Updated Results from the SLAC ESTB T-506 Irradiation Study

SiD Workshop
SLAC
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Bruce Schumm
UCSC/SCIPP

FCAL Collaboration
High precision design

T-506 Motivation

BeamCal maximum dose ~100 MRad/yr

BeamCal is sizable: ~2 m^2 of sensors.

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

➔ Are these radiation tolerant?

➔ Also, might mainstream Si sensors be of use?

Some reasons for optimism for Si…

Hadronic Processes in EM Showers

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

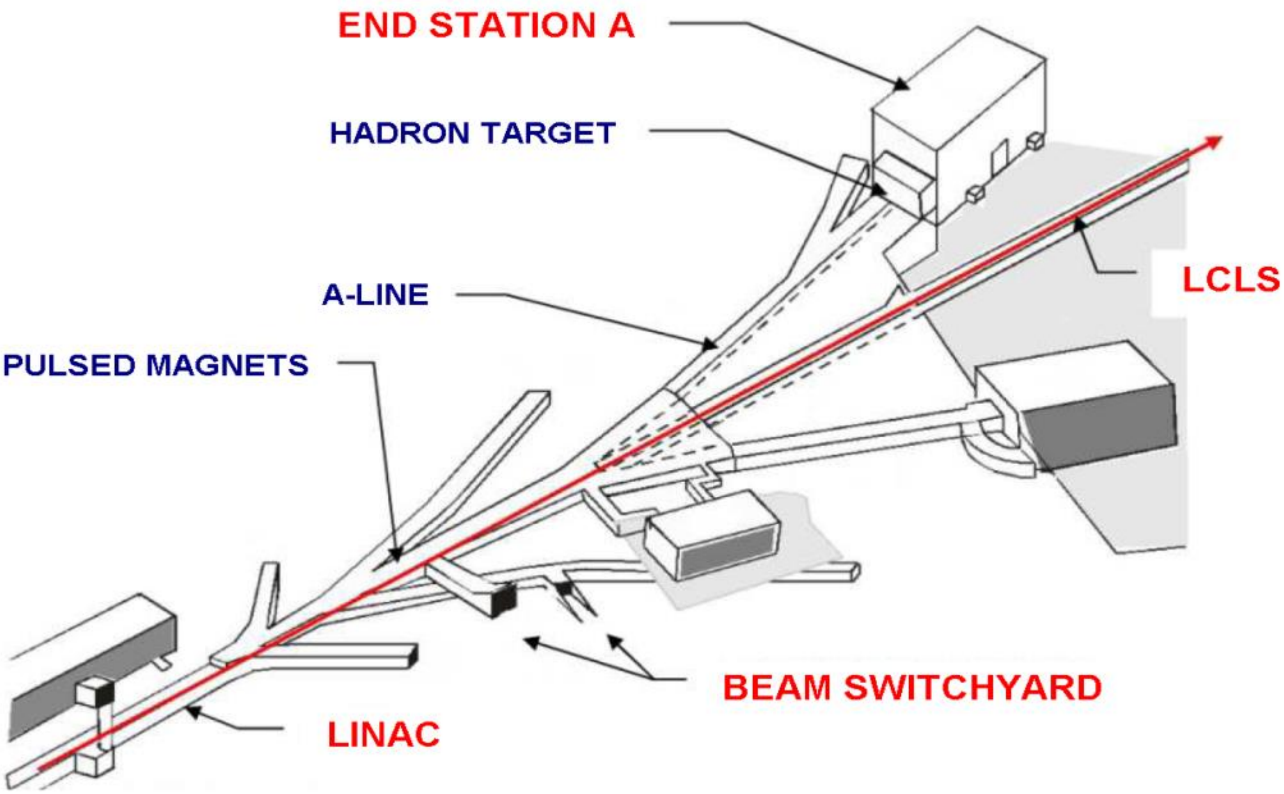
- Nuclear ("giant dipole") resonances
  Resonance at 10-20 MeV ($\sim E_{critical}$)
- Photoproduction
  Threshold seems to be about 200 MeV
- Nuclear Compton scattering
  Threshold at about 10 MeV; Δ resonance at 340 MeV

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

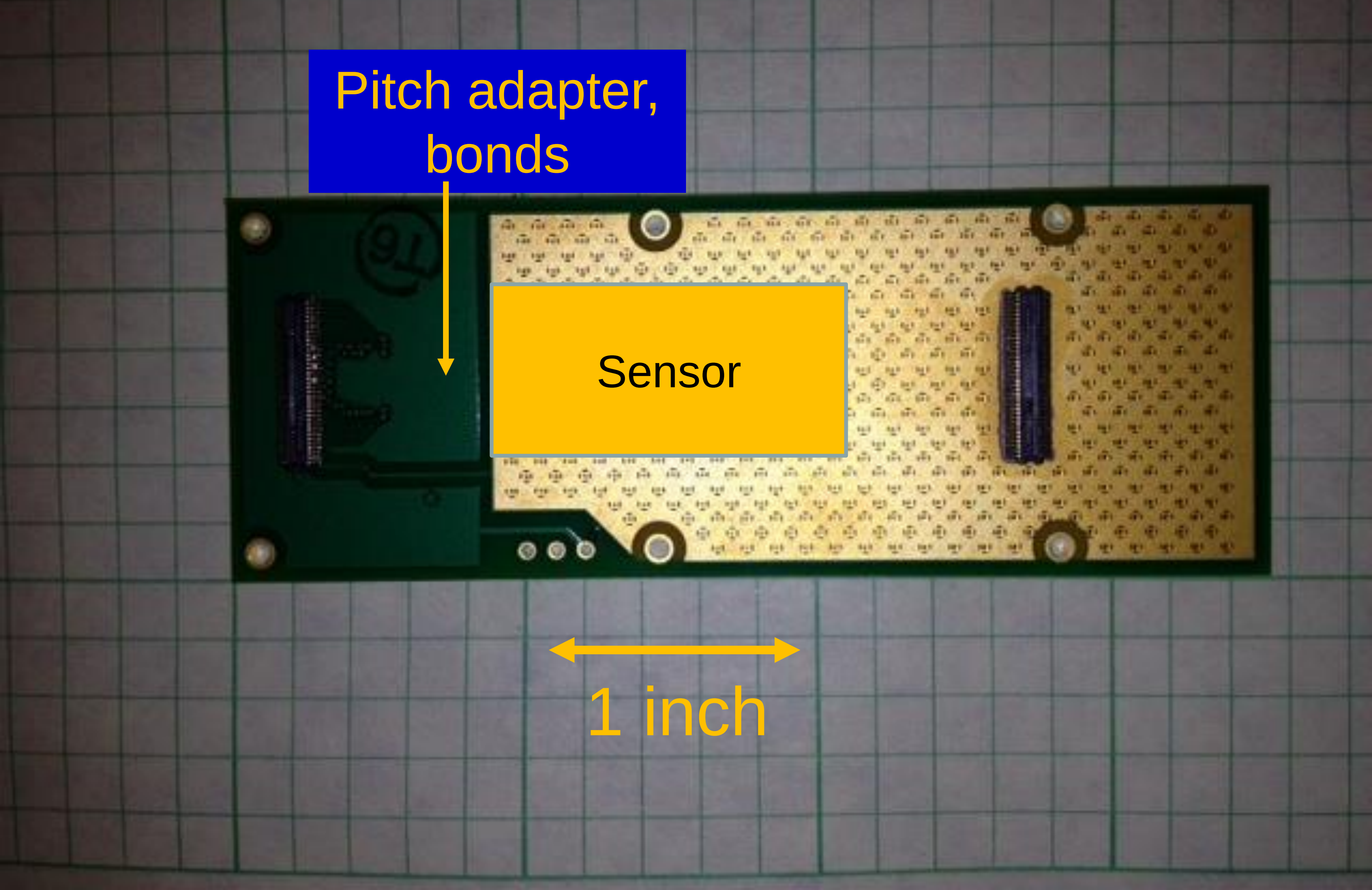
Irradiating the Sensors

LCLS and ESA

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



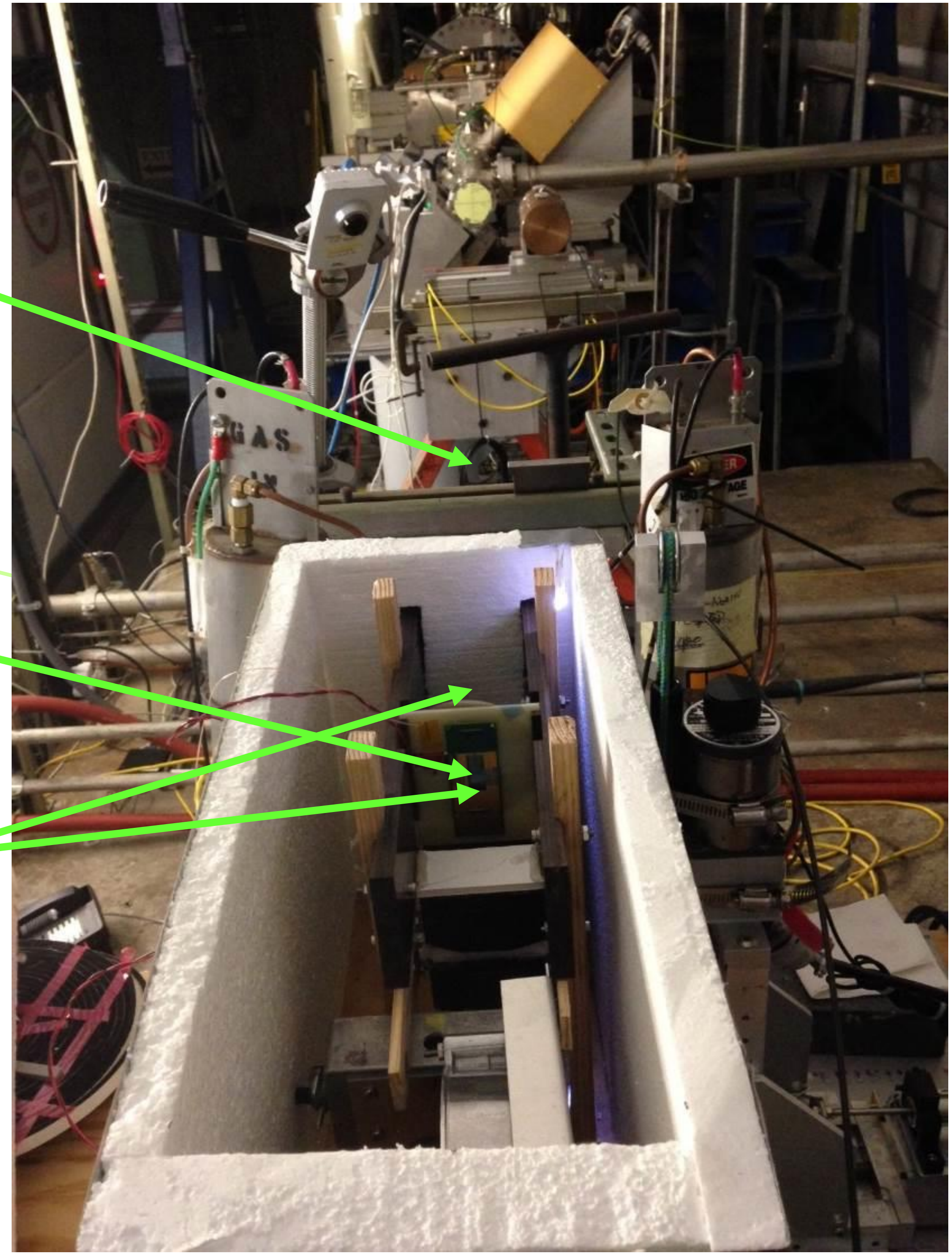
Daughter Board Assembly



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

Sensor sample

Not shown: $4\ X_0$ and $8\ X_0$ radiators just before and after sensor



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

T506 Si Doses

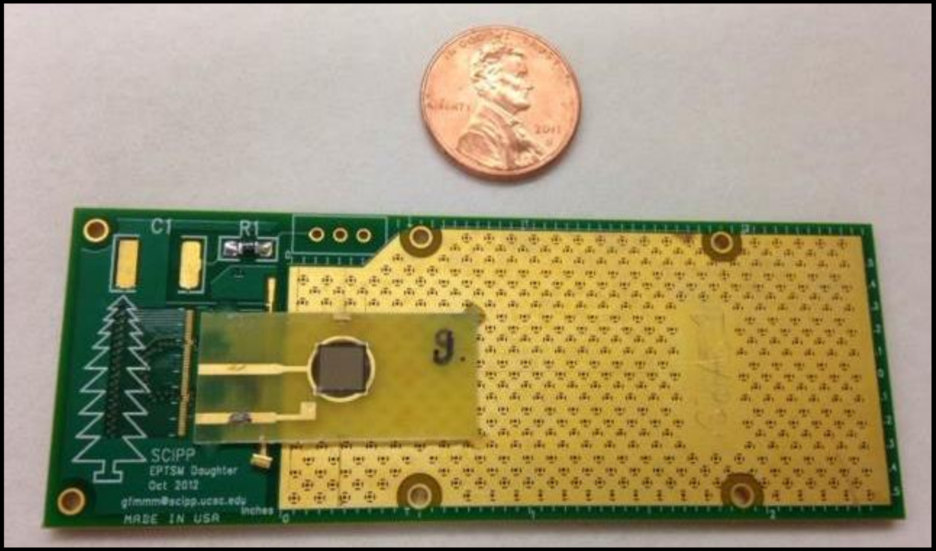
"P" = p-type "N" = n-type

"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

T506 GaAs Doses

New this year: GaAs pad sensors via Georgy Shelkov, JINR Dubna



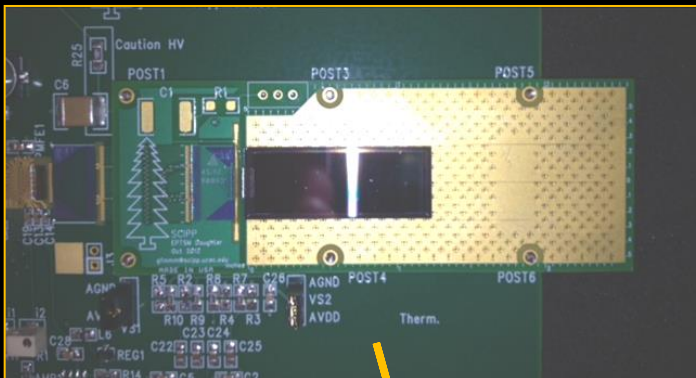
Irradiated with 5.7 and 21.0 Mrad doses of electromagnetically-induced showers

Irradiation temperature 3^{o}C; samples held and measured at -15^{o}C

Assessing the Radiation Damage

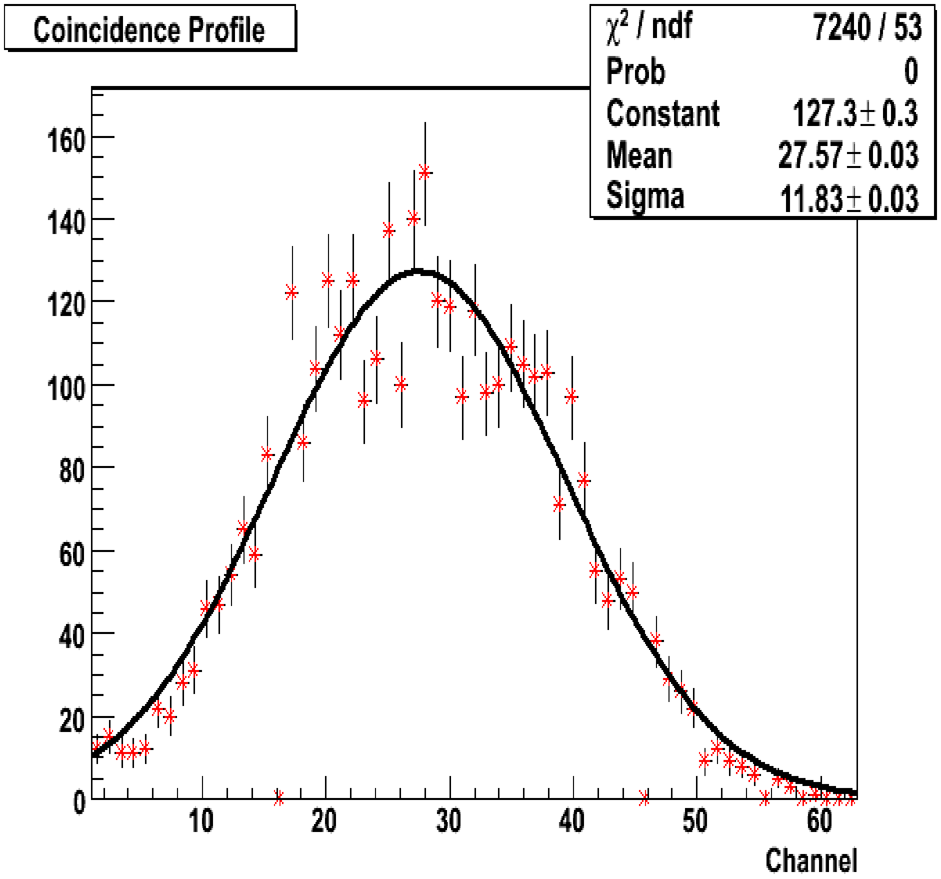
Charge Collection Apparatus

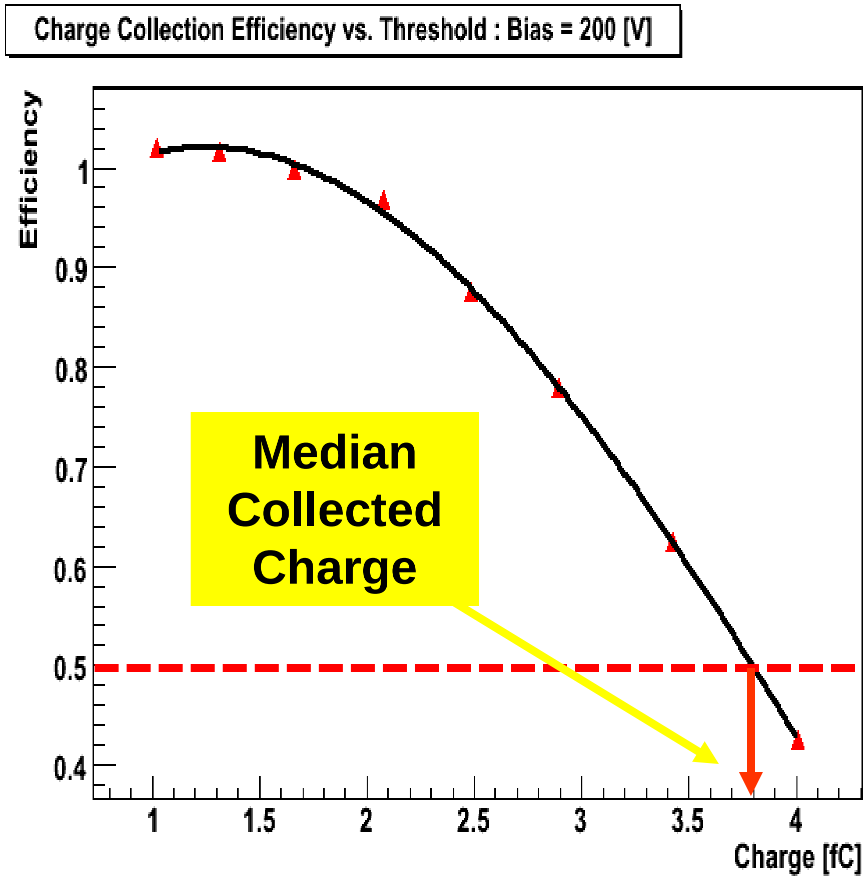
- Readout: 300 ns



Charge Collection Measurement

2.3 MeV e^- through sensor into scintillator



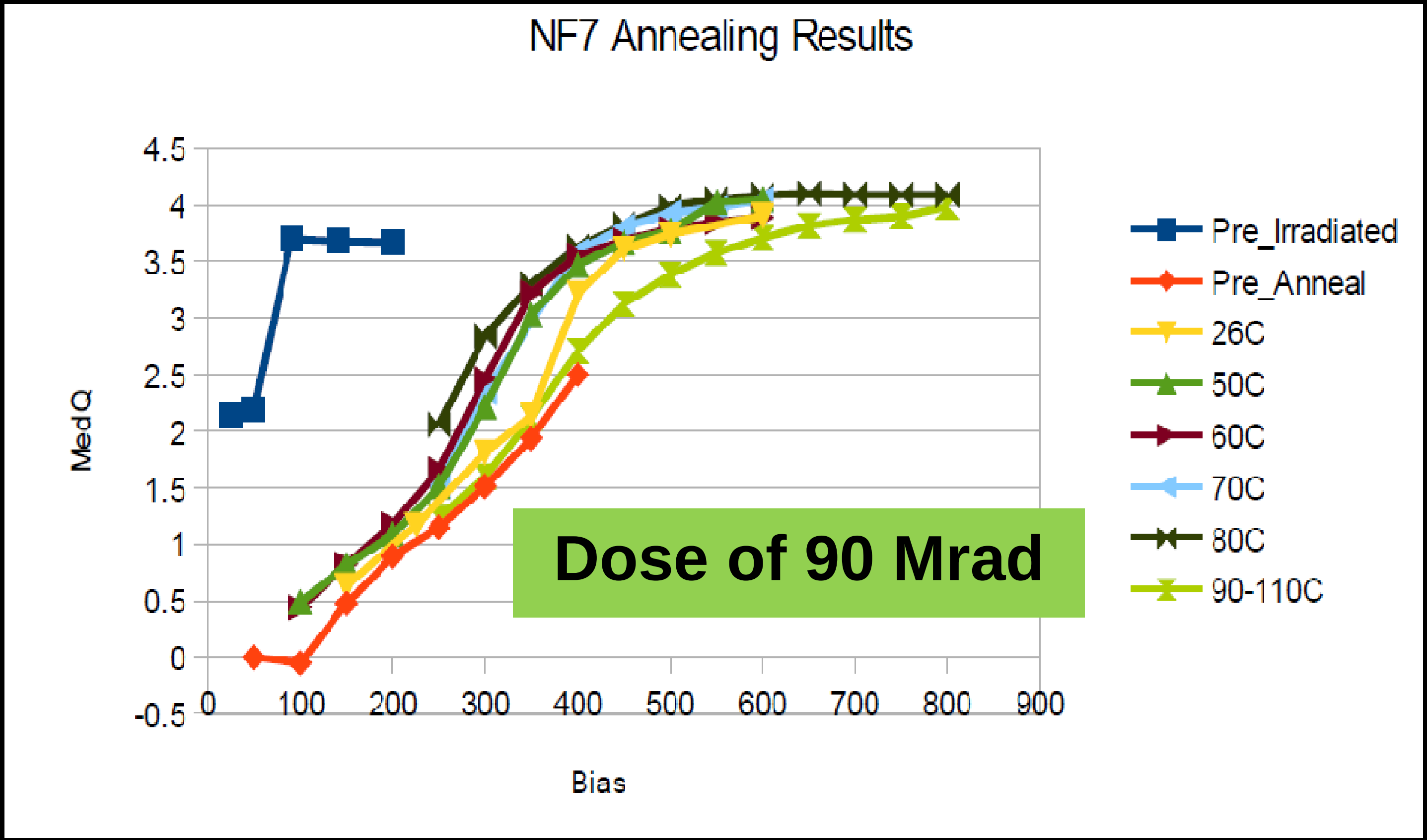


Channel-over-threshold profile

Efficiency vs. threshold

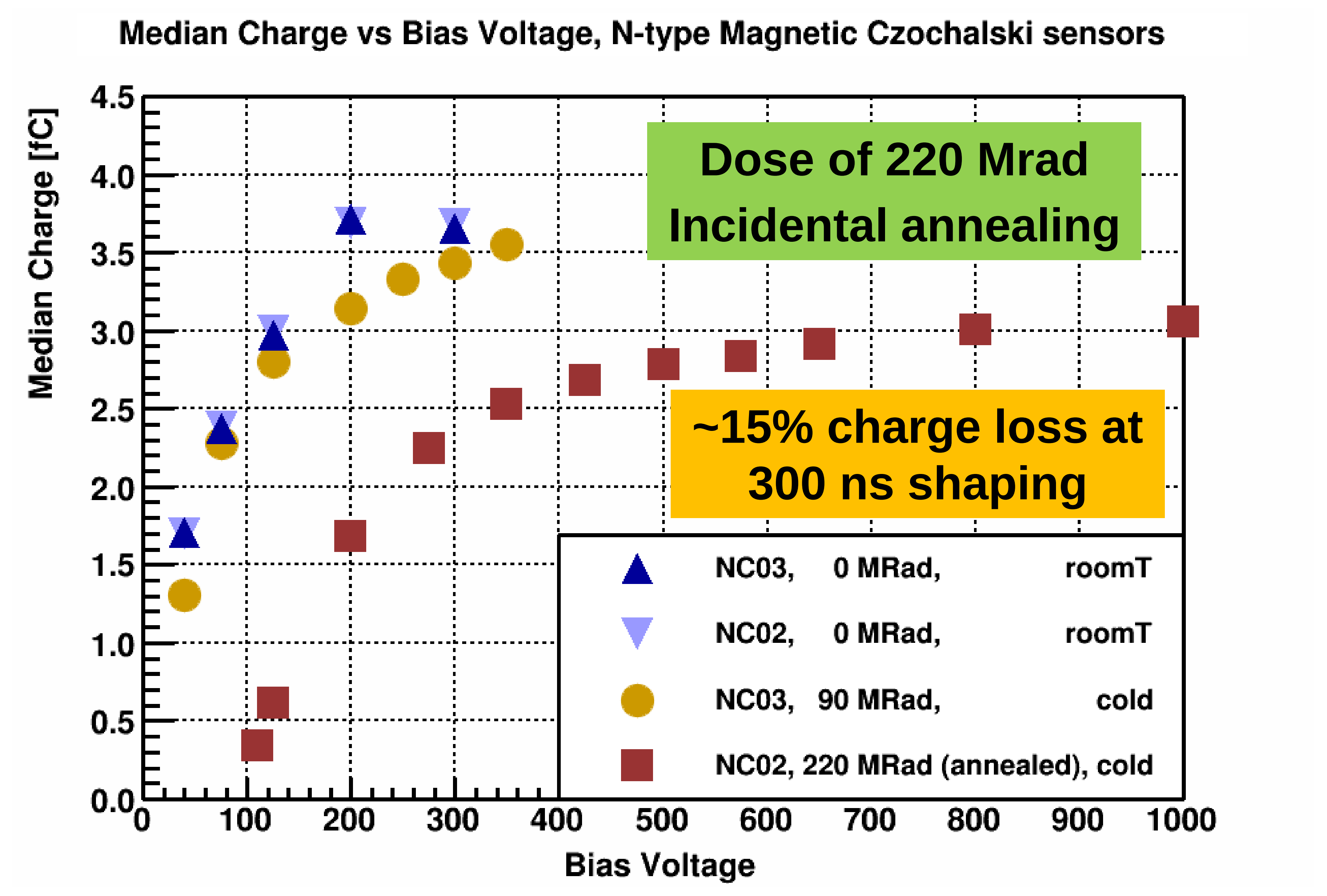
Results

Results: NF Sensor to 90 Mrad, Plus Annealing Study

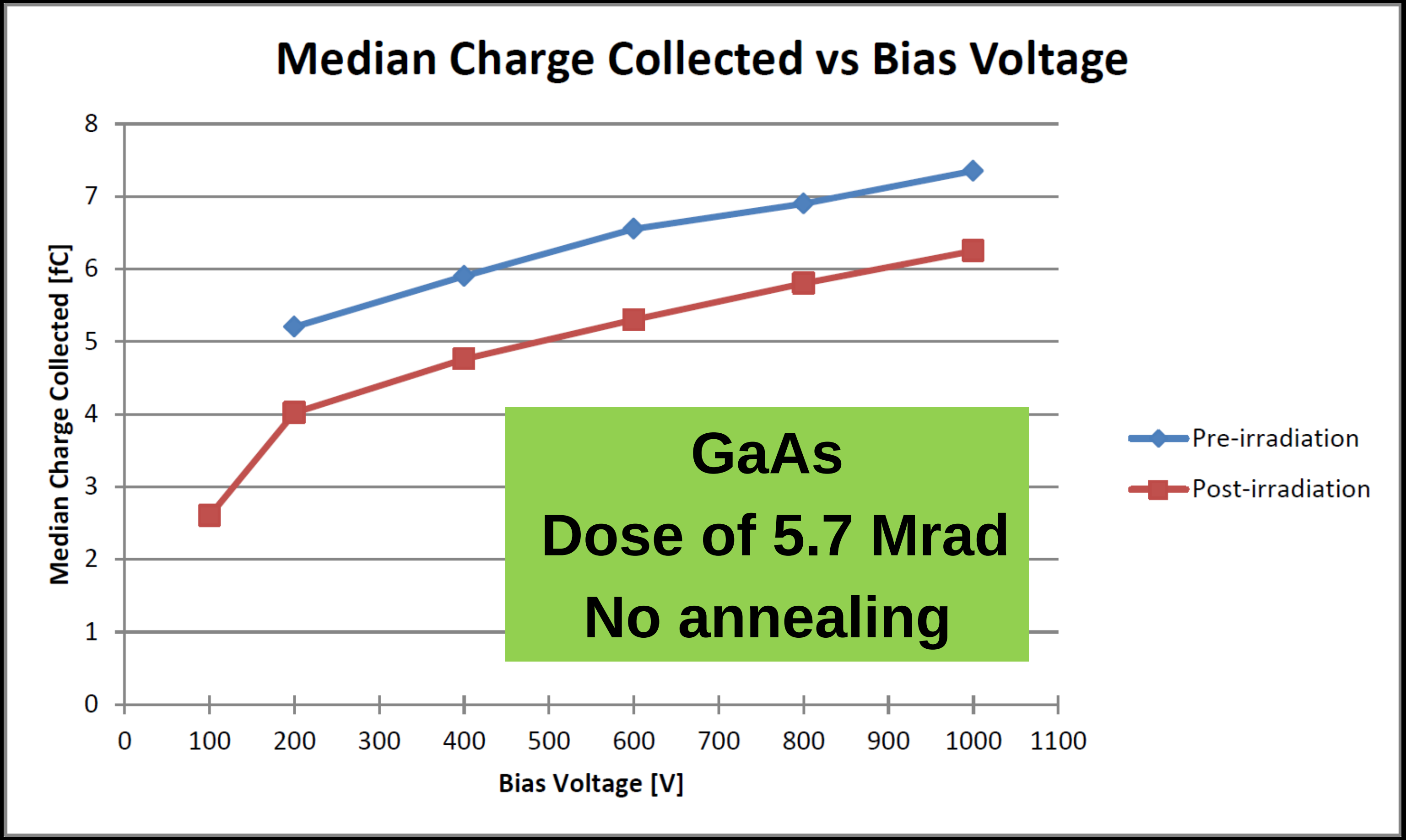


Limited beneficial annealing to 90ºC (reverse annealing above 100ºC?)

Results: NC sensors

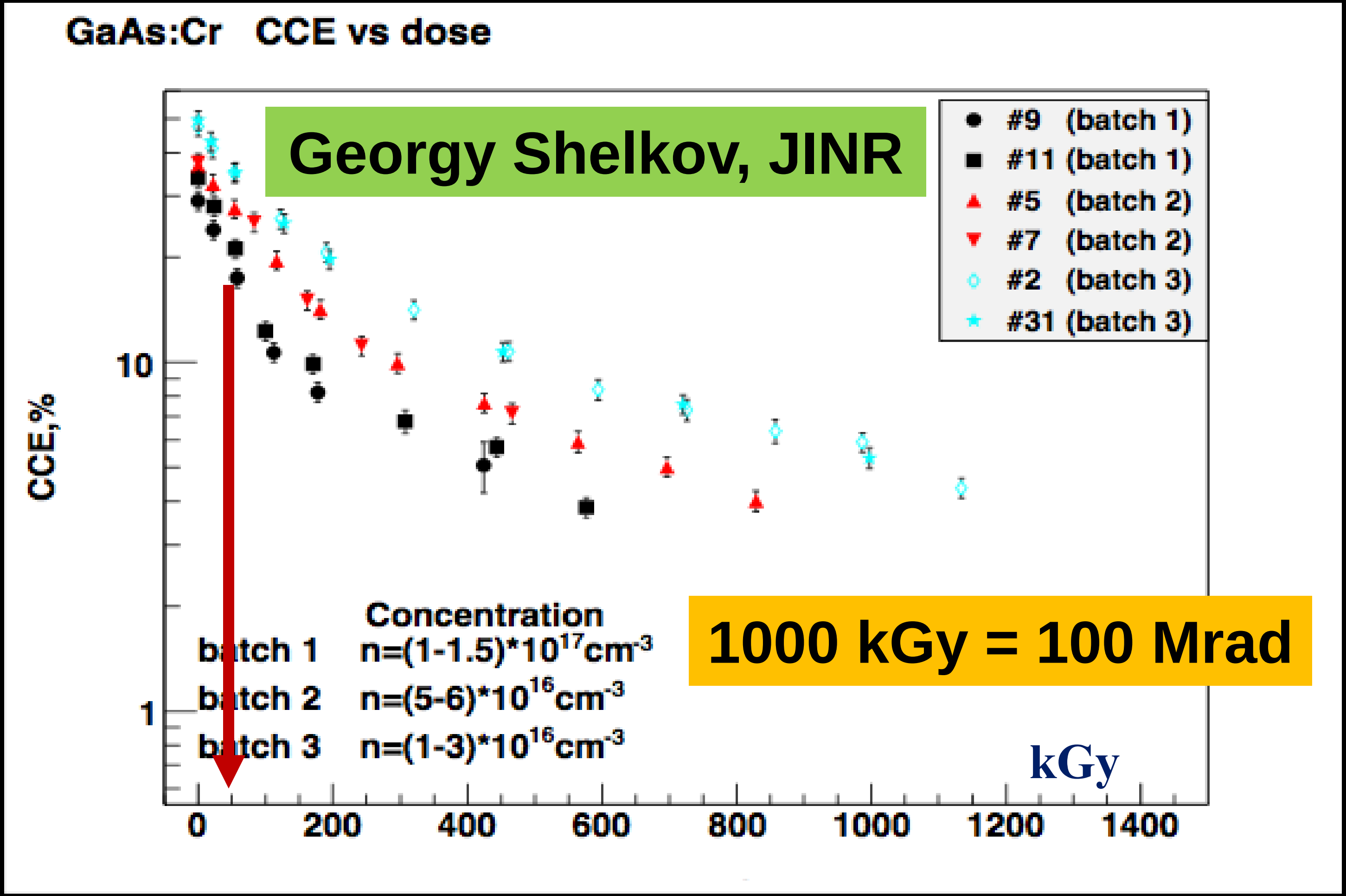


GaAs Charge Collection after 5.7 Mrad Exposure



15-20% charge loss at 300 ns shaping

Compare to Direct Electron Radiation Results (no EM Shower)

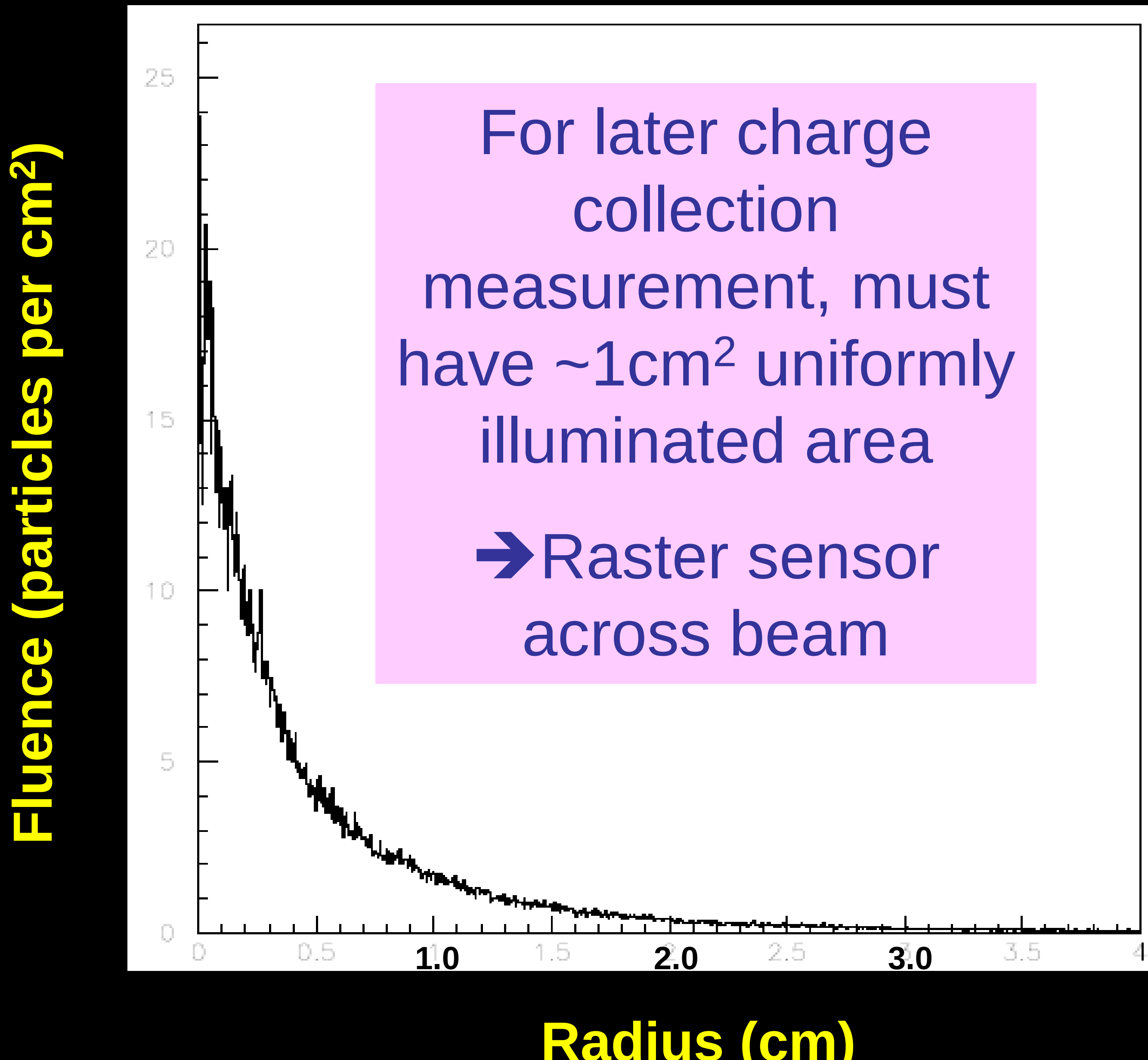


Roughly consistent with direct result

Summary and Conclusions

- In midst of a program of study of radiation damage in a realistic EM shower environment
- Have irradiated and several Si sensors to as much as 220 Mrad, and GaAs to 20 Mrad.
- Si sensors show some promise to survive the BeamCal integrated dose
- GaAs shows charge loss at 6 Mrad, but still need to do annealing studies (underway)
- Will soon explore 21 Mrad GaAs sensor and do annealing studies on both GaAs sensors
- Expect to run at higher fluence in 2015

Detector Fluence Distribution (per incident e^-)

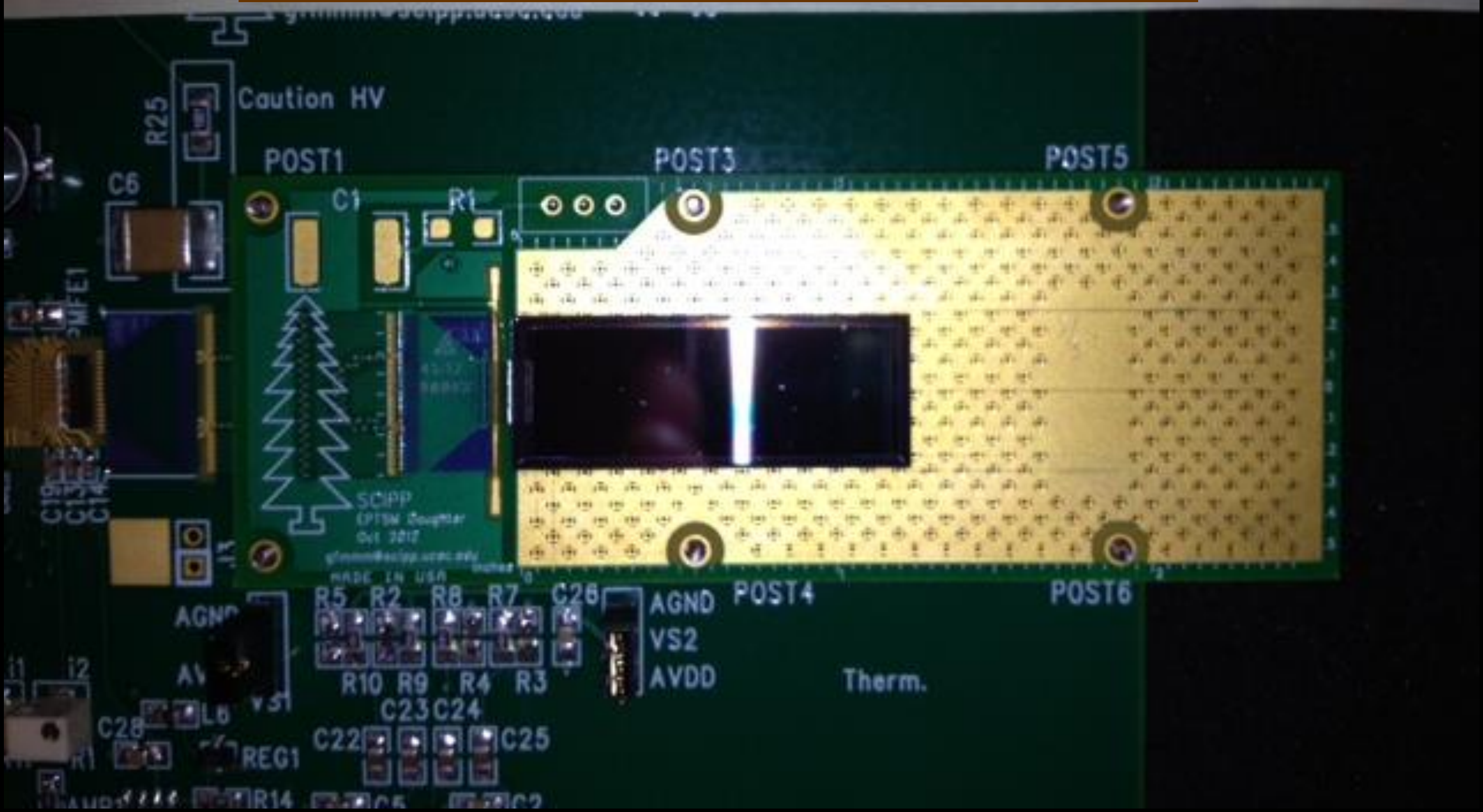


ESTB parameters

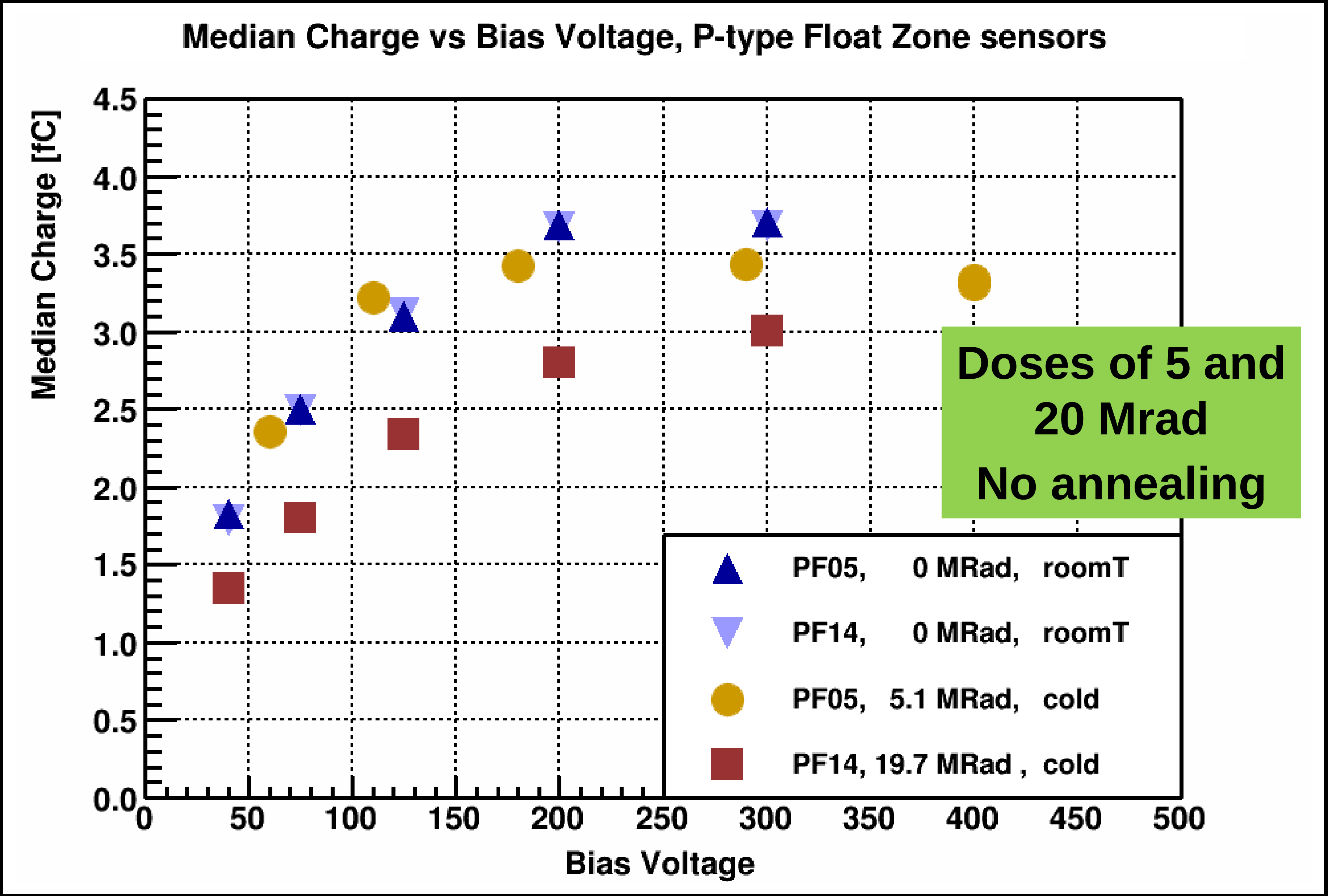
Table 1.1.1. ESTB primary electron beam parameters and experimental area at the BSY and in ESA

Parameters	ESA
Energy	~~15 GeV~~ 3.5-10.5 (for now)
Repetition Rate	5 Hz Up to 10 Hz!
Charge per pulse	~~0.35 nC~~ ≤ 0.15 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

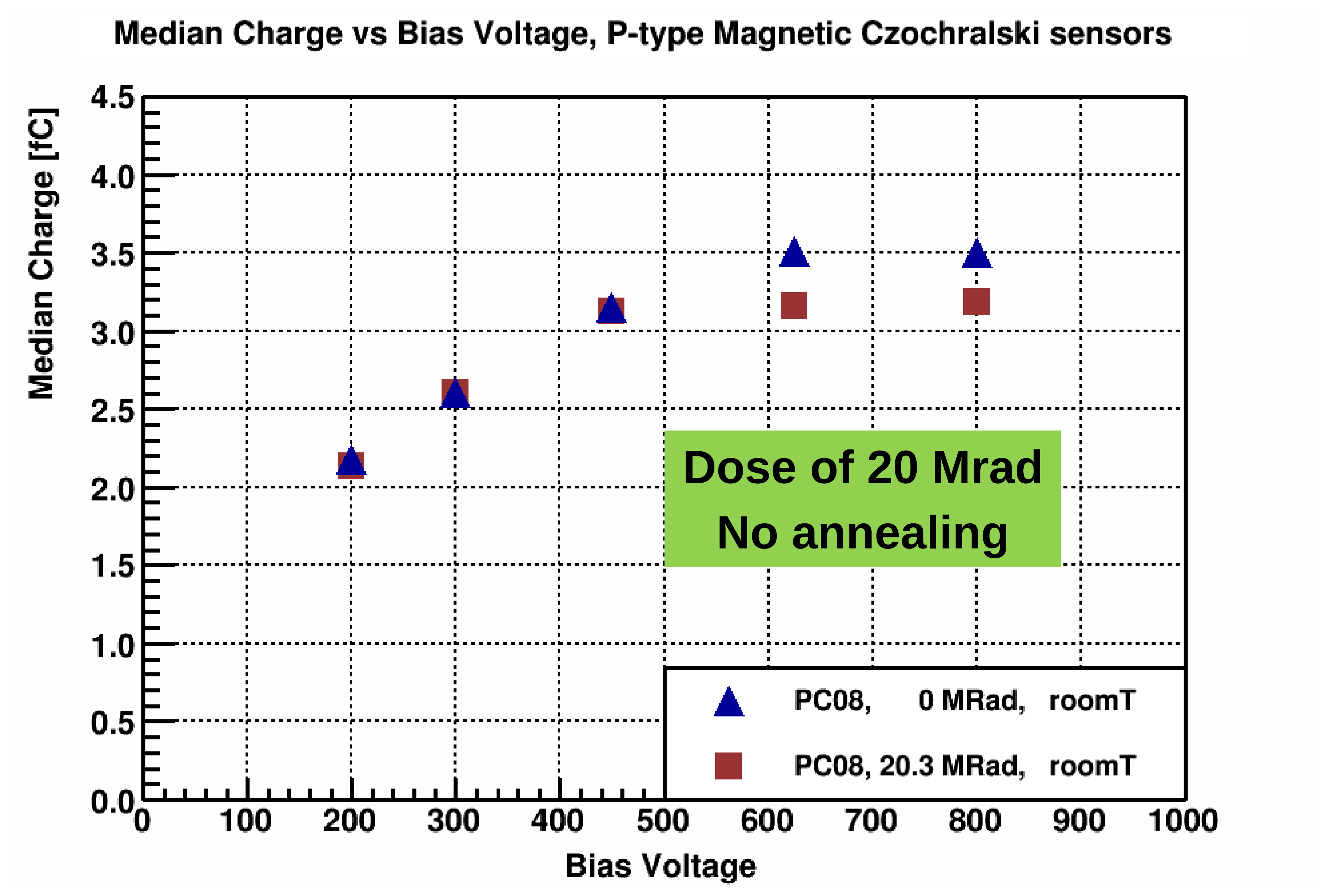
Daughter/Readout Board Assembly



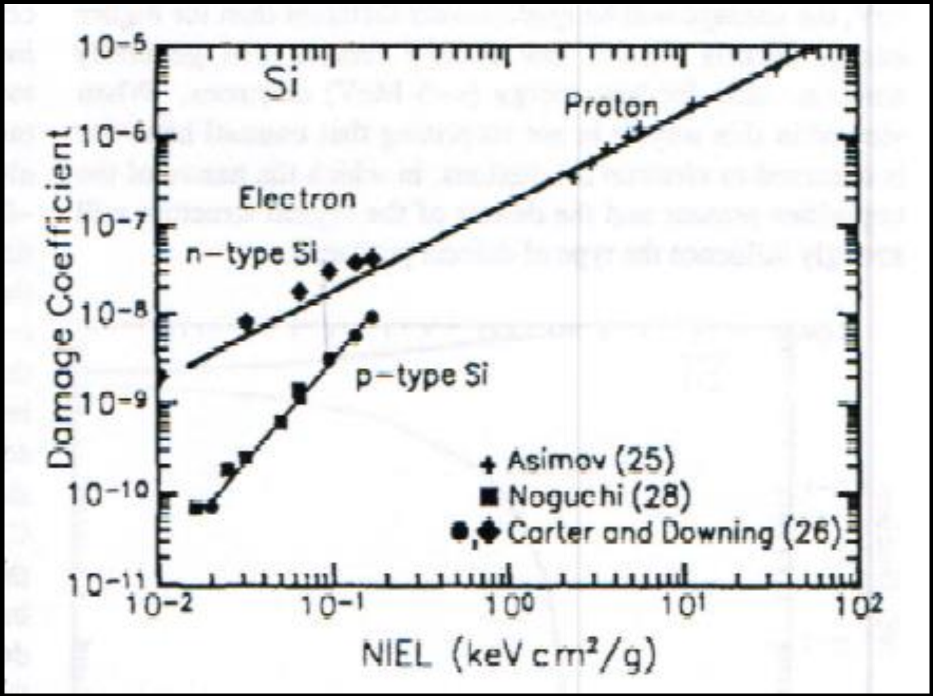
Results: PF sensors



Results: PC sensors



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?

Results: NF sensor for low dose