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Time resolution studies for SpaCal technology with single-sided readout

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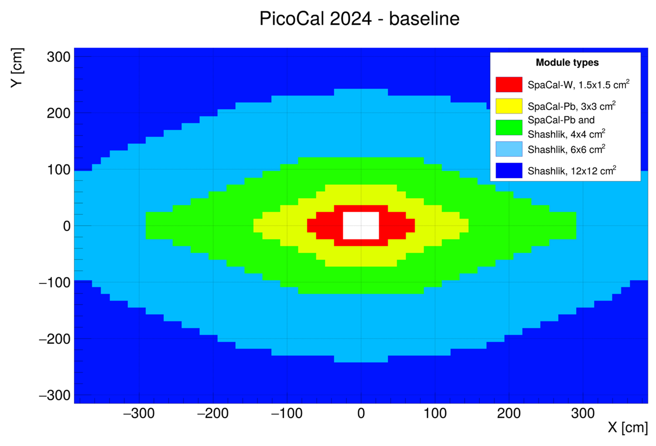
Introduction: LHCb ECAL Upgrade II

High luminosity phase after LS4 → Upgrade of the LHCb ECAL required [1][2]

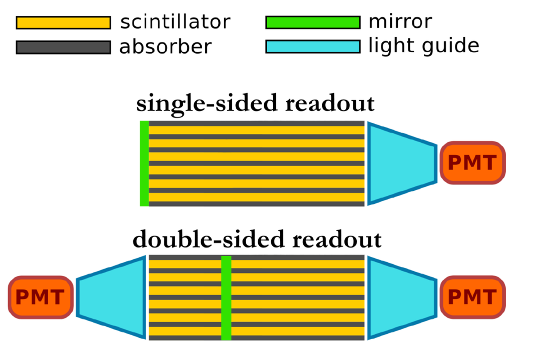
- Improved radiation hardness
- Time resolution of few tens of picoseconds → Mitigate pile-up effects
- Energy resolution comparable to the current one (10% sampling term, 1% constant term)

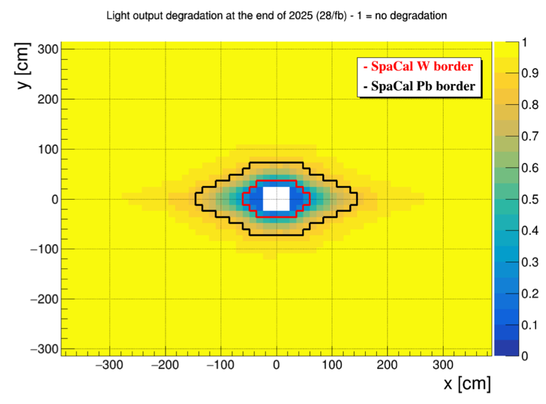


SpaCal technology

- **Spaghetti Calorimeter (SpaCal)**: scintillating fibres in a dense absorber
- Currently: Shashlik modules
- The innermost 176 modules will be replaced with SpaCal technology in LS3, more SpaCal modules will be added in LS4

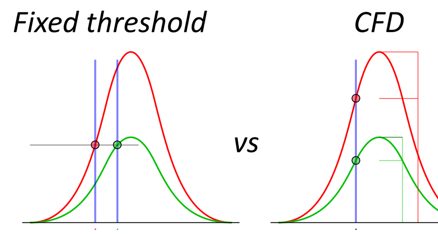
LS3	LS4
▪ Single-sided readout ▪ Plastic (polystyrene) fibres	▪ Double-sided readout ▪ Both polystyrene and crystal fibres



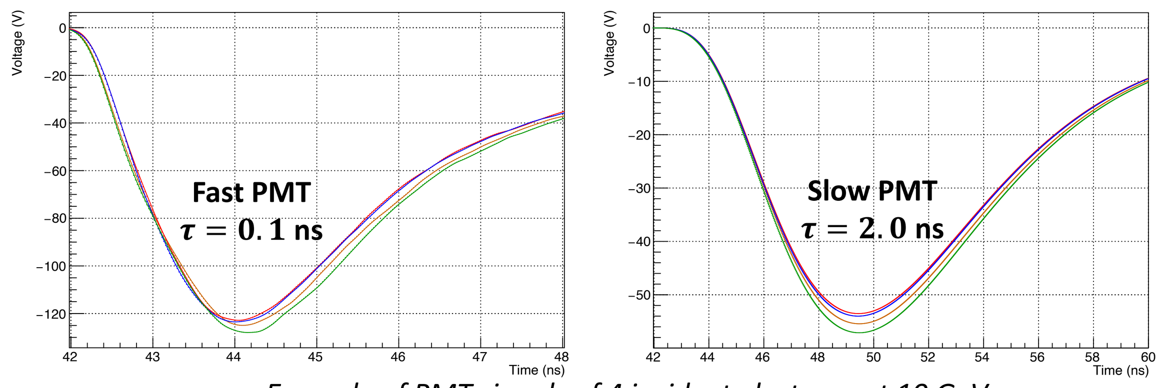


Simulation of a Pb-Poly module

- Time stamp by means of the **CFD algorithm**
- Single photoelectron pulse: $f(t) = {}^{A}/_{\tau^3}\, t^2 e^{-t/\tau}$

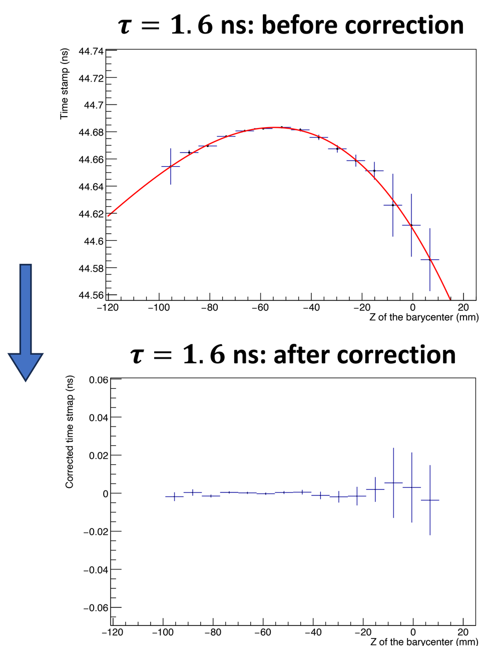


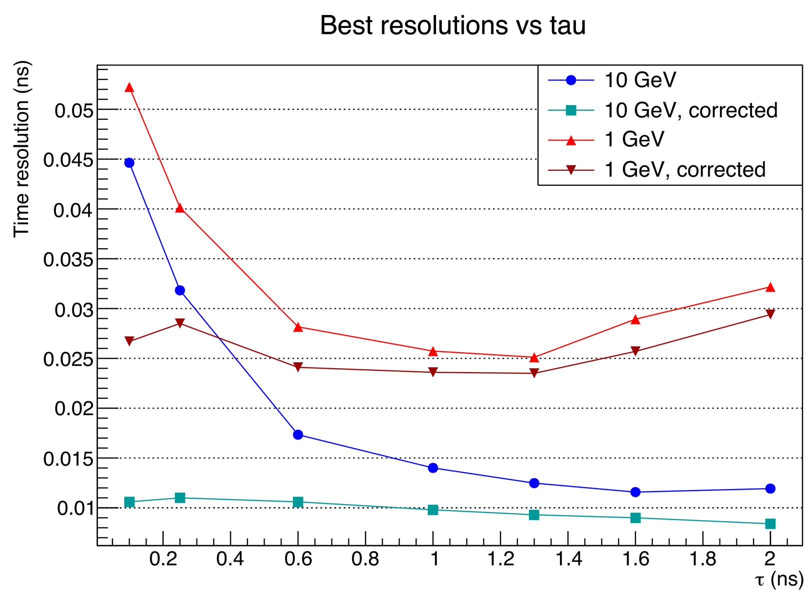
The presence of direct and reflected photons modifies the shape of the fast (low τ) PMT signals, which changes on an event-by-event basis



Example of PMT signals of 4 incident electrons at 10 GeV

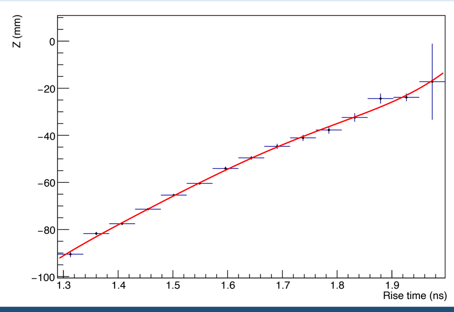
- The shower depth biases the CFD time stamp of the PMT signals [3]
- Slow PMTs (high τ) perform better: less biased by shower depth
- **Procedure to remove the bias → Corrected resolution**
- The unbiased time stamp is defined by means of a polynomial fit to the scatter plot of *time stamp* vs *shower depth*: $\hat{t}_{j,\,unbiased} = f_j - t_j$





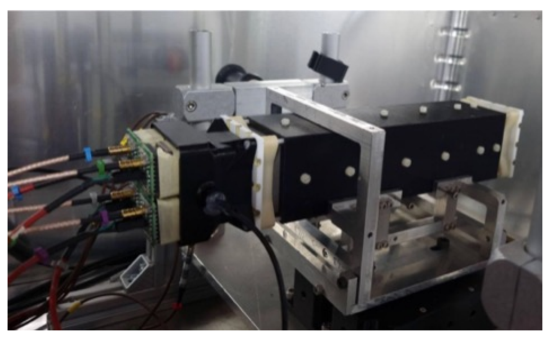
- Simulations also show that **rise time is highly correlated with the shower depth** → Deep showers feature higher rise times
- Rise time: time interval between 10% and 90% of the pulse on the rising edge

Idea: since the shower depth is not known in real applications, we can apply the correction procedure exploiting the rise time instead



SPS testbeam data analysis

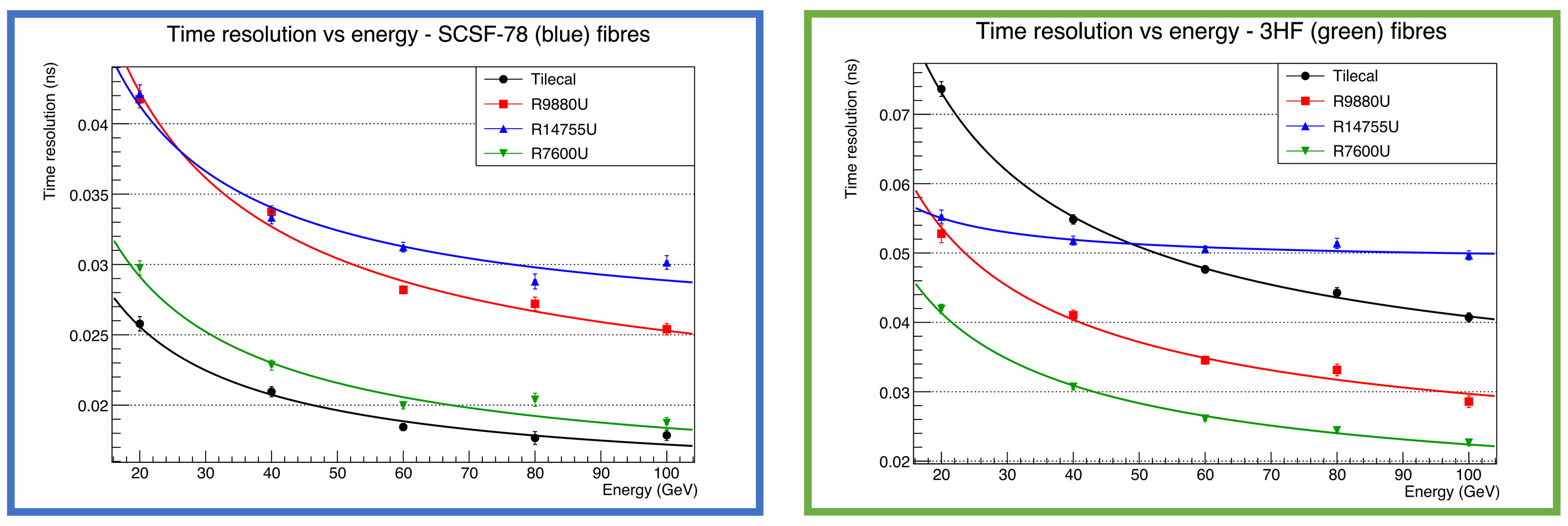
- **Studies of the time resolution using a prototype in the LS3 configuration** (tungsten absorber, polystyrene fibres, 2x2 cm² cell size) as detailed test beam data is available (incident electrons between 20 GeV and 100 GeV)



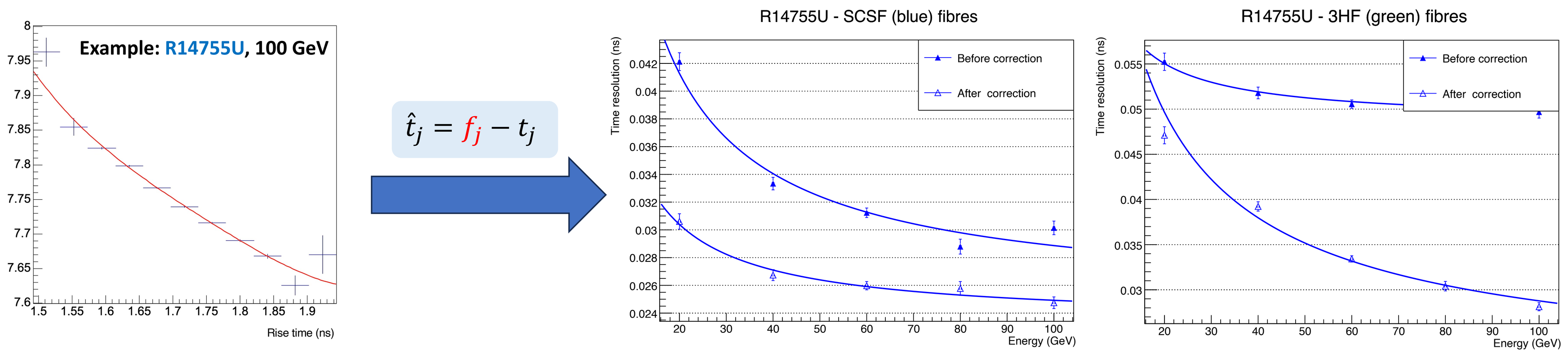
- 5 cm – square to octagon light guides
- Polystyrene fibres: Kuraray SCSF-78 or 3HF
- PMTs: R14755U-100, R9880U-20, R7600U-20, R11187

$$\sigma_t(E) = \frac{a}{\sqrt{E}} \oplus b$$

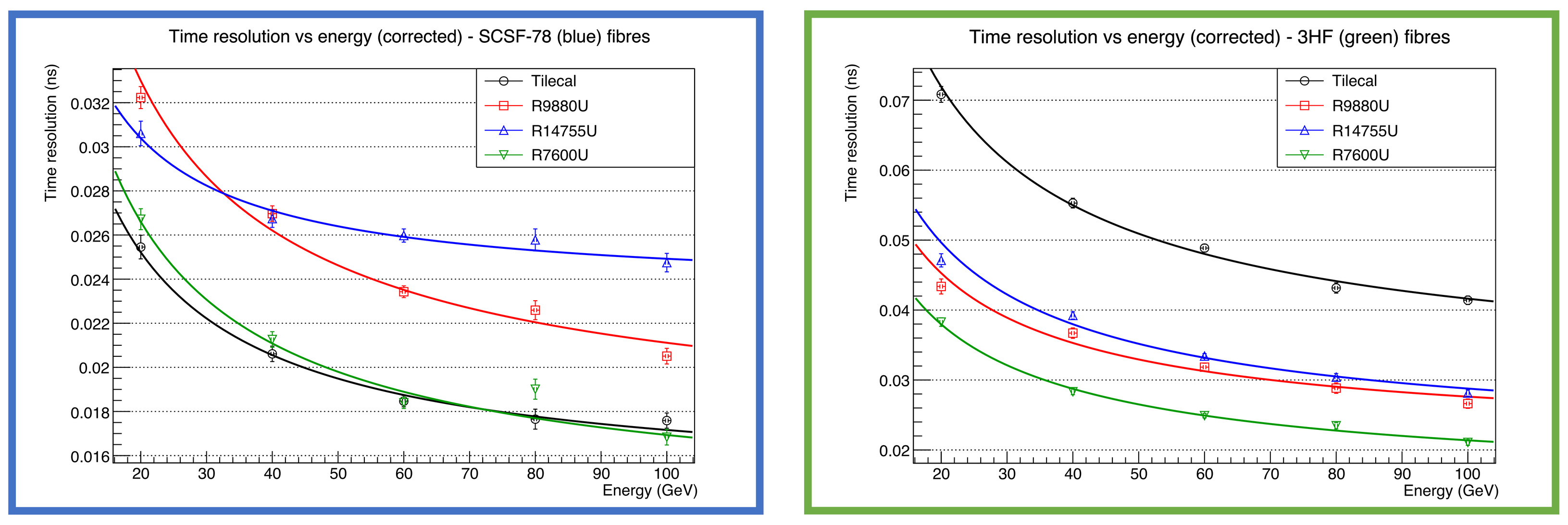
Before correction



- Correction procedure exploiting the rise time



After correction



Conclusions

- The CFD time stamp is biased by the shower depth → This worsens the time resolution
- A procedure aiming at removing such bias has been developed, exploiting the rise time of the signals
- A comparison among several PMT candidates and two kinds of fibres has been performed
- Time resolution < 20 ps reached at high energies → Good timing capabilities even with single-sided readout configuration

References

[1] LHCb collaboration. *LHCb Particle Identification Enhancement Technical Design Report*. Technical report, CERN, Geneva, 2023.
[2] LHCb collaboration. *LHCb Upgrade II Scoping Document. Technical report*, CERN, Geneva, 2024 (in preparation).
[3] A. Bellavista. *"Study of the simulations of the readout for the future LHCb Electromagnetic Calorimeter and characterization of photomultipliers"*. Master Thesis (2024).

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