Electroweak-scale exotica with LHCb

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on behalf of the LHCb collaboration

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LHCb: a general-purpose detector in the forward direction

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Electroweak-scale exotica with LHCb


2 < η < 5
LHCb: a general-purpose detector in the forward direction

Tracking system

Magnet

ECAL HCAL

MUON

VELO

RICH

2 $< \eta < 5$

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Electroweak-scale exotica with LHCb

JINST3(2008)S08005;
IntJModPhysA30(2015)1530022
1. Search for long-lived heavy charged particles using a ring imaging Cherenkov technique at LHCb

2. Search for Higgs-like bosons decaying into long-lived exotic particles \( \text{NEW} \)

3. Search for long-lived particles decaying to jet pairs

4. Prospects for run 2 and the LHCb upgrade

5. Short-lived physics at the electroweak scale
   → talk by Xabier Cid Vidal and poster by Donatella Lucchesi
Search for pairs of detector-stable charged particles

- Drell-Yan production assumed
- Discriminated from \( \mu^{\pm} \) using
  - Energy loss in the Velo
  - RICH below threshold
  - ECAL and HCAL deposits
- ANN classifier with PID variables, product of the two responses is used for final selection
- Selection calibrated on \( Z \rightarrow \mu^{+}\mu^{-} \)

![Graphs showing signal, background, and data distributions for RICH and normalized distributions for simulation efficiency.](image-url)
Search for pairs of detector-stable charged particles


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Exotic particles decaying in the detector volume

- particles with mass $25-55$ GeV/c$^2$, lifetime $1-100$ ps ($\gamma\beta c\tau \lesssim 20$ cm)
- predicted by Hidden Valley models, GMSB, SUSY models with baryon number violation trilinear couplings


- benchmark signals:
  $H \rightarrow \pi_\nu\pi_\nu$, $\pi_\nu \rightarrow b\bar{b}$ (HV) and
  $H \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \rightarrow 3$ jets (BV)

Complementary analysis strategies:
vertex finding in software trigger, and
- two candidates coming from a resonance
- a single candidate with particle flow jets
Inclusive displaced vertex reconstruction in Hlt2

- Starting from all reconstructed VELO tracks, like a PV search
- Selections on track multiplicity ($\geq 4$), radial displacement ($R_{xy} \geq 0.4 \text{ mm}$), track invariant mass etc., in different $R_{xy}$ categories
- Loose selection for two-candidate events

Additional veto for other instrumental backgrounds
Higgs-like bosons decaying to pairs of long-lived particles

- 0.62 fb⁻¹ of pp collisions at 7 TeV
- Baseline selection: $N_{\text{trk}} > 6$, $m_{\text{trk}} > 6 \text{ GeV}/c^2$, small vertex position uncertainty
- Good compatibility of remaining data with shapes from $b\bar{b}$ simulation
Higgs-like bosons decaying to pairs of long-lived particles

- Template fit to di-LLP (long-lived particle) invariant mass distribution
- Background shapes from data control regions (different methods as cross-check)
- No excess observed

![Graph showing di-LLP mass distribution](image)

![Graph showing cross-section vs. LLP lifetime](image)

![Graph showing cross-section vs. LLP mass](image)
Higgs-like bosons decaying to pairs of long-lived particles

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Search for long-lived particles decaying to jet pairs

Alternative analysis on the same dataset, based on the presence of a single candidate vertex (larger acceptance), with two jets attached (HV model).

**Vertex reconstruction**

**Particle Flow jets**
Search for long-lived particles decaying to jet pairs

Red long-dashed: best fit signal
Green dash-dotted: signal for SM Higgs cross-section, 100% BR
arxiv:1307.1347
Search for long-lived particles decaying to jet pairs

\[ \sigma(H) \times B(H \rightarrow \pi^+\pi^-) \] [pb]

\begin{align*}
LHCb
\times \quad m_{\pi^\pm} &= 25 \text{ GeV/c}^2 \\
+ \quad m_{\pi^\pm} &= 35 \text{ GeV/c}^2 \\
\star \quad m_{\pi^\pm} &= 50 \text{ GeV/c}^2 \\
\diamond \quad m_{\pi^\pm} &= 35 \text{ GeV/c}^2, \pi^\pm \rightarrow c\bar{c} \\
\circ \quad m_{\pi^\pm} &= 43 \text{ GeV/c}^2 \\
\square \quad m_{\pi^\pm} &= 35 \text{ GeV/c}^2, \pi^\pm \rightarrow s\bar{s}
\end{align*}

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Electroweak-scale exotica with LHCb
Prospects for run 2 and the LHCb upgrade

- 13 TeV
  - higher cross-sections
  - better geometrical acceptance
- Run 2
  - more integrated luminosity
  - better reconstruction in the trigger
  - opportunities with “turbo” processing
- Upgrade
  - pixel vertex detector: lower ghost rate
  - improved tracker
  - full software trigger

For more information, see the talk by Stefano De Capua and the posters by Marina Artuso and Renatoagliani.

LHCb 2015 Trigger Diagram

- 40 MHz bunch crossing rate
- L0 Hardware Trigger: 1 MHz readout, high \( E_T/P_T \) signatures
  - 450 kHz \( h^\pm \)
  - 400 kHz \( \mu/\mu\mu \)
  - 150 kHz \( e/\gamma \)

Software High Level Trigger

- Partial event reconstruction, select displaced tracks/vertices and dimuons
- Buffer events to disk, perform online detector calibration and alignment
- Full offline-like event selection, mixture of inclusive and exclusive triggers

12.5 kHz (0.6 GB/s) to storage
Prospects for run 2 and the LHCb upgrade

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Conclusions

- LHCb offers unique opportunities to search for exotic long-lived particles
  - Precise vertex detector and flexible software trigger allow to cover the low-mass low-lifetime region
  - Fully instrumented in the forward region, can use RICH detectors to identify heavy stable charged particles

- Presented bounds on the production of heavy stable charged particle pairs, pairs of long-lived particle pairs decaying to high-multiplicity final states, and long-lived particles decaying to jet pairs

- More results in preparation — and more exotic ideas are always welcome
Additional material
Search for long-lived particles decaying to jet pairs

$10^{-2}$ $10^{-1}$ $1$ $10$ $10^2$ $10^3$
cτ (cm)

$20$ $40$ $60$ m (GeV/c$^2$)

$m_H \geq 200$

CMS

$m_H = 130–170$

CDF

$m_H = 120–140$

LHCb

$m_H = 120$

$m_H = 90–200$

DO

$m_H = 120–140$

ATLAS

$m_H \geq 200$
Results


- **LHCb collaboration**, Search for Higgs-like boson decaying into pair of long-lived particles, **LHCb-PAPER-2016-014**, in preparation.

References

