Performance evaluation of U2 options

U2 workshop March 30, 2020

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Motivation

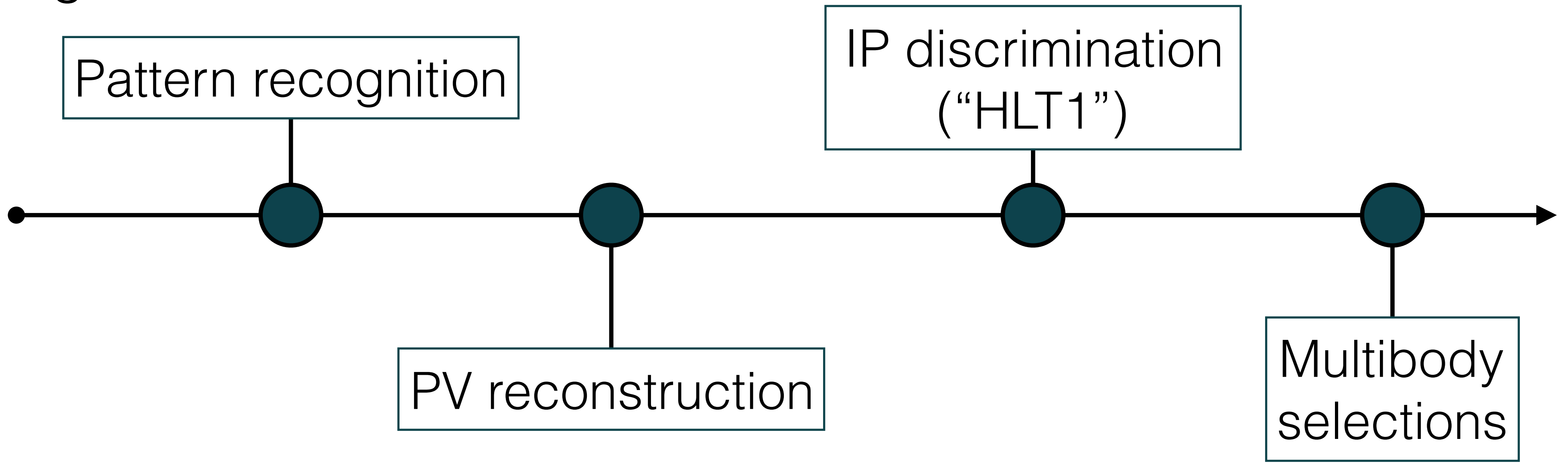
The vast increase in luminosity with the upgrade-II is particularly challenging for the vertex detector, which has the highest track density. Reasoning from **first principles** and toys **several options** for the Upgrade-II vertex detector have been proposed (foil, timing, pitch, barrel).

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

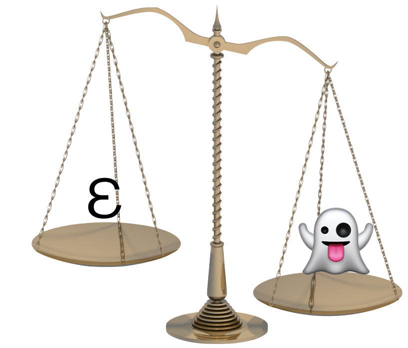
Using the full simulation, tried to evaluate the impact of **timing** and a **much thinner foil** (~ no foil) on four stages of the event reconstruction. Do so by using the Upgrade-I detector, adding 50ps timing[1] and/or removing foil.



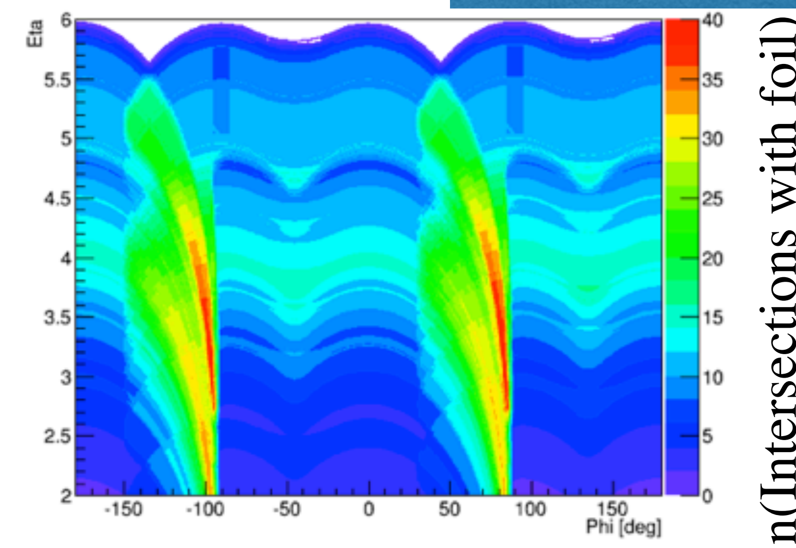
Disclaimer These parameters are considered as reasonable options, but it does not mean we propose this detector as a concrete option at this stage. The goal is to **motivate R&D**, not to focus on the **implementation**.

[1]: Result from first-principle estimates and achievability

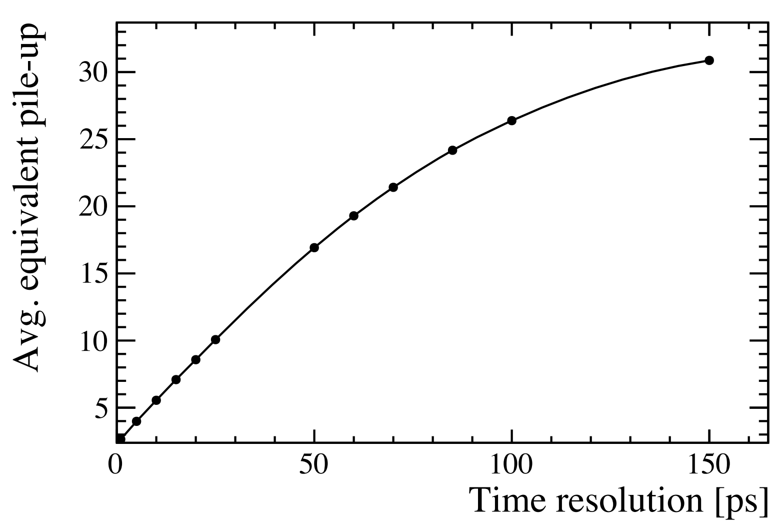
Gains in the pattern recognition



W. Hulsbergen



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



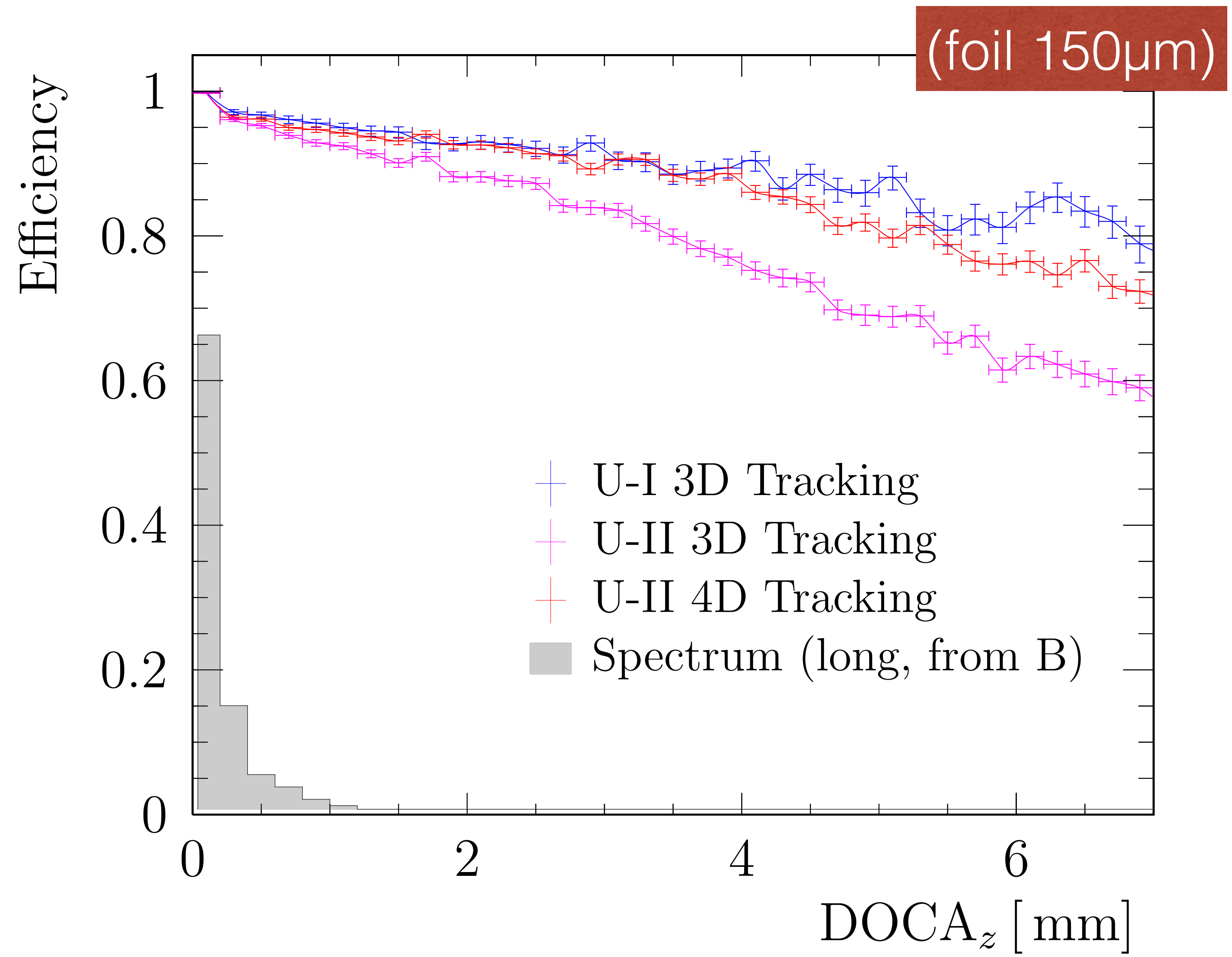
With a **timestamp** on each **hit**, can reject out-of-time hit combinations, directly reducing the ghost rate. Run with looser windows to increase efficiency.

Gains in the pattern recognition

	Foil thickness	Per-hit timing	ε_{VELO} [%]	ε_{LONG} [%]	P_{GHOST} [%]
Upgrade-I (reference)	150µm	✗	98.1	99.1	0.5
Upgrade-II ↓	150µm	✗	96.6	98.1	3.2
	150µm	50ps	97.2	98.7	1.1
	0µm	✗	97.8	98.9	2.3
	0µm	50ps	98.0	99.2	1.0

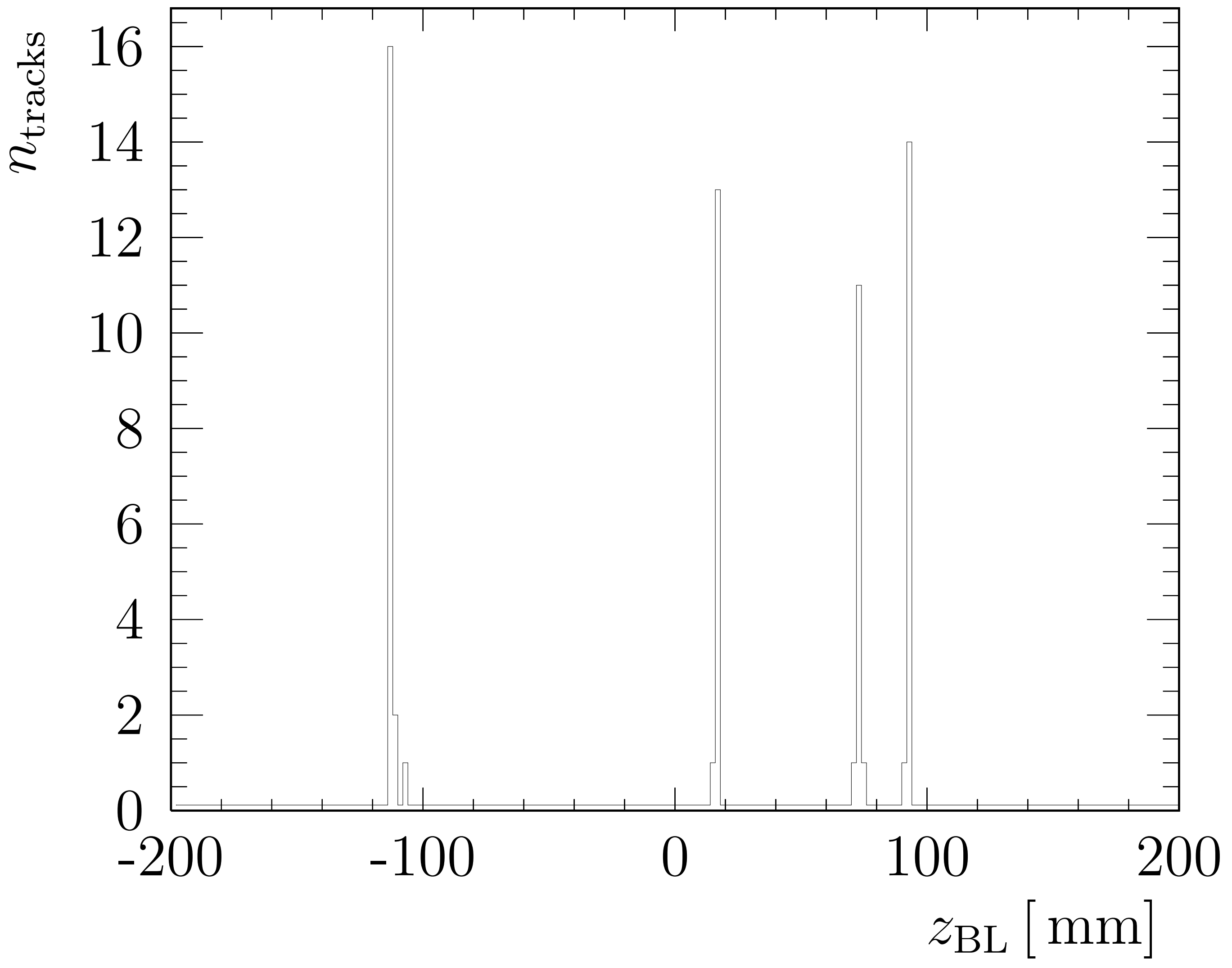
Remember: this is an efficiency *per track*!

Effect of search windows



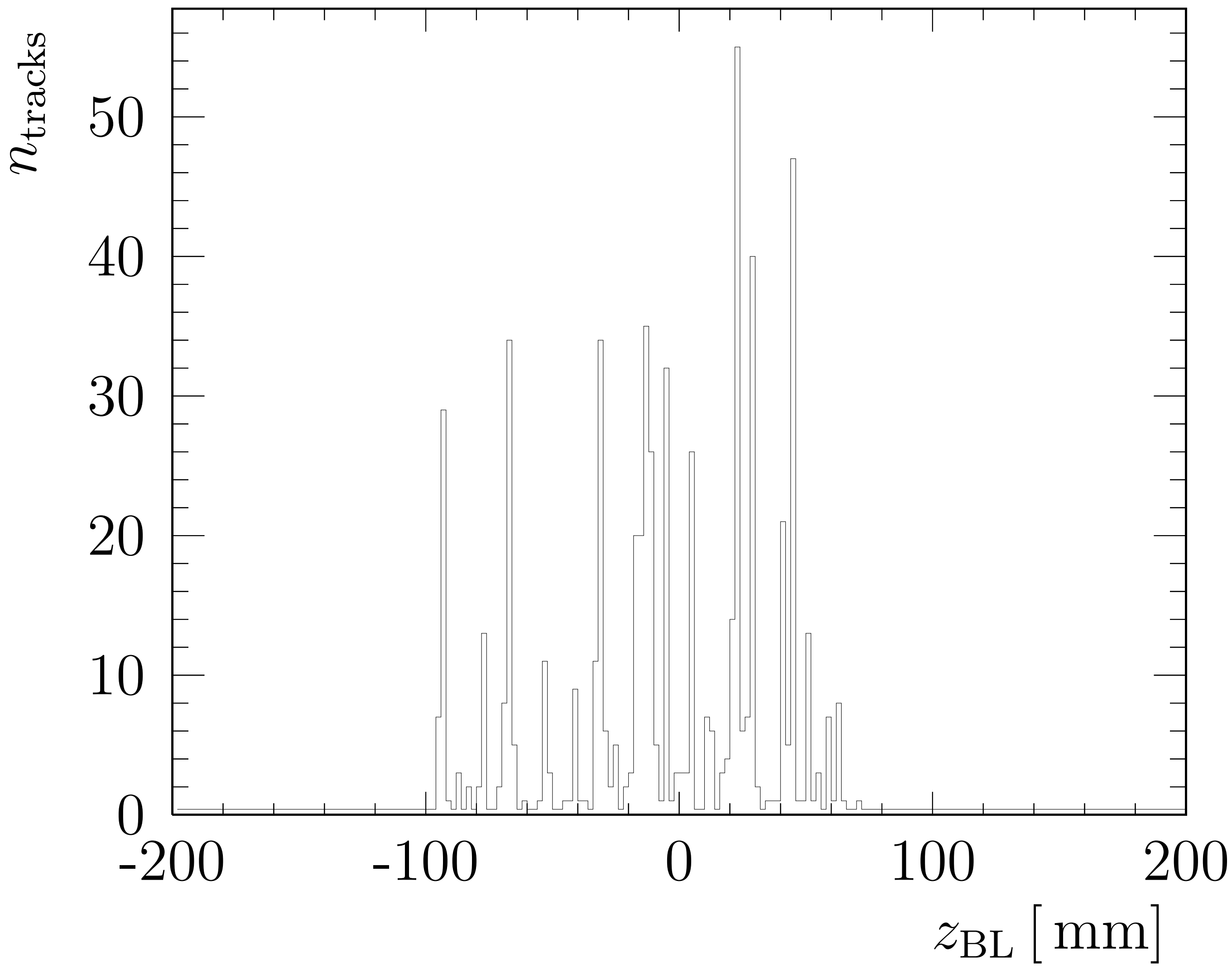
Variation less drastic for 4D tracking

Primary vertex reconstruction



Run-3 PV algorithm: histogramming on the beam line

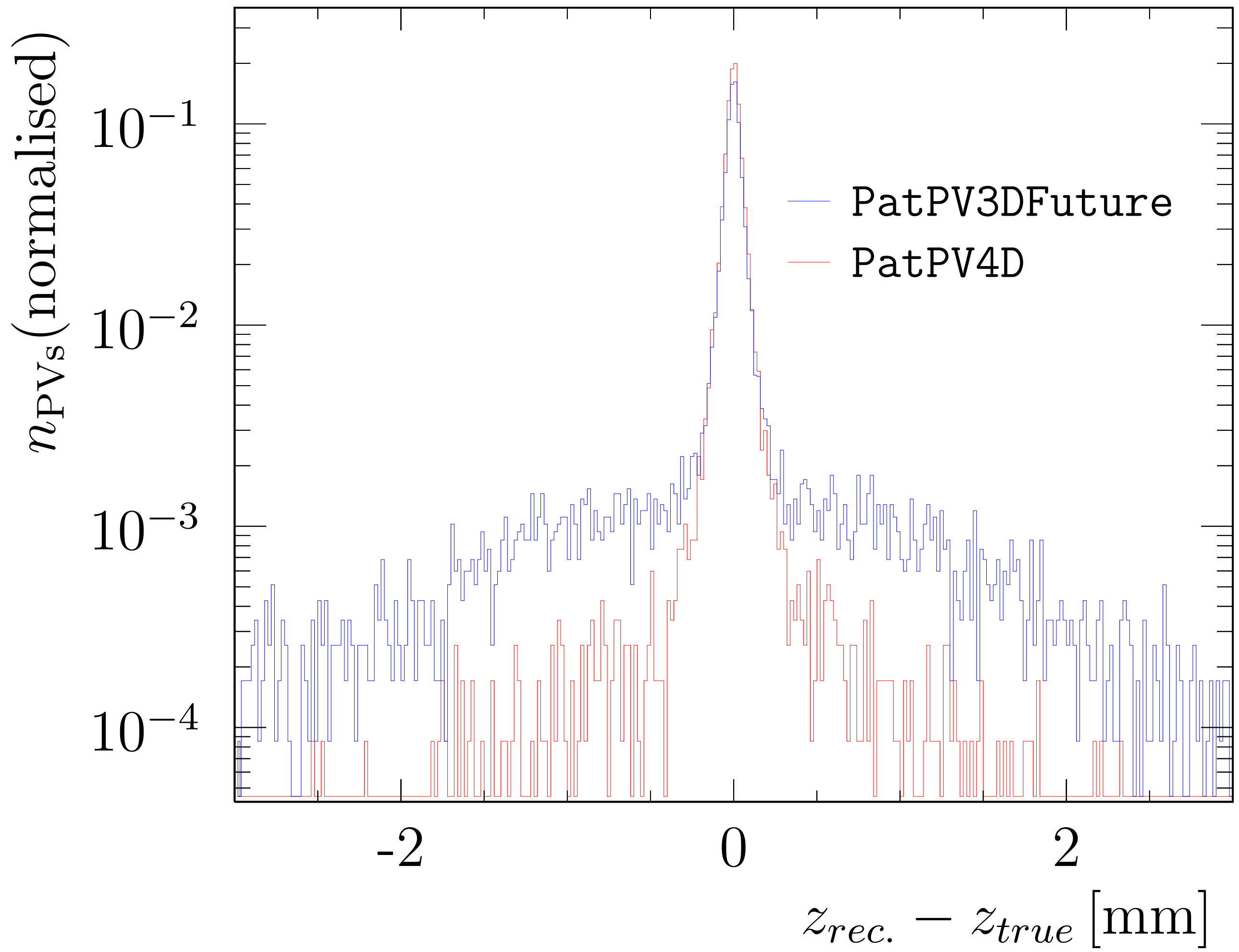
Primary vertex reconstruction



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

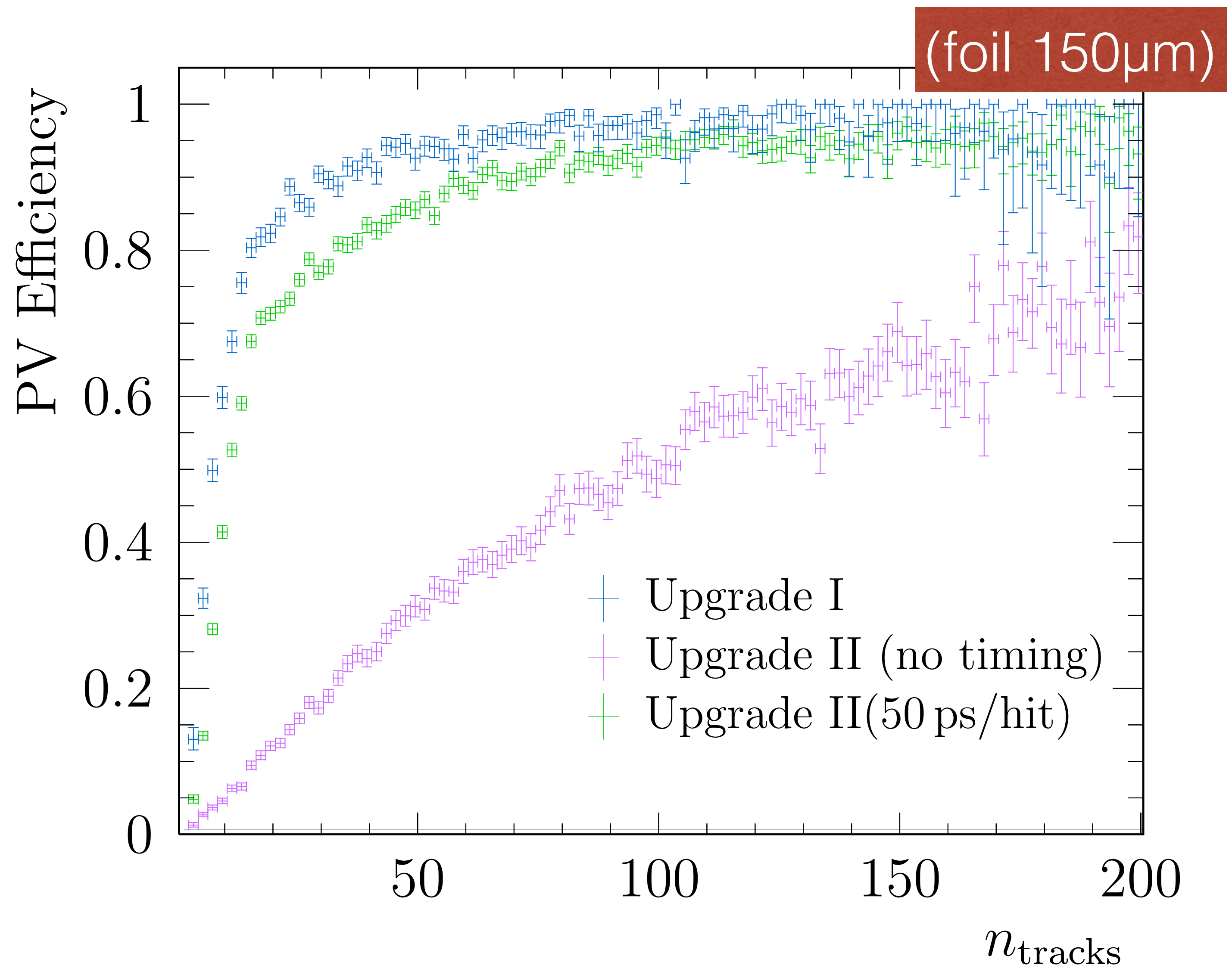
Impact on physics

Should you care about merging PVs?



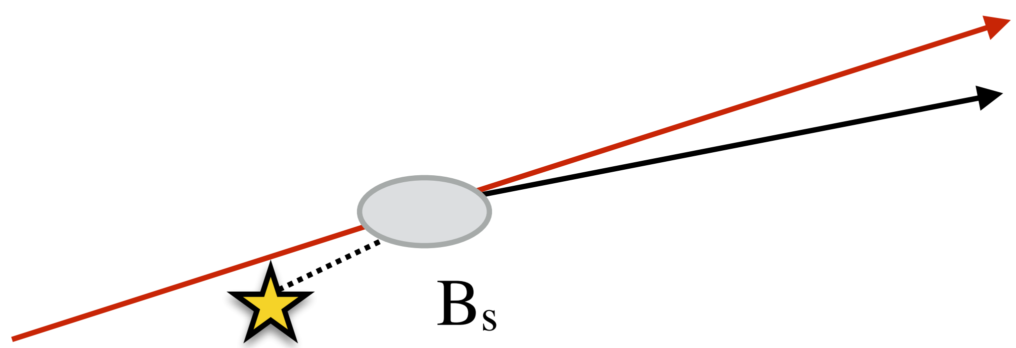
If two PVs sit close to one another and get merged, the impact on the resolution is dramatic (even for nTracks > 25 in the PV)

Primary vertex reconstruction



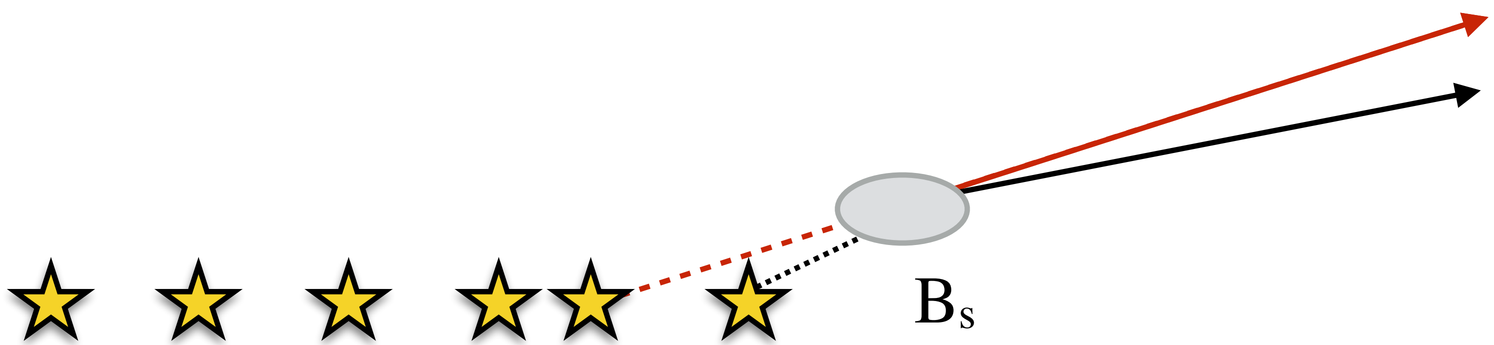
Considerable recovery seen with timing, although not on the level of U-1 yet. Tuning of algorithm still a degree of freedom.

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



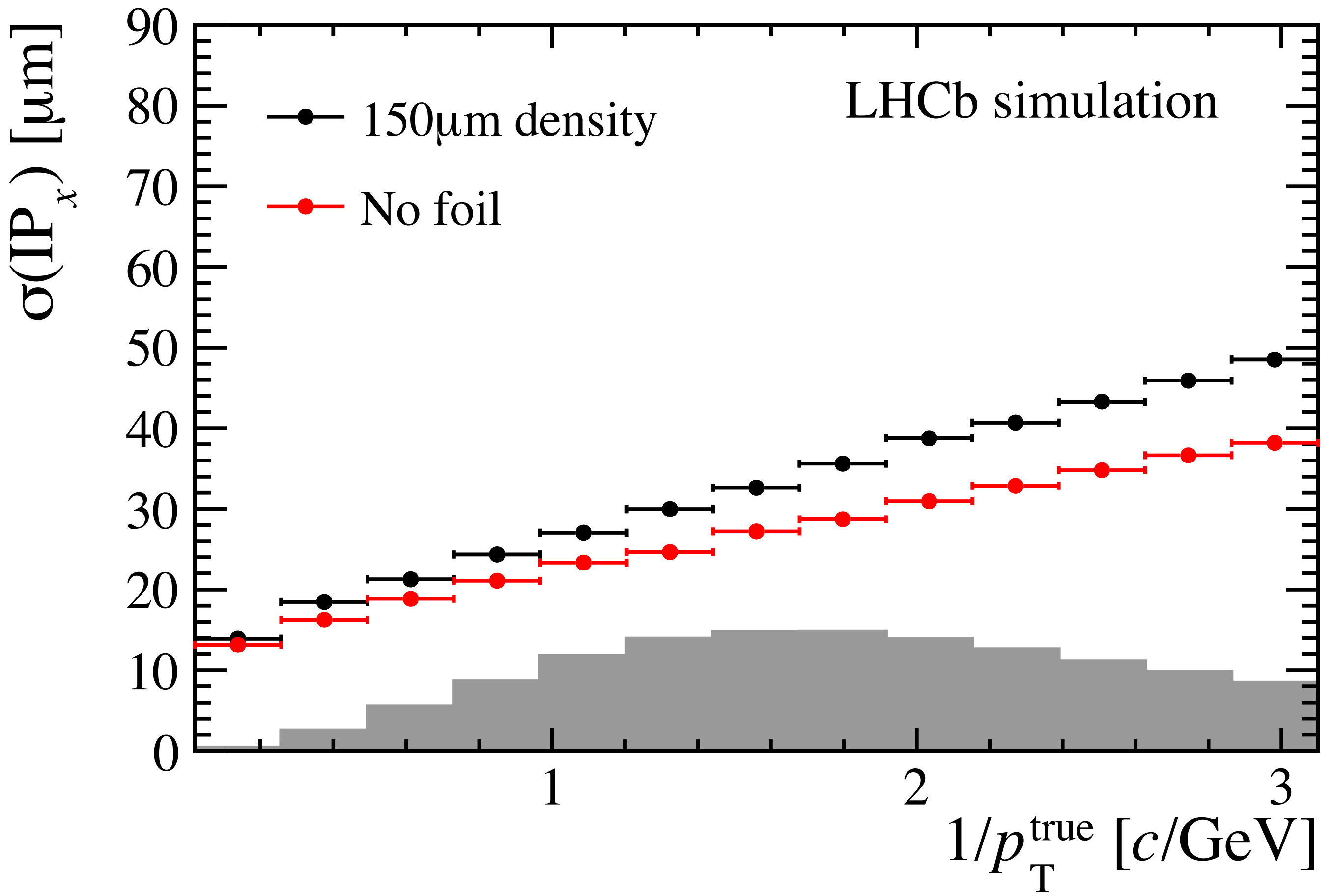
With the high multiplicity of primary vertices, the sheer chance of a track pointing to another PV increases - a **displaced** track can appear **prompt-like** (esp. given resolutions)!

Is the impact parameter still a good discriminant?

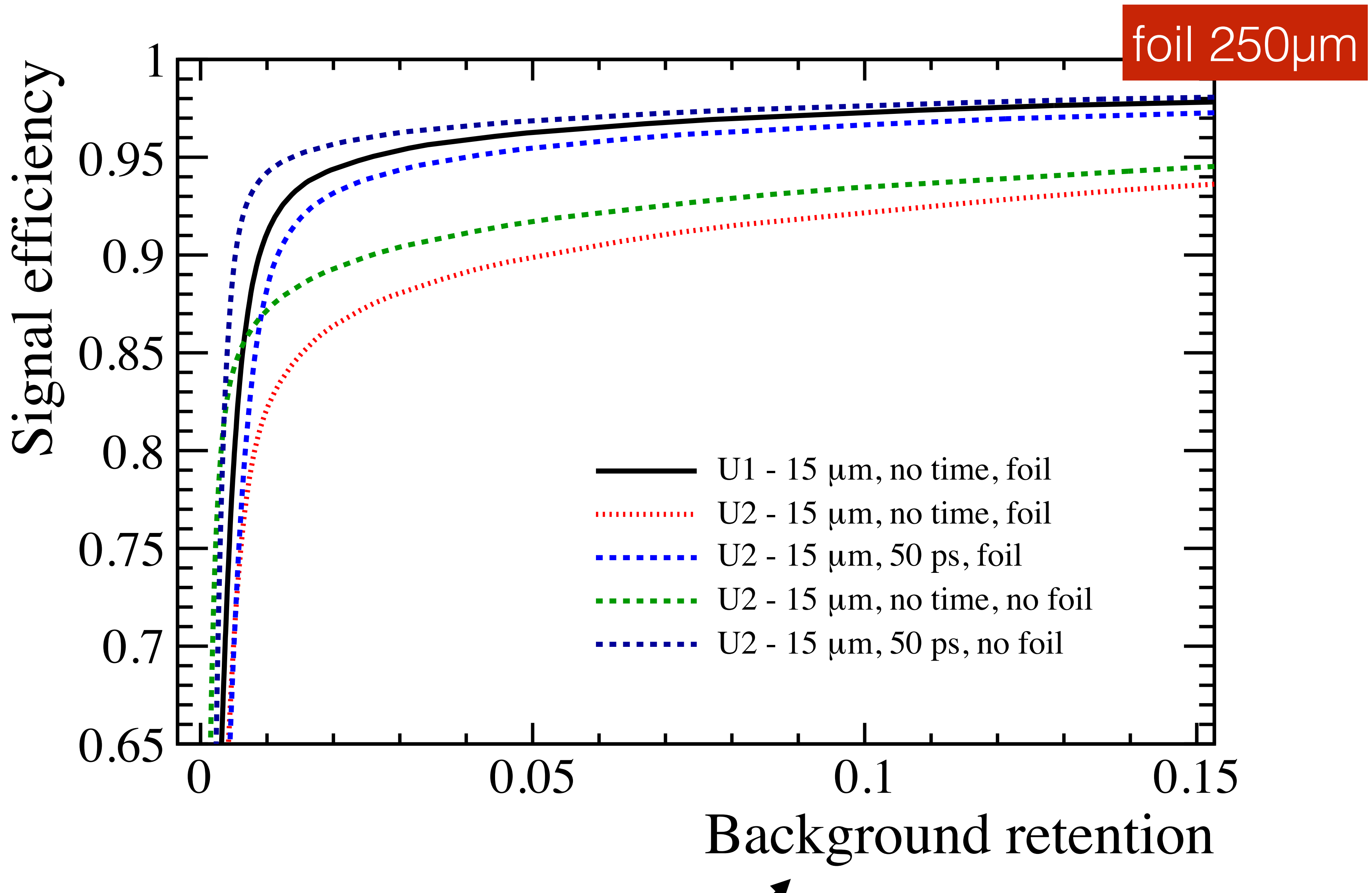
Impact parameter discrimination

Foil: discrimination improved by better IP resolution

Timing: Can limit the number of PVs under consideration for the minimum IP requirement

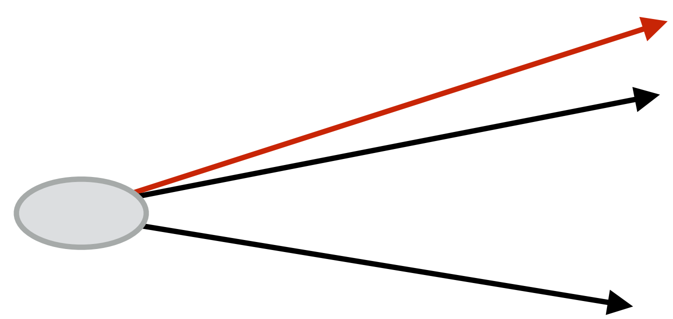


Impact parameter discrimination



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

Combining tracks

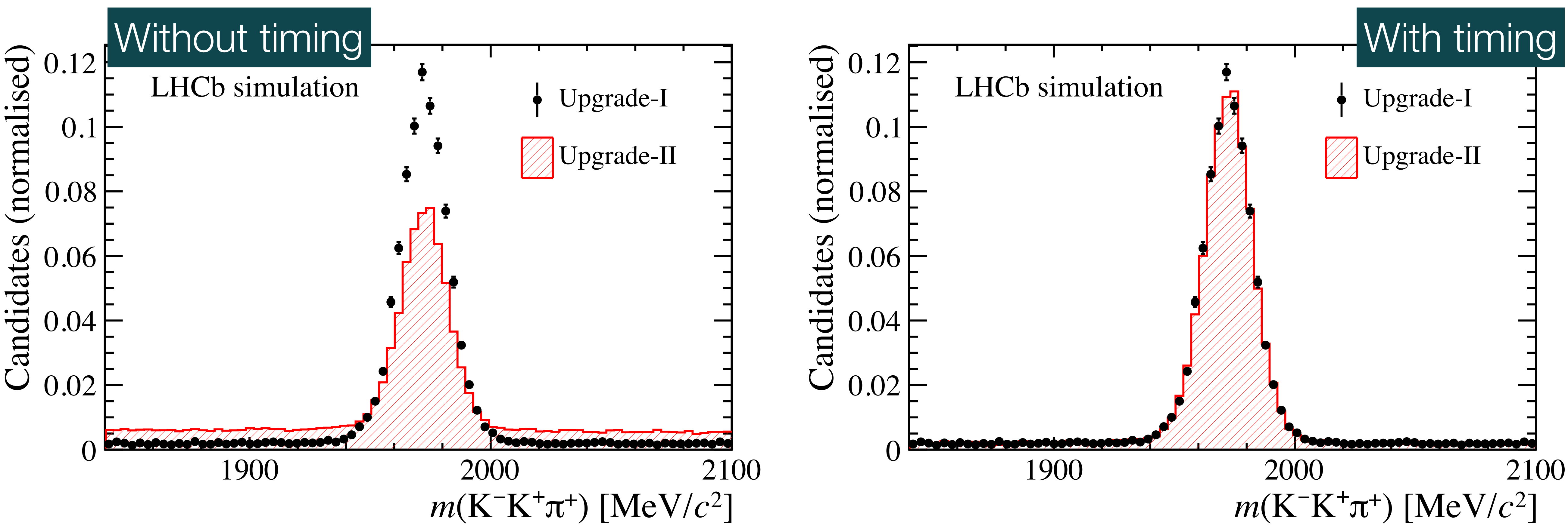


Typical selection After selecting displaced tracks with a reasonable pT, combine them to try and find the signal candidate.

With the increased **track density**, more **combinatorial background** is expected ("event mixing").
Is a ~20ps track resolution already helpful to reject this background?

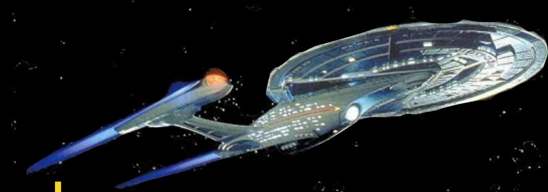
Combining tracks

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



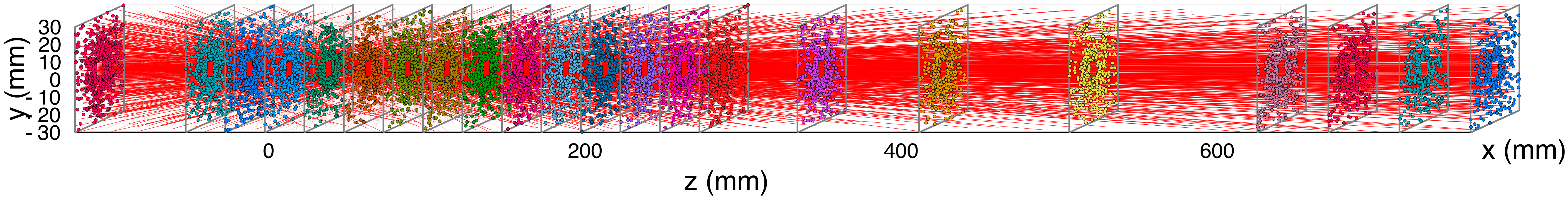
Already here a clear increase in combinatorial background visible, the per-track time significantly helps recovering. Particularly helpful in trigger!

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

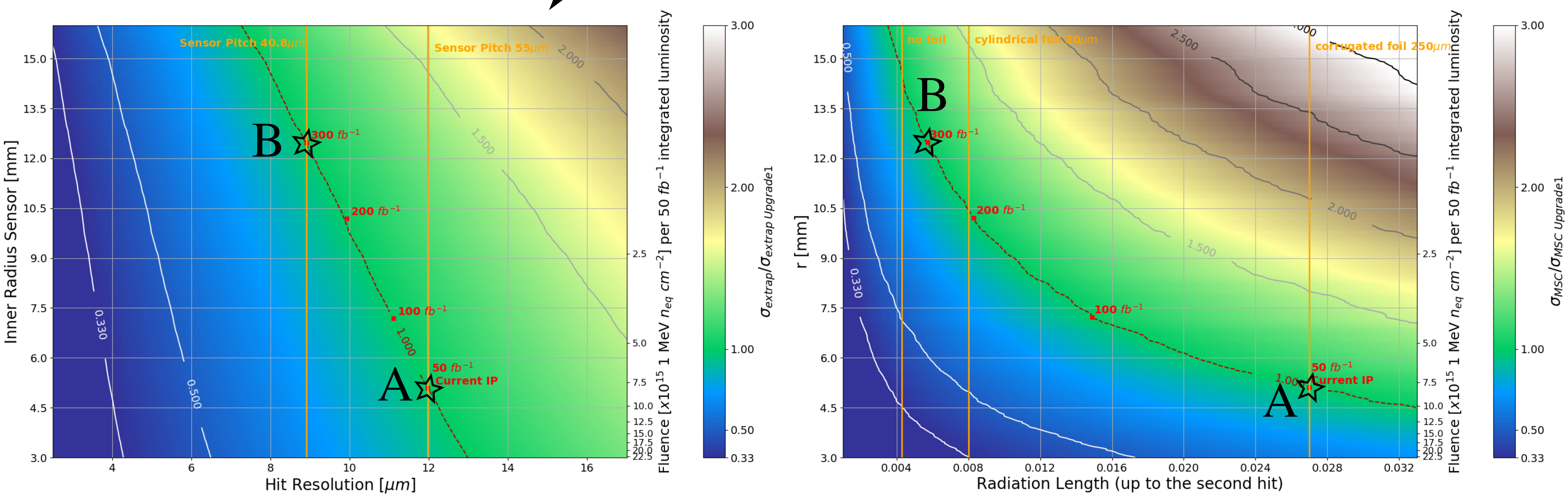


Will be used for exploring different sensor radii and barrel layers

Different sensor radii

$$\sigma_{IP} = \sigma_{extrap} + \frac{\sigma_{MCS}}{p_T}$$

@ $\eta = 3.5$



Take-home message

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 al 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.

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CPU time for PR algorithm

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.

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

Mis-association