INFN BARI
Istituto Nazionale di Fisica Nucleare

INFN Workshop on Future Detectors 2022

"Quantum-dot light emitters for chromatic calorimetry"

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INFN Bari

IFD 2022, 17-19 Ottobre, Bari

Motivations

Potential of quantum sensing

- the possible applications are incredibly varied
- within few years from the laboratory to real-world/ commercial
- many advantages over traditional semiconductors: compact size, fast operation, superior transport and optical properties

Why QT for HEP?

- increasingly **ambitious physics targets** require **dedicated detector R&D**

R&D for future calorimeters:

- **Demanding needs** from HEP: radiation-hard, enhanced electromagnetic energy and timing resolution, high-granularity with multi-dimensional RO for particle-flow
- R&D with existing technologies can potentially meet this **challenge** at the cost of a high complexity of the readout system

Technology-driven ('blue-sky') R&D to **push detectors beyond state-of-the-art**

Low Dimensional materials for scintillating detectors

Conventional semiconductor bulk material:
- continuous conduction and valence band

→ broad spectrum
- typical 1 photon/Mev/ps (LYSO)

→ small yield from fast signal component

Nanocrystals (NC) 1 - 10 nm size:
- discrete energy levels
- energy gap depends on size **[keypoint]**

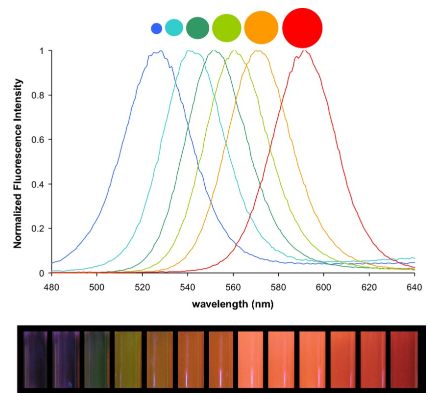
→ tuning of opto-electronic properties, such as for instance the **emission wavelength**

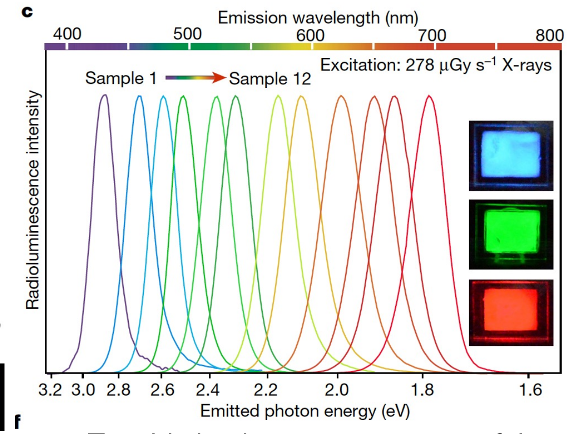
- In direct-band-gap-engineered semiconductor NCs:

→ **scintillation decay times below 1 ns**

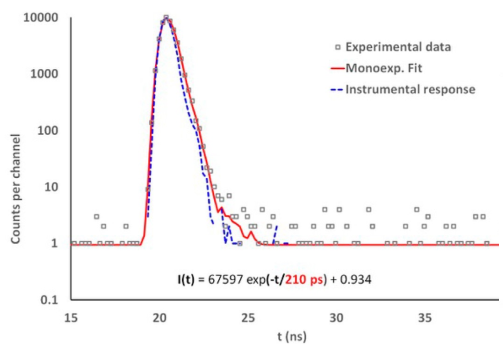
Limitations:
- small energy deposited
- low stopping power
- self-absorption

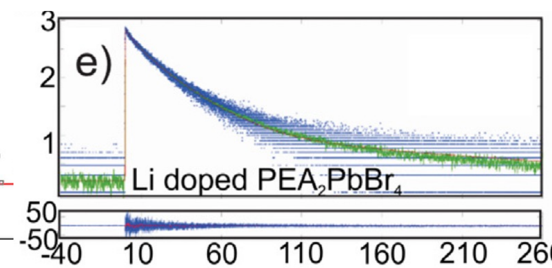
→ **combine bulk scintillators and NCs**



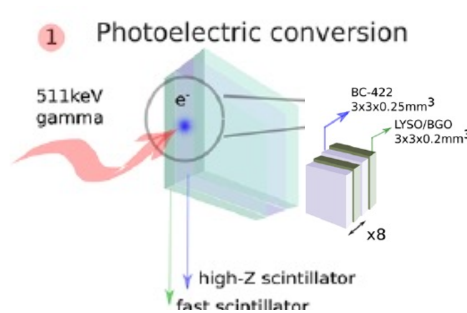


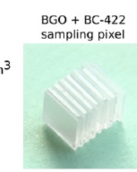
Tunable luminescence spectra of the perovskite QDs under X-ray
[https://doi.org/10.1038/s41586-018-0451-1]





Scintillation light time decay. Left: ZnO(Ga) under irradiation by X-rays [doi:10.1016/j.optmat.2015.07.001]. Right: Li-doped PEA_2PbBr_4 [doi:10.1063/5.0093606]



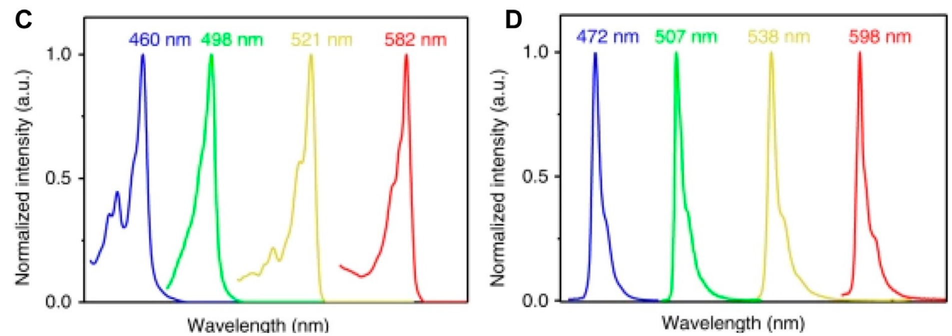


Left: fast plastic BC-422 layers combined with high-Z LYSO as proof-of-principle [doi: 10.1088/1361-6560/ab18b3]. Right: Quantum-dot doped polymer [doi:10.1016/j.radmeas.2018.02.008]

Chromatic calorimeter

- High tunability and narrow emission bandwidth of NCs
- Possibility to combine NCs with bulk scintillators

→ **idea of chromatic calorimeter**



Normalized UV-vis absorption (C) and photoluminescence (D) spectra of triangular carbon quantum dots [doi:10.1038/s41467-018-04635-5]

Single high-Z material doped with NCs with different emission wavelengths (wl)

- longest wl towards the beginning
- shortest wl towards the end

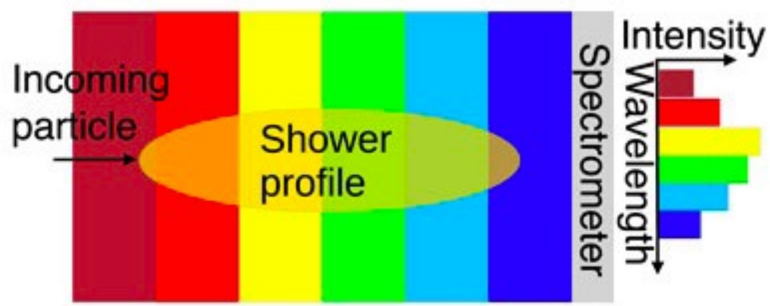
→ **longitudinal tomography of the shower profile**

  → particle ID

  → high-granularity

→ **potentially fast response**

  → trigger



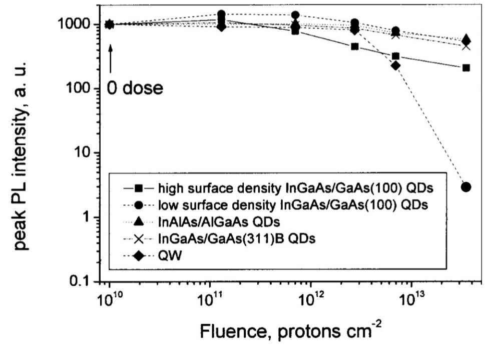
Chromatic calorimeter sketch [doi:10.3389/fphy.2022.887738]

Many technological challenges

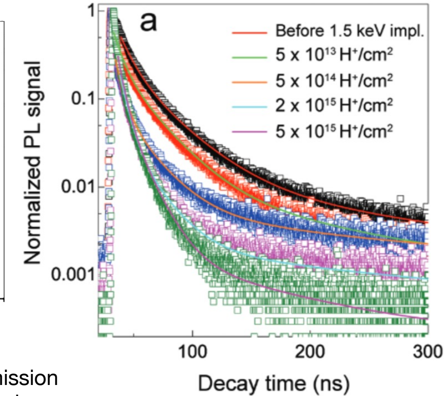
- radiation hardness of nano materials
- readout electronics
- light guiding → transparency (self-absorption)
- light yield
  - bulk doping technique
  - NC density, device geometry

R&D needed to make this real

1) Access radiation hardness of nano materials (perovskites, QDs, quantum wells)
- few studies with protons and HIP in literature
- damage depends on metamaterial structure
- → systematic studies for different NC families and deposition/doping techniques

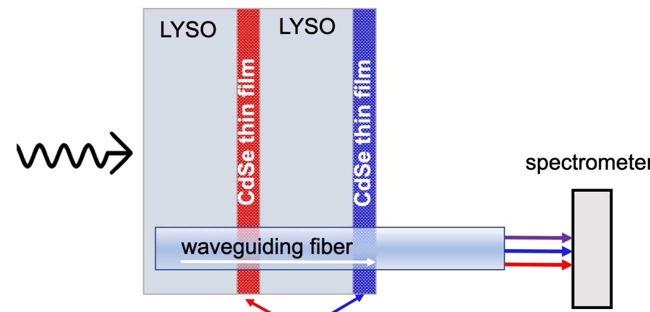


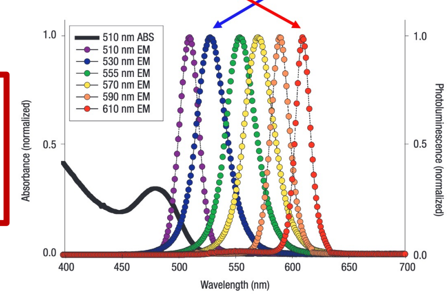
Effects of proton irradiation on luminescence emission and carrier dynamics of self-assembled III-V quantum dots [DOI:10.1109/TNS.2002.806018]



PL after proton-irradiation on CdSe/CdS Core/Shell Quantum Dots [**doi.org/10.1002/adfm.201904501**].

2) Proof-of-principle device
- simplified layered structures
- use «well»-known materials (LYSO bulk, CdSe/CdS QDs)
- → prove that different layers are resolved
- → assess light guide design (one fiber, array)
- → measure PL time resolved spectrum and yield





https://doi.org/10.1038/nmat1390

A great technical challenge
→ enhanced QT expertise in the HEP community