Exploiting Pulse Shape Discrimination for Dual-Readout Calorimetry based on Inorganic Scintillating Crystals

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Aim of the Study

The study shows the possibility and effectiveness of the **Pulse Shape Discrimination** (PSD) **to separate scintillation and Cherenkov emissions using one single photodetector readout on a single bulk material** instead of two or different materials as traditionally proposed for electromagnetic calorimeters.

Motivations

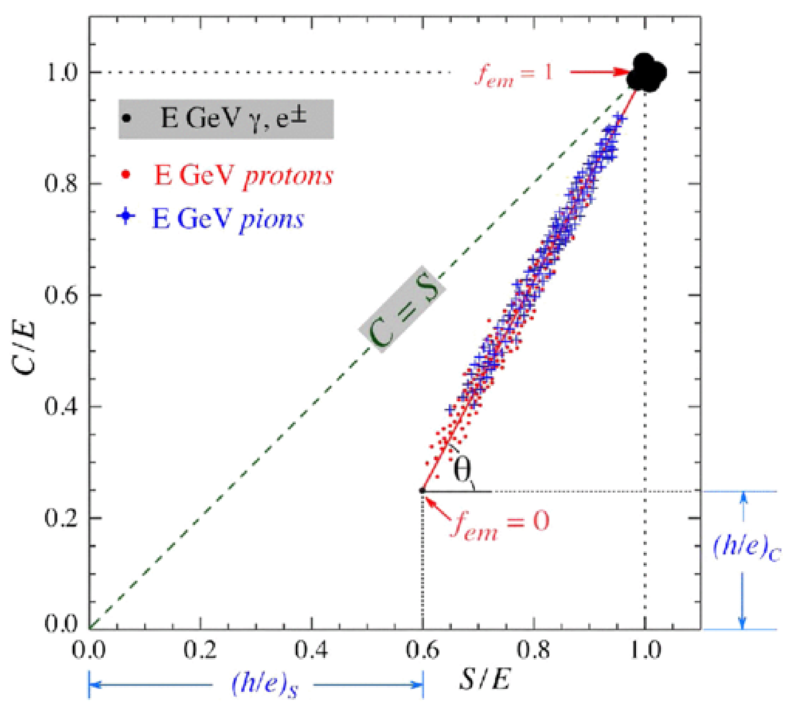
Calorimeter's response for hadronic showers

$$R_h = e f_{em} + h(1 - f_{em}) \quad (1)$$

with e,h respectively the electromagnetic (em) and hadronic (h) components weighed by the electromagnetic fraction of the hadronic shower (f_{em}).

- f_{em} **fluctuates** for each event.
- Deterioration of the energy resolution for hadrons.

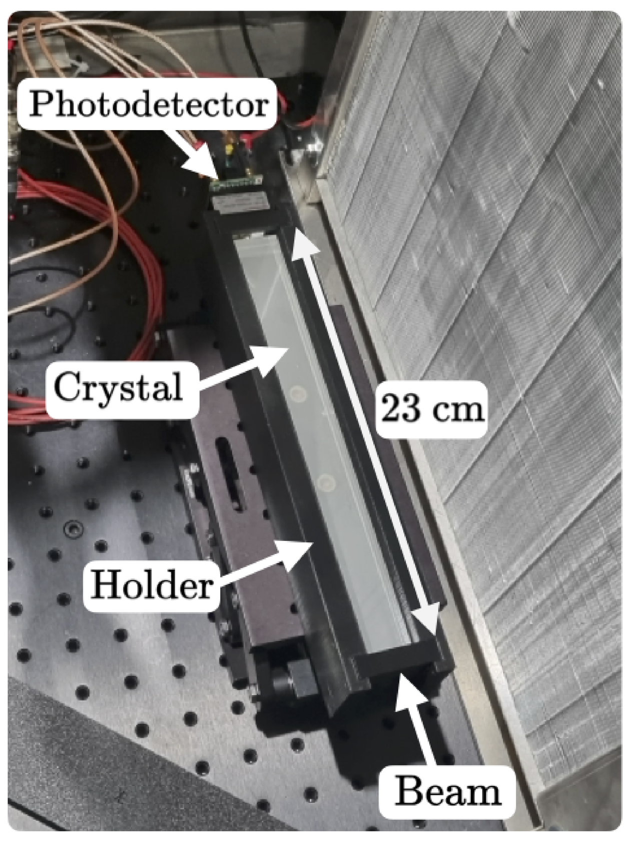
⇒ Estimate f_{em} on **event-by-event** basis using the **dual-readout** technique (DRO) which consists in extracting the **scintillation** (S) and **Cherenkov** (C) emissions.[1] → M.Lucchini's talk (MAXICC, 18/02).



Materials & Methods

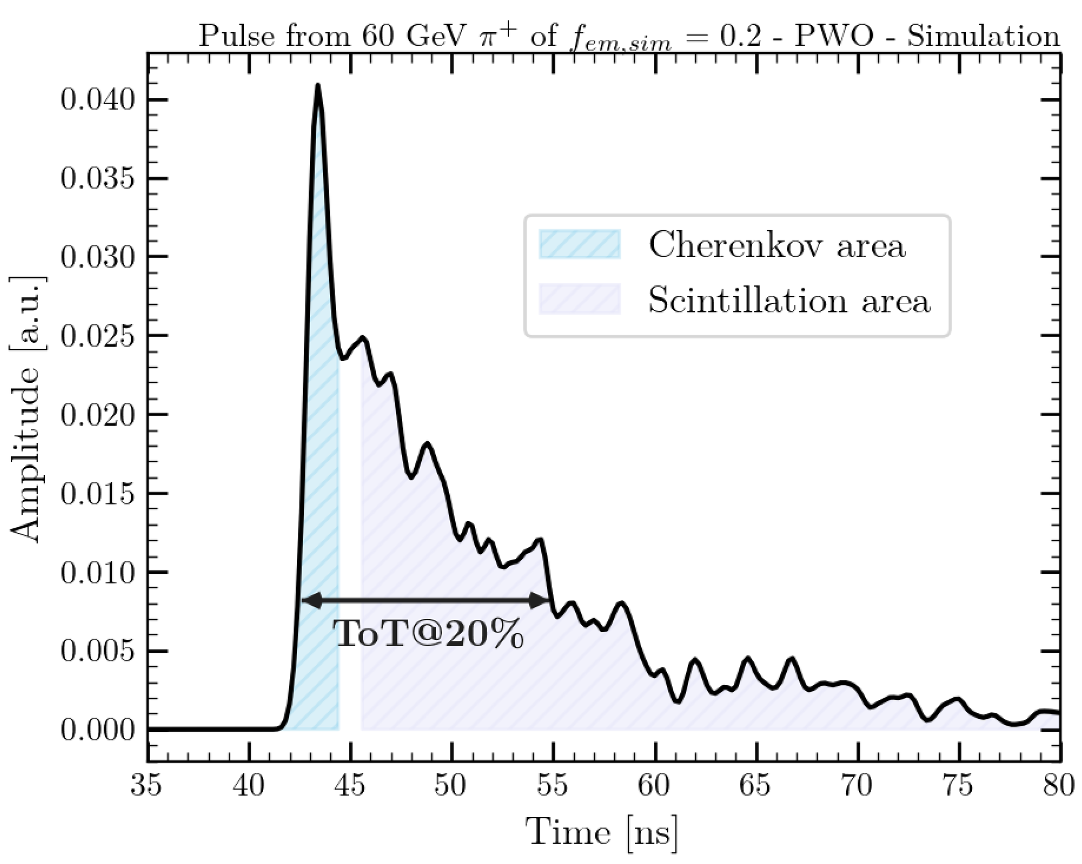
$PbWO_4$ scintillating crystal

- A **2.3×2.3×23 cm³ $PbWO_4$** crystal, coupled on one side with R7600U-M4 Hamamatsu.
- Prototype tested with electrons and mixed hadrons beams at CERN SPS North Area.



PSD for dual-readout purposes

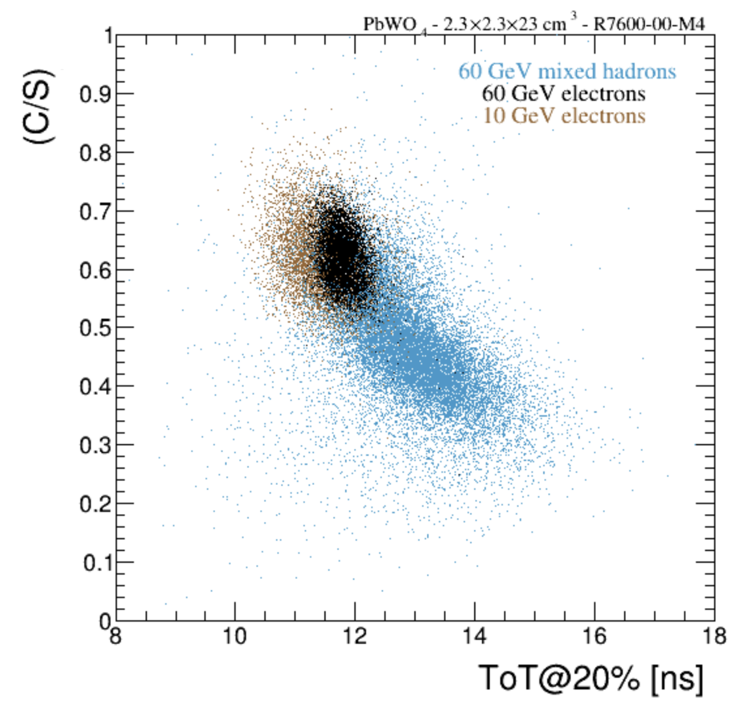
- This technique exploits the difference between **Cherenkov** (C) – **prompt** light emission – and **Scintillation** (S) emissions – excitation + relaxation stages – in case of light-based detectors.



- Various parameters are tested for each pulse as estimators of f_{em}:
  - The **time over threshold** : ToT (time interval when the signal is above a certain value, e.g. ToT@20%).
  - **(C, S) areas** defined respectively as the integral of the first few ns (mainly Cherenkov contribution) and the rest of the pulse (mainly scintillation contribution).

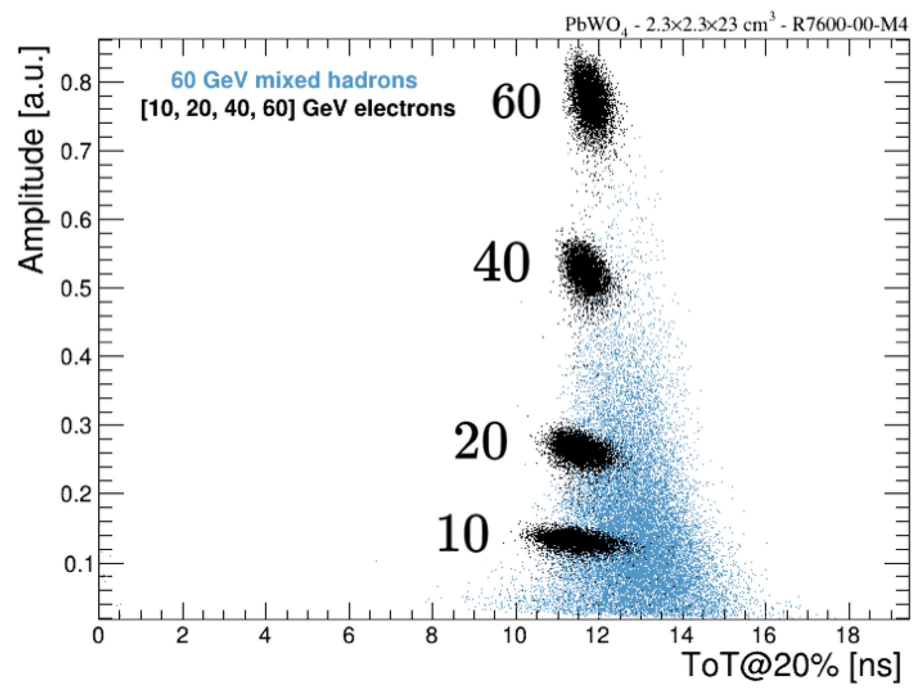
Testbeam Results

Dual-readout



- The ratio between the C and S areas of the pulse is **anticorrelated** with the ToT@20%.

Particle identification

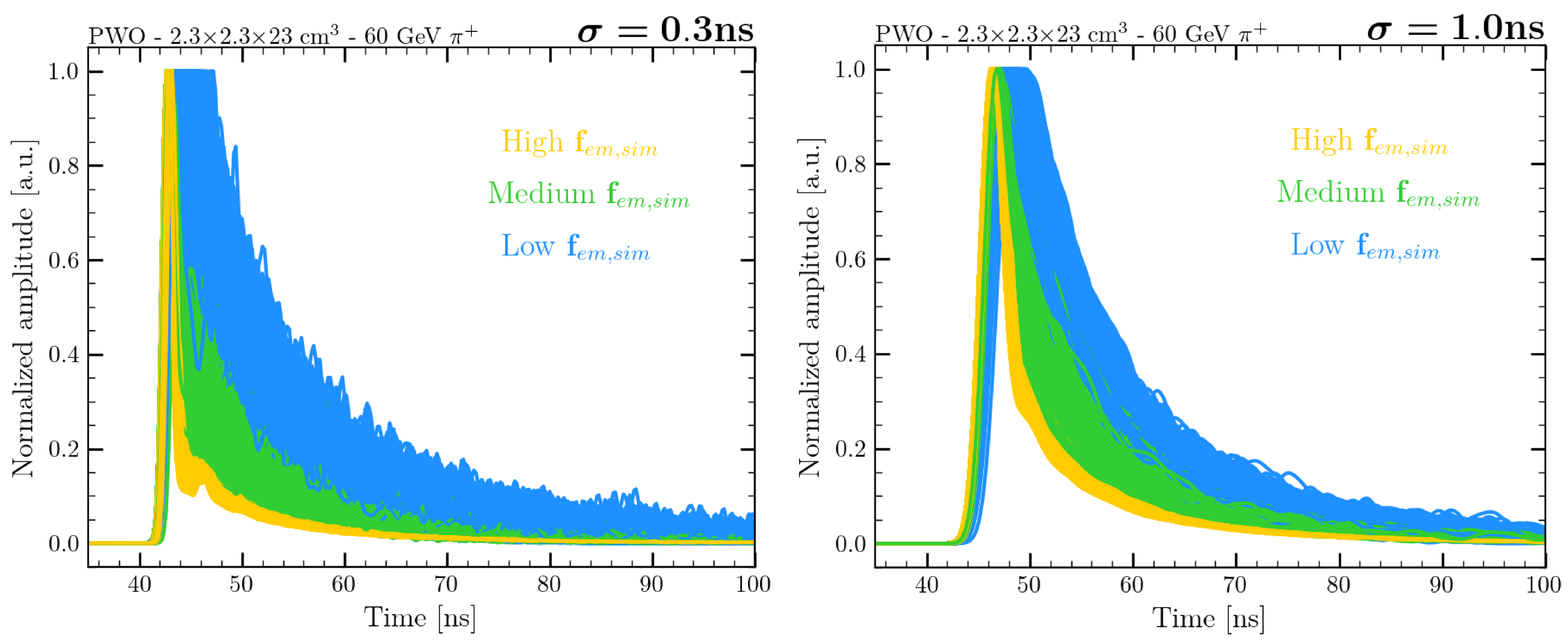


- **ToT@20%** is an effective discriminant between electrons and hadrons.

Geant4 Monte Carlo Simulation

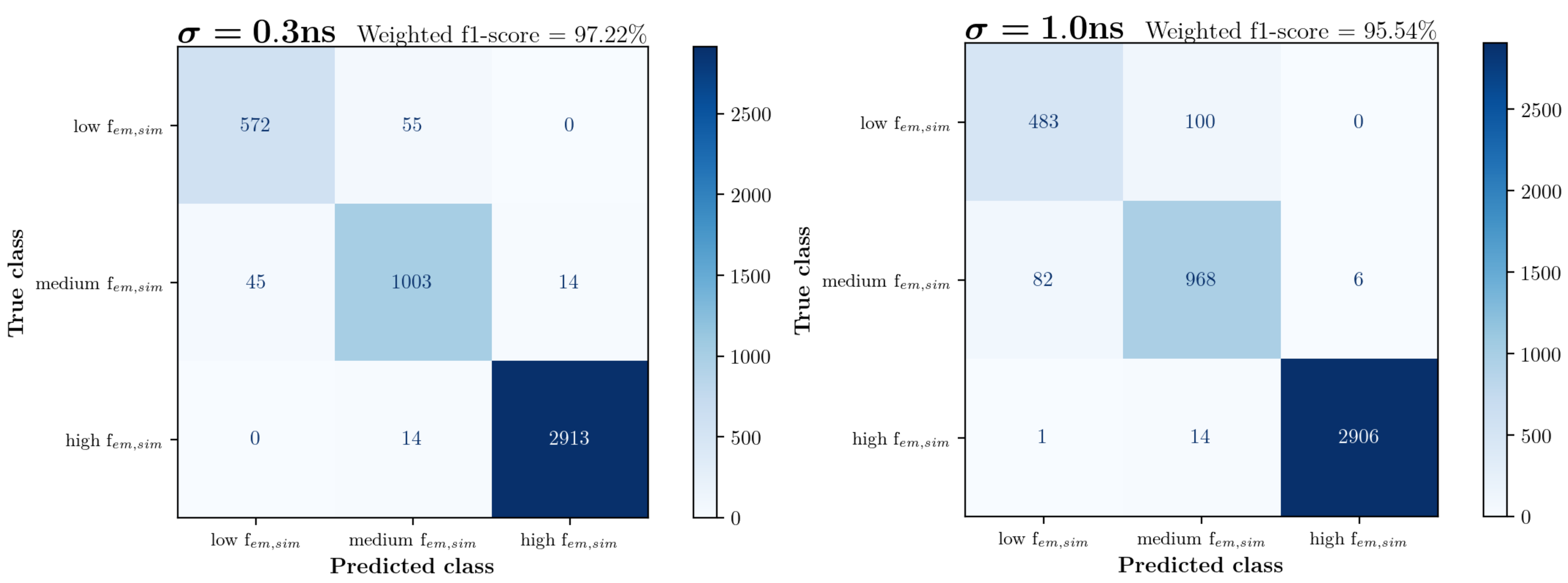
Study of the photodetector response

- **Single photoelectron pulse** modeled by a Gaussian distribution.
- Study the discrimination probability varying the **response width** σ.
  ⇒ A slower photodetector produces smeared pulses.



Impact of the width on prediction accuracy

- **Prediction of $f_{em,sim}$ with ToT@5%** as an estimator for the two different photodetector responses, using **a machine learning classifier**.
- The **f1-score** metric balances precision and recall, helping evaluate a classifier's overall effectiveness.



F1-score	low $f_{em,sim}$	medium $f_{em,sim}$	high $f_{em,sim}$
σ = 0.3ns	91.96%	94.00%	99.52%
σ = 1.0ns	84.07%	90.55%	99.64%

Conclusions

- **Pulse shape discrimination** is an efficient method for particle identification and **dual-readout**.
- **High-speed photodetectors** are required to discriminate the scintillation and Cherenkov components of each event.

Acknowledgment and References

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[1] S. Lee et al. Rev. Mod. Phys. 90, 025002 (2018).

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