Search for heavy long-lived exotic particles in LHCb

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On behalf of the LHCb collaboration

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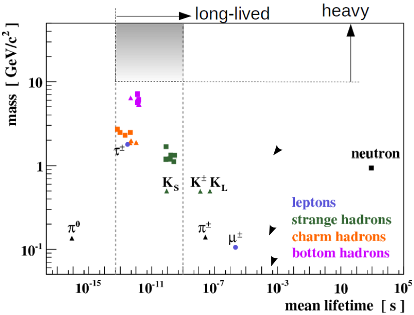
Long-lived exotic particles

- Many new-physics models feature massive long-lived exotics ($\tilde{\chi}^0$, π_ν^0, ...) which decay into Standard Model particles
- A decaying long-lived particle produces a displaced vertex, which LHCb would be able to trigger and reconstruct
- Standard Model background is low



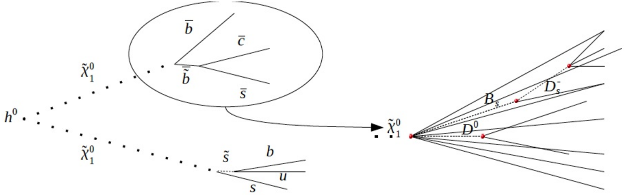
Signature of the displaced vertex

- Large decay length $\rightarrow$ LHCb is sensitive to $\sim$ 1mm -1m
- High track multiplicity $\rightarrow$ for decay to quarks
- High mass $\rightarrow \gtrsim$ 20 GeV
- Fully hadronic, semi-leptonic, fully leptonic
- Combine pairs of back-to-back long-lived particles $\rightarrow$ reducing background

Long-lived particles can be produced in pairs through Higgs decay: $h^0 \rightarrow \tilde{\chi}^0 \tilde{\chi}^0$

Example Model

- mSuGRA with baryon number violation [Carpenter, Kaplan, Rhee]
  $\tilde{\chi}^0 \to q\tilde{q} \to q\{qq\}$

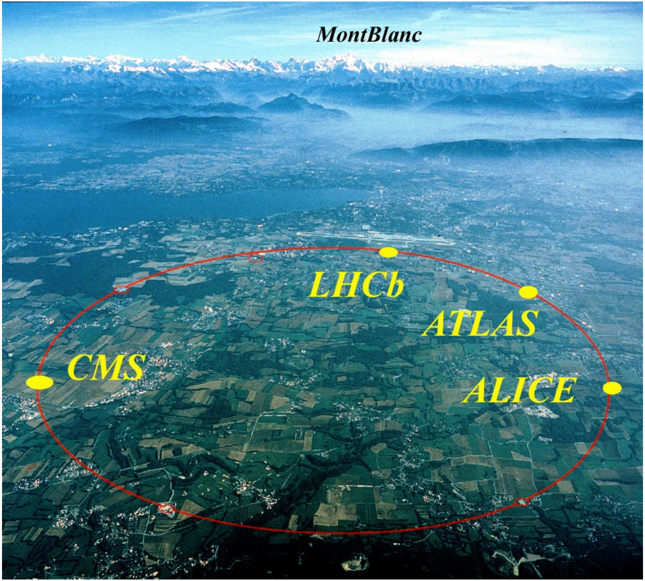


Monte Carlo sample "BV48":
m_{h_0} = 114 GeV, $m_{\tilde{\chi}^0}$ = 48 GeV, $\tau_{\tilde{\chi}^0}$ = 10 ps

Other options:

- Hidden Valley ($h_0 \to \pi_v^0 \pi_v^0 \to b\bar{b}b\bar{b}$) Monte Carlo sample "HV10" [Strassler, Zurek]
- SUSY with R parity violation, unstable Lightest SUSY Partner ($\tilde{\chi}^0 \to \nu\ell^+\ell^-$, $\tilde{\chi}^0 \to \nu q\bar{q}$, $\tilde{\chi}^0 \to \ell q\bar{q}$) [Carpenter, Kaplan, Rhee], [De Campos, Eboli, et al]

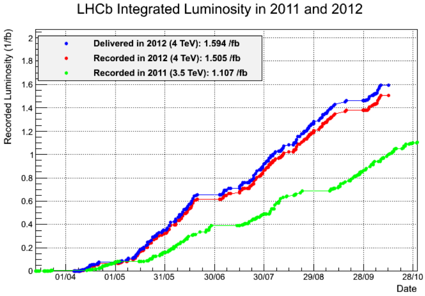
Large Hadron Collider

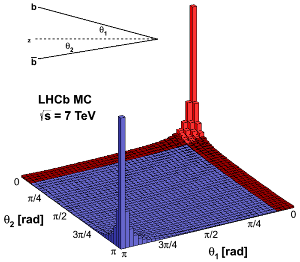


LHCb DETECTOR [2008 JINST 3 S08005]

LHCb is designed to detect *b*-hadrons, produced in the forward region

- Reconstruct *b*- and *d*-hadron decays (flight distance $\sim$1cm)
- Measure CP-violation
- Search for rare decays

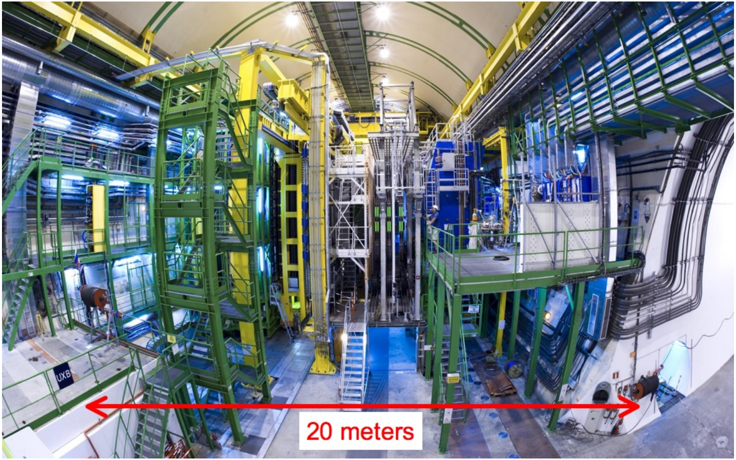




- This analysis uses 2010 data (35.8 pb^{-1})

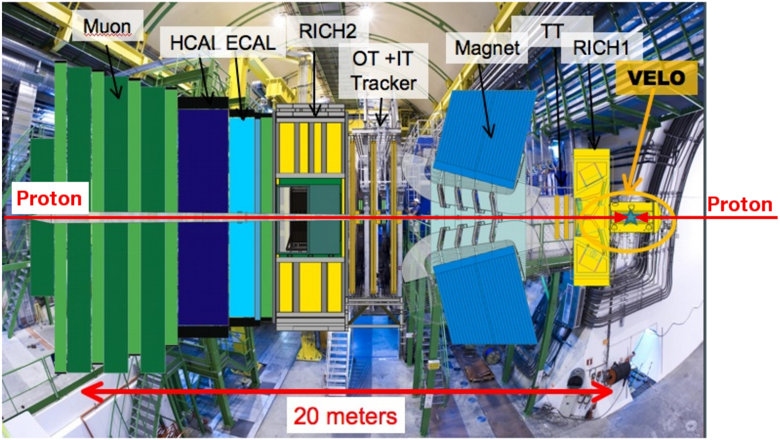
LHCb detector

[2008 JINST 3 S08005]



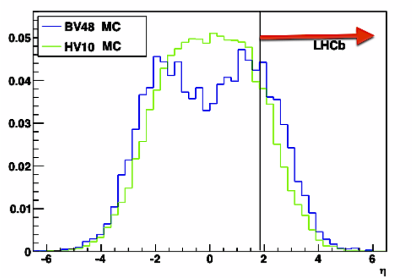
LHCb detector

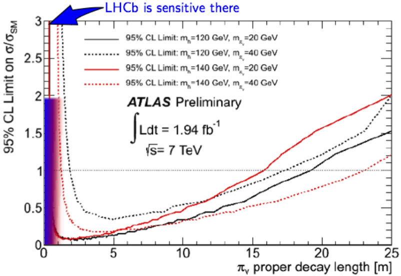
[2008 JINST 3 S08005]



Why LHCb?

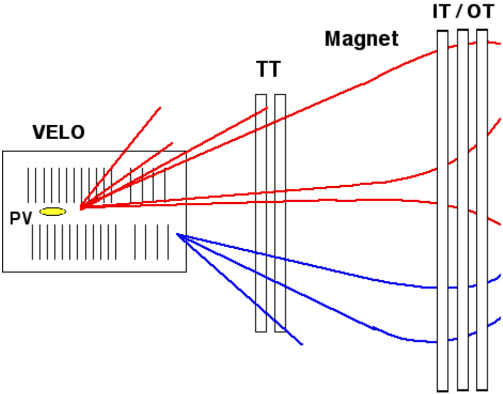
- Displaced vertex trigger
- VELO provides excellent vertex reconstruction
- Unique coverage: $2 < \eta < 5$ (ATLAS/CMS tracking systems: $|\eta| < 2.5$)
  Distribution of MC signal samples at generator level
  (BV48$\rightarrow$ mSuGRA, HV10$\rightarrow$Hidden Valley)





- 25% of the generated events have a long-lived particle in the acceptance
- For the 2010 dataset (35.8 pb^{-1}) we expect about 50-100 events with two decay vertices in the acceptance for the model BV48

Tracking System

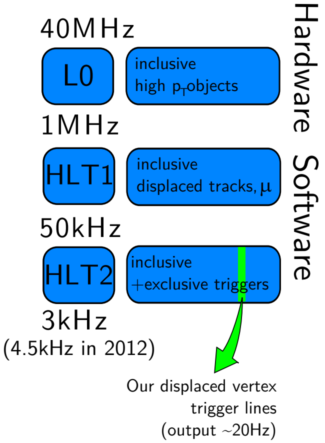


Reconstruction of 1-100 ps lifetime is possible.

- Flight distance <40cm: Tracks include VELO segment
- Flight distance 20cm-2m: Tracks without VELO segment (future analysis)

Trigger

The trigger reduces the total data rate from 40 MHz to 3 kHz



Vertexing

- VELO tracking, PV reconstruction run at 1 MHz
- Displaced vertex reconstruction run at 50 kHz
- Make seed with neighbouring tracks, run adaptive least square fit

Trigger

Trigger on a displaced vertex:

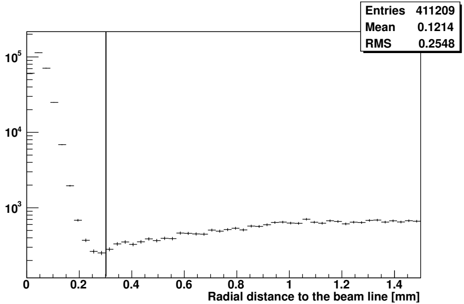
Trigger Selection

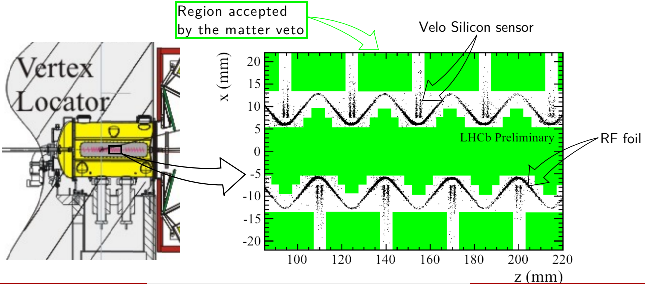
- At least two displaced vertices
- Radius $\geqslant$ 0.4 mm
- N tracks $\geqslant$ 4
- Mass $\geqslant$ 3 GeV (charged particles only)
- Passes material veto

- The trigger efficiency on reconstructible MC signal is $\sim$40%
- In 2010 the efficiency on offline reconstructed events was 67%
- Improved trigger for 2011 and 2012 data taking

Backgrounds

- Primary vertices
  - Centered in interaction region
    → Reject by requiring large radius from beamline
- Interactions with detector material
  - High track multiplicity, large mass
    → Material veto



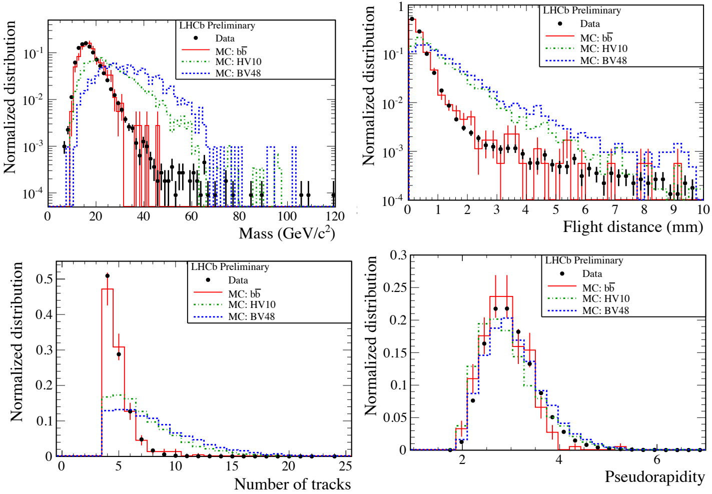


Backgrounds

- Decay of Standard Model particles
  - Inclusive $b\bar{b}$, $c\bar{c}$, $t\bar{t}$
  - Displaced, low track multiplicity, low mass
  - These should not fall in the signal region,
    but they will if we make a mistake in the vertex reconstruction
    (e.g. merge two b-vertices or include a primary vertex track in the displaced vertex)

$\rightarrow$ $b\bar{b}$ is the main background

PRELIMINARY ANALYSIS ON 35.8 pb^{-1} (2010 DATA)



Expected number of $b\bar{b}$ events: $75 \pm 13 \times 10^3$

Observed in data: 59×10^3 events

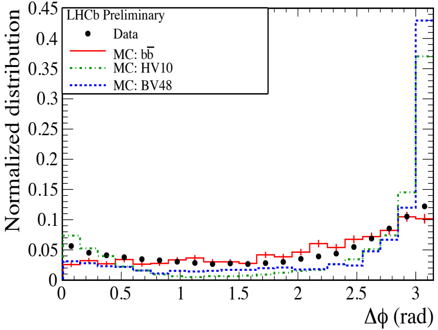
Shapes compatible with $b\bar{b}$ background

[LHCb-CONF-2012-014]

Reconstruct the h_0 candidate

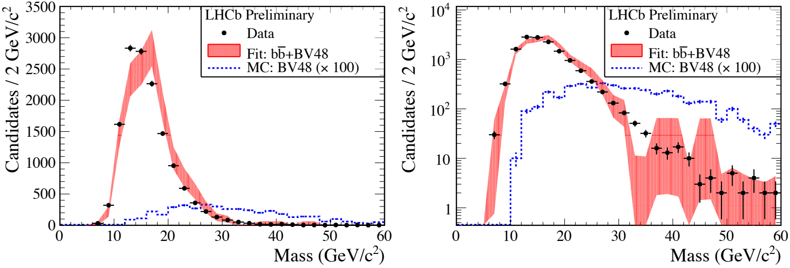
Candidates coming from a low-p_T $h0$ are back-to-back

Select pairs of long-lived particles with $\Delta\phi > 2.8$ to reconstruct the h_0 candidate



[LHCb-CONF-2012-014]

We are left with 13,893 candidate pairs, which are consistent with $b\bar{b}$ background:



Final selection to remove SM background

- Two candidates
- $|\Delta\phi| > 2.8$ rad
- N tracks $\geqslant 6$
- Mass $\geqslant 6$ GeV

No events left in data

Total efficiency on signal: $0.384\% \pm 0.017\%$

$\rightarrow$ expect 2 events for mSuGRA model

Efficiencies

Detection efficiency of reconstructible long-lived particle (LLP) candidates determined on signal MC:

Requirement	ϵ (%)
One LLP in acceptance (generator cut)	29.4
LLP preselection	44.1
Trigger	35.5
Fiducial volume	95.8
LLP selection	66.4
Two LLP found	19.1
$\lvert\Delta\phi\rvert$ cut	68.4
Total	0.384
Total without trigger	0.589

Efficiencies

- (Pre)selection is optimised to reduce backgrounds
- Trigger has limited bandwidth
- Main loss from the first (HLT1) level of the software trigger for very displaced vertices. A dedicated algorithm has been implemented for future analyses
- Requiring two LLP and $\lvert\Delta\phi\rvert$ to reduce backgrounds

Systematics

Source	%
Integrated luminosity	4
Trigger	15
Track reconstruction	7
p_{T} and mass calibration	6
Vertex reconstruction	12
Fiducial volume	4
Beam line position	1
Total	22

Trigger

15% sensitivity in the comparison of efficiencies in data and MC by using $b\bar{b}$ events with relaxed cuts

Vertex reconstruction

Account for differences in vertex resolution between data and MC

Preliminary results

Monte Carlo generated for different parameters of the mSuGRA model:

Model	τ_{LLP} ps	m_{LLP} GeV/c^2	m_{h^0} GeV/c^2	ϵ (%)	σ_{UL} pb
BV48-5	5	48	114	0.184 ± 0.011	66
BV48	10	48	114	0.384 ± 0.017	32
BV48-15	15	48	114	0.418 ± 0.017	29
BV20-10	10	20	114	0.010 ± 0.003	1425
BV35-10	10	35	114	0.146 ± 0.010	84
BV48-mh100	10	48	100	0.190 ± 0.013	64
BV48-mh125	10	48	125	0.293 ± 0.019	42

95% CL upper limit

Preliminary result

The mSuGRA model BV48 with:
m_{h_0} = 114 GeV, $m_{\tilde{\chi}^0}$ = 48 GeV, $\tau_{\tilde{\chi}^0}$ = 10 ps
gives a 95% confidence level upper limit of 32 pb [LHCb-CONF-2012-014]

Fast Simulation

To extrapolate the results to a larger variety of models, use a fast simulation of the LHCb detector

Fast Simulation

- Generate charged particles and feed them to the vertexing algorithm
- Apply inefficiencies as function of vertex position
- Enables us to extend the results for different m_{h0}, $m_{\tilde{\chi}_1^0}$ and $\tau_{\tilde{\chi}_1^0}$

For a fixed lifetime $\tau_{\tilde{\chi}_1^0}$ respectively fixed m_{h0}:

95% CL upper limit [pb]

m_{LLP}	30	35	40	48	55
m_{h^0}					
100	101	58	44	58	
105	100	75	44	39	
110	132	75	56	34	
114	128	91	47	32	46
120	148	93	58	34	31
125	179	90	61	41	29

m_{LLP}	30	35	40	48	55
τ_{LLP}					
3	210	156	136	168	410
5	145	101	68	58	137
10	129	91	47	32	46
15	155	90	49	31	33
20	131	93	63	32	31
25	142	100	61	34	25

$\rightarrow$ Good agreement with full simulation in control points

Summary

- A search was performed for a Higgs-like boson decaying to a pair of long-lived particles in 35.8 pb^{-1} of 2010 data [LHCb-CONF-2012-014]
- No events passed our selection, which was optimised to reduce the main background components (detector material and $b\bar{b}$ events)
- A preliminary 95 % CL upper limit for the production cross-section of 32 pb has been set for one specific model:
  mSUGRA with baryon number violation ($m_{h_0} = 114$ GeV, $m_{\tilde{\chi}^0} = 48$ GeV, $\tau_{\tilde{\chi}^0} = 10$ ps)
- The result can be extended to other models using a fast simulation

Outlook

- $\sim$70 times more integrated luminosity from 2011: 1 fb^{-1} and 2012: $\sim$2.2 fb^{-1}
- More inclusive analysis:
  - Single-vertex signatures
  - Specific searches for semileptonic decays
- Improve systematic uncertainties:
  - Add more control trigger lines to better estimate uncertainty
- Improve efficiency:
  - More advanced selection
  - Improve vertex reconstruction efficiency
  - Use substructure and flavour to distinguish between models and to reduce background
  - Improve mass reconstruction using jets