UNIVERSITY OF CALIFORNIA SANTA CRUZ

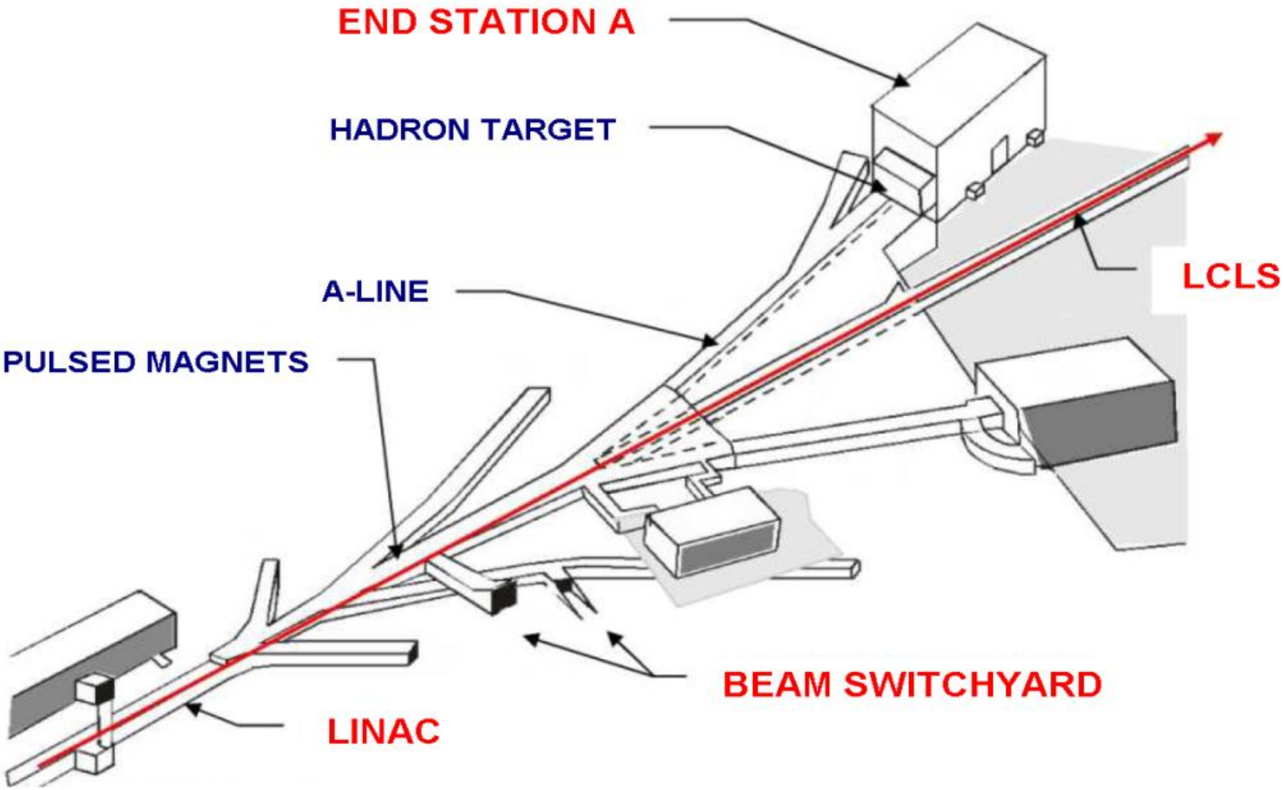
International Linear Collider

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

International Linear Collider Workshop
University of Texas at Arlington
October 22-26, 2012

LCLS and ESA

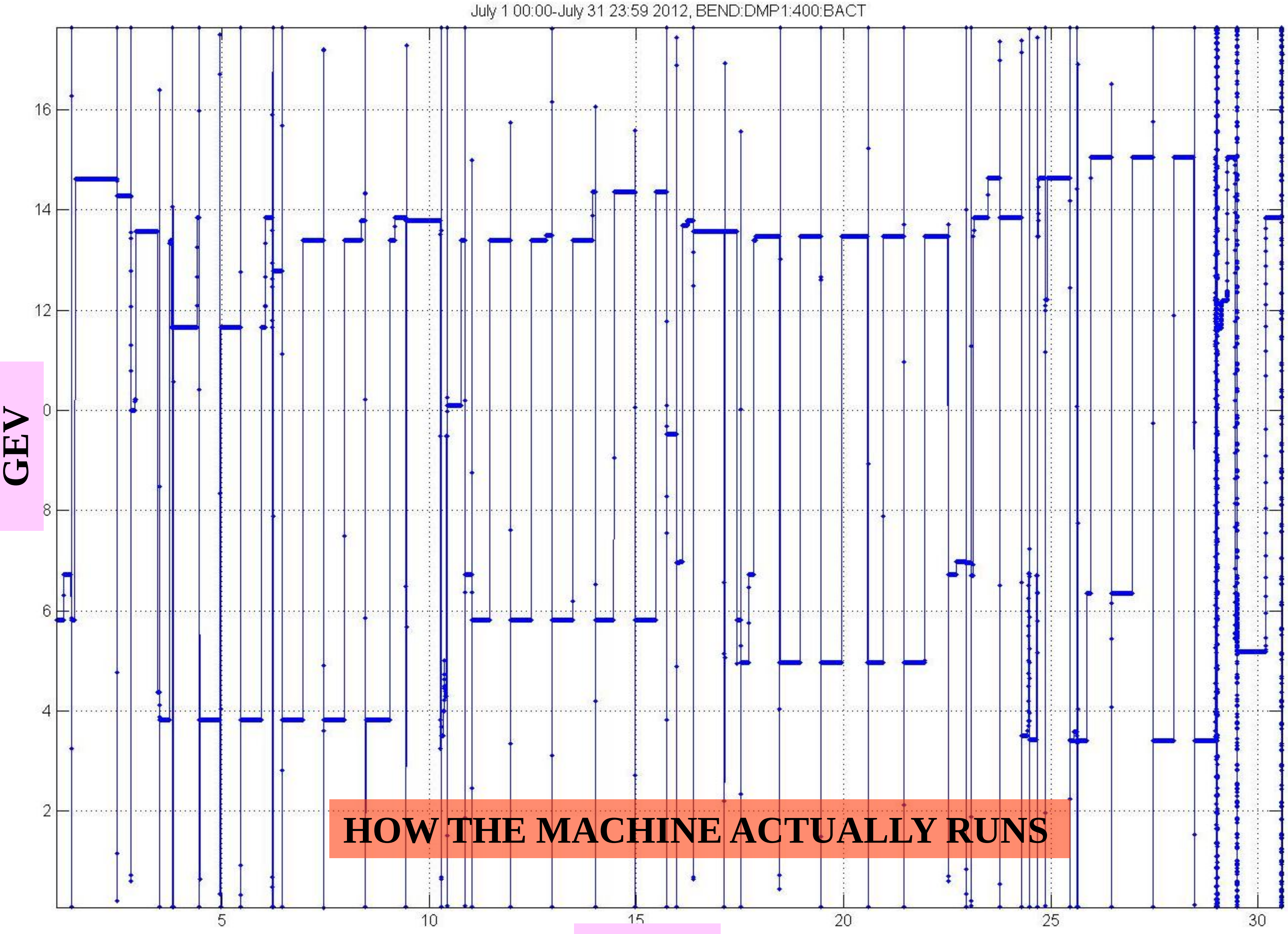
Use pulsed magnets in the beam switchyard to send beam in ESA.



ESTB parameters

Table 1.1.1. ESTB primary electron beam parameters and experimental area at the BSY and in ESA

Parameters	ESA
Energy	15 GeV
Repetition Rate	5 Hz
Charge per pulse	0.35 nC
Energy spread, σ_E /E	0.02%
Bunch length rms	100 μm
Emittance rms ($\gamma\varepsilon_x$,$\gamma\varepsilon_y$)	(4, 1) 10^{-6} m-rad
Spot size at waist ($\sigma_{x,y}$)	< 10 μm
Drift Space available for experimental apparatus	60 m
Transverse space available for experimental apparatus	5 x 5 m

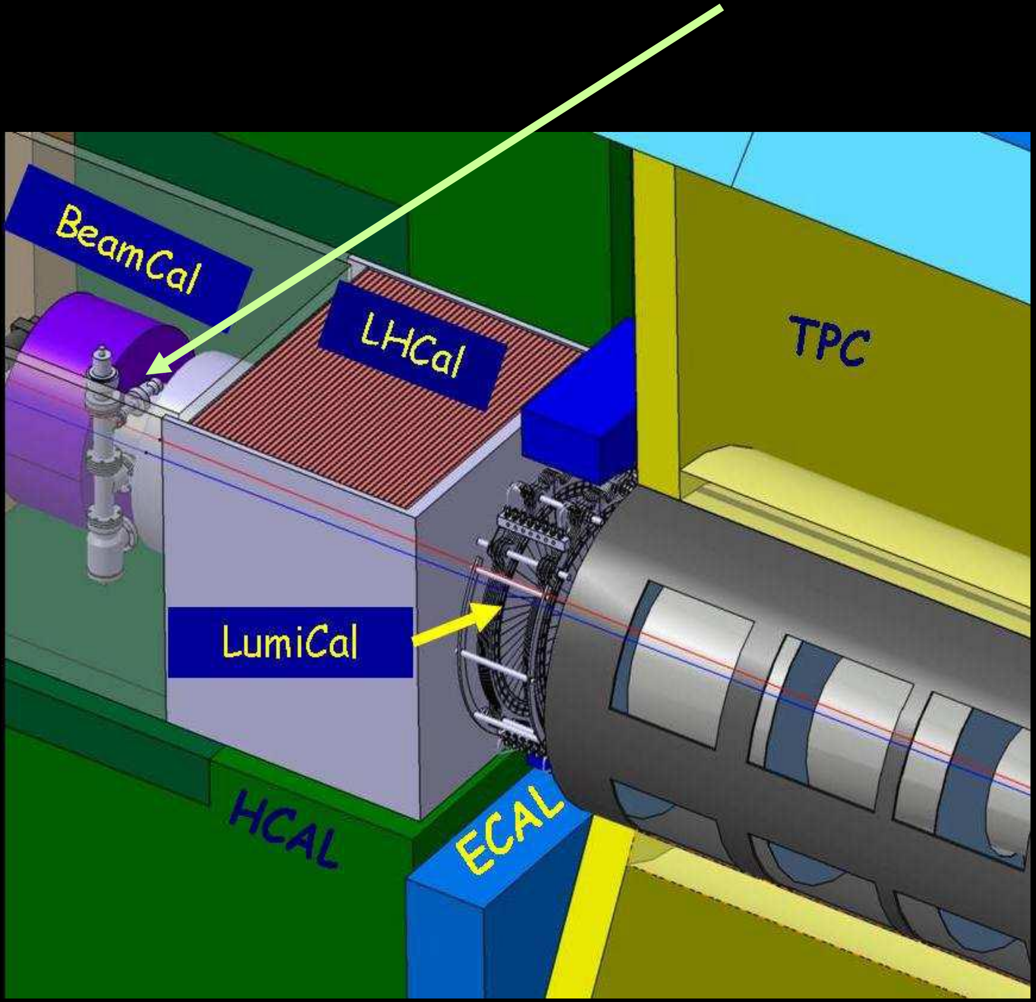


GEV

HOW THE MACHINE ACTUALLY RUNS

DAY

The Issue: ILC BeamCal Radiation Exposure



ILC BeamCal:

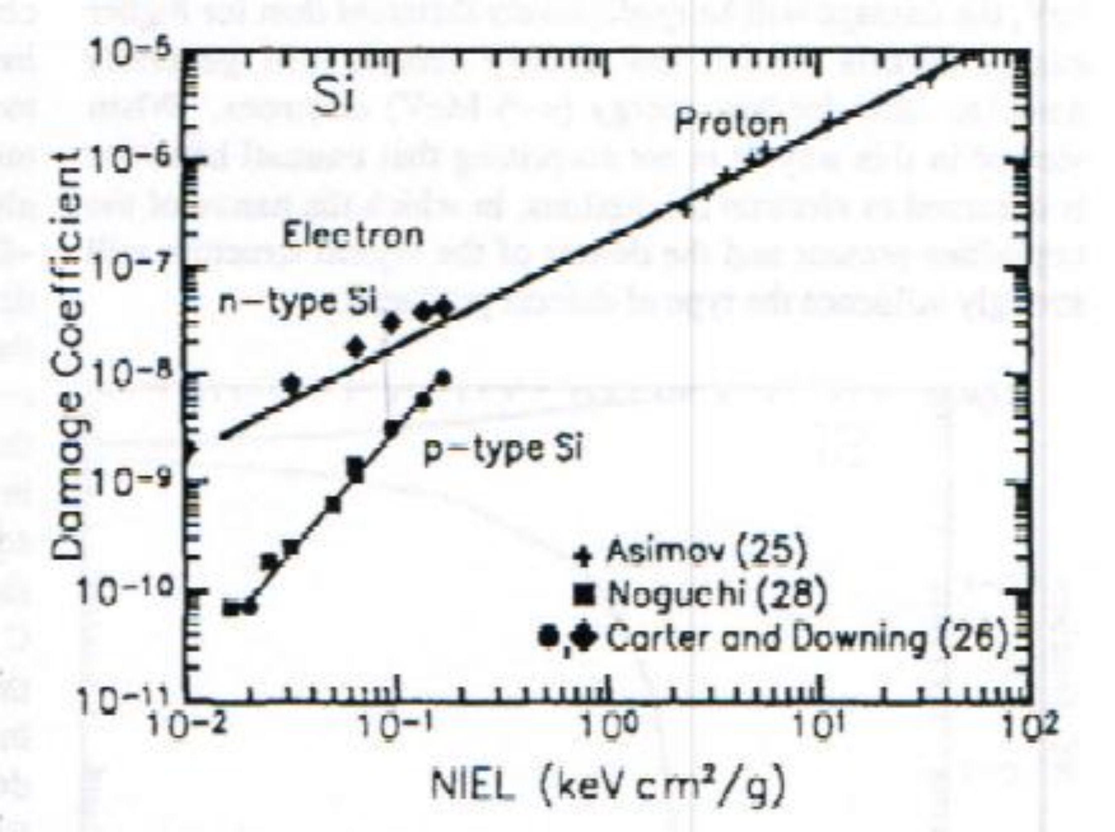
Covers between 5 and 40 miliradians

Radiation doses up to 100 MRad per year

Radiation initiated by electromagnetic particles (most extant studies for hadron – induced)

EM particles do little damage; might damage be come from small hadronic component of shower?

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



NIEL	e^- Energy
2x10^{-2}	0.5 MeV
5x10^{-2}	2 MeV
1x10^{-1}	10 MeV
2x10^{-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?

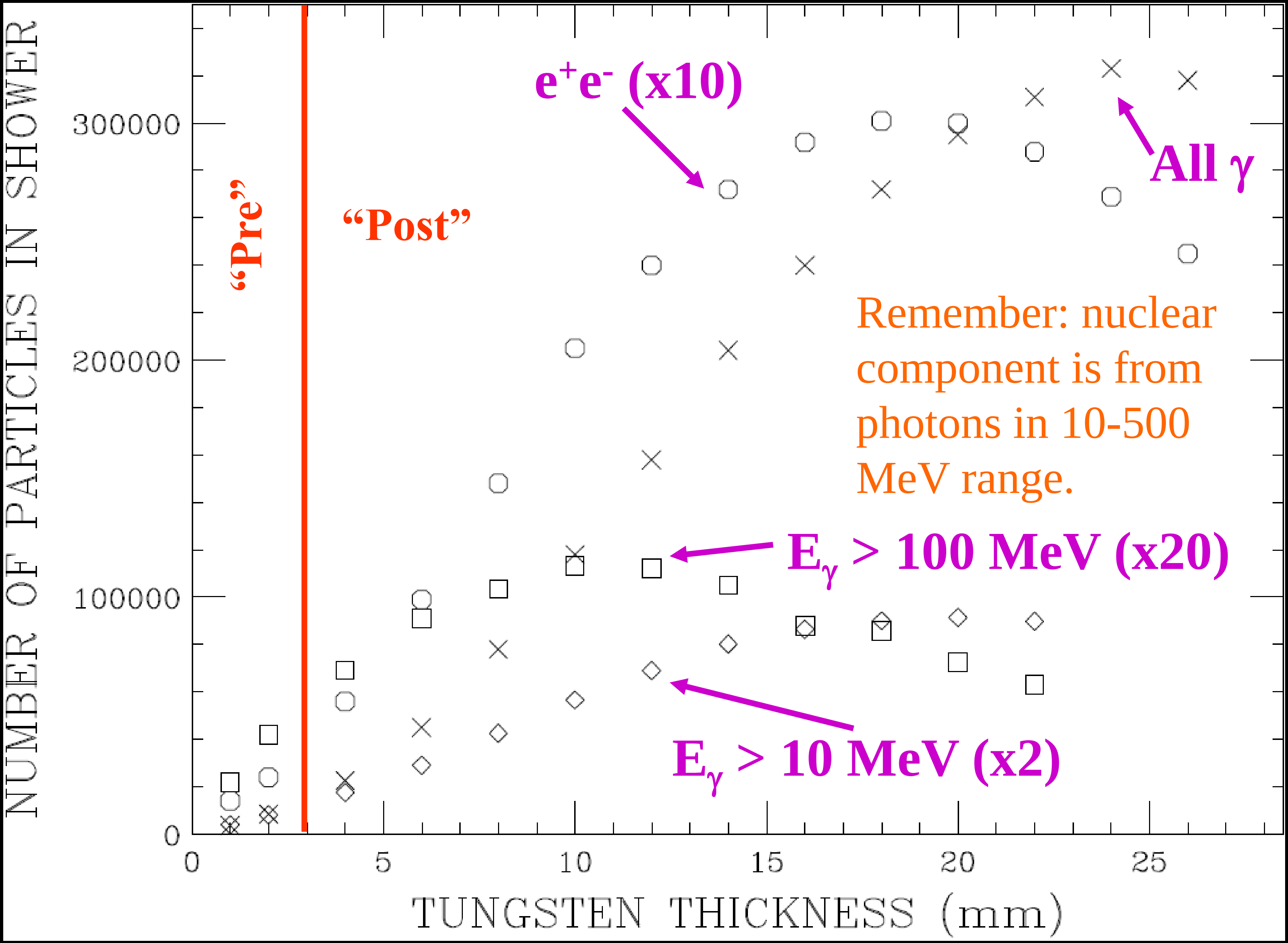
Hadronic Processes in EM Showers

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 (~$E_{critical}$)
- Photoproduction
  Threshold seems to be about 200 MeV
- Nuclear Compton scattering
  Threshold at about 10 MeV; Δ resonance at 340 MeV

➔ These are largely isotropic; must have most of hadronic component develop near sample

5.5 GeV Shower Profile



e^+e^- (x10)

All γ

“Pre”

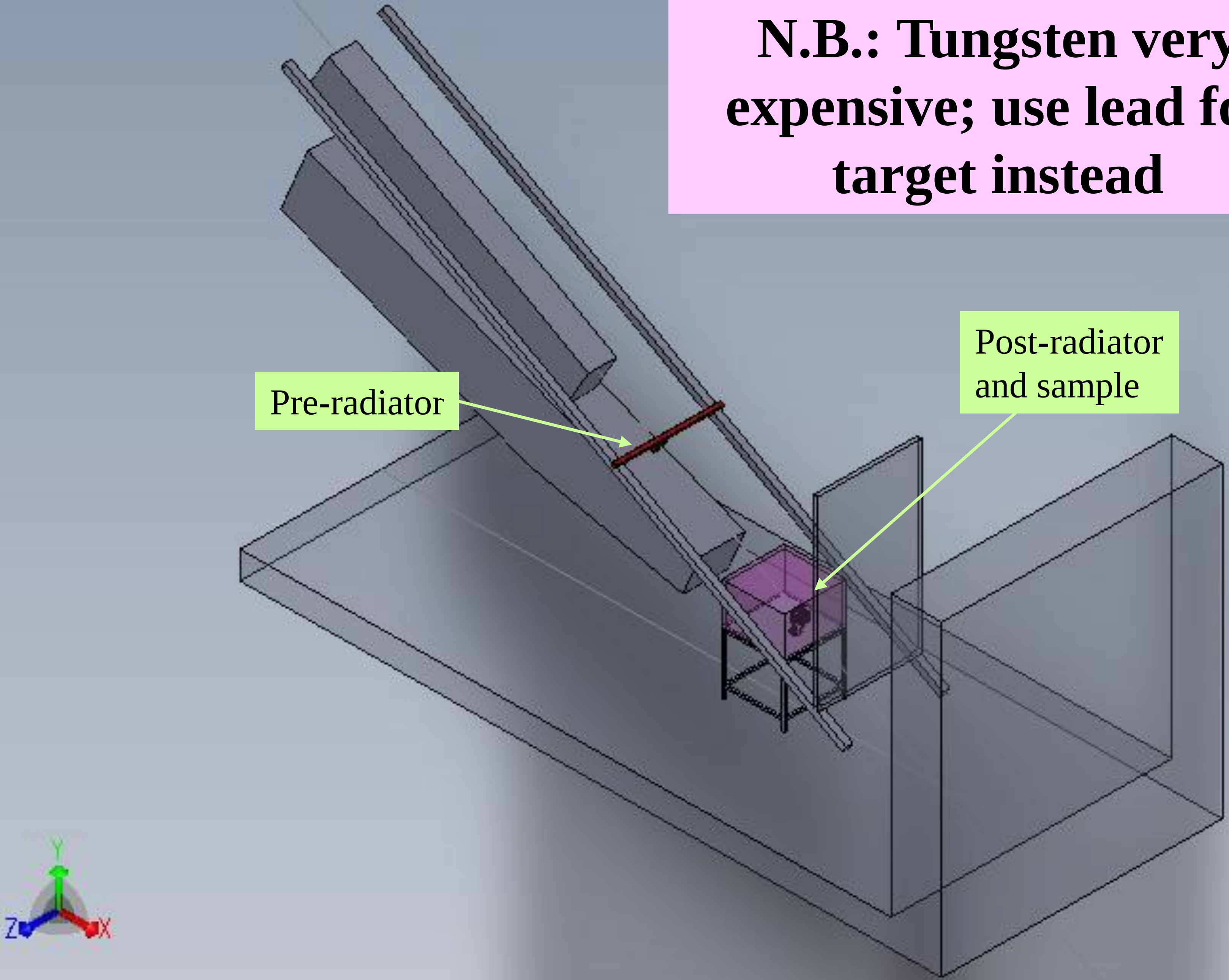
“Post”

Remember: nuclear component is from photons in 10-500 MeV range.

$E_\gamma > 100$ MeV (x20)

$E_\gamma > 10$ MeV (x2)

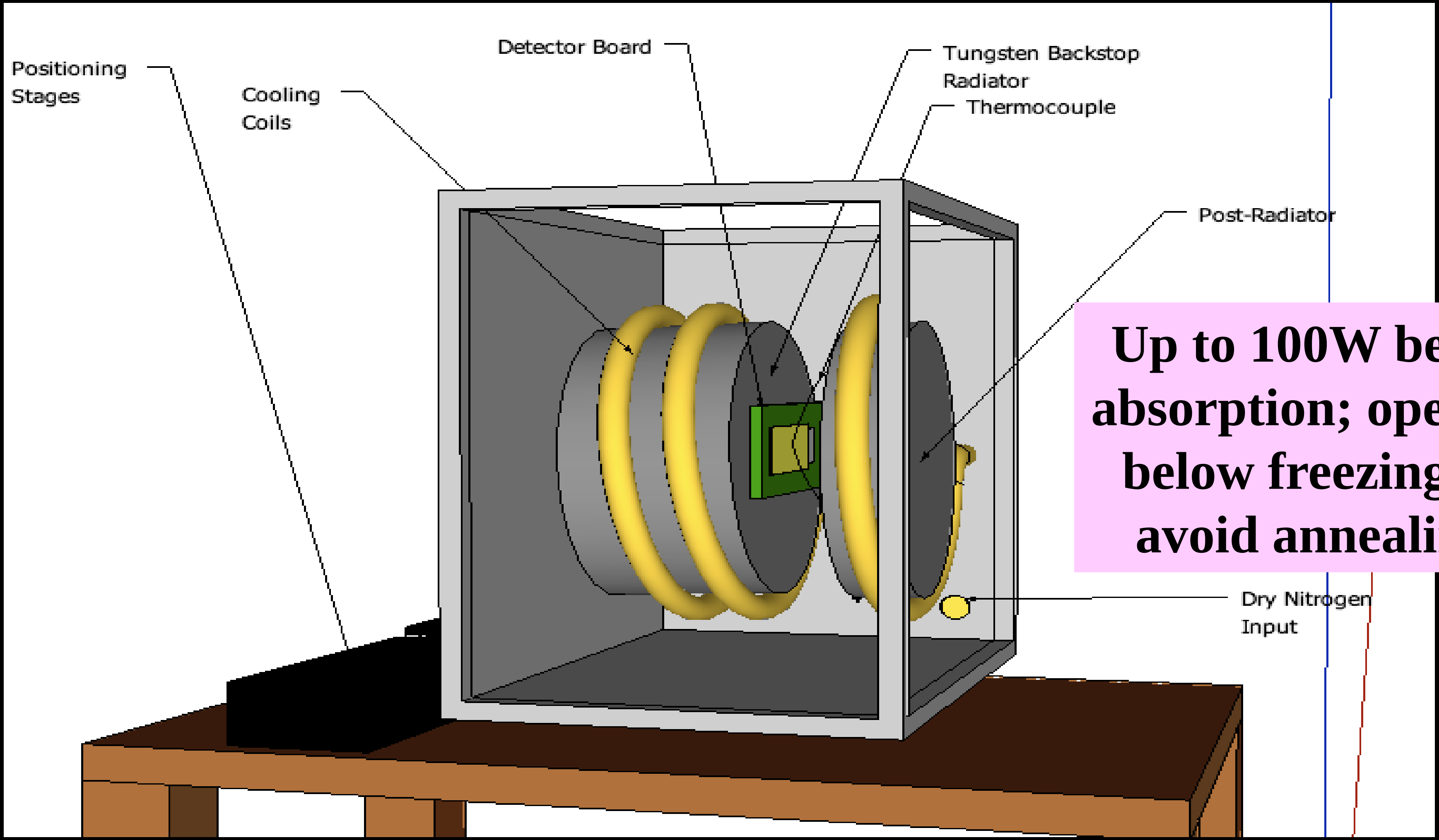
N.B.: Tungsten very expensive; use lead for target instead



Pre-radiator

Post-radiator and sample

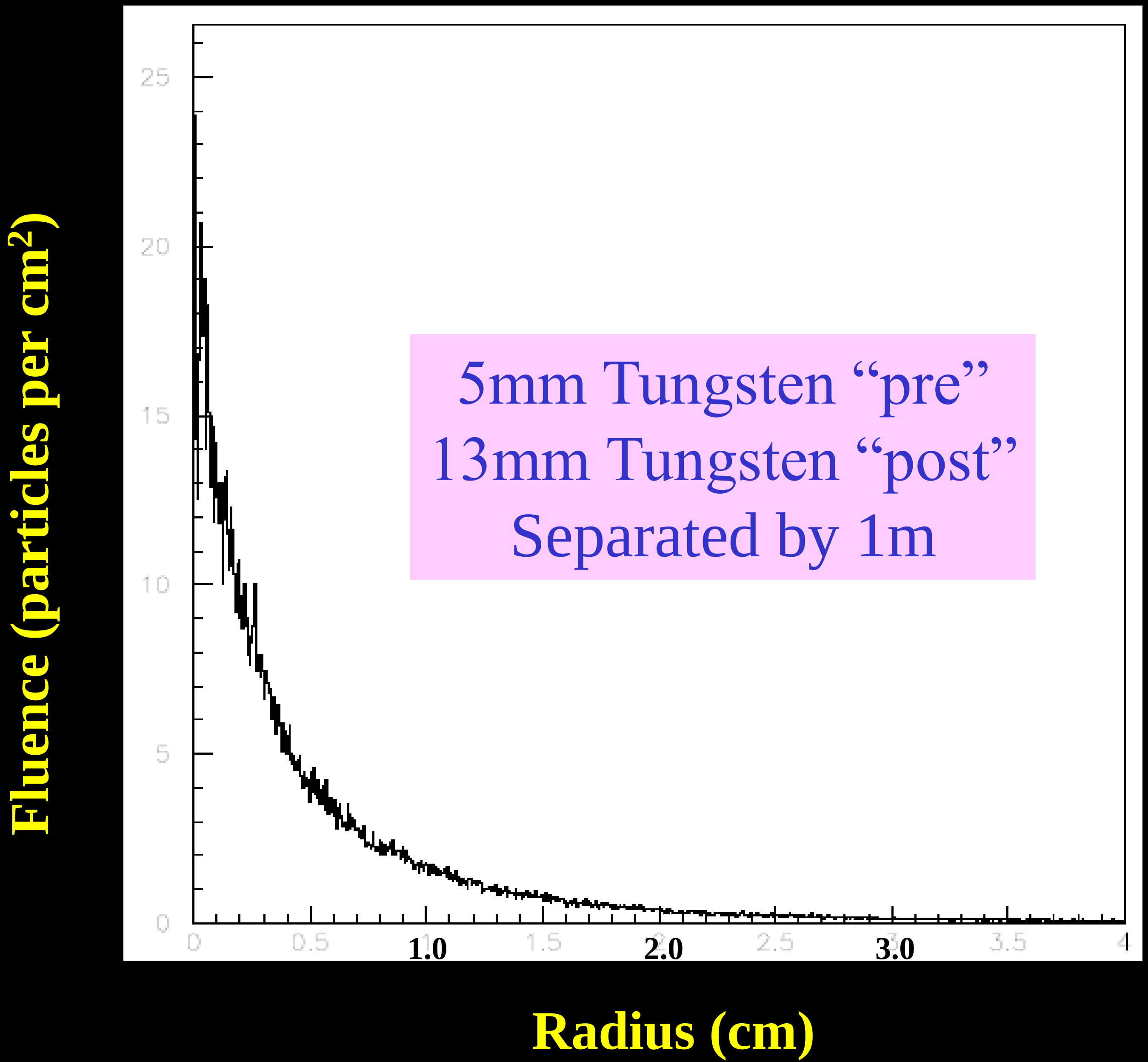
Hadronic Processes in EM Showers



Up to 100W beam absorption; operate below freezing to avoid annealing

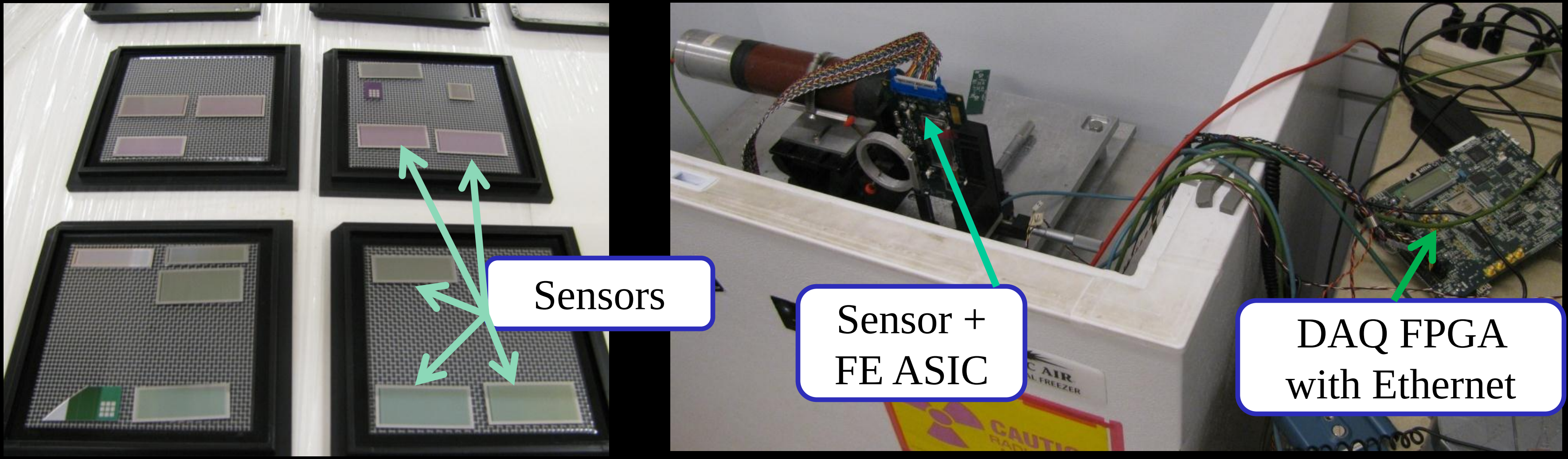
Status: Thermal prototype under testing at SCIPP

Proposed split radiator configuration



5mm Tungsten “pre”
13mm Tungsten “post”
Separated by 1m

Charge Collection Apparatus



Need to upgrade CC Apparatus for multiple samples

- New detector board to modularize system (connector rather than bonds)
- Two pitch adapters (lithogaphic) to accommodate different detector pitches
- Modifications to ASIC board
- Most components in hand now

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:

$$1\,GRad \approx \frac{600}{I_{beam}(nA) \bullet E_{beam}(GeV)}\,hours$$

e.g. 100 MRad at 1 nA 13.6 GeV e^- → ~ 5 Hrs

RUN PLAN

At SCIPP (left over from ATLAS rad. damage studies)

- Oxygenated Float-Zone and Magnetic Czochralski sensors
- Both n- and p-type for both

Proposed "real-time" charge-collection measurement after stepped exposures of (1, 3, 10, 30, 100) MRad.

Will assess results and then run one or two large exposures with single distant radiator (eliminate hadronic component) (4-5 shifts for 100 MRad)

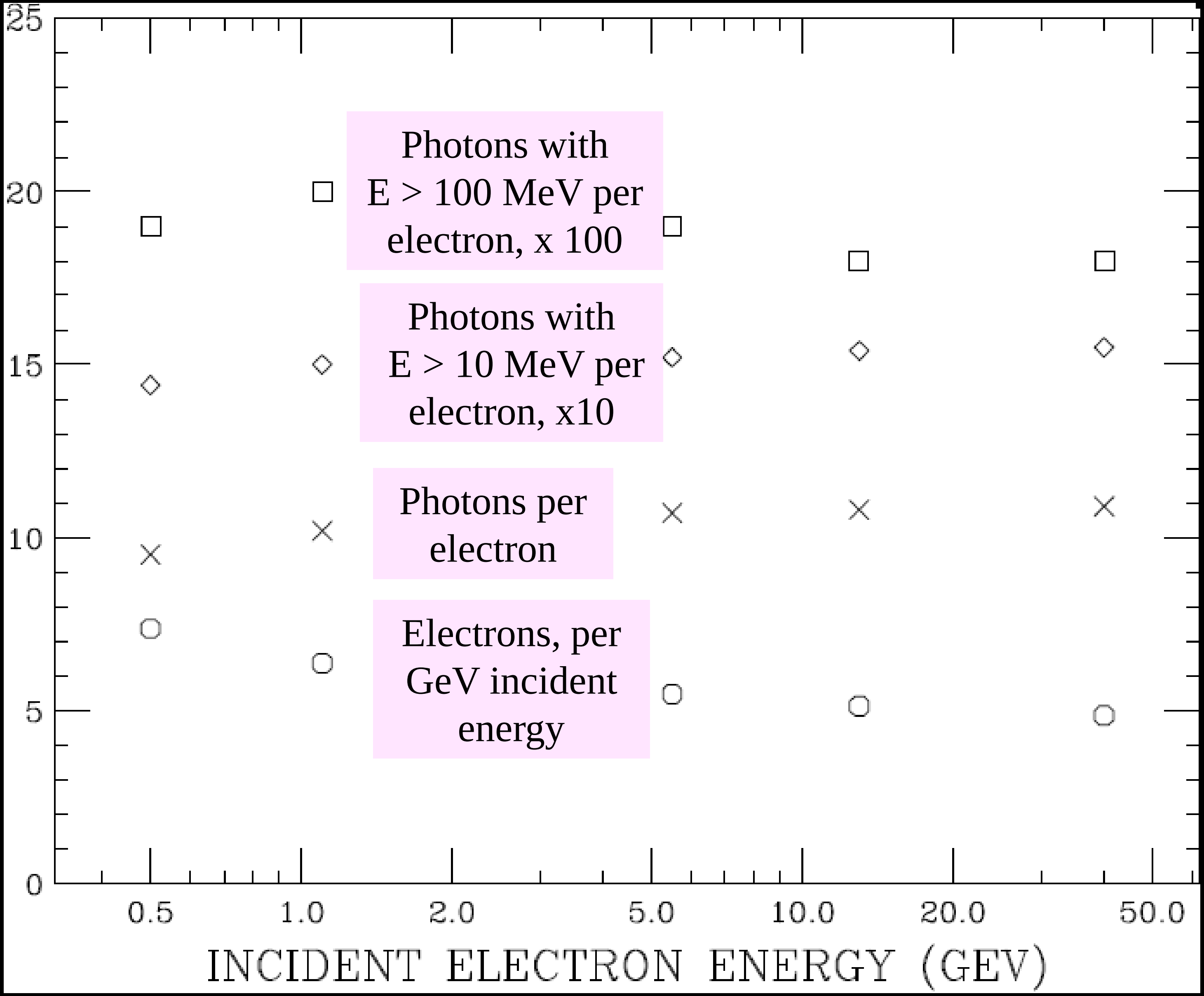
WRAP-UP

- A somewhat involved study of radiation damage to silicon diode sensors
- Will look at n- and p-type float-zone and Czochralski sensors
- Will include nuclear component in shower; perform control study with EM-only beam
- Will operate ~100 W target at sub-freezing to avoid annealing
- Need to be able to accommodate beam energy ranges between 3 and 15 GeV

Have applied for beam time in early winter

Backup

Shower Max Results



Photons with E > 100 MeV per electron, x 100

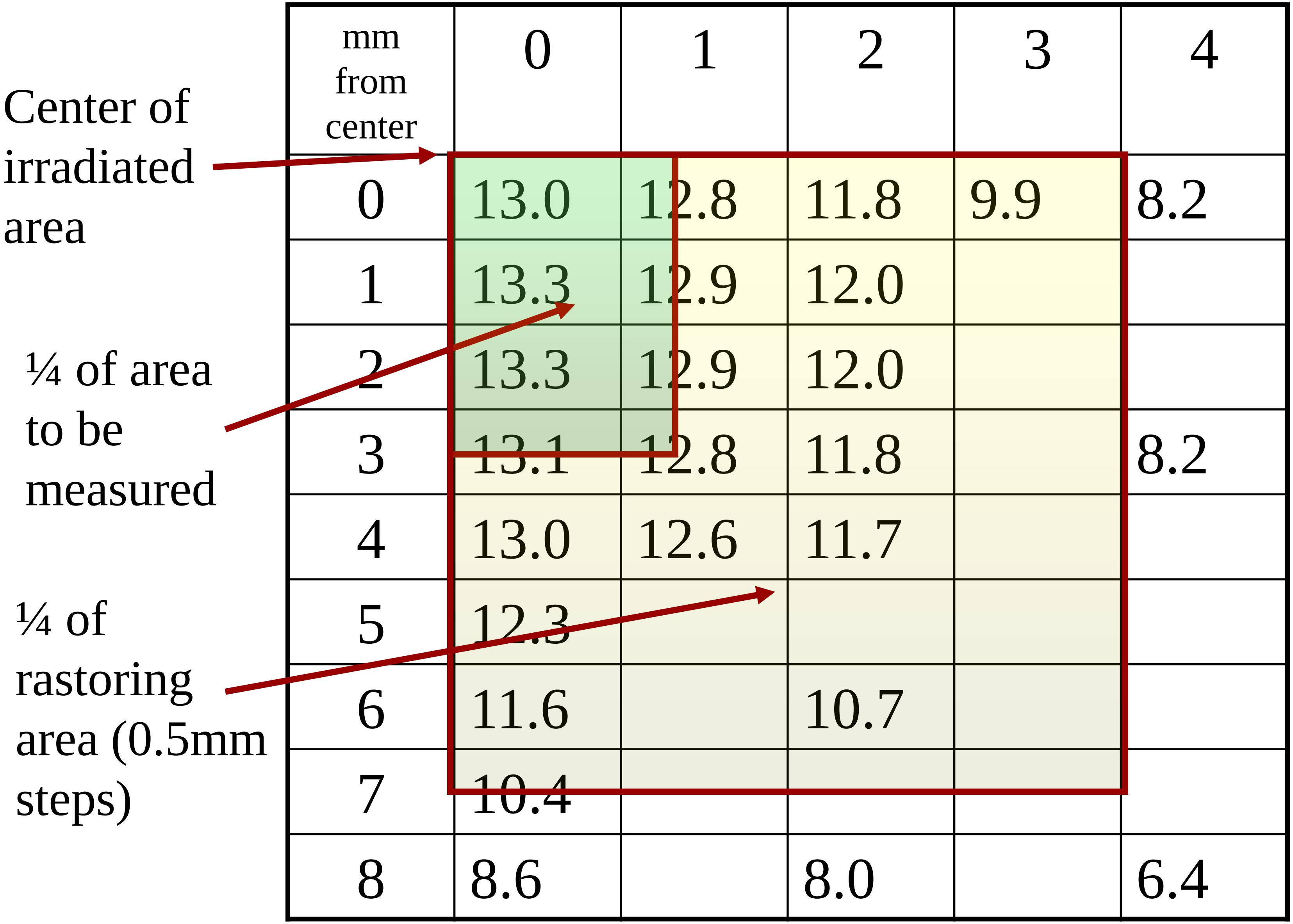
Photons with E > 10 MeV per electron, x10

Photons per electron

Electrons, per GeV incident energy

➔ Photon production ~independent of incident energy!

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



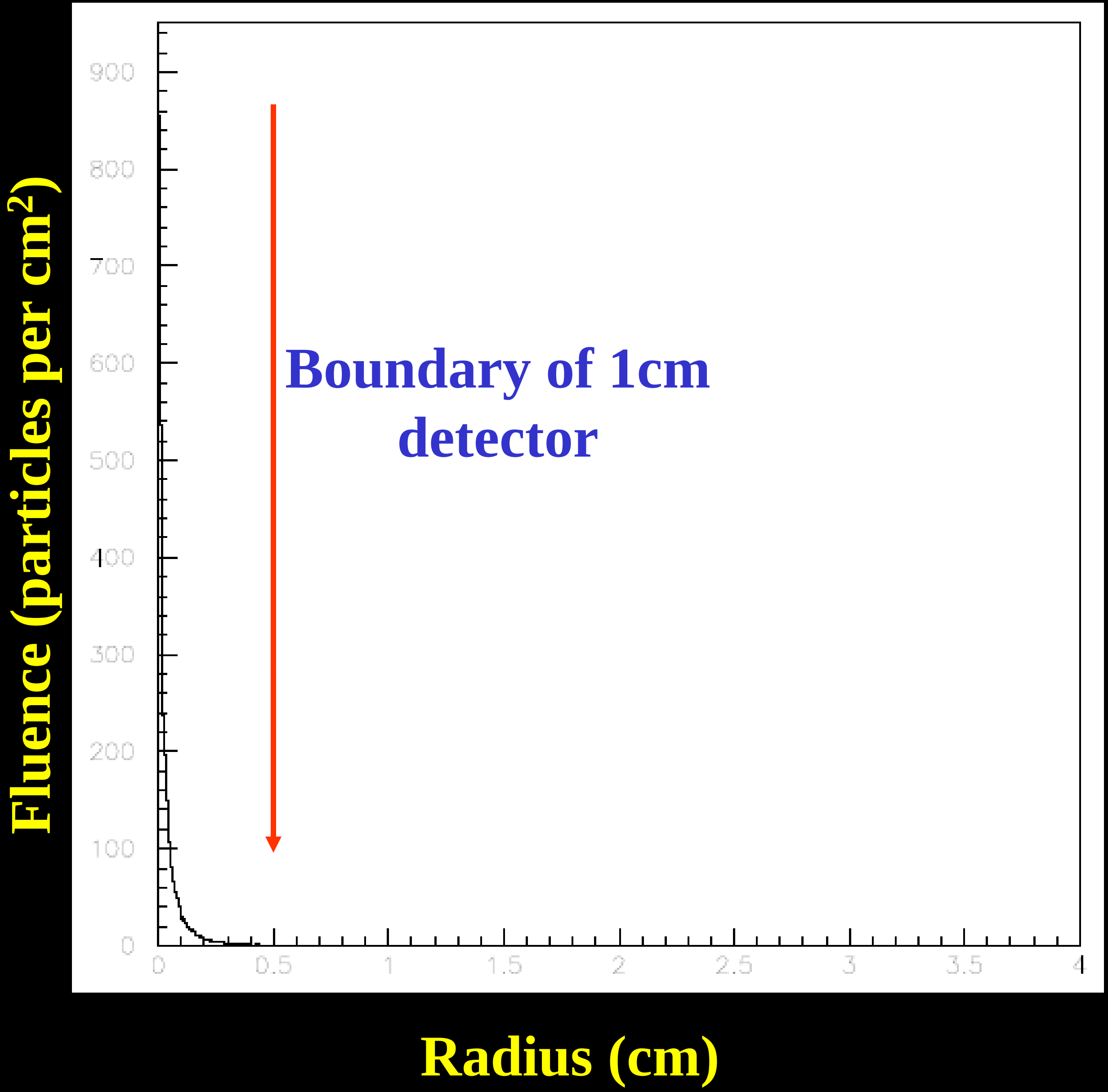
mm from center	0	1	2	3	4
0	13.0	12.8	11.8	9.9	8.2
1	13.3	12.9	12.0		
2	13.3	12.9	12.0		
3	13.1	12.8	11.8		8.2
4	13.0	12.6	11.7		
5	12.3				
6	11.6		10.7		
7	10.4				
8	8.6		8.0		6.4

Center of irradiated area

¼ of area to be measured

¼ of rastoring area (0.5mm steps)

5.5 GeV Electrons After 18mm Tungsten Block



Boundary of 1cm detector

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!

NIEL (Non-Ionizing Energy Loss)

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

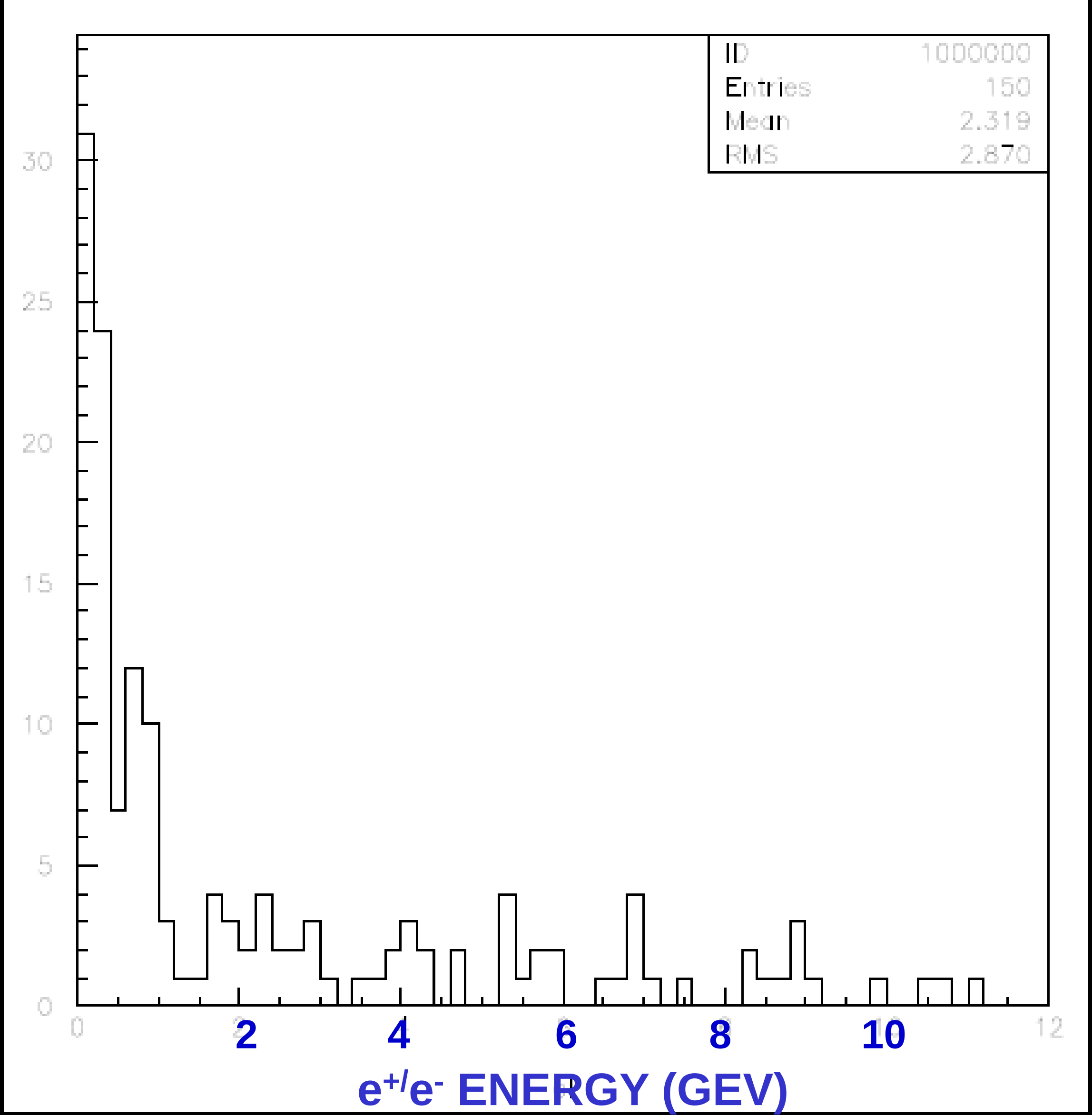
NIEL can be calculated (e.g. G.P. Summers et al., IEEE Trans Nucl Sci **40**, 1372 [1993])

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?

BeamCal Incident Energy Distribution



Rates (Current) and Energy

Basic Idea:

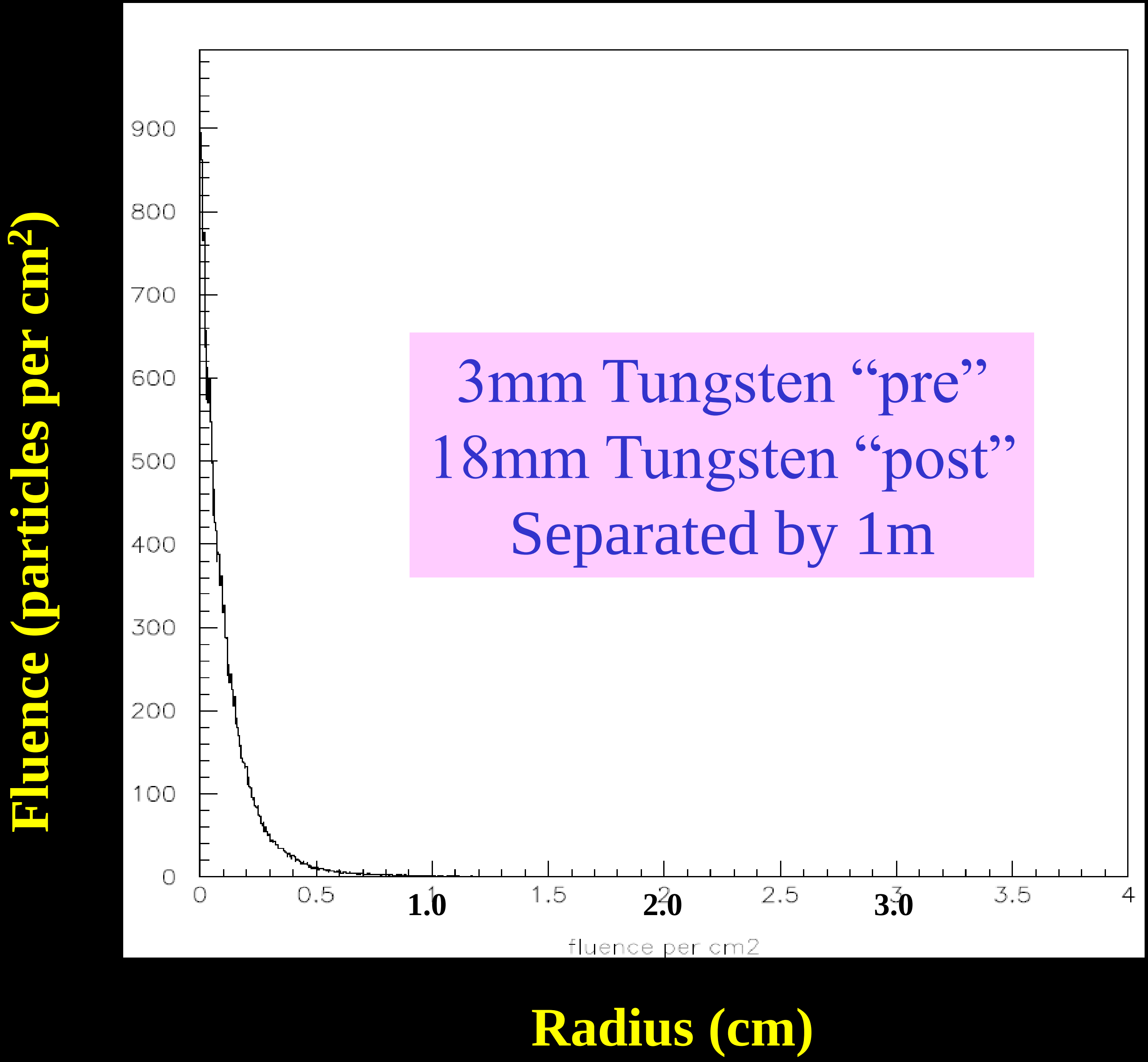
Direct electron beam of moderate energy on Tungsten radiator; insert silicon sensor at shower max

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

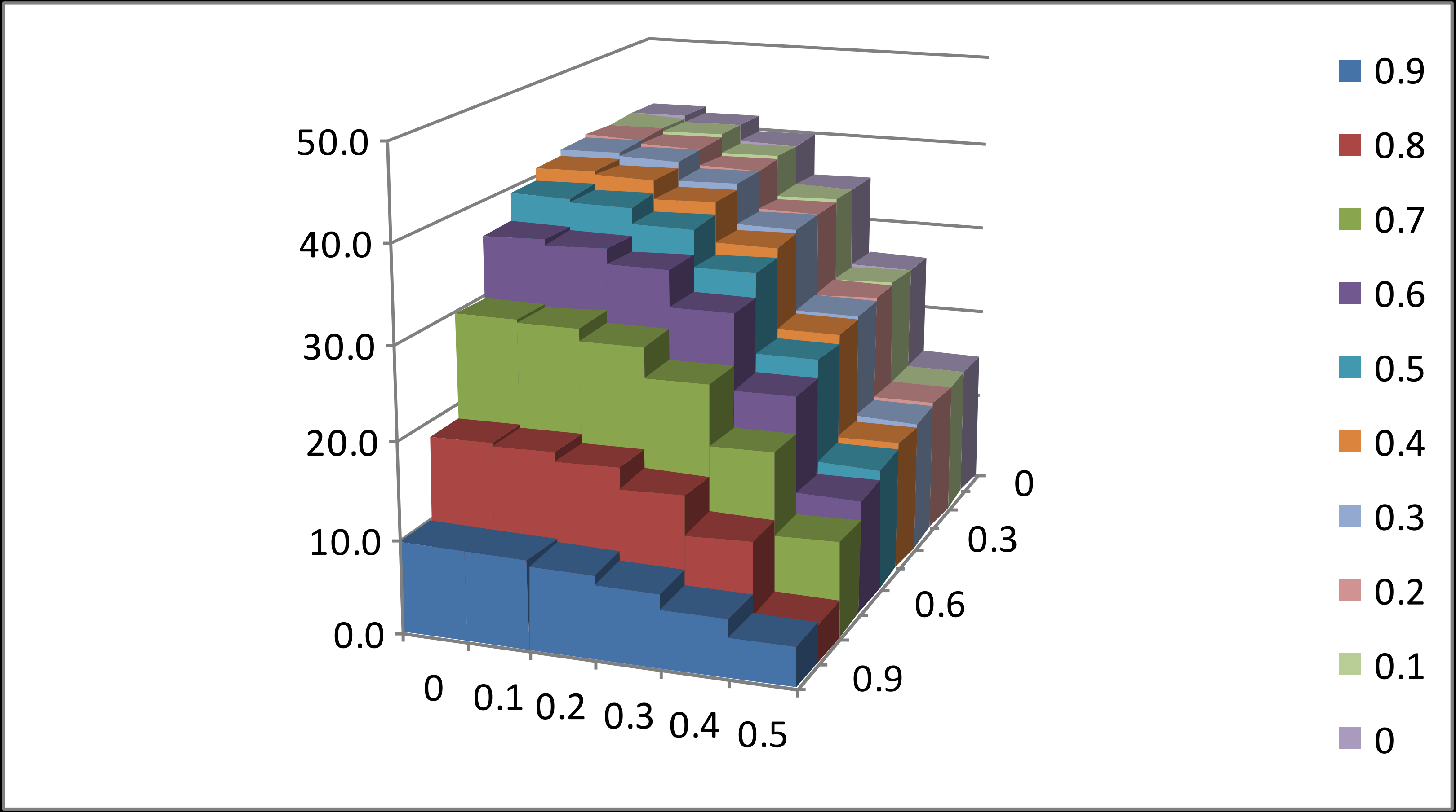
What energy…?

Proposed split radiator configuration



3mm Tungsten “pre”
18mm Tungsten “post”
Separated by 1m

Illumination Profile



Uniform to ± 10% over (3x6)mm area