Development of a large acceptance timing detector with picosecond resolution

Riccardo Polles

University of Trieste / INFN Trieste

Supervisor: Prof. K. Matsuoka

Motivation and detector principle

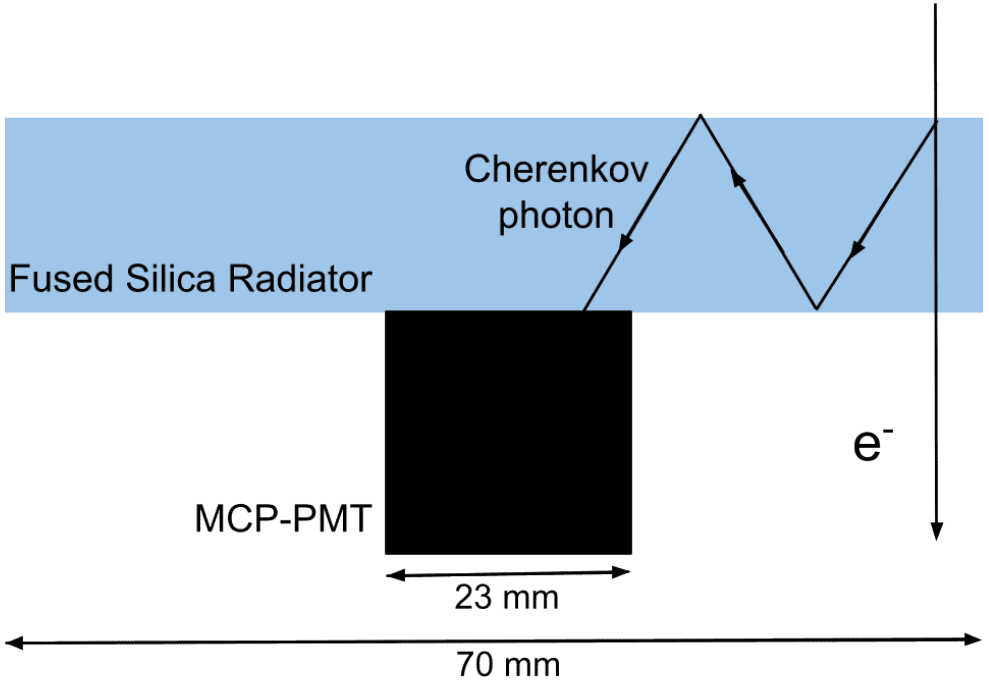
- **PID is crucial for most Belle II physics measurements** e.g. CP violation in B-meson decays
- **The new detector aims to extend PID to the backward region**
  - currently not covered by any dedicated PID detector
  - in view of a possible future reduction of the beam asymmetry

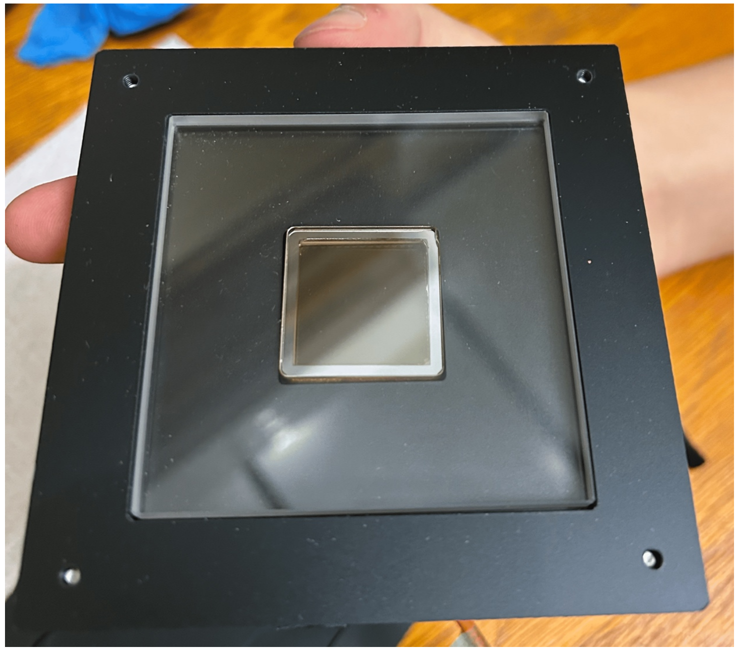
Concept

- Large **fused silica radiator** coupled to a smaller **MCP-PMT**, a photomultiplier based on microchannel plate multiplication that has picosecond time resolution.
- **Goal**: Extend photo-sensitive coverage of the recycled, decommissioned TOP MCP-PMTs, to cover large areas with small cost.

Time Resolution

- Photons generated far from the sensor undergo multiple reflections -> **time dispersion** depends on the impact position.
- Target: gaussian σ_{TOF} < 40 ps (K/π separation at 1.5 GeV/c)





Beam test

Objective

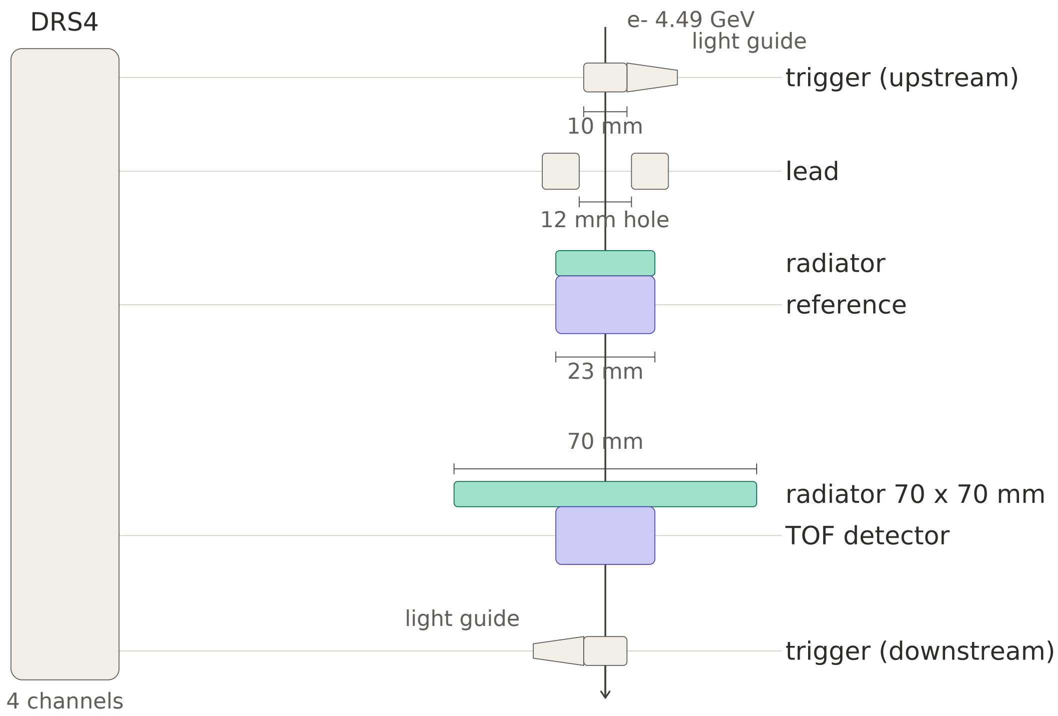
- Measure the timing performance of the detector under controlled beam conditions.

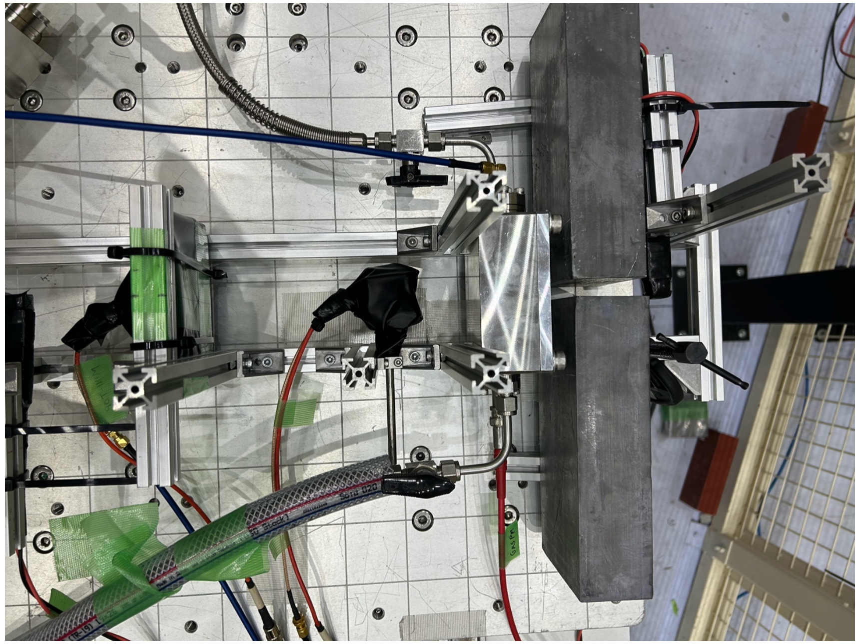
Experimental setup

- 4.49 GeV electron beam, at 130 Hz.
- **Trigger scintillators** define the beam crossing.
- A **reference MCP-PMT** provides the reference timestamp.
- The detector prototype is placed downstream and records the Cherenkov signal.
- Waveforms are digitized using a **DRS4** board for offline analysis.

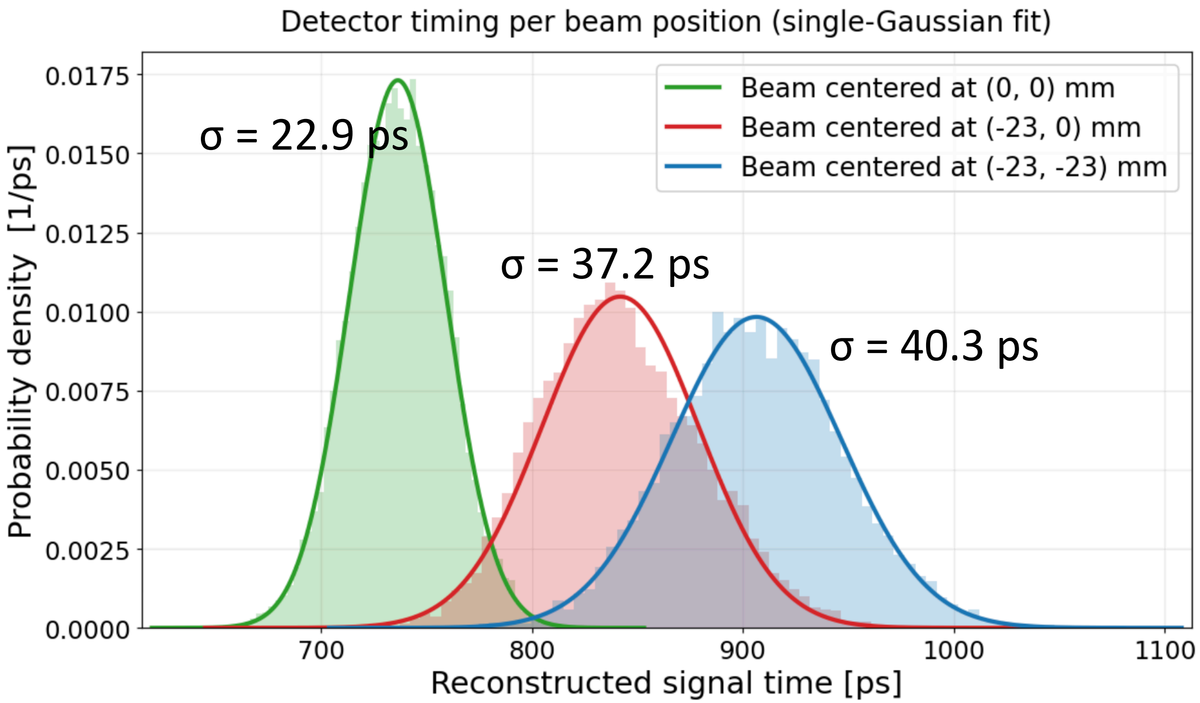
Results

- Data were successfully acquired for three different beam position, and the subsequent analysis is performed to evaluate the detector time resolution.





Beam test simulation



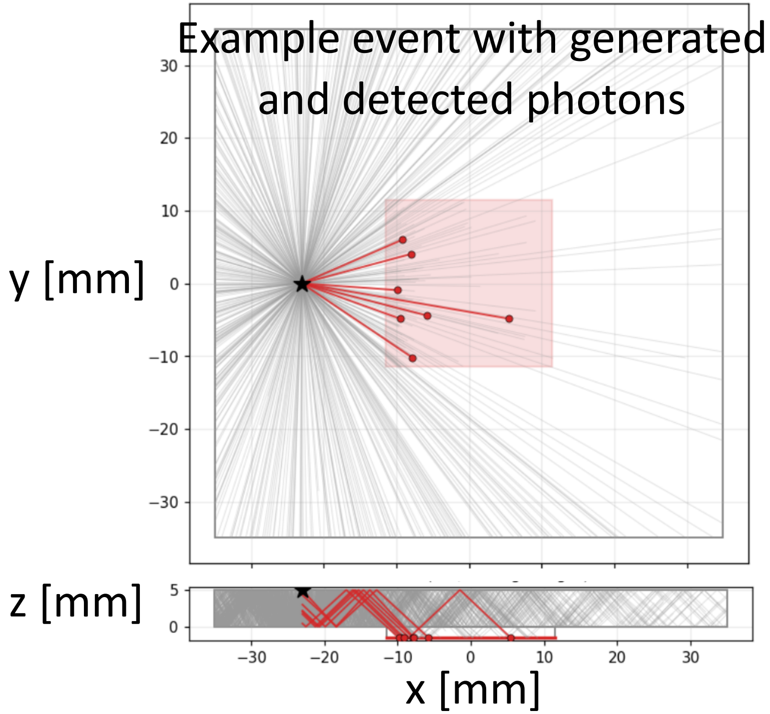
Objective

- Determine the expected time resolution by simulating **photon propagation** and **detection** for the beam position used on the beam test.

Simulation model

- **Beam-test geometry reproduced** using the same experimental configuration.
- **Uniformly distributed particle impact position** over the beam spot.
- **Random photon emission depth** along the particle trajectory.

$$t_{signal} = t_{particle\ flight\ until\ emission} + t_{photon\ flight} + + \mathcal{N}(t_{transit}, \sigma_{TTS}) + \mathcal{N}(t_{reference}, \sigma_{ref})$$



Results

- Number of detected photon and time resolution **degrade with the distance** between incident particle path and MCT-PMT
- **Off-center positions:** distribution not purely Gaussian → secondary, delayed component (extra bounce) → fitted σ is an effective value, not the genuine width.
- **σ still within our target resolution requirement**, despite this overestimation, for every beam position.

Data analysis

Waveform Reconstruction

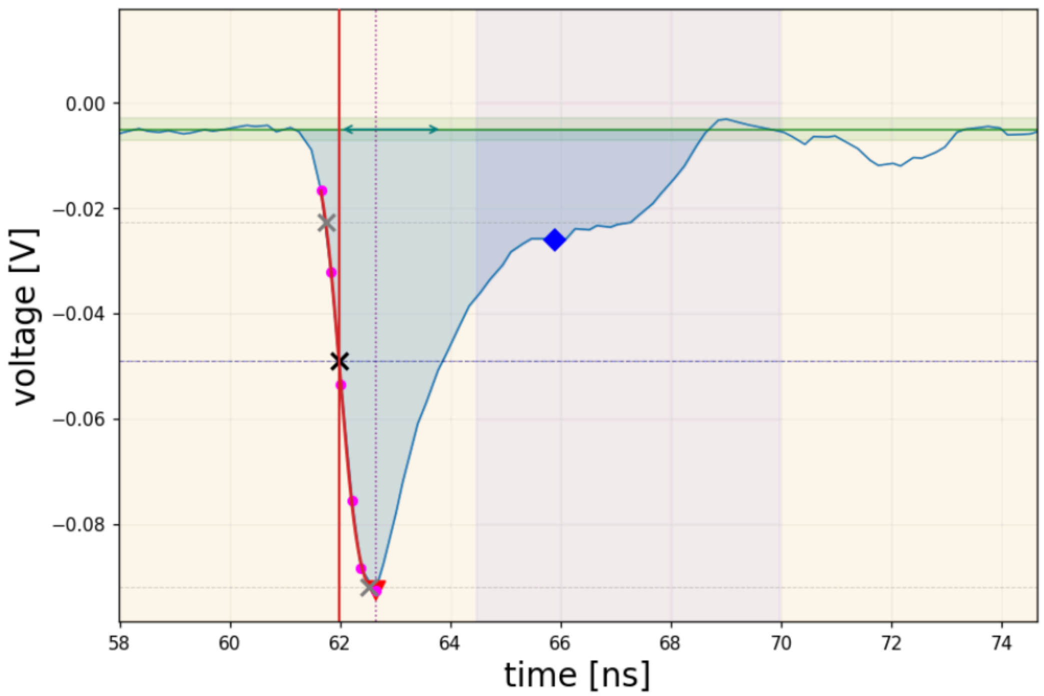
- Extract waveform features using an **error-function** or **polynomial fit**.
- Determine pulse height, baseline, rise time and signal arrival time.

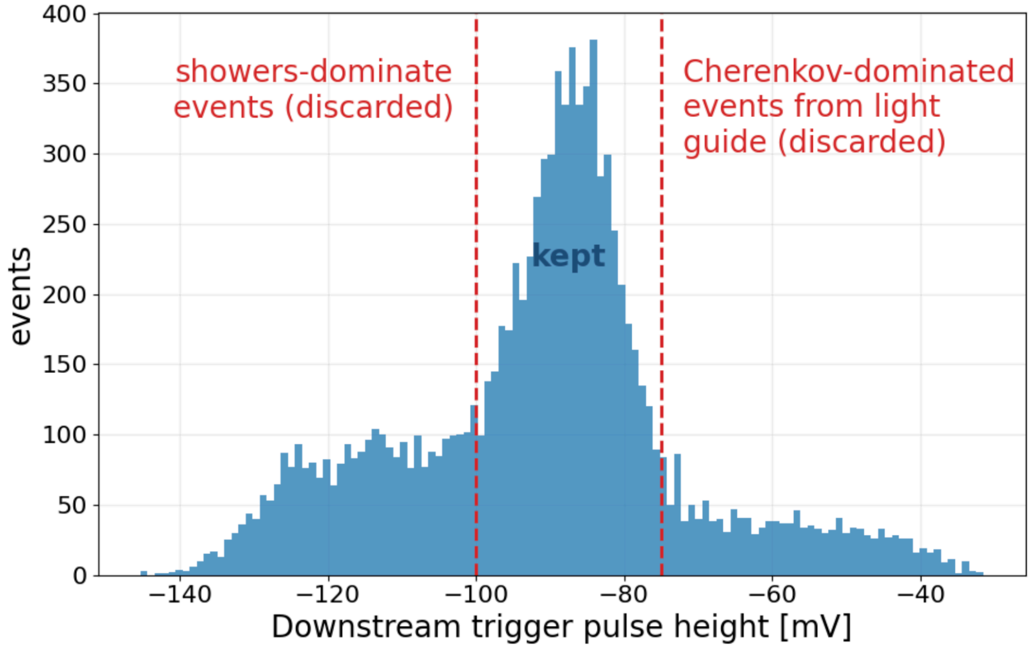
Event Selection

- Remove **shower events** by applying cuts on the trigger pulse height distributions.
- Remove **light guide events**, also with cuts on trigger pulse height.
- Reject **outlier events** to retain only clean particle signals.

Time Jitter Correction

- Study the dependence of the measured time resolution on the signal pulse height.





Results

Detector efficiency by beam position:

- **Center:** 100.00%
- **Edge:** 99.95%
- **Corner:** 99.86%

Valid beam events defined strictly via triggers and reference MCP selection.

Overall Time Resolution reference subtracted:

- **Center:** σ = 14.2 ± 0.7 ps
- **Edge:** σ = 82.2 ± 1.1 ps
- **Angle:** σ = 87.2 ± 1.1 ps

Edge Intrinsic Resolution: σ = 53.3 ± 1.8 ps

- Jitter & reference subtracted.
- *Sample:* Removed possible shower events at high |PH|

Data vs. Sim: Intrinsic resolution ~53 ps, still exceeds simulation ~30 ps

Discrepancy points to unmodeled systematics (e.g., beam misalignment, detector tilt).