Micro-channels activities at CPPM

S. Beurthey, J. Cogan, G. Hallewell, O. Leroy, M. Perrin-Terrin

Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

6 avril 2020

Meeting with CPPM direction

Introduction

Timeline and origin of the project

- Since 1994, CPPM has great expertise in pixels/vertex detectors, both in electronics and mechanics (DELPHI, ALEPH, ATLAS)
- In Feb 2017, LHCb presented an expression of interest to upgrade the detector for Run 5 (2030) Expression of Interest for Upgrade II “U2”, (2030)

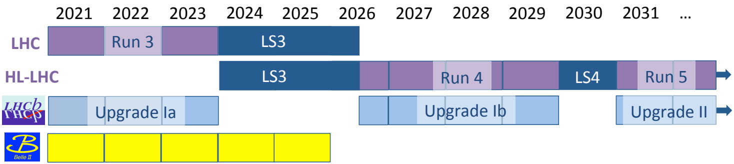
⇒ July, 7th 2018, we organized at CPPM a Workshop on Vertex Detector for LHCb Upgrade II

⇒ Well received and a synergy emerged between several actors: LHCb, CPPM mechanic service, NA62/P2O, LP3 lab with laser expertise, ATLAS expertise on gas.

- On Sep. 2018. Excellent LHCC feedback to LHCb U2: the LHCC “supports the effort of LHCb to start preparing for HL-LHC running. LHCb should prepare the framework TDR by mid-2021.”
- 2019: started an R&D with CPPM/LP3 on micro-channels, with laser-etched silicon wafers. (→ next talks)
- Jan 24th, 2020: S. Beurthey, contribution au GT08 des propspectives nationales de l'IN2P3. Three IN2P3 Labs interested by micro-cooling: CPPM, LAPP, LPNHE (10 persons).

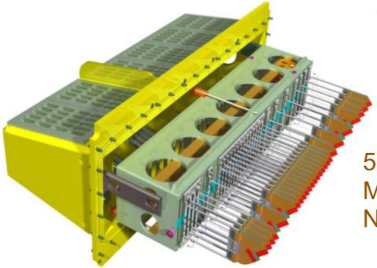
Timeline and vocabulary in LHCb

	Date	Runs	Instantaneous $\mathcal{L}$ [cm^{-2}s^{-1}]	Integrated $\mathcal{L}$ [fb^{-1}]	Status
LHCb	2010 – 2018	Run 1 & 2	4×10^{32}	9	Done
LHCb Upgrade I	2021 – 2029	Run 3 & 4	2×10^{33}	50	Approved
LHCb Upgrade II	2031 –	Run 5 & beyond	1.5×10^{34}	300	FTDR 2021

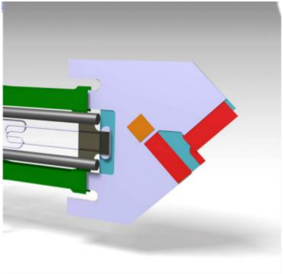


Upgrade I = U1. Upgrade II = U2.

VELO Upgrade I (Run 3–4: 2020–2029)

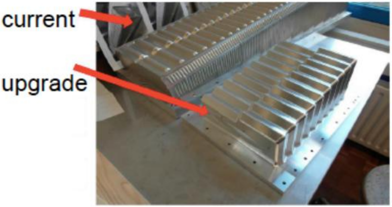


52 modules
Module pitch
N*25 mm



featuring pixel
sensors 5 mm
from the beam line

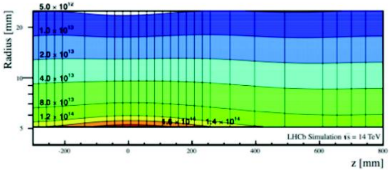
enclosed in
an “L” shape foil



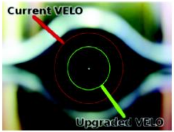
VELO Upgrade I (Run 3–4: 2020–2029)

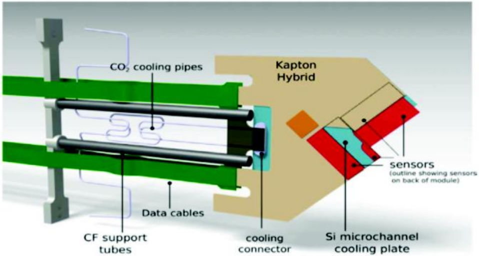
VELO challenges in Run 3:

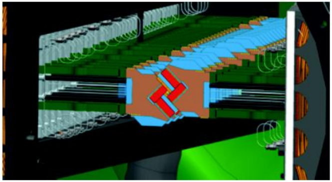
- Retain high vertex and track reco. efficiency with ~ 5x increase in interactions per bunch crossing
- Increased radiation (order of magnitude higher than current doses), highly non-uniform



- Use silicon hybrid pixels
- 52 modules, two retractable halves
  - Innermost sections ~5.1 mm from beam pipe
  - 4 silicon sensors per module, 55 µm x 55 µm







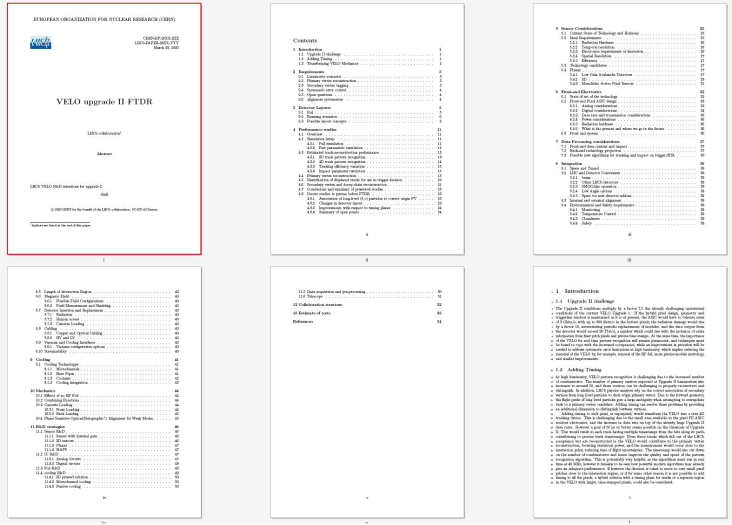
Challenges for Upgrade II

- First $C0_2$ micro-cooling solution in HEP was used by NA62 GigaTracker (4D tracking).
- LHCb VELO-U1 pionneered micro-cooling with bi-phasic CO_2 in HEP
- Efficient and elegant cooling solution, but **expensive** (complicated processes). One cooling substrate cost $\sim 10 - 20$ k€.
- Main limitations of LHCb-U1: bonding of large surface (8 inches wafers) to close the micro-channels (a small defect imply throwing away the wafer).

Challenges for LHCb U2:

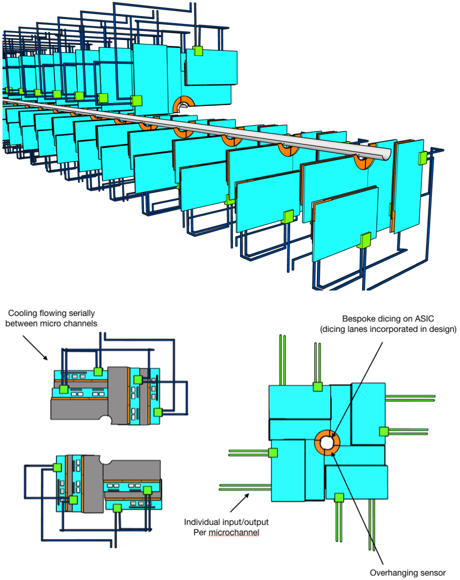
- **Radiation** hardness: expected Fluence $5 - 8 \times 10^{16}$ 1 MeV n_{eq} cm^{-2} at 5.1 mm of the beam during the life of the detector ($> \times 5$ ATLAS ITK !) $\Rightarrow$ modules will have to be regularly **replaced** ($\sim$ 1 year?)
- Mutiplicity of vertex $\times 10 \Rightarrow$ add timing information: "4D tracking" $\Rightarrow$ **more power to dissipate**
- To limit the leak current of the sensors, probably need to **go below -40°C** $\Rightarrow$ study alternative gas to CO_2, like Krypton
- **Reduce the cost by at least a factor 10**
- **Improve the yield of production** $\Rightarrow$ **reduce substrate size**: several "small substrate" instead of the large 8 inches used in U1 $\Rightarrow$ Many connectors
- Think to a "**global solution**": ASIC - mechanical support - cooling substrate - connectors - "high voltage pists". Two solutions considered: **Titanium 3D printing** (NIKHEF) and **improved etched micro-channels** (CPPM).

Status of VELO LHCb Upgrade II Framework TDR



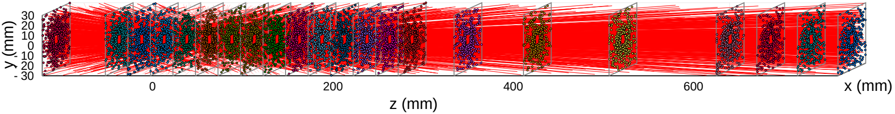
→ to be submitted early 2021

VELO U2: example of cooling solutions



VELO U2: simulation of collisions

A challenging environment:



Conclusions and prospects

- Current microchannels used by LHCb for U1 are **too expensive for U2**: we need to reduce the costs.
- The LHCb collaboration consider: **3D Titanium printing** and/or **low-cost micro-cooling** $\Rightarrow$ CPPM investigation on micro-cooling $\rightarrow$ next talks;
- As a reminder: **we need a room** to continue our pressure tests and future connector developpements.
  Ideally, close to existing CO_2 facility (i.e. in current building).
- A **publication** is planned with the outcome of the laser-etched wafer, in a laser journal, with LP3.
- We also plan a section in the **VELO Framework TDR** (by the end of this year).
- Now, we work with existing resources (LHCb, mechanics, NA62) and a “stagiaire en mécanique”. In case first steps are successful, **we anticipate the need for money and manpower**.

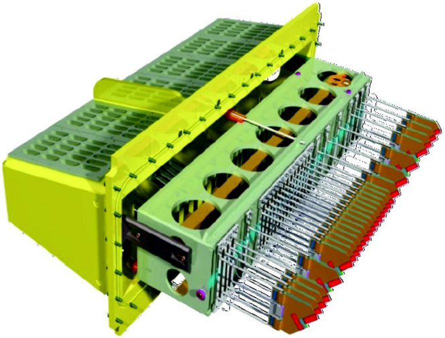
Backups

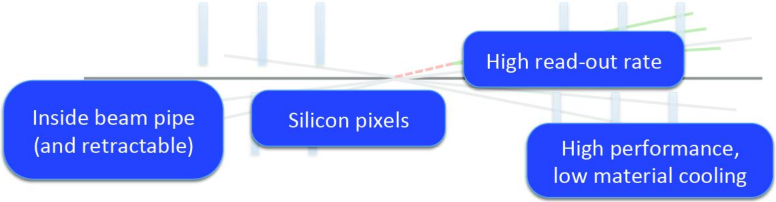
VELO Upgrade II (Run 5–6: 2030–)

We want to achieve same or better physics performance as Upgrade-I VELO, at 10x luminosity…

- 10x higher particle multiplicity
- 10x denser vertex environment
- 10x higher radiation damage

Can it be done? How?



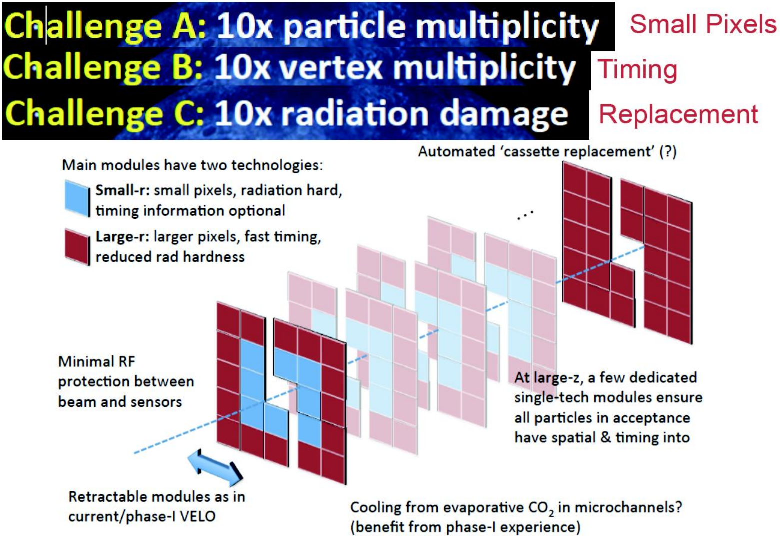


VELO Upgrade II (Run 5–6: 2030–)

- Multiplicité des particules 10$\times$ $\rightarrow$ petits pixels (27.5$\times$27.5 μm)
- Multiplicité des vertex 10$\times$ $\rightarrow$ info en temps (4D, 200 ps)
- Taux de radiation 10$\times$, fluence attendue $5-8\times10^{16}$ 1 MeV $n_{eq}cm^{-2}$ à 5.1 mm des faisceaux pendant la durée de vie du détecteur ($>\times$5 ATLAS ITK !) $\Rightarrow$ 2 technologies pour les parties internes et externe? Capteurs rempla*c* cables?
- Sensor thickness = 100μm.
- Il se peut qu'une telle technologie ne voit pas le jour si nous ne la poussons pas!

- Enlever la feuille RF: capteurs directement dans le vide primaire du LHC? Refroidissement?

VELO Upgrade II (Run 5–6: 2030–)

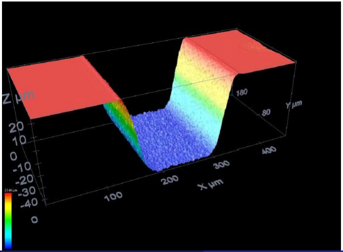


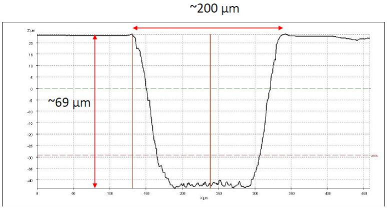
Micro-cooling

[S. Beurthey, J. Cogan, G. Hallewell, O. Leroy, M. Perrin-Terrin, A. Mouskeftaras]

Stéphan Beurthey (CPPM-mécanique), Julien Cogan et Olivier Leroy (CPPM-LHCb), Mathieu Perrin-Terrin (CPPM-P2O), Greg Hallewel (CPPM-ATLAS) et Alexandros Mouskeftaras (LP3)

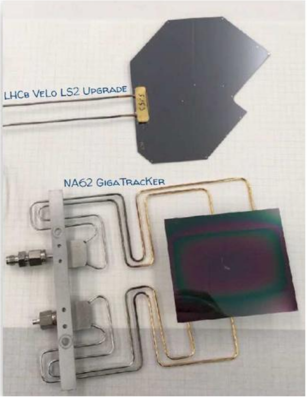
- VELO-Upgrade-I pionneered micro-cooling with bi-phasic CO_2 in HEP.
- Efficient and elegant cooling solution, but expensive (complicated processes)
- For VELO-Upgrade-II, with replacable modules, need to improve the cooling
- We are investigating the micro-cooling with laser etching (instead of the traditional photolithography).
  Collaboration cross-experiments and cross-laboratories

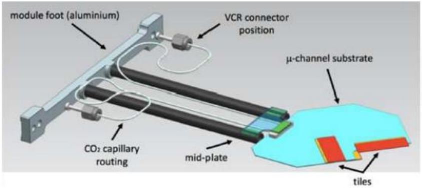


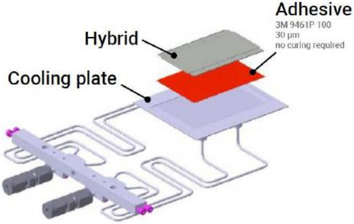


Micro-cooling

REFROIDISSEMENT: ÉTAT DE L'ART







LHCb VELO U1 - 2021