Time-over-threshold method based on the time properties of plastic scintillators equipped with silicon photomultipliers for the BM@N High-Granular Neutron detector

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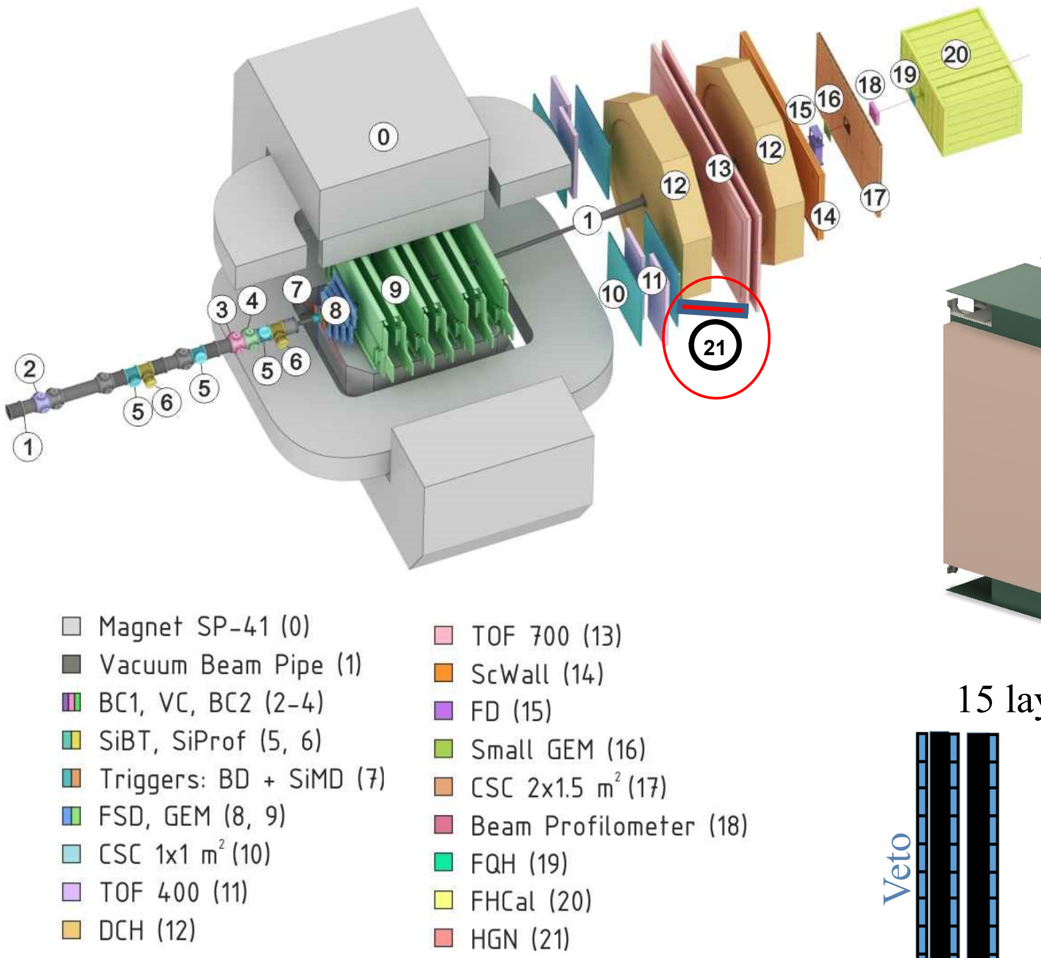
New High-Granular Neutron detector of the BM@N experiment

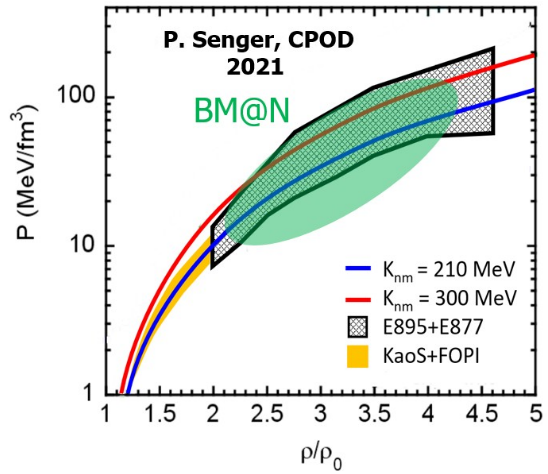
BM@N setup

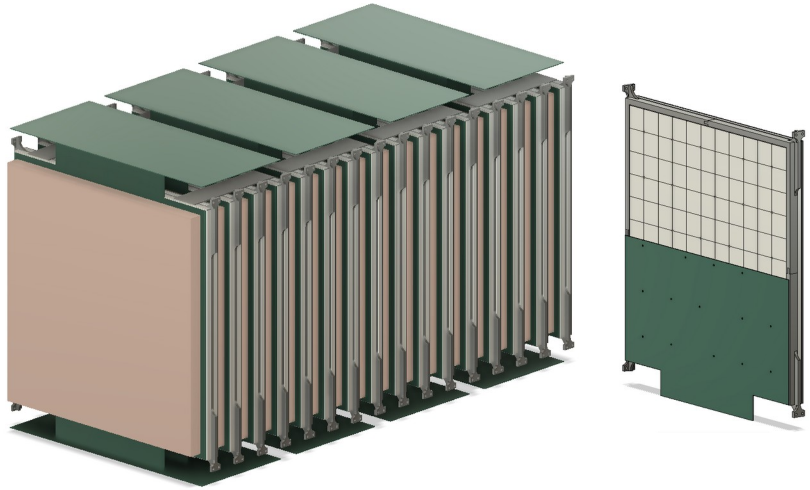


Goal: understanding the symmetry energy term of the EoS of strongly interacting matter in the uncovered energy region (2-4) ρ_0

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

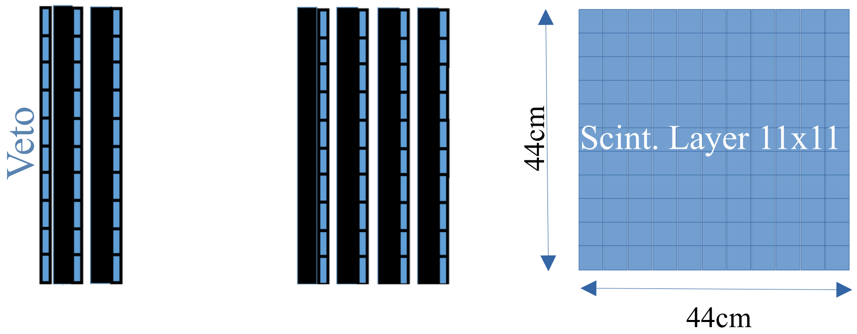
Measure: kinetic energy of neutrons by ToF

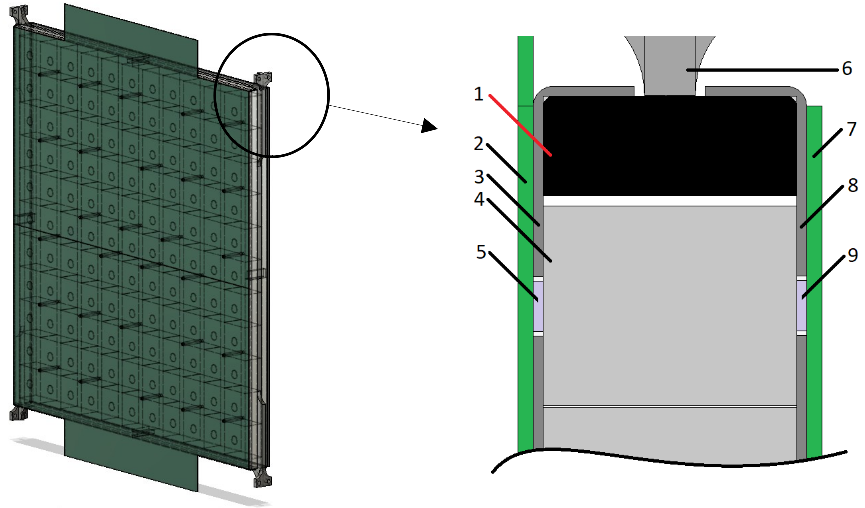




- Transverse size: 44 x 44 cm^2
- number of layers: 15 + Veto
- total length of the HGN: ~ 95 cm (~3 λ_{in})
- structure of layer:
  - 3 cm Cu (absorber) + 2.5cm Scint. + 0.5cm (SiPM+FEE)
  - size of scintillation detectors (cells): 4x4x2.5 cm^3
  - total number of cells: 1936
  - light readout: one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

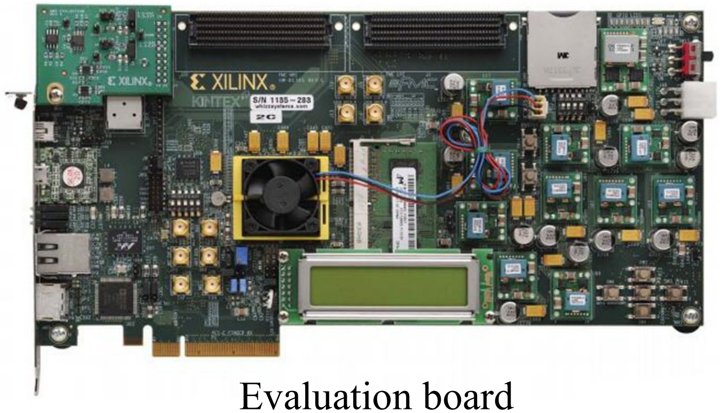
6 – layer support bracket

7 – LED PCB

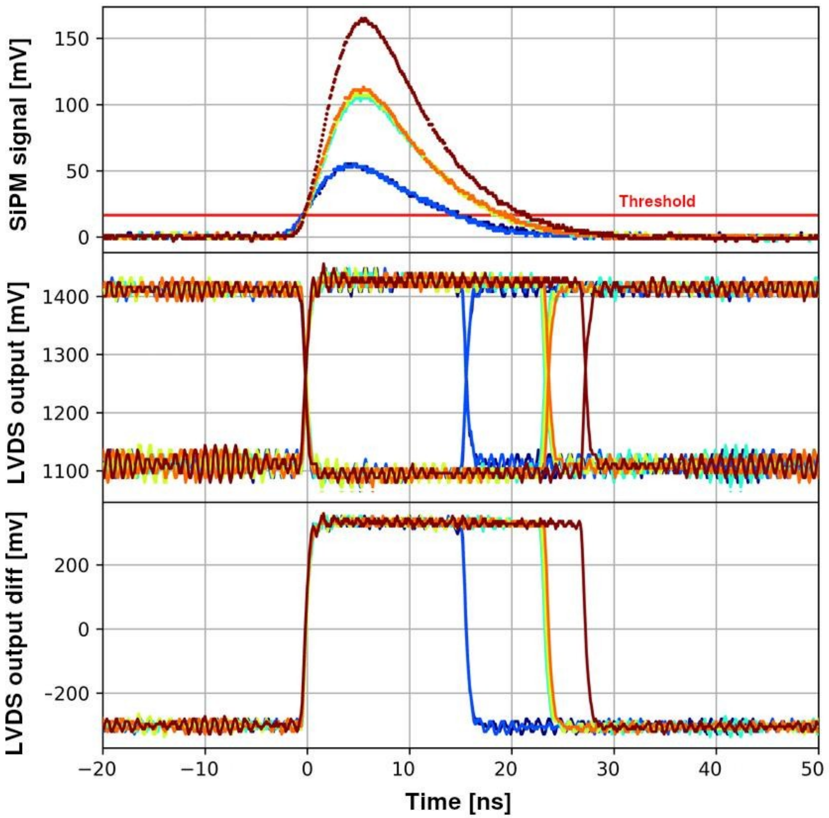
9 – LED

SiPM: NDL EQR15 11-6060D-S

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



Evaluation board
Xilinx Kintex 7



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

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

Alalytical 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 $g(t)$

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

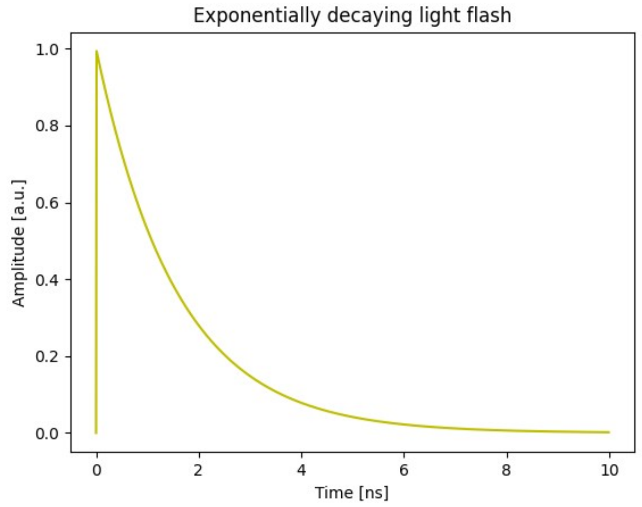
η – PDE, e – electron charge, R_s – load resistance + low intrinsic SiPM resistance, C_T – total SiPM capacitance.

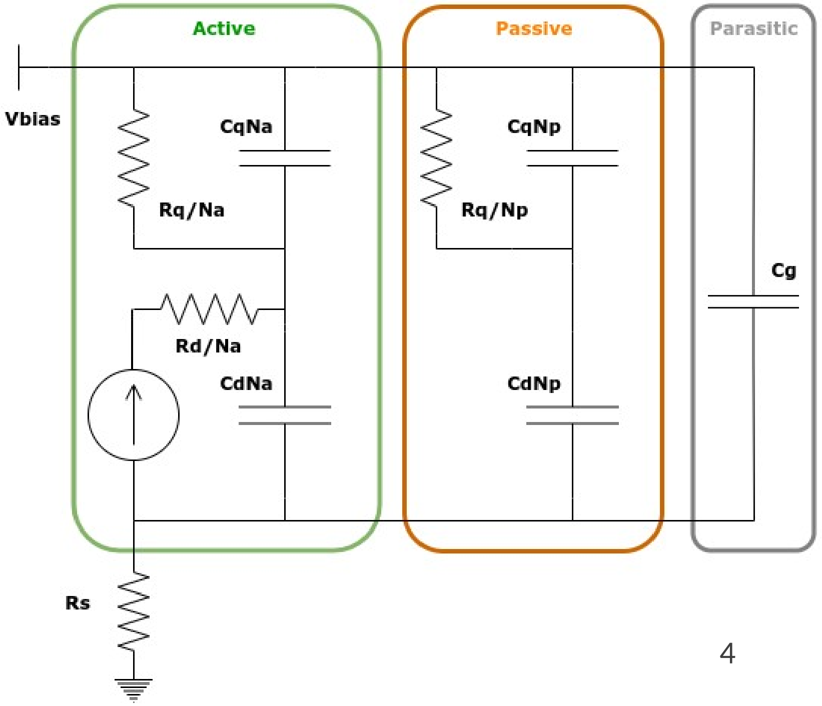
$$V(t) = R_s(f*g)(t) = -\frac{\eta e N_{ph}^0}{C_T \tau_{in}} \int_0^t e^{-\frac{x}{\tau_{in}}} e^{-\frac{t-x}{R_s C_T}} dx = \frac{\eta e N_{ph}^0 R_s}{R_s C_T - \tau_{in}} \left(e^{-t/R_s C_T} - e^{-t/\tau_{in}} \right). \qquad (1)$$

Solution 2 – Proccess as differential equation

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

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





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

- Phase shift to the fast exponent by a value

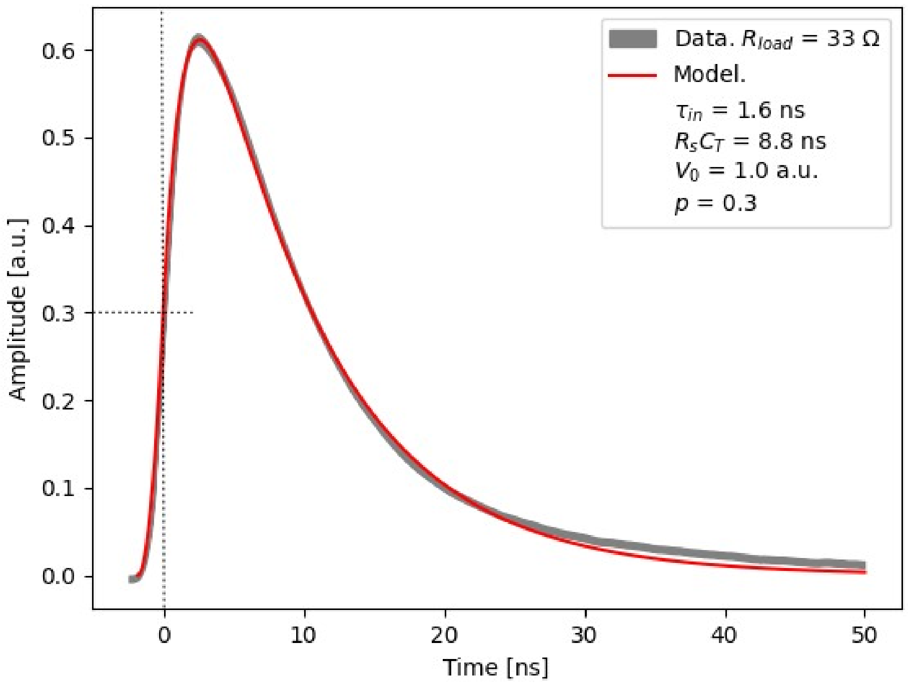
$$\tau_{in} \ln(1-p)$$

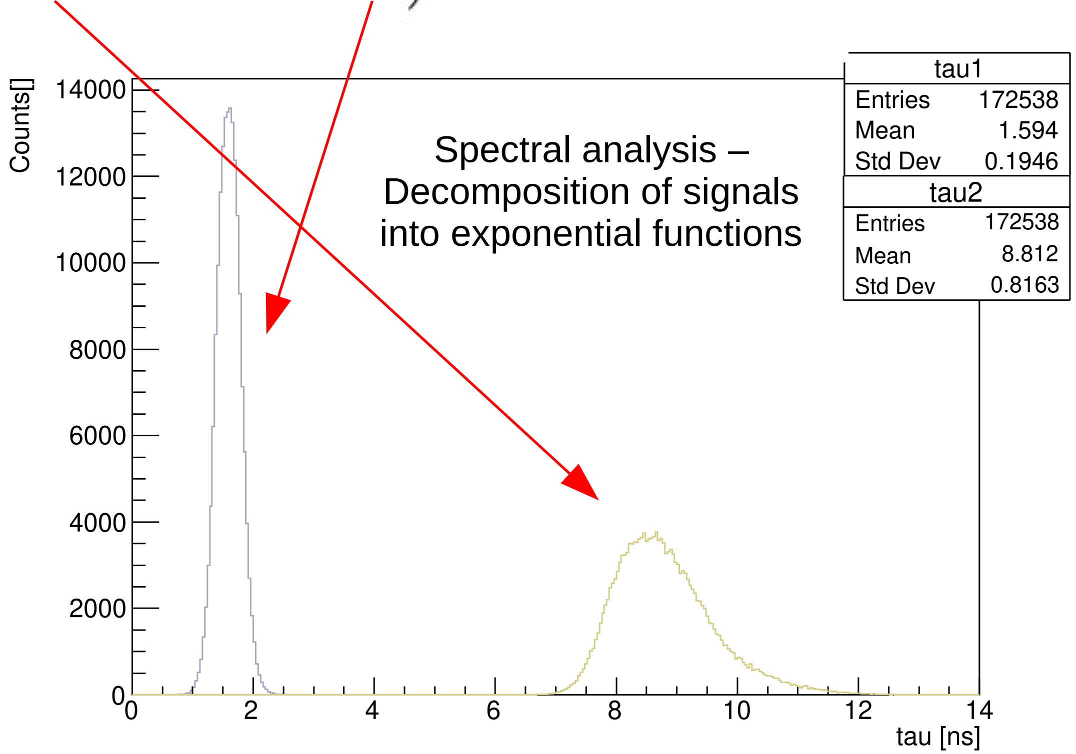
- Match conditions with parabolic solution at time 0

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

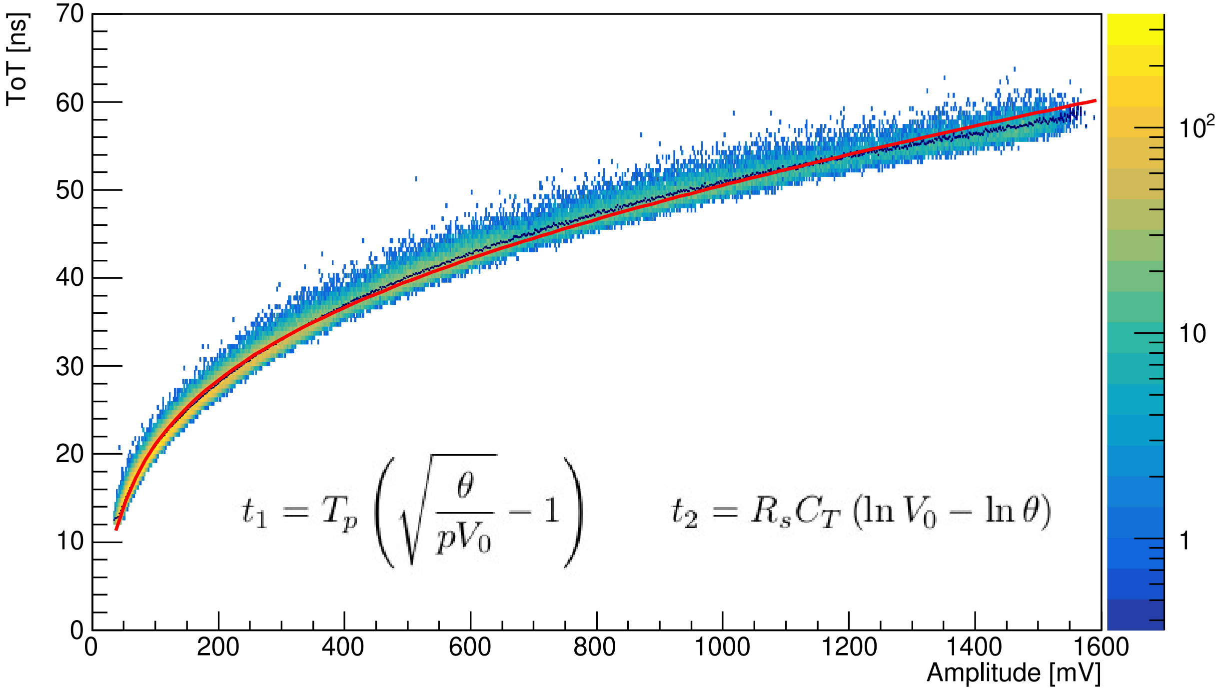
- Final form of analytic description

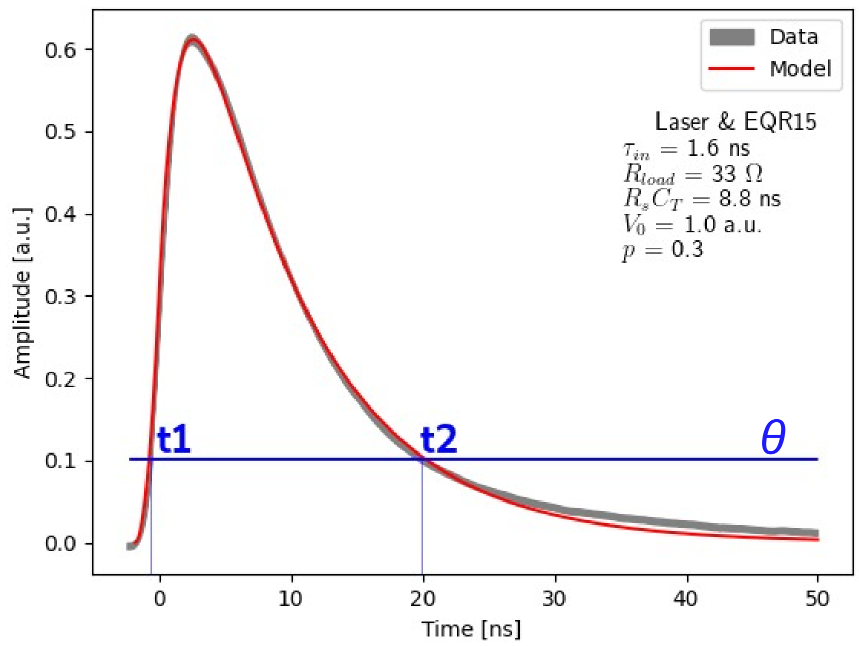
$$V(t) = \begin{cases} pV_0\left(\frac{t}{T_p}+1\right)^2 & \text{if } -T_p < t < 0 \\ V_0\left(e^{-\frac{t}{R_s C_T}} - (1-p)e^{-\frac{t}{\tau_{in}}}\right) & \text{if } t \geq 0 \end{cases}$$

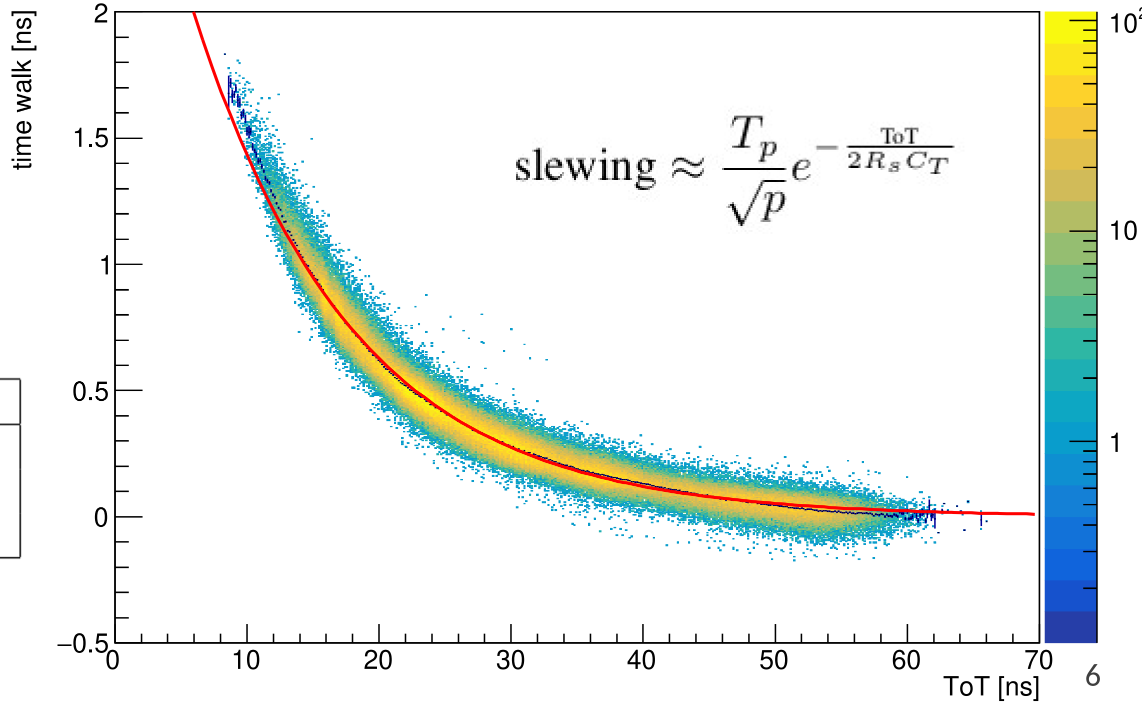




Alalytical description of light signals captured by SiPM: parametrisation of slewing and ToT



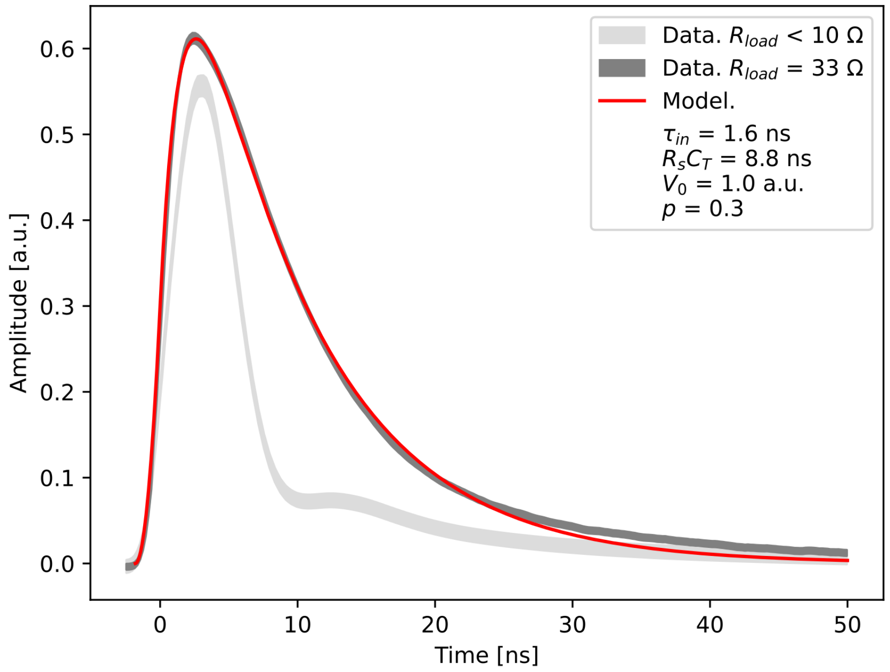




Light source	Decay time [ns]	Time res. w/o corr. [ps]	Time resolution [ps]
Laser	1.6 ± 0.2	88 ± 2	45 ± 0
EJ-230	2.8 ± 0.5	146 ± 2	74 ± 1
JINR	3.9 ± 0.7	261 ± 2	117 ± 1

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.
- 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