IRRADIATION TESTING OF

COMMERCIAL DC|DC BUCK CONVERTERS FOR ePIC

May 15th 2024, UC Davis Crocker Cyclotron

Presentation for DAQ & Electronics

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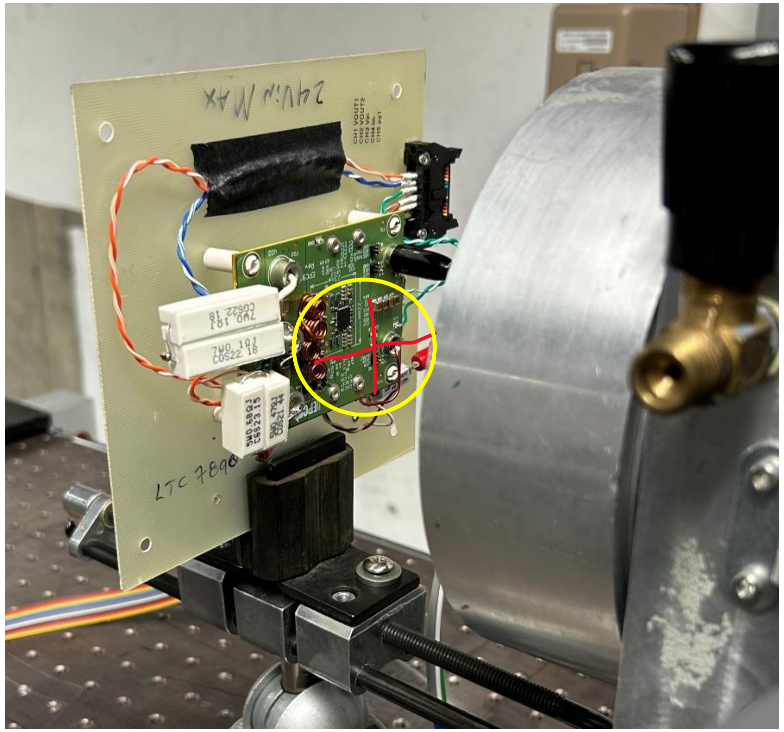
With contributions from:
Alex Jentsch, BNL (simulations for ePIC)
James Kierstead, BNL (Instrumentation Division)

- **Testing requirements**
- **Irradiation results & plots**
- **Next steps**



DUT at Cyclotron facility, proton exit window (Ø6cm)

Brookhaven National Laboratory

UCDAVIS CROCKER NUCLEAR LABORATORY

ePIC

General Power Requirements

- All devices selected for testing were selected on their electrical characteristics & are candidates for various detector electronics use at ePIC

  ✓ Noise < 0.5% , $\text{Ripple}_{(20\text{MHZ BW})}$ < 0.3%

  ✓ Efficiency: at least 70%

  ✓ V_{IN} 12V – 15V V_{OUT} 1V – 5V

  ✓ Power Density & Footprint Constraints

  ✓ Magnetic field (2 Tesla) => non-iron core inductors

Radiation testing requirements

- **Radiation Tolerant to a Fluence of (1 x 10^{12} /sec/ cm^2) ten operational Years, 1MeV equivalent damage**
- **TID (100K_{RAD})**

IRRADIATION REQUIREMENTS & BEAM CONDITIONS

Reference slide 16 for cyclotron configuration screen

A. Akkerman et al. / Radiation Physics and Chemistry 62 (2001) 301–310

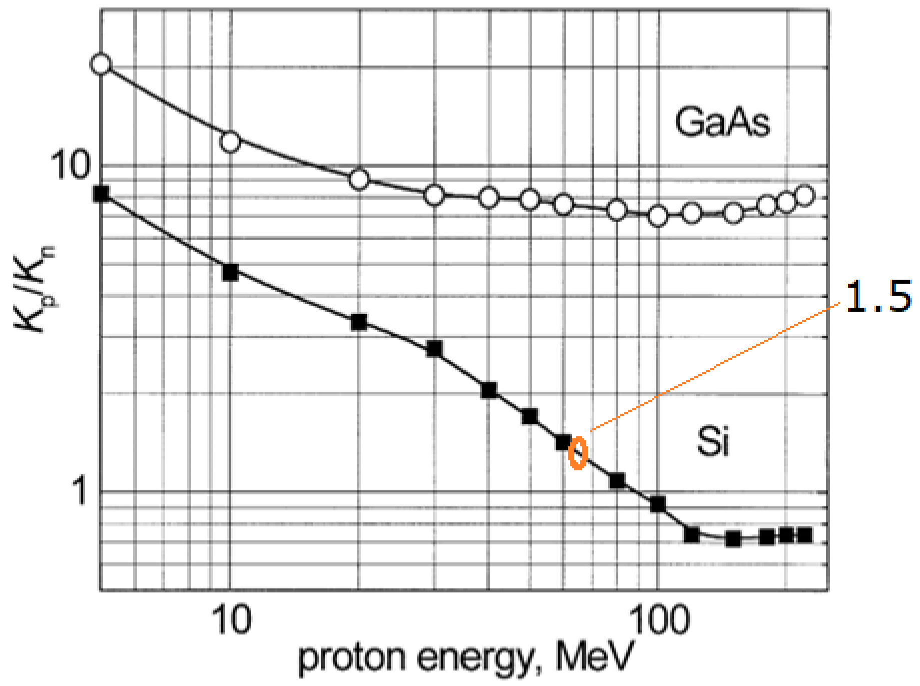


Fig. 6. The relative damage, K_p/K_n, as a function of proton energy where K_n is taken for 1 MeV neutrons.

Proton energy => **64MeV**

Cyclotron flux => **1.24E8 /sec cm^2** (what the cyclotron delivers)

Beam width => **6.0cm**

Beam Current => **2.0nA** scaled for 1MeV neutron equivalent damage (0.67x)

Flux at 2nA => 2.0nA x 1.24E8 /sec cm^2 = **2.48E8/sec cm^2**

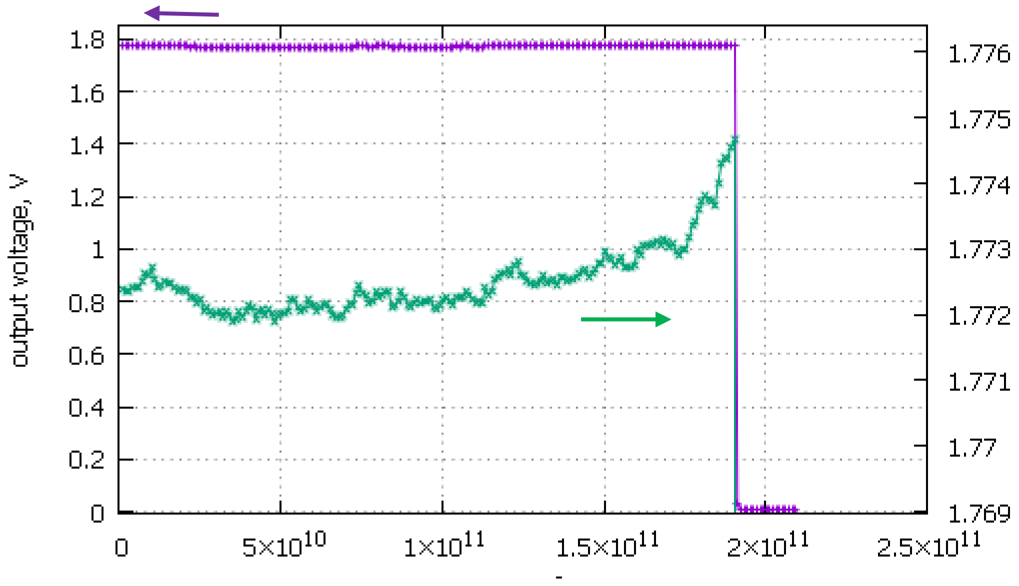
Proton fluence integrated for 10 operational years (1MeV neutron equivalent)

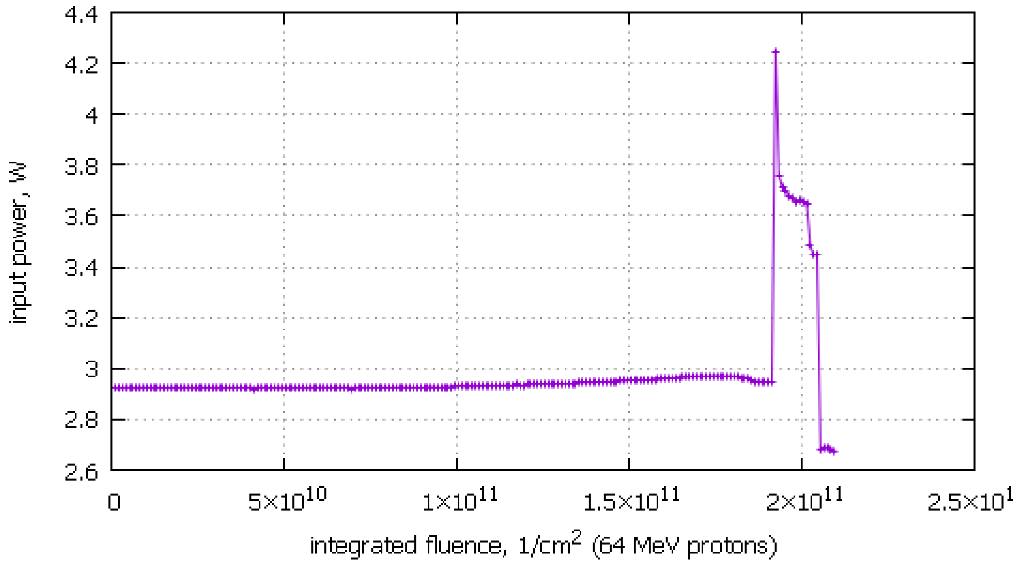
=> 1.0E12 n /sec cm^2

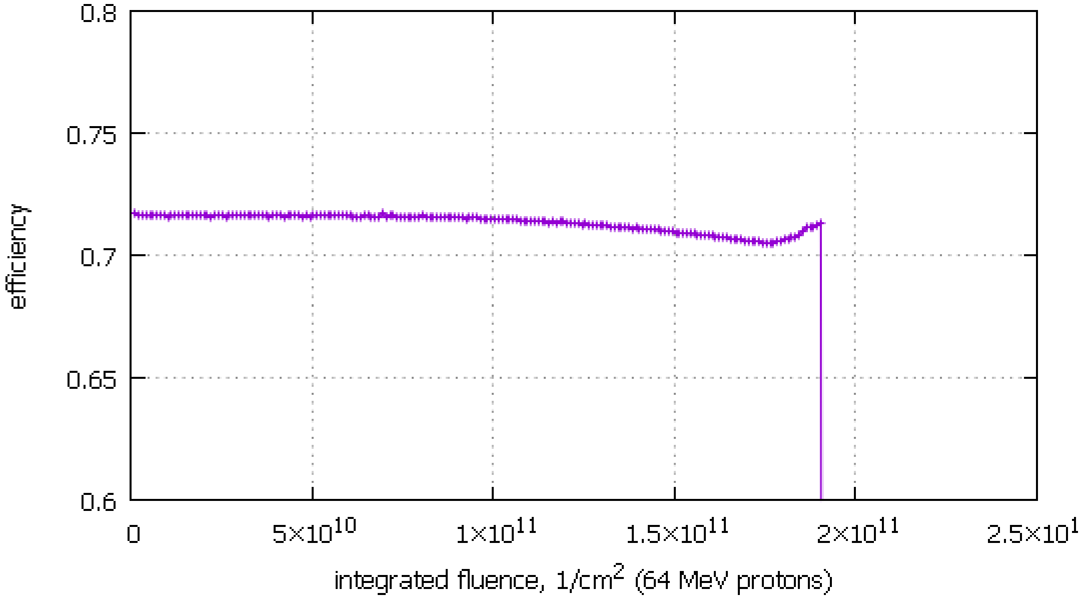
Irradiation time to full fluence => 2700 seconds (45 min)

IRRADIATION TEST RESULTS

DEVICE	LTC3600 (1.5A)
Vin to Vout	13 V to 1.8 V
load	1.5 Ω (1.2A)
64 MeV p flux	2.49E8 p/cm^2*s
2% output deviation	no significant deviation
unstable/flaky	no
output dead	1.90E11 p/cm^2





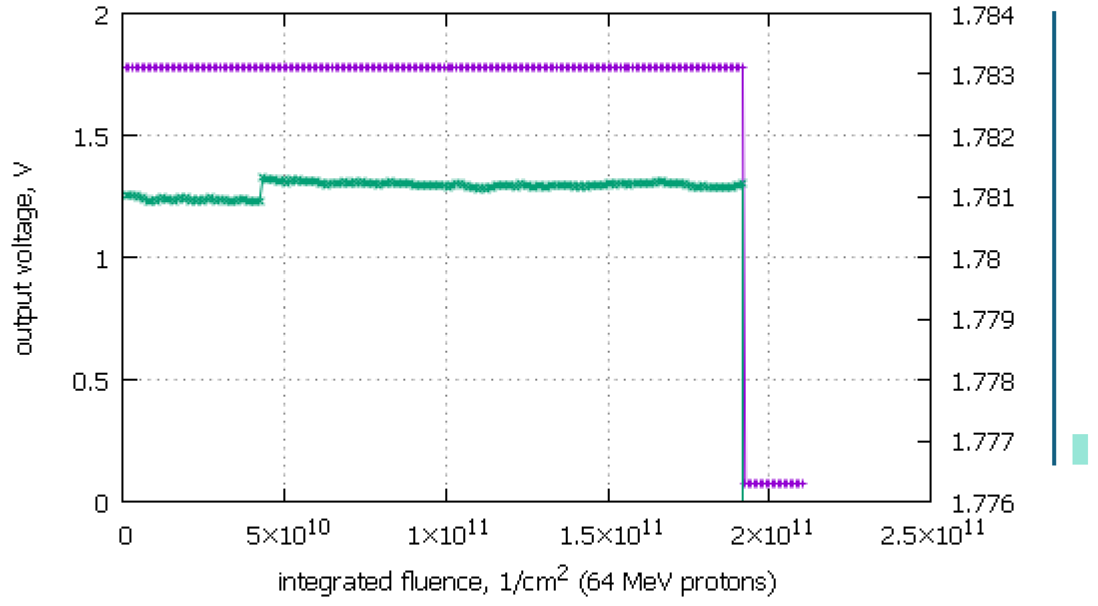


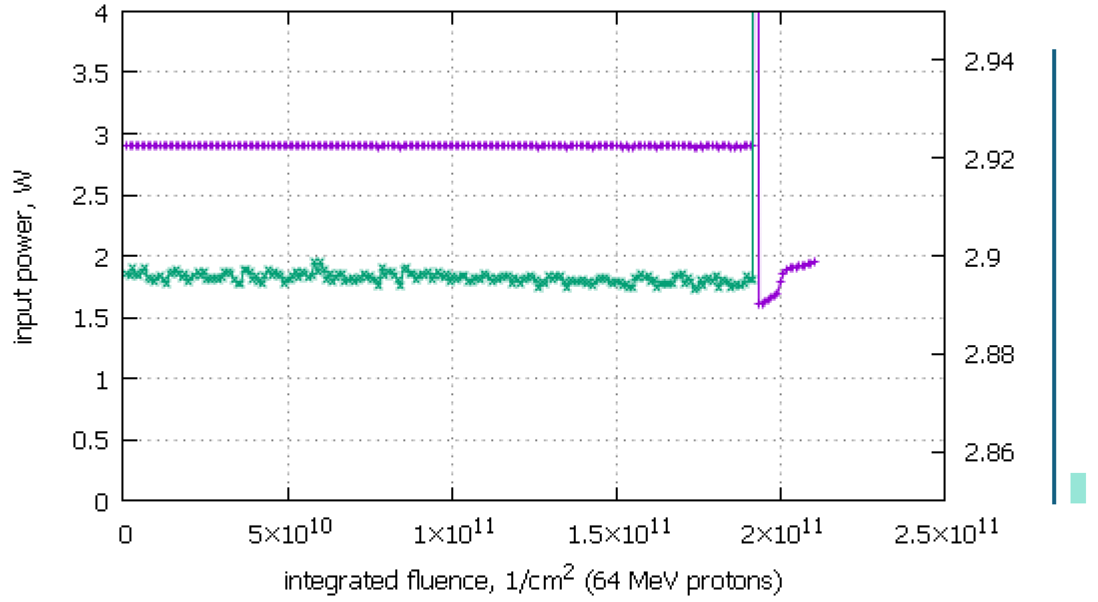
also see bonus plots in backup slides for Vref out

IRRADIATION TEST RESULTS

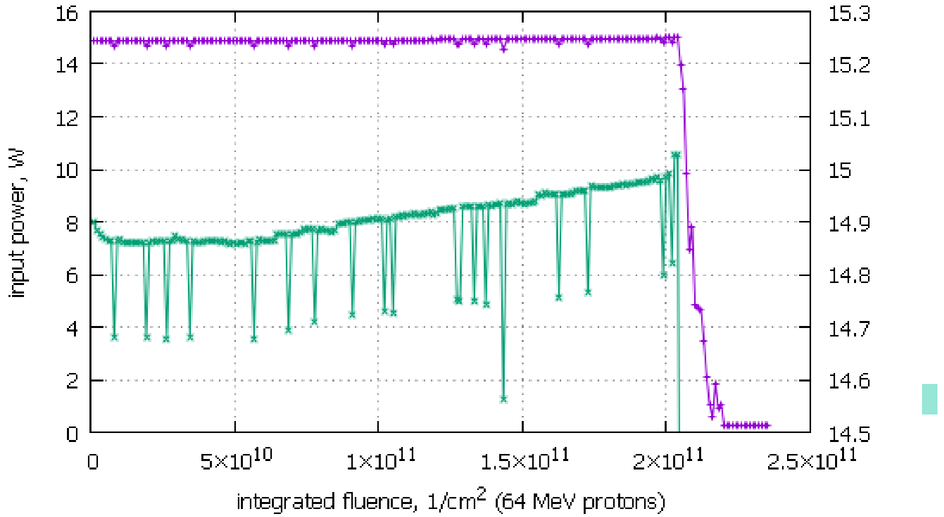
DEVICE	LTC3626 (2.5A)
Vin to Vout	16 V to 1.8 V
load	1.5 Ω (1.2A)
64 MeV p flux	2.33E8 p/cm^2*s
2% output deviation	no significant deviation
instability	no
output dead	1.92E11 p/cm^2

Exposure time until part failed: 1.9E11 / 2.48E8 /sec = 13 minutes => ~30% of specified fluence

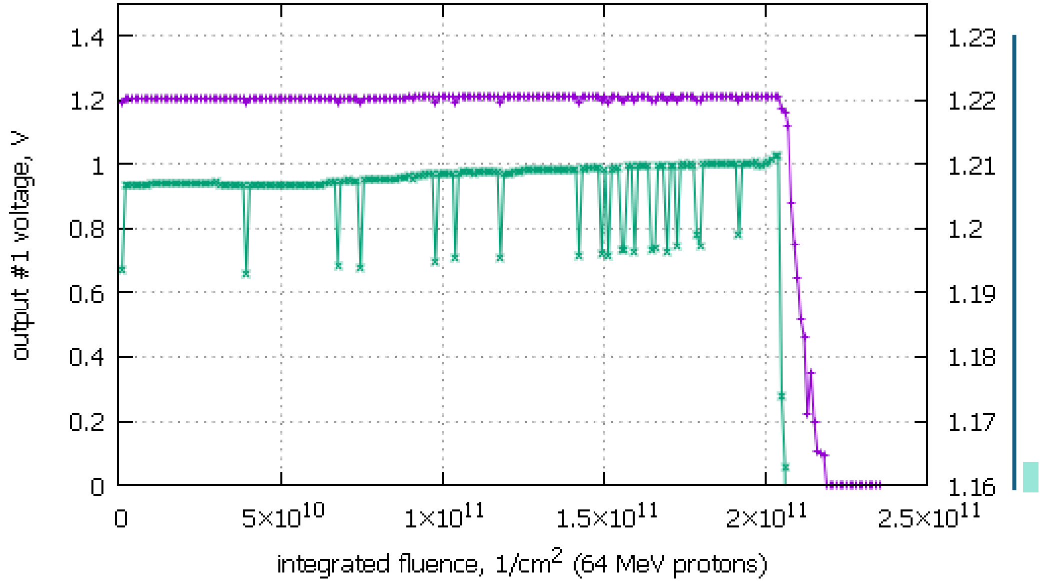


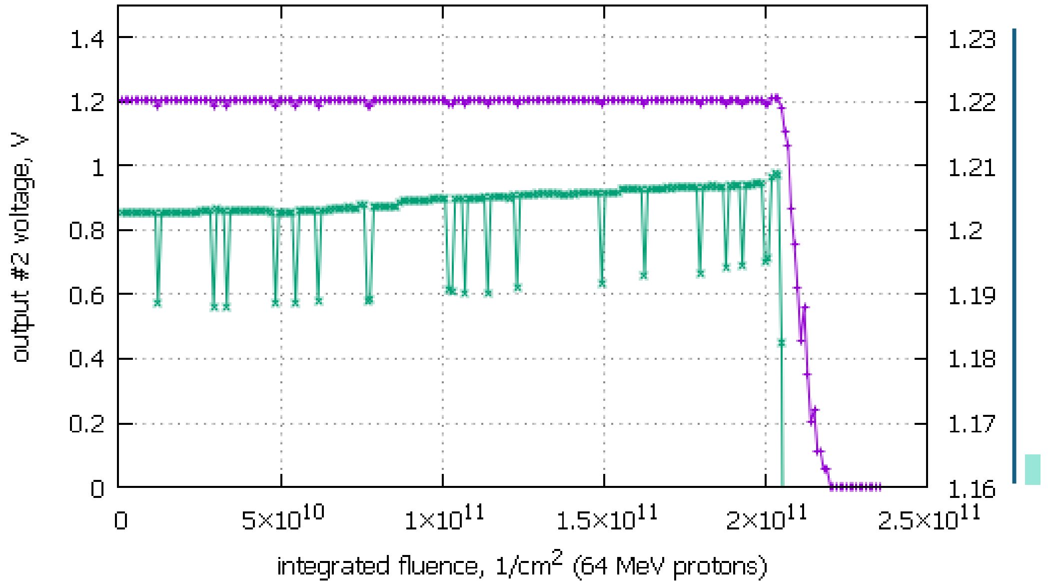


DEVICE	LTC7890 (2-ch) (15A /ch)
Vin to Vout	12 V to 1.2 V
load	0.2 Ω, 0.28 Ω (6A, 4.3A)
64 MeV p flux	2.51E8 p/cm^2*s
2% output deviation	(<20mV$_{P-P}$)
instability	slight instability observed
output dead	2.06E11 p/cm^2

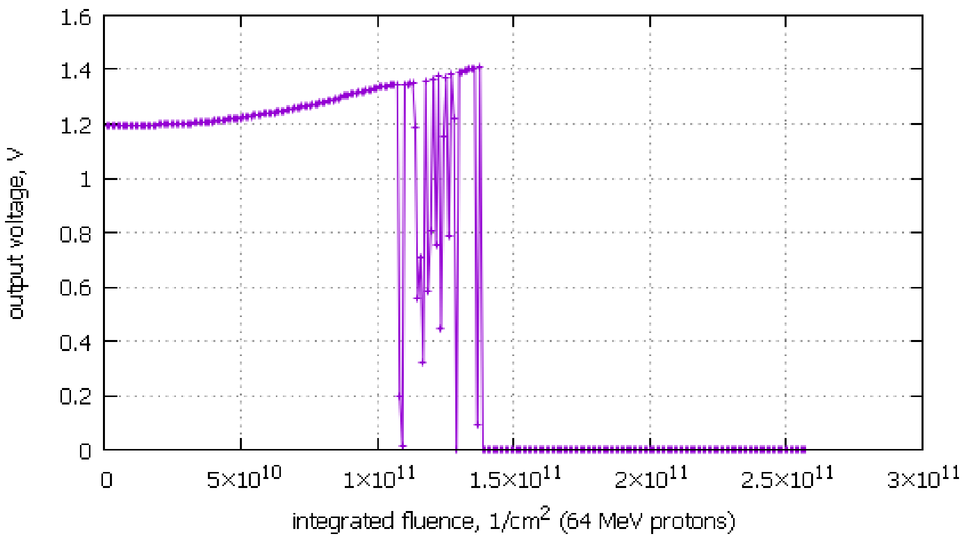


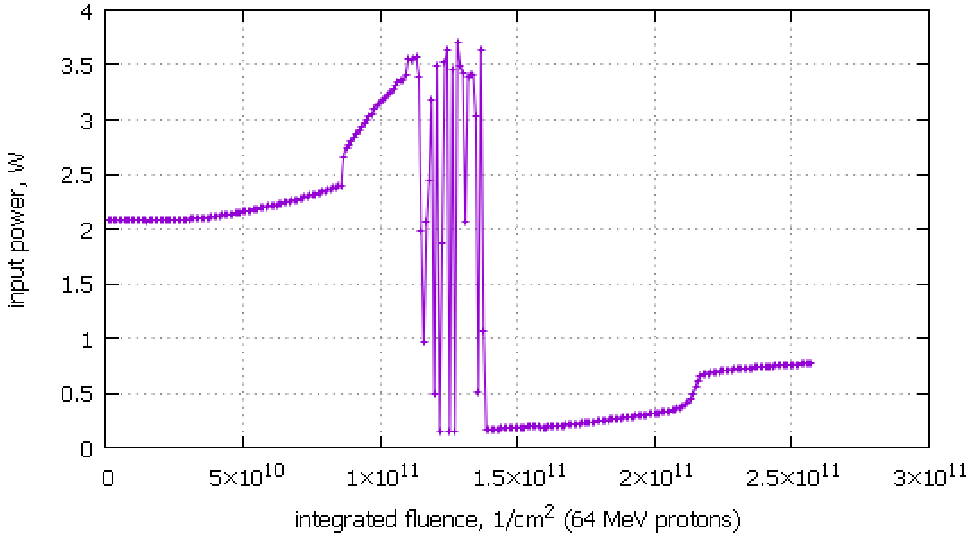
NOTE: Some efficiency effects can be contributed to variations caused by temperature coefficient (±400ppm/°C) of the load resistors. This applies to all tested devices.

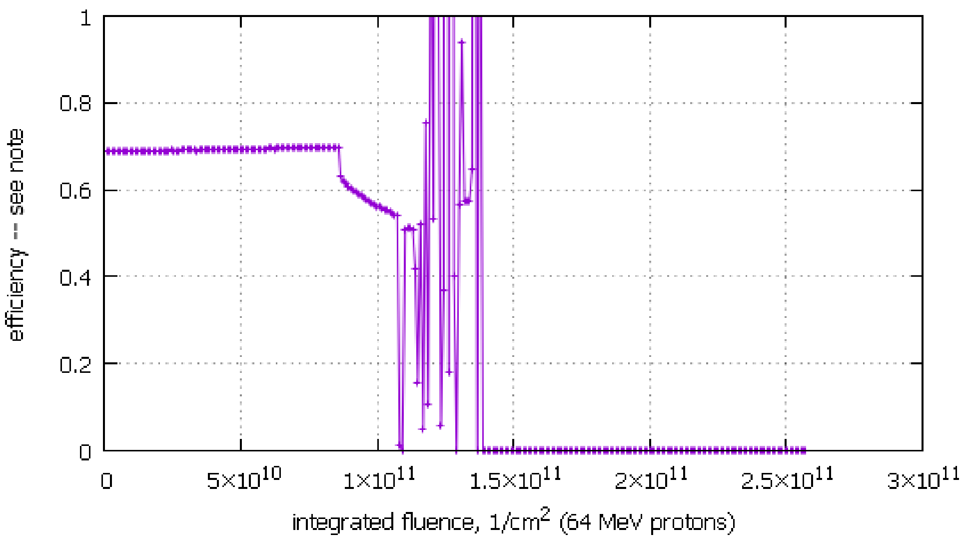




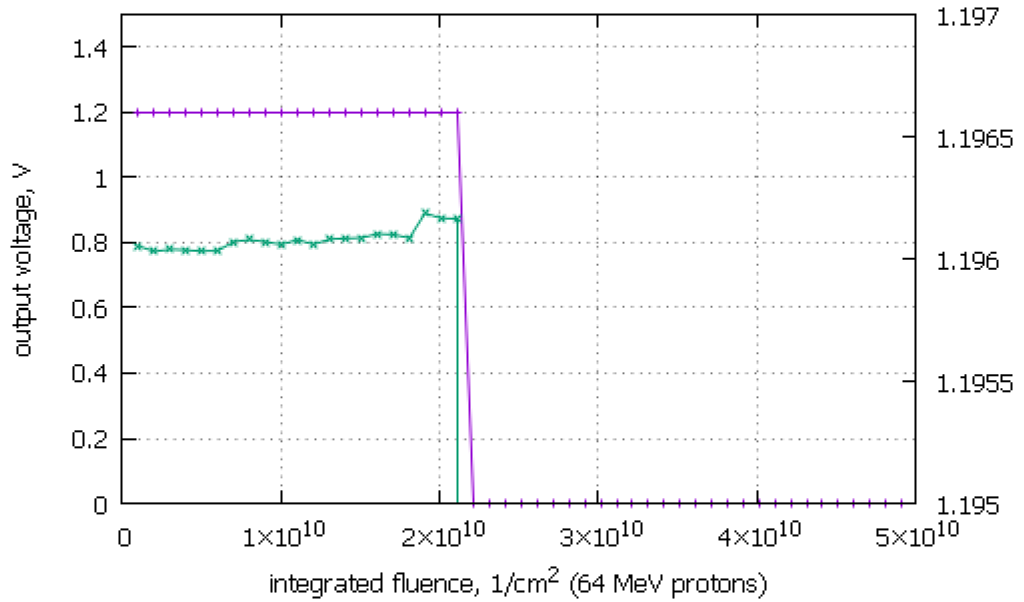
DEVICE	MP2318 (2A)
Vin to Vout	14 V to 1.2 V
load	1 Ω (1.2A)
64 MeV p flux	2.35E8 p/cm^2*s
2% output deviation	4.83E10 p/cm^2
instability	1.08E11 p/cm^2
output dead	1.38E11 p/cm^2

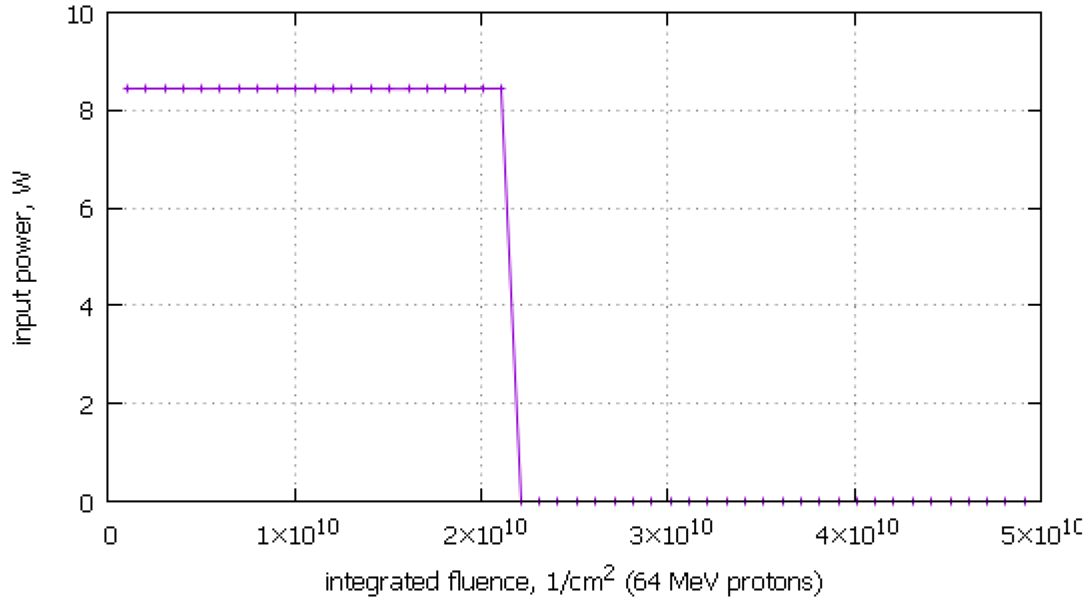




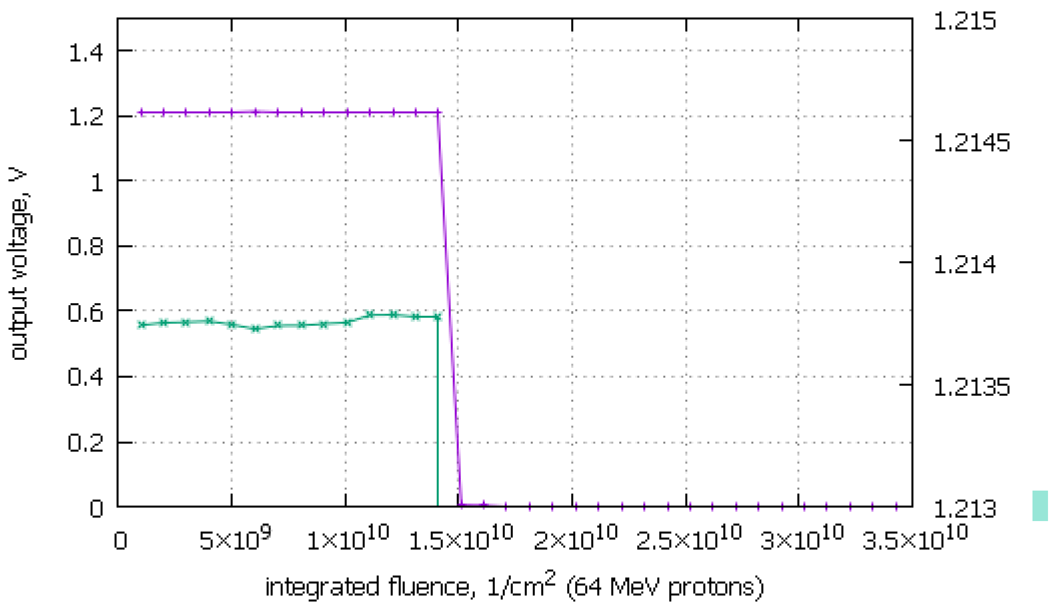


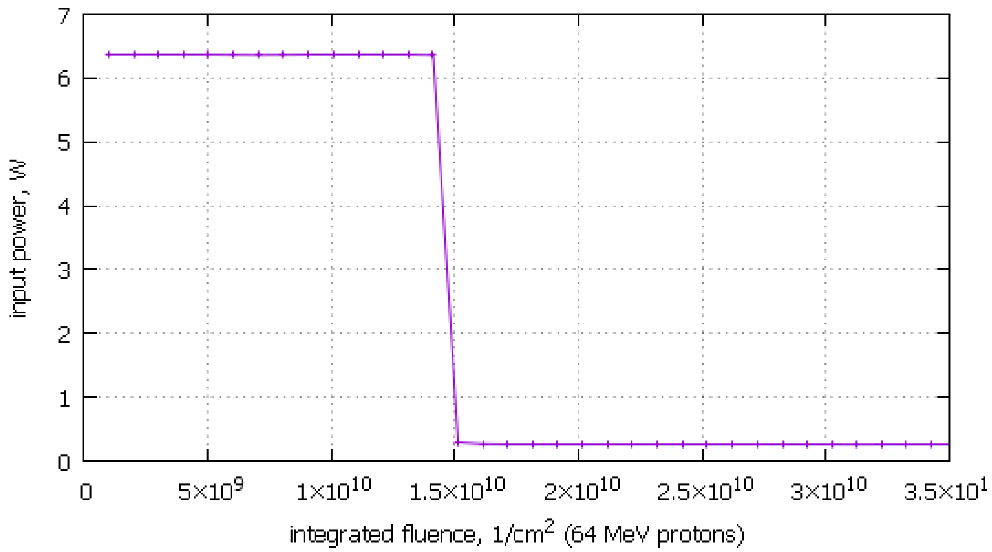
DEVICE	LTC7151 (15A)
Vin to Vout	16 V to 1.2 V
load	0.2 Ω (6A)
64 MeV p flux	2.49E8 p/cm^2*s
2% output deviation	no significant deviation
instability	no
output dead	2.21E10





DEVICE	MP2276 (8A)
Vin to Vout	12 V to 1.2 V
load	0.28 Ω (4.3A)
64 MeV p flux	2.50E8 p/cm^2*s
2% output deviation	no significant deviation
instability	no
output dead	1.41E10 p/cm^2





Neutron Fluence at ePIC:

(1MeV equivalent) fluence normalized for 1 fb^{-1}
100 x fb-1 = 1 year. Very conservatively, we can expect an upper bound of 100 fb-1/year of data when the machine reaches top luminosity

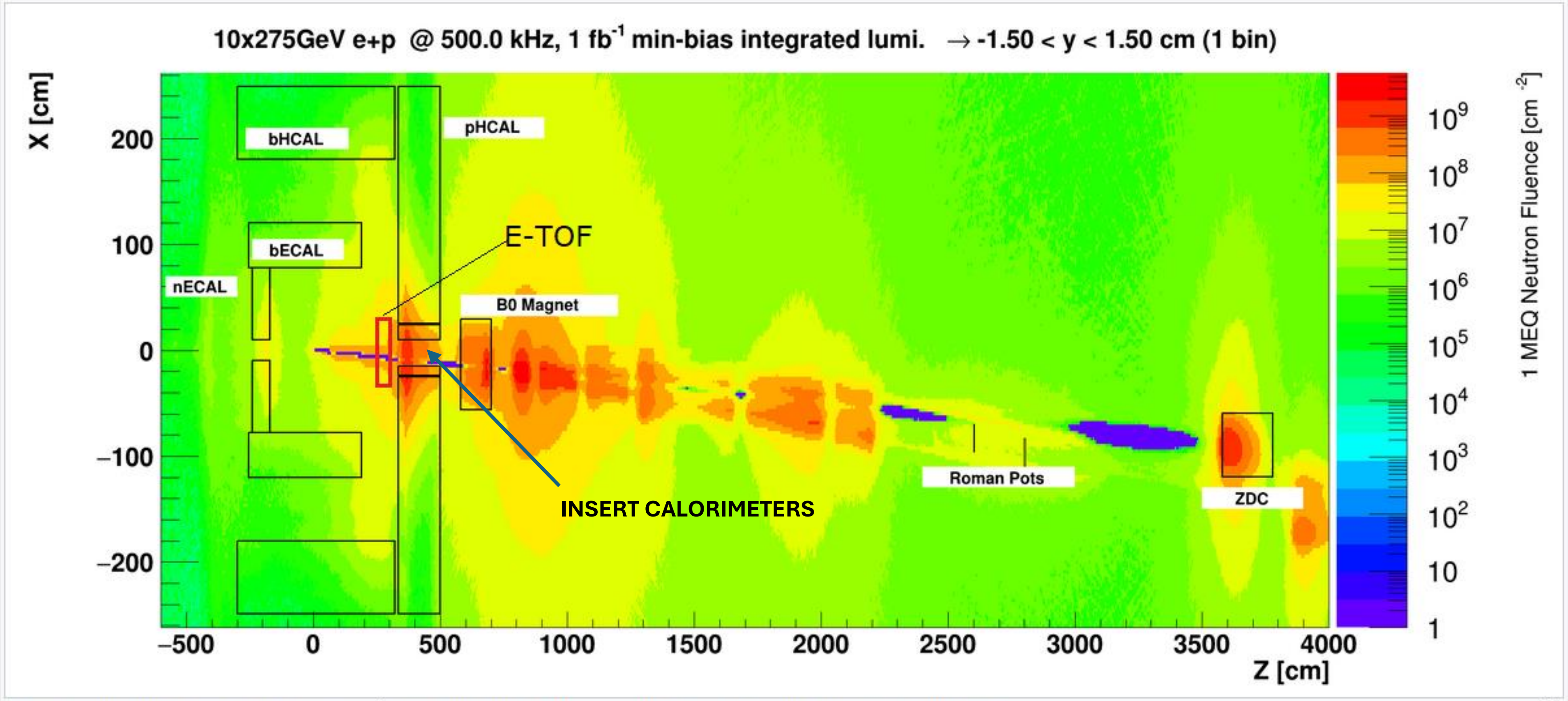


Figure 3: 1 MEQ neutron equivalent fluence per fb^{-1} for minimum-bias PYTHIA e+p events at 10x275 GeV. ROOT files can be found here.

Radiation simulation from Alex Jentsch, BNL

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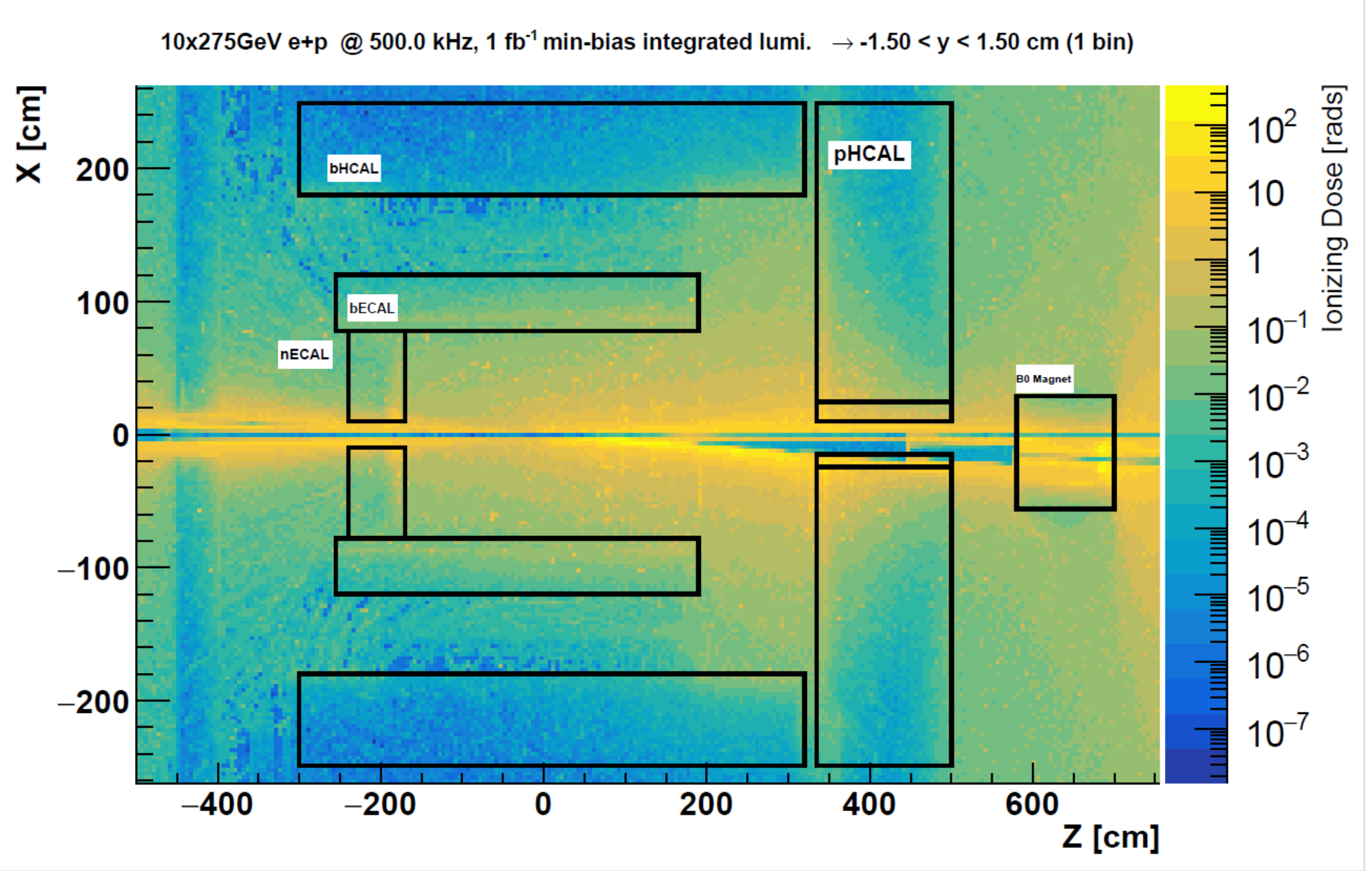
ePIC

TID from Hadron & Electron at ePIC:



Combined ionizing dose from Hadron & Electron sides

[Radiation simulation from Alex Jentsch, BNL]

Note: to get the TID for one year of operation:

Ionizing dose (normalized for fb^{-1})

Ionizing dose of $3x10^2$ x 100 = 30kRads/ year x 10 years = 300kRads

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ePIC

Non Ionizing Energy Loss

Neutron induced displacement damage in silicon & equivalent damage

A. Akkerman et al. / Radiation Physics and Chemistry 62 (2001) 301–310

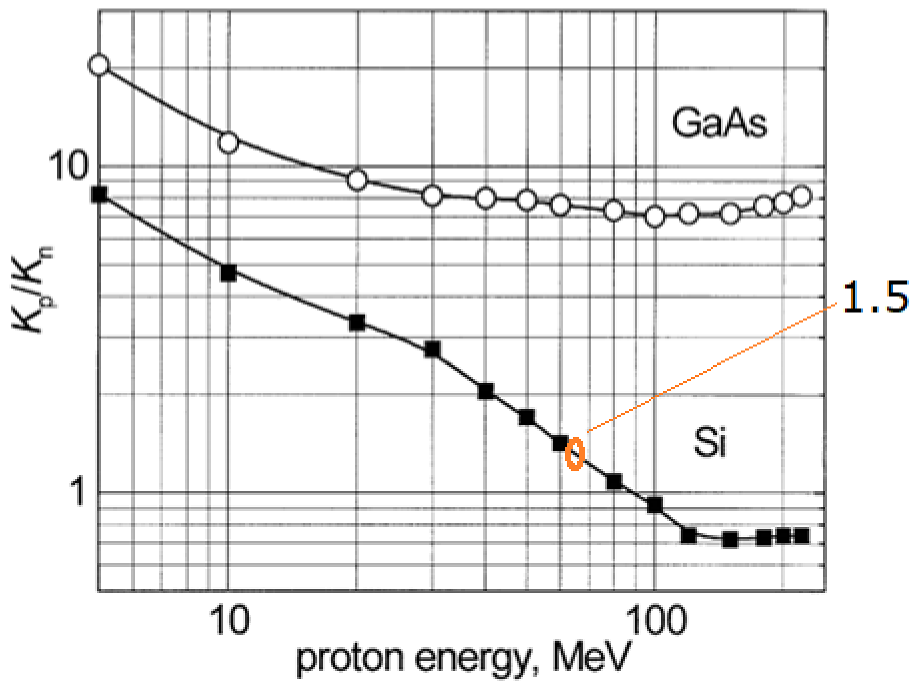


Fig. 6. The relative damage, K_p/K_n, as a function of proton energy where K_n is taken for 1 MeV neutrons.

Ekin [MeV] P	D/(95MeVmb) Huhtinen
6.500E+01	1.580E+00
1.000E+00	3.133E+01

https://rd50.web.cern.ch/niel/protons.pdf

Ekin [MeV] N	D/(95MeVmb) Konobeyev
6.000E+01	1.644E+00
7.000E+01	1.499E+00
6.500E+01	1.572+00 (1.644+1.499)/2
1.050E+00	8.020E-01

https://rd50.web.cern.ch/niel/neutrons.pdf

Source: https://rd50.web.cern.ch/niel/

Testing Conclusions

- LTC7890, LTC3600, LTC3626 => operated SAT for ~ 30% of goal
- LTC7151, MP2318, MP2276 => failed test < 30% of goal
- Any difference between manufacturer? => LT devices seem to hold up better than MPS but inconclusive
- Any of the parts suitable for use in ePIC? => Possible depending on location (need safety margin also)

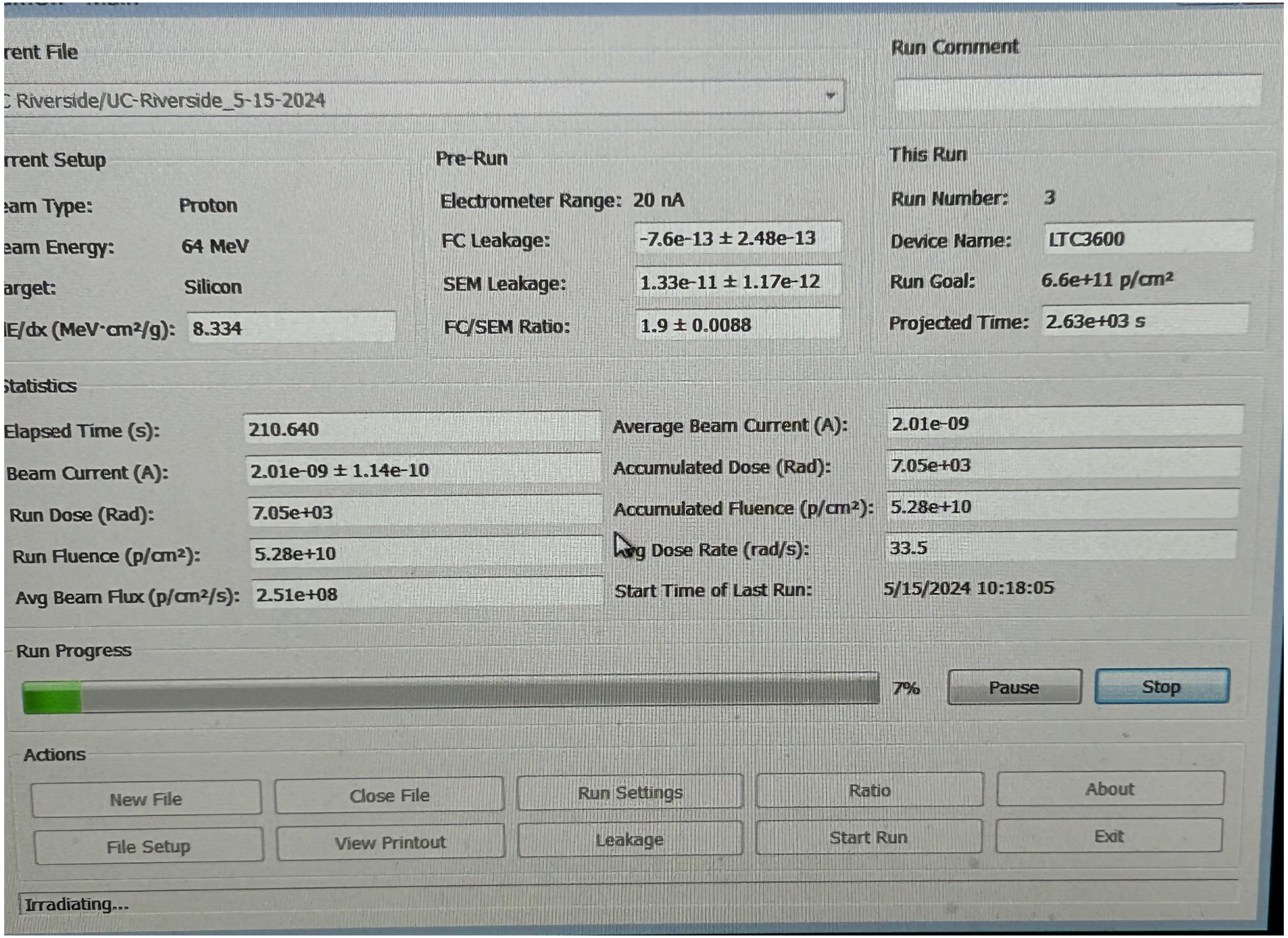
What's Next

Ionized dose testing at BNL gamma facility scheduled for July 2024

From bPOL12V data sheet

particle	source	Energy	fluence (particle 1e15/cm2)	1MeV equivalent e15	TID (Mrad)	number of samples	bias?	version tested	notes
neutrons	Triga	<10 MeV	2.00	2.00	2	2	unbiased	V5	
			5.00	5.00	5	2	unbiased		
			6.00	6.00	6	2	unbiased		
			7.00	7.00	7	2	unbiased		
neutrons	ouvain la Neuve		0.28	0.28		1	biased Vin=10V, enabled	V5	
rotons+neutro	MC40+Triga		0.4p+0.6n	1.48	54	4	unbiased	V5	
protons	MC40	27 MeV	0.41	0.91	108	6	unbiased	V5	
			0.53	1.16	137	6	unbiased		
			0.65	1.43	169	6	unbiased		
			0.90	1.98	234	5	unbiased		
			1.20	2.64	312	5	unbiased		
protons	Boston GH	230MeV	1.43	0.95		2	unbiased	V5	
			1.82	1.21		2	unbiased		
			2.34	1.55		2	unbiased		
protons	IRRAD	24GeV	0.90	0.50	24	4	unbiased	V6	
			1.91	1.06	52	4	unbiased		
			2.41	1.34	66	4	unbiased		
			2.86	1.59	78	2	unbiased		
			3.07	1.71	84	2	unbiased		
			4.71	2.62	128	2	unbiased		
			4.58	2.54	125	1	biased =0, turned on every 5 min	V6	V33driver drops, irradiaeted up to 7e15p/cm2, 1 week of annealing 100C, back operative
			4.22	2.34	115	1	iased Vin=10V, enable	V6	
protons	Cyrce	27 MeV	*0.53*	*1.166*	*150*	*1*	Biased Vin=9V	V6	still operative , thanks to RWTH Aachen
			0.6	1.32	171.4	1			

Cyclotron configuration setup screen



References

Lindstroem, G. (n.d.). *gunnar*. https://rd50.web.cern.ch/niel/default.html

Radiation doses - Electron-Proton/Ion collider experiment. (n.d.). https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses#Radiation_Doses_and_Fluences_from_10x275_GeV_e+p_minimum-bias_events

About CNL :: Crocker Nuclear Laboratory. (n.d.). https://crocker.ucdavis.edu/about-cnl

https://indico.bnl.gov/event/14948/contributions/60508/subcontributions/1796/attachments/40039/66750/20220228_ITkStripPower.pdf

https://power-distribution.web.cern.ch

Damaging effects:

https://rd50.web.cern.ch/niel/default.html

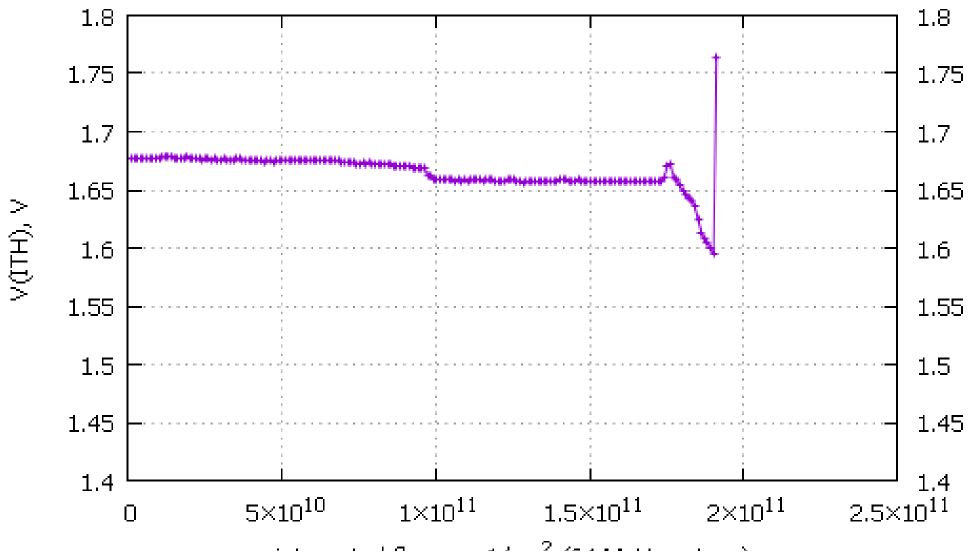
Enhanced proton and neutron induced degradation and its impact on hardness assurance testing. In *Sandia National Lab. (SNL-NM), Albuquerque, NM (United States)*. https://www.osti.gov/servlets/purl/1146194

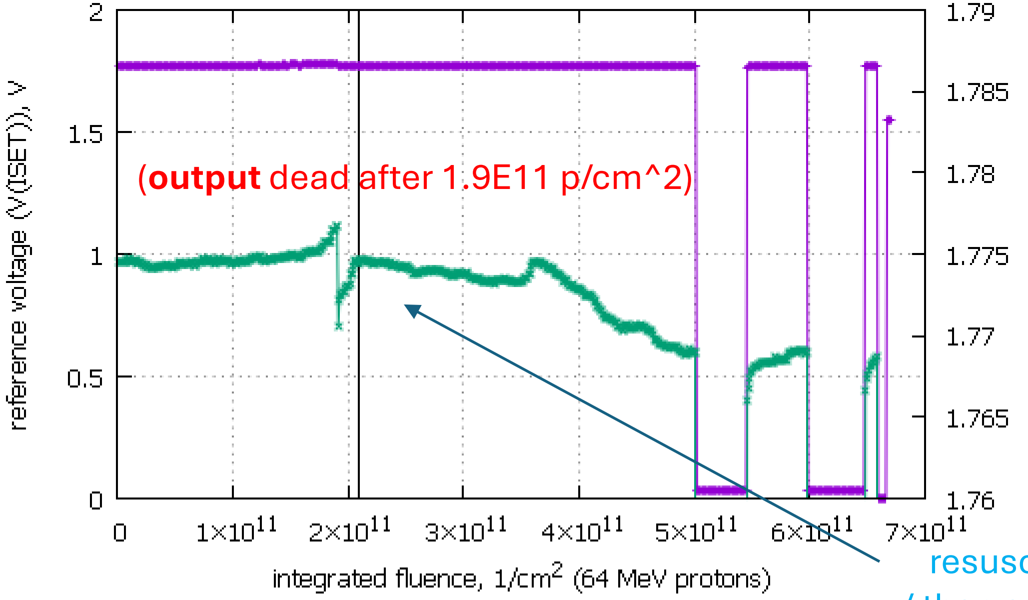
https://www.ti.com/pdfs/hirel/space/HEART05-G1paper.pdf

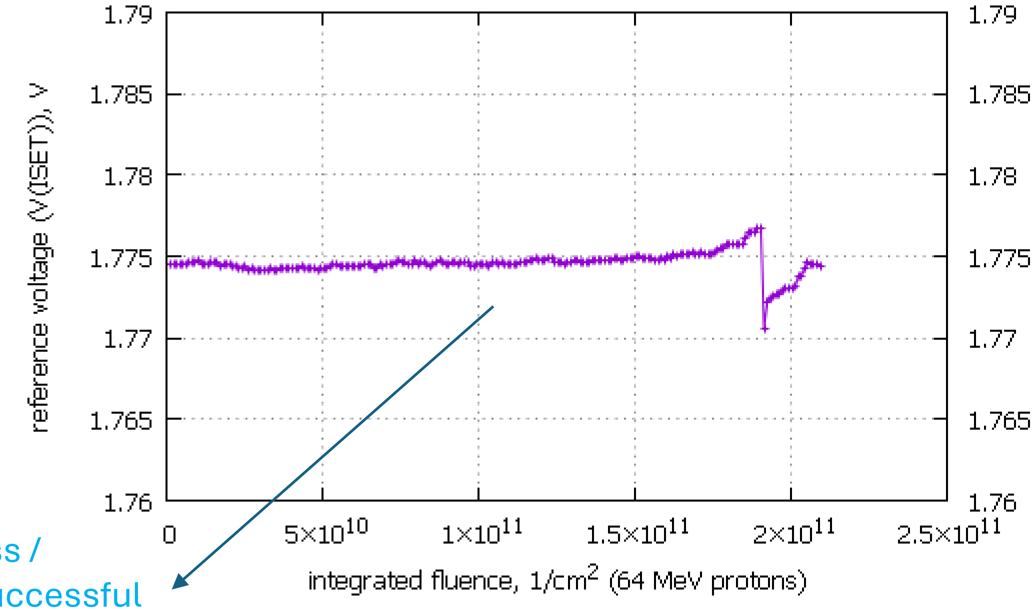
https://nepp.nasa.gov/DocUploads/C688DA3C-F0B2-460E-97E0F71B28EE85FE/DispLin-98.pdf

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4337442

DEVICE	LTC3600
Vin to Vout	13 V to 1.8 V
load	1.5 Ω
64 MeV p flux	2.49E8 p/cm^2*s
2% output deviation	no significant deviation
instability	no
output dead	1.90E11 p/cm^2





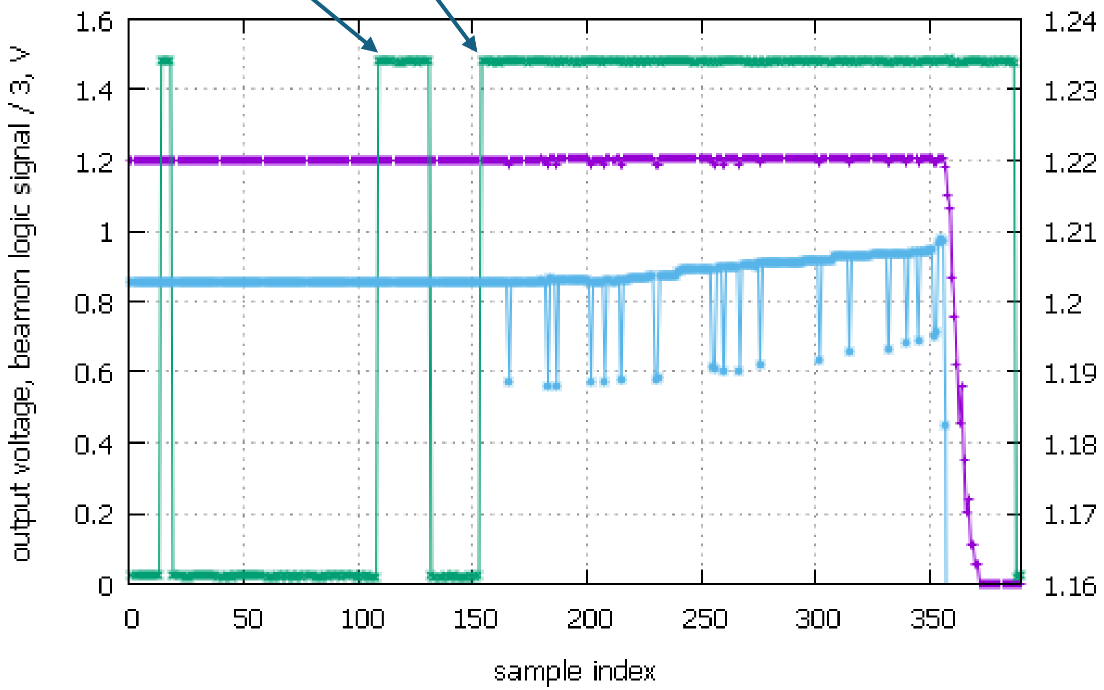


made access /
resuscitation unsuccessful
/ then continued watching V_{REF}

LTC7890 Output deviation under 64MeV proton beam

Faraday cup open (t=0) start logging

Beam on, Faraday cup closed



Output deviation

Slight instability (output deviation) observed only when beam is on (Faraday cup open)