IRRADIATION TESTING OF

COMMERCIAL DC|DC BUCK CONVERTERS FOR ePIC

May 15th 2024, UC Davis Crocker Cyclotron

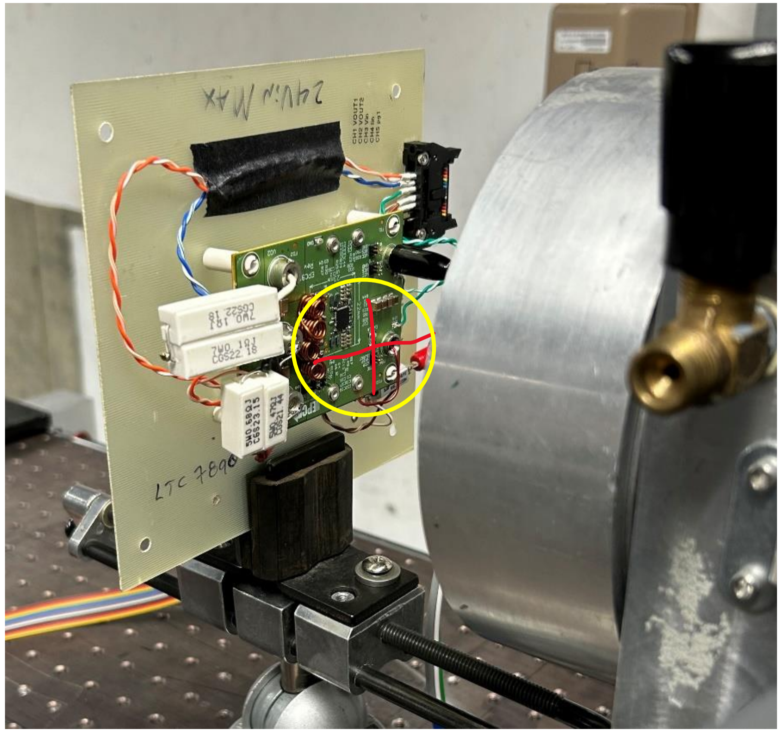
Presentation for DAQ & Electronics

Gerard Visser Indianna CEEM

Tim Camarda for BNL

With contributions for irradiation studies from:
Alex Jentsch, BNL (simulations for ePIC)

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



DUT at Cyclotron facility, proton exit window (Ø6cm)

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% , $\text{Ripple}_{(20MHZ\ BW)}$ < 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

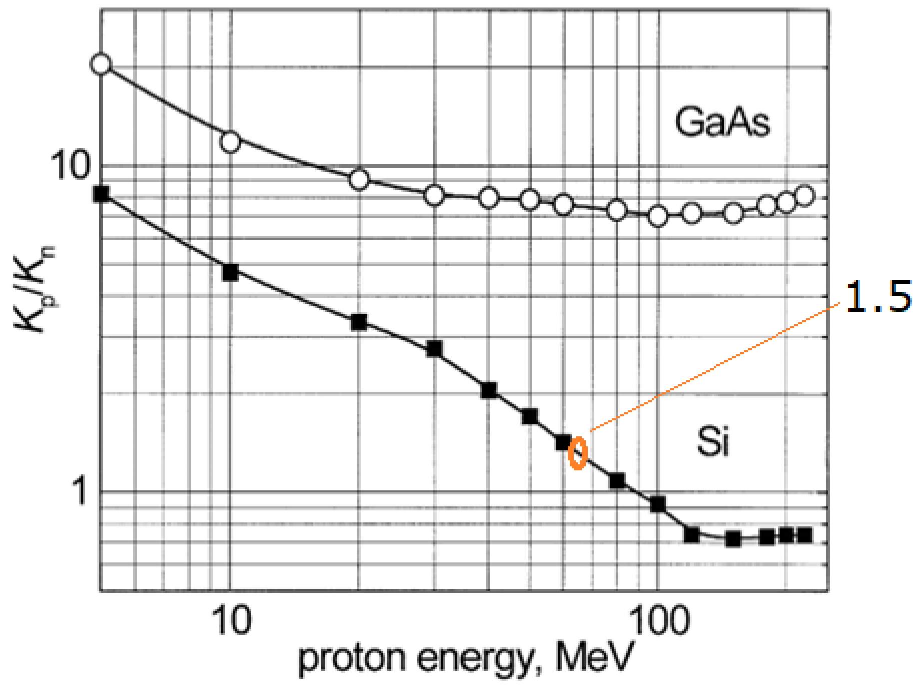


Fig. 6. The relative damage, K_p/K_n, as a function of proton energy where K_n is taken for 1 MeV neutrons.

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

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

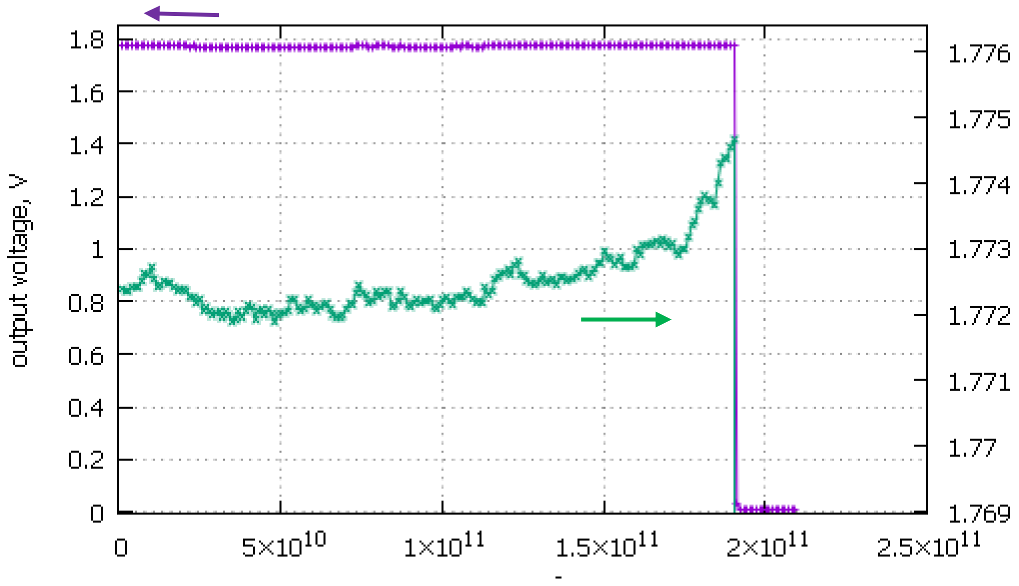
Proton fluence integrated for 10 operational years (1MeV neutron equivalent)

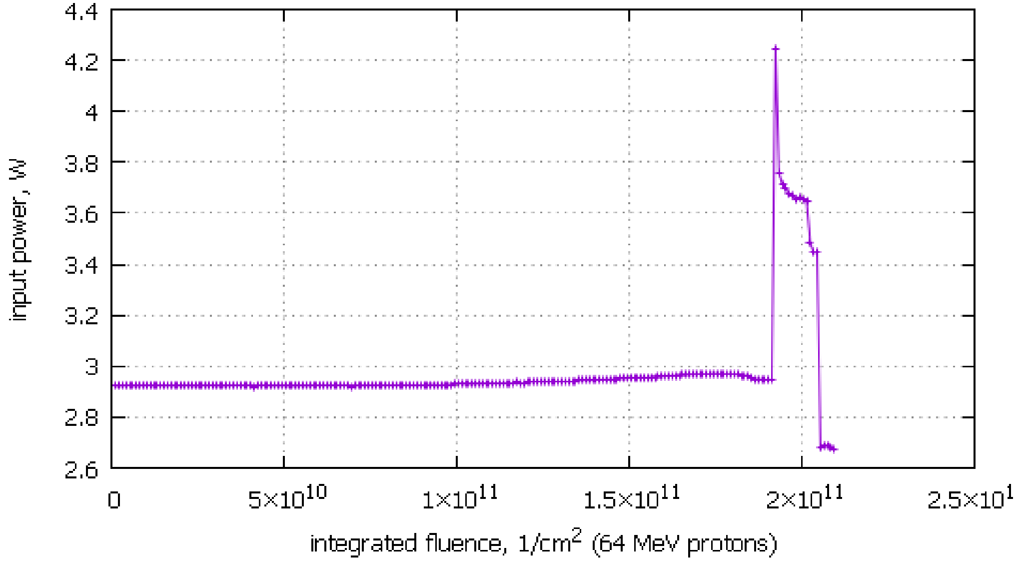
=> 1.0E12 n /sec cm^2

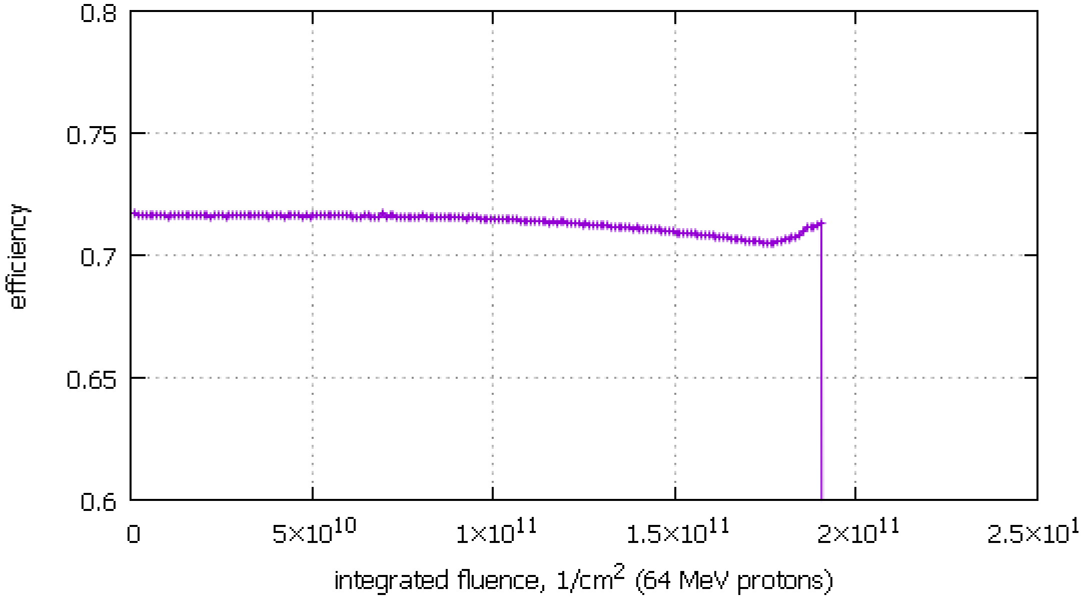
Irradiation time to full fluence => 2700 seconds (45 min)

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





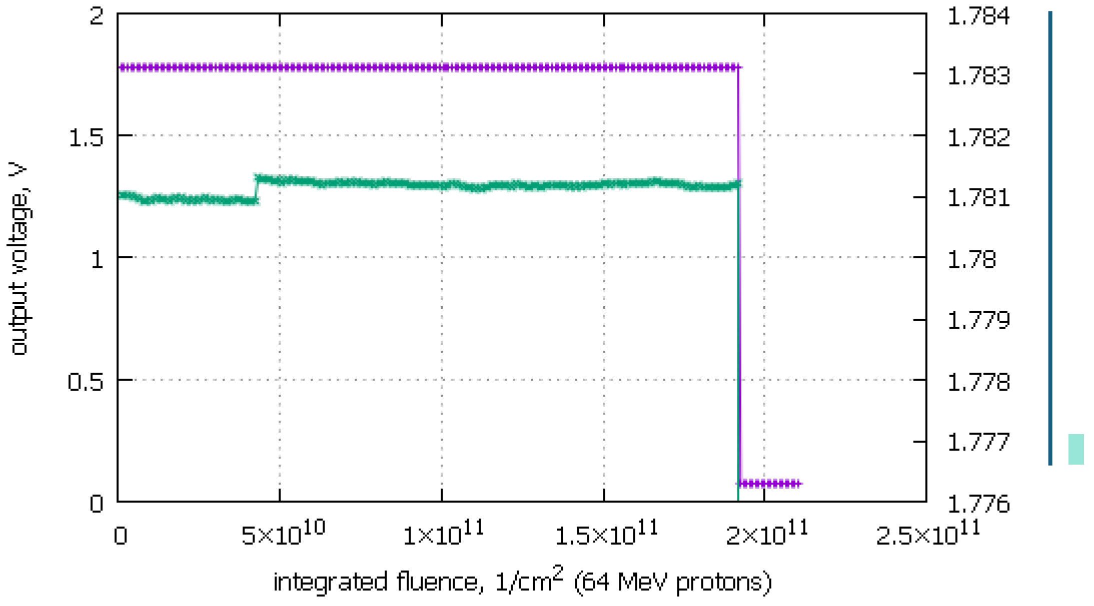


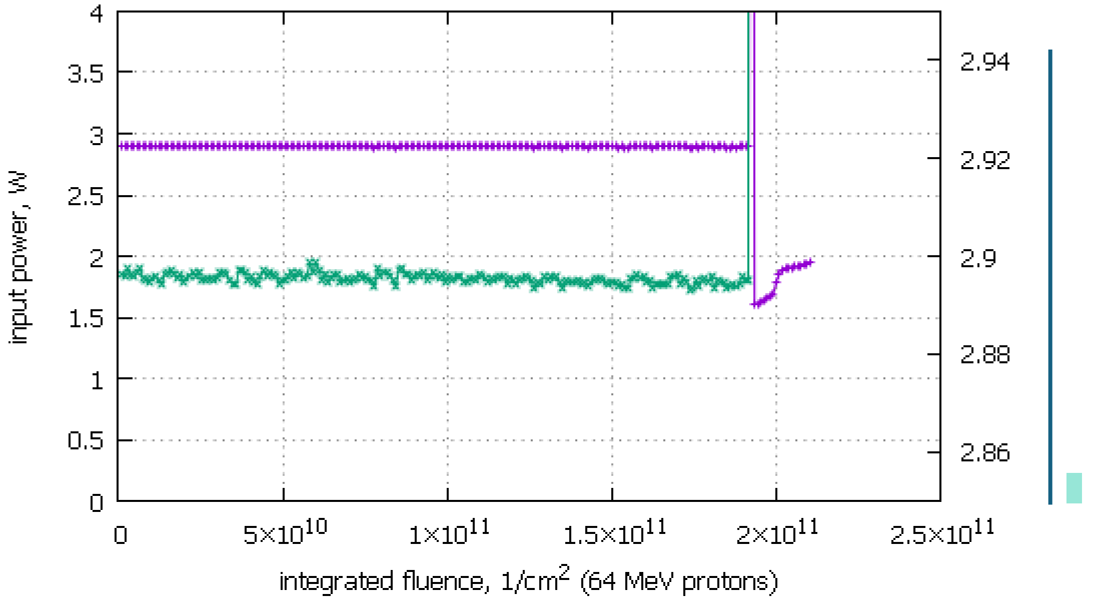
also see bonus plots in backup slides for Vref out

IRRADIATION TEST RESULTS

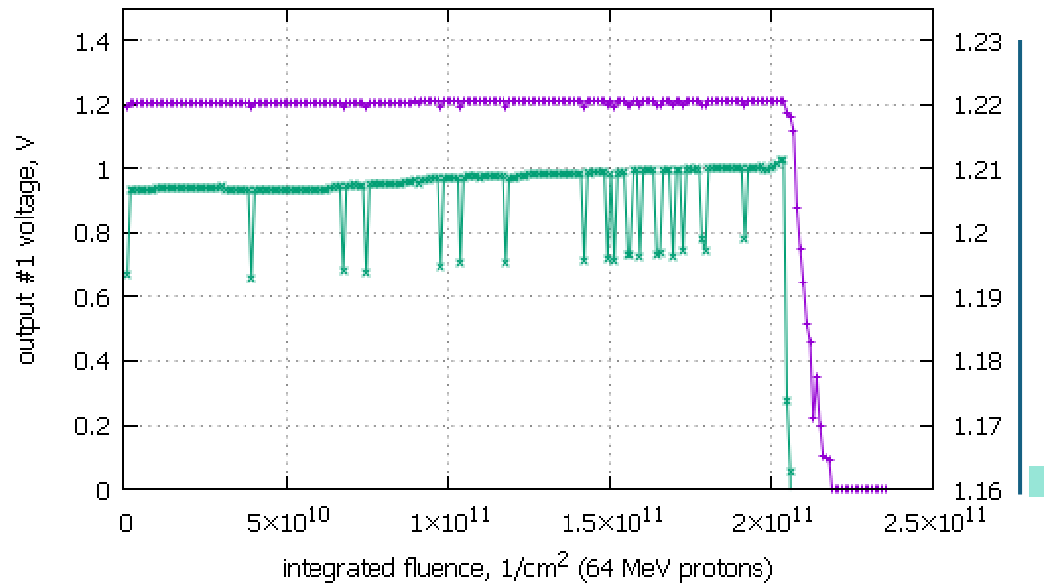
DEVICE	LTC3626 (2.5A)
Vin to Vout	16 V to 1.8 V
load	1.5 Ω (1.2A)
64 MeV p flux	2.33E8 p/cm^2*s
2% output deviation	no significant deviation
instability	no
output dead	1.92E11 p/cm^2

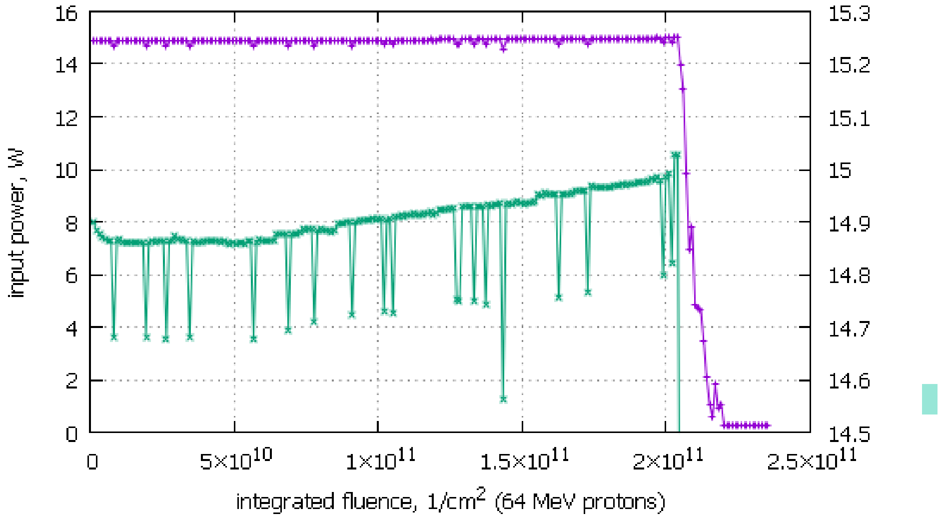
Exposure time until part failed: 1.9E11 / 2.48E8 /sec = 13 minutes => ~30% of specified fluence

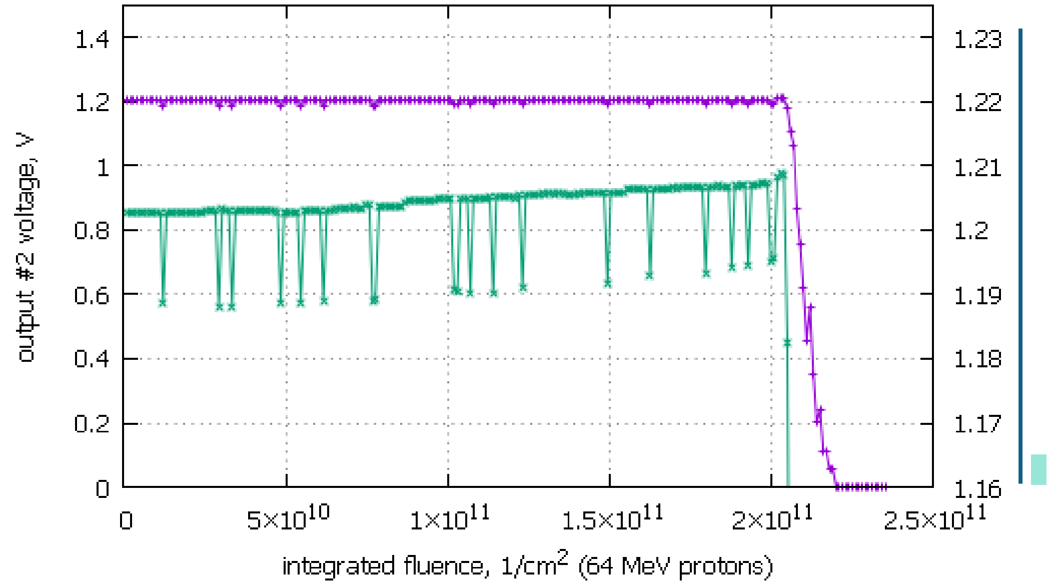




DEVICE	LTC7890 (2-ch) (15A /ch)
Vin to Vout	12 V to 1.2 V
load	0.2 Ω, 0.28 Ω (6A, 4.3A)
64 MeV p flux	2.51E8 p/cm^2*s
2% output deviation	(<20mV_{P-P})
instability	slight instability observed
output dead	2.06E11 p/cm^2

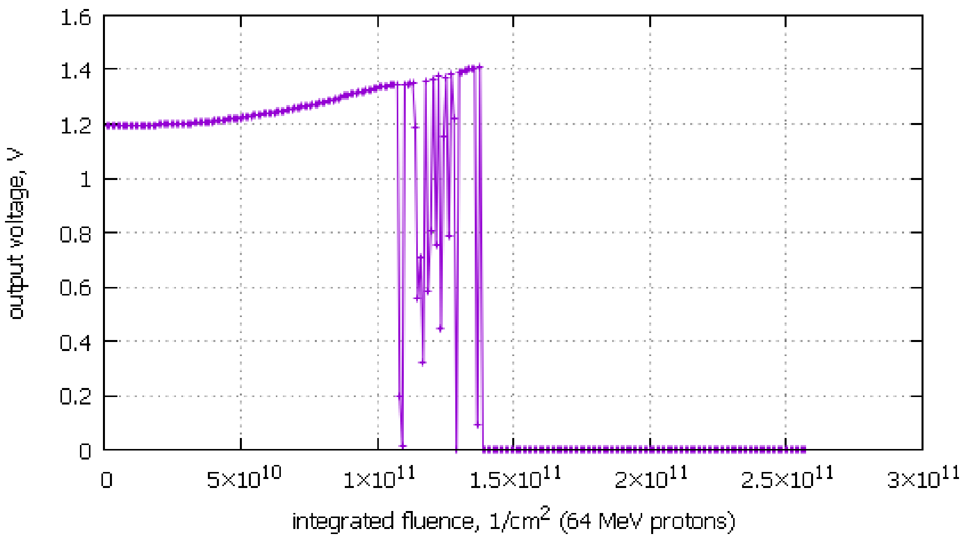


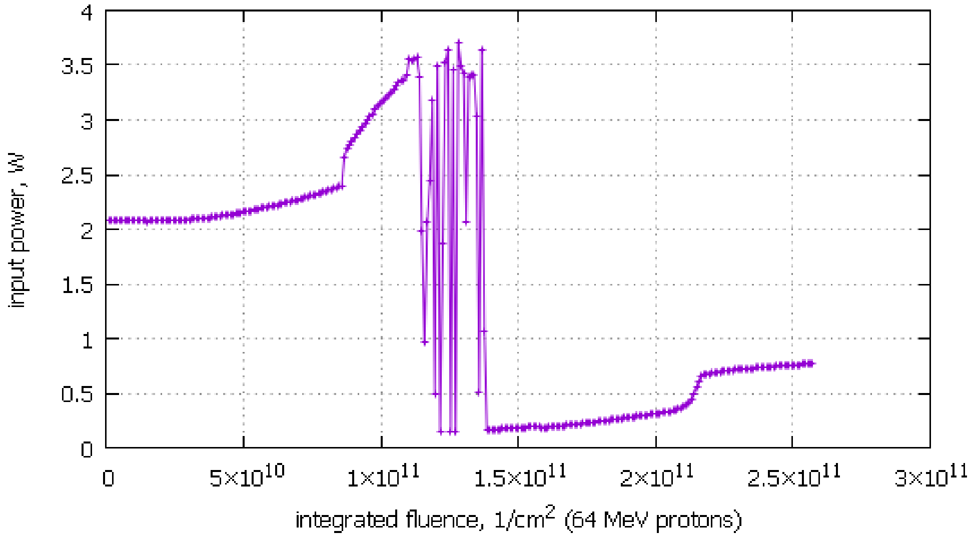


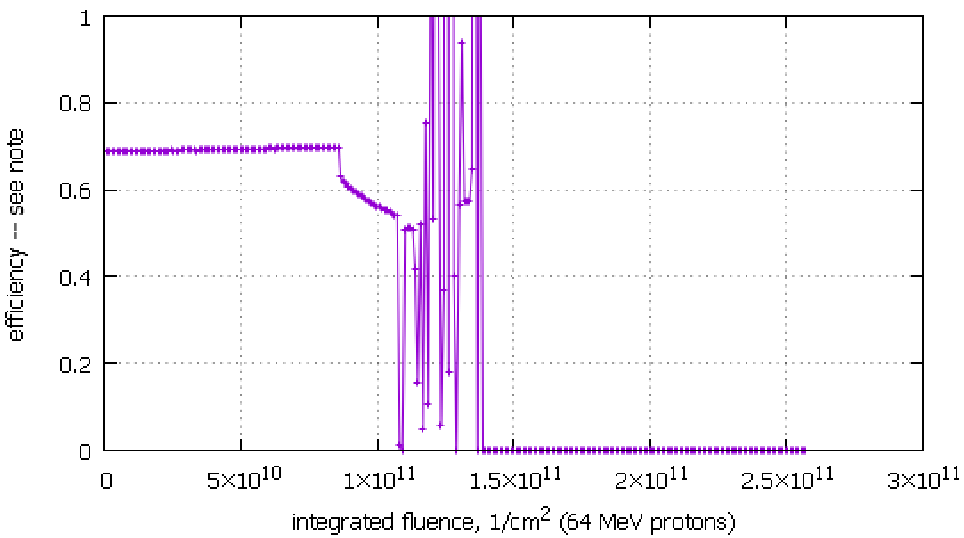


NOTE: Some efficiency effects can be contributed to variations caused by temperature coefficient (±400ppm/°C) of the load resistors. This applies to all tested devices.

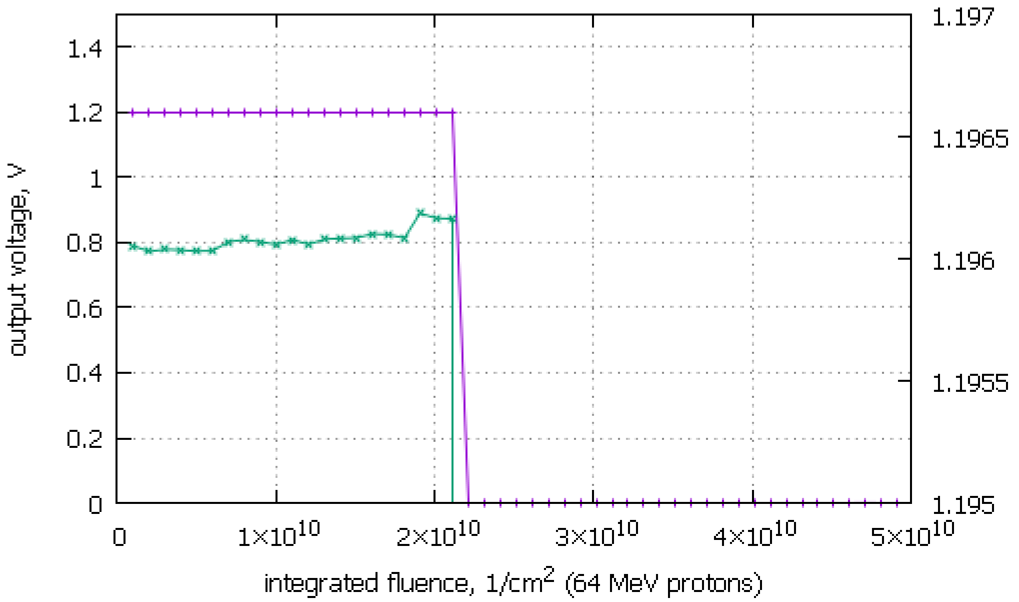
DEVICE	MP2318 (2A)
Vin to Vout	14 V to 1.2 V
load	1 Ω (1.2A)
64 MeV p flux	2.35E8 p/cm^2*s
2% output deviation	4.83E10 p/cm^2
instability	1.08E11 p/cm^2
output dead	1.38E11 p/cm^2

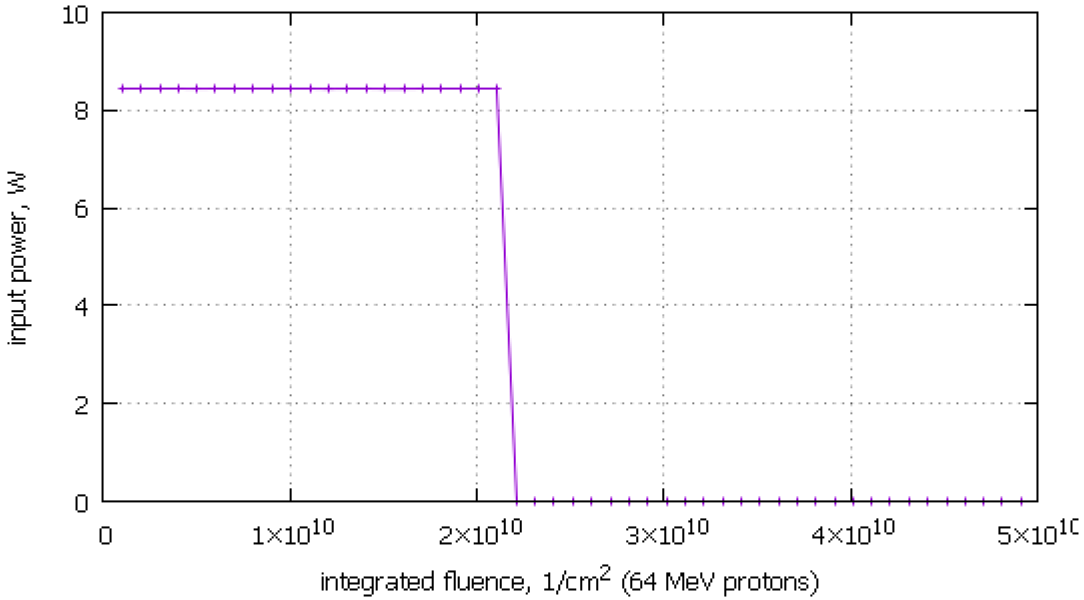




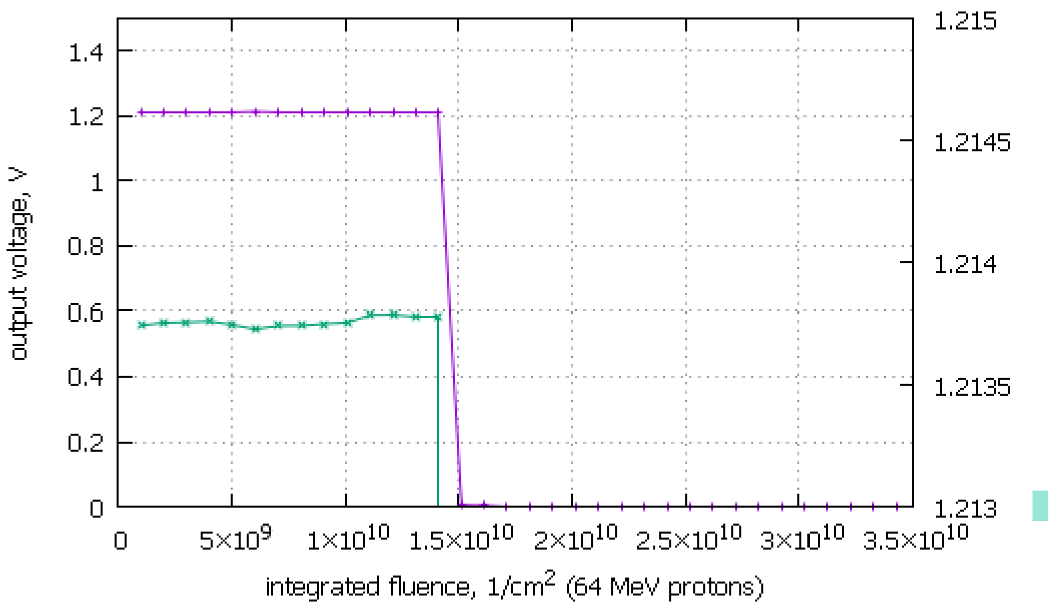


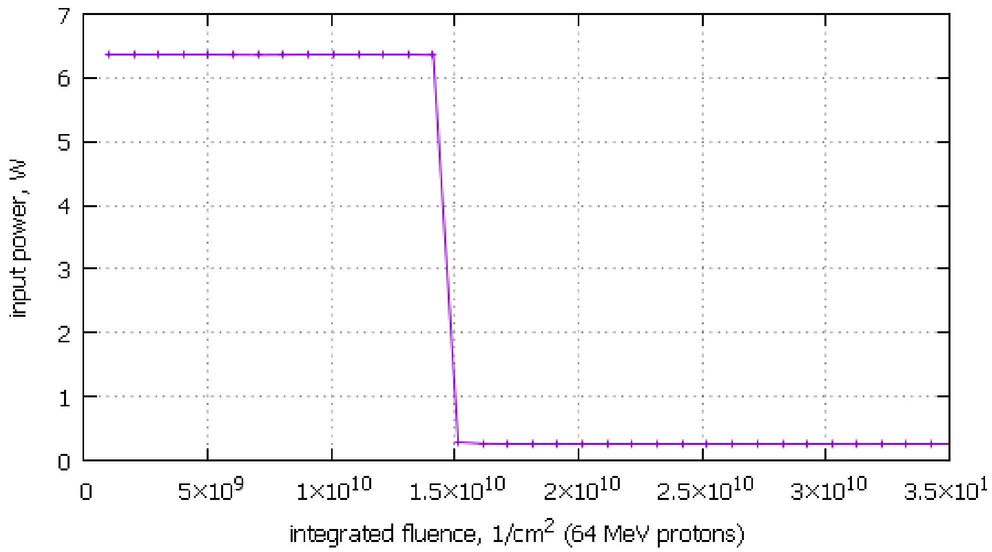
DEVICE	LTC7151 (15A)
Vin to Vout	16 V to 1.2 V
load	0.2 Ω (6A)
64 MeV p flux	2.49E8 p/cm^2*s
2% output deviation	no significant deviation
instability	no
output dead	2.21E10





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

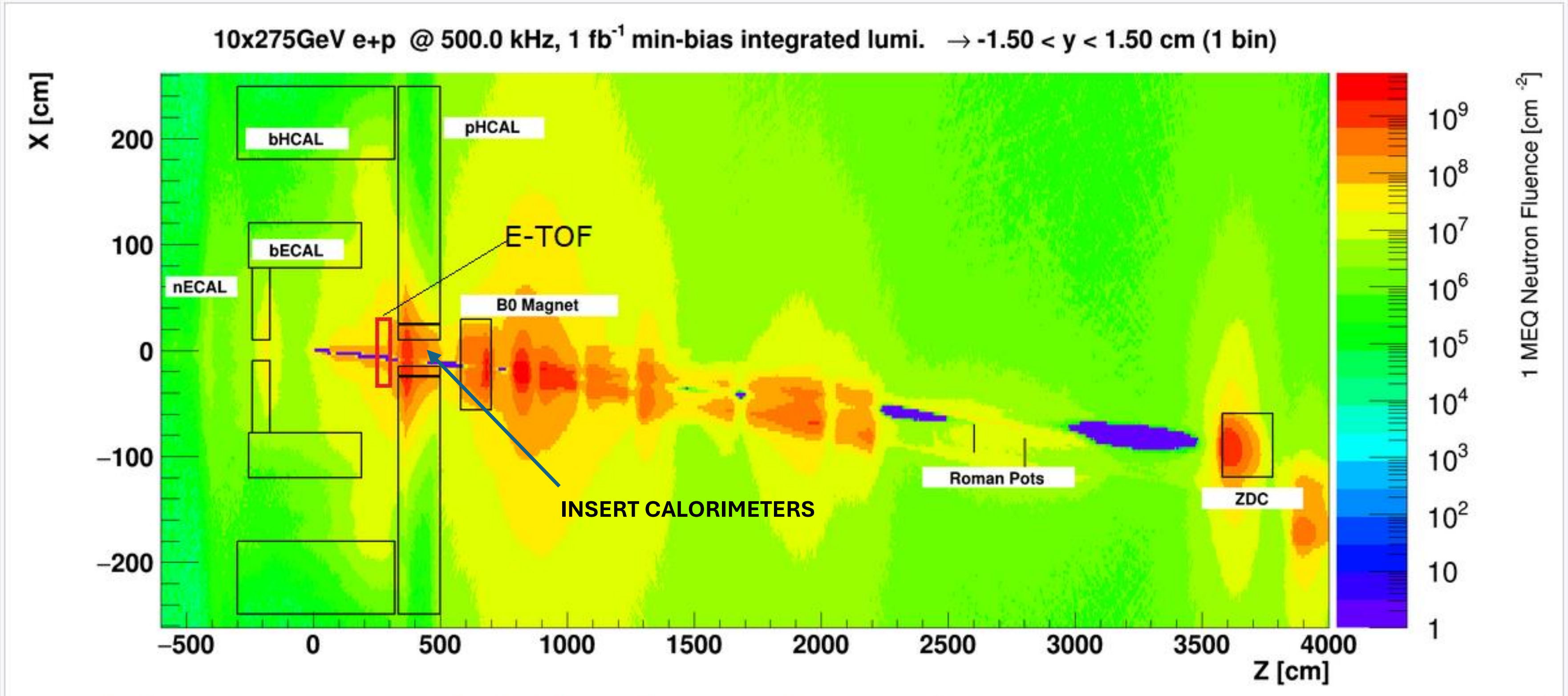


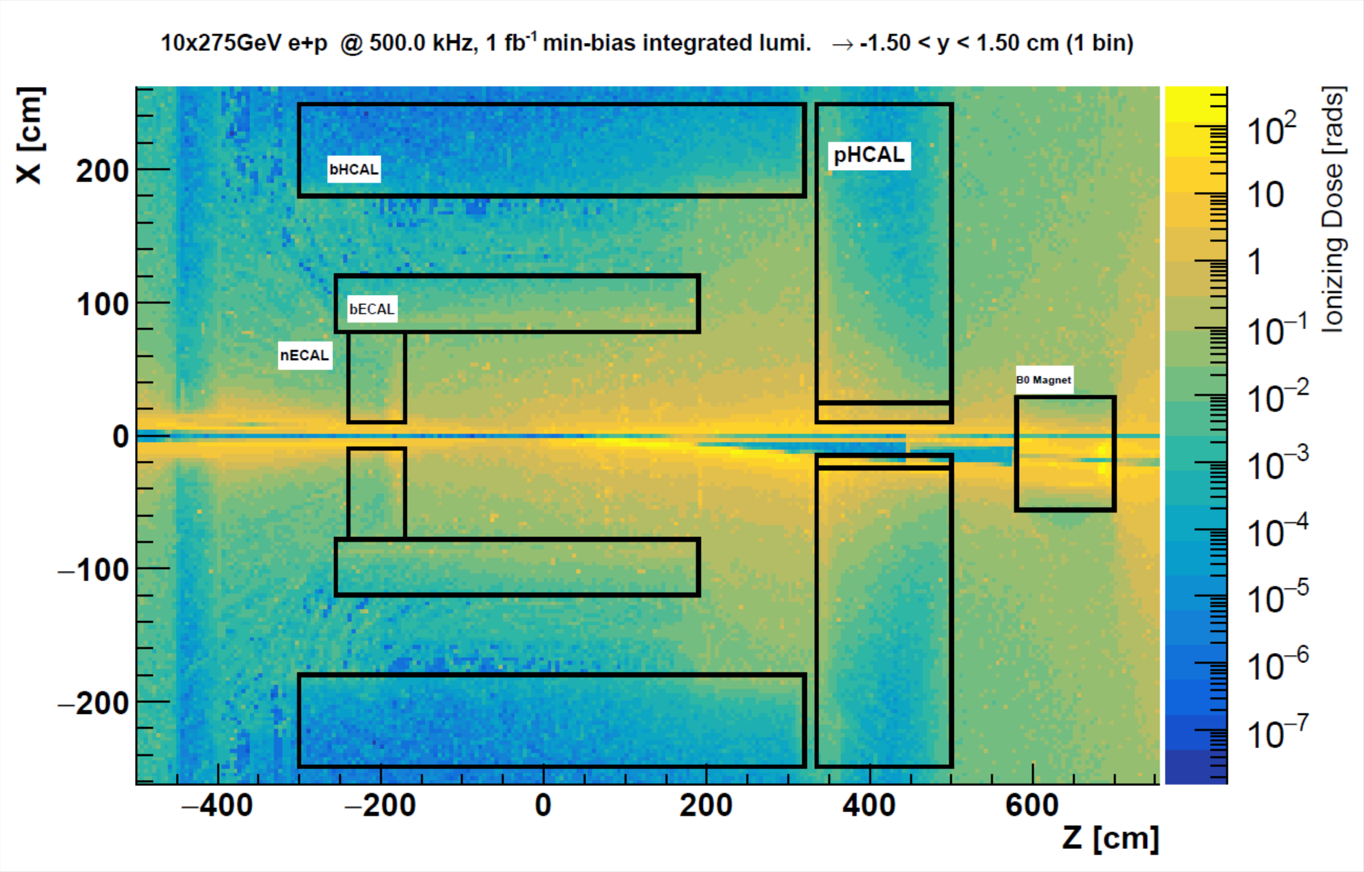
Figure 3: 1 MEQ neutron equivalent fluence per fb^{-1} for minimum-bias PYTHIA e+p events at 10x275 GeV. ROOT files can be found here.

Radiation simulation from Alex Jentsch, BNL

Brookhaven National Laboratory

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

Brookhaven National Laboratory
ePIC

Non Ionizing Energy Loss

Neutron induced displacement damage in silicon

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

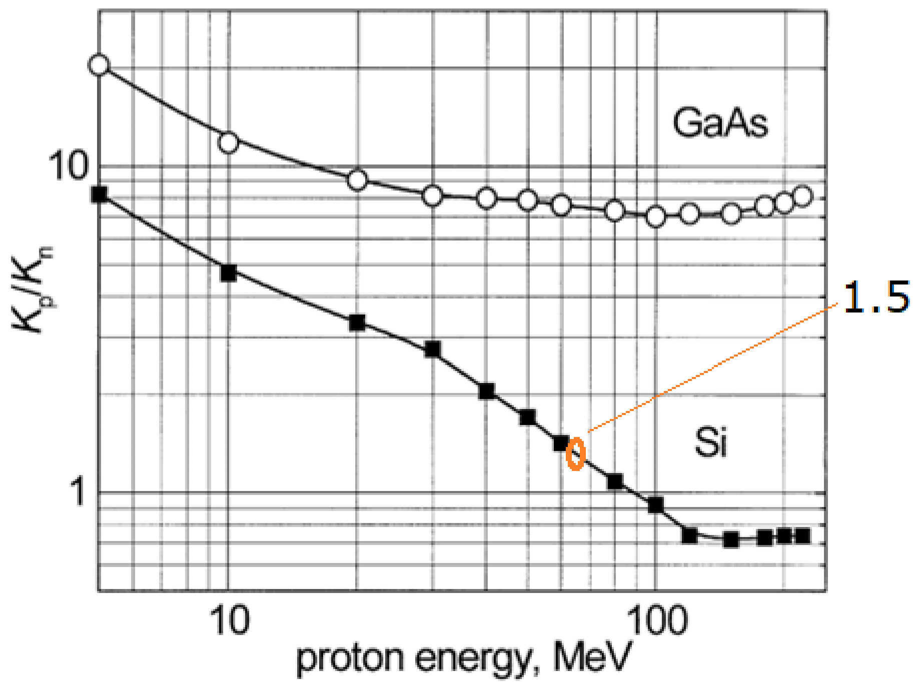


Fig. 6. The relative damage, K_p/K_n, as a function of proton energy where K_n is taken for 1 MeV neutrons.

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

From our meeting on Tuesdays discussion of ePIC radiation studies:
Meeting attendees: Elke, Alex, Fernando, Gerard, Oleg, Tim

We would like to consult with CERN collaborators who have direct experience with rad hardened specifications & testing.

For example: we would like to see how CERN test their devices compared to our test at UC Davis. This is so that we have a direct 1:1 comparison with CERN rad hard specs.

PLAN FORWARD FOR POWERING ePIC ELECTRONICS

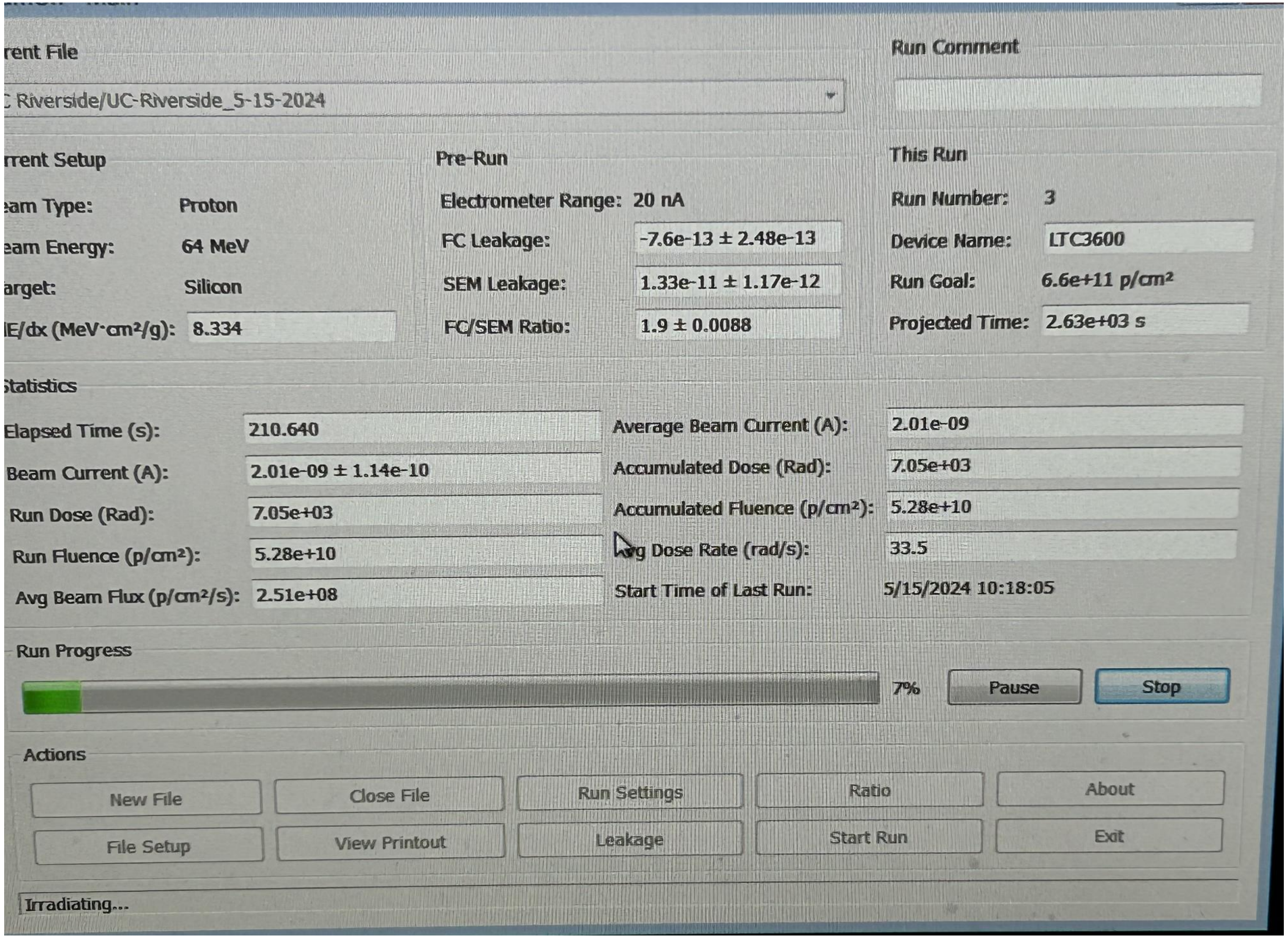
Depending on location at ePIC & sub detector, COTS devices will be not suitable:

- Use a combination of bPOL48V buck controller and Linear Regulators: Example => (24 Vin to 3.3Vout)
    - Output voltage - Vout 0.6 to 24 V => Testing @ 3.3Vout & 1.2Vout
    - Testing @ 1.2Vout:
    - Testing @ 3.3Vout:
- Stock still remains for bPOL12V...but would need to purchase a head of time (including spares)

CERN DCDC WEBSITE

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	
otons+neutr	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

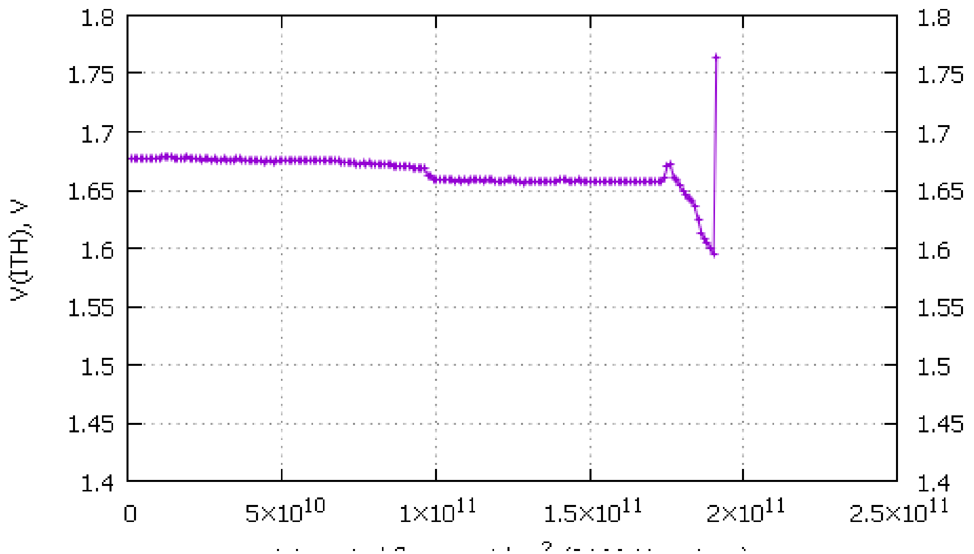
Enhanced proton and neutron induced degradation and its impact on hardness assurance testing. In *Sandia National Lab. (SNL-NM), Albuquerque, NM (United States)*. https://www.osti.gov/servlets/purl/1146194

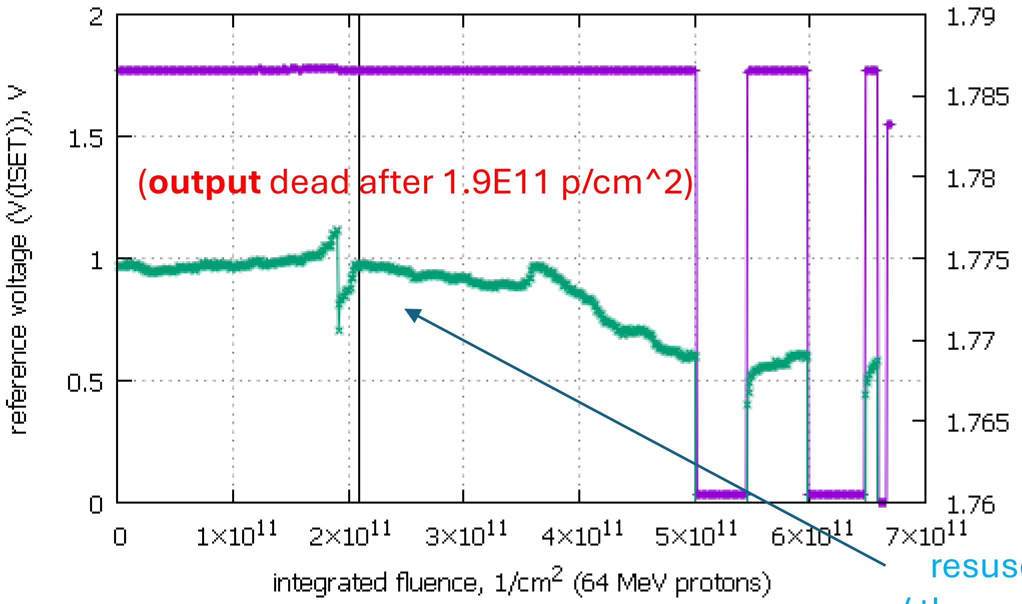
https://www.ti.com/pdfs/hirel/space/HEART05-G1paper.pdf

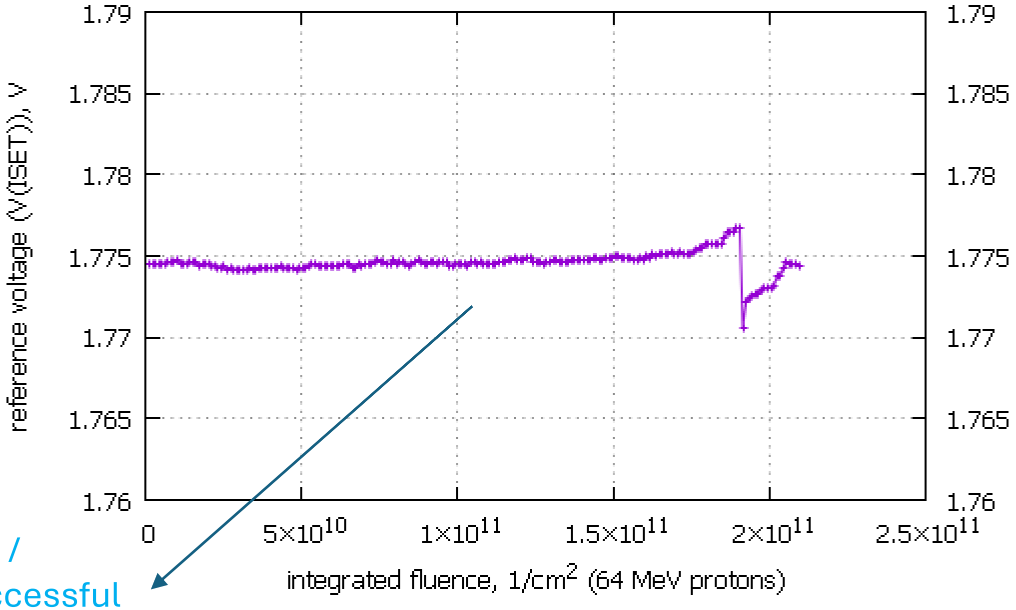
https://nepp.nasa.gov/DocUploads/C688DA3C-F0B2-460E-97E0F71B28EE85FE/DispLin-98.pdf

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





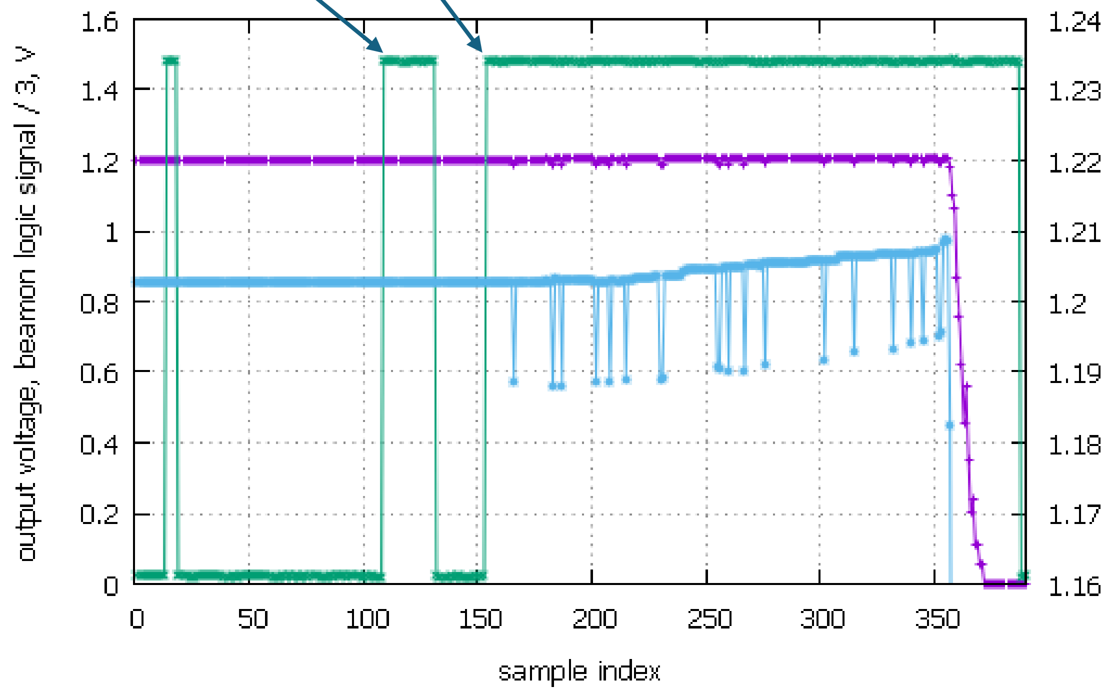


made access /
resuscitation unsuccessful
/ then continued watching ref V

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)