UNIVERSITY OF CALIFORNIA SANTA CRUZ

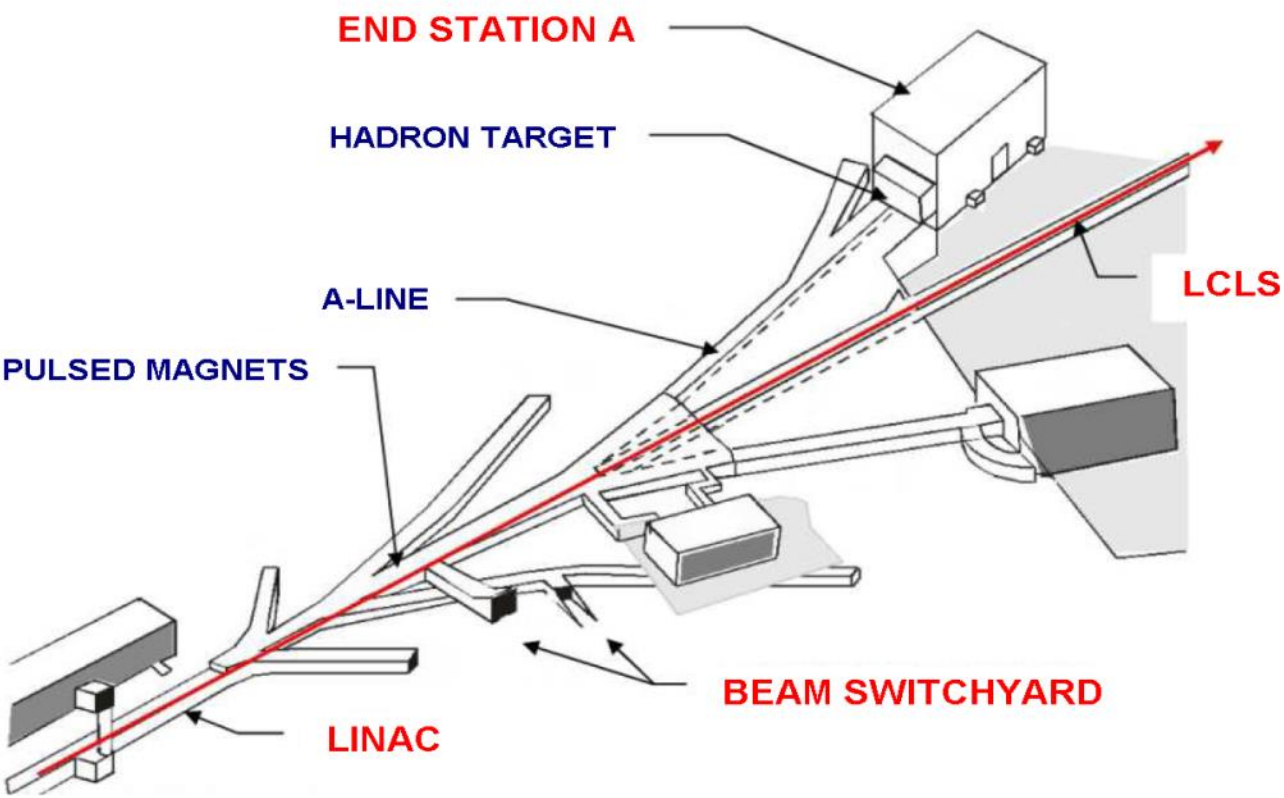
International Linear Collider

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

FCAL Collaboration Meeting
Cracow, Poland
29-30 April, 2013

LCLS and ESA

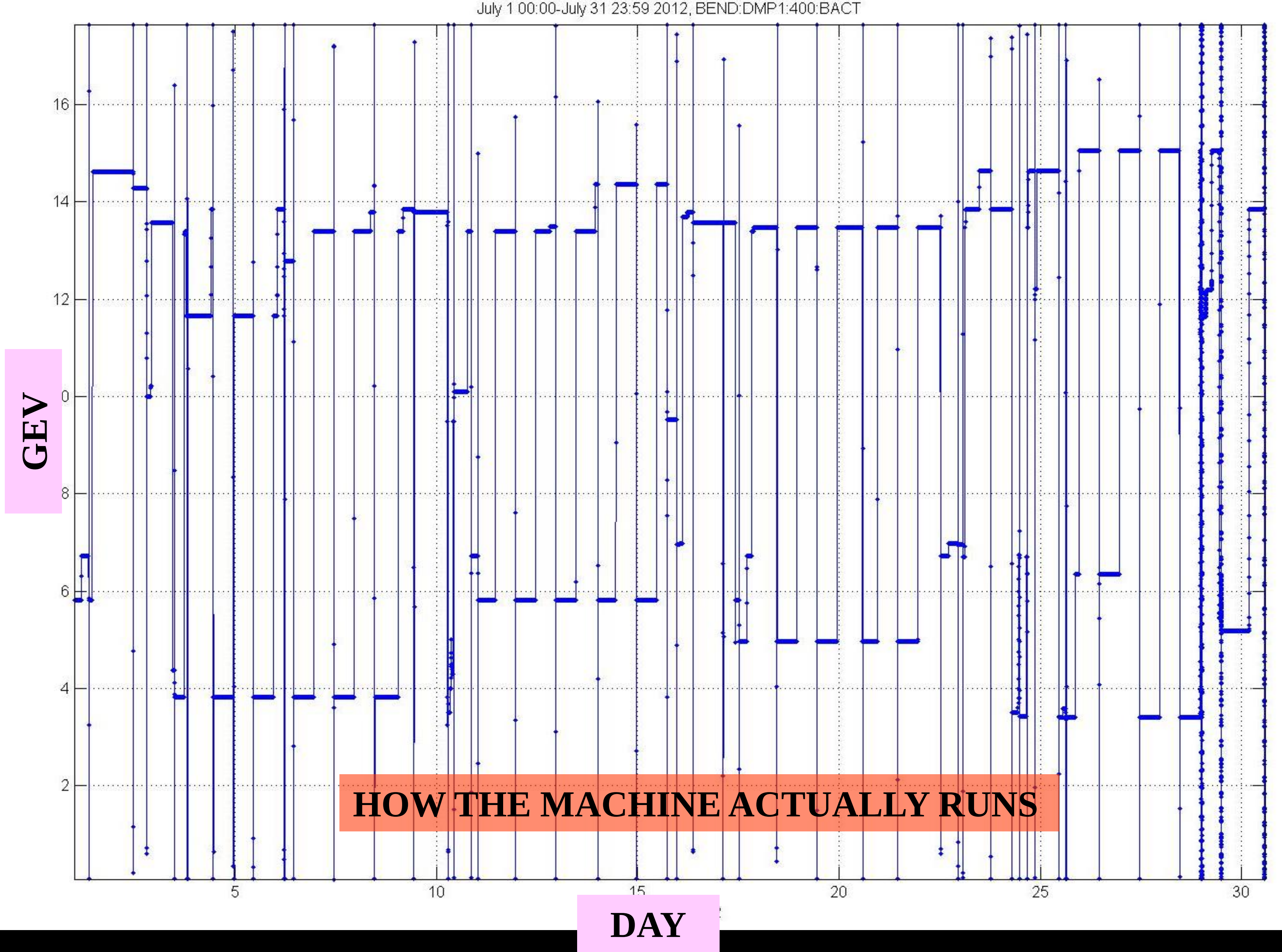
Use pulsed magnets in the beam switchyard to send beam in ESA.



ESTB parameters

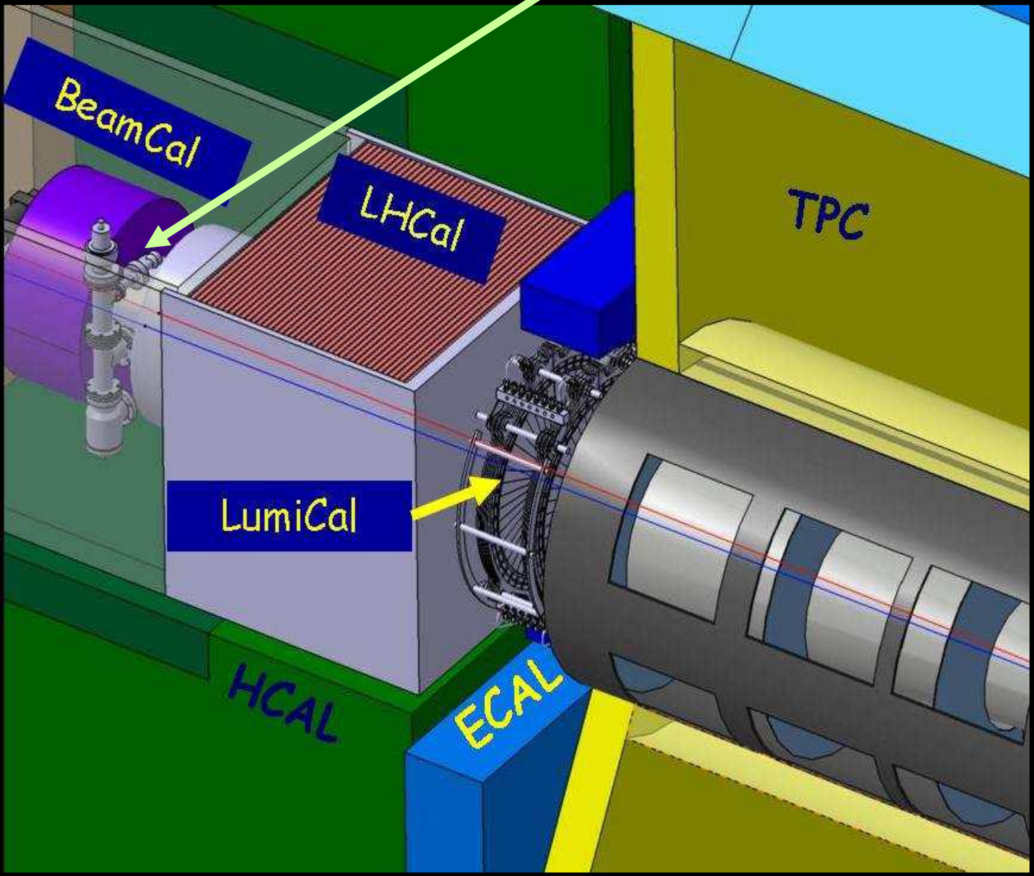
Table 1.1.1. ESTB primary electron beam parameters and experimental area at the BSY and in ESA

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



July 1 00:00-July 31 23:59 2012, BEND:DMP1:400:BACT
GEV
16
14
12
0
8
6
4
2
5
10
15
20
25
30
HOW THE MACHINE ACTUALLY RUNS
DAY

The Issue: ILC BeamCal Radiation Exposure



ILC BeamCal:

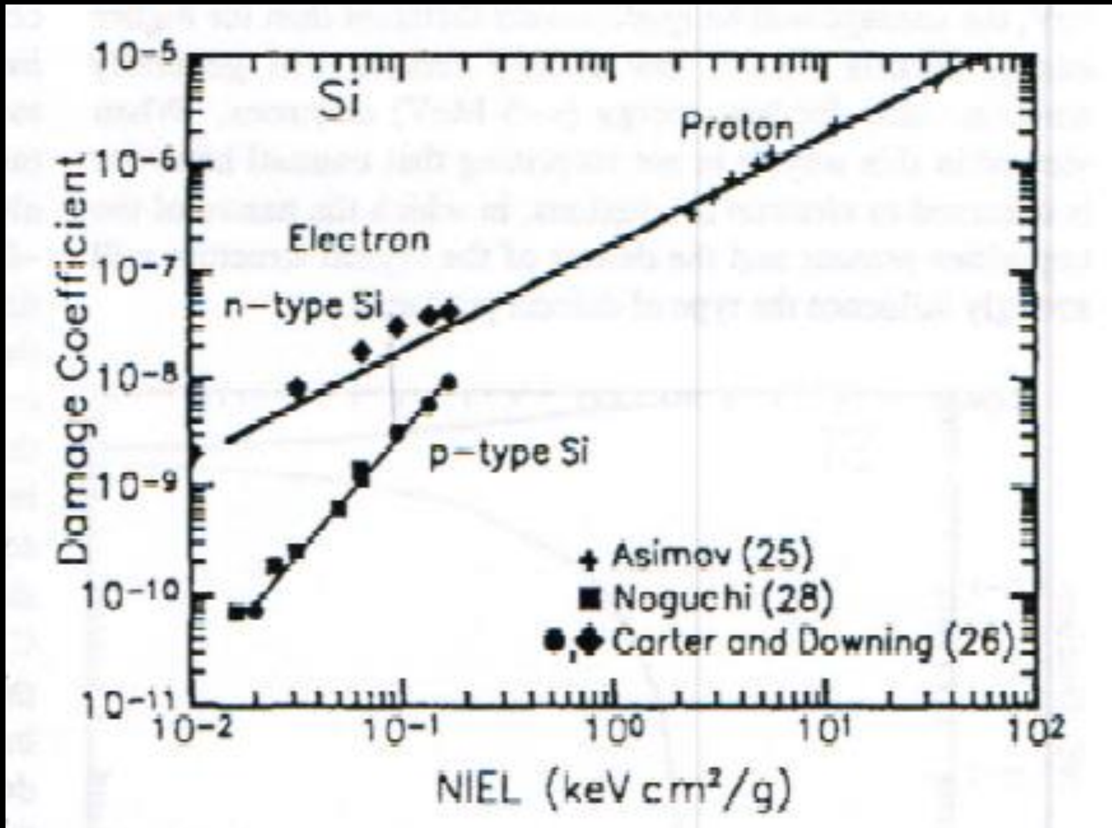
Covers between 5 and 40 miliradians

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
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?

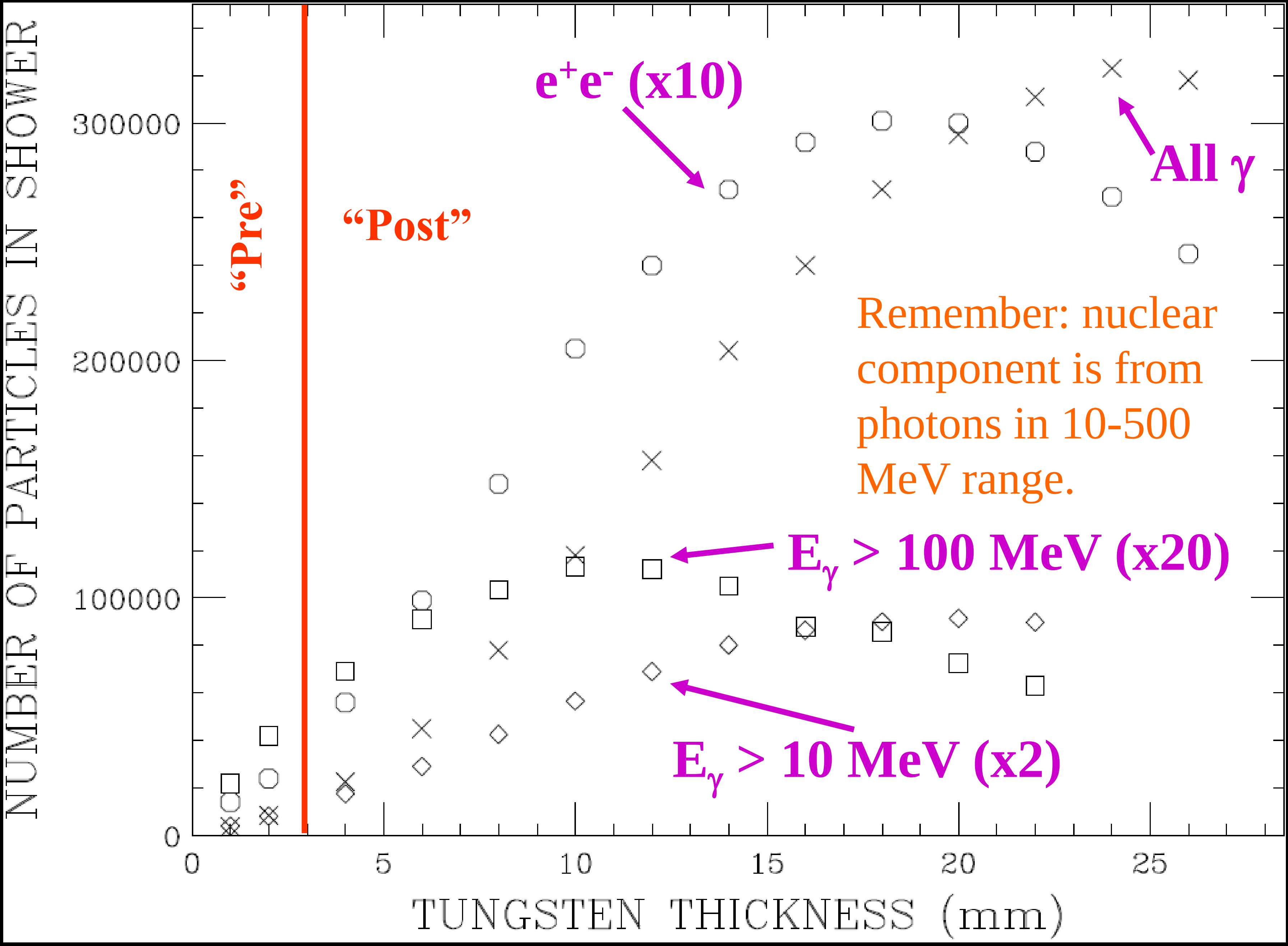
Hadronic Processes in EM Showers

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

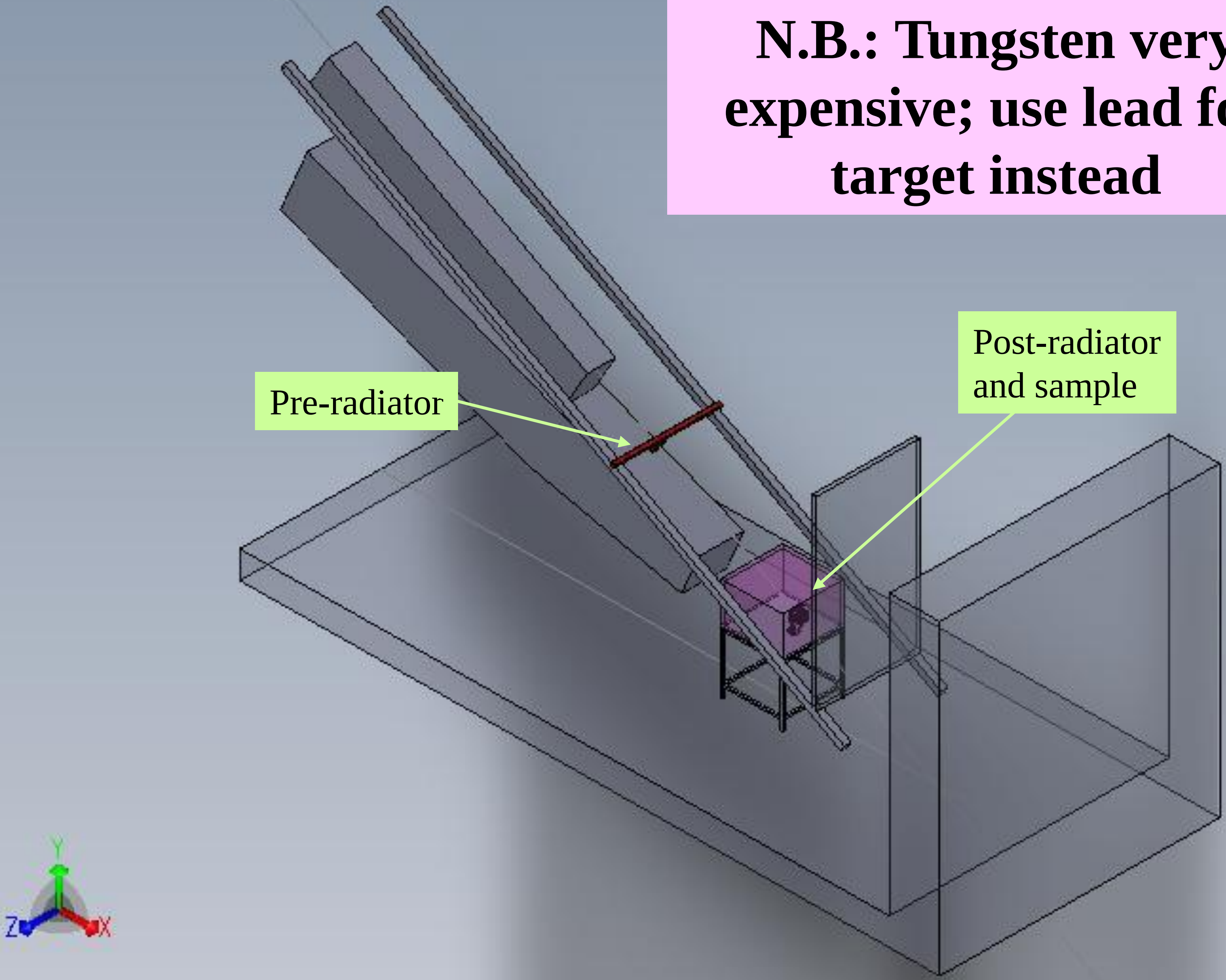
- Nuclear (“giant dipole”) resonances
  - Resonance at 10-20 MeV (~$E_{critical}$)
- Photoproduction
  - Threshold seems to be about 200 MeV
- Nuclear Compton scattering
  - Threshold at about 10 MeV; Δ resonance at 340 MeV

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

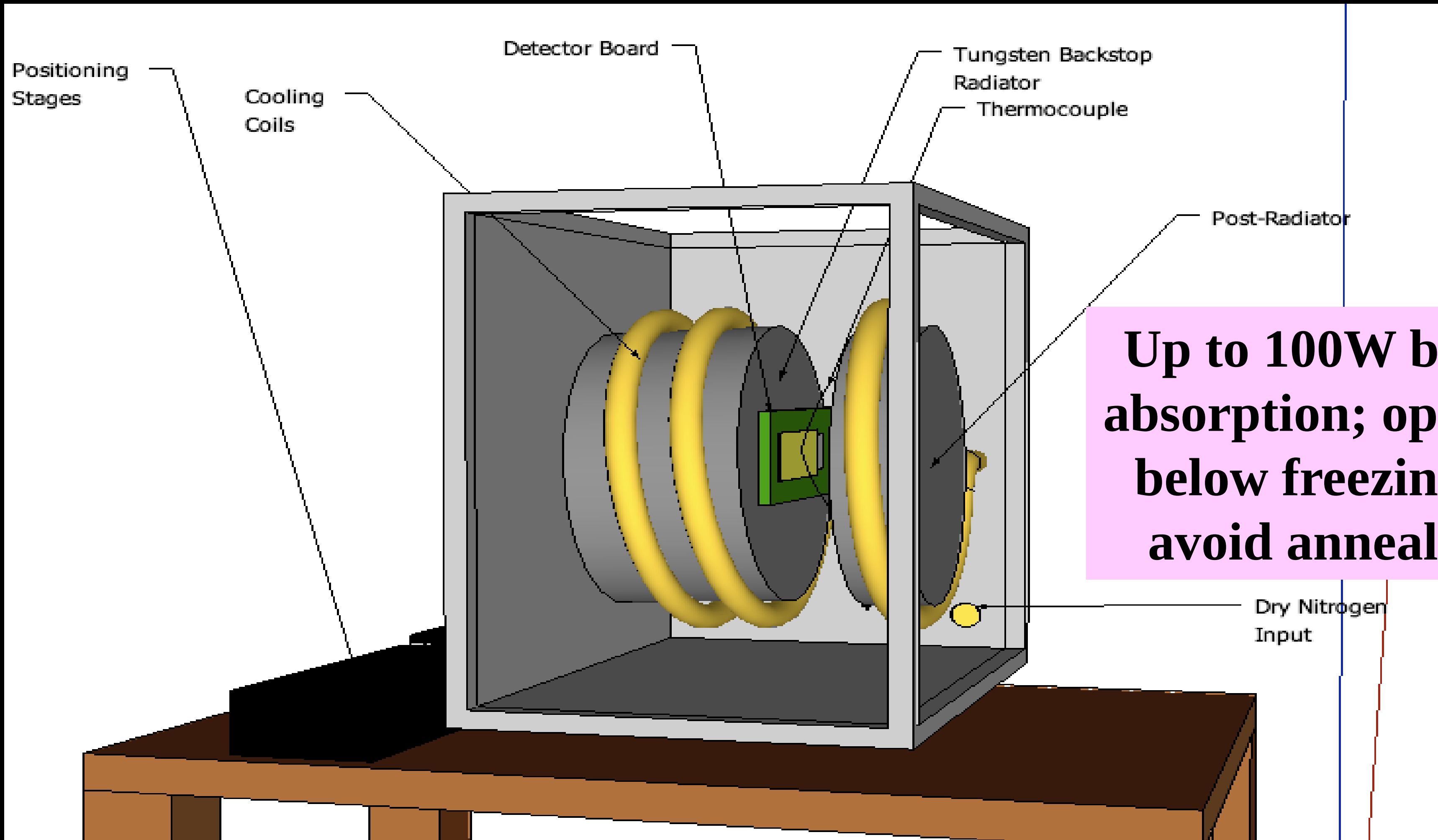
5.5 GeV Shower Profile



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



Hadronic Processes in EM Showers



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

Status: Thermal prototype under testing at SCIPP

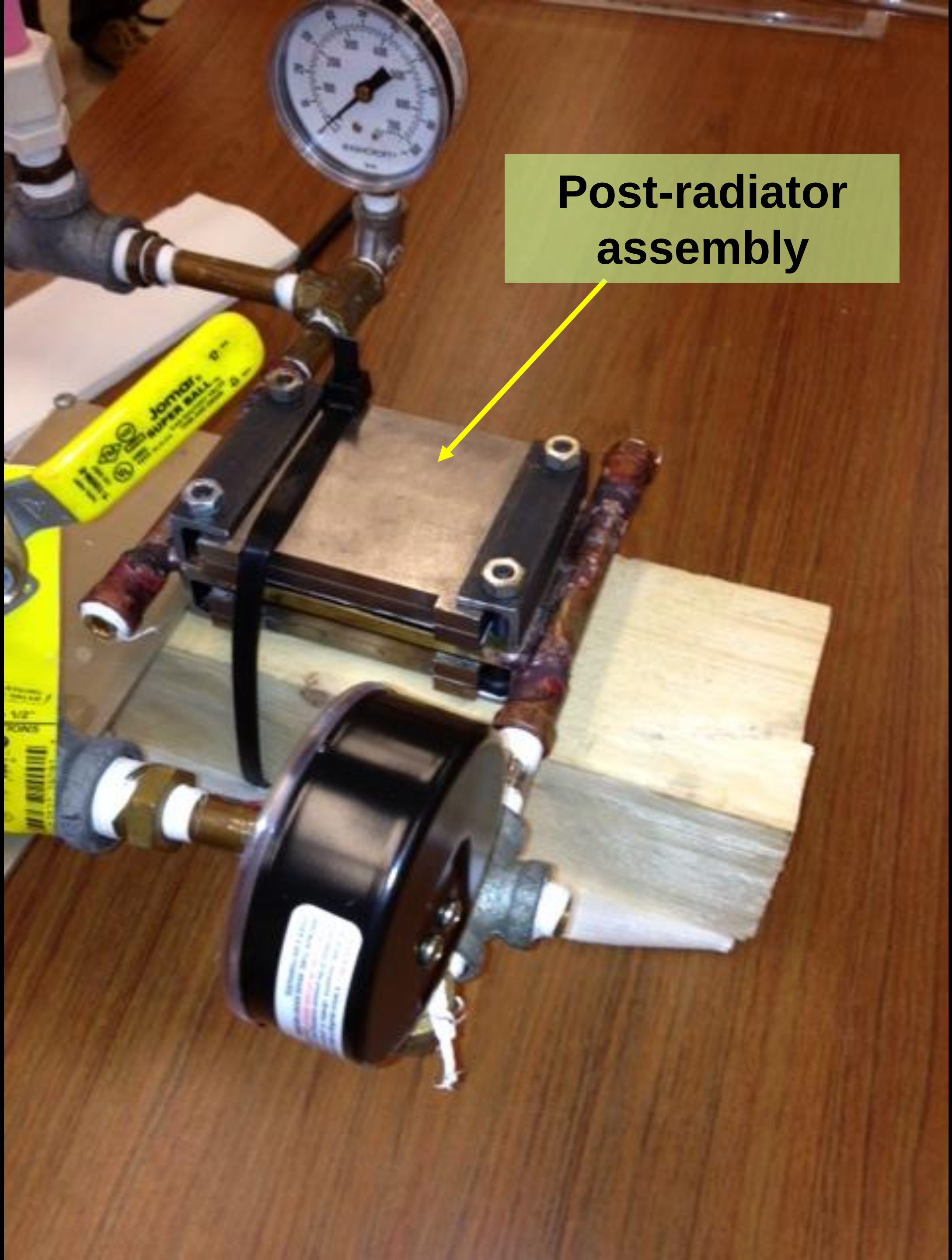
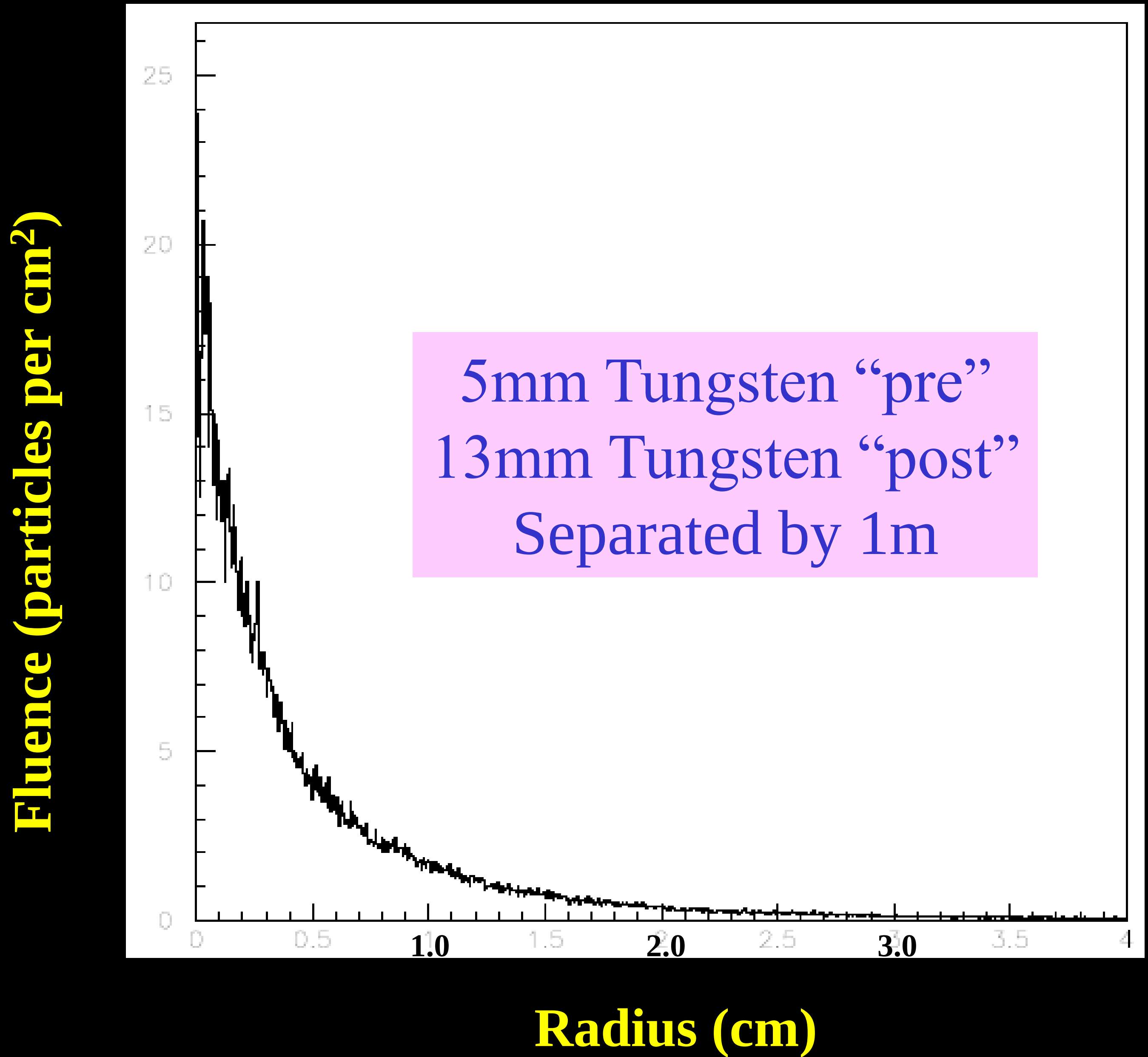


Photo of Target Assembly

Sensor will be lightly biased and mounted Peltier cooler that exhausts into the tungsten

Goal is to keep sensor at -10^{0} C during irradiation and charge-collec-tion measurement

Proposed split radiator configuration



Rastering

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

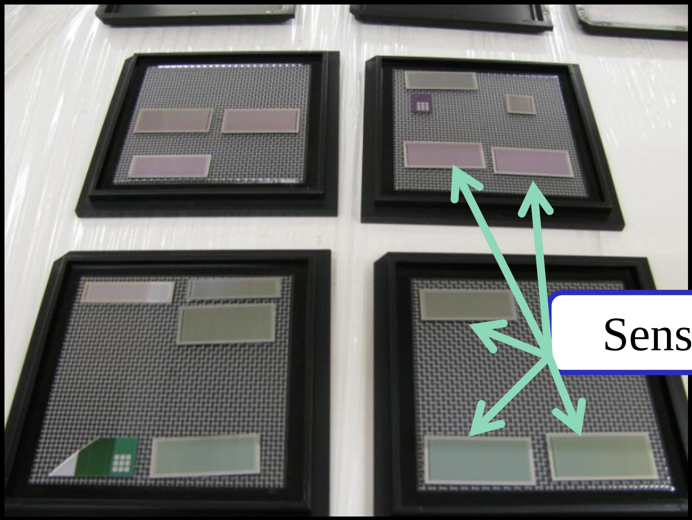
➔Raster in 0.05cm steps over 0.6x1.5 cm, assuming fluence profile on prior slide (see next slide for result)

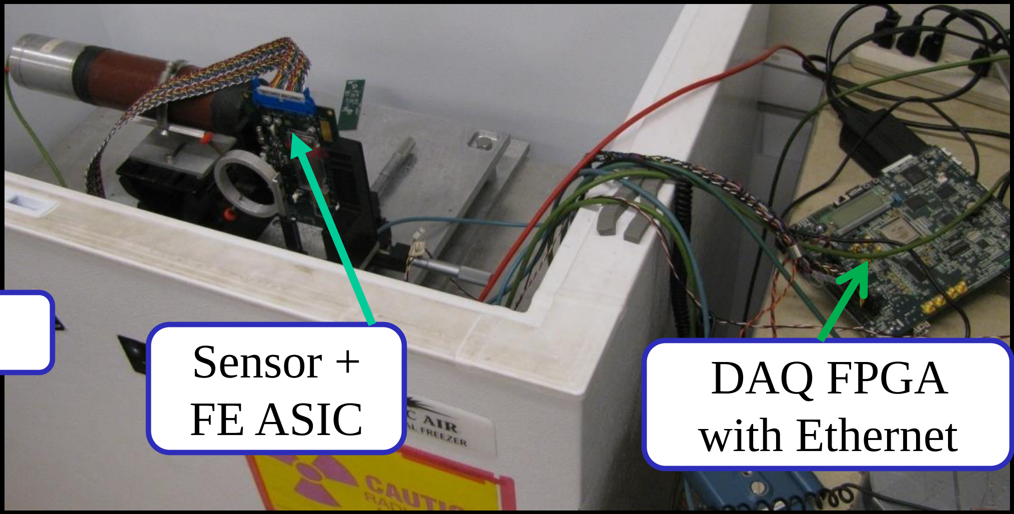
Exposure rate:

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

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

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

IDEAL 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)

CURRENT REALITIES

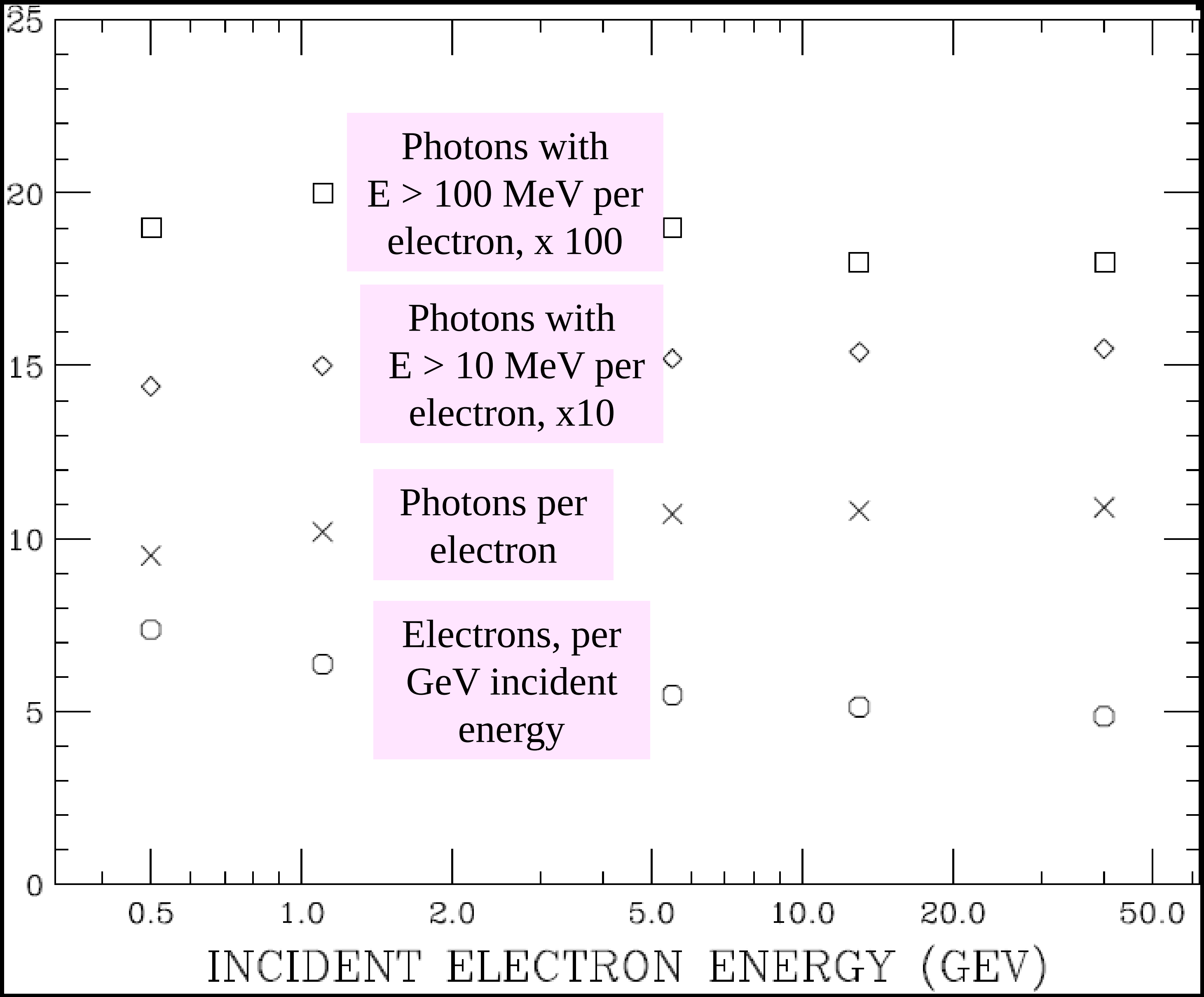
- SLAC End-station Test Beam will be limitied to ~few GeV
- Changes of sensor must occur during day shift
- We have been given 4 weeks: June 18 – July 15, with the run name T-506
- Beamline will operate again October 2013 – March 2014; hopefully at higher energy
- Might be possible to follow up or do additional sensor technologies.

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
- Expect to run in June; can study other sensor technologies if they are provided to us (may be able to do them in a later run).

Backup

Shower Max Results



➔ 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)

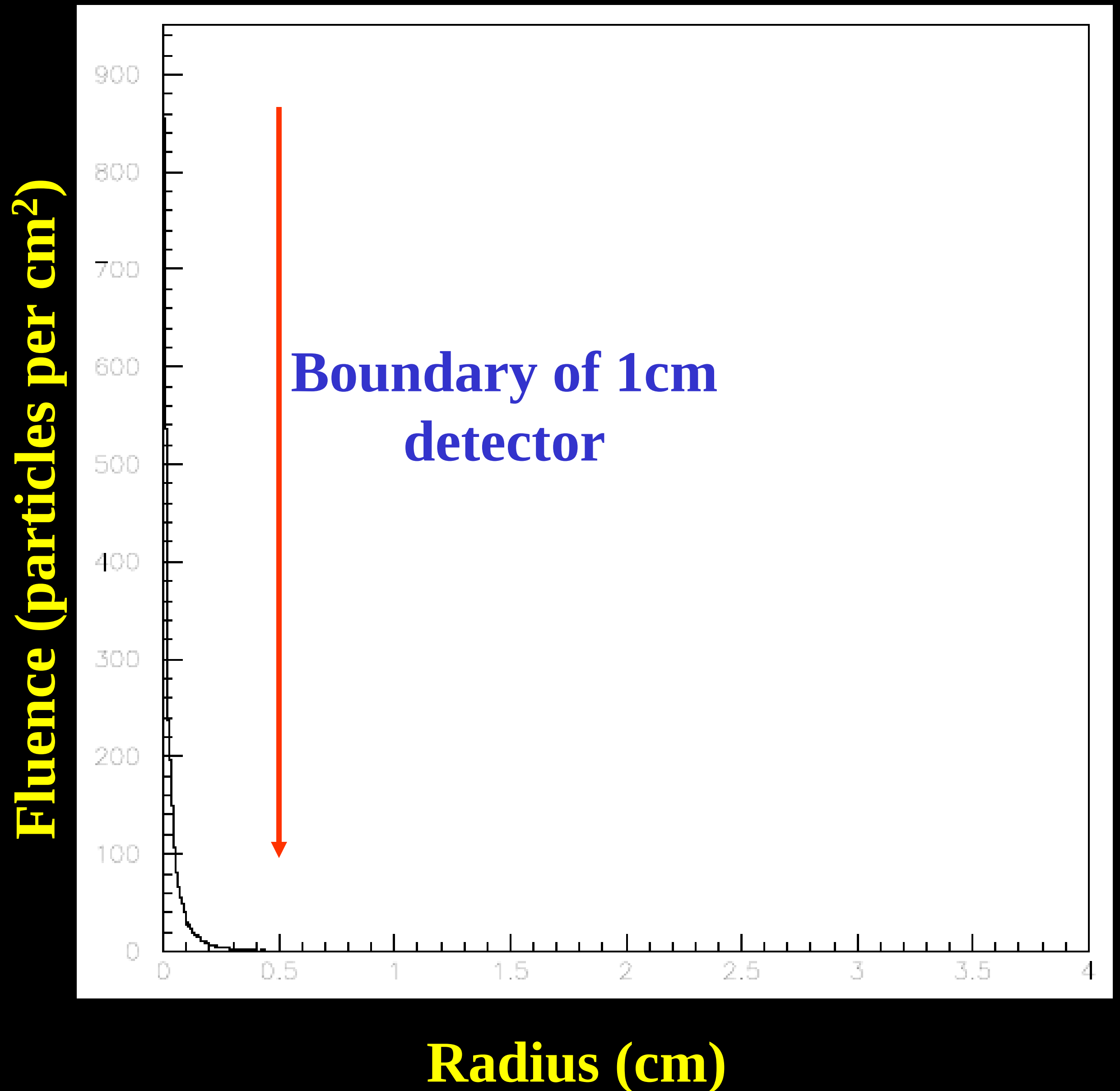
Center of irradiated area

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

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!

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])

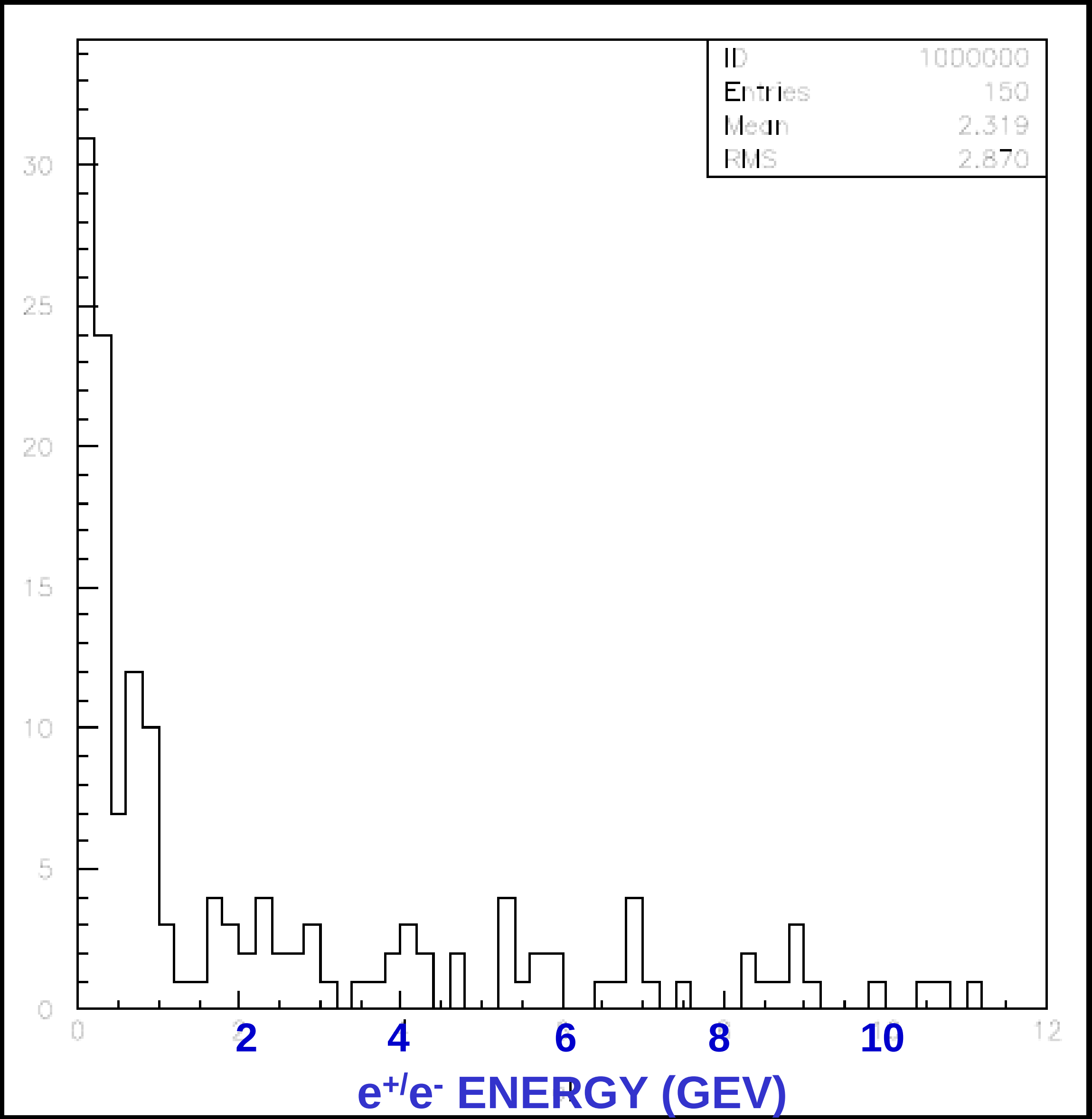
At $E_c^{Tungsten}$ ~ 10 MeV, **NIEL** is 80 times worse for protons than electrons and

• **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:

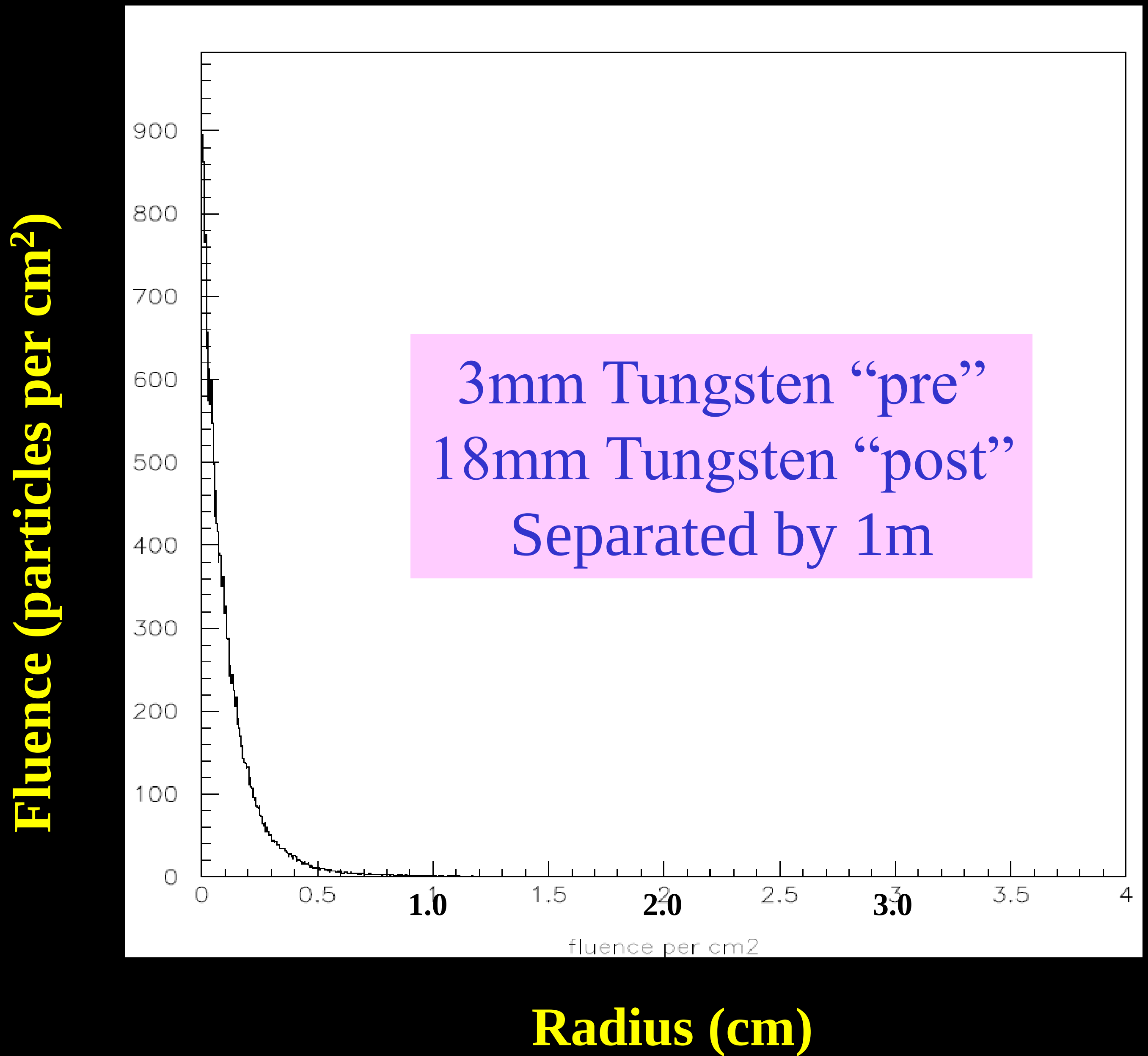
Direct electron beam of moderate energy on Tungsten radiator; insert silicon sensor at shower max

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

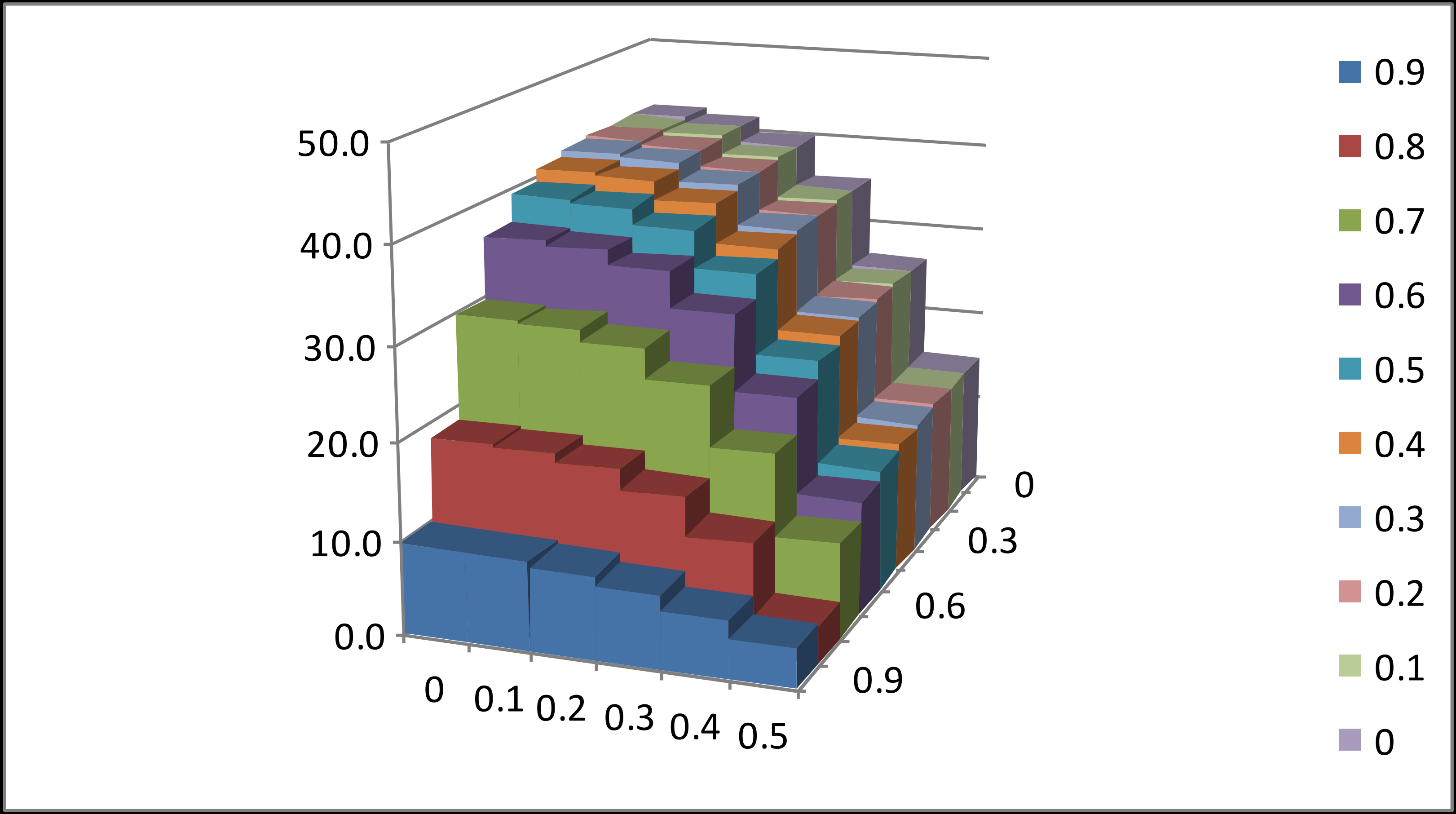
➔ Reasonably intense moderate-energy electron or photon beam necessary

What energy…?

Proposed split radiator configuration



Illumination Profile



Uniform to ± 10% over (3x6)mm area