Upgrade-II VELO studies

U2 Tracking workshop December 15, 2020

Laurent Dufour, presenting the work of many others:
Kazu Akiba, Victor Coco, Tim Evans, Robbert Geertsema, Misha Mikhashenko & Mark Williams

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?

Studies thus far: 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 U-II vertex detector

Methods used

Detailed simulation

Gauss
+
Boole & Brunel

✔ Developed reconstruction
❌ Geometry hard to adjust

Stand-alone toys

“VPFast”, DD4HEP toys
etc.
(@ next talk)

✔ Not bound to any geometry
❌ Have to revalidate reconstruction

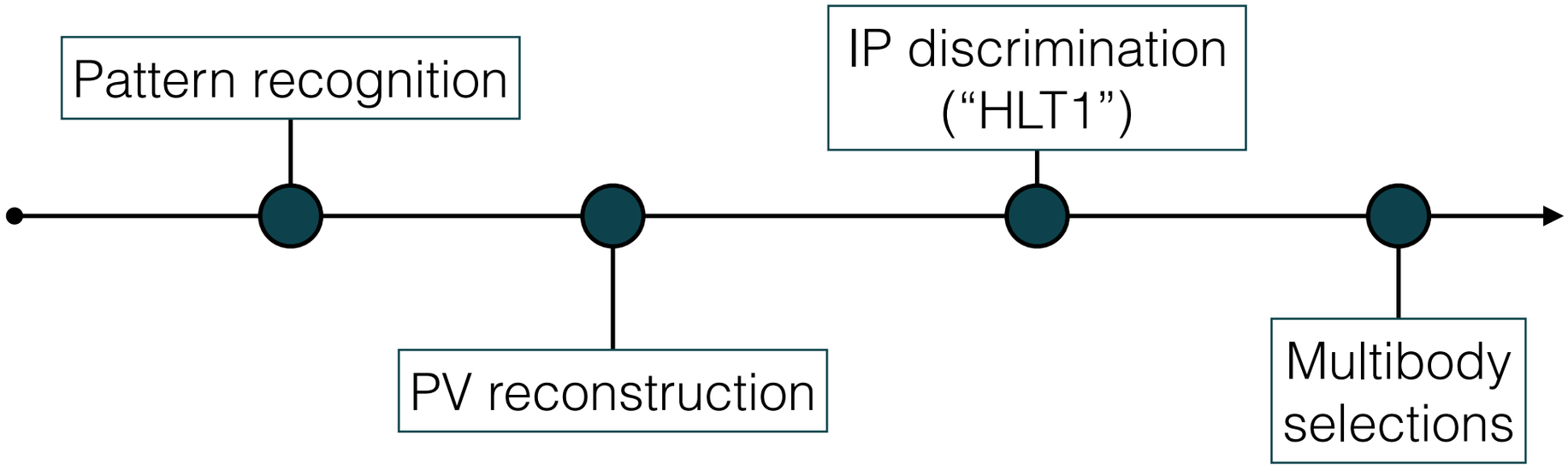
Optimal numbers

$$\frac{\partial \text{Physics}}{\partial \text{R\&D}}$$

Crude design

Full simulation

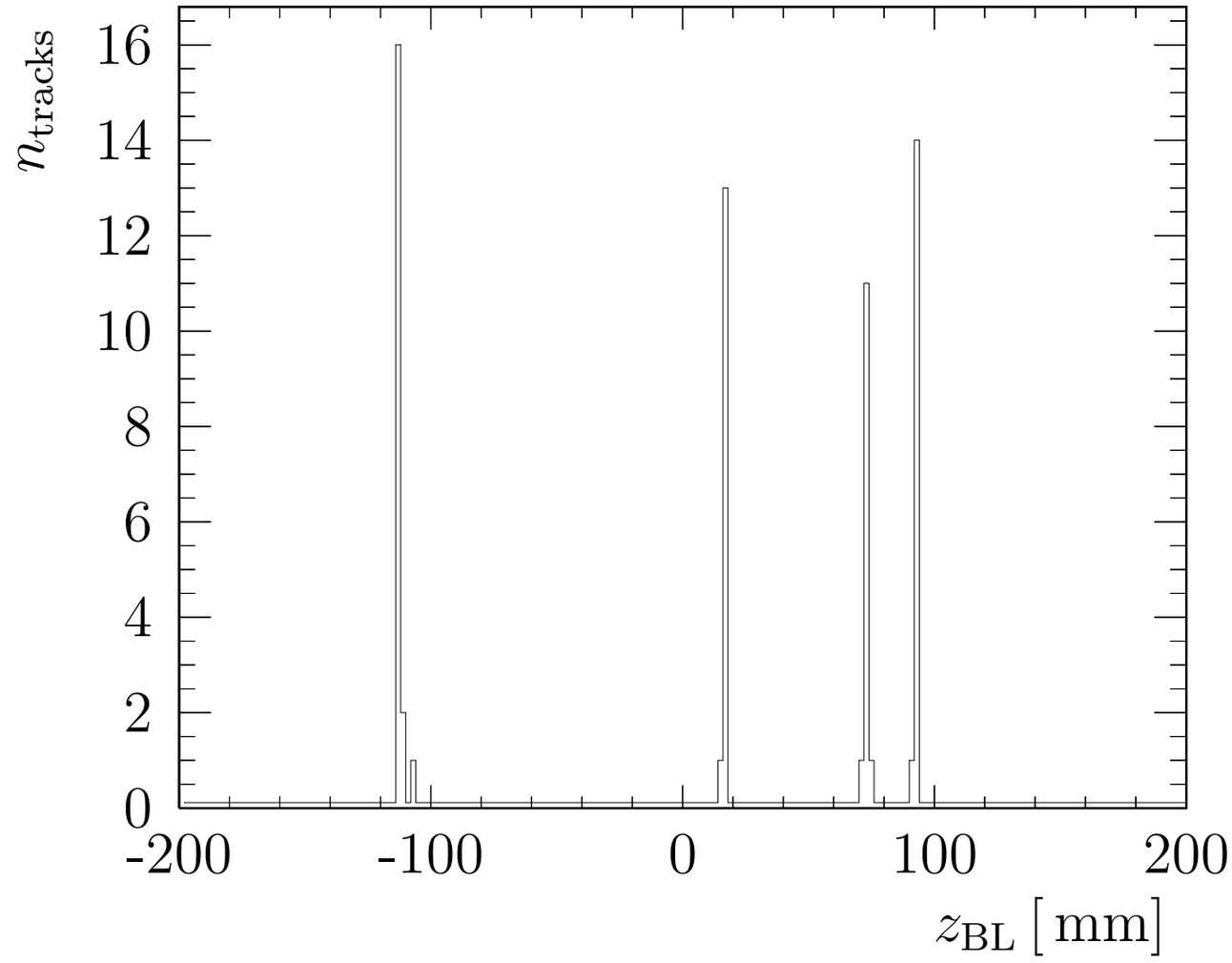
Using the detailed simulation (Gauss), tried to evaluate the impact of **timing per hit** and a **much thinner foil** (~ no foil) on four stages of the event reconstruction. Do so by using the Upgrade-I detector, adding 50ps timing[1] and/or removing foil.



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

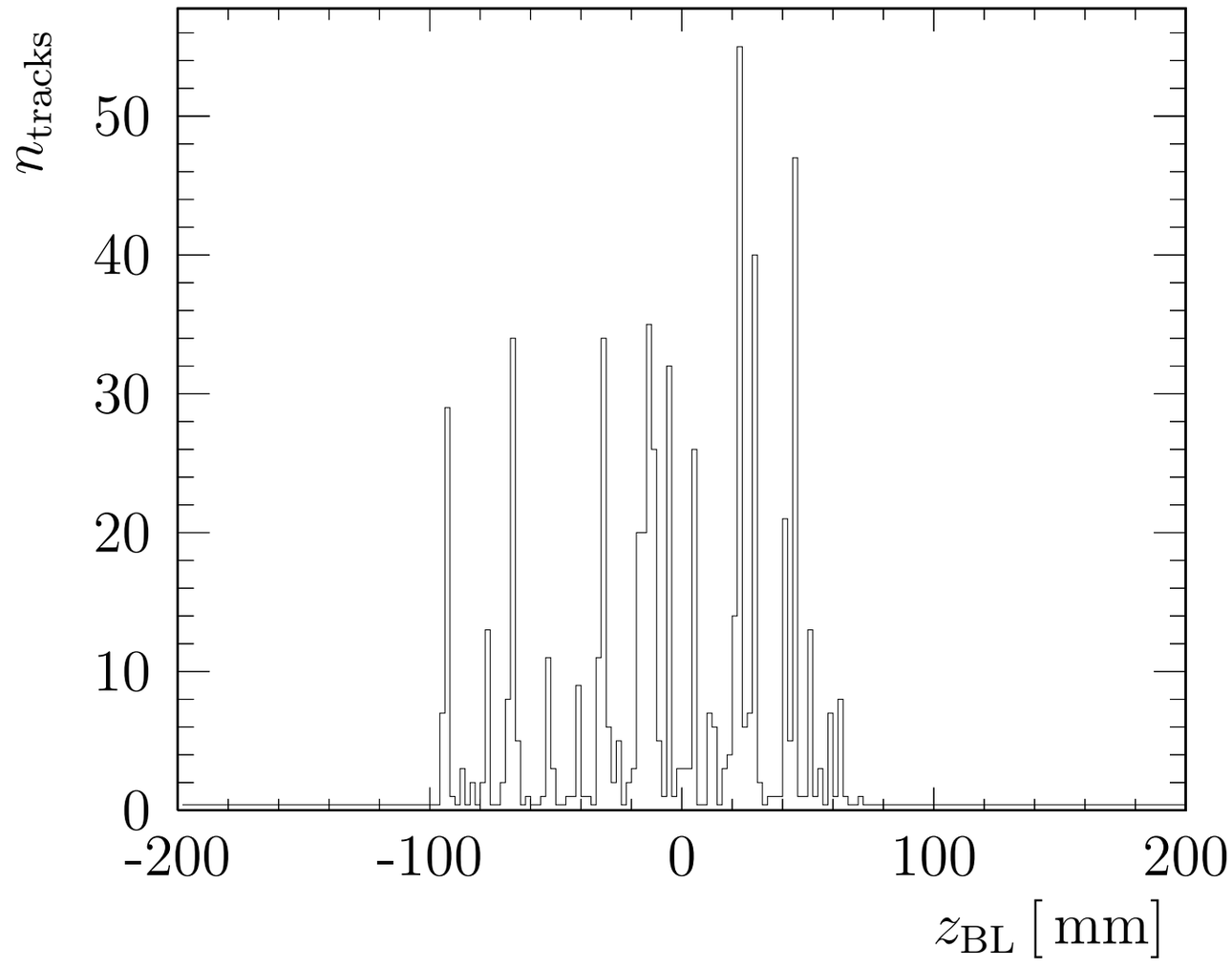
Why timing?



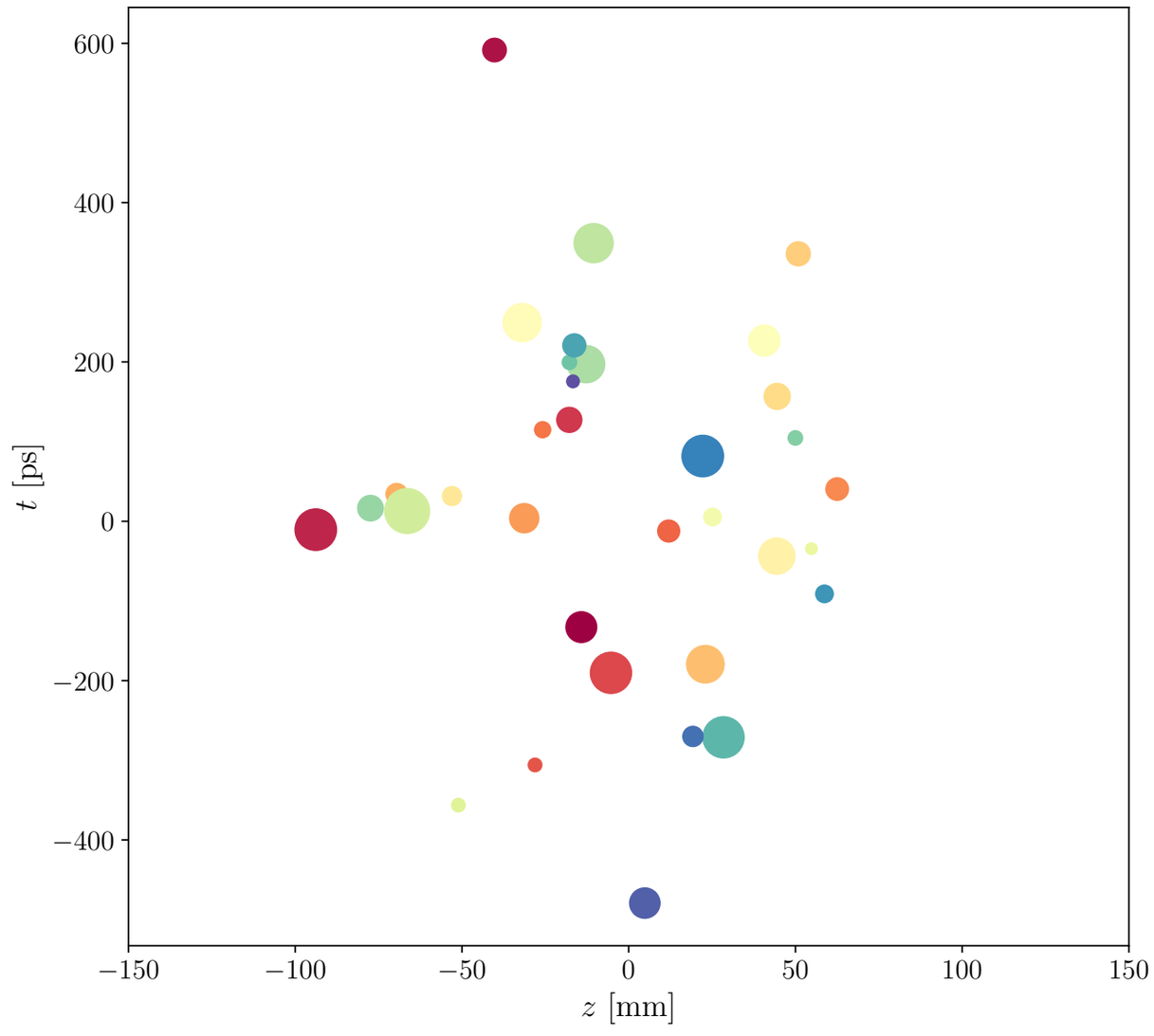
Run-3 PV algorithm: histogramming on the beam line

Why timing?

Upgrade 2: ~ 40 peaks

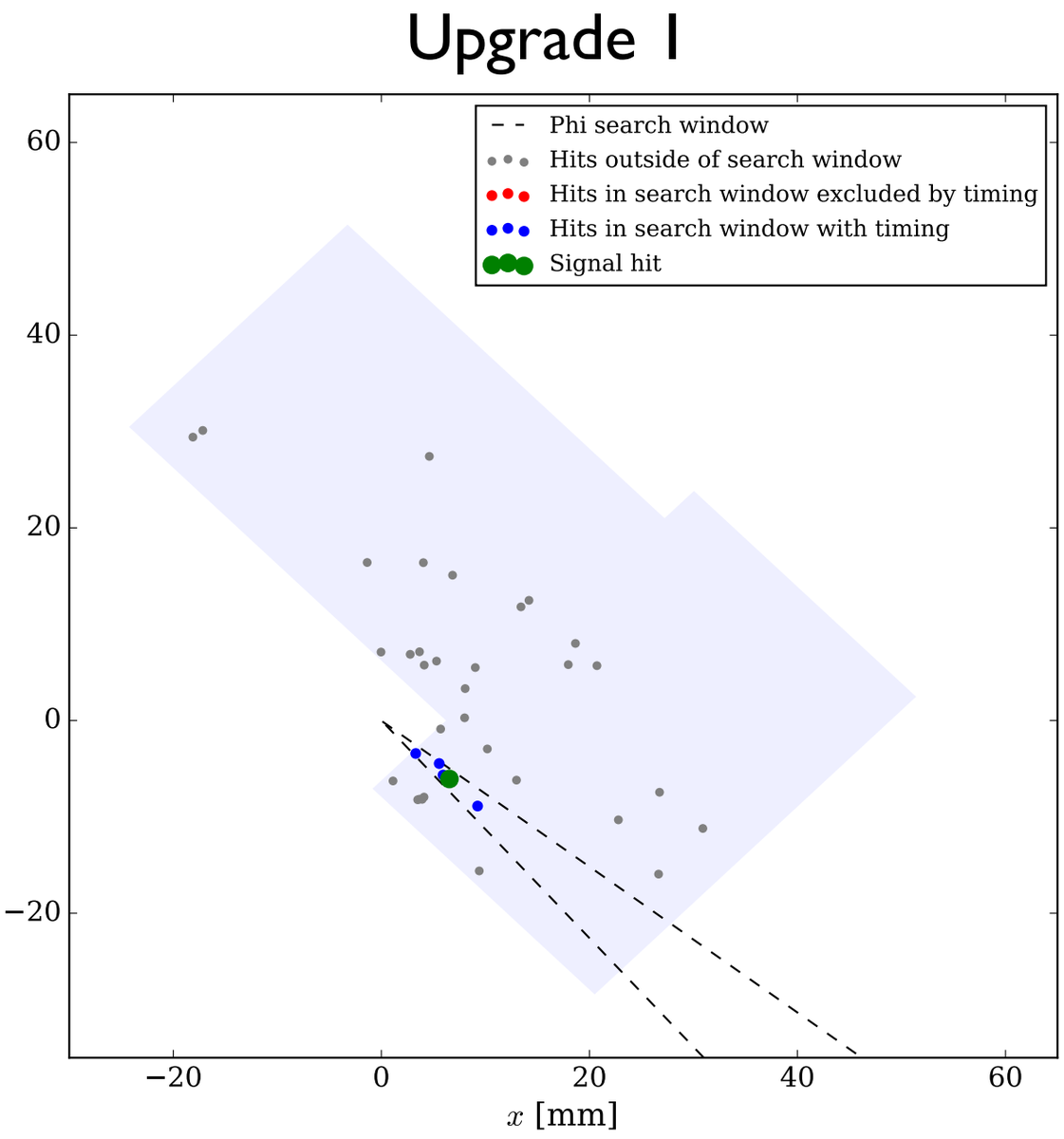


Why timing?



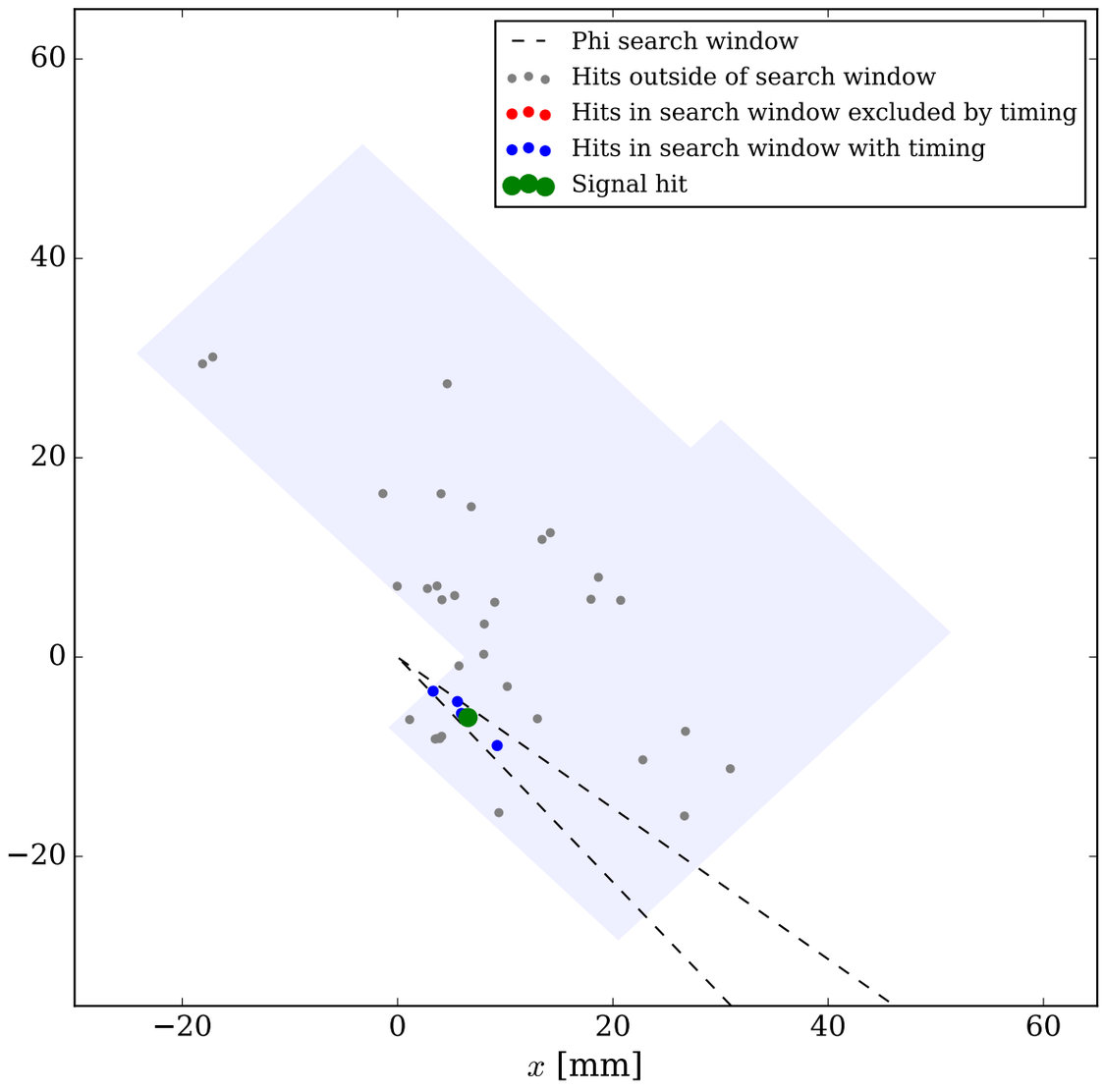
Primary vertices are also spread in time

Using timing in tracking

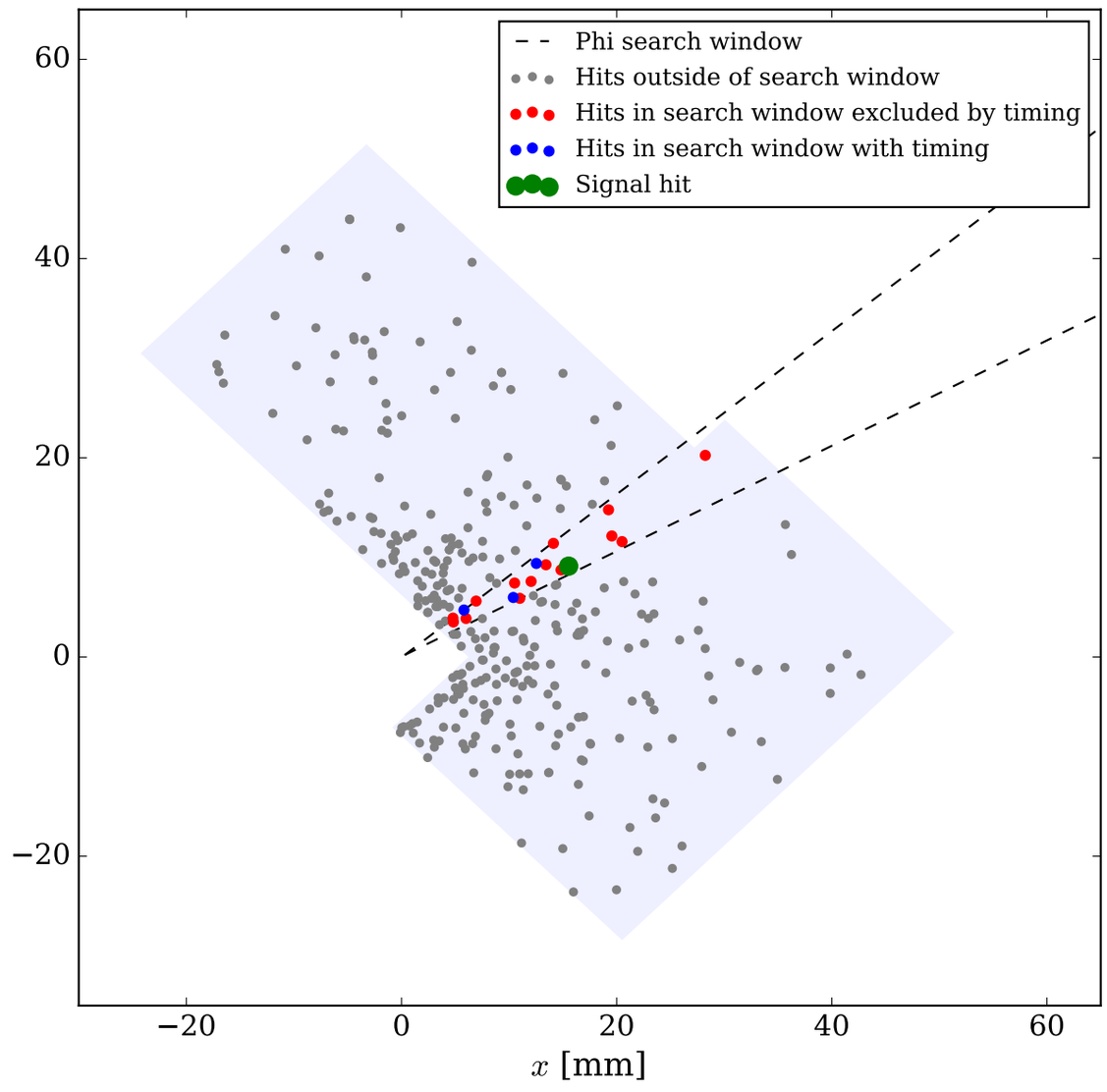


Using timing in tracking

Upgrade 1



Upgrade 2 (50ps resolution)



(Algorithm timing under control)

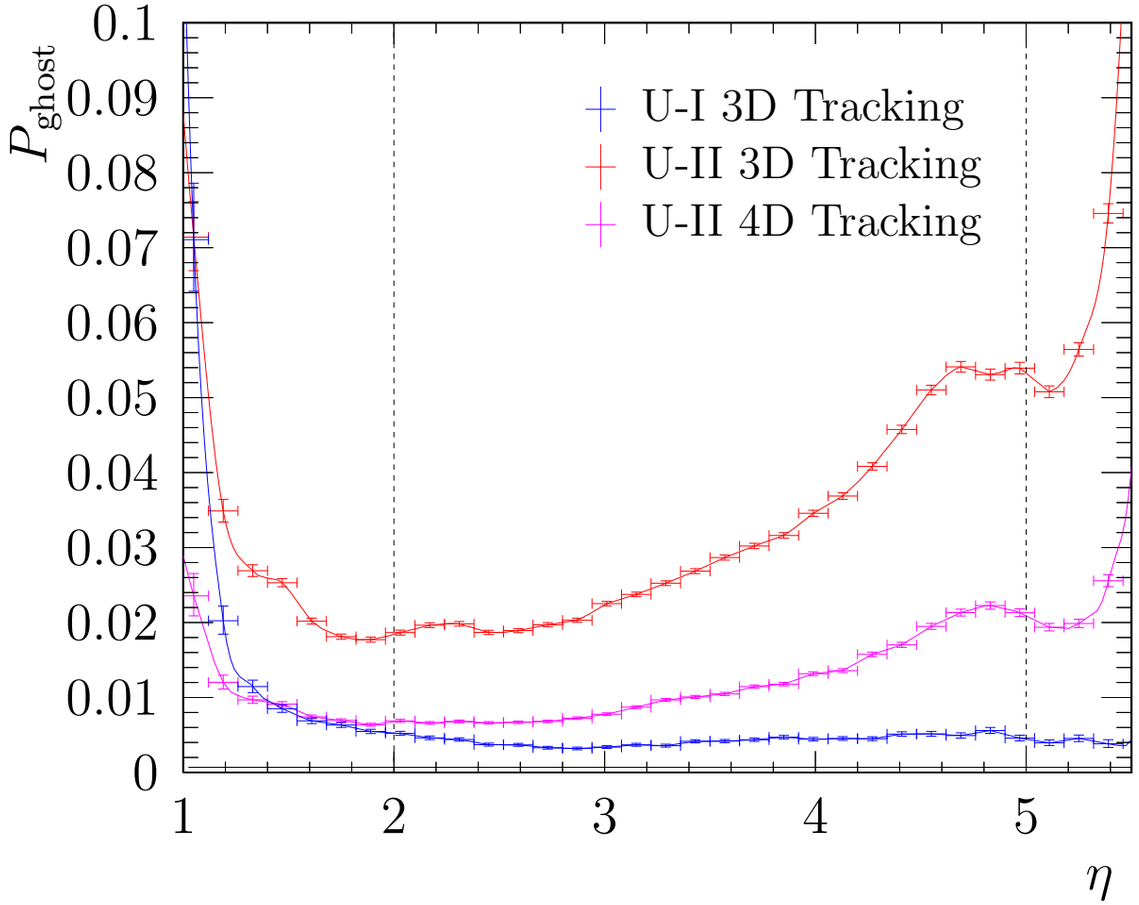
Gains in the pattern recognition

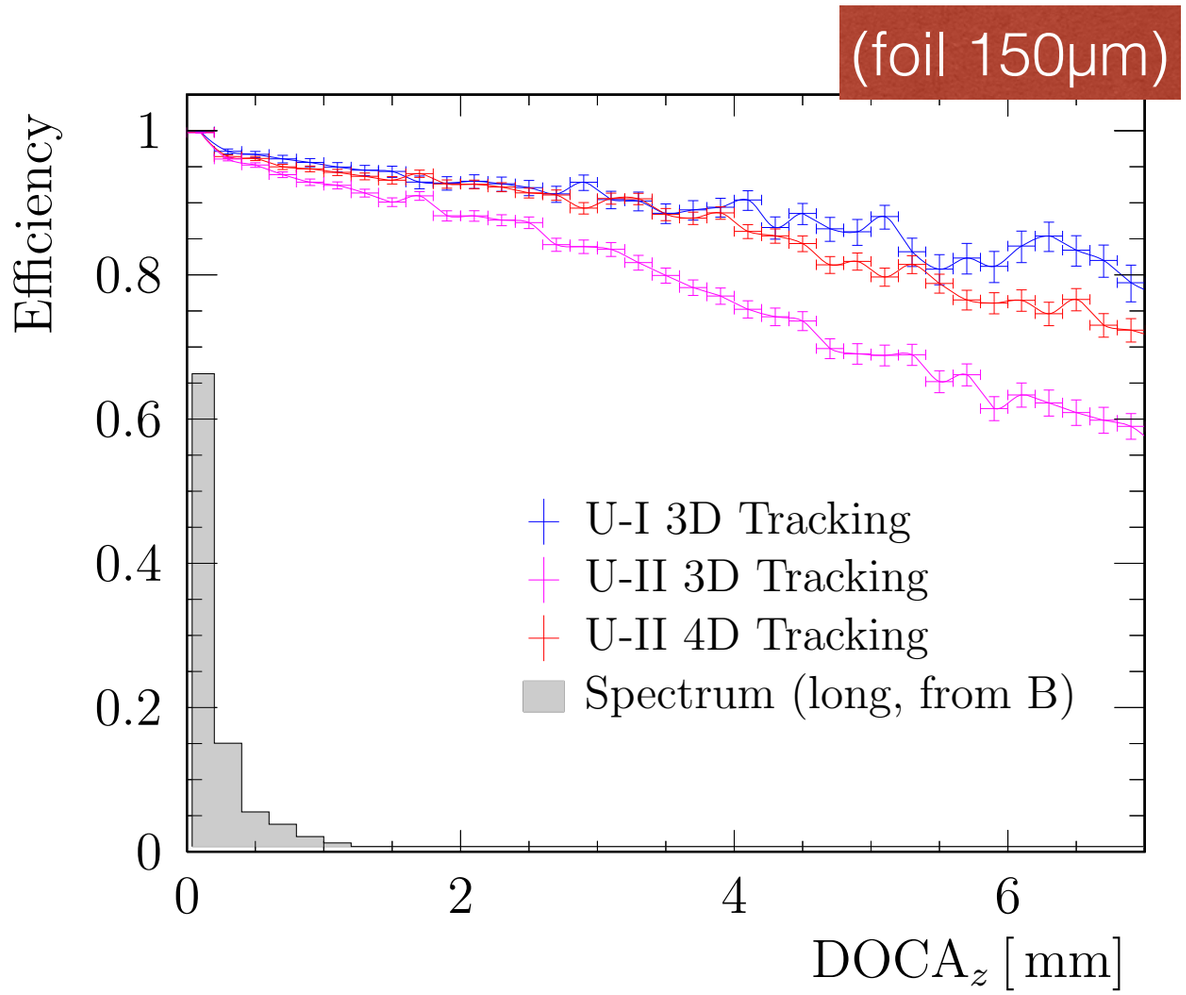
Improved recent HLT1 VP tracking algorithm: cut of 3 sigma on hit time

	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

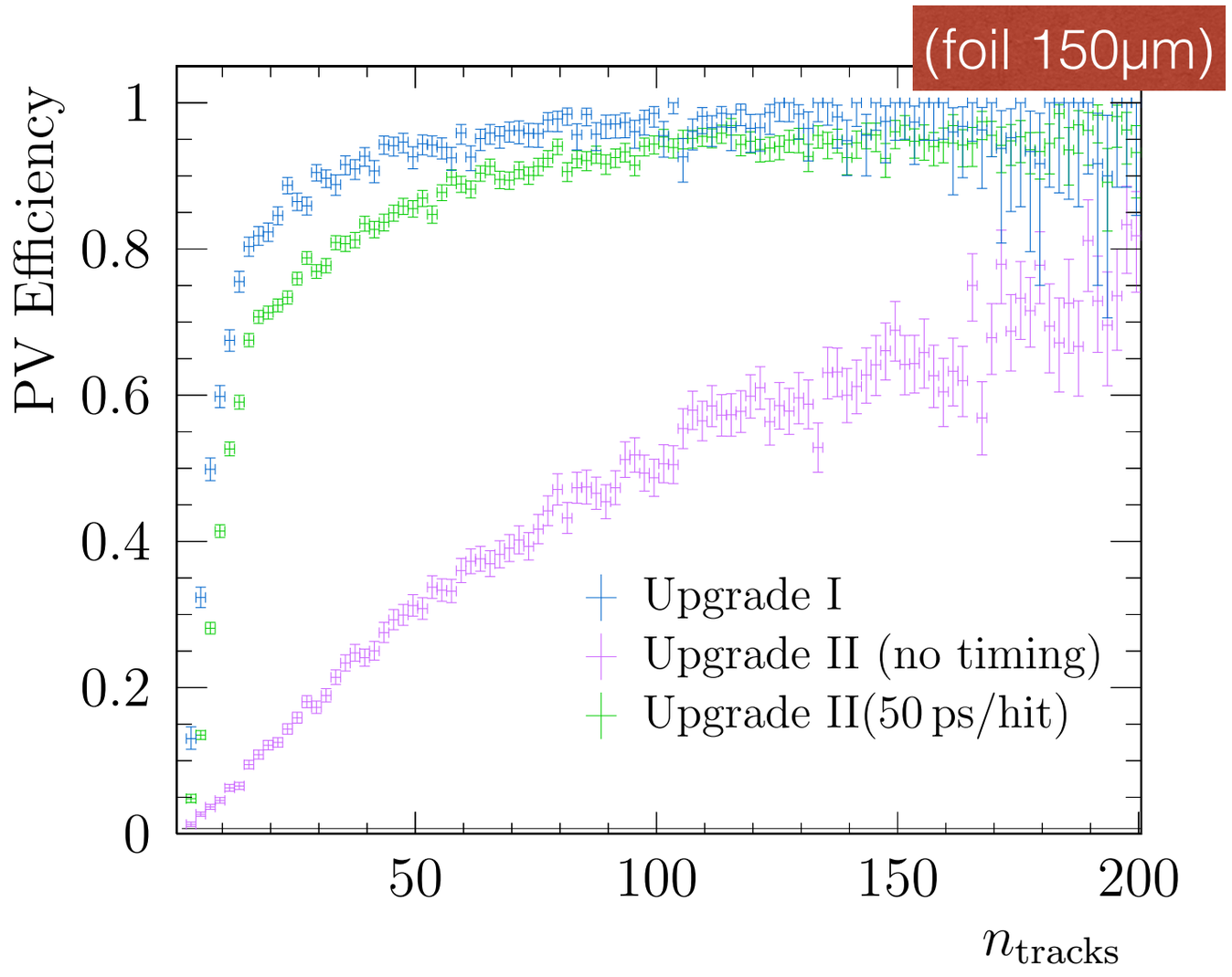
Would be very good to know how sensitive the forward tracking is to VP ghost rates & efficiencies

Efficiencies





Primary vertex reconstruction



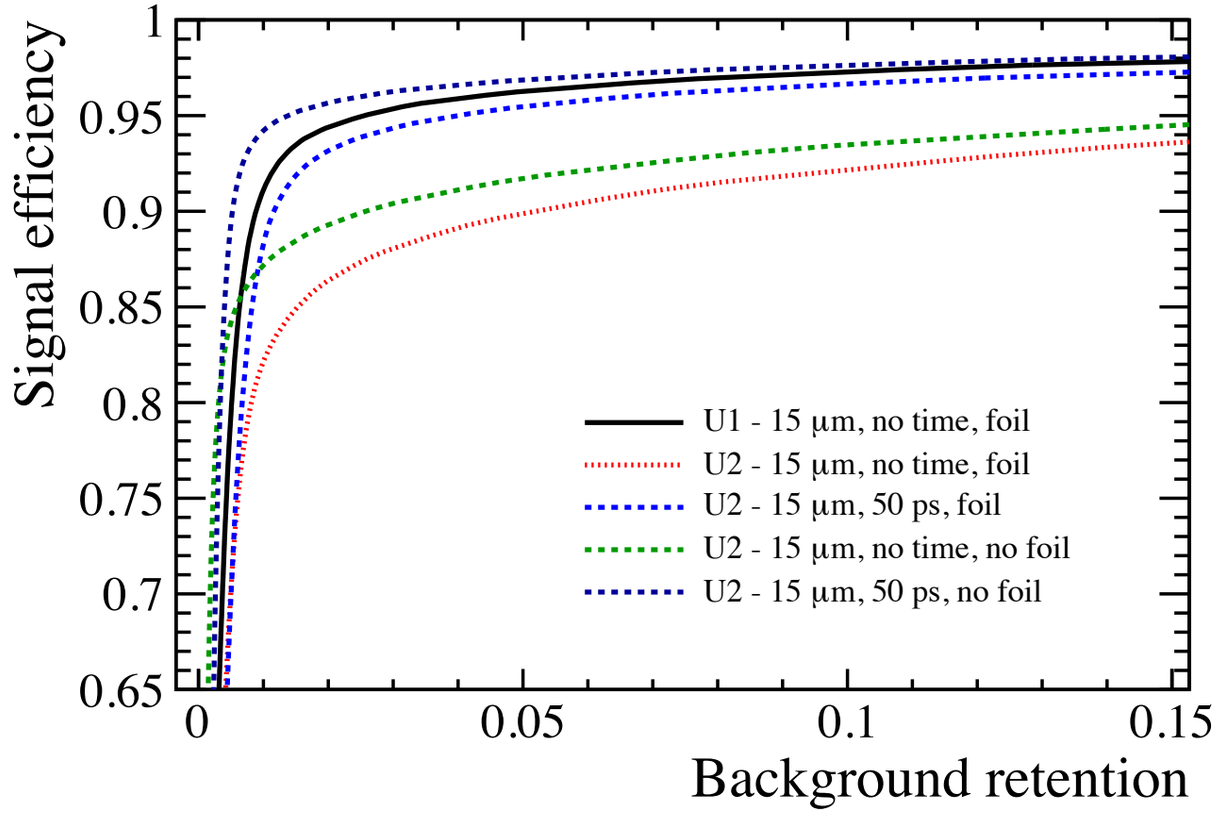
Considerable recovery seen with timing, although not on the level of U-1 yet.
Tuning of algorithm still a degree of freedom.

IP discrimination & combinatorics

Run the HLT1-like VELO-only track fit to get the best estimates and covariance matrix of VELO tracks.

See a decrease in discrimination power of the **impact parameter** in Upgrade-II events: both PV resolution and more PVs.

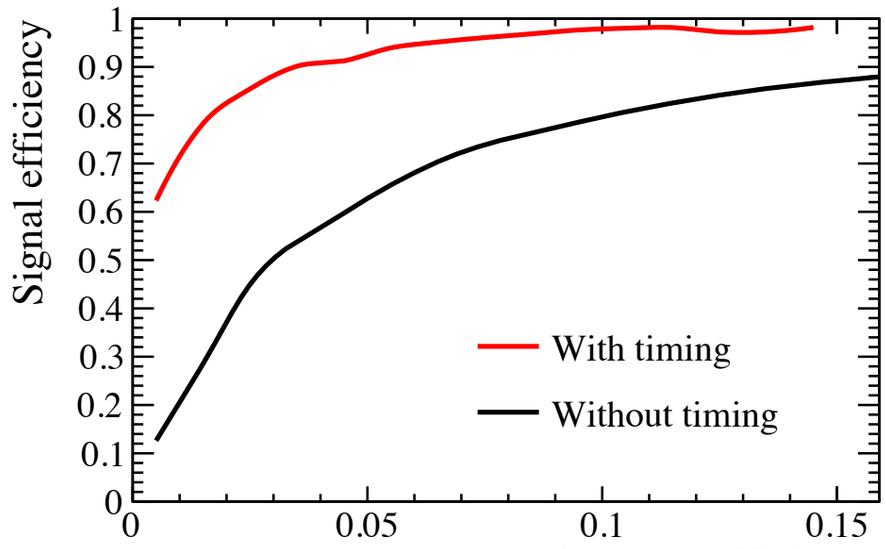
Concerning: there is also significantly more background!



IP discrimination & combinatorics

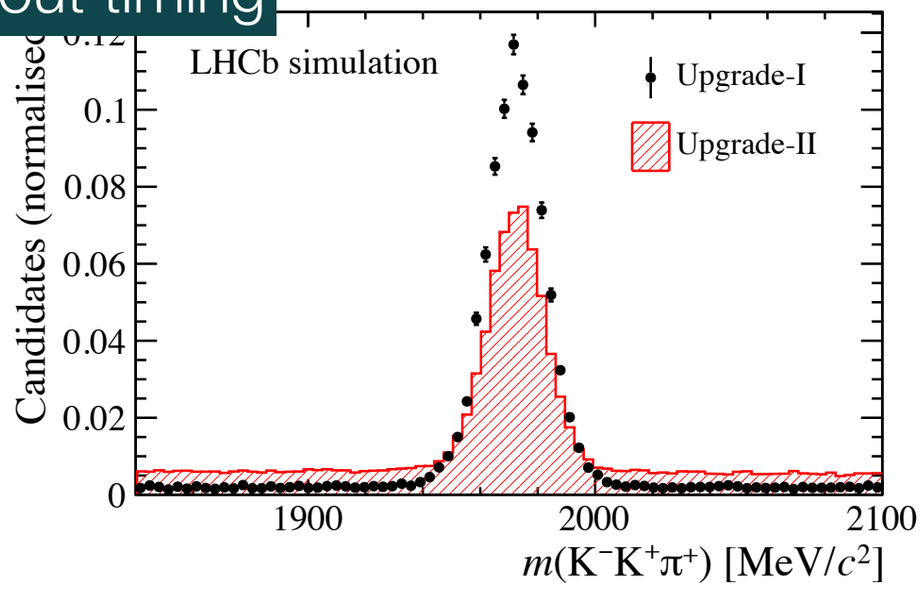
Information on the per-track timing is as well important to form **secondary vertices**; time compatibility rejects combinatorial background from different PVs.

Classical “DOCA” not enough



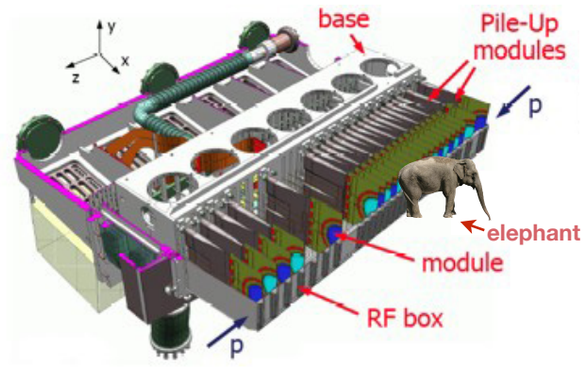
Timing information not only relevant in **tracking**, but need to exploit to this in **selections** as well to get back to U-1 performance.

Without timing



Perfect PID, 1% momentum resolution, vertex detector track fit

Layout & position



It’s unrealistic to ask for the radiation hardness & **data rates** to operate at 5mm from the beam. What layout is best?

✔ The supporting document describes a split between “Scenario A” and “Scenario B”: 5mm (or 12.5mm) away from the beam to illustrate the dependence of fluence & data rates on the radius.

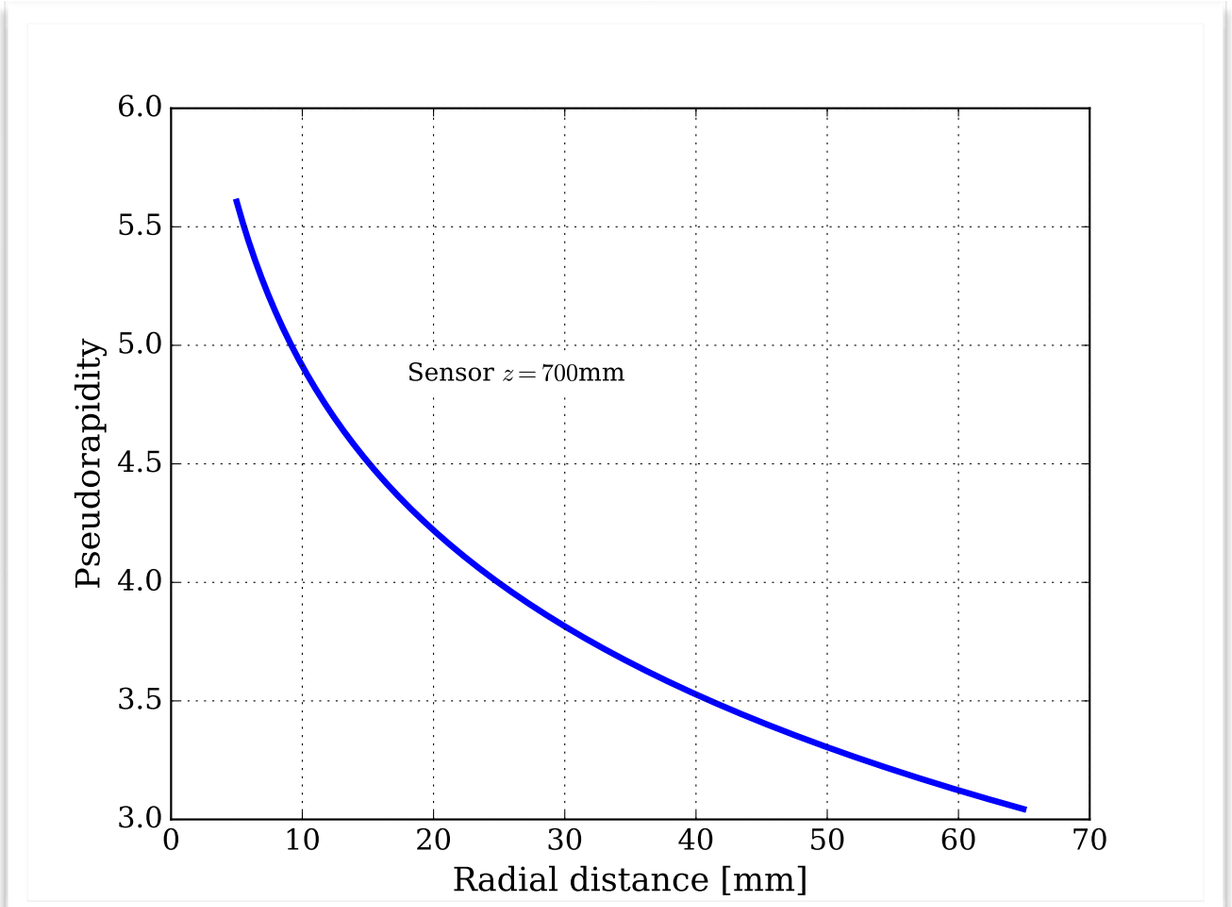
Todo (FTDR) Show how sensors perpendicular to the beam line affect the PV resolution, and implement a realistic scenario with sensors further away from the beam line (preserving acceptance).

Biggest task ahead. Risk of only being toy studies at the time of FTDR.
Might never find a suitable moment to start this later.

Global detector aspects

Placing sensors further away from the beam reduces the radiation damage and rates, but hurts the **acceptance** at high pseudorapidity. Making the VELO longer?

Fluence downstream of detector ~ 30% lower than interaction region, not the full solution.



Compromise: a radial distance of ~ 9mm to keep detector fully instrumented to eta~5. Important to **know what we can still do** with these high-angle tracks at this pile-up. Fewer (time) hits!

Conclusion & summary

For the Upgrade-II vertex detector we (thus far) consider performance in:

- Pattern recognition (timing, efficiencies and ghost rates);
- PV reconstruction (resolution, efficiencies and ghost rates);
- Higher-level quantities: IP discrimination, secondary vertex S/(S+B) and decay-time resolution

Radiation damage and data rates force us to consider **other designs** as well, starting with moving away from the beam. **Fast simulation** studies (next talk) to show whether these give factors of improvement.

Upgrade-II VELO studies

U2 Tracking workshop December 15, 2020

Laurent Dufour, presenting the work of many others:
Kazu Akiba, Victor Coco, Tim Evans, Robbert Geertsema, Misha Mikhashenko & Mark Williams

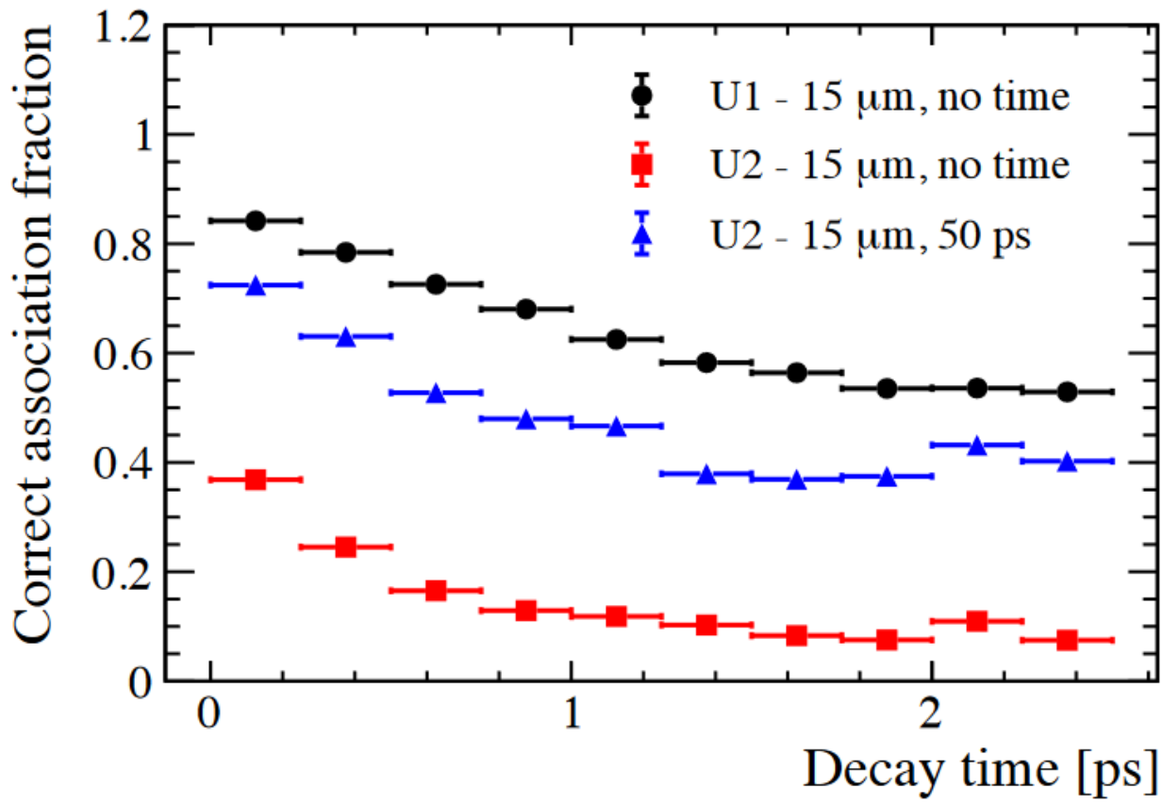
My personal wish list

- How crucial are the ghost rates for the forward tracking at high eta?

- How do other detectors cope between eta~4.8-5.0?

- Can we use the TORCH timing information only for high momentum tracks to make a T3+TORCH combination for the forward tracking?

Secondary association



Data rates

The Upgrade II luminosity multiplies by a factor 7.5 the already challenging operational conditions of the current VELO Upgrade I. If the hybrid pixel design, geometry and triggerless readout is maintained as it is at present, the ASIC would have to tolerate rates of 8 Ghits/s, with up to 500 khits/s in the hottest pixels; the radiation damage would rise by a factor 10, necessitating periodic replacements of modules, and the data output from the detector would exceed 30 Tbit/s, a number which could rise with the inclusion of extra information from finer pitch pixels and precise time stamps. At the same time, the importance of the VELO for real time pattern recognition will remain paramount, and techniques must be found to cope with the increased occupancies, while an improvement in precision will be needed to address systematic error limitations at high luminosity, which implies reducing the material of the VELO by, for example, removal of the RF foil, more precise module metrology, and similar improvements.