MANCHESTER 1824
The University of Manchester

LHCb

22nd International Conference on Supersymmetry and Unification of Fundamental Interactions

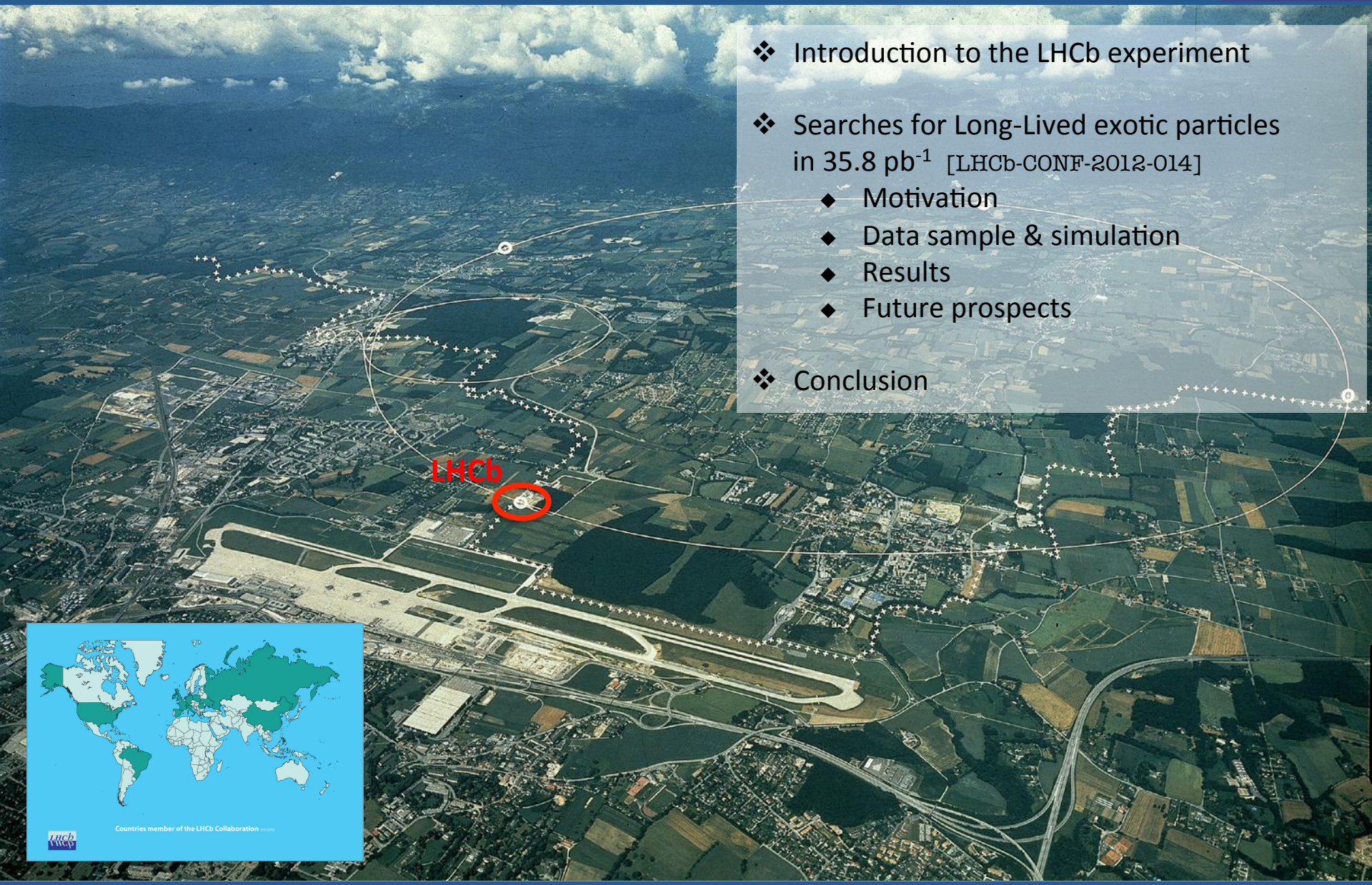
21 - 26 July 2014, Manchester, England

LHCb searches for No-SUSY exotics

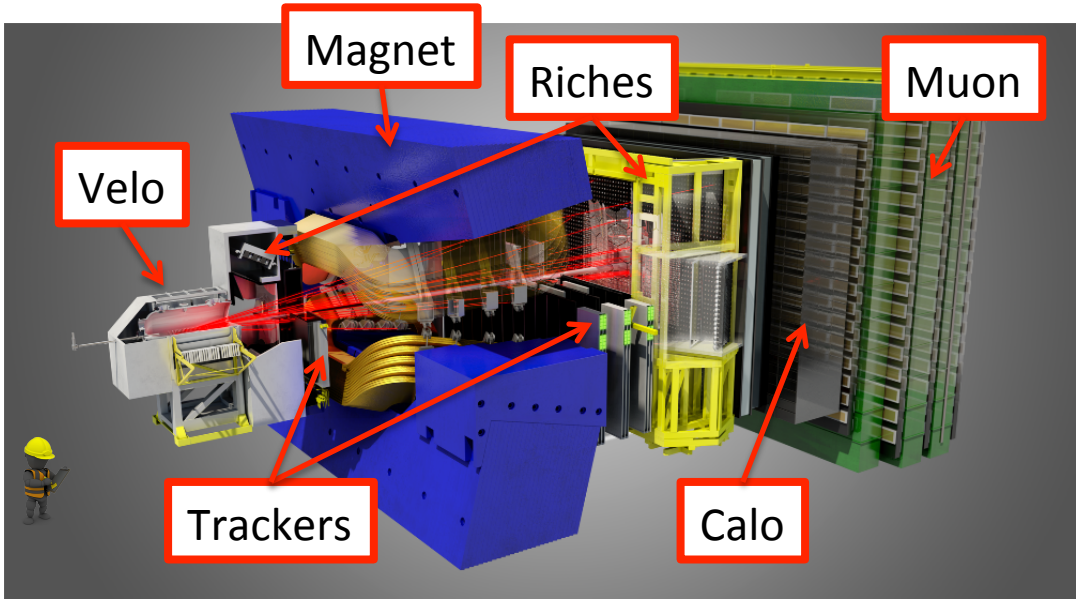
Stefano de Capua
on behalf of the LHCb collaboration

Outline

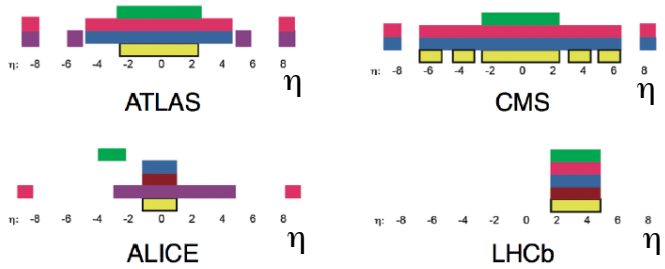
- Introduction to the LHCb experiment
- Searches for Long-Lived exotic particles in 35.8 pb^{-1} [LHCb-CONF-2012-014]
  - Motivation
  - Data sample & simulation
  - Results
  - Future prospects
- Conclusion



The LHCb detector

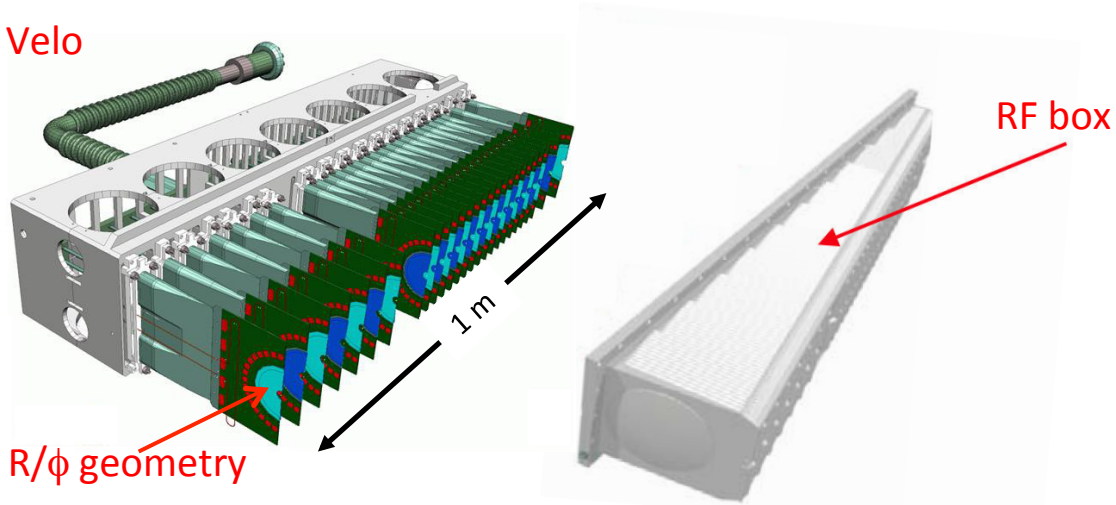


LHCb is designed for *CP* violation and rare decays of heavy mesons, in a unique kinematic range:



tracking, ECAL, HCAL, counters lumi, muon, hadron PID

+ precise tracking, excellent vertex resolution, access to low p_T,…



Data samples:

- 2010: 0.037 fb^{-1} at $\sqrt{s}$=7 TeV
- 2011: 1.1 fb^{-1} at $\sqrt{s}$=7 TeV
- 2012: 2 fb^{-1} at $\sqrt{s}$=8 TeV

Search for long-lived exotic particles

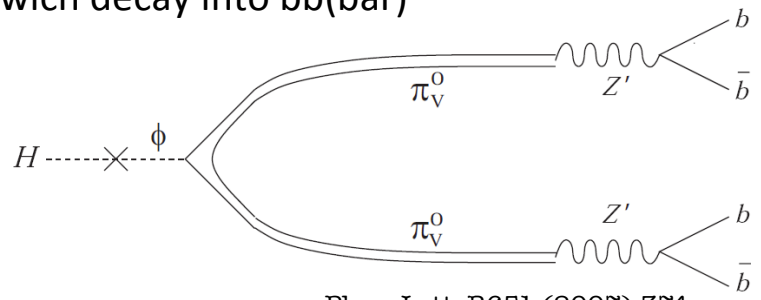
Motivation

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

Signature

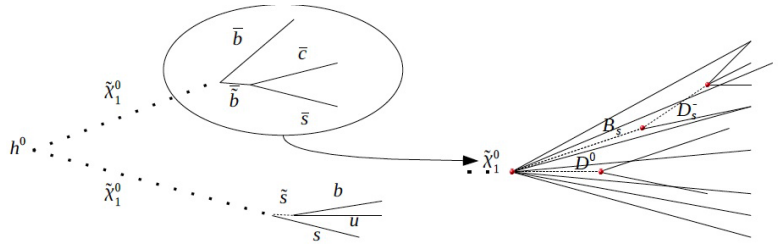
- Large decay length (LHCb is sensitive to 1mm - 1m)
- High track multiplicity (for decay to quarks)
- $m_{LLP} > 20$ GeV/c^2, $\tau_{LLP} > 1$ ps
- far from PV and beam axis
- Combine pairs of back-to-back long-lived particles to reduce background.

- Hidden Valleys models:
  SM Higgs may decay into 2 HV particles wich decay into bb(bar)



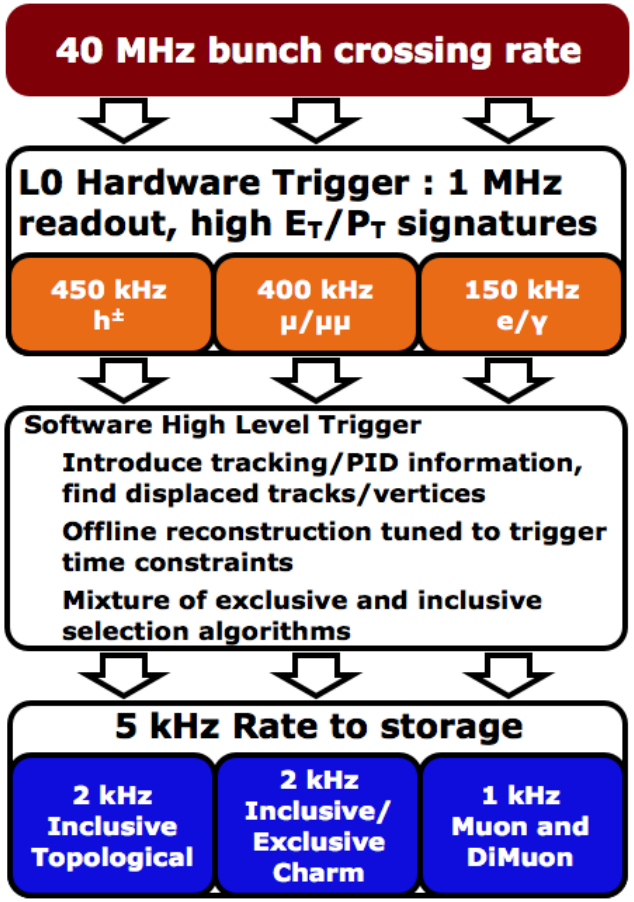
Phys. Lett. B651 (2007) 374

- mSUGRA with baryon number violation:
  Higgs decays in neutralinos, which decay into six quarks.



Phys. Rev. Lett. 99 (2007) 211801

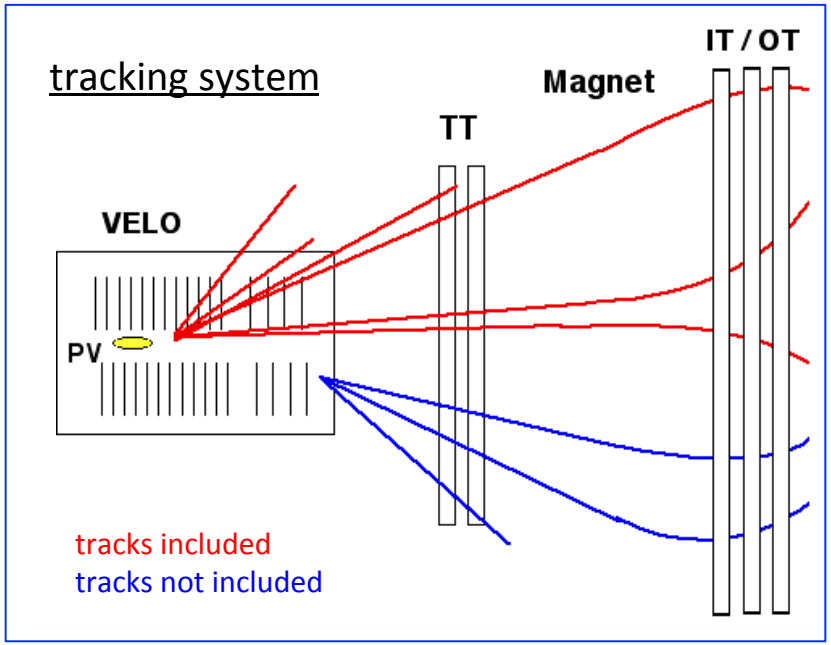
The LHCb Trigger



20 Hz output for the displaced vertex line (specific to this study)

Trigger selection

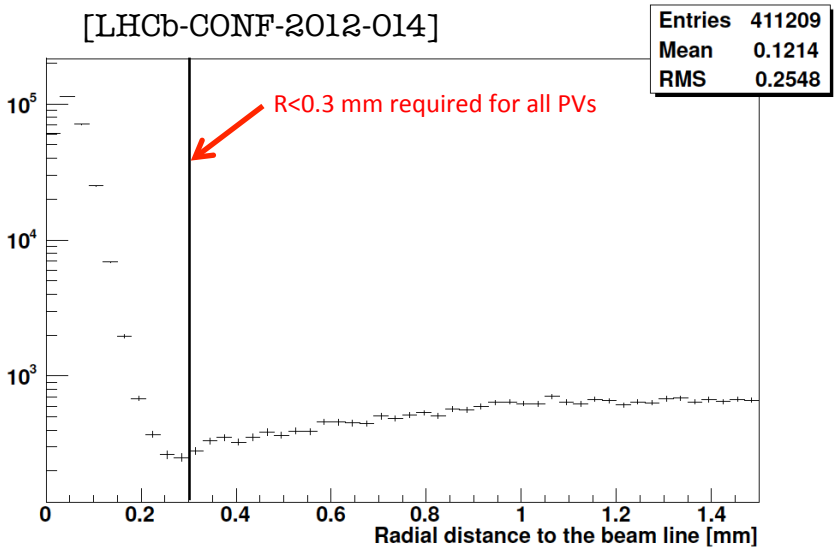
- Displaced vertices ≥ 2
- Radius ≥ 400 μm
- $N_{tracks} \geq 4$
- $M_{LLP} \geq 3$ GeV/c^2 (charged particles only)
- Passes material veto

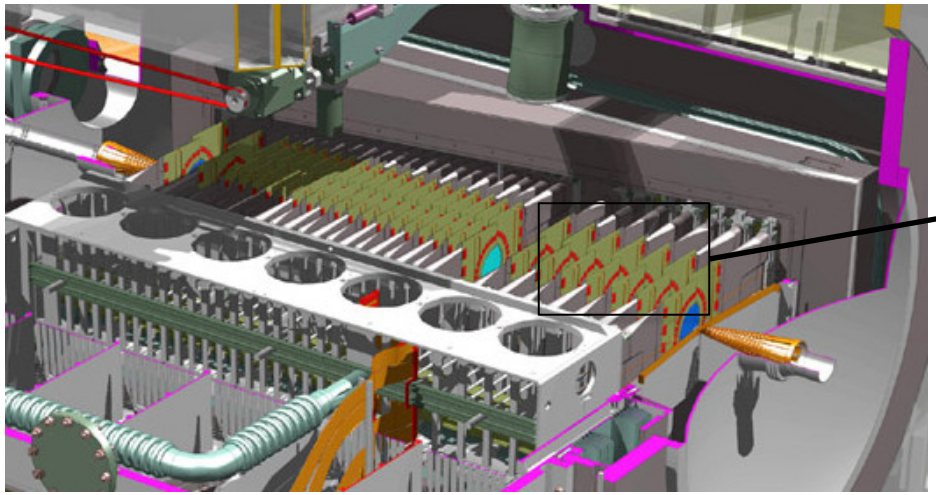


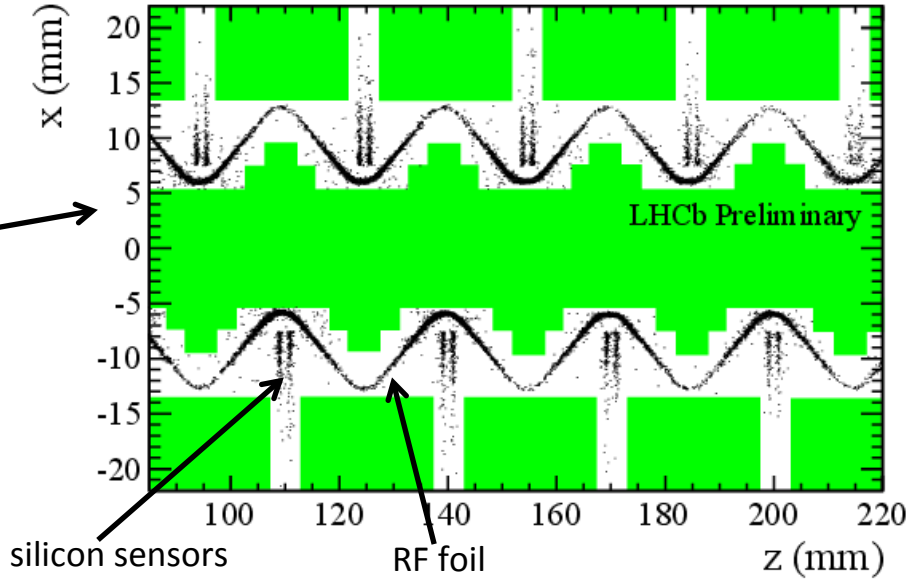
Backgrounds

Main sources

- Primary vertices: centred in the interaction region ➔ rejected by requiring radius ≥ 0.4 mm.
- Interactions with detector material: high track multiplicity, large mass ➔ rejected by material veto.







Backgrounds

Decay of Standard Model particles

- Inclusive bb(bar), cc(bar), tt(bar)
- Displaced, low track multiplicity, low mass

➔ These may fall in the signal region if we merge two b-vertices or include a PV track in the displaced vertex

Other sources

- Interactions with the residual gas in the beam pipe is negligible.

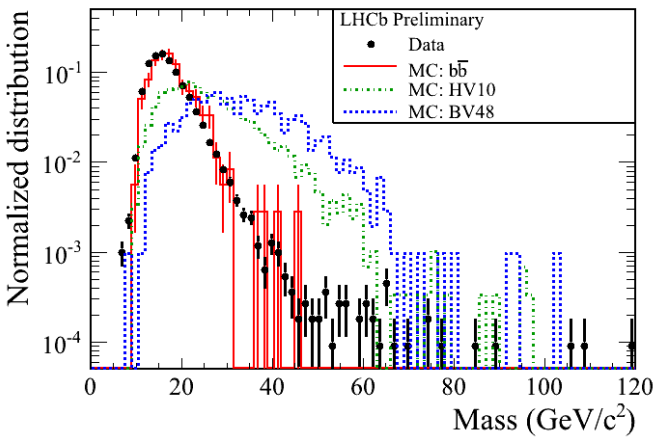
interactions with the detector material and inclusive bb(bar) are the dominant background components

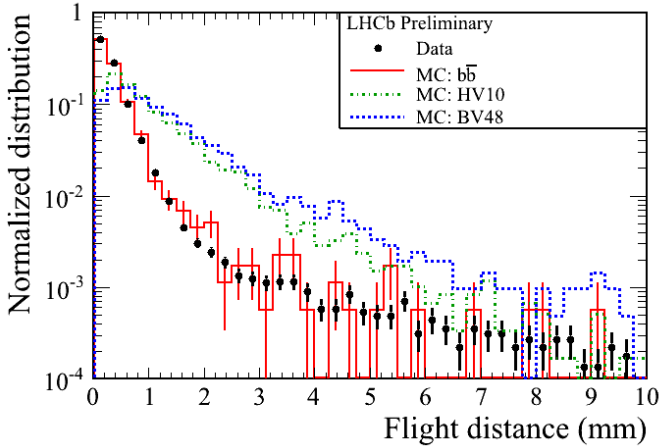
Data sample & simulation

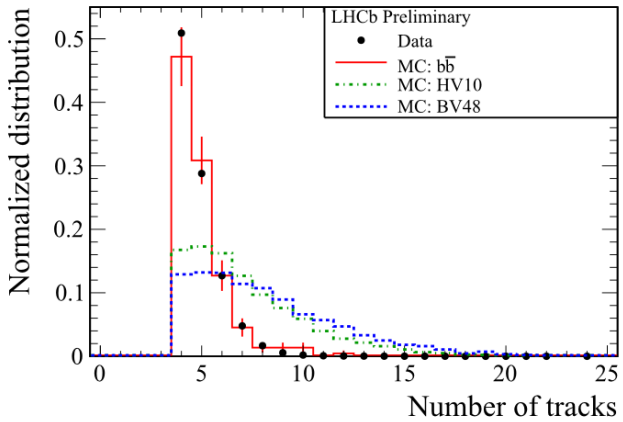
Data sample from 2010 data taking: 35.8 pb^{-1}
Monte Carlo samples: bb, HV10, BV48

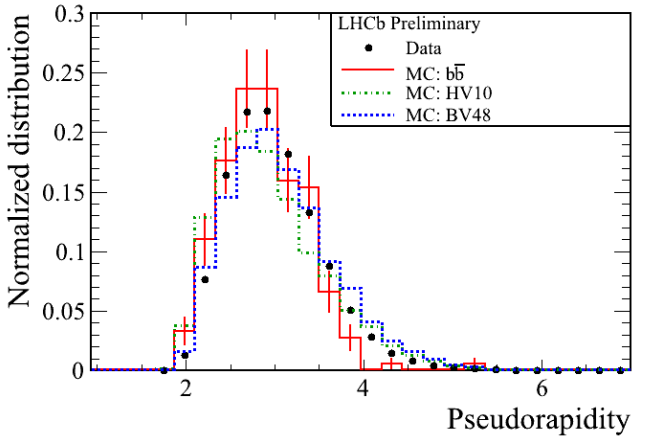
Model	τ [ps]	M1	M2	$\tan\beta$	μ	m_{LLP}	m_{h^0}
HV10	10					35	120
BV48	10	63	250	5	140	48	114

Distributions of combinations of two LLPs to form the Higgs









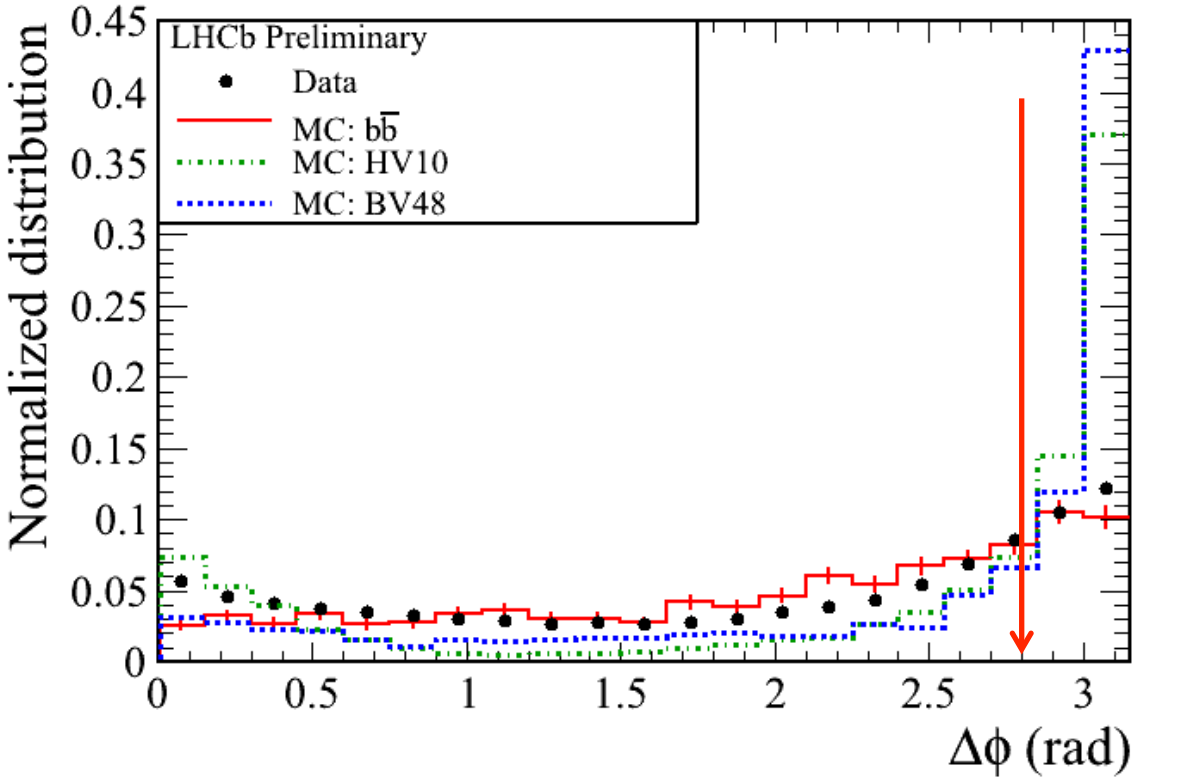
[LHCb-CONF-2012-014]

Expected number of bb(bar) events: 75±13 ×10^3, observed in data: 59 ×10^3
All shapes and yields compatible with bb(bar) background

Further selection

In absence of radiative effects, the two LLPs are expected to travel back-to-back in the transverse (x,y) plane:

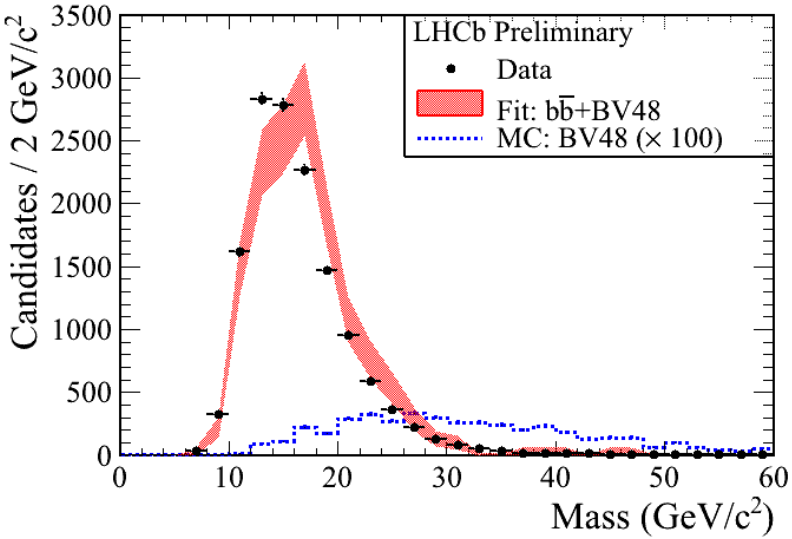
[LHCb-CONF-2012-014]

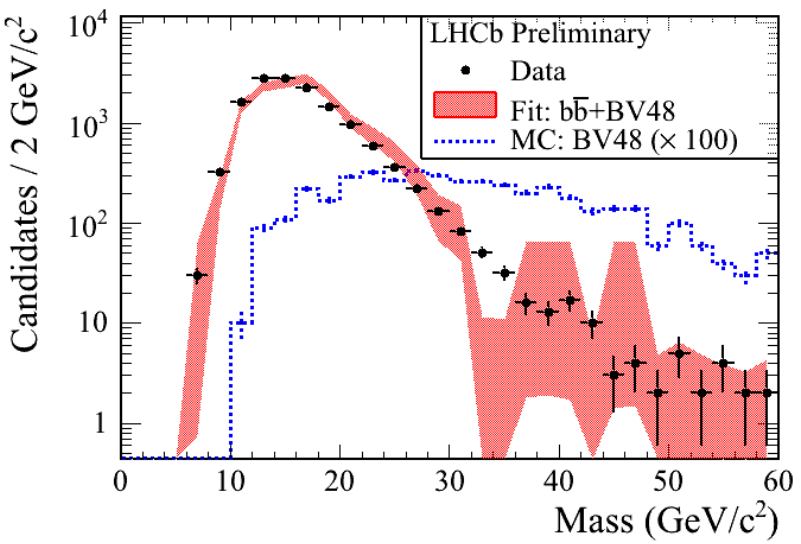


Select pairs of long-lived particles with $\Delta\phi > 2.8$ to reconstruct the Higgs candidate

Further selection

After the $\Delta\phi > 2.8$ cut, 13893 Higgs-like candidates are left, which are consistent with the bb(bar) background.





To remove the SM background, while optimizing the Higgs signal detection efficiency, a further selection is performed:

- $N_{tracks} \geq 6$
- $m_{LLP} \geq 6$ GeV/c²
- $\sigma_r(vtx_{LLP}) < 0.05$ & $\sigma_z(vtx_{LLP}) < 0.24$

and we predict $\varepsilon = (0.38 \pm 0.02)\%$ for the BV48 MC.

No data event survives the final selection.

[LHCb-CONF-2012-014]

Efficiencies

Detection efficiency of BV48 LLP candidates:

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 $\Delta\phi > 2.8$ to reduce backgrounds

Systematics

Systematic uncertainties on the Higgs detection efficiency, estimated from MC-data comparisons:

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 bb(bar) events with relaxed cuts.

Vertex reconstruction: account for differences in vertex resolution between data and MC.

Results

95% CL upper limits

MC efficiencies for other BV sets:

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

The mSUGRA model BV48 with $m\left(h^0\right)=114\,\mathrm{GeV/c^2}$, $m\left(\tilde{\chi}^0\right)=48\,\mathrm{GeV/c^2}$, $\tau\left(\tilde{\chi}^0\right)=10\,\mathrm{ps}$

gives $\sigma\left(h^0\right)\times BR\left(h^0\rightarrow 2LLPs\right)<32\,\mathrm{pb}$ @ 95% CL.

The predicted number of BV48 events in 35.8 pb^{-1} is 2.

Results

Use a fast simulation of the LHCb detector to extrapolate the results to a larger region of the parameter phase space of the theoretical models:

- Generate charged particles and feed them to the vertex reconstruction algorithm
- Apply inefficiencies as function of vertex position
- Compare to the full simulation and tune it to get the right shape for the relevant distributions
- Extend results for different values of $m\left(h^0\right)$, $m\left(\tilde{\chi}^0\right)$ and $\tau\left(\tilde{\chi}^0\right)$

95% CL upper limit [pb]

LPP lifetime = 10 ps

m_{LLP} / m_{h^0}	30	35	40	48	55
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

HV10

Higgs mass = 114 GeV/c^2

m_{LLP} / τ_{LLP}	30	35	40	48	55
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

BV48

[LHCb-CONF-2012-014]

Next steps

- Most of the uncertainties are dominated by statistical uncertainties. Update results with the integrated luminosity from 2011 (1 fb^{-1}) and 2012 (2.2 fb^{-1}) => 90x more statistics!

- More inclusive analysis:
  - Single-vertex signatures
  - Specific searches for semileptonic decays

- Improve systematic uncertainties by adding 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

Conclusions

- A search was performed for a Higgs-like boson decaying to two long-lived particles in 35.8 pb^{-1} of 2010 data [LHCb-CONF-2012-014]
- The selection has been optimised to reject the dominant background components (detector material and bb(bar) events).
  No events passed our selection.
- An upper limit for the production cross-section of 32 pb @ 95% C.L. has been set for the specific model BV48: mSUGRA with baryon number violation ($m\left(h^0\right)=114\,\mathrm{GeV/c^2}$, $m\left(\tilde{\chi}^0\right)=48\,\mathrm{GeV/c^2}$, $\tau\left(\tilde{\chi}^0\right)=10\,\mathrm{ps}$).
- The result can be extended to other models using a fast simulation.
- A new result based on larger statistics and improved selection will be ready soon.