Status of Scintillator Based Calorimetry

EP R&D Day 2021

Matteo Salomoni
on behalf of WP3.2/WP3.2.1 team

11th November 2021

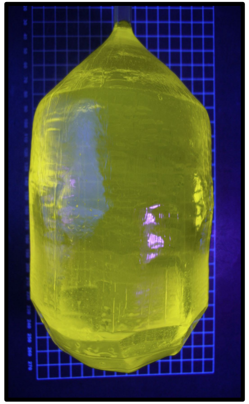
R&D activities: from scintillators to calorimetry

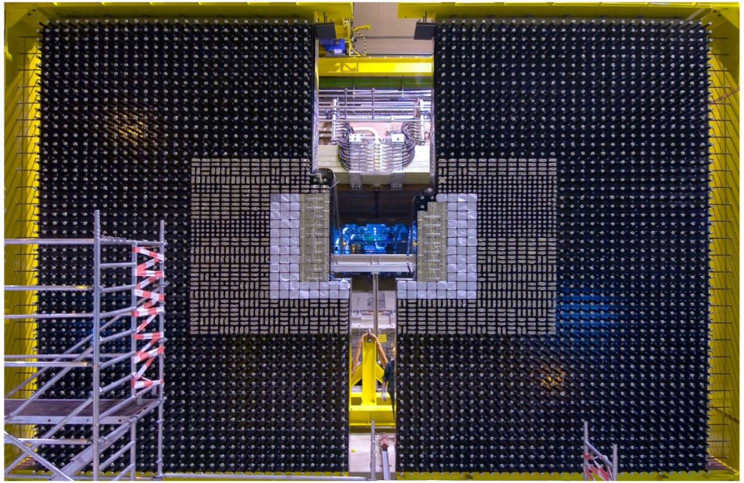
Scintillators R&D

Improve the performance of future HEP calorimeters with timing capabilities

LHCb ECAL Upgrade 2 R&D
benefits from the scintillators R&D

1. **Bulk materials:**
   PWO, BGSO, GAGG, BaF_2,PbF_2, glass, etc..
2. **Nanomaterials:**
   InGaN/GaN QW, Perovskite, MOF, etc..





Fast scintillators R&D in the frame of Crystal Clear Collaboration:

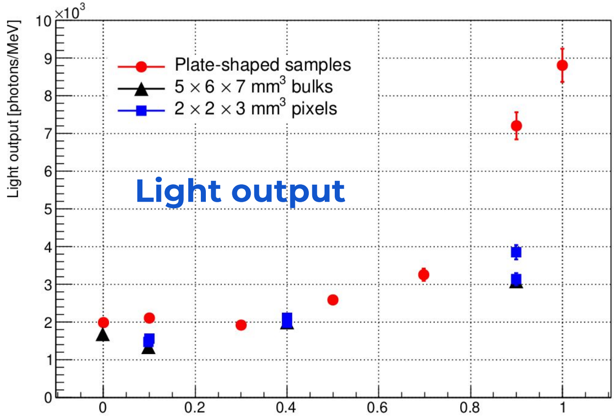
WP objective:
Develop the enabling technologies for future HEP calorimeters capable of timing information. Could be operating both at low or high radiation environment.

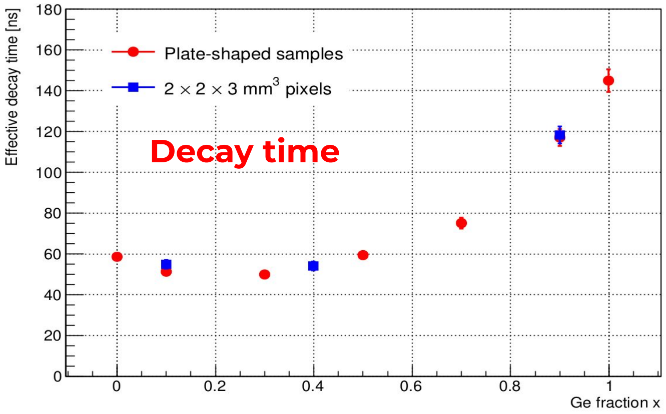
Work plan:

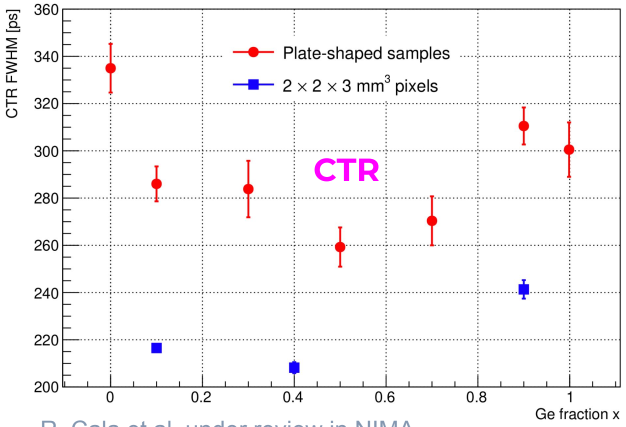
- Identify key requirements in terms of scintillation properties
- Investigate fast emission processes in different scintillators materials (cross-luminescence, hot intraband luminescence, etc..).
- Investigate the possibility to use fast nanomaterials.
- Assess timing performances in test beam.

BGSO crystal: timing properties as a function of the Ge fraction

Change the properties of BGO by substituting Ge with Si







R. Cala et al, under review in NIMA

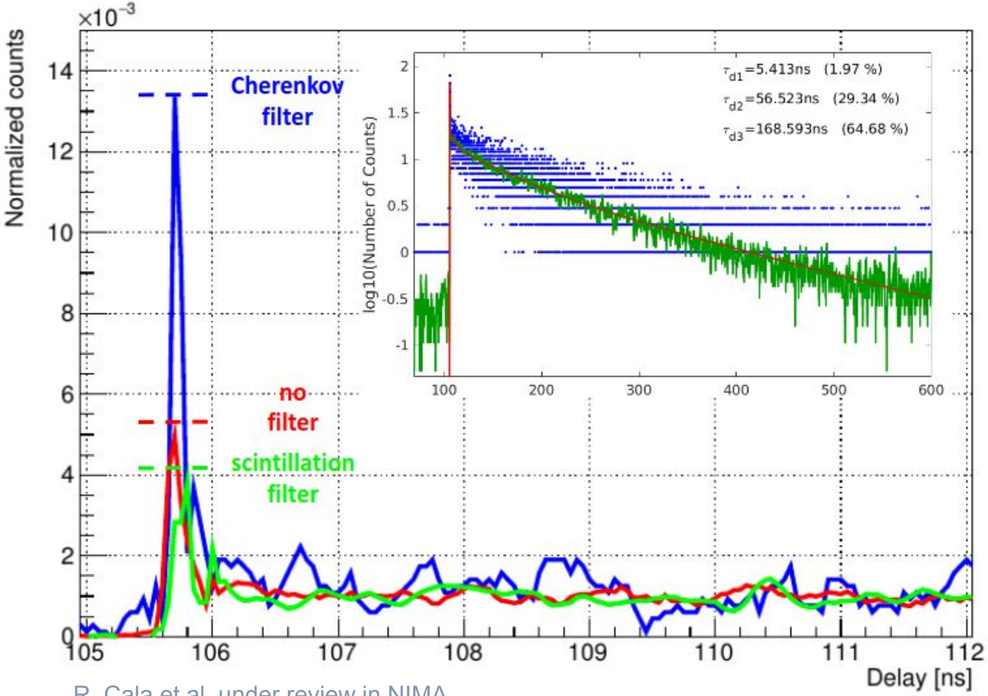
Light output improves with % of Ge and **effective decay time** decreases up to 30 - 40 % Ge. Optimal coincidence time resolution (**CTR**) for 40% Ge.

For a plate geometry:
CTR BGO = 302 ps -> CTR BGSO (50% Ge) = 260 ps
For 2x2x3
CTR BGO = 241 ps -> CTR BGSO (40%) = 207 ps

BGSO: fast Cherenkov emission

Cherenkov emission is visible at the beginning of the pulse.

- Timing improves
- Enable to use dual readout techniques.

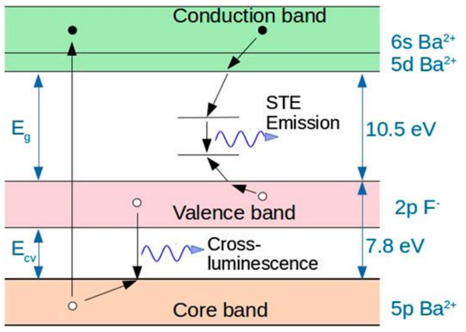


R. Cala et al, under review in NIMA

Cross-luminescence

from BaF_2 to $CsCaCl_3$

BaF_2



Sub ns emission but in UV
& additional slow component (BaF2)

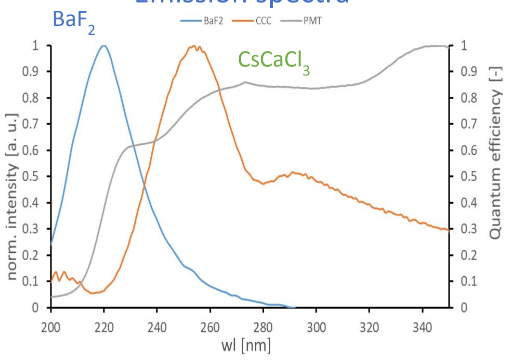
R&D to improve cross-luminescence:

- ⇒ Slow component suppression by doping
- ⇒ Improve PDE
- ⇒ Develop new materials

$CsCaCl_3$ shows an emission shifted towards the **visible (260 nm)** compared to traditional cross luminescence samples (BaF_2).

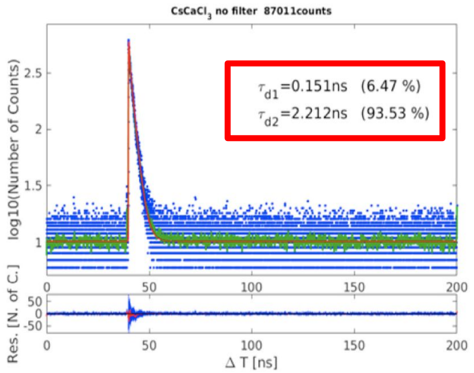
Fast decay components:
0.151 ns and **2.212 ns** decay time.

Emission spectra



Courtesy V. Vanecek, M. Nikl, FZU Prague
Data for BaF_2 from M. Laval et al. , NIM Phys. Res., 206 (1983) 169–176

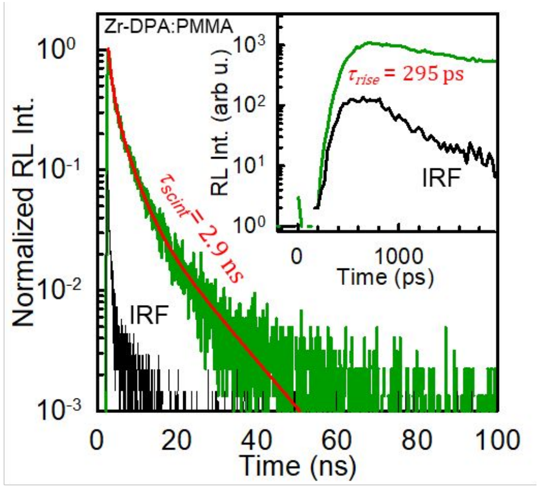
Decay



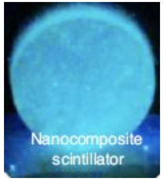
Vanecek et al, Optical Materials X 12 (2021) 100103

Example of fast Nanomaterials

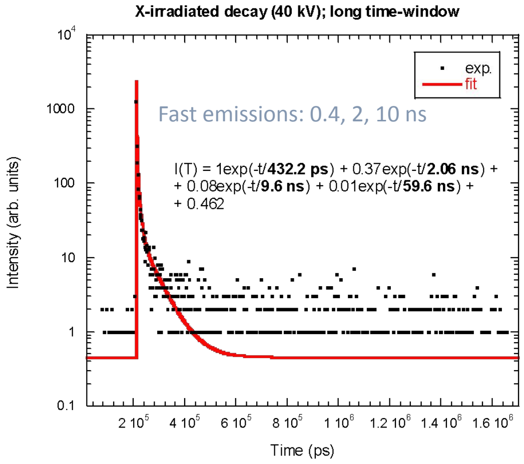
Metal-organic framework (MOF)
UNIMIB

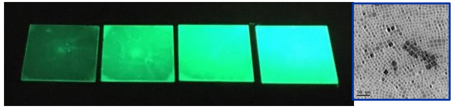


Perego, Jet *al. Nat. Photonics* (2021). https://doi.org/10.1038/s41566-021-00769-z



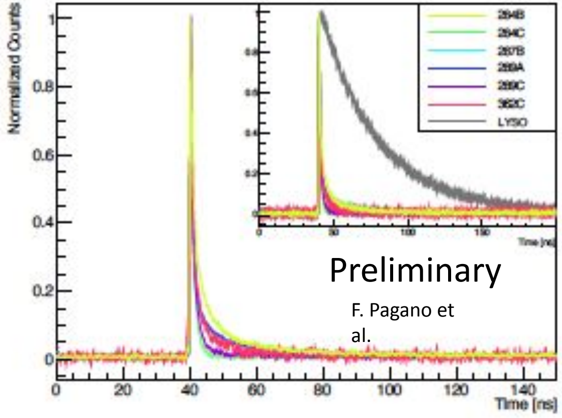
$CsPbBr_3$ thin films deposited on glass substrate
CTU

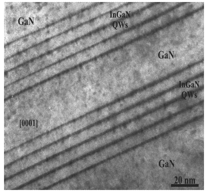




Courtesy V. Čuba, K. Děcká, A. Suchá
CTU, Prague

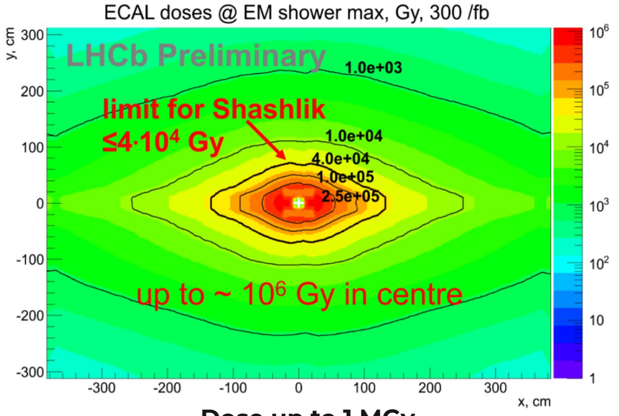
InGaN/GaN QW
FZU



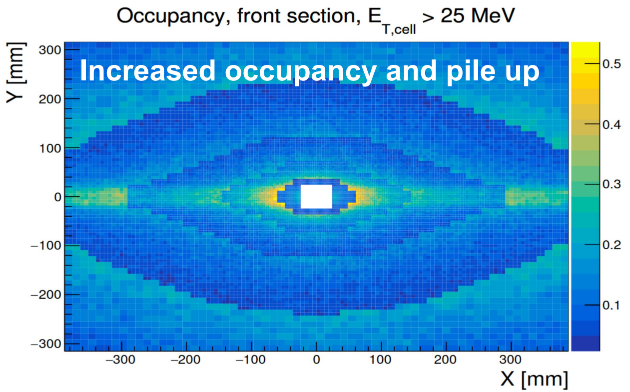


Courtesy A. Hospodkova , FZU Prague

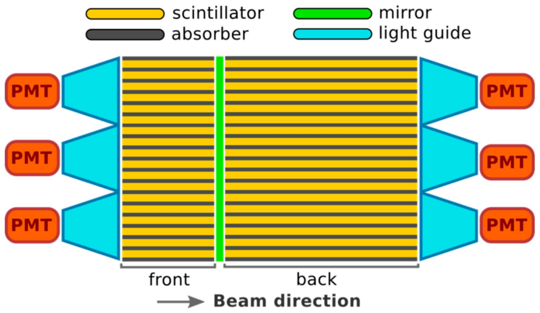
LHCb ECAL upgrade 2 activities



Dose up to 1 MGy
40 kGy region limit for shashlik



Down to 1.5 cm cell size to mitigate occupancy



New rad hard technology: SPACAL
(previous technology Shashlik)

Objectives:

- ❑ Develop **faster and higher radiation hardness fibers** (to be place in the innermost part of the ECAL up to 1 MGy).
- ❑ Obtain a SPACAL detector capable of **good timing** performance (**< 20 ps @ 50 GeV**) with small spill over.
- ❑ **Keep the module intrinsic energy resolution** in the order of $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1\%$

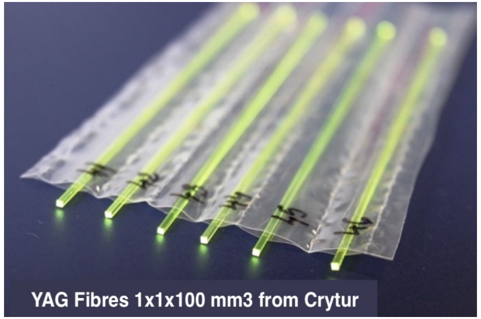
Aluminum garnets

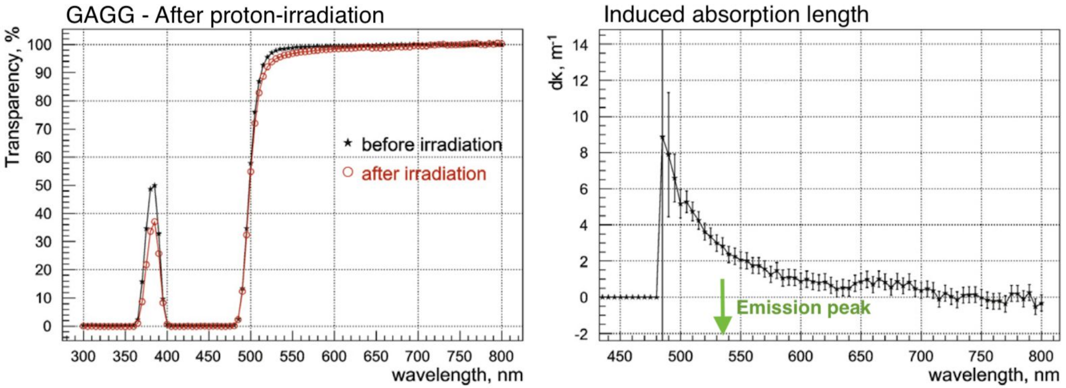
GAGG ingot, courtesy of K. Lebbou, ILM Lyon France

Intensive R&D to produce high quality crystal of fiber shape (up to 10 cm)
Garnets crystal are radiation hard!
GAGG irradiated with protons of 24 GeV/c

- Fluence of $3.1x10^{15}$ cm^{-2}
- **910 kGy** dose
- Induced absorption below $4m^{-1}$ at the emission peak

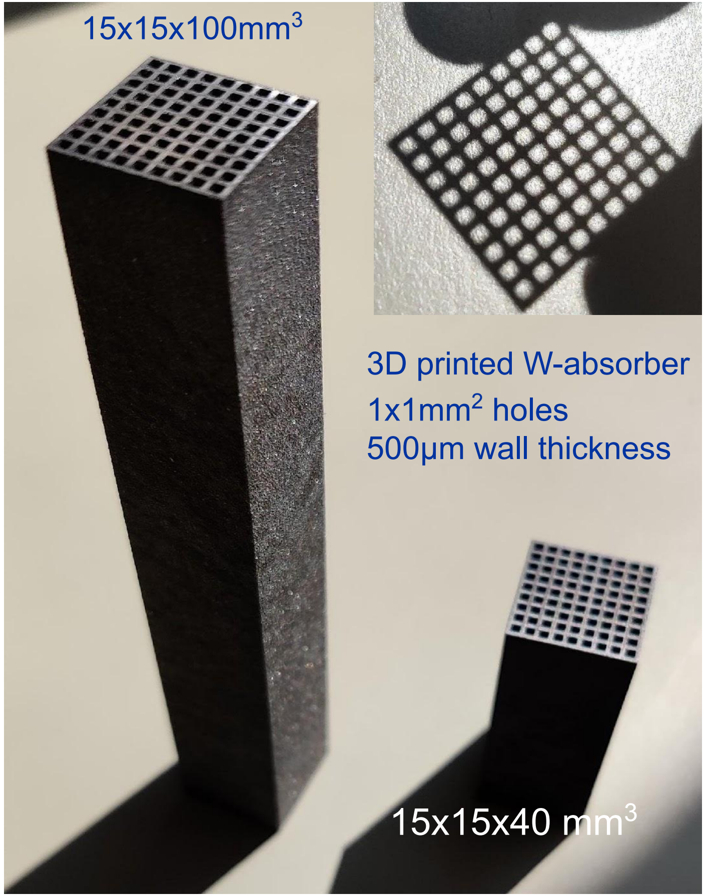
[See: V. Alenkov et al., NIM A 816 (2016) 176]

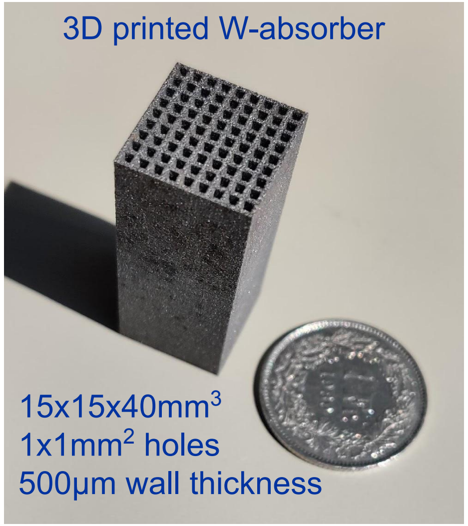




Dense absorber to reach a moliere of 1.5 cm cell region

3D printed tungsten R&D (SPACAL W with GAGG)



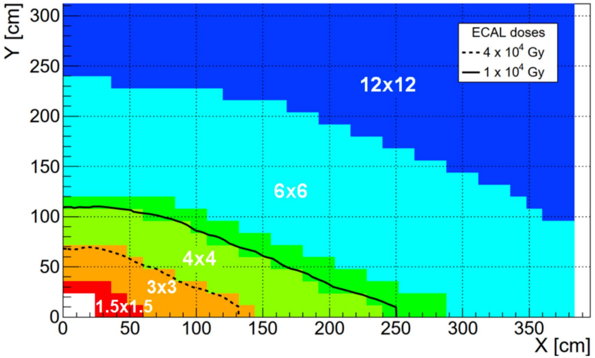


Surface quality obtained allowed to insert scintillating fibers without damaging them (Ra = 5 µm, Rt = 51 µm).

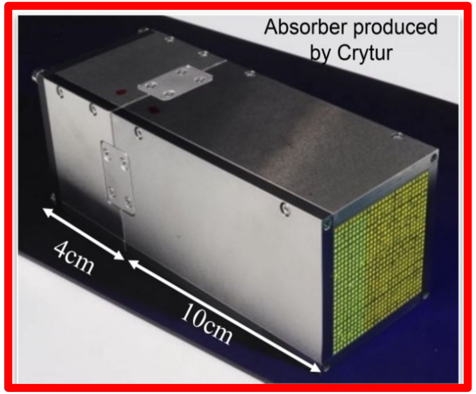
Feature size small enough to fulfill the required geometry.

LHCb ECAL U2: prototypes and readout

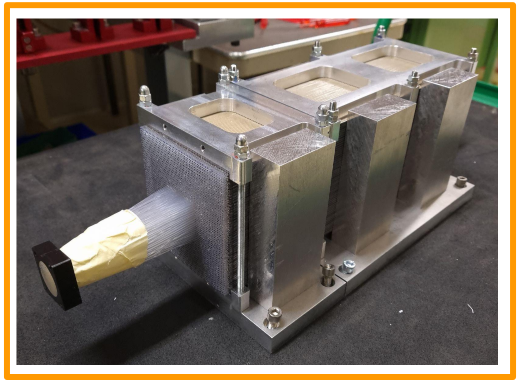
Occupancy requires to have different cell sizes in ECAL.
Regions layout:



SPACAL W GAGG
9-cells of 1.5x1.5 cm^2



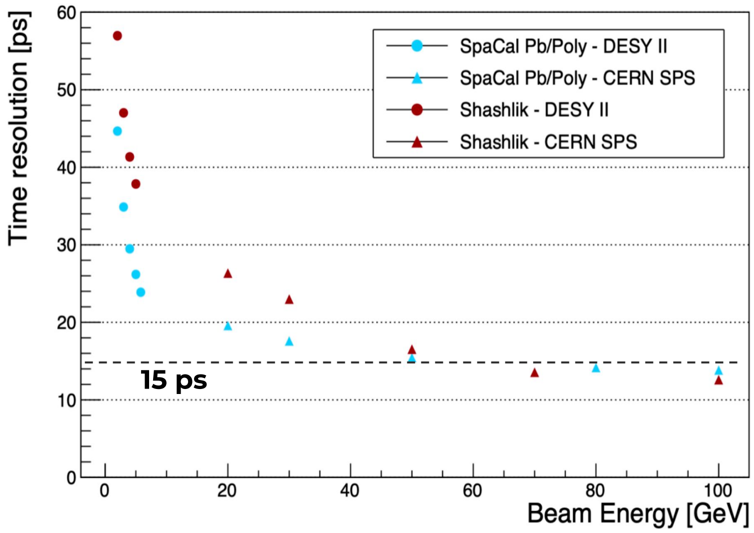
SPACAL Pb poly
9-cells of 3x3cm^2



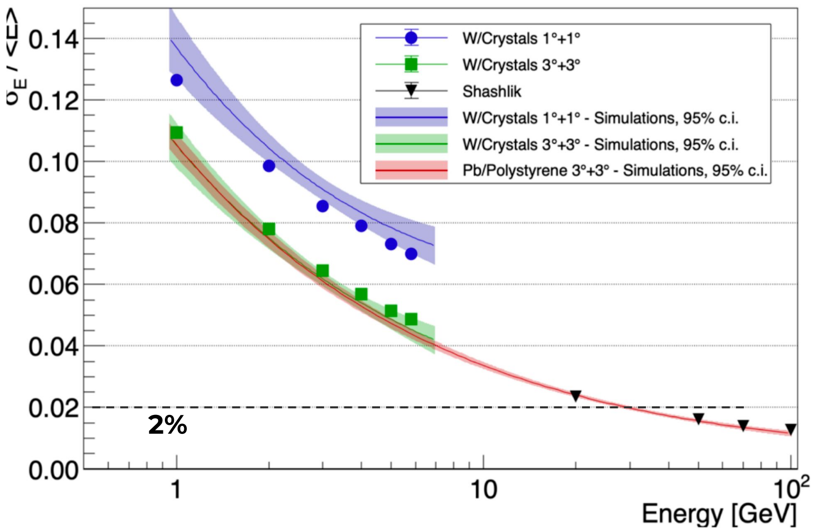
LHCb ECAL U2: results obtained in SPS and DESY (e^-)

- Above **50 GeV we reach 15 ps** with all the prototypes
- Energy resolution below **2% const. term** for both the SPACAL Pb and SPACAL W.

Time resolution

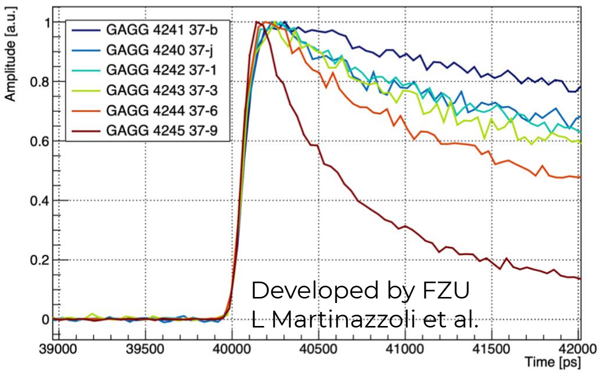


Energy resolution



Ongoing & future R&D

Preliminary



- Embed a high concentration of nanomaterials in a dense matr
- Test capability of dual readout (BGO, BGSO, PWO, etc..).
- Optimize garnet fiber production (e.g. micro pulling technique,
- Spill over mitigation: development of ultrafast garnets (reduce the main component and the slow component)
- R&D on radiation hard plastique (polysiloxane)

-> opportunity not only for LHCb (use case), but for future colliders (eIC, FCC, ...).