Silicon Sensors Irradiation Study for ILC Extreme Forward Calorimetry

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BeamCal Motivation

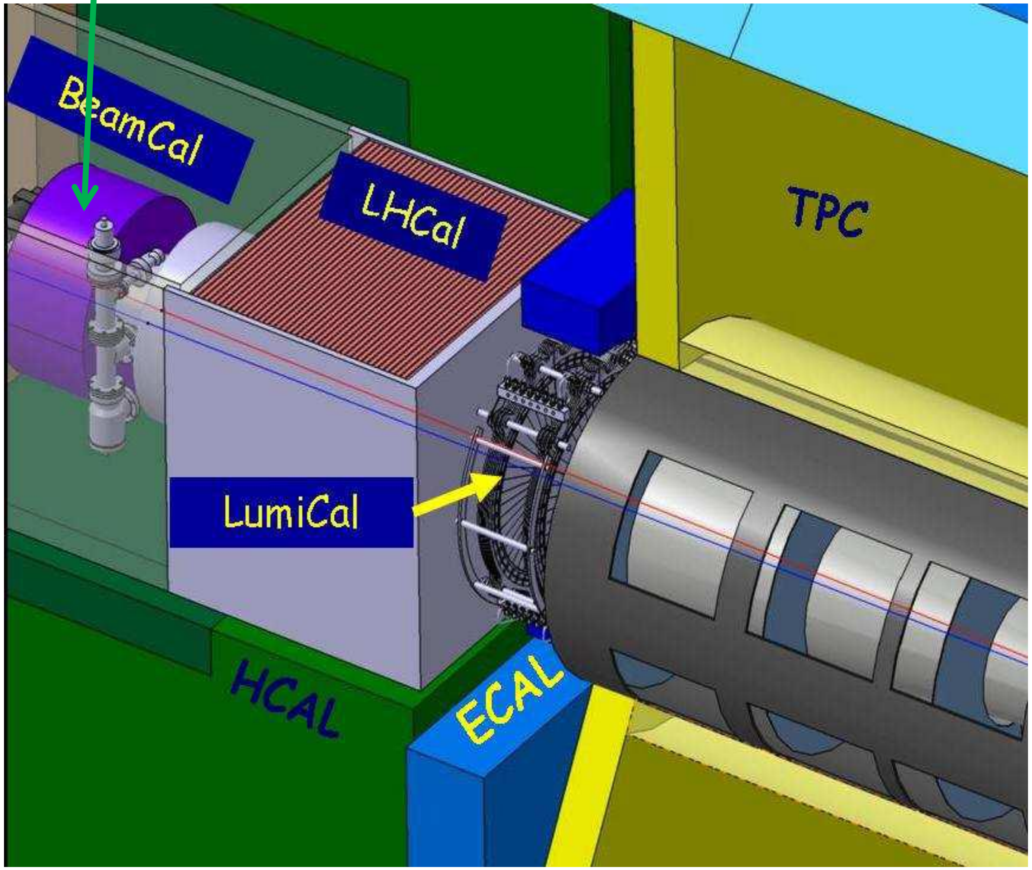
<u>Basic Idea</u>: At ILC two-photon processes with missing scattered electrons can mimic New Physics phenomena. BeamCal is meant to capture the primary particles scattered at small angles: 5 to 40 mrad. This is a sampling calorimeter with tungsten layers as absorber and sensors in-between.

<u>Challenge</u>: GRad of radiation.

<u>Studies of sensor material</u>:

- GaAs
- Diamond
- Saphire
- Silicon Carbide

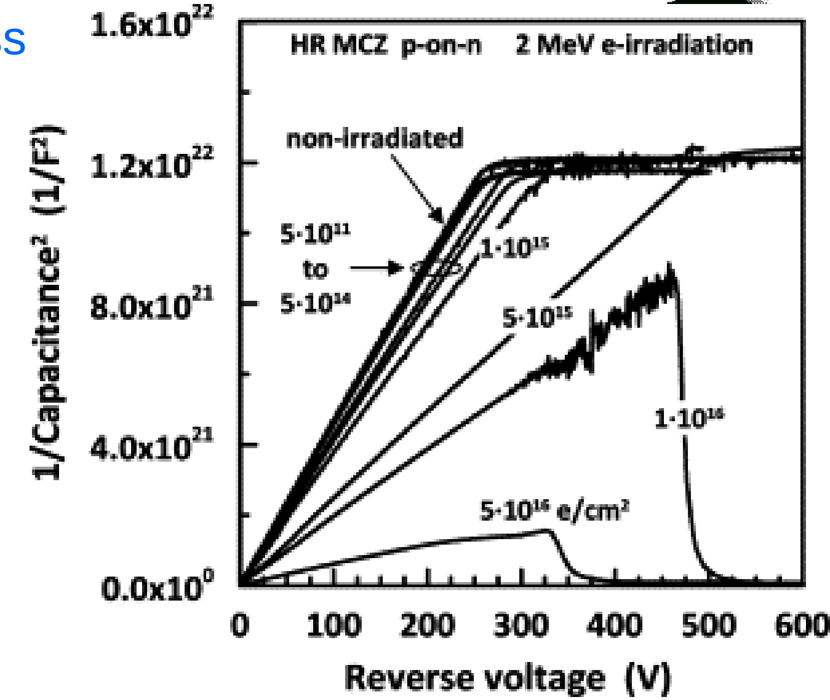
→We want to find out suitability of "conventional" Si sensors for this purpose.



Prior Electron Radiation Studies

There were prior studies of Si radiation hardness with electrons:

- J.M. Rafi et al, NIM A 604 (2009) 258: studied HR Si with 2 MeV e- up to 5x10^16 e-/cm^2. They observed *x36* less damage from IV studies than expected from NIEL.



- S. Dittongo et al, NIM A 546 (2005) 300: studied HR Si with 900 MeV e- up to 6.1x10^15 e-/cm^2. Observed *x4* less damage than expected from NIEL.
- S. Dittongo et al, NIM A 530 (2004) 110: studied HR Si with 900 MeV e- up to 2.1x10^15 e-/cm^2. Observed *<3% CCE decrease* after annealing.

→ Is there energy-dependent NIEL hypothesis breakdown with electrons? (Origination of point-like defects rather than clusters at lower energy intuitively makes sense…) There is an "effective NIEL" with reduced damage for electrons, as was presented by R. Radu on Monday.

What to study?

Besides EM radiation, there will be a shower => energy spread and potentially a nuclear component:

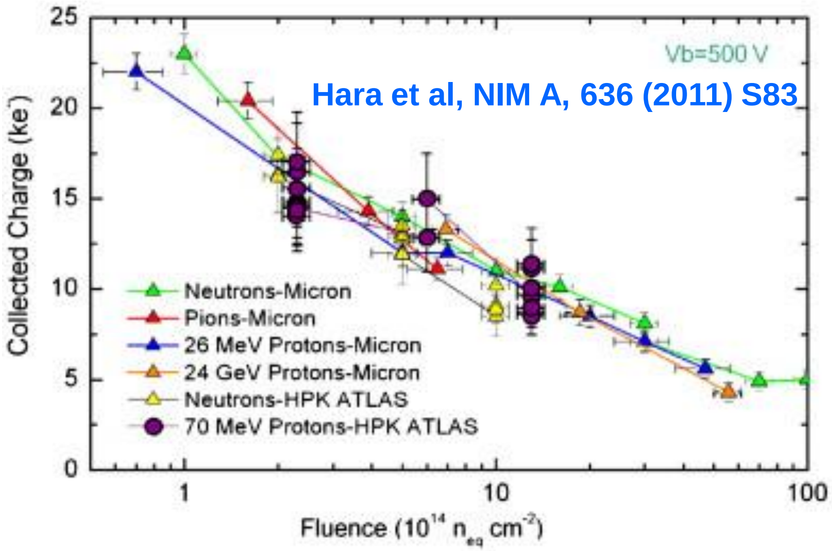
- Nuclear ("giant dipole") resonances at 10-20 MeV (~$E_{critical}$)
- Photoproduction: Threshold seems to be about 200 MeV
- Nuclear Compton scattering: Threshold at about 10 MeV; Δ resonance at 340 MeV

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

Want to assess CCE under realistic conditions. Example from known studies (N-on-p FZ):

- Assuming 50% CCE drop as the FOM (depends on electronics!) => ~0.6x10^15 neq
- NIEL scaling to max D(E, el) => 7.9x10^15 e-/cm^2, or ~260 MRad.

In reality NIEL scaling issue and presence of hadrons can significantly modify the guesstimate.



LCLS and ESA (FACET)

Want to use > 1 GeV beam to capture the nuclear processes

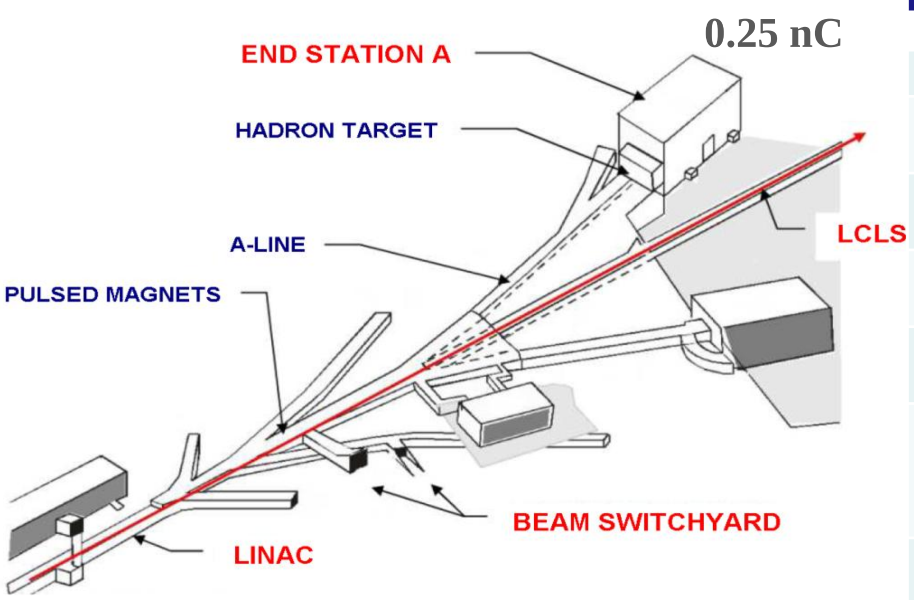
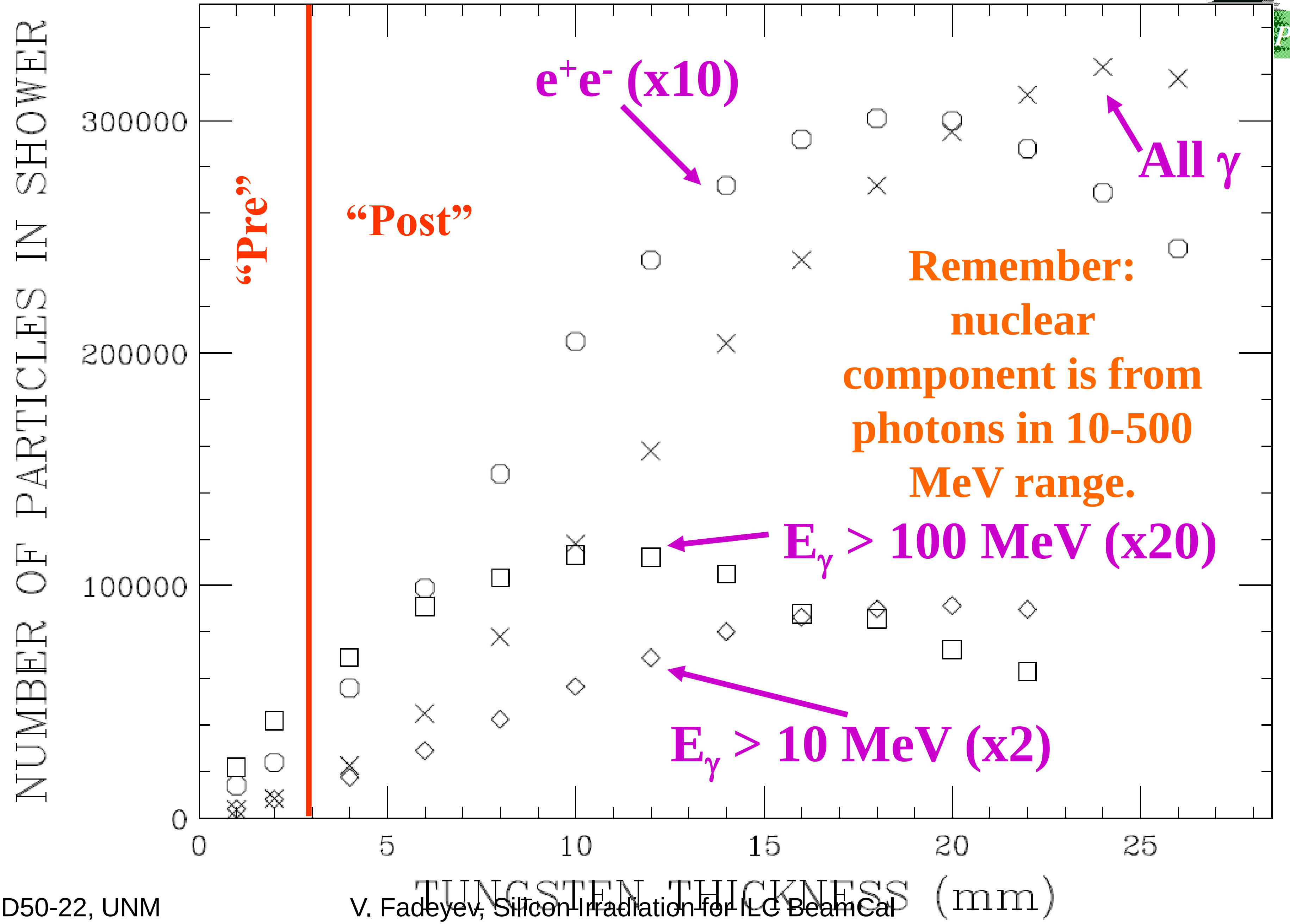


Table 1.1.1. ESTB primary electron beam parameters and experimental area at the BSY and in ESA

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

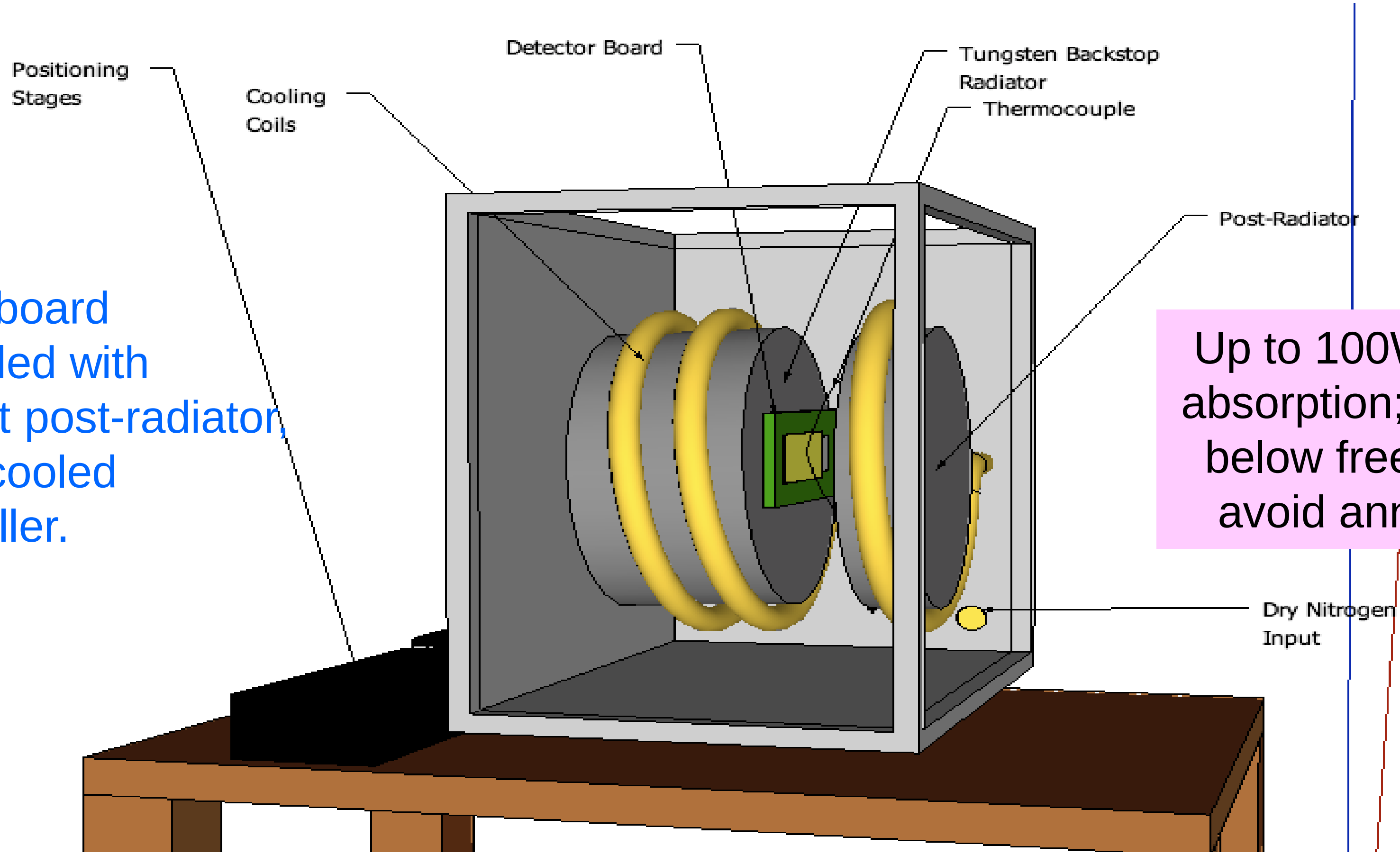
5.5 GeV Shower Profile



Hadronic Processes in EM Showers

Modeling hadronic components: tungstedn pre- and post-radiator
(a stack of 7 mm tungsten plates borrowed from Leszek Zawiejski, INP, Krakow)
Sensors to be lightly biased and cooled by Peltier elements to <-10 C.

Detector board to be cooled with Peltier wrt post-radiator, which is cooled with a chiller.



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

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Rastering

Want to irradiate a sizable region of the sensor => will use rastering.

Plan on covering $0.6 \times 1.5\ cm^2$ region with 0.05 cm steps.

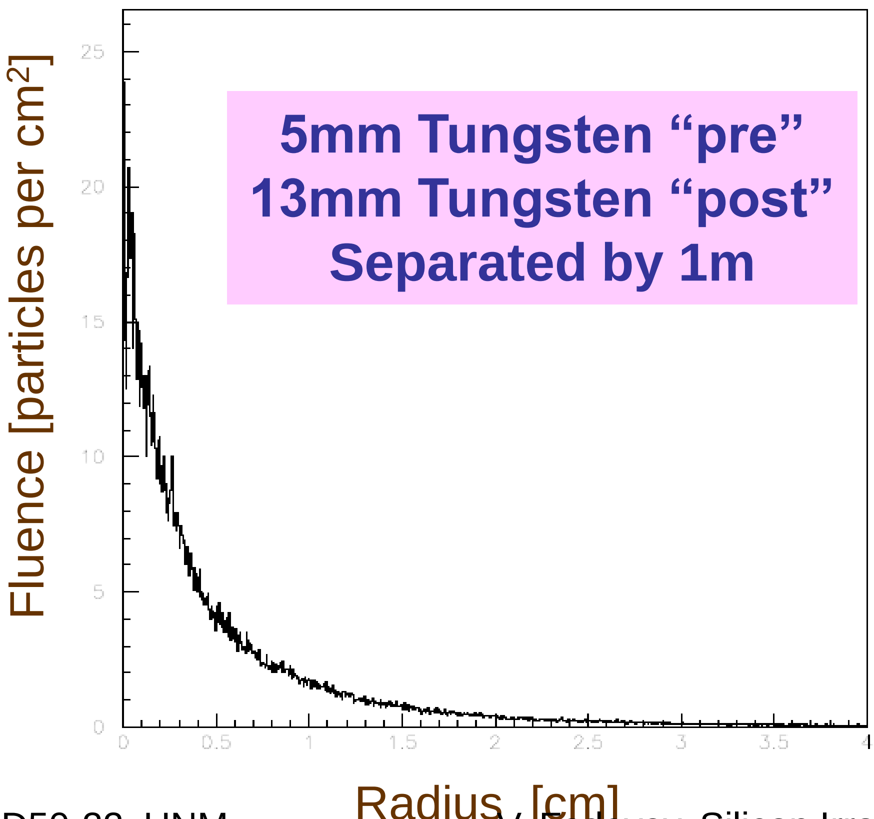
Dose rate:

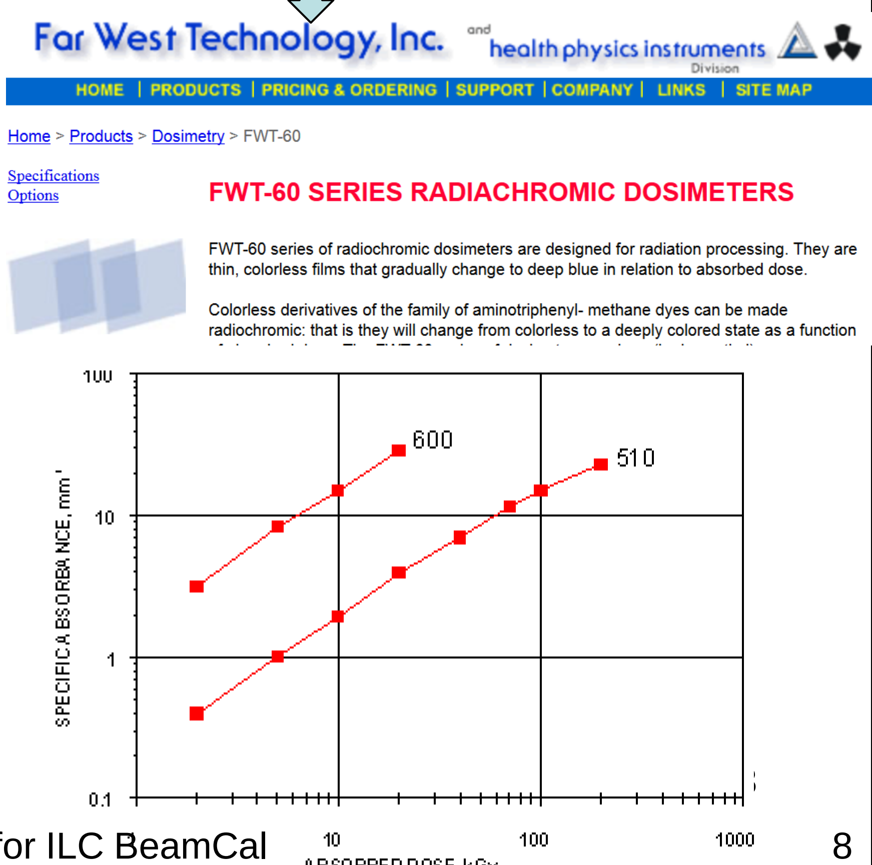
$$1\,GRad \approx \frac{600}{I_{beam}(nA) \bullet E_{beam}(GeV)}\, hours$$

(100 MRad at 1 nA with 13.6 GeV beam in 5 hours)

Will use CCE with collimated Sr-90 source as a primary observation.

Will need good alignment, dose cross-calibration.





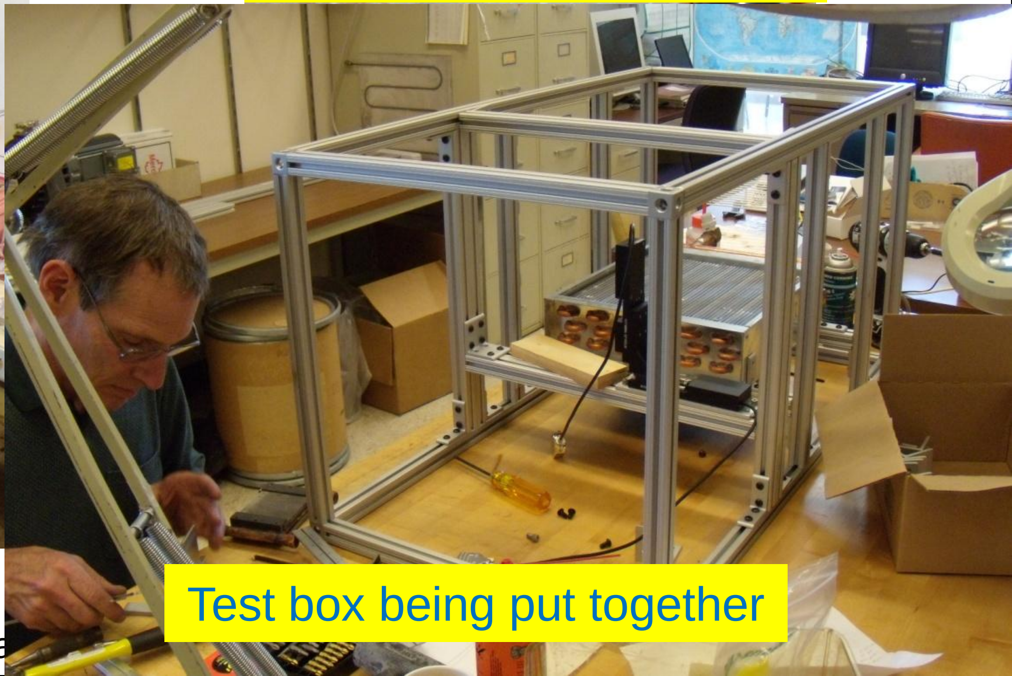
Cooling

Sizable irradiation duration => Special considerations for cooling and measurements. Target <= -10C:

- Sensors mounted on boards allowing repeated CCE measurements on the same devices at different doses.
- Cooling the devices to avoid annealing (the "quick disconnect" boards avoid warmp-up diruing wirebonding)
- Cooling the tungsten.
- Cold CCE measurements, and transport.

Post-radiator with cooling

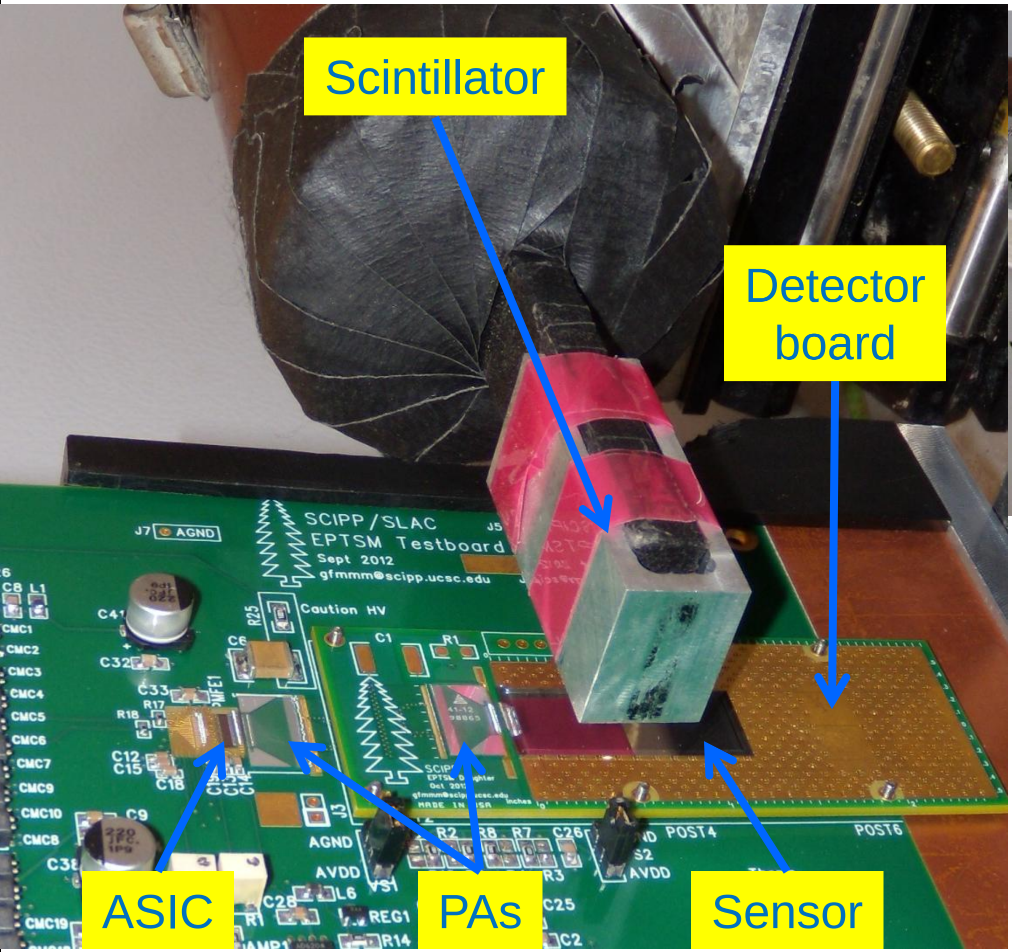
Chiller system for the post-radiator and ambient air

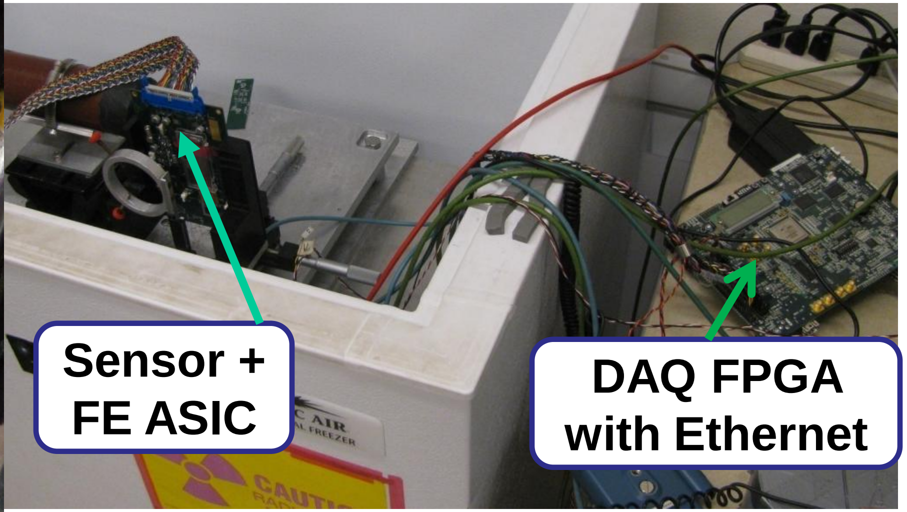


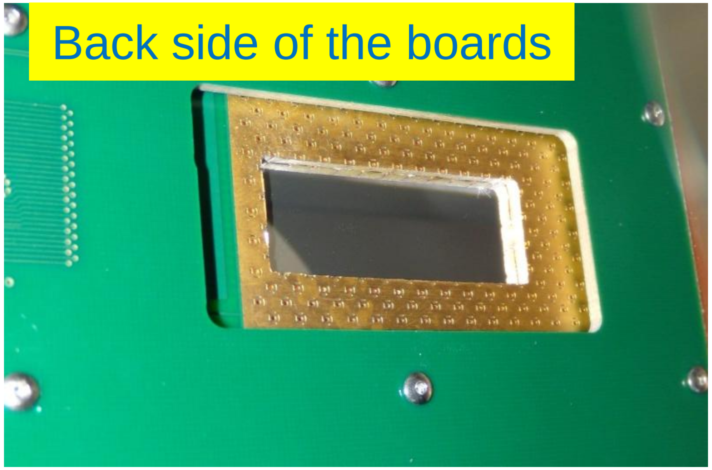
Test box being put together

CCE system

Will use binary readout CCE system, that was used in prior irradiation studies. It gives the same answer as AliBaVa within 10%.
Redesigned the FE board to accommodate the “quick connect” detector boards.
The FE and detector boards have permanent pitch adaptors made by AliBaVa.







Run Plan

Will use Micron and HPK strip sensors covering 4 technologies:

	N-on-p	P-on-n
FZ	HPK (ATLAS07 test minis)	Micron
MCz	Micron	Micron

Proposed:

- On-going measurements after stepped exposures of (1, 3, 10, 30, 100) MRad.
- Then assess the results and do 1 or 2 long exposures. An exposure without post-radiator will allow to evaluate the influence of hadronic component.
- Then annealing studies.

Realities:

- End station Test beam is limited to a few GeV.
- Sensor changes must happen during day shift.
- We are given 4 weeks: June 18-July 15, run T-506.
- Beam line will operate again in October 2013 – March 2014, possibly at higher energy. Might be possible to follow up or do different sensor technologies.

Conclusions

A radiation study of high-fluence EM damage with a hadronic component for ILC BeamCal.

Will attempt to: a) model, and b) evaluate the influence of the hadronic damage.

Will use a few GeV beam from SLAC facility with rastering.

CCE evaluation at several steps during the exposure.

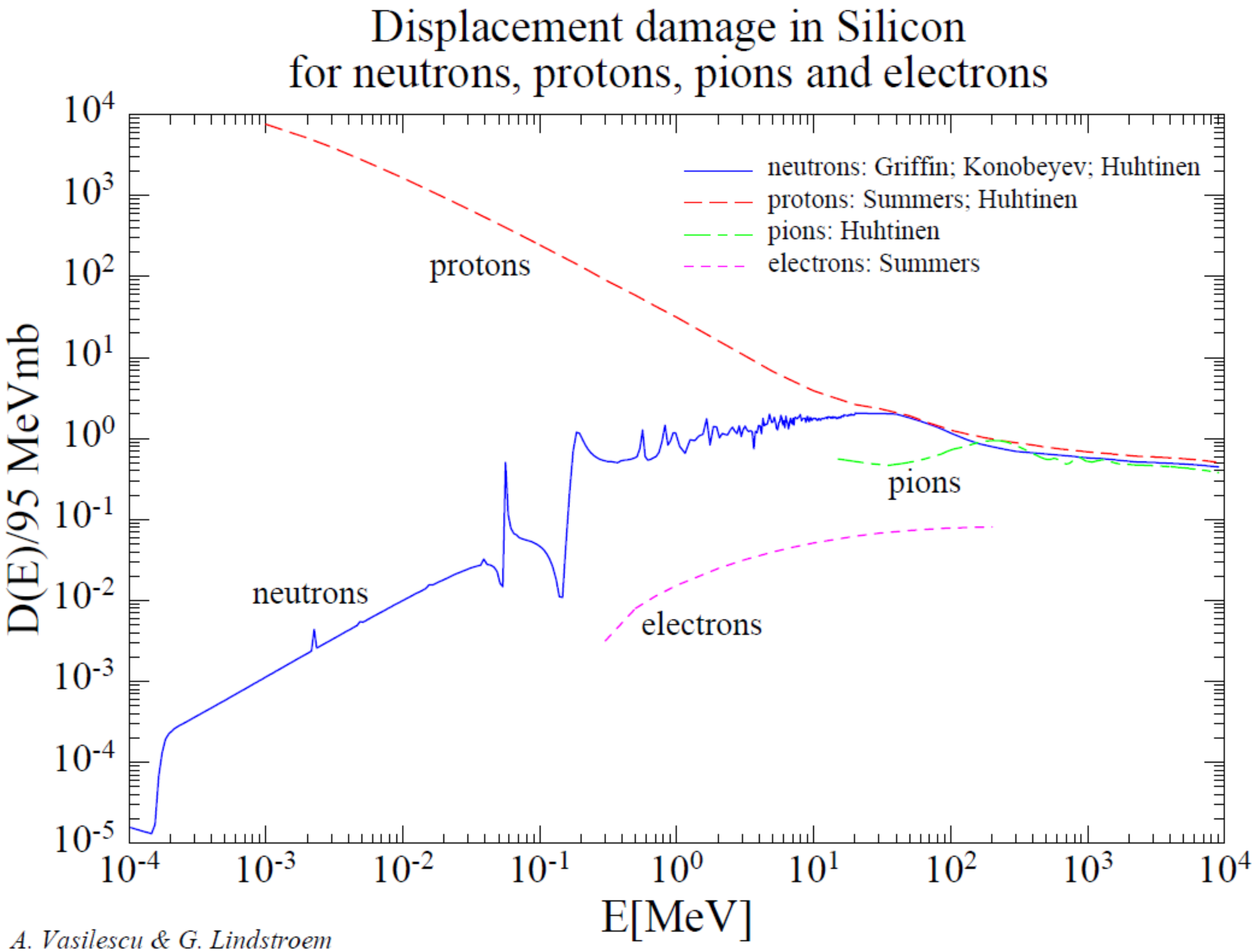
Cooling infrastructure to avoid annealing effects during the long exposure.

The run will start in 2 weeks!

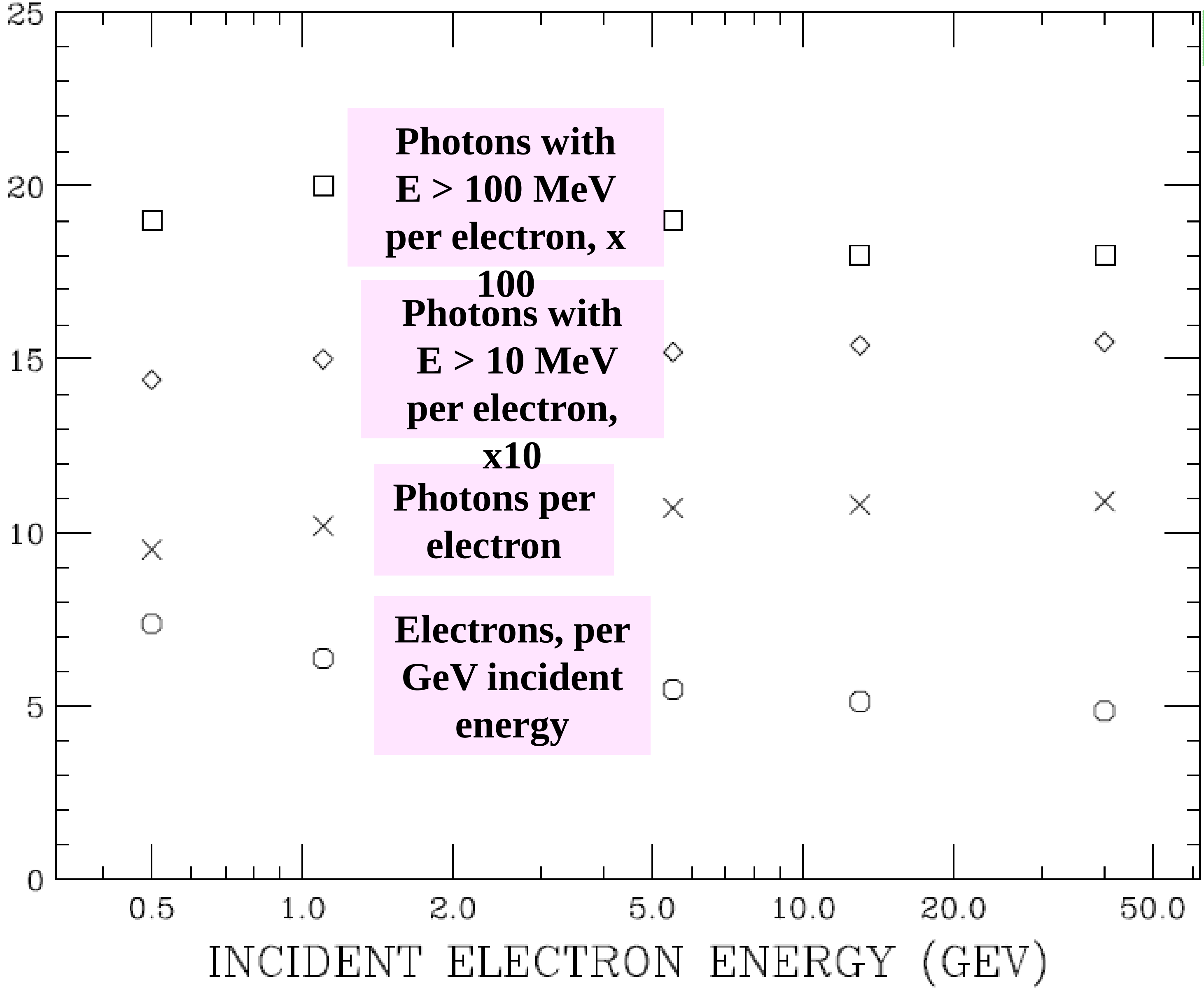
Back-Up Slides

NIEL Plot

D(electrons,max) = (1/13) D(1MeV, n)



Shower Max Results



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

Fluence (e⁻ and e⁺ per cm²) per incident 5.5 GeV electron (5cm pre-radiator 13 cm post-radiator with 1m separation)

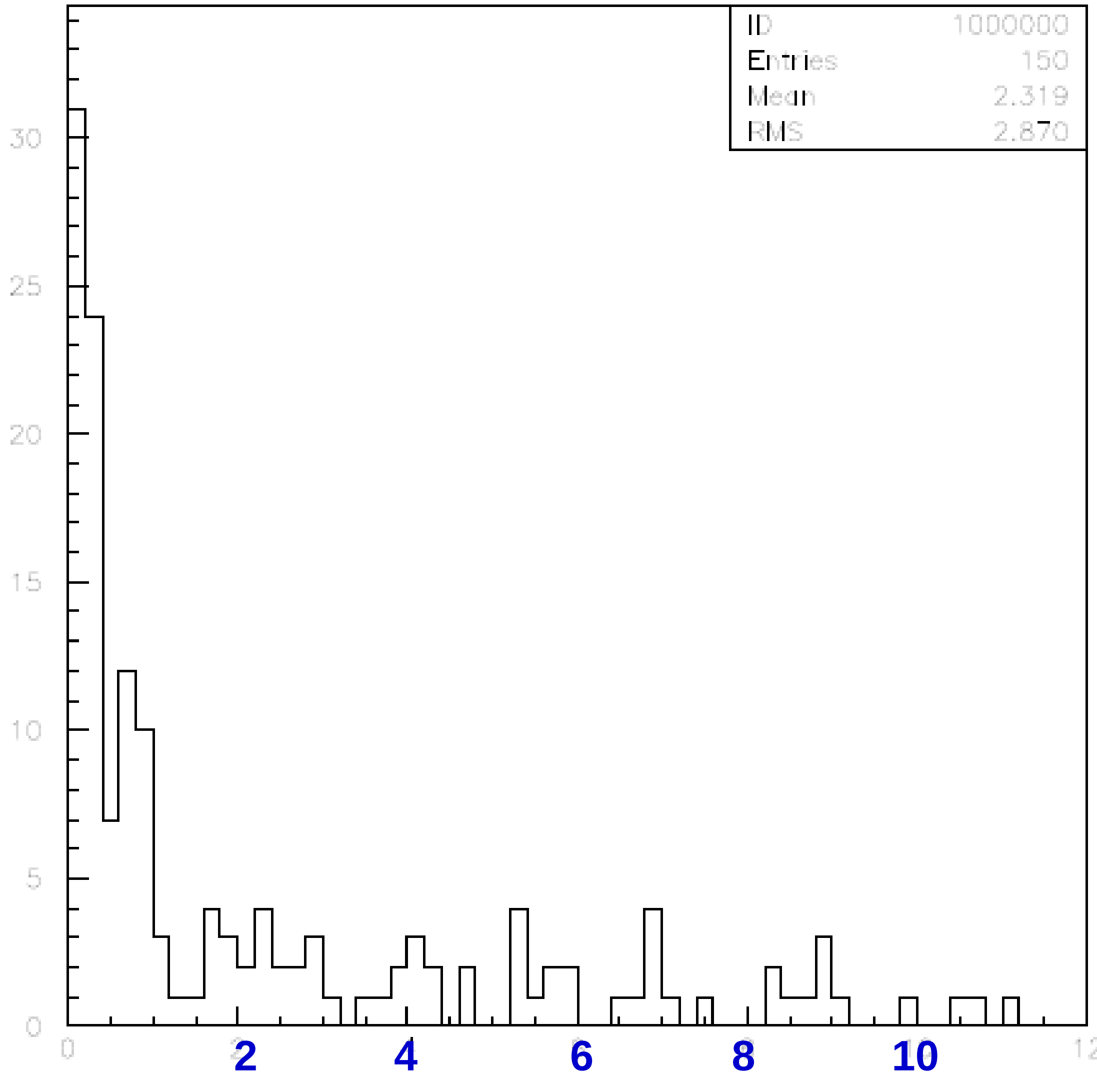
Center of irradiated area

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

BeamCal Incident Energy Distribution



$e^{+/}e^{-}$ ENERGY (GEV)

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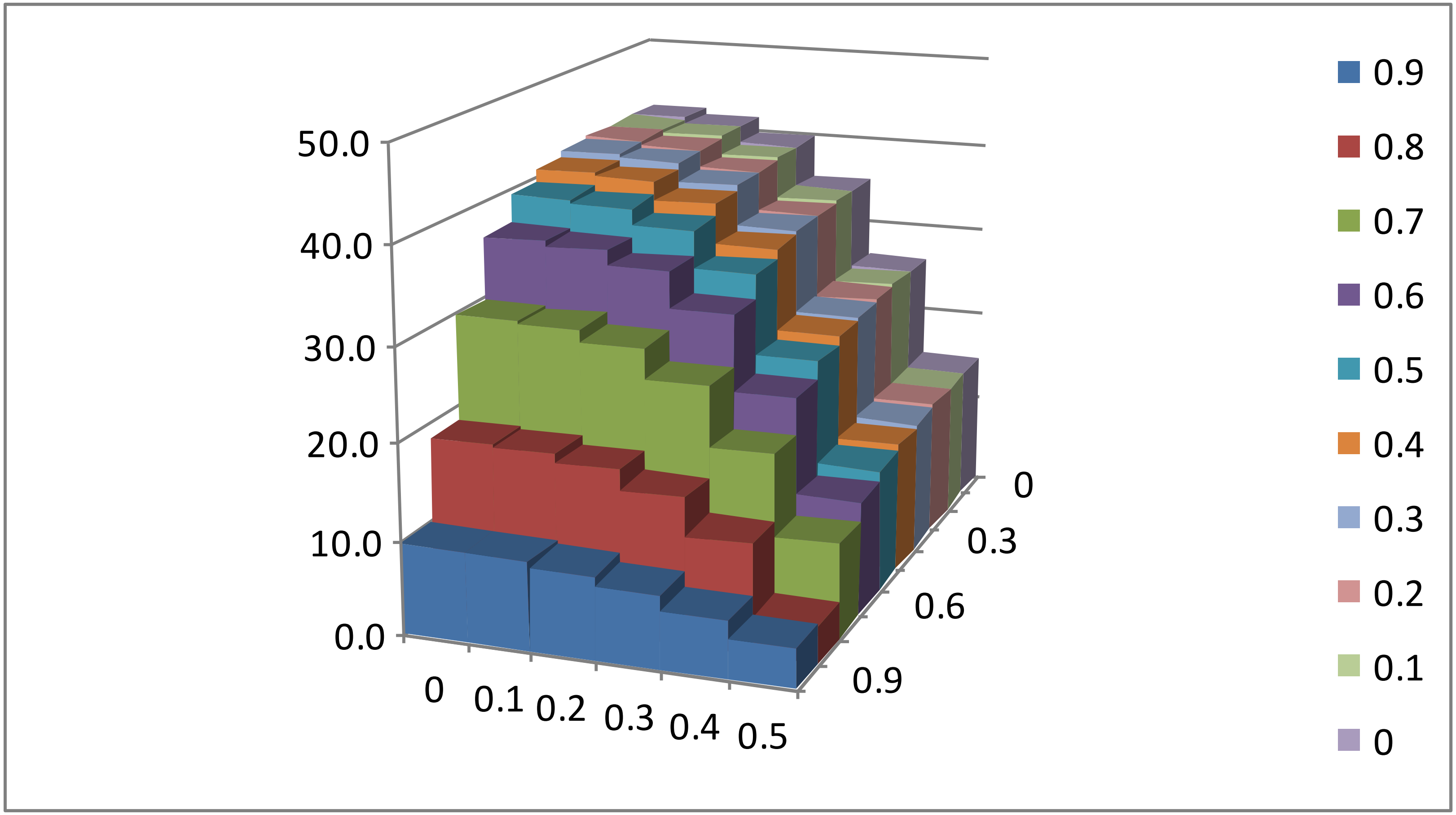
Illumination Profile



Uniform to ± 10% over (3x6)mm area

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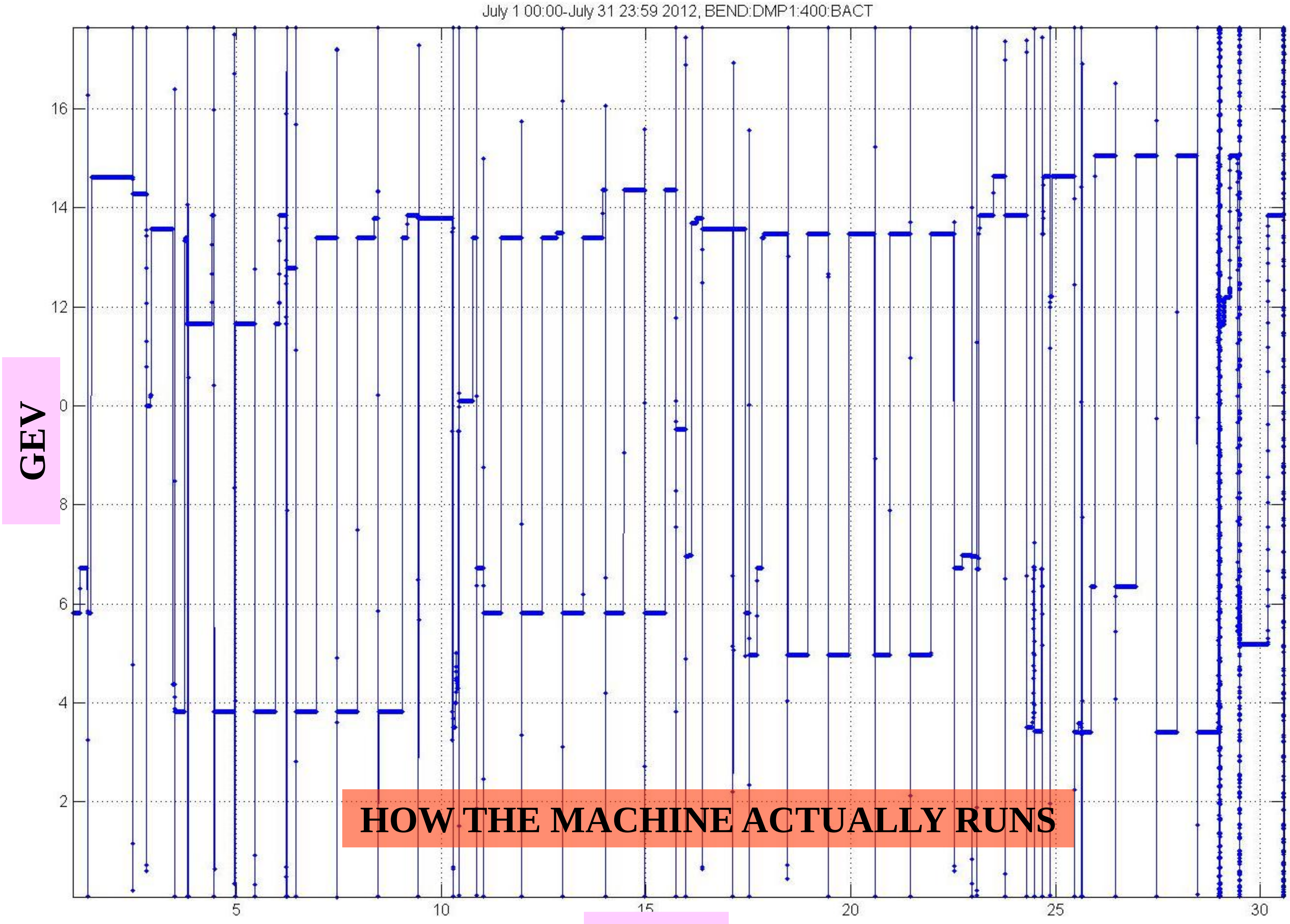
July 1 00:00-July 31 23:59 2012, BEND:DMP1:400:BACT
GEV
DAY
HOW THE MACHINE ACTUALLY RUNS