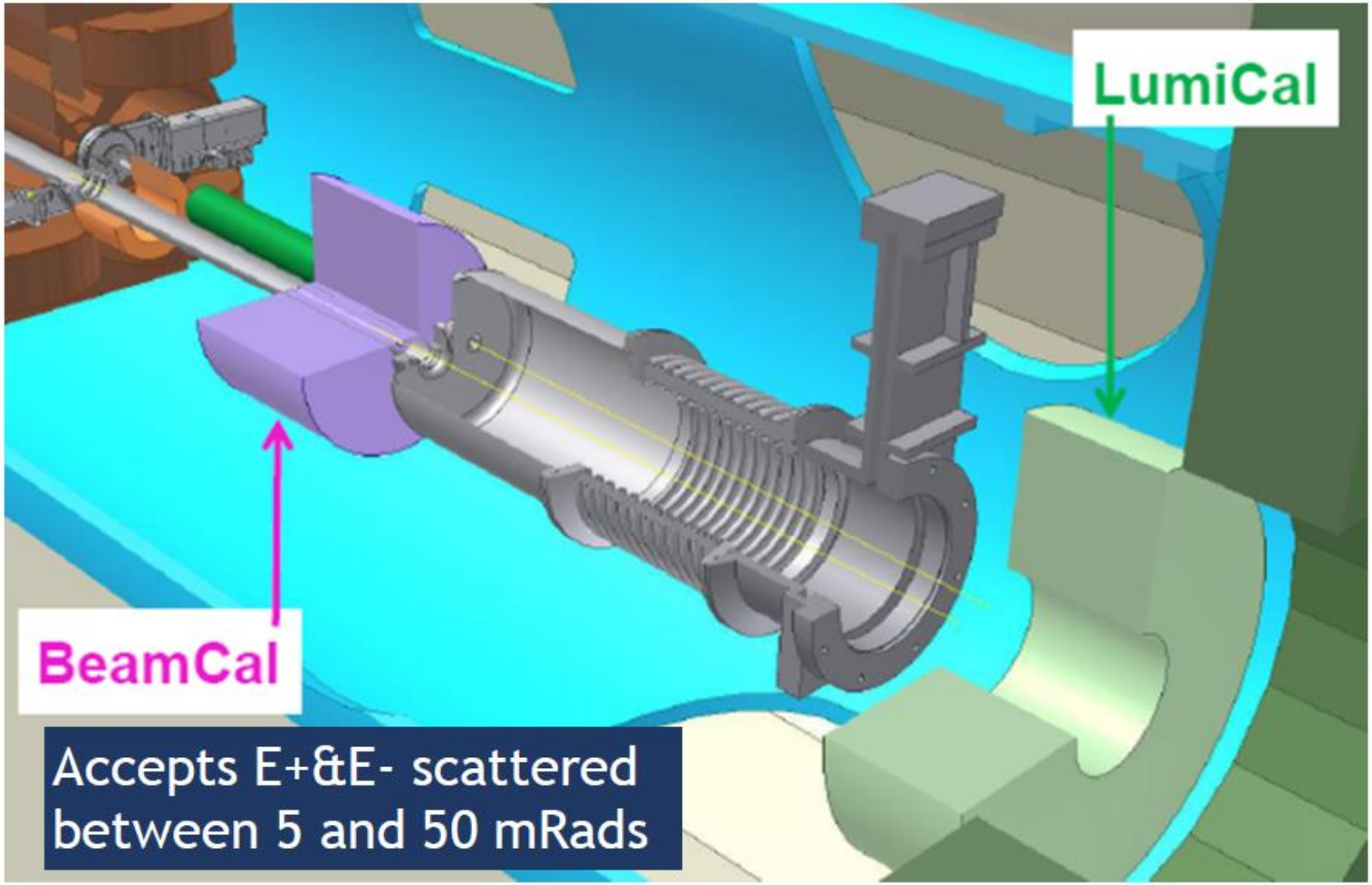
Compressed SUSY and BeamCal Simulation Studies

AWLC 2017

Benjamin Smithers
On behalf of SCIPP FCAL/SiD Sim Group

June 30 2017

ILC BEAMCAL


LumiCal
BeamCal
Accepts E+&E- scattered
between 5 and 50 mRads

Introduction

- SCIPP ILC group involved in Beamline Calorimeter design, studies of its use in looking for Compressed SUSY

- Has led to recent developments:
  - Prediction algorithm to estimate location of deflected e^+/e^- from two photon events in BeamCal
  - "Statistically-correct" 4-vector overlays of ILC background (two photons, Bhabhas, pairs, etc.)
  - FLUKA model of Beamline Calorimeter
  - Implications of IP parameter reconstruction on BeamCal design

STAU DECAY WITH SMALL MASS SPLITTINGS

Benchmark signature is stau decay,

$$\tilde{\tau}^{\pm} \rightarrow \tau^{\pm} + \tilde{\chi}_1^0$$

with mass splittings on the order of a few GeV.

Events look very much like two-photon events for which the deflected electron and positron are not detected.

Main challenge seems to be separating two-photon background from SUSY signal.

TWO-PHOTON RECOIL KINEMATICS

- Two-photon interactions are modeled with contributions from both the Beamstrauhlung distribution and the Weizsacker-Williams approximation.
- Beamstrauhlung photons have zero transverse momentum, while about 30% of Weizsacker-Williams photons have transverse momentum, leading to a deflected e^{+-} that might be detectable in the BeamCal.
- Four event categories: eBpW (electron from Beamstrauhlung distribution, positron from Weizsacker-Williams approximation), eWpB, eBpB, eWpW.

TWO-PHOTON EVENT RATES

ILC has a luminosity of 3.6 nb^{-1} per train with 1312 crossings per train, so we have

$$\frac{L}{crossing} = \frac{2.74\ pb^{-1}}{crossing}$$

Even samples are generated using Wizard MC. Using the Wizard cross sections:

Event Type	BB	BW	WB	WW
Crossing (fb)	134427168.3	93474234.88	94353013.33	81276125.5867
Events/Crossing	0.368855	0.256484181	0.2588954634	0.2230137589

There are an average of 1.1 two-photon interactions per beam crossing.

PREDICTION ALGORITHM

Jane Shtalenkova

MOTIVATION

- A two-photon event for which neither the electron or positron is deflected into the BeamCal can look like SUSY
- These must be rejected based on an algorithm that estimates the position of the deflected e^{+-} at the face of the BeamCal, based only on information from the rest of the detector (from the "hadronic system" only)
- Develop a "prediction algorithm" and explore performance as a function of hadronic system coverage (detector hermeticity)

PREDICTION ALGORITHM FOR TWO-PHOTON EVENTS

- Set of particles arising from the fusion of the two photons is called the "hadronic system"
- We define the hadronic system 4-vector

$$\vec{h} = (H, h_x, h_y, h_z),$$

- Prediction algorithm assumes
  - perfectly reconstructed hadronic system
  - no more than one deflected beam particle
  - energy and momentum conservation

We define electron and positron (anti-electron) momentum vectors

$$\vec{e} = (e_x, e_y, e_z), \qquad \vec{a} = (a_x, a_y, a_z)$$

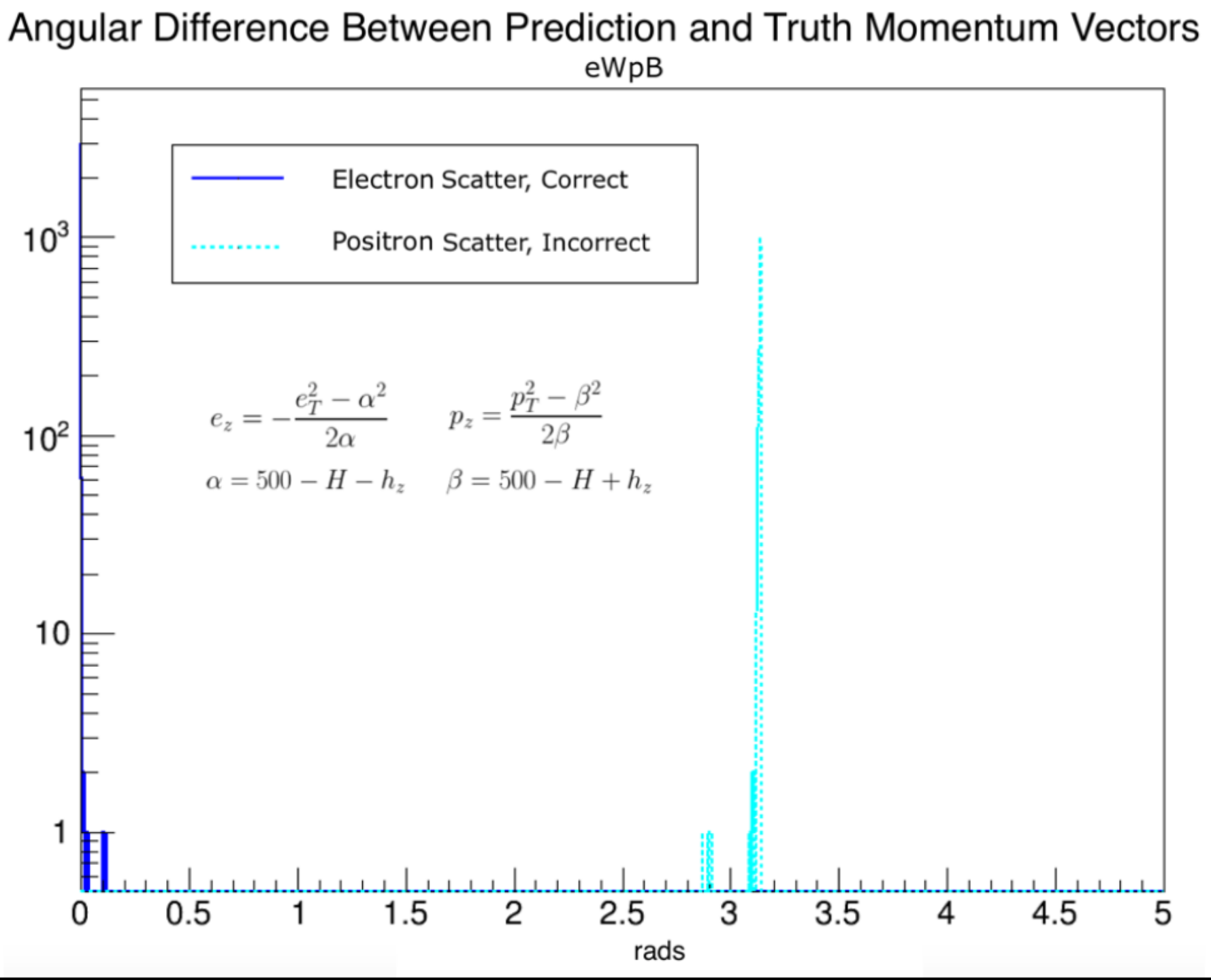
Positron deflects

$$\vec{a} = (-h_x, -h_y, \frac{h_x^2 + h_y^2 - \beta^2}{2\beta}) \qquad \beta = 500 - H + h_z,$$

Electron deflects

$$\vec{e} = (-h_x, -h_y, \frac{h_x^2 + h_y^2 - \alpha^2}{-2\alpha}) \qquad \alpha = 500 - H - h_z.$$

We cannot know which beam particle deflected leading to a two-fold ambiguity.


Angular Difference Between Prediction and Truth Momentum Vectors
eWpB
Electron Scatter, Correct
Positron Scatter, Incorrect
$e_z = -\frac{e_T^2 - \alpha^2}{2\alpha}$
$p_z = \frac{p_T^2 - \beta^2}{2\beta}$
$\alpha = 500 - H - h_z$
$\beta = 500 - H + h_z$
10^3
10^2
10
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
rads

PREDICTION ALGORITHM PERFORMANCE

- We projected the momentum vectors onto a position on the face of the BeamCal
- Assigned a hit status of "Miss" if particle went down either of the beampipe holes, status of "Hit" otherwise
- Four scenarios in the form Prediction Hit Status/Truth Hit Status: Hit/Hit (H/H), Hit/Miss (H/M), Miss/Hit (M/H), Miss/Miss (M/M)
- Dangerous category is HM: algorithm predicts an $e^{+/-}$ hit the BeamCal, but none did. Such a two-photon event would be incorrectly identified as a candidate for SUSY.

PERFORMANCE VS HERMETICITY

Let z_{max} be the limit of the detector's coverage of the hadronic system, where $z = |cos\theta|$.

For eBpW and eWpB events with greater than 1 GeV of transverse energy, we look at the population of the H/M category across a series of cuts on z_{max}.

Hit Status Prediction/Truth Averaged Over eWpB and eBpW Events

z_{max}	No Cut	0.999	0.99	0.95	0.9	0.8	0.5
H/H	0.118	0.112	0.084	0.059	0.048	0.037	0.019
H/M	0.029	0.040	0.045	0.050	0.050	0.045	0.029
M/H	0.014	0.019	0.047	0.072	0.083	0.095	0.112
M/M	0.839	0.823	0.824	0.848	0.819	0.822	0.839

FURTHER INVESTIGATION

- Gain an understanding why algorithm does not work perfectly for the case of a single deflected beam particle and perfectly reconstructed hadronic system
- Need to consider the case of eWpW events with two deflections (2% of two-photon background)
- Test performance of prediction algorithm using realistic ILC beam crossings with correct statistical representations of all standard-model processes

BACKGROUND OVERLAYS

William Wyatt

OVERLAY

- Used Overlay utility within Marlin, modified to allow for the statistical selection from multiple event files in a single job
- In order to generate a large sample, working at generator (4-vector) level
- Generated 10^5 ILC crossings (15 seconds of beam time or . 0.27 pb^{-1}) with contributions from the four two-photon event types and, for now, Bhabha events with no secondary photon radiation
- Pairs not included since they impact only the BeamCal. Instead, fast MC (based on full simulation) of BeamCal reconstruction under development

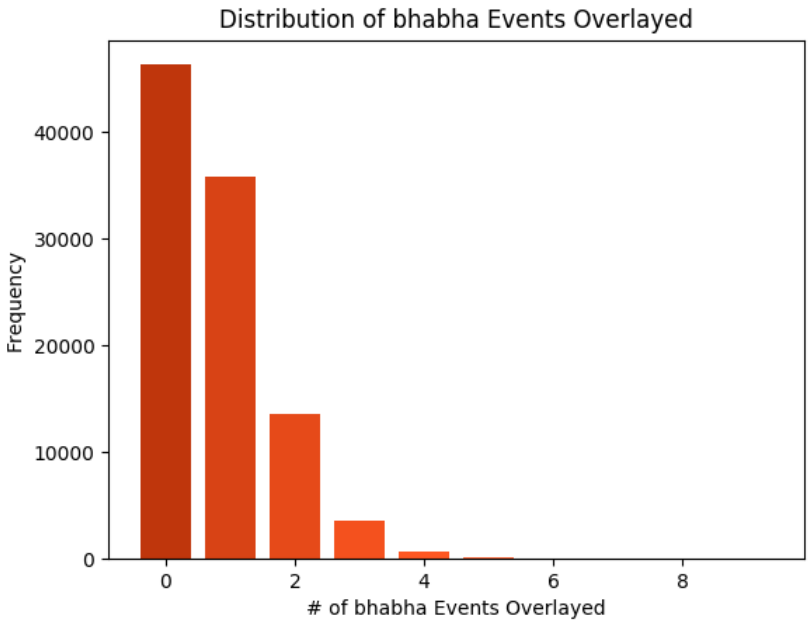
Two-photon Cross Sections and Event Rates

Event Type	BB	BW	WB	WW
Crossing (fb)	134427168.3	93474234.88	94353013.33	81276125.5867
Events/Crossing	0.368855	0.256484181	0.2588954634	0.2230137589

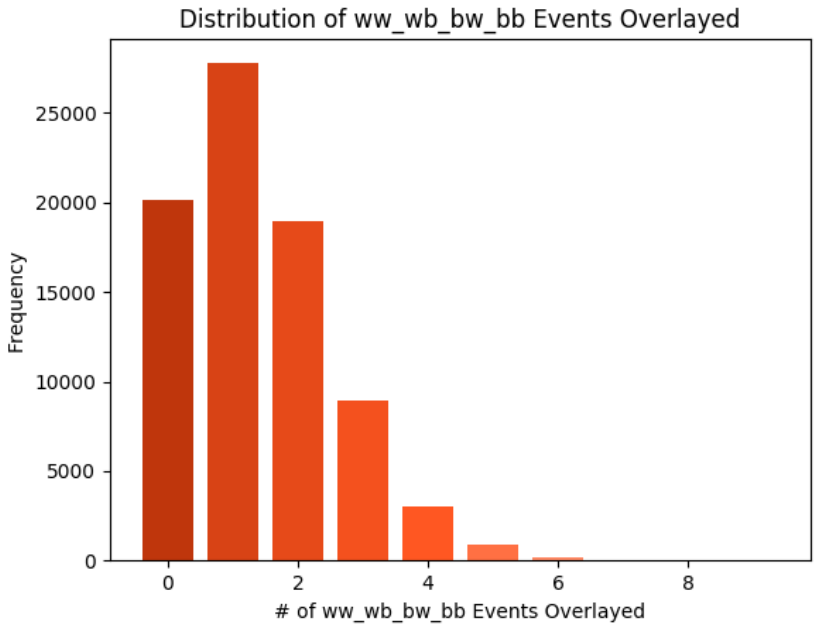
Bhabha Scattering Cross Sections and Event Rates

Secondary Radiation	e^+e^-	$e^+e^-\gamma$	$e^+e^-\gamma\gamma$
Crossing (fb)	278555100.0	853356.41.88	15389.98.33
Events/Crossing	0.764327339	0.002341525	0.000042229

Number of Event Distribution for Bhabha Component of Overlay Background



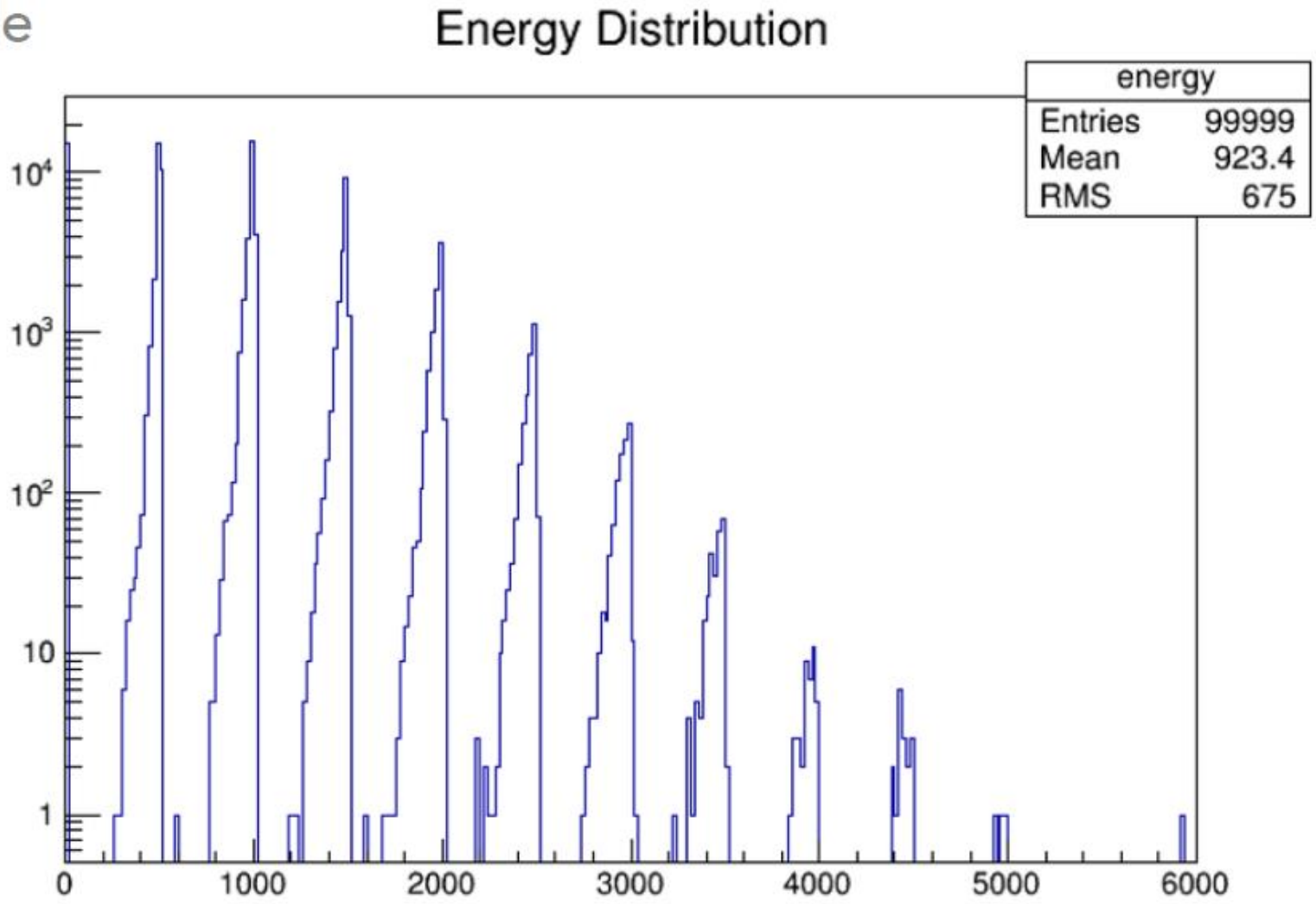
Number of Event Distribution for Total $\gamma\gamma$ Overlay Background



Extract numbers of events distribution from log file of Overlay processor

Poisson distributions reflect correct mean

Histogram of total final state particle energy for 10^5 crossing sample



Next step is to overlay compressed SUSY models (already in hand) and begin realistic studies

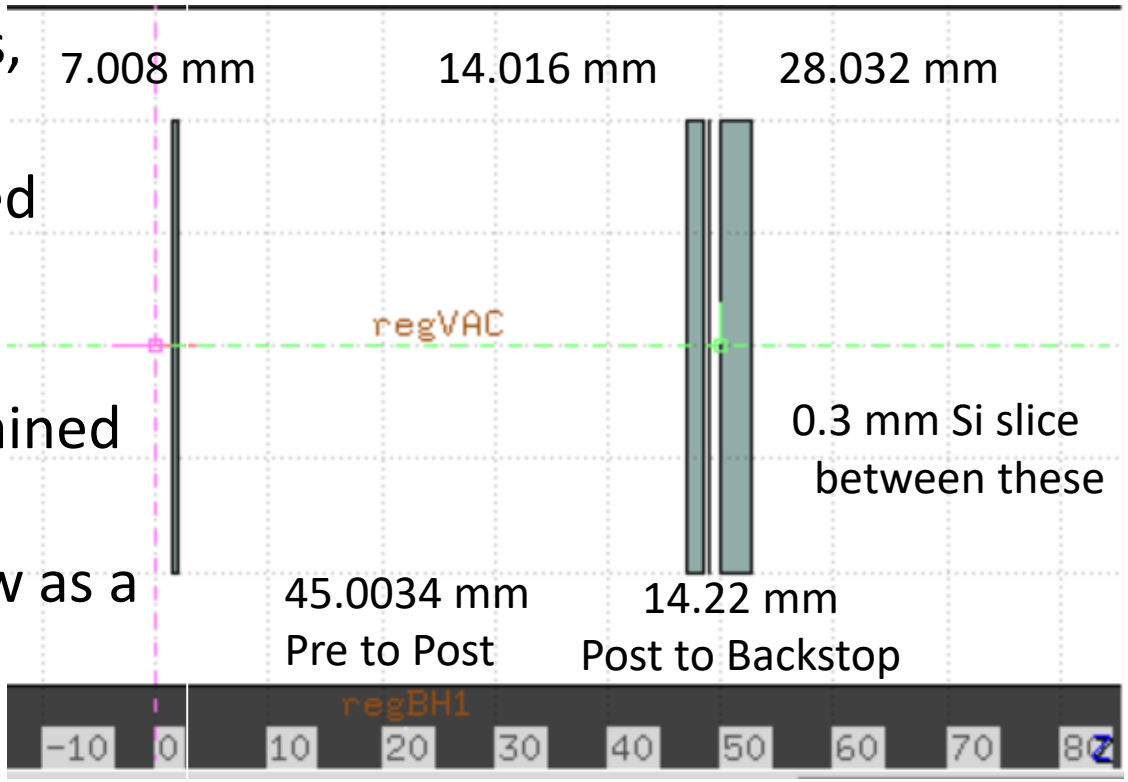
FLUKA MODEL

Benjamin Smithers

T506 Experiment

- Irradiated p-type Silicon Detector to 270 MRad
- Realistic mix of leptons, hadrons, and photons
- 13.3 GeV beam scanned over 1cm^2 area

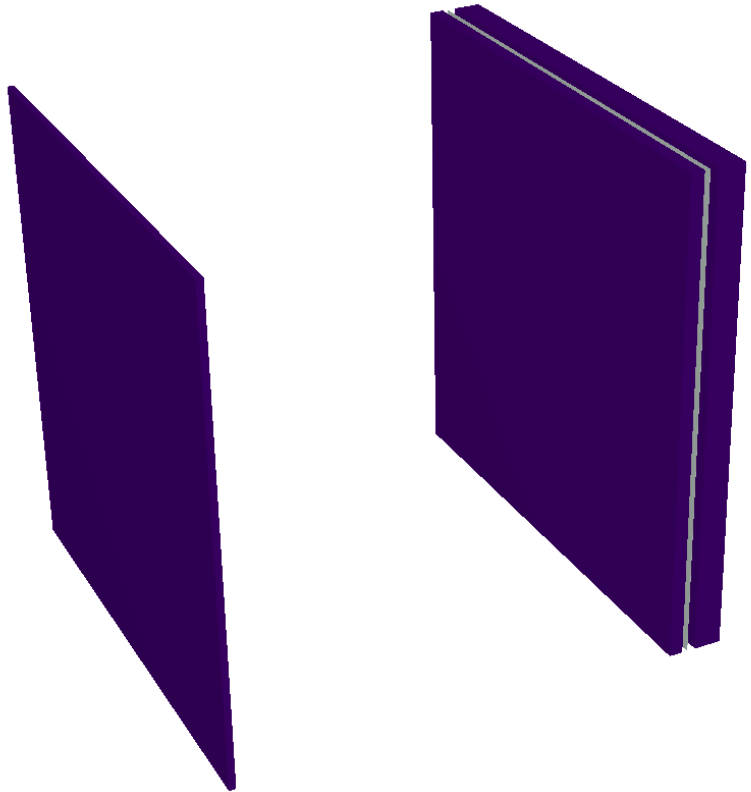
- Charge collection remained high
- Measured current draw as a function of bias and temperature



Combine with FLUKA Simulation to estimate BeamCal Power Draw

FLUKA Simulations (T506)

- Needed for neutron production and transport
- Using T506 to develop neutron damage factor that will scale FLUKA model of BeamCal
  - NIEL Scaling (1MeV Equiv)
  - Path length
- Neutrons scored, two way
  - Binned wrt dE (GeV), dΩ (SR)
- E+&E- scored ballistically
  - Binned in Energy



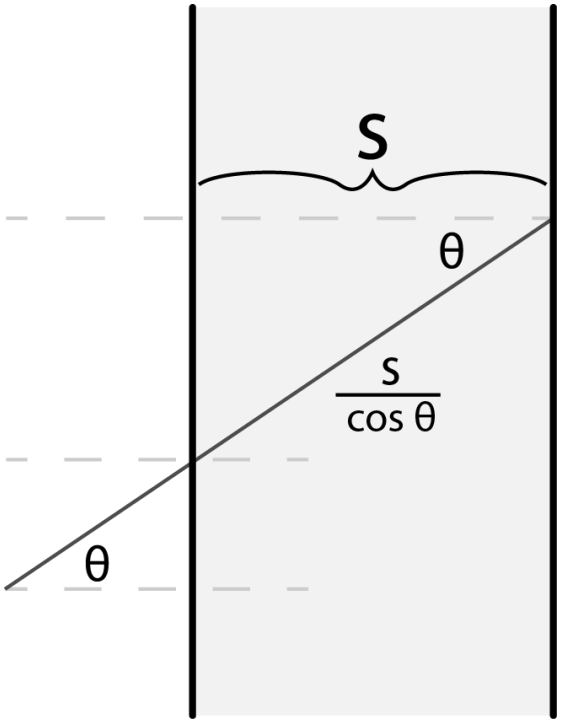
Calculating Damage Factor

- Damage is related to total path length of neutrons through the sensor per unit area
  - Begin by calculating Neutron Fluence

$$f = \frac{1}{A}\sum_{bins}\frac{dn}{dEd\Omega}(E,\theta)dEd\Omega$$

  - And adjust to find total neutron path length per cm3 of detector area

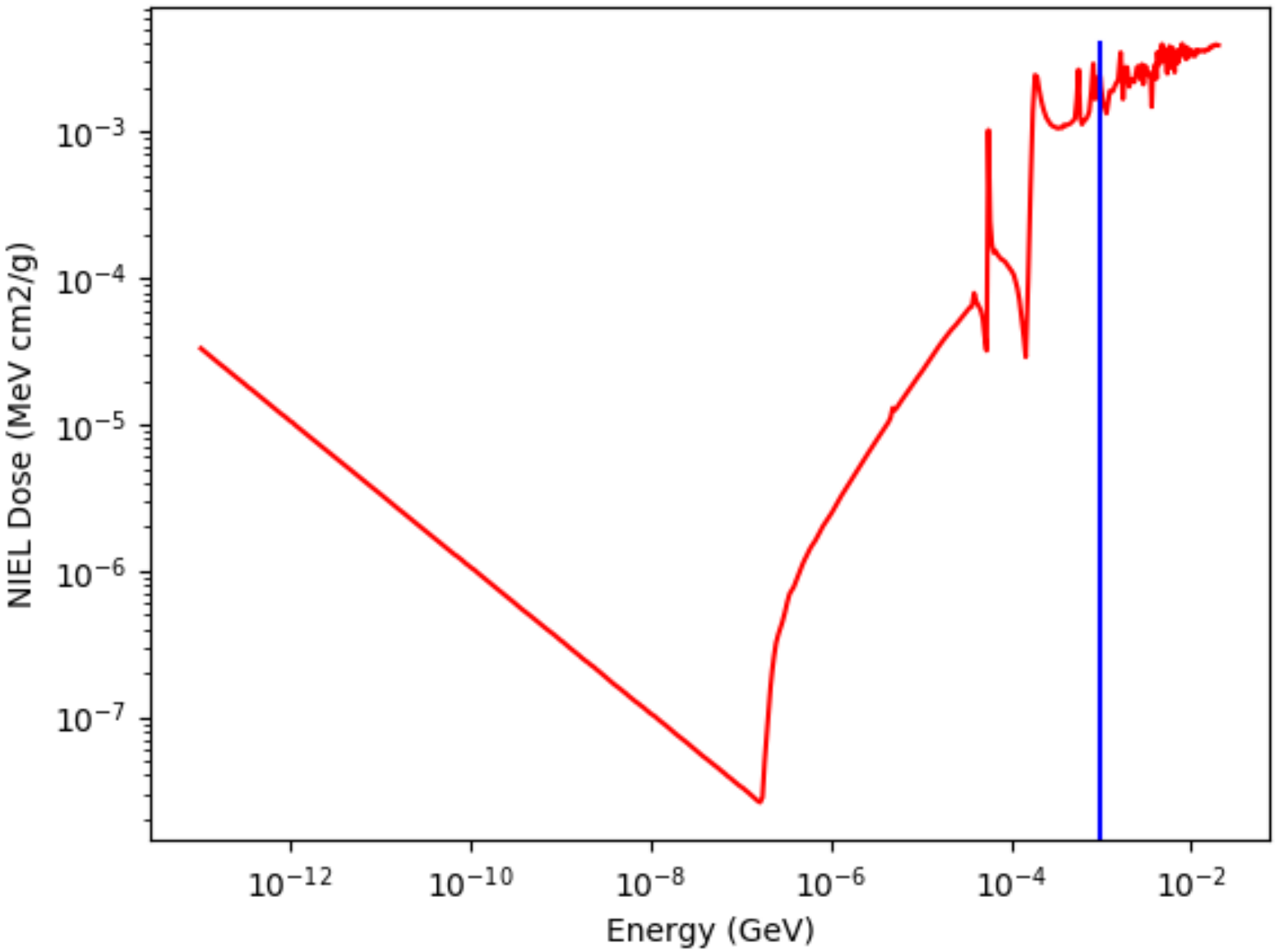
$$\lambda = \frac{1}{sA}\sum_{bins}\frac{dn}{dEd\Omega}(E,\theta)\frac{s}{cos\theta}dEd\Omega$$



The NIEL Scaling Hypothesis

- Damage is directly proportional to density of Non Ionizing Energy Loss (NIEL) in a semiconductor crystal
- We will use this and assume all NIEL is due to neutrons
- The rate of energy loss is steeply dependent on neutron energy
  - therefore make use of existing calculations of NIEL vs. Energy for Si
  - Rate is expressed in terms of path length in (g/cm2)
  - Include conversion factor of density (ρ) in simulation

Neutron NIEL in Si



Calculating Damage Factor – Contd.

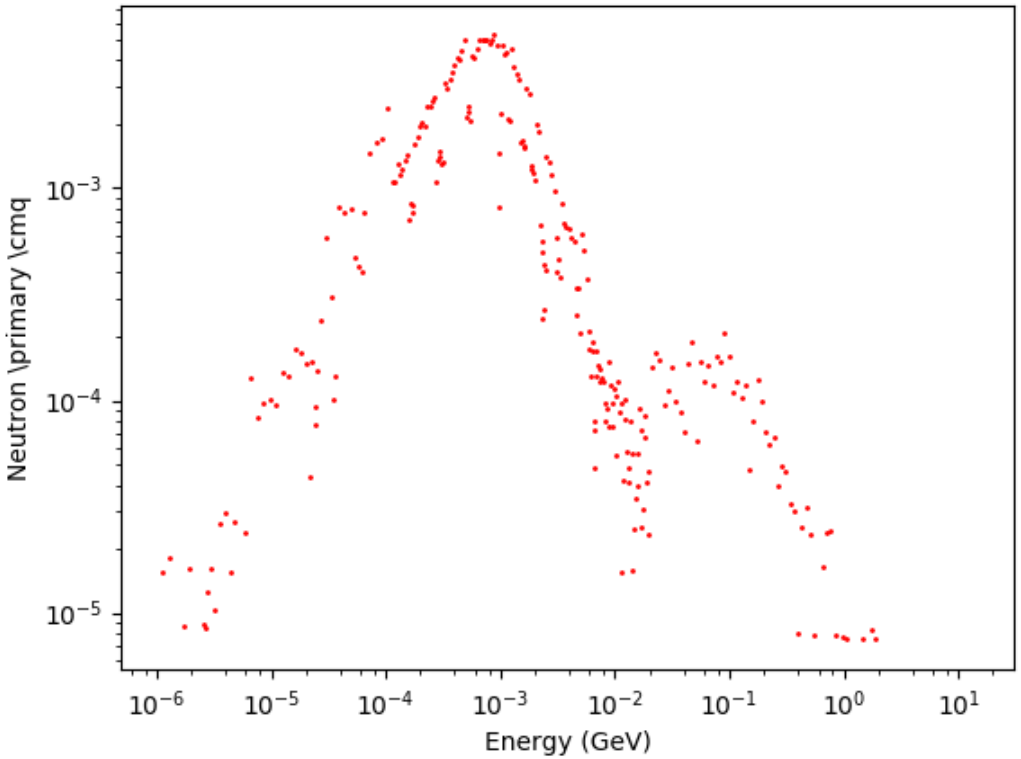
- Incorporating NIEL scaling hypothesis leads to full damage factor estimate

$$\lambda_{NIEL} = \frac{1}{A}\sum_{bins} \frac{dn}{dEd\Omega}(E,\theta)N(E)\frac{\rho}{cos\theta}dEd\Omega$$

in MeV/cm^3, with N(E) being the NIEL for neutron of energy E.

- Define 1 "**Rand**" as a neutron induced, non ionizing, energy deposition of 1 MeV per cm^3

T506 Rand Calculation



T506 Neutron Fluence (Integrated over Sold Angle)

Per 13.3 GeV primary into T506 Aparatus

After taking path length and NIEL scaling into account, T506 simulation yields 1.3 mRand per 13.3 GeV primary.

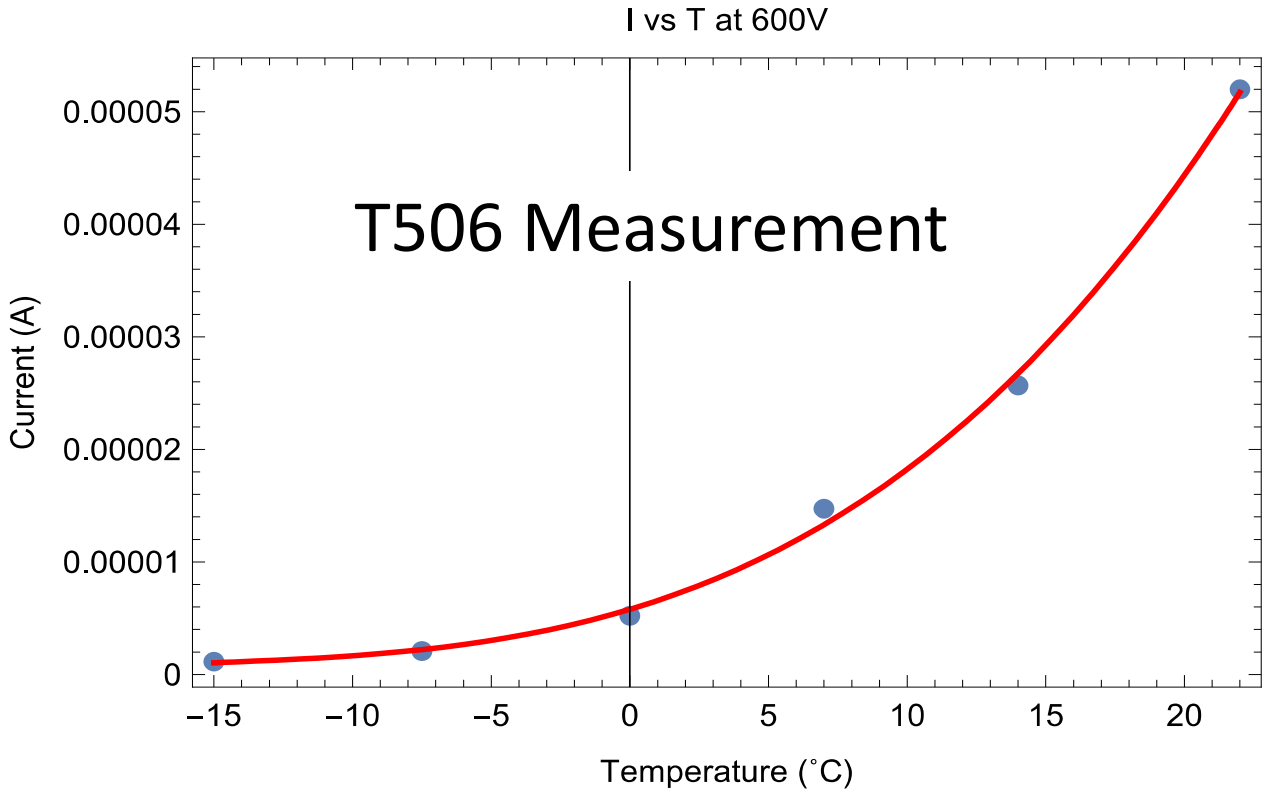
T506 – 270 Mrad Run

- The T506 run was characterized by 270 Mrad of electromagnetically induced radiation
- This dose was accumulated by directing 50.9 μC of 13.3 GeV electrons into the T506 apparatus

- We calculate no. of primaries from the charge collected
- By the described method, we then calculate Rands from the Neutron Fluence

Quantiy		Units
Primaries	50.9 (3.181 x 10^{14})	μC (particles)
Neutron Fluence	7.4 x 10^{13}	Neutrons/cm2
Rand Calculation	1.3	milli Rand/pr
Total Rands	410	Giga-Rand

T506 Power Draw – 600 V bias

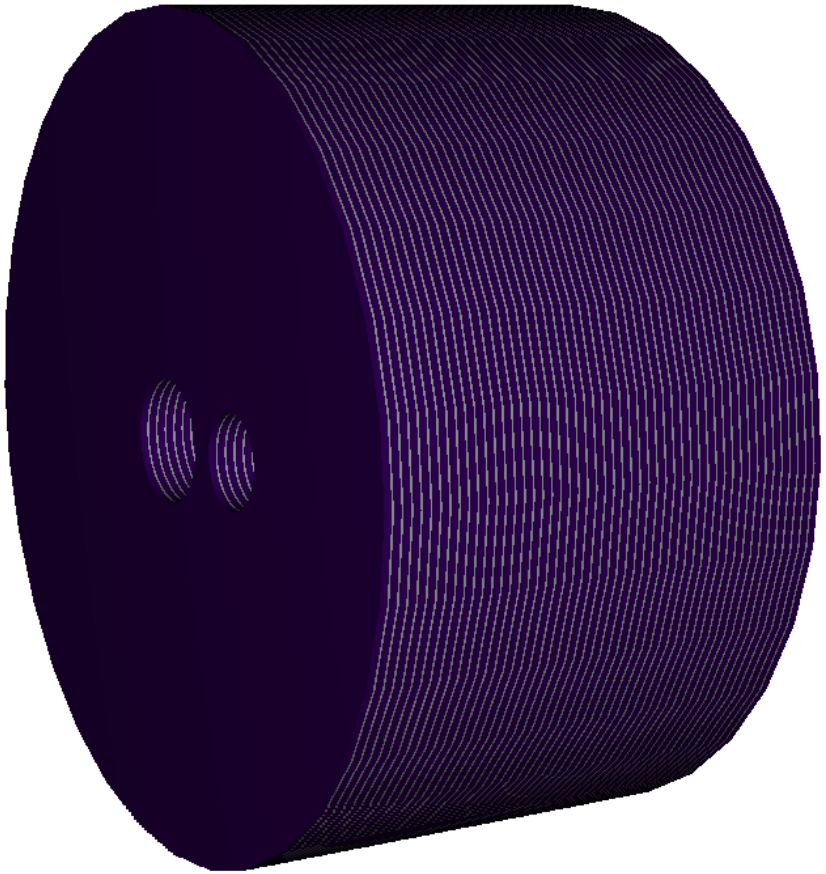


Under assumption of linearly dependent current upon dose

$$P = \frac{Rand}{410\ GRand} \times (600\ V) \times I(T)$$

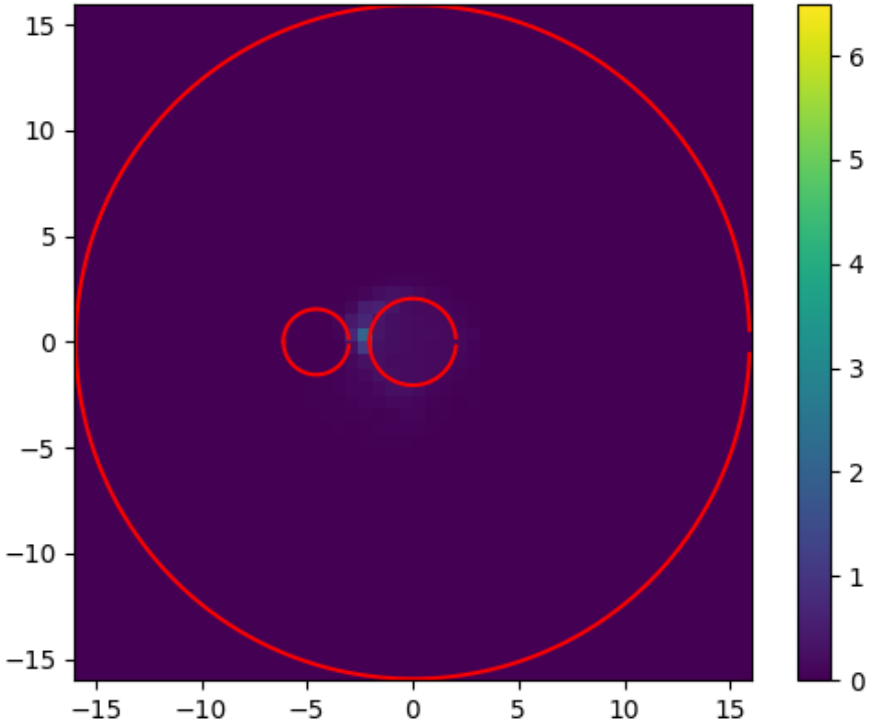
BeamCal Simulation in Fluka

- Design parameters from detailed baseline description (DBD)
- Primaries sourced from single Guinea Pig bunch crossing

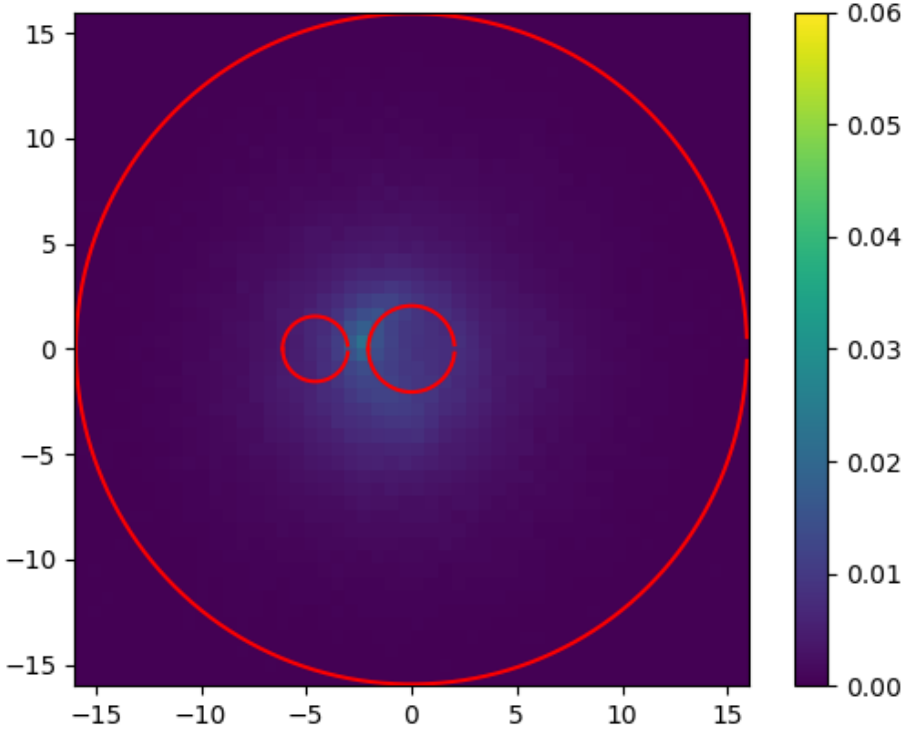


Layer 2 Detector - Fluence

E+&E-

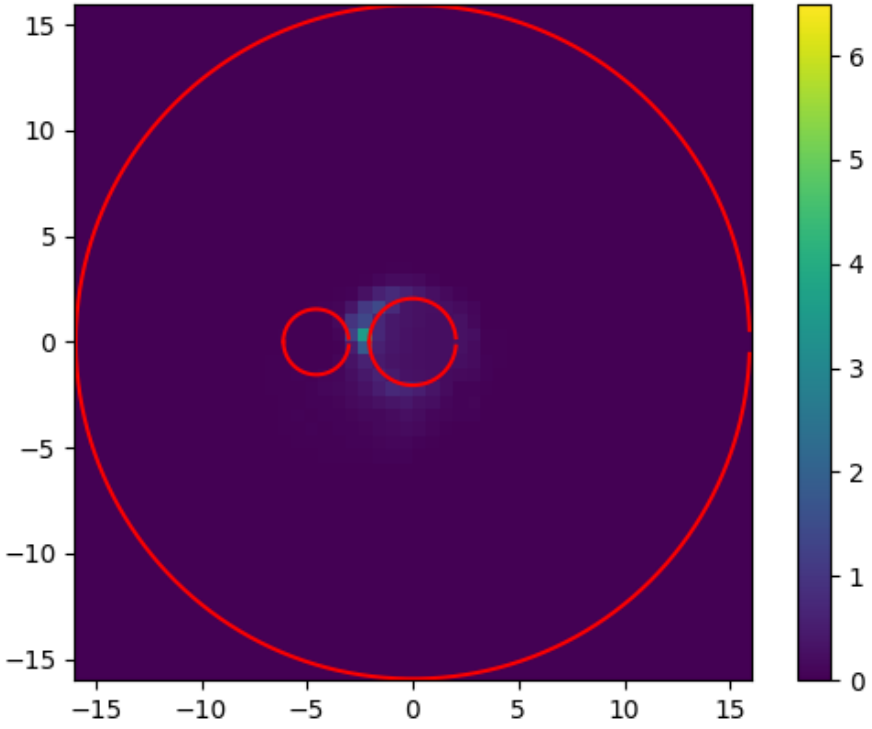


Neutrons

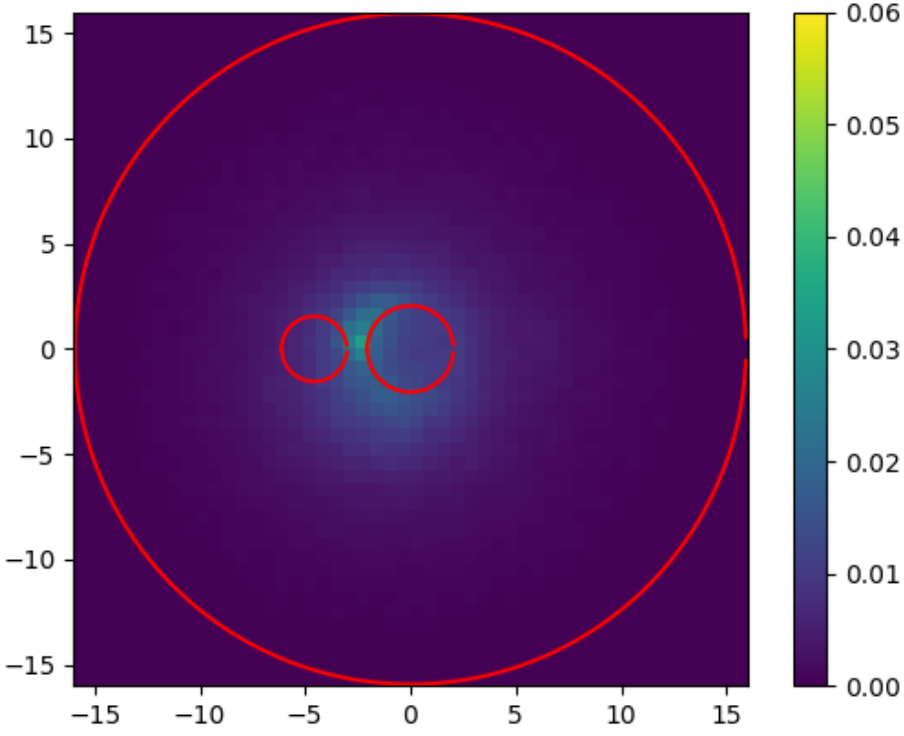


Layer 4 Detector - Fluence

E+&E-

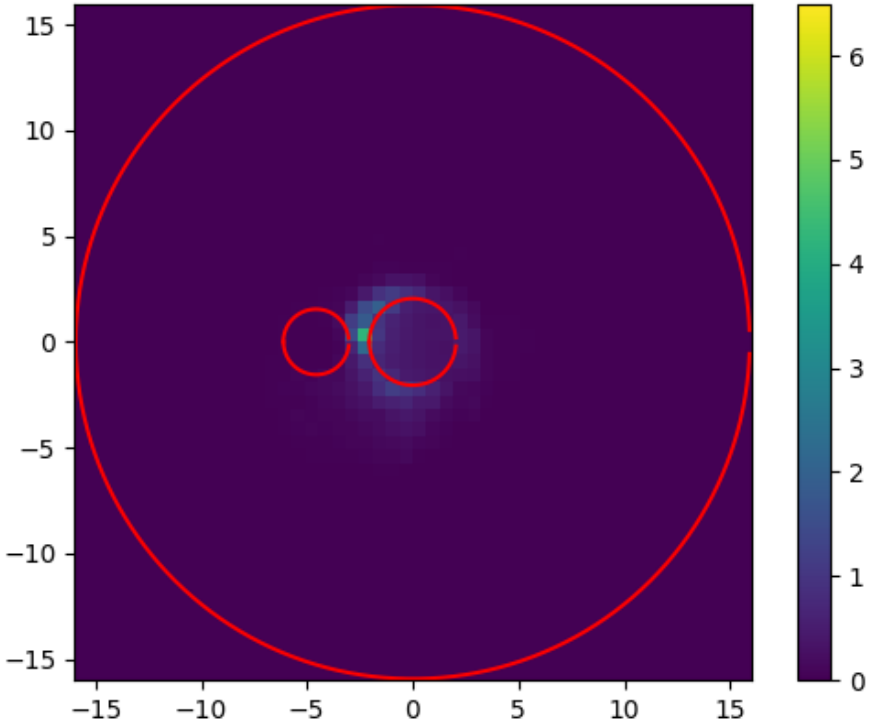


Neutrons

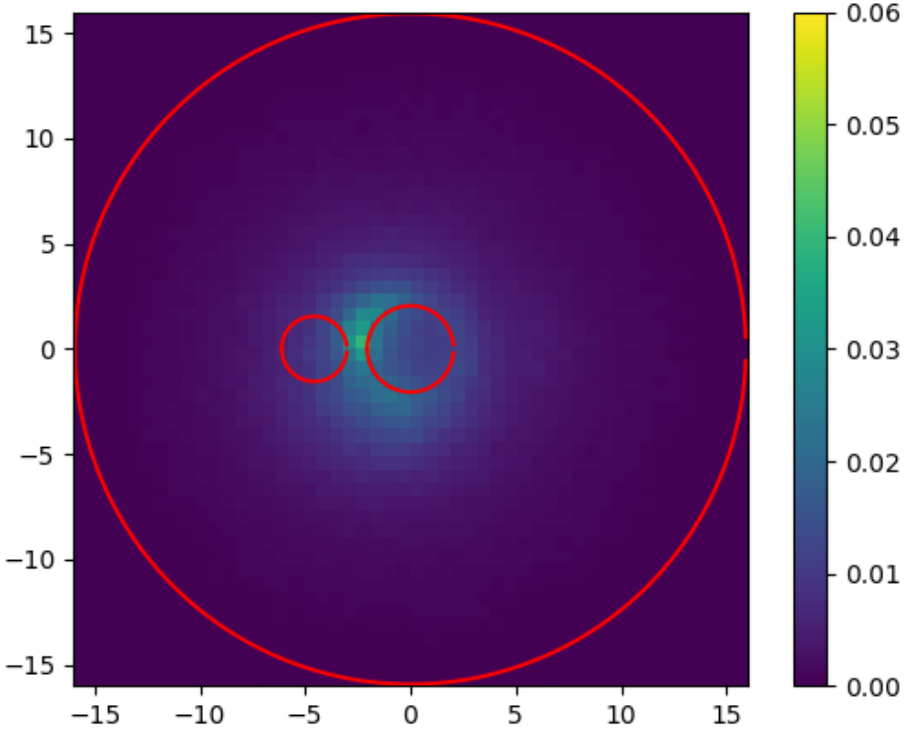


Layer 6 Detector - Fluence

E+&E-

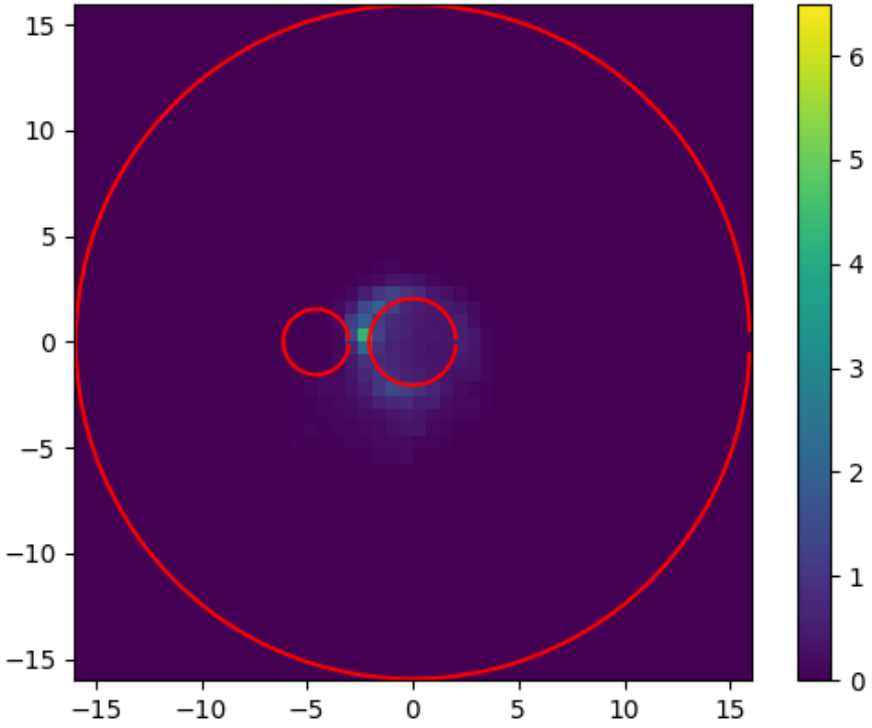


Neutrons

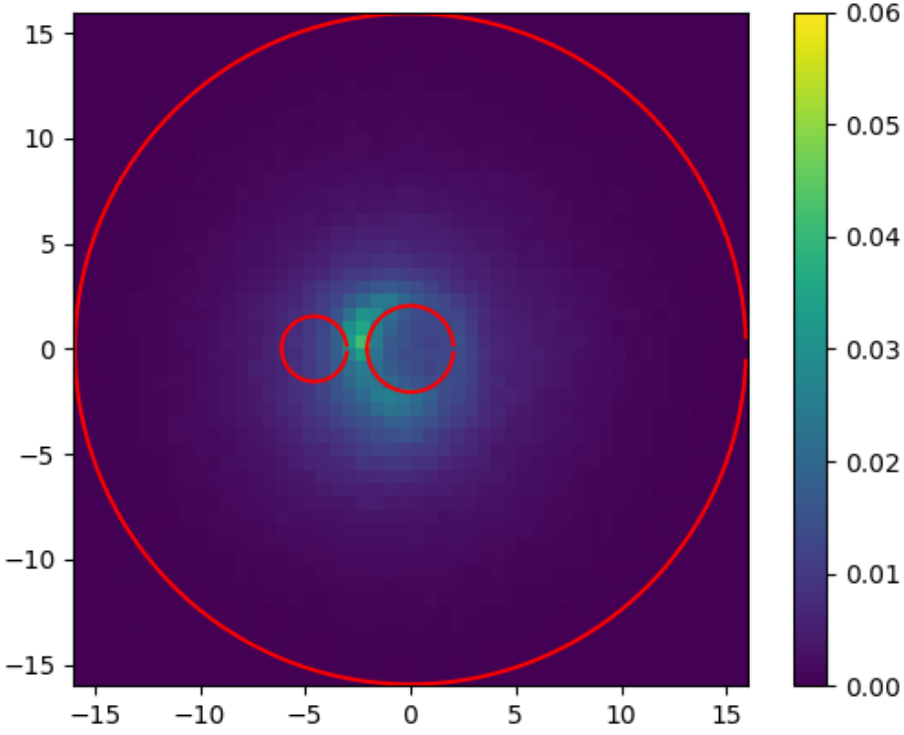


Layer 8 Detector - Fluence

E+&E-

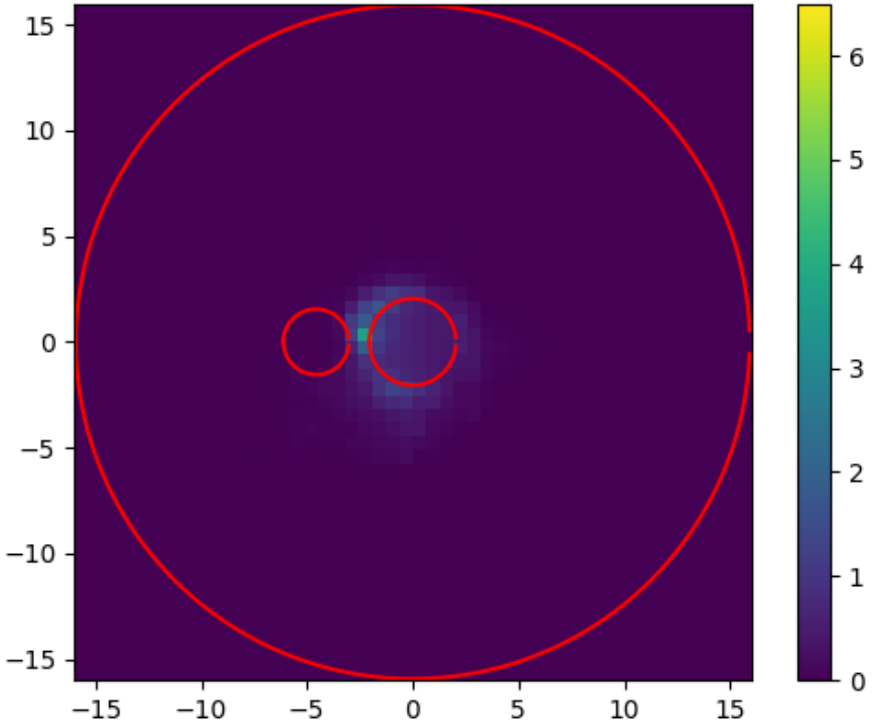


Neutrons

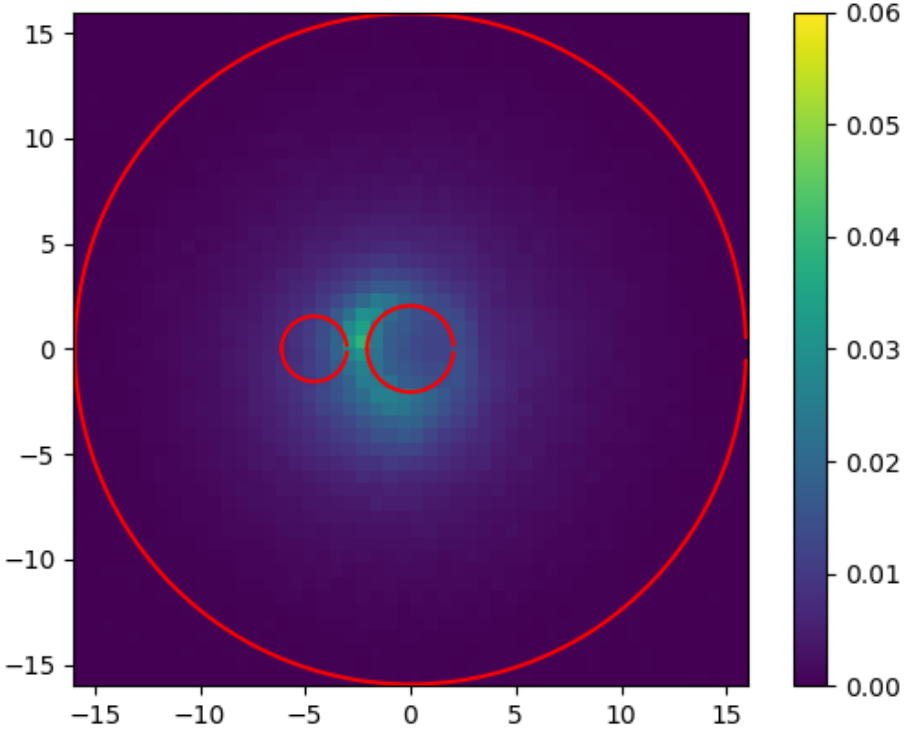


Layer 10 Detector - Fluence

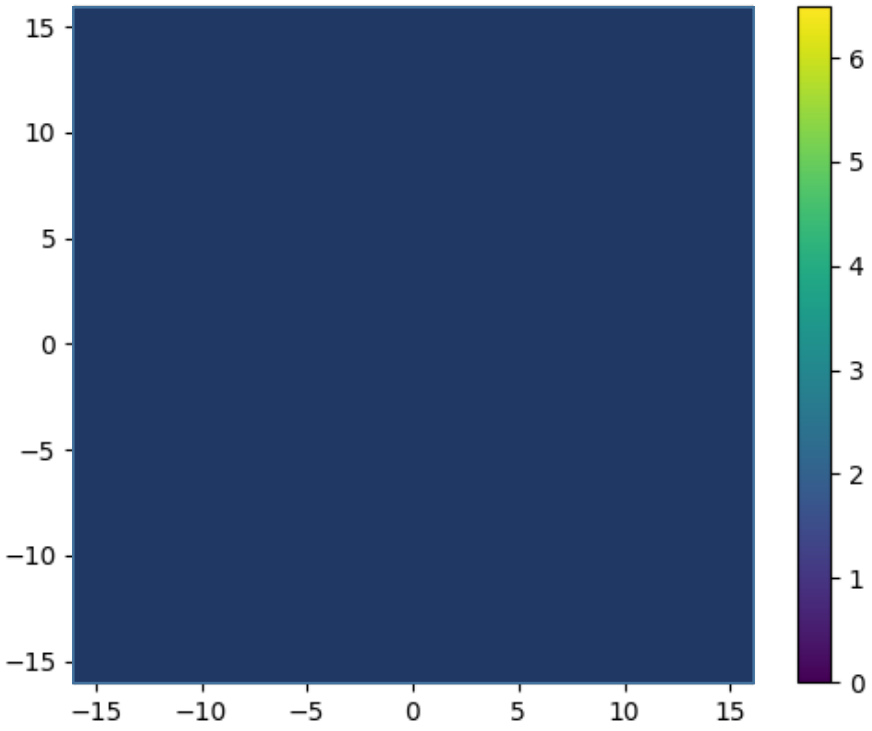
E+&E-



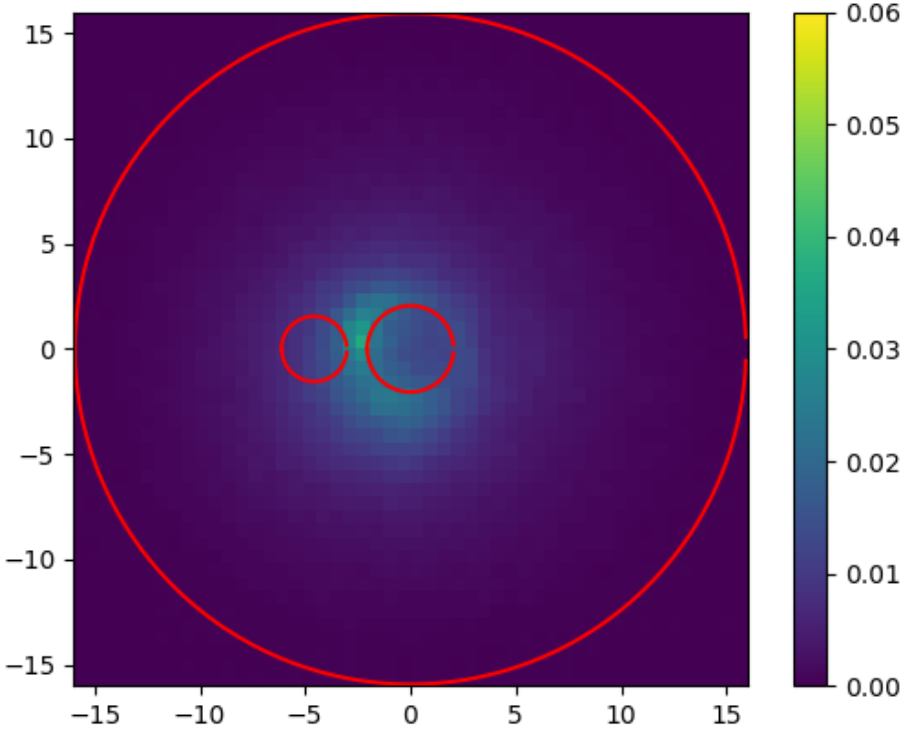
Neutrons



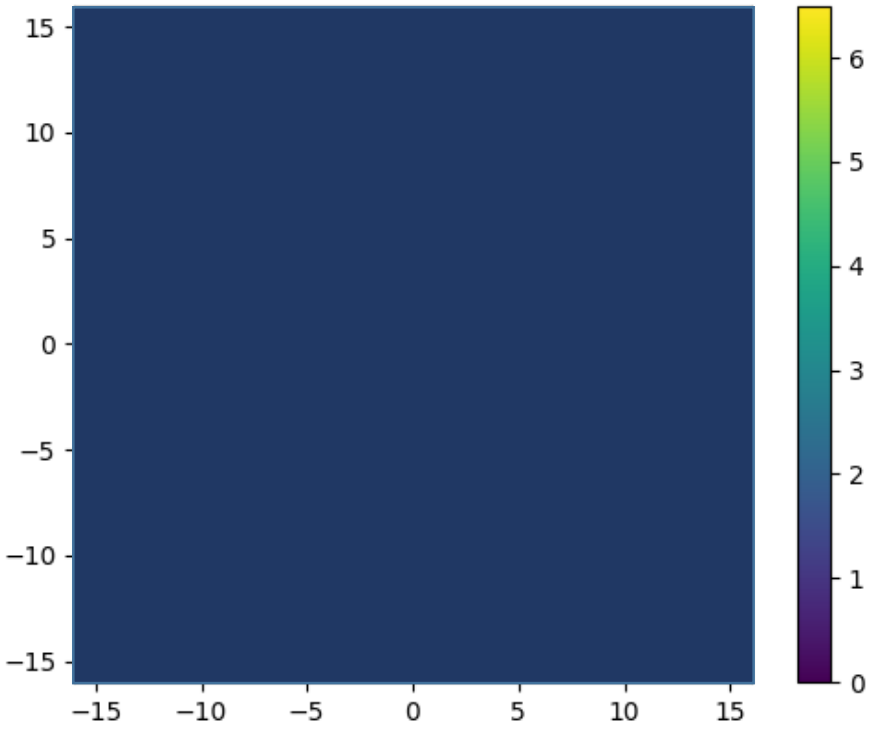
Layer 12 Detector - Fluence



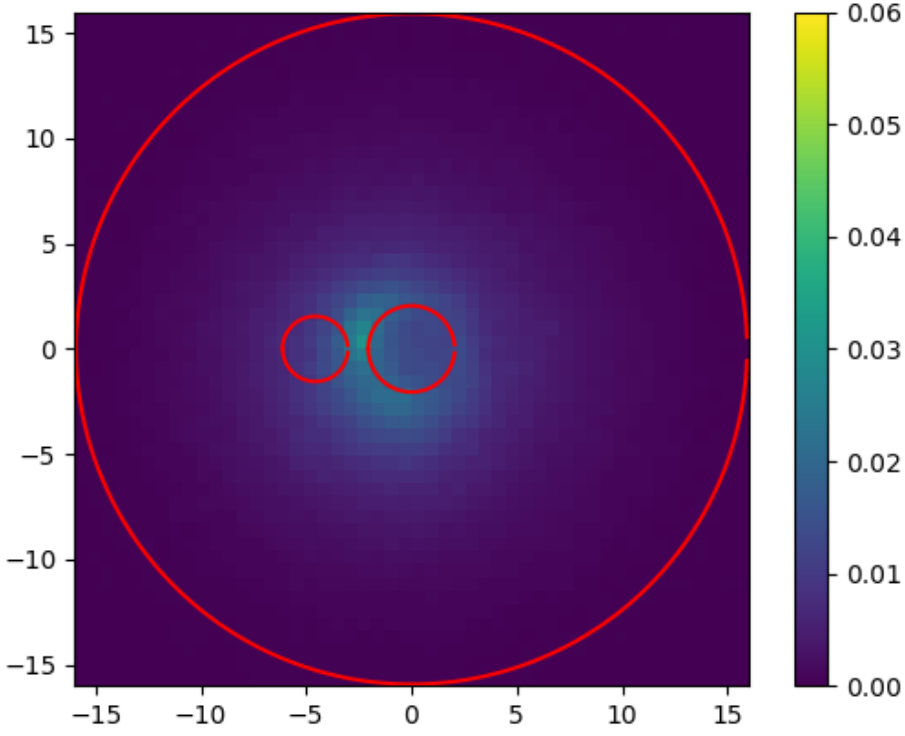
Neutrons



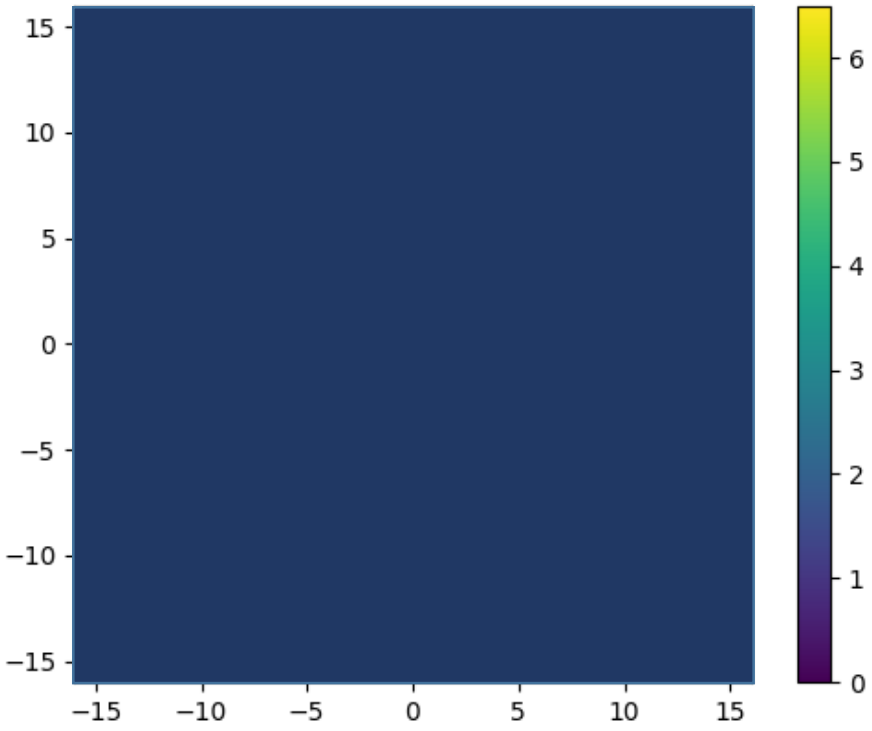
Layer 14 Detector - Fluence



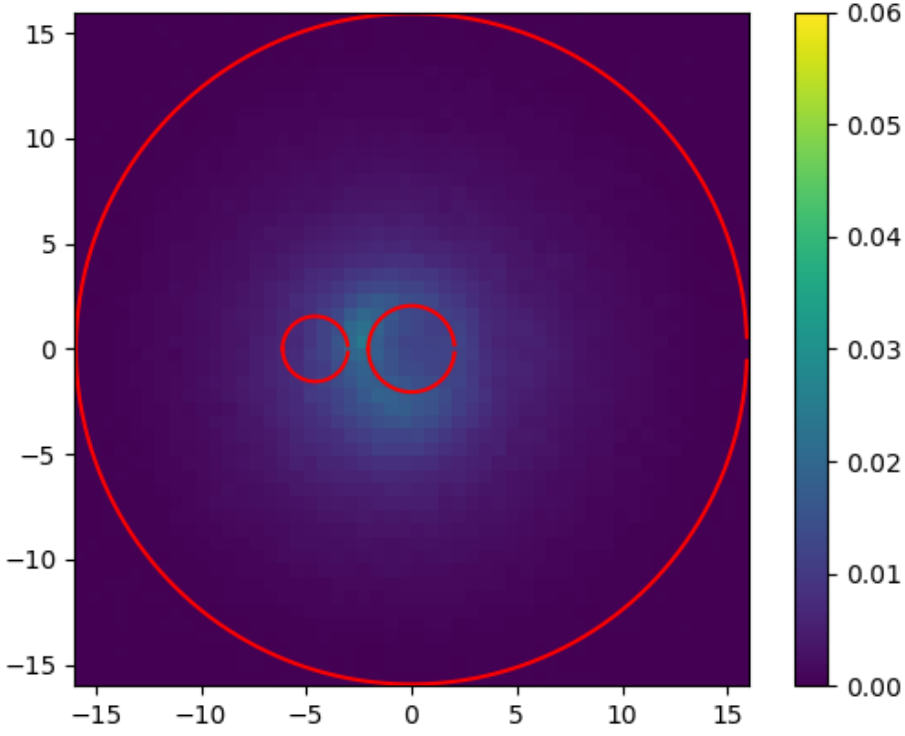
Neutrons



Layer 16 Detector - Fluence



Neutrons



Beamcal – Maximum Power Draw

- Picked the pixel maximizing neutron fluence

Layer 12		Units
Neutron Fluence	0.0136	/pr/cm2
Bunch Crossing	46868	E+&E-

Quantiy		Units
Rand Calculation	0.00028	Rand/pr
Total Rands	13.3	Rand
Rand Rate	87.1	kRand/s
Yearly Rand Rate	871	GRand/yr

One bunch crossing

$$P = \frac{BC\ Rand}{410\ GRand} \times (600\ V) \times I(T)$$

BeamCal

- Snow Mass year of usage results in 871 Giga-Rands
- At -7.5C, the power draw by a 1mm^2 pixel is given by

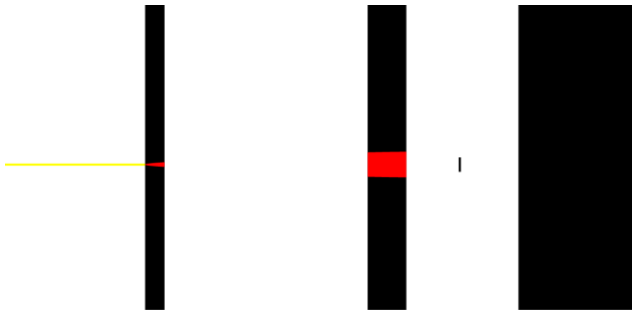
Temperature (C)	Current (uA)
-15	1.15
-7.5	2.05
0	5.21
7	14.7
14	25.7

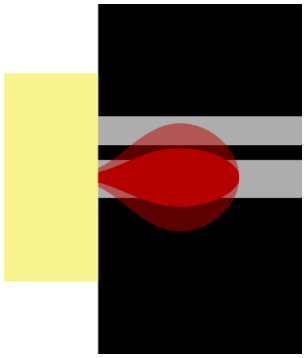
$$P = \frac{871\ GRand}{410\ GRand} \times\ (600\ V) \times (2.05 \mu A) = 2.63\ mW$$

Overall

- Most Damaged Pixel draws
  - Previous predictions: ~ 0.20 mW
  - If neutrons responsible : 2.63 mW

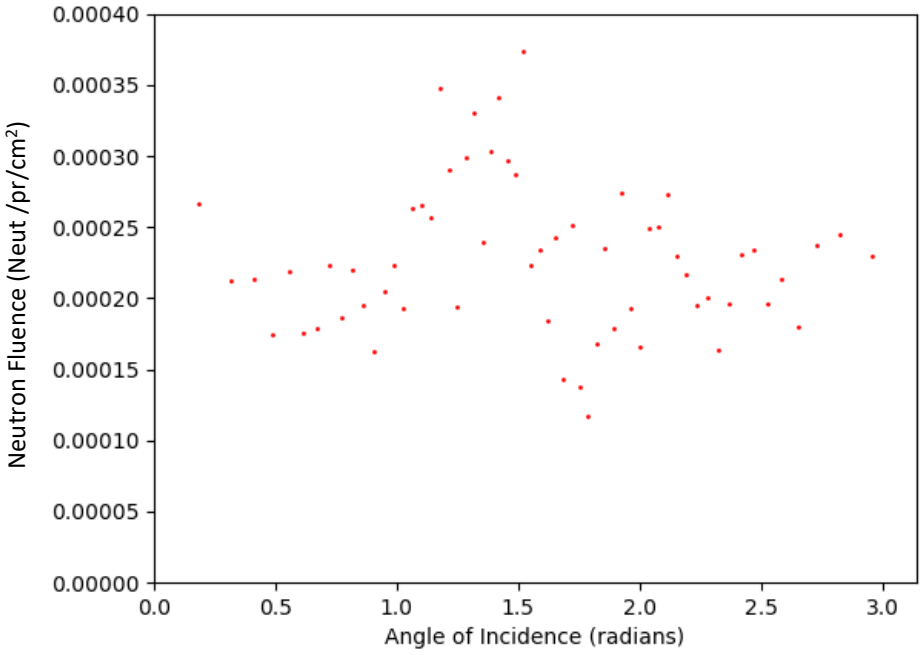
- Culprit? The Rand to rad ratio is found to be a factor of 10 higher for the Beamcal than the T506.
  - Predicts ten times the wattage
  - Could be due to shapes of neutron fields



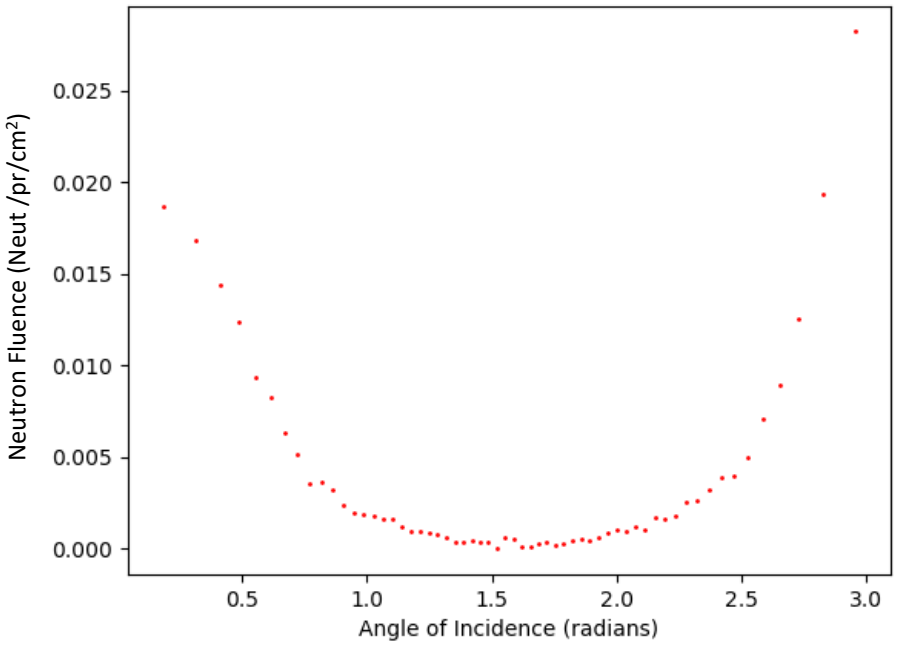


Neutron Fluence

BeamCal – Layer 12

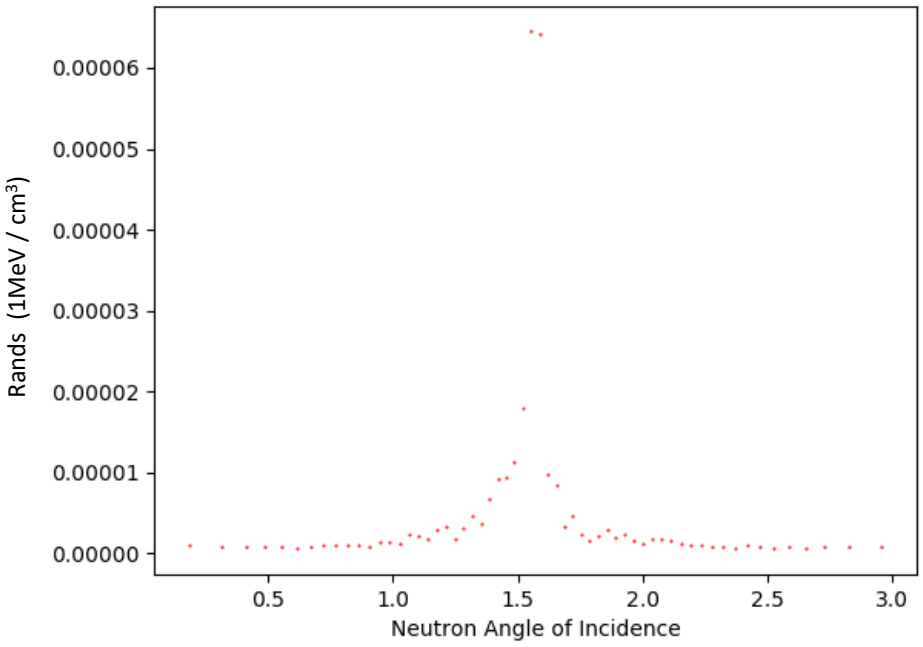


T506

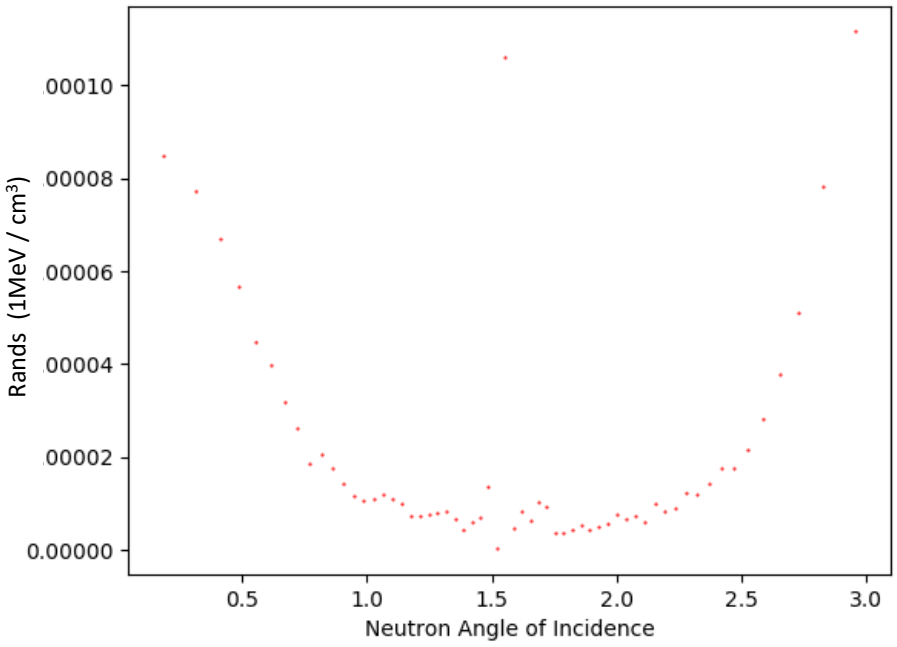


Rand Contribution vs Angle

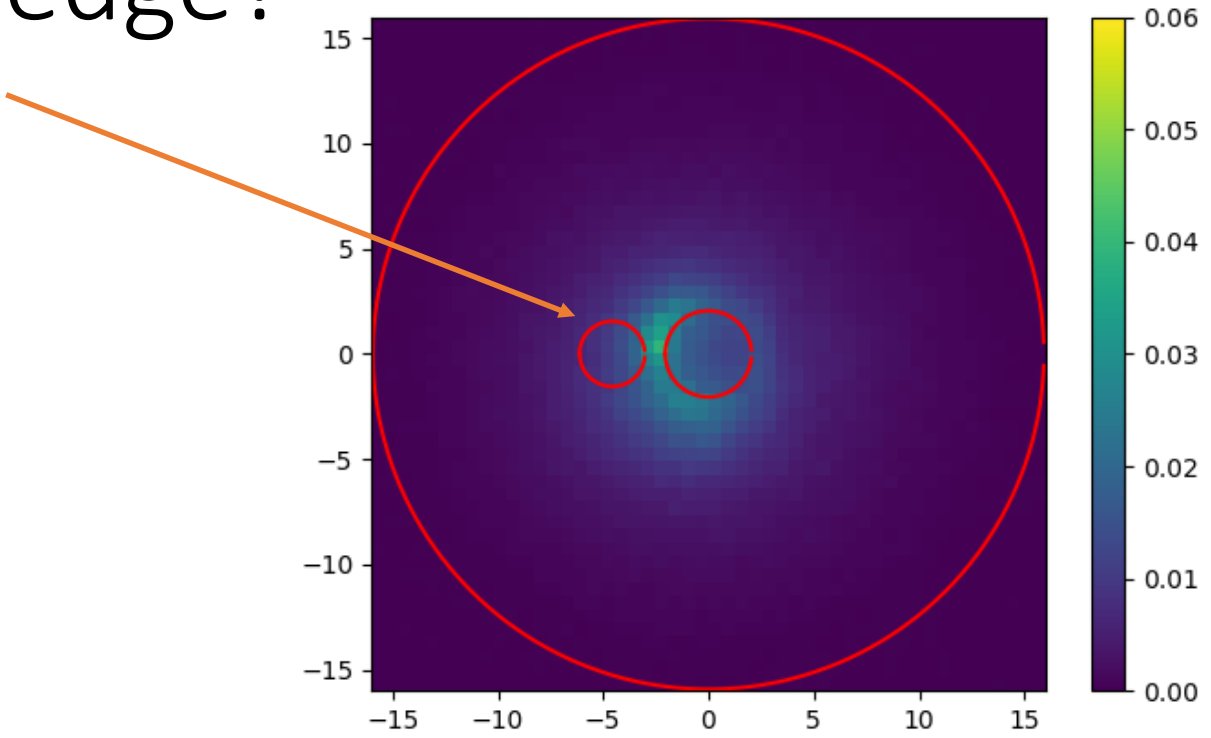
BeamCal – Layer 12



T506



Why the wedge?



Using the BeamCal to Obtain Information about Collision Parameters, and Impact of BeamCal Geometry Options

Contributors

- Luc D'Hauthuille, UCSC — Undergraduate (thesis)
- Anne Schuetz, DESY — Graduate Student
- Christopher Milke, UCSC — Undergraduate

With input from Glen White, Jan Strube, B.S.

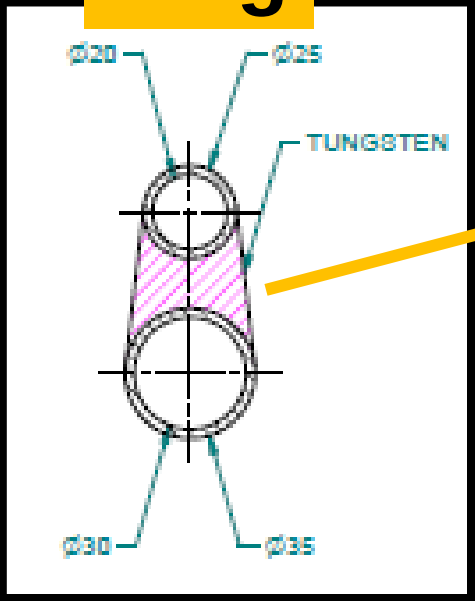
Goal

Idea is to explore the sensitivity of various beamstrahlung observables, as reconstructed in the BeamCal, to variations in IP beam parameters. The sensitivity will be explored with various different BeamCal geometries.

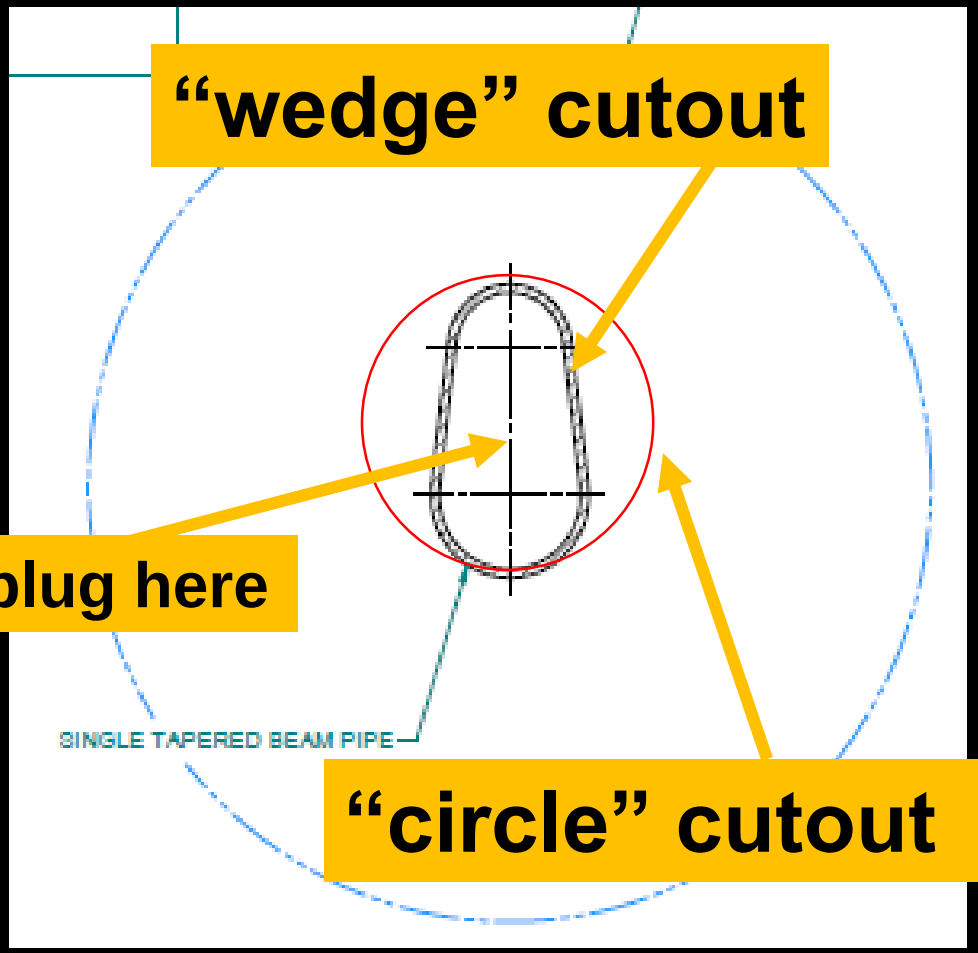
BeamCal Face Geometry Options

- "plugged"
- Wedge cutout
- Circle cutout

Plug



Insert plug here



IP Parameter Scenarios

Thanks to Anne Schuetz, GuneaPig expert

Relative to nominal:

- Increase beam envelop at origin (via β-function), for electron and positron beam independently, by 10%, 20%, and 30%
- Move waist of electron and positron beam (independently) back by 100μm, 200 μm, 300 μm.
- Change angle φ of orientation of transverse electron and positron beam profile (independently) by 5 mrad and 20 mrad

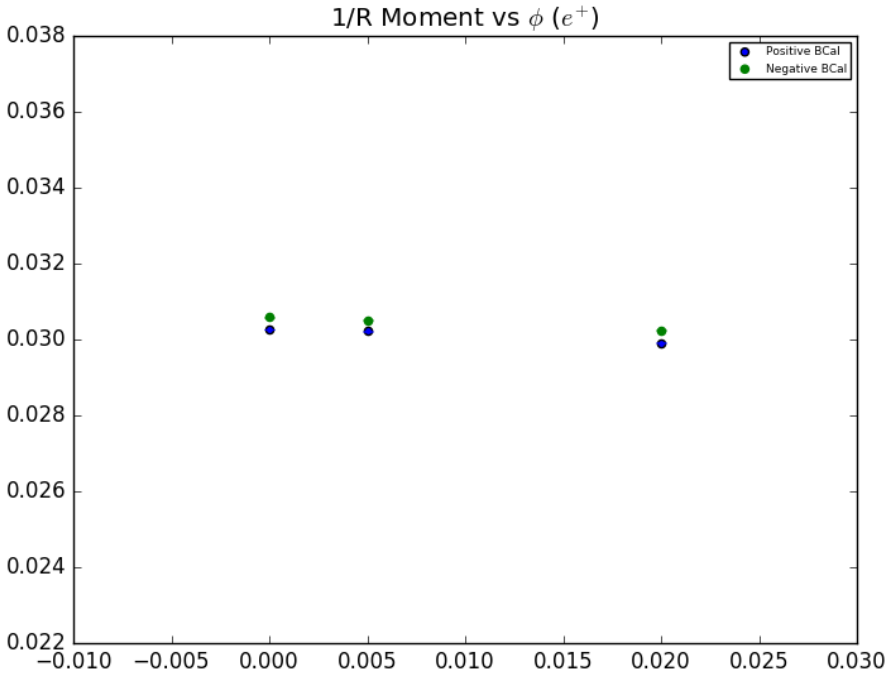
Details at

https://wikis.bris.ac.uk/display/sid/GuineaPig+simulations+for+BeamCal+study

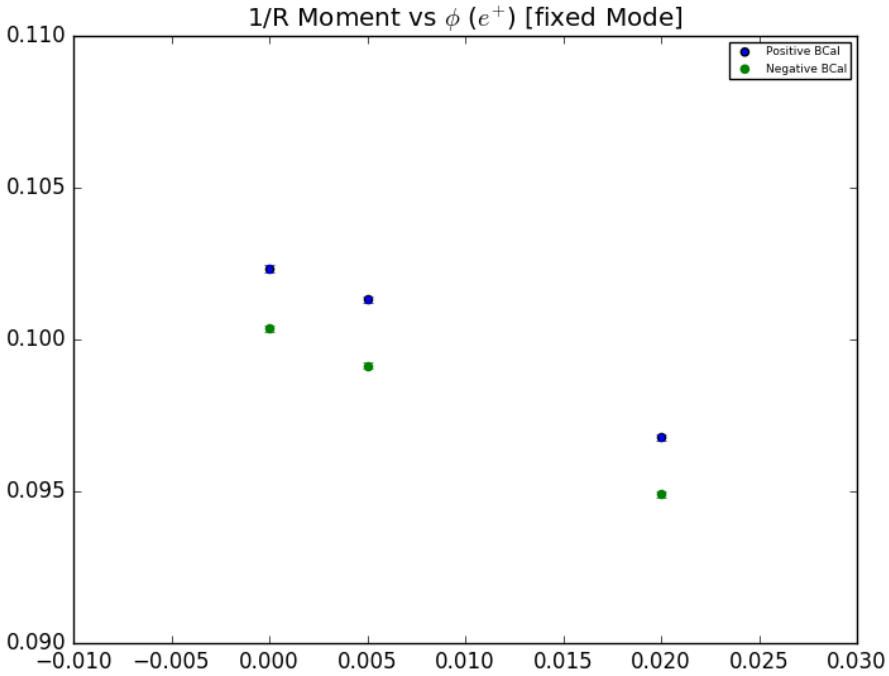
Example comparison between performance with and without wedge

1/R Moment sensitivity to relative angular rotation of beams

Without Wedge



With Wedge

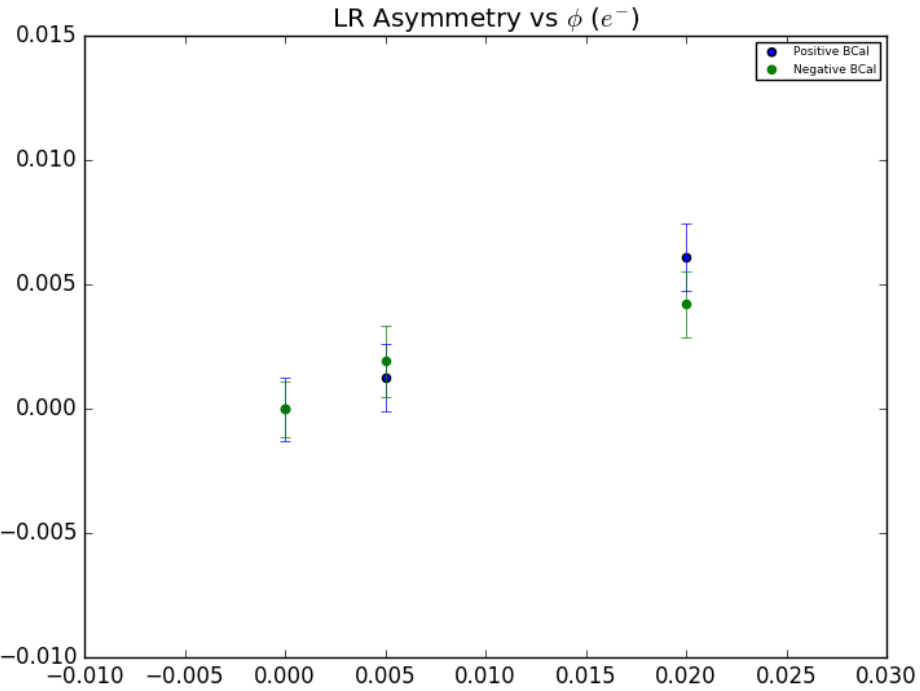


SUMMARY

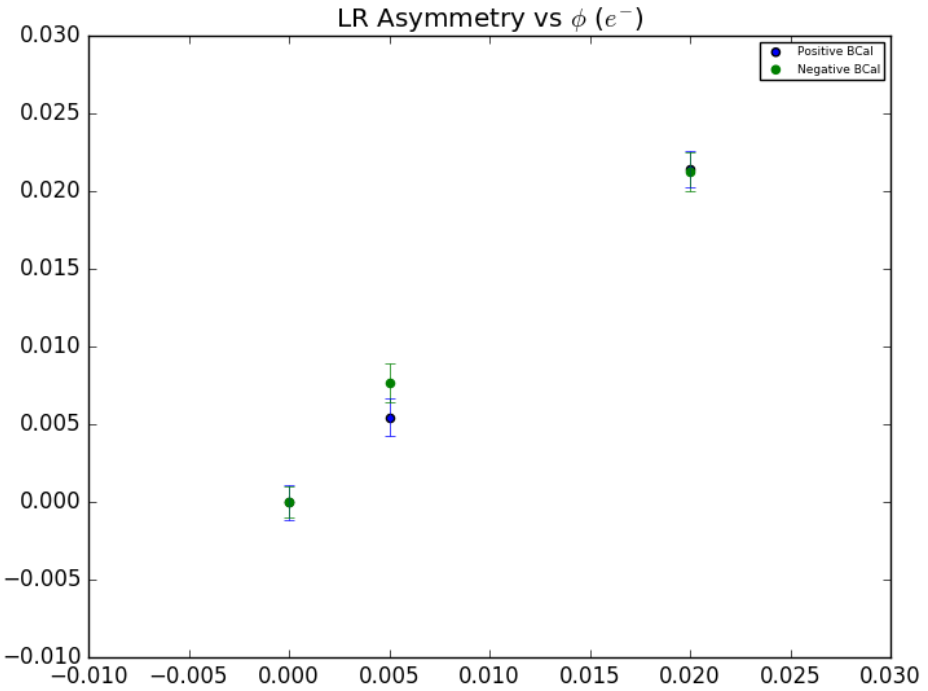
- Tools in place to begin more realistic study of compressed SUSY (physics reach, motivation for far-forward hadronic coverage)
- FLUKA simulation coming together: need to confirm neutron NIEL rates. Next step is to incorporate within the SiD simulation framework
- Continue to explore need for “wedge” region of BeamCal (IP parameters, two-photon even veto)
- Continue T506 radiation damage studies; need to think a bit about implications of FLUKA results

BACKUP

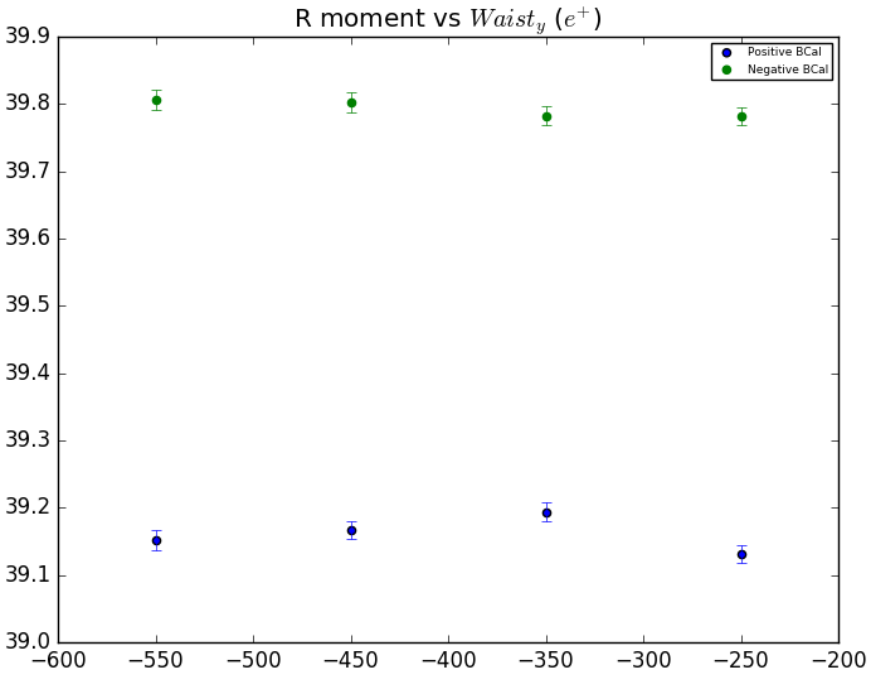
Without Wedge



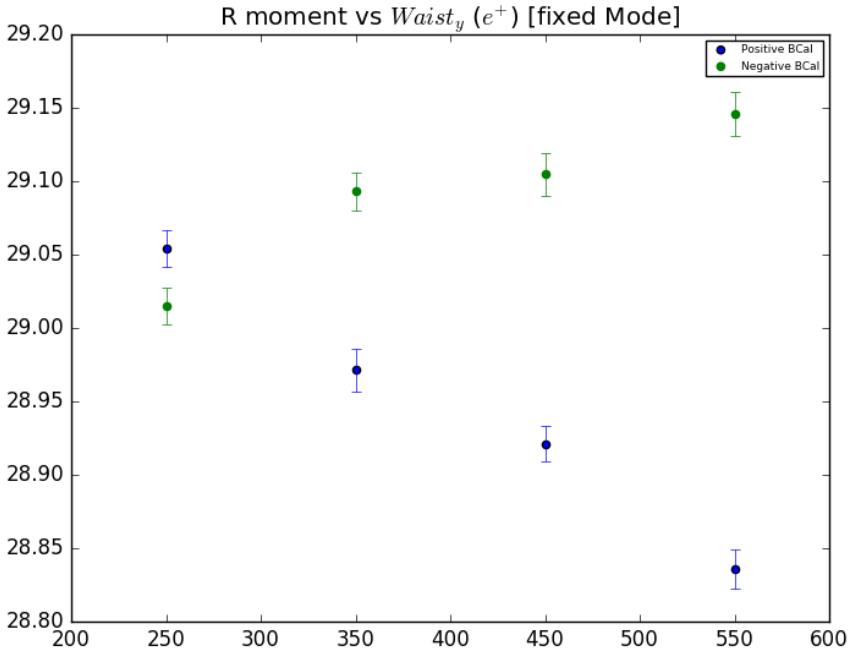
With Wedge



Without Wedge



With Wedge



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