Using Hadronic Interactions to Assess the LHCb RF Box Deformation

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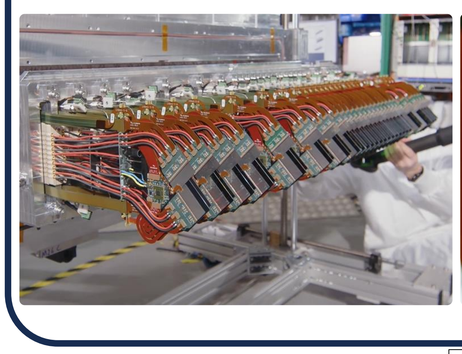
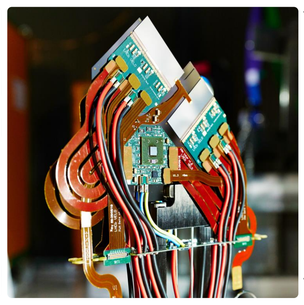
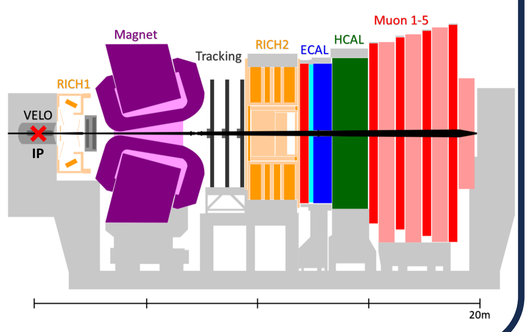
1. LHCb Vertex Locator (VELO)

- LHCb VELO is a **pixelated hybrid silicon detector** that surrounds the proton-proton interaction region.
- Enables LHCb to reconstruct primary and displaced vertices [1].
- Two **retractable halves**, each housing 26 L-shaped detector modules.
- Stable beams: Inner-most tip 5.1mm from beam axis.
- Injection/ramping beams: Halves retracted by 29mm.

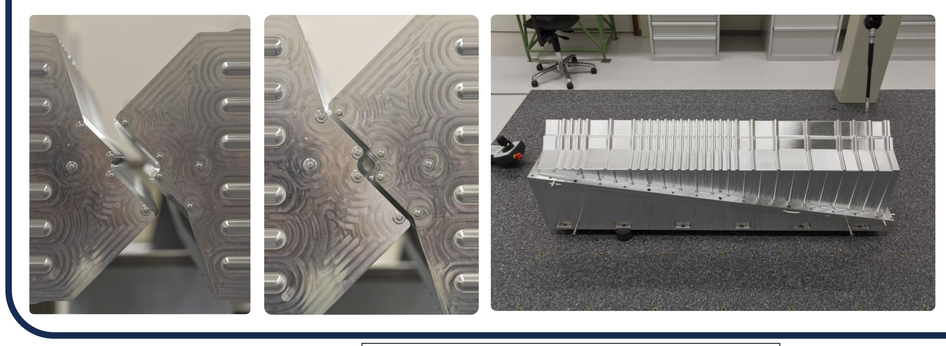






2. Radio Frequency (RF) Shielding

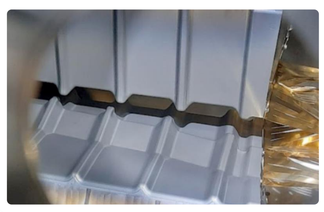
- RF boxes are **thin-walled corrugated enclosures**.
- Provide a **barrier** between the primary (beam) and secondary (detector) vacuum and protect the VELO modules from strong wakefields produced by the LHC beams.
- Milled from a single solid 300kg block of $AlMg_3$ and thinned to ~250μm.

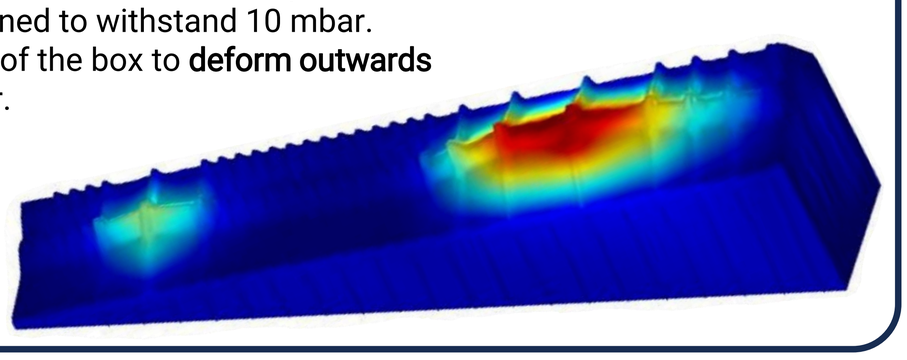


Scan here to see me being milled out!

3. Vacuum Incident

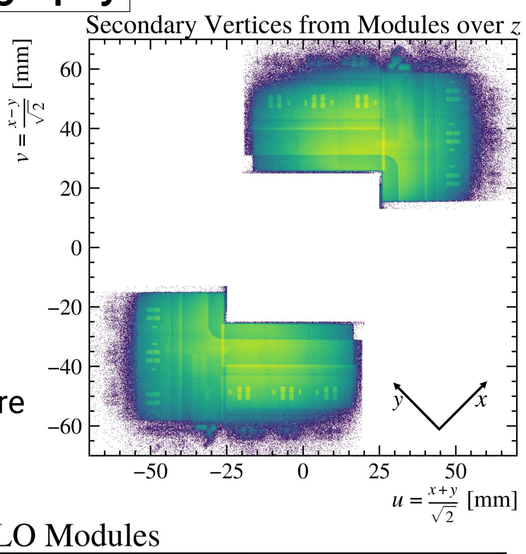
- During a VELO warm up, there was a loss of control of the protection system.
- 10 mbar pressure differential switch was activated, but its corresponding relay failed and shorted the power supply - multiple equipment failures and a pumping action on the primary volume.
- **Pressure differential of 200 mbar** built up between the two volumes, whereas the RF boxes are designed to withstand 10 mbar.
- Caused both sides of the box to **deform outwards** towards each other.

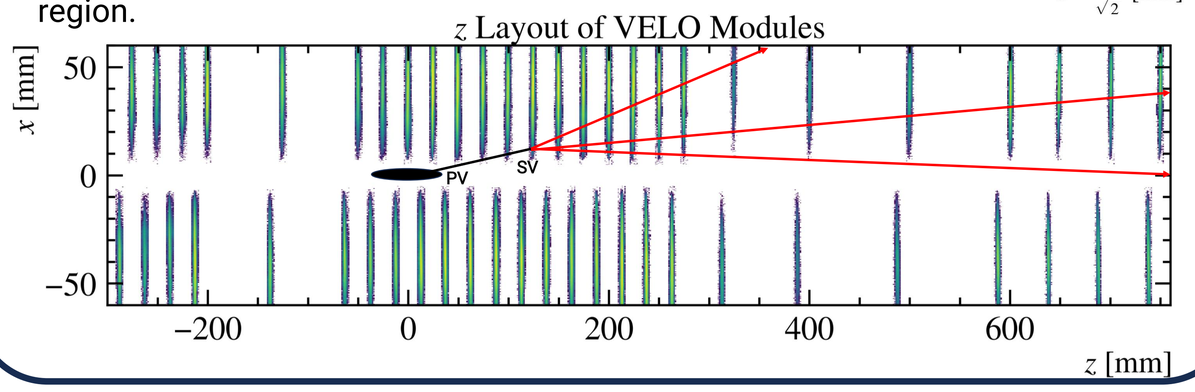




4. VELO Tomography

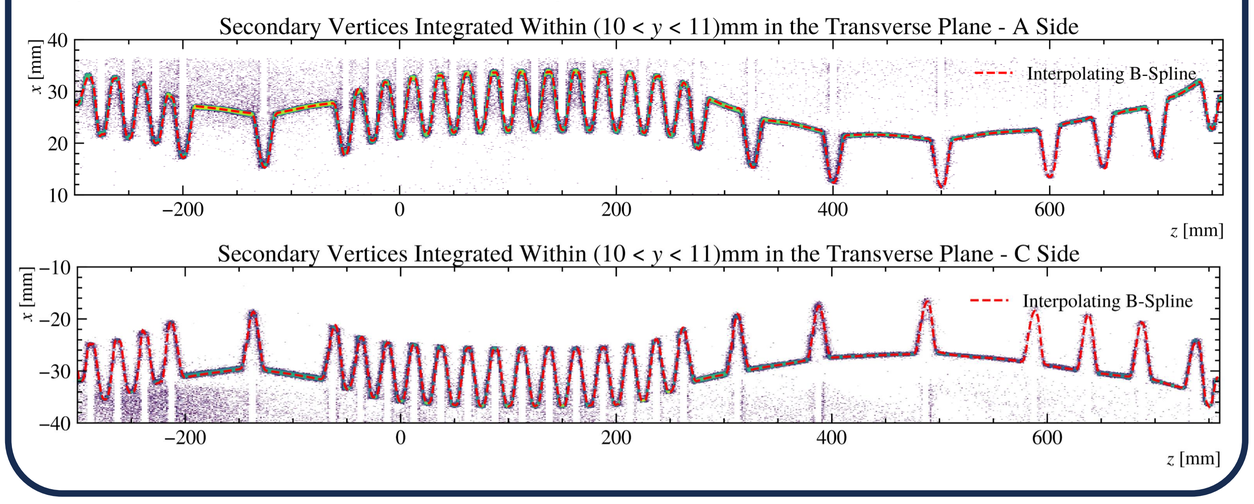
- To assess the deformation of the RF box, **secondary hadronic vertices** from material nuclear interactions are used to locate detector material.
- LHCb detector includes a **System for Measuring beam Overlap with Gas** (SMOG) that allows gas to be injected into the beam pipe.
- SMOG typically used for luminosity measurements and fixed target physics. Here it is used to enhance the production of particles outside the typical interaction region.





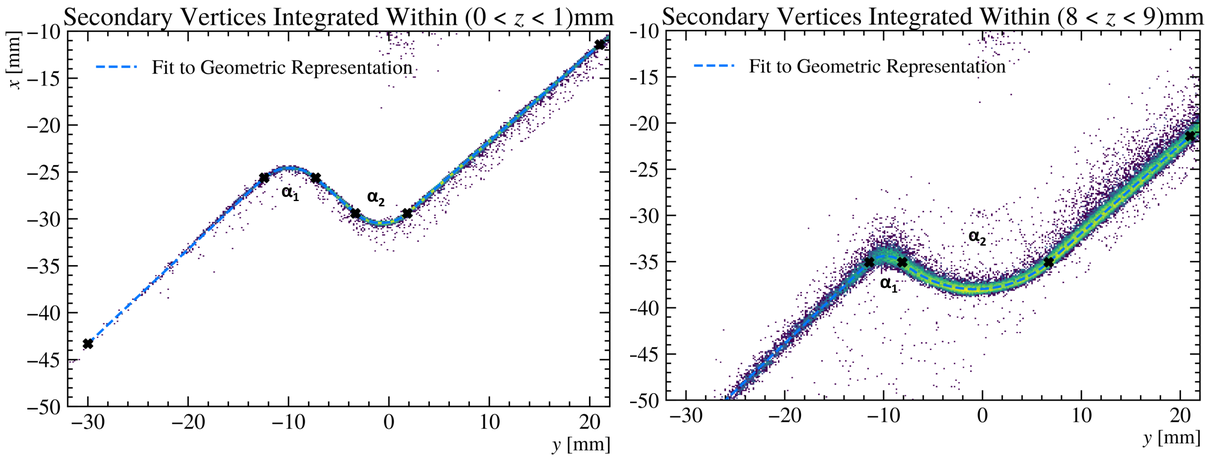
5. Interpolating B-Splines

- Due to the complex nature of the RF box shape and areas of low statistics, two approaches are taken to map its material.
- Interpolating B-splines with knots placed at and around the nominal module positions are fit in the transverse plane to the data in 1mm wide bins.

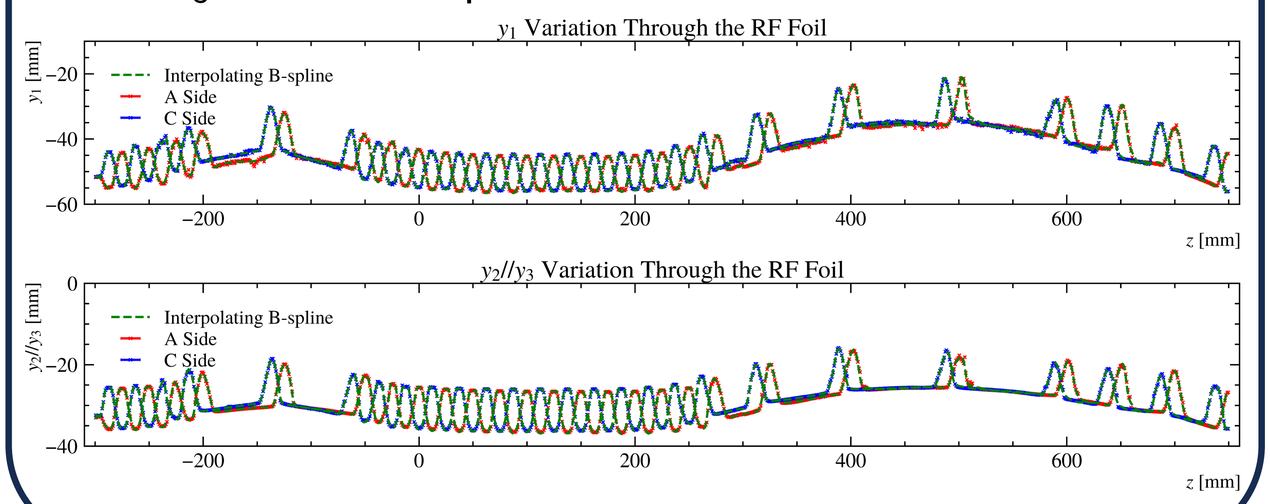


6. Mapping Method

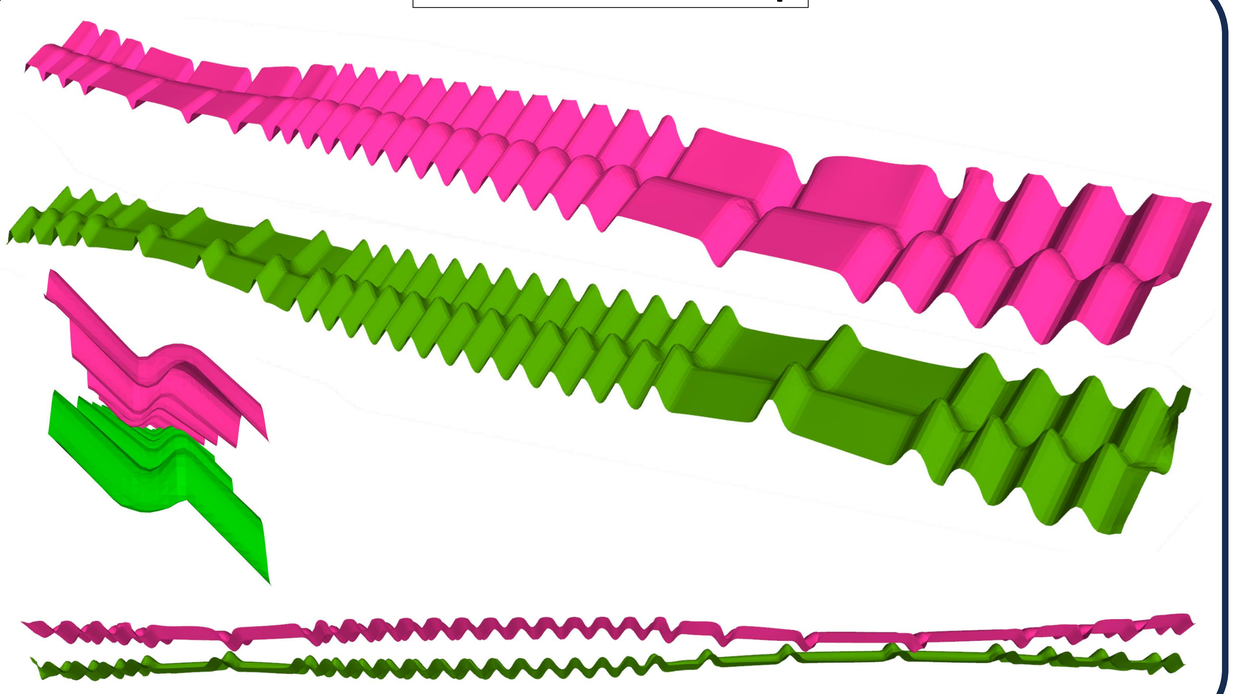
- 1D least squares fit is performed to the RF box in 1mm bins to a geometric representation defined by **three linear sections** and **two circular segments.**
- Away from VELO modules, the central linear section is excluded from the fit.



- Fit is stepped through the RF box, using a given bin's results as the starting parameters for the next.
- Fit floats **11 free parameters**, which define the boundaries between the linear and circular segments and the angle subtended by the circular segments, α.
- Parameter variation through the RF box is also fitted to interpolating B-splines, allowing a full **material map** of the RF box to be created.



7. The Material Map



8. Great! Why Bother?

- The **maximum deflection** of the deformed RF box from nominal is found to be 32-34 mm between the two halves.
- Assign a p-value to the hypothesis that a secondary vertex originates from a material interaction – a **material veto** tool is essential in reducing the background in searches for **long-lived exotic particles** (see [2]).
- The RF box is being replaced in this YETS, with another VELO tomography campaign expected in early 2024, where the material map could feed into LHCb **Run 3 simulation**.

9. References

[1]. The LHCb Upgrade I, LHCb Collaboration, arXiv:2305.10515
[2]. Search for Dark Photons Produced in 13 TeV pp Collisions, LHCb Collaboration, arXiv:1710.02867