THE HERON PROJECT

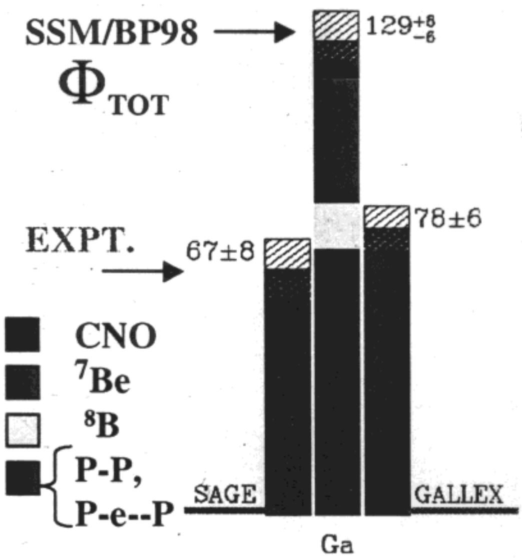
AN IMPORTANT QUESTION IN SOLAR ν PHYSICS :

<u>WHAT IS THE COMPOSITION OF THE LOW ENERGY</u>

<u>(< 1 MeV) ν FLUX ?</u>

PRESENT STATUS $\Phi_{TOT}(\nu_e)$: $\Phi_{TOT}(\nu_e) / {}^{SSM}\Phi_{TOT}$ = ~ 1/2

for $E(\nu_e) > 233$ keV



*** HOW MUCH OF $\Phi_{TOT}(\nu_e)$ IS P-P?**

*** HOW MUCH OF $\Phi_{TOT}(\nu_e)$ IS ^{7}Be ?**

*** HOW MUCH OF Φ_{TOT} IS $\nu_{\mu,\tau}$?**

LIKELY TO BE AN IMPORTANT PART OF FULL UNDERSTANDING OF SOLAR NEUTRINO PICTURE.

TO ADDRESS THOSE ISSUES HERON PROJECT SEEKS TO ANSWER A RELATED, NECESSARY QUESTION:

<u>CAN ONE MAKE A REAL-TIME, HIGH RATE DETECTOR TO MEASURE THE TOTAL FLUX AND SPECTRA OF THE P-P & Be ?</u>

- HIGH RATE IMPLIES >20 EVENTS /DAY.
- P-P and ^{7}Be MEANS >50 keV DETECTED ENERGY.
- SENSITIVITY TO TOTAL FLUX IMPLIES IMPLIES USING:

$$\nu_{e,\mu,\tau} + e^- \longrightarrow \nu_{e,\mu,\tau} + e^-$$

{ A PRECISELY KNOWN CROSS-SECTION & NEEDED COMPLEMENT TO ν_e + N ----> e + N' of GALLEX, SAGE,LENS(?) }

- SPECTRA IMPLIES GOOD ENERGY RESOLUTION.

GOOD NEWS :

DETECTOR NEED NOT BE VERY MASSIVE:

* $\Phi_{P\text{-}P}$ IS BY FAR HIGHEST FLUX (6×10^{10} cm^{-2} - sec^{-1})
* RELATIVELY LARGE CROSS-SECTION

10 TONNES (~ 15 P-P & 7 ^{7}Be /day SSM)

BAD NEWS :

AT THESE ENERGIES BACKGROUNDS IN TARGET MATERIALS CAN BE ORDERS OF MAGNITUDE >> SIGNAL:

* COSMOGENIC RADIOACTIVITY
* HEAVY ELEMENT SERIES - U & Th (in or out of equilibrium)
* LIGHTER ISOTOPES (^{3}H, ^{40}K, ^{14}C)

HOWEVER, ^{4}He IN SUPERFLUID STATE HAS SOME IMPORTANT & ATTRACTIVE FEATURES AS A CANDIDATE FOR DETECTOR MATERIAL

- **DENSITY AT < 2.1 K = 0.145 gm/cc.**
  (10 TONNES IS A ~ 4 METER-CUBE)
- **IT IS SELF-CLEANING** (ALL OTHER ATOMIC SPECIES. FREEZE-OUT TO WALLS OR FALL TO BOTTOM ---- $kT \sim 10^{-25}$ Joules)
- **NO LONG-LIVED He ISOTOPES.**
- **HELIUM IS INEXPENSIVE ($4 / liter)**
- **STANDARD INDUSTRIAL TECHNIQUES FOR HANDLING.**

SUPERFLUID HELIUM CAN BE A COMPACT & RADIOACTIVITY FREE TARGET MATERIAL

TO BE PRACTICAL NEED:

A) TO HAVE A WAY TO EXTRACT THE SIGNAL.

B) TO CONTAIN THE CRYOGENIC LIQUID IN A VESSEL.

C) TO DISCRIMINATE AGAINST BACKGROUNDS CREATED BY CONTAINMENT VESSEL.

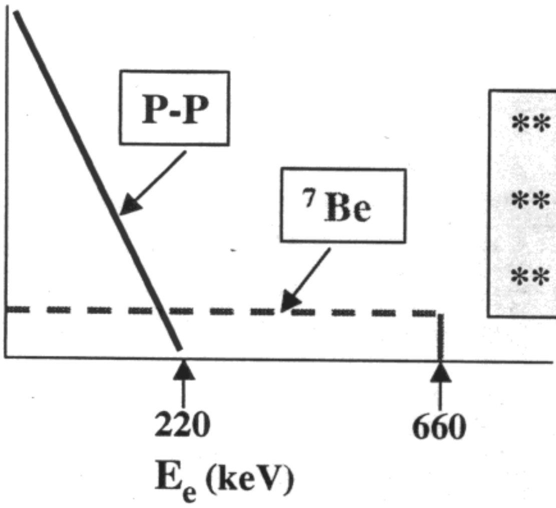
IN HERON PROJECT :

For (A) : WE HAVE DEVELOPED A NEW METHOD OF PARTICLE DETECTION BASED IN BULK SUPERFLUID HELIUM.

For (B & C): HAVE MADE PRELIMINARY STUDIES TESTING SCALE OF PROBLEM & CONDITIONS FOR SOLUTIONS.

PARTICLE DETECTION IN SUPERFLUID HELIUM

•*WHAT IS NATURE OF SOLAR ν EVENTS ARE LOOKING FOR ?*



** SINGLE RECOIL ELECTRON.

** LESS THAN 2 cm. LONG.

** WITH $E_e < 660$ keV.

•*WHAT HAPPENS WHEN A PARTICLE DEPOSITS ITS ENERGY BY STOPPING IN SUPERFLUID HELIUM ?*

GENERAL: ** INITIAL IONIZATION LOSS:

e.g., 300 keV electron loses 30 keV/mm

3 MeV alpha loses $3x10^4$ keV/mm

** CASCADE OF PROCESSES: Energy appears finally as phonon/rotons + UV photons + excited isomers)

PARTICULAR: ** IMPORTANT DIFFERENCES FROM ENERGY LOSS IN OTHER LIQUID, NOBLE GASES.

** LITTLE KNOWN PRIOR TO OUR EXPERIMENTS.

** FIND: MINIMUM IONIZING PARTICLE (e) & DENSELY IONIZING (α) PRODUCE STRONGLY DIFFERING DIVISION AMONG FINAL CHANNELS.

% UV PHOTONS: (Electrons) : (Alpha) = 3 : 1

% PHONON/ROTONS: (Electrons) : (Alpha) = 1 : 4

BOTH UV PHOTONS & PHONON SIGNAL DETECTABLE ON SAME CALORIMETERIC DEVICE.

BROWN UNIV. EXPERIMENTS ON PARTICLE DETECTION

(Adams, Bandler, Enss, Huang, Kim, Lanou, Maris, More, Porter, Seidel)

** DILUTION FRIDGE (30 -- 50 mK).

** 3 LITER TEST CELL OF SUPERFLUID HELIUM-4.

** MOVABLE/ROTATABLE RADIOACTIVE SOURCES IN LIQUID

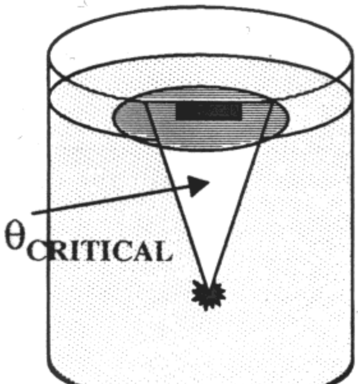
^{113}Sn (364 keV e's); ^{241}Am (3 - 5 MeV α's); ^{55}Fe/^{113}In calib. Xrays

** CALORIMETRIC DETECTION OF
UV PHOTONS & PHONON/ROTONS.

- **CALORIMETRIC DETECTION METHOD:**

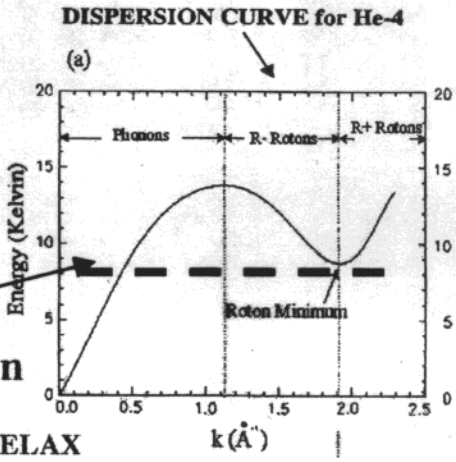
** THIN (~3 gm) SAPPHIRE or SILICON WAFERS (High Θ_{DEBYE})

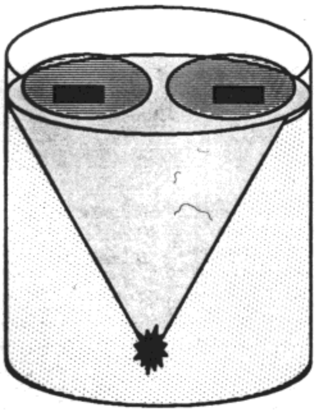
** Ir-Au SUPERCOND. Thin Film THERMOMETER w/ SQUID
MEASURE ΔT FROM ΔE DEPOSIT.



PHONON/ROTONS:

* Velocity ~200 m/s
* E and P conservation
-----> Θ critical
* 1/3 Evaporate if E> E_{EVAP}
* Adsorption binding x 10 gain
* Measure pulse ht. & $\tau_{RISE/RELAX}$

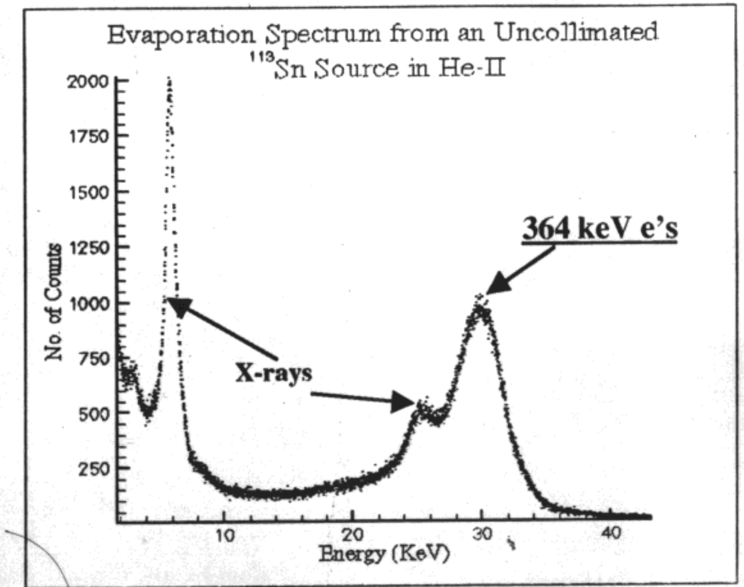




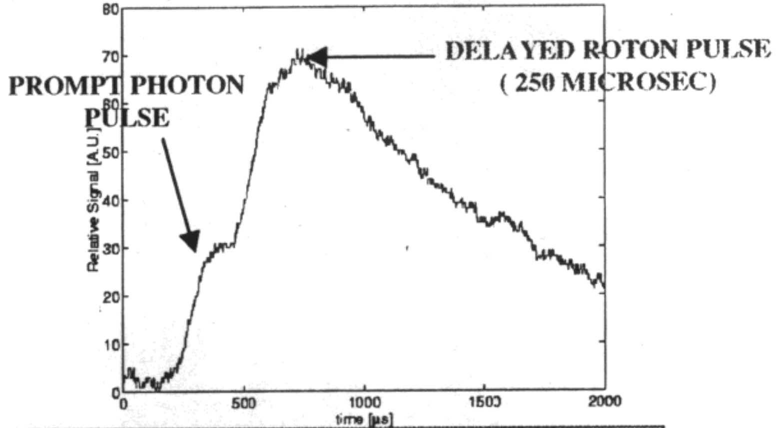
PHOTONS:

* UV AT ~16 eV (EXCITED STATES OF He_2 DIMER.
* He TRANSPARENT @ 16 eV (1st atomic level 20eV)
* WAFERS HIGHLY ABSORB AT FULL ENERGY
(Photo-electron)
* DISTINGUISH SIGNALS: PROMPT PHOTONS versus
DELAYED PHONON/ROTONS.

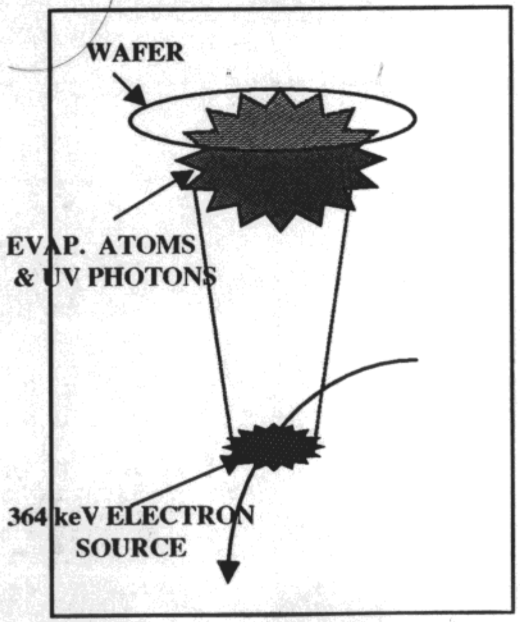
ENERGY SPECTRUM



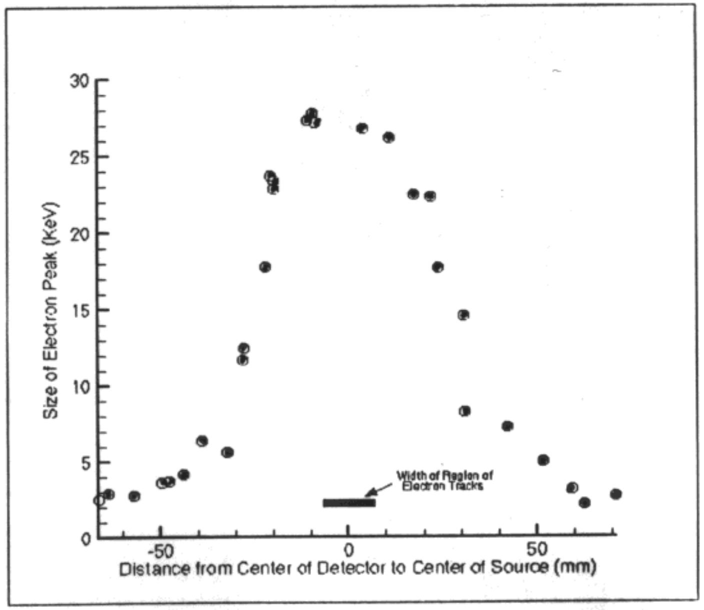
RECENT HERON RESULTS ON 364keV ELECTRONS



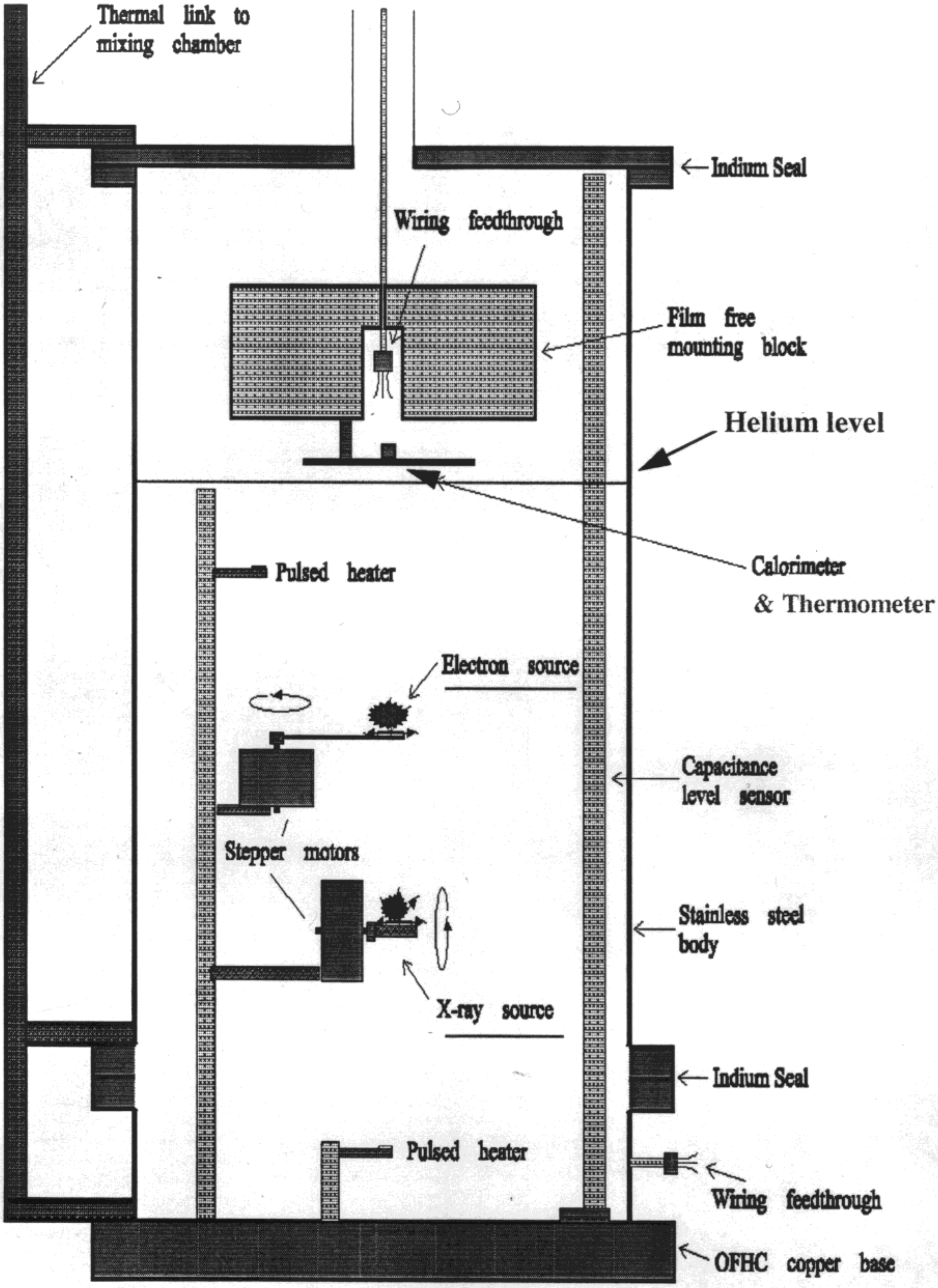
SINGLE ELECTRON PULSE ON WAFER
(SOURCE - WAFER SEPARATION = 5 cm)



SWEEP OF e SOURCE
2 cm BELOW WAFER
TO CHECK CRITICAL
CONE

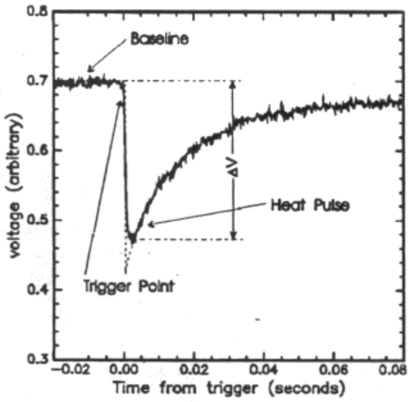


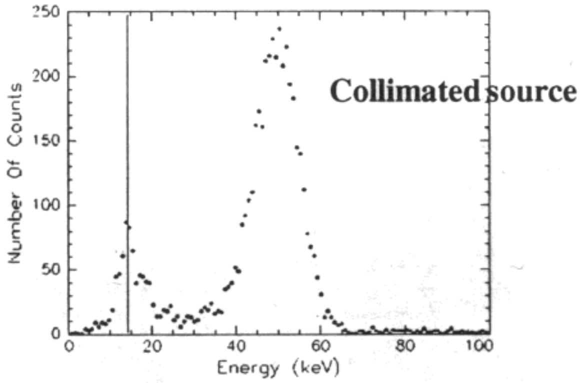
Intensity profile of evaporated He-4 atoms above liquid surface
(364 keV electrons)



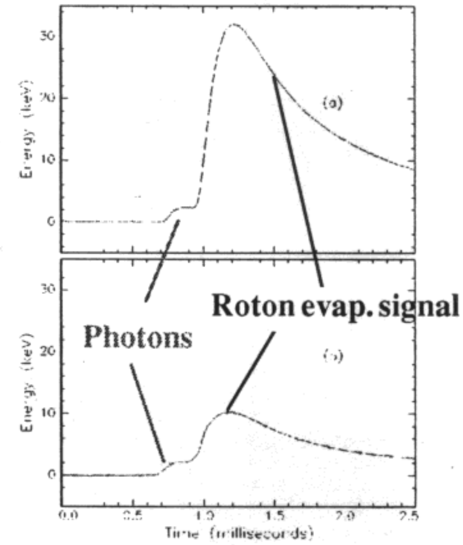
CELL CONFIGURATION FOR AN ELECTRON EXPERIMENT

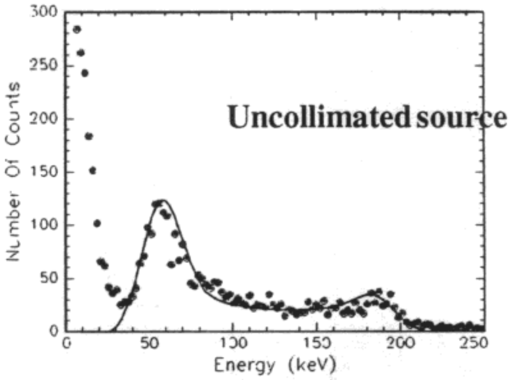
SYNOPSIS OF ALPHA PARTICLE DETECTION:



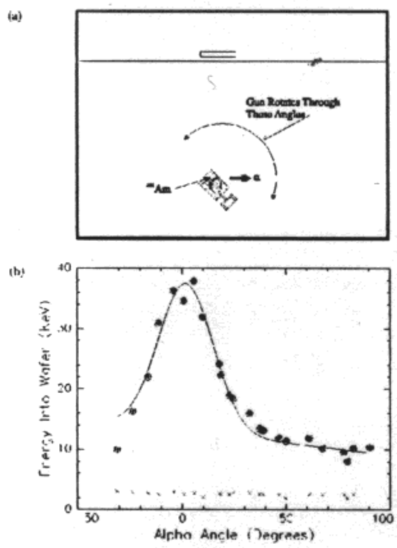


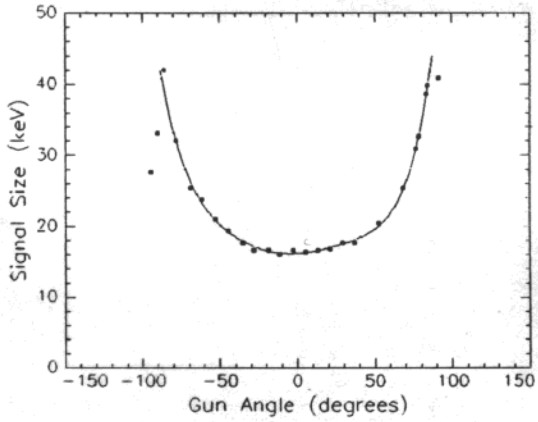
Scintillation:

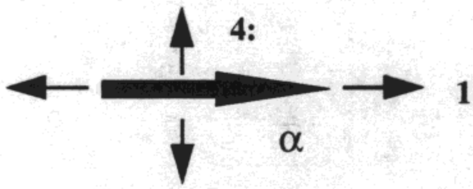


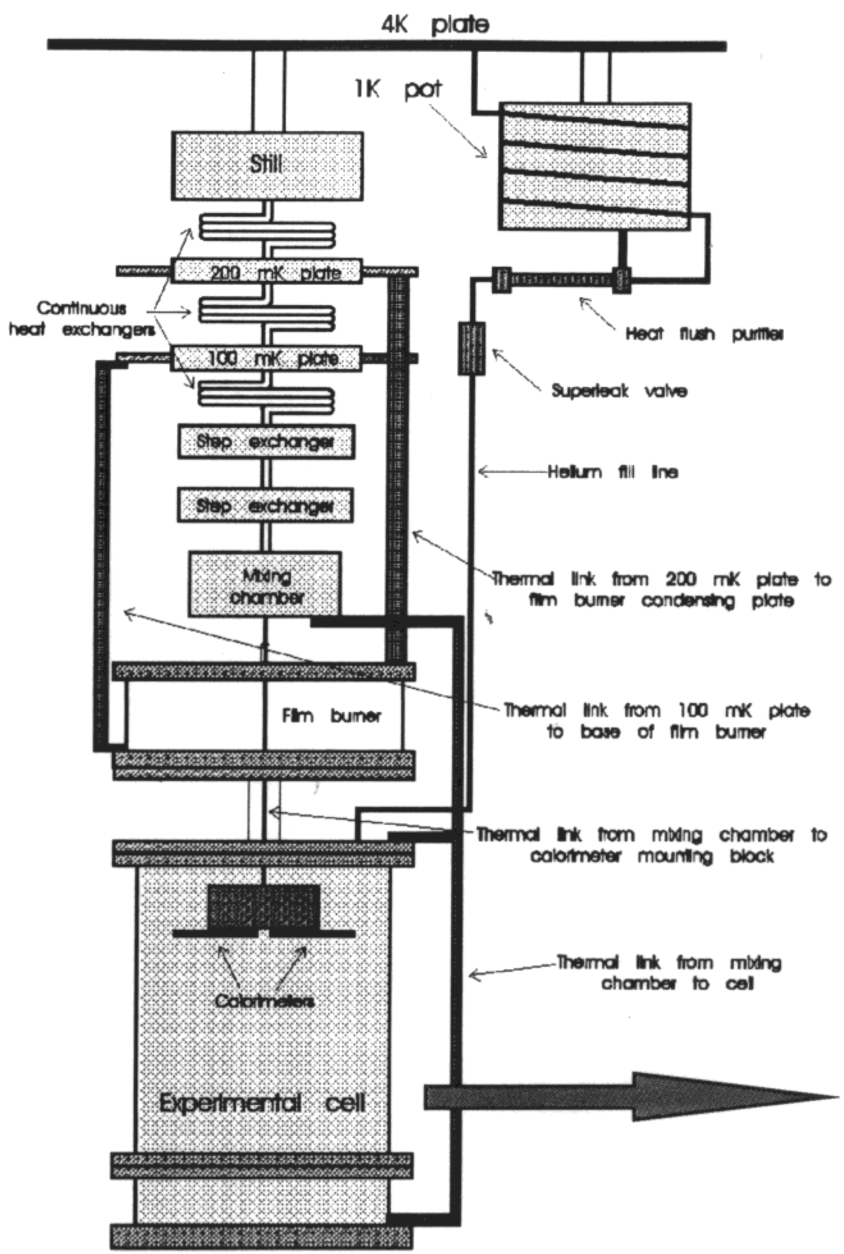


Roton Emission asymmetry:

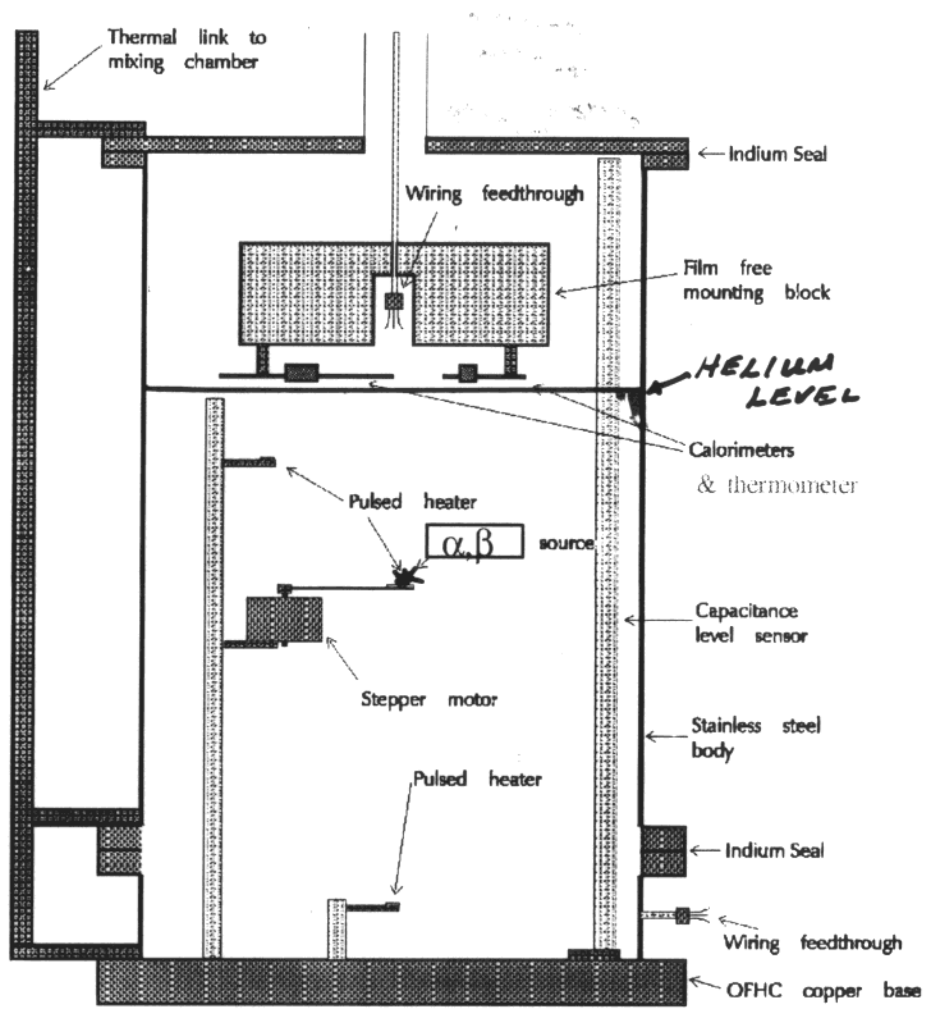






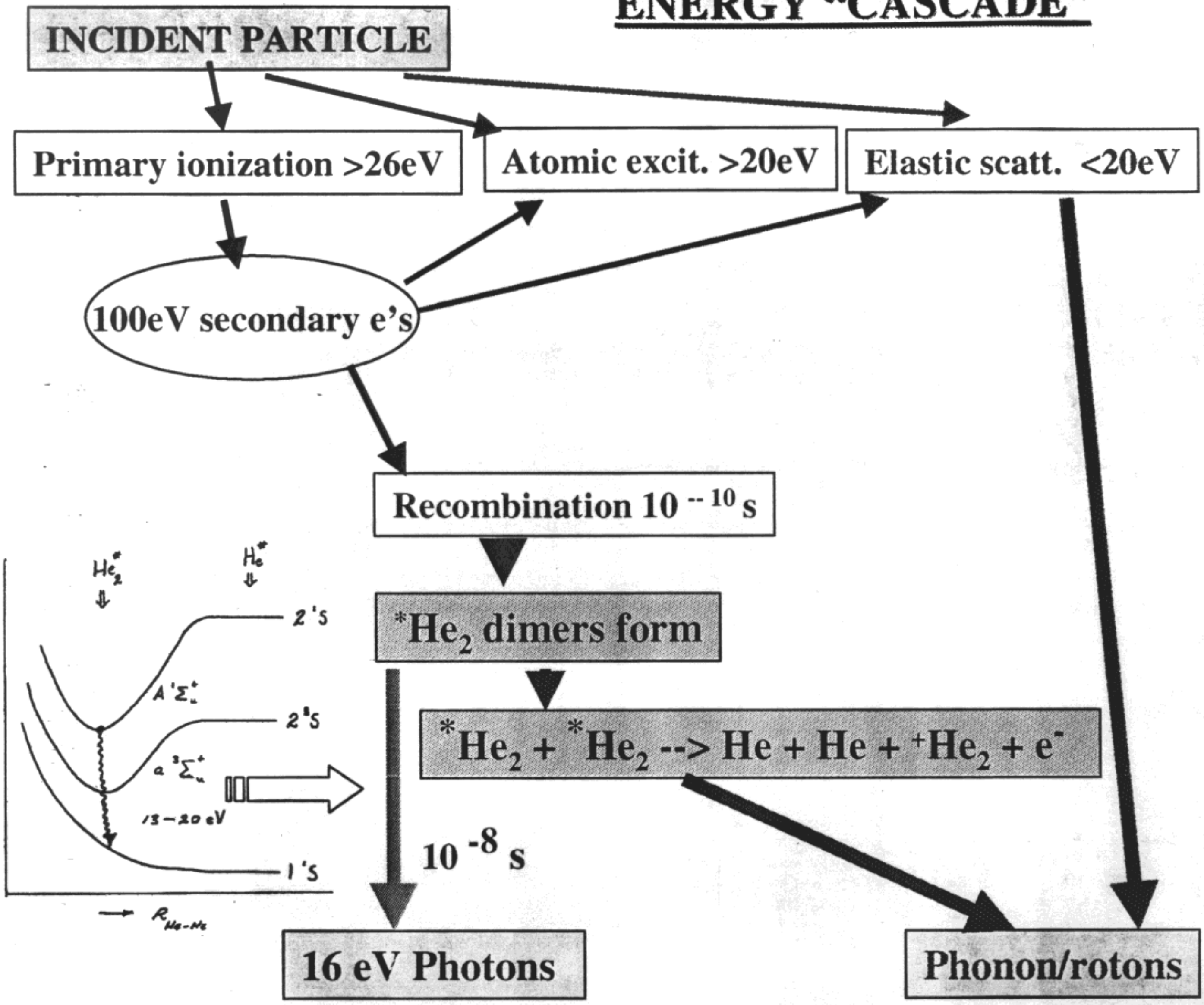


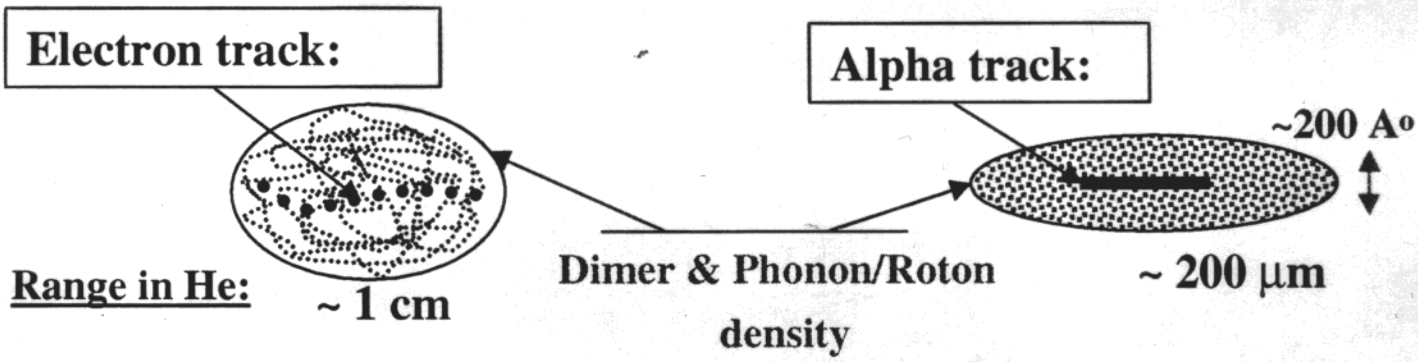
DILUTION REFRIGERATOR & ATTACHMENTS



TYPICAL CONFIGURATION OF SUPERFLUID TEST CELL

ENERGY "CASCADE"





FINAL ENERGY BUDGET:

Electrons: 25% (15 photons/keV) and 10% (10^5 phonons/keV)

Alphas: 8% photons and 40% phonons/rotons

FINAL FRACTION OF DEPOSITED ENERGY

	Electron	Alpha
Photons:	25 %	8 %
Phonon/Rotons: ($E > E_{evaporate}$)	10 %	40 %

FRACTION OF ENERGY DETECTED IN LARGE DETECTOR

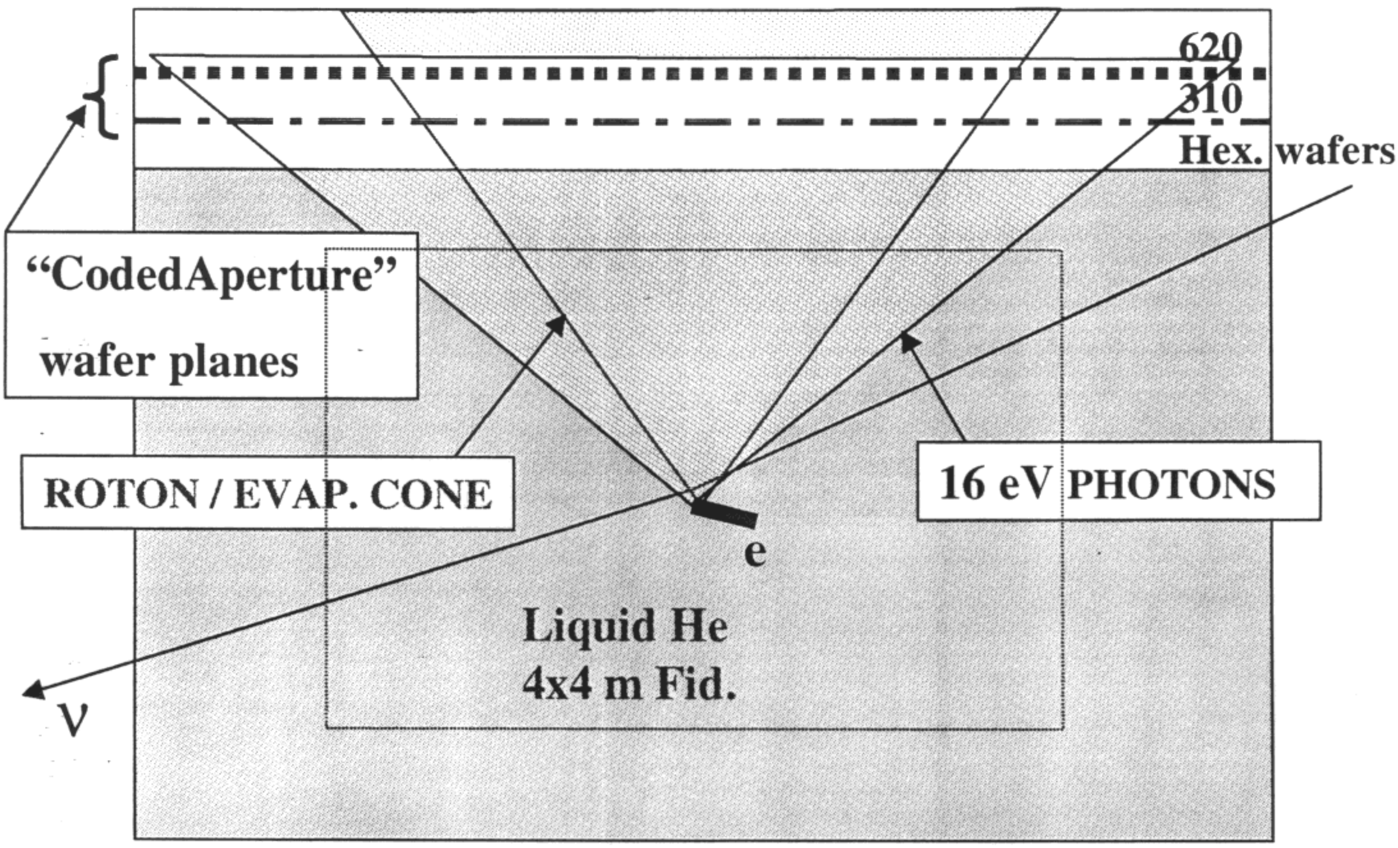
(effect of solid angle and critical angle)

	Electron		Alpha
Photons:	1.7 % -- 4.3 %		0.5 % -- 1.4 %
Phonons/Rotons ($E > E_{evaporate}$)	3.3 %		3 %
	5 -- 7.5%	TOTALS	3.5 -- 5.4%
$\theta_{critical}$	~ 30^0		~ 17^0

FOR SOLAR ν RECOIL DETECTION USE BOTH PHOTONS & PHONON/ROTONS :

- PHOTONS PROVIDE A PROMPT TRIGGER (say, > 20 wafers).
- 16 eV PHOTONS UN-ATTENUATED IN HELIUM.
- AIM FOR SINGLE PHOTON SENSITIVITY.
- MEASURE DELAYS FOR PHONON/ROTON SIGNAL (200 m/s) (SIMPLIFIES ENERGY SUM & BCKGND REJECTION).

MEASUREMENT OF EVENT POSITION & ENERGY IN "*HERON*"



EXAMPLE: 100 keV in middle

* 250 PROMPT PHOTONS detected ON "A" & "B" (~ 4 keV)
* 4 x 10 ^{5} EVAPORATED ATOMS detected on " A" & "B" (~ 3.5keV)

POSITION: * USE PHOTONS IN METHOD SIMILAR TO X-RAY ASTRONOMY & TOMOGRAPHY ---- BUT WITH BOTH PLANES ACTIVE DETECTORS.

* WAFER PLANE "A": 90% COVERAGE IN 25x25 UNIFORM GRID.
  WAFER PLANE "B"; 50% COVERAGE IN 25x25 PATTERNED GRID.
* EXPECTED HIT PATTERN (mean # hits/wafer & variances) FOR ANY EVENT POSITION CAN BE CALCULATED & PRECISELY TESTED IN ADVANCE & IN-SITU (with ^{55}Fe x-ray source).
* FROM OBSERVED PATTERN ON ALL WAFERS ---MAX. LIKRLIHOOD FOR BEST X,Y,Z (NEED 10 cm. ACCURACY).

ENERGY: * EXPECTED TIME DELAY OF EVAP. SIGNAL TO EACH WAFER KNOWN FROM t_o, POSITION AND KNOWN ROTON SPEED.

* GROUP WAFERS & FORM COMBINED SUMS OF BOTH PHOTONS AND EVAP. SIGNAL FROM BOTH PLANES "A" & "B".

QUESTION OF SINGLE, 16 eV PHOTON SENSITIVITY

- **GOAL: 10 eV THRESHOLD with $\tau_{rise} \sim 1$ ms & $\tau_{relax} \sim 20$ ms ON A 20 CM (hexagonal) WAFER.**

- **OUR TEST CELL STUDIES ON α's and e HAD E_{THRESH}=300 eV (~ 20 photons) ON 5 cm WAFER (superconducting thin films).**

- **MUCH MORE PROMISING: FAST, MAGNETIC μ -CALORIM. BEING DEVELOPED @ BROWN (Seidel) & HEIDELBERG(Enss)**

  **** MATERIAL w/ T DEPENDENT MAGNETIZATION.**
  (e,g., dilute system of atomic spins in a metal --- Er-Au)

  **** MEASURE CHANGES IN MAGNETIZATION.**
  (a direct measure of change in eqilibrium energy)

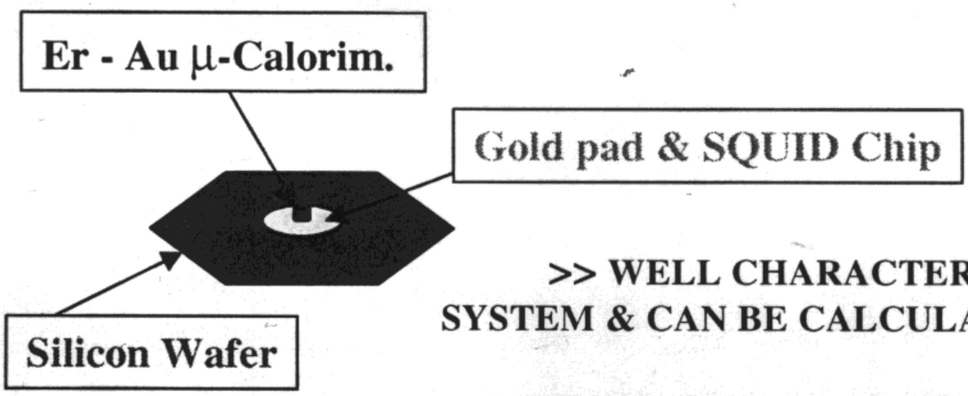
  **** D.C. SQUID --- THE ULTIMATE SESITIVITY TO ΔM.**

$$\Delta E = K(\text{geom.})\, H\, (C_{TOTAL}/C_{SPINS})\, \Delta\Phi_{SQUID\ NOISE}$$

  **** ATTACH & COUPLE TO A WAFER:**

$$C_{TOTAL} = C_{WAFER} + C_{SPINS} + C_{ELECTRONS}$$

(Optimum: $C_{WAFER} = C_{SPINS} = C_{ELECTRONS}$)



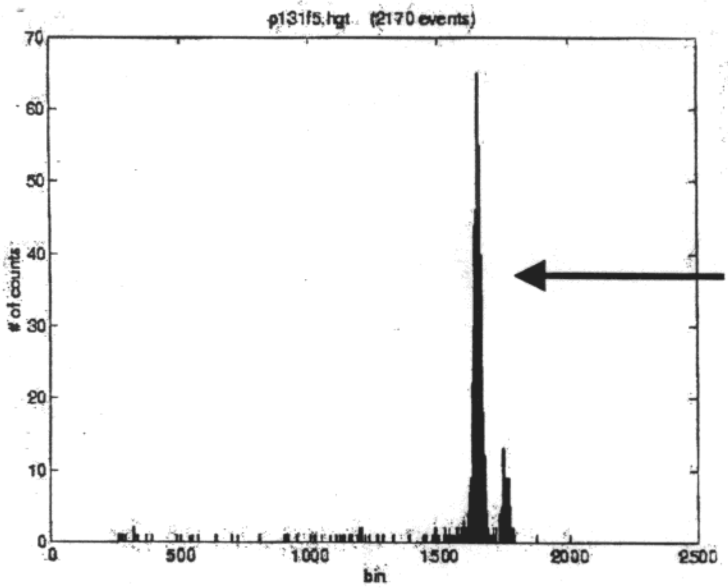
>> WELL CHARACTERIZED THERMODYN. SYSTEM & CAN BE CALCULATED ACCURATELY.

>> FIRST EXPERIMENTAL RESULTS ON SMALLER SYSTEMS ENCOURAGING ------ 20% AGREEMENT w/ THEORY.

PRELIMINARY RESULTS ON MAGNETIC CALORIM.

At Brown:

- **Er-Au (1000 ppm)**
  Diam: 0.95 mm, Ht. 0.6 mm
- **50 mK and 6 Gauss on SQUID chip.**
- **Coupled to heat capacity of 3×10^{-12} J/K**



Achieved 90 eV FWHM at K_α and K_β of Fe^{55} (5.9 keV)

At Heidelberg:

Achieved 120 eV FWHM on a heat capacity 2×10^{-9} J/K ---- same as 20 cm Si wafer in our *HERON* application.

Need another factor x10

Factors to be worked on:
*** SQUID chip re-wire.**
*** 6G ⟶ 50G**
*** Better coupling geometry.**
*** 50mK ⟶ 30mK.**
*** SQUID noise & filtering.**

BACKGROUND CONSIDERATIONS

•**SIGNAL:** ν + e ----> ν + e ; SINGLE e < 2 cm

•**BACKGROUND:** γ + e ---> γ + e ; COMPTONS with γ's from:

From HELIUM: NONE; SELF CLEANING.

From WAFERS: 24 kg ; 1.28 MeV γ from ^{22}Na (0.3 ct/kg/d)
(< 1 count/day in Helium)

From COPPER CRYOSTAT:

** COSMOGENICS (^{54}Mn, ^{57}Co, ^{60}Co); 47 microBq/kg
(2 months above gnd; 2 years below gnd)

** U & Th: AIM FOR ~ 1/10 of COSMOGENICS.
Requires < 3×10^{-13} gm/gm in Cu.
Our ID-Mass Spec. measure: ^{238}U < 1×10^{-12} gm/gm
in electr_form Cu,

BACKGROUND Monte Carlo STUDIES with GENERIC HERON

- HERMETIC CONTAINMENT by ~ 4 METERS of LIQUID HELIUM CAUSES MULTIPLE COMPTON SCATTERS OF GAMMA.

- ENHANCE THIS SIGNATURE DIFFERENCE BY LINING CRYOSTAT with 25 cm CELLS OF "MODERATOR" (CO_2 or frozen non-polar liquid) ------- DEGRADES THE PHOTON ENERGIES. NEEDS < 10^{-14} gm/gm.

RESULTING ENERGY DEPOSITION:

SIGNAL

* SINGLE e < 2 cm.
* E_e(p-p) < 230 keV.
* E_e(^{7}Be) < 660 keV.
* UNIFORM SPATIALLY.

BACKGROUND

* MULTIPLE e 's OVER LARGE LENGTH

  <N> = 10 ; Length ~ 60 cm.
* E_e STRONGLY PEAKED below100 keV.
* STRONG SPATIAL DEPTH DEPENDENCE.

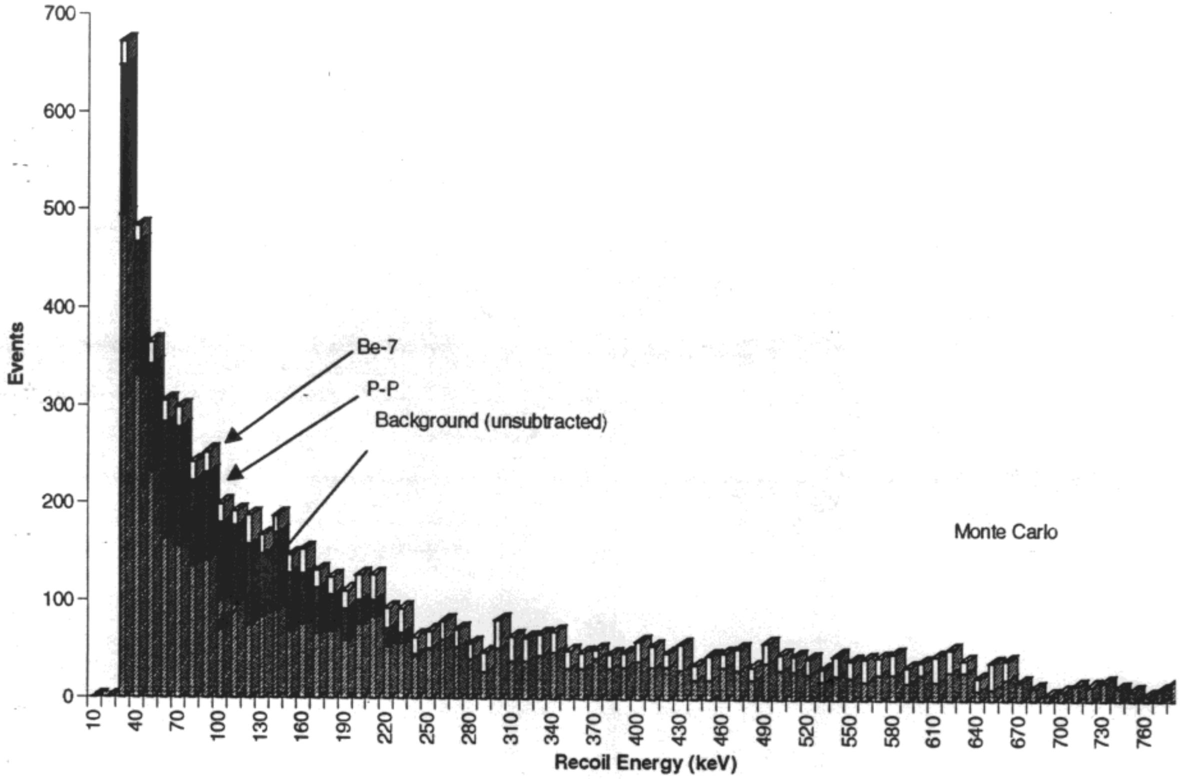
- GENERATE EQUIVALENT OF 6 MONTHS RUN (@ 70% duty factor)

CUTS CRITERIA:

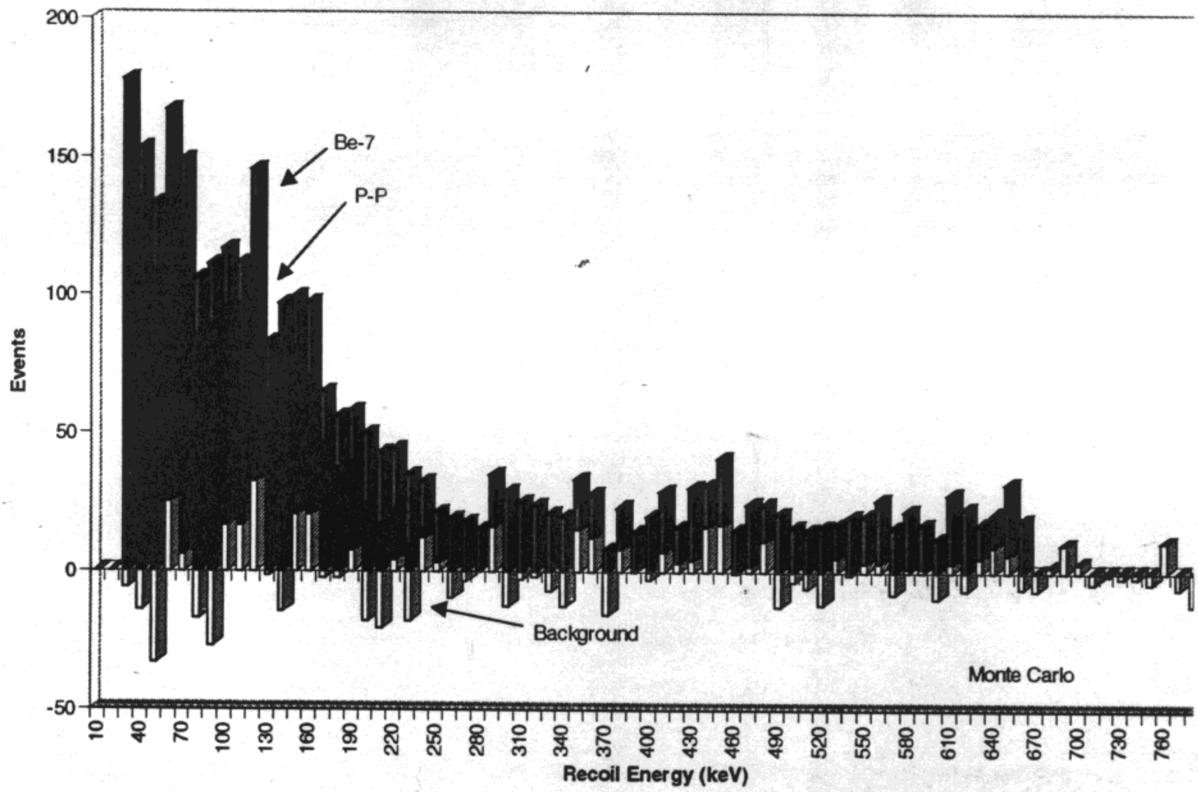
** +/- 5 cm. SPATIAL RESOLUTION.
** DIVIDE EVENTS INTO FID. & NON-FID. VOLUMES.
** ONE LOCALIZED ENERGY DEPOSITION.
** E_{TOT} < 800 keV .

RESULTS IN A SIGNAL/BCKGND of 1:1 (with stated activity) BEFORE NORMALIZATION & SUBTRACTION (Fid. - Non-fid.)

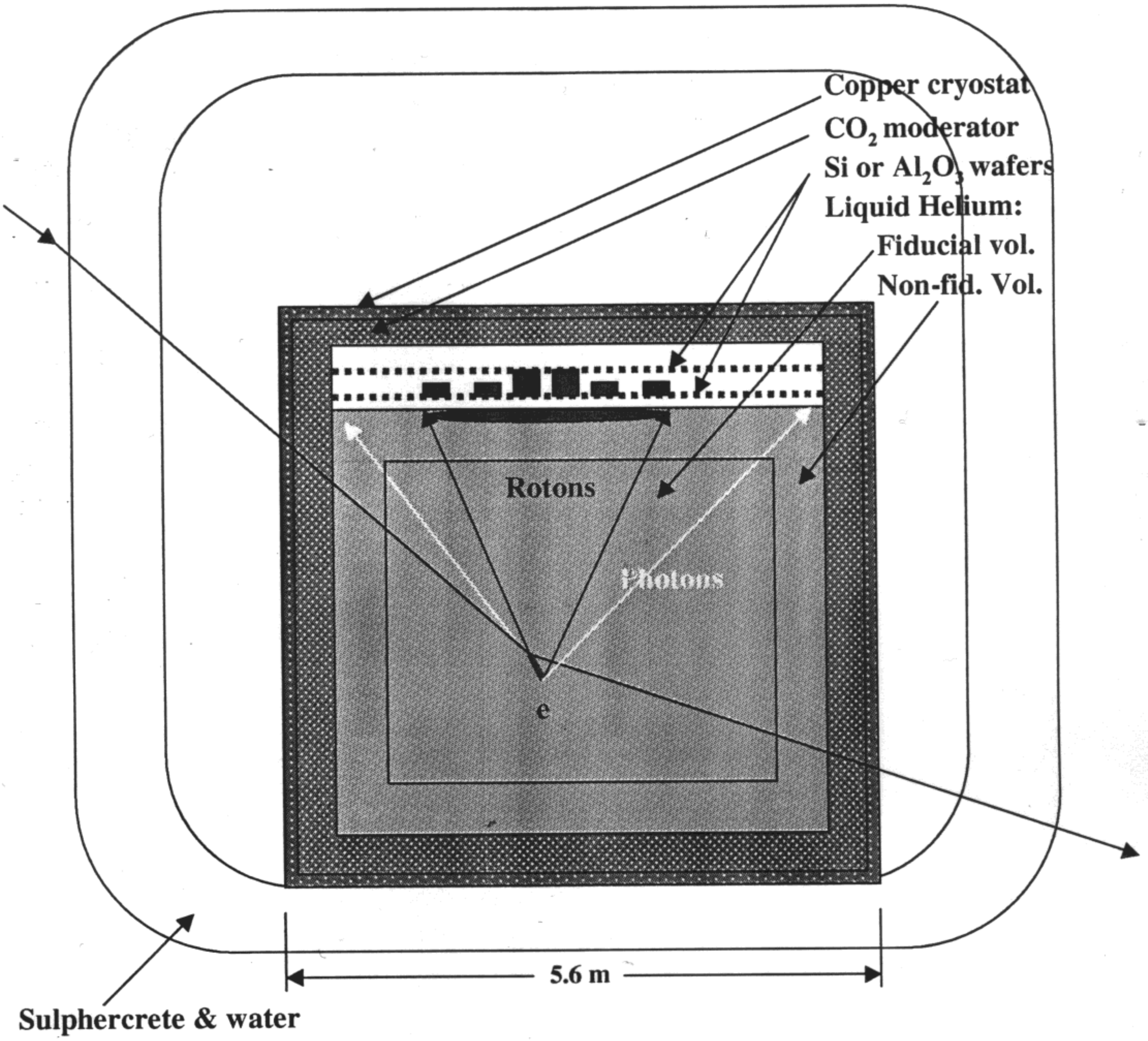
Data for 6 months



Background subtracted data (6 mo.)



Generic HERON (not to scale)



SUMMARY STATUS & FUTURE

SUMMARY PRESENT STATUS:

** PHYSICS OF NEW, PARTICLE DETECTION SCHEME IN SUPERFLUID WELL UNDERSTOOD & TESTED.

** SIGNIFICANT ADVANCES MADE IN WAFER SENSITIVITY.

** PRELIMINARY STUDIES OF BACKGROUNDS & REJECTION.

WHAT OF THE FUTURE?

IMMEDIATE GOALS:

- INTENSIVE WORK ON NEW, MAGNETIC CALORIMETERS TO REACH SINGLE PHOTON SENSITIVITY.

- M.C. MODELING INVESTIGATION OF EVENT POSITION FINDING RESOLUTION ("QUASI-CODED APERTURE").

MULTI-WAFER, 3-liter TEST CELL ENERGY RESOLUTION TESTS & SIGNAL COMBINING ELECTRONICS.

BEYOND THE IMMEDIATE:

** ASSUMING SUCCESS, NOW TIME TO INITIATE & EXTEND WORK ON ALL ASPECTS ---> CRYOGENIC ENGINEERING, BACKGND/MATERIALS, TRIGGER ELECTRONICS, DATA ACQU., SIMULATION STUDIES, SITE IMPACT / REQUIREMENTS, +++++.

** WE ARE A VERY SMALL GROUP & WELCOME SOLID, CRITICAL (EVEN SKEPTICAL !) STUDY EFFORT FROM OTHERS ON ABOVE.

** AND TO MAKE A HERON DETECTOR A CONTIBUTOR TO:

"WHAT IS FULL NATURE OF THE LOW E SOLAR NEUTRINO FLUX?"