Messung der Gamma-Aktivität im Large Volume Detektor im Gran Sasso Untergrundlabor

Bachelor Arbeit

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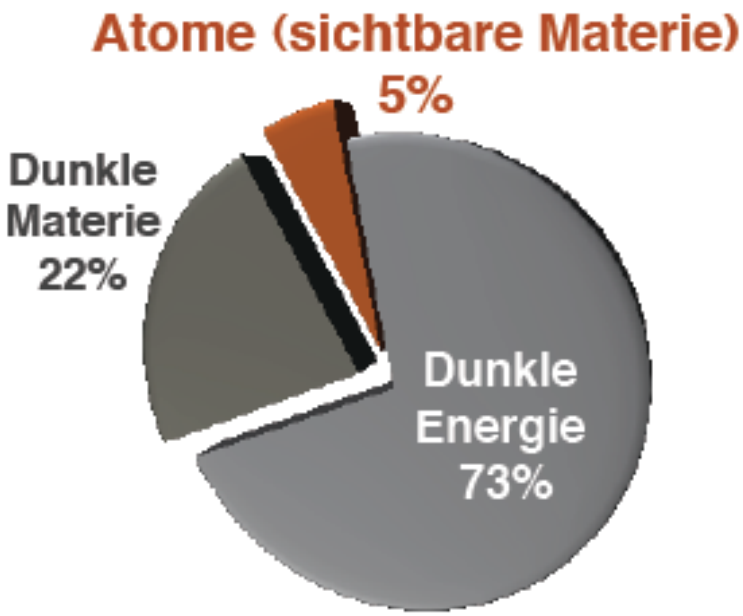
Dunkle Materie

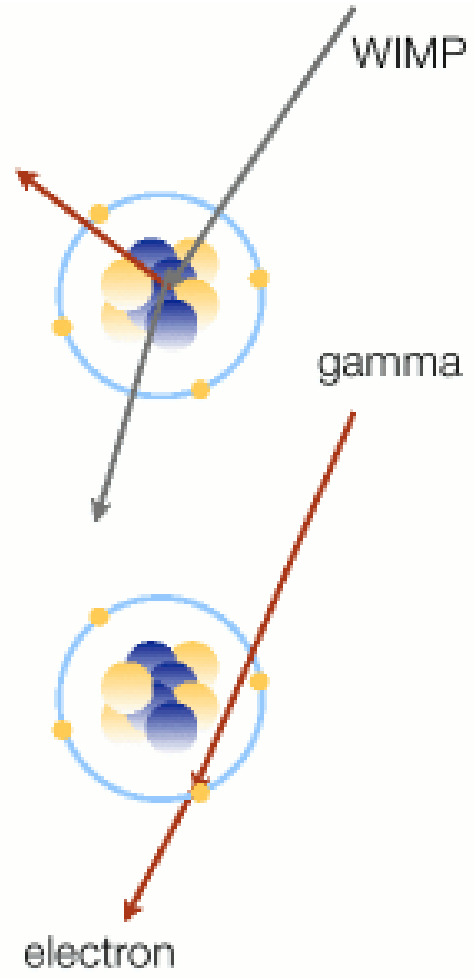
- Eine für uns nur über die Gravitation wahrnehmbare Masse
- WIMPs („Weakly Interacting Massive Particles“)
- Gegenwärtiger Kanditat für nicht baryonische dunkle Materie:

⇨ das leichteste supersymmetrische SUSY Teilchen, Neutralino



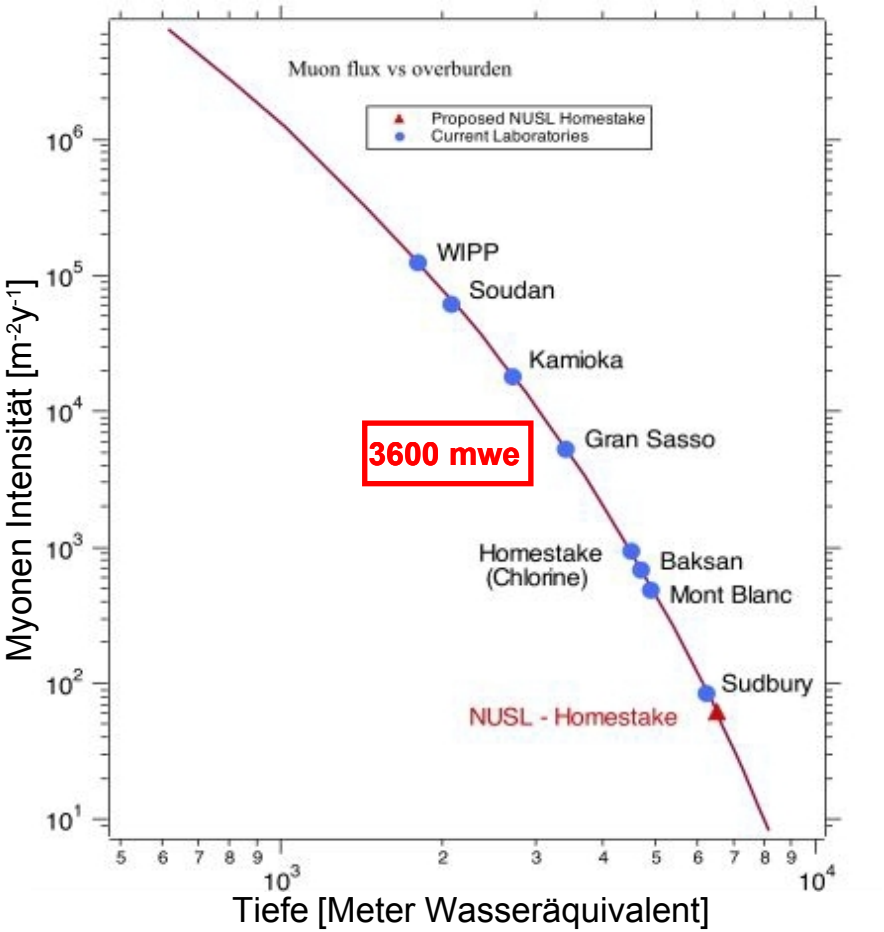
Das XENON Experiment

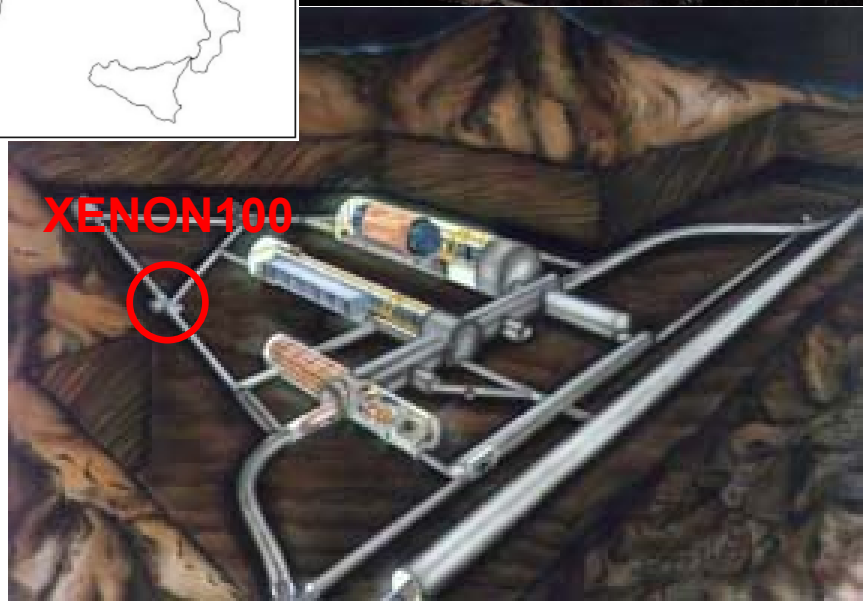
- **Detektion von dunkler Materie**
  - Flüssiges Xenon als Detektormaterial
  - Ziel: kleine Ladungs- und Lichtsignale detektieren
  - Untergrundsignal: Neutronen und Gammastrahlung



Wo befindet sich XENON100?

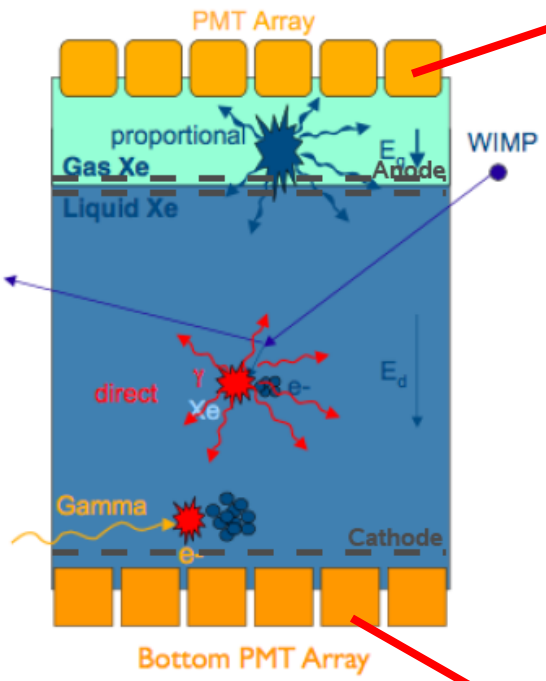
- Untergrundsignal: Neutronen und Gammastrahlung



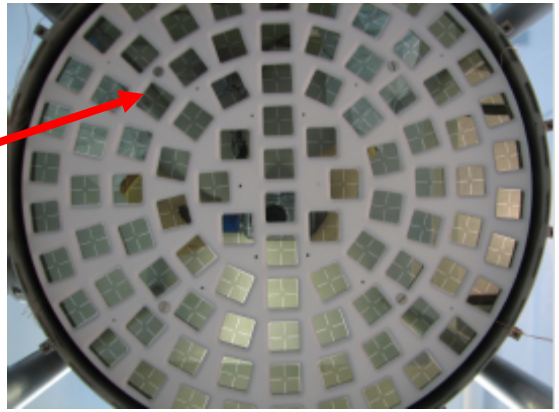


XENON100

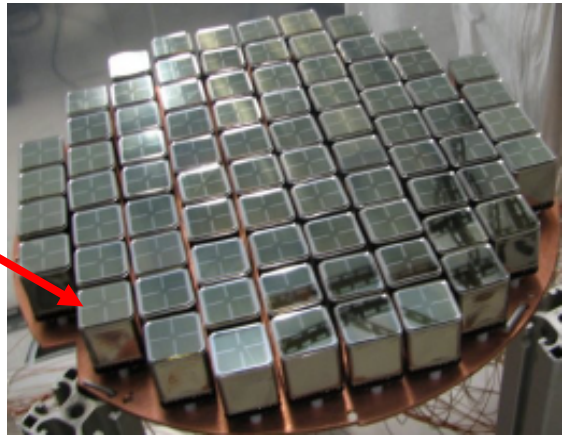
- 170 kg flüssiges Xenon
- ~50 kg sensitives Volumen



UV-Lichtdetektoren (98)



UV-Lichtdetektoren (80)

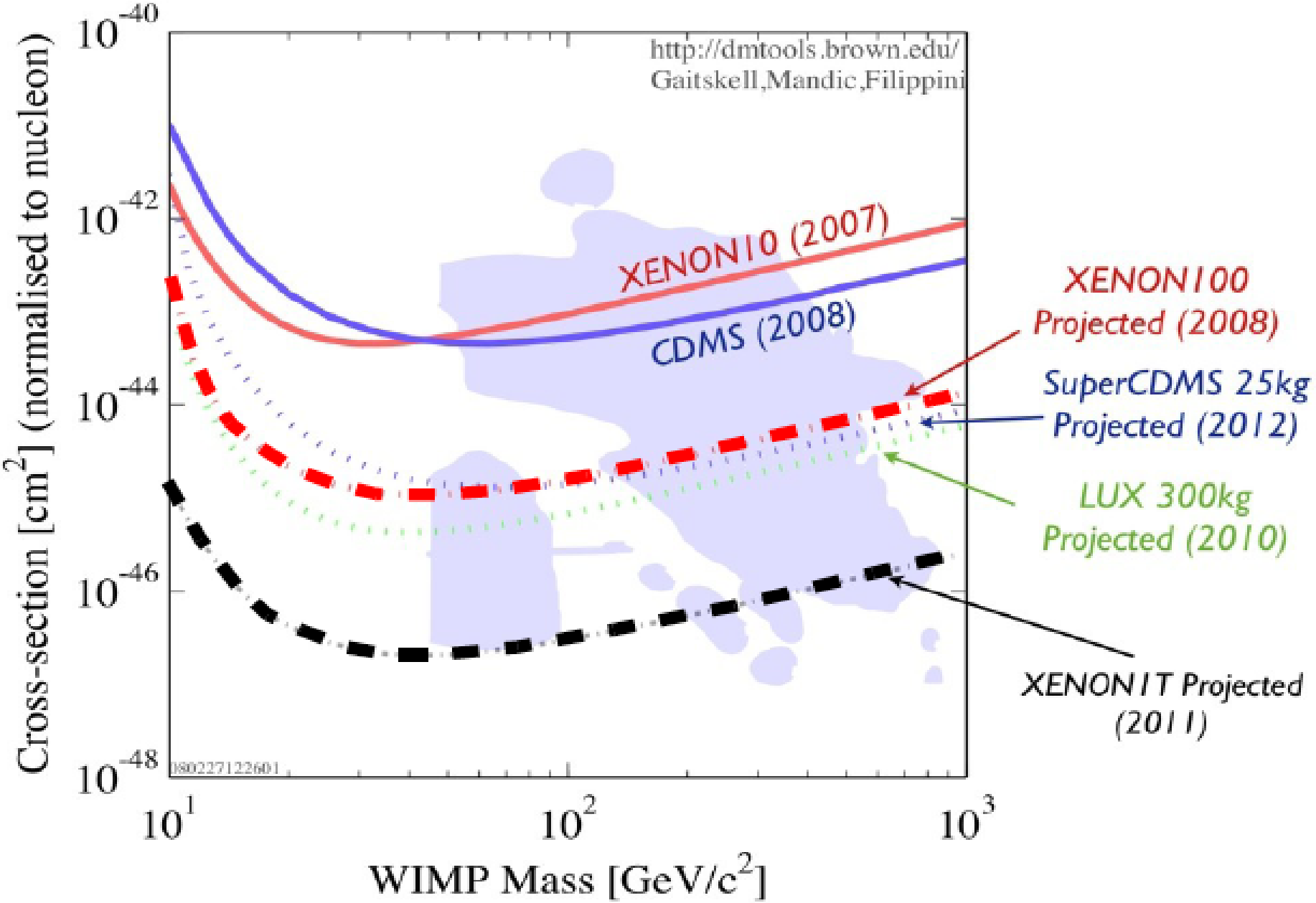


XENON1t

- Nächste Phase von XENON100
- 3 t flüssiges Xenon
- 1t sensitive Masse
- Ziele:

Experiment	XENON10	XENON100	XENON1t
effektive Masse [kg]	5	50	1000
Gamma-Untergrund [events/kg/keV/Tag]	1	10^{-2}	$< 10^{-4}$
Neutron Untergrund [pro Jahr]	< 1	< 1	< 0.5
WIMP-Sensitivität bei 100 GeV [cm^2]	$0.9 \cdot 10^{-43}$	$2 \cdot 10^{-45}$	$3 \cdot 10^{-47}$

Geplante Sensitivität für XENON1t



XENON1t

- Herausforderungen:
  - Reduktion der Untergrundsignale
  - Eine geeignete Positionierung finden

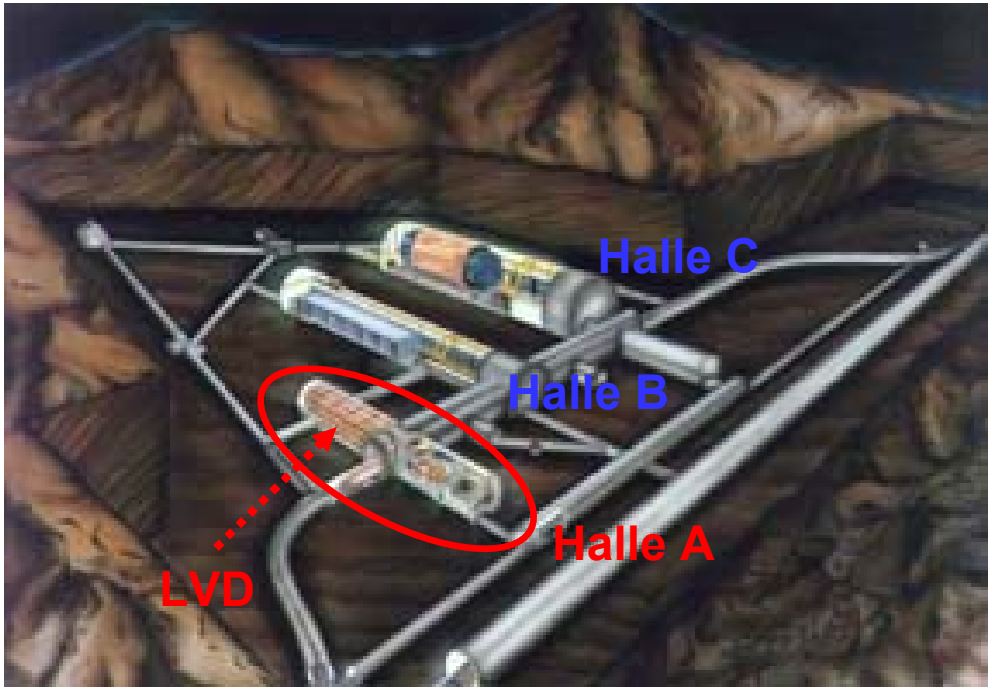
- Mögliche Positionierung:
  - Im Large Volume Detektor (LVD) im Gran Sasso Untergrundlabor

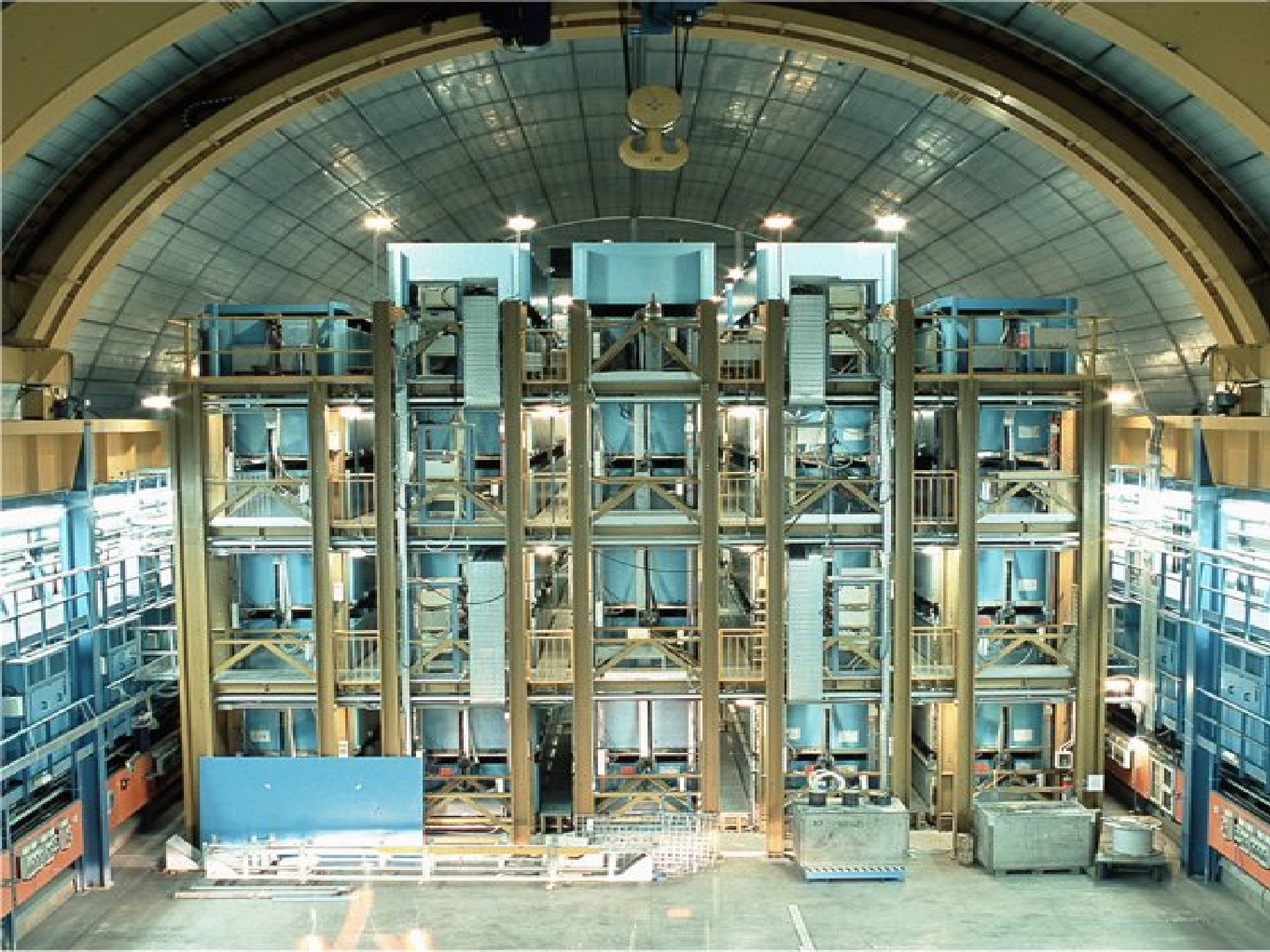
Meine Arbeit:

Gamma Messungen im LVD, Xenon Box und Halle A

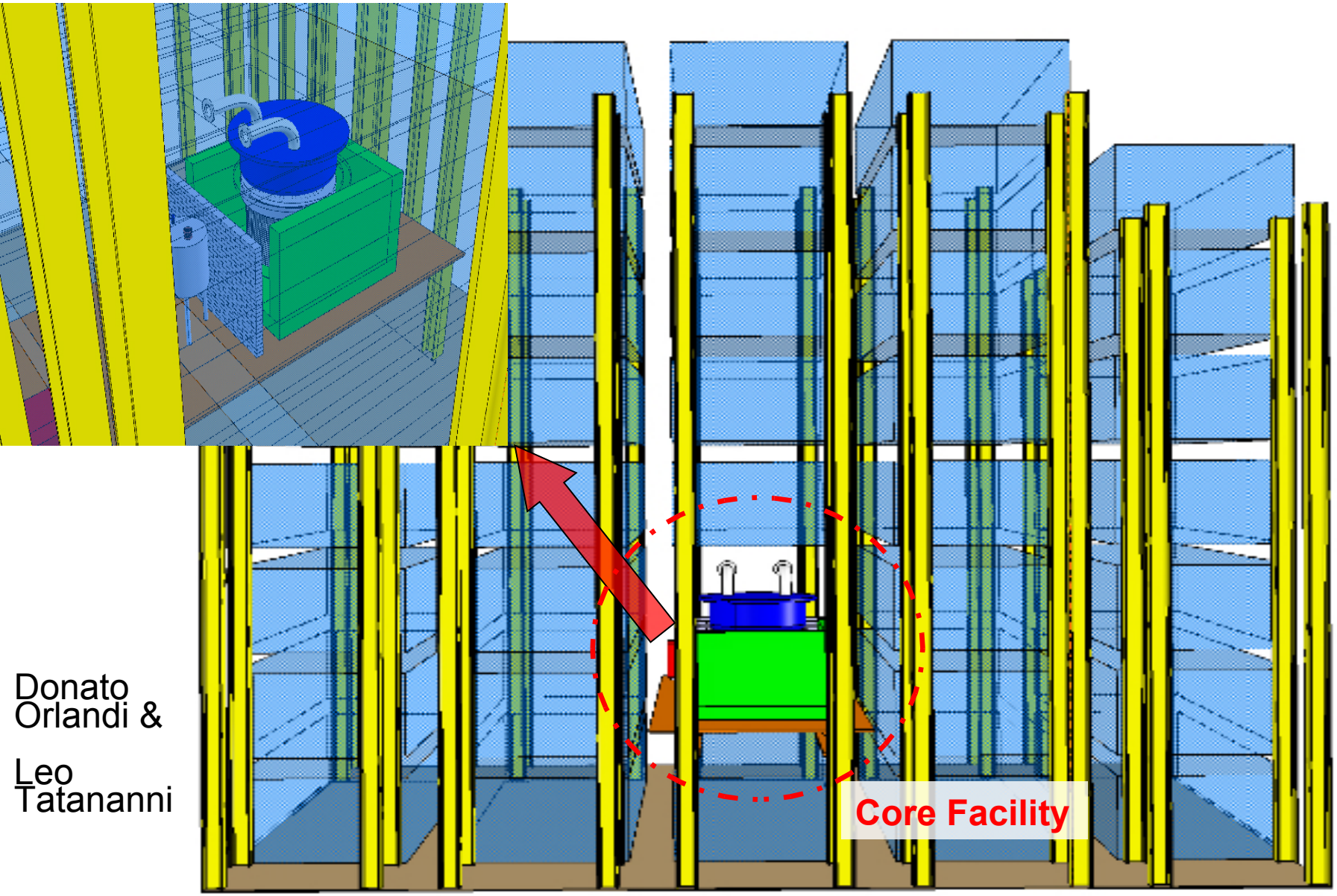
Large Volume Detektor LVD

- In der Halle A im Gran Sasso Untergrundlabor
- Ziel: Detektion von Supernova-Neutrinos
- Dimensionen:
  - Länge: 22.7 m
  - Breite: 13.2 m
  - Höhe: 10.0 m





XENON1t im LVD



Donato Orlandi &

Leo Tatananni

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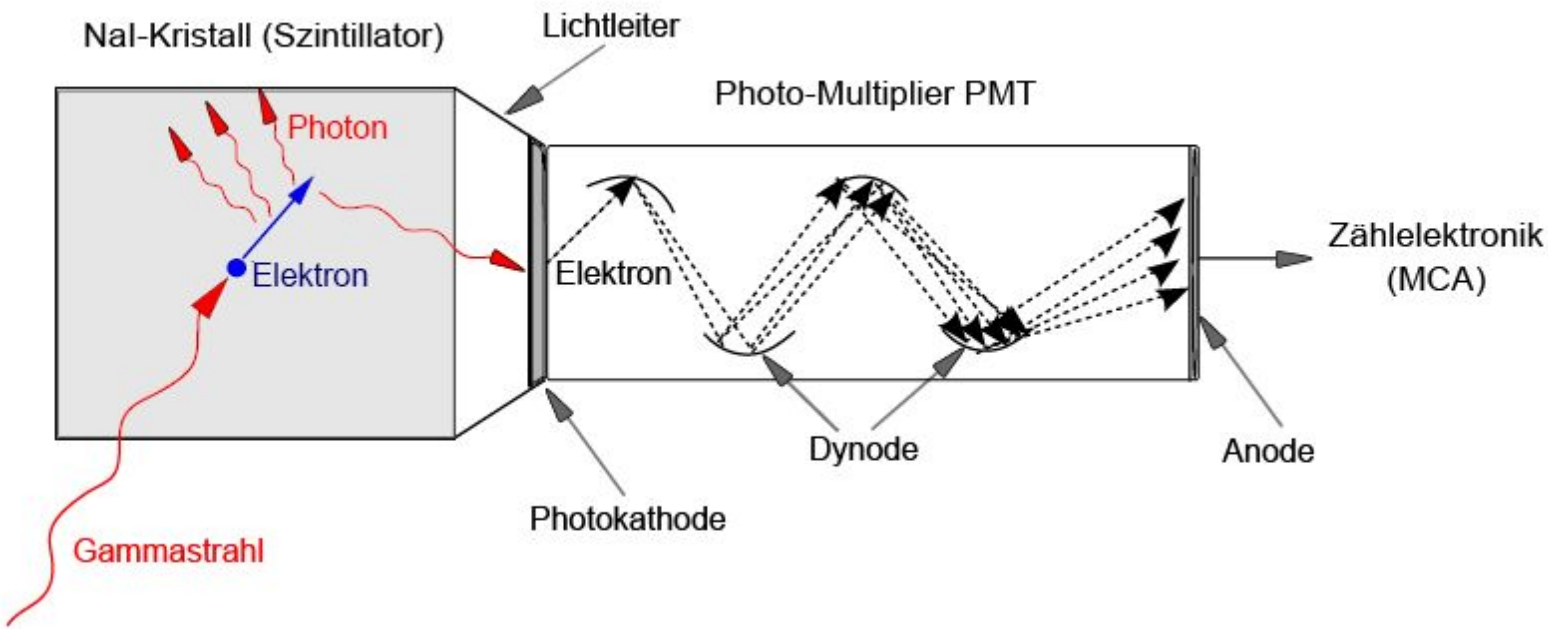
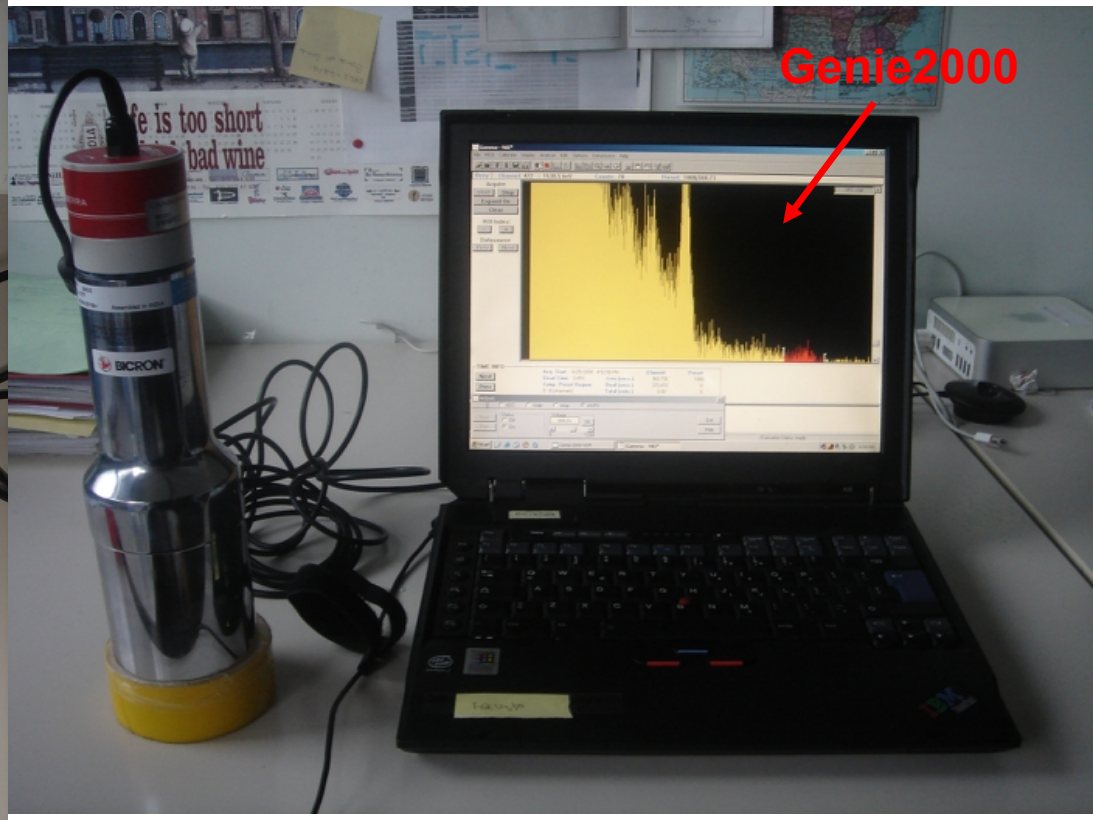
NaI-Detektor



NaI-Detektor

3x3 inches NaI-Detektor



NaI-Detektor

- Eigenschaften:
  - Energie-Kalibrierung
  - Energie-Auflösung

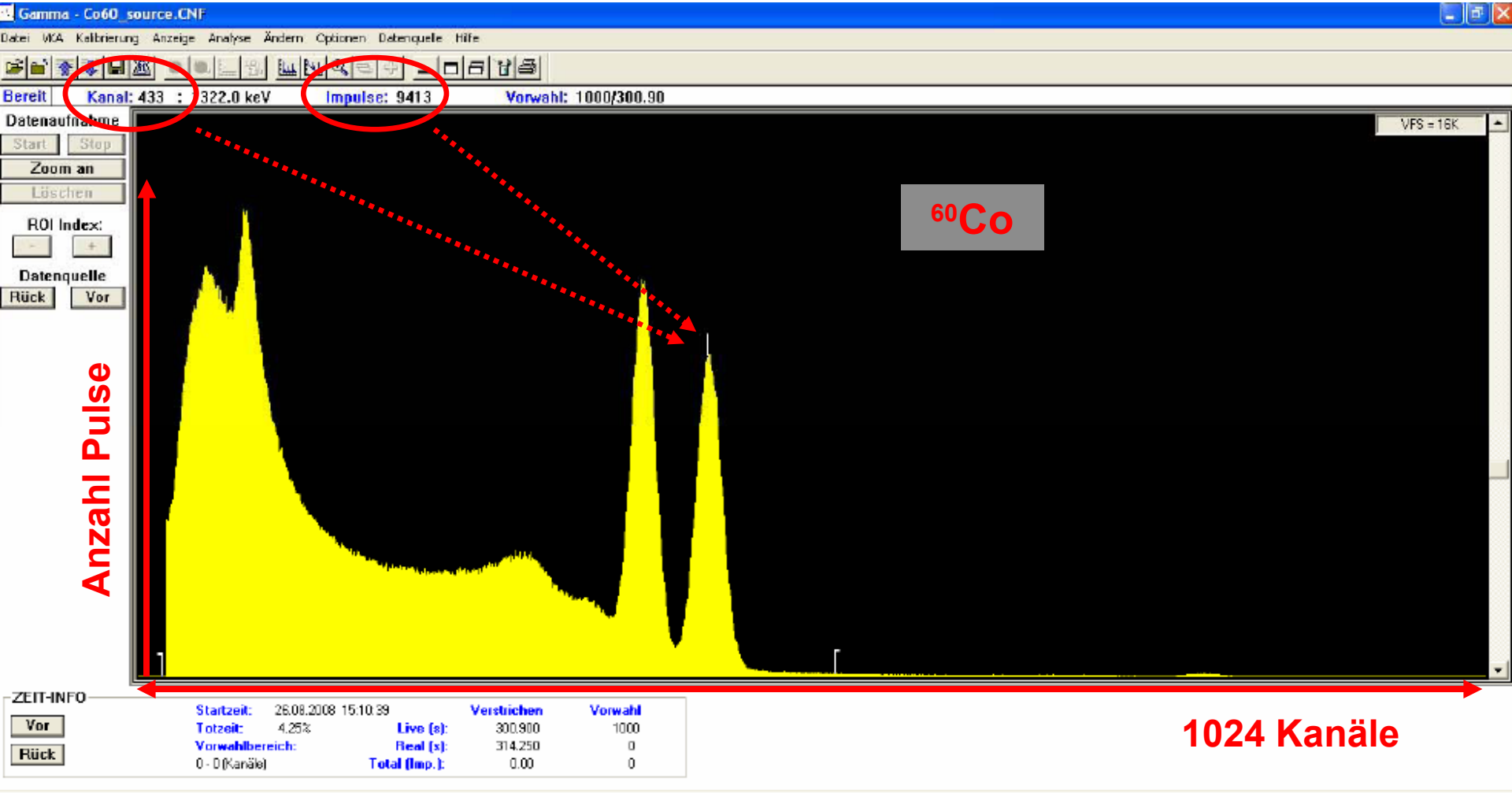
  } **Mit Th^{228}, Cs^{137}, Co^{60}, Co^{57} Quellen**
  - Intrinsischer Untergrund des Detektors

Co^{57}

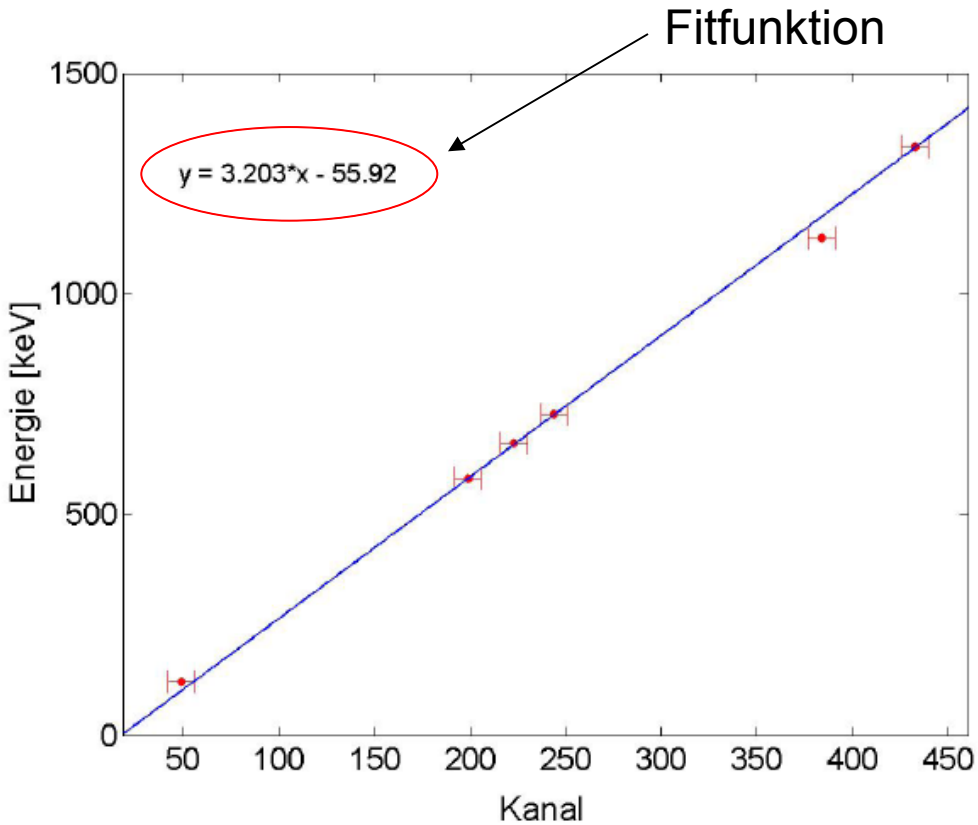
Th^{228} und Co^{60}

Cs^{137}

Energie-Kalibrierung

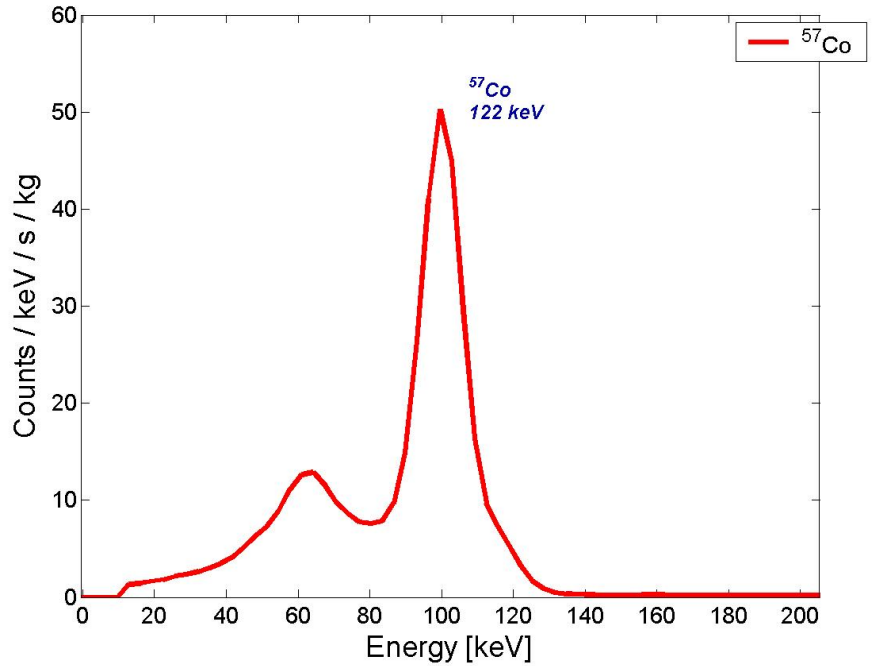


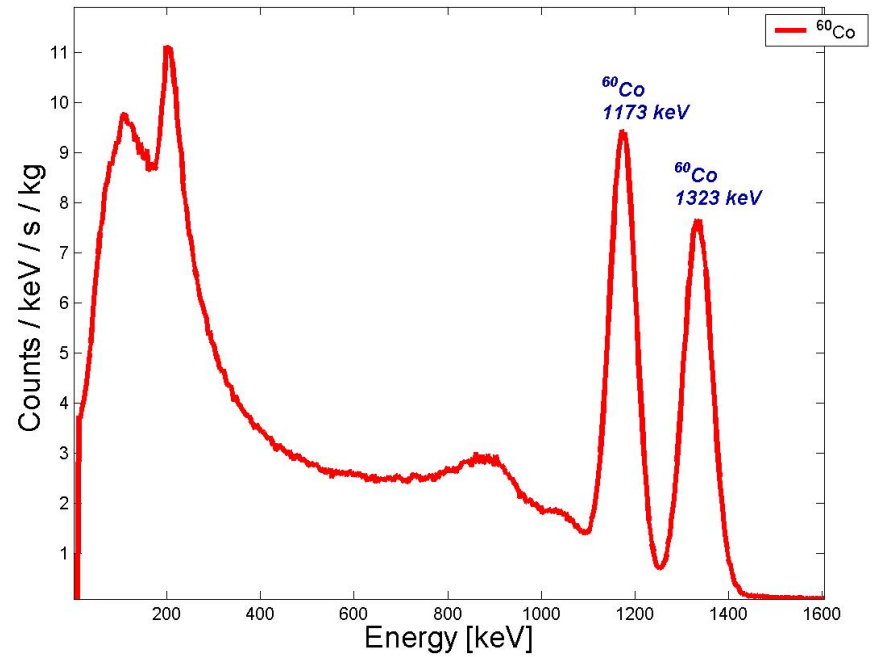
Energie-Kalibrierung

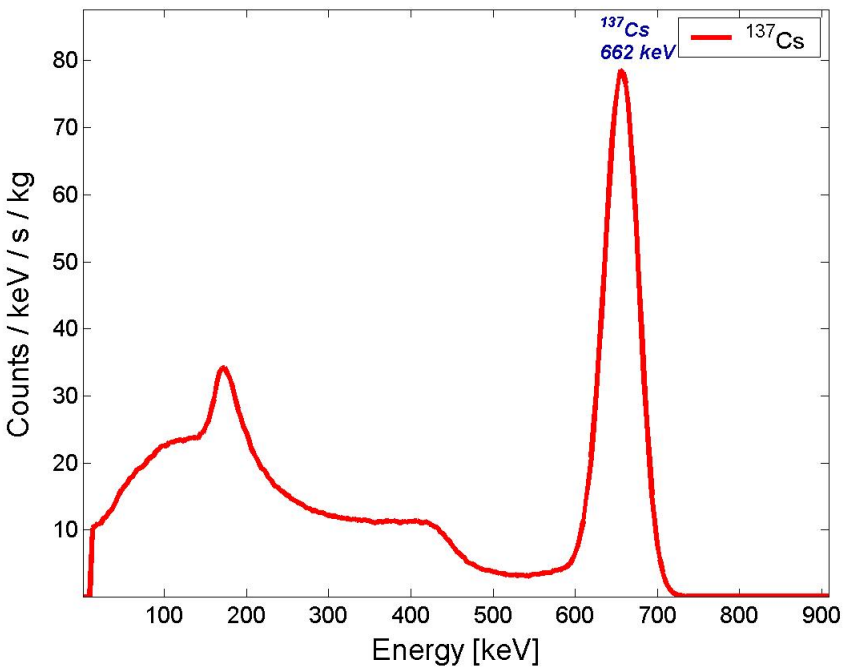


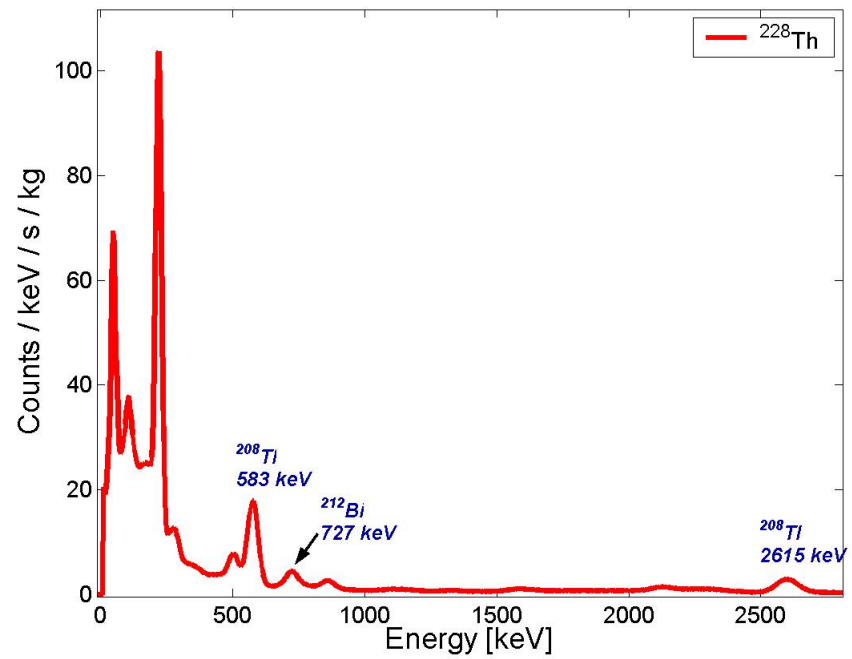
Nuklid	Gammalinie [keV]	Channel
^{57}Co	122.061	49
^{137}Cs	661.657	223
^{60}Co	1173.237	384
^{60}Co	1332.501	433
^{208}Tl	583.191	199
^{212}Bi	727.330	244

Beispiel: **264.38 [keV]** = 3.203 * **100 [Kanal]** – 55.92


57Co
57Co
122 keV
Counts / keV / s / kg
Energy [keV]


60Co
60Co
1173 keV
60Co
1323 keV
Counts / keV / s / kg
Energy [keV]


137Cs
137Cs
662 keV
Counts / keV / s / kg
Energy [keV]


228Th
208Tl
583 keV
212Bi
727 keV
208Tl
2615 keV
Counts / keV / s / kg
Energy [keV]

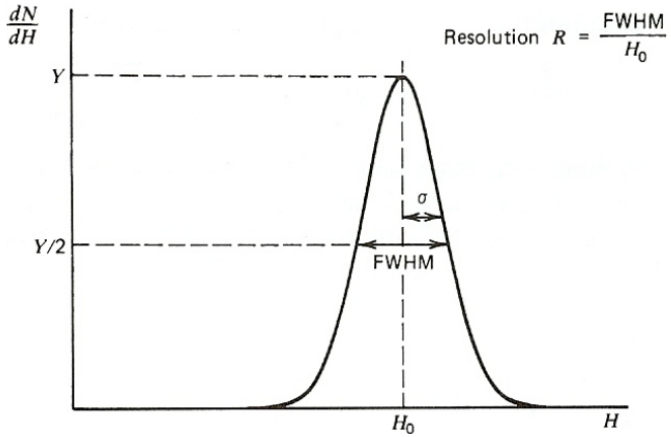
Energie-Auflösung

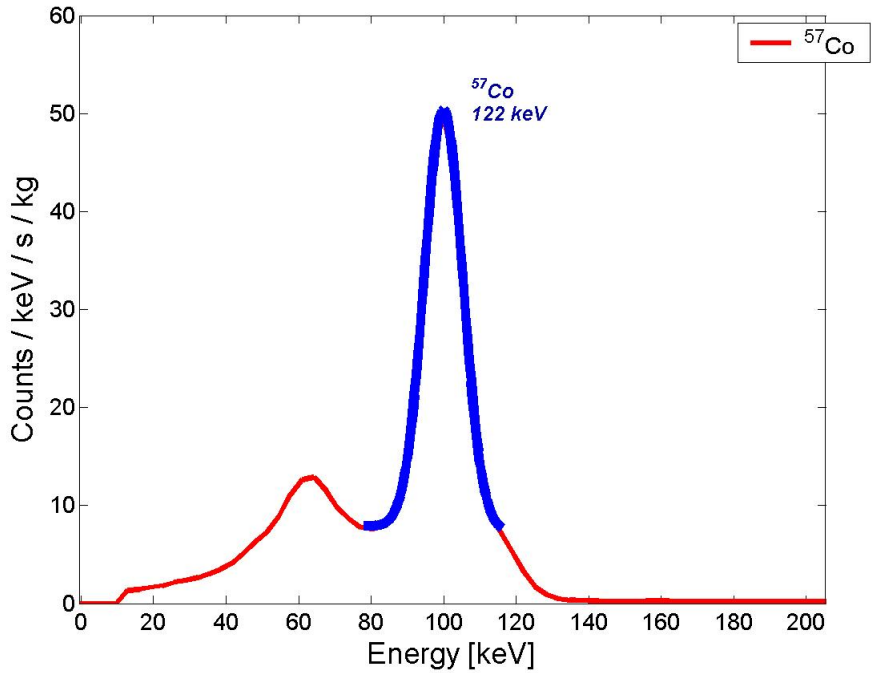
Ein Mass für das Vermögen, zwei Photonen mit minimaler Energiedifferenz aufzulösen

$$R \equiv \frac{FWHM}{E}$$ Definition der Energie-Auflösung

$$FWHM = K \cdot \sqrt{E} + C$$

$$\Rightarrow \quad R = \frac{K}{\sqrt{E}} + \frac{C}{E}$$

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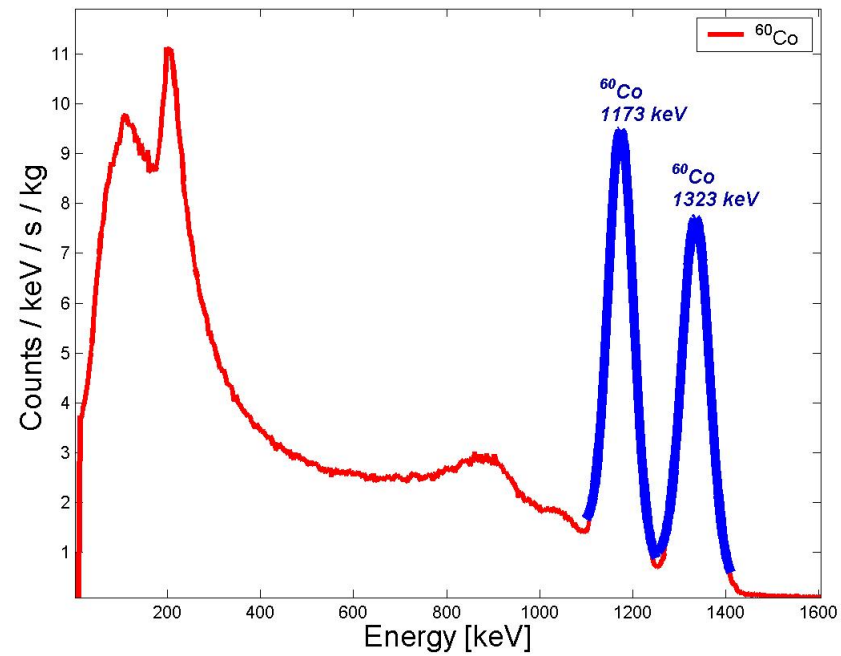
Counts / keV / s / kg
Energy [keV]


60Co
60Co
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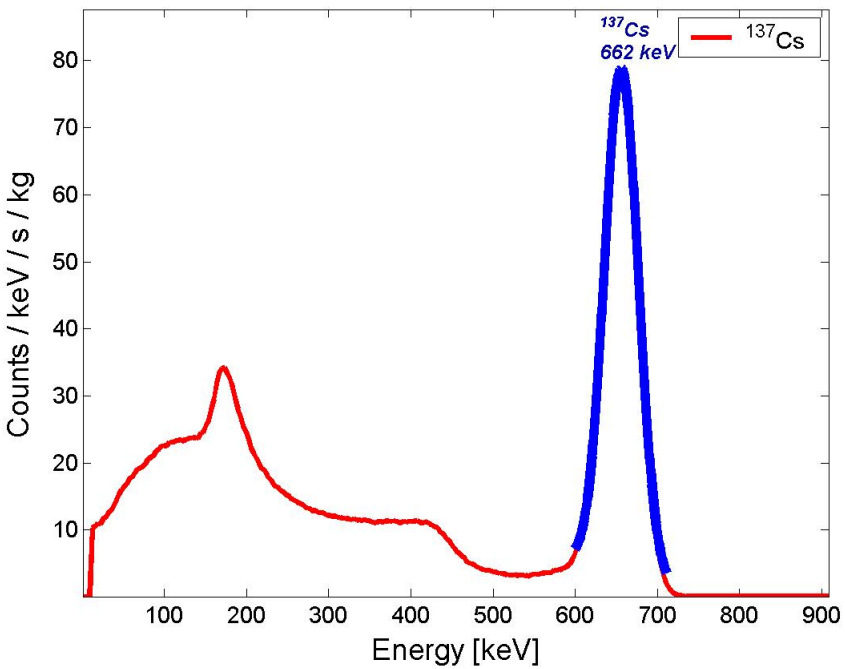
60Co
1323 keV
Counts / keV / s / kg
Energy [keV]


137Cs
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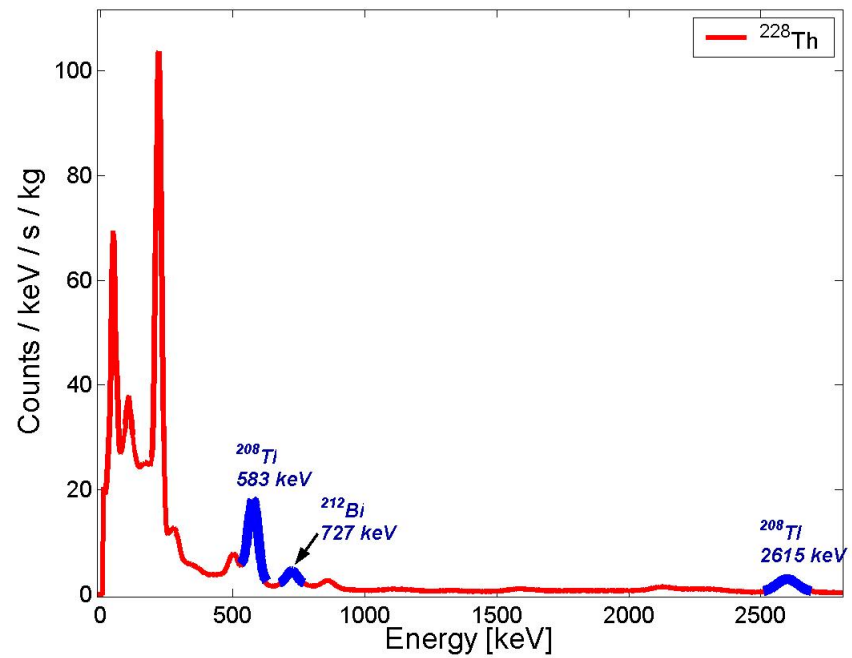
662 keV
Counts / keV / s / kg
Energy [keV]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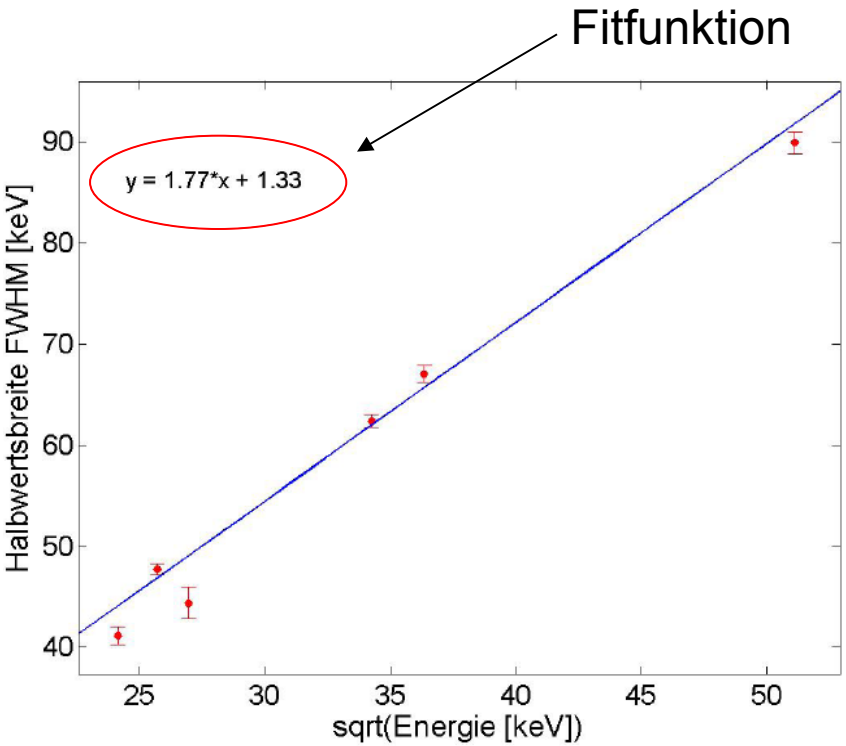
208Tl
583 keV
212Bi
727 keV
208Tl
2615 keV
Counts / keV / s / kg
Energy [keV]

Energie-Auflösung



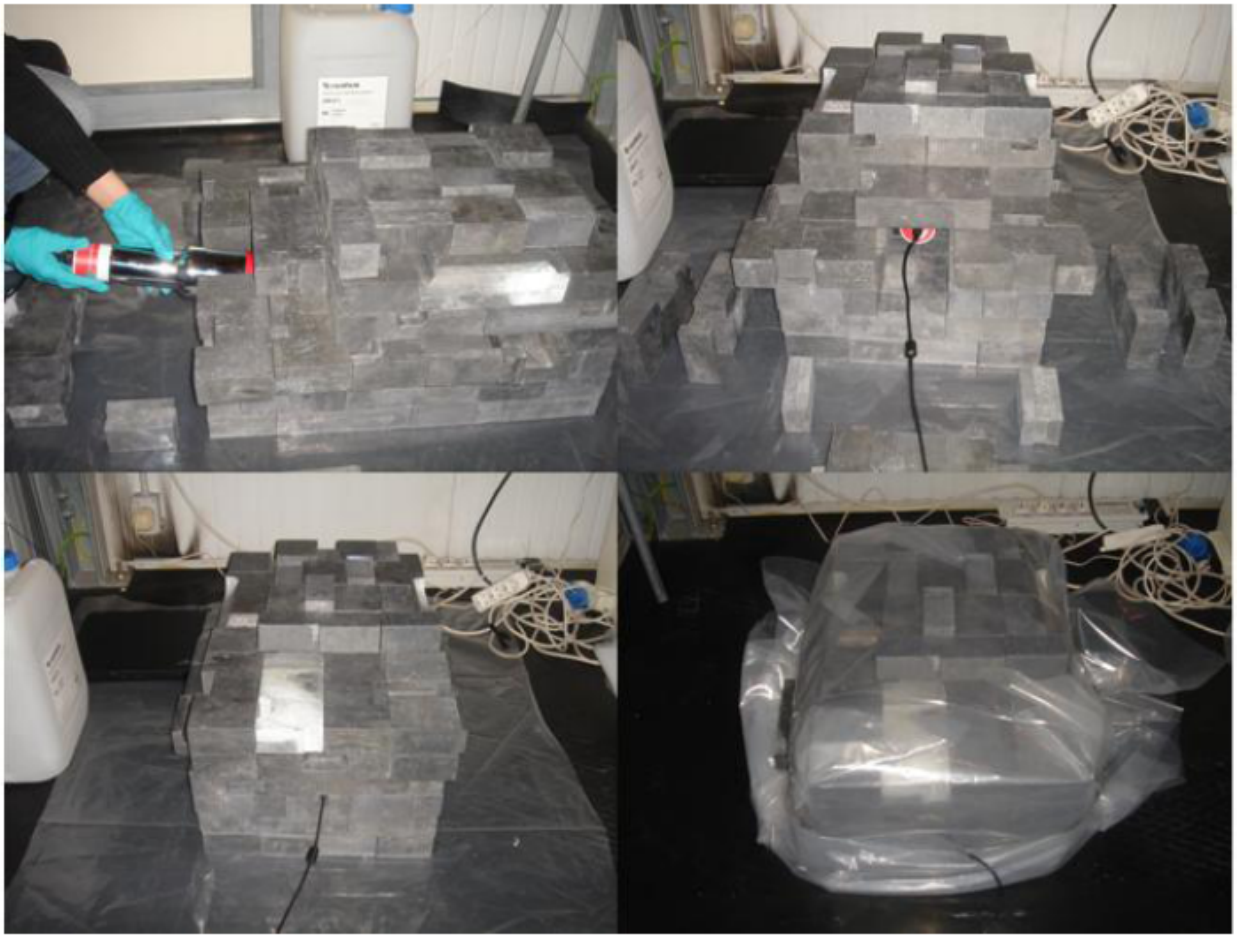
$$FWHM = K \cdot \sqrt{E} + C$$

Nuklid	Gammalinie [keV]	Halbwertsbreite FWHM [keV]
^{137}Cs	661.657	47.74(±0.56)
^{60}Co	1173.237	62.36(±0.63)
^{60}Co	1332.501	67.07(±0.86)
^{208}Tl	583.191	41.16(±0.86)
^{208}Tl	2614.533	89.93(±1.06)
^{212}Bi	727.330	44.38(±1.58)

$$R = \frac{K}{\sqrt{E}} + \frac{C}{E}$$ mit $$K = (1.77 \pm 0.308)\sqrt{keV}$$ $$C = (1.33 \pm 10.021)keV$$

Energie [keV]	Energie-Auflösung R [%]
500	8.18(±2.43)
1000	5.73(±1.39)
1500	4.66(±1.04)
2000	4.02(±0.85)
2500	3.59(±0.74)
3000	3.27(±0.65)

Intrinsischer Untergrund des NaI-Detektors



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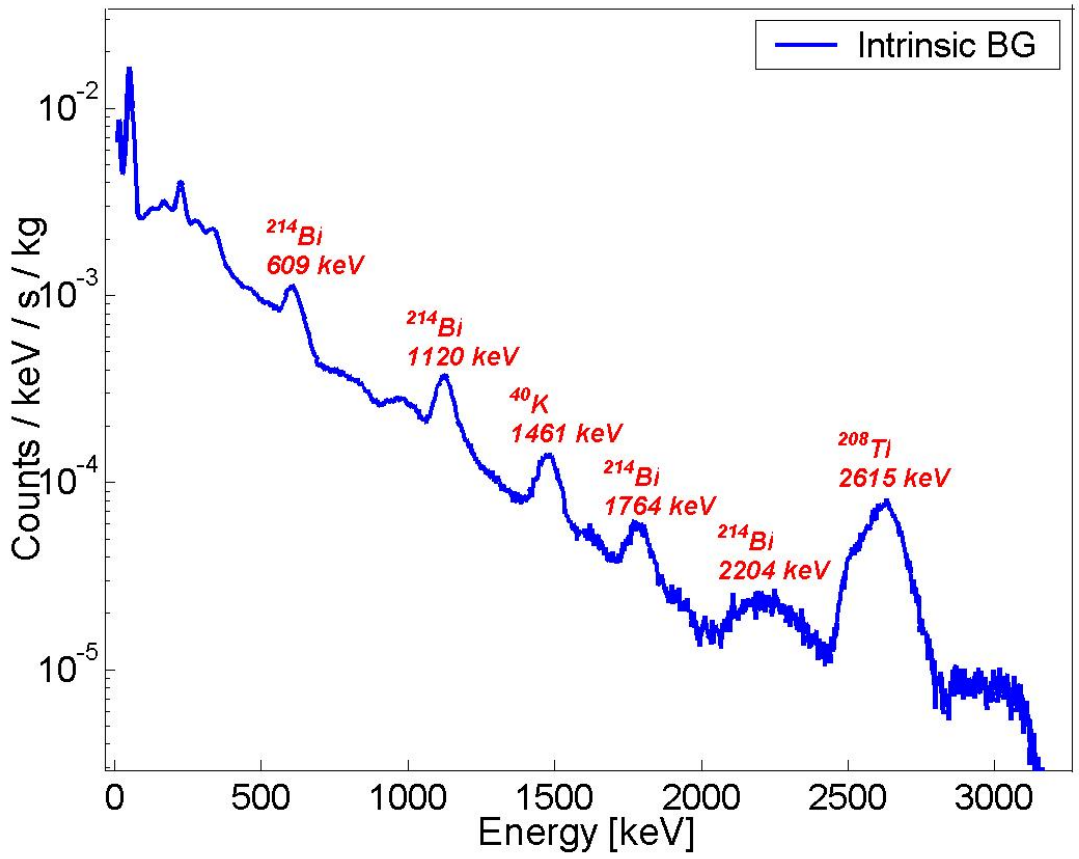

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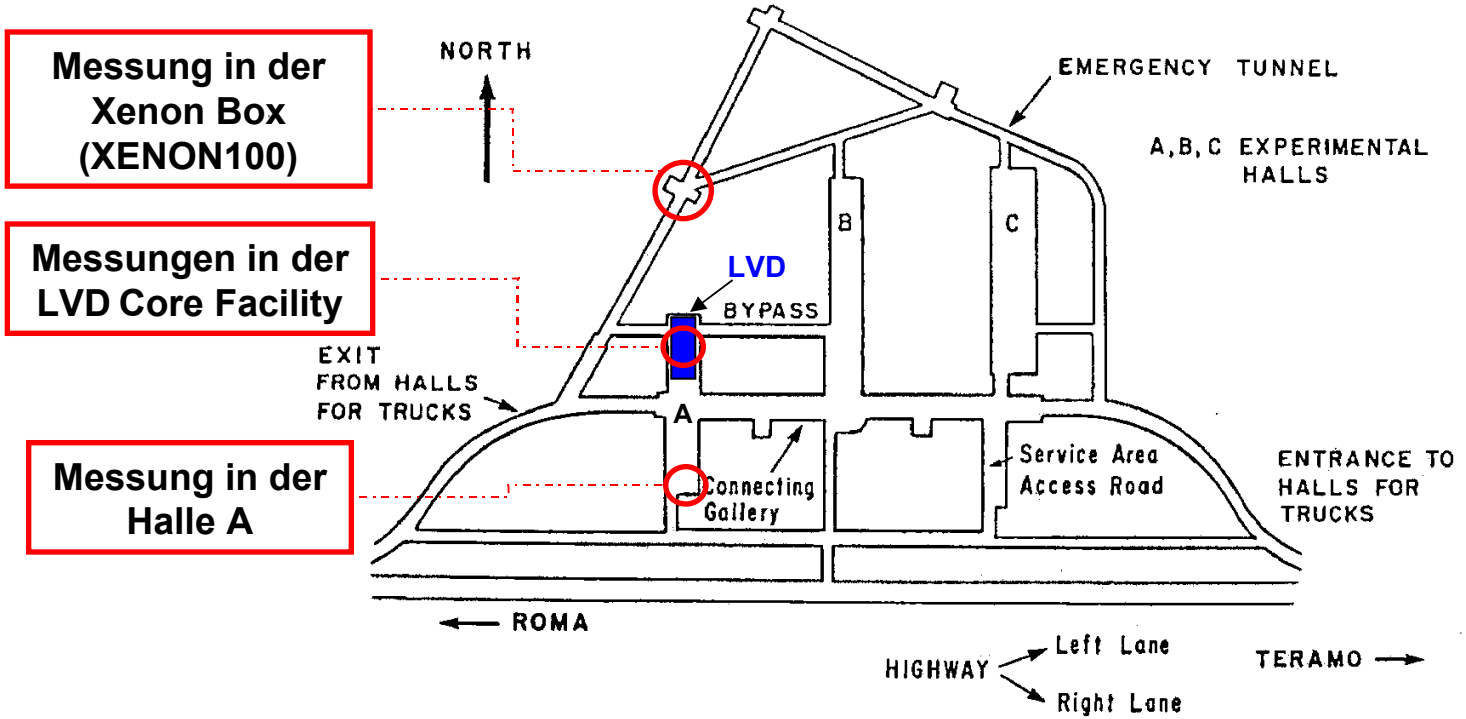
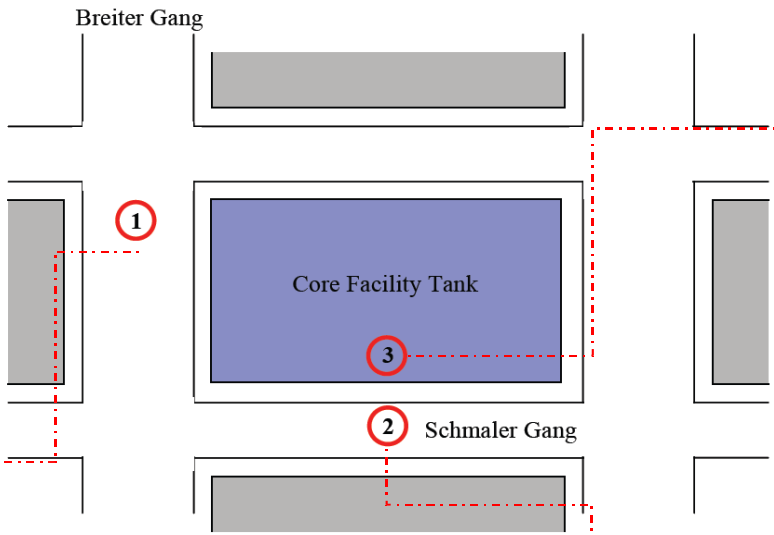
Gamma Messungen

- Ziele:
  - Gamma-Aktivität in der LVD Core Facility
  - Vergleich der Gamma-Aktivität in LVD Core Facility, Xenon Box und Halle A



Gamma Messung in der LVD Core Facility



Messung zwischen den CF Tanks

(Messzeit: 8 Tage)

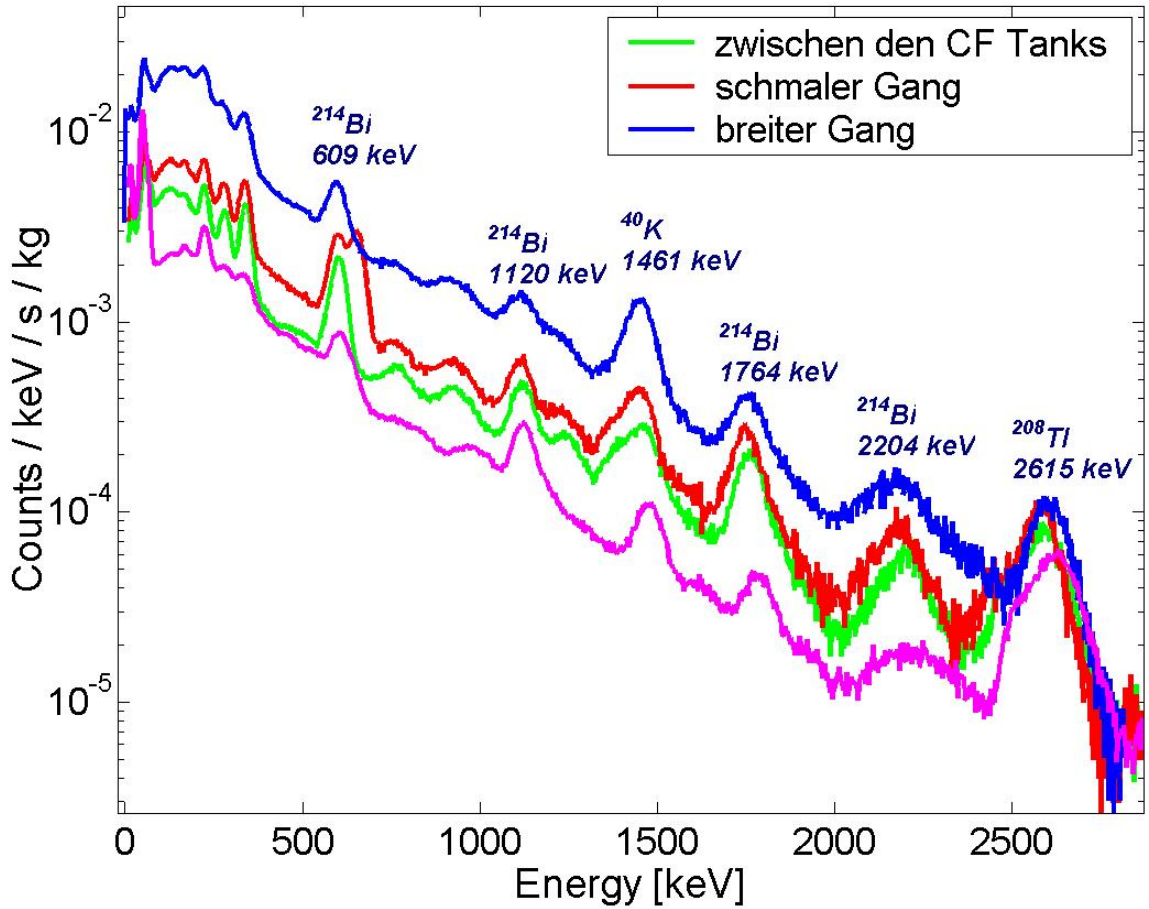
Messung im breiten Gang

(Messzeit: 10 Tage)

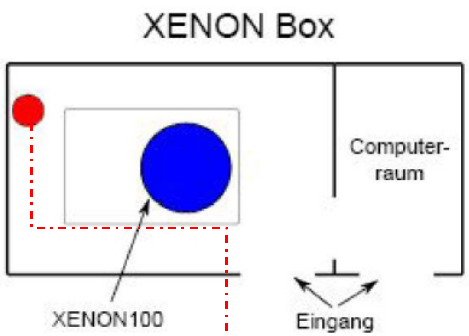
Messung im schmalen Gang

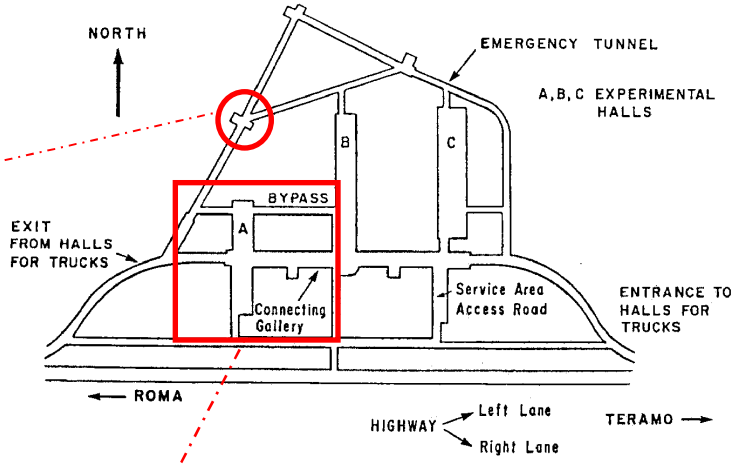
(Messzeit: 3 Tage)

Gamma Messung in der LVD Core Facility



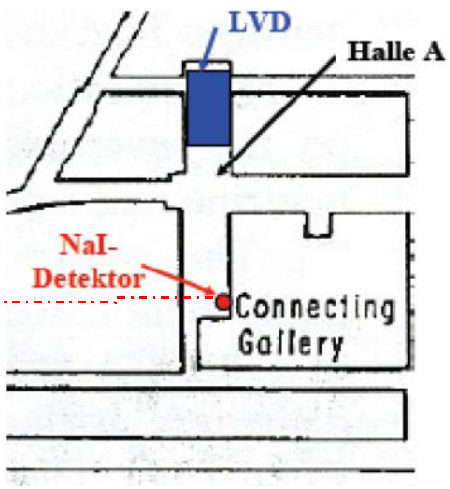
Messung in Xenon Box & Halle A





Messung in der Xenon Box

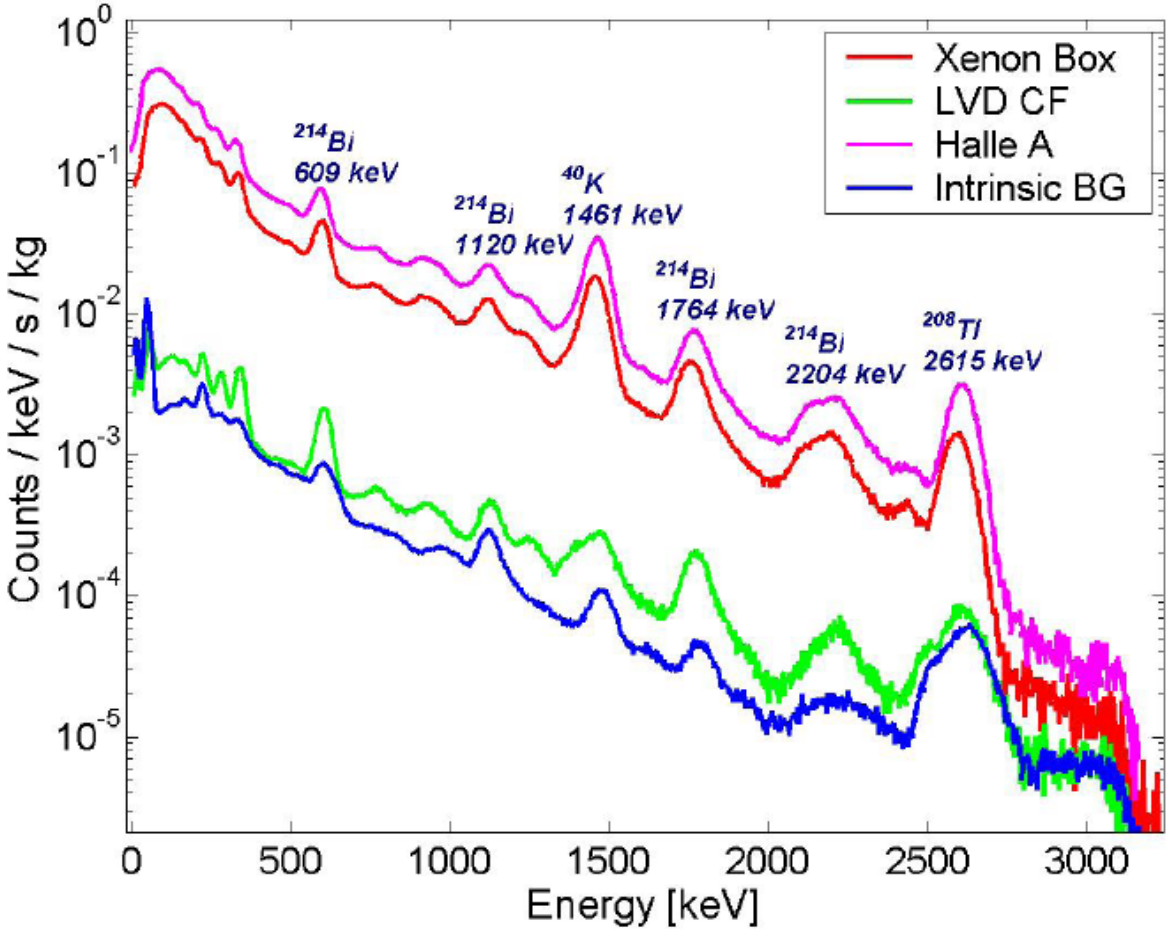
(Messzeit: 2 Tage)



Messung in der Halle A

(Messzeit: 4 Tage)

Vergleich der Gamma Messungen



Vergleich der Gamma Messungen

Ausgeprägte Peaks:

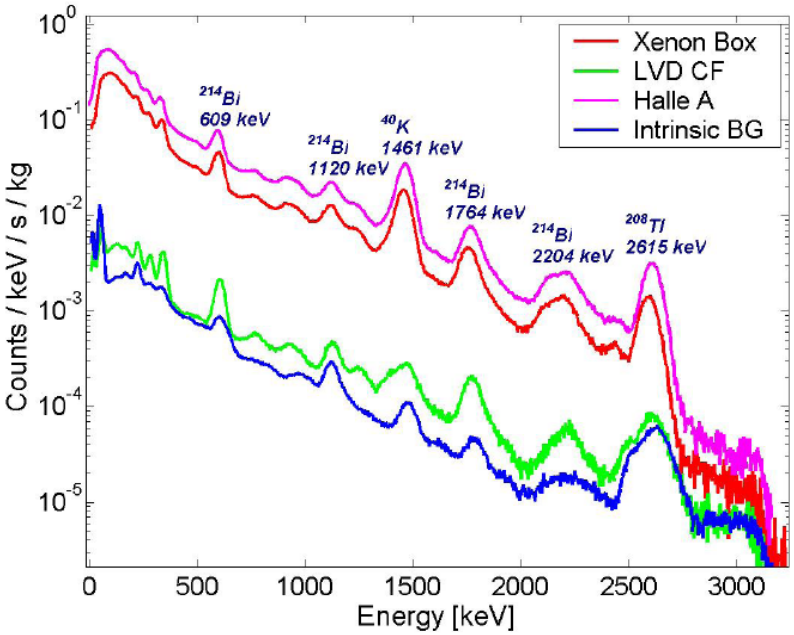
- ^{214}Bi: 609.312 keV
- ^{214}Bi: 1120.287 keV
- ^{214}Bi: 1764.494 keV
- ^{214}Bi: 2204.21 keV
- ^{40}K: 1460.830 keV
- ^{208}Tl: 2614.533 keV

aus der Zerfallskette von ^{238}U

aus der Zerfallskette von ^{232}Th

Quellen für Gamma-Untergrundsignale:

⇨ ^{238}U, ^{232}Th, ^{40}K im Felsen



Vergleich der Gamma Messungen

Verhältnisse der gemessenen Gammas in Halle A, Xenon Box und LVD Core Facility

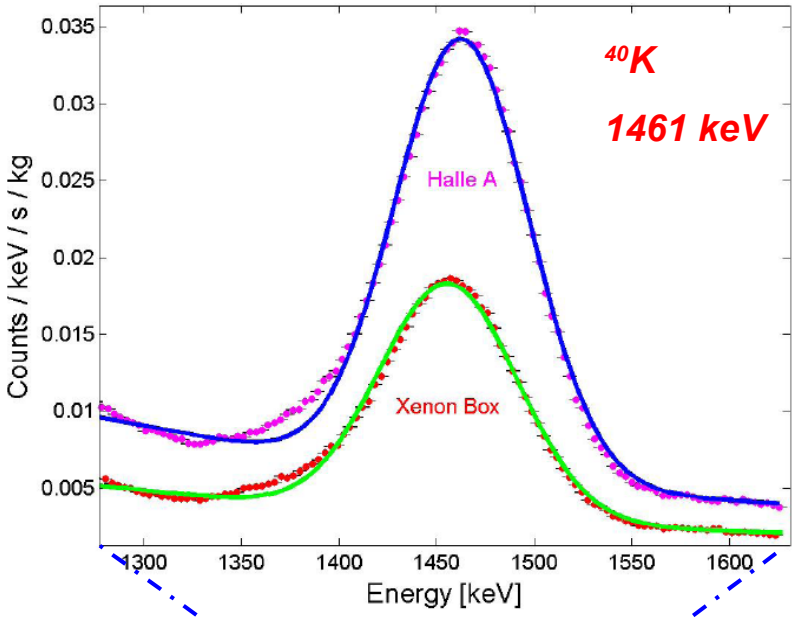
$$F_{gauss}(x) = a_1 \cdot exp\left[-\left(\frac{x-b_1}{c_1}\right)^2\right]$$

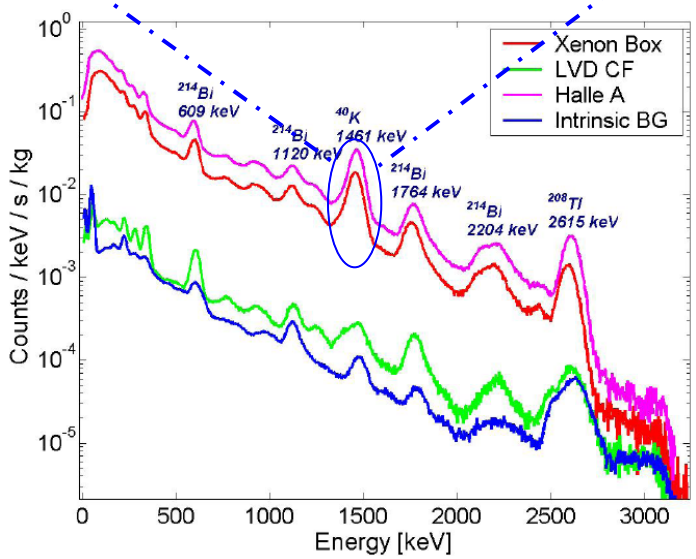
$$F_{quadr.}(x) = p_1 \cdot x^2 + p_2 \cdot x + p_3$$

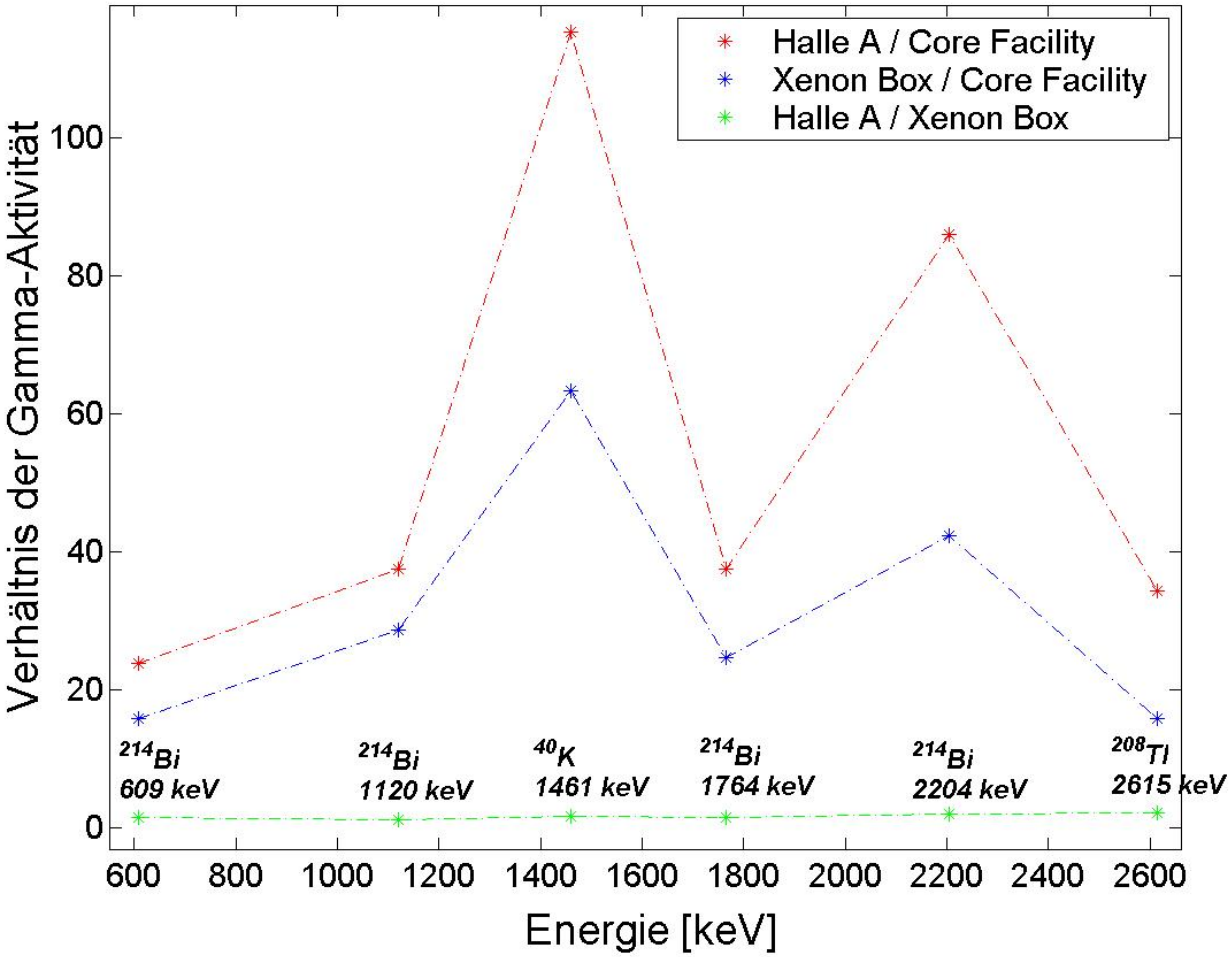
mit

$$a_1 = \frac{\lambda_1}{\sqrt{2\pi}\sigma_1} \; ; \; c_1 = \sqrt{2}\sigma_1$$

Bestimmung der Zählrate unter einem Peak!





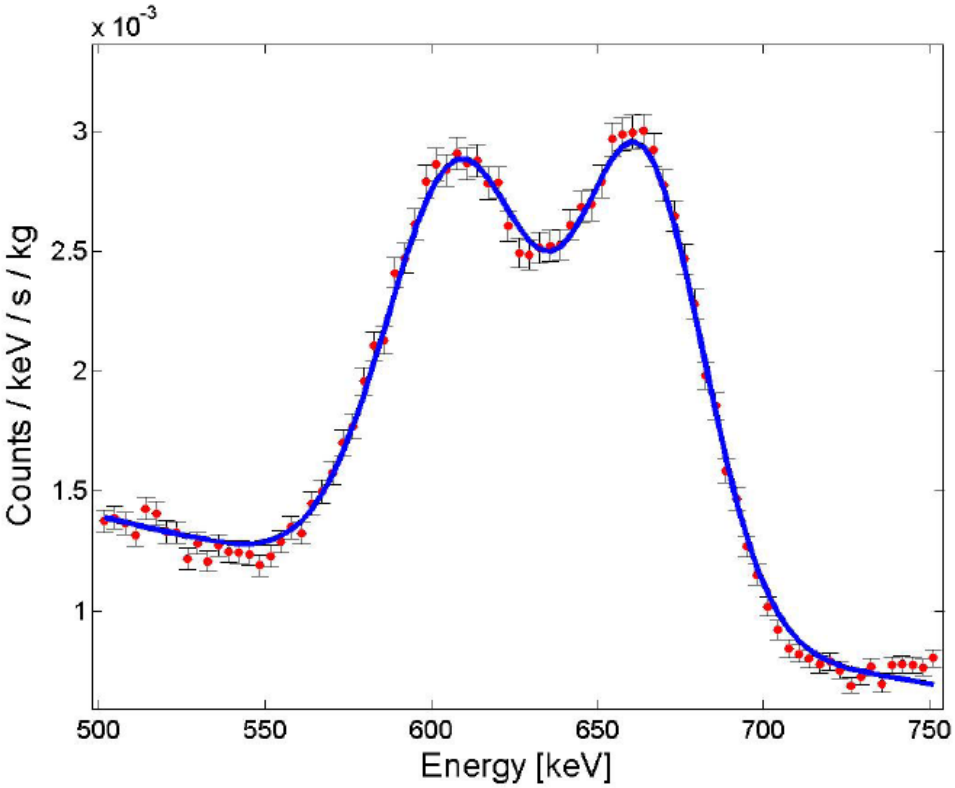


	Halle A / CF	Xenon Box / CF	Halle A / XenonBox
^{214}Bi: 609.312 keV	23.89($\pm$1.32)	15.85($\pm$0.93)	1.51($\pm$0.09)
^{214}Bi: 1120.287 keV	37.57($\pm$4.70)	28.65($\pm$3.22)	1.31($\pm$0.06)
^{40}K: 1460.830 keV	115.39($\pm$10.50)	63.36($\pm$5.77)	1.82($\pm$0.04)
^{214}Bi: 1764.494 keV	37.58($\pm$3.49)	24.69($\pm$2.32)	1.52($\pm$0.06)
^{214}Tl: 2204.21 keV	85.99($\pm$23.20)	42.37($\pm$9.88)	2.03($\pm$0.47)
^{208}Tl: 2614.533 keV	34.45($\pm$3.32)	15.92($\pm$1.61)	2.16($\pm$0.09)

Zusammenfassung

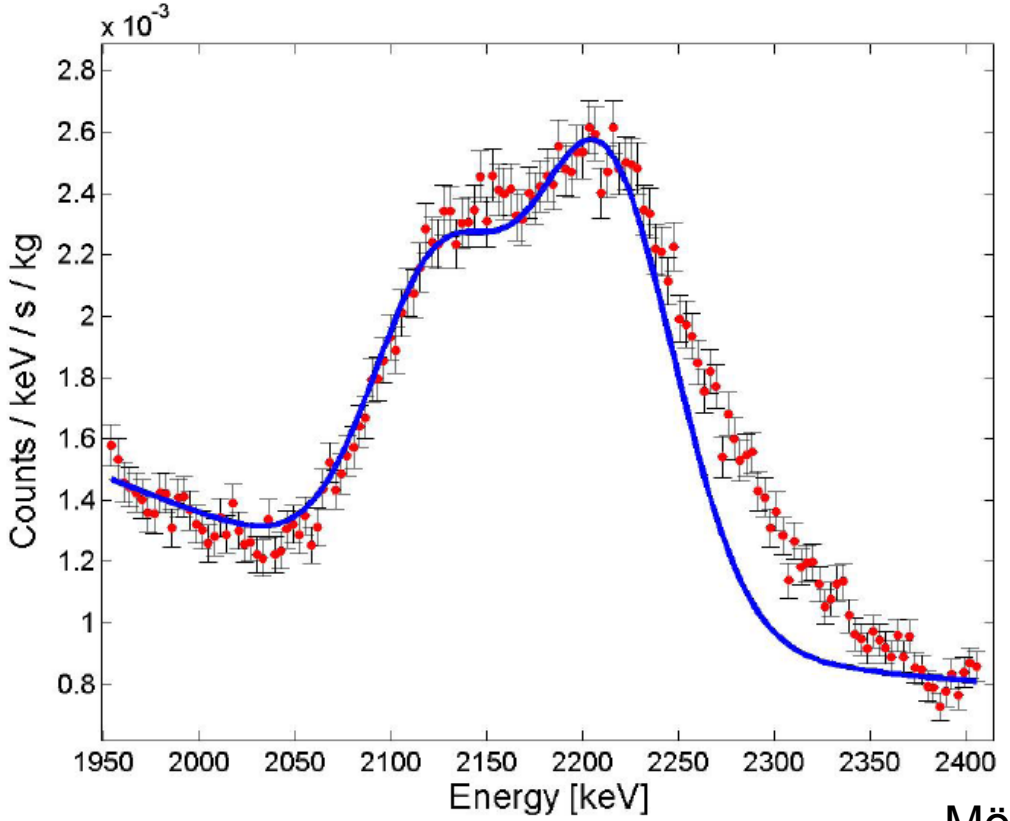
- Gamma Messungen im Gran Sasso Untergrundlabor
  - Aus der Sicht der Gamma-Aktivität lohnt es sich, XENON1t in die LVD Core Facility zu platzieren.
  - Die gemessenen Aktivitäten werden als Input für Monte Carlo Simulationen benutzt
- NaI-Detektor
  - Einige wichtige Eigenschaften des Detektors analysiert
  - Guter Detektor!

Fragen?



Gaussfit 1	
a1	0.002283(±7.3e-5)
b1	608.7(±1.1)
c1	31.12(±1.91)
Gaussfit 2	
a2	0.002478(±7.5e-5)
b2	663.3(±1.4)
c2	26.64(±1.31)
quadratischer Fit	
p1	1.954e-9(±3.999e-9)
p2	-6.013e-6(±4.817e-6)
p3	0.004295(±0.001401)

Sehr wahrscheinlich ^{137}Cs!



Gaussfit 1	
a1	0.00195 (festgesetzt)
b1	2204 (festgesetzt)
c1	53 (festgesetzt)
Gaussfit 2	
a2	0.00129 (festgesetzt)
b2	2121($\pm$5)
c2	49 (festgesetzt)
quadratischer Fit	
p1	2.853e−9($\pm$2.182e-9)
p2	-1.429e−5($\pm$9.017e-6)
p3	0.0189($\pm$0.0093)

Mögliche Gammaenergien:

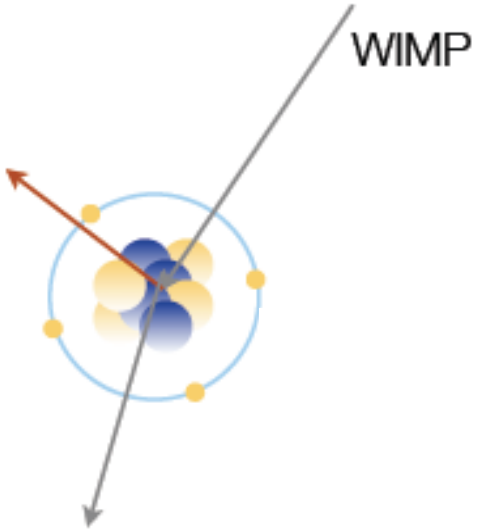
1. ^{214}Bi mit 2118.55 keV
2. „single escape“ von ^{208}Tl mit 2104 keV

Summation dieser Gammas!

Das XENON Experiment

- **Detektion von dunkler Materie**

  - Ziel: kleine Ladungs- und Lichtsignale detektieren



- **Vorteile von Xenon:**

  - Hohe Massenzahl (A = 131): $\sigma \propto A^2$
  - Hohe Atomzahl (Z = 54) und Dichte (3 g/cm^3)

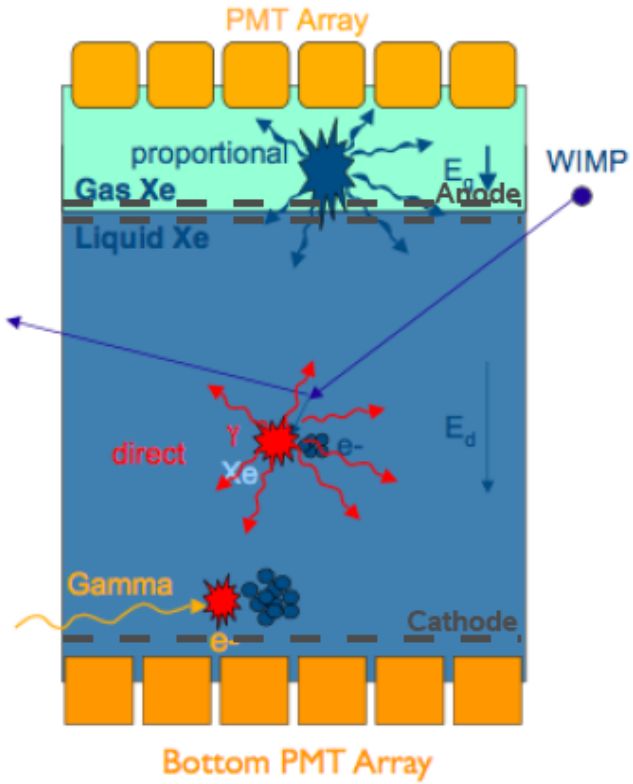
    ⇨ selbstabschirmende und kompakte Geometrie
  - In grossen Mengen verfügbar
  - Hohe Licht- und Ladungsausbeute
  - Keine radioaktiven Xe-Isotope

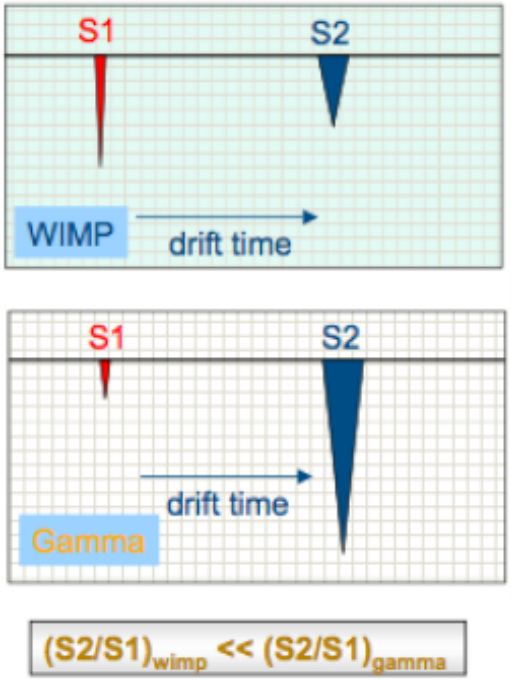
Element	Liquid Density (ρ/cm^3)	Energy loss dE/dx (MeV/cm)	Radiation length X_0 (cm)	Collision length λ (cm)	Boiling point @ 1 bar (K)	Electron mobility (cm^2/Vs)	Cost
Neon	1.2	1.4	24	80	27.1	high&low	$
Argon	1.4	2.1	14	80	87.3	500	$$
Krypton	2.4	3.0	4.9	29	120	1200	
Xenon	3.0	3.8	2.8	34	165	2200	$$$

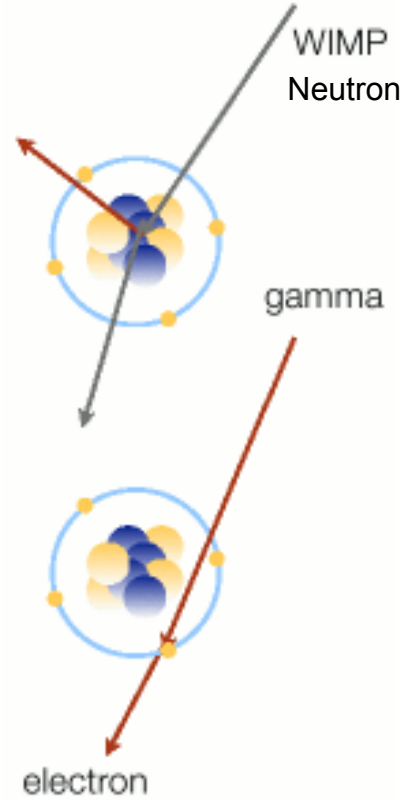
Das XENON Experiment

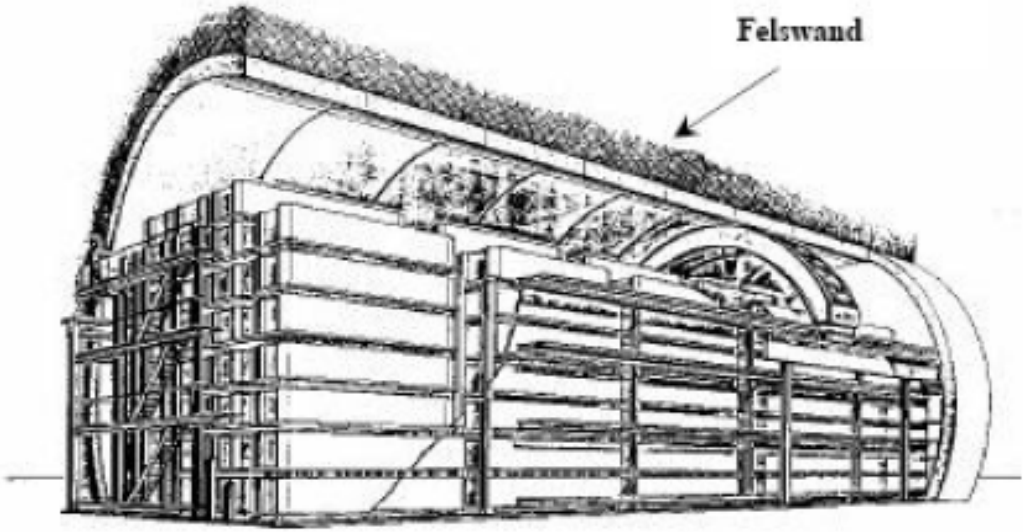
- **Detektion von dunkler Materie**
  - Ziel: kleine Ladungs- und Lichtsignale detektieren
  - Untergrundsignal: Neutronen und Gammastrahlung

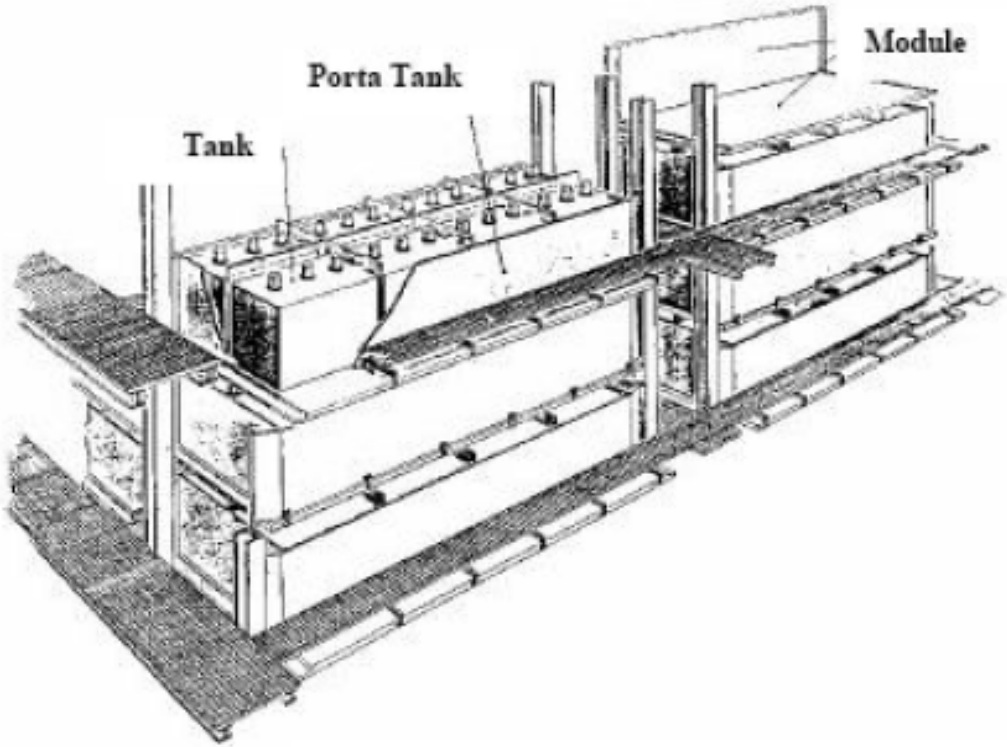
2-Phasen Kammer





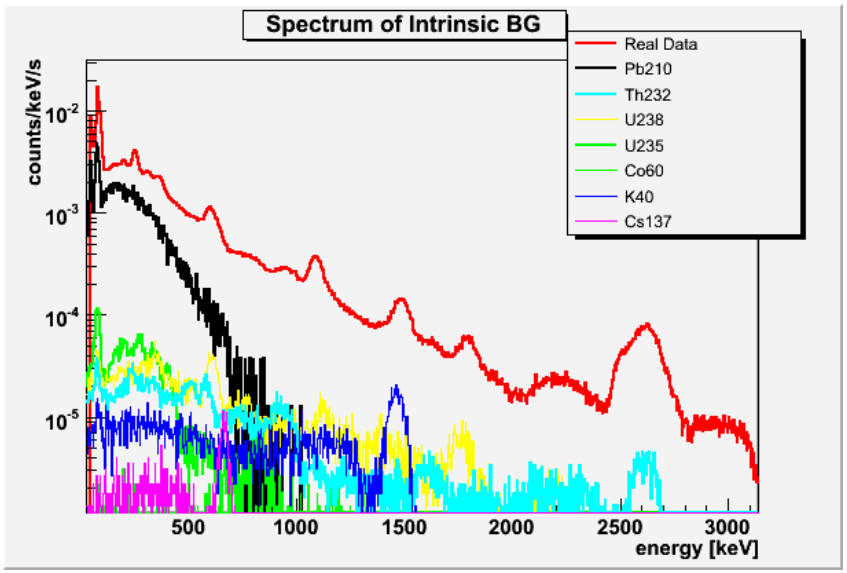


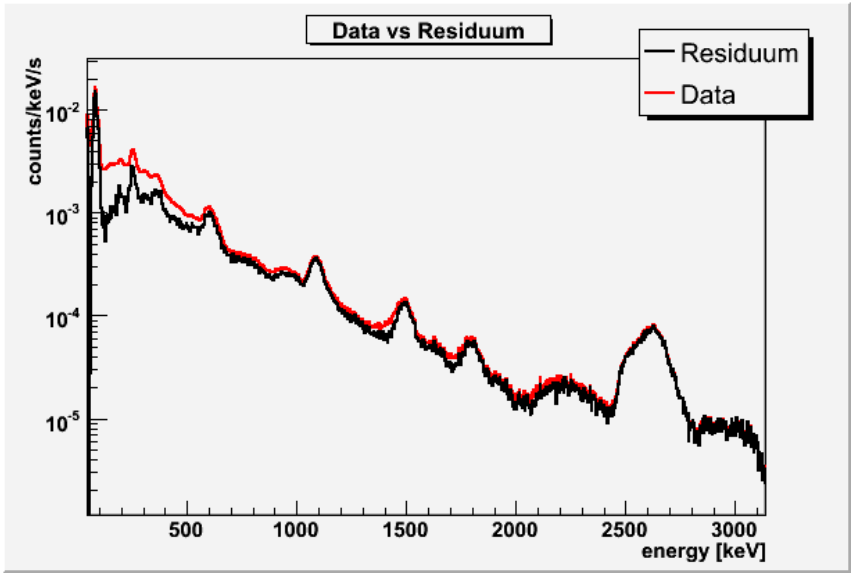

Felswand


Module
Porta Tank
Tank

Nuclide	Half-life	Major radiation energies (MeV) and intensities*		
		α	β	γ
^{238}U	4.468×10^{9}y	4.15 (23%) 4.19 (77%)	–	–
^{234}Th	24.1d	–	~0.103 (19%) 0.191 (81%)	0.063 (3.5%) 0.093 (4%)
^{234}Pa	1.18m	–	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
99.86% / 0.14%				
^{234}Pa	6.7h	–	0.53 (66%) 1.13 (13%)	0.10 (50%) 0.70 (24%) 0.90 (70%)
^{234}U	2.48×10^{5}y	4.72 (28%) 4.77 (72%)	–	0.053 (0.2%)
^{230}Th	7.52×10^{4}y	4.62 (24%) 4.68 (76%)	–	0.068 (0.6%) 0.142 (0.07%)
^{226}Ra	1602y	4.60 (5.5%) 4.78 (94.5%)	–	0.186 (4%)
^{222}Rn	3.825d	5.49 (~100%)	–	0.510 (0.07%)
^{218}Po	3.05m	6.11 (100%)	0.33 (100%)	–
99.98% / 0.02%				
^{214}Pb	26.8m	–	1.03 (6%)	0.295 (19%) 0.352 (36%)
^{218}At	2s	6.65 (6%) 6.70 (94%)	0.67 (94%)	–
^{214}Bi	19.7m	5.61 (100%)	3.26 (100%)	0.609 (47%) 1.120 (17%) 1.764 (17%)
99.96% / 0.04%				
^{214}Po	164μs	7.83 (100%)	–	0.799 (0.014%)
^{210}Tl	1.32m	–	2.3 (100%)	0.296 (80%) 0.795 (100%) 1.31 (21%)
^{210}Pb	~22y	3.7 (1.8×10^{-8}%)	0.017 (85%) 0.064 (15%)	0.047 (4%)
^{210}Bi	5.02d	4.93 (60%) 4.89 (34%) 4.59 (5%)	1.155 (100%)	–
~100% / ~.00001%				
^{210}Po	138.3d	5.30 (100%)	–	0.803 (0.0011%)
^{206}Tl	4.19m	–	1.520 (100%)	–
^{206}Pb	Stable	–	–	–

Nuclide	Half-life	Major radiation energies (MeV) and intensities*		
		α	β	γ
^{232}Th	1.39×10^{10}y	3.95 (24%) 4.01 (76%)	–	–
^{228}Ra	5.75y	–	0.055 (100%)	–
^{228}Ac	6.13h	–	2.11 (100%)	0.34 (15%) 0.908 (25%) 0.96 (20%)
^{228}Th	1.913y	5.34 (28% 5.42 (71%)	–	0.084 (1.6%) 0.214 (0.3%)
^{224}Ra	3.64d	5.45 (5.5%) 5.68 (94.5%)	–	0.241 (3.7%)
^{220}Rn	55.6s	6.30 (~100%)	–	0.55 (0.07%)
^{216}Po	0.145s	6.78 (100%)	–	–
^{212}Pb	10.64h	–	0.580	0.239 (47%) 0.300 (3.2%)
^{212}Bi	60.5m	6.05 (70%) 6.09 (30%)	2.25 (100%)	0.040 (2%) 0.727 (7%) 1.620 (1.8%)
64.0% ^{212}Po	304ns	8.78 (100%)	–	–
36.0% ^{208}Tl	3.1m	–	1.80 (100%)	0.511 (23%) 0.583 (86%) 0.860 (12%) 2.614 (100%)
^{208}Pb	Stable	–	–	–





^{232}Th	3.9 mBq/kg
^{238}U	6.8 mBq/kg
^{235}U	20 mBq/kg
^{40}K	28 mBq/kg
^{210}Pb	17.5 mBq/kg
^{137}Cs	0.85 mBq/kg
^{60}Co	0.19 mBq/kg