



SUSY(-like) searches at LHCb

Oscar Augusto on behalf of the LHCb Collaboration

CERN/CNPq attached to Liverpool

Implications of LHCb measurements and future prospects

CERN

13/10/16

Outlook

Introduction

- LHCb experiment

This talk will cover

- [arXiv:1609.03124](https://arxiv.org/abs/1609.03124) [hep-ex] (Submitted to the EPJ C) - Search for higgs-like bosons decaying into long-lived particles
- LHCb-PAPER-2016-047 in preparation - Search for exotic massive particles decaying semileptonically
- [Eur. Phys. J. C 75 \(2015\) 595](https://arxiv.org/abs/1508.07249) - Search for heavy charged long-lived particles using RICH
- LHCb-CONF-2016-006 - Search for the SM Higgs boson decaying in $b\bar{b}$ or $c\bar{c}$ in association with W or Z boson

Conclusion

LHCb experiment

[Int. J. Mod. Phys. A 30 \(2015\) 1530022](#)

Excellent vertex reconstruction

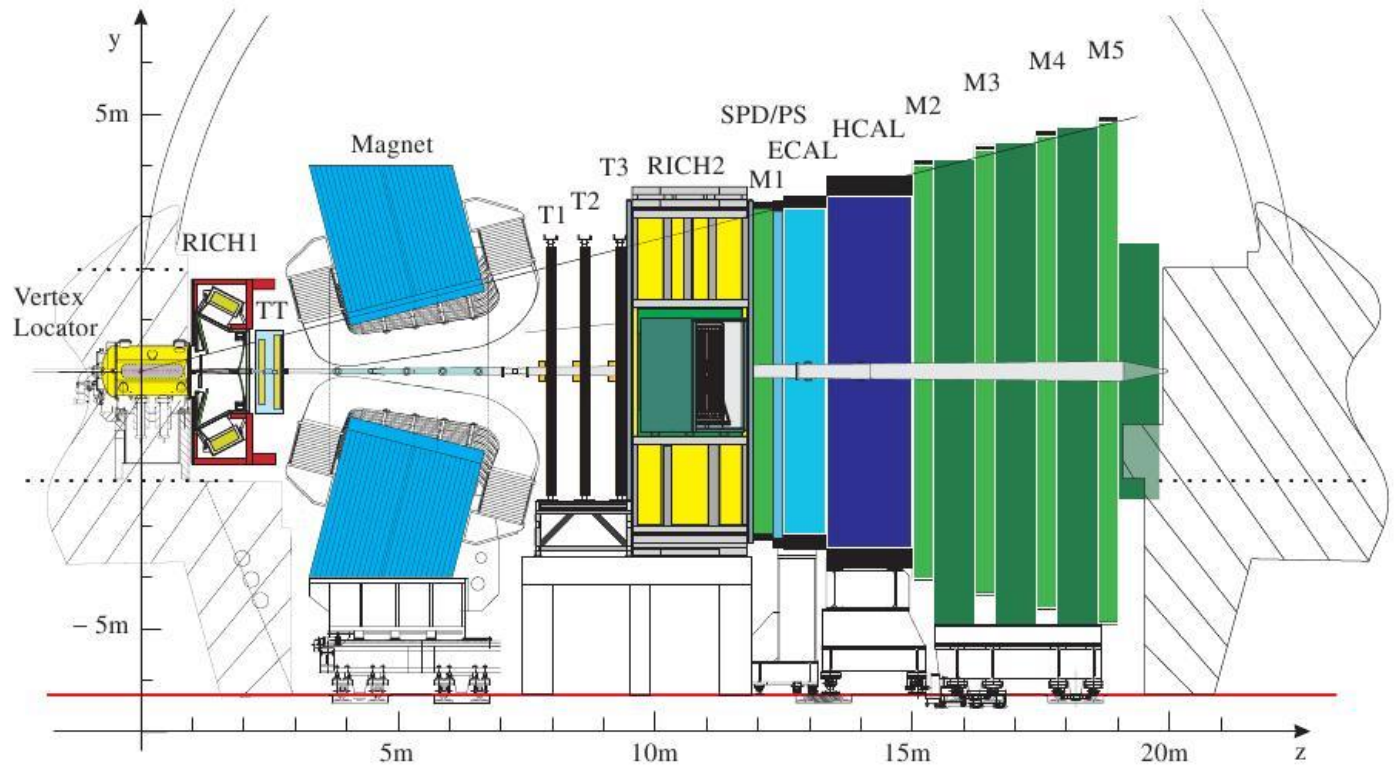
- for a primary vertex (PV) with 25 tracks:
 - $\sigma_{PV_Z} = 71 \mu\text{m}$
 - $\sigma_{PV_T} = 13 \mu\text{m}$

Great particle identification

Flexible trigger readout (Run III)

Luminosity collected in the Run I:

- $\sim 1 \text{ fb}^{-1}$ in 2011
- $\sim 2 \text{ fb}^{-1}$ in 2012



How long-lived?

- Up to $\sim 1\text{m}$, the decay will be inside the Vertex detector
- Up to $\sim 2\text{m}$, before the first tracking station (TT)
- More than $\sim 20\text{m}$, it will pass through all the detectors

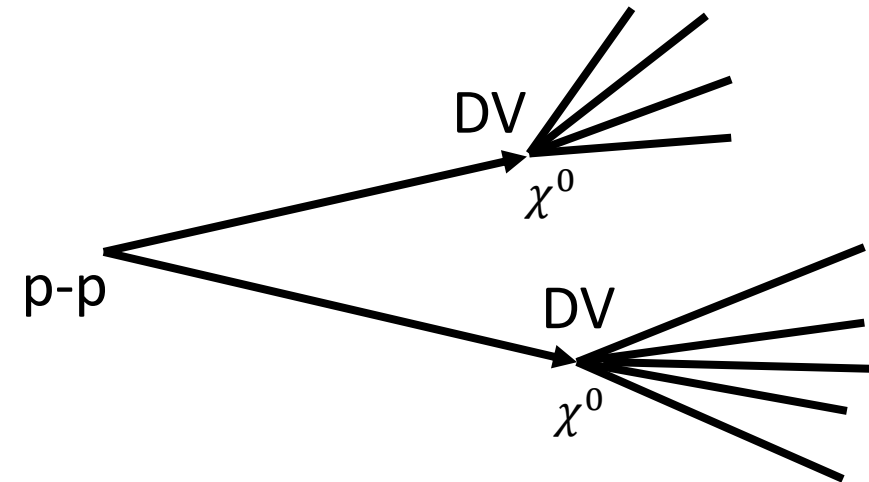
Search for higgs-like bosons decaying into long-lived particles

Benchmark model: MSSM mSUGRA with baryon number violation
[JHEP 10 (2007) 056, JHEP 07 (2012) 149]

The small baryon violation allow the lightest supersymmetric particle to decay to standard model particles ($\chi^0 \rightarrow q\bar{q}\bar{q}$)

The topology considered is $h^0 \rightarrow \chi^0\chi^0$ where the χ^0 is the LLP

Search based on the reconstruction of the displaced vertex



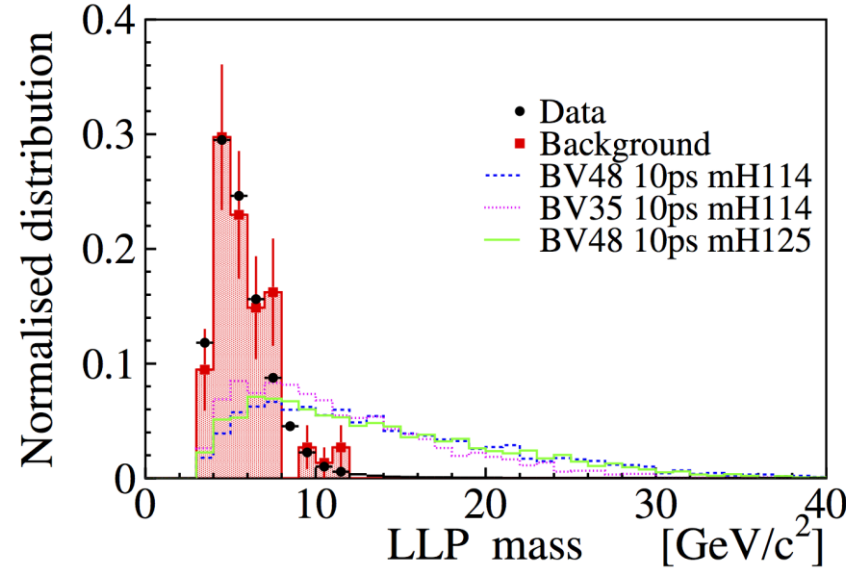
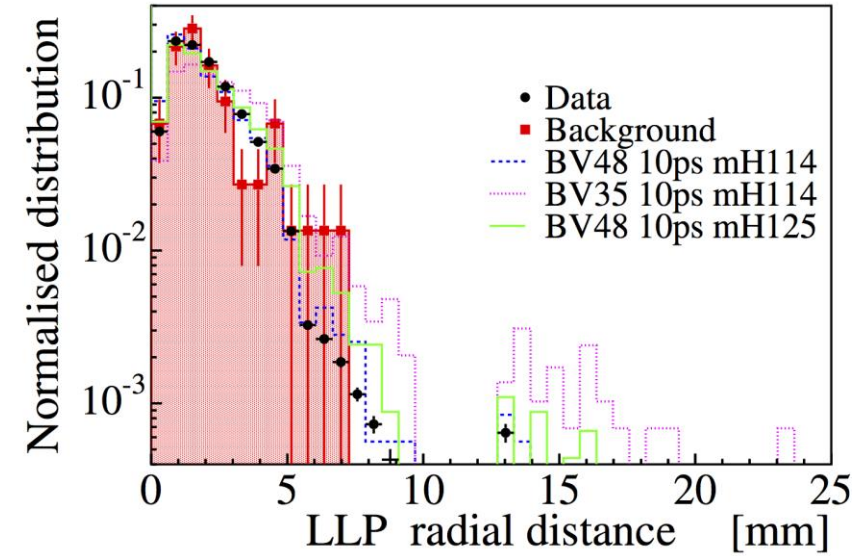
Search strategy

- Higgs mass particle from 80 GeV to 140 GeV
- $\tau_{LLP} = 5-100$ ps (up to 30 cm flight distance in average)
- $M_{LLP} = 20 - 60$ GeV

Search for higgs-like bosons decaying into long-lived particles

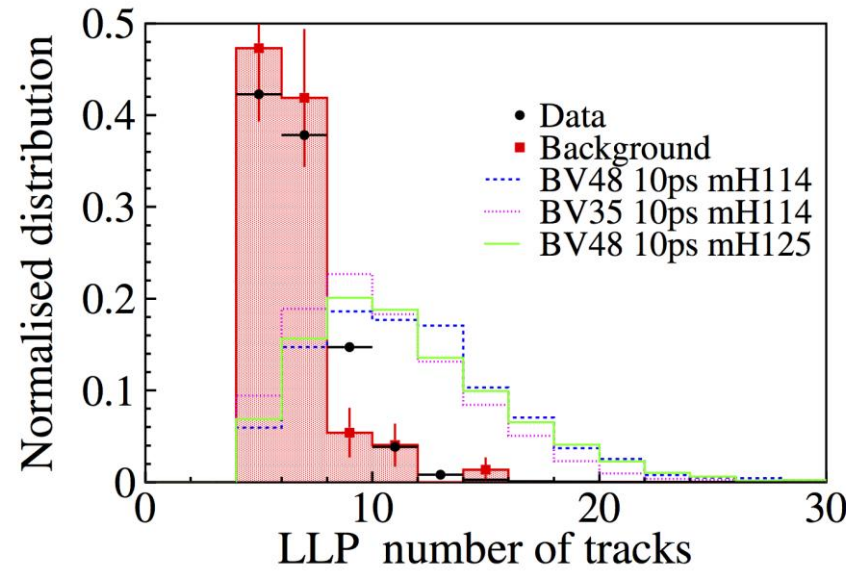
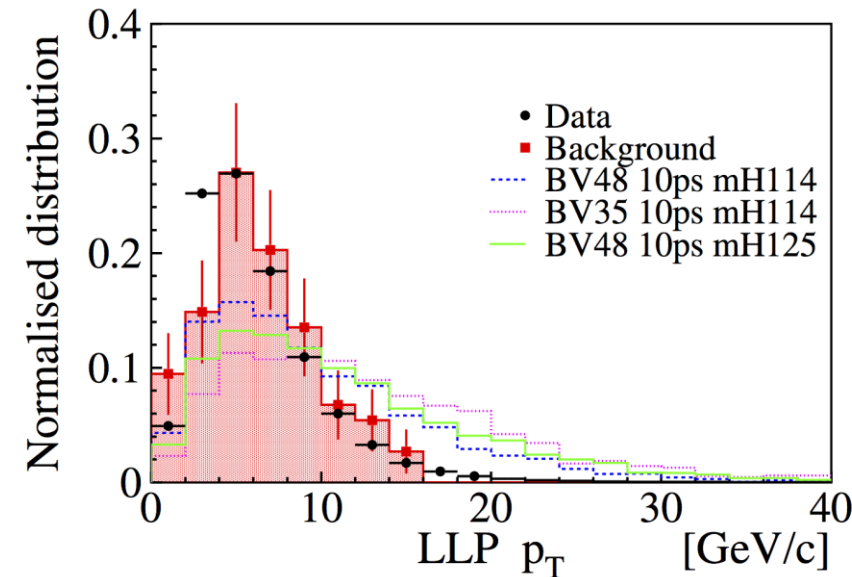
[arXiv:1609.03124](https://arxiv.org/abs/1609.03124) [hep-ex]

Submitted to EPJ C



Main source of background comes from $b\bar{b}$ events

The observed yield corresponds to 1.8 ± 0.5 times the expected yield using the $b\bar{b}$ cross section measured at the LHCb ($288 \pm 4 \pm 48 \mu\text{b}$).

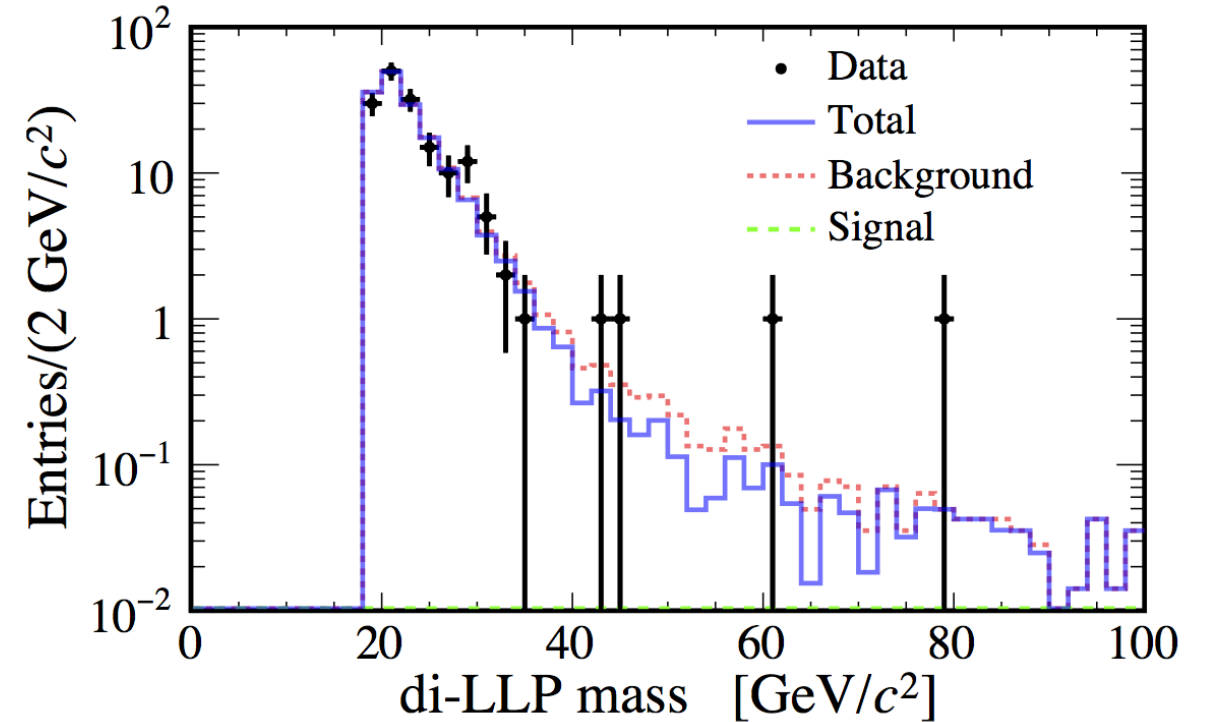
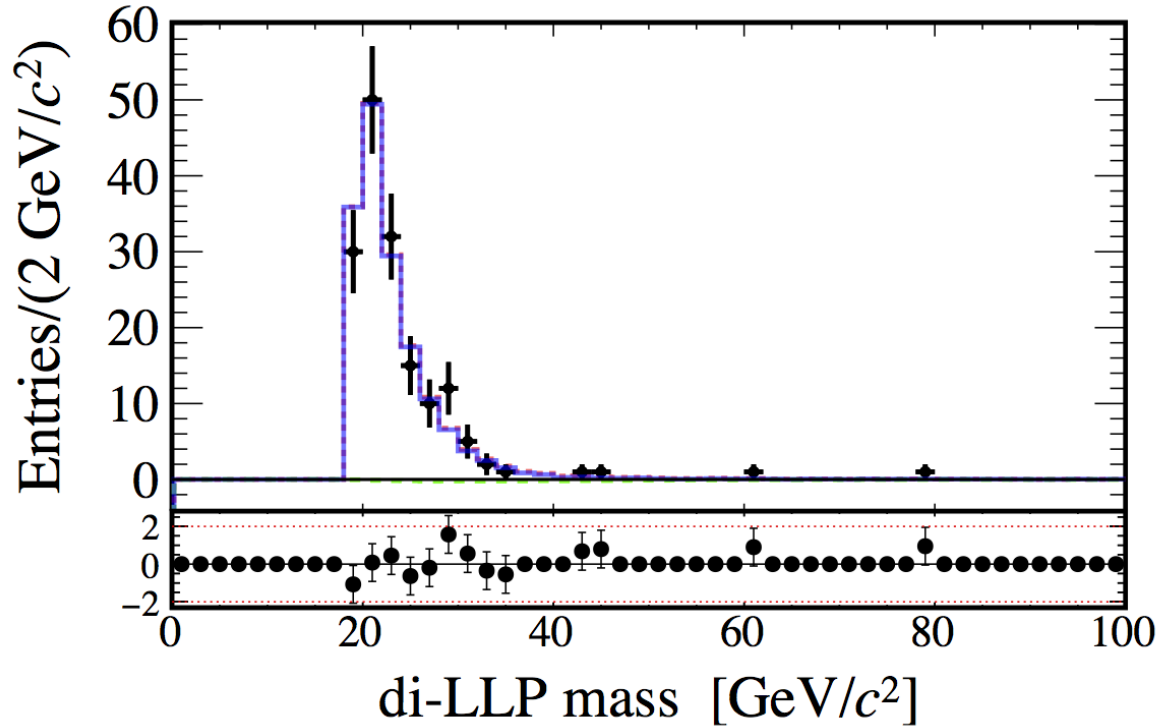


Only 37 events survives the preselection of $17.1 \times 10^6 b\bar{b}$ events which corresponds to an integrated luminosity of 0.3 pb^{-1} .

Search for higgs-like bosons decaying into long-lived particles

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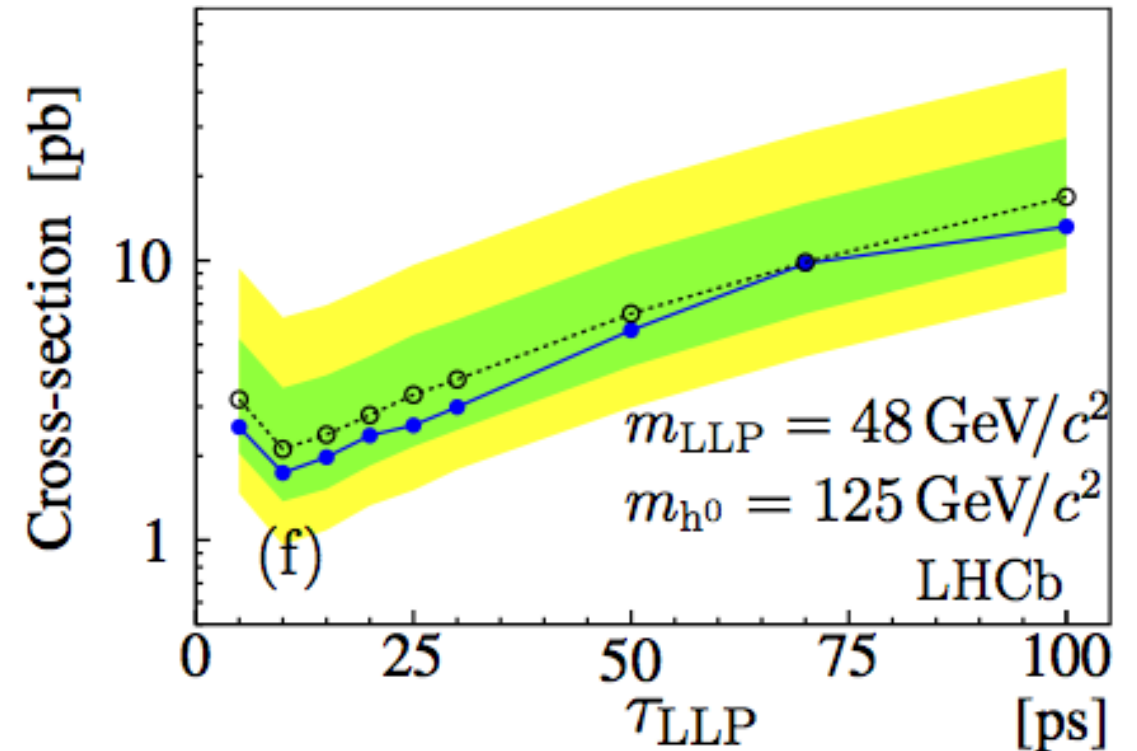
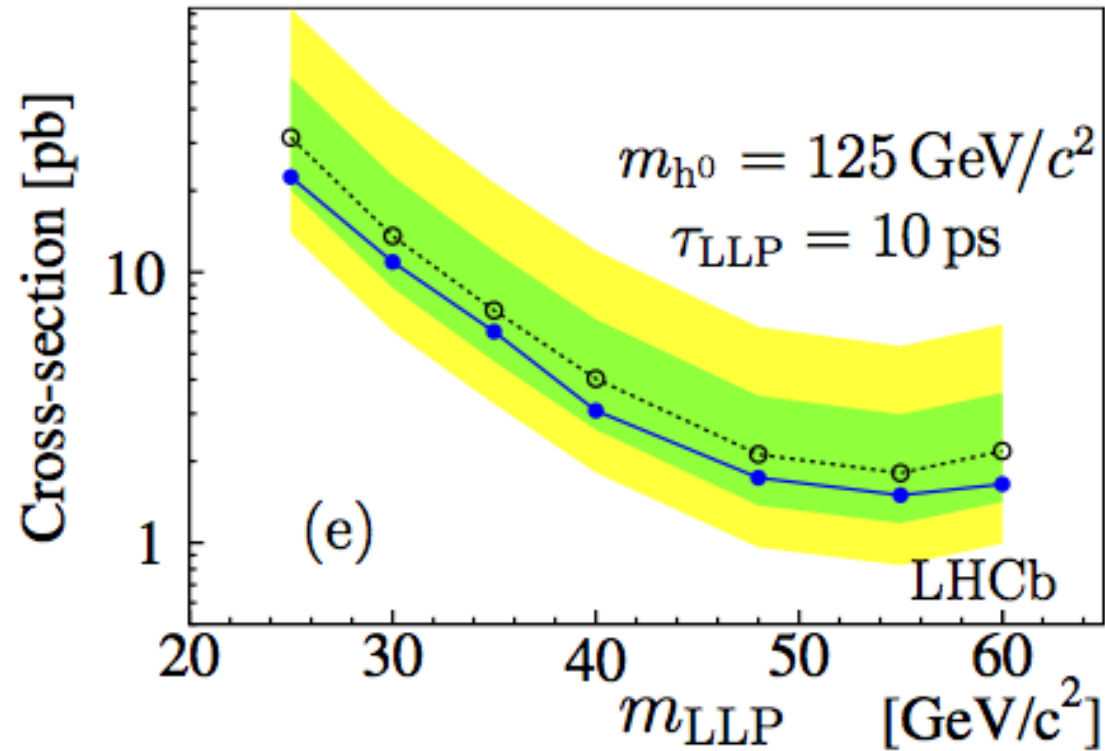


Selection	N_{track}^{min}	m_{min}^{LLP} [GeV]	σ_{max}^R [mm]	σ_{max}^Z [mm]
Final	6	6	0.05	0.25
Background from data	4	4	-	-

Search for higgs-like bosons decaying into long-lived particles

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Submitted to EPJ C



Search for exotic massive particles decaying semileptonically

LHCb-PAPER-2016-047
In preparation

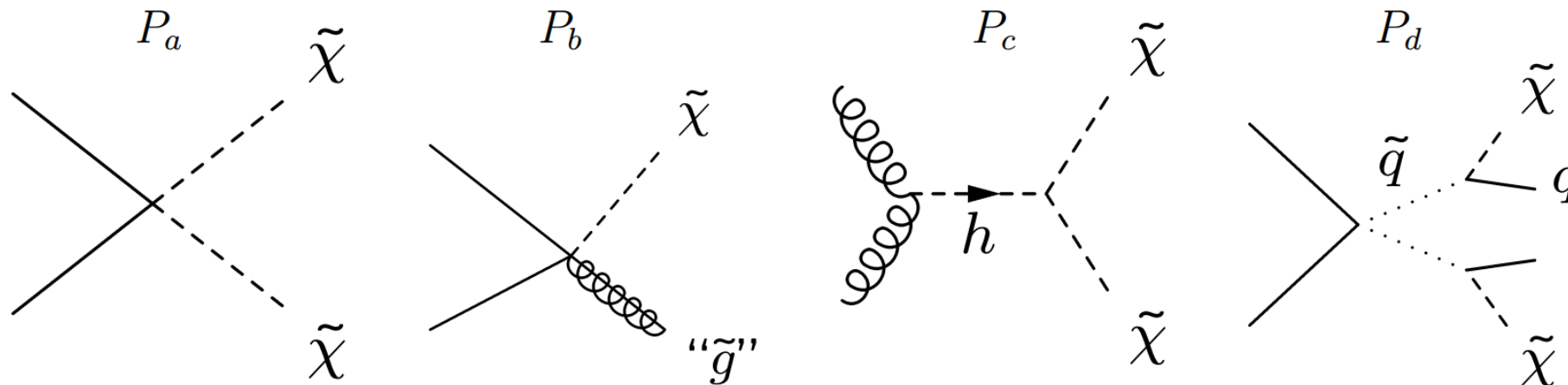
Benchmark model: MSSM mSUGRA with R-parity violation
[Phys. Rev. D69 (2014) 115002]

The neutralino is a LLP that decays into $\chi^0 \rightarrow lq\bar{q}$

Four productions mechanisms are considered

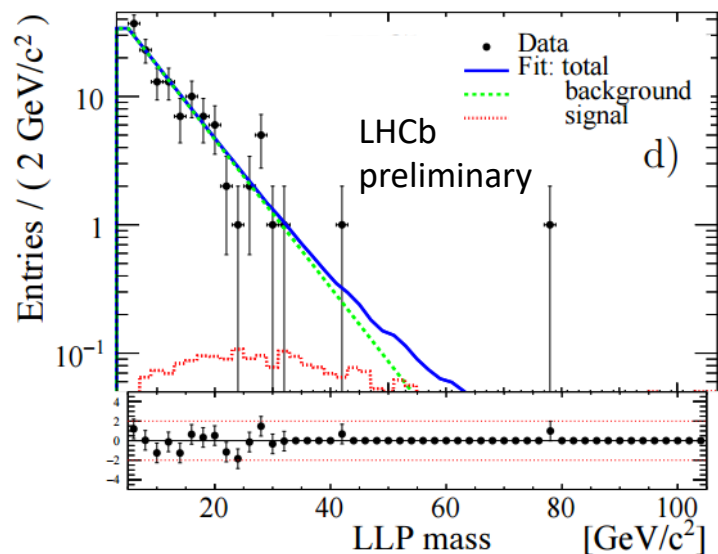
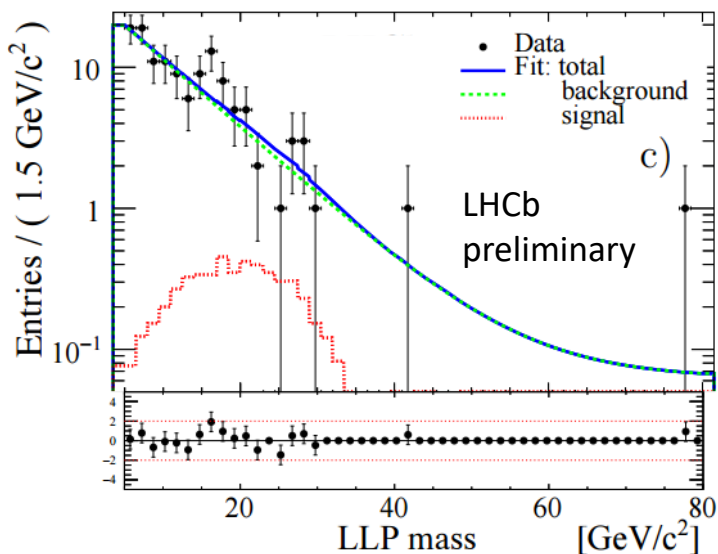
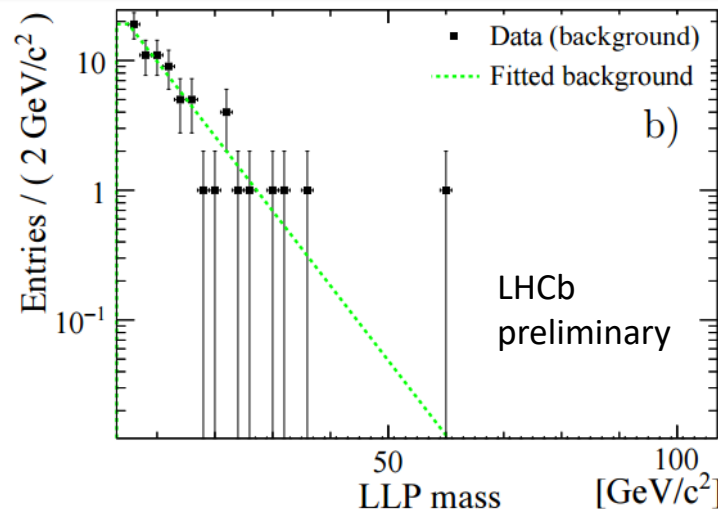
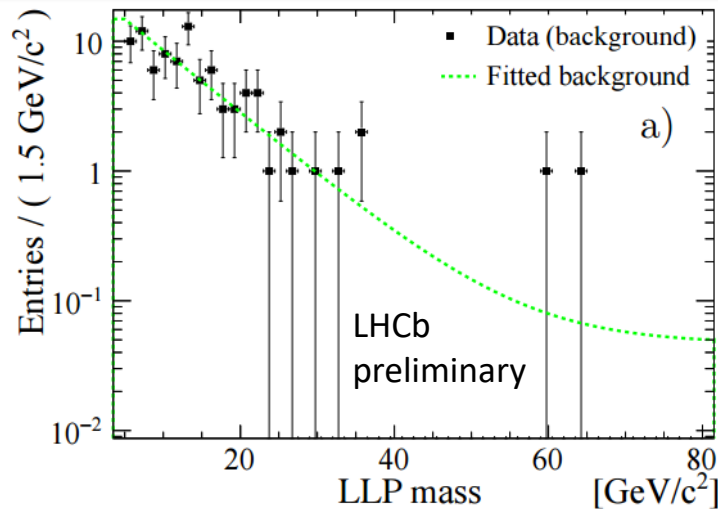
Search strategy

- Displaced vertex reconstruction
- Higgs mass particle from 50 GeV to 130 GeV
- $\tau_{LLP} = 5\text{--}100$ ps (up to 30 cm flight distance in average)
- $M_{LLP} = 20 - 200$ GeV



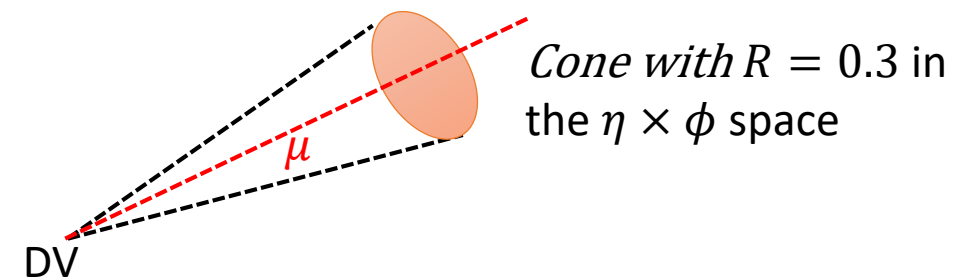
Search for exotic massive particles decaying semileptonically

LHCb-PAPER-2016-047
In preparation



MVA (NN) is used to purify the data with the inputs: σ_{DVR} , σ_{DVZ} , $p_{T\mu}$, $IPPV_{\mu}$ and R_{DV}

Data-driven method to obtain the shape of the background based in the muon isolation



$$I_{\mu} = E_{\mu} / E_{tracks} \text{ in } R < 0.3$$

Background selection: $1.4 < I_{\mu} < 2$

Signal selection: $I_{\mu} > 1.4$

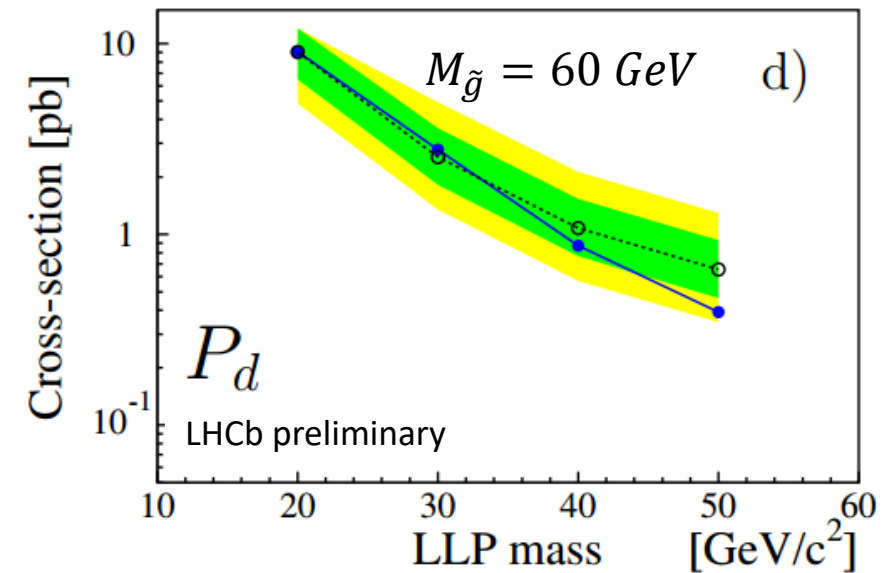
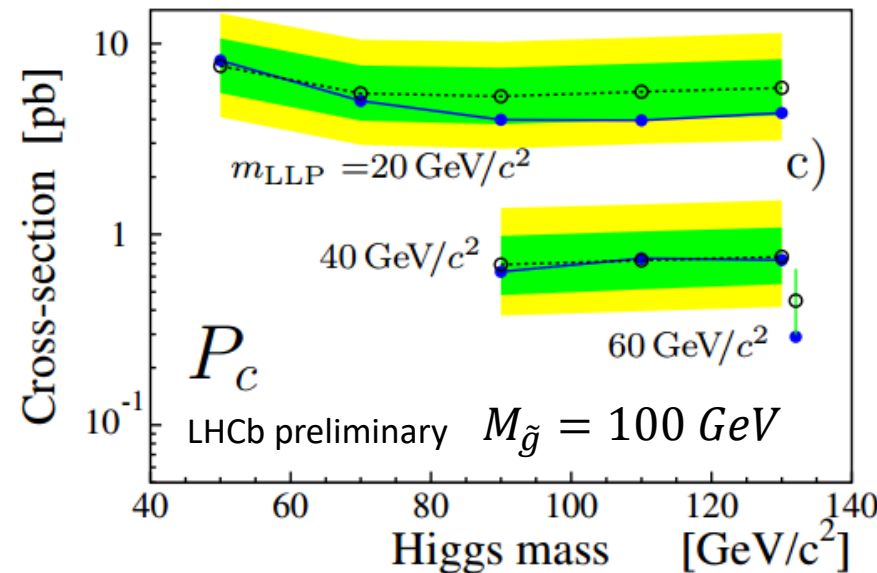
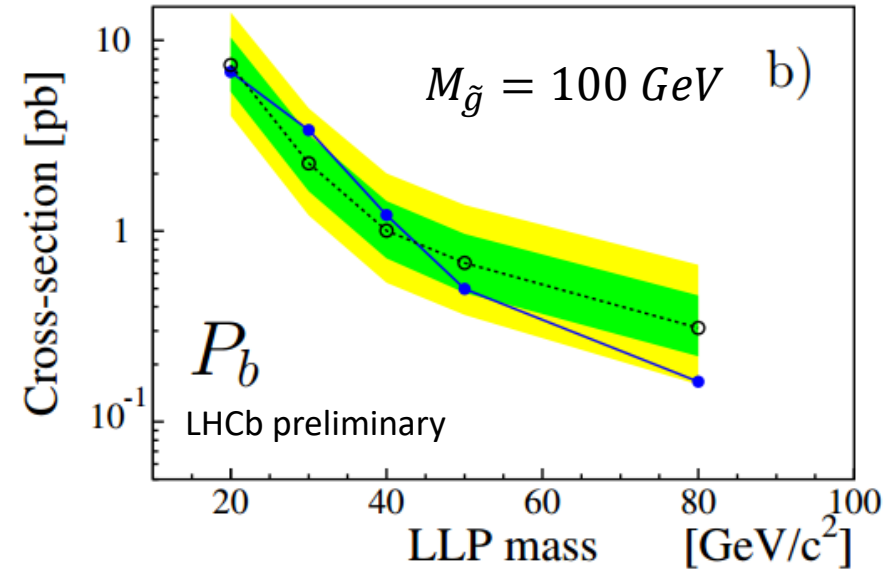
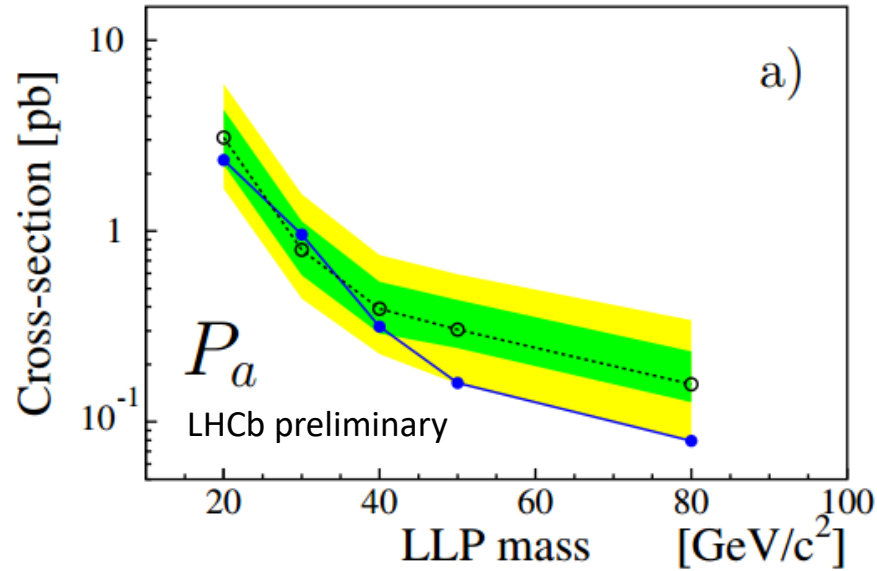
Pre-selection: $p_{T\mu} > 12.5 \text{ GeV}$

$IPPV_{\mu} > 0.25 \text{ mm}$

All signal yields are compatible with zero.

Search for exotic massive particles decaying semileptonically

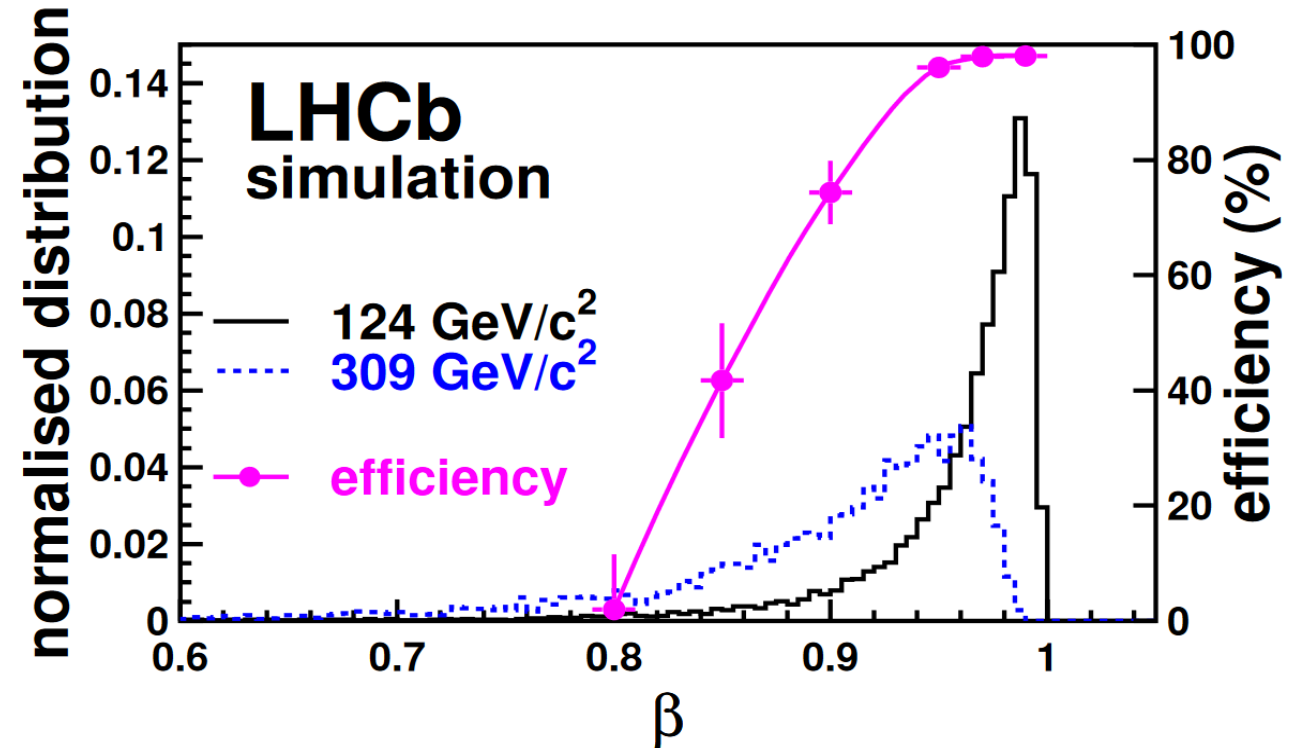
LHCb-PAPER-2016-047
In preparation



Search for heavy charged long-lived particles using RICH

- Benchmark model: minimal gauge-mediated supersymmetry breaking (mGMSB SPS7)
[arXiv:hep-ph/9609434 , arXiv:hep-ph/9801271, arXiv:hep-ph/0202233v1]
- For a particular range of parameter the next-to-LSP can be a long-lived $\tilde{\tau}$ with a mass of order of 100 GeV
- LLP is charged massive stable particle (CMSP) that can travel through all detectors without decaying
- This analysis considers that the CMSP is produced by a Drell-Yan mechanism

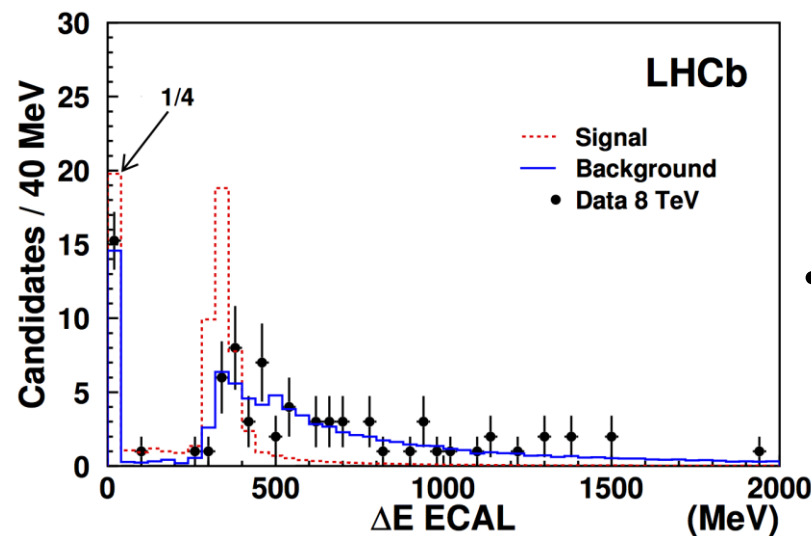
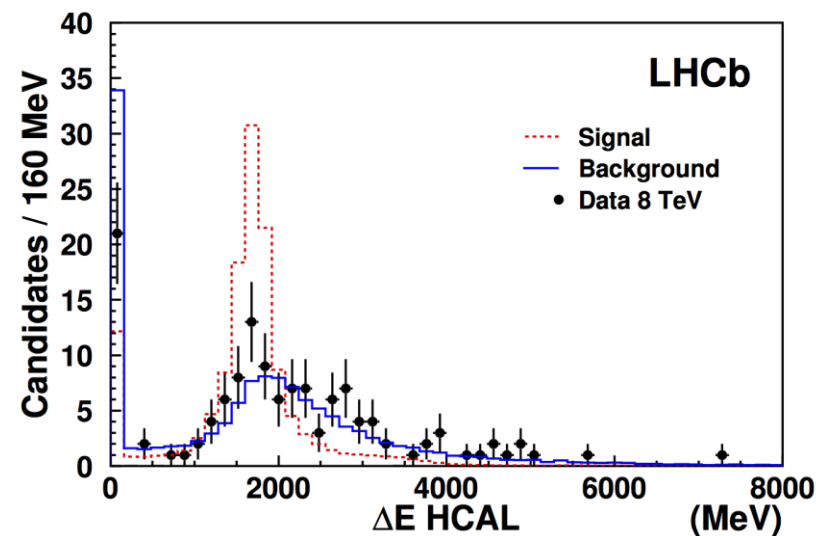
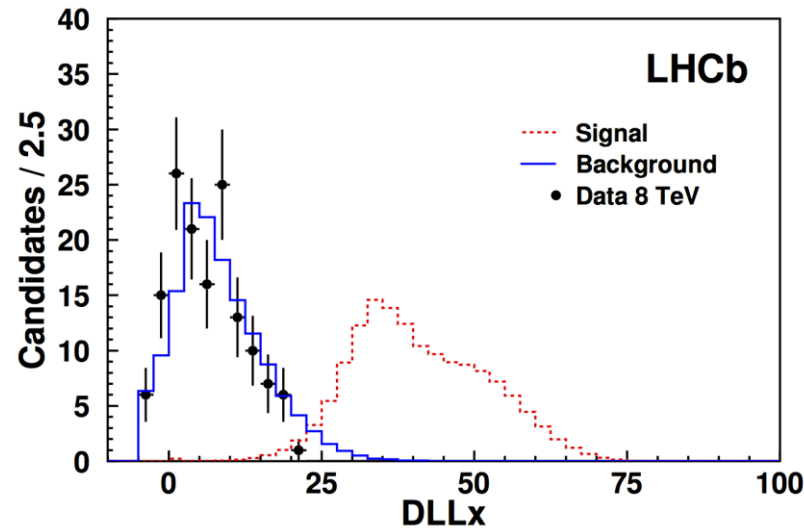
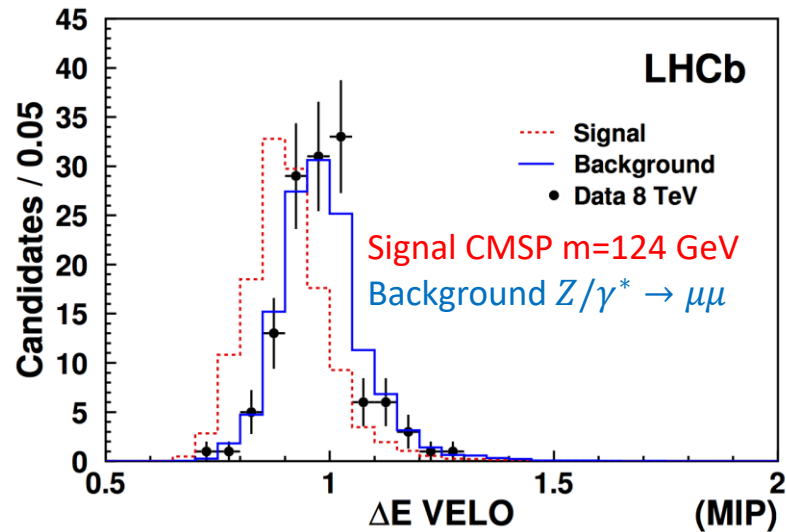
Track reconstruction efficiency



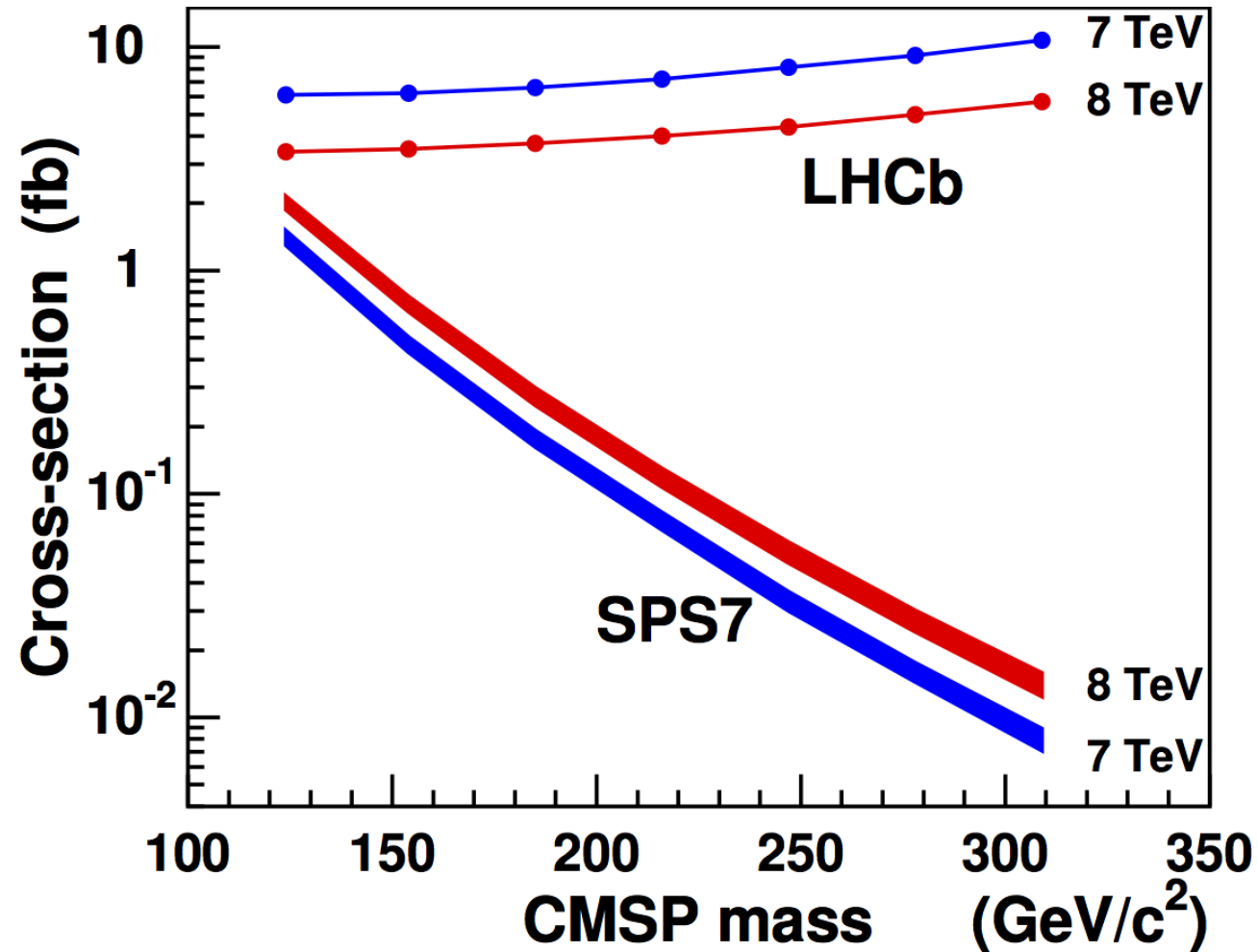
The efficiency drops to nearly zero for values below $\beta < 0.8$. The delay in this case becomes ~ 12.5 ns for the last muon chamber.

Search for heavy charged long-lived particles using RICH

- Only candidates with momenta above 200 GeV are considered
- DLLx was designed to identify high momentum particles that don't radiate in the RICHs or have a small radiation angle that doesn't fit with the p , π , e , μ and K hypothesis
- High DLLx indicates that the candidates has relatively low velocity
- Most discriminant variable
- These four variables are inputs to an Artificial Neural Network (ANN)
 - optimized to achieve 95% efficiency in the final selection



Search for heavy charged long-lived particles using RICH

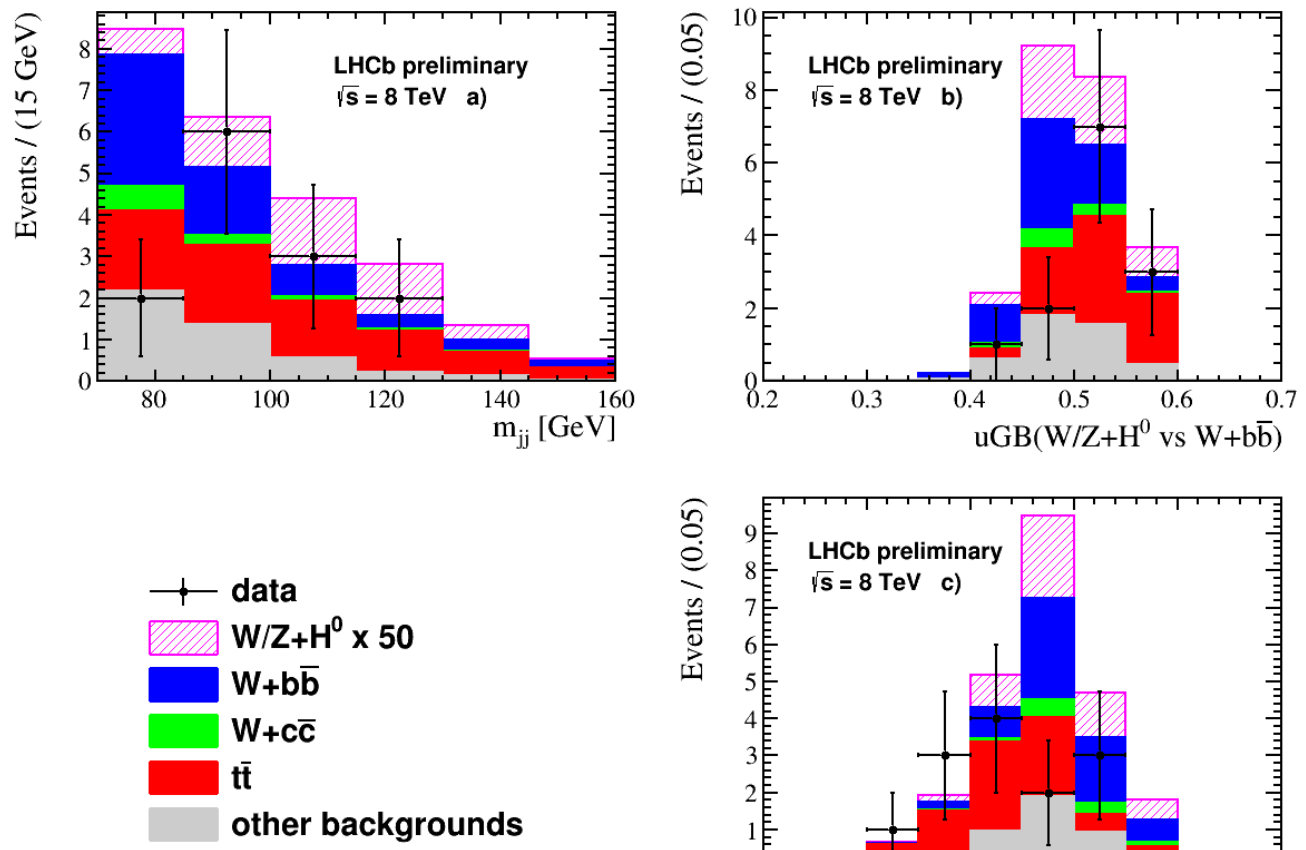


- 95% CL on the cross section pair production of CMSPs in the LHCb acceptance

Search for the SM Higgs boson decaying in $b\bar{b}$ or $c\bar{c}$ in association with W or Z boson

- Extension of the $t\bar{t}$, $W + b\bar{b}$ and $W + c\bar{c}$ analysis (See Katharina's talk for more details)
- Enhanced $H(c\bar{c})$ might be a source of new physics
- Additional requirements:
 - Z/W decays into muons or electrons
 - **20 GeV < p_T^J**
 - 70 GeV < M_{jj} < 150 GeV (Higgs mass window)
 - Isolated leptons and jets ($\Delta R > 0.5$)
- For the Z/W+H($c\bar{c}$), an additional requirement is applied to the BDT(**b|c**)
 - ~90% of Z/W + H($b\bar{b}$) is removed
 - ~60% of Z/W + H($c\bar{c}$) is retained
- No significant excess was found with respect to the backgrounds
- The limits were set:
 - $\sigma[WZ + H^0(c\bar{c})] < 9.4 \text{ pb at } 95 \% \text{ CL } (6200 \times SM)$
 - $\sigma[WZ + H^0(b\bar{b})] < 1.6 \text{ pb at } 95 \% \text{ CL } (50 \times SM)$

Z/W+H($b\bar{b}$) distributions with μ in the final state



Conclusion

LHCb

- Efficient displaced vertex reconstruction
 - Complementary region with respect to ATLAS and CMS
- Good particle identification
 - Additional suggestions are welcome! 😊
- Powerful heavy jet tagging

More analysis at LHCb

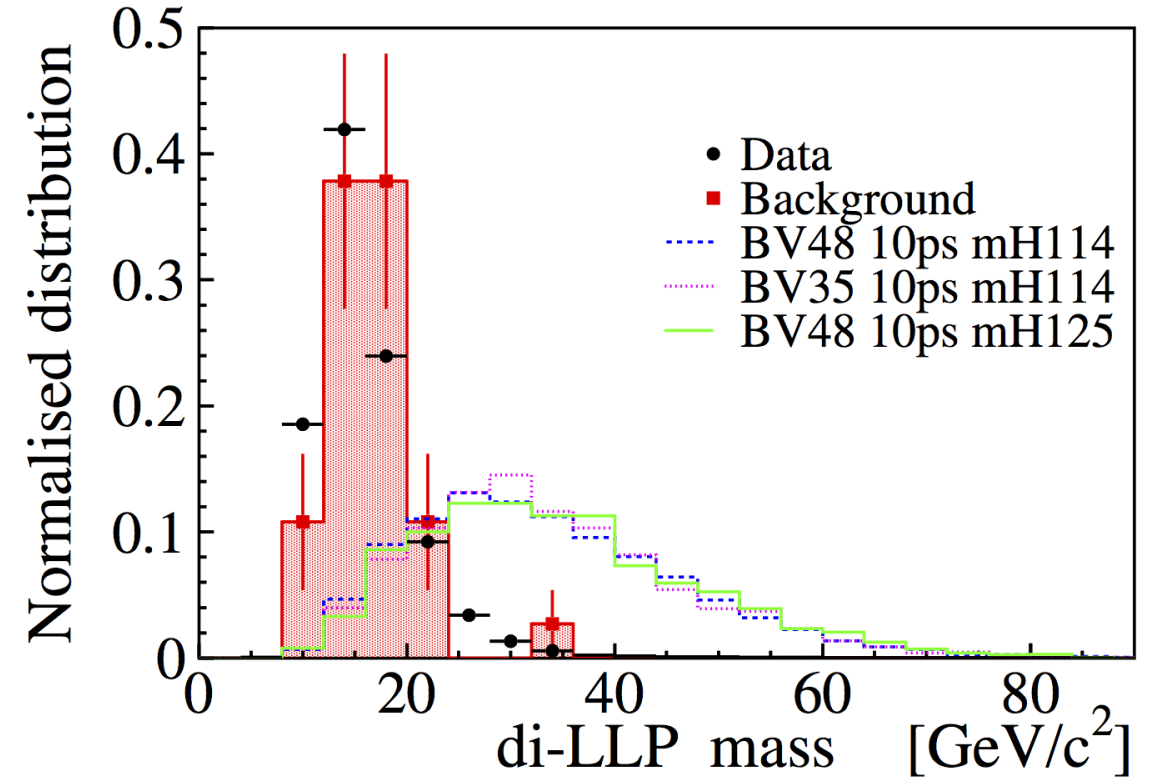
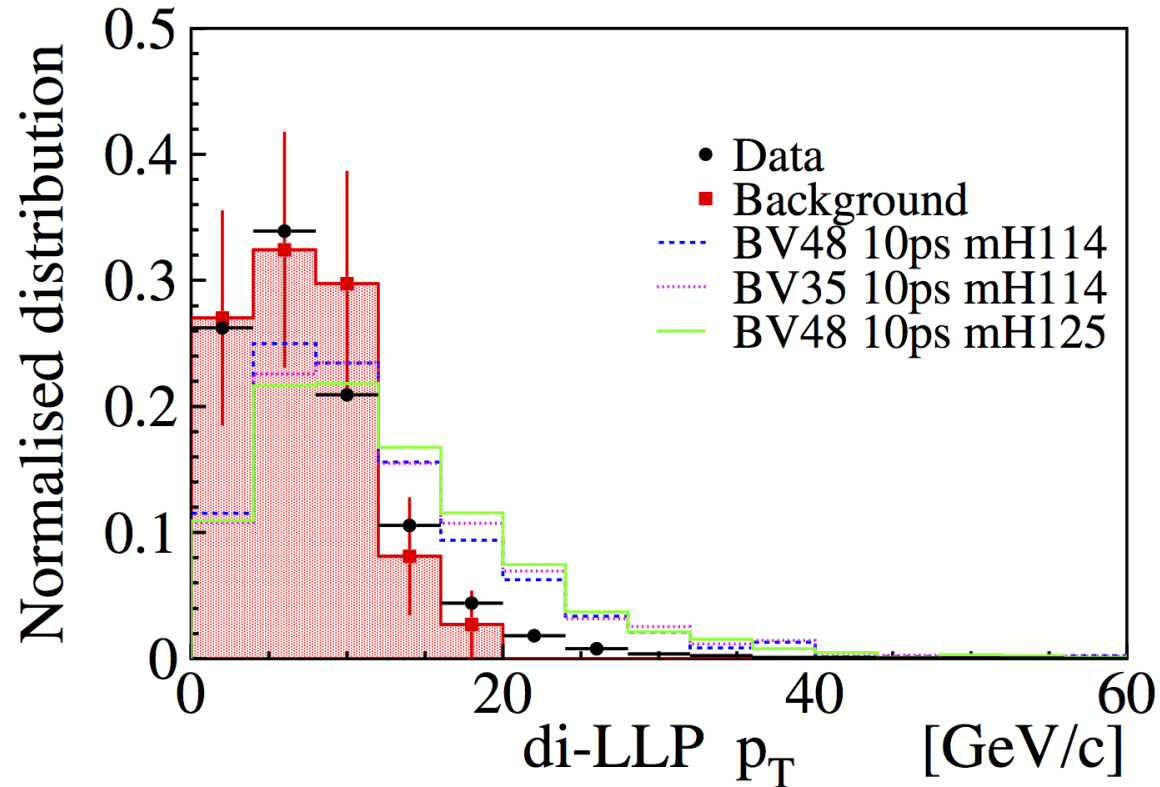
- [Eur. Phys. J. C 75 \(2015\) 152](#) - Search for long-lived particles decaying to jet pairs (Update on going)
- [Phys. Lett. B 724 \(2013\) 36-45](#) - Searches for violation of lepton flavour and baryon number in tau lepton decays at LHCb

More data to come

- $\sim 5 \text{ fb}^{-1}$ in Run II
- 50 fb^{-1} in Run III (will start in 2021 after the LHCb Upgrade)

Backup slides

Search for higgs-like bosons decaying into long-lived particles



Search for higgs-like bosons decaying into long-lived particles

- Benchmark model: MSSM mSUGRA with baryon number violation

[JHEP **10** (2007) 056, JHEP **07** (2012) 149]

- $h^0 \rightarrow \chi^0 \chi^0$ with $\chi^0 \rightarrow q\bar{q}\bar{q}$
- χ^0 is an LLP
- $\sim 70\%$ contains a b quark in the decay
- Higgs mass particle from 80 GeV to 140 GeV
- $\tau_{LLP} = 5\text{--}100$ ps (up to 30 cm flight distance in average)
- $M_{LLP} = 20 - 60$ GeV

Event selection:

At least one PV and two LLP candidates

LLP selection:

At least 4 forward tracks

No backwards tracks

$M_{LLP_1} > 3.5$ GeV

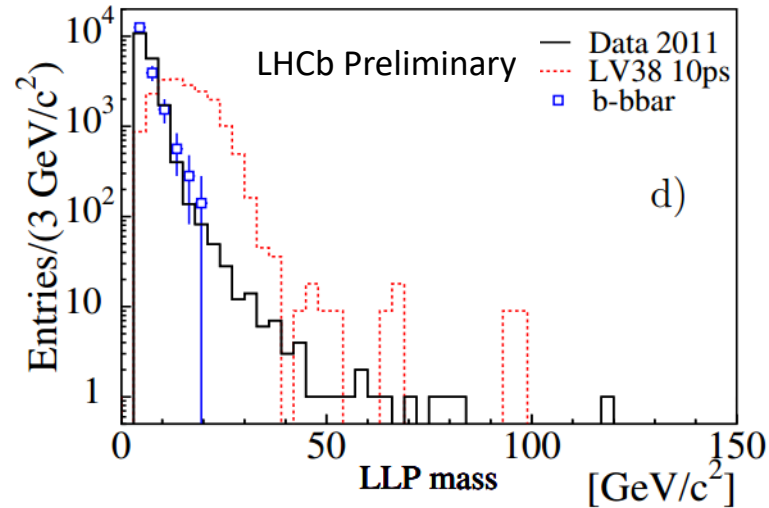
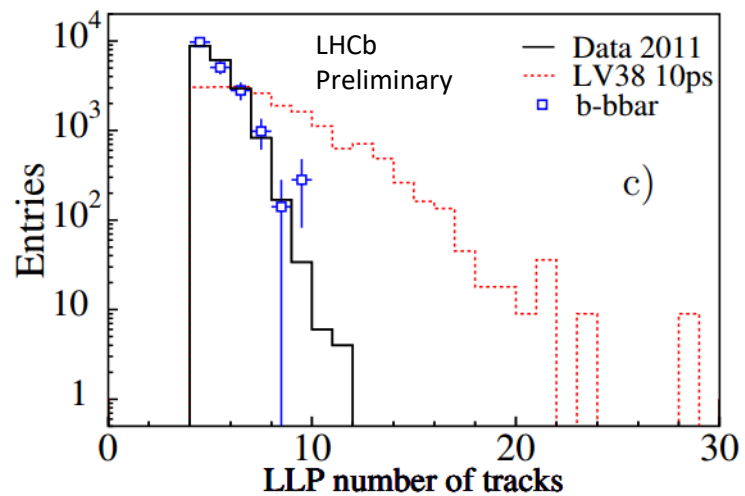
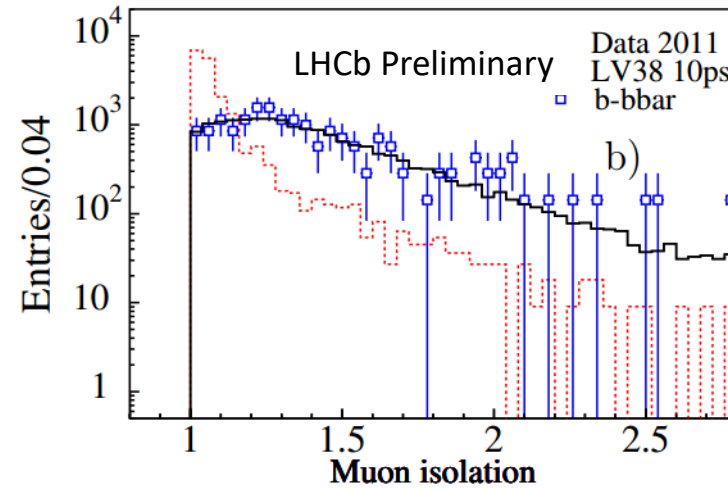
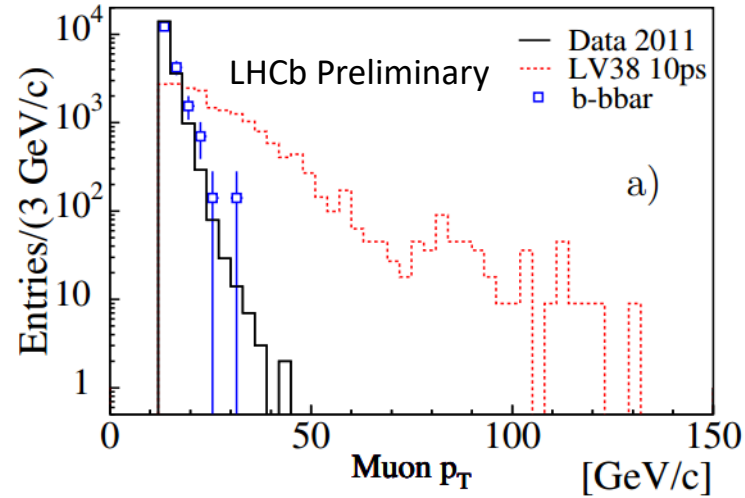
$M_{LLP_2} > 4.5$ GeV

Two $R_{xy_LLP} > 0.4$ mm

Pass the material veto

Search for exotic massive particles decaying semileptonically

LHCb-PAPER-2016-047
In preparation



Search for heavy charged long-lived particles using RICH

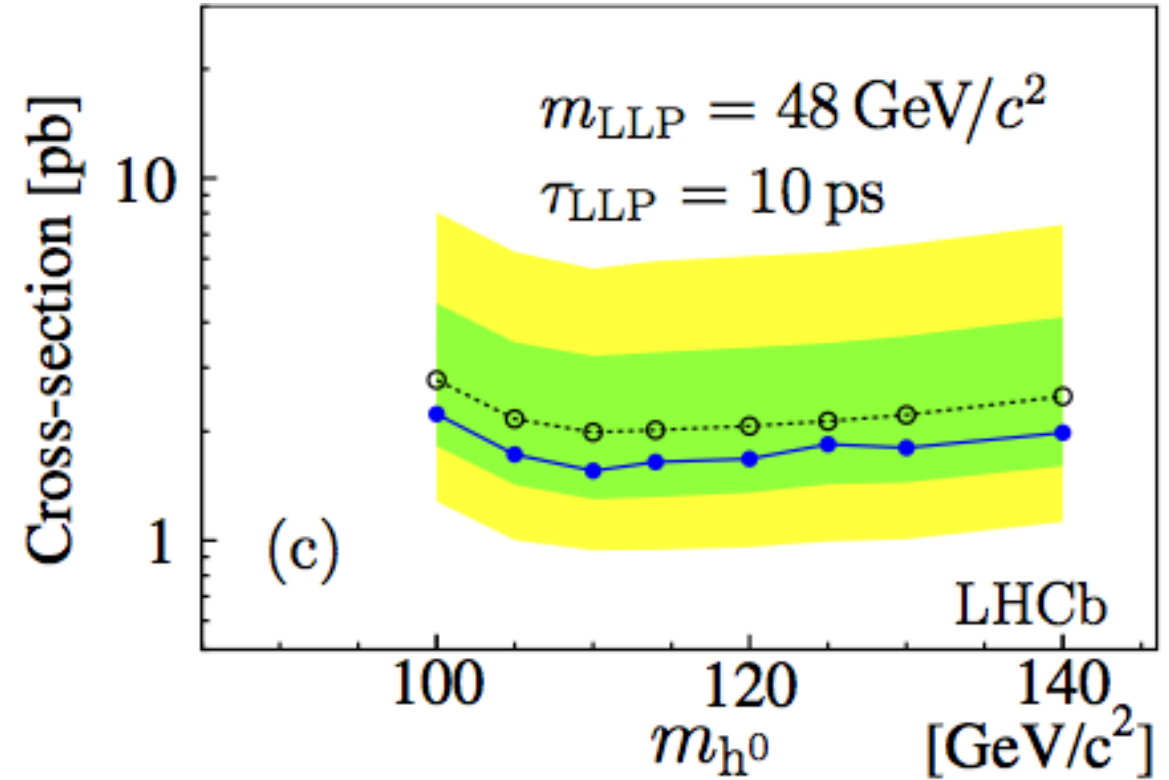
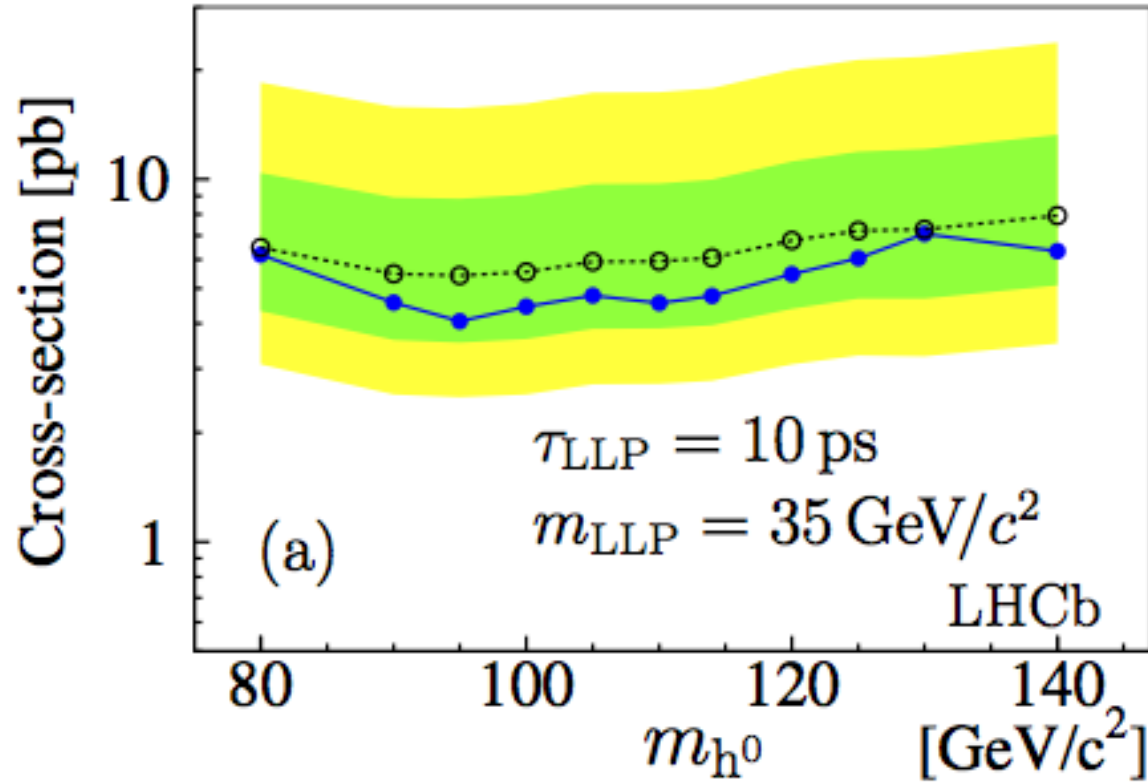
Table 3: Refractive indices and Cherenkov β thresholds for the three radiators. The momentum threshold is given for muons, protons, and 124 and 309 GeV/c² CMSPs.

Radiator	n	β_{thresh}	p_{thresh} (GeV/c)			
			μ	p	CMSP(124)	CMSP(309)
Aerogel	1.03	0.9709	0.428	3.8	502	1252
C ₄ F ₁₀	1.0014	0.9985	2.00	17.7	2342	5069
CF ₄	1.0005	0.9995	3.34	29.7	3921	9767

Search for higgs-like bosons decaying into long-lived particles

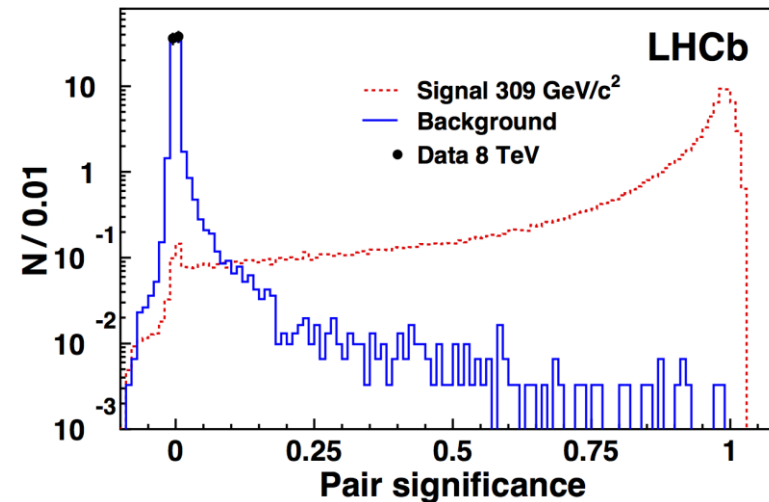
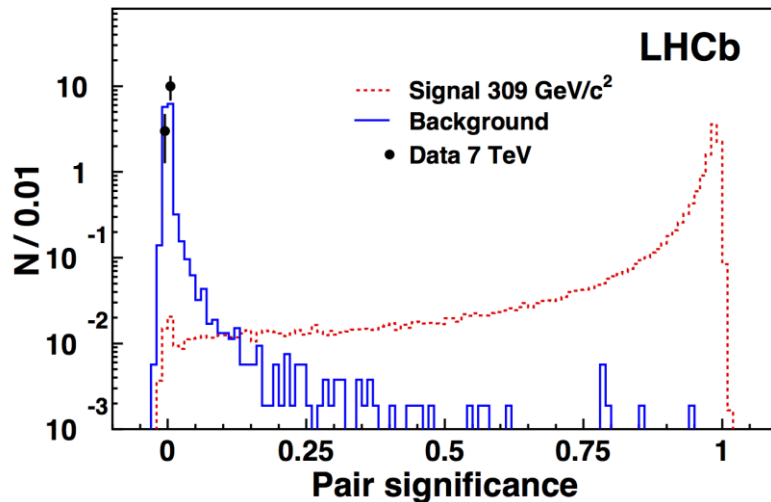
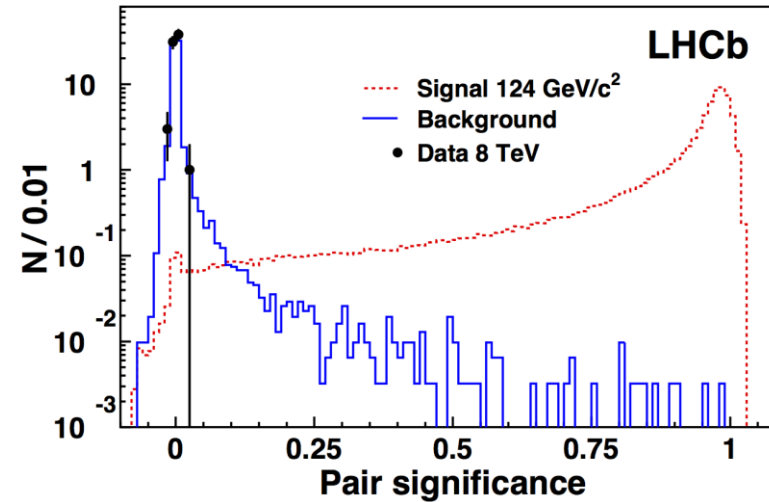
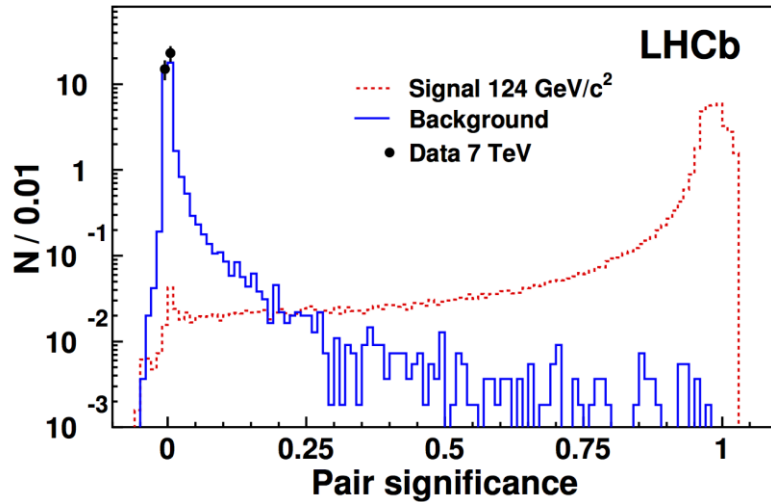
[arXiv:1609.03124](https://arxiv.org/abs/1609.03124) [hep-ex]

Submitted to EPJ C



For $m_{LLP} = 48$ GeV, the observed upper limit is smaller than 2 pb.

Search for heavy charged long-lived particles using RICH



- The pair significance is the product of the response from the ANN
- For the final selection, this value is optimized to achieve 95% efficiency in the final selection

Identification of beauty and charm quark jets at LHCb

[J. Instrum. 10 \(2015\) P06013](#)

Variables used for the BDT(bc|udgs) and BDT(b|c):

- the SV mass M
- the SV corrected mass (M_{corr})
- the transverse flight distance of the two-track SV closest to the PV
- the fraction of the jet p_T carried by the SV
- ΔR between the SV and the jet
- the number of tracks in the SV
- The number of tracks in the jet ($\Delta R < 0.5$)
- the net charge of the tracks that form the SV
- The flight distance χ^2
- The sum of all SV track $\chi^2 (IP)$

