Applications of the UCSC/SCIPP FLUKA Simulation of the BeamCal

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Overview

ERRATUM

- small but interesting oversight in my last presentation on BeamCal power draw; arose during peer review

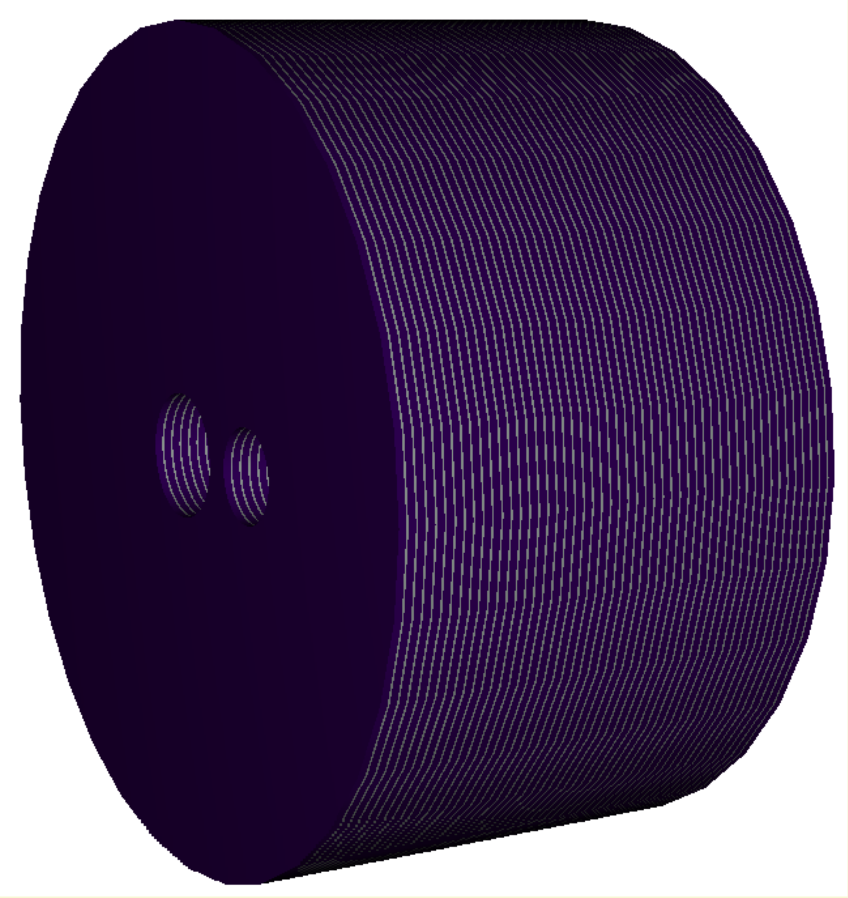
TEASER

- Use of FLUKA simulation to explore impact of BeamCal albedo on inner tracking

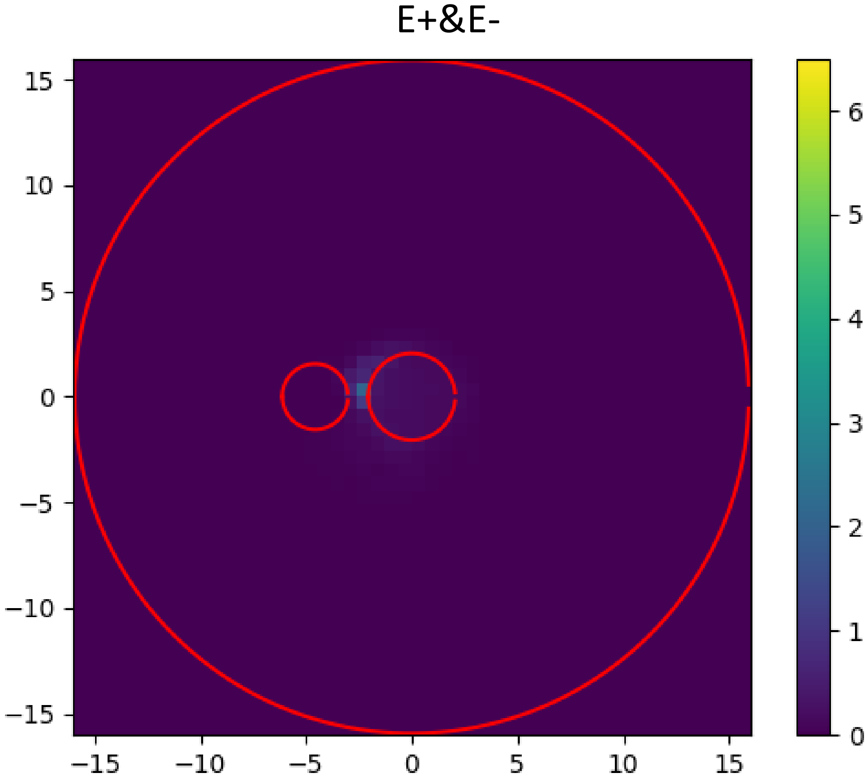
BeamCal Simulation in FLUKA

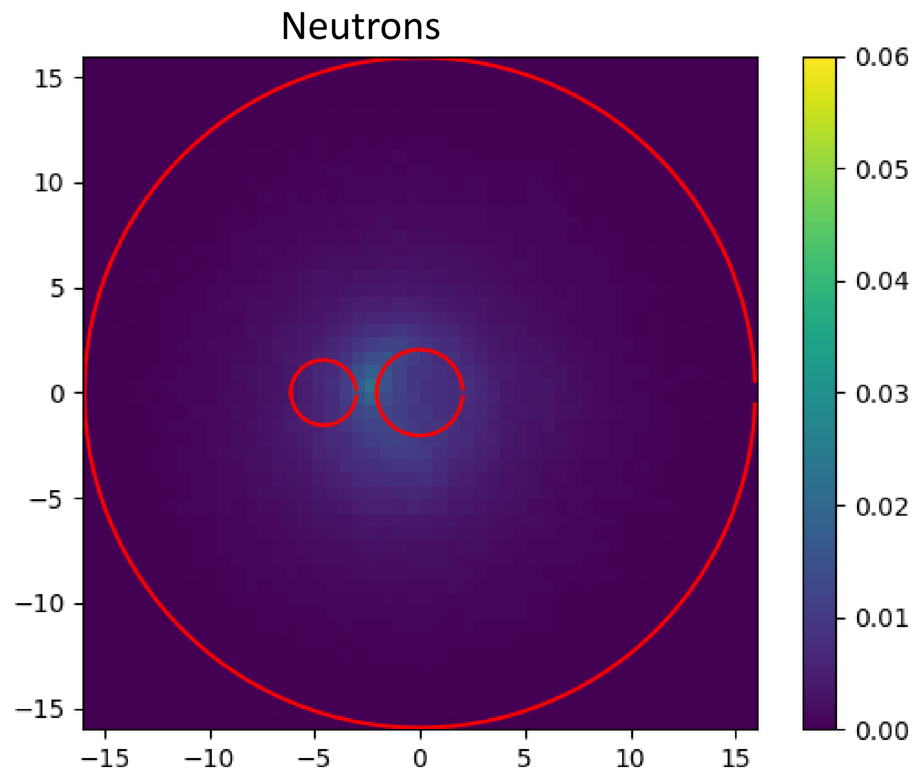
Ben Smithers

- BeamCal absorbs about 10 TeV per crossing, resulting in electromagnetic doses as high as **100 Mrad/year**
- Associated neutrons can damage sensors and generate backgrounds in the central detector
- GEANT not adequate for simulation of neutron field ➔ implement FLUKA simulation
- Design parameters from detailed baseline description (DBD)
- Primaries sourced from single Guinea Pig simulation of e^{+-} pairs associated with one bunch crossing

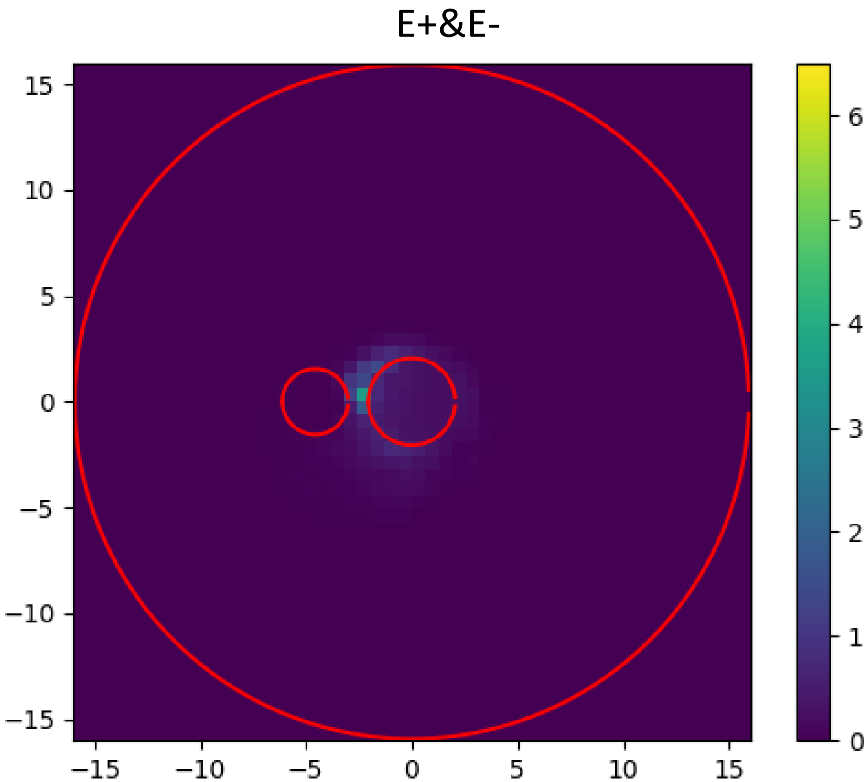


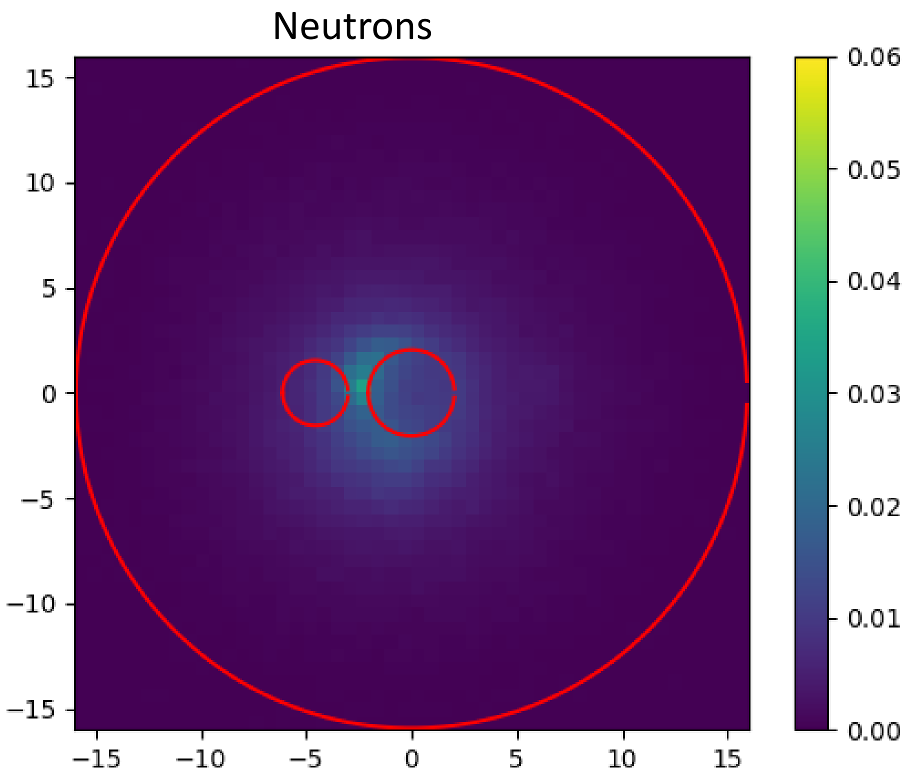
Layer 2 Detector - Fluence



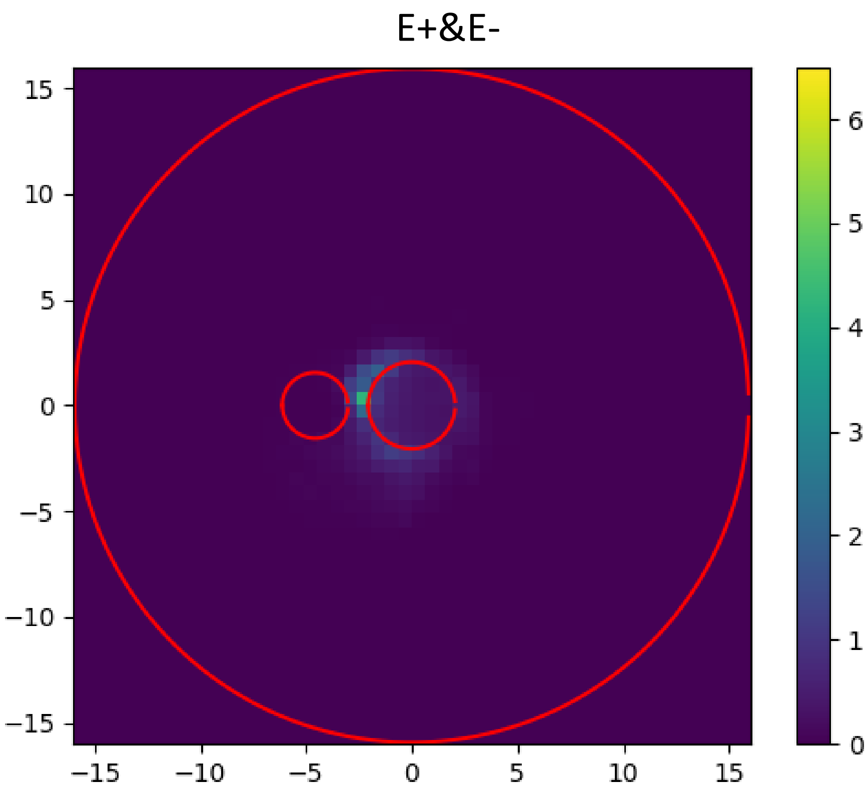


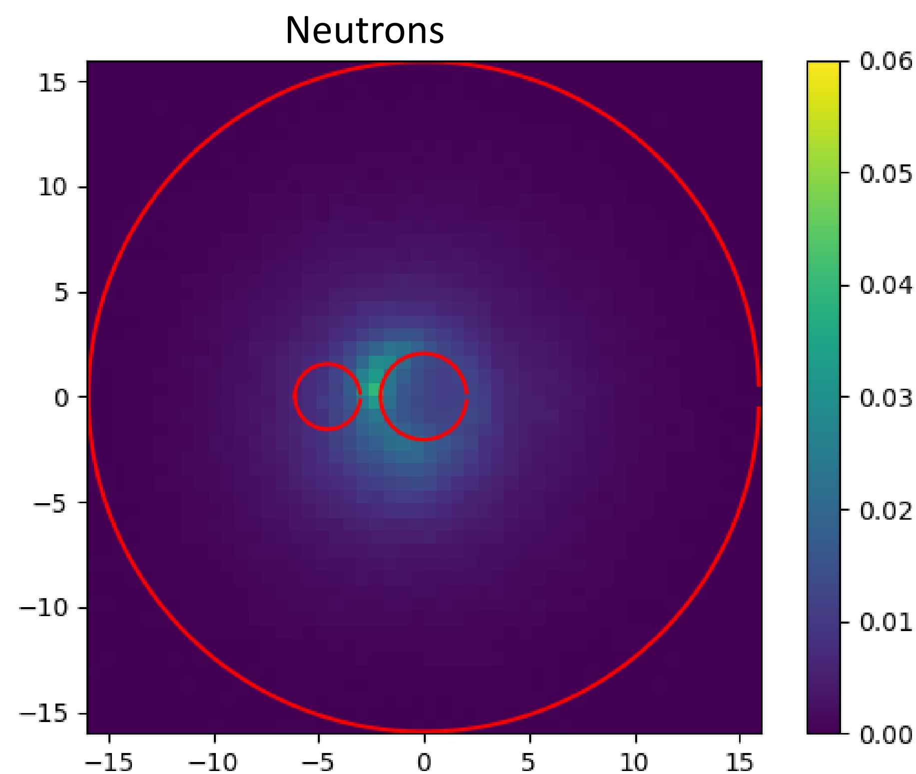
Layer 4 Detector - Fluence



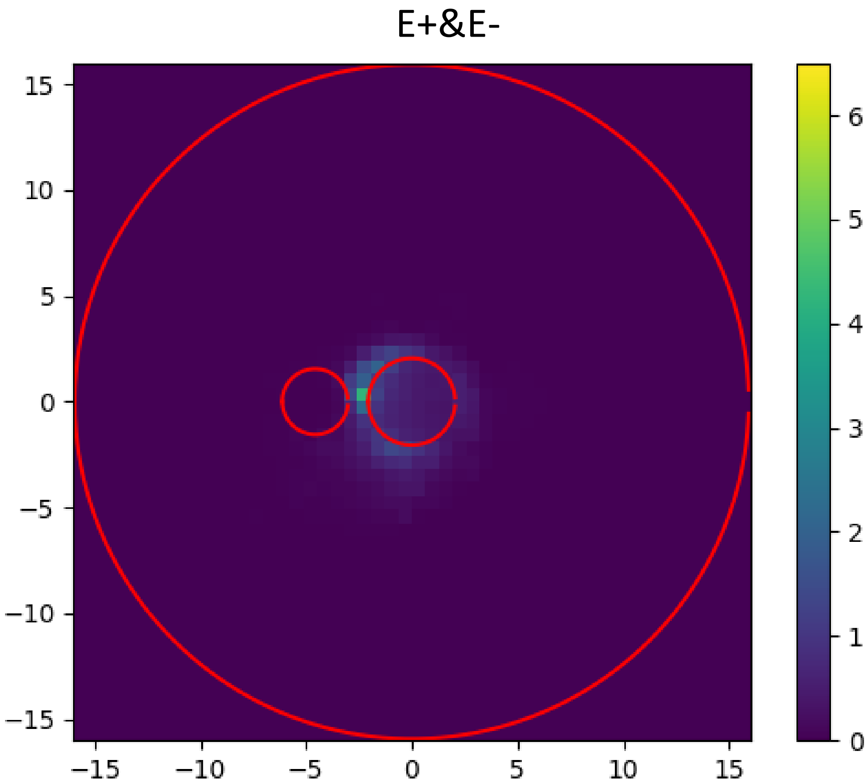


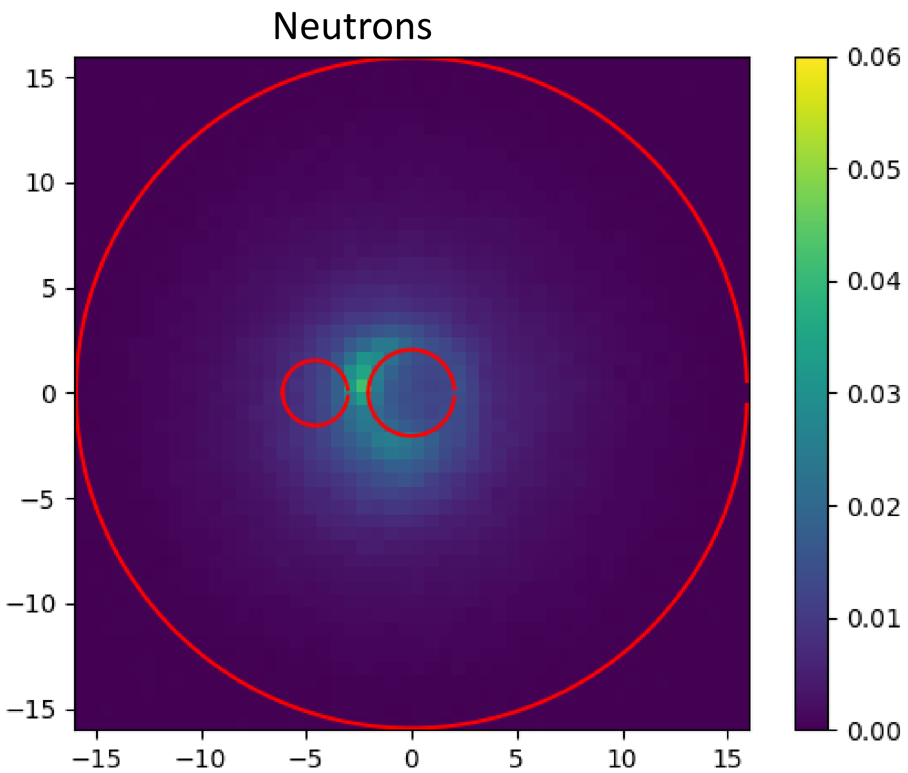
Layer 6 Detector - Fluence



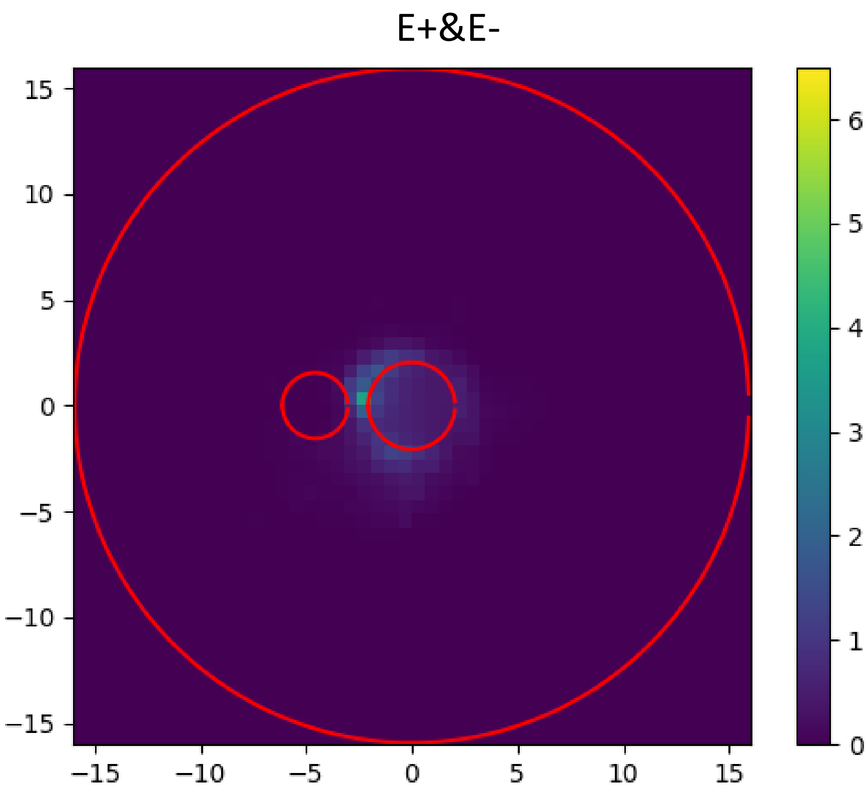


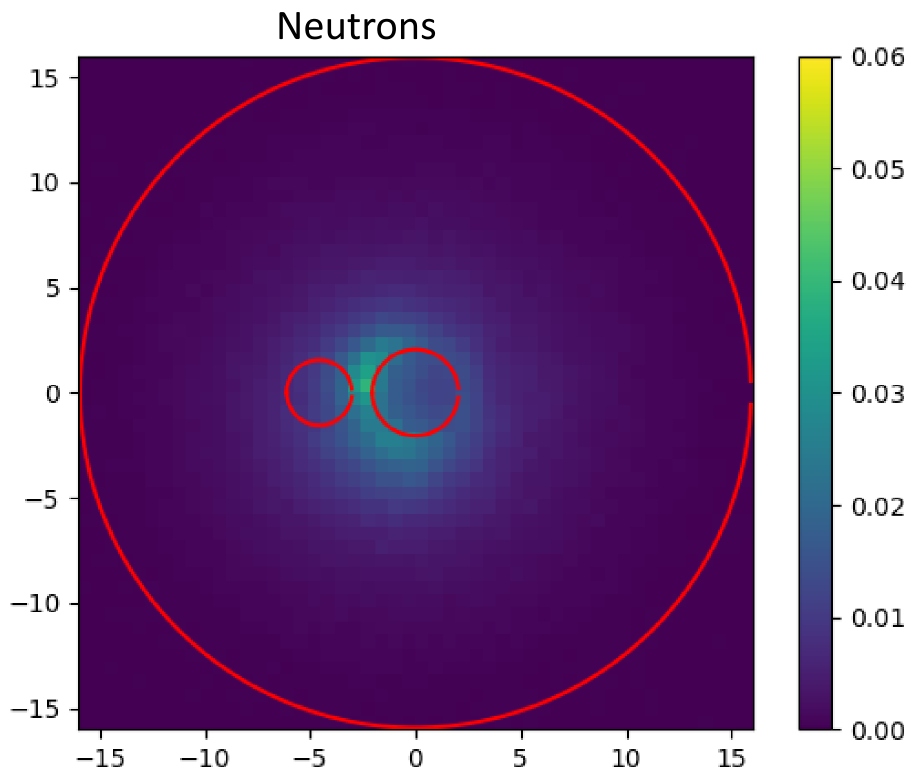
Layer 8 Detector - Fluence





Layer 10 Detector - Fluence





POWER DRAW ESTIMATE FOR A SILICON-DIODE BASED BEAMCAL READOUT

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Operation of the prospective beamline calorimeter in the high-radiation forward environment of the international linear collider☆

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ABSTRACT

Results on electromagnetically-induced radiation damage to silicon diode sensors, obtained from the T506 experiment at SLAC, are used in concert with detailed shower simulations to project the effects of radiation damage on the proposed International Linear Collider Beamline Calorimeter (BeamCal) detector system. The study makes use of the FLUKA Monte Carlo to simulate electromagnetic showers in both the T506 apparatus and the prospective BeamCal detector system. Under the conservative assumption that damage leading to sensor leakage currents is dominated by the neutron component of the electromagnetic shower, and assuming that resulting leakage currents depend linearly on neutron fluence, the power consumption required to operate the BeamCal detector at a temperature of −10° C would be expected to increase by approximately 100 W per year of operation. Lowering the operating temperature to −30 °C would be expected to reduce the growth in power consumption to approximately 10 W per year. Under other assumptions about the source of damage, the accumulated power draw would be expected to be significantly less. Results on fluences of both electromagnetic and hadronic particles in regions peripheral to the bulk of the BeamCal detector system, where front-end electronics would be mounted, are also presented.

➔ Interesting oversight discovered during review process

Idea: Use FLUKA to extrapolate from T506 radiation-damage studies

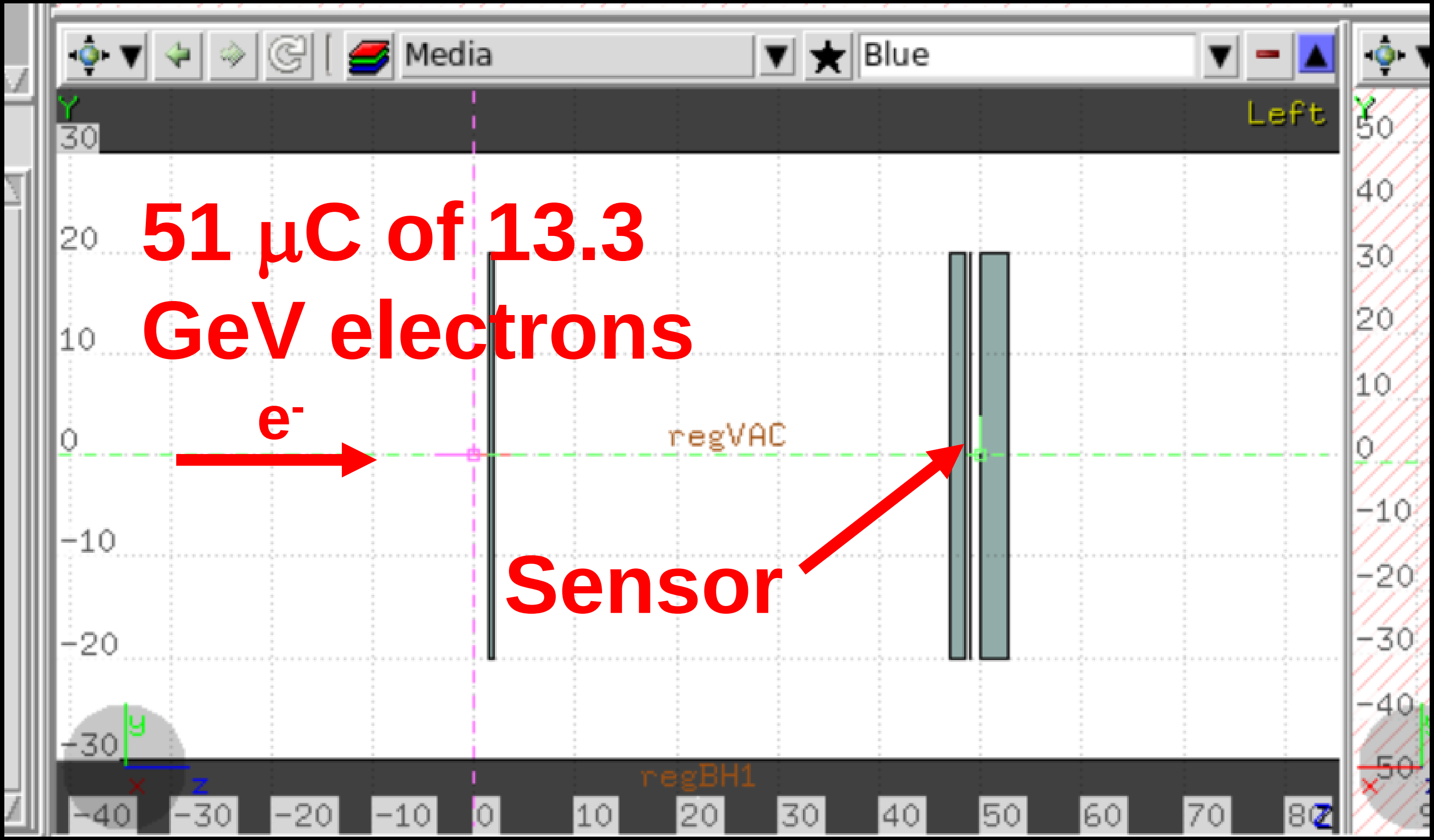
Standard working assumption: bulk damage dominated by non-ionizing energy loss (NIEL); confirmed by many experiments and meta-analysis

Sources of NIEL:

- **Neutrons**
- **Electrons and positrons**
- **Photons**

Assumption of neutron-dominance is conservative since neutron field is most dispersed; results presented in Krakow were based on this assumption

T506 simulation



Total neutron NIEL dose of

$$\lambda_{T506} = 2.7 \times 10^{11}\ \mathrm{MeV/cm^3}$$

T506 Leakage Current (270 Mrad Exposure)

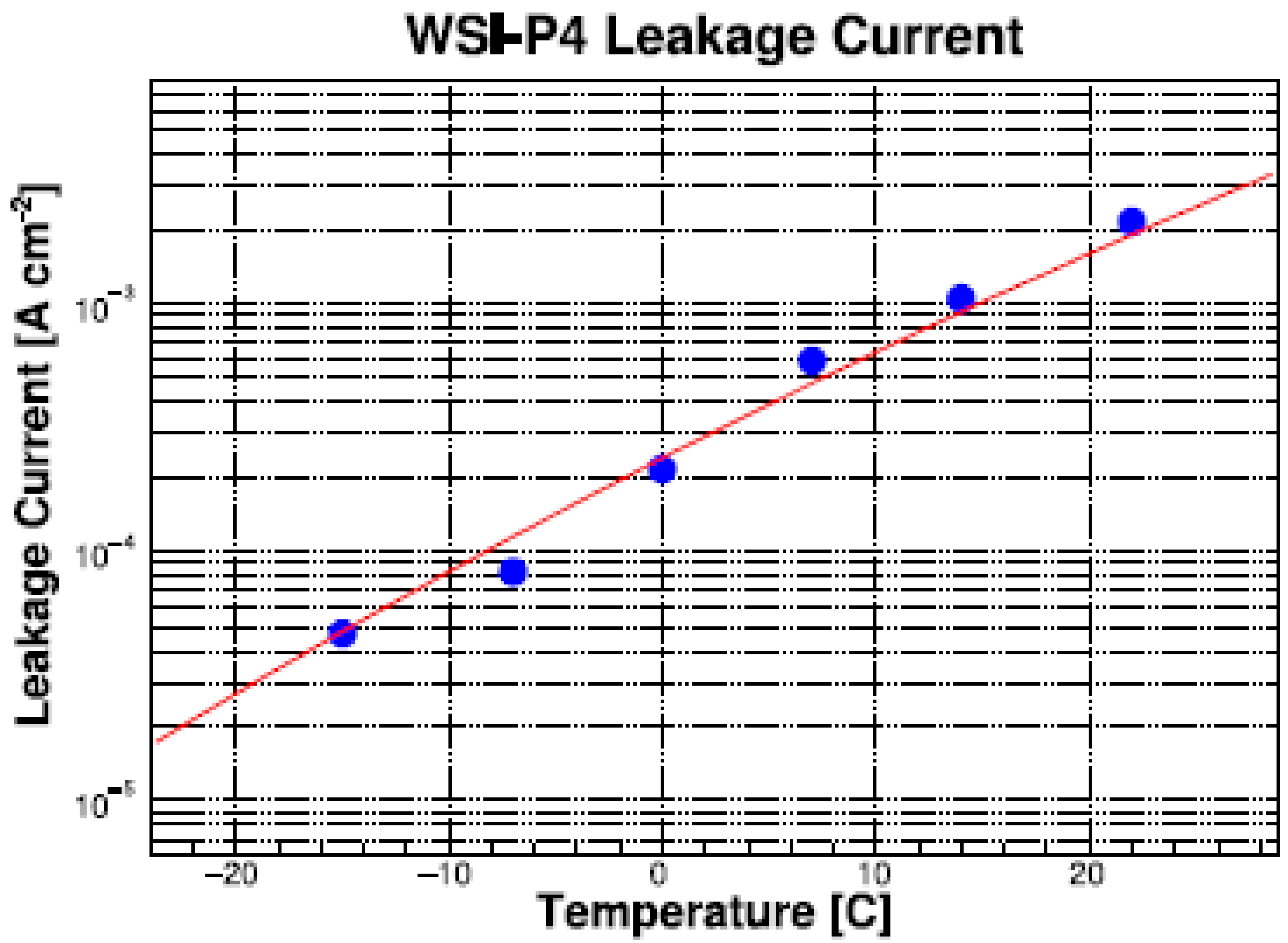
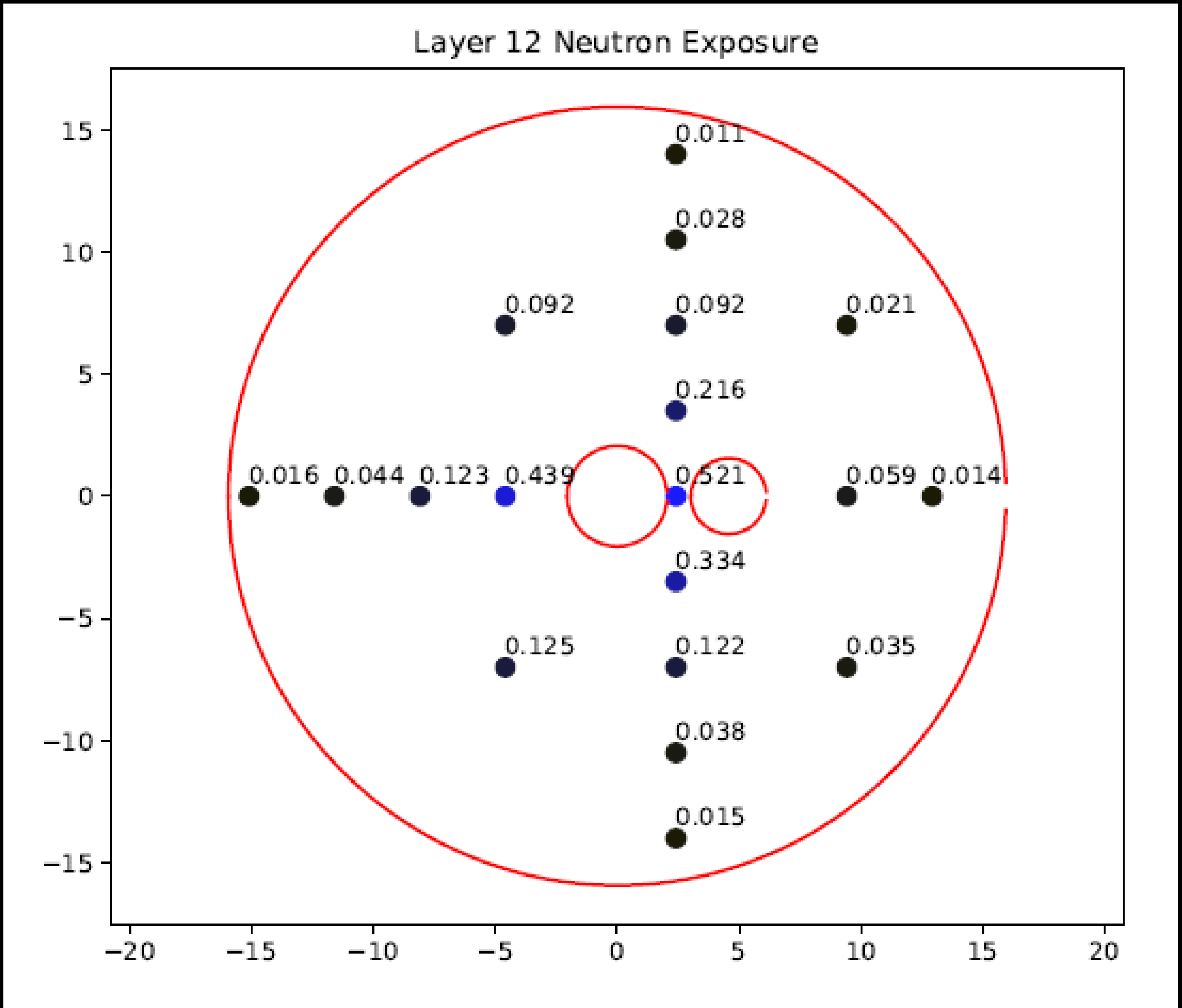


Fig. 2. Observed temperature dependence of the area current density of the WSI-P4 silicon diode sensor biased at 600 V, after irradiation. The fit is to the function of the form of Eq. (1).

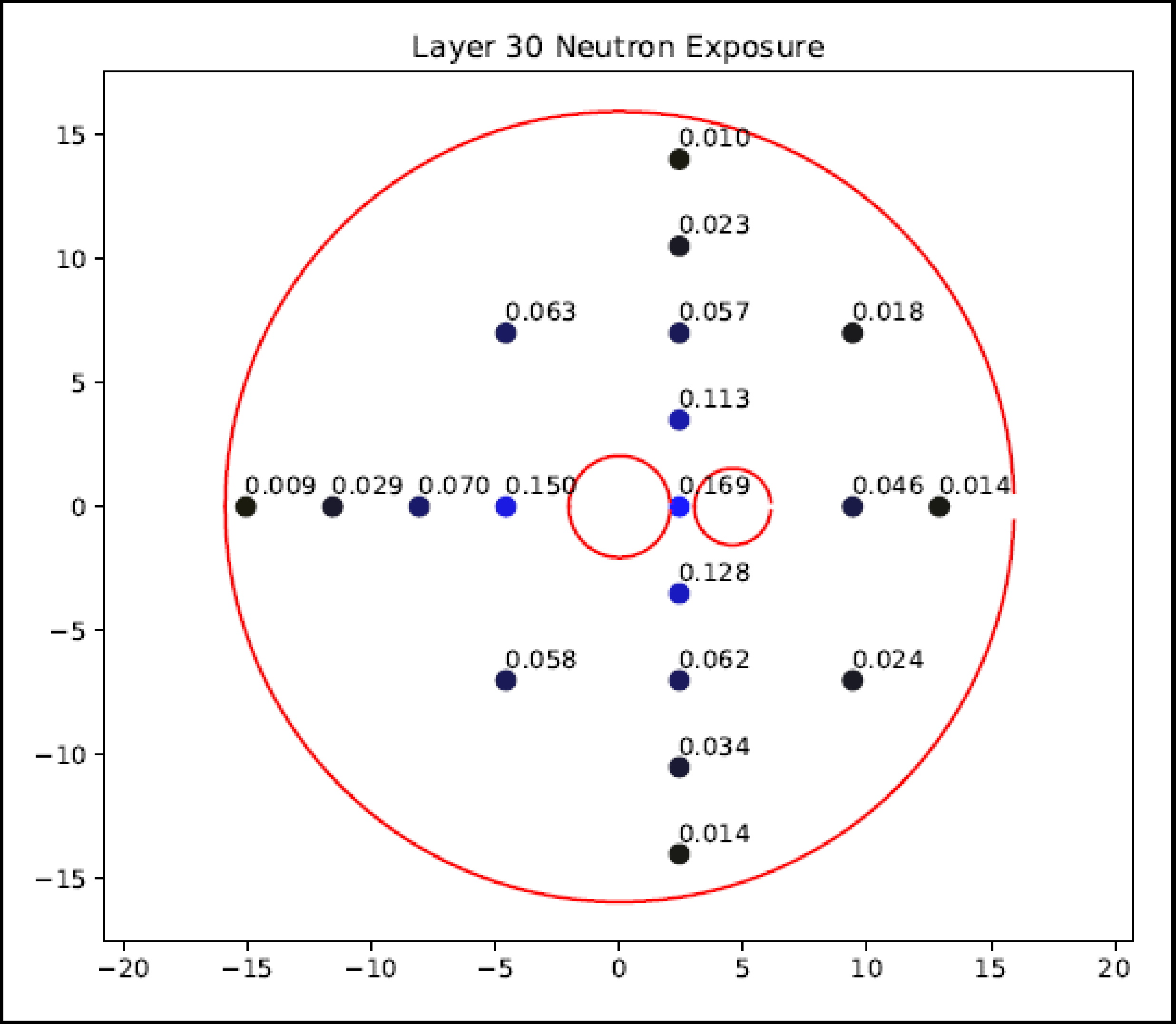
- Establishes "T506 dose unit" λ_{T506}

Simulated BeamCal NIEL Dose – Layer 12



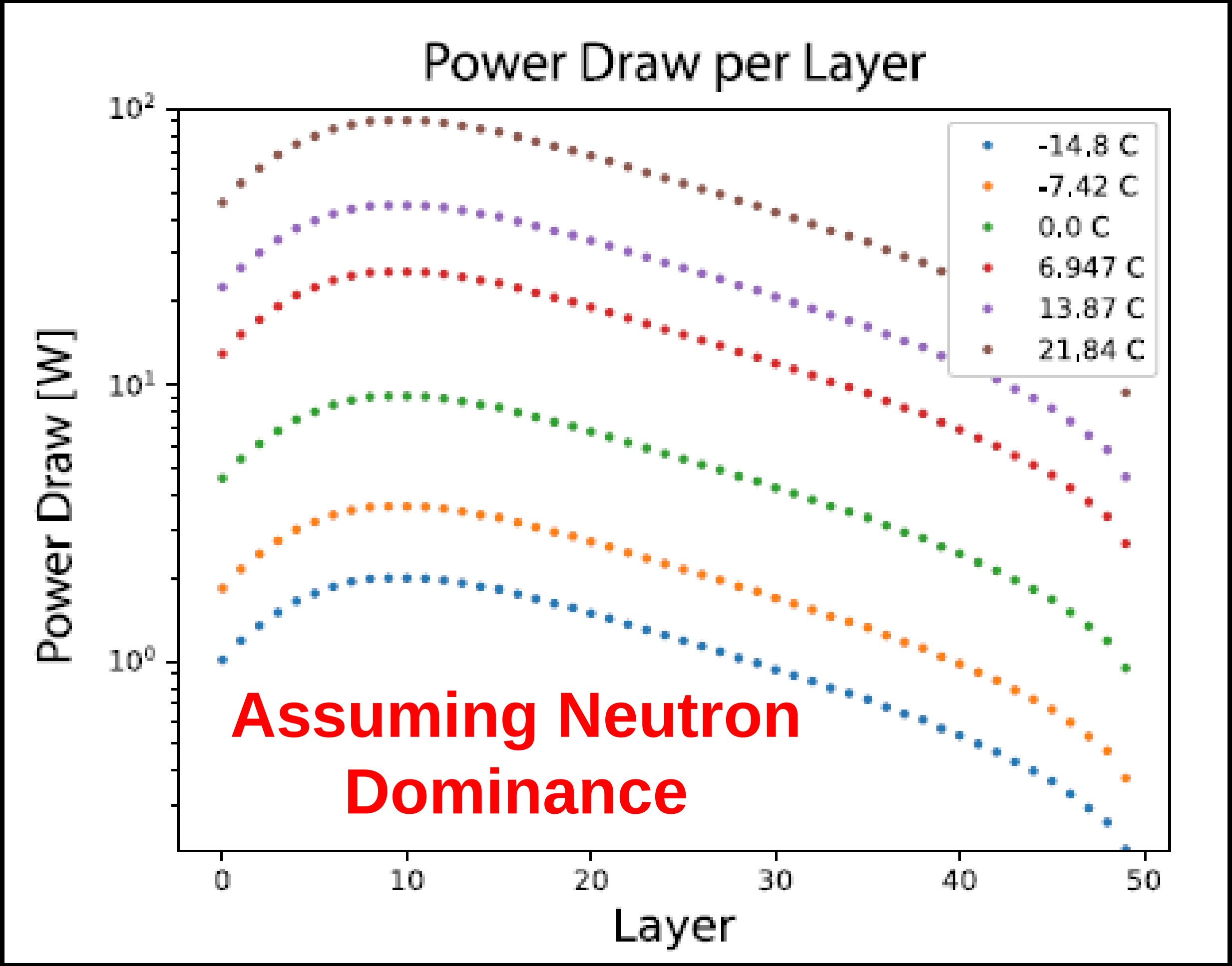
- Per year (10^7 seconds) of ILC operation
- In T506 dose unit λ_{T506}

Simulated BeamCal NIEL Dose – Layer 30



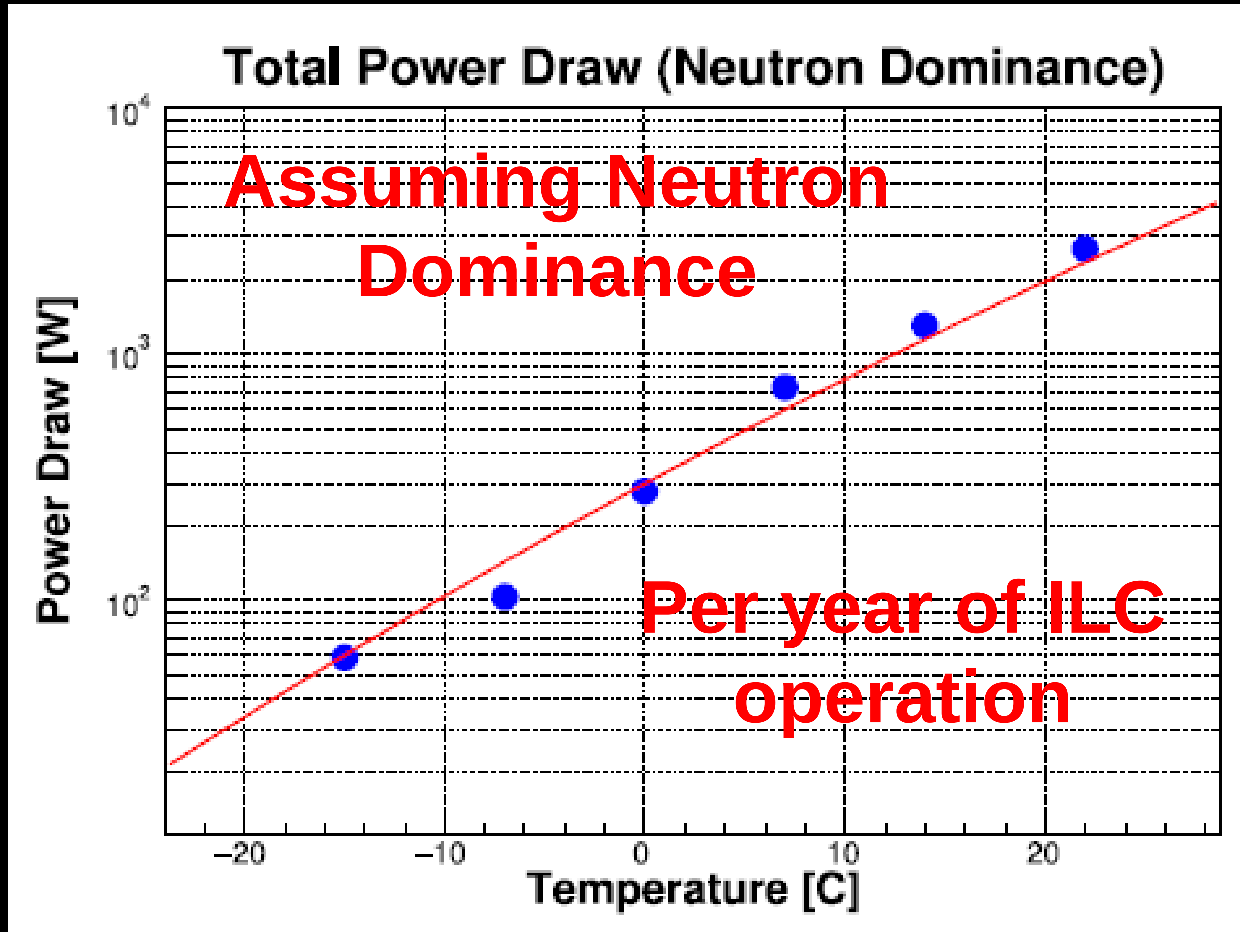
- Per year (10^7 seconds) of ILC operation
- In T506 dose unit λ_{T506}

Layer-by-Layer Power Draw vs Temperature



- Accumulation per year (10^7 s) of ILC operation
- Maximum power-draw density is ~25 mW/cm^2 at V_B = 600 V and T = -10^o C (< 5 mW/cm^2 at -30^{o}C)

Overall Power Draw vs Temperature



- Can limit accumulation to less than 100W per year by operating below -10º C
- At -30º C (standard for LHC sensor operation), accumulation would be of order 10 W per year

Neutron Dominance: Previous Justification

RD48 Collaboration: Universal behavior under neutron irradiation, Φ = neutron fluence

$$I = \alpha \Phi_{eq} V ,$$

$$\alpha_{RD48}^{+20} = 4.0 \times 10^{-17} \ \mathrm{A/cm}.$$

From the FLUKA simulation T506 current value,

$$\alpha_{T506} = 4.2 \times 10^{-17} \ \mathrm{A/cm}$$

This agreement was cited as support for the neutron dominance assumption.

However, the reviewer pointed out that the RD48 value of α was for room temperature, while the T506 value was for operation at -10^0 C. We had assumed -10^0 C for the RD48 value of α.

Electronic NIEL

Silicon diode leakage currents increase by x2 per 7^0 C (well documented, and consistent with T506 data)

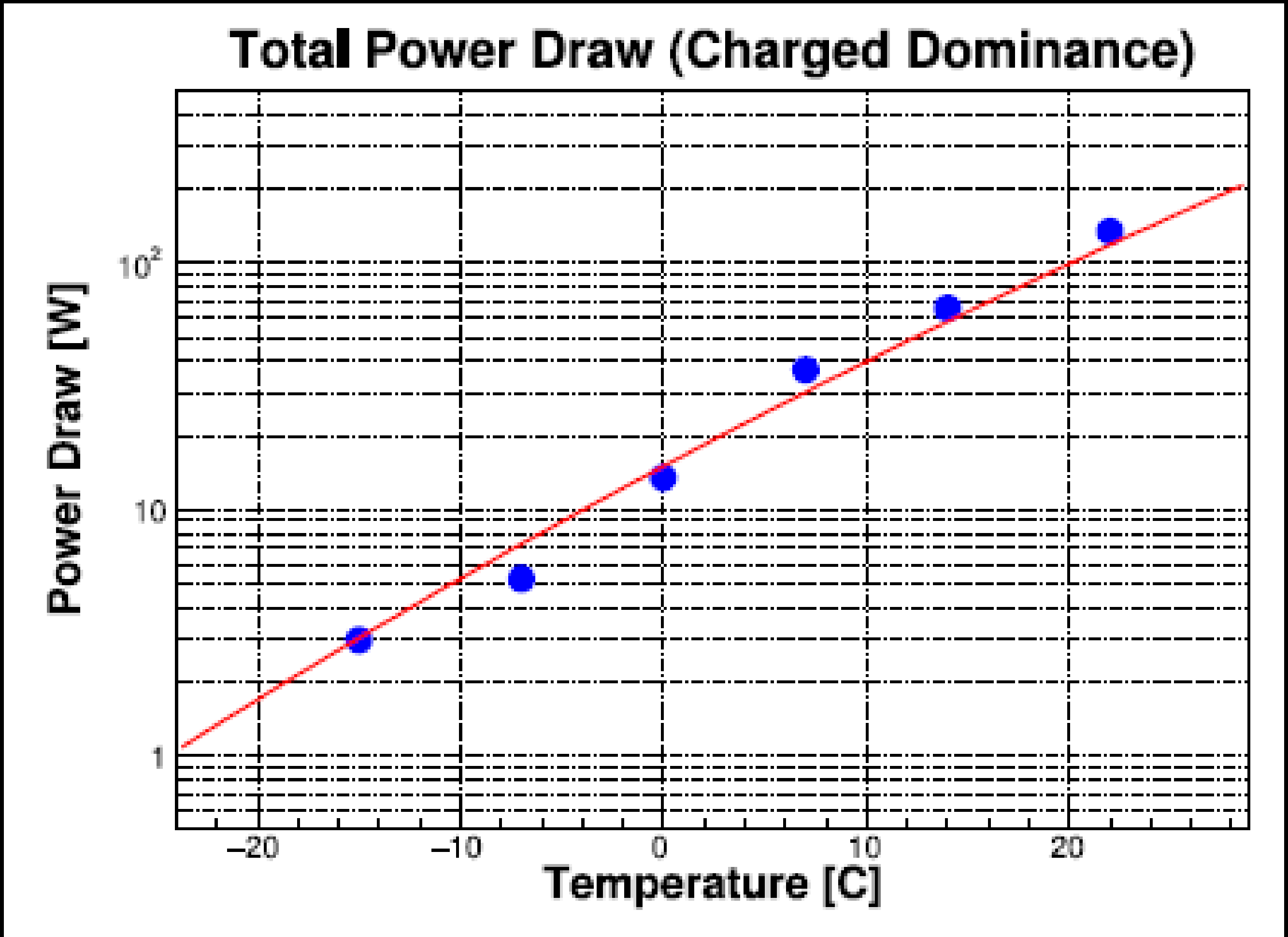
➔ T506 damage much greater than expected for neutron-induced damage.

Went back to lab, confirmed leakage current measurements (for several different sensors, and linearity of dependence upon dosage)

Electron/positron NIEL yields are also well measured; FLUKA simulation of $e^{\pm}$ fluxes imply x10 greater NIEL from $e^{\pm}$ than from neutrons.

➔ Leakage current could well be electron-dominated for T506, and by extension, the BeamCal

Power Draw: Charged-Particle Dominance



- Less than 10 (1) W per year at -10^0 C (-30^0) C
- Maximum power-draw density after 1 year is <10 mW/cm^2 at V_B = 600 V and T = -10^o C

BeamCal Albedo

FLUKA ➔ GEANT

Were able to get list of all particles from BeamCal with negative p_z (ASCII file)

Developed ASCII ➔ SLCIO conversion tool

Exercised full simulation of SiD detector (had fallen a bit out of order due to a slack period)

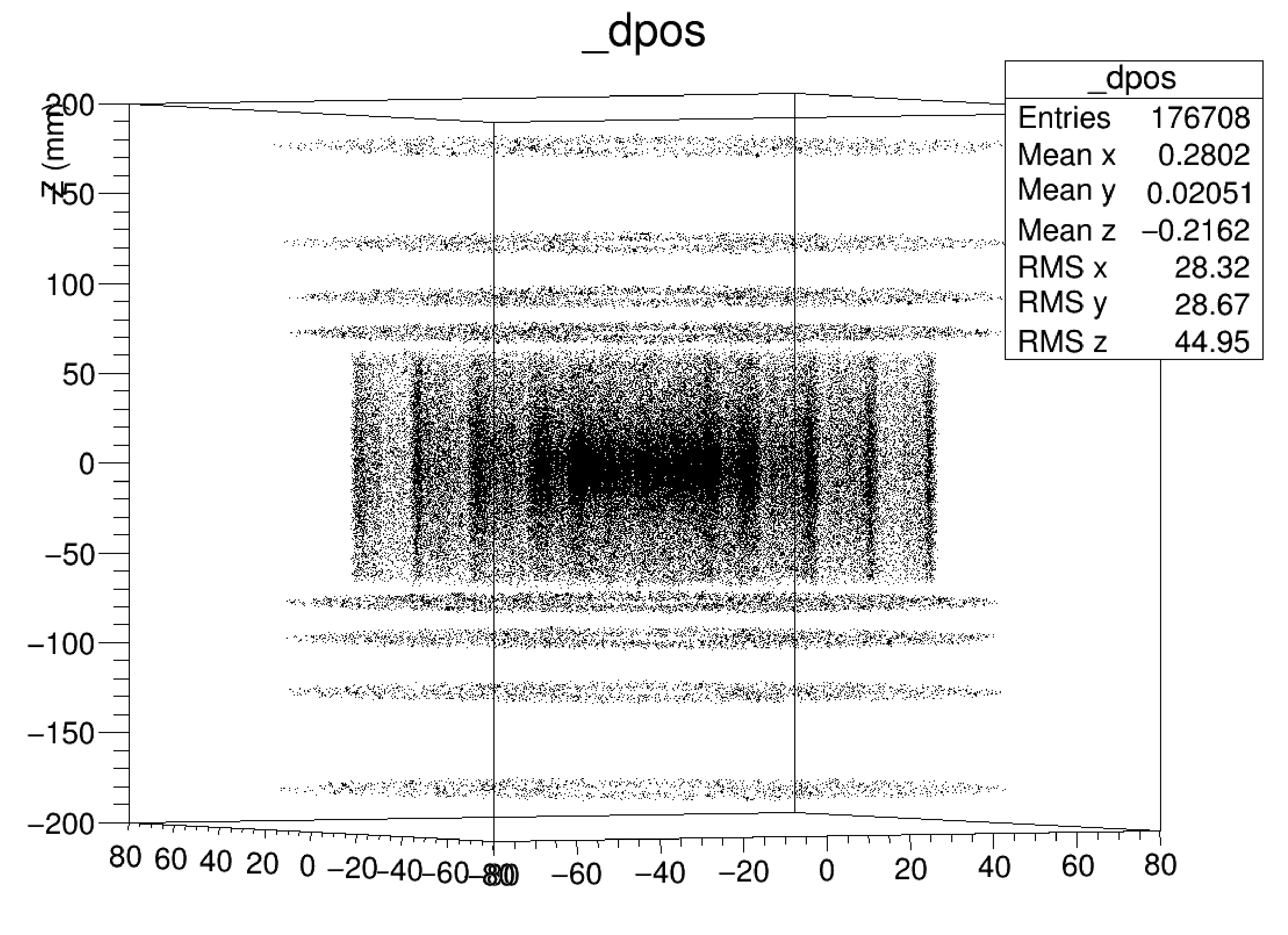
Simulated nine beam crossings in forward BeamCal (so 4.5 total beam crossings since there are two BeamCal halves shining back into the IP)

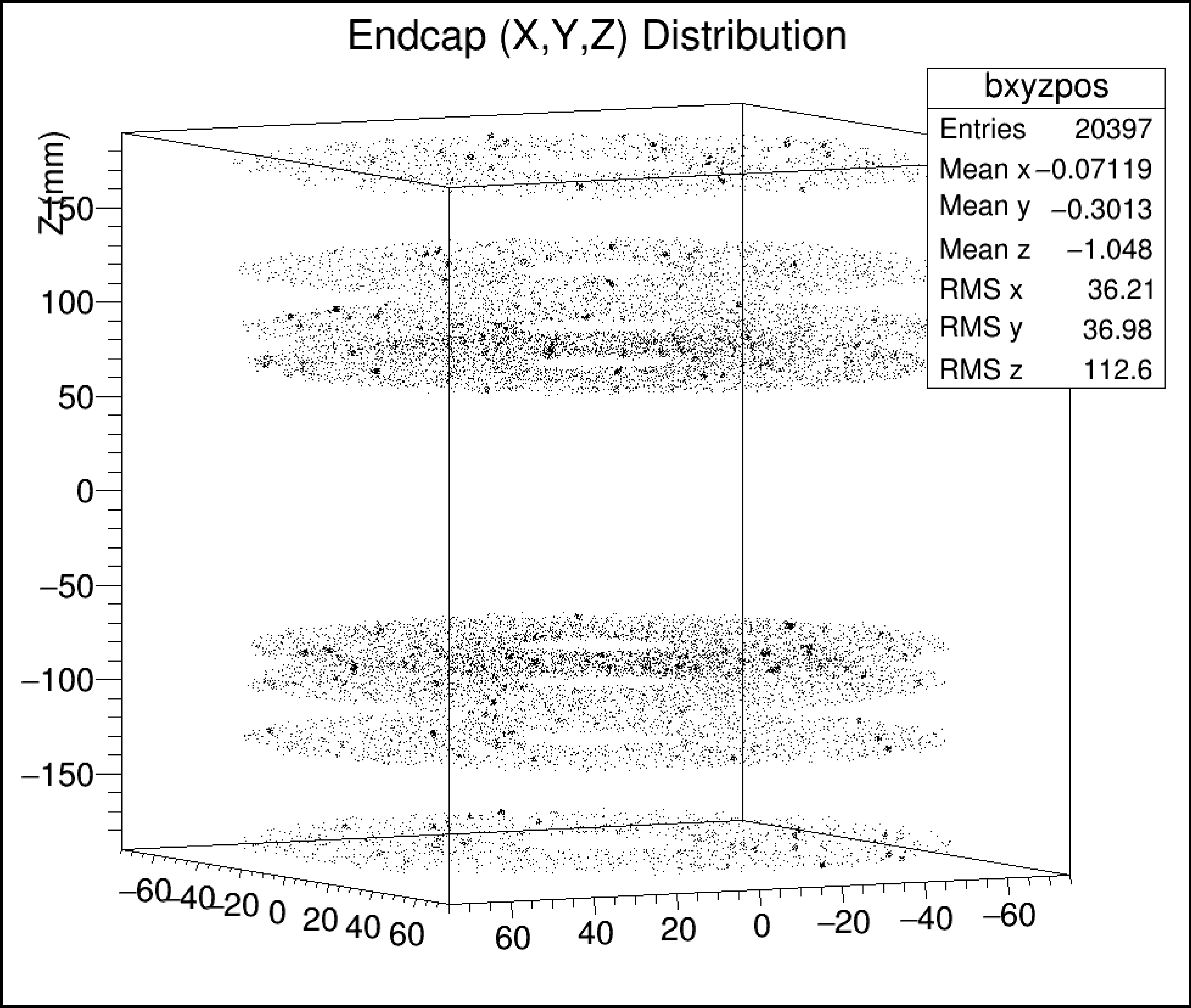
SiD/ILD inner geometry very similar

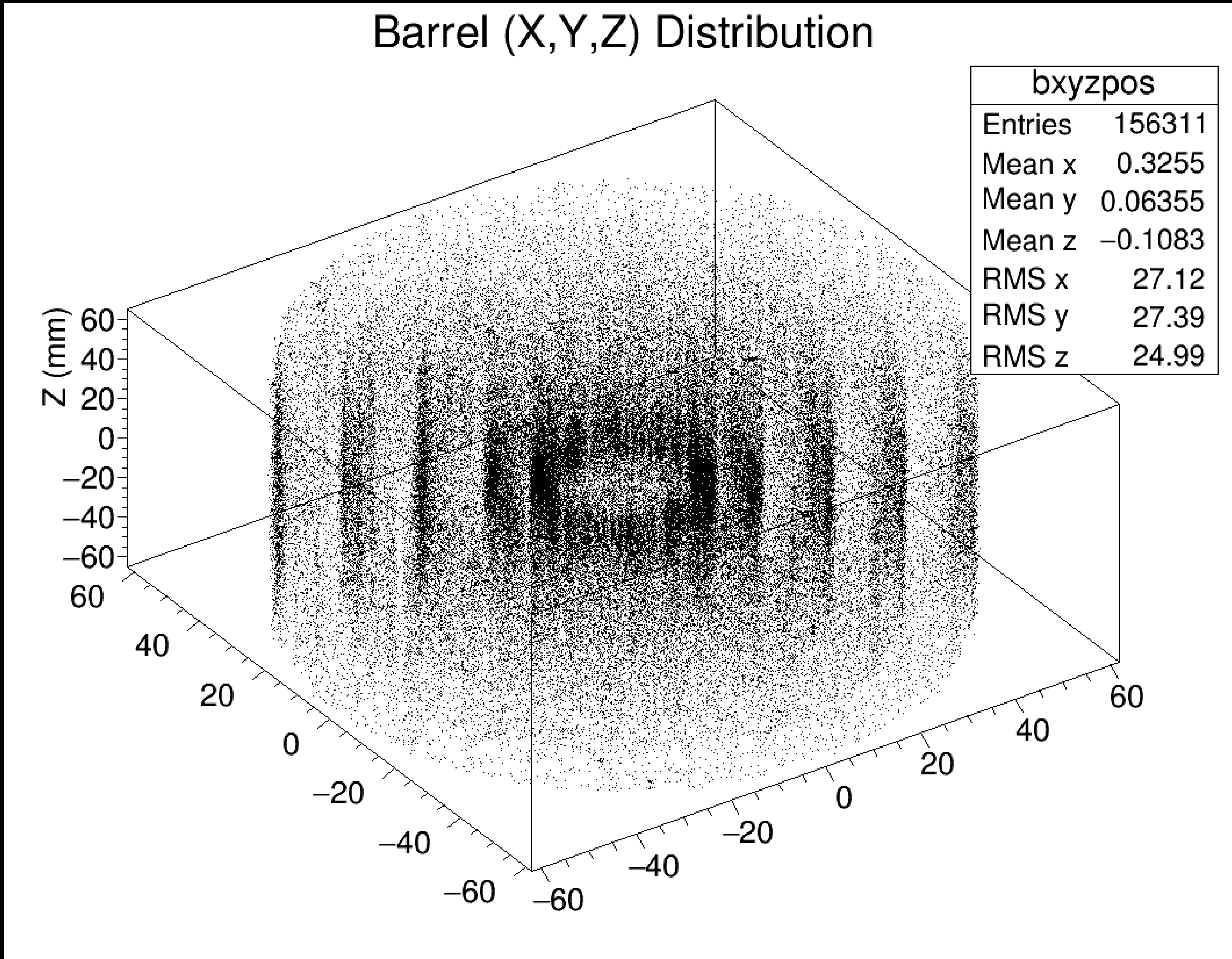
Next step will be to develop flexible pixelization of vertex detector (should be straightforward)

Following thanks to Gregory Blockinger, with support from William Wyatt (UCSC undergraduates)

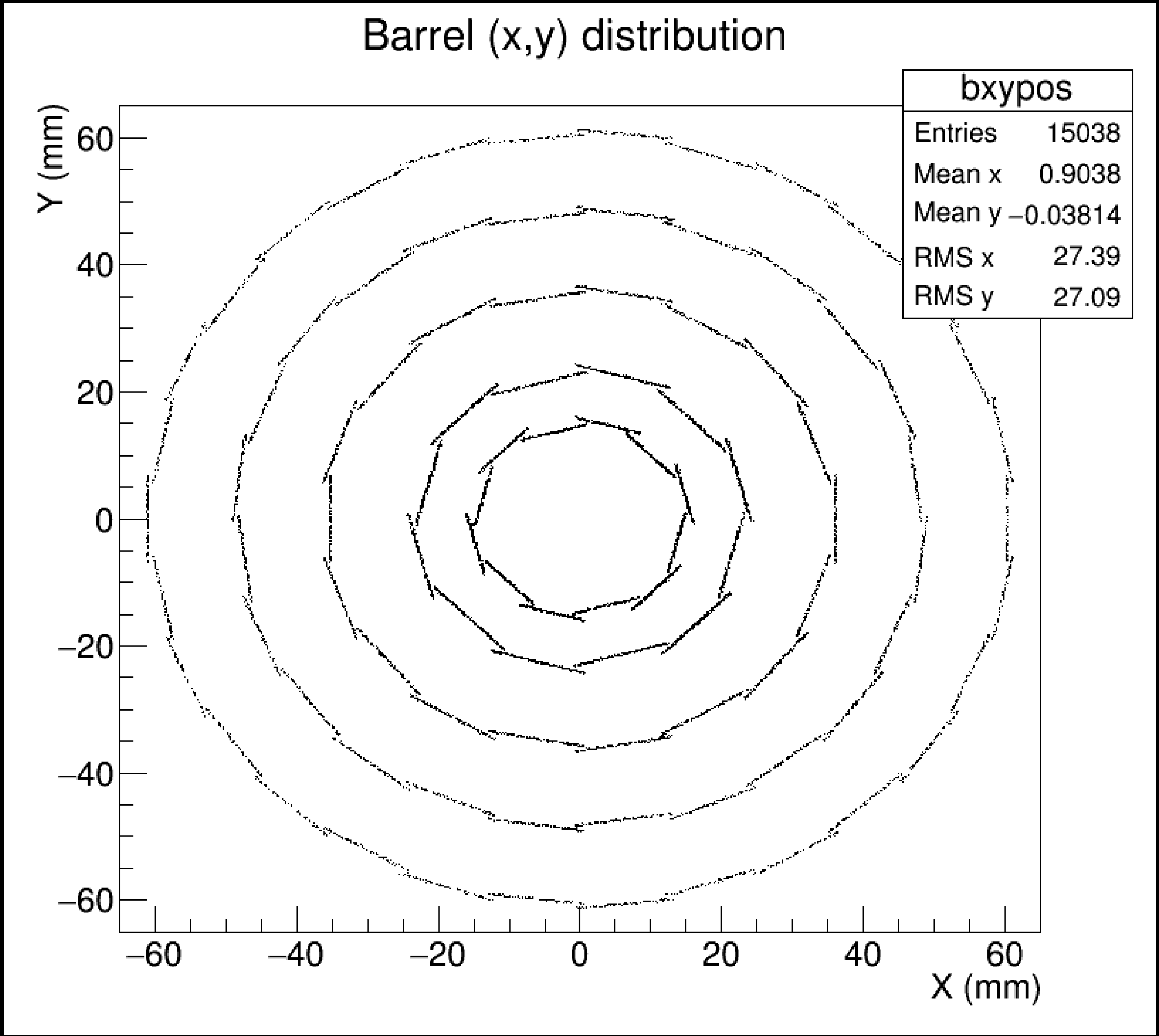
Observed Hit Distribution




Endcap (X,Y,Z) Distribution
bxyzpos
Entries 20397
Mean x −0.07119
Mean y −0.3013
Mean z −1.048
RMS x 36.21
RMS y 36.98
RMS z 112.6
Z (mm)
150
100
50
0
−50
−100
−150
−60 −40 −20 0 20 40 60
60 40 20 0 −20 −40 −60



Barrel (X,Y,Z) Distribution
bxyzpos
Entries 156311
Mean x 0.3255
Mean y 0.06355
Mean z −0.1083
RMS x 27.12
RMS y 27.39
RMS z 24.99
Z (mm)
60
40
20
0
−20
−40
−60


Barrel (x,y) distribution
bxypos
Entries 15038
Mean x 0.9038
Mean y −0.03814
RMS x 27.39
RMS y 27.09
Y (mm)
X (mm)
60
40
20
0
−20
−40
−60
−60
−40
−20
0
20
40
60

Summary/Conclusions

Mistake found in comparison between T506 and RD48 leakage current results

New comparison suggests that BeamCal radiation damage may be charged-particle (rather than neutron) dominated

For charged-particle dominance, estimates of the power-draw accumulation are in the range of several Watts per year (cooling still required)

BeamCal albedo simulation from FLUKA successfully translated into SiD simulation. Occupancy studies commencing.

BackUp…

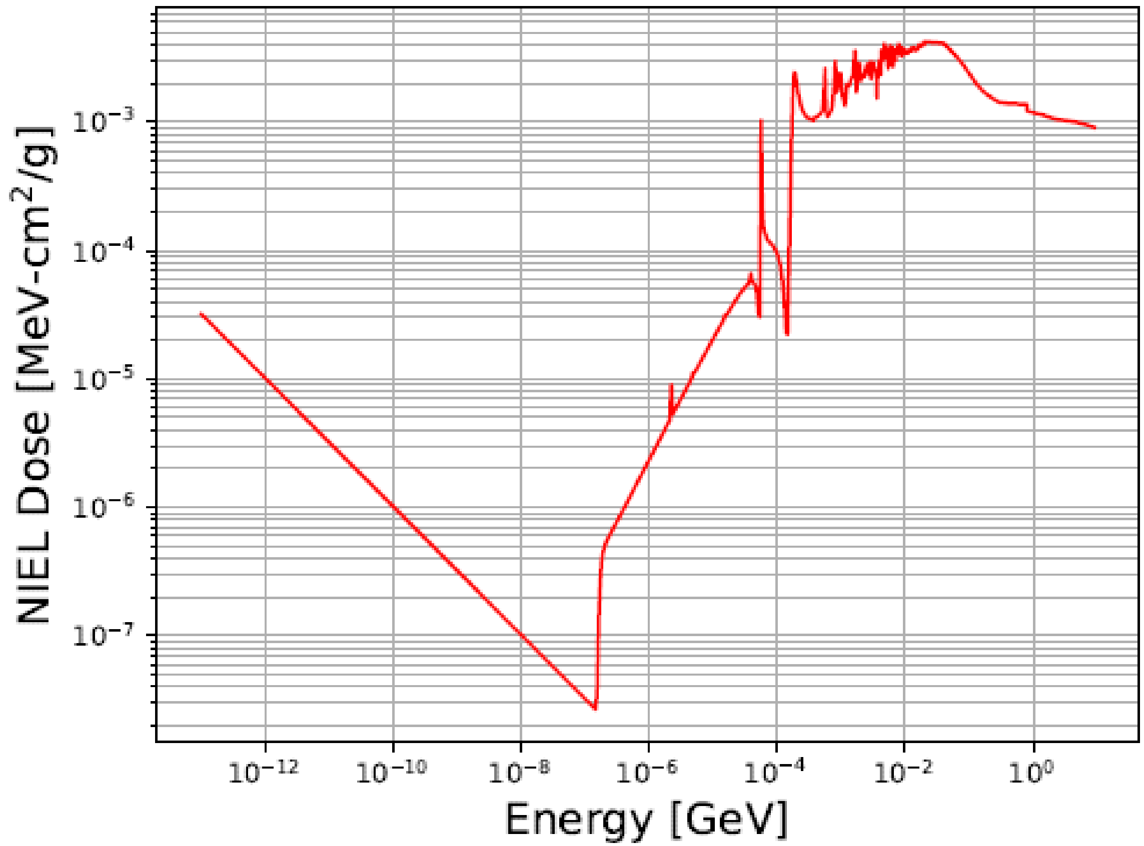
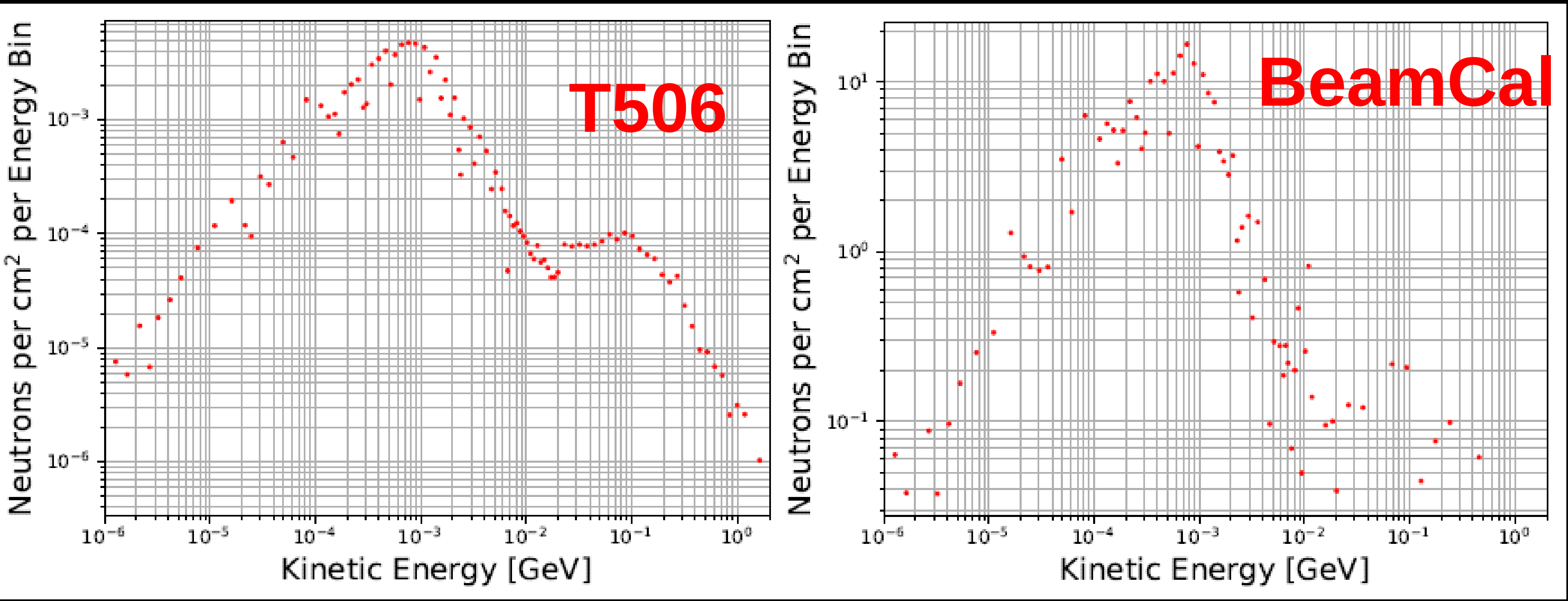


Figure 4: Energy dependence of neutron-induced NIEL in silicon, in MeV per g/cm^2 of silicon traversed per through-going neutron. This plot displays the data tabulated in [9].

[9] A. Vasilescu and G. Lindstroem, *Displacement damage in silicon, on-line compilation*, 2006, http://rd50.web.cern.ch/RD50/NIEL/default.html.



N.B.: Energy distribution of neutrons for T506 and for BeamCal very similar, so damage estimates not particularly dependent upon details of NIEL scaling specific to silicon

Estimated Power Draw per Layer

- Based on average neutron NIEL λ_L in given layer
- One year (10^7 seconds) of ILC operation
- Operation at V_B = 600 V

$$P_L(T) = V_B I_L(T) = V_B \frac{\lambda_L}{\lambda_{T506}} A\sigma(T)$$

- Leakage current density $\sigma(T)$ from T506 results (shown above)

$$\sigma(T) = a e^{T/T_s}$$

$T_S = 9.2^o$ C

$a = 220\ \mu A/cm^2$

Peripheral Fluence Estimates

- **Front-end electronics will likely be mounted just outside BeamCal instrument**

Table 2: Neutron fluences at various positions 1 cm outside the BeamCal instrument, for 10^7 seconds of ILC operation, in cm^{-2}. The angle is measured relative to the axis defined by the center of the BeamCal and the centerline of the smaller circular cutout.

Angular position	0	$\pi/2$	π	$3\pi/2$
Layer 12 fluence (cm^{-2})	4.9×10^{11}	5.9×10^{11}	7.3×10^{11}	8.0×10^{11}
Layer 30 fluence (cm^{-2})	4.8×10^{11}	4.6×10^{11}	5.7×10^{11}	5.4×10^{11}

- **Electromagnetic fluence less than $10^{11}/\mathrm{cm}^2$ (less than 2.5 krad) per year at any position**
- **These levels far below conventional levels of concern**