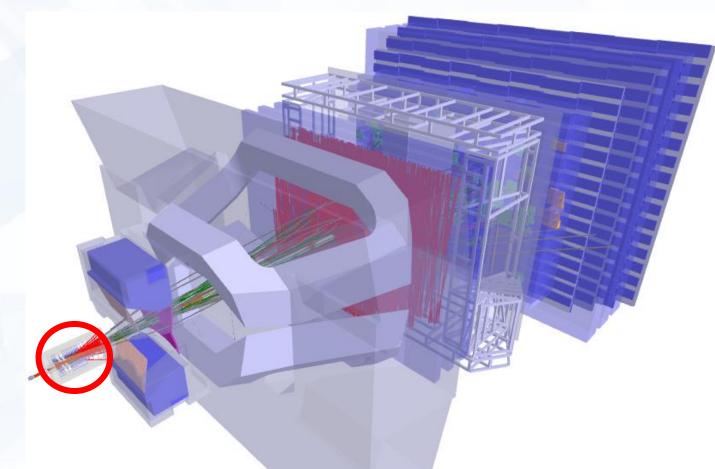
Status of the LHCb Pixel Detector



Edgar Lemos Cid, On behalf of the LHCb VELO Group







Outline

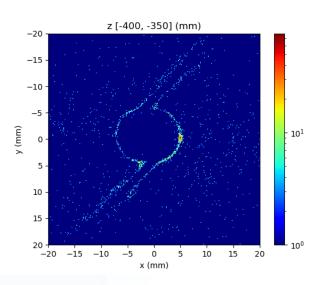
- LHCb VELO Upgrade.
- Module Assembly.
- Detector Assembly and Installation.
- VELO Safety System (VSS) and Detector Monitoring.
- VeloPix Calibration: Equalization and Bxid Spread.

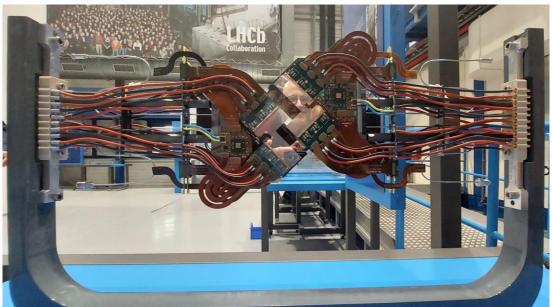
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- Time Alignment.
- VELO Closing.
- Vertex reconstruction.
- DAQ and FPGA clustering.
- HV performance.

USC

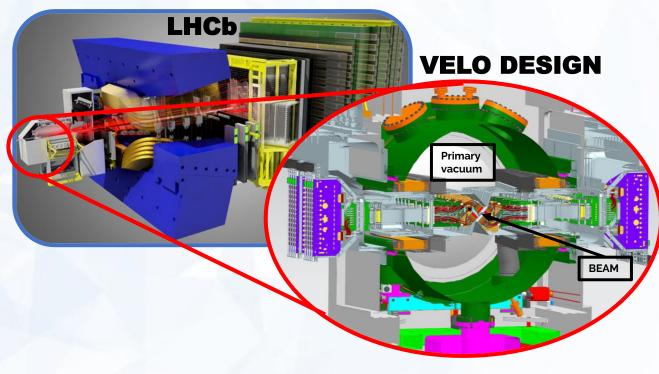
• SMOG 2.







LHCb VELO Upgrade



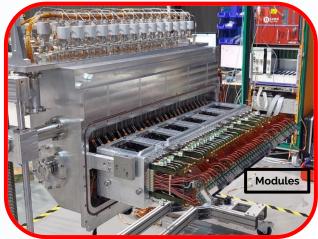
- LHCb is a forward (2 < η < 5) arm spectrometer focusing in b-hadron and c-hadron decays. Studies CP violation, rare decay, ...
- The Vertex detector (VELO) was successfully updated from silicon strips to pixels in 2022.
 - Closest pixel at 5.1 mm to the LHC beam.
 - Use increased luminosity (5x).

JSC

• Readout all the events at every bunch crossing (40 MHz).

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VELO HALF





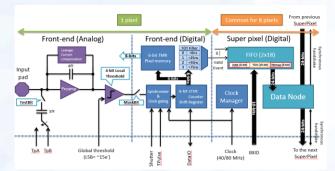


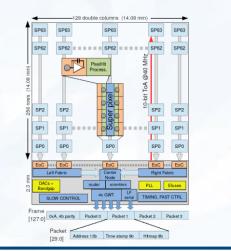
- 41M pixels across 52 modules in vacuum.
- Evaporative CO₂ cooling through microchannels.
- RF foil down to thickness of 150 µm.

Module Assembly

VeloPix:

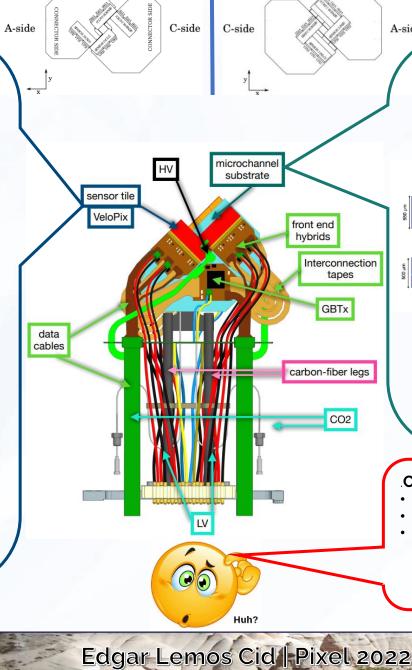
- 256x256 pixels of 55 x 55 μm.
- 800 Mhits/s/ASIC.
- Continuous, trigger-less and binary readout.
- Radiation hard up to 400 Mrad and SEE tolerant. *Talk 2018: <u>VeloPix Readout and ASIC</u>.





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A-side Silicon microchannel substrates: Two phase evaporative CO₂ cooling. 500 μ m wafer with 120 x200 μ m² microchannels. Cooling power up to 40 W at -30 °C. *Microchannel cooling for the LHCb VELO Upgrade I. First etching of main channels 550 µm double polished Si wafer Second etching of main channels and etching of restrictions Thinning of cap wafer Hydrophilic bonding of cap wafer to 240 µm hinning of channels wafe Metallisation: Plasma dicing and Etching of inlets/outlet to 260 µm Ti (200 nm) Ni (350 nm) Au (500 nm) packaging on UV tap Solder lave - 200 un Au 500 nm Ni 350 nn Ti 200 nm Challenges in the way. Glue between ASIC and Substrate. GBTx cold operation. ٠ Connectors metallization.

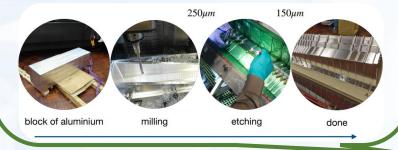


Detector Assembly and Installation

RF Foil:

- 150 µm thick shield that separate VELO vacuum from LHC vacuum.
- 3.5 mm from the beam and 900 μ m from the sensors.
- Thermally stable, shield against RF pick-up from the LHC Beam.
- Torlon and Neg coating.

GFAE



Cooling:

- 52 microchannel cooling plates boiling at the same time.
- Safety system to avoid CO_2 leaks. Max ΔP of 10 mbar between LHC and VELO vacuum.



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Challenges in the way:

- Cooling gasket replacement.
- Feedthrough board replacement.

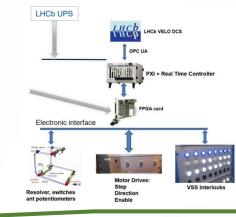




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Motion:

Movement to protect the detector during injection.
 (Min 3.5 mm).



Metrology:

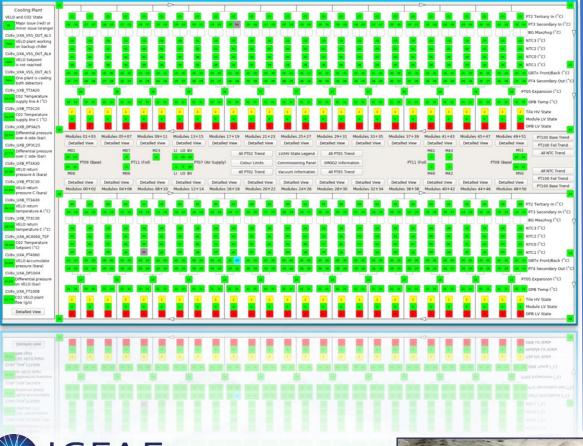
- µm precision measurement needed.
- Measurements performed at the module assembly, detector assembly (cold) and before detector installation (Foil & Modules).



VELO Safety System (VSS) and Detector Monitoring

Detector Monitoring:

- Monitoring of 1209 temperatures, LV and HV. 624 more to add one per VeloPix bandgap.
- Readings from Vacuum system, SMOG 2 system, cooling plant.



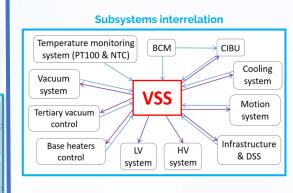
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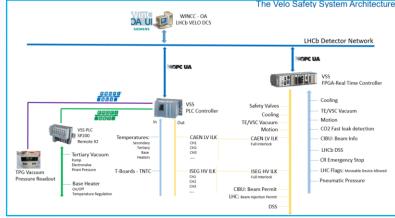
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VELO Safety System:

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PT100			Enable t	hreshold							NTC			
Signal	Temp	HW	W Temp Low	Temp Hi	Signal	Тетр	HW	sw	Temp Low	Temp Hi	Signal	нพ	Signal	HW
INLET1	-016.30	•	010.00		MODULE_42_OUTLET	-028.20					HYB_MOD_00-02-0	4 0	GBTX MOD 00-0	02-04
INLET2	-019.30	•	0 050.00		MODULE_44_OUTLET	-028.70	٠	٠			HYB_MOD_06-08-1		GBTX MOD 06-0	08-10
MODULE_00_OUTLET	-025.10	•	(a) (0) (0) (0) (0) (0) (0) (0) (0) (0) (0		MODULE_46_OUTLET	-028.00	٠	٠			HYB_MOD_12-14-1		GBTX MOD 12-1	164-00
MODULE_02_OUTLET	-025.40	•	-3300.00		MODULE_48_OUTLET	-029.00	٠	٠					SAL STREET, SAL	
MODULE_04_OUTLET	-029.20	•	-3300.00		MODULE_50_OUTLET	-028.30	٠	٠			HYB_MOD_18-20-2		GBTX_MOD_18-2	
MODULE_06_OUTLET	+027.70	•	(a) 300 (0)		EXP_VOL_MODULE_00-02	+019.50	٠	٠			HYB_MOD_24-26-2	8 😐	GBTX_MOD_24-2	26-28
MODULE_08_OUTLET	-028.60	•	(-)1300,00()		EXP_VOL_MODULE_04-06	+019.50	٠	٠			HYB_MOD_30-32-3	4 0	GBTX MOD 30-3	32-34
MODULE_10_OUTLET	-028.90	•	(8100.80.)		EXP_VOL_MODULE_08-10	+019.40	•	•			HY8_MOD_36-38-4		GBTX MOD 36-3	
MODULE_12_OUTLET	-028.80	•	0 3300.00		EXP_VOL_MODULE_12-14	+019.20	٠	٠						
MODULE_14_OUTLET	+029.20	•	(a)		EXP_VOL_MODULE_16-18	+019.20	٠				HYB_MOD_42-44-4	1.000	GBTX_MOD_42-4	
MODULE_16_OUTLET	-029.20	•	(3300.00)		EXP_VOL_MODULE_20-22	+018.50	٠	٠			HY8_MOD_48-50	•	GBTX_MOD_48	-50
MODULE_18_OUTLET	-028.90		- 43300.00		EXP_VOL_MODULE_24-26	+018.70	•				100000000000000000000000000000000000000			
MODULE_20_OUTLET	-029.10	•	(3300.00)		EXP_VOL_MODULE_28-30	+018.60	٠				OPB_MOD_00to16	•		
MODULE_22_OUTLET	-028.90	•	0 (3300.00)		EXP_VOL_MODULE_32-34	+018.90	•				OPB MOD 18to34	•		
MODULE_24_OUTLET	-028.40	•	(93300.00)		EXP_VOL_MODULE_36-38	+018.80								
MODULE_26_OUTLET	-027.60	•	0 (21100.00)		EXP_VOL_MODULE_40-42	+018.90					OPB_MOD_36to50	•		
MODULE_28_OUTLET	-028.30	•	0 3300.00		EXP_VOL_MODULE_44-46	+019.00	ō				RF Foil	HW S	W Limit	
MODULE_30_OUTLET	+028.30	•			EXP_VOL_MODULE_48-50	+019.00	٠				KEFOI	1144 3	A Limit	
MODULE_32_OUTLET	-027.70	•	(A300.00)		OUTLET_1	-029.90					Foil 1		070.00	Low
MODULE 34 OUTLET	-028.40	•	0 [15500.00]		OUTLET_2	-029.70		ē			+003.30		+000.00	High
MODULE_36_OUTLET	-028.70	•	A 100 80 1		AIR FIRST	-006.50								
MODULE 38 OUTLET	-028.10	•	0 3300 00 1		AIR LAST	+001.50					Foil 2		-020.00	Low
MODULE_40_OUTLET	-029.10		0 (3300.00)		EXP_VOLUME_CAP	-000.70		ē			+002.30		Constanting of	High
VALVE BELL	-020.20		33000.00)		BYPASS VALVE	-017.80							+088.00	myn
-											Foil 3			Low
											+3276.70	1.0		High
												•	►8000.00	nign
			COOLING A		OS2AIR	DS	IS NO E	MERG	ENCY		Foil 4		Cana on the	Low
OOLING AND	VACUL	M		100000000000000000000000000000000000000	OS28EAMVOL		INFEED	IN D	ANGE 😑		+000.00	1000		High
			COOLING_C	0.000 To 0.000	VACUUM OK							•	+989.00	nign
			COOLING_PC	OWER_OK					VSS Digital In	put	Sigmanetics Sensors			
			COOLING_AT_S	ETPOINT		-			To a					
			OOLING FULL A		NO CO2 LEAK	 Ind 			n		m			

HV Interlocks LV Interlocks NY, MOD, 00 10, yrm, yoo, 00, 64, 68, 10 NY, MOD, 02 10, yrm, yoo, 06, 64, 86, 10 NY, MOD, 04 10, yrm, yoo, 06, 64, 86, 10 NY, MOD, 04 10, yrm, yoo, 06, 64, 86, 10 NY, MOD, 04 10, yrm, yoo, 164, 68, 10 NY, MOD, 04 10, yrm, yoo, 124, 24, 84 NY, MOD, 10 10, yrm, yoo, 124, 24, 84 NY, MOD, 10 10, yrm, yoo, 124, 24, 84 NY, MOD, 12 10, yrm, yoo, 124, 24, 84 NY, MOD, 14 10, yrm, yoo, 124, 24, 84 NY, MOD, 14 10, yrm, yoo, 124, 24, 84 NY, MOD, 14 10, yrm, yoo, 124, 24, 84 NY, MOD, 14 10, yrm, yoo, 124, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 84 NY, MOD, 14 10, yrm, yoo, 24, 24, 10, 96, 10, 10, 10, 10, 10, 10, 10, 10, 10, 10	VSS OUTPUTS C-SIDE						
HV (x00, 02) LV (ym) x00, 05 es as a HV (x00, 06) LV (ym) x00, 05 as as a HV (x00, 06) LV (ym) x00, 13 14 18 HV (x00, 06) LV (ym) x00, 13 14 18 HV (x00, 10) LV (ym) x00, 13 14 18 HV (x00, 10) LV (ym) x00, 13 20 22 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) LV (ym) x00, 13 24 34 HV (x00, 10) Coling Interlects Trait HV (x00, 10) Coling Interlects Trait HV (x00, 14) Coling (x00, 14, LUWE) Coling (x00, 14, LUWE) HV (x00, 14) Coling (x00, 14, LUWE) Coling (x00, 14, LUWE) HV (x00, 14) Coling (x00, 14, LUWE	HV Interlocks	LV Interlocks					
IVI, YMD, DO, 24-24-8 IVI, YMD, DOD, 24-24-8 IVI, YMD, DOD, 24-24-8 IVI, YMD, DOD, 26-23-4 IVI, YMD, DOD, 24-24-4 IVI, YMD, MOD, 26-34-4 IVI, YMD, DOD, 26-34-4 IVI, YMD, MOD, 26-34-4 IVI, YMD, DOD, 26-34-4 IVI, YMD, MOD, 26-34-4 IVI, YMD, DOD, 27 IVI, YMD, MOD, 26-34-4 IVI, YMD, DOD, 27 IVI, YMD, MOD, 26-34-4 IVI, YMD, DOD, 27 IVI, YMD, MOD, 26-34 IVI, YMD, DOD, 28 IVI, YMD, MOD, 28-34 IVI, YMD, DOD, 28 IVI, YMD, MOD, 28-34 IVI, YMD, DO, 28 IVI, YMD, YMD, 28-34 IVI, YMD, 28 COD, SMETTY, YMLY, C, SMET, CME, ALLOWED IVI, YMD, 24 COD, JML, XML, C, SMETTY, YMLY, C, SMETT, ALLOWED IVI, YMD, 24 COD, JUN, XMLT, ZLOW, ALLOWED	HV_MOD_02 HV_MOD_04 HV_MOD_06	LV_HYB_MOD_06-08-10					
Int / Moo, 30 Cooling Interlocks Environment Int / Moo, 34 Cool, SAFETY, VALVE, C, SIDE, ONN, ALLOWED Environment Environment Int / Moo, 34 Cool, SAFETY, VALVE, C, SIDE, CHIN, ALLOWED Environment Environment Int / Moo, 34 Cool, SAFETY, VALVE, C, SIDE, CHIN, ALLOWED Environment Environment Int / Moo, 42 Cool, Int, C, Mart, J, LOWED Environment Environment Int / Moo, 44 Cool, Int, C, Mart, J, LOWED Environment Environment Int / Moo, 44 Cool, Int, C, Mart, J, LOWED Environment Environment Int / Moo, 44 Cool, Int, C, Mart, J, LOWED Environment Environment Int / Moo, 44 Cool, Int, C, Mart, J, LOWED Environment Environment	HV_MOD_10 HV_MOD_12 HV_MOD_14 HV_MOD_16 HV_MOD_18 HV_MOD_20 HV_MOD_22 HV_MOD_24	LV_JHB_HOD_24-24-28 LV_JHB_HOD_36-32-34 LV_JHB_HOD_36-32-34 LV_JHB_HOD_42-44-6 LV_JHB_HOD_42-44-6 LV_JHB_HOD_48-50 LV_JHB_HOD_601016 LV_JHB_HOD_501016					
MOTION DO_1 MOTION DO_2	HV_MOD_30 HV_MOD_32 HV_MOD_34 HV_MOD_36 HV_MOD_38 HV_MOD_40 HV_MOD_42 HV_MOD_44 HV_MOD_44 HV_MOD_48	Cooling Interfocks Enable ack CO2_SAFETY_VALVE_C_SIDE_OFIN_ALLOWED CO2_BF7#ASS_VALVE_C_SIDE_CLOSE_ALLOWED COCUMO_COAL_ALOWED COCUMO_FILANT_ALLOWED COCUMO_FILANT_ALLOWED ERAN_FEARIT_S BEAN_FEARIT_S HINDING_FO_1					

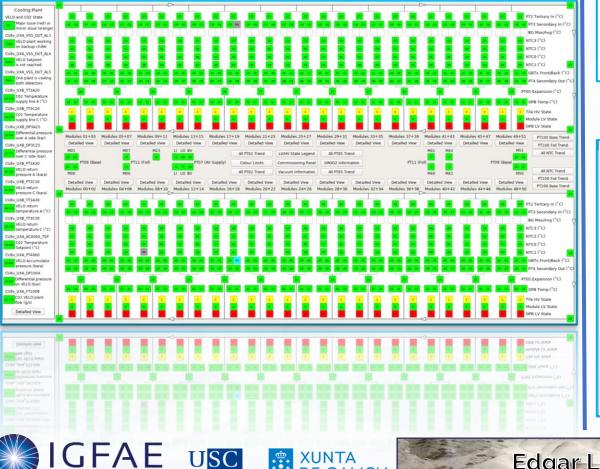
6



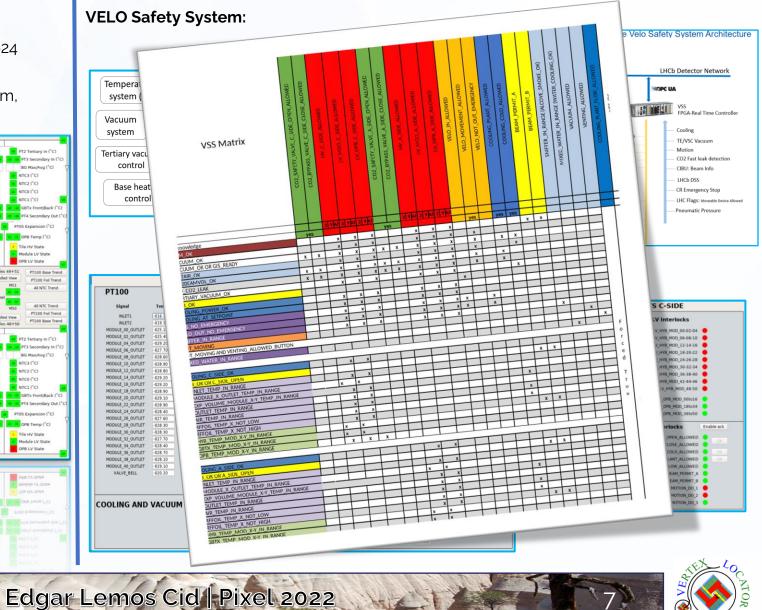
VELO Safety System (VSS) and Detector Monitoring

Detector Monitoring:

- Monitoring of 1209 temperatures, LV and HV. 624 more to add one per VeloPix bandgap.
- Readings from Vacuum system, SMOG 2 system, . cooling plant.



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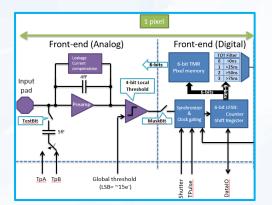
VeloPix Calibration: Equalization & Bxid Spread

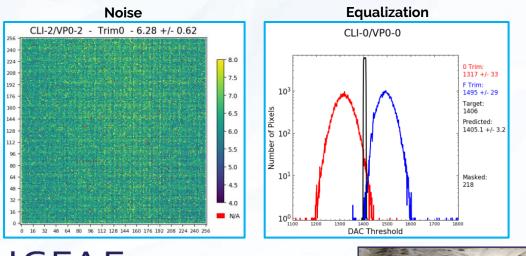
Equalization:

- Estimated using the noise baseline at different threshold values.
- 16 fine tune values per each pixel.

JSC

• Use the extreme values (0, 15) for global Threshold scan and calculation of the optimal value.



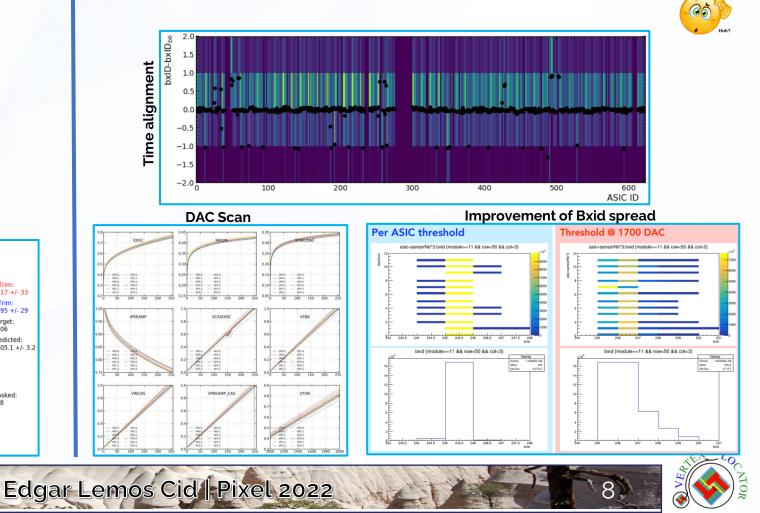


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Bxid spread:

- Equalization not tuned in terms of analog circuit parameters and threshold. First approach to keep the same settings for the full detector.
- During time alignment. ToA Bxid different in pixels of the same ASIC. Analog TP see the same effect.
- DAC scan and Threshold set to eliminate this effect.



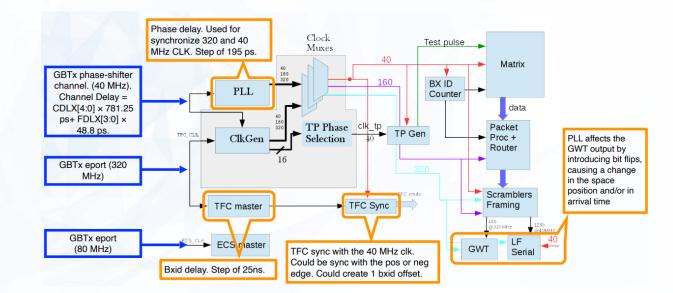
Time Alignment

Time alignment depends on:

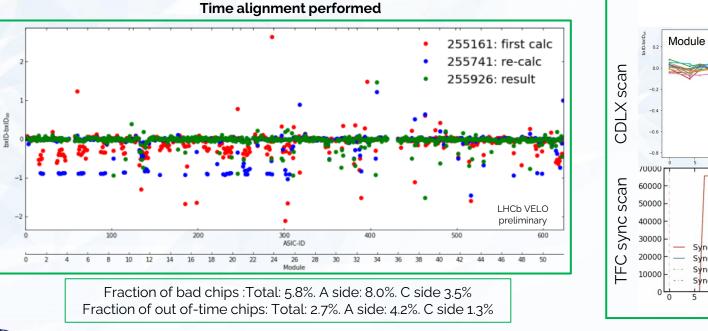
JSC

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- Control FPGA placed on surface.
- GBTx and VeloPix clks
- Time fast control (TFC) & 40 MHz clk sync.
- Multiple scan done to understand the detector behaviour.
 - PRBS test while scanning the PLL phase.
 - Coarse delay scan on the GBTx.
 - Scan of the sync of TFC with the 40 MHz clk.





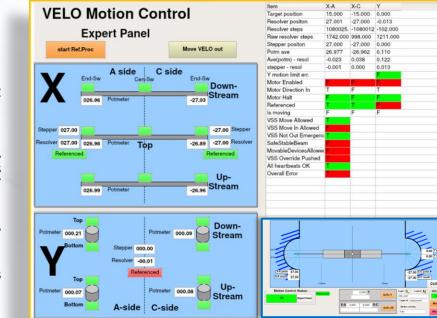


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BxID Module 11 Module 0 BxID 10 15 10000 គ្គ 60000 50000 40000 BxID 30000 Sync Pos:Pos Count Sync Pos:Pos Count 20000 Sync Pos:Neg Count Sync Pos:Neg Count Sync Neg:Pos Count Sync Neg:Pos Count 10000 ync Neg:Neg Coun nc Neg:Neg Count AC 10 15 20 25 30 10 15 20 25 30 cdl cdl

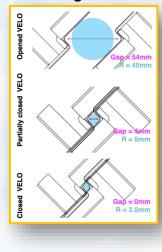
VELO Closing

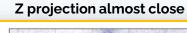
- Closing is based in the Primary Vertex reconstruction from the detector.
- Multiple criteria need to be satisfied: VSS, stable beam, FPGA communication, Beam Conditions Monitors, Beam Position Monitors, HV current, ...
- RF foil reconstructed to proceed to the final closing.
- Increased number of colliding bunches to study the temperature and vacuum variation and validate the closing.

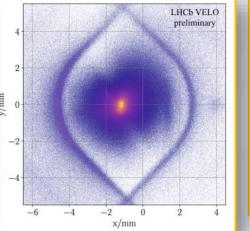


1.12	Reference Values		nd Trends —		-BCM (%)			
B	PM: last update on 23-Jul-2022 at 14							
8	V: waiting for Velo fully closed	SELE	CTION +		50.R52	50.RS32		
					0.010	0.004	0.038	0.0
	Quantity	ActualValue	Criterion	Status	BPM (mn	n) — — —		
-	1 BCM: 50.R502	0.010 %	< 5.000 %	OK	B1L8(hor)	B1L8(ver)	B2L8(hor)	821.80
	2 BCM: 50.8532	0.004 %	< 5.000 %	OK	3.820	0.462	-4.436	0.73
	3 BCM: S1.RS02	0.038 %	< 5.000 %	OK				
	4 BCM: \$1.R\$32	0.014 %	< 5.000 %	OK	B1R8(hor)	B1R8(ver)	B2R8(hor)	8288
	5 BPM: D(B1L8H)	0.013 mm	< 0.200 mm	OK	-4.593	0.194	3.696	-0.18
	6 BPM: D(B1L8V)	0.039 mm	< 0.200 mm	OK	B1 Xev	-	B2 Xav	
	7 BPM: D(B2L8H)	0.011 mm	< 0.200 mm	OK		B1 Yav		B2 Ya
	8 BPM: D(B2L8V)	0.026 mm	< 0.200 mm	OK	-0.386	0.328	-0.370	0.275
	9 BPM: D(B1R8H)	0.063 mm	< 0.200 mm	OK	B1 Xdr	B1 Ydr	B2 Xdr	82 Y
13	LO BPM: D(B1R8V)	0.107 mm	< 0.200 mm	OK	0.000	0.000	0.000	0.00
	L1 BPM: D(B2R8H)	0.006 mm	< 0.200 mm	OK	0.000	0.000	0.000	0.000
	12 BPM: D(B2R8V)	0.035 mm	< 0.200 mm	OK				
	L3 BPM: [B1 Xav]	0.386 mm	< 4.000 mm	OK	-Velo Res	olvers (mi	(m	
	4 BPM: B1 Yav	0.328 mm	< 4.000 mm	OK				
	L5 BPM: B2 Xav	0.370 mm	< 4.000 mm	OK	XA	XC	YAC	
	6 BPM: B2 Yav	0.275 mm	< 4.000 mm	OK	27.000	-27.000	-0.001	
	L7 BPM: [B1 Xdr]	0.000 mm/s	< 0.100 mm/s	OK				
	L8 BPM: B1 Ydr	0.000 mm/s	< 0.100 mm/s	OK	- VeloHalv	es distand	ce (mm)	1
	19 BPM: IB2 Xdrl	0.000 mm/s	< 0.100 mm/s	OK				
	20 BPM: IB2 Ydrl	0.000 mm/s	< 0.100 mm/s	OK				
	21 VTX: XVA + XVC	1.583 mm	< 10.000 mm	OK	53.9	98 0.0	28	
			< 0.300 mm	OK	- Beam Po	sition A-si	ide (mm) -	
	23 VTX: SXVA	0.046 mm	< 0.600 mm	OK	XVA	YVA	ZVA	
	4 VTX: SYVA	0.046 mm	< 0.600 mm	OK	-26.208	0.116	-5.316	tin
	25 VTX: SXVC	0.042 mm	< 0.600 mm	OK	-26.208	0.116	-5.316	elap
	26 VTX: SYVC	0.042 mm	< 0.600 mm	OK	SXA	SYA	SZA	1
	27 VTX: D(XVA)	973.792 mm	< 99999.000 mm	OK	0.046	0.046	50.003	
	28 VTX: D(YVA)	1000.116 mm	< 9999.000 mm	OK				
	29 VTX: D(XVC)	1027.791 mm	< 9999.000 mm	OK	- Ream Po	sition C-si	de (mm) -	
	0 VTX: D(YVC)	1000.088 mm	< 9999.000 mm	OK				
	31 HV: bias current (A-side)	7411.712 uA	< 15000.000 uA	OK	XVC.	YVC	ZVC	
	32 HV: bias current (C-side)	9398.467 uA	< 15000.000 uA	OK	27.791	0.088	5.891	
P	a riv, bids current (c-side)	9990.407 UA	- 13000.000 UA	UR.	SXC	SYC	SZC	
-					0.042	0.046	50.008	
					0.042	0.046	30.008	

Closing Process



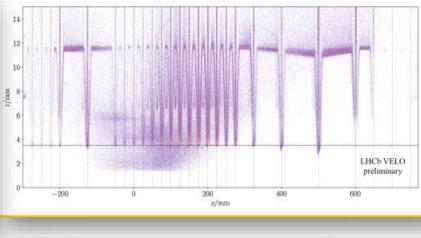




XUNTA

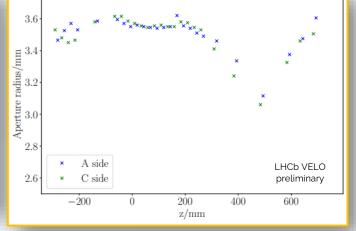
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Z positions with vertex reconstruction



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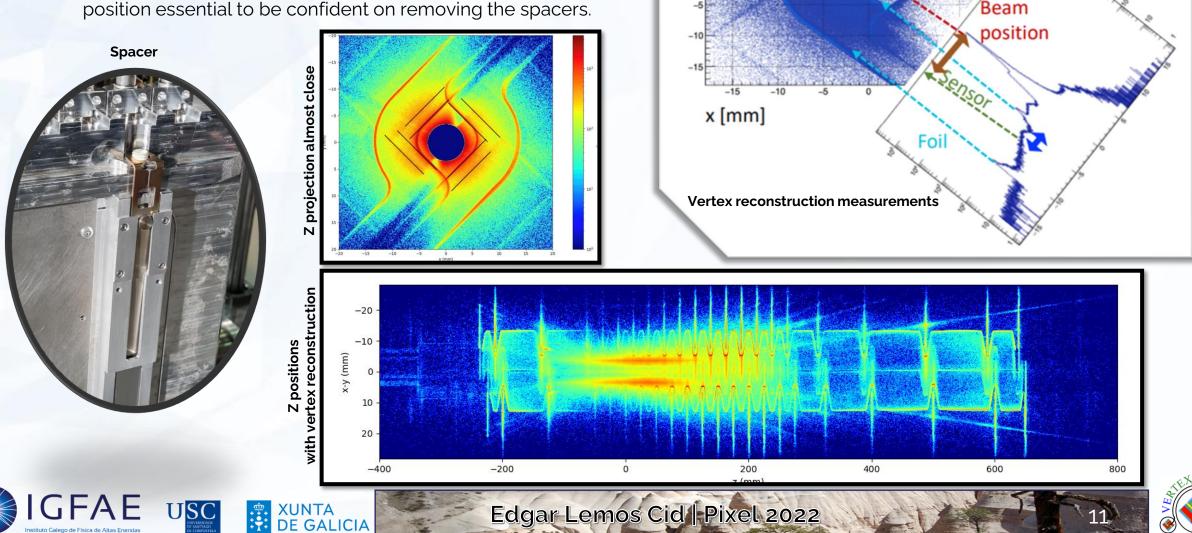
Aperture measurements





Vertex reconstruction

- One spacer was placed in each fixation point (3 per side) of the detector to the motion system to increase the clearance 1 mm.
- Vertex reconstruction measurement of module and RF foil position essential to be confident on removing the spacers.



y [mm]

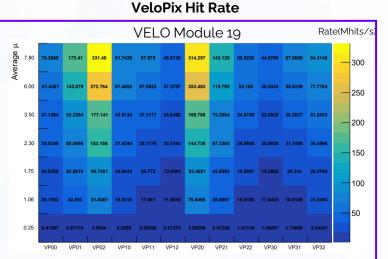
DAQ and FPGA Clustering

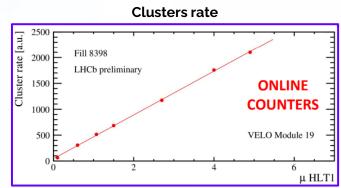
- VELO DAQ: 20 readout links at 5 Gb/s per module.
- Integrating the clustering in the FPGA.
 - 11% reduction of HLT1 reconstruction sequence.
 - O(50) less power consumption in the FPGA compare with the GPU.

<u>Phase I Upgrade of the Readout System of the Vertex Detector at the LHCb Experiment</u>

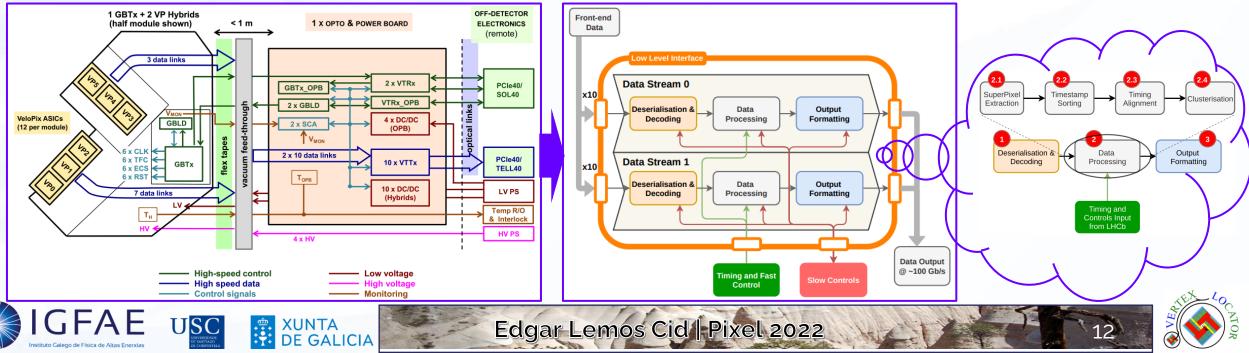
*Readout Firmware of the Vertex Locator for LHCb Run 3 and Beyond

 μ (Number of collisions) scan in terms of VeloPix activity. Clusters and hit rate per VeloPix to measure luminosity.
 Front end



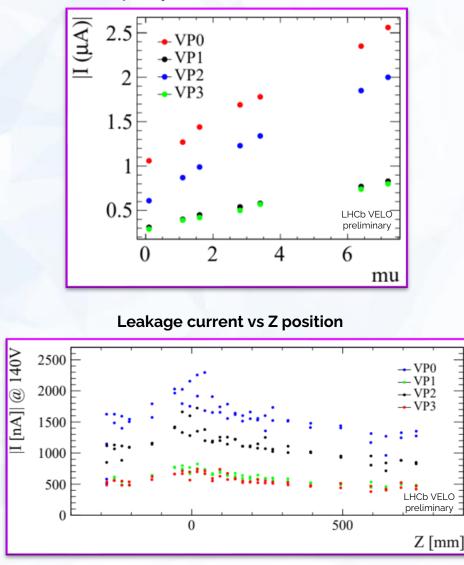


Back end



Leakage current evolution

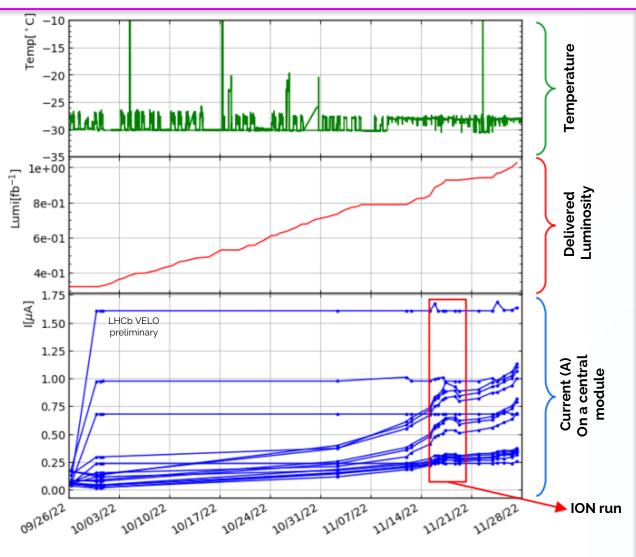
Multiplicity scan. Current increase linear



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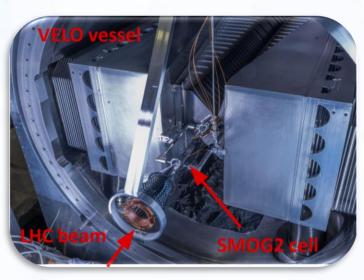
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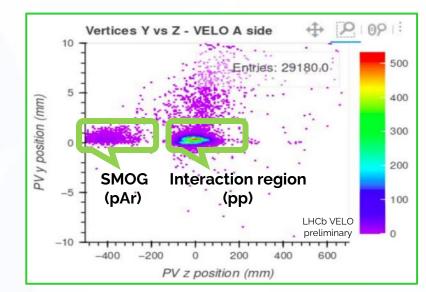
Current evolution in the last 2 months

SMOG 2

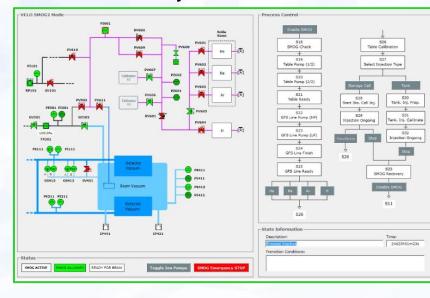
- SMOG 2 system inject gases (Ar, NE, He and H2) in the LHC beam pipe, acting as the highest-energy fixed-target experiment. (TDR, Physics).
- Gas feed system fully commissioning this year.



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System control



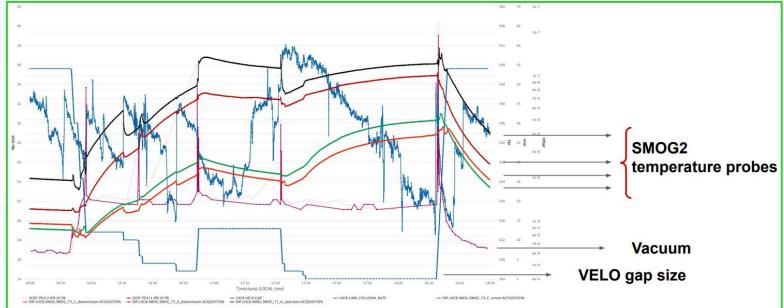
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GFA

Temperature, vacuum and VELO position



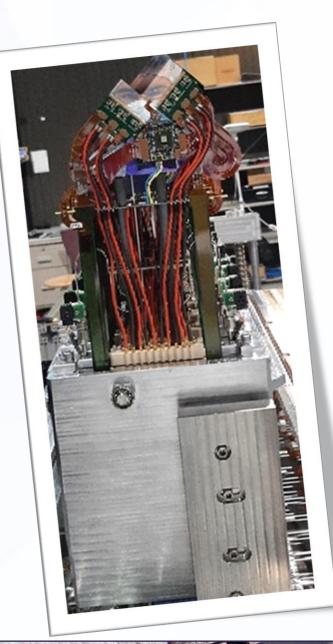


Conclusions

- Successful years of detector assembly and commissioned.
- Infrastructure systems (cooling, vacuum, LV, HV, motion, mechanics) properly working from first day.
- VeloPix tuned to get better performance.
- Time alignment performed with the full LHCb.
- Closing procedure stabilized and daily operational.
- First results on data rate and radiation damage.
- SMOG 2 system commissioning for fix target experiment.

Looking forward for a successful commissioning and data taking year 2023

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