Analytical description of signals from HGND scintillator cells with SiPM readout and results of the time resolution measurements

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on behalf of HGND team

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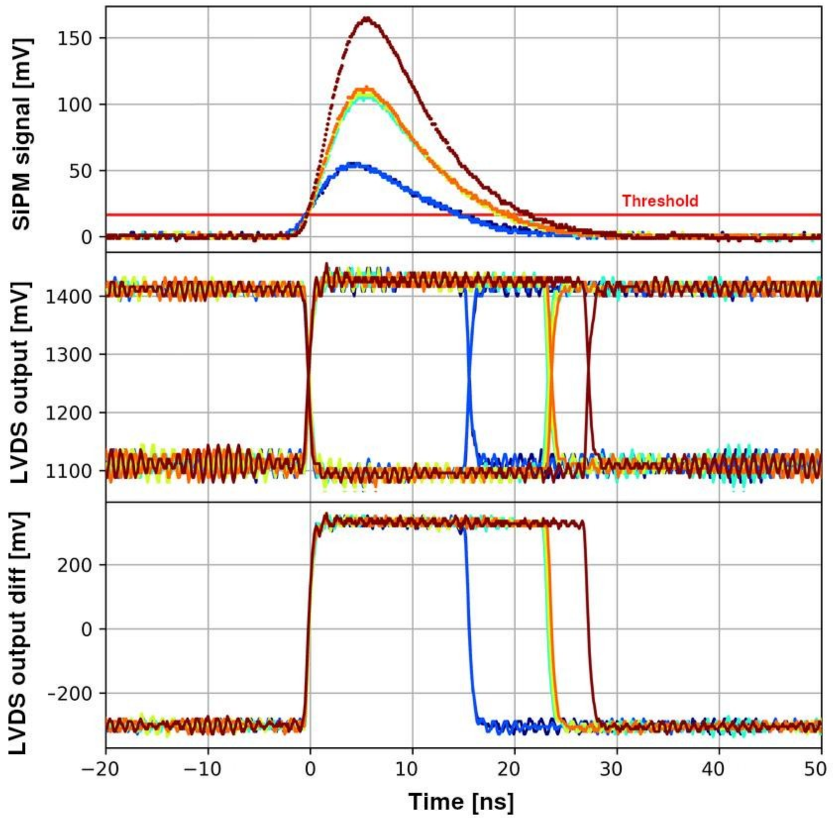
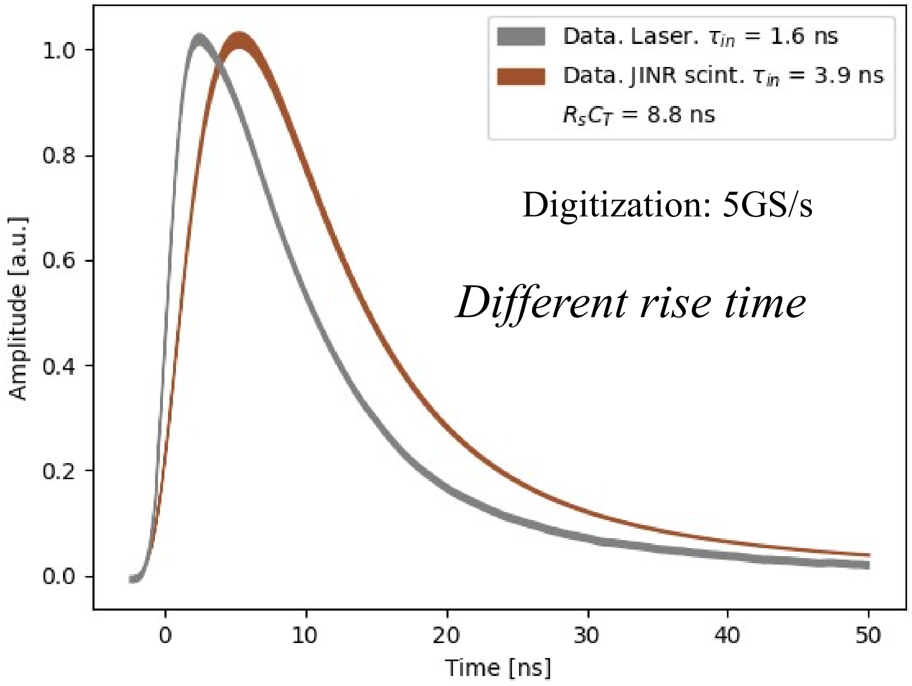
Time & Amplitude determination in HGND



Readout scheme

1. Plastic scintillator light flash
2. SiPM EQR15 11-6060D-S
3. High-speed comparator with differential LVDS output
4. FPGA-based TDC (100 ps bin width)

= Response time + ToT



Digitization: 5GS/s

Different rise time

SiPM: NDL EQR15 11-6060D-S

- Active area 6×6 mm^2
- Pixel size15×15 μm^2
- Total pixels: 160 000
- PDE: 45%
- Gain: $4*10^5$

Tasks

- Amplitude will be measured indirectly through ToT. It is necessary to convert ToT into amplitude
- It is necessary to correct for the time-amplitude dependence (slewing correction)
- Requires the ability to calibrate readout channels using an LED and recalculate calibration parameters to apply to scintillator signals
- *Physical description of signals is required*

Analytical description of light signals captured by SiPM: main behavior

$$N_{ph}(t) = N_{ph}^0 e^{-t/\tau_{in}}$$

N_{ph}^0 – initial number of photons, τ_{in} – light decay constant.

Solution 1 – Proccess as convolution of photoelectron current $f(t)$ with SiPM impulse response function $g(t)$

$$f(t) = I_{p.e.} = \eta e \frac{dN_{ph}}{dt} \qquad g(t) = \frac{1}{R_s C_T} e^{-t/R_s C_T}$$

η – PDE, e – electron charge, R_s – load resistance + low intrinsic SiPM resistance, C_T – total SiPM capacitance.

$$V(t) = R_s (f * g)(t) = -\frac{\eta e N_{ph}^0}{C_T \tau_{in}} \int_0^t e^{-\frac{x}{\tau_{in}}} e^{-\frac{t-x}{R_s C_T}} dx = \frac{\eta e N_{ph}^0 R_s}{R_s C_T - \tau_{in}} \left(e^{-t/R_s C_T} - e^{-t/\tau_{in}} \right). \quad (1)$$

Solution 2 – Proccess as differential equation

$$\frac{dq}{dt} = I_{p.e.} + I_{recharge} \qquad V_{bias} - R_s I_{recharge} = \frac{q}{C_T} \qquad q(0) = C_T V_{bias}$$

$$V(t) = R_s I_{recharge} = \frac{\eta e N_{ph}^0 R_s}{R_s C_T - \tau_{in}} \left(e^{-t/R_s C_T} - e^{-t/\tau_{in}} \right). \quad (2)$$

Analytical description of light signals captured by SiPM: addressing derivative discontinuity

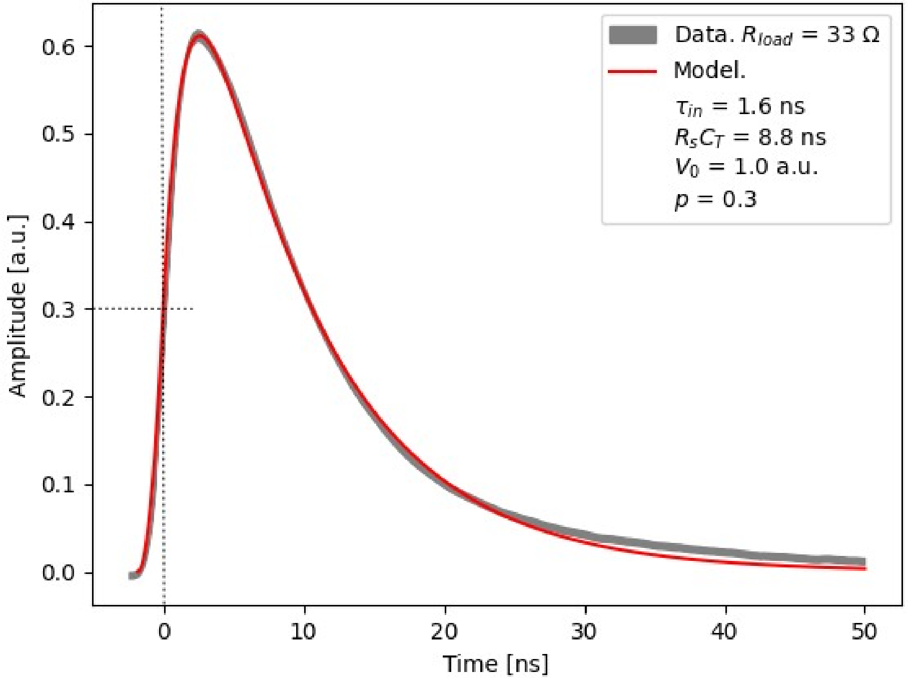
- Phase shift to the fast exponent by a value $\tau_{in} \ln(1-p)$

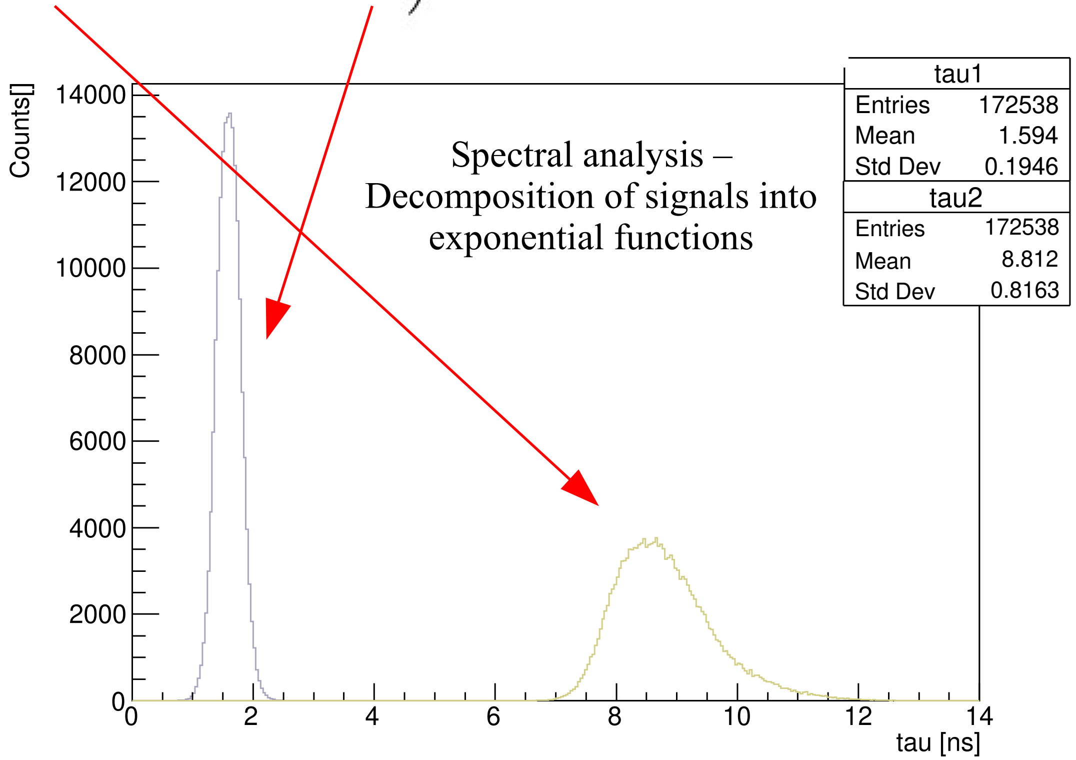
- Match conditions with parabolic solution at time 0

$$V_0 = \frac{\eta e N^0_{ph} R_s}{R_s C_T - \tau_{in}} \qquad T_p = \frac{2p\tau_{in} R_s C_T}{(1-p)R_s C_T - \tau_{in}}$$

- Final form of analytic description

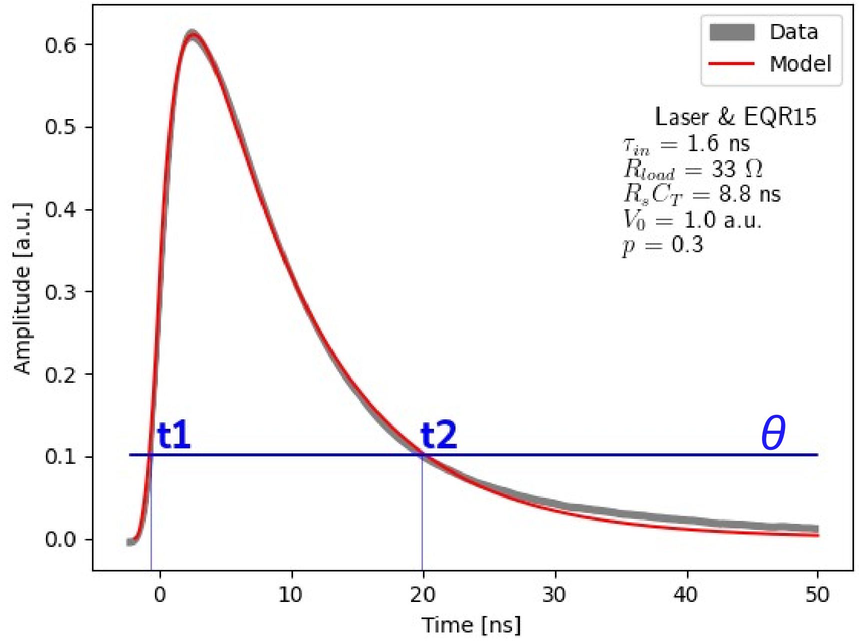
$$V(t) = \begin{cases} pV_0 \left(\frac{t}{T_p} + 1\right)^2 & \text{if } -T_p < t < 0 \\ V_0 \left(e^{-\frac{t}{R_s C_T}} - (1-p)e^{-\frac{t}{\tau_{in}}}\right) & \text{if } t \geq 0 \end{cases}$$

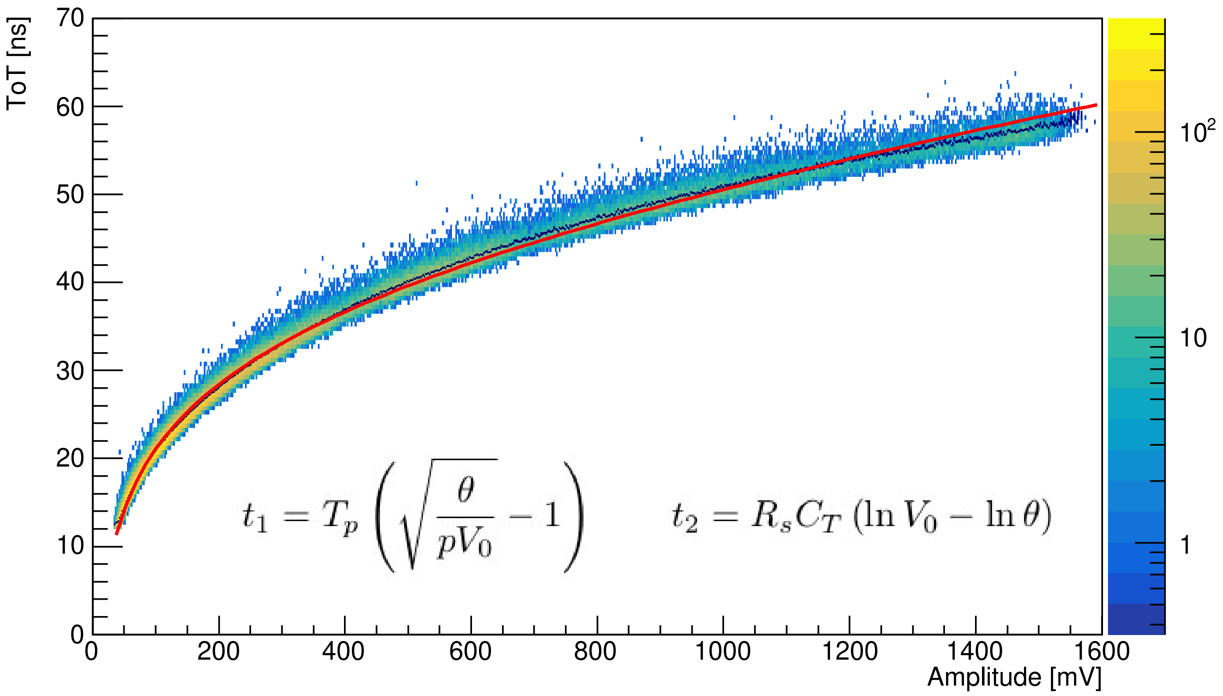


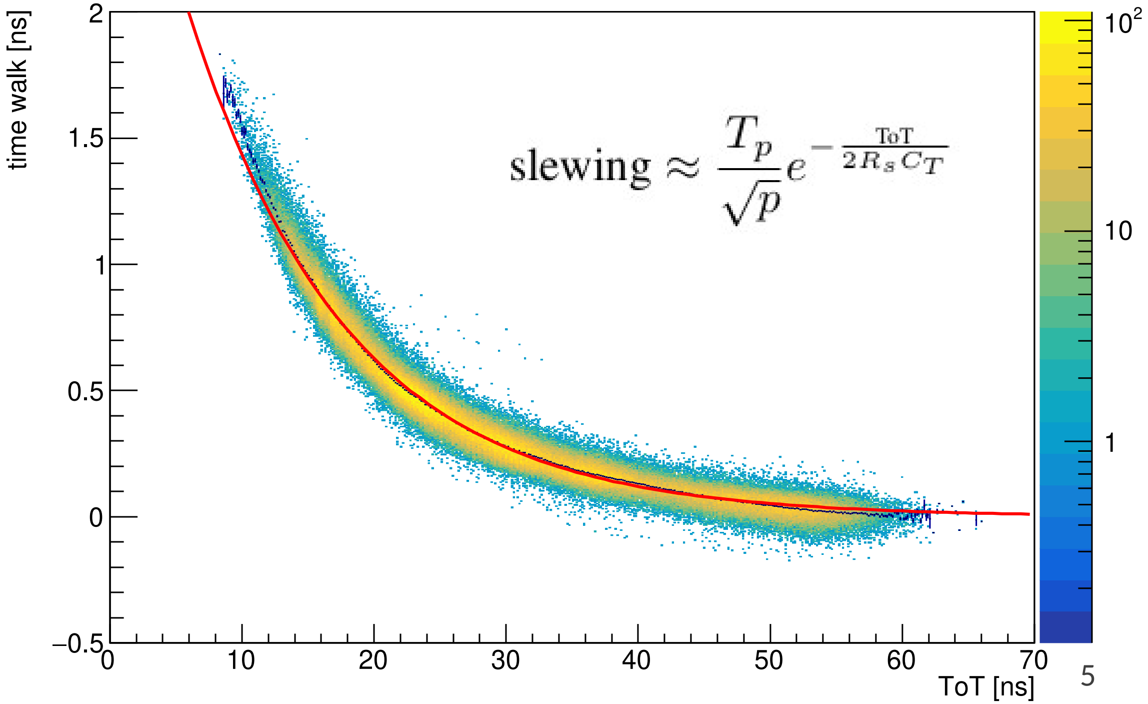


Spectral analysis – Decomposition of signals into exponential functions

Analytical description of light signals captured by SiPM: parametrisation of slewing and ToT

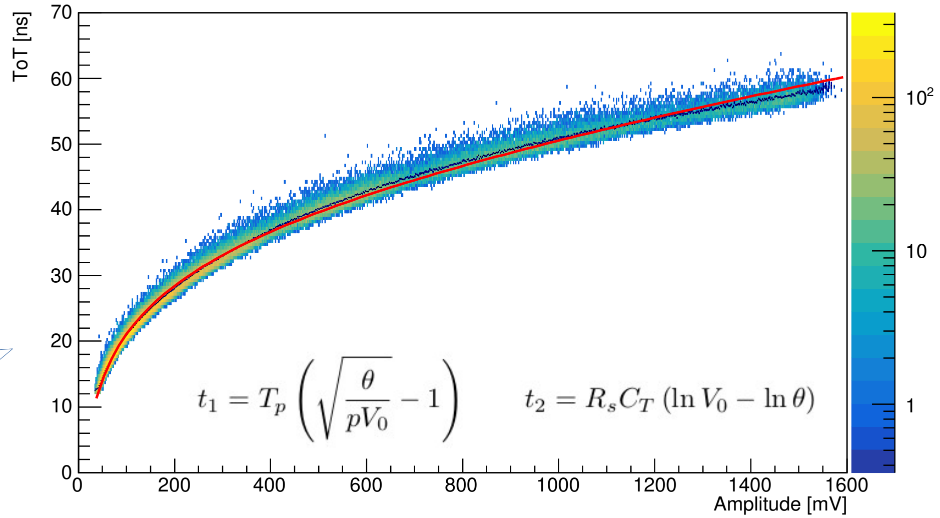


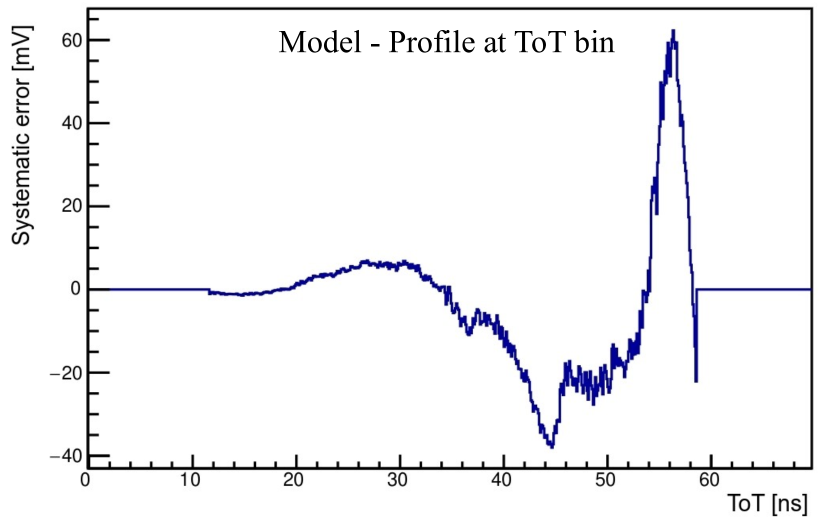


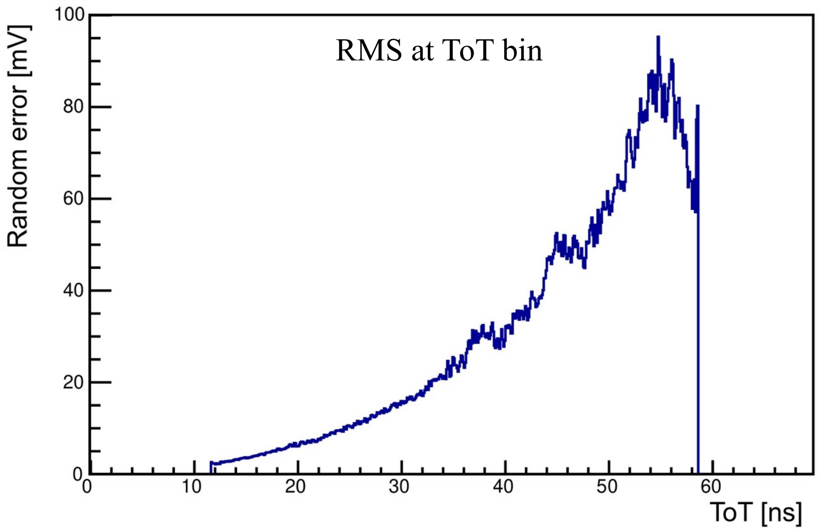


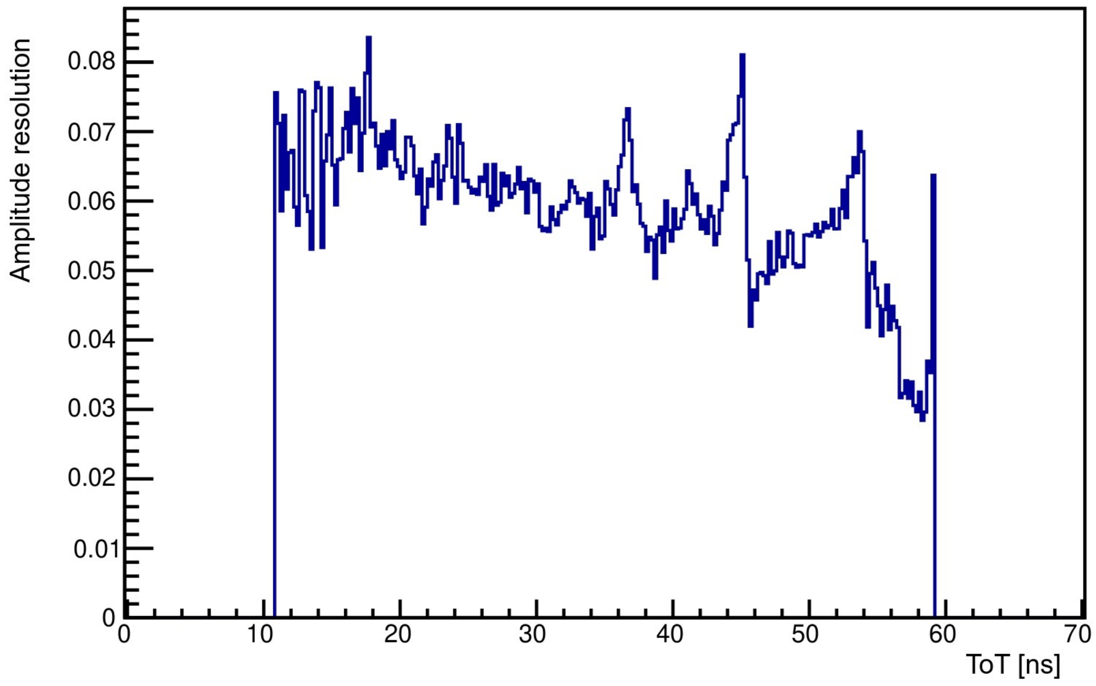
Comparison of Laser data with model

Analytical description of light signals captured by SiPM: estimation of amplitude resolution

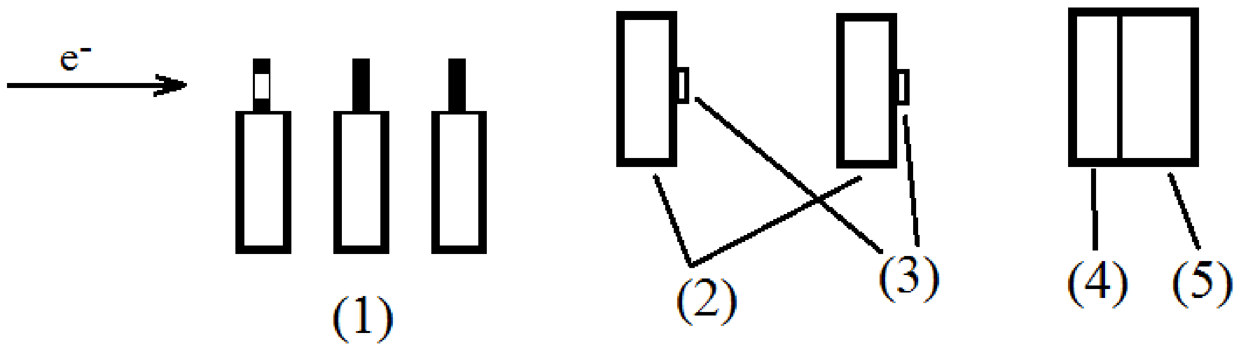








Analytical description of light signals captured by SiPM: Results of beam tests



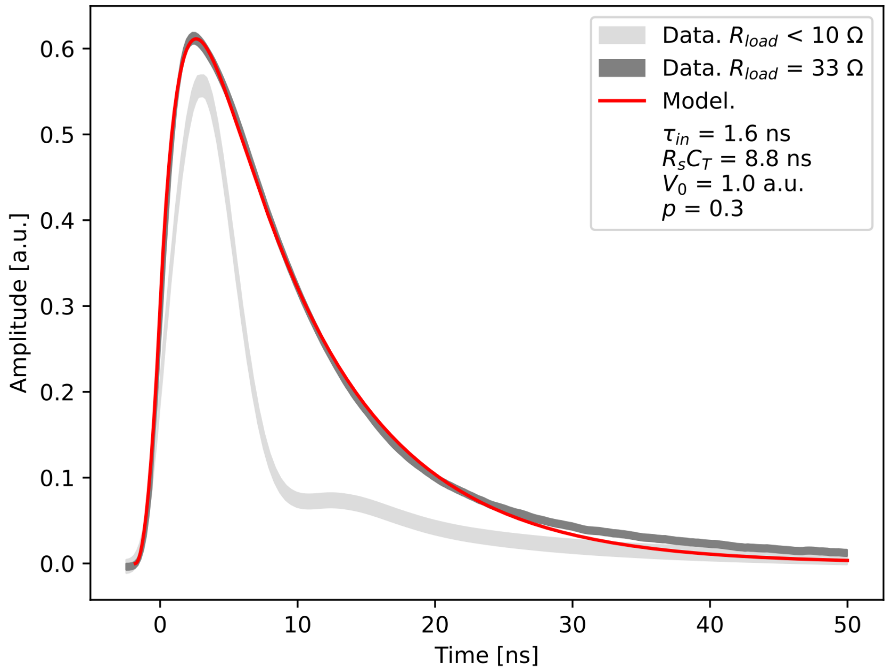
280 MeV electron beam of the
”Pakhra” synchrotron (LPI, Troitsk)

(1) Beam counters
(2) Scintillator samples
(3) SiPM
(4) Quartz Cherenkov radiator
(5) MCP PMT

Light source	Decay time [ns]	Time res. w/o corr. [ps]	Time resolution [ps]	Amplitude res. [%]
Laser	1.6 ± 0.2	88	45	8
EJ-230 sc.	2.8 ± 0.5	146	74	20
JINR sc.	3.9 ± 0.7	261	117	16

Conclusion and next steps

- The analytical description of ToT is based on physical principles - parameters of light sources and SiPM response.
- The electronics are tuned so as not to distort the smooth physical behavior. The load resistance is chosen to be large enough to cover the spurious response pulse of the silicon photomultiplier and small enough to avoid a long tail.
- Time resolution is significantly improved by applying slewing correction.
- It is possible to recalculate the calibration parameters taken from the LED for application to the light signals of a plastic scintillator (in the case of an undistorted SiPM impulse response).
- The method will be tested on larger amount of channels.

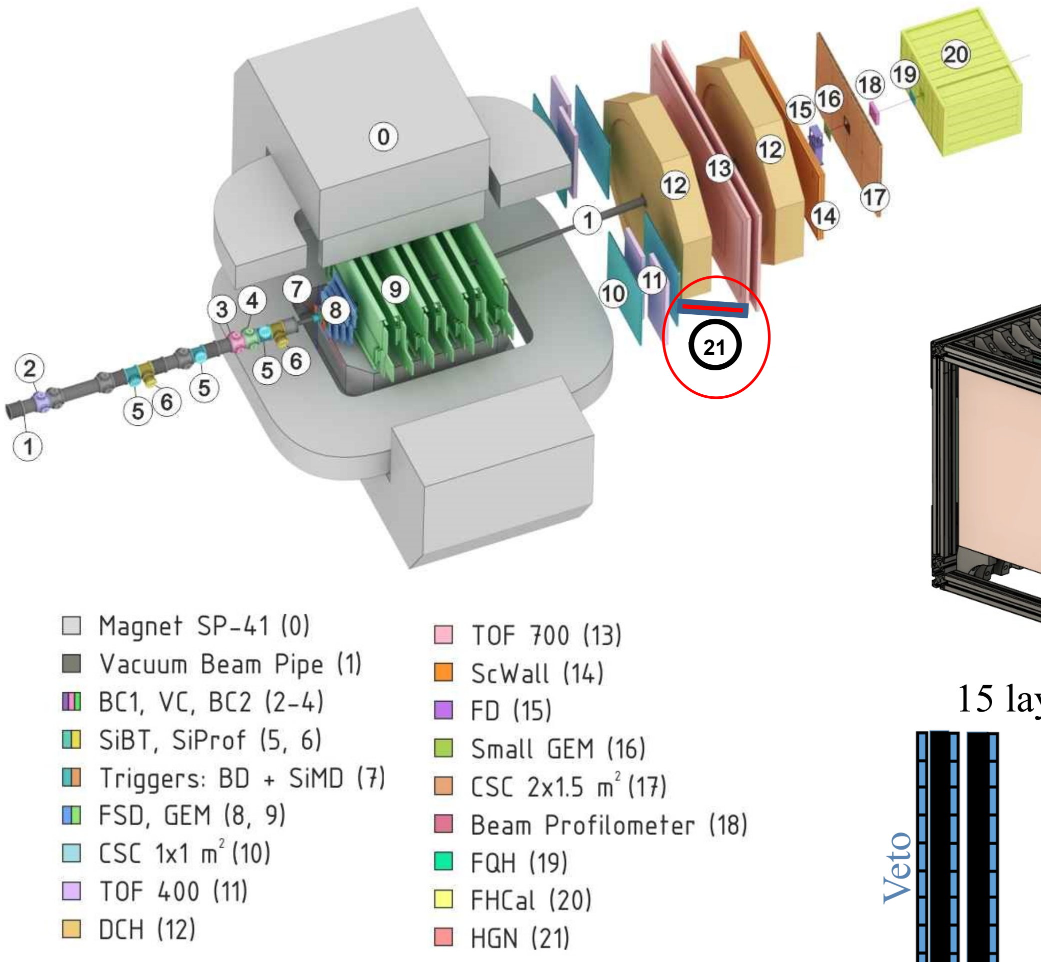


Thank you for your attention!

BACKUP

New High-Granular Neutron detector of the BM@N experiment

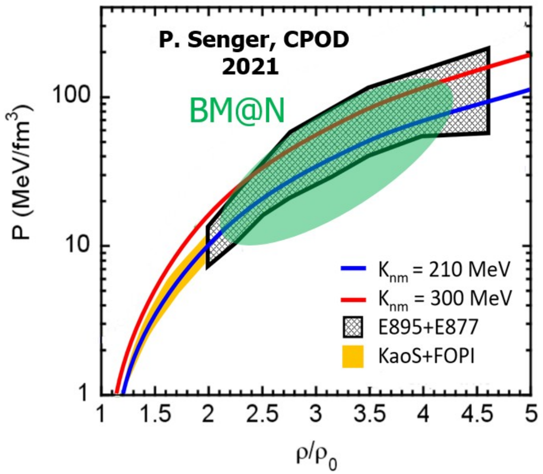
BM@N setup

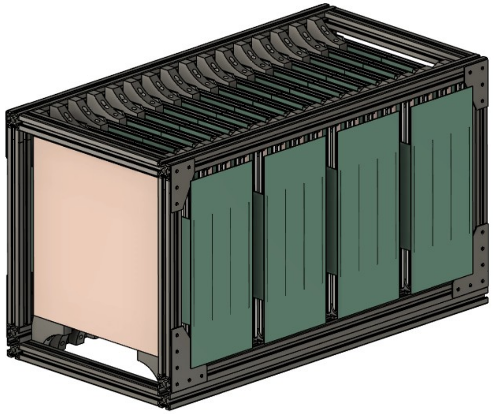


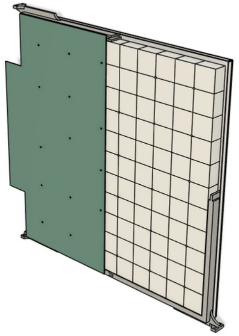
Goal: understanding the symmetry energy term of the EoS of strongly interacting matter in the uncovered energy region (2-4) ρ_0

How: by calculating anisotropic neutron flow and extracting $v^n_{1,2} / v^{ch}_{1,2}$

Measure: kinetic energy of neutrons by ToF

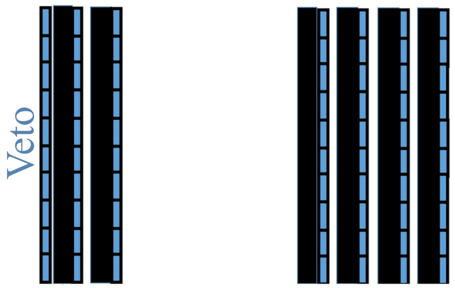


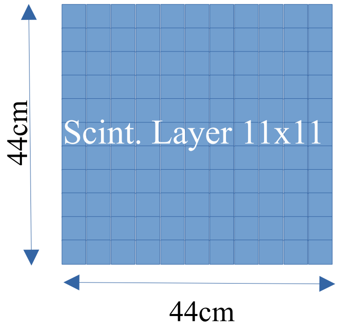


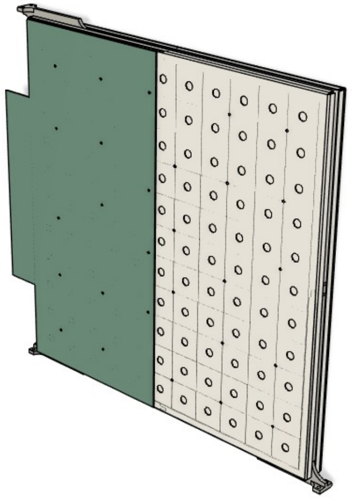


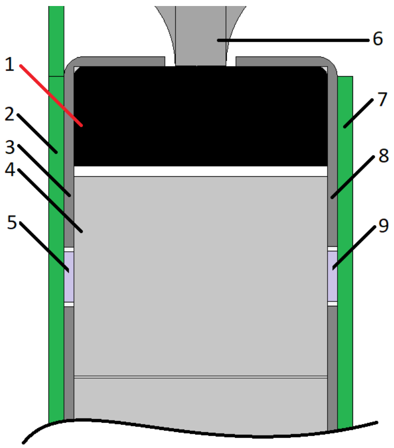
- Transverse size: 44 x 44 cm^2
- number of layers: 15 + Veto
- total length of the HGN: ~ 95 cm (~3 λ_{in})
- structure of layer:
  - 3 cm Cu (absorber) + 2.5cm Scint. + 0.5cm (SiPM+FEE)
  - size of scintillation detectors (cells): 4x4x2.5 cm^3
  - total number of cells: 1936
  - light readout: one SiPM 6x6 mm^2 per cell

15 layers (Cu/Scint)









1 – the frame of layer case

2 – two PCBs with 55 and 66 SiPMs

3 and 8 - aluminum plates for both sides of the frame case with cutouts for SiPMs and LEDs

4 – scintillator

5 – SiPM

6 – layer support bracket

7 – LED PCB

9 – LED

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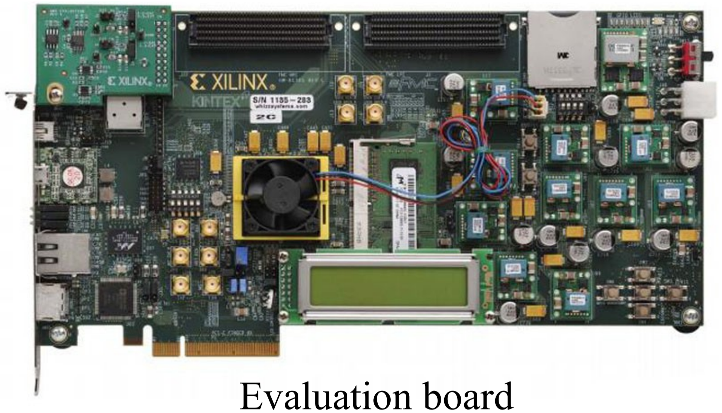
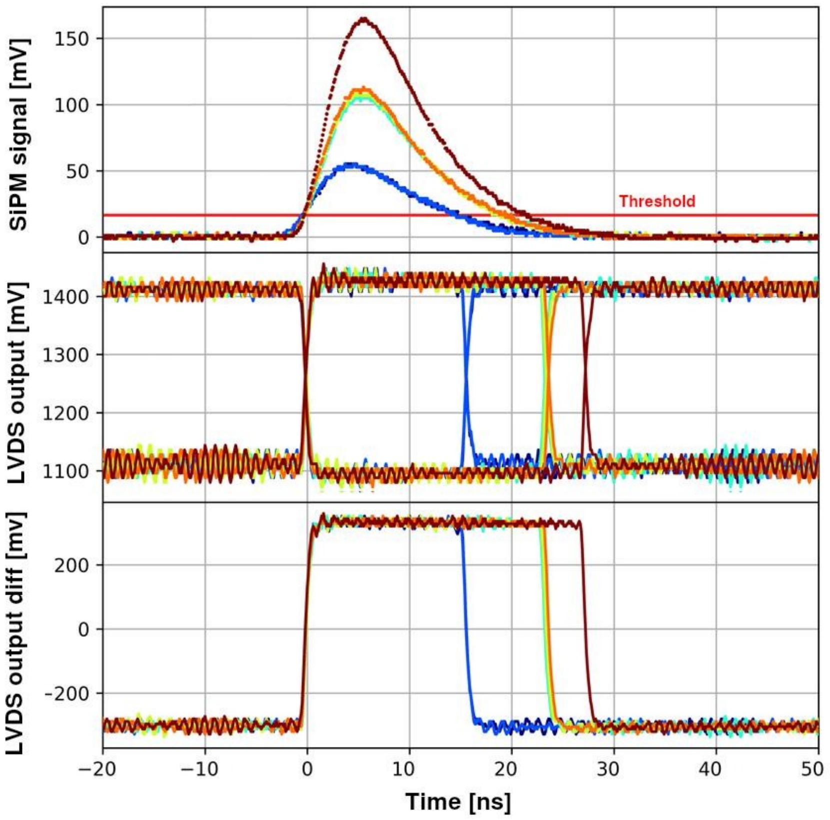


Evaluation board
Xilinx Kintex 7



Why do we need analytical description of signals?

- Need to correct for time-amplitude dependance
- Need the ability to calibrate readout channels with LED and recalculate calibration parameters to apply to scintillator signals