Far-Forward Calorimetry with the SiD and FCAL collaborations

ALCW15 Meeting, KEK
April 20-24 2015

Bruce Schumm
UC Santa Cruz Institute
for Particle Physics

FCAL Collaboration
High precision design

FCAL Collaboration

SiD efforts on ILC far-forward calorimetry (LumiCal, BeamCal are done within the context of the broad FCAL collaboration

~70 physicists; ~20 institutions

Current SiD contributions are solely to BeamCal:

*) Front-end electronics design (BEAN chip)

*) Sensor technology studies (SLAC T506 radiation damage studies)

*) Beamcal reconstruction and physics studies

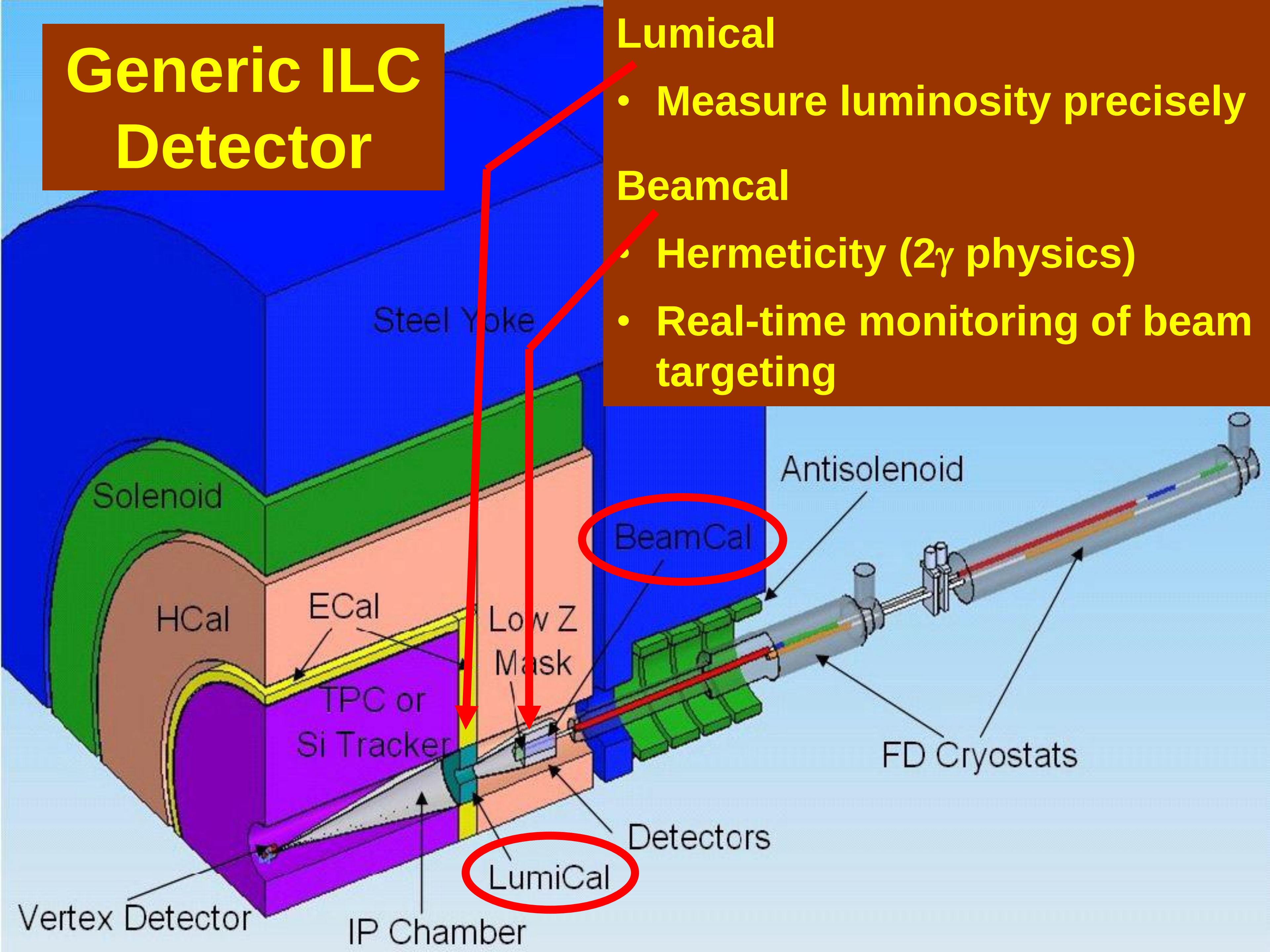
Generic ILC Detector

Lumical

- **Measure luminosity precisely**

Beamcal

- **Hermeticity (2γ physics)**
- **Real-time monitoring of beam targeting**



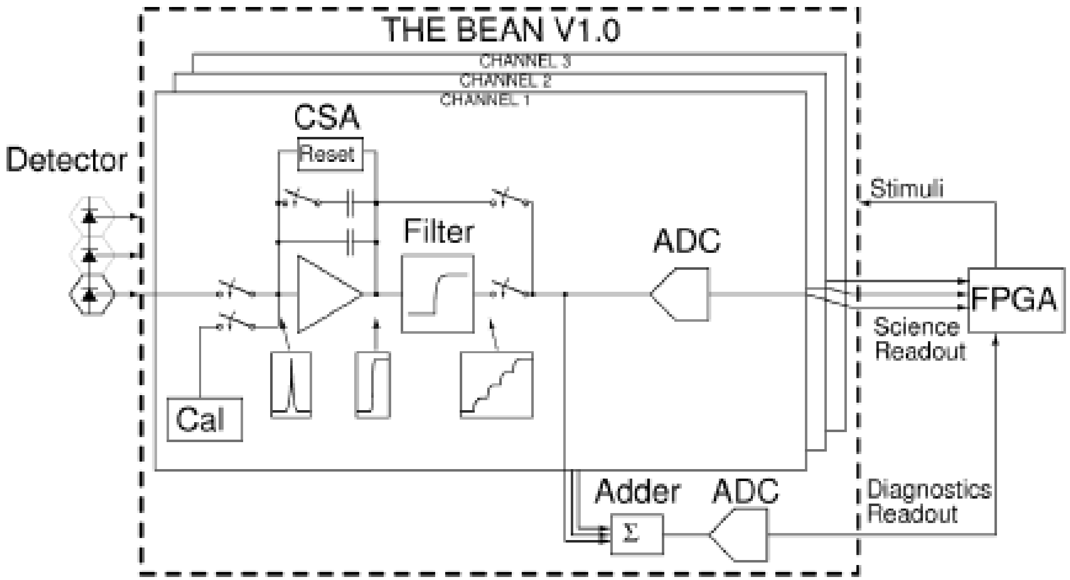
BeamCal Front-End Electronics (BEAN Chip)

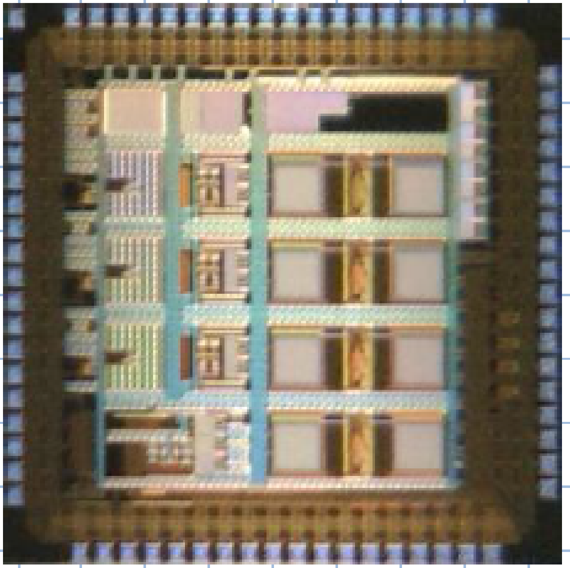
Lead: Prof. Angel Abusleme
Pontifica Universidad Catolica de Chile

Basic BeamCal Readout Design Considerations

- 100% occupancy: beam-beam backgrounds will illuminate most channels on every beam crossing
- Large dynamic range (up to 40pC)
- MIP calibration
- Real-time beam condition monitoring (real-time addition of 32 readout channels)

The Bean V1.0: 3-channel readout chain in 180nm (2010)





- 72 pads, 2.4mm x 2.4mm (including pads)
- 7306 nodes, 35789 circuit elements
- 360µm channel pitch (including power bus)
- 3 charge amplifiers, 4 x 10-bit, fully diff. SAR ADCs, 1 SC adder, 3 SC filters, etc.

BEAN Chip Ongoing Work

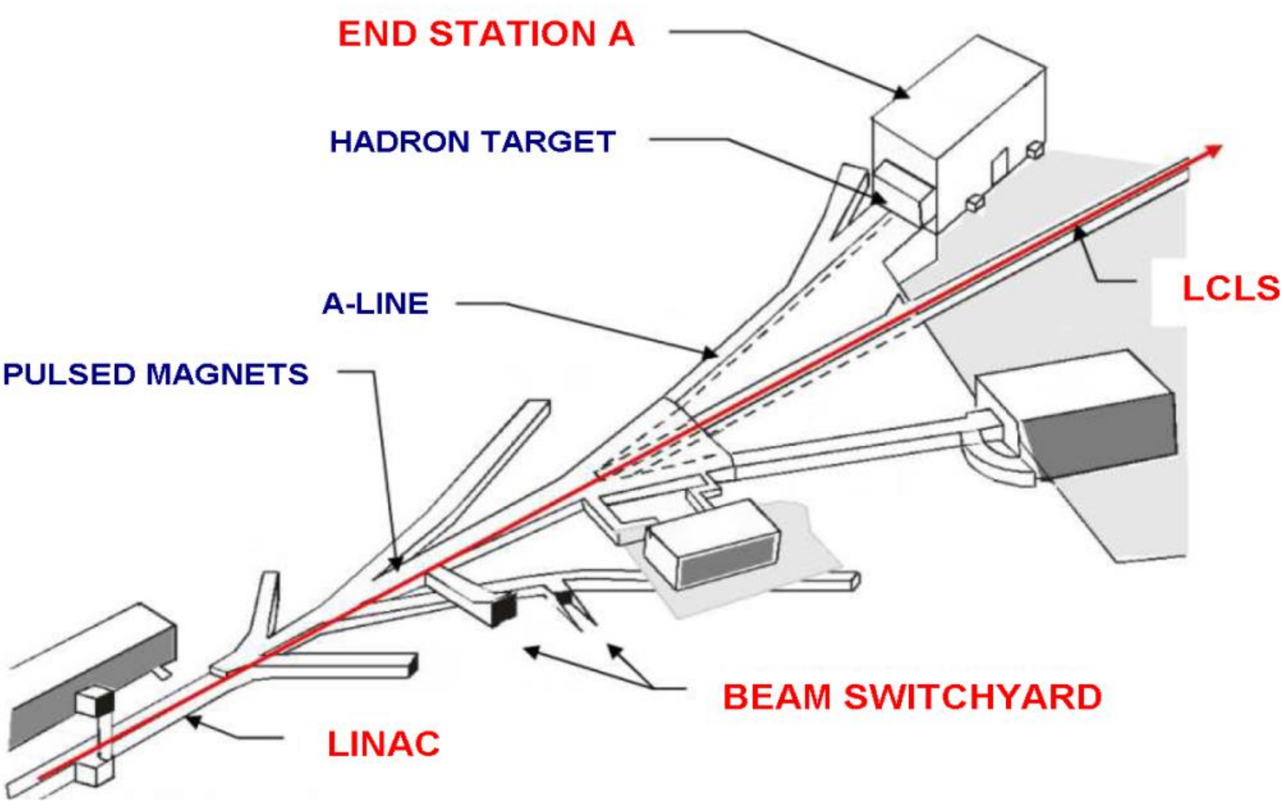
- Refined filtering techniques to maximize S/N
- Explore non-linear ADC
- Testing and characterization
- Digital back-end (must store entire train)
- Contribution to systems development (testbeam prototype)

SLAC T506 Electromagentic Radiation Damage Study

Update and Plans

LCLS and ESA

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



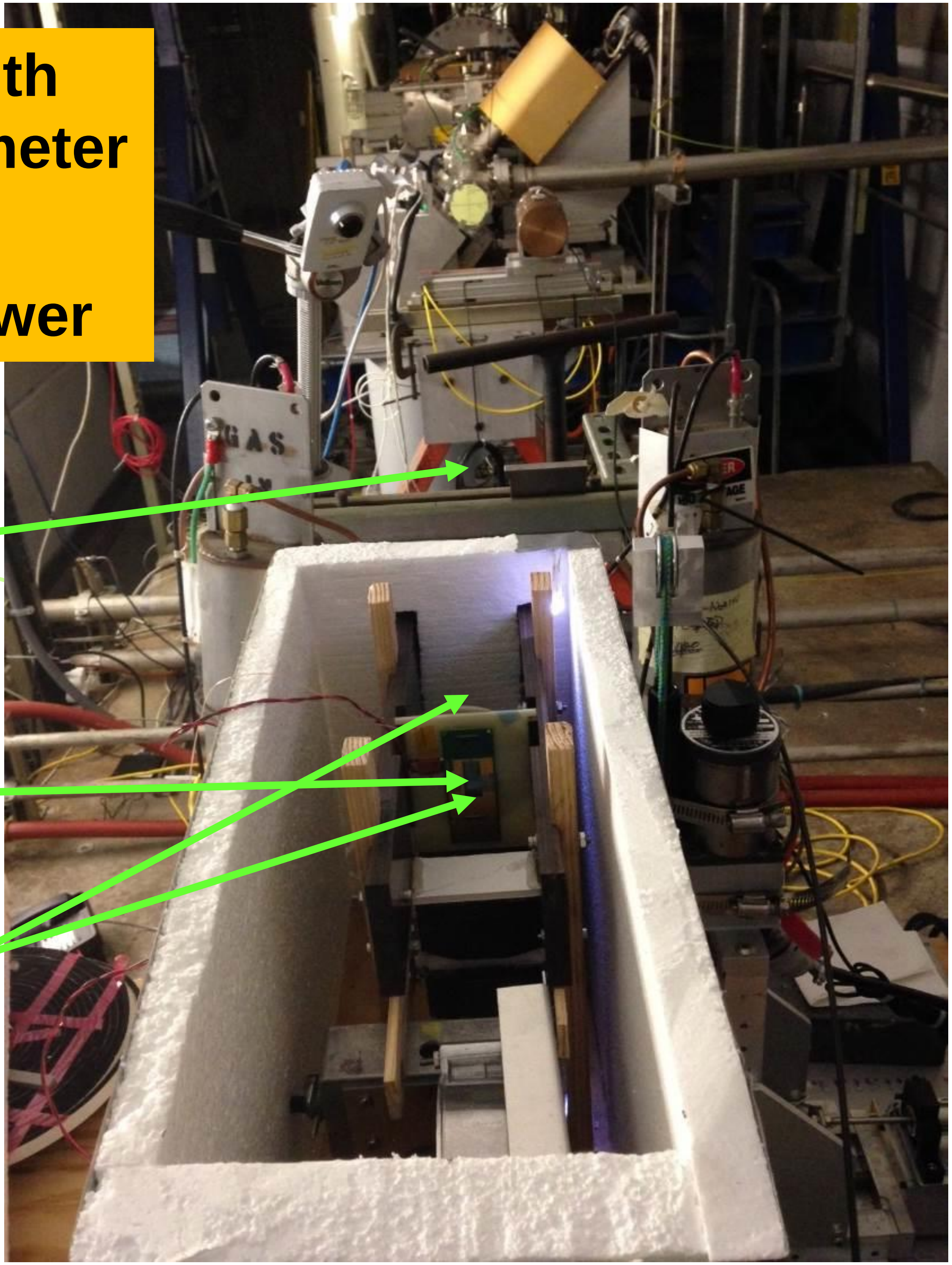
Surround sensor with Tungsten as in calorimeter

➔ Realistic electromagnetic shower

$2\ X_0$ 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

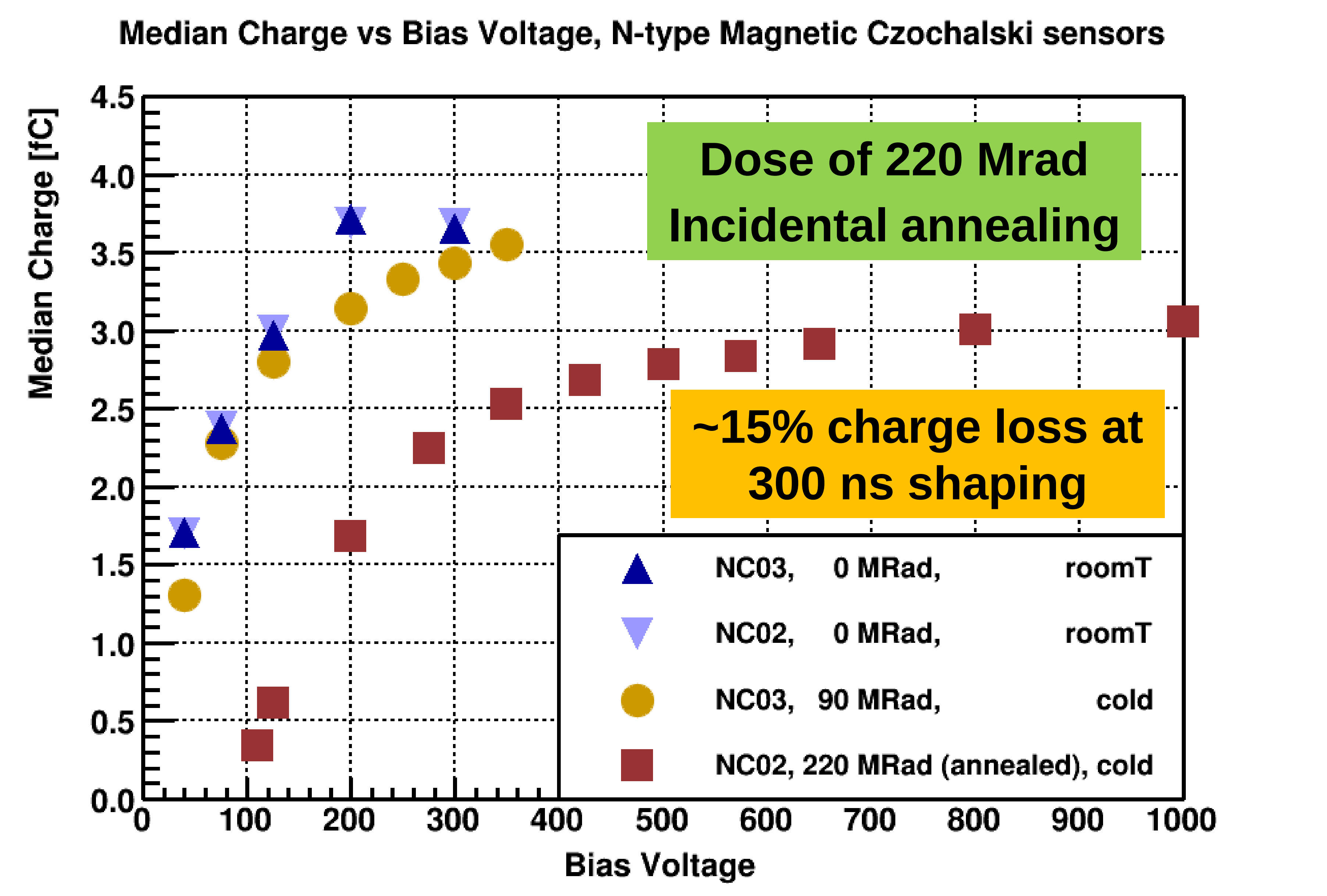
T506 Si Doses

“P” = p-type “N” = n-type

“F” = float zone “C” = Czochralski

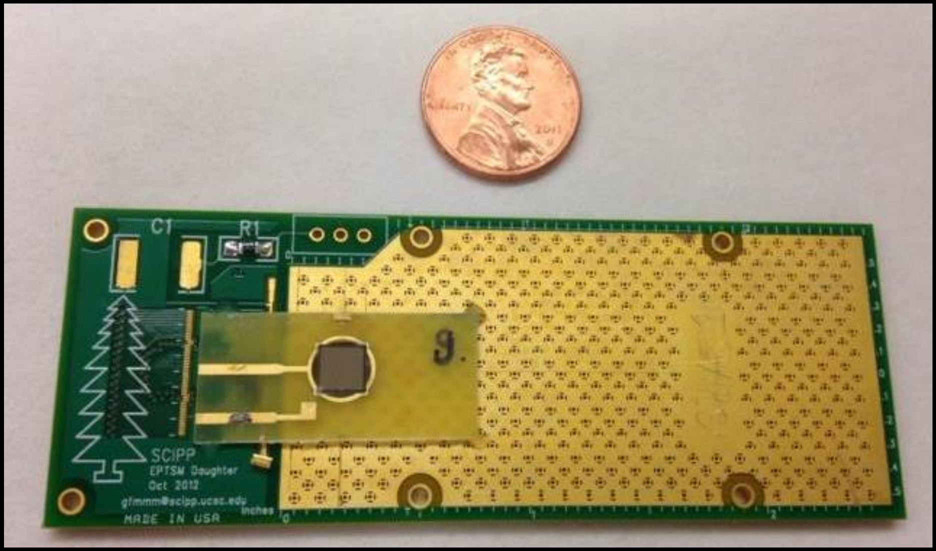
Sensor	V_{FD}	Irradiation Temp. (C)	Beam Energy (GeV)	Delivered Charge (μC)	Dose (MRad)
PF05	190	0	5.88	2.00	5.13
PF14	190	0	3.48	16.4	19.7
PC10	660	0	5.88	1.99	5.12
PC08	700	0	(5.88, 4.11, 4.18)	(3.82,3.33,3.29)	20.3
NF01	90	0	4.18	2.30	3.68
NF02	90	0	4.02	12.6	19.0
NF07	100	5	8.20	23.6	91.4
NC01	220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

Results: NC sensors



T506 GaAs Doses

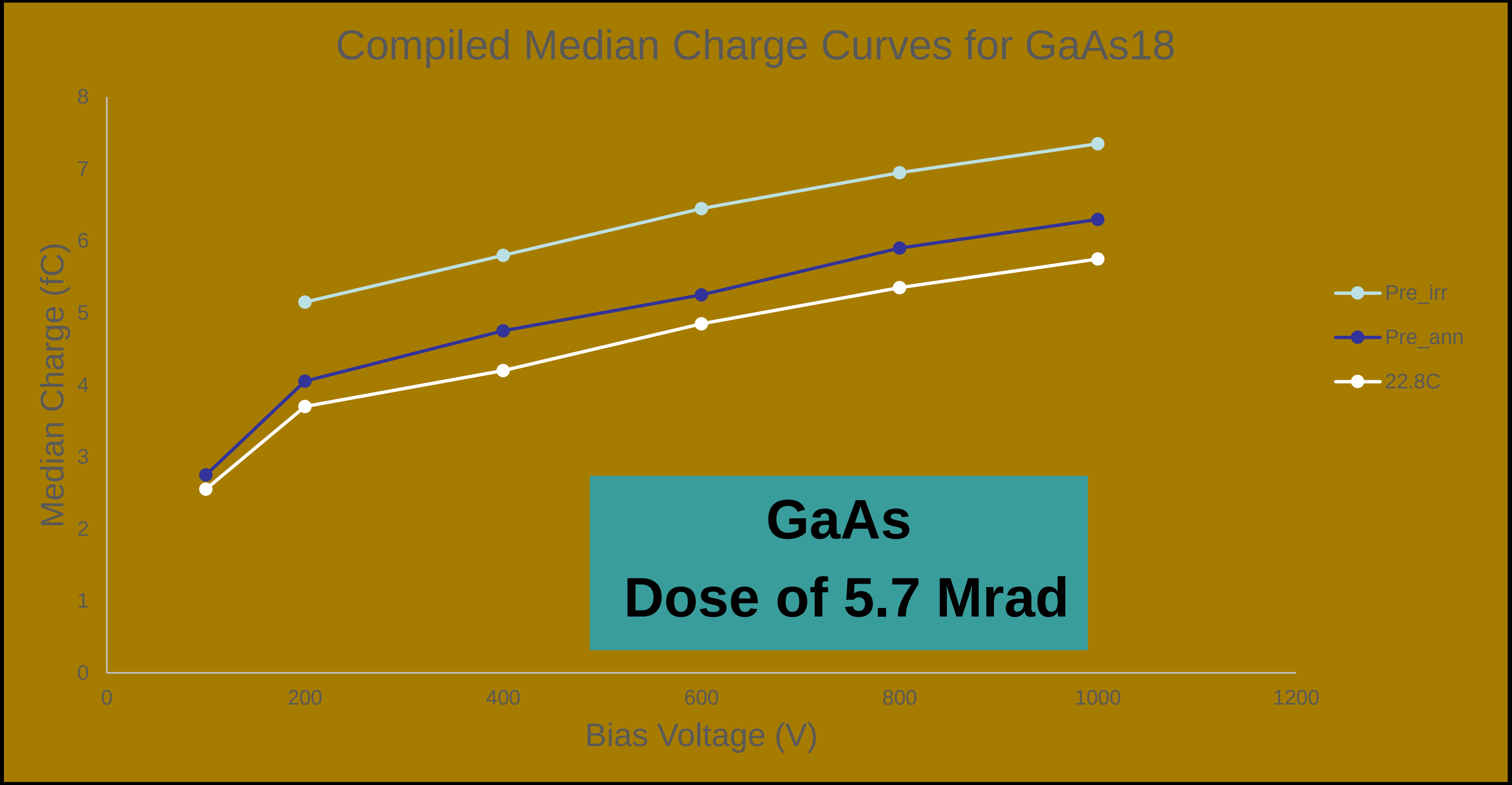
New this past year: (5x5)mm^2 GaAs pad sensors via Georgy Shelkov, JINR Dubna



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

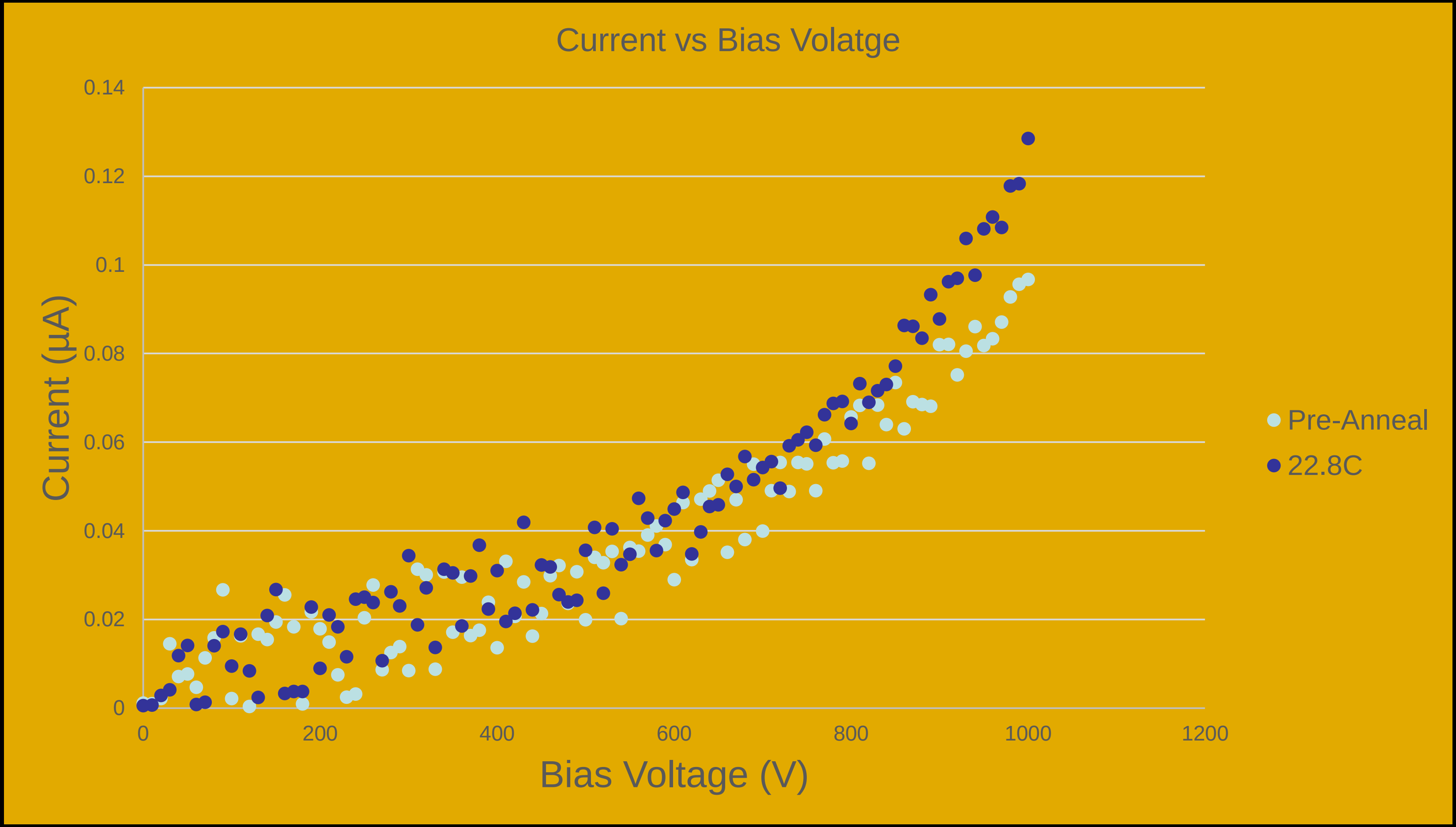
Irradiation temperature 3^{o}C; samples held and measured at -15^{o}C

GaAs Charge Collection: 5.7 Mrad Exposure



- 15-20% charge loss at 300 ns shaping
- Seems to worsen with annealing
- Sensor detached at 30º annealing step

GaAs Dark Current (-10^0 C)



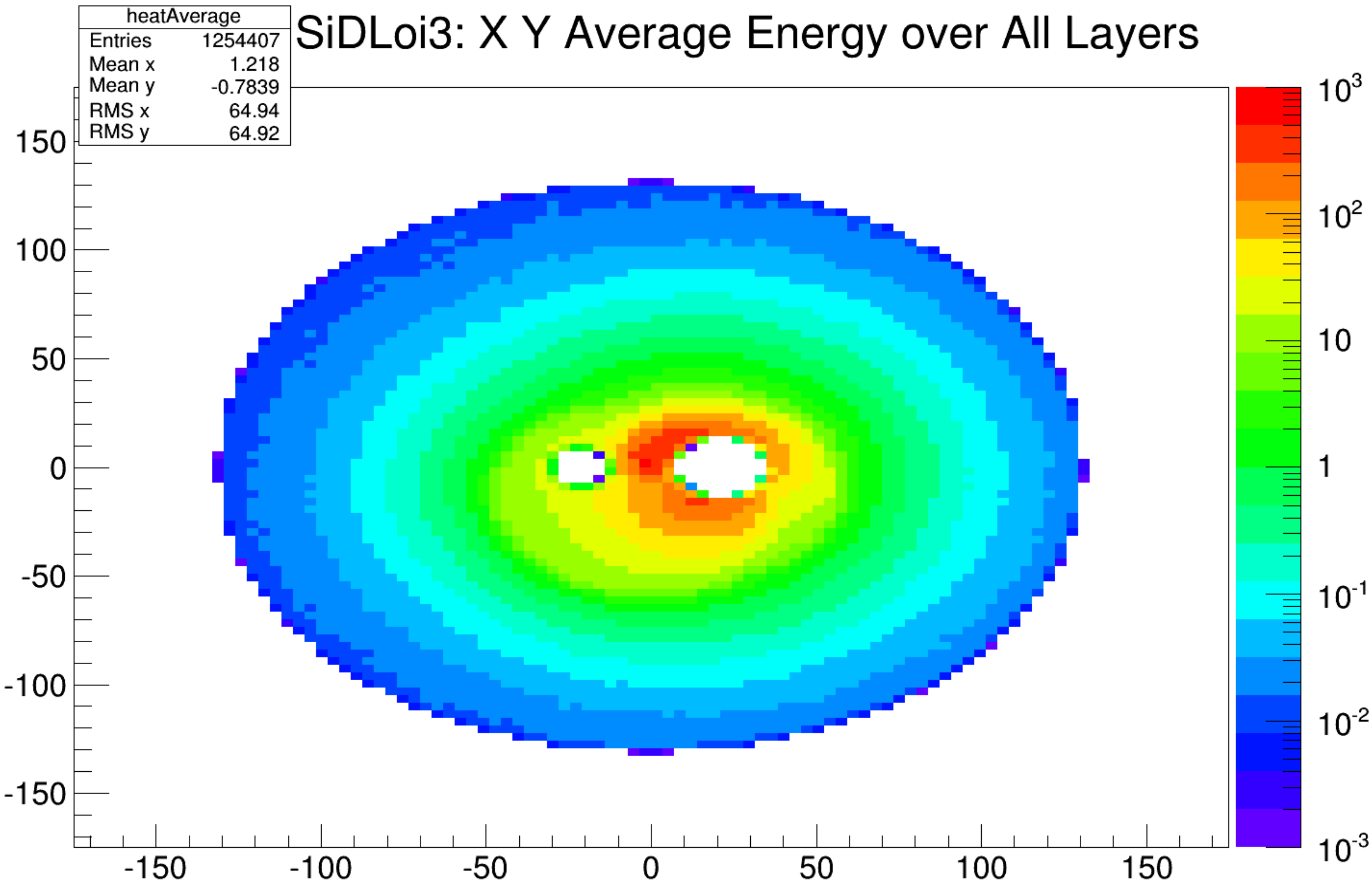
- O(100 nA/cm^2) after 6 MRad irradiation
- Not observed to improve with annealing

Radiation Damage Plans/Opportunities

- Silicon sensor studies to high dose, careful monitoring/control of currents, annealing
- Further sensor types (GaAs, Sapphire, SiC)
- Instrumentation support (FPGA, analysis software)
- Silicon sensor for prototype FCAL (ongoing CERN/DESY testbeam studies)

BeamCal Simulation Efforts

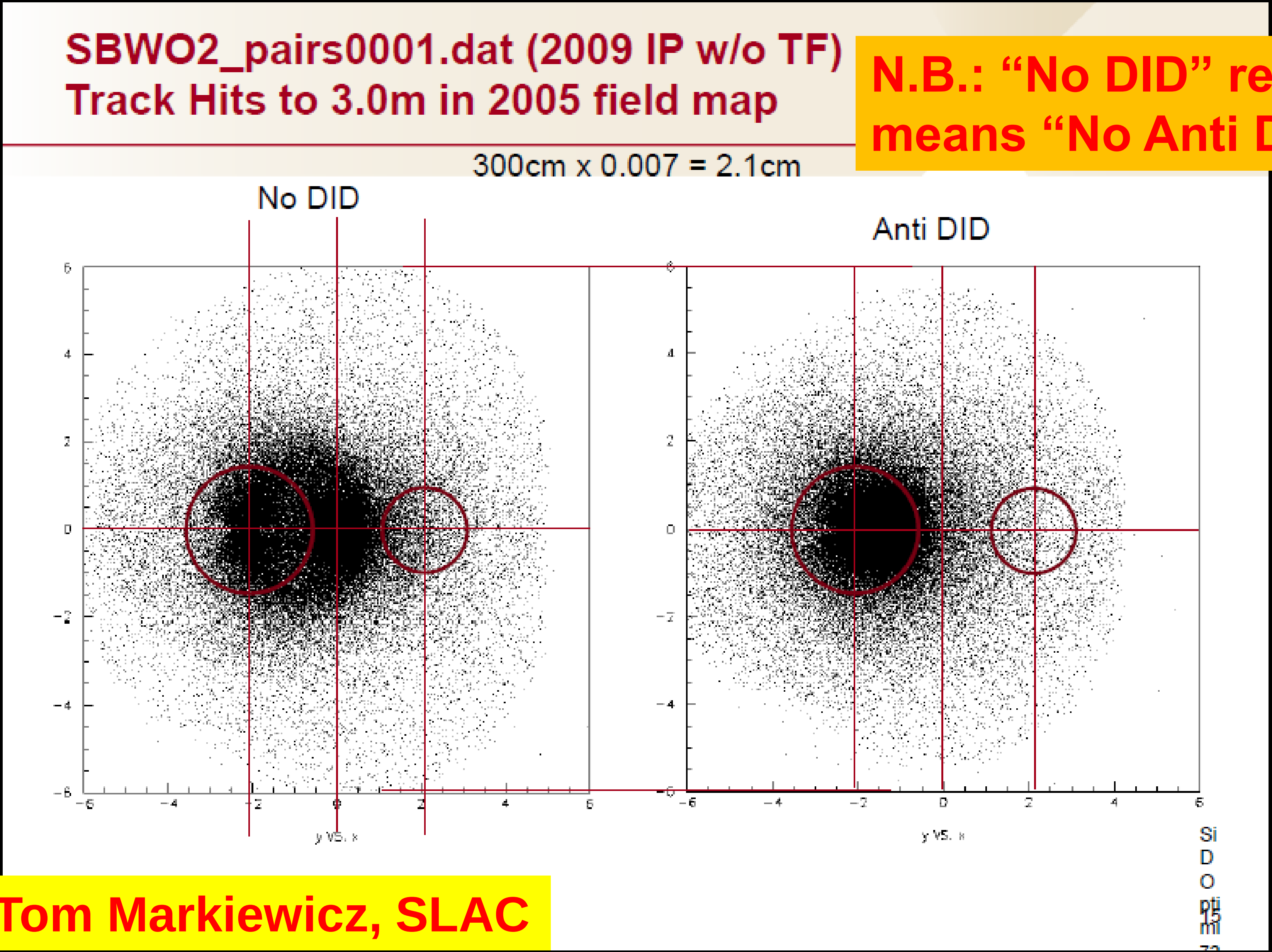
Pairs from Beam-Beam Interaction: ~10 TeV per Crossing



BeamCal Reconstruction: Basic Idea

- **Find top 50 energy depositions in layer near shower max**
- **Extend each longitudinally and sum energy in layers**
- **If one is some number of sigma (σ_{cut}) above mean background, accept as signal**
- **σ_{cut} is single number (r,φ-independent) chosen to select 10% of events for which there is nothing but pair background**

Sample Study: Value of AntiDiD



N.B.: “No DID” really means “No Anti DID”

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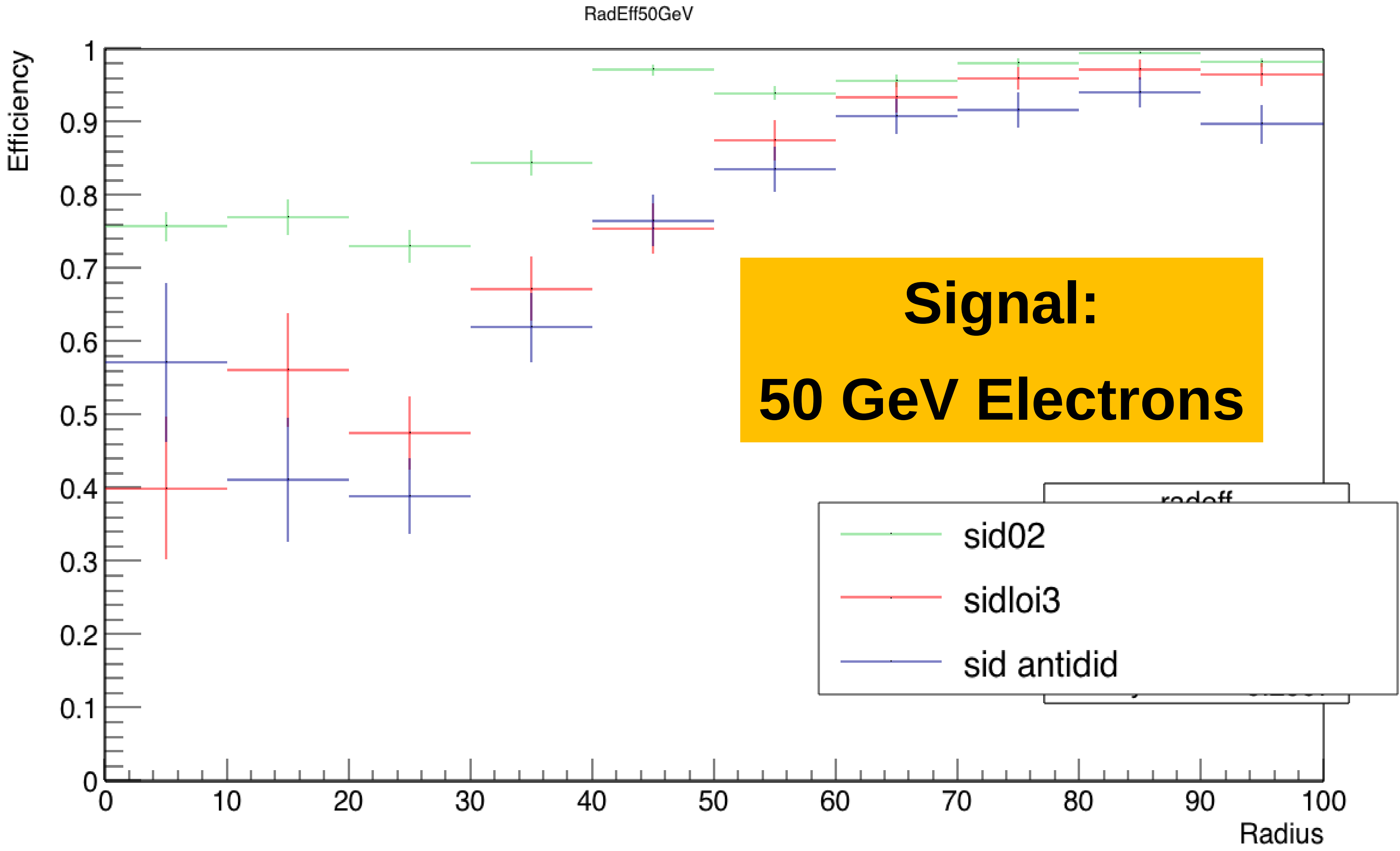
Preliminary Results: With and Without AntiDID; also, comparison with DBD (SiD02)

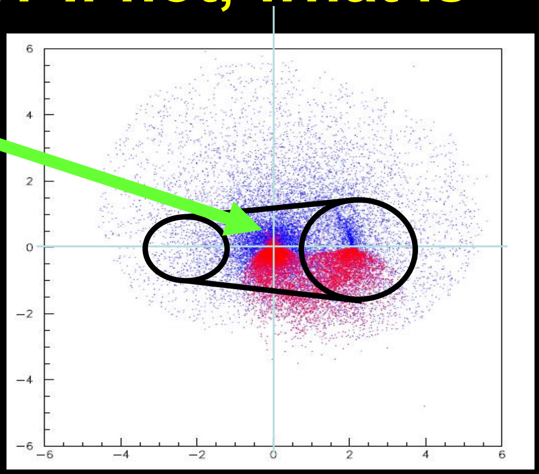


BeamCal Simulation Cornucopia

Many studies underway/planned/need planning

Instrumentation

- AntiDID of any use?
- "Plug region" between two holes needed? If not, what is optimal geometry?
- Efficiency vs. L^* (common SiD/ILD L^*?)
- Further optimization of reconstruction



Physics:

- Rejection of two-photon backgrounds to
  - Nearly-degenerate SUSY
  - Hvv
- Rejection of (radiative) Bhabha

Etc…

SiD BeamCal "Opportunties"

Many areas of ongoing work that offer opportunities for increased effort and collaboration

- **BEAN chip development (contact Angel Abusleme)**
- **T506**
- **Simulations**
- **Or: whatever you see as relevant and of interest**

➔ Talk to us

➔ Attend next FCAL collaboration meeting

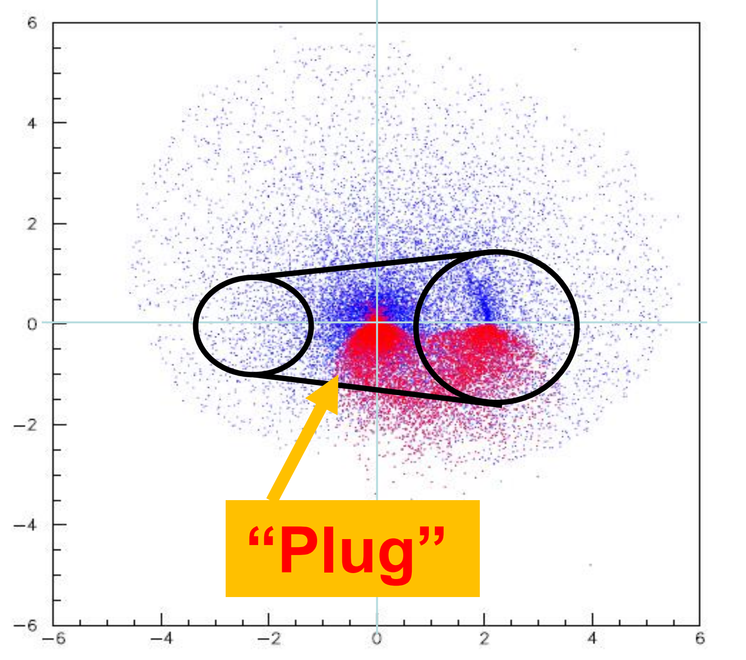
- **➔ DESY Zeuthen 20-21 October**

If this machine moves forward, we are going to need to really focus seriously on design.

Backup

MDI Q1 cont'd: Anti-DiD needed?

	No DID		AntiDID	
	# Hits	Energy	#Hits	Energy
Out 3cm exit	17.9%	78.4%	81.9%	85.4%
Out 2cm entrance	1.8%	0.4%	0.6%	0.3%
Hit the plug	74.9%	15.2%	6.7%	2.8%
Outside the plug	5.4%	6.0%	10.9%	11.4%



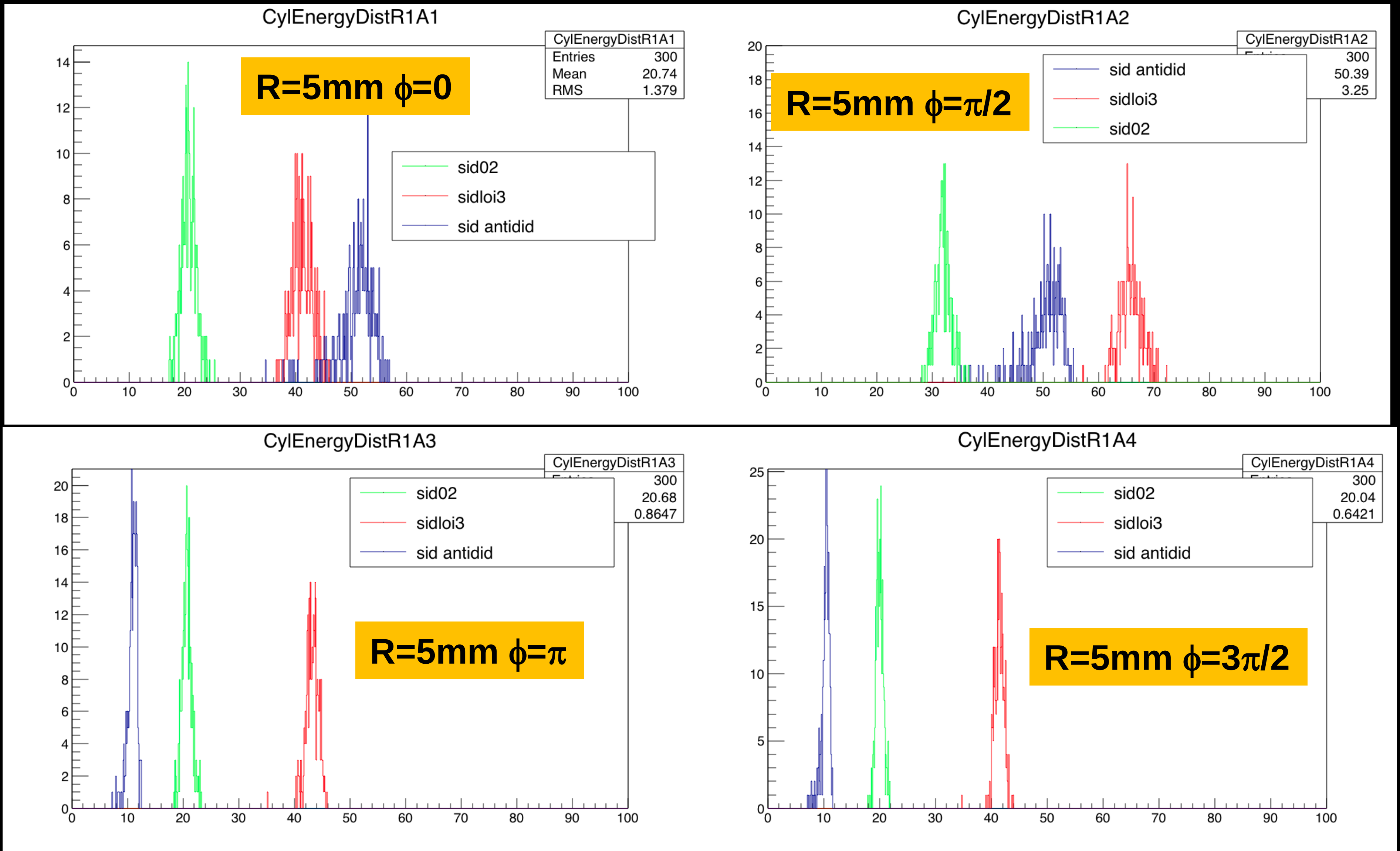
Tom Markiewicz, SLAC

Conclusion:

- The Anti-DID really only helps in the plug region between the beam pipes
- Without the plug to create secondaries, VXD backgrounds should be LESS with no Anti-DID and radiation dose to BEAMCAL should be less

➔ **What about the physics?**

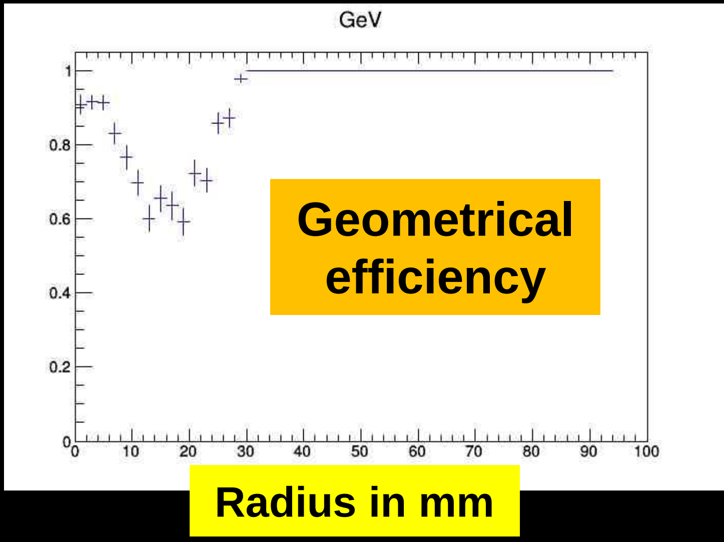
Energy deposition (summed longitudinally) for various low-radius points on BeamCal

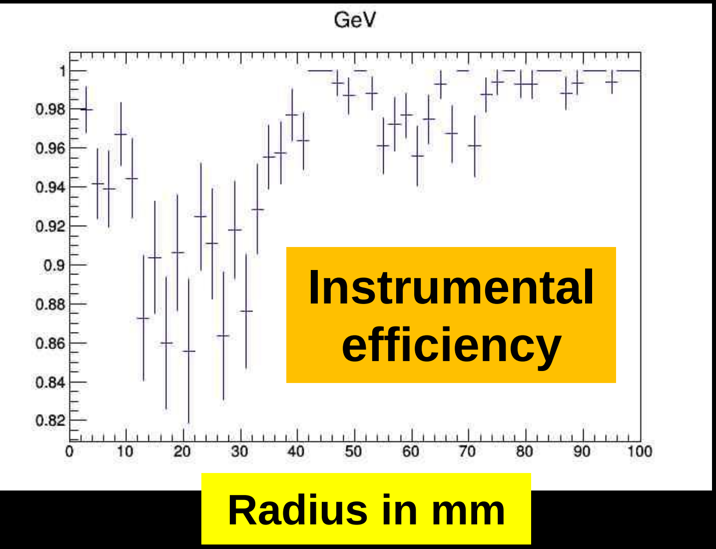


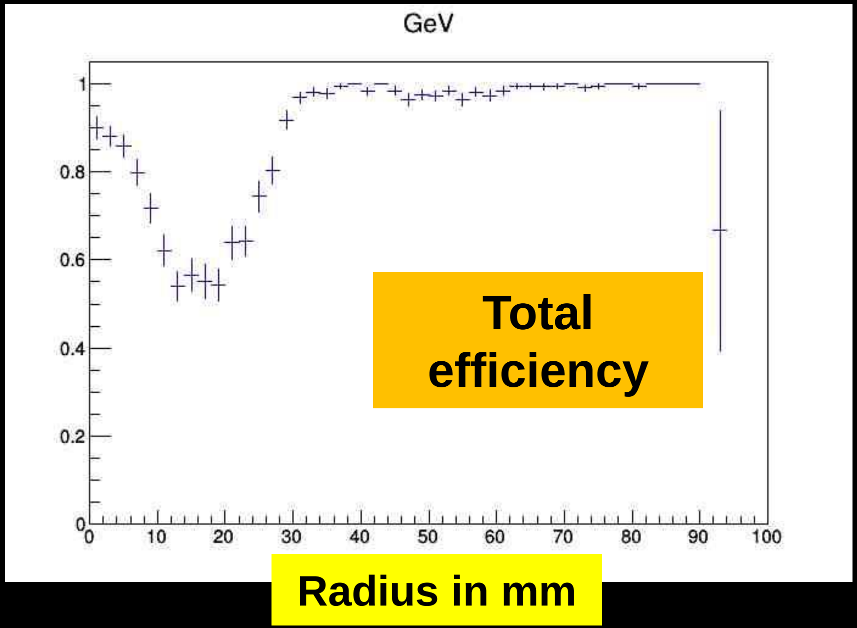
MDI Q2: BeamCal Location and Geometry

- First step: Need to (re)-learn how to simulate the SLD IP and BeamCal environment ➔ underway
- Need to center BeamCal on exit hole (correct?)
- Factorize BeamCal efficiency estimates: total efficiency a product of
  - Geometrical efficiency (did the electron hit the instrumented region?)
  - Instrumental efficiency (if so, was an electron reconstructed?)

Factorized efficiency vs radius results for 100 GeV electrons







- What happens if “plug” is removed (VXD and BeamCal backgrounds)?
- What is effect on SUSY sensitivity in degenerate scenarios?

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

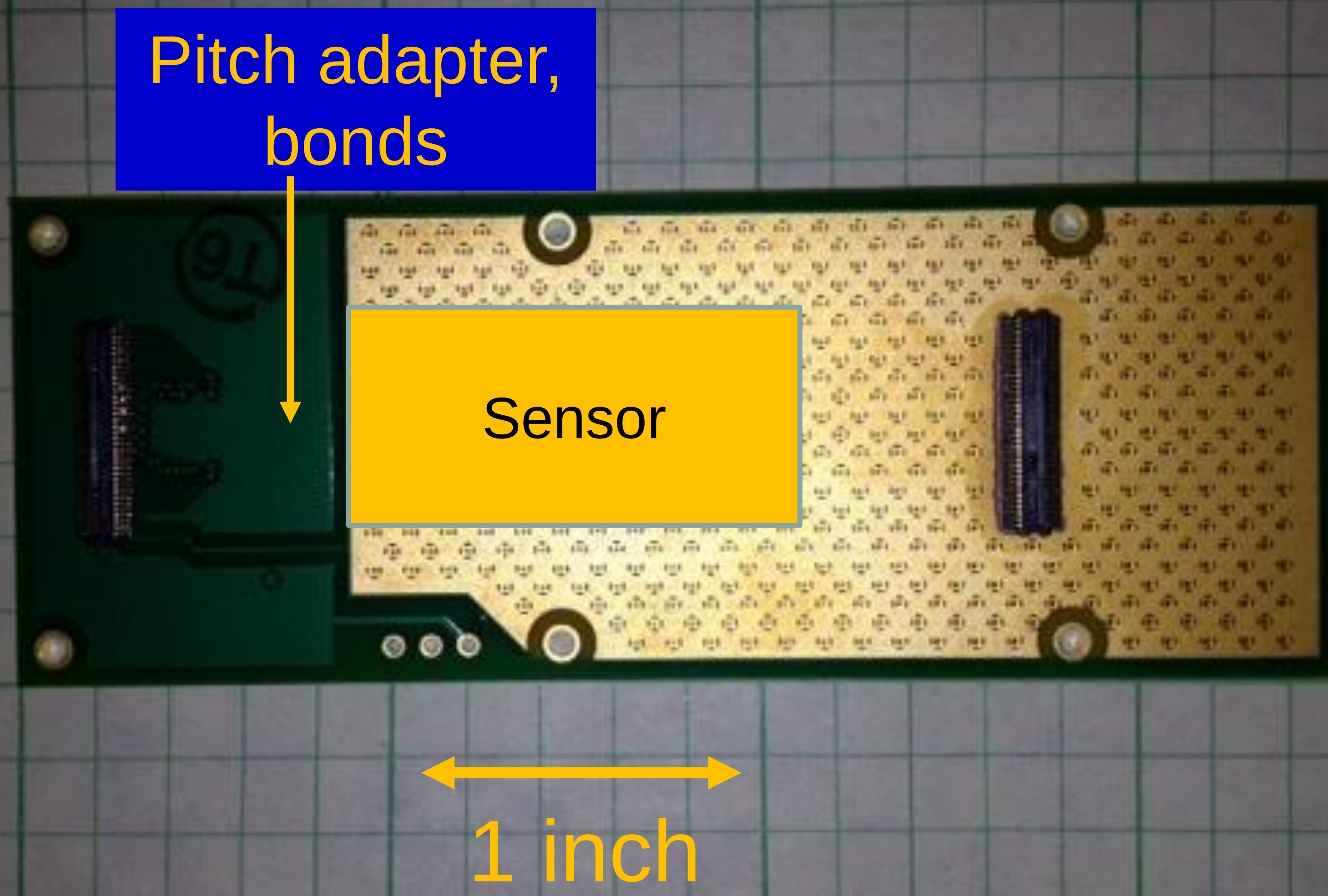
Threshold seems to be about 200 MeV

• Nuclear Compton scattering

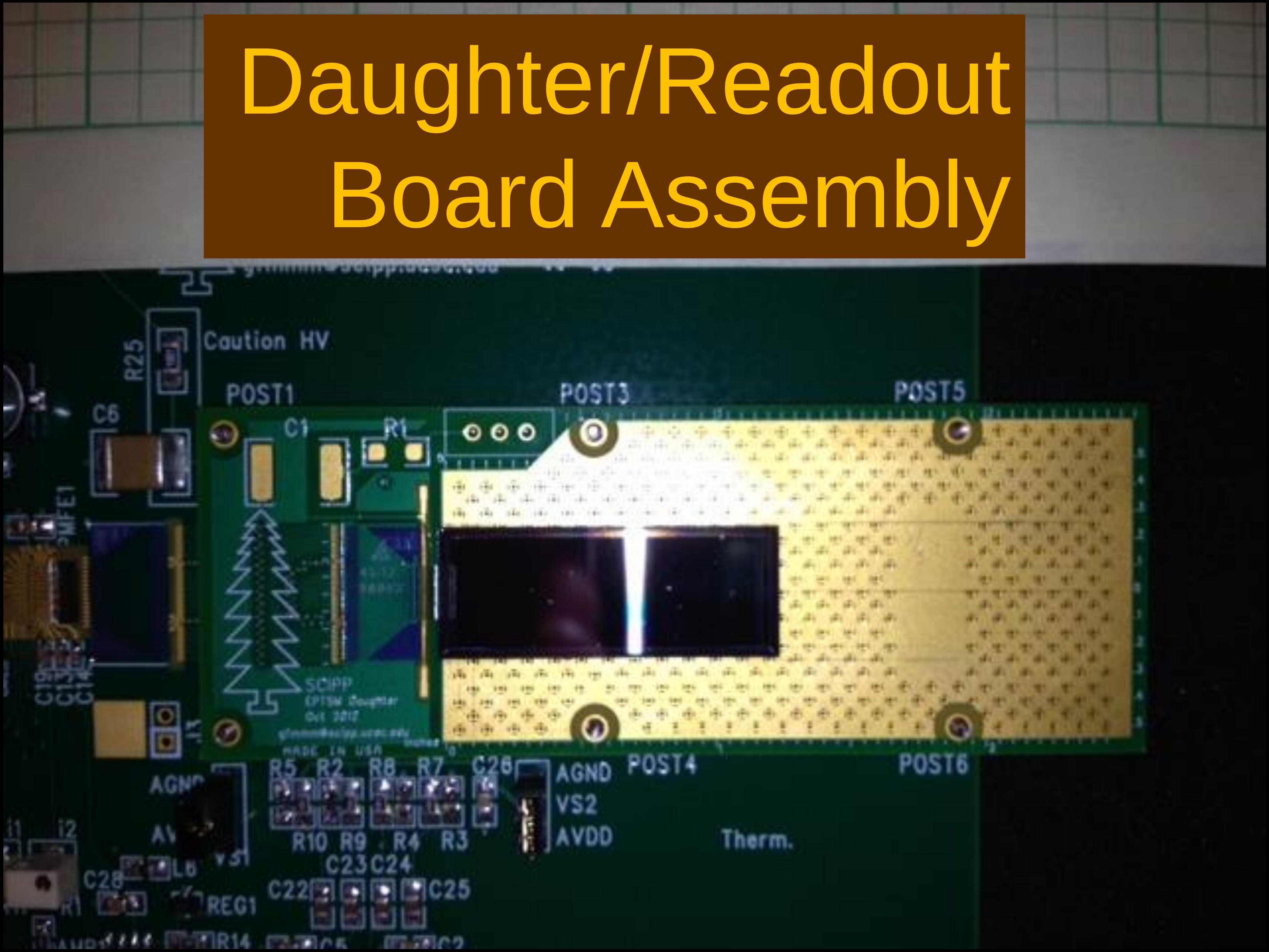
Threshold at about 10 MeV; Δ resonance at 340 MeV

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

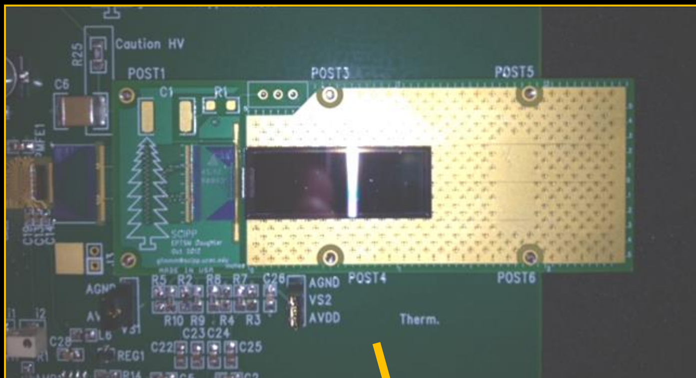
Daughter Board Assembly



Daughter/Readout Board Assembly



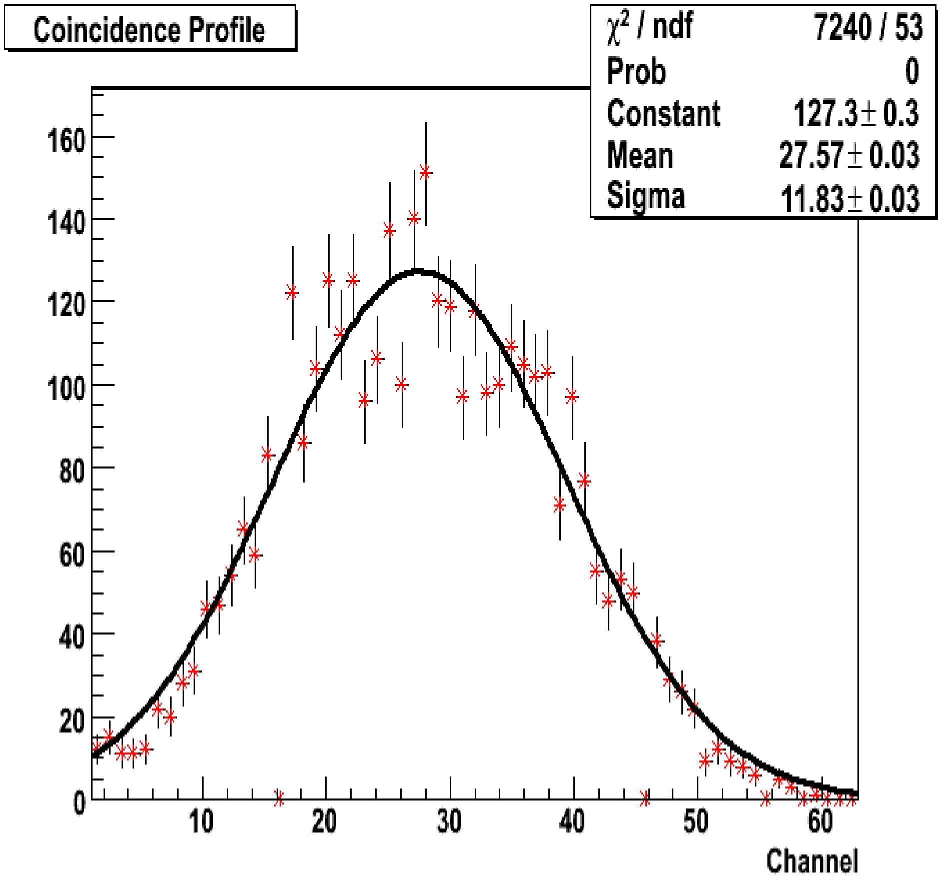
Charge Collection Apparatus

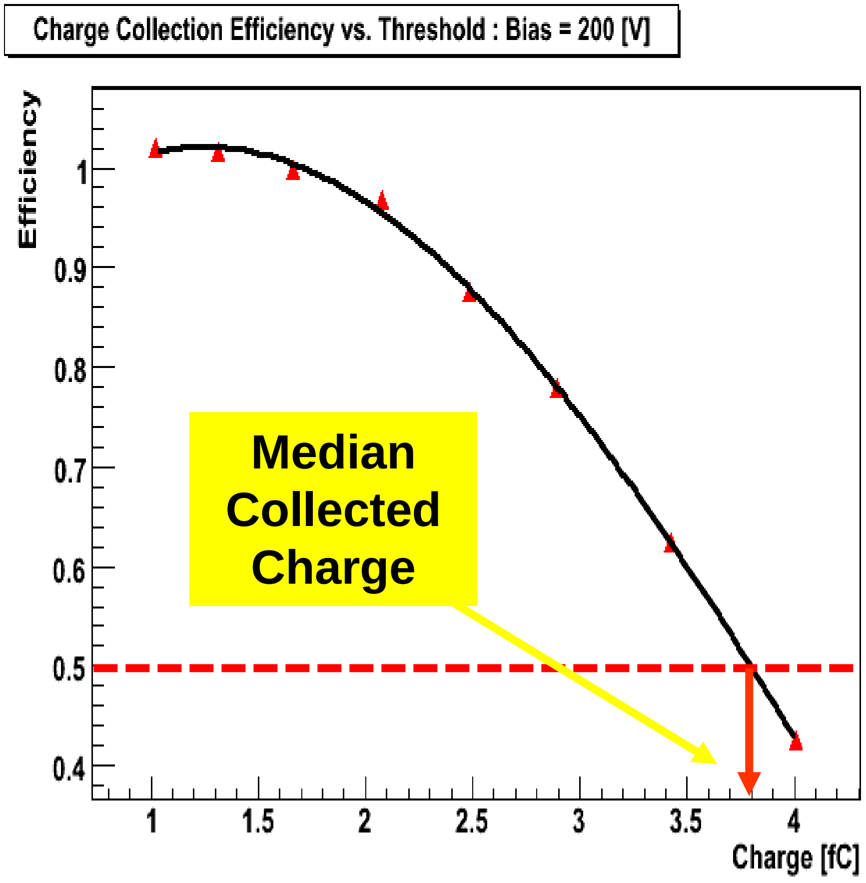


- Readout: 300 ns

Charge Collection Measurement

2.3 MeV e^- through sensor into scintillator

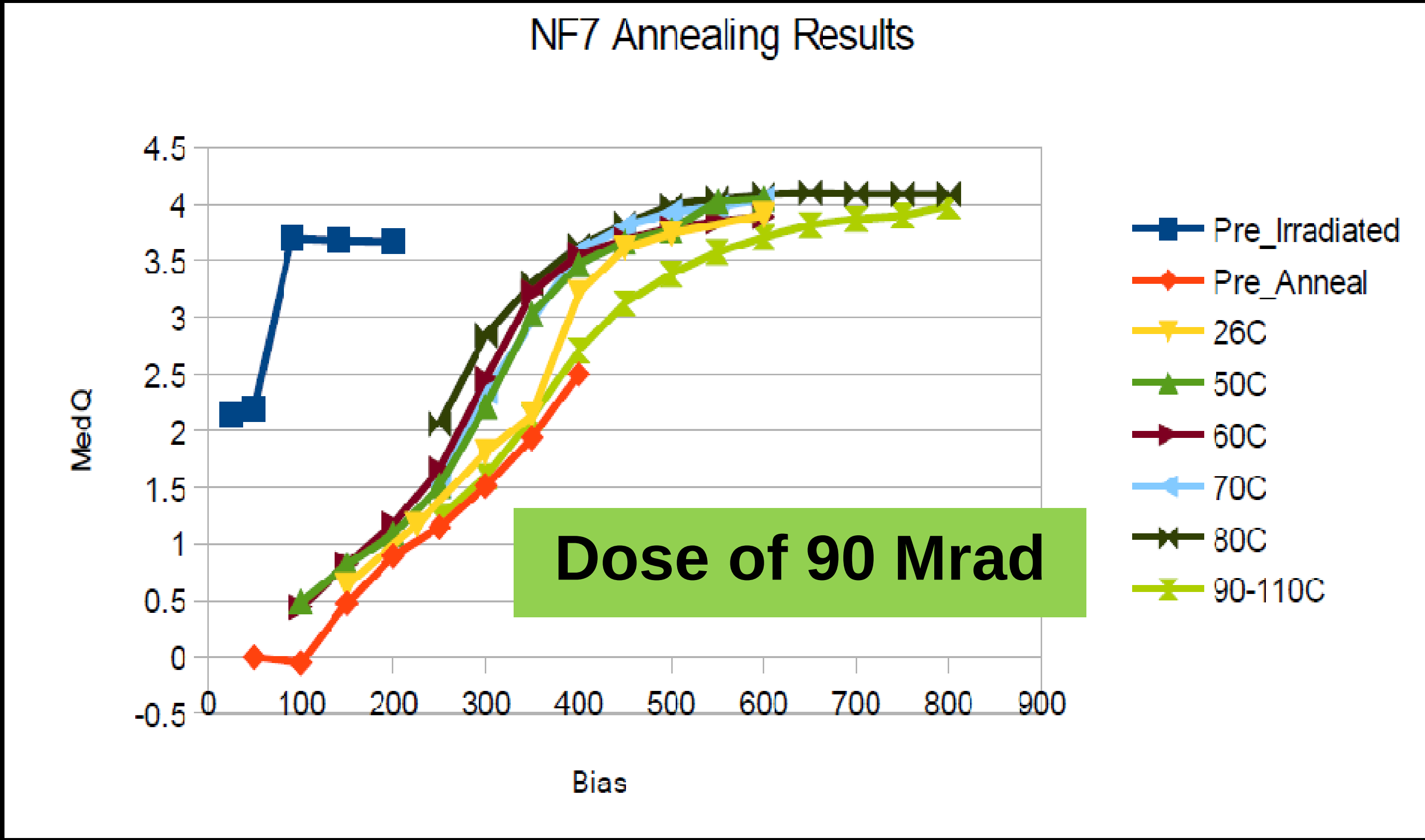




Channel-over-threshold profile

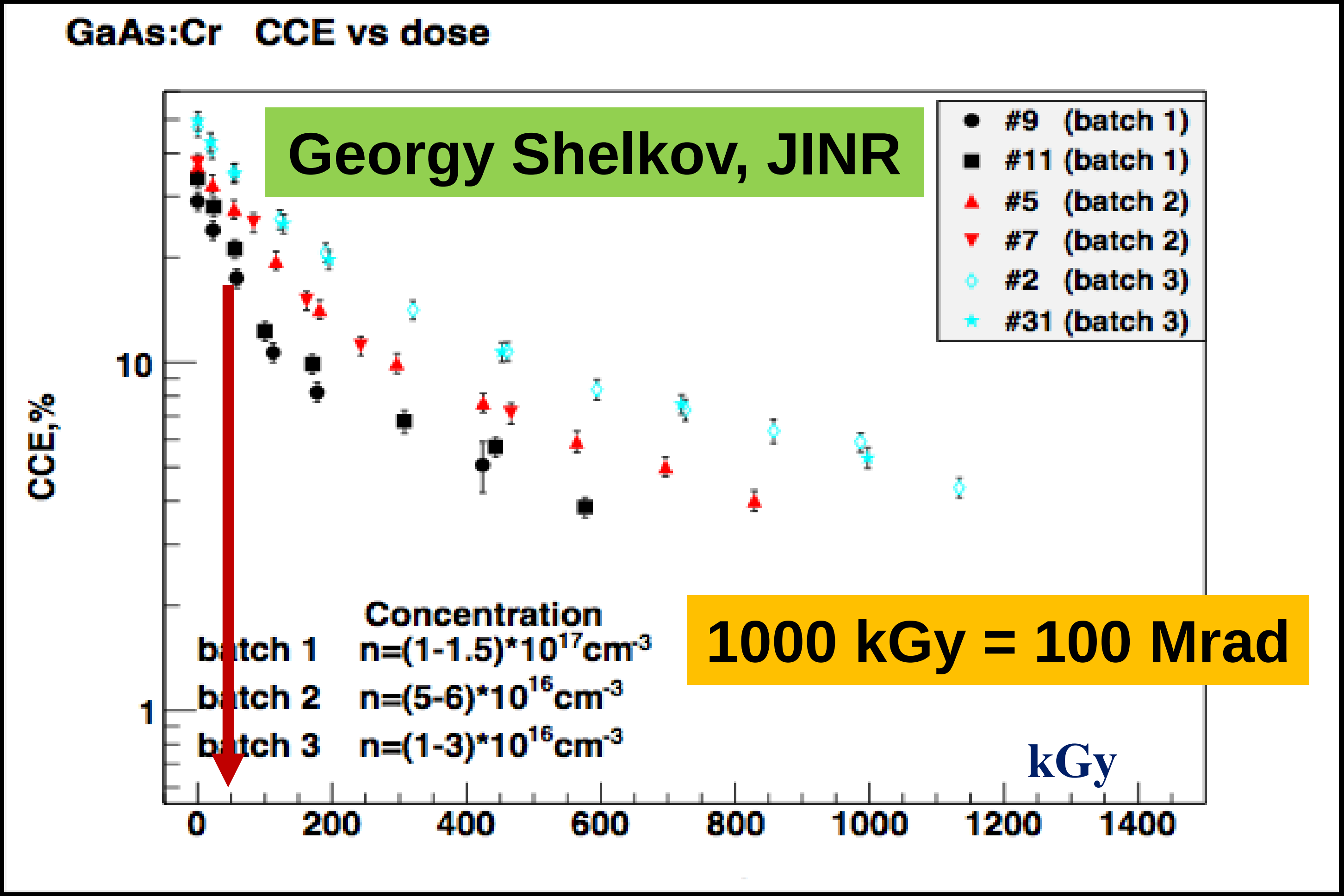
Efficiency vs. threshold

Results: NF Sensor to 90 Mrad, Plus Annealing Study



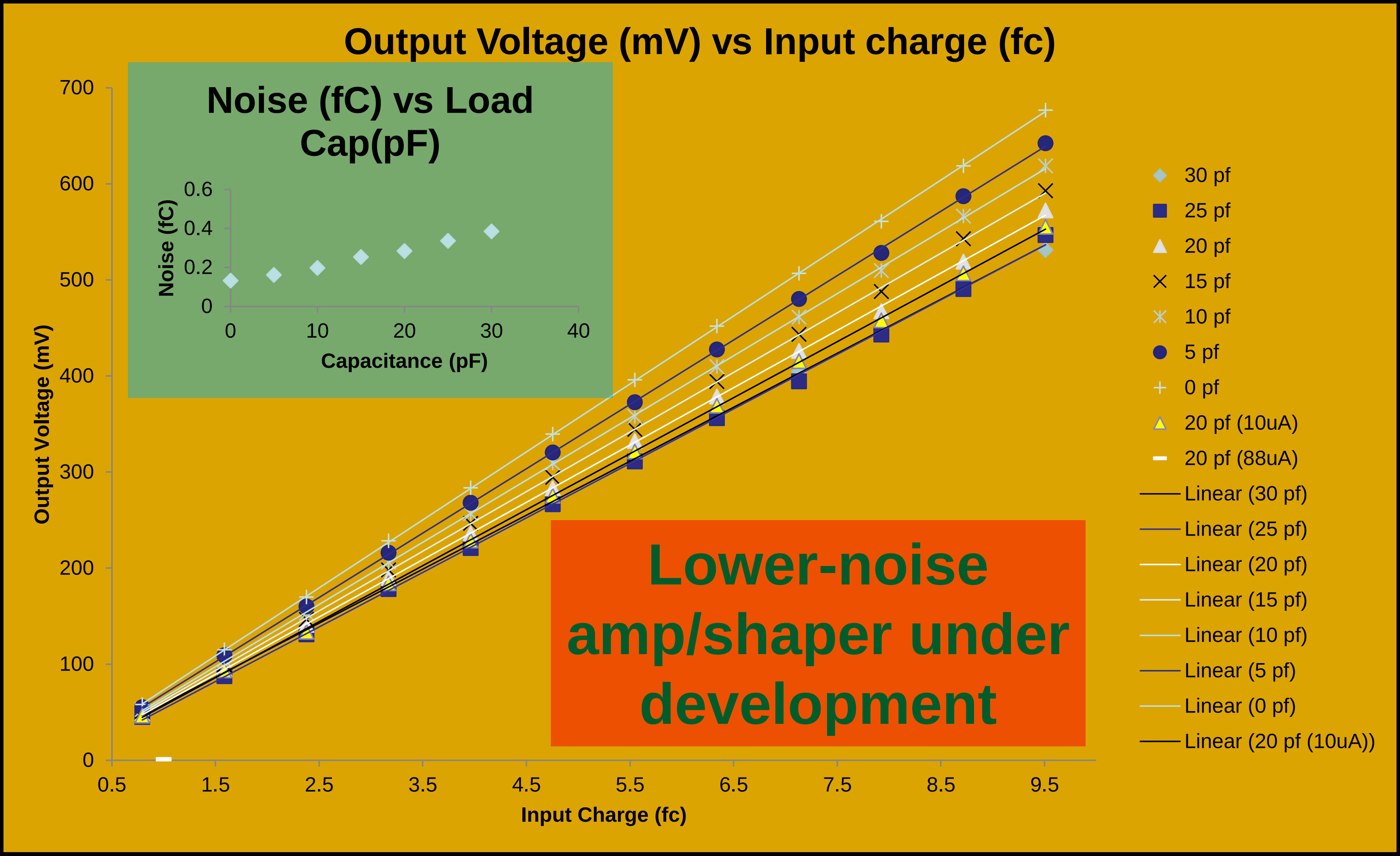
Limited beneficial annealing to 90ºC (reverse annealing above 100ºC?)

Compare to Direct Electron Radiation Results (no EM Shower)



Roughly consistent with direct result

Single-Channel Readout



Needed for high-dose GaAs, and SiC (0.25 fC signal) and Sapphire (0.09 fC signal)

Plans for T506

Have been promised beam time this spring/summer

Hoping for high intensity running; SLAC has not yet announced plans and offered running slots

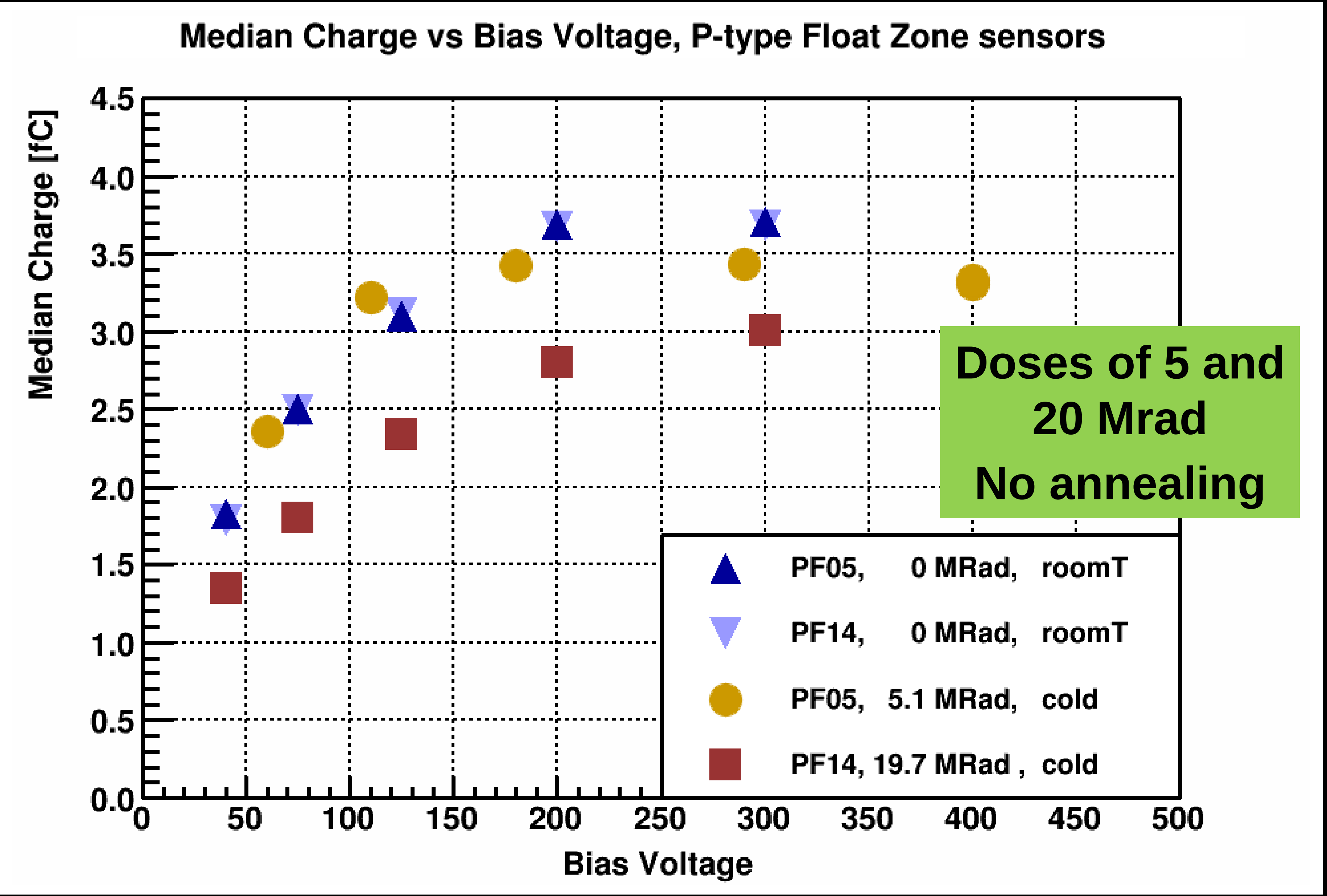
Continue Si irradiation studies to high fluence

- Careful annealing studies
- Studies leakage currents as well as charge collection

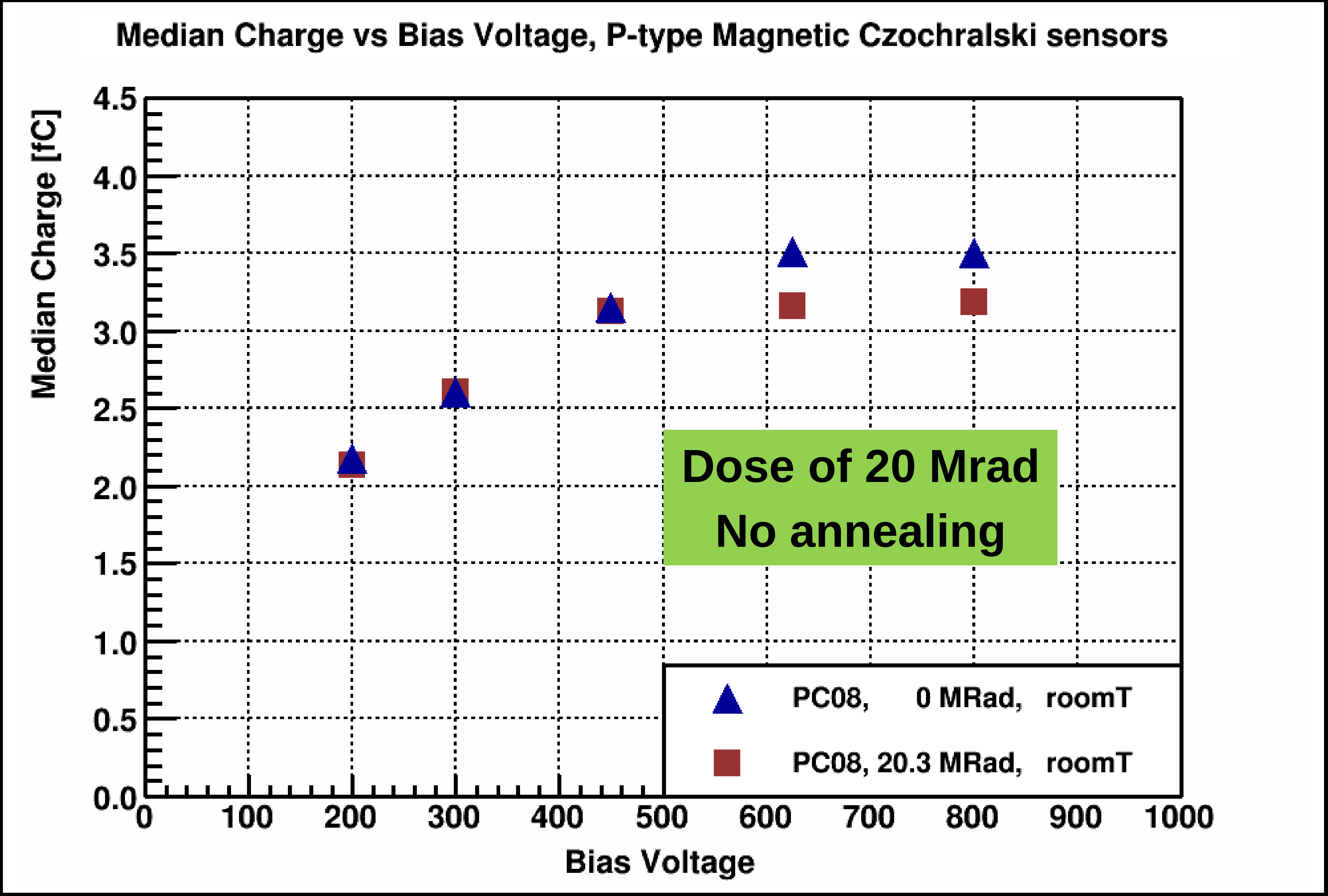
Single-channel readout for novel sensors

- Assess 20 Mrad GaAs sample
- Sapphire irradiation (levels?)
- Silicon Carbide (levels?)

Results: PF sensors



Results: PC sensors



Results: NF sensor for low dose