# Scintillating sampling ECAL technology for the Upgrade II of LHCb


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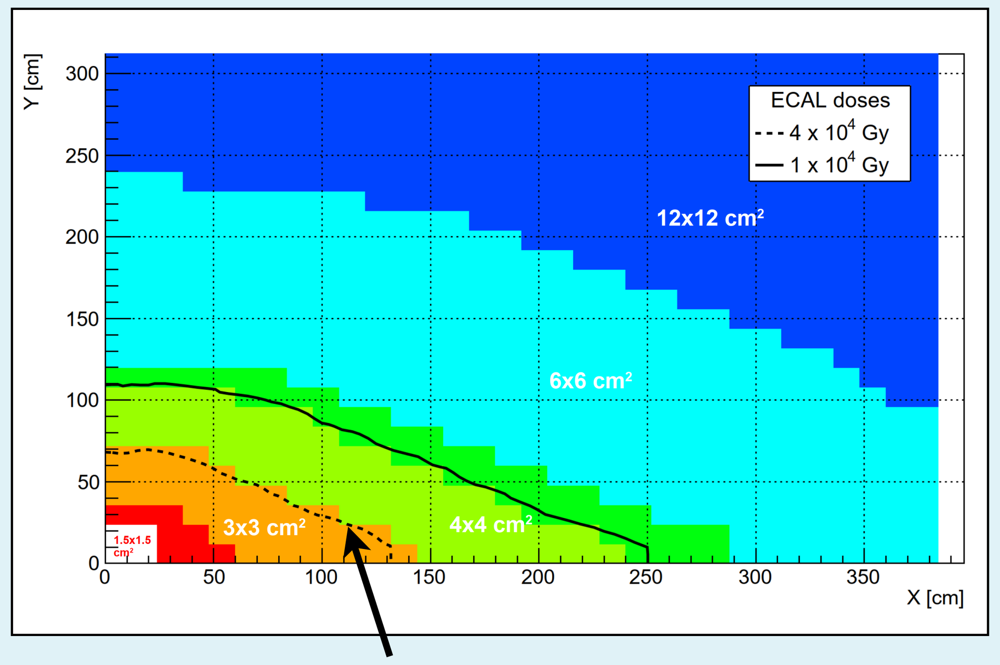
## Motivations

Expected luminosity during **Upgrade II** at LHCb:
$\mathscr{L} = 1 - 2 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

➡ New requirements on the electromagnetic calorimeter (ECAL):

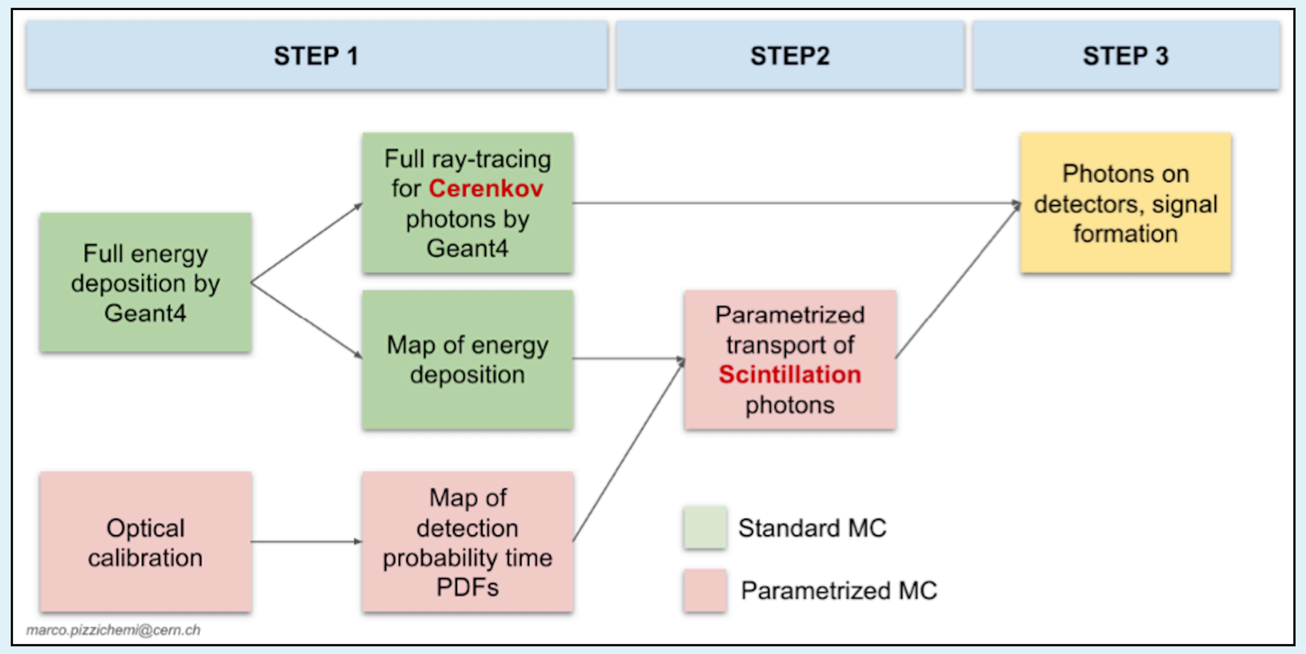
- Sustain up to **1 MGy** in the innermost region
- Mitigate pile-up with high **granularity** and $\mathcal{O}(10)$ **ps** precision timing capabilities
- Keep the current **energy resolution** $\sigma(E)/E \simeq 10\,\%/\sqrt{E} \oplus 1\,\%$




Radiation limit of current Shashlik technology

## Simulation

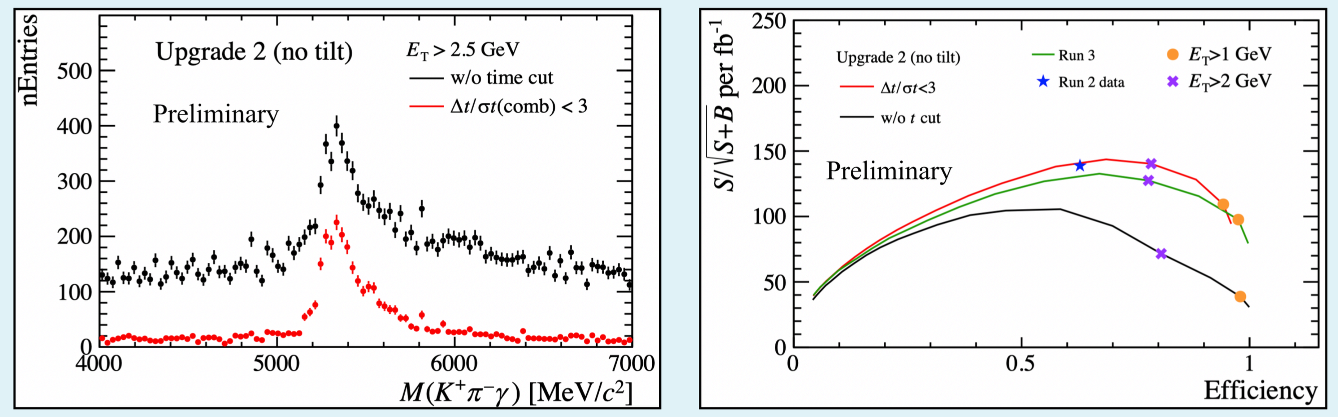
- **Geant4** simulation of energy deposit
- **Parameterised** ray-tracing transport of scintillation photons and photodetector response
- Particle **flux** from the LHCb simulation used as input for physics studies

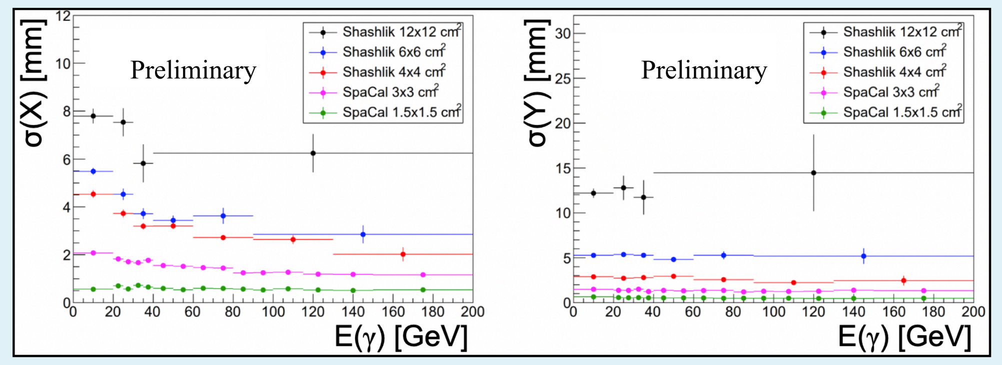



| Region | Module type | Cell size $[\mathrm{cm}^2]$ | Segmentation $[\mathrm{mm}]/[X_0]$ | $R_M$ [mm] | | $\sigma_E/E = A/\sqrt{E} \oplus B$ A/B [%] |
|---|---|---|---|---|---|---|
| 1 | SpaCal W/GAGG | $1.5 \times 1.5$ | 45+105 / 7+18 | 14.5 | MC | 9.1 / 1.4 |
| 2 | SpaCal Pb/PS | $3.0 \times 3.0$ | 80+210 / 7+18 | 29.5 | MC | 10.4 / 0.6 |
| 3 | Shashlik | $4.0 \times 4.0$ | Continuous fibres | 35.0 | Design goal | 10.0 / 1.0 |
| 4 | Shashlik | $6.0 \times 6.0$ | Continuous fibres | 35.0 | Design goal | 10.0 / 1.0 |
| 5 | Shashlik | $12.0 \times 12.0$ | Continuous fibres | 35.0 | Design goal | 10.0 / 1.0 |

## Physics studies

- Study of $B^0 \to K^{*0}\gamma$
- Large combinatorial background suppressed with **timing cut** on photon candidate
- Photon position **resolution** $\simeq 0.5$ mm ($\simeq 1.5$ mm) for SPACAL-W (SPACAL-Pb) and $2-15$ mm for Shashlik [2]



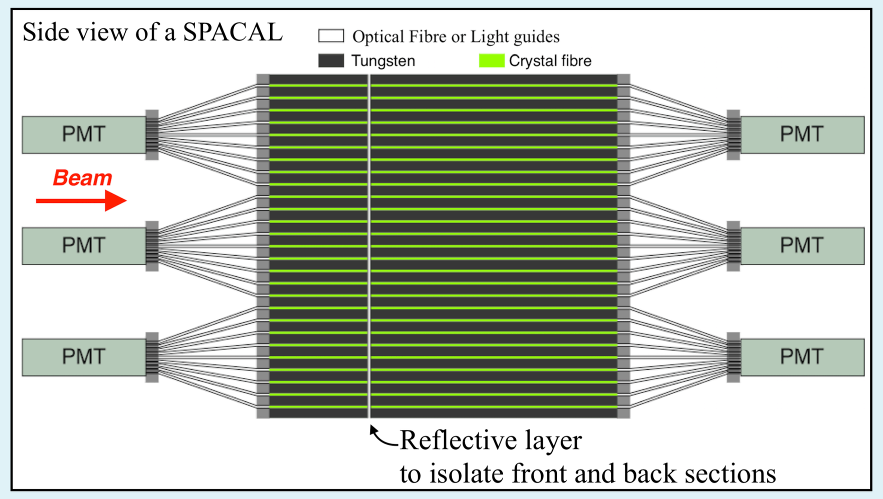

## Spaghetti Calorimeter (SPACAL)

- Innermost region with $1.5$ cm cells with scintillating **garnet crystal** [1] fibres and **W absorber** ($1$ MGy area)
- Inner region with $3$ cm cells scintillating **plastic** fibres and **Pb** absorber ($200$ kGy area)
- Longitudinal **segmentation** and **double-sided** readout

➡ mitigate radiation effect

➡ improve reconstruction

➡ allow for an optional **timing layer** in the shower maximum



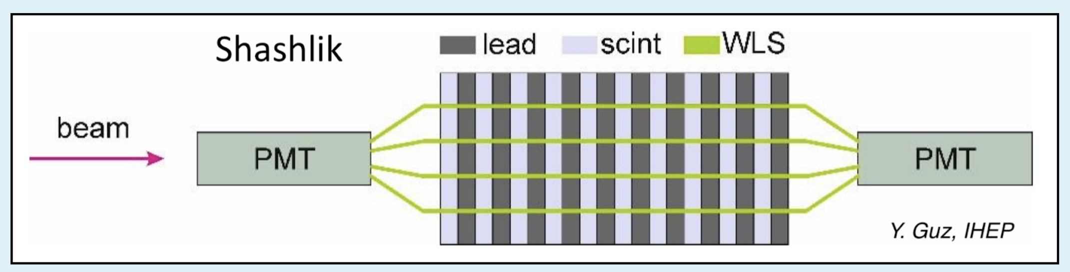

## Shashlik Calorimeter

- Used for current ECAL (in regions with $4$, $6$ and $12$ cm cells)
- $4$ mm scintillating **plastic** and $2$ mm **lead** absorber tiles with wavelength shifting (WLS) fibers
- Will be used for periphery of ECAL ($< 40$ kRad)
- Will be upgraded with:

➡ **Double-sided** readout

➡ Better **PMTs** with smaller time transit spread

➡ WLS fibres with **faster** decay time (KURARAY YS-4)




## Test beam campaigns

- Several prototypes tested with electron beams at **DESY II** and **CERN SPS**
- **Energy** resolution [2]:

➡ Best with incidence angles $\theta_x, \theta_y \geq 3^\circ$, close to $\sigma(E)/E \simeq 10\,\%/\sqrt{E} \oplus 1\,\%$

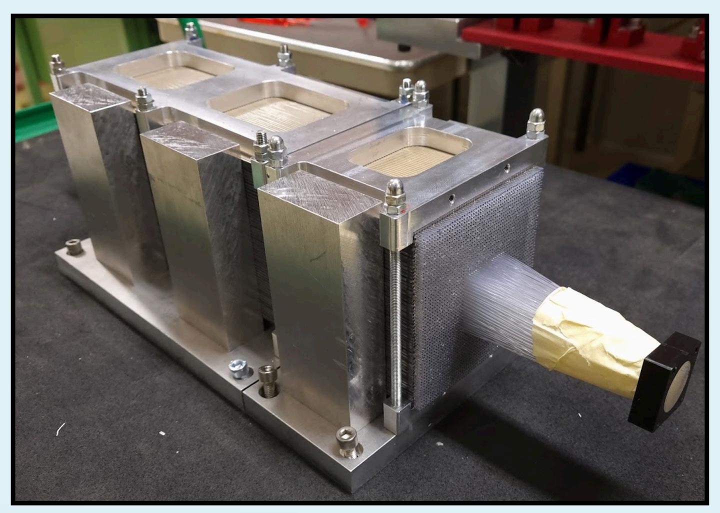
➡ Good agreement with **simulation**

- **Time** resolution [2]:

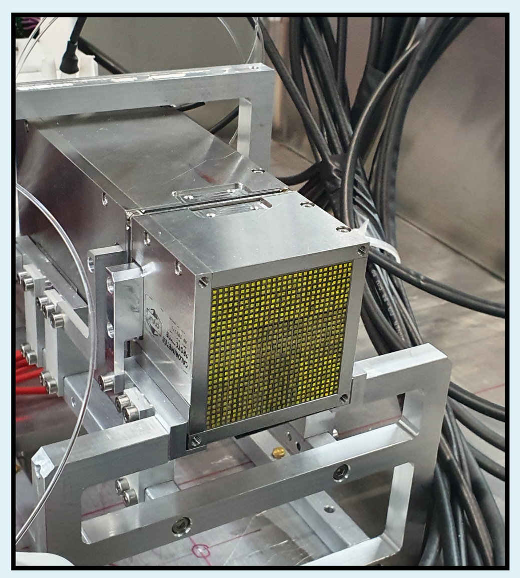
➡ SPACAL slightly better than Shashlik at energies below $50$ GeV

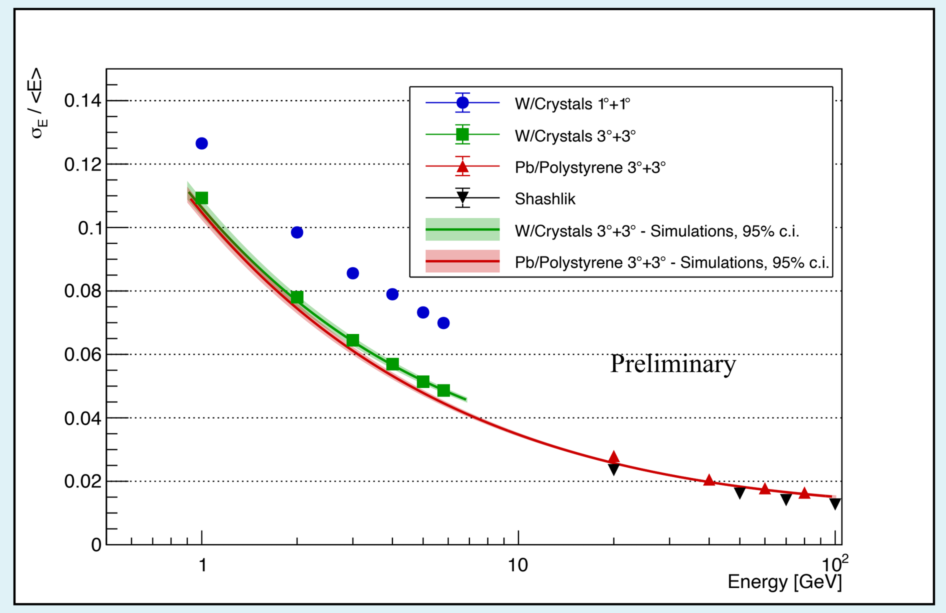
➡ Above $50$ GeV all prototypes reach $\sigma(t) \simeq$ **15 ps**

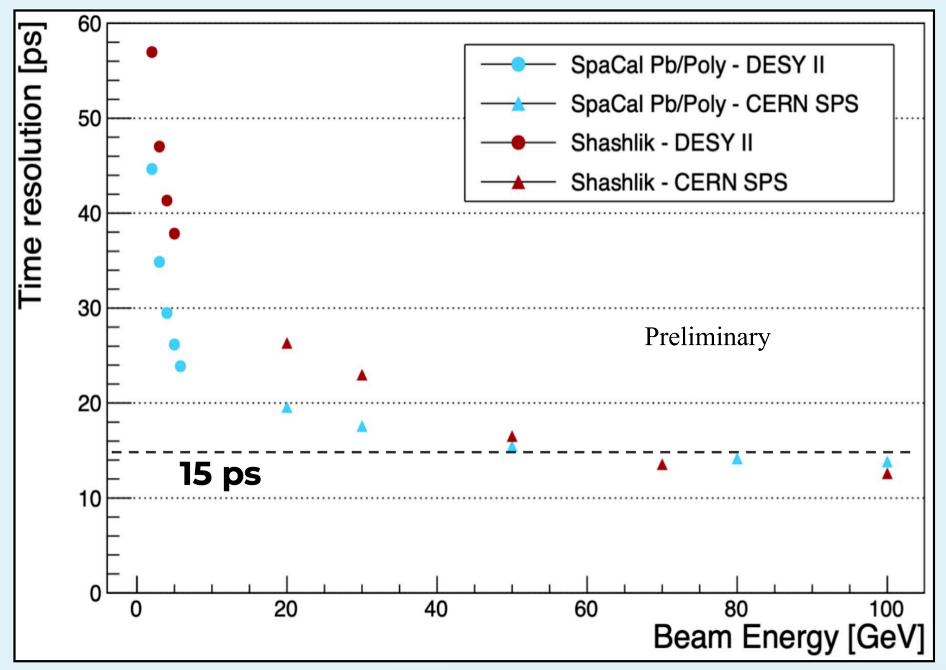
Pb/Poly



W/GAGG







**References:** [1] NIM A 1000, 165231 (2021) [2] Framework TDR for the LHCb Upgrade II (CERN-LHCC-2021-012)