Characterisation of home-made plastics

Vojtěch Zabloudil[1]

[1]Department of Physics
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague

September 14, 2023

Contents

Motivation

- Scintillators are crucial part of today's HEP detectors
- Increasing energies of collisions and interaction rates → radiation hardness and fast response
- Need to cover large areas (tens of cm to m) → low cost
- In general, we need to develop novel materials
    - Production of custom-made scintillators with $CsPbBr_3$ nanocrystals and their characterisation

- Prospect for future HEP detectors or TOF-PET with ultrafast subnanosecond response
- Semiconductor nanocrystals with dimensions around 5 nm in all three dimensions
  - Leads to quantum confinement effect → impacts the luminescence properties
- Lead halide perovskites

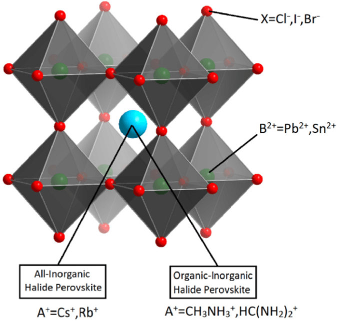
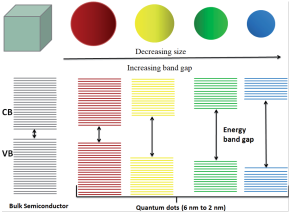
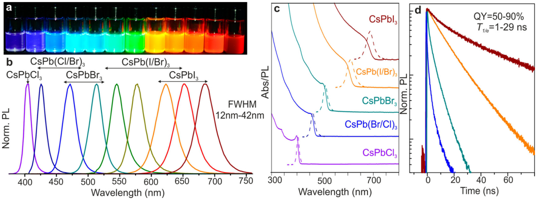


Figure: Diagram of metal halide perovskite ABX_3.

Quantum dots II

- Different sizes and halides influence the band gap → different emission wavelength over the whole visible spectrum
- Size is easily tunable during the synthesis
- Tunability also due to possible combination of different halides





Quantum dots III

- Nanocrystals suffer from external influence such as humidity or atmospheric oxygen $\rightarrow$ need to protect them
- Nanocrystal aggregation $\rightarrow$ no confinement anymore
- $CsPbBr_3$ in toluene prepared by colleagues from the Department of Chemistry [1, 2]
- Production of nanocomposites

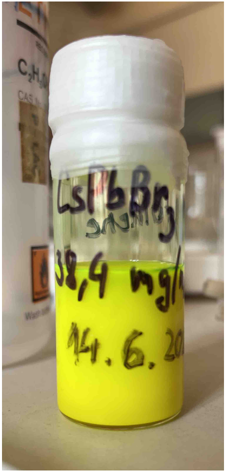


Figure: $CsPbBr_3$ in toluene.

Plastic scintillator production

- Done in UAS, Mexico
- Two matrices: polystyrene and silicone
- Samples with dimensions of $2.5 \times 2.5 \times 1$ cm^3
- Various concentration of quantum dots
- Addition of PPO

Figure: Set-up for scintillator production.

Characterisation of the samples

- Done at CTU
- Test bench using cosmic-ray muons
- Two trigger scintillators $\rightarrow$ coincidence on vertical muons
- Studies of amplitude and charge of the custom-made scintillators
- Small sample area and low muon rate $\rightarrow$ several days of data-taking needed
- Small signal-to-background

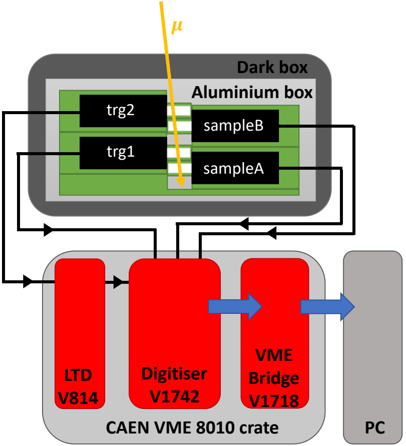


Figure: Set-up for sample characterisation using cosmic-ray muons.

Characterisation of the samples: setup

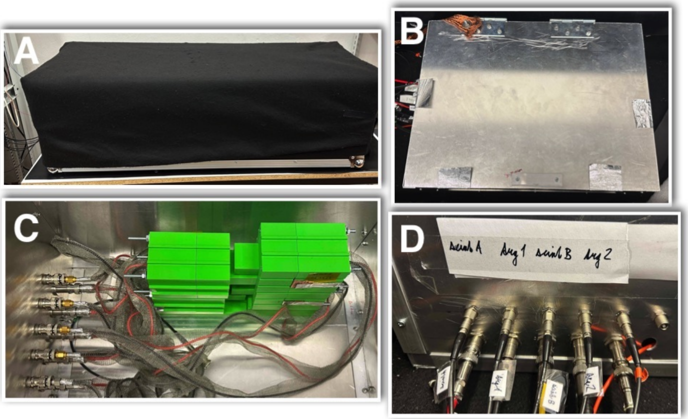


Figure: Set-up for sample characterisation using cosmic-ray muons: A) dark box, B) aluminium box, C) samples with PMTs, D) signal and HV patch panel.

Data analysis I

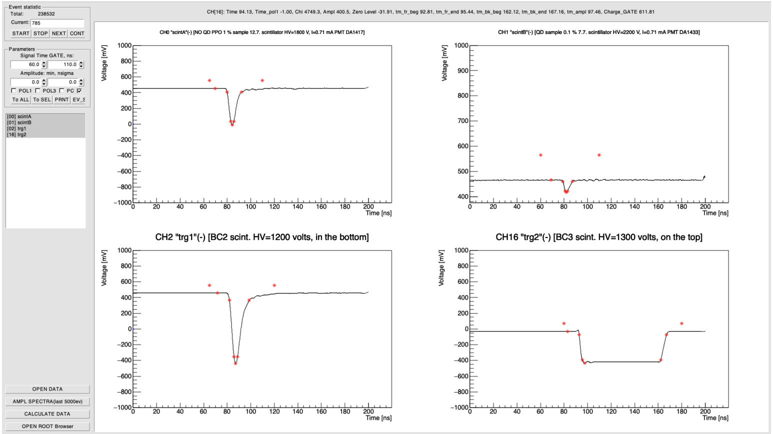


Figure: Program for the analysis of the raw data from the scintillator characterisation with cosmic-ray muons.

Data analysis II

- Events above electrical crosstalk → minimum signal amplitude of 8 mV
- Events coming from MIP → minimum signal charge in trigger module of -25 fC

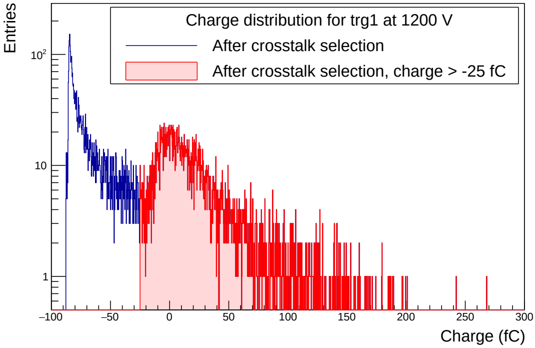


Figure: Charge distribution for BC-420 sample in module trg1 at 1200 V with charge selection.

Data analysis III

- Many events arise from photocathode hits → pedestal runs measuring PMT background without any scintillator coupled to the PMT

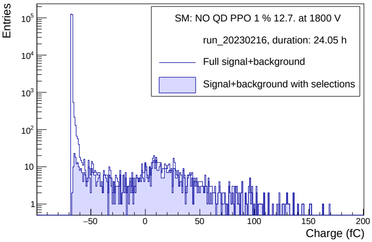


Figure: Signal+background charge distribution: PMT with sample

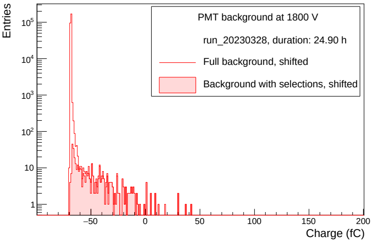
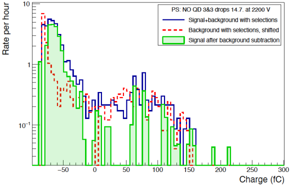


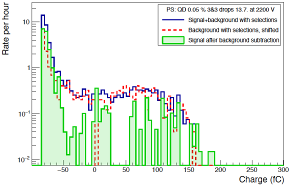
Figure: Background charge distribution: PMT without sample

Polystyrene matrix: results

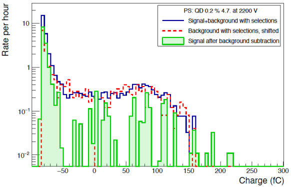
- Different concentrations of QD
- No visible signal enhancement



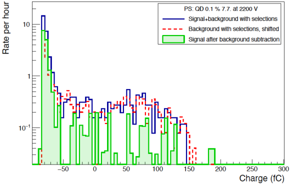
(a) NO QD 3&3 dr. 14.7. 2200 V



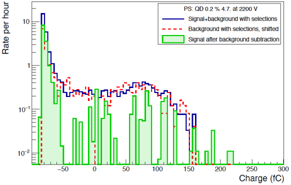
(b) QD 0.05 % 3&3 dr. 13.7. 2200 V



(e) QD 0.3 % 4.7. 2200 V



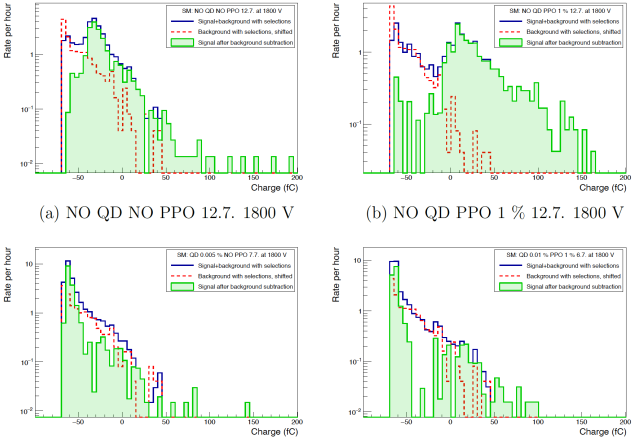
(c) QD 0.1 % 7.7. 2200 V



(d) QD 0.2 % 4.7. 2200 V

Silicone matrix: results

- Different composition of the samples
- Successfully observed charge shift with PPO
- QD attenuate the light through strong self-absorption → need for WLS



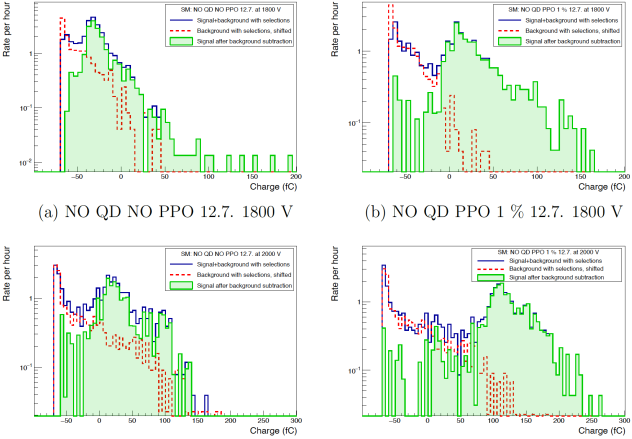
(a) NO QD NO PPO 12.7. 1800 V

(b) NO QD PPO 1 % 12.7. 1800 V

(c) QD 0.005 % NO PPO 7.7. 1800 V

(d) QD 0.01 % PPO 1 % 6.7. 1800 V

- Increased PMT voltage → expect MIP peak shift
- Successfully observed



(a) NO QD NO PPO 12.7. 1800 V

(b) NO QD PPO 1 % 12.7. 1800 V

(c) NO QD NO PPO 12.7. 2000 V

(d) NO QD PPO 1 % 12.7. 2000 V

Summary and outlook

- Successful production of plastic scintillators with QD
- Characterisation of the custom-made samples
  - Need more statistics
    $\rightarrow$ laser irradiation
  - More studies
    $\rightarrow$ spectra, homogeneity
- Many more samples with different compositions and concentrations are on the way!

Thank you for your attention

Backup: QD spectra

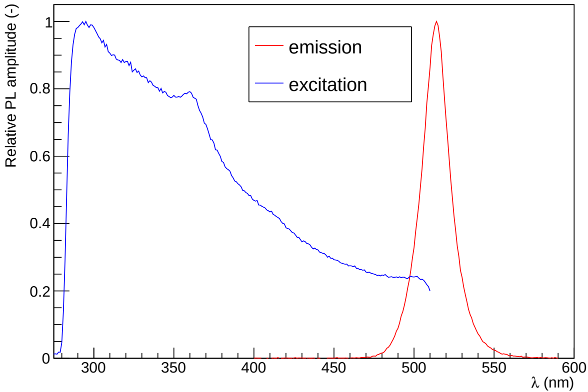


Figure: QD excitation (blue line) and emission (red line) spectra.

Backup: QD time response

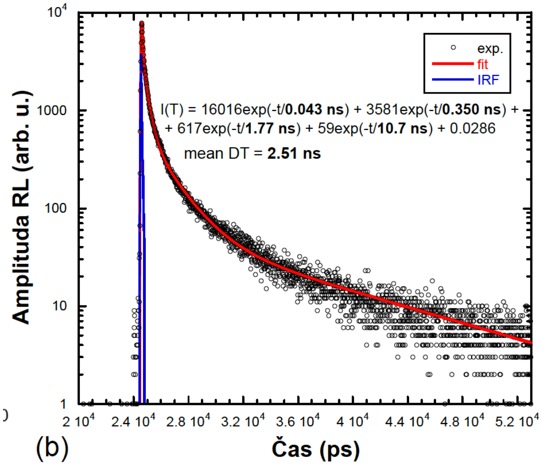


Figure: Time response of thin $CsPbBr_3$ layer on glass [3].

Bibliography

[1] K. Děcká et al. "On the Role of Cs4PbBr6 Phase in the Luminescence Performance of Bright CsPbBr3 Nanocrystals". In: *Nanomaterials* 11.8 (2021). ISSN: 2079-4991. DOI: 10.3390/nano11081935. URL: https://www.mdpi.com/2079-4991/11/8/1935.

[2] K. Děcká et al. "Scintillation Response Enhancement in Nanocrystalline Lead Halide Perovskite Thin Films on Scintillating Wafers". In: *Nanomaterials* 12.1 (2022). ISSN: 2079-4991. DOI: 10.3390/nano12010014. URL: https://www.mdpi.com/2079-4991/12/1/14.

[3] J. Král. *Synthesis and characterisation of scintillating nanocomposites based on $CsPbBr_3$ nanocrystals.* https://dspace.cvut.cz/handle/10467/105397. Accessed: 2023-03-17. 2022.