Title: Recent Results from the CRESST dark matter search

Date: Nov 18, 2010 02:00 PM

URL: http://pirsa.org/10110061

Abstract: CRESST is a cryogenic dark matter search located at the Laboratori Nazionali del Gran Sasso in Italy. Scintillating CaWO4 crystals are operated as cryogenic calorimeters. The phonon (heat) signal measured with a tungten transition edge sensor on the surface of these crystals allows a precise determination of the energy deposited in the crystal, independent of the type of interaction. A light signal, simultaneously registered by a separate cryogenic detector, serves to identify the type of interaction. This phonon/light technique allows a discrimination of electron recoils induced by radioative backgrounds from the searched nuclear recoils with high efficiency ,and, to some extent, even to determine which type of nucleus was recoiling. I will present results from 564 kg-days of data of the presently still ongoing run, which reveal an unexpected excess of oxygen recoils. To shine some light on the nature of these events, I will discuss possible backgrounds in some detail.

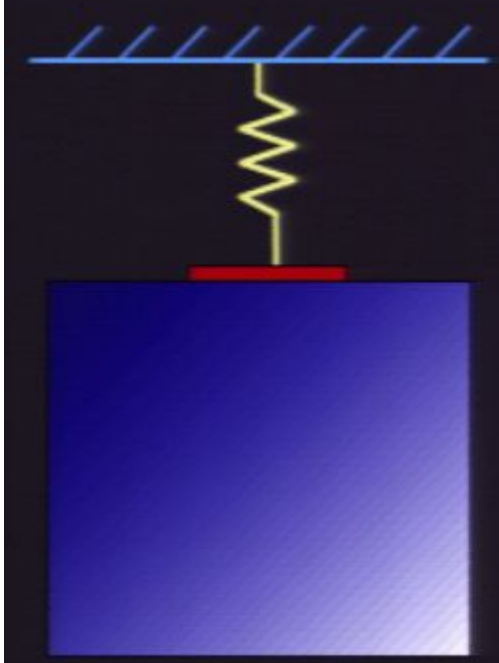
Outline

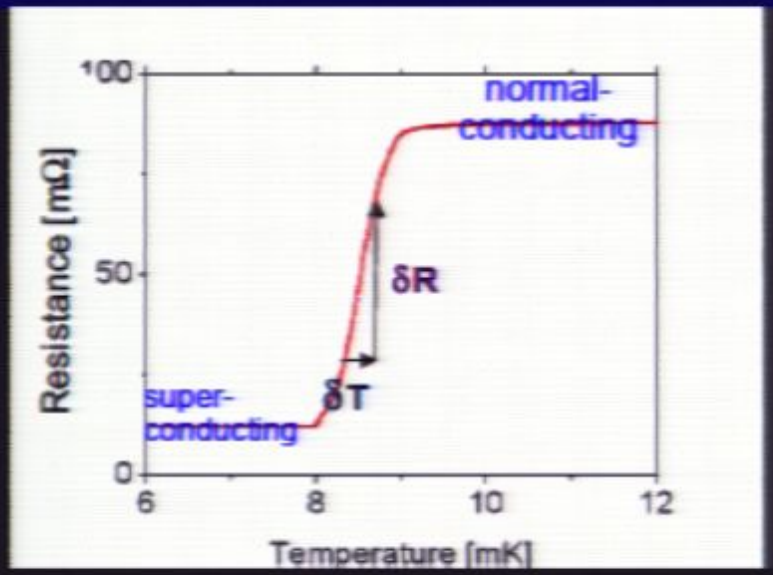
CRESST detectors and setup

Results from present run

Conclusion

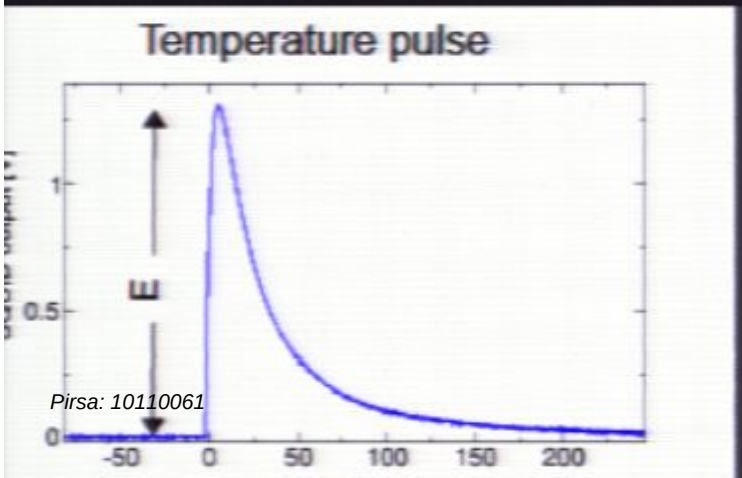
CRESST type cryogenic Detectors





SQUID based read out circuit

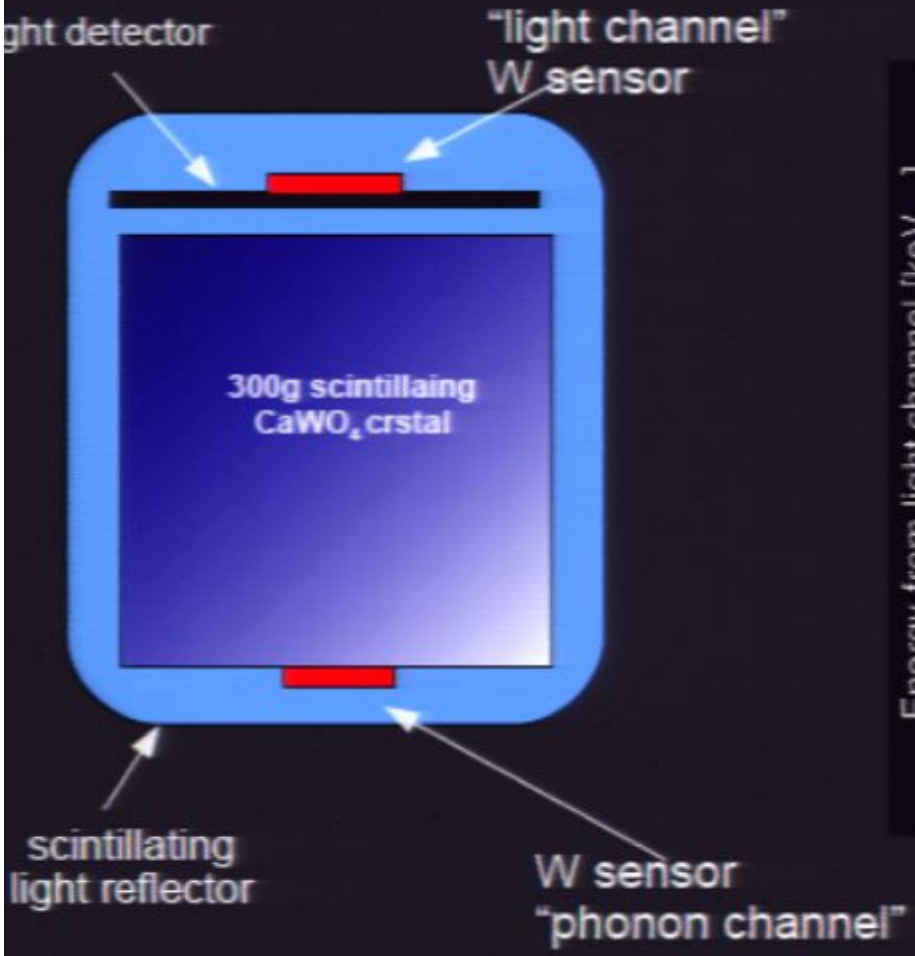
Operating temperature: 10 to 20 mK
Width of transition: ~1mK, keV signals: few µK
Longterm stability: ~ µK

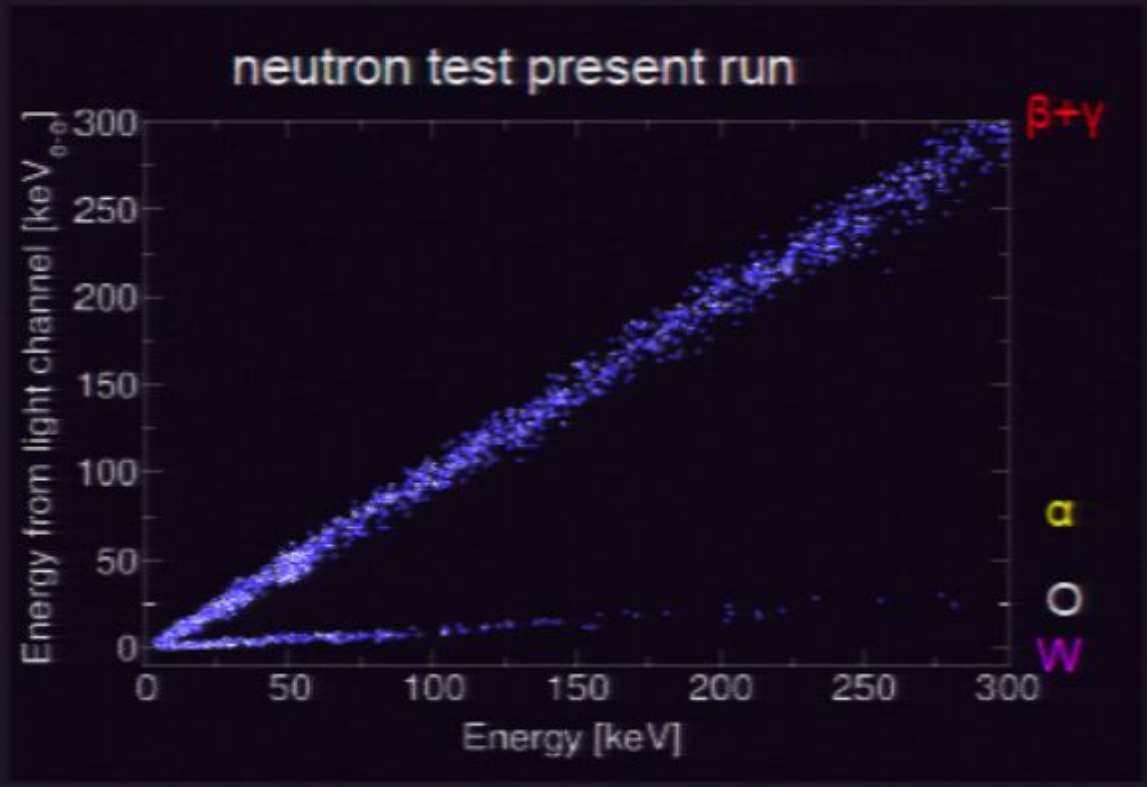


Advantages of technique:

- measures deposited energy independent of interaction type
- Low energy threshold and excellent energy resolution
- Different materials

CRESST Detectors





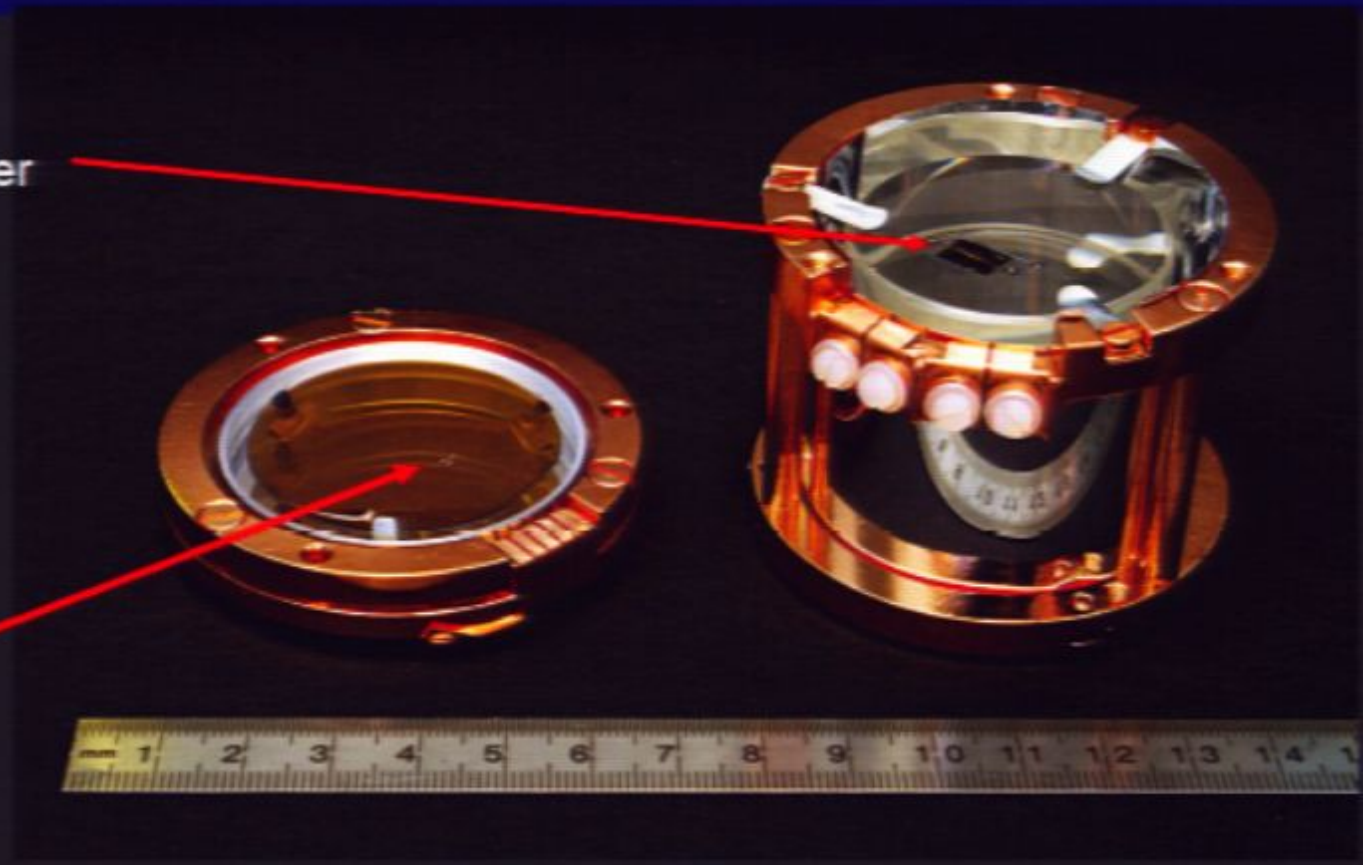
-- phonon channel measures deposited energy with high precision, independent of of interaction type

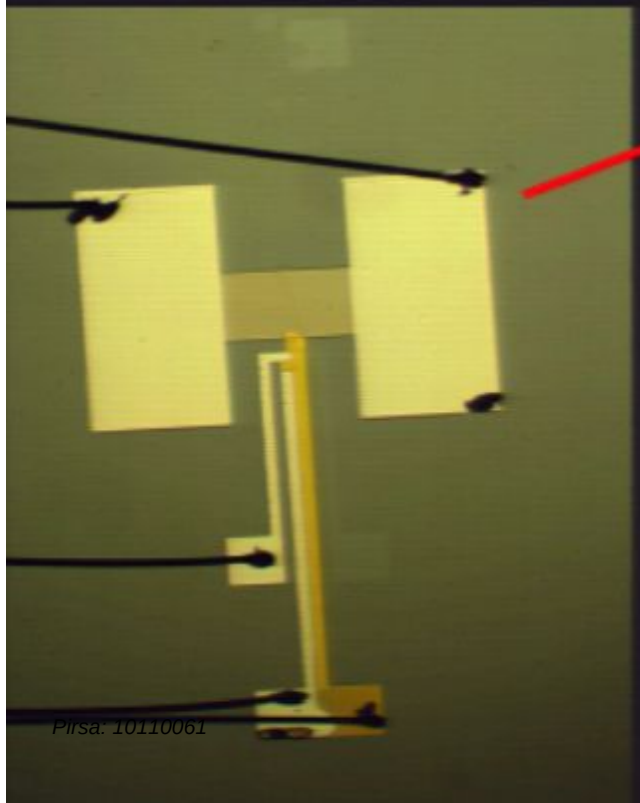
-- efficient discrimination of nuclear recoils from electron recoils of β+γ backgrounds

-- distinguish different types of recoiling nuclei by different slopes in light phonon

300 g Detector Module

The phonon detector:
300 g cylindrical $CaWO_4$ crystal,
evaporated tungsten thermometer
with attached heater.





The light detector:
Ø=40 mm silicon on sapphire wafer.
Tungsten thermometer with attached
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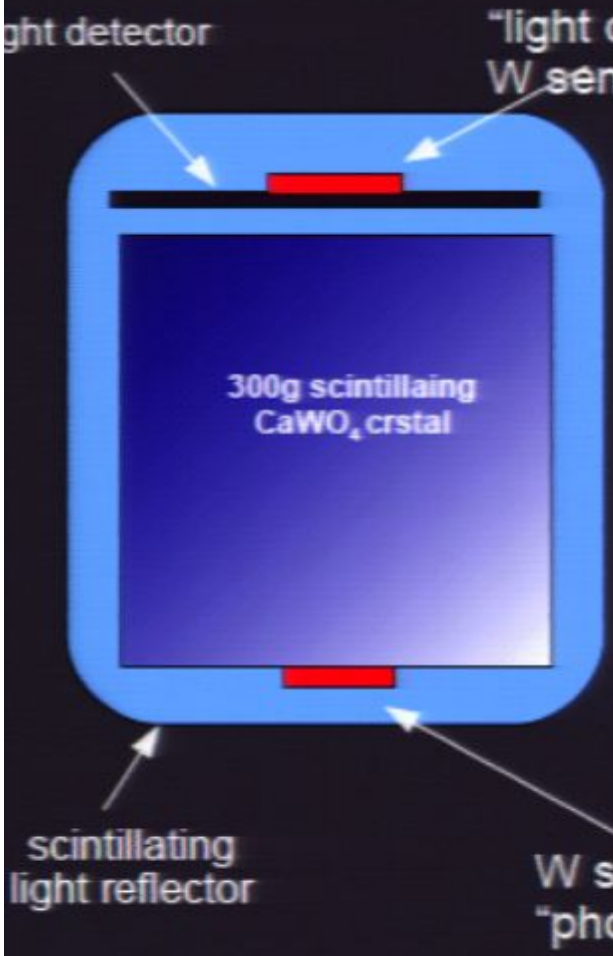
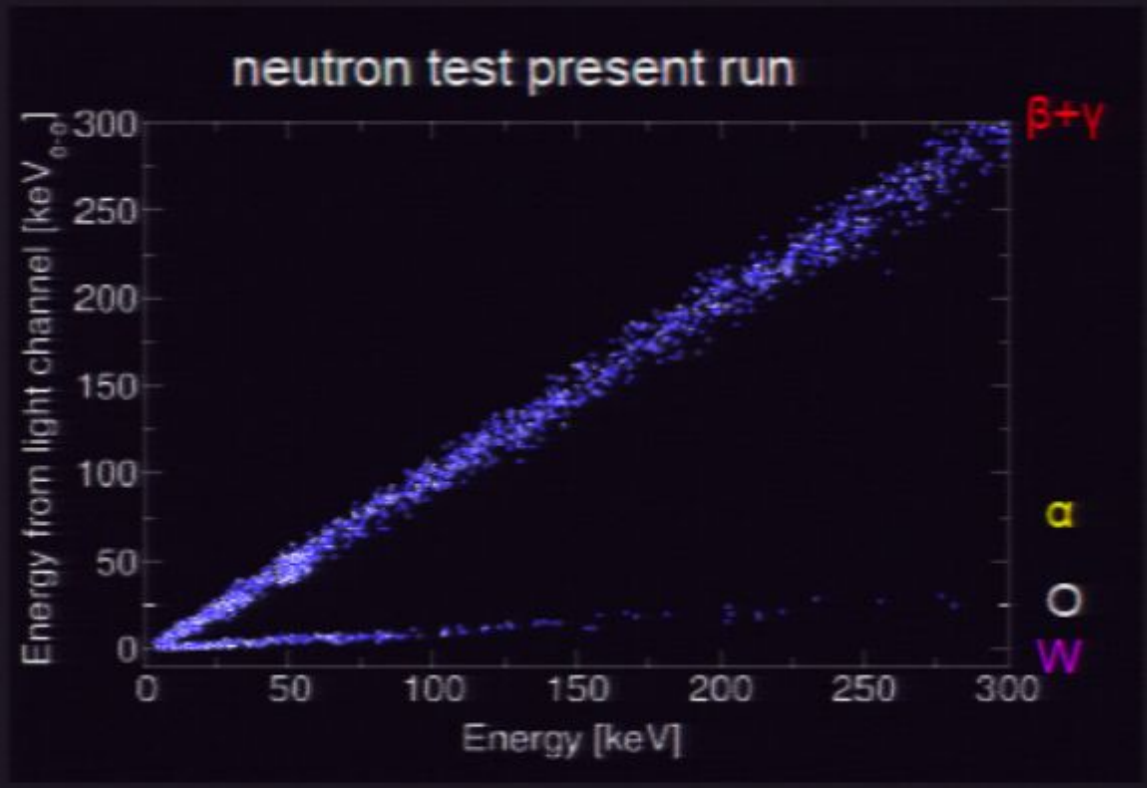
CRESST Detectors





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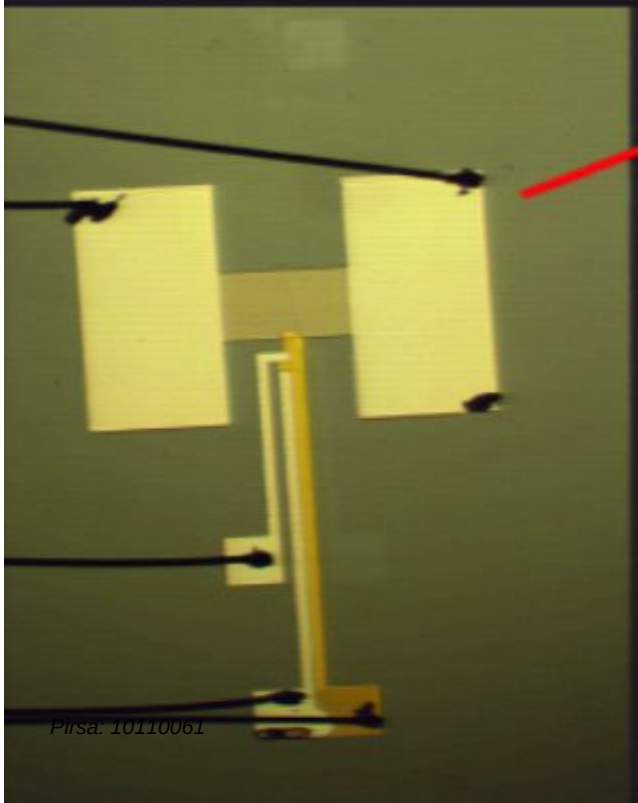

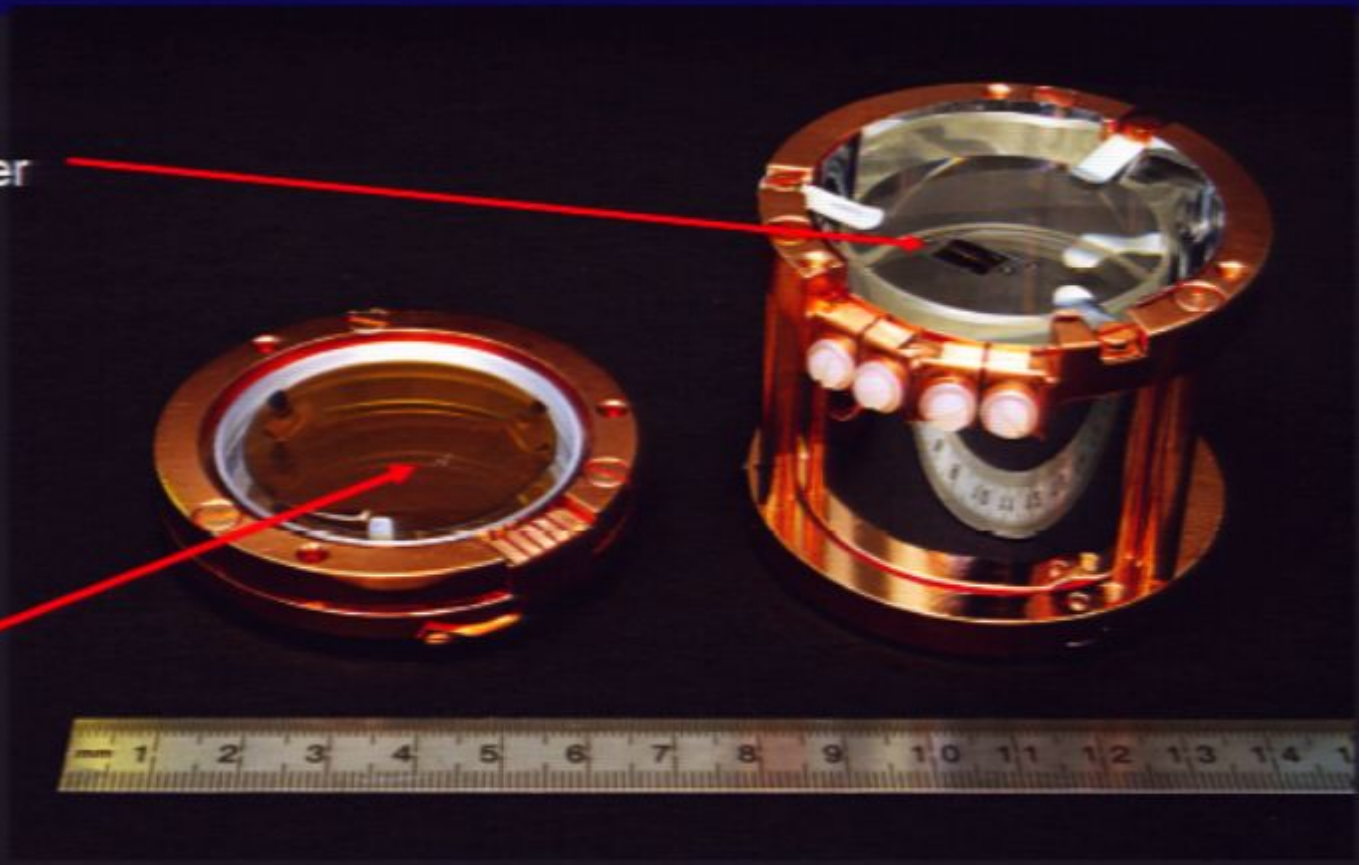

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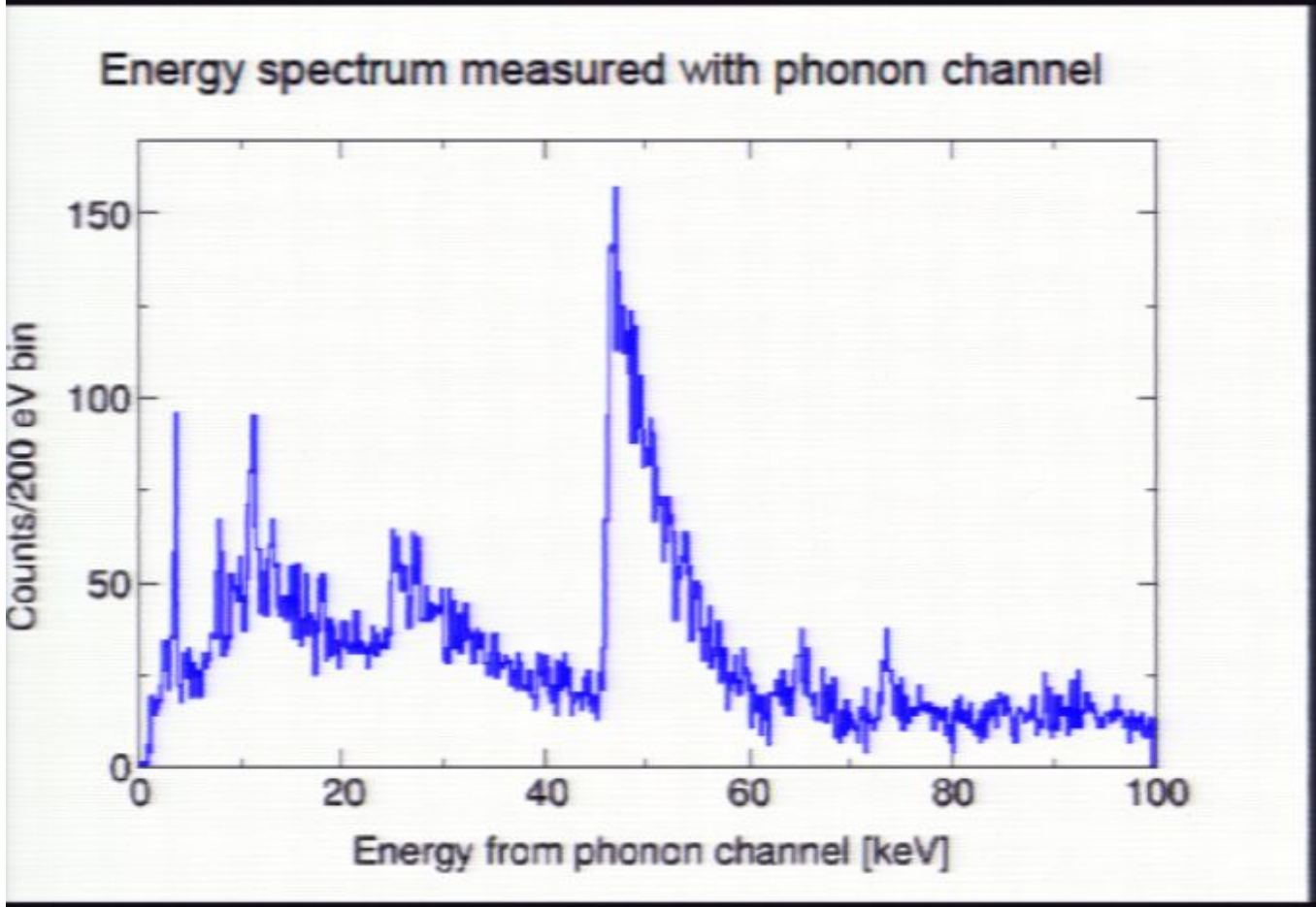
Detector performance at low energies



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found @8.2 keV

^{41}Ca 3.61 keV found
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^{210}Pb 46.5 keV
@ 46.5 keV

- Very precise energy calibration
- Lines down to 3.6 keV identified with excellent energy resolution of 300 eV (FWHM).

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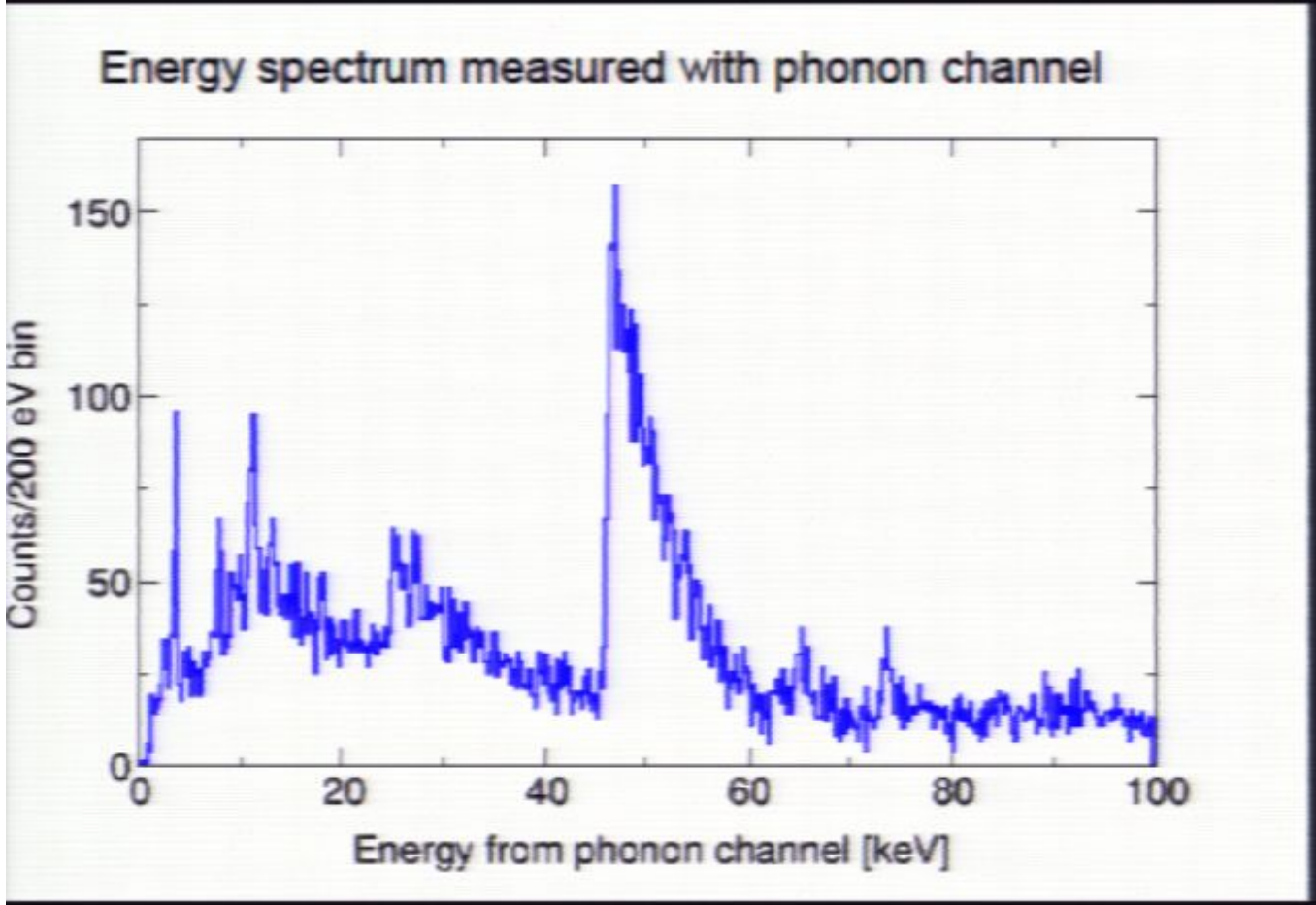

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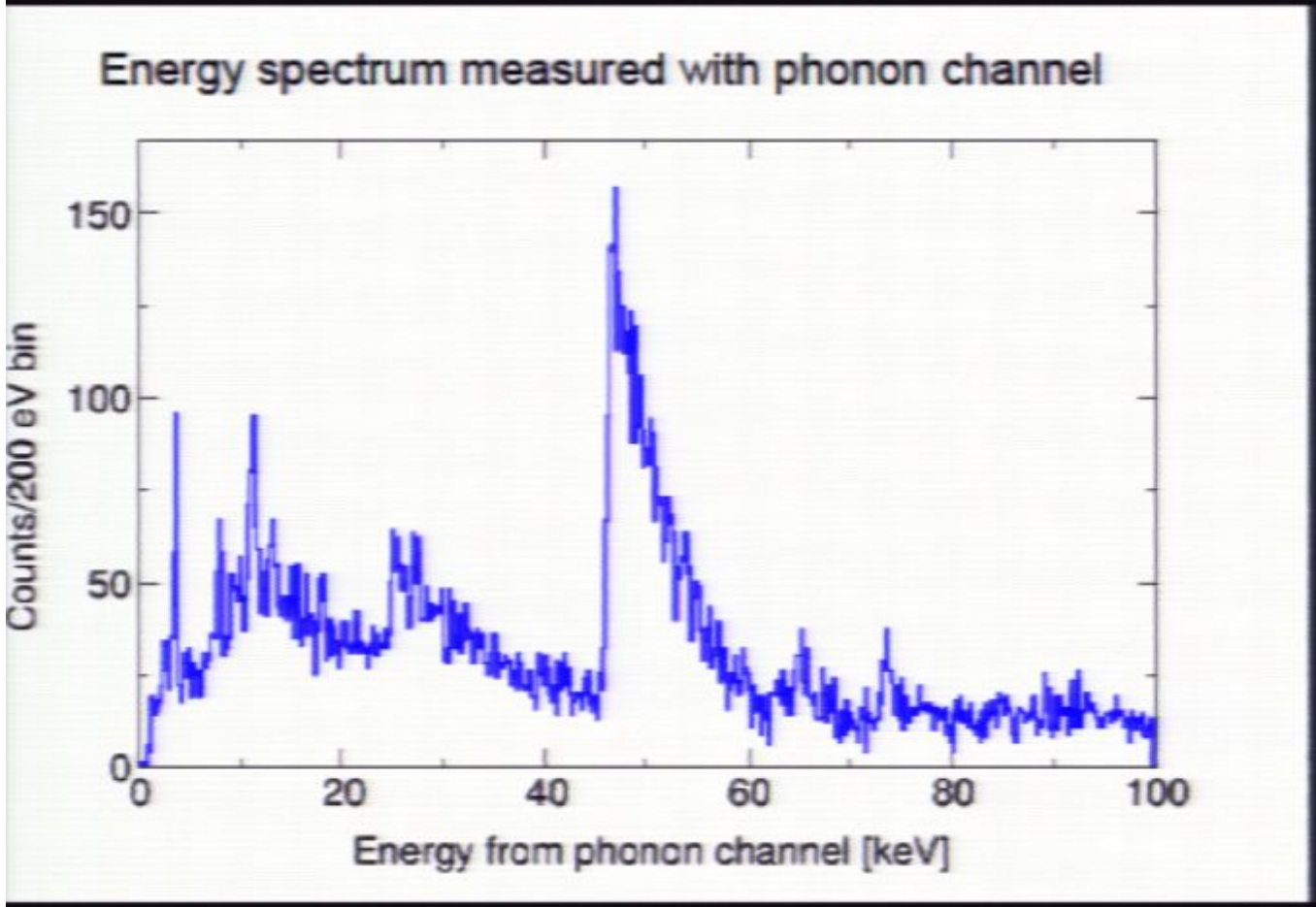

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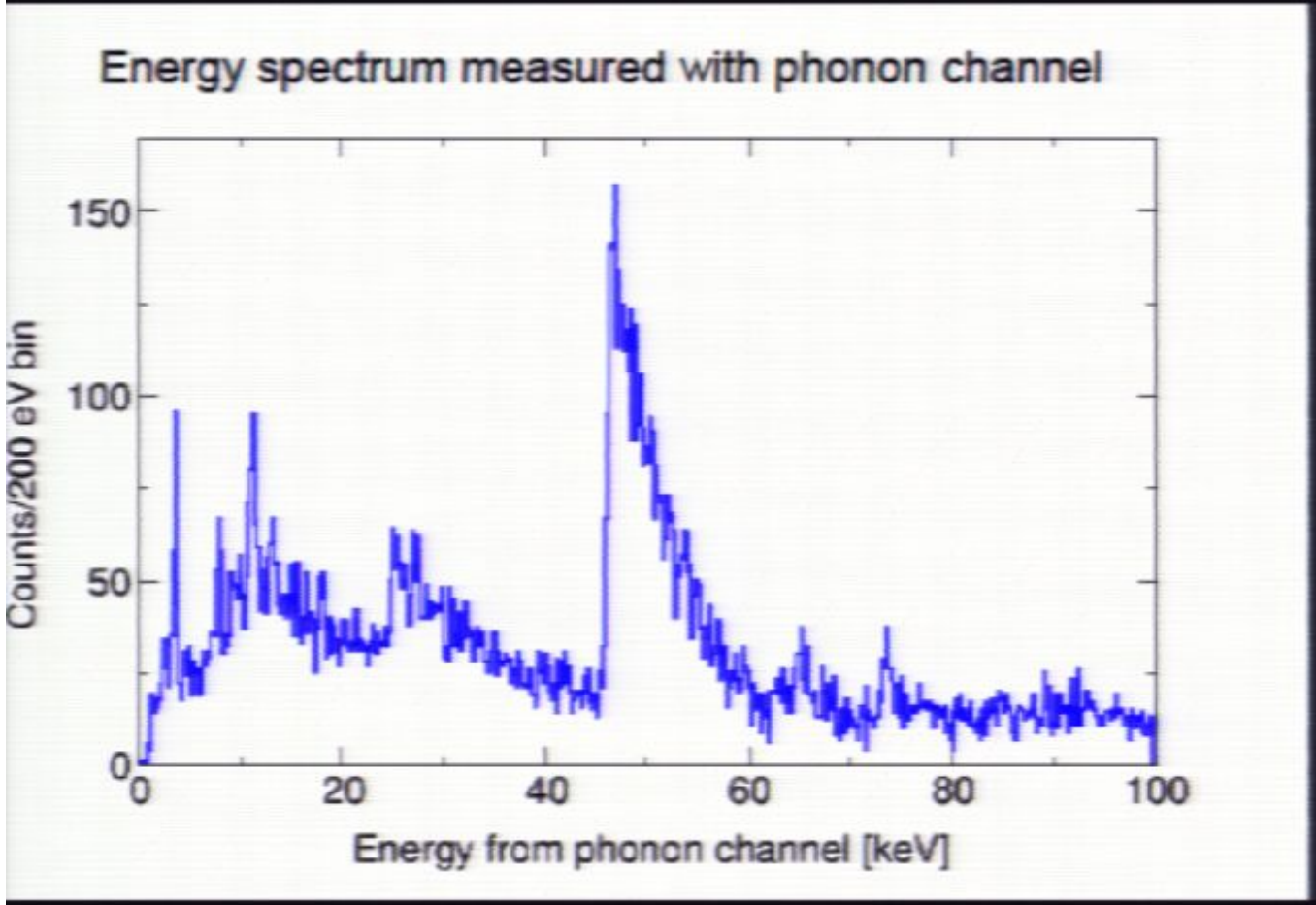

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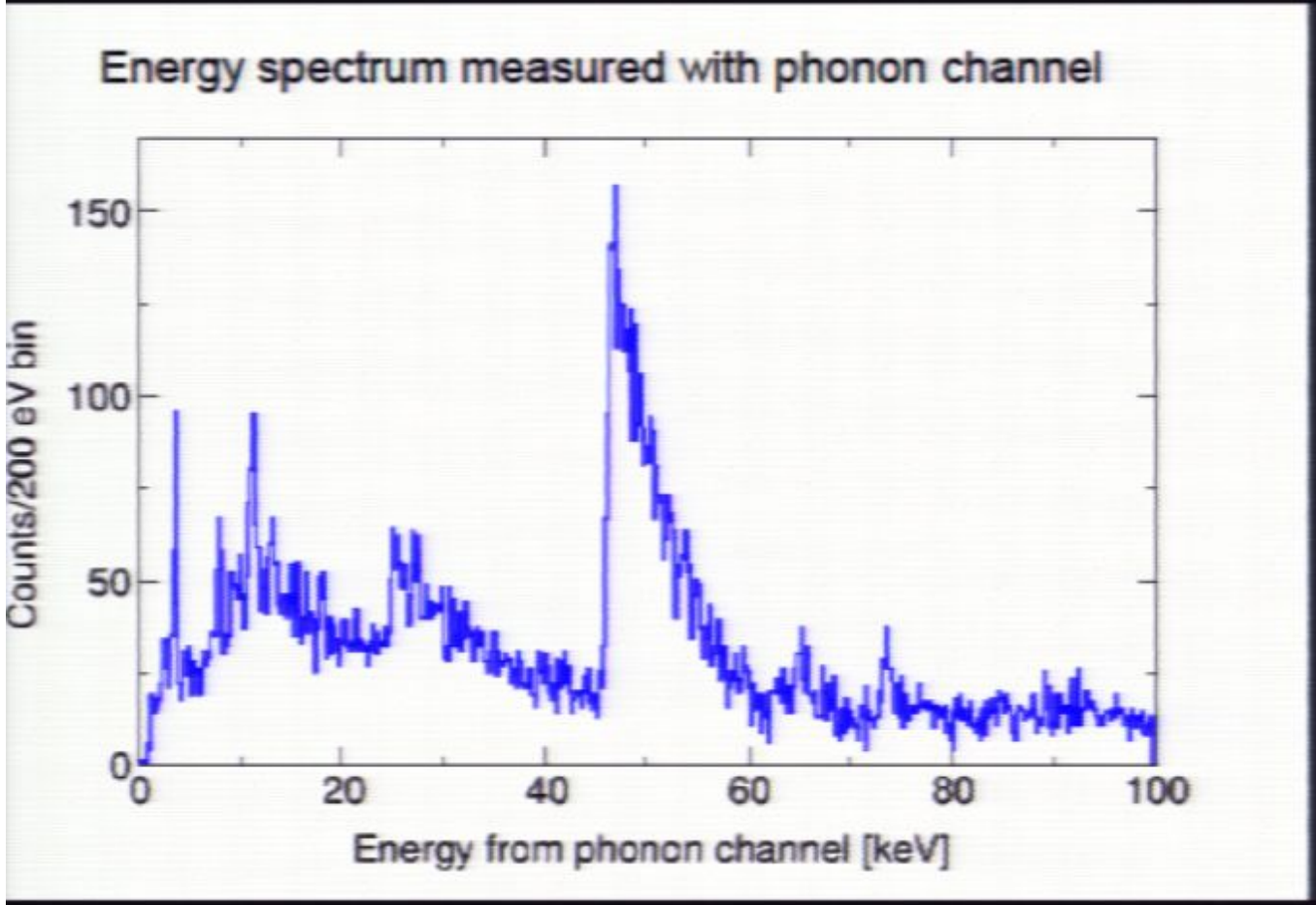

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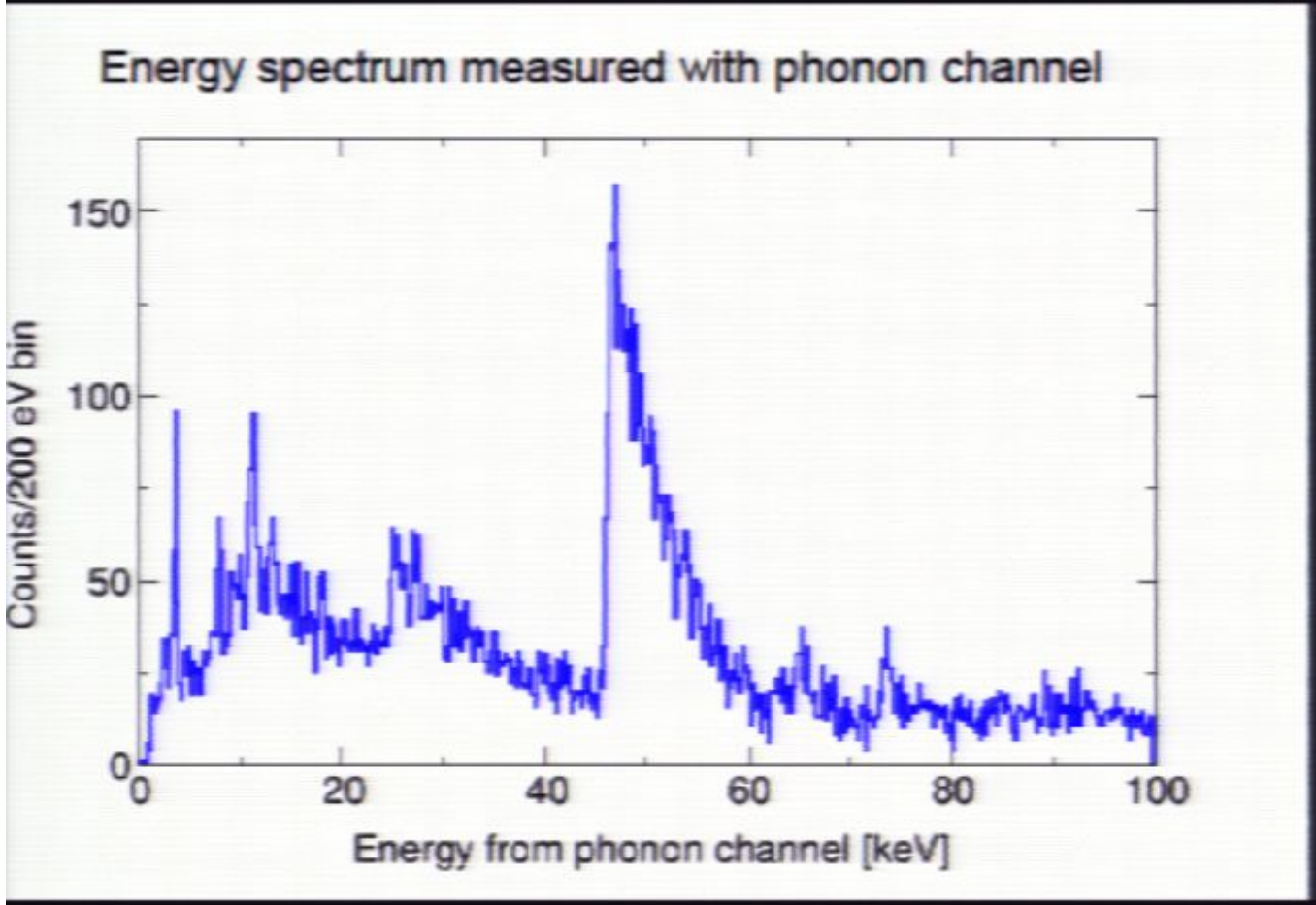

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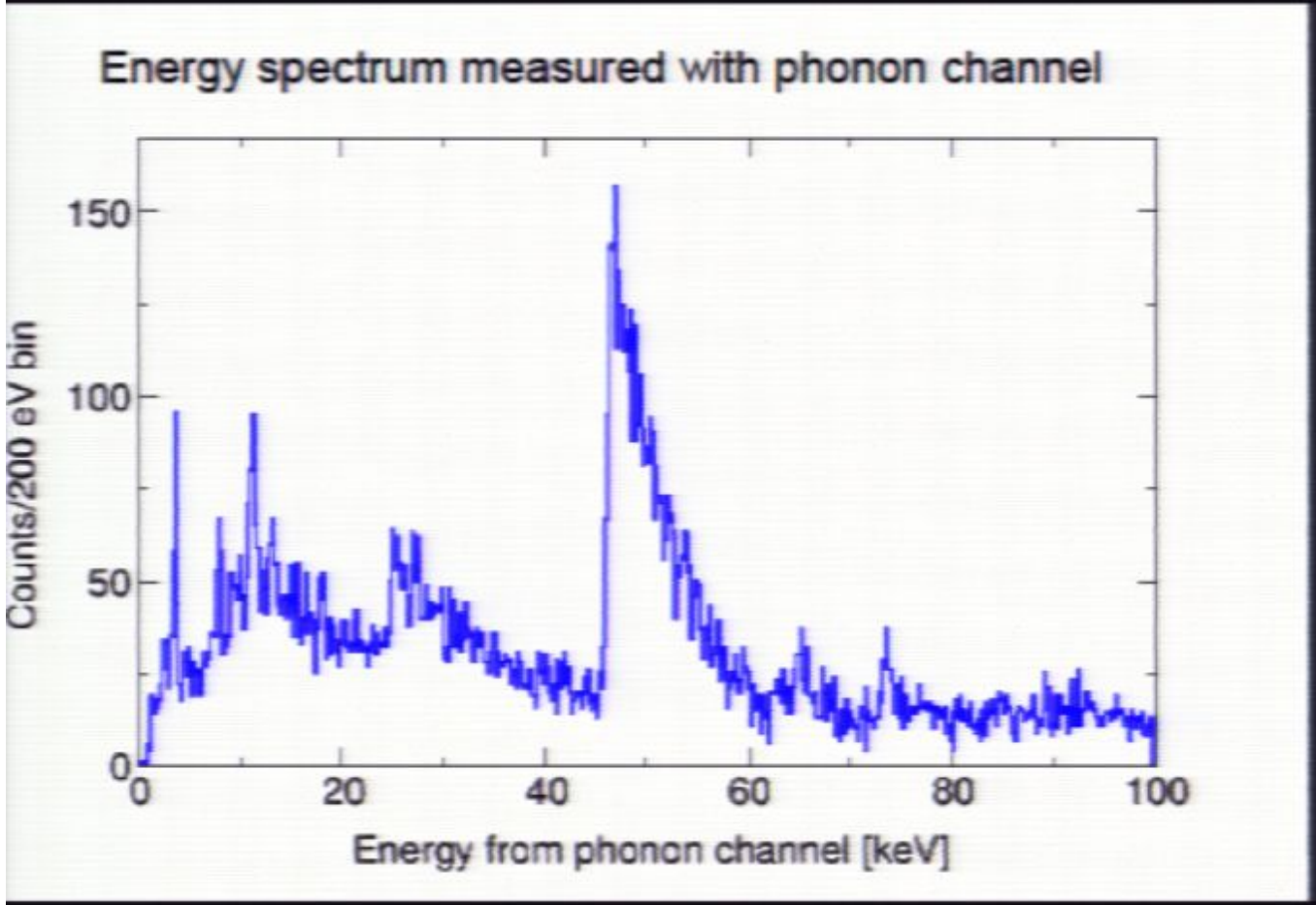

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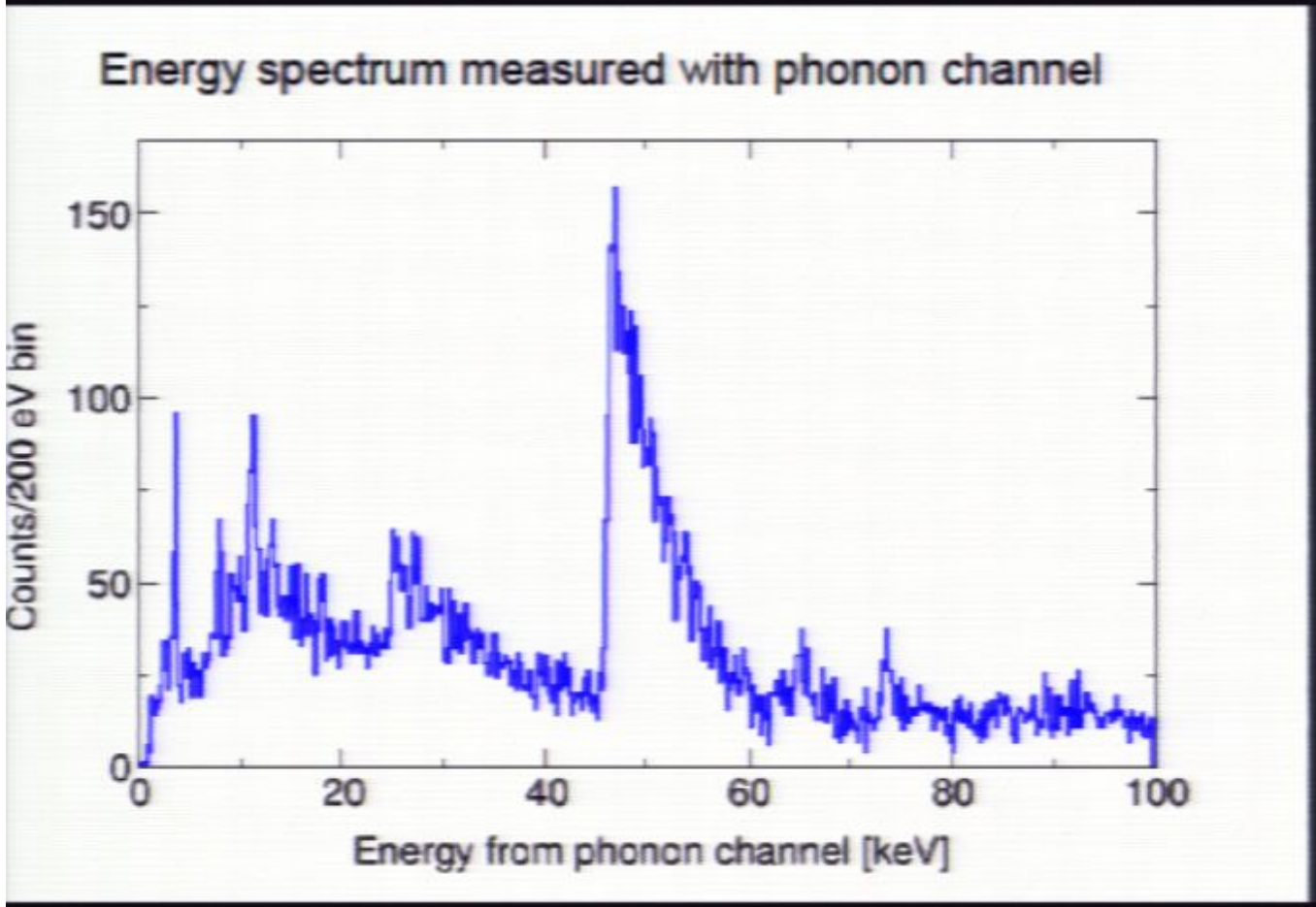

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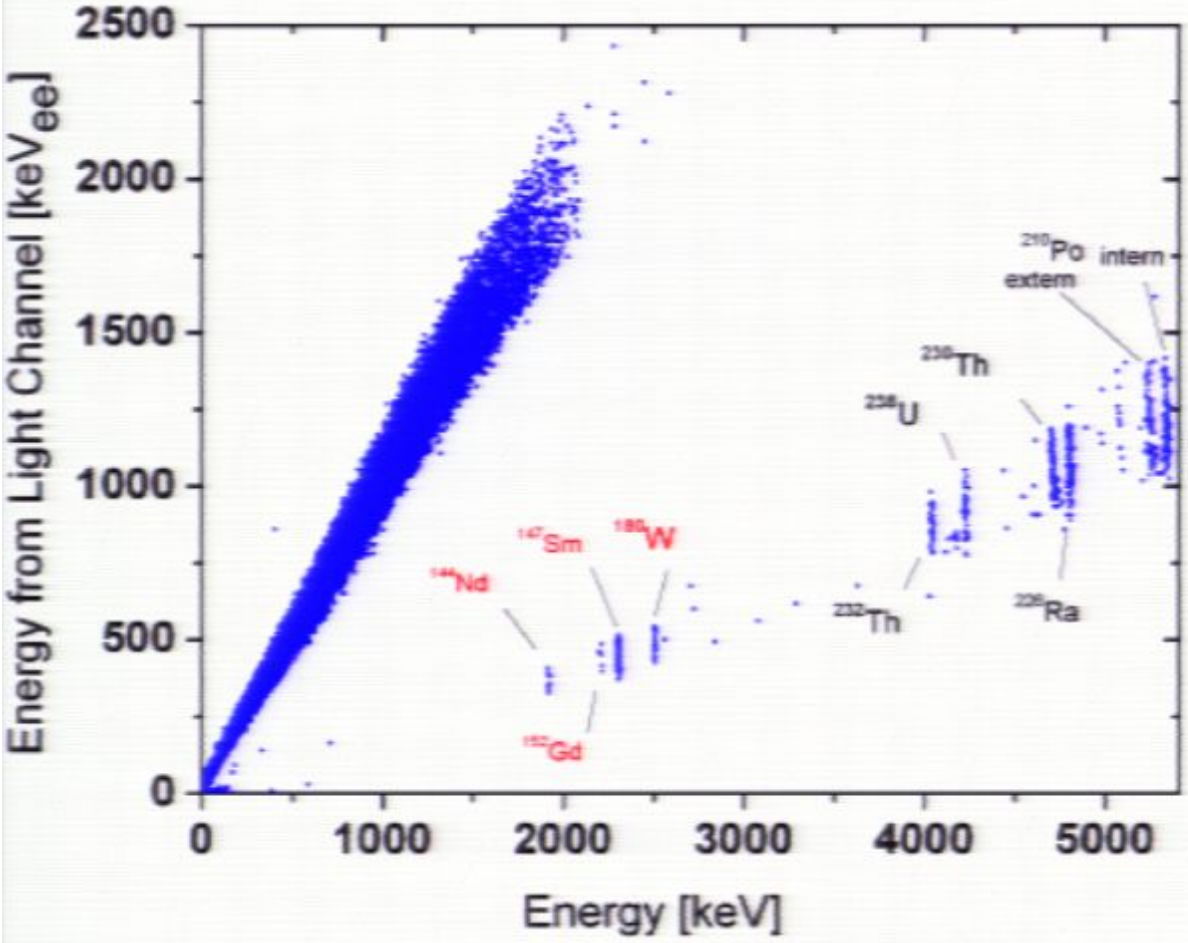
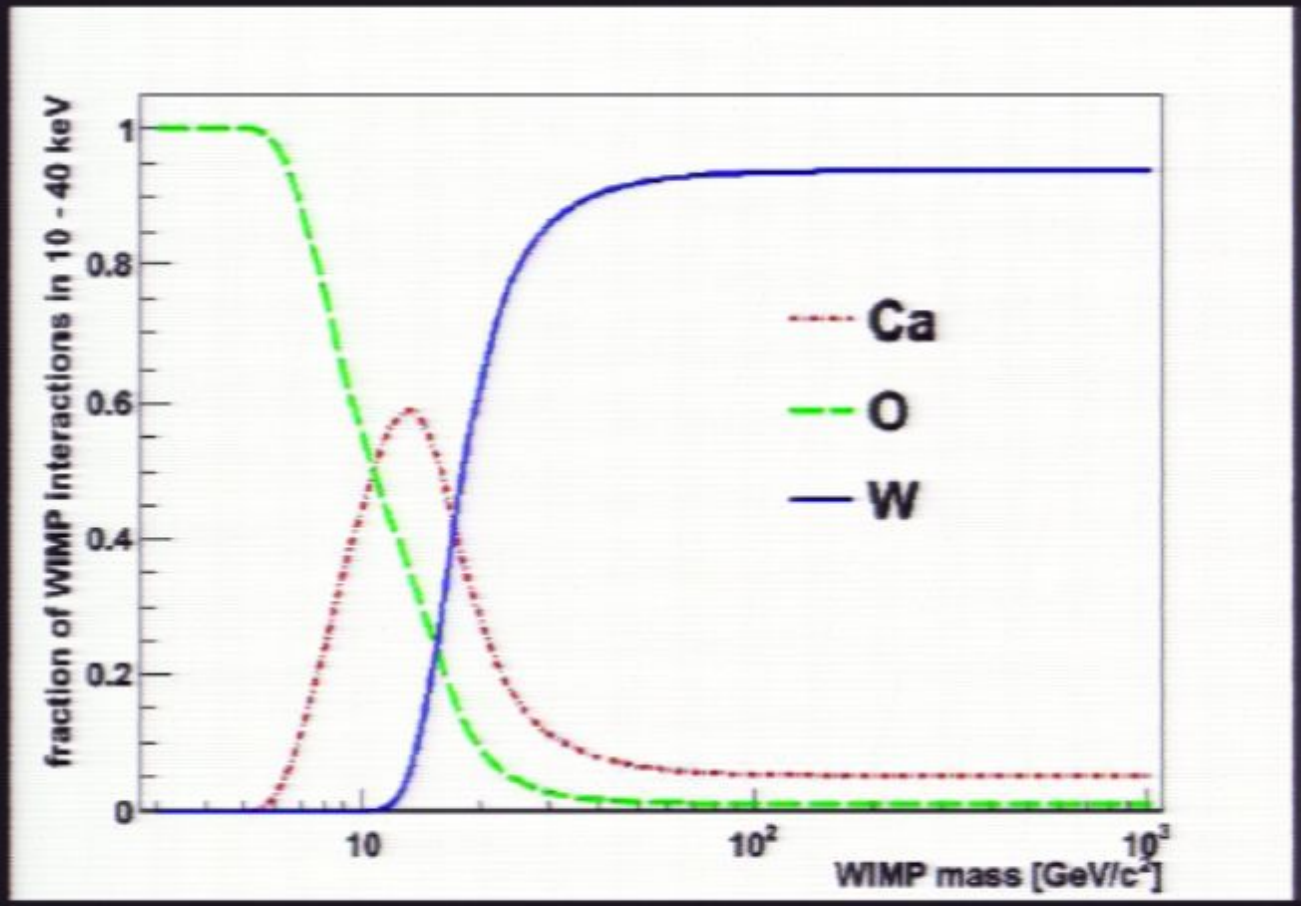
Detector Performance in wide energy range



- Enormous dynamic range
- Excellent linearity and energy resolution in whole energy range
- Perfect discrimination of β/γ from α's
- Identification of alpha peaks from emitters in crystal

Which recoil nucleus is seen in $CaWO_4$



assuming
$\sigma \propto A^2$

sensitive range:
10 to 40 keV

For small WIMP masses <10 GeV only O recoils above threshold
Ca is important around 10 GeV
For large masses W dominates due to $\sigma \propto A^2$

CRESST setup at LNS

Passive shielding:

underground laboratory

45 cm PE (12 tons)

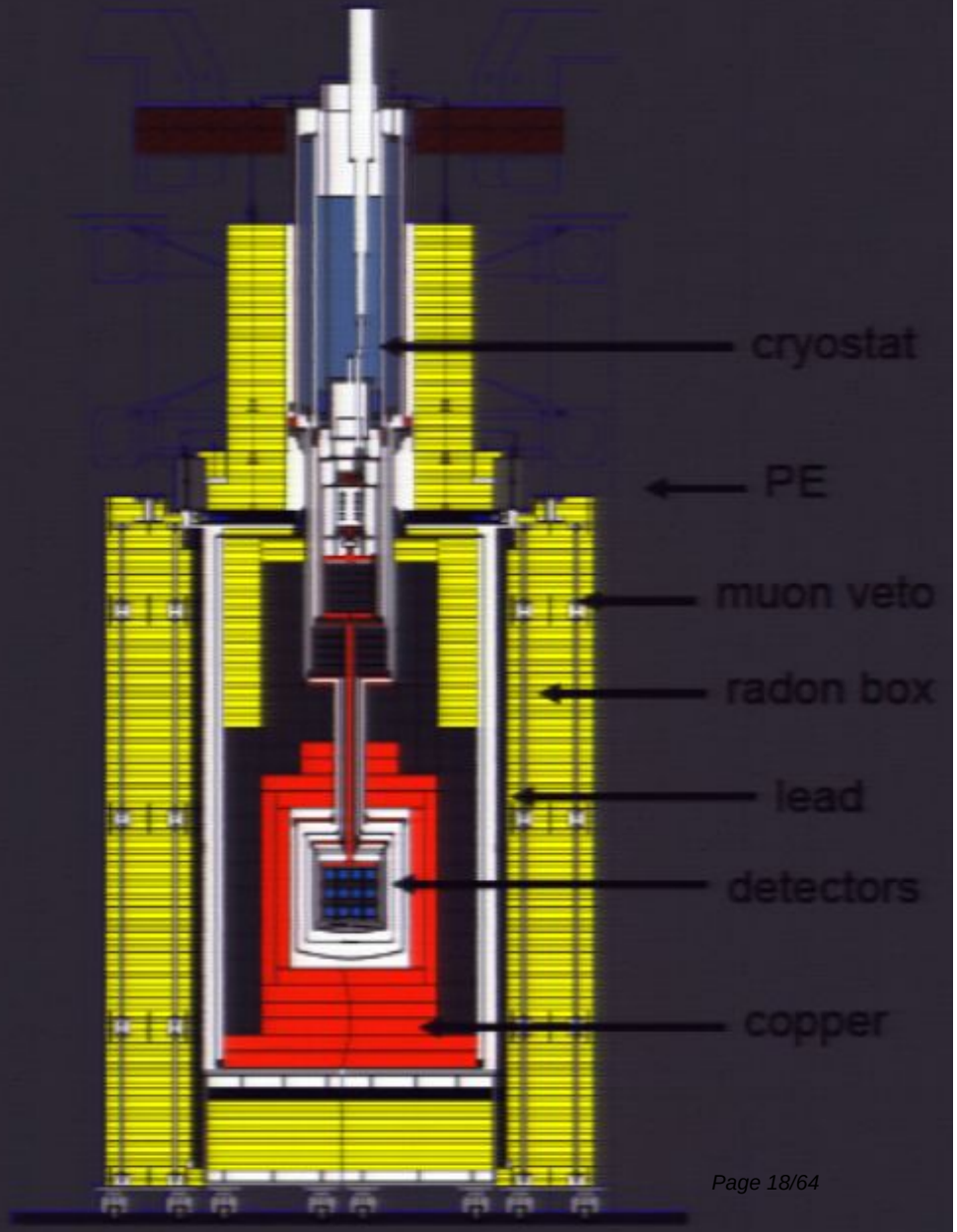
radon box

muon veto

20cm Pb (24 tons)

14 cm Cu (10 tons)

only radio-pure materials



Results from Present Run

- Cold since May 2009
- 10 complete modules (9 $CaWO_4$+1 $ZnWO_4$) + 7 single channels deliver data
- Clamps holding the crystals not covered with scintillator
- Data analysis in progress and results still preliminary
- Data (564 kg-days) from 9 $CaWO_4$ crystals, a neutron test in May and open neutron shield data will be discussed

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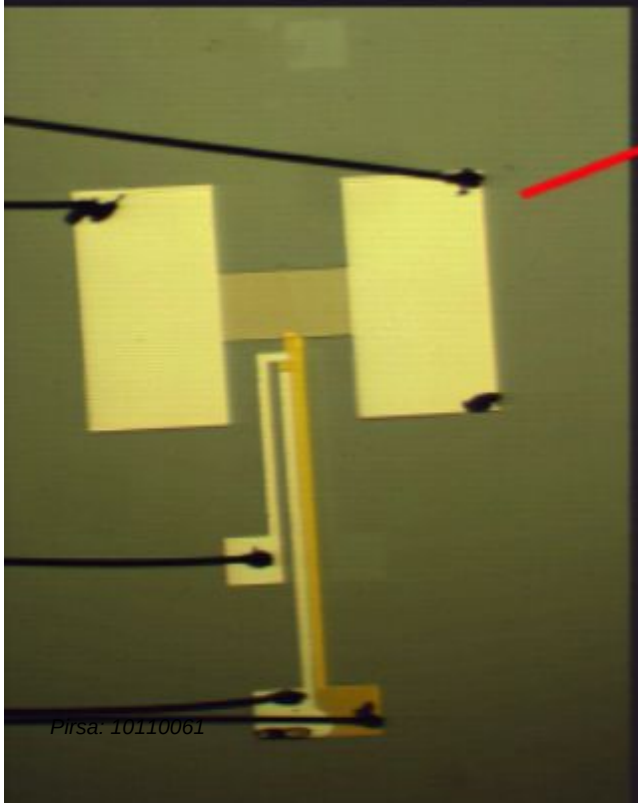

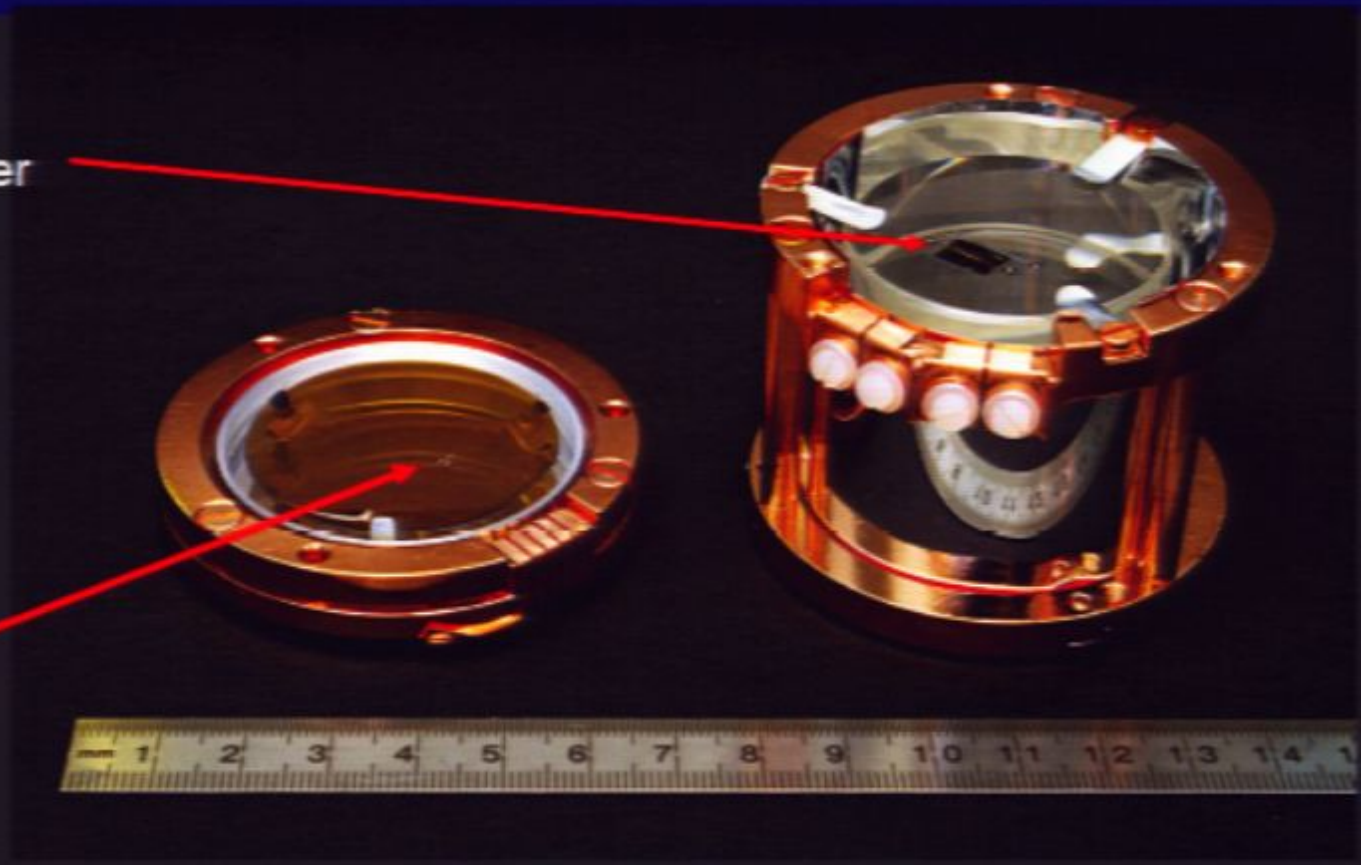

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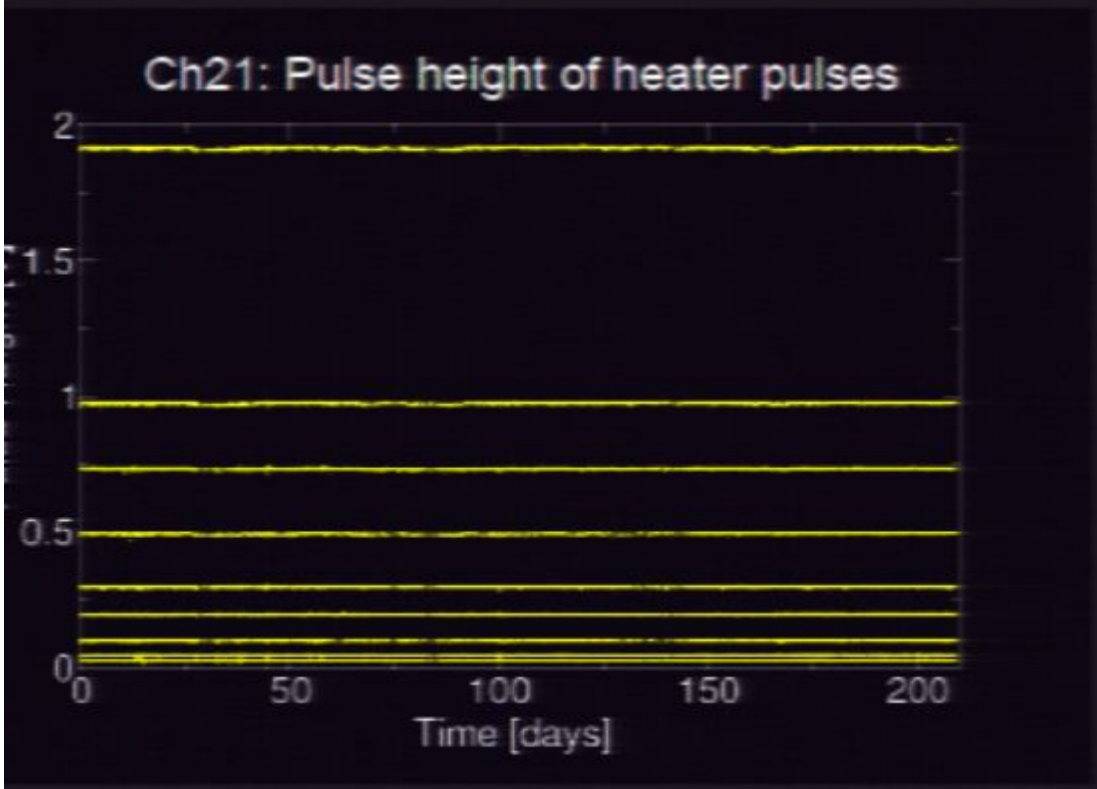
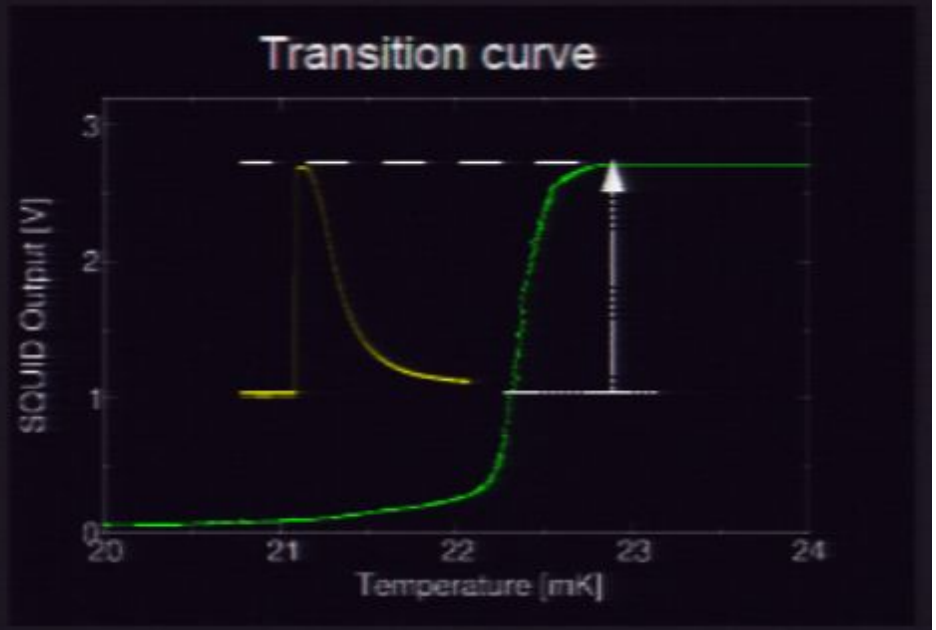
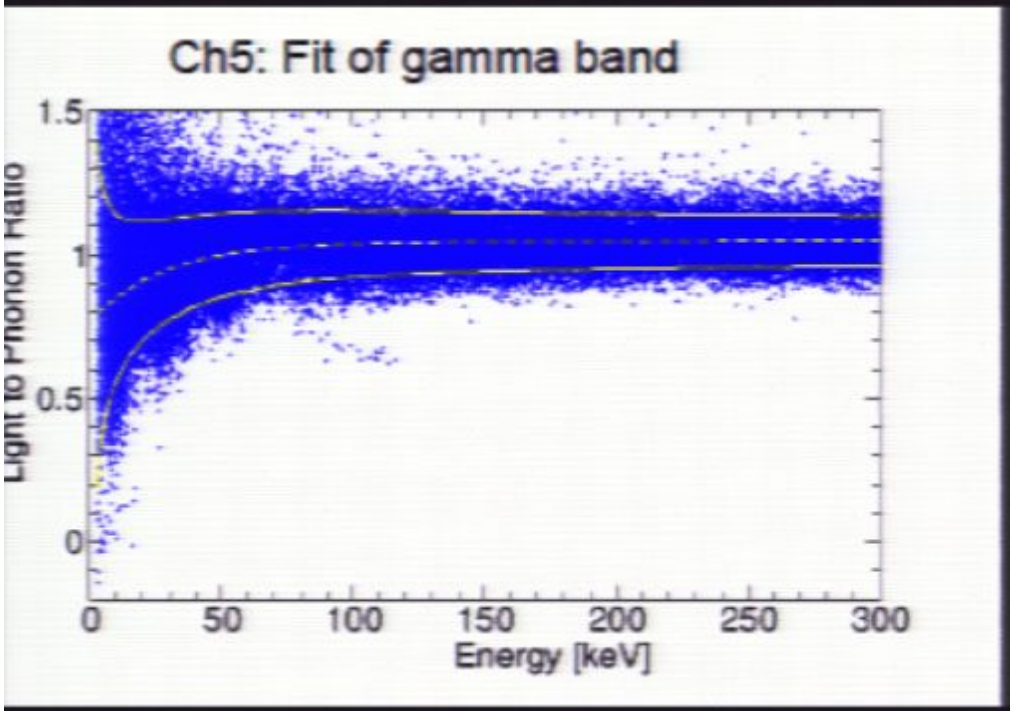
Stability of Energy Response

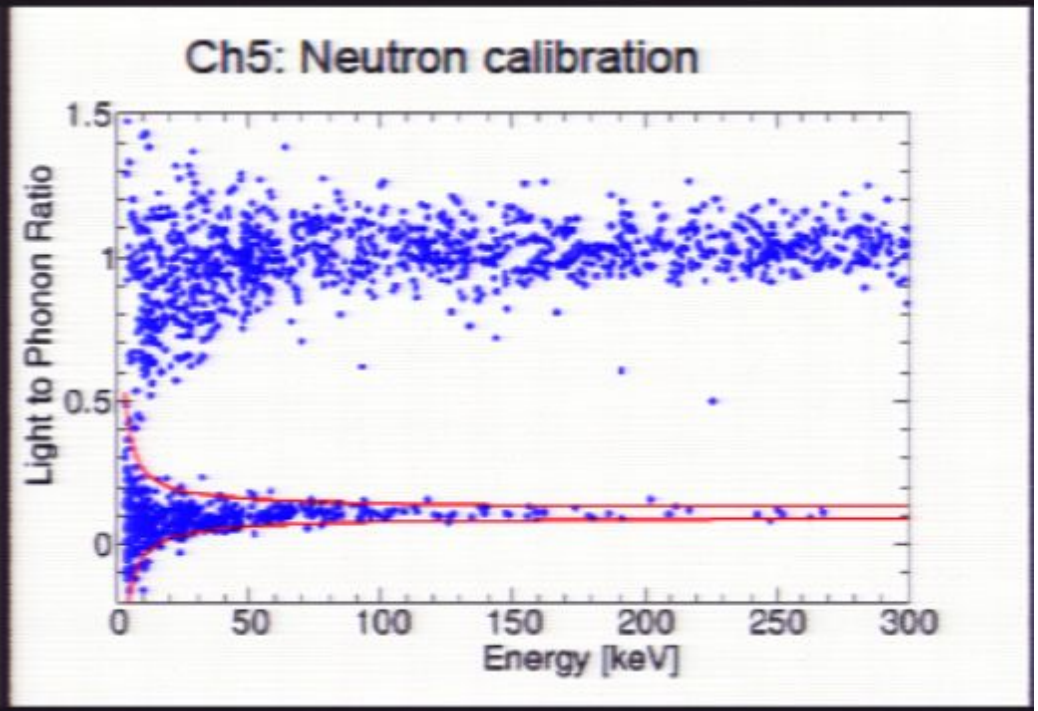




- Operating temperature controlled with large heater pulses
- Calibration continuously monitored with heater pulses
- 100% trigger efficiency close to threshold confirmed with lowest energy heater pulses

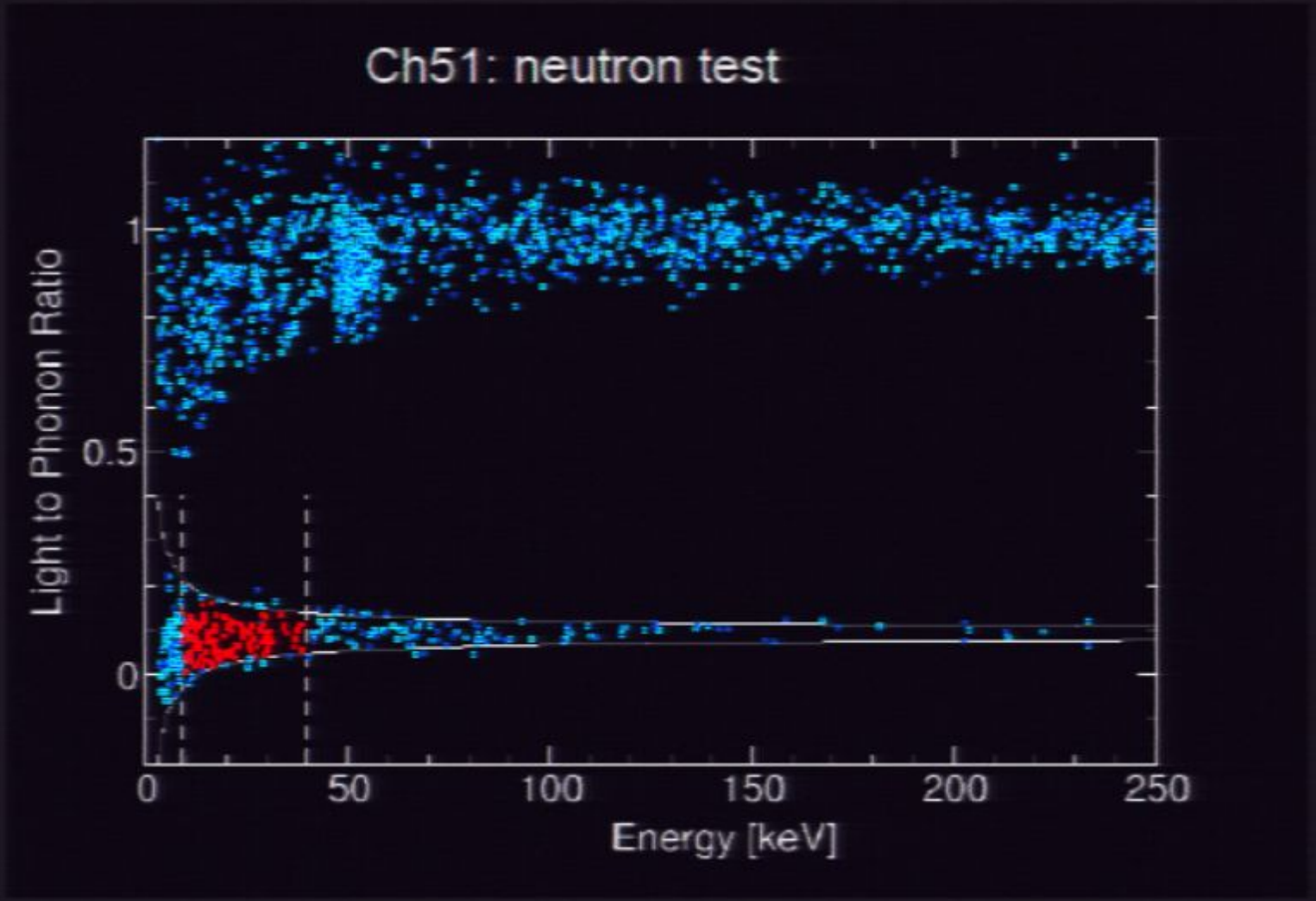
Definition of Recoil Acceptance Region





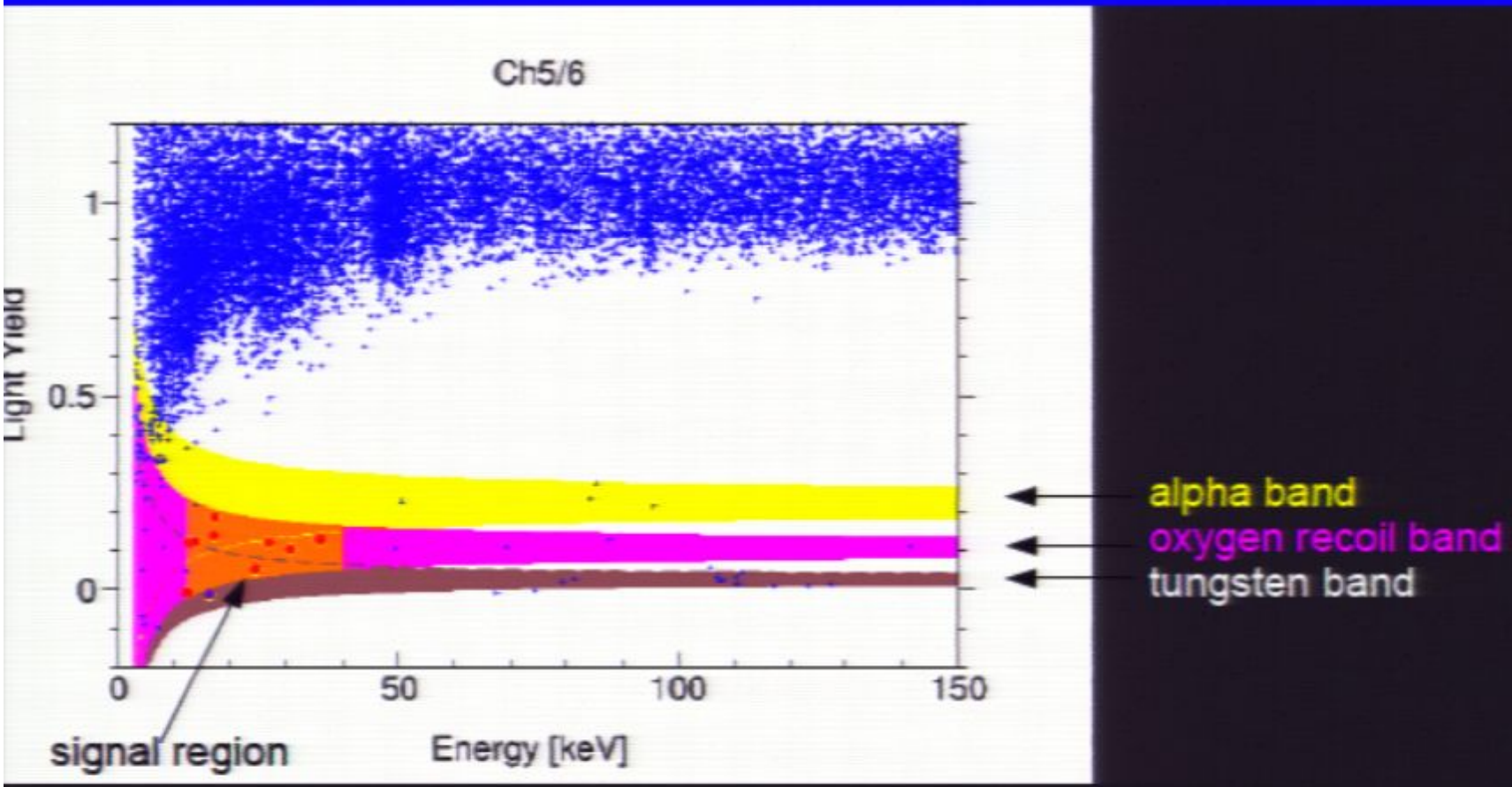
- Width of nuclear recoil bands given by energy resolution of light detector
- Detected light energy and dependence of resolution of light detector on detected light energy extracted by an unbinned likelihood fit of gamma band
- Application of known quenching factor gives nuclear recoil acceptance band

Oxygen Recoil Band with Signal Energy Range



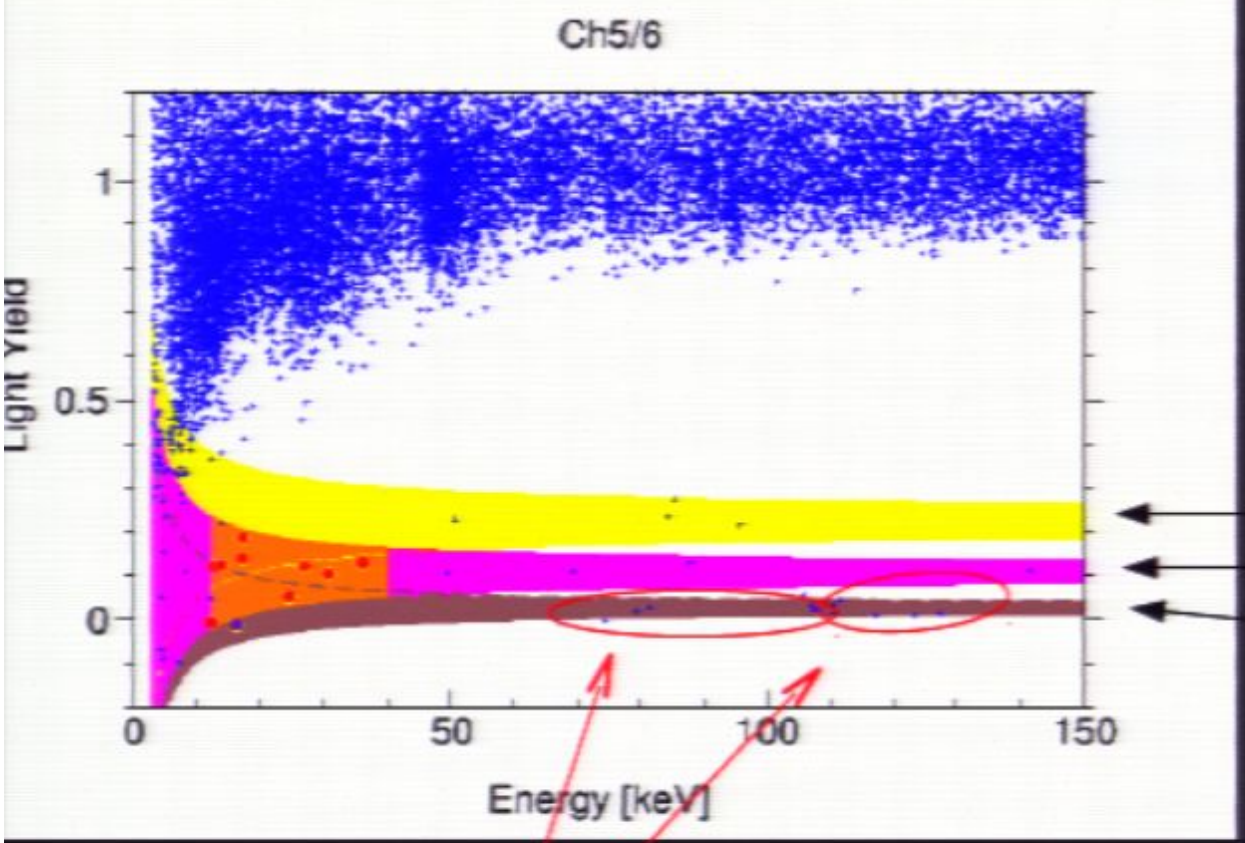
Excellent nuclear recoil discrimination confirmed in neutron test

Data of single detector module



Clear signals in oxygen recoil band in signal energy range

alpha decay related backgrounds

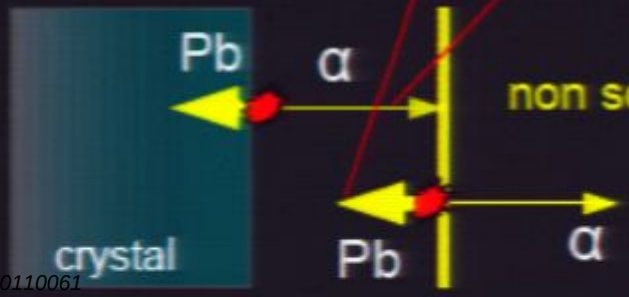


Clamps holding target crystal not covered with scintillator in this run

alpha band
oxygen band
tungsten band

Degraded α's in alpha band and ^{206}Pb recoils in W band from contaminated non scintillating clamps used in this run.

Light Yield of W and Pb is too similar to distinguish.
Some leakage of Pb recoil into signal energy range of W



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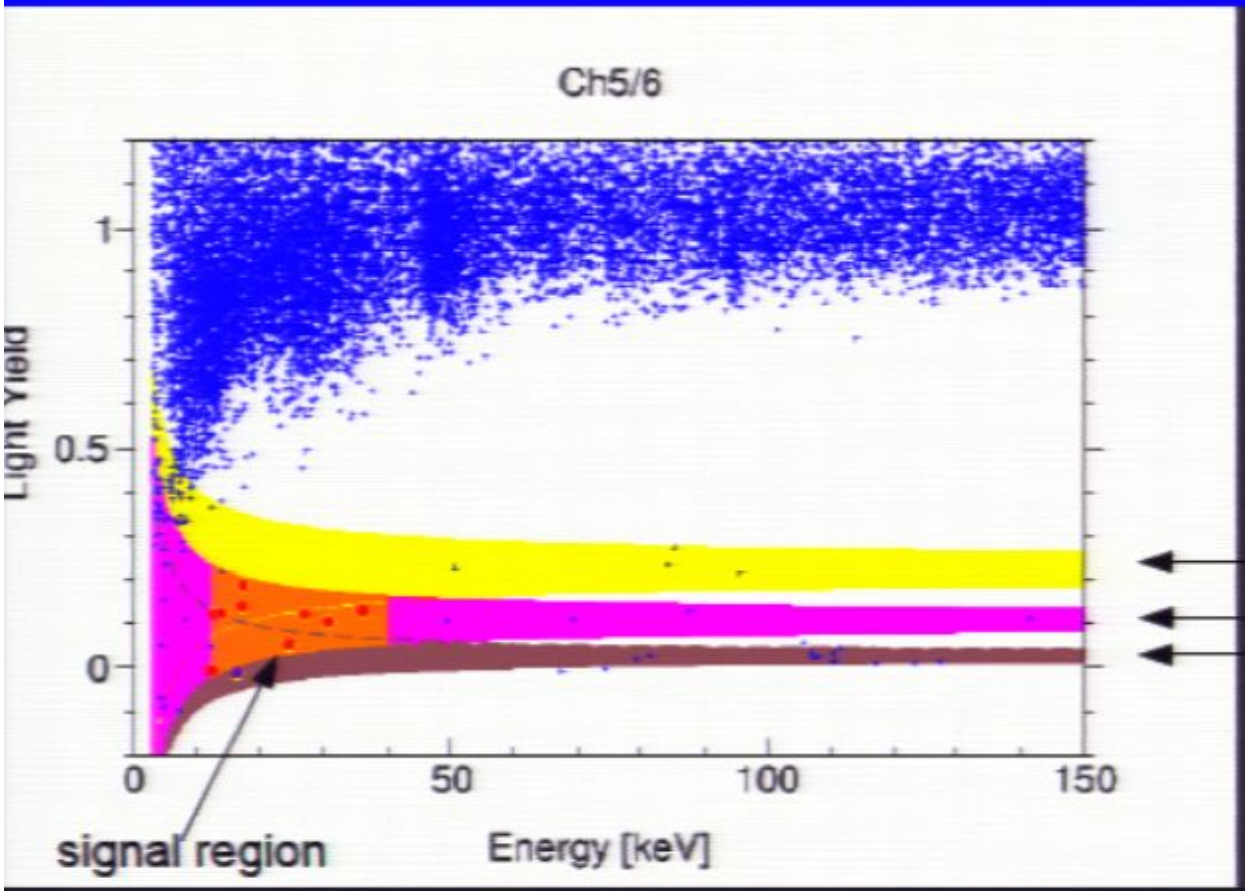

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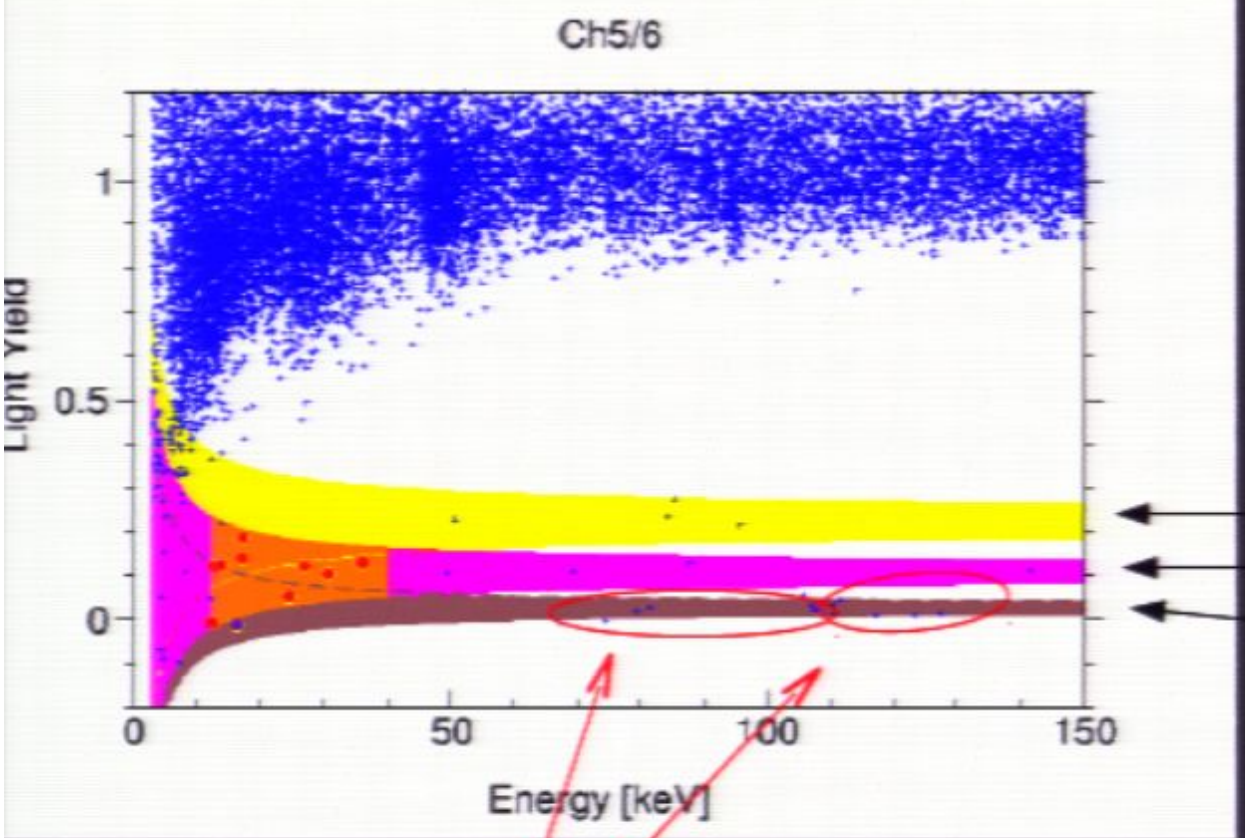

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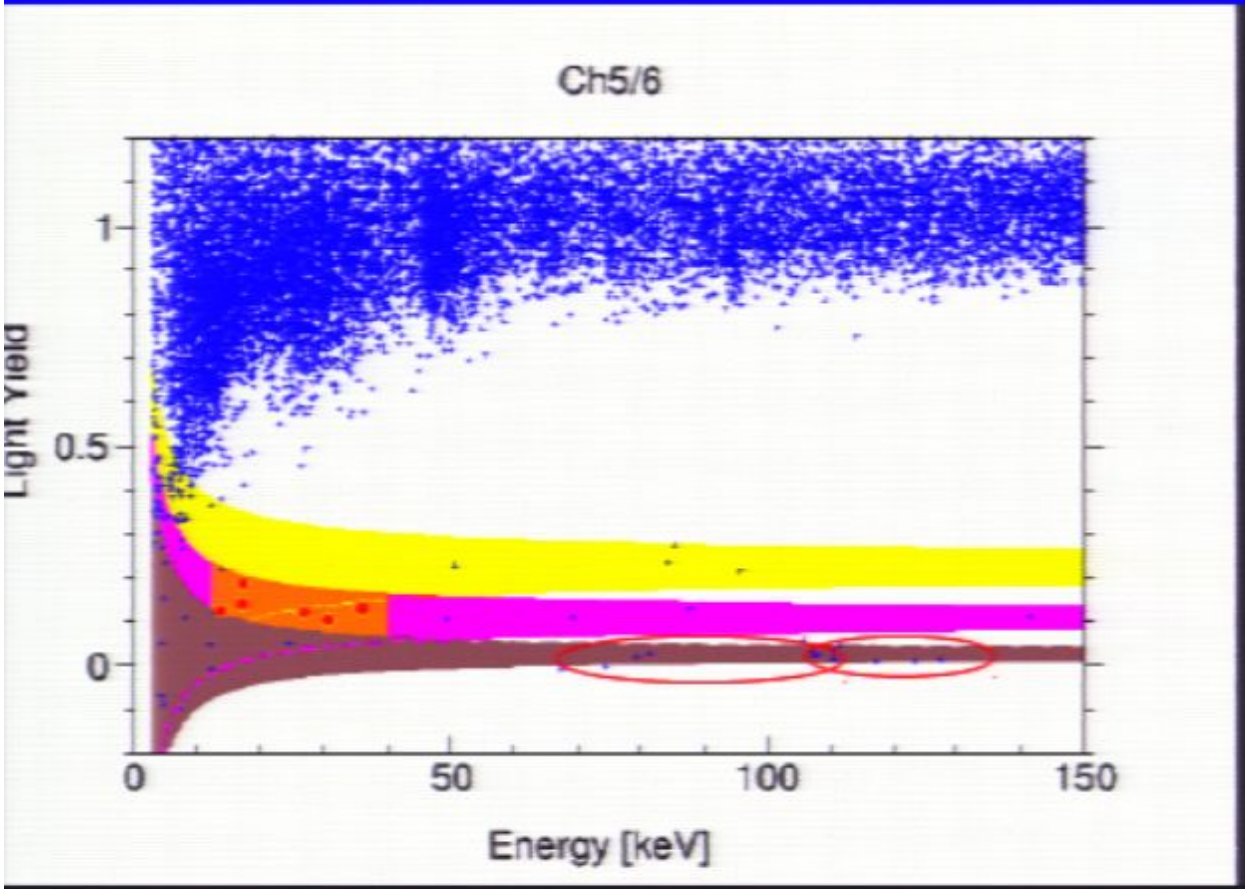
Avoiding influence of background in W band



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Some leakage of ^{206}Pb recoils from non scintillating clamps into the signal region of W band can not be excluded. Difficult to estimate.

==> Concentrate on signals in upper part of the oxygen band which does not overlap with tungsten band.

Events in Oxygen Recoil band

- **Data** (July 11, 2009 to May 17, 2010 + Aug 11 to Oct 6 2010)
- 564 kg-days net exposure

Detector	E0.1	counts in W band	counts in overlap	counts in O band	O overlap free
ch05	12.35	4	3	9	6
ch20	11.85	4	3	6	3
ch29	11.65	12	6	8	2
ch33	15.55	6	3	3	0
ch43	15.55	2	0	6	6
ch45	19.15	2	2	2	0
ch47	17.35	2	2	5	3
ch51	9.65	6	1	6	5
ch55	22.25	0	0	7	7
total		38	20	52	32

Signal energy range $E_{0.1}$ to 40 keV.
$E_{0.1}$ chosen that leakage of 0.1 counts from gamma band is expected for each detector.

- 32 events in W-O overlap free part of oxygen band
- 2 coincident events with at least one O recoil in signal energy range

The 2 coincidences must be from neutrons

32 events can be from neutrons, leakage of alpha's or low mass WIMPs
==> try to estimate backgrounds

Origin of coincident events in oxygen band

- Observed 2 coincident events are both triple coincidences with MeV gammas in one of the detectors

- When there are coincident neutron events, there are also singles.
  ==> Estimate number of single oxygen recoils from observed coincidences.

- Ratio of coincidences/singles depends on the type of neutrons.

Two types of neutrons

Source type, sf or alpha-n

mostly oxygen double scatters, few triple coincidences and almost none with MeV gammas

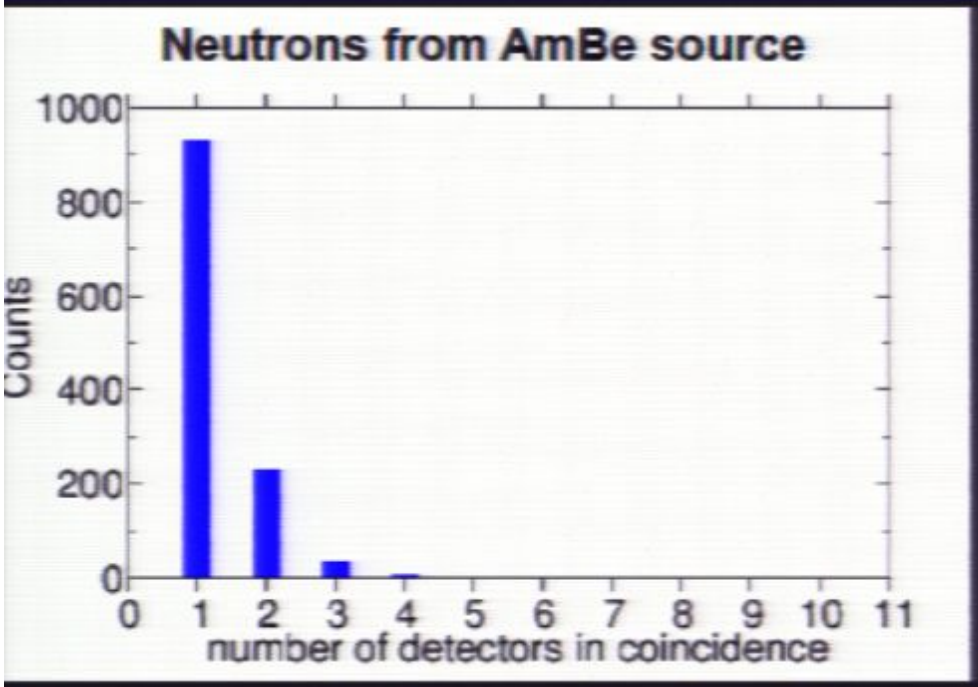
unlike observed 2 events

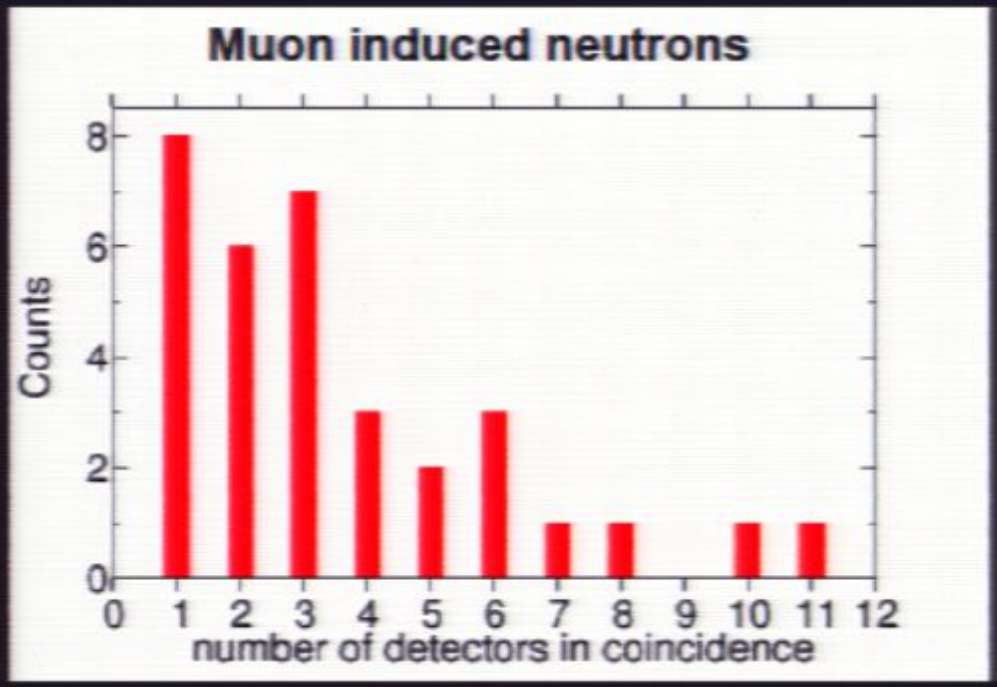
Muons induced

shower like events with higher multiplicity and high energy gammas

similar to observed 2 events

Multiplicity of Neutron Induced Events





Mostly oxygen double scatters, very few triple coincidences and almost none with MeV gammas.

unlike observed coincidences

single/coinident=3.41

2 observed coincident events translate into ~7 oxygen singles in signal region

Shower like events, oxygen recoils coincident with larger number of other detector modules, often with high energy gammas.

Similar to the observed events

single/coincident = 0.32

2 observed coincident events translate into <1 oxygen singles in signal energy range

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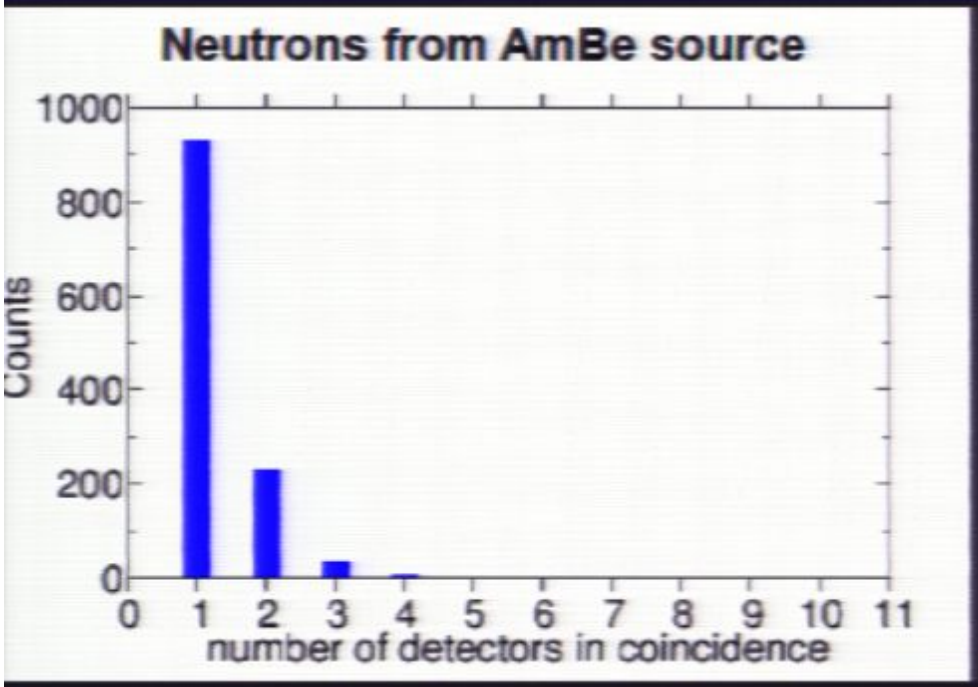

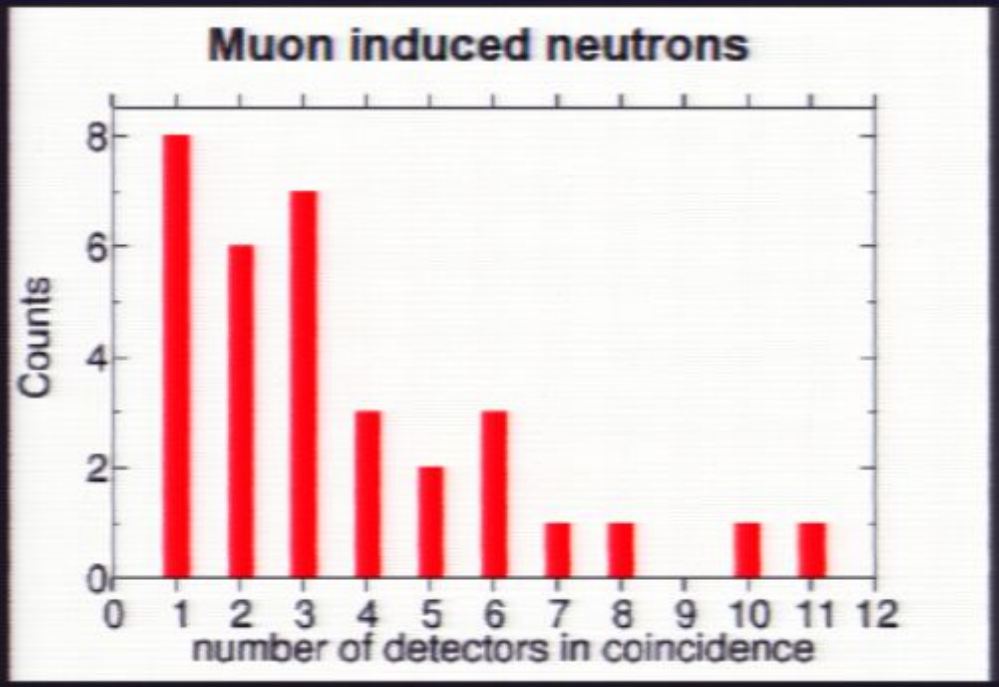

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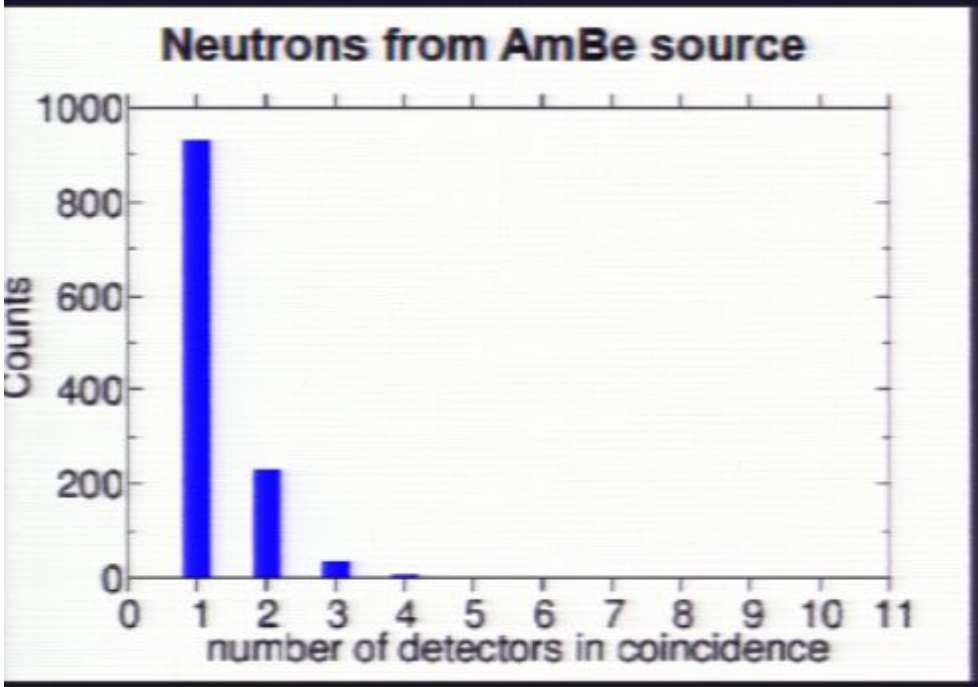

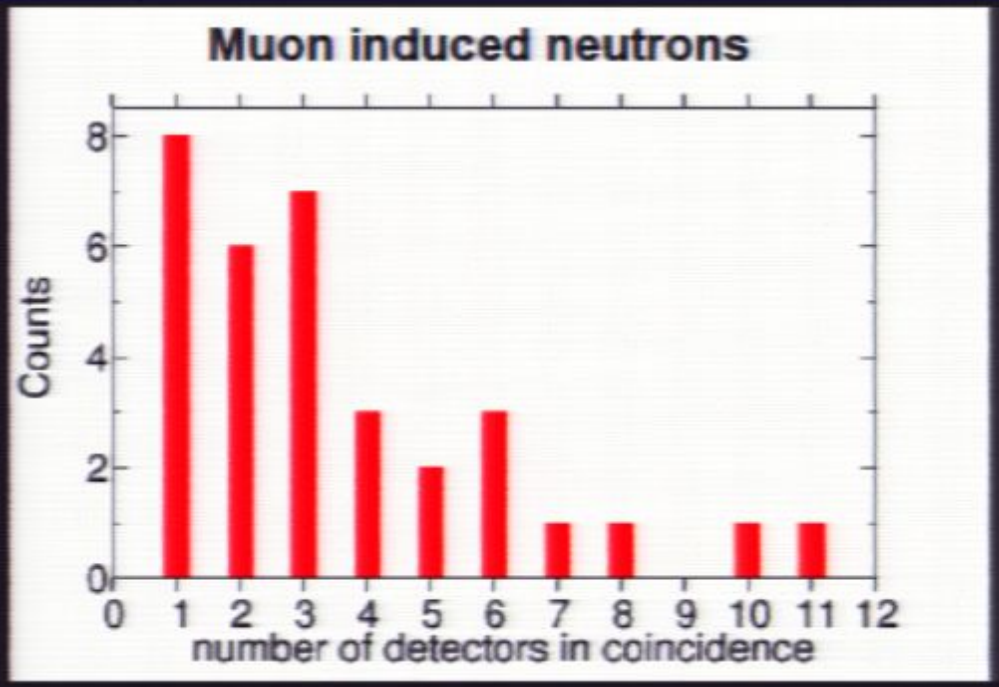

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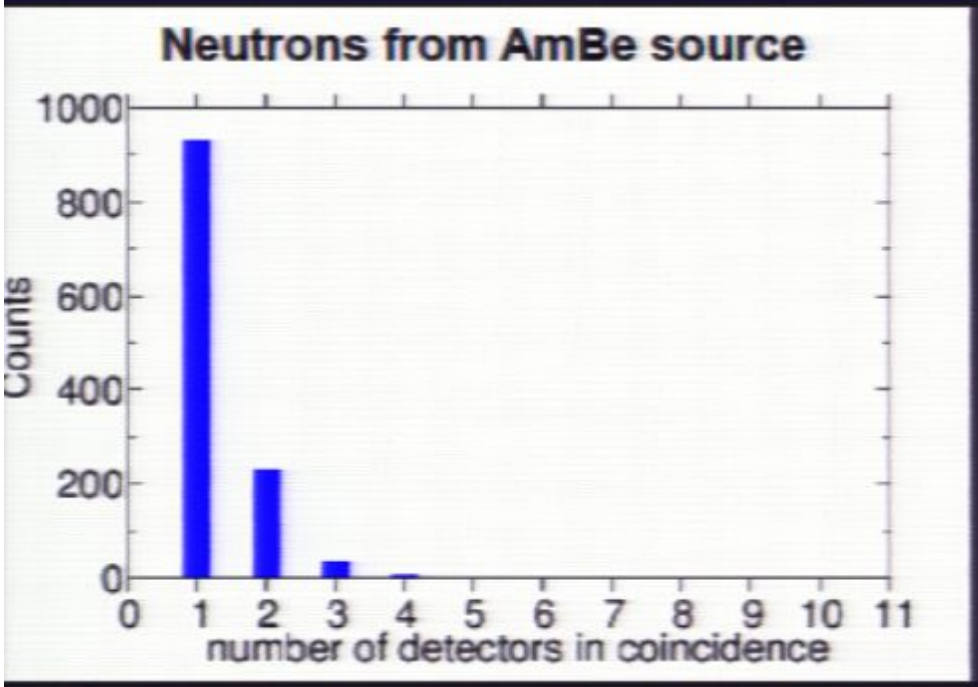

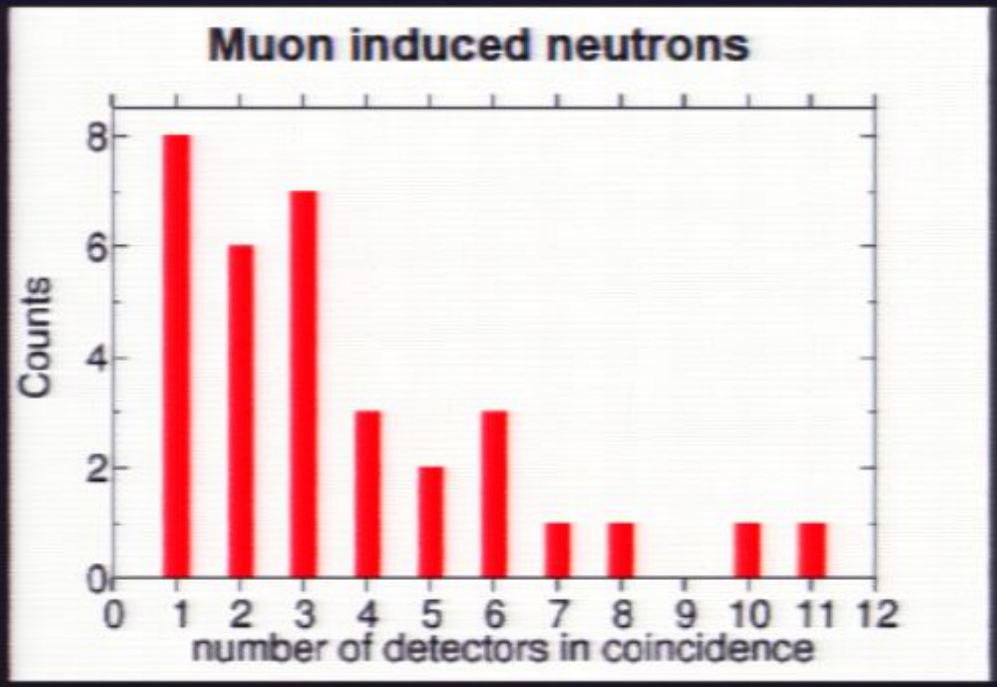

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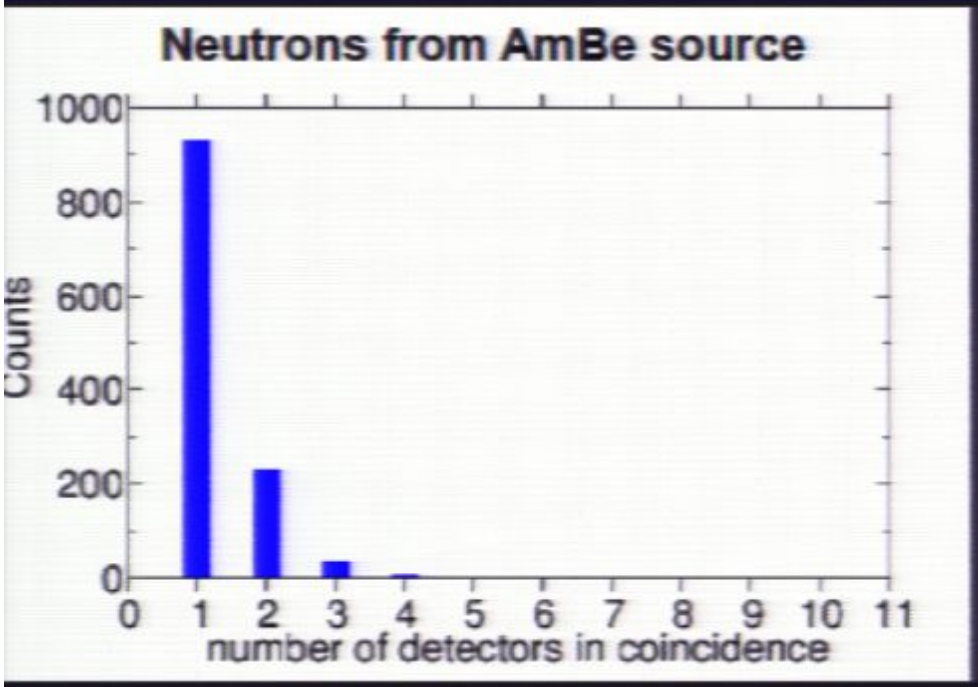

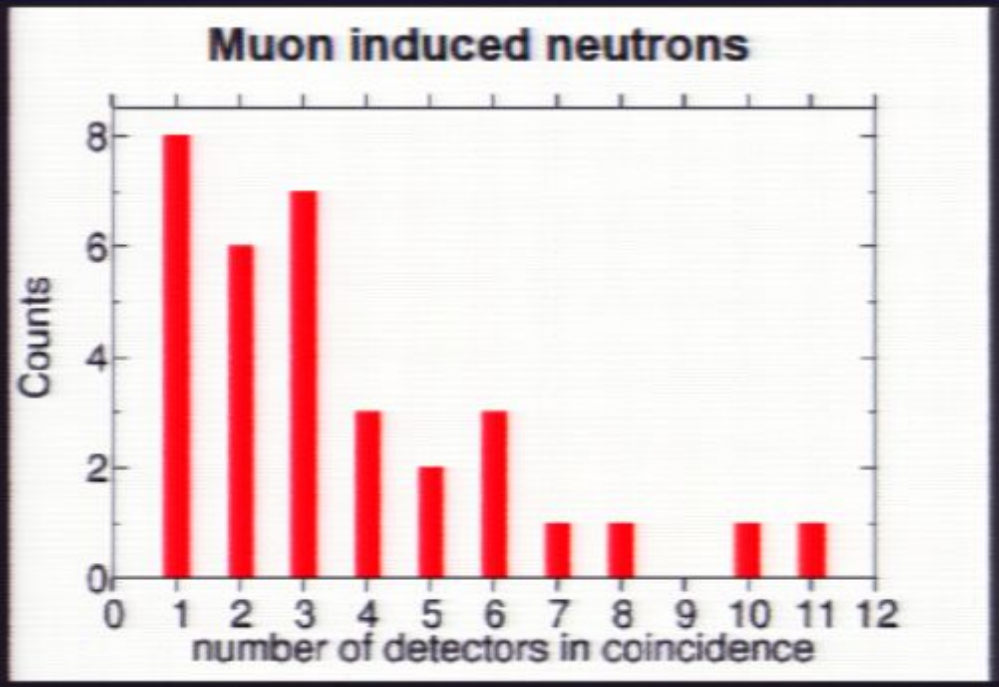

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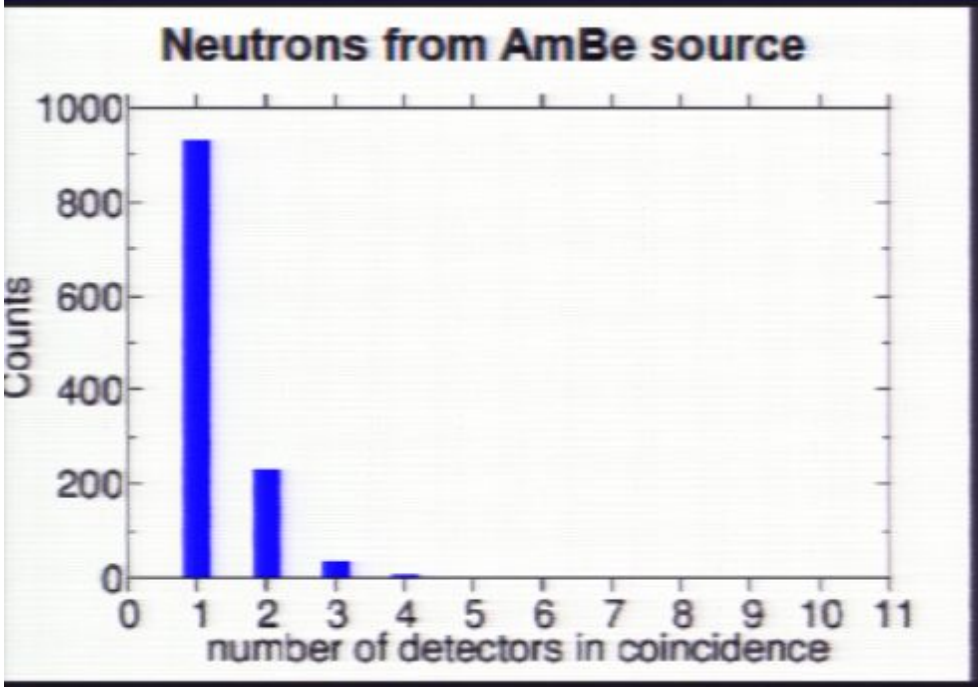

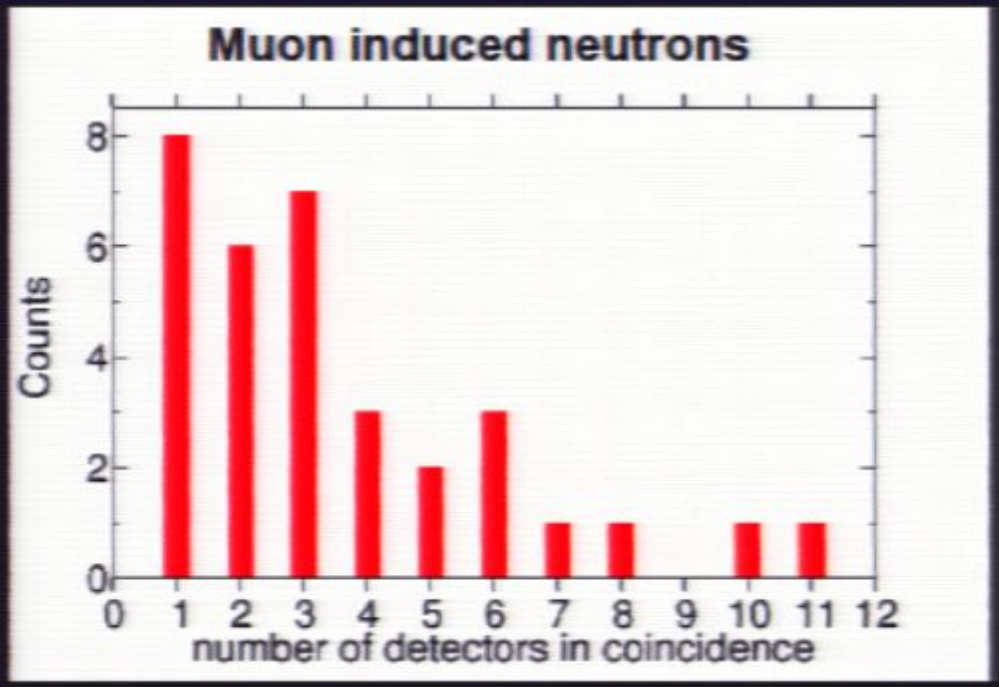

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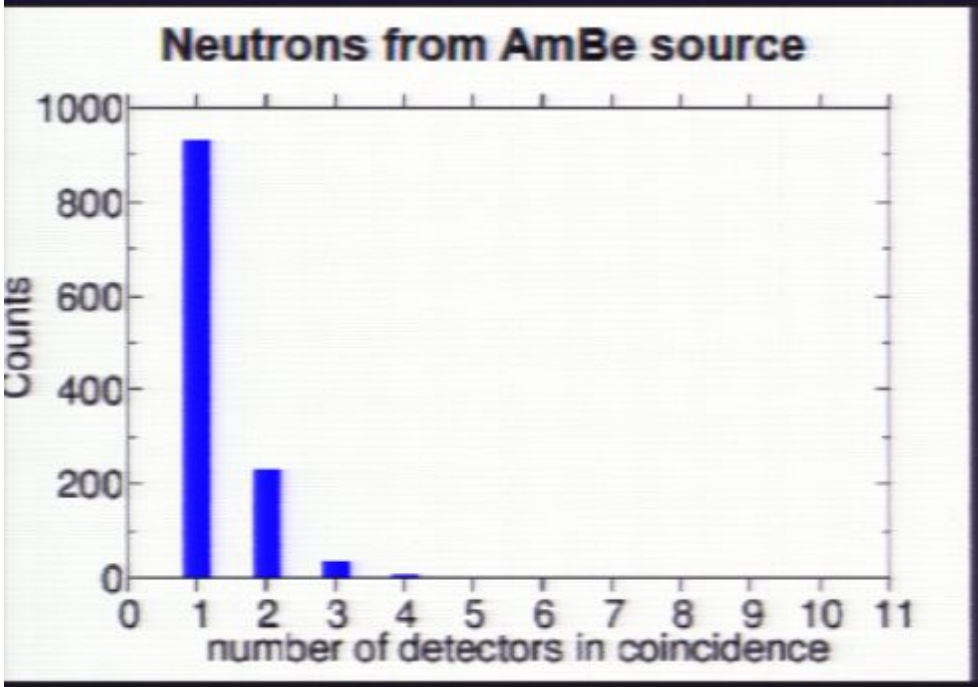

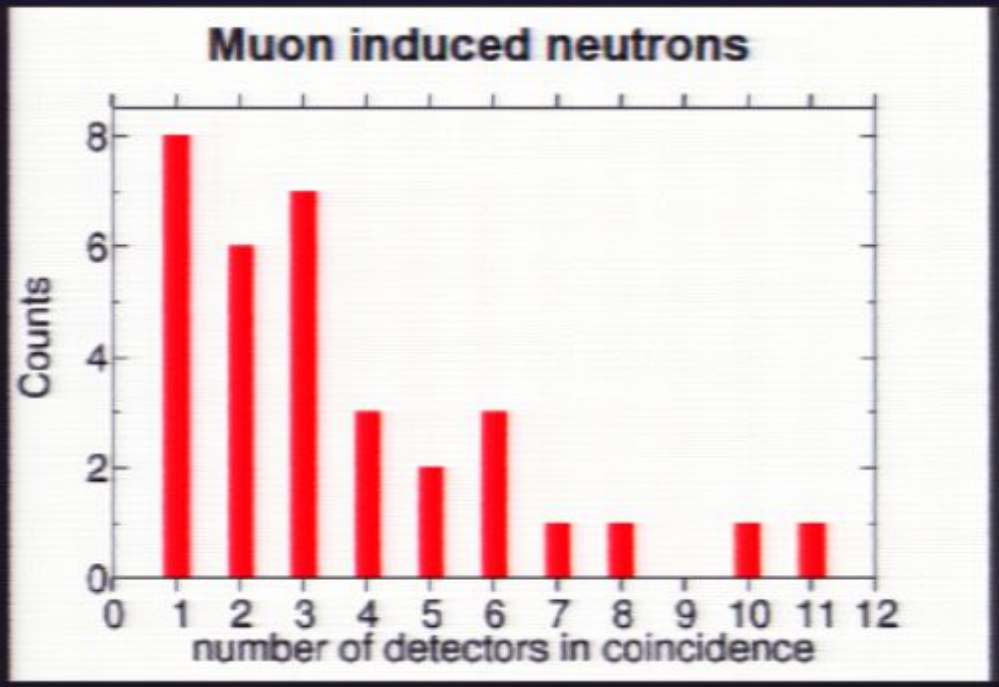

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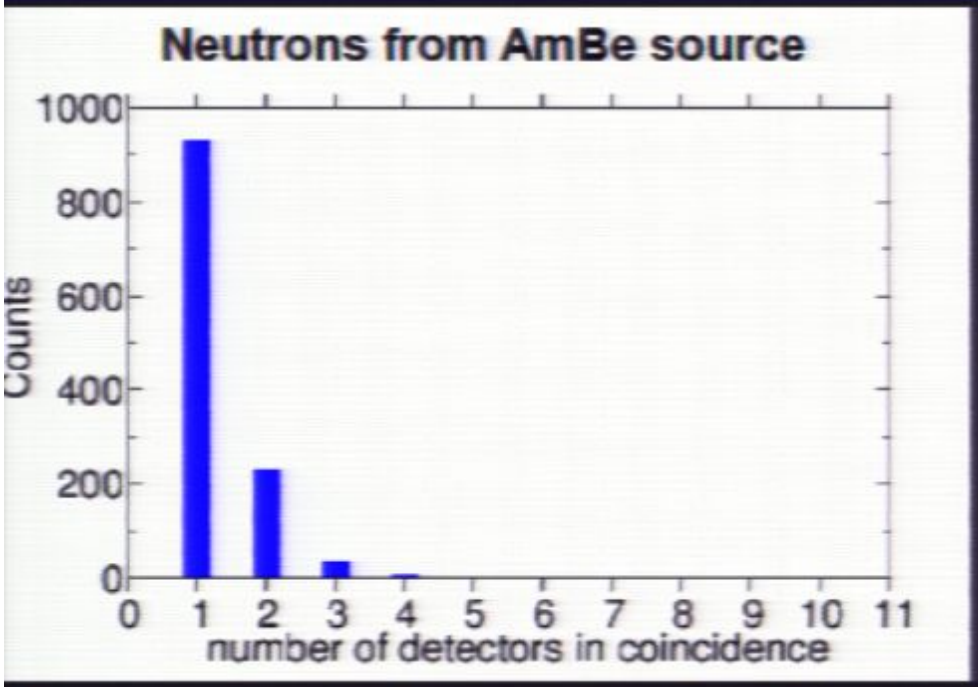

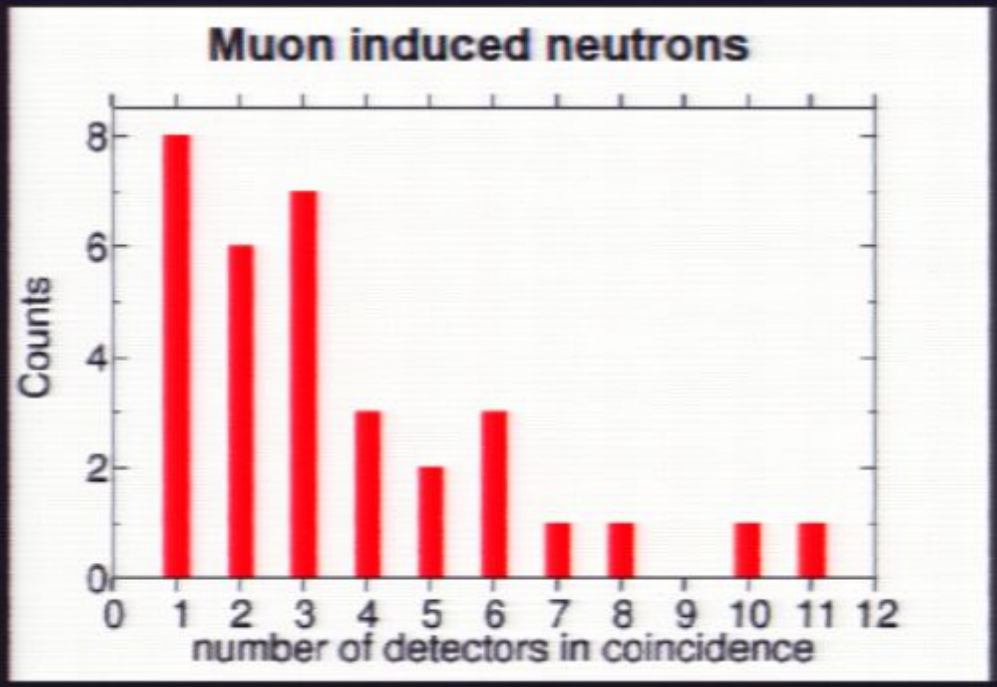

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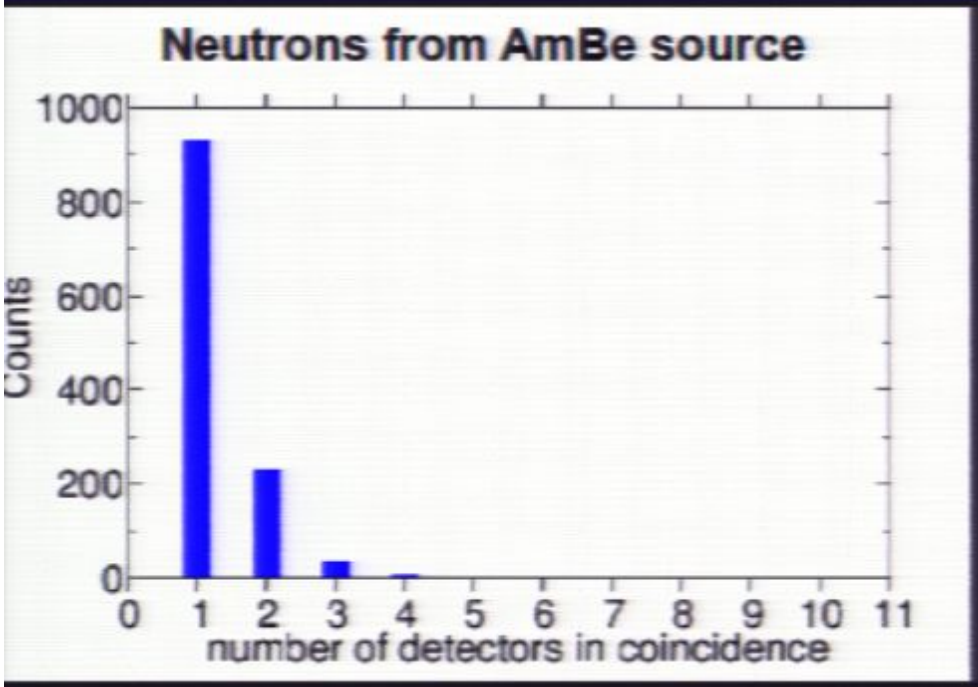

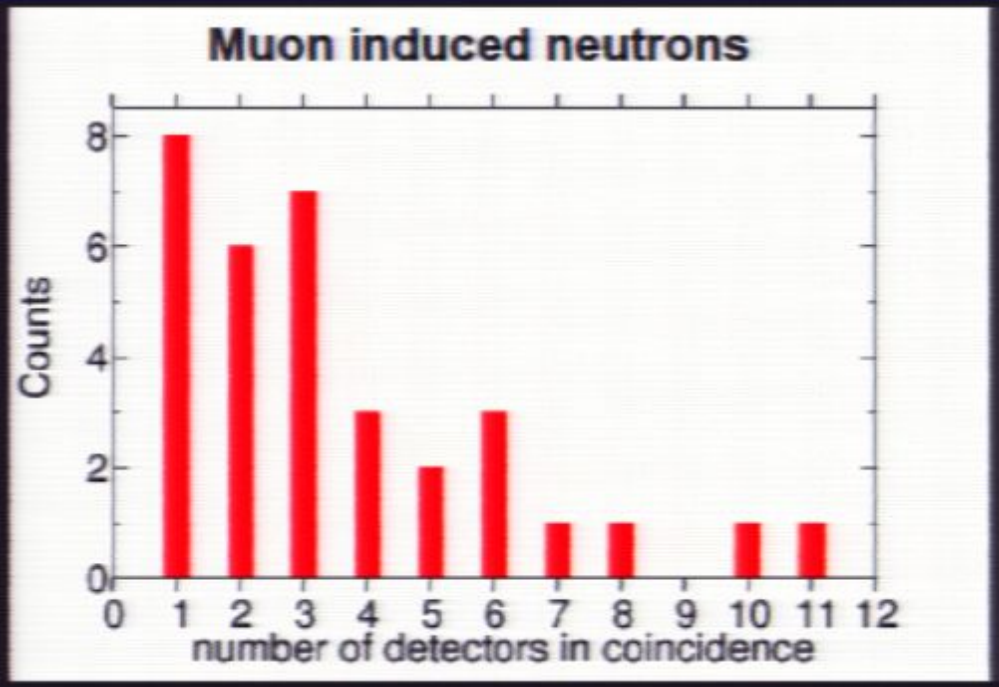

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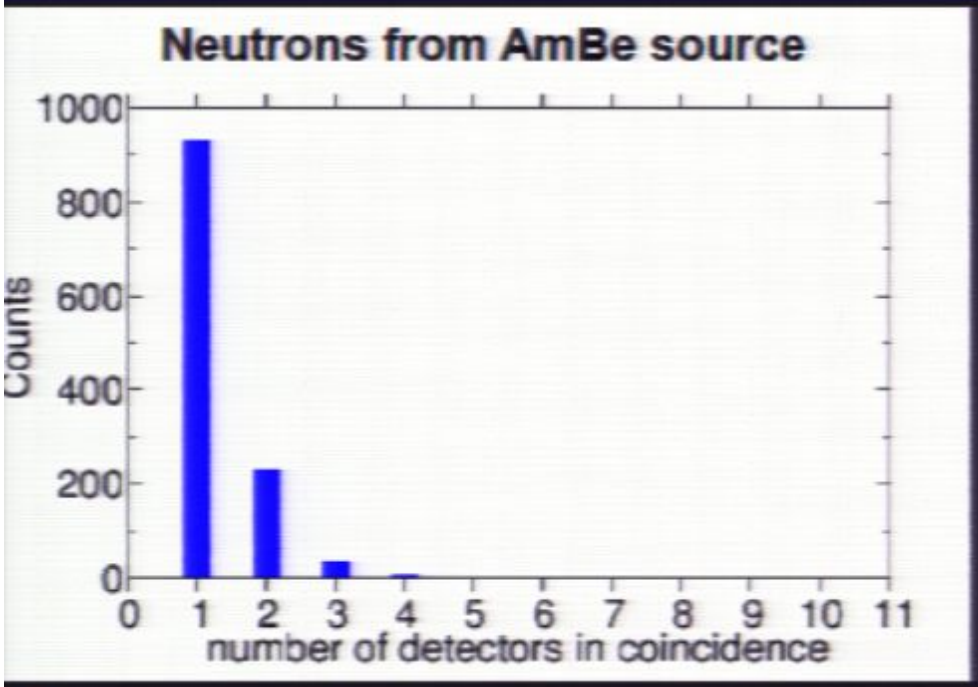

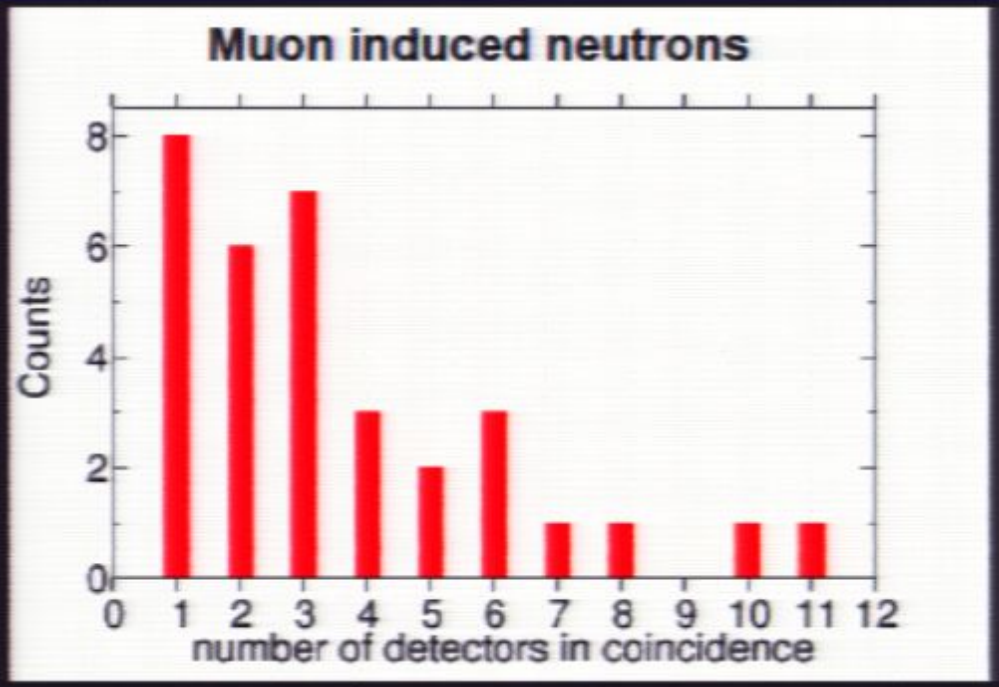

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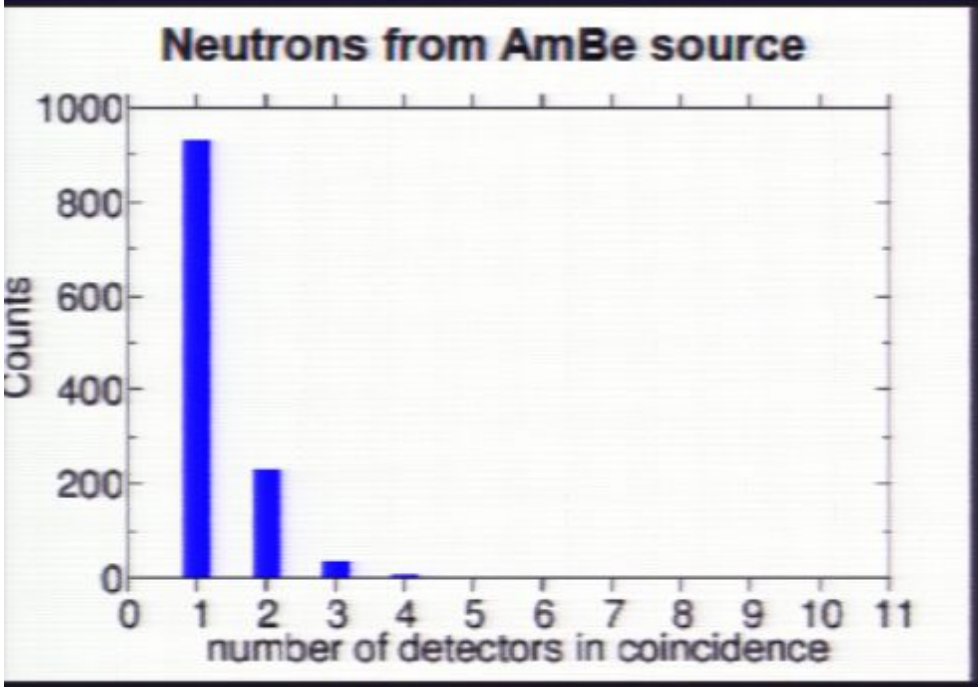

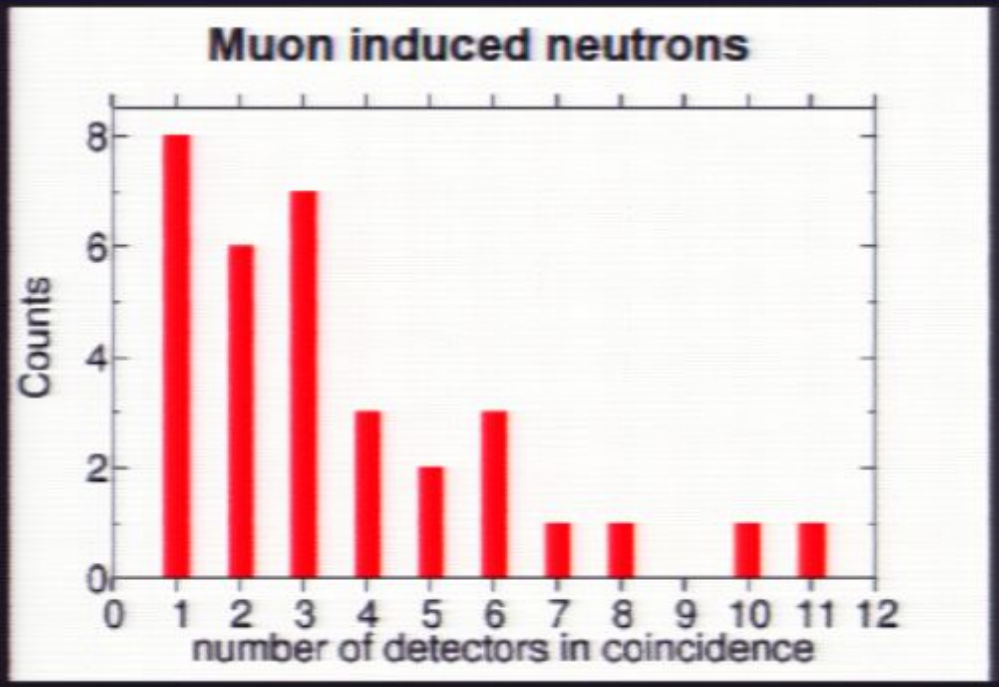

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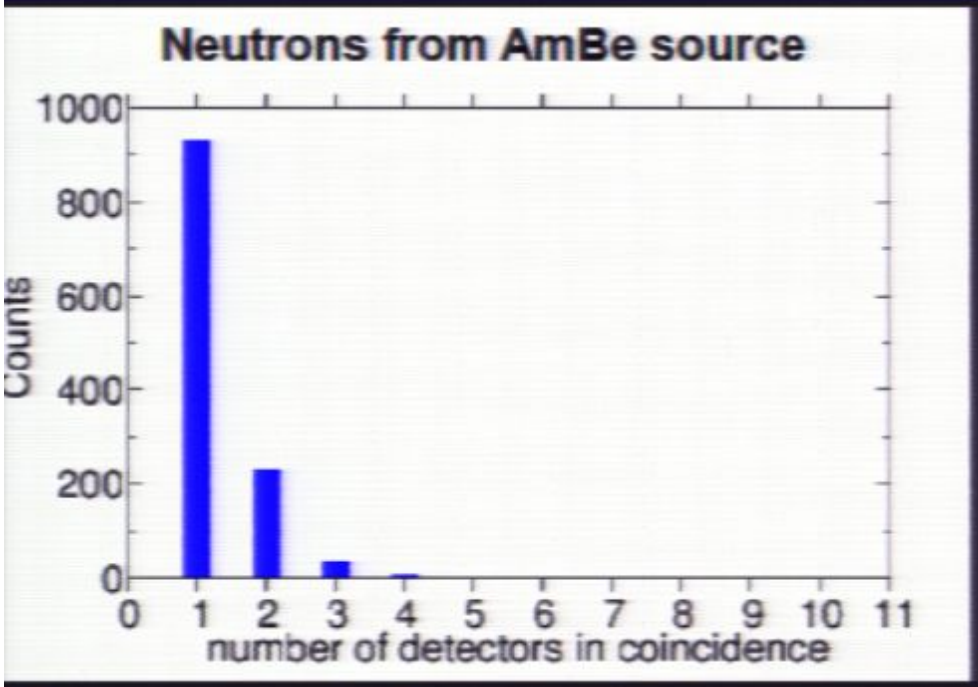

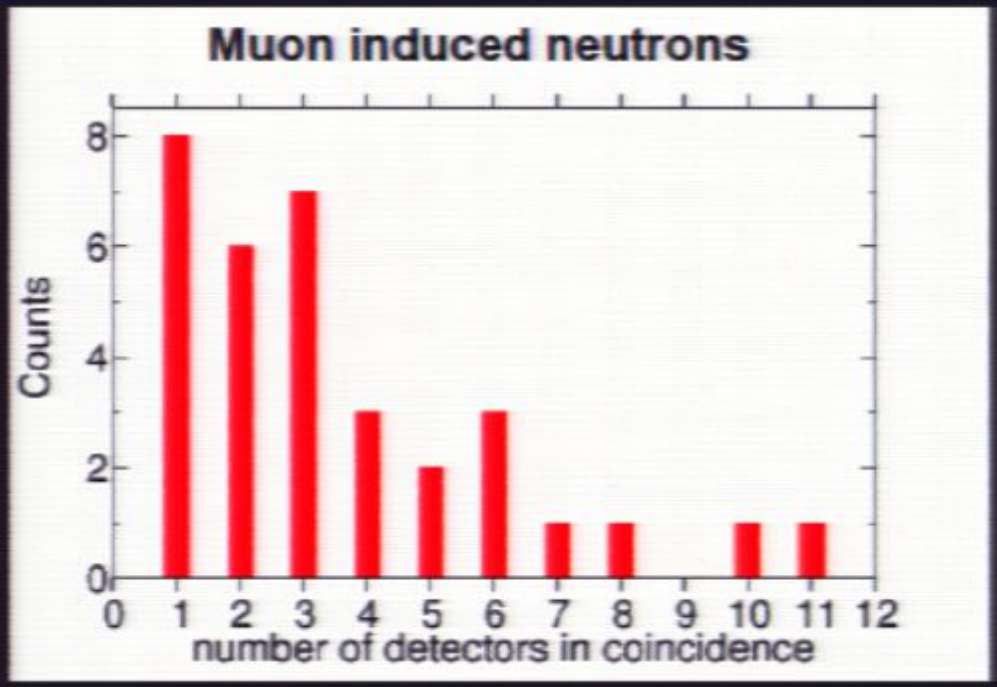

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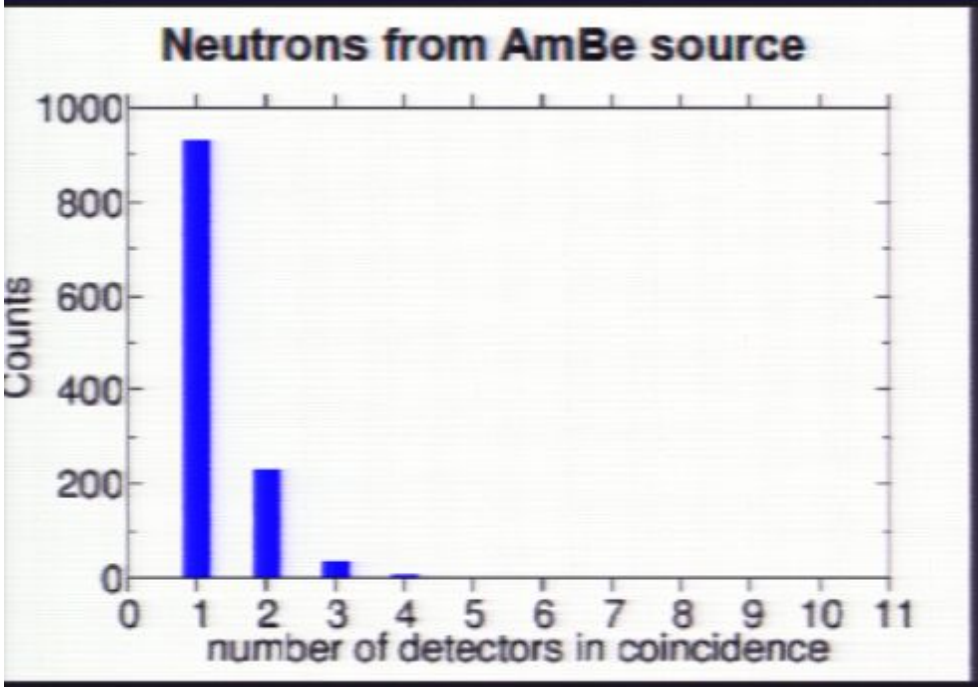

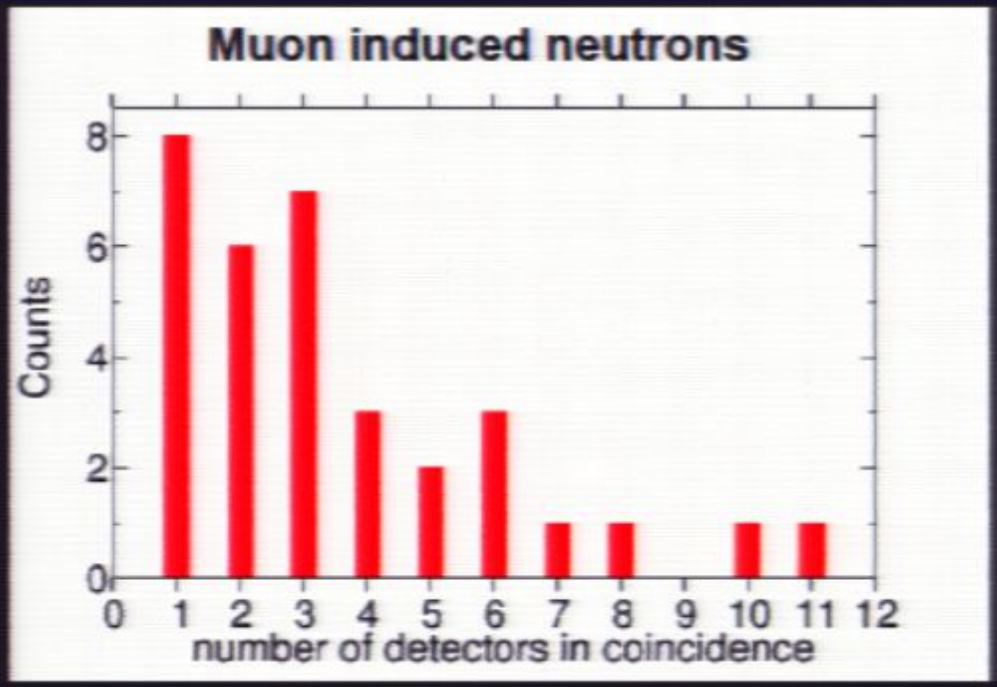

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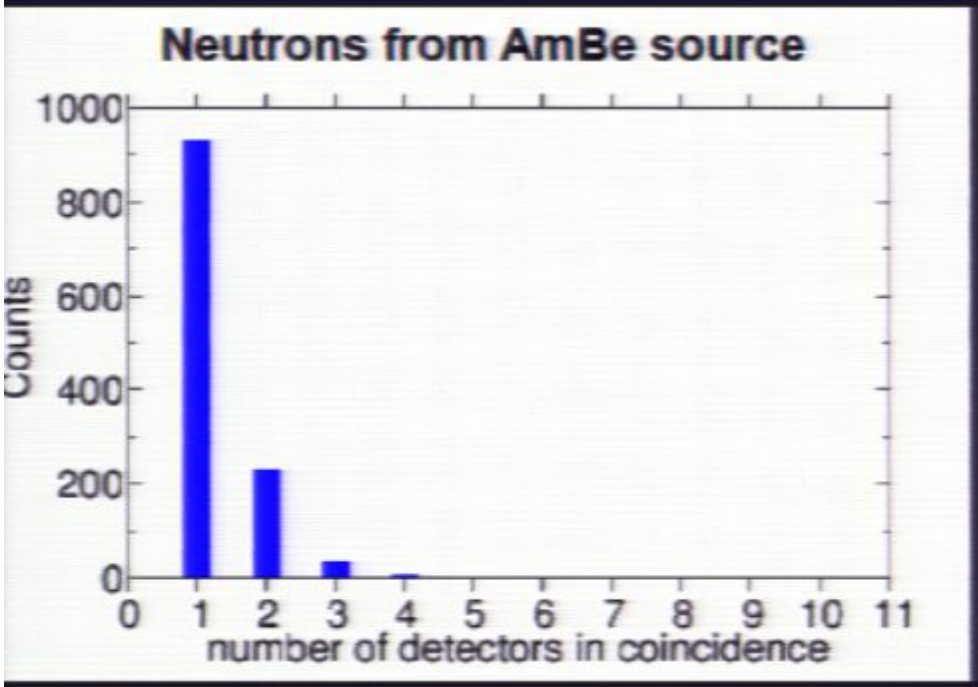

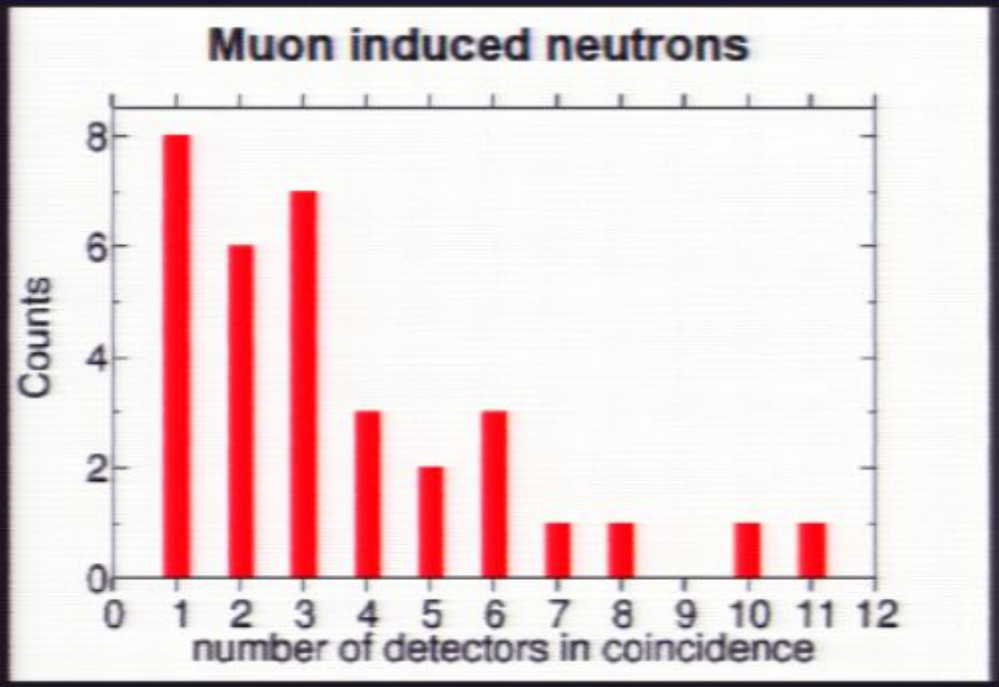

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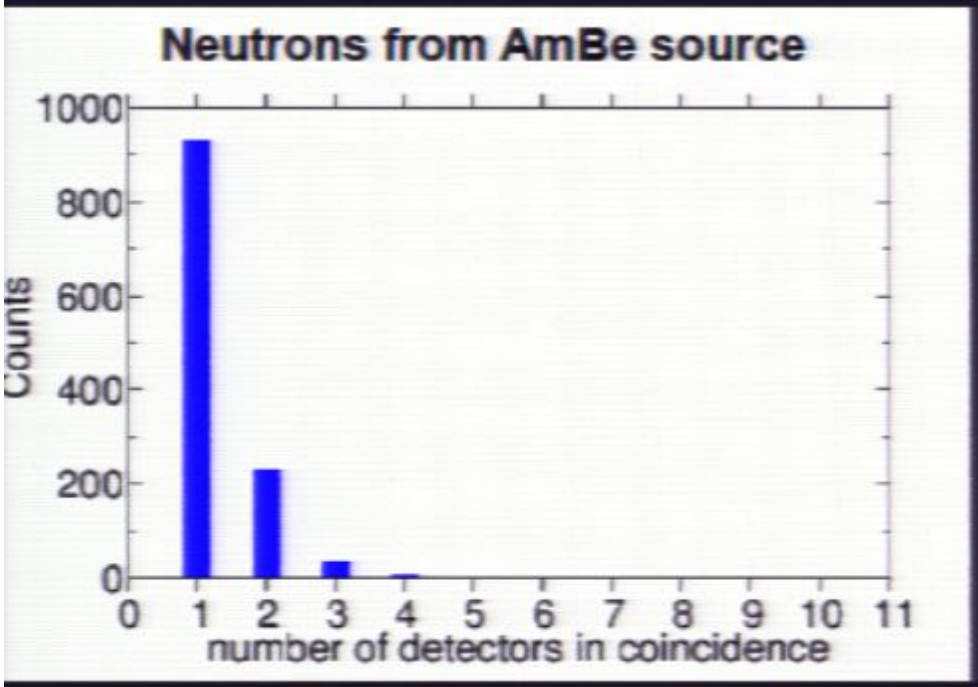

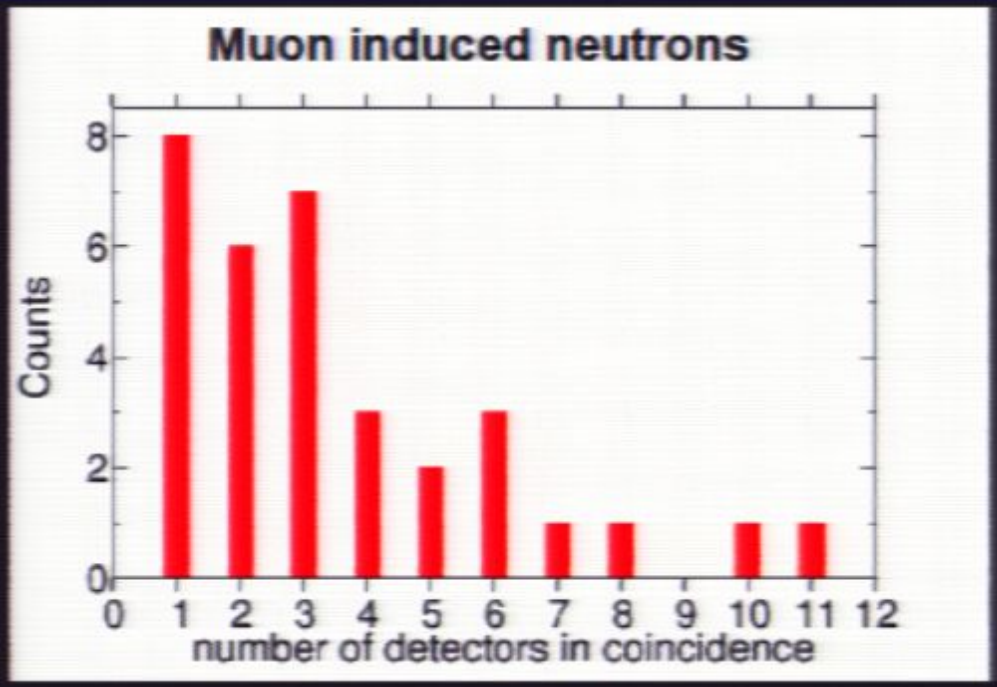

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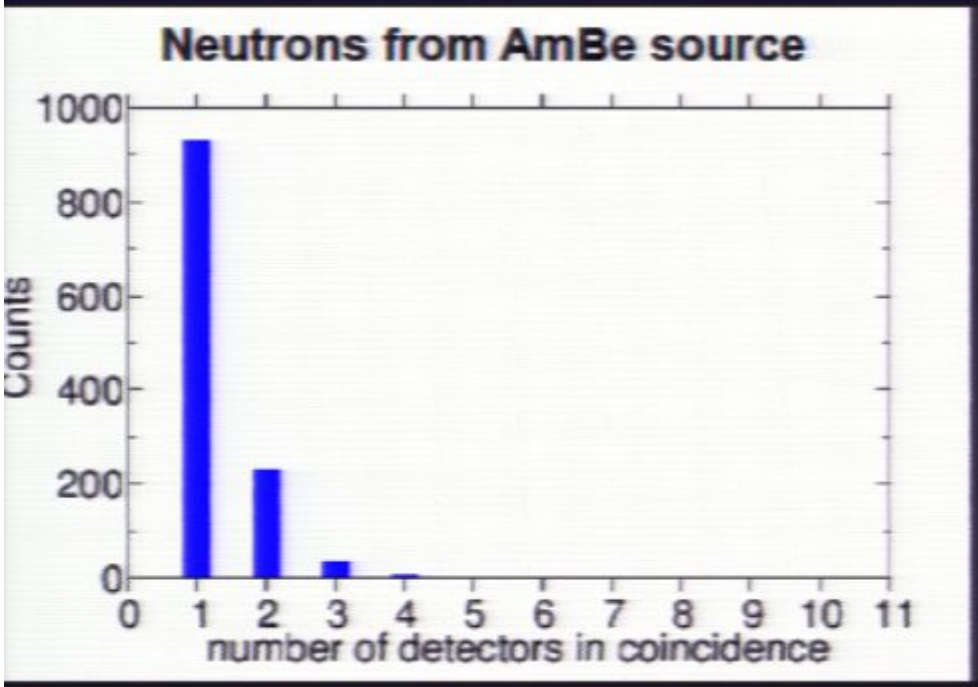

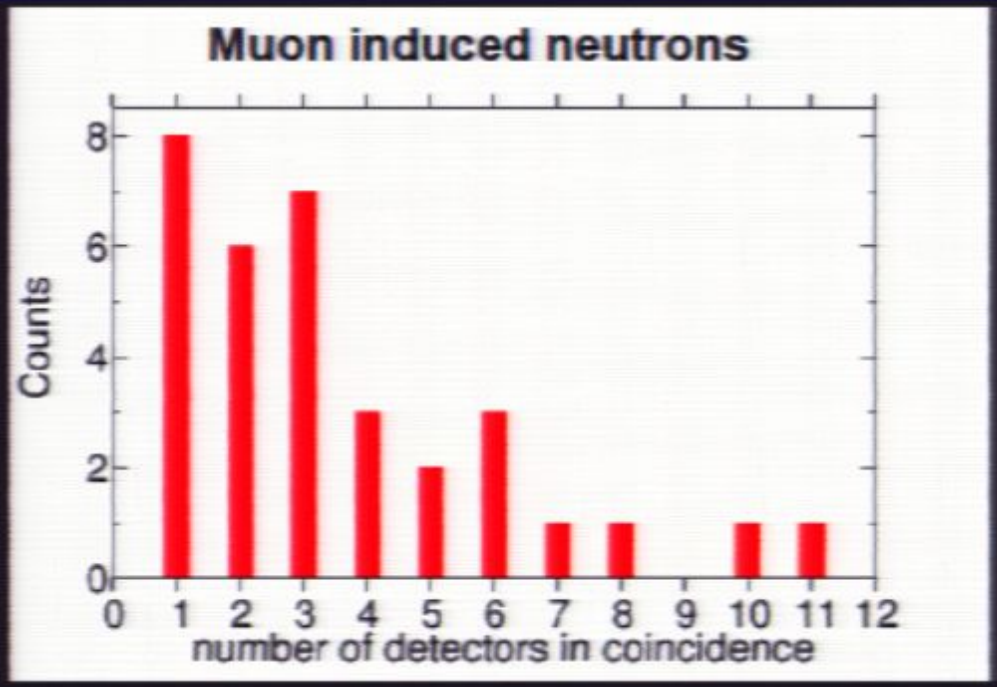

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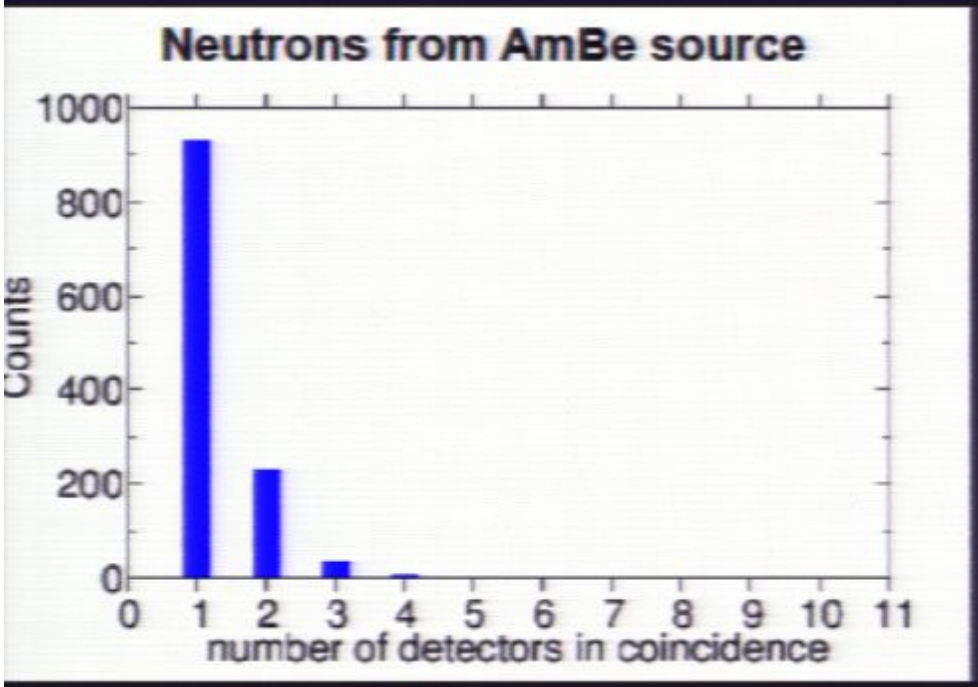

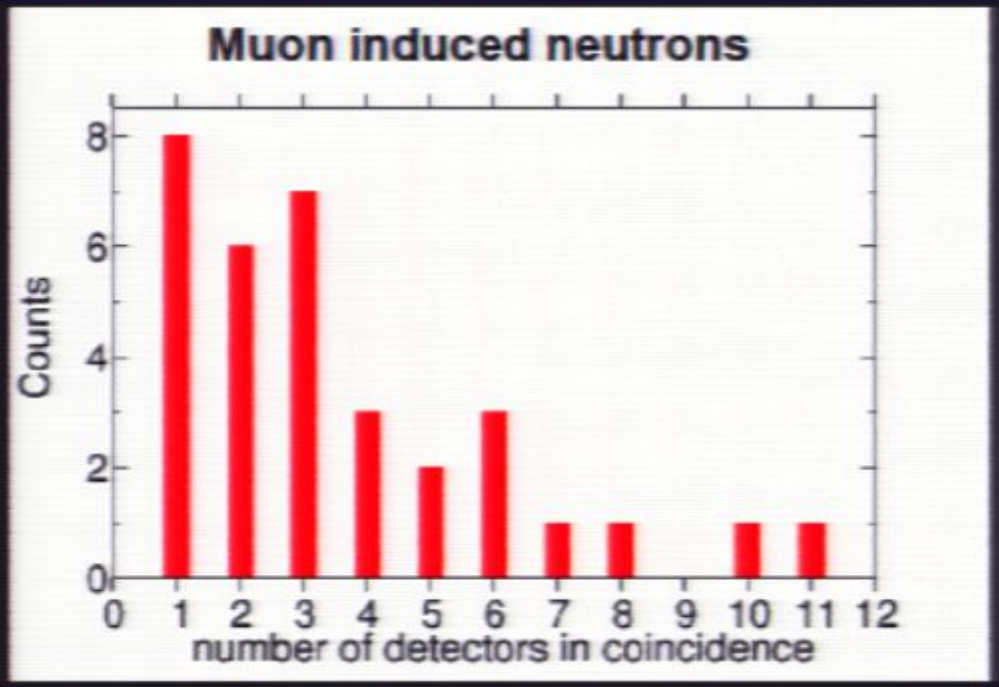

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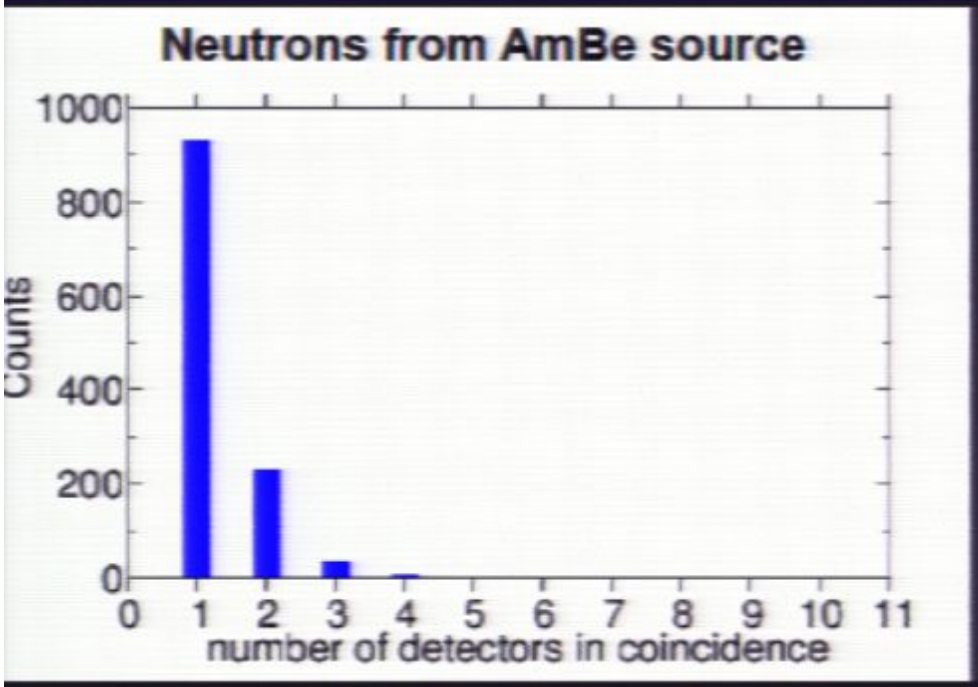

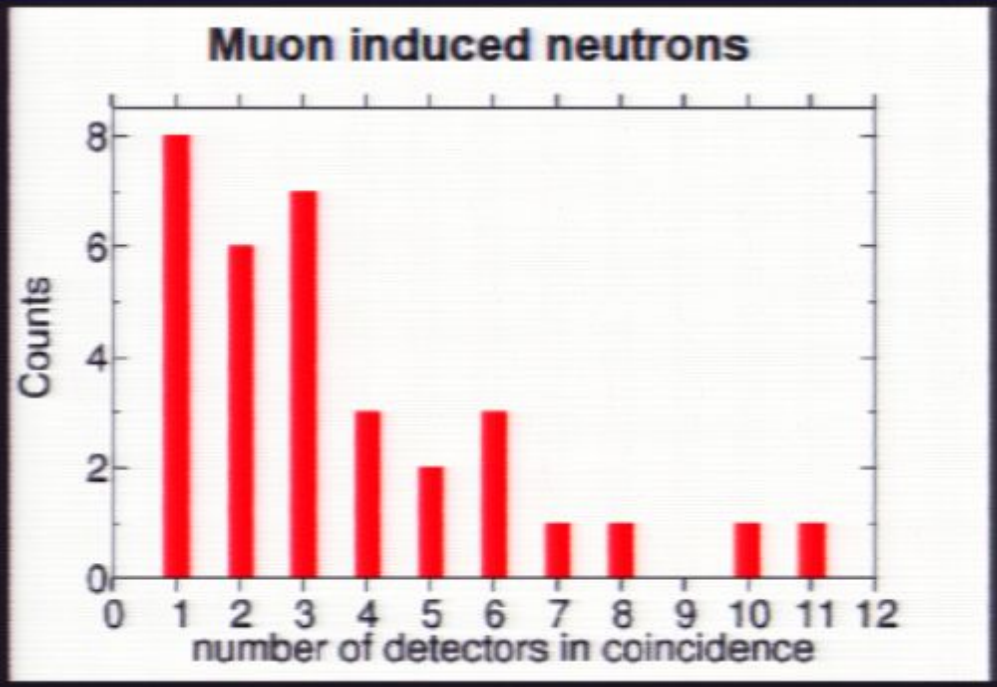

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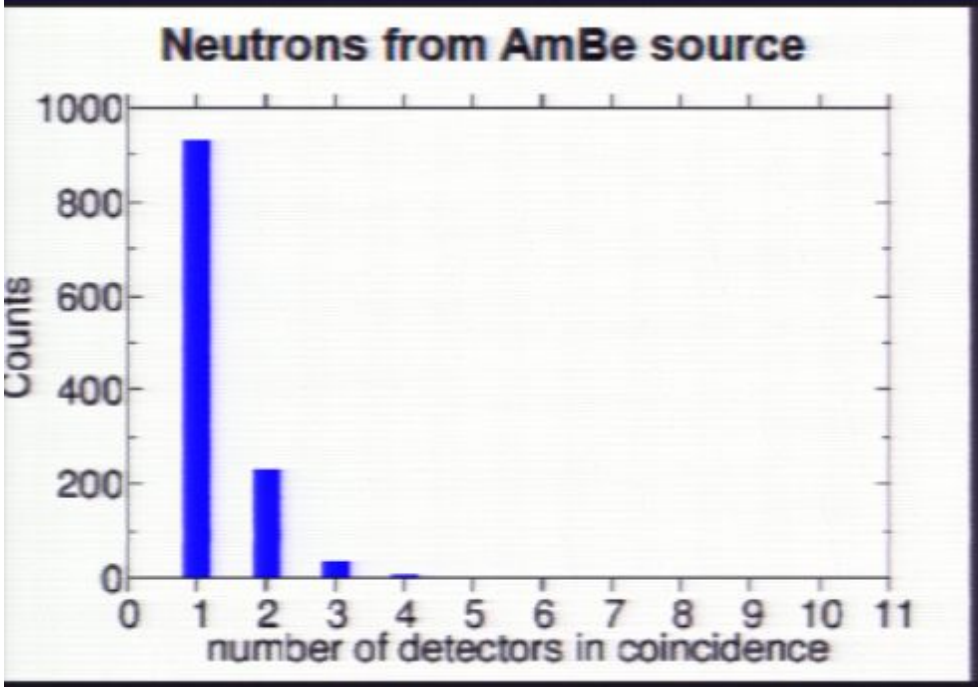

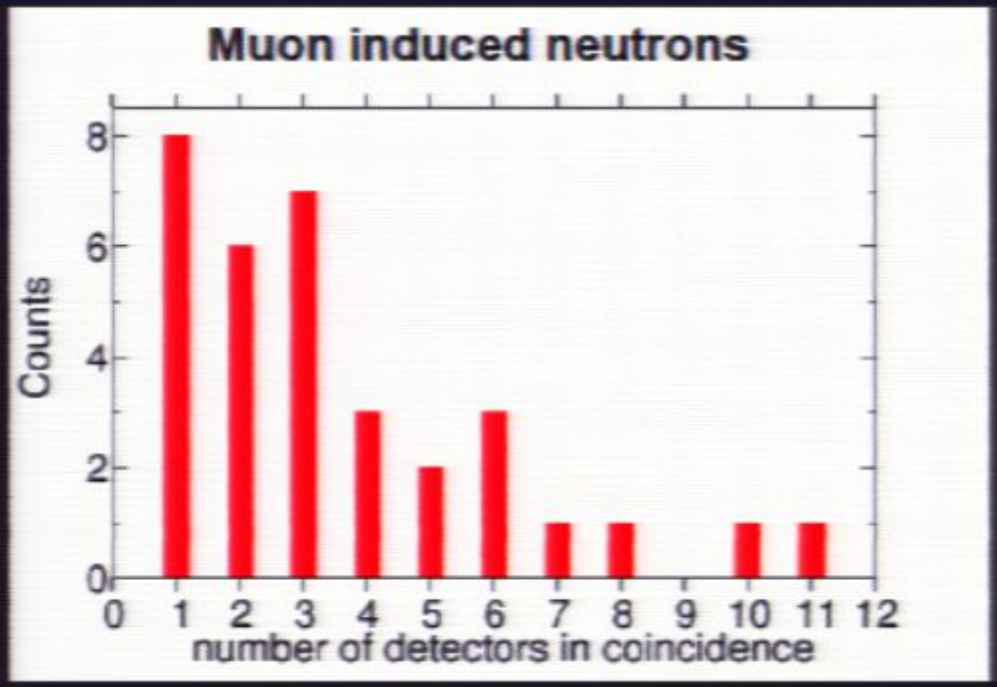

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Measurement with open neutron shield

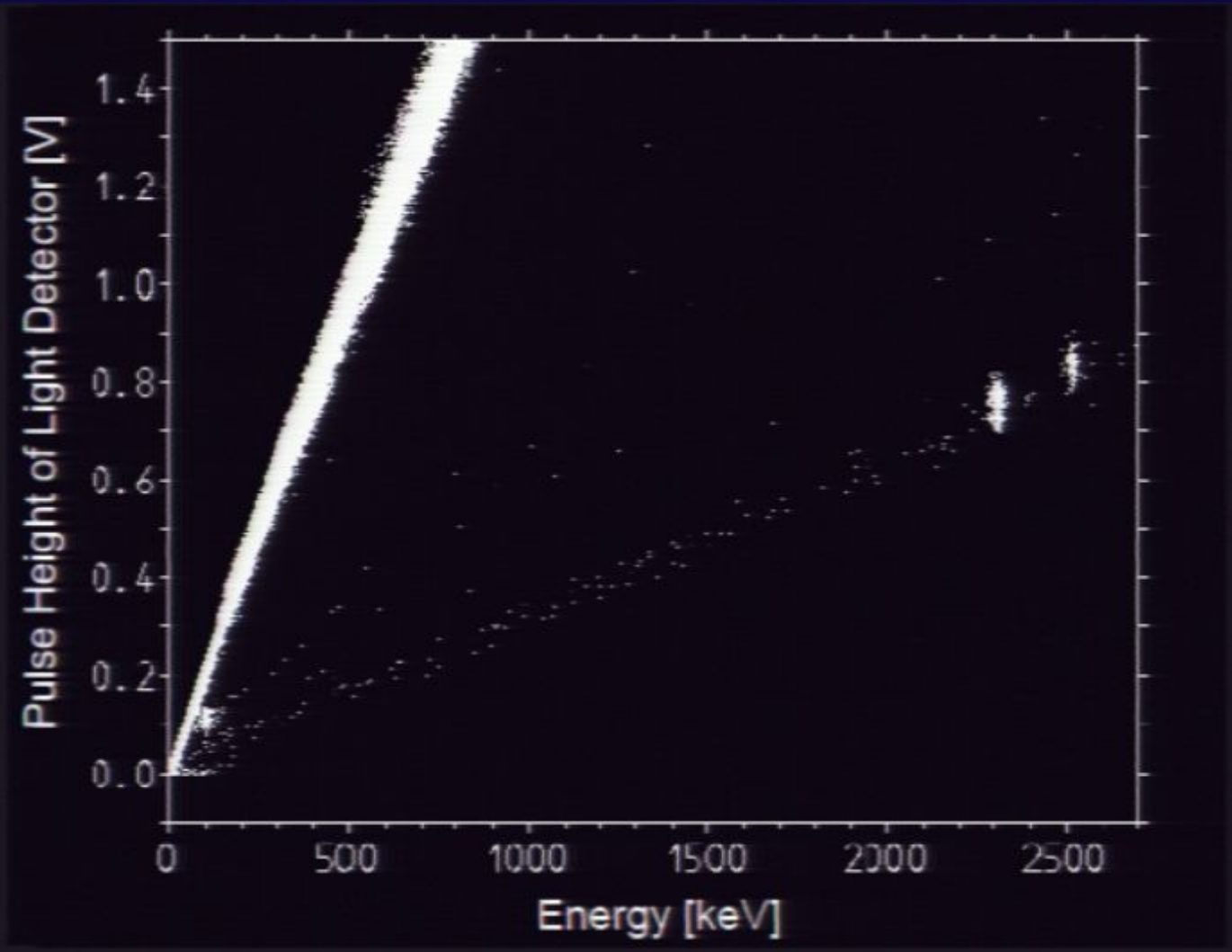
- Simple plausibility test with two of the 6 sides open (36.9 kg-days)

Recoil rates in signal range of oxygen band:
open shield: 8 counts / 36.91 kg-days =0.217 ± 0.076 counts/kg-day
closed shield: 52 counts /564 kg-days = 0.092 ± 0.013 counts/kg-day

Two sides of the neutron shield completely open doubles oxygen recoil rate

==> some small gaps in the neutron shield can never explain observed oxygen singles

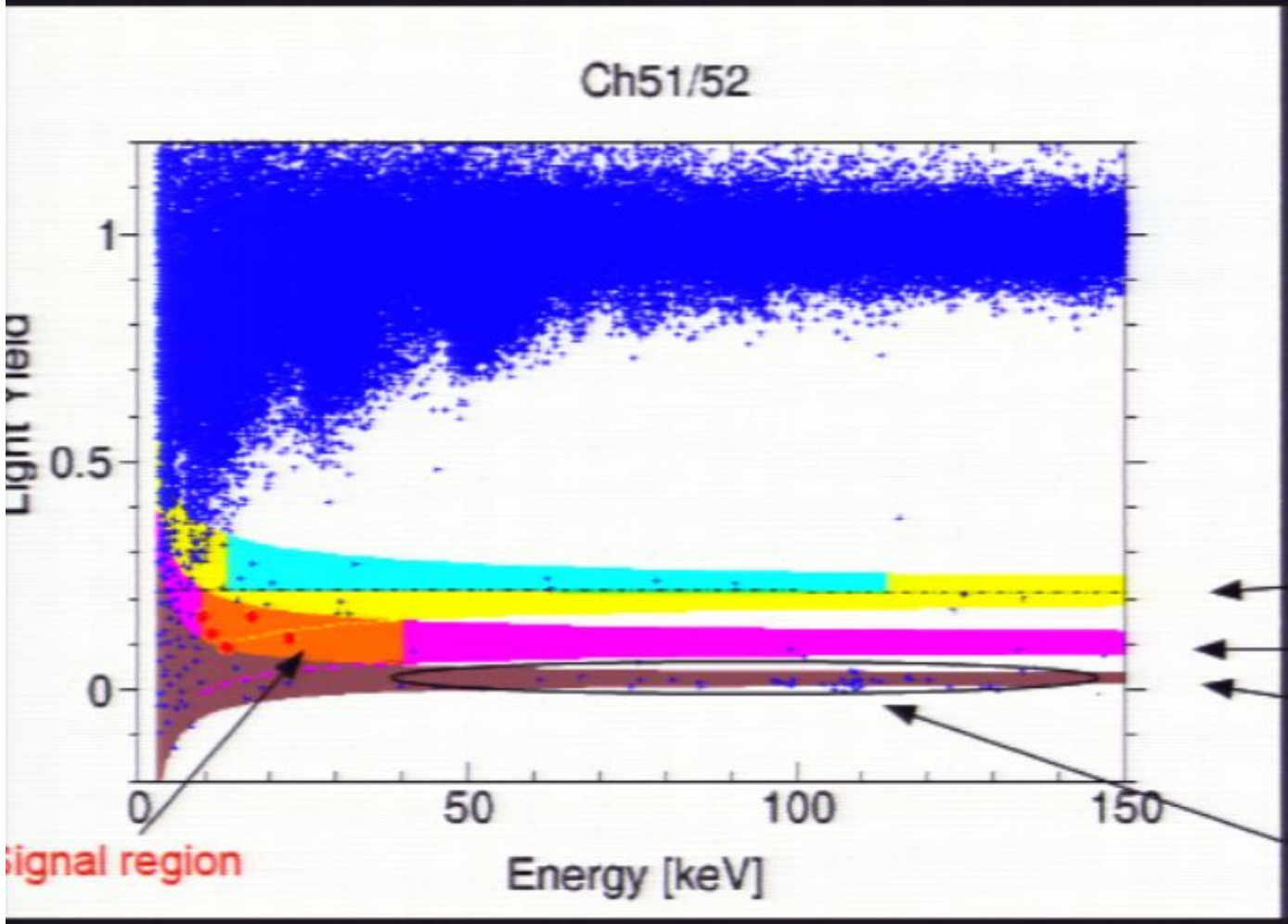
Degraded alphas from external contamination in clamps



Discrete alpha lines from contamination in crystal are no problem

Degraded alphas with continuous energy distribution down to lowest energies from external contamination in clamps holding the crystal

Estimation of alpha background in oxygen band



Detector with highest external alpha background

also highest ^{206}Pb recoil background, with long tail extending from 100 keV down to 40 keV

Background of degraded α's from contaminated clamps.
Oxygen and α band partially overlap and some α's may leak into signal band.
Count alphas in overlap free reference region and project into signal range of oxygen band assuming constant dn/dE.

Summary of Background Estimates

Counts in signal region	**32**
Neutron background	0.8
Alpha background:	6.8
Leakage from gamma band:	1.2
Remaining signal:	**23.2**

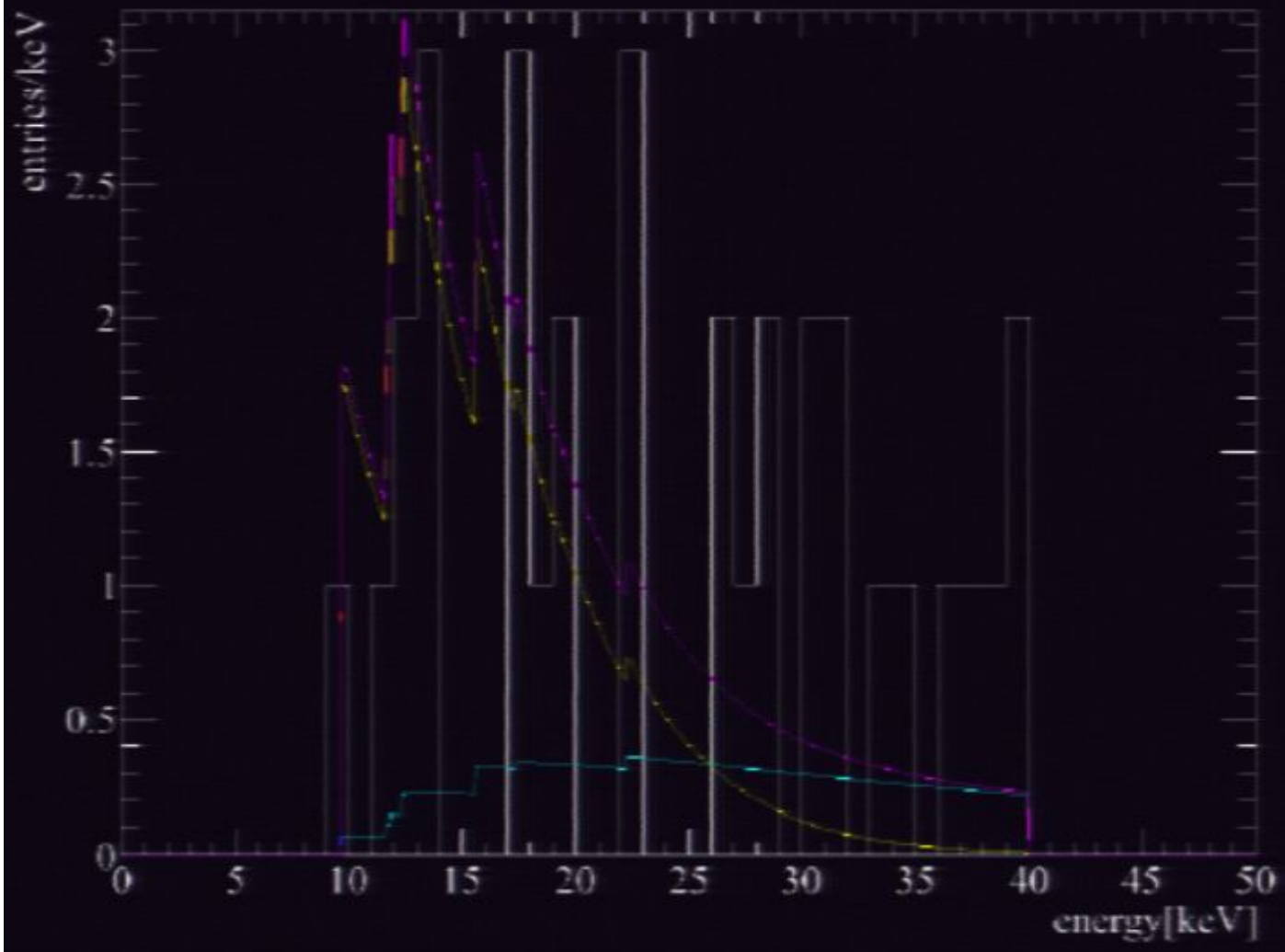
The two coincident events are most likely muon induced. Likelihood ratio test gives **significance of signal=5.4 σ**

No sign of neutron background from sf or alpha-n in the data (no double oxygen scatters) and we do not expected any. If we nevertheless include them in likelihood ratio test we get **significance of signal=2.7 σ**

In any case it is interesting and it should be confirmed in a new run with new scintillating clamps to completely avoid alpha related backgrounds.

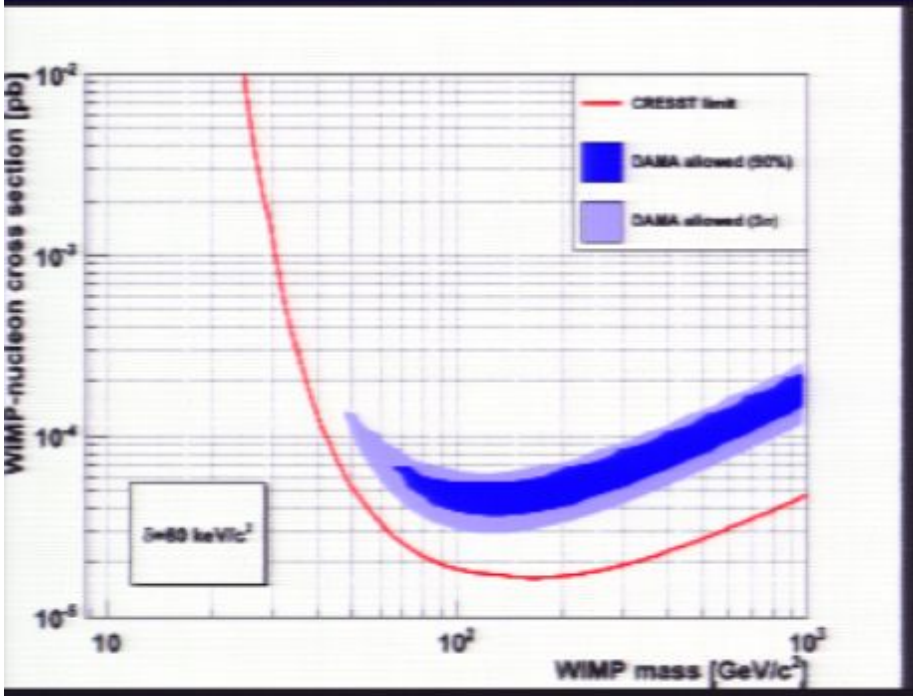
Recoil Energy Spectrum

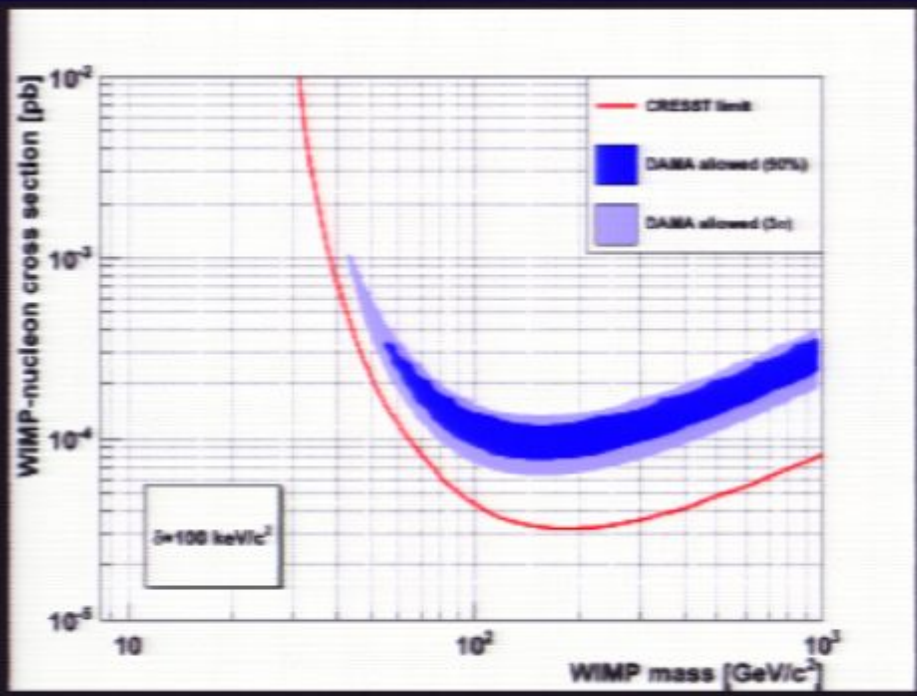
Energy spectrum of accepted events

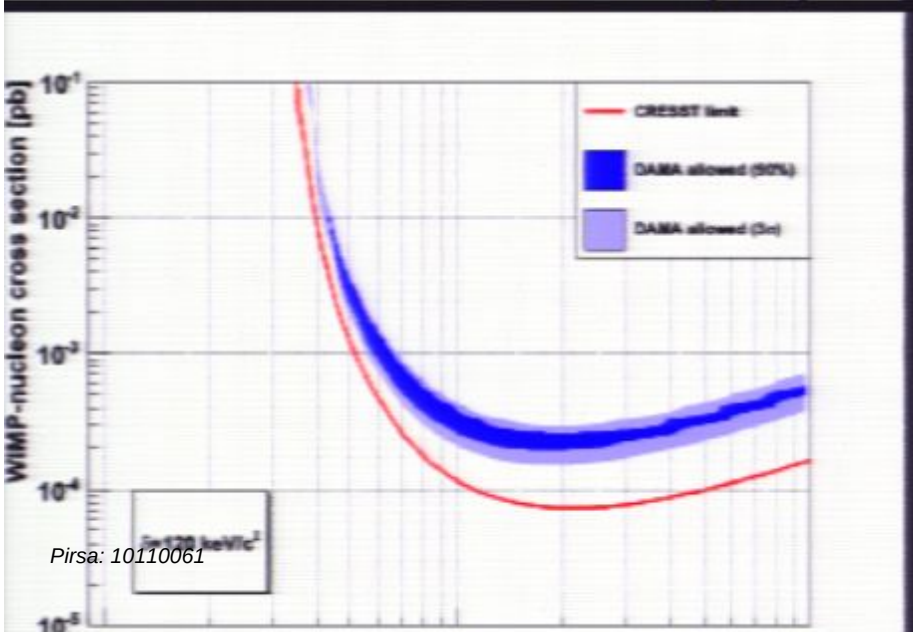


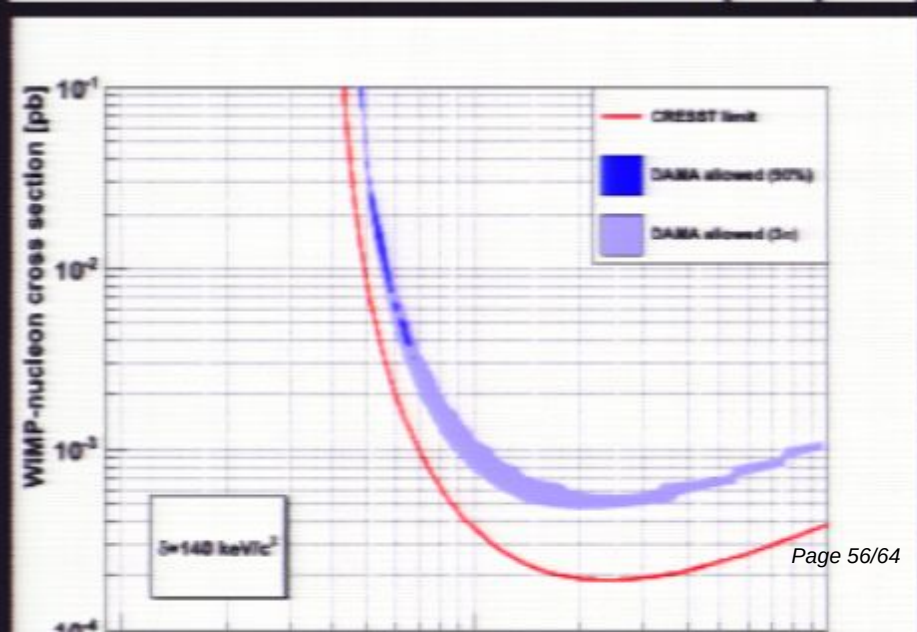
- 32 events in W-O overlap free part of oxygen band
- M_χ ~12 GeV

Inelastic Dark Matter for relevant range of mass splittings δ









Conclusions

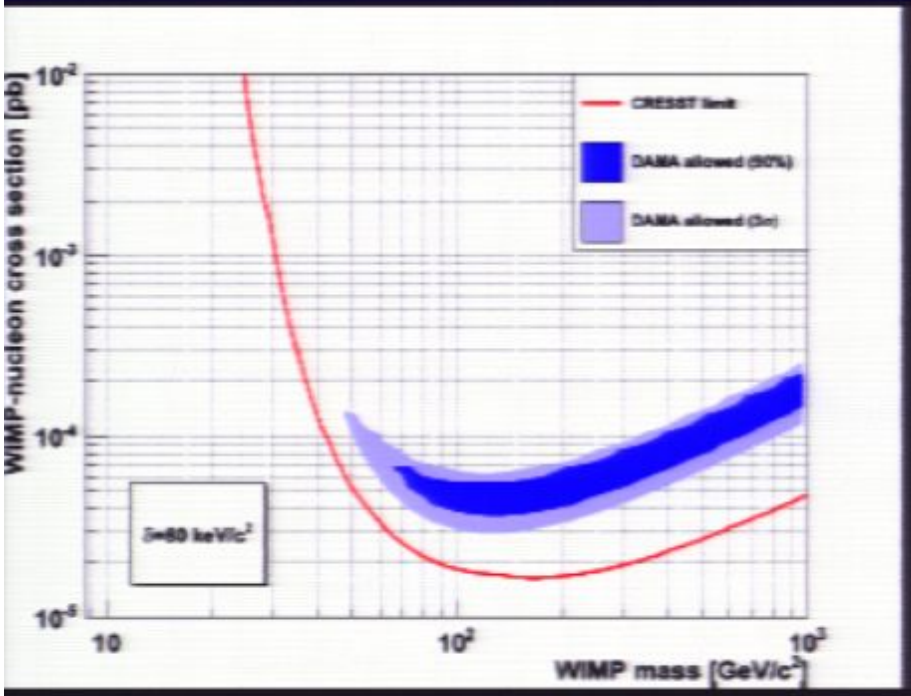
Inelastic Dark Matter scenario is practically ruled out as an explanation of the DAMA result (std halo assumptions).

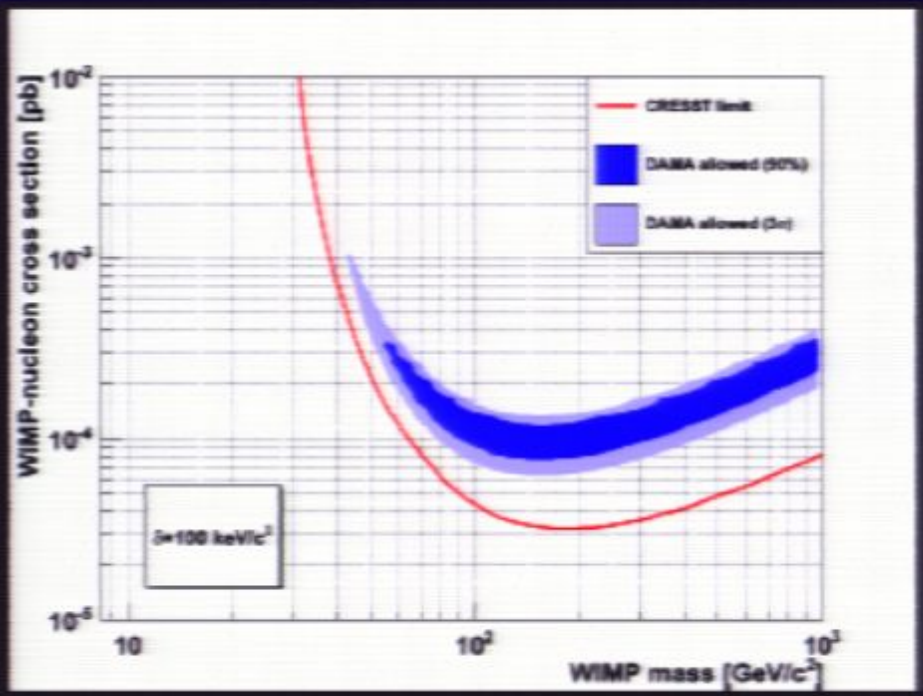
If alpha estimate is roughly O.K and if there are no unexpected surprises with alpha related recoil backgrounds, there is a clear excess of oxygen recoil signals

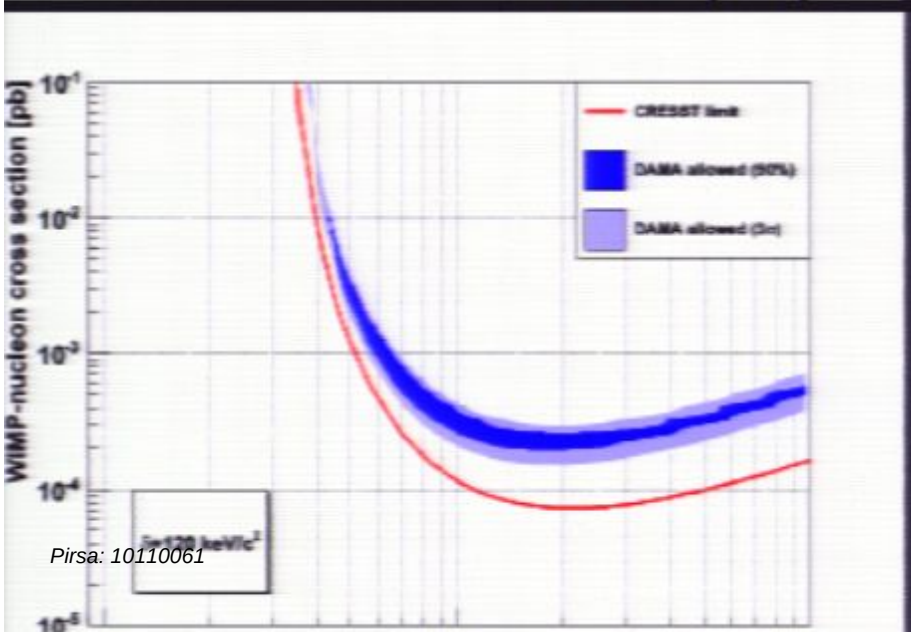
A new run with strongly reduced alpha related backgrounds is the next step. It should allow to pin down the nature of the observed oxygen recoil with high confidence and also constrain the neutron background with higher significance. Replacing light detectors with too low transitions may double number of running detector modules.

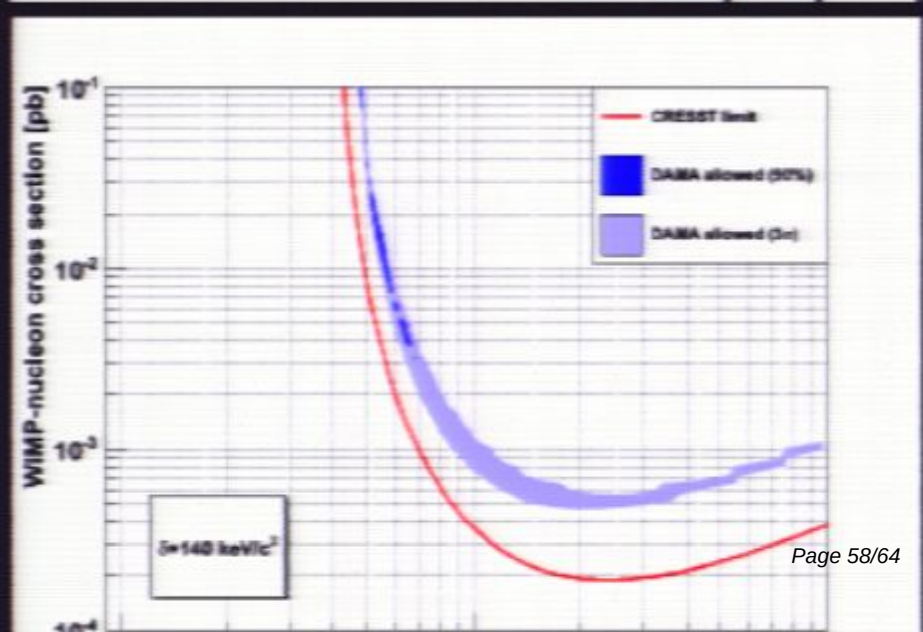
If signal is confirmed, a next larger step would be to mount more SQUIDs and increase capacity of present cold box by factor of ~3 to increase detector mass by factor of ~10 compared to present run. More efficient targets e.g. Al_2O_3

Inelastic Dark Matter for relevant range of mass splittings δ



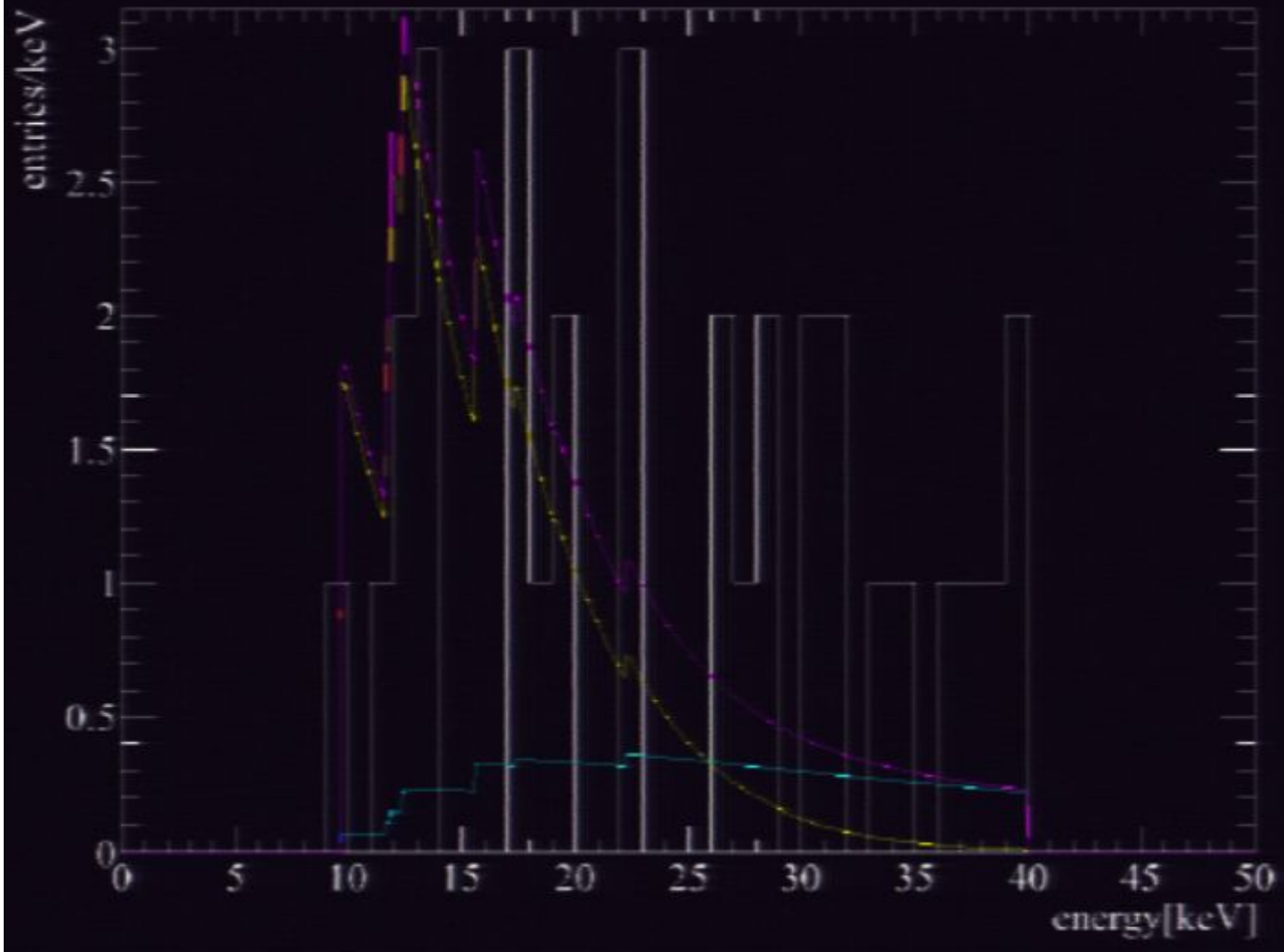






Recoil Energy Spectrum

Energy spectrum of accepted events



- 32 events in W-O overlap free part of oxygen band
- M_χ =12 GeV

Origin of coincident events in oxygen band

- Observed 2 coincident events are both triple coincidences with MeV gammas in one of the detectors

- When there are coincident neutron events, there are also singles.
  ==> Estimate number of single oxygen recoils from observed coincidences.

- Ratio of coincidences/singles depends on the type of neutrons.

Two types of neutrons

Source type, sf or alpha-n

mostly oxygen double scatters, few triple coincidences and almost none with MeV gammas

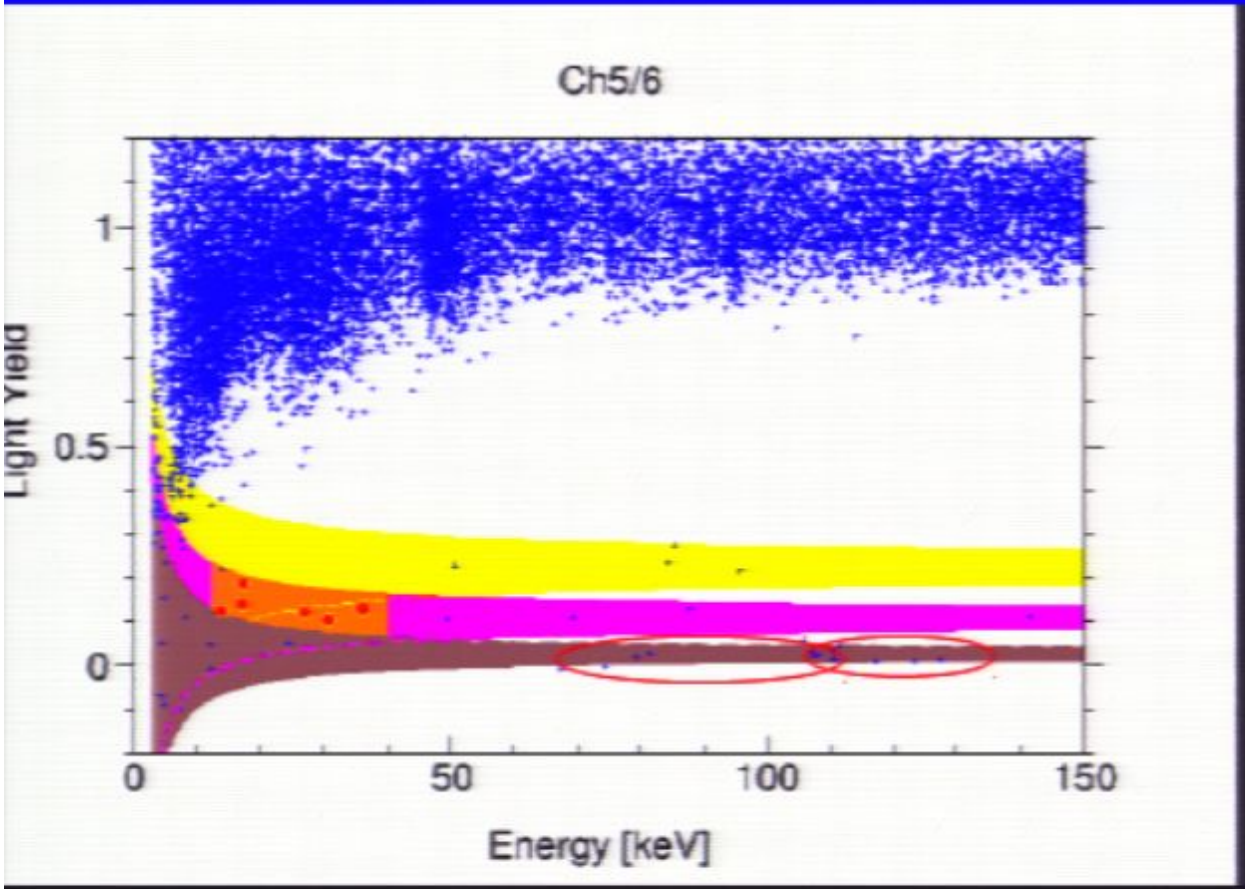
unlike observed 2 events

Muons induced

shower like events with higher multiplicity and high energy gammas

similar to observed 2 events

Avoiding influence of background in W band

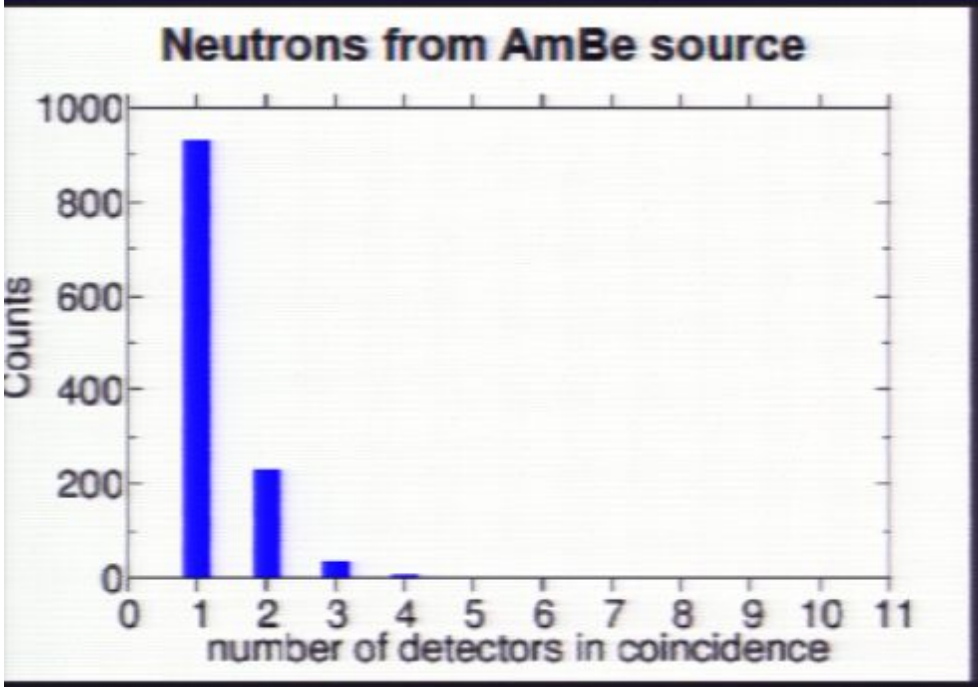


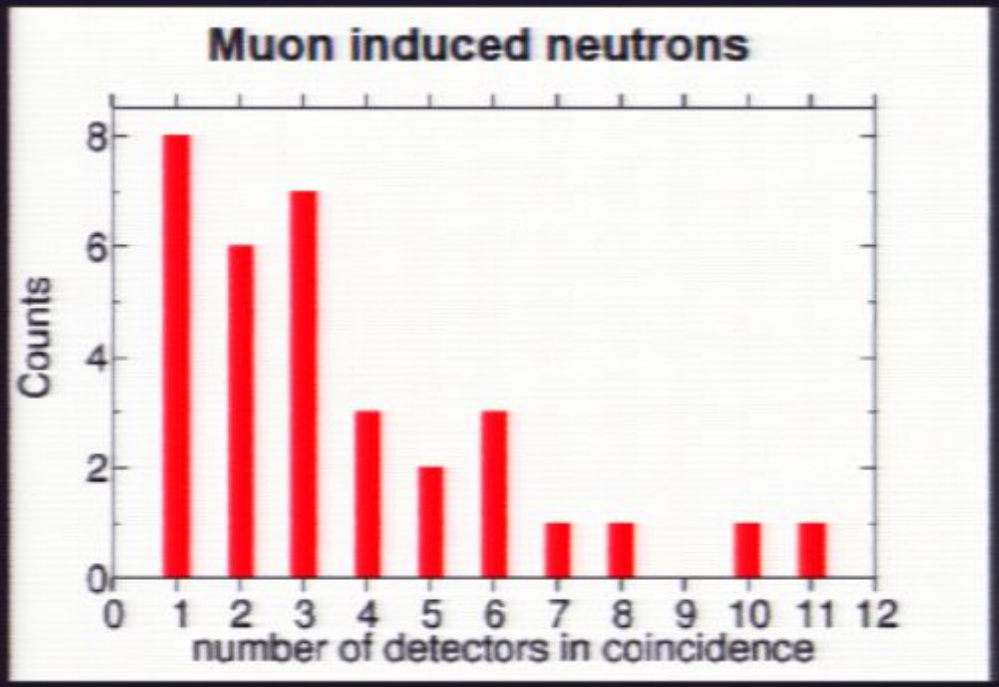
alpha band
oxygen band
tungsten band

Some leakage of ^{206}Pb recoils from non scintillating clamps into the signal region of W band can not be excluded. Difficult to estimate.

==> Concentrate on signals in upper part of the oxygen band which does not overlap with tungsten band.

Multiplicity of Neutron Induced Events





Mostly oxygen double scatters, very few triple coincidences and almost none with MeV gammas.

unlike observed coincidences

single/coinident=3.41

2 observed coincident events translate into ~7 oxygen singles in signal region

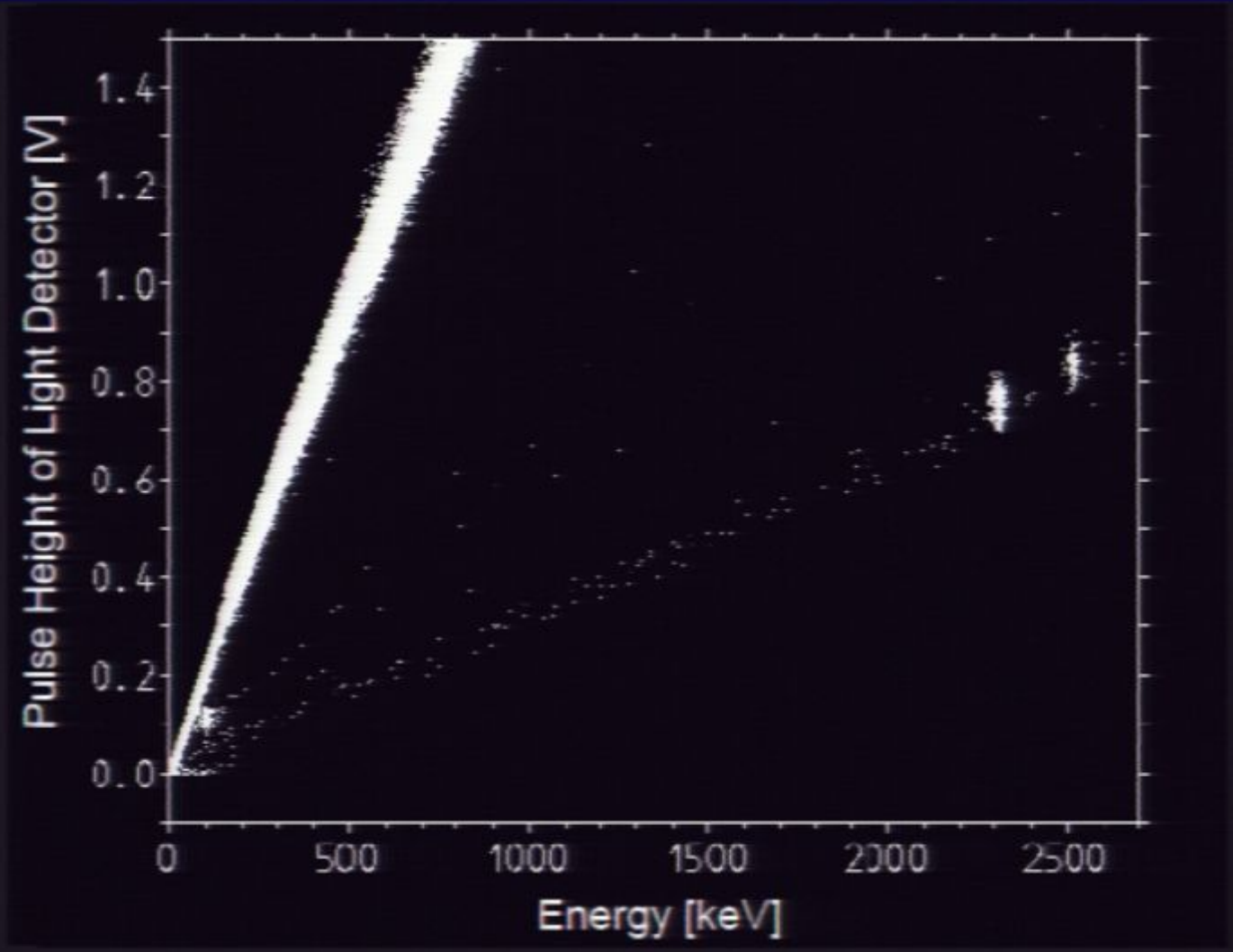
Shower like events, oxygen recoils coincident with larger number of other detector modules, often with high energy gammas.

Similar to the observed events

single/coincident = 0.32

2 observed coincident events translate into <1 oxygen singles in signal energy range

Degraded alphas from external contamination in clamps



Discrete alpha lines from contamination in crystal are no problem

Degraded alphas with continuous energy distribution down to lowest energies from external contamination in clamps holding the crystal

Summary of Background Estimates

Counts in signal region	**32**
Neutron background	0.8
Alpha background:	6.8
Leakage from gamma band:	1.2
Remaining signal:	**23.2**

The two coincident events are most likely muon induced. Likelihood ratio test gives **significance of signal=5.4 σ**

No sign of neutron background from sf or alpha-n in the data (no double oxygen scatters) and we do not expected any. If we nevertheless include them in likelihood ratio test we get **significance of signal=2.7 σ**

In any case it is interesting and it should be confirmed in a new run with new scintillating clamps to completely avoid alpha related backgrounds.