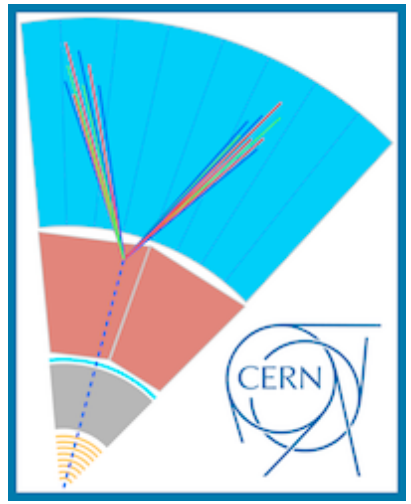
Few highlights from the workshop on searches for long-lived particles at the LHC

Martine Bosman

9 May 2017

Institut de Física d'Altes Energies
EXCELENCIA SEVERO OCHOA
BIST Barcelona Institute of Science and Technology

Searches for long-lived particles at the LHC: Workshop of the LHC LLP Community



https://indico.cern.ch/event/607314/

- Theory/pheno overview of LLP searches at the LHC
  Brian Shuve (SLAC)
- Experimental overview of LLP searches at the LHC
  Heather Russell (Mc Gill)
- WG 1 Report (Simplified models / MC / RECASTing and reinterpretation for LLPs)
  Jared Evans (UIUC)

The world is full of long-lived particles In the Standard Model: p,n,π,μ,τ,... Why?

conservation laws

e.g. quark flavour only violated by EW interaction

$$\Gamma_{\pi^+} \approx g_W^2 \left(\frac{M_\pi}{M_W}\right)^4 M_\pi$$

highly off-shell π decay

e.g. lepton flavour only violated by tiny yukawa couplings

$$BR(\mu \to e\gamma) \approx 10^{-54}$$

approximate symmetries particles nearly degenerated:

e.g. isospin symmetry highly off-shell neutron decay

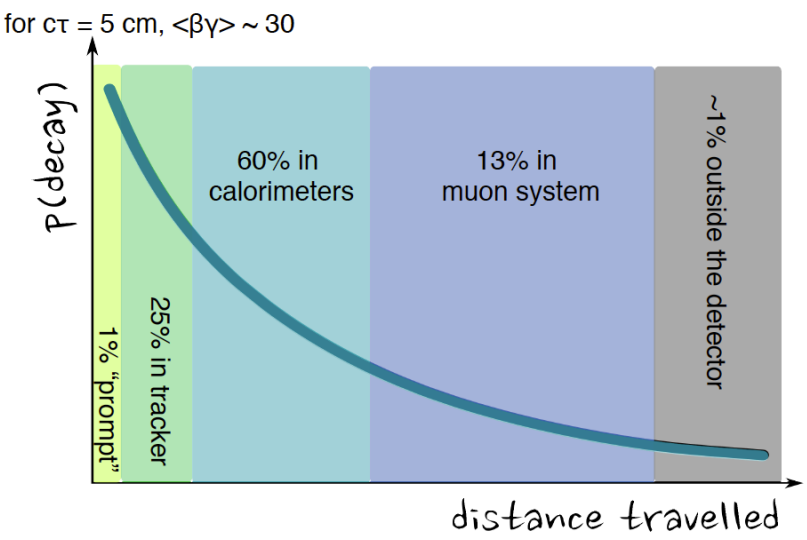
$$\Gamma_N \approx g_W^2 \left(\frac{M_N - M_P}{M_W}\right)^4 (M_N - M_P)$$

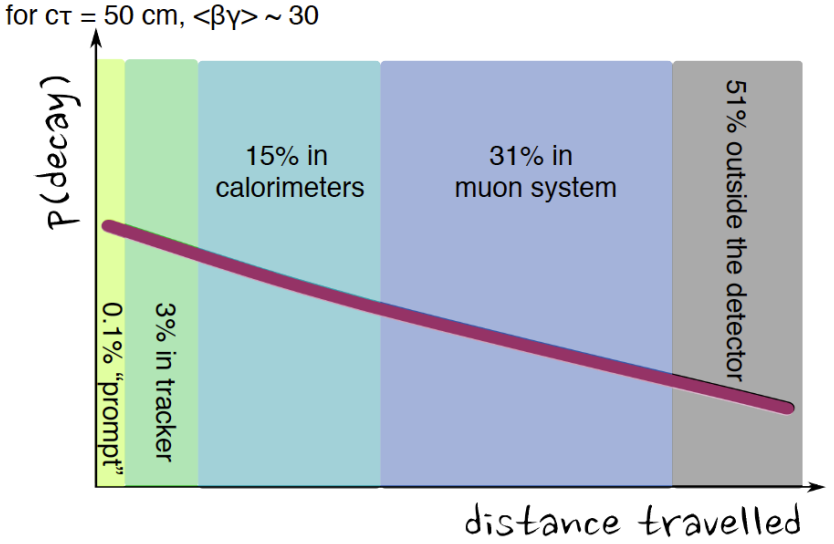
Also happens in BSM models !

Characteristics of Long Lived Particles

- neutral or charged particle with macroscopic reconstructable flight distance or quasi stable (charged)
- light or heavy, fast or slow, can decay to quarks, leptons, gluons...

They need dedicated searches, ... very sensitive to lifetime

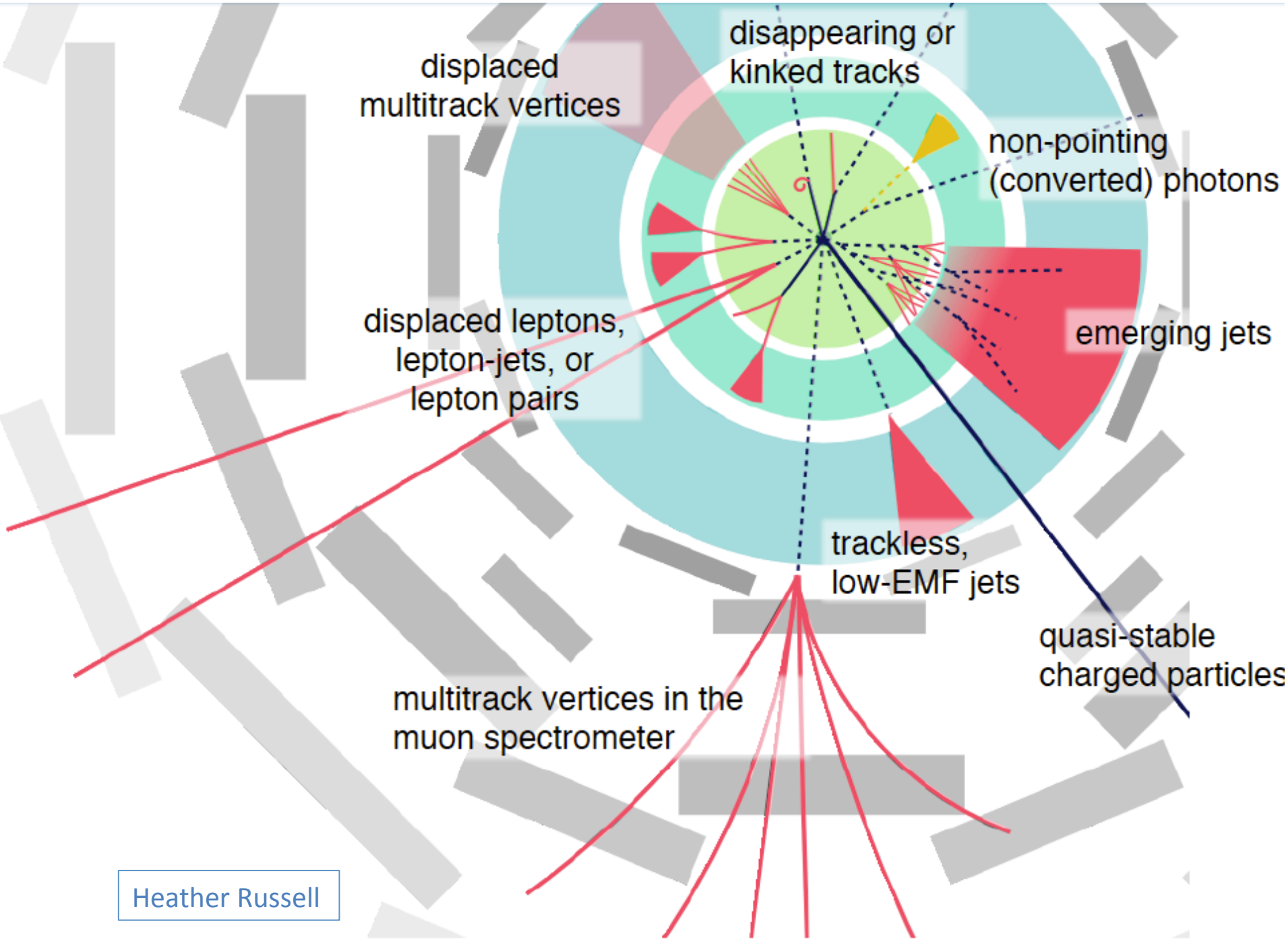




No one-size-fits-all approach – decay products, lifetime, mass, boost all dramatically affect the detector signature

...and all subdetectors must be used for optimal results

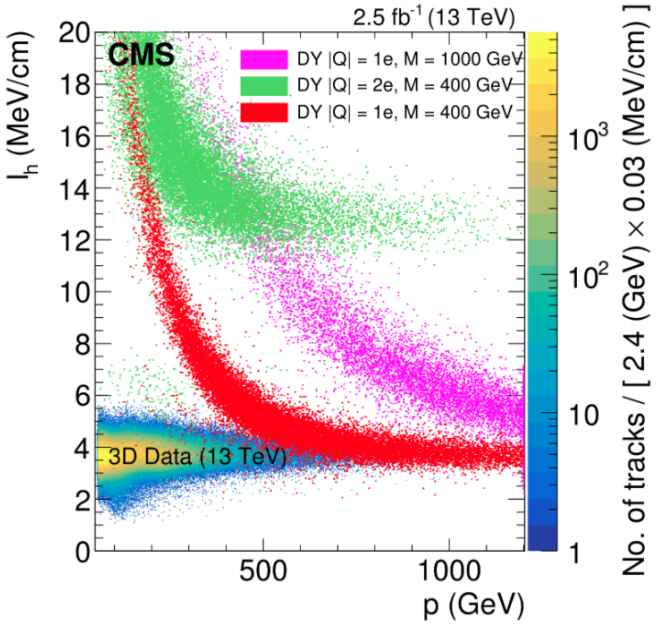
Heather Russell



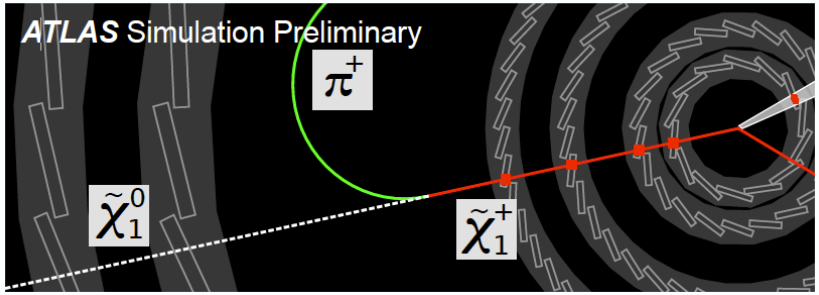
Heather Russell

Charged tracks

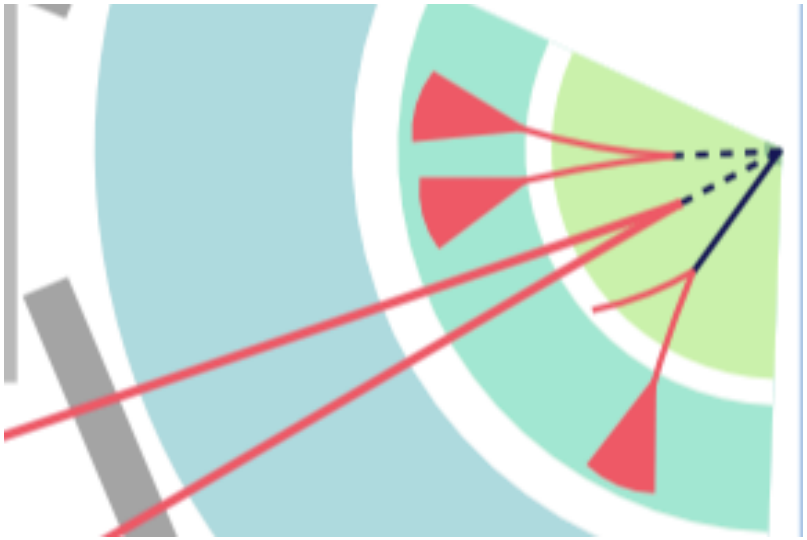
(meta-)stable charged particles
travel through the detector like muons but different ionization
consider models with "muon-like", quasi-stable sleptons, R-hadron (may change from charged to neutral)
trigger: muon, (or large Etmiss)
NB trigger is important for acceptance!
(Phys. Rev. D 94 (2016) 112004)



charged LLP may generate **disappearing tracks**, for example SUSY Winos (ATLAS-CONF-2017-017)
degeneracy of NLSP-LSP masses if little mixing between Higgsino/gauginos
Need to trigger on rest of events (ETmiss)



Heather Russell



LLPs decays to leptons in inner tracker

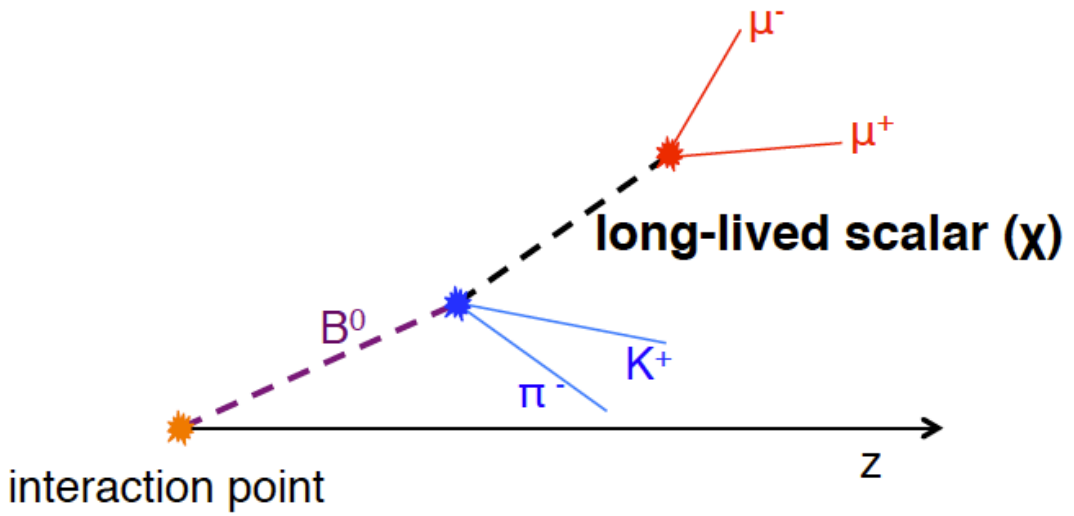
CMS and ATLAS

1) Look for displaced di-lepton vertices
(with no track pointing back to the IP)
2) Look for displaced leptons in charged LLP decays

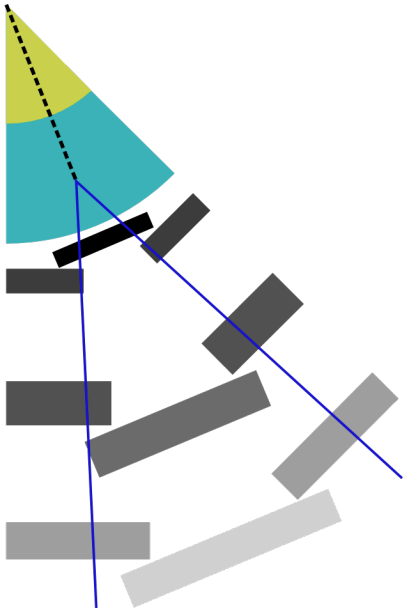
specialized triggers needed for both ATLAS and CMS
for example e-mu pairs without pointing requirement
CMS-PAS-EXO-16-022

LHCb

designed to reconstruct "displaced" vertices from B-meson decays.
adapt to look for long-lived particles produced in the B-meson decays (PRL 115, 161802 (2015))



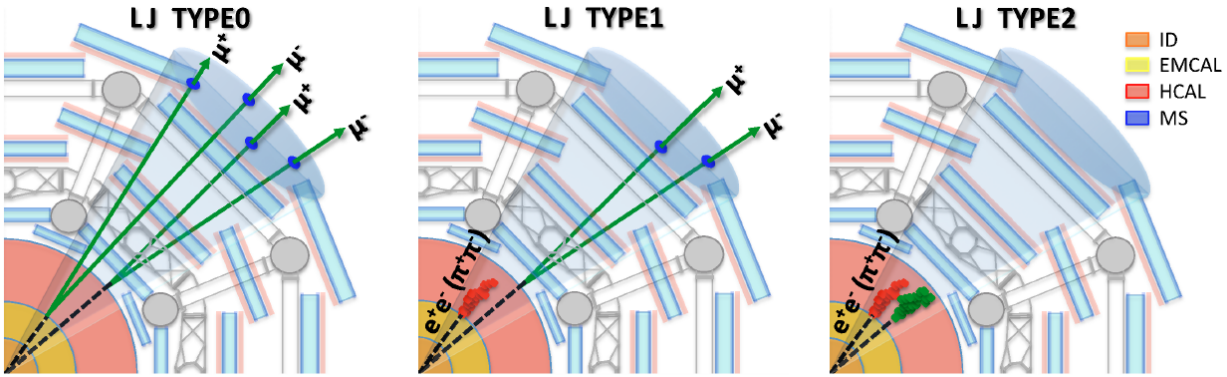
Heather Russell



LLPs decays to leptons after the inner tracker

Di-muon vertex outside of the tracker
example CMS-PAS-EXO-14-012

boosted, light LLPs produce
collimated leptons (lepton-jet)
example ATLAS-CONF-2016-042



Muons without associated inner detector tracks are more susceptible to cosmic backgrounds, beam halo. Specialized trigger needed in both cases

Heather Russell

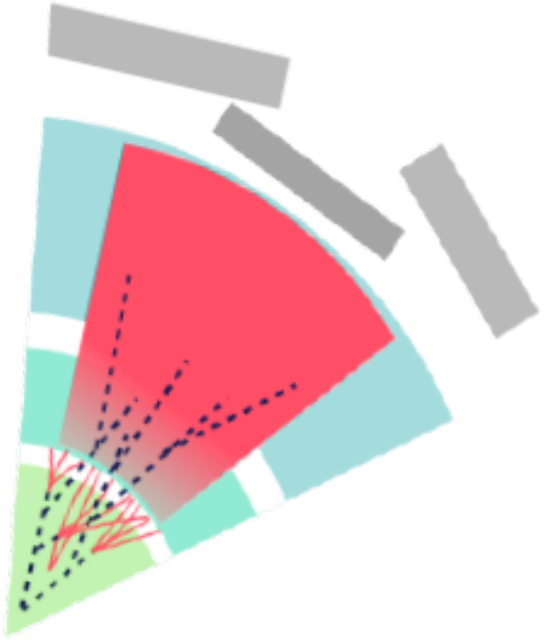
emerging jets

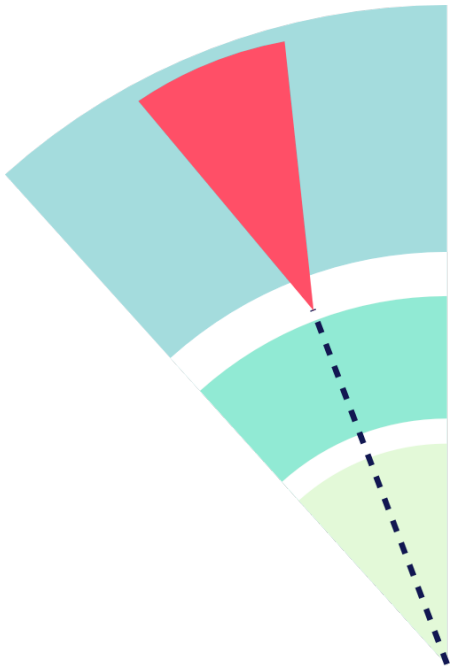
new signature, resulting from a **dark shower**

jet slowly emerges as the LLPs decay to SM particles

- many secondary vertices in the jet cone
- non-standard model jet evolution

issues: trigger (beyond HT), jet reconstruction efficiency, displaced vertices reconstruction efficiency





decays in the calorimeter

leave a narrow**, low-ElectromagneticFraction trackless jet**

issues: background from cosmic showers, beam halo

similar signature whether the LLP decays to hadrons or to collimated electrons (lepton-jets)
valid for LLP masses: 400 MeV to 400 GeV

Heather Russell

late decays in calorimeters

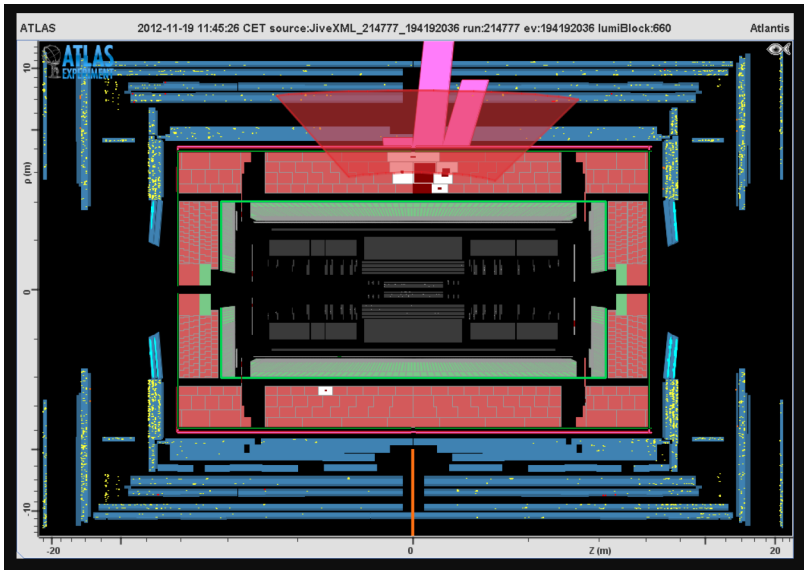
out-of-time energy deposits

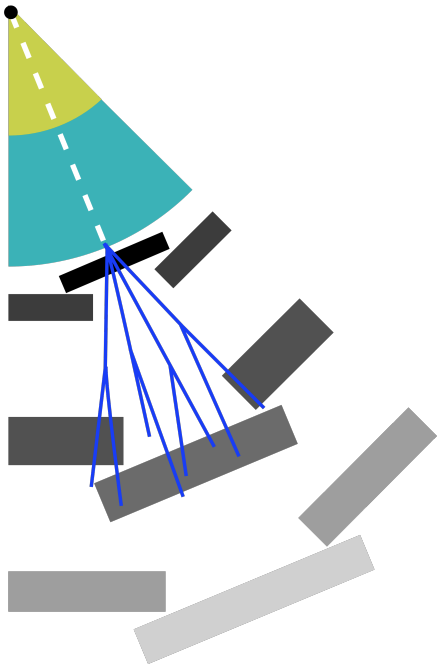
→ use empty bunch-crossings

sensitive to lifetime of the order of days

- CMS uses standard jets
- ATLAS jets with > 50% of energy in HCAL

issues: cosmic muons, beam halo





decays in the muon system

ATLAS: tracking in the muon system

multitrack vertices not associated to inner detector tracks or calorimeter jets.

Apply to H→LLP pairs requires two displaced vertices:

- both in muon spectrometer
- one in MS with one multitrack ID vertex

different sensitivity to mass and lifetime of LLP

arXiv:1504.03634; arXiv:1501.04020

Heather Russell

Difficulties of high energy, high luminosity regime

- 13 TeV searches vs 8 TeV searches
  - for equivalent benchmarks LLPs are more boosted at 13 TeV
- Pileup is getting ever higher
  - LLPs might not seem as “isolated” from prompt activity as they once were: need pileup mitigation techniques
- Background
  - some specific backgrounds to LLP: non-prompt, non-collision backgrounds (cosmics, beam halo)
  - many searches are background free but maybe not true anymore in pushed to low mass
- Rate of collisions is also increasing
  - Triggering on low-mass states is becoming more difficult
  - less dependent on event activity beyond LLP itself: tracking at L1, use of timing …
  - but keep using associated activity when possible
  - seeding LLP analysis with more than one trigger

Brian Shuve

Heather Russell

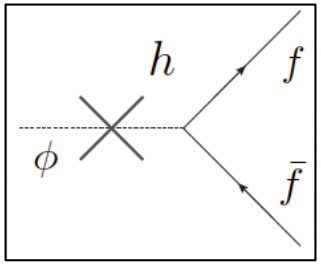
LLP Models: Supersymmetry

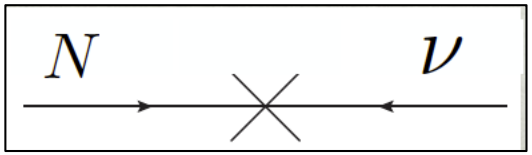
- Production typically through new particles charged under SM gauge interactions (gluinos, stops, Higgsinos, etc.)
  - Some new, heavy particles in spectrum
  - Can have prompt production of jets, leptons, MET, …
  - Often LLP pairs
- LLP decays give jets, leptons, MET, or could be stable & charged
- Sometimes spectra are compressed, so there is still benefit in looking at searches for softer objects

Brian Shuve

LLP Models: Hidden Sectors

- New particles may (likely) be SM singlets, dominantly couple to SM via singlet portals
- Different "portals": Higgs, vector, neutrino, axion





- Could be any mass! Want to look for low-mass LLPs in addition to larger than weak scale
- Can have many different:
  - Masses
  - Lifetimes
  - Associated objects
  - Decay modes/stable exotic particle states
  - LLP multiplicities

Brian Shuve

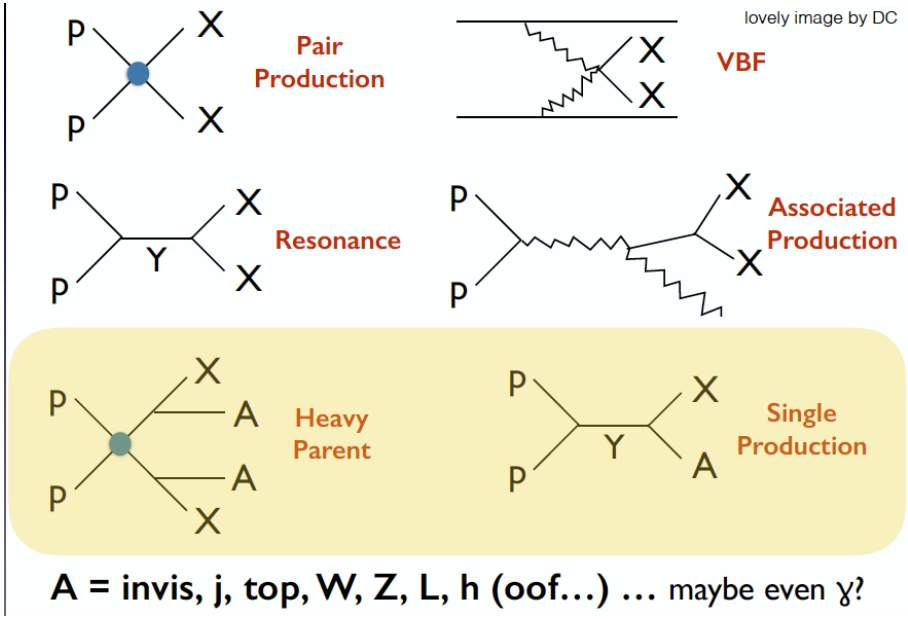
A Systematic Approach to Searches

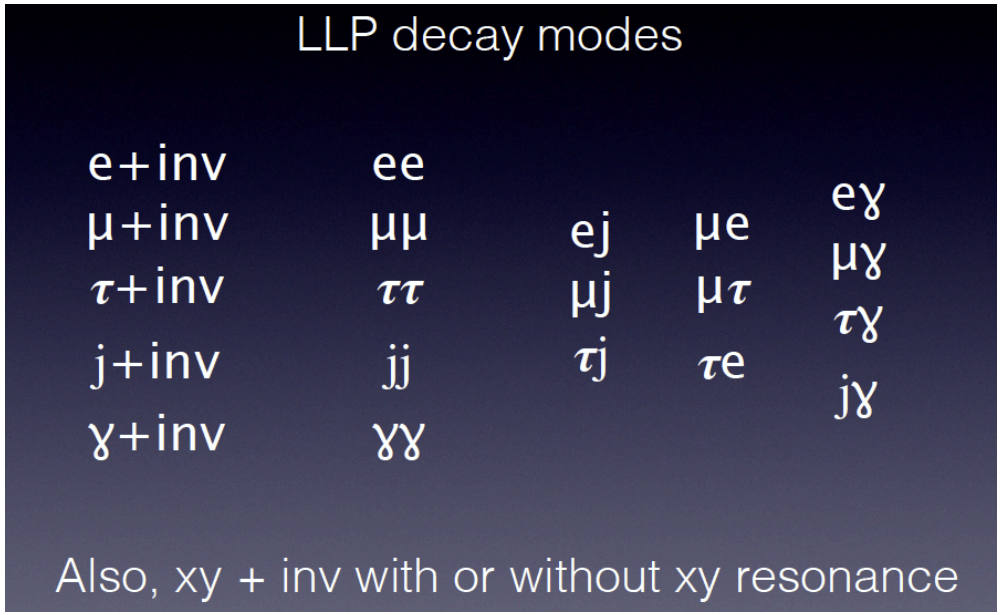
- Searches often target/are optimized for particular model
  - Fine balance between targeting a well-motivated model and providing reinterpretable results
  - If each analysis uses its own model, combinations and comparisons are difficult
  - LLP searches can be inclusive enough to have excellent sensitivity to a range of scenarios
- Want to identify a minimal set of motivated searches that covers as many scenarios as possible while being reasonably achievable
  - Identify motivated, non-redundant list of simplified models

Brian Shuve

Simplified models

production ⊗ decay





spans most LLP simplified models, but nor dark showers

Jared Evans

Presentation of results

- Searches should be (reasonably) easily re-interpretable: RECASTING

  provide cut flow tables, detailed description of signal, trigger, efficiency maps, etc.

  – Efficiency maps for LLPs: eff(m,β,θ,L)

  – Simplified models, m vs cτ efficiencies

  Or compromise? eff(L,β) for a few m / Δm

Jared Evans

Conclusion

- A very active field
- The community is getting organised
- Room for contributions!
  - Run 2 data will provide interesting coverage
  - Many specific experimental challenges
  - Input from theorists is needed (also in workshop discussion)
  - Upgrade may open additional possibilities