ATLAS EXPERIMENT

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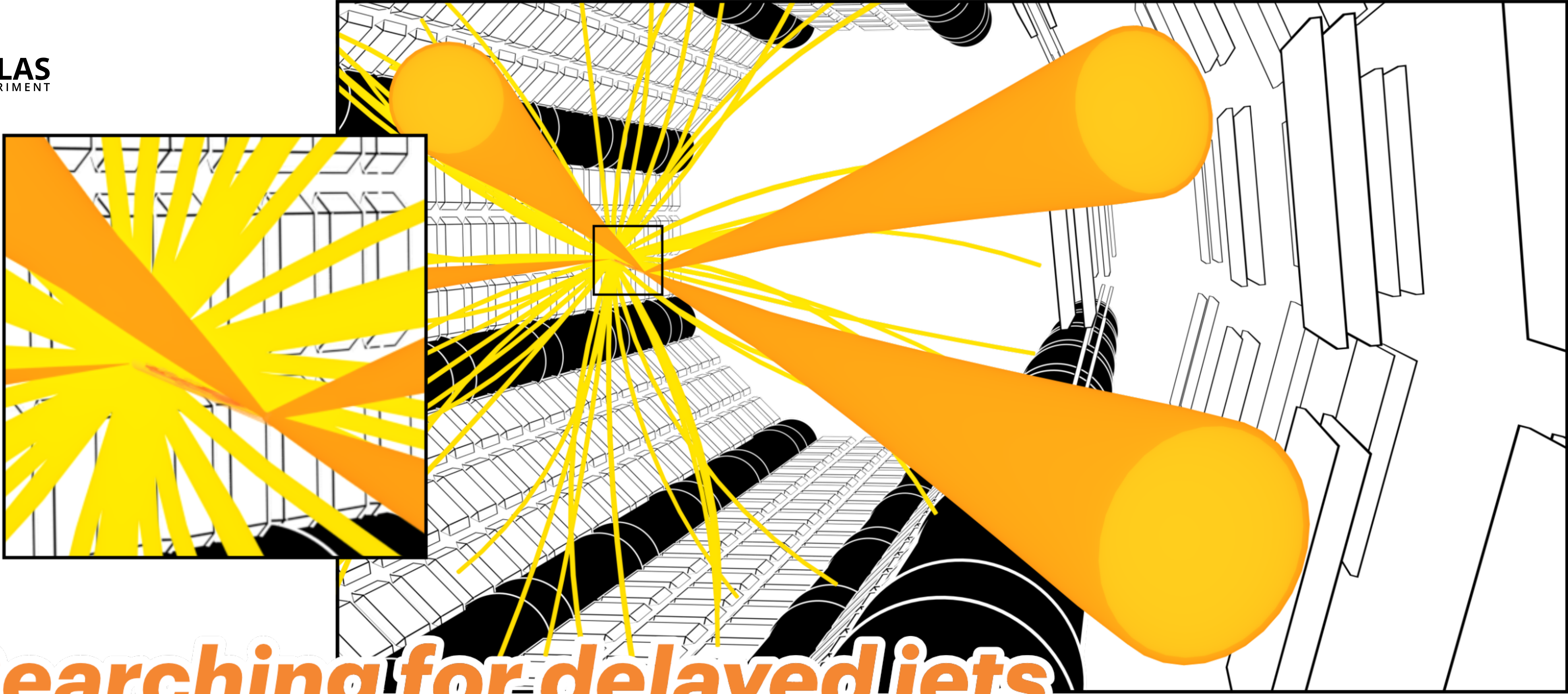

Searching for delayed jets from long-lived particles with the ATLAS detector

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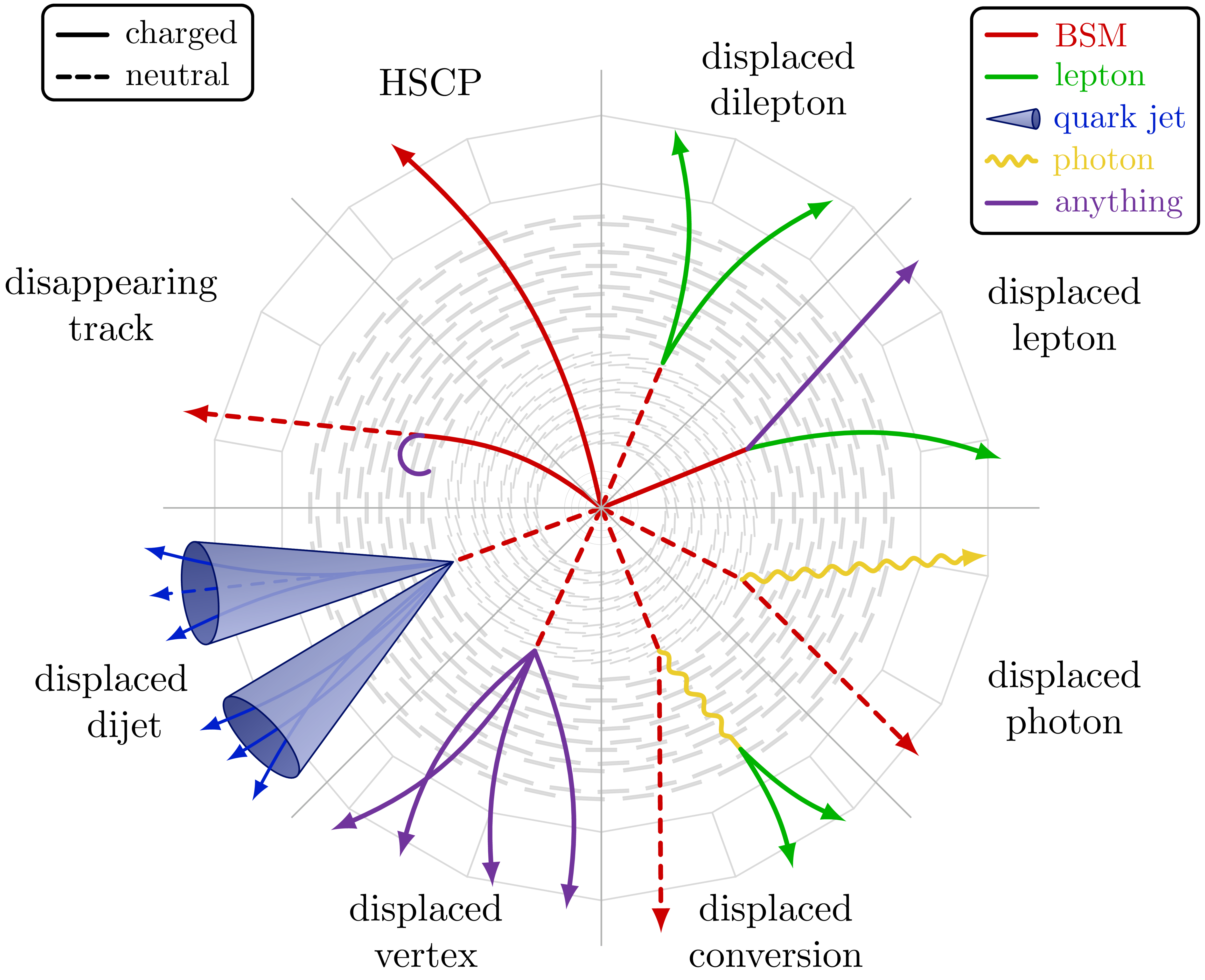
Long-lived particles

Long-lived particles (LLPs): particles with finite lifetimes that decay noticeably away from the interaction point (IP)

Many searches target the displacement, e.g. an invisible LLP decaying to displaced vertices, leptons/photons or jets



Credit: Izaak Neutelings on tikz.net

From displacement to delay

The time-of-arrival of a particle is calculated w.r.t. the speed of light, so a photon produced exactly at the IP arrives anywhere in the detector at $t = 0$

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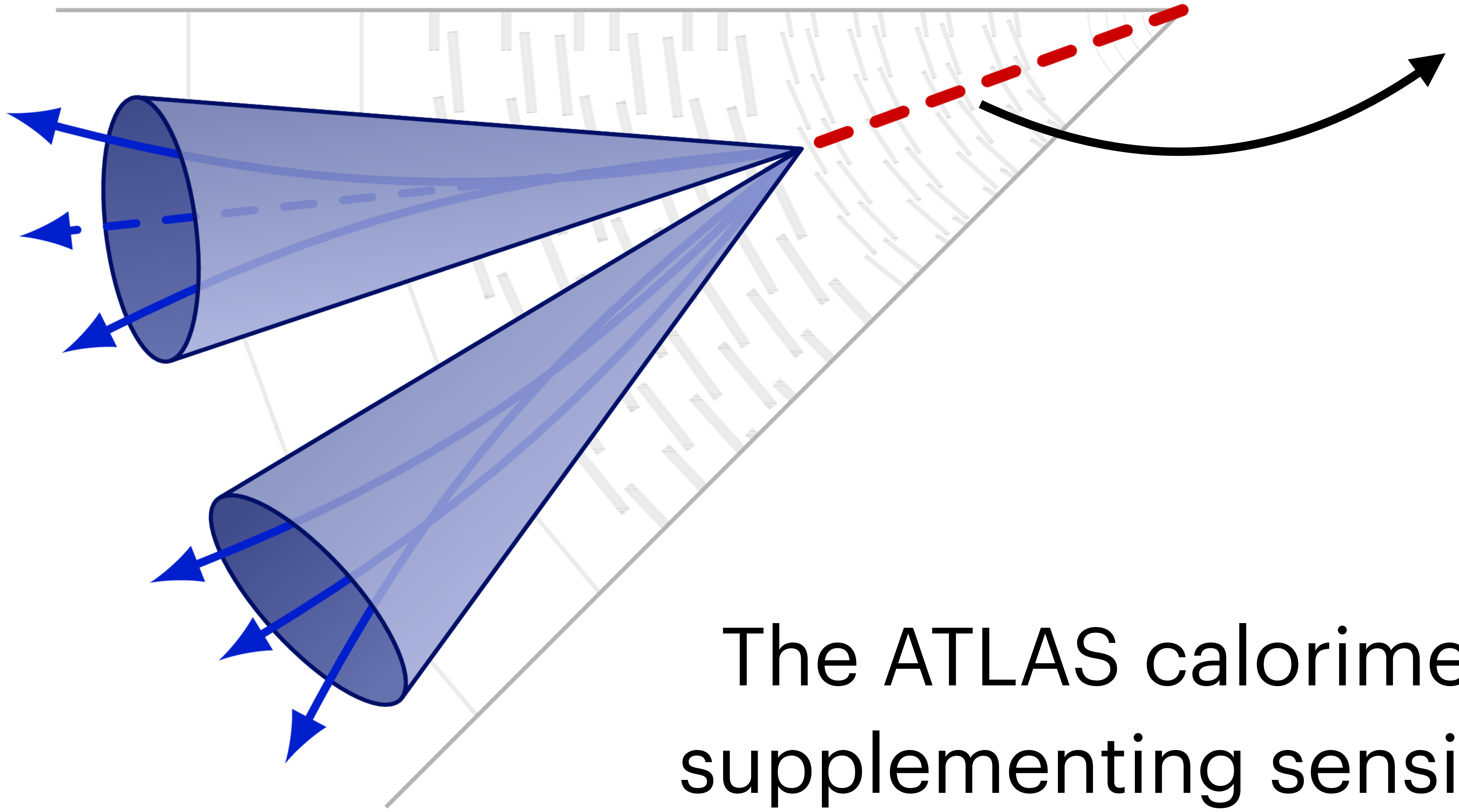


If LLP is low mass ($\beta \approx 1$), it's solely a displaced jet

However, if it's high mass ($\beta < 1$), it's ***both displaced and delayed***

The ATLAS calorimeters have good timing capabilities, supplementing sensitivity in a region where sensitivity to displacement is more limited

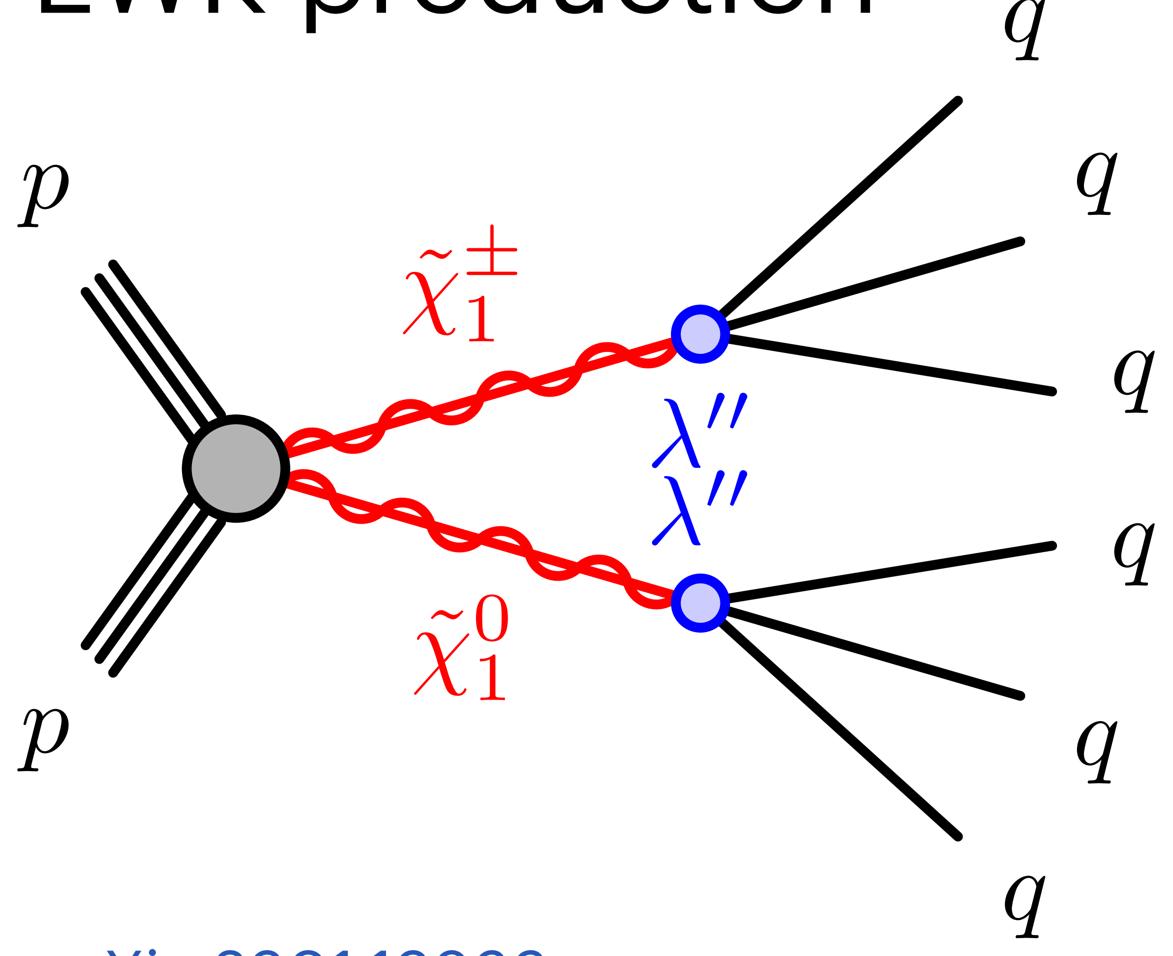
Signal models

Generally: we target models with heavy LLPs that decay into quarks before or inside the calorimeter systems

Specifically: we use three different signal models for benchmarking

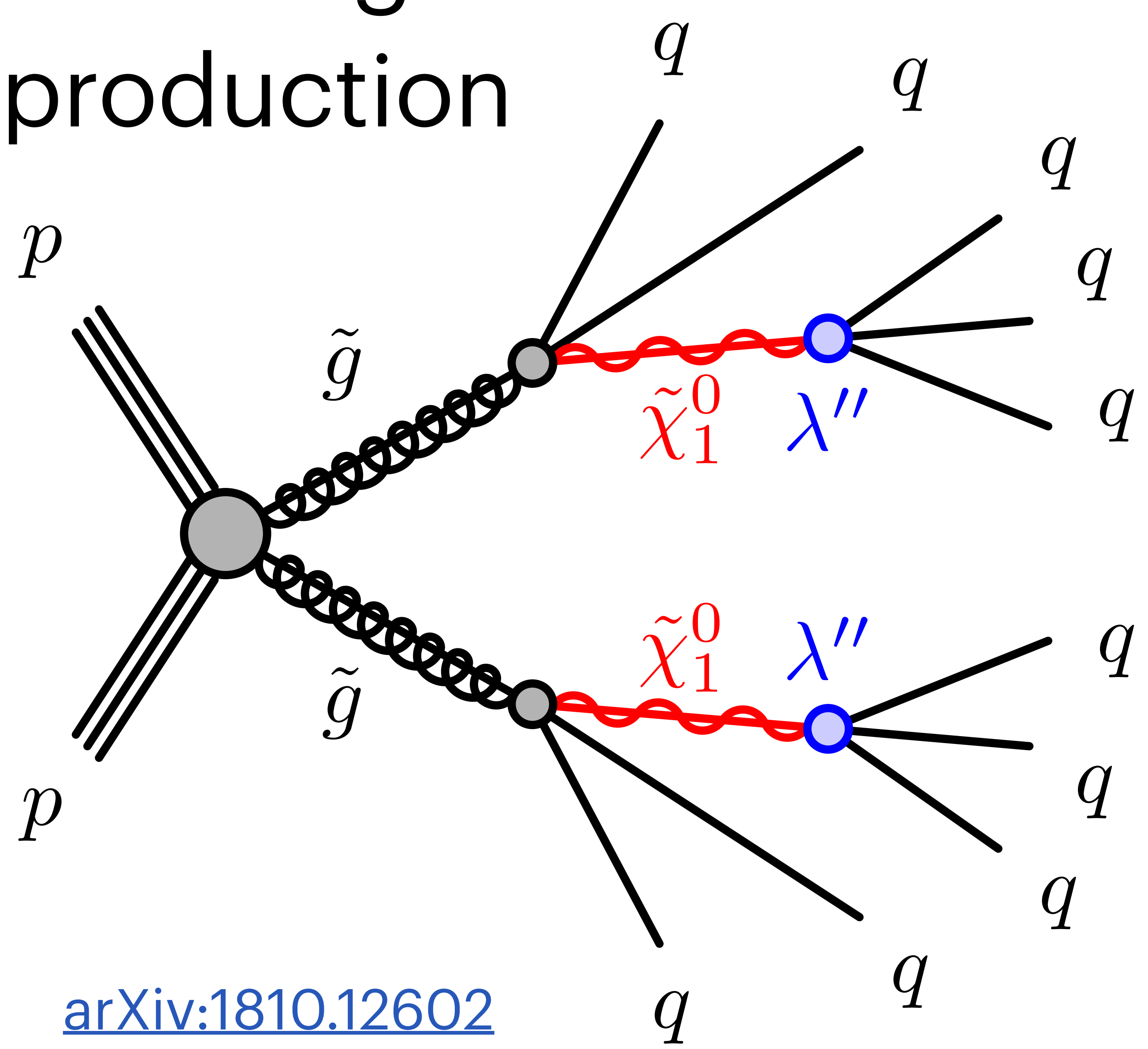
R-parity violating (RPV) neutralinos

EWK production



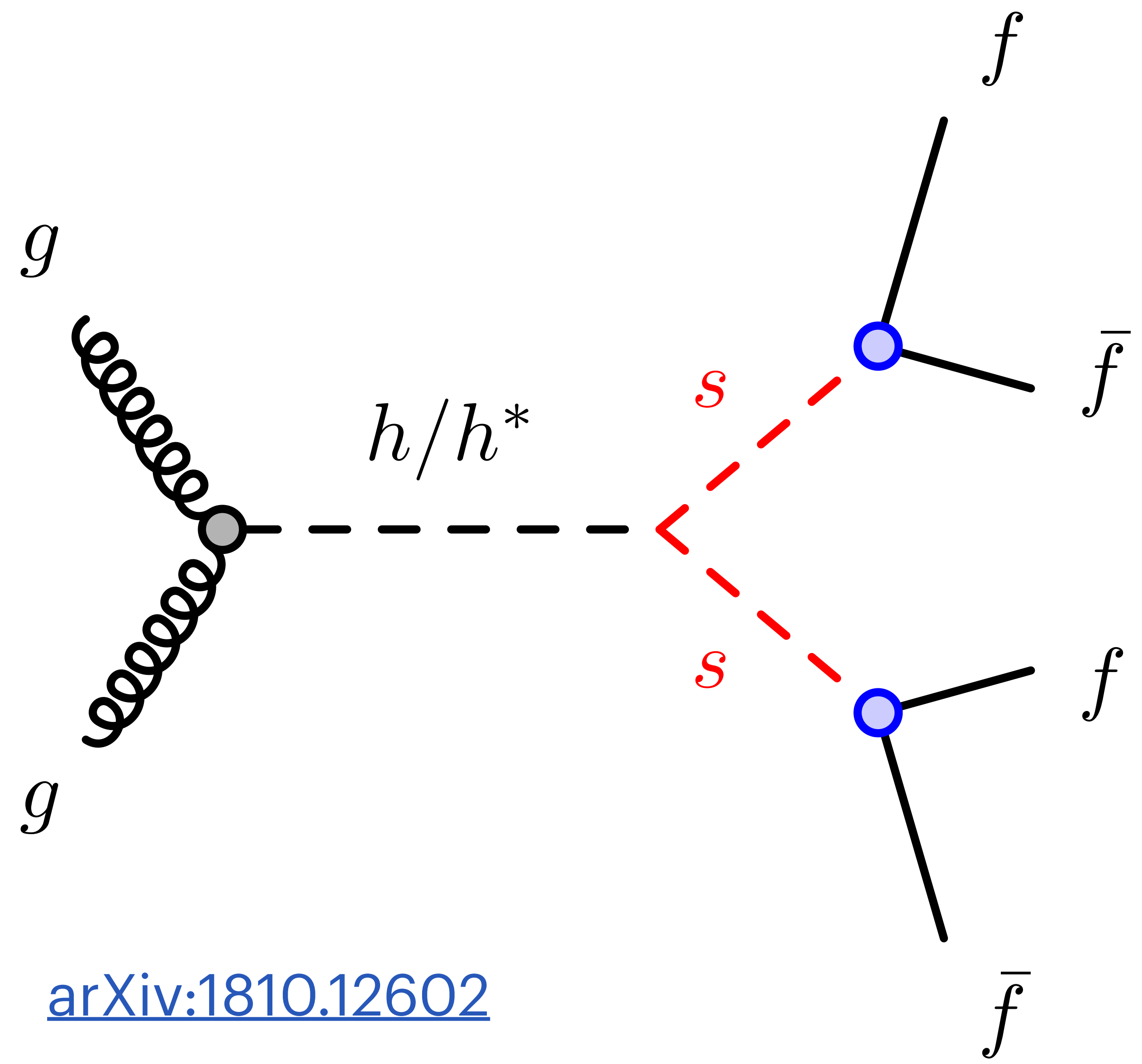
arXiv:2301.13866

Strong production



arXiv:1810.12602

Higgs to heavy scalar (HSS)



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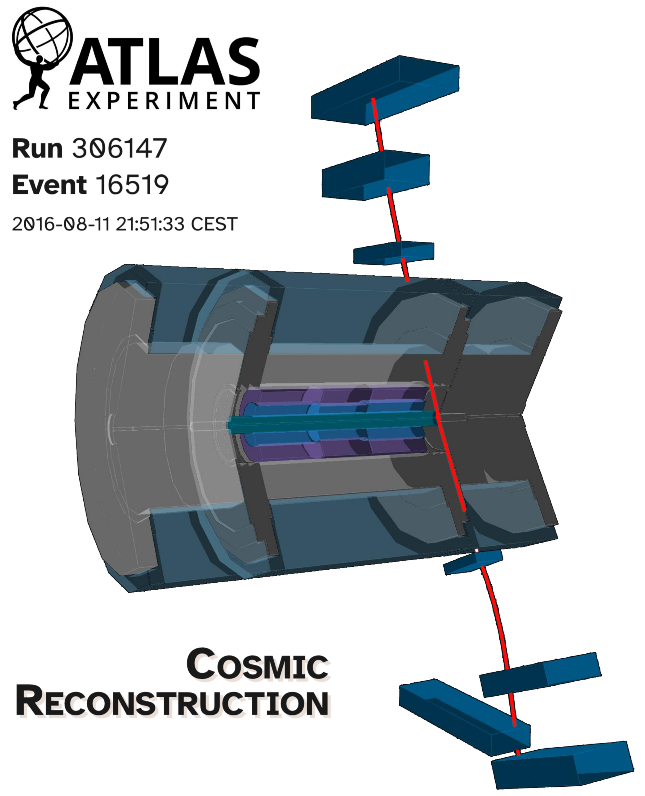
Background overview

Non-collision backgrounds

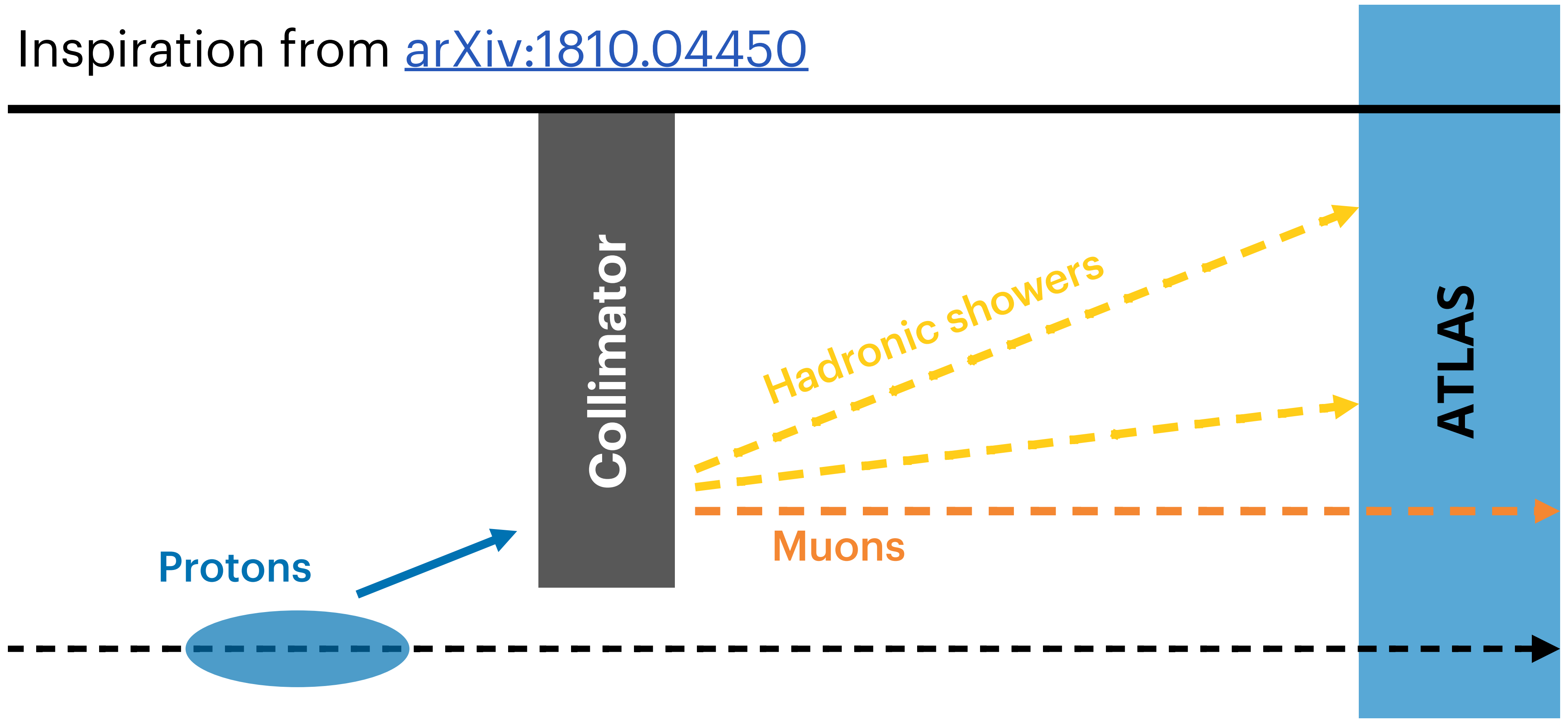
Cosmic muons



Adapted from arXiv:2104.03050

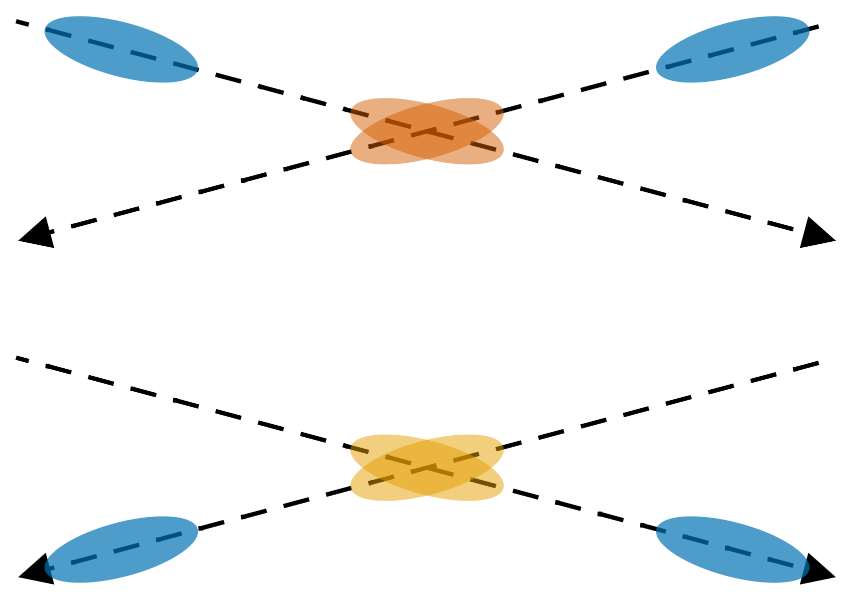
Beam-induced background (BIB)

Inspiration from arXiv:1810.04450

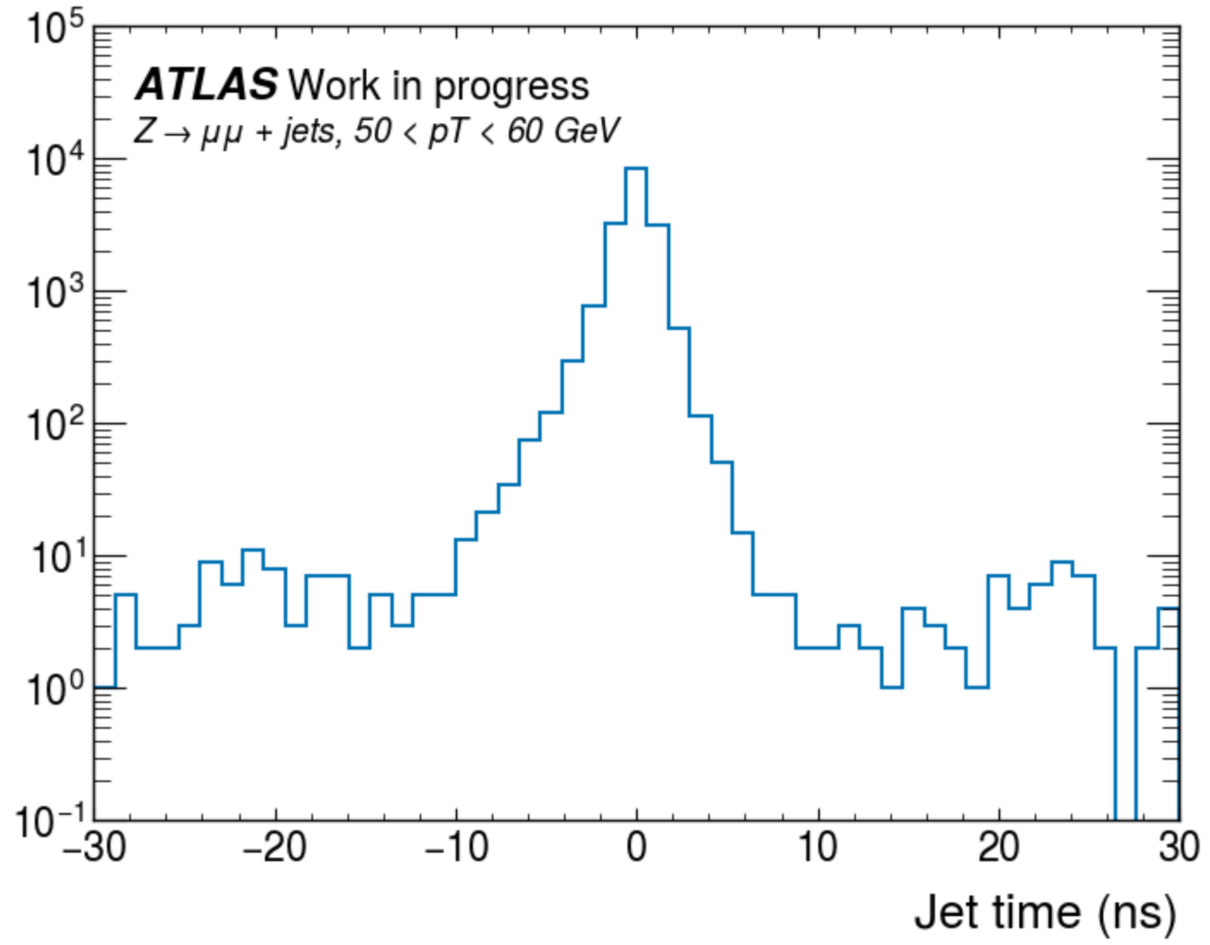


Collision backgrounds

Satellite collisions



Mis-timed SM jets



Analysis overview

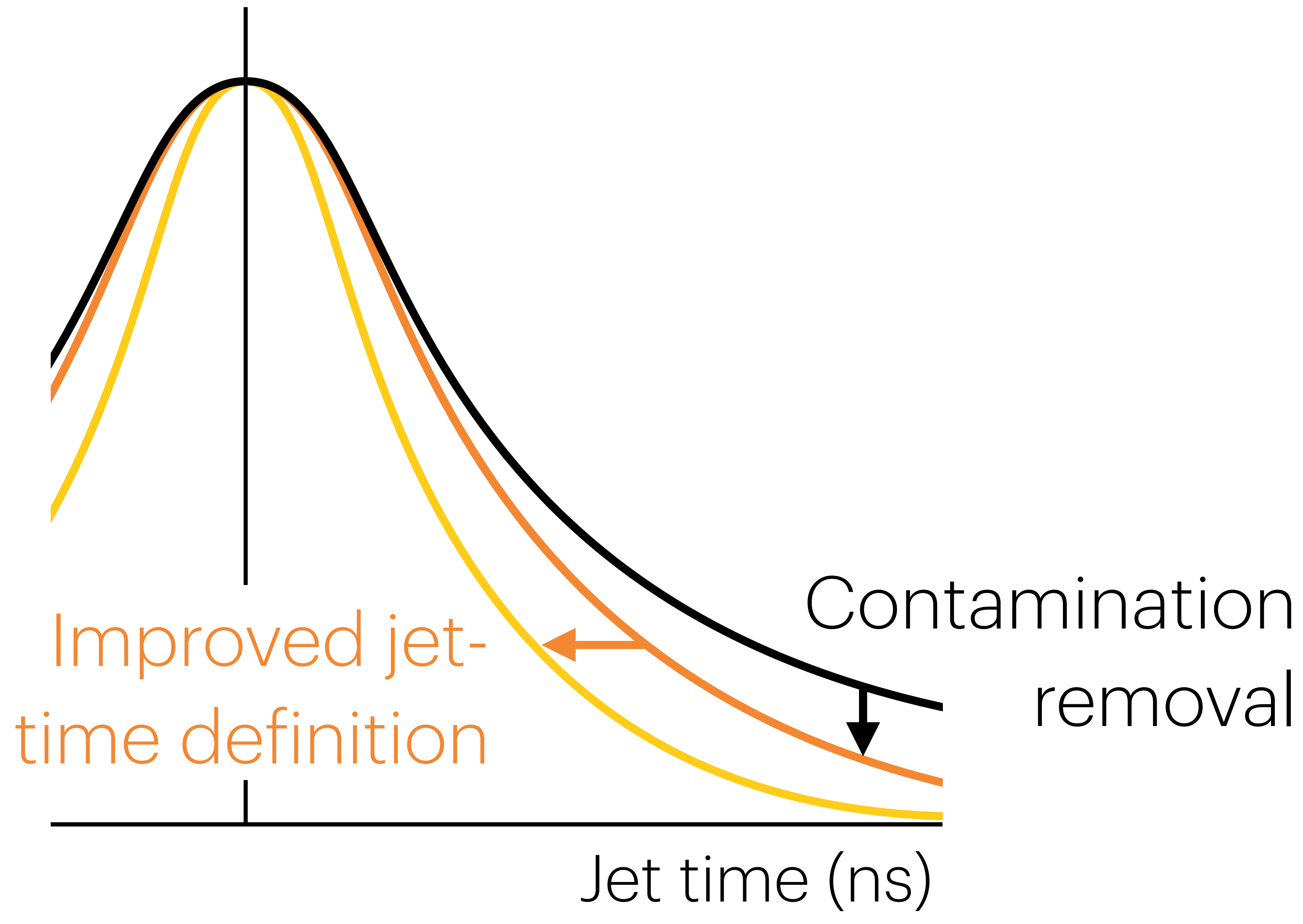
Goal: low-background search for high-pT and significantly-delayed jets

Backgrounds are not modelled in MC, so all require data-driven methods:

- **Cosmic muons**: custom tag to remove cosmics based on muon segments
- **BIB**: custom tag to remove BIB based on calorimeter cell positions
- **Mis-timed SM jets**:

  which I also work on!

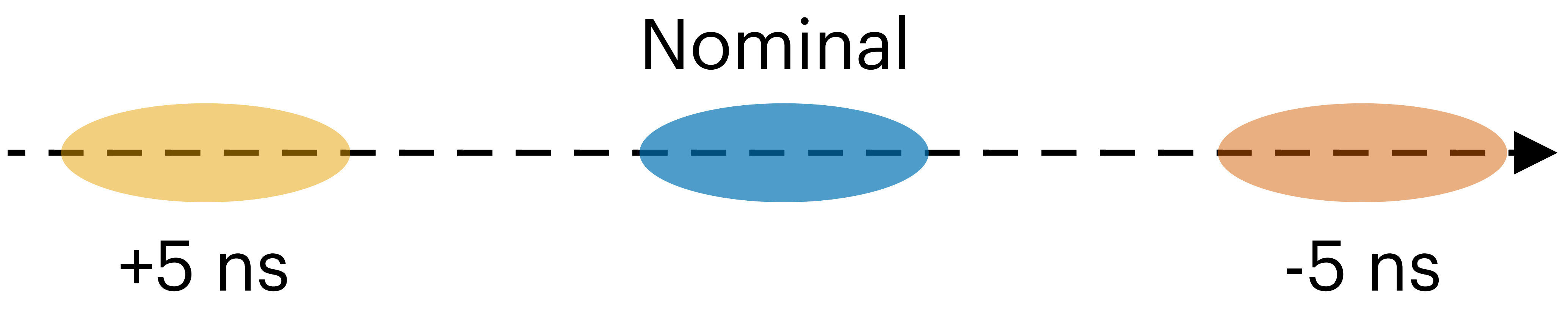
  1. Custom tag to remove contaminated jets (including anomaly detection R&D)
  2. Improved jet-timing calculation compared to ATLAS default (including GNN R&D)
- **Satellites**: up next!



Satellite collisions

What are satellite collisions?

Bunch structure:



Satellite collisions are collisions between protons in RF-buckets other than nominal buckets

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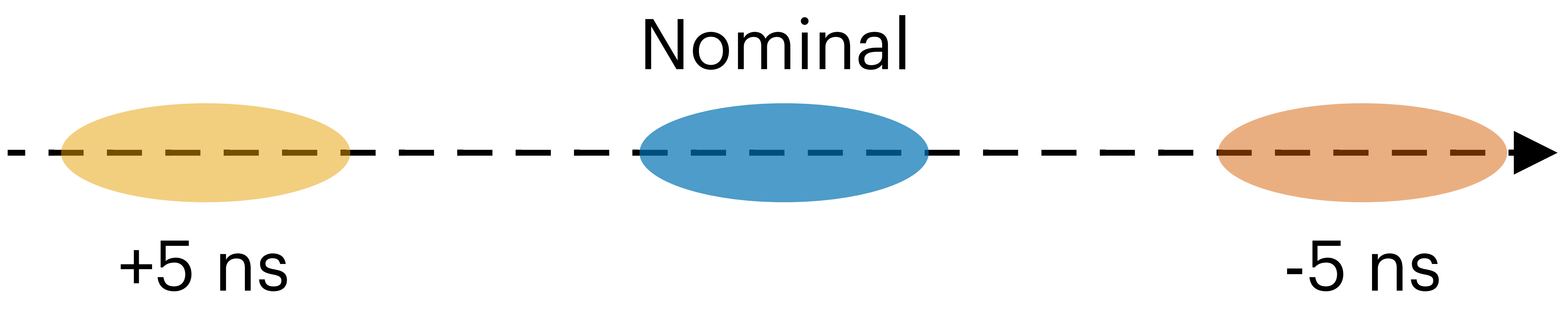
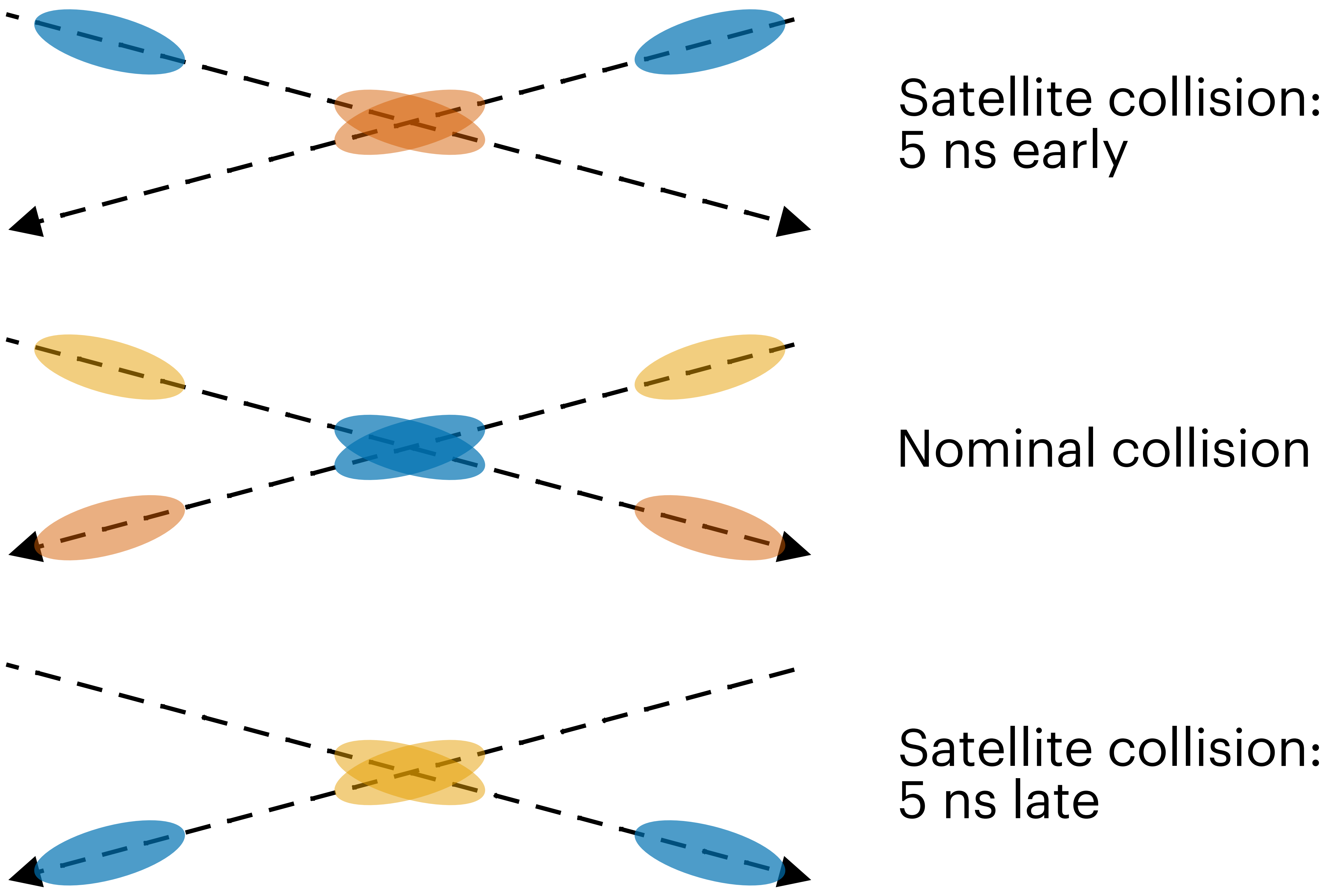


Collision types:



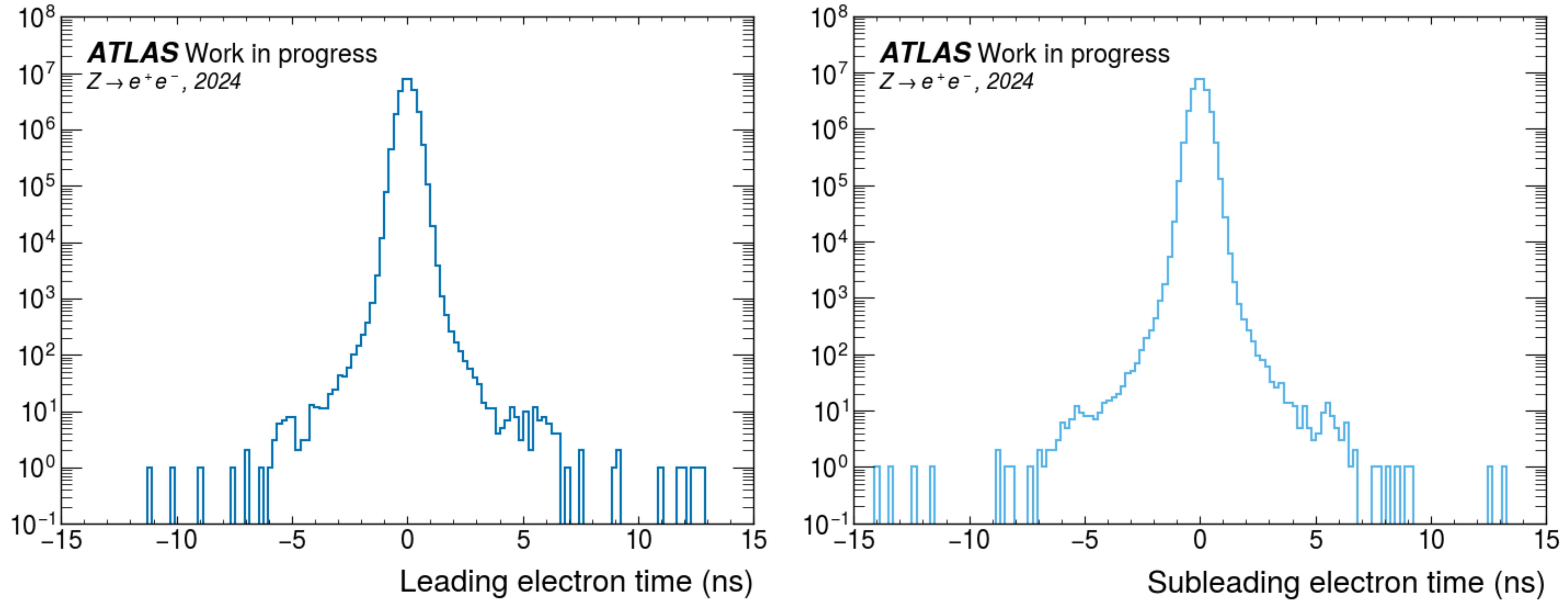
Satellite collisions are collisions between protons in RF-buckets other than nominal buckets

This produces genuinely delayed jets (but localised in time and with tracks in the inner detector)

Satellites in $Z \rightarrow e^+e^-$

LAr has high precision (~200 ps) for high-energy electrons, so look at $Z \rightarrow e^+e^-$ (since it can be cleanly selected) and require cell energy > 10 GeV

1D distributions are still too broad to clearly see electrons from satellite events



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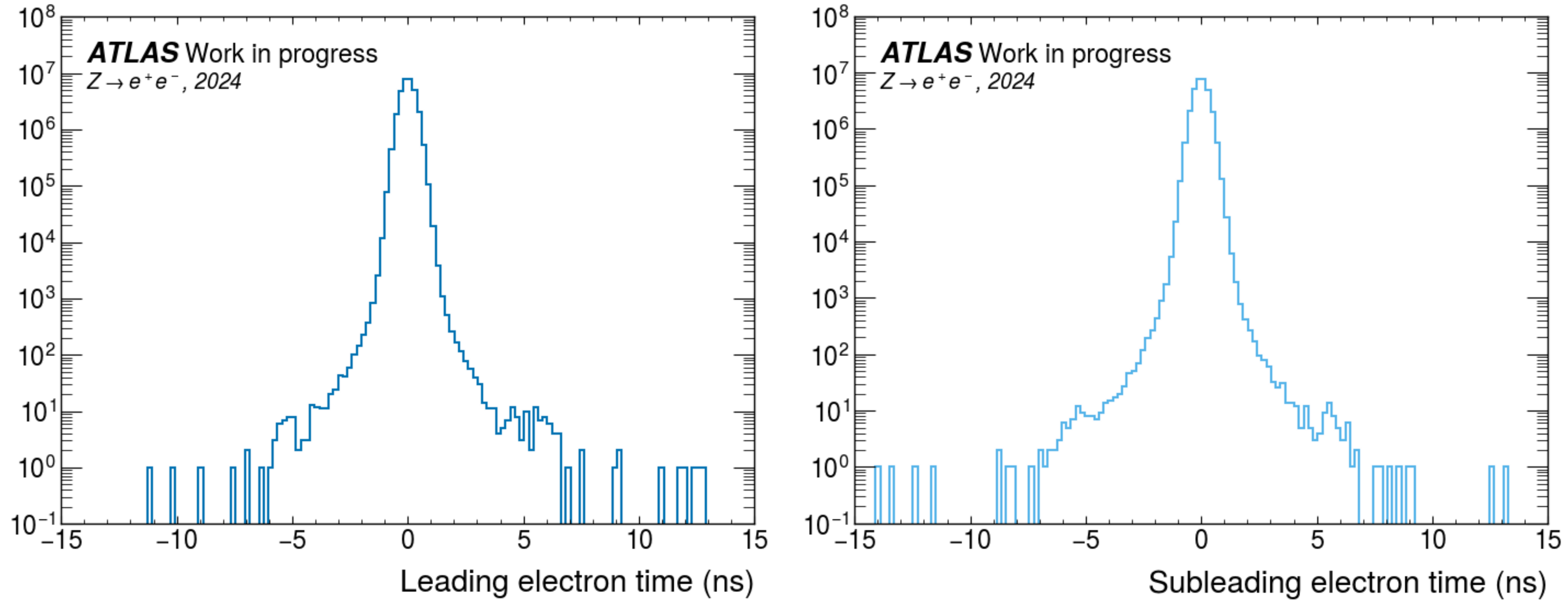

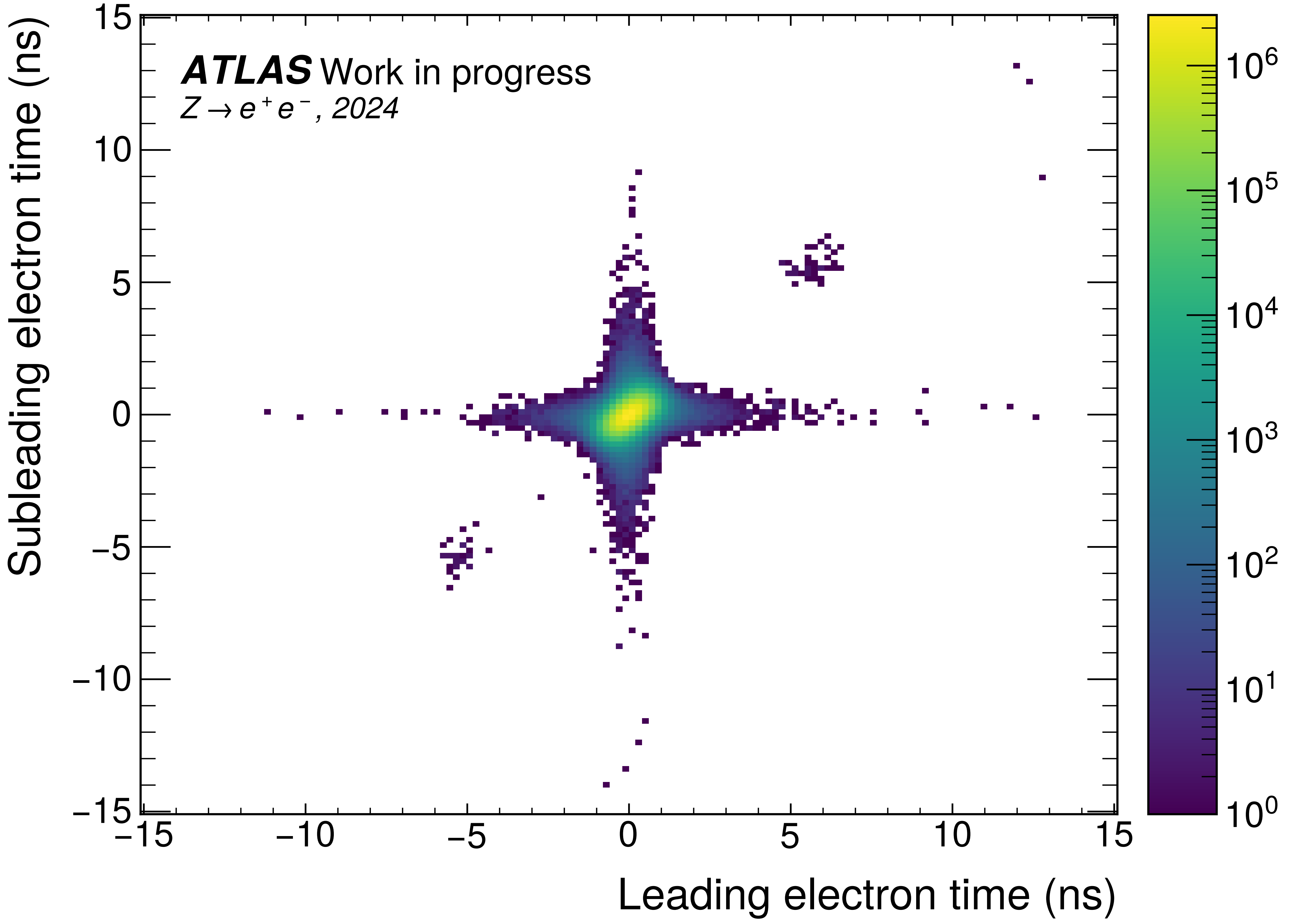

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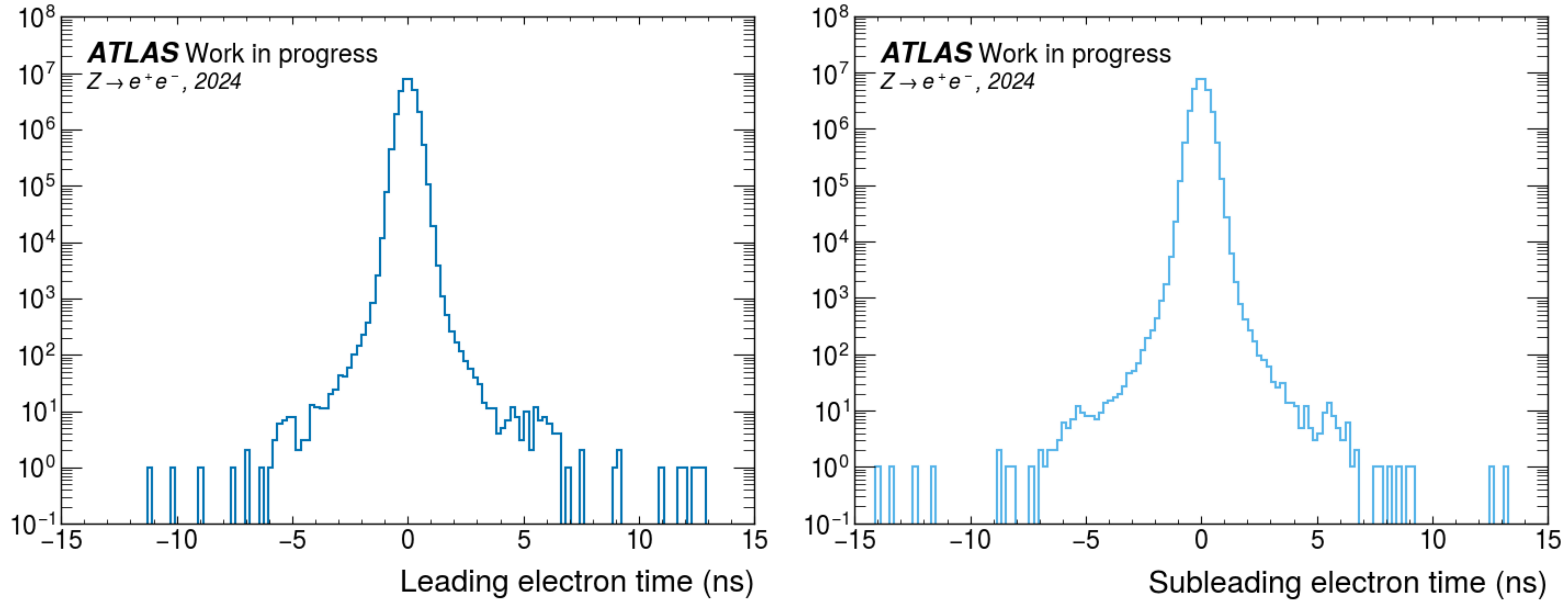
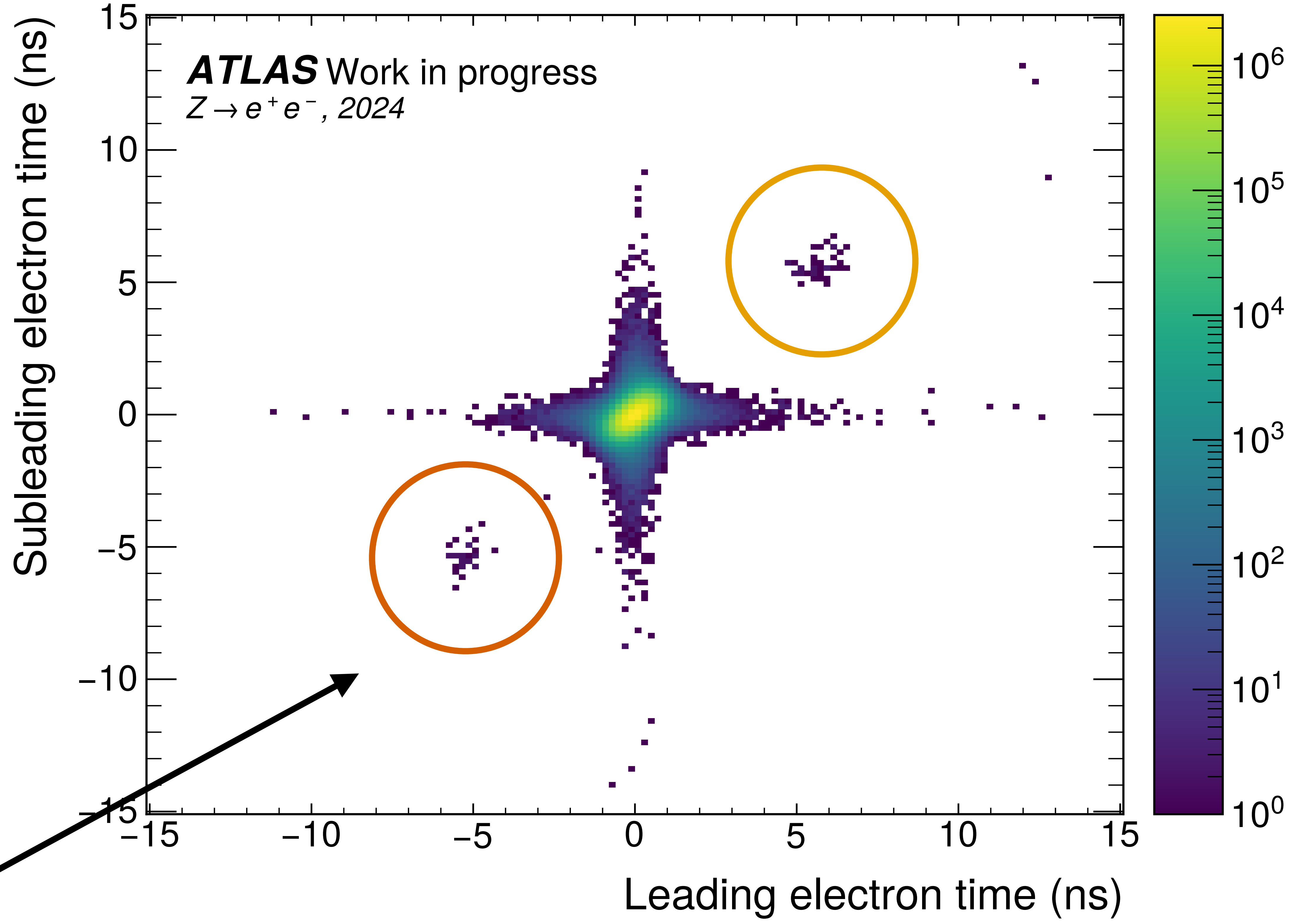




However, leading vs. subleading electron time clearly shows clusters at ±5 ns —> **Z bosons produced in early and late satellite collisions!**

Relative counts: $r_{\text{early}} = (1.0 \pm 0.2) \times 10^{-6}$

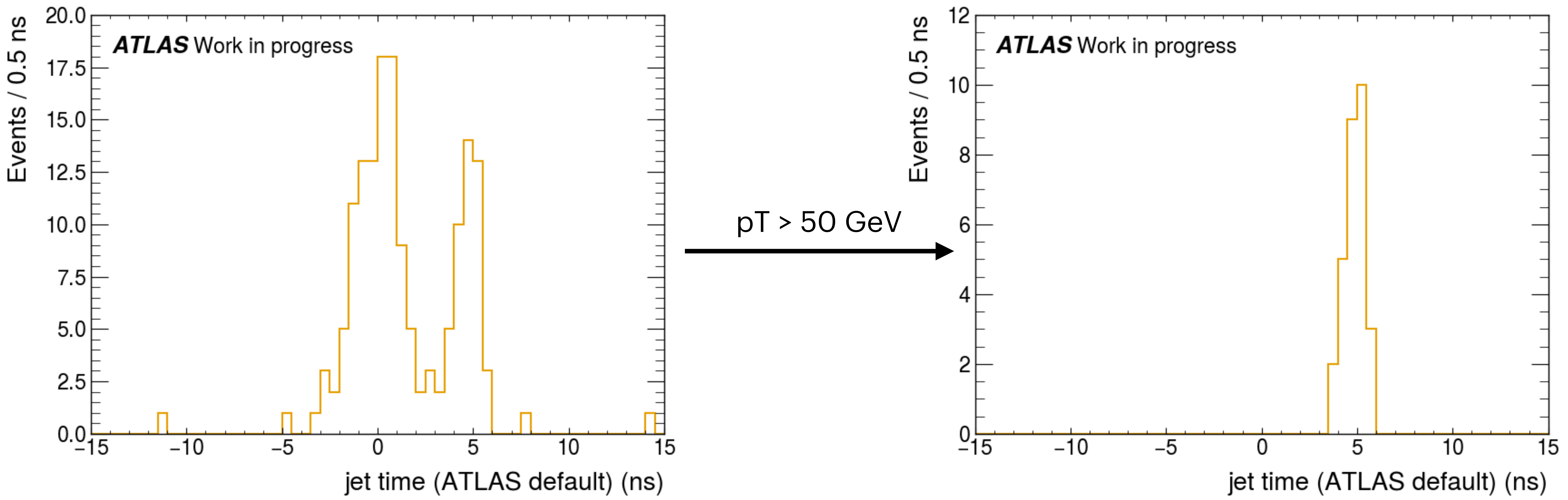
(compared to nominal collisions) $r_{\text{late}} = (1.3 \pm 0.2) \times 10^{-6}$

Moving from electrons to jets

Jet-time distribution is different from electrons, but expected to follow SM jets (just shifted)

But shifted by how much? Exactly ±5 ns, or are there some biases?

Let's look at jets in known satellite events from $Z \rightarrow e^+e^-$ (pictured here: late)

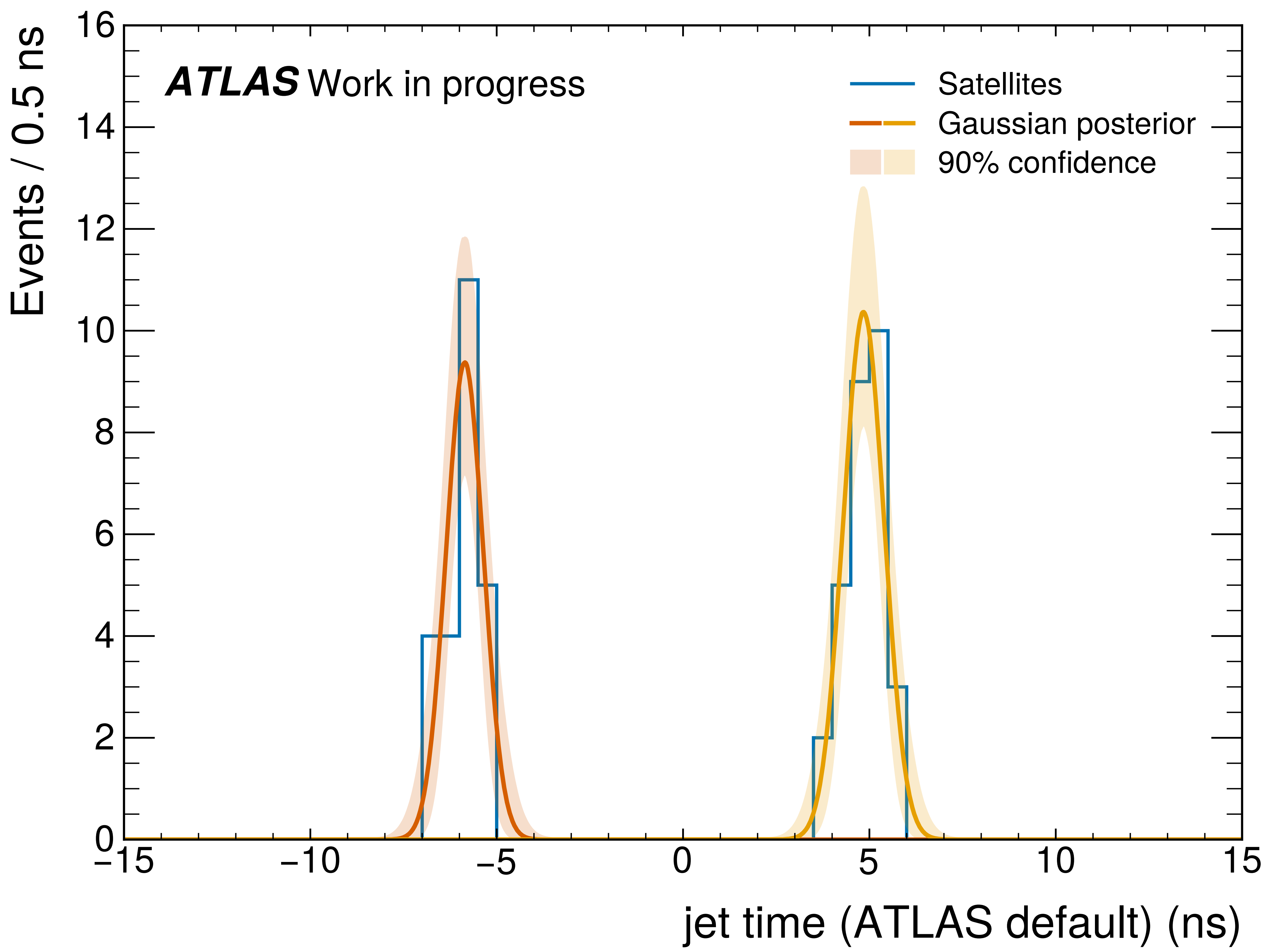


Bayesian analysis

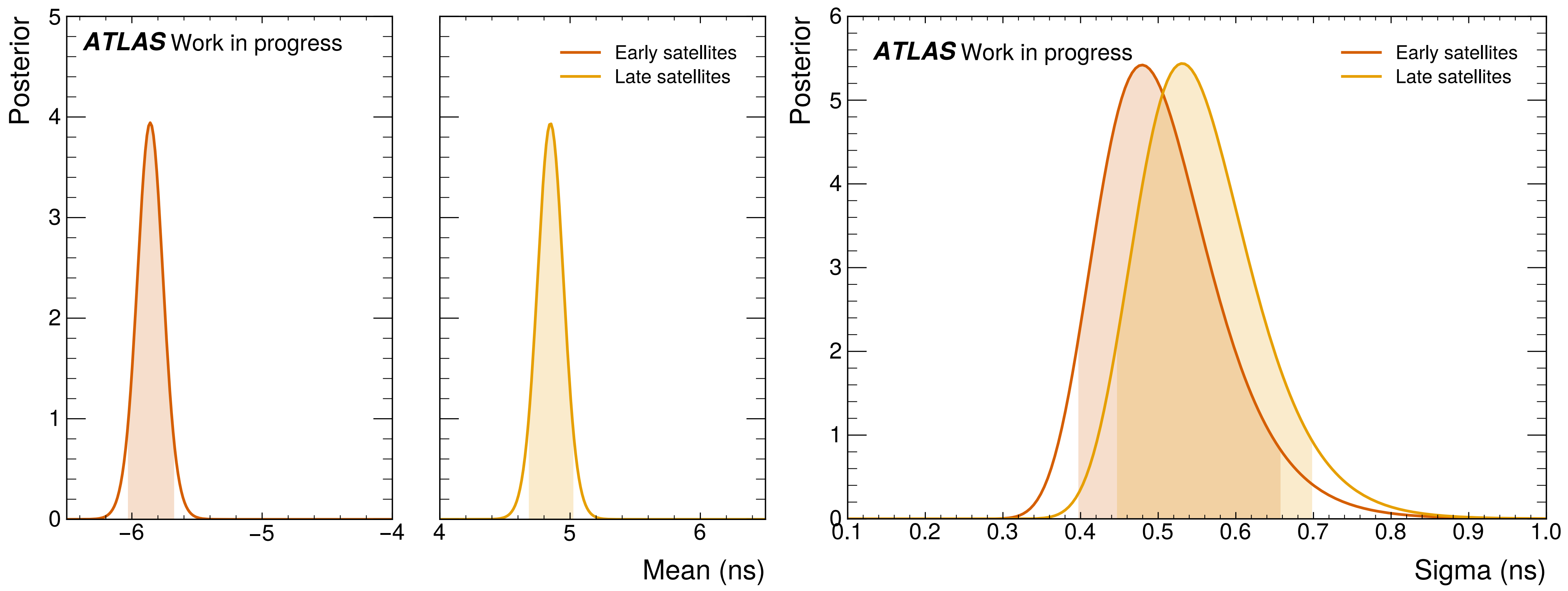
- 24 jets in early and 29 in late satellites
  —> Small sample size, ideal for Bayesian inference with a Gaussian model

- Jet times aren't perfectly centred on ±5 ns
  —> Jet-time calculation isn't independent of absolute time

  Not enough data to fully model this effect, but we can use this analysis to inform a systematic uncertainty



Combining distribution posteriors with relative counts and a signal-region definition will give the final satellites estimate!



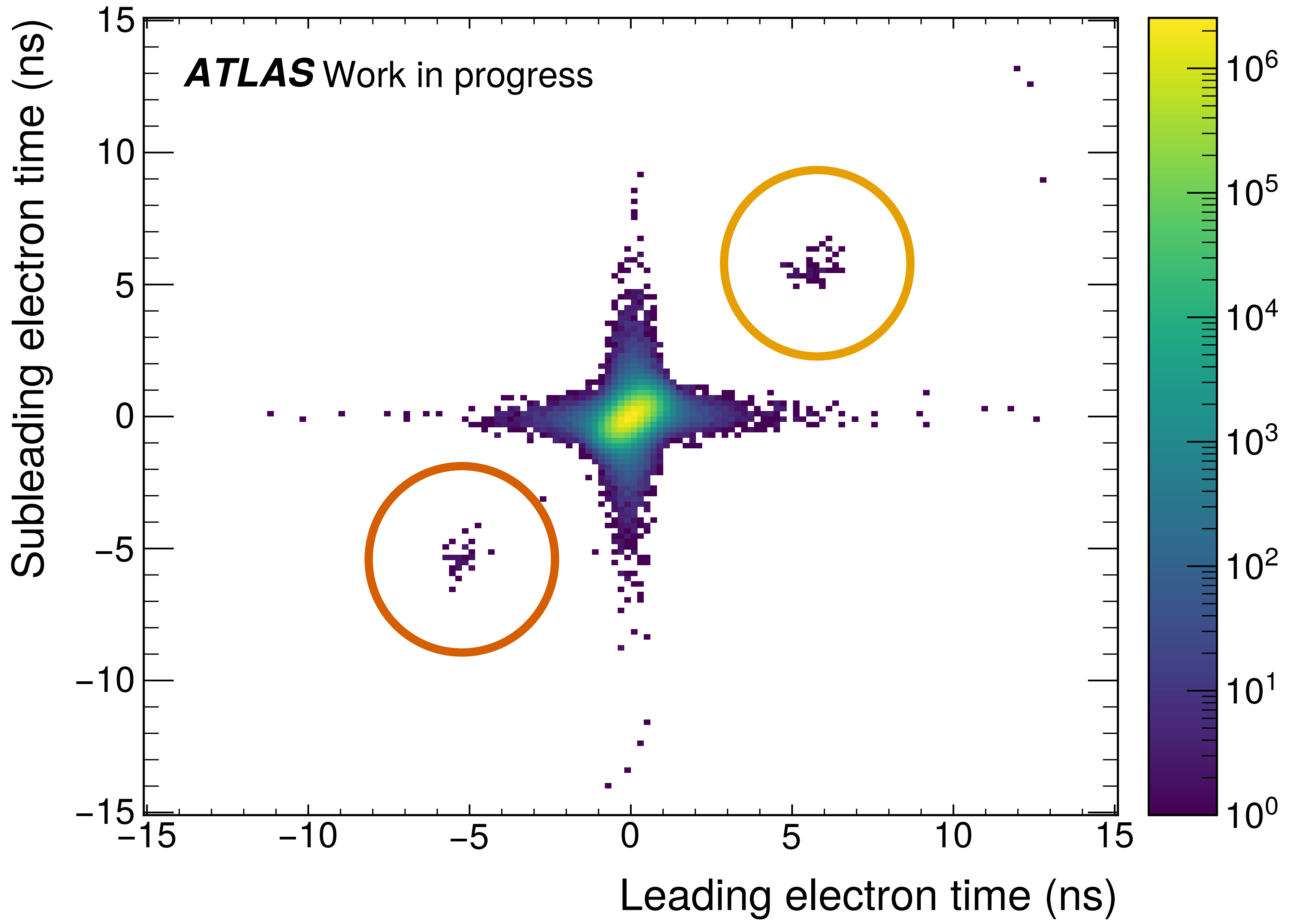
Recap & outlook

Heavy long-lived particles produce ***delayed*** decays, which complements their displacement and gives additional sensitivity in calorimeter systems

The search for ***delayed jets*** requires modelling of unconventional backgrounds, with almost all new estimation techniques

One such background: ***satellite collisions*** happening at ±5 ns, estimated with:

- Relative count estimated at $\mathcal{O}(10^{-6})$ from $Z \to e^+e^-$
- Jet-time distribution and systematics estimated from SM jets from $Z \to e^+e^- + \text{jets}$



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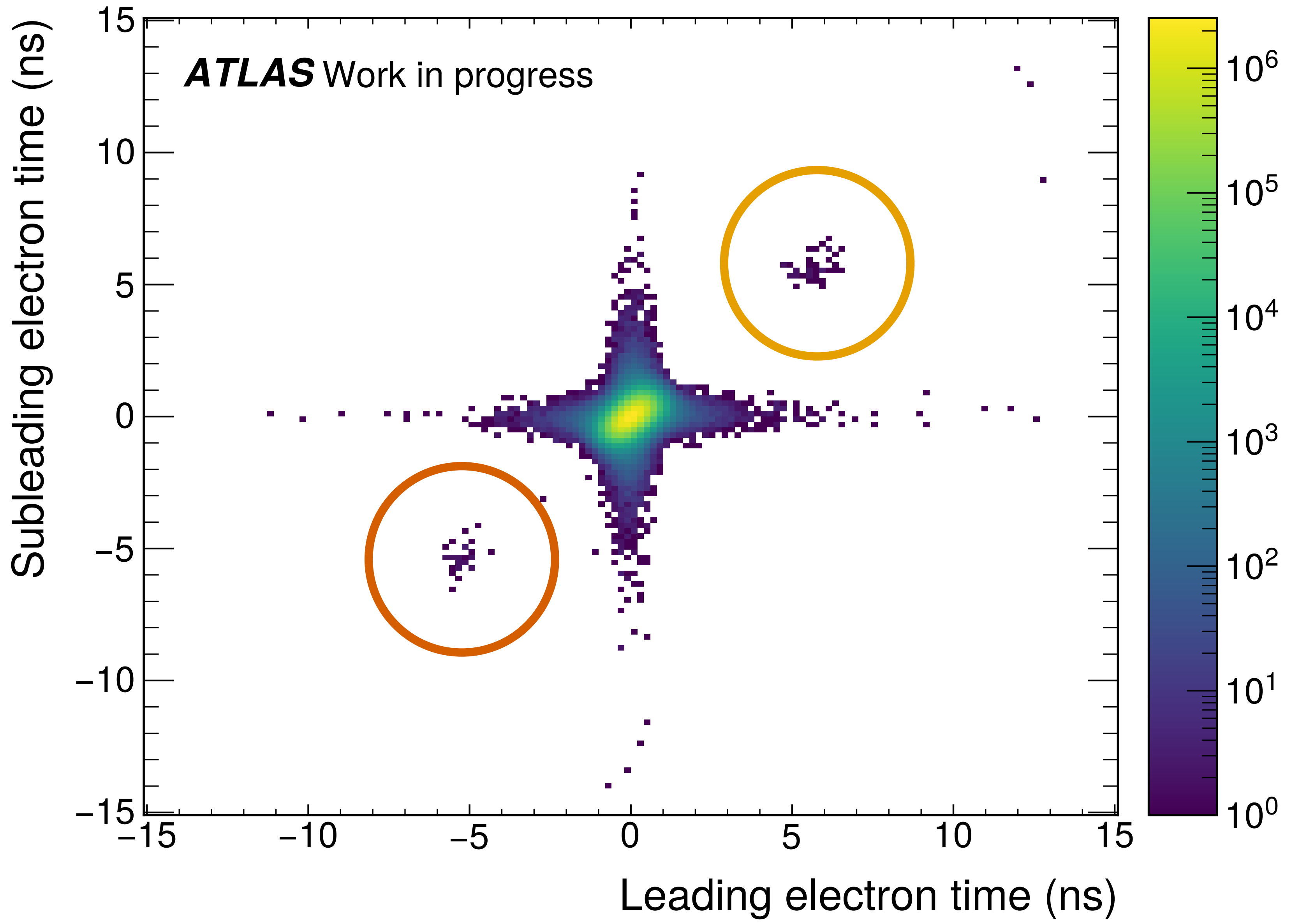

In Run 4, ATLAS will have a new timing detector: ***HGTD***! Timing information will become more important to overall ATLAS reconstruction, and this search can provide important groundwork


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Satellites in $W^{\pm} \rightarrow e^{\pm}\nu$

- $W^{\pm} \rightarrow e^{\pm}\nu$ has much more stats than $Z \rightarrow e^{+}e^{-}$ so it's also a candidate for satellites estimation
- Two problems:
  - Satellite collisions are overlayed on the instrumental background, requiring a fitting procedure and making it harder to select satellite events to study the jets
  - LAr's timing response is calibrated on $W^{\pm} \rightarrow e^{\pm}\nu$, introducing biases in the satellite counts from fits (when compared to $Z \rightarrow e^{+}e^{-}$)