Long-Lived Particle Experimental Signatures - Tracking in ATLAS and CMS

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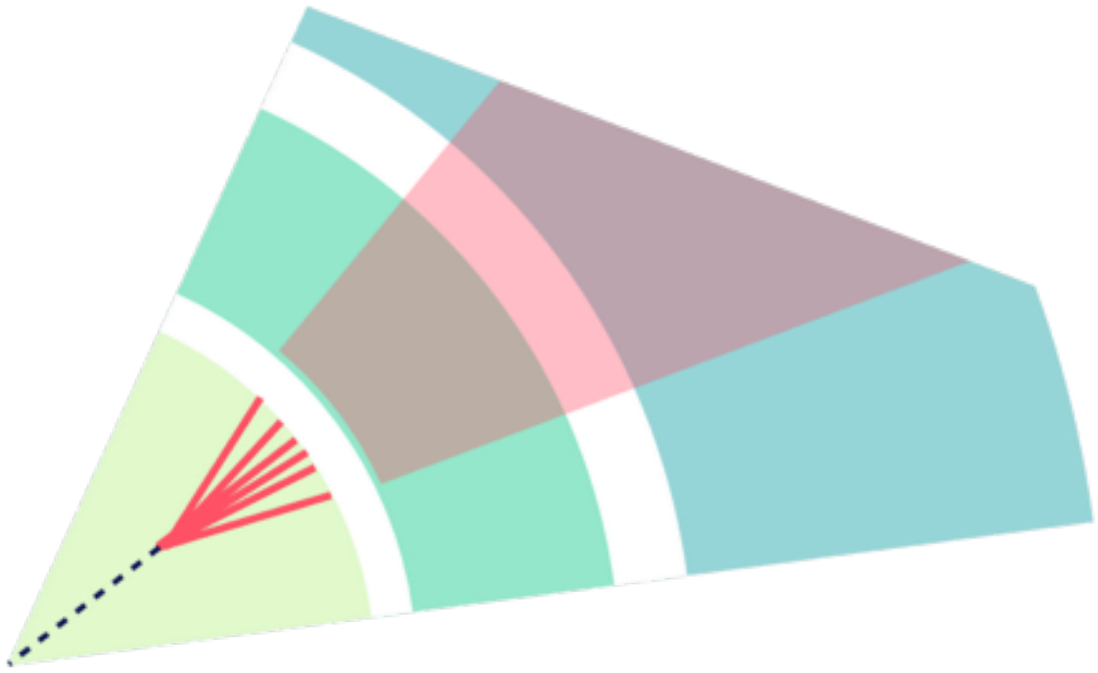
NCTS Displaced Vertex Physics Workshop
Thursday, June 21 2018

Slide materials from Heather Russell, Claudia Gemme, Hide Otono

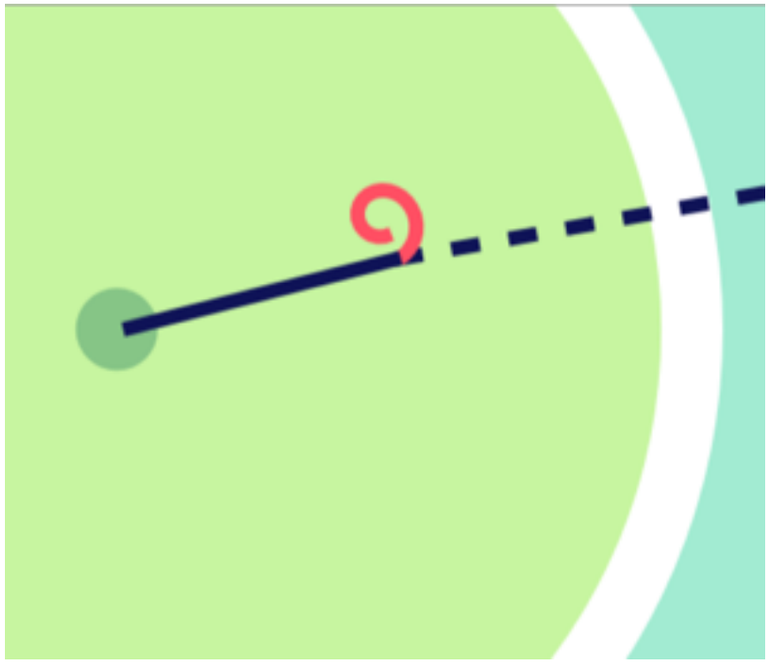
Long-lived particle - collider experimentalist's view

New long-lived particles are both theoretically and experimentally strongly motivated. See excellent talks in the Wednesday section!

a neutral particle that decays a macroscopic, *reconstructable* distance from the $p - p$ interaction point.



a charged particle that decays as above, or is quasi- stable on the scale of the relevant detector.



Timing, ionization and "displacements" are the key ingredients.

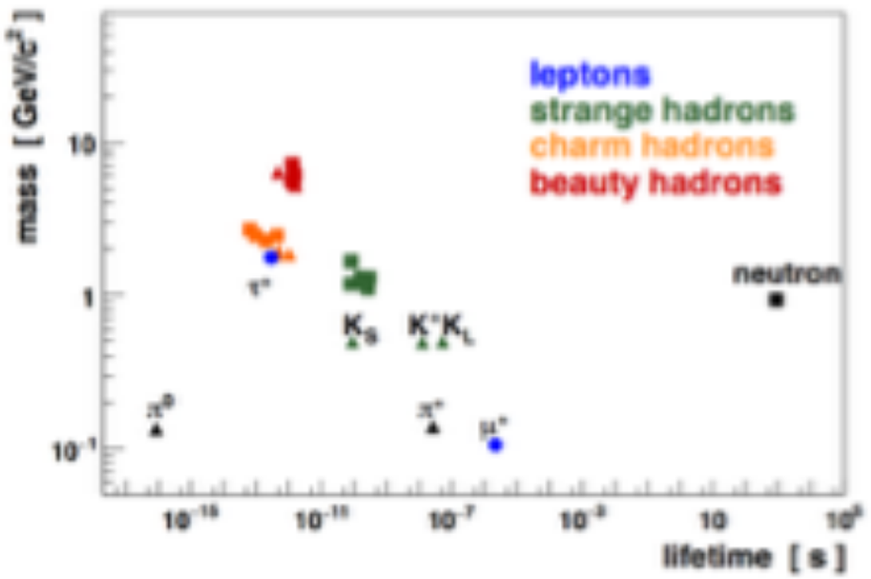
Despite the different signatures, BSM LLPs have one thing in common:

they need dedicated tools!

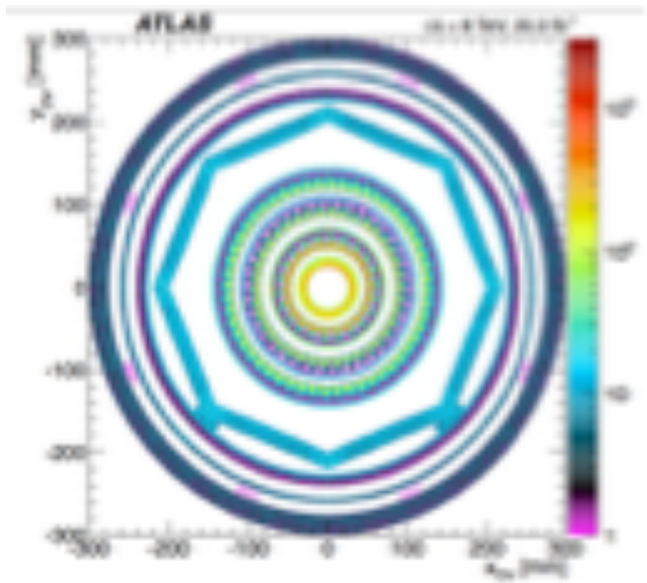
This talk will focus on the Tracking Signature relevant for **Displaced Vertex**.

Background

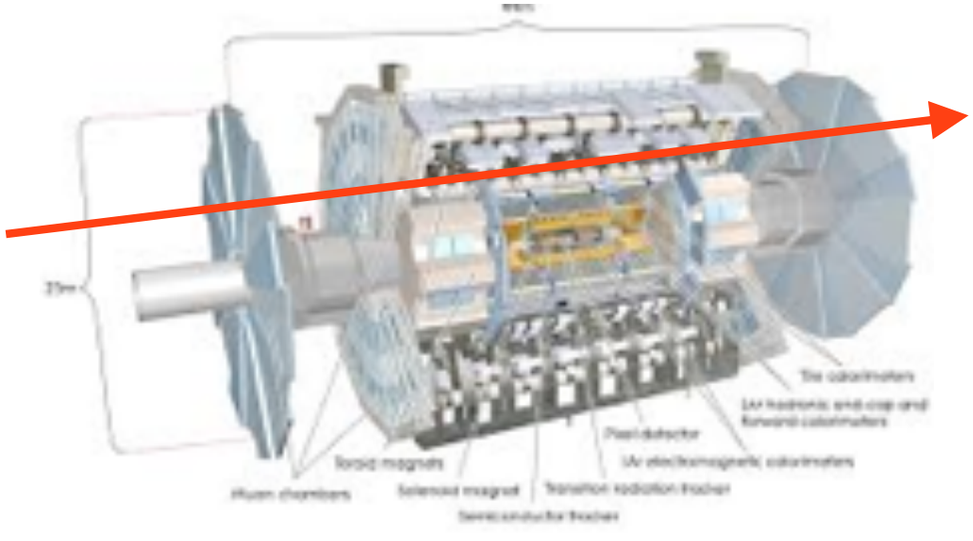
Weak decay of heavy flavor



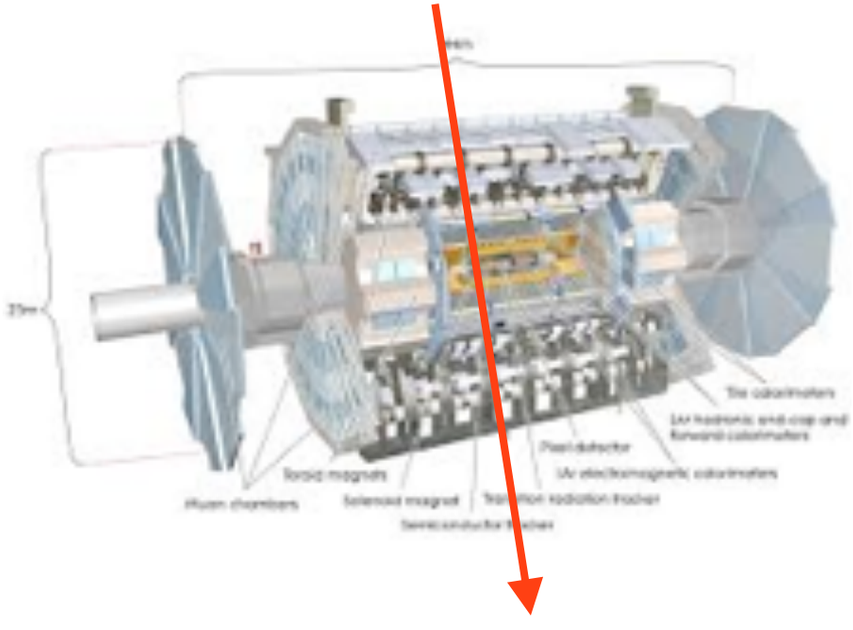
Material interactions



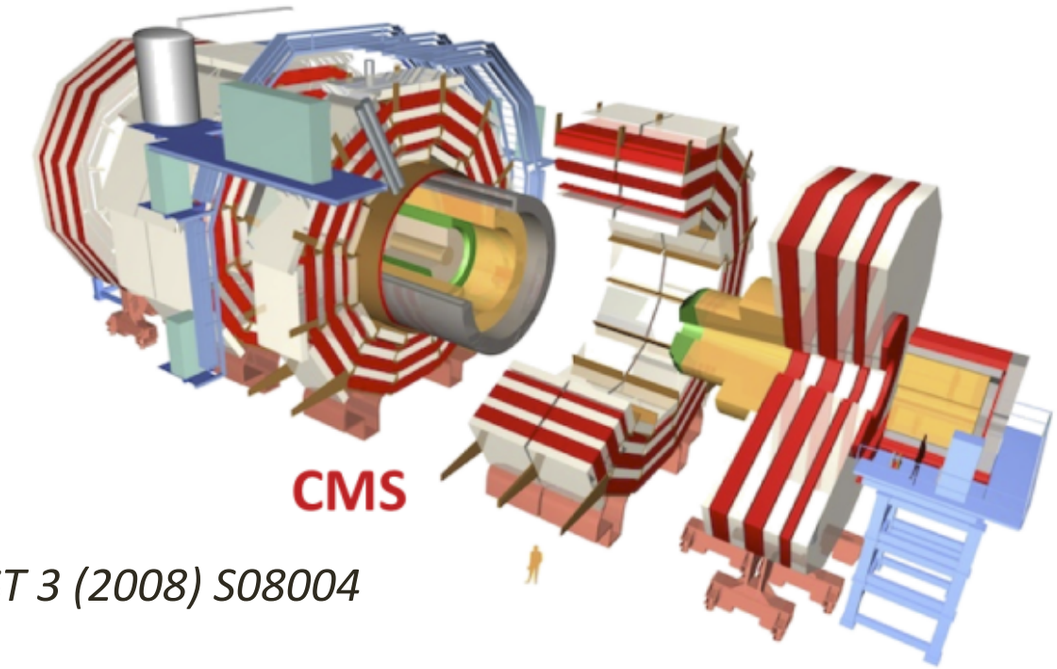
beam halo muons



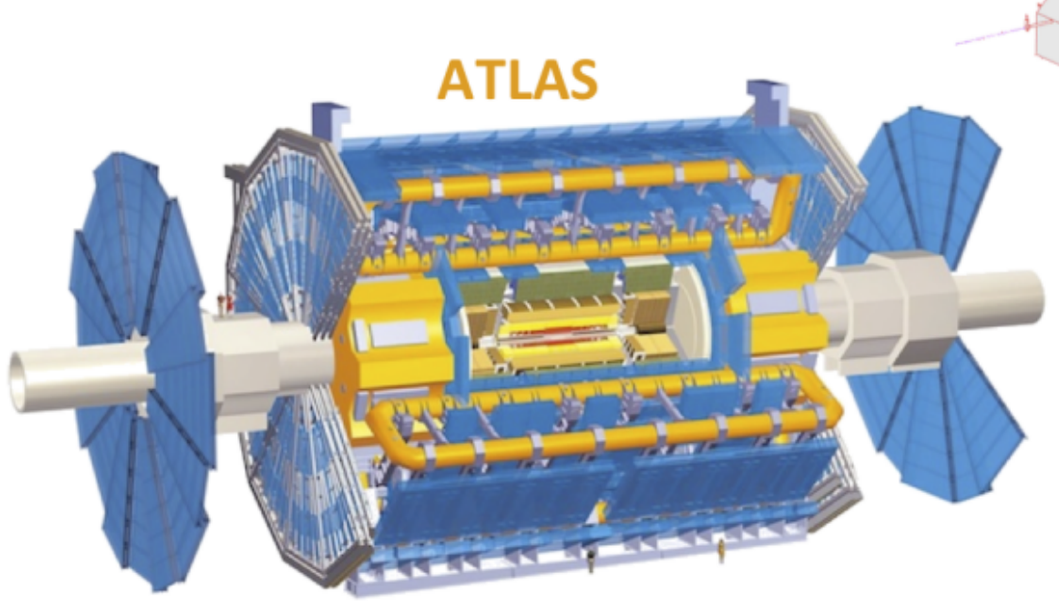
cosmic muons



The experiments



JINST 3 (2008) S08004



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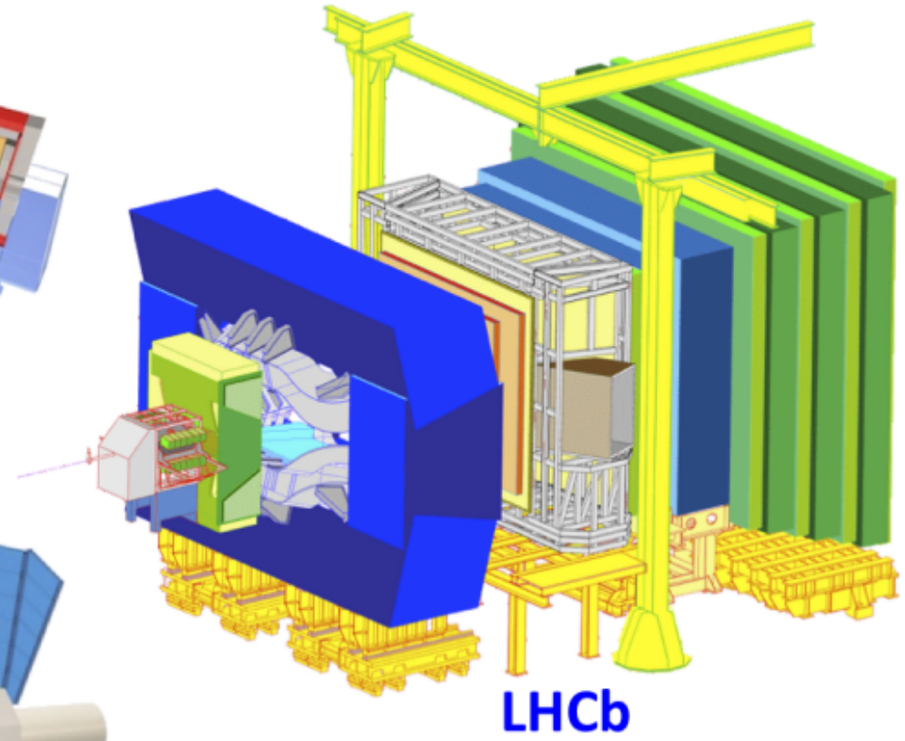
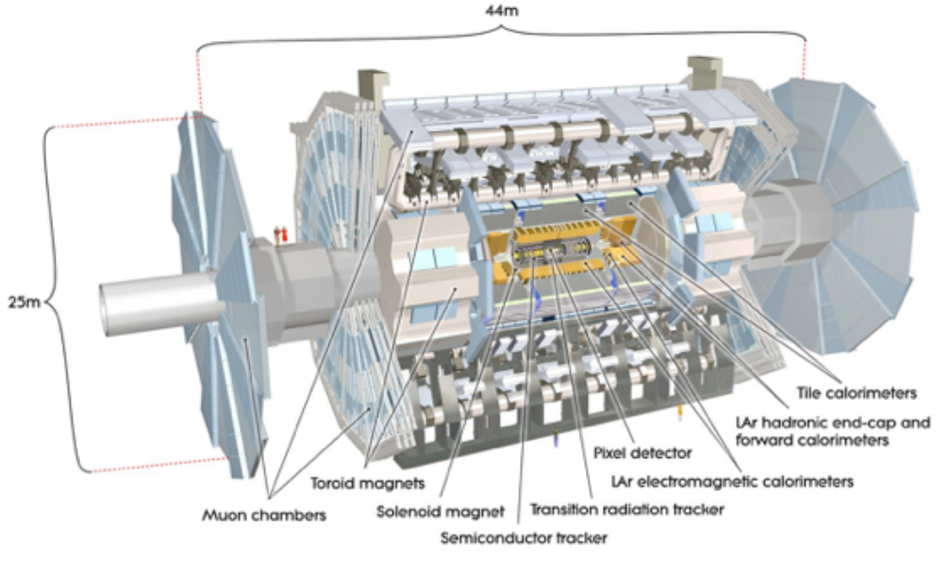
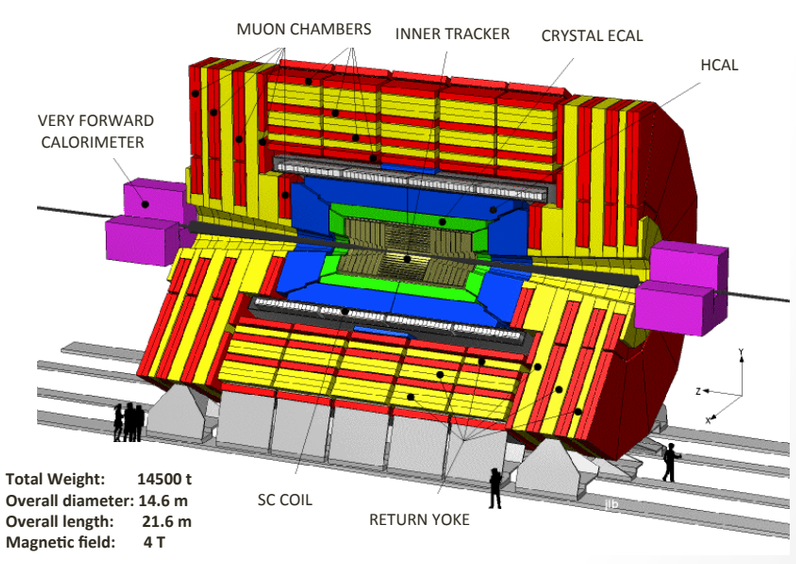


JINST 3 (2008) S08005

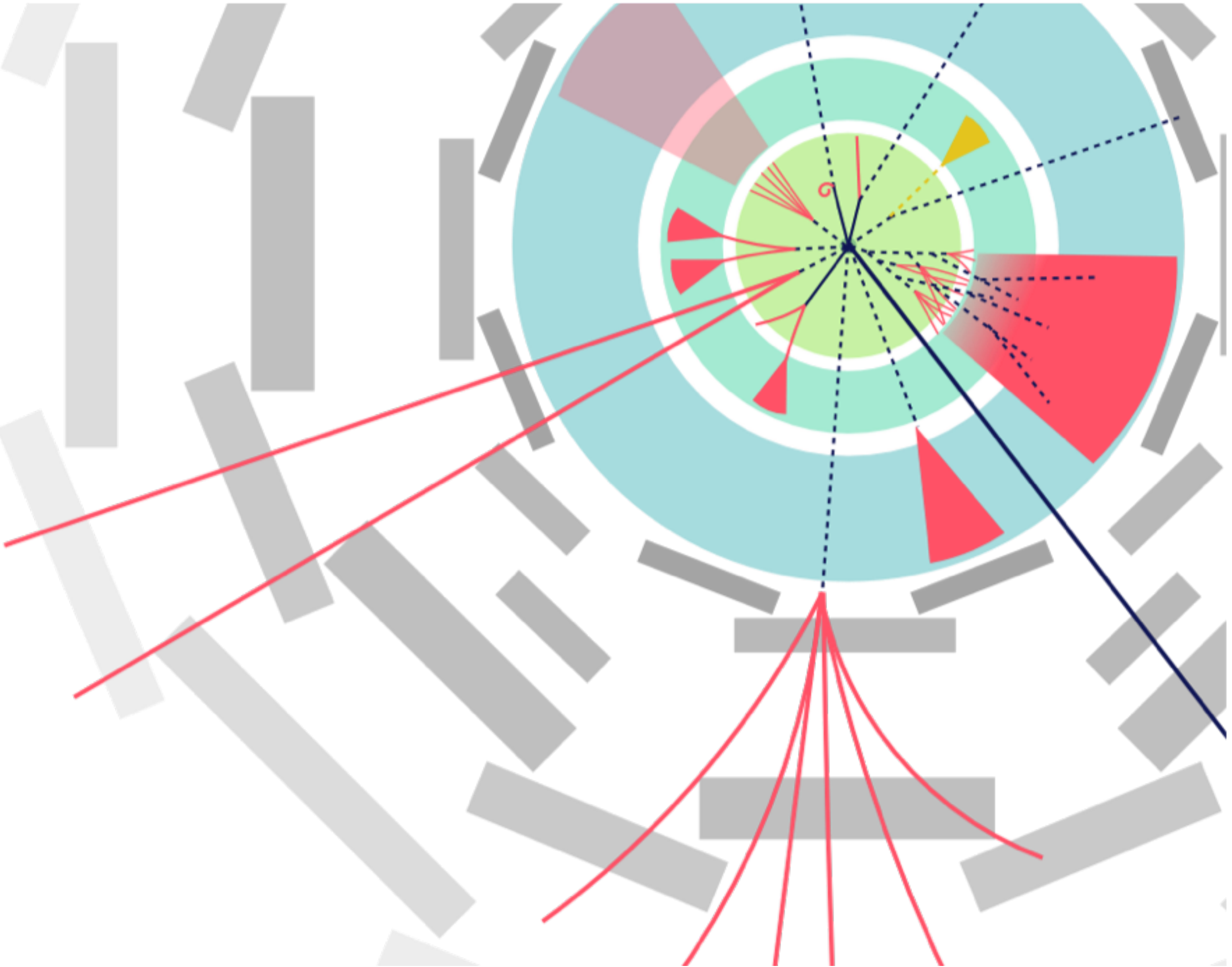
ATLAS and CMS

	ATLAS	CMS
Magnetic field	2T solenoid + toroid (0.5T barrel, 1T endcap	4T solenoid + return yoke
Tracker	Si pixel, strips + TRT $\sigma/p_T \approx 5 \bullet 10^{-4}\ p_T + 0.01$	Si pixel, strips $\sigma/p_T \approx 1.5 \bullet 10^{-4}\ p_T + 0.005$
EM calorimeter	Pb + Lar $\sigma/E \approx 10\% / \sqrt{E} + 0.007$ GeV	PbWO4 crystals $\sigma/E \approx 3\% / \sqrt{E} + 0.003$ GeV
H calorimeter	Fe + scint. / Cu + Lar (10λ) $\sigma/E \approx 50\% / \sqrt{E} + 0.03$ GeV	Brass + scint. (7λ+catcher) $\sigma/E \approx 100\% / \sqrt{E} + 0.05$ GeV
Muon	$\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV	$\sigma/p_T \approx 1\%$ @ 50GeV to 10% @ 1TeV (DT/ CSC+Tracker)
Trigger	L1 + RoI-based HLT (L2+EF)	L1 + HLT (L2+L3)

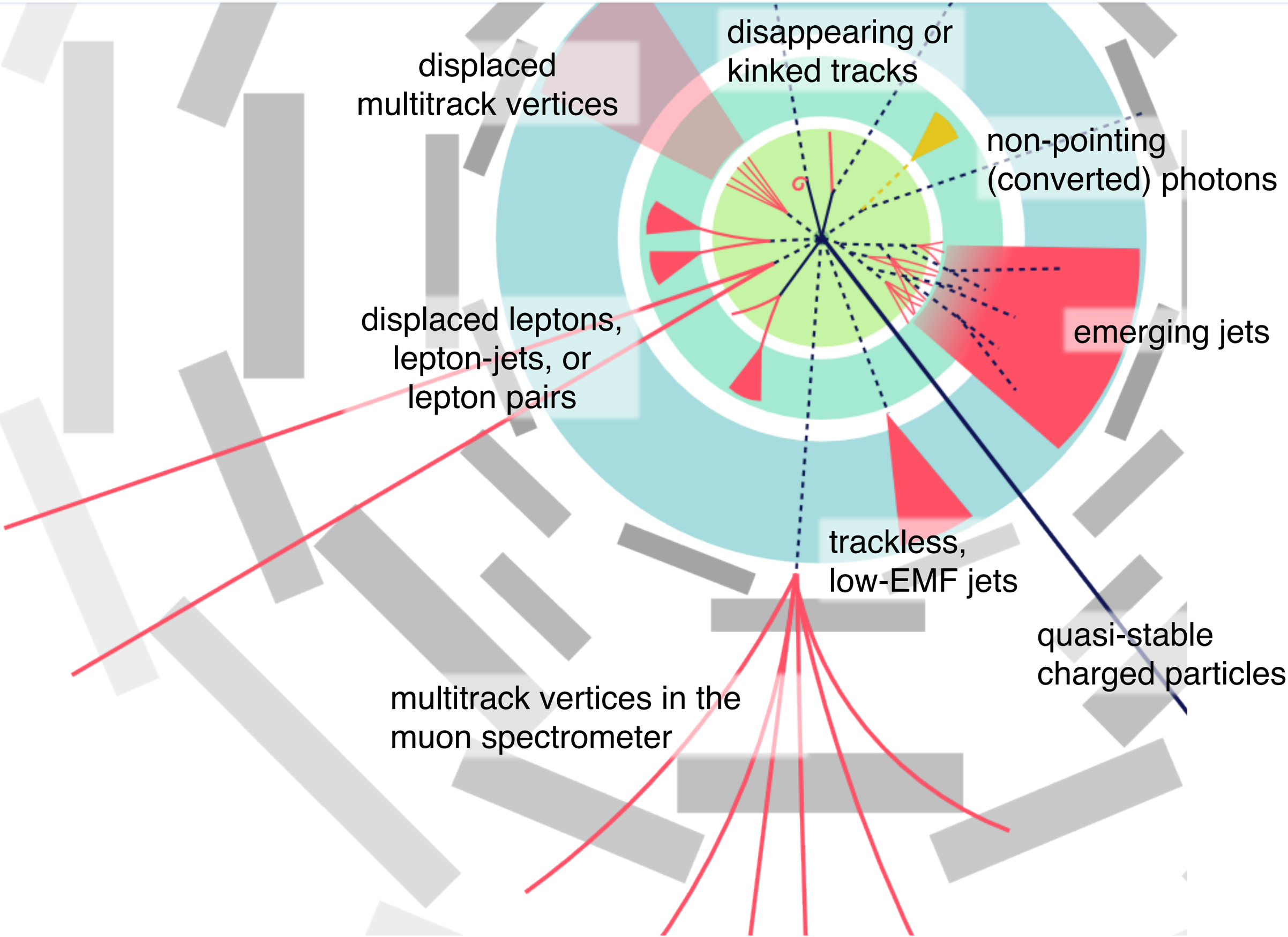




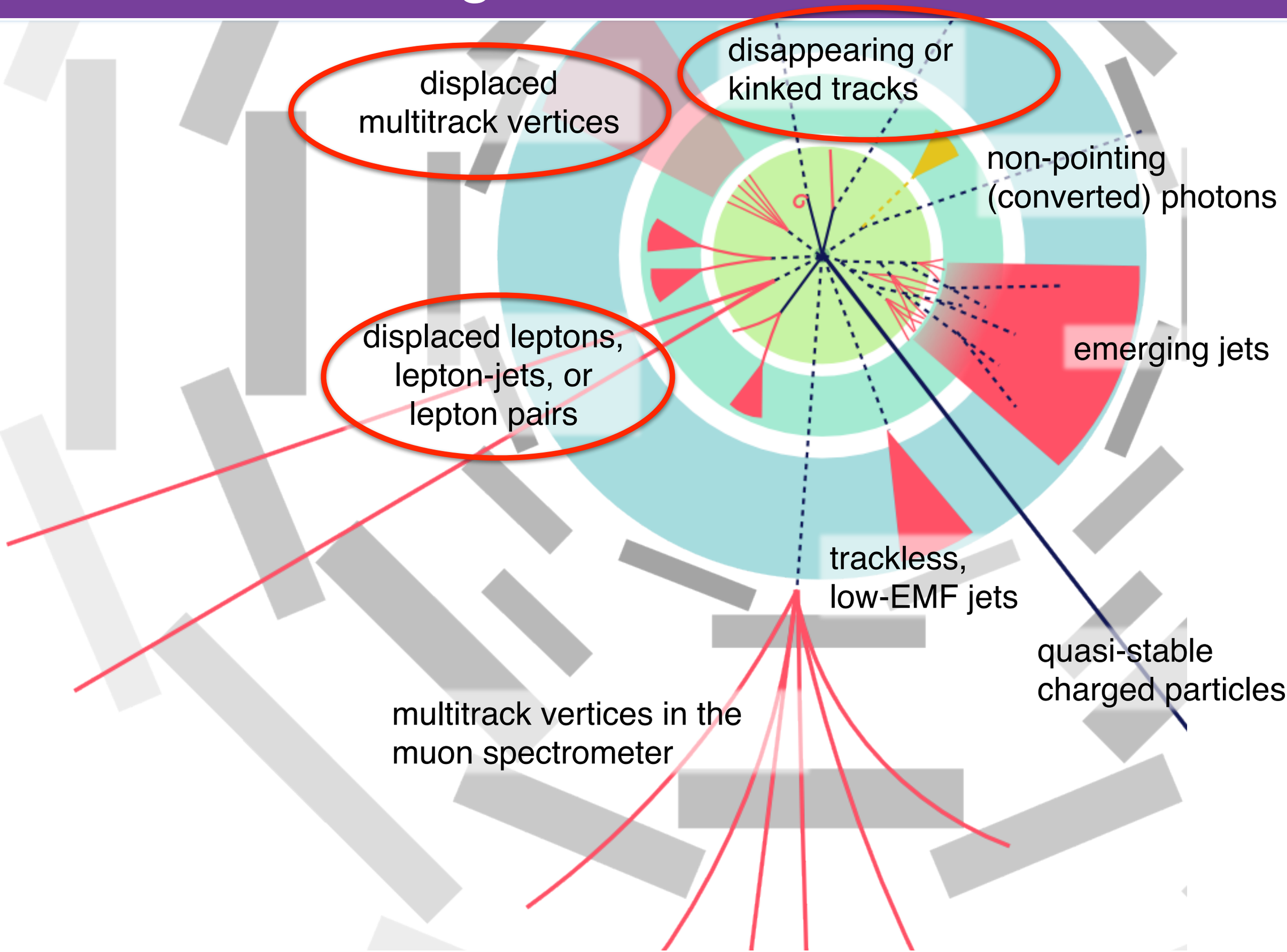
Experimental signature



Experimental signature



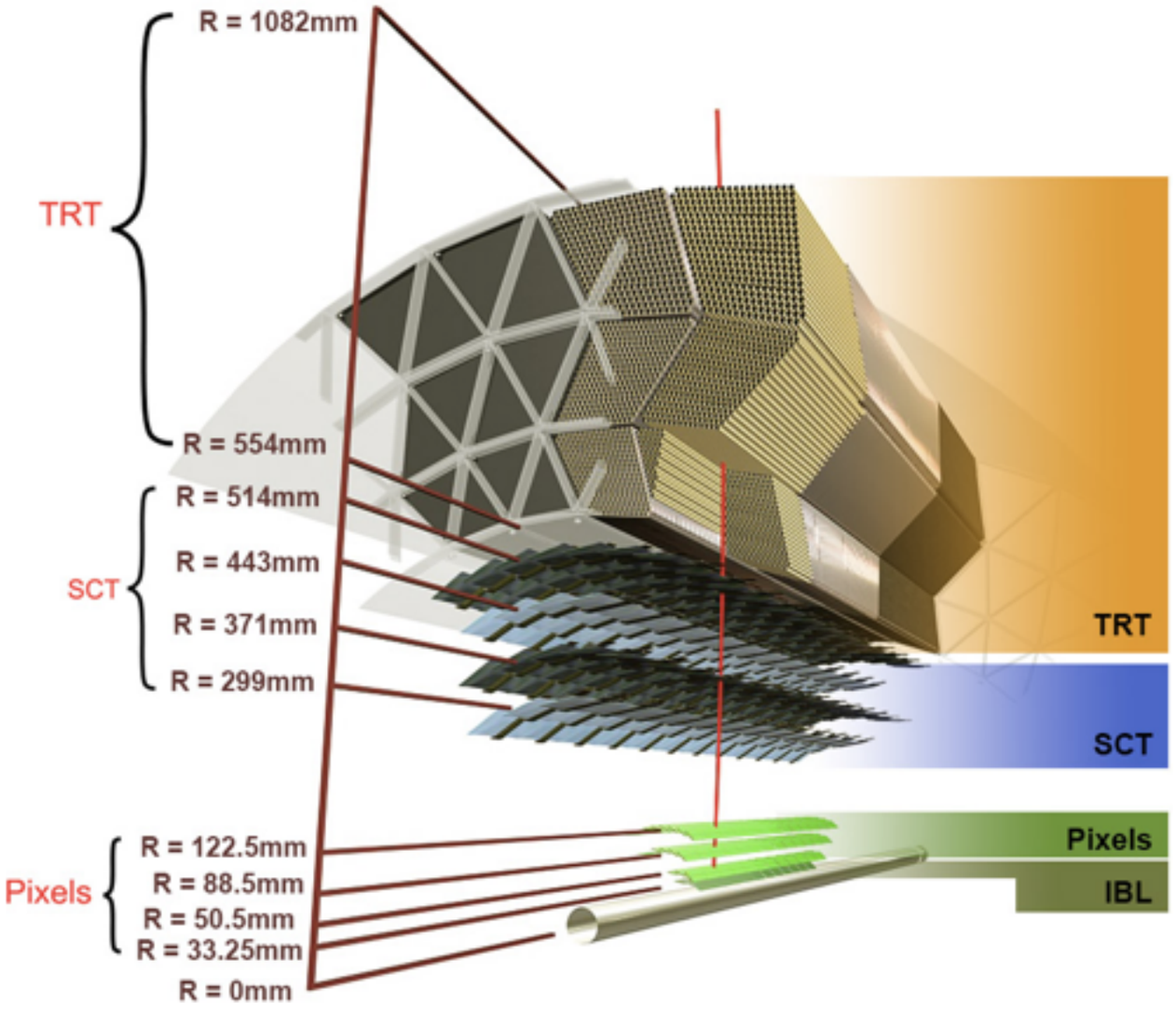
LLP - Inner Tracking



Standard Tracking

Standard tracking in the ATLAS detector consists of

- Silicon seeded tracking – seeds and creates tracks in the silicon detectors (pixels and SCT) and extends them out into the TRT
- TRT seeded tracking – takes seeds in the TRT and extends them inwards towards the proton-proton interaction point



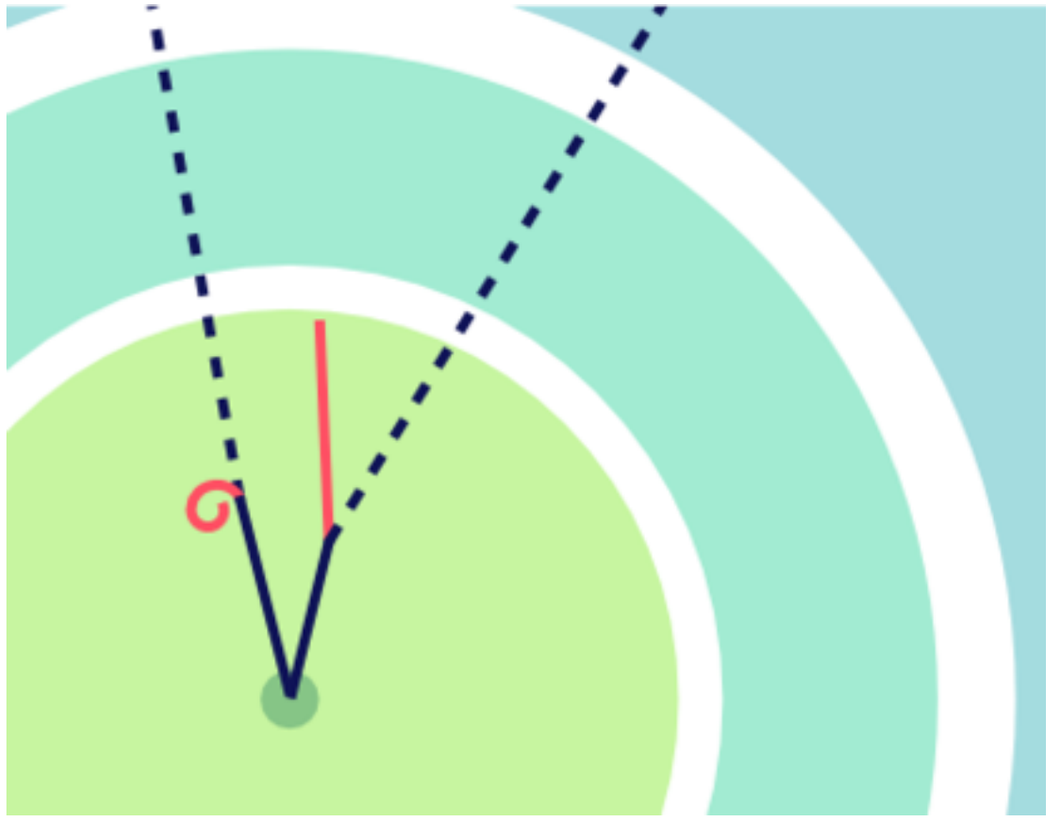
Disappearing or Kinked Tracks

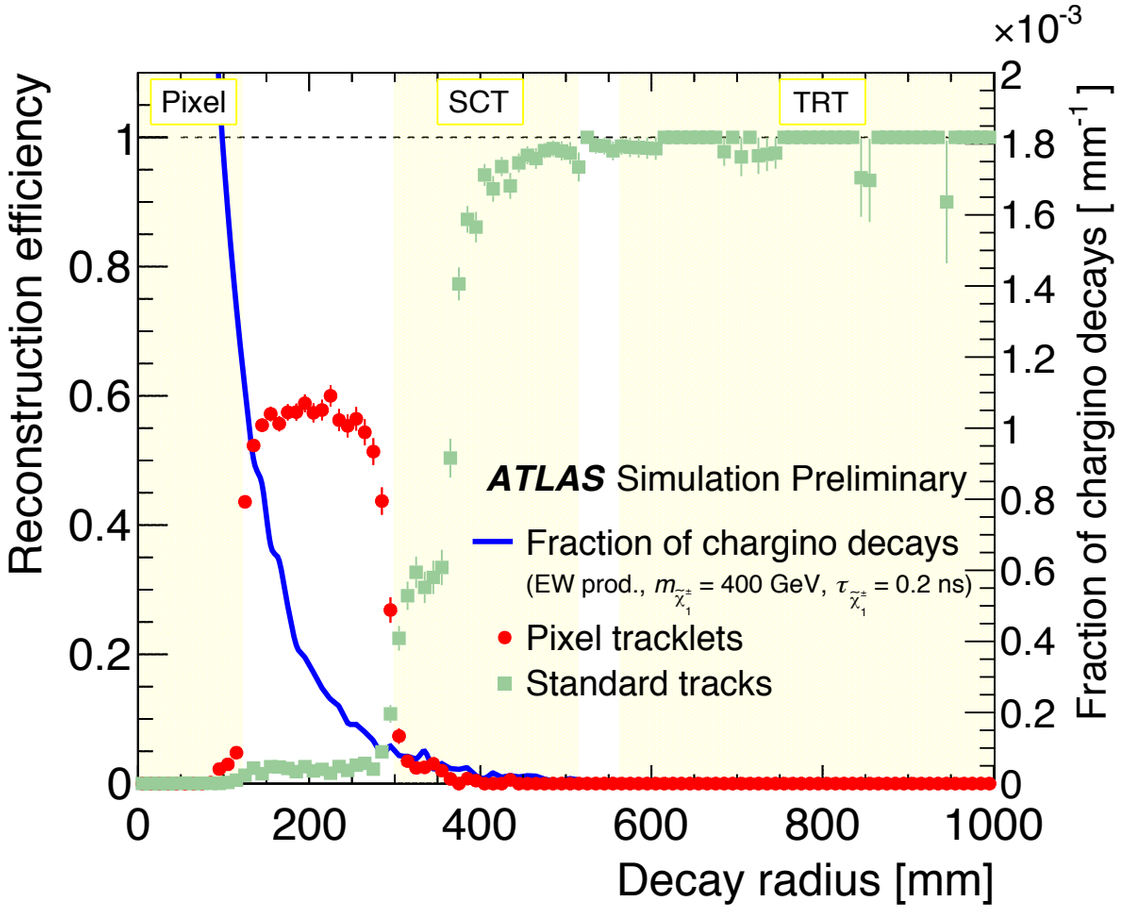
arXiv:1712.02118

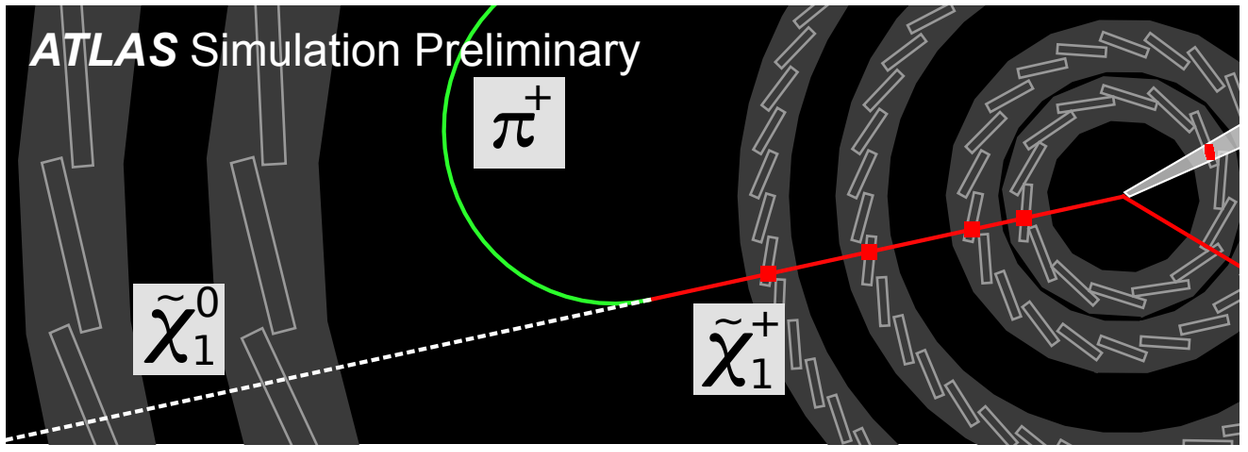
Charged LLPs that are not stable on the detector scale

- Decay to a neutral stable particle and a SM particle

- Predicted by various SUSY scenarios where a chargino and a neutralize are nearly mass-degenerate





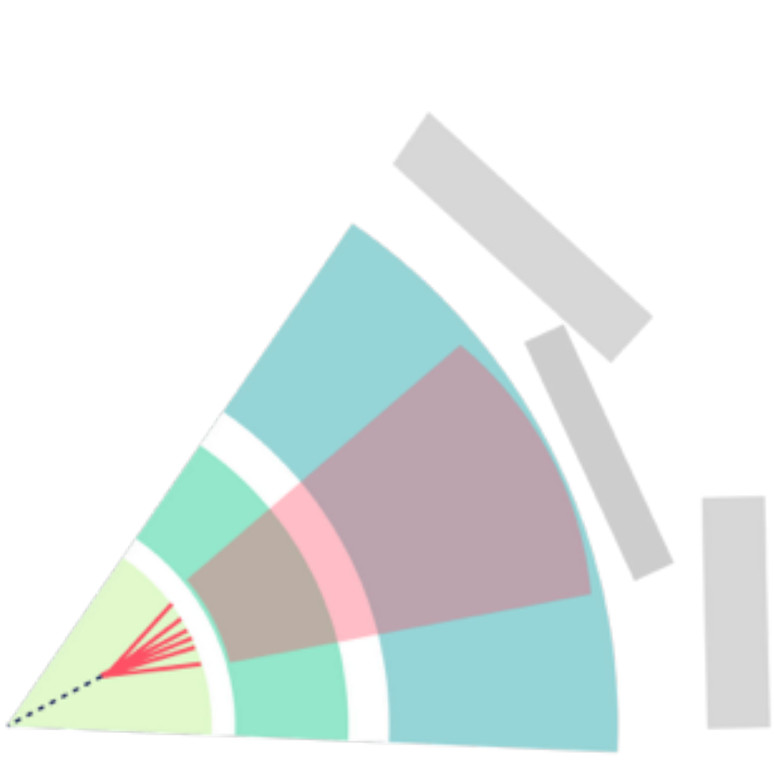


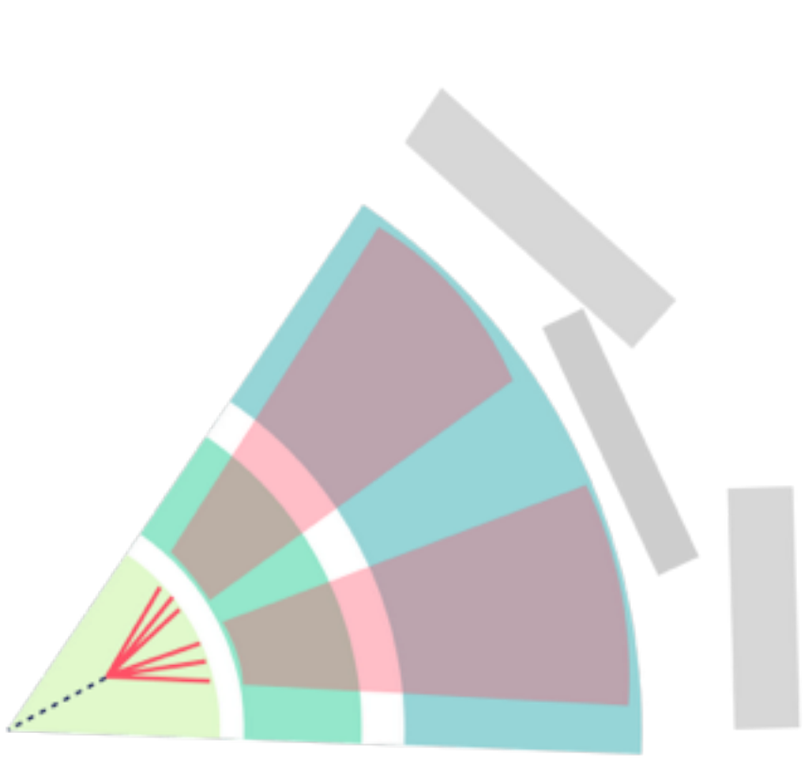
Disappearing or Kinked Tracks

arXiv:1712.02118

Single or multi-track vertices with specialized large transverse impact parameter and secondary vertex reconstruction.

- Follow with jet reconstructions
- or simply displaced lepton pair.





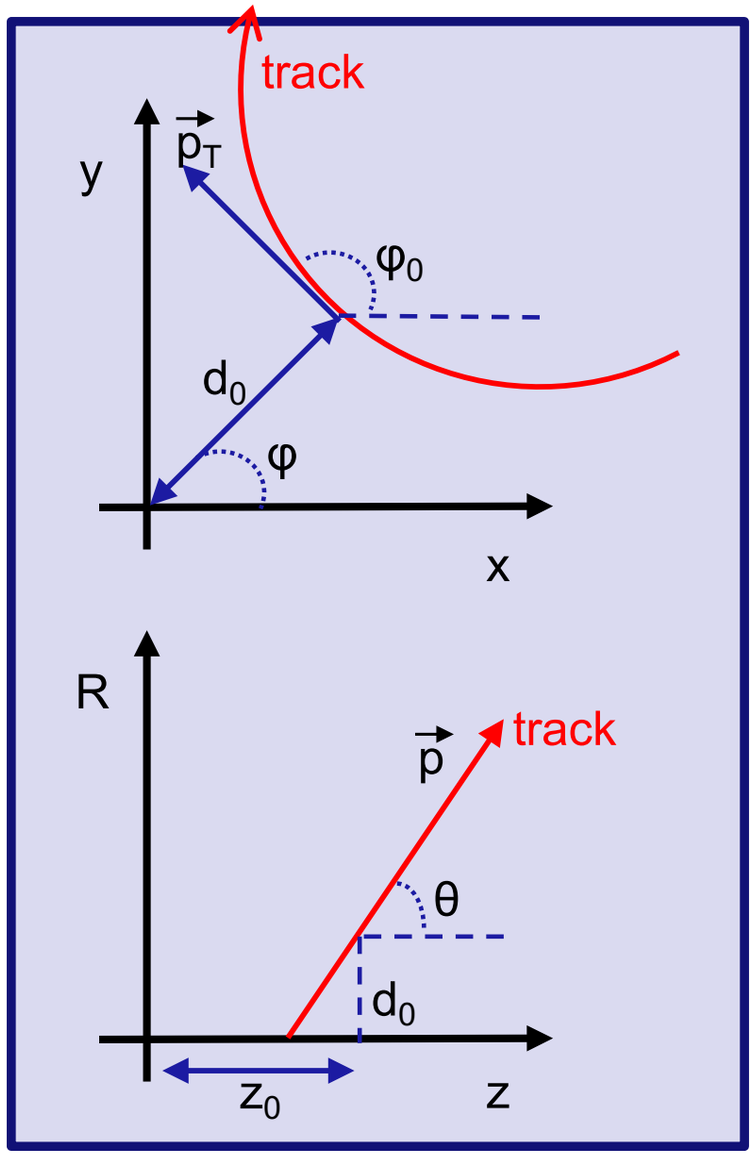
Large Radius Tracking

ATL-PHYS-PUB-2017-014

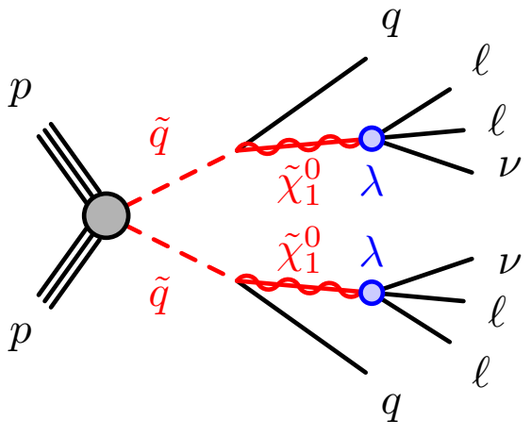
A third tracking pass for reconstructing tracks with large impact parameters

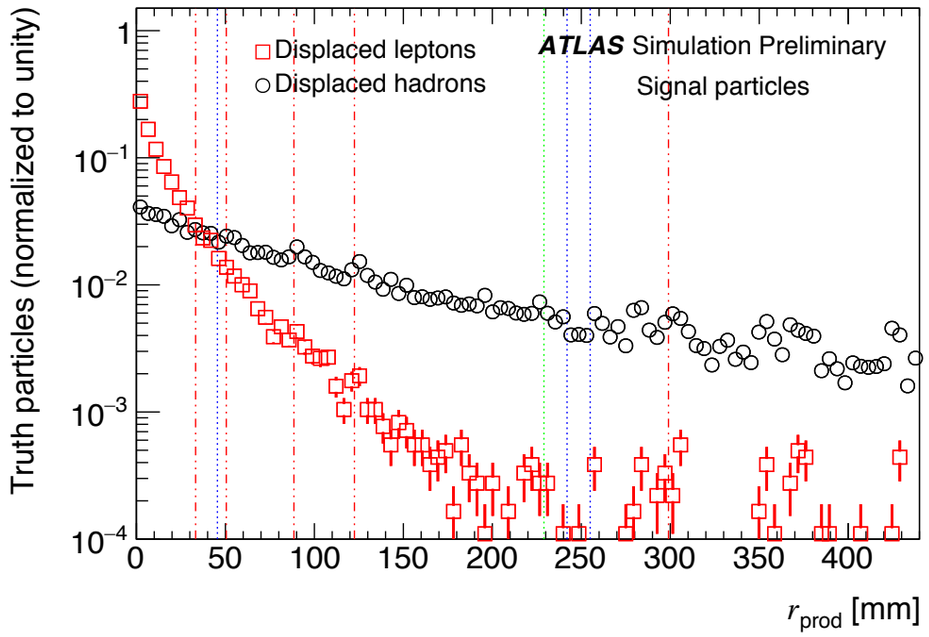
- Uses the hits left over from standard tracking
- Like the first standard tracking pass, seeds tracks in the silicon subdetectors and extends them into the TRT
- Certain tracking parameters loosened

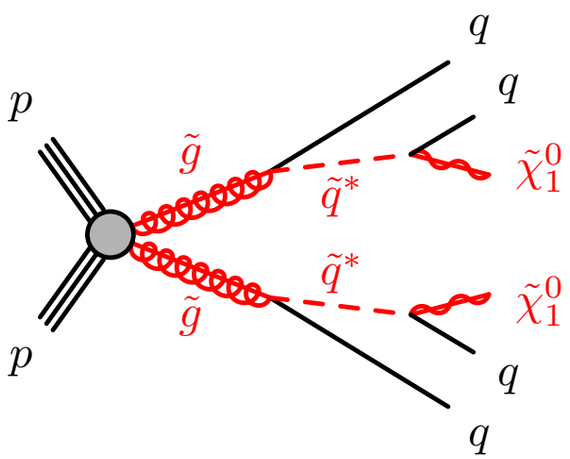
	Standard	Large radius
Maximum d_0 (mm)	10	300
Maximum z_0 (mm)	250	1500
Maximum $\|\eta\|$	2.7	5
Maximum shared silicon modules	1	2
Minimum silicon hits	7	7
Minimum unshared silicon hits	6	5
Seed extension	Combinatorial	Sequential

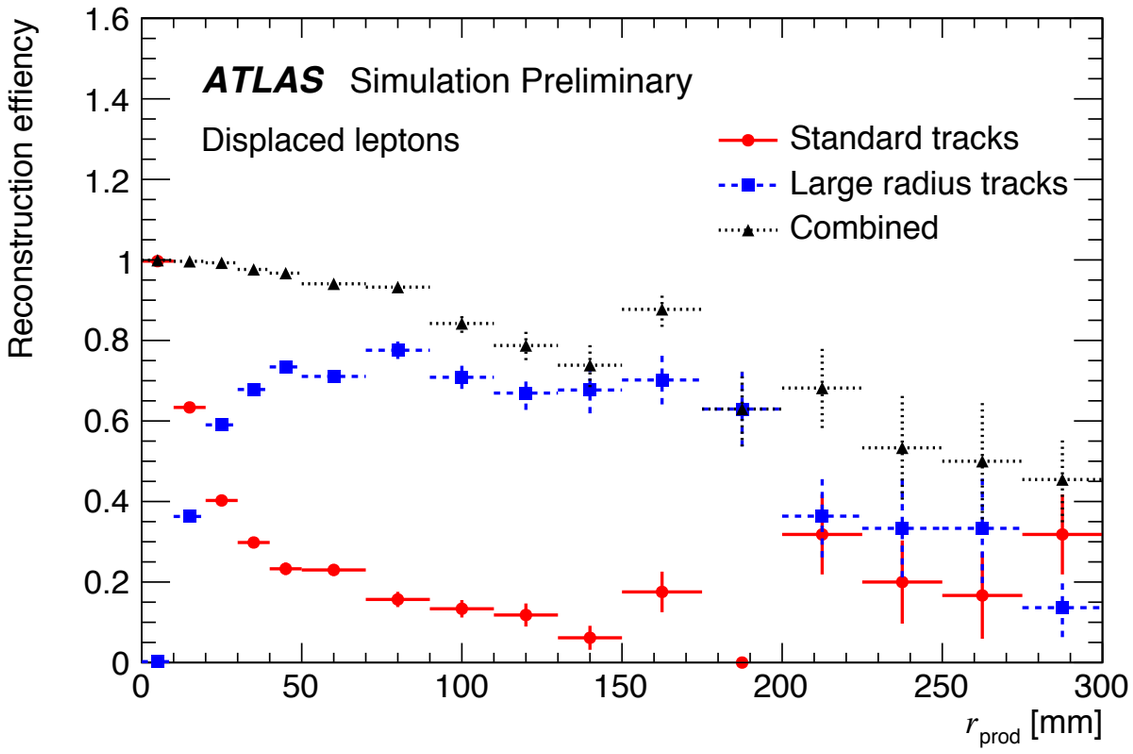


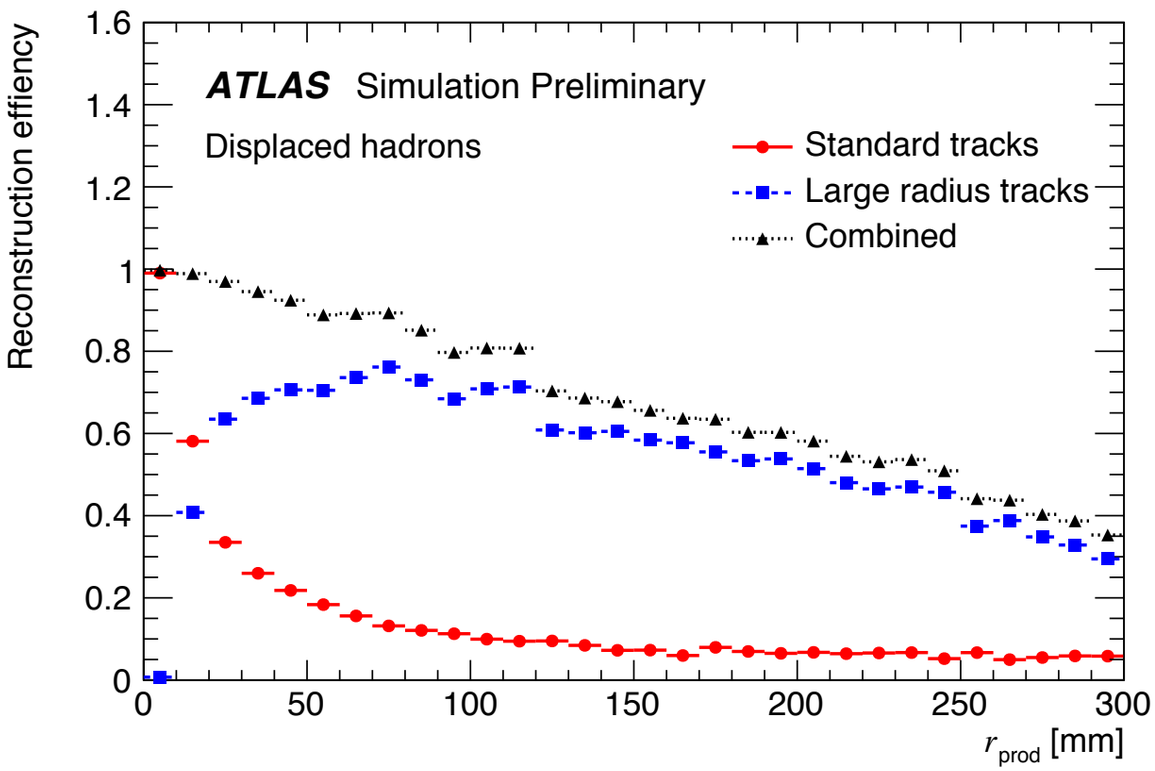
Large Radius Tracking







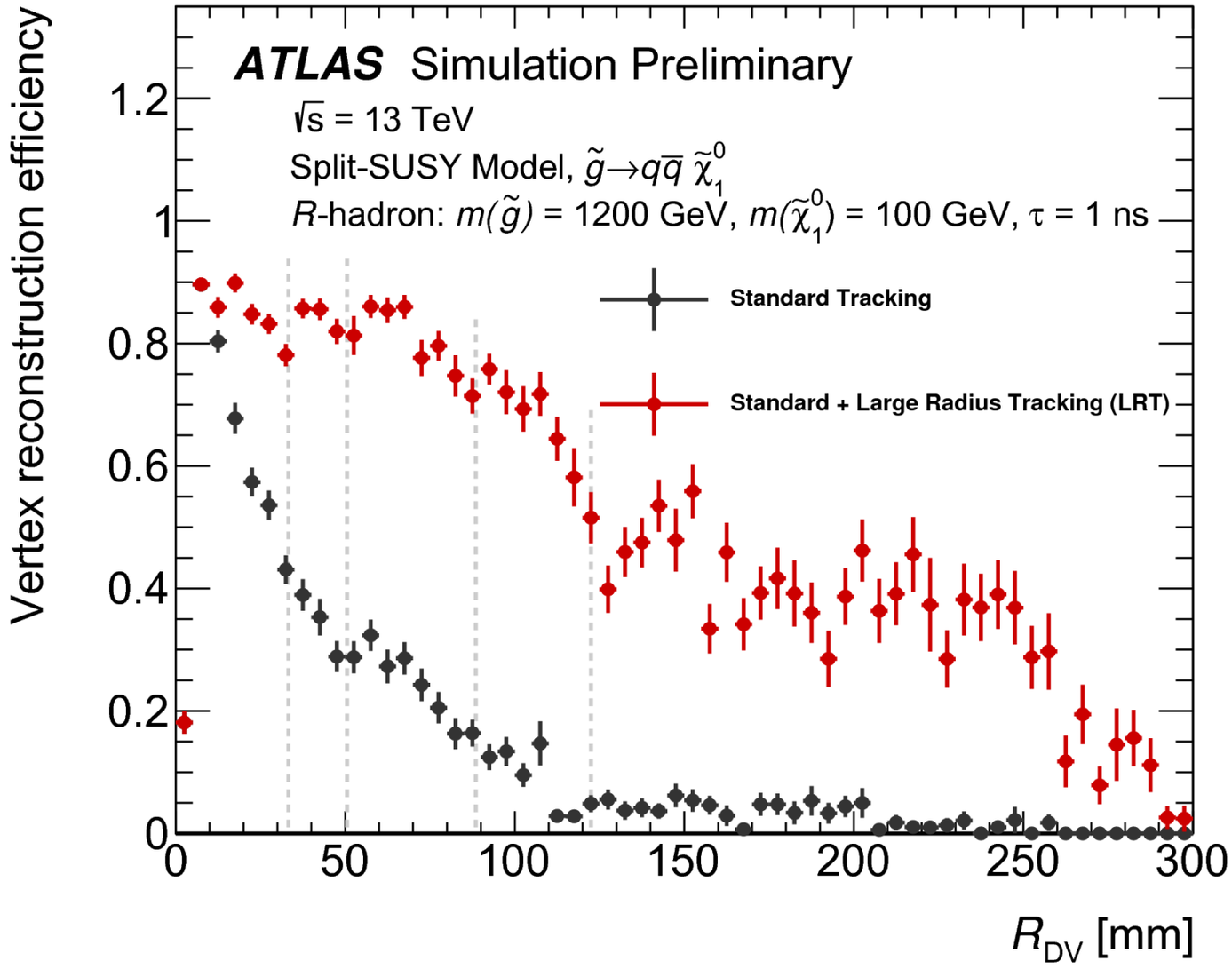




Displaced Vertex

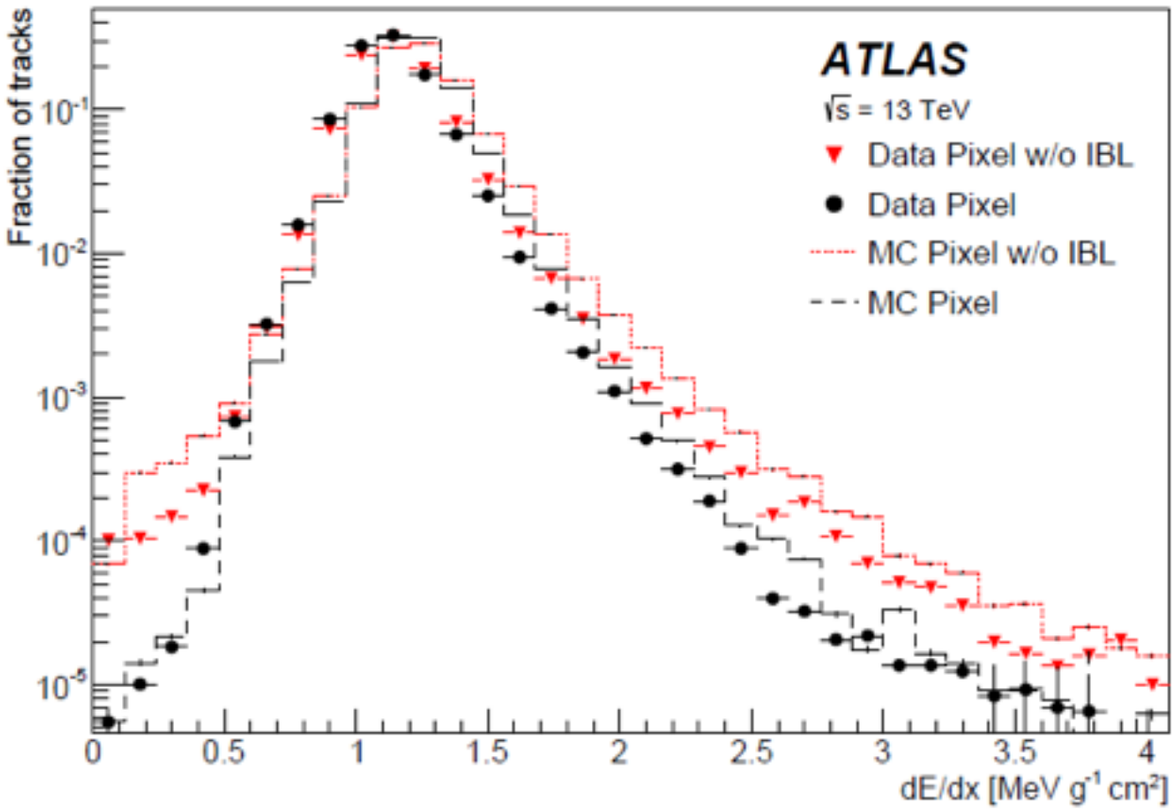
ATLAS-CONF-2017-026

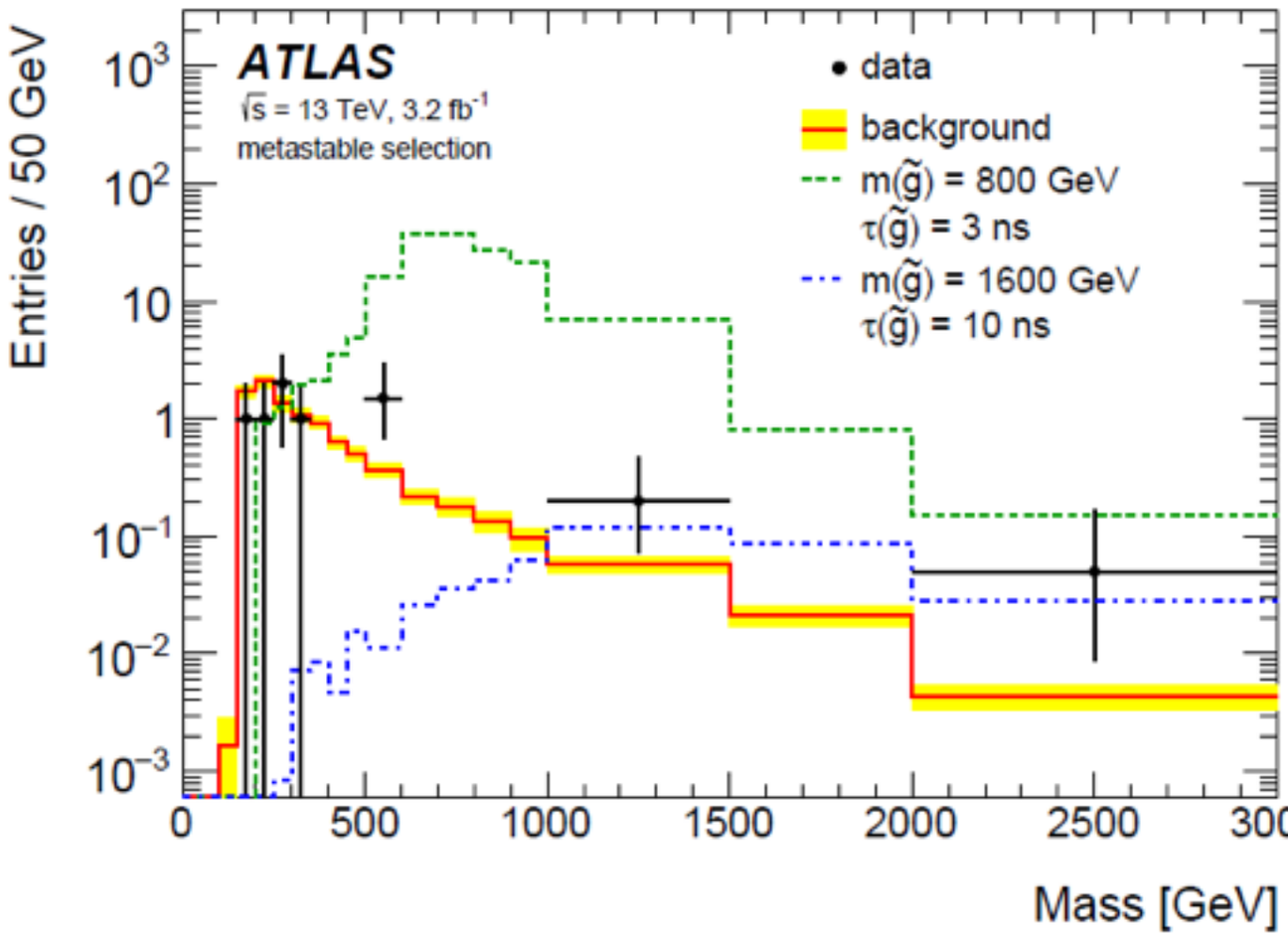
Significant improve on vertex reconstruction efficiency with addition of large radius tracks

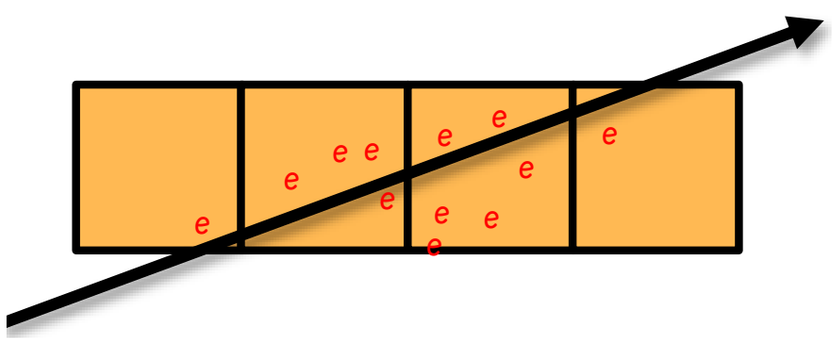


dE/dx: heavy stable charged particles

- LLP with a larger unit of charge than expected by SM particles
  Measured by the energy loss in the pixel subsystem dE/dx
  If lifetime is long enough, HSCP may look like slow muons.





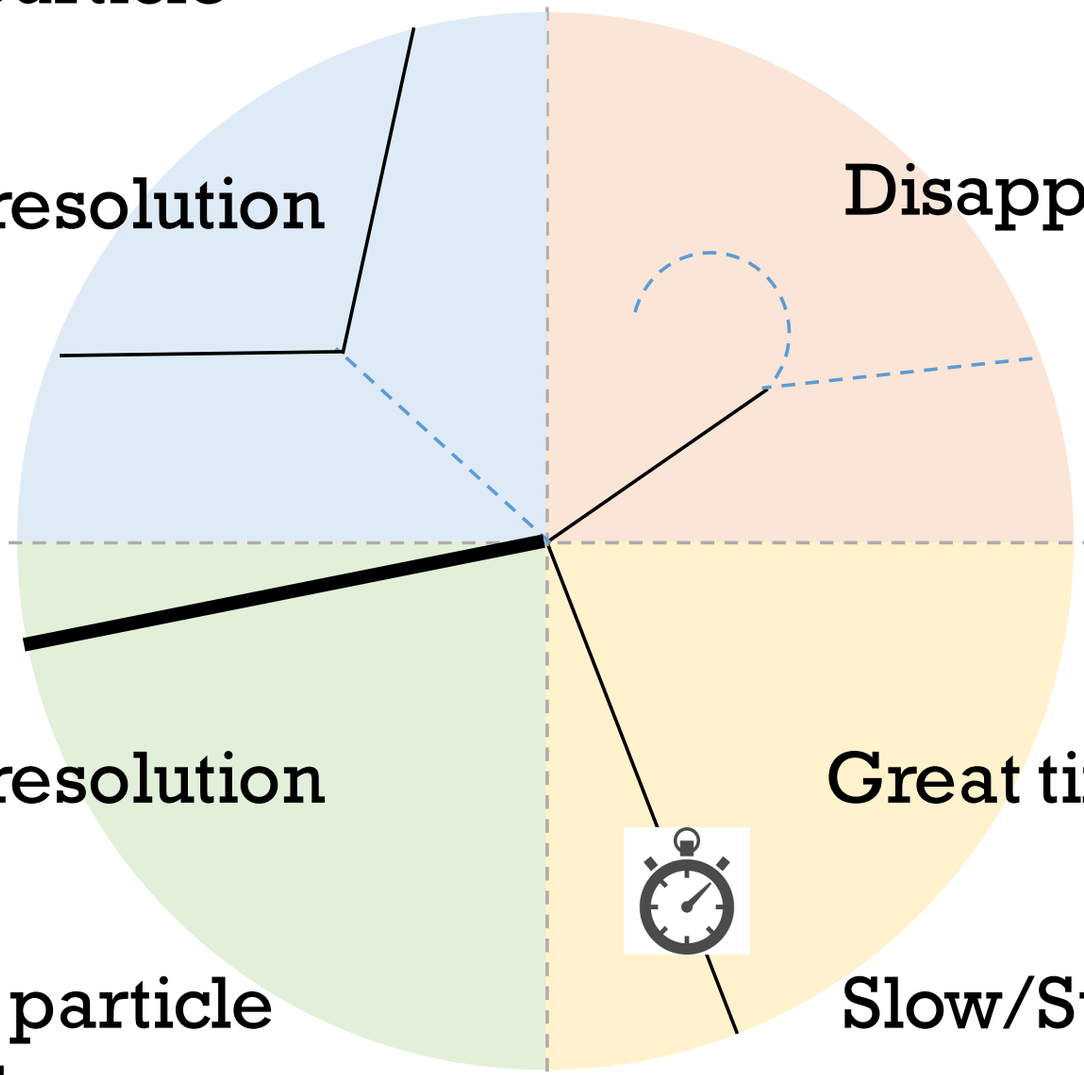


Improvement metrics

Displaced particle

↓

Great spatial resolution



Great tracking performance

↓

Disappearing particle search

Great energy resolution

↓

Large dE/dx particle search

Great timing resolution

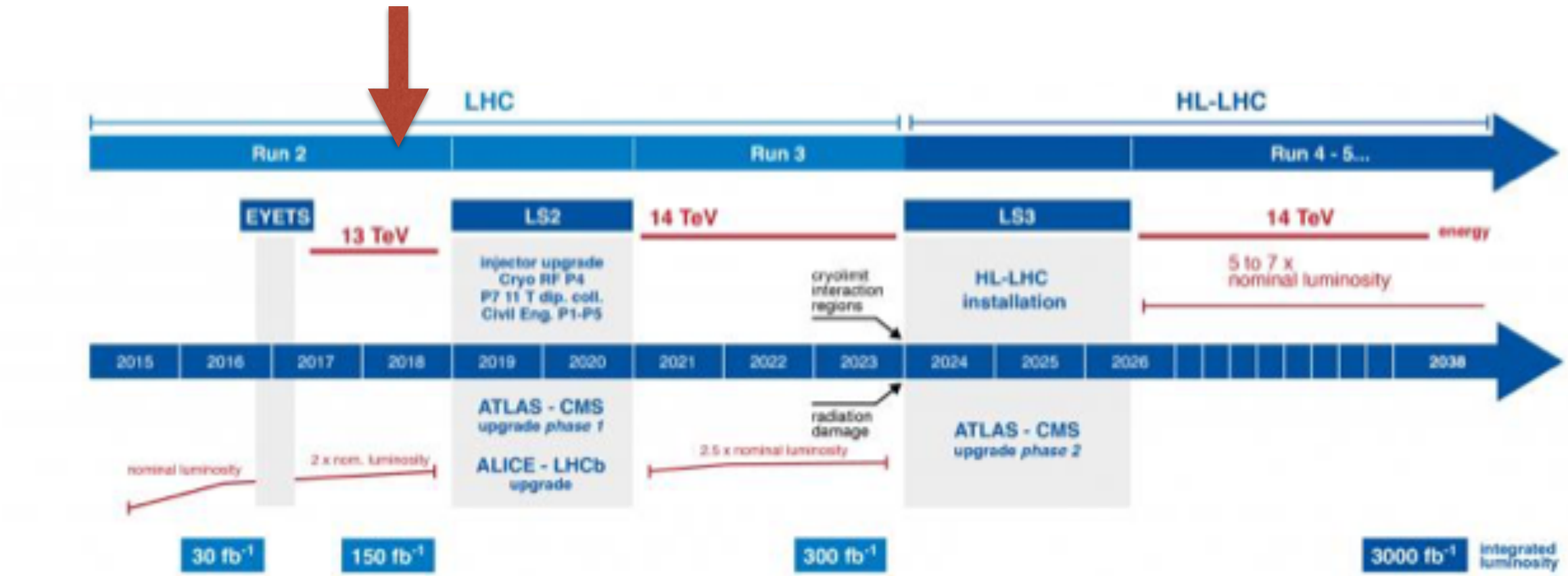
↓

Slow/Stopped particle search

Calorimeter
(beyond the scope of this talk)

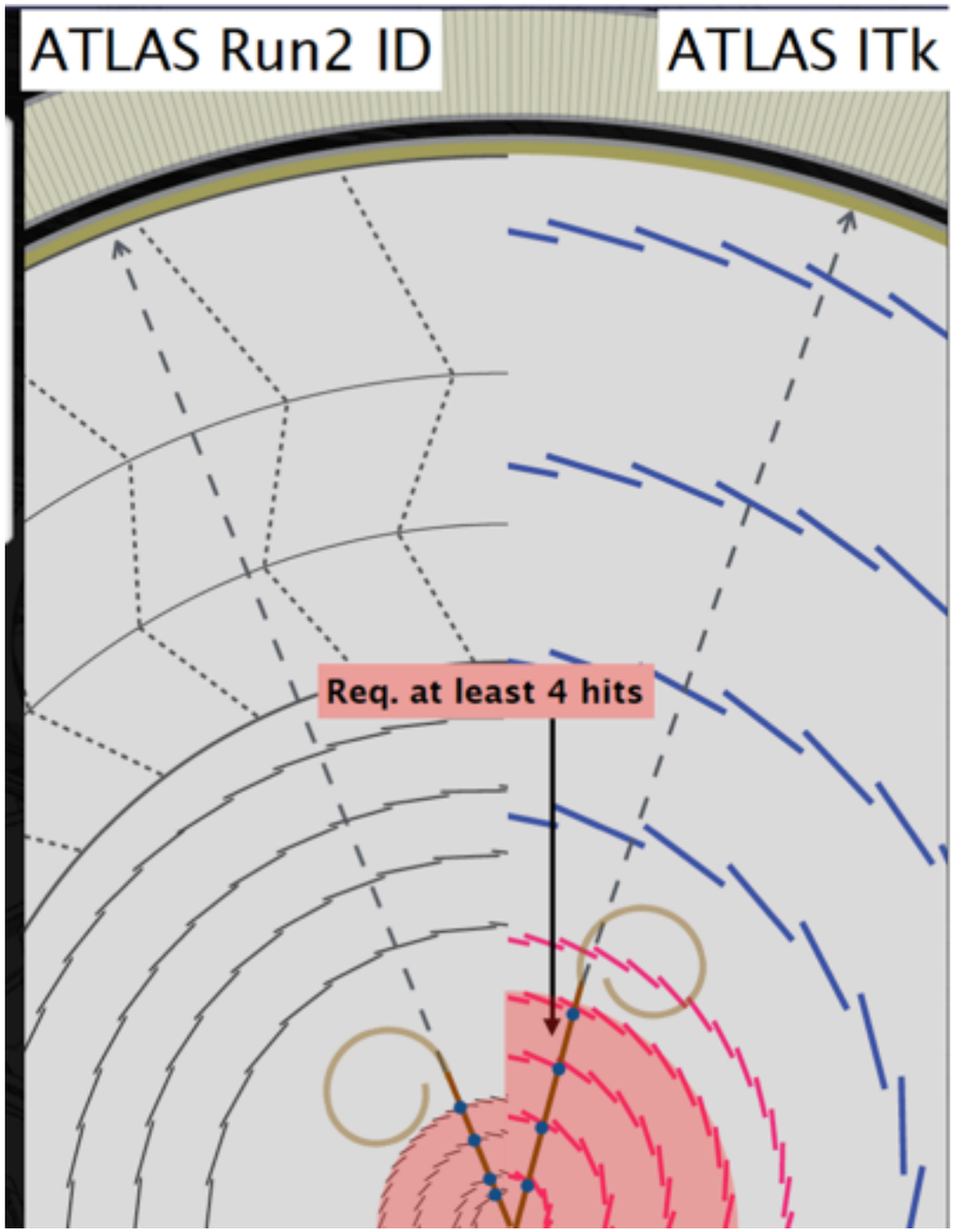
HL-LHC

We are here



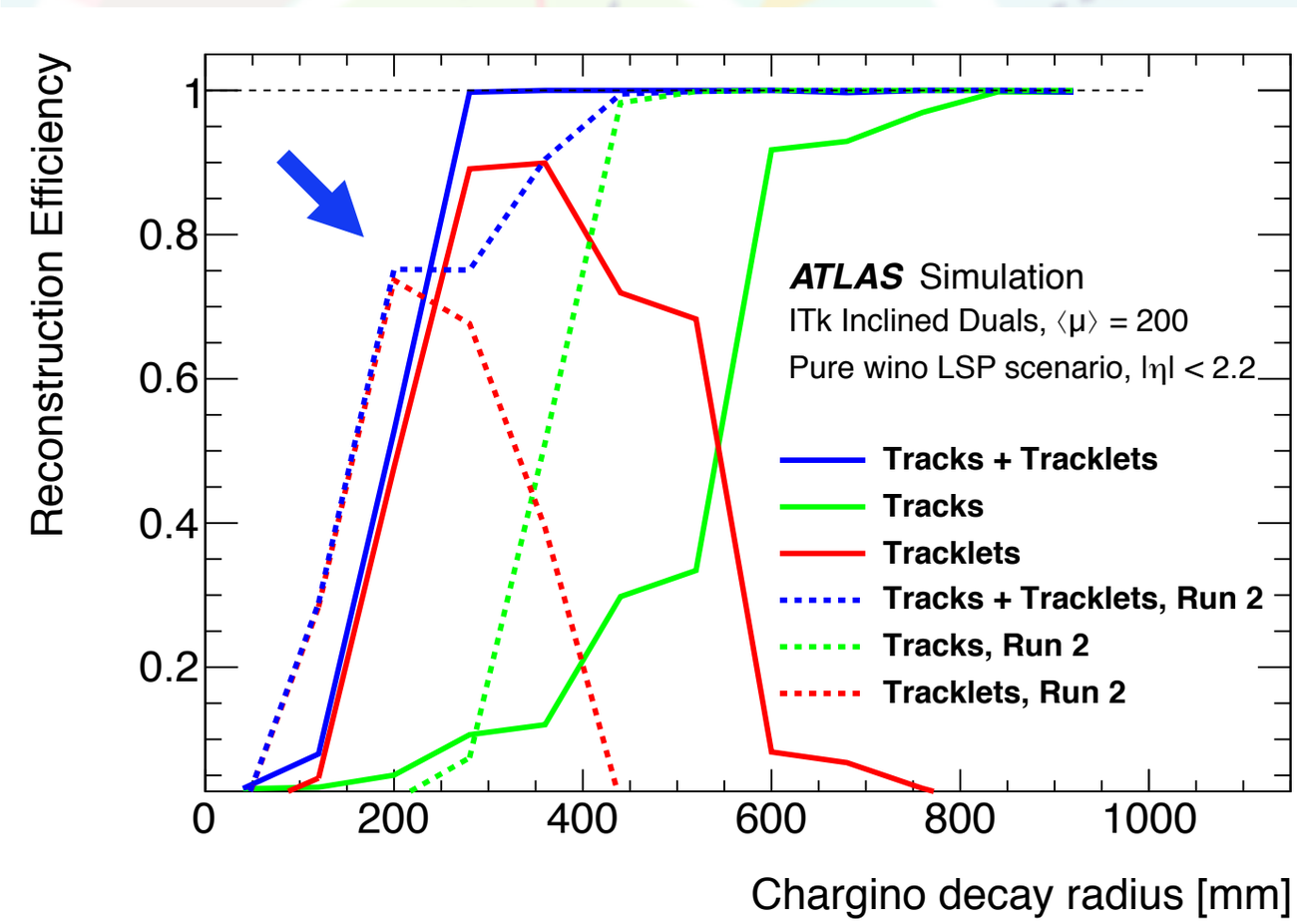
- ✓ Instantaneous luminosity: up to $7.5 \sim 10^{34}\ cm^{-2}s^{-1}$ (ultimately)
- ✓ Average pileup: $<\mu> \sim$ 140 (baseline) → 200 (ultimately)
- ✓ Integrated luminosity: 3 ab^{-1} (baseline), ultimately up to 4 ab^{-1}
- ✓ Starting from 2026, 10+ years of operation

Disappearing Tracks

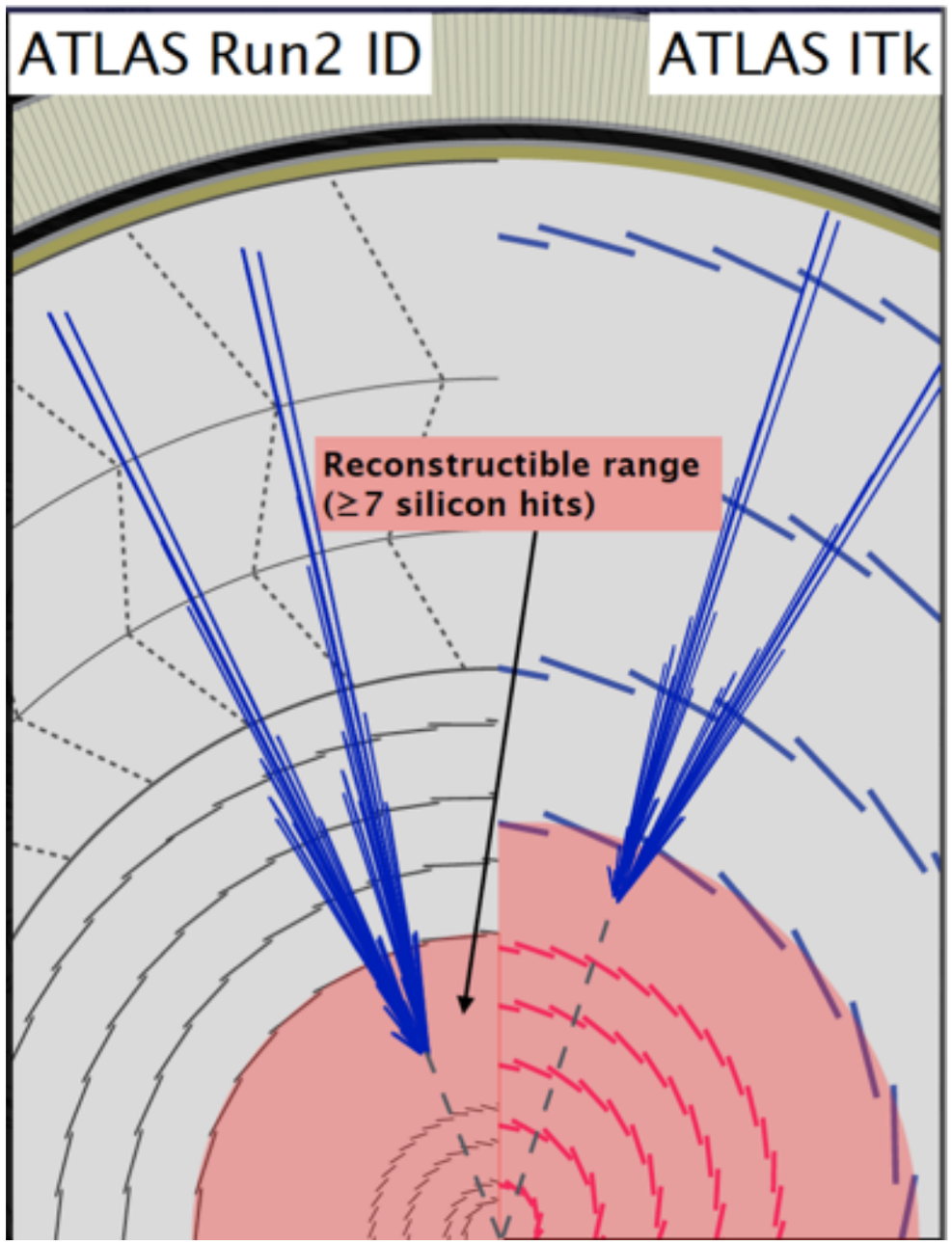


Lifetime: 10ps -10ns

- It is expected a decrease of acceptance due to the new layout.
  - mainly for short lifetime due to 4 hits requirements.

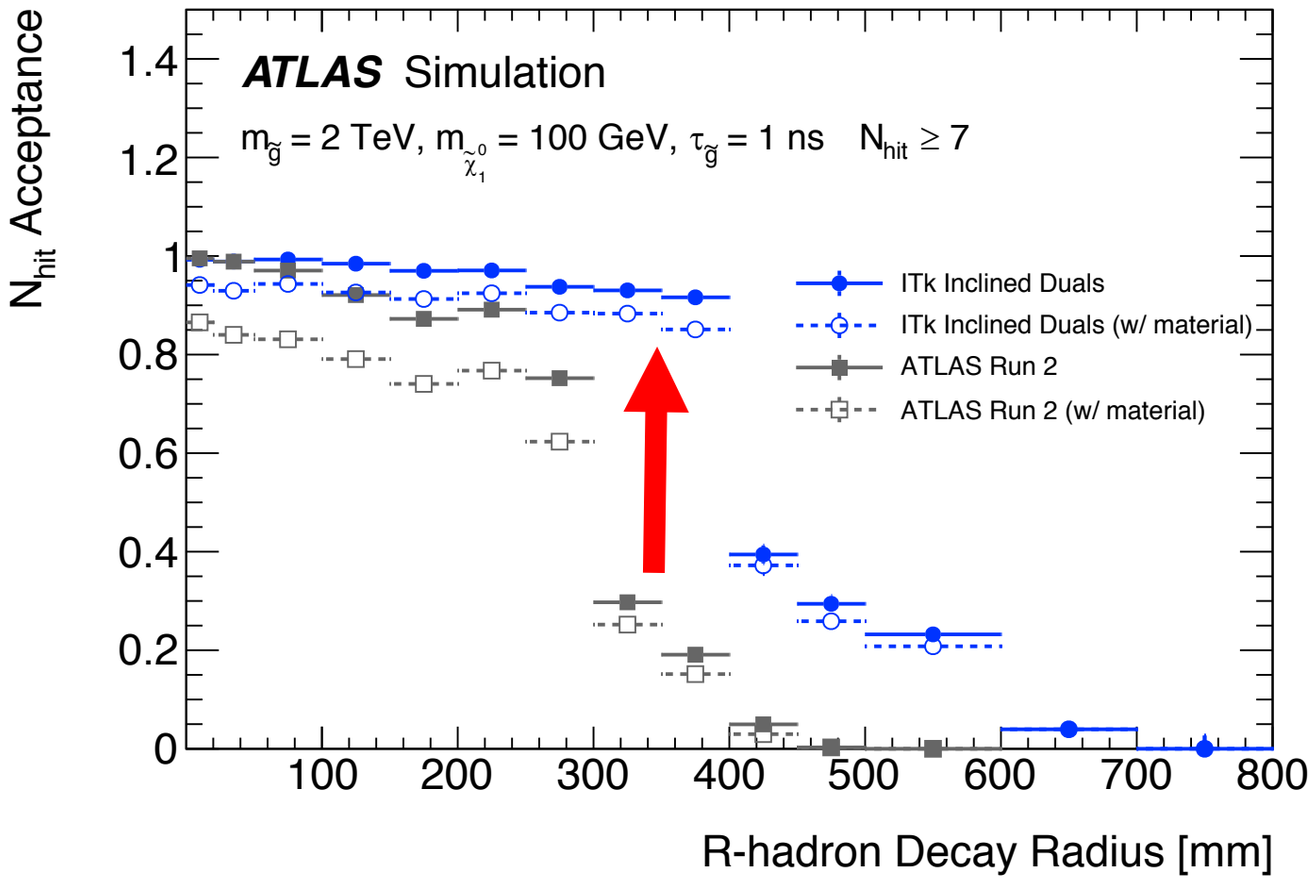


LLP at the HL-LHC



Lifetime: 10ps -10ns

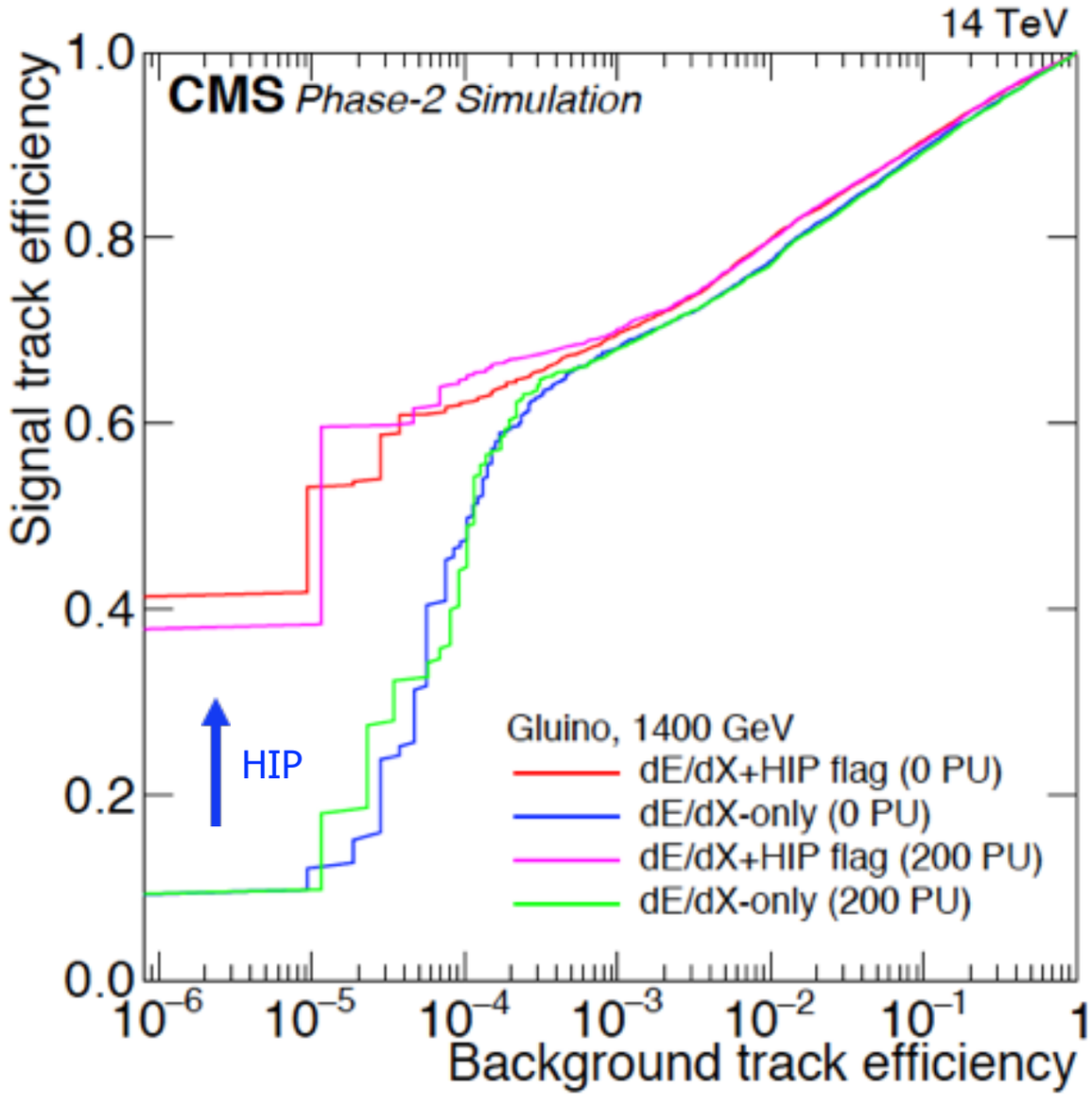
Increase of acceptance is significant thanks to new full Silicon tracker (Inner Tracker)

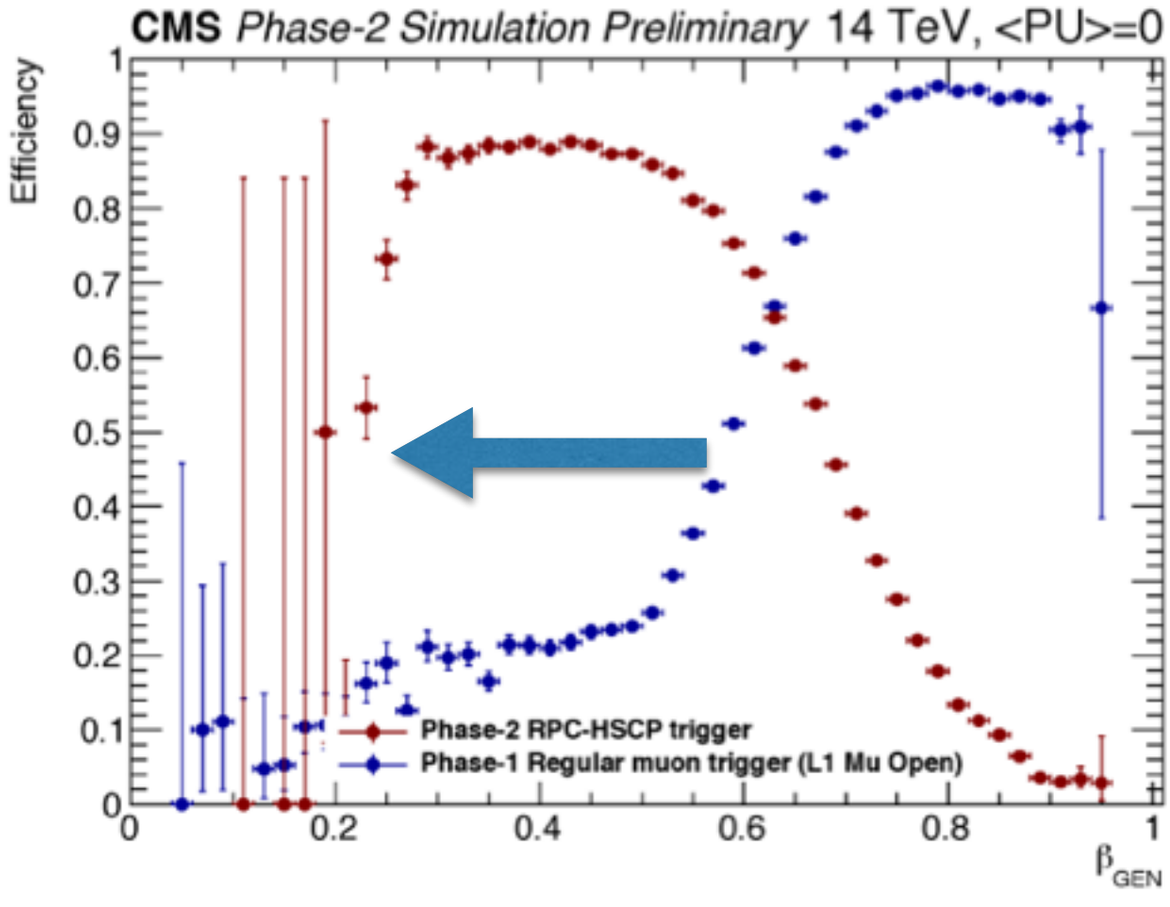


CMS Heavy Stable Charged Particle

ATLAS-CONF-2017-026

Anomalously high dE/dx is measured by the Inner Tracker. The Outer Tracker provides a binary readout only but a High Ionization Flag is implemented to restore some sensitivity





Summary

- Dedicated tools have been developed to probe non-conventional long-lived particle signature
  - A playground to practice creative ideas

- More improvements are being developed for the HL-LHC

- To go **beyond** the current LHC experiments
  - dedicated LLP experiments are clearly needed.

Backup

LHCb experiment

	LHCb
Magnetic field	Bending power of 4Tm
Tracker	Si strips + straw drift tubes $\sigma/p_T \approx 1 \bullet 10^{-2}\ p_T$ @200GeV
EM calorimeter	Pb + sci. pads ($25X_0$) $\sigma/E \approx 10\% / \sqrt{E} + 0.01$ GeV
H calorimeter	Fe + scint. (5.6λ) $\sigma/E \approx 69\% / \sqrt{E} + 0.09$ GeV
Muon	Iron and MWPC
Trigger	L0 + HLT