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Future Upgrade for LHCb VELO

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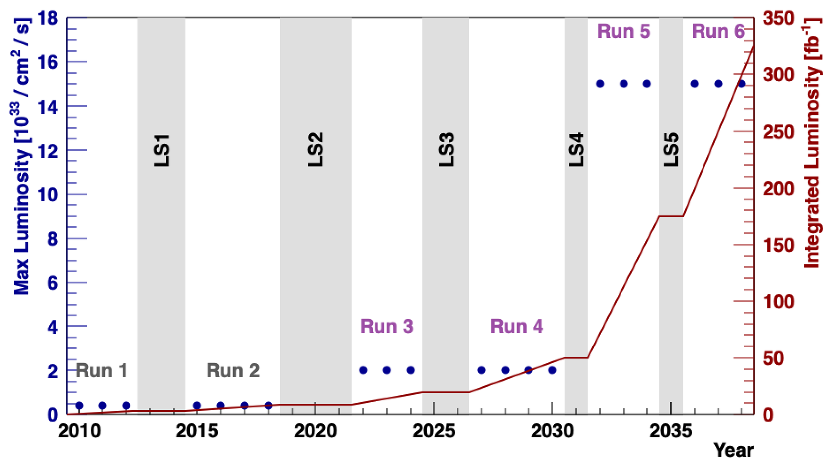
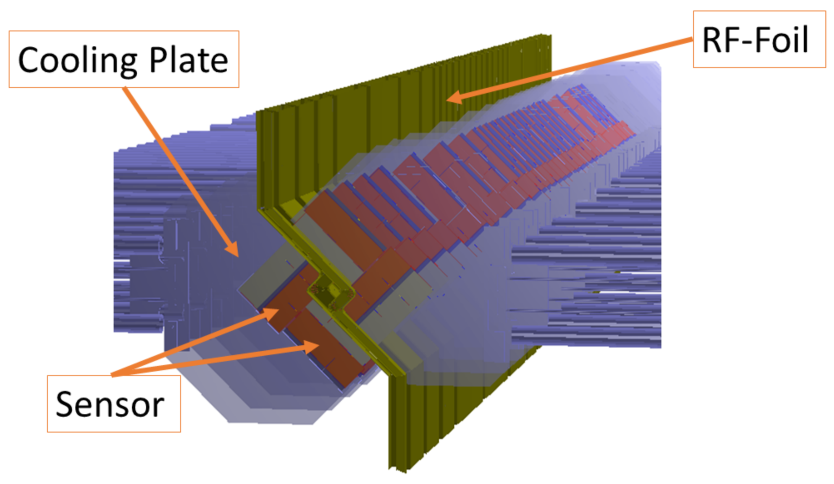
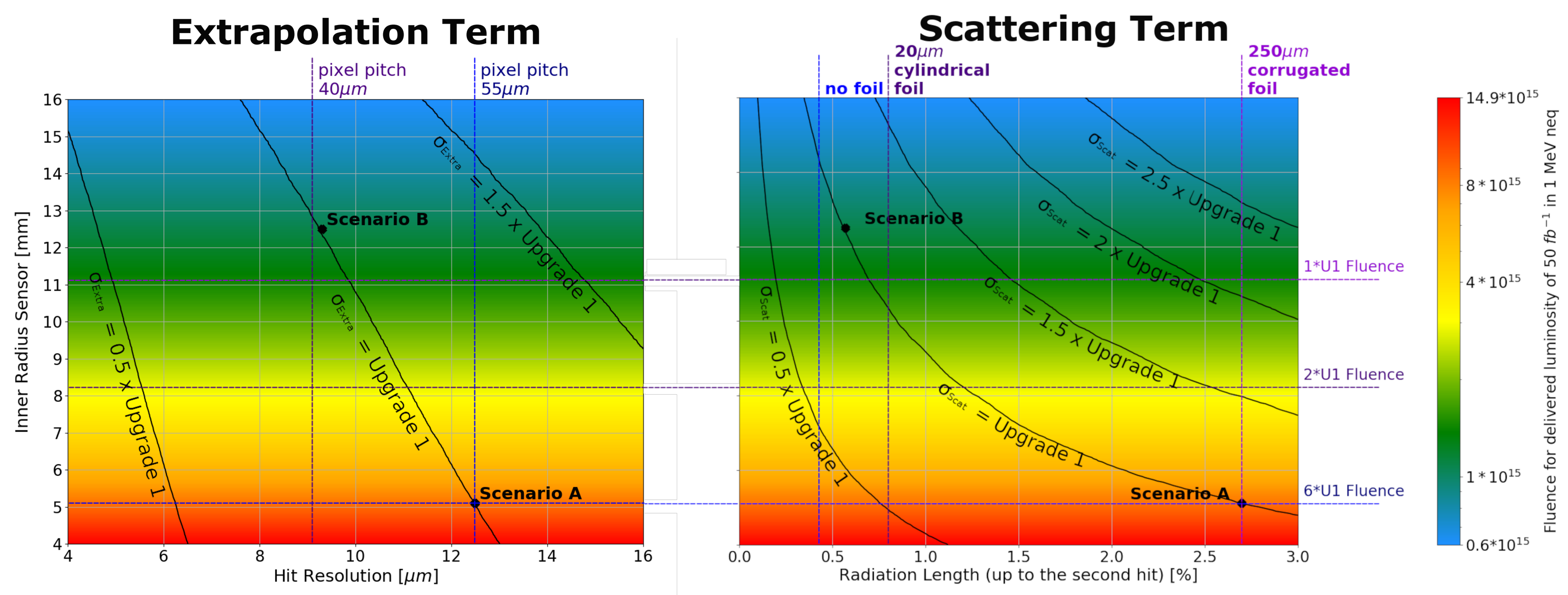
Vertex Locator (VELO) Upgrade II [1]

- To collect 300 fb^{-1} at a luminosity of 16x10^{33}cm^2/s **LHCb Upgrade II** will see **7.5** times higher occupancy and **6** times higher fluence than in Run 3/4.
- The Vertex Locator (VELO) is an array of hybrid silicon pixel detectors surrounding the interaction point
- The detector modules operate in a secondary vacuum separated from the primary vacuum by a thin aluminium foil (RF foil)
- Mean number of vertices per event from 5 to 42 → higher track density





Detector Layout

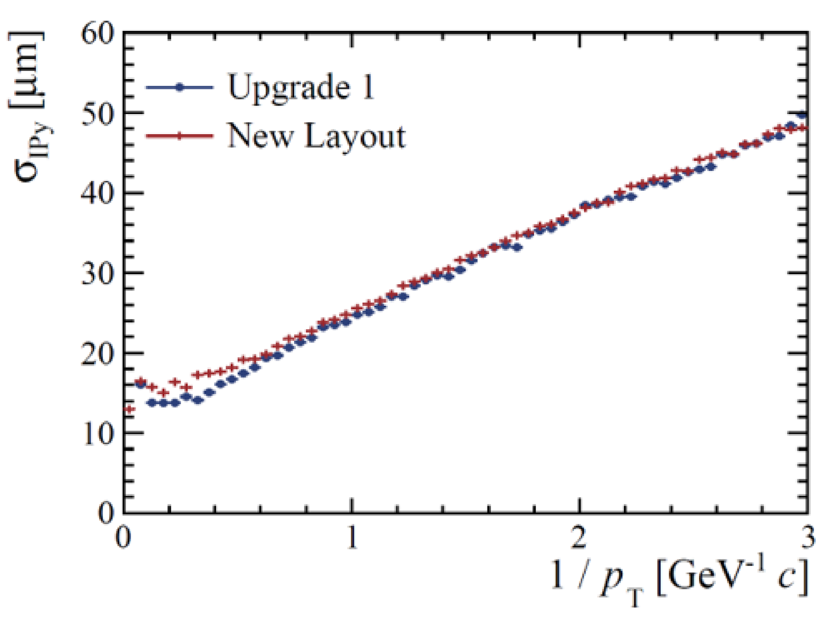


The impact parameter resolution approximation ($\sigma_{IP} = \sigma_{extrap} \oplus \sigma_{scat}/p_T$) for the extrapolation and multiple scattering terms

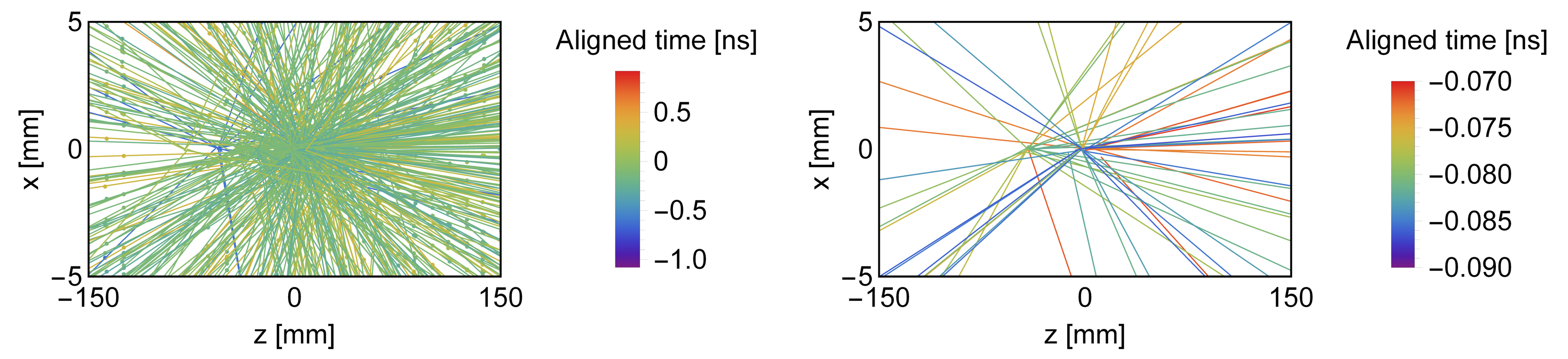
- The IP resolution can be approximated as a function of the minimal distance to the beam line, the amount of traversed material and the single hit resolution
- The Upgrade I layout (sensors at 5.1 mm from the beam line) imposes challenging requirements in terms of radiation hardness and data rate
- Radiation damage and cluster occupancy are roughly proportional to r^{-2}
- If we move from current layout (**Scenario A**) to **Scenario B** we have to reduce the material budget and improve pixel resolution.
- Same IP resolution can be achieved with a pixel resolution of 9 μm and 20 μm thick cylindrical foil
- To decrease the size of the detector in Scenario B:
  - Reduce maximum first hit radius by changing shape of inner hole
  - Move sensors located further away from the interaction point closer to the beam
  - Reduce acceptance from $\eta < 5$ to $\eta < 4.8$

Requirement	Scenario A	Scenario B
TID Lifetime [MGy]	> 28	> 5
Sensor+ASIC Timestamp per Hit [ps]	≤ 50	≤ 50
Hit Efficiency [%]	≥ 99	≥ 99
Power per Pixel [μW]	≤ 23	≤ 14
Pixel Rate Hottest Pixel [kHz]	> 350	> 40
Max Discharge Time [ns]	< 29	< 250
Bandwidth per ASIC of 2 cm^2 [Gb/s]	> 250	> 94
Minimum Sensor Distance from Beam [mm]	5.1	12.5
Mean Pixel Resolution [μm]	12.5	9
RF Foil [μm]	180 corrugated	20 cylindrical
Length of the Detector [cm]	80	up to 140

- Scenarios in between are also possible: Layout with sensor position at 9.5 mm, 10.5 μm pixel resolution and a cylindrical foil with 20 μm thickness at 8.6 mm



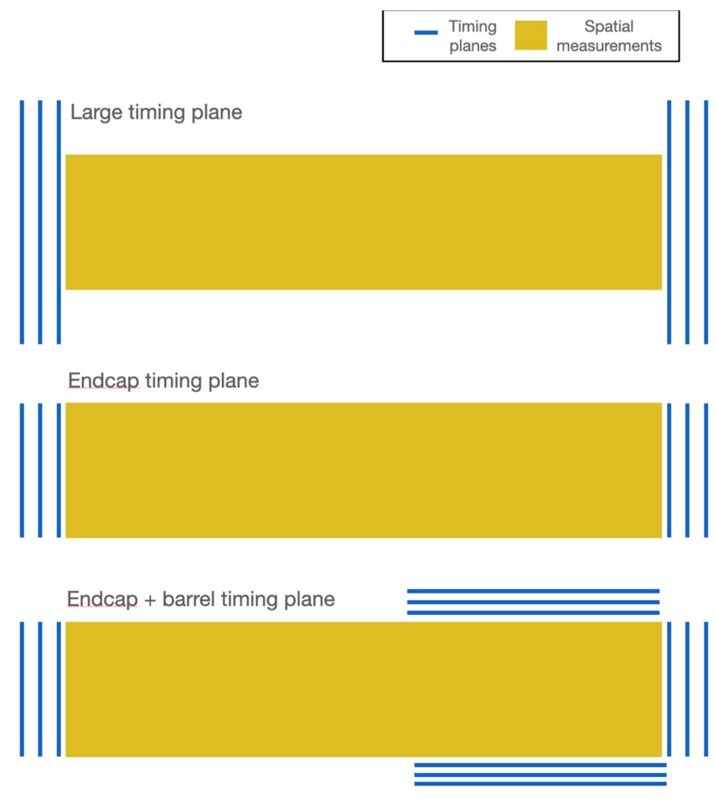
Timing



Upgrade II track density for a 2000 ps time window (left) and a 20 ps time window(right)

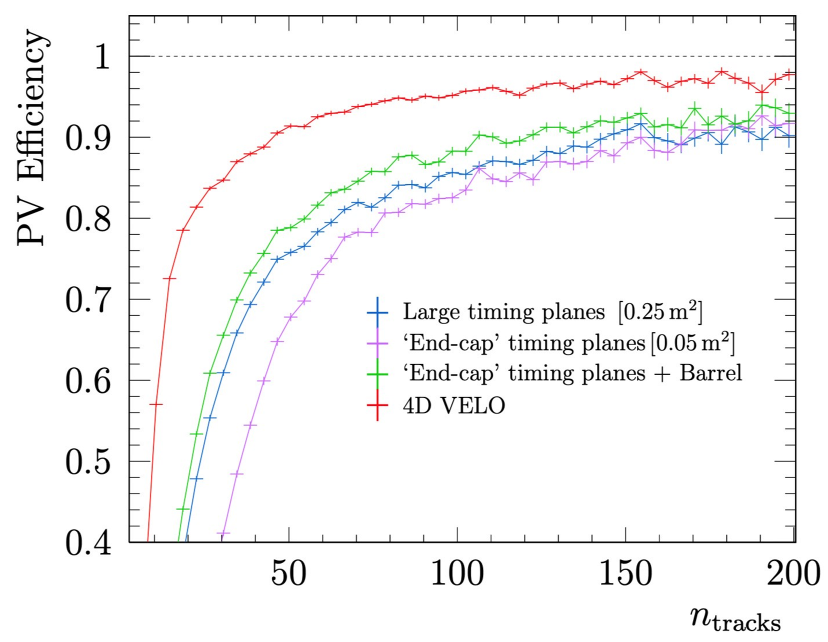
- Upgrade II will lead to an drastic decrease in primary vertex reconstruction efficiency and an increase in the number of falsely reconstructed vertices
- Adding timing with at least 20 ps time resolution per track is needed to compensate, which can be achieved by either a 4D VELO or separate timing planes
- 50 ps time resolution in each hit (4D VELO) results in 20 ps time resolution per track

- Separate timing planes considered:
  - Big timing planes at the end to cover the full VELO acceptance
  - Smaller end caps with reduced acceptance
  - End caps + barrel to recover the reduced acceptance due to small end caps
- At least 3 planes in each direction for hit rejection
- Each plane hast to have at least 25 ps time due to the limited number of planes, but only a spatial resolution of around 100 μmm is needed
- Timing planes suffer an additional error due to different t.o.f. for low momentum particles



Schematics of possible timing plane solutions

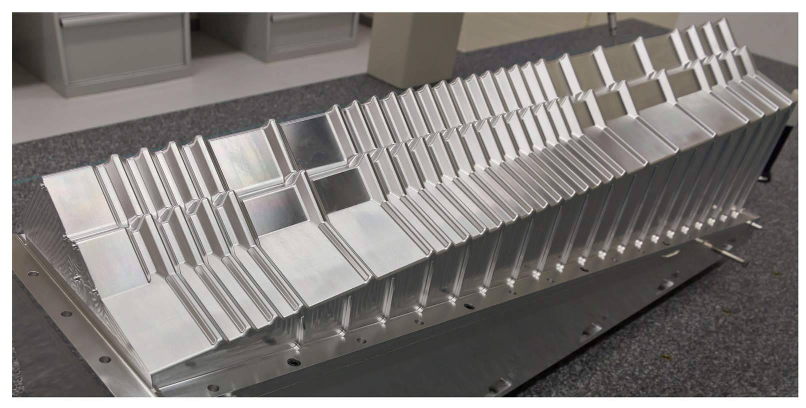
- 3 sensor types are considered for 4D VELO and timing planes:
  - **Thin Planar Sensors**:
    - 👍: Radiation hard up to 1.6*10^{17} MeV n$_{eq}$/cm^2
    - 👎: low signal
  - **Low Gain Avalanche Diode**:
    - 👍: fast and sizeable signal
    - 👎: radiation hard only up to 2*10^{15} MeV n$_{eq}$/cm^2
  - **3D**:
    - 👍: radiation hard, fast collection time
    - 👎: inefficient volumes at the columns or trenches
- On hit timing with 50 ps resolution is sufficient to recover reconstruction and is preferred over dedicated timing planes



Primary vertex reconstruction efficiency as a function of multiplicity for different timing solutions

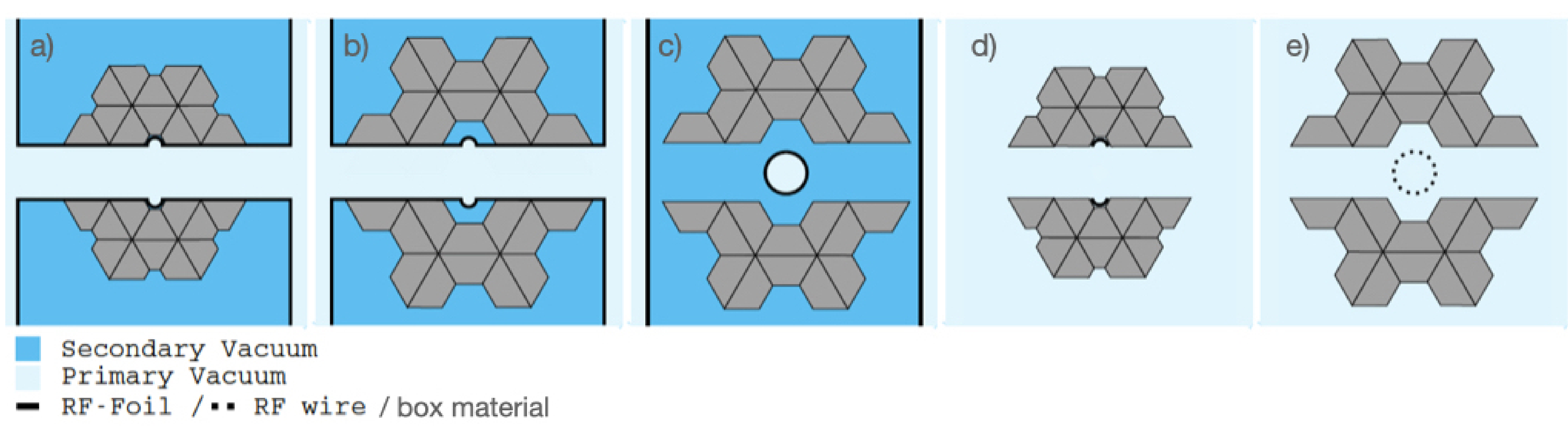
Material Budget

- Material before first hit most important → RF foil
- Current corrugated foil hard to thin down more→ Cylindrical foil or wire frame
- If the inner radius is increased to at least 8.6 mm it can be constructed out of a single piece, without problems during injection



Upgrade 1 corrugated RF foil [3]

- Requirements for new foils:
  - Mechanical stability
  - Conducting the beam current
  - Containing the primary vacuum (if vacuum is still separated)
  - Shield sensors from wake field



Schematics of possible RF foil shapes

References
[1] https://cds.cern.ch/record/2653011/files/LHCb-PUB-2019-001.pdf
[2] https://cds.cern.ch/record/1624070/files/LHCB-TDR-013.pdf
[3] https://www.nikhef.nl/pub/departments/mt/projects/lhcb-vertex/production/UpgradeRFbox/IMG_9824.jpg