My first year at CERN

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19.9.2024

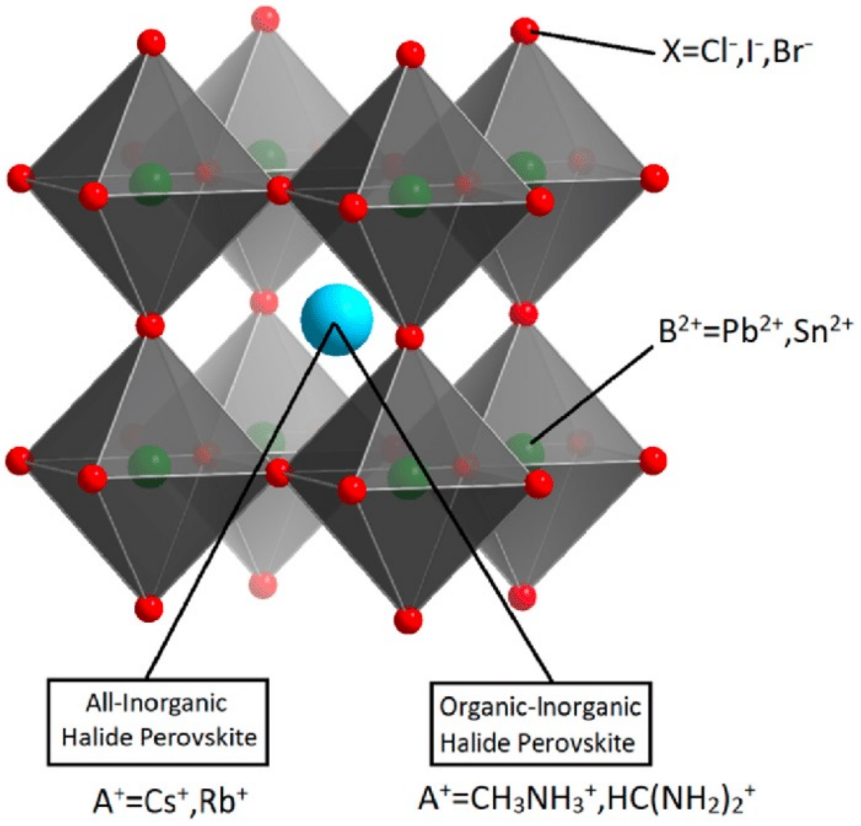
DUCD24

Introduction

- Doctoral Student Programme
  - 3 years at CERN
- Experimental characterisation of generic nanocomposite samples
  - Decay time
  - Detector time resolution
  - Light yield (very difficult with nanocomposites)
- UNICORN
  - European project
  - Novel scintillators based on nanocomposites
  - Slight focus on neutrinoless double beta decay
- Numerical simulations in GEANT4

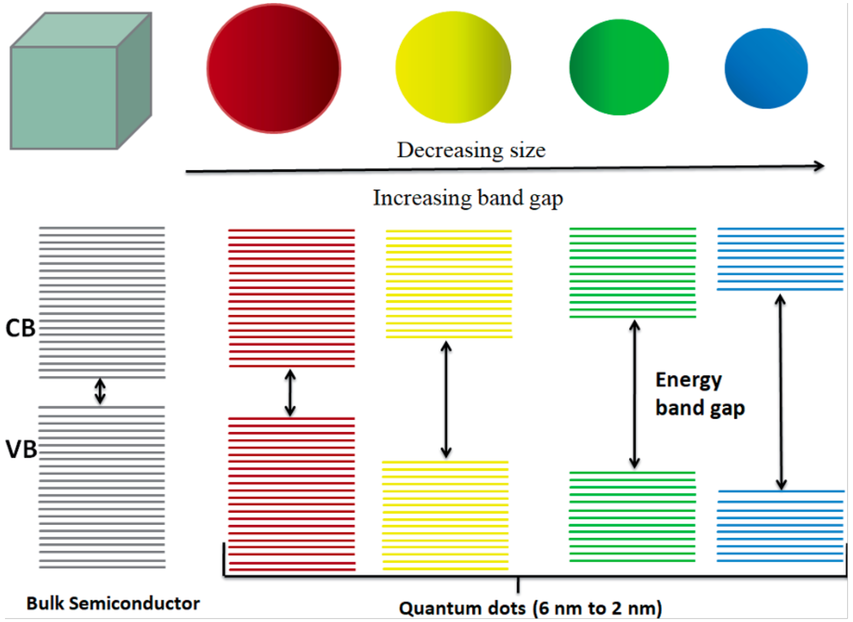
Quantum dots intro

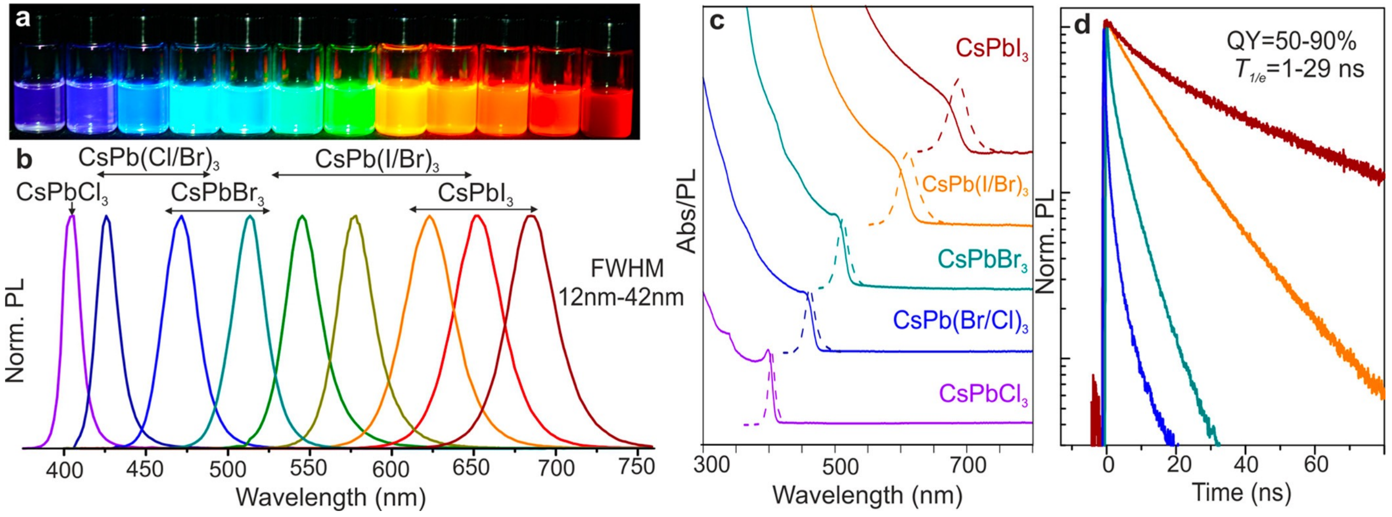
- = nanoparticles, nanocrystals
- Semiconductor nanocrystals of nm dimensions
  - Quantum confinement effect → excellent luminescense properties
- Ultrafast subnanosecond time response
- Metal halide perovskites (ABX_3)
- CdSe, CdS, ZnS and many others



Quantum dots intro

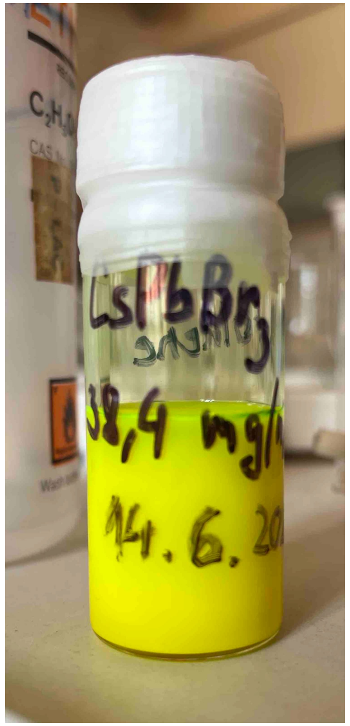
- Tunable emission over the whole visible spectrum
  - Size influences the band gap
- For ABX_3 one can also exhange X = Cl, I, Br

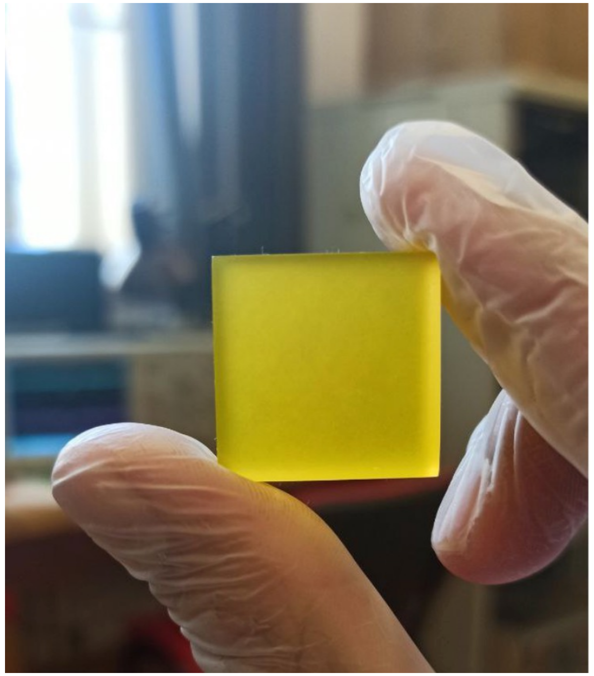


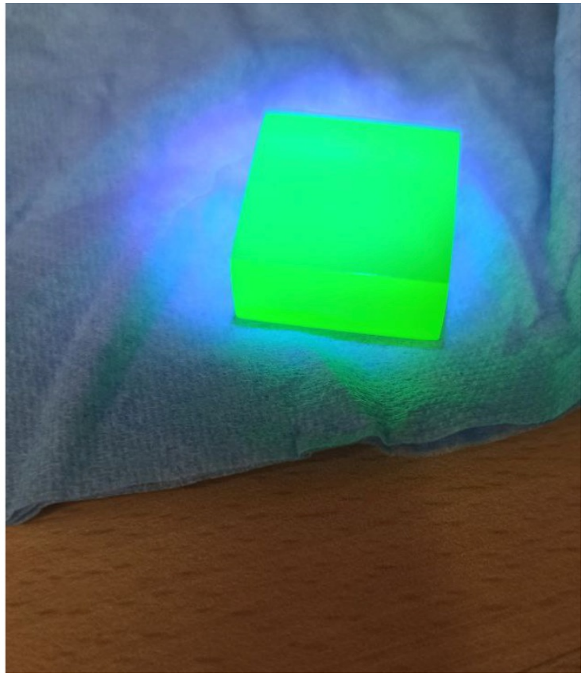


Nanocomposite intro

- QDs suffer from external influence (humidity or atmospheric oxygen)
- Embedding of QD into host matrices → nanocomposites





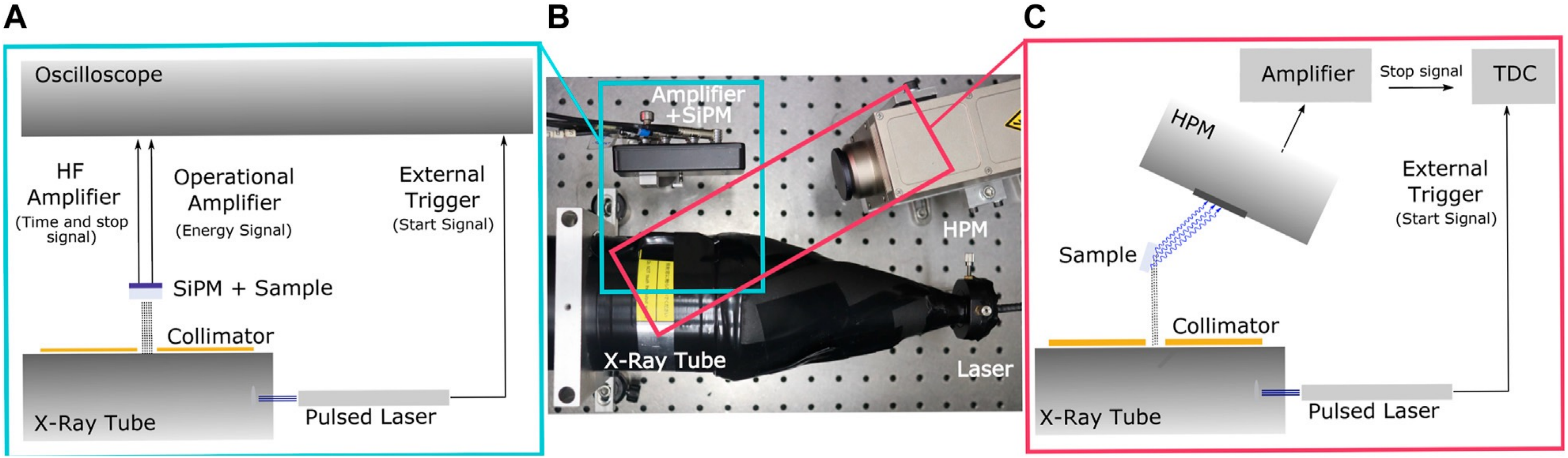


Nanocomposite characterisation

- Absorption, excitation and emission, scintillation kinetics, light yield
- Difficult, why?
- Composites based on plastics (PVT, PMMA) → density ≈ 1 g/cm^3
- Low stopping power → not possible to use e.g. ^{137}Cs source
- Unknown way of energy transfer between host and QD
- Not much theory behind scintillation kinetics (unlike in crystals)

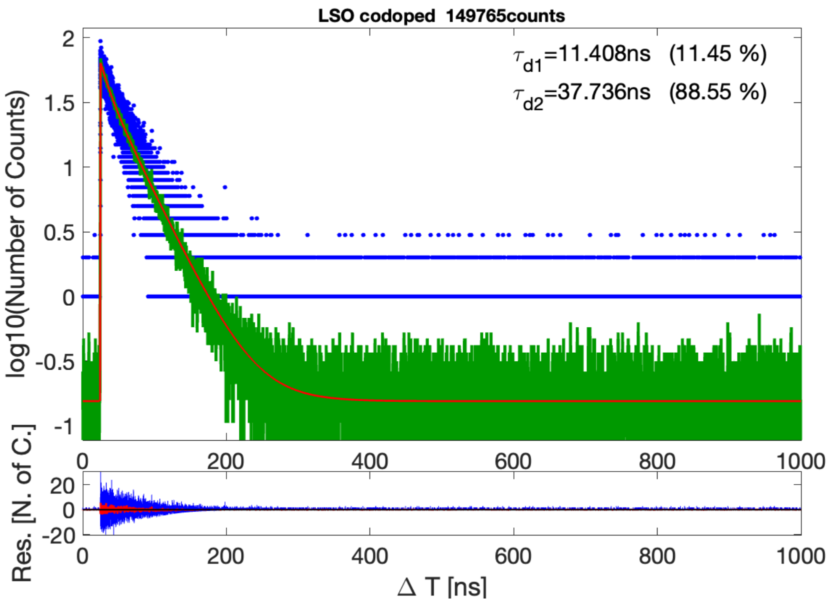
X-ray bench

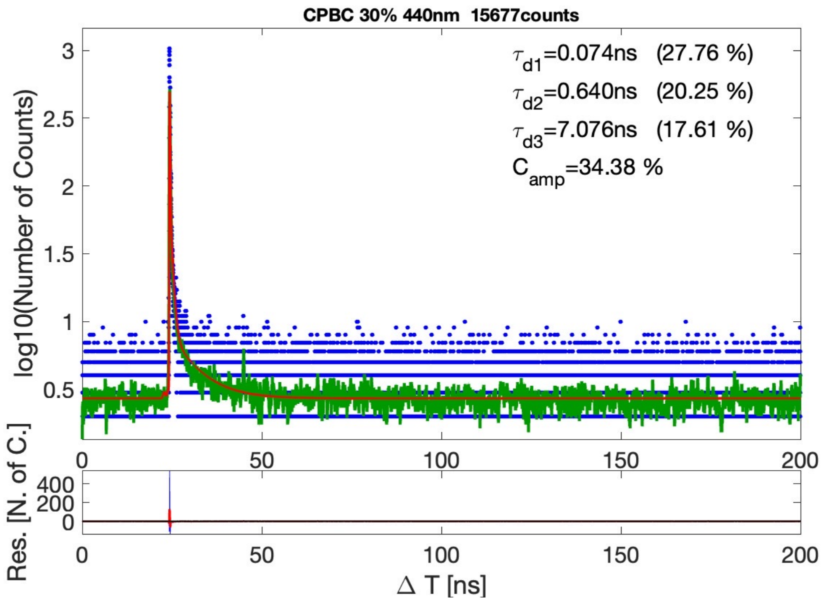
- A: Detector time resolution (DTR)
- C: Time correlated single photon counting (TCSPC)



TCSPC

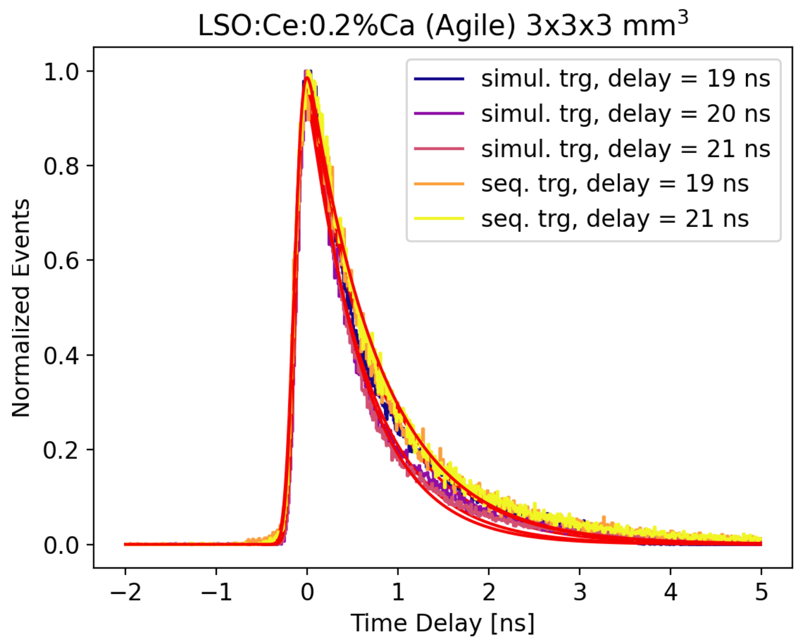
- Scintillation kinetics: rise and decay time
- Used for very fast samples (sub-us)
- Using hybrid-PMT to achieve better timing resolution
- Complicated analysis unlike for inorganic crystals

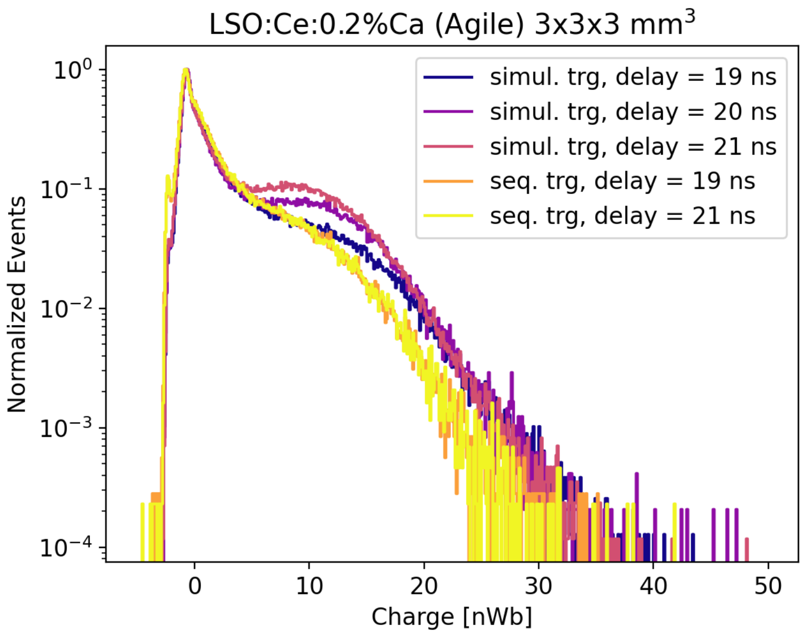




Detector time resolution

- Inspired by PET (TOF-PET) community
  - Coincidence time resolution (CTR)
- Use of trigger signal instead of coincidence crystal
- Using SiPM as a photodetector
- Possible way to estimate light yield
  - If the set-up is well-known and calibrated



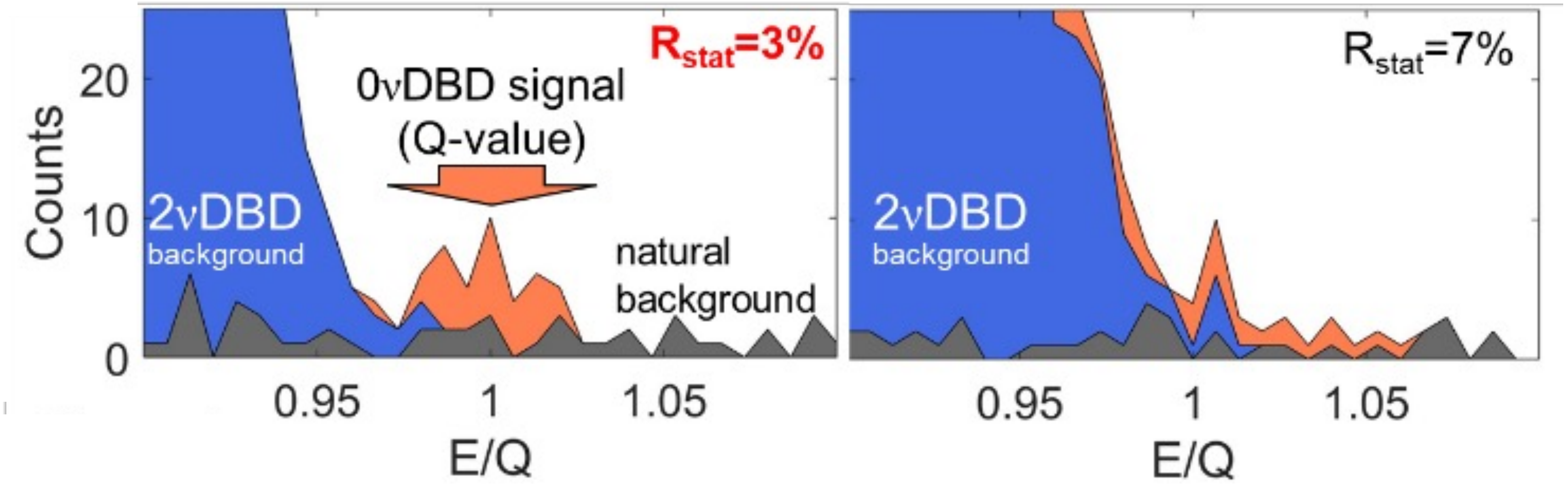


UNICORN

- Novel scintillators for radiation detection
  - QDs embedded in polymer or glass matrices
- Rare event search
  - Neutrinoless double beta decay
- Numerical simulations, Material development, Prototype fabrication
- Currently month 16/48 → simulations and material development

$0\nu\beta\beta$ signiture and requirements

- Monochromatic peak at Q-value
- Excellent energy resolution
  - 3-5 % at 3 MeV
- Large volumes
  - Mass scalability and reasonable cost (impossible with inorganic crystals)

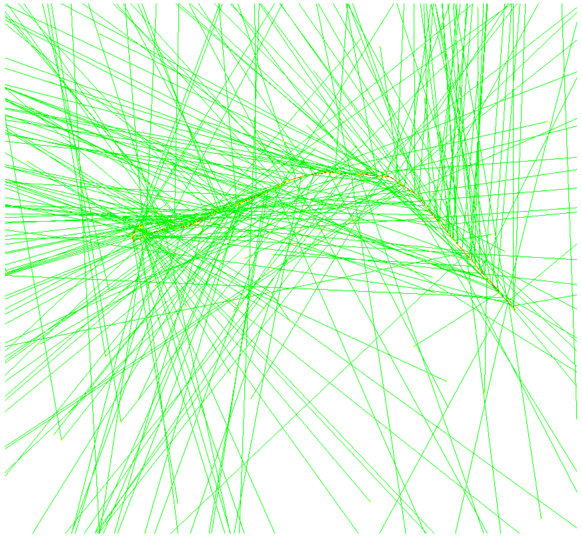
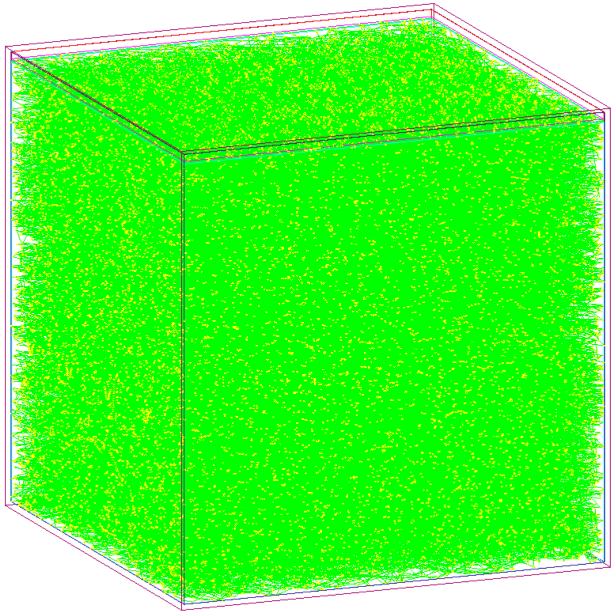
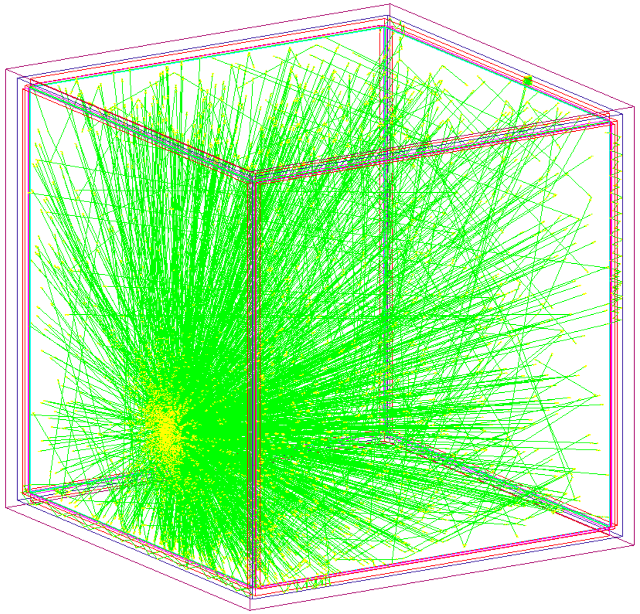


Why CdSe/CdS QD?

- Neutrinoless double beta decay emitters!
    - Q-value around 3 MeV
- Can be used as a source and detector at the same time
    - Better energy containment
- Some samples already available
    - Absorption too high
    - Significant amount of scattering

UNICORN: GEANT4 simulations

- 5x5x5 cm^3 composite volume
- 1.5 MeV primary electron (1 out of 2 with Q = 3 MeV)
- Production of scintillation and Cherenkov photons
- Light transport and its collection at the photodetector

GEANT4 input parameters

- Not possible to include nanocrystals in geometry
  - Homogeneous composite material with macroscopic properties
- Emission and absorption spectra extracted from NC solution or composite measurements
- Unknown light yield → how to measure it?
- Uknown scattering properties (Rayleigh for QDs, Mie for clusters and supercluster, is something else missing?)
  - Perfoming scans with varying attenuation lengths

Influence of light scattering on energy resolution

- High energy resolution requires many photons
  - Light production $\rightarrow$ light yield of the composite
  - Light transport within the composite
  - Photodetection efficiency (SiPM with 40 % or even SDD with 80 %)
- Light transport affected by scattering and absorption processes
- Calculation of light collection efficiency (LCE)

$$LCE = \frac{\#\text{ of }\gamma\text{ reached photodetectors}}{\#\text{ of Cherenkov } + \text{ scintillation }\gamma\text{ created}}$$

Light collection efficiency scan

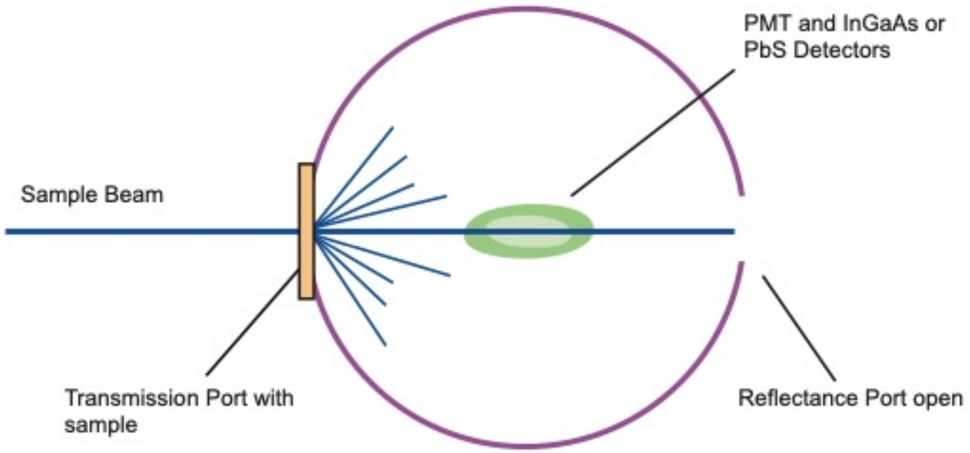
- Varying Rayleigh and Mie attenuation lengths
- 2 geometries: 1 (bottom) and 6 (top) photodetectors
- Properties of Cu-doped CdSe QD solution

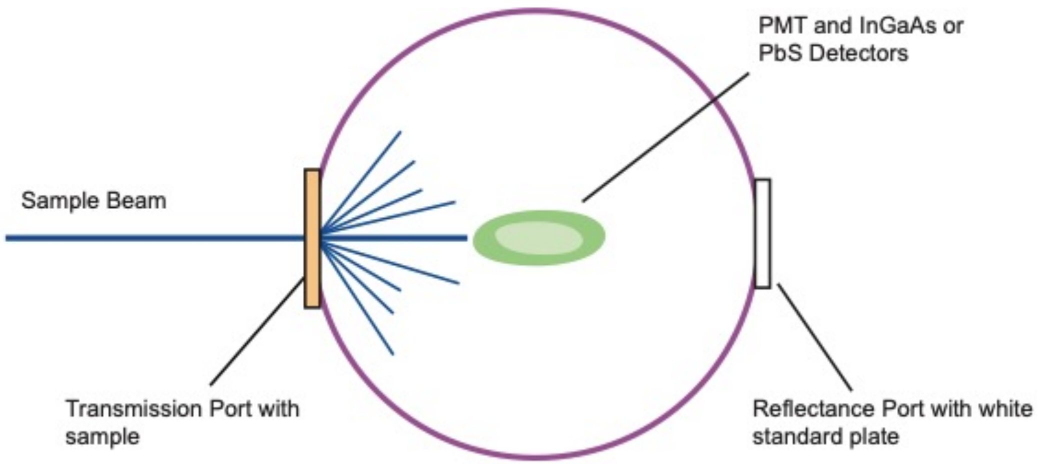
λ_{Ray} [mm]	10^9	10^9	10^9	10^9	10^9	100	10	1	0.1
λ_{Mie} [mm]	10^9	100	10	1	0.1	10^9	10^9	10^9	10^9
LCE [%]	78.2	78.1	77.4	69.4	40.3	77.3	70.1	42.4	14.1

λ_{Ray} [mm]	10^9	10^9	10^9	10^9	10^9	100	10	1	0.1
λ_{Mie} [mm]	10^9	100	10	1	0.1	10^9	10^9	10^9	10^9
LCE [%]	11.7	11.8	11.9	11.6	7.3	11.9	11.6	7.6	2.6

Decoupling of Rayleigh and Mie scattering

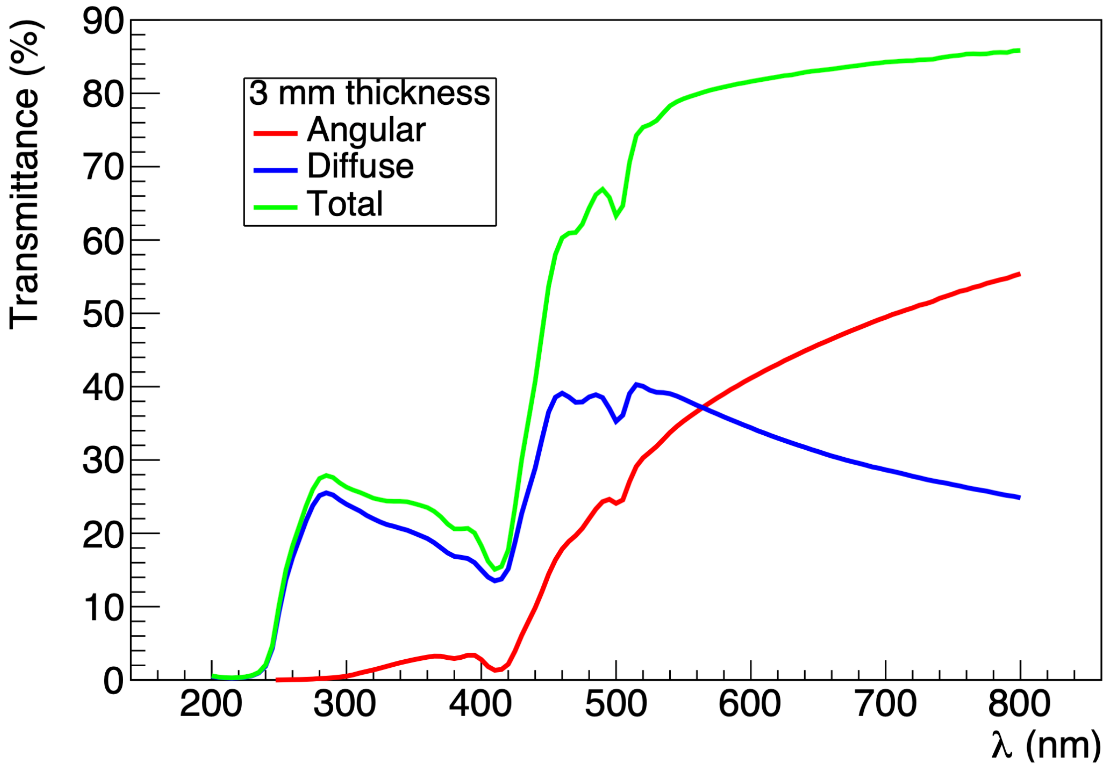
- Using transmittance measurements
  - Lambda spectrometer by PerkinElmer
- Plug-in integrating sphere
- Angular, total, and diffuse transmittance





Transmittance measurements

- Preliminary measurement with samples of 0.1% CdSe/CdS in PMMA
- Induced increase of transmittance below 475 nm
- Ratio between Rayleigh and Mie?
  - Varying distance from integrating sphere
- Additional GEANT4 simulations



Nanocomposites are exciting prospects as future scintillators that exhibit various difficulties in both experimental characterisation and numerical simulations that we have the opportunity to overcome!

Thank you for your attention!