DC|DC BUCK CONVERTER TESTING

Update 5/10/2024

Presentation for TOF frontend electronics working group meeting

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

- **Update on performance evaluation**
- **Irradiation testing at UC Davis (May 14th)**
- **Next steps**

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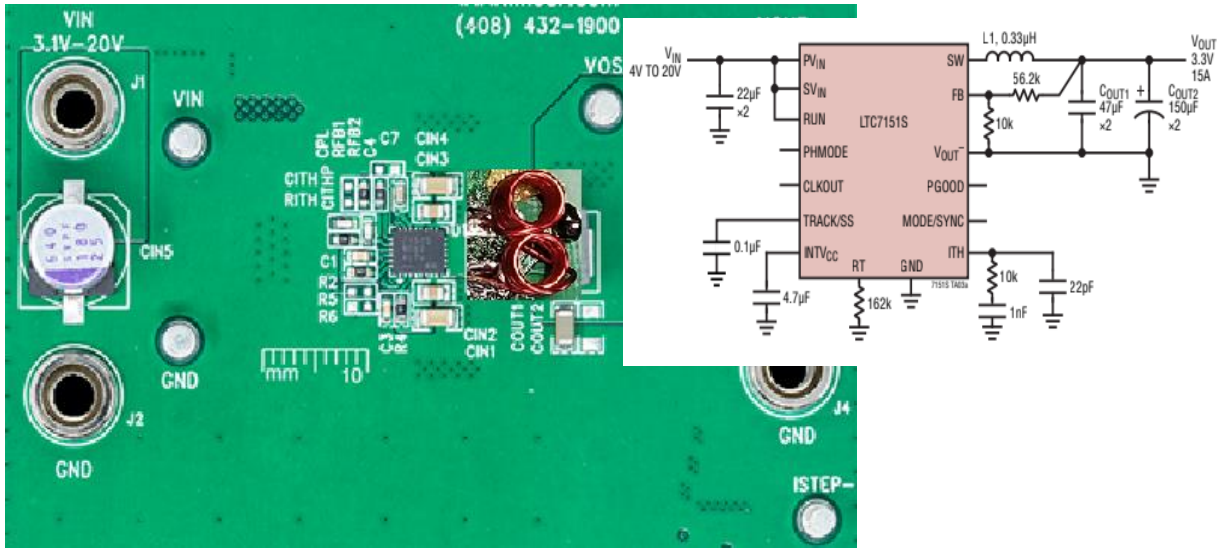
ePIC

ASIC Power Requirements (review)

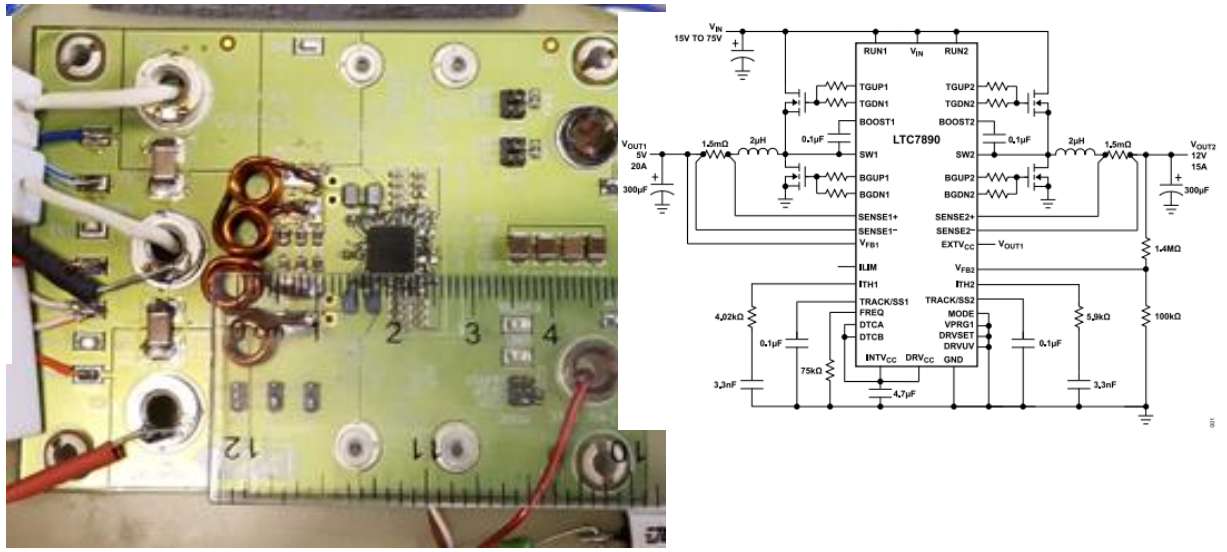
- EICROC: 1W @ 1.2V
- Power 16x ASICs => 16W => 13.3A (*could be higher though so figure 16A*)
- Noise < 0.5% , $Ripple_{(20MHZ\,BW)}$ < 0.3%
- Efficiency: at least 70%
- Power Board Footprint: 100mm x 28mm
- Magnetic field (2 Tesla) => non iron core inductors => air core
- Radiation Tolerant (1 x $10^{12}\,CM^2$) => 1MeV fluence
- TID ($600K_{RAD}$)

Evaluation board testing (synchronous buck converters)



LTC 7151 DC|DC regulator evaluation board

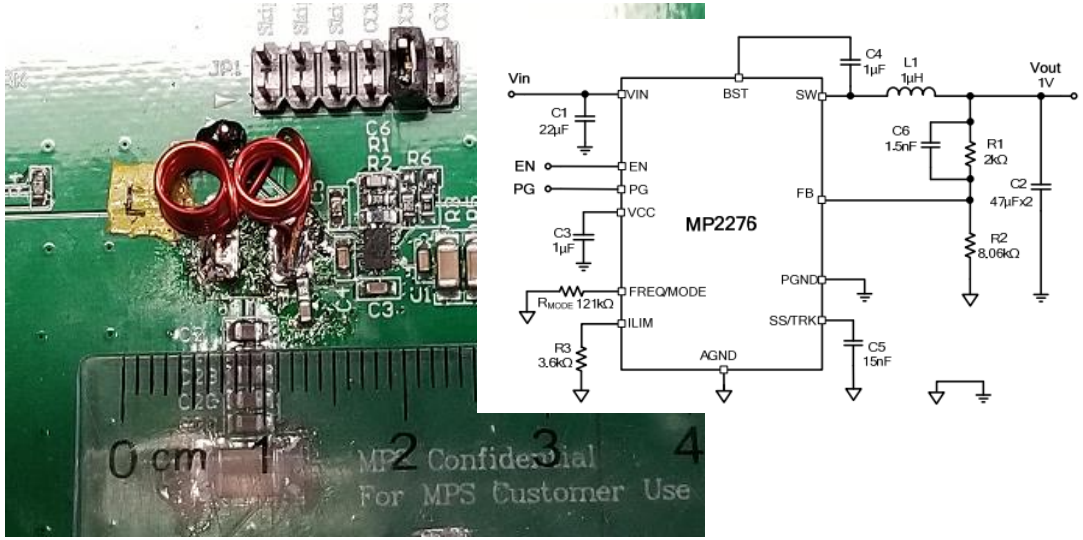
- Package size: 5mm x 4mm (QFN)
- Power FET (Internal)
- T °C (need to record)
- Vin: 4 to 20V, Vout 0.5 to 5.5V
- F_{Sw} => 0.4 – 3MHz
- Power Output => 14.5W => 1.2V @ 12A (80%)
- Switching phase: 180° out (reduce EMI)
- P_{EFF} > 80% ($12V_{IN}$, 12A)
- Noise/ Ripple < 0.5% @ 12A
- Regulation => 99%
- Will require 2x for ASIC power boards
- Tested w/ 300nH solenoid inductor 2MHz



LTC 7890 (GaN Controller) evaluation board (replacement candidate for CERN bPOL48V controller for lesser harsh rad environments)

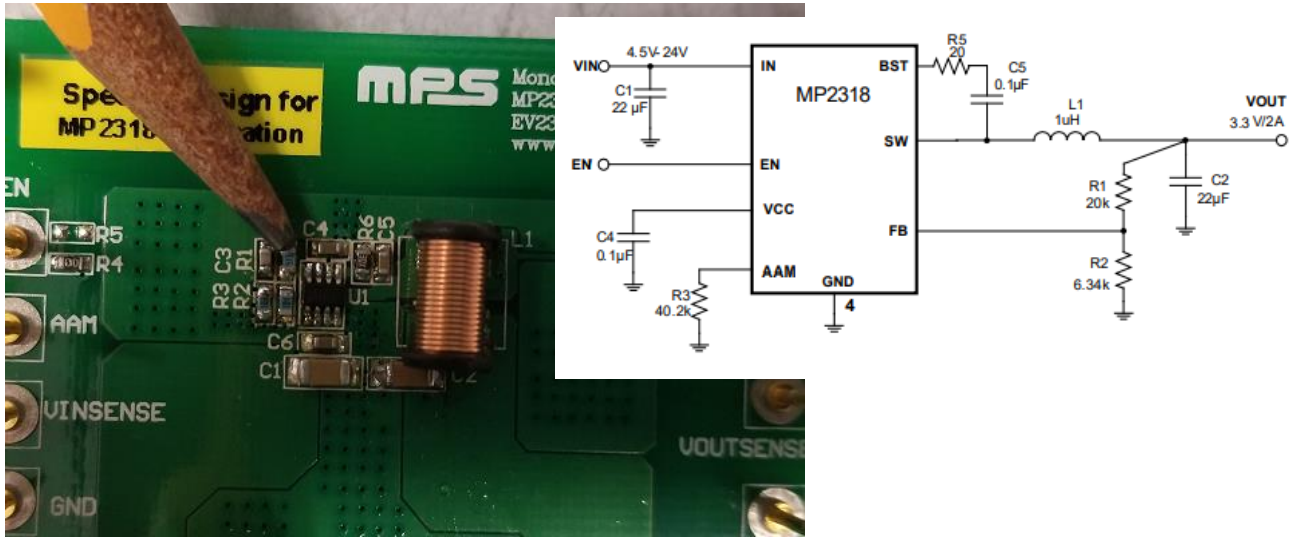
- Package size: 6mm x 6mm (QFN)
- Power FET (external GaN)
- T_{CHIP}:54°C , T_{IND} 56°C, T_{PCB} 46°C (open air, no heat sink)
- Vin 4 to 100V, Vout 0.8 to 60V
- F_{Sw} => 0.1 – 3MHz
- Power Output => 30W => CH1 1.2V @ 12A, CH2 1.2V @12A (80%)
- Switching phase: 180° out (reduce EMI)
- P_{EFF} ~ 80% ($12V_{IN}$, CH1 12A, CH2 12A)
- Noise/ Ripple < 0.5% @ 12A/ channel
- Regulation => 99%
- Will require 1x for ASIC power boards
- Tested w/ 300nH solenoid ind. 2MHz

Evaluation board testing (synchronous buck converters)



MP2276 DC|DC regulator evaluation board

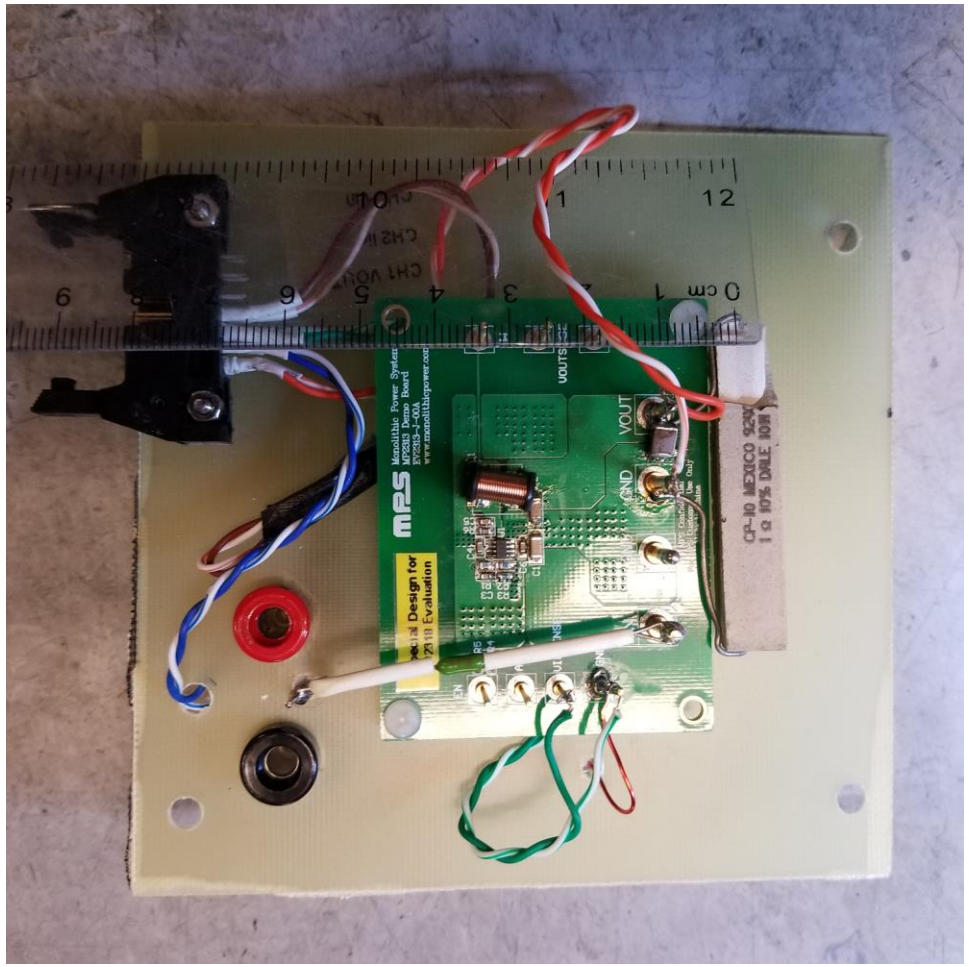
- Package size: 2mm x 3mm (QFN)
- Power FET (Internal)
- T_{2276} 50°C, T_{IND} 40°C
- Vin: 2.7 to 16V, Vout 0.8 to 6V
- F_{Sw} => fixed 2MHz
- Power Output => 8W => 1.2V @ 6.5A (80%)
- Switching phase: (fixed)
- P_{EFF} > 80% ($12V_{IN}$, 6A out)
- Noise/ Ripple < 0.5% @ 6.5A
- Regulation => 99%
- Tested w/ 300nH solenoid inductor 2MHz



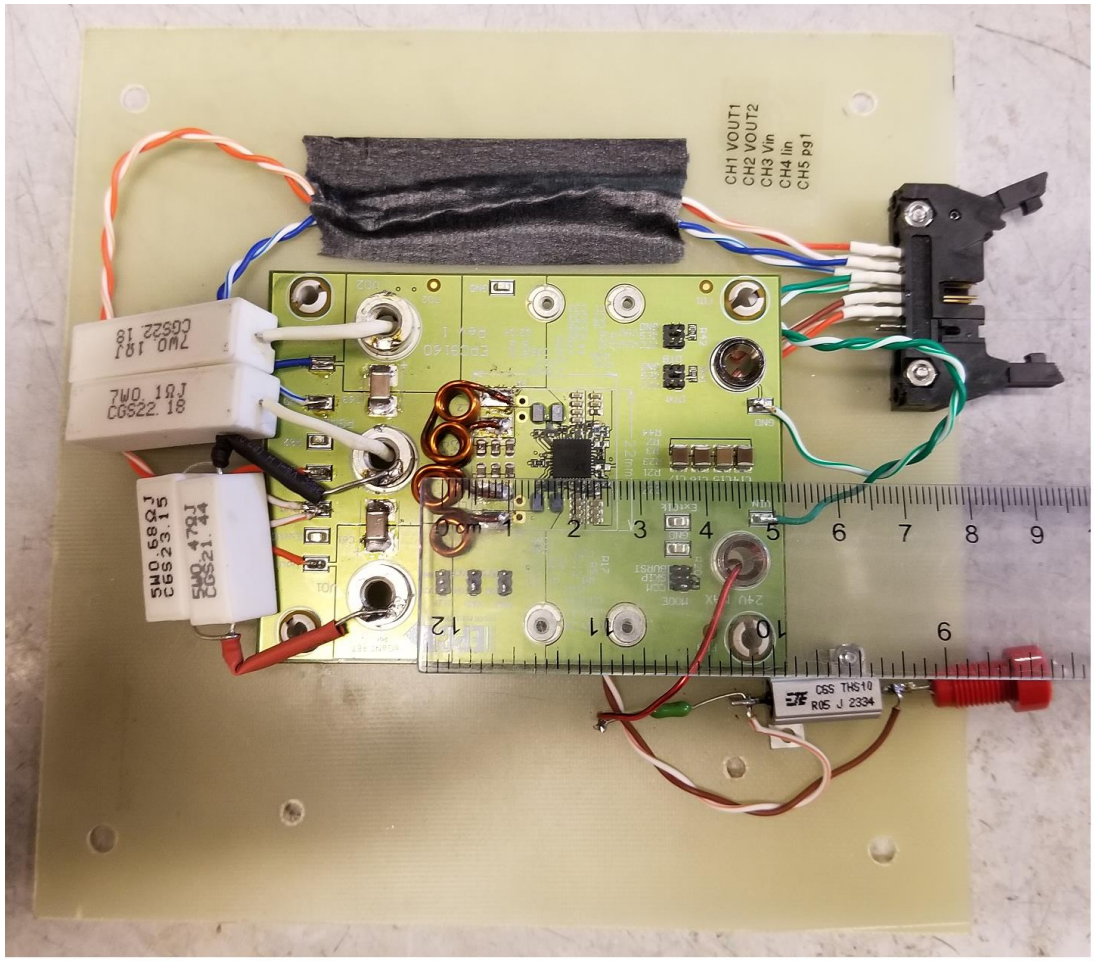
MP2318 DC|DC regulator evaluation board (possible to use on ASIC board)

- Package size: 3mm x 3mm (TSOT23-8)
- Power FET (Internal)
- T_{IND} = 30°C, T_{CHIP} = 34°C
- Vin: 4.5 to 24V, Vout 0.8 to ~ Vin
- F_{Sw} => fixed 2MHz
- Power Output => 2W => 1.2V @ 1.6A (80%)
- Switching phase: (fixed)
- P_{EFF} ~ 75% ($12V_{IN}$, 1.2A out)
- Noise/ Ripple < 0.2% @ 1.2A
- Regulation => 99%
- Tested w/ 760nH solenoid inductor 2MHz

Buck Converter Test Fixtures for Irradiation Testing



MP2318 2A, DC converter test fixture for rad testing



LTC7890 dual channel controller 16A/ ch DC converter test fixture for rad testing

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

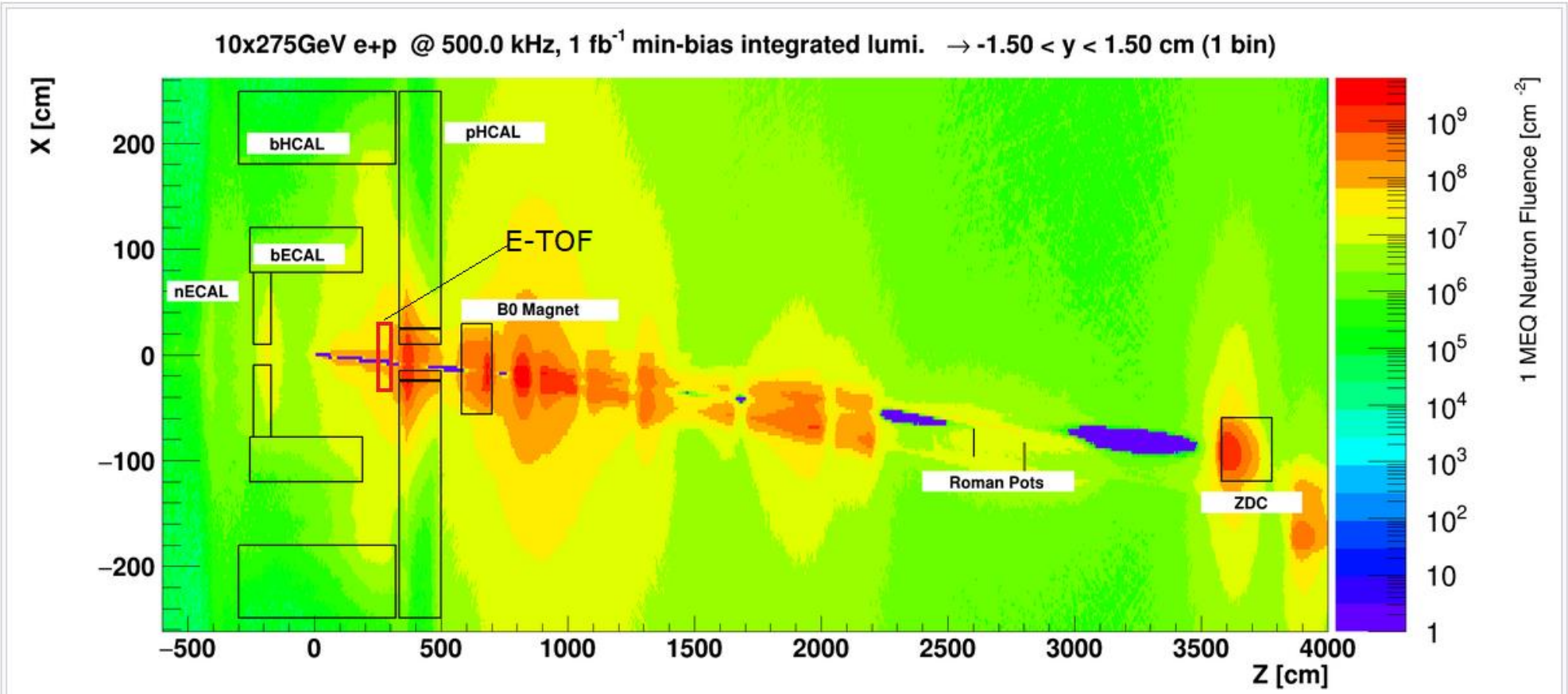


Figure 3: 1 MEQ neutron equivalent fluence per fb^{-1} for minimum-bias PYTHIA e+p events at 10x275 GeV. ROOT files can be found here.

Radiation simulation from Alex Jentsch, BNL

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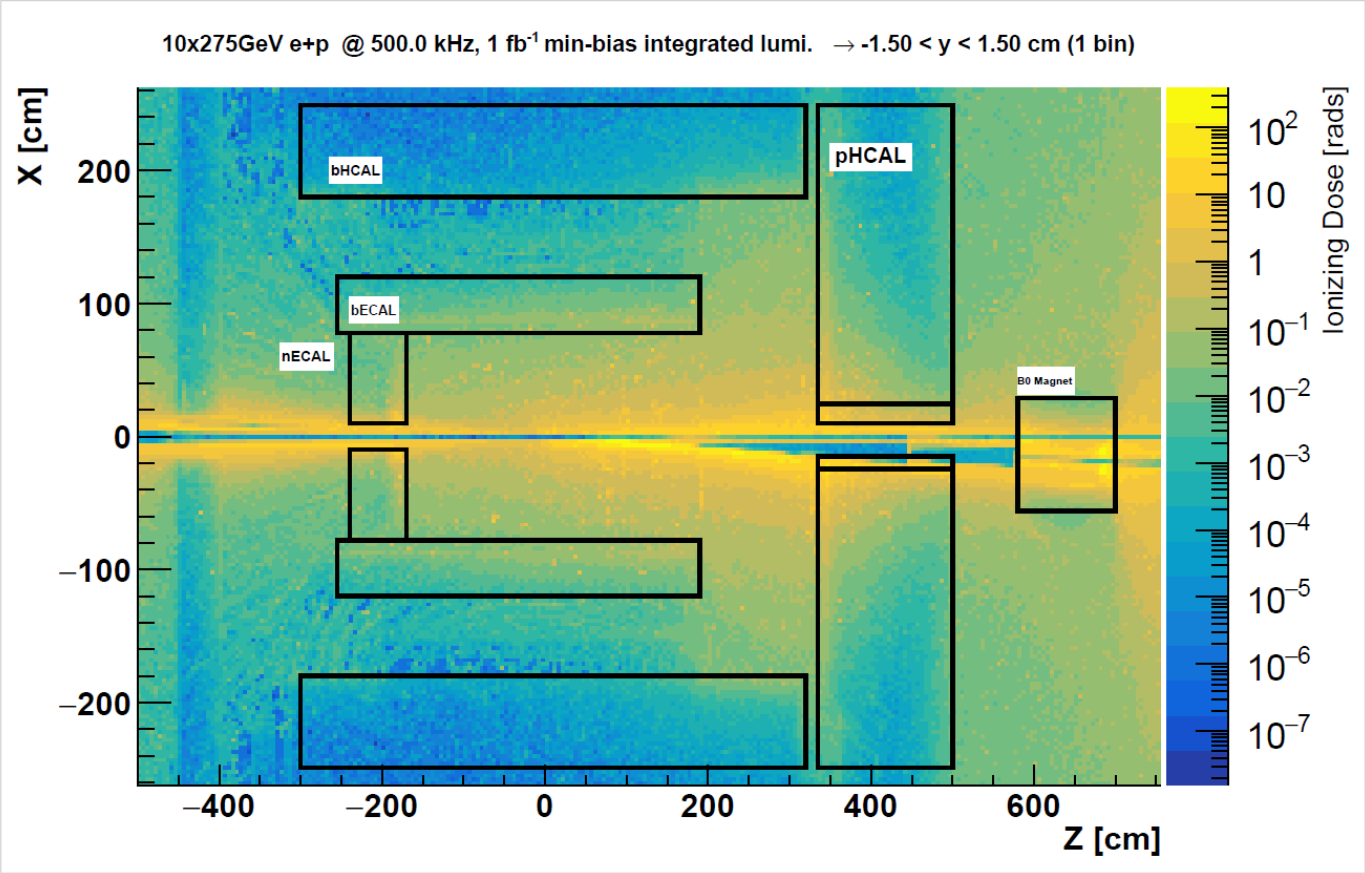
ePIC

TID from Hadron & Electron at ePIC:



Combined ionizing dose from Hadron & Electron sides

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

Note: to get the TID for one year of operation:
100 x fb-1 = 1 year

Ionizing dose of $3x10^2$ x 100 = 30kRads/ year x 20 years = 600kRads

Radiation simulations from Alex Jentsch, BNL

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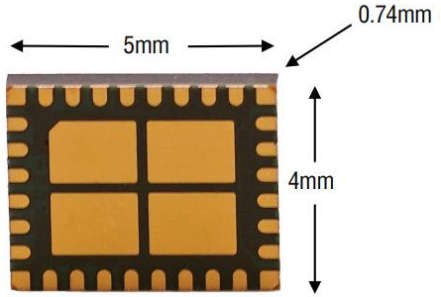
ePIC

Radiation Testing Requirements

Testing Facility: UC Davis Cyclotron UCDAVIS CROCKER NUCLEAR LABORATORY

- Particles: Protons => measure total dose/fluence (1MeV equivalent)
- ePIC fluence for 1 year of operation => $5x10^{8}$ / cm^{2} x $100_{(scale\ fb^{-1}\ to\ years)}$ x 20_{YEARS} = $1x10^{12}$ /cm^{2}
- Testing fluence full dose **1E12/ cm^{2}** *this is what the SiPMs are being tested to/* ***Neutron displacement damage in Si***
- Flux rate => 30_{MIN} – 1_{HOUR} to full dose
- Logging: 1mV resolution, 10 samples/ sec at 100ms intervals ($V_{OUT,}$ V_{IN} , I_{IN})



Type of damage to be observed

Displacement damage from Neutrons (Non-Ionizing Energy)=> 1 MeV equivalent fluence
Looking for degraded performance => sagging output Voltage, efficiency loss (monitor V_{IN} & I_{IN})

Ionization damage (TID) => Most likely to effect MOS devices and cause catastrophic failure

Not Tested => SEU (single event upset) => Maybe not an issue for these devices but could cause upset to internal logic controller.

Brookhaven National Laboratory ePIC

What's next after Irradiation Testing?

If evaluation boards pass irradiation testing

⇒ Send components out for batch testing (send 10 samples from two different batches to be irradiated, then assemble test/ prototype board)

⇒ **Circuit Design & testing for:** (*Note: the fowling looks good so far from evaluation board testing*)

- ⇒ Power efficiency (optimize switching inductor)
- ⇒ Optimize footprint & PCB layout
- ⇒ Noise & Ripple (mitigate EMI)
- ⇒ Thermal Analysis (temperature rise over 30°C)
- ⇒ First article testing => performance, durability (power cycle testing), burn in time

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

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