PhotoDet2012 Int. Workshop on New Photon-detectors

Evaluation of high UV sensitive SiPMs from MEPhI/MPI for use in liquid argon

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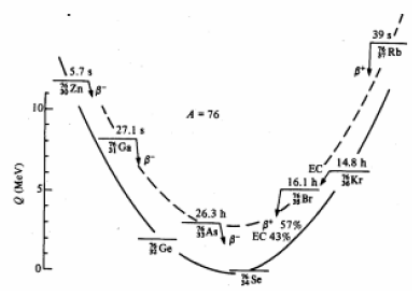
LAL Orsay

The search for neutrinoless double beta decay with GERDA: GERmanium Detectors Array

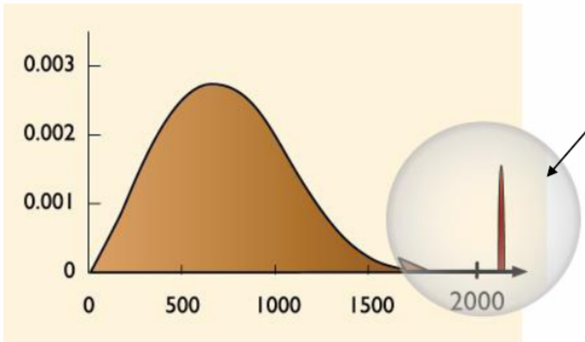
Neutrinoless double β-decay experiments



2νββ: (A,Z) → (A,Z+2) + 2e⁻ + 2 $\bar{\nu}_e$ **ΔL=0**

$$T_{1/2}^{2\nu} = (10^{18} - 10^{21})\mathrm{y}$$

0νββ: (A,Z) → (A,Z+2) + 2e⁻ **ΔL=2**



Experimental signatures:
- peak at $Q_{\beta\beta} = E_{e1} + E_{e2} - 2m_e$
- two electrons from vertex
- production of grand-daughter isotope

Discovery would imply:
- neutrino is its own anti-particle, (Majorana particle)
- absolute neutrino mass scale & hierarchy
- lepton number violation ΔL = 2
- further new physics beyond the standard model

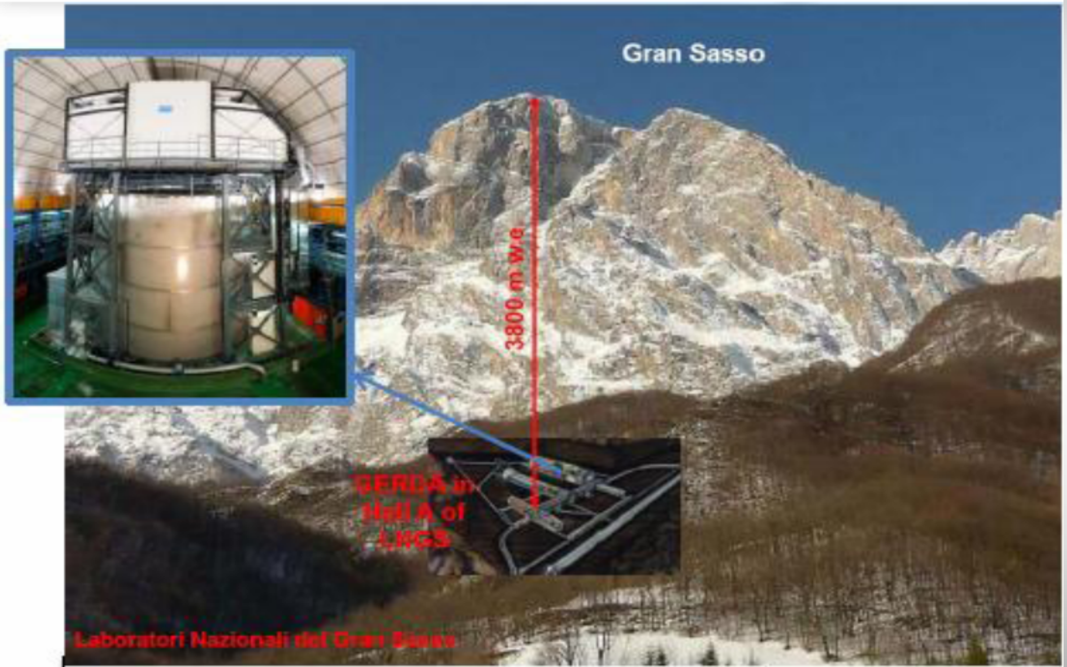
Deep underground laboratory at LNGS - 3400 m.w.e.

18 kg ^{76}Ge (enriched 86%) + 15 kg ^{nat}Ge (Phase I)

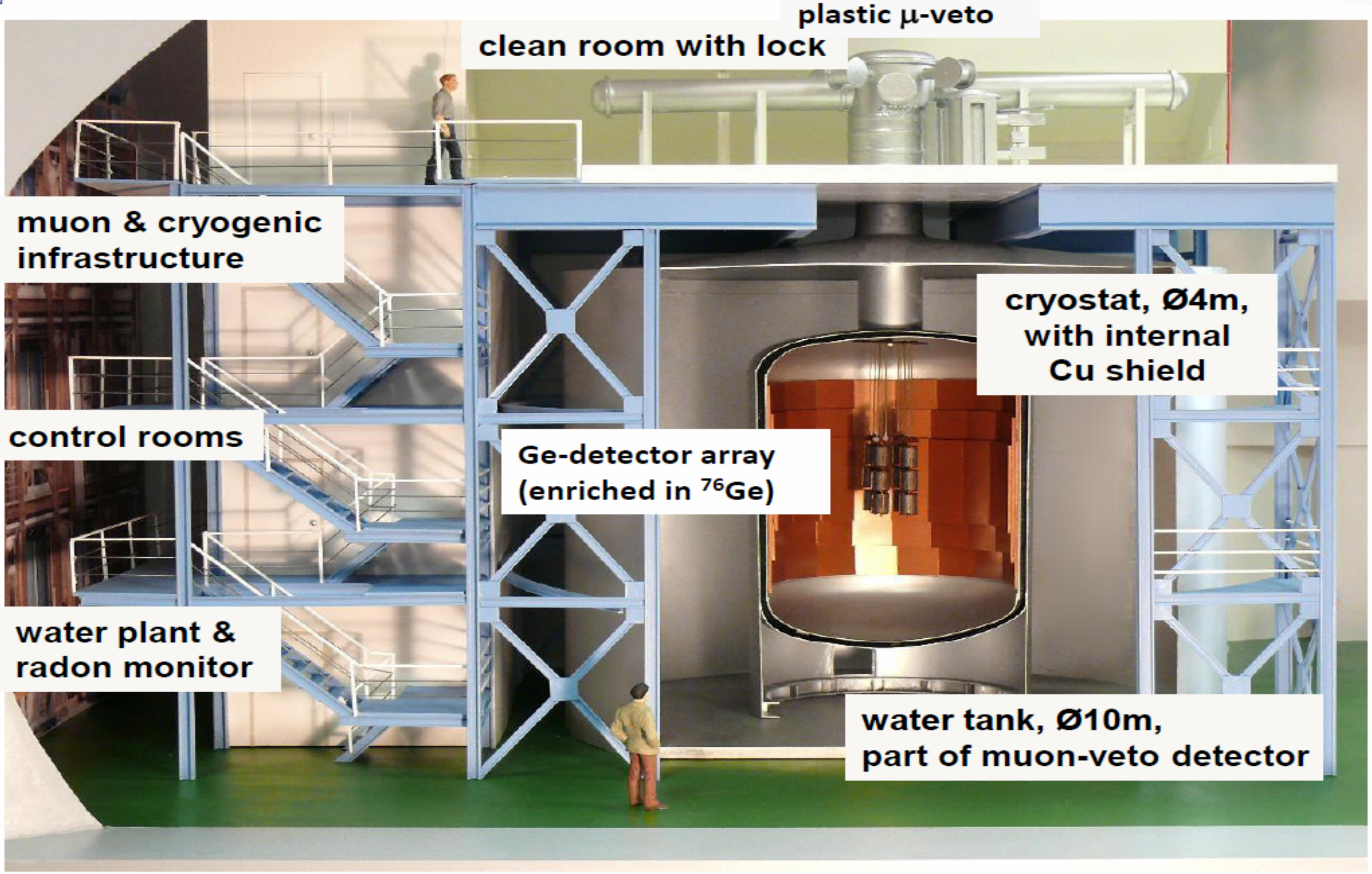
70 m^3 LAr

650 m^3 ultra pure water

^{76}Ge detectors were manufactured in Russia



Suppression of μ-flux > 10^6


plastic μ-veto
clean room with lock
muon & cryogenic infrastructure
cryostat, Ø4m, with internal Cu shield
control rooms
Ge-detector array (enriched in ⁷⁶Ge)
water plant & radon monitor
water tank, Ø10m, part of muon-veto detector

Phase I of GERDA experiment has been successfully completed
One of the tasks for Phase II is:

Liquid Argon instrumentation:

LAr – from passive to active shielding

Detection of LAr scintillation

WLS + Cryogenic PMT:

- several designs under consideration
- MC in progress

WLS +Cryogenic SiPMs:

- under preparation for testing in LAr,
- MC shows ~100 noise from ^{228}Th suppression

Cryogenic SIPMs for direct LAr light redout:

- VUV sensitive (128 nm)
- Large area (≥1cm^2)
- MC study just started

UV SiPMs from MEPhI/MPI can be the possible candidates

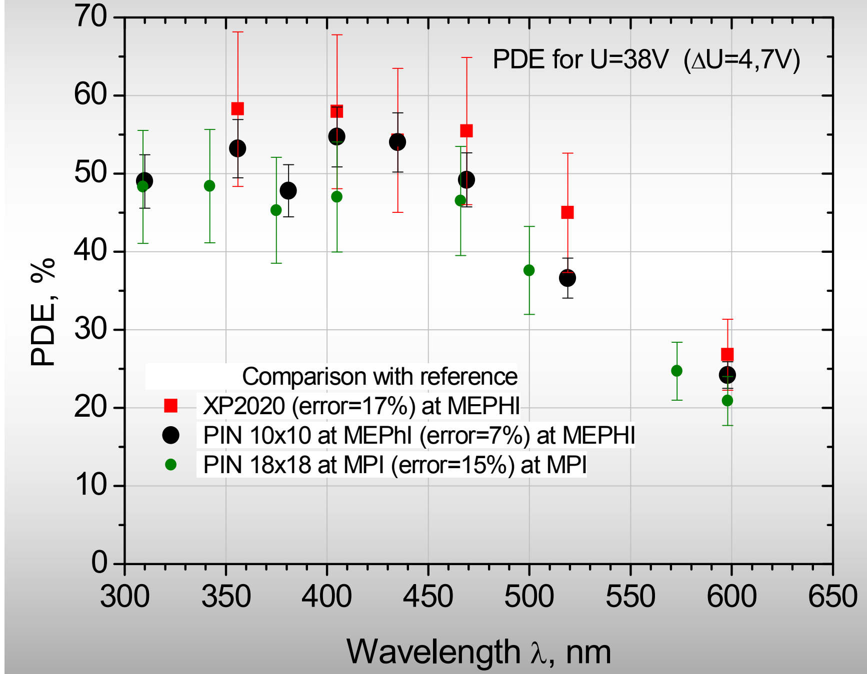
UV SiPMs from MEPhI/MPI/Excelitas collaboration

(produced at Zelenograd, Russia)

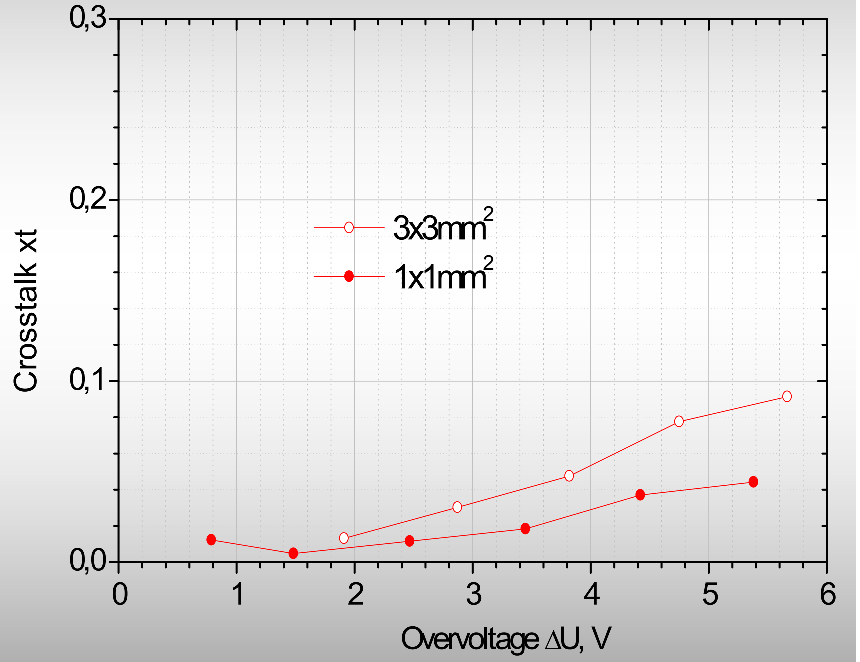
100 micron pixel size (100B type), geometrical efficiency 80%

Spectral sensitivity

Measurements at MEPHI and MPI



Crosstalk



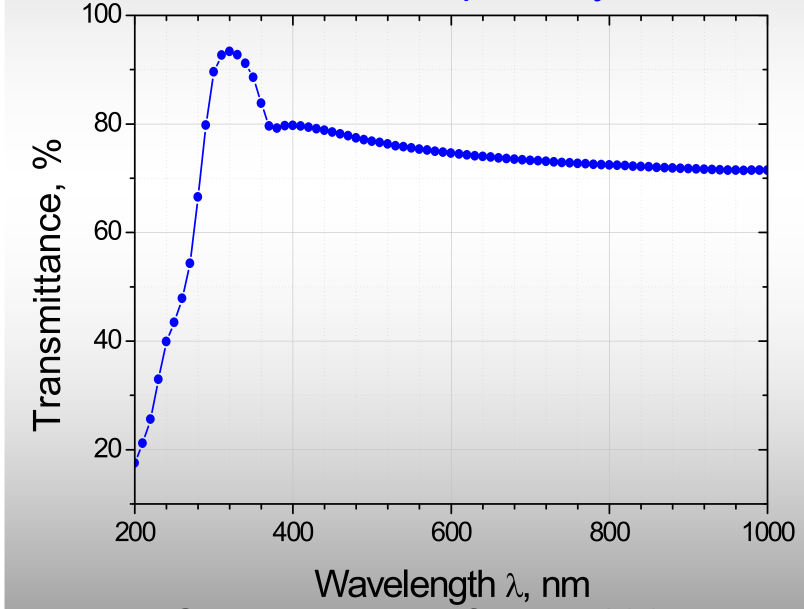
- Dark rate at room temperature is 400-800 kHz/mm^2
- Gain temperature stability is 0.5%/C

GERDA requirements. Task 1: VUV sensitivity

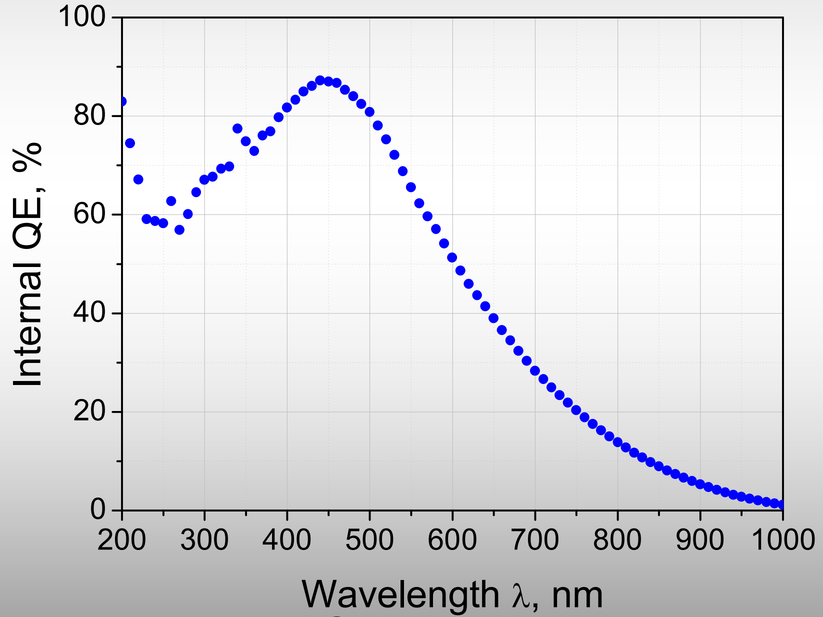
- AR coating
- High internal quantum efficiency (abs. length for 128nm ≈5 nm)

actual MEPhI/MPI/Excelitas SiPMs

ARC transparency



Internal QE



ARC should be shifted to 128nm

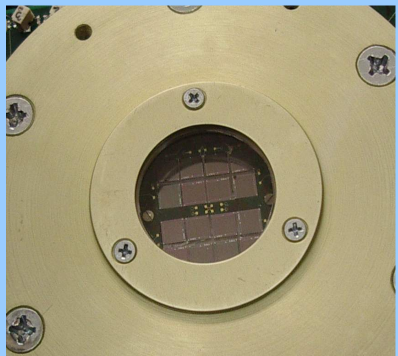
internal QE aready is quite high

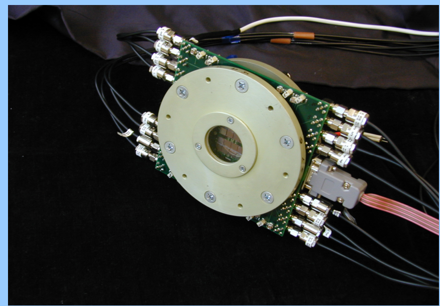
Task 1 seems to be possible to solve

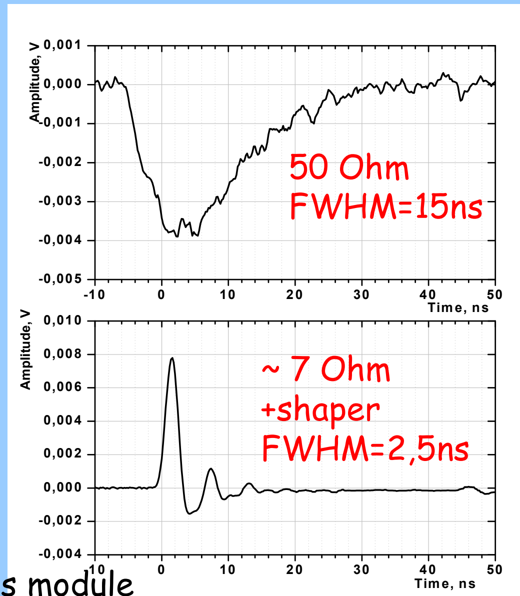
GERDA requirements. Task 2: Large area SiPMs

- yield
- electronics

MEPhI/MPI already several years ago produced and tested SiPMs with area 5x5mm^2 and FE electronics for astroparticle application







23-28 october 2007 VI Int.Workshop LIGHT2007 Cooled SiPM matrixes module

Task 2 seems to be possible to solve too, however

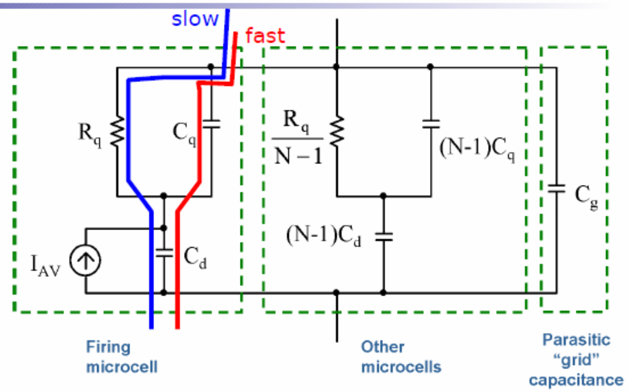
SiPM with area 10x10mm2 and more has significant C_{tot}

- Electrical signal from SiPM
- Frond-end electronics

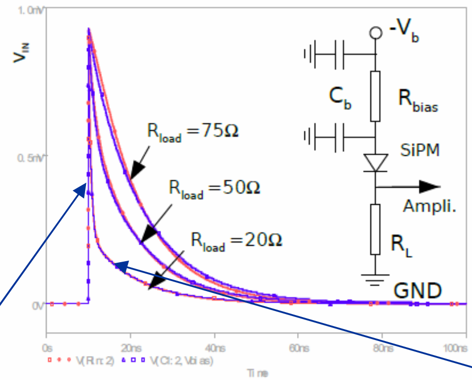
→ Requires SiPM electrical model and precise SPICE parameters extraction

Electrical model of a SiPM

R_q: quenching resistor (hundreds of kΩ)
C_d: junction capacitance (few tens of fF)
C_q: parasitic capacitance in parallel to R_q (few tens of fF, $C_q < C_d$)
I_{AV}: SiPM ~ ideal current source
current source modeling the total charge delivered by a cell during the avalanche $Q=\Delta V(C_d+C_q)$
C_g: parasitic capacitance due to the routing of Vbias to the cells (metal grid, few tens of pF)



N- total number of cells in SiPM



G.Collazuol - IPRD08 4/10/2008

1) the peak of V_{IN} is independent of R_s RL

A constant fraction Q_{IN} of the charge Q delivered during the avalanche is instantly collected on $C_{tot}=C_g+C_{eq}$.

2) The circuit has two time constants:

- $\tau_{IN} = R_L\ C_{tot}$ (fast) where Ctot=N*[CqCd/(Cq+Cd)]+Cg
- $\tau_r = R_q\,(C_d+C_q)$ (slow) for n pixels of Rq>>N*R_L

R_L

Decreasing R_s, the time constant τ_{IN} decreases, the current on R_s increases and the collection of Q is faster

F. Corsi, C. Mazzocca et al.

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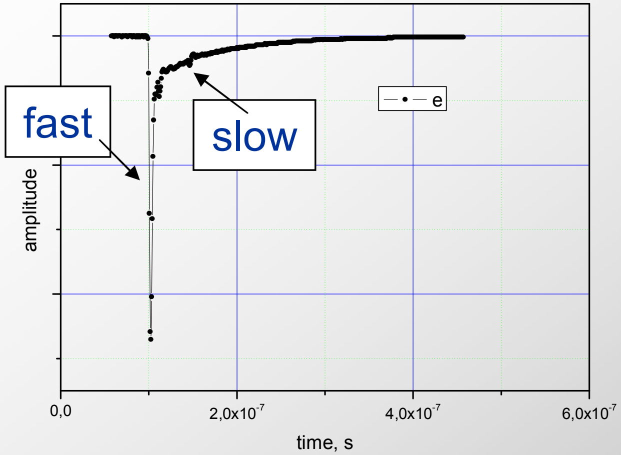
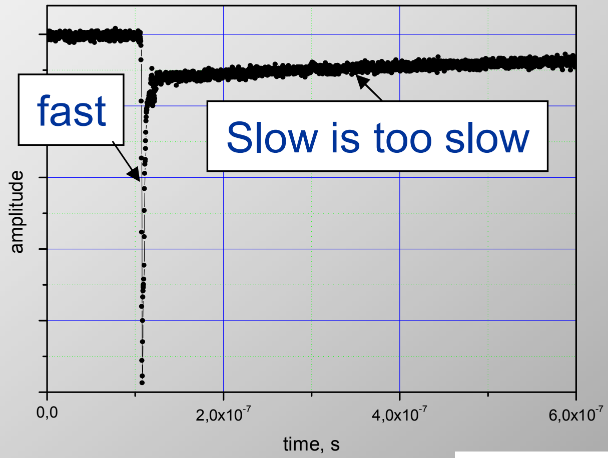
Fast component (geiger discharge)

Slow component (pixel recovery)

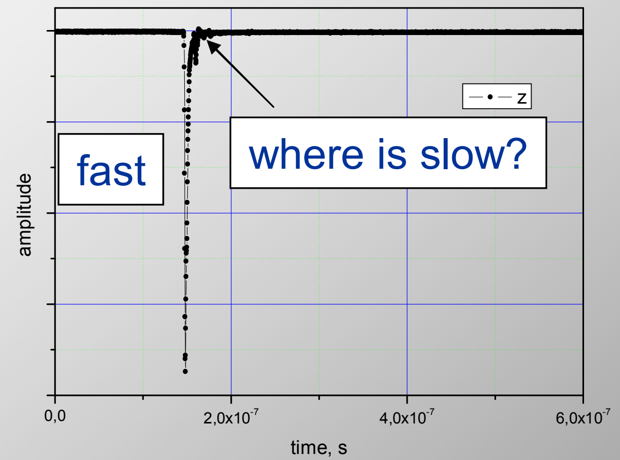
Important image!
To analyze SiPM waveform one needs to be sure that there are no external network influence

Pulses from SiPMs with different topology and quench resistor value (50 Ohm load)





For these pulses
Rq>>N*RL



Useful relations:

$$Q_{total} = Q_{fast} + Q_{slow}$$
$$Q_{total} = \Delta U * (C_q + C_d)$$
$$Q_{fast} = \Delta U * C_q$$
$$Q_{slow} = \Delta U * C_d$$
$$\tau r = Rq*(Cq + Cd)$$

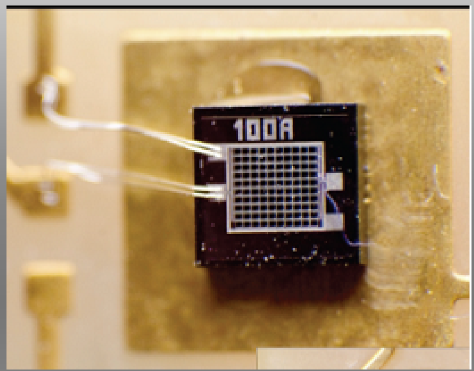
BUT:

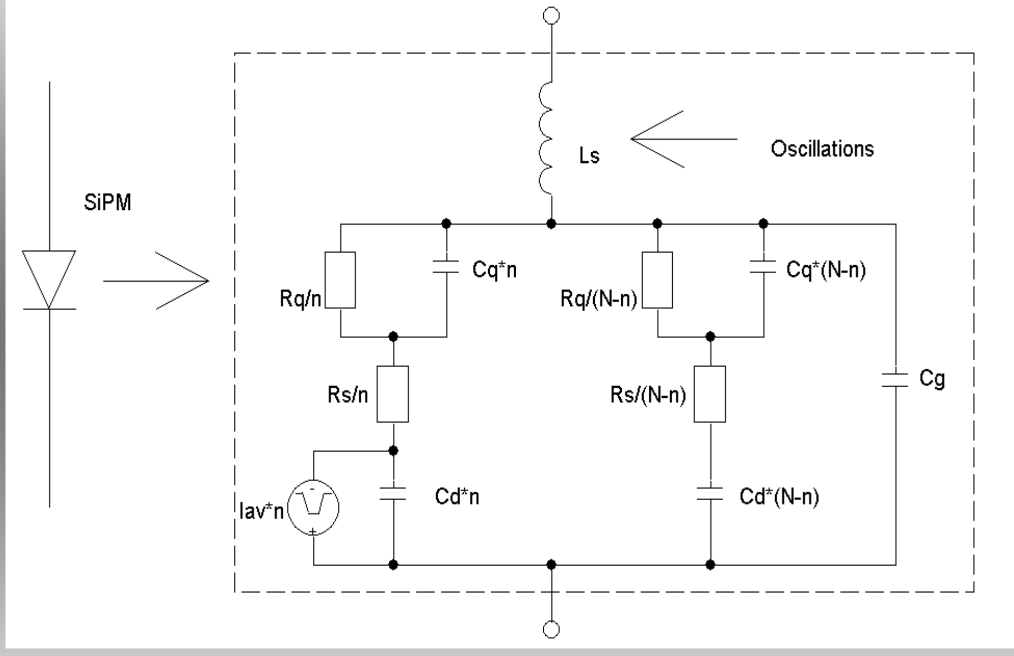
- Some times we can't see fast or slow part of pulse
- Or slow part maybe too slow for precise integration
- Or even fast part is more longer then slow part

One needs to be careful with waveform analysis

SiPM electrical model

UV SiPMs from MEPhI/MPI/Excelitas collaboration (produced at Zelenograd, Russia)
100 micron pixel size (100A type), 1x1 mm^2





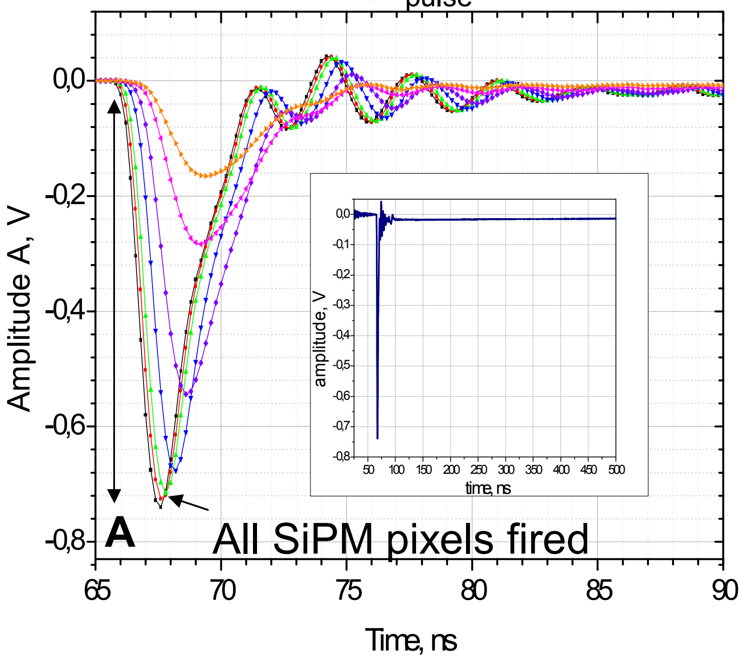
Needs to be noted –
Cq is very difficult for estimation
even for SiPM developers

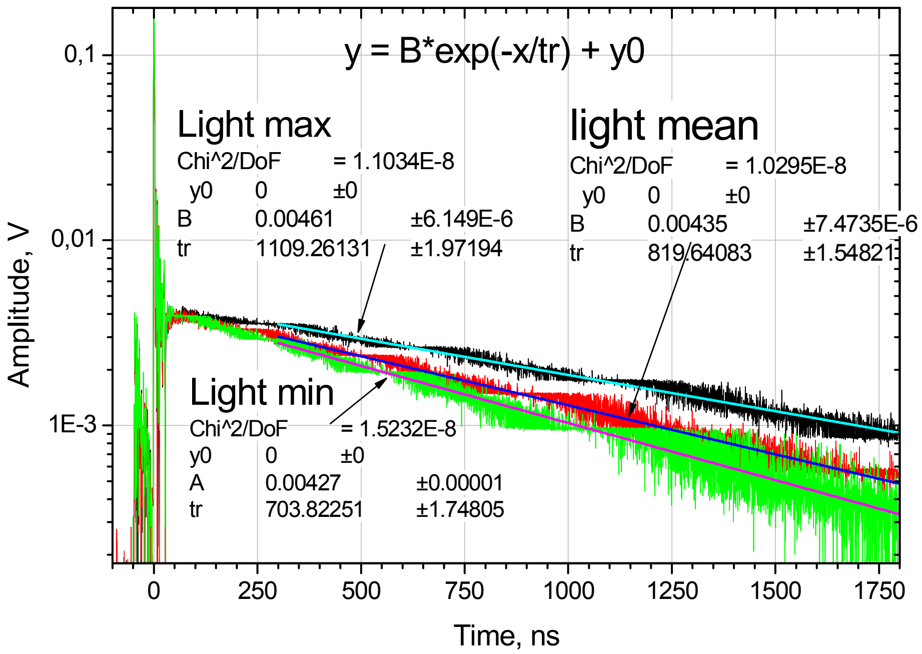
Our goals:
- to predict SiPM pulses from 10x10mm2 and larger device
- to develop appropriate FE electronics → SPICE SiPM parameters

SiPM waveform analysis

UV SiPMs from MEPhI/MPI/Excelitas collaboration (produced at Zelenograd, Russia)
100 micron pixel size (100A type), 1x1 mm^2

LED 405 nm, t_{pulse}=3ns





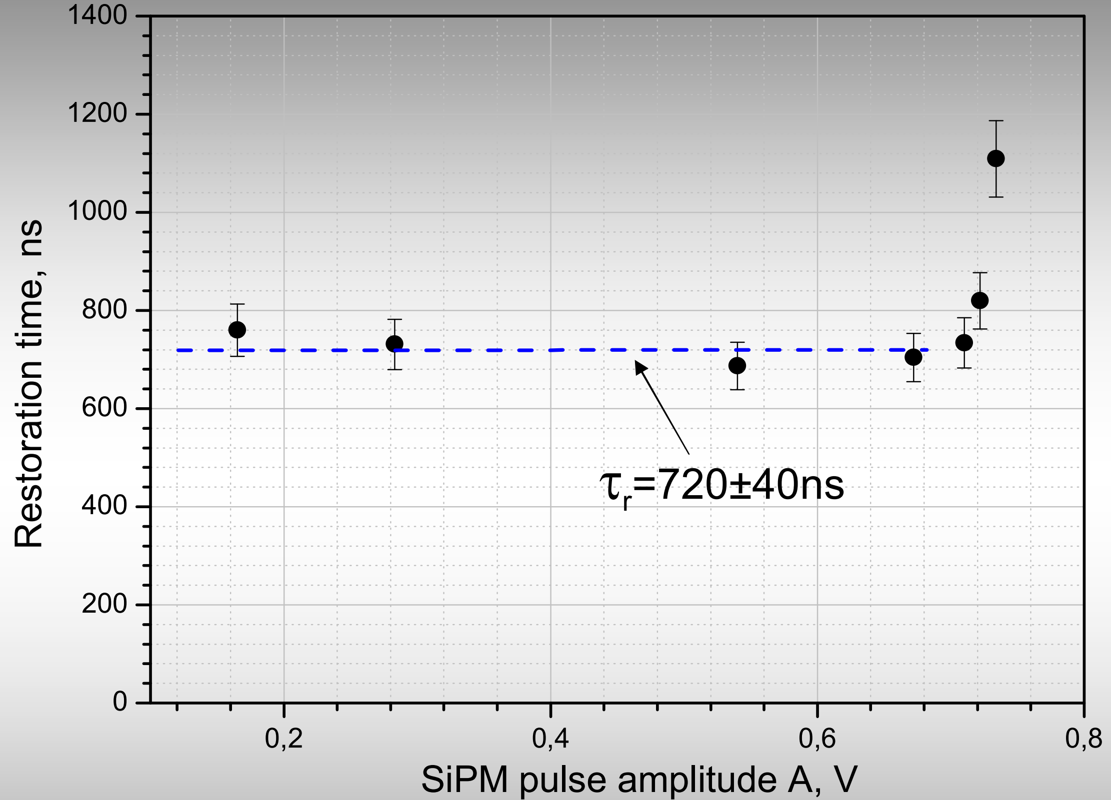
Light of different intensity
From ¼ of total number of pixels fired
To total number (and even more)

$$R_q + R_s \geq (10...20)NR_L,$$

(785kOhm+2kOhm>20*100*50 Ohm)

$\tau_r = R_q*(C_q+C_d)$ slow component

SiPM Restoration time for different light intensities



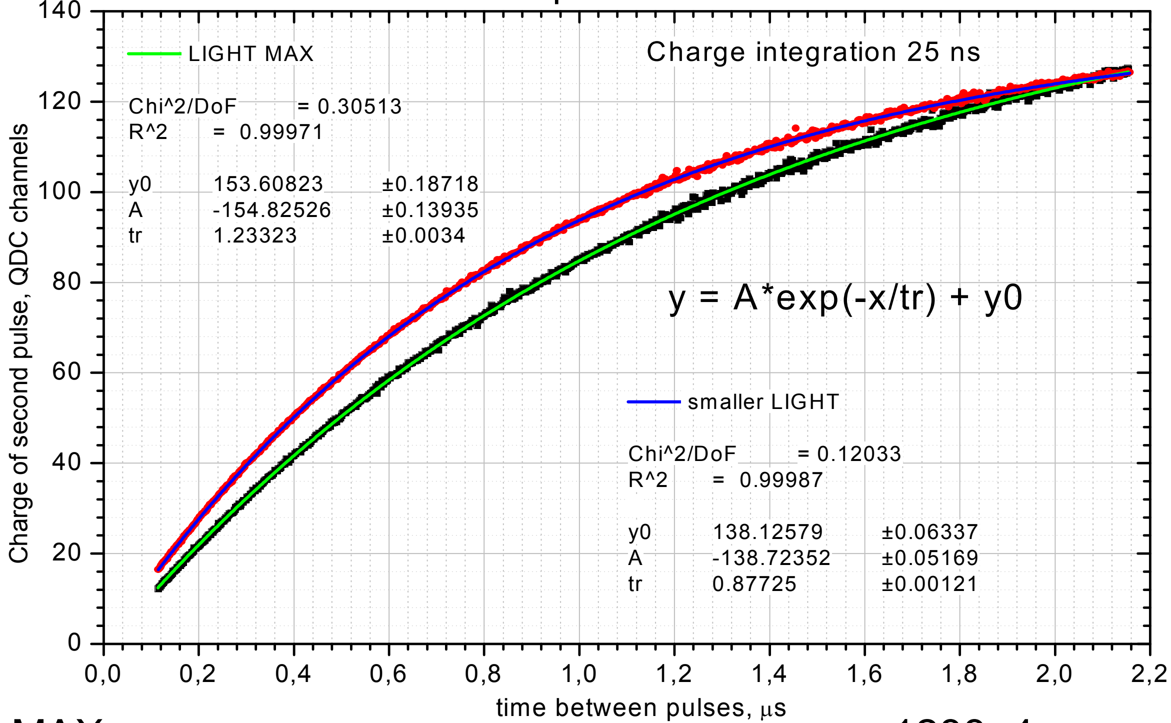
Restoration time depends from light intensity

Possible explanation: for very high light intensities Cd is not only barrier capacity of pn-junction but additionally some diffusion capacity (Cd=Cpn+Ceh)

SiPM restoration time. Double light pulse method.

Comparison of second pulse SiPM amplitude with first one in dependence from time interval inbetween the pulses

Such method doesn't demand strict requirements to SiPM waveform correctness



Light MAX τr=1233±4ns

Smaller light (but still with SiPM saturation) τr=877±2ns

However here we observe the similar behavior for restoration time vs light intensity

Precise SiPM’s SPICE parameters extraction.

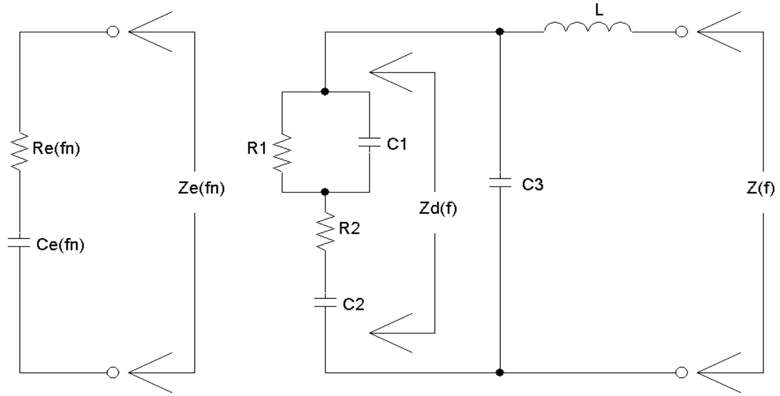
- Waveform analysis – too difficult in some cases (large number of cells, very low (very high) quenching resistivity, large Cq, large Cd, high noise…)
- Double pulses method in case of fast SiPM’s recovery time requires very short light pulses
- Waveform analysis and double pulses method both are sensitive to light intensity

We are propose to use for SPICE parameters extraction method based on network analyzer data

Precise SiPM's SPICE parameters extraction

RLC 4287A
(network analyzer)

SiPM in LCR-meter



$\omega = 2\pi f$

$$Z_e(f_n) = R_e(f_n) + jX_e(f_n) = R_e(f_n) + \frac{1}{j2\pi f_n C_e(f_n)}$$

Complex impedance

Fitting procedure: minimization of

E-experimental points, T-fitting function values

$$Q(\omega_1,...\omega_N, R_1, R_2, C_1, C_2, C_3, L) = \sum_{n=1}^{N} \left\{ \frac{[R_T(\omega_n^2) - R_E(\omega_n^2)]^2 + [X_T(\omega_n) - X_E(\omega_n)]^2}{R_E^2(\omega_n^2) + X_E^2(\omega_n)} \right\}$$

$$R_T(\omega^2) = R_d \frac{C_d^2}{(C_d + C_3)^2 + \omega^2 (C_3 R_d C_d)^2}$$

, where

$$R_d(\omega^2) = \frac{R_1}{1 + \omega^2 (R_1 C_1)^2} + R_2$$

$$C_T(\omega^2) = \frac{C'}{1 - \omega^2 L C'}$$

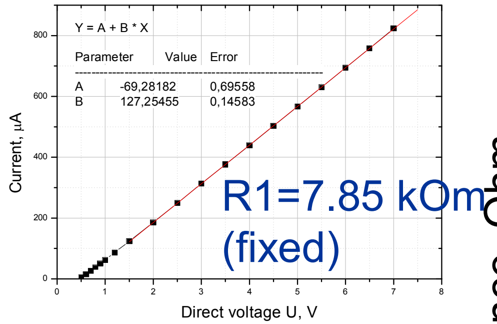
$$C' = \frac{(C_d + C_3)^2 + \omega^2 (C_3 R_d C_d)^2}{C_d + C_3 + \omega^2 C_3 (R_d C_d)^2}$$

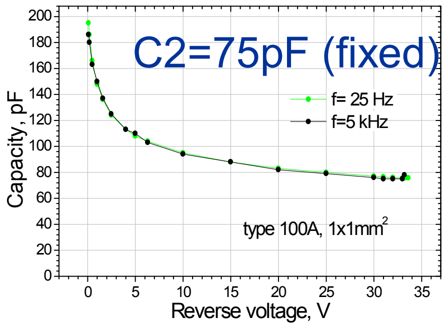
$$C_d(\omega^2) = C_2 \frac{1 + \omega^2 (R_1 C_1)^2}{1 + \omega^2 (R_1)^2 C_1 (C_1 + C_2)}$$

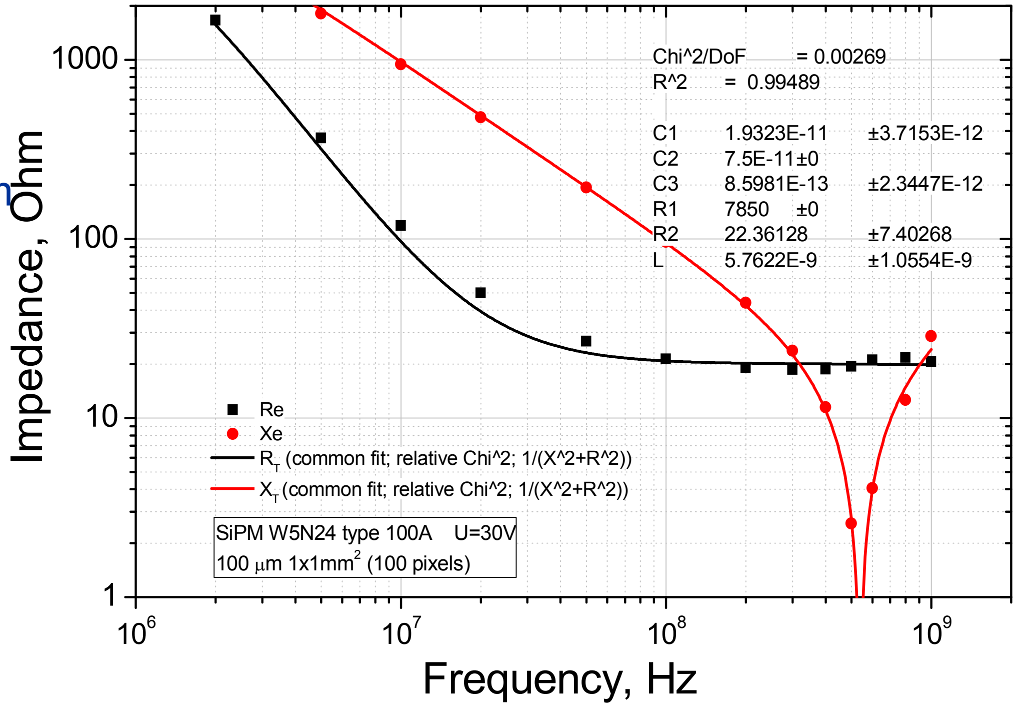
Precise SiPM's SPICE parameters extraction.

SiPM 1x1mm^2, 100μ pixel type 100A   Network analyzer

In order to increase fitting accuracy R1 and C2 have been measured additionally. These values have been fixed during the fitting procedure







C_q=C1/100=190±40fF, R_q=R1*100=785 kOhm, C_g=C3≈0 ⇨ **τ_r=740±40ns**

C_d=C2/100=750±10fF R_s=R2*100=2.2kOhm Ls=L=6±1nH

In agreement with waveform analysis

Summary:

- MEPhI/MPI/Excelitas UV SiPMs look like promising candidates for LAr instrumentation usage in GERDA experiment

It requires developments of:

- VUV SiPM
- large area> 10mm^2 SiPMs
- precise experimental methods for extraction of SiPM SPICE-parameters