The LHCb RICH Upgrade

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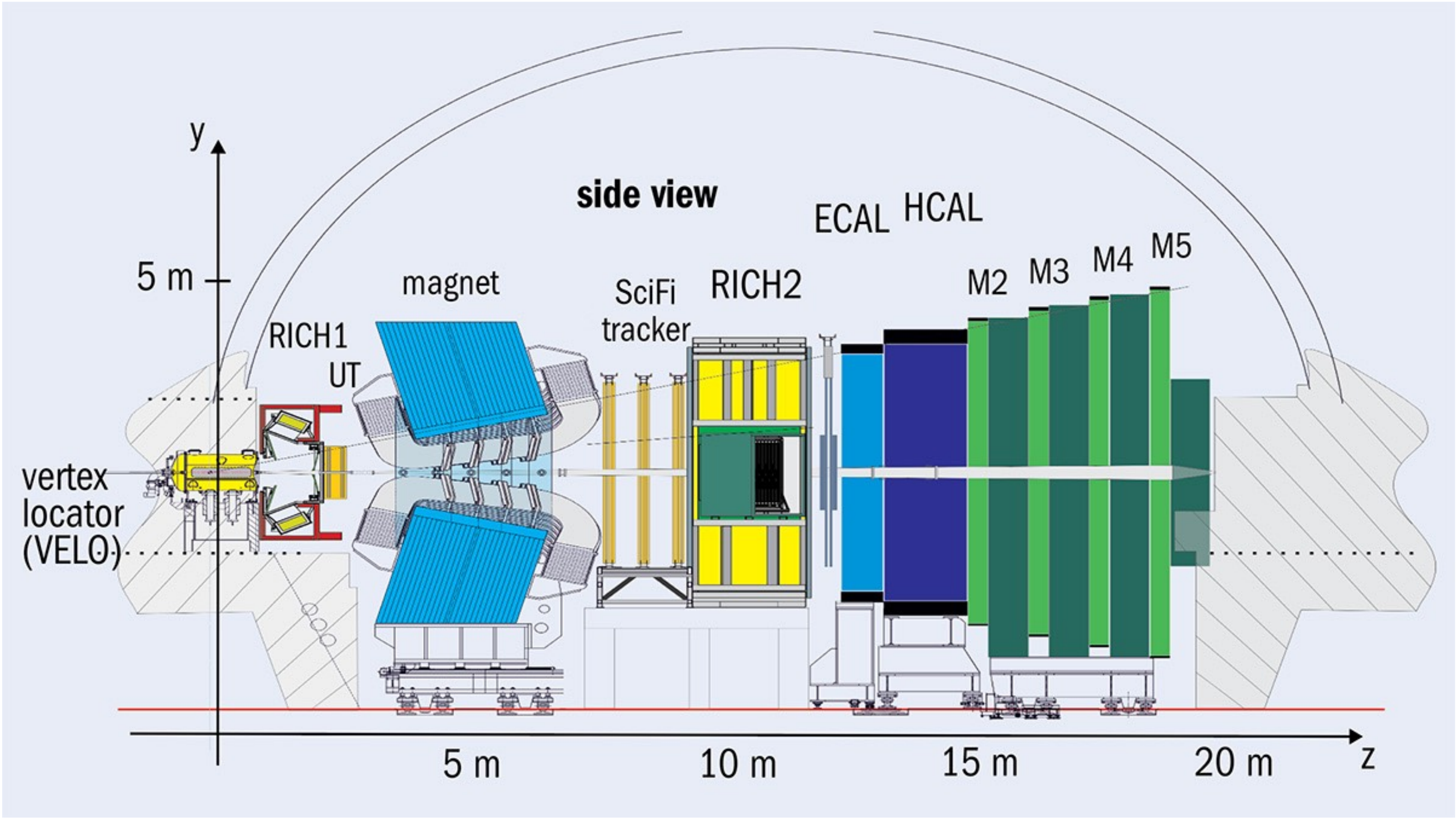
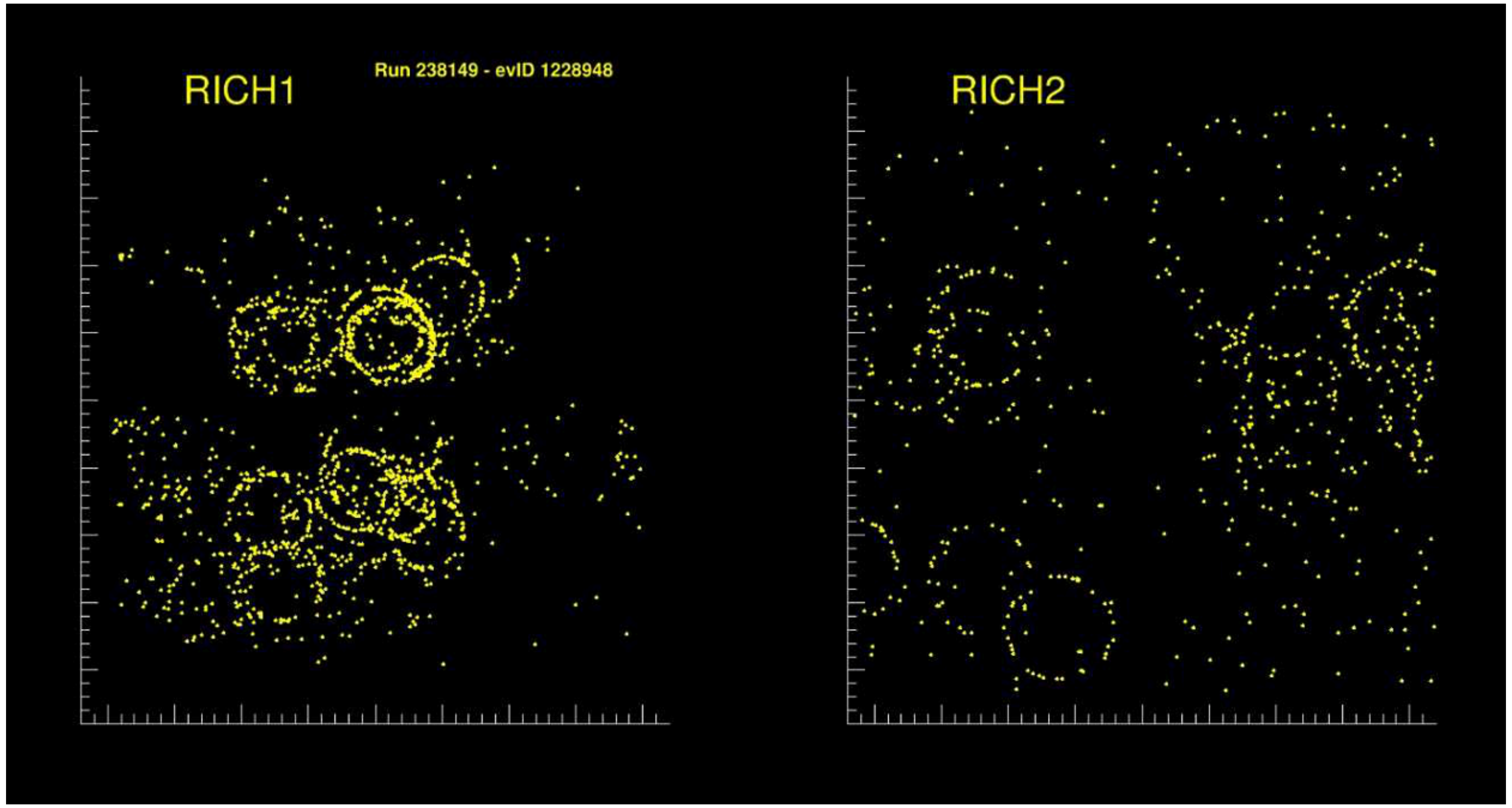
The LHCb RICH detectors

LHCb relies on the **Ring Imaging Cherenkov** (RICH) **detector** system for the charged hadron identification in the momentum range [2;100] GeV/c.



The **Cherenkov light** produced by those particles is redirected by an **optical system** towards the **photodetector planes**, composed by **Multi-Anode PMTs**, and outside the acceptance of the spectrometer.



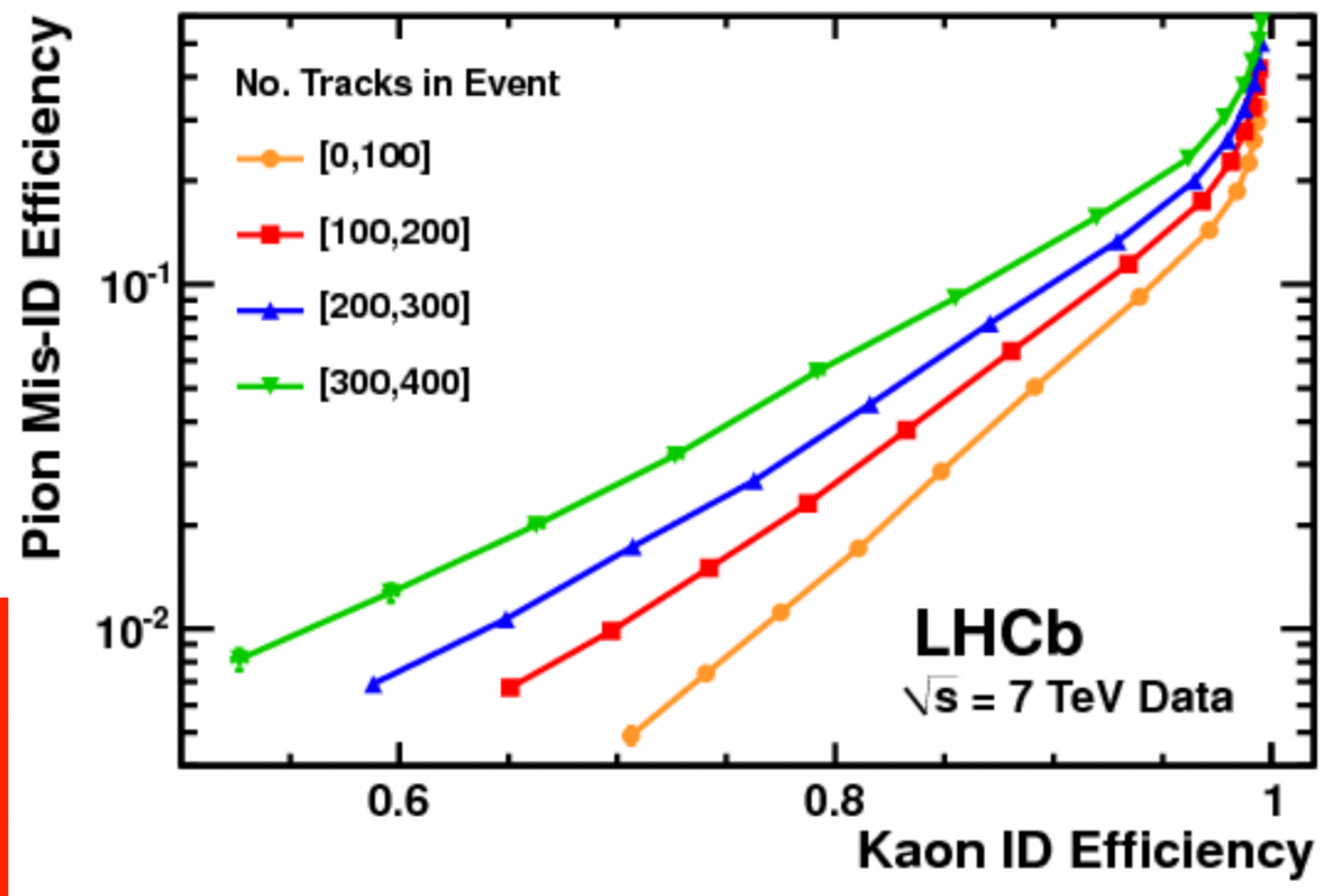
The **commissioning** of the current **RICH detector** (Upgrade 1a) is ongoing.

Upgrade 1a	Long Shutdown 2
Upgrade 1b	Long Shutdown 3
Upgrade 2	Long Shutdown 4

The LHCb RICH in Upgrade 1b/2

The **PID** performance is affected by **high detector occupancy**

→ In **Upgrade 1a** the expected maximum occupancy is ≈**30%** and very non-uniform



Upgrade 2 conditions:

- Keep or reduce maximum occupancy in the detector, make it more uniform, zooming into the high-occupancy central region
- Improve Cherenkov ring angle resolution

Many requirements for Upgrade2!

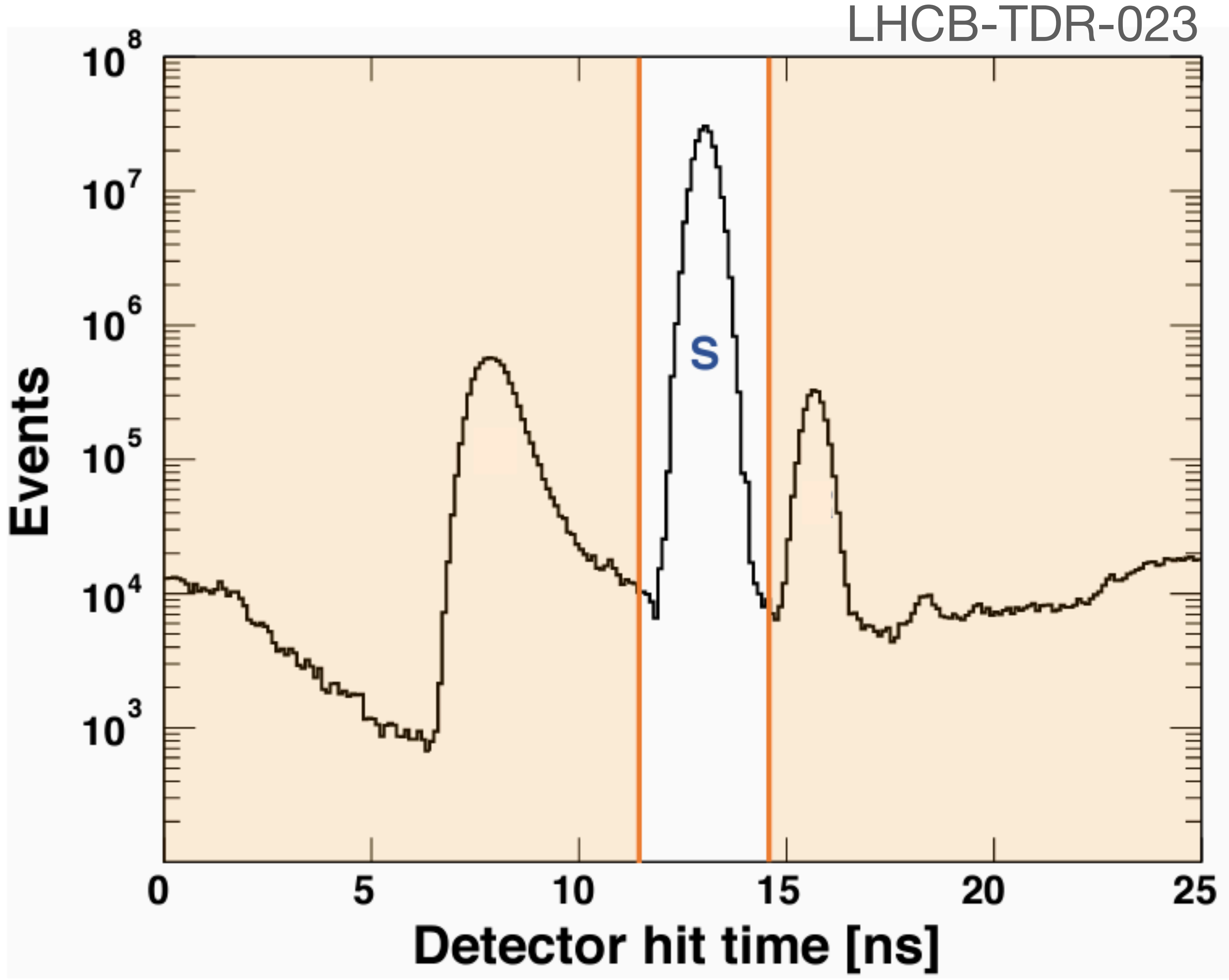
- Reduce occupancy → Reduce pixel size to focal length ratio, extend readout to include timing, change optical design
- Improve Yield → New photo-sensors with enhanced overall photo-detection efficiency
- Improve pixel size error → Reduce pixel size to focal length ratio
- Improve chromatic error → Improve $\sigma_{chromatic}/\sqrt{N}$
- Improve emission error → New optical design

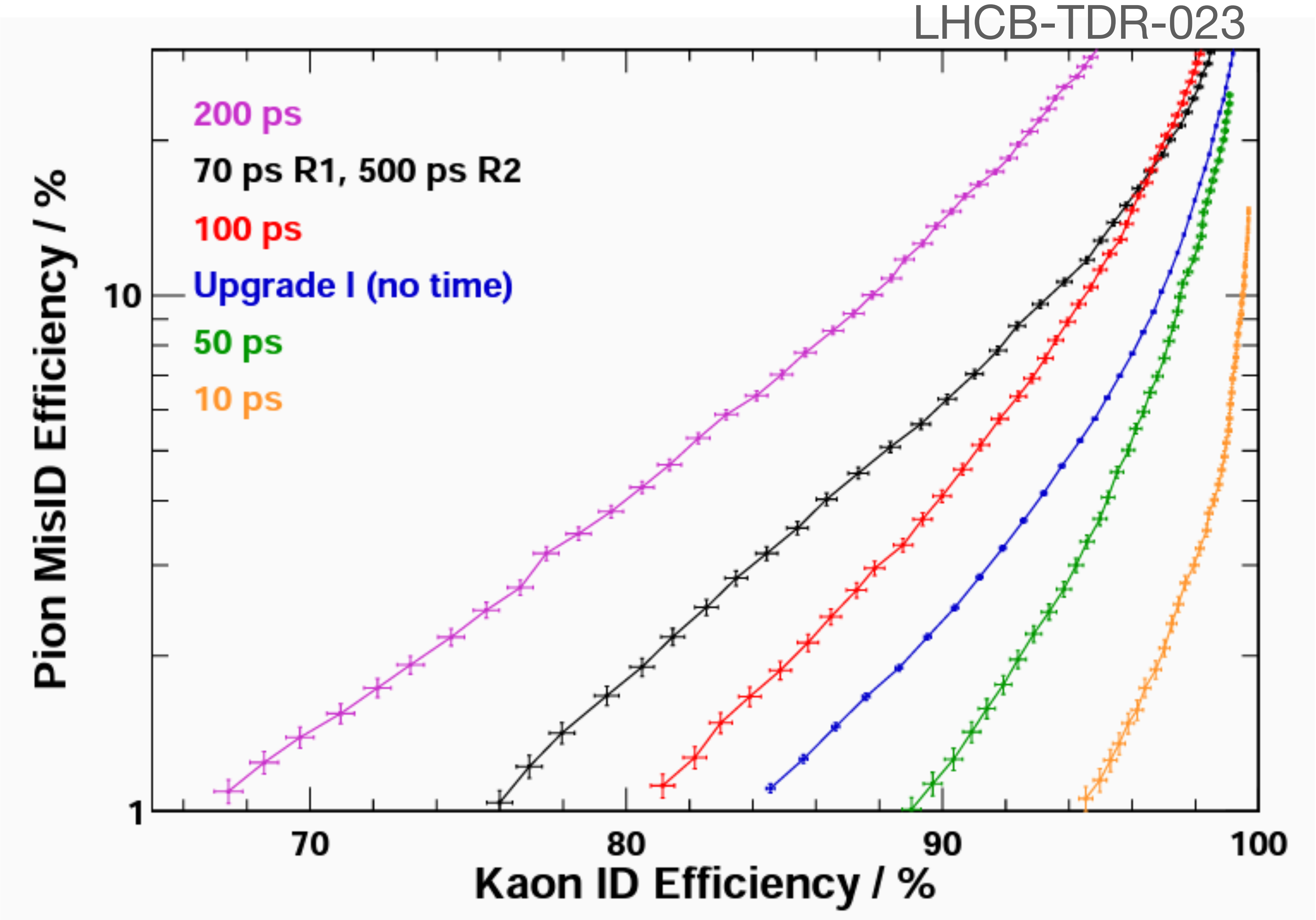
RICH PID with timing in Upgrade 1b/2

Cherenkov photons from a given track arrive almost **simultaneously** (about tens of ps) and it is possible to **predict the time of arrival of photons** from a track with an **excellent precision**.

Using a **fast timing information** would allow to **improve the RICH PID performance**:

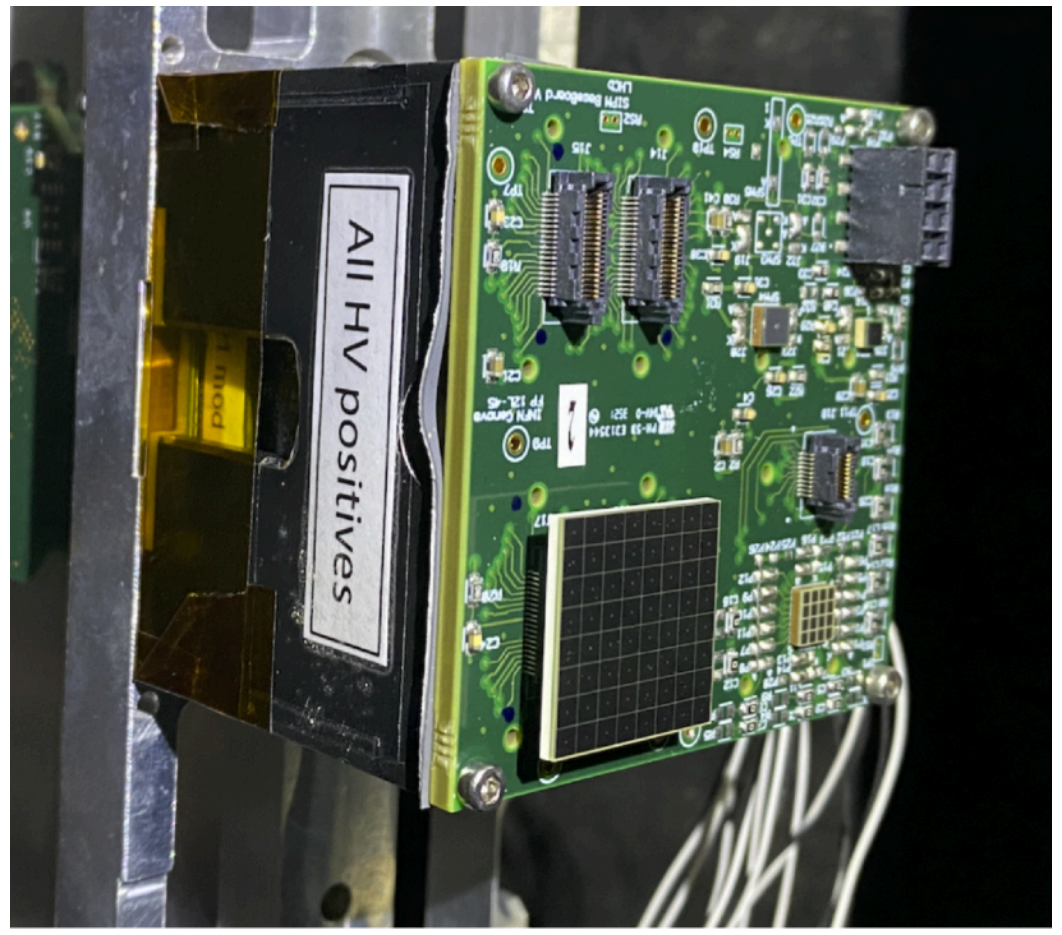
- **Nanosecond-scale time shutter** around the expected RICH detector hit time (Upgrade 1a-b)
- **10 picosecond-scale timestamp of photon hits** to be compared to the predicted time in the event reconstruction (Upgrade 2)





Photodetectors for Upgrade 1b/2

	SiPM	MCP-PMT	MaPMT
Time resolution [ps]	100	20	200
Pixel size	<1mm	<1mm	≈3mm
Bias voltage [V]	10-70	$\approx 10^3$	$\approx 10^3$
Dark count rate	✗	✓	✓
Radiation Hardness	✗	✓	✓
Gain Aging	✓	✗	≈



SiPM

PROs
- High photon detection efficiency
- Good single photon time resolution
- Able to sustain high photon rates
- High granularity

CONs
- Radiation hardness
- High noise (dark count rates)

R&D ongoing to improve those aspects!

MCP-PMT

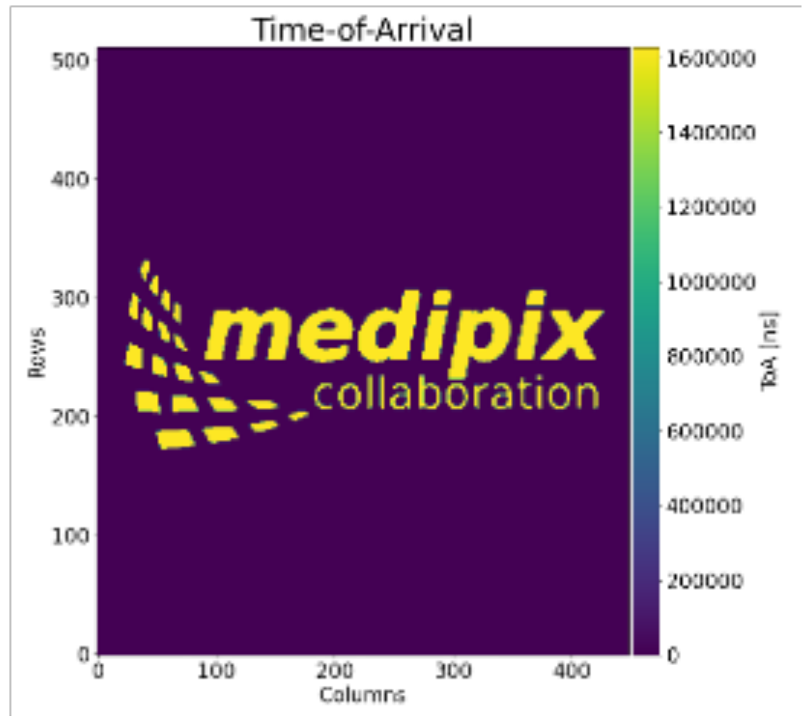
Hybrid vacuum photo-detector development:
Photocathode + MCP multiplication +
Timepix4 anode in vacuum tube

PROs
- Simultaneous excellent time and space resolution
- Low noise at room temperature
- Large active area

CONs
- High bias voltage
- Current saturation at high rates
- Ageing

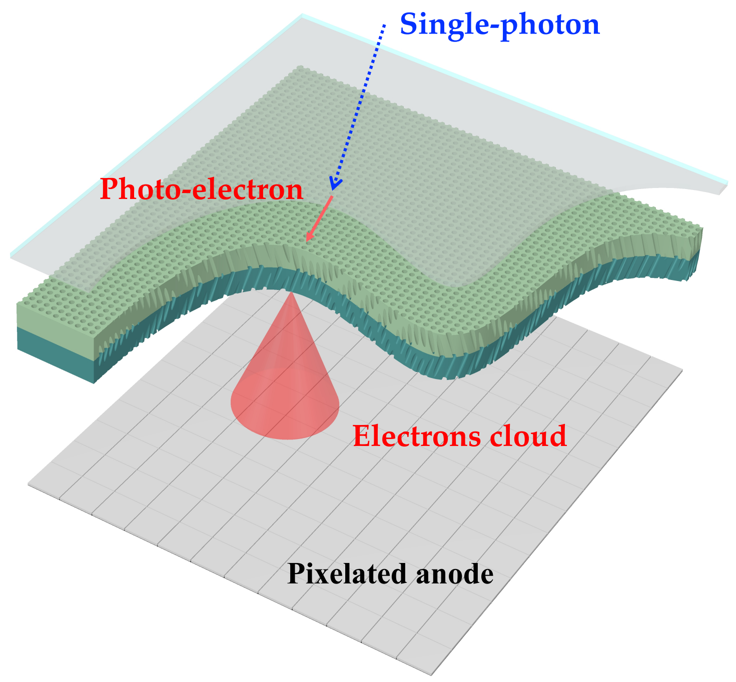
Hybrid MCP development

- Hybrid vacuum photo-detector development
  - Photocathode + MCP multiplication + Timepix4 anode in vacuum tube
  - Funded by ERC: 4DPHOTON (INFN, CERN, UniFE)
- Timepix4 ASIC productions: v0 (Q1-2020), v1 (Q4-2020), v2 (Q4-2021)
  - v2 bare ASIC extensively tested; first tests with Si sensor in summer 2022
  - ASIC, read-out electronics, software and expertise available to the INFN community (MEDIPIX4 project in CSN5)



Advantages:

- On-detector signal processing and digitization with large number of active channels (~230 k pixels), with limited number of external interconnections (~200)
- Longer lifetime due to low gain operation
- Excellent timing (<100 ps) and position (5-10 μm) resolutions
- Timing resolution and radiation hardness can be improved with next generation ASICs (e.g. PicoPix project at CERN for future VeloPix2 ASIC, 20-30 ps TDC LSB, or Timespot)



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Cons:

- Saturation at high rates and ageing for large integrated charge