Initial Results from the SLAC ESTB T-506 Irradiation Study

International Workshop on Future Linear Colliders
University of Tokyo, 11-15 November 2013

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T-506 Motivation

BeamCal maximum dose ~100 MRad/yr

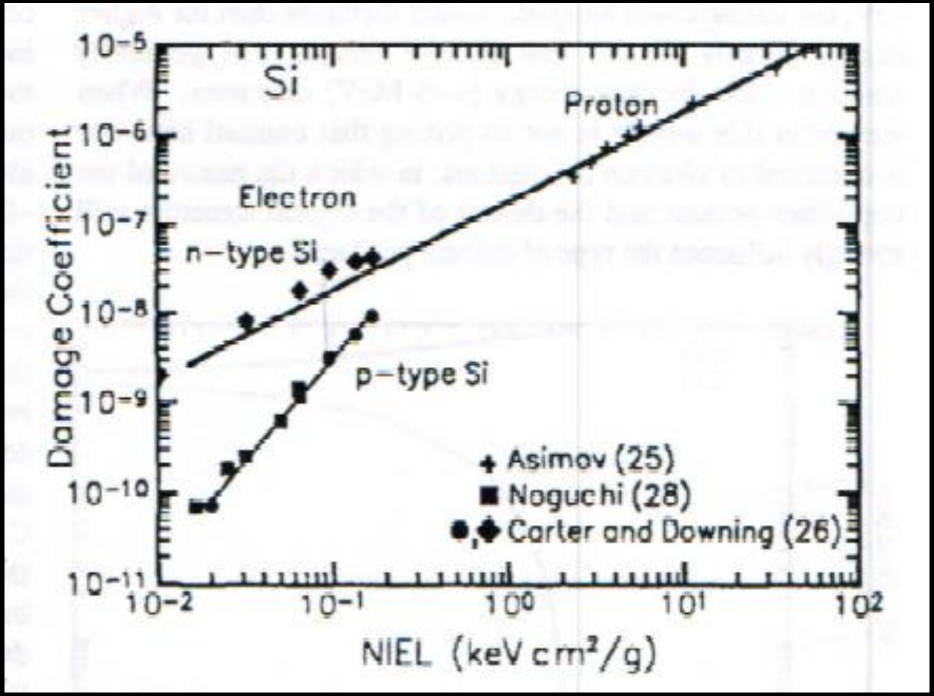
Beam Calorimeter is a sizable: ~2 m^2 of sensors.

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
2×10^{-2}	0.5 MeV
5×10^{-2}	2 MeV
1×10^{-1}	10 MeV
2×10^{-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?

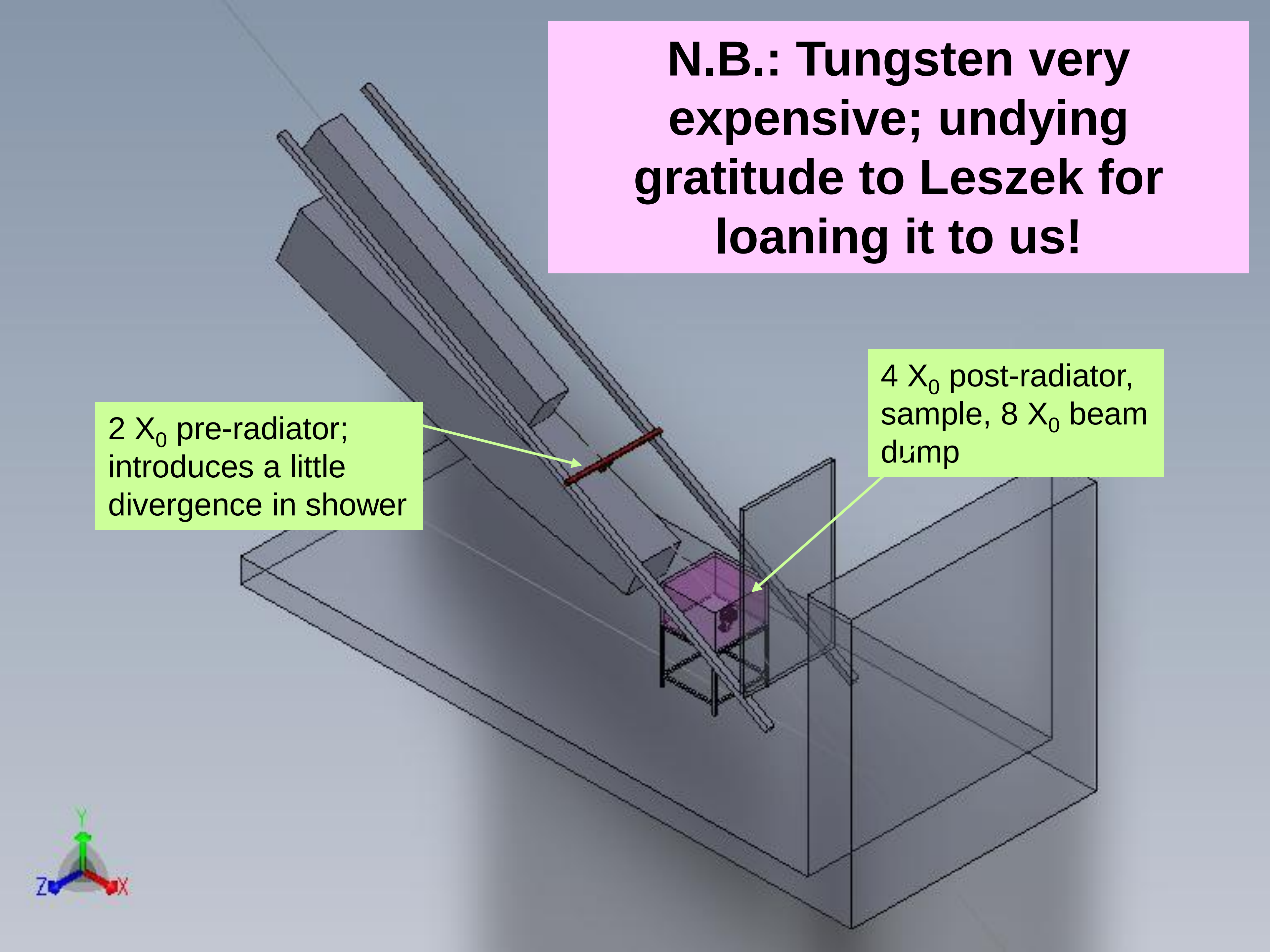
Hadronic Processes in EM Showers

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

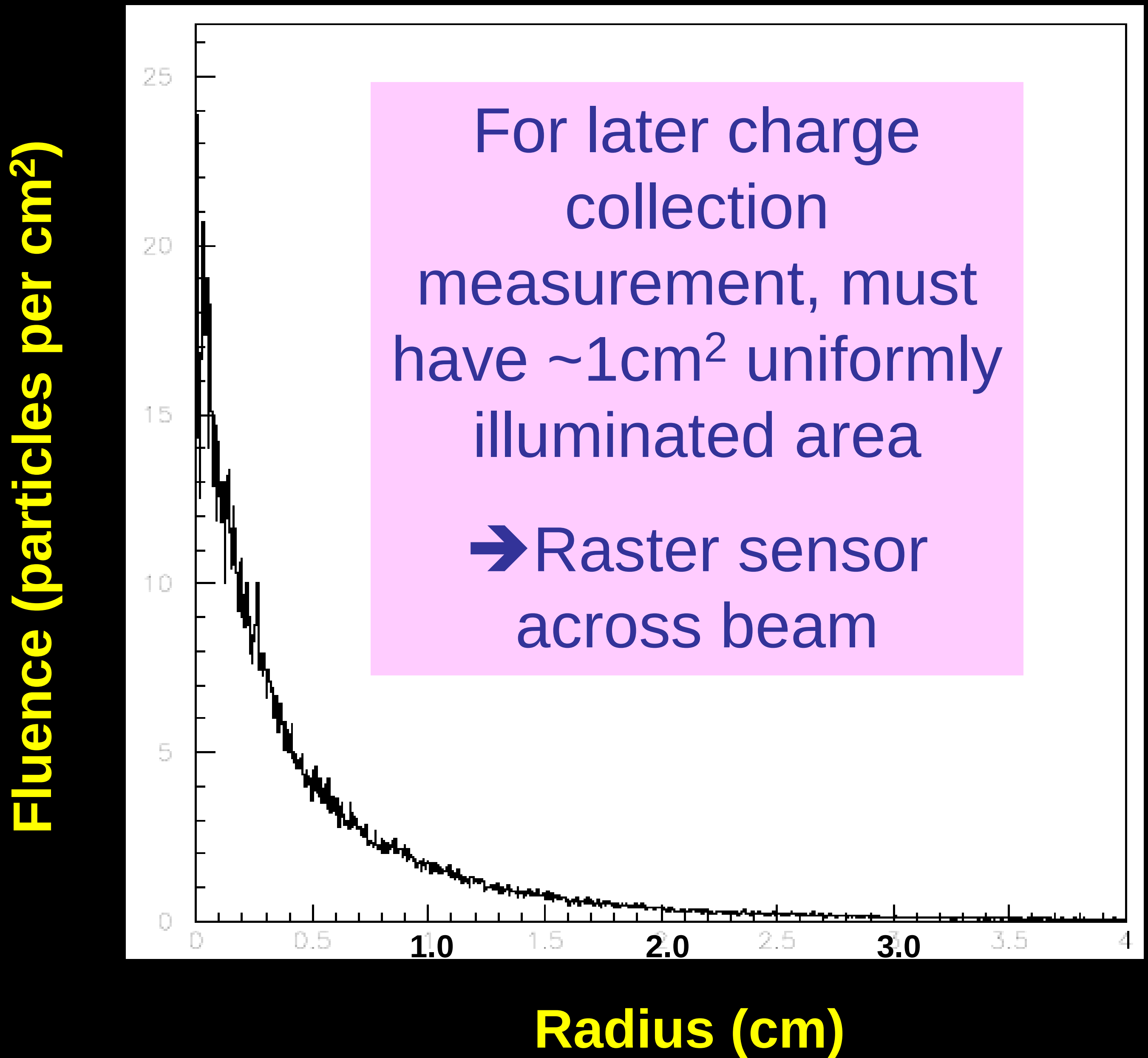
- Nuclear ("giant dipole") resonances
  Resonance at 10-20 MeV ($\sim E_{critical}$)
- Photoproduction
  Threshold seems to be about 200 MeV
- Nuclear Compton scattering
  Threshold at about 10 MeV; Δ resonance at 340 MeV

➔ 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!

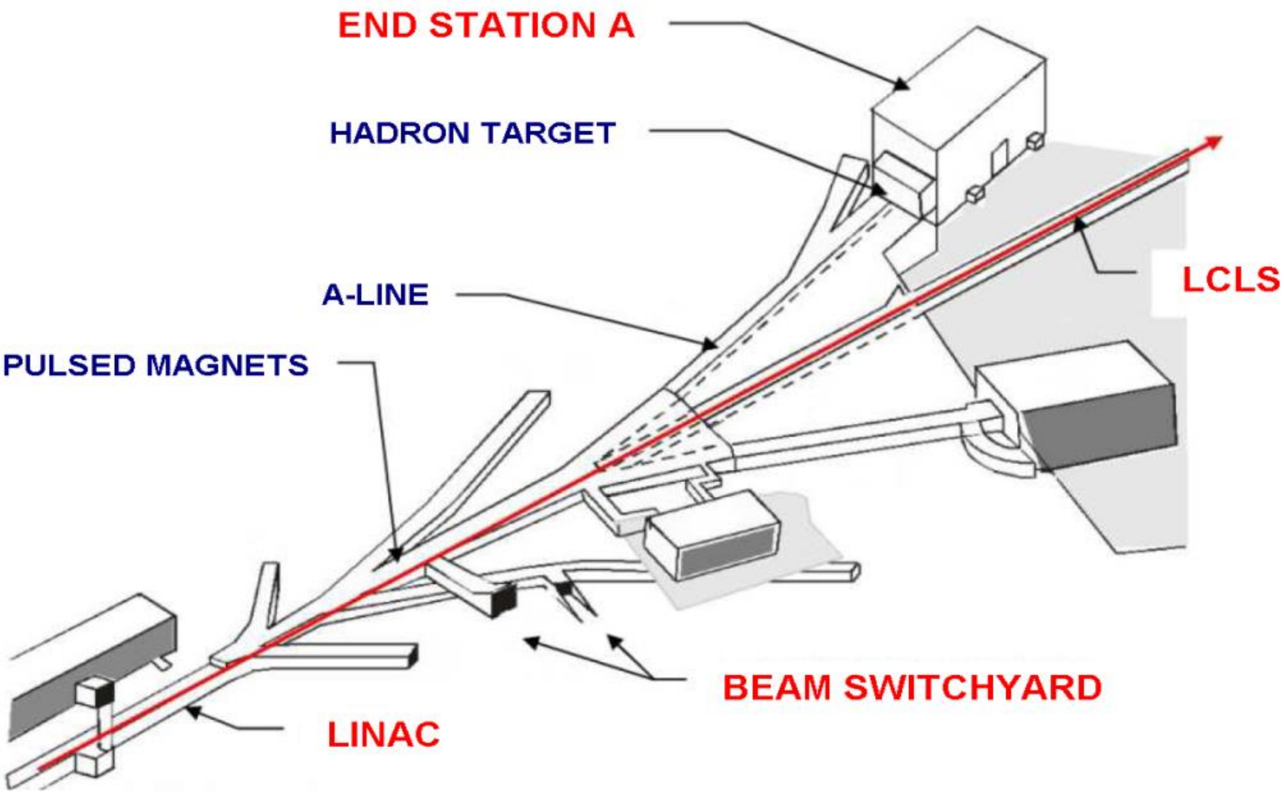


Detector Fluence Distribution (per incident e^-)



LCLS and ESA

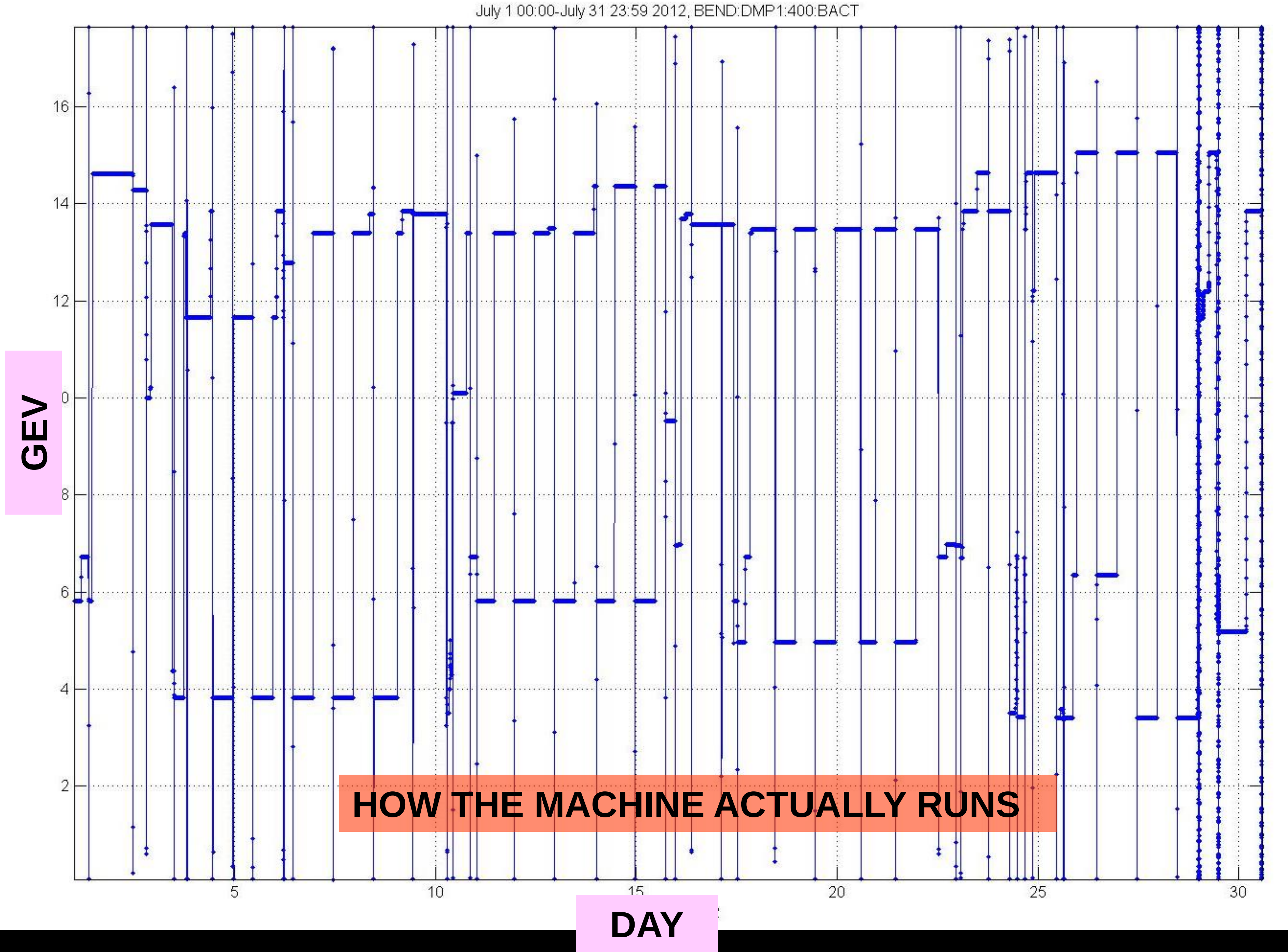
Use pulsed magnets in the beam switchyard to send beam in ESA.



ESTB parameters

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

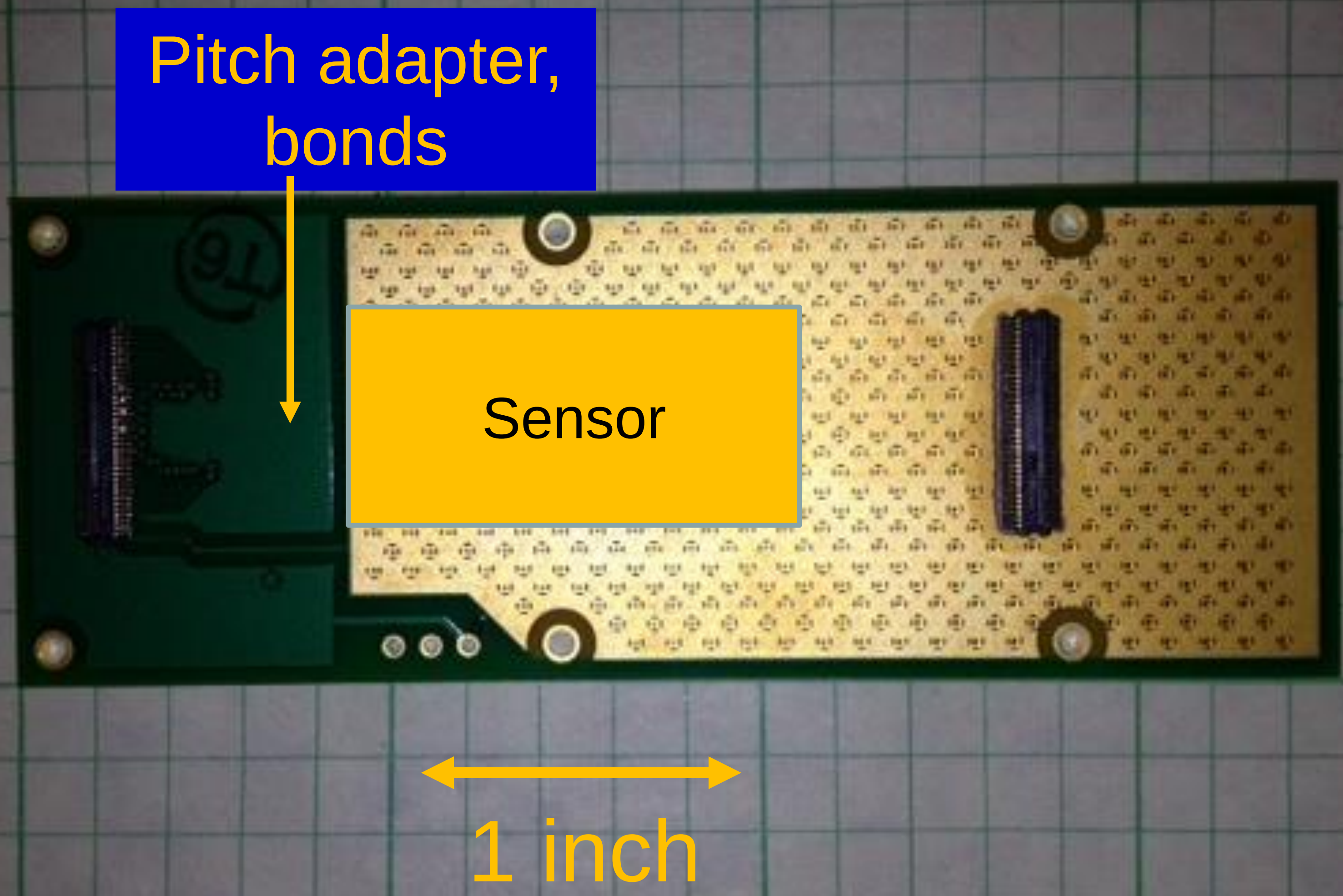
Parameters		ESA
Energy	3..5-10.5 (for now)	~~15 GeV~~
Repetition Rate	Up to 10 Hz!	5 Hz
Charge per pulse	≤ 0.15 nC	~~0.35 nC~~
Energy spread, σ_E /E		0.02%
Bunch length rms		100 μm
Emittance rms ($\gamma\varepsilon_x$,$\gamma\varepsilon_y$)		(4, 1) 10^{-6} m-rad
Spot size at waist ($\sigma_{x,y}$)		< 10 μm
Drift Space available for experimental apparatus		60 m
Transverse space available for experimental apparatus		5 x 5 m

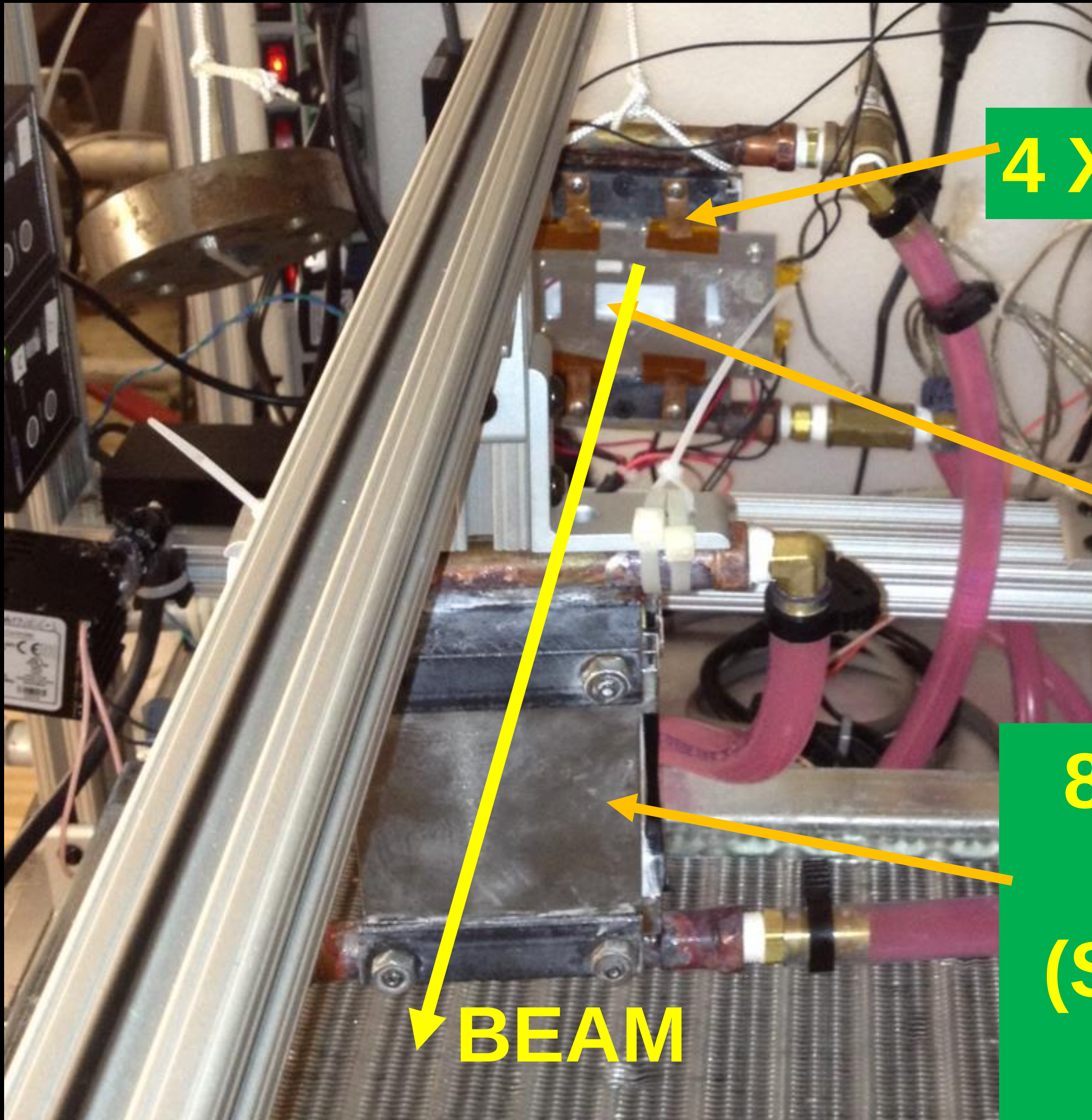


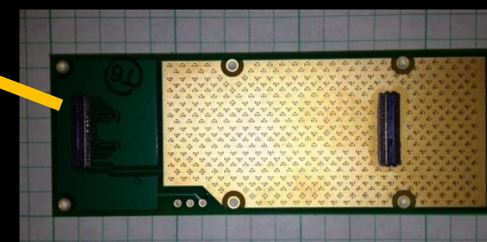
July 1 00:00-July 31 23:59 2012, BEND:DMP1:400:BACT
GEV
DAY
HOW THE MACHINE ACTUALLY RUNS


BEAM
CAUTION

Daughter Board Assembly




4 X_0 Radiator
BEAM
8 X_0 Beam Dump (Slides into position)



Dose Rates (Including 1 cm^2 Rastering)

Mean fluence per incident e^-

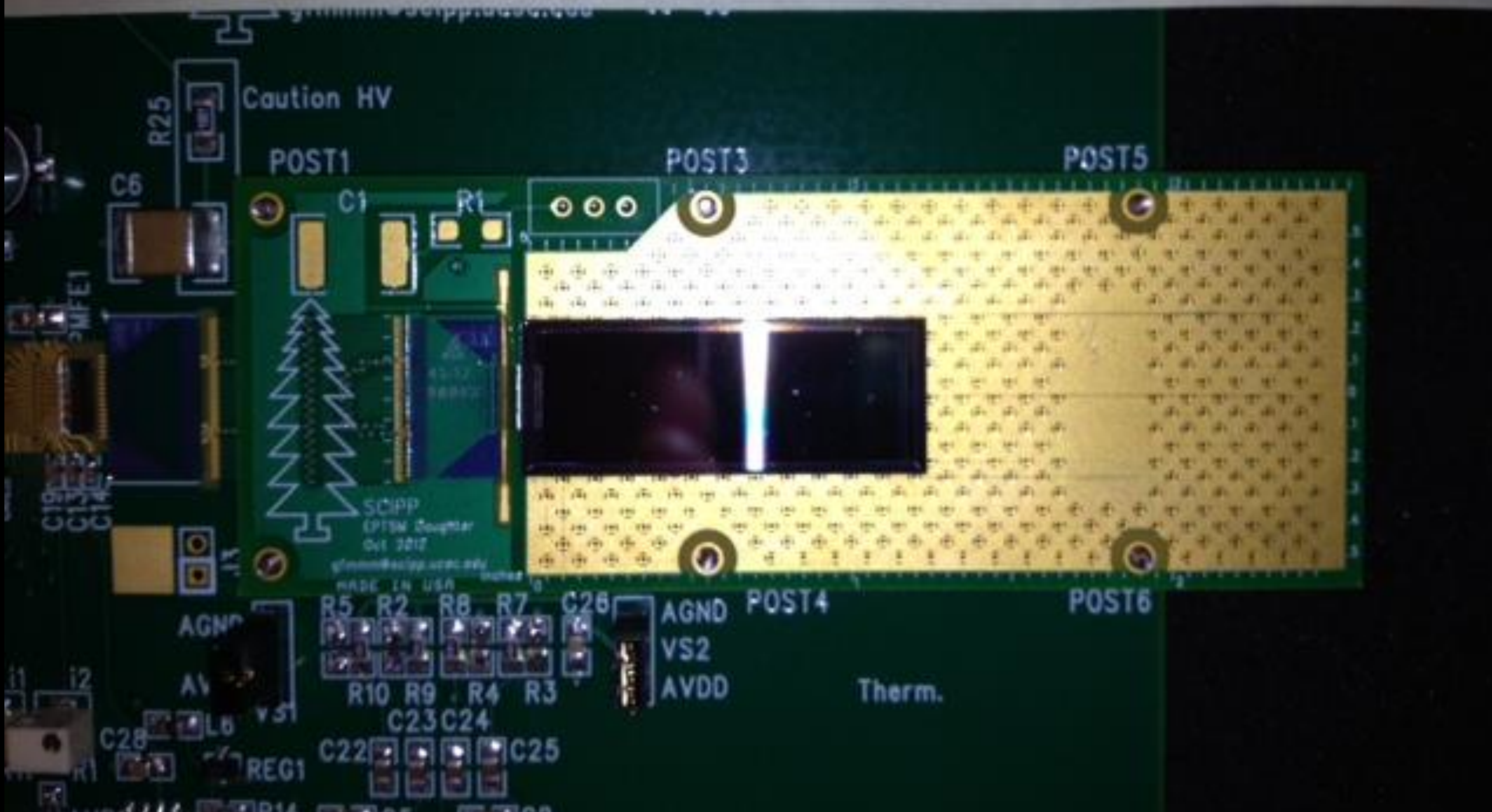
Electron Energy (GeV)	Shower Conversion Factor α	Dose per nC Delivered Charge (kRad)
2	2.1	0.34
4	9.4	1.50
6	16.5	2.64
8	23.5	3.76
10	30.2	4.83
12	36.8	5.89

Confirmed with RADFET to within 10%

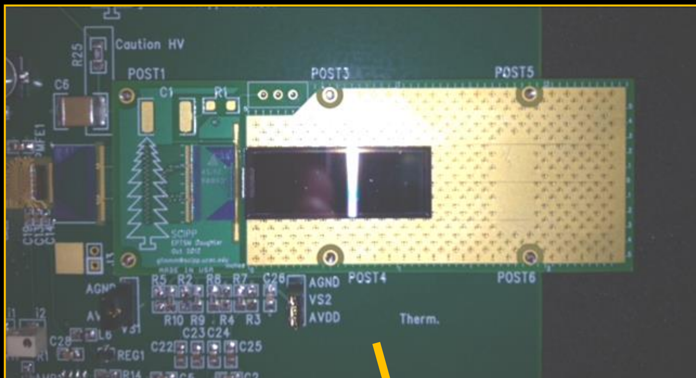
Maximum dose rate (10.6 GeV; 10 Hz; 150 pC per pulse):

28 Mrad per hour

Daughter/Readout Board Assembly

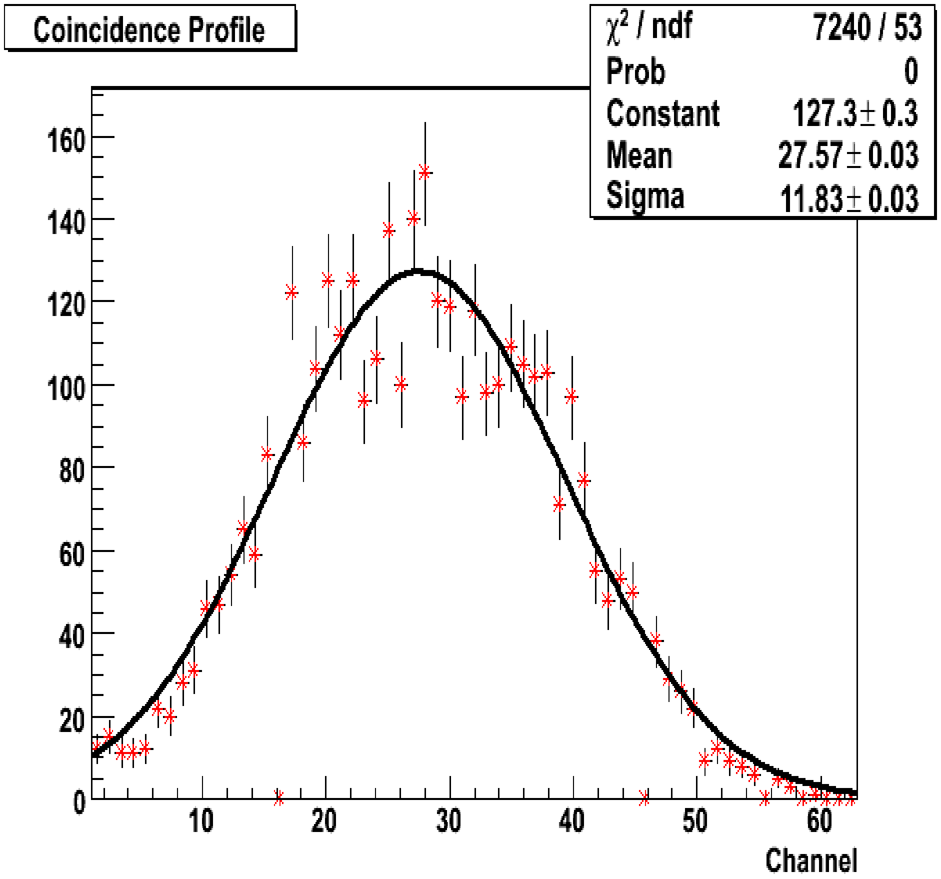


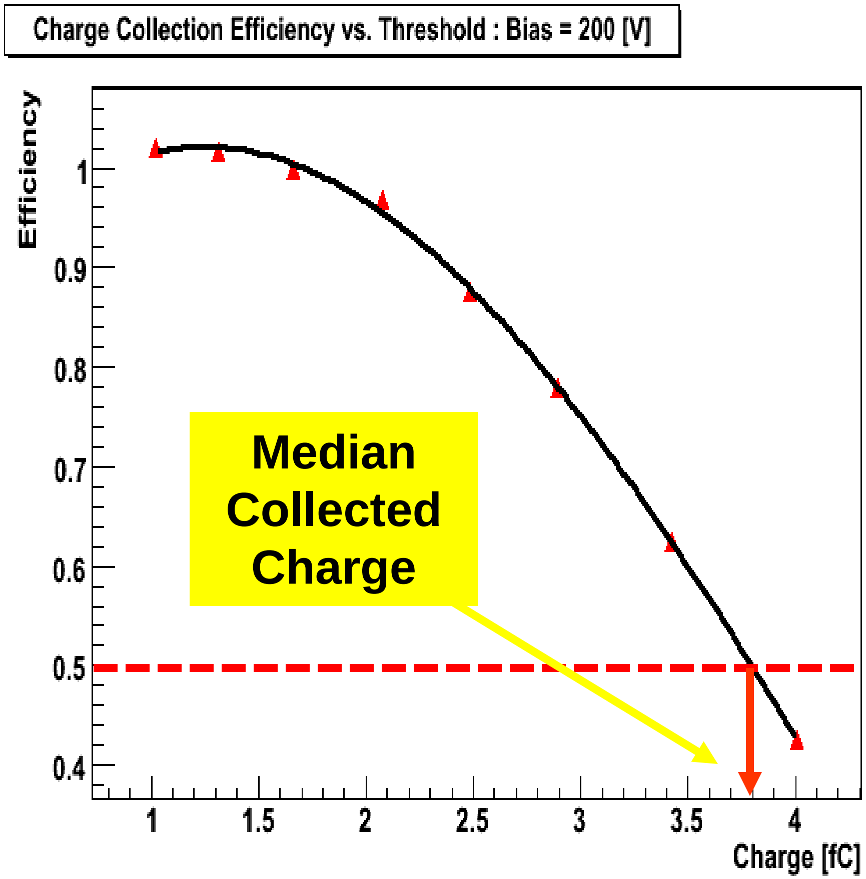
Charge Collection Apparatus



Charge Collection Measurement

2.3 MeV e⁻ through sensor into scintillator





Channel-over-threshold profile

Efficiency vs. threshold

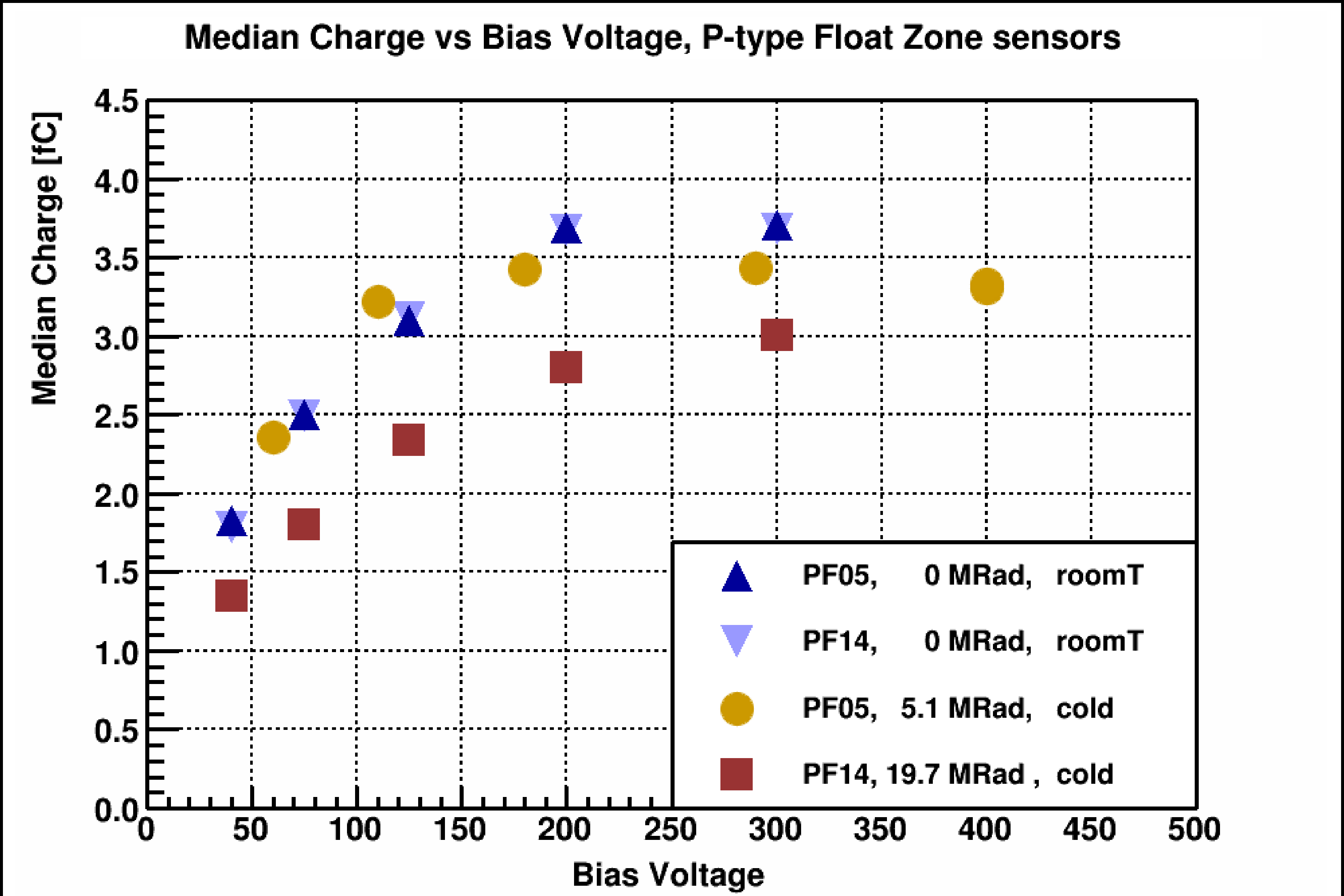
T506 Doses

"P" = p-type "N" = n-type

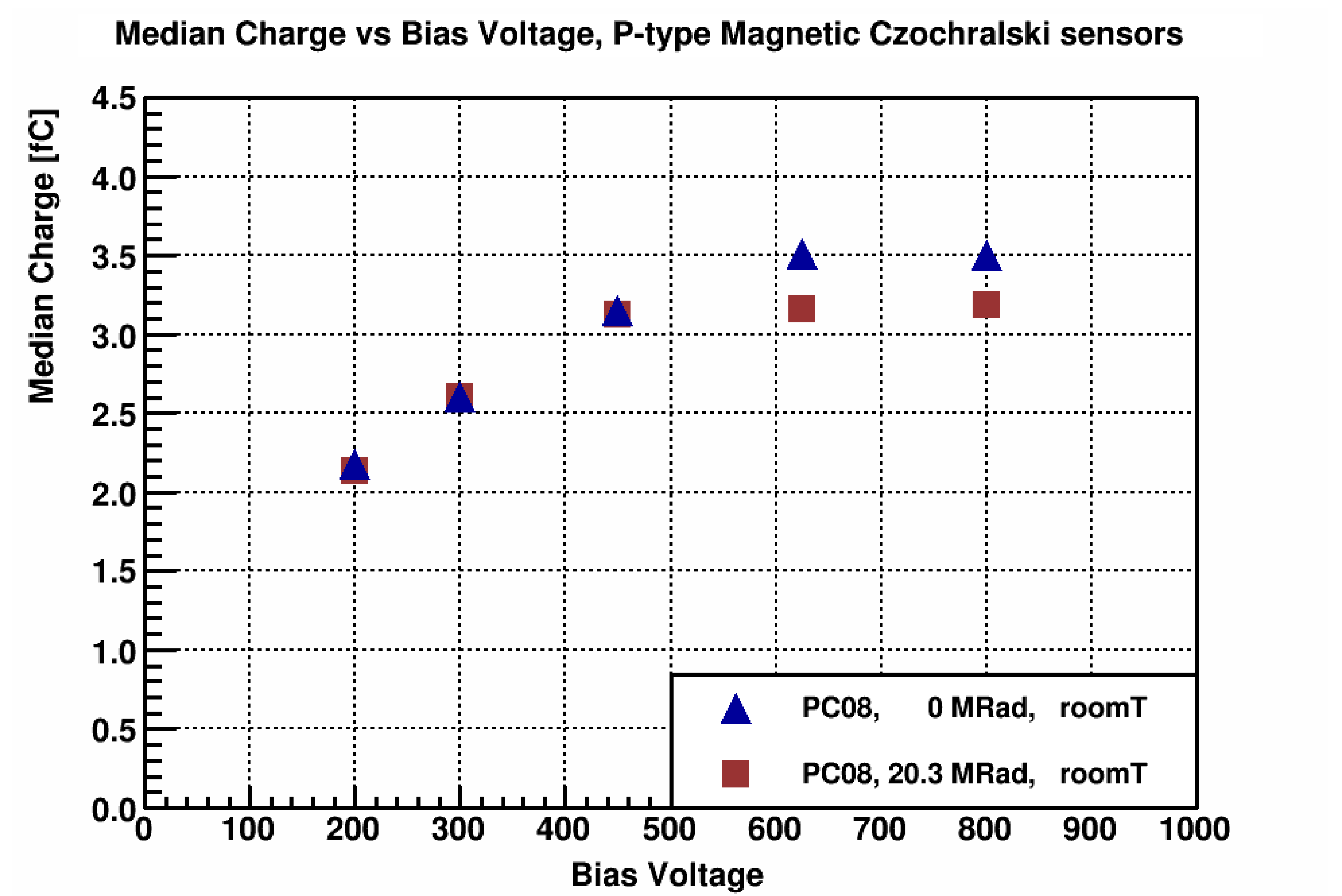
"F" = float zone "C" = Czochralski

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

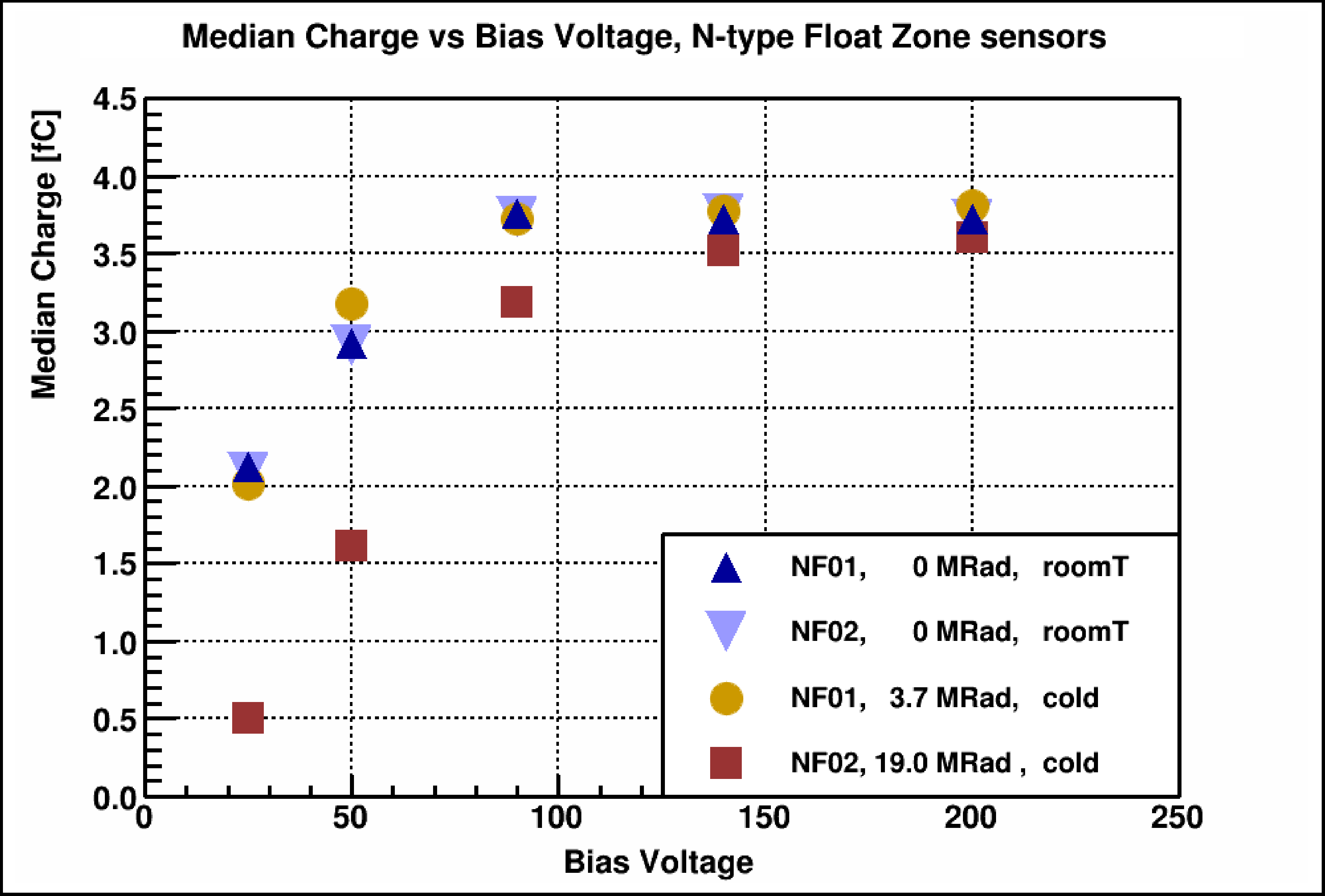
Results: PF sensors



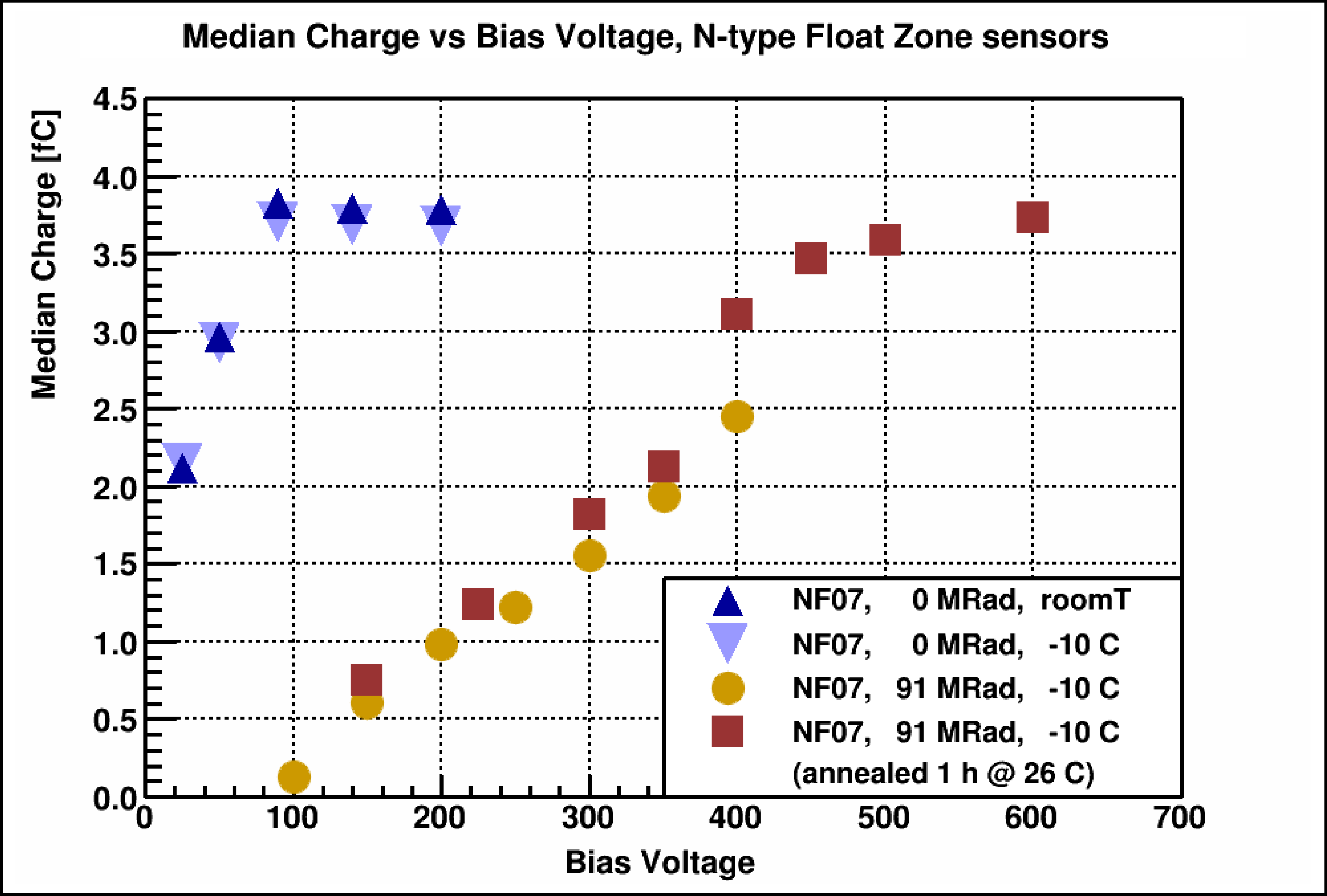
Results: PC sensors



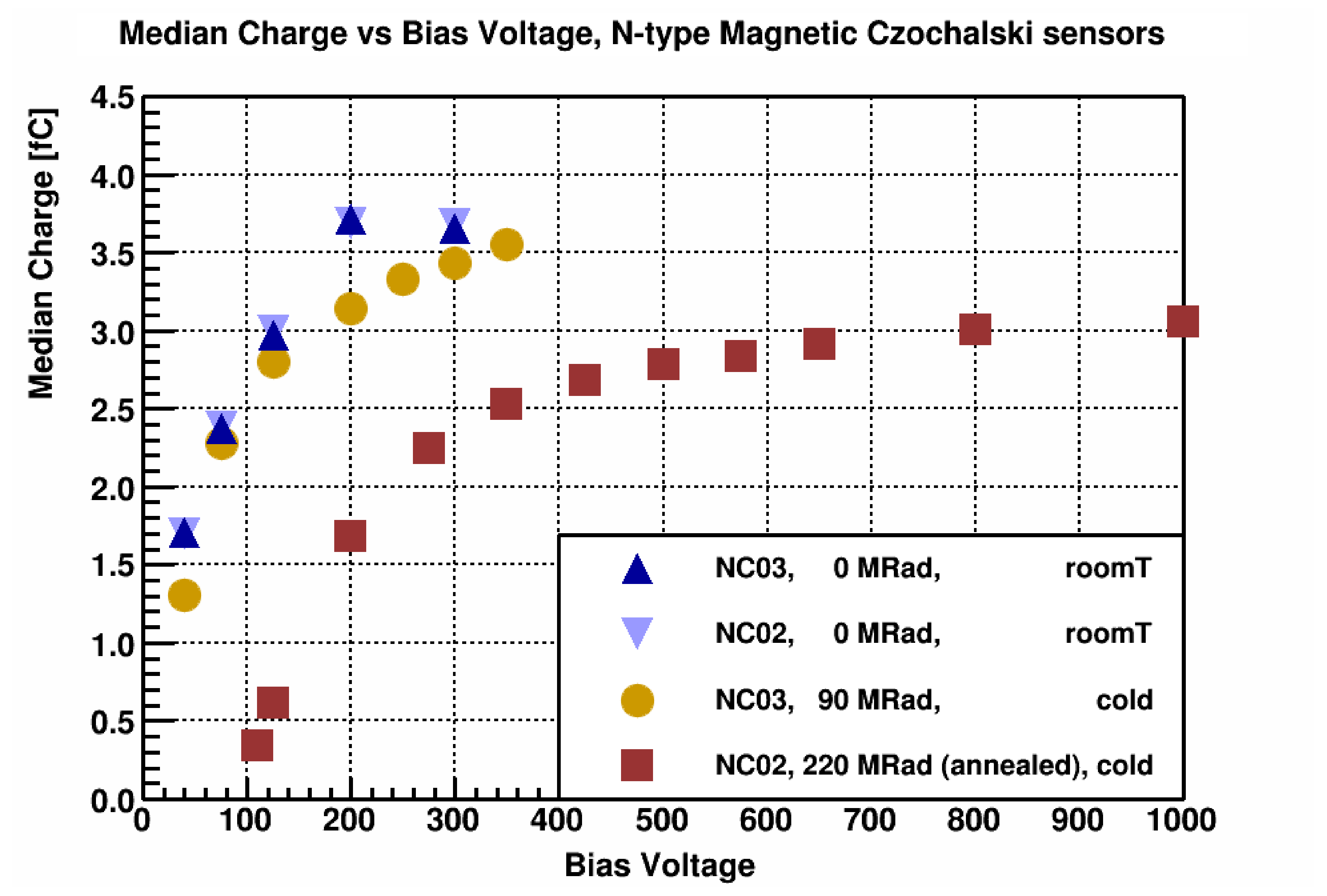
Results: NF sensors low dose



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?