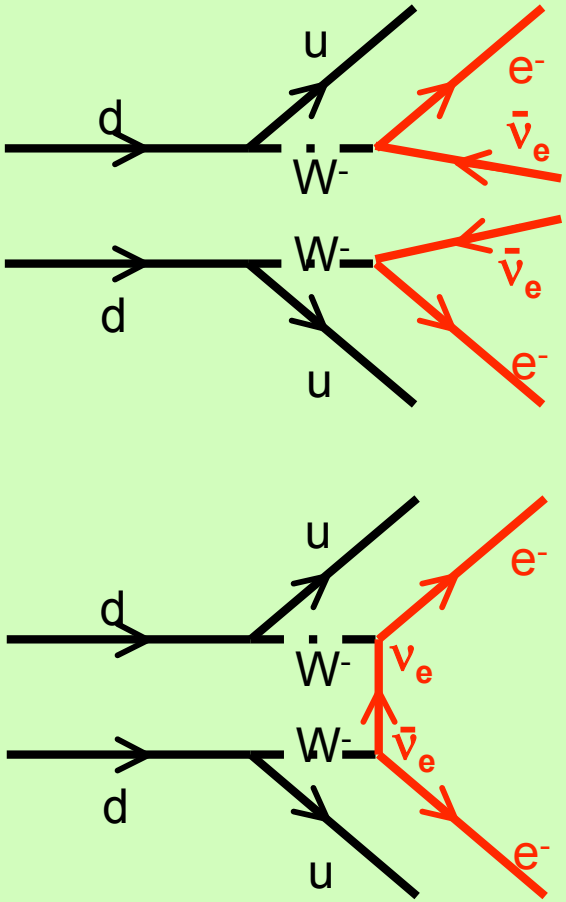
High-Pressure Gas TPC Development for Double Beta Decay Studies in ^{136}Xenon

C. K. Hargrove[1], O. Abouzeid[1], M. Bowcock[1], P. Colas[2], M. Dixit[1,3], K. McFarlane[1], I. Giomataris[2], K. Graham[1], P. Gravelle[1], C. Greene[1], D. Sinclair[1,3] V. Strickland [1,3], & R. Woods[1]

[1]*Carleton University Ottawa, Canada,*
[2]*CEA-Dapnia Saclay, France*
[3]*TRIUMF Vancouver, Canada*

N62-6 IEEE NSS Dresden
24 October 2008

Neutrinoless Double Beta Decay



$$\Gamma_{0\nu} = G_{0\nu} \left| M_{0\nu} \right|^2 \left\langle m_{\beta\beta} \right\rangle^2$$

G = phase space factors (easy)
|M| = nuclear matrix elements (hard)
$m_{\beta\beta}$ = effective neutrino mass (want to measure)
$\Gamma_{0\nu}$ → half-life/count rate (limit already 10^{25}yrs)

neutrino must be Majorana

$$\left\langle m_{\beta\beta} \right\rangle = \sum_i \left| U_{e,i} \right|^2 m_i \varepsilon_i$$

$0\nu\beta\beta$: $(A,Z) \rightarrow (A,Z+2) + 2e^-$

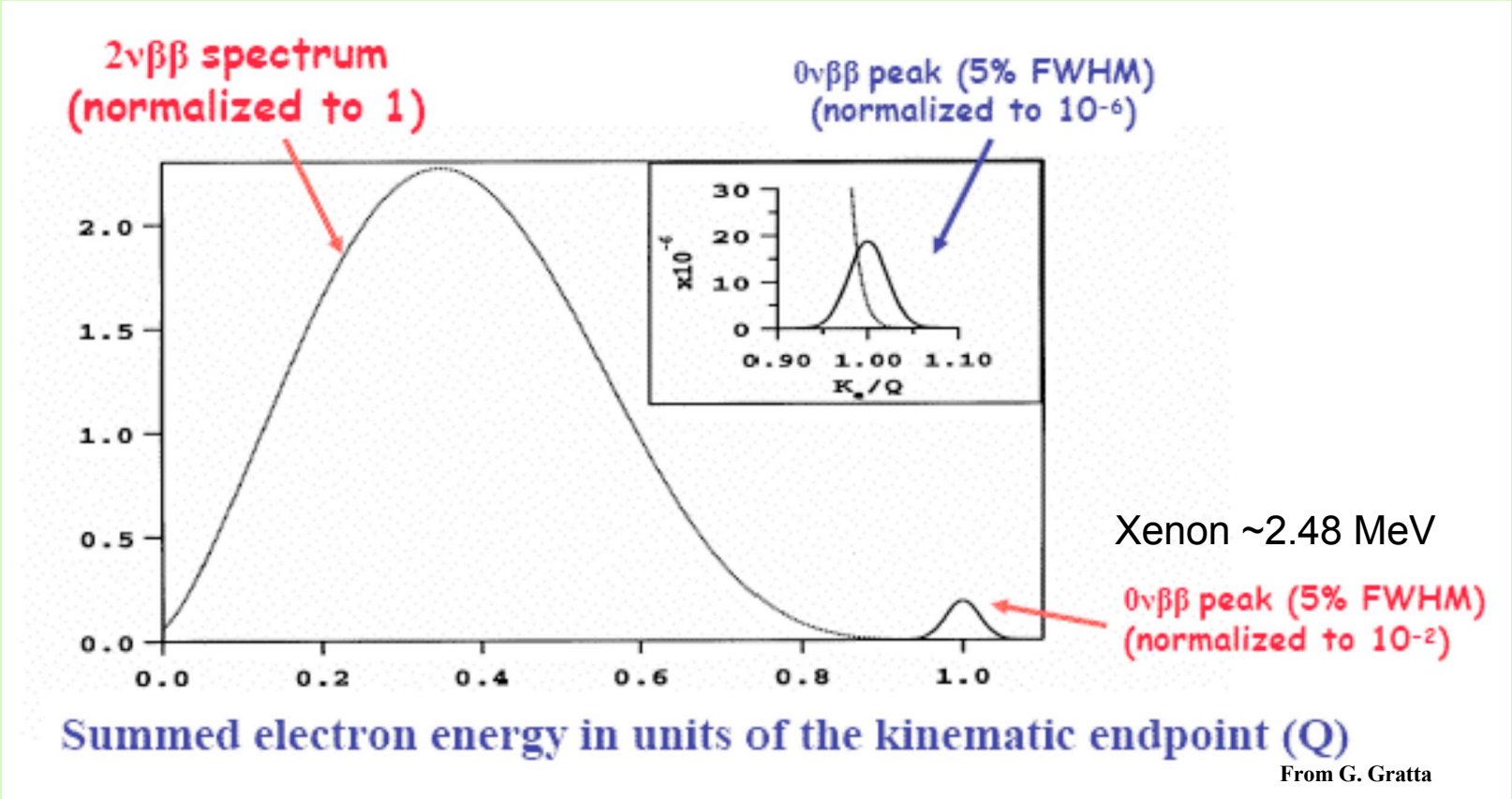
$^{136}Xe \rightarrow Ba^{++} + 2e^- + (2\nu)$

$\Delta L=2$ lepton number violation? Neutrino mass scale, neutrino mass hierarchy?

Observing 0νββ

$$T^{0\nu}_{1/2}(y) \approx \sqrt{\frac{\text{Mass} \cdot \text{time}}{N_{Bkg} \cdot \Delta E}}$$

Event Selection:
- 2 electrons (tracks+dE/dx)
- single vertex
- total energy 2.48 MeV



From G. Gratta

background suppression & good energy resolution paramount

EXO Program: First measurement of ^{136}Xe $2\nu\beta\beta$

Search for $0\nu\beta\beta$ with 200 kg liquid xenon TPC

EXO200 installed at WIPP (New Mexico)

Double beta decay in ^{136}Xe - Liquid vs Gas

	Liquid Phase TPC	Gas Phase TPC
Energy resolution	challenging	Better in principle
Position reconstruction	single site	Identify two electron tracks with Bragg peaks
Barium tag	**ex-situ experimental tour de force**	**in-situ may be possible less difficult**
Scale up	straightforward	gets large pressure vessel
Physics	rates, energy spectrum	plus angular correlation

- both options being pursued at present

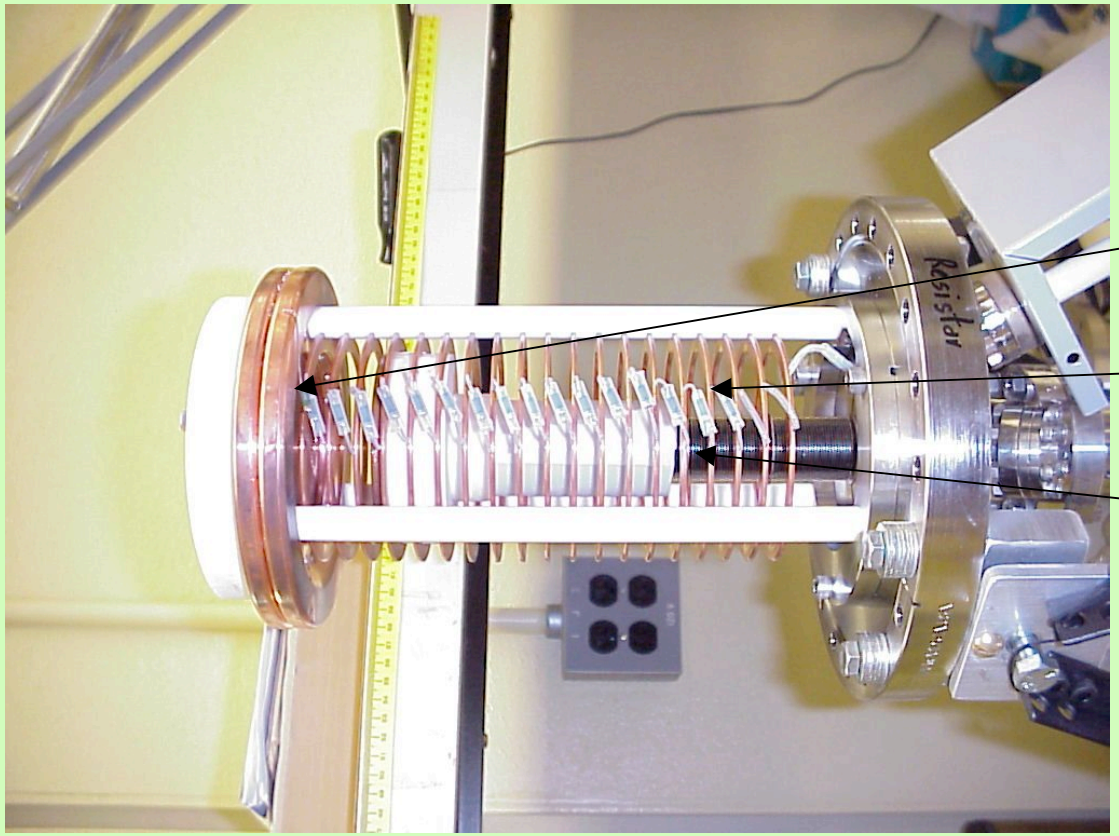
-**Gas TPC R&D items**: Barium tag, scintillation light detection, simulation

This talk → Energy resolution for mono-energetic electron tracks in a high pressure xenon gas TPC

High pressure gas TPC drift cell

- Adjustable maximum 16 cm drift, moveable source holder
- operated at 2 bar pressure with argon and xenon
- **single readout channel**
- ^{55}Fe, ^{109}Cd, and ^{241}Am sources (~5.5 MeV)

Measurements in ion chamber mode & with Micromegas



readout

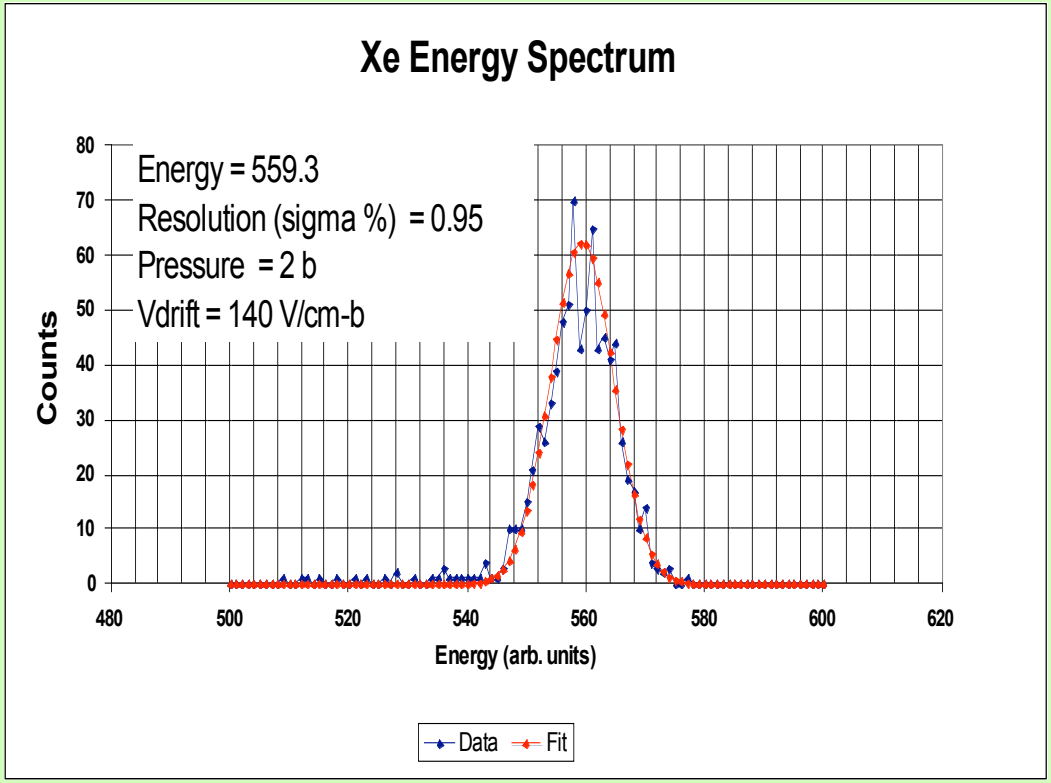
field cage

source holder

connected to vaccum/gas system with purification

Ion Chamber Results ^{241}Am 5.5 MeV

Gases studied:Argon, Xenon, P10, Xe + CH4 (1,2,5 %), Xe + TEA (1 and 2 %)



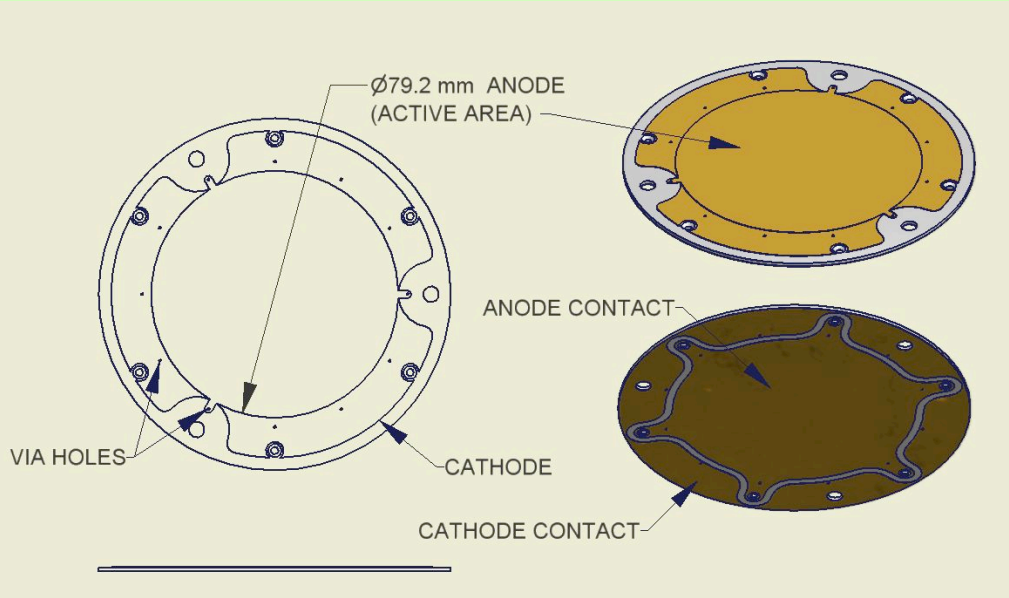
~1% E resolution (σ) for all cases

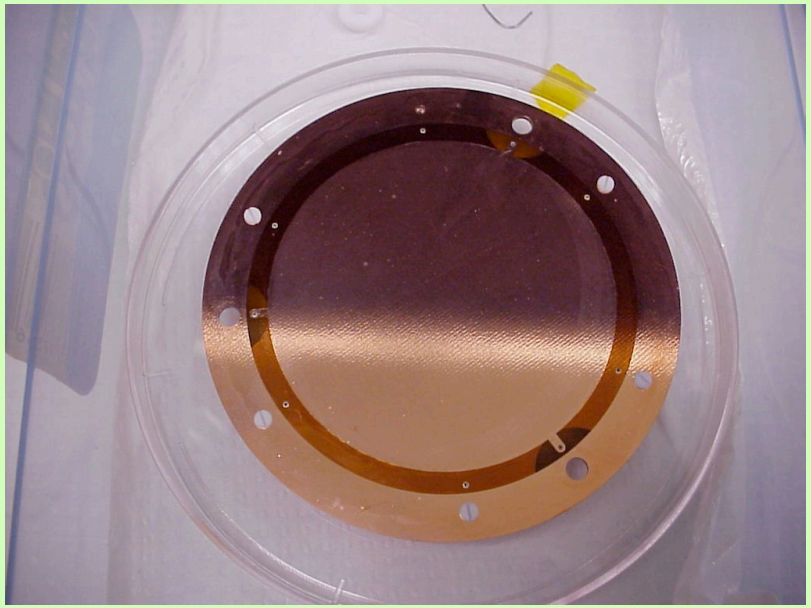
but electron loss due to attachment with TEA

a gas purity question?

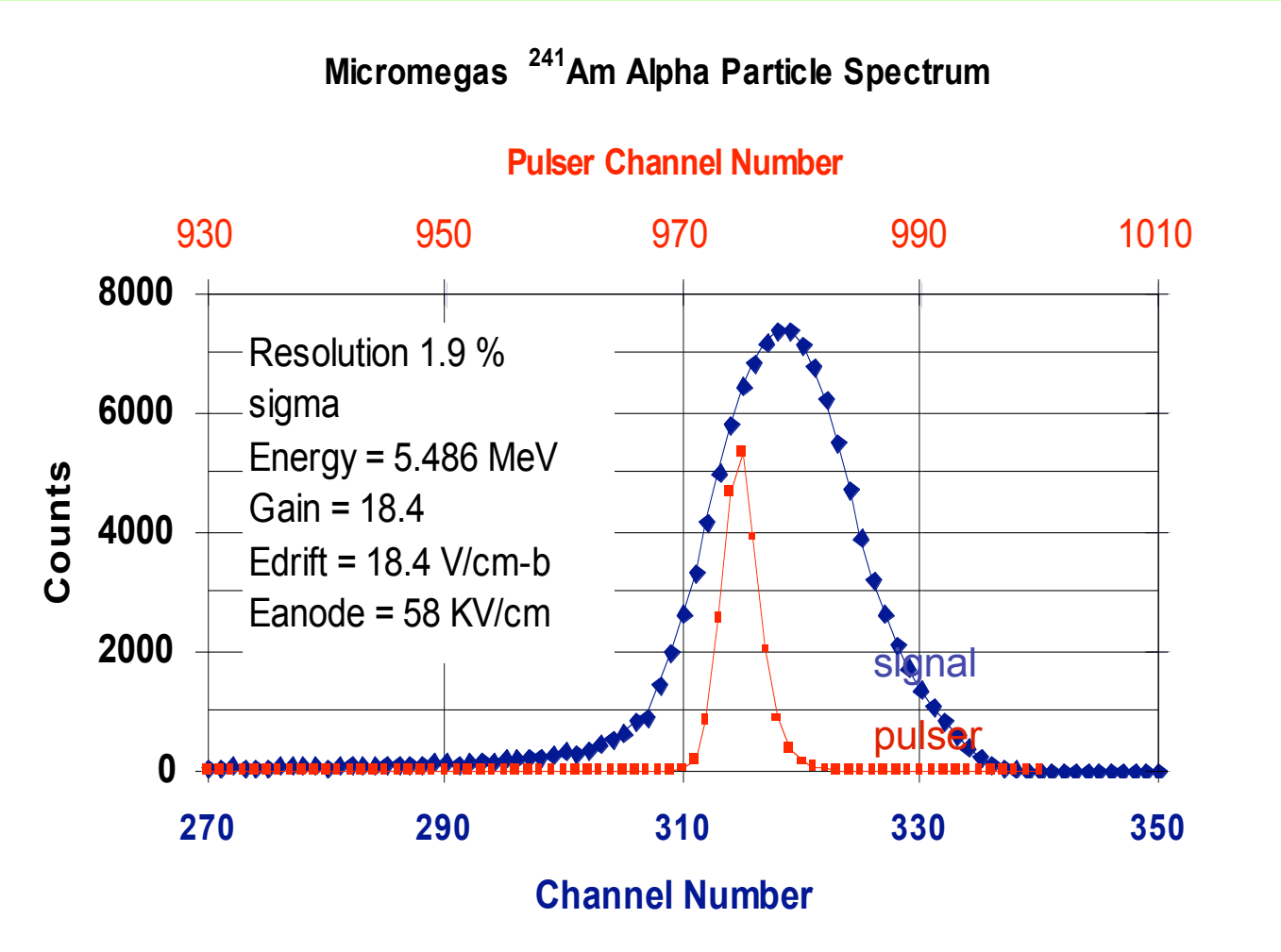
Micromegas (Microbulk)

- Micromesh thickness — 5 μm (copper)
- Micromesh hole diameter — 30 μm
- Micro-holes (square grid) — 100 μm pitch,
- Pillar height (anode-cathode gap) — 50 μm
- Optical Transparency: — 7%
- Capacitance — ~3 nF



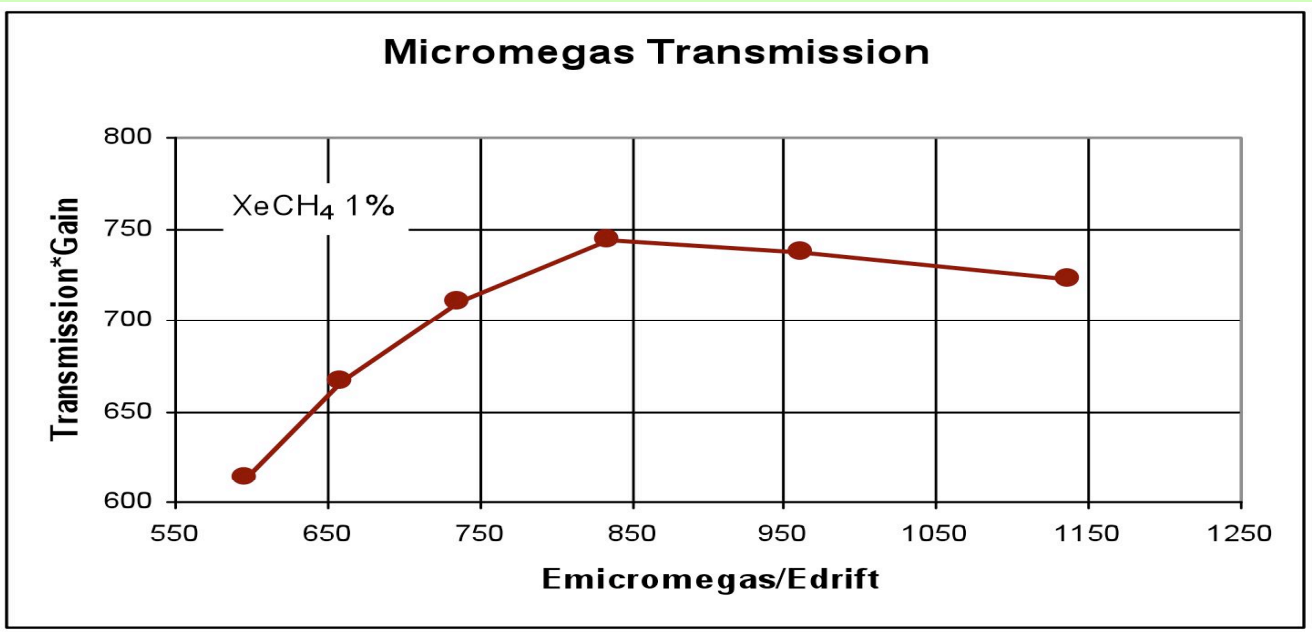


Resolution for 5.5 MeV αs in P10

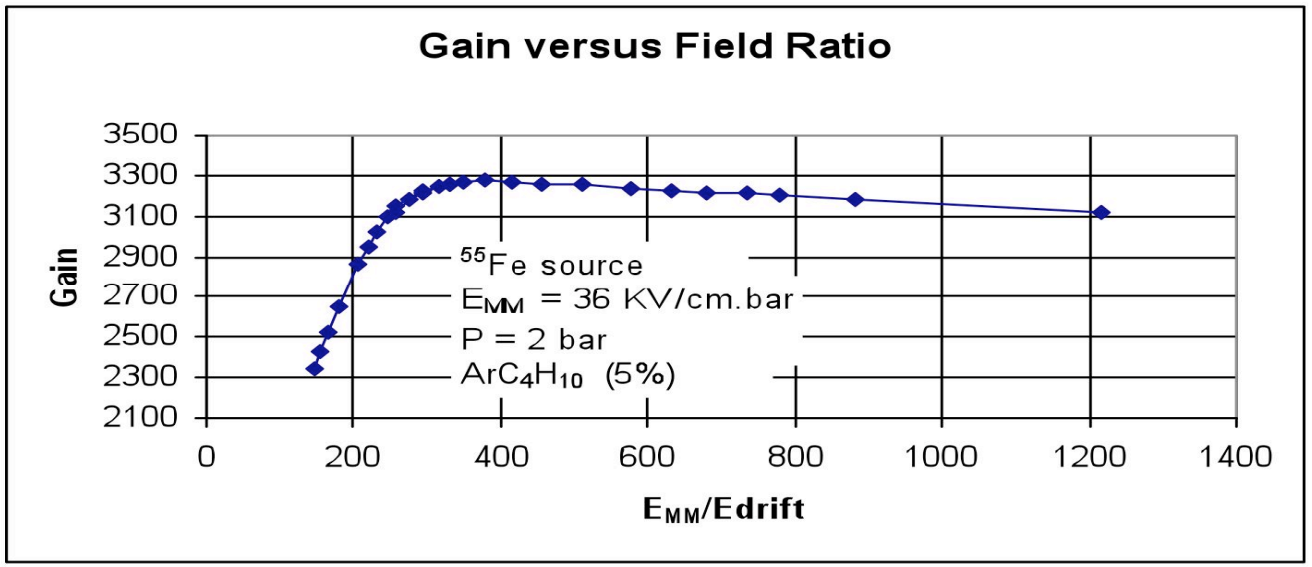


Relatively high Micromegas field ratios required!

Gain x Trans. differ for αs & ^{55}Fe and ^{109}Cd

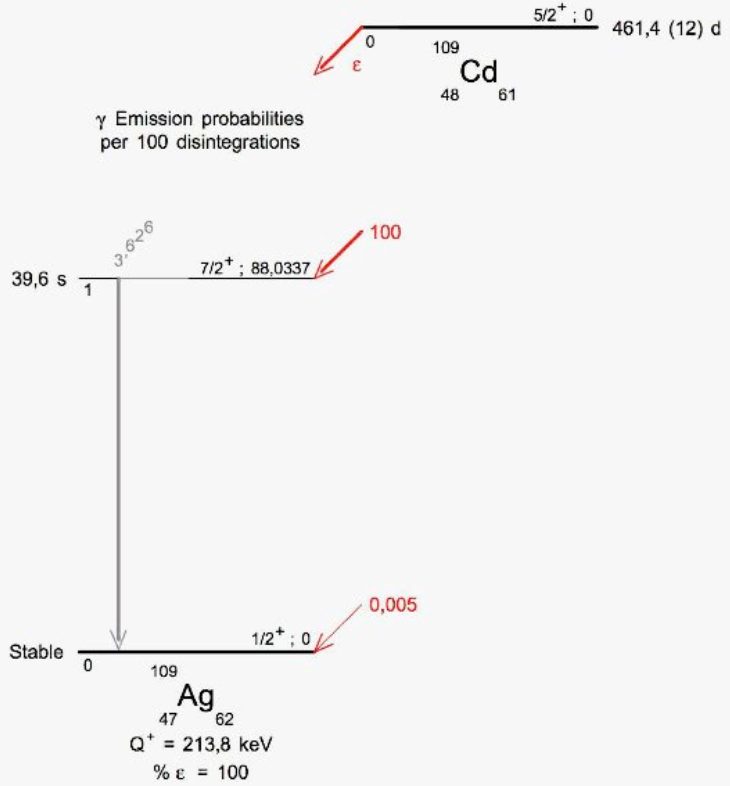


- ^{241}Am



- ^{55}Fe

^{109}Cd electron source ~ 150 μg/cm^2 Mylar window



Electron capture to ^{109}Ag m (40 s)

Complicated spectrum

Strong conversion electron lines

- **62.5 keV from K conversion (40 per 100 disintegrations)**
- **85 keV L conversion (45 per 100 disint.)**
- **87 keV M conversion (10 per 100 disint.)**

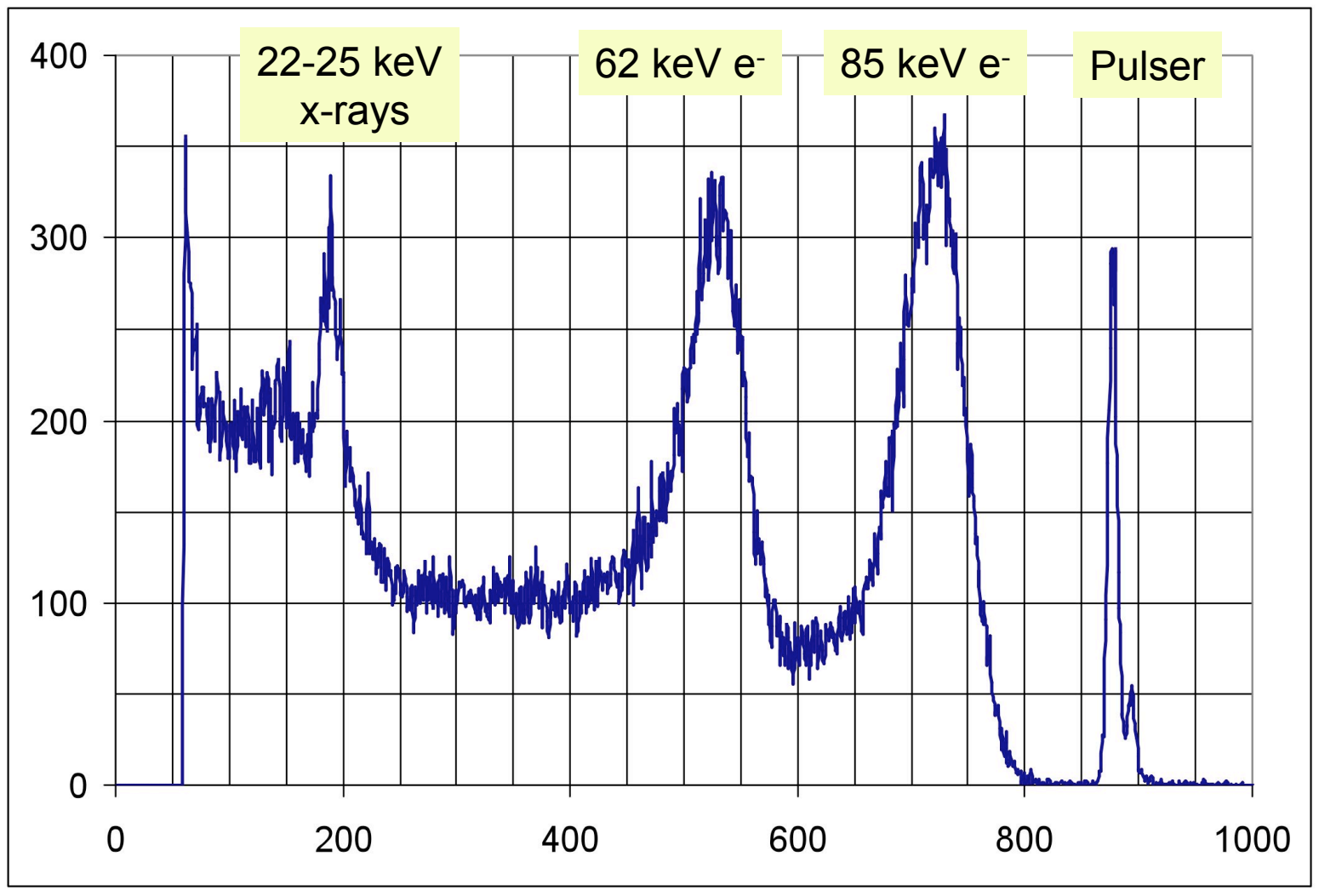
18-25 keV Auger e^- (~ 20/100 disint.)

22-25 keV Ag x rays

88 keV gamma (4 per 100 disint.)

Observed ^{109}Cd spectrum distorted by Mylar window

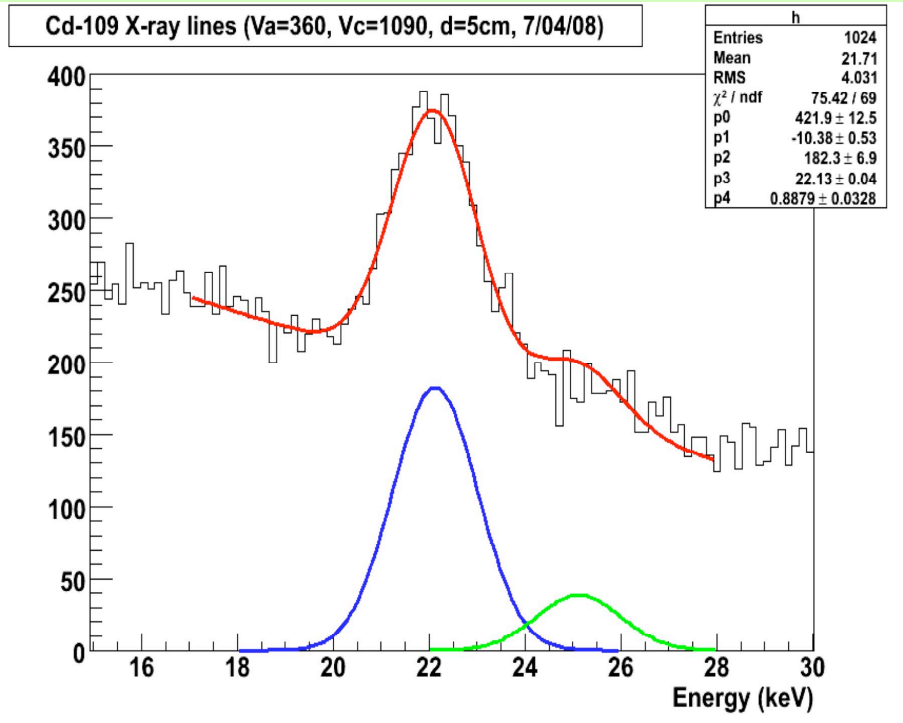
^{109}Cd spectrum in Ar + 5% iC_4H_{10} @2bar

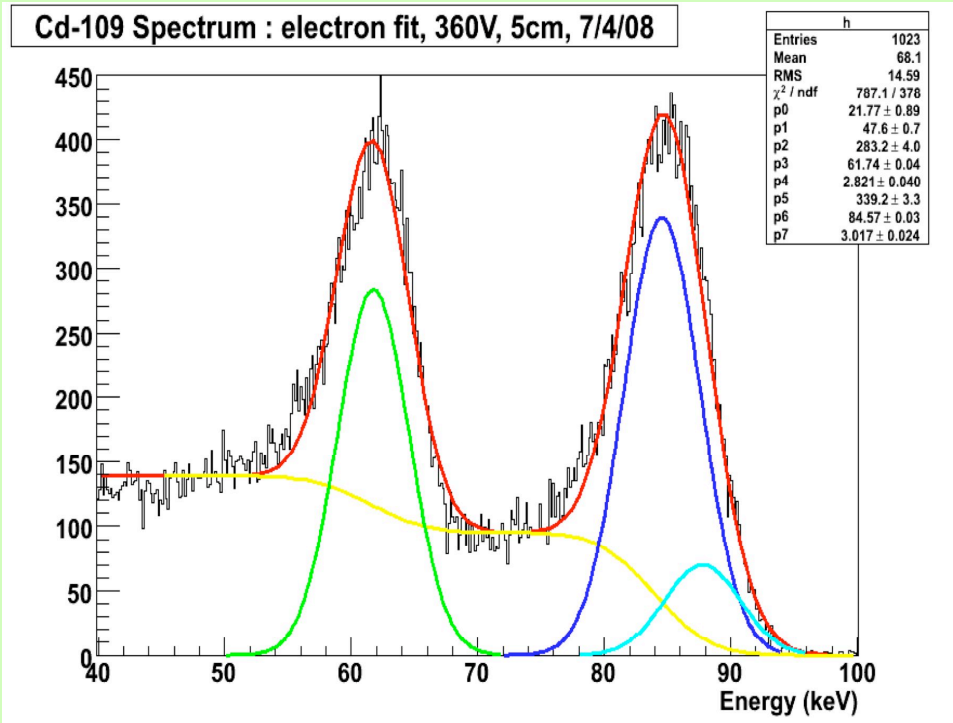


^{109}Cd energy resolution with Micromegas in Ar + 5% iC_4H_{10} @2bar

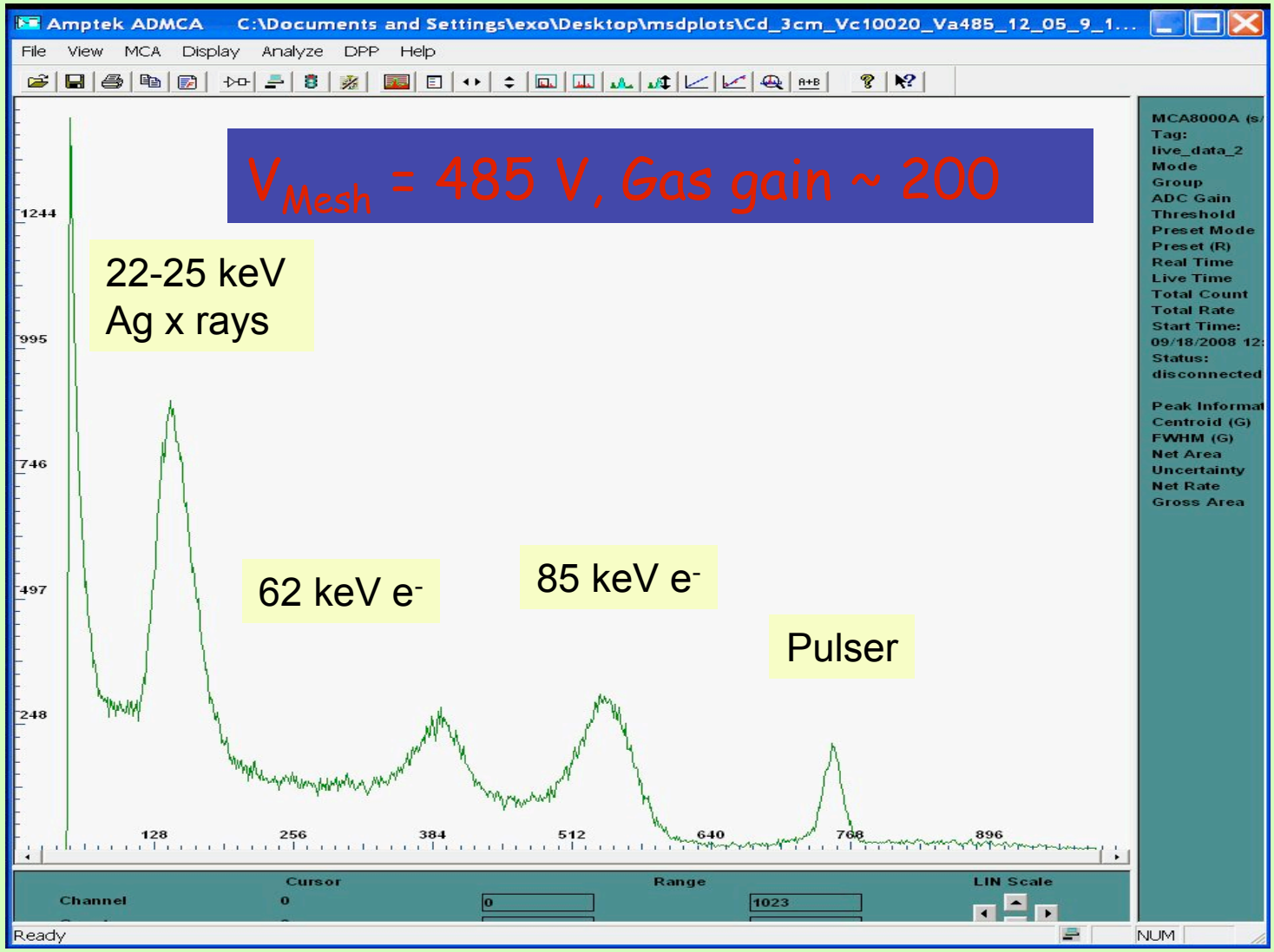
22-25 keV Ag x rays

62-85 keV electron lines



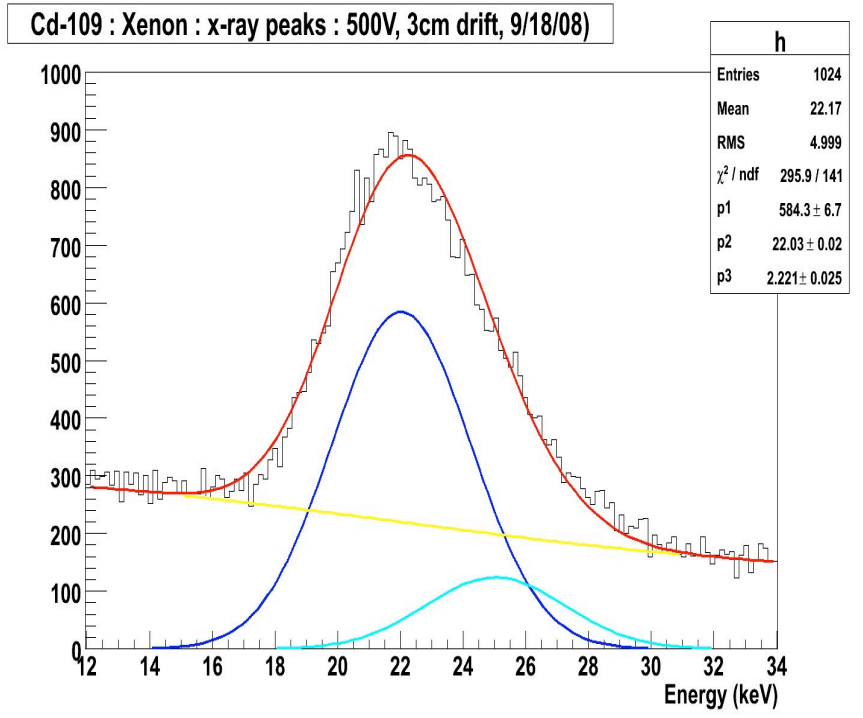


^{109}Cd electrons & x rays in Xenon + 5% iC_4H_{10} @2bar

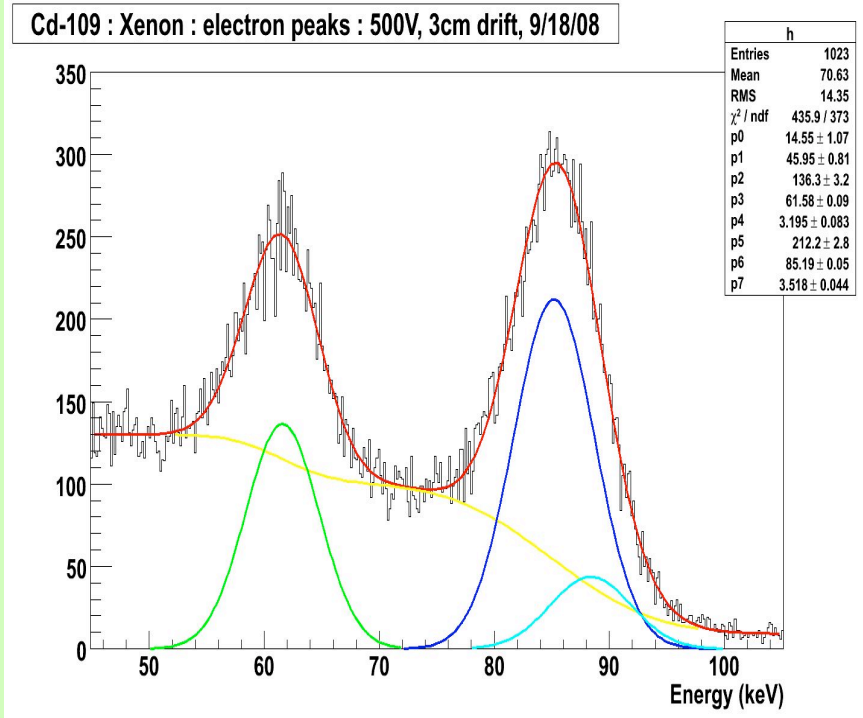


^{109}Cd measurement with Micromegas in Xe + 5% iC_4H_{10} @2bar

22-25 keV Ag x rays



62-85 keV electron lines



Measurements limited by high backgrounds and low gain

Summary

- Good energy resolution for 5.54 MeV ^{241}Am αs in a Xenon TPC ion chamber
- **Alphas non-representative for double beta decay studies with our Microbulk. Large difference in field ratios observed for highly ionizing α particles and ^{55}Fe & ^{109}Cd**
- **A first measurement of extended electron track energies in a Xenon gas TPC at 2 bar with Micromegas readout**
- **Measured ^{109}Cd spectrum distorted by ~ 150 μg/cm^2 Mylar window. About 5% (σ) energy resolution for 62 keV electrons**
- **Simple $1/\sqrt{E}$ scaling would give less than 1% resolution at 2.5 MeV for the ^{136}Xe zero neutrino double beta decay electrons**
- Microbulks appear to be less robust than conventional Micromegas
- Micromegas as large as 1 meter x 2 meter with segmented mesh and pad readout may be needed for ^{136}Xe high pressure gas TPC

Extra Slides

^{109}Cd gammas and electron spectrum in xenon after passing through ~ 150 μg/cm^2 Mylar window

Cd109 gammas and electrons in xenon at 2 bar after energy loss in ~150 micro-gm Mylar window					
Mylar thickness ~ 150 micro-gm/cm2		Mylar density	1.4		
Xenon density (gm/ml)	0.01180	at 2 bar			
Particle emitted in 109 Cd decay	Gamma or electron energy keV	No. per 100 disint.	Gamma or electron energy in gas keV	Relative probability %	Electron range /gamma att. lenth xenon at 2 bar
electron eal	1.8 - 3.8	167.0	0	72.3	Stops in Mylar
photon Ll, Lgamma	2.63-3.75	10.3	2.63-3.75	4.5	0.23 cm@4 keV
electron eak KLL	17.8 - 18.7	14.0	13.9 - 14.8	6.1	0.046cm@15keV
electron eak KLX	20.9 - 22.2	6.0	17.9 - 19.2	2.6	0.075mm@19keV
electron eak KXY	24.1 - 25.5	0.6	21.4 - 23.1	0.3	1.1mm@23keV
photon XKalpha2	21.99	29.0	21.99	12.6	4 cm@22keV
photon XKalpha1	22.16	54.7	22.16	23.7	4 cm@22keV
photons XK'beta1	24.91-25.15	15.1	24.91-25.15	6.6	5.3 cm@25keV
photons XK'beta2	25.46 - 25.51	2.6	25.46 - 25.51	1.1	5.5cm@25.5keV
electron ex1,0 K	62.50	40.8	61.5	17.7	0.73 cm
electron ec1,0 L	84.2 - 84.7	44.8	83.3 - 83.8	19.4	1.2 cm
electron ec1,0 M	87.3 - 88.0	9.3	86.4 - 87.1	4.0	1.3 cm
gamma1,0	88.03	3.6	88.03	1.6	42.4 cm
All		230.9		100.0	

Atten length at 4 keV in Mylar = 18.5 mg/cm2		
Gamma energy (keV)	mu/rho in xenon (cm2/gm)	Atten. length (cm)
3.0	770.9	0.11
4.0	372.8	0.23
5.0	601.5	0.14
22.0	21.2	4.00
25.0	16.1	5.26
25.5	15.3	5.54
88.0	2.0	42.37

Electron energy keV	dE/dX in Mylar MeV.cm2/gm
17.8 - 18.7	13.3
20.9 - 22.2	12.2
24.1 - 25.5	10.3
62.50	5.1
84.2 - 84.7	4.26
87.3 - 88.0	4.04