Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps

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RadiaBeam

- Founded in 2004
- ~50 employees and growing
- 30,000 ft^2 headquarters in Santa Monica, CA

- Accelerator R&D, design, engineering, manufacturing and testing all under one roof in a dynamic, small-business setting

Tour: Machine Shop

RadiaBeam

- Multiple CNC milling and turning centers, > $3 million investment
- Dedicated “clean shop” for RF and UHV machining
- Full-suite of inspection equipment, including CMM
- 10 highly-skilled machinists
- ISO 9001 compliant quality system

Project Goals

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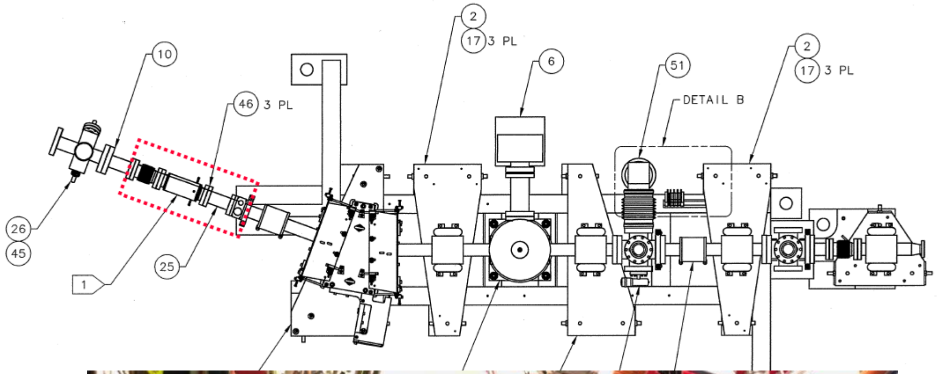
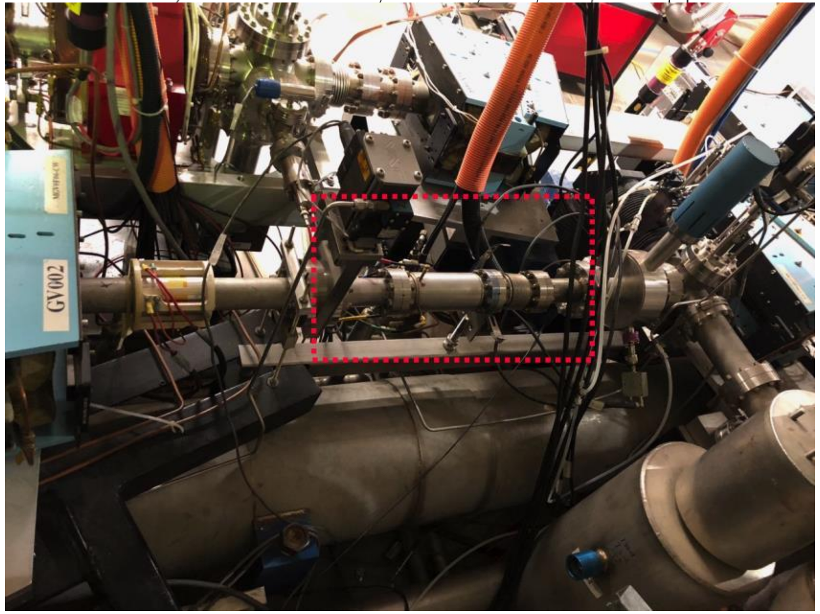
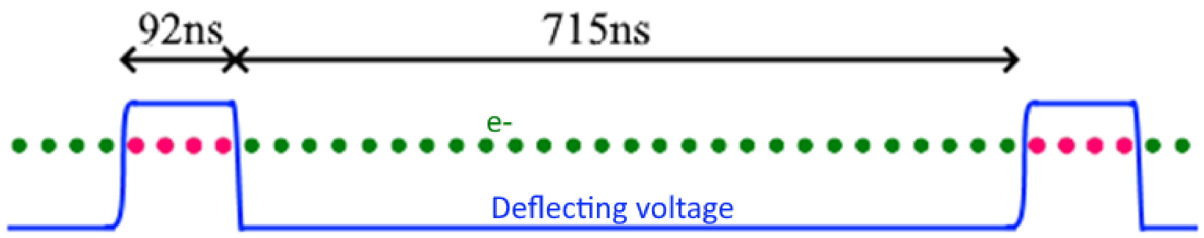
The ionization scattering of the electron beam with residual gas molecules causes ion trapping in the electron rings, both in the collider and electron cooling system. The trapped ions may cause emittance growth, tune shift, halo formation, and coherent coupled bunch instabilities. Therefore, the beam temporal structure needs gaps to clear the ions to prevent them from accumulating turn after turn. Typically, the gap in the bunch train has a length of a few percent of the ring circumference.

- A fast deflector (kicker) is needed for EIC ERL cooler to form a ~100ns gap at ~1MHz (37.5MHz, ultimately 98.5MHz micro-bunches)
- Aperture 14 mm
- Maximum insertion length is 75cm
- Stripline kicker is a practical solution for such need
- Radiabeam is building a kicker and two-channel pulsed power source intended to be installed and tested at Jefferson Lab



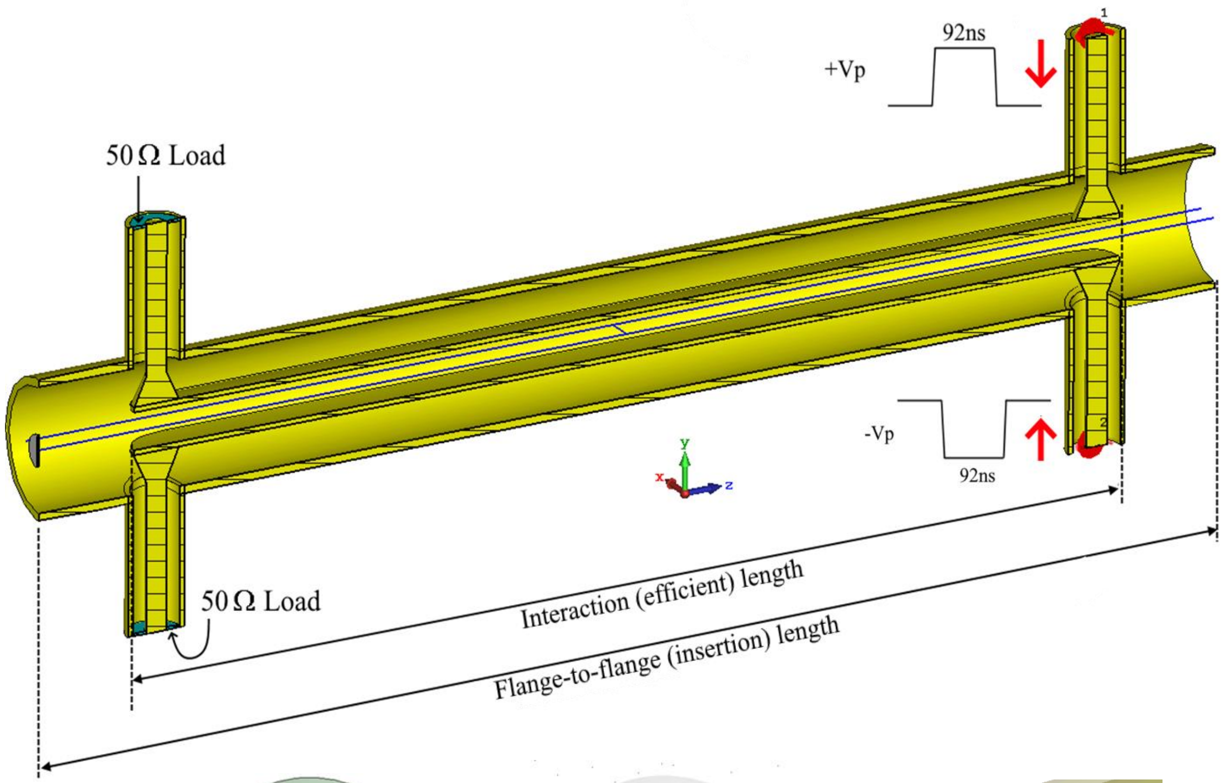


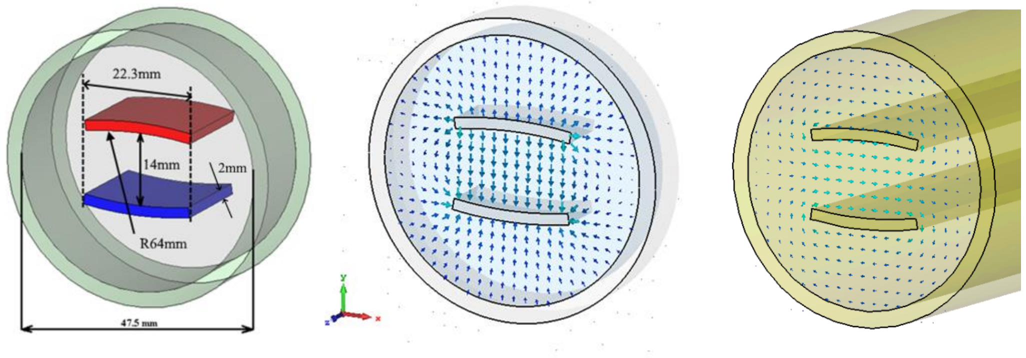
Kicker Specification



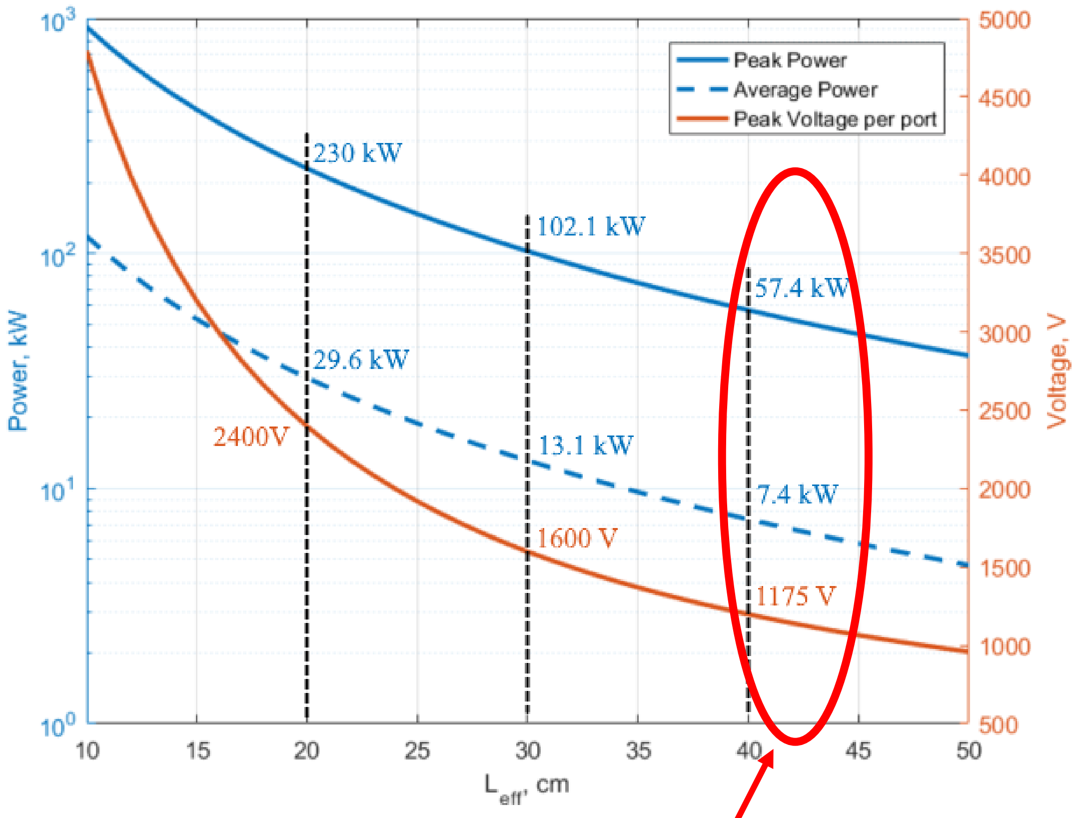
Parameter	Value
Deflecting angle	20 mrad (deflecting voltage 140 kV)
Flange-to-flange length	50 – 60 cm
Electron Beam Energy	7 MeV
Bunch Repetition Rate	37.5 MHz
Bunch rms transverse size	σ=1 mm
Deflecting Pulse Width	92 ns flat-top required to deflect 4 out of 31 bunches in train
Kicker operation per rate	1.4 MHz (715ns between the pulses)
Rise + Fall Time	<20 ns (10ns desired)
Aperture (gap)	14 mm
Required pulsed power	27.6 kW peak power per channel (55.2 kW total); 3.8 kW average power per channel (7.6 kW total)

RF design





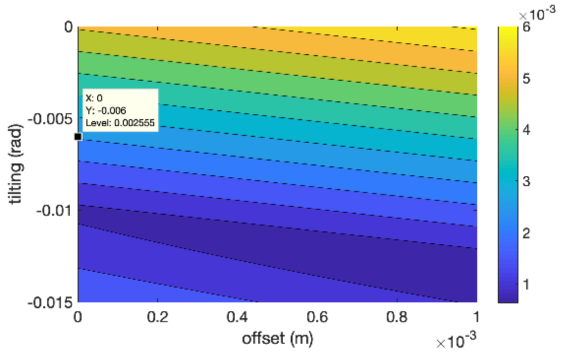
Power required for 20mrad deflection



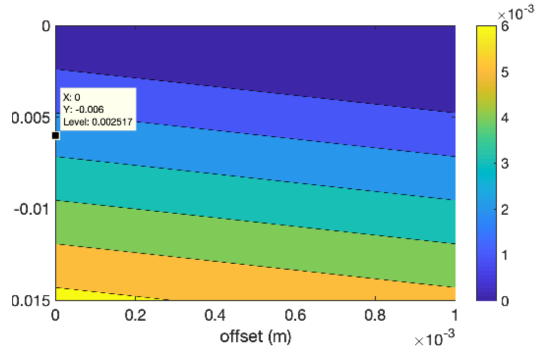
40cm interaction length

Beam dynamics study

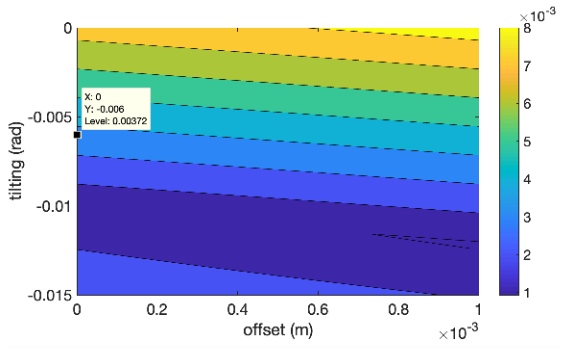
Exit offset spectrum over injection parameters



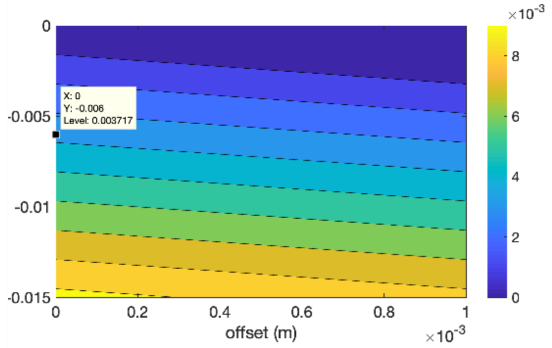
Kicked bunch (400mm)



Unkicked bunch (400mm)



Kicked bunch (600mm)



Unkicked bunch (600mm)

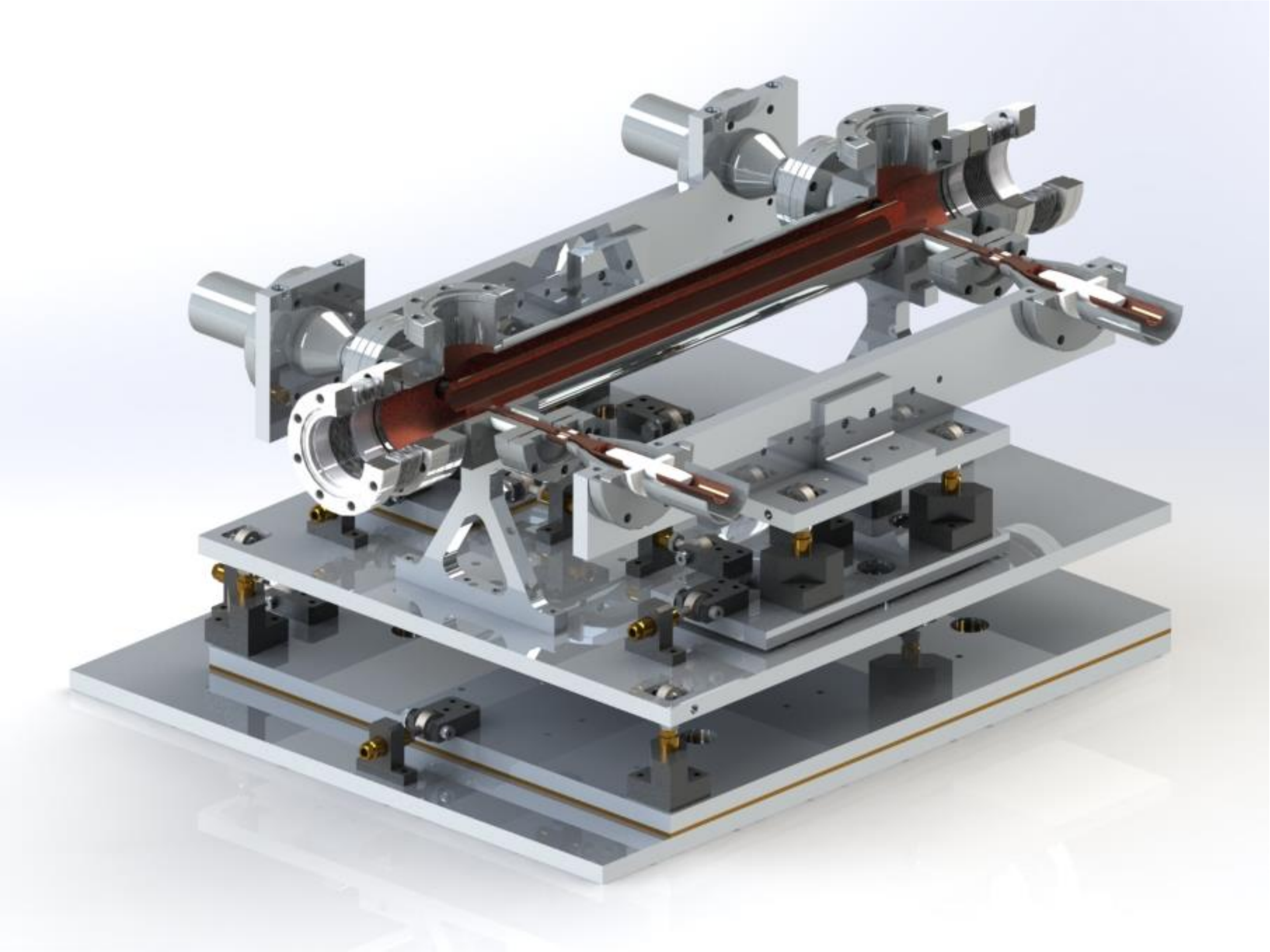
Beam loss with various interaction lengths

Analytic evaluation	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
20mrad Kick	yes	yes	yes	yes	yes	no	yes	no
L_{eff} (mm)	200	300	400	600	400	400	600	600
g (mm)	14	14	14	14	14	14	14	14
V_p (V)	2275	1560	1175	790	1175	1175	790	790
$Offset_i$ (mm)	0	0	0	0	0	0	0	0
$Tilt_i$ (mm)	0	0	0	0	-5	-5	-6	-6
Beam loss (%)	1×10^{-6}	8.8×10^{-5}	0.0027	0.21	5.4×10^{-5}	4.7×10^{-5}	$.6\times10^{-3}$	4.8×10^{-3}
P_b (W) LERF	4×10^{-4}	0.04	1.1	87.3	0.022	0.02	2	2
P_b (W) JLEIC	0.04	3.4	104.5	8.1×10^{3}	2.1	1.8	178	186
P_{RF} (kW)	14.5	6.8	3.85	1.75	3.85	3.85	1.75	1.75
CST simulation								
Beam loss (%)	7×10^{-6}	4×10^{-5}	1.6×10^{-3}	0.38	4.65×10^{-5}	4.66×10^{-5}	$.6\times10^{-3}$	3.6×10^{-3}
P_b (W) LERF	0.003	0.02	0.66	158	0.02	0.02	1.5	1.5
P_b (W) JLEIC	0.27	1.55	62	1.47×10^{4}	1.8	1.8	140	140
Space charge								
Beam loss (%)	-	-	-	-	1.8×10^{-3}	4.7×10^{-5}	-	-
P_b (W) LERF	-	-	-	-	0.7	0.02	-	-
P_b (W) JLEIC	-	-	-	-	70	1.8	-	-

40cm interaction length

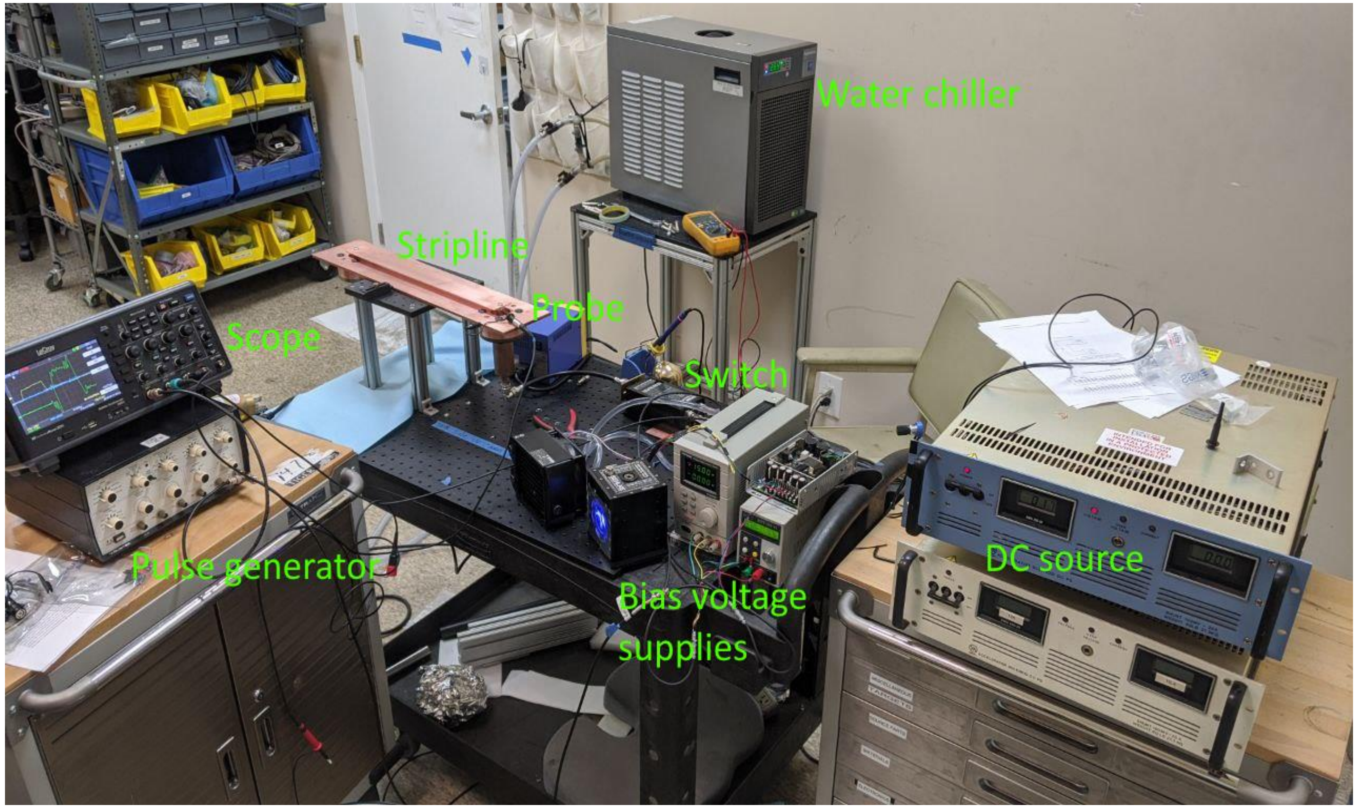
Engineering model

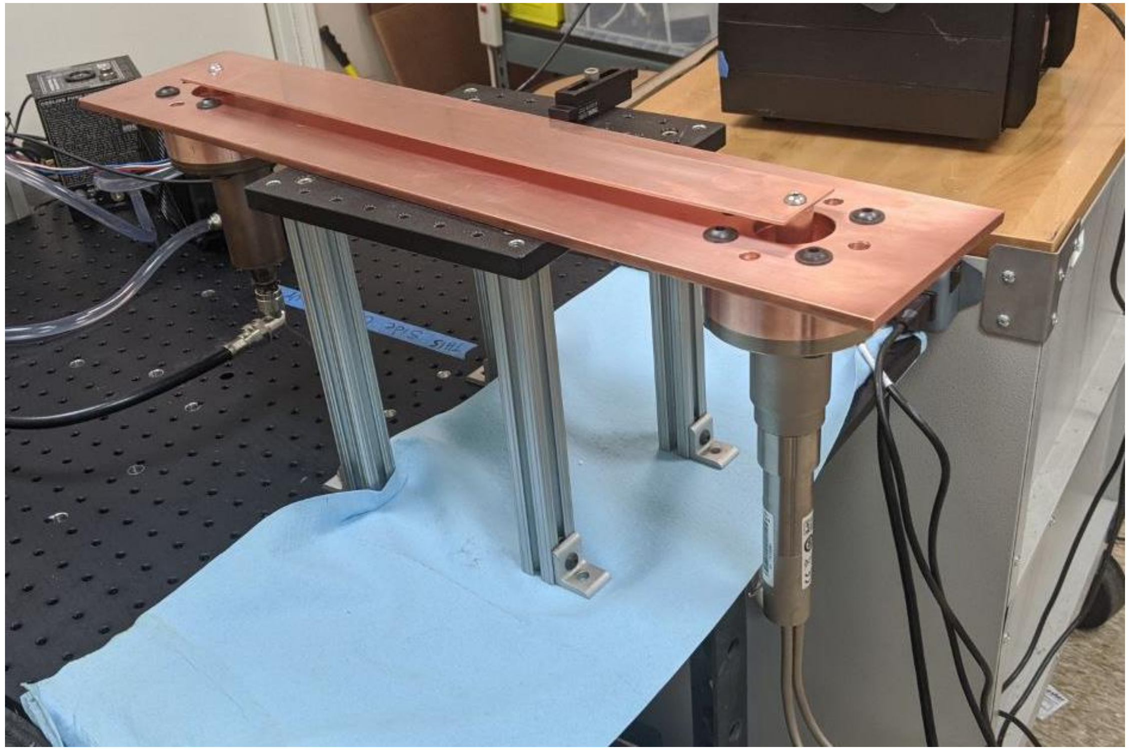
- Standard 1-5/8” EIA compatible
- 60 cm flange-to-flange
- 40 cm interaction length
- XYZ Positioning stage
- Independent electrodes alignment
- Dielectric-free



Pulser testing setup

- 50cm-long 50 Ohm stripline, VSWR <1.1 from DC to 1 GHz
- Si MOSFET and GaN water-cooled high-power switches
- 500 V / 10 A DC supply





Pulser testing (Si MOSFET)

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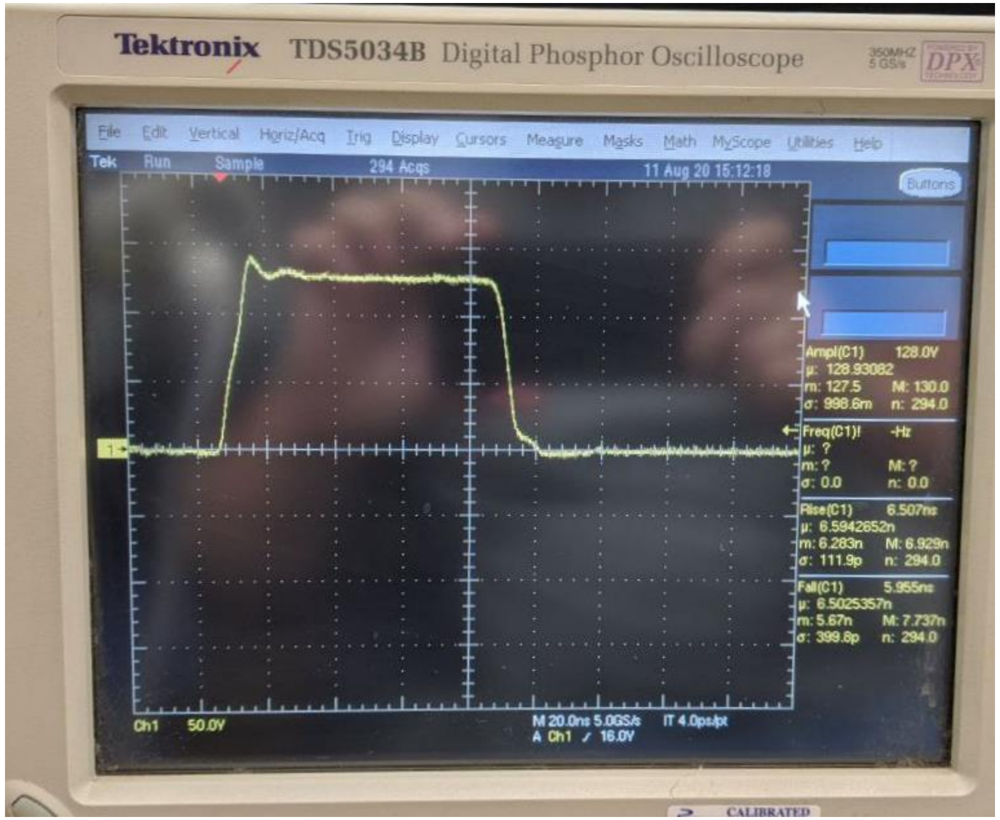
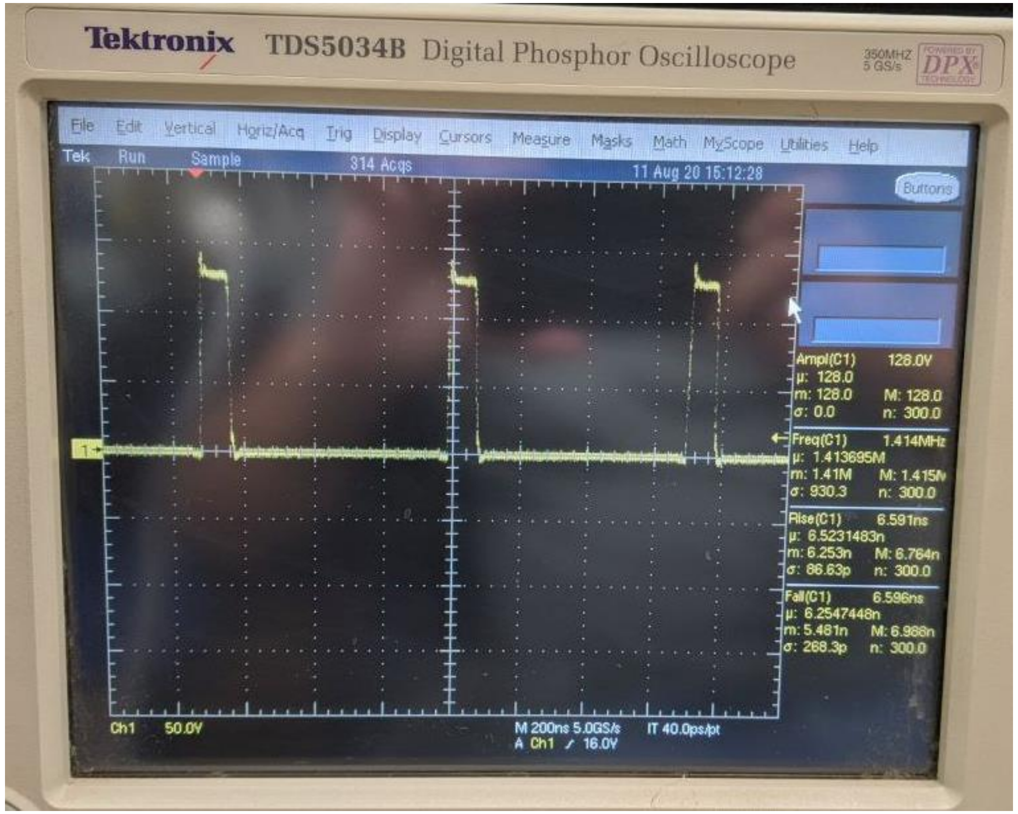
Achieved:

- 7ns rise and 6ns fall times at 100 ns flat-top with 87ps rms timing jitter
- Highly stable and controllable pulse length
- 1.4 MHz repetition rate
- **50% efficiency**





Pulser testing (Gallium Nitride)

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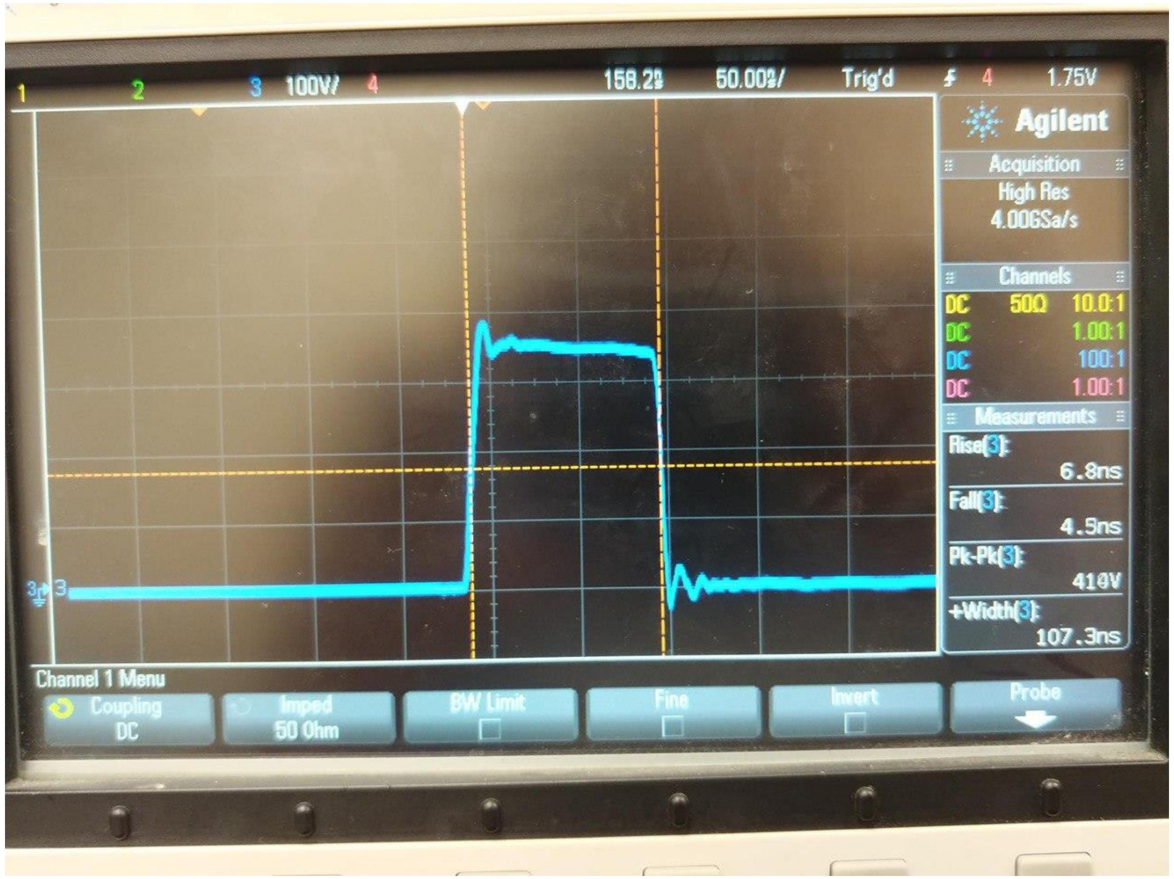
Achieved:

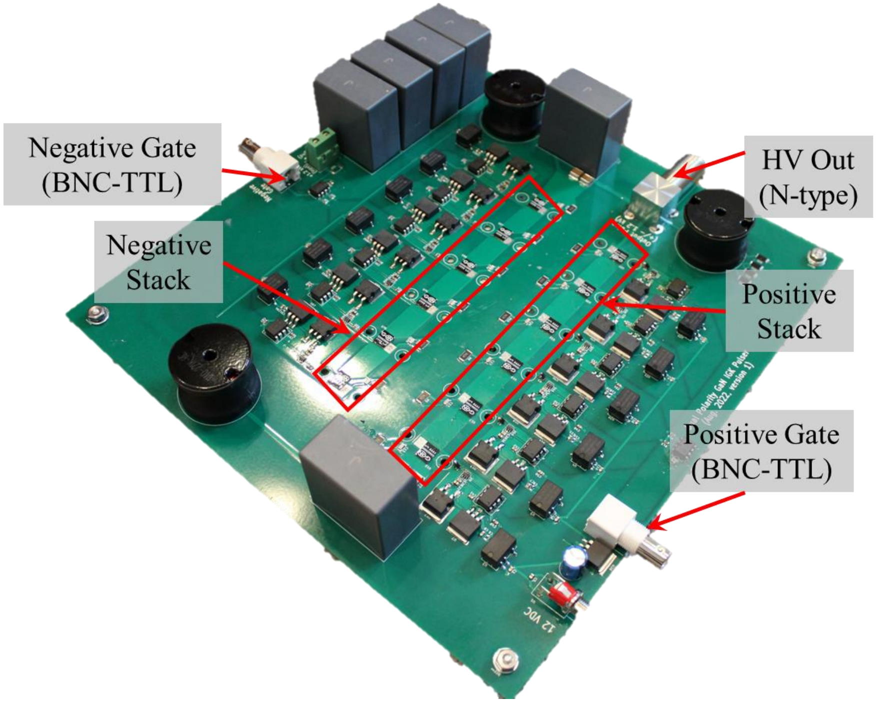
- 6.8ns rise and 4.5ns fall times @ 107 ns flat-top with 100ps rms timing jitter
- Highly stable and controllable pulse length
- 1.4 MHz repetition rate
- **82% efficiency**
- **Failed at 800 V**

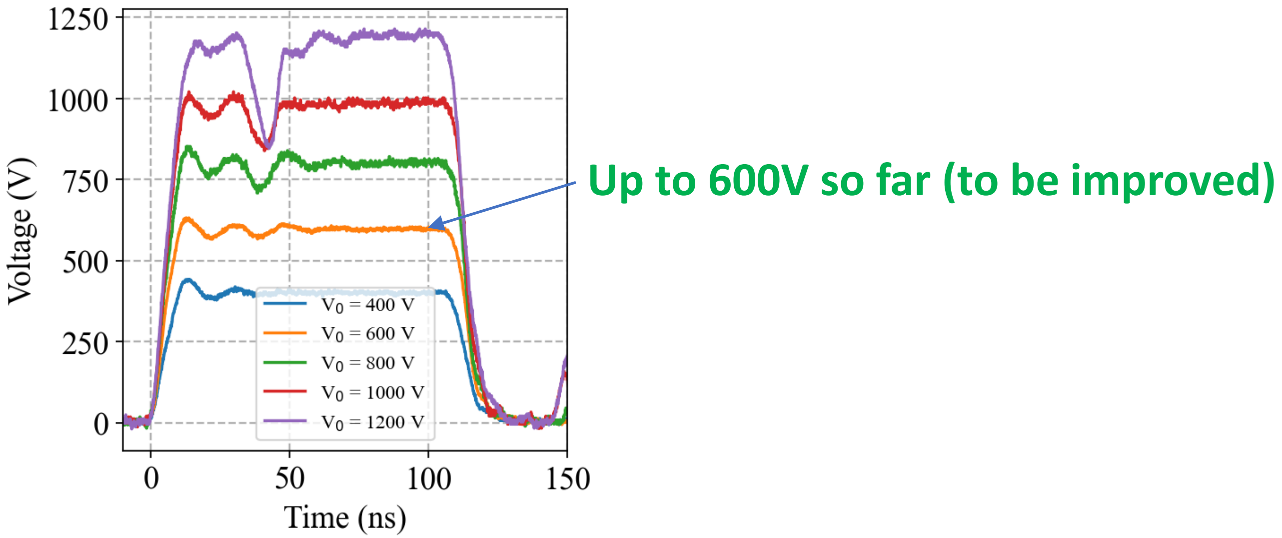


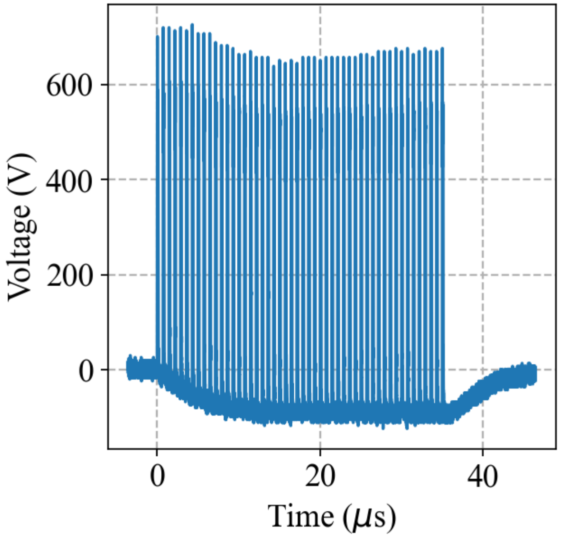
RadiaBeam pulser development (GaN) - v1

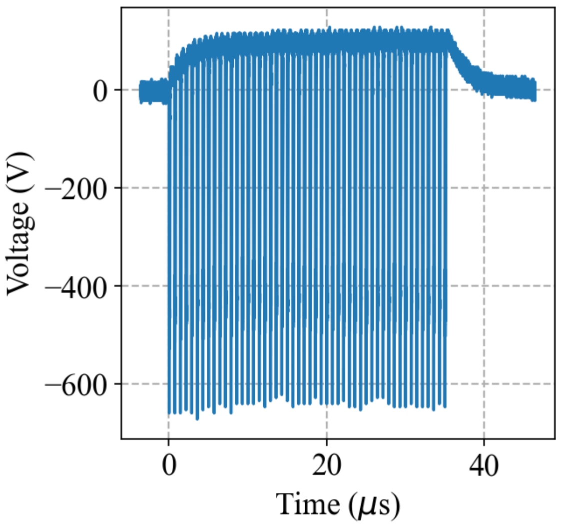
Achieved:

- 10 ns rise and 11 ns fall times @ 107 ns flat-top
- 1.4 MHz repetition rate (short bursts)
- **85% efficiency**





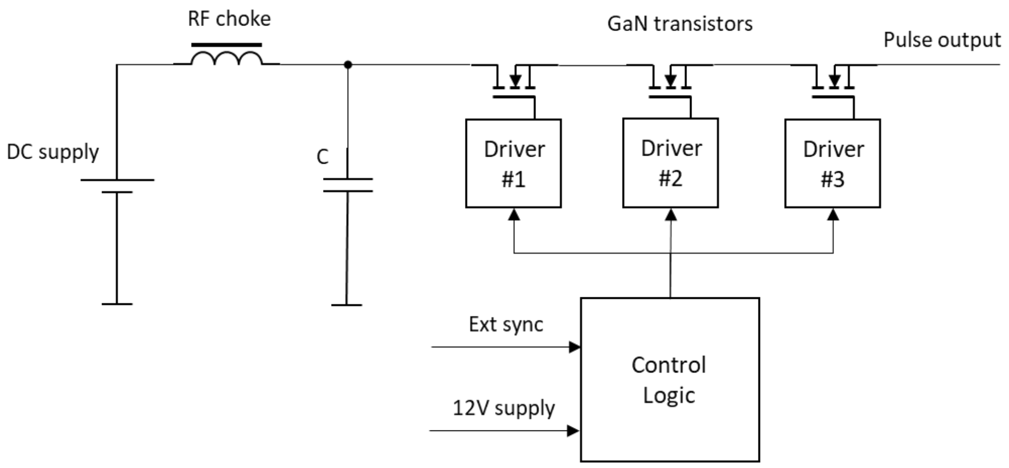




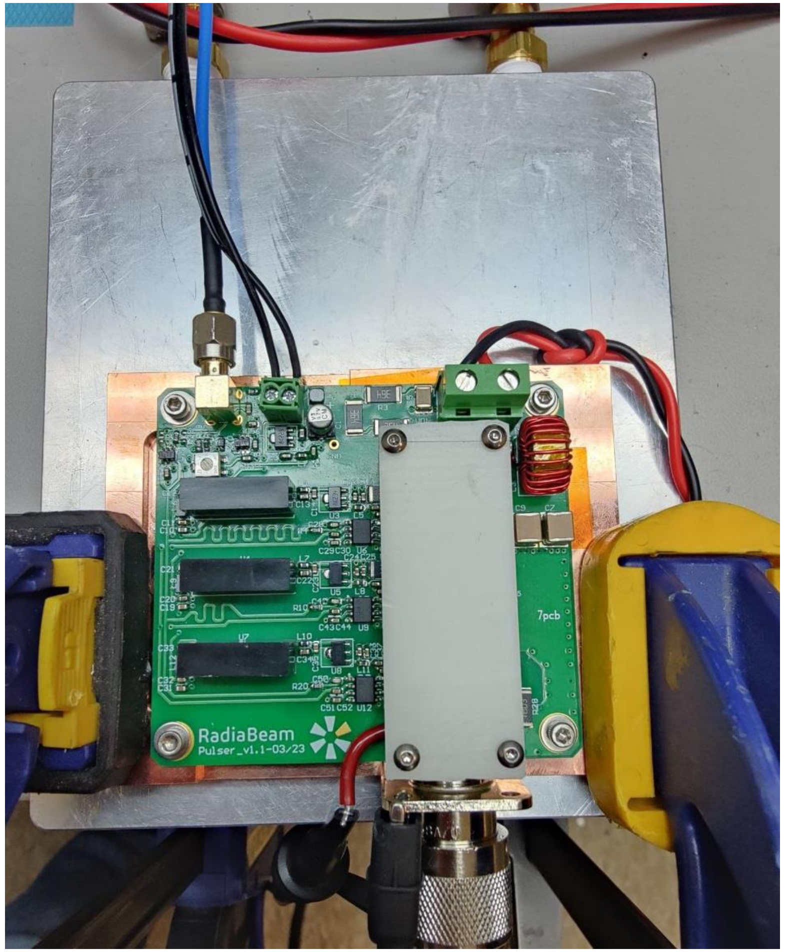
Positive channel Negative channel 1.4 MHz bursts

RadiaBeam pulser development (GaN) – v2

Simplified circuit diagram

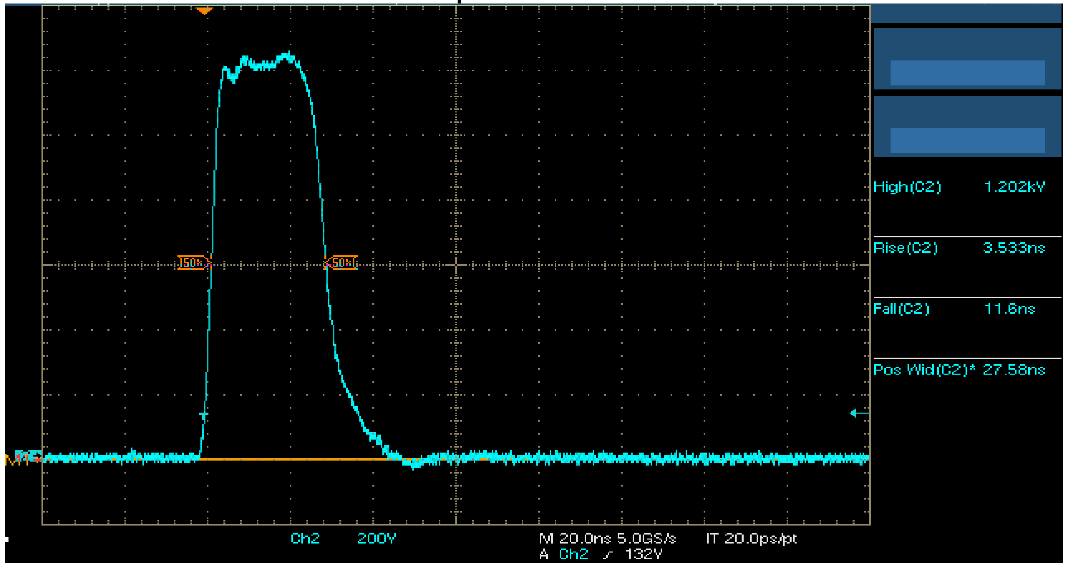


Assembled Pulser PCB

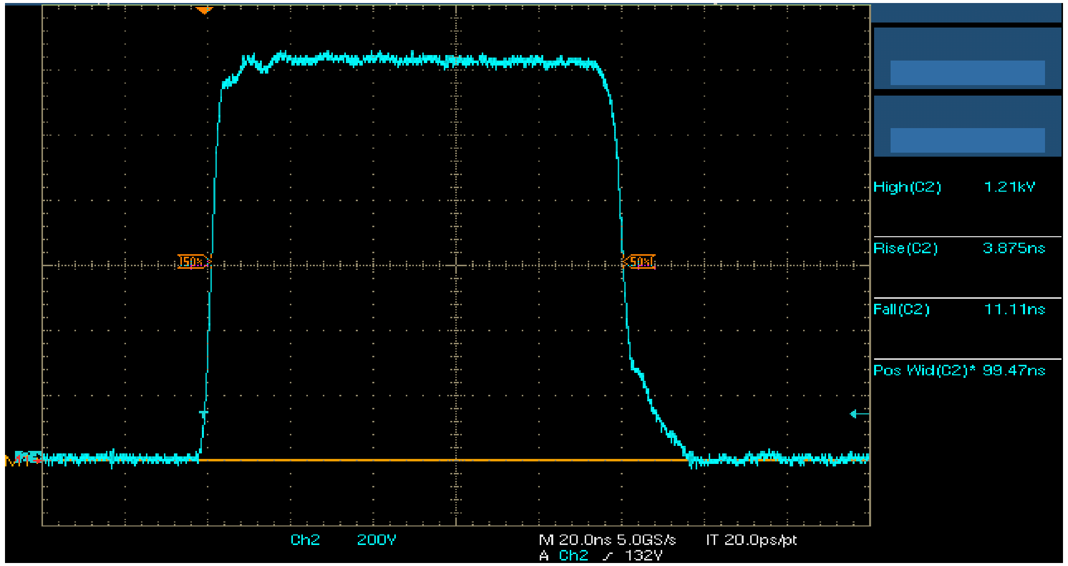


RadiaBeam pulser development (GaN) – v2

27 ns pulse width

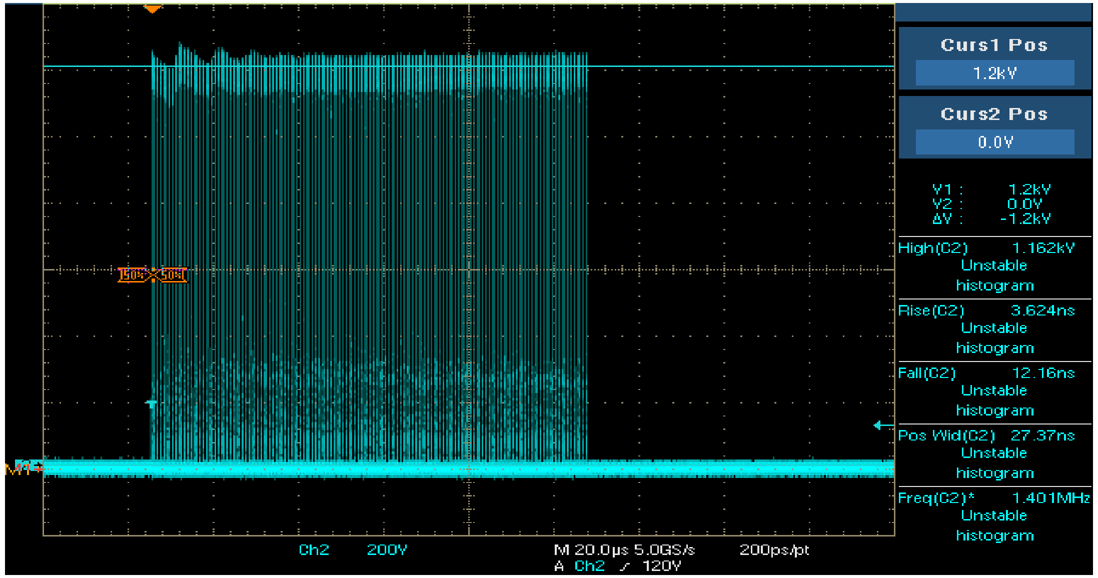


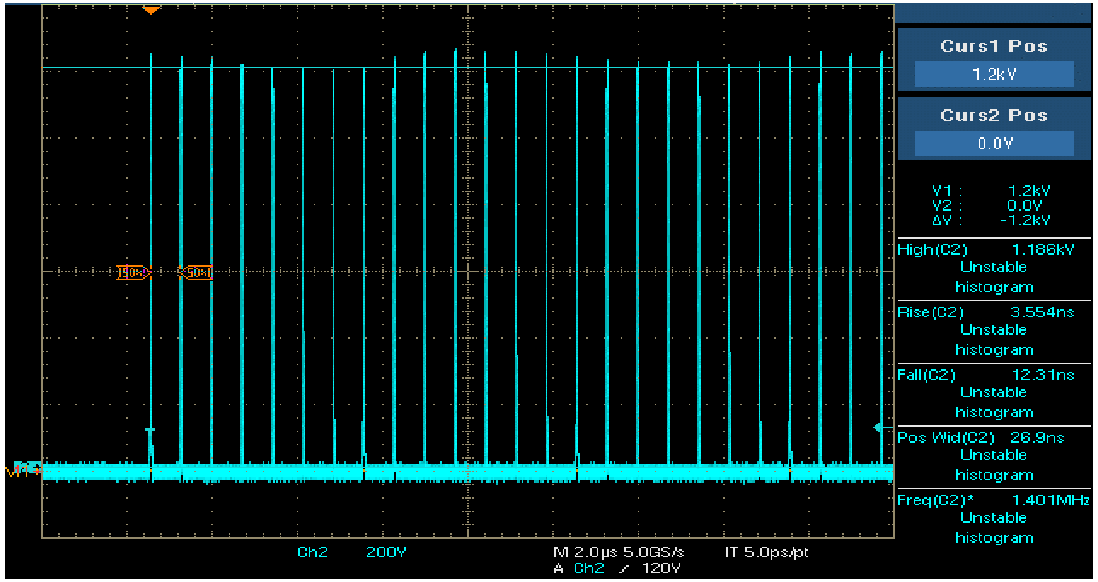
100 ns pulse width



Parameter	Value
Output voltage	1200 V
Pulse length	from 25 ns
Rise/fall time	3.9/11 ns
Repetition rate	up to 1.4 MHz
Dimensions	3.15 x 2.84 x 1 in

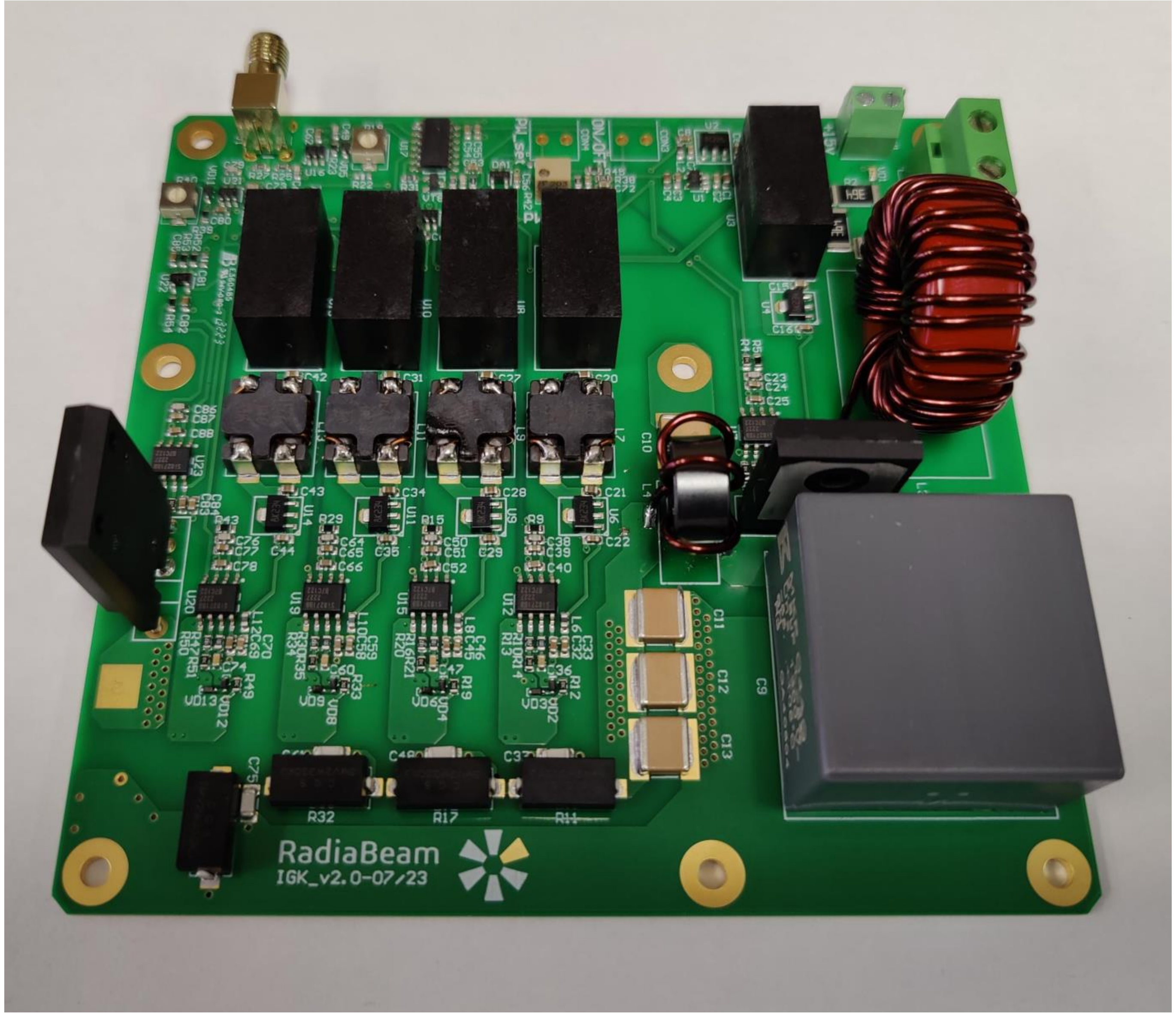
RadiaBeam pulser development (GaN) – v2





- 100 us (150 pulses) burst
- 1200 V, 100 ns FWHM
- 1.4 MHz rep rate
- 10% of the required duty factor is achieved

RadiaBeam pulser development (GaN) – v3



- 4 transistors
- Improved cooling
- Testing is in progress

Summary:

- Kicker EM and mechanical design are complete
- Pulser development status: 1200 V, 4ns/11ns rise/fall, 1.4 MHz, 10% power
- Improve GaN-based pulser cooling to achieve full 3.8 kW output
- Assemble two-channel pulser with control system
- Kicker fabrication, assembly and tests
- Installation and beam-based tests at JLAB