Heidelberg-Moscow experiment and Evidence for 0nubb?

Daniel Lenz

Cresst – Gerda – FMC(?) Seminar

Overview

Theory Introduction to 0nubb

Experimental Setup of Heidelberg Moscow Experiment

Phys. Rev. D 55, 54 (1997)

Background Reduction and Background

Phys. Rev. D 55, 54 (1997)

Latest results from the Heidelberg-Moscow double beta decay experiment

Eur. Phys. J. A 12, 147-154 (2001)

EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY

Mod. Phys. Lett. A16 2409-2420 (2001) hep-ph/0201231

COMMENT ON “EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY“

Mod. Phys. Lett. A 17 1475-1478 (2002) hep-ex/0202018

Reply to the Comment on “Evidence for Neutrinoless Double Beta Decay“

hep-ph/0205293 v1

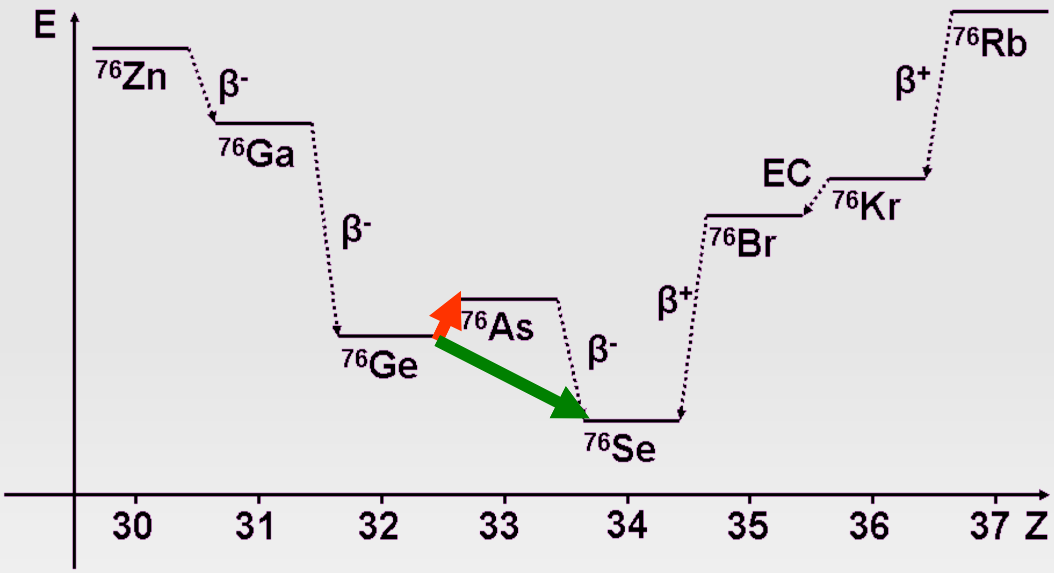
REPLY TO A COMMENT OF ARTICLE “EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY“

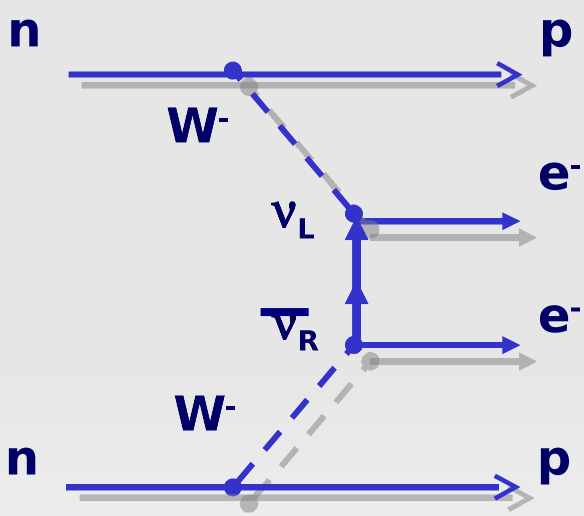
hep-ph/0205228 v2

Explanations? Summary Conclusion

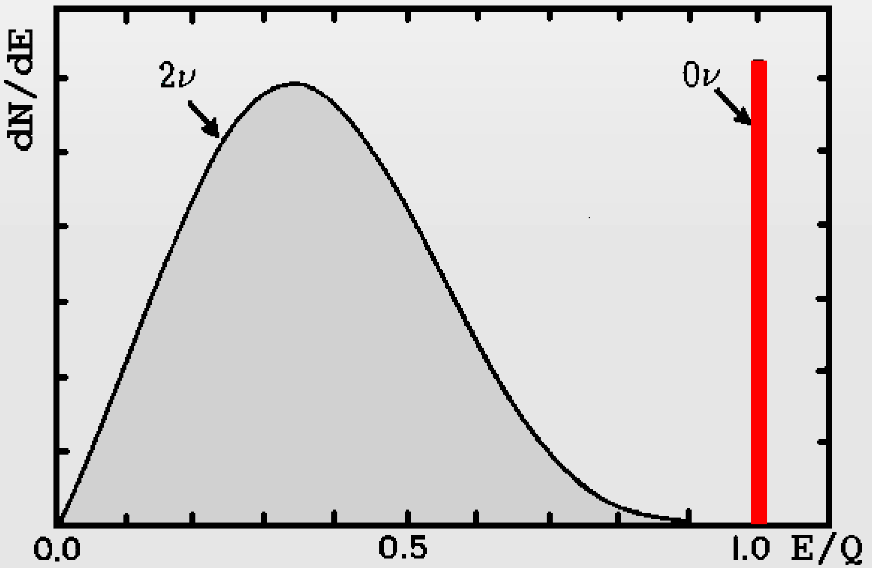
nucl-ex/0704.0306v4

Theory Introduction to 0nubb





- $(A,Z) \rightarrow (A, Z+2) + 2e^-$
- $\Delta L \neq 0$
- happens, if $\nu = \overline{\nu}$ & $m_\nu > 0$



Experimental Setup

5 enriched (86%) HPGe p-type detectors used

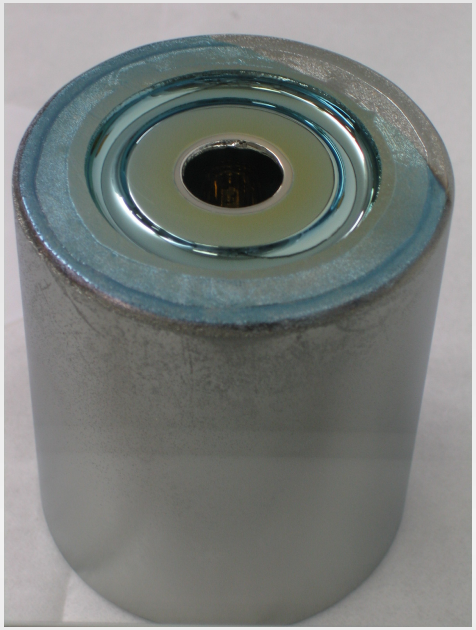


TABLE I. Technical parameters of the five enriched detectors.

Detector number	Total mass [kg]	Active mass [kg]	Enrichment in ^{76}Ge [%]	FWHM[a] at 1332 keV [keV]
enr No. 1	0.980	0.920	85.9±1.3	2.22±0.02
enr No. 2	2.906	2.758	86.6±2.5	2.43±0.03
enr No. 3	2.446	2.324	88.3±2.6	2.71±0.03
enr No. 4	2.400	2.295	86.3±1.3	2.14±0.04
enr No. 5	2.781	2.666	85.6±1.3	2.55±0.05

[a]Full width at half maximum.

total: 11.51 kg 10.96 kg

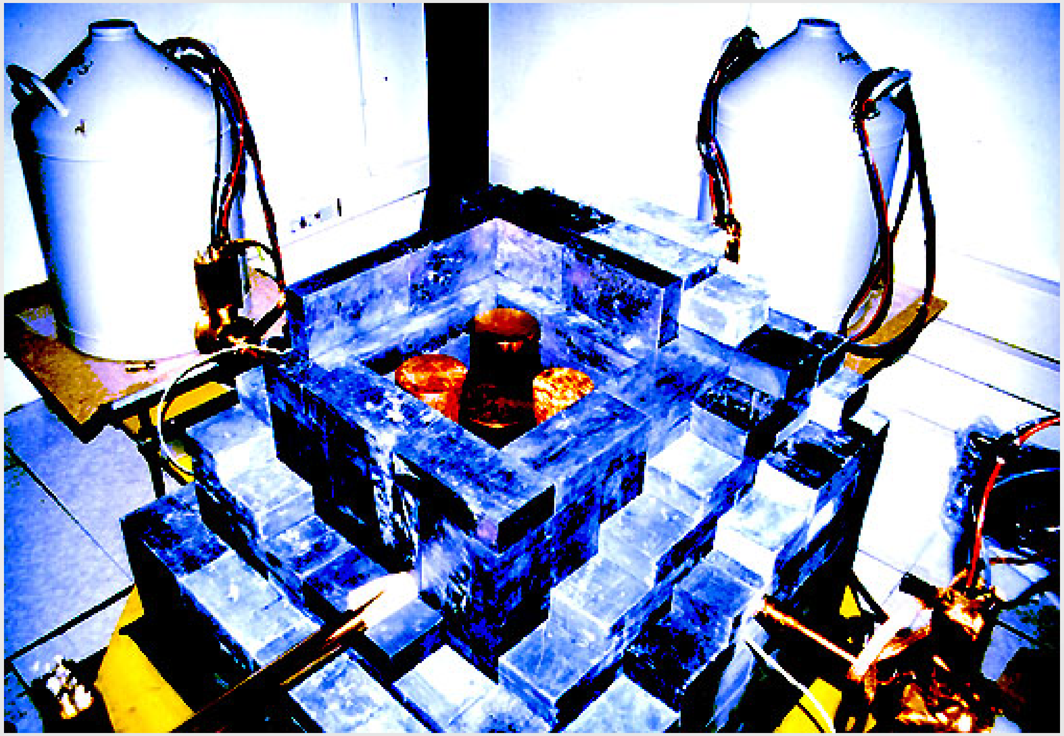
Advantages:

- excellent energy resolution at 2039 keV of 3.59 +- 0.26 keV
- large size => large peak to compton ratio
- source = detector => large source strength and high efficiency

Experimental Setup

- Underground in Gran Sasso approx. 3500 m.w.e

- Detector “enr No. 1,2,3,5“ in Pb cryostat



Shielding:

- muon shield
- boron PE shield (added later on)
  - air-tight steel box with nitrogen gas
    - 30 cm Pb shield:
      - outer 20 cm Boliden (standard) Pb
      - inner 10 cm radiopure LC2-grade (~10Bq/kg) Pb

Experimental Setup

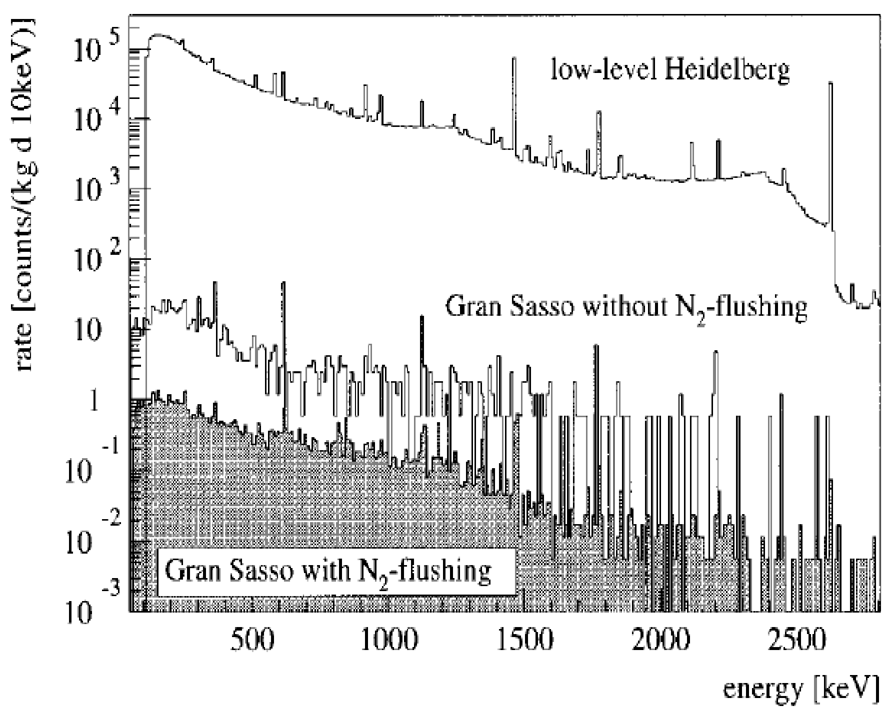
- Detector “enr No. 4“ in Cu cryostat

Shielding:

- air-tight steel box with nitrogen gas
- boron PE shield
- 47.5 cm shield:
  - outer 20 cm Pb
  - 27.5 cm electrolytical Cu

Background Reduction

Detector “enr No. 4“



10E5 count rate reduction

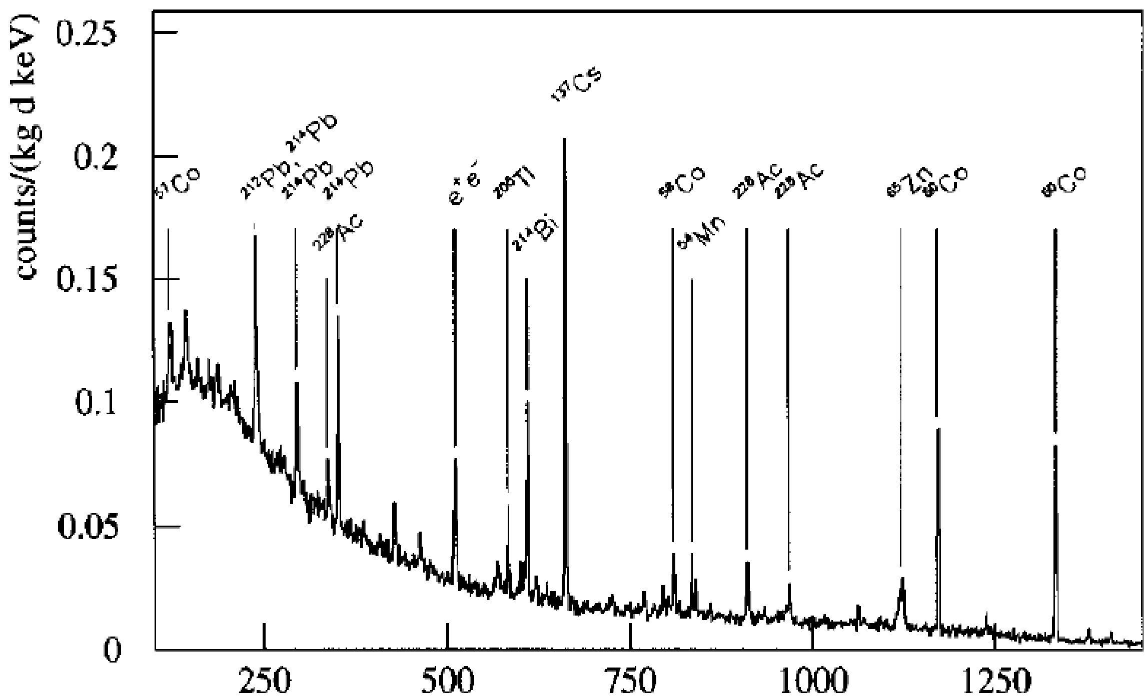
Detector number	Measuring time [days]	Date start end	Shielding: Cu	Shielding: Pb	Shielding: boron -polyethylene	Background [counts/keV yr kg] 100–2800 keV	Background [counts/keV yr kg] 2000–2100 keV
first low-level setups							
enr No. 1	387.6	8/90–8/91 1/92–8/92	×			9.74	0.56
enr No. 2	225.4	9/91–8/92		×		6.09	0.29
common shielding for three detectors							
enr No. 1	382.8			×		7.81	0.22
enr No. 2	383.8	9/92–1/94		×		4.86	0.22
enr No. 3	382.8			×		6.67	0.21
enr No. 1	263.0			×	×	6.96	0.20
enr No. 2	257.2	2/94–11/94		×	×	4.48	0.14
enr No. 3	263.0			×	×	6.06	0.18
Full setup four detectors in common shielding, one detector separate (since 2/95 enr No. 5 with digital pulse shape analysis)							
enr No. 1	203.6	12/94–8/95		×	×	7.06	0.14
enr No. 2	203.6	12/94–8/95		×	×	4.20	0.17
enr No. 3	188.9	12/94–8/95		×	×	5.50	0.20
enr No. 5	48.0	12/94–1/95		×	×	7.55	0.23
enr No. 4	147.6	1/95–8/95	×			6.62	0.43

After Bo-PE shield installation:

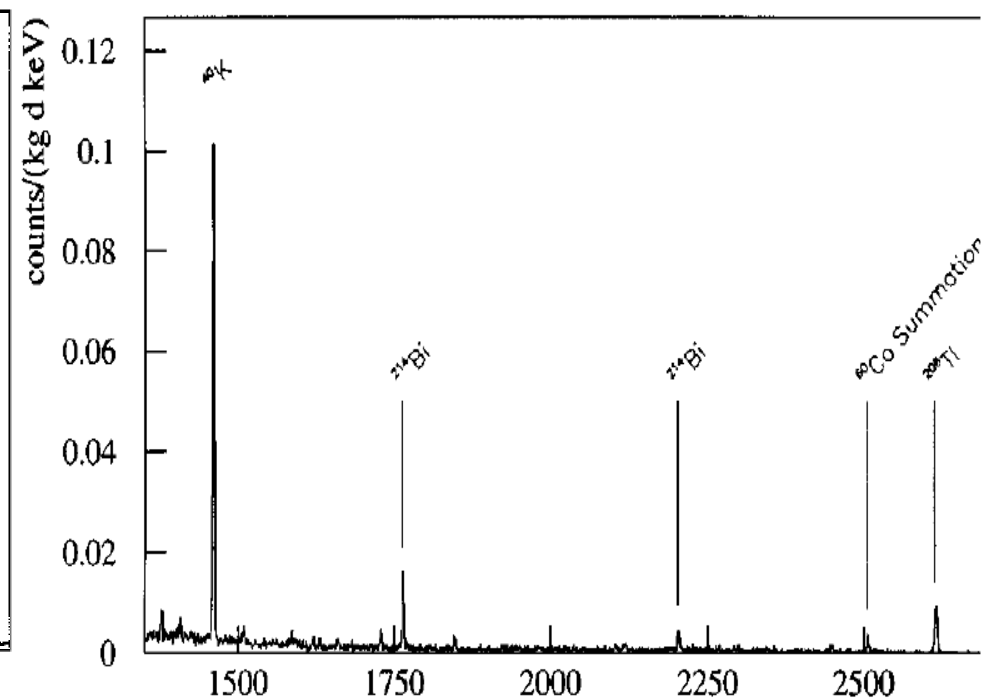
Overall decrease in count rate: (7.5 +- 0.5)%

Decrease in ROI count rate: (22.5 +- 13)%

Background



Phys. Rev. D 55, 54 (1997)



Phys. Rev. D 55, 54 (1997)

<u>Backgrounds</u>:

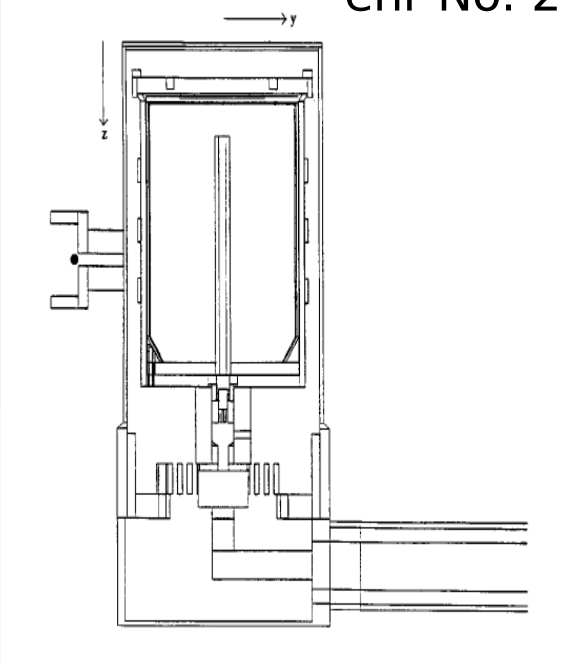
- gammas: cosmogenic: Co60 — anthropological: Cs137 — natural decay chains: U238, Th232, K40
- elastic & inelastic neutron scat
- direct muon induced events

NO external alphas & betas due to 0.7 mm dead-layer

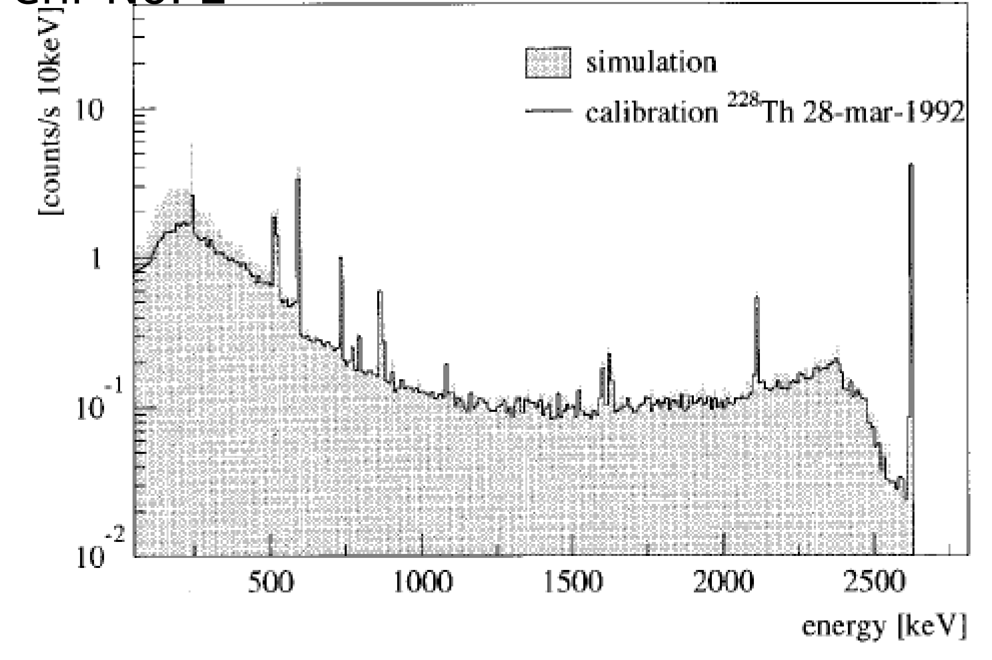
BUT slight contamination of detector 4,5 with Pb210 ~muBq/kg

Background Simulation

enr No. 2



enr No. 2



- each detector scanned with collimated Ba133 source
- detector enr No. 1,2,3 simulated
- evaluation done using 4 strongest gamma lines => error of ~6 %

  Figure: Th228 data-MC:

  low energy bad, 2mm uncertainty in src-position, src partially covered Pb
  above 500 keV less than 10 % deviation

Latest Results from the HDM 0nubb...

Eur. Phys. J. A12, 147-154 (2001) *hep-ph/0103062*

- Identified 142 lines in spectrum

Bkg simulated

position estimated from least square fit of peak intensity

=> **5 main locations** of radioactive contamination

- LC2-Pb shield,
- Copper shield,
- Copper+plastic parts of cryostat,
- Ge-crystals

No muon induced events simulated (too large uncertainties in GEANT3.21)

Activities of K40 and Pb210 in LC2 Pb measured

Latest results from the **Heidelberg-Moscow** experiment 3

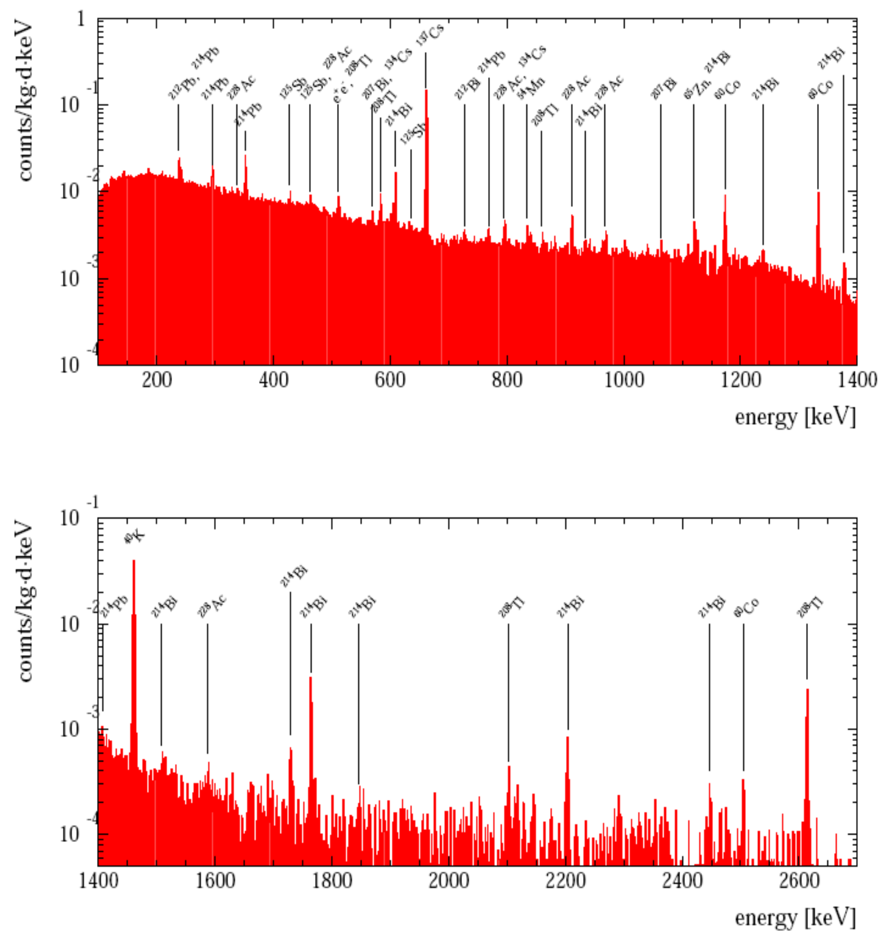


Fig. 1. Sum spectrum of all five ^{76}Ge detectors after 47.4 kg y of measurement. The most prominent identified lines are labeled.

Latest Results from the HDM 0nubb...

Eur. Phys. J. A12, 147-154 (2001) *hep-ph/0103062*

energy resolution(2039keV):
(4.23+-0.14)keV

expected background(2-2.080 MeV)
(0.19+-0.01) cts/(kg y keV)

expected background 3 sigma region
(110.3+-3.9) events

measured:
112 events

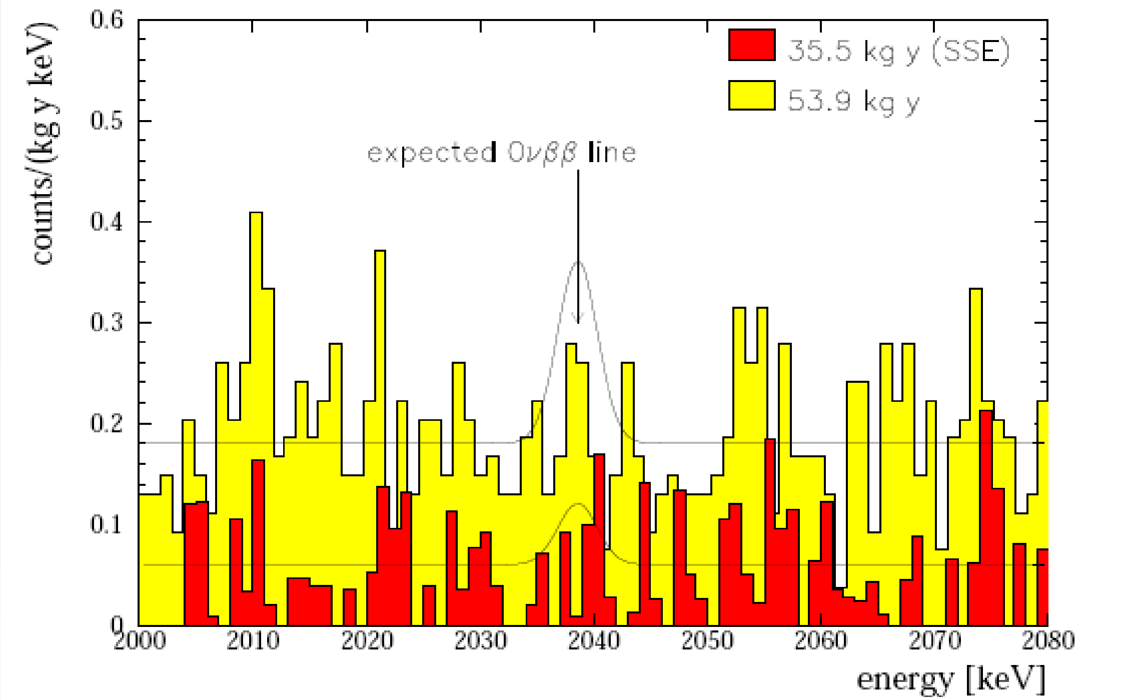


Fig. 4. Sum spectrum of all five detectors with 53.9 kg y and SSE spectrum with 35.5 kg y in the region of interest for the $0\nu\beta\beta$ -decay. The curves correspond to the excluded signals with $T^{0\nu}_{1/2} \geq 1.3 \times 10^{25}$ y (90% C.L.) and $T^{0\nu}_{1/2} \geq 1.9 \times 10^{25}$ y (90% C.L.), respectively.

Result:

T1/2 >= 1.3 E25 y (90% C.L.) 53.9 kg * y

T1/2 >= 1.9 E25 y (90% C.L.) 35.5 kg * y PSA!!!

Evidence for 0nubb decay

Mod. Phys. Lett. A16 2409-2420 (2001)   hep-ph/0201231

~ same dataset as before!

In this paper, we present a new, refined analysis of the data obtained in the HEIDELBERG-MOSCOW experiment during the period August 1990 - May 2000 [15]. The analysis concentrates on the neutrinoless decay mode which

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<u>energy resolution(2039keV):</u>

(4.00+-0.39) keV

<u>background rate (2. -2.08 MeV):</u>

(0.17+-0.01) cts / (kg y keV)

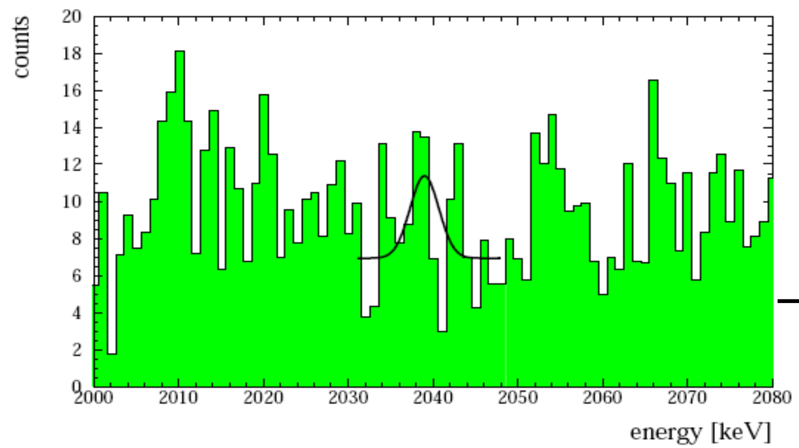
assume all data = bkg

<u>statistical significance:</u>

54.981 kg * y

Evidence for 0nubb decay

Mod. Phys. Lett. A16 2409-2420 (2001) hep-ph/0201231



All detectors

Figure 1. Sum spectrum of the ^{76}Ge detectors Nr. 1,2,3,4,5 over the period August 1990 to May 2000, (54.981 kg y) in the energy interval 2000 - 2080 keV, around the $Q_{\beta\beta}$ value of double beta decay ($Q_{\beta\beta}$ = 2039.006(50) keV). The curve results from Bayesian inference in the way explained in the text. It corresponds to a half-life $T^{0\nu}_{1/2}$=(0.80 − 35.07) × 10^{25} (95% c.l.).

Bayesian peak detection algorithm applied

<u>known Bi214 lines:</u>

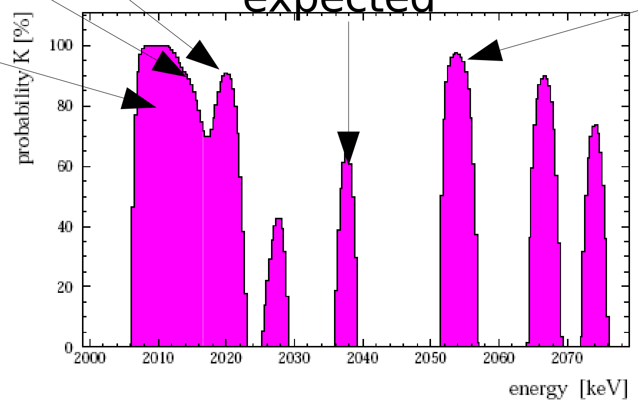
2021.8 keV

2016.7 keV

2010.7 keV

not expected

2052.9 keV



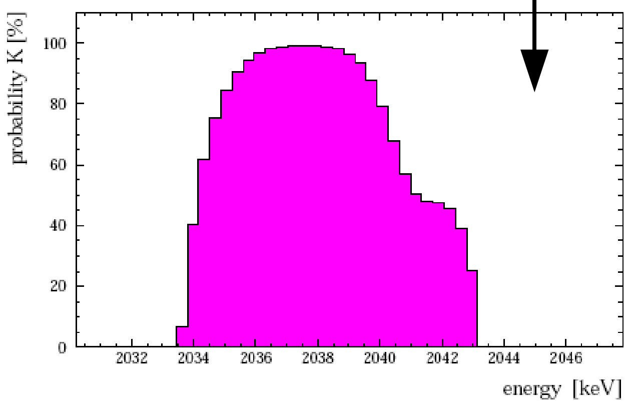


Figure 4. Scan for lines in the full spectrum taken from 1990-2000 with detectors Nr. 1,2,3,4,5, (Fig. 1), with the Bayesian method. The ordinate is the probability K that a line exists at energy E. Left: Energy range 2000 -2080 keV. Right: Energy range of interest around $Q_{\beta\beta}$.

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Detectors 1,2,3,5

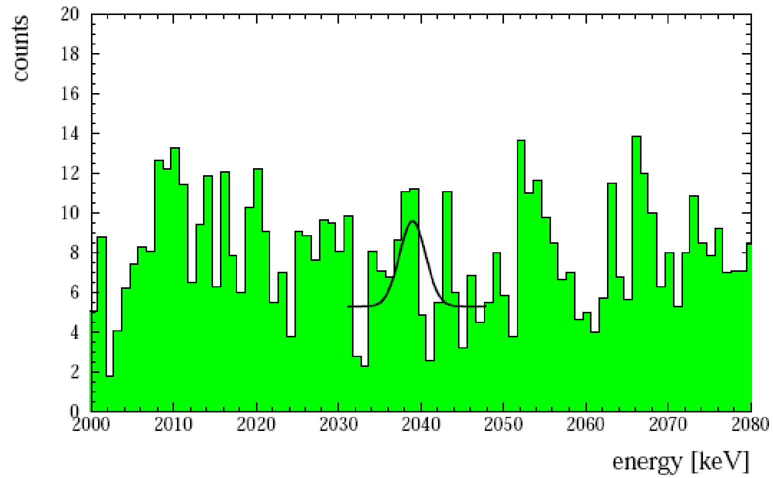

Figure 2. Sum spectrum of the ^{76}Ge detectors Nr. 1,2,3,5 over the period August 1990 to May 2000, 46.502 kg y. The curve results from Bayesian inference in the way explained in the text. It corresponds to a half-life $T^{0\nu}_{1/2}$=(0.75 - 18.33)$\times 10^{25}$ y (95% c.l.).

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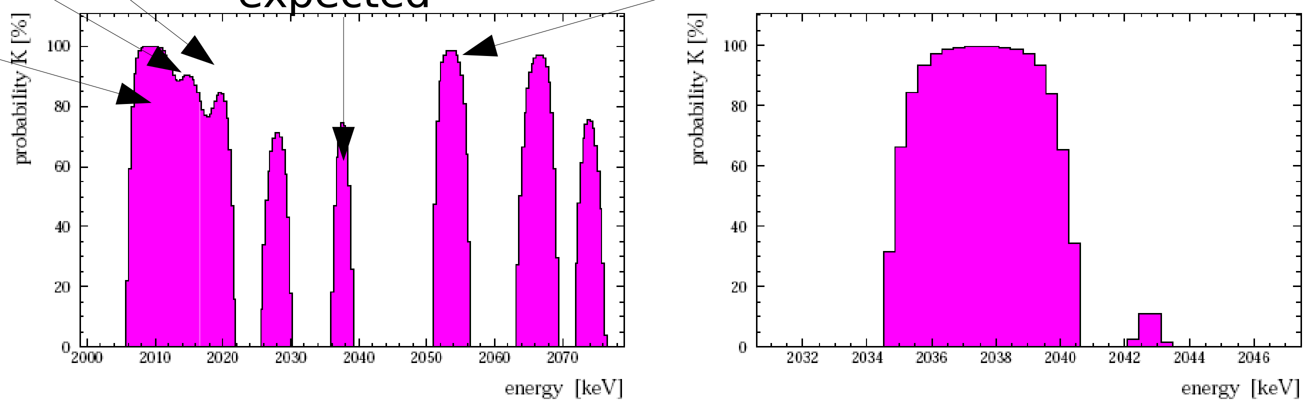

Figure 5. Left: Probability K that a line exists at a given energy in the range of 2000-2080 keV derived via Bayesian inference from the spectrum shown in Fig. 2. Right: Result of a Bayesian scan for lines as in the left part of this figure, but in the energy range of interest around $Q_{\beta\beta}$.

Evidence for 0nubb decay

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Detectors 2,3,5 with PSA

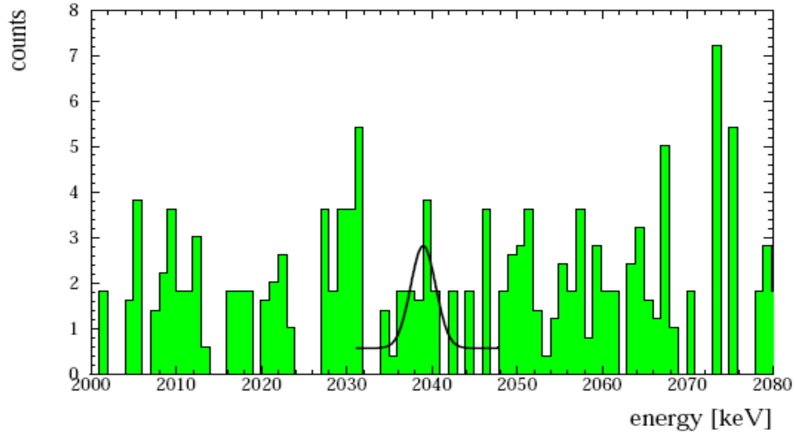

Figure 3. Sum spectrum, measured with the detectors Nr. 2,3,5 operated with pulse shape analysis in the period November 1995 to May 2000 (28.053 kg y), in the region of interest for the $0\nu\beta\beta$ - decay. Only events identified as single site events (SSE) by all three pulse shape analysis methods [18,19] have been accepted. The spectrum has been corrected for the efficiency of SSE identification (see text). The curve results from Bayesian inference in the way explained in the text. The signal corresponds to a half-life $T^{0\nu}_{1/2}=(0.88-22.38)\times 10^{25}$ y (90% c.l.).

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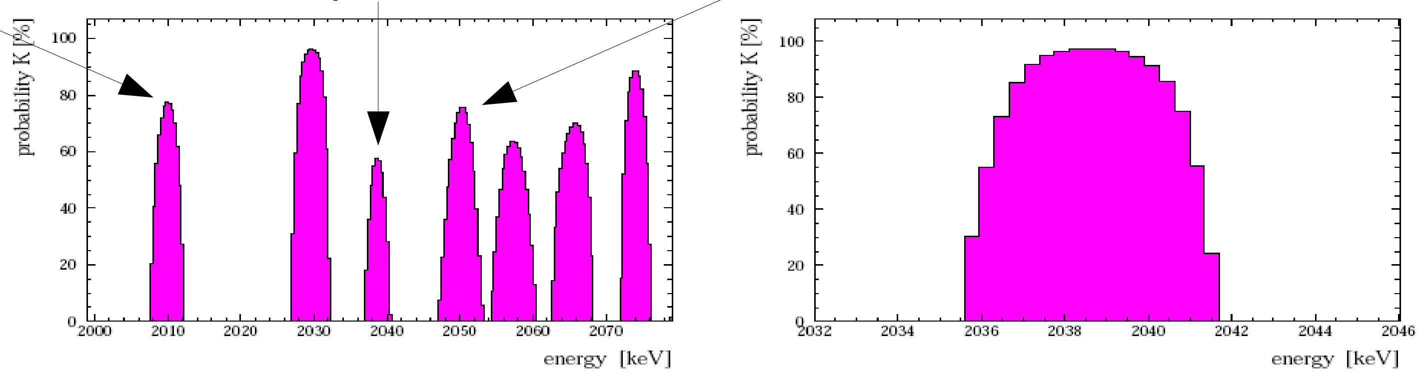

Figure 6. Scan for lines in the single site event spectrum taken from 1995-2000 with detectors Nr. 2,3,5, (Fig. 3), with the Bayesian method (as in Figs. 4,5). Left: Energy range 2000 -2080 keV. Right: Energy range of interest around $Q_{\beta\beta}$.

Evidence for 0nubb decay

Mod. Phys. Lett. A16 2409-2420 (2001) hep-ph/0201231

- with probability 97.4% C.L. line found at Q_bb
- # events: 1.2 – 20.4 (95% C.L.)
- best value: 14.8 events
- 0.11 eV < <m> < 0.56 eV

Significance $[kg\,y]$	Detectors	$T^{0\nu}_{1/2}$ y	$\langle m \rangle$ eV	Conf. level
54.9813	1,2,3,4,5	$(0.80 - 35.07) \times 10^{25}$	(0.08 - 0.54)	95% *c.l.*
54.9813	1,2,3,4,5	$(1.04 - 3.46) \times 10^{25}$	(0.26 - 0.47)	68% *c.l.*
54.9813	1,2,3,4,5	1.61×10^{25}	0.38	Best Value
46.502	1,2,3,5	$(0.75 - 18.33) \times 10^{25}$	(0.11 - 0.56)	95% *c.l.*
46.502	1,2,3,5	$(0.98 - 3.05) \times 10^{25}$	(0.28 - 0.49)	68% *c.l.*
46.502	1,2,3,5	1.50×10^{25}	0.39	Best Value
28.053	2,3,5 SSE	$(0.88 - 22.38) \times 10^{25}$	(0.10 - 0.51)	90% *c.l.*
28.053	2,3,5 SSE	$(1.07 - 3.69) \times 10^{25}$	(0.25 - 0.47)	68% *c.l.*
28.053	2,3,5 SSE	1.61×10^{25}	0.38	Best Value

Table 2. Half-life for the neutrinoless decay mode and deduced effective neutrino mass from the HEIDELBERG-MOSCOW experiment.

<u>Evidence for 0nubb decay</u>:

T1/2 = (0.8-18.3) E25 y (95% C.L.)

Comment on “Evidence for 0nubb...“

hep-ex/0202018v3

- **No null hypothesis** in analysis!
  No MC simulation done to **confirm** peak finding method!

- 3 **unidentified peaks** with **greater significance** than 2039 keV peak!

- **No discussion** of **sensitivity of conclusions** to different **mathematical models**!
  i.e. HDM T1/2 limits in conflict with best fit Evidence T1/2

Cross checks to be done:

- How does **variation of window size** affect peak finding? Not shown!
- **No relative peak strength analysis** of Bi214 peaks
  - **No discussion** of rel. peak strenght of Bi214 peaks
    before and after SSE cut

Evidence for 0nubb decay

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energy resolution(2039keV):
(4.00+-0.39) keV ⟷ *(4.23+-0.14) keV*

background rate (2. -2.08 MeV):
(0.17+-0.01) cts / (kg y keV) ⟷ *(0.19+-0.01) cts/(kg y keV)*
assume all data = bkg

statistical significance:
54.981 kg * y ⟷ *53.93 kg * y*

Evidence for 0nubb decay

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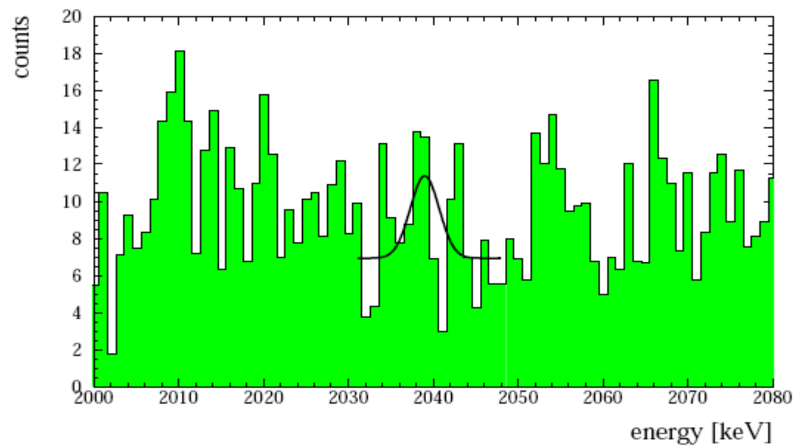

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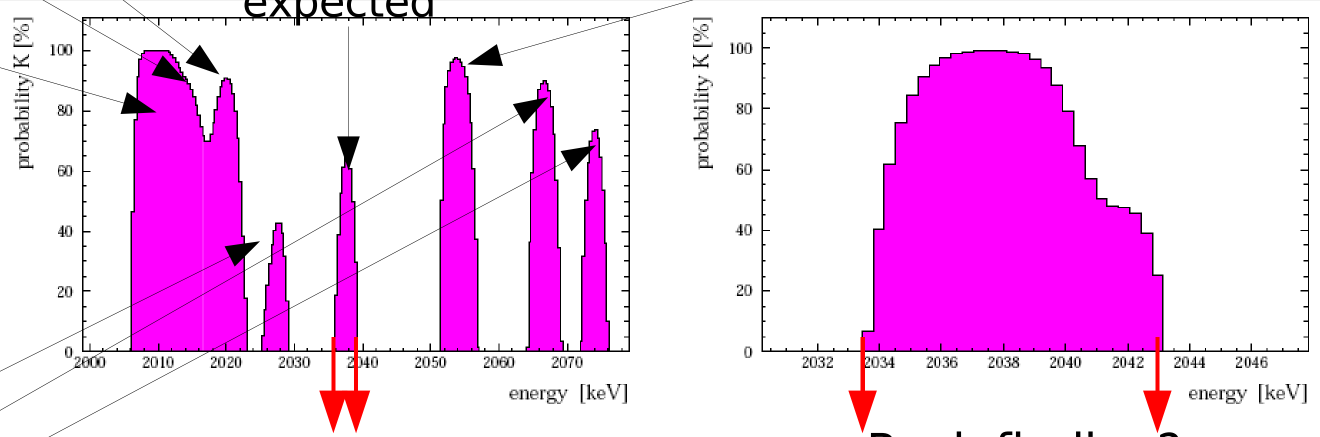

Peak finding?

?

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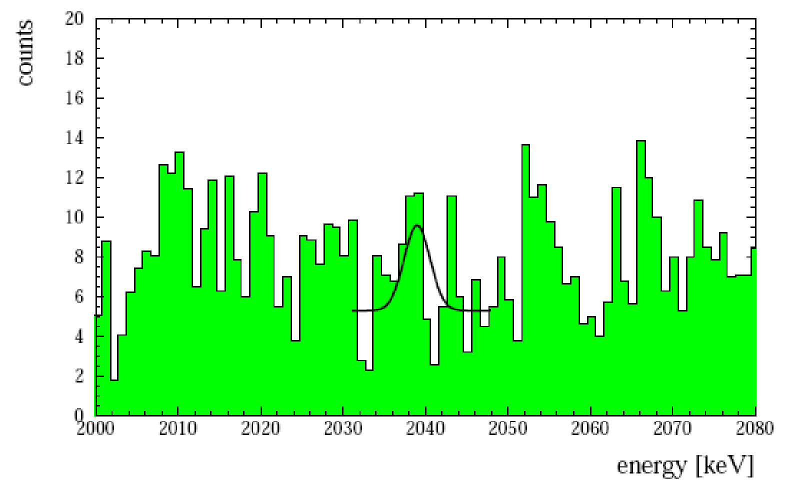

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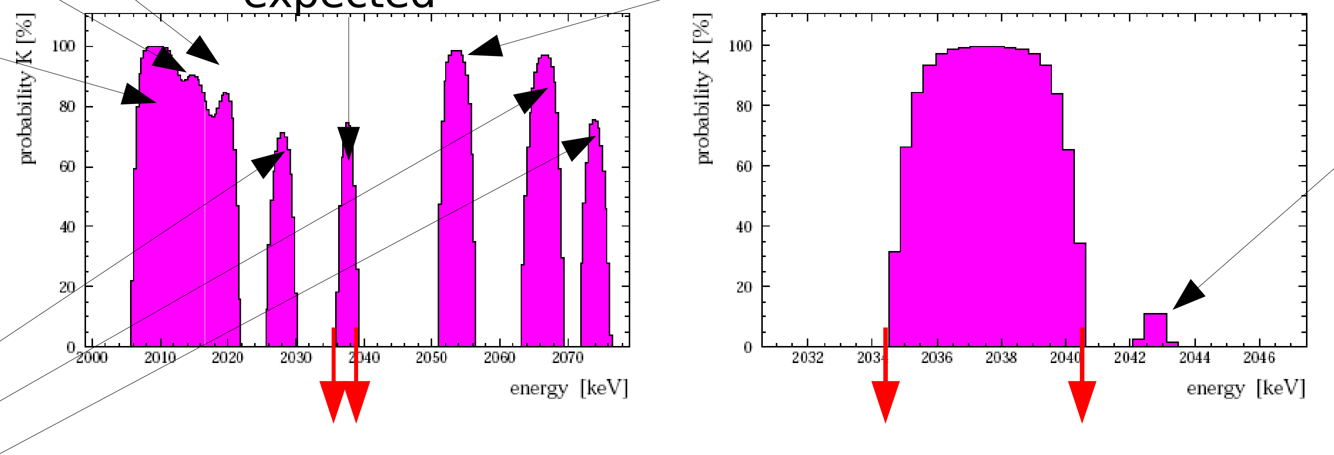

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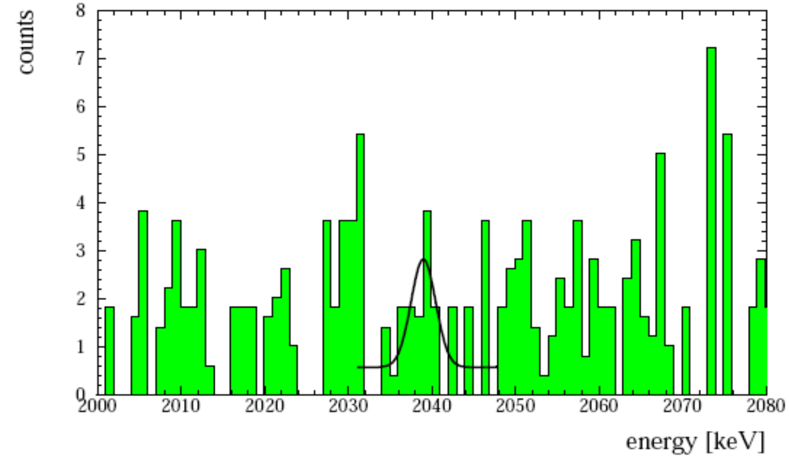

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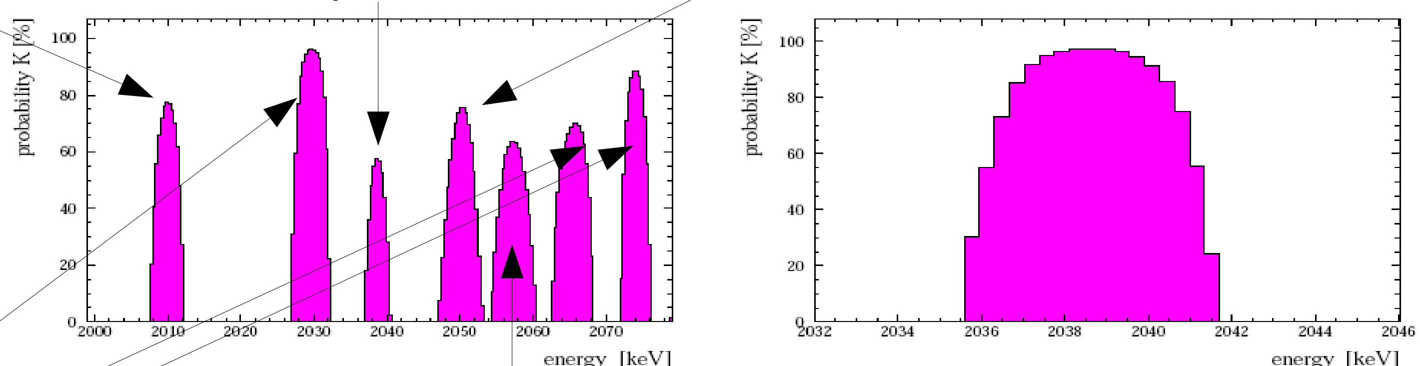

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Relative Strength of Bi214 Peaks

- No full spectrum given in “Evidence“ paper, but in “Latest results...“ paper
- Dataset similar,
  give similar background values....

Estimate rate in Bi214 peaks

Peak (keV)	Rate (c/(kg·yr))	Branching Ratio[4]	Relative Efficiency	Expected Rate (c/(kg·yr))
609.3	44	44.8%	1	Ref. Peak
1764.5	16	15.36%	1.08	Ref. Peak
2010.7	-	0.05%	1.11	0.05
2016.7	-	0.0058%	1.11	0.006
2021.8	-	0.02%	1.11	0.02
2052.9	-	0.078%	1.11	0.08
2204.2	5.2	4.86%	1.13	Ref. Peak

Table of Isotopes

Assume: peak width ~ 4 keV

0.08 cts/(kg y) * 1 / 4 keV
= **0.02 cts/(keV kg y)** in peak!!!

Remember: Bkg = 0.17 cts/(keV kg y)

After 46.5 (kg y): 4 cts **in peak** over bkg of ~ 32 cts

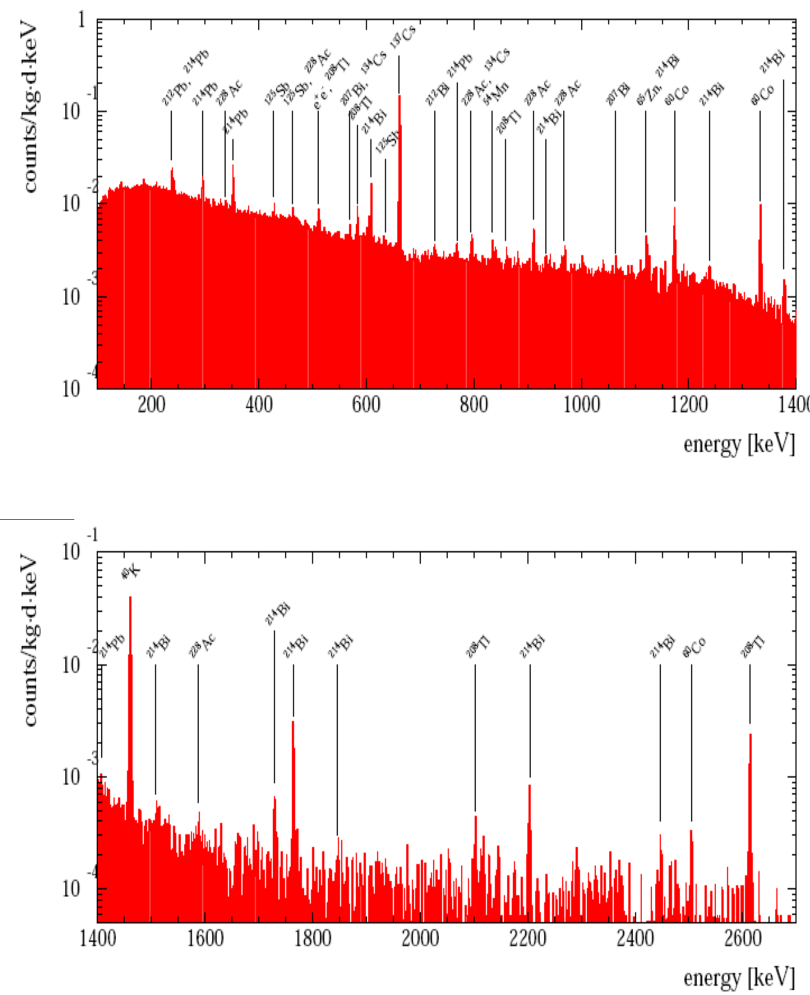


Fig. 1. Sum spectrum of all five ^{76}Ge detectors after 47.4 kg y of measurement. The most prominent identified lines are labeled.

Replys to Comments on “Evidence...“

Harney: hep-ph/0205293v1 — Klapdor-Kleingrothaus: hep-ph/0205293v1

- *“There is no rel. peak strength analysis of all the Bi214 peaks“*

H: Analysis done under **assumption** that **peaks** showing up in (a) **can be identified** at least ones closest to Q_bb. **<u>Otherwise significance decreases</u>**.

- Peak strength: Situation is not as bad as critics conclude for 2 reasons:

1: Exp. rate is larger by factor of ~ 9 since **plot normalization** is **wrong!**

2: Not taken into account “**Coincidence Summing**“ effect
=> Intensities not prop to branching ratios!

MC Simulation needed!

K: 2 reasons: see above 1,2
simulation: lines are **consistent within 2 sigma** experimental errors

Energy (keV) *)	Intensity of Heidelberg-Mos.Exper.	Expect. rate accord. to sim.**)	Expect. rate accord. to[7]++)	Aal-seth et al.[34] ***)
609.312(7)	4399±92			
1764.494(14)	1301±40			
2204.21(4)	319±22			
2010.71(15)	37.8±10.2	12.2±0.6	4.1±0.7	0.64
2016.7(3)	13.0±8.5	15.6±0.7	0.5±0.1	0.08
2021.8(3)	16.7±8.8	1.2±0.1	1.6±0.5	0.25
2052.94(15)	23.2±9.0	4.7±0.3	6.4±1	0.99
2039.006	12.1±8.3			

Comment on the Evidence
including factor 9

Firestone

H: If **peaks cannot be identified** by way of simulation, **confidence will be lower**.
I expect from Table that **this is the case** because **half of intensity to left** and **about 20% of peak at 2053 keV** are predicted by simulation.

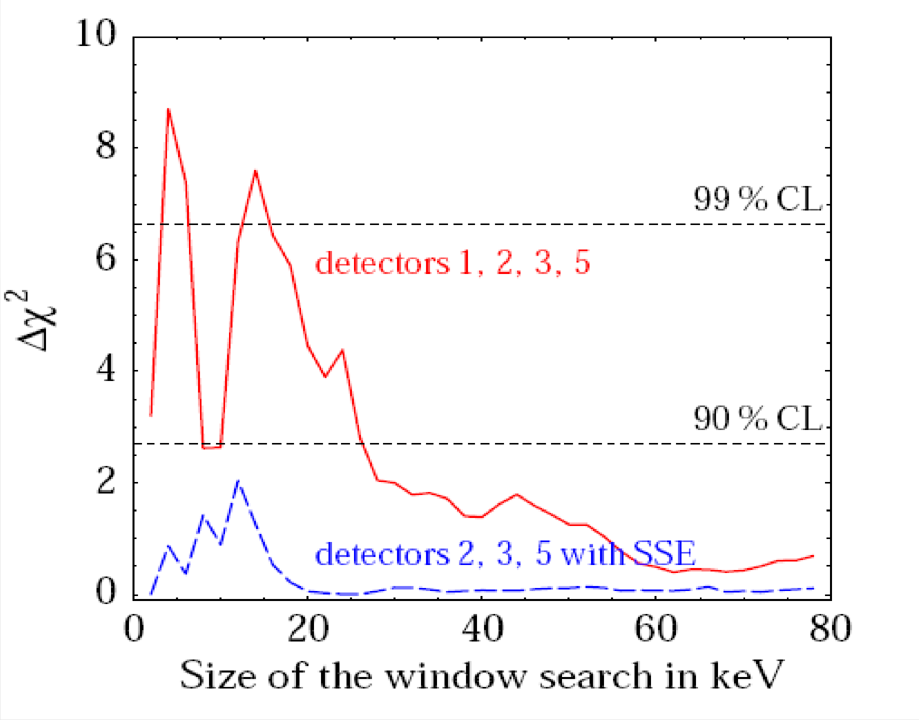
Replys to Comments on “Evidence...“

Harney: hep-ph/0205293v1 Klapdor-Kleingrothaus: hep-ph/0205228v2

- “*No discussion of how variation of size of the analysis window would affect the significance*“

H: This is not true. **Impact of variation was qualetatively shown** in comparison of parts (a) and (b) of figures. Still **I consider the size of the analysis window** the **most serious part** of the critisism.

K: This is not true. **Figures show difference** obtained for the probability of signal in large and small window. Details in forthcoming paper.



“with an **appropriate window** the **evidence** for a peak at Q_0 can **reach the 3 sigma level**. Both the **evidence** and the **central value** of the signal **change** when the **size of the window** is **varied**. There is almost no evidence when a large window is chosen; but if the backgrounds were constant, a **large window would be the fairest** way to estimate its level“

Feruglio *et al.* hep-ph/0201291v5

Replys to Comments on “Evidence...“

Harney: hep-ph/0205293v1 Klapdor-Kleingrothaus: hep-ph/0205293v1

- *“There are three unidentified peaks in the region of analysis that have greater significance than the 2039 keV peak“*

  H: Since they have higher significance than the significance claimed for the peak at Q_bb, **even future improved analyses need not** necessarily **consider these peaks to be part of the background**. In principle there is no reason to consider all non-identified structures as fluctuations of the background. Peaks that have a high significance may be considered a spectral line although unknown at present.

  K: True, there **are lines beyond 2060 keV** which cannot be identified. However this is **not relevant to conclusions** concerning the signal at 2039 keV.

- *“No simulation performed to demonstrate that analysis correctly finds true peaks or none, if none exsisted “*

  H: This **cannot be demonstrated**. The randomness of data entails probabilistic conclusions.

  K: Not true, simulations performed to show that programs work OK. Ensemble-tests have shown that probability to find line if none present above 95% C.L. is 4.2%

Replys to Comments on “Evidence...“

Harney: hep-ph/0205293v1 Klapdor-Kleingrothaus: hep-ph/0205293v1

- *“There is no discussion of how sensitive the conclusions are to different mathematical models[...] There is a previous HDM publication that gives lower limit of 1.9E25 y (90%C.L.). This is in conflict with “best value“ of new paper 1.5E25 y. “*

  H: Unfortunately **any results are sensitive to the model** one chooses to describe peak plus background. The comparison between (a) and (b) shows it since size of the window is part of the model.

  K: **This is not true. No discrepancy!**

- *“There is no null hypothesis analysis demonstration that data requires peak“*

  H: Statement that there is peak with probability K i**mplies that there may be none.**
  Results are probabilistic **impossible** to **demonstrate data requires peak**.

  K: This is not true. Fit allows for case: *only* background, line intensity zero

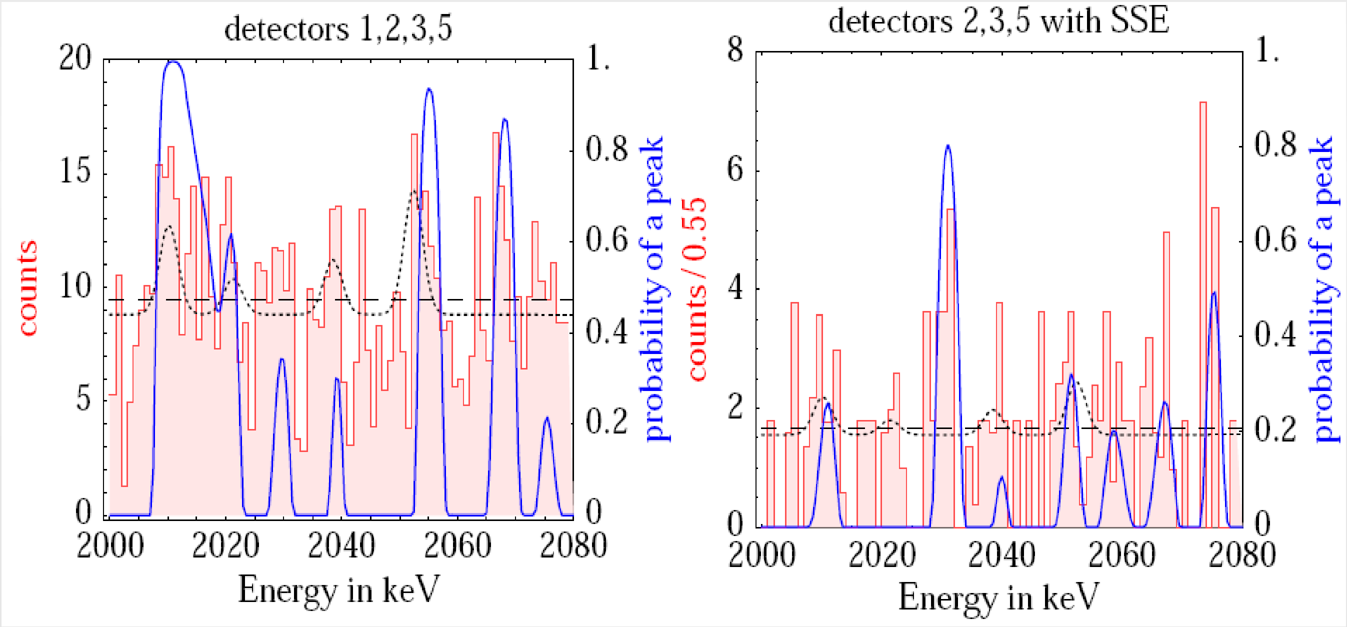
Replys to Comments on “Evidence...“

Harney: hep-ph/0205293v1 Klapdor-Kleingrothaus: hep-ph/0205293v1

- *“There is no discussion of the relative peak strengths before and after single-site cut.“*

  H: Intensitiy at Q_bb **before and after cut are compatible** if efficiency taken into account.

  K: **90% of signal** after SS cut, **Bi214 lines reduced to about 25% same reduction as stronger Bi214** lines and 2614 keV Th line.



Feruglio *et al.* hep-ph/0201291v5

const bkg suppression:
~ 3.5/0.55

identified gammas:
~ 3.8/0.55

0nubb:
~ 3.2/0.55

Replys to Comments on “Evidence...“

Harney: hep-ph/0205293v1 Klapdor-Kleingrothaus: hep-ph/0205293v1

Summary:

Harney:

The critics have made a **valuable point** with their **concern about the size of the analysis window**;the **simulation** of the experimental setup **indicates** that the **significance of the possible structure** at Q_bb is **lower than claimed** by KDHK.

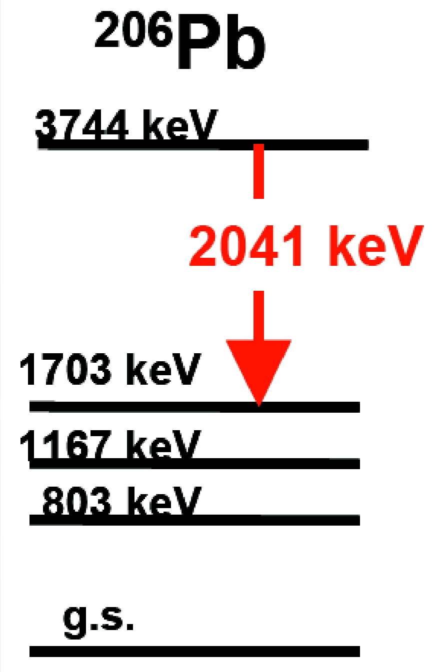
Klapdor:

The **criticism made** in the 'Comment' is, in view of the Replies given here, **not justified in any of the points raised**.
We think that it **remains useful and inspiring** to have informed the neutrino community about our **evidence for a 2.2 – 3.1 sigma** result on the 0nubb decay.

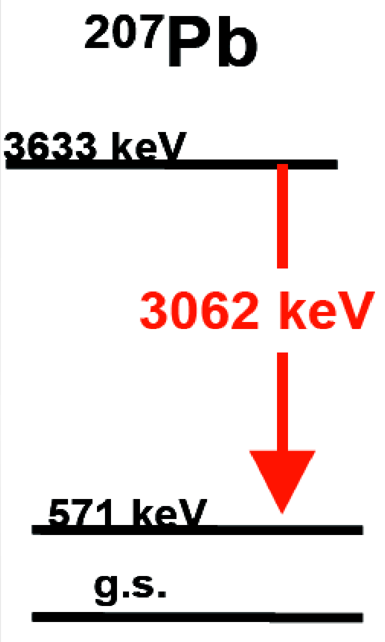
Explanations?

nucl-ex/0704.0306v4

- Excited states of Pb through neutron inelastic scattering

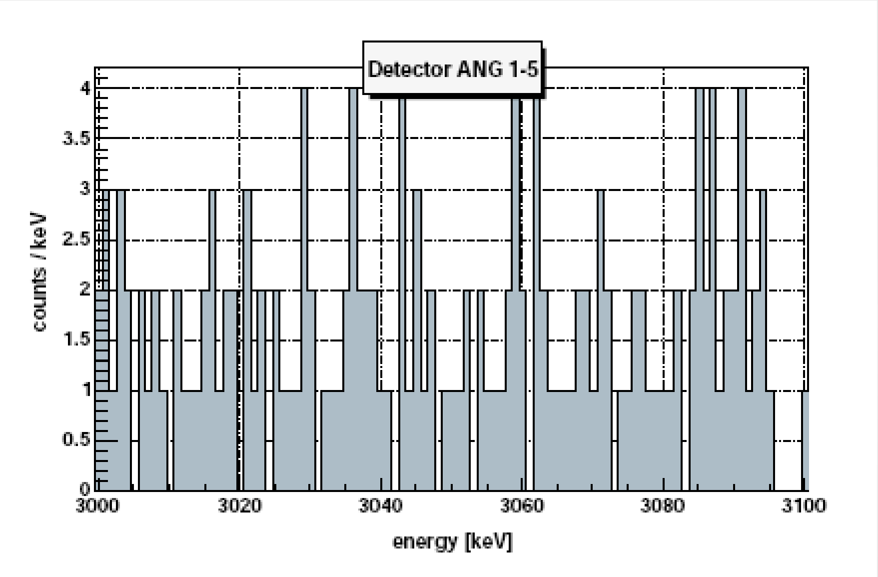


predicted rate too low to explain peak



DEP @ 2040 keV

DEP: single site event
=> Possible candidate



No peak at 3062 keV would expect ~175 cts in peak

Summary

- HDM sees no evidence but set lower limit

- Klapdor & Co. sees evidence **if** peaks close to Q_bb are identified (Energy,Intensity)
  - **Harney** doubts that peak with that high significance exists after MC simulations
  - **Klapdor** sees no problem with MC simulation of peaks since agree within 2 sigma

- Pulse shape analysis:

  H: Signal before after cut compatible

  K: 90% of signal left, 25 % of gammas left

  F: all peaks reduced in the same way

- Other explanations failed to describe spectrum

- Latest Klapdor paper sees 6 sigma evidence with same dataset !

Conclusions

?