Detection asymmetries
challenges and solutions

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University of Warwick
On behalf of LHCb

Towards the ultimate precision in flavour physics
IPPP 2-4 April 2019

WARWICK

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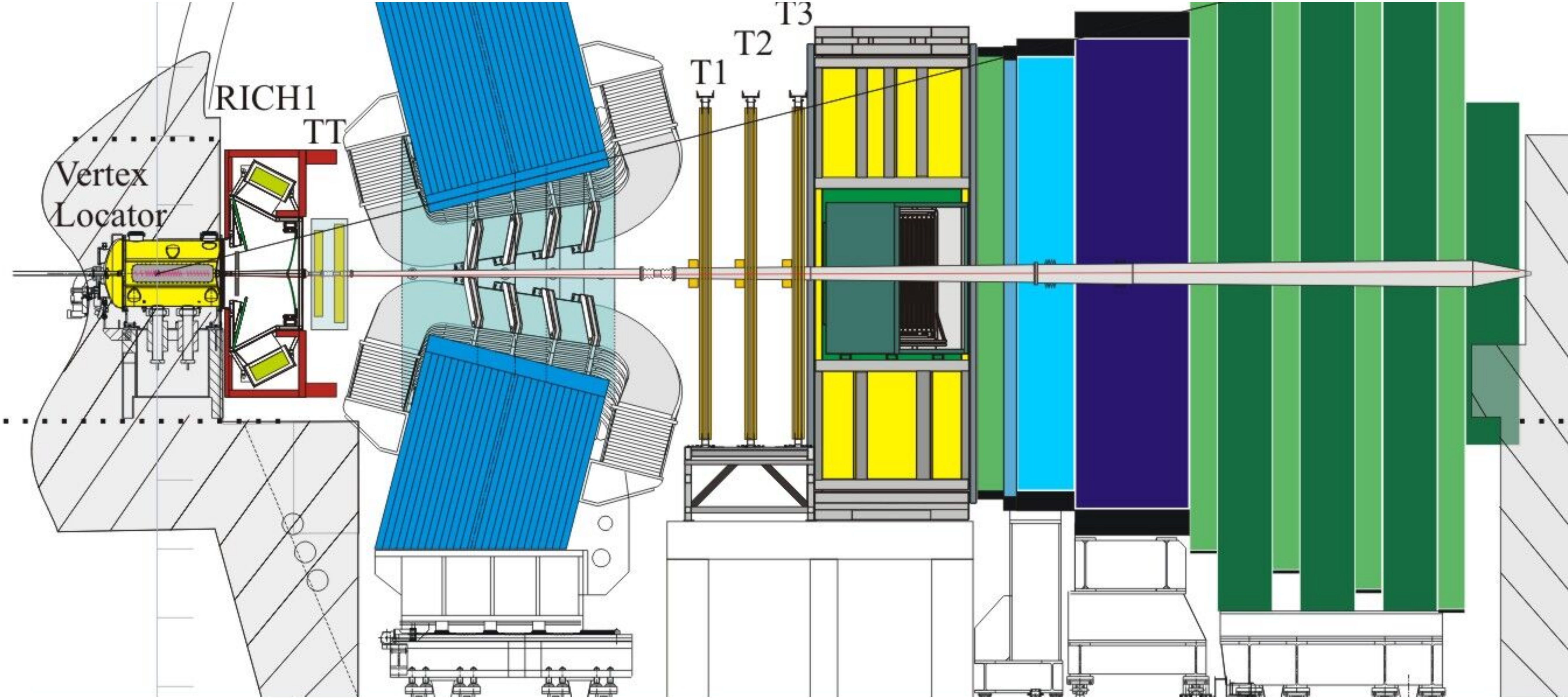

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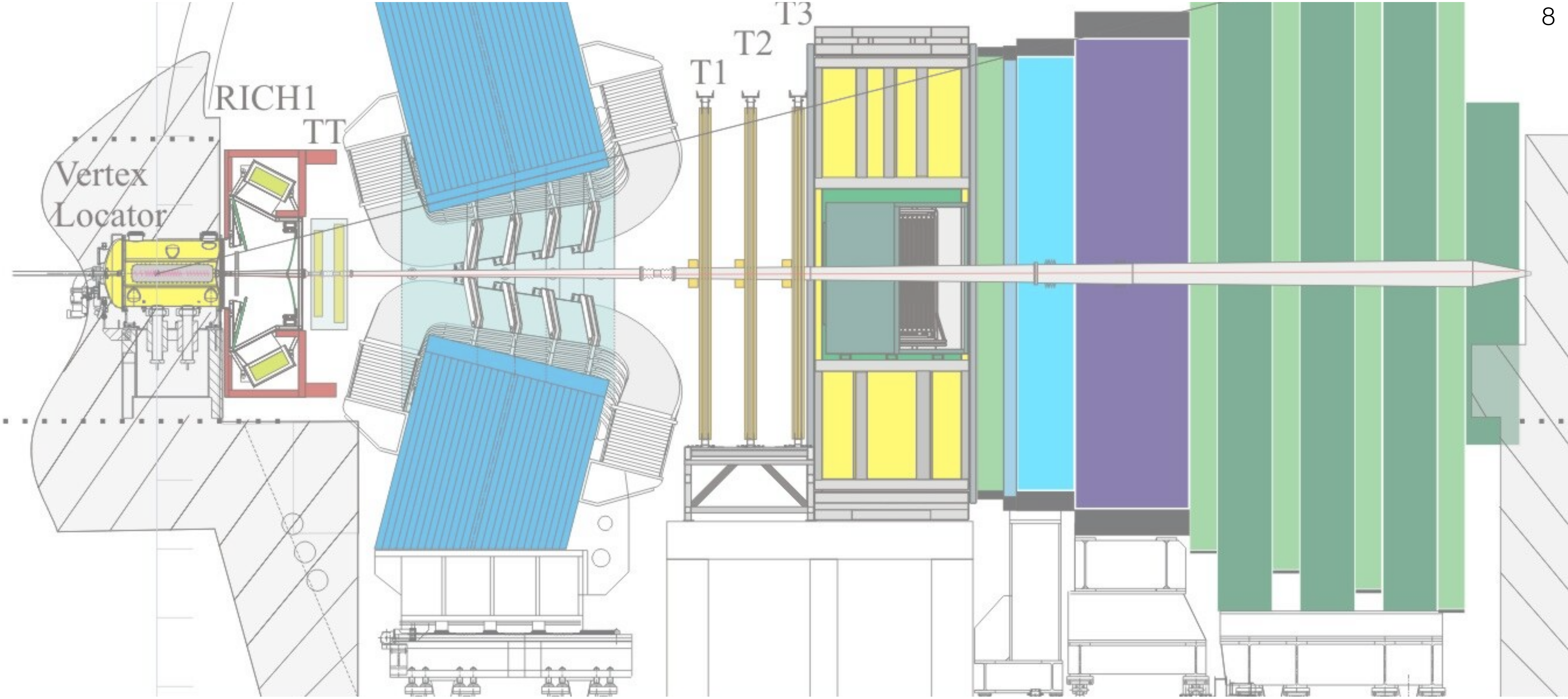
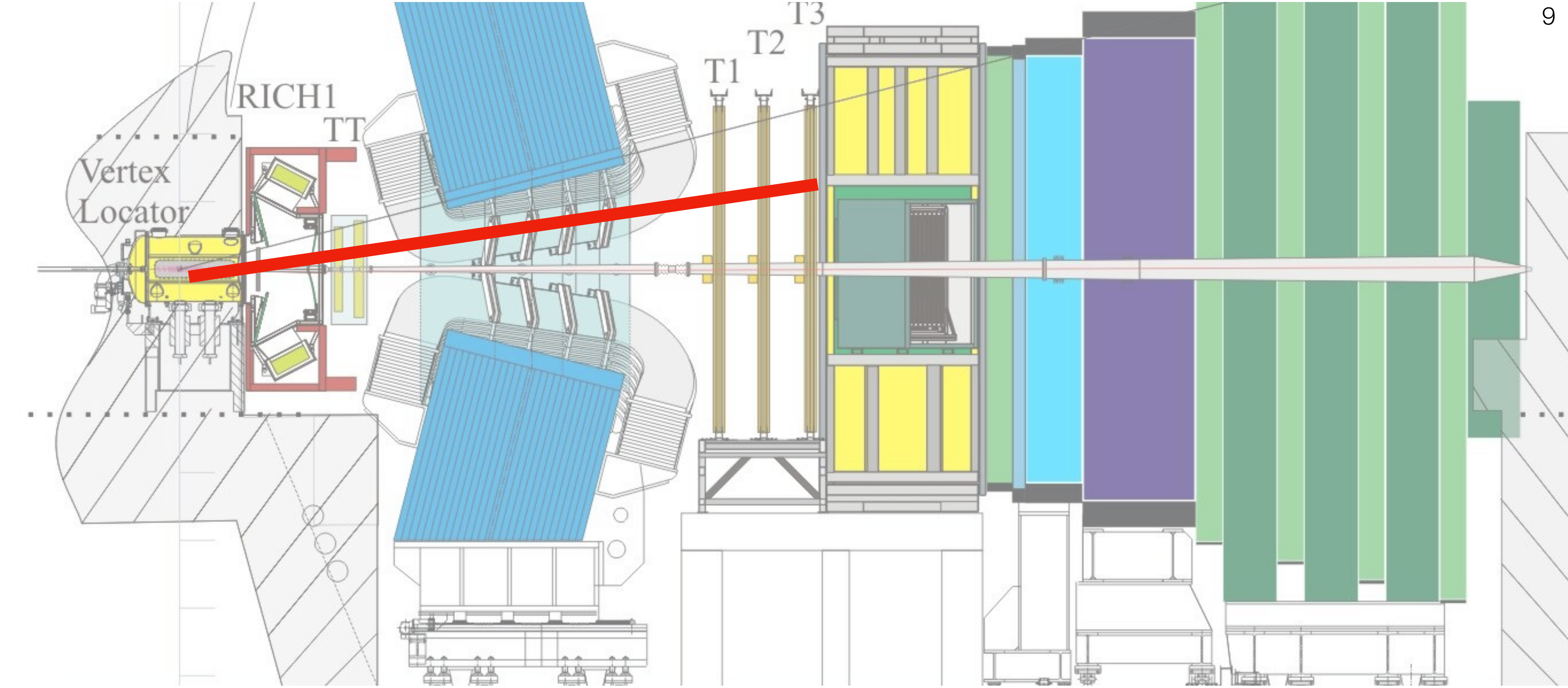


The biggest challenge is tracking.

“track” usually means a *Long* track*.

*Which means hits in, at least, the VELO and T-stations. See e.g. https://arxiv.org/abs/1408.1251 for definitions of track types.



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(and kinematics, detector/machine conditions etc..)

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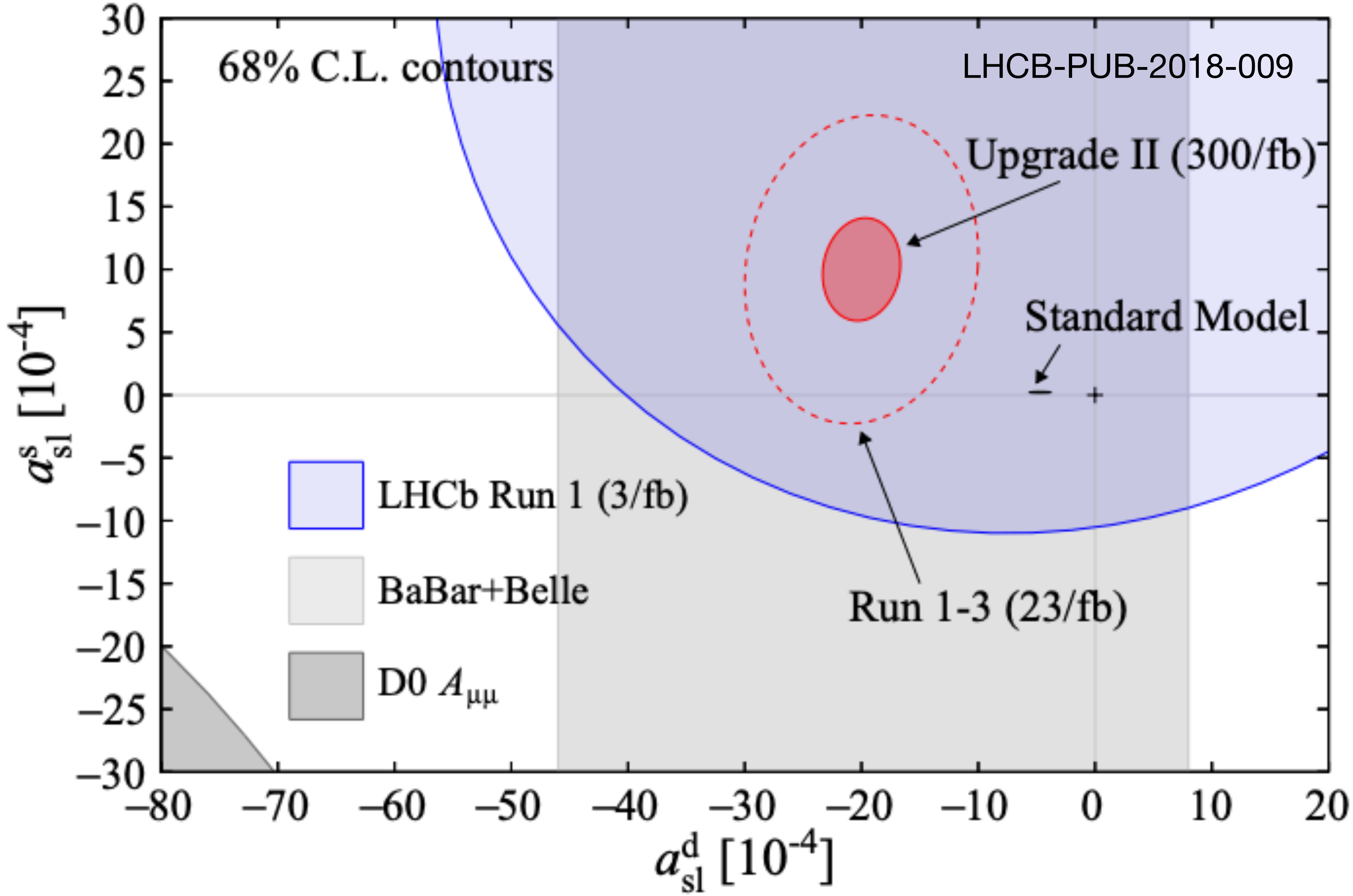
LHCB-PUB-2018-009



Sample ($\mathcal{L}$)	$\delta a_{sl}^{s} [10^{-4}]$	$\delta a_{sl}^{d} [10^{-4}]$
Current theory [34, 200]	0.03	0.6
Run 1 (3 fb^{-1}) [210, 211]	33	36
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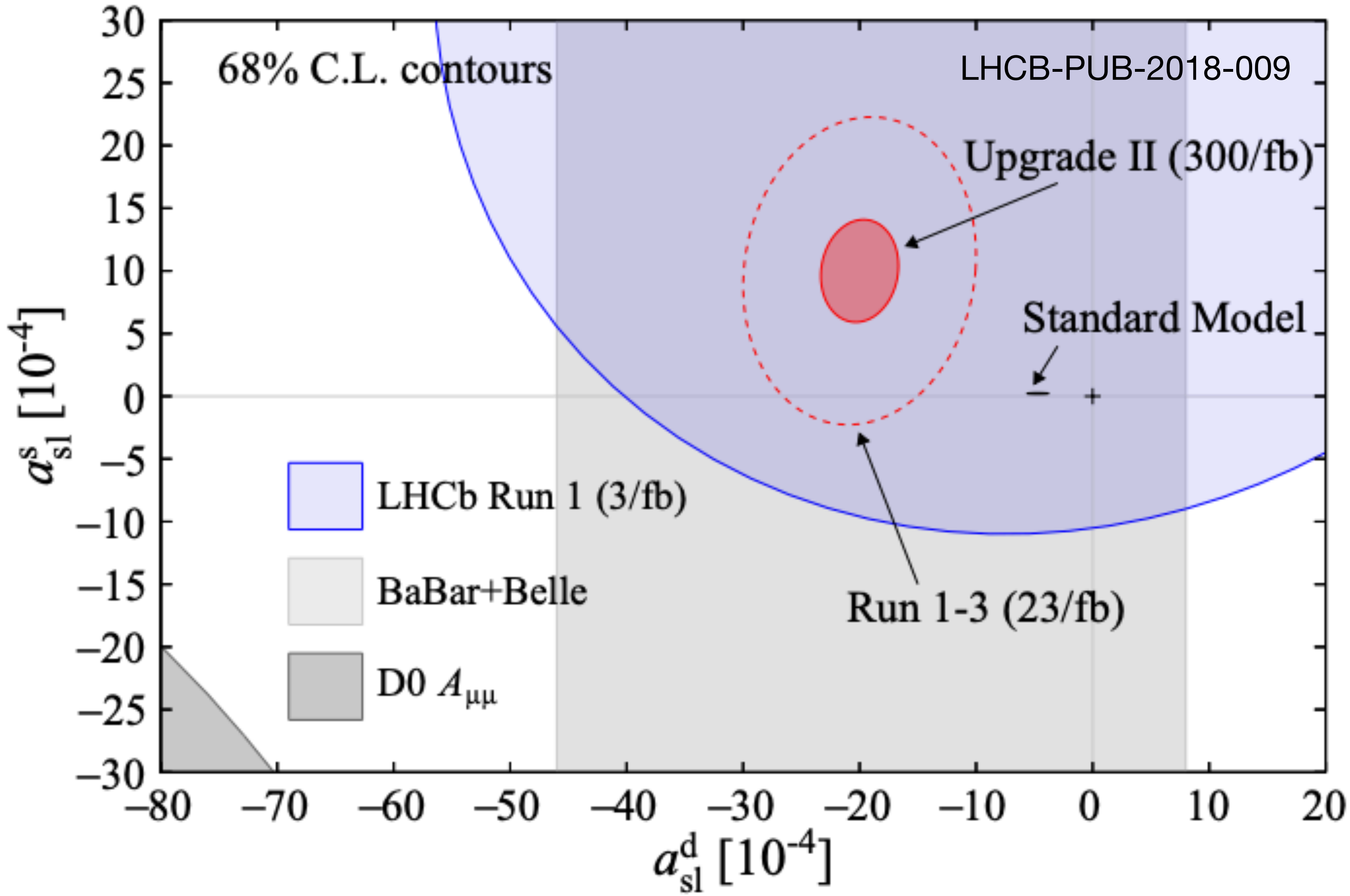

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A_{det} almost entirely data-driven.

$\sigma_{syst} / \sigma_{tot} \sim 1/3$

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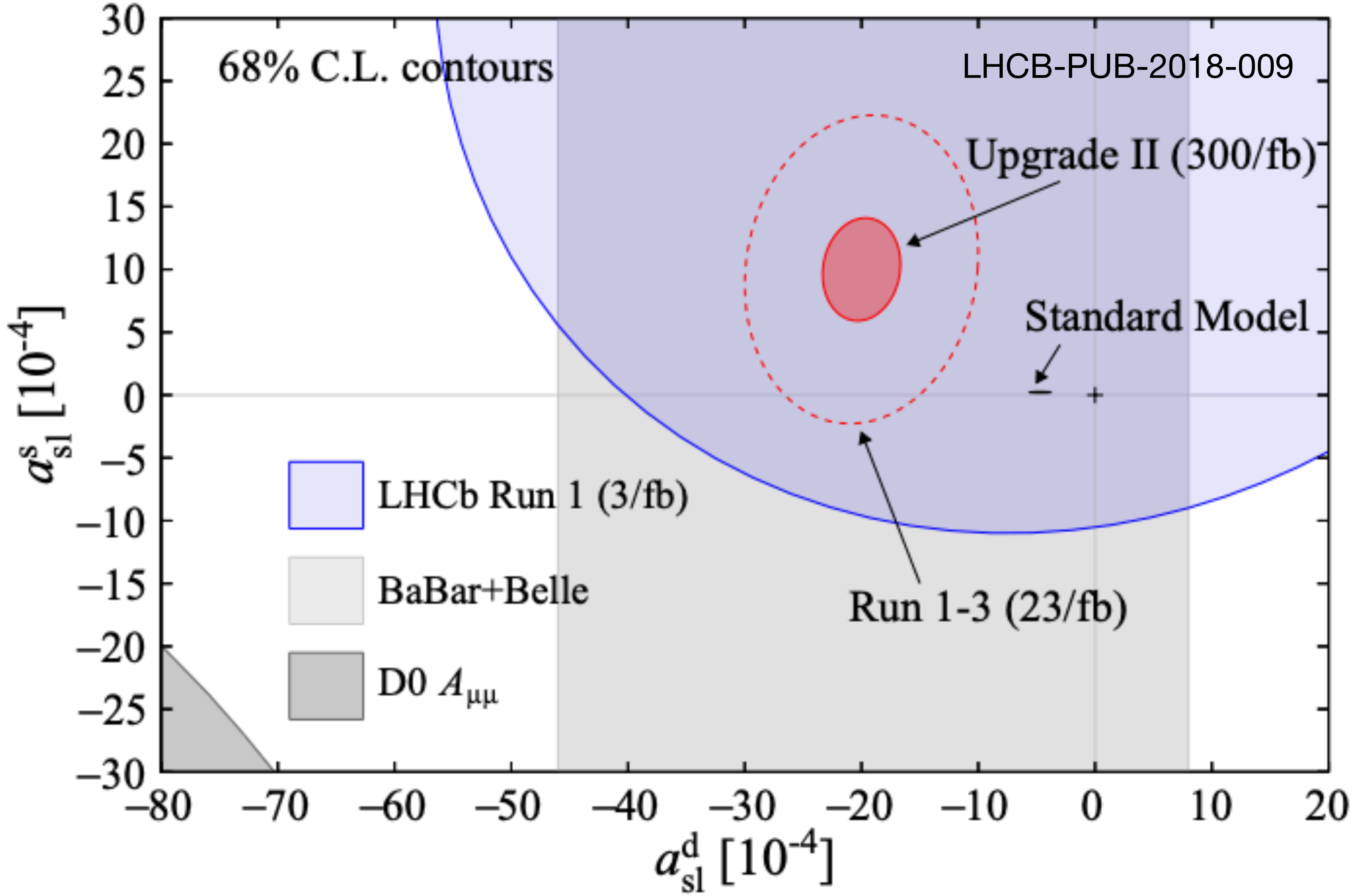

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a_{sl}^{d} measured with $B_d \rightarrow D(K\pi\pi)\mu\nu X$

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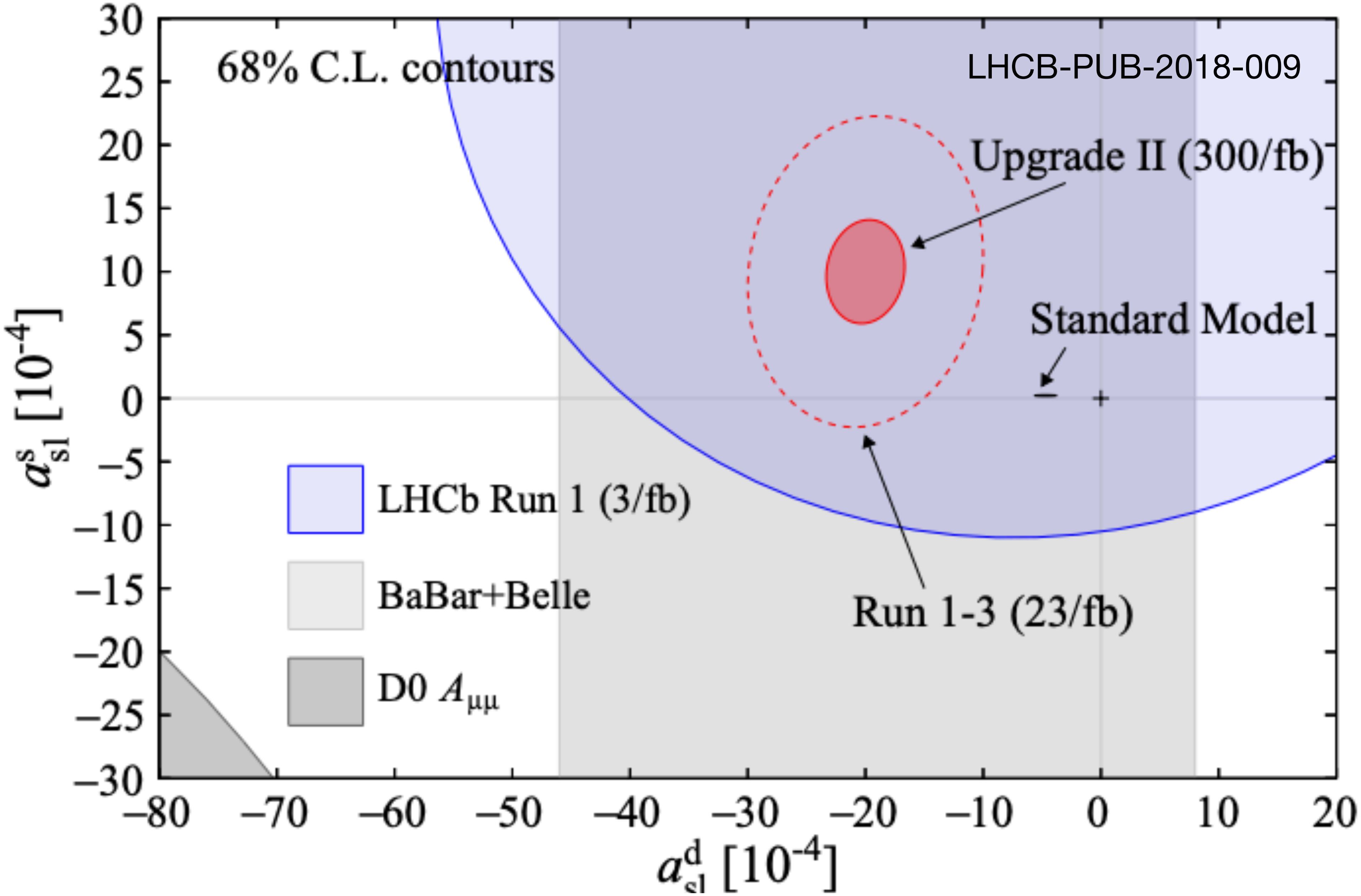
[LHCB-PUB-2018-009]



$$A^q_{\rm sl}(t) \equiv \frac{N-\bar{N}}{N+\bar{N}} = \frac{a^q_{\rm sl}}{2} - \left[a_p + \frac{a^q_{\rm sl}}{2}\right] \cdot \left[\frac{\cos\Delta M_q t}{\cosh \Delta\Gamma_q t/2}\right]$$

What precision do we need then?

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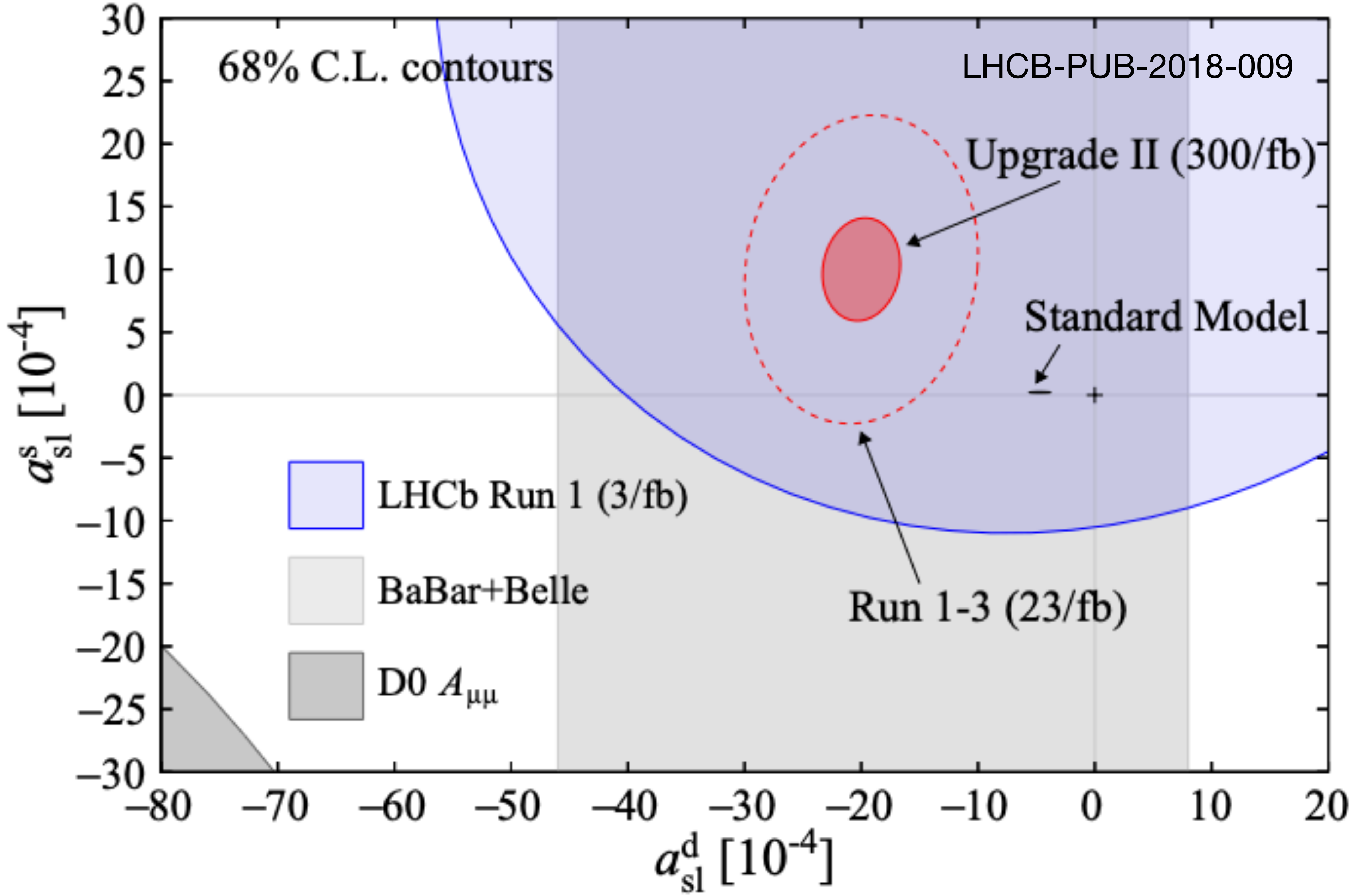
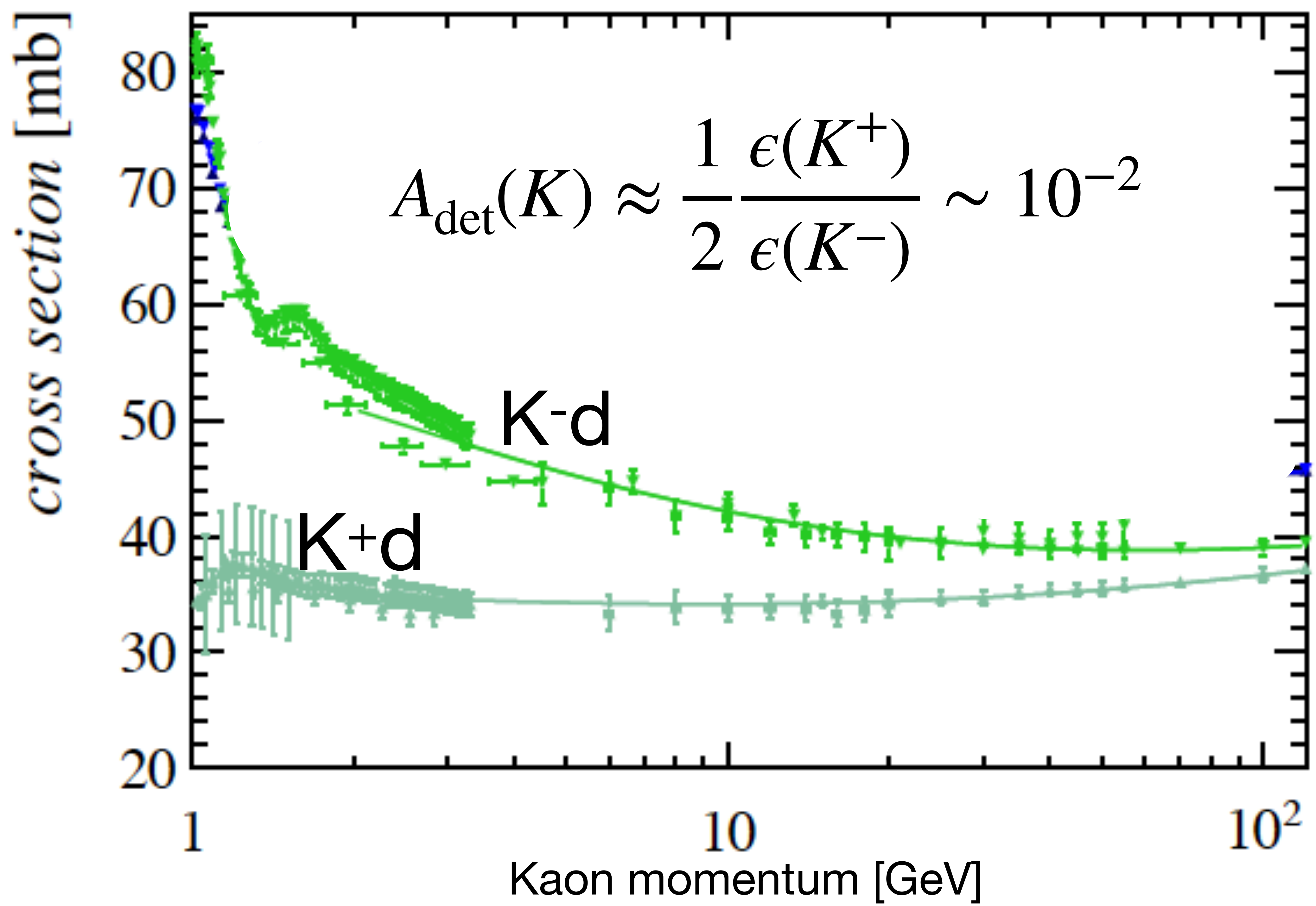
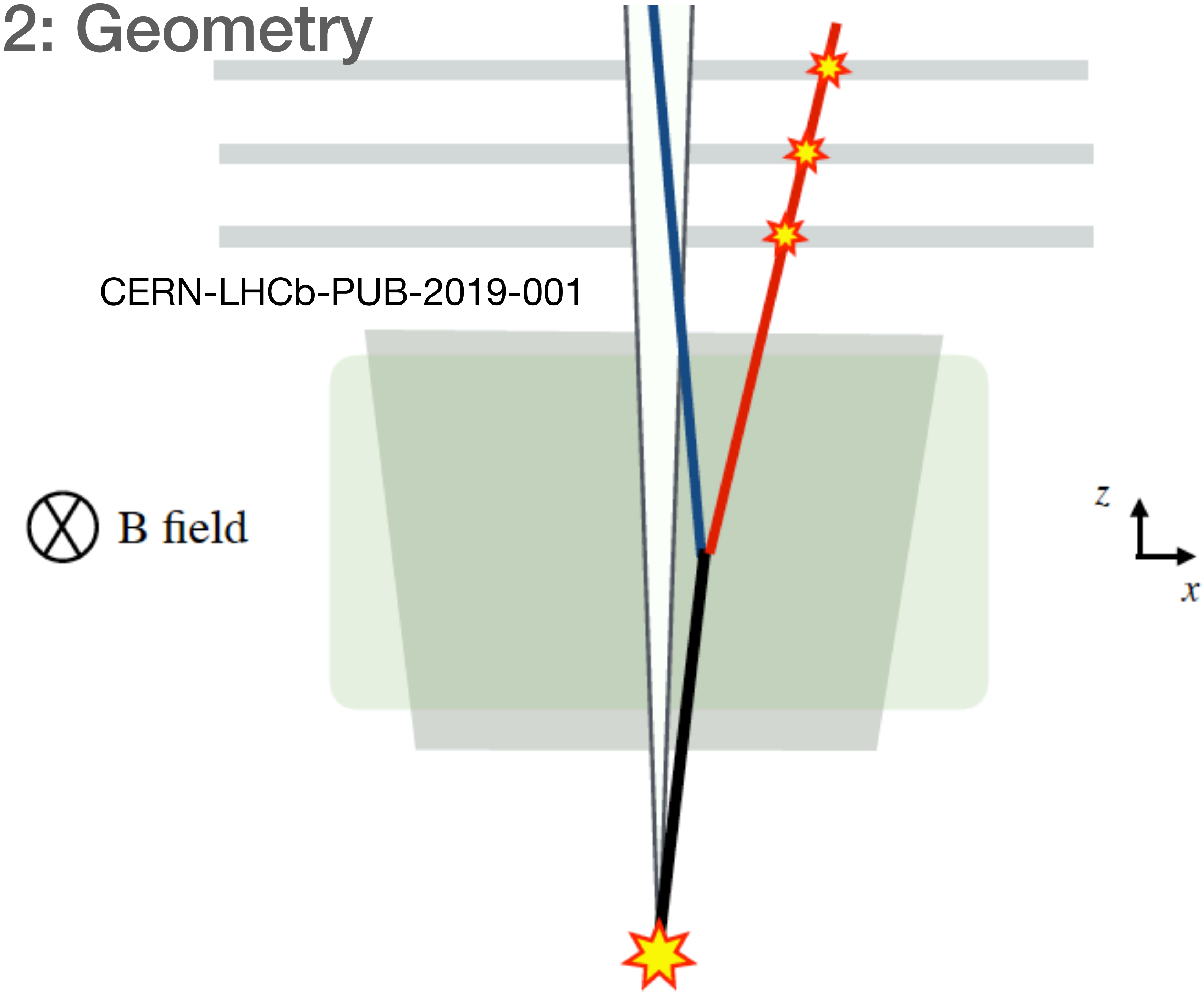


Must control A_{det} to **10^{-4}** or better.

Source 1: Material interactions



Source 2: Geometry

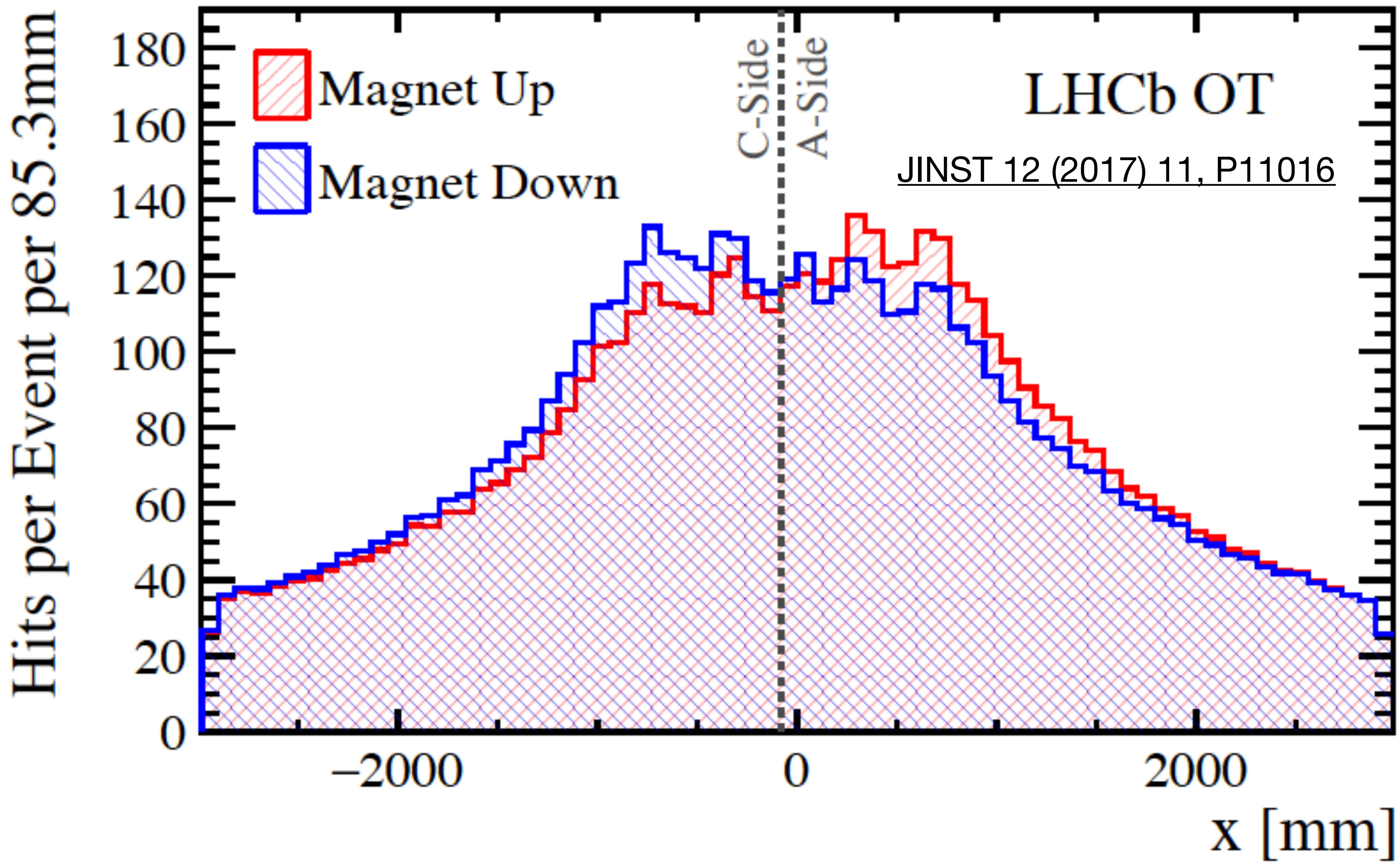


Asymmetries canceled to first order by magnet flips.

However, the beams collide with a crossing angle, and the detector varies with time.

LHCb-PUB-2014-006 discusses the importance of frequent magnet flips.

Source 3: Tracking



Most secondary charged particles are *electrons,* which implies a higher average local occupancy for negatively charged tracks.

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3. **Calibration:** measure and correct for A_{det}.

Direct measurement of single-particle efficiencies

Exploit the built in *redundancy* of the detector.

D→hh, J/Ψ→μμ, …, are “test-beams” of pions, kaons, muons, etc..

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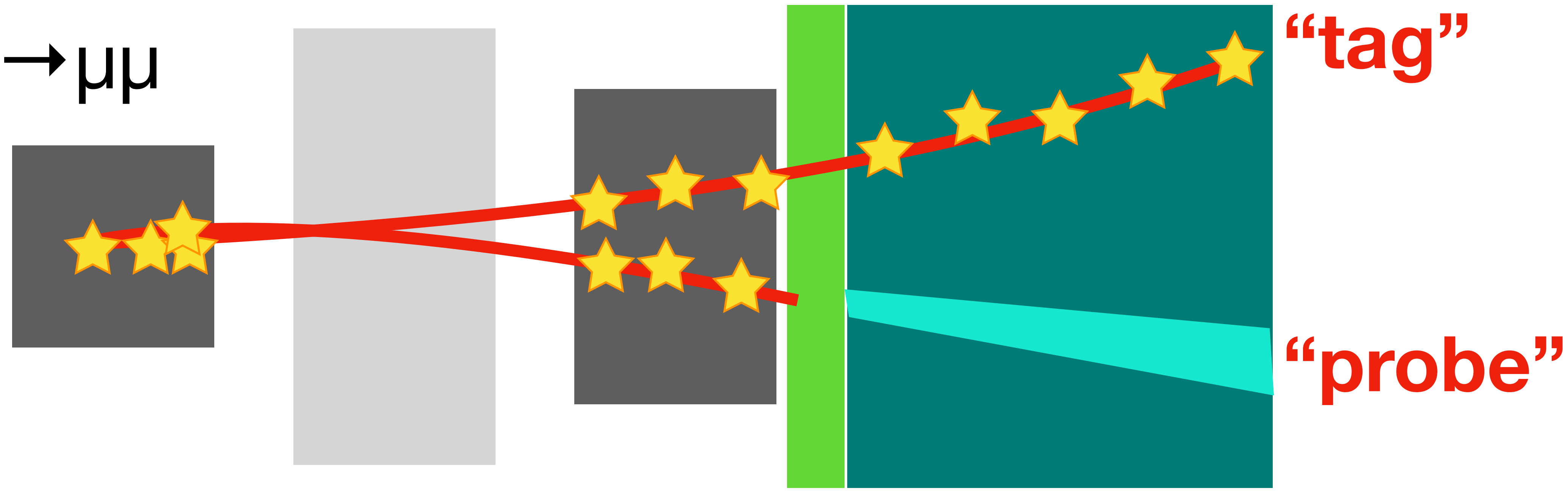
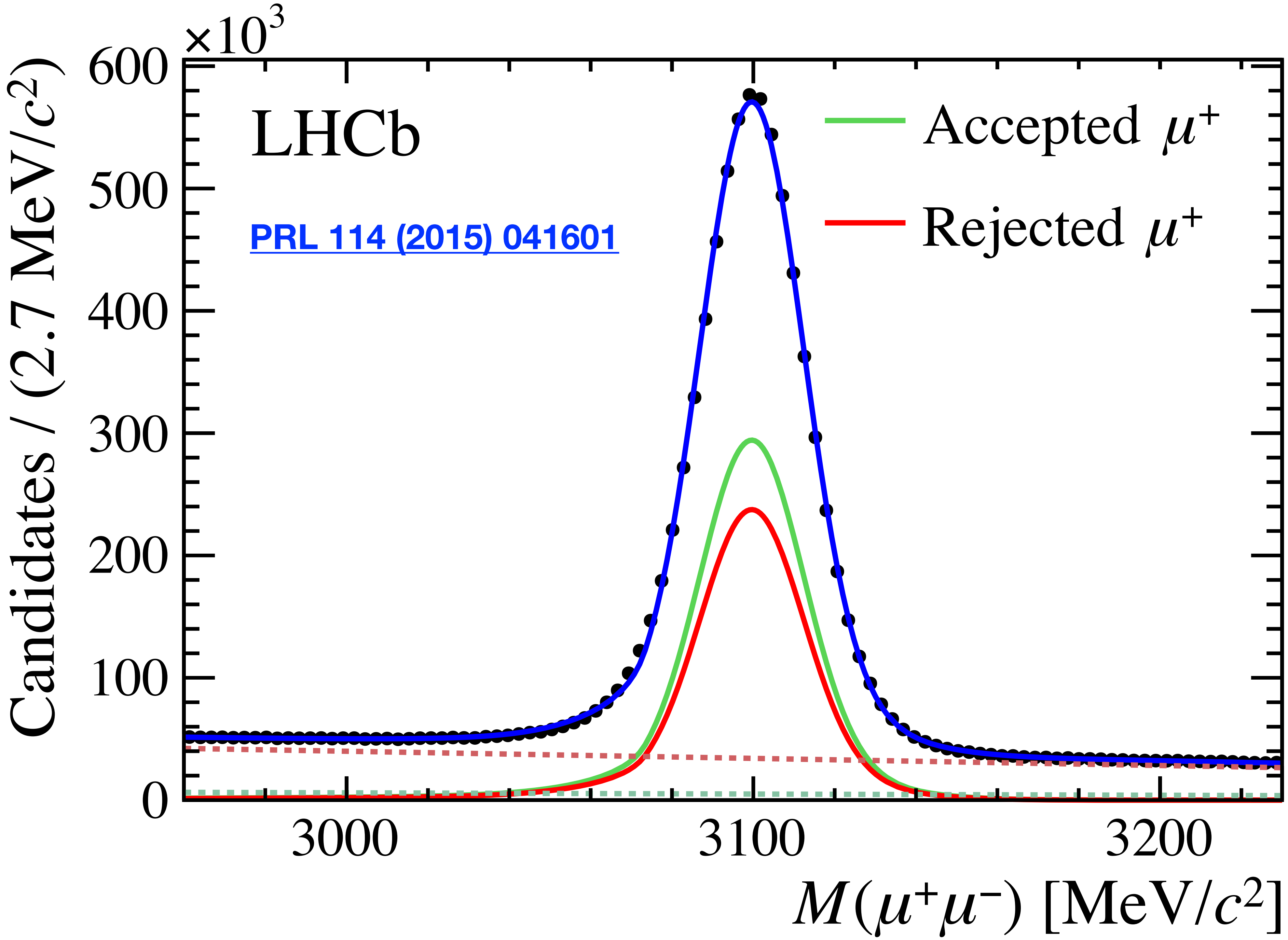


Example: muon identification



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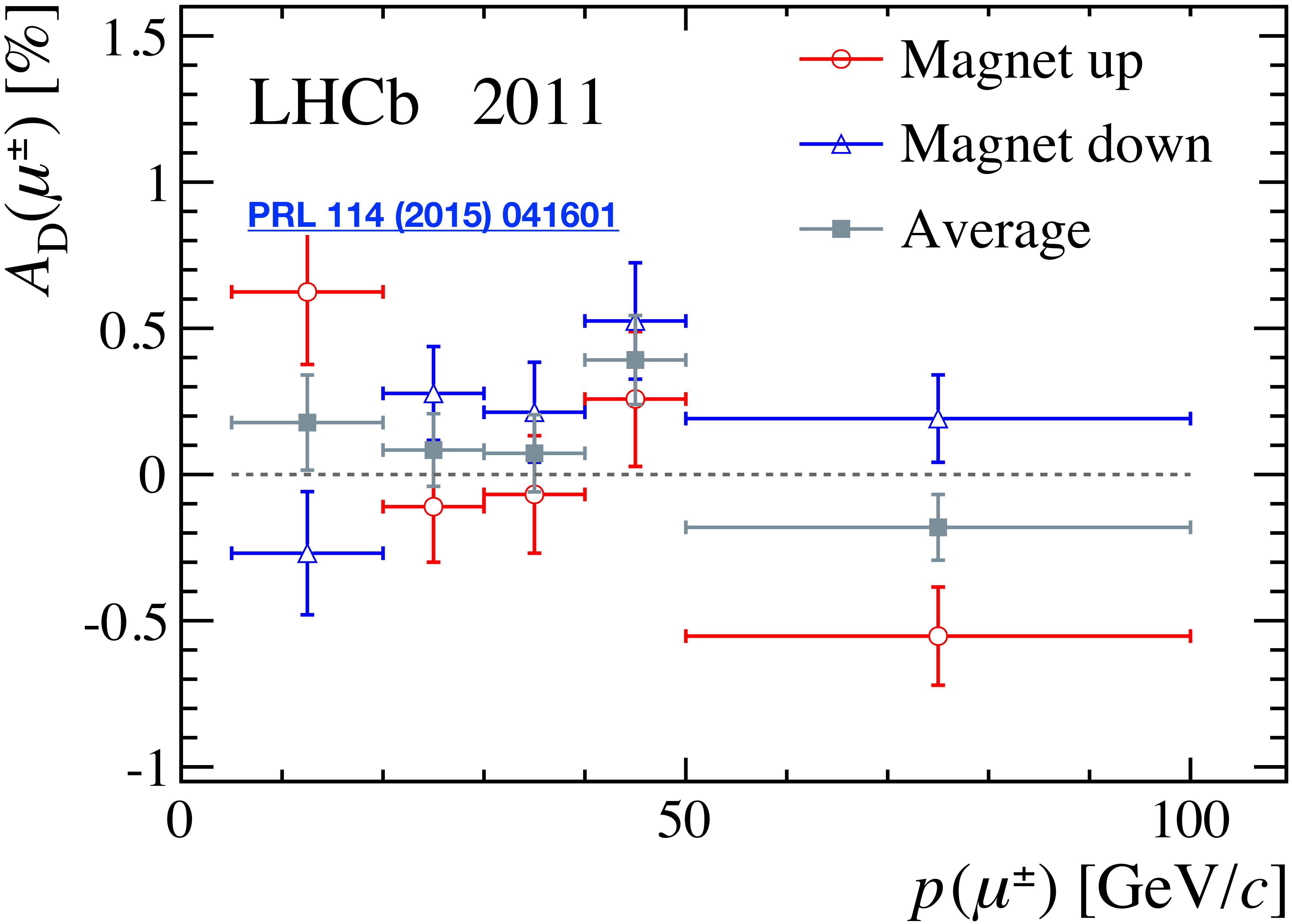
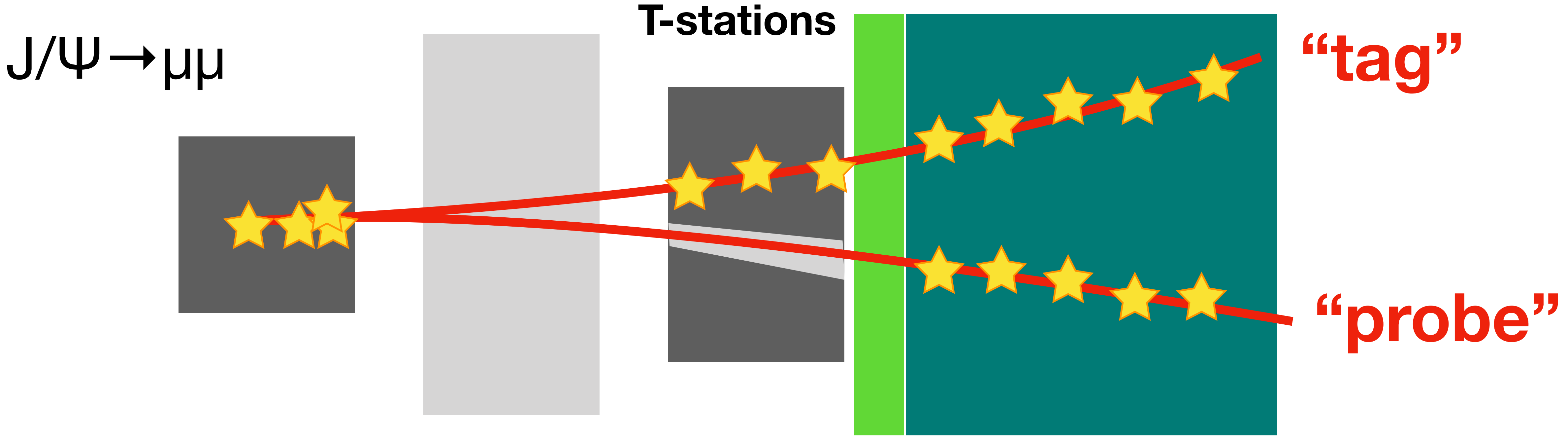
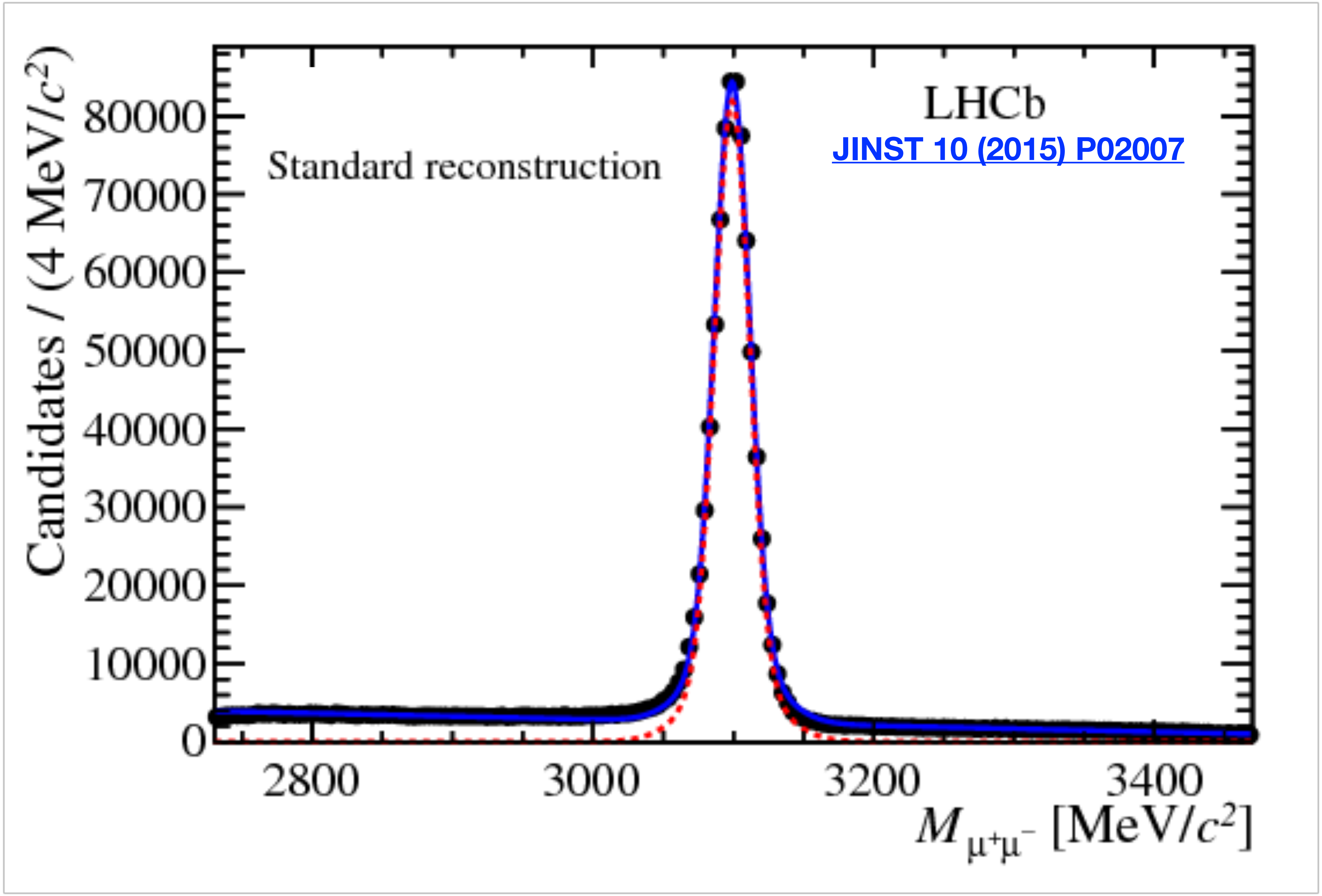


Direct measurement of single-particle efficiencies

Tracking efficiencies with e.g. the “T-station method”



J/Ψ→μμ mass peak



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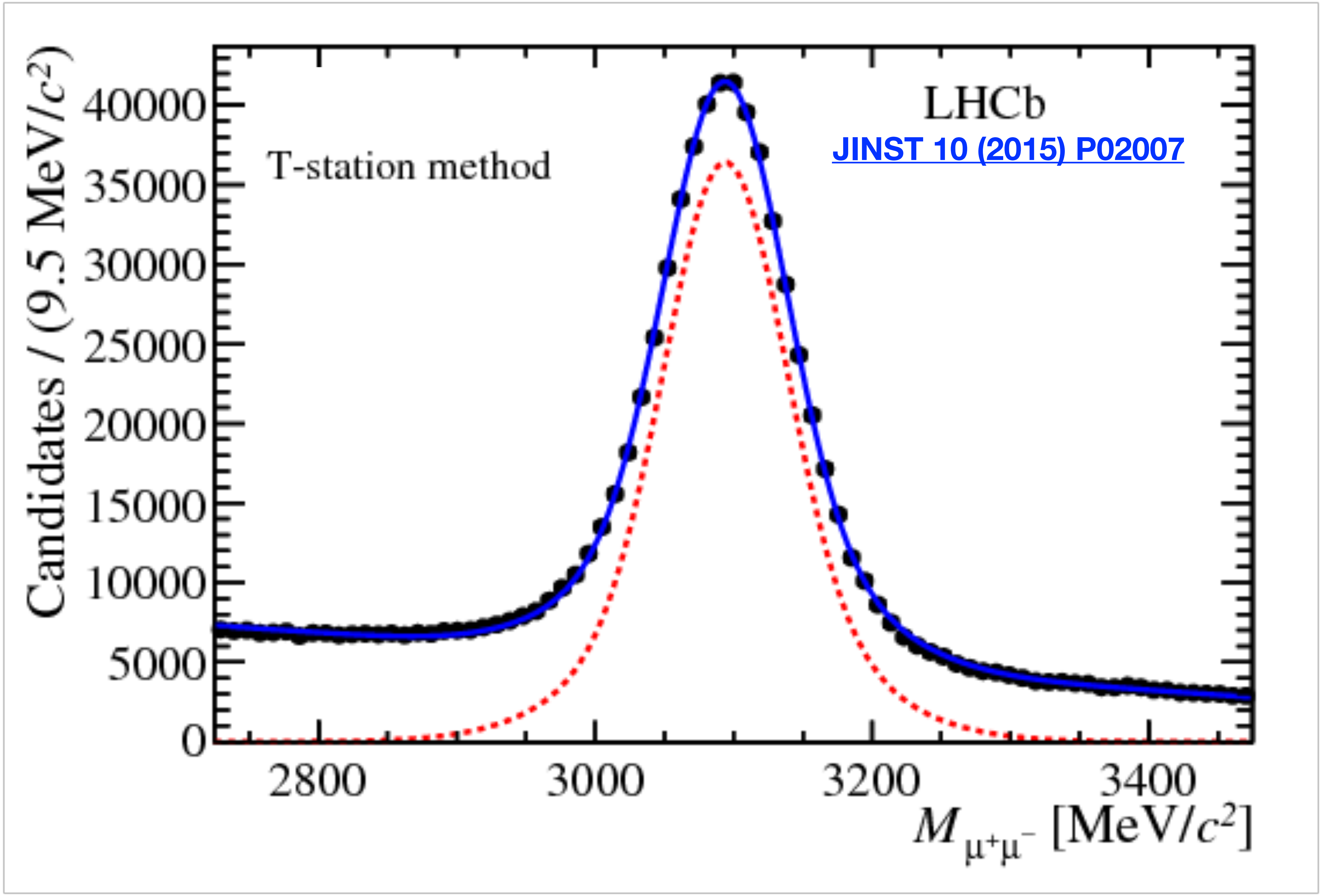
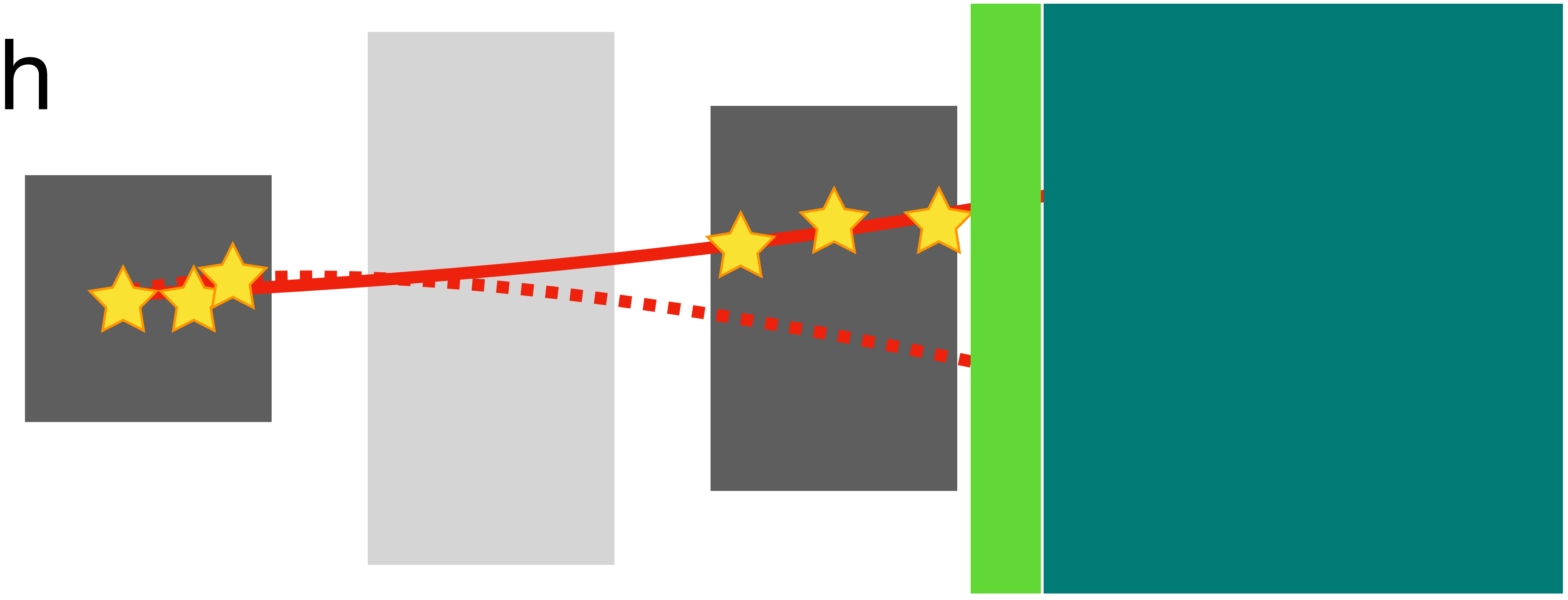


Direct measurement of single-particle efficiencies

How to measure the hadronic interactions?

D→hh



Alternative approach for kaon asymmetry

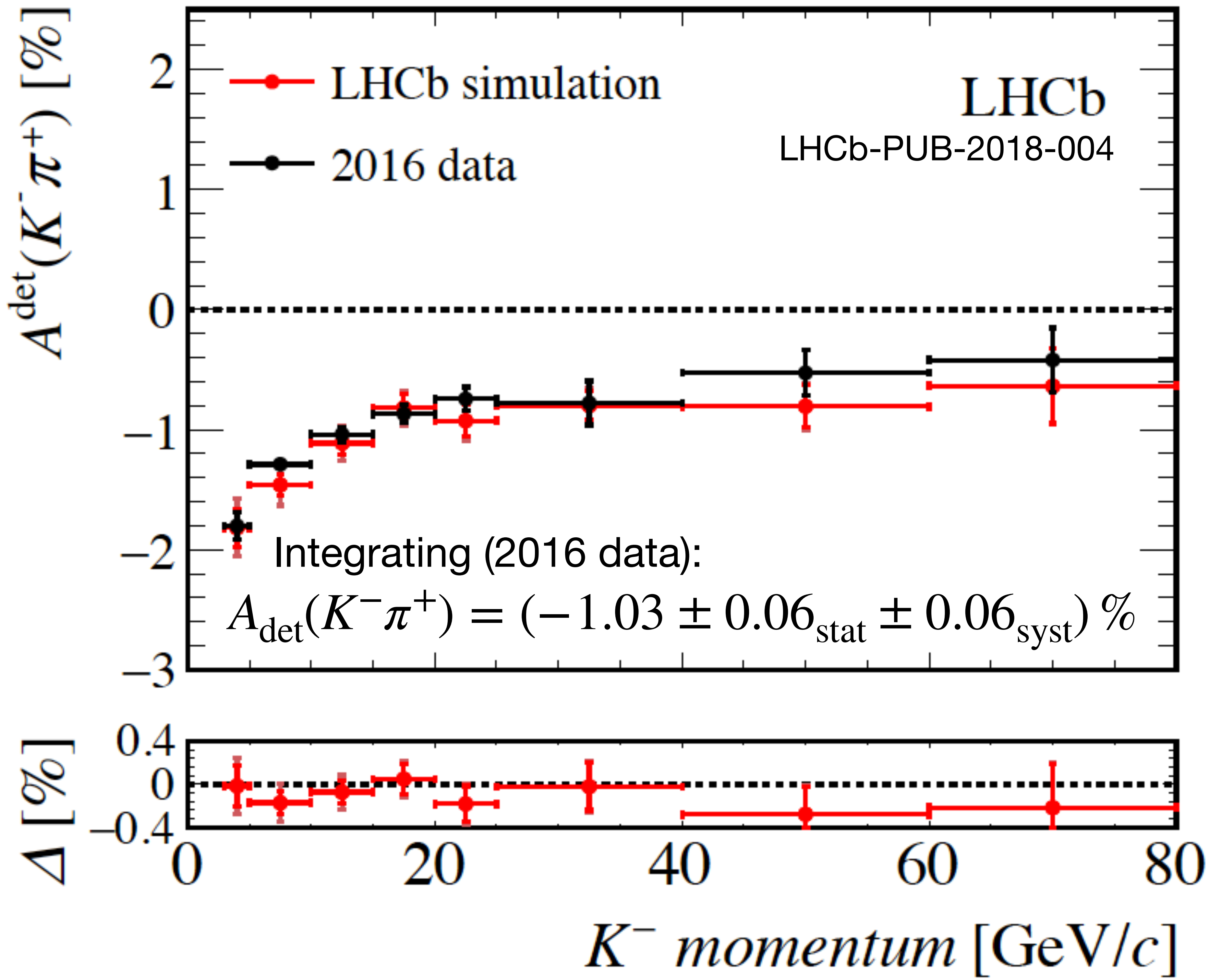
$$
\begin{aligned}
A_{\mathrm{det}}(K^{\mp}\pi^{\pm}) = & +A_{\mathrm{raw}}(D^{+} \to K^{-}\pi^{+}\pi^{+}) \\
& -A_{\mathrm{raw}}(D^{+} \to K_{s}^{0}\pi^{+}) \\
& +A_{\mathrm{det}}(K_{s}^{0})
\end{aligned}
$$

Assume $A_{CP} = 0$ for both decays.

Complicated weighting scheme needed to cancel nuisance asymmetries, in particular the $D^{\pm}$ production asymmetry.

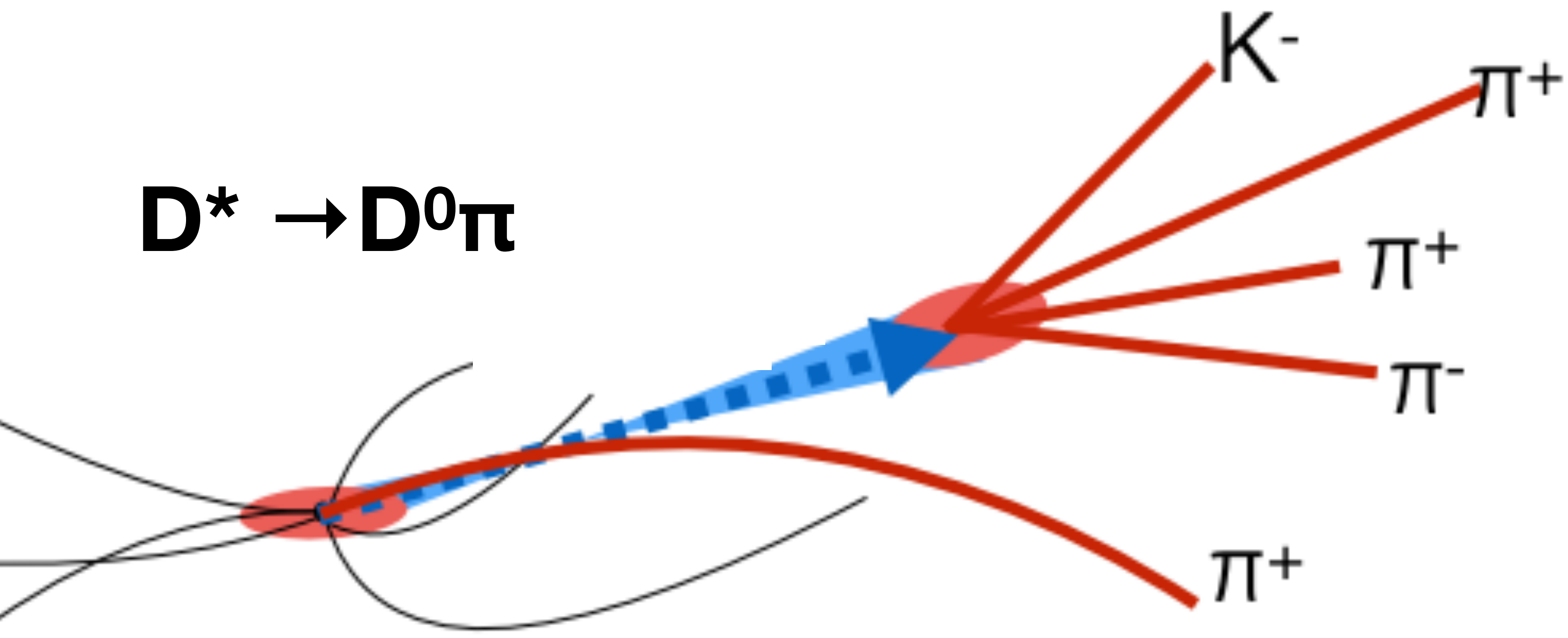
*And one pion asymmetry, which further complicates the weighting prescription.

Alternative approach for kaon asymmetry



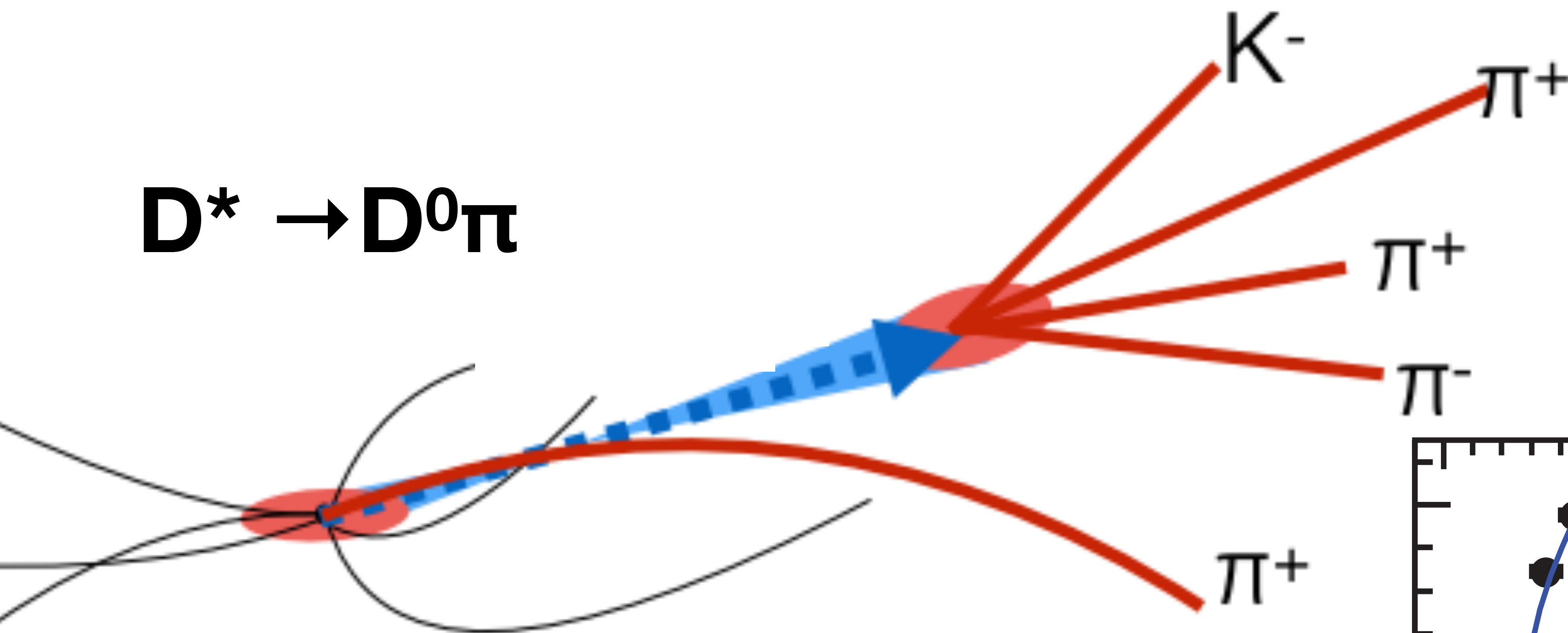
A lesson from Run-I/II: Idea developed after the Run-I data were recorded. Far better precision in Run-II thanks to dedicated HLT selections, rather than parasitic use of generic charm-physics selections.

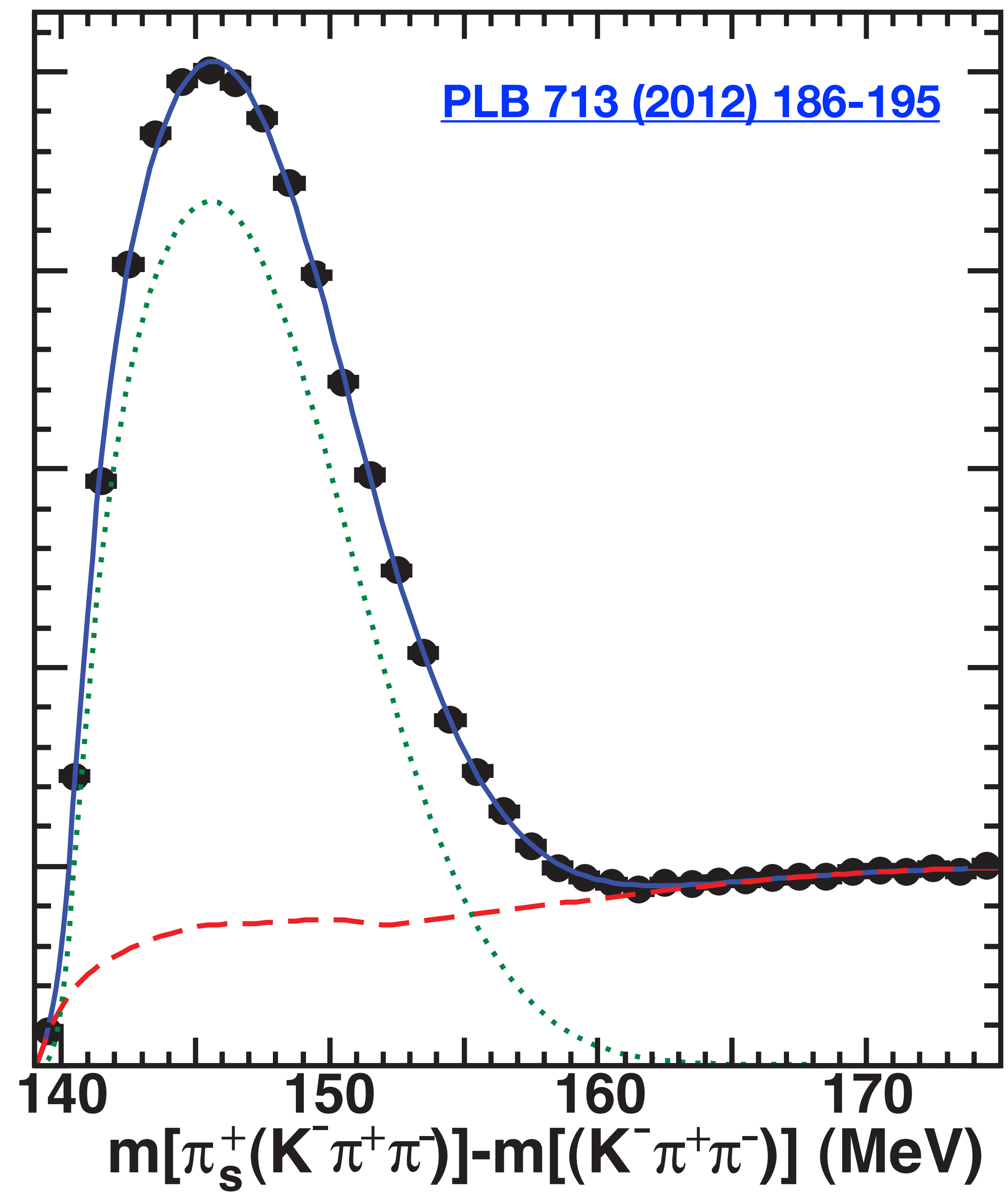
Partial reconstruction



Partial reconstruction

$D^* \rightarrow D^0\pi$





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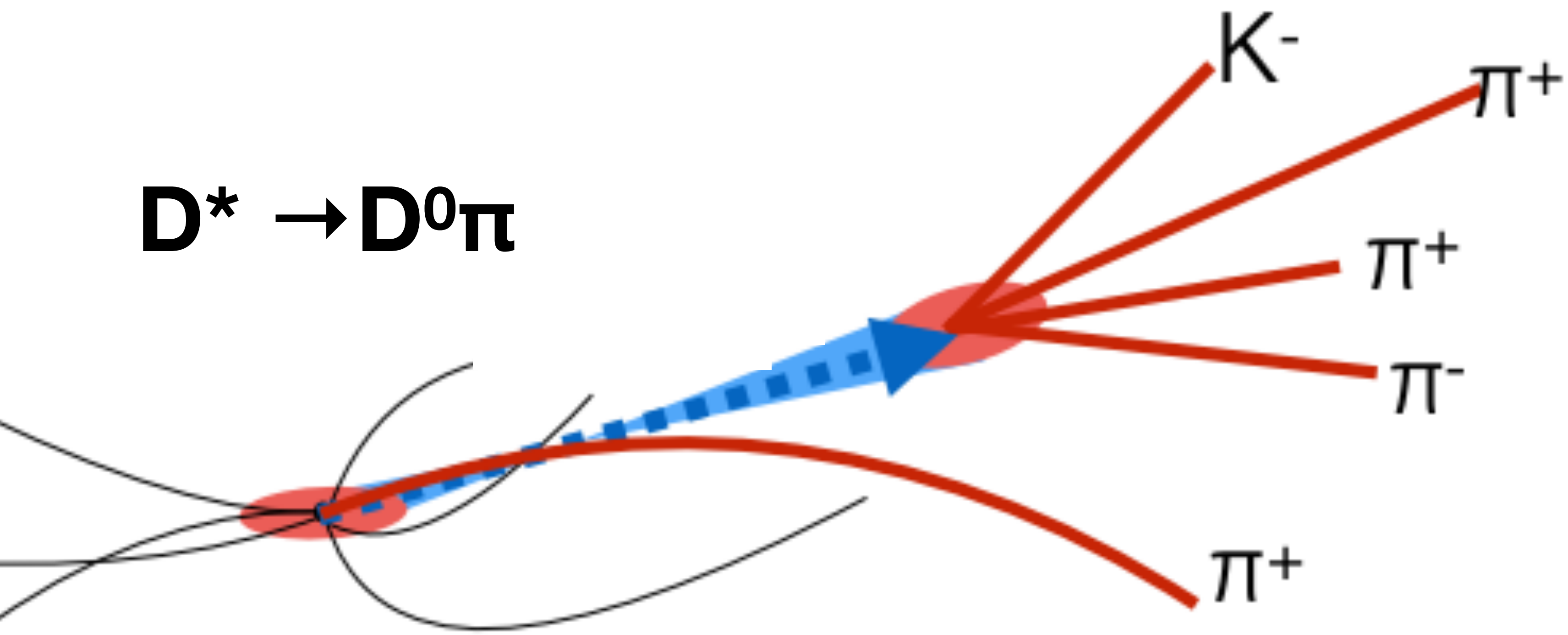
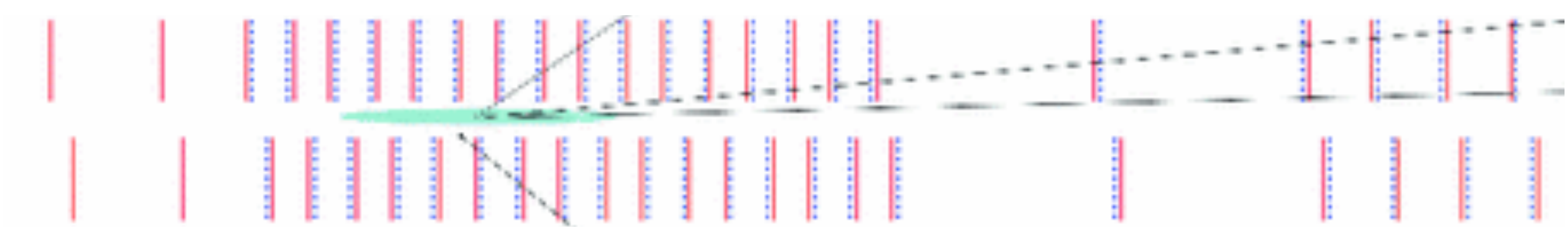


Can potentially do better with

$$\varepsilon_{\mathrm{det}}(\mathrm{long}) = \varepsilon_{\mathrm{det}}(\mathrm{long}|\mathrm{VELO})\varepsilon_{\mathrm{det}}(\mathrm{VELO})$$



The VELO is up to 50% of the material budget.
However, only 3 stations required for VELO track.

Partial reconstruction

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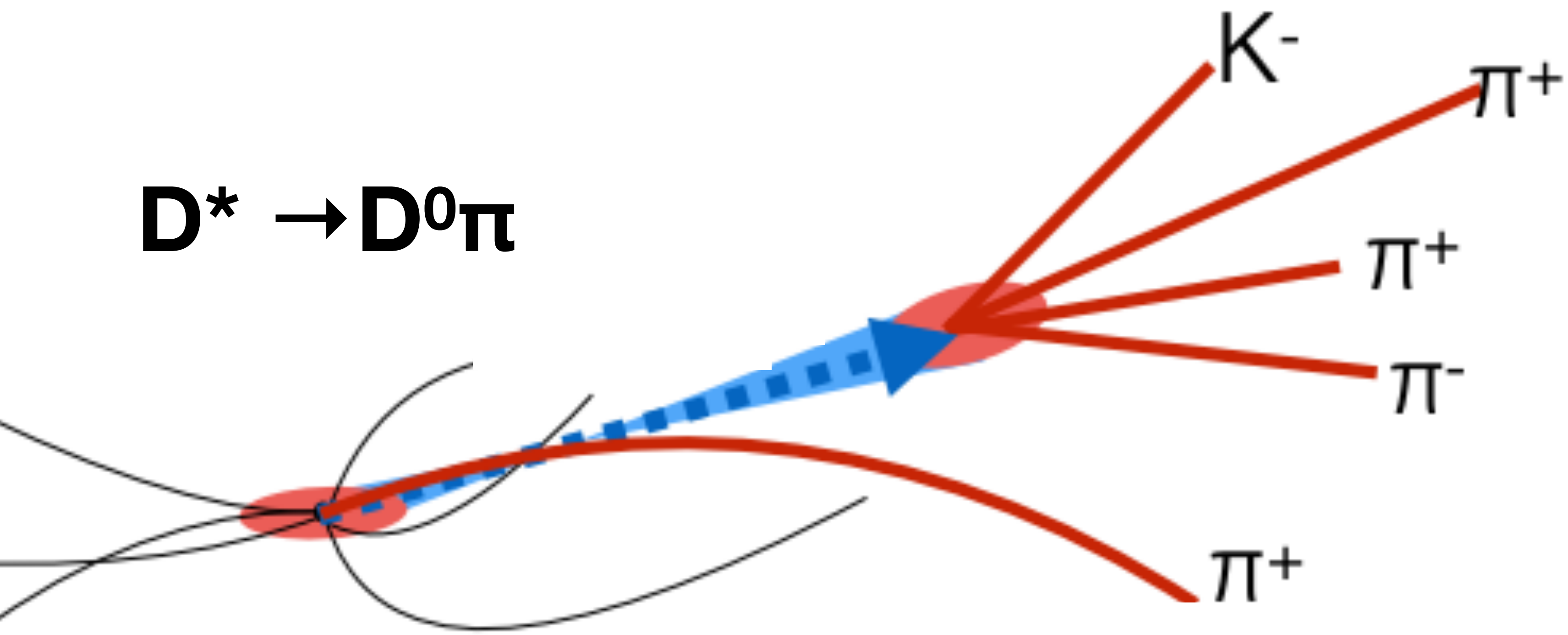
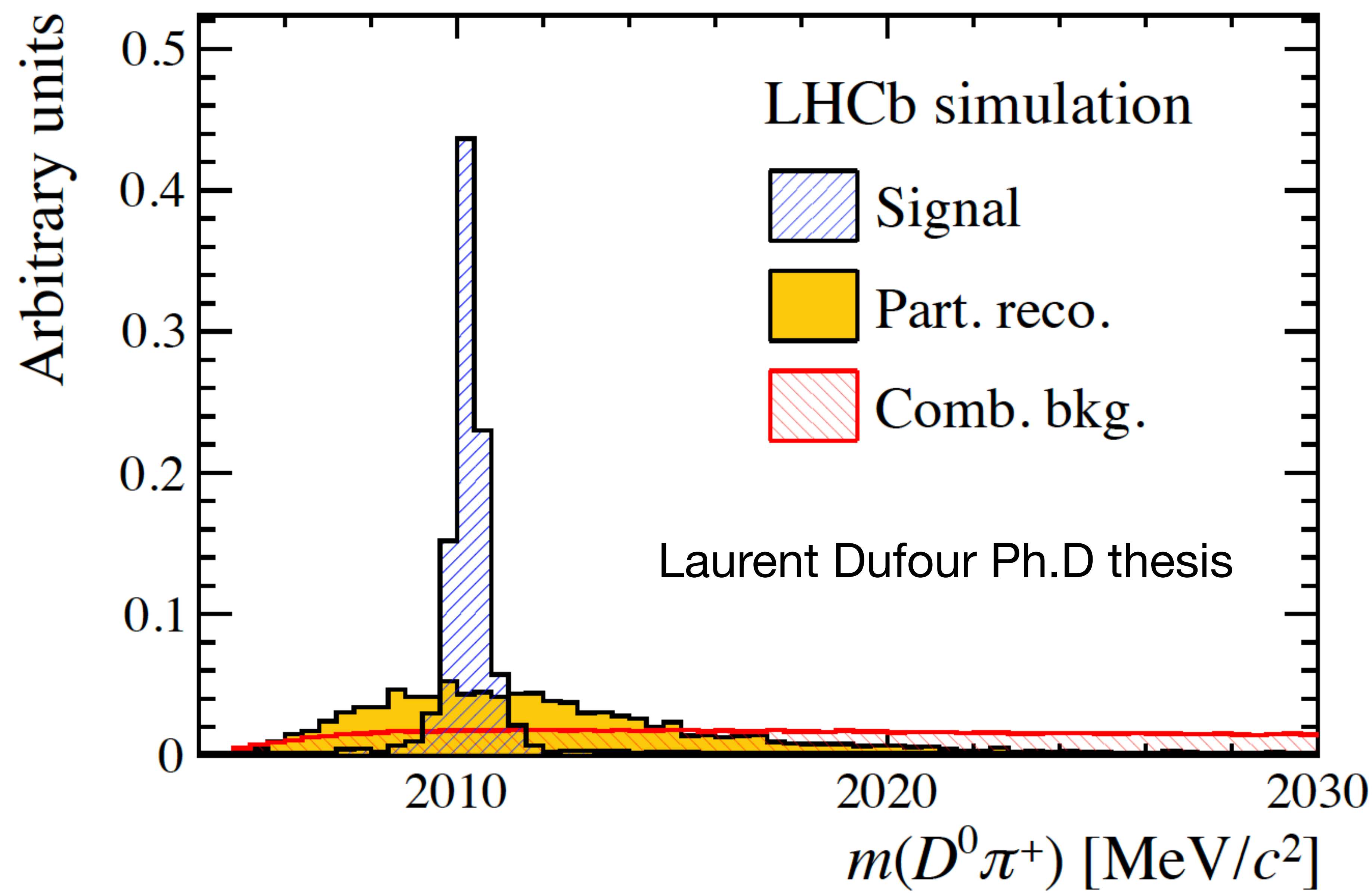
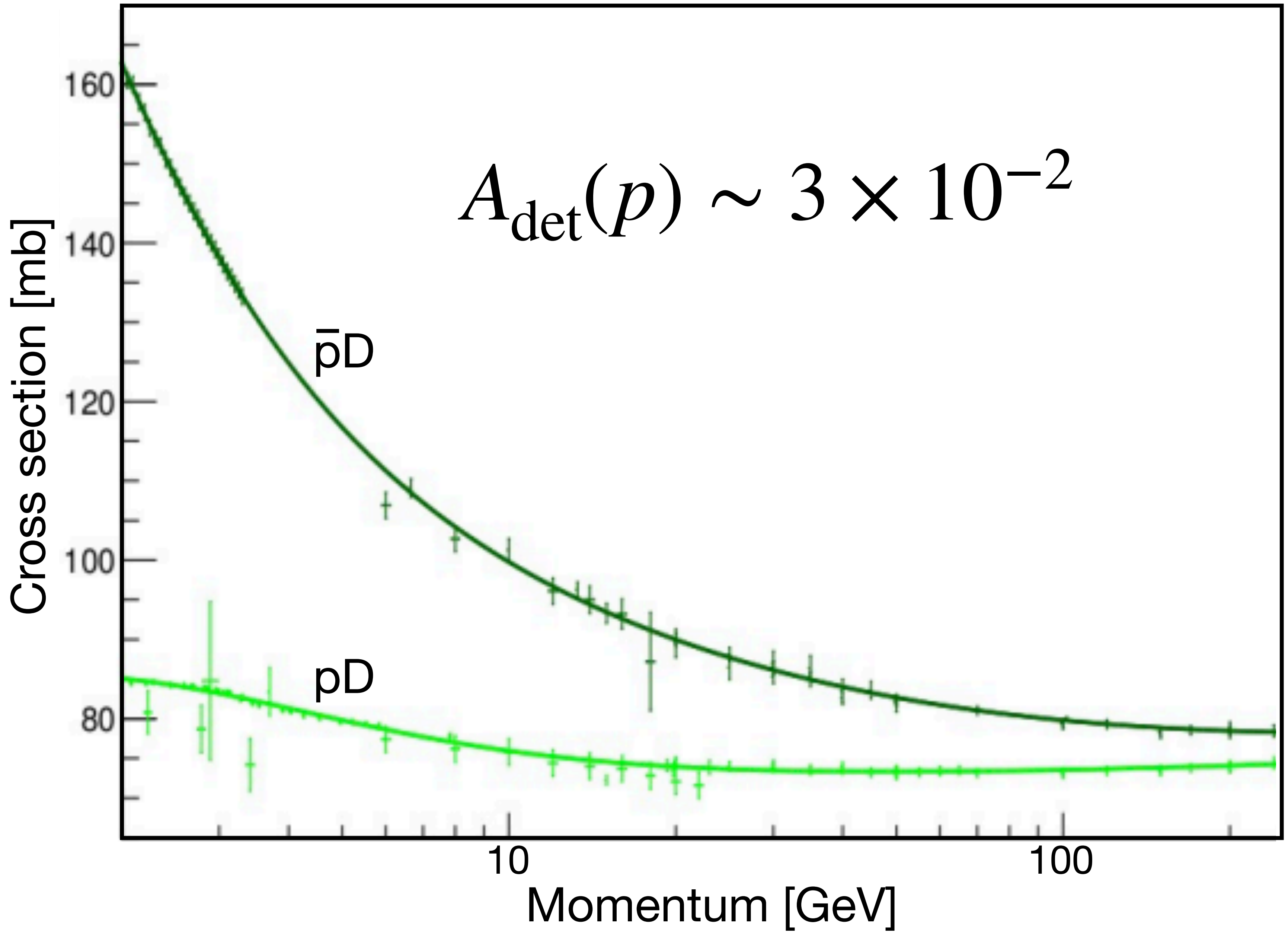




Protons



No A(Kpi) method.

Single-particle measurements challenging, but ideas in the pipeline…

Current understanding from simulation is at the 0.5-1% level.

Solutions 1: calibration data

- Detector redundancy, resolution, and granularity for efficiency measurements.
- Select the relevant samples and information in the High Level Trigger.

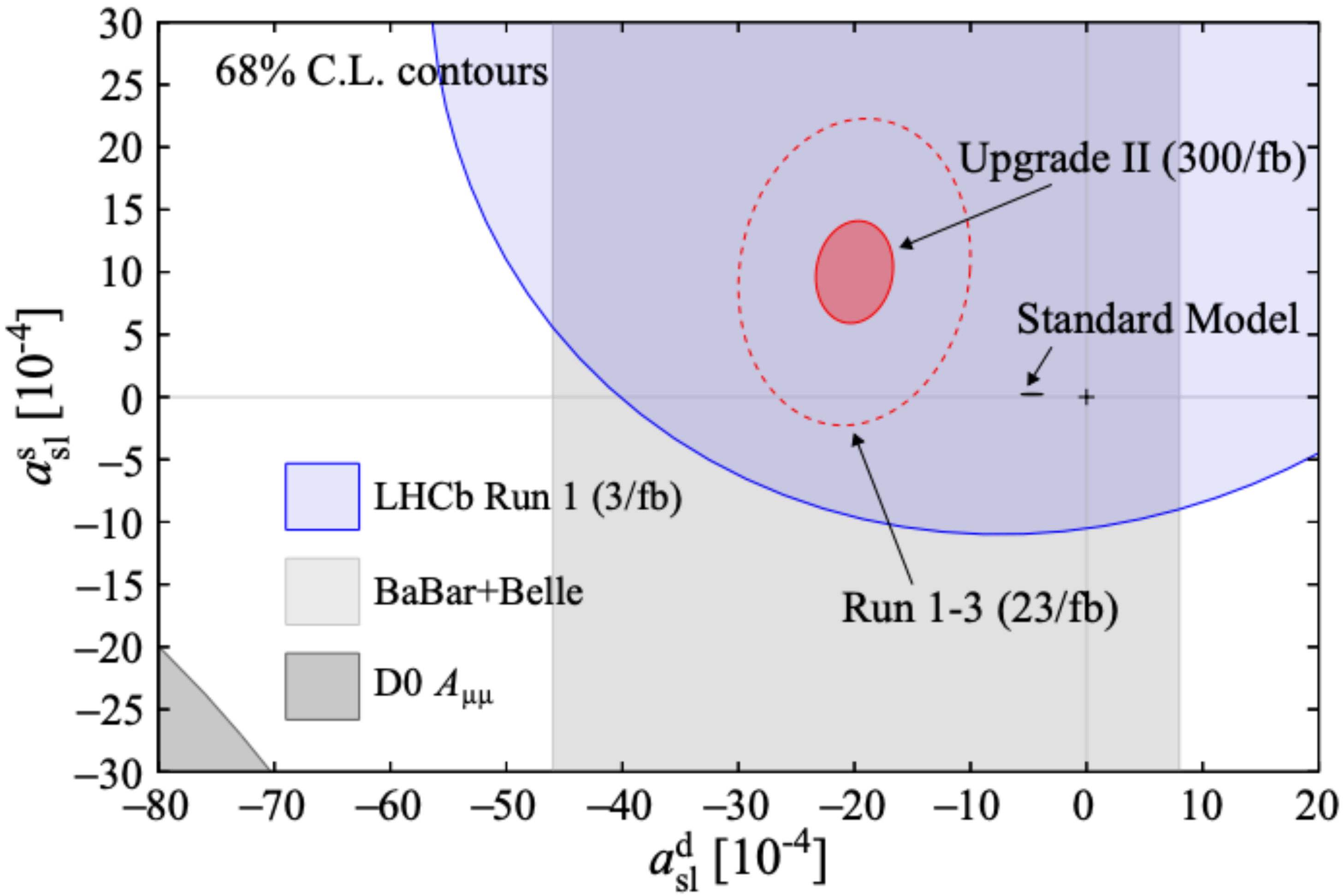
Solutions 2: simulation

- All data-driven methods are prone to biases.
- Simulation will be required to fully exploit the data.
- *Careful* application of fast-simulation approaches.

Solutions 3: detector and machine

- Compromise between magnet flip frequency/ symmetry and total L_{int}.
- Prefer crossing angles with same magnitude and sign for both polarities.
- Real time alignment and calibration! 1812.10790 (2018)

Conclusions



Hadron colliders provide many calibration processes, and we know how to use these to measure (most) detection asymmetries, and I'm sure that many great new ideas will emerge.

However, I think we will become more sensitive to subtle details that will be difficult to fully understand/control with the data alone.

Important detector and trigger design considerations to reduce the initial size of the asymmetries and improve ability to calibrate them.

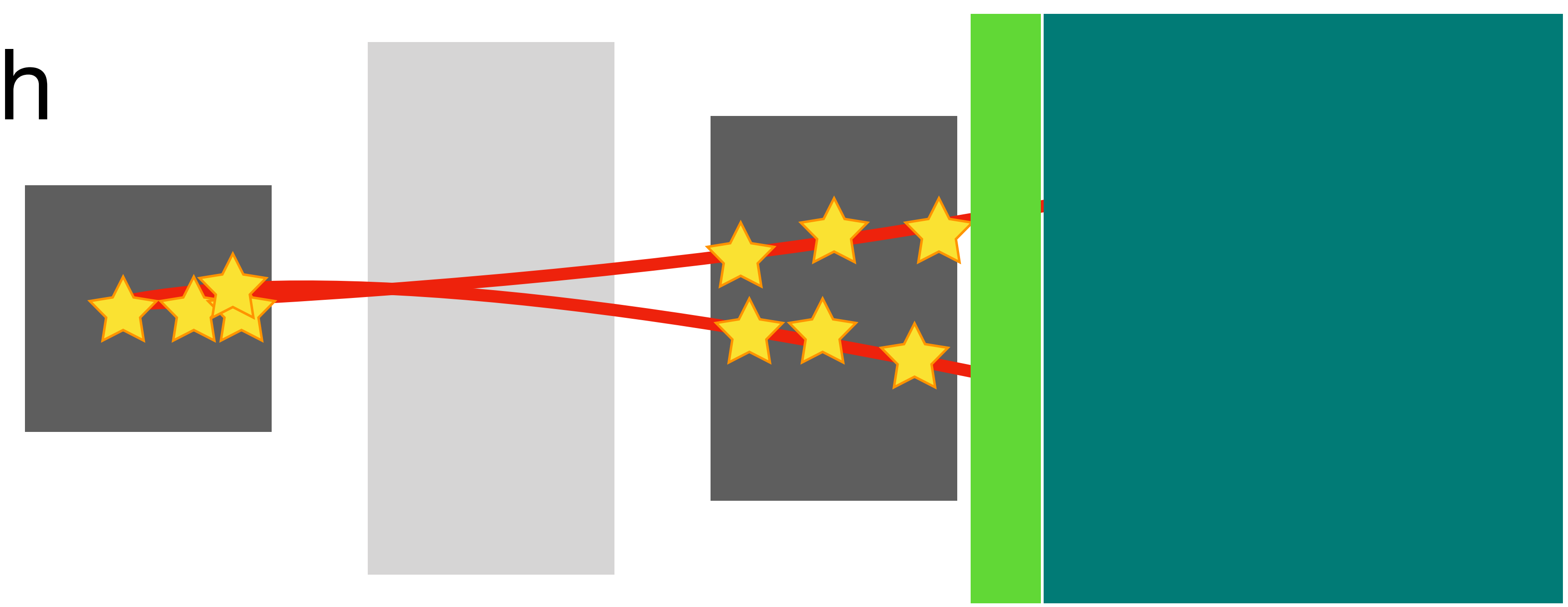
Backup slides

Direct measurement of single-particle efficiencies

Assume a *universal* detector response to particles of the same species and 3-momentum.

The Level-0 hadron challenge:

$D \to hh$



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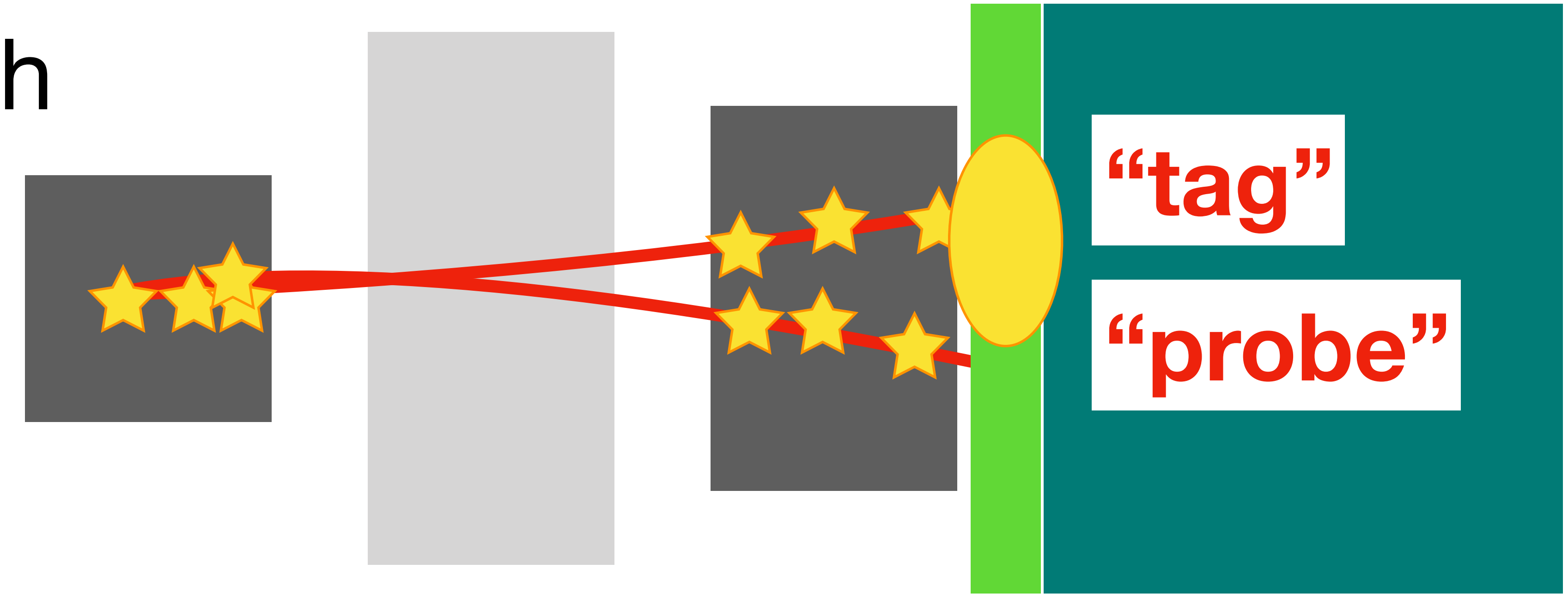

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