Wavelength-shifter coated polystyrene as a low-cost plastic scintillator detector

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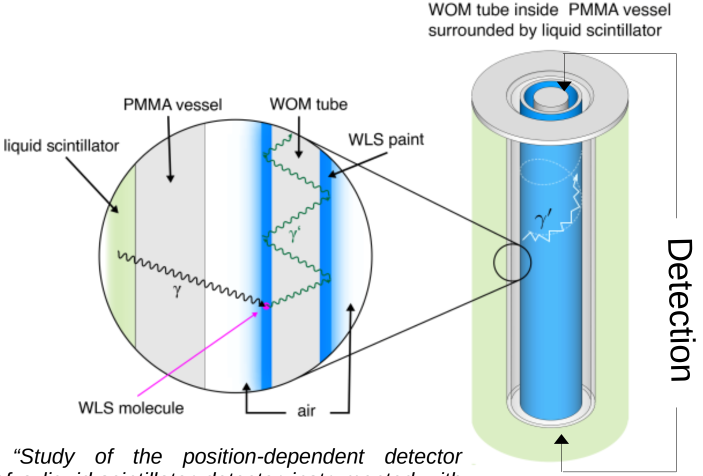
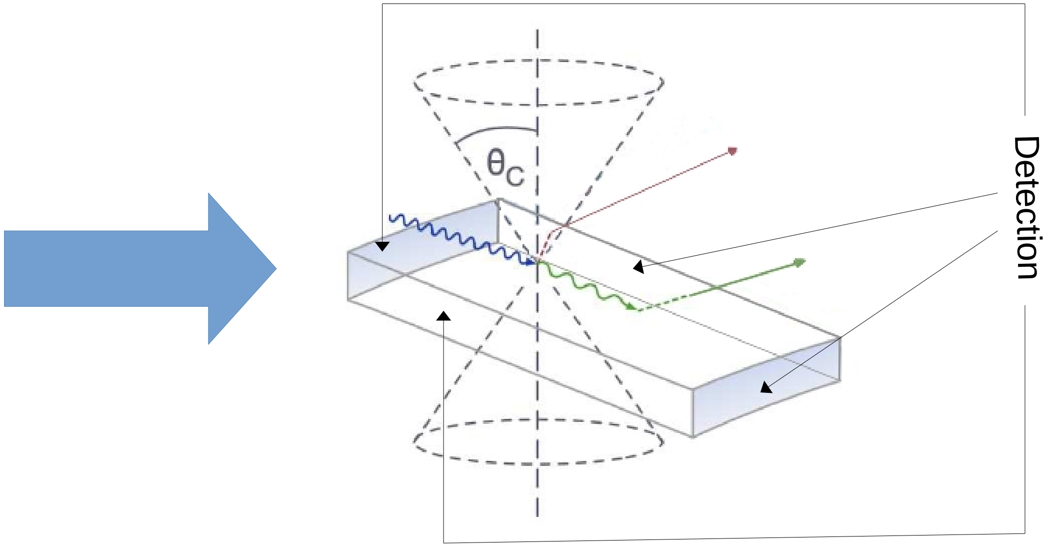
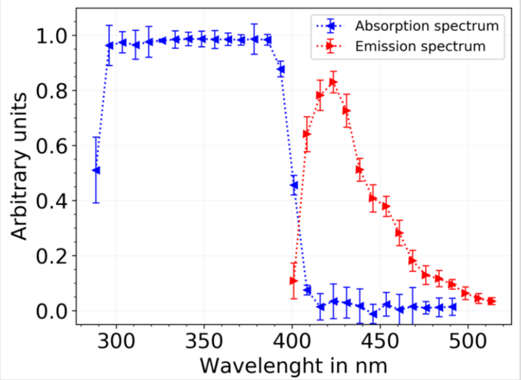
WOM's working principle



A. Ernst, "Study of the position-dependent detector response of a liquid-scintillator detector instrumented with WOMs and SiPMs using cosmic muons"



Wavelength-shifting (WLS) paint spectra



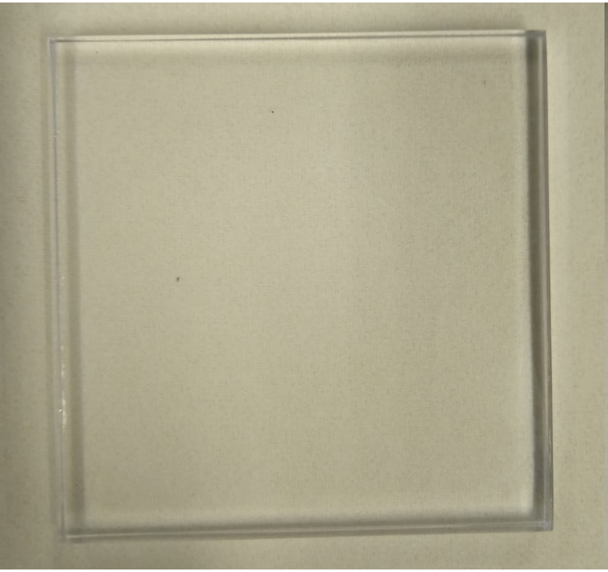
DPG Spring Meeting, T 42: Detector Systems 1

- WOM: Wavelength-shifting Optical Module
- Cylindrical geometry → works in principle for a planar geometry
- Can we replace the PMMA WOM material with an intrinsically scintillating material so that we directly coat the active detector material?

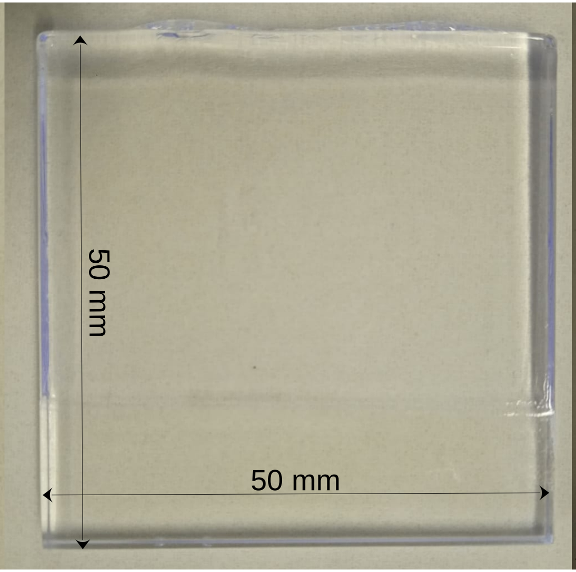
Setup: Polystyrene (PS)

- Commercially bought 5 x 500 x 1000 mm plate → 24,75 €
- 5 x 50 x 50 mm^3 plates were cut and polished
- Dupont™ Tyvek® 1073D paper wrapping

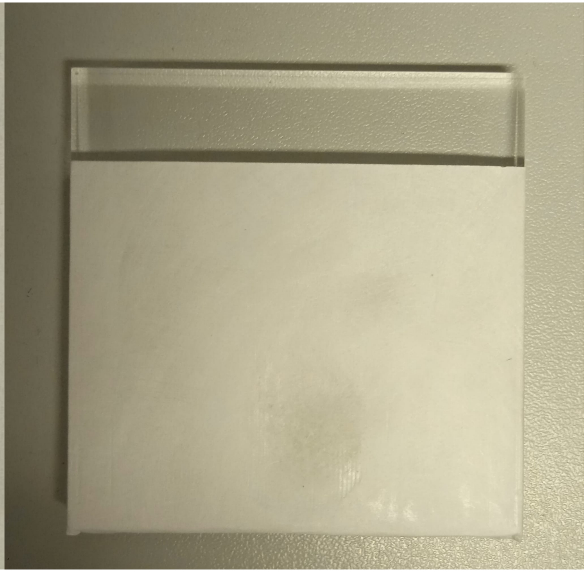
Uncoated PS



Double coated PS

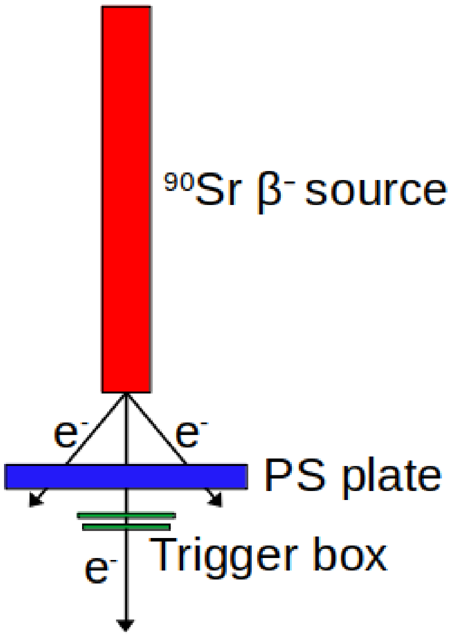


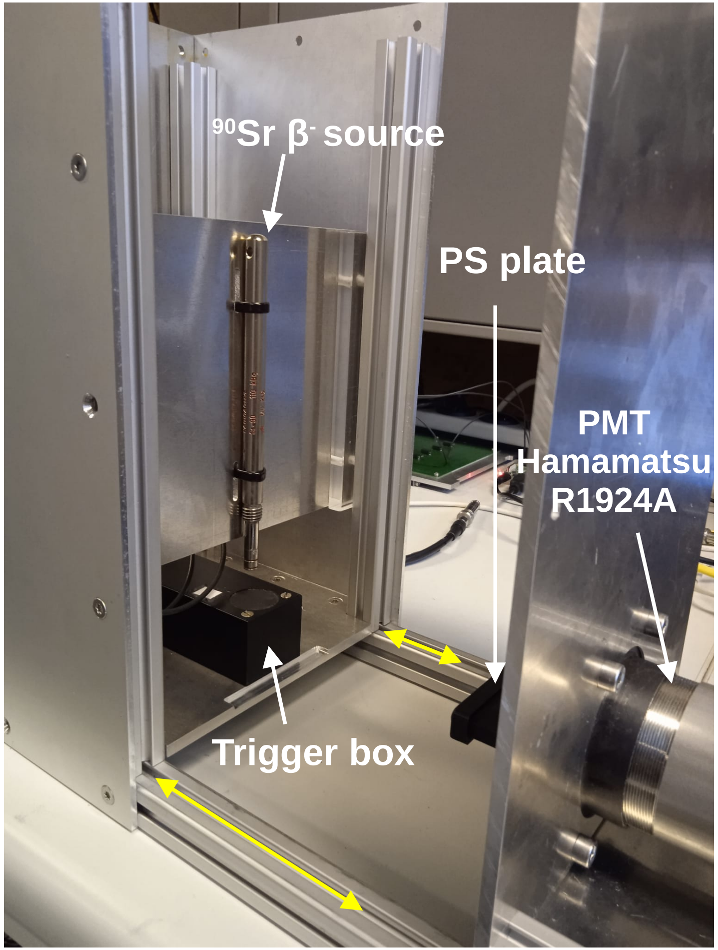
Wrapped PS

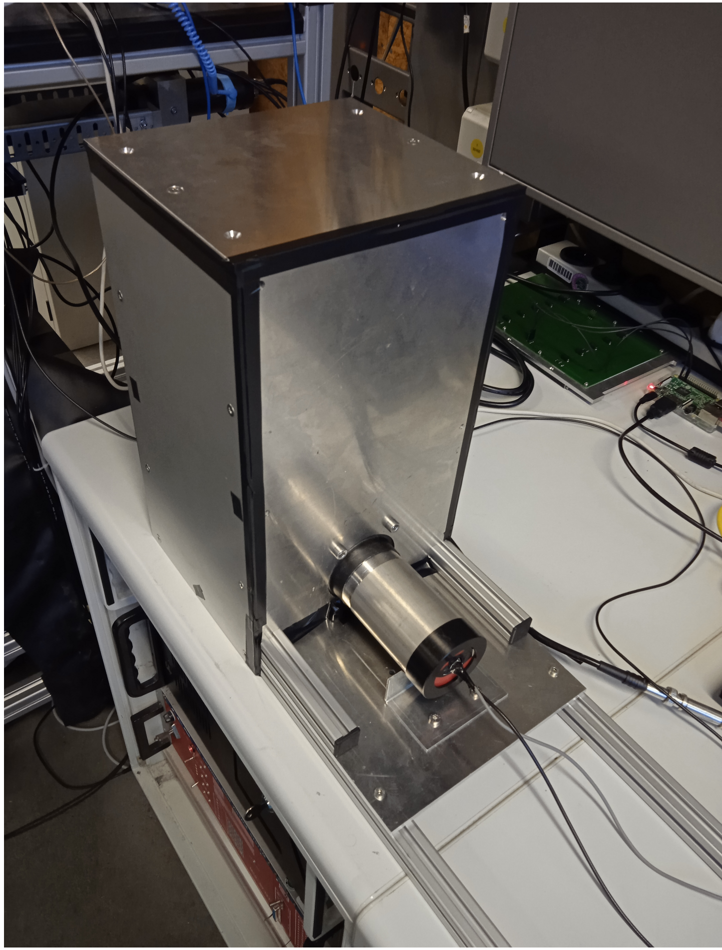


Dipcoater

Setup: General view

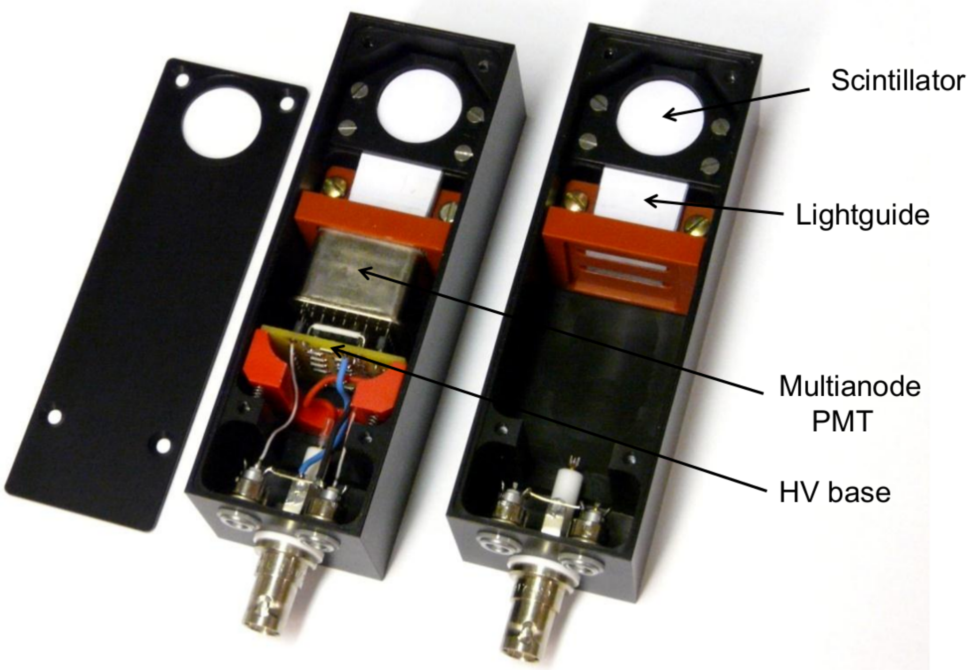






Setup: Trigger box

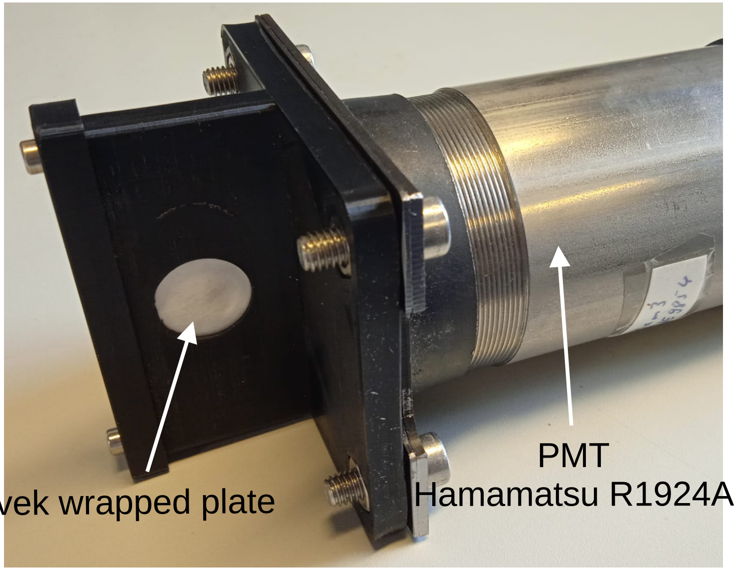
- Two scintillators of 1 mm of thickness and Tyvek paper wrapping
- Two PMMA light guides
- Optical gel coupling to the PMT Hamamatsu R5900
- Working at 780 V

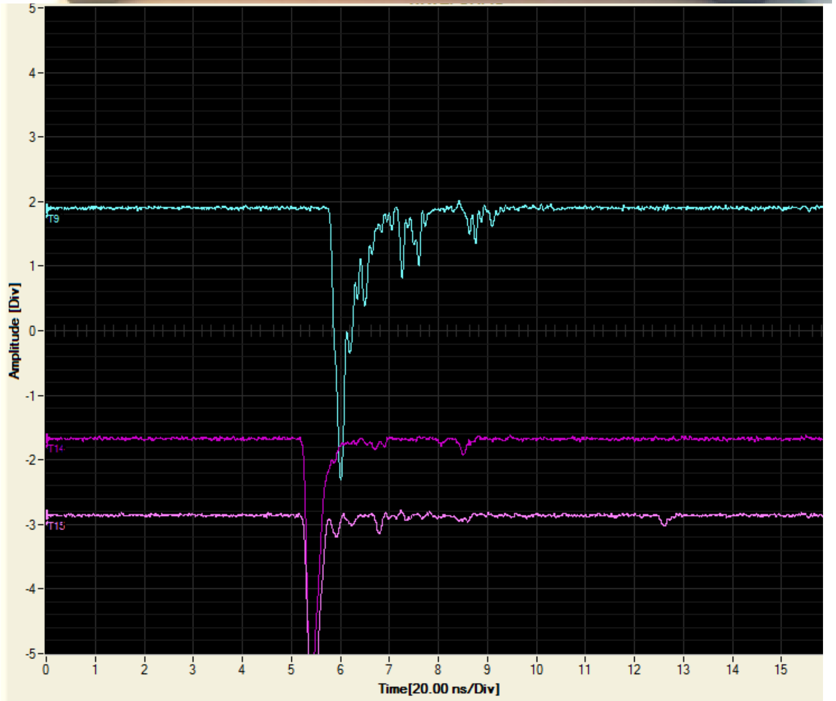


https://indico.cern.ch/event/198640/contributions/1480489/attachments/294406/411441/Sr_setup_FCAL.pdf

Setup: PMT and digitizer

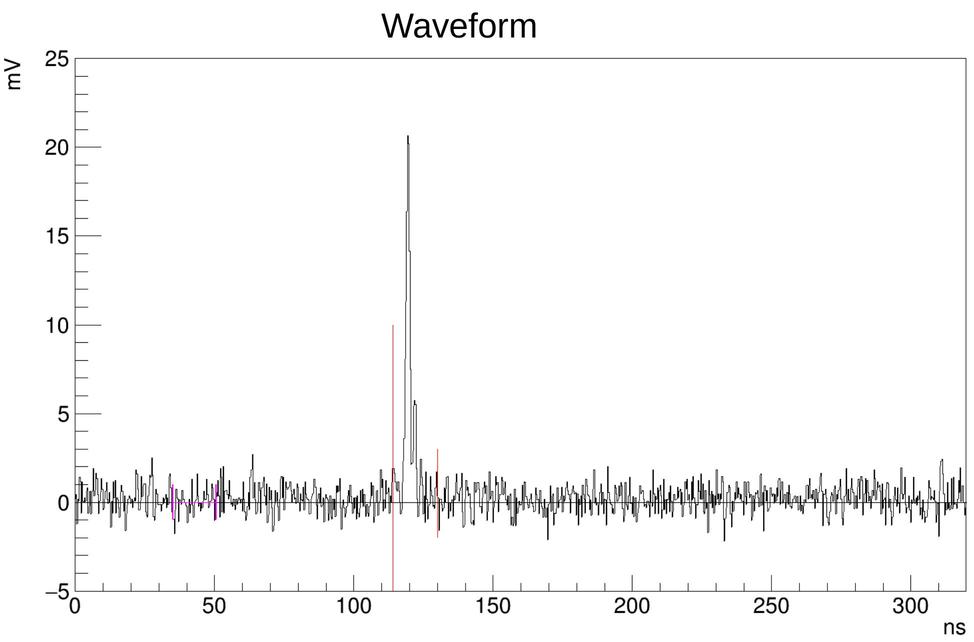
- PMT : Hamamatsu R1924A working at 1000 V
- PS: 5 x 50 x 50 mm plate wrapped
- Optical gel coupling
- Digitizer: 16+2 channel WaveCatcher
- Data analysis: C++ (ROOT software framework)

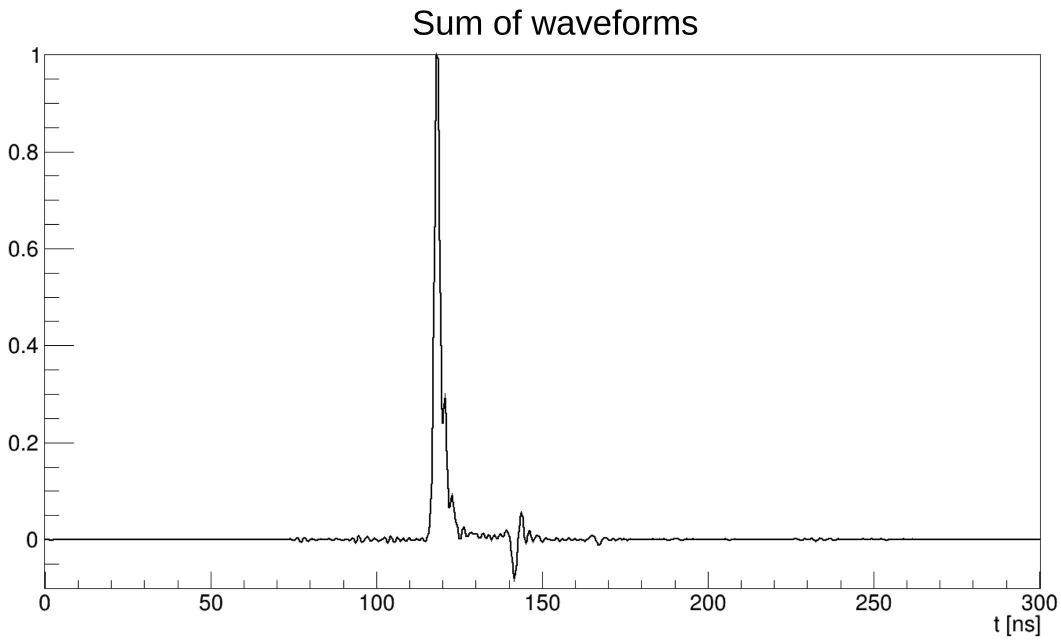




PMT Hamamatsu R1924A calibration measurements

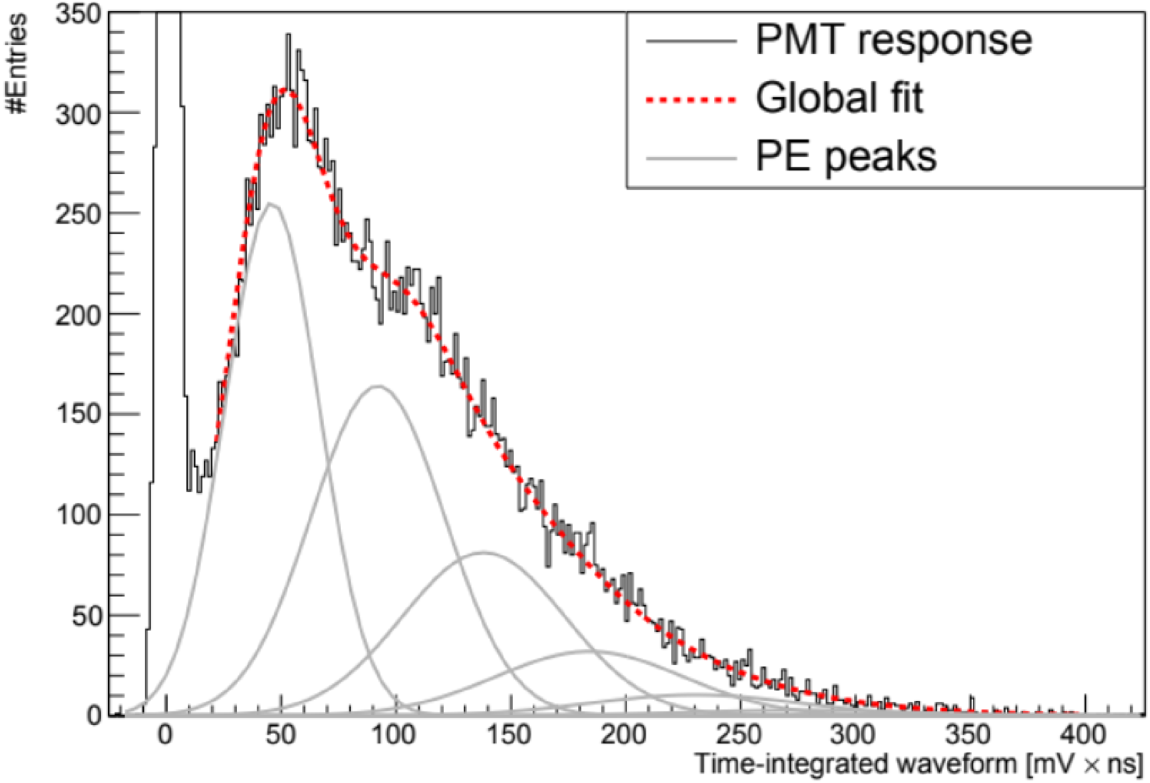
- Pulsed laser, 402.6 nm wavelength
- 30000 events
- Integration window of 16 ns





PMT Hamamatsu R1924A calibration measurements

- COLLECTION → *Poisson*
- AMPLIFICATION → *Gaussian*



$$f(x) = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \frac{1}{\sigma_1 \sqrt{2\pi n}} e^{\frac{(x-nQ_1)^2}{2n\sigma_1^2}}$$

μ → Mean number of photoelectrons (PE)

Q_1 → Gain

σ_1 → Standard deviation of the gain

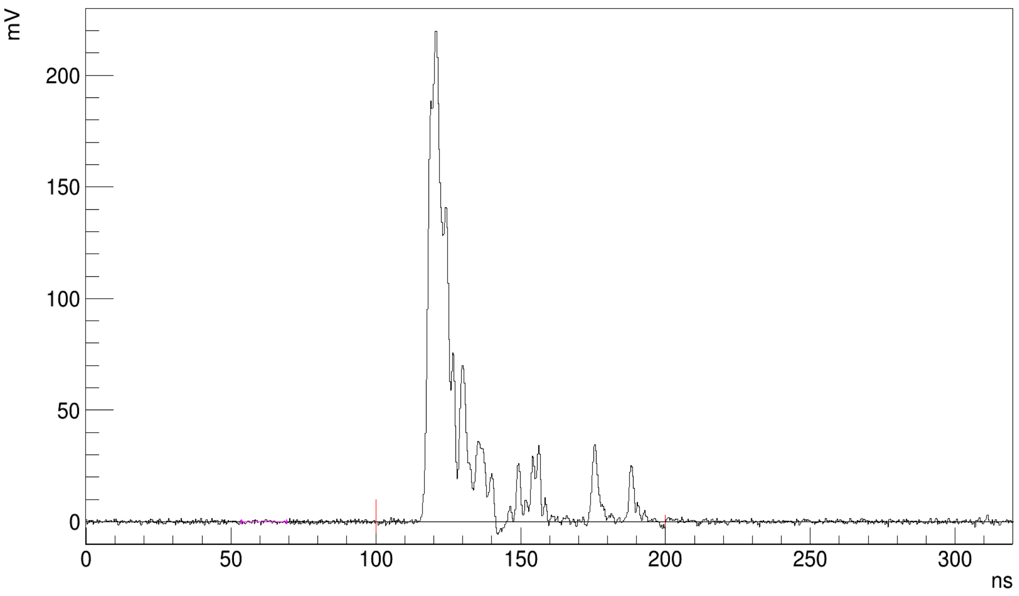
G. Bellettini, "Absolute calibration and monitoring of a spectrometric channel using a photomultiplier", *Nuclear Instruments and Methods in Physics Research A 339, 1994*

1 PE = Q_1 = $46{,}05 \pm 0{,}47$ mV·ns

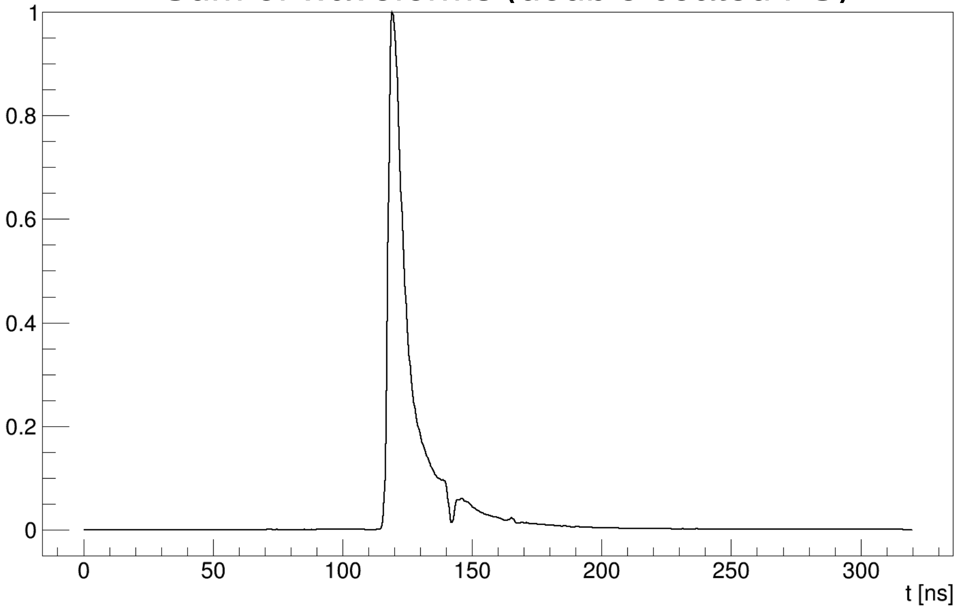
PS measurements

- Scintillation + Cherenkov radiation
- Integration window: 110 ns – 200 ns

Waveform (double coated PS)

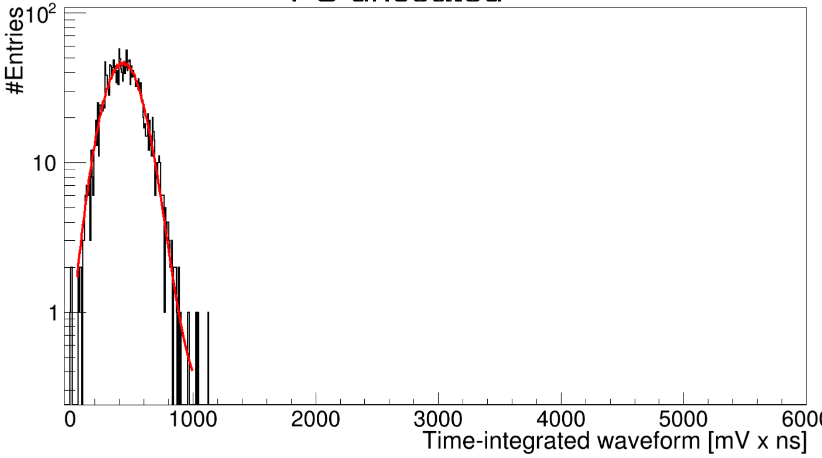


Sum of waveforms (double coated PS)

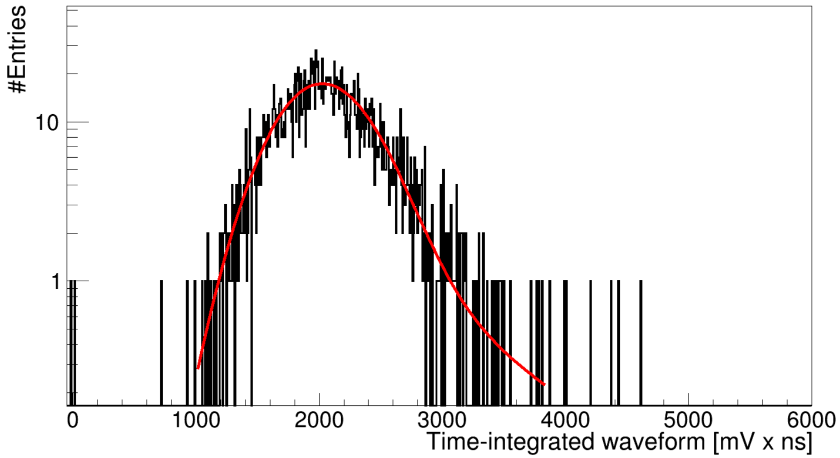


PS time-integrated spectra

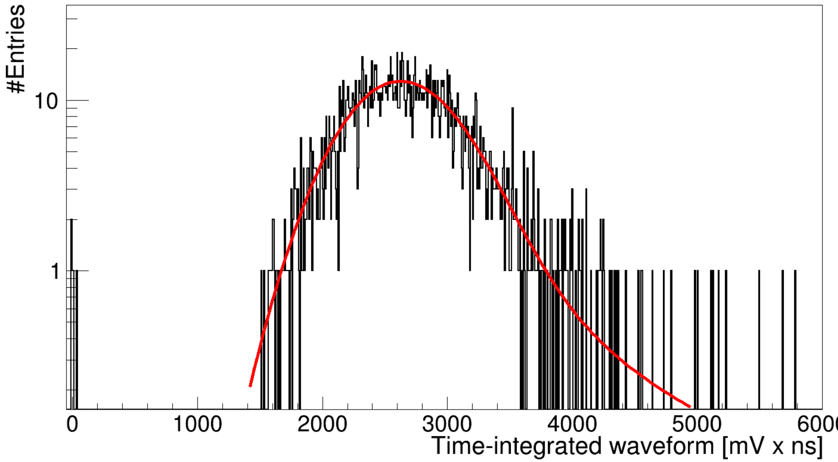
PS uncoated



PS single coated



PS double coated

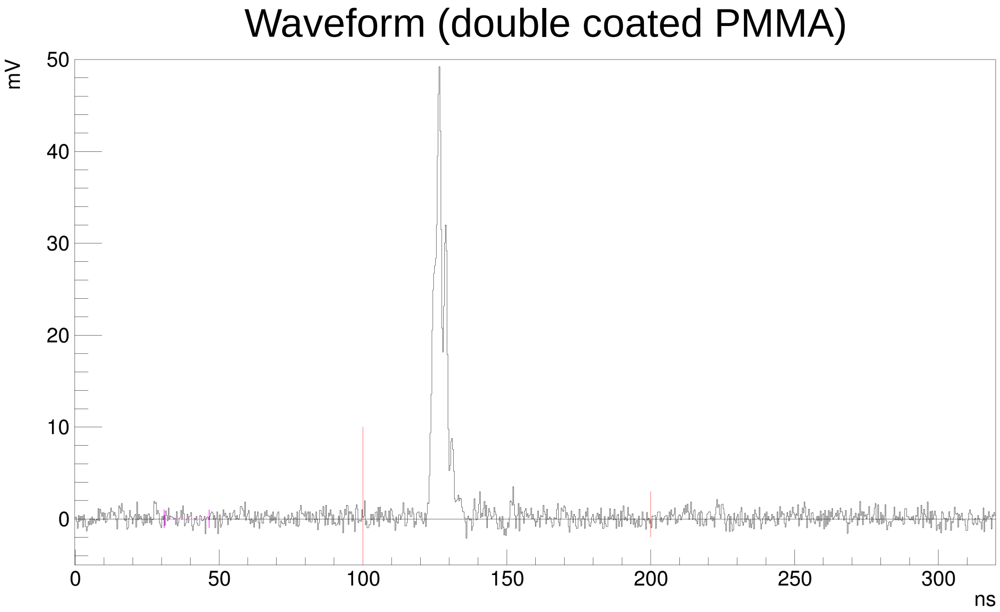


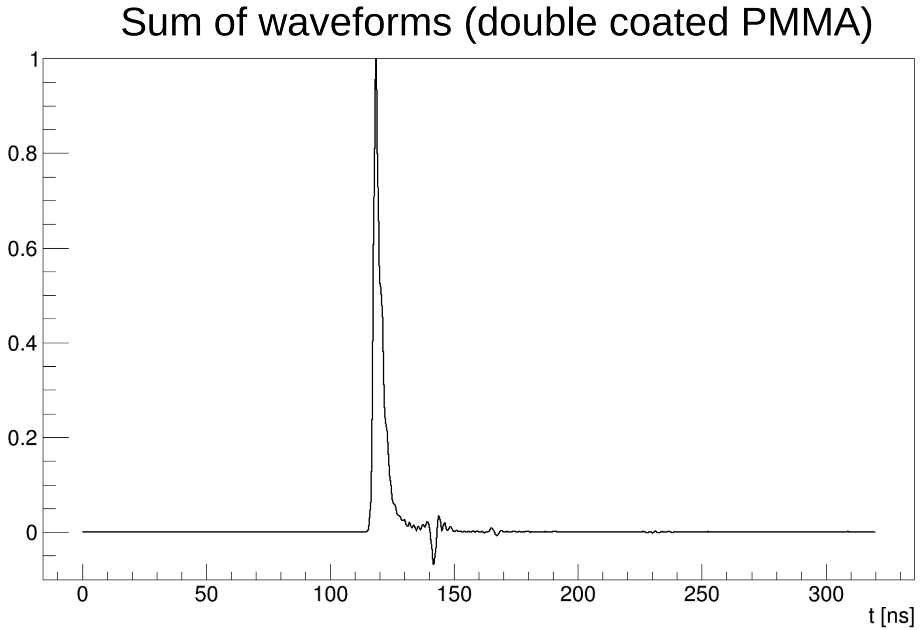
- Energy loss of a charged particle inside a thin layer of material → *Landau*
- Non-negligible electronic noise → *Gaussian*

Convoluted Landau ∗ Gaussian fitting function

PMMA measurements

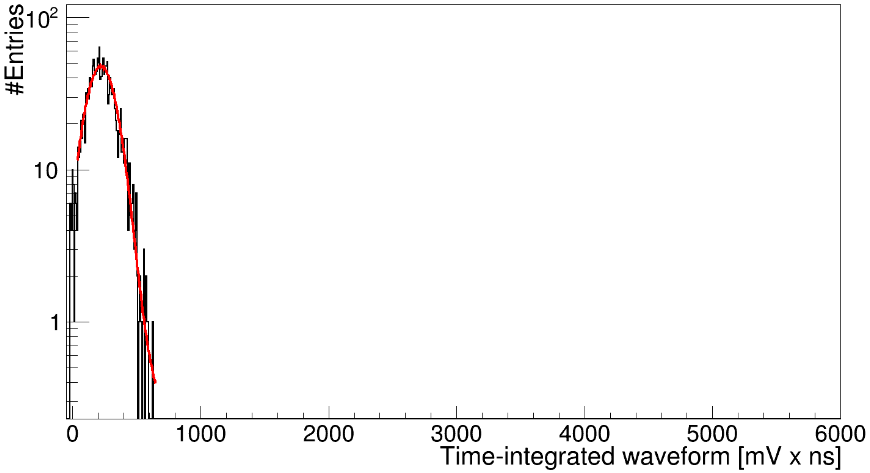
- Only Cherenkov radiation
- Integration window: 110 ns – 200 ns



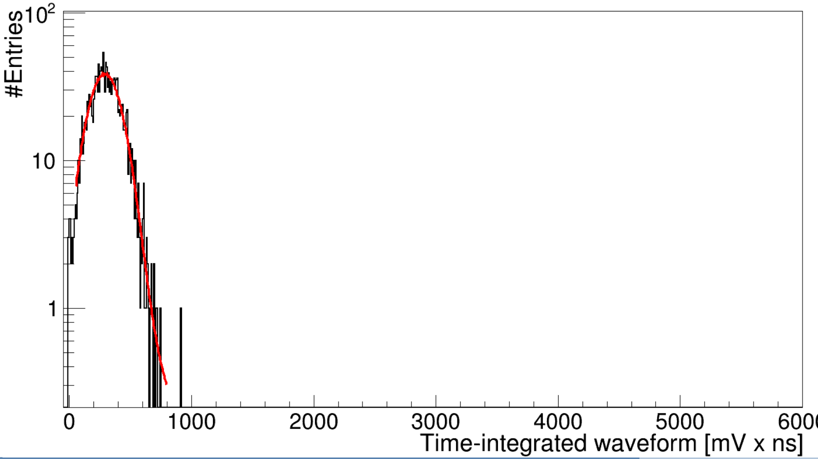


PMMA time-integrated spectra

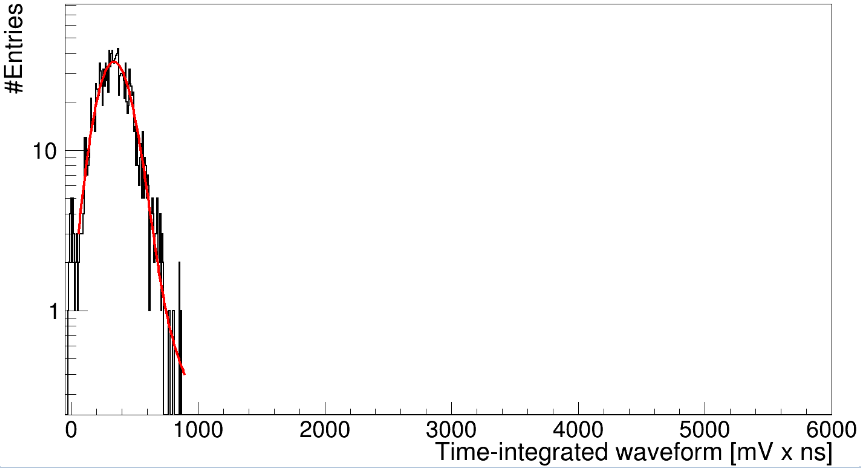
PMMA uncoated



PMMA single



PMMA double coated



Results

MPV [mV·ns] of the Langaus fit

	UNCOATED	SINGLE COATED	DOUBLE COATED
PS	$398{,}96 \pm 2{,}94 \pm 13{,}07$	$1938{,}55 \pm 12{,}45 \pm 10{,}50$	$2513{,}18 \pm 13{,}04 \pm 15{,}55$
PMMA	$201{,}72 \pm 1{,}71 \pm 0{,}55$	$274{,}52 \pm 1{,}45 \pm 0{,}71$	$318{,}67 \pm 1{,}67 \pm 1{,}90$

1 PE ~ $46{,}05 \pm 0{,}47$ mV·ns

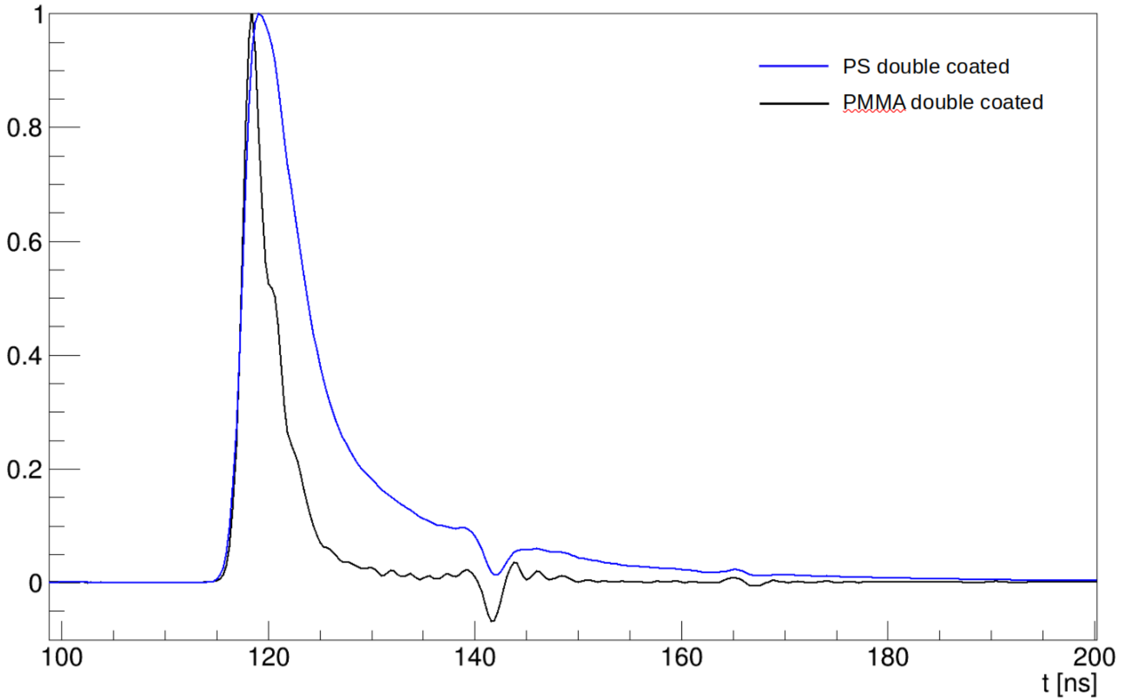
Mean number of PE collected

	UNCOATED	SINGLE COATED	DOUBLE COATED
PS	$8{,}66 \pm 0{,}06 \pm 0{,}28$	$42{,}10 \pm 0{,}27 \pm 0{,}23$	$54{,}58 \pm 0{,}28 \pm 0{,}34$
PMMA	$4{,}38 \pm 0{,}04 \pm 0{,}01$	$5{,}96 \pm 0{,}03 \pm 0{,}02$	$6{,}92 \pm 0{,}04 \pm 0{,}04$

Is the detected signal in coated PS mainly from scintillation?

- Rise-time for PS longer than for PMMA → Cherenkov light always arrives earlier ✔
- Long tail for PS while no tail for PMMA → Scintillation light with significant decay times ✔

Sum of waveforms distribution normalised to maximum value



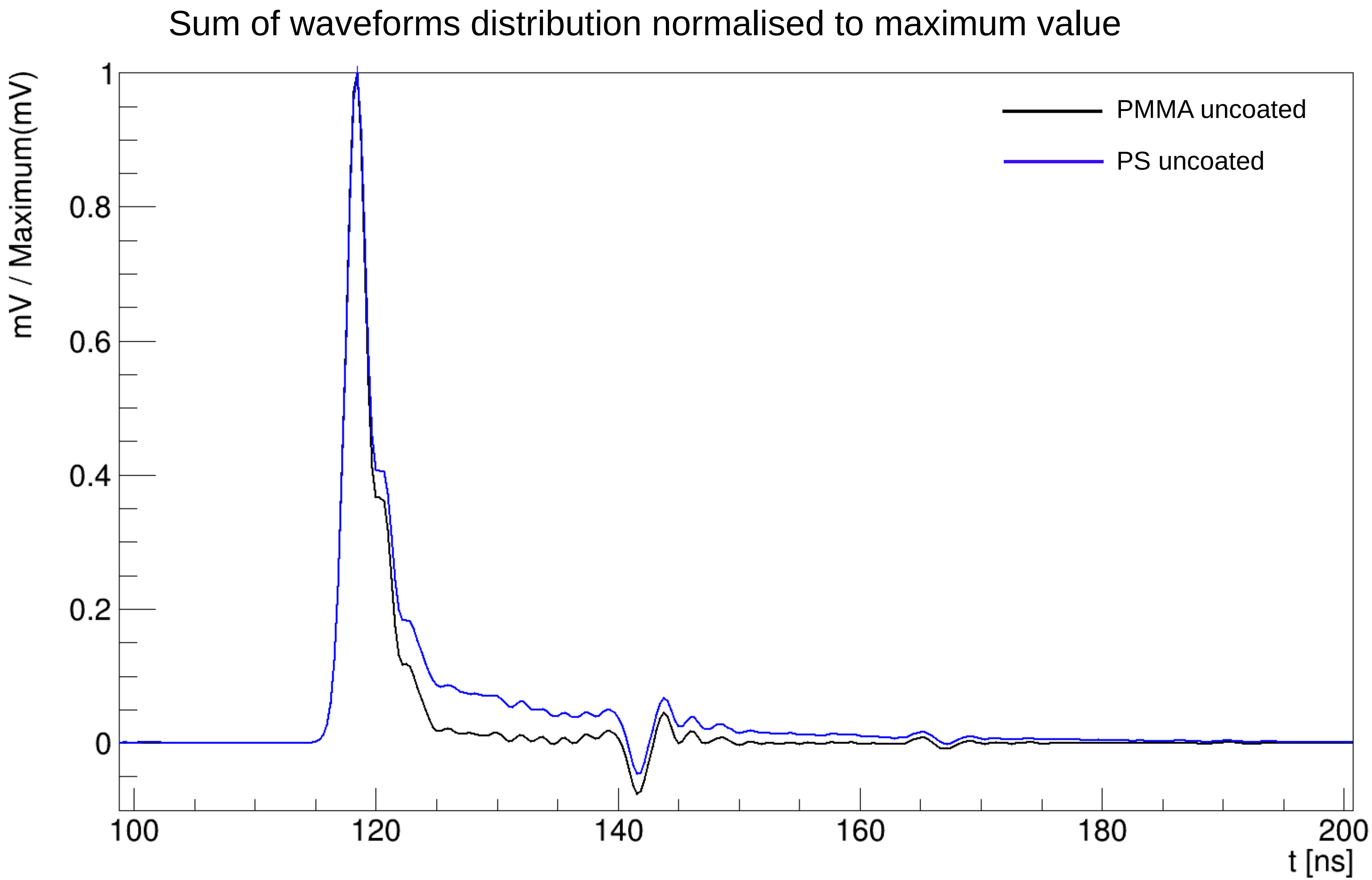
Conclusions

- The WOM principle as a light collector and light guide in a cylindrical geometry can be also used in a planar geometry.
- The WLS paint can be applied directly to the active detector material.
- Pure, commercial PS is a possible active detector material, since it scintillates in the UV and is rather cheap.
- The detected light yield of 55 PE makes the material interesting.

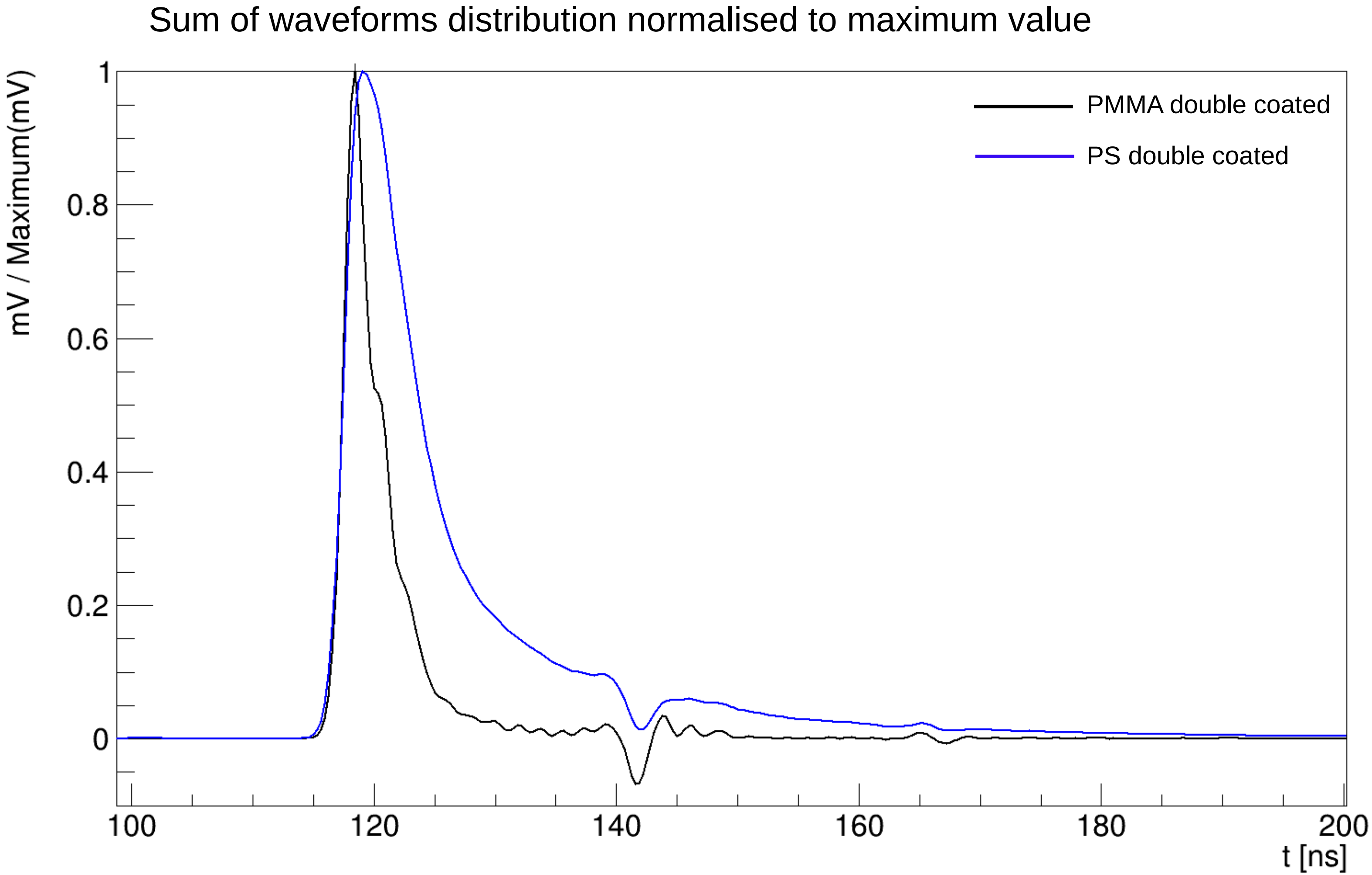
Next steps…

- Quantification of the fraction of Cherenkov and scintillation radiation
- Study of the time and spatial resolution
- Study of the light yield per energy deposit
- Study of the radiation hardness of the material

Backup

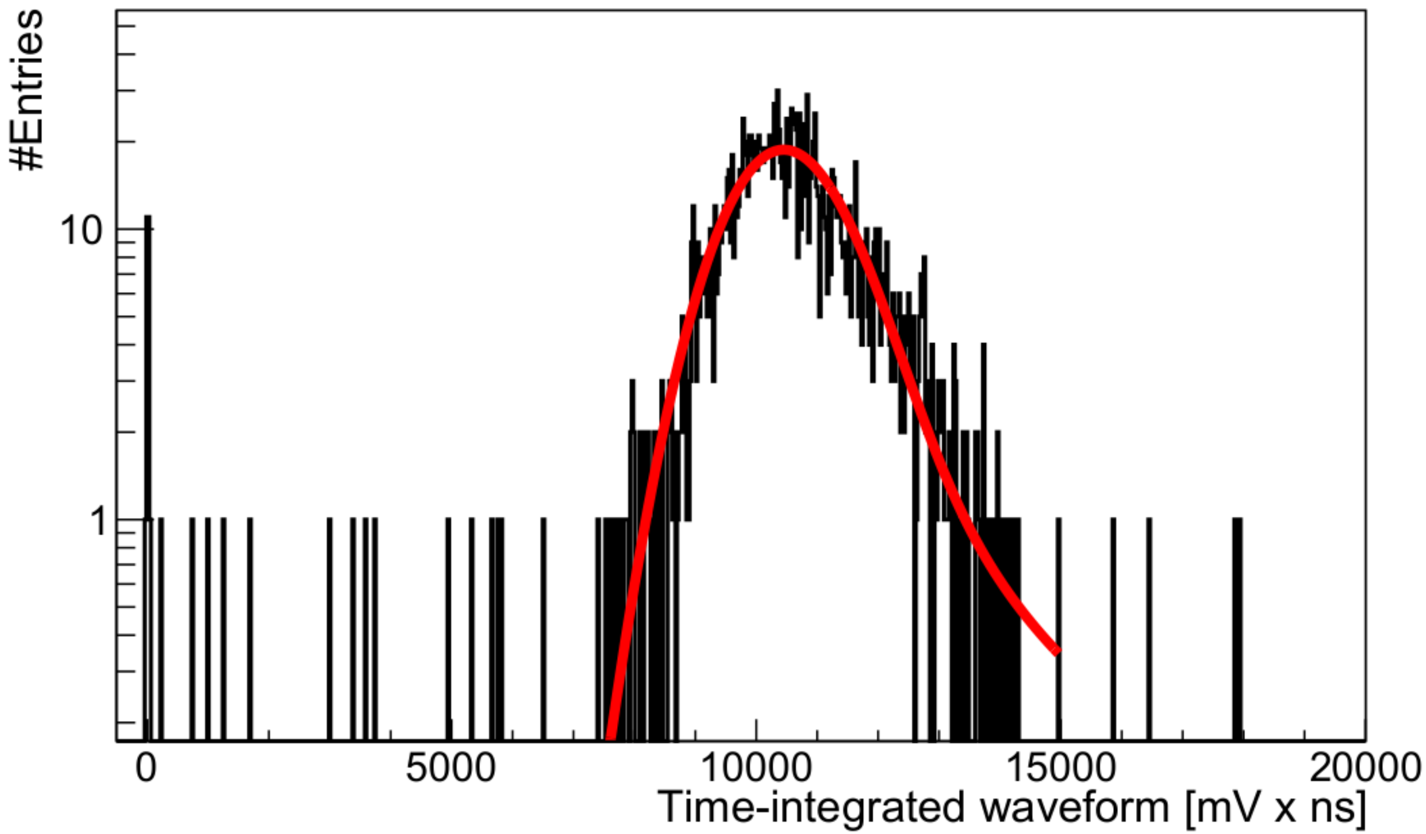

Sum of waveforms distribution normalised to maximum value
mV / Maximum(mV)
1
0.8
0.6
0.4
0.2
0
100
120
140
160
180
200
t [ns]
PMMA uncoated
PS uncoated

Backup


Sum of waveforms distribution normalised to maximum value
mV / Maximum(mV)
1
0.8
0.6
0.4
0.2
0
100
120
140
160
180
200
t [ns]
PMMA double coated
PS double coated

Backup

Uniplast



PE: $506{,}22 \pm 1{,}66 \pm 7{,}17$

Backup

- Events cut:
  - Trigger box → integral < 200 mV·ns (*)

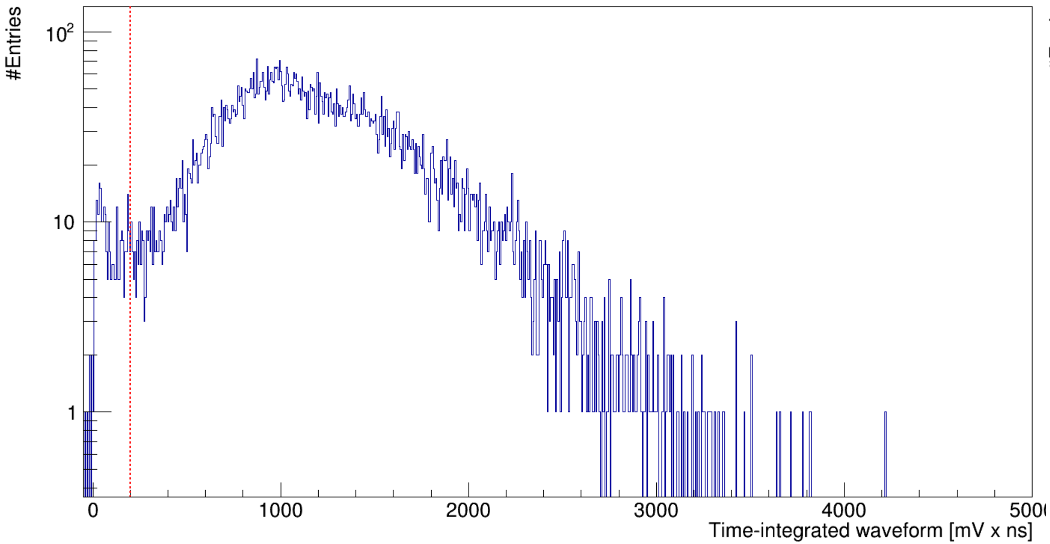
(*) We need ~1.4 MeV to traverse 7 mm of polystyrene

$^{90}Sr \rightarrow {}^{90}Y$: 0.546 MeV

$^{90}Y \rightarrow {}^{90}Zr$: average of 0.9 MeV

max of 2.28 MeV

Time-integrated spectrum of upper scintillator of the trigger box



Time-integrated spectrum of lower scintillator of the trigger box