Long-lived particles in ATLAS

Unconventional challenges

FSP Workshop (online): Long-lived particles at Belle II
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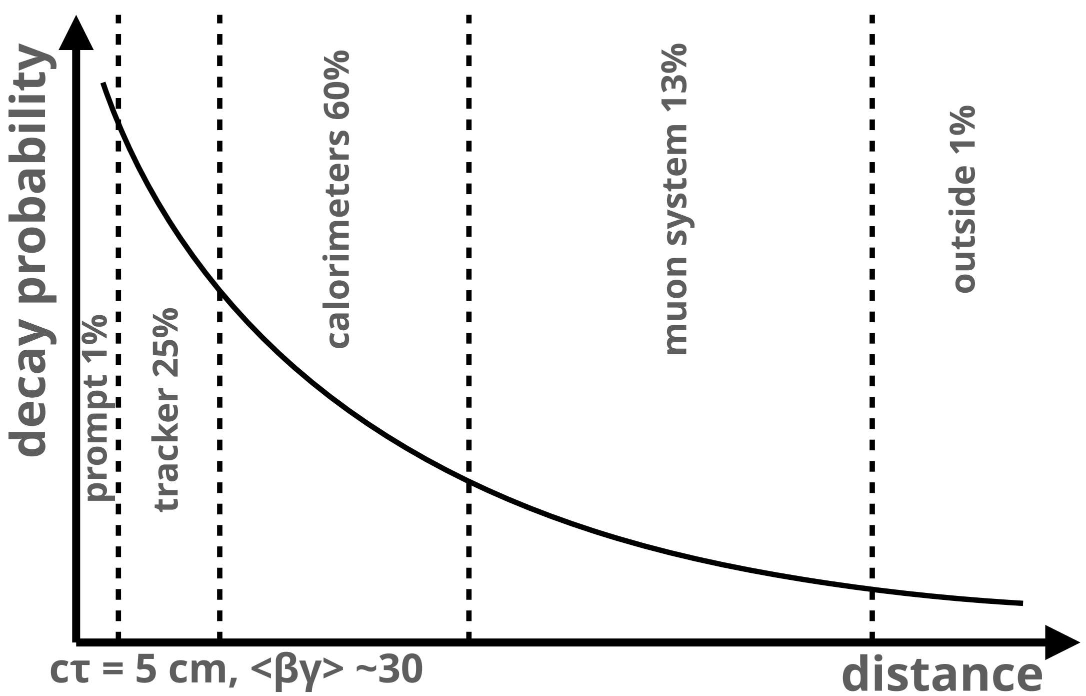
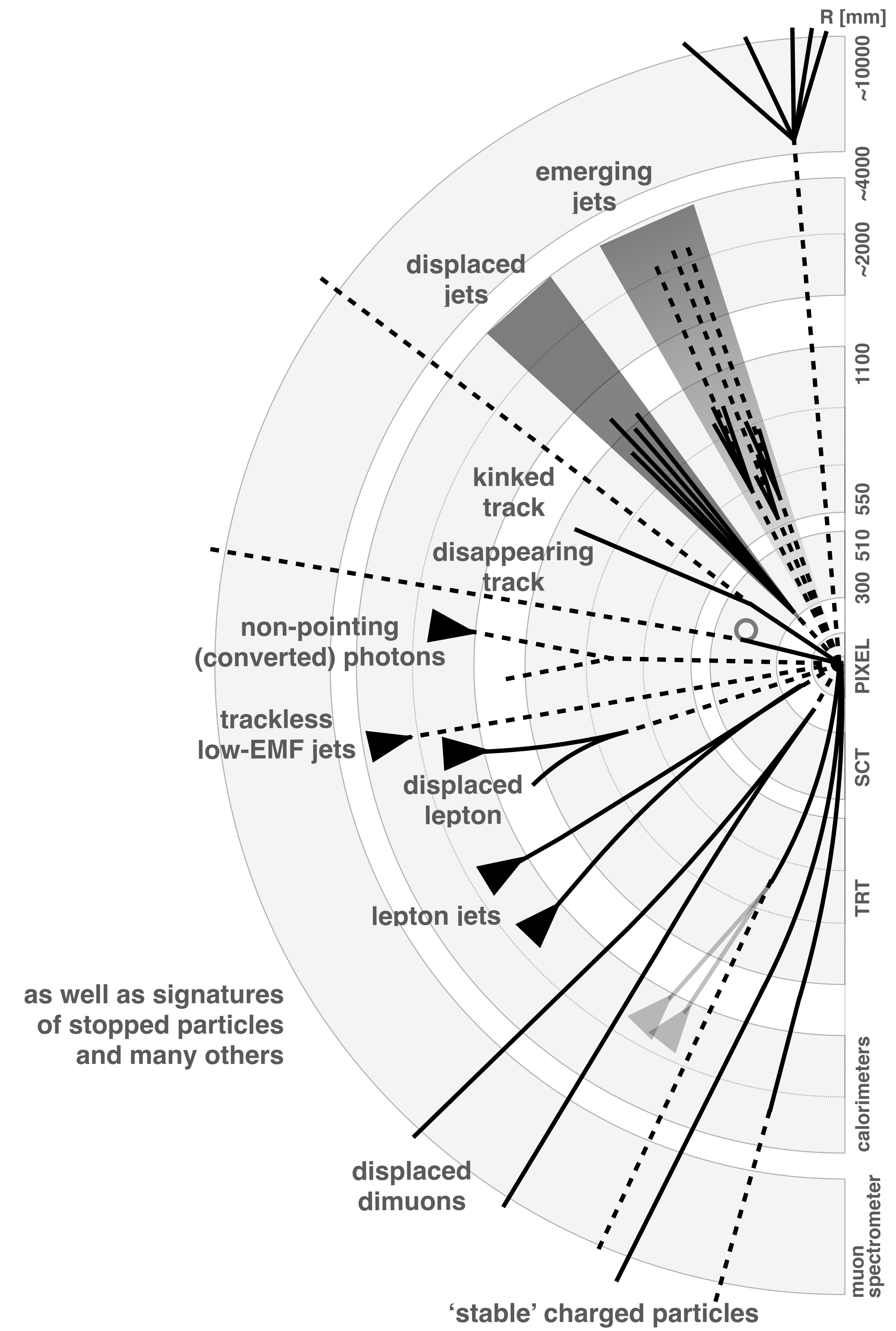
What signatures are we looking for?

Particles that live long enough to deposit most of their energy or decay to Standard Model particles within the detector volume or leave it entirely

Multiple search strategies can be applied to one signature, as observed lifetime is governed by an exponential defined by the proper lifetime cτ





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What challenges do we face?

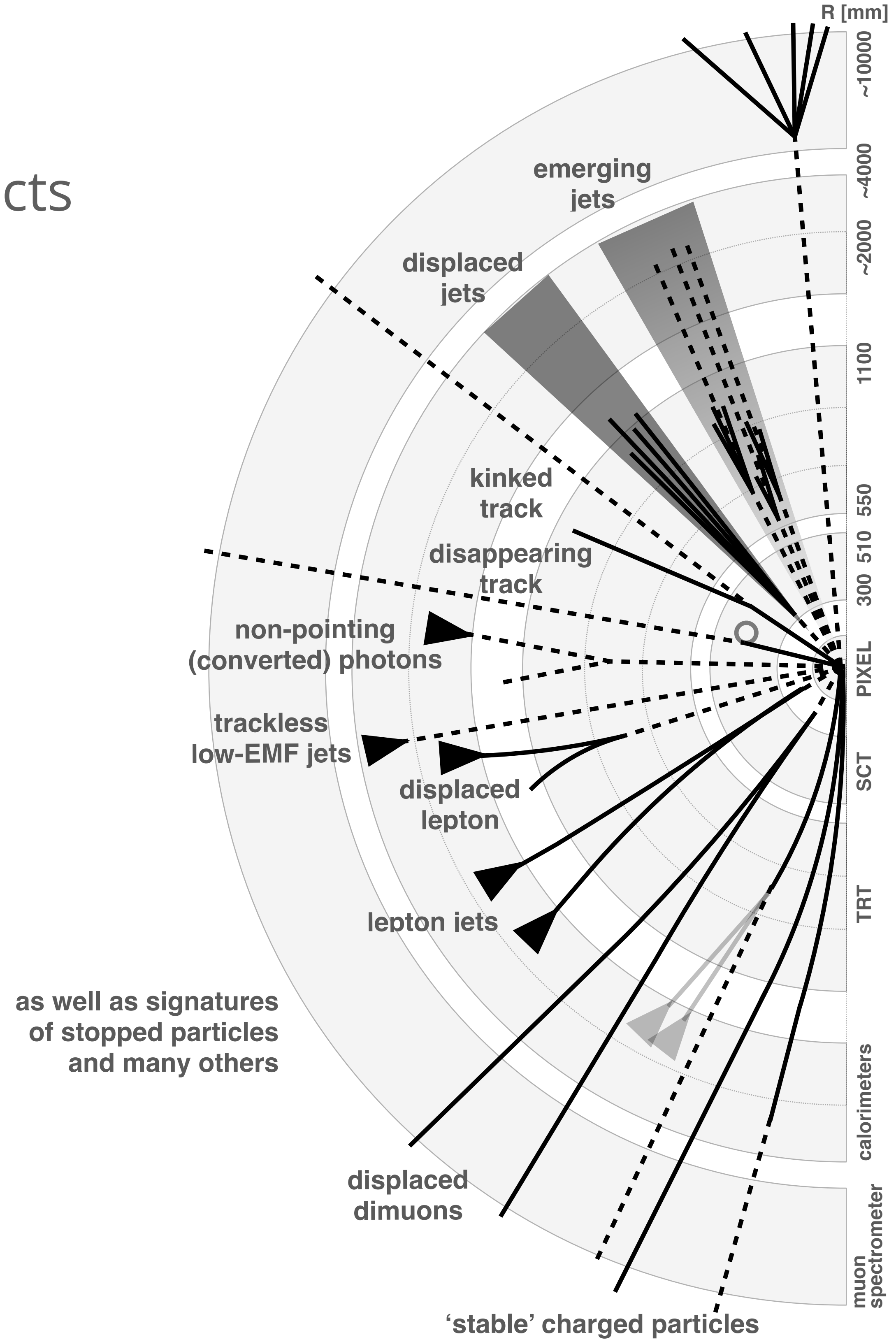
We are dealing with unconventional signatures/objects that require non-standard **reconstruction**

Displaced vertices
→ Large-radius tracking
→ Displaced-vertex reconstruction

Disappearing/kinked tracks
→ Silicon/pixel-only tracking

Emerging jets / decays of neutral particles in the calorimeters
→ 'Trackless' jets

Heavy charged long-lived particles
→ Low-β tracking and time-of-flight measurements

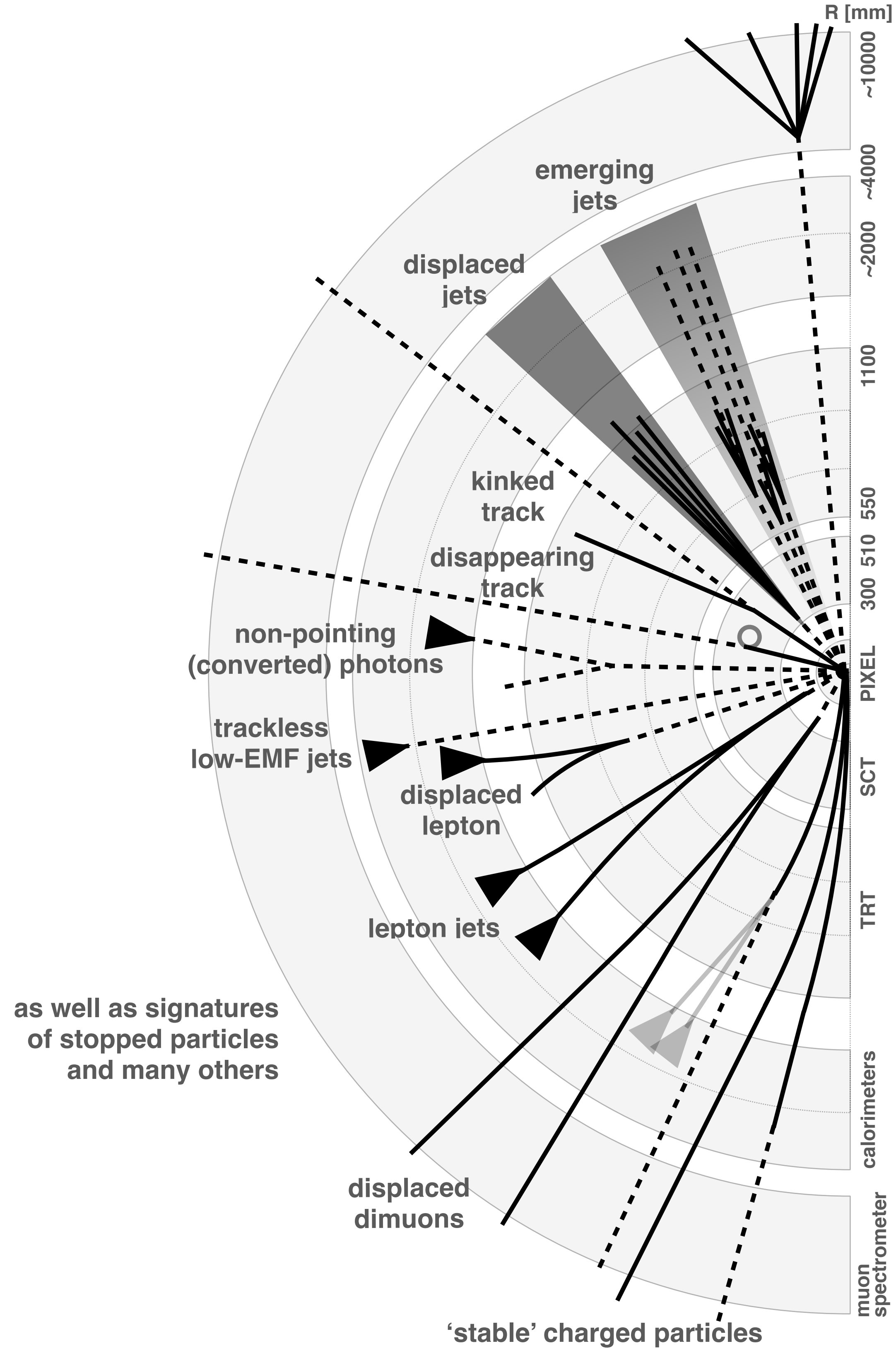


What challenges do we face?

Standard **triggers** often inefficient or analyses have to rely on MET triggers
→ dedicated LLP triggers

Standard **recommendations/calibrations** often don't apply to unconventional observables and signatures
→ dedicated calibrations

Unconventional signatures come with unconventional **backgrounds**
→ often little to no Standard Model background
→ dedicated (usually data-driven) estimates or rejection techniques



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Large-radius tracking and displaced-vertex reconstruction

Standard tracking inefficient for particles decaying further than a few mm from the IP

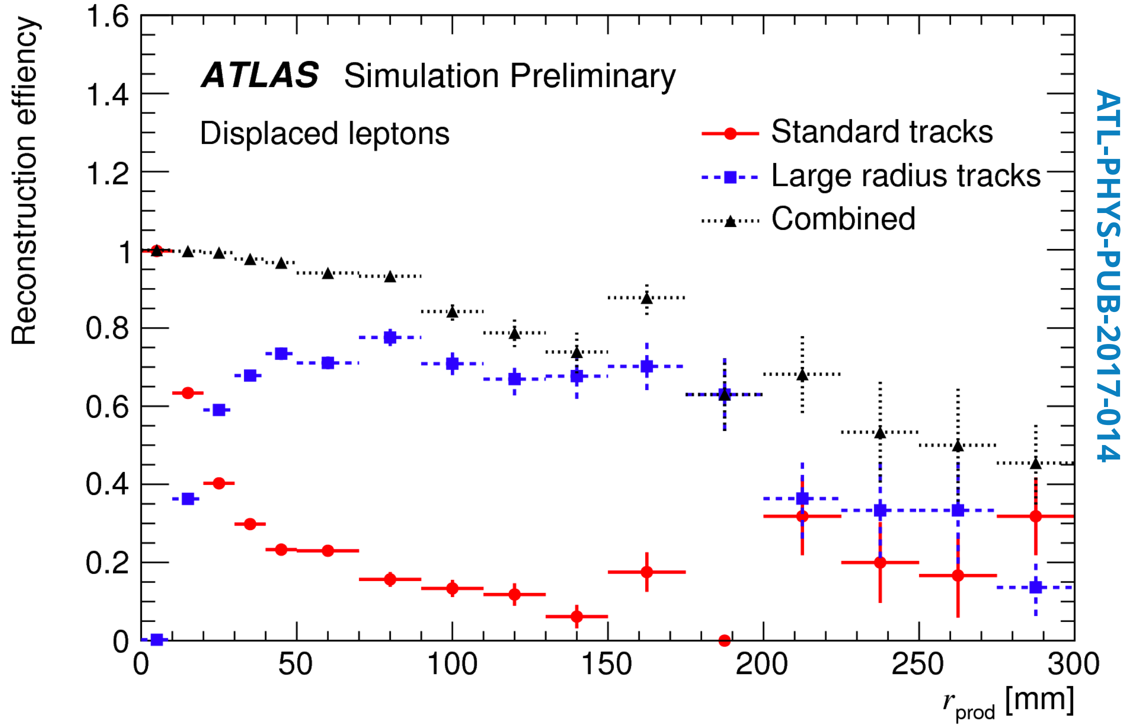
inside-out + outside-in tracking

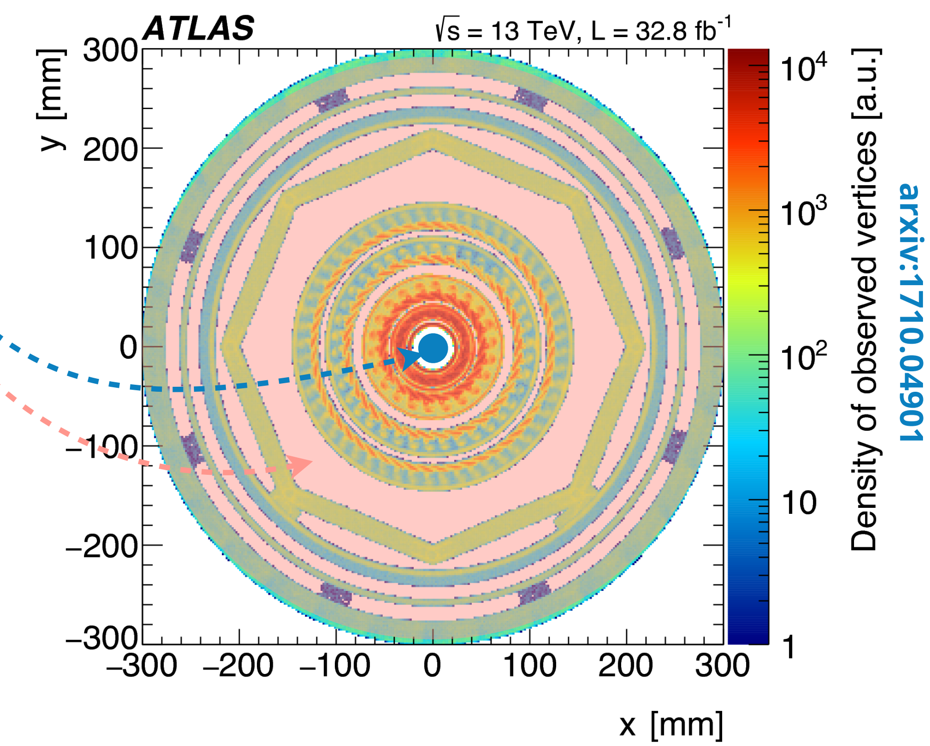
Large-radius tracking adds another **inside-out step with relaxed selections** and track seeding on un-used hits

d_0, z_0, $\#_{\text{Hits}}$, $\#_{\text{shared}}$, …

In Run 2 only affordable for a small fraction of events processed in a **dedicated event stream**

Can be avoided by drastically reducing fake rate and thereby CPU intensive track finding and ambiguity solving

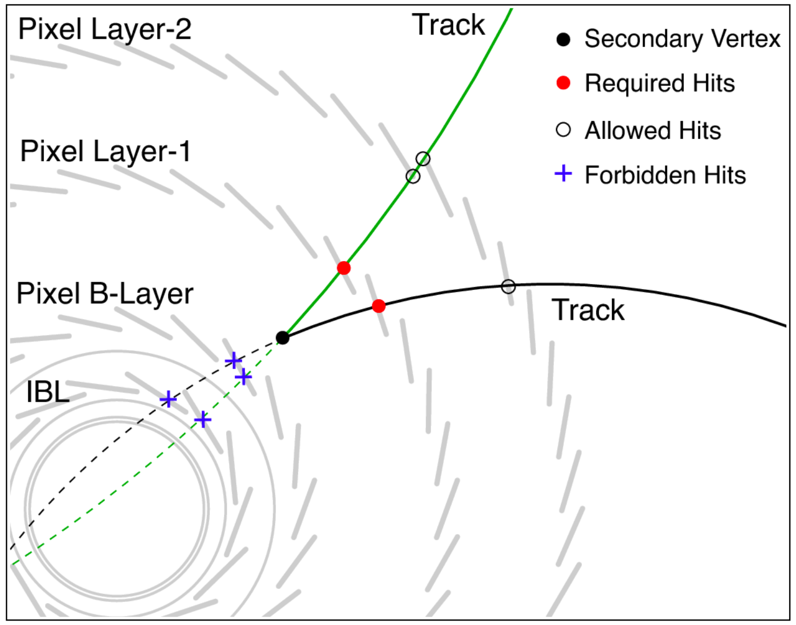




Large-radius tracking and displaced-vertex reconstruction

Large-radius tracking followed by displaced-vertex reconstruction using **two-track seed vertices**

- Preselection of tracks to **reduce combinatorics** (d_0 and combinations of p_T, η, $\#_{\mathrm{Hits}}^{\mathrm{Pixel}}$, $\#_{\mathrm{Hits}}^{\mathrm{SCT}}$, $\#_{\mathrm{Hits}}^{\mathrm{TRT}}$, ...)
- Two-track seed vertices are extended through **vertex merging** and **track attachment**
- Reconstruction **efficiencies around 80%** for high-multiplicity signatures over a wide range in decay radii



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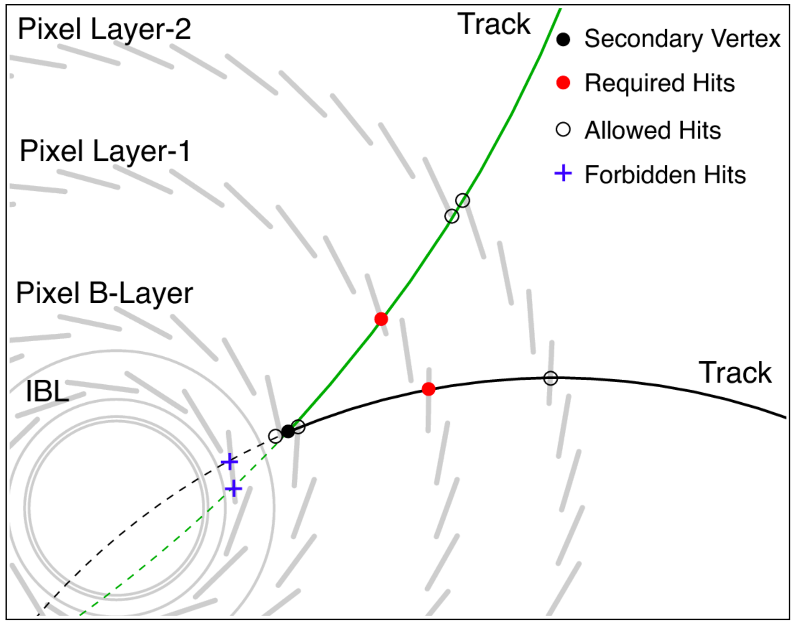

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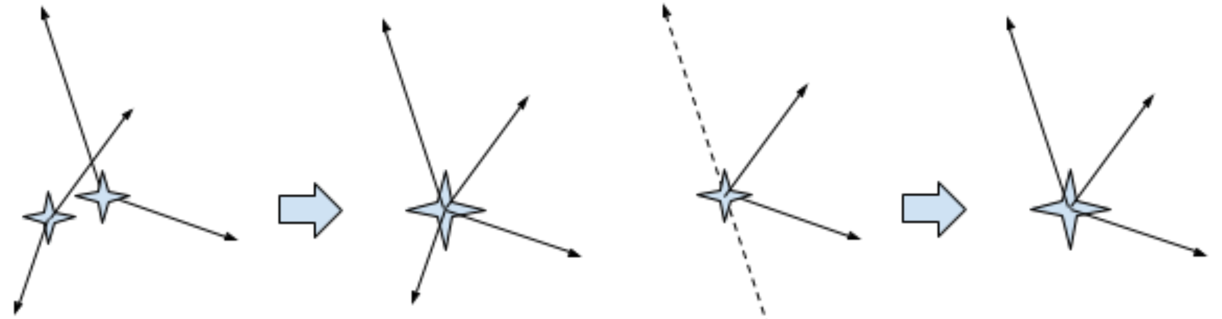
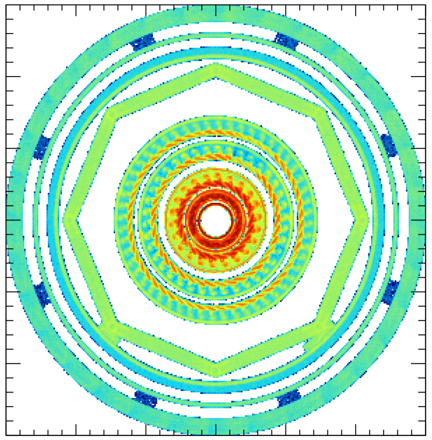
Dealing with peculiar **backgrounds**

- Long-lived particles in the Standard Model,
- Real particles from detector interactions,
- Algorithmically induced fakes (random/merged vertices, randomly crossing tracks, ...)



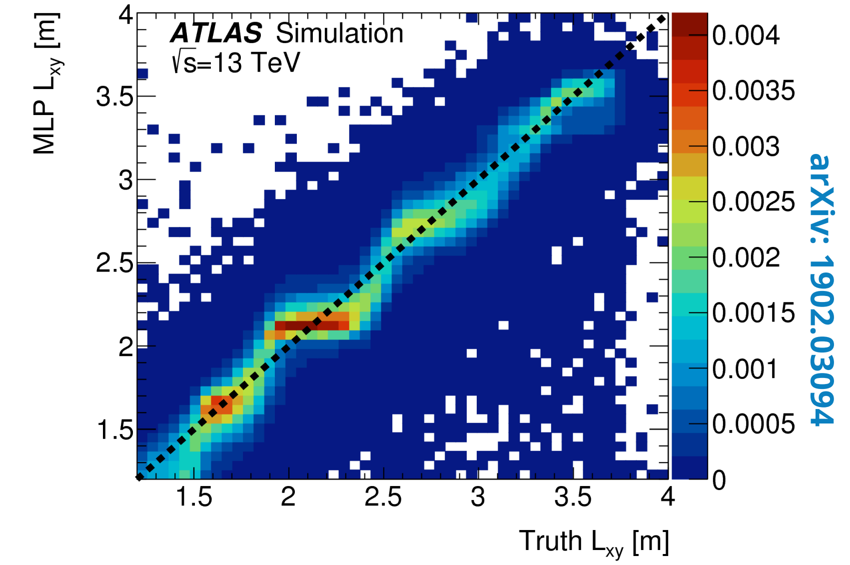


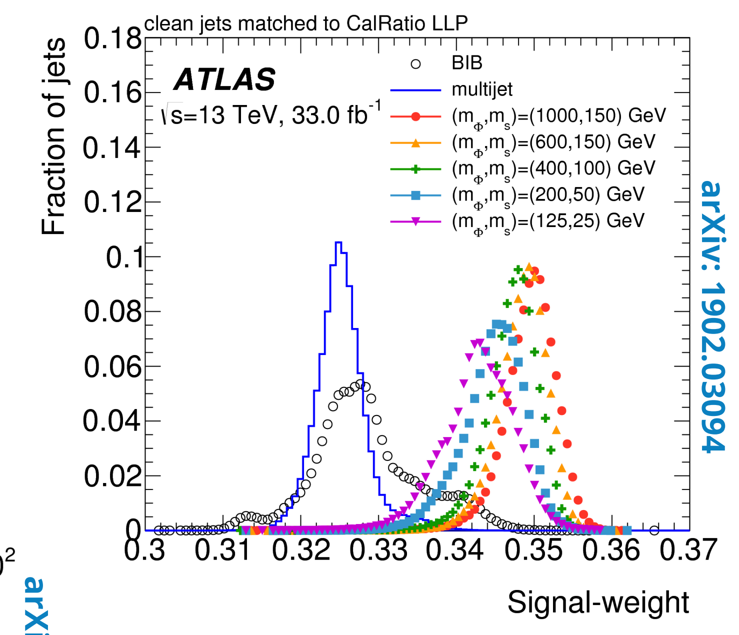
arxiv:1710.04901

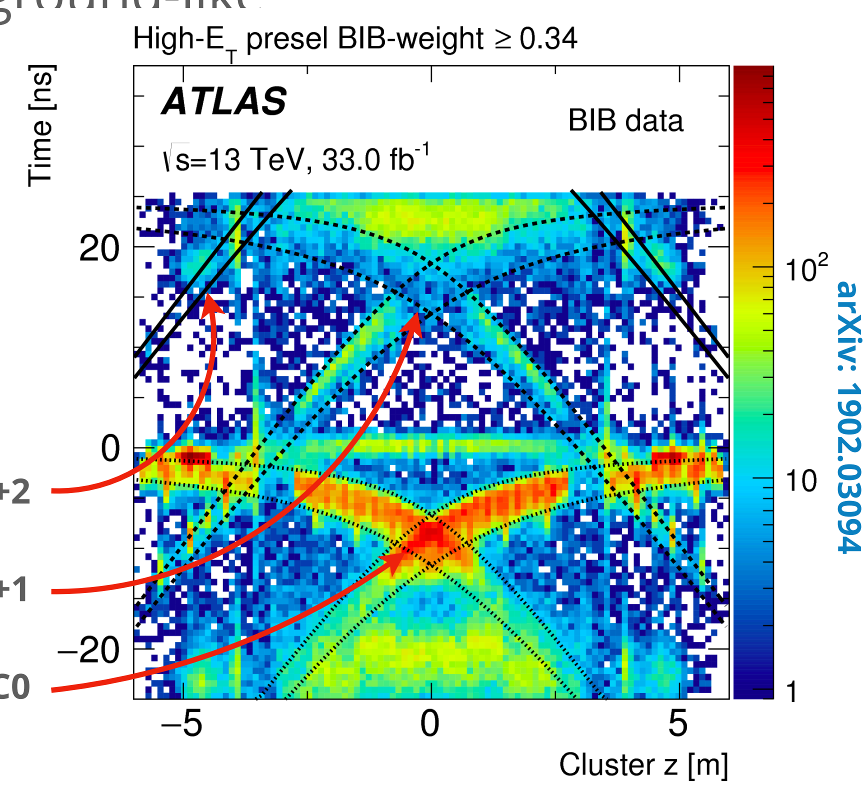
‘Trackless’ jets

Calorimeter activity with large **E_{HCAL}/E_{ECAL} fraction** and no/little activity in inner tracker

- Targeting specifically scenarios where particles decay in HCAL, or end of ECAL
- Without pointing information, neural networks are used to estimate the jet origin
- **Non-collision, mainly beam-induced, backgrounds** dominate and are treated care of using per-jet BDTs to classify jets as signal-like, multijet-like or beam background-like
- Per-jet BDT uses MLP jet-origin information, track information, shower shape and energy-distribution information as well as jet-timing information



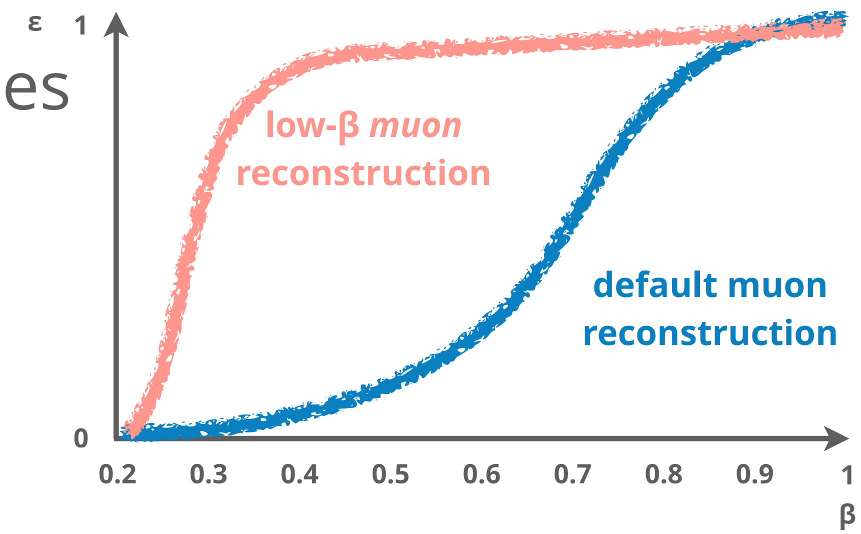




Low-β tracking and time-of-flight measurements

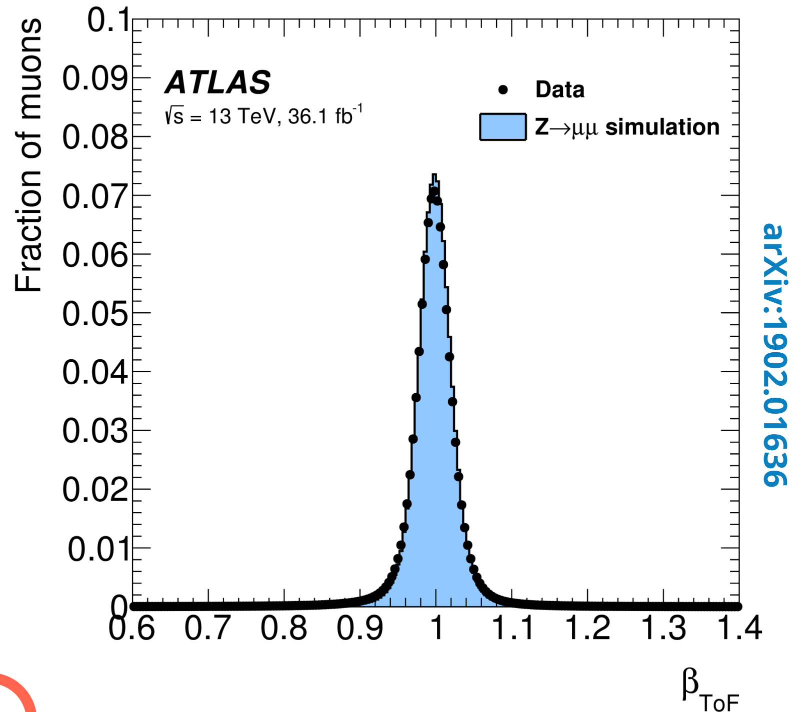
Default **muon reconstruction assumes β = 1** and becomes inefficient for heavy charged *detector-stable* particles

- Similar problem also arises at trigger level

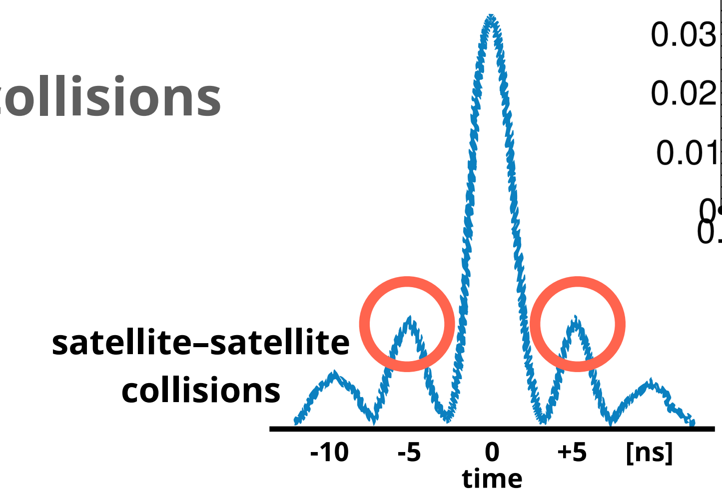


Dedicated **low-β algorithm** treats β as a free parameter

- Increased efficiency at lower β value and β estimate based on **time-of-flight** measurement
- Using high-pT inner detector tracks as seeds and trigger/RPC hits from multiple bunch crossings as velocity input
- Requires a **dedicated multi-step offline timing calibration** involving more than 700k elements (RPC strips and MDT tubes) using β ≃ 1 muons as reference
- Data-driven verification using **satellite–satellite collisions**



arXiv:1902.01636



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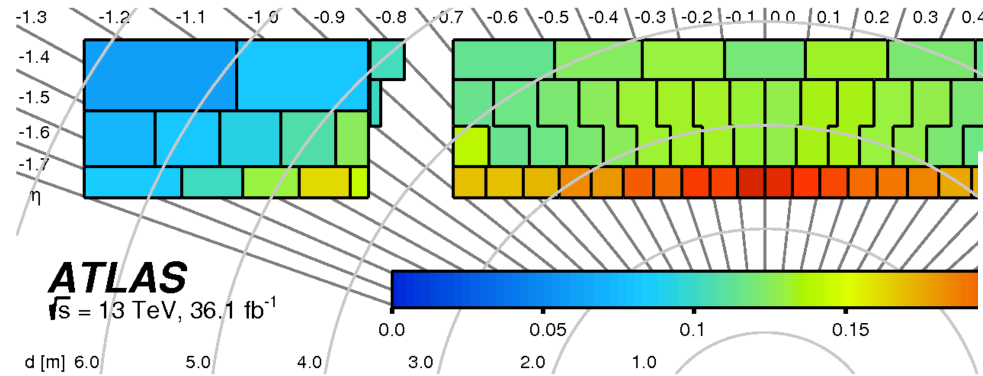
Other observables used in LLP searches

Time-of-flight measurements in the hadronic tile calorimeter

- again offline timing calibration necessary



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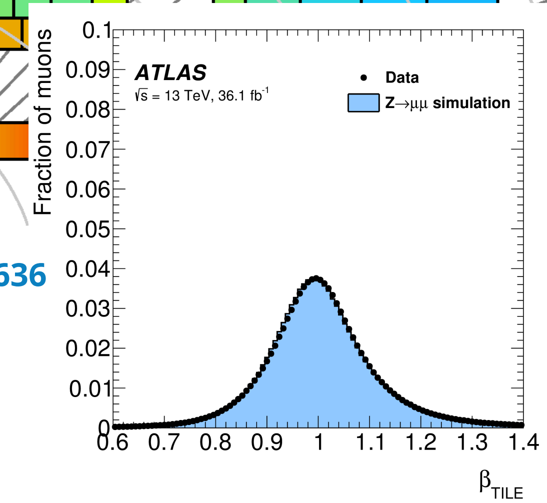


dE/dx in pixel detector, transition-radiation tracker and muon drift tubes

- calibrated using Standard Model candles and interesting for different signatures

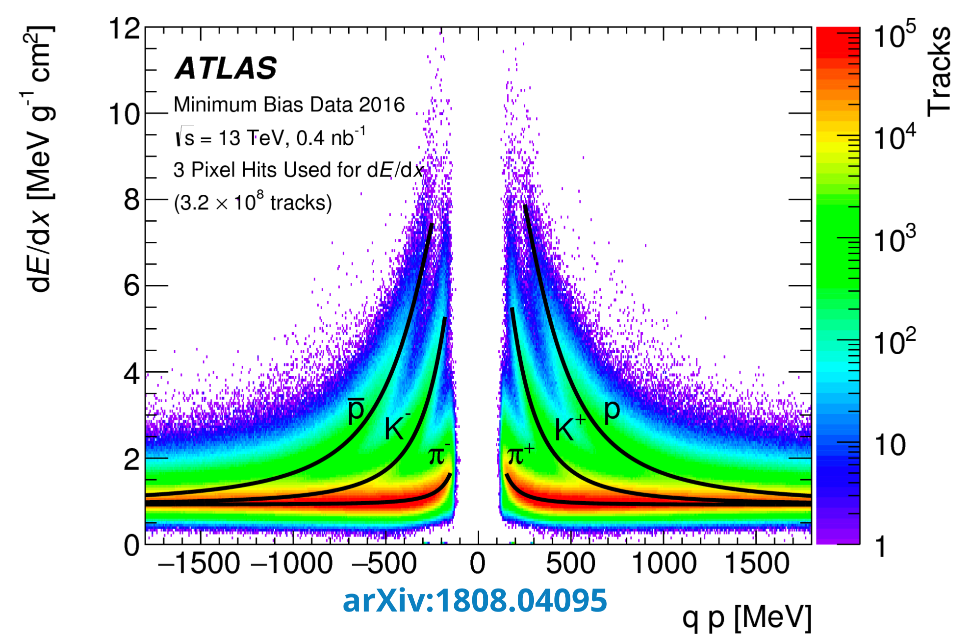
Fraction of **high-threshold hits** in transition-radiation detector

- even accessible without tracking

Silicon/pixel-only tracking

- can rely on interaction point as possible anchor

obviously there's **more** ...

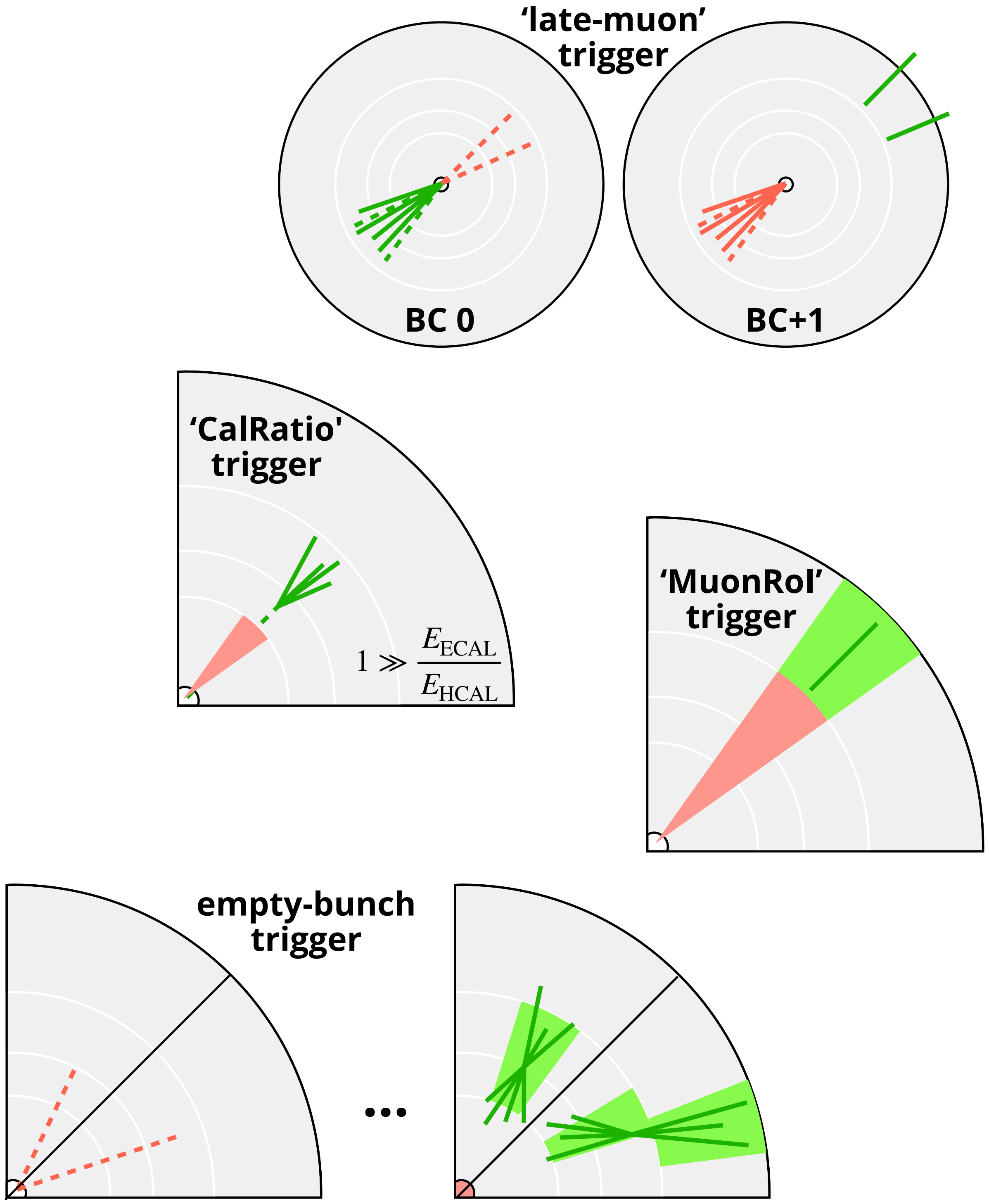


arXiv:1808.04095

LLP triggers

Also on the trigger level dedicated approaches are necessary and in use

- multiple-object–multiple-bunch-crossing trigger
- “CalRatio” / trackless-jet trigger
- “MuonRoI” / inner-detector-veto muon trigger
- empty-bunch trigger / collision-veto trigger
- …
- would be good to add some inner-tracker-decays trigger e.g. by counting hits not assigned to *trigger tracks*, but within a jet/MET-selected region of interest
- …



Conclusion

Many distinct signatures to cover

Many different (non-standard) observables required/used

Significant efforts in analyses go into observables
and understanding backgrounds

Didn't talk so much about actual results (on purpose),
but there is plenty already and plenty to come
https://twiki.cern.ch/twiki/bin/view/AtlasPublic (LLP filter)