Search Strategy for Long-Lived Particles that Decay to ee, eμ or μμ with ATLAS

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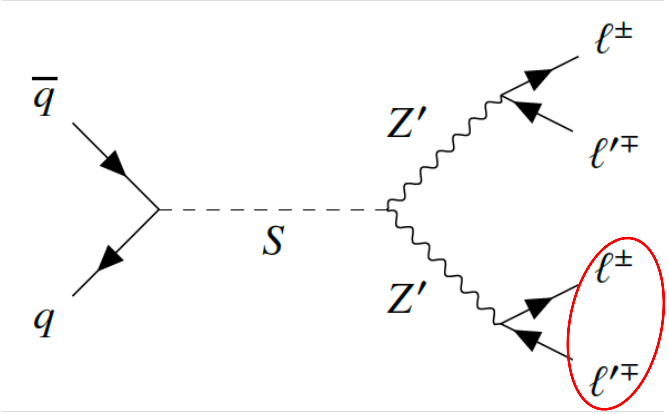
Outline

- Introduction
- Long-Lived Particles Reconstruction/Selection
- Background Estimates
- Systematic Uncertainties
- Summary

Introduction

- No evidence of beyond Standard Model particles in extensive searches by ATLAS and CMS
  - ⇨ search for long-lived particles is of particular interest
- ATLAS searches in *pp* collisions at $\sqrt{s}$ =13 TeV
- Integrated luminosity: 140 fb^{-1}
  - update of previous analysis based on 32.8 fb^{-1} Phys. Lett. B 801, 135114 (2020)

Models Investigated

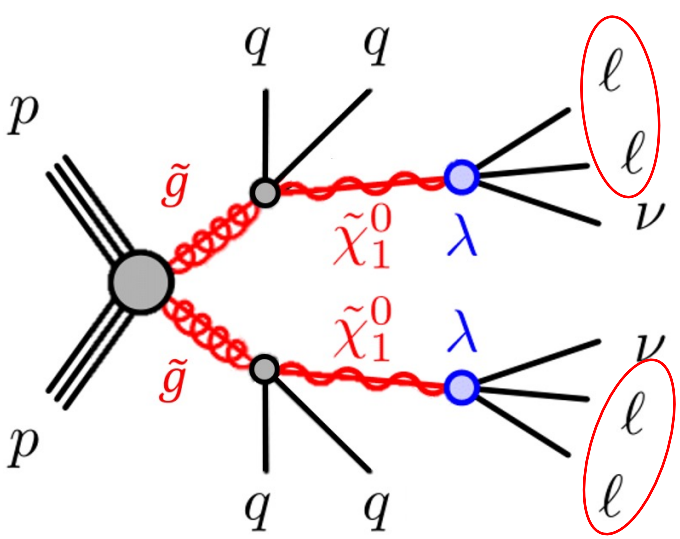


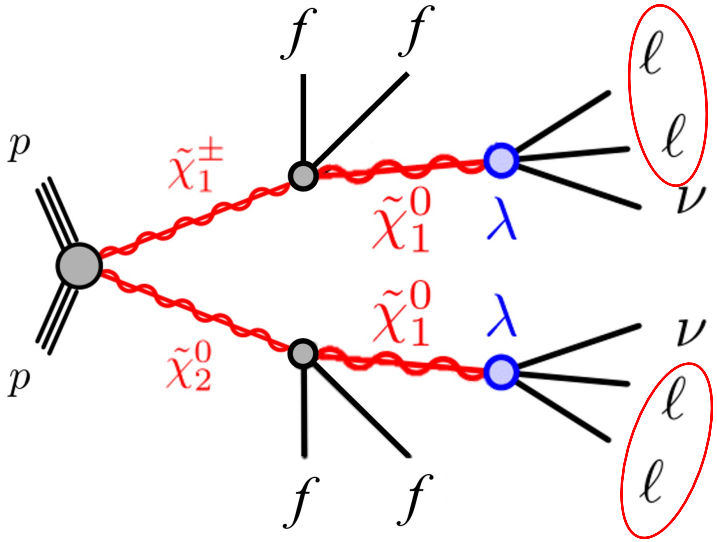
Displaced

- Previous toy model: Drell-Yan production of Z'
  - known problem: Z' produced in $q\bar{q}$ interaction would also decay predominately into $q\bar{q}$ and hence excluded
  - ⇨ new model with a scalar decaying to two Z'
    - Z' can decay to lepton pair or dark matter

https://scipost.org/SciPostPhys.5.4.036/pdf

Models Investigated





- Replace $\tilde{q}\bar{\tilde{q}}$ production by $\tilde{g}\tilde{g}$ with larger cross-section
  - ⇨ better sensitivity
- Electroweak production is new

Challenge in Long-Lived Particle Search

- Standard ATLAS trigger + track/vertex reconstruction are designed for particles originated near *pp* collision region
  - need special triggers without using inner tracker information
    - loose enough without producing too much data
    - γ: $P_T > 160$ GeV
    - 2γ: $P_T > 60$ GeV
    - μ: $P_T > 60$ GeV and $0 < |\eta| < 1.05$
      - using muon chamber only
  - need to recover tracks not originated near *pp* collision region
    - Large radius tracking (LRT) + vertexing

Large Radius Tracking

- special tracking program to recover tracks with large impact parameters not found by standard tracking program
  - use hits not used by the standard tracking

Allow tracks with larger impact parameters

Reconstruction Phase	Requirement	Standard	Large Radius
Forward tracking	Min. p_T (MeV)	500	900
	Max. η	2.7	5.0
	Max. d_0 (mm)	10	300
	Max. z_0 (mm)	250	1500
Clustering	Min. unshared Si hits	6	5
	Max. shared Si modules	1	2
	Min. Si hits	7	7
	Seed extension	Combinatorial	Sequential
Back-tracking	Min. p_T (MeV)	1000	–
	Max. d_0 (mm)	100	–

Require less silicon hits

Vertex Requirements

- track not allowed to have pixel hits smaller than the vertex radius
- must have nearby pixel or strip hits at larger radius
- vertex cannot be inside disabled pixel module
- no vertex with electron in pixel/strip modules or structure
- candidate tracks must match to trigger and pre-selection objects

Background

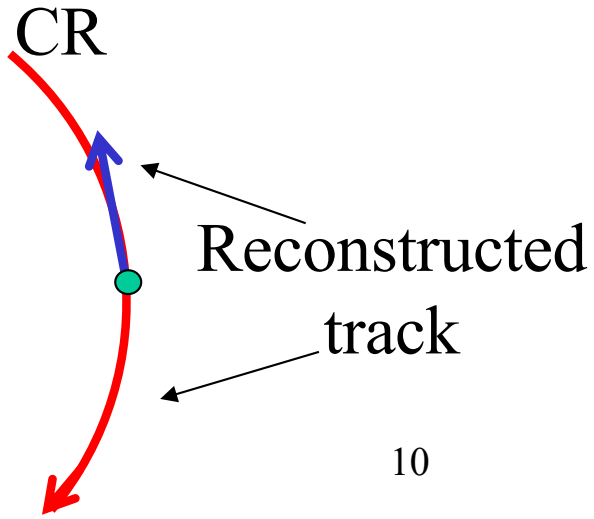
- no standard model process can produce heavy lepton pair with displaced vertex
- two potential backgrounds
  - cosmic ray
  - two random leptons forming a displaced vertex

Cosmic Ray Veto

- one segment of cosmic ray could be reconstructed in opposite direction
  - ⇨ two opposite signed track forming a detached vertex
    - two tracks separated in ϕ by π
    - two tracks of opposite η
      - ⇨ CR veto:

$$\Delta R_{\cos} = \sqrt{(\Delta\phi - \pi)^2 + (\Sigma\eta)^2} < 0.01$$

    - estimate the background by fitting the distribution and extrapolate into the signal region



Random Crossing Background

- select one lepton from one event and combine with a lepton from a different event
- calculate probability for forming detached vertex
  - calculation is CPU intensive because probability ~ 10^{-7}
  - need to reconstruct several hundred million events/channel
- multiple this by number of lepton pairs in data to predict number of vertices from random crossing
- validated with high statistics without the lepton requirement

Systematic Uncertainties

- tracking and vertexing efficiency for LLP
  - use $K_s \rightarrow \pi\pi$
  - K_s can be reconstructed using standard or large radius tracking
  - number of K_s is not well simulated by MC
    - ⇨ normalize number of K_s found in data with standard tracking to MC
    - ⇨ compare number of K_s found in data with large radius tracking to MC as a function of transverse decay radius
- Other systematic uncertainties are estimated from data using Z bosons with "tag-and-probe"

Summary

- Presented search strategy for long-lived particles that decay into two oppositely charged leptons: ee, eμ, μμ
  - requiring a detached vertex in the inner tracking volume greatly suppresses the SM background
  - vertices from random crossing of tracks comprise large source of background but is small and estimated from data
  - cosmic ray background is even smaller and estimated from data
- Stay tuned…