Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps

PI: Sergey V. Kutsaev, Ph.D.

Presenter: Alexander Smirnov, Ph.D.

DOE SBIR Award DE-SC0019684

DOE NP SBIR/STTR Phase II PI Exchange Meeting, August 25, 2022

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

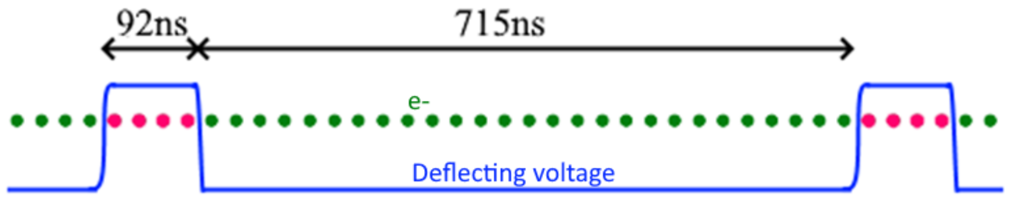
Project Goals and Specs

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)

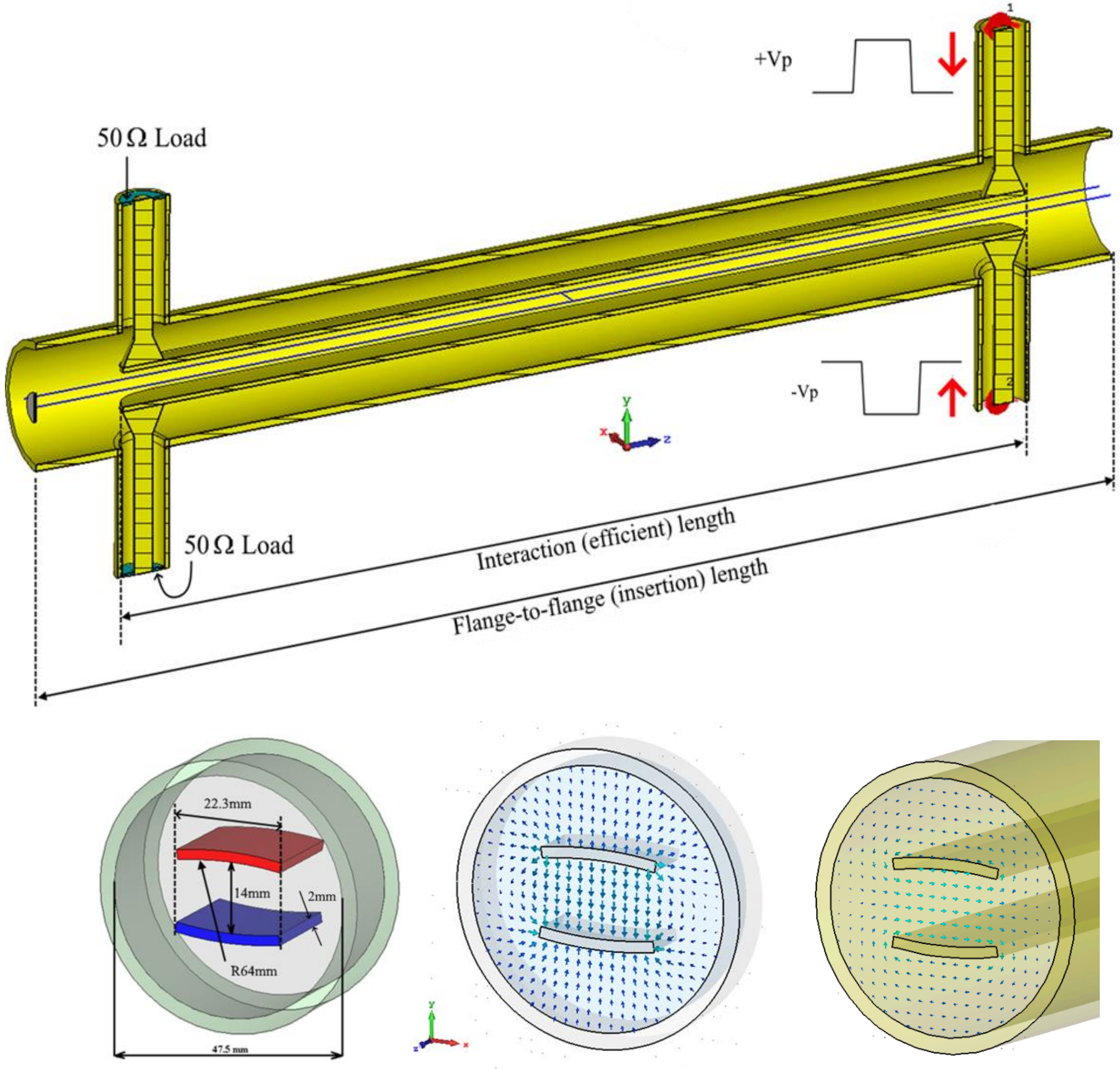
  Most recently 200ns at 470KHz

- 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
  - Aperture 14 mm
  - Maximum insertion length 75cm

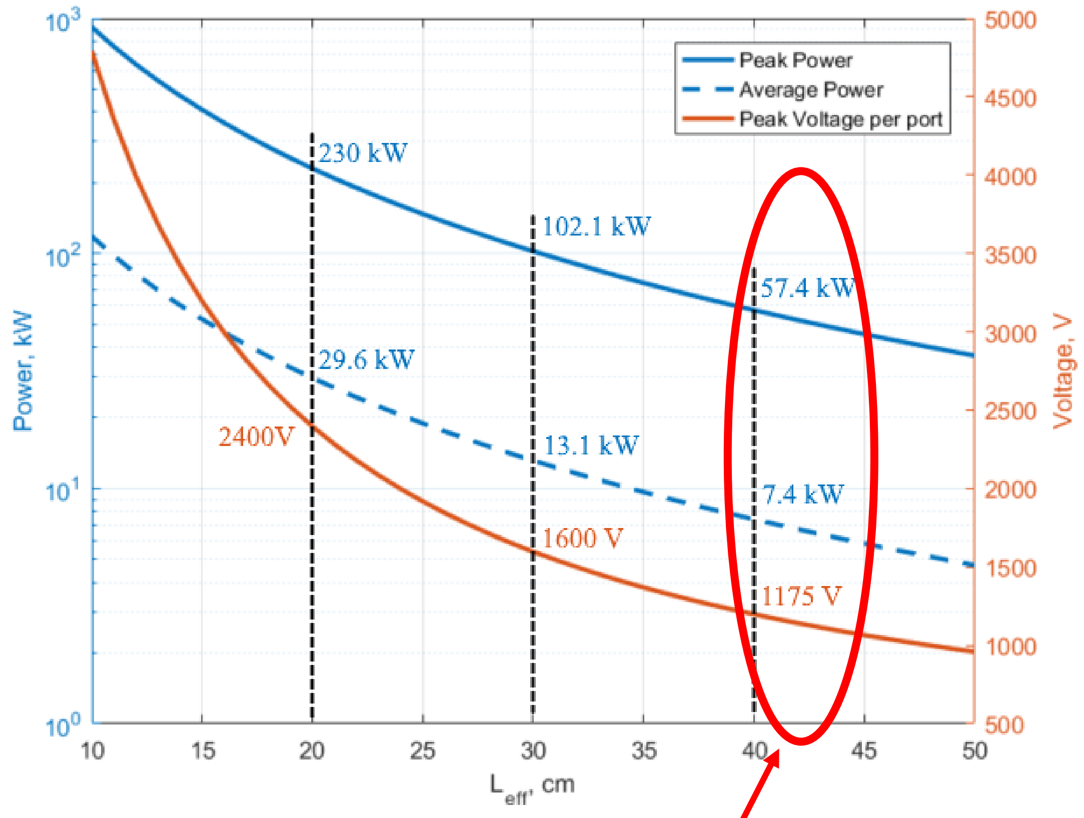


Parameter	Value
Deflecting angle	20 mrad (deflecting voltage 140 kV)
Electron Beam Energy	7 MeV
Bunch Repetition Rate	37.5 MHz
Bunch rms transverse size	σ=1 mm
Deflecting Pulse Width	100 ns flat-top required to deflect 4 out of 31 bunches in train
Kicker operation per rate	1.4 MHz (715ns between the 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)

EM design



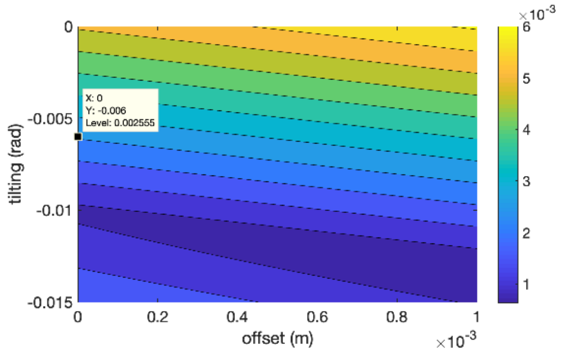
Power required for 20mrad deflection



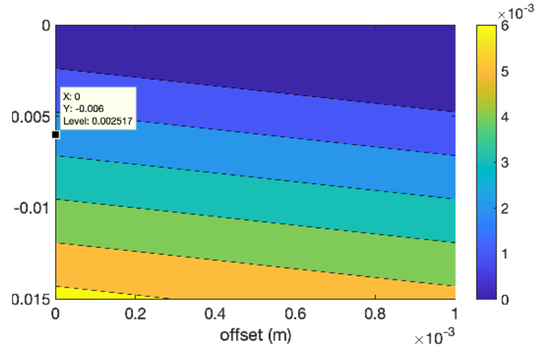
40cm interaction length

Beam dynamics study

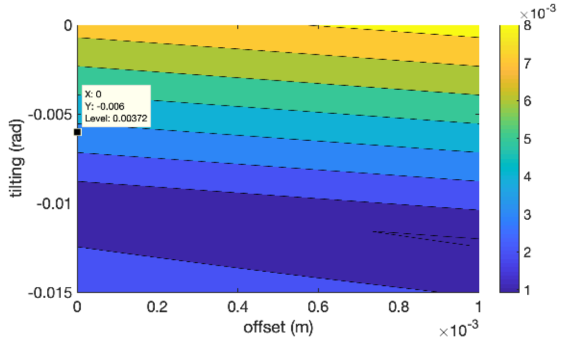
Exit offset spectrum over injection parameters



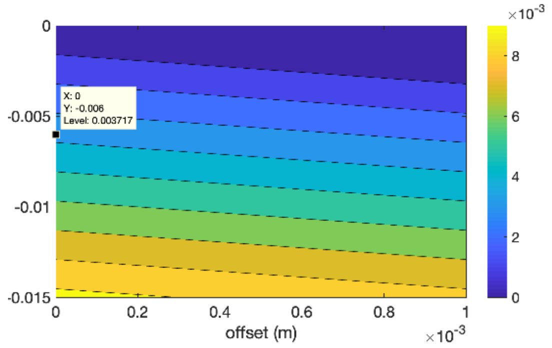
Kicked bunch (400mm)



Unkicked bunch (400mm)



Kicked bunch (600mm)



Unkicked bunch (600mm)

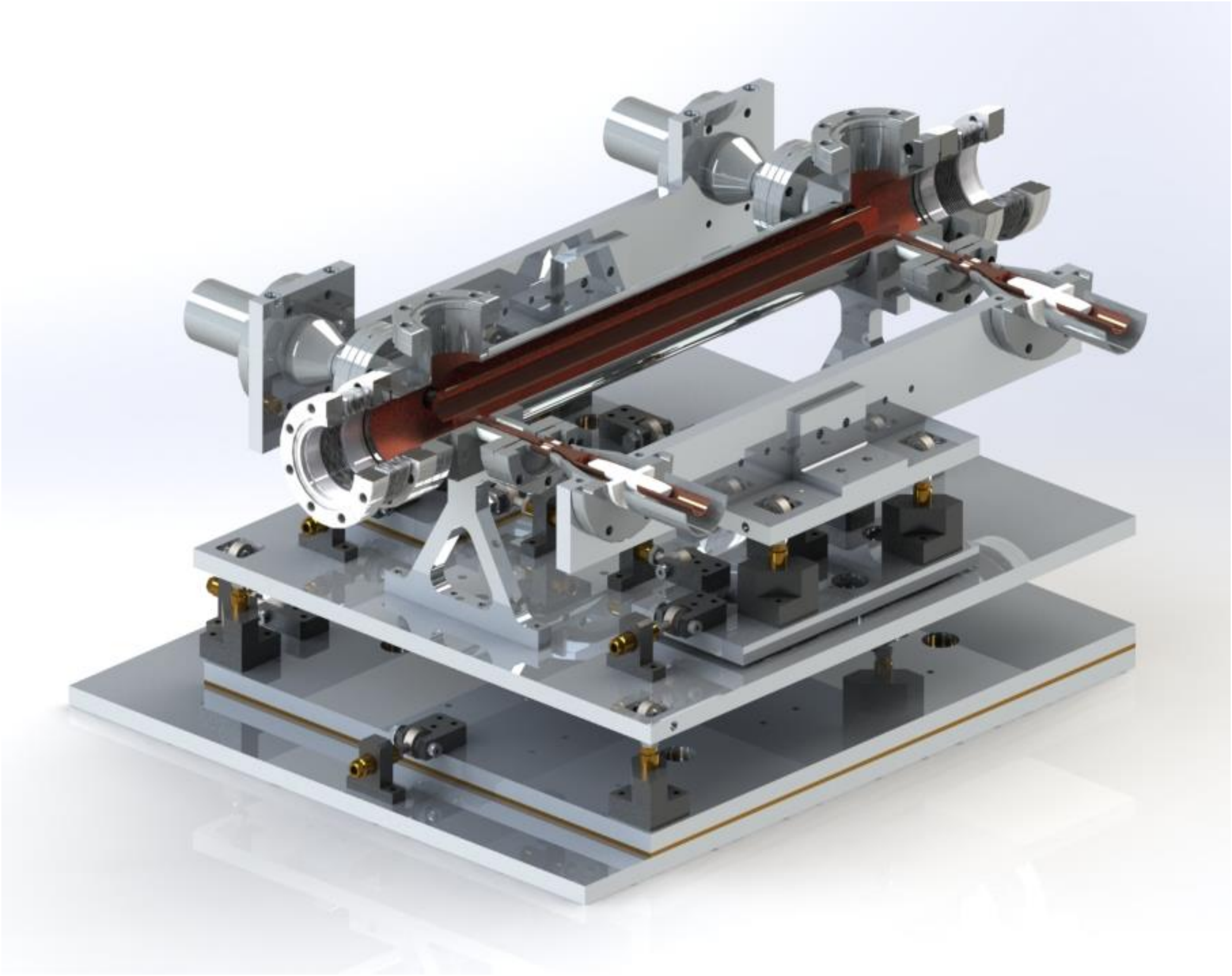
Beam loss with various interaction lengths

Analytic evaluation	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
20 mrad 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}	$.6 \times 10^{-3}$	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}	$.6 \times 10^{-3}$	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

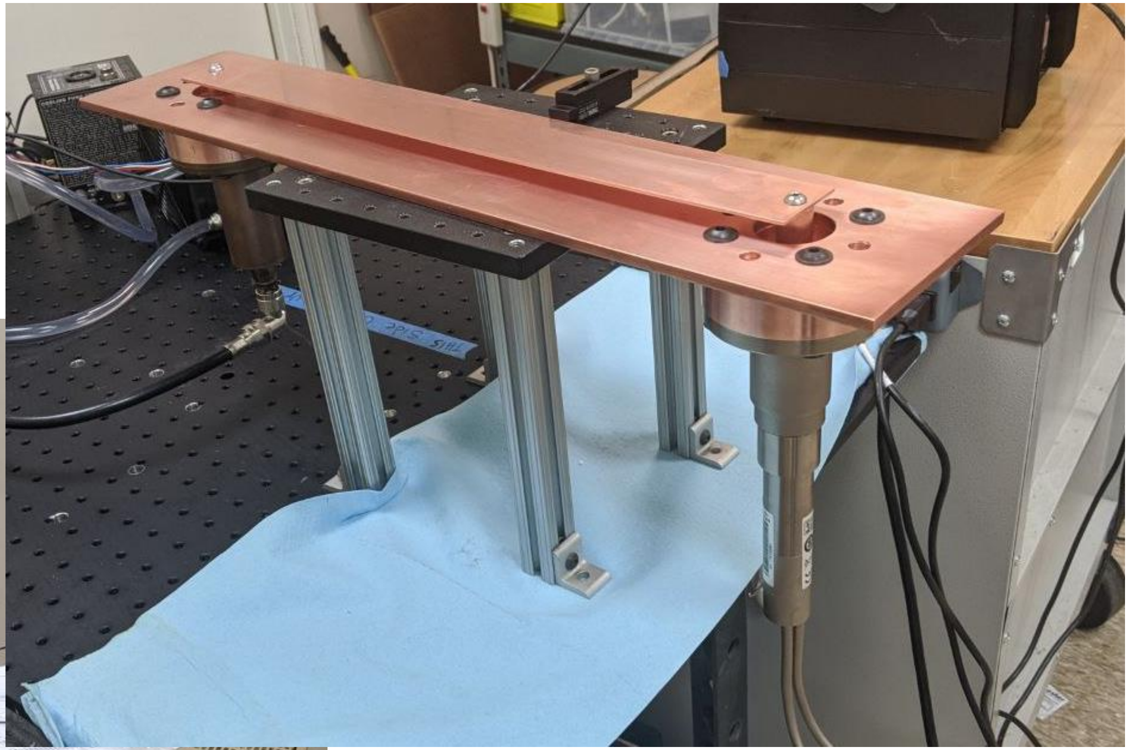
Engineering model

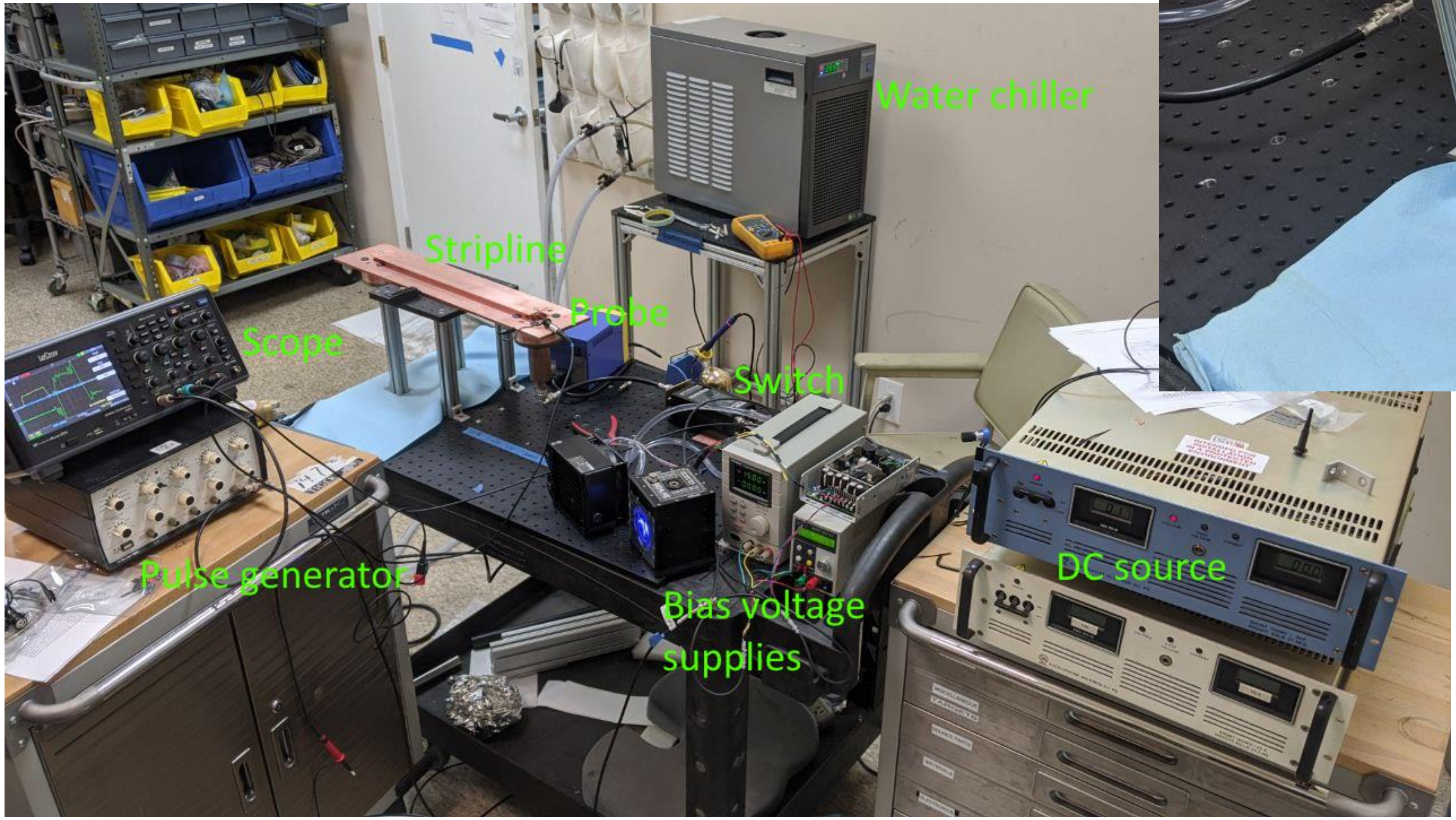
- Standard 1-5/8” EIA compatible
- XYZ Positioning stage
- No dielectric supports



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
- 2000 V / 10 A DC supply

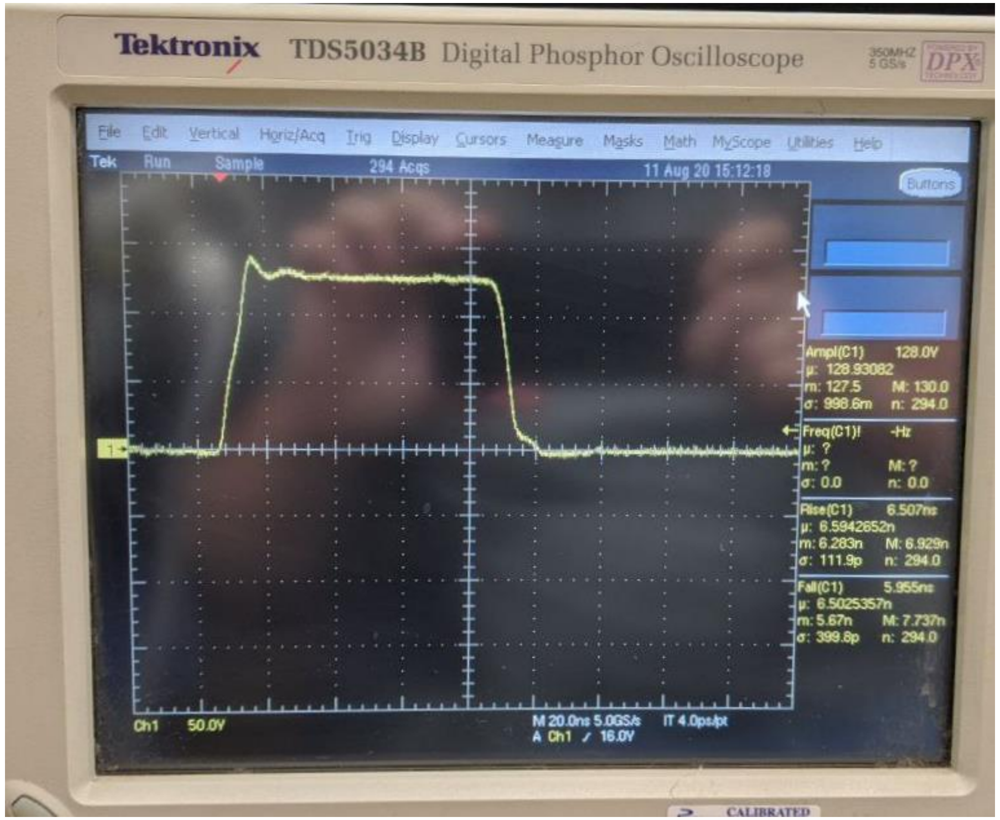


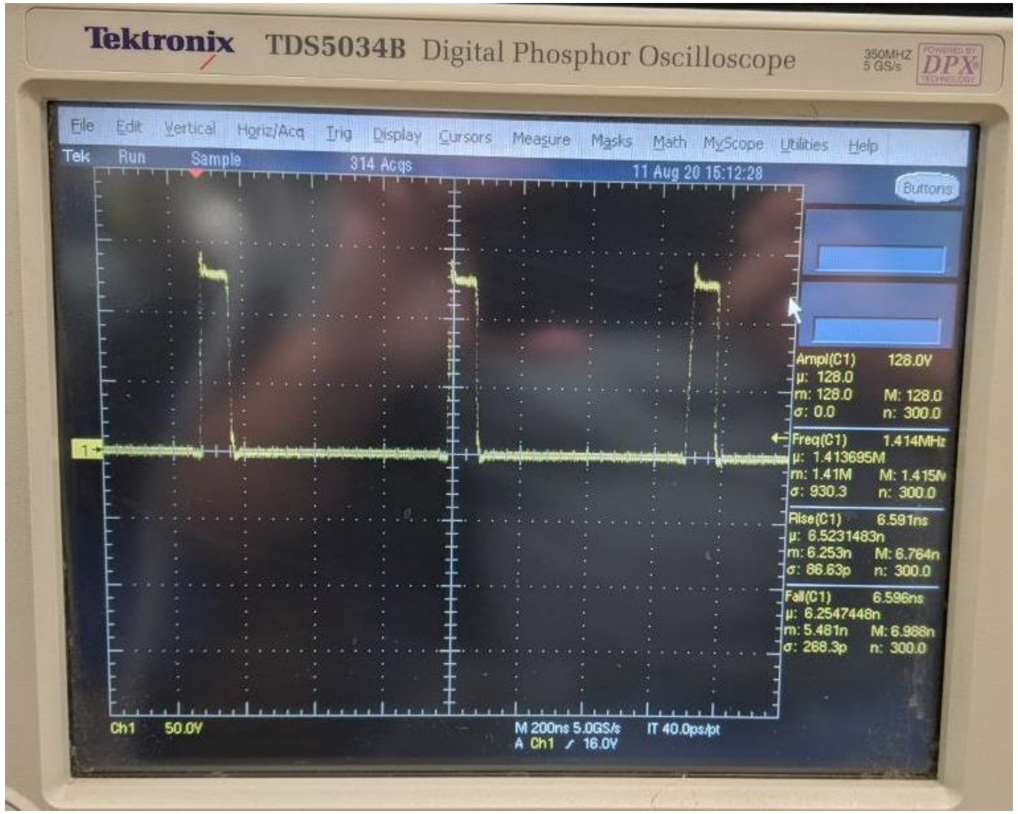


Pulser testing (Si MOSFET)

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**

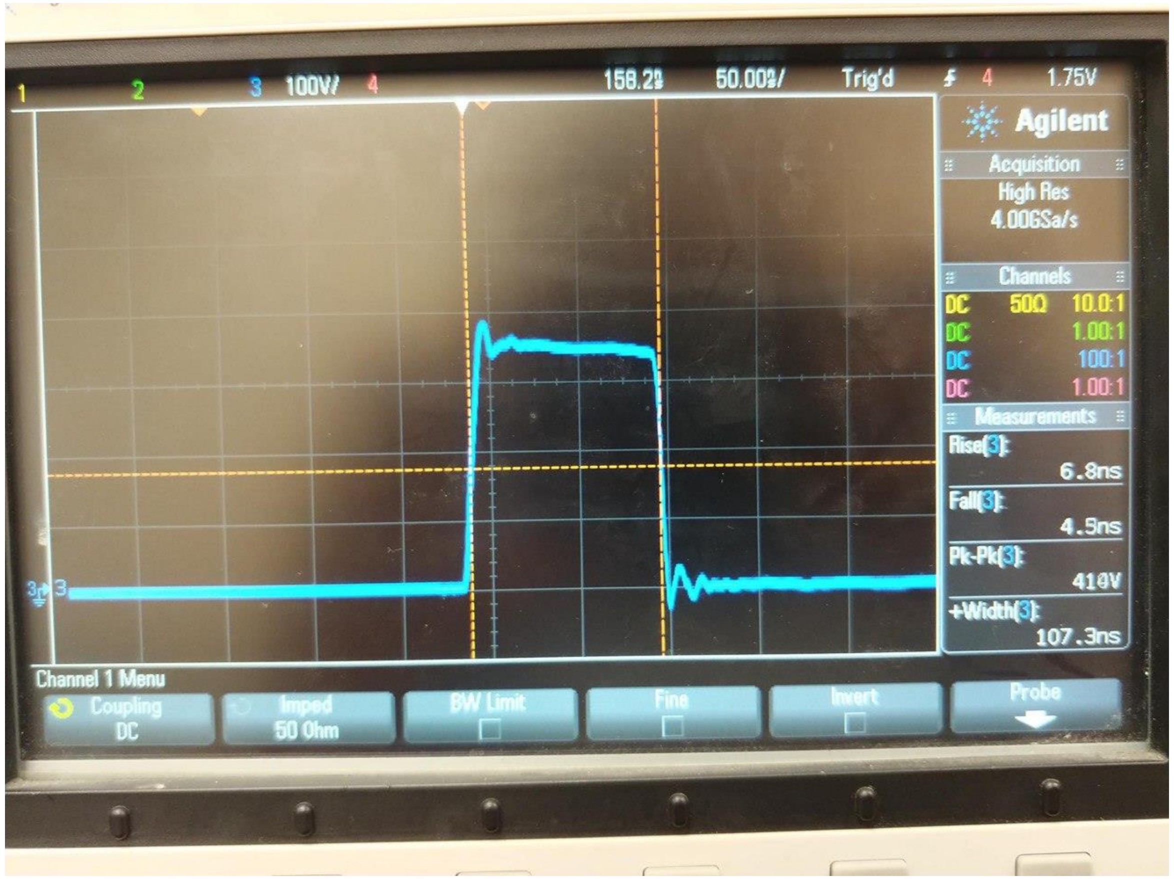




Pulser testing (Gallium Nitride)

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**



RadiaBeam pulser development (GaN) - 1

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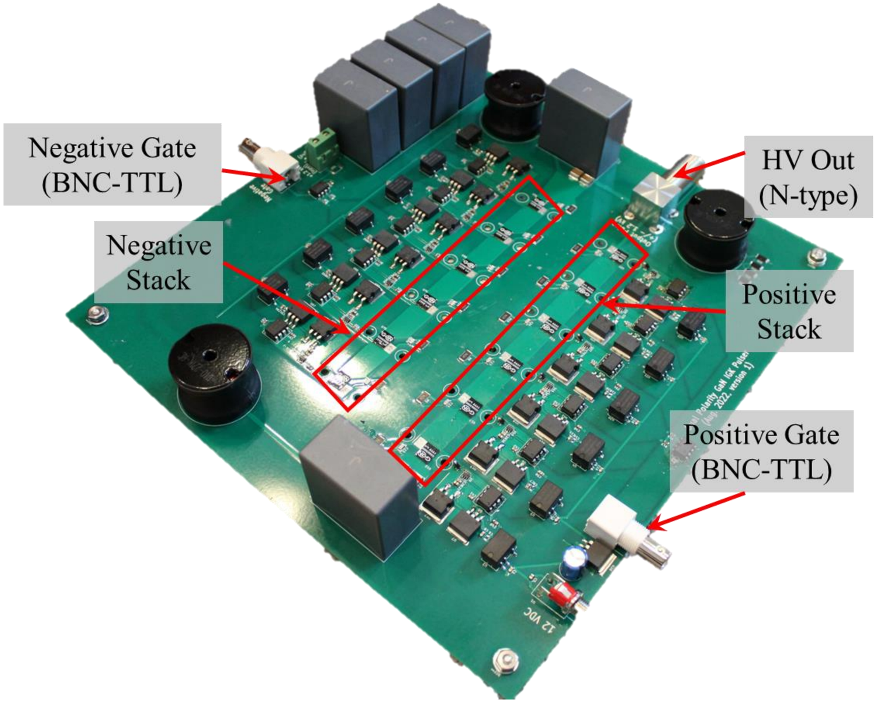
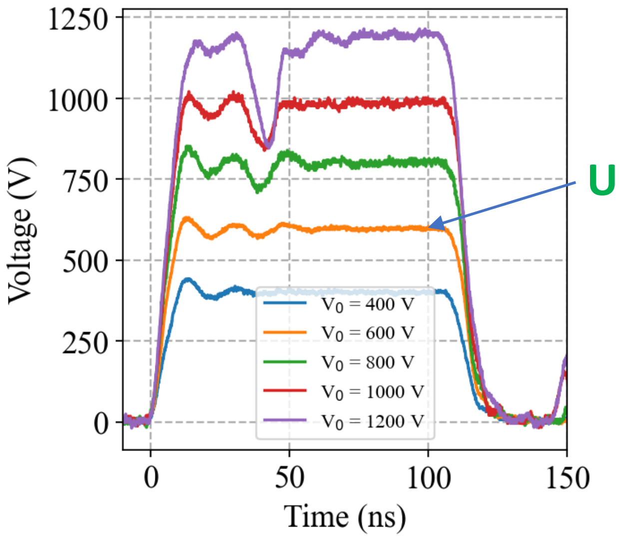
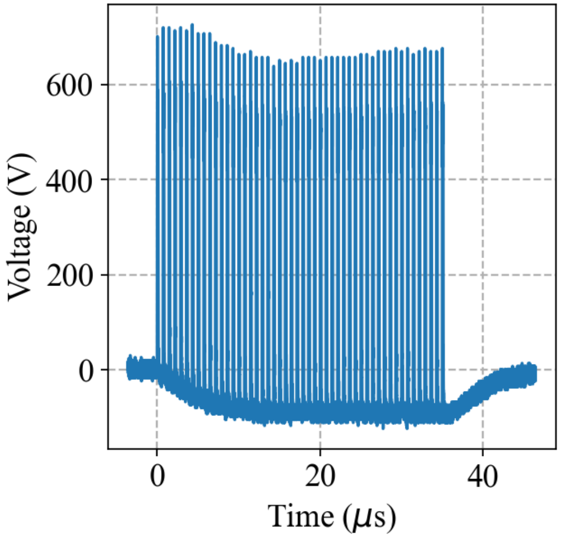
Achieved:

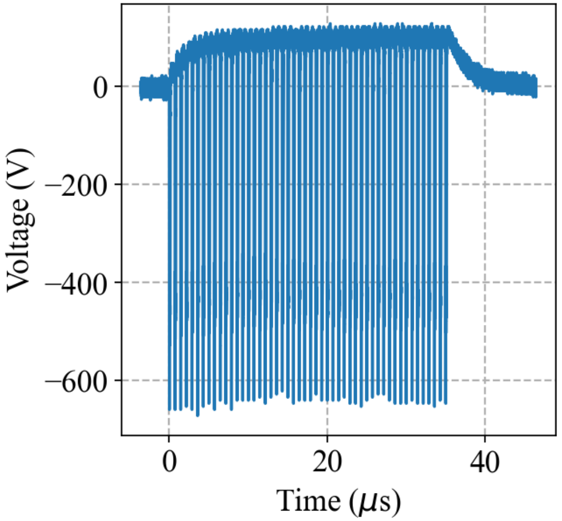
- 10 ns rise and 11 ns fall times @ 107 ns flat-top
- 1.4 MHz repetition rate (short bursts)
- **85% efficiency**





Up to 600V so far (to be improved)





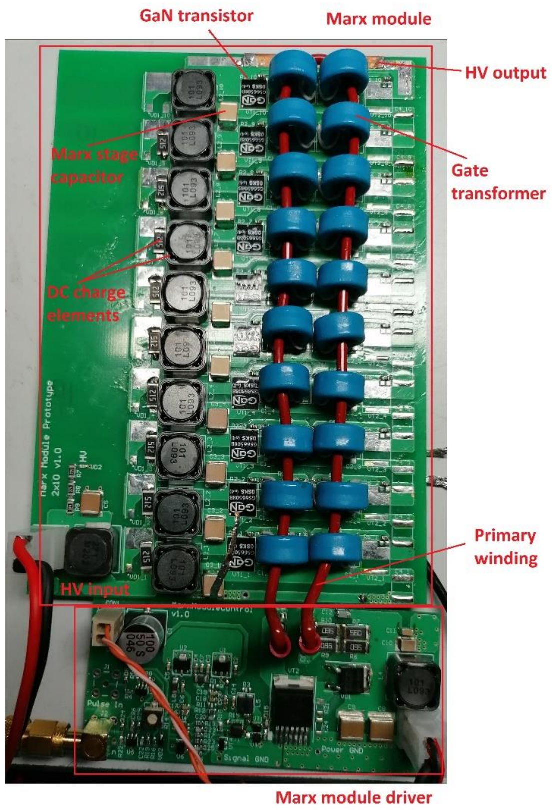
Positive channel Negative channel 1.4 MHz bursts

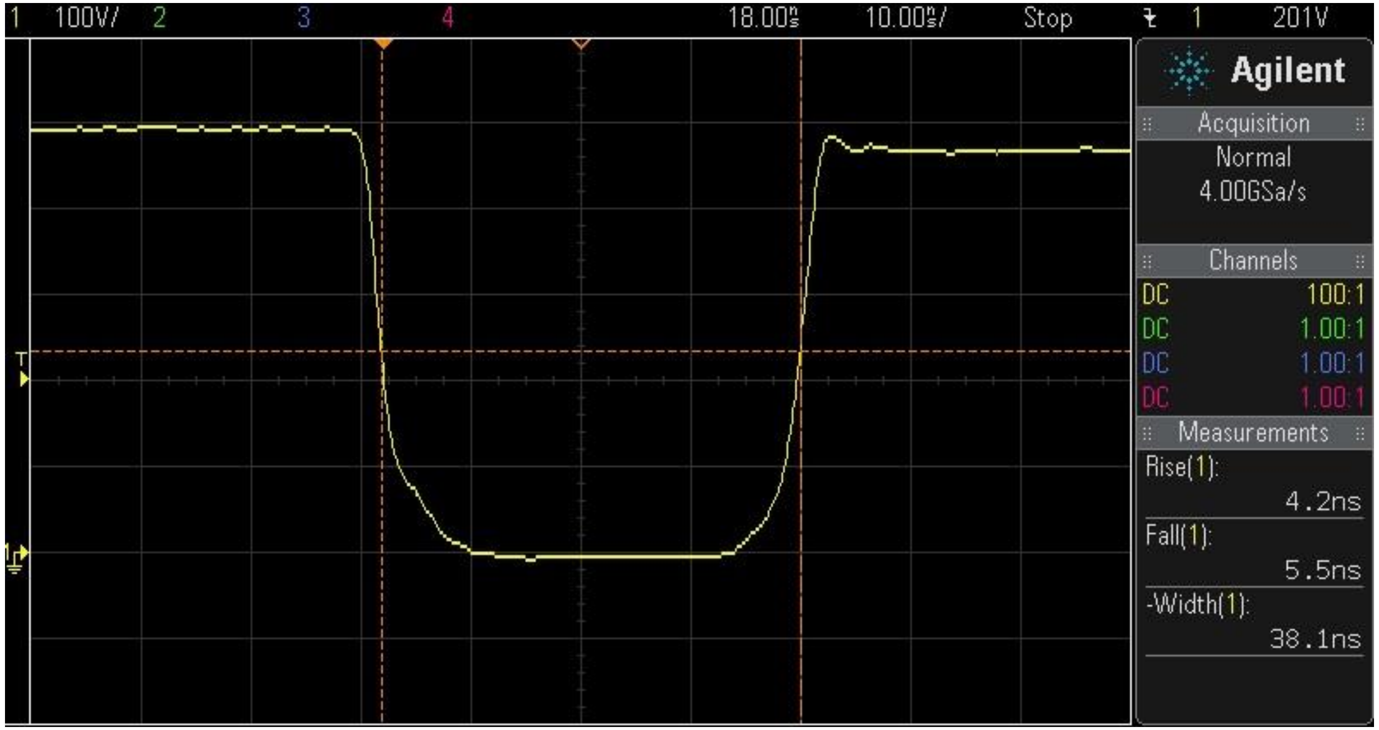
RadiaBeam pulser development (GaN)

Achieved*:

- 4.2 ns rise and 5.5ns fall times @ 38 ns flat-top
- 100 Hz repetition rate
- **95% efficiency**

*under Phase I project DE-SC0021548
2022 PHASE II for EIC pulser, **50kV** 7ns rise/fall (4.5ns – achieved in Phase I), 30ns * 100 Hz





Summary:

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- Kicker EM and mechanical design are complete
- Improve GaN-based pulser to achieve 1175V, 5/6ns rise/fall, 1.4 MHz
- Assemble two-channel pulser
- Kicker fabrication, assembly and tests
- Installation and beam-based tests