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Long-lived particles

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Agenda

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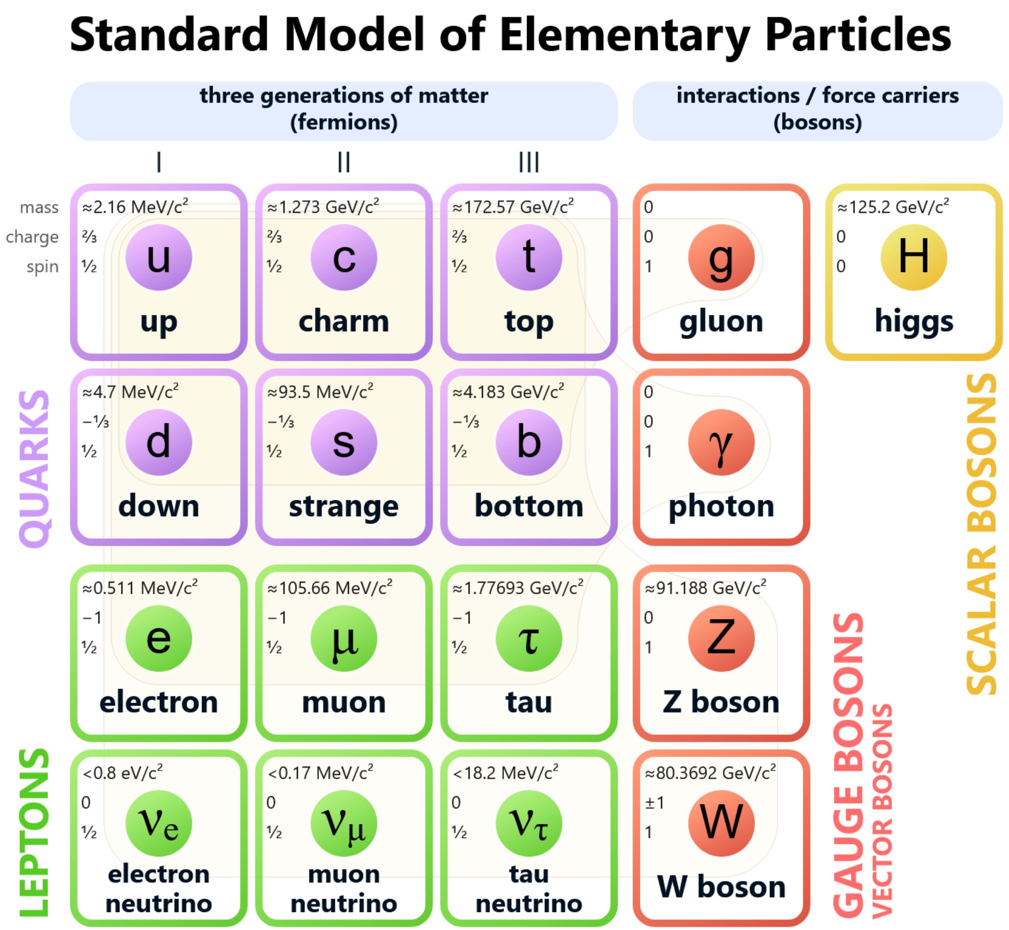
1. Introduction

BSM - Beyond the standard model

- Standard model as we know it is incomplete
  - Gravity
  - Dark matter
  - …and many more
- New theories are necessary



[2] Wikipedia, Standard model

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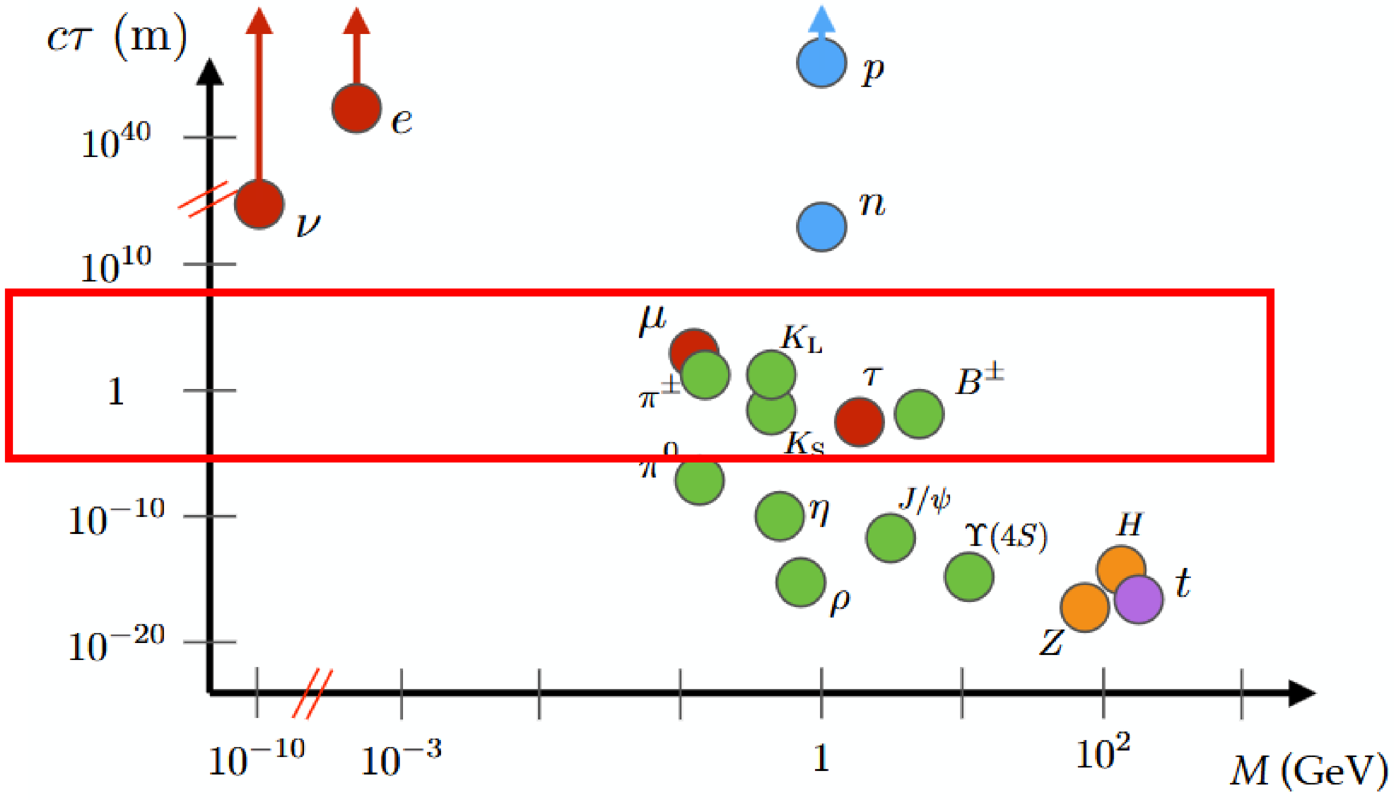
LLPs - long lived particles

- Definition: Particles with non-negligible lifetimes
- Common theoretical prediction of BSM models explaining SM shortcomings
- Examples in SM include B-Mesons or K-mesons
- Usually only weakly interacting



[2] B. Shuve

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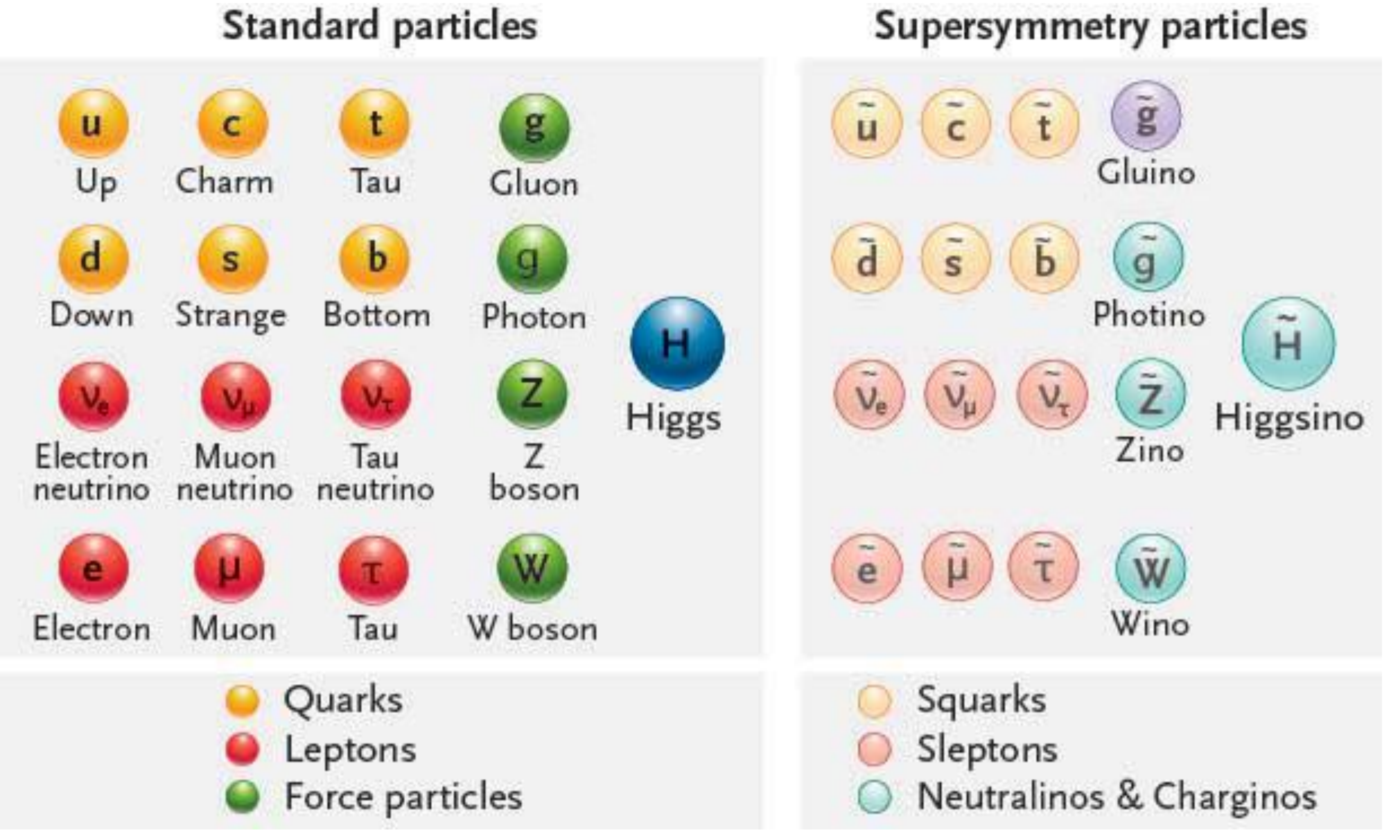
2. Theory

SUSY - Supersymmetry

- General framework for new theories
- For any “standard” particle there is a SUSY-counterpart
- Mass contributions to Higgs mass from each pair nearly cancel
- Examples include:
  - Minimal SSM: only lowest amount of new particles
  - Higgs sector extensions: Higgs particle has new decays into other scalar “Higgs-like” particles



[3] Francis Naukas

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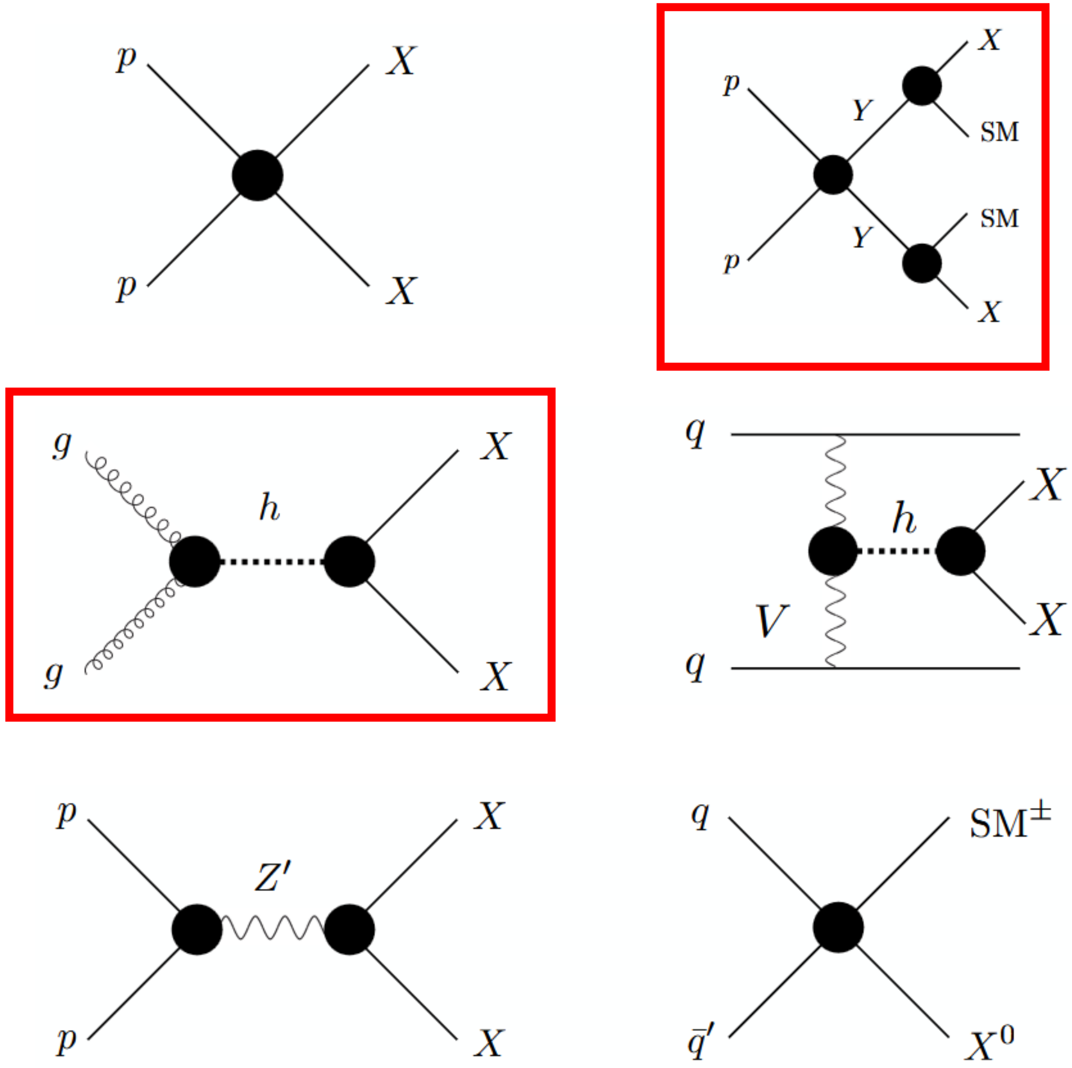
Production mechanisms

- Feynman diagrams of the different LLP productions, LLP noted as X
- We have:
  - Direct pair production
  - Heavy parent production
  - Higgs modes
  - Resonances through heavy force carriers
  - Charged currents



[4] Alimena, Juliette, et al

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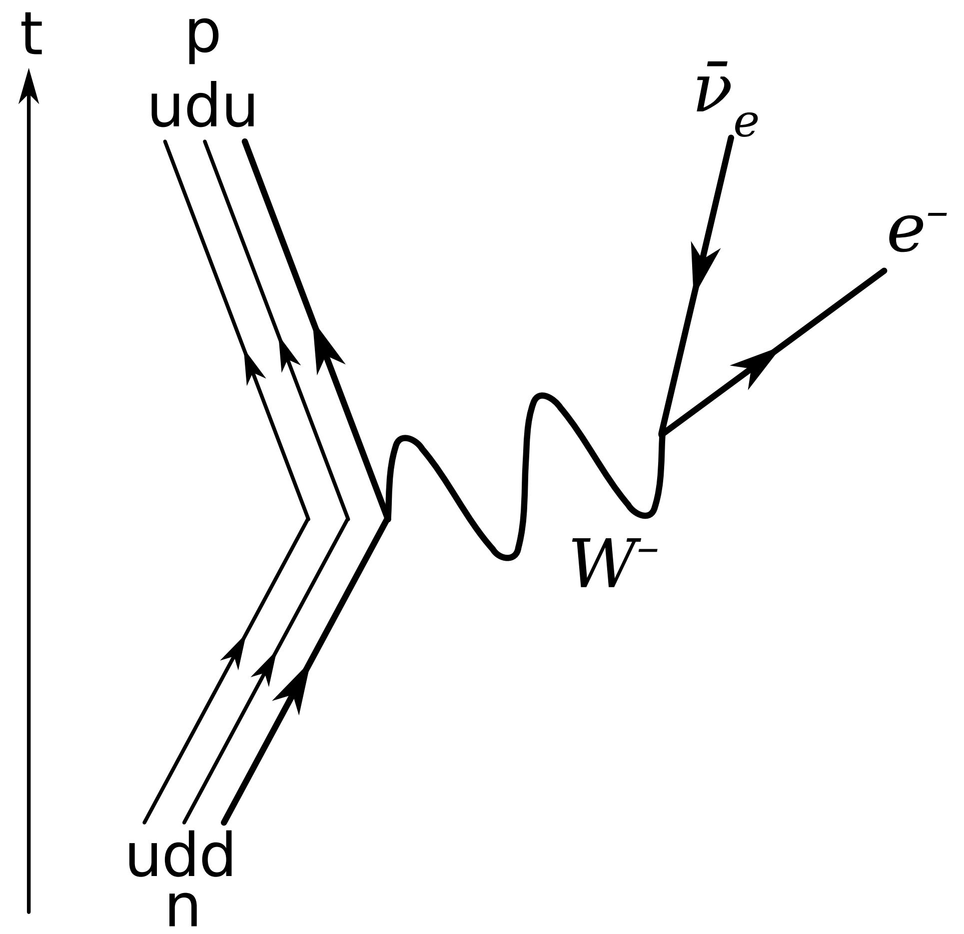
Why long-lived anyway?

- Long lifetimes associated with suppressed decays
- Decay products have similar masses as LLP
  - Small phase space of products



[5] Wikipedia, beta decay

Why long-lived anyway?

- Long lifetimes associated with suppressed decays
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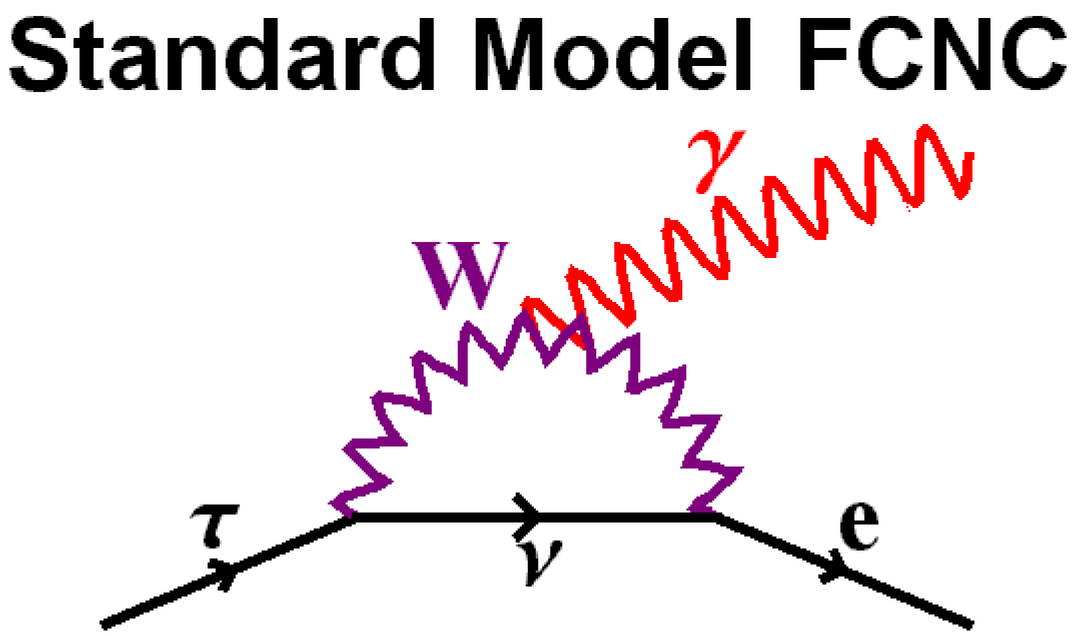
- Weak couplings
  - Only decays via very weakly coupled processes possible



[5] Wikipedia, flavor changing neutral currents

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Why long-lived anyway?

- Long lifetimes associated with suppressed decays
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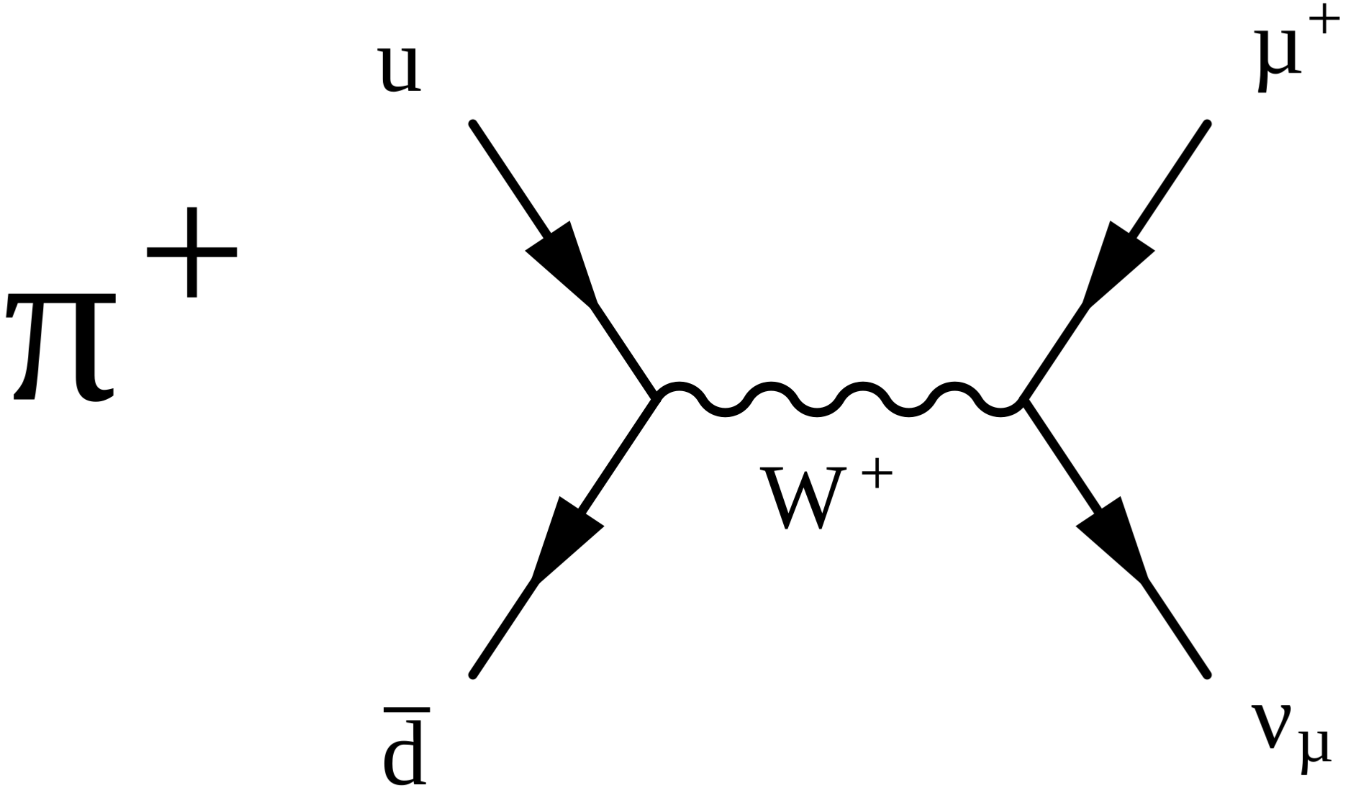
- Weak couplings
  - Only decays via very weakly coupled processes possible
- Off-shell decays
  - Decay only possible through a much heavier particle



[6] Wikipedia, pion

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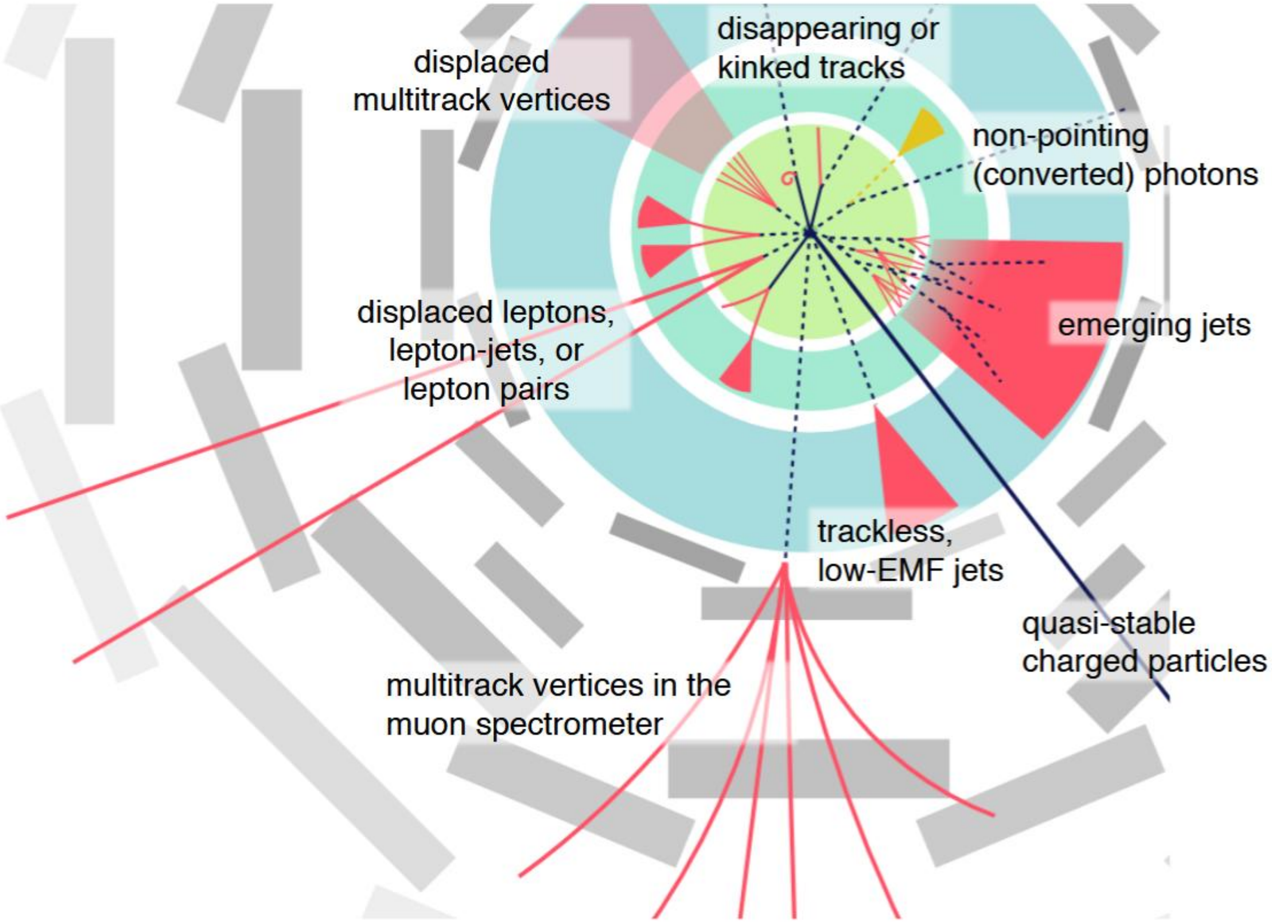
3. Experimental signatures

Long-lived Signatures

- Vastly different from normal signatures
- LLPs themselves often don't leave tracks
- Exact type of signature differs on detector part
  - Where the particle is measured depends on its lifetime
  - Leads to many different types of searches
  - Makes triggering difficult



[8] H. Russell

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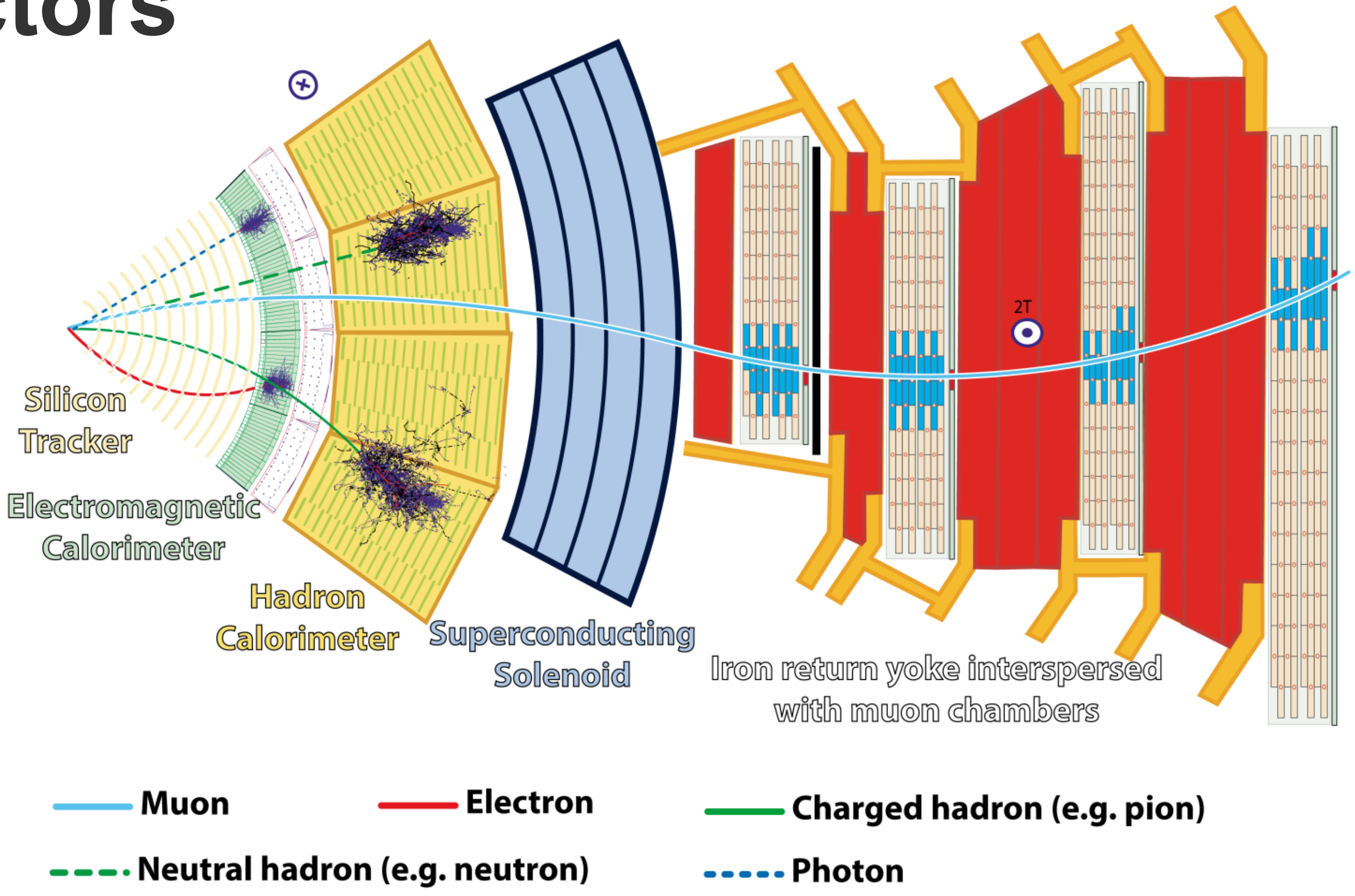
General purpose detectors

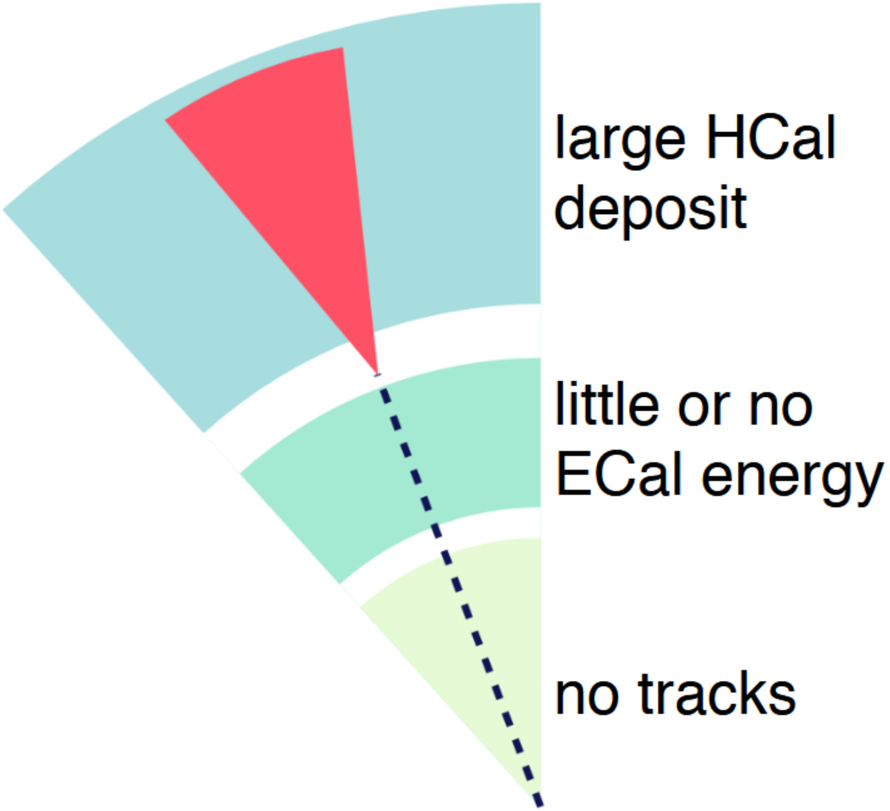
- Detectors usually have shell structure
- Tracker
  - Momentum and tracking
- Calorimeters
  - Total energy measurements based on decays
- Muon chambers
  - Measures muons via ionization
  - Made for few, well separated particles



[9] CMS collaboration

Displaced Vertices/Jets

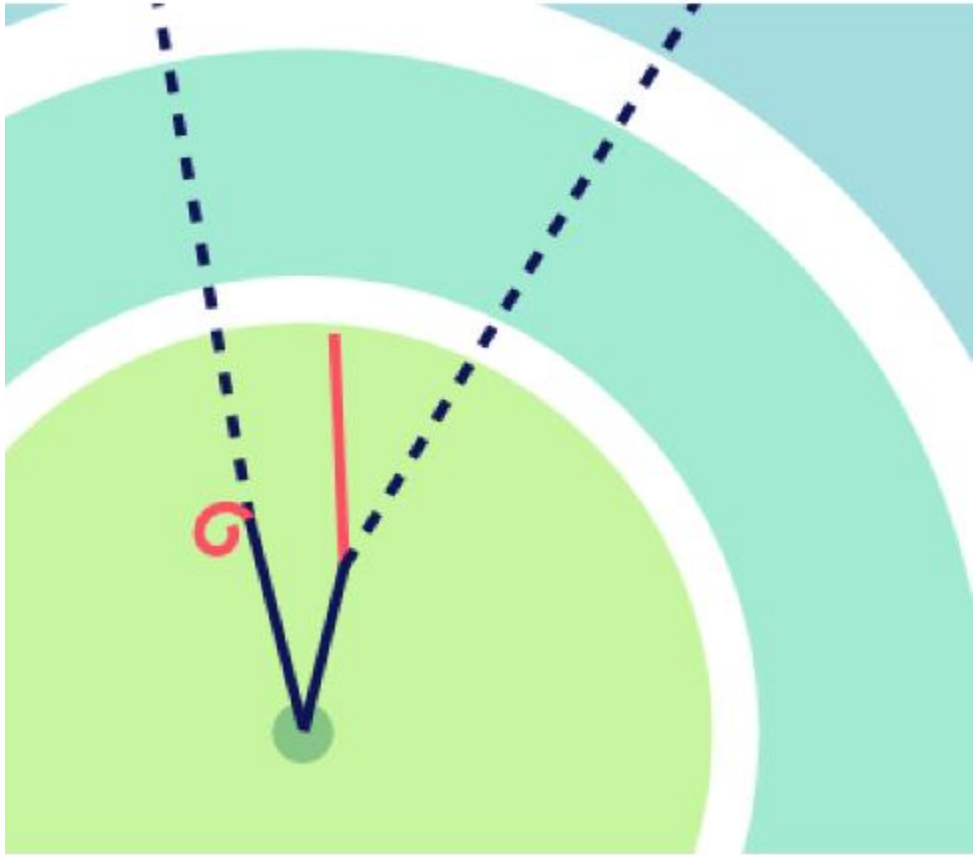
- LLPs can decay in various ways
  - E.g. leptonic decays or quarks, which lead to jets
- Decays happen well outside of interaction point
  - Decay is “displaced”
  - Usually no tracker information
- Triggering on Jets easy
  - Difficulty for “wrong kind” of decay for given calorimeter
  - Low-Energy LLPs difficult to measure



[8] H. Russell

Disappearing Tracks

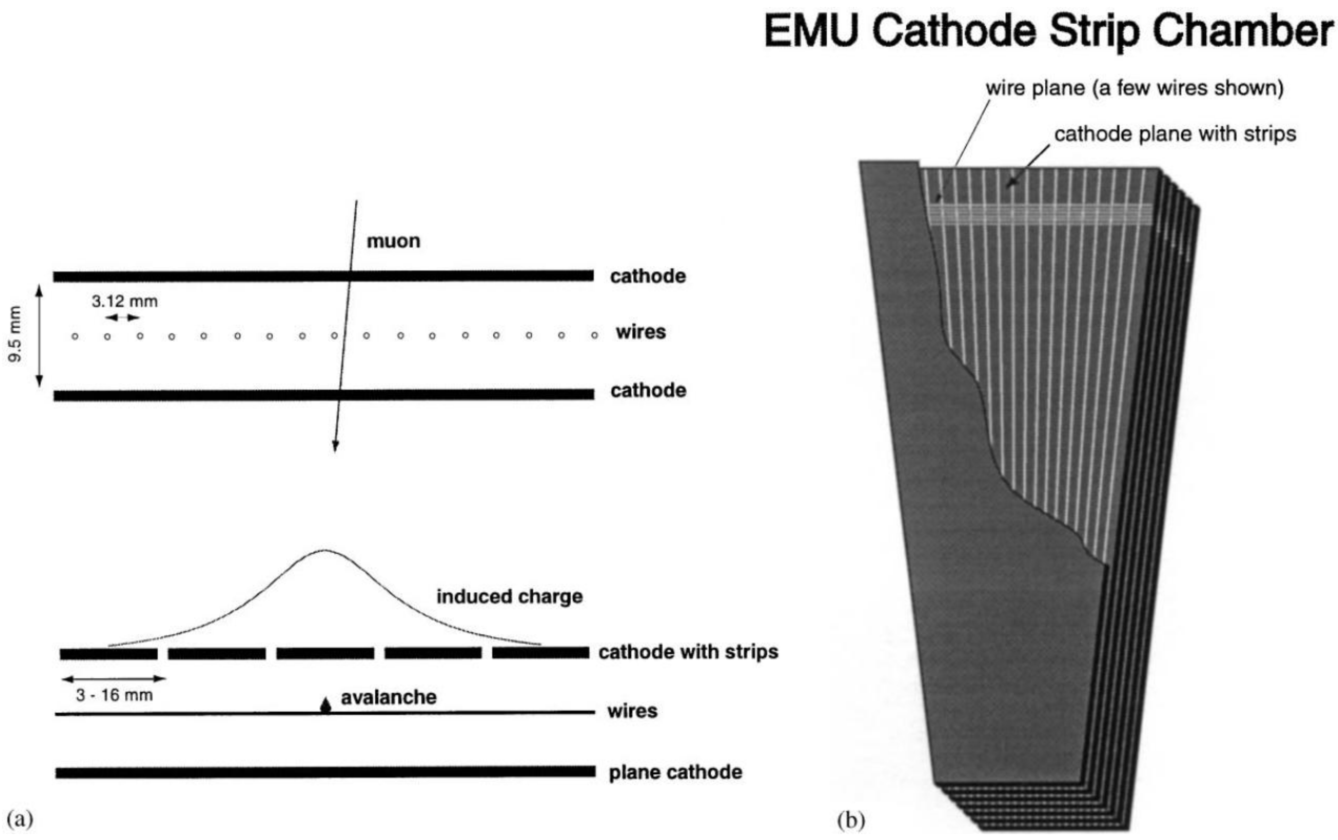
- Especially important for charged LLPs
- LLP decays into neutral stable particle and charged particle with only small energy
  - Track seems to "disappear"
- Very hard triggering, since energy deposition low
- Variant: "Kinked" track, with non negligible energy deposit



[8] H. Russell

Decays in the muon system

- Muon endcaps use the CSC systems
- Muons passing through ionize gas inside
- Positive Cations flow to strips, electrons to wires
    - “Hit” position reconstructed based on the 2 data points
    - Problem: What if there are multiple particles close to each other?
    - No deterministic way to find hit positions



[10] M.C. Fouz

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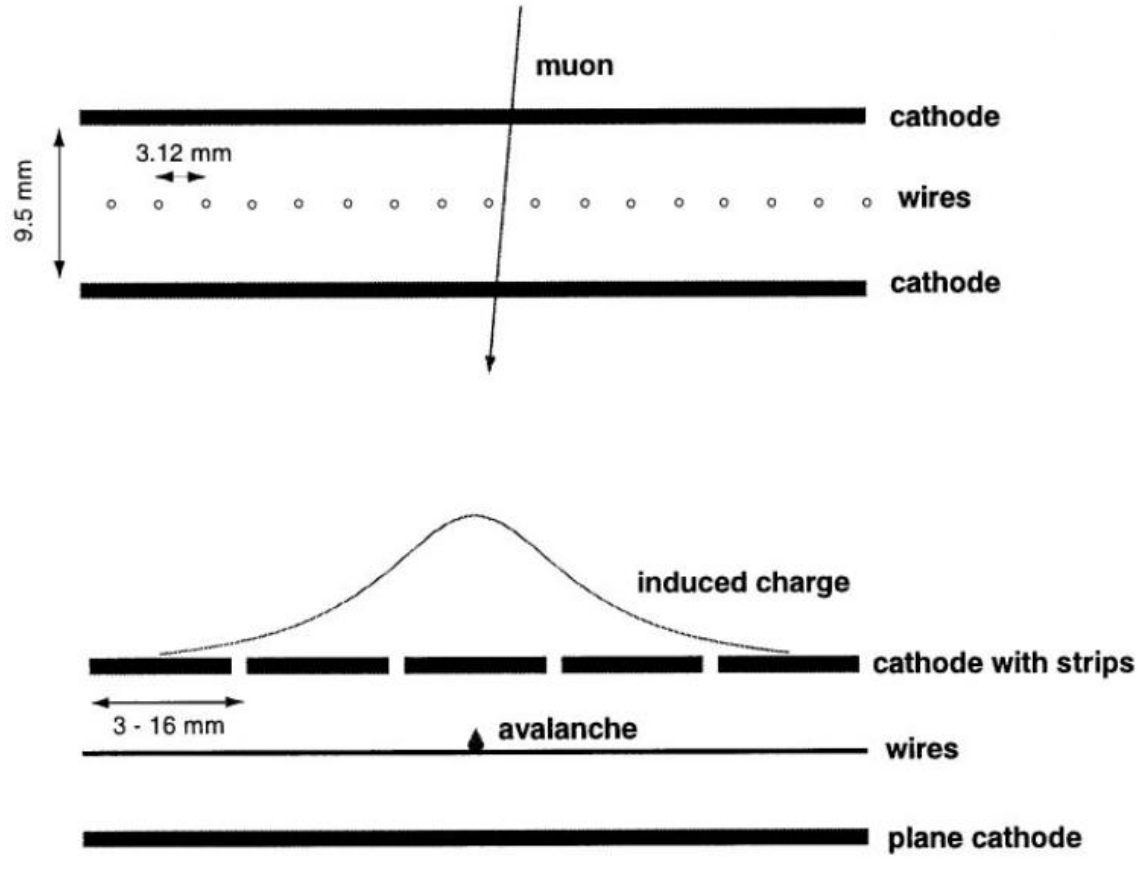
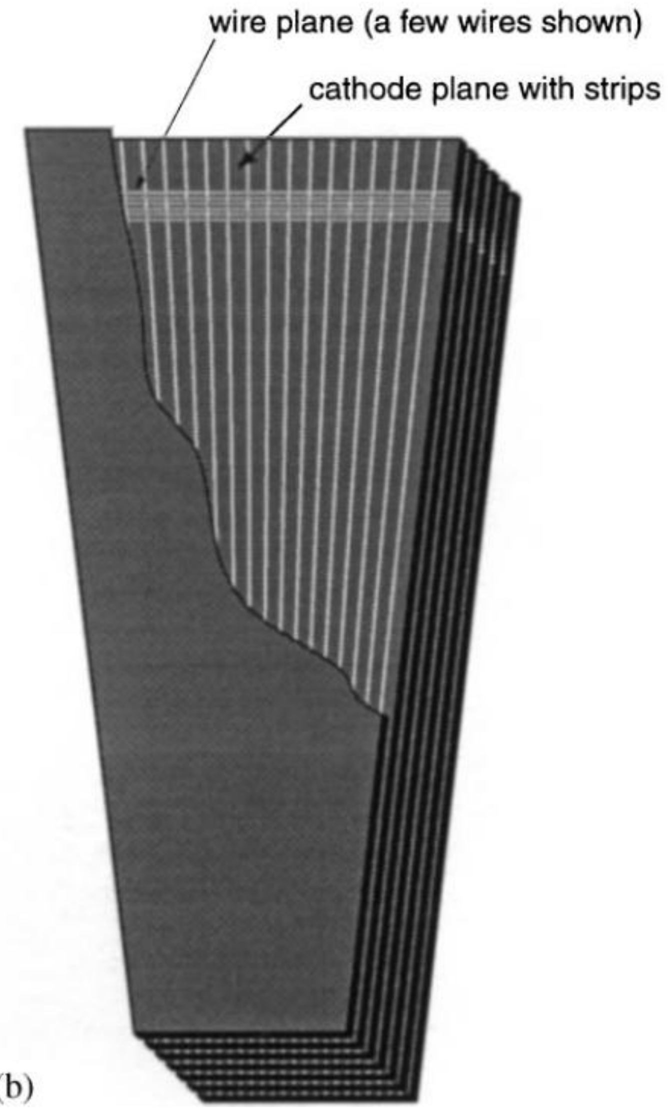
EMU Cathode Strip Chamber



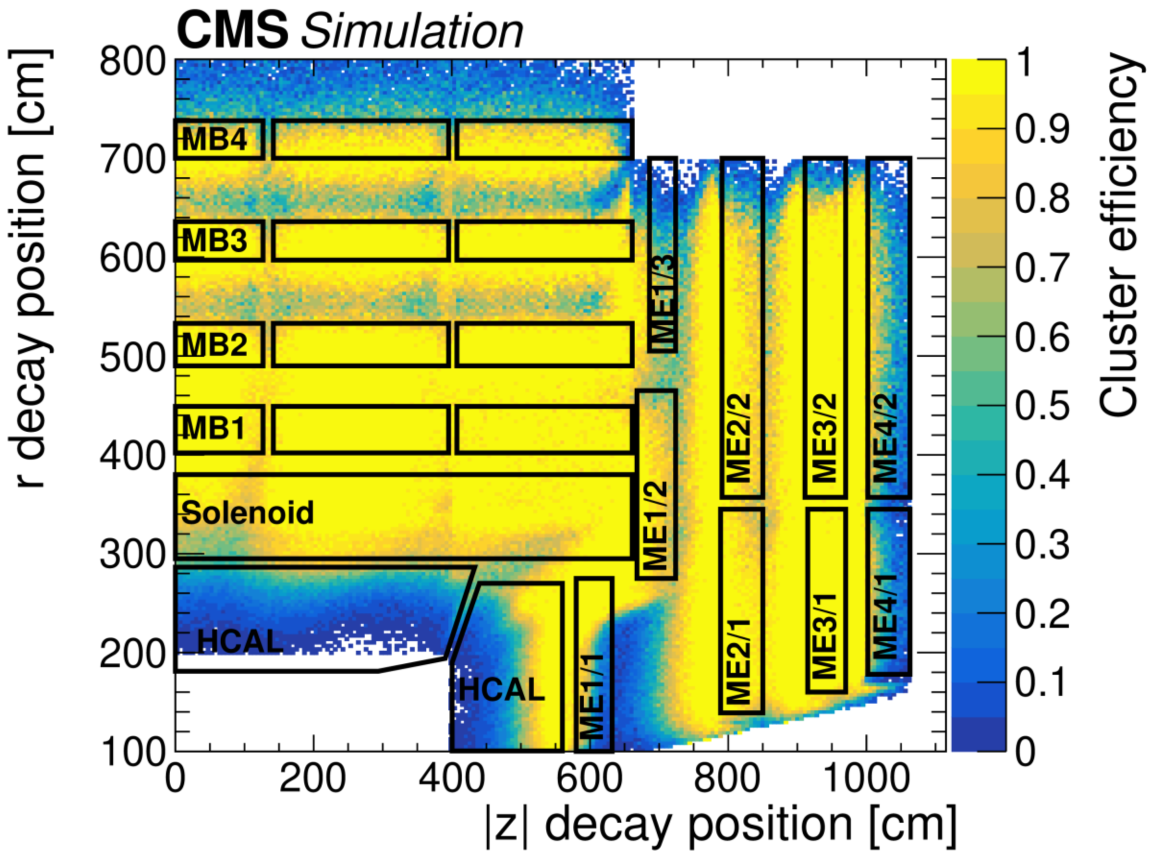
(a)



(b)

Decays in the muon system

- LLPs may decay in muon system, causing particle showers
- Muon detector showers (MDS): many hits in confined space
  - Hit clusters are formed, efficiency important for measuring physical properties
  - Energy, momentum, vertex position…



[11] Hayrapetyan, A. et al., CMS Collaboration

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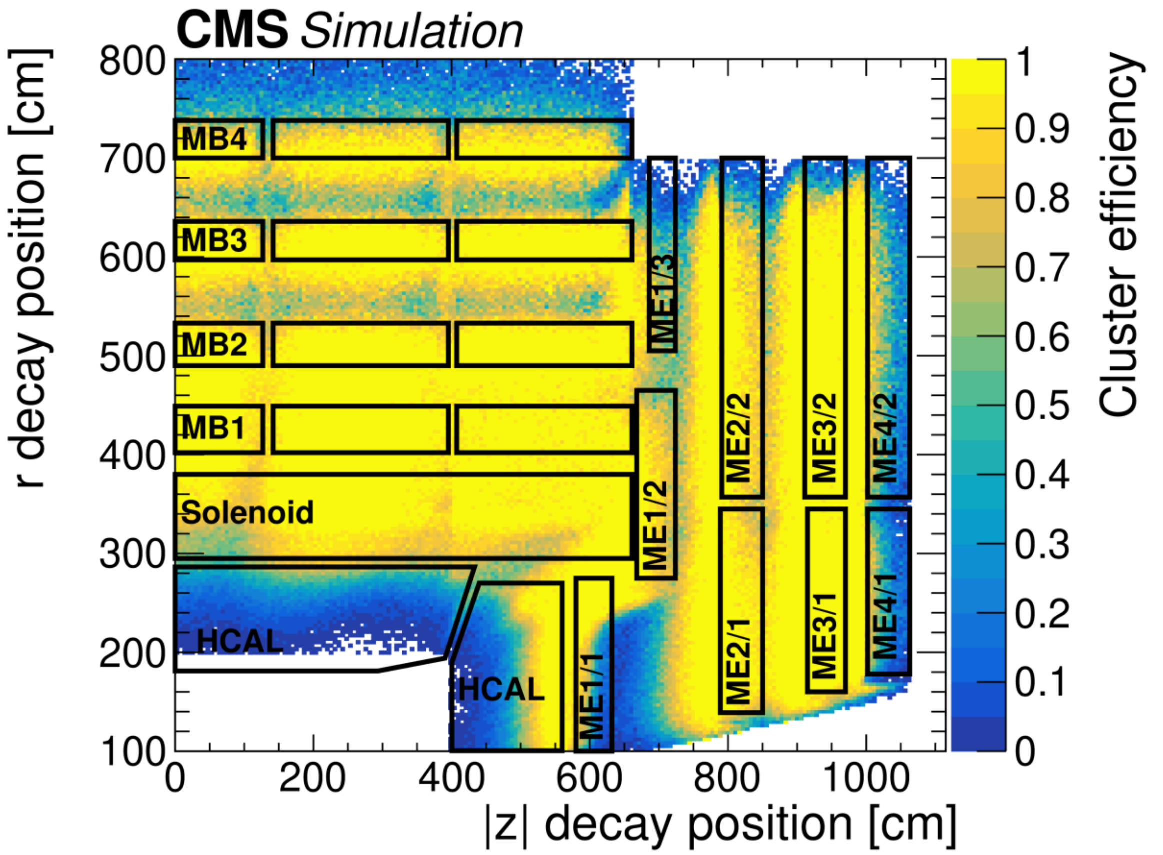
4. Backgrounds

MDS Backgrounds

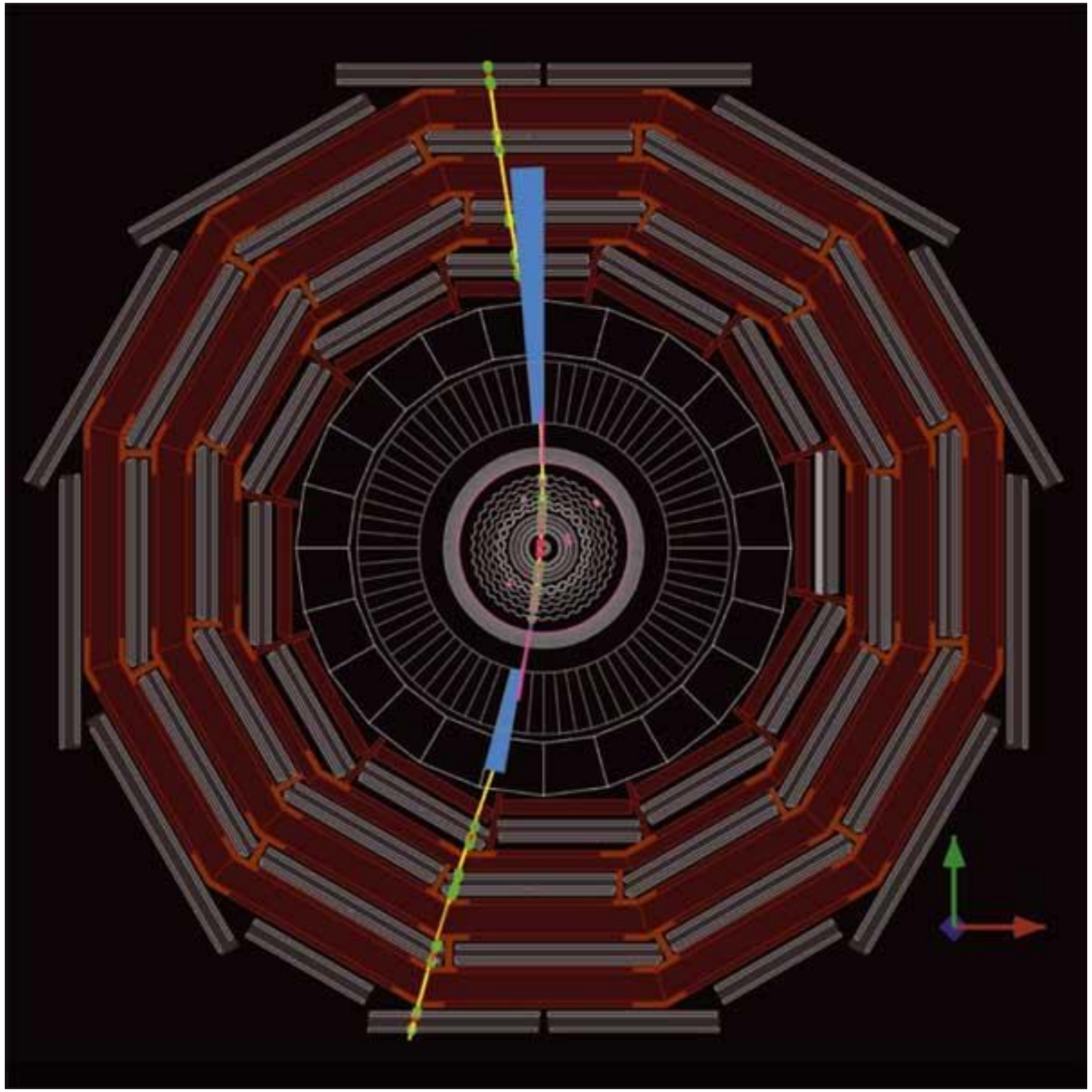
- Muon detector showers can be caused by high energetic muons
- Emission of high energetic photons: "Bremsstrahlung"
- Photons can pair produce in the steel return yoke and create particle showers
  - Steel yoke functions as a "calorimeter"



[11] Hayrapetyan, A. et al., CMS Collaboration

Other Background types

- Cosmic muons
  - CMS and ATLAS have good cosmic muon detection
- Detector noise
  - Can look like low energy depositions
- Detector/algorithm failure
  - Signal seems to exist but is only a detector anomaly



[12] CERNCourier

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Summary

- LLPs are important product of BSM theories
- Searches for LLPs depend highly on lifetime and given detector
  - Experimental signatures vastly differ from conventional ones
  - Searches for displaced vertices, jets, etc. already happening in many current detectors
  - High expectations for future detectors
- Background estimations often difficult due to unusual and detector-based origins
- More to be discovered in the future!

Literature sources

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