The FastRICH ASIC
for a time resolved LHCb RICH

George Ramsey and Daniel Foulds-Holt

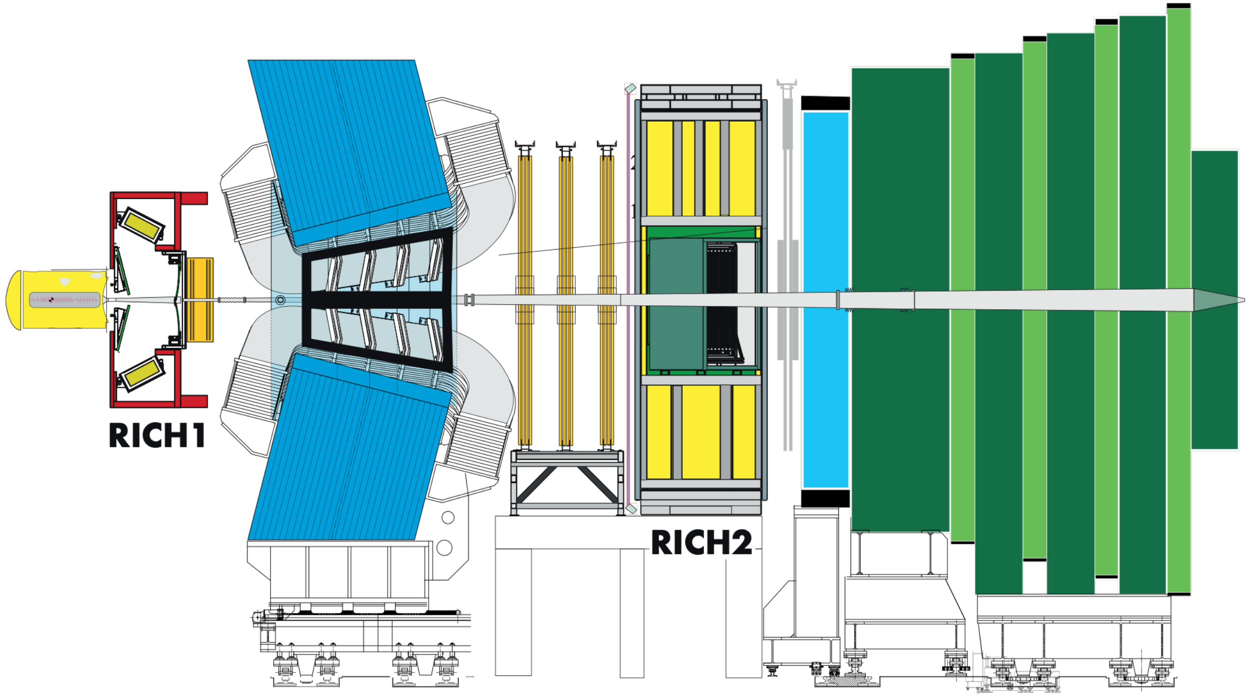
IOP Joint APP and HEPP Annual Conference

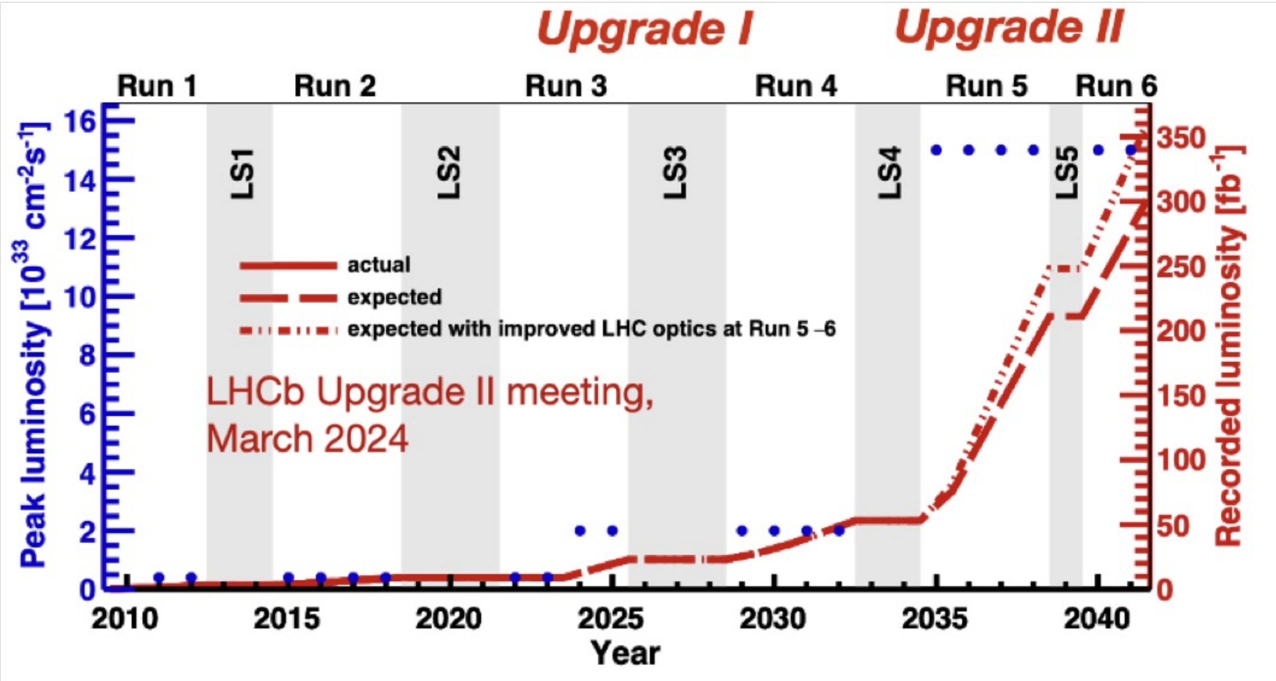
9th April 2026

THE UNIVERSITY of EDINBURGH

LHCb

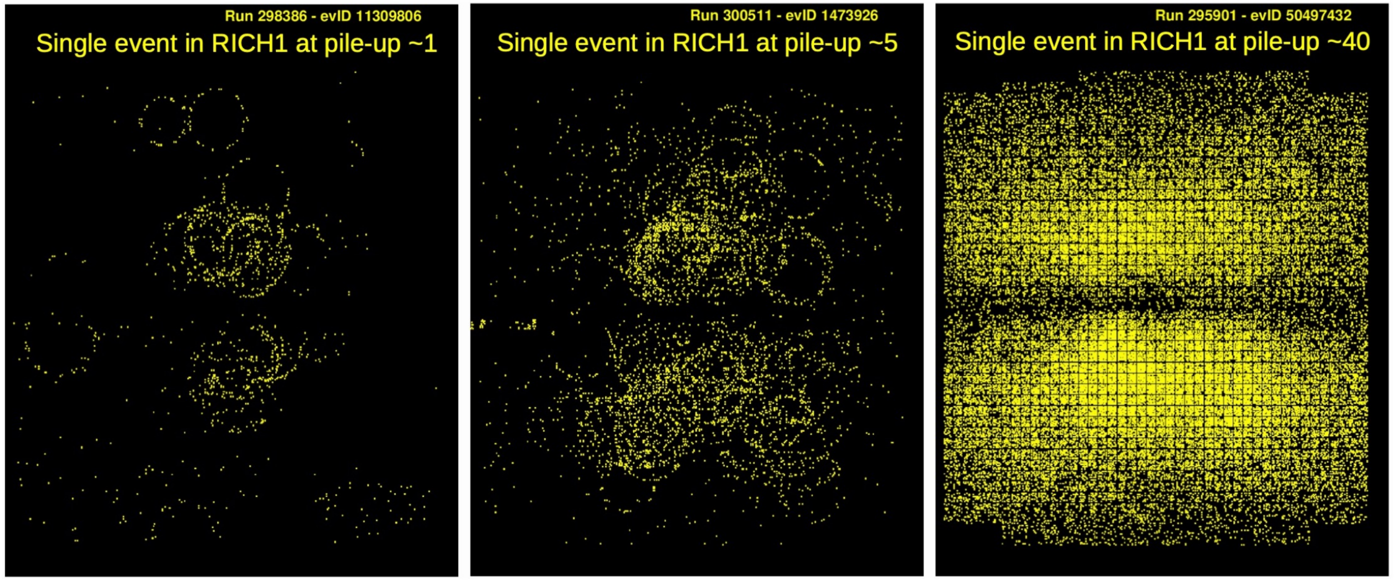
LHCb RICH

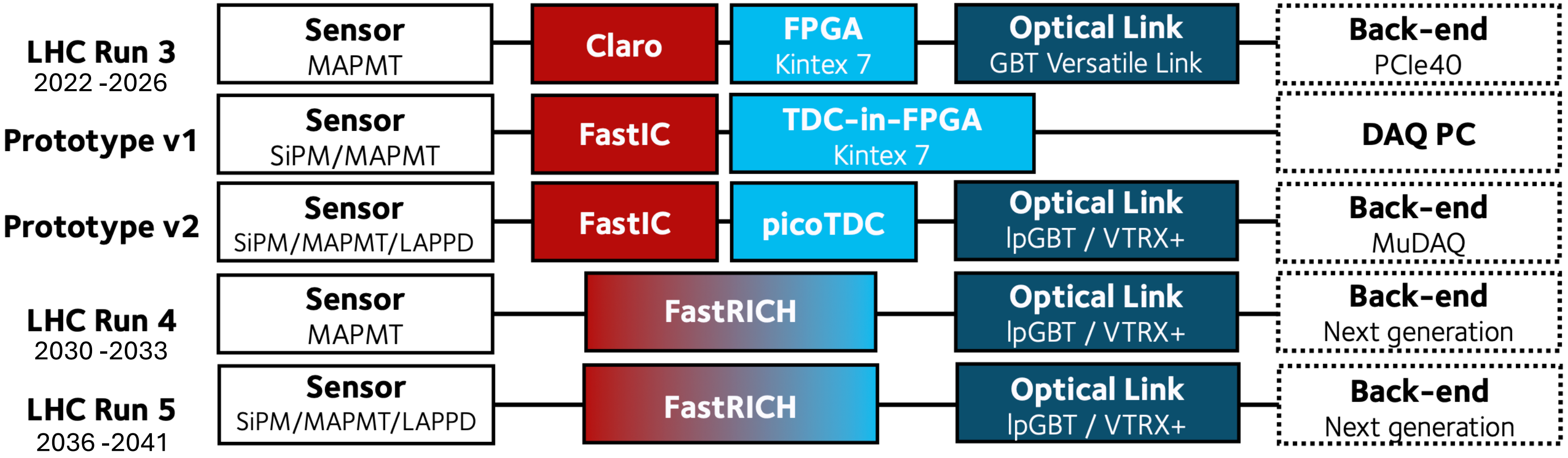




LHCb Detector and LHCb Luminosity increase

High-Lumi LHC: LS3 and Upgrade II



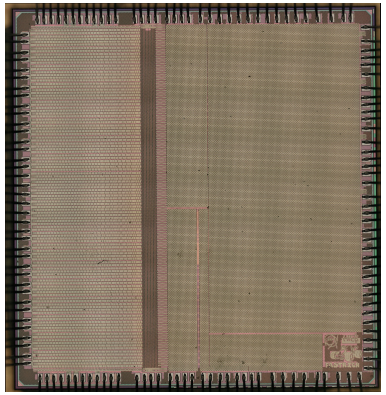


- High-Lumi RICH occupancy increase by an order of magnitude
- **100ps required resolution** to maintain Run 3 PID performance
- LS3 Enhancements for Run 4: **Readout upgrade** (FastRICH) with same detector technology
- Upgrade II for Run 5: **New detector technology** compatible with FastRICH readout

LS3 TDR, the LHCb framework TDR and Upgrade II scoping document

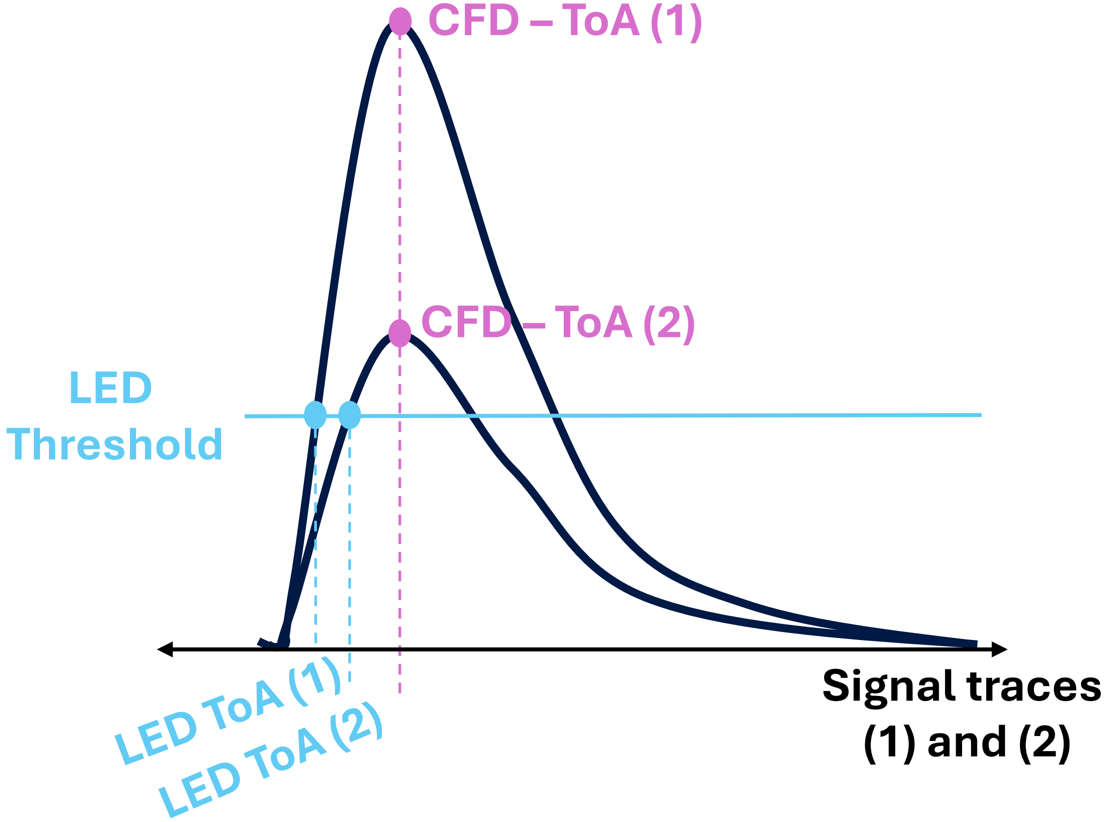
FastRICH ASIC

- CERN/Barcelona design in 65nm CMOS
- 16 Channels, **triggerless readout**, with ToA acquisition via Leading Edge (**LED**) or Constant Fraction (**CFD**) discriminators, configurable **hardware shutter**, **40MHz** readout
- ToA: **24.41ps (gate)** or 97.64ps (no gate) bins, ToT: 390.625ps bins
- Sensor Coupling: MaPMT, SiPM and MCP
- Data encoding: AURORA 64b/66b
- **Radiation hard design**: triple modular redundancy (TMR) for configuration and enclosed layout transistors (ELT) for analogue blocks.



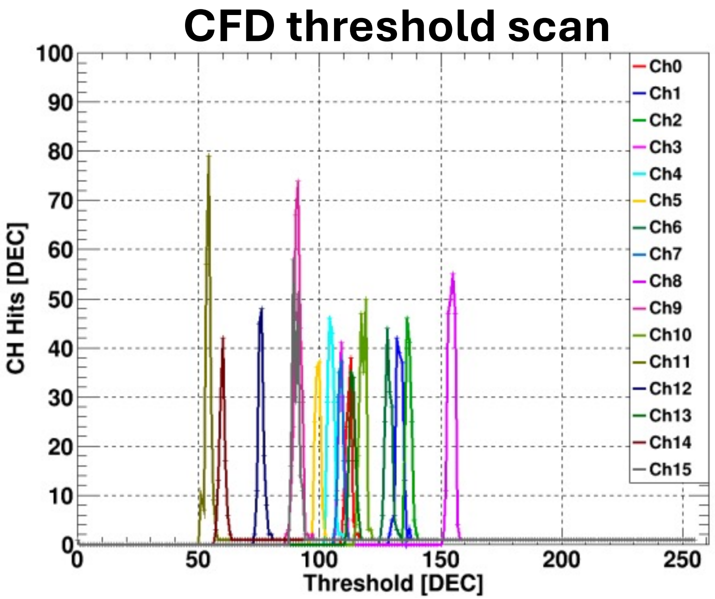
FastRICH Die

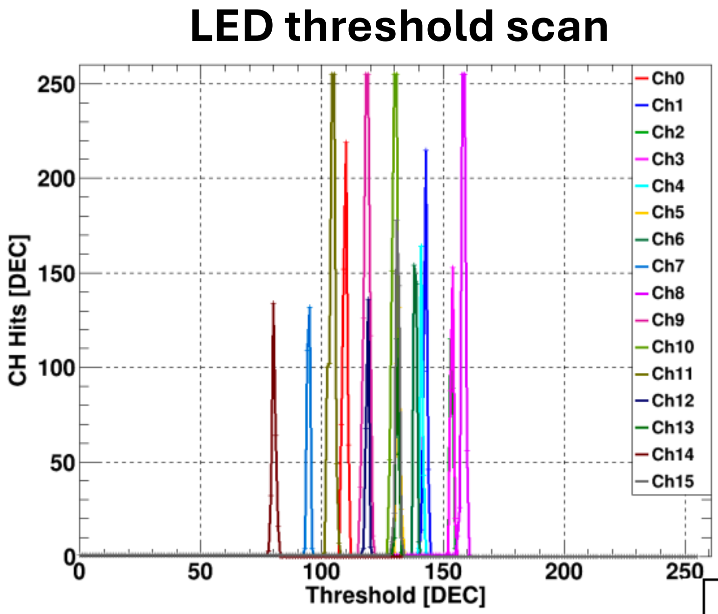
Example of two different signal traces

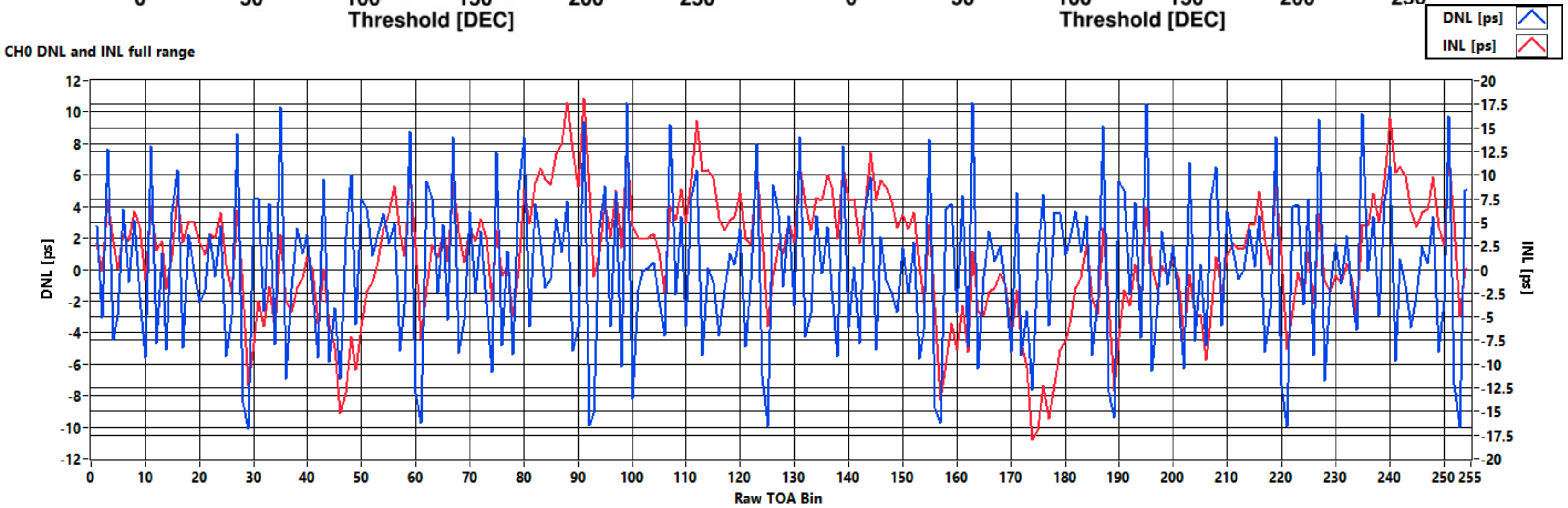


✓ CFD corrects Time of Arrival (ToA) timewalk

Functionality Testing







Functionality Testing Data from [Vlad Mihai Placinta]

- **Full functionality** of blocks and interfaces tested without issues - key outcomes:
- CFD and LED perform as expected
- Internal threshold scan FastRICH functionality tested successfully
- TDC tested with differential non-linearity (DNL) and integrated non-linearity (INL) measurements at 1.2V for bin consistency: DNL standard deviation < 6ps, INL range approximately ±24 ps

Radiation Testing

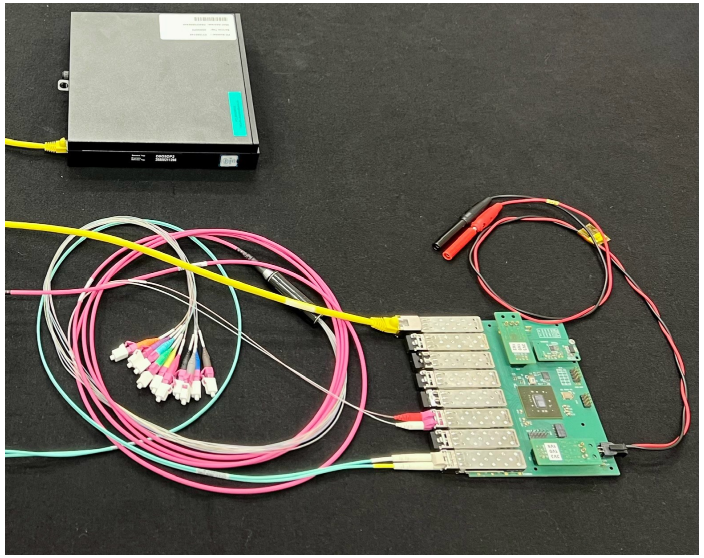
X-Ray testing at the "AsteriX" X-ray facility in CERN EP-ESE at CERN (left) and Ion testing at UCL-HIF in Belgium (right)

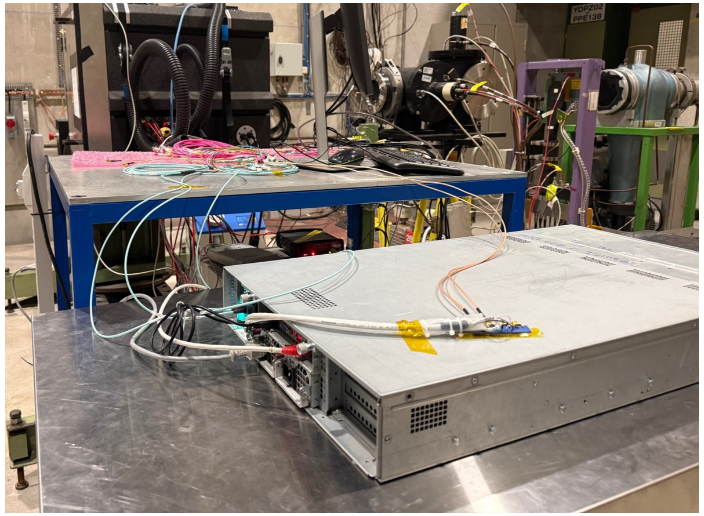
4 wire bonded FastRICHs tested with:

- Ion flux: 15000 particles/cm^2/s (maximum).
- Fluence per run: 0.8 x10^7 – 3 x10^7 particles/cm^2.
- Linear energy transfer (LET) between 3.2 – 125 MeV cm^2/mg.

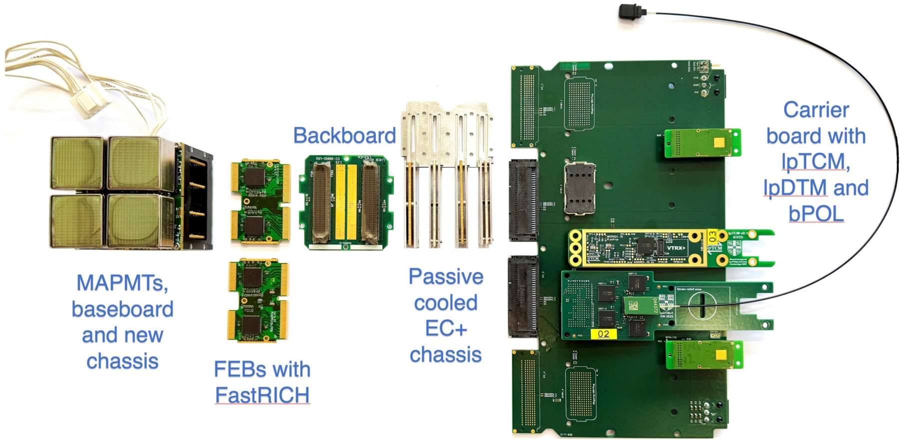
- Tests designed to exceed HL-LHC conditions and total dosage over operational lifetime
- **No single-event latchups** (require power cycle recovery) recorded up to maximum tested LET
- Configuration single-event upsets observed at all LETs, **corrected by the TMR.**
- Radiation induced fake hits observed in beam on data. Seem to originate from analogue part of chip. Were not observed after test pulse circuitry is disabled. *(Work in progress.)*
- **Data corruptions** observed in the readout, although **self mitigated** after a few orbits.
- **Upcoming**: ion run in April at Louvain, and an X-ray run for TID testing in May

Readout Chain

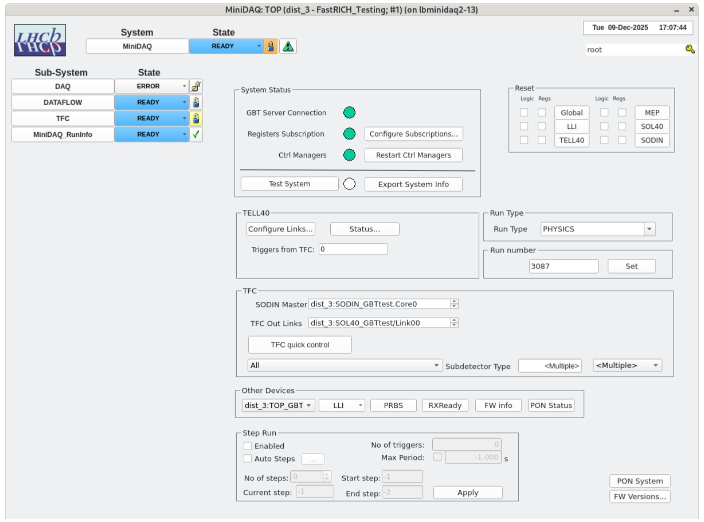




MuDAQ (top) and MiniDAQ (bottom)



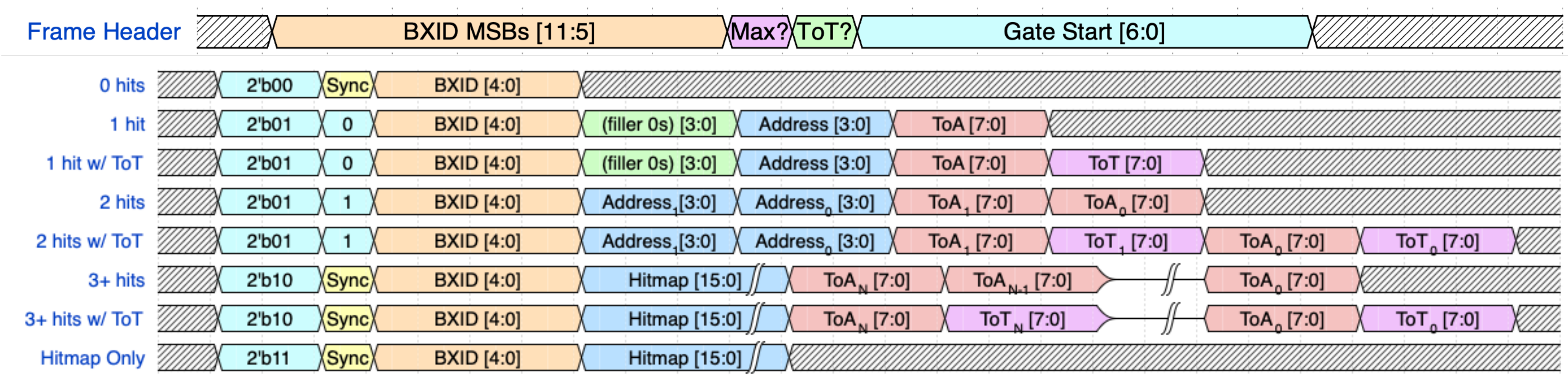
FastRICH front end



WinCC configuration settings from Alessandra Latham

- FastRICH on front end board (FEB), **readout by MuDAQ /MiniDAQ**
- Both DAQs run in bypass mode so decoding offline
- **MuDAQ** custom readout FPGA; more simple format and prior testbeam experience but bandwidth limitations
- **MiniDAQ** readout equivalent technology to that **used in Run 3 and 4**
- Configuration and control functionality implemented in WinCC, same as LHCb

Decoding



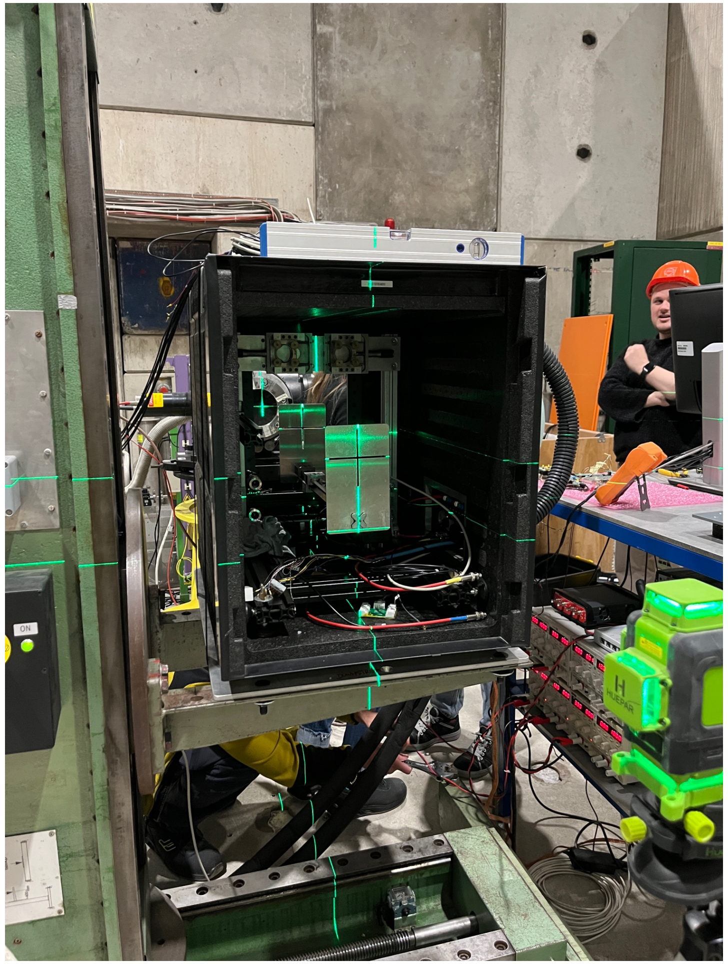
AURORA Blocks - MuDAQ

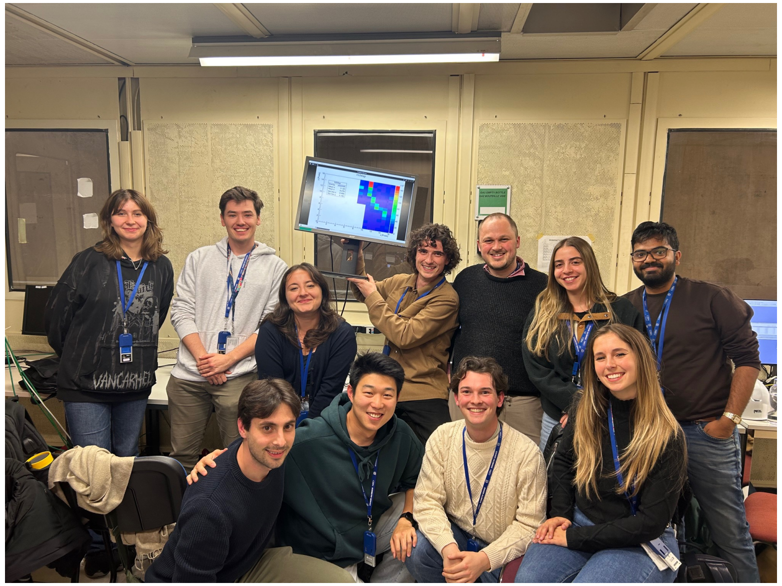
Fragments - MiniDAQ

FastRICH data format with header and packet structure (FastRICH documentation), and muDAQ and miniDAQ data packaging

- **FastRICH frames are reconstructed** from AURORA blocks (MuDAQ) or Fragments (MiniDAQ) and **written to a ROOT tree**
- Multiple file streams can be **decoded in parallel** allowing for Bunch Crossing ID (BXID) alignment across FastRICH and PicoTDC data, used for an external time reference
- Decoding corrects BXID rollovers from FastRICH, and is designed to **recover after data corruptions**
- Widely used analysis class and event building using BXID for consistent analysis in the group

Testbeam Campaigns





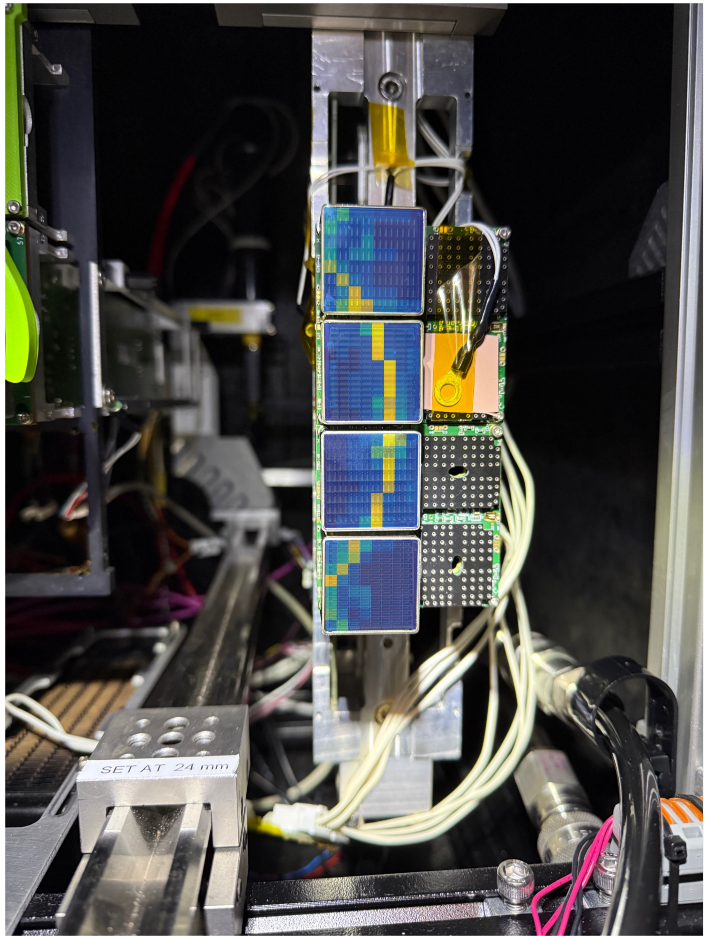
2025 FastRICH testbeam photos

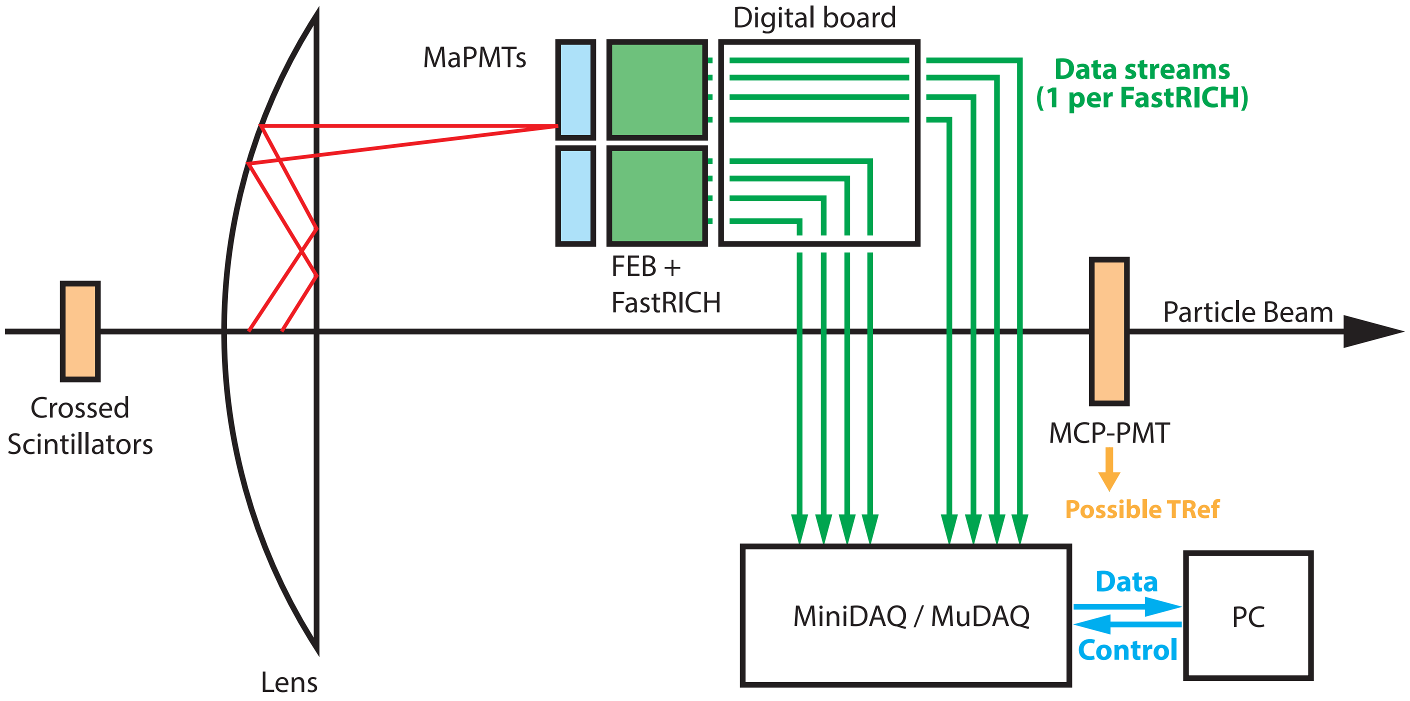
- Oct (SPS) and Dec (PS) 2025 with MaPMTs – Use of first protype FastRICH readout chains, decoding implemented, first ever readout rings with FastRICH, timing plots with muDAQ/miniDAQ, alongside lab characterisation

Upcoming:

- April (SPS), July (SPS) and August (PS) 2026 – full LS3 module, first coupling to novel photon detectors (cryo SiPMs and MCPs), novel radiator

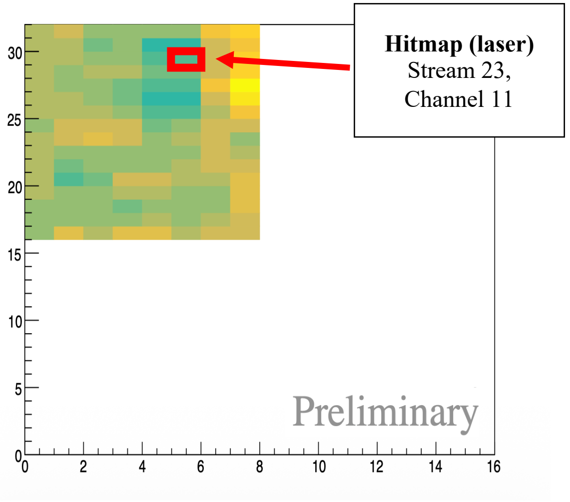
Testbeam Setup

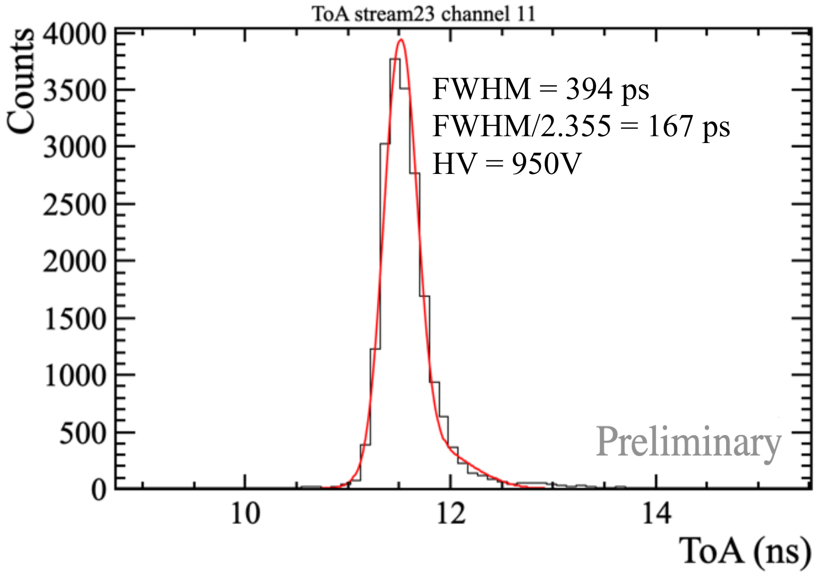


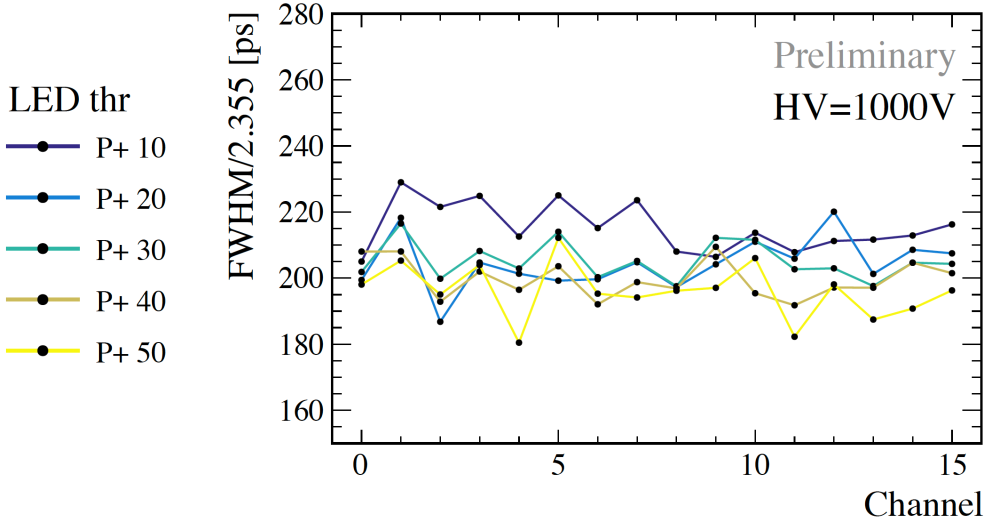


Superimposed ring and testbeam setup in a dark box

Testbeam Results – Lab time resolution

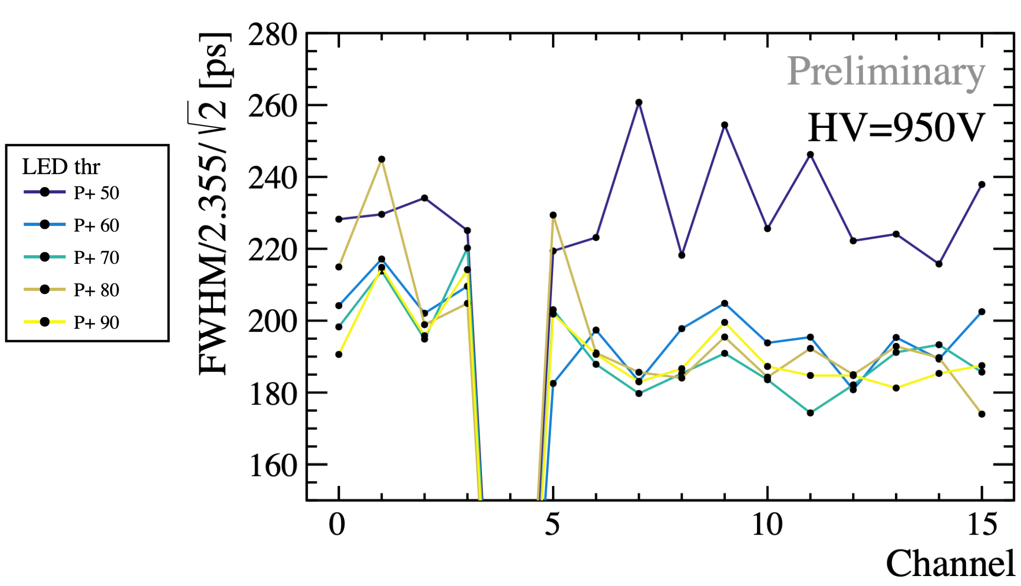




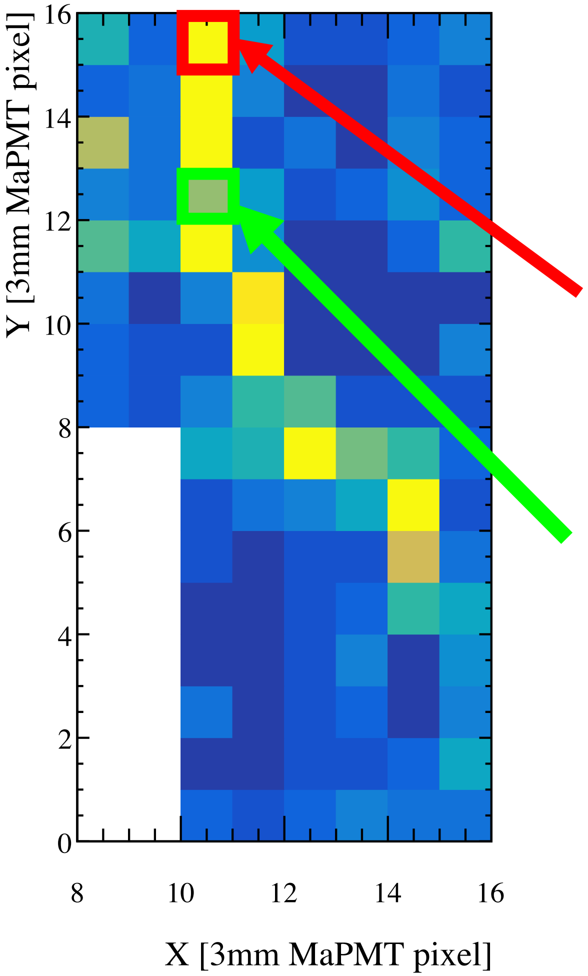


- Laser data taken in lab, with laser triggered by MuDAQ pulser synchronously with the FastRICH clock, so no external time reference necessary
- **Time resolutions consistent** with previous MaPMT resolution of ~180ps and beam data.
- Time resolution plots of lab data for MuDAQ readout, 6ns gate, CFD mode, ToT enabled, from Federica Borgato

Testbeam Results – no time reference

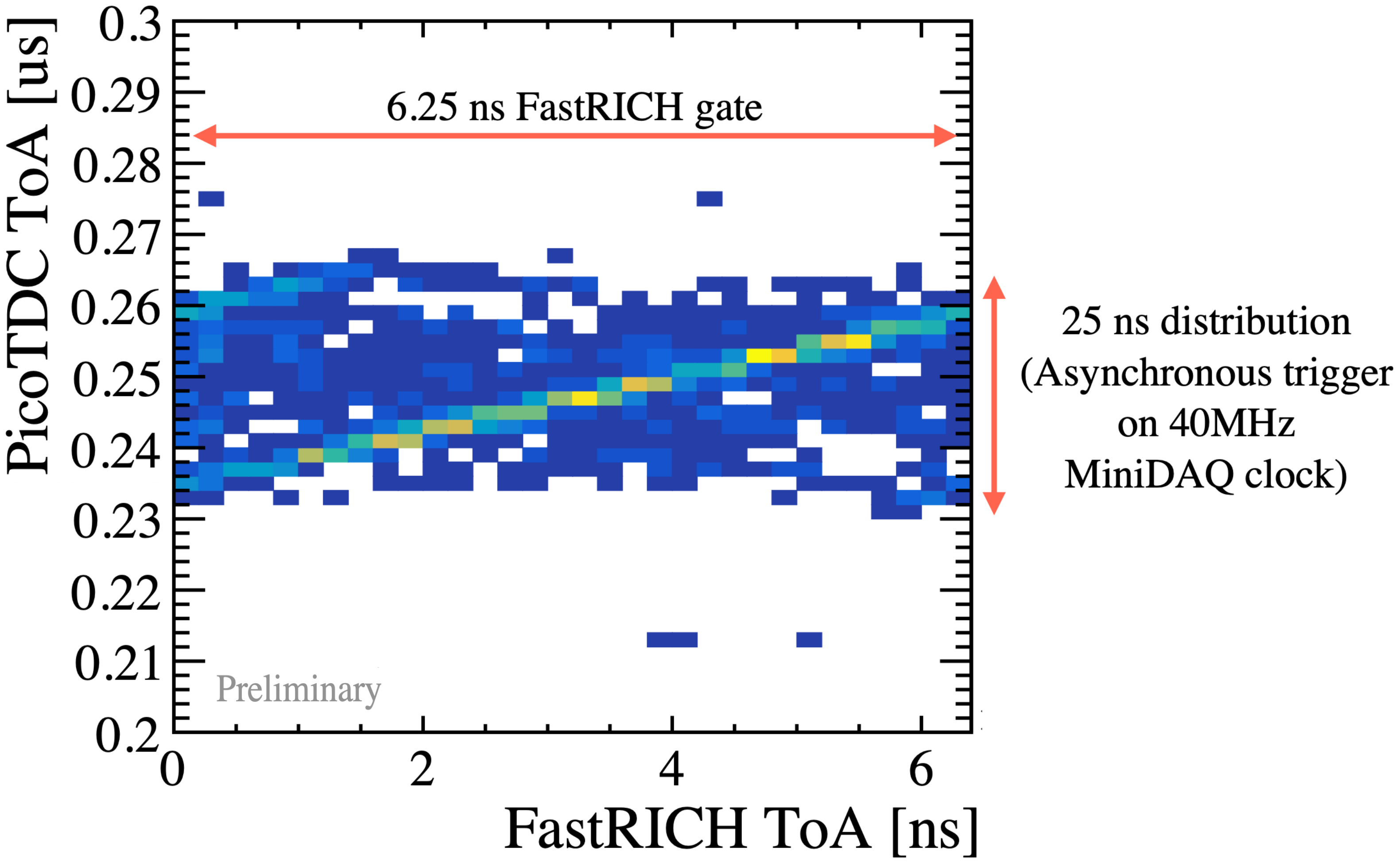


Time resolution plot of SPS beam data at varying LED thresholds for muDAQ readout, Channel 4 as reference, 6ns gate, CFD mode, ToT enabled, comparing two FastRICH channels on the ring from Federica Borgato



- Without synchronized picoTDC data there is no external time reference available for FastRICH
- Time reference constructed from the **time of arrival of other photons in an event (ring)**
- **ToA is then measured with respect to this time reference**
- Able to replicate previously measured MaPMT time resolution

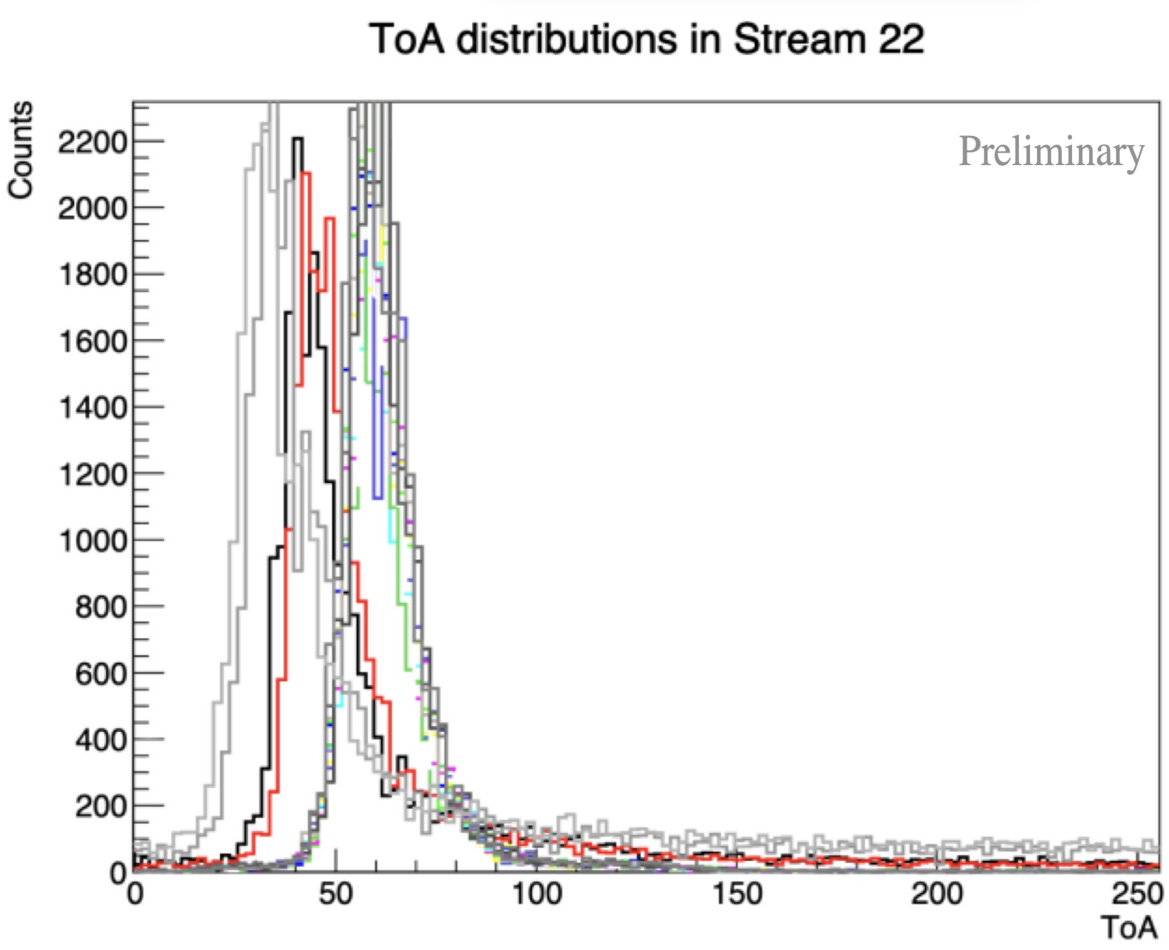
Testbeam Results – with time reference

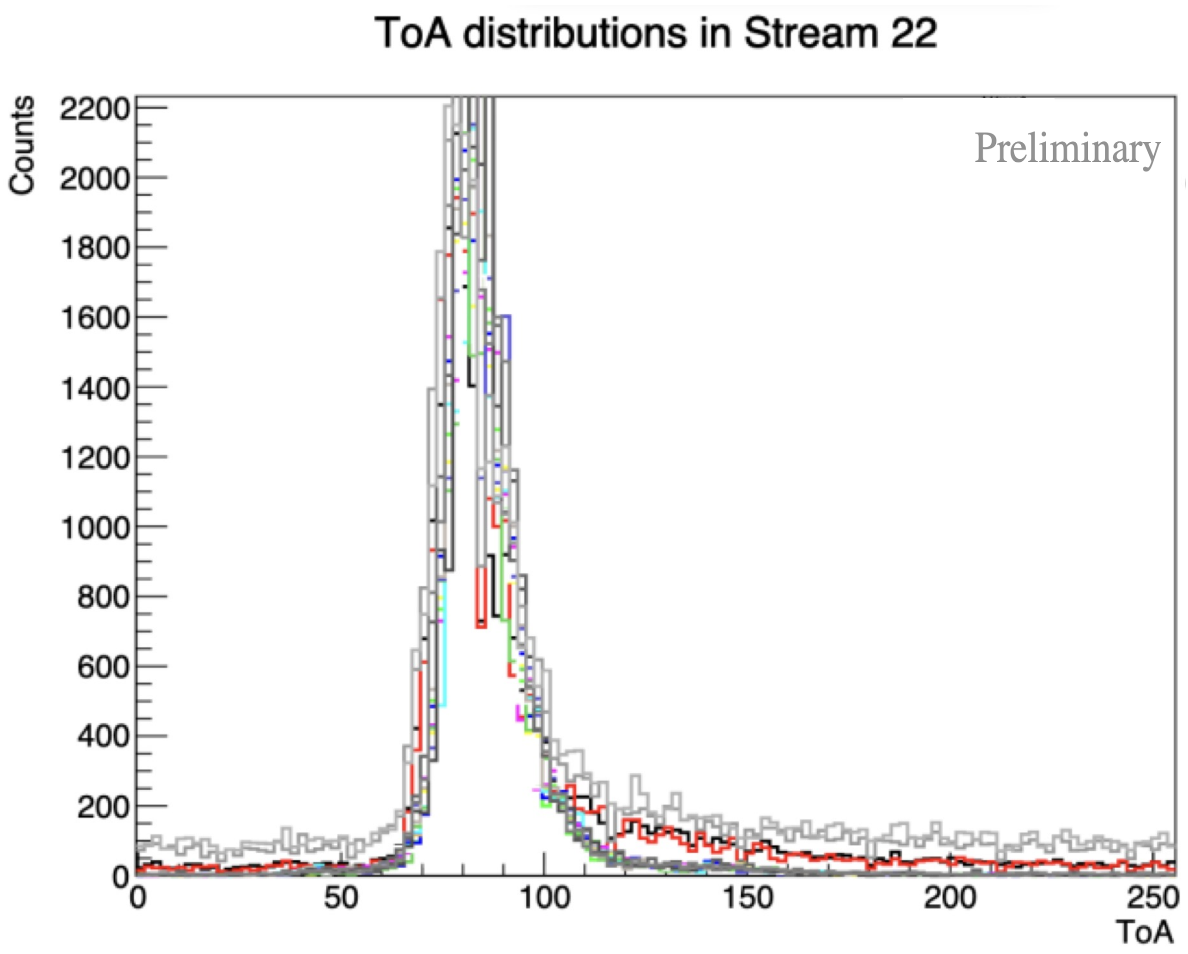


Correlation plot from Henry James Linton

- MiniDAQ can readout picoTDC data simultaneously with FastRICH, and so we can construct a time reference in this configuration with the picoTDC connected to a downstream MCP-PMT
- Correlation of FastRICH and picoTDC photons allows external time reference analysis, currently ongoing

FastRICH channel by channel offsets





Channel to Channel timing offset exists (left) and using the BERO shift register in FastRICH, an alignment can be performed (right), from Stella Paniskaki

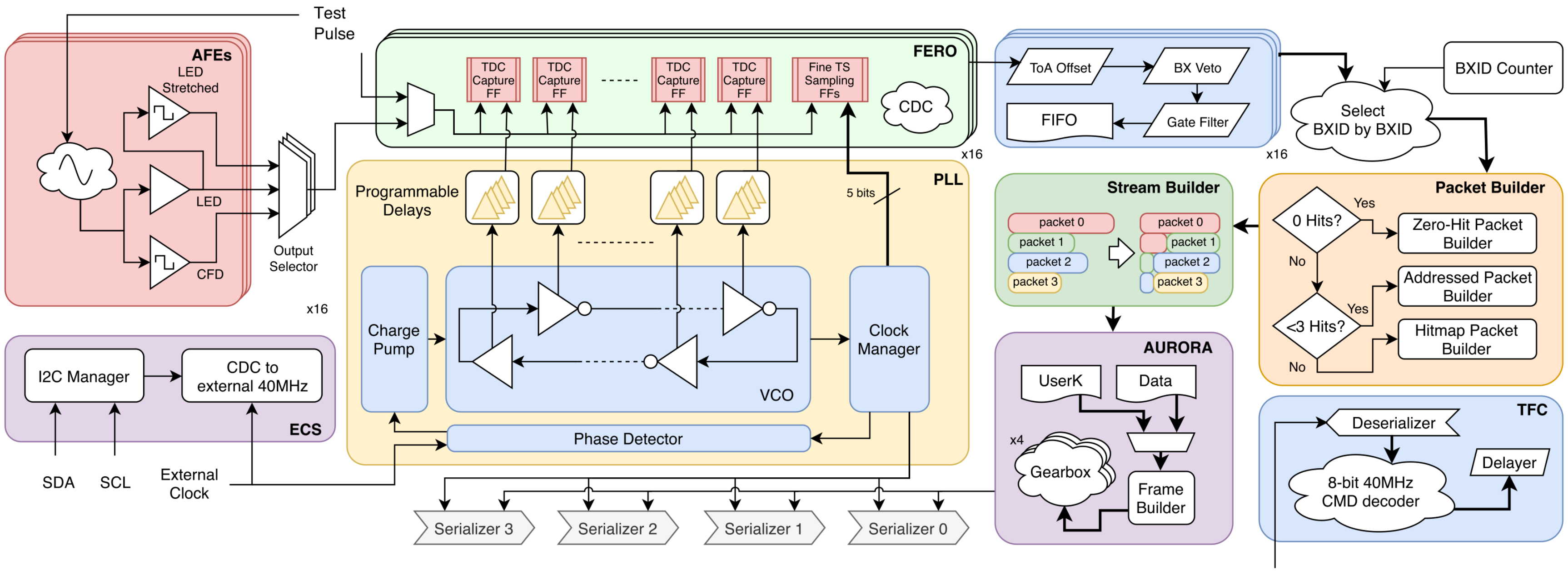
Conclusions

- High-Lumi RICH requires a readout upgrade to maintain Run 3 PID performance
- FastRICH design passed functionality and radiation testing
- Integration into testbeam readout for LS3 enhancements has been very successful and analysis is ongoing
- Further testbeams planned, also including Upgrade II detectors

Backup

FastRICH ASIC

Specification	FastRICH ASIC
Target Application	**LHCb-RICH**
Technology	CMOS 65nm
Final package	QFN88 (10mm x 10mm)
Sensor Coupling	**MaPMT, SiPM, MCP**
Channels	16 (single ended)
Input polarity	Positive or Negative
Input dynamic range	~ 30 μA – 2 mA
Discriminator	Leading Edge (**LED**) and Constant Fraction (**CFD**)
TDC bin	**ToA**: 24.41 ps (gate) or 97.64 ps (no gate) **ToT**: 390.625 ps
Bins per hit	~10 bits, dynamic length
Data Encoding	**AURORA** 64b/66b
Data rate	0.32 Gbps – 5.12 Gbps
Power	~11 – 13mW/ch
Target radiation environment	~2 Mrad; 7 x 10^{12} HeH/cm^2; 1 MeV n eq, 2 x 10^{13}/cm^2
Die	5mm x 5.25mm (146 pads)



FastRICH specifications and schematic with blocks from Vlad Mihai Placinta