Development of high performance heterostructured calorimeter for future intensity frontier experiments (HetCal)

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EM calorimetry for future experiments

Many key issues for high performance detectors for HL-LHC, FCC and intensity frontier experiments are also issues for electromagnetic calorimetry

Inorganic crystal		Organic scintillators
• High density, compact, good energy resolution • High light yield and/or fast emission • High cost, difficult to build large system • Radiation resistance ?	**VS**	• Good light yield and fast emission • Economical • Low density: usually used in sampling configuration → inferior energy resolution • Radiation resistance ?

Can very fine sampling/heterostructured electromagnetic calorimeters be optimized to obtain performance approaching that of crystal calorimeters?

HetCal goal

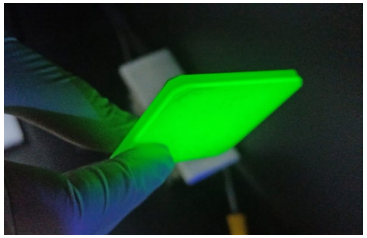
- **Establish a technological solution to be adopted for electromagnetic calorimeters to be used in the next generation high intensity experiments.**
  Physics case: NA62x4, KLEVER main ecal → HIKE

- **Obtain energy resolution and efficiency comparable to that for homogenous detectors based on inorganic crystals, with sub ns time resolution**

- **Two alternative solutions proposed:**

  ✓ **Shashlyk, based on the KOPIO calorimeter design, with spy tiles**

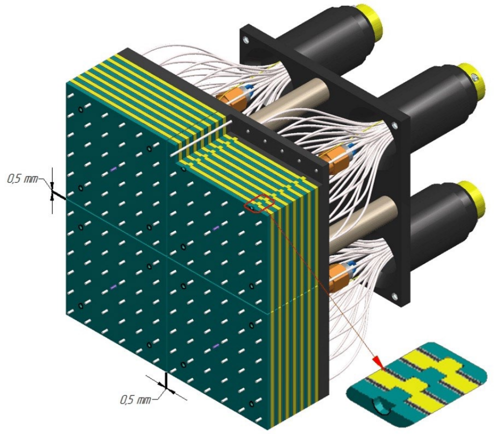
  ✓ **Heterostructures with lead glass + quantum confined nanocrystals in combination with standard scintillators**



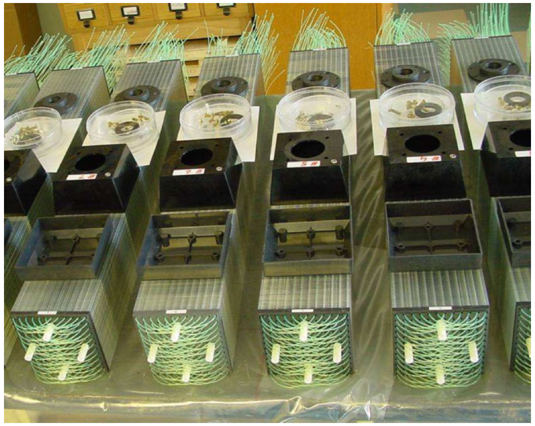
Shashlyk calorimetry: state of the art

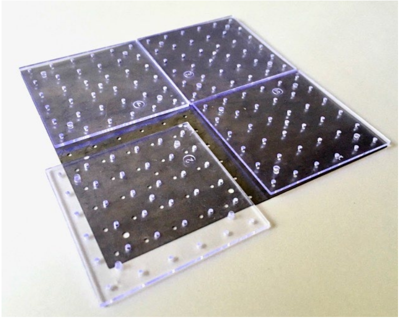
Very-fine sampling calorimeters for high-precision EM calorimetry can provide good energy and time resolution

Calorimeter	Pb/scint [mm]	Energy res	Sampling fraction
ALICE EMCAL	1.44/1.76	$10\%/\sqrt{E} \oplus 5\%$	16%
LHCb ECAL	2.0/4.0	$8\%/\sqrt{E} \oplus 1\%$	24%
PANDA/KOPIO	0.275/1.500	$2.8\%/\sqrt{E} \oplus 1.3\%$	47%



Fine-sampling shashlyk for **PANDA/KOPIO** produced at Protvino
0.275 mm Pb + 1.5 mm scintillator
$\boldsymbol{\sigma_E/\sqrt{E} \sim 3\%}$ $/\sqrt{E}$ (GeV)
$\boldsymbol{\sigma_t \sim 72}$ **ps** $/\sqrt{E}$ (GeV)
$\boldsymbol{\sigma_x \sim 13}$ **mm** $/\sqrt{E}$ (GeV)





PANDA style:
Scintillator: extrusion molded polystyrene, 1.5% PTP + 0.04% POPOP
WLS fibers: Kuraray Y-11(200), 1 mm, $\lambda_{att} \sim 3.5$ m; $\tau_{decay} \sim 7.5$ ns

Shashlyk calorimeter with spy tiles

Main electromagnetic calorimeter (MEC):

Fine-sampling shashlyk based on PANDA forward EM calorimeter produced at Protvino

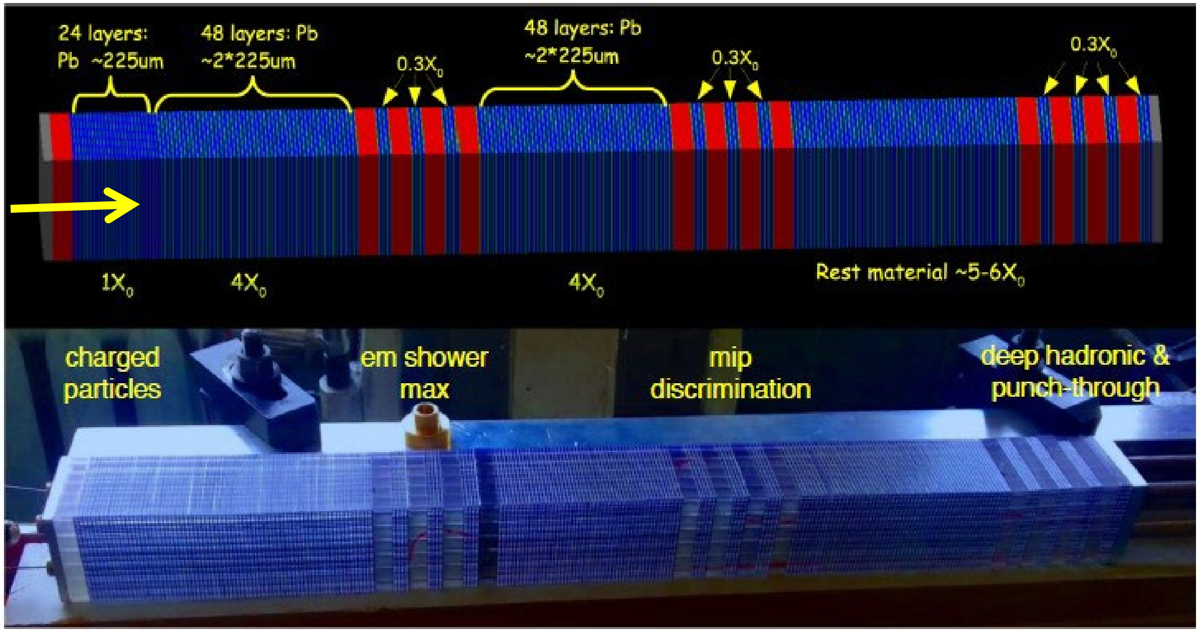
0.275 mm Pb + 1.5 mm scintillator

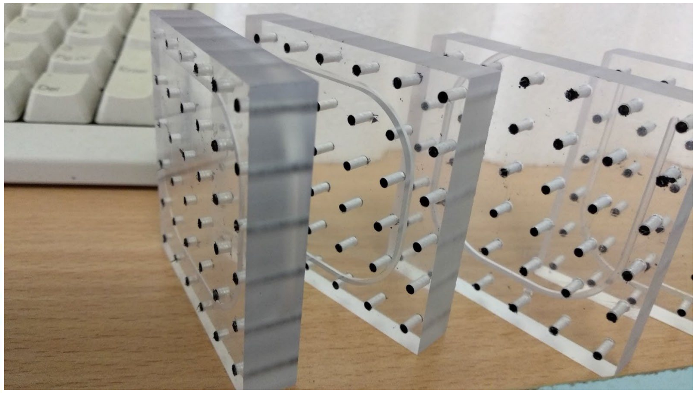
PANDA/KOPIO prototypes:

- $\sigma_E/\sqrt{E} \sim 3\% /\sqrt{E}$ (GeV)
- $\sigma_t \sim 72$ ps $/\sqrt{E}$ (GeV)
- $\sigma_x \sim 13$ mm $/\sqrt{E}$ (GeV)

New for PRIN: Longitudinal shower information from spy tiles

- PID information: identification of μ, γ, n interactions
- Shower depth information: improved time resolution for EM showers

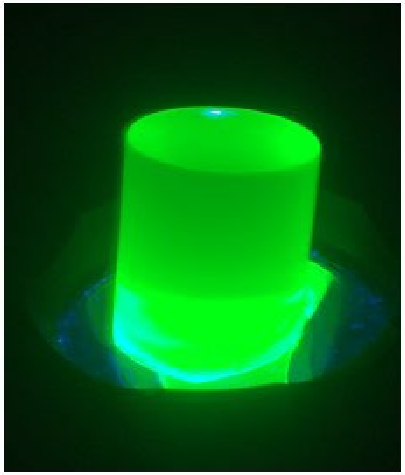




Nanomaterial composites

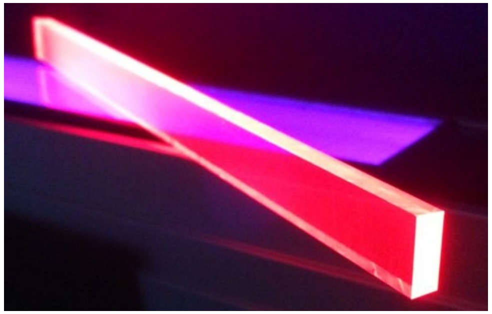
Semiconductor nanostructures can be used as sensitizers/emitters for ultrafast, robust scintillators:

- Perovskite or chalcogenide (oxide,sulfide) nanocrystals
- Cast with polymer matrix
- Decay times down to O(100 ps)
- Radiation hard to O(1 MGy)



Nanocrystals and composite can be engineered to obtain performance requirements

- Nanocrystal: emission wavelength, decay time, etc.
- Composite: concentration of nanocrystals and/or additional fluors,

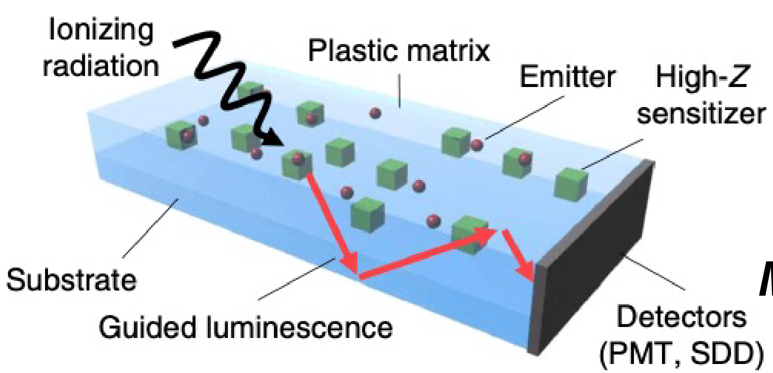


Can realize thin nanocrystal films to realize fast timing layers
Nanocrystal composites could make very fast WLS devices to efficiently couple light from fast scintillators to SiPMs

Nanomaterial composites: state of the art

nature nanotechnology
ARTICLES
https://doi.org/10.1038/s41565-020-0683-8
Check for updates

Efficient, fast and reabsorption-free perovskite nanocrystal-based sensitized plastic scintillators



S. Brovelli
Bicocca
GLASS to POWER

R&D on practical scintillators for HEP:
1. Perovskite sensitizer ($CsPbBr_3$, 2% wt)
2. Non-radiative transfer to fluor (perylene dyad, 0.15% wt)
3. Light propagation and readout via PMMA matrix

M. Gandini et al., Nat. Nanotechnol. 15 (2020) 462

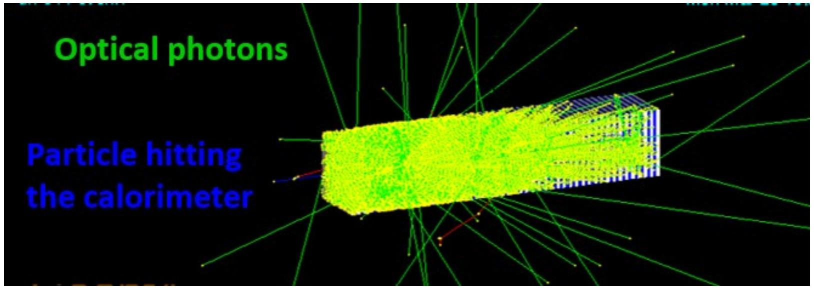
Tests with perovskite composite:
$CsPbBr_3$ NC + perylene dyad + PMMA
- **Peak emission ~ 620 nm**
- **BGO-like light yield at peak**
- **τ_{decay}(fast) = 3.4 ns (87%)**
- **τ_{decay}(slow) = 14.1 ns (13%)**
- **No degradation up to 800 Gy**

Since in conventional scintillators much of the radiation damage is from loss of transparency of the matrix material (increased absorption at small wavelengths UV/blue and material becomes more yellow), NC emission wavelength can be adjusted

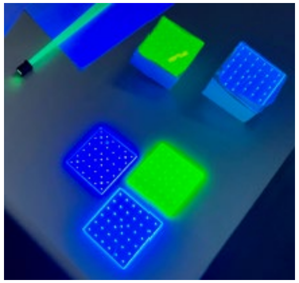
Heterostructured calorimeter with nanocrystals

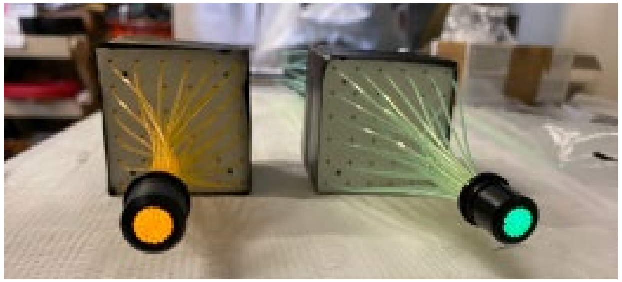
Thanks to the expertise of GLASStoPOWER, that will collaborate as external industry to the project, :

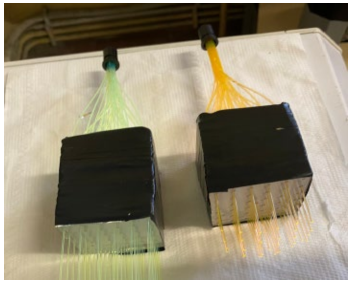
- **make use of lead glass block as high density material together with NC-scintillator tiles:**
  - **a single block can provide both fast cerenkov light (from lead glass) and scintillation light (from NC material)**
  - **lead-glass can act as light-guide for both light sources**



- **demonstration of a NC-scintillator-based, fine-sampling EM calorimeter (AIDAinnova NanoCal based)**







Readout: comparative studies for the photomultiplier (SiPM or phototubes) optimization depending on several constraints: optical coupling /cost/radiation hardness/etc.

Team and plans for HetCal PRIN

Research team

- Marco Mirra (PI)
- Paolo Massarotti
- Fabio Ambrosino

- Mario Merola (coPI)
- Guglielmo de Nardo

- External partner: spin off UniMiB, nanocomposite R&D

Funded PRIN for 2 years starting from autumn 2023. Work packages:

- WP1 - Detailed Monte Carlo simulations of the different proposals for the ECAL, together with their integration in a complete HIKE simulated environment (mainly UNINA unit)
- WP2 - Comparative studies of scintillators and fibers for Shashlyk proposal and NC scintillators for heterostructured calorimeter. Construction of final prototypes for one or both proposals with full readout (SiPMs+analog frontend). Test beam at BTF and/or in NA62 experimental hall (mainly INFN unit and external partner)
- WP3 - Dissemination and public engagement (UNINA and INFN)