Plans for Radiation Damage Studies for Si Diode Sensors Subject to 1 GRaD Doses

CERN Linear Collider Workshop
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NIEL (Non-Ionizing Energy Loss)

Conventional wisdom: Damage proportional to Non-Ionizing Energy Loss (**NIEL**) of traversing particle

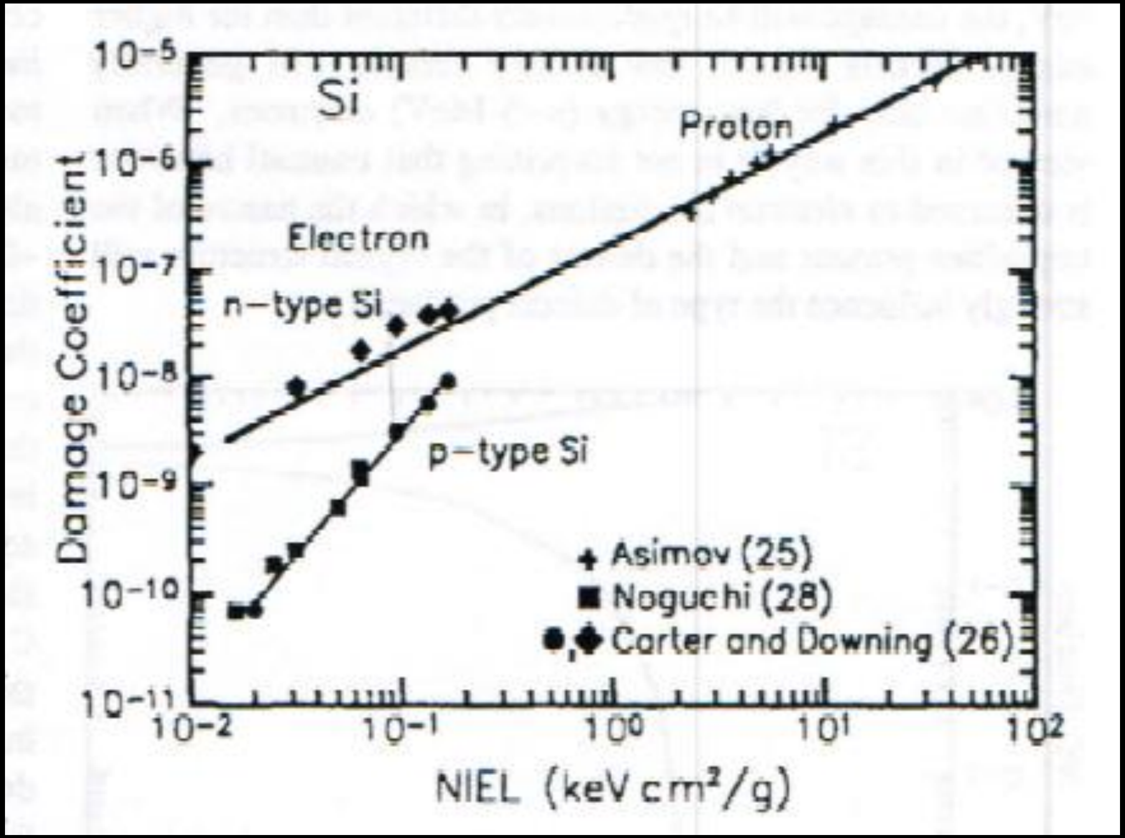
NIEL can be calculated (e.g. G.P. Summers et al., IEEE Trans Nucl Sci **40**, 1372 [1993])

At $E_c^{Tungsten}$ ~ 10 MeV, **NIEL** is 80 times worse for protons than electrons and

- **NIEL** scaling may break down (even less damage from electrons/positrons)
- **NIEL** rises quickly with decreasing (proton) energy, and fragments would likely be low energy

➔ Might small hadronic fractions dominate damage?

G.P. Summers et al., IEEE Trans Nucl Sci **40**, 1372 (1993)



NIEL	e^- Energy
2×10^{-2}	0.5 MeV
5×10^{-2}	2 MeV
1×10^{-1}	10 MeV
2×10^{-1}	200 MeV

Damage coefficients less for p-type for E_{e-} < ~1GeV (two groups); note **critical energy** in W is **~10 MeV**

But: Are electrons the entire picture?

Hadronic Processes in EM Showers

There seem to be three main processes for generating hadrons in EM showers (all induced by **photons**):

- Nuclear ("giant dipole") resonances
  - Resonance at 10-20 MeV ($\sim E_{critical}$)
- Photoproduction
  - Threshold seems to be about 200 MeV
- Nuclear Compton scattering
  - Threshold at about 10 MeV; Δ resonance at 340 MeV

➔ Flux through silicon sensor should be ~10 MeV e/γ, but also must appropriately represent hadronic component

Rates (Current) and Energy

Basic Idea:

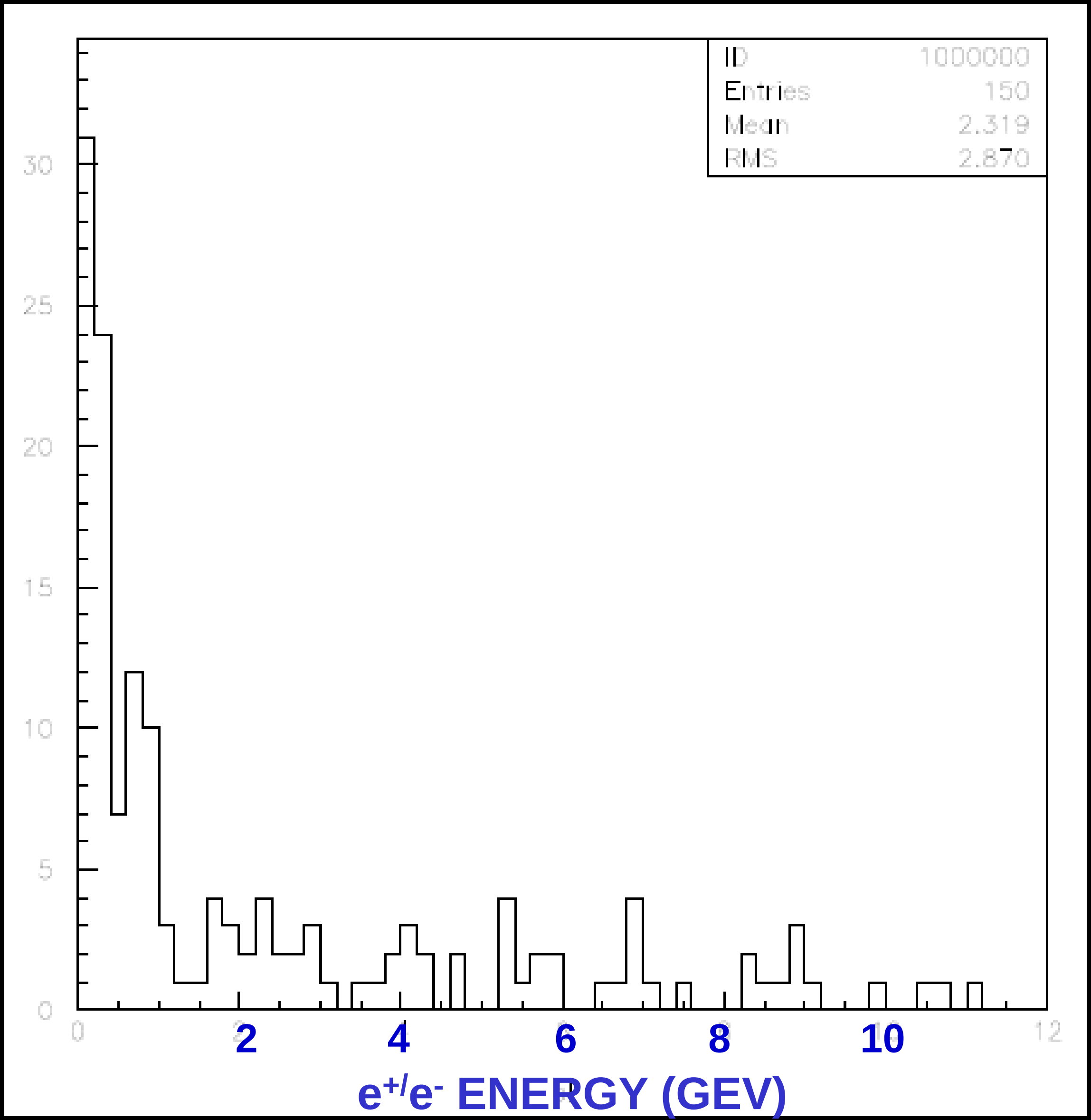
Direct electron beam of moderate energy on Tungsten radiator; insert silicon sensor at shower max

For Si, 1 GRad is about 3 x 10^{16}/cm^2, or about 5 mili-Coulomb/cm^2

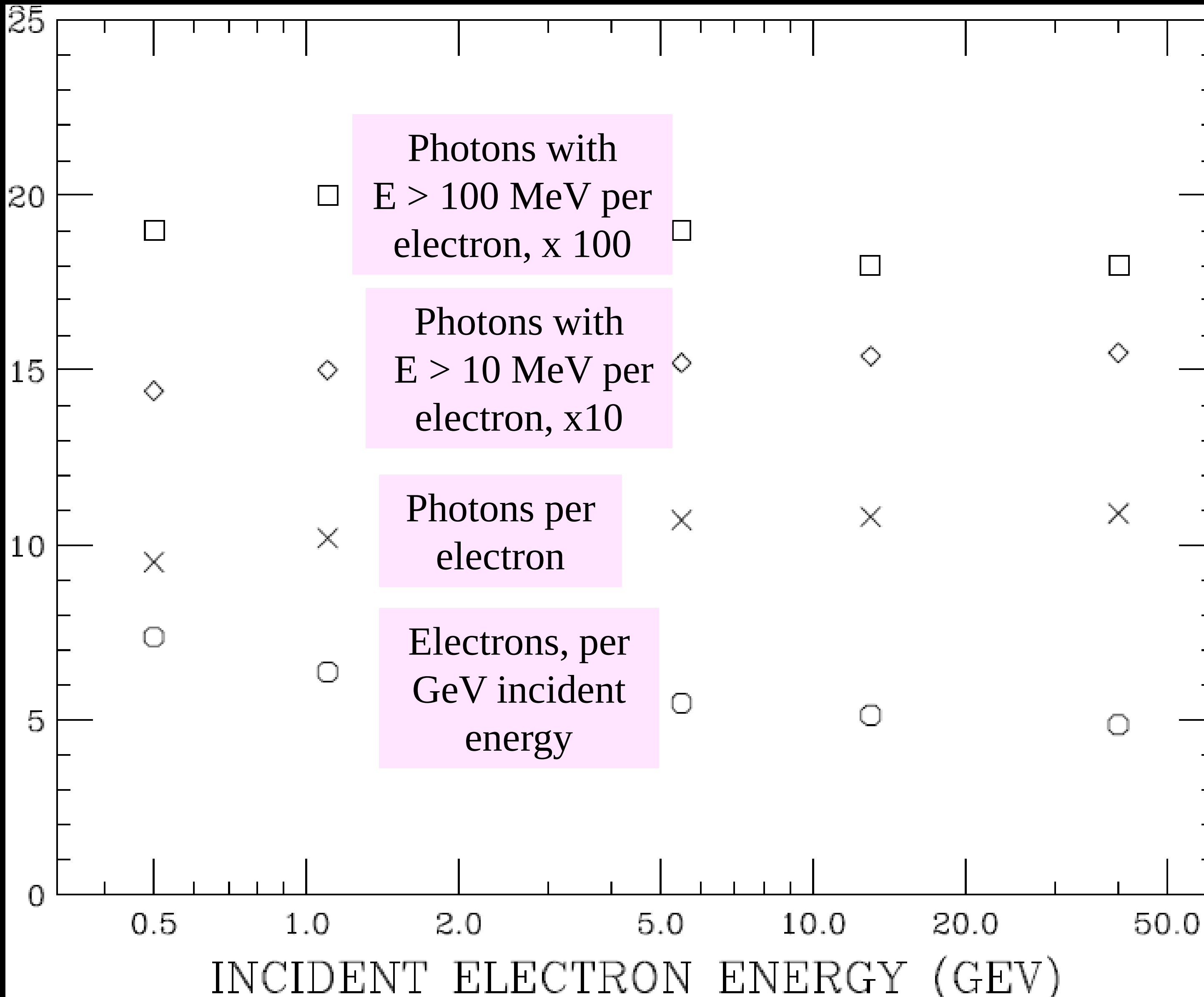
➔ Reasonably intense moderate-energy electron or photon beam necessary

What energy…?

BeamCal Incident Energy Distribution

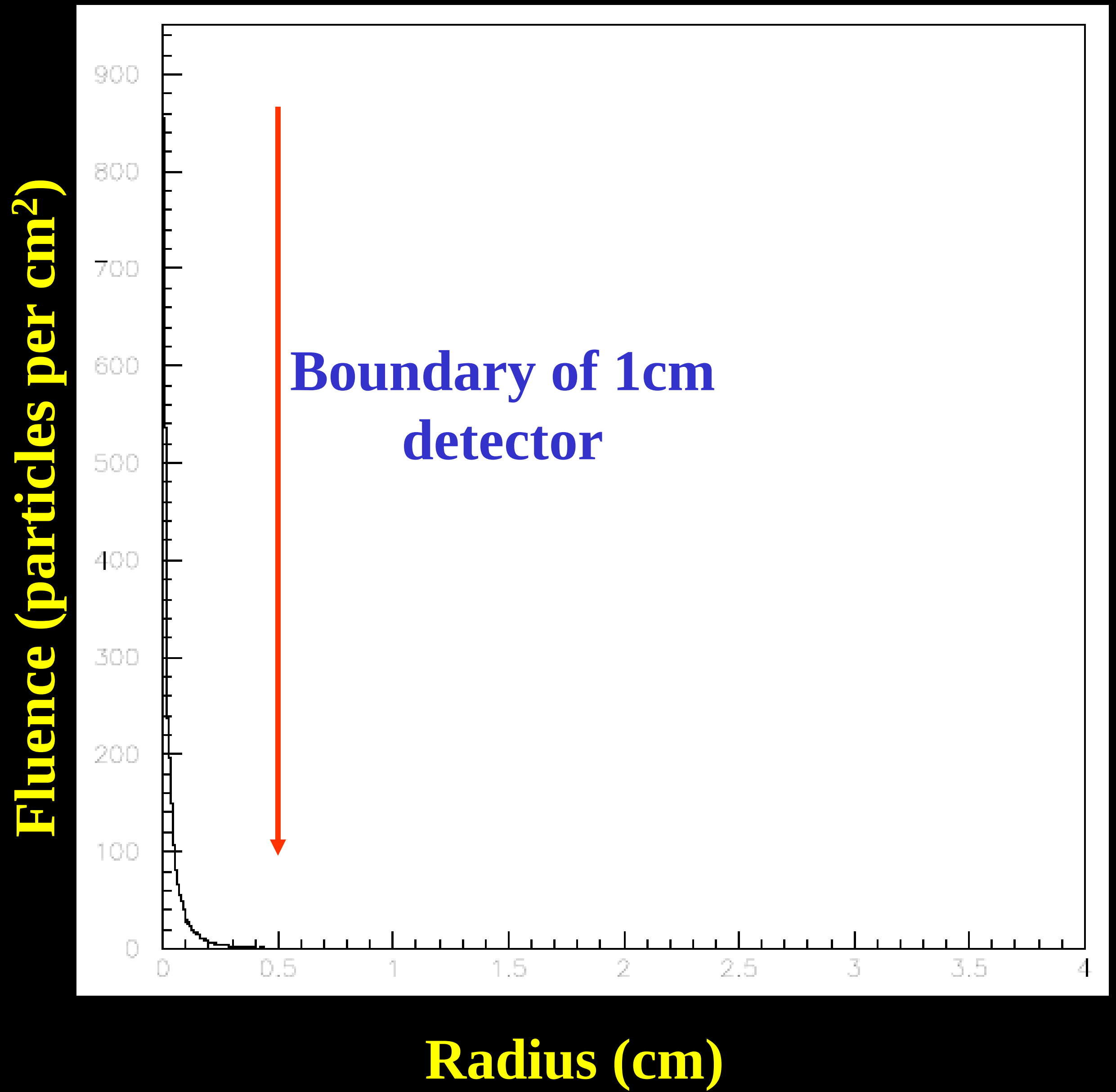


Shower Max Results



➔ **Photon production ~independent of incident energy!**

5.5 GeV Electrons After 18mm Tungsten Block

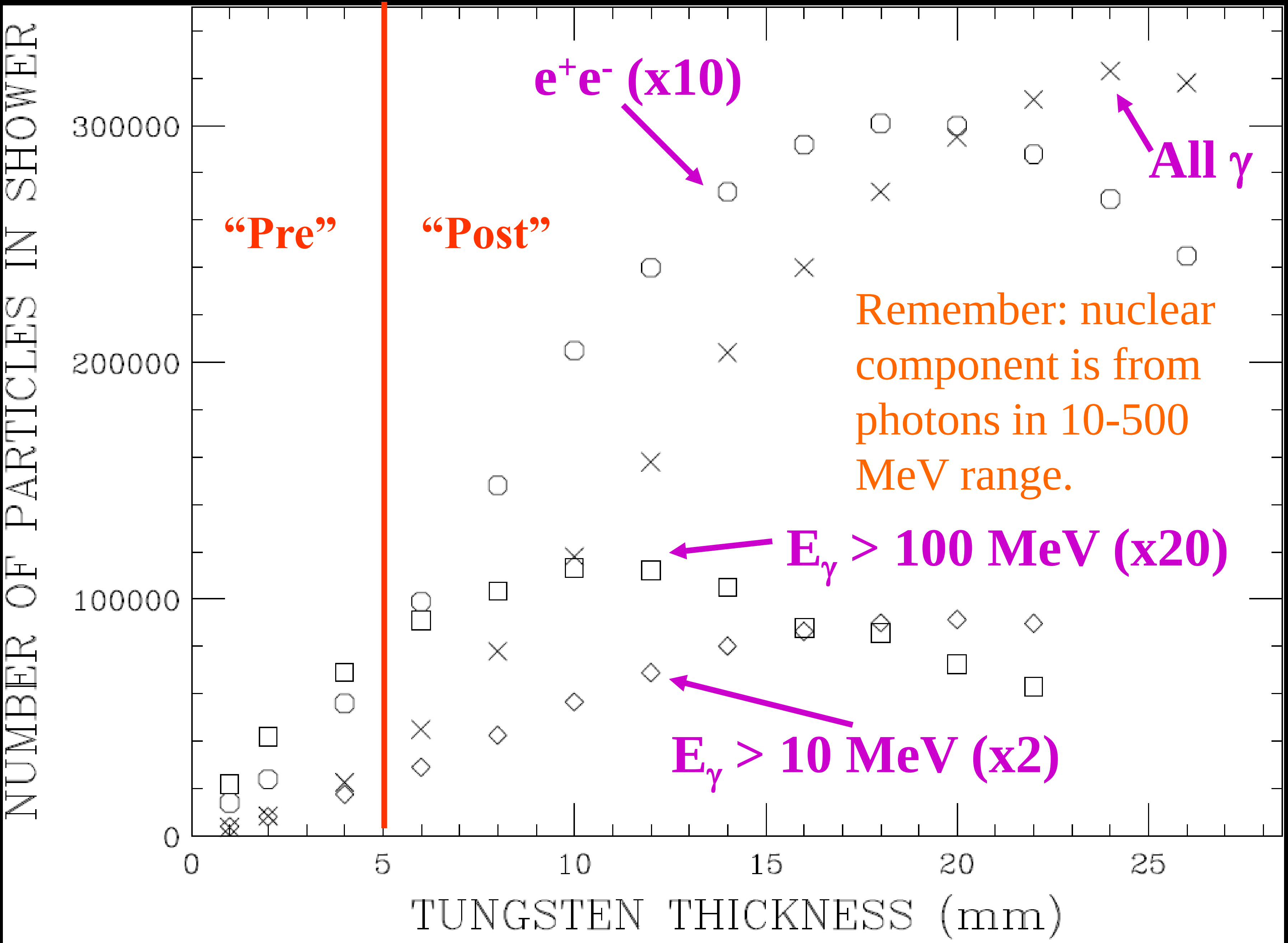


Not amenable for uniform illumination of detector.

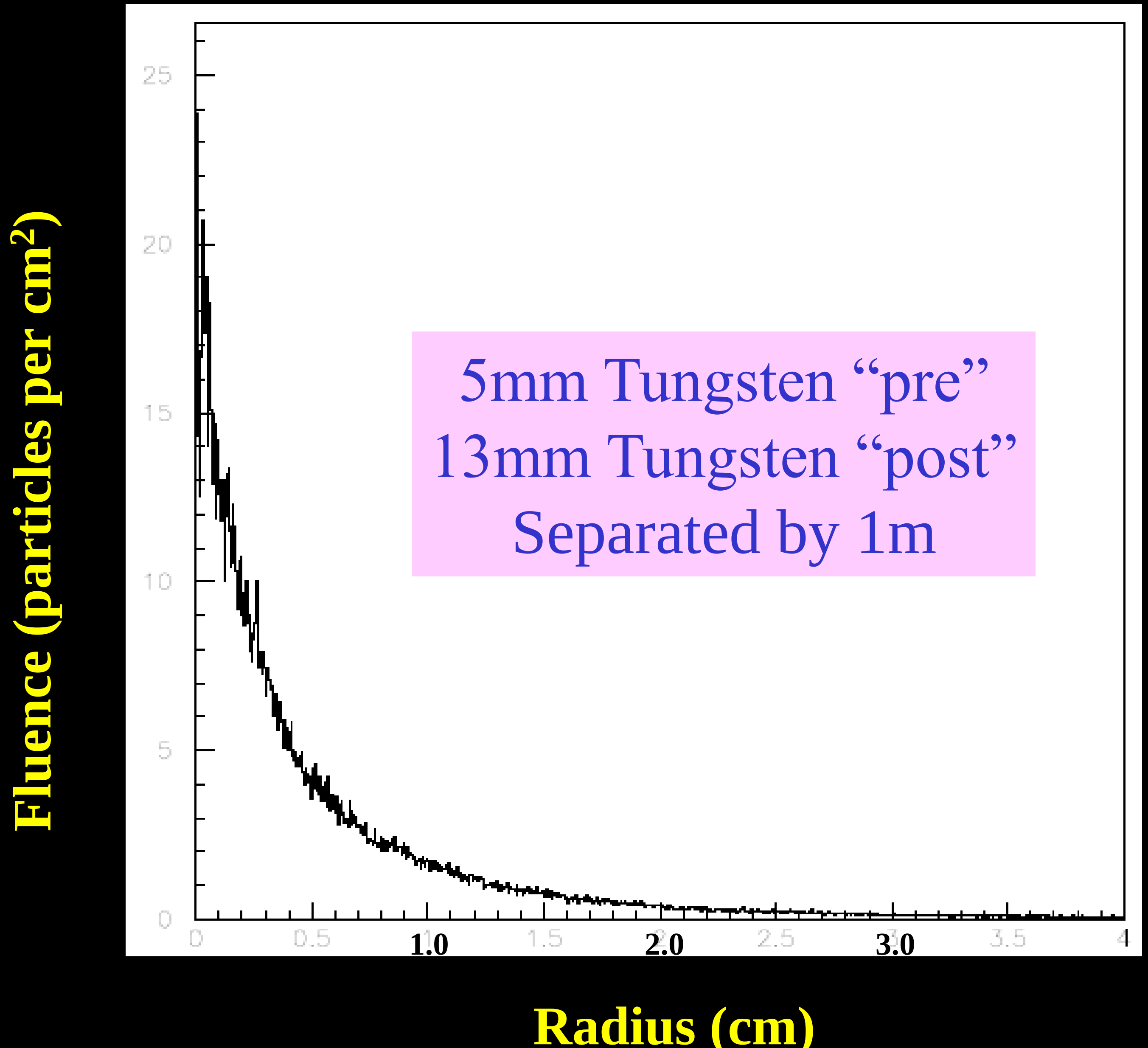
Instead: split 18mm W between "pre" and "post" radiator separated by large distance

Caution: nuclear production is ~isotropic ➔ must happen dominantly in "post" radiator!

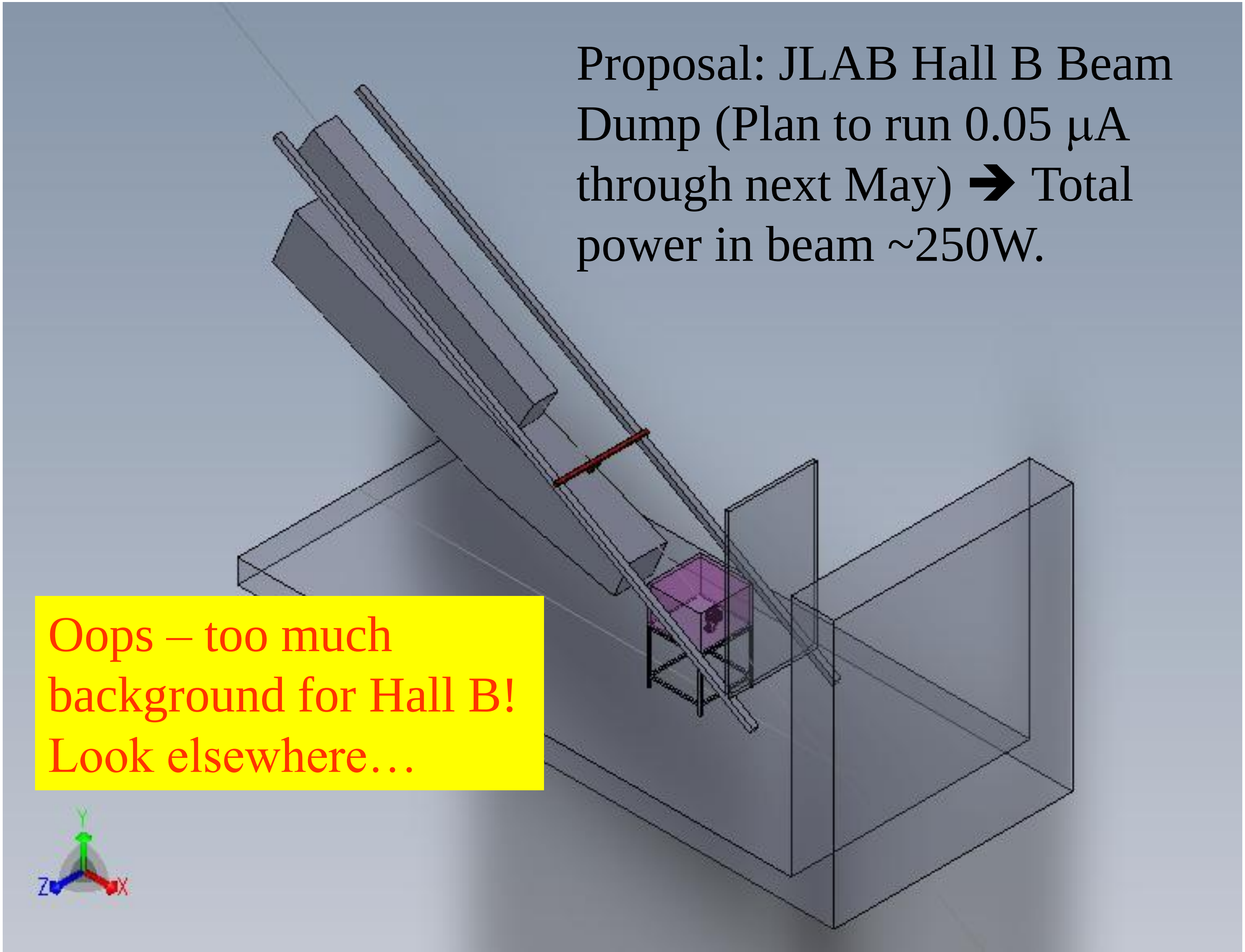
5.5 GeV Shower Profile



Proposed split radiator configuration



Proposal: JLAB Hall B Beam Dump (Plan to run 0.05 μA through next May) ➔ Total power in beam ~250W.



Oops – too much background for Hall B! Look elsewhere…

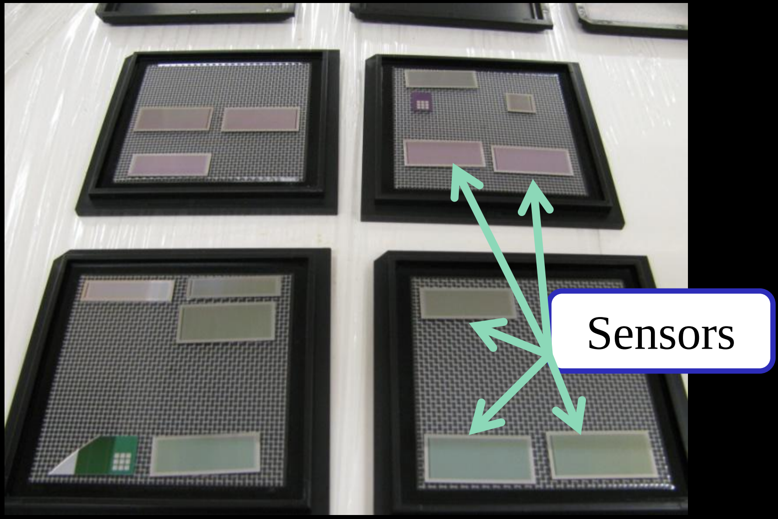
Irradiation Plan

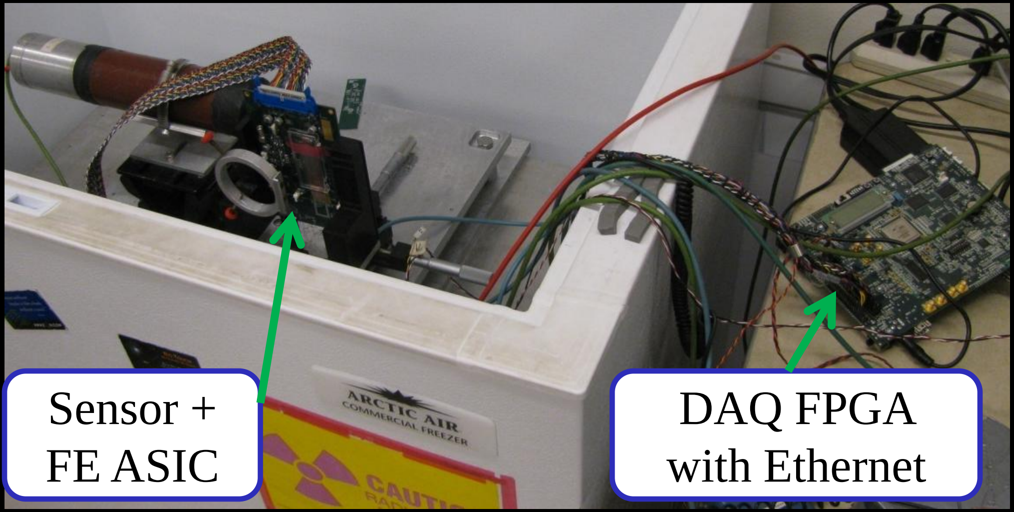
Use existing Micron sensors from ATLAS R&D

- n-type and p-type
- Standard float-zone and Magentic Czochralski
- Runs of 0.1, 0.3, and 1 GRad for each sample
- Runs with samples far from radiator (no hadronic effects)

➔Total integrated dose of ~10 Grad

Will assess the bulk damage effects and charge collection efficiency degradation.





Rastering

Need uniform illumination over 0.25x0.75 cm region (active area of SCIPP's charge collection measurement apparatus).

➔Raster in 0.05cm steps over 0.6x1.5 cm, assuming fluence profile on prior slide (see next slide for result)

Exposure rate:

$$1\,GRad \approx \frac{800}{I_{beam}(nA)\bullet E_{beam}(GeV)}\,hours$$

e.g. 10 GRad at 50 nA 5.5 GeV e^- ➔ ~ 30 Hours

Fluence (e^- and e^+ per cm^2) per incident 5.5 GeV electron (5cm pre-radiator 13 cm post-radiator with 1m separation)

Center of irradiated area

¼ of area to be measured

¼ of rastoring area (0.5mm steps)

mm from center	0	1	2	3	4
0	13.0	12.8	11.8	9.9	8.2
1	13.3	12.9	12.0		
2	13.3	12.9	12.0		
3	13.1	12.8	11.8		8.2
4	13.0	12.6	11.7		
5	12.3				
6	11.6		10.7		
7	10.4				
8	8.6		8.0		6.4

Wrap-up

Worth exploring Si sensors (n-type, Czochralski?)

Need to be conscious of possible *hadronic* content of EM showers

Energy of e^- beam not critical, but intensity is; for one week run require E_{beam}(GeV) x I_{beam}(nA) > 50

SLAC: Summer-fall 2011 ESA test beam with E_{beam}(GeV) x I_{beam}(nA) ≥ 17 – is it feasible to wait for this?

Some notes:

- Beam Calorimeter is a sizable project, ~2 m^2 of sensors.

- Sensors are in unusual regime: ~ 1 GRad of e^+/e^-; 10^{14} n/cm^2 after several years.

- There are on-going studies with GaAs, Diamond, Sapphire materials (FCAL report, Nov 2009).

- We'll concentrate on mainstream Si technology proven by decades of technical development.

- There is some evidence that p-type Si may be particularly resilient…

Concluding Remarks

A number of generic and specific tracking R&D studies; here focused on two things:

• Charge division for 10cm sensors. Looks interesting, but would need to know how to do 0-suppression for split signal…

• Radiation hardness of Si sensors in electromagnetic (electron-induced) showers. Need to probe 1 Grad scale, and worry about hadrons in the shower. Running scheme in hand and hardware under development. Need final work from JLAB.