Performance evaluation of U2 options
Motivation

The vast increase in luminosity with the upgrade-II is particularly challenging for the vertex detector, which has the highest track density. Reasoning from **first principles** and toys **several options** for the Upgrade-II vertex detector have been proposed (foil, timing, pitch, barrel).

Do these options allow to make the Upgrade-II **physics case** a reality?

**Goal of this talk:** motivate, based on the impact on the chain of event reconstruction (and as realistic as possible), two of the attractive R&D paths considered for the Upgrade-II vertex detector.
Method

Using the full simulation, tried to evaluate the impact of **timing** and a **much thinner foil** (~ no foil) on four stages of the event reconstruction. Do so by using the Upgrade-I detector, adding 50ps timing\(^1\) and/or removing foil.

![Diagram showing the four stages of event reconstruction: Pattern recognition, PV reconstruction, IP discrimination (“HLT1”), and Multibody selections.]

**Disclaimer** These parameters are considered as reasonable options, but it does not mean we propose this detector as a concrete option at this stage. The goal is to **motivate R&D**, not to focus on the **implementation**.

\(^1\): Result from first-principle estimates and achievability
Gains in the pattern recognition

Without foil: fewer scatters (also from layer to layer). Windows can be tighter, reducing the ghost rate for the same efficiency.

With a timestamp on each hit, can reject out-of-time hit combinations, directly reducing the ghost rate. Run with looser windows to increase efficiency.
### Gains in the pattern recognition

<table>
<thead>
<tr>
<th>Foil thickness</th>
<th>Per-hit timing</th>
<th>ε\text{VELO} [%]</th>
<th>ε\text{LONG} [%]</th>
<th>P\text{GHOST} [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade-I (reference)</td>
<td>150µm</td>
<td>✗</td>
<td>98.1</td>
<td>99.1</td>
</tr>
<tr>
<td>Upgrade-II</td>
<td>150µm</td>
<td>✗</td>
<td>96.6</td>
<td>98.1</td>
</tr>
<tr>
<td></td>
<td>150µm</td>
<td>50ps</td>
<td>97.2</td>
<td>98.7</td>
</tr>
<tr>
<td></td>
<td>0µm</td>
<td>✗</td>
<td>97.8</td>
<td>98.9</td>
</tr>
<tr>
<td></td>
<td>0µm</td>
<td>50ps</td>
<td>98.0</td>
<td>99.2</td>
</tr>
</tbody>
</table>

Remember: this is an efficiency *per track*!
Effect of search windows

Variation less drastic for 4D tracking

(foil 150µm)

U-I 3D Tracking
+ U-II 3D Tracking
+ U-II 4D Tracking

Spectrum (long, from B)

DOCA$_z$ [mm]

Efficiency
Primary vertex reconstruction

Run-3 PV algorithm: histogramming on the beam line
Primary vertex reconstruction

This projection breaks down for Upgrade-2
(can you distinguish the ~42 peaks?)
Impact on physics

Should you care about merging PVs?

If two PVs sit close to one another and get merged, the impact on the resolution is dramatic (even for nTracks > 25 in the PV)
Considerable recovery seen with timing, although not on the level of U-1 yet. Tuning of algorithm still a degree of freedom.
Trigger selections

In the main trigger selections up to now, charm and beauty decays are selected through high-pT tracks with a significant **impact parameter** with respect to **any primary vertex**.
Trigger selections

With the high multiplicity of primary vertices, the sheer chance of a track pointing to another PV increases - a displaced track can appear prompt-like (esp. given resolutions)!

Is the impact parameter still a good discriminant?
Impact parameter discrimination

**Foil:** discrimination improved by better IP resolution

**Timing:** Can limit the number of PVs under consideration for the minimum IP requirement
Impact parameter discrimination

Keep in mind: 10% of U2 background >> 10% of U1 background
Combining tracks

**Typical selection** After selecting displaced tracks with a reasonable pT, combine them to try and find the signal candidate.

With the increased **track density**, more **combinatorial background** is expected ("event mixing").

Is a ~20ps track resolution already helpful to reject this background?
Combining tracks

Generated signal $B_s \rightarrow D_s^+ \pi^+$ Monte Carlo, samples artificially pure (every event contains signal!). Try and reconstruct the $D_s^+$. 

Already here a clear increase in combinatorial background visible, the per-track time significantly helps recovering. Particularly helpful in trigger!
Beyond the Upgrade-I geometry

Discussed the timing and foil reduction, but studies shouldn’t stop here: need to do studies out-of-the-box (literally).

In parallel, a **parametric simulation** was developed for the VP, tuned to reproduce spectra and resolutions from full simulation.

Will be used for exploring different sensor radii and barrel layers.
Different sensor radii

\[ \sigma_{IP} = \sigma_{\text{extrap}} + \frac{\sigma_{\text{MCS}}}{\rho_T} \]
\[ \odot \; \eta = 3.5 \]

Moving **away from the beam** drastically reduces radiation requirements, but need better spatial requirements to **compensate** (making the foil removal even more important)
Conclusions

Studies on full simulation underline the added value of a time per hit in all considered phases of the event reconstruction.

While a step forward, certainly not finished:
In the end, would combine results from parametric simulation to motivate the geometric design, which is then tested in all detail using the full simulation.

All details of these studies are planned to be available in the Upgrade-II VP FTDR supporting document, to be circulated in ~2 weeks from now.
Performance evaluation of U2 options
Table 1: Comparison of the performance of tracking algorithms between Upgrade-I and Upgrade-II conditions. Shown are the CPU time used both per event and per track, track-finding efficiencies and the ghost rate. The Upgrade-I baseline includes raw bank decoding and clustering within the tracking algorithm.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>$n_{tracks}$</th>
<th>$t$/event [µs]</th>
<th>$t$/track [µs]</th>
<th>$\varepsilon_{velo}$ [%]</th>
<th>$\varepsilon_{long}$ [%]</th>
<th>$P_{ghost}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upgrade-I baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-I</td>
<td>215</td>
<td>314</td>
<td>1.46</td>
<td>98.1</td>
<td>99.1</td>
<td>0.5</td>
</tr>
<tr>
<td>U-II (150 µm foil)</td>
<td>1690</td>
<td>5780</td>
<td>3.42</td>
<td>95.4</td>
<td>97.3</td>
<td>2.4</td>
</tr>
<tr>
<td>U-II (no foil)</td>
<td>1690</td>
<td>5303</td>
<td>3.13</td>
<td>97.1</td>
<td>98.4</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Upgrade-II optimised</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-I</td>
<td>215</td>
<td>244</td>
<td>1.10</td>
<td>97.6</td>
<td>98.9</td>
<td>0.4</td>
</tr>
<tr>
<td>U-II (150 µm foil)</td>
<td>1690</td>
<td>1792</td>
<td>1.06</td>
<td>95.1</td>
<td>97.0</td>
<td>1.9</td>
</tr>
<tr>
<td>U-II (no foil)</td>
<td>1690</td>
<td>1623</td>
<td>0.96</td>
<td>96.7</td>
<td>98.1</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Mis-association