



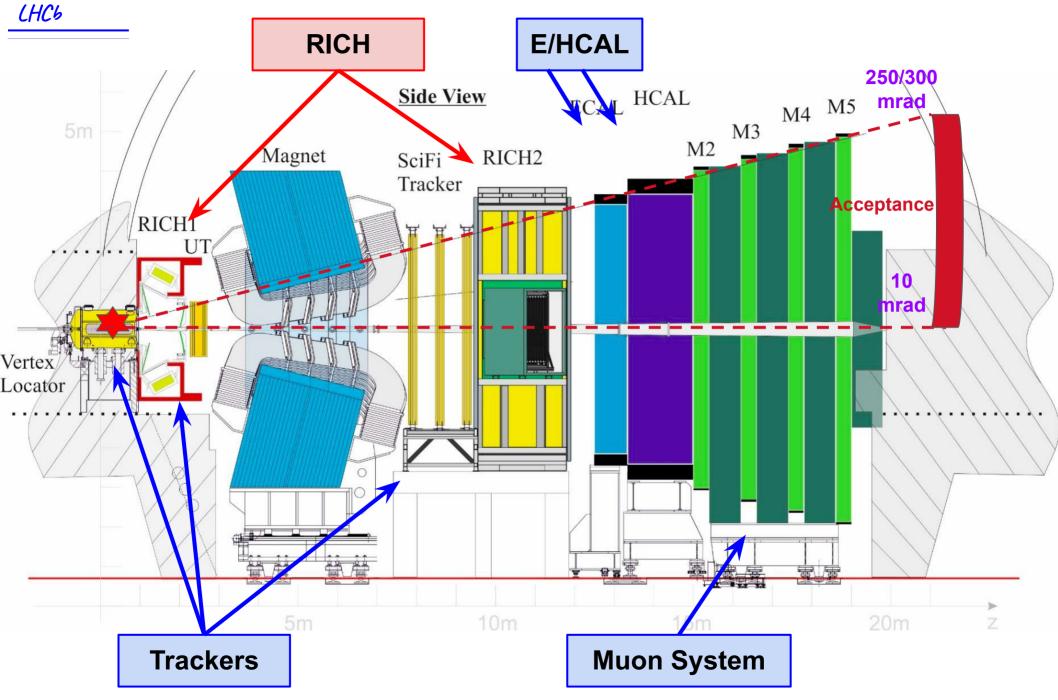
LHCb Upgrade of the RICH Detectors

Antonino Sergi University of Genova and INFN on behalf of the LHCb RICH collaboration

11th International Workshop on Ring Imaging Cherenkov Detectors "RICH 2022"

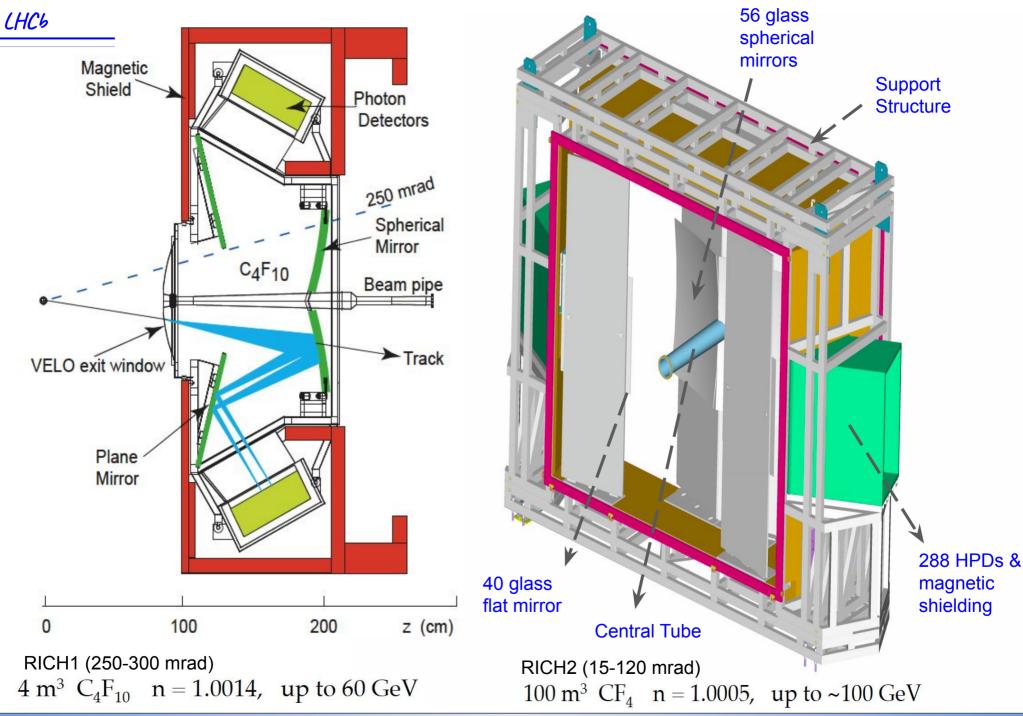
Edinburgh, 12-16 Sept

THE LHCb Experiment



RICH2022

RICH Detectors



RICH2022

RICH Upgrade

- Adapt the current RICH detectors to run at higher luminosity and with continuous 40 MHz read-out
- Mechanical and optical changes
 - RICH1 spherical mirrors focal length increased to reduce occupancy (optical system re-designed)
 - New support mechanics and cooling
- Electronics and data acquisition changes
 - Replace HPDs with commercial MultiAnode PhtotoMultiplier Tubes (MaPMTs) with 64 channels
 - Use 40 MHz front-end electronics and data acquisition
 - CLARO8 amplifier/discriminator ASIC
 - FPGA-based digital board
 - GigaBit Transceiver (GBT) chip for data transmission

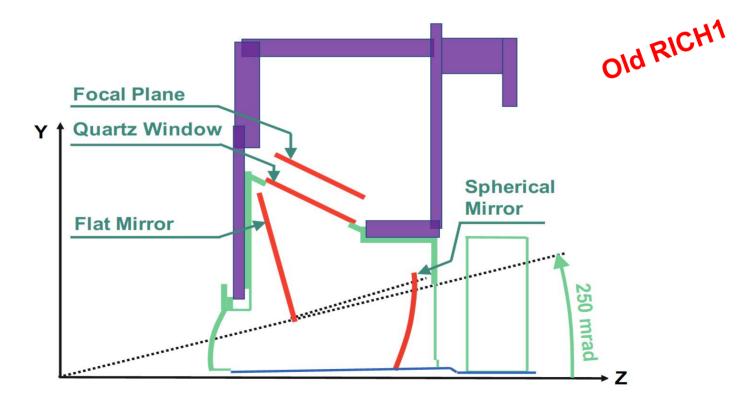
New Mechanics

- Peak occupancy should remain < 30% to maintain PID performance
- Focal plane and spherical mirror moved back to increase ring size
- New spherical mirrors with larger curvature radius
- Larger gas enclosure

LHC6

RICH2022

• Compact photo-detection system required



New Mechanics

- Peak occupancy should remain < 30% to maintain PID performance
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LHC6

RICH2022

• Compact photo-detection system required

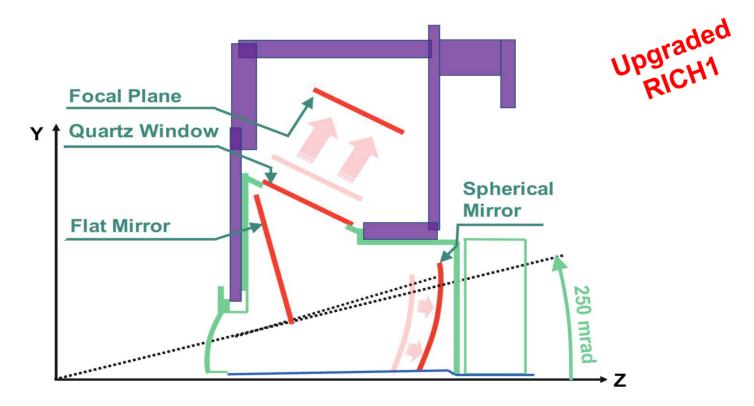
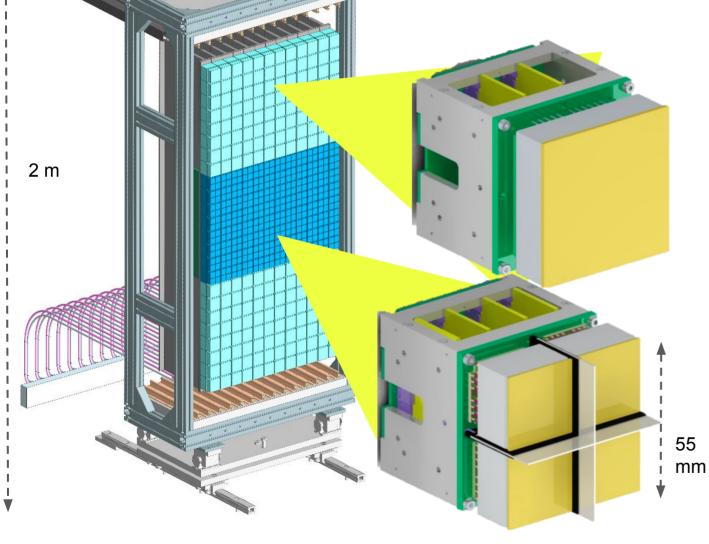






Photo-Detector Assembly

- Hamamatsu MaPMTs with 8×8 pixel matrix, arranged in Elementary Cells (EC)
 - A. 1" R13742 (from R11265 series)
 - B. 2" R13743 (from R12699 series)



- EC-H type: 2" MaPMT
 - ~400 modules
 - Outer regions of RICH2
 - One "A"MaPMT per EC (larger model 2×2 inches)
- EC-R type: 4×1" MaPMTs
 - 2×2 matrix of "B" MaPMT per EC (smaller module 1×1 inches)
 - ~ 2700 MaPMT
 - \circ ~700 modules
 - RICH1 and central region of RICH2

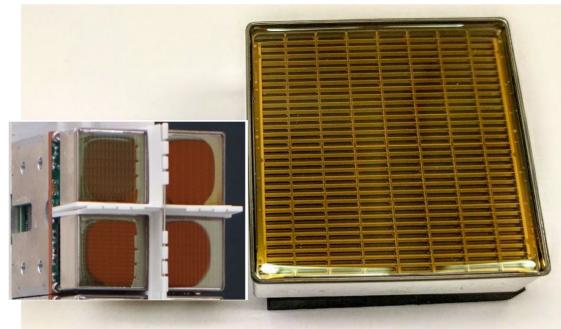
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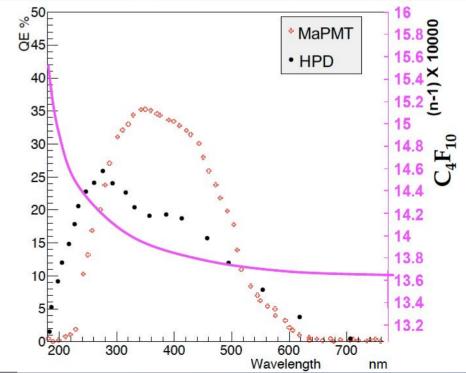
MultiAnode PhotoMultipliers

• Hamamatsu MaPMTs

LHC6

- 3100 R13742 and 450 R13743, including spares
- Super-bialkali photocathode
- UV glass window
- Minimum gain 1×10⁶ at 1 KV
- 1:4 pixel gain spread in 1" PMTs, 1:3 pixel gain spread in 2" PMTs
- Low dark count rate
- Single photon spectrum well separated from the noise pedestal
- Higher QE of MaPMT in the green
 - Chromatic error reduction
- Sensitive to magnetic fields
 - Shielding applied

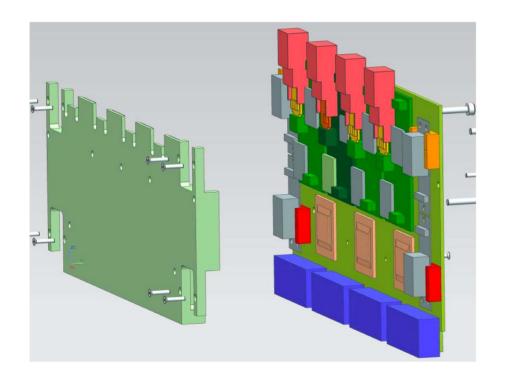




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Front-End Digital Board

- Capture (asynchronous) CLARO outputs, synchronize to LHC clock, data algorithm, format and transmission
- Motherboard with FPGAs and power distribution (PDMDB)
 - \circ Each serves 4 × half EC-R or 4 × EC-H
 - \circ $\,$ Plugins for control and data link
- Thermally coupled to cooled column



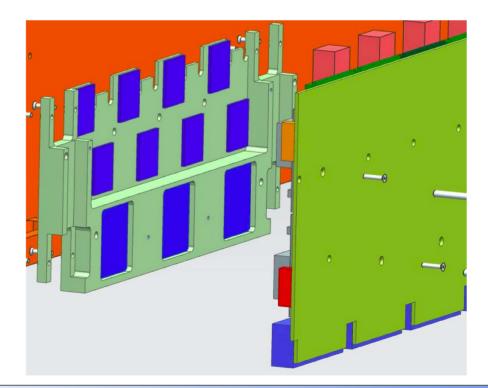
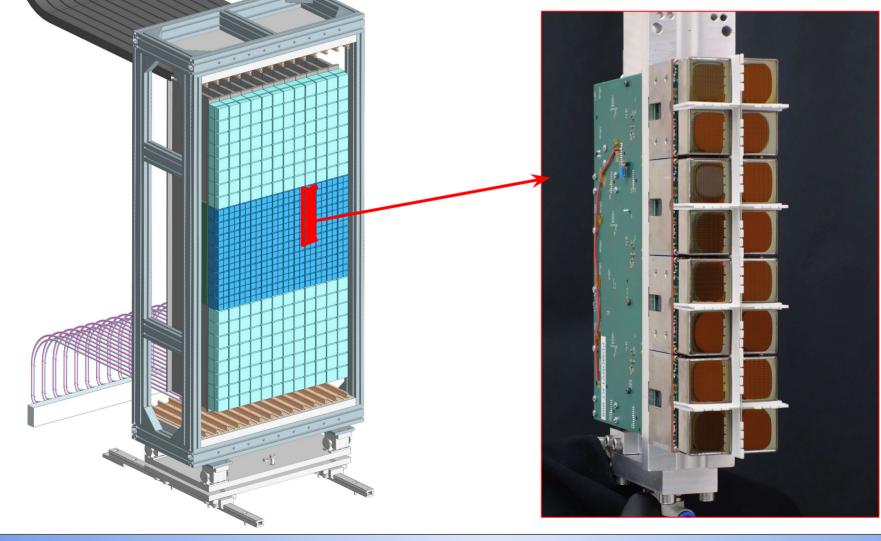




Photo-Detection Module

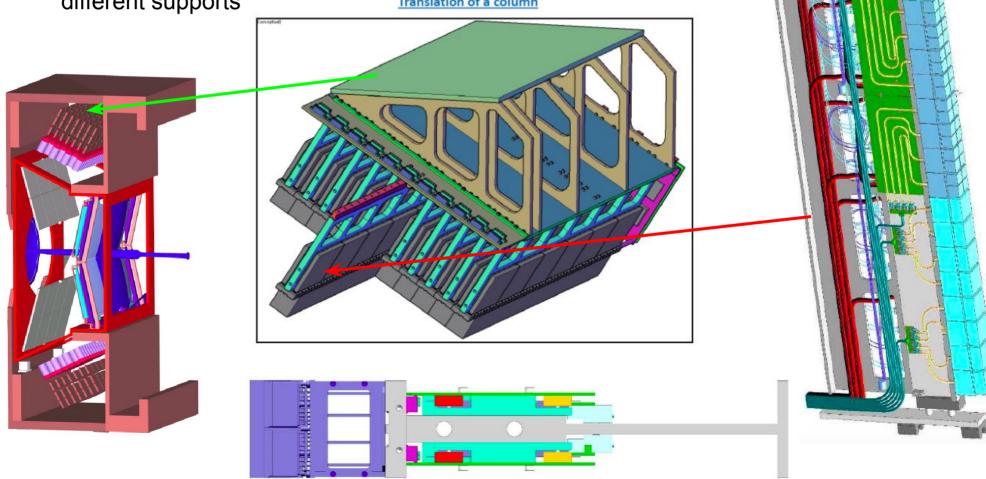
- PDM: 2 digital boards + 4 elementary cells
 - MaPMTs (magnetic shield for RICH1 only), CLARO
 ASIC read-out, FPGA read-out, fast data transmission



RICH2022

Columns

- Mechanical support for Elementary Cells, PDMDB, harness and cooling
 - \circ $\;$ Easy to remove a column for maintenance
 - Same mechanical structure for columns in RICH1 and RICH2 but different supports
 Translation of a column



Antonino Sergi

Brief history

LHC6

- Lab test of MaPMTs since 2011
- Test beams with MaPMTs and prototype FE electronics since 2014
- Test beams with MaPMTs, analog FE and prototypes FE Digital Board and TELL40 since 2016
- MaPMT Quality Assurance since 2016
- FE Digital Board firmware radiation hardness tests in 2017
 - Triple Module Redundancy, Partial Reconfiguration, stateless architecture (helped by BE)
- Idea to implement lossless compression in TELL40 (BE) firmware
- Integration of 1 prototype Photo-Detection Module in the operational RICH2 in 2018
 - Discovery of Signal-Induced Noise (SIN) in MaPMTs (see Giovanni Cavallero's talk)
- EC Quality Assurance since 2018
- Column assembly and commissioning (at CERN) started towards the end of 2019
- Detector Installation started at the end of 2020
- Detector Commissioning started mid 2021
- First light in October 2021
- Detector Installation finished mid 2022
- Enough with spoilers ...

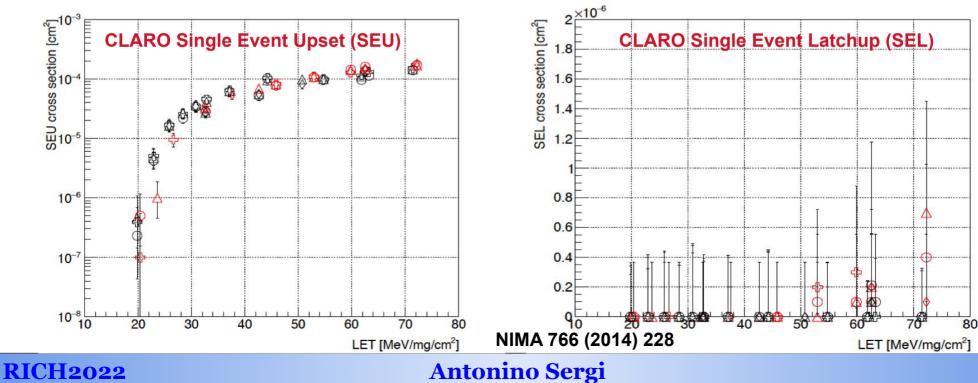
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Radiation Hardness

- High radiation levels expected for whole upgrade phase (50 fb⁻¹) at the RICH photodetector plane location
 - 200 krad, 3×10^{12} 1 MeV n_{eq}/cm² , 1.2×10^{12} HEH/cm² Ο

- The read-out (CLARO and FPGA) have been tested for Single Event Effects (SEE) and Total Ionizing Dose (TID)
 - CLARO uses radiation-hard by design cells(IMS-CNM Sevilla) Ο
- Xilinx Kintex-7 FPGA is suitable for operation in LHCb RICH

Periodic scrubbing foreseen for error mitigation Ο



RICH2 Column Commissioning Summary





- Fully automated test to commission 24 columns
- Few issues encountered due to software (data-writing speed, firmware programming)
- 258 automatically sent emails on both successful tests but also tests failing
- Experts on call recovering stuck tests whenever needed
- Operation-like experience carried out with the help of many collaborators travelling to CERN until pandemic hit
- Commissioning stopped for ~ 1.5 months during lockdown
- Programme concluded in 07/20 with very limited number of people due to pandemic

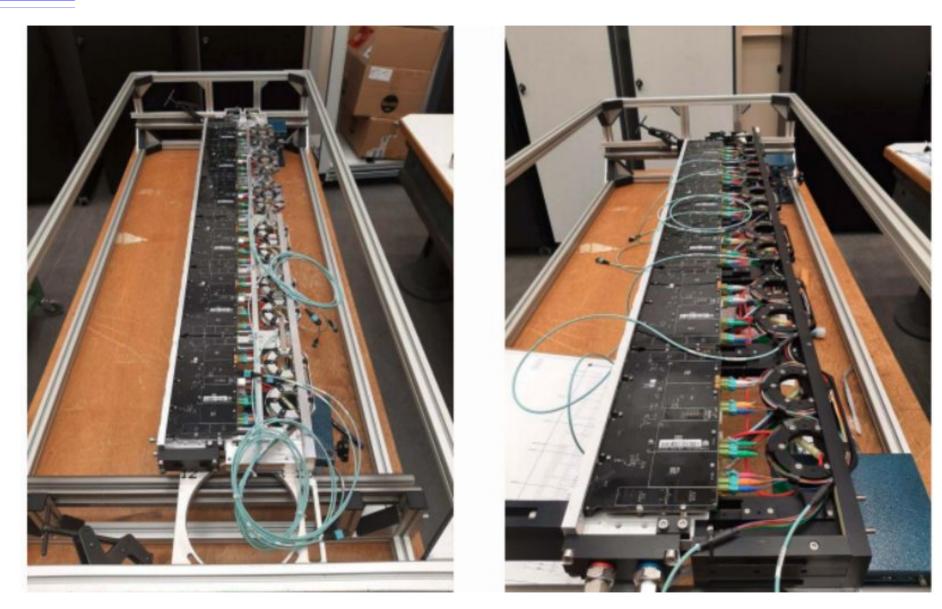
RICH2022

Commissioning automation

MiniDAQ: TOP (MultiMiniDAQ2 - MultiMiniDAQ2; #1)				lbRichECS_comLab (MultiMiniDAQ2 - MultiMiniDAQ2; #1) ×						
$\overline{\mathbb{X}}$	System MiniDAQ	State RUNNING -		Configuration Type RICH2	• • Write	to Elog 🗌 showPlots				
Sub-System	State			ID COL O	4 - ✓ autoR	ecover 🖌 saveECSD	ata			
DAQ	RUNNING 🔮	System Status	Reset							
DATAFLOW	RUNNING -	GBT Server Connection	load Global							
TFC	PAUSED -						-			
MiniDAQ_Runinfo	PAUSED -	Registers Subscription Configure Su	ubscriptions	- Switch off	We	orking points		Thresh	old Scans	
RICH2_HV	OFF -	Ctrl Managers 🔵 Restart Ctr	rl Managers				- T			_
RICH2_DCS	READY *			Switch on LV and configur	e Test	working points			SIN	
		Test System	ystem Info	Functional test		IV training)			
		Configure Links Status	Run Type OTHER TY	DAC scans		ark counts	0			
Write to El	og	Triggers from TFC: 23'000	Run number		R	un All Steps				3 2
Run commence.		Events Accepted: Mismatch	4789							
TFC SODIN Master MultiMiniDAQ2:sodin_004 TFC Out Links MultiMiniDAQ2:sol40_004 TFC quick control Click to e				Status Error log Trying to autorecover Waiting 9s for TFC to become PAUSED Waiting 10 s after RECOVER command Configuring Waiting 10 s after CONFIGURE command						
Power Supplies Over	rview	All Other Devices	Subdetector Type RICH_TB2	Alarm Screen	StartMor StartMo		and the second se		Close	
ComLab		top_018 + LLI + PRBS	RXReady FW info FE monitorin		view (MultiMiniDAQ2 - Mu	(H)M(H)D((02) #1)	_	_	_	_
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Messages			Channel R2A_HV_COL00_PDM2/PK	0.1 V	0.00 uA	OFF	ON	OFF	Settings	Plot
28-Nov-2019 16:03:48 - *** WARNING - Can not Take: RICH2_HV is owned by R2HV1:Manager1 (Ibrich@ibrichecs01) ***		Channel	vMon	iMon	status					
28-Nov-2019 16:03:48 - *** WARNING - Can not Take: RICH2_DCS is owned by R2DCS1:Manager1 (lbrich@lbrichecs01) *** 28-Nov-2019 20:36:34 - *** INFO - Resetting SODIN			R2A_HV_COL00_PDM3/PK	0.0 V	0.00 uA	OFF	ON	OFF	Settings	Plot
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RICH1 Column assembly





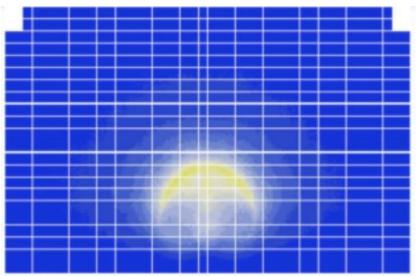


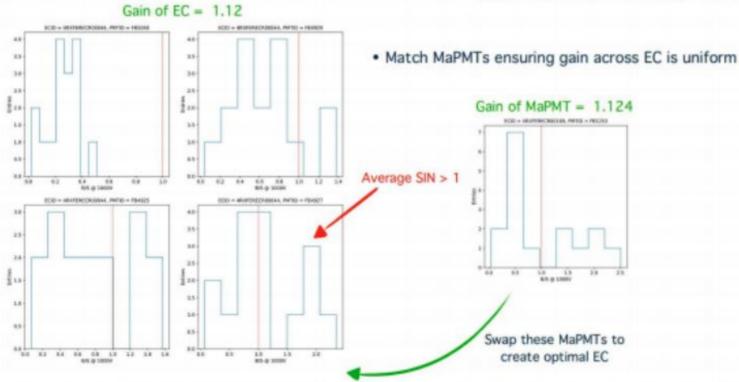
ECs grouping in RICH1: mitigation for SIN

- SIN data collected at ECQA and analysed
- SIN model developed

LHC6

- Occupancy map with number of MaPMTs per category produced
- Global analysis and selection of "gold" ECs defining regrouping of MaPMTs

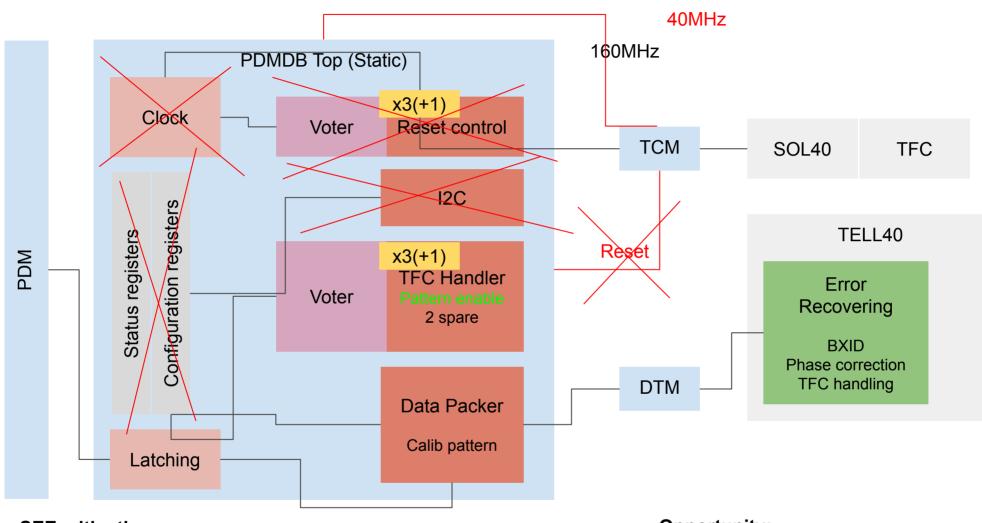




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PDMDB Firmware for radiation hardness

LHC6



SEE mitigation:

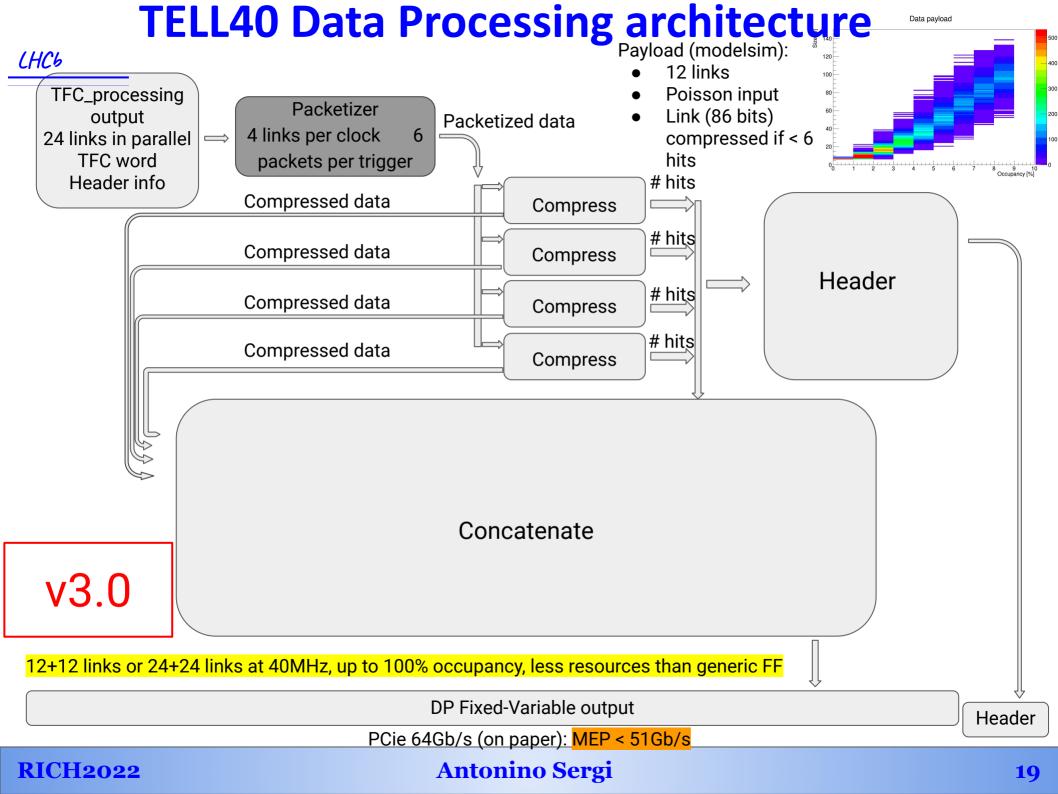
- Minimized (~4% logic)
- Triple Module Redundancy (with monitoring in data frame)
- Partial Reconfiguration
 - No interruption of data stream for SEU not involving I/O pins
 - 2 seconds otherwise

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Opportunity:

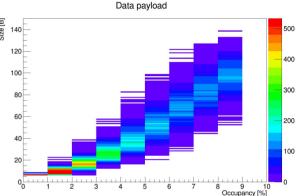
 Latching at 360MHz allows "nano-gating"

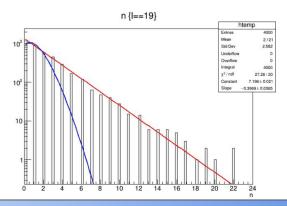


V3.0 Simulation

LHC6

- Generic data generator
 - Link occupancy with Poisson distribution of the number of hits
 - Limited always to the same bits (from MSB down to MSB # hits)
 - No errors up to the maximum allowed bandwidth
- Text files prepared with Toys
 - Link occupancy with Poisson distribution of the number of hits
 - Random bit location
 - No errors up to the maximum allowed bandwidth
- Text files prepared from Gauss+Boole output
 - Defined a simple file format
 - Samples for minbias and b events in multiple conditions
 - 4000 events per sample
 - Prepared a battery of scripts
 - Convert hits into bits based on PDM-R(H) mapping: data for 2544 links
 - Format link payloads for injection (adding BXID and SYNCH)
 - Map links to TELL40s with preselected 24/12 links assignment
 - Run Modelsim for all TELL40s (4k events in ~2h/#licenses)
 - Some surprises
 - Occupancy is not Poisson distributed
 - Minor bugs found and fixed
 - More realistic bandwidth estimates





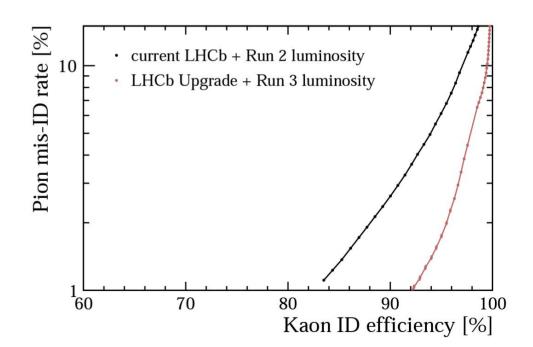
RICH2022

Estimated performance

-	Photor	v	Cherenkov angle resolution [mrad]				
	$N_{\rm ph}^{\rm optimal}$	$N_{\rm ph}^{\rm typical}$	$\operatorname{chromatic}$	emission point	pixel	$\sigma_{ heta}$	$\Delta \theta_{\rm C}$
RICH1	63	59	0.52	0.36	0.50	0.81	0.18
RICH2	34	30	0.34	0.32	0.22	0.52	0.17

Included in the current simulation

- All measured parameters of optical components
- All feedback from test beams and commissioning
- Experience from the simulation of the previous implementation of this detector



RICH2022

LHC6

Beam test with RICH2: Frictions in October 2021

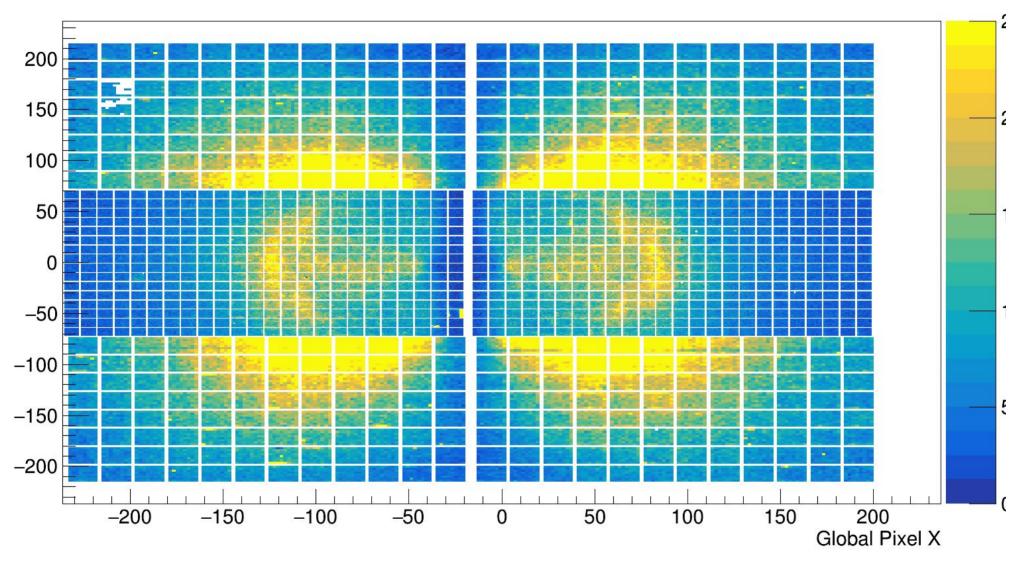
• Setup

- 2 noisy channels (out of 73728)
- 1 data link not operational
 - Fixed afterwards
- Occasional link instabilities
 - Improved since then
- Tests performed
 - Time
 - Synchronized with LHC orbit
 - Identified corresponding delays for test pulses and laser pulses
 - Space
 - Observed rings
 - Occupancy
 - Reasonably as expected
- Control and Software
 - Some instabilities
 - Significant improvement after few days

RICH2022

First Occupancy with Frictions

Rich2 Global Pixel Map



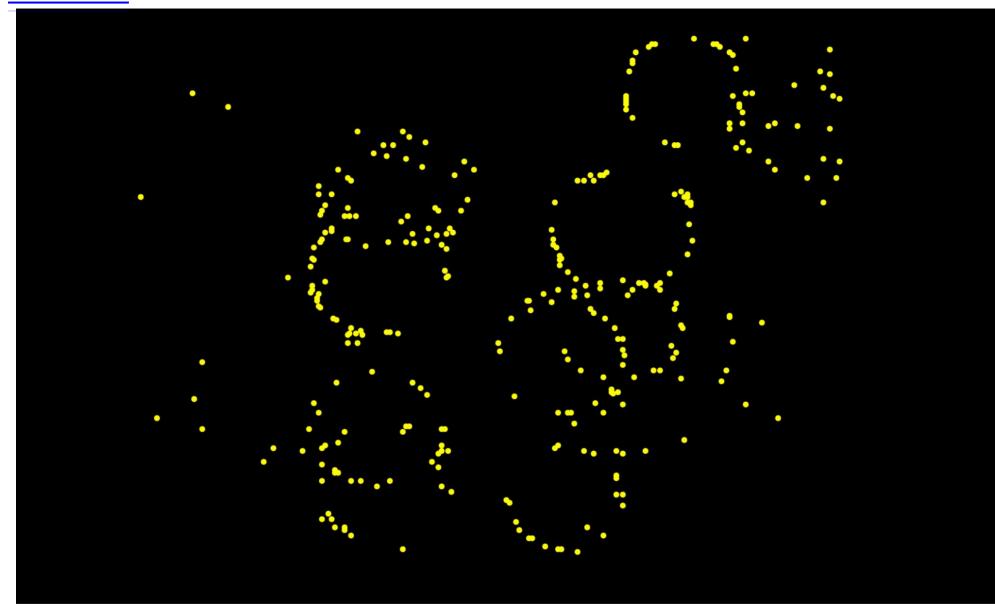
• Reasonably as expected

RICH2022

 \circ $\,$ $\,$ The hole corresponds to the only inactive data link at the time

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First Rings with Frictions



• Nice to see

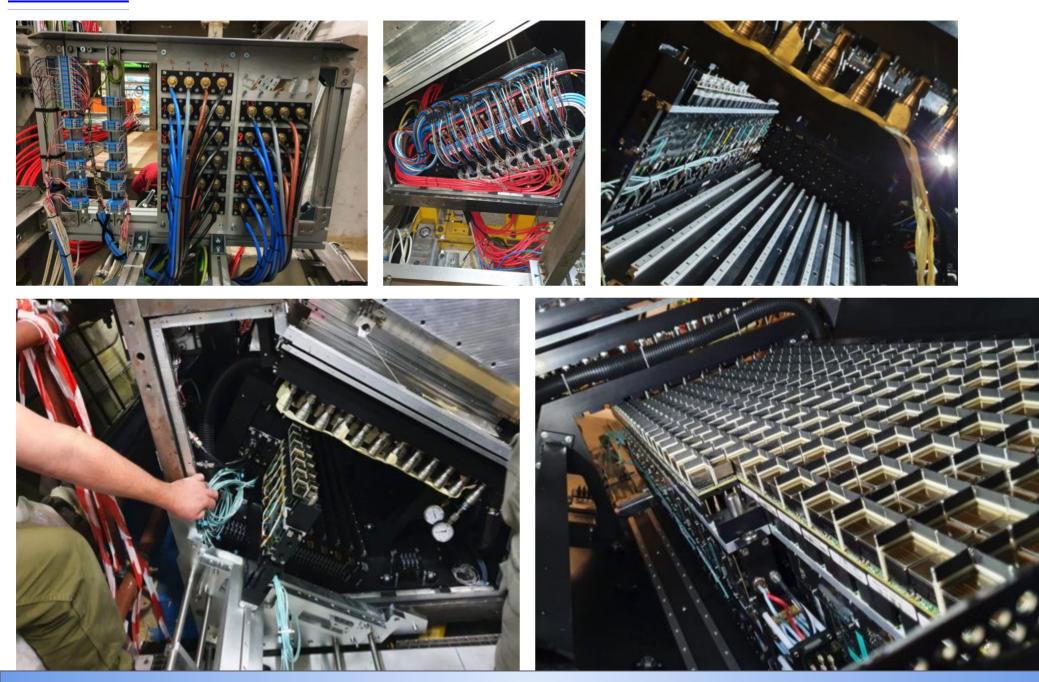
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LHC6

• Lots of things to check before claiming anything

RICH1 Installation: Down Box (12/2021)

LHC6



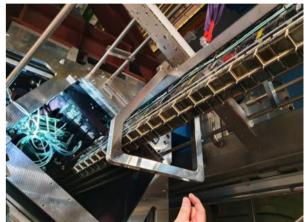
RICH2022

RICH1 Installation: Up Box (01/2022)

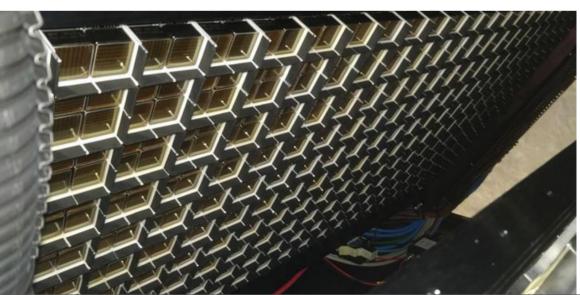
LHC6





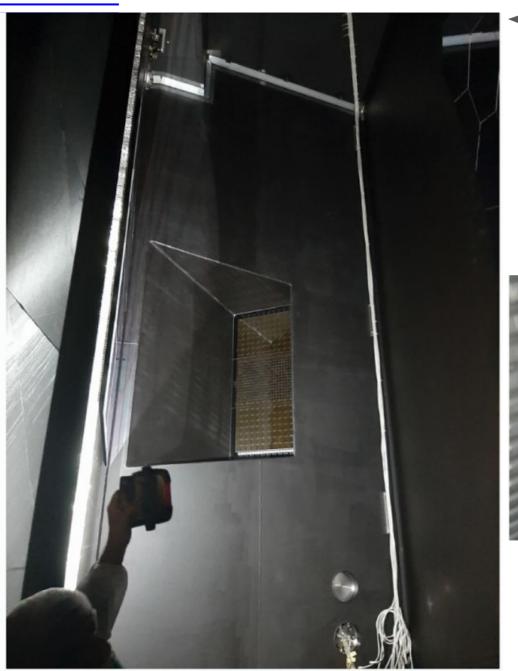






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Installation Summary

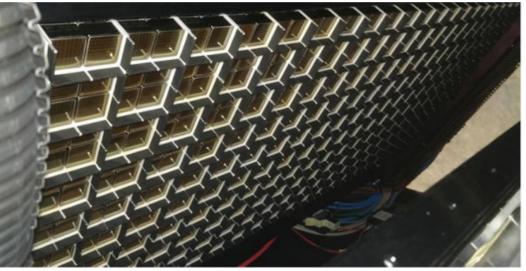


RICH2 :

A-side installed in Feb 2021 C-side installed in Ap 2021

RICH1 :

Down-box installed in Dec 2021
 Up-box installed in Jan 2022,
 Completed in March 2022



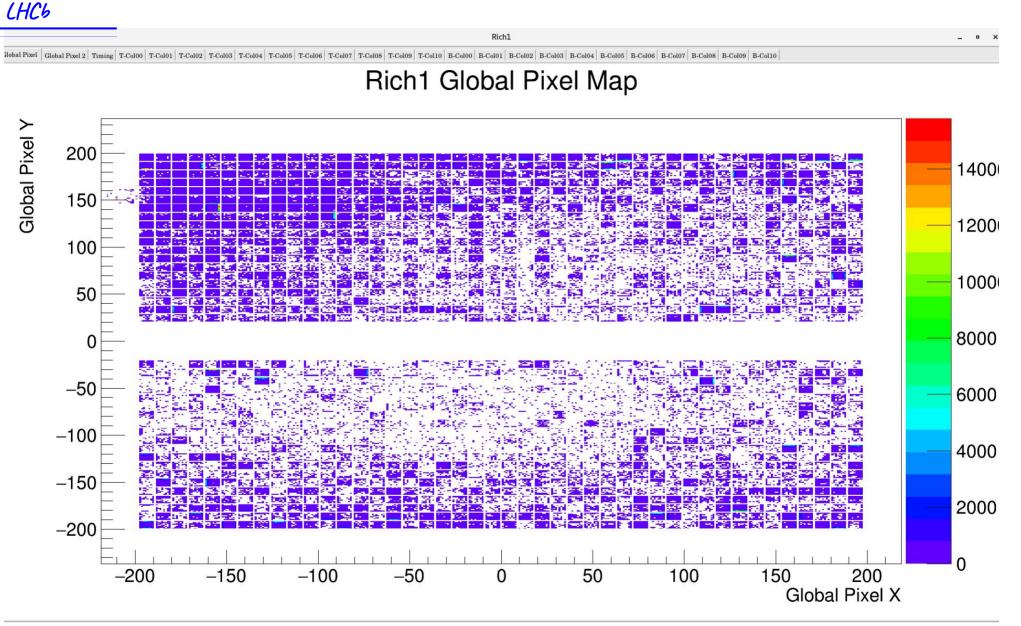
Both RICH1 and RICH2 fully installed:

- Commissioning in Myin completed
- Commissioning at P8 ongoing

RICH2022

LHC6

RICH1 Early Dark Counts



• Mostly ok

RICH2022

• Few PMTs needed more HV training

RICH1 and RICH2 FE status

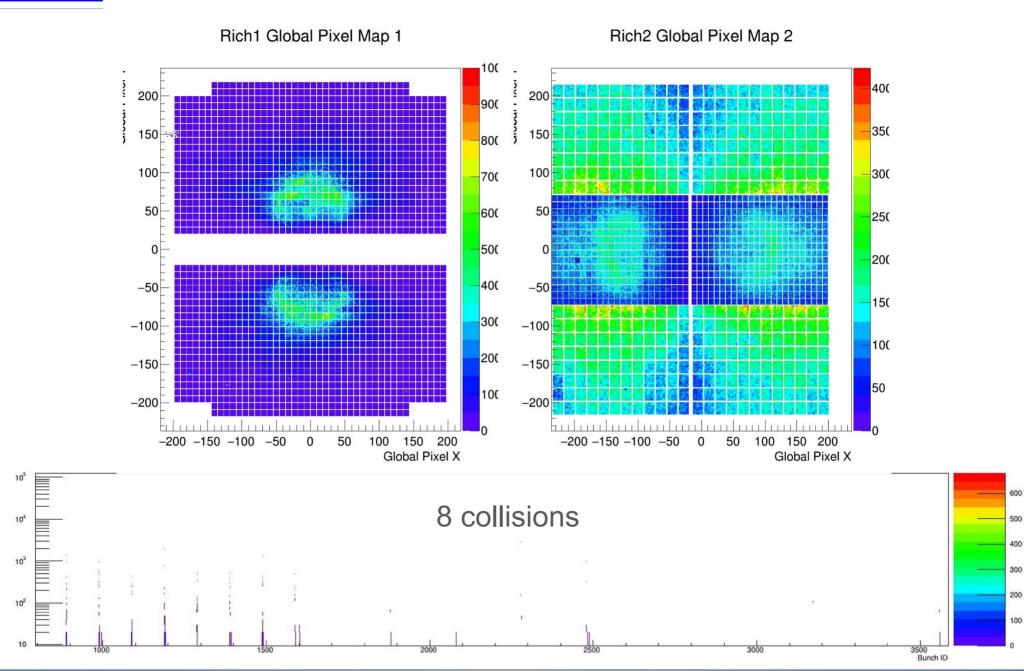
LHC6



- A handful of noisy or dead channels (<10⁻⁴)
- All control and data links operational
- Controls:
 - DAQ, HV, DCS well
 advanced and
 integrated in run control
 - Constant monitoring and alarms implemented
 - Run like recipes for front-end and HV implemented

RICH2022





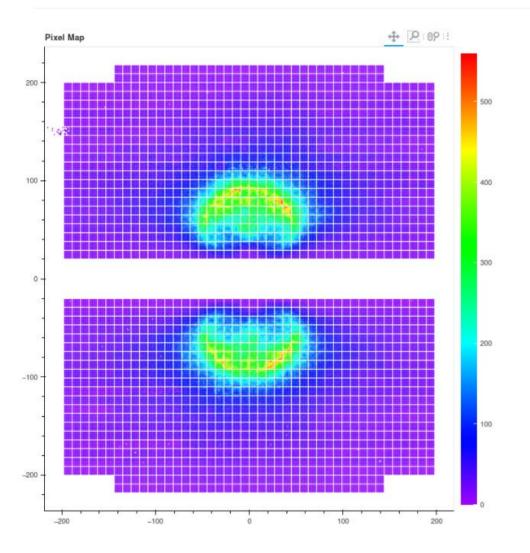
RICH2022

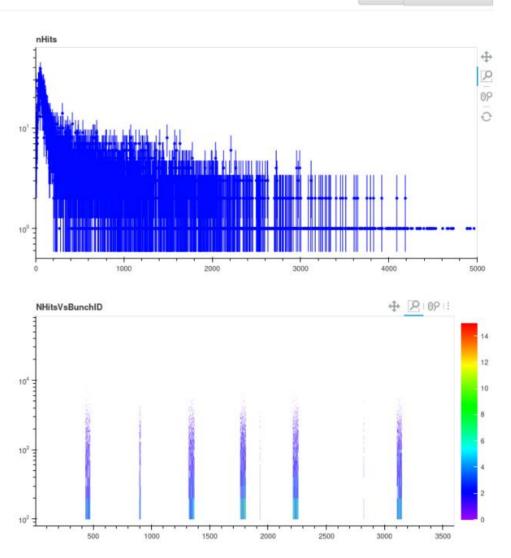
of hits

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*LHC*_b

OnlineMon/RICH/RICH1





Save -

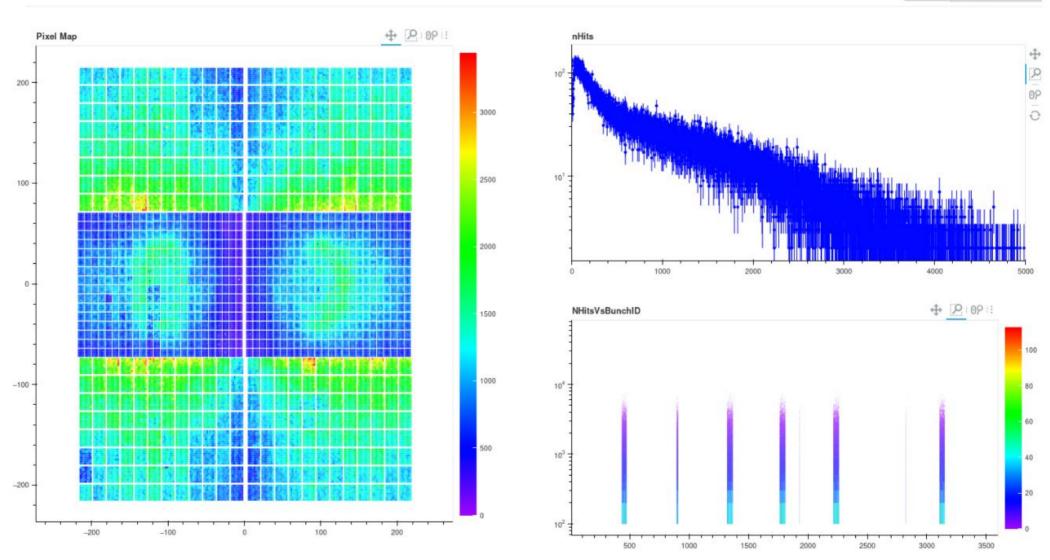
C Rendering Info

RICH2022

LHC6

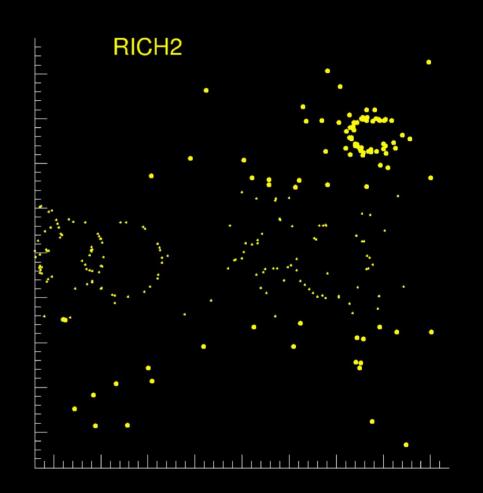
OnlineMon/RICH/RICH2



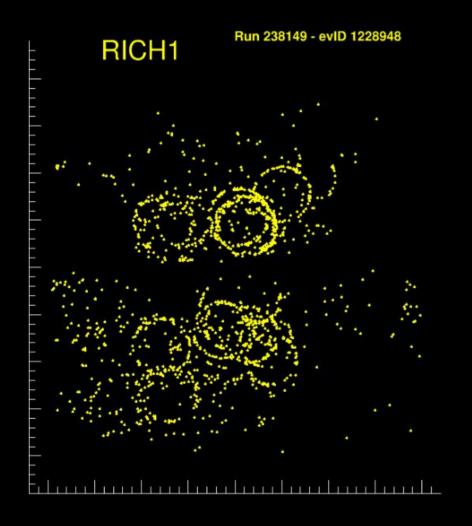


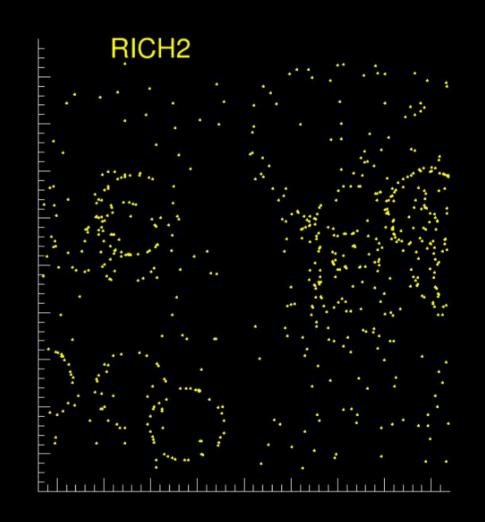
RICH2022

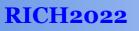
Run 232428 - evID 4766269 **RICH1**





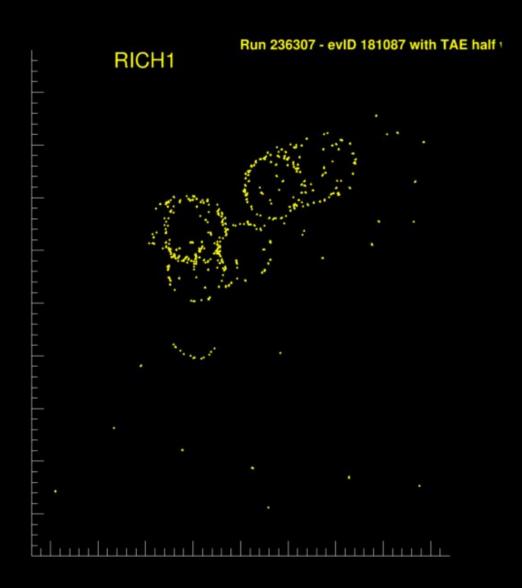


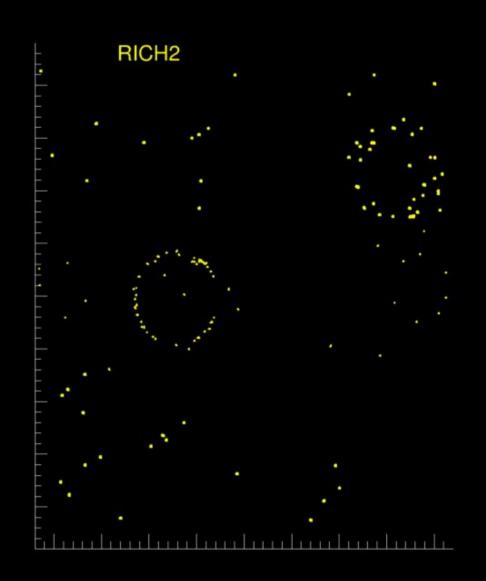


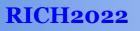


LHC6

LHC6







RICH2

• Status

- Operational
- Always on, when safe

• Hardware

- Generally ok
- A handful of noisy channels (now masked)
- Thresholds optimized
- HV tuned

RICH1

• Status

- Operational
- Always on, when safe
- Hardware
 - Few channels (at the edge of one column, up box) not readable:1 FPGA rarely configuring
 - Replacement to be scheduled
 - A handful of noisy channels (now masked)
 - Threshold optimized
 - HV tuned
 - 1 control link unstable (~24h) being investigated

• Firmware & Software

- Minor bugs in the TELL40 firmware; almost completely solved
- Online monitoring is operational
- Timing
 - Trying to optimize time alignment down to 6ns

RICH2022

Antonino Sergi

Summary and Outlook

- A new Detector
 - New photo-detectors, FE and BE electronics
 - Modified optics in RICH1
 - 2 sizes of Hamamatsu MaPMTs
 - CLARO based FE electronics for signal discrimination
 - Kintex-7 based FE electronics for data frame preparation and high speed transmission to BE
 - Arria10 based BE electronics (TELL40) for data compression and packing
 - Larger number of smaller pixels
 - Better performance at higher luminosity
- Development
 - About 10 years
 - Almost smooth sailing, with some surprise along the way (SIN)
- Commissioning
 - Physiological progress
 - Getting close to physics readiness
 - Hardware ok
 - Working point should be achieved by the end of the year

RICH2022