition.





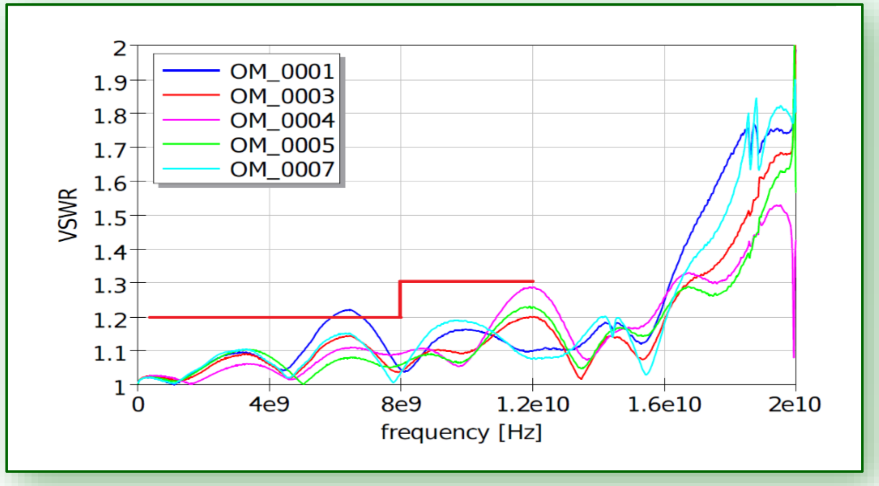
SLS 2.0 Fast Kicker Prototype – Electrical Characteristics

Coaxial line asymmetry and vacuum feedthrough



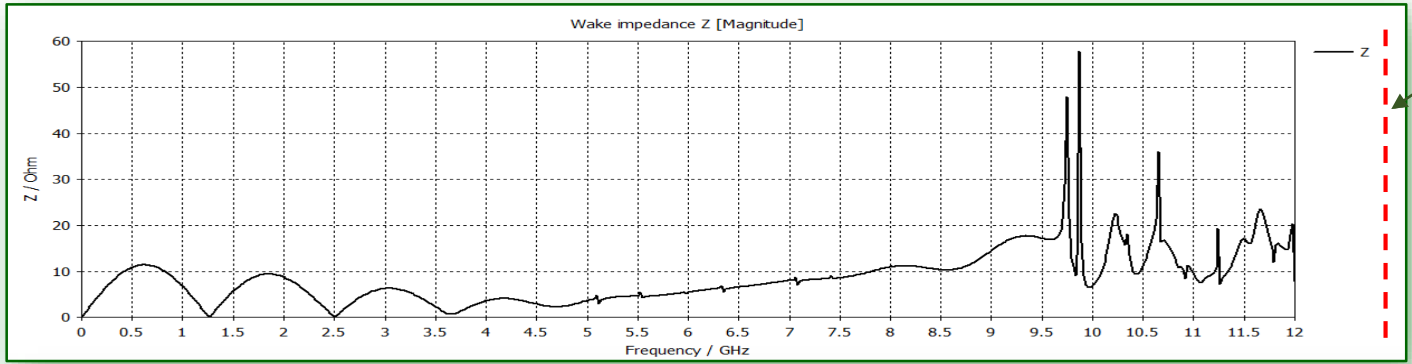
Example of one trapped mode in the coaxial transmission line

Orient microwave feedthrough.



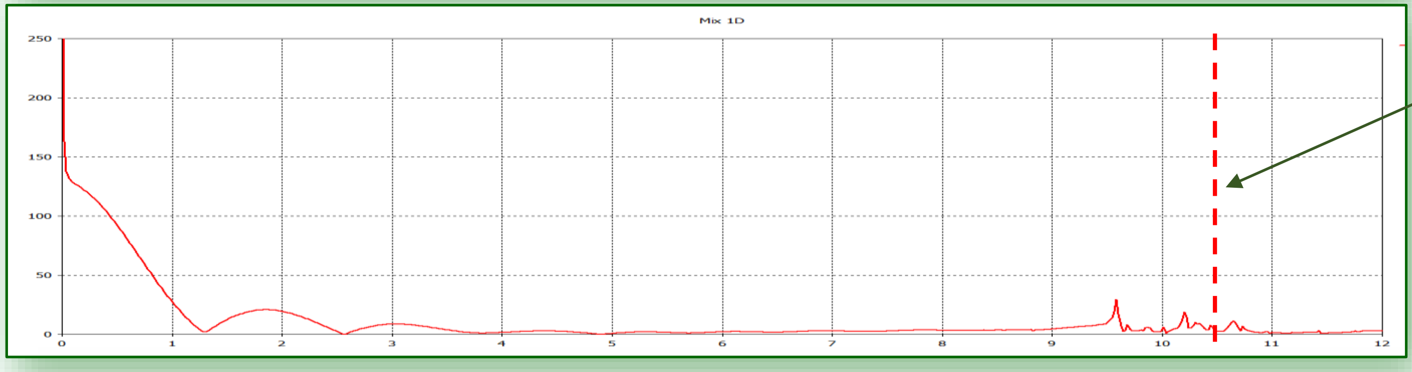
Measured voltage standing wave ratio of OM feedthroughs

SLS 2.0 Fast Kicker Prototype – Beam Impedance



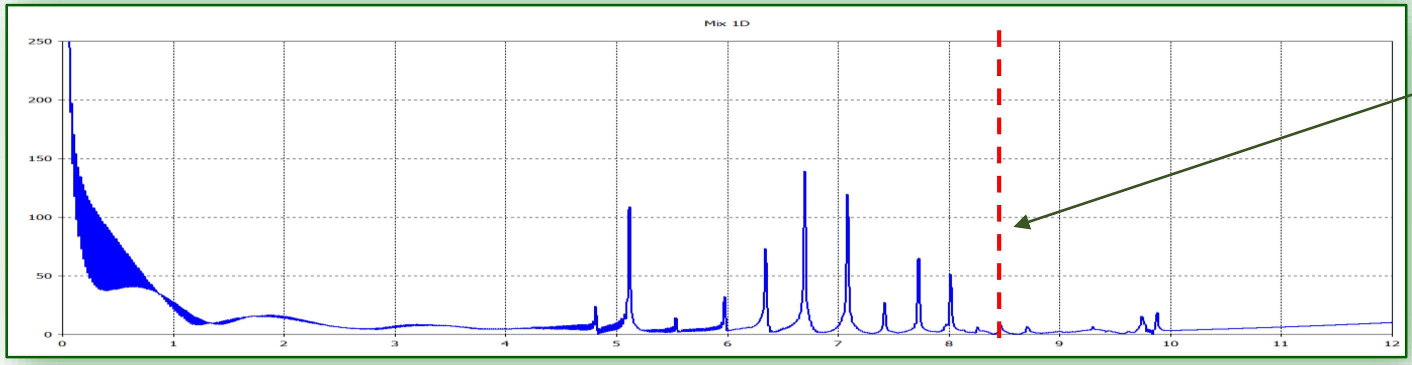
f_{cutoff} = 13.3 GHz

Longitudinal



f_{cutoff} = 10.5 GHz

Transverse X

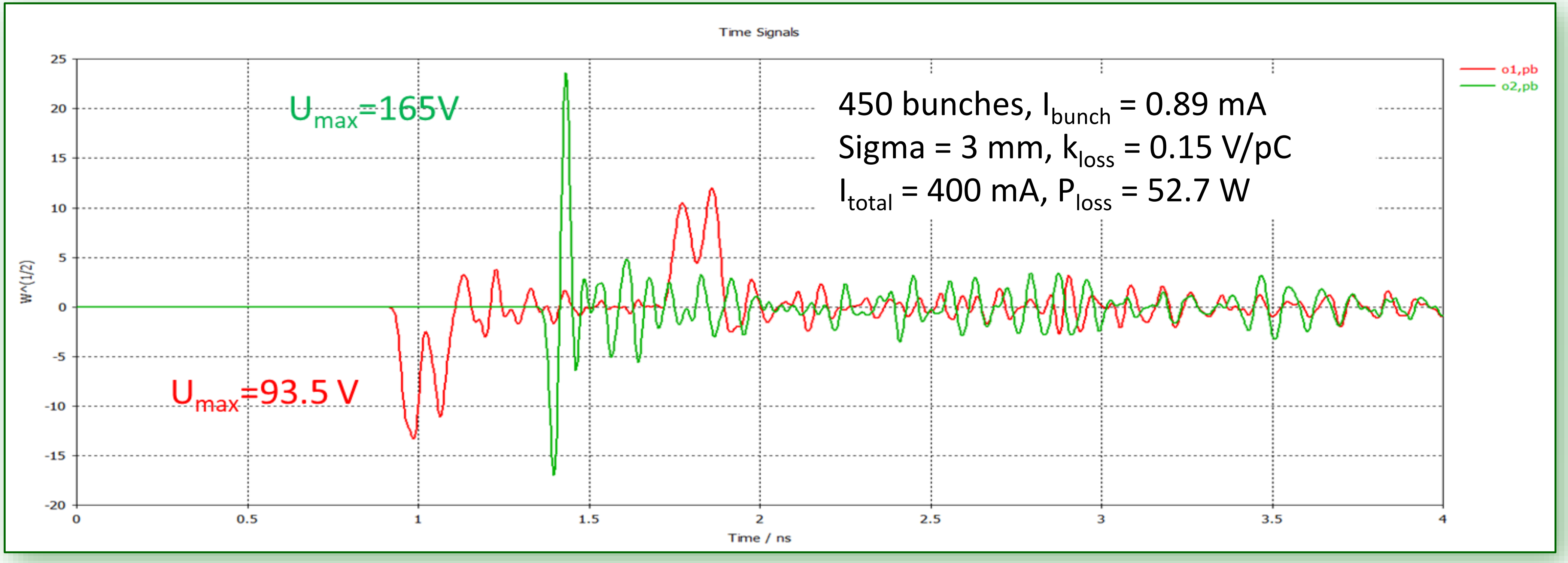


F_{cutoff} = 8.4 GHz

Transverse Y

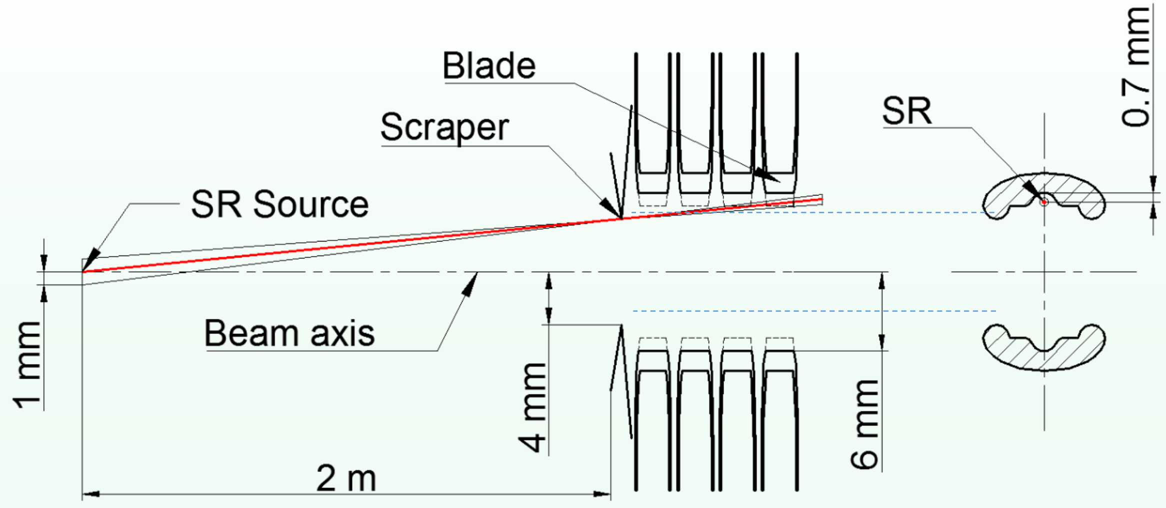
SLS 2.0 Fast Kicker Prototype – Wakefield simulations

The stripline kicker is a bidirectional device – beam deposited power



Beam induced pulses at excitation and termination ports of single kicker section

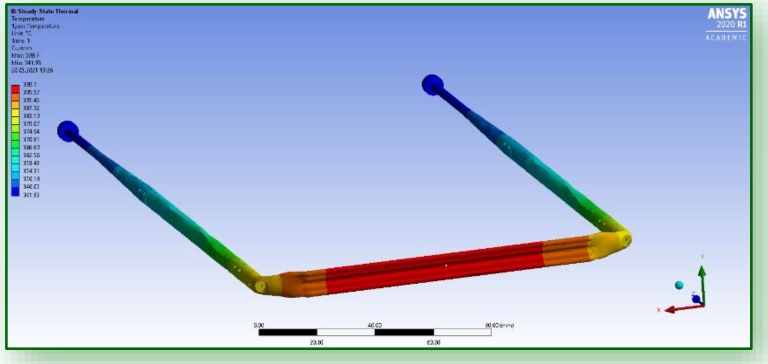
SLS 2.0 Fast Kicker Prototype – SR heating



Avoiding direct illumination of SR

with conduction trough glass ceramic at 25°C					
case	emissivity [-]	heat flow[W]	max. Temperatur [°C]	total deformation [mm]	max. equivalent stress [MPa]
1	0.1	10	337.3005371	1.784642906	17.28462074
2	0.6	10	174.7341003	1.784624027	16.65466362
3	0.1	1	72.09762573	1.784616976	16.41698591
4	0.6	1	46.01613998	1.784613989	16.31476629
without conduction					
case	emissivity [-]	heat flow[W]	max. Temperatur [°C]	total deformation [mm]	max. equivalent stress [MPa]
1	0.1	10	399.6990662	1.784759351	17.27150764
2	0.6	10	187.5480957	1.78463395	16.60498231
3	0.1	1	123.0246048	1.784629528	16.54325199
4	0.6	1	50.40020752	1.784615783	16.31480104

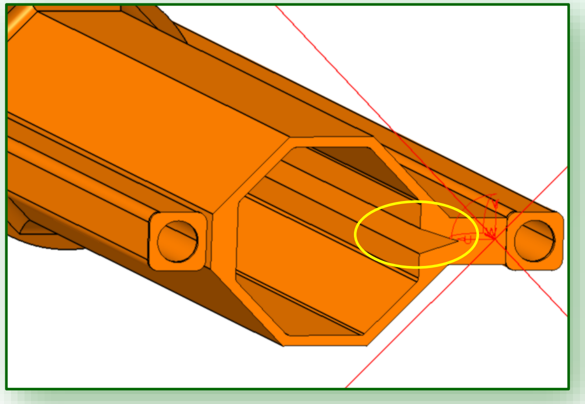
Maximum blade temperature with 0.1 and 0.6 emissivity coefficient, 1 W and 10 W heat load



Temperature distribution with 10 W heat load (courtesy of J. Buchmann)

The synrad simulations showed relatively high scattered light irradiation in order of 10W per blade.

Some measures are under consideration to reduce trapped scattered radiation in the beam chamber.



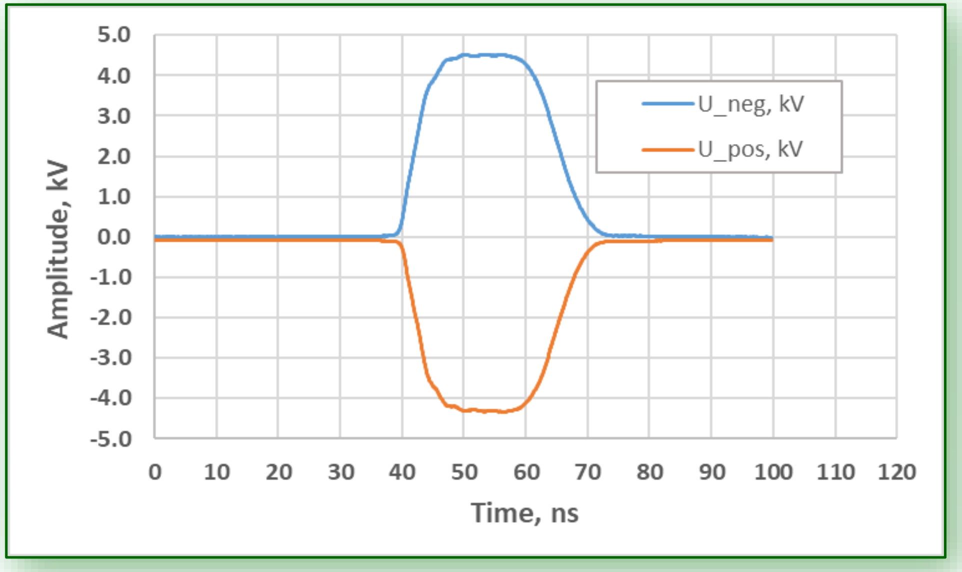
Antechamber (courtesy of R. Ganter)

Fast kicker pulse generation (FID)

FID GmbH 5 kV
positive/negative pulse
generator

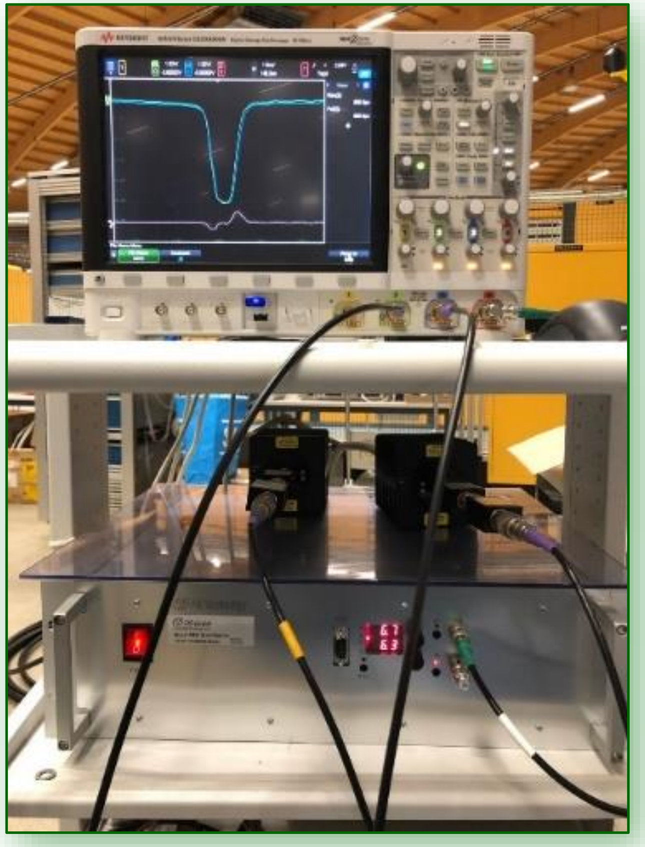
Measurement setup
with 20 m cables
- for pulse generator protection

Full pulse length ~30 ns



Output pulses (positive and negative)

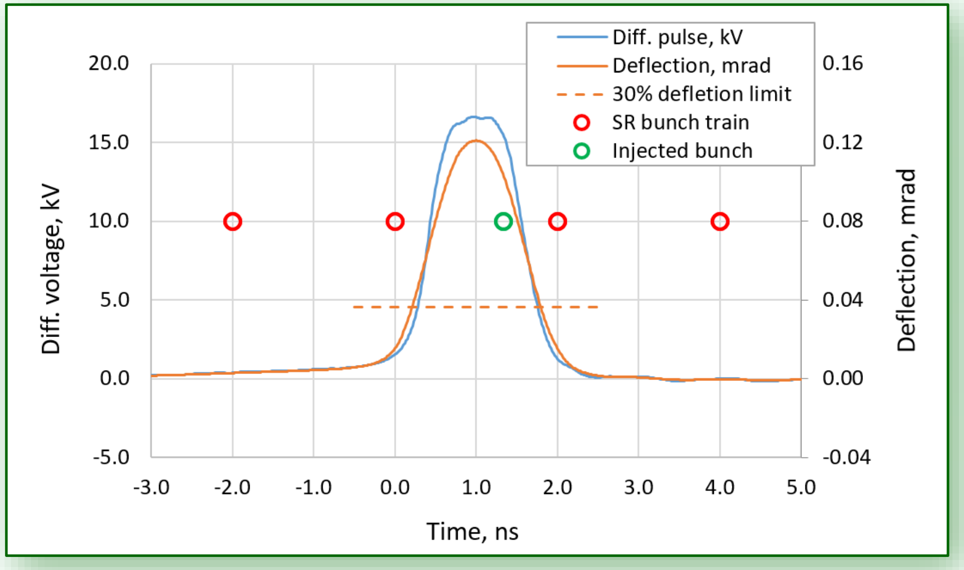
Super-fast kicker pulse generation (FID)



FID GmbH 10 kV
positive/negative pulse
generator

Measurement setup
with 20 m cables
- for pulse generator protection

Full pulse length ~2 ns



Output pulse and expected deflection from one section

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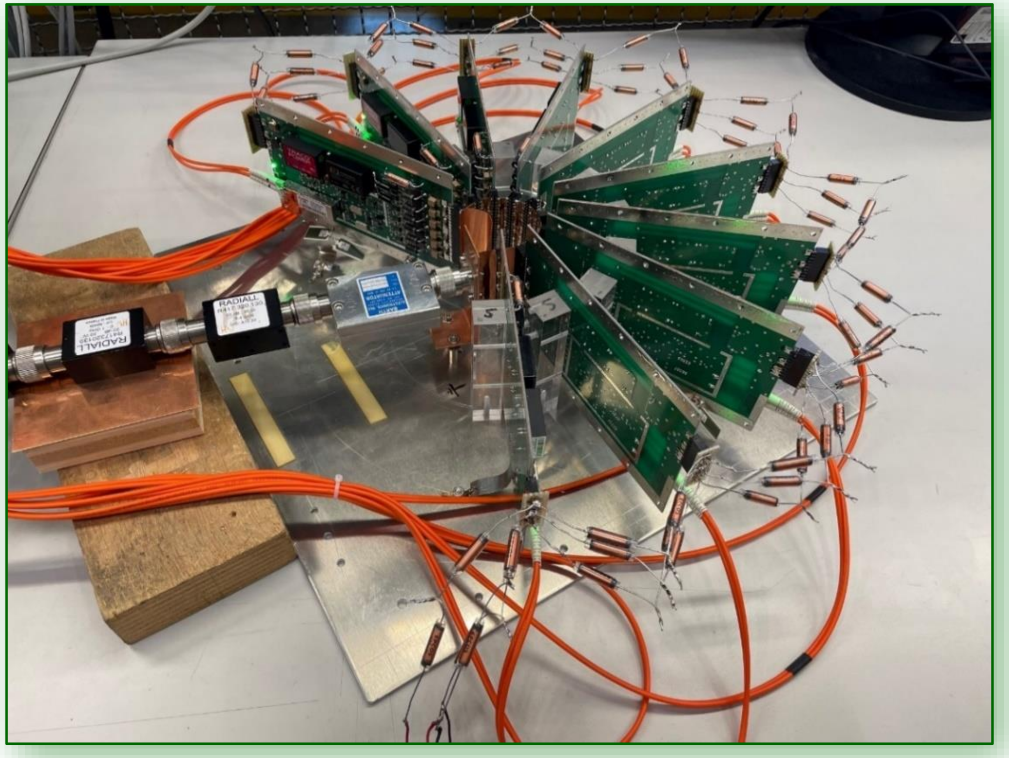
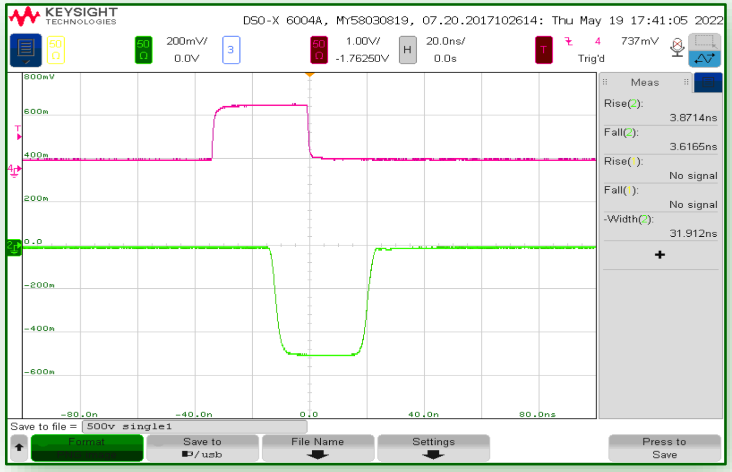
Fast kicker pulse generation – Inhouse design

- 6 discrete 600 V, GaN FETs in parallel in one stage
- Enhancement mode, normally Off, GaN HEMT (IGLD60R070D1)
- Adjustable delay optical triggering
- Inductance isolated Marx structure

Single GaN FET stage



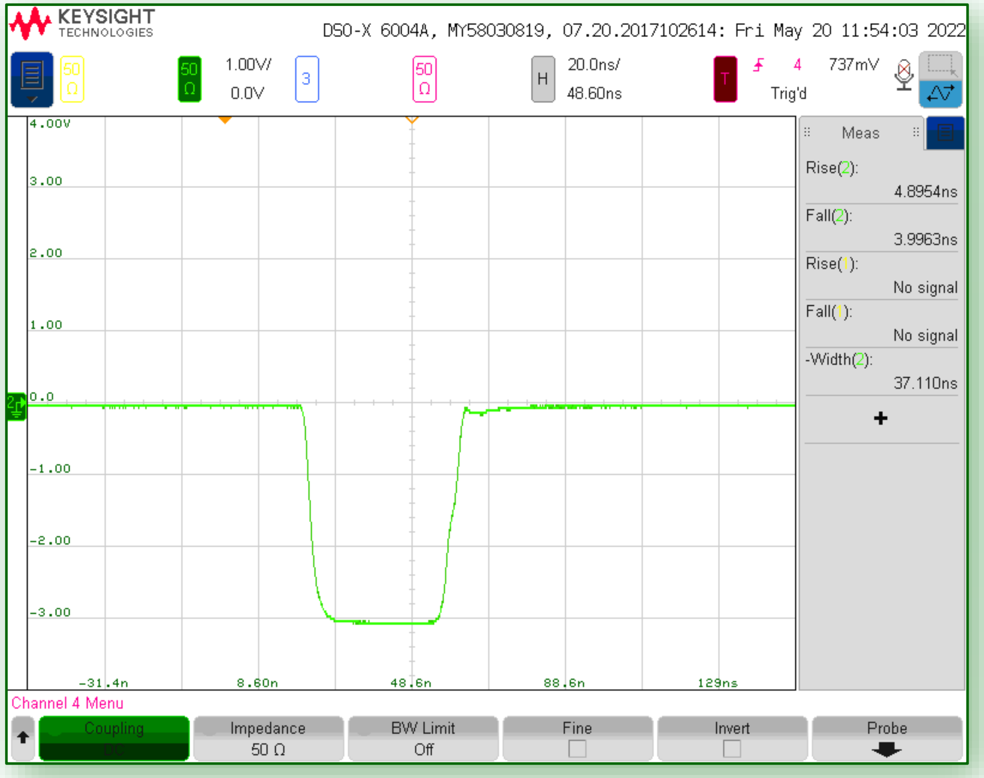
10 stage GaN FET based pulse generator



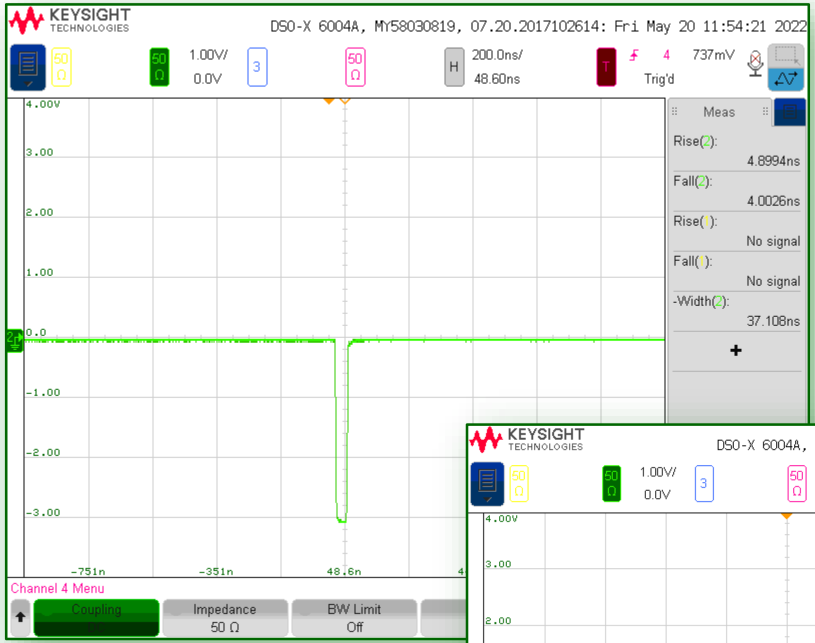
Output pulse from a single stage

Fast kicker pulse generation – Inhouse design

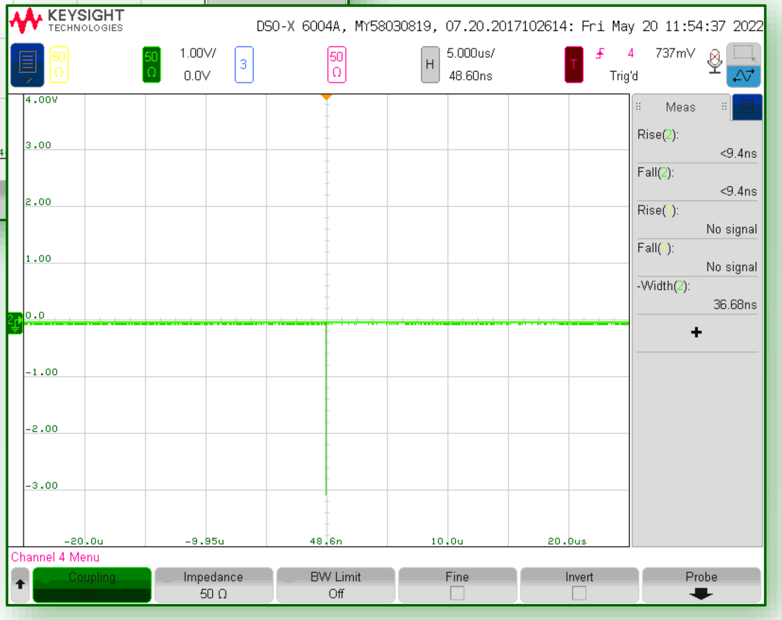
U = 6 kV, t_f = 4.0 ns, t_r = 4.9 ns



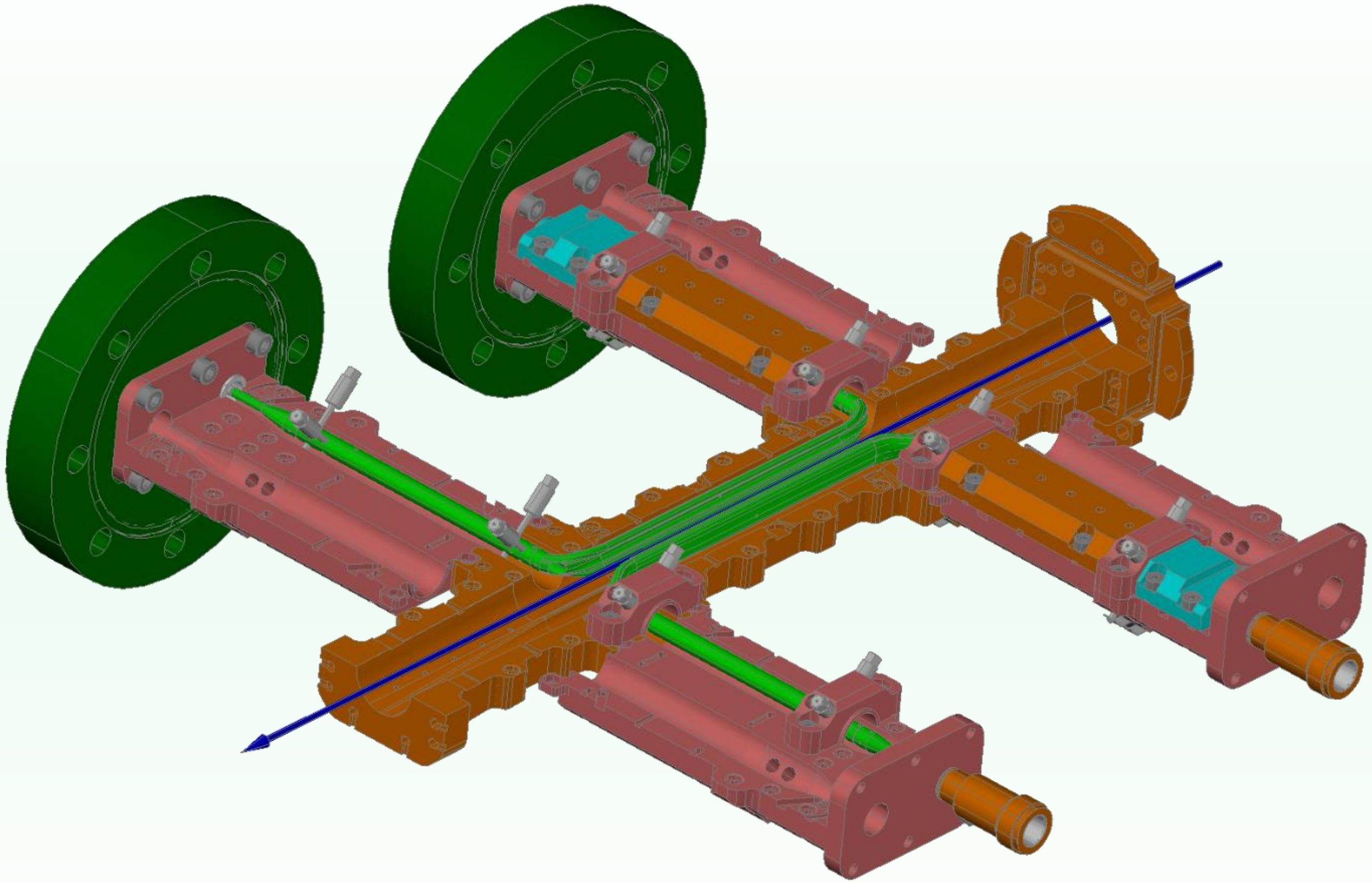
6 kV output pulse of the 10 stage GaN FET based pulse generator (20 ns/div, 2 kV/div)



200 ns/div, 2 kV/div



5 us/div, 2 kV/div



Thank you for your attention