The Future of CDMS: SuperCDMS Soudan, SuperCDMS SNOLAB, & GEODM DUSEL + iZIP Huge Detector Advance

KITP - December 18, 2009

Blas Cabrera
Spokesperson for SuperCDMS
Stanford - KIPAC

Archive submission problem

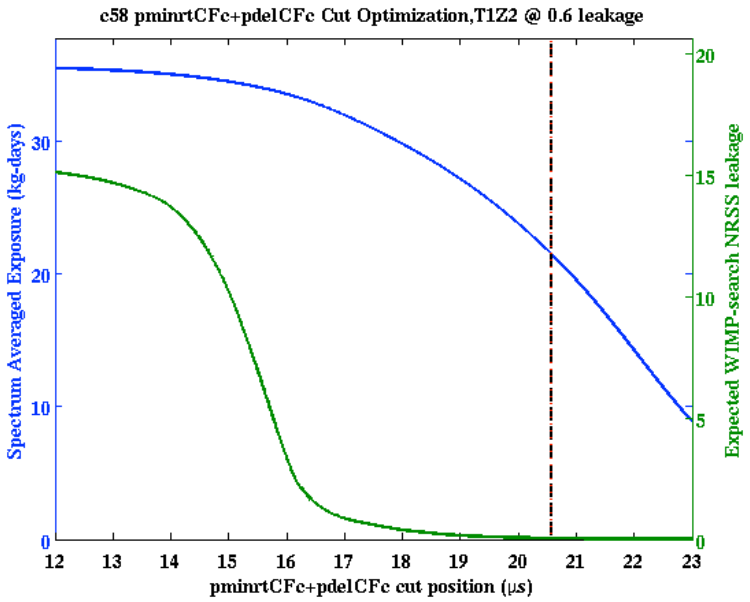
New - arXiv:0912.3592

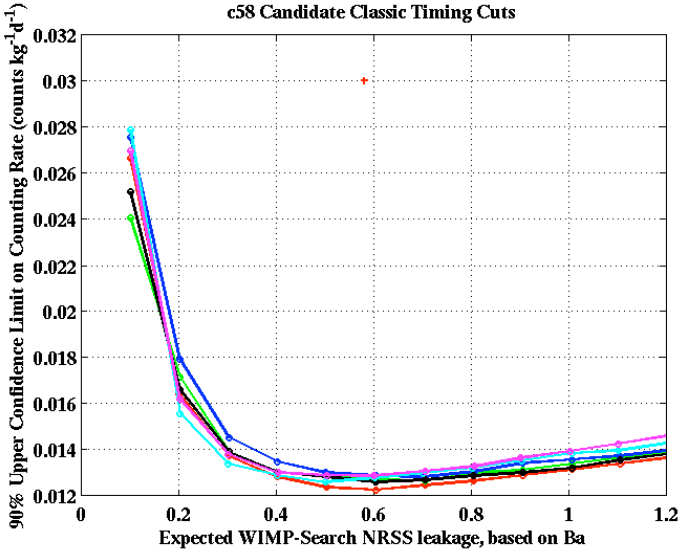
also on CDMS website at

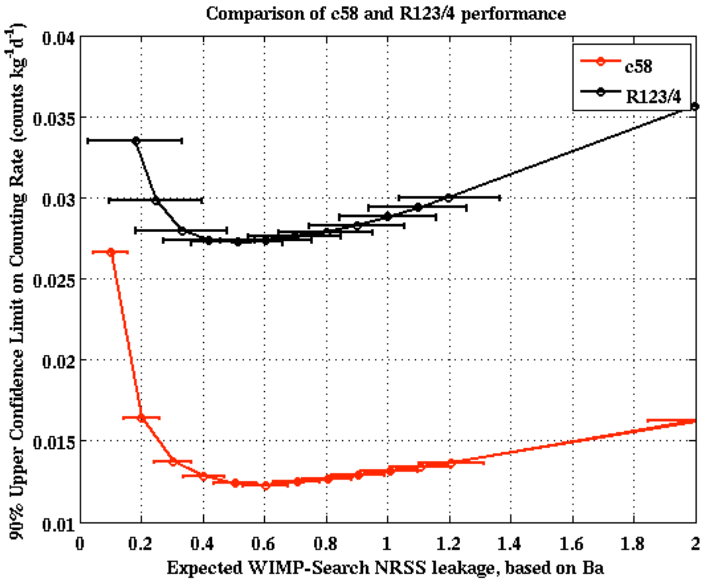
http://cdms.berkeley.edu/

CDMS-II pre-unblinding analysis

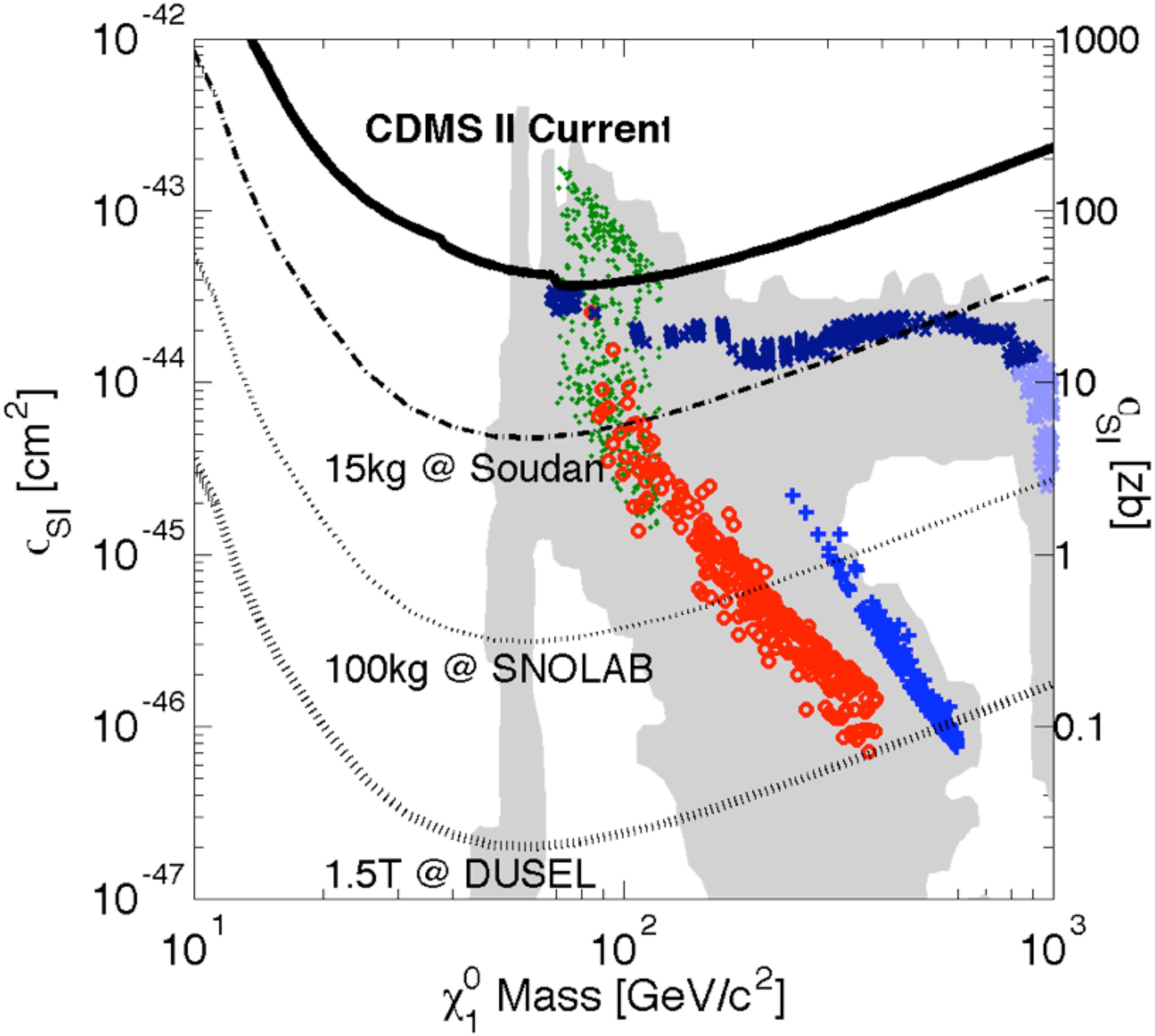
- <u>Classic Timing Cuts</u>
  - Optimum sensitivity ~0.6 event leakage
  - Optimum cuts for each detector (x2 exposure)
  - Reach 2E-44 cm^2



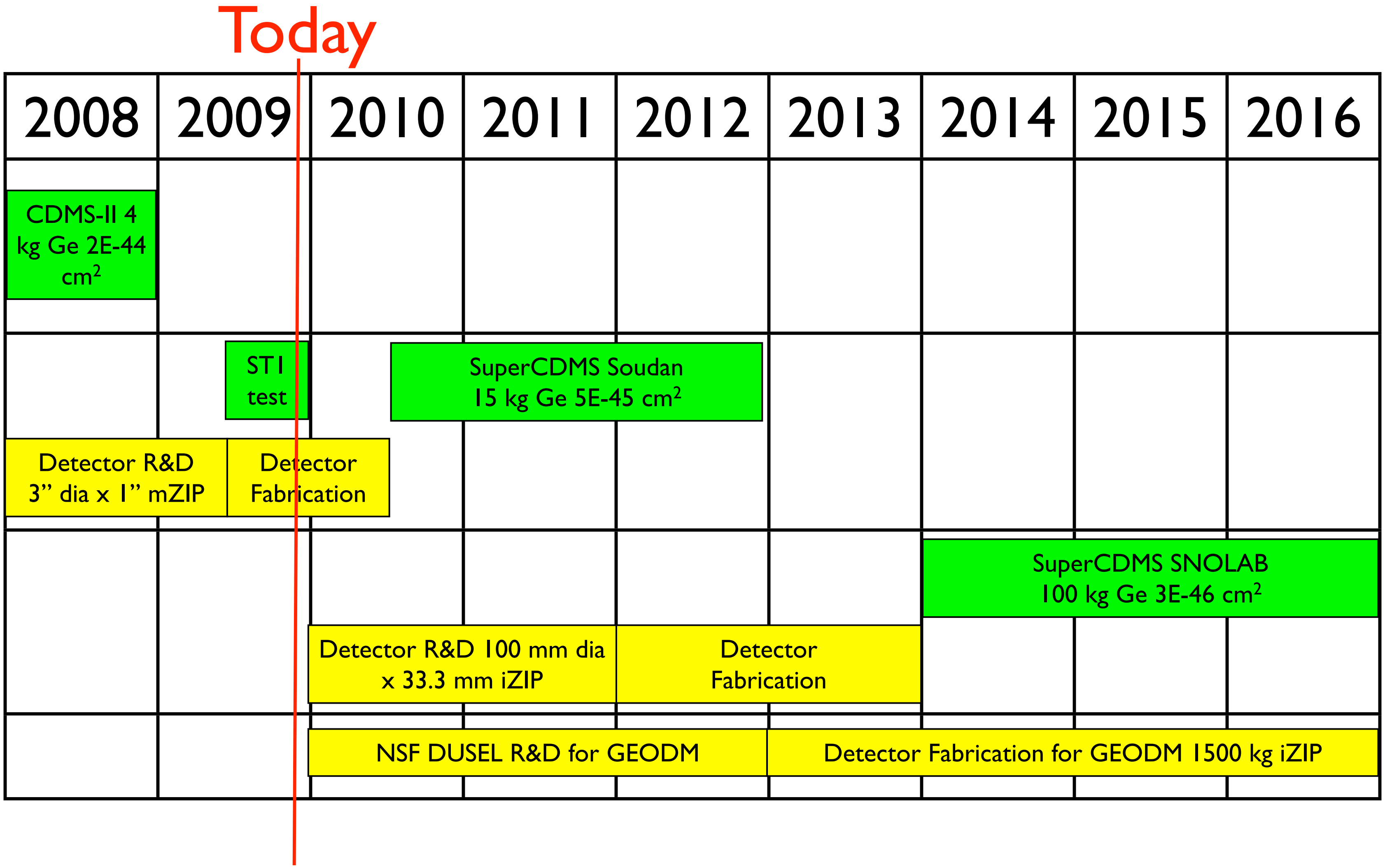




Sensitivity of Future Detectors



SuperCDMS Schedule



Today

2008 2009 2010 2011 2012 2013 2014 2015 2016

CDMS-II 4 kg Ge 2E-44 cm^2

ST1 test

SuperCDMS Soudan 15 kg Ge 5E-45 cm^2

Detector R&D 3” dia x 1” mZIP

Detector Fabrication

SuperCDMS SNOLAB 100 kg Ge 3E-46 cm^2

Detector R&D 100 mm dia x 33.3 mm iZIP

Detector Fabrication

NSF DUSEL R&D for GEODM

Detector Fabrication for GEODM 1500 kg iZIP

From CDMS to SuperCDMS to GEODM

CDMS II

7.5 cm x 1 cm ~0.23 kg / det
15 detectors = 3.5 kg

SuperCDMS Soudan

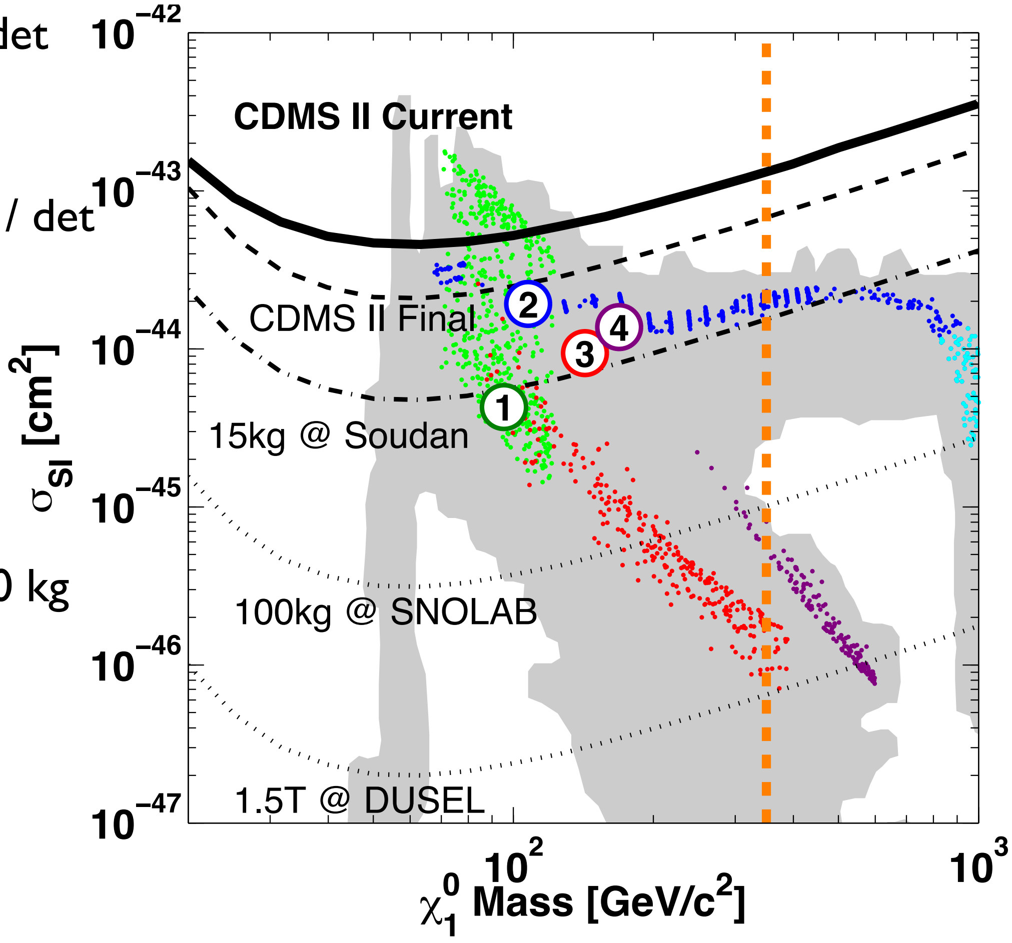
7.5 cm x 2.5 cm ~ 0.60 kg / det
25 detectors = 15 kg

SuperCDMS SNOLAB

10 cm x 3.3 cm
~1.4 kg / det
84 detectors = 120 kg

Ge Observatory for Dark Matter
GEODM DUSEL

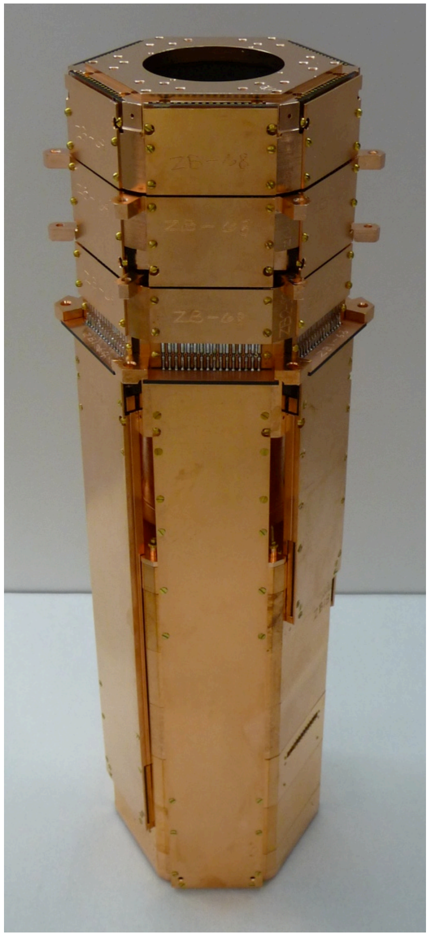
15 cm x 5 cm ~5 kg / det
300 detectors = 1500 kg



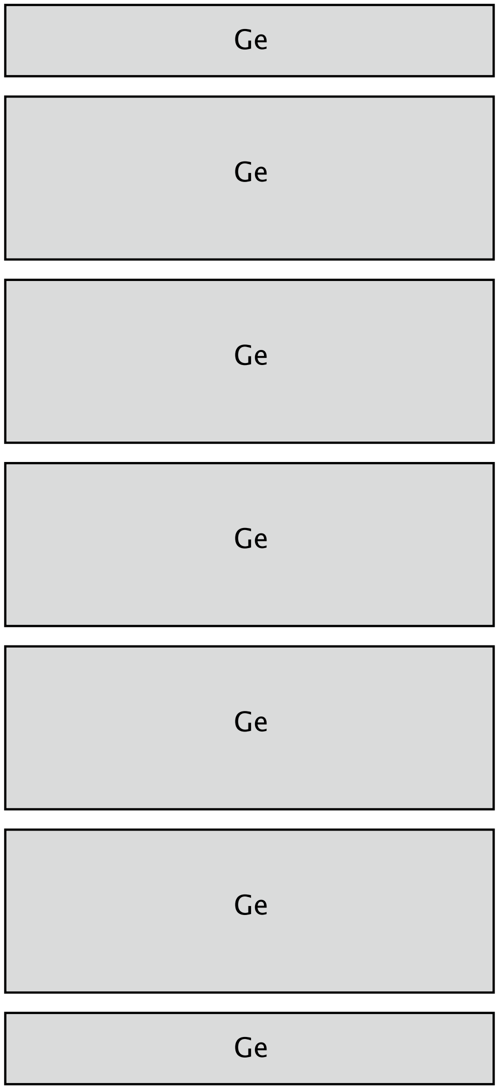
SuperCDMS Soudan

SuperCDMS Soudan approved

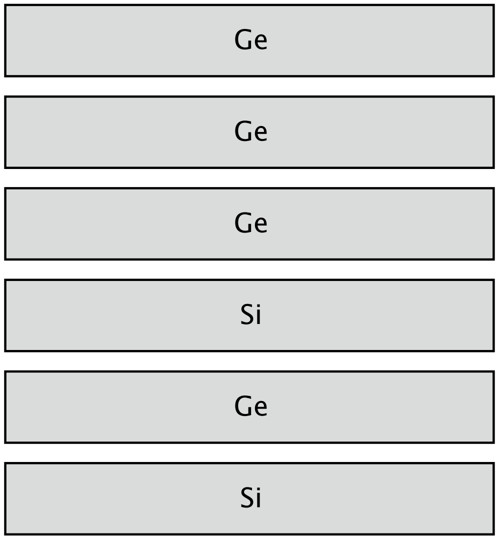
- ST1 now operating
- ST2 now complete

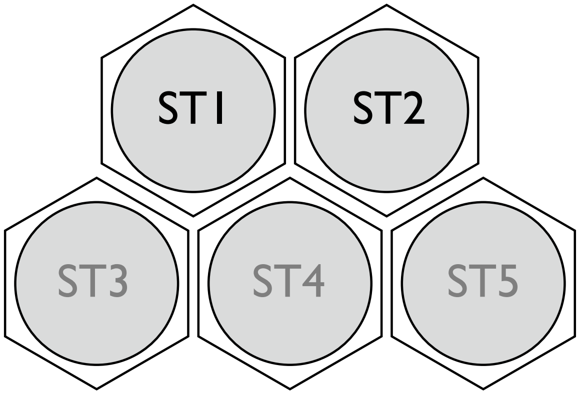


SuperCDMS Soudan Tower
3 kg Ge plus end caps



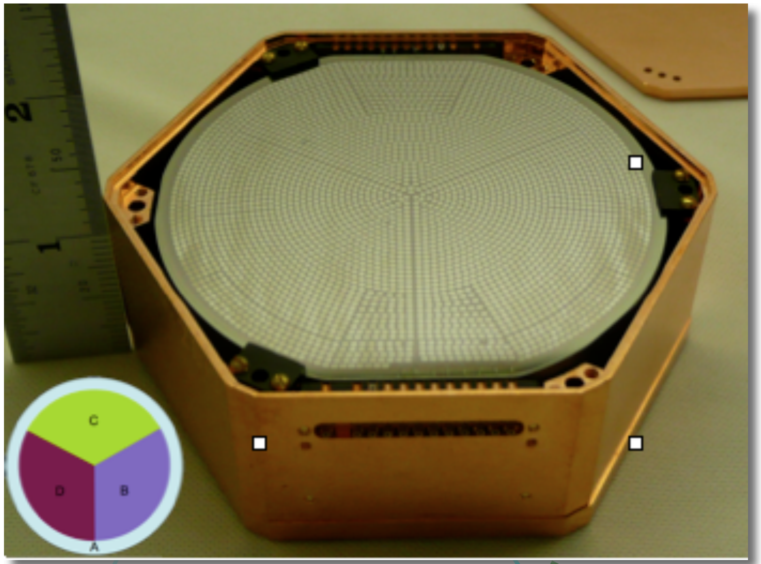
CDMS-II Soudan Tower
1 kg Ge plus 0.2 kg Si on average

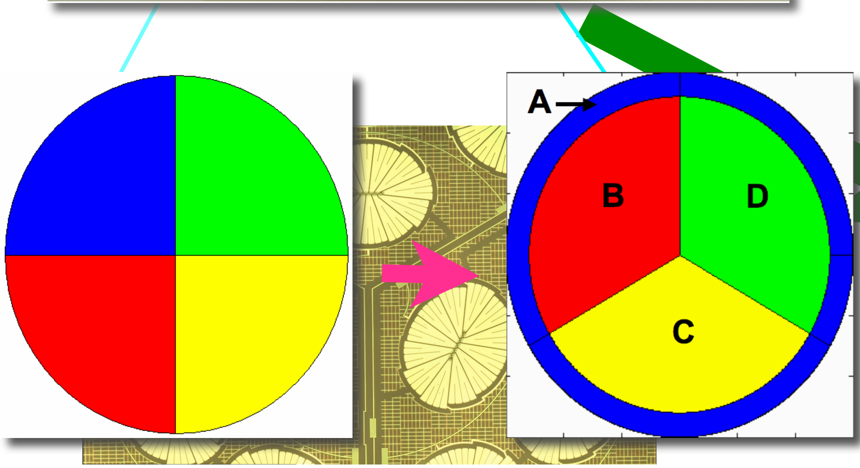




Use same five tower striplines and electronics
to operate 15 kg of Ge inner detectors
instead of 3 kg of Ge for CDMS-II

Detector Improvements

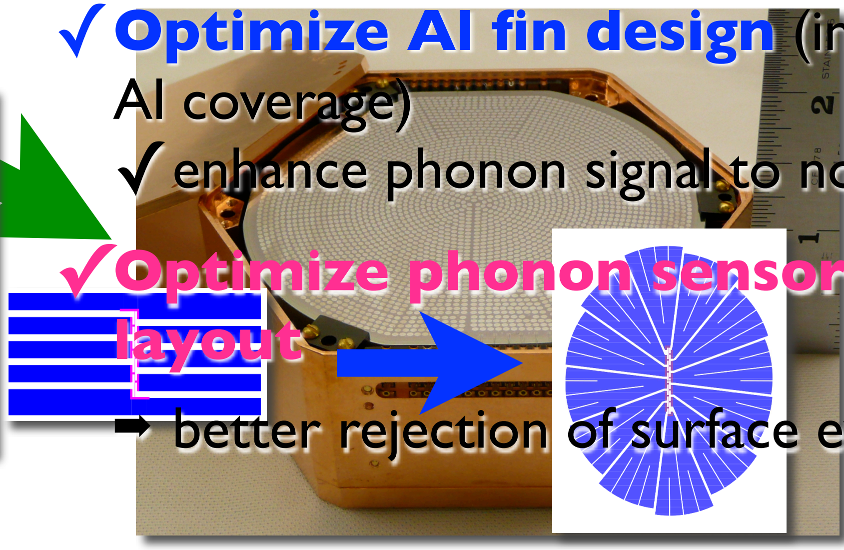




✓ **SuperTower** = five 1-inch thick detectors + two 1-cm thick ionization only detectors

✓ **Increase thickness** (2.5 x).

- ➡ better surface/volume
- ➡ increase manufacture



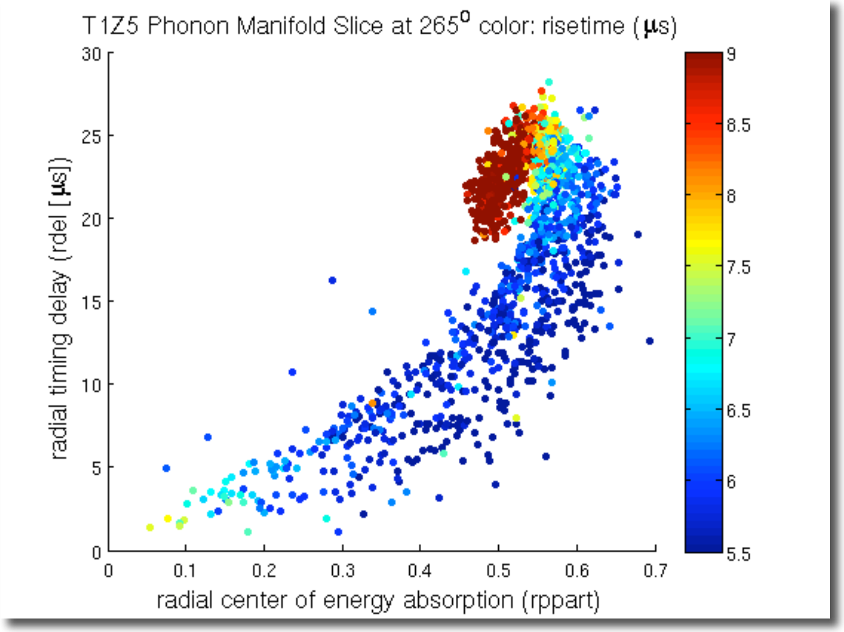
✓ **Optimize Al fin design** (increase Al coverage)

- ✓ enhance phonon signal to noise

✓ **Optimize phonon sensor layout**

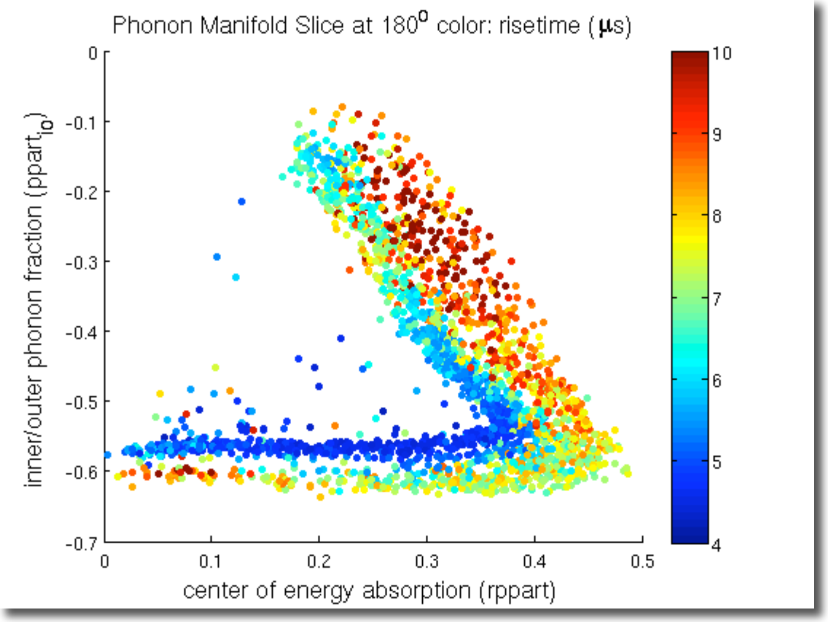
- ➡ better rejection of surface events

Phonon Sensor Layout

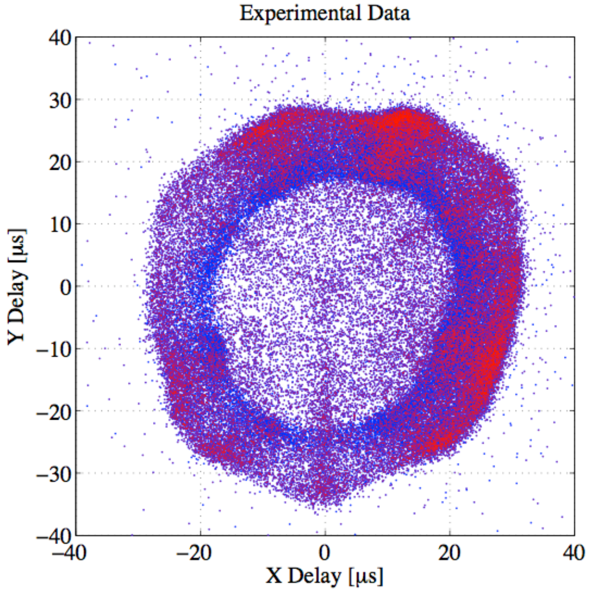


- Events at large radius have delay times similar to events at intermediate radius.
- Effect due to phonons reflecting off outer cylindrical walls back into central region of detector.

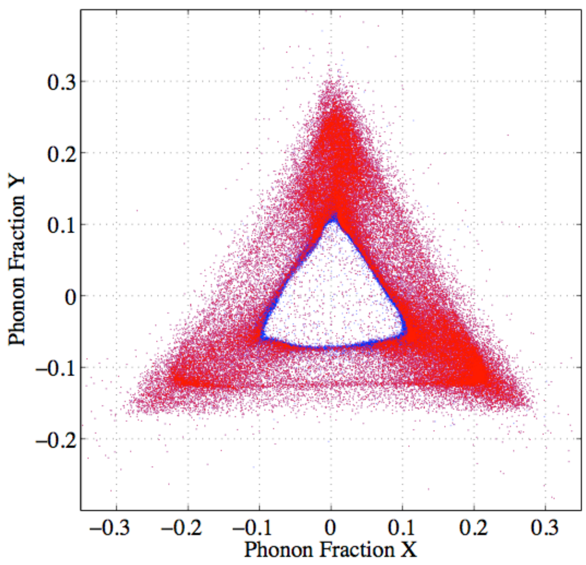
- New metric compares start times of inner 3 channels to the start time of outer channel, breaks degeneracy.

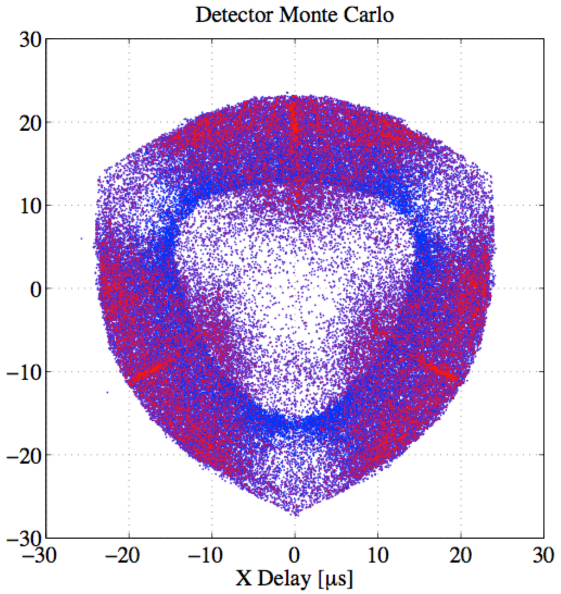


Detector performance versus MC

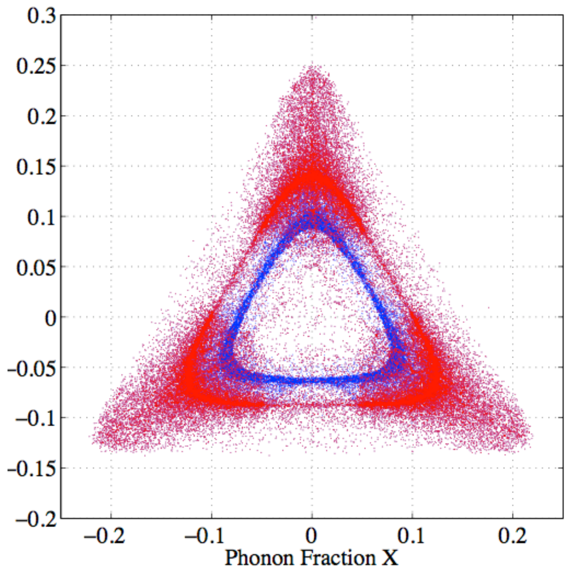

Experimental Data

SuperCDMS
detector

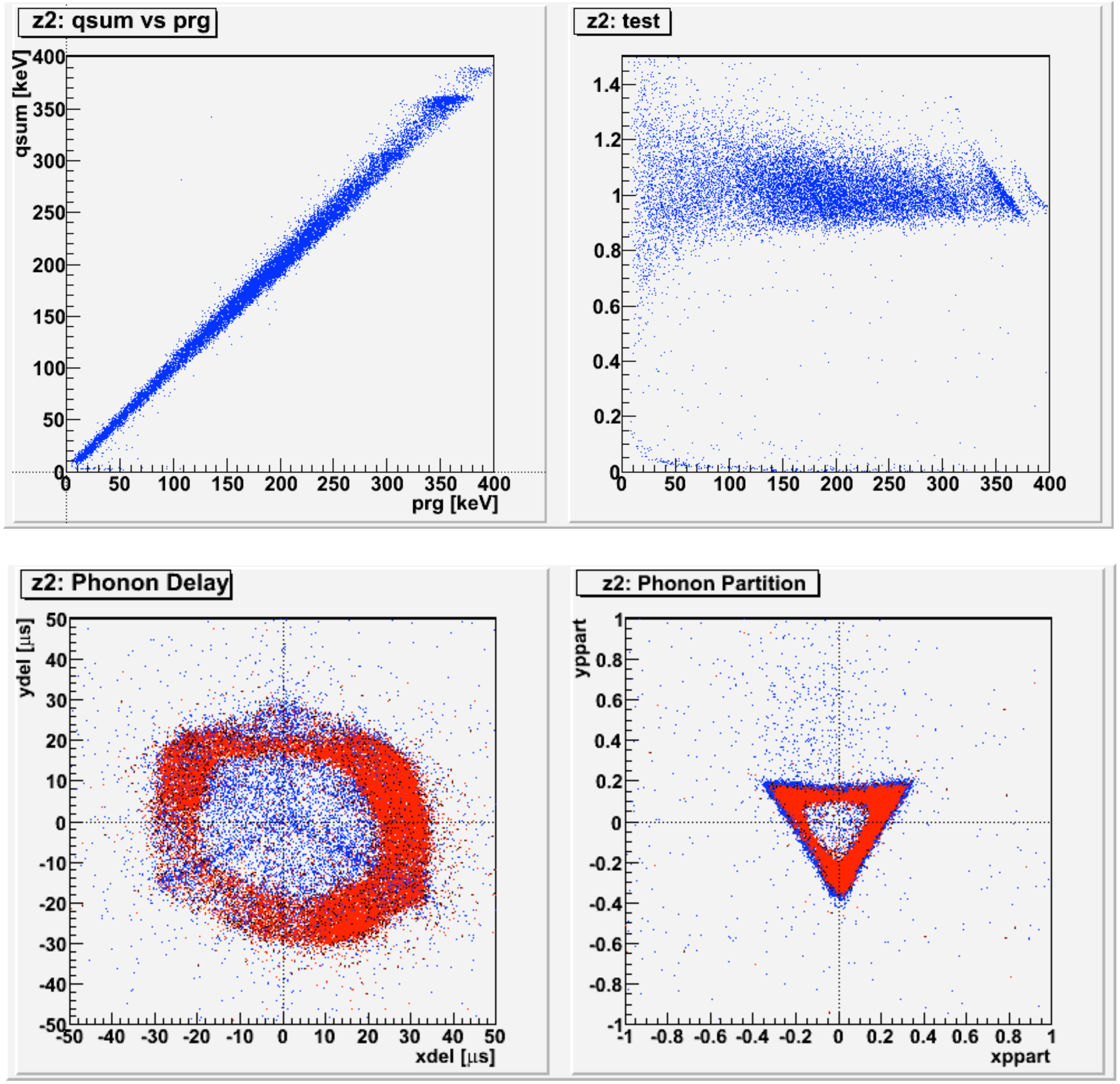



Detector Monte Carlo

Detector
Monte Carlo



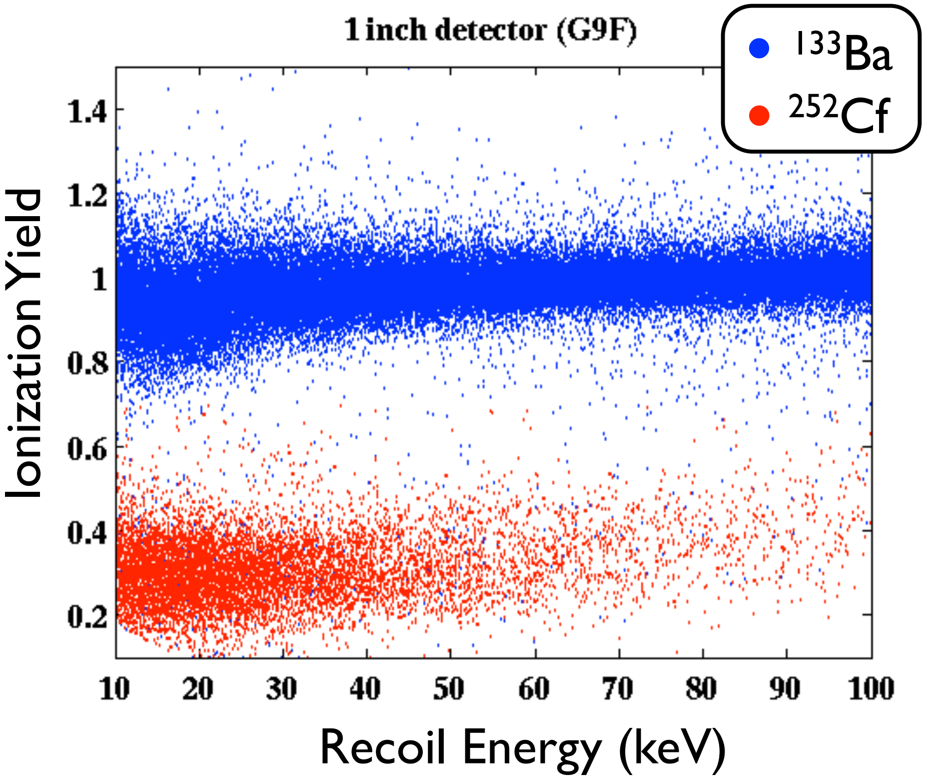
SuperTower 1 taking data



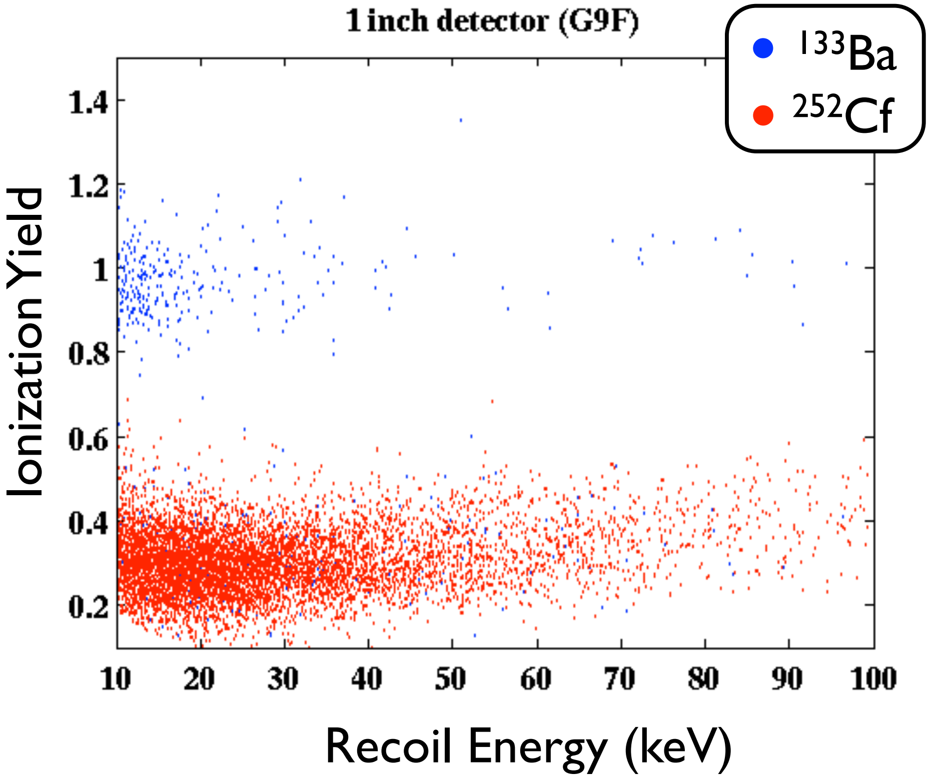
- <u>ST1 Soudan data</u>
- 4 of 5 ST1 mZIPs operating well (one channel failed)
- alpha rates meet specifications of less than 0.3 alphas per day per detector
- Plan to take huge calibration data sets through end of 2009

ST1 Surface Testing

Before Timing Applied



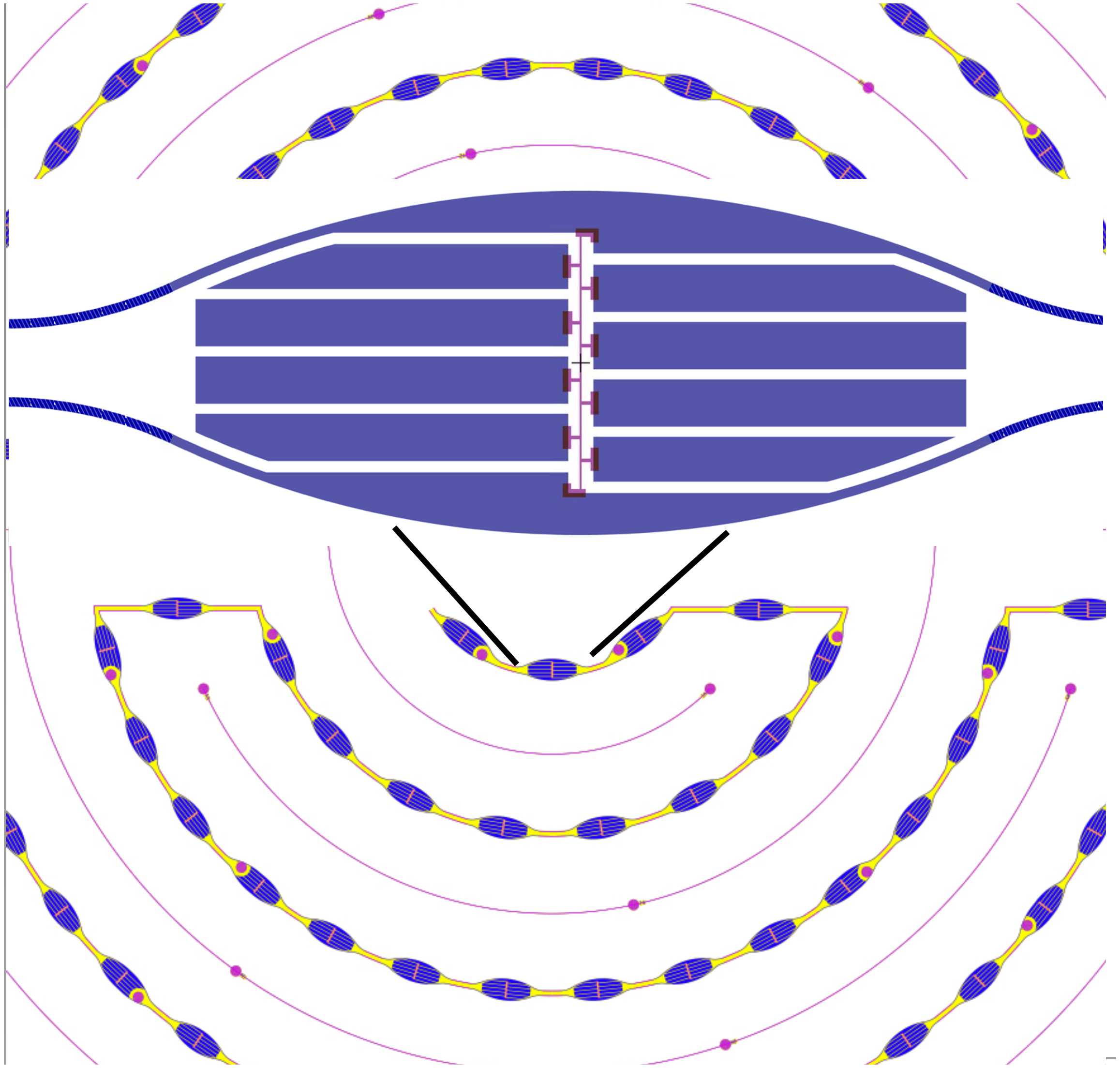
After Timing Applied



iZIP Detector Advance

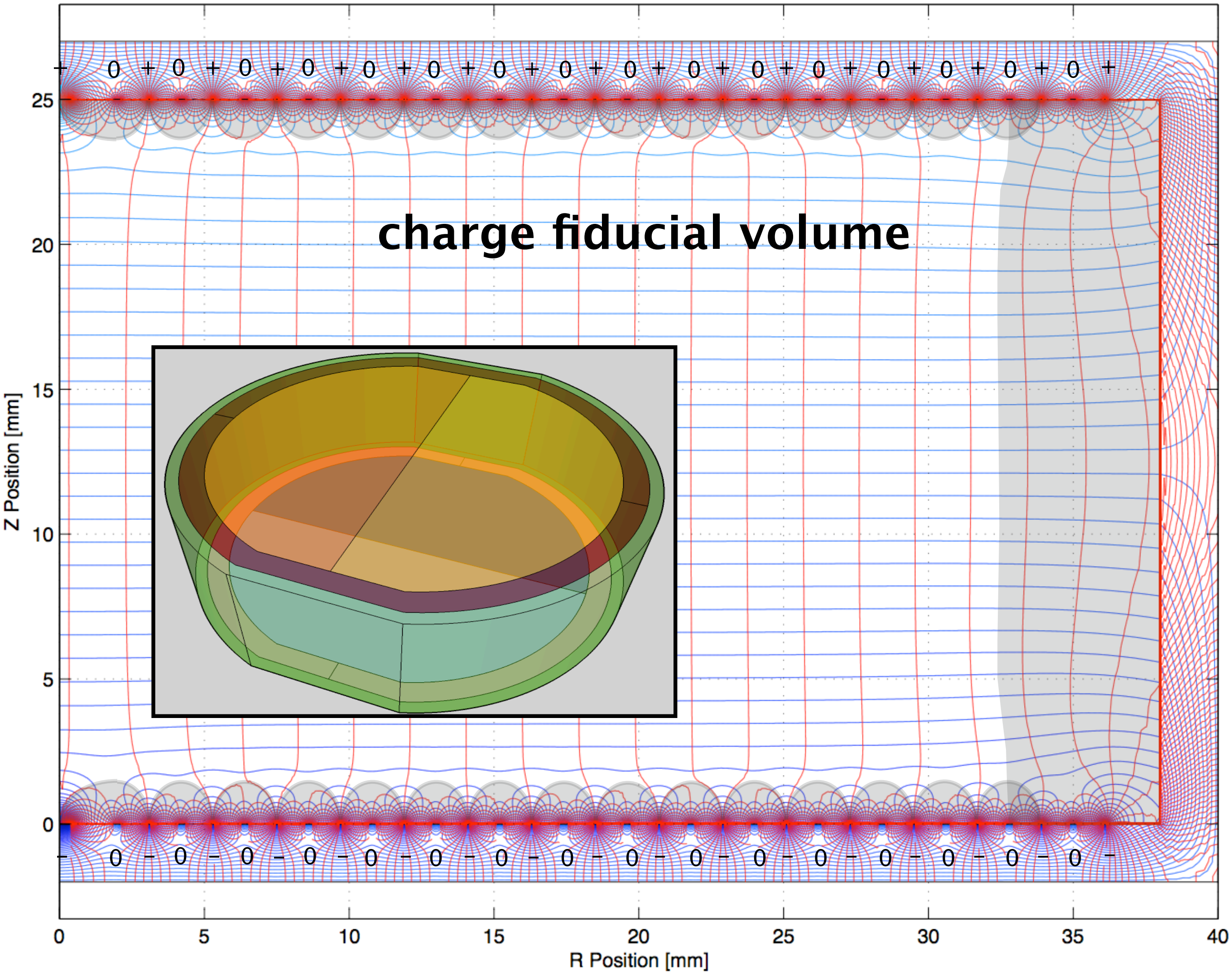
IZIP Interleaved Design

- Interleaved electrodes and phonon sensors on both sides of the detector.
- Alternating +2V/ground (-2V/ground, opposite side) phonon sensors.



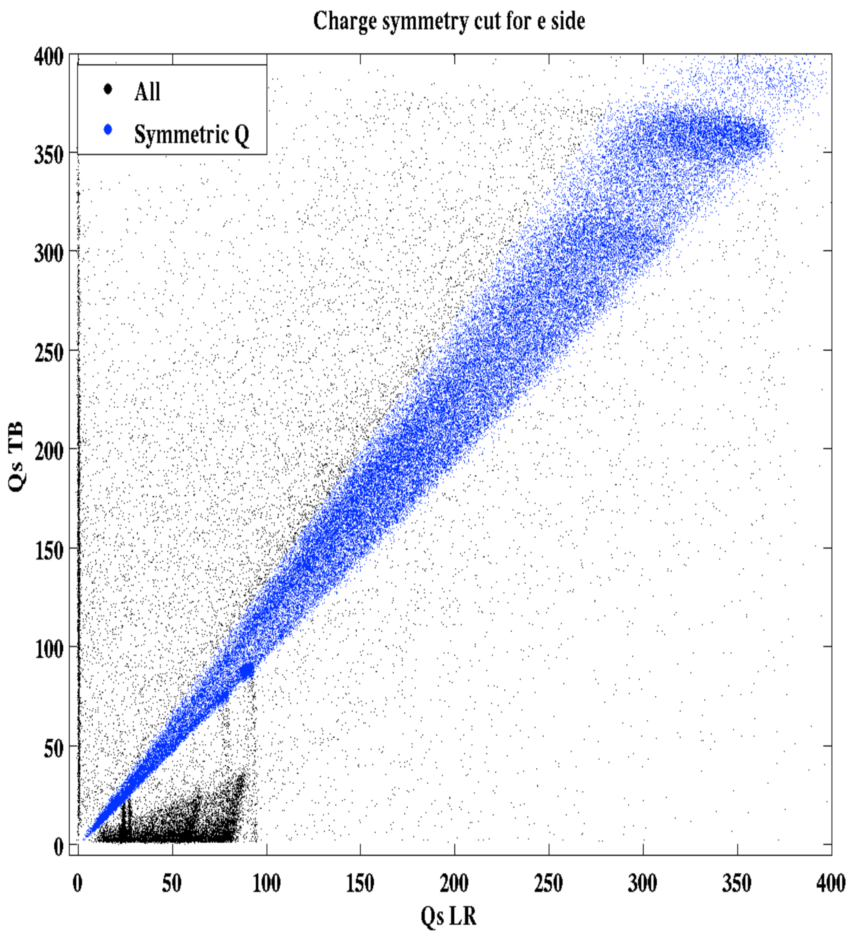
iZIP double-sided design

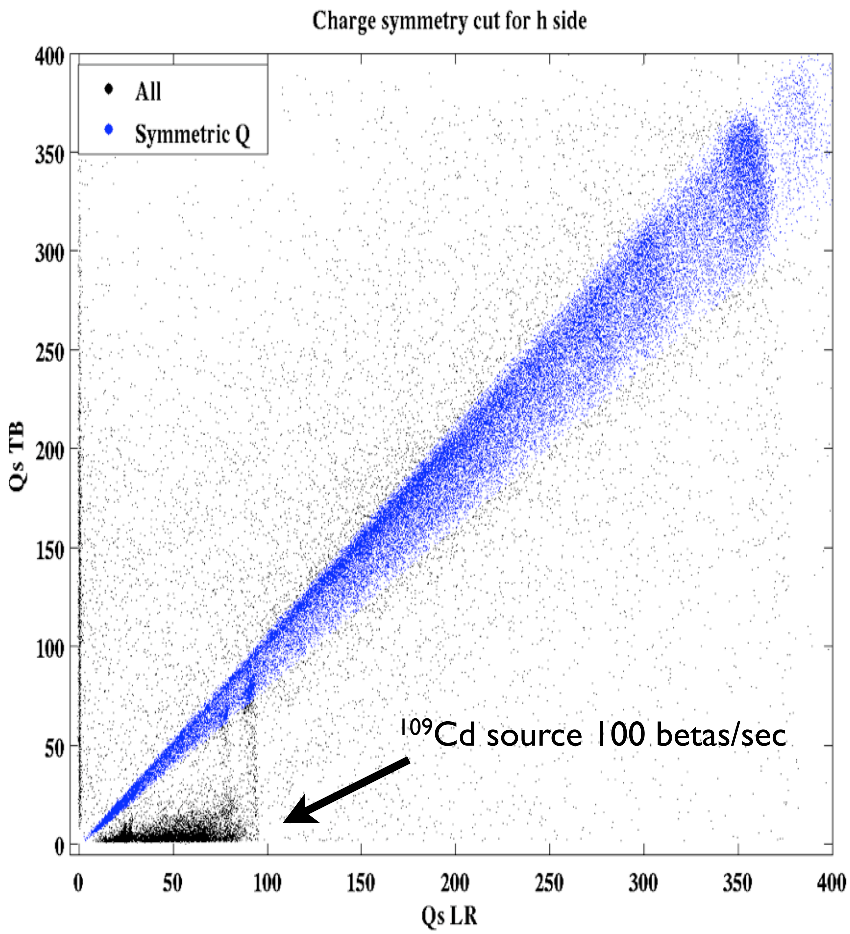
- Interleaved charge and phonon on both sides
- Demonstrated 3” dia x 1”
- For SNOLAB baseline is 100 mm dia x 33.3 mm (Ortec & Umicore accepting orders)



Surface charge discrimination demonstrated

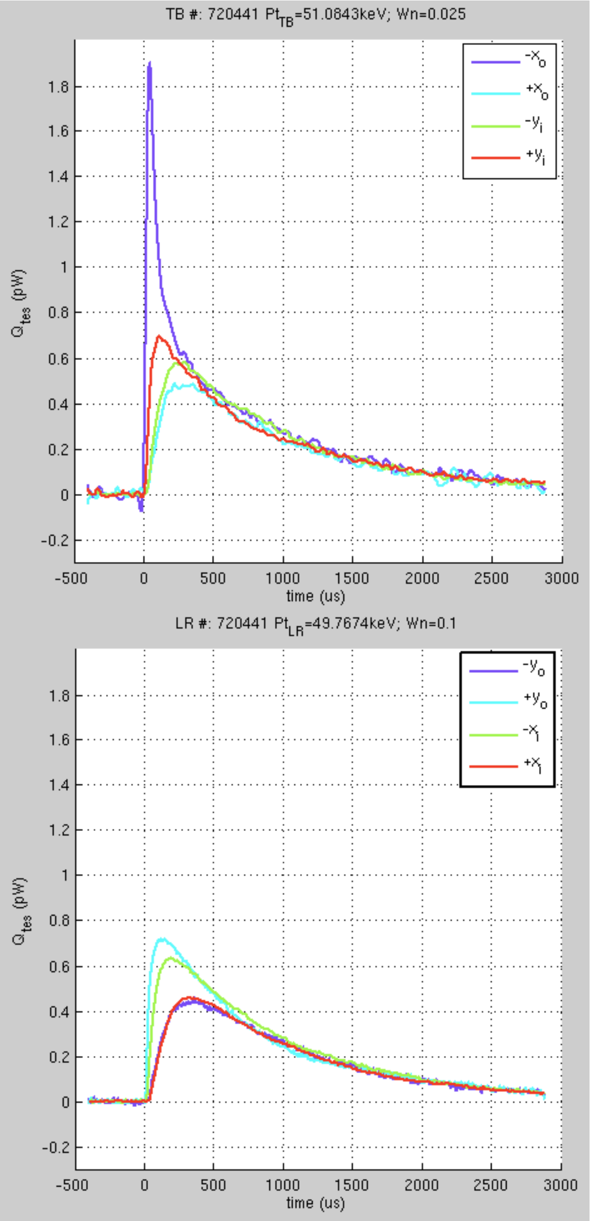
- less than 1:1000 surface electrons leak into bulk



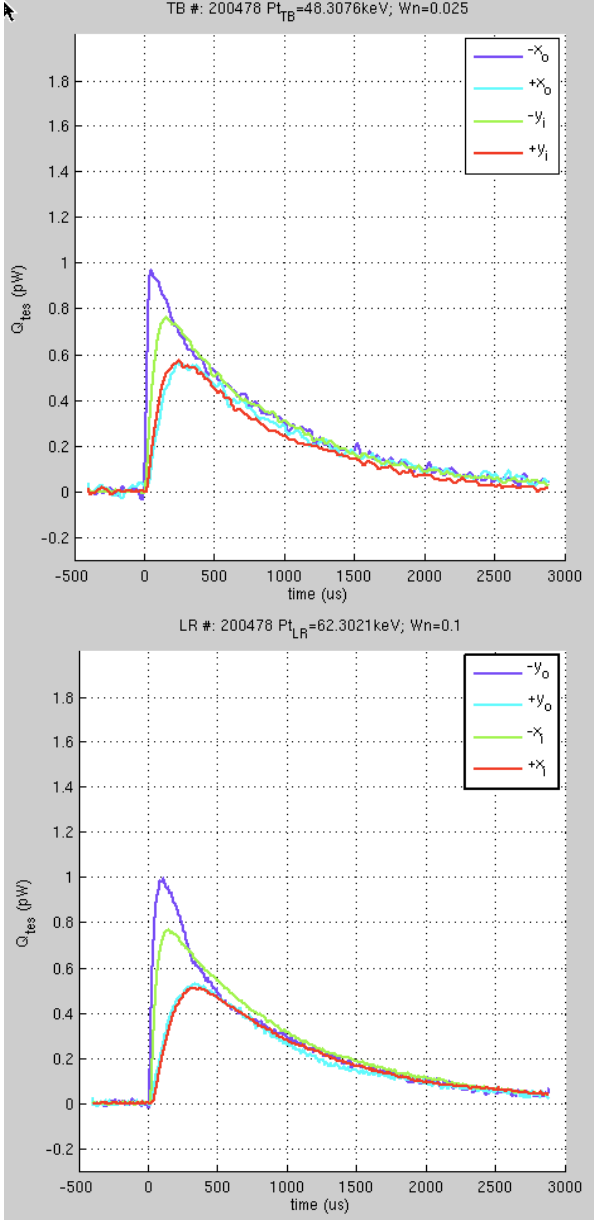


^{109}Cd source 100 betas/sec

Remarkable phonon properties

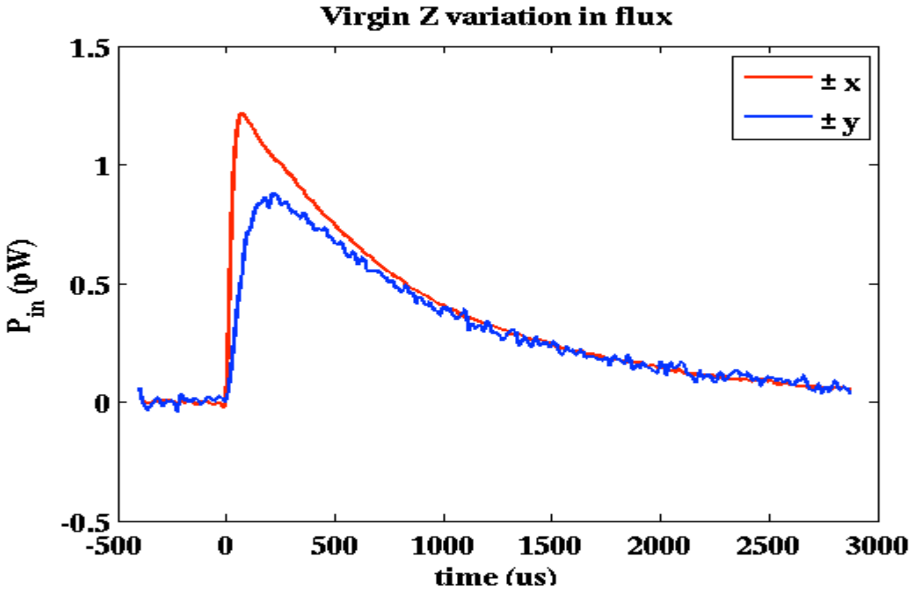


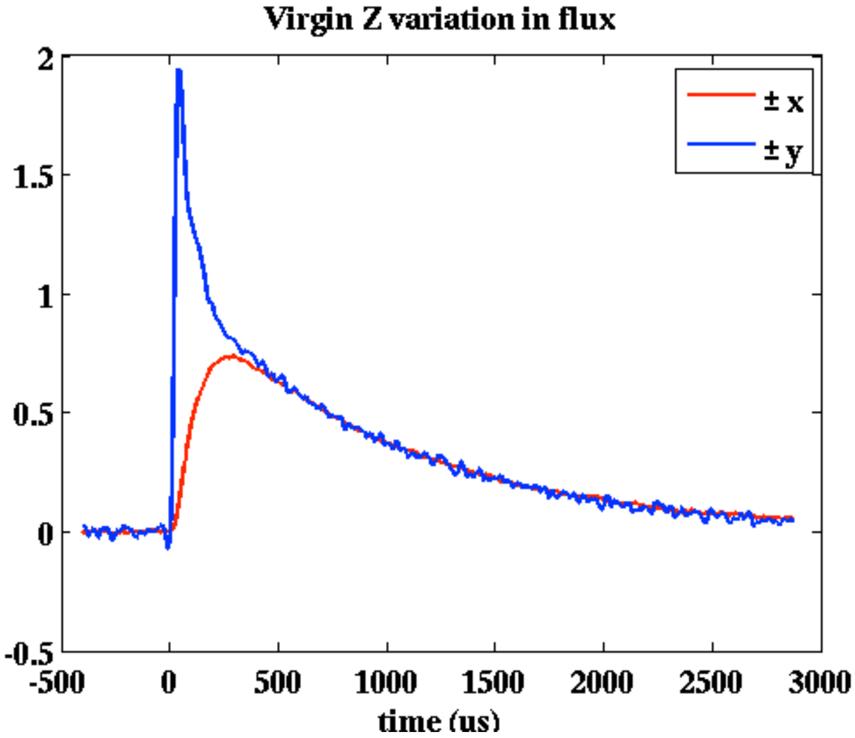
- two separate events on left and right hand side
- top is top side and bottom is the bottom side
- note that after 500 µs all channels identical
- position information in leading part



Summed phonon channels

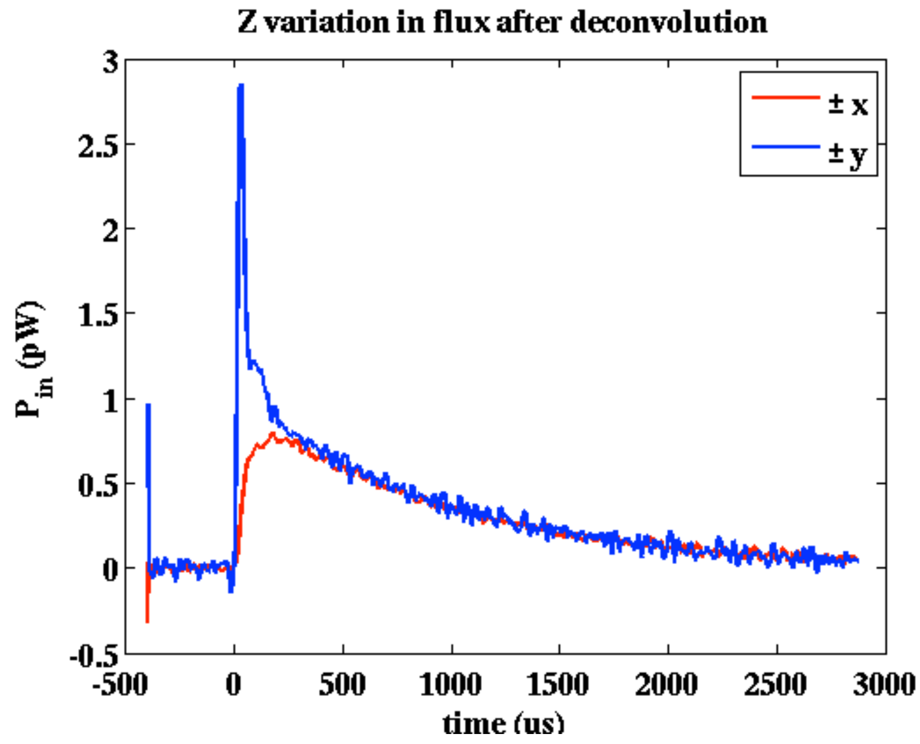
- Two traces in each plot correspond to summed phonon pulses on top (blue) and bottom (red)
- Left event close to bottom and right event close to top
- Top Tc = 105+/-3 mK & bottom Tc = 46+/-2 mK

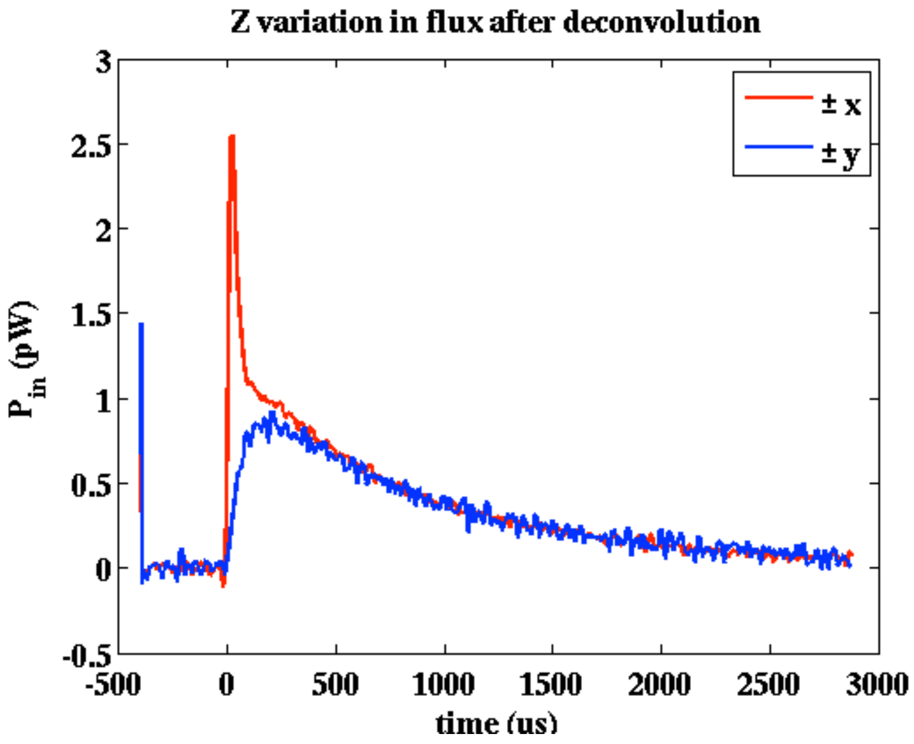




Deconvolution removes TES time constants

- Top with Tc = 105 mK has τ_{ETF} = 20 μs deconvolute to 10 μs
- Bottom with Tc = 46 mK has τ_{ETF} = 60 μs deconvolute to 10 μs

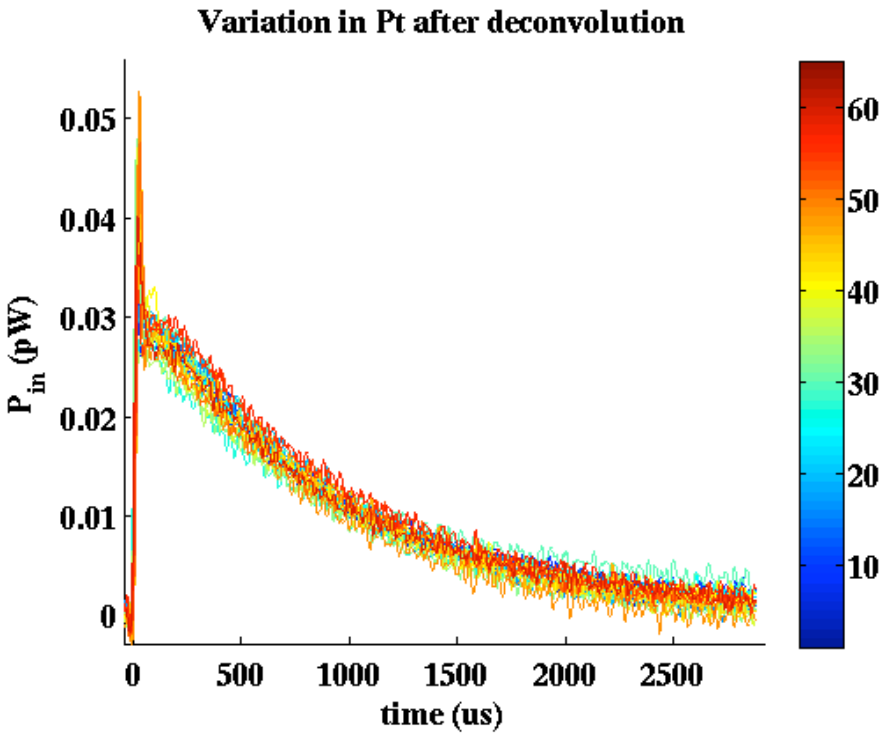


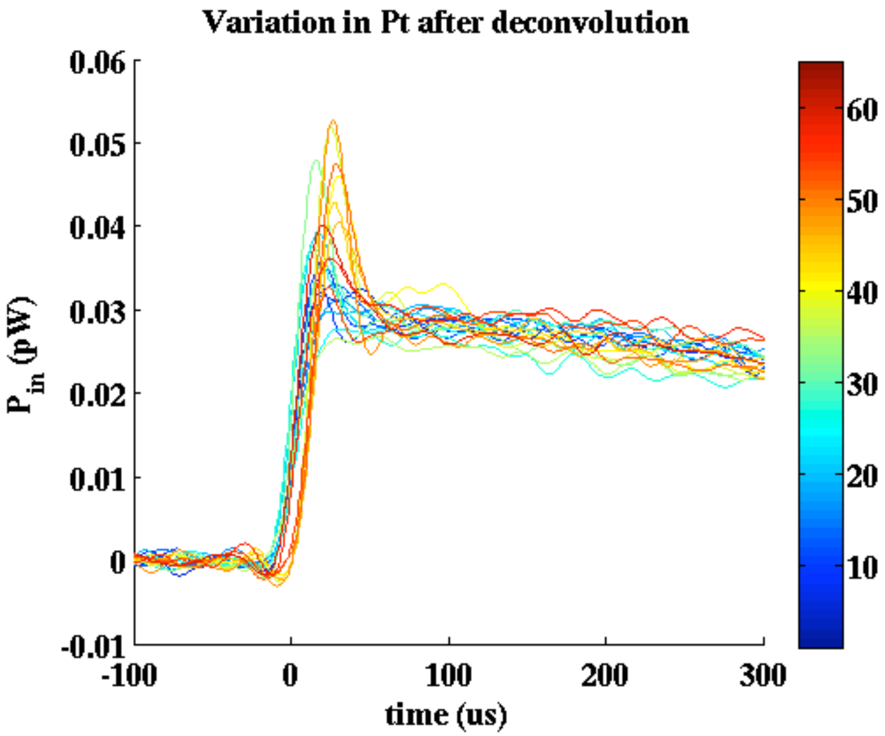


Phonon total sum

- Summing top and bottom for each event produces pulses that are remarkably proportional to energy

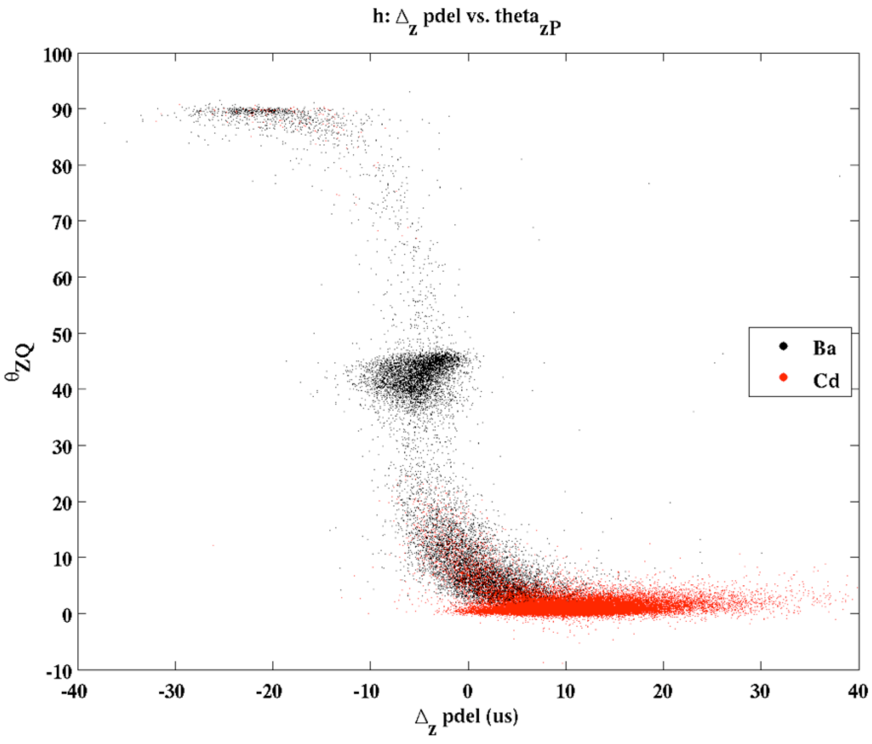
- As shown in right leading edge, only minor leading edge differences

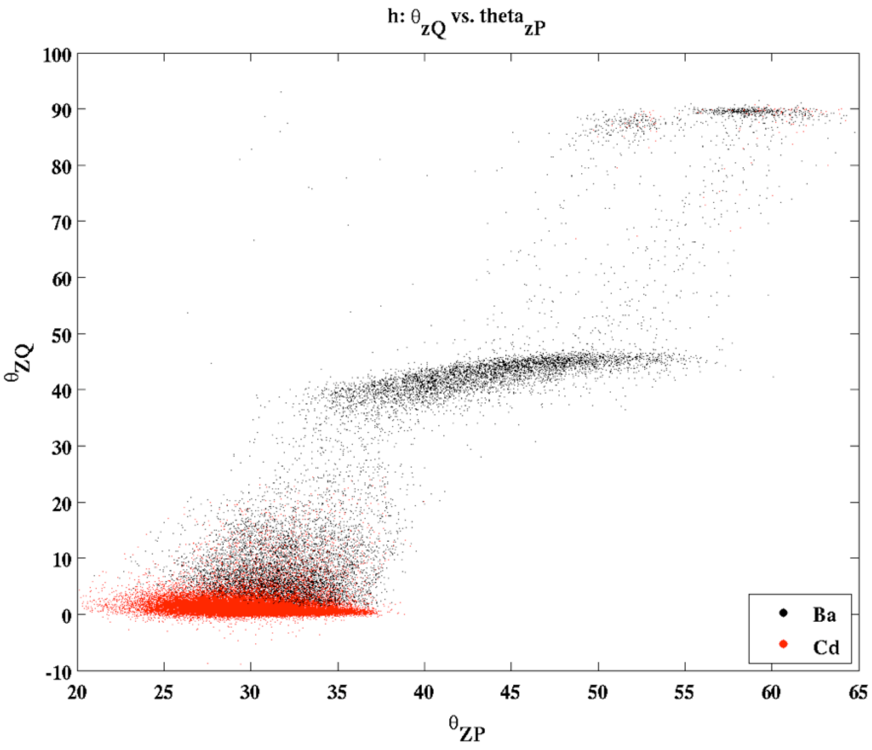




Phonon discrimination better than mZIP

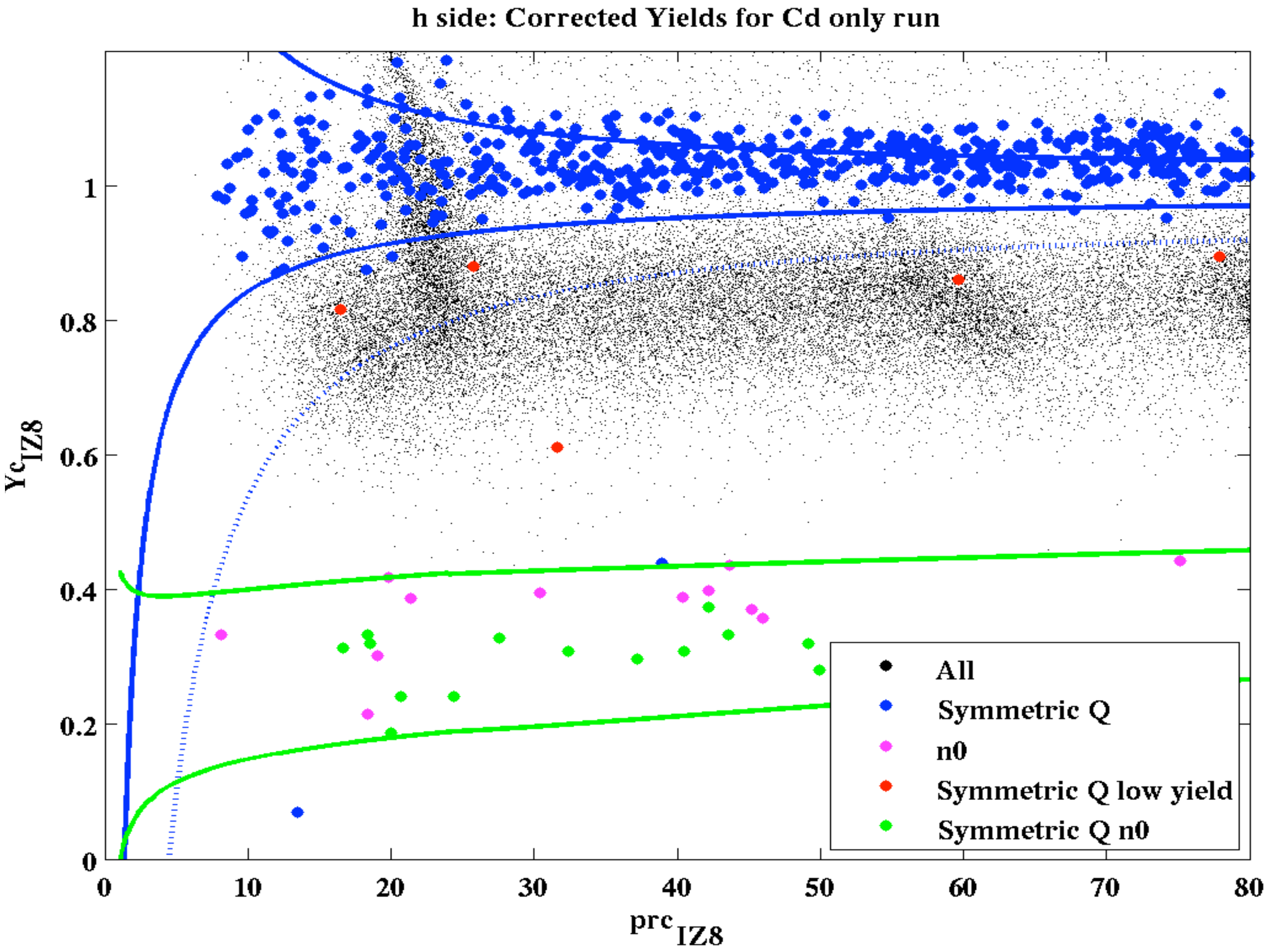
- In addition phonon symmetry and timing better with iZIP than with mZIP- 1:3,000 demonstrated



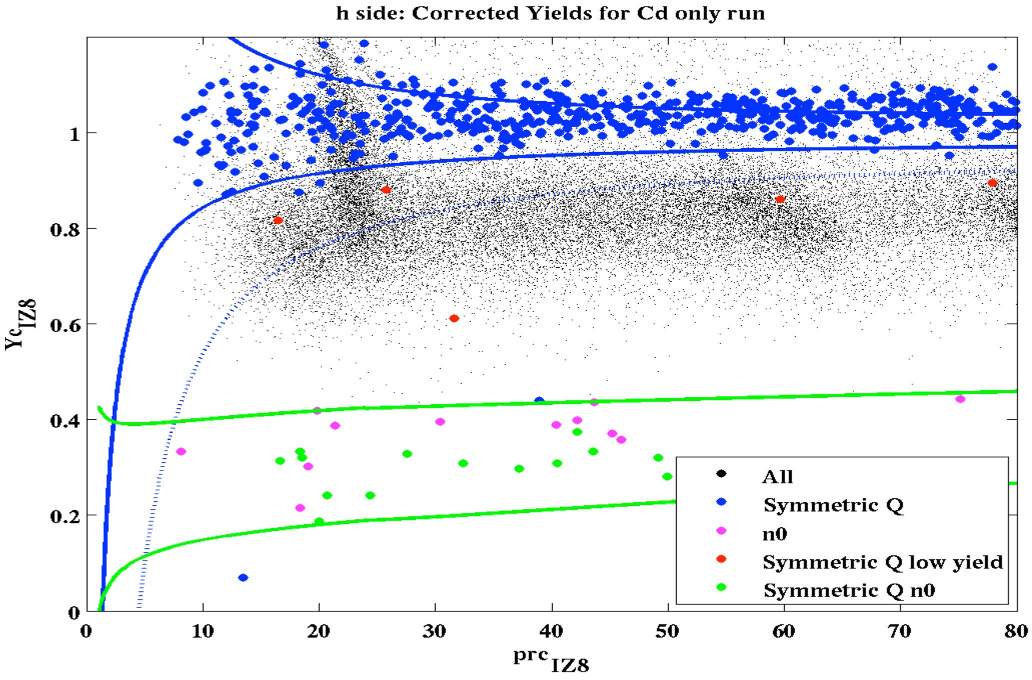


Yield rejection

- 1000:1 rejection of low yield Surface Events
- Due to cosmogenic neutron leakage, misidentification study on NR band surface events impossible

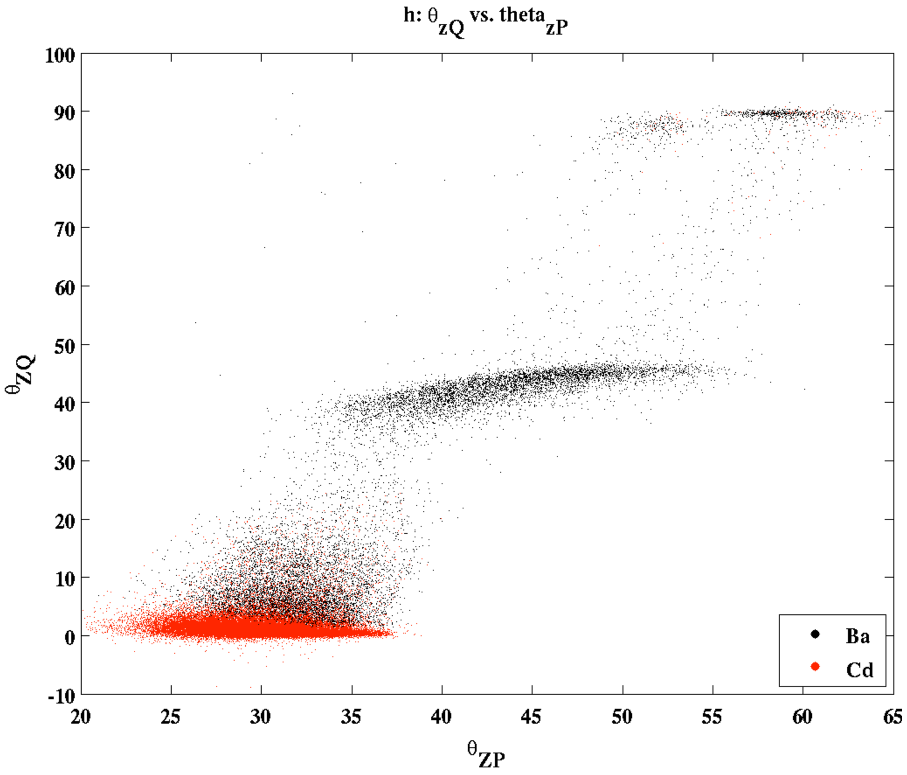


Surface Rejection Estimates



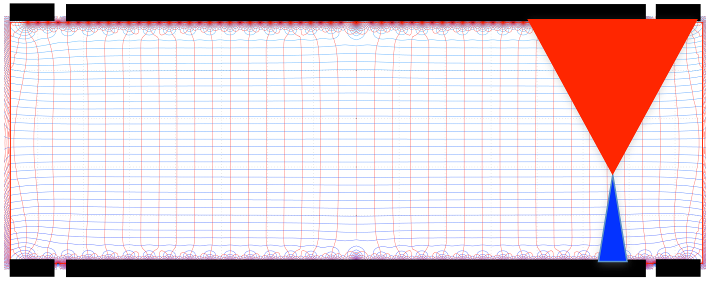
Yield Leakage	1:3000
Q symmetric	1:1000
P χ^2 Leakage	1:3000
Total Surface-NR leakage	**1:3e6-1e10**

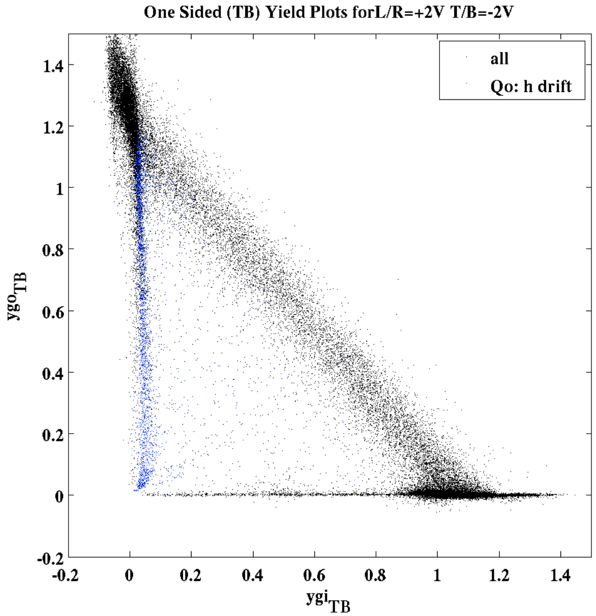
- Naively expect Yield Leakage to anticorrelate with Q & P discrimination
- Naively expect some correlation between Q & P discrimination

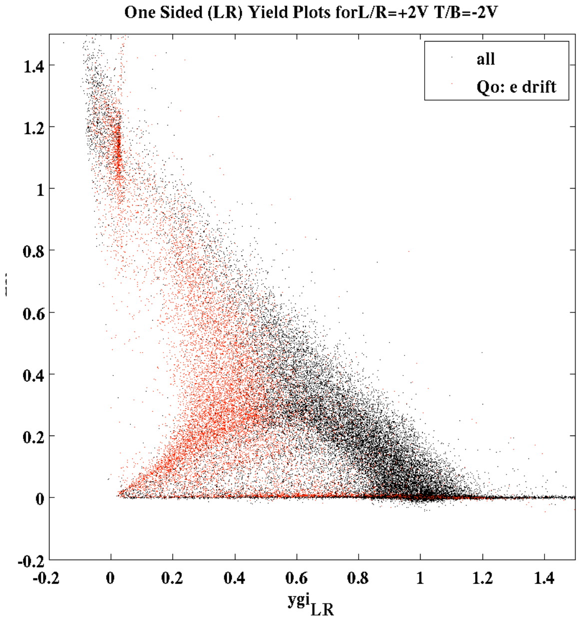


Radial Fiducial Volume

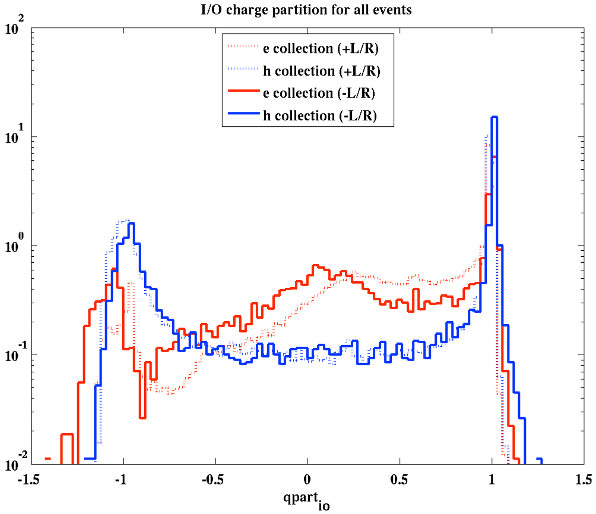
- e&h n0 efficiency:
  55 ±2±10%
- h only n0 efficiency:
  85 ±2±10%





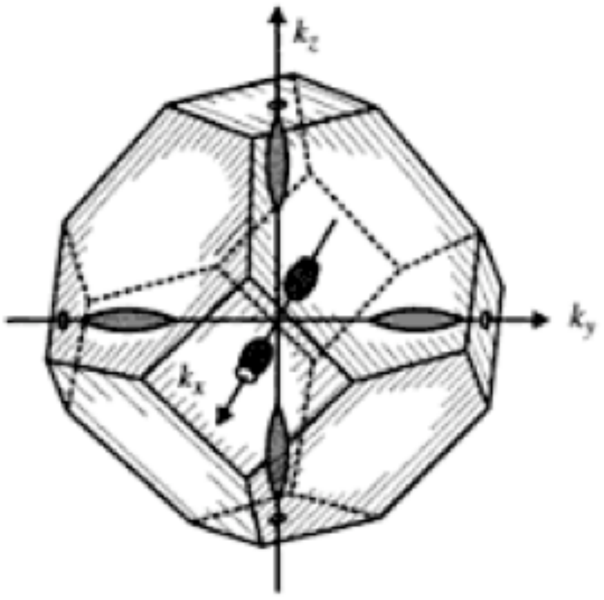


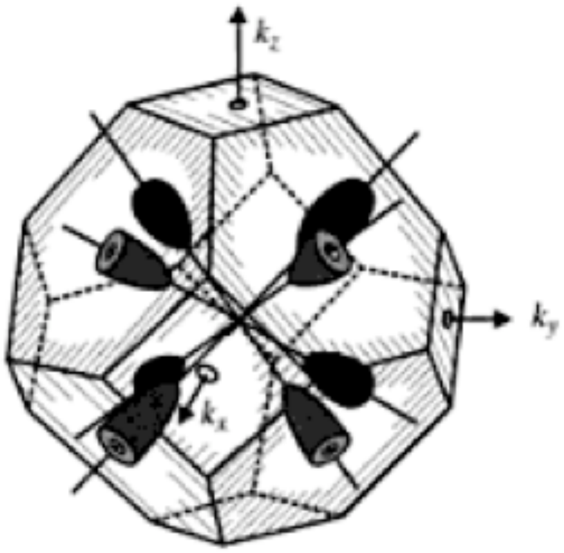
- Huge Funnel for e collecting electrode
- Shared events: e >> h
- Lateral charge diffusion for e >> h



Indirect gap semiconductors

- Conduction electrons in valleys along [111] for Ge and have very anisotropic effective masses





- holes have minimum energy at center of zone so behave more isotropically

Model valley energy

- Elliptical potential wells given by

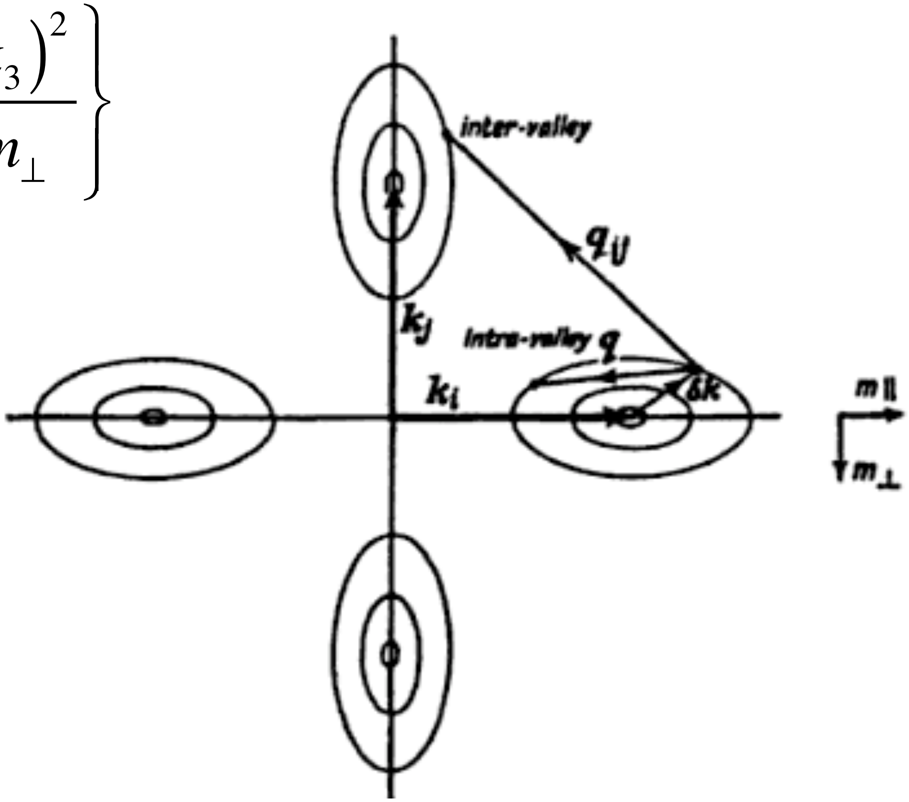
$$\varepsilon_{\vec{k}} = \hbar^2 \left\{ \frac{(\delta k_1)^2}{2m_{||}} + \frac{(\delta k_2)^2}{2m_{\perp}} + \frac{(\delta k_3)^2}{2m_{\perp}} \right\}$$

where for Ge

$$m_{||} = 1.58\, m_e$$

$$m_{\perp} = 0.081 m_e$$

nearly a factor of 20 !



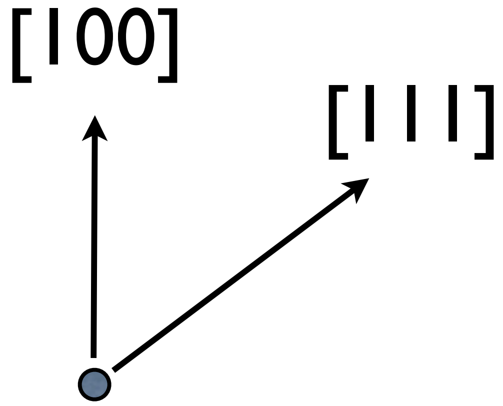
Oblique propagation necessary

- Electric field along [100]

$$e\vec{E} = \frac{d\vec{p}}{dt}$$

so that change in momentum
is along [100] since

$$\vec{p} = \overline{\overline{m}} \cdot \vec{v} = m_\perp v_\perp \hat{n}_\perp + m_{||} v_{||} \hat{n}_{||}$$



- However, change in velocity
is nearly along perpendicular to [111] since

$$\vec{v} = v_\perp \hat{n}_\perp + v_{||} \hat{n}_{||}$$

Drift velocity direction

- For each valley the drift velocity vector is

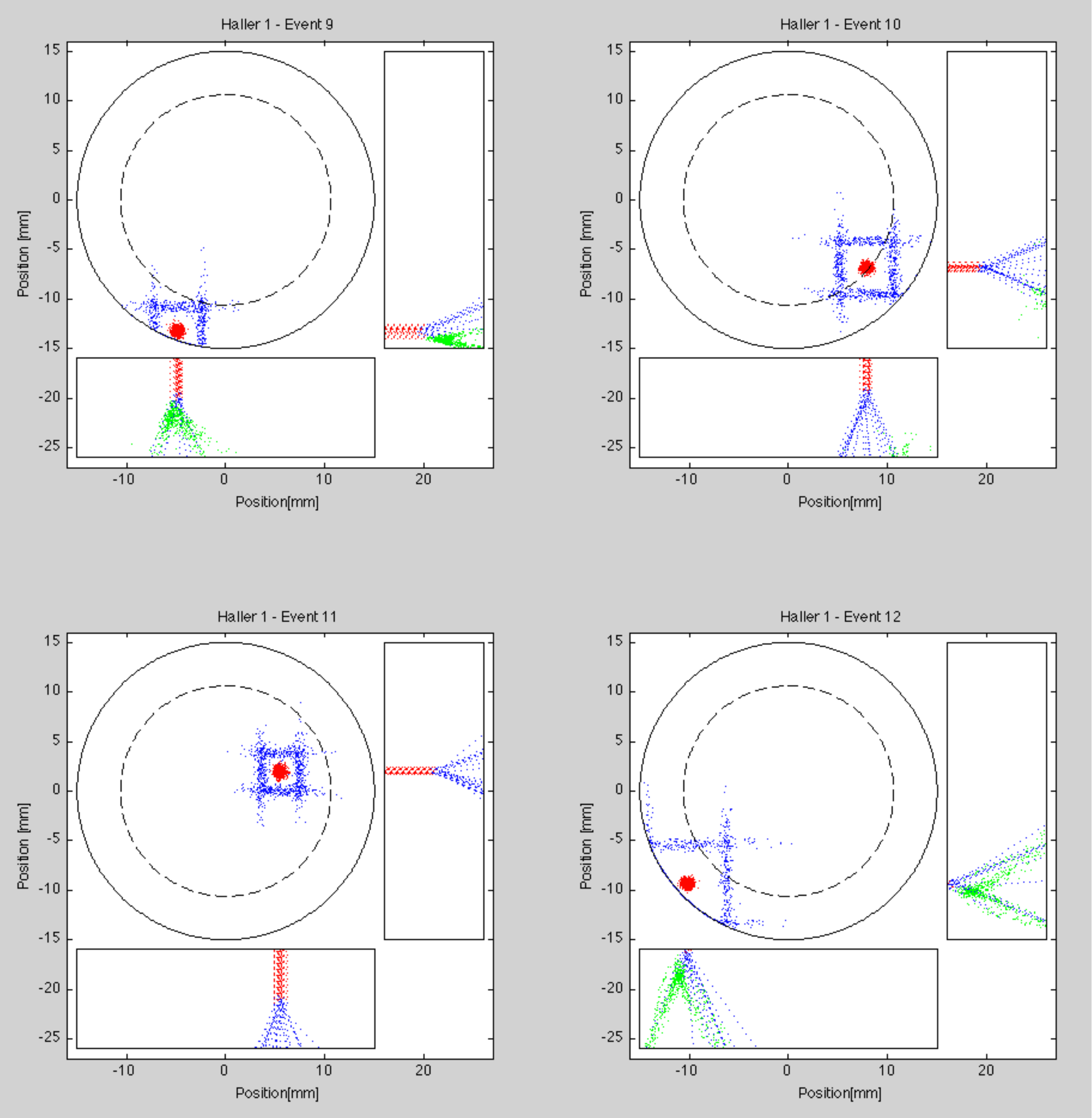
$$\begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} = \frac{2e\left[\varepsilon\tau(\varepsilon)\right]}{3m_e kT} \begin{pmatrix} m_e/m_{\parallel} & 0 & 0 \\ 0 & m_e/m_{\perp} & 0 \\ 0 & 0 & m_e/m_{\perp} \end{pmatrix} \bullet \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix}$$

and for $\vec{E} = E\left(\sqrt{1/3}\,\hat{x} + \sqrt{2/3}\,\hat{y}\right)$

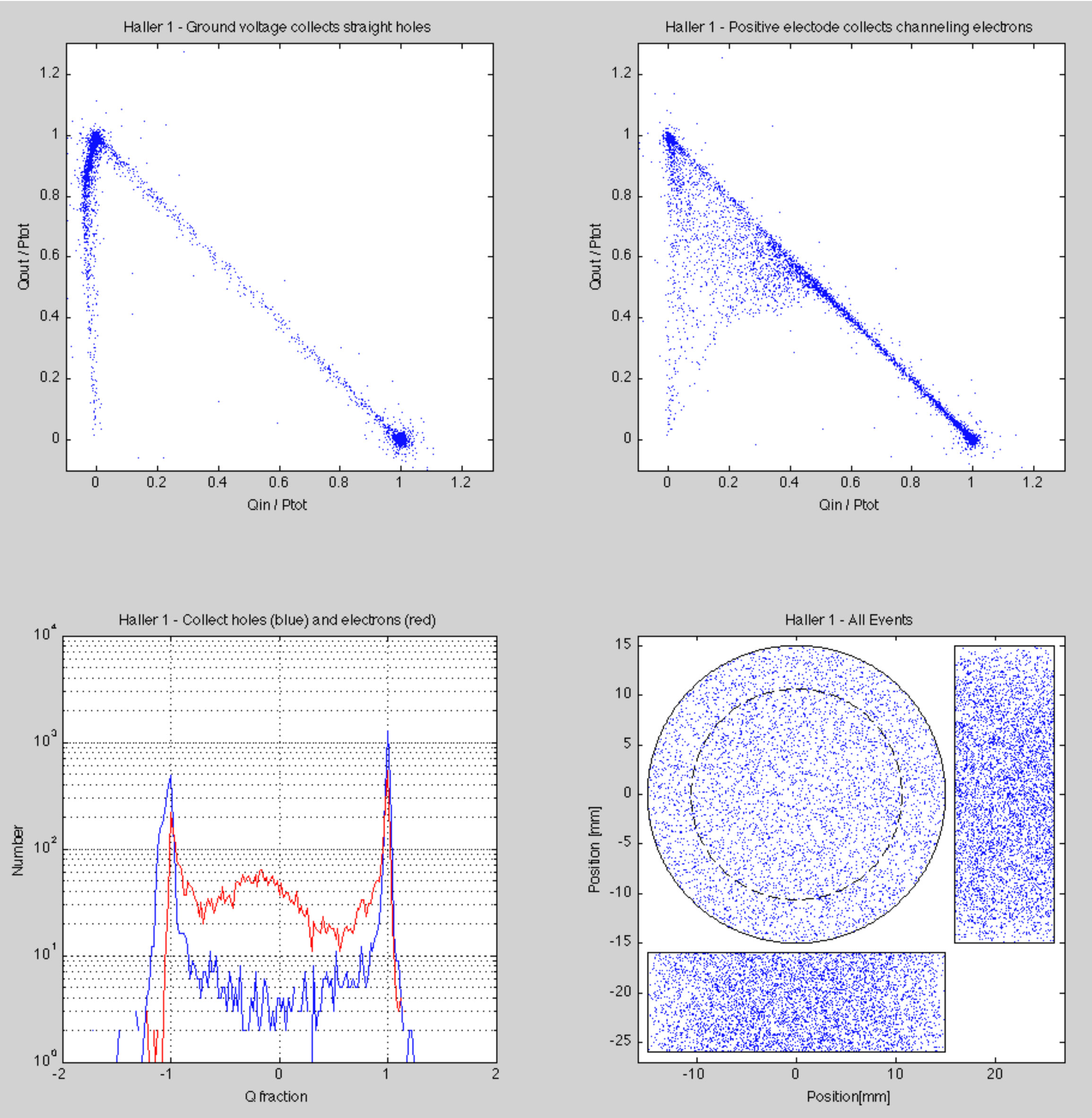
we obtain $\vec{v} = \frac{2e\left[\varepsilon\tau(\varepsilon)\right]}{3m_e kT} E\left(\frac{\sqrt{1/3}}{1.59}\hat{x} + \frac{\sqrt{2/3}}{0.081}\hat{y}\right) = v_\varepsilon\left(0.363\,\hat{x} + 10.08\,\hat{y}\right)$

which is 2 deg from y-axis which is perpendicular to [111] and back towards [100].

Oblique propagation simulation



Qualitatively similar features



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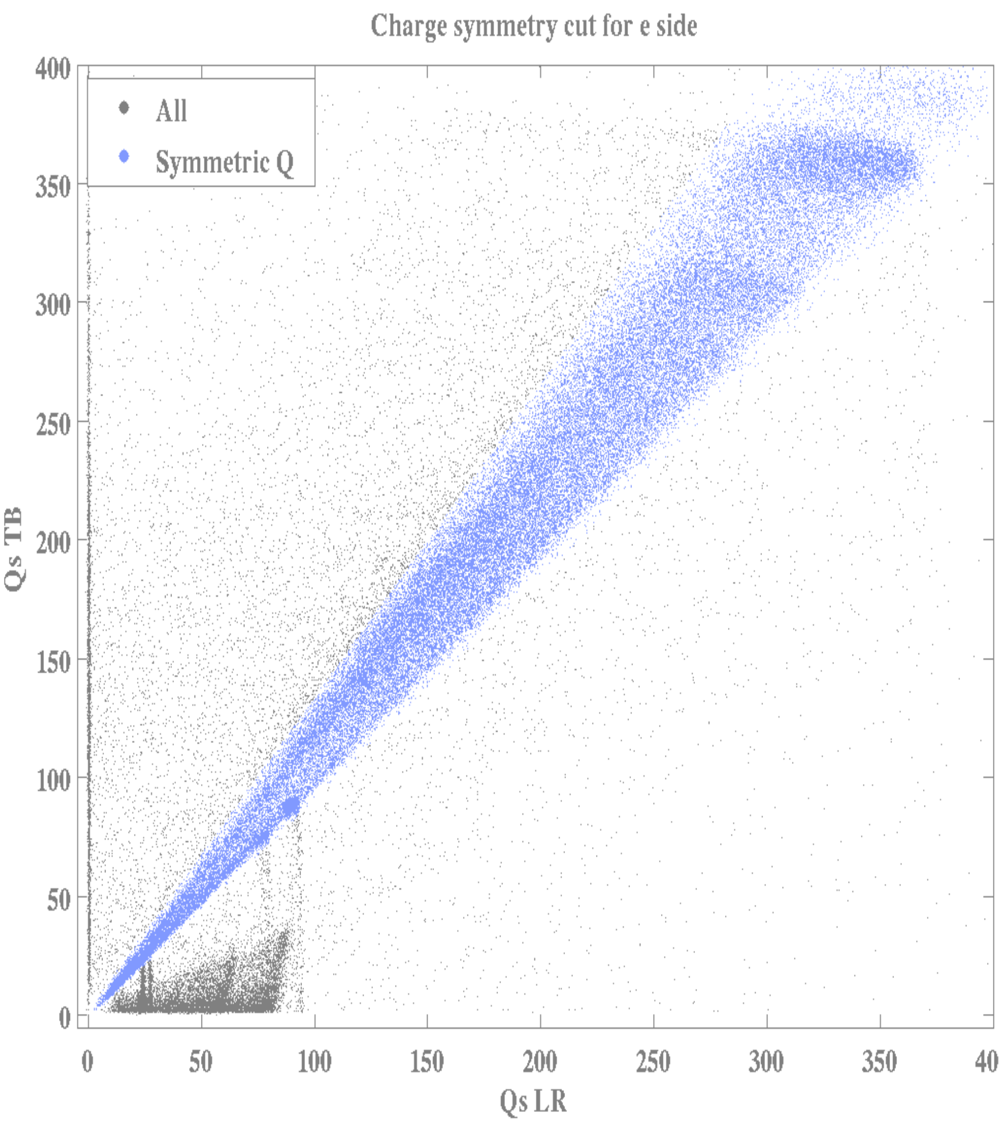
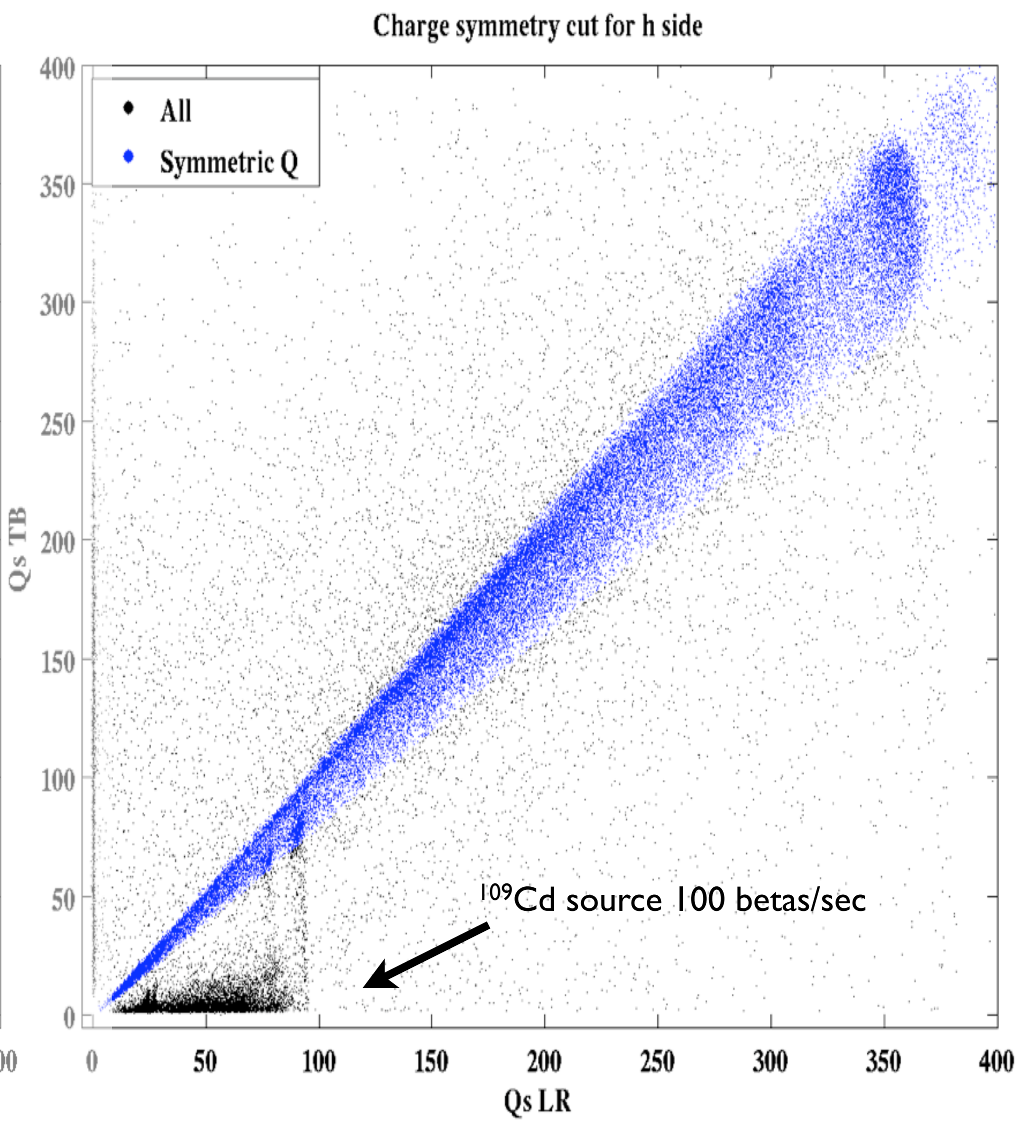
Blas Cabrera

Electrons and Holes behave differently

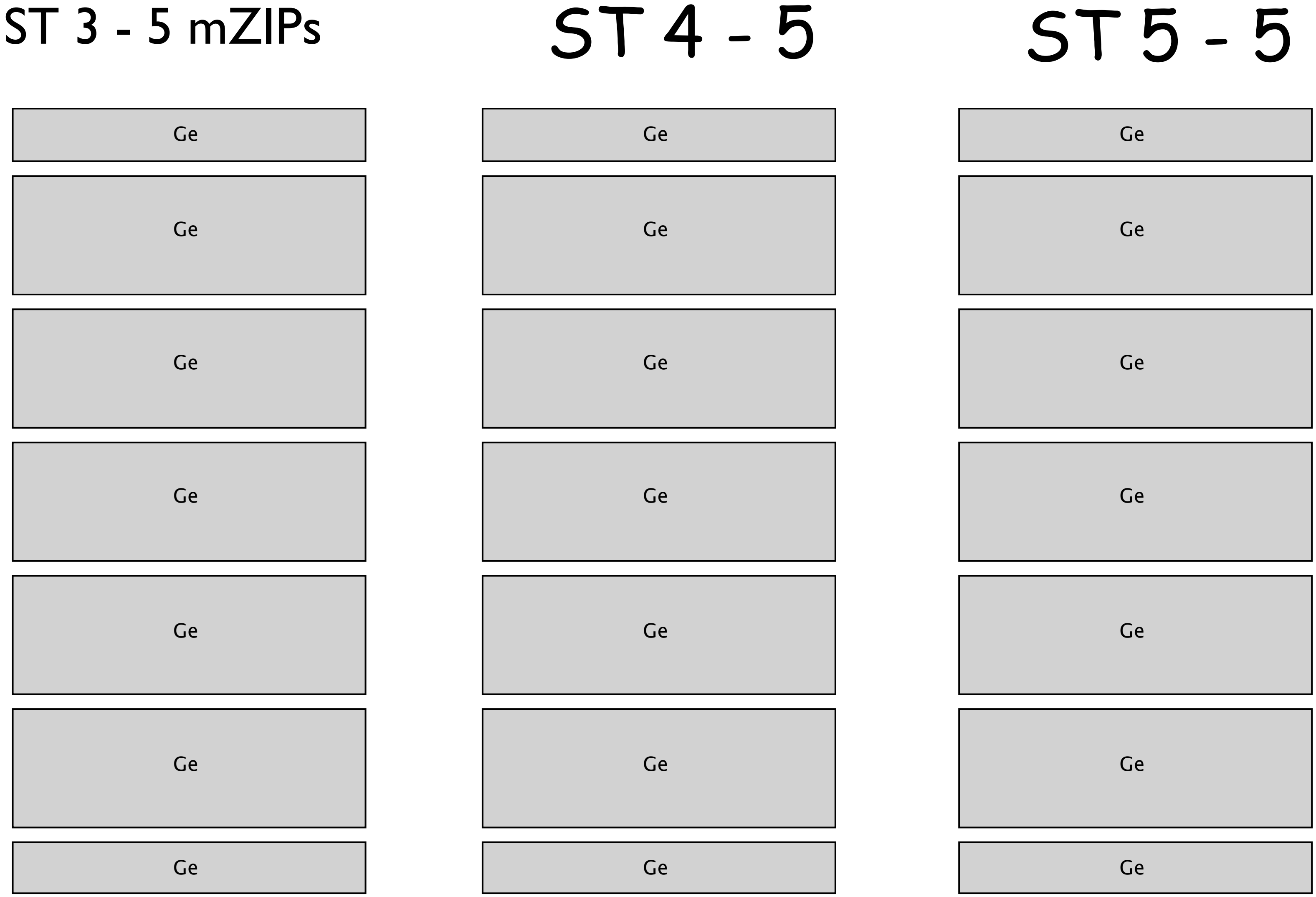




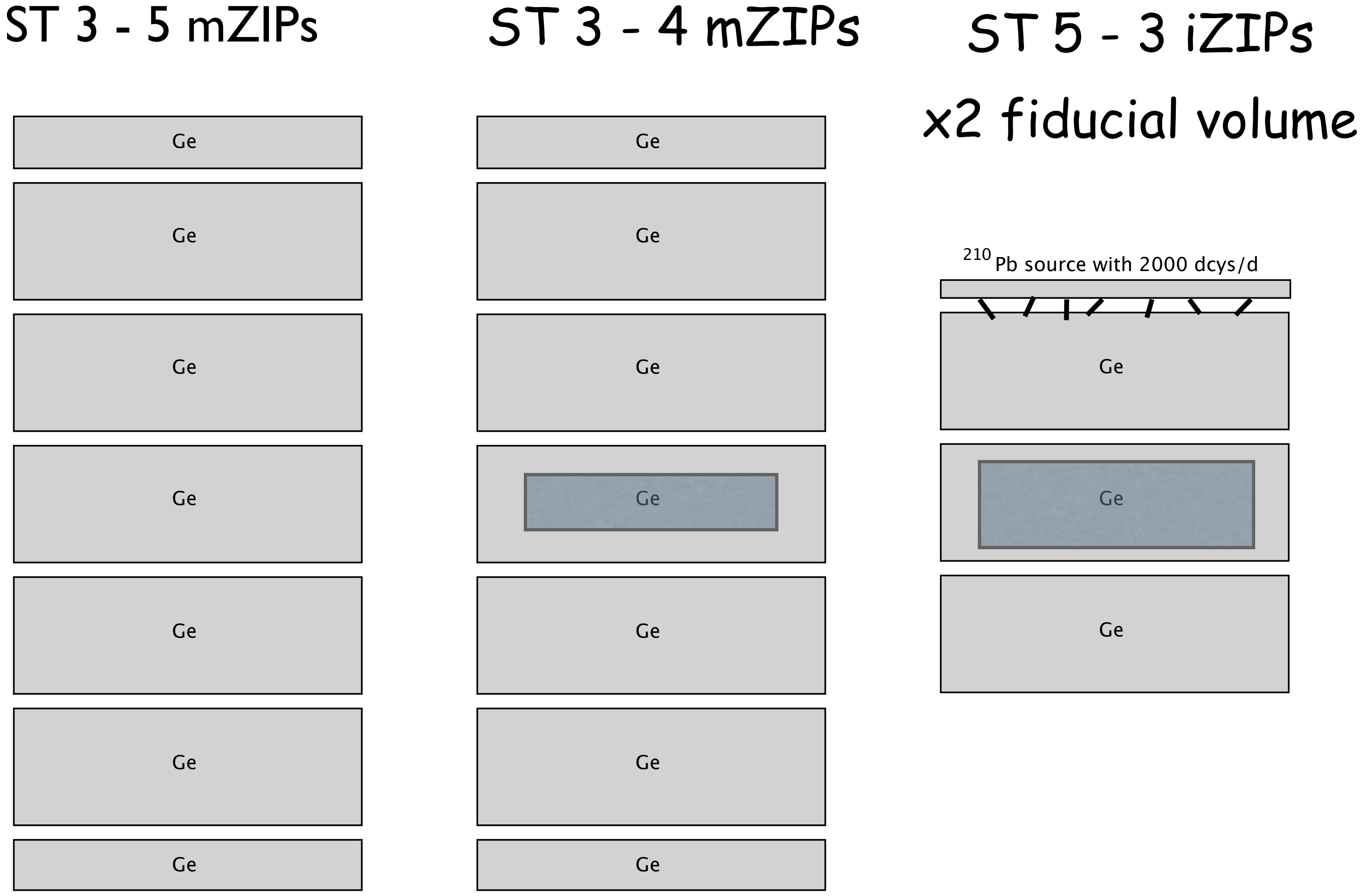
^{109}Cd source 100 betas/sec

iZIP for Soudan

SuperCDMS Soudan (3 more STs)



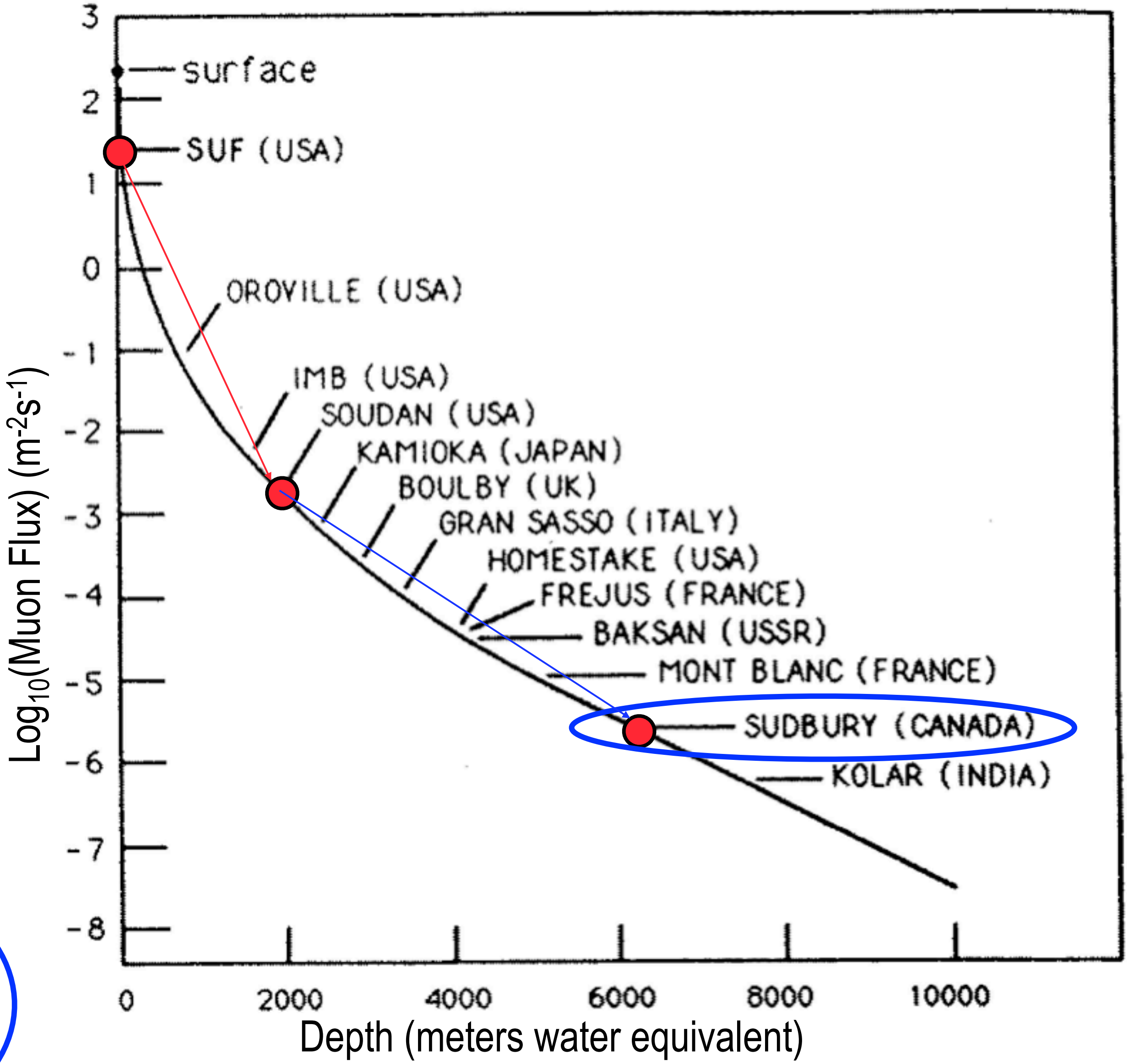
SuperCDMS Soudan (iZIP)



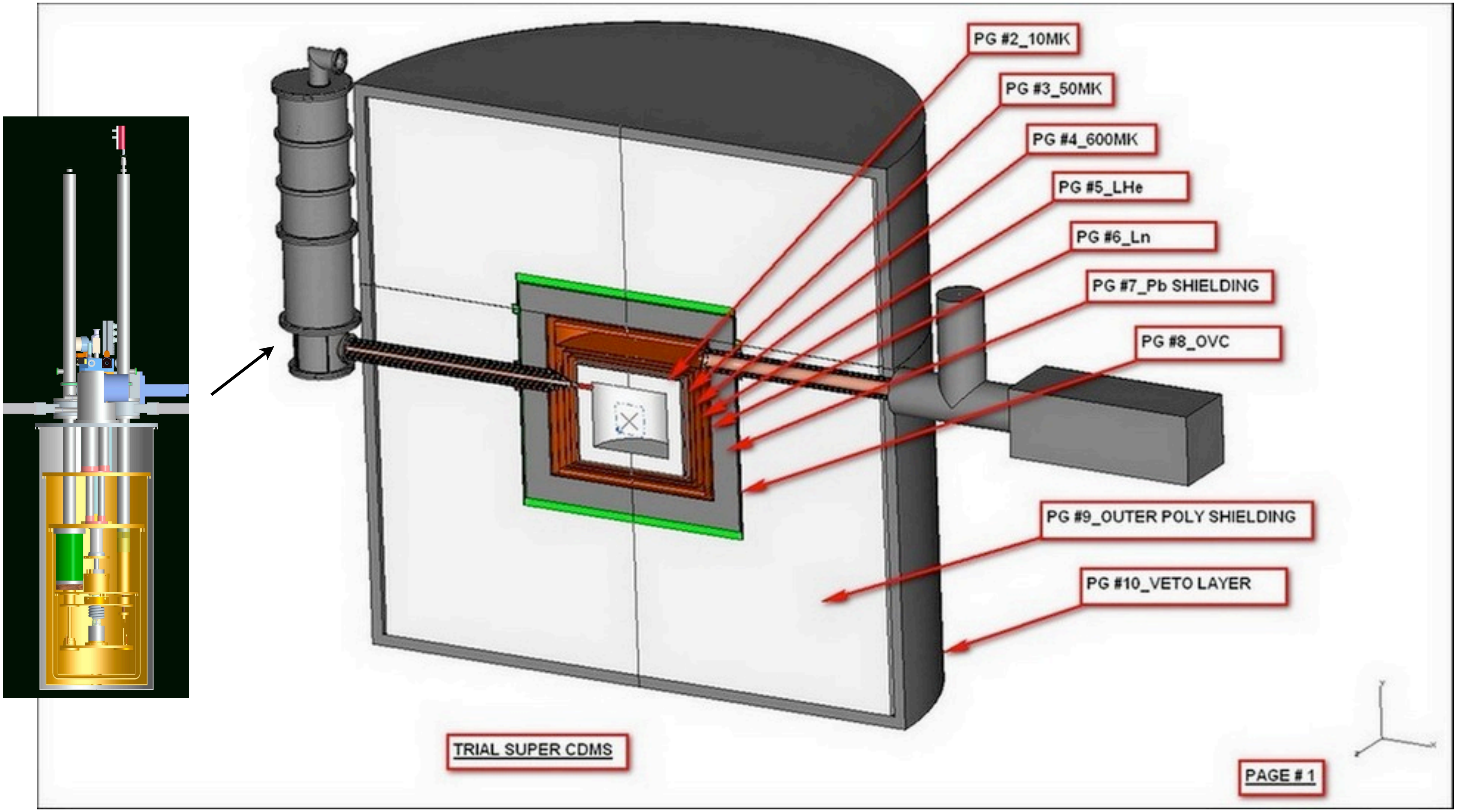
SuperCDMS SNOLAB
100 kg Ge
12 X 7 = 84 iZIP
10 cm dia X 3.3 cm thick

SUF (17 mwe), Soudan (2090 mwe), & SNOLab (6060 mwe)

- At SUF
  - 17 mwe
  - 0.5 n/d/kg
- At Soudan
  - 2090 mwe
  - 0.01 n/y/kg
- At SNOLab
  - 6060 mwe
  - < 1 n/y/ton

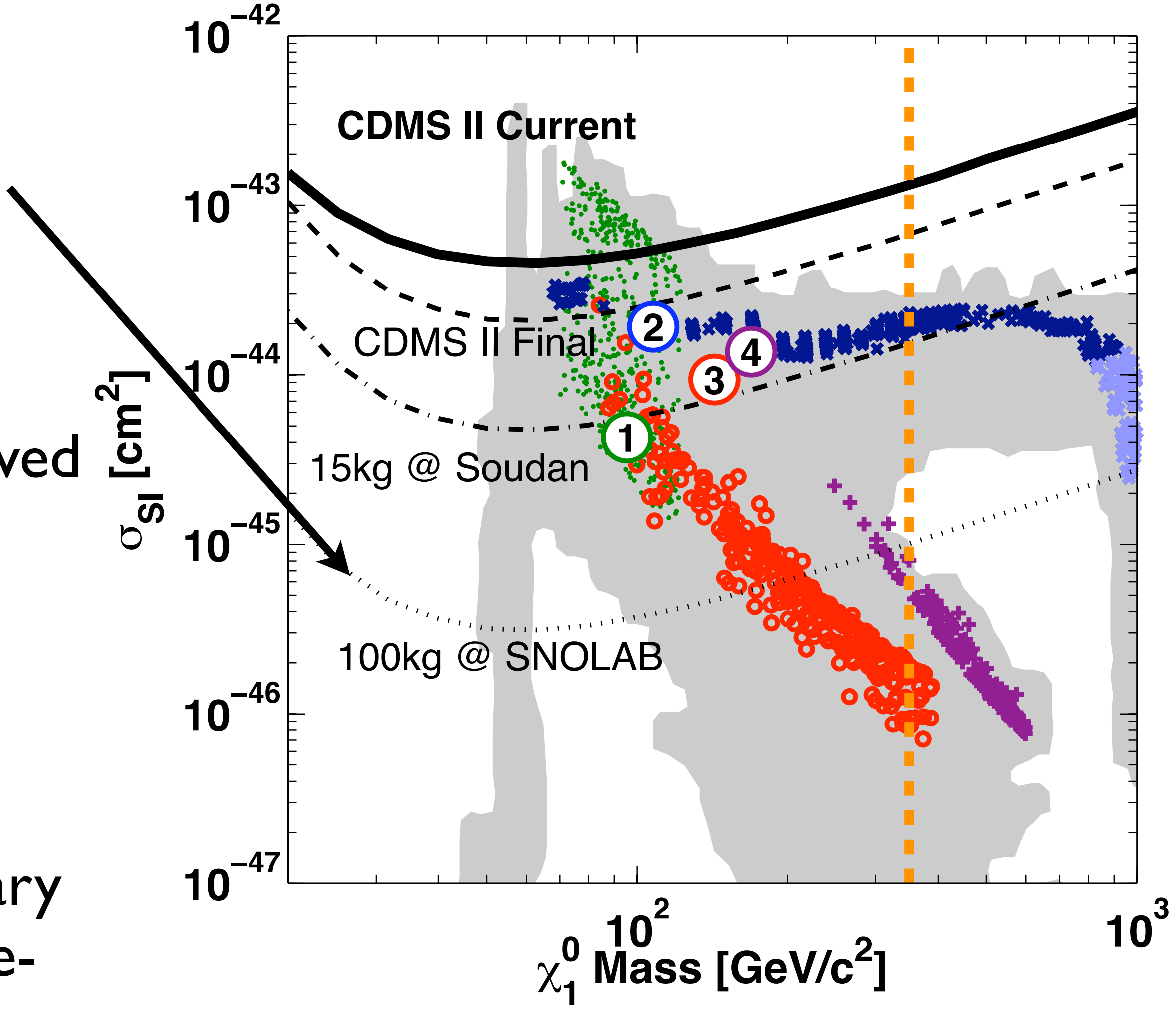


Schematic of new ‘SNObox’



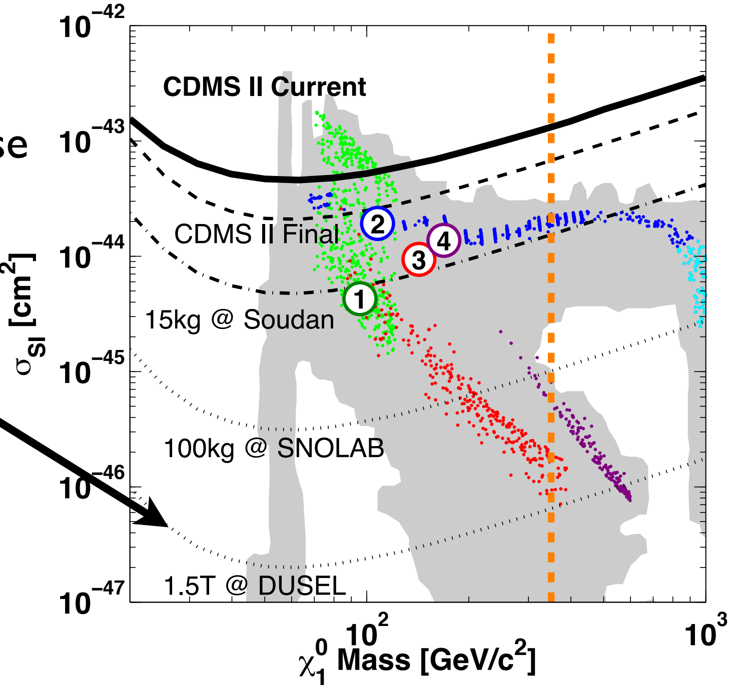
Future SuperCDMS SNOLAB project

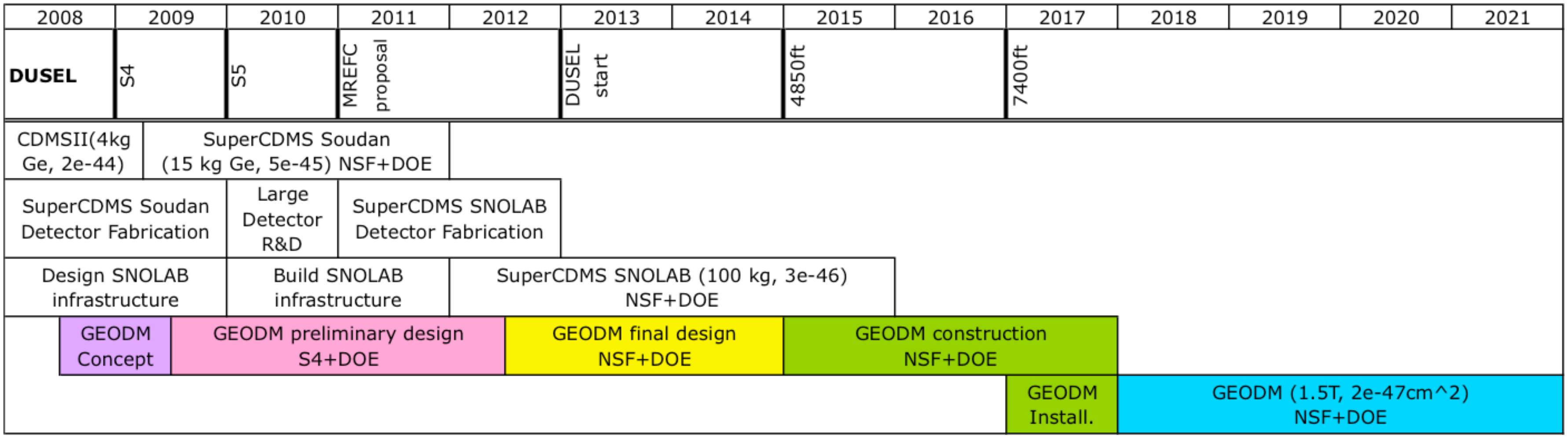
- Plan SuperCDMS SNOLAB
  - new advanced Ge iZIP design looks very promising for 100 kg experiment
  - new higher radiopurity cryosystem with improved shielding
  - We have strong endorsement from PA SAG of our SNOLAB strategy - complementary with other intermediate-scale experiments (Xenon 100, LUX, WARP140,...)



Relationship of GEODM to SuperCDMS

- Best case DUSEL 4800’ in 2015 and 7400’ in 2017
  - All direct detection experiments need intermediate phase
  - Ge 100 kg at SNOLAB enables future 1.5 ton at DUSEL
- Engineering for future GEODM at DUSEL
  - S4 NSF proposal for large detector engineering
  - need DOE partnership for engineering program





2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
DUSEL	S4	S5	MREFC proposal		DUSEL start		4850ft		7400ft				
CDMSII(4kg Ge, 2e-44)	SuperCDMS Soudan (15 kg Ge, 5e-45) NSF+DOE												
SuperCDMS Soudan Detector Fabrication		Large Detector R&D	SuperCDMS SNOLAB Detector Fabrication										
Design SNOLAB infrastructure		Build SNOLAB infrastructure		SuperCDMS SNOLAB (100 kg, 3e-46) NSF+DOE									
GEODM Concept	GEODM preliminary design S4+DOE			GEODM final design NSF+DOE			GEODM construction NSF+DOE						
									GEODM Install.	GEODM (1.5T, 2e-47cm^2) NSF+DOE			

Summary

- Nero-zero background strategy very successful and vital for maintaining discovery potential
- SuperCDMS Soudan 15 kg improves sensitivity by another factor of x5 beyond CDMS-II
    - Probing central supersymmetry region
    - Complementary to LHC and indirect detection
- New iZIP detector provides dramatic improvement in surface electron rejection
    - Enables 100 kg Ge at SuperCDMS SNOLAB and 1500 kg Ge at GEODM DUSEL