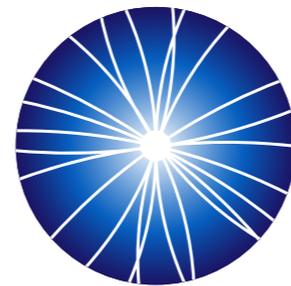


LLP and dark sectors

X. Cid Vidal (IGFAE) on behalf of WG3
HL/HE-LHC physics jamboree
March 1st 2019

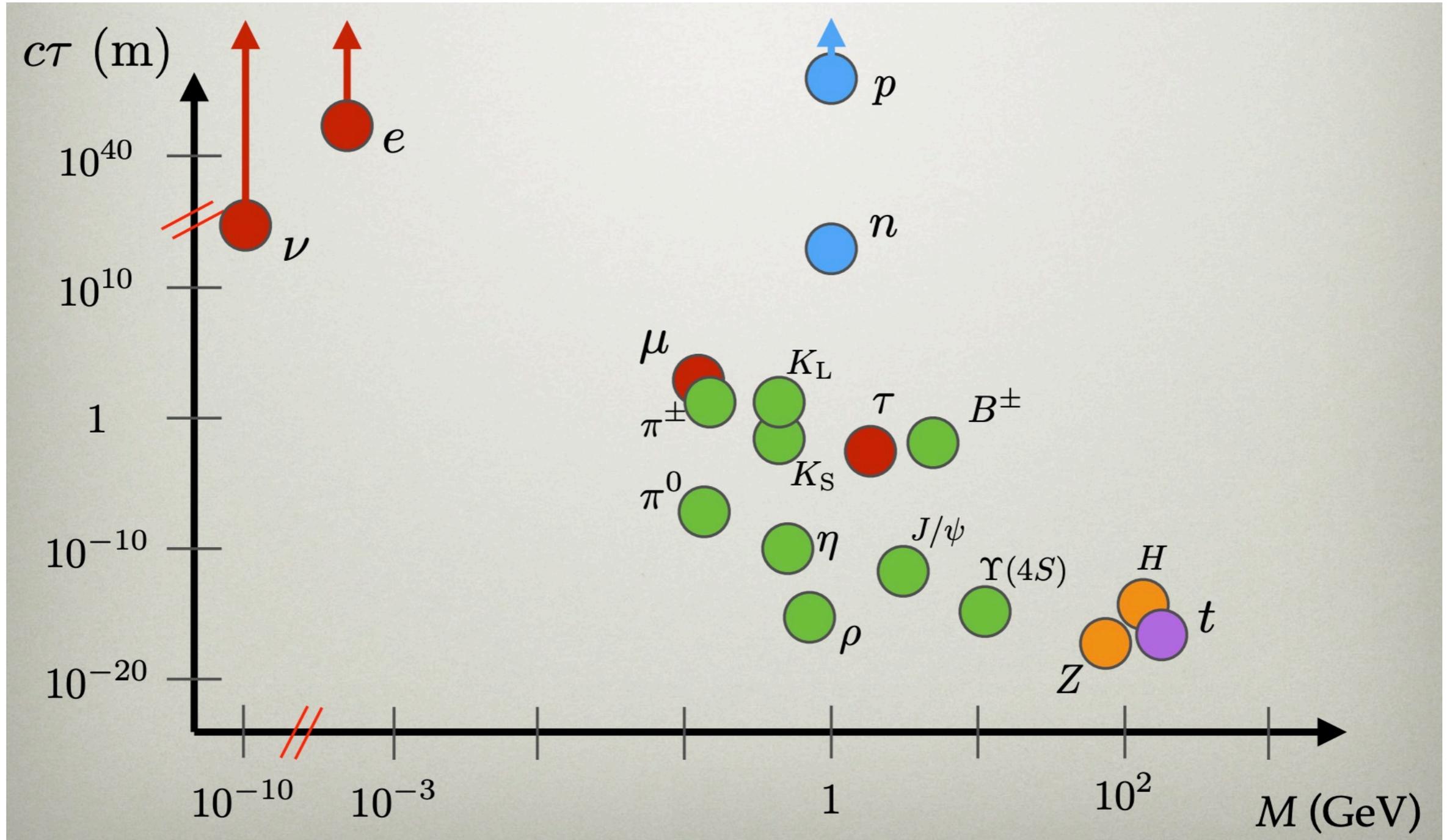


IGFAE
Instituto Galego de Física de Altas Enerxías

Long-Lived Particles (LLPs)

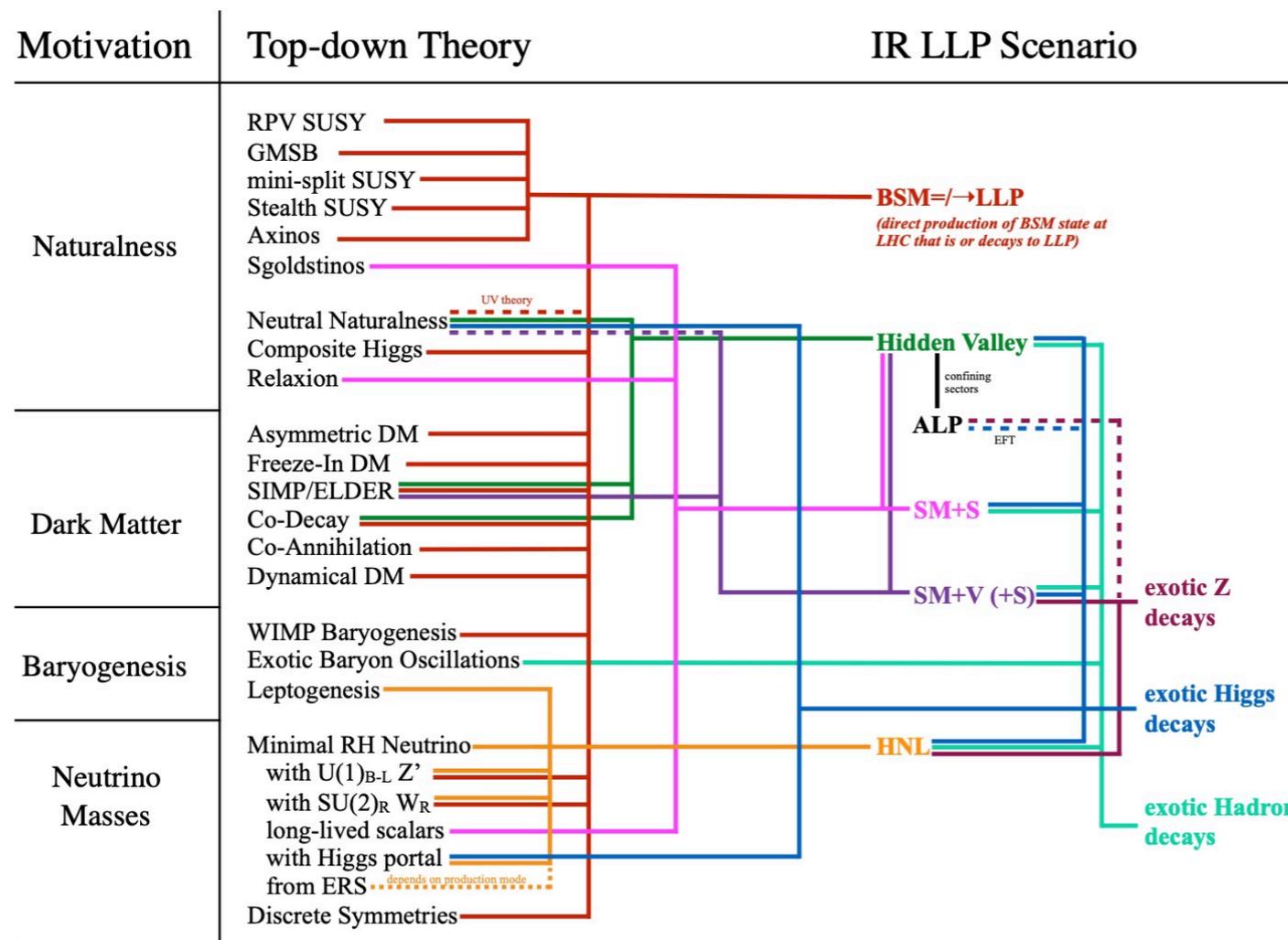
◆ The world is full of LLPs!

B. Shuve



◆ LLPs are very well motivated in **several** BSM models

➔ Same motivations providing LLPs in SM: Feeble couplings, no definite mass scale

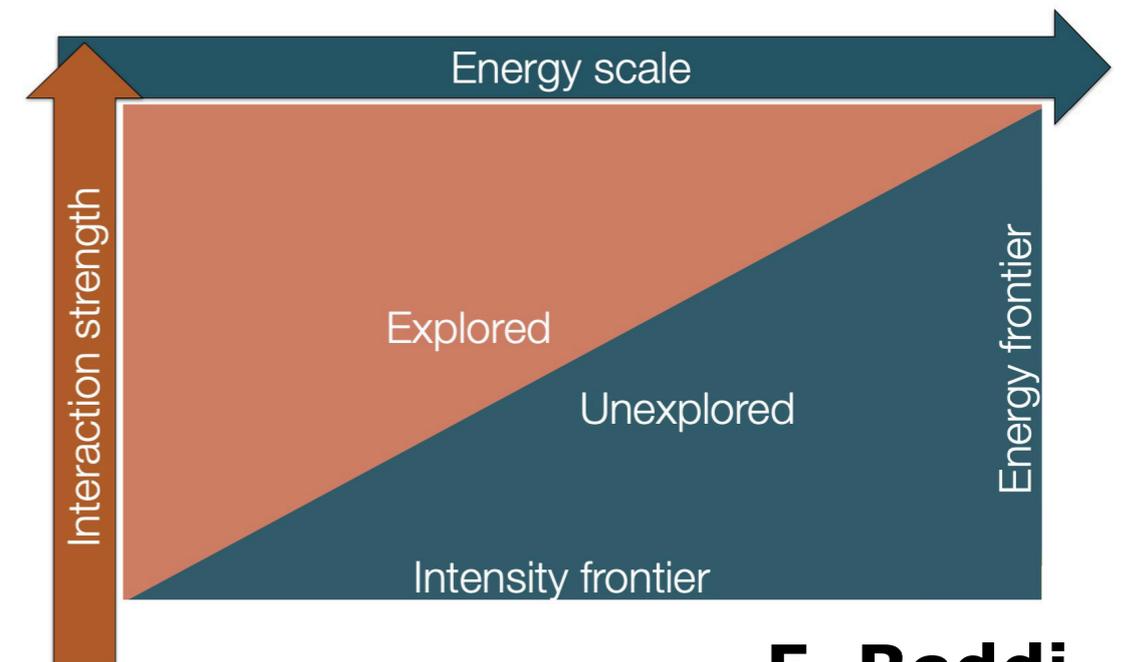


Mathusla physics case
arxiv:1806.07396

- ◆ The appearance of long-lived particles in BSM models is usually more related to weak couplings than to high energy scales.

- LLPs are a **perfect example of the relevance of the HL-LHC**

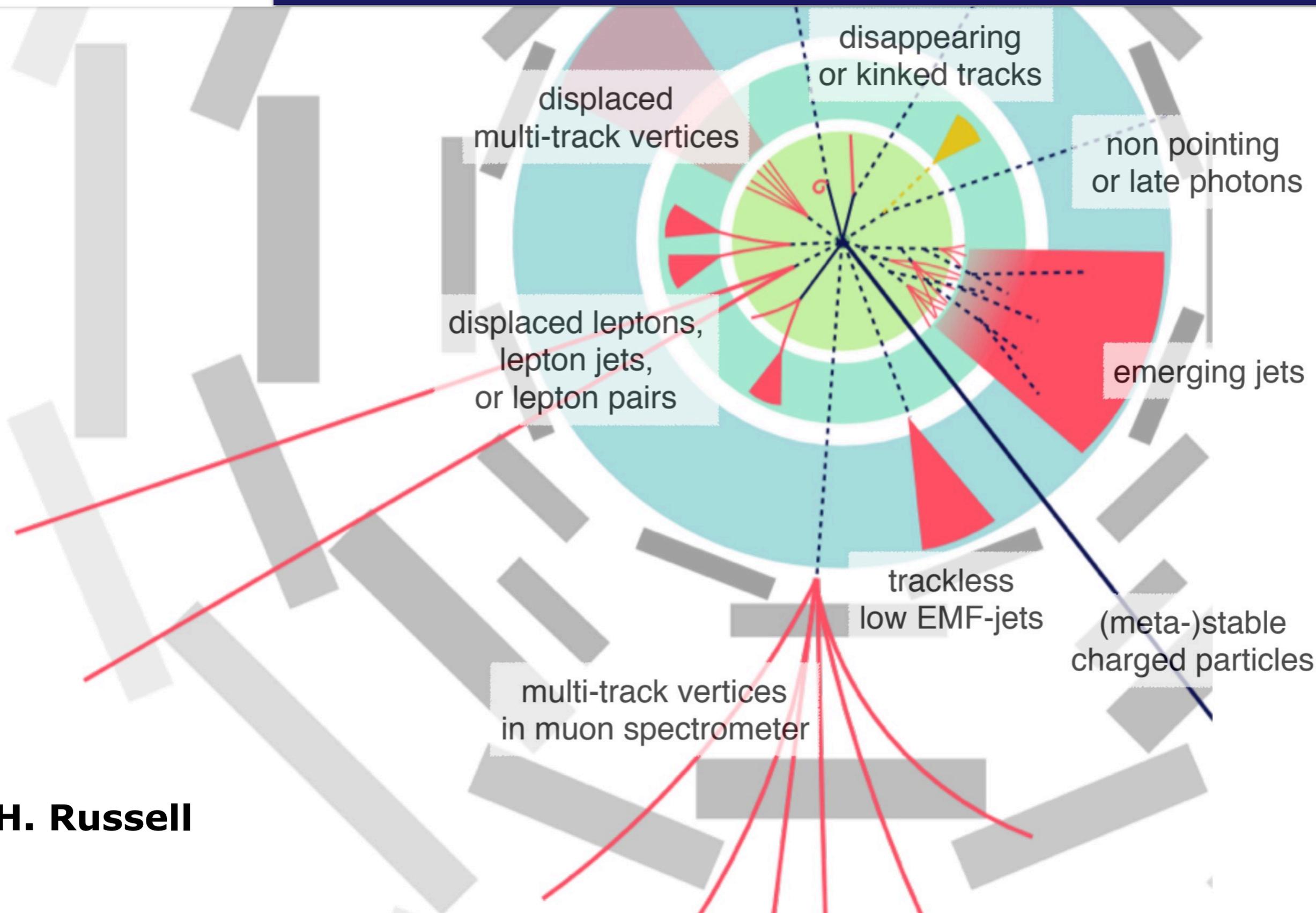
- Look for BSM physics by exploring the intensity frontier



F. Reddi

- In several cases, new detector technologies associated to the HL upgrades will be very useful

- ◆ Most of the above applies to dark sectors (later)

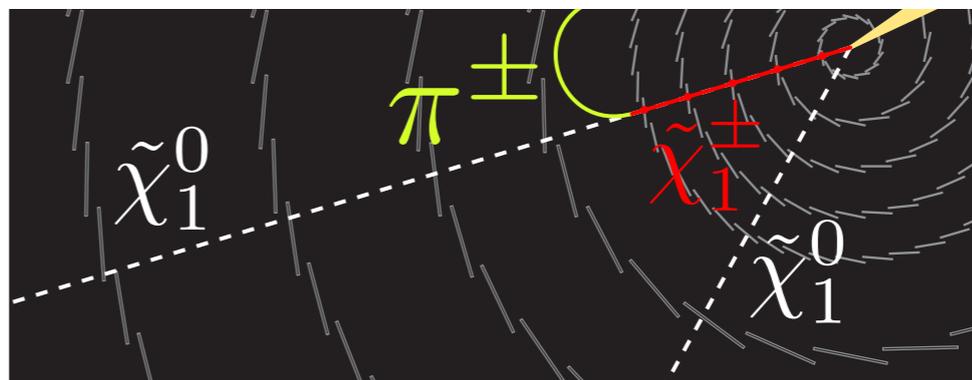
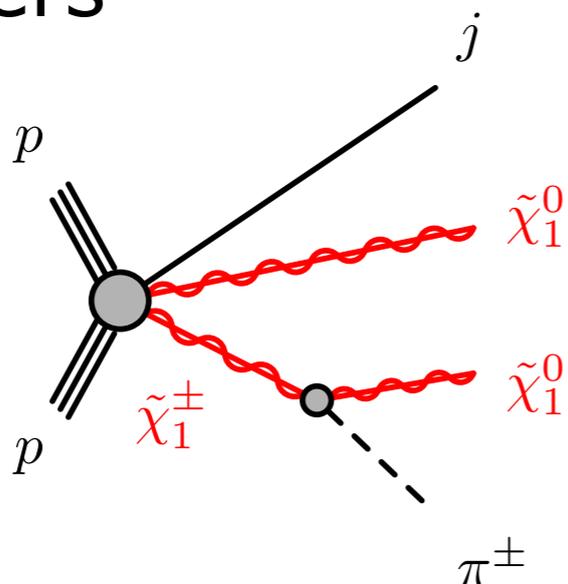


H. Russell

Long-Lived Particles (LLPs)

Disappearing tracks

- ◆ Scenarios with almost degenerate masses of SUSY particles
 - ➔ Long lifetime of mother, very soft charged daughter
 - ➔ Track disappears in the detector after traversing some layers

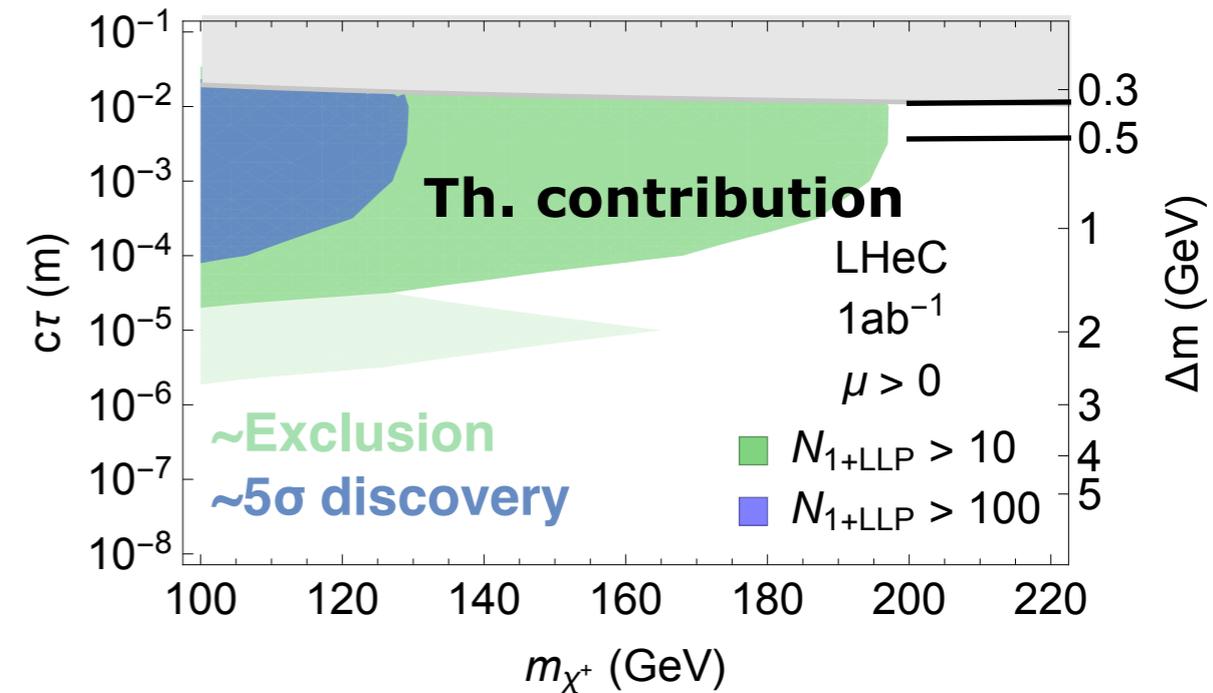


- ➔ LHC detectors can cover wide range of mass and lifetime of the charginos

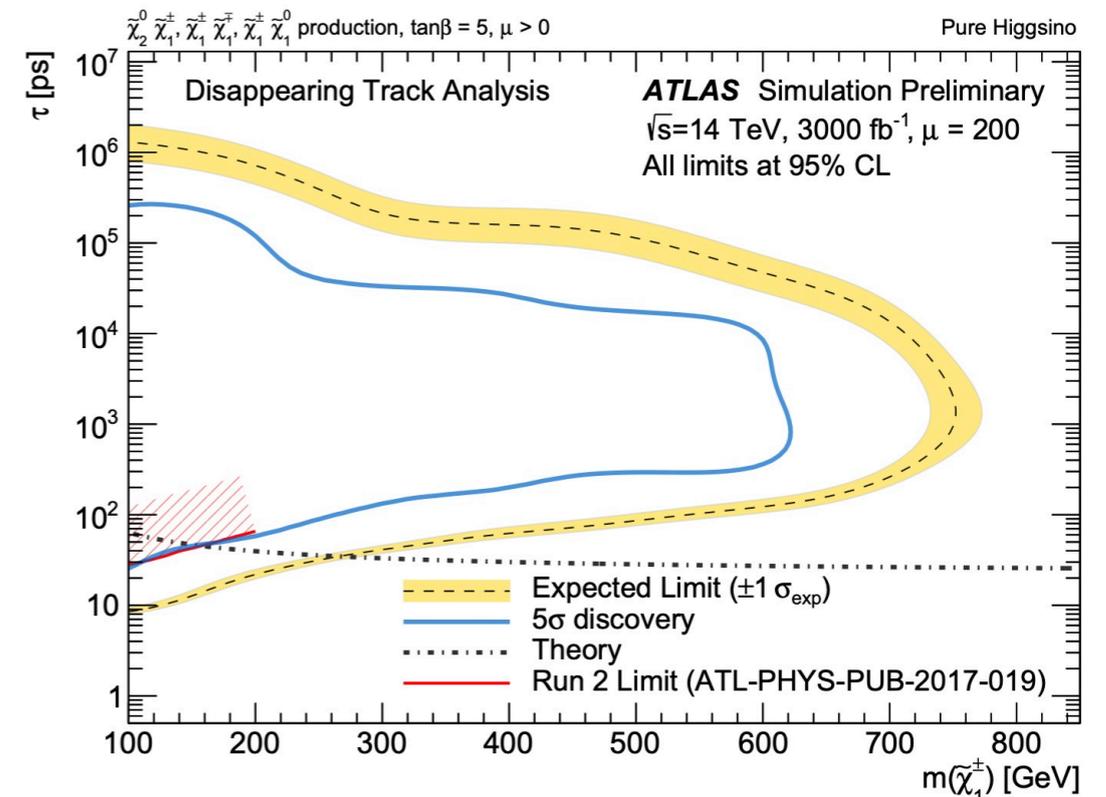
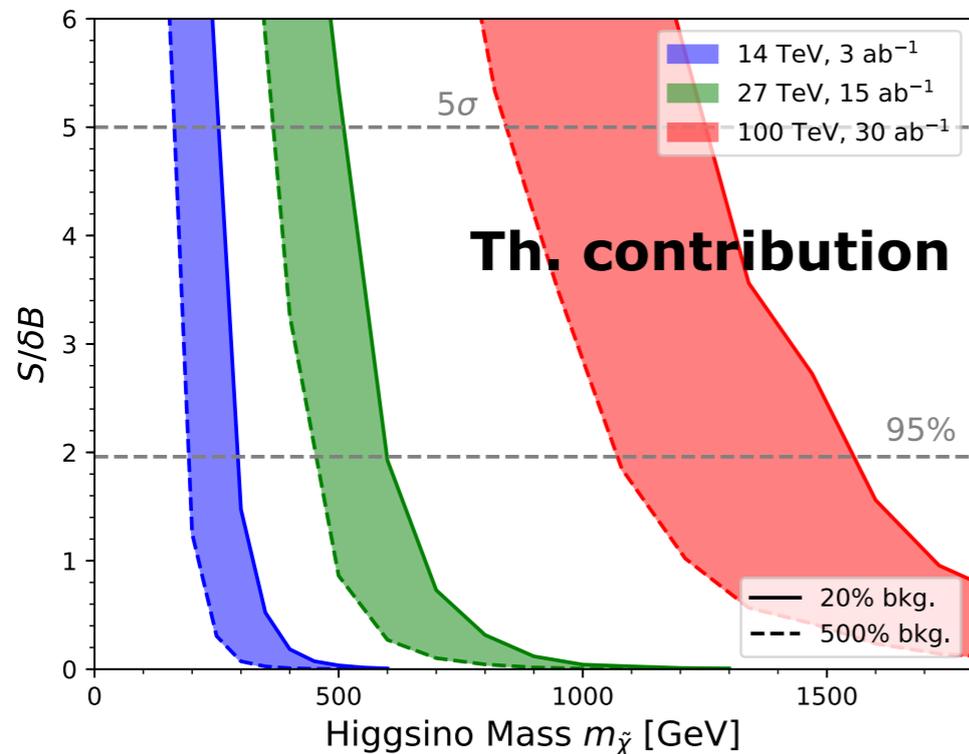
◆ Showing different Higgsino scenarios as benchmarks

➔ Comparison between HL-LHC, HE-LHC and even LHeC

JHEP (2018) 2018: 24



Specific DM scenario with defined lifetimes!



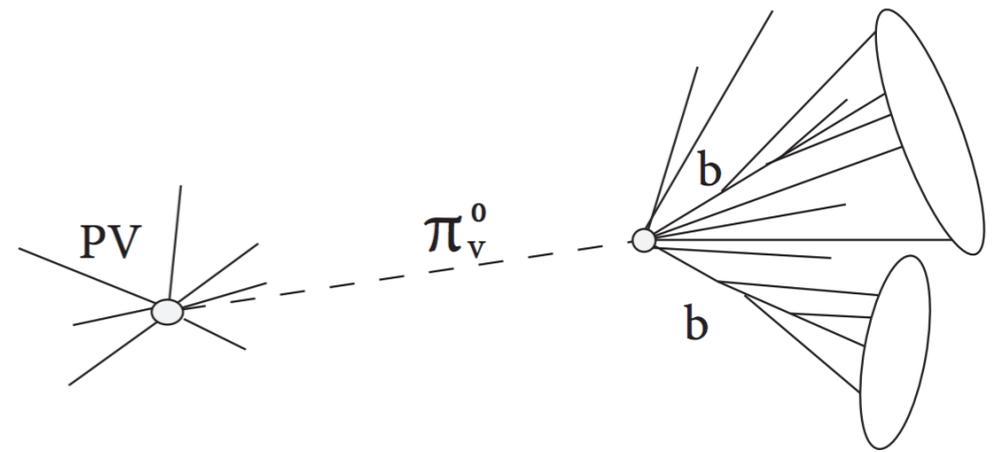
Phys.Rev. D98 (2018) no.3, 035026

ATL-PHYS-PUB-2018-031

Long-Lived Particles (LLPs)

Displaced vertices

- ◆ Common feature: displaced BSM particles that decay back to SM particles
- Different final states possible: jets, leptons, ... as well as multiple displaced vertices
- Examples from the 3 experiments for this signature. Significant complementarity!
- In some cases, additional handles, such as MET, needed to trigger or discriminate against background
- Different well motivated theoretical models possible, some degree of overlap with SUSY and dark sectors, e.g. dark photons (covered later)

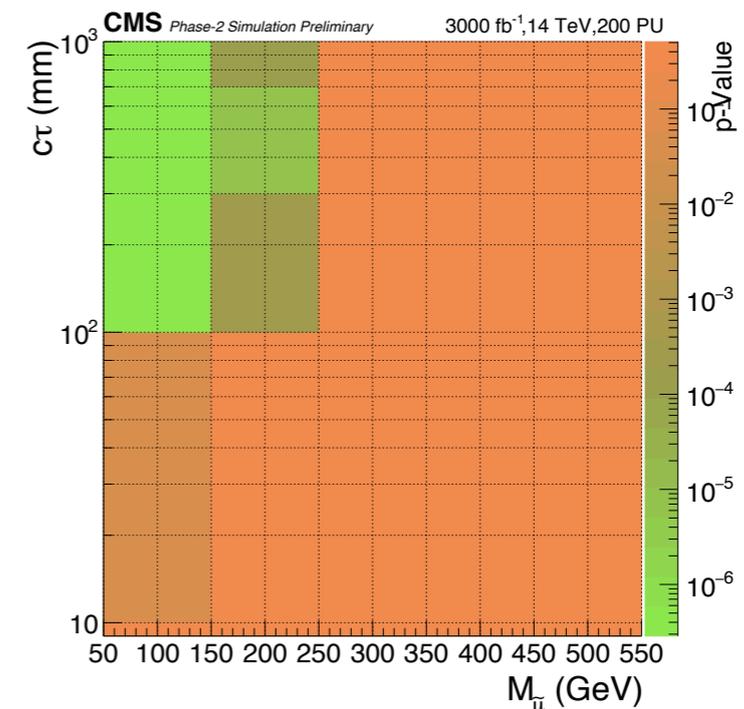
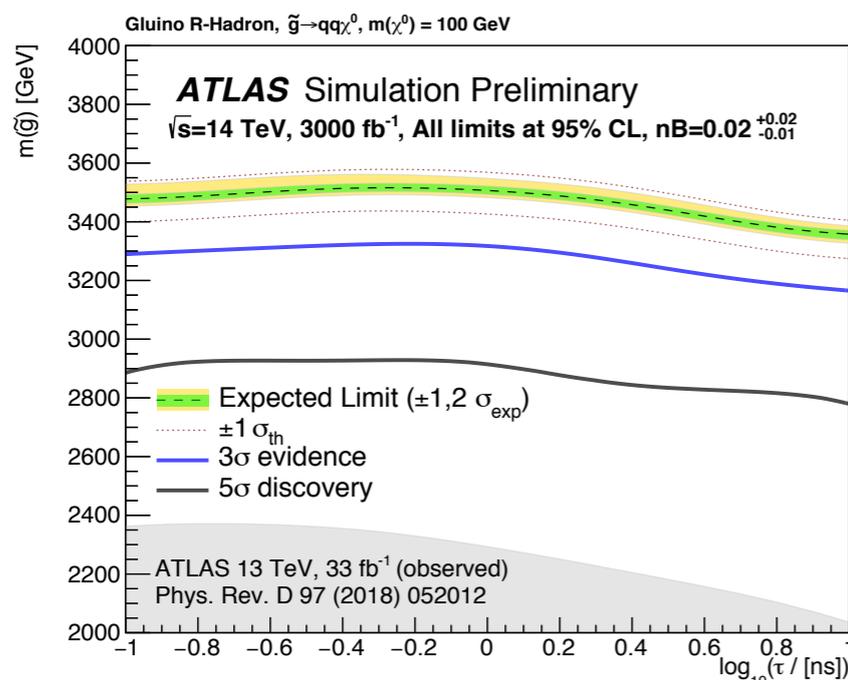


- ◆ Example of new detector features or techniques at HL-LHC in ATLAS and CMS. Different models under consideration

- ➔ Split SUSY: Gluinos decaying to quarks + neutralino
- ➔ ATLAS projections on displaced-tracking capabilities of new inner tracker (ITk)
- ➔ MET + tracks in displaced vertex

- ➔ SUSY GMSB smuon to muon and gravitino (muon + MET)
- ➔ smuon can be very long-lived, make use of standalone muons with no constraint on the vertex position

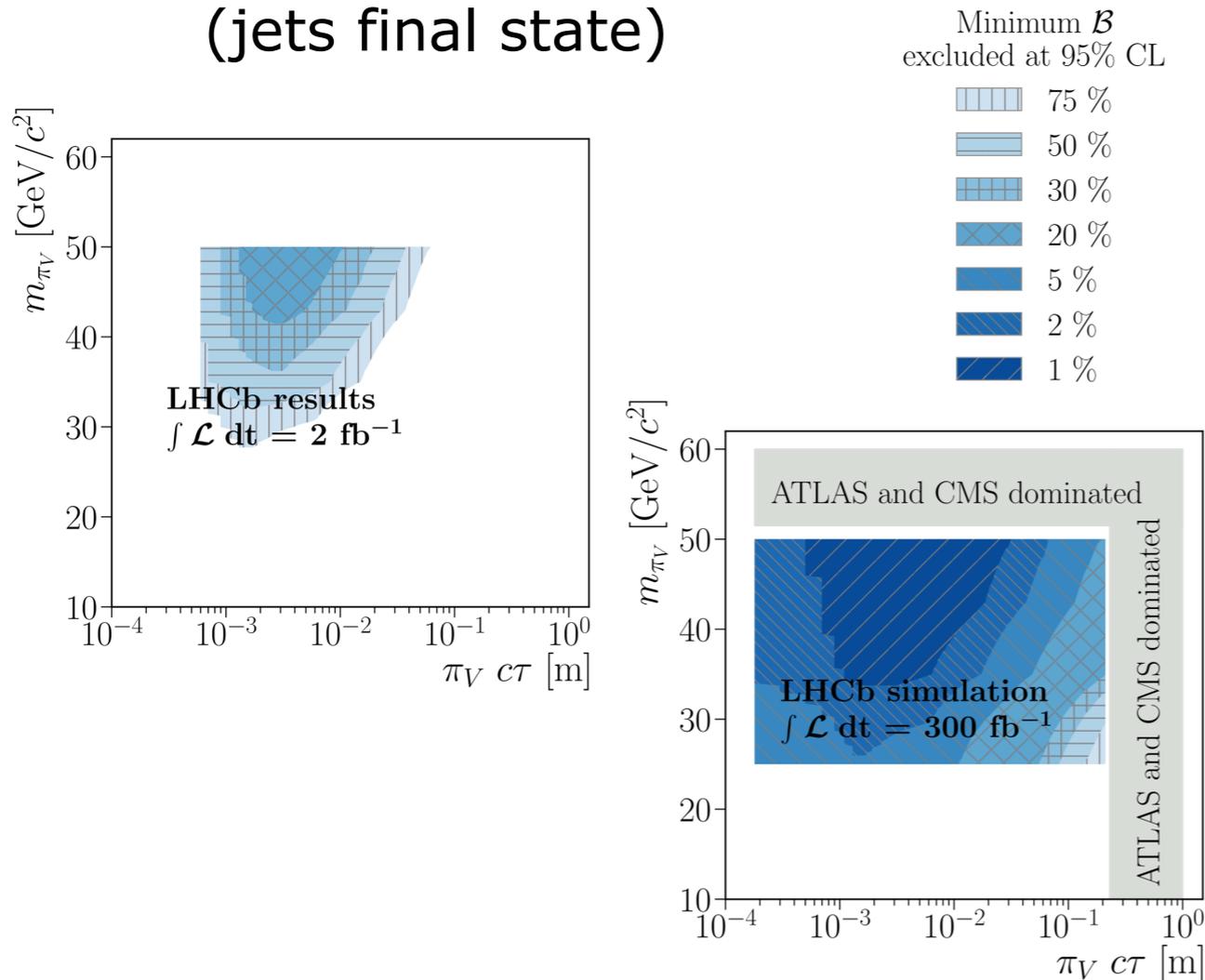
ATL-PHYS-PUB-2018-033



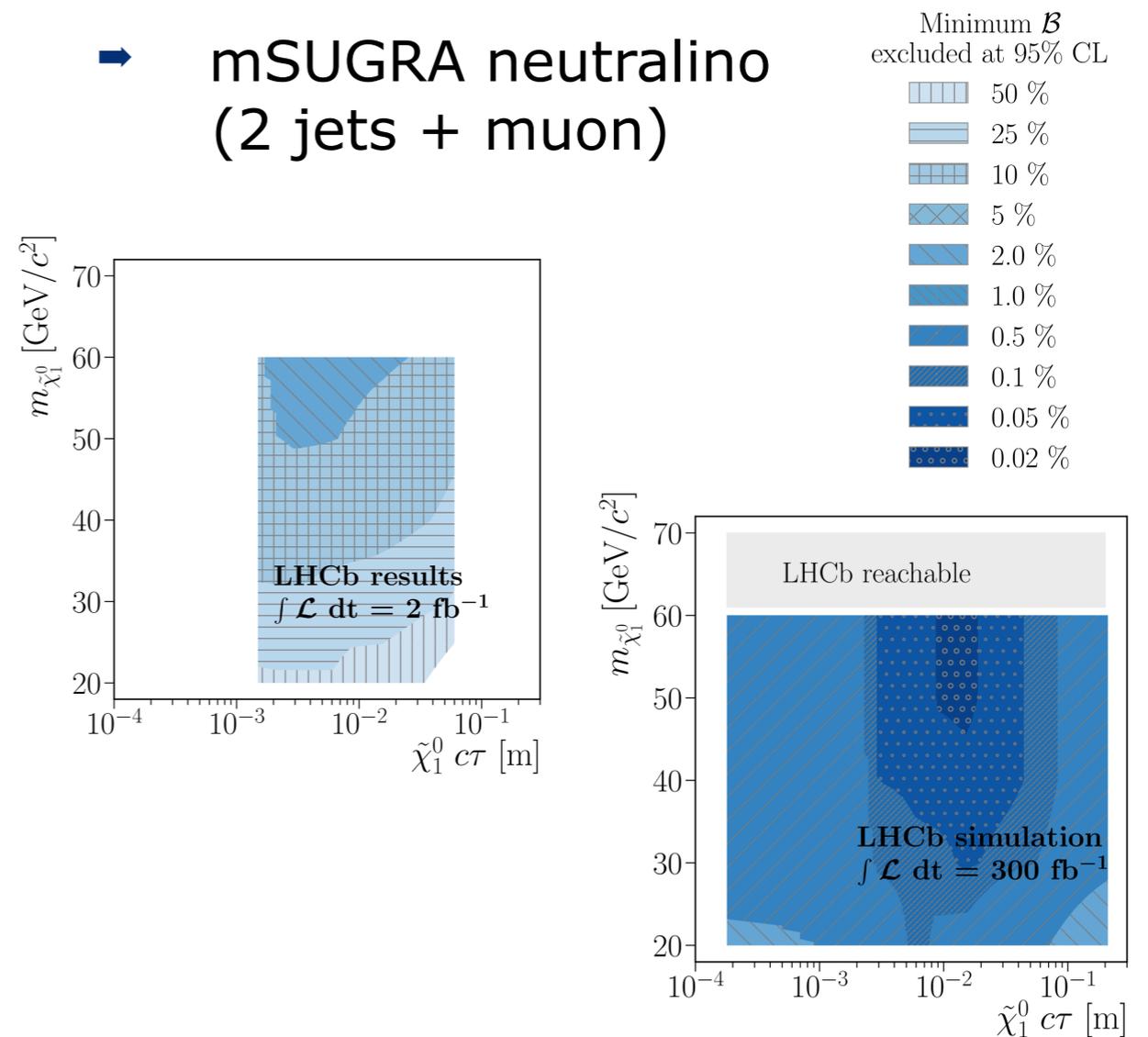
CMS-PAS-FTR-18-002

- ◆ LLPs produced through Higgs portal
 - ➔ Project from Run 1 analyses, scale to the upgrade(s) luminosities, conservative assumptions
 - ➔ Different benchmark models lead to different final states (different limits)

➔ Hidden valley V-pions (jets final state)



➔ mSUGRA neutralino (2 jets + muon)

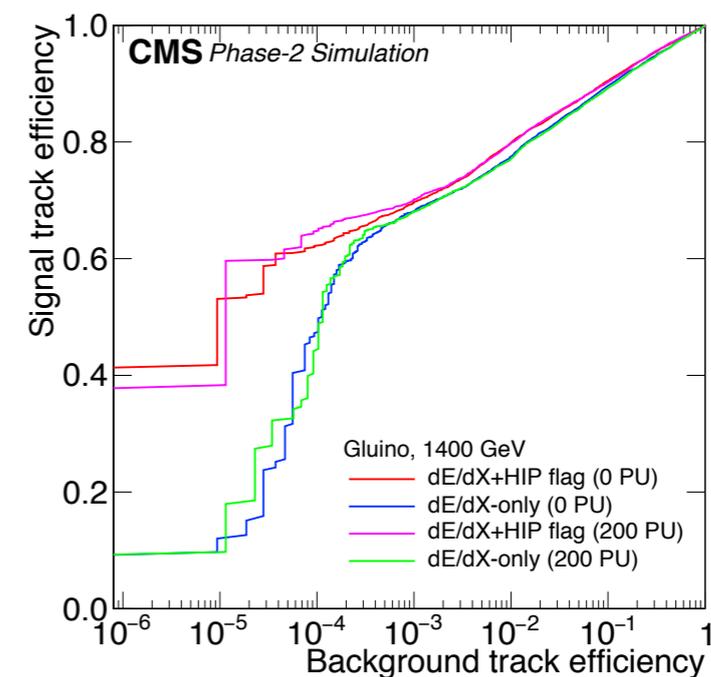
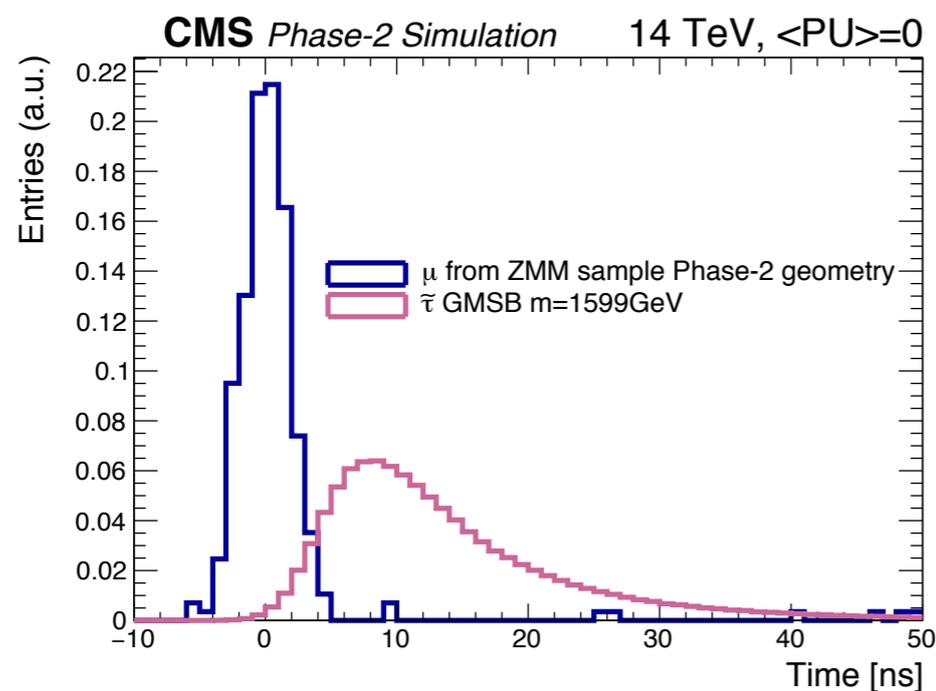


Long-Lived Particles (LLPs)

Overcoming technical challenges

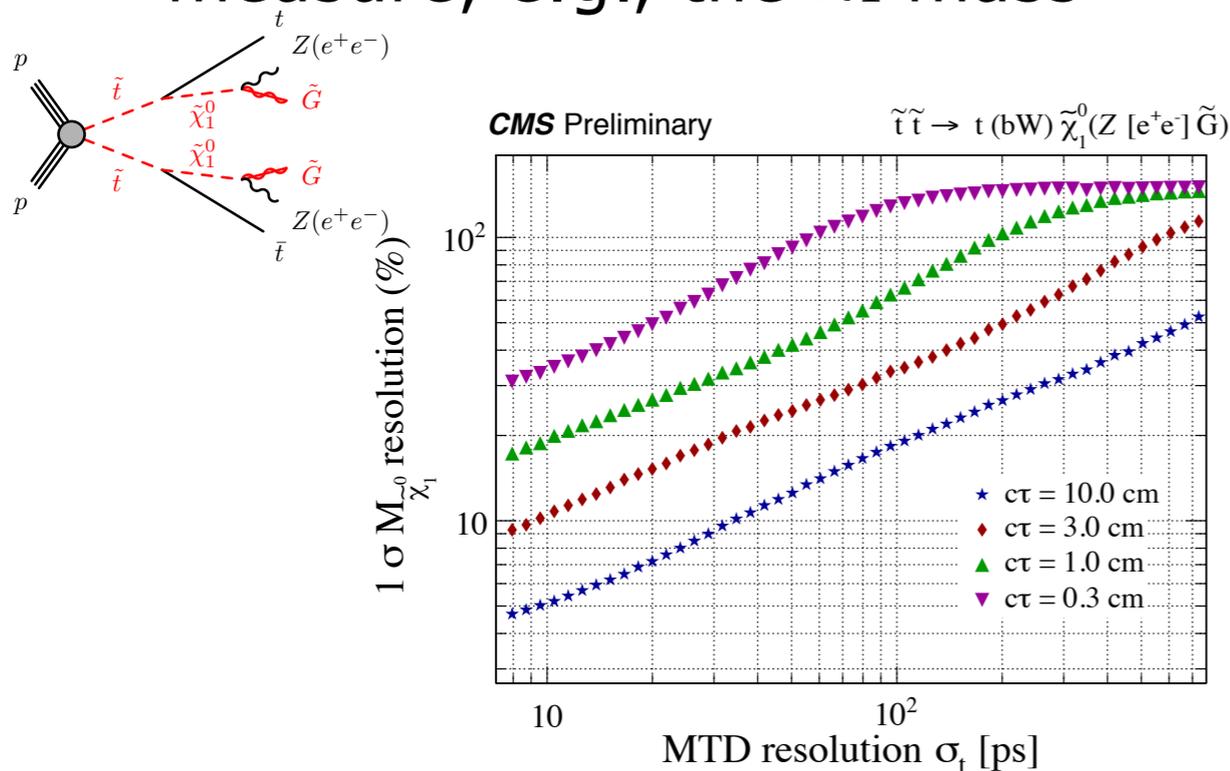
- ◆ New BSM charged particles, long-lived enough to traverse the detector. Results from **CMS**: technical challenges

- Time of flight measurements: HSCP similar to muons, but traveling more slowly
- Use TOF to discriminate (use factor of 25 better time resolutions at HL-LHC CMS muon system)
- Anomalous high energy loss through ionisation (dE/dx) in silicon sensors
- Sensitivity enhanced by change in the electronics of the outer tracker ("HIP flag")



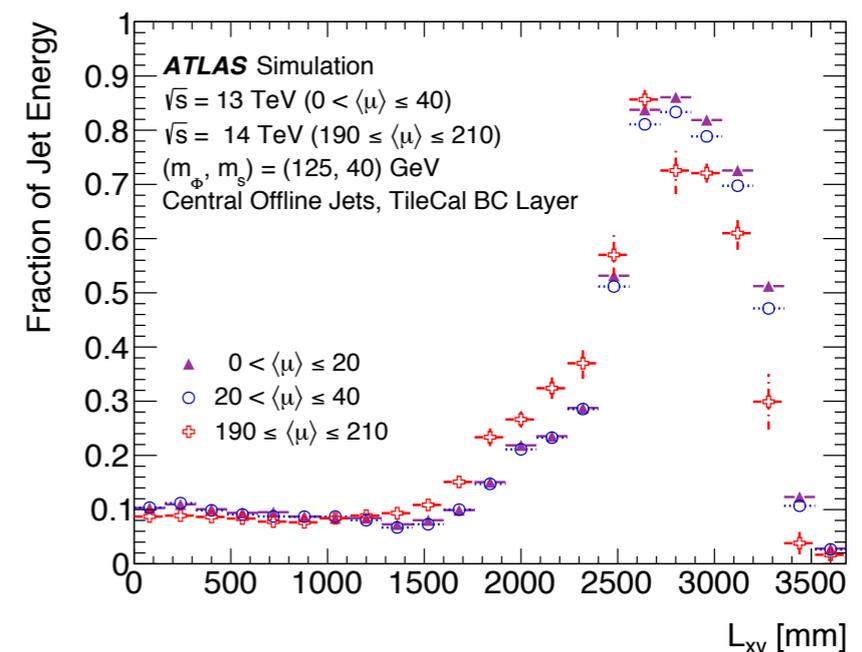
◆ Fast timing signatures at CMS

- MIP timing detector (MTD): Measure displacement b/t primary and secondary vertices in space and time
- Can use the kinematics of the event+timing information to measure, e.g., the $\tilde{\chi}_1^0$ mass



◆ ATLAS: Jet reconstruction techniques for neutral LLPs

- Target LLPs decaying inside the hadronic calorimeter. Main challenge, discriminate against non-collision bkg.
- Benefit from increased longitudinal granularity in HL-LHC ATLAS



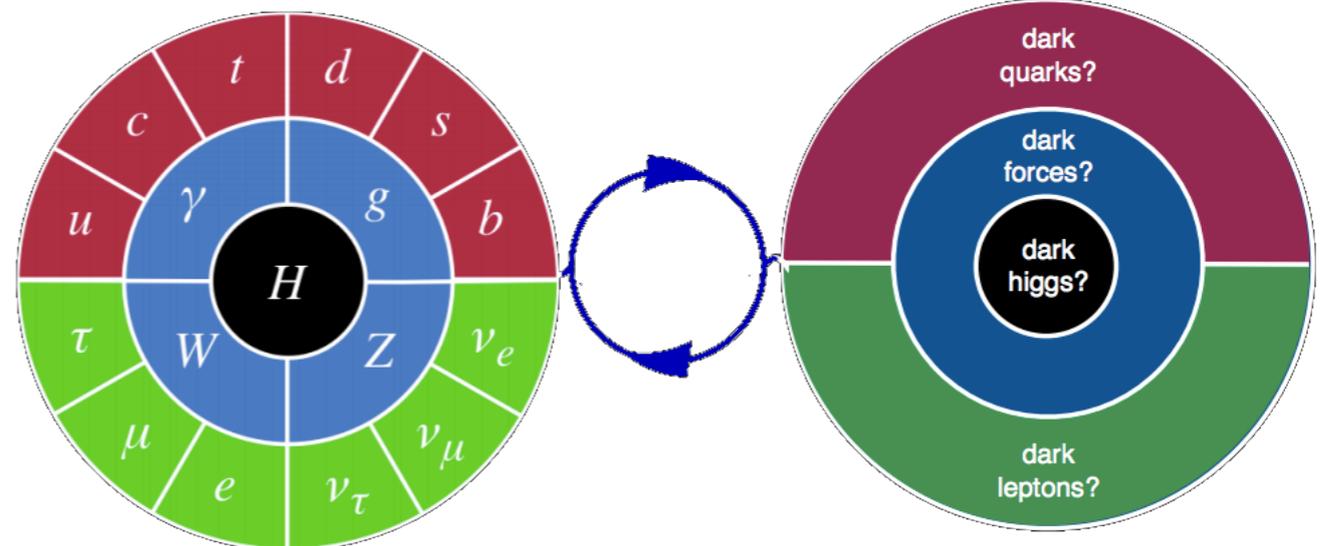
Dark sectors (dark photons)

- ◆ Weakly coupled Dark Sectors help to address SM problems

- Can get also DM candidate (e.g. freeze-in)

- ◆ Dark sector portals:

- Scalar portal (ϕ)
 - **Vector** portal (A')
 - Neutrino portal (N)
 - Axion portal (a)

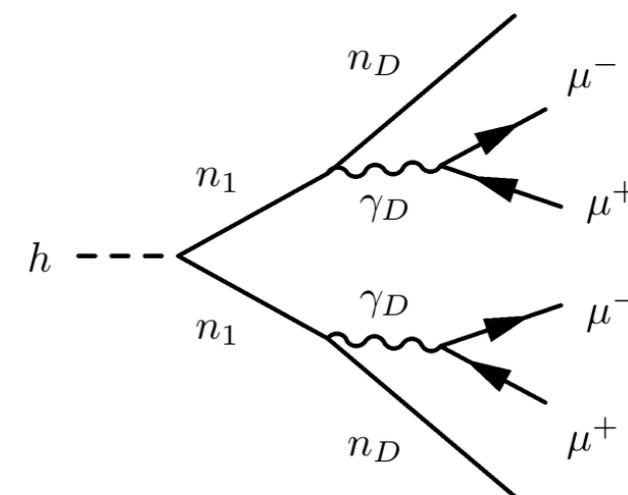
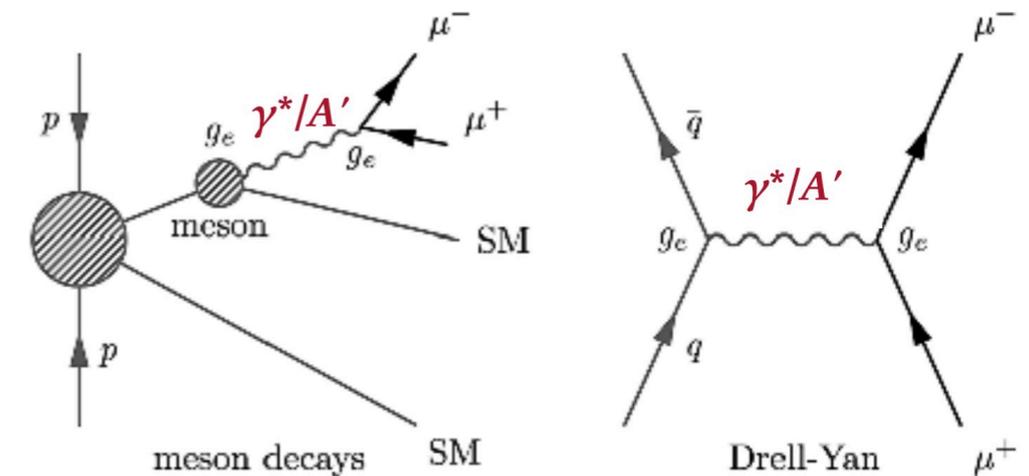


- ◆ For light mediators, cross sections at the LHC can be huge!

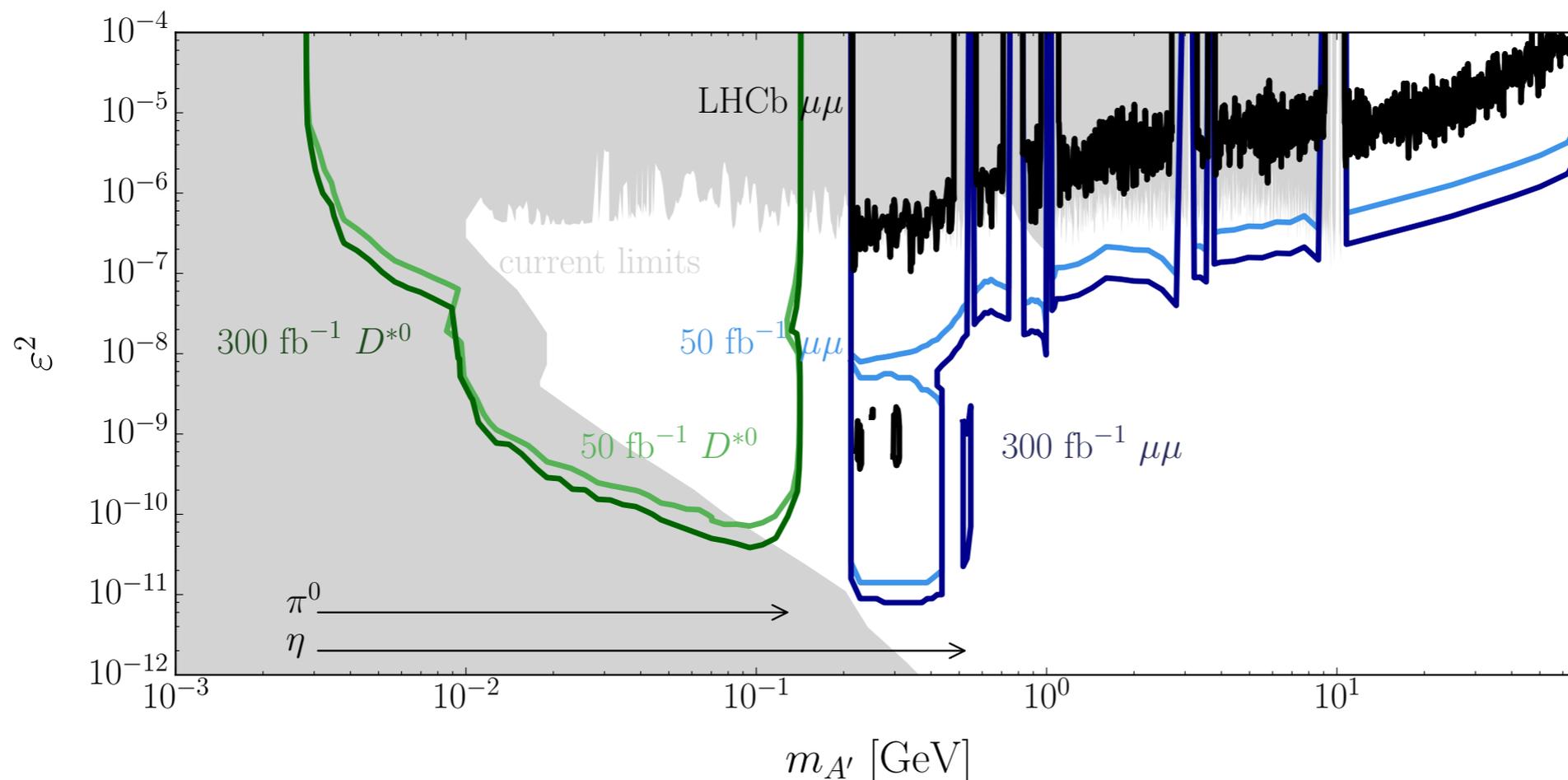
- Main challenge is triggering and discriminating backgrounds

◆ Most spectacular example of vector portal: **dark photon**

- massive dark sector photon A' couples to SM photon via kinetic mixing
- signature: resonance in (prompt or displaced) di-lepton spectrum
- world wide effort for their detection: LHC, B-factories, fixed target experiments....
- if minimal scenario dropped, production also possible by other means. Example: Higgs portal



- ◆ LHCb features allow searching for the dark photon in the minimal scenario. Two strategies:
 - ➔ di-muon direct search or look for $A' \rightarrow e^+e^-$ in $D^{*0} \rightarrow D^0 A'$ decays
 - ➔ Main advantage, self-normalize to $\gamma^* \rightarrow \mu\mu$ or ee modes
 - ➔ Depending on ε^2 value, dark photons long-lived or not



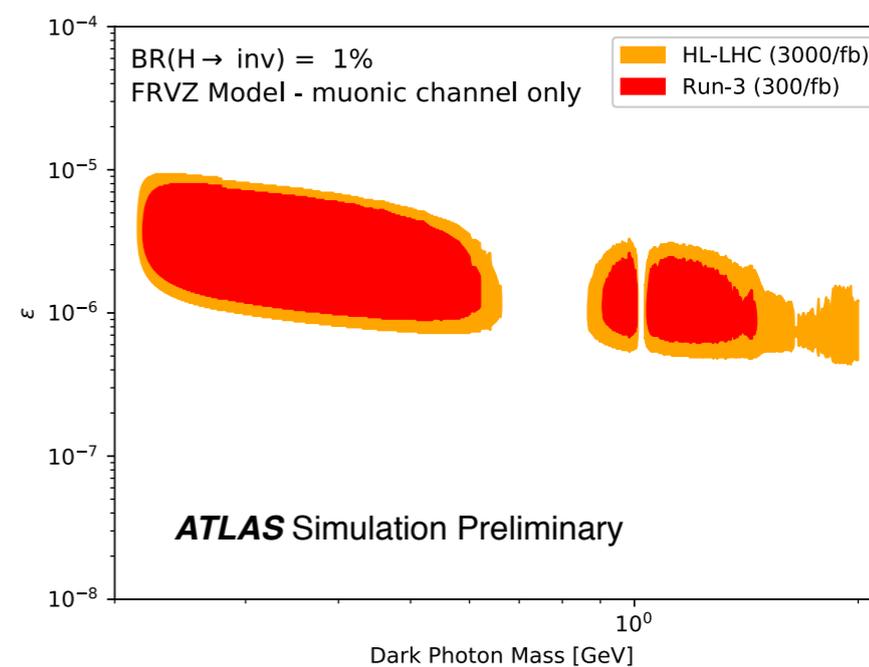
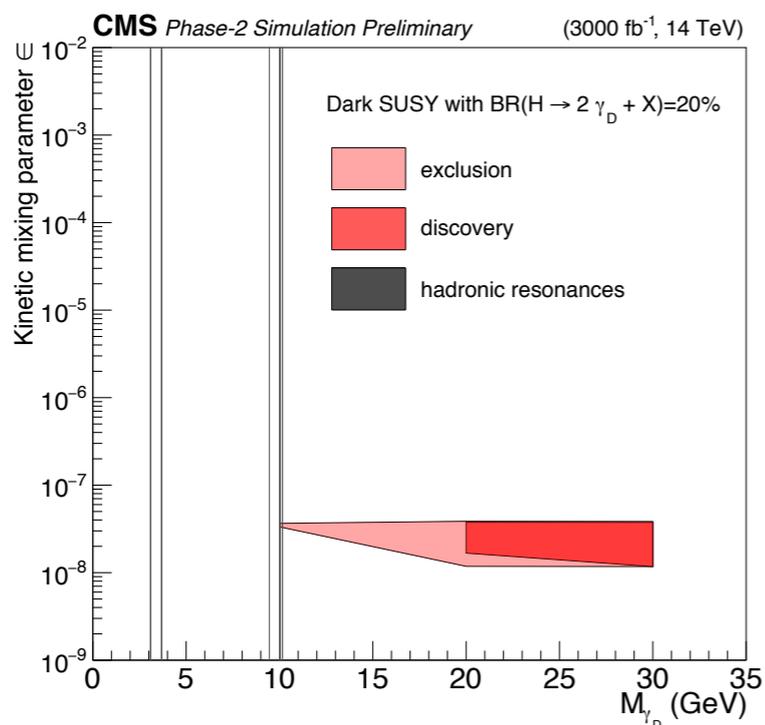
Phys. Rev. Lett. 116, 251803 (2016)
 Phys. Rev. D 92, 115017 (2015)

◆ Search for long-lived dark photons produced through the Higgs portal

- ➔ Use of Displaced standalone (DSA) muon algorithm at **CMS**
- ➔ Require at least two DSA muons. Discriminate against backgrounds using impact parameter

- ➔ Since dark-photons are light, decay products boosted: displaced collimated jets of muons at HL-LHC **ATLAS**
- ➔ Special L0 triggers designed, using features of upgrade

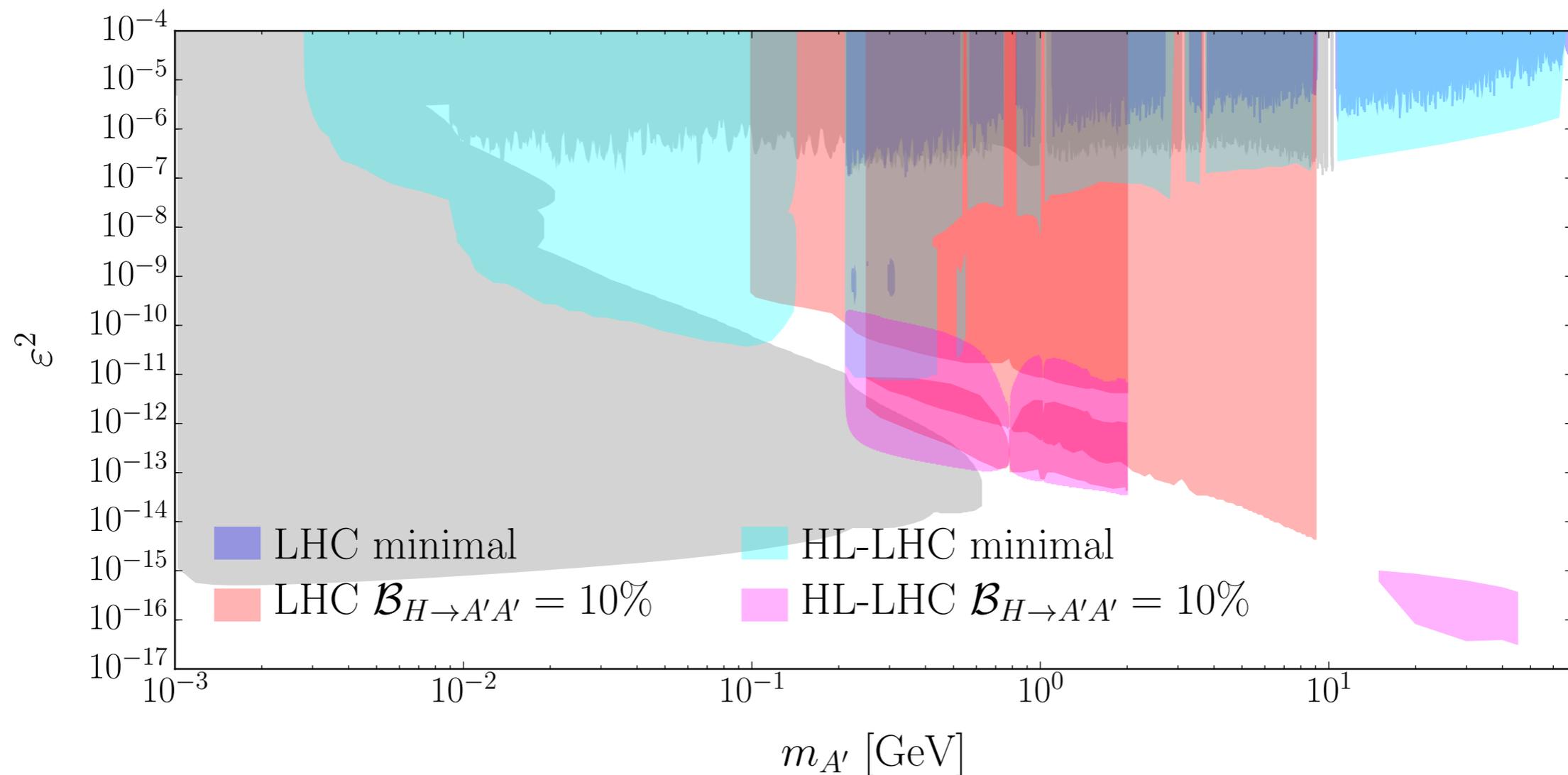
CMS-PAS-FTR-18-002



ATL-PHYS-PUB-2019-002

- ◆ Combine prospects of minimal scenario with those of Higgs portal

➔ Assume $H \rightarrow A'A'$ BR to be 10%



- ◆ Dark-sector scenario to solve the flavour hierarchy problem, while providing suitable candidates for DM
 - ➔ Model predicts massless dark photon: exotic signature corresponding to the Higgs decay given by a monochromatic photon plus massless MET, both resonating at the SM Higgs mass
 - ➔ Follow CMS analysis cuts to provide sensitivity
 - ➔ Alternative strategy tried to control the QCD background, by applying a jet veto within $|\eta_j| < 4$

$\mathcal{B}_{\gamma\bar{\gamma}}(\%)$	$3 \text{ ab}^{-1} @ 14 \text{ TeV}$		$15 \text{ ab}^{-1} @ 27 \text{ TeV}$	
significance	2σ	5σ	2σ	5σ
CMS inspired	0.012	0.030	0.0052	0.013
jet veto in $ \eta^j < 4.5$	0.020	0.051	0.021	0.053

Th. contribution

Phys. Rev. D 89 (2014) 015008
 Phys. Rev. D 95 (2017) 035005

- ◆ The search for long-lived particles will be one of the stars in the HL(HE)-LHC
 - ➔ The landscape is really wide and many ideas are yet to come
 - ➔ We can profit many of the technological developments foreseen at the detectors
- ◆ Great enthusiasm for dark sectors in the theory and experimental communities
 - ➔ World-wide effort in the search for dark photons
- ◆ In both areas, competition will come from other experiments as well, exciting times ahead!