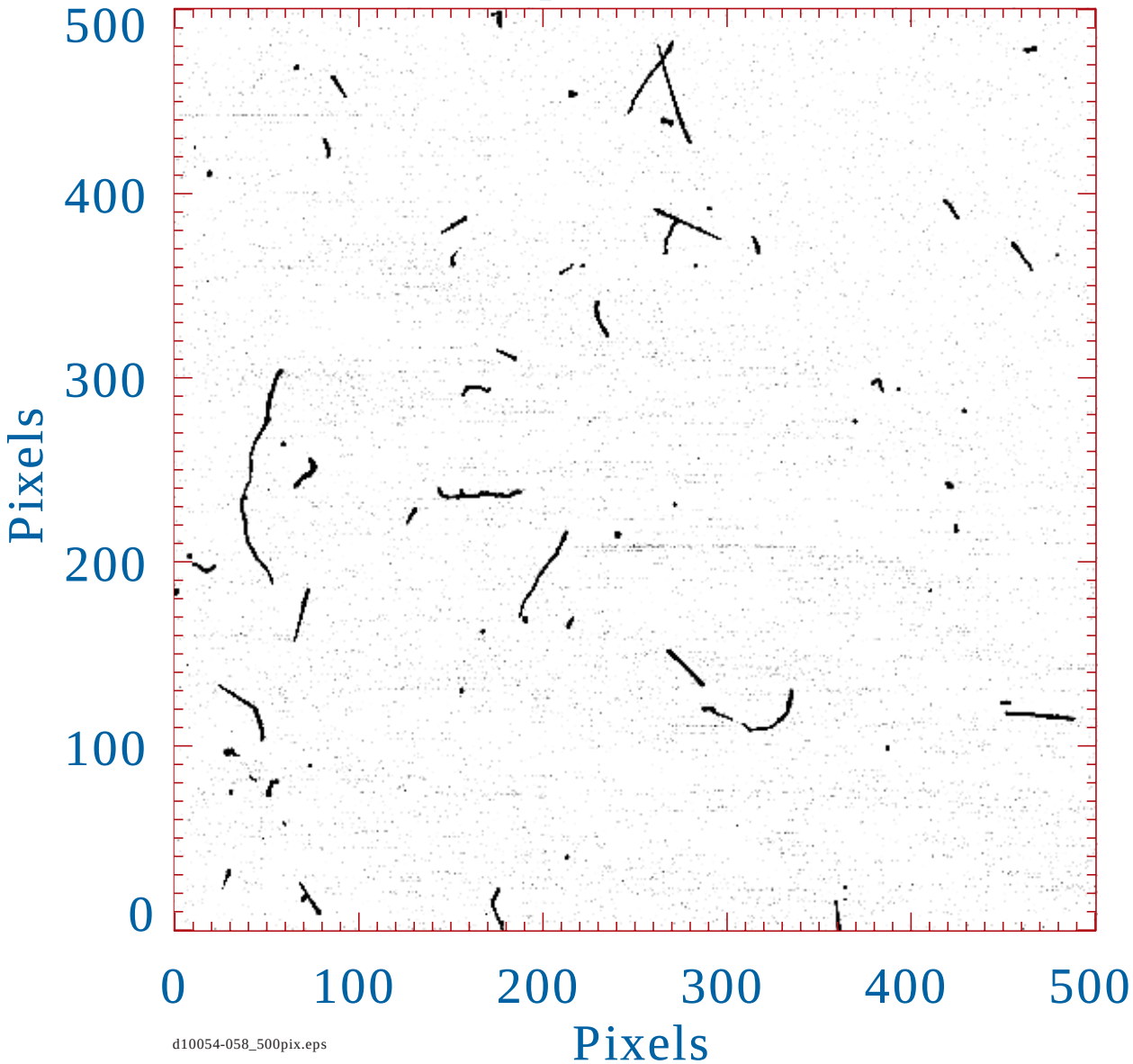
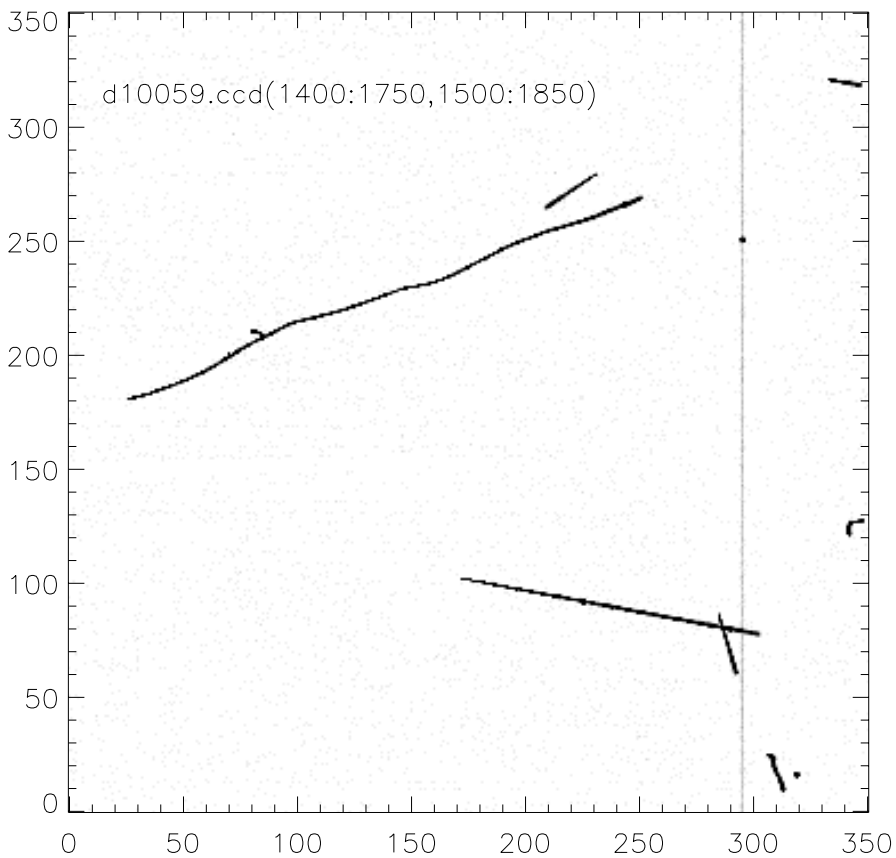
Subfield of a 4×1000 s dark
(Lick 3-m spectrometer room)



d10054-058_500pix.eps

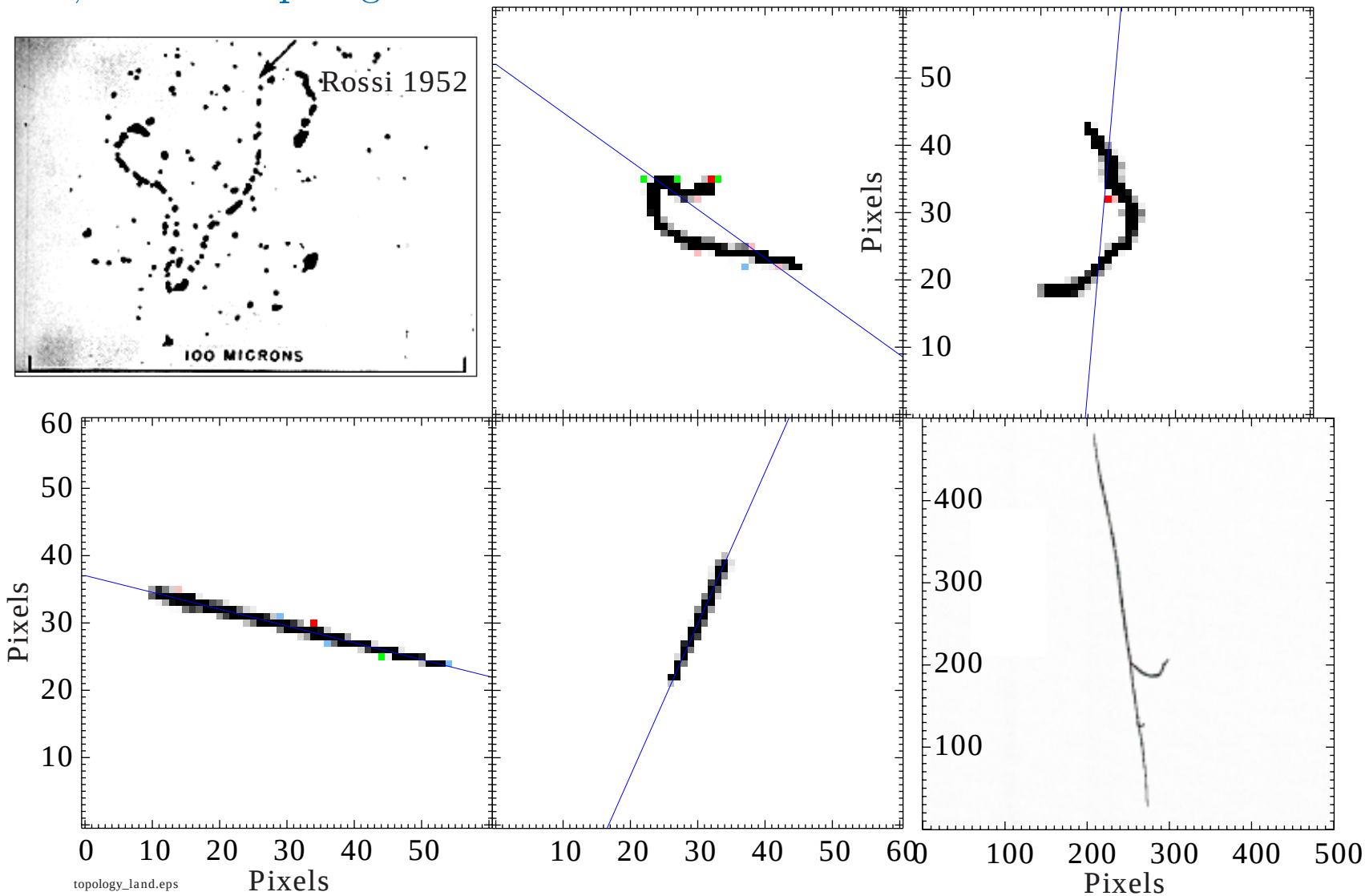
Outline of talk



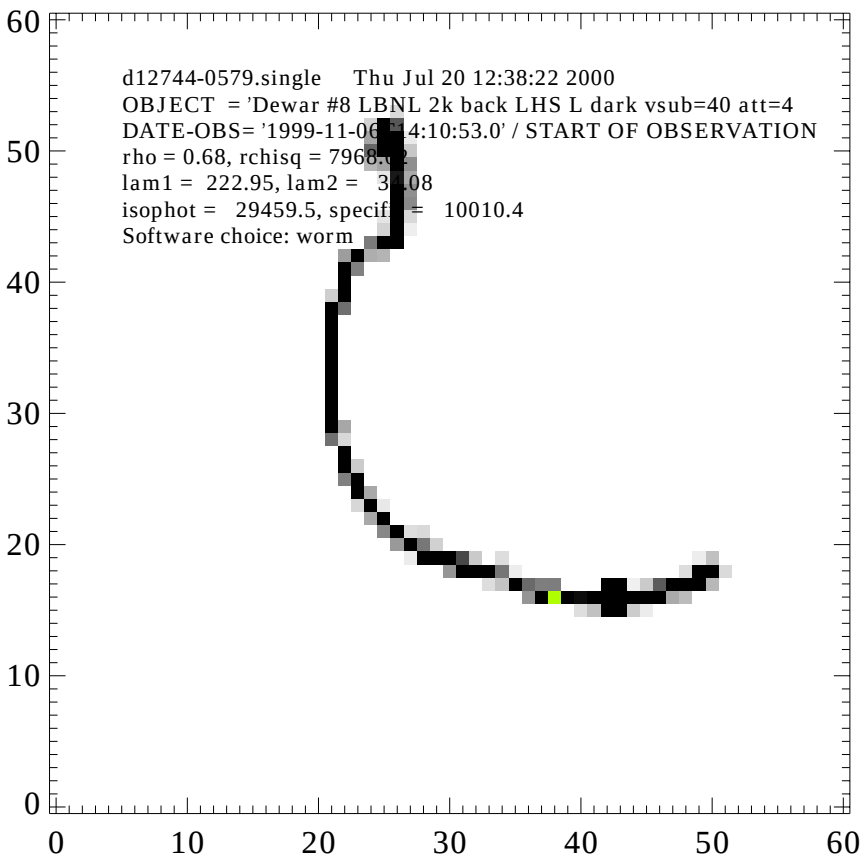
- Topology
- Event selection & classification
- Nature of worms and spots
- The KPNO and NOAO darks
- Shielding and gamma spectra
- Activation levels in materials
- The Keck lead box mystery
- Observations and conclusions

Worms and muons

—first, I must topologize:



Event selection

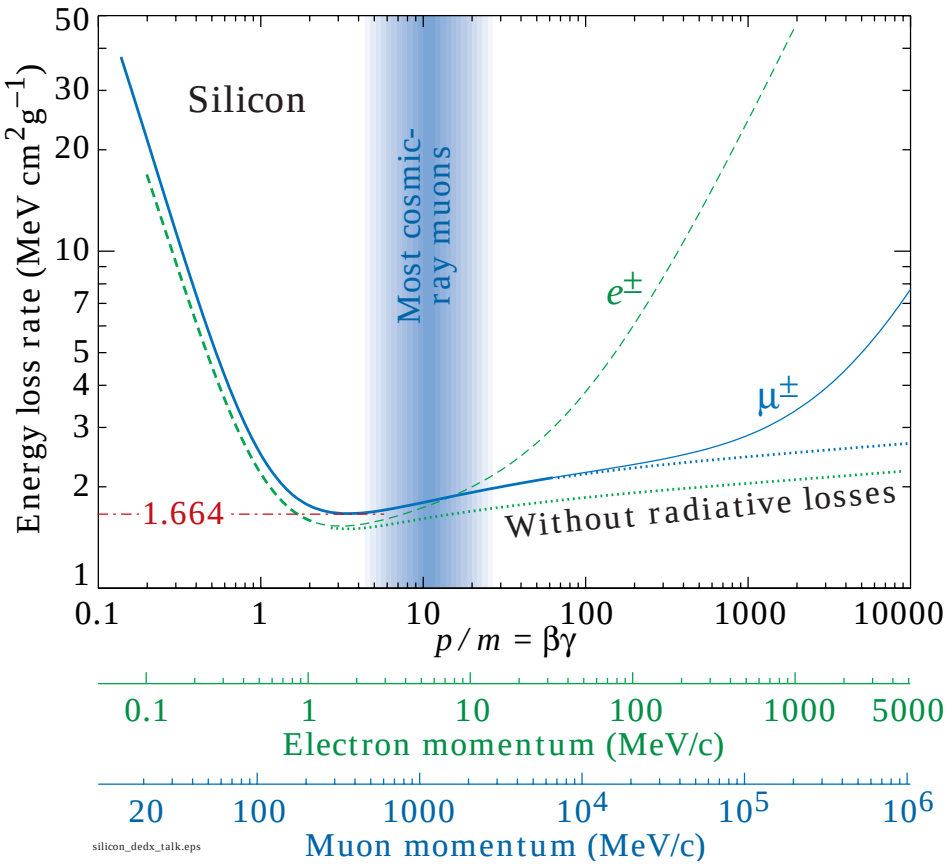


- "sky:" σ, mean, etc.
- "edgsurface:" Boxcar average image within a few σ of the mean
- subtract "flat"
- "sky" again
- "isophot:" Select discrete objects—one high pixel (5 σ or so) and contiguous pixels above noise (1.5 σ or so). Returns number of counts, n pix, moments m_{xx}, m_{xy},m_{yy}, *etc.*

Event classification

How do we tell genuine cosmic ray events (muons) from the other artifacts (worms and spots)?

Cosmic rays:



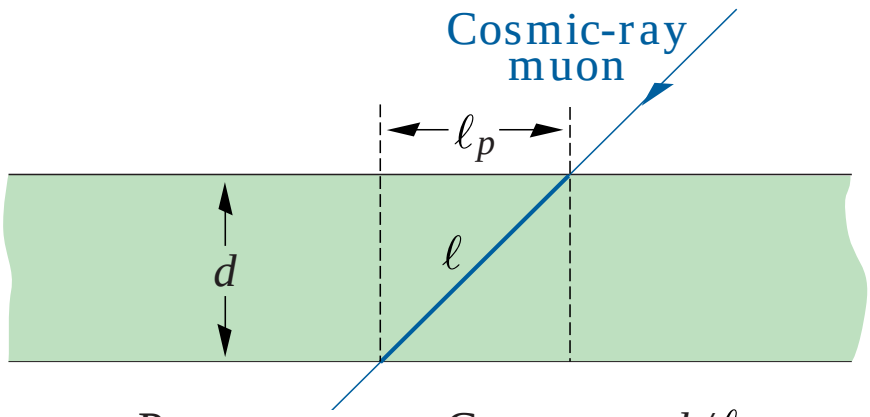
- $> 95\%$ of sea-level cosmic rays are muons, with energy near 1 GeV
- For a horizontal detector, the rate is 0.8–1.0 cm^{-2}min^{-1}

$$\left.\frac{dE}{dx}\right|_{\text{min}} = 1.664 \text{ MeV g}^{-1}\text{cm}^2$$

$\approx 32,000$ e-h pairs per 300 μm

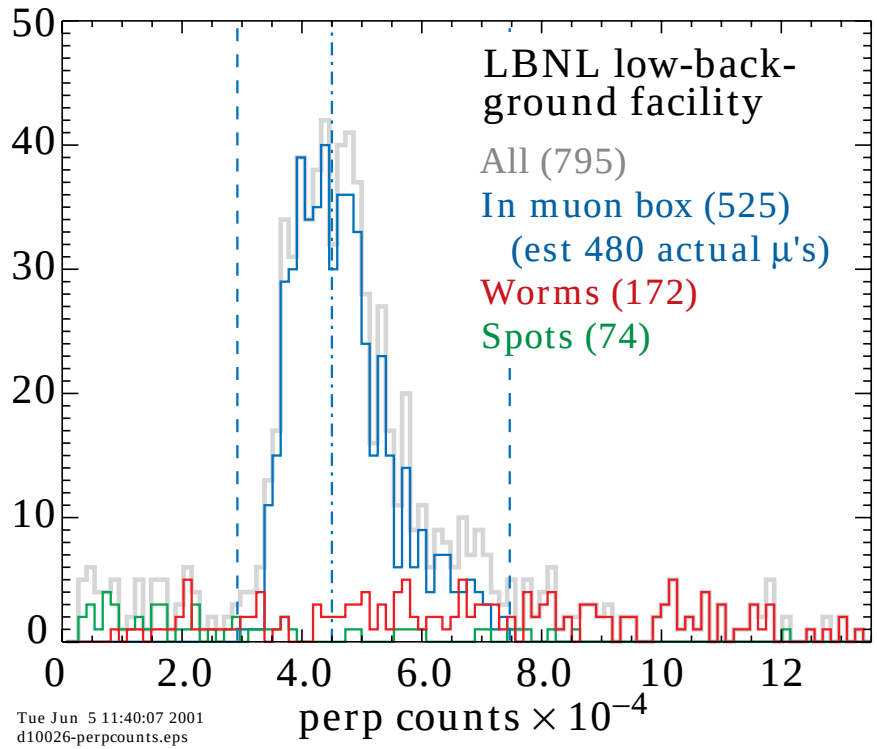
Muon identification

A muon leaves a *straight* track with a ≈ known rate of *e*-*h* production.



$$\text{Perp counts} = \text{Counts} \times d/\ell$$
$$\propto dE/dx|_{\text{min}}$$

perp_counts.eps



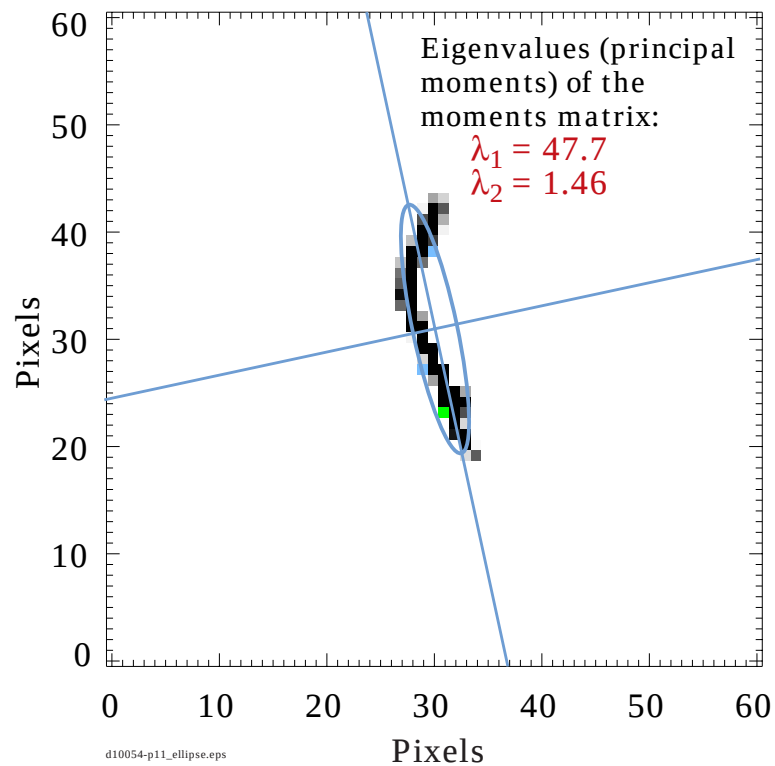
Principal moments

There is still contamination by other stuff under the peak. The only other really good cut we've found is a measure of *straightness*. The data reduction finds the moments of the "object:"

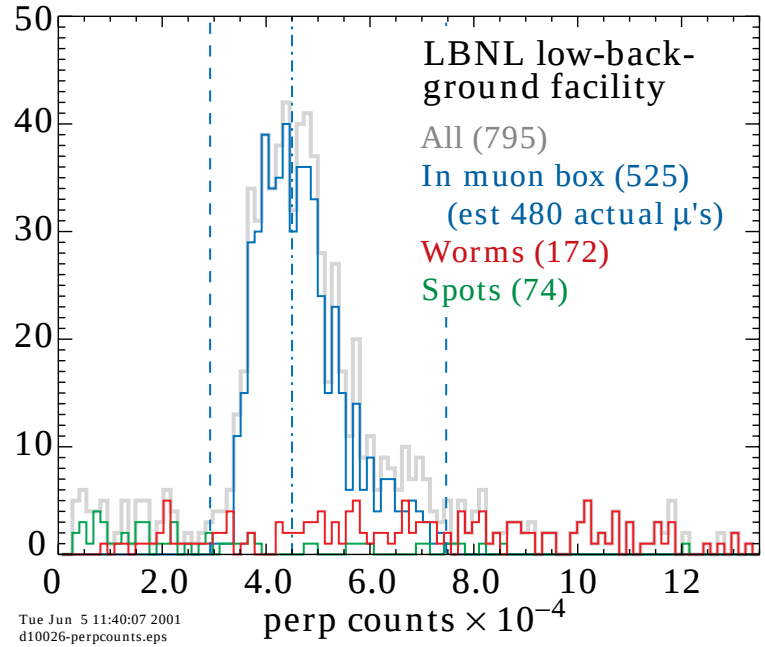
$$\begin{pmatrix} m_{xx} & m_{xy} \\ m_{xx} & m_{xy} \end{pmatrix}$$

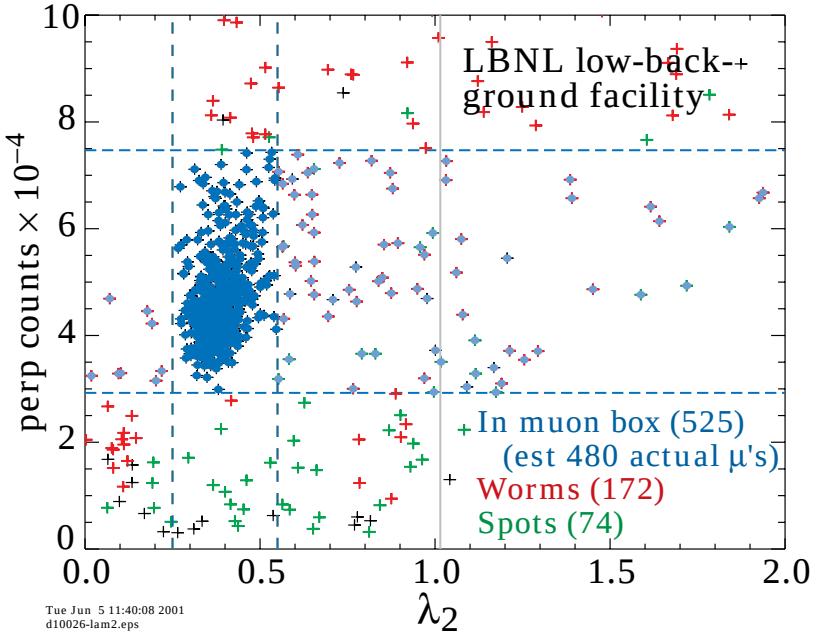
with eigenvalues (the matrix after rotation to the principal axes) $\lambda_1 > \lambda_2$

λ_2 is *small* for a muon, otherwise any size

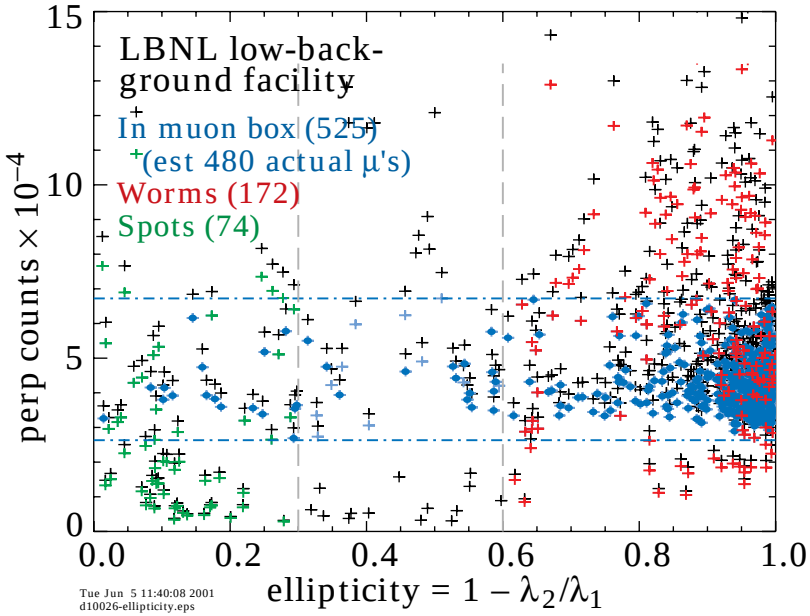


"Perp counts" and λ_2 cuts





"Ellipticity" is also a somewhat useful idea



WHAT causes the worms and spots?

Al Smith and Dick McDonald, LBNL low-level radiation experts, (along with Steve Holland, Richard Stover and Mingzhi Wei) suggested and carried out a series of long dark exposures at different places:

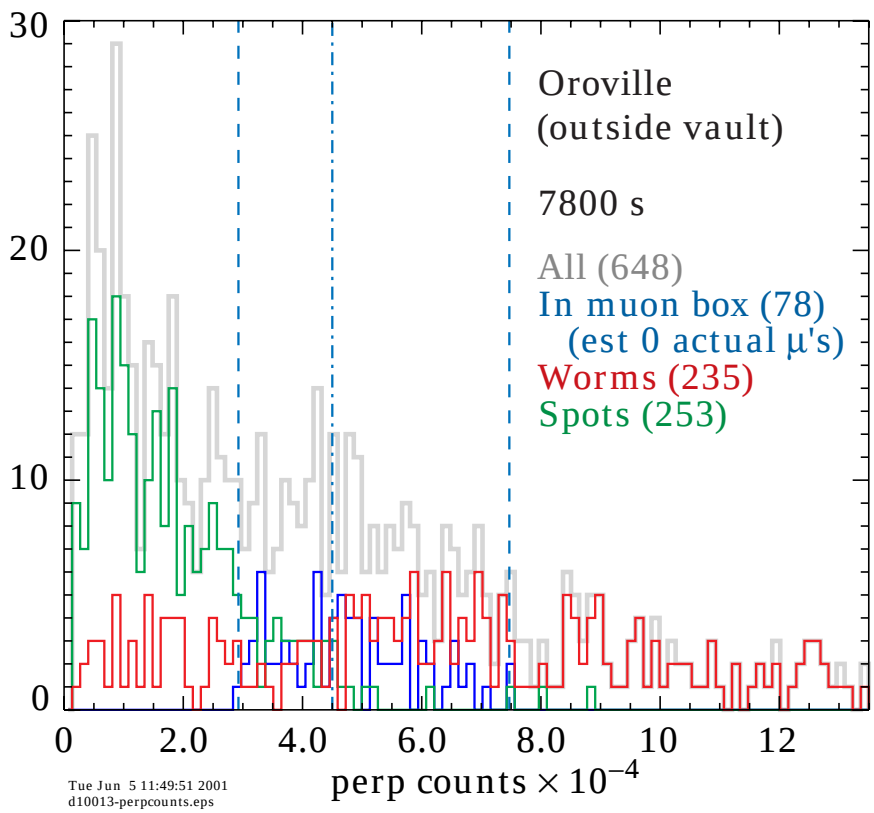
1. In the basement UCO/Lick CCD
   $\Longrightarrow$ muons (about half), worms, and spots

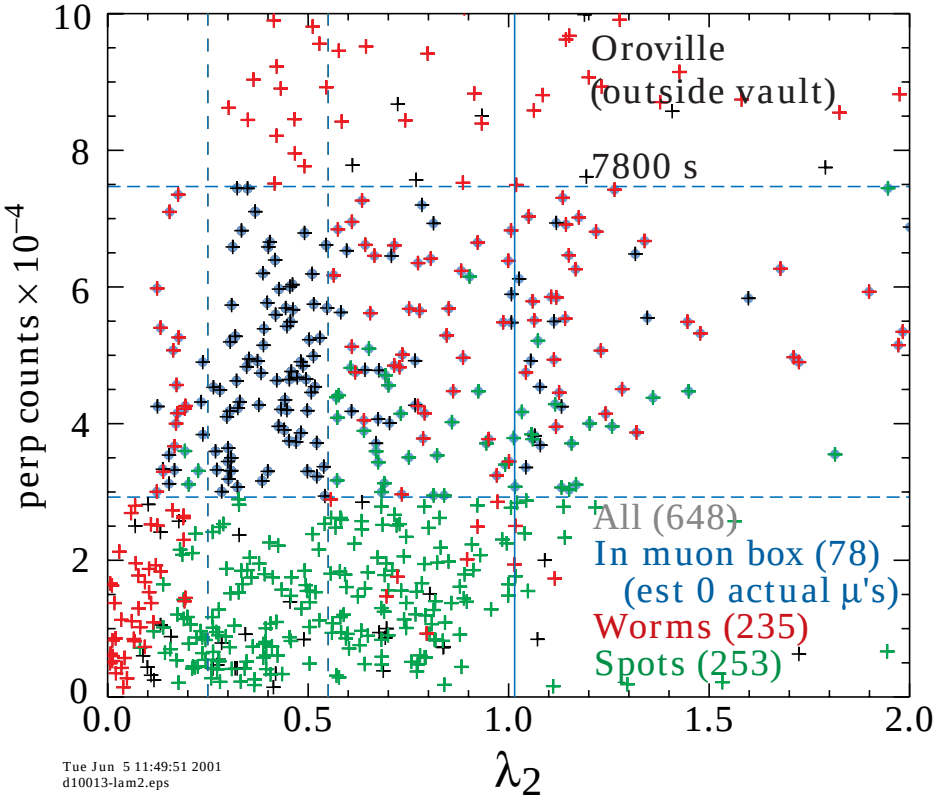
2. In the low-background facility (LBF) at LBNL (a room with 1.5 thick concrete walls; the concrete has very low radioisotope content)
   $\Longrightarrow$ almost entirely muons

3. At the power plant of the Oroville (California) dam, 160 m under rock, where cosmic rays are attenuated by 10^4
   $\Longrightarrow$ worms and spots, no muons

4. Again at Oroville, but this time in a lead vault built for exotic low-level experiments
   $\Longrightarrow$ almost nothing—171 events in 8400 s

Oroville outside lead vault





KPNO 4-m 09/14/01, CCD at 60°

a0076-a0080 1189 events

Dark 3600 with tel at zenith; CCD 60 deg from vert

DATE = '2000-11-14T23:06:10'

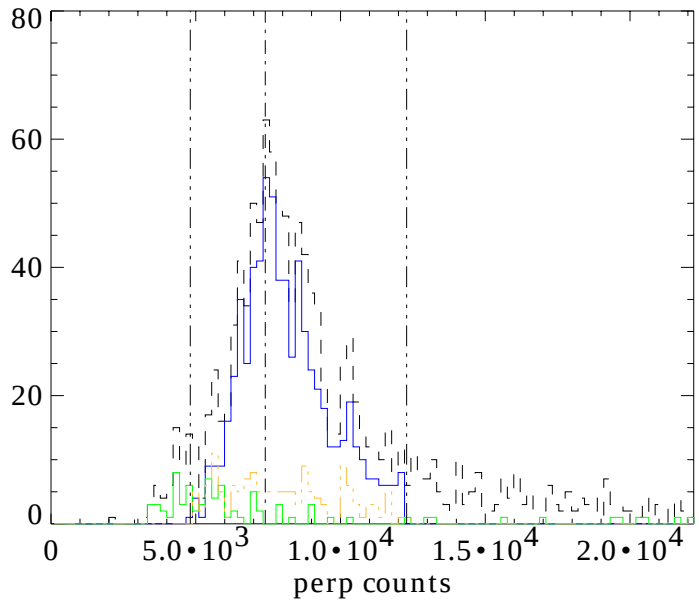
Rates in (cm^2 minute)^-1

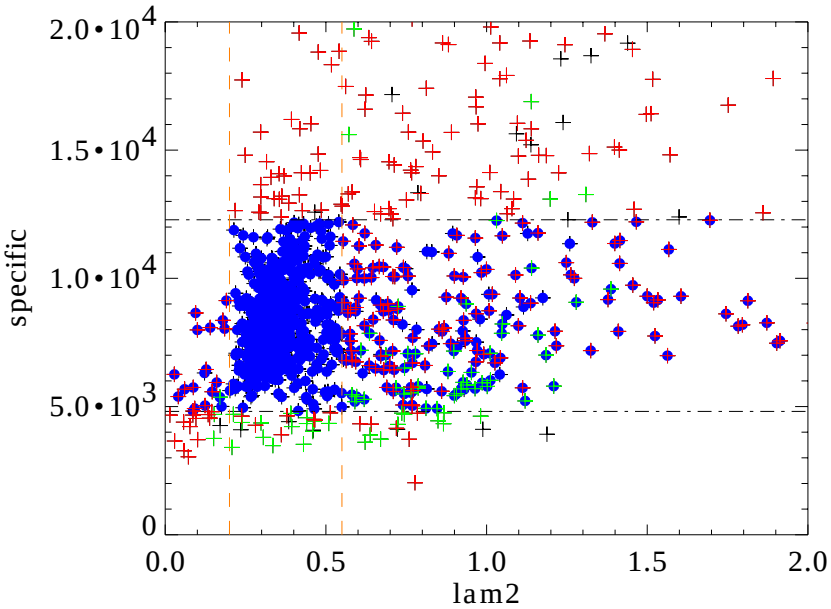
area,exposure,nevents,total rate:

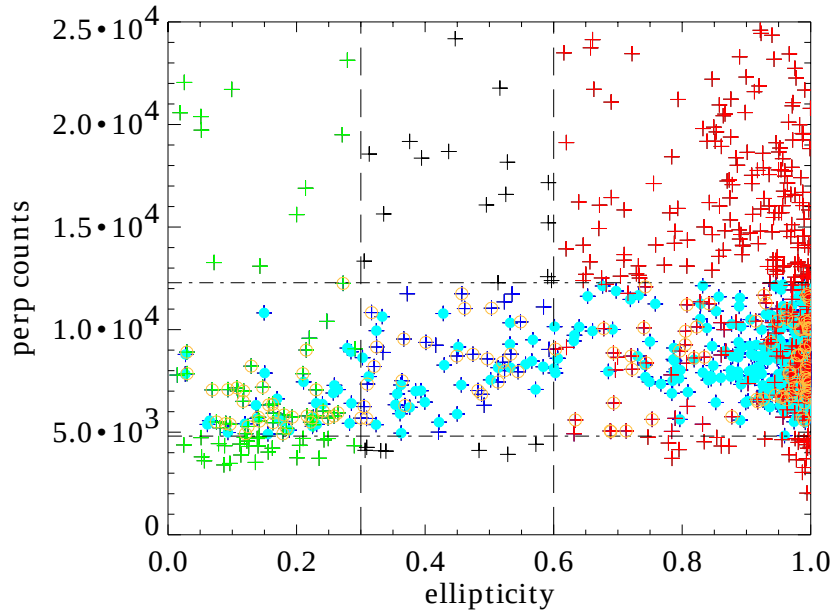
3.39 18000.00 1189 1.2

	num	rate	sig	pixfrac
muon box	672	0.66	0.03	0.51
not mu box	517	0.51	0.02	0.49

Frac pix lost/min 1.73e-04







KPNO 4-m 09/15/01, CCD at 60°

a0085-a0091 785 events

Dark 1200 00nov15ut PA=142.45 Telescope straight up

DATE = '2000-11-15T11:26:50'

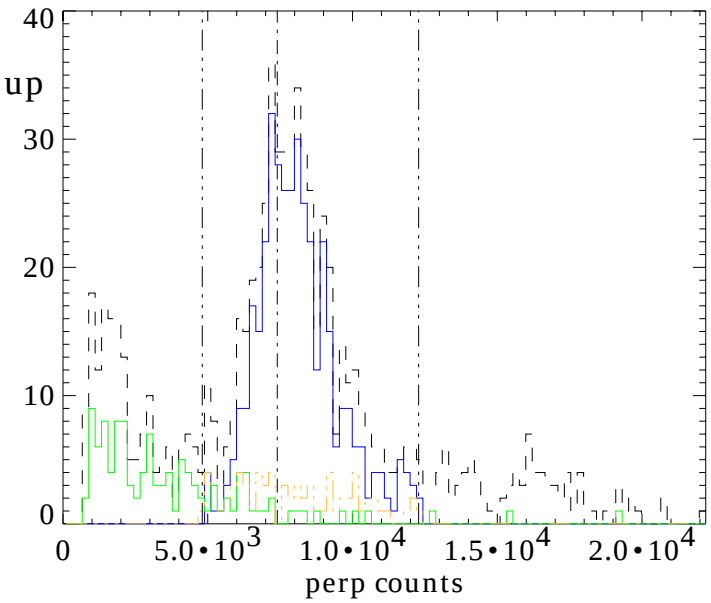
Rates in (cm^2 minute)^-1

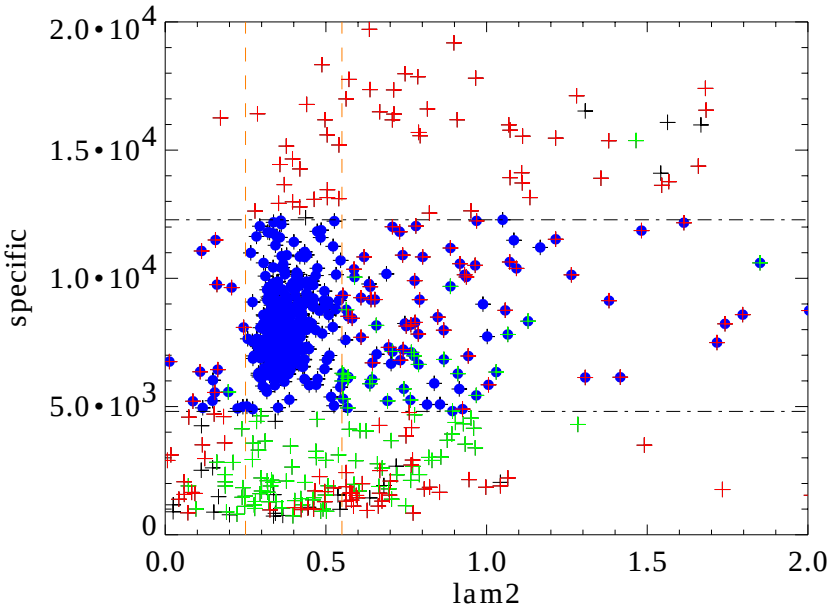
area,exposure,nevents,total rate:

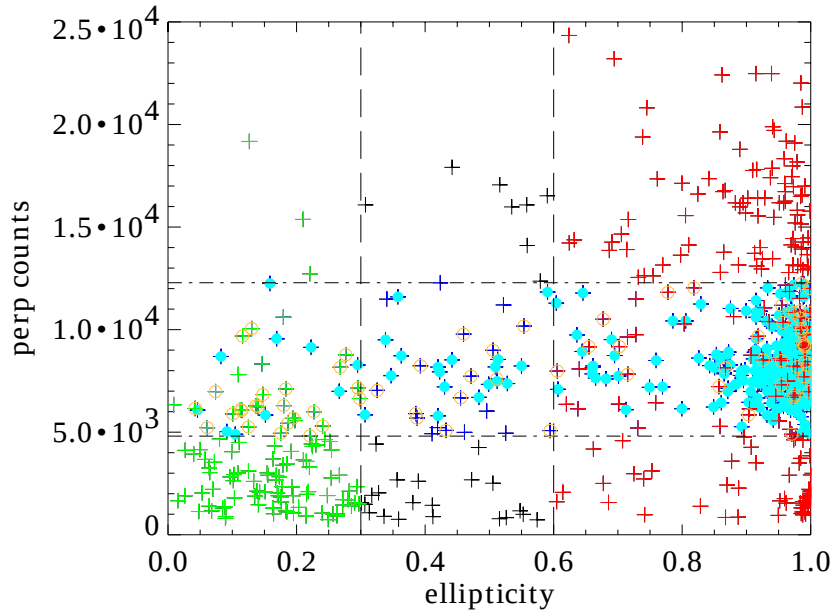
3.39 8400.00 785 1.7

	num	rate	sig	pixfrac
muon box	387	0.81	0.04	0.46
not mu box	398	0.84	0.04	0.54

Frac pix lost/min 2.28e-04







KPNO 4-m 09/15/01, CCD at 90°

a0130-a0138 800 events

Dark 1200 00nov15ut PA=90 Telescope at ZD=49 white spot

DATE = '2000-11-15T16:18:21'

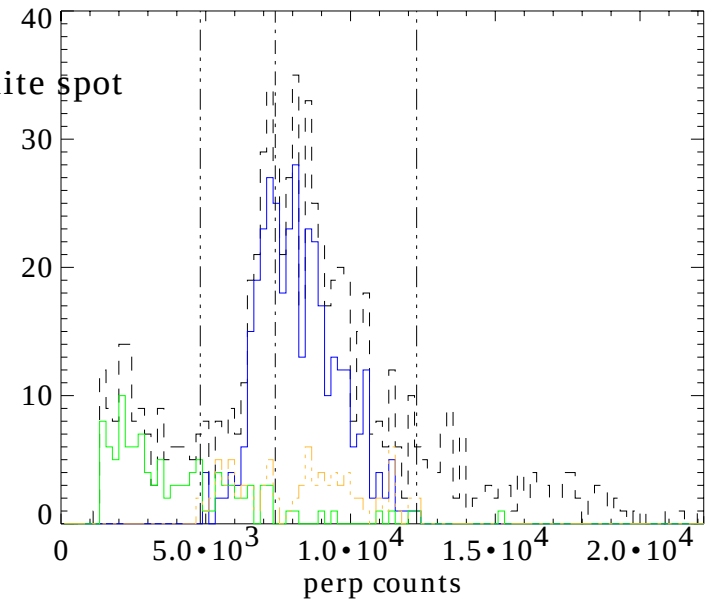
Rates in (cm^2 minute)^-1

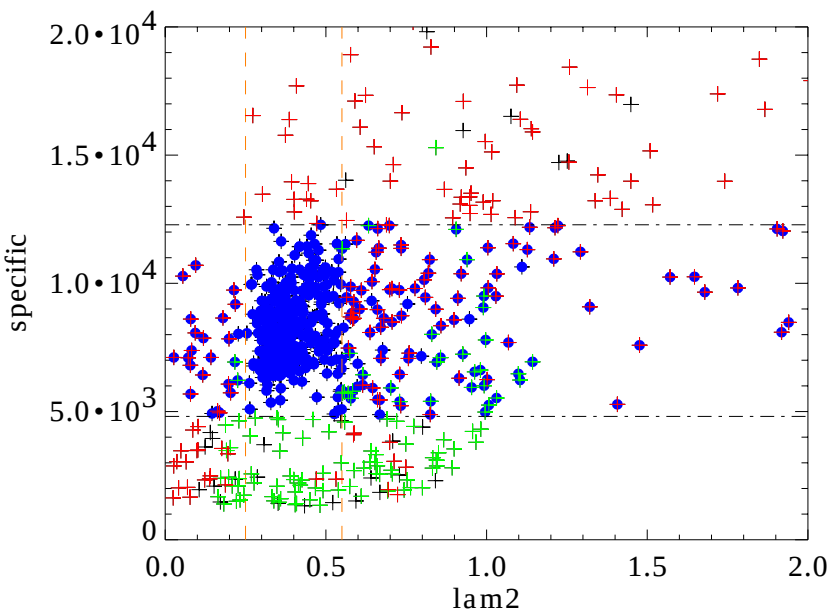
area,exposure,nevents,total rate:

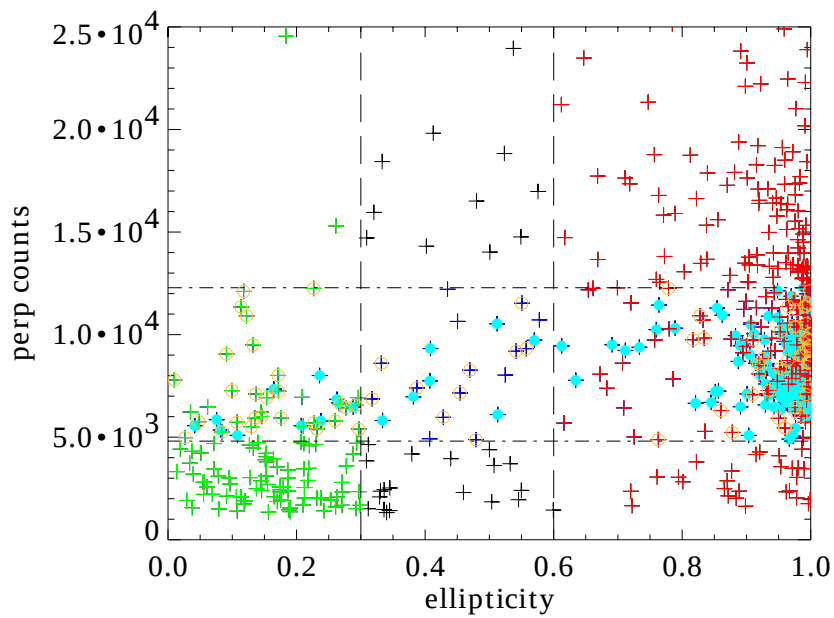
3.39 10800.00 800 1.3

	num	rate	sig	pixfrac
muon box	363	0.59	0.03	0.51
not mu box	437	0.72	0.03	0.49

Frac pix lost/min 2.53e-04







NOAO Tucson 09/10/01, CCD at 60°

a4-a8 2652 events

Dark 3600 no lead; Tucson NOAO lab

DATE = '2000-11-10T16:28:32'

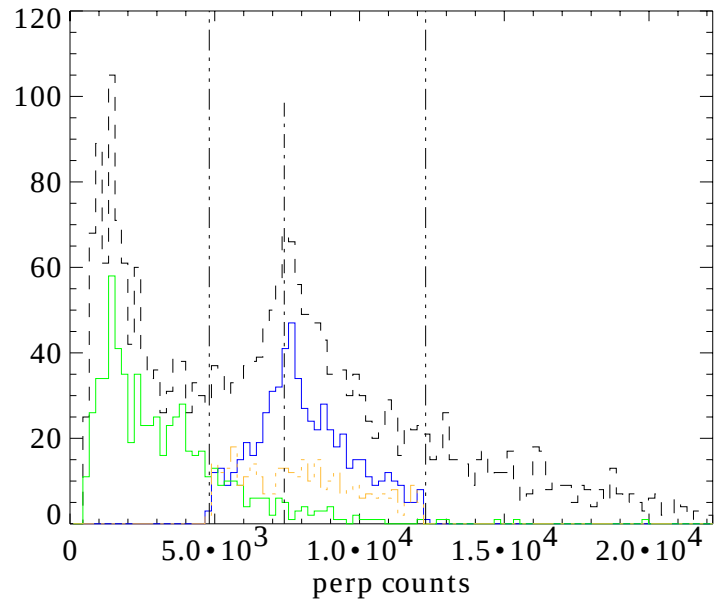
Rates in (cm^2 minute)^-1

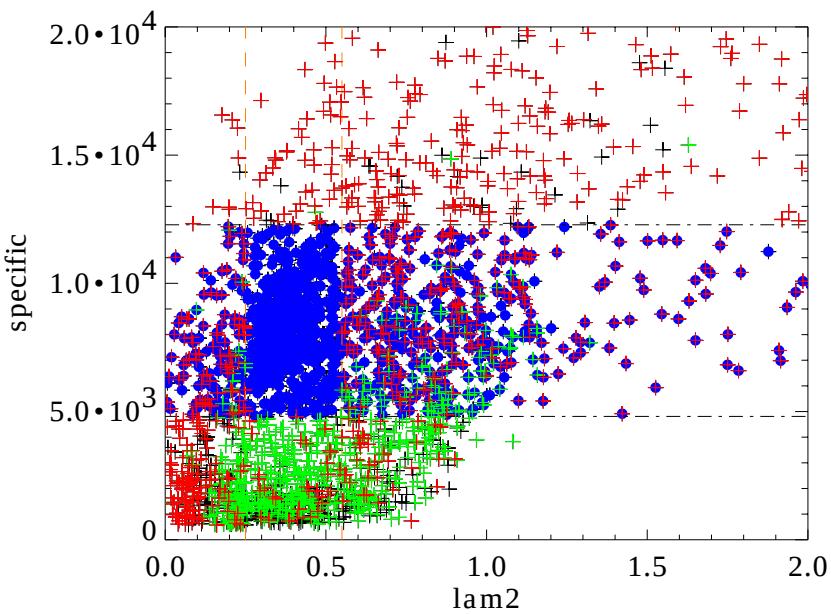
area,exposure,nevents,total rate:

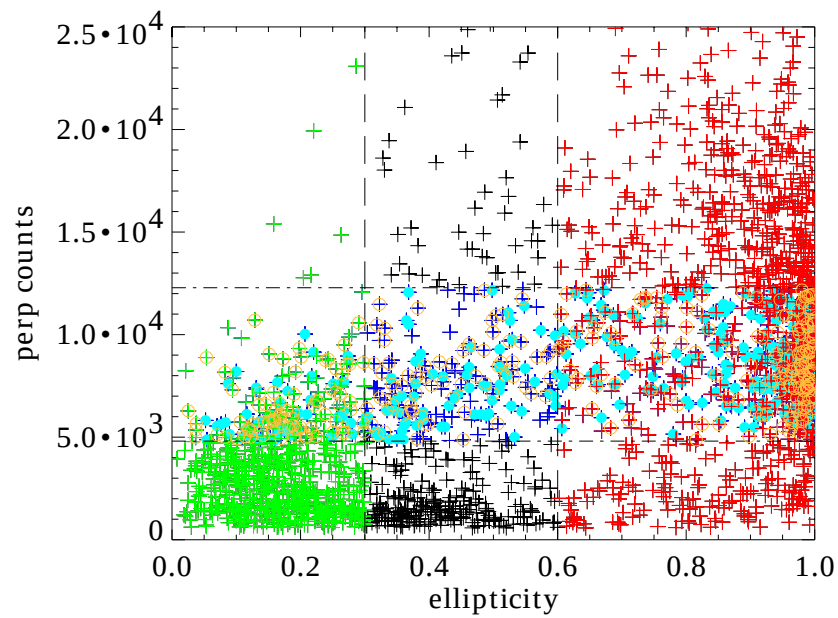
3.39 18000.00 2652 2.6

	num	rate	sig	pixfrac
muon box	614	0.60	0.02	0.27
not mu box	2038	2.00	0.04	0.73

Frac pix lost/min 2.88e-04

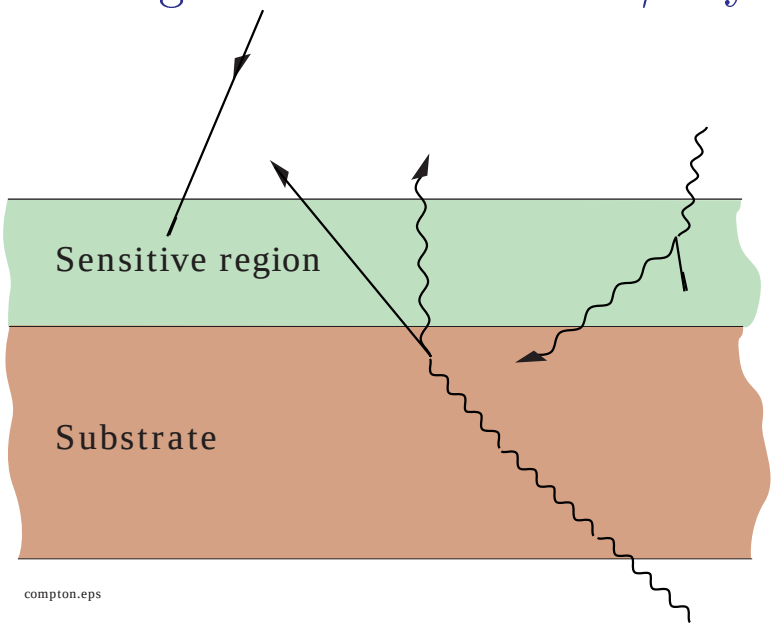


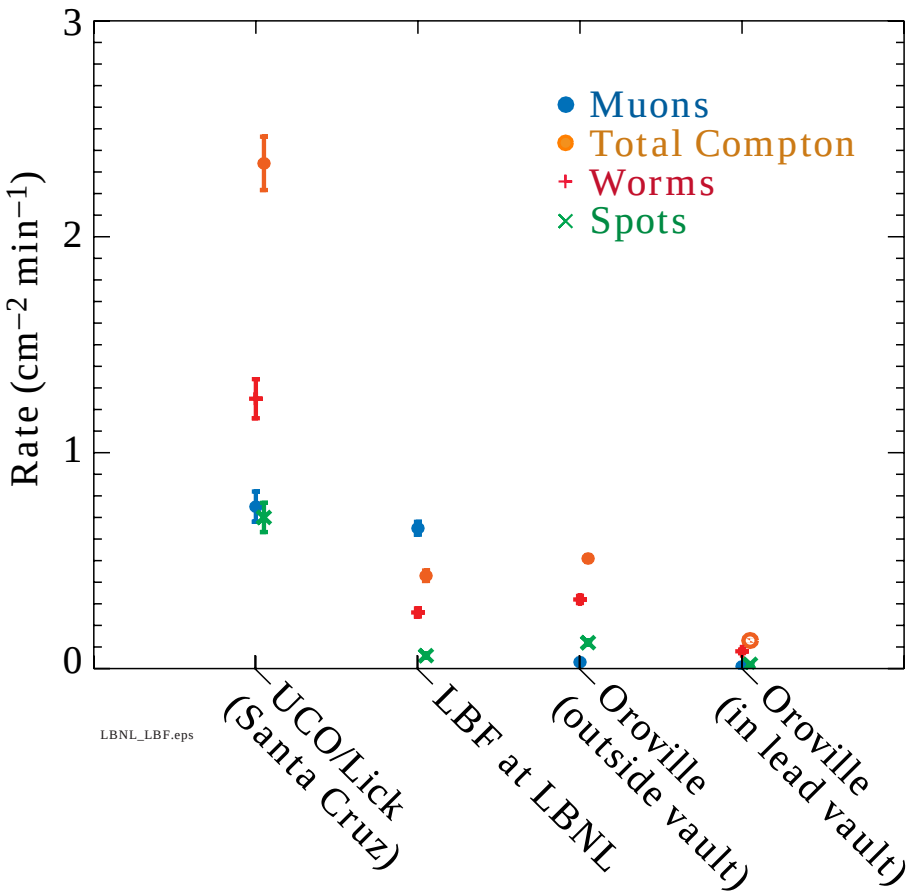




Ambient gamma sources

The worms and spots are almost certainly recoil electrons from Compton scattering of environmental γ rays

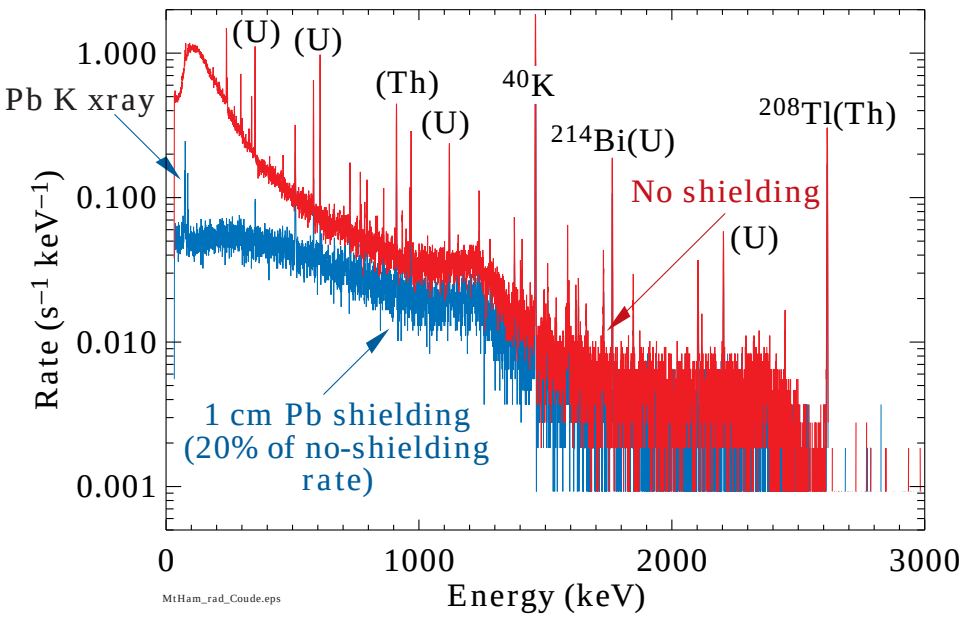




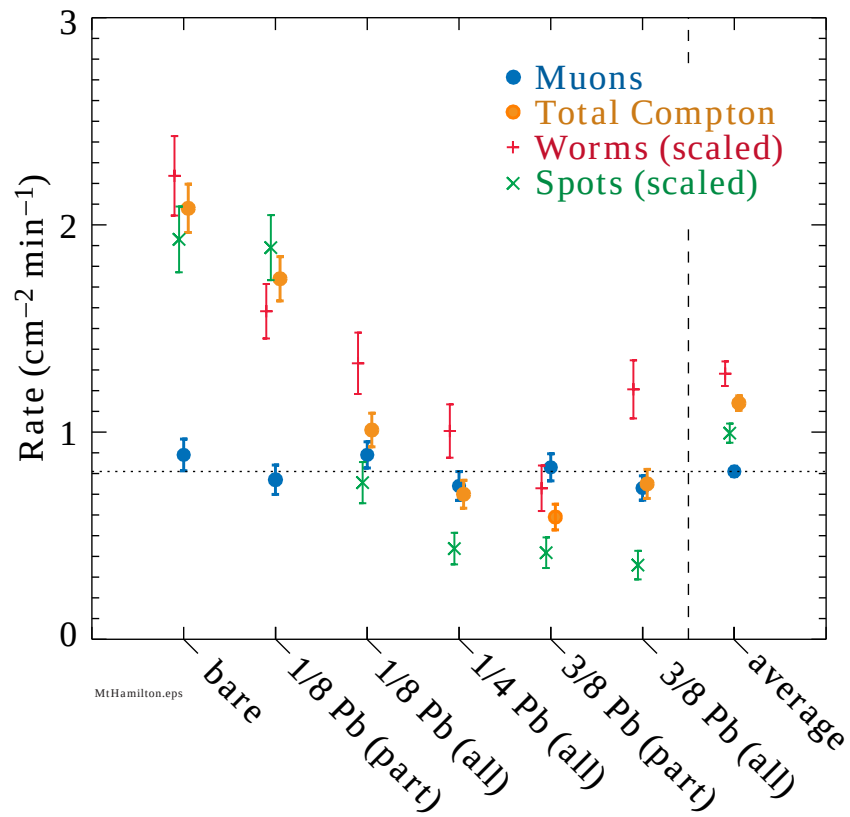
Trace uranium and thorium

The γ's are from U and Th decay chains, some degraded by multiple Compton scattering

Spectrum at the Lick 3-m spectrometer as observed in a Ge γ-ray spectrometer:



A small amount of shielding is effective—



Concrete lab walls and Mauna Kea lava

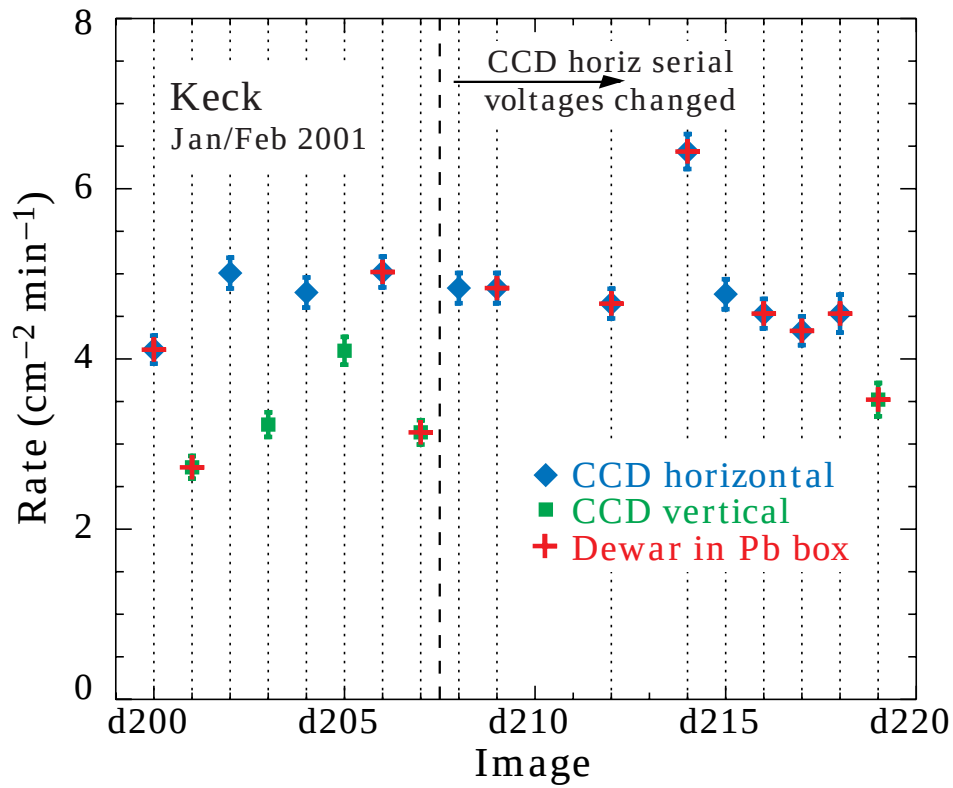
Sample	Element	Abundance	Activity
Lick 3-m core	U	1.35 ppm	0.45 pCi/g
Total Compton:	Th	4.0 ppm	0.44 pCi/g
$2.2/\mathrm{cm}^2/\mathrm{min}$	K	0.72 %	6.1 pCi/g
UCO/Lick lab core	U	1.2 ppm	0.39 pCi/g
Total Compton:	Th	1.2 ppm	0.14 pCi/g
$2.2/\mathrm{cm}^2/\mathrm{min}$	K	1.23 %	10.5 pCi/g
Mauna Kea lava	U	1.5 ppm	0.50 pCi/g
	Th	4.7 ppm	0.51 pCi/g
	K	1.52 %	12.9 pCi/g

Activity near our CCD

Sample	U (ppm)	Th (ppm)	K (%)
CCD black socket (up)	0.34(4)	0.98(6)	0.008(1)
CCD black socket (down)	0.64(4)	1.38(6)	0.011(1)
Si wafers (3 in box)	0.025(6)	0.16(2)	ND
Aluminum nitride	0.010(2)	0.019(5)	ND
Aluminum sputter	ND	0.044(14)	ND
Circuit boards (Lick)	0.064(4)	2.07(8)	0.016(2)
Epoxy (Lick)	0.012(3)	0.010(3)	ND
INVAR, bar stock	ND	ND	ND
Molybdenum, bar stock	0.020(3)	0.020(3)	ND
Sn/In alloy	5.0(1)	4.6(1)	ND

The Keck lead box mystery

Kirk Gilmore (UCO/Lick) obtained long darks on the dome floor and Nasymth platform of the Keck; a CCD controller problem limited the analysis. But:



The cosmic ray rate muon rate is 2.3 times higher on Mauna Kea than at near sea level, consistent with these data

—and the proton/neutron intensity is 30 times that at sea level

Cosmogenic activation

Grasping at straws:

The CCD in its dewar had just been flown to Hawaii (at great expense). Could the expsure to cosmic rays at 11 km altitude, where the flux is mainly proton and neutron, have *activated* the stainless steel to the level of, say, ordinary concrete?

$\Longrightarrow$ To test this crazy idea, we got 7 kg of stainless plate (same recipe),

1. Counted it at the LBNL-LBF at Oroville
2. Shipped it by FedEx overnight for morning delivery
   LBNL $\rightarrow$ Harvard $\rightarrow$ LBNL $\rightarrow$ Harvard $\rightarrow$ LBNL
   within 5 days
3. Took it immediately to the LBNL-LBF in Oroville for counting.

$\neq$ cosmogenic activation

We in fact found cosmogenic isotopes not there before the flight:

$$^{7}\mathrm{Be},\ ^{44\mathrm{m}}\mathrm{Sc},\ ^{51}\mathrm{Cr},\ ^{52}\mathrm{Mn},\ ^{54}\mathrm{Mn},\ ^{56}\mathrm{Co},\ ^{58}\mathrm{Co},\ ^{60}\mathrm{Co}$$

–but these together produce about 0.15 decays/min/kg

$\Longrightarrow$ and in the meantime, Richard Stover's lead box at the Lick 3-m spectrometer failed to shield.

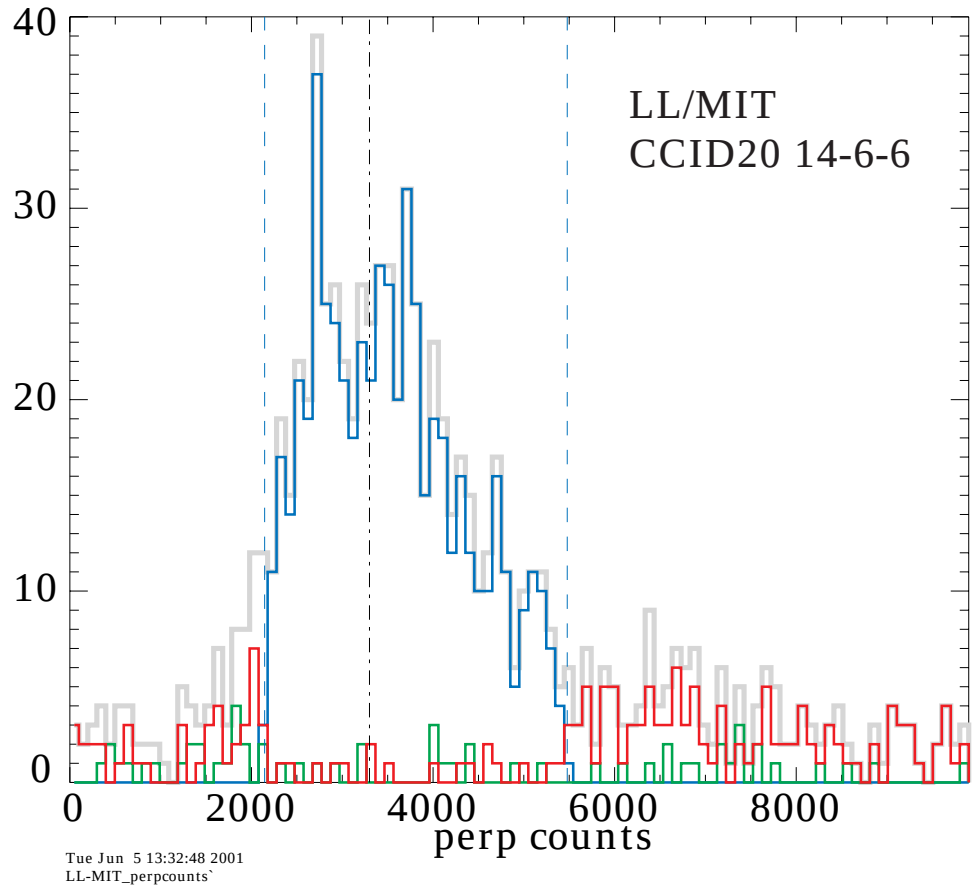
Worm treatment

We need to find a way to *dependably* shield the CCD from environmental γ's sufficiently that the Compton rate is below the (irreduceable) cosmic ray muon rate

Muons in LL/MIT CCD's

- And everybody's CCD has all these problems

Richard Stover & Mingzhi Wei obtained long darks for a 2k × 4k LL/MIT CCD's for DEIMOS. The tracks are too short for muon/worm distinction, but most of the events fall into the minimum-ionization peak:



Thick LL/MIT γ sensitivity

With lead shielding, the total rate (in the UCO/Lick lab at Santa Cruz) was $1.28\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, perhaps 40% above the cosmic-ray rate.

The unshielded total rate was 82% higher, *consistent with the worms/spot rate + cosmic-ray rate observed with the LBNL CCD's under the same conditions*

$\Longrightarrow$ The sensitive region is 40 μ rather than our 300 μ, so the evidence from the "perp counts" spectrum *and* the rates is that many/most of the Compton recoil electrons are produced *outside* the sensitive region, in the substrate or dewar walls/window

Conclusions?

To be continued