Thoughts on MaDPhoX Tracker Optimization

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MaDPhoX Tracking Meeting

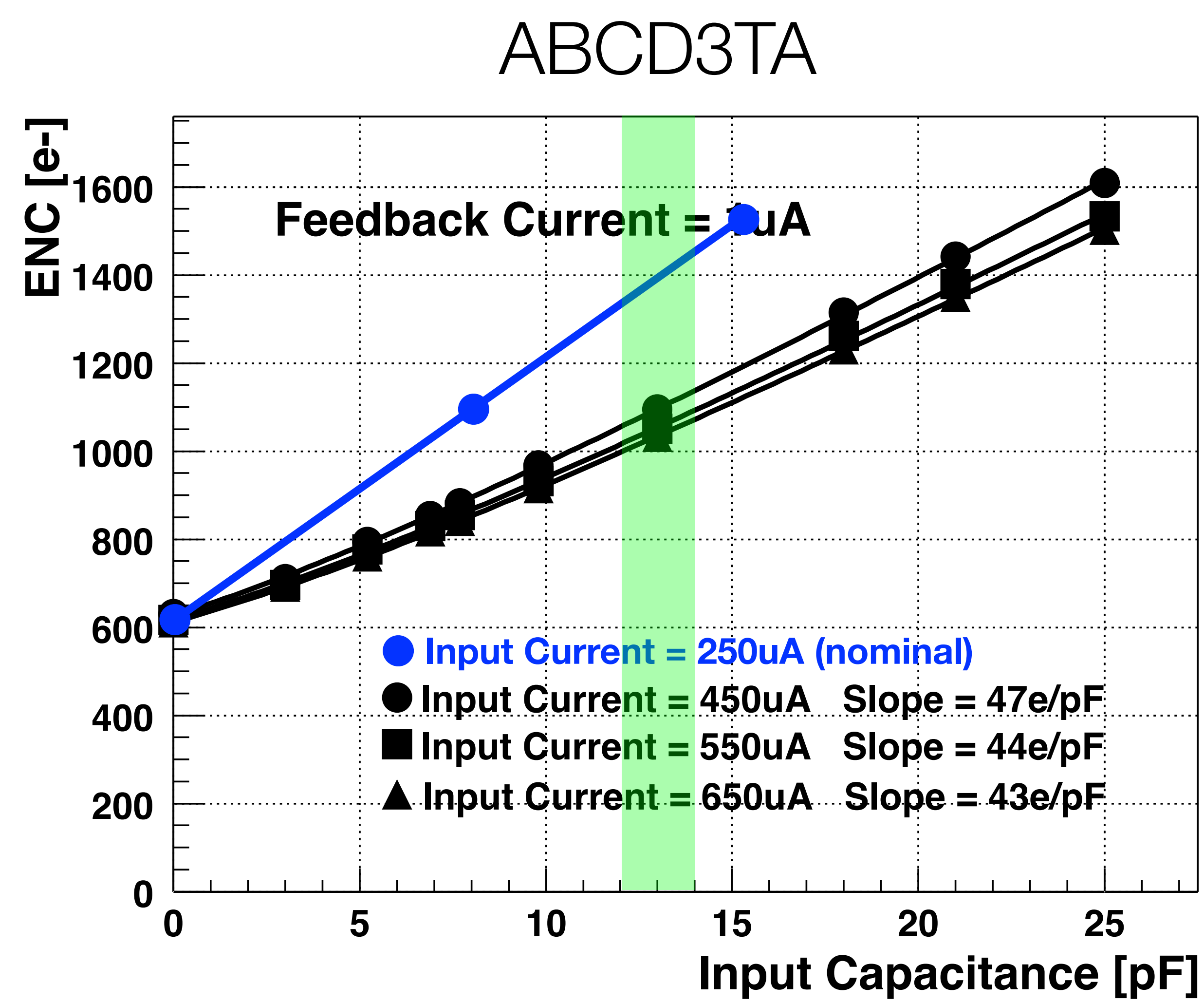
December 18, 2009

Critical Performance Issues

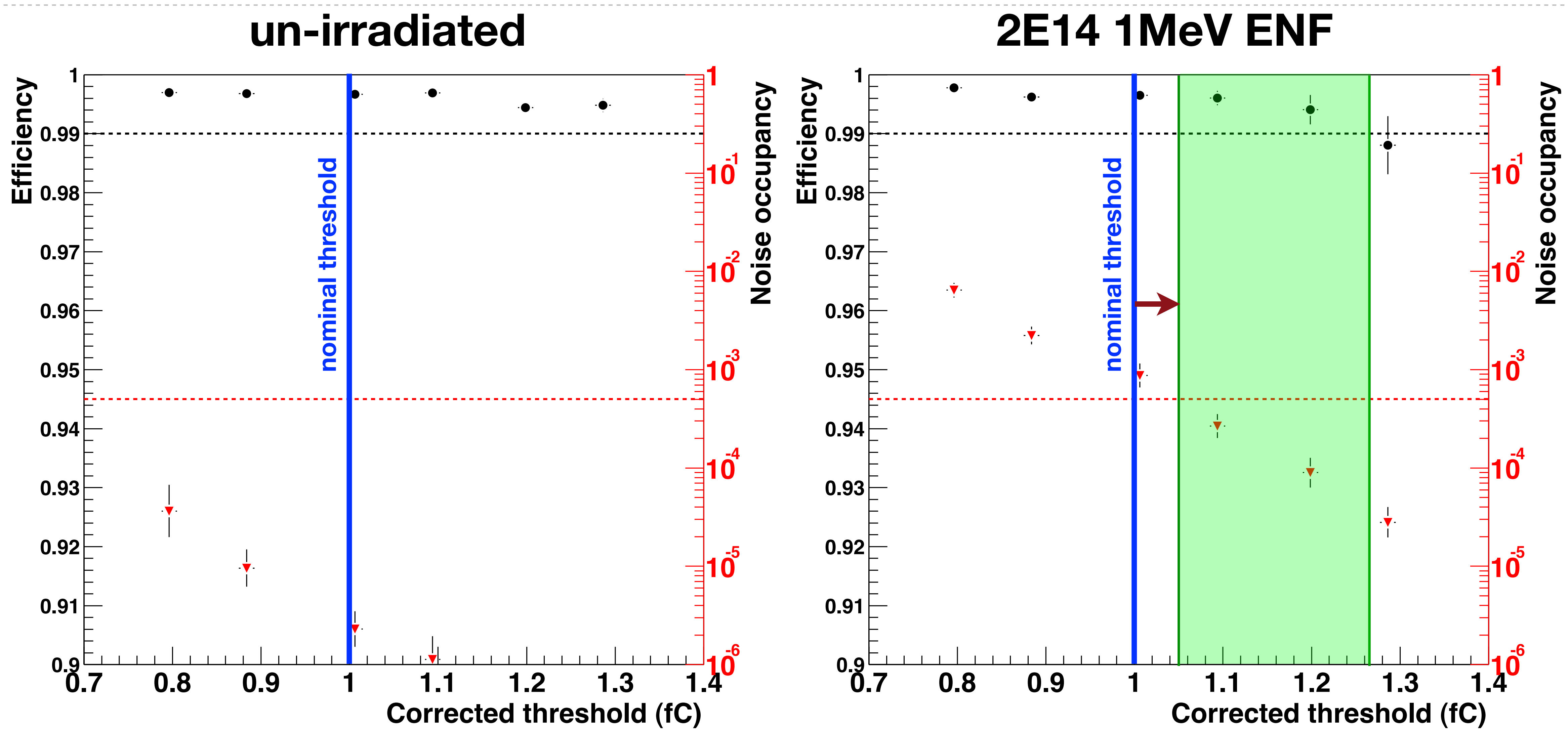
- Acceptance and efficiency/fake rate
  - Optimal placement of detector planes vs. radiation environment
  - Rate of noise hits/efficiency (vs. radiation environment)
- Mass resolution
  - Material
- Vertex resolution
  - Material
  - Optimal placement of detector planes vs. radiation environment

ABCD3TA

- 0.8um DMILL, binary readout
- ENC = 600 + 65*C e^-/pF
  at nominal input current (250 uA)
  - SCT strips are ~15pF for ~1550e^- ENC. 280um silicon results in MIP deposit of 21.5ke^- for S/N = 14.0
  - RunIIb strips will be 12-14pF before irradiation. 320um silicon results in MIP deposit of 24.9ke^- for S/N = 17.8
- ***May*** be able to reduce noise slope by increasing input current at the cost higher heat load.



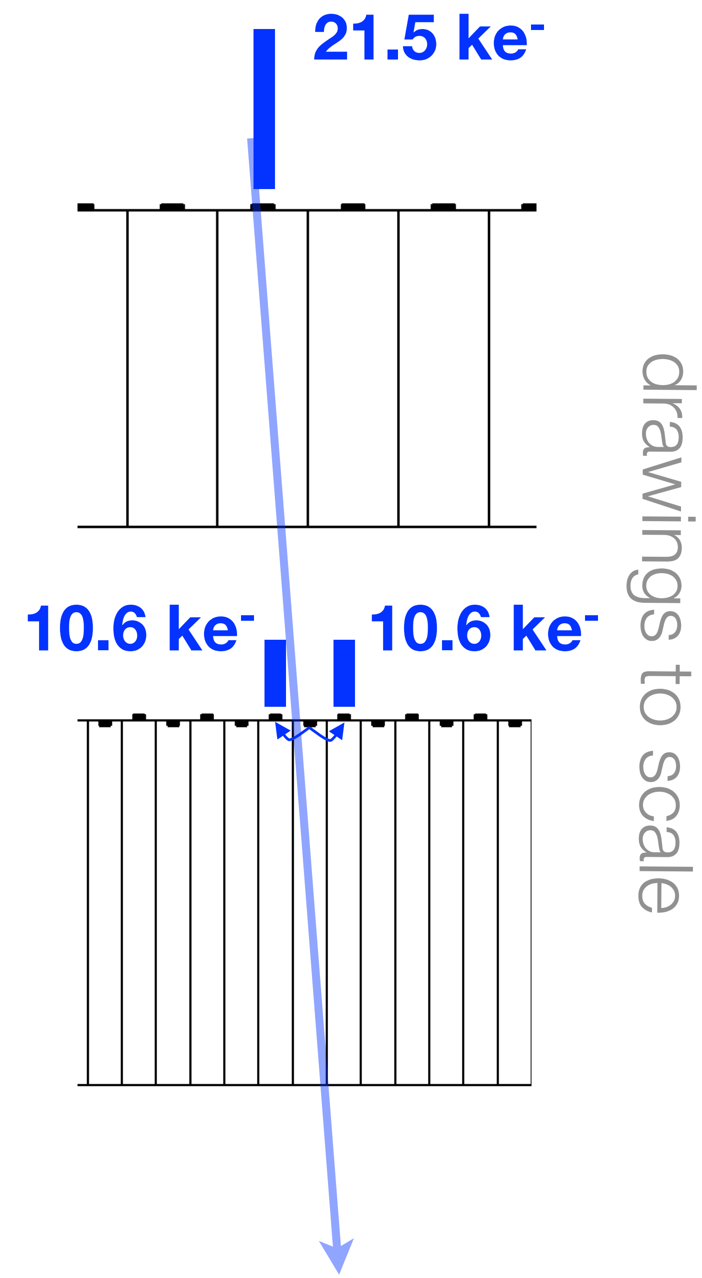
Where's the Rub?



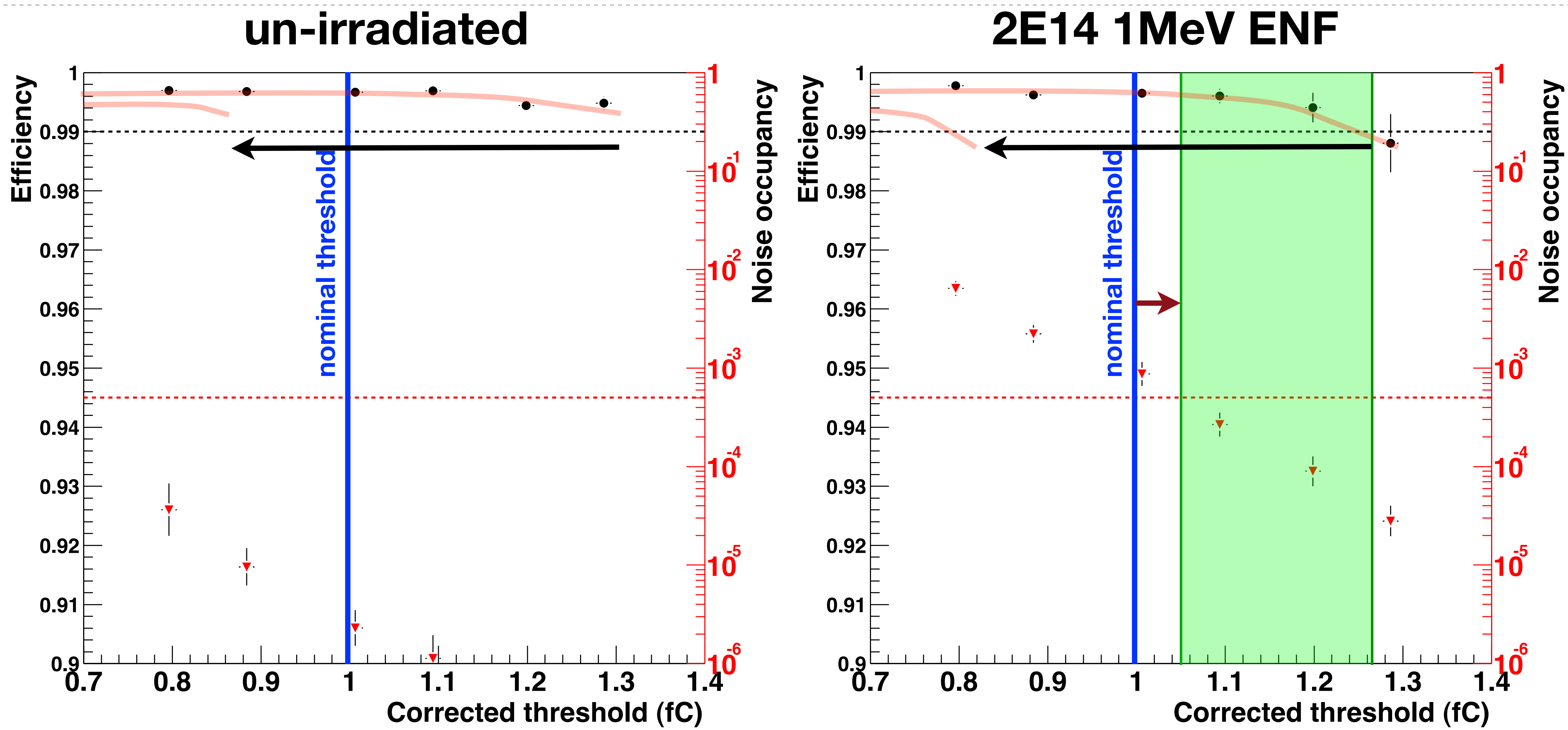
- Binary readout makes this tricky business. Threshold selection is a one shot deal.
- But these are SCT sensors, we have additional headroom, right?

For RunIIb Sensors

- In SCT sensors, most tracks near normal incidence deposit all of their charge on a single strip.
  - Ensures good efficiency
  - Well matched to binary readout.
- In RunIIb sensors the majority tracks, *including* those at normal incidence, deposit charge on multiple strips.
  - Optimizes resolution for “analog” readout.
  - For binary readout, this does nothing but spread out and discard signal (~15% of signal on intermediate strips goes to backplane).



Charge Sharing Eats Into "Safe Zone"



- In order to ensure good efficiency, threshold will have to be much lower.
- Thinning sensors makes things worse

Efficiency Comments and Material

- Binary readout makes this a very tricky business. Parameter tuning must be perfect. One cannot run with low thresholds and then come back later to re-cluster more carefully. *Once the data is taken, it's done.*

- Do we need 99% efficiency?

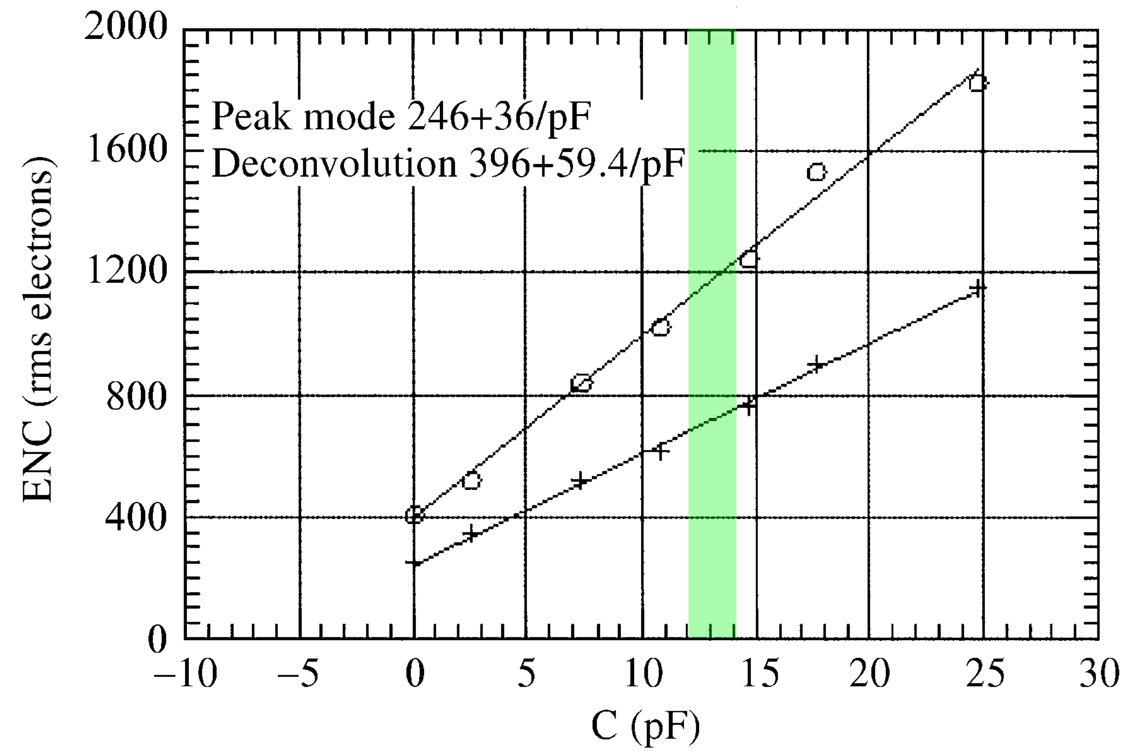
    - Imagine 4 stereo planes with all needed for good purity: $(0.99)^8$ = 92% tracking efficiency, $(0.92)^3$ = 79% reconstruction efficiency.

➡ The option to high efficiency is redundancy, AKA here as "extra material".

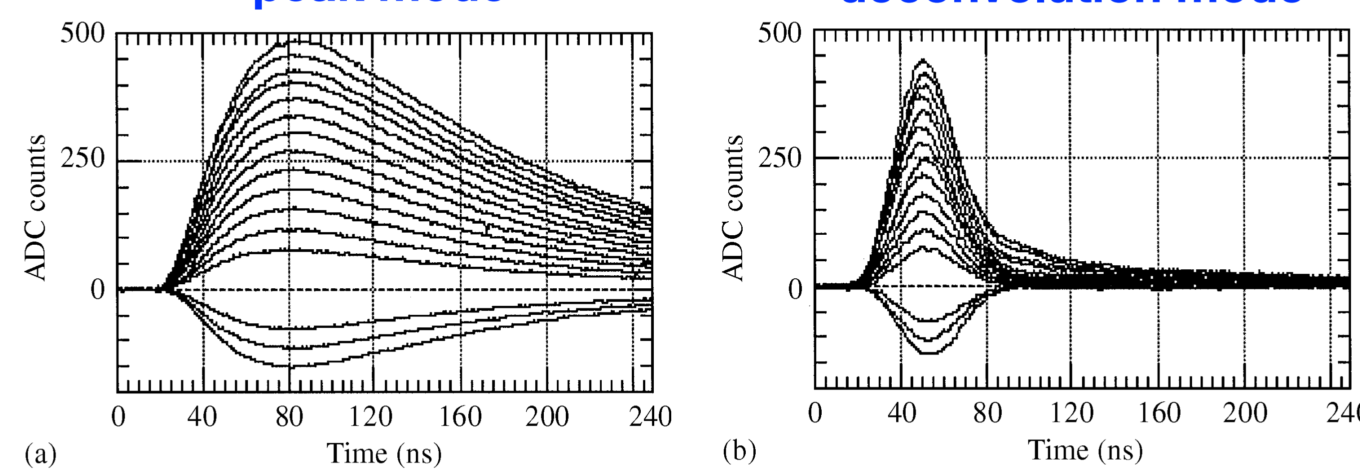
Is There an Option?

CMS APV25

- Used throughout CMS tracker: (~75K chips total)
- 0.25um CMOS improves noise performance
- Analog readout also improves single-hit resolution, especially for alternating-strip readout
- dead-time limitation of peak mode is adequate for most, if not all, of our acceptance.

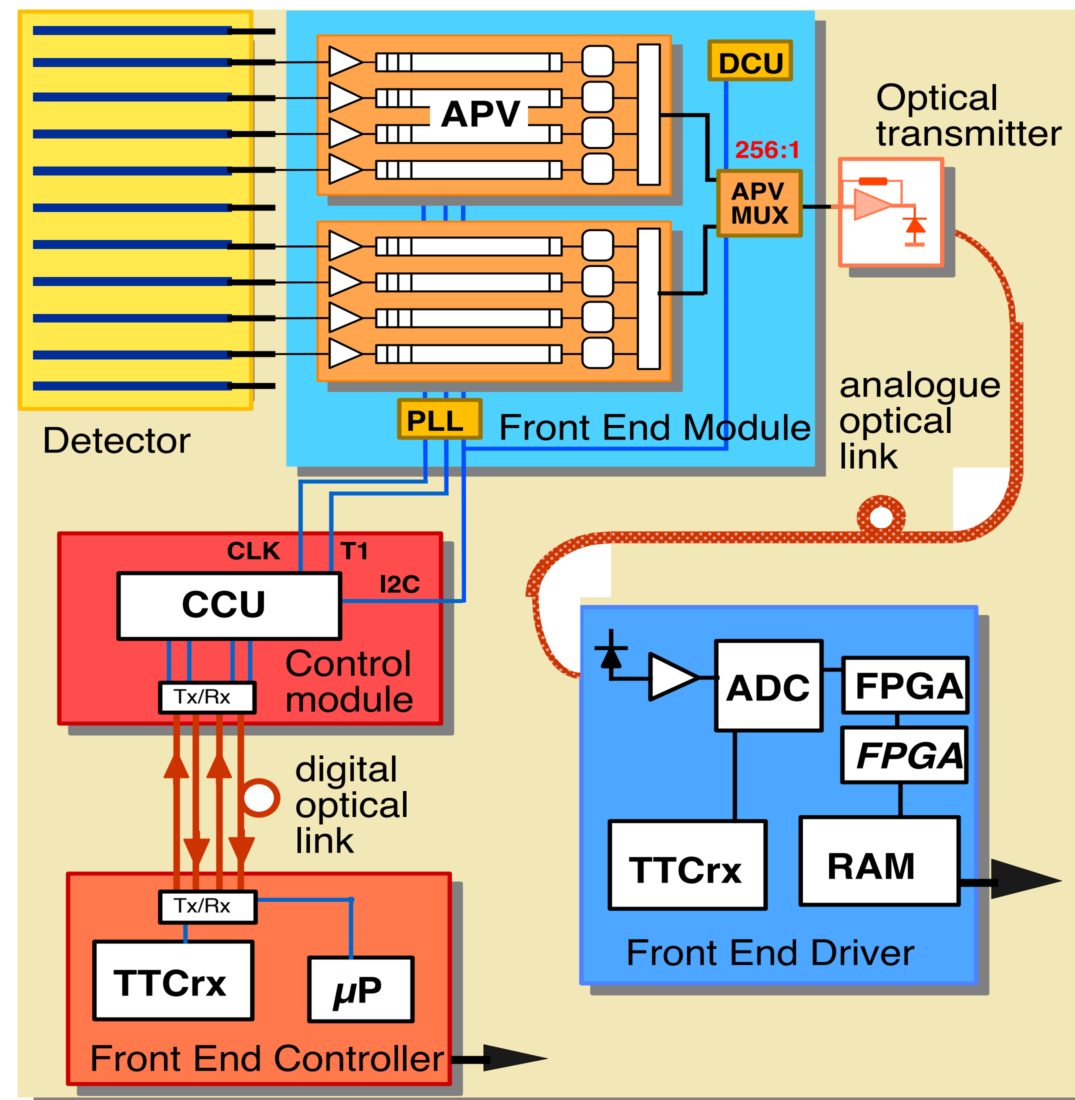


peak mode **deconvolution mode**



APV25 Availability and DAQ

- 100% perfect APV25 available at CERN for 28CHF (~$27) each.
- For an 8-plane tracker, becomes a $10K-$12K item.
- May be more flexible in terms of rest of DAQ. Only other item at detector is analog optical transmitter. Digitization can take place well outside tracking volume.



Summary 1

- The ABCD3TA will work adequately with fresh RunIIb silicon
  - Resolution will be (30-60 microns)/sqrt(12) = 9-17um depending upon noise, but MS still dominates.
  - Binary readout allows one shot: once you've set it, you can forget it!
  - Combinations of other factors will create problems:
    - increased noise and signal loss from high radiation doses
    - thinned silicon
- The APV25 addresses these concerns at a cost.

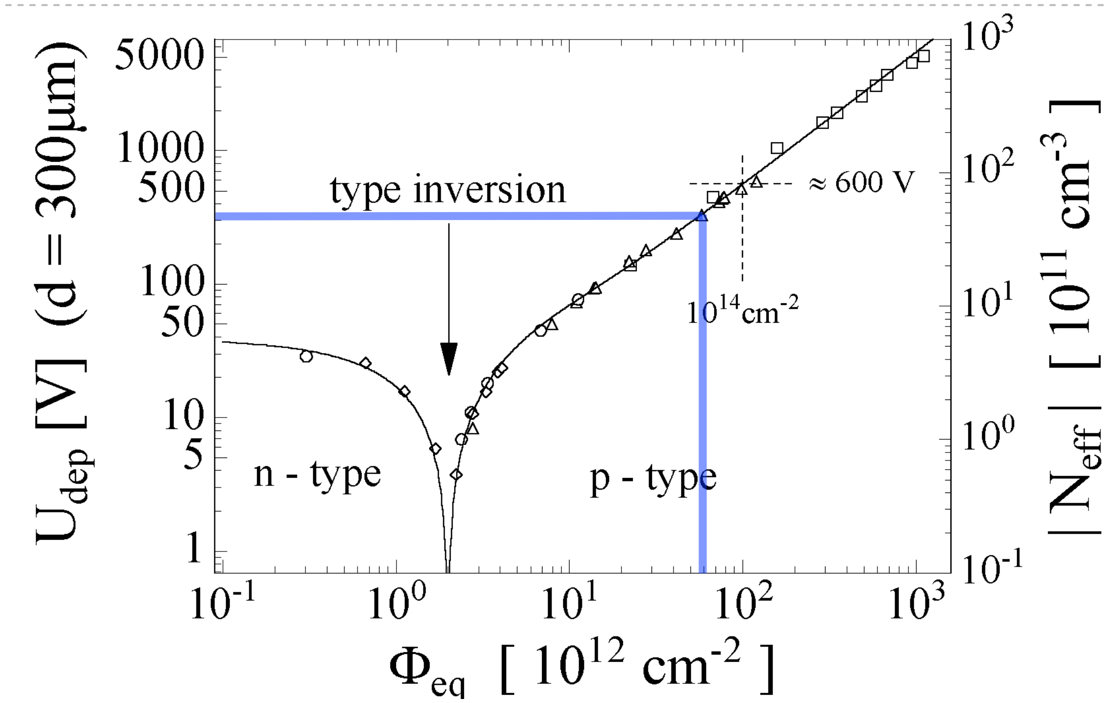
Radiation Tolerance

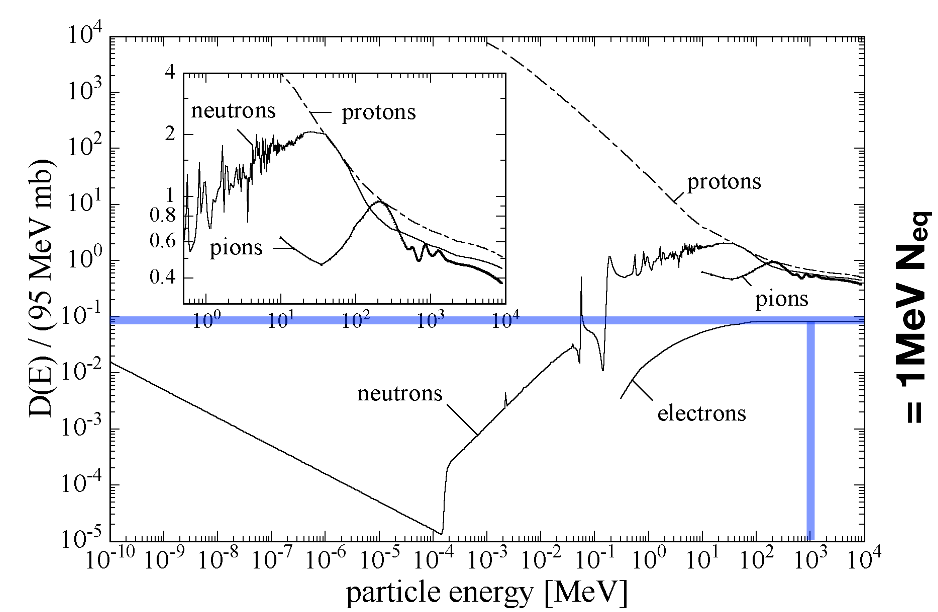
Some misunderstandings regarding radiation tolerance have crept into the design. It's a tricky (and evolving) business!

- Two critical details:
  - Misunderstanding of sensor specifications
  - Misunderstanding of corrections to NIEL scaling hypothesis for electrons
- How far can these sensors be pushed?
- What kind of sensors could we push further?

Limitations of RunIIb Sensors

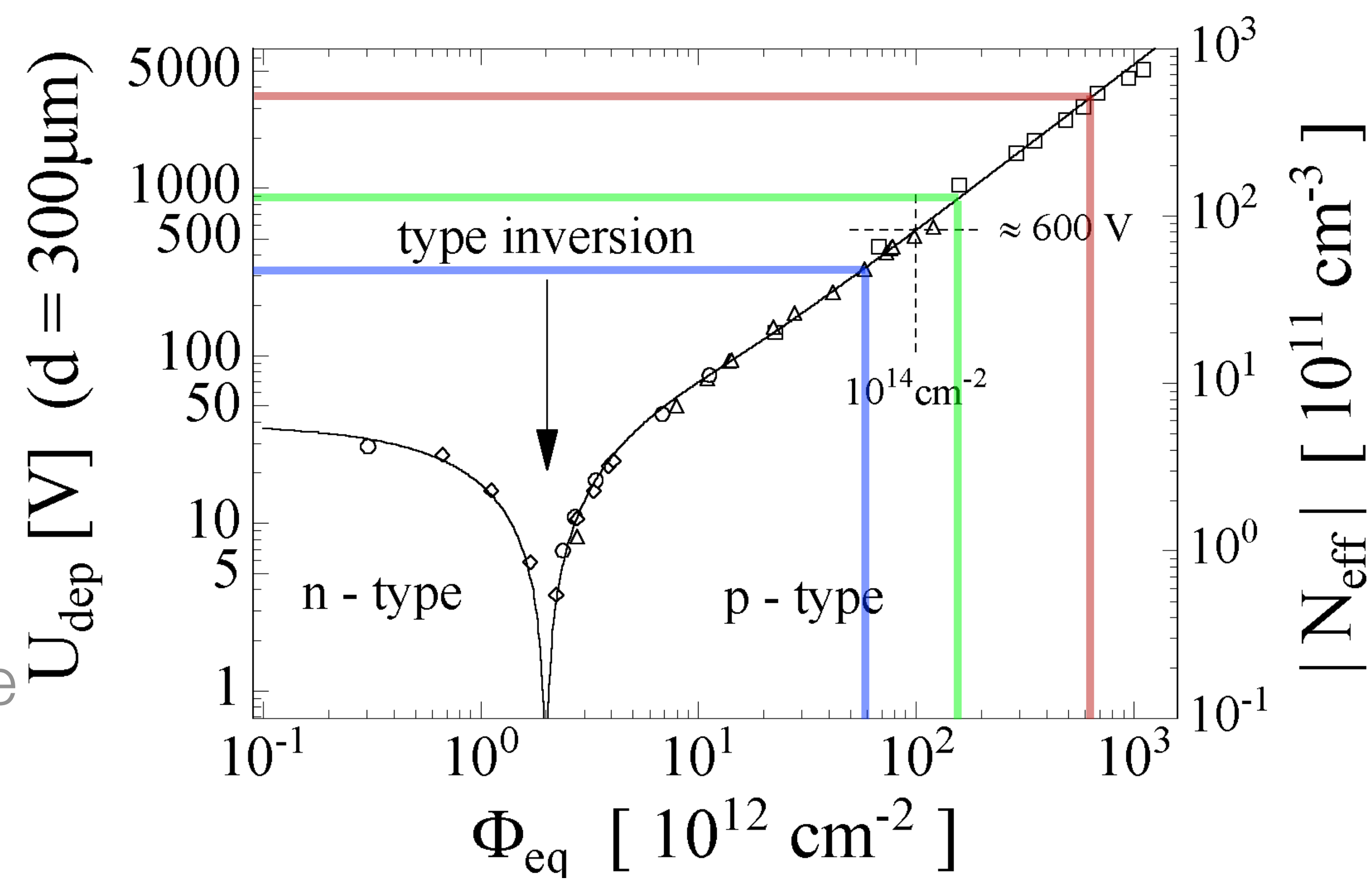
- Sensor specification calls out maximum operating voltage of 350V
- Correcting V_{depl} for thickness (α t^2), sensors should be fully depleted up to $\Phi_{eq} = 6\times10^{13}$ cm^{-2}
- Assuming NIEL scaling, this is equivalent to 7.2×10^{14} cm^{-2} 1 GeV e^-
- However, studies with 900 MeV electrons have shown that NIEL scaling is broken for electrons: damage is ~1/3 of expected value at fluence
- Surface effects negligible (overcome at 20-30V bias)
- Actual equivalent dose: ~2.2×10^{15} cm^{-2} 1 GeV e^- (5.5× previous assumption)





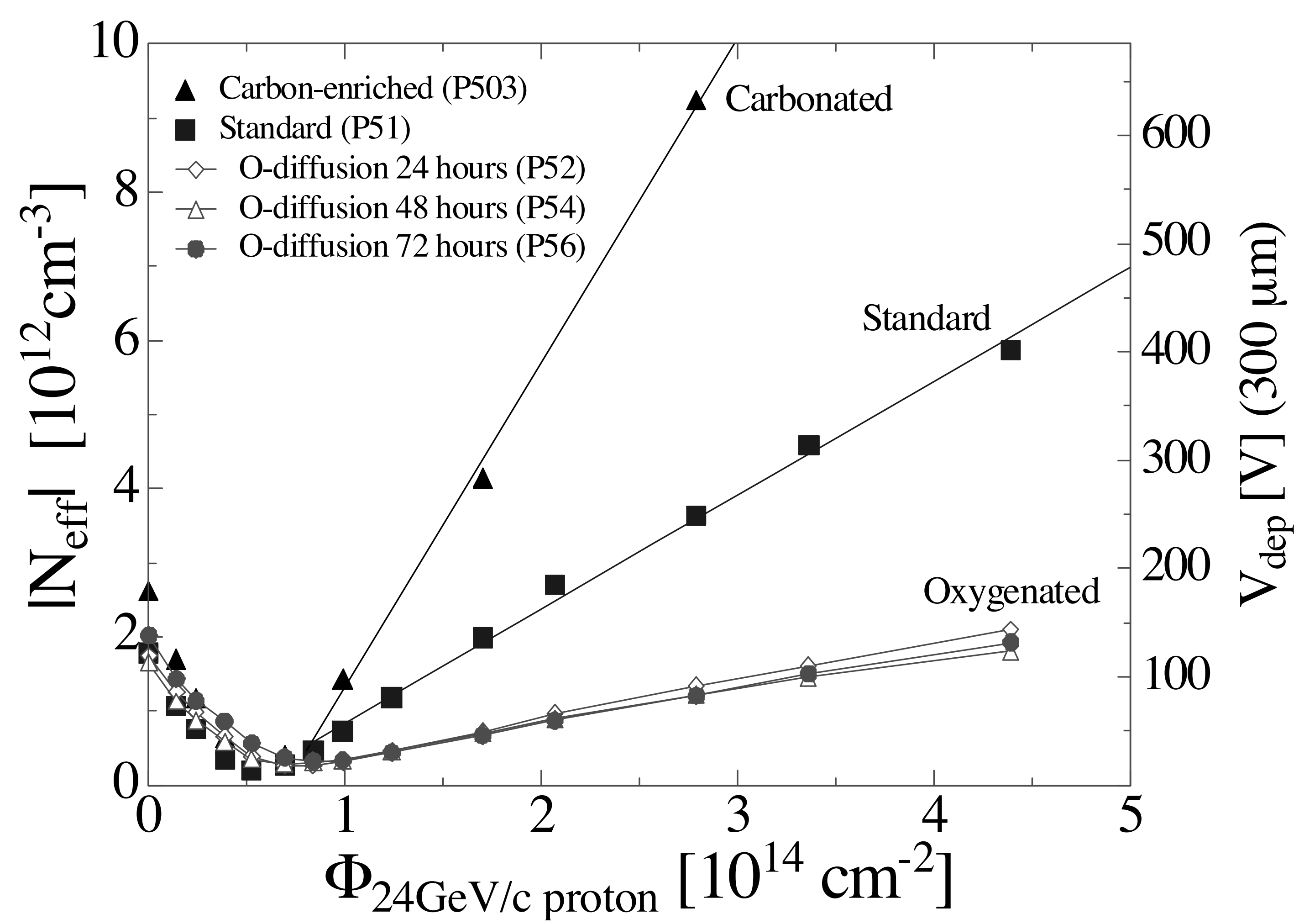
Stretching the Limits

- RunIIb sensors were (I believe) prototyped by HPK with same design features as Layer 00 sensors.
  - Many of these sensors are likely capable of operation at 1000V. If so, finding them is easy.
  - 1000V operation gets you to $5{\times}10^{15}$ 1 GeV e^-
- If under-depleted, depletion depth α sqrt(V_{bias}). Each factor of 2 in fluence costs you almost same factor in signal once $V_{depl} > V_{bias}$
- Having extra S/N to burn = extra radiation tolerance



Breaking the Limit

- Defect engineering: oxygenated silicon reduces slope after inversion
  - Increases radiation tolerance by approximately a factor of 3.
- Thinner: lowers depletion voltage.
  - Same situation as under-depletion: each factor of two thinner buys you slightly more than factor of two in fluence ... but without the material!



Resolution Limitations

From John's estimates:

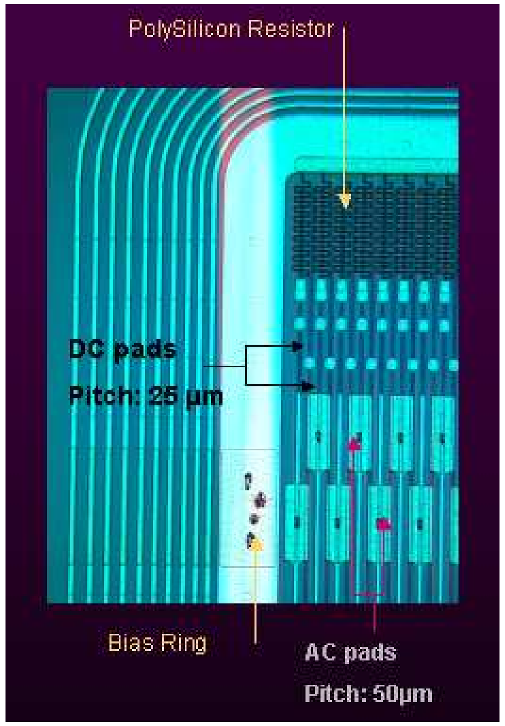
- $\sigma_{d0} = 22 \oplus 66/p \ \mu\text{m}$
- $\Delta m/m = 0.0035 \oplus 0.008$
- Both of these problems are attacked by thinning upstream of the second measurement.

Term from angular resolution at vertex.

N.B. Refitting tracks with vertex constraint should improve this somewhat (on order of 30-40% for three tracks)

Thinned Layer00 Sensors

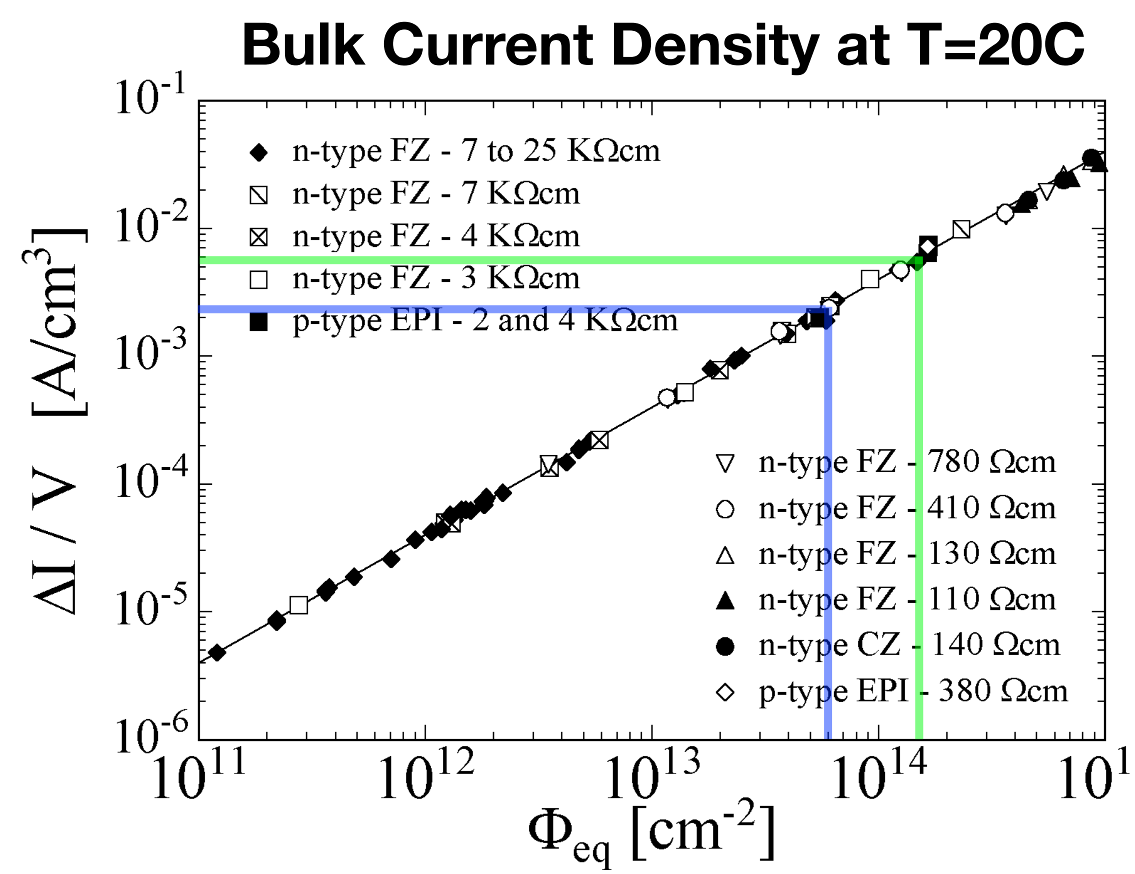
- CDF Layer 00 used radiation-tolerant sensors
  - 300 micron <100> p on n silicon
  - 50(25) micron readout(sense) pitch
  - Micron produced oxygenated sensors
    1/12 of the detector uses this silicon
- Purdue used masks (Gino Bolla) for ILC R&D on fabrication of sensors on thinned wafers
  - 150um, 200um, and 300um thick sensors procured from Micron
  - Preliminary results were very encouraging
    - Sensor parameters as expected
    - Charge collection with SVX4 as expected
- These sensors (6.4mm wide, 78mm long) could be great in the first plane pair. Under discussion...



	I_{leak}	C_C pF/cm	C_{IS} pF/cm	R_{Is} GΩ	R_{bias} MΩ
Specs	Grade	> 10	<1.2	> 1	1.5 ± 0.5 < 10 % variation
300μm	3 Grade A 2 grade B	> 15	< 0.9	> 1	0.5 ± 0.2 < 5 % variation
200μm	3 Grade A 2 Grade B	> 20	< 0.9	> 10	1.8 ± 0.10 < 10 % variation
150μm	7 Grade A 0 Grade B	>15	< 0.9 pF/cm	> 10	1.8 ± 0.10 < 10 % variation

And What About Cooling?

- Radiation damage increases bulk current
  - $I \alpha$ (thickness)
  - $I \alpha$ log(temperature): doubles every 7C
- Sensors generate heat according to P=IV, factors cancel so that:
  - at V_{dep} = 350V fluence (T=-8C): 1.6mW/cm^2
  - at V_{dep} = 1000V fluence (T=-8C): 11mW/cm^2
- For RunIIb sensors at 350V, cooling from edge of sensor is sufficient. At 1000V cooling at edge may be sufficient depending upon spatial distribution of radiation damage
- Less clear for thinned silicon. Very thin layer of unidirectional CF may be necessary.



Summary 2

- We clearly have 5× more radiation tolerance than previously assumed.
- With careful selection of RunIIb sensors, we should have of 11× more radiation tolerance than previously assumed.
- With a lower-noise chip we might buy another 1.5× - 2× more radiation tolerance by simply running under-depleted at the end.
- An ideal (but still realistic) setup might be 150 um oxygenated silicon, which would result in radiation tolerance to 3×10^{16} 1 GeV e^- (66× previous assumption!!) This clearly requires a different readout chip.
- How far we push has consequences for cooling design.

Conclusions

- The APV25 is an attractive option here
  - more headroom in S/N
  - analog readout safer with rapidly changing operating point of irradiated sensors
  - choice of modes, chip-by-chip, depending upon occupancy
  - better ultimate resolution with intermediate strip
  - it's not free
- We can design more aggressively w.r.t. radiation tolerance
  - Minor changes can deliver significant improvement
  - Working hard on the first plane-pair can deliver major improvements in mass resolution and radiation tolerance.
- Cooling is in a regime that allows for creative, low-mass solutions