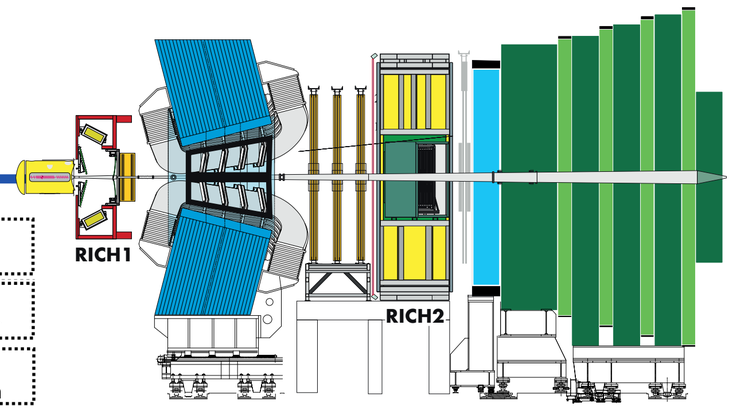
The FastRICH ASIC
for a time resolved LHCb RICH

George Ramsey on behalf of LHCb RICH, for IOP Joint APP and HEPP Annual Conference



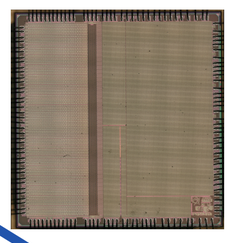
Specification

LHC Run 3	**Sensor** MAPMT	**Claro**	**FPGA** Kintex 7	**Optical Link** GBT Versatile Link	**Back-end** PCIe40
LHC Run 4	**Sensor** MAPMT	**FastRICH**		**Optical Link** lpGBT / VTRX+	**Back-end** Next generation
LHC Run 5	**Sensor** SiPM/MAPMT/LAPPD	**FastRICH**		**Optical Link** lpGBT / VTRX+	**Back-end** Next generation

The FastRICH is a novel ASIC central to a time resolved readout chain for LHCb's two ring-imaging Cherenkov (RICH) detectors. The upgraded electronics will be installed during Long Shutdown Three (LS3) to retain the RICH's excellent particle identification (PID) performance after transition to the high multiplicity environment provided by the High Luminosity LHC (HL-LHC)

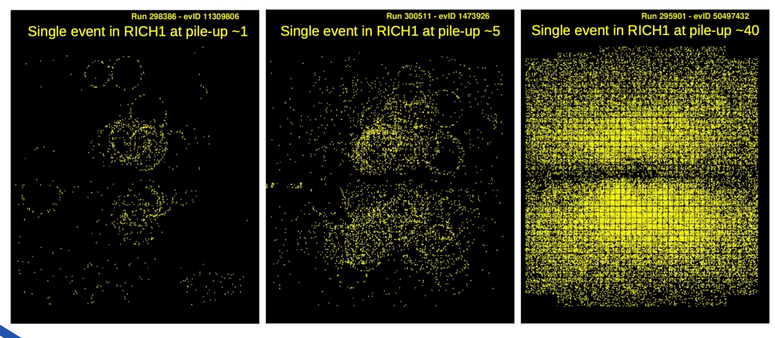
Specification	FastRICH ASIC
Target Application	**LHCb-RICH**
Technology	CMOS 65nm
Final package	QFN88 (10mm x 10mm)
Sensor Coupling	**MaPMT, SiPM, MCP**
Channels	16 (single ended)
Input polarity	Positive or Negative
Input dynamic range	~ 30 μA – 2 mA
Discriminator	Leading Edge (**LED**) and Constant 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 Die



Decoding

Occupancy will increase by an order of magnitude at HL-LHC



An essential milestone was to decode FastRICH data from the MuDAQ and MiniDAQ readout chains into ntuples

FastRICH frame data is packaged into AURORA blocks

MuDAQ writes AURORA blocks directly to file
MiniDAQ unpacks AURORA blocks into Fragments and writes to a Frag file

Radiation hard design: triple modular redundancy (TMR) for configuration and enclosed layout transistors (ELT) for analogue blocks

FastRICH Frame Structure

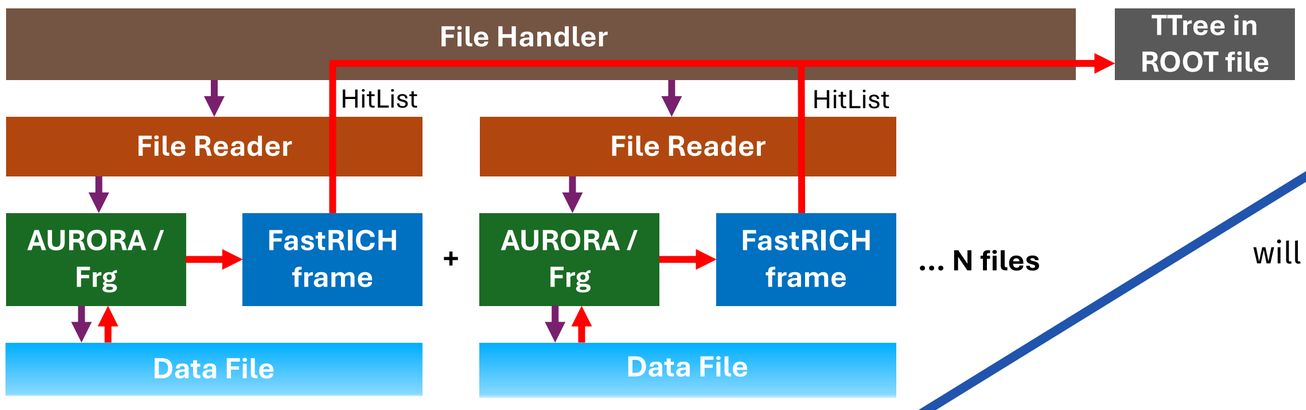
Frame Header	BXID MSBs [11:5]	Max?	ToT?	Gate Start [6:0]				
0 hits	2'b00	Sync	BXID [4:0]					
1 hit	2'b01	0	BXID [4:0]	(filler 0s) [3:0]	Address [3:0]	ToA [7:0]		
1 hit w/ ToT	2'b01	0	BXID [4:0]	(filler 0s) [3:0]	Address [3:0]	ToA [7:0]	ToT [7:0]	
2 hits	2'b01	1	BXID [4:0]	Address$_1$[3:0]	Address$_0$ [3:0]	ToA$_1$ [7:0]	ToA$_0$ [7:0]	
2 hits w/ ToT	2'b01	1	BXID [4:0]	Address$_1$[3:0]	Address$_0$ [3:0]	ToA$_1$ [7:0]	ToT$_1$ [7:0]	ToA$_0$ [7:0] ToT$_0$ [7:0]
3+ hits	2'b10	Sync	BXID [4:0]	Hitmap [15:0]	ToA$_N$ [7:0]	ToA$_{N-1}$ [7:0]		ToA$_0$ [7:0]
3+ hits w/ ToT	2'b10	Sync	BXID [4:0]	Hitmap [15:0]	ToA$_N$ [7:0]	ToT$_N$ [7:0]		ToA$_0$ [7:0] ToT$_0$ [7:0]
Hitmap Only	2'b11	Sync	BXID [4:0]	Hitmap [15:0]				

The FastRICH frames are reconstructed from AURORA blocks (MuDAQ) or Fragments (MiniDAQ)

AURORA Blocks - MuDAQ

Fragments - MiniDAQ

Multiple file streams can be decoded in parallel allowing for Bunch Crossing ID (BXID) alignment across FastRICH and PicoTDC (older readout ASIC) data, used for an external time reference



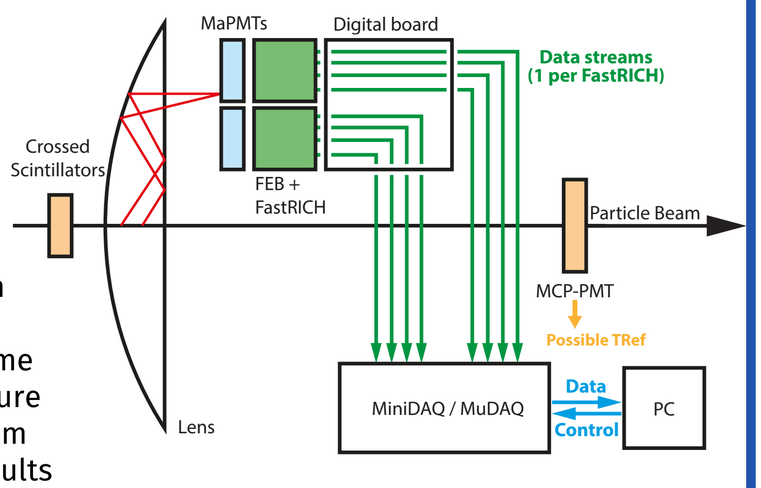
Decoding corrects BXID rollovers from FastRICH and is designed to recover after data corruptions

Data is written to a ROOT tree in BXID order

Widely used analysis class and event building based on BXID for consistent analysis in the group

Testbeams

2025 testbeams implemented the first ever FastRICH readout from photon detectors (MaPMTs). Upcoming testbeams will instrument a full LS3 module with FastRICH and couple to Upgrade II photon detectors



Full analysis of testbeam data is ongoing

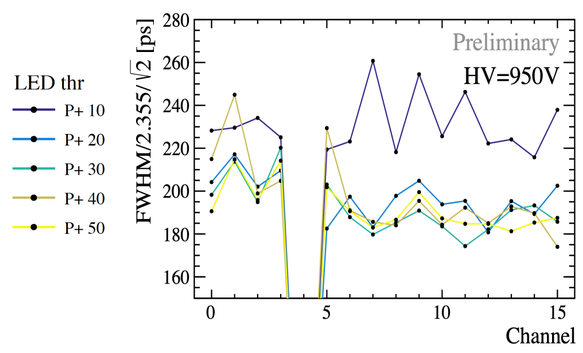
Timing measurements were taken with respect to other channels on the ring for data taken without a synchronised external time reference. This method is able to accurately measure the 1-inch MaPMT time resolution to ~180ps in the beam (left plot below), agreeing with previous testbeam results

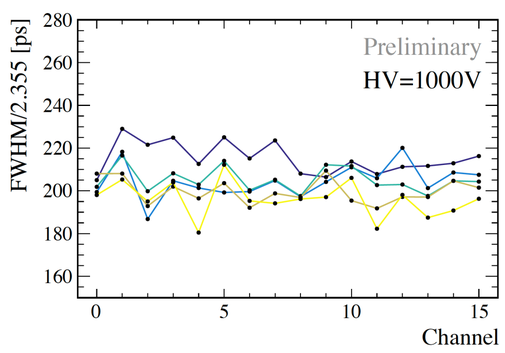
Laser data (middle plot), synchronous with the FastRICH clock, produces time resolutions consistent with beam data

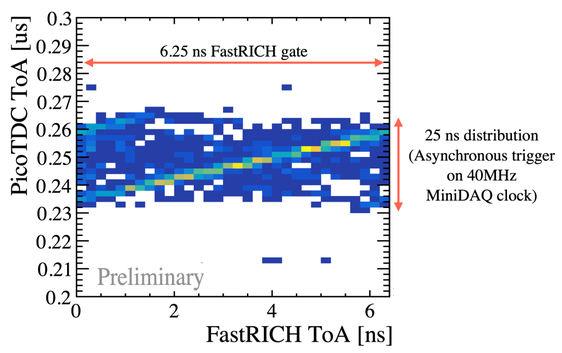
Correlation between FastRICH and external time reference provided by an MCP-PMT, timestamped by a PicoTDC, is seen (right plot)

Timing measurements compared between two channels on the ring

$$ToA_A - ToA_B = \Delta ToA$$







References

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