Thick Silicon Compton Imager for ACT

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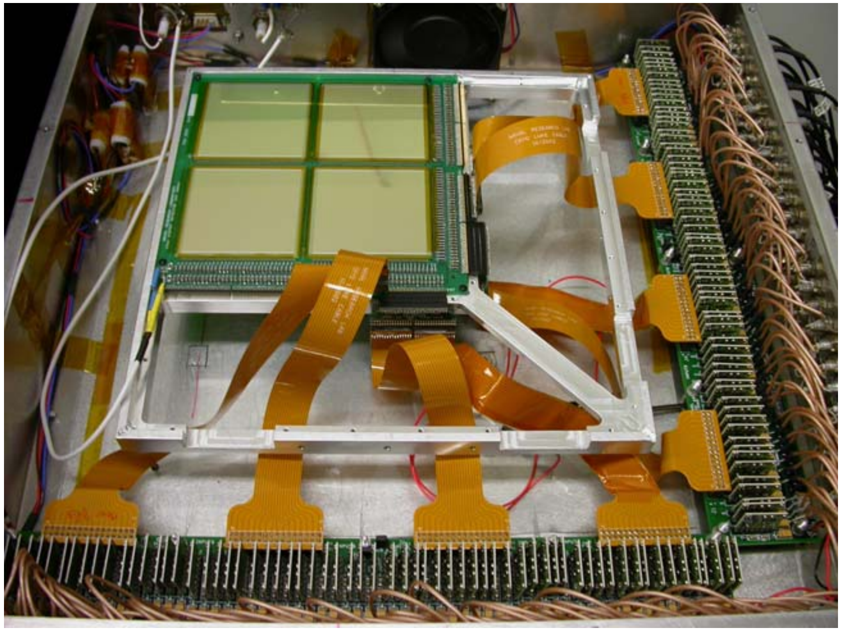
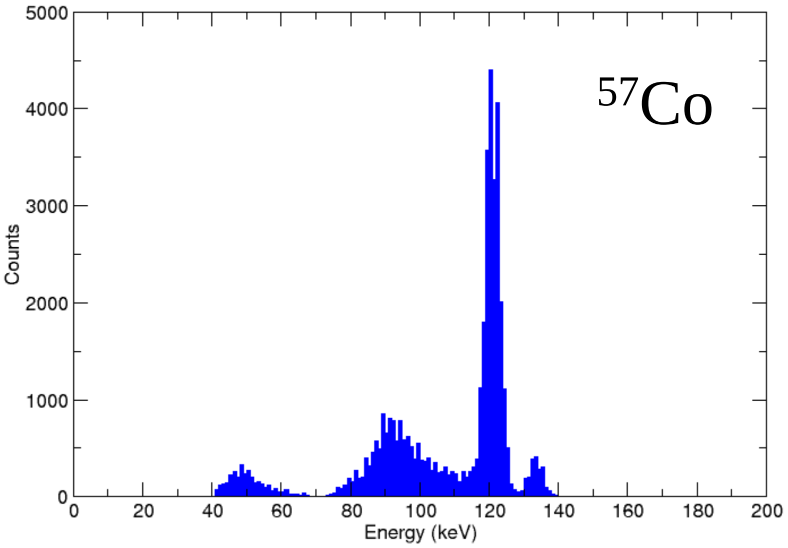
Advantages of Silicon Compton Telescope

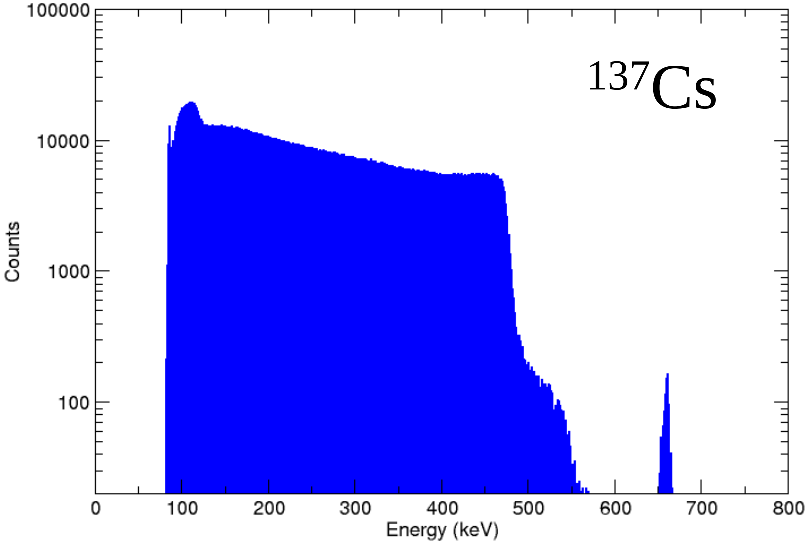
- Excellent energy resolution using solid state detectors
- Near Room Temperature operation
- Doppler Broadening

  better angular resolution with low-Z material
- Commercially available rugged detectors
- Longer mean free path –better energy and angular resolution for partially absorbed events
- Good prospects for larger area detectors
- Broad FoV provides full sky orbital coverage

2 x 2 Array Detector Performance

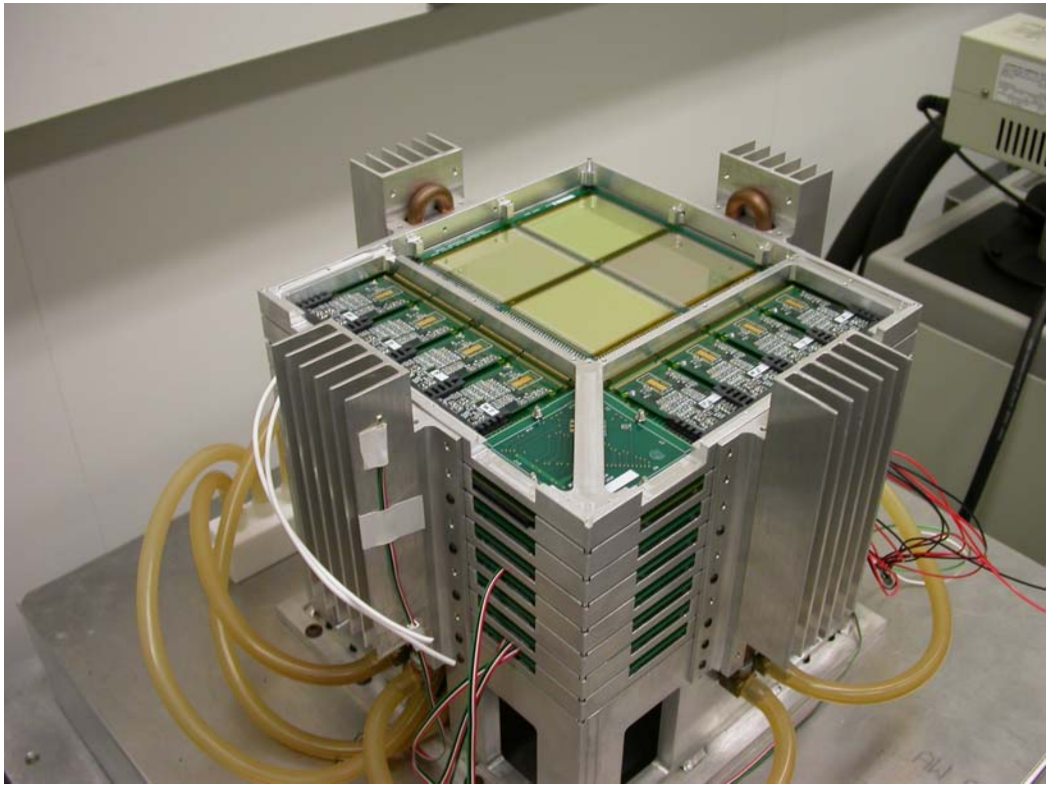






- Test 2 x 2 tray with laboratory electronics
- Spectra at right for 2x2 array for ^{57}Co (full array) and ^{137}Cs (single daisy chained strip)
- Both spectra show good room temperature energy resolution of 4.5-5 keV FWHM

Thick Silicon Prototype

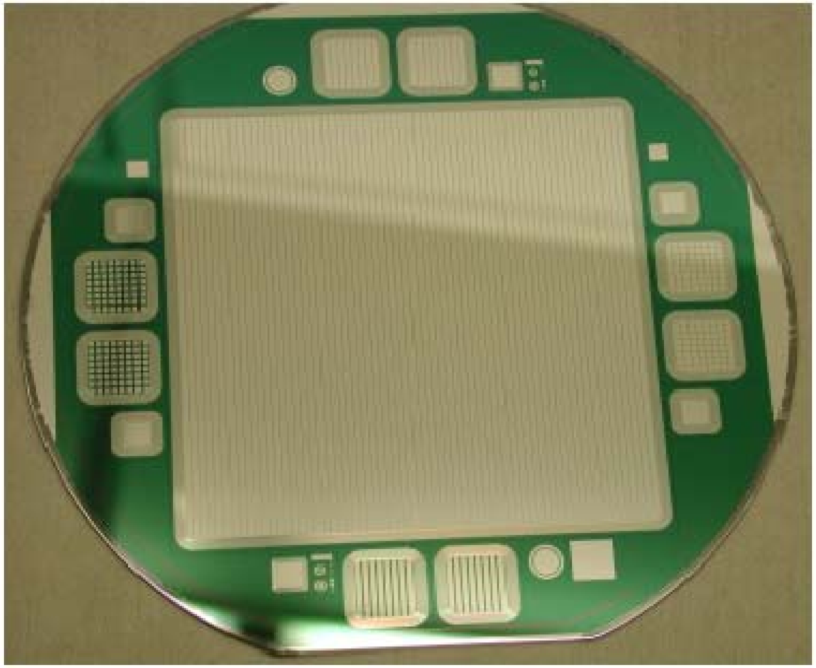


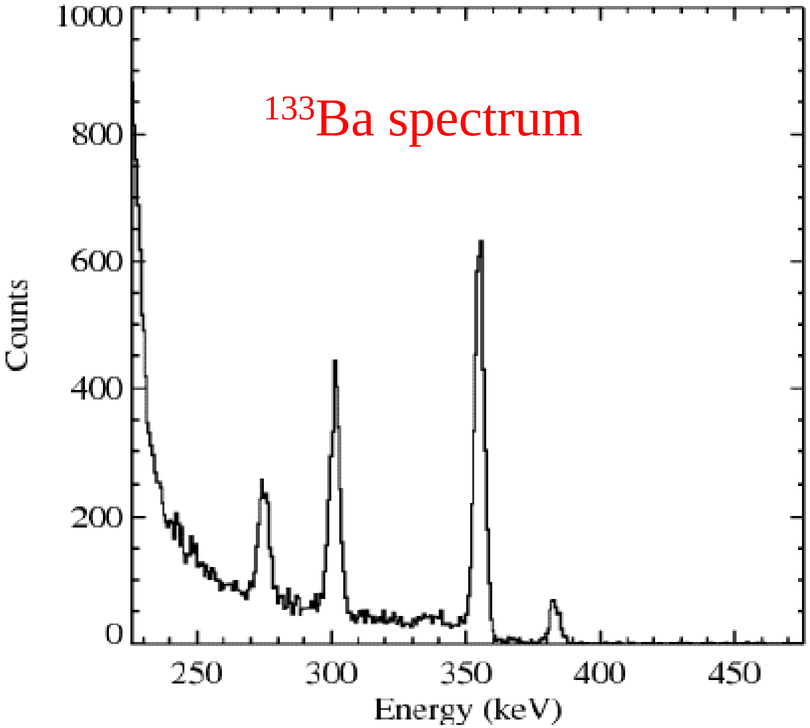
Eight layer instrument currently under assembly

2x2 arrays of 6.3cm x 6.3cm x 2mm thick detectors

Test performance from -50C to +25C

Detector from 150mm Diameter Wafer





Room temperature spectrum: 4 keV resolution

This is limited by electronics (capacitance) expect 2-2.5 keV with thicker detector

Instrument Parameters

Detectors:

10cm x 10cm x 3mm; 80 strips/side (2 mm wide guard rings)
super module: 4x4 array; 64 layers (1 cm pitch); 44.5 g/cm^2
3x5 array of super modules; total Active frontal area: 2.21 m^2

Instrument Mass:

Active Si:	990 kg
Passive Si:	84 kg
Passive material in detector volume	150 kg (15%)

Electronics:

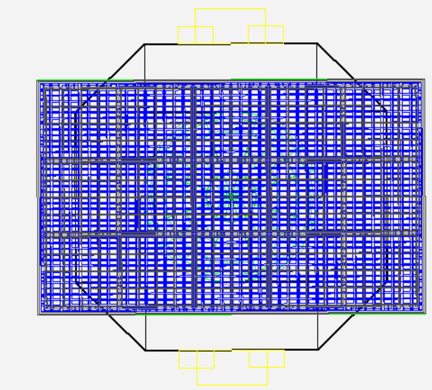
4x4 array	640 channels	1.2mm pitch X,Y (Z resolution ~ 1 mm)
SuperModule	64 layers	
Instrument (3x5):	614400 channels	
Noise	15 keV threshold	
Resolution	1.75 keV sigma	

Power:

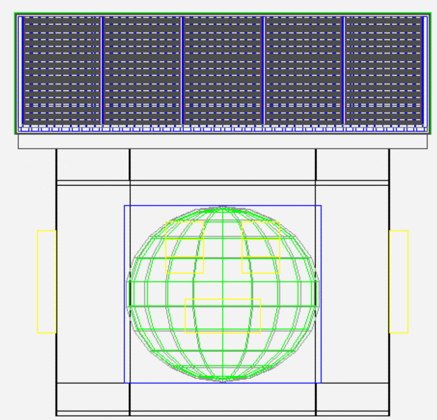
Front-end electronics:	615 watts (1 mW/channel)
Cryogenic System	615 watts (unchanged for RT operation)
ACD	25 watts
Data Processing electronics	100 watts
Heaters/LV Supplies	300
Contingency (20%)	331
Total	1986 watts

Thick Silicon ACT Instrument: Mass Model

Parameter	Thick Si Baseline
D1 Detector Ass'y	1331 kg
ACD Detector	131 kg
Other	228 kg
Instrument	1690 kg
Spacecraft	1505 kg
S/C Mass	3194 kg

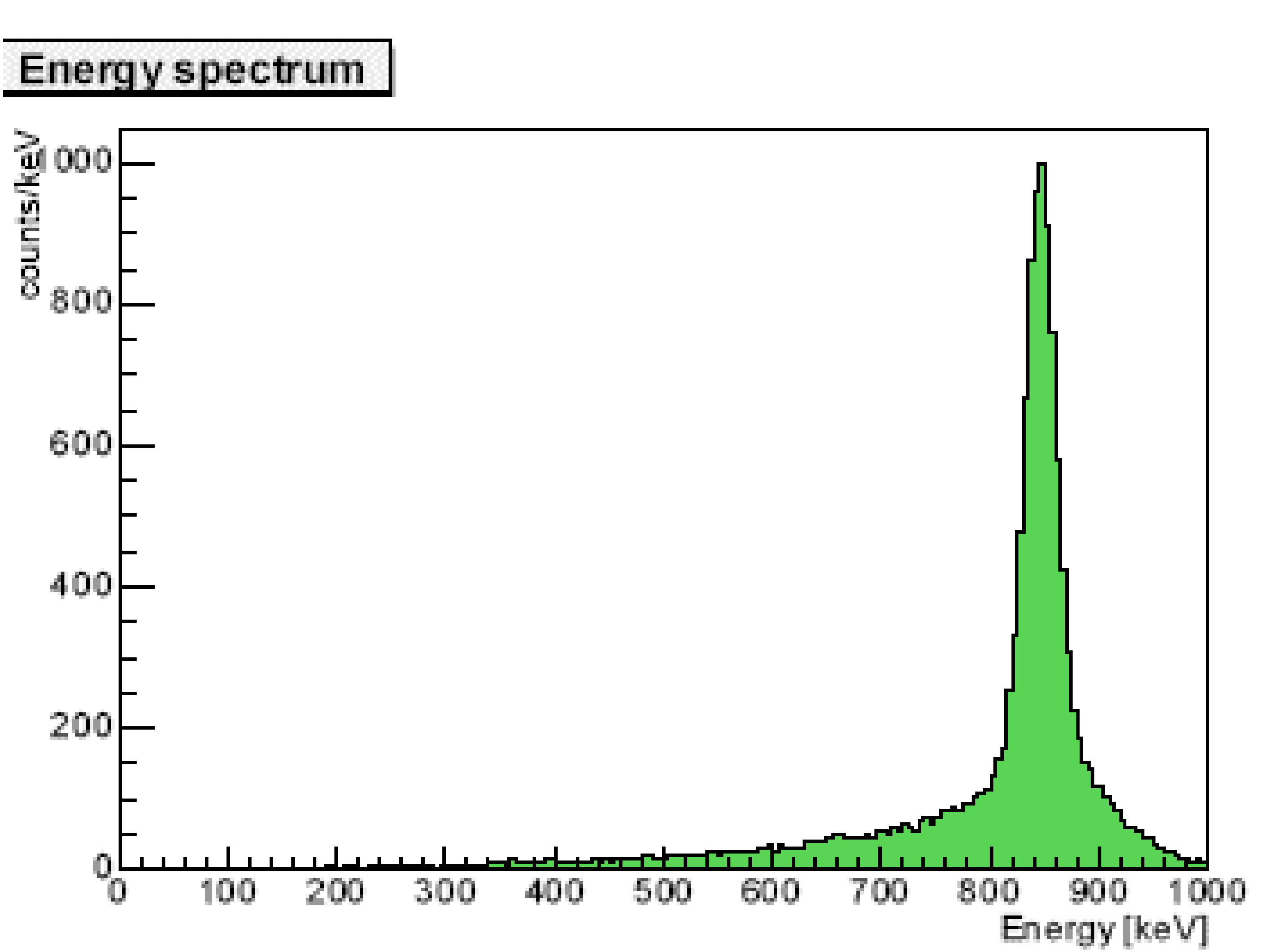


Top View



Side View

847 Broad Line Re-constructed Spectrum



Thick Silicon ACT Instrument: Simulations

Line	Effective Area(cm^2)	Sensitivity (3σ 10^6 s)
Broad lines		
847 keV		
0°	860	2.4×10^{-6}
30°	746	2.8×10^{-6}
60°	403	4.4×10^{-6}
85°	85	10.0×10^{-6}
Narrow lines		
415 keV	370	4.9×10^{-6}
511 keV	420	5.2×10^{-6}
847 keV	460	1.9×10^{-6}
1809 keV		
0°	433	2.0×10^{-6}
30°	353	2.1×10^{-6}
60°	215	3.2×10^{-6}
85°	50	4.6×10^{-6}

Note: This is with 15% passive mass inside active volume

847 keV Sensitivity Details

847keV broad line, on axis

Component	Scaled counts in window	Exposure time	Counts/ 1e6 sec	Error	Sensitivity	Sensitivity Error	Eff. Area
albedo photons	61.58	210.80	292,148.2	39,393.3	1.89E-06	1.3E-07	859.6
cosmic photons	409.64	4,712.10	86,933.6	4,953.5	1.03E-06	2.9E-08	
trapped protons activation	158.92	3,517.00	45,186.2	4,195.4	7.42E-07	3.4E-08	
cosmic protons activation	696.78	24,000.00	29,032.5	1,333.5	5.95E-07	1.4E-08	
albedo neutrons prompt	70000.00	13,979,700.00	5,007.3	2,239.3	2.47E-07	5.5E-08	
albedo neutrons activation	1764.00	2,010,000.00	877.6	2,533.4	1.03E-07	1.5E-07	
cosmic protons prompt	2.60	644.36	4,035.0	2,853.2	2.22E-07	7.8E-08	
cosmic electrons	0.16	35,765.60	4.4	12.6	7.29E-09	1.1E-08	
cosmic positrons	0.02	131,074.00	0.1	1.1	1.27E-09	5.5E-09	
trapped protons prompt	2.60	27.92	93,139.9	65,859.8	1.07E-06	3.8E-07	
			463,224.9	40,191.0	2.38E-06	2.2E-07	

847 broad line on axis, Hor. cut 2.5, Energy 847 +/- 22.75, ARM = 1 deg (radius)

Fit: sigma = 16.25 keV ARM = 1.44 deg

1809 keV Sensitivity Details

1809keV narrow line, on axis

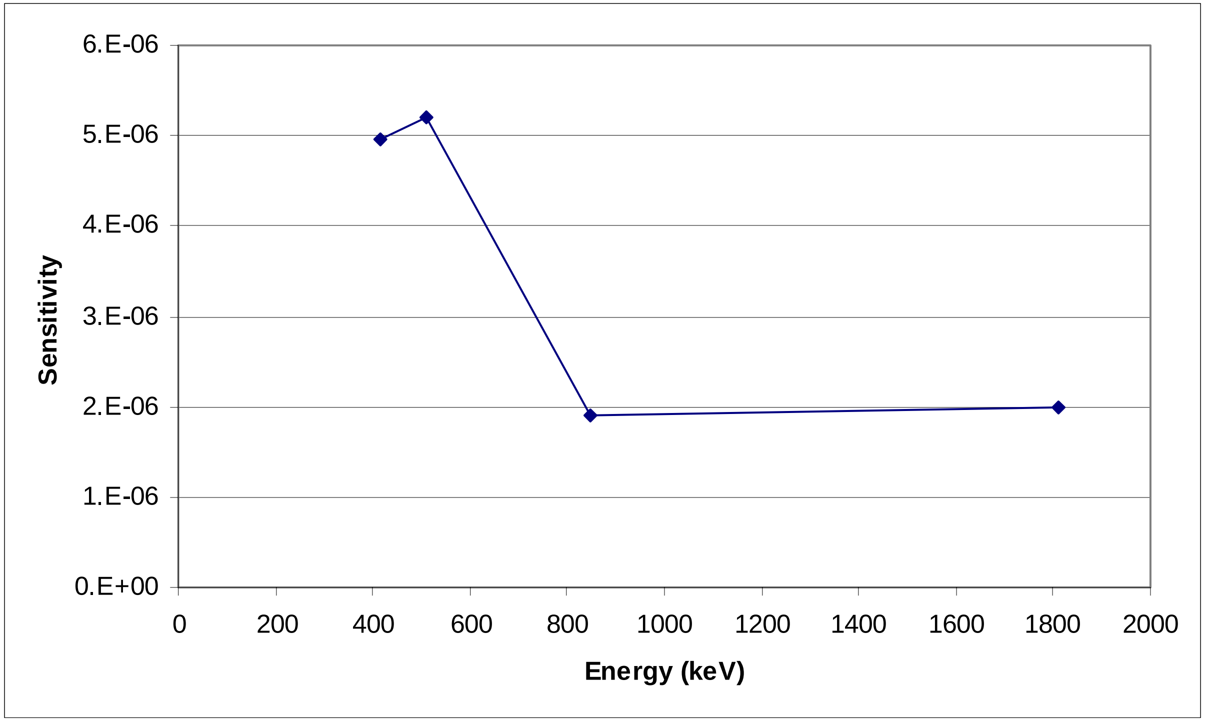
Component	Scaled counts in window	Exposure time	Counts/ 1e6 sec	Error	Sensitivity	Sensitivity Error	Eff. Area
albedo photons	9.23	210.80	43,769.1	15,474.7	1.45E-06	2.6E-07	433.4
cosmic photons	18.75	4,712.10	3,978.3	1,063.2	4.37E-07	5.8E-08	
trapped protons activation	81.38	3,517.00	23,138.5	3,120.0	1.05E-06	7.1E-08	
cosmic protons activation	276.51	24,000.00	11,521.1	881.0	7.43E-07	2.8E-08	
albedo neutrons prompt	45360.00	13,979,700.00	3,244.7	1,873.3	3.94E-07	1.1E-07	
albedo neutrons activation	377.21	2,010,000.00	187.7	1,228.7	9.48E-08	3.1E-07	
cosmic protons prompt	0.01	644.36	10.8	149.6	2.27E-08	1.6E-07	
cosmic electrons	0.00	35,765.60	0.0	0.8	8.80E-10	2.1E-08	
cosmic positrons	0.00	131,074.00	0.0	0.1	2.65E-10	1.1E-08	
trapped protons prompt	0.05	27.92	1,678.5	8,972.8	2.84E-07	7.6E-07	
			85,850.1	16,004.7	2.03E-06	4.6E-07	

1809 narrow line on axis, Hor. cut 2.5, Energy 1809 +/- 9.38, ARM = .54 deg (radius)

Fit: sigma = 6.7 keV ARM = 0.81 deg

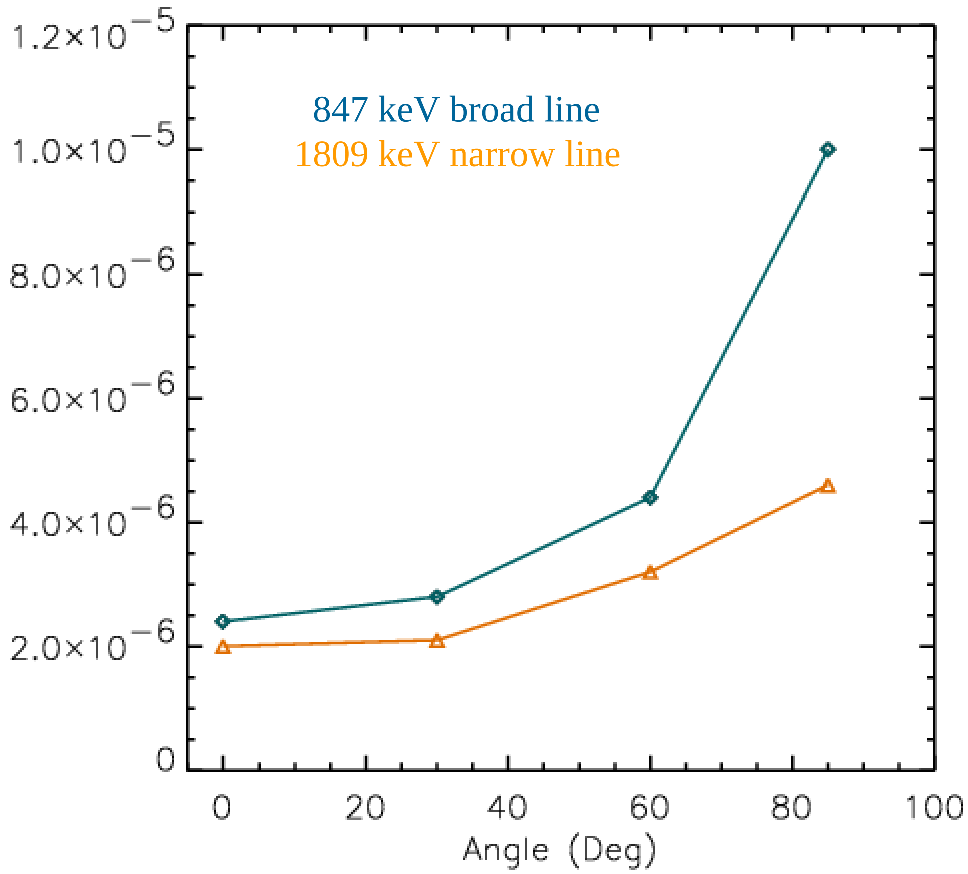
Energy Dependence of Sensitivity

3-σ narrow-line on-axis sensitivity in 10^6 seconds



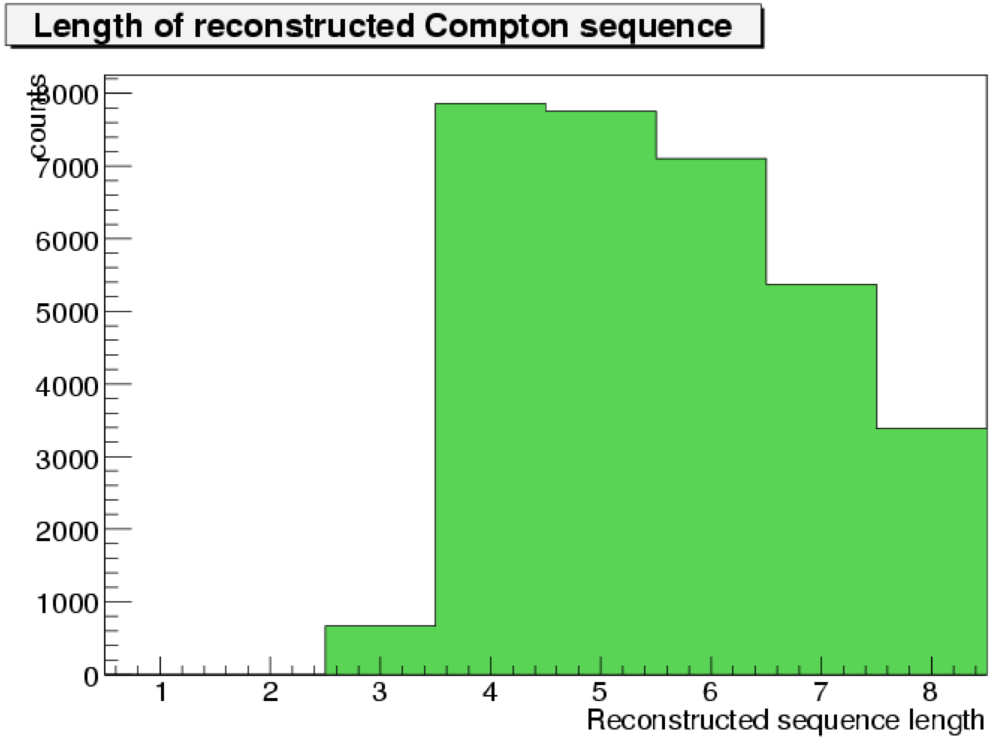
Angular Dependence of Sensitivity

3-σ sensitivity in 10^6 seconds



Event Multiplicity for 847 keV Broad Line

Instrument as described in slides 6-7, with performance as shown in slides 8-10



- Reject all 2-interaction events and 3-interaction events because no check on “true” energy of photon. These events degrade the sensitivity.
- Reject events with >8 interactions because of computer time
- Keep events with 4-8 interactions and events with (3 interactions and full energy deposition)

Preliminary Conclusions

Silicon Compton telescope strong candidate for ACT

New detectors allow operation at room temperature

Major power savings!!!

Albedo photons are dominant source of background

=> - Reducing area of sides should reduce background

- Not currently limited by position resolution, so reduction in lever arm OK.
- Try "squat" geometry, although off-axis FoV smaller

Neutrons are not dominant source of background

Still needs investigating, comparison with other elements used as active detector

Need to work on higher multiplicity (9-10)

Straightforward gain in efficiency, but computer intensive

Need to work on Clustering across layers

electrons crossing layers are now considered 2 separate events

Hybrid Design should be considered

Insert a few layers of CZT to absorb low energy photons

Squat Geometry

Detectors:

10cm x 10cm x 7.5mm; 80 strips/side (1 mm wide guard rings)

super module: 4x4 array; 25 layers (11.5 mm pitch); 43.7 g/cm^2

3x5 array of super modules; total Active frontal area: 2.30 m^2

Instrument Mass:

Active Si:	1007 kg
Passive Si:	~42kg
Passive material in detector volume	75 kg (7.5%)

Electronics:

4x4 array	640 channels	1.2mm pitch X,Y (Z resolution ~ 1 mm)
SuperModule	25 layers	
Instrument (3x5):	240000 channels	
Noise	15 keV threshold	
Resolution	1.75 keV sigma	

Power:

Front-end electronics:	240 watts (1 mW/channel)
Cryogenic System	240 watts (unchanged for RT operation)
ACD	25 watts
Data Processing electronics	100 watts
Heaters/LV Supplies	300
Contingency (20%)	331
Total	966 watts

Squat Geometry Sensitivity

847keV broad line, on axis

squat geometry

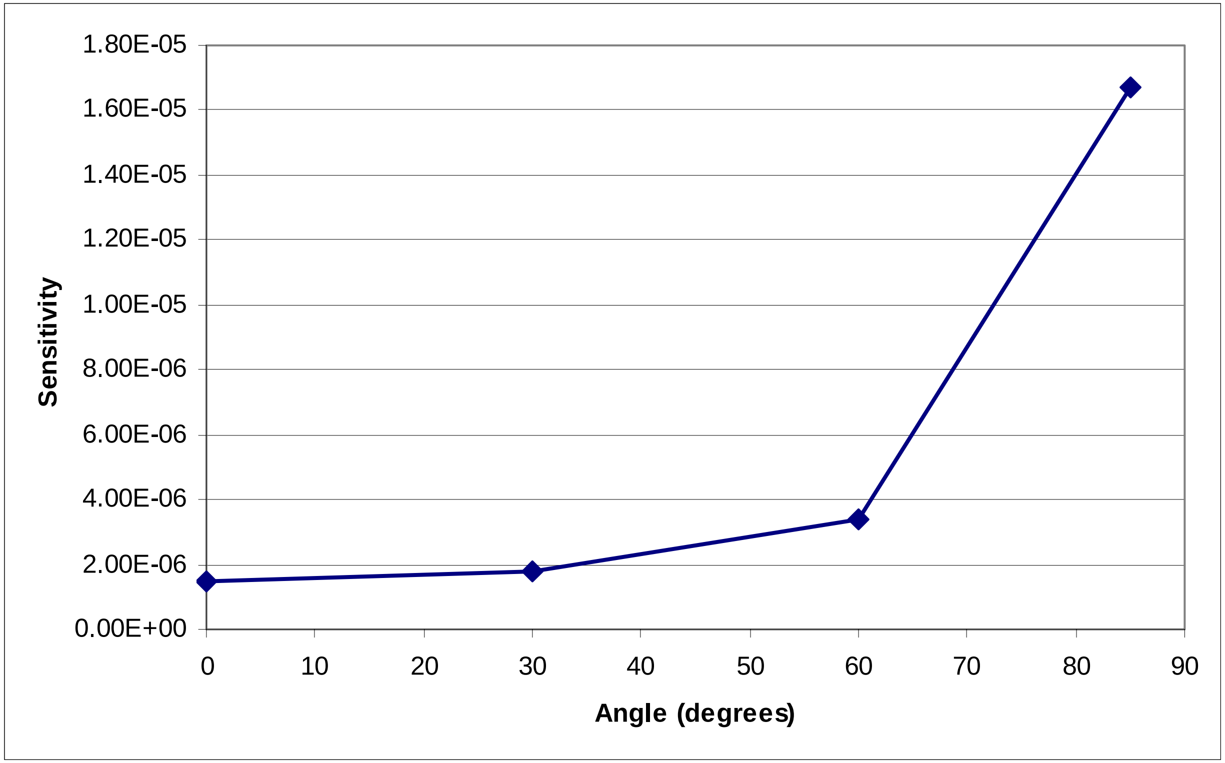
Component	Scaled counts in window	Exposure time	Counts/ 1e6 sec	Error	Sensitivity	Sensitivity Error	Eff. Area
albedo photons	85.00	392.28	216,695.7	29,857.5	1.16E-06	8.0E-08	1203.3
cosmic photons	94.52	1,101.72	85,793.1	10,403.9	7.30E-07	4.4E-08	
			302,488.8	31,618.2	1.37E-06	9.1E-08	
				projected	1.52E-06		

847 broad line on axis, Hor. cut 2.5, Energy 847 +/- 22.75, ARM = 1.29 deg (radius)

Fit: sigma = 16.25 keV ARM = 1.94 deg

Squat Geometry Angular Dependence

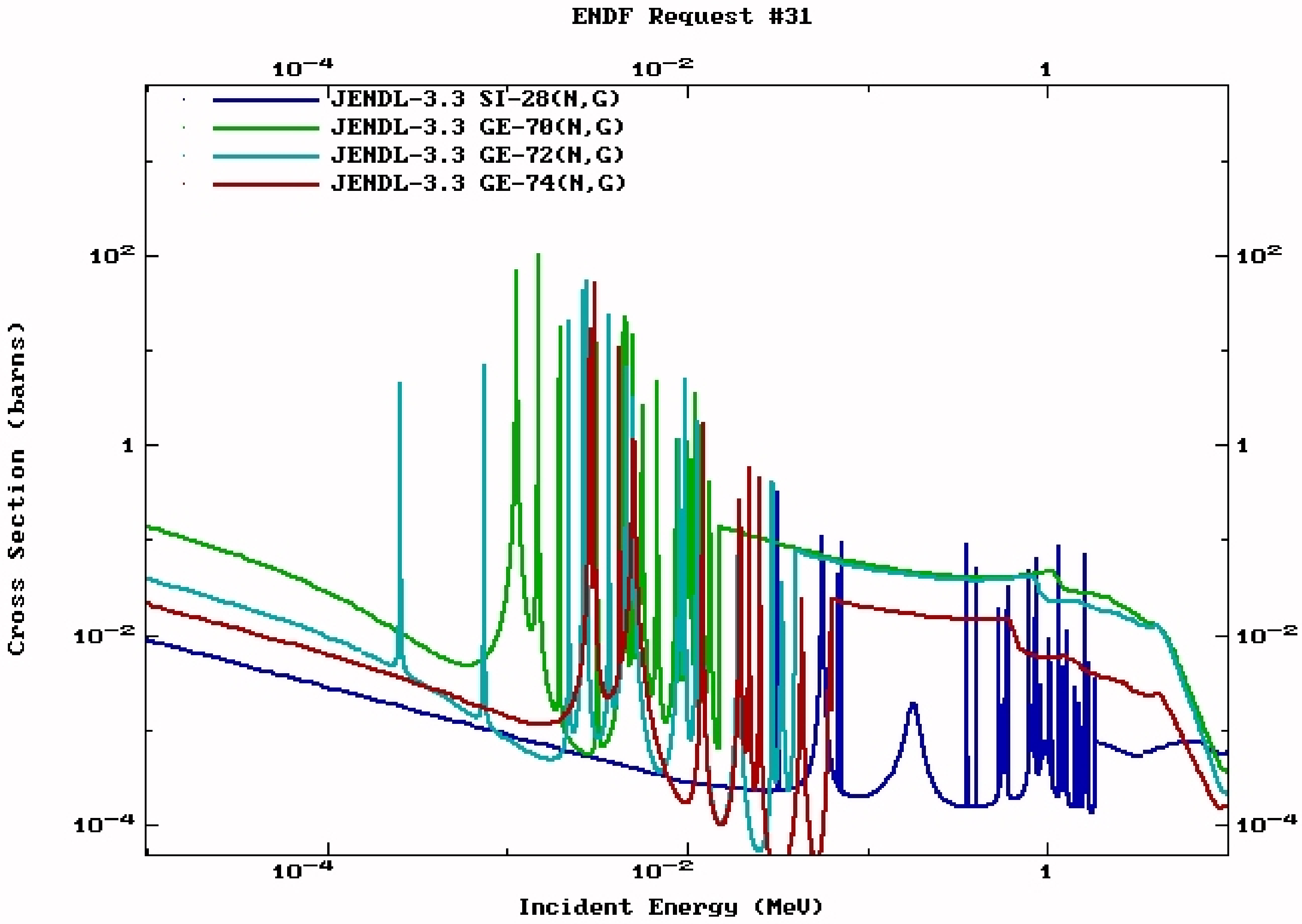
3-σ sensitivity for 847 keV broad line in 10^6 seconds



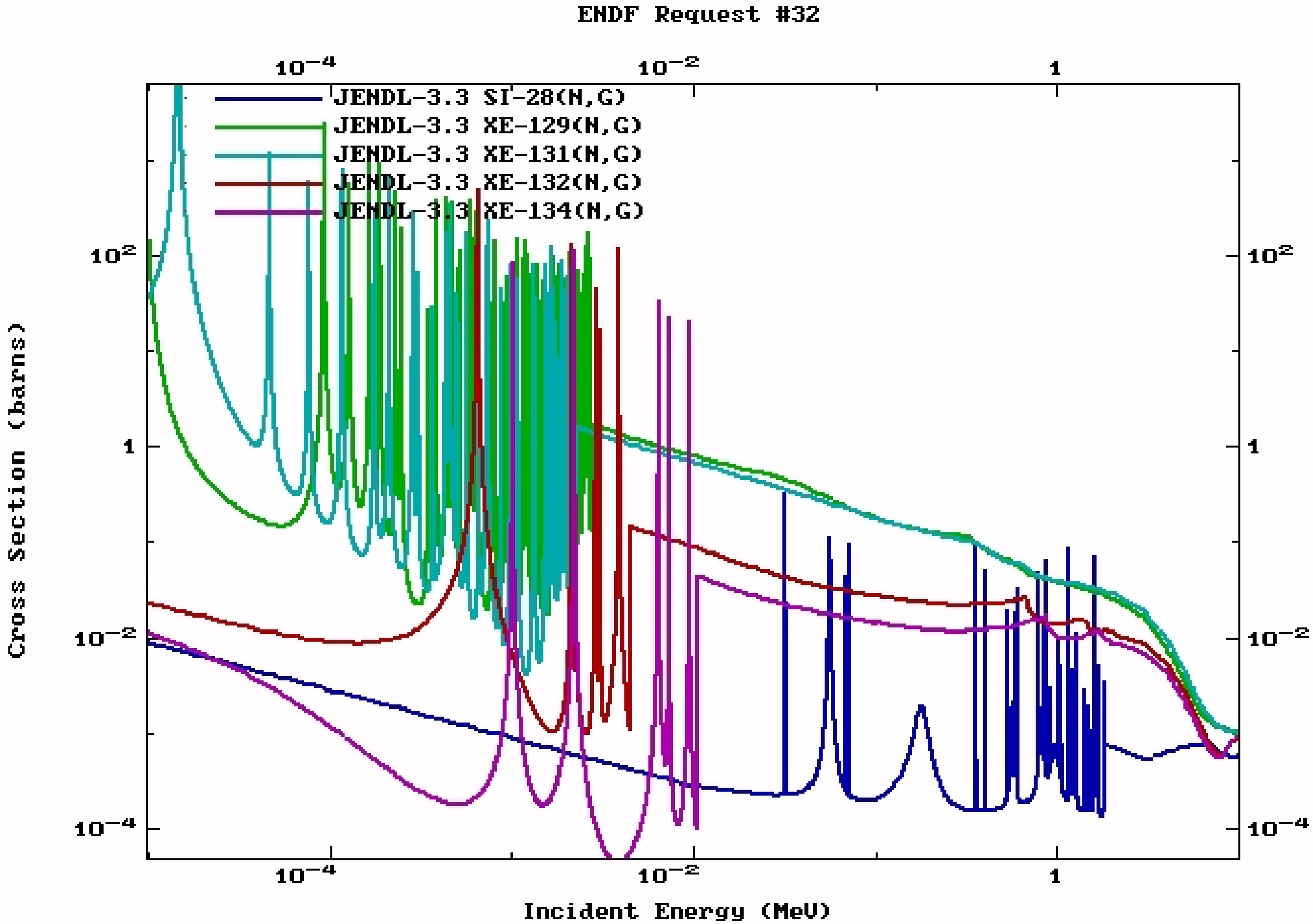
As expected, a squat instrument has a much more drastic fall-off in effective area, ie increase in sensitivity. But on-axis sensitivity is better.

847 keV narrow-line sensitivity is ~ 1.2 e-6

(n,g) Cross-Sections in Silicon and Germanium



(n,g) Cross-Sections in Silicon and Xenon



For Si, background counts due to neutrons are ~7% of cosmic photon background counts. If this fraction is not higher for Ge, and much higher for Xe, one should doubt neutron absorption part of code.

Technology Development

Low leakage current, Larger Area, Larger Volume Detectors

- Room temperature 3 mm thick detectors currently doable (6-inch wafers)
- 8-inch diameter float zone material is now available
- 12-inch wafers not yet available in float zone, but standard in industry

Wafer Bonded Detectors offer possibility for even thicker detectors

- Preferred thickness ~ 6 mm
- Reduced Cost
- Improved Performance

Detector to detector epoxy bonding

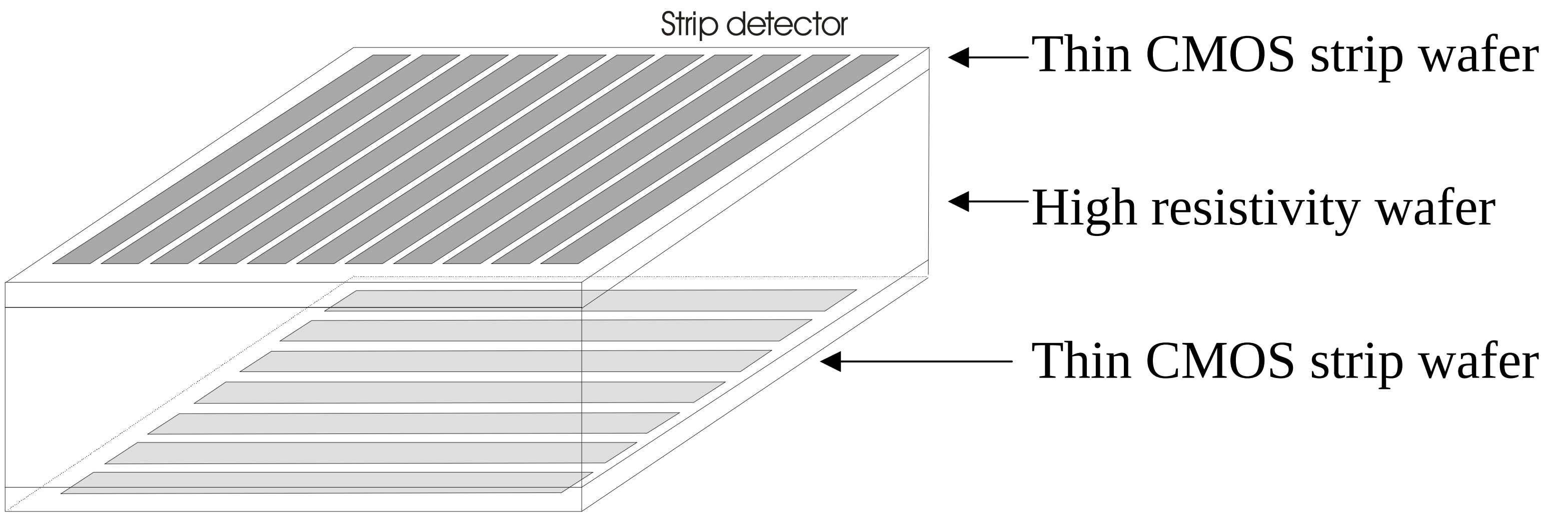
- Reduce passive material
- Common in particle physics
- Done for GLAST
- Preliminary tests at NRL look encouraging

ASICs

- Always need better ASICs

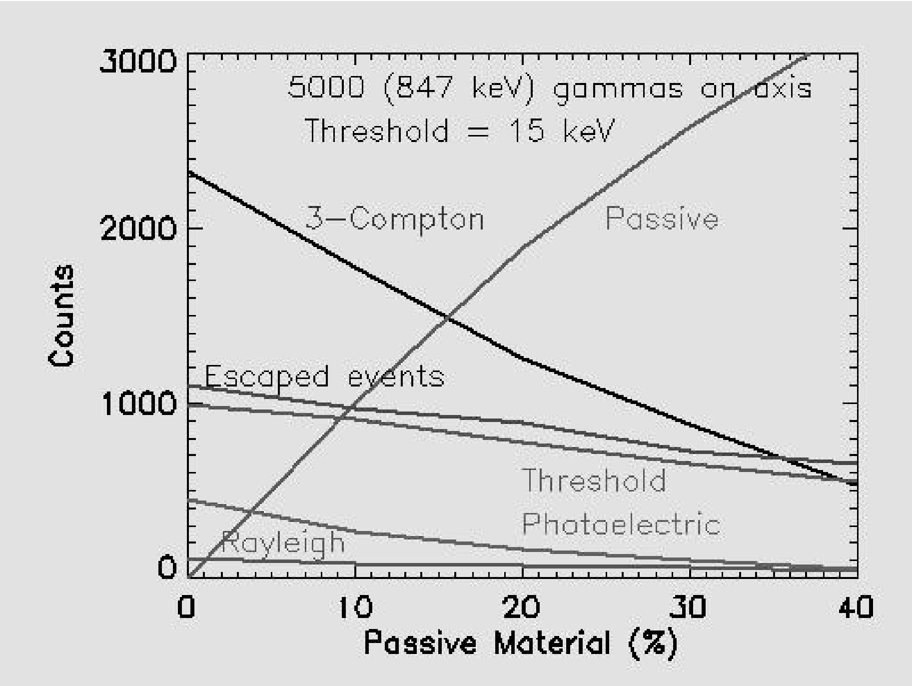
Thick Strip detector

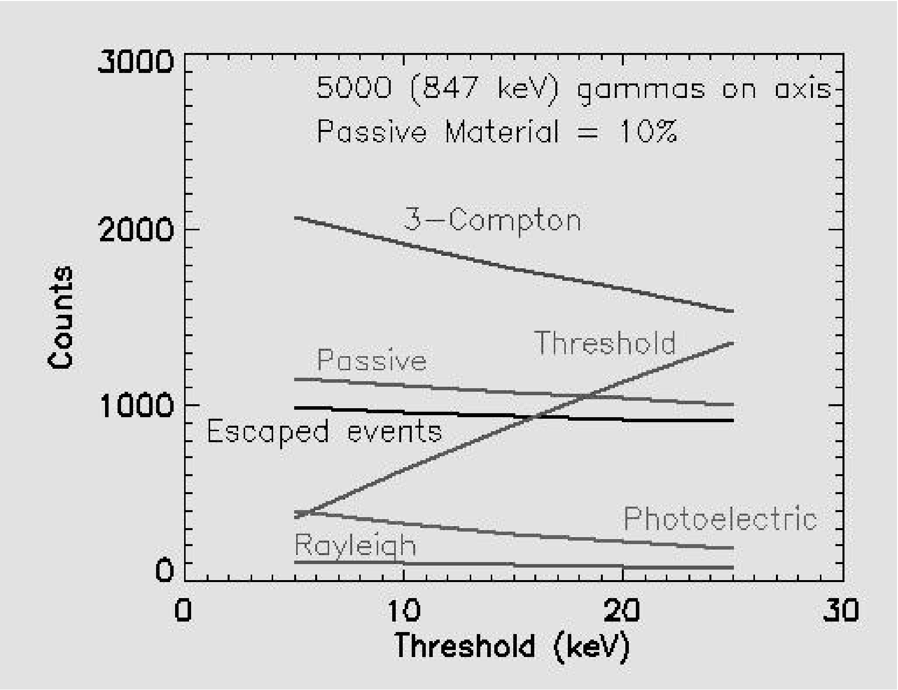
3-layer device



- Thicker detectors improve efficiency of detecting gamma rays because of the reduce passive material
- Reduce number of electronic channels/power

Sensitivity Improvement with New Technologies





- Current simulations result in about 2-4% effective area
- This is ≤ 10% of the potential events that could be used
- Clearly worth effort to substantially improve this performance

Reduce passive material

Reduce thresholds

Summary

• Silicon Compton Imager concept is proven as a high sensitivity gamma ray instrument providing excellent spectral and imaging capabilities

• Eight-layer Prototype Unit to be completed soon.

• Larger volume detectors from 150mm wafers have very low leakage currents. 2mm-thick detectors to be delivered soon. SINTEF facility can process 3mm-thick wafers.

• Wafer bonding technique has potential for further size improvements, cost reduction, and dramatic improvements in sensitivity.