A Real-time, Output-Targeting Beam Control System for the UHDR Mobetron

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- Petr Bruza and Brian Pogue are affiliated with Dose Optics LLC, which provided hardware support for this study.

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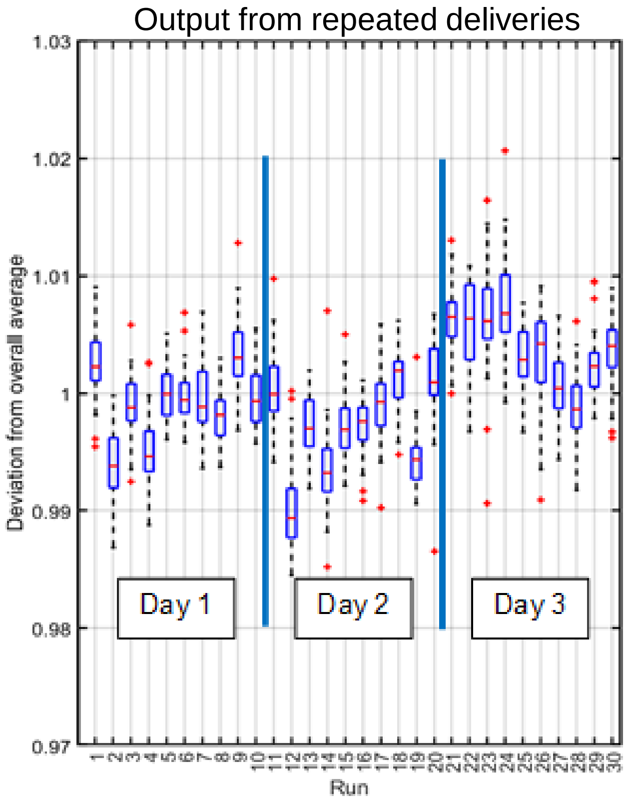
State of electron UHDR / FLASH-RT irradiation:

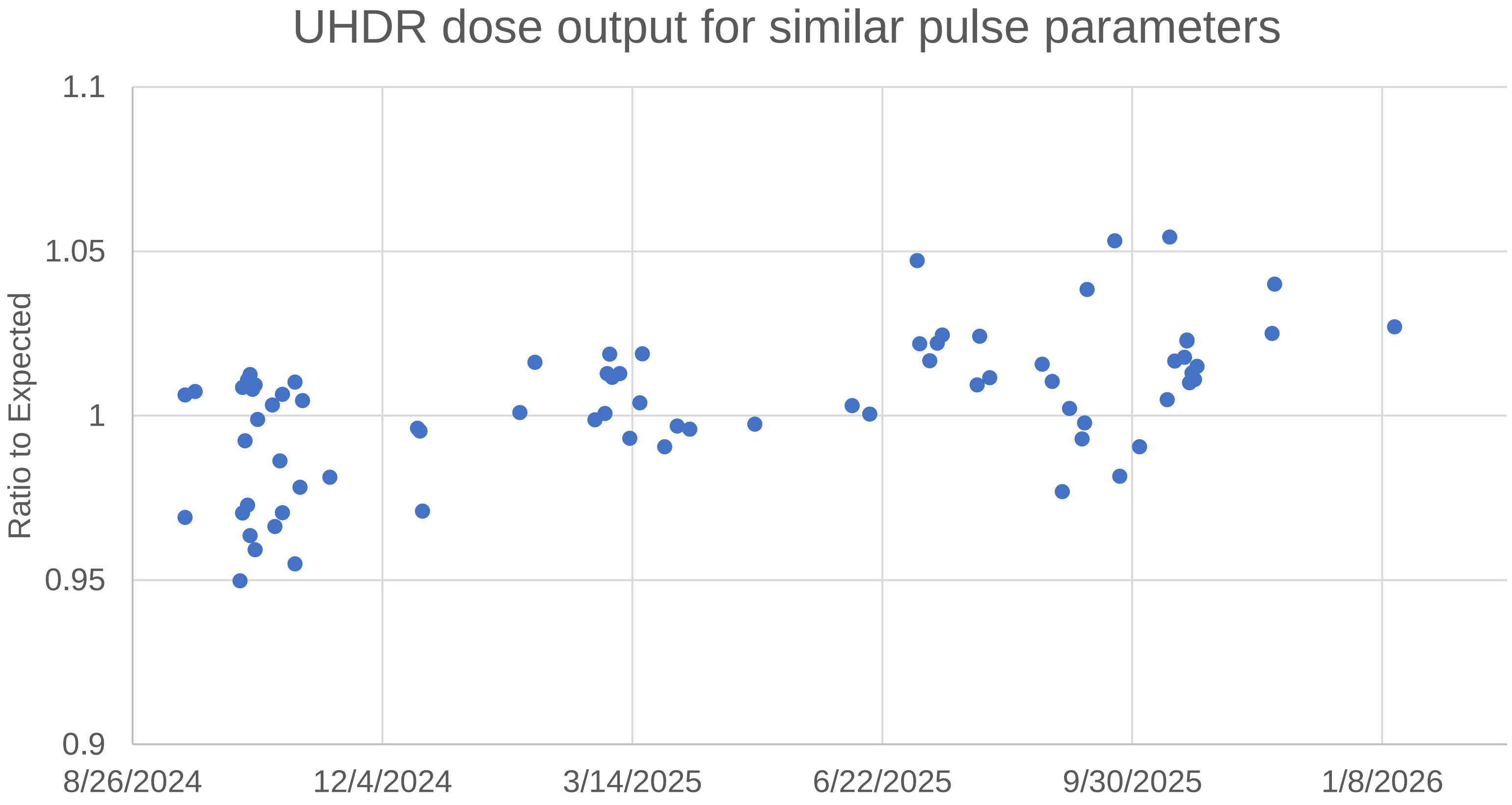
- All irradiations relied on pre-programmed treatments and post-delivery verification of delivered dose

- There was no mechanism to monitor output in real-time and adjust the accelerator to meet a prescribed target.

DeFrancisco J, A systematic review of electron FLASH dosimetry and beam control mechanisms utilized with modified non-clinical LINACs. *Journal of Applied Clinical Medical Physics*. 2025;26(4):e70051. doi:10.1002/acm2.70051

Our UHDR Mobetron Output Variability

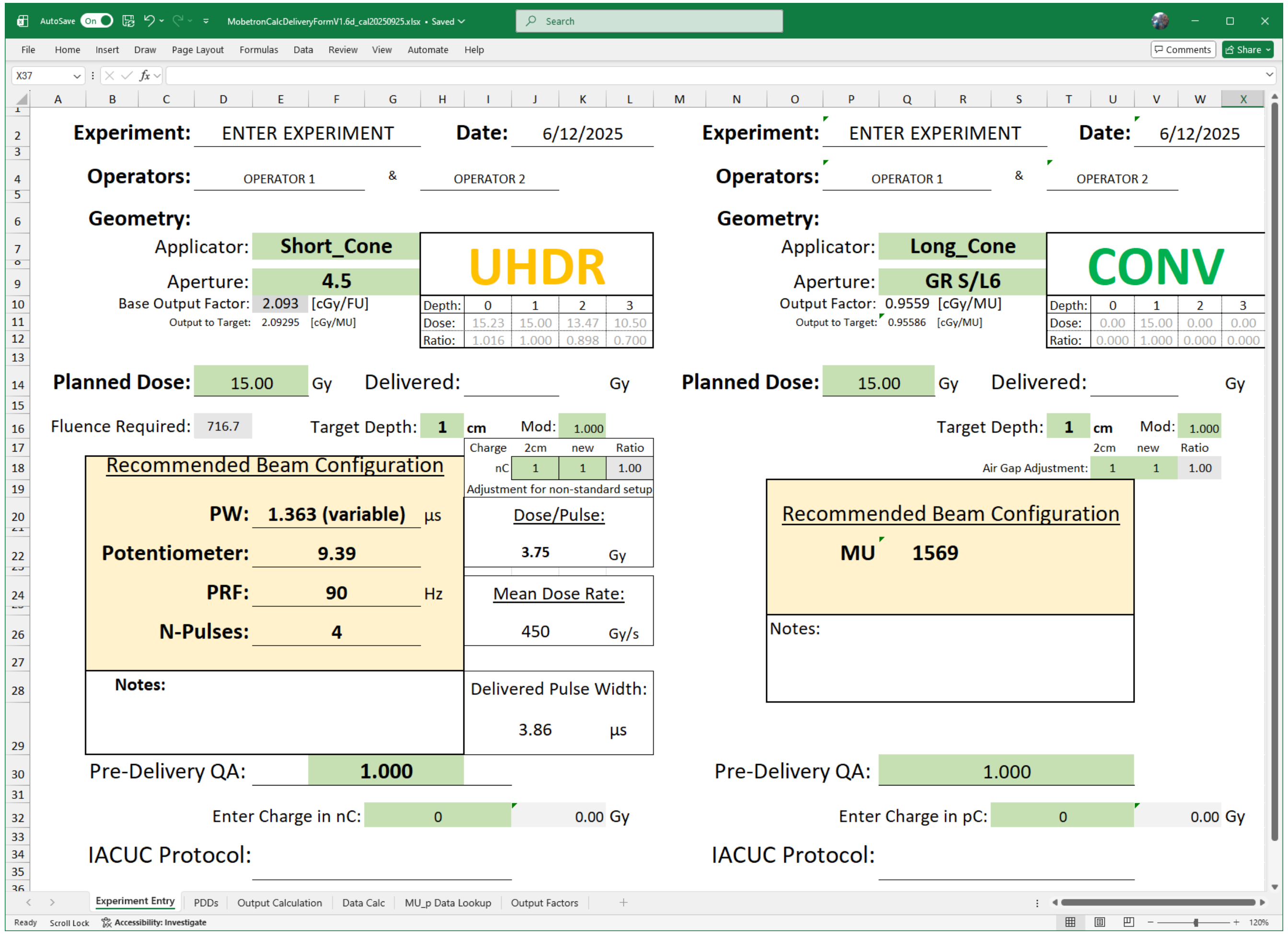




Short term / beam-to-beam is very consistent

Long-term QA generally measured within 3% of our targets, but we need to account for drifts

Our prior TPS could adjust for machine variability up to ±5% (larger excursions would trigger recalibration)



This **cannot** prevent under/over-dose situations if the machine malfunctions.

Core Technological Hurdles to Improve the Safety and Reliability of UHDR Deliveries

Measure dose per-pulse in real-time

Manipulate the accelerator to adjust per-pulse output

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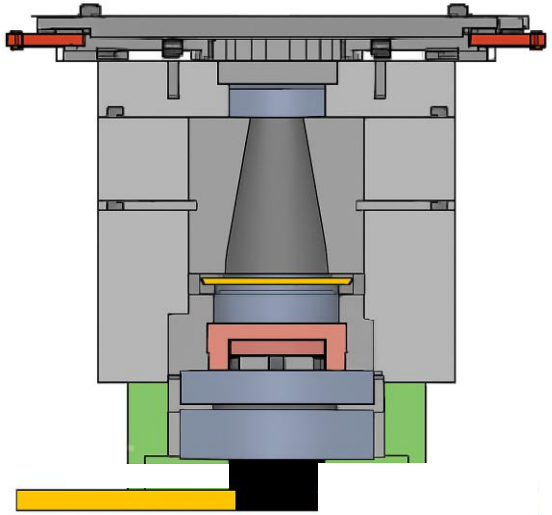
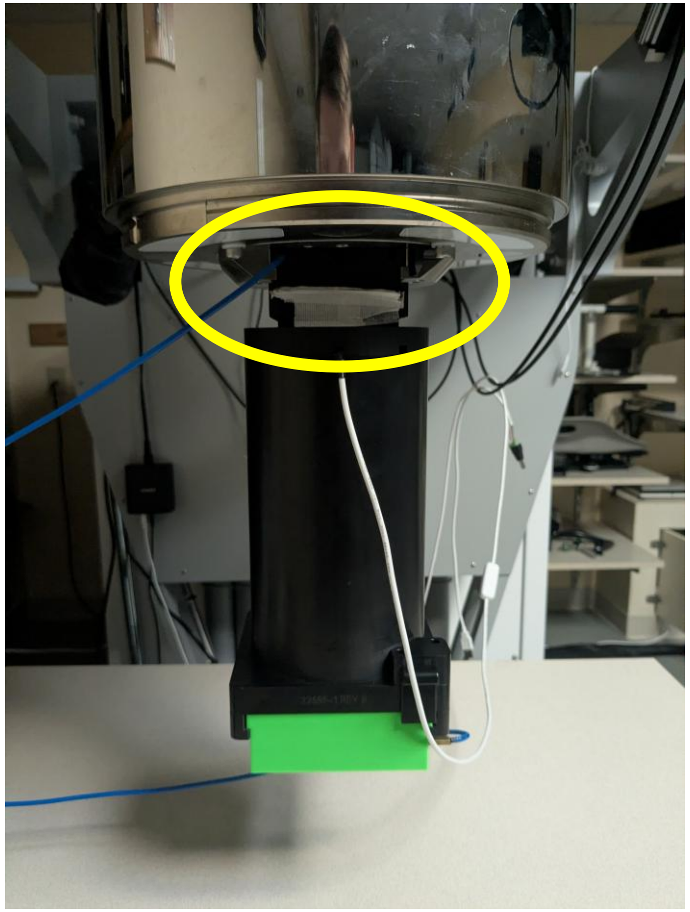
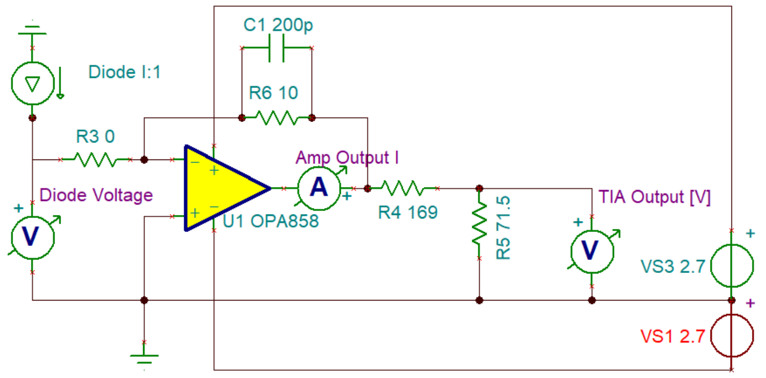
Real-time Output Measurements

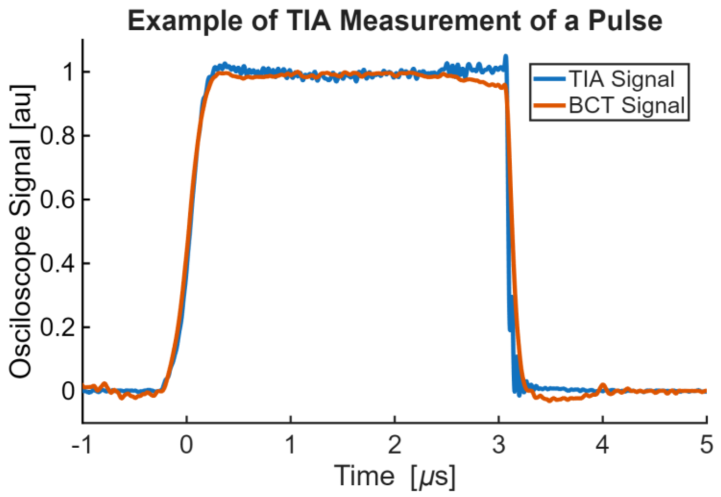


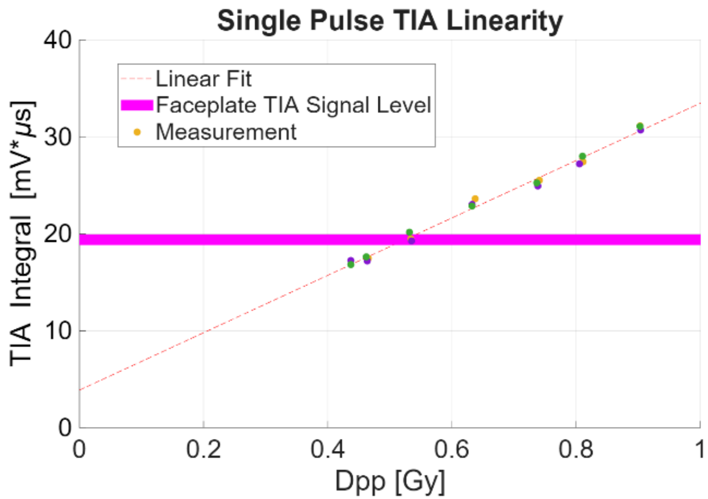


A PLA adapter places the EDGE diode in the periphery of the beam at the exit window

Real-time dose measurements







A custom transimpedance amplifier produces a voltage signal from the high current produced by the EDGE.

This signal is linear against radiation intensity.

The integral signal is proportional to dose

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Logic controlling the accelerator

Major systems:

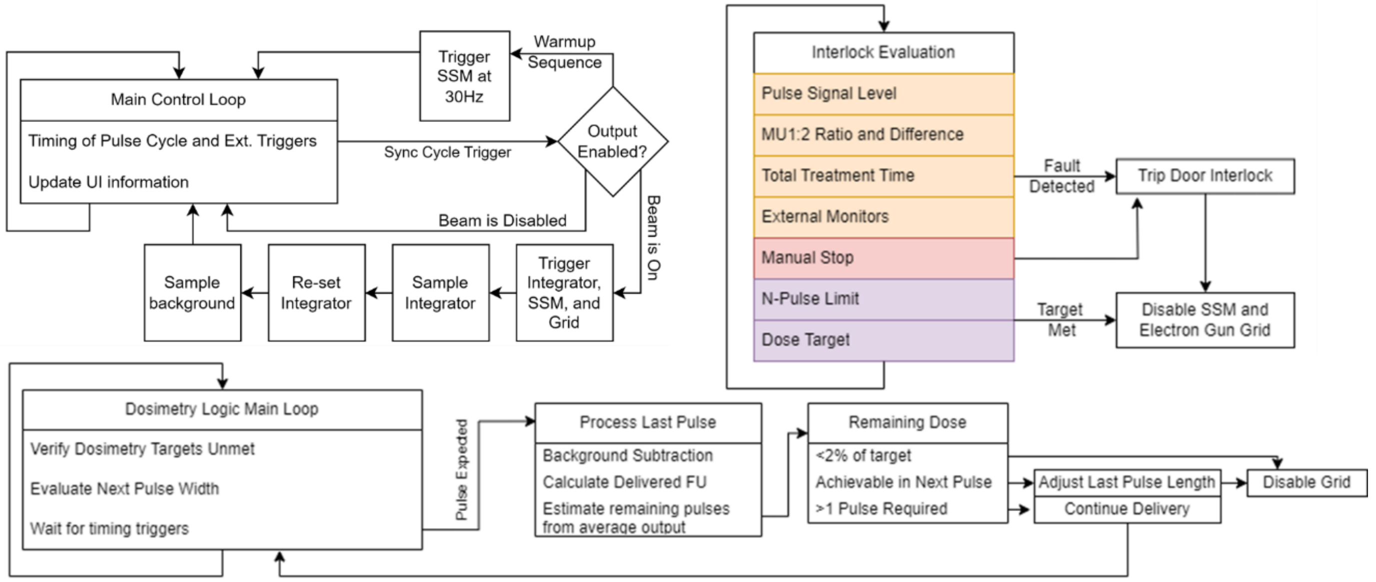
Timing of RF activation and electron injection

Measurement of the dose produced in each pulse

Logic to determine the remaining number of pulses required

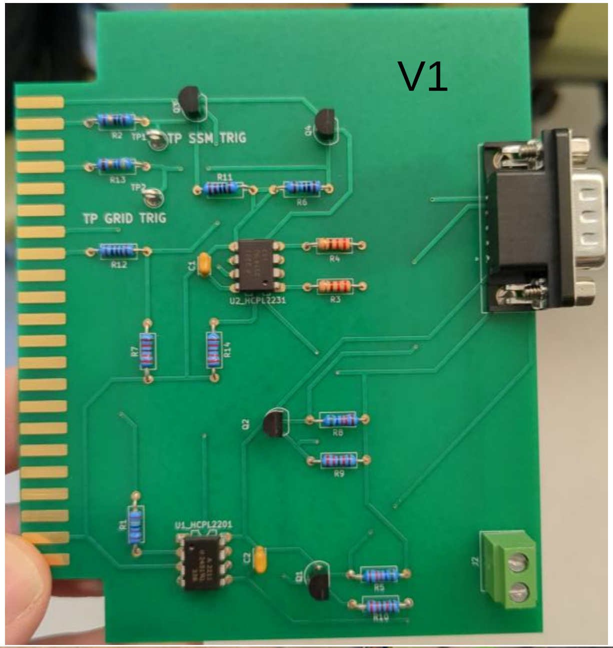
Logic to determine how large the pulses should be

Continual evaluation of key safety signals and interlocks

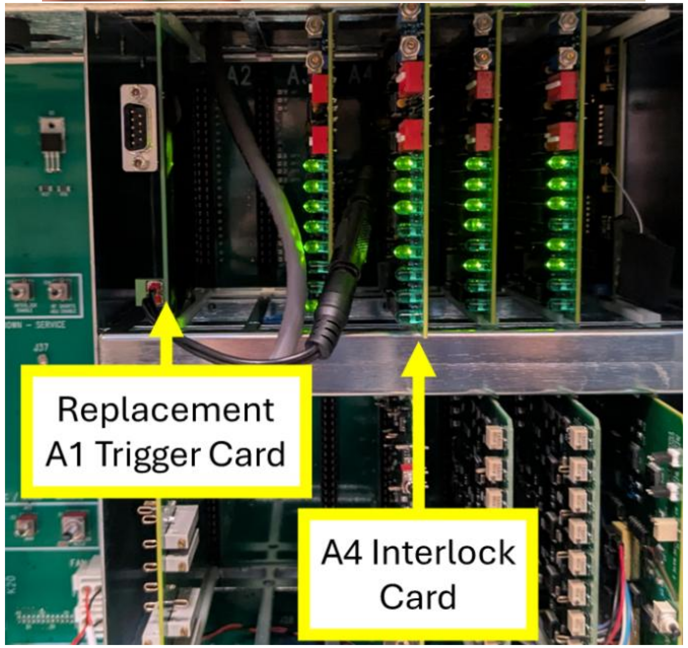


Interfacing with the Mobetron console

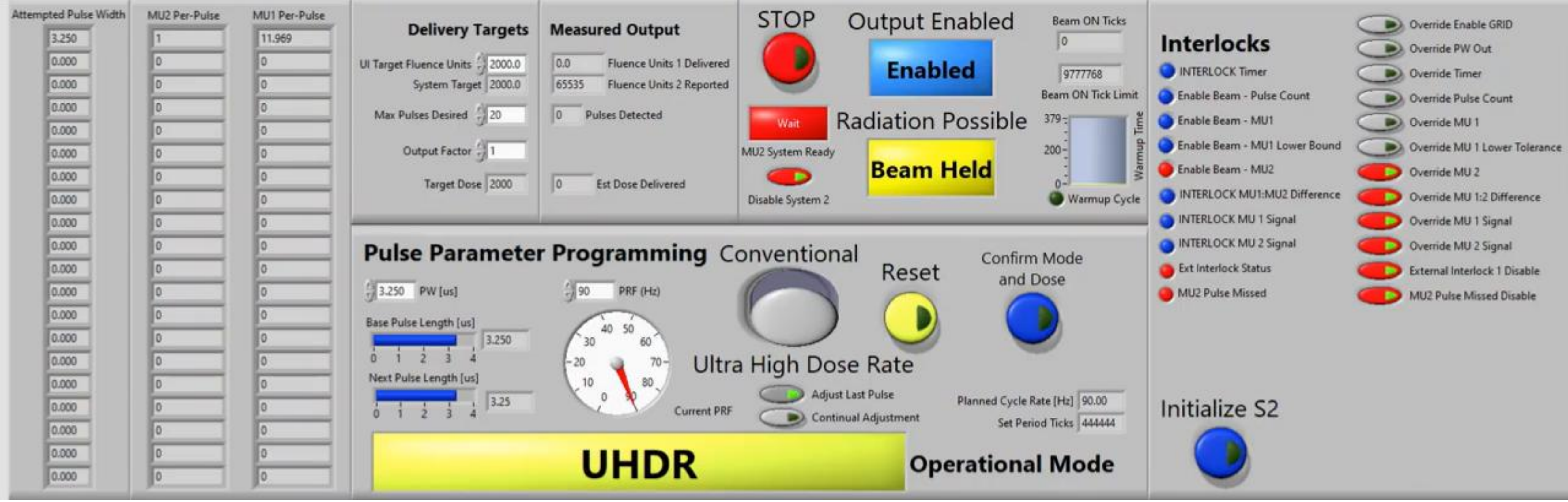
The data connections between the FPGA and console must be isolated to protect the equipment.

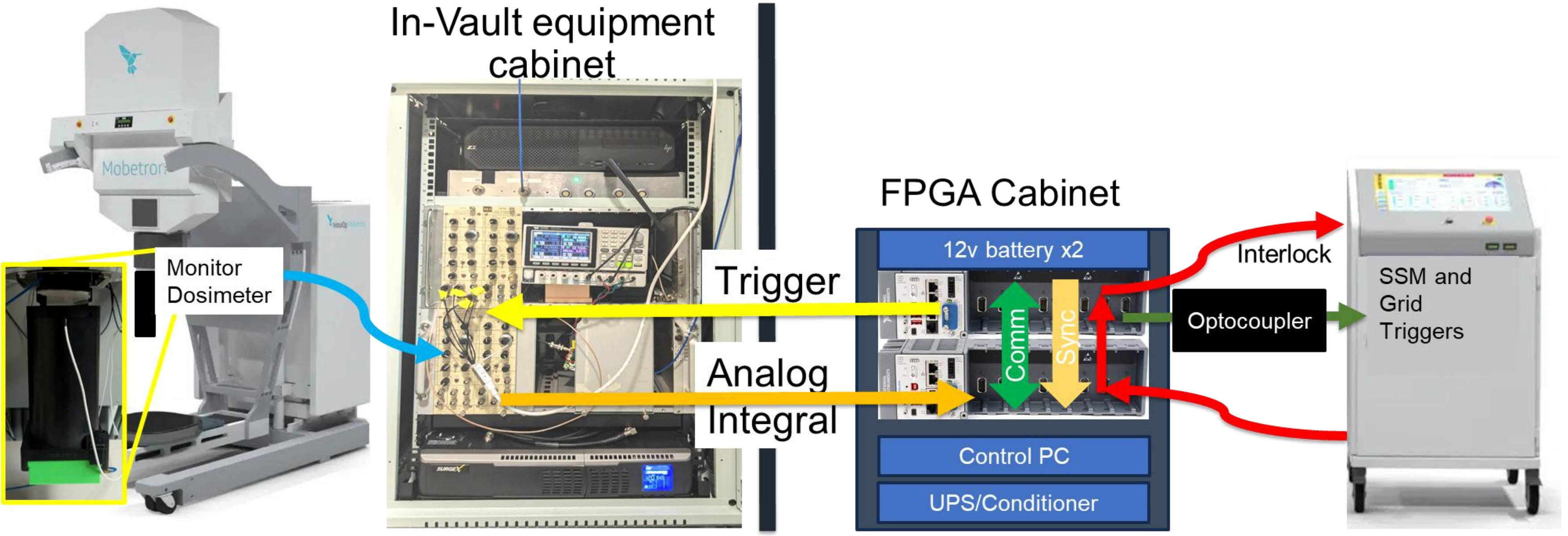


A custom PCB replaces one control board of the linac and passes signals between the FPGA and Console

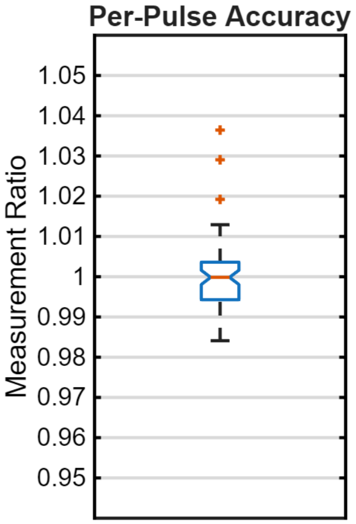


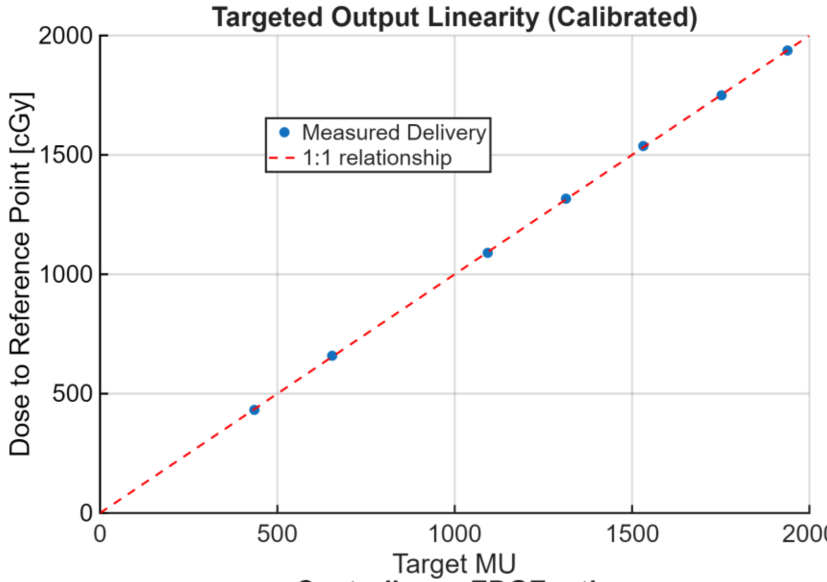
This enables direct control over RF system activation timing and pulse duration

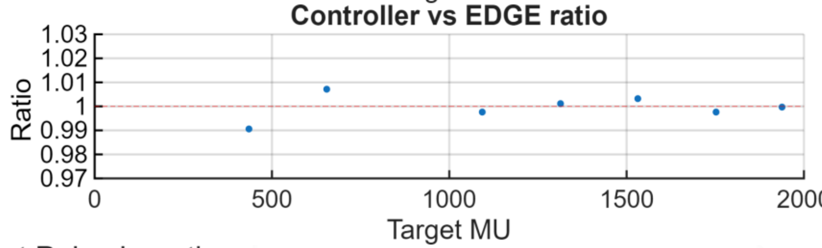

Attempted Pulse Width
MU2 Per-Pulse
MU1 Per-Pulse
3.250
1
11.969
Delivery Targets
UI Target Fluence Units 2000.0
System Target 2000.0
Max Pulses Desired 20
Output Factor 1
Target Dose 2000
Measured Output
0.0 Fluence Units 1 Delivered
65535 Fluence Units 2 Reported
0 Pulses Detected
0 Est Dose Delivered
STOP
Output Enabled
Enabled
Wait
MU2 System Ready
Disable System 2
Radiation Possible
Beam Held
Beam ON Ticks
0
9777768
Beam ON Tick Limit
Warmup Time
Warmup Cycle
Interlocks
INTERLOCK Timer
Enable Beam - Pulse Count
Enable Beam - MU1
Enable Beam - MU1 Lower Bound
Enable Beam - MU2
INTERLOCK MU1:MU2 Difference
INTERLOCK MU 1 Signal
INTERLOCK MU 2 Signal
Ext Interlock Status
MU2 Pulse Missed
Override Enable GRID
Override PW Out
Override Timer
Override Pulse Count
Override MU 1
Override MU 1 Lower Tolerance
Override MU 2
Override MU 1:2 Difference
Override MU 1 Signal
Override MU 2 Signal
External Interlock 1 Disable
MU2 Pulse Missed Disable
Pulse Parameter Programming
Conventional
3.250 PW [us]
90 PRF (Hz)
Base Pulse Length [us]
3.250
Next Pulse Length [us]
3.25
Current PRF
Ultra High Dose Rate
Adjust Last Pulse
Continual Adjustment
Reset
Confirm Mode and Dose
Planned Cycle Rate [Hz] 90.00
Set Period Ticks 444444
UHDR
Operational Mode
Initialize S2


Mobetron
Monitor Dosimeter
In-Vault equipment cabinet
Trigger
Analog
Integral
FPGA Cabinet
12v battery x2
Comm
Sync
Control PC
UPS/Conditioner
Interlock
Optocoupler
SSM and Grid Triggers

Output-Targeting Performance



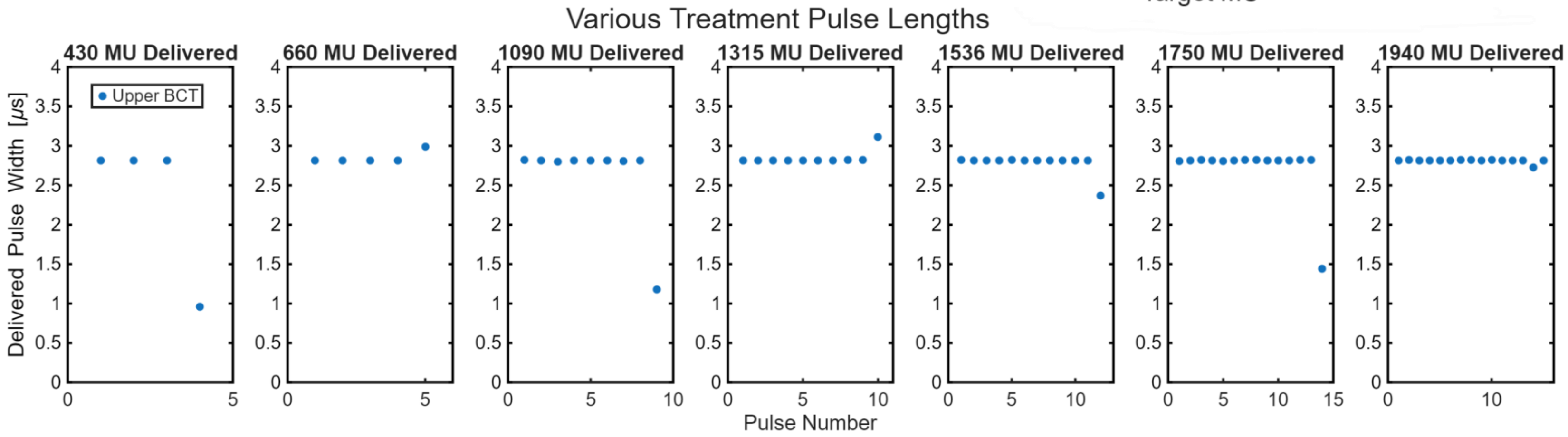




Accurate measurement of each pulse across a wide range of PWs

Adjustment of the last pulse achieves <1% accuracy in total output

The timing and duration of all pulses is logic-determined



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Conclusions

- First demonstration of real-time dosimetry being used as a part of a beam-control system
- First beam-control platform capable of adjusting pulse-to-pulse intensity during a delivery
- This system can increase the reliability of experiment deliveries

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Next steps?

- Redundancy
- Simplified electronics
- Hard-mounted installation

Acknowledgements

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NIH National Institutes of Health

Questions?