

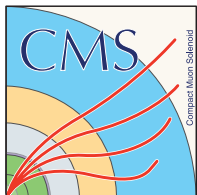
The 10th Annual
Large Hadron Collider Physics Conference
May 16-21, 2022



Online/offline development for LLP

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Nikhef, Amsterdam

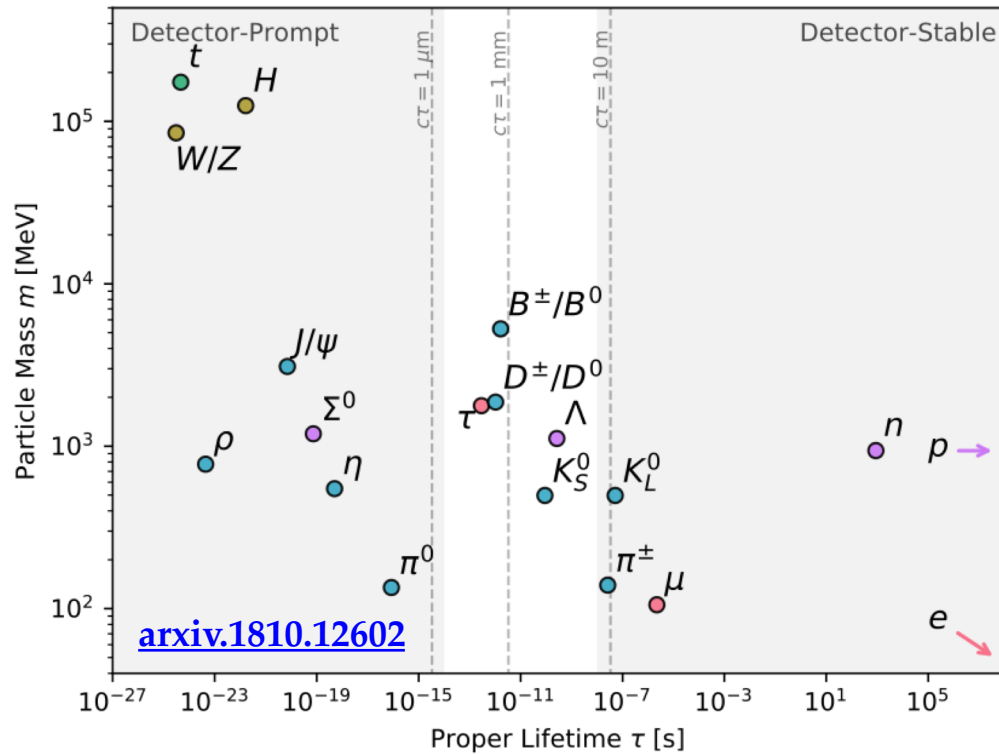
on behalf of the LHCb, CMS and ALICE collaborations
19/05/2022



Check other LLP related talks

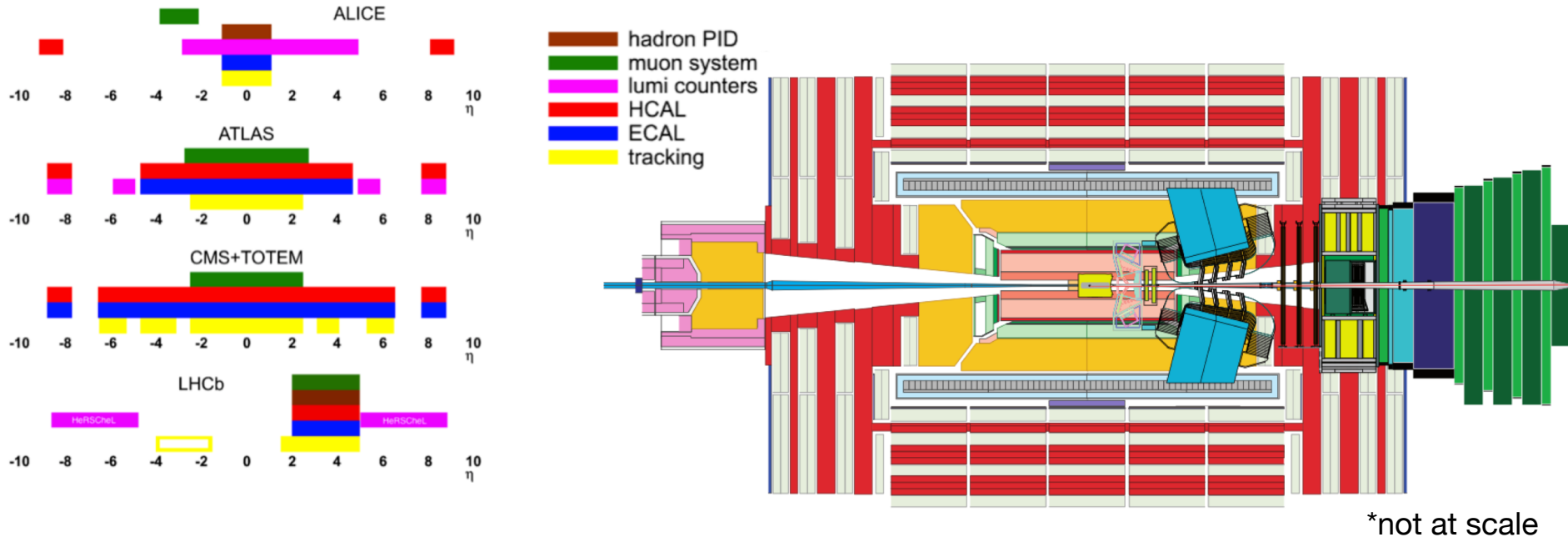
- [Dedicated LLP experiments beyond the LHC](#)
by L. Bueno
- [Prospects for LLPs searches at the LHC in Run 3 and HL-LHC](#)
by L. Shchutska
- [Searches for displaced jets at the LHC](#)
by M. Darwish
- [Searches for displaced vertices at the LHC](#)
by L. Henry
- [Searches for non-hadronic displaced objects not from a common vertex at the LHC](#)
by M. Shapiro
- [Searches for charged long-lived particles at the LHC](#)
by H. Oide

What are LLPs?



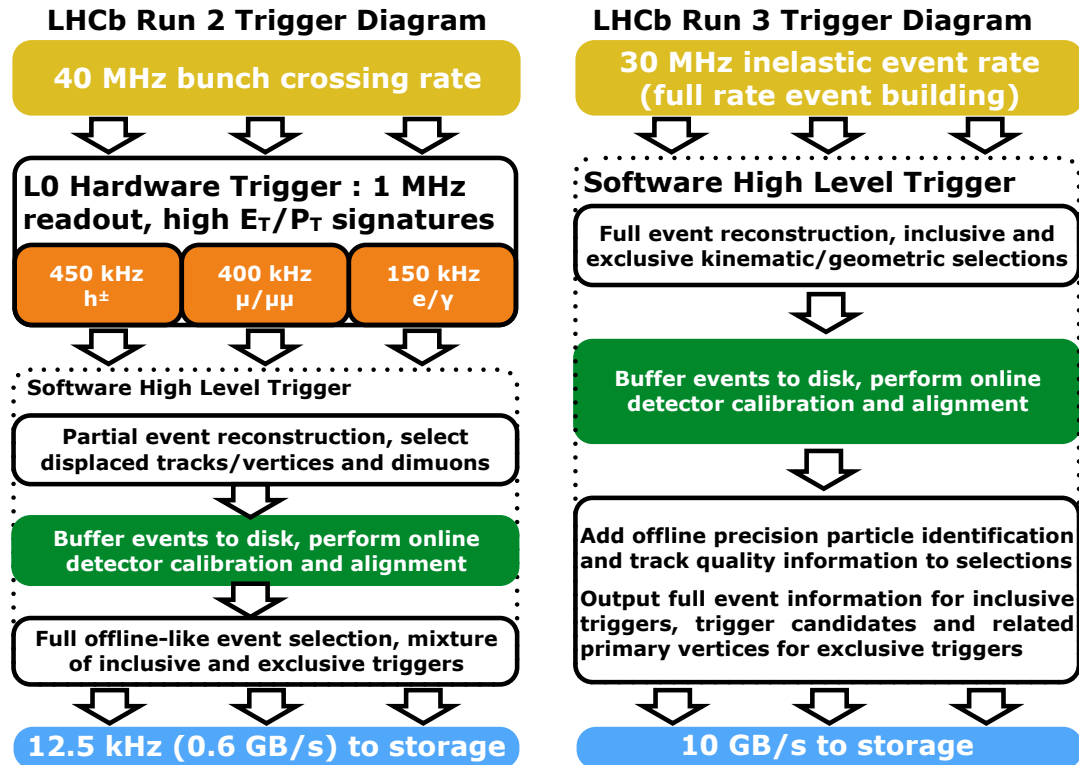
- Long-lived particle (LLP) – neutral or charged object decaying at *macroscopic* and *reconstructible* distance from IP
- Several LLPs in SM
- This talk: **focus on searches for BSM LLPs with an LHCb bias**
 - diverse signatures
 - challenge for trigger and reconstruction

LHC experiments vs LLPs



- Complementary coverage by LHC experiments
- High-mass searches by **ATLAS/CMS**
 - rich program of **LLP searches**
 - diverse list of explored signatures
- Access to low masses by **LHCb**
 - *x10* less data compared to ATLAS/CMS
 - flexible trigger allowing soft selections
- Possible searches in heavy-ion collisions by **ALICE** but also other experiments

LHCb in Run 3



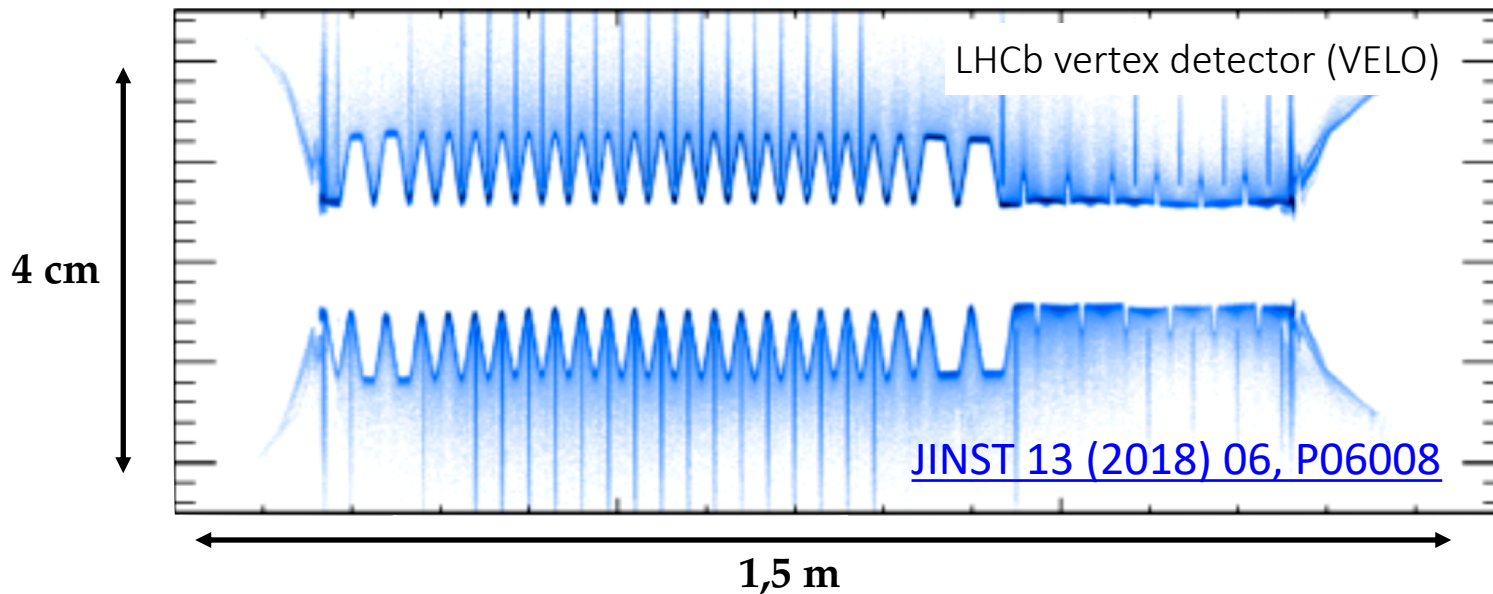
[LHCb-FIGURE-2020-016](#)

- x5 luminosity compared to Run 2
- **fully-software trigger**, 30 MHz event reconstruction
- GPU-based first trigger stage (HLT1) [Comput.Softw.Big Sci. 4 \(2020\) 1](#) compared to CPU implementation [Comput.Softw.Big Sci. 6 \(2022\) 1](#)
→ convenient to trigger exotic signatures
- STEALTH white paper with suggested NP signatures [arXiv.2105.12668](#)

LLP searches at LHCb

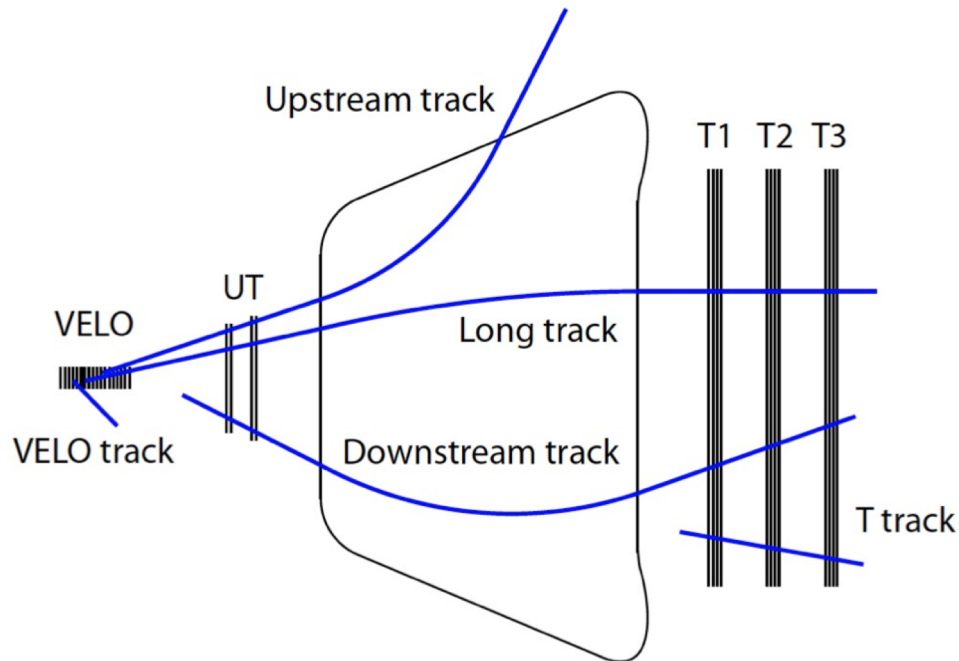


- So far only within VELO



- Displacement up to ~ 20 cm
 - decays of B-mesons with $\tau = 1.5$ ps correspond to displacement of $O(mm)$
 - Thin VELO envelope (RF foil) - background dominated by
 - heavy flavour decays at < 5 mm
 - material interactions at > 5 mm
 - Precise **material veto tool** thanks to imaging with reconstructed vertices
 - used in dark photon search [PRL 124 \(2020\) 041801](#)
-
- Can be extended to downstream region in Run 3

LHCb tracking



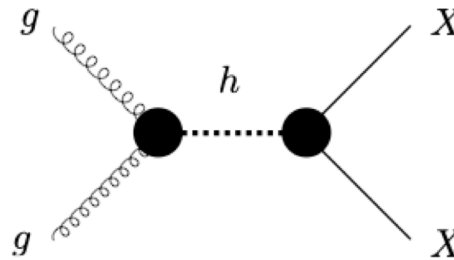
- HLT1 in Run1/2 – selection of **displaced Long tracks**
- Possible **downstream tracking** in HLT1 in Run 3 with GPUs ?
 - would extend LLP program (see [talk by L. Henry](#))
 - improved efficiency
 - access to longer lifetimes
 - studies of Λ **electric dipole moment** using T-tracks [EPJC \(2017\) 77 181](#)
- Reconstruction of T-tracks with FPGAs for LHCb Upgrades [Phys.Conf.Ser. 1525 \(2020\) 1 012101](#)

LHCb: searches for LLPs decaying to jets

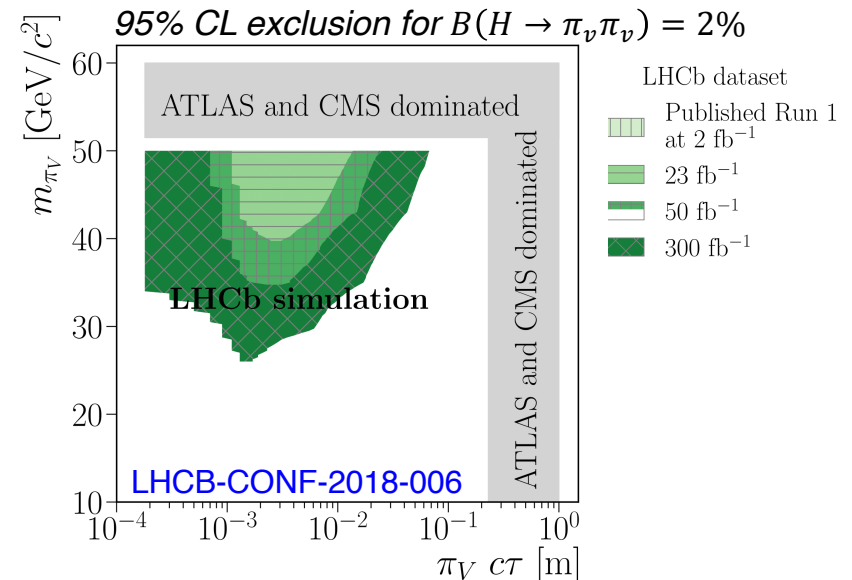
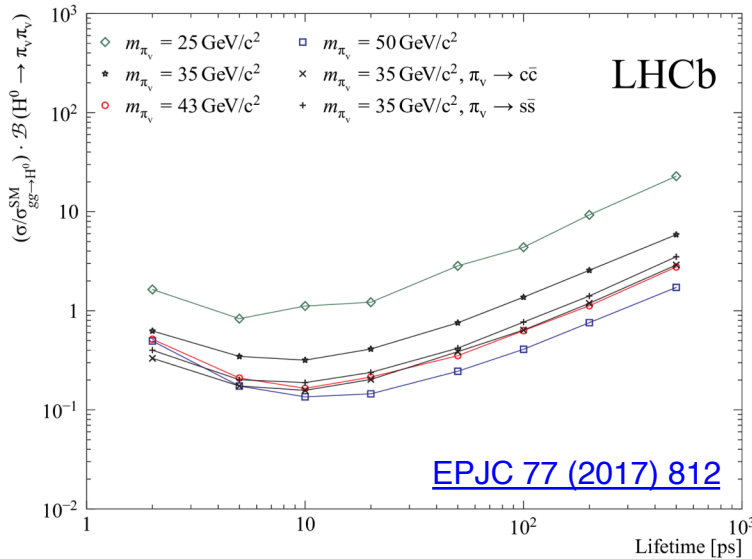
[EPJC 77 \(2017\) 812](#)

Signature: single displaced vertex with two (b-) jets

Model: Hidden Valley dark pions through Higgs portal



- Invariant mass range explored: 25-50 GeV
- Complementary limits to ATLAS and CMS

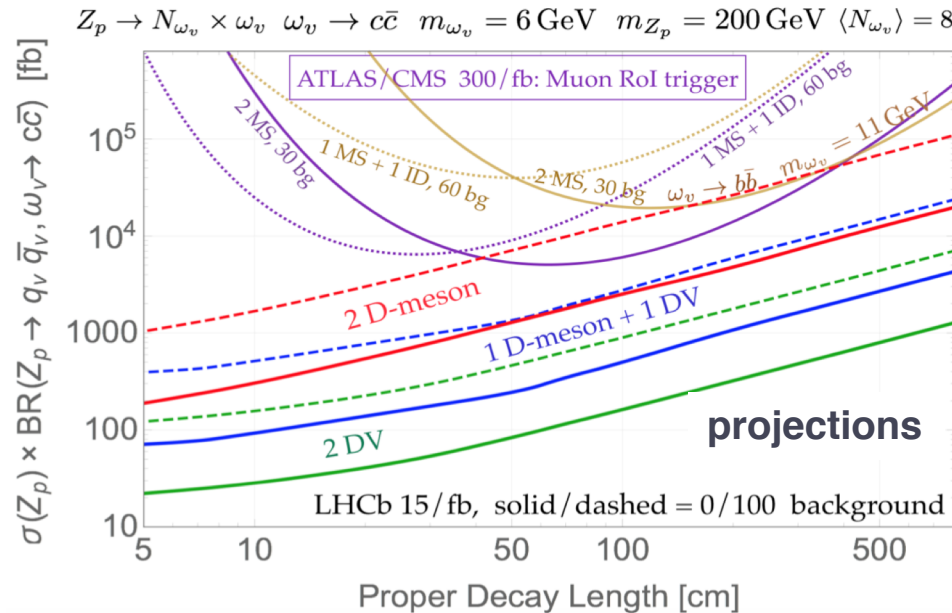


- Can be pushed to lower masses in Run 3 using jet substructure

[LHCb-CONF-2018-006](#)

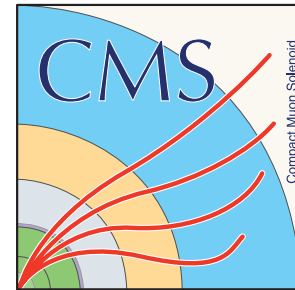
LLP decays to light hadrons

- Access to low masses $O(\text{GeV})$
- Trigger on displaced vertices
- LHCb: use charged hadron ID from RICH in trigger
- Complicated mixture of heavy flavor background
- Several searches suggested:
 - Model-independent search for $H \rightarrow SS, S \rightarrow K^+K^-$
 projections: [JHEP 01 \(2020\) 115](#)
 - Dark hadrons via decays to D -mesons / displaced vertices
 projections: [PRD 97 \(2018\) 9, 095033](#)



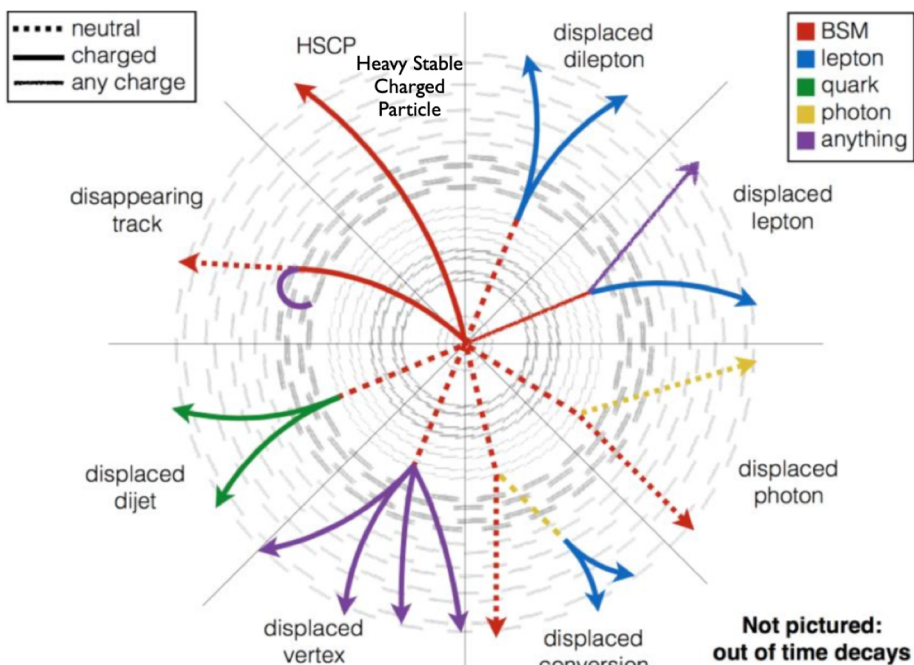
credit: Y. Tsai

CMS trigger



Two-level trigger L1+HLT [JINST 15 \(2020\) P10017](#) :

- L1
 - uses limited input from ECAL, HCAL, Muon chambers only
 - hard limit of 100 kHz
 - main constraint for LLPs
- HLT
 - uses complete information
 - only lacks final calibrations and time



[Phil.Trans.R.Soc.A377:20190047](#)

LLP triggers – very rich program!

MET triggers:

- disappearing tracks, delayed jets

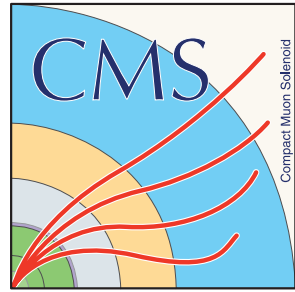
Standard triggers

- Displaced vertices, emerging jets, HSCP
- Photon triggers
- Can also trigger on prompt objects in the event

Dedicated LLP triggers

- Displaced objects
- Stopped particles

Dedicated LLP triggers



- Displaced jet [EXO-19-021](#)
 - two jets with ≤ 2 prompt tracks
 - *dedicated displaced track iteration on jets*
- Displaced photon + HT [EXO-19-005](#)
- Stopped particles [EXO-16-004](#)
- Displaced muon [EXO-16-022](#)
 - tracking + muon stations
 - displacements up to 0.1cm
- Very displaced muons [CMS-DP-2019-028](#)
 - muon system only, no tracking
- Disappearing tracks [EXO-19-010](#)
 - Based on MET trigger

Run 3 improvements

- **HCAL** timing and depth information in trigger

- new TDC with 0.5 ns resolution
- available in L1 !
- **beneficial for LLP triggers**

- **ECAL** timing

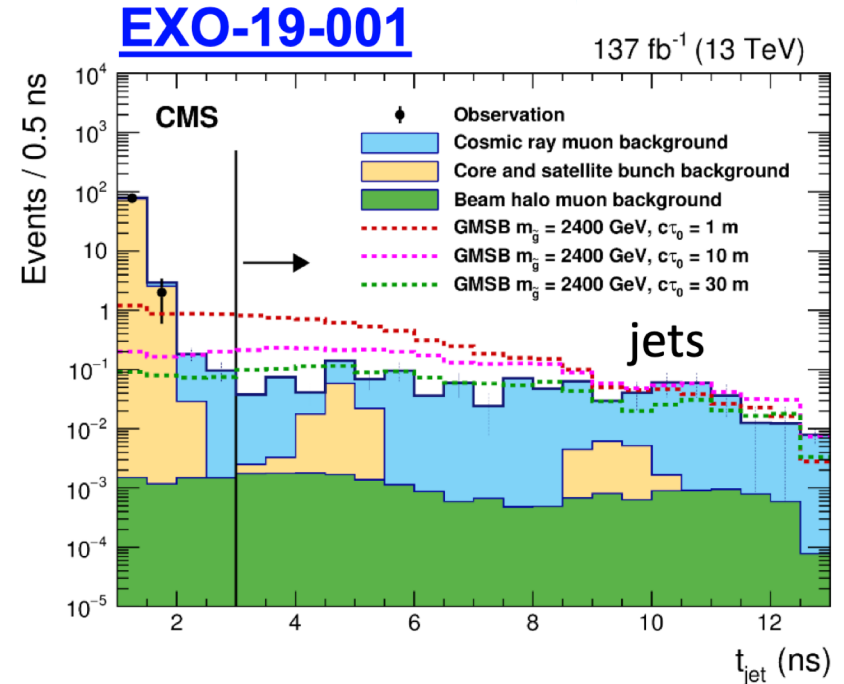
- was already used offline
- possible use in HLT

- **Muon**

- possible removal of vertex constraint
- detect showers by Muon system in L1?
extension of lifetime range

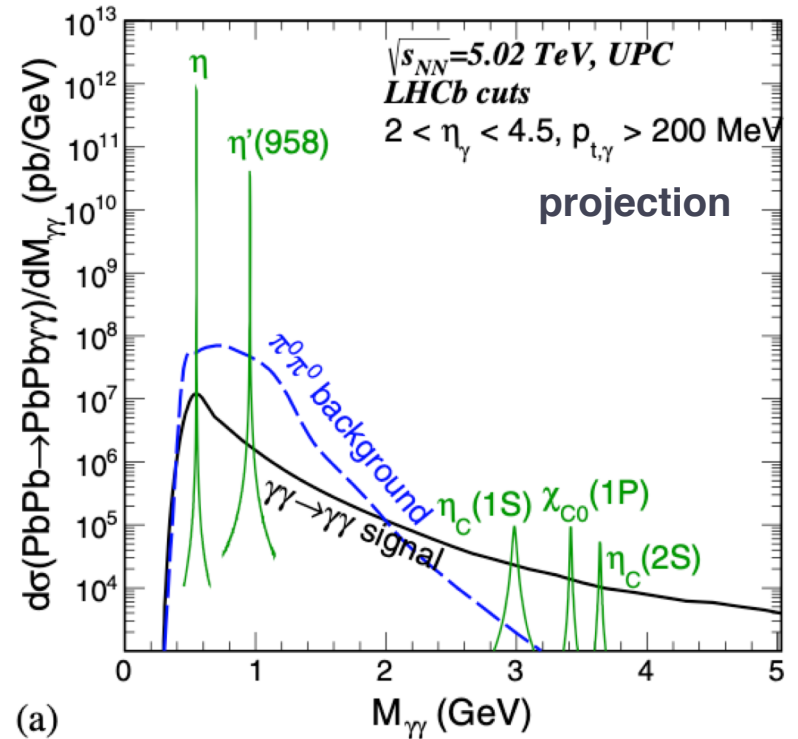
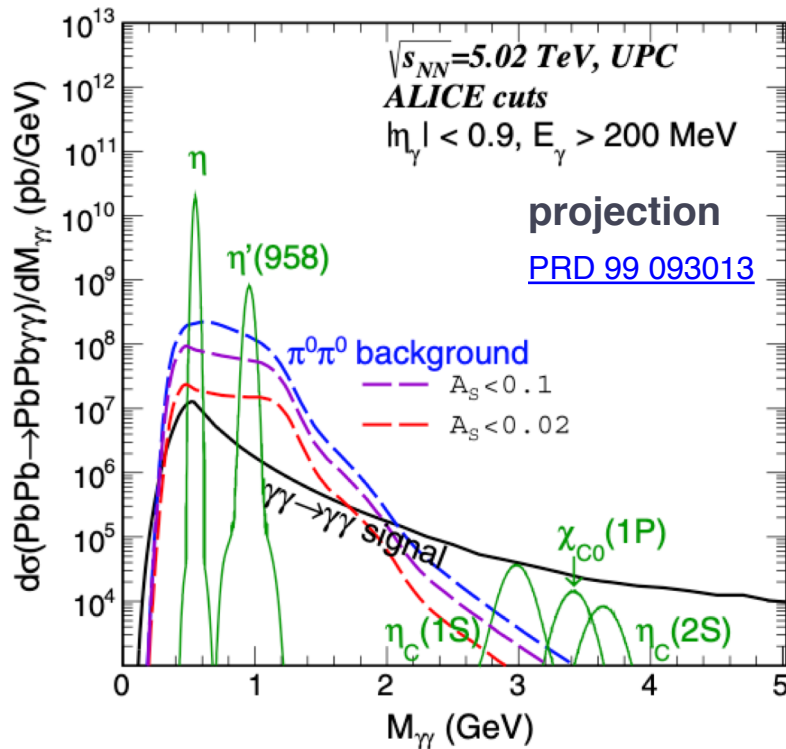
- Better physics reach **by scouting and parking**

- Possible use of cross triggers [JINST 15 \(2020\) P10017](#)



Searches in ultraperipheral PbPb collisions

- Use LHC as $\gamma\gamma$ collider
- All experiments can contribute
- Possible search for ALPs below 5 GeV – ALICE, LHCb
- Direct low- P_T photons or $\gamma \rightarrow e^+e^-$ conversions [PRD 99 093013](#)
- Background from $\pi^0\pi^0$ and SM mesons



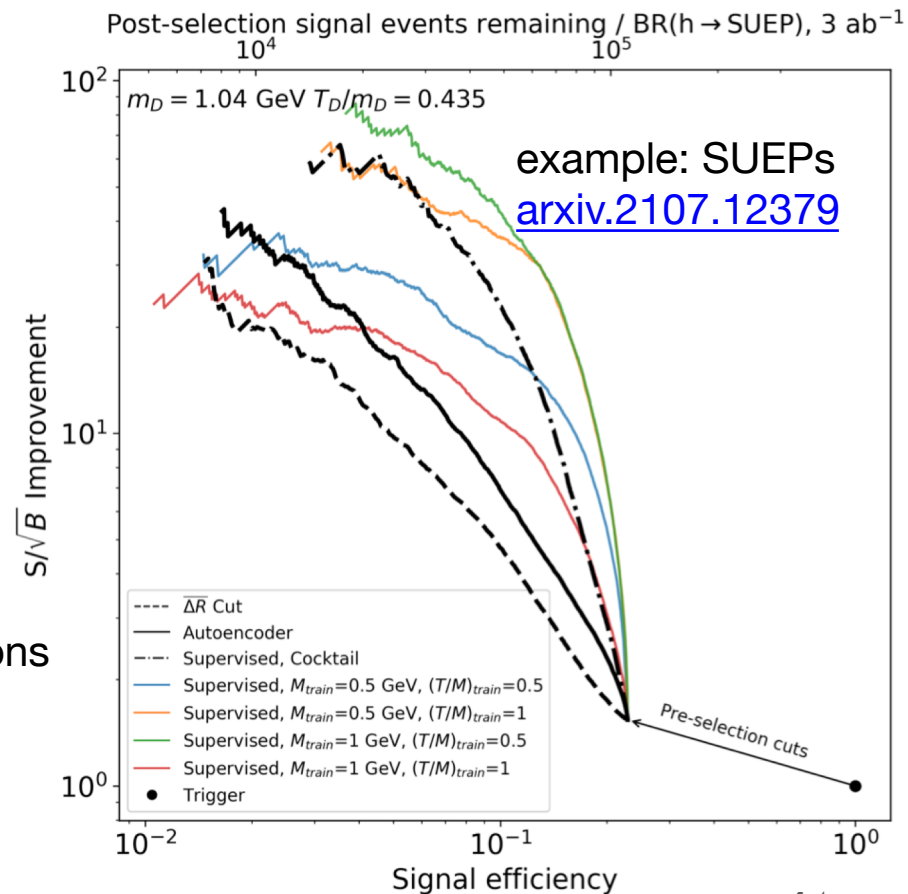
(a)

Autoencoders for LLP searches

- BSM searches are often model-dependent
 - degradation of sensitivity if not “right” model was used
- **Autoencoder** – unsupervised ML algorithm [arxiv.1312.6114](https://arxiv.org/abs/1312.6114)
 - trained on known SM processes only
 - identify anomalies in data

- Could be used in trigger?
- Proposed for L1 in CMS [arxiv.1811.10276](https://arxiv.org/abs/1811.10276)
- Relevant for all experiments

- *Suggested applications:*
 - identifying SUEPs: high-multiplicity showers of dark hadrons [arxiv.2107.12379](https://arxiv.org/abs/2107.12379)
 - semi-visible jet detection [arxiv.2112.02864](https://arxiv.org/abs/2112.02864)



Summary

- LHC experiments will provide complementary searches for LLPs
- Online triggers on exotic signatures significantly extend the physics reach
 - Dedicated long-lived particle tracking and vertexing **LHCb** would provide new opportunities with GPUs
 - Rich **CMS** program includes reconstruction of displaced vertices, jets, emerging jets, etc
 - Search for light ALPs in ultraperipheral HI collisions by **ALICE** and other experiments

- (Not full) overview of possible Run 3 triggers at LHC

[CERN-LPCC-2021-01](#)

Review of opportunities for new long-lived particle triggers in Run 3 of the Large Hadron Collider

Produced for the LPCC Long-Lived Particles Working Group.

- Use of novel autoencoders is beneficial for offline analysis and trigger