Initial Results from the SLAC ESTB T-506 Irradiation Study

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T-506 Motivation

BeamCal maximum dose ~100 MRad/yr

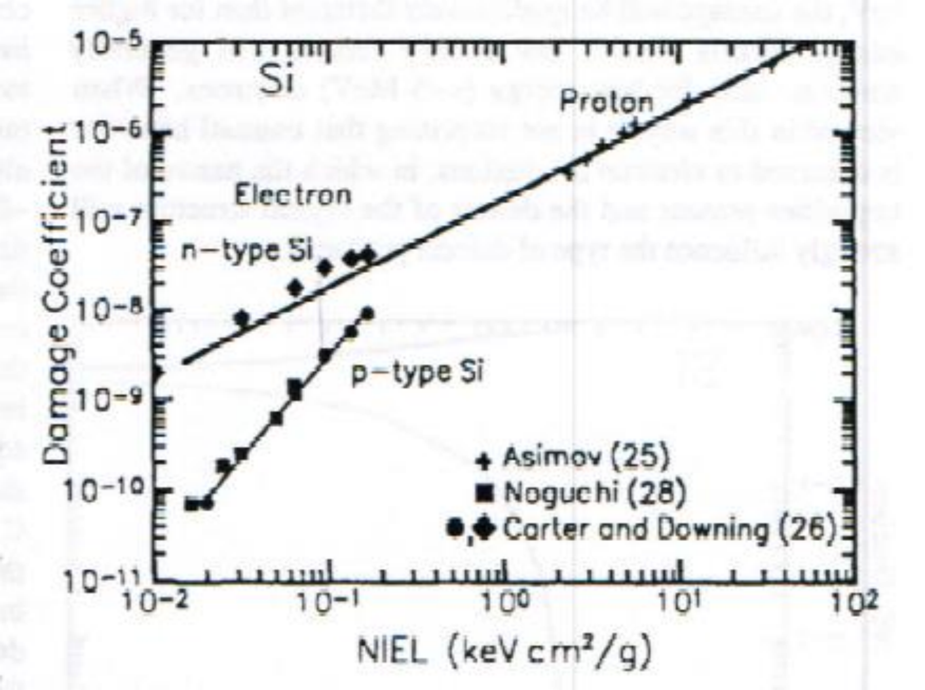
Beam Calorimeter is a sizable: ~2 m^2 of sensors.

A number of ongoing studies with novel sensoers: GaAs, CVD diamond

Might mainstream Si sensors be of use?

Some reasons for optimism…

Departure from NIEL (non-ionizing energy-loss) scaling observed for electron irradiation



NIEL	e^- Energy
2x10^{-2}	0.5 MeV
5x10^{-2}	2 MeV
1x10^{-1}	10 MeV
2x10^{-1}	200 MeV

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

Also: for ~50 MRad illumination of 900 MeV electrons, little loss of charge collection seen for wide variety of sensors (S. Dittongo et al., NIM A 530, 110 (2004)

But what about the hadronic component of EM shower?

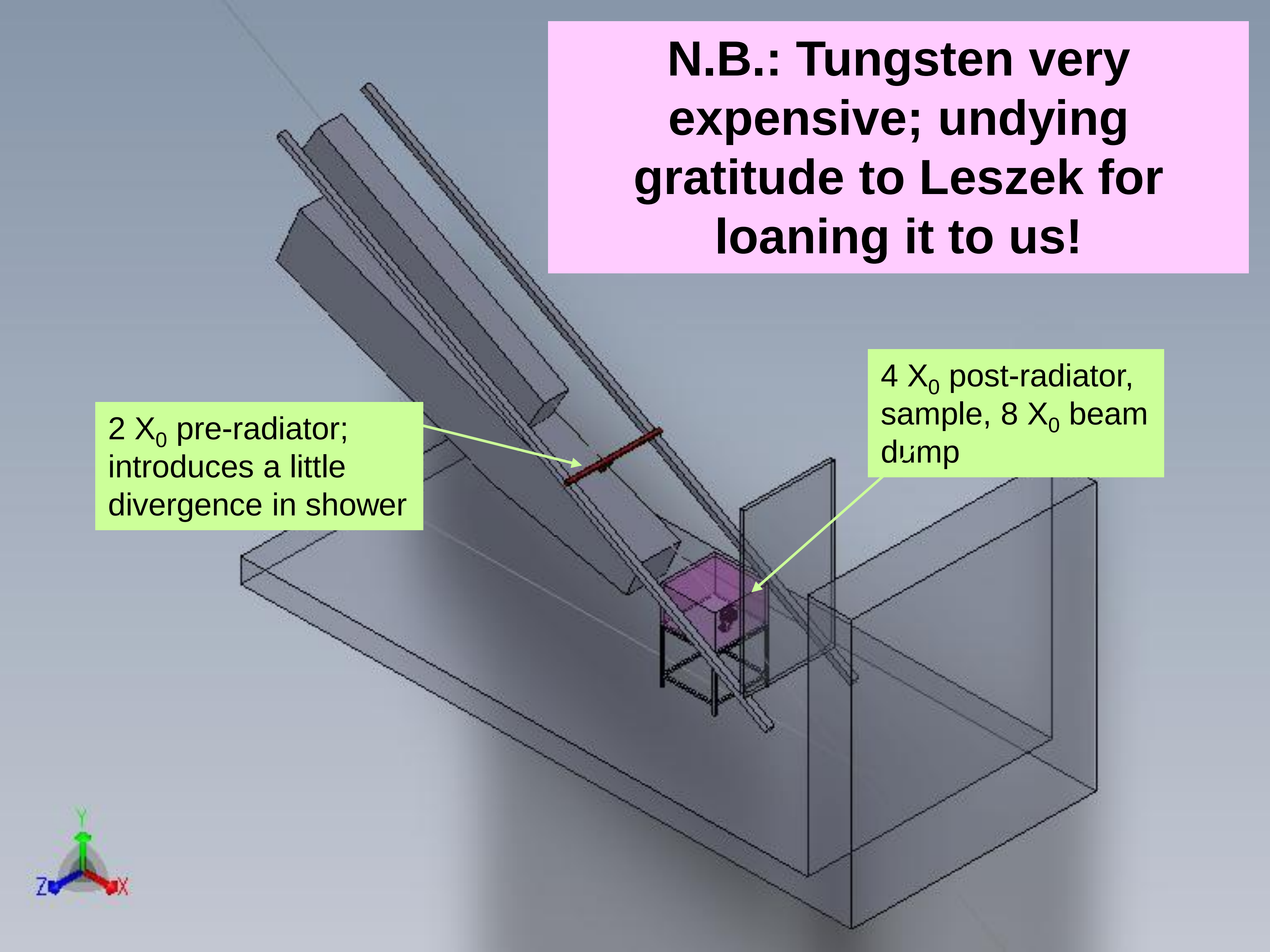
Hadronic Processes in EM Showers

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

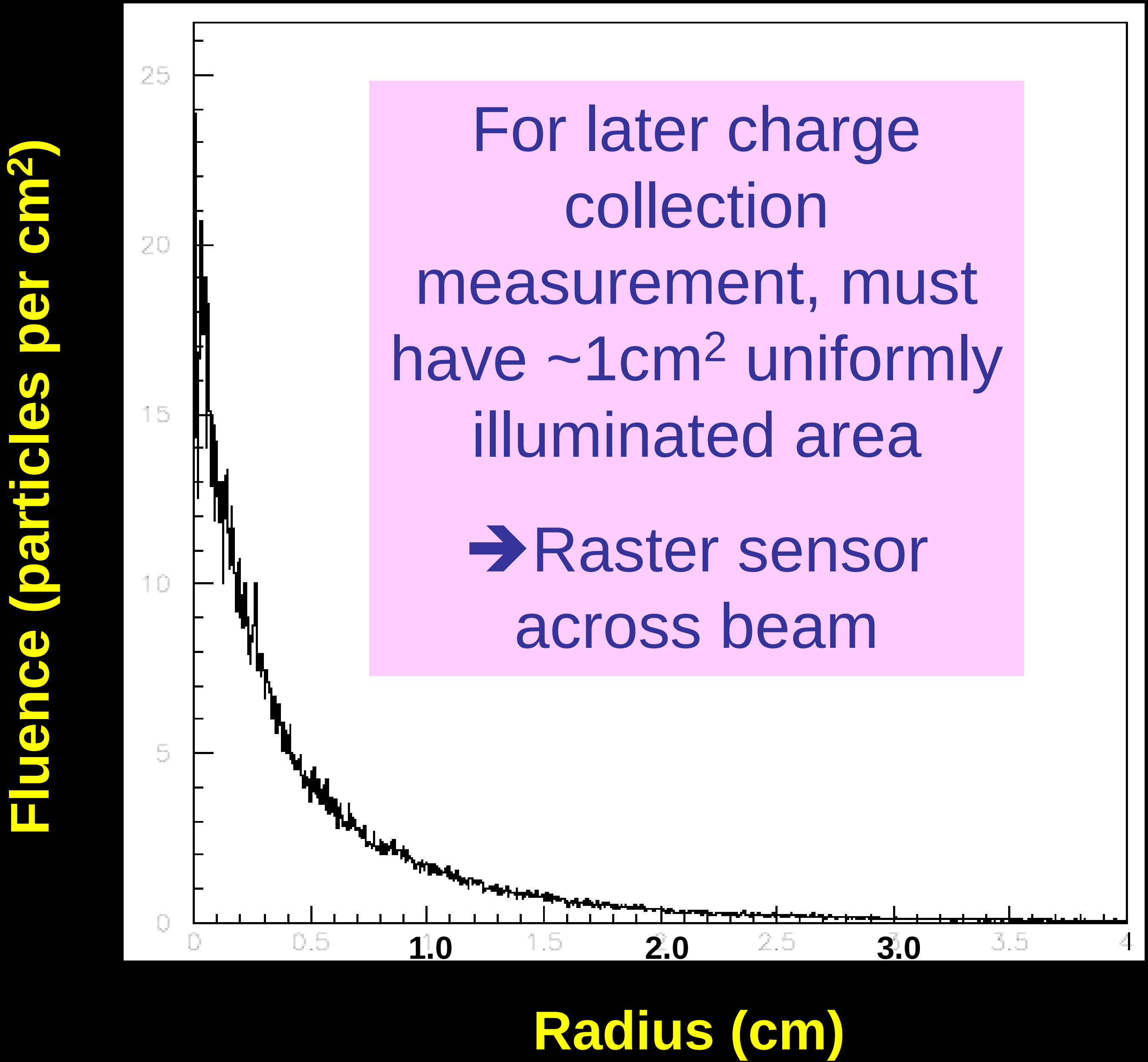
N.B.: Tungsten very expensive; undying gratitude to Leszek for loaning it to us!



2 X_0 pre-radiator; introduces a little divergence in shower

4 X_0 post-radiator, sample, 8 X_0 beam dump

Detector Fluence Distribution (per incident e$^-$)

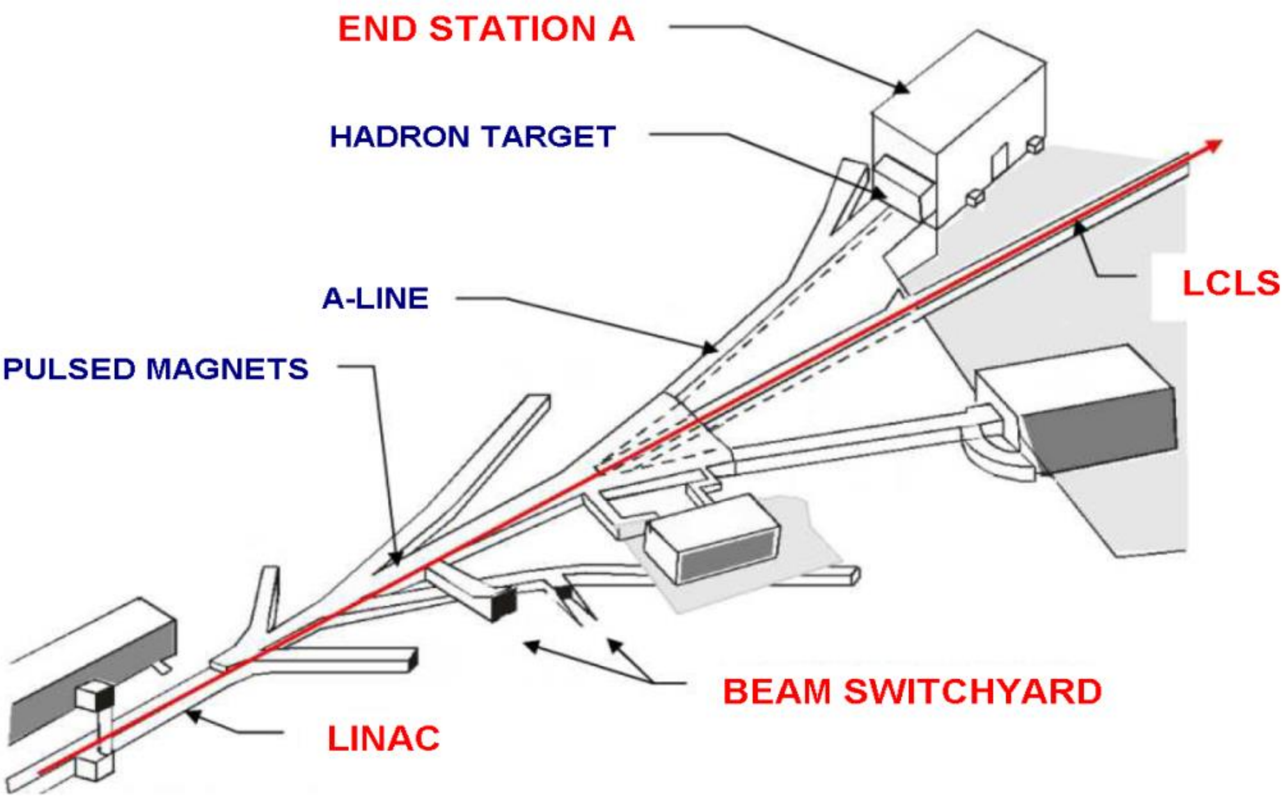


For later charge collection measurement, must have ~1cm^2 uniformly illuminated area

➔Raster sensor across beam

LCLS and ESA

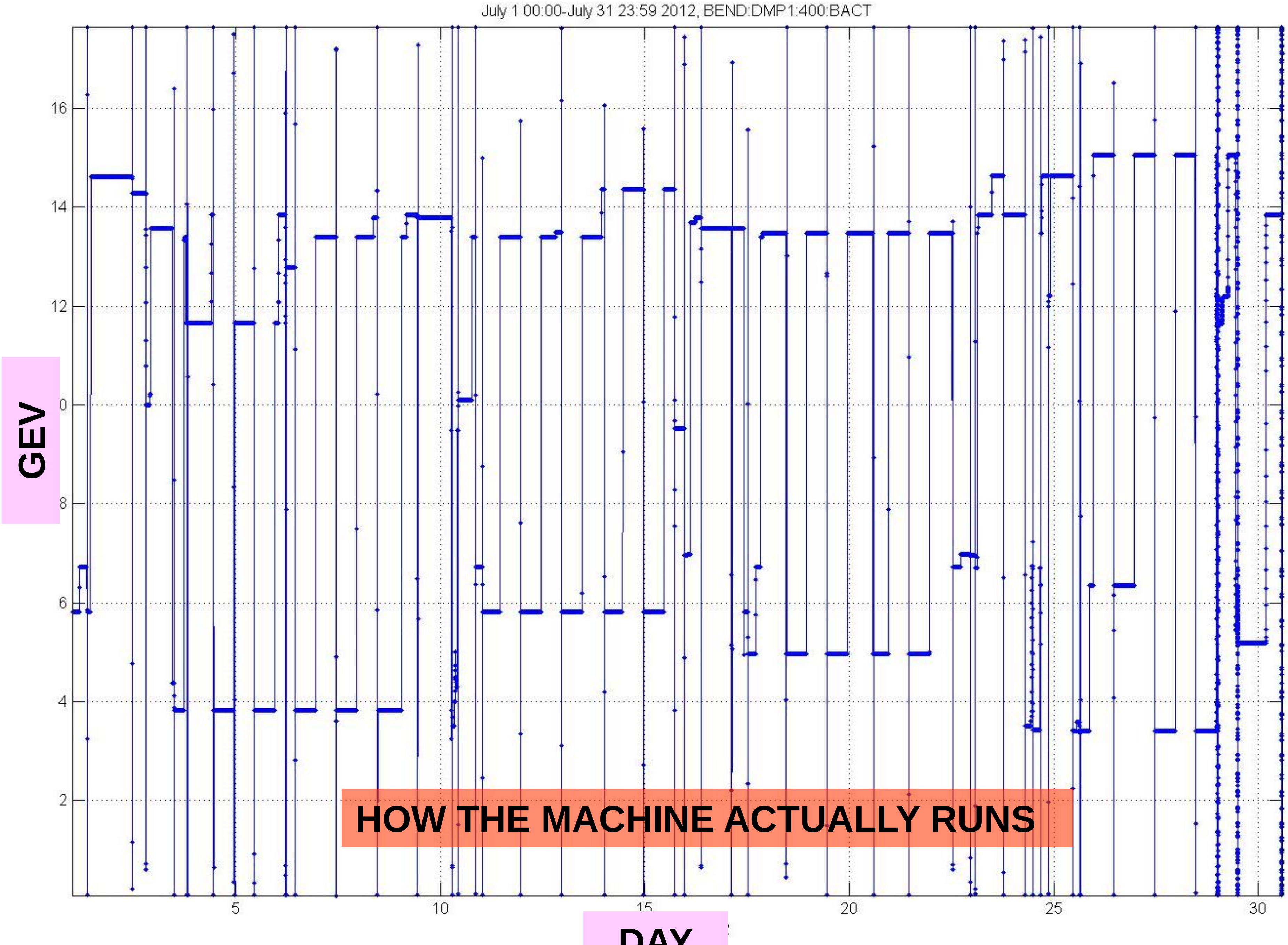
Use pulsed magnets in the beam switchyard to send beam in ESA.



ESTB parameters

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

Parameters		**ESA**
Energy	3..5-10.5 (for now)	~~15 GeV~~
Repetition Rate	Up to 10 Hz!	5 Hz
Charge per pulse	≤ 0.15 nC	~~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



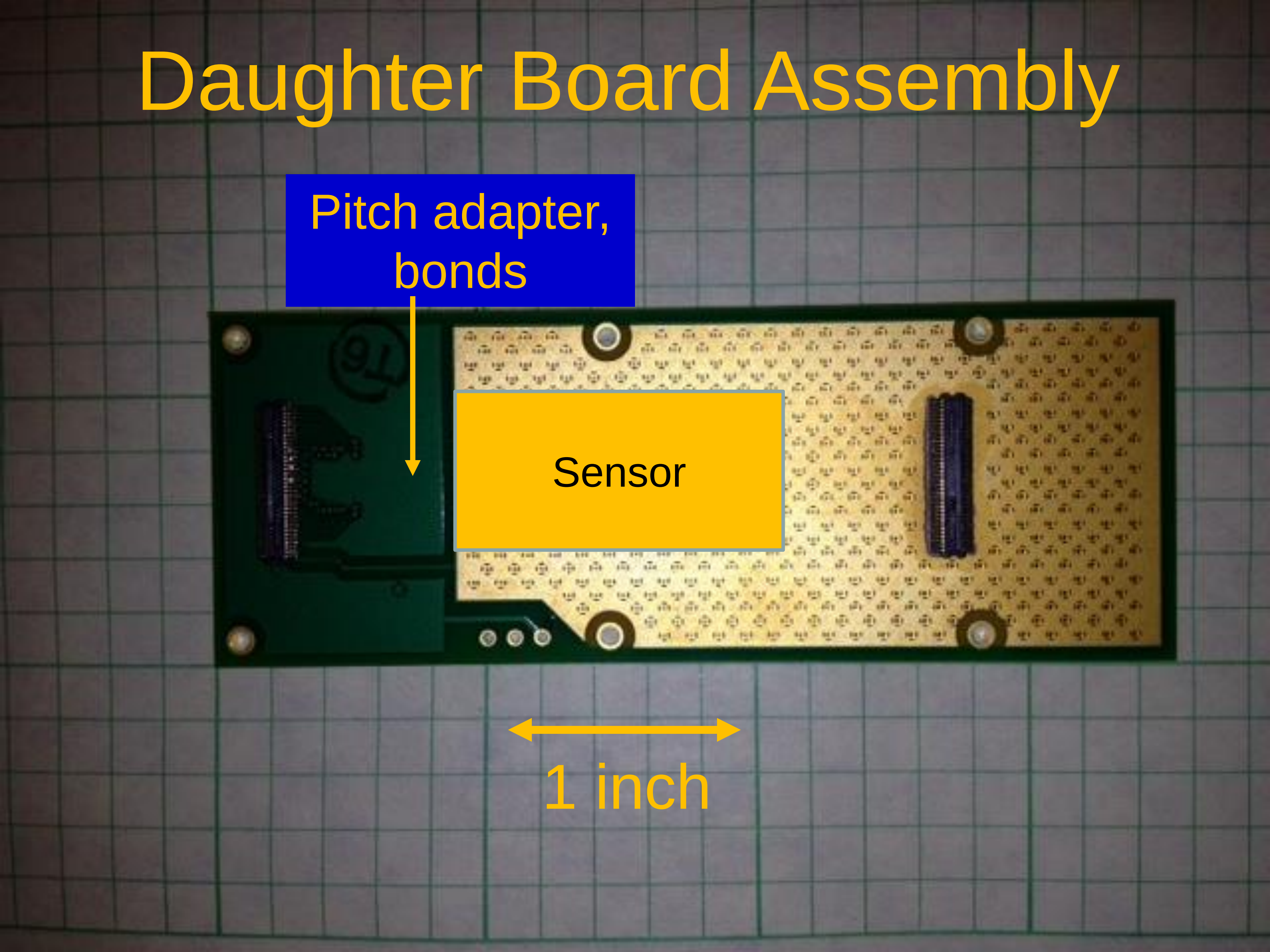
GEV

HOW THE MACHINE ACTUALLY RUNS

DAY

BEAM

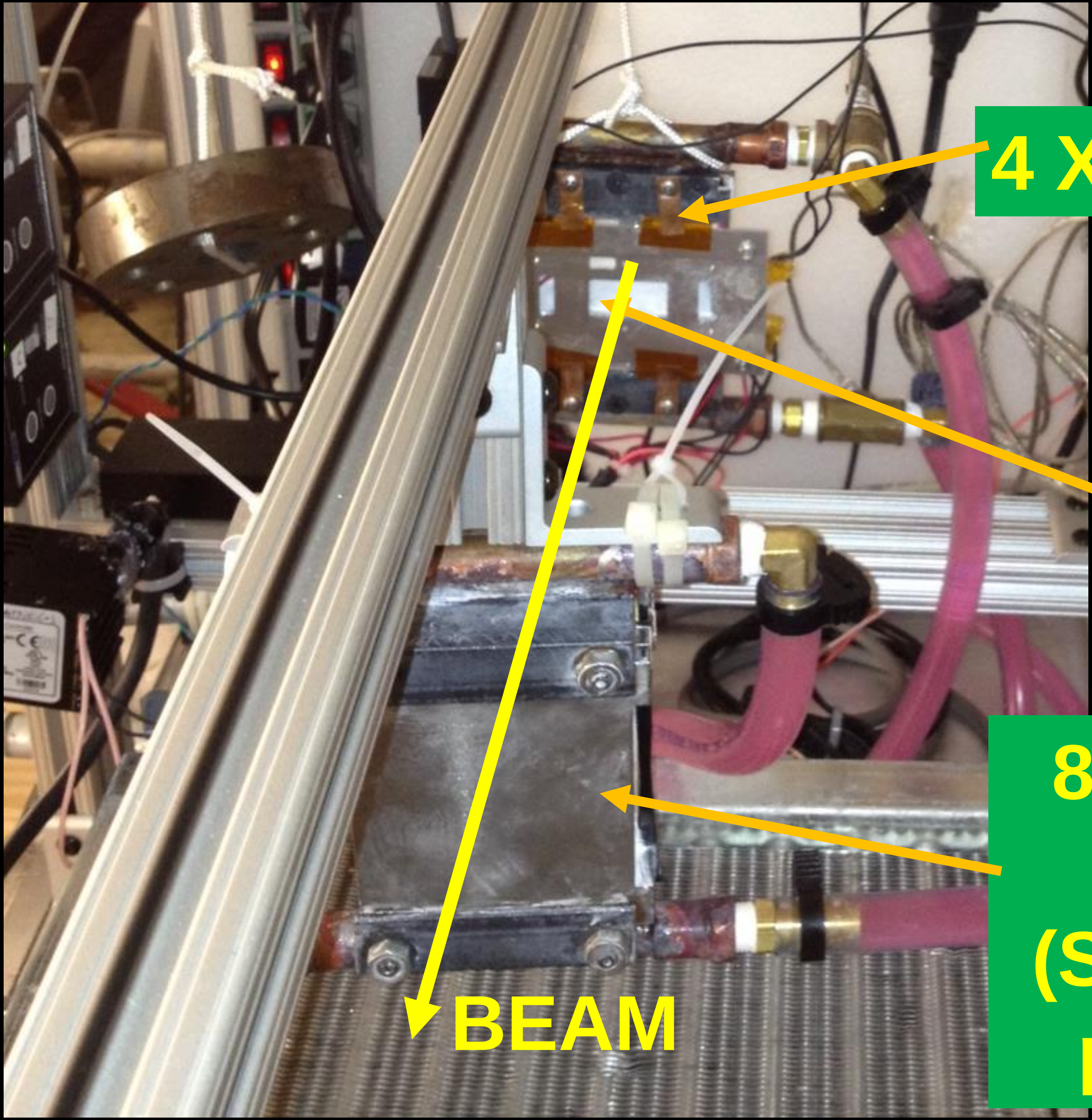
Daughter Board Assembly



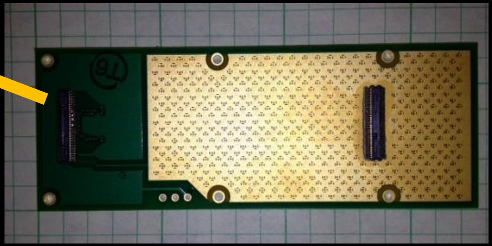
Pitch adapter, bonds

Sensor

1 inch



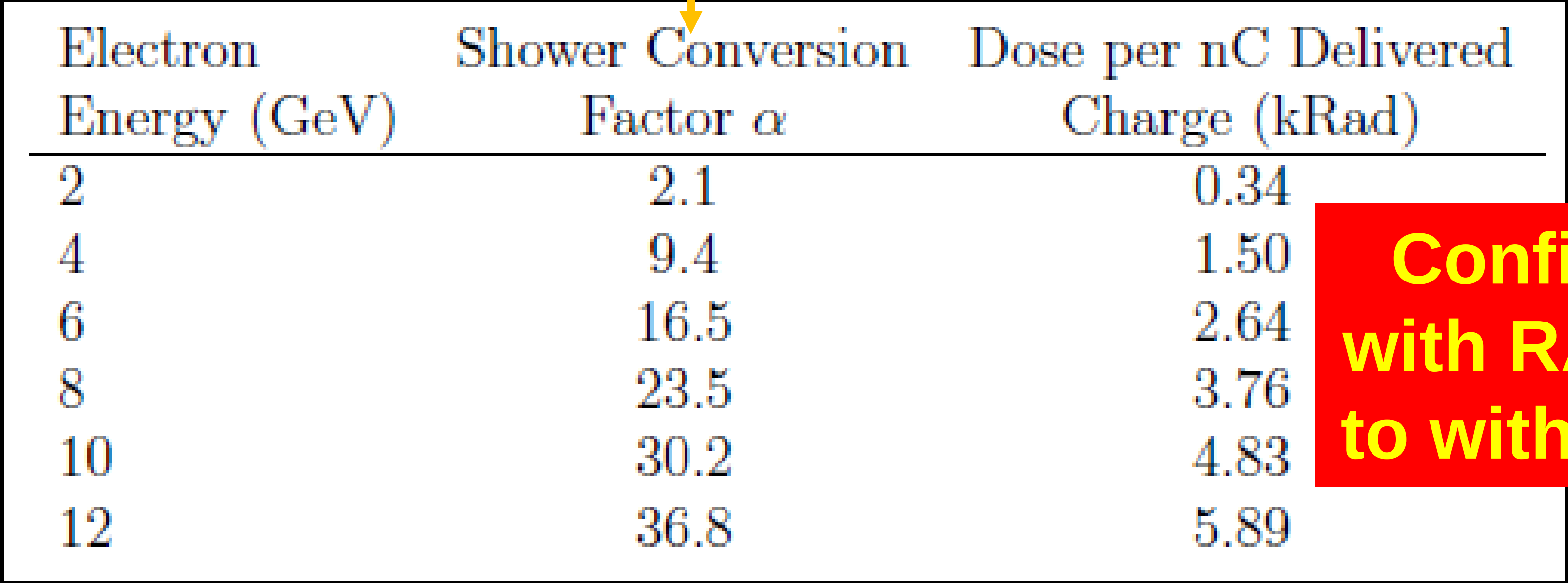
4 X_0 Radiator



8 X_0 Beam Dump (Slides into position)

Dose Rates (Including 1 cm^2 Rastering)

Mean fluence per incident e^-



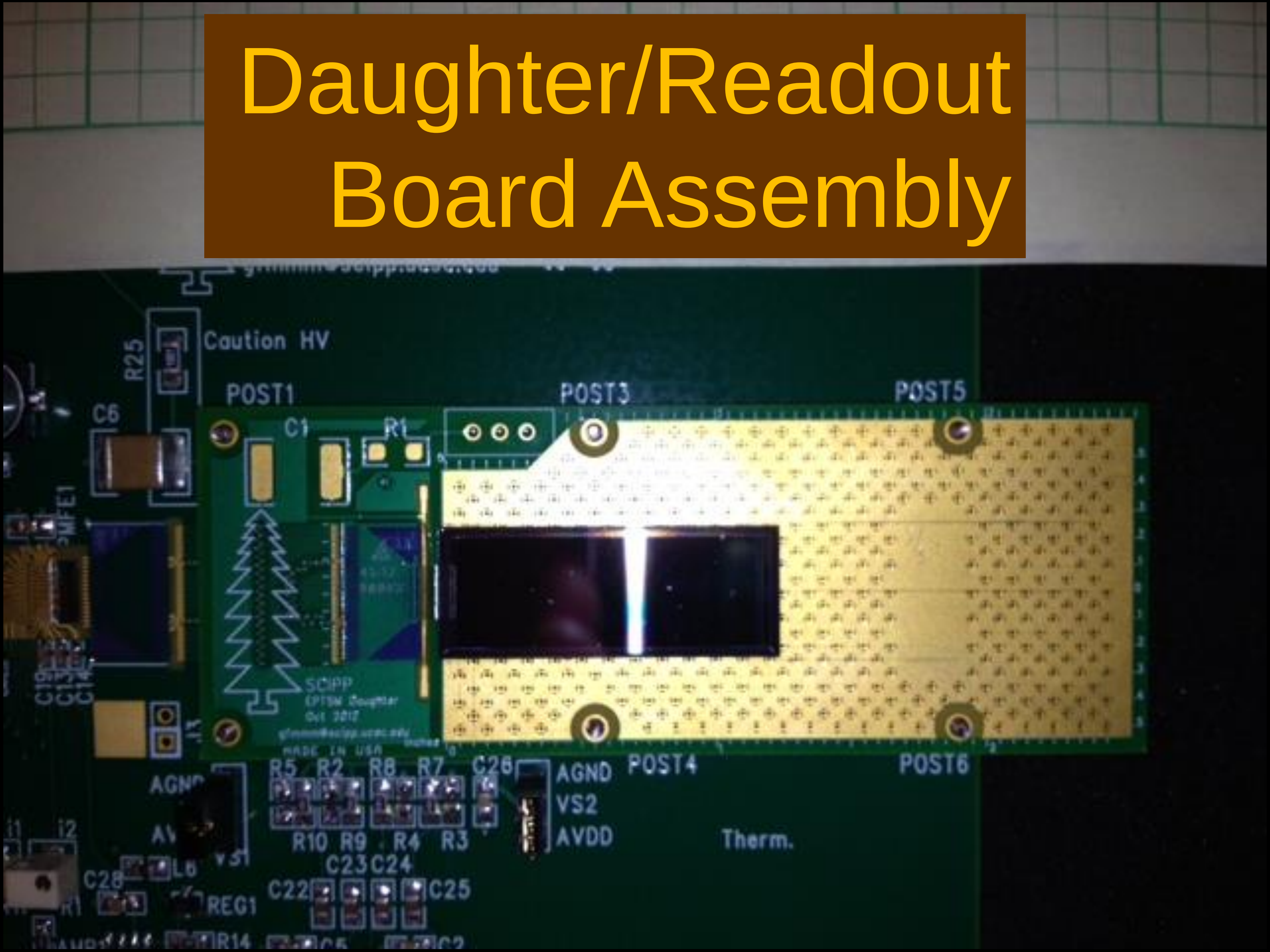
Electron Energy (GeV)	Shower Conversion Factor α	Dose per nC Delivered Charge (kRad)
2	2.1	0.34
4	9.4	1.50
6	16.5	2.64
8	23.5	3.76
10	30.2	4.83
12	36.8	5.89

Confirmed with RADFET to within 10%

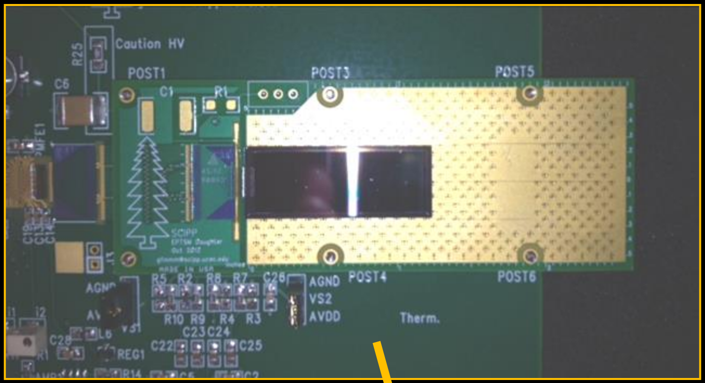
Maximum dose rate (10.6 GeV; 10 Hz; 150 pC per pulse):

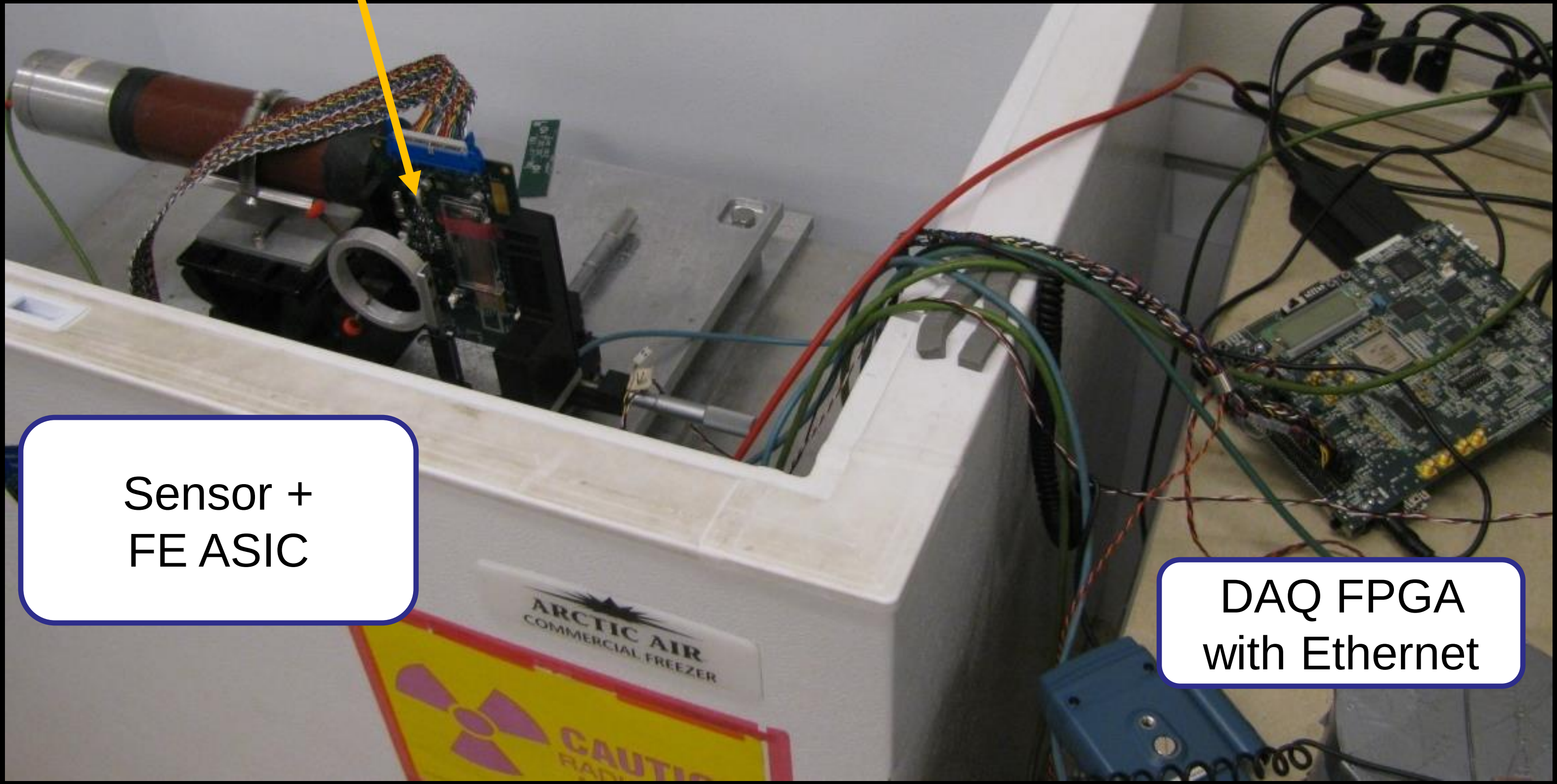
28 Mrad per hour

Daughter/Readout Board Assembly



Charge Collection Apparatus



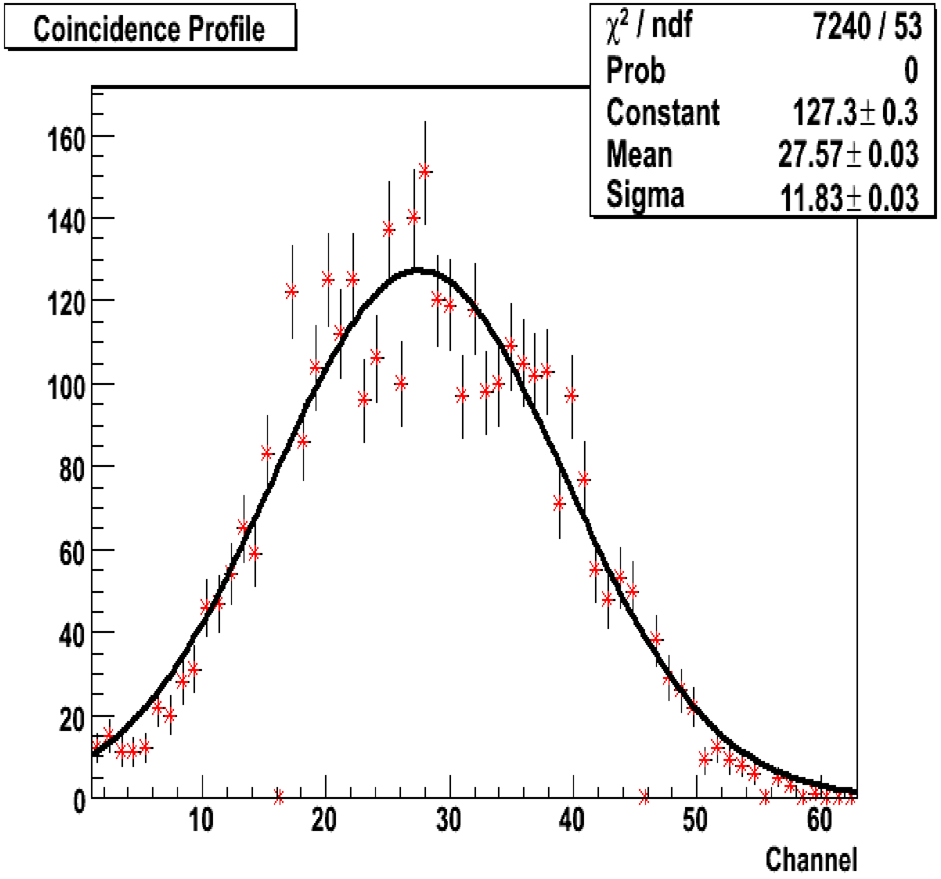


Sensor +
FE ASIC

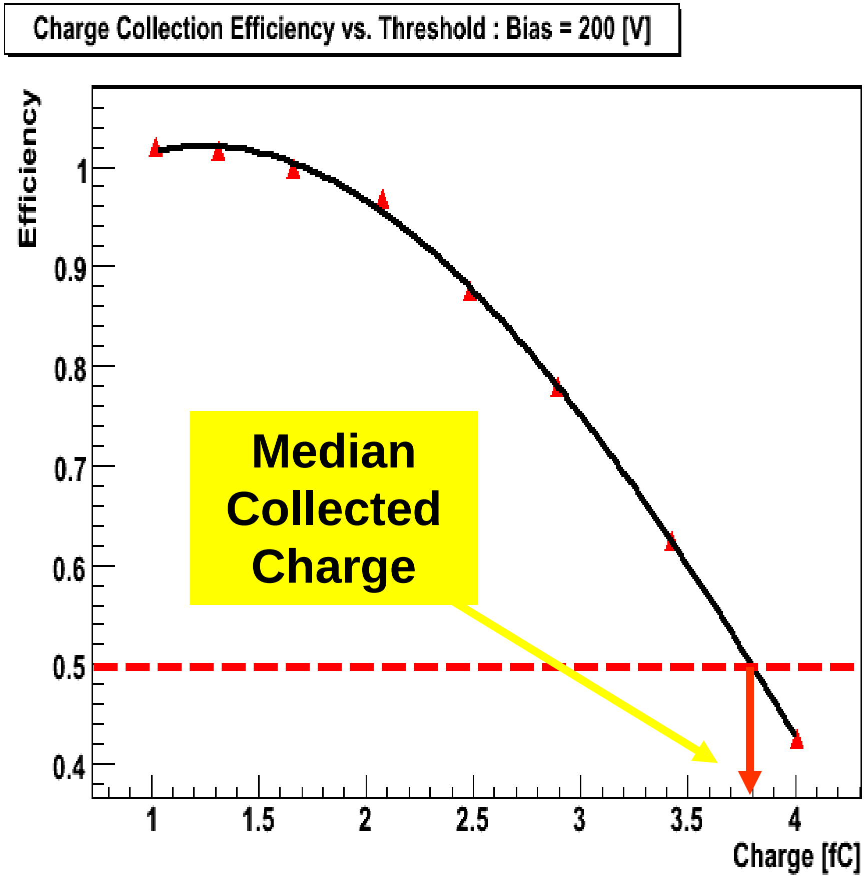
DAQ FPGA
with Ethernet

Charge Collection Measurement

2.3 MeV e^- through sensor into scintillator



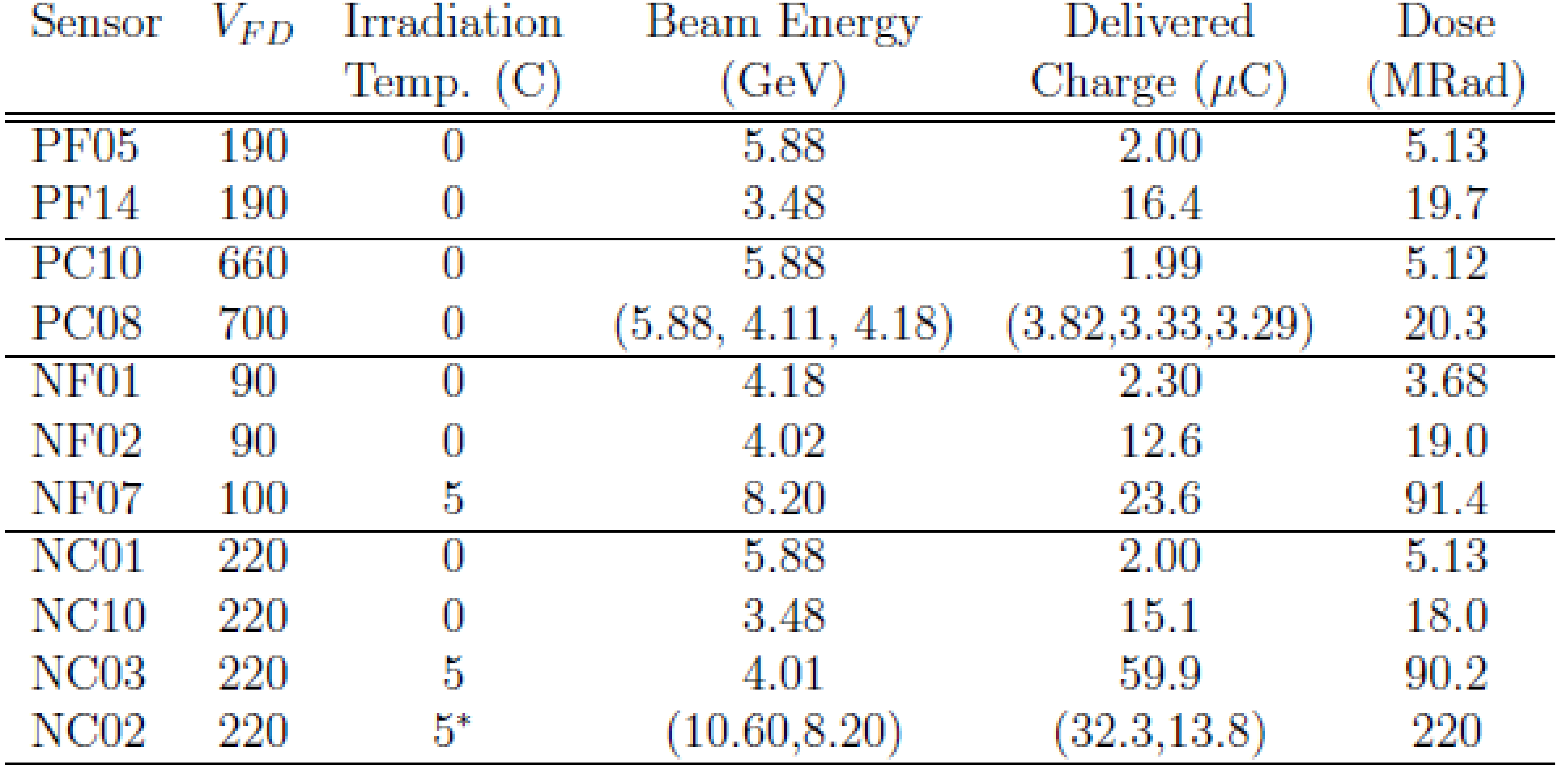
Channel-over-threshold profile



Efficiency vs. threshold

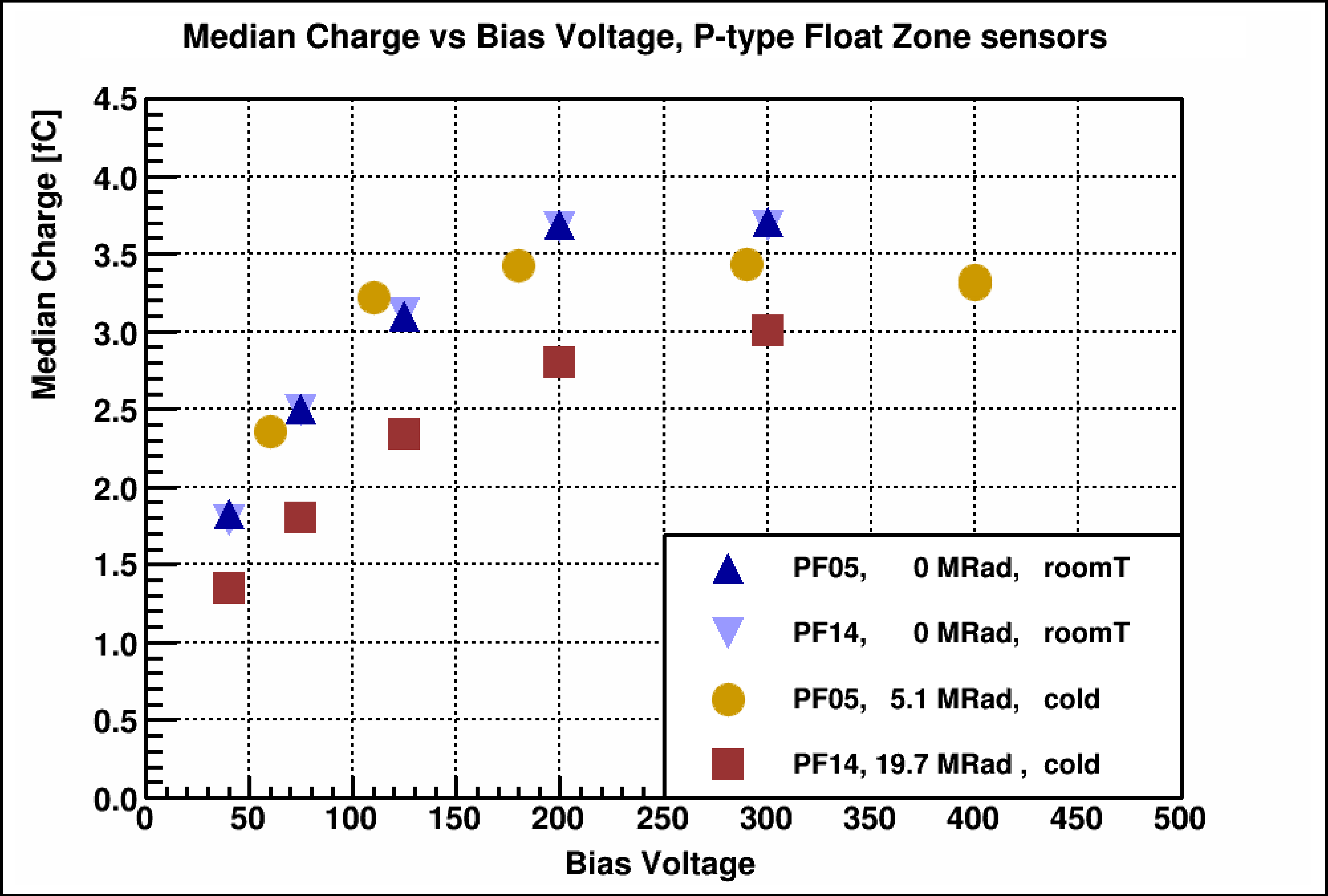
T506 Doses

“P” = p-type “N” = n-type
“F” = float zone “C” = Czochralski

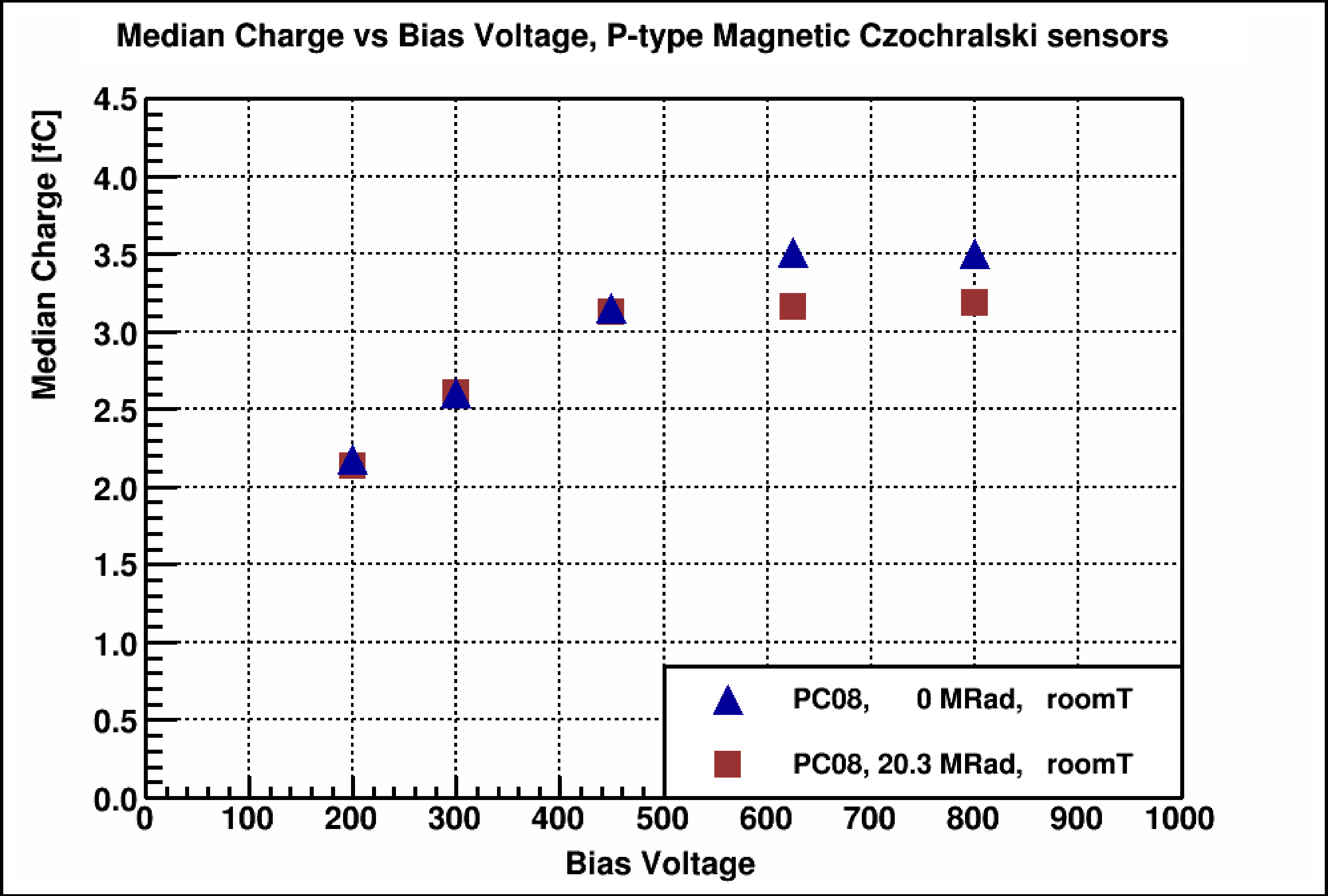


Sensor	V_{FD}	Irradiation Temp. (C)	Beam Energy (GeV)	Delivered Charge (μC)	Dose (MRad)
PF05	190	0	5.88	2.00	5.13
PF14	190	0	3.48	16.4	19.7
PC10	660	0	5.88	1.99	5.12
PC08	700	0	(5.88, 4.11, 4.18)	(3.82,3.33,3.29)	20.3
NF01	90	0	4.18	2.30	3.68
NF02	90	0	4.02	12.6	19.0
NF07	100	5	8.20	23.6	91.4
NC01	220	0	5.88	2.00	5.13
NC10	220	0	3.48	15.1	18.0
NC03	220	5	4.01	59.9	90.2
NC02	220	5*	(10.60,8.20)	(32.3,13.8)	220

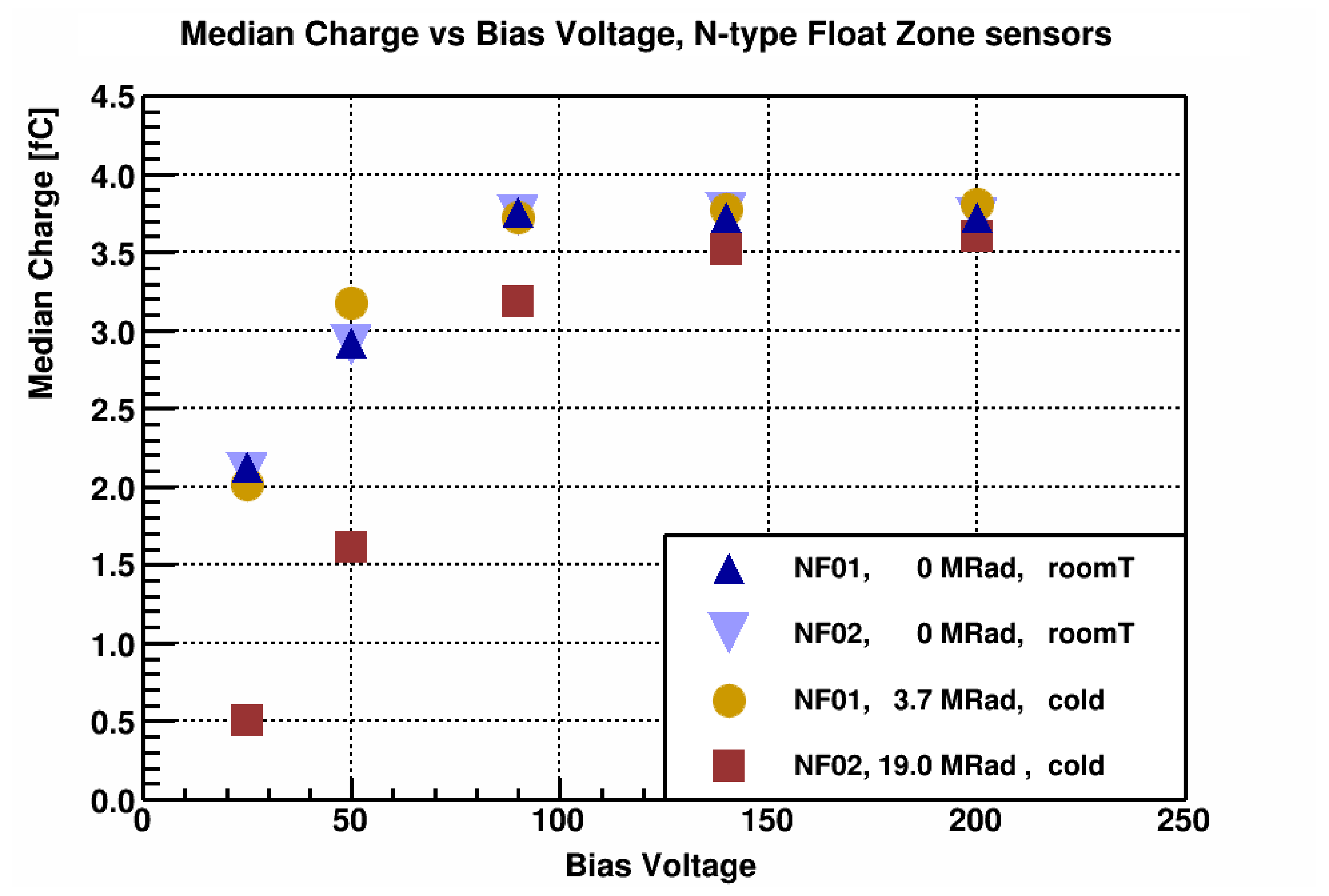
Results: PF sensors



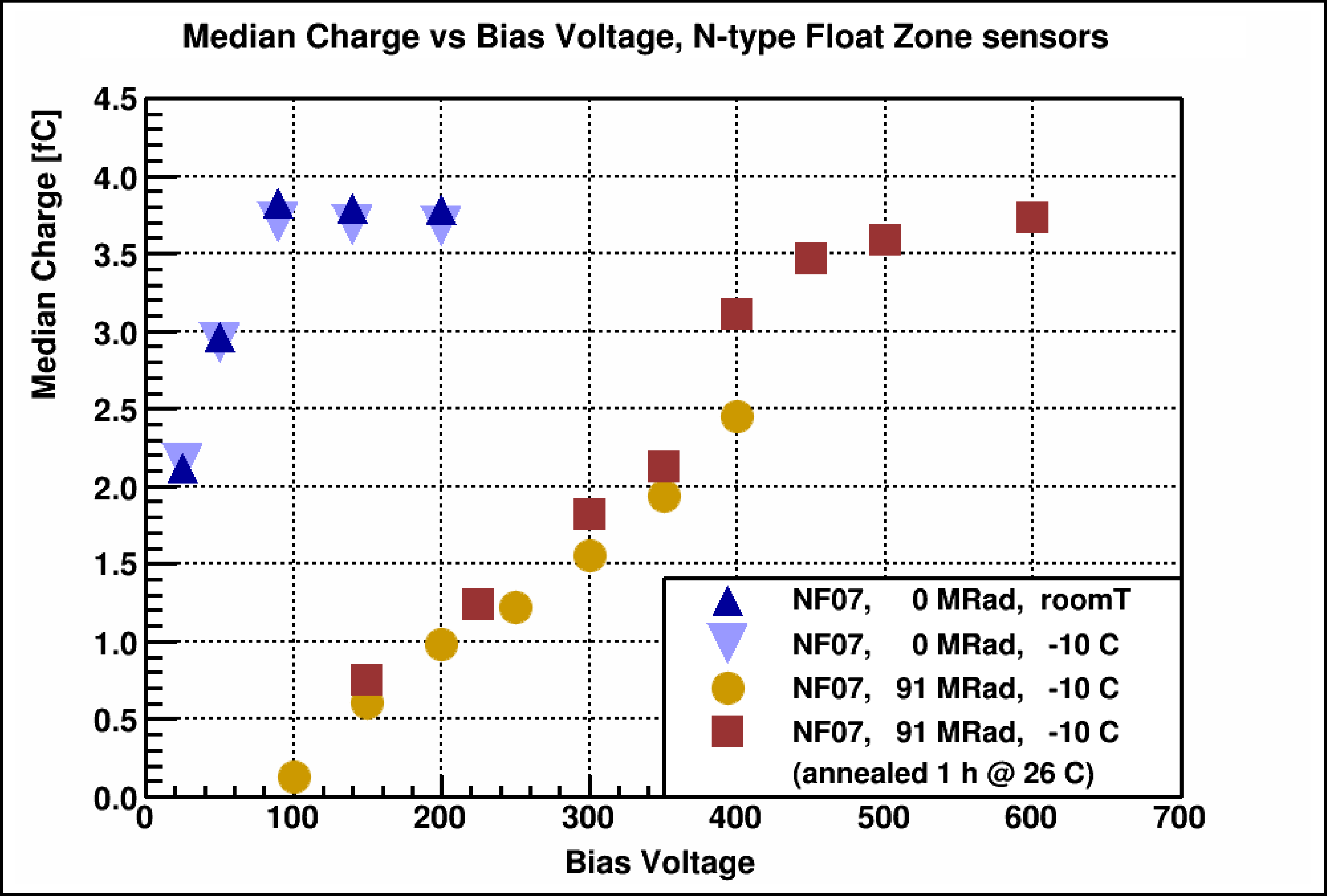
Results: PC sensors



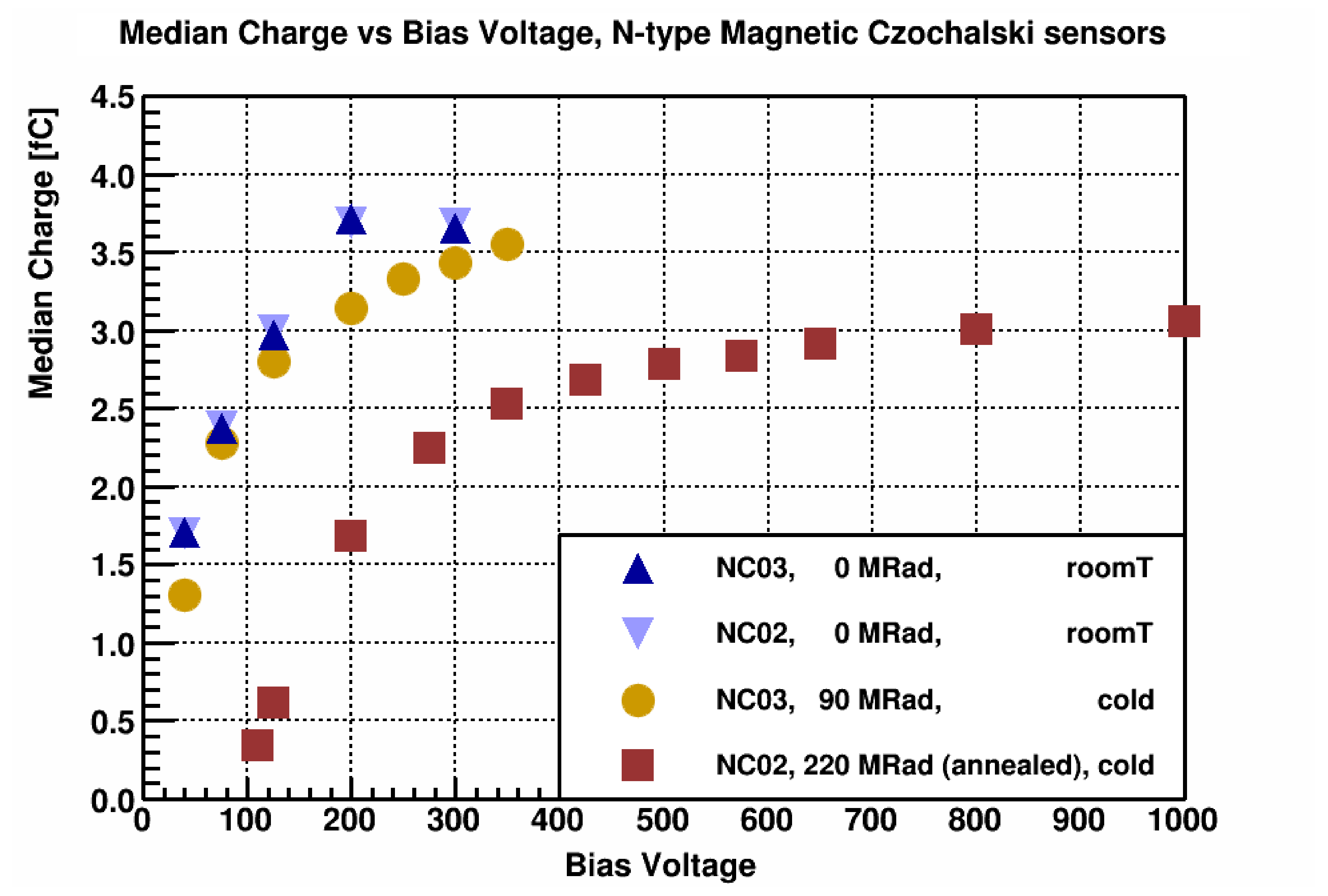
Results: NF sensors low dose



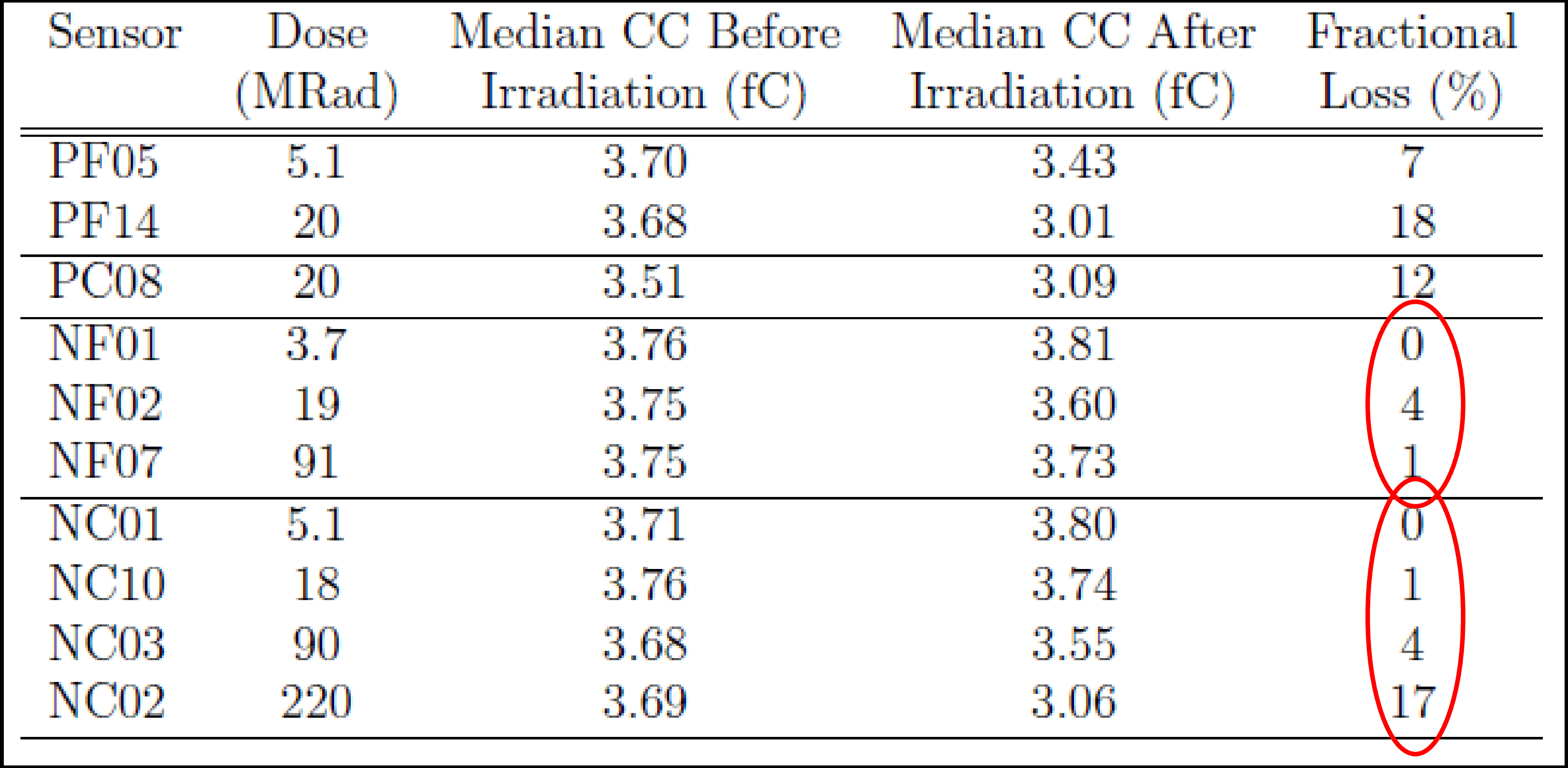
Results: NF sensors high dose



Results: NC sensors



Summary of Results by Sensor Type



Sensor	Dose (MRad)	Median CC Before Irradiation (fC)	Median CC After Irradiation (fC)	Fractional Loss (%)
PF05	5.1	3.70	3.43	7
PF14	20	3.68	3.01	18
PC08	20	3.51	3.09	12
NF01	3.7	3.76	3.81	0
NF02	19	3.75	3.60	4
NF07	91	3.75	3.73	1
NC01	5.1	3.71	3.80	0
NC10	18	3.76	3.74	1
NC03	90	3.68	3.55	4
NC02	220	3.69	3.06	17

Summary and Conclusions

- We have completed the first irradiation damage study at SLAC ESTB (article submitted to NIM)
- N-bulk sensors show promise
- Need to carry out annealing studies with CV/IV measurements on selected sensors
- Want to confirm results, go to higher fluence
- Further runs with other sensor technologies (GaAs, CVD diamond?) [US funding issues…]
- One scenario: Si in most of BeamCal detector, more costly/higher-risk technologies in highest-dose regions?