

A high-energy axion detector for CAST

(J.I. Collar, D. Miller, J. Vieira, EFI UoCh)

- **Goal:** extend sensitivity of CAST to axion-induced gammas from few tens of keV to ~150 MeV
- **Motivation:** If new boson couples to nucleons, it can substitute for a γ in plasma and nuclear processes [1]. Solar luminosity via axion emission can be as high as few % of total. Search with helioscope has not been performed before.
 - Weak experimental limits already exist from observed solar γ flux below 5.5 MeV ($a \rightarrow \gamma\gamma$ following $p + d \rightarrow \text{He} + a$) [2].
 - Other reactions of interest exist (e.g., 2.2 MeV from $p + n \rightarrow d + a$, 511 keV from $e^+ + e^- \rightarrow a + \gamma$, 477 keV from ${}^7\text{Be} + e^- \rightarrow {}^7\text{Li}^* + \nu_e$ [3], etc.)
 - A generic search should not be limited to M1 transitions [4]. Should surpass sensitivity of searches for anomalous production of single γ 's in accelerators [5]. May surpass sensitivity to small branching ratios ($\sim < 10^{-5} - 10^{-6}$) in laboratory searches [6]. (calculation of expected sensitivity in progress)
- **Must be compact and non-intrusive, yet reach the lowest possible sea-level background and highest efficiency**
 - Careful design and selection of detector and shielding materials
 - Use of Pulse-shape background discrimination in lieu of additional shielding

[1] G. Raffelt, "Stars as laboratories for fundamental physics", University of Chicago Press, Chicago and London (1996).

[2] G. Raffelt and L. Stodolsky, Phys. Lett. B119, 323 (1982).

[3] M. Krcmar et al., Phys. Rev. Lett. (hep-ex/0104035)

[4] G. Raffelt, Priv. Comm..

[5] C. Hearty et al., Phys. Rev. D 39(1989)3207.

[6] A. V. Derbin et al., Phys. At. Nucl. 65 (2002)1335; M. Minowa Phys. Rev. Lett. 71(1993)4120.

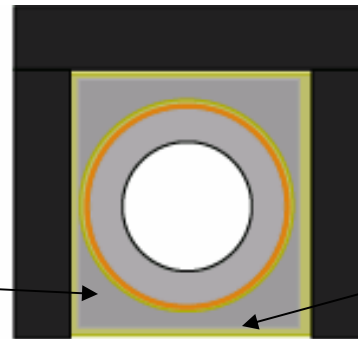
DAQ: XIA Polaris DSPEC digital spectrometer (shoebox-sized package offers event-by-event waveform capture for pulse-shape analysis (PSD), muon veto input and all power supplies)



Minimalistic detector and DAQ

(space between μ Ms and CCD very limited, also must not add to platform burden)

Front View



Plastic Muon Veto

Cd thermal-neutron absorber (2mm)

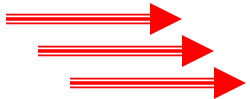
Pb shielding

Thin brass endcap (Tedarlar seals against Rn)

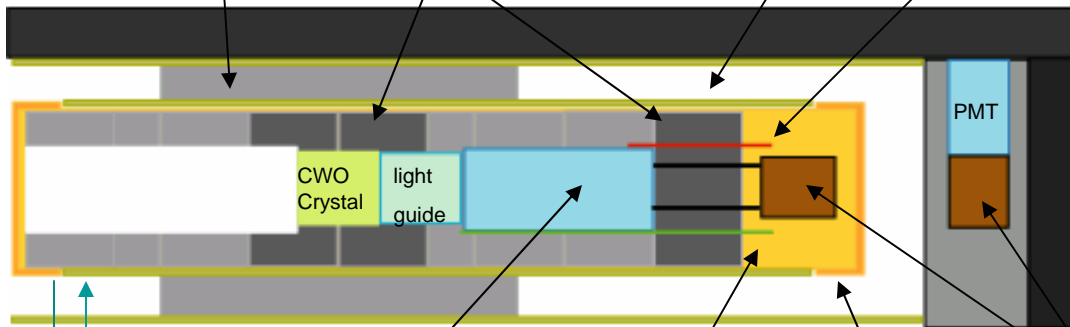
Ultra-low bckg Pb ($<0.02 \text{ Bq } ^{210}\text{Pb/kg}$)

thermocouple (gain monitoring)

Incoming gammas (magnet bore)



"tunnel" design reduces bckg from open end (good alignment essential)



Rn displacement (N2 purge gas)

Low-bckg PMT (Electron tubes, $< 20 \text{ } ^{40}\text{K}$ gamma / day)

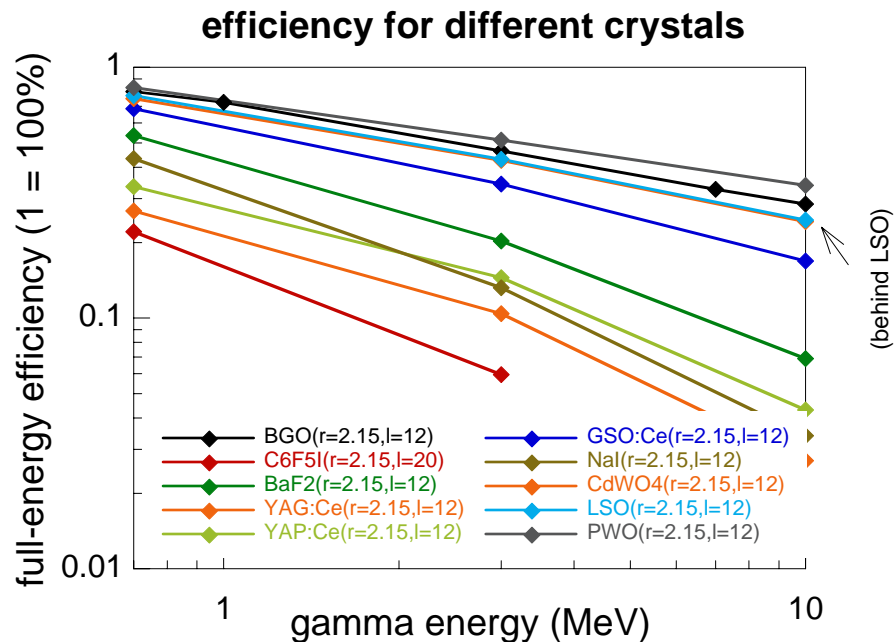
Fiber optic and LED (to pulser, for dead time monitoring)

brass support canister

PMT low-voltage (5V) power bases



Side View (total length 60 cm, weight ~ 25 kg)

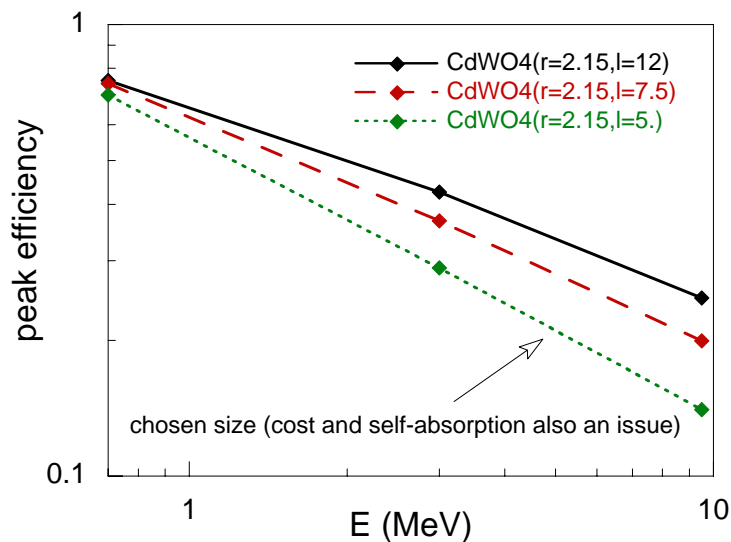


Decisions, decisions:

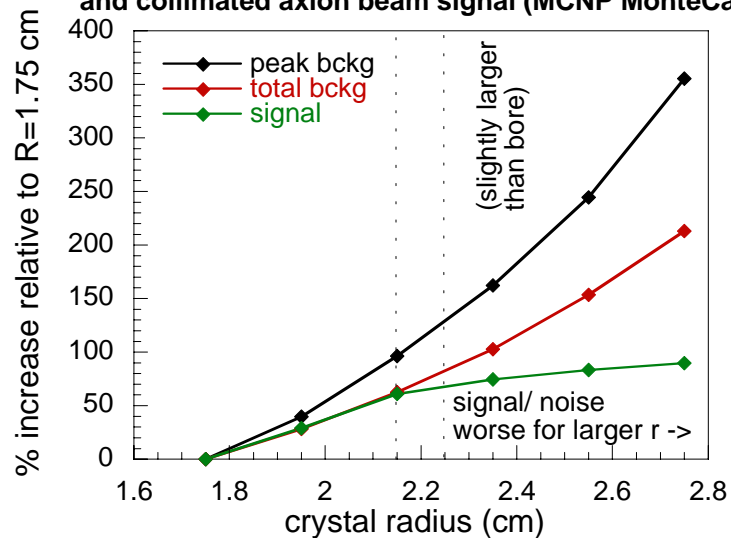
Monte Carlo of inorganic crystal response reduced best choices to BGO or CWO (PWO has too low a light yield)

Choice of optimal crystal length and radius via Monte Carlo of collimated signal and isotropic backgrounds. Crystal must be well-aligned with magnet bore (only slightly larger than it).

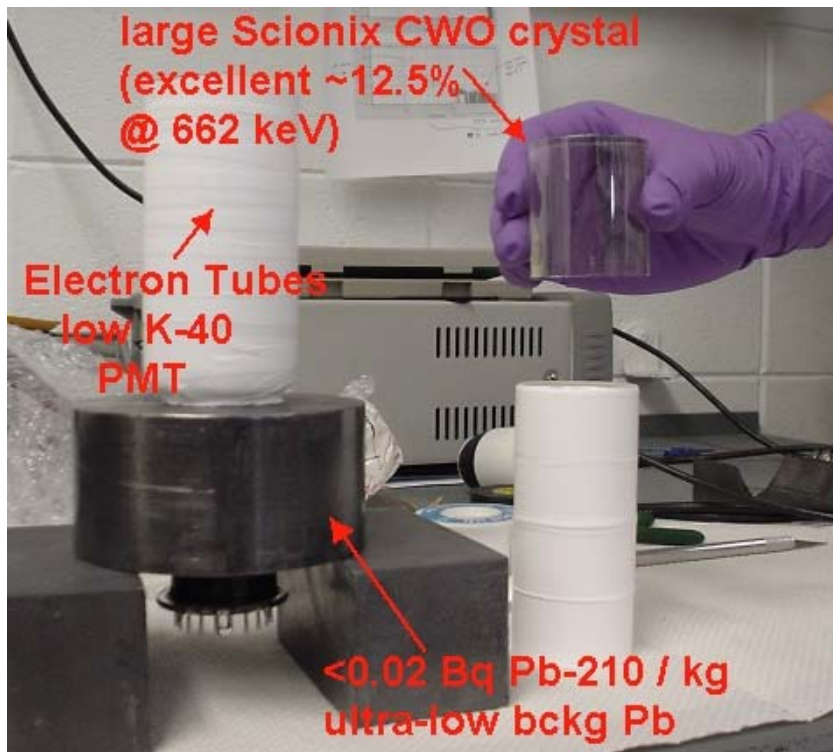
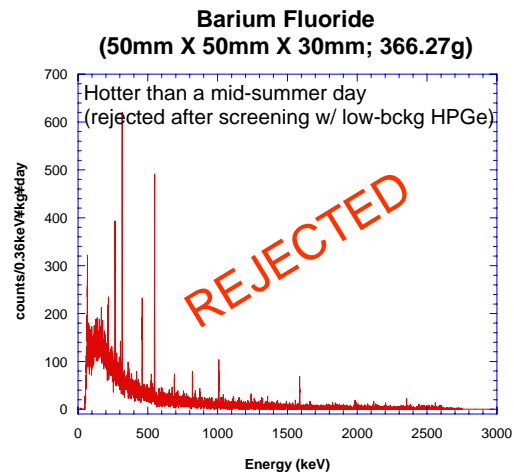
MCNP calculated full-energy (peak) efficiency for collimated axion-induced gammas



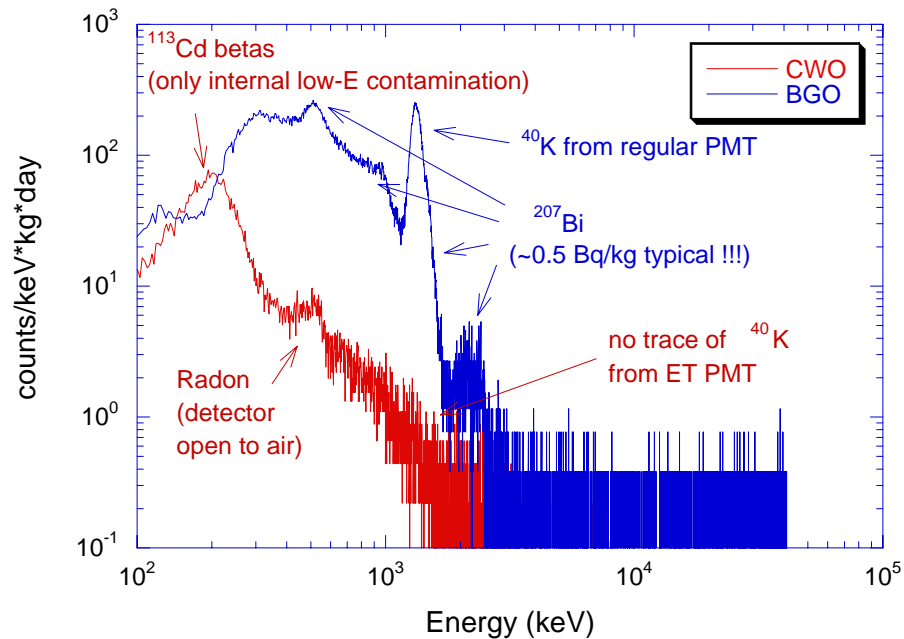
CWO crystal (l=7.5cm) in Pb shielding (R=4.75cm) response to 1 MeV isotropic bckg and collimated axion beam signal (MCNP MonteCarlo)



Crystal selection in EFI low-background lab (6-60 m.w.e)



Comparison of standard BGO and CAST CWO (muon veto, low Pb-210 shielding, 6 m.w.e. depth)



XIA Polaris DSPEC allows event-by-event analysis

PSD Program v. 9.1b.vi Front Panel

File Edit Operate Tools Browse Window Help

13pt Application Font

Master Control: STOP

Create binary file? YES

Create log file? NO

Dynamic Range (MeV): 95.87

Events per Spill: 3.00

Points for Digital Filter: 400

Points for Integrtd Energy: 1000

Trace Delay (μ s): 10.00

Energy Threshold in Analysis (MeV): 0.00

Offset (ns): 10354.37

Risetime(ns): 403.96

PID: 2.049

Energy (MeV): 0.6437

Peak Center: 0.5100

FWHM(%): 23.60

Signal: -581.20

BCKG: 35221.01

mse: 2.5335

Derivative: numeric

Event by Event: Continuous

PID max: 20.00

PID min: 0.00

Alpha Template File	Event #	Hit Pattern	Energy (MeV)	Baseline	Pulse Onset (pts)	Unnorm.PID	Run Start Date	Event Date	Time Since Run Start (sec)
ALPHA	30000	1.00	0.6437	1685.786	406.096	5.803	9/30/2003	9/30/2003	2672.0

Gamma Template File	# Words	Vetoed Events	PID	Baseline disp.	Integrtd light	# After Cuts	Run Start Time	Event Time	(ms)
GAMMA	2409	0	2.0486	2.822	47088.29	2041	12:12:31 PM	12:57:03 PM	625.638

POLARIS waveform

Pulse Amplitude vs Time (units of 25ns)

PID vs Event number (not from origin)

rise time (ns) vs Polaris Energy (MeV)

Left limit: 0.50, Peak center: 0.4900

Right limit: 0.70, FWHM(%): 23.6000

Signal: 993.52, BCKG: 3078.14

mse: 32.2857

	Leftmost pts		Rightmost pts	
Upper Bound	E (MeV): 0.000	PID: 0.00	E (MeV): 0.000	PID: 0.0
Lower Bound	E (MeV): 0.000	PID: 0.00	E (MeV): 0.000	PID: 0.00

Boundary (MeV) (lwr cutoff): 0.000, 0.000

	E (MeV)	PID	RiseTime
Upper Bound	0.500	30.0000	1.0E+4
Lower Bound	0.050	5.0000	0.00

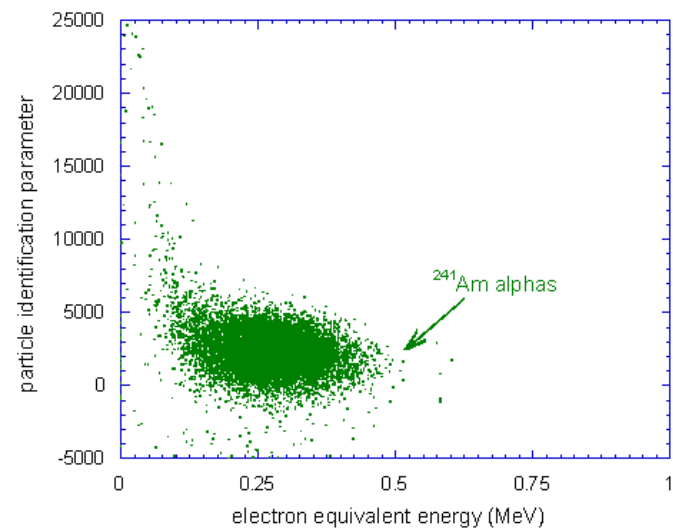
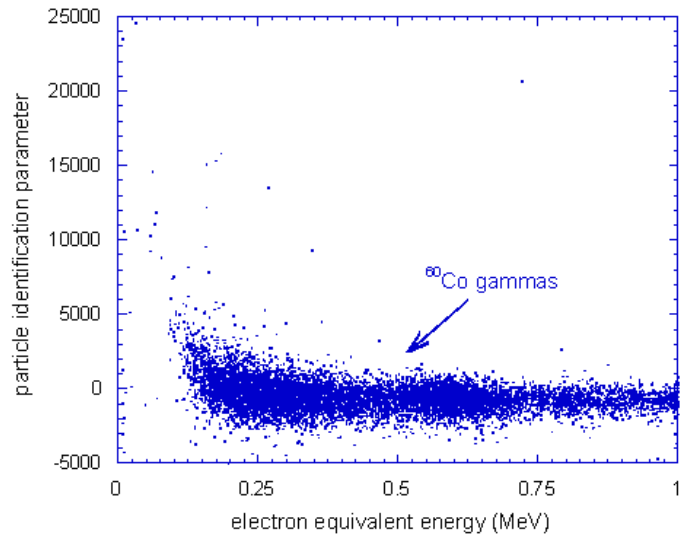
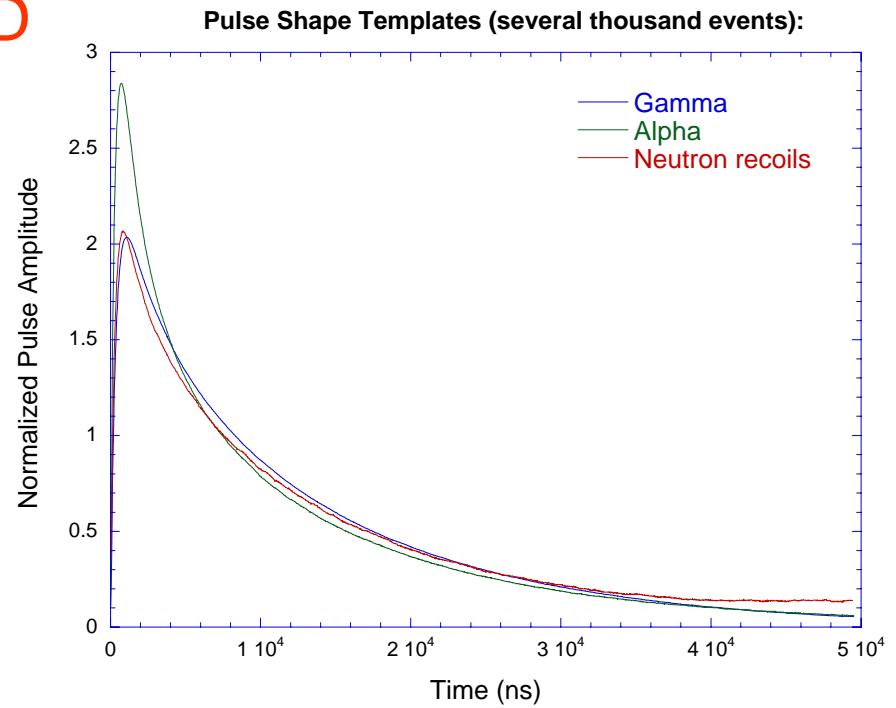
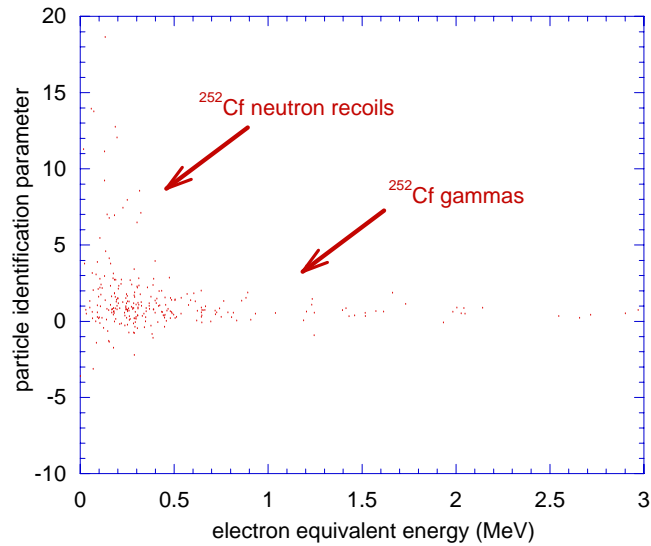
Pause (s): 0.B, 1.B, 0.00

mean: NaN, std dev.: NaN, variance: NaN

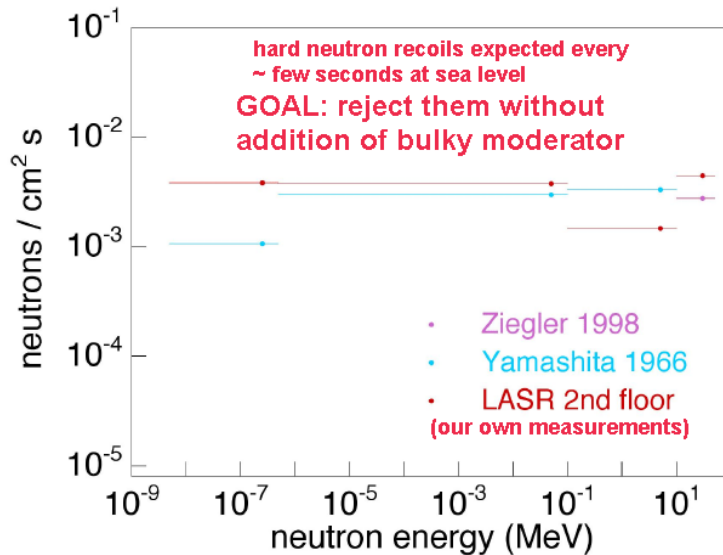
Windows: LabVIEW 7.0 Dev..., Inbox - Microsoft Out..., KaleidaGraph

10:10 PM

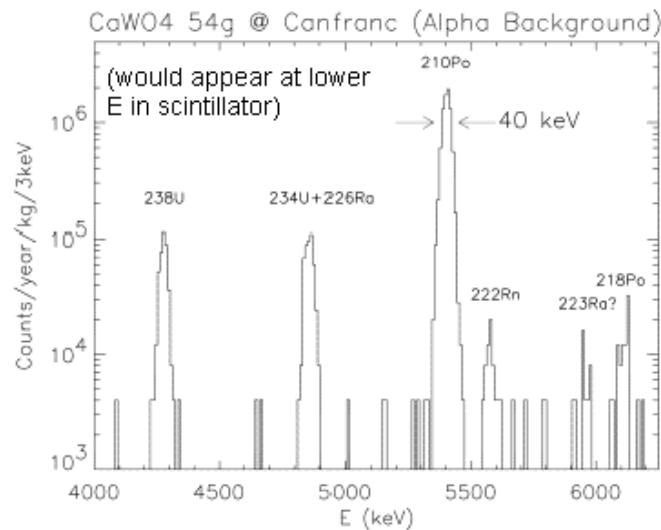
CWO is also excellent for PSD



PSD can reject non gamma-like backgrounds while keeping shielding to a minimum



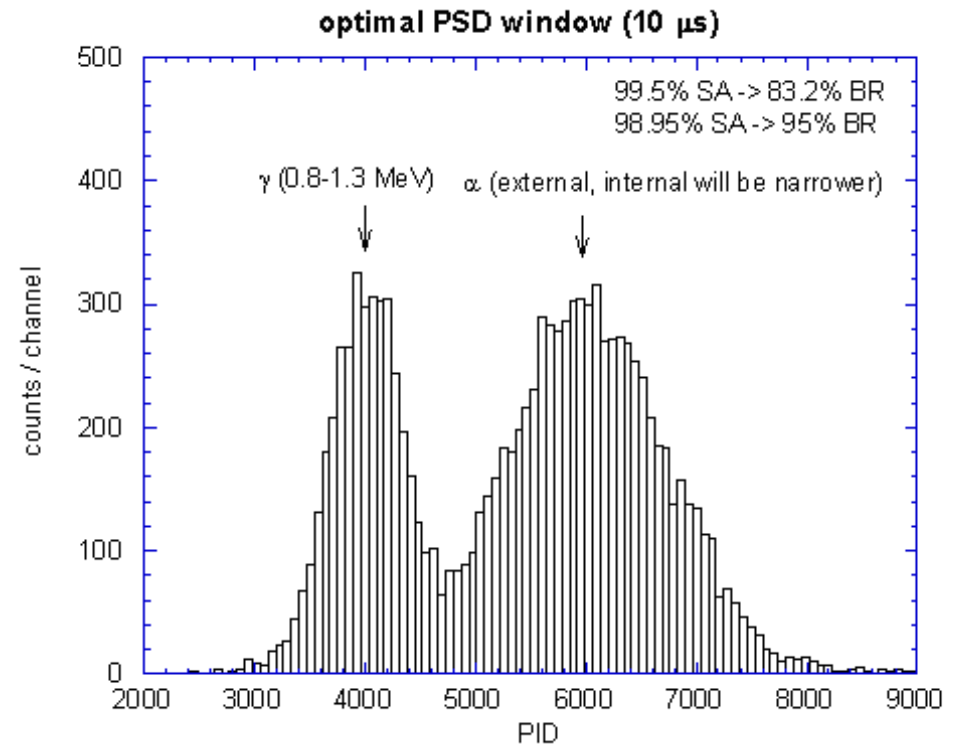
Possible internal alpha contamination can be rejected



Bolometer data from S. Cebrian et al.
(U. Zaragoza)

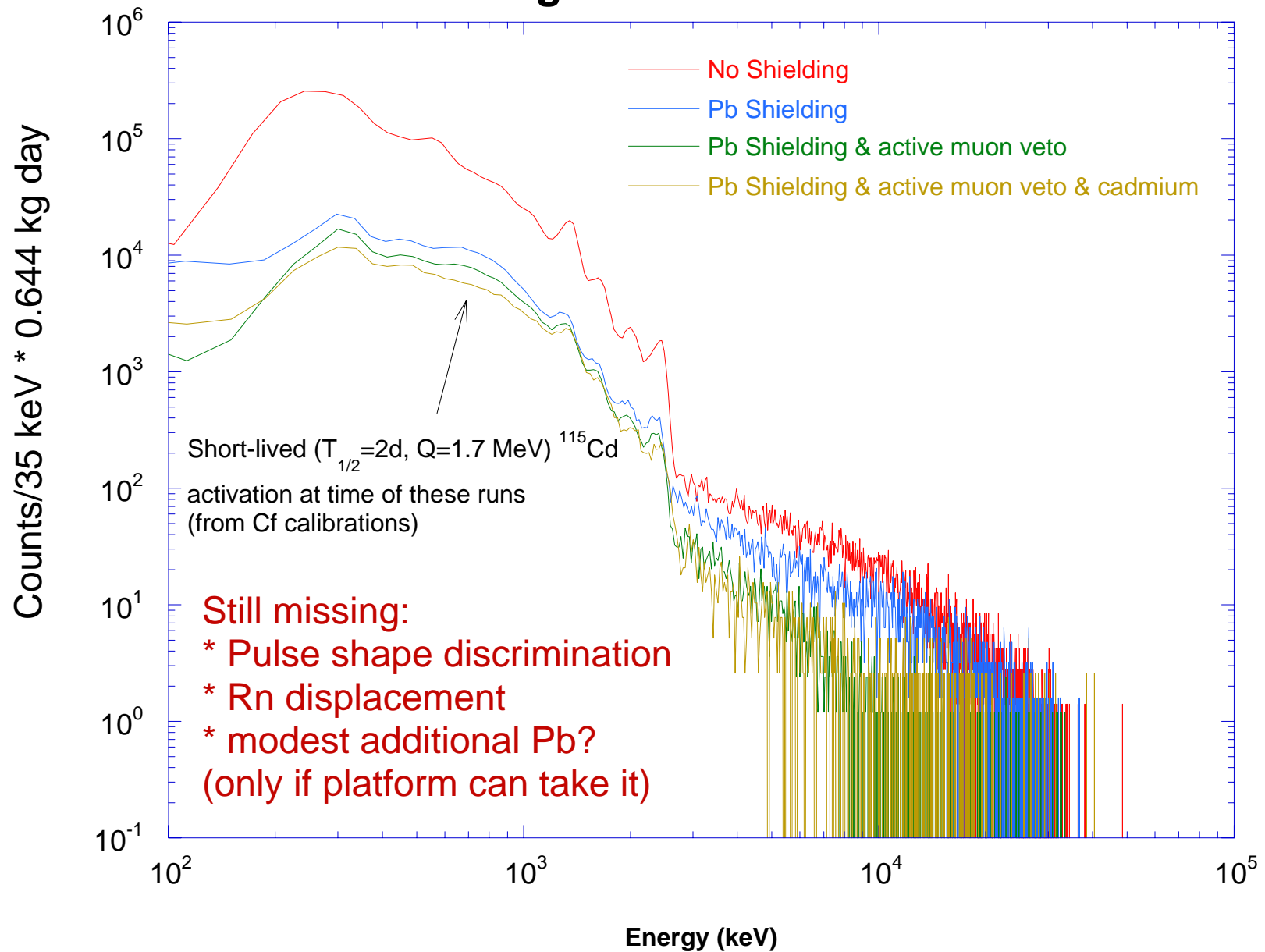
Achieved PSD surpasses that of CWOs used in $\beta\beta$ -decay

(T. Fazzini et al. NIM 410(98)213;
F.A. Danevich et al. PLB 344(95)72;
F.A. Danevich et al. nucl-ex/0003001)



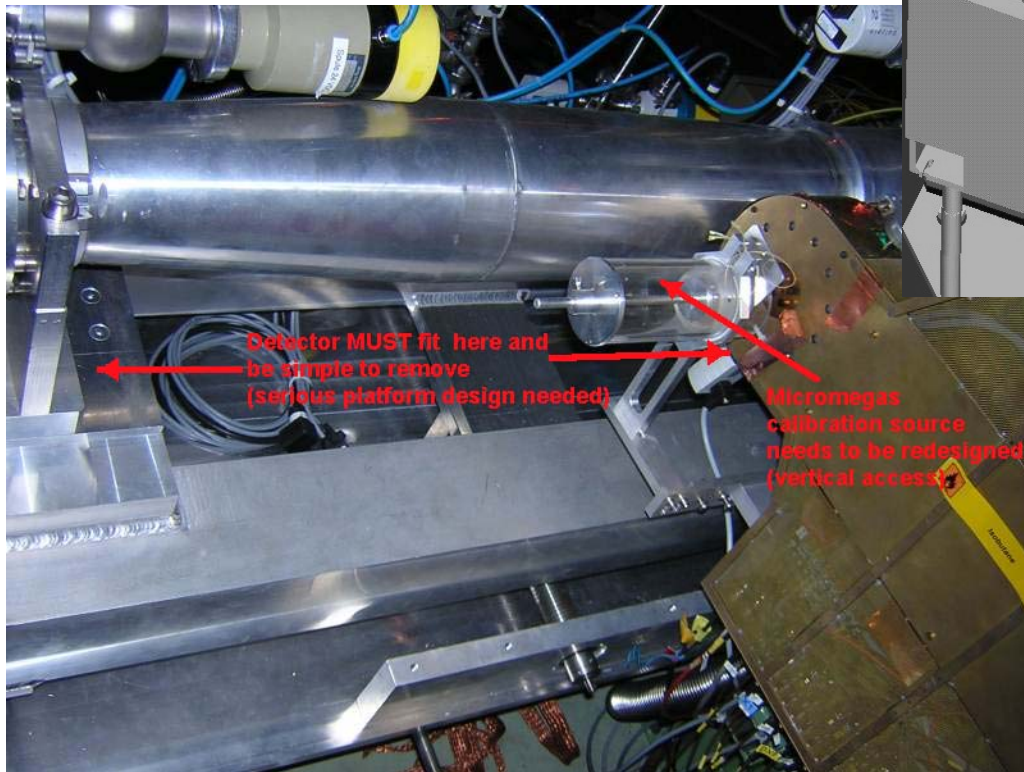
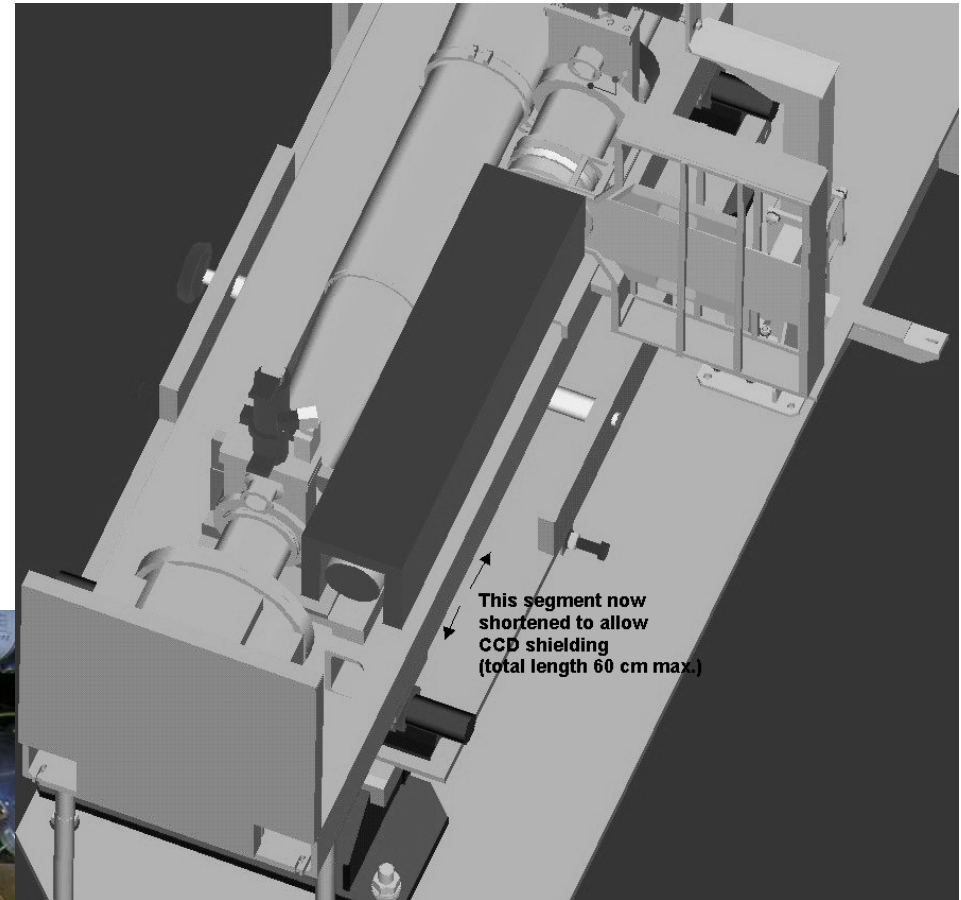
98.8% Signal acceptance for
95% α -background rejection

PRELIMINARY: Background Reduction data



Detector essentially ready for placement as early as this December

(but platform design must be carefully prepared to avoid interference and allow fast removal if needed)



Need exact Micromegas cross-section to determine low-E threshold (~200-300 keV expected)