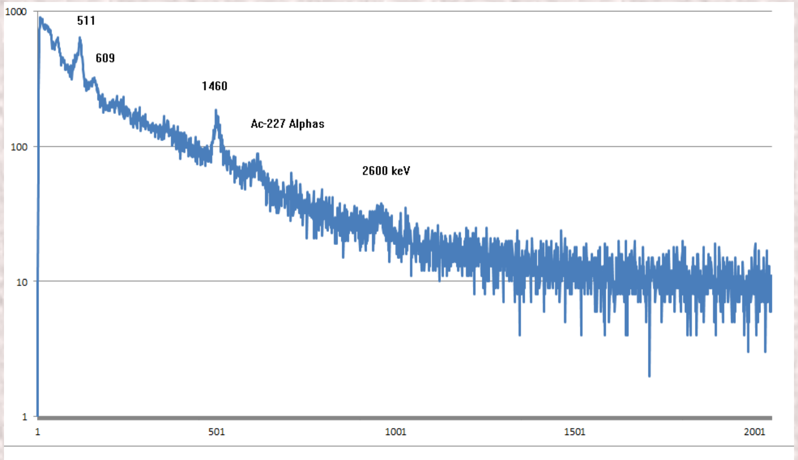


SCIONIX

www.scionix.nl

P. Schotanus

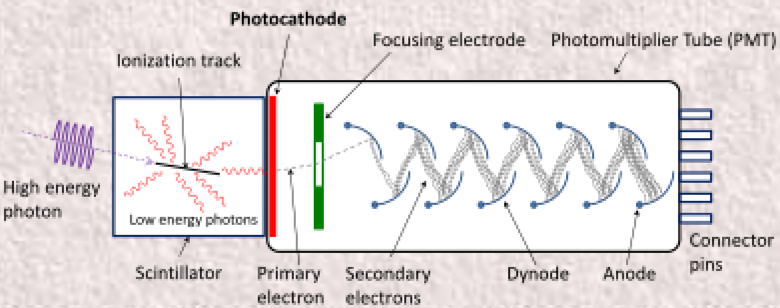
Developments in low level scintillation detector technology

Scintillation Detectors :

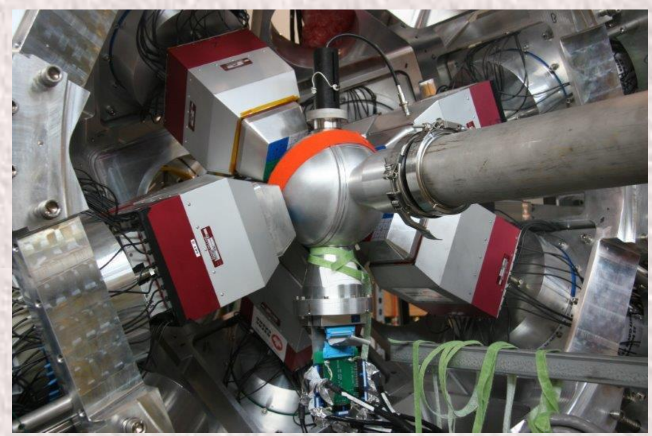
Instruments using inorganic ***scintillation crystals or organic scintillators (plastics/ liquids)***

Radiation + Crystal → Light → Electrical signal

SCIONIX : **Designs and manufactures scintillation detectors and - probes for many different applications.**

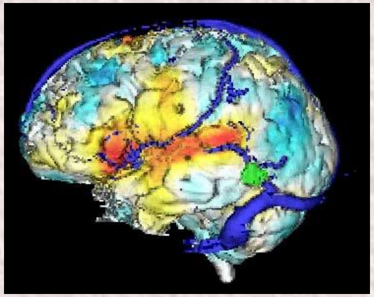


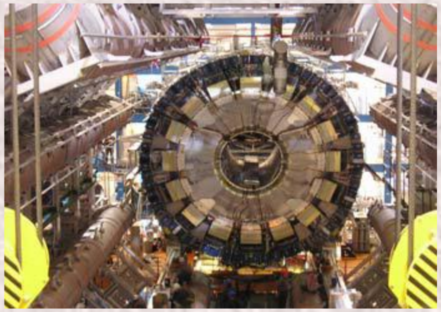
"Classic" scintillation detector



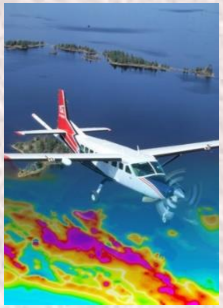
- Direction interaction (semiconductors, HpGe, CdTe , Gascounter)
- Indirect via Light

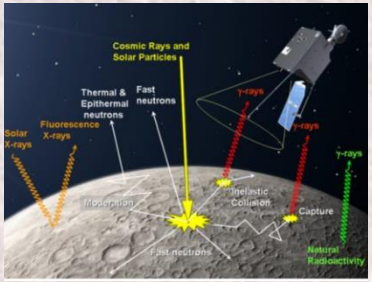
Scintillation detectors : standard tools in many disciplines



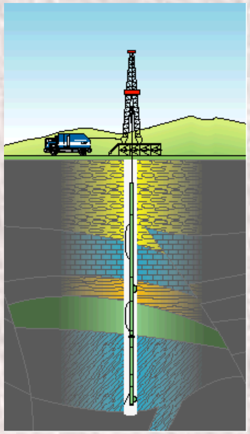


- Medical (SPECT/PET/CT) : Imaging, density
- Health Physics : Dose (particles, photons, neutrons)
- Security (finding/identifying sources) : spectroscopy
  (luggage scanners/imaging)
- High Energy Phyics (HEP) : particles, photons, calorimetry
- Nuclear Physics : Gamma rays spectroscopy / timing
- Geology: finding U, Th via spectroscopy,
- Mineral exploration (density, PNGA elemental analysis)
- Oil industry (density, well logging, PNGA)
- Space (gamma) spectroscopy, neutrons
- ……………………………………





Radiation Energies from keV to GeV, temperatures from -40 to +200 C, from laboratory to space environment…



EACH DISCIPLINE has a vastly different requirements,

Material	Density (g/cm^3)	Emission Maximum (nm)	Decay Constant (1)	Refractive Index (2)	Photo-electron yield (3)	Hygroscopic
NaI(Tl)	3.67	415	0.23 µs	1.85	100	yes
CsI(Tl)	4.51	550	0.6/3.4 µs	1.79	45	slightly
CsI(Na)	4.51	420	0.63 µs	1.84	85	yes
CsI(Undoped)	4.51	315	16 ns	1.95	4-6	no
Cs_2LiYCl_6:Ce (CLYC)	3.31	370	1/50/1000 ns	1.81	30-40	yes
CaF_2(Eu)	3.18	435	0.84 µs	1.47	50	no
$Cs_2LiLaBr_{4.8}Cl_{1.2}$:Ce (CLLBC)	4.08	420	120 ns 500 ns	1.90	70	yes
SrI_2(Eu)	4.60	450	1-5 µs	1.85	120-140	yes
$LaBr_{2.85}Cl_{0.15}$:Ce (LBC)	4.90	380	35 ns	1.90	140	yes
^{6}Li-glass	2.6	390	60 ns	1.56	4-6	no
^{6}Li(Eu)	4.08	470	1.4 µs	1.96	35	yes
BaF_2	4.88	315 220	0.63 µs/ 0.8 ns	150 1.54	16 5	no
LaBr3:Ce	5.03	380	20-25 ns	1.90	140	yes
$CeBr_3$	5.23	370	18-25 ns	2.09	130	yes
YAP(Ce)	5.55	350	27 ns	1.94	35-40	no
$Gd_3Al_2Ga_2O_{12}$:Ce (GAGG)	6.60	520	100 ns (average)	1.85	35-40	no
LYSO:Ce	7.20	420	50 ns	1.82	70-80	no
BGO	7.13	480	0.3 µs	2.15	15-20	no
$CdWO_4$	7.90	540	20/5 µs	2.3	25-30	no
$PbWO_4$	8.28	420	7 ns	2.16	0.20	no
Plastics(+ organics)	1.023	375-600	ns range	1.58	25-30	no

List of commercially available scintillators is extensive.

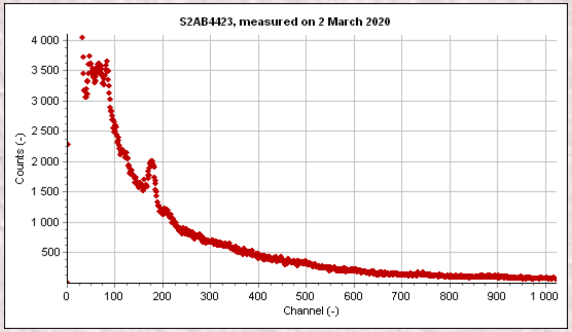
Many different parameters (speed, brightness etc. etc,_ Many materials are hygroscopic → encapsulation is needed

What is low level spectroscopy counting ?

- standard 10 cm lead shield ?
- Underground ?
- With Muon shielding ?
- Energy window ?
- “ultra” ?

The quesion : “I need a low background detector needs to be specified”,

Usually a parameter like “minium detectable is here the “keyword”
This related to energy resolution (gamma-ray spectroscopy)

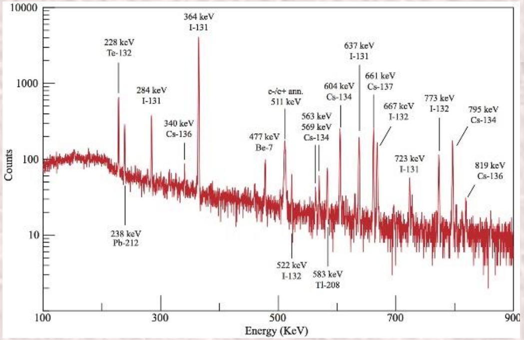


How well or quickly or at all can we detect a small line in a gamma ray spectrum (example shows 511 keV) ?

What is high resolution ?

Usually we refer then to energy resolution of scintillators

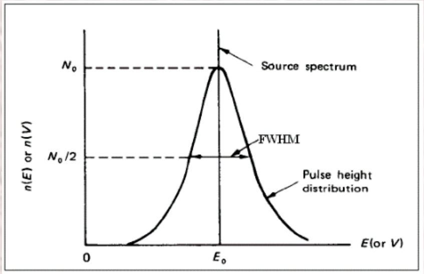
HpGe detectors (direct interation devices) : approx. 2 keV over energy range from keV to MeV.   Superb energy spectrum .



HpGe = REAL high resolution

In % :

59.5 keV (^{241}Am)	:	3.4 %
122 keV (^{57}Co)	:	1.6 %
662 keV (^{137}Cs)	:	0.3 %
1332 keV (^{60}Co)	:	0.15 %



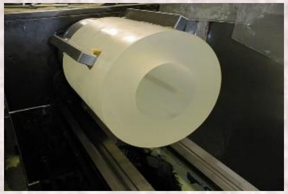
The very best scintillators (“high” energy resolution) offer

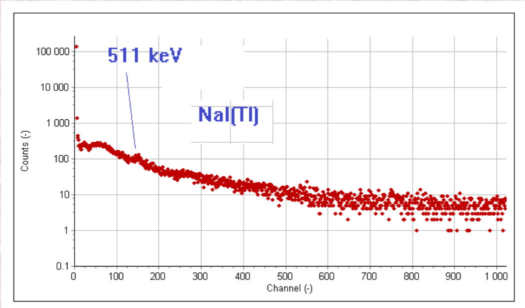
59.5 keV (^{241}Am)	:	7 % (NaI(Tl) / LBC/LaBr3
122 keV (^{57}Co)	:	6 % LBC LaBr3 /SrI_2(Eu)
662 keV (^{137}Cs)	:	2.5 %LBC/LaBr3
1332 keV (^{60}Co)	:	1.5 % LBC/LaBr3

HpGe far superior in energy resolution but low Z, cooling, size are disadvantages

Origin of intrinsic background in scintillation materials

- Crystal material
- Sealing material (special epoxies)
- Housing material
- Reflector material
- Optical window
- Light detector





Best low background scintillators :		
	NaI(Tl)	Large size possible
	$SrI_2(Eu)$	only small size (100 cc)
	Organics	large size possible

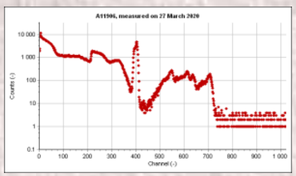
When you bring a scintillation sensor inside a shielding you will increase the background due to the presence of above materials.

Extreme high background scintillators :

L(Y)SO 250 c/s/cc betas (up to 1 MeV)

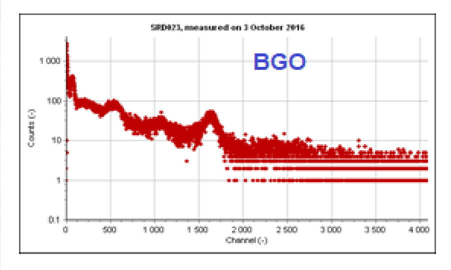
Lanthanum halides
(about 1-2 c/s/cc (betas/gammas)
+ Ac-2227 alphas

LaBr3
LBC
CLLBC



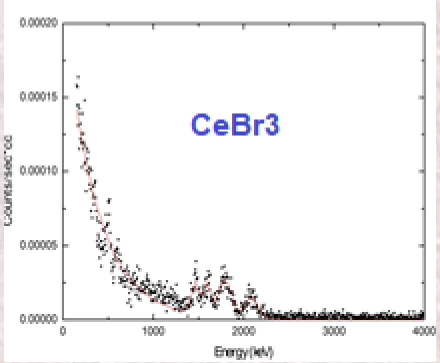
BGO (used for Compton suppression shields has background)

0.6, 1 and 1.6 MeV lines due to activation by cosmics



0.01 – 0.02 c/s/cc (Net in peaks)

Of the high resolution scintillators, **$CeBr_3$** as lowest background of 0.002 c/s/cc in the Ac-227 peaks
Otherwise clean.



Sealing materials

There is little improvement possible since the number of epoxies qualified to seal metals to glasses is limited. No compromise possible

Housing materials/windows

Stainless steel or OHFC copper are the best option but prevent X-ray detection. Beryllium can be relatively radiopure

Optical windows light guides / reflectors :

- Quartz (fused silica) is always used also for optical transission
- Reflectors of qualified Al2O3 powder or PTFE have proven to be fine

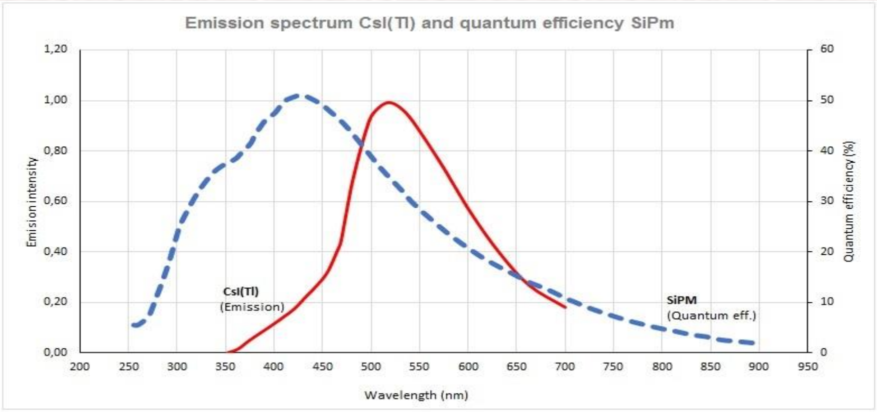
Light detectors :

- **Classic PMTs contain glass, glass joints, lots of metals…..**

  The use of silicon technology allows higher wavelength emitting scintillators; PMTs dictated an emission in the 400 nm region.

ADVANCES in scintillation light detection

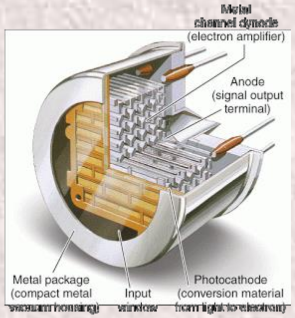
Range of possibilities for readout of scintillation light :



- **PMTs**
- **(PIN) Diodes**
- **Avalanche Photodiodes (APDs)**
- **(EM) CCDs**
- **Si-PMs (MPPCs)**

Range of possibilities for readout of scintillation light :

- PMTs
- (PIN) Diodes
- Avalanche Photodiodes (APDs)
- (Drift Diodes)
- (EM) CCDs
- Si-PMs (MPPCs)

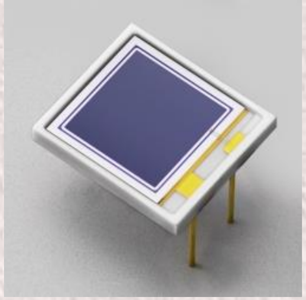


PMTs

- Made of glass (fragile + K-40 background)
- Large signals, good S/N ratio, fast (ns)
- Large dimension, low price per cm^2
- Sensitive to B fields
- Existing old technology (vacuum tubes)

PIN diodes

- No amplification (small signals)
- Maximum cm size
- Stable (temperature)

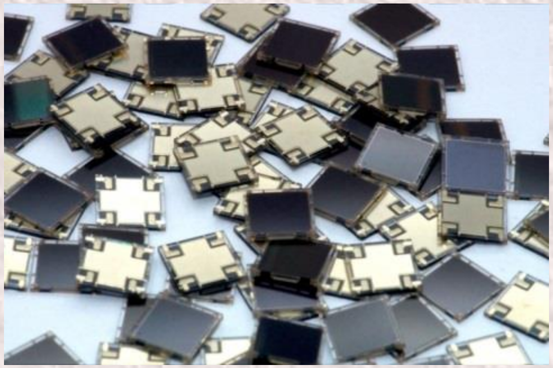


CCDs :

- DC measurement mostly
- Imaging
- For higher radiation fields

APDs

- Amplification 100-1000
- rather Unstable (temp)
- rel expensive, small (max 10x10mm)



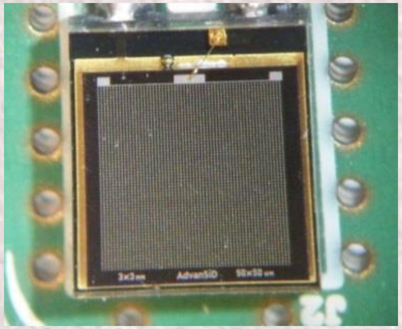
Silicon Photomultipliers (SiPMs, MPPCs)

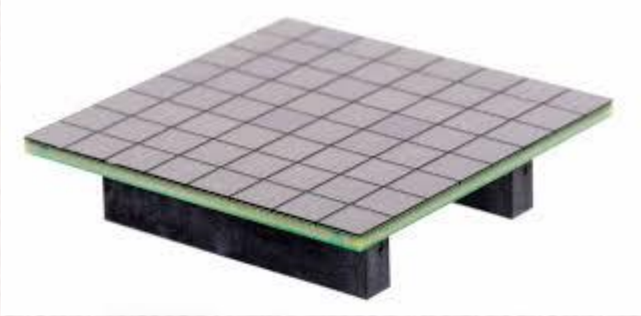
Silicon photomultipliers

Large improvement of SiPms since last years does open up many possibities :

- Higher PDE

- Lower noise





PRO's

- Large gains (10^6), fast
- Affordable cost (6x6 mm< 50-100 €) (mass production process)
- Higher basic QE than PMTs : Si
- Low voltage (30-70 V) e.g. ATEX
- Compact

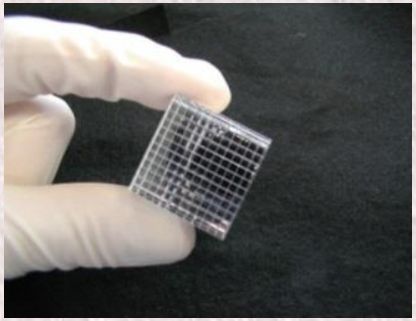
CON's

- high price per cm^2
- filling factor
- pixel saturation easy (fast bright scintillators !)
- temperature dependent gain rel. large (-1-2 % / ^oC)
- Noisy !

Price per cc much higher than PMTs !

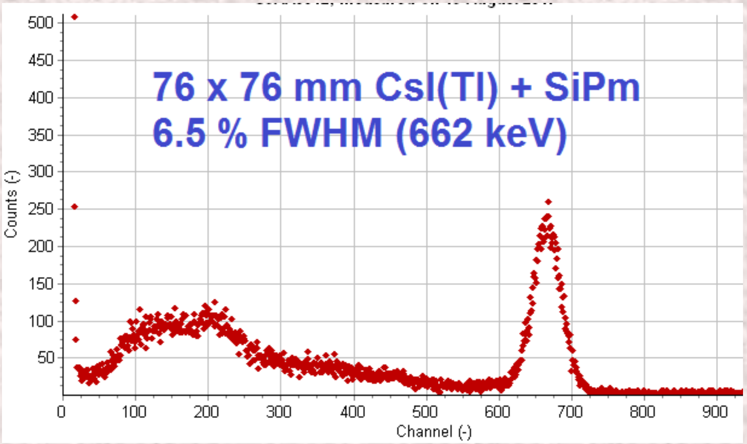
Readout of crystal pixels with SiPm obvious :

Med. Imaging
(WLS) Fibers



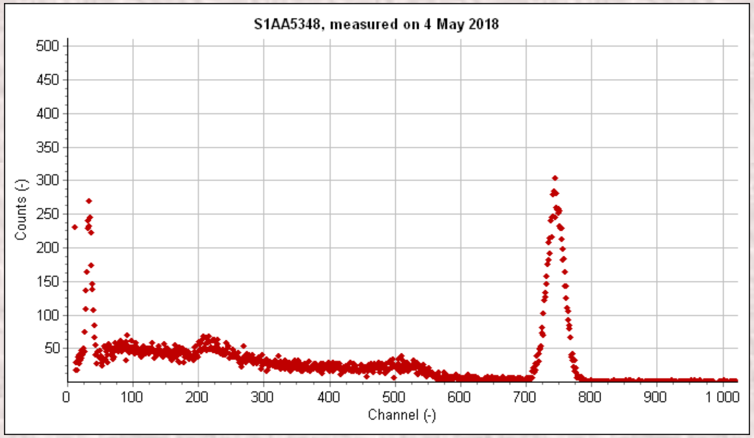
SiPm readout becomes mature :

New ranges of sensors are developed : Small size
Low voltage



NaI(Tl)
CsI(Tl)
CsI(Na)
$CeBr_3$

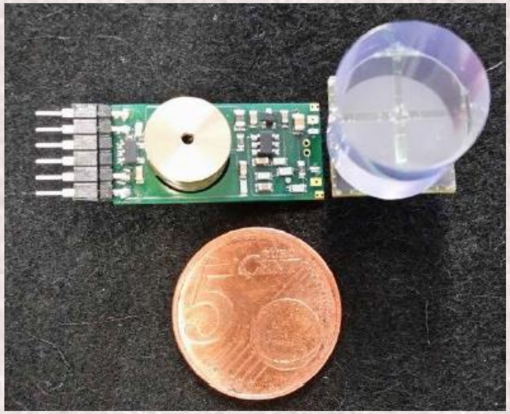
SiPm technology can also be applied to “neutron scintillators”

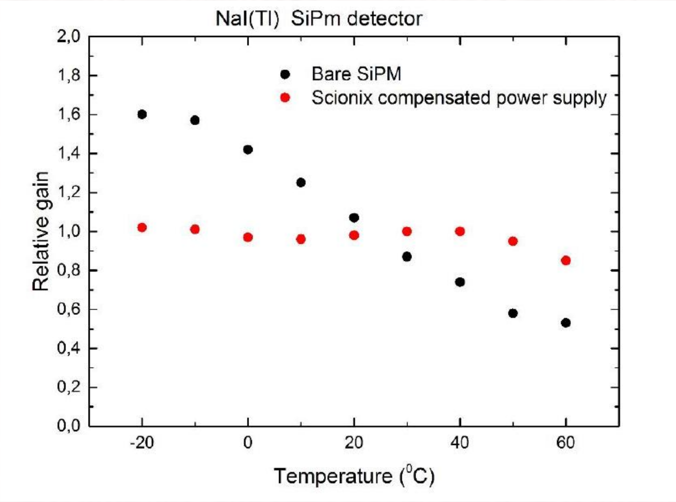


51 mm cubic $CeBr_3$ orn 51 x 51 mm SiPm array : 4.0 % FWHM * 662 keV)

= PMT Comparable

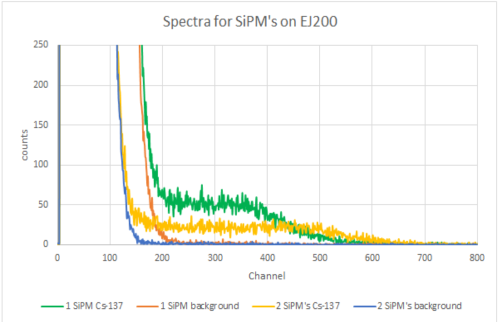
Temperature compensated bias generators / preampifier can compensate for the SiPm gain drift

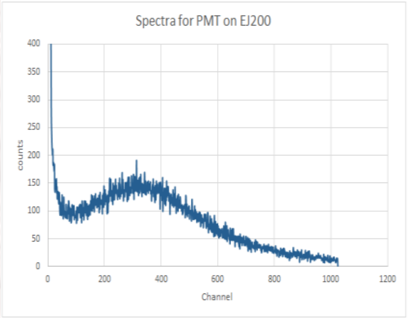




However, noise increases approx. 5-fold from 20 to 60 C

Careful choice of No. Of SiPms on every scintillation module needs to be made to optimise s/n. More SiPms more noise….

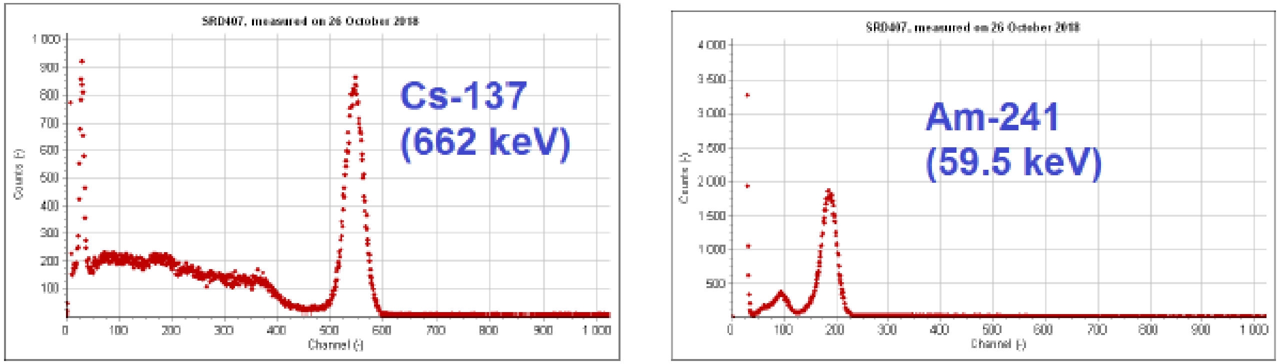




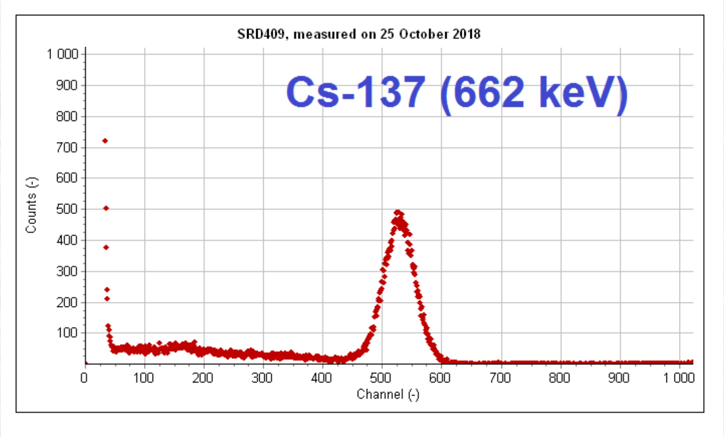
200x120x10 mm plastic scintillator with 25x10 mm readout surface

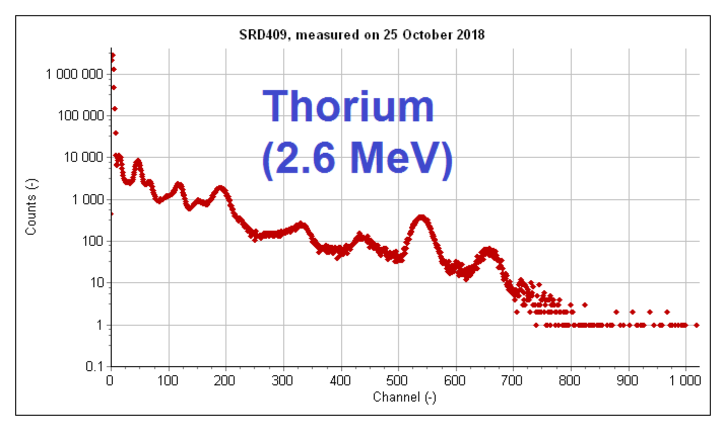
The new generation scintillator / Sipm detectors

- Compact
- Low power (5 V , 5 mA)
- Built-in temperature compensated bias generator / preamplifier
- PMT readout comparable energy resolution
- Wide choice of scintillator

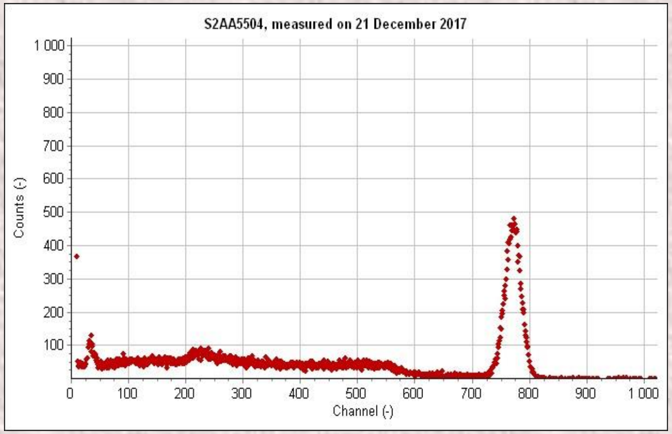


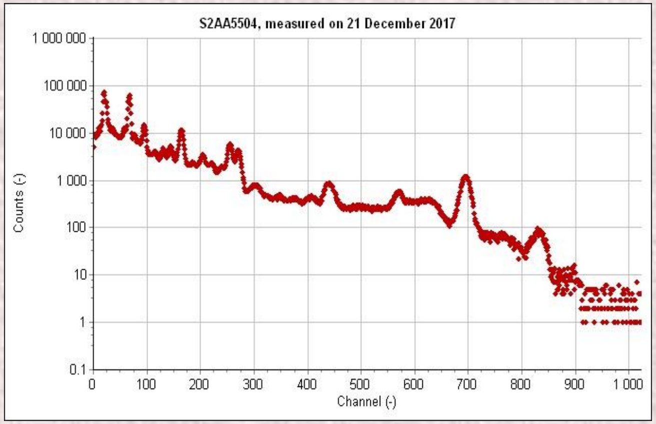
NaI(Tl)





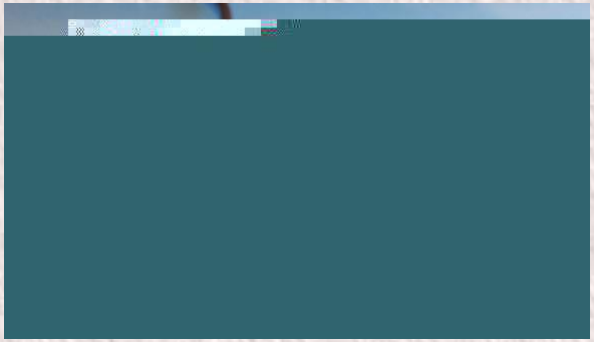
BGO

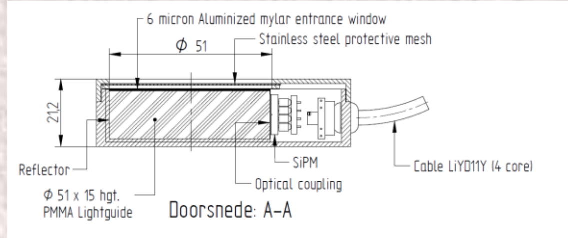


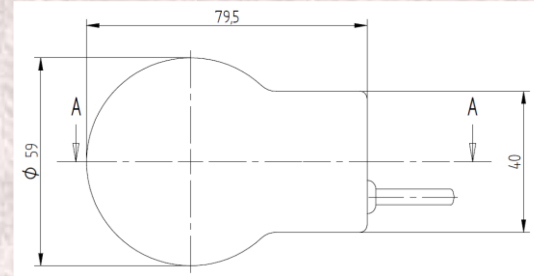


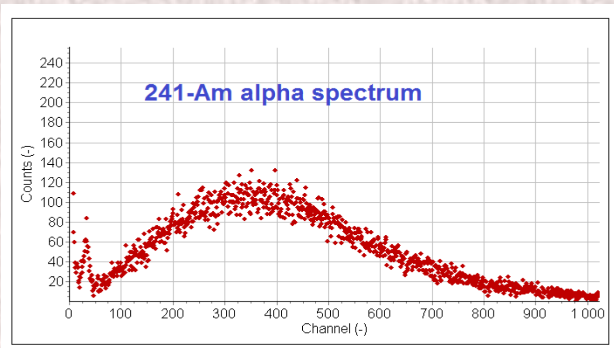
$CeBr_3$

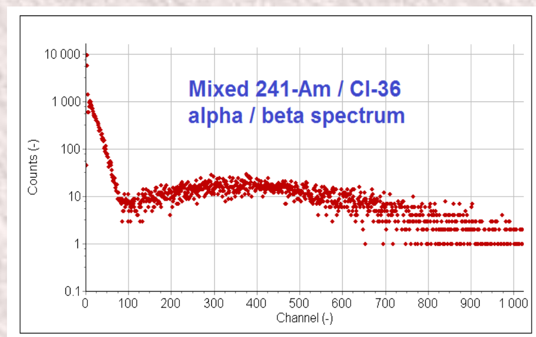
Also Alpha/beta detectors with SiPm readout are developed.

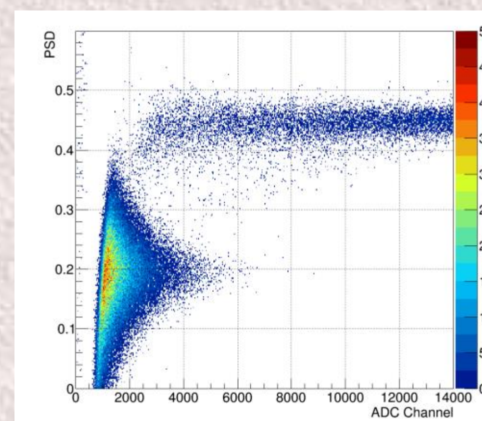


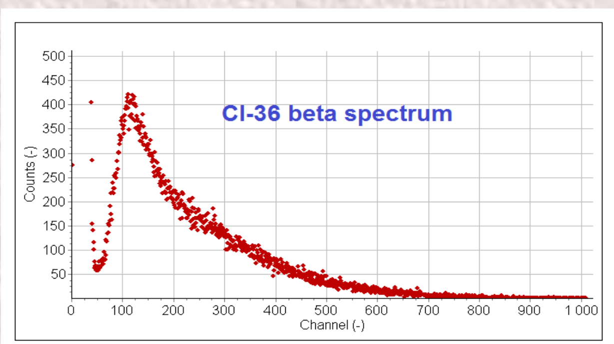

6 micron Aluminized mylar entrance window
Φ 51
Stainless steel protective mesh
21,2
Reflector
SiPM
Cable LiYD11Y (4 core)
Optical coupling
Φ 51 x 15 hgt.
PMMA Lightguide
Doorsnede: A-A

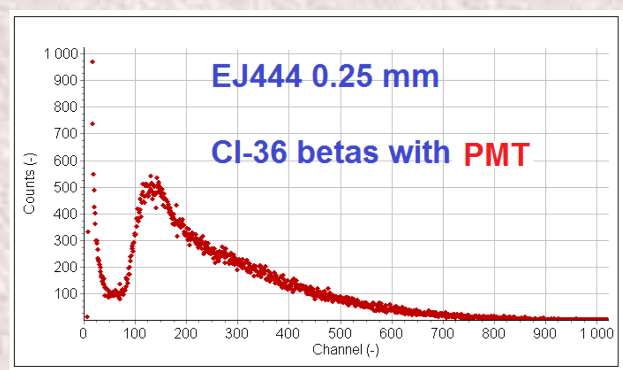

79,5
A
A
Φ 59
40


241-Am alpha spectrum
Counts (-)
Channel (-)


Mixed 241-Am / Cl-36
alpha / beta spectrum
Counts (-)
Channel (-)

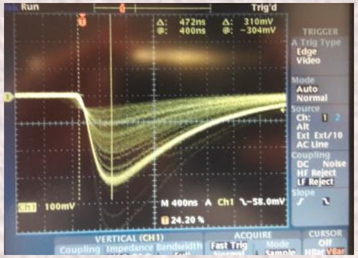

PSD
ADC Channel

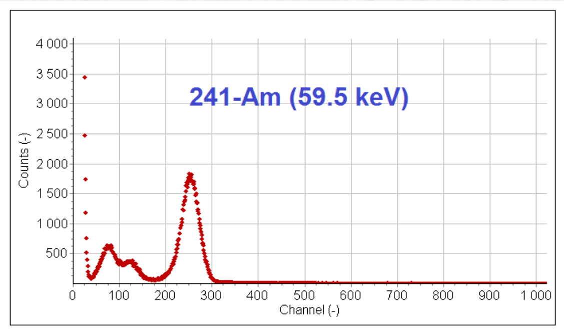

Cl-36 beta spectrum
Counts (-)
Channel (-)

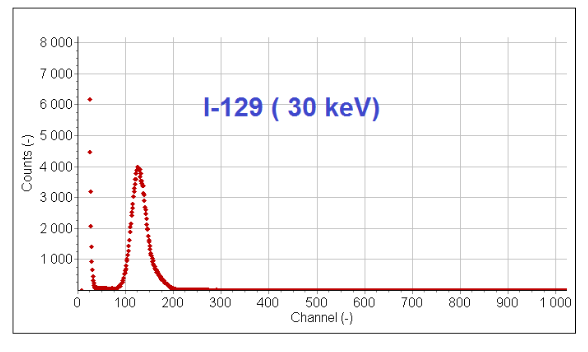

EJ444 0.25 mm
Cl-36 betas with PMT
Counts (-)
Channel (-)

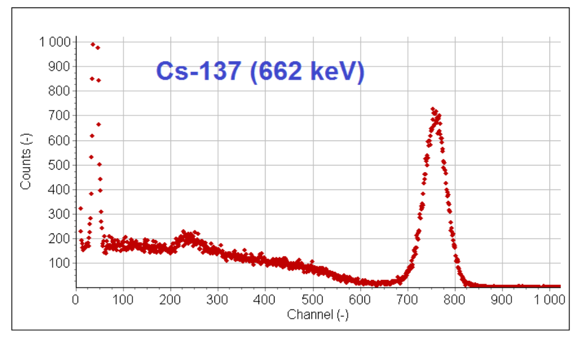
NaI(Tl) well detectors with SiPm readout

- Compact, easy to shield
- SiPm temperature compensated
- Low power
- Many digital MCA compatible
- Noise < 10 keV (20 C)



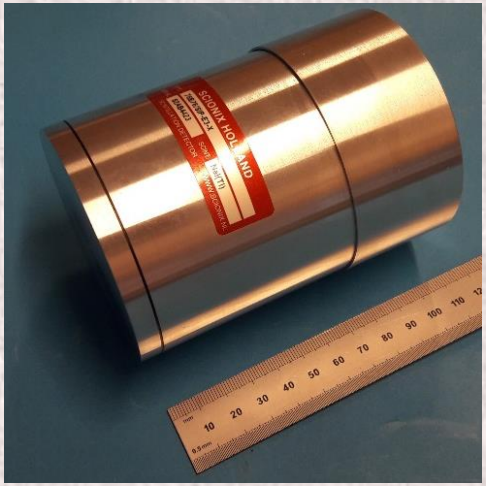




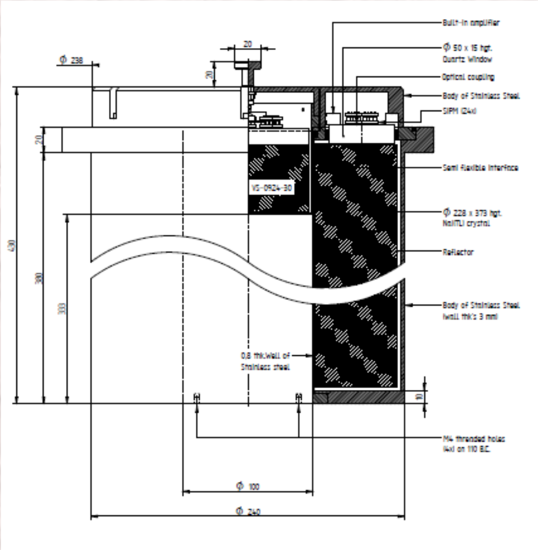


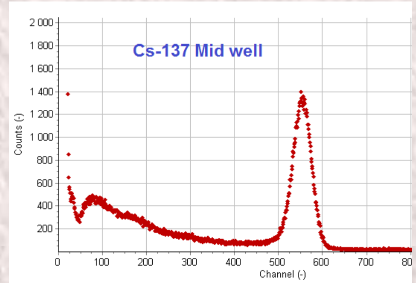
With SiPm readout of scintillators one can :

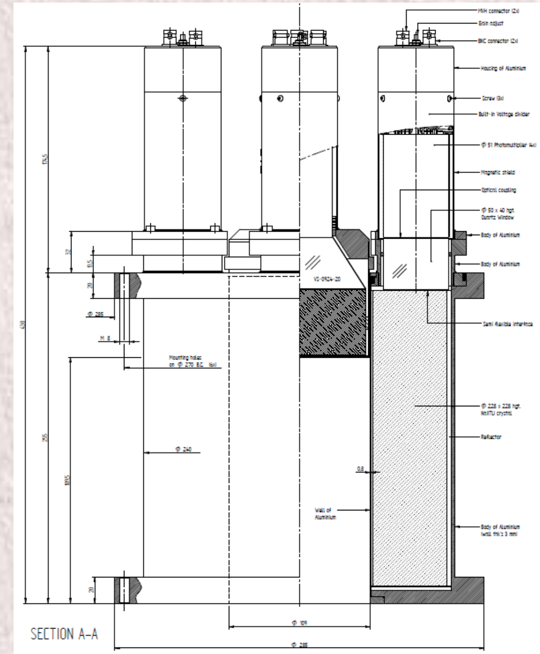
1. Remove the relatively high background PMT (metals, glass)
2. Reduce the amount of hardware (smaller lighter, less metals)
3. Operate the sensor at +5 V

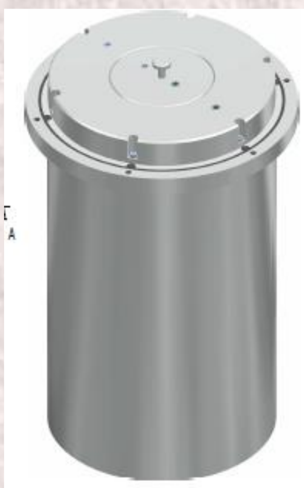


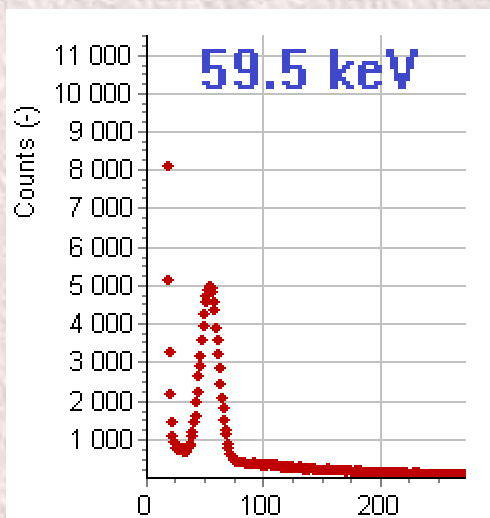
Complete Compron suppression shields with SiPm readout

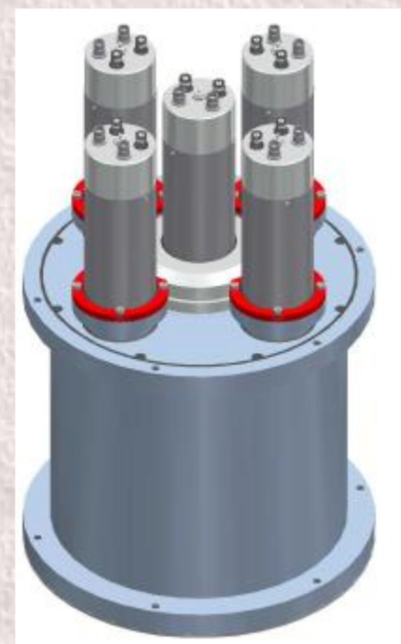












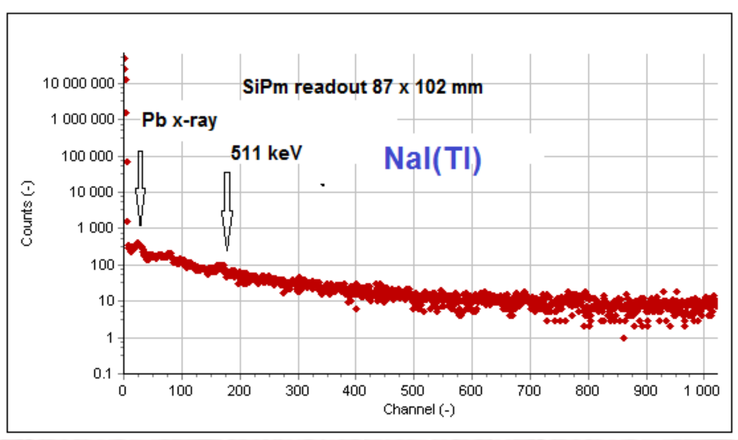
Compton suppression is about “background” due to scattering
There is also background due to :

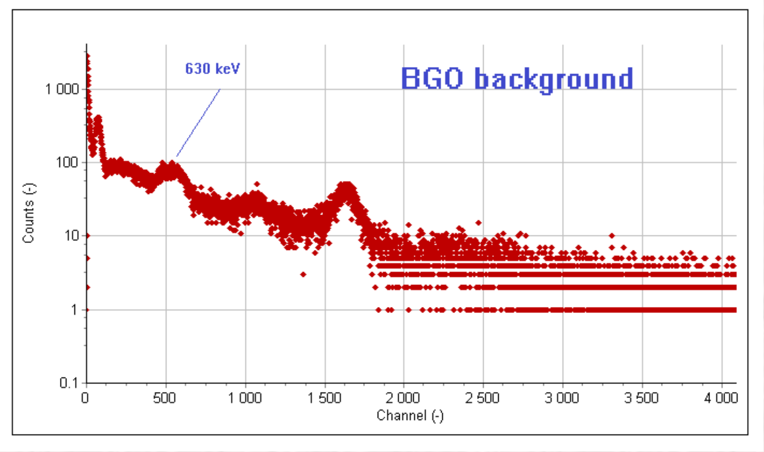
A. Internal contamination
B. Cosmic ray background

A **All you wil bring with a HpGe inside a shielding will increase the background !**

Use pure materials, low background PMTs and other materials !

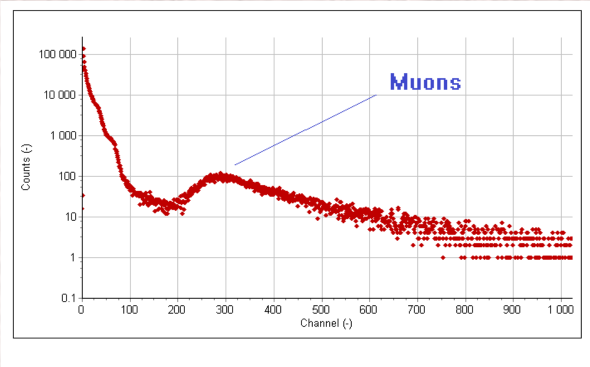
BGO shields have more background due to intrinsic activity of BGO
For low background systems, NaI(Tl) is better.



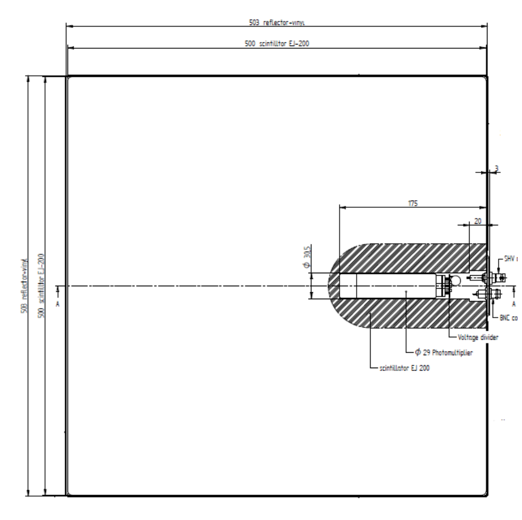


B

Cosmic (muon) background on a HpGe spectrum can be eliminated by Mounting plastic scintillation panels outside of Lead shielding



Cosmic muons Produce signals in the 3 MeV + region



Up to 1000 mm , SiPm readout is also possible but does not lead to lower cost.

Plastic scintillator muon shield are usually custom made and mounted outside the Lead shielding

A few final remarks

1. What a manufactuer can measure with respect to background is limited.
   we do select materials and use some recipes….

2. Many newly developed high resolution crystals are not at all ”low background”

3. SiPm readout of scintillators opens some possibilities. Performance at room temperature comprable to PMTs these days.

Thanks for your attention