DARHT 2nd Axis Refurbishment and Commissioning Project

Commissioning the DARHT-II Scaled Accelerator Downstream Transport

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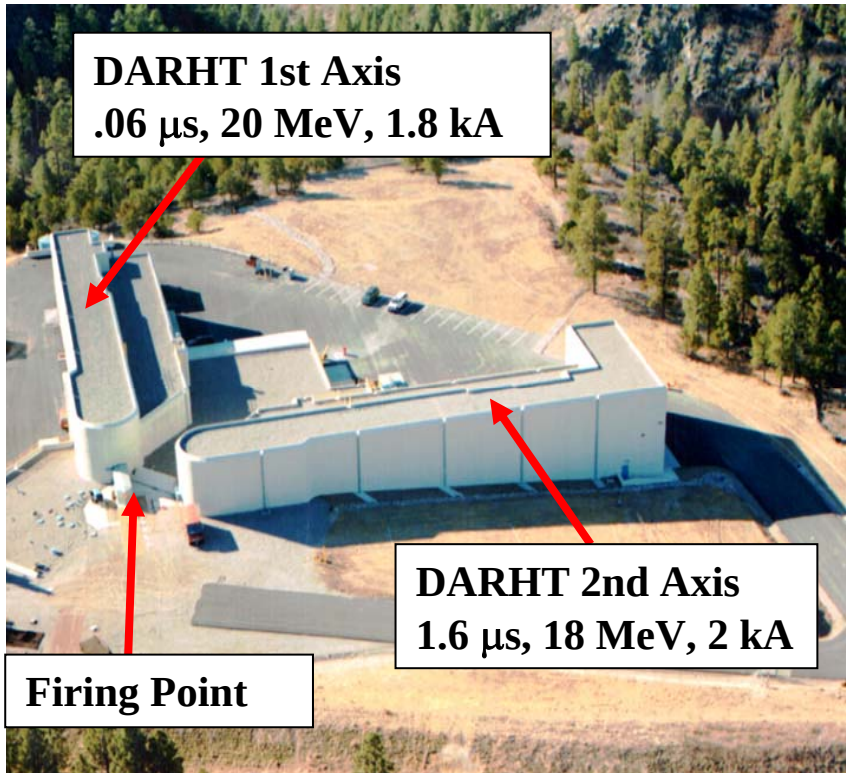
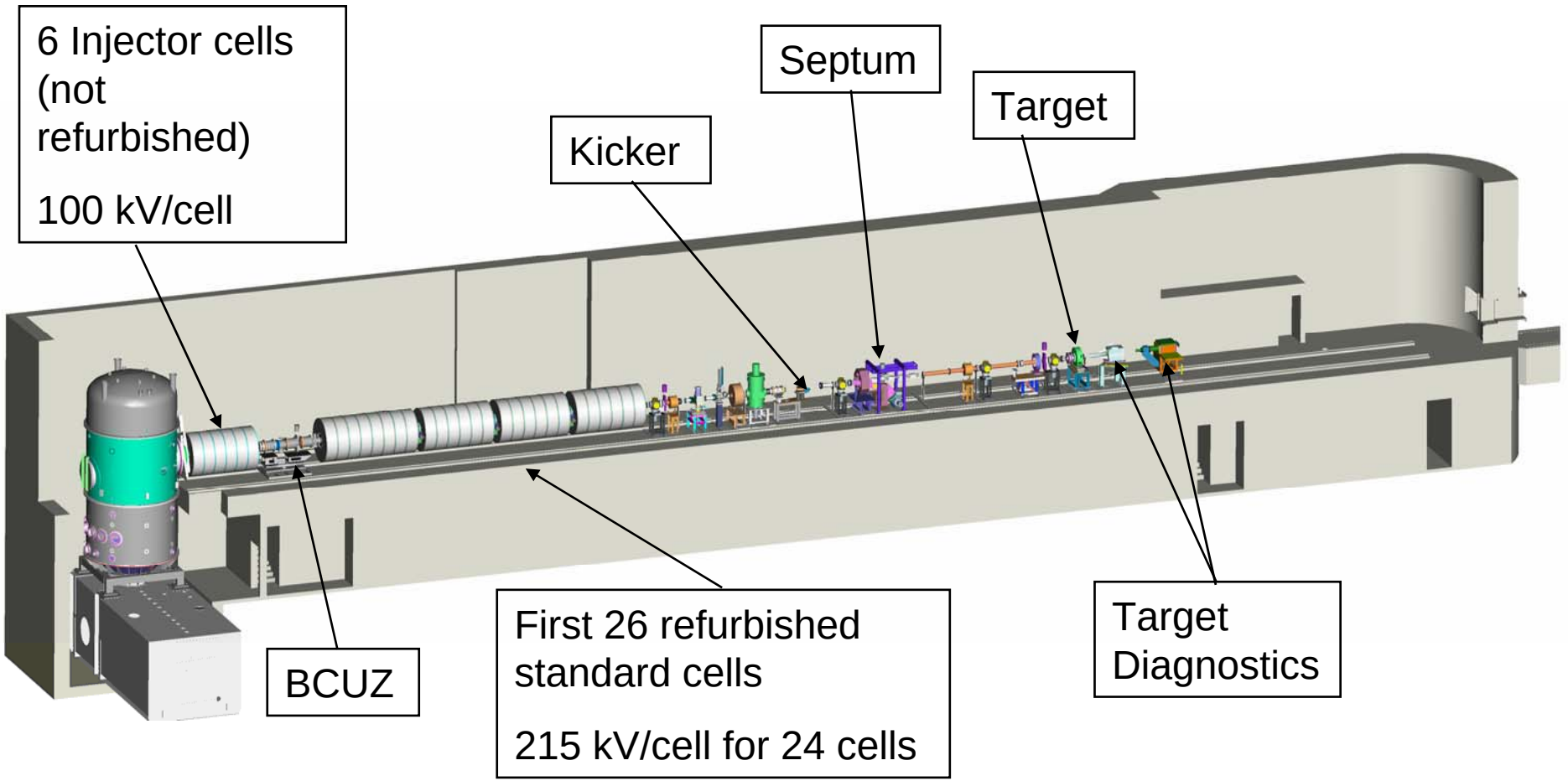
When the DARHT 2nd Axis is completed, the DARHT facility will provide orthogonal-multiframe images

Injector Voltage	2.5 MV
Injector Current	2 kA
Flattop time	1.6 μsec
Injector Cells	6 @ 190 kV
Accelerator Cells	68 @ 220 kV
Total Energy	18 MeV
Pulses to target	4
X-ray output	100, 100, 100, 300 Rads @ 1 m
X-ray spot size (FWHM)	< 1.4 mm

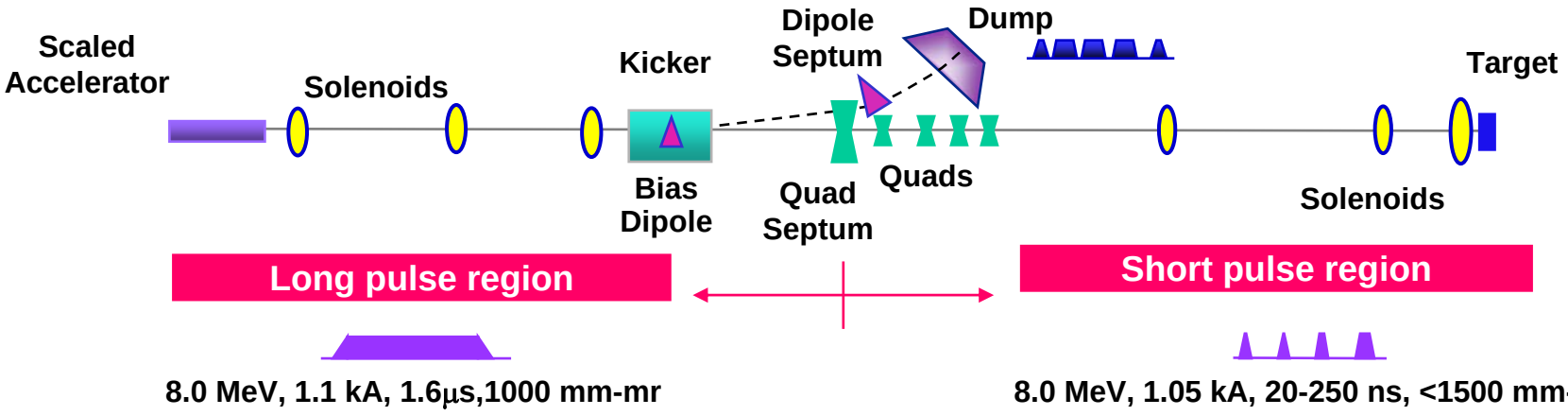


Scarpetti - TUXC01

The Scaled Accelerator has provided the Beam Needed for a Scaled Test of the Kicker and Multi-Pulse Target



Scaled accelerator downstream transport system addressed multi-pulse and long pulse physics issues



Scaling considerations impacting system design and tune

From the Kicker and Transport:		***Scaling***
Kicker operation & control system	4 pulses, 1.6 μs	none
Septum gas desorption	4 pulses, 1.6 μs	$I\, n_p\, \tau_{kicker\_sw}$
Beam induced kicker steering	1.6 μs	$I/\gamma\beta$
Background gas focusing	1.6 μs	$IP/\gamma\beta$
Ion-hose instability	1.6 μs	$I\, P/\gamma\beta$
Transverse resistive wall instability	1.6 μs	$I/\gamma\beta$
Spot size dilution due to kicker switching	20 – 200 ns	none

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The beam transport optics has four semi-independent regions

- **Accelerator to septum quad**
  - Produce small waist at septum quad using S1 and S3
  - Minimizes sensitivity to ion hose with large variation in beam envelope
- **Septum dump**
  - Defines fields in “bending magnets”
    - Bias dipole, Septum quad, Septum dipole
  - Dispersion ~1.2 cm/%
  - Energy acceptance ~15%
- **Kicker and Collins Quadrupoles**
  - Produce four short beam pulses of adjustable length
  - Recover round beam
    - Determine fields in 2nd and 3rd Collins quads as a function of 1st Collins quad
- **Transport to target with S4 and FF**
  - Minimize kicker smear
  - Produce small spot on target

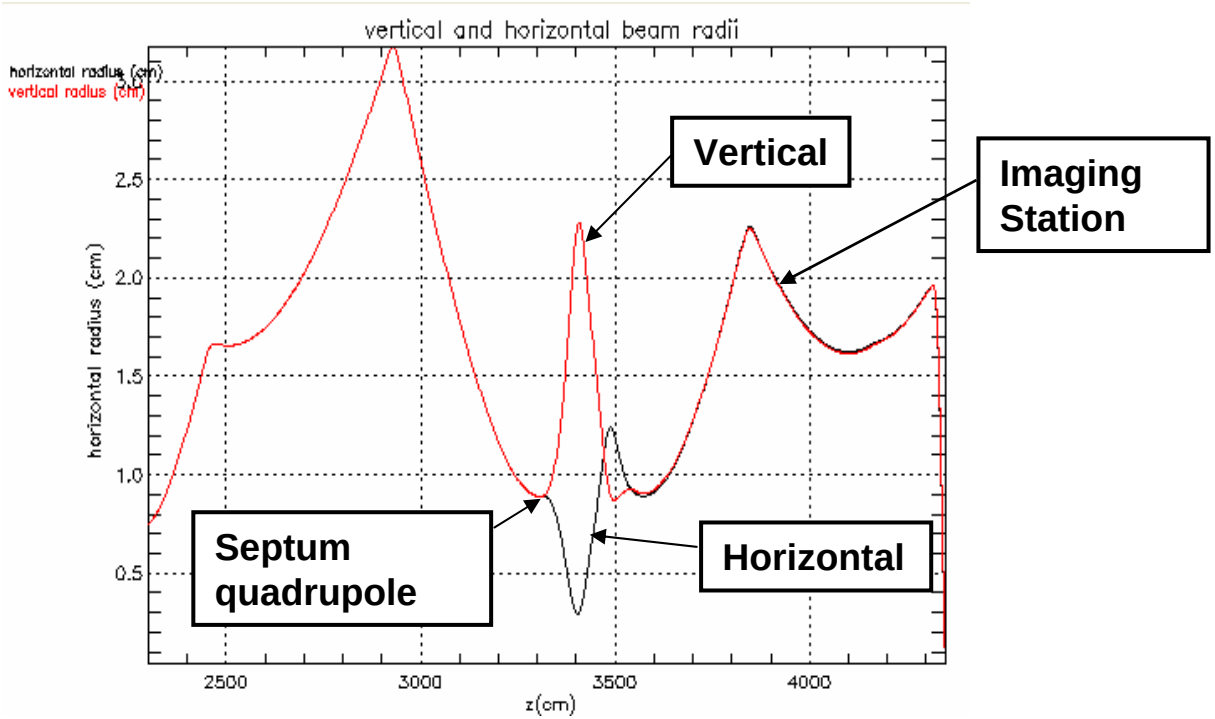
We Measured the Beam Parameters at the Accelerator Exit by Varying the Strength of a Focusing Solenoid

- The beam size was measured as a function of the solenoid magnet current.
- With knowledge of the beam energy and current from independent measurements, we determine the best fit to the transverse beam parameters from the beam size measurements.

Parameter	Value
Energy	8.0 MeV
Current	0.9 to 1.1 kA
Size	0.8 cm
Divergence	3.2 mrad
Normalized emittance	617 π(mm-mrad)

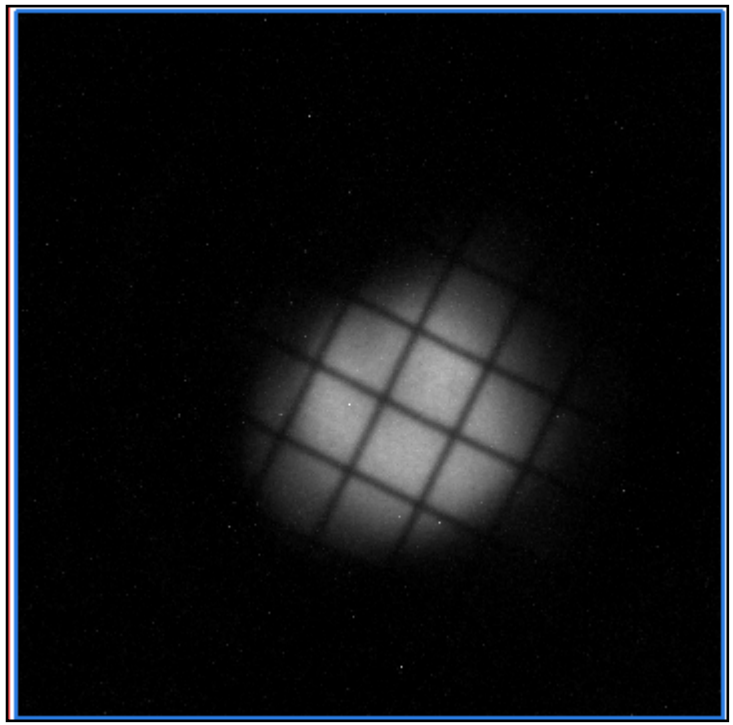
Ekdahl et al. - WEPMS020

Downstream transport tune is optimized to minimize kicker smear without measurable impact on target spot size

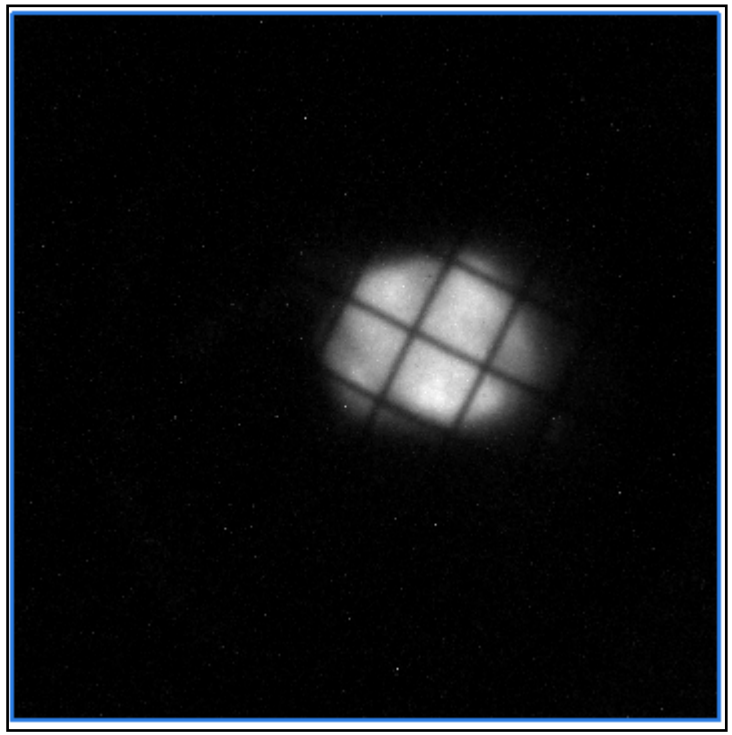


- Different tunes to minimize sensitivity to “kicker smear” were studied
  - Different Collins quadrupole settings
- Each tune has a different beam size and convergence angle at the target

After kicking a 40 ns pulse, we restored the round symmetry on the first attempt



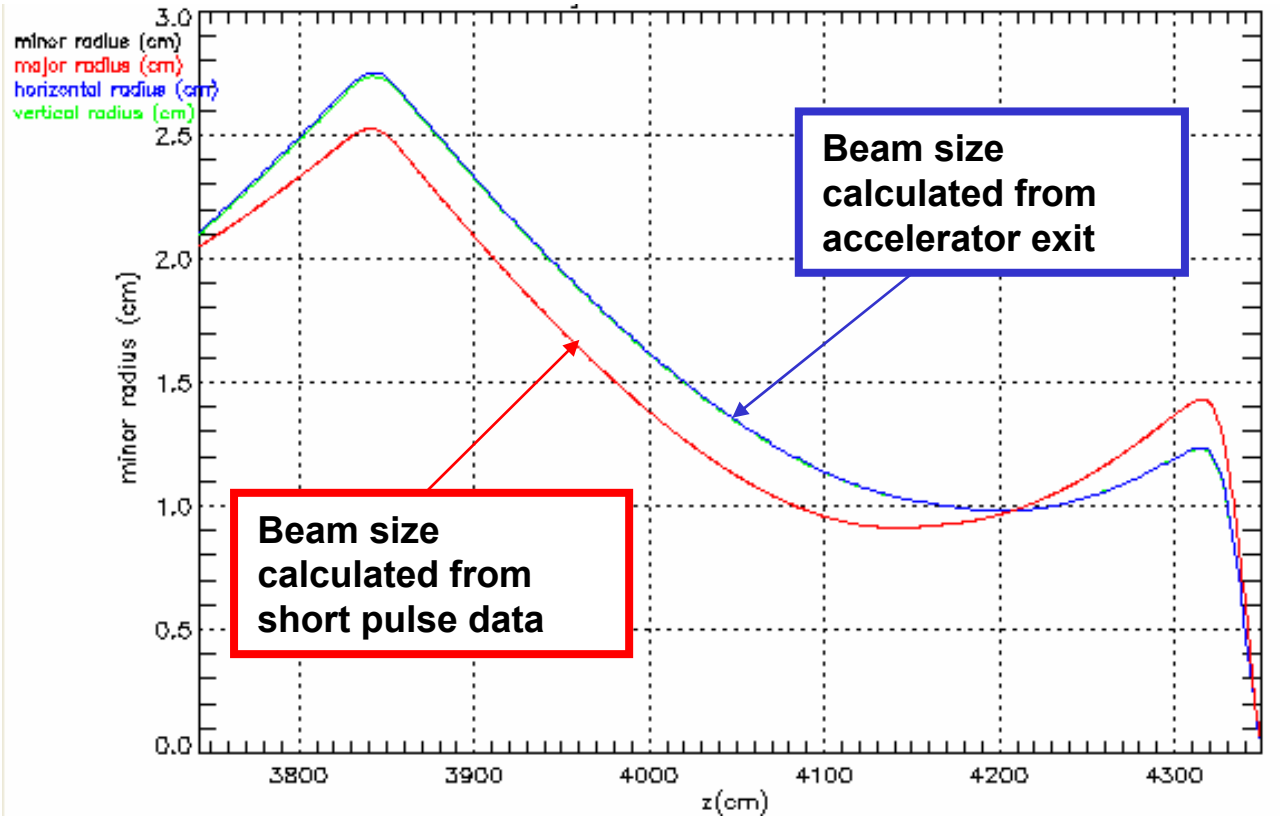
$\langle x^2 \rangle / \langle y^2 \rangle = 1.07$
Beam is 1.1 x LAMDA prediction



$\langle x^2 \rangle / \langle y^2 \rangle = 1.11$
Beam is 1.07 x LAMDA prediction

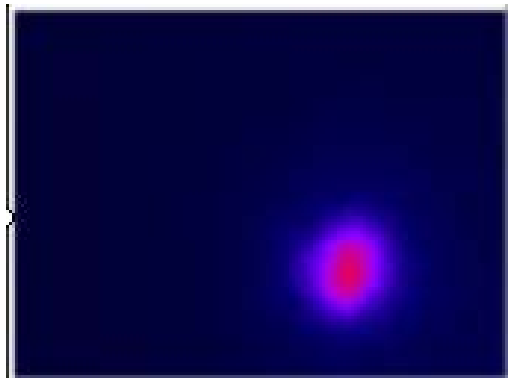
Measured beam size is in very good agreement with model simulations.

Measurement of the short pulse beam parameters agrees well with the predicted tune from the accelerator exit

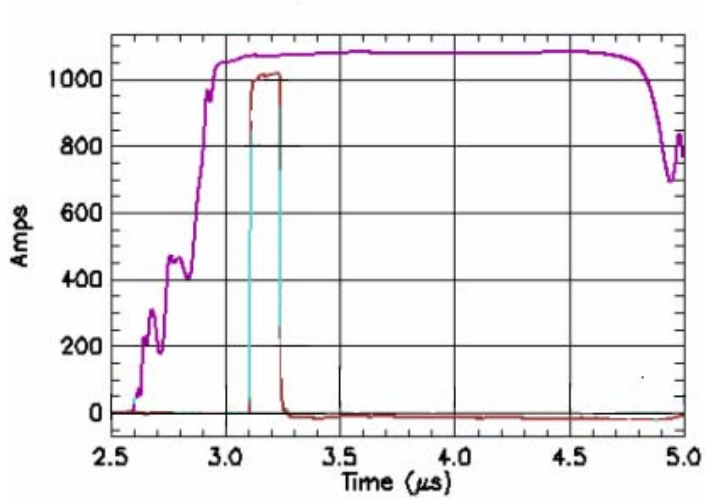


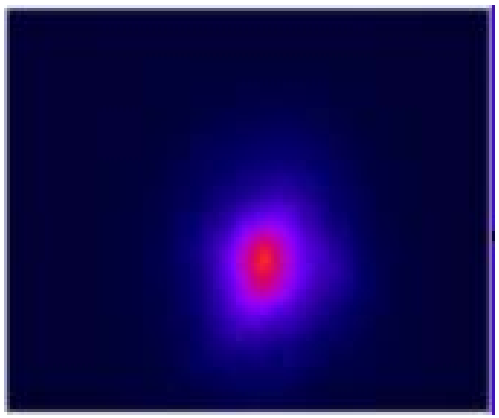
A normalized beam emittance of about 900 π(mm-mrad) is inferred from the beam size on the target and convergence angle.

The beam size on target at P1 and P4 times are essentially the same

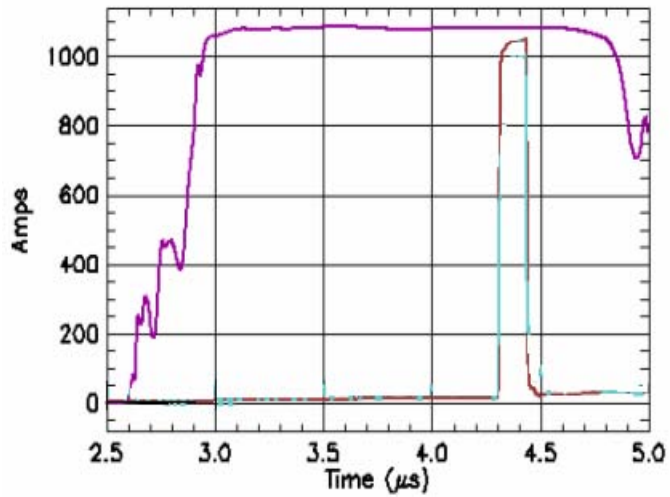


P1 time r = 1.50 mm (FWHM)

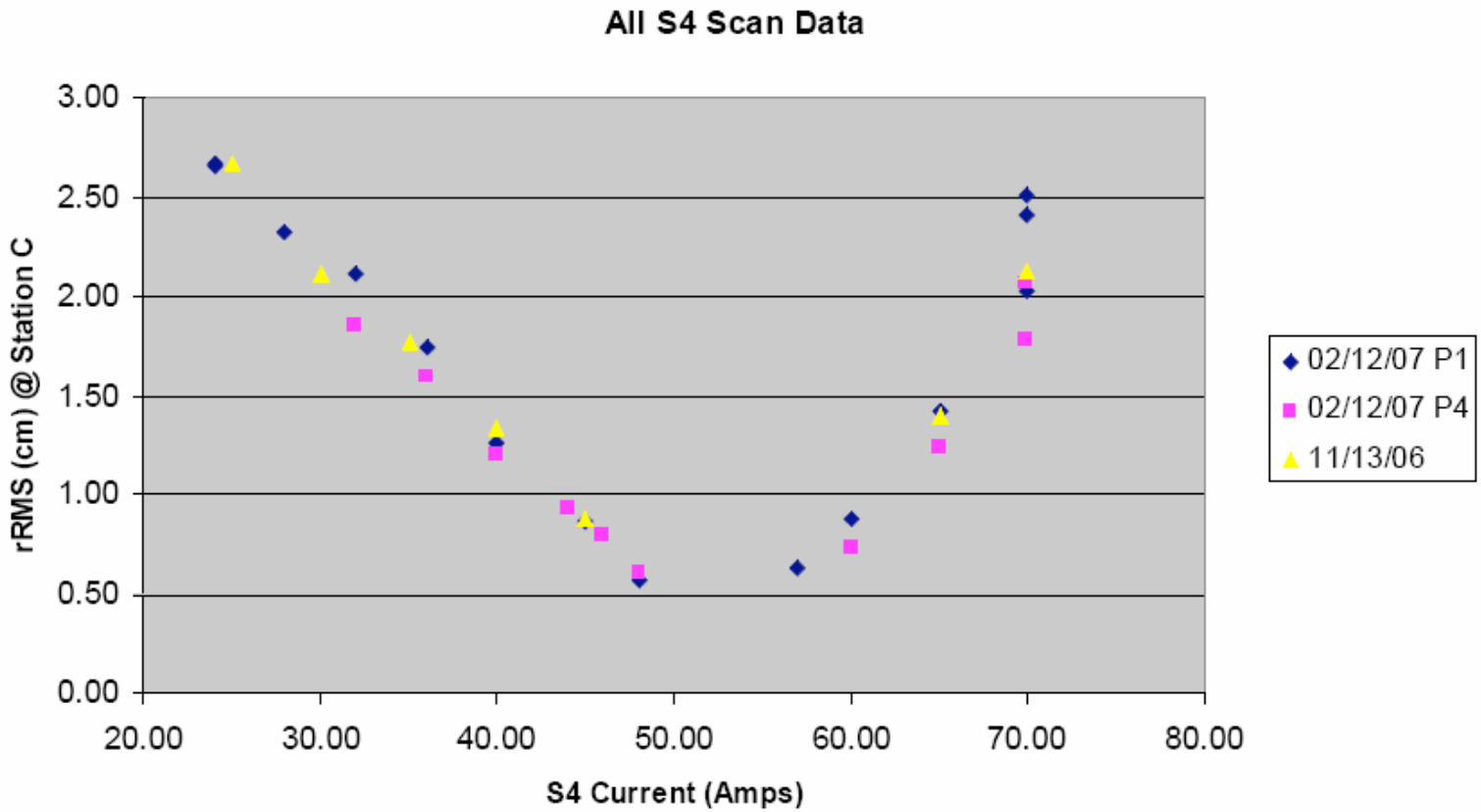




P4 time r = 1.43 mm (FWHM)



Solenoid Scan at imaging station shows flattop and accelerator stability

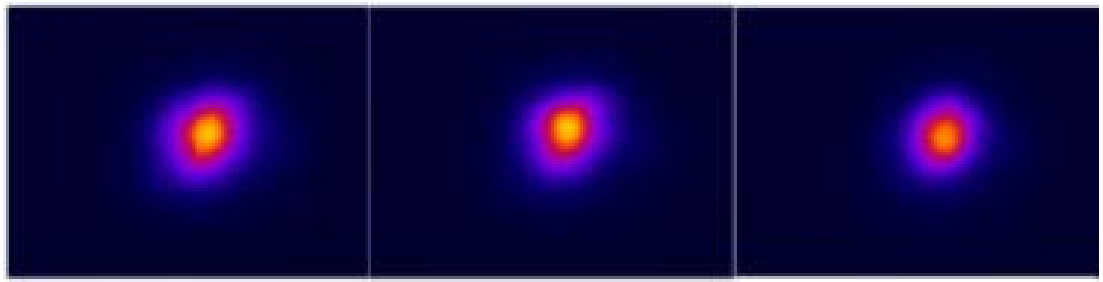


Scans at P1 and P4 times are essentially identical

Scans taken many months apart are essentially identical

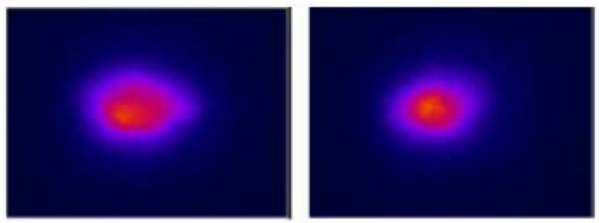
We were able to minimize the kicker smear in the scaled accelerator tests

- **Single pulse shots with effective correction of kicker smear.**
  - **The differences between the 15, 30 and 60 ns pulses show the reduced sensitivity to kicker smear as the pulse length increases.**



15 ns	30 ns	60 ns
FWHM=1.14	FWHM=1.08	FWHM=1.03
x/y=.983	x/y=.962	x/y=.961

- **Pulse 1 of multi-pulse shots with poor kicker smear correction.**



30 ns	60 ns
FWHM=1.57	FWHM=1.43
x/y=1.48	x/y=1.37

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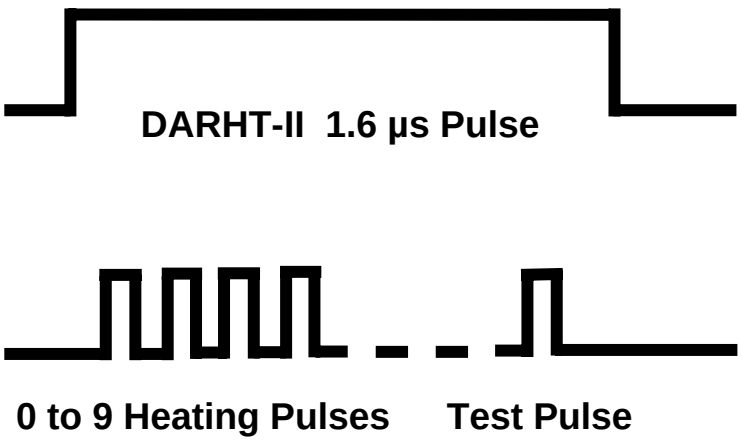
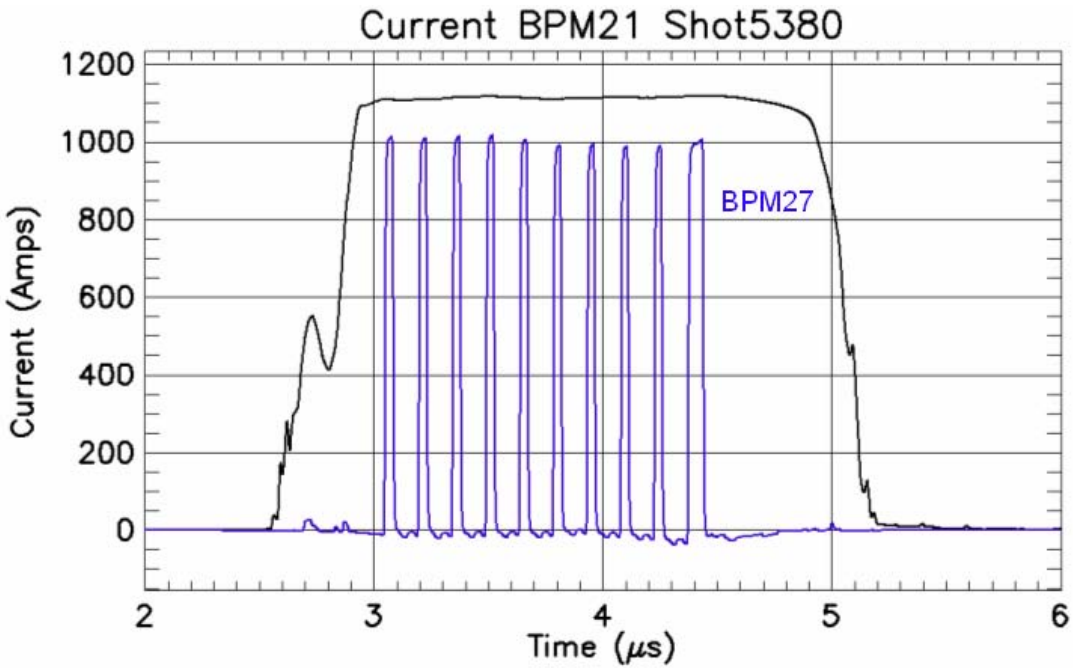
Septum edge heating was studied by kicking up to 9 pre-pulses prior to a test pulse

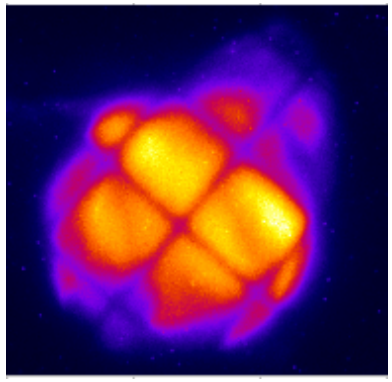
- Beam properties were measured as a function of the amount of total charge deposited on the septum edge.
- The test pulse was at the same time as the fourth beam pulse.
- The beam deposition at the septum edge was adjusted to levels that exceed the beam deposition at full energy.



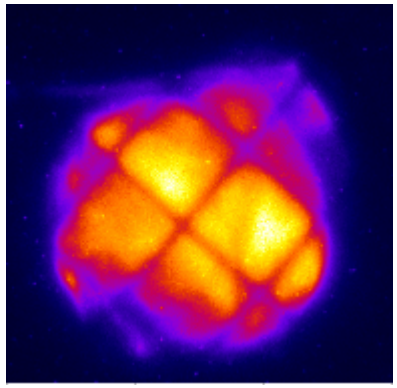
10 kicker pulses



No Effect on Beam Observed, even when Tested to 150% of Nominal Septum Heating at Full Energy



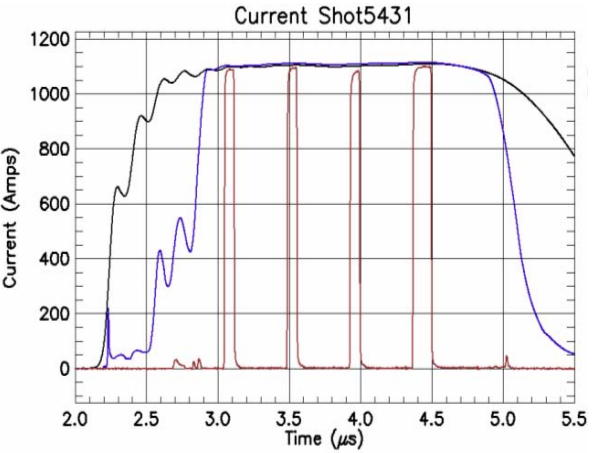
Single kicked pulse at P4 time



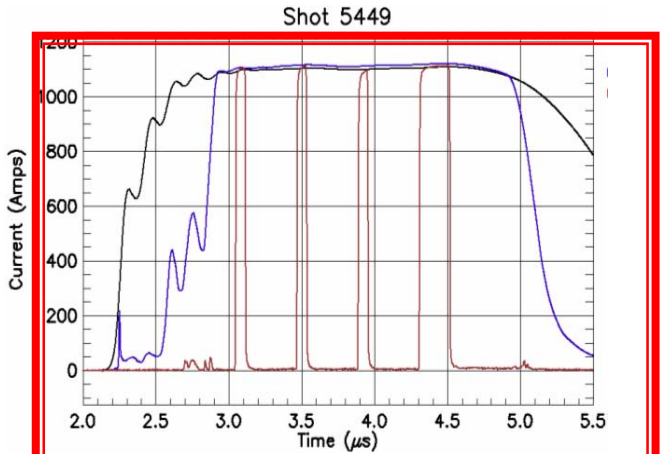
Beam at P4 time after nine pulses

- No significant differences in the beam shape and size were observed.
  - Numerous shots were fired to distinguish between normal pulse-to pulse variations and actual effects.
- The beam position did not vary as measured by the BPMs between the septum and the imaging target.
- No effects of ions from the septum dump were observed

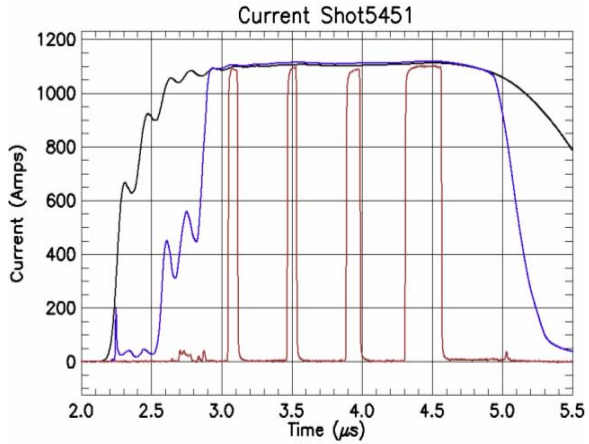
Kicker pulse formats covered a 1.5-1.6 μs flattop and exceed the pulse lengths needed to achieve the dose goals



Four pulses
60 ns
60ns
60 ns
120ns



Four pulses
60 ns
60ns
60 ns
200ns



Four pulses
60 ns
60ns
90 ns
250ns

- **Center pulse format expected to meet the x-ray dose goals of 100R, 100R, 100R, 300R.**
- **Pulse lengths are reduced by factor of 2 at full current**

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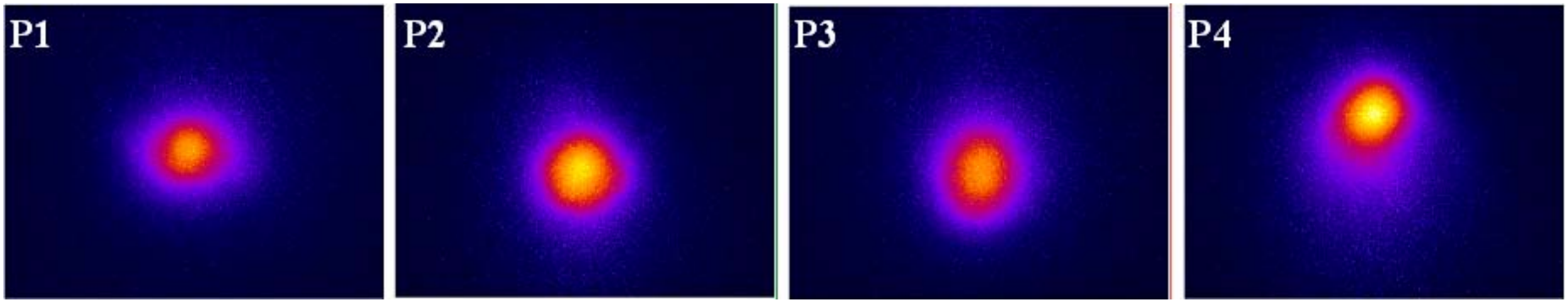
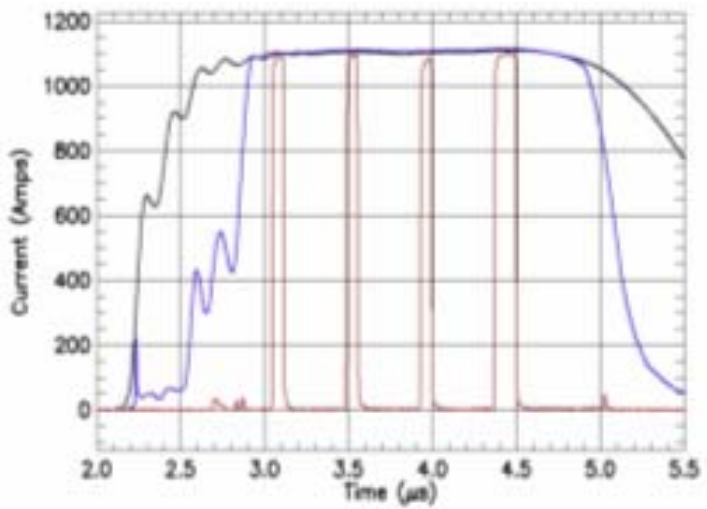
The Scaled Accelerator Test demonstrated four-pulse radiographic feasibility





Four pulses
60 ns
60ns
60 ns
120ns

Measured beam sizes are ~1.0 mm FWHM for all four pulses

DARHT-II requirement: 4 pulses with < 1.4 mm FWHM

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DST and Kicker Commissioning Objectives for the Scaled Accelerator Test Were Achieved

- **Matched beam from accelerator to downstream transport.**
- **Demonstrated stable long pulse beam transport to septum dump.**
- **Demonstrated capability of kicker to produce four short beam pulses of adjustable length.**
- **Demonstrated four pulse spot size on target consistent with meeting project goals and requirements.**

Summary and Conclusions

- **The downstream transport and kicker operated reliably and reproducibly.**
- **We have high confidence in scaling the beam transport system to full energy.**
  - **Scaling parameter, $I/\beta\gamma$, exceeded requirements for scaling to full energy by 10%**
  - **No evidence of instabilities was observed.**
- **The downstream transport is capable of delivering a four beam pulses to the x-ray conversion target consistent with the program requirements.**