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Inclusive search for Majorana Neutrinos at LHCb

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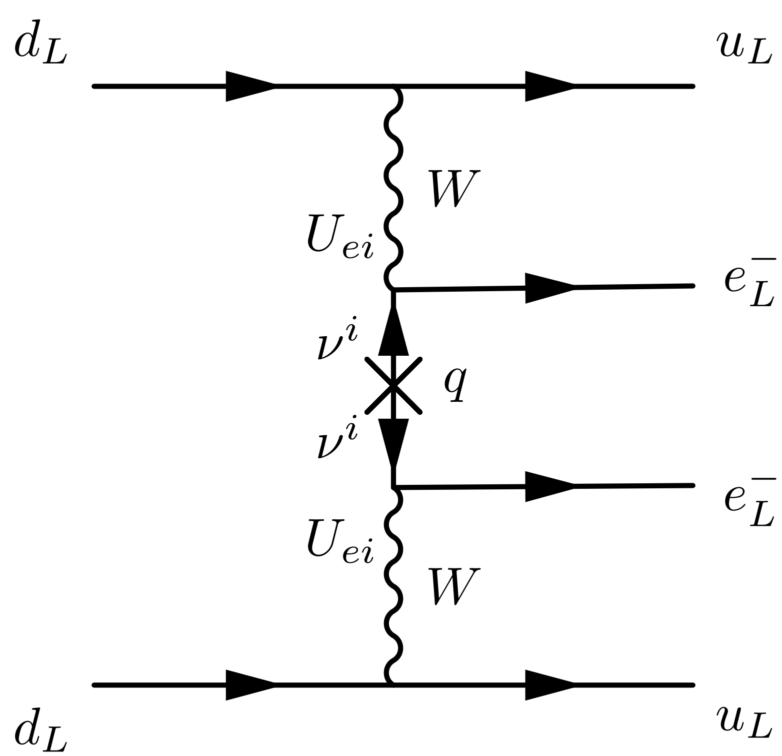
On behalf of the LHCb Collaboration

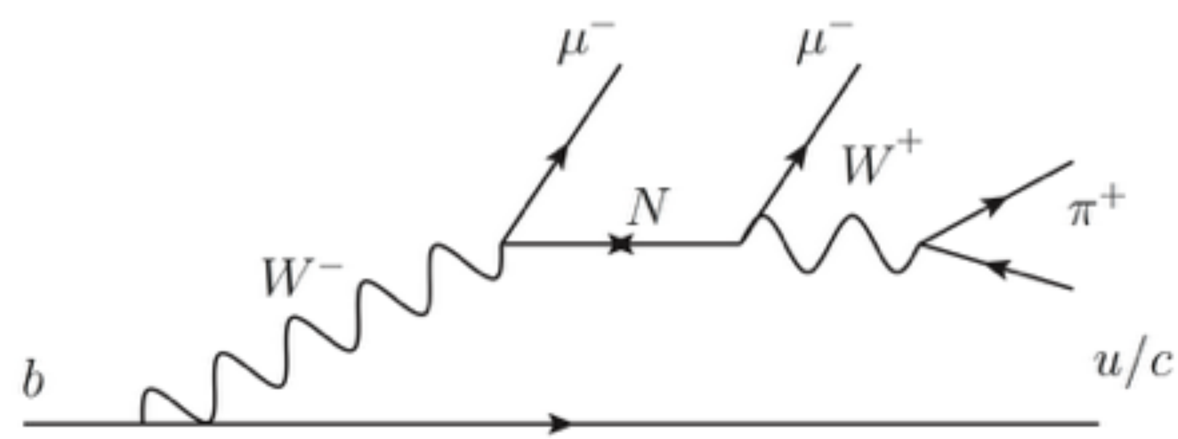
Institute of Physics
Joint annual HEPP and APP conference 2016

Motivation

Neutrinoless double beta decay



Heavy right handed neutrinos in *b* decays

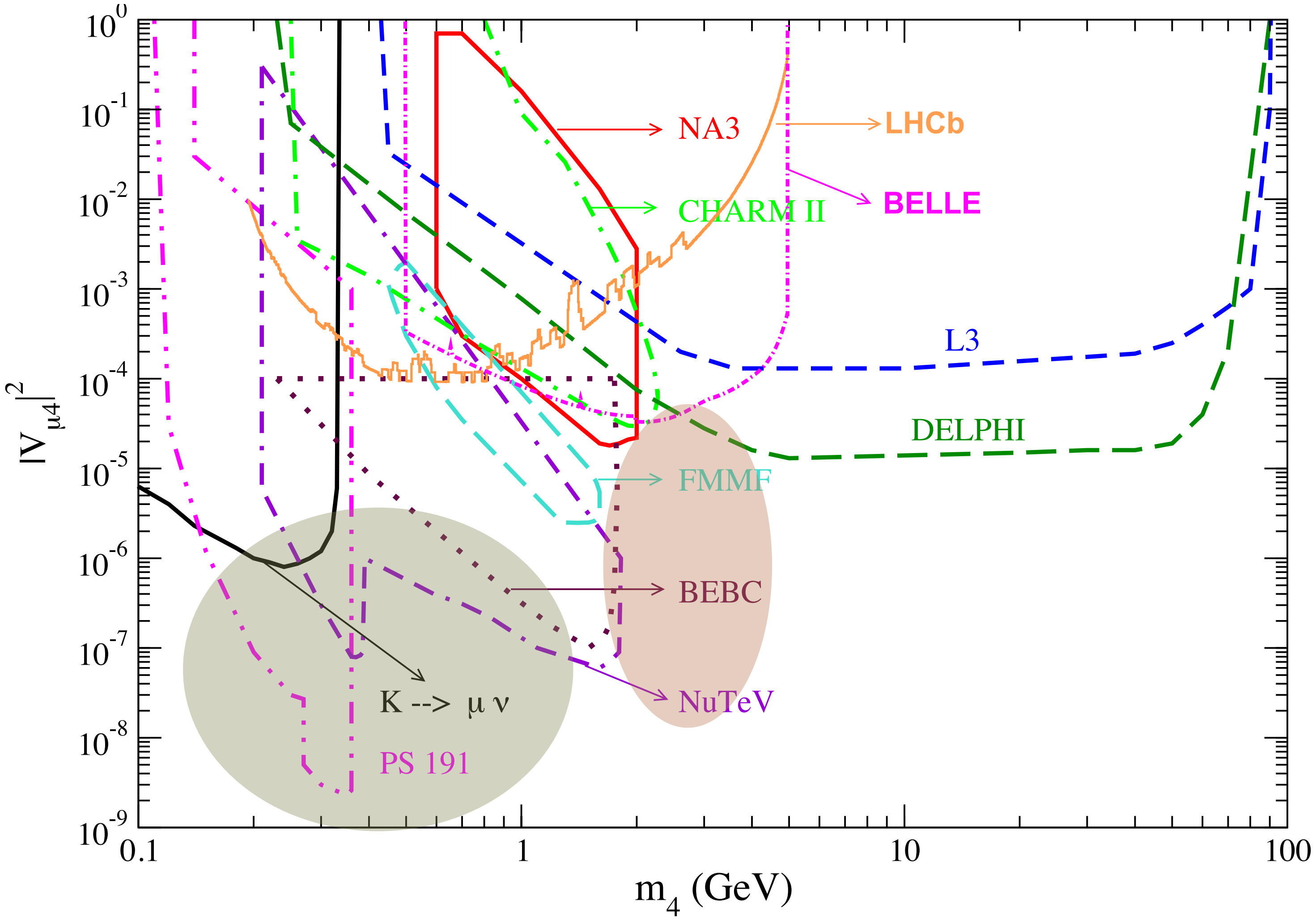


LHS fig. from New J.Phys. 17 (2015)

Present limits

- Search for new particle(s) that exist in addition to the SM neutrinos.
- Strong theoretical motivation backing this search: ***νMSM*** (Shaposhnikov *et.al.*).
- **LHCb** is only competitive in a region of phase space above charm mass.
- Next generation experiment **SHiP** focuses on neutrinos from charm to cover the *0.5 – 2.0 GeV* region.

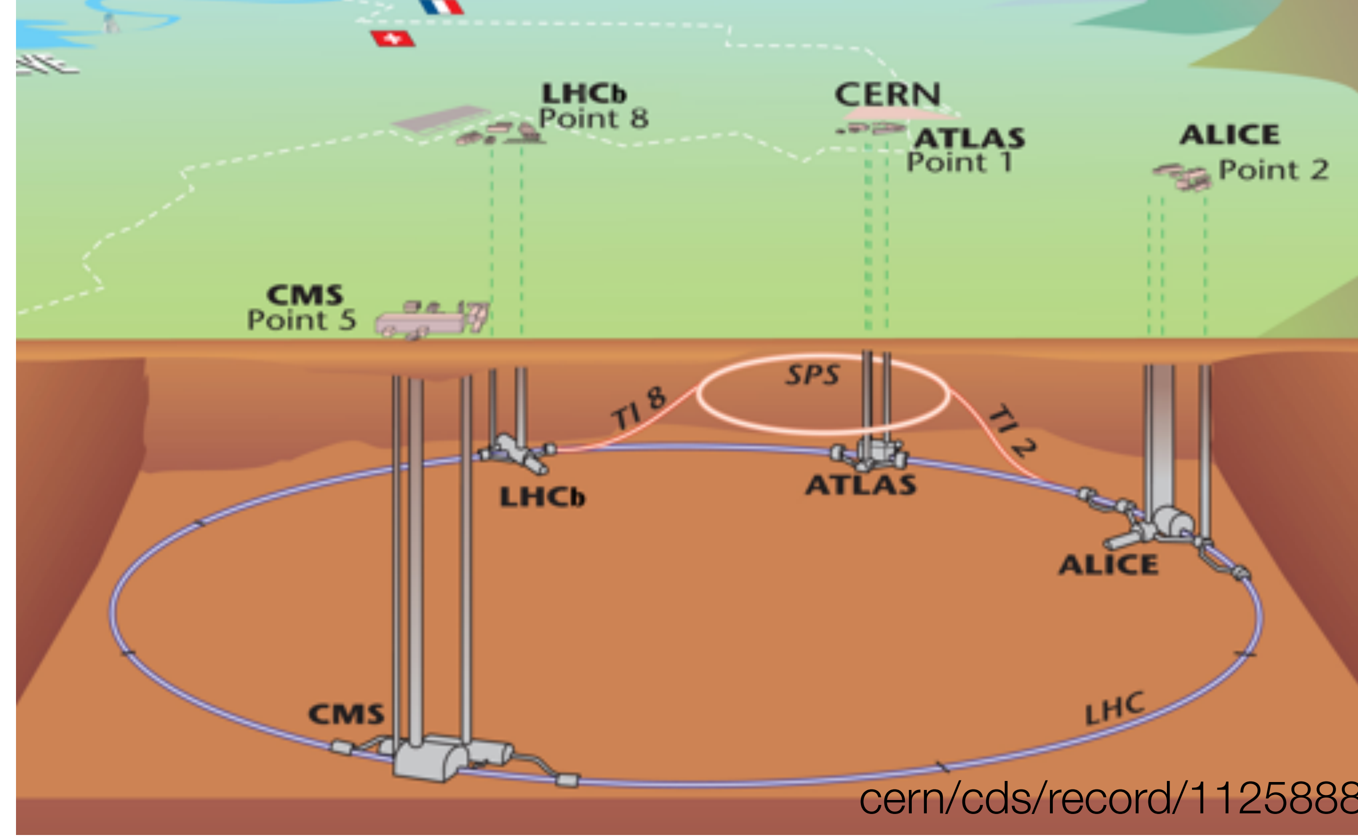
JHEP 0905 (2009) 030 including LHCb and BELLE

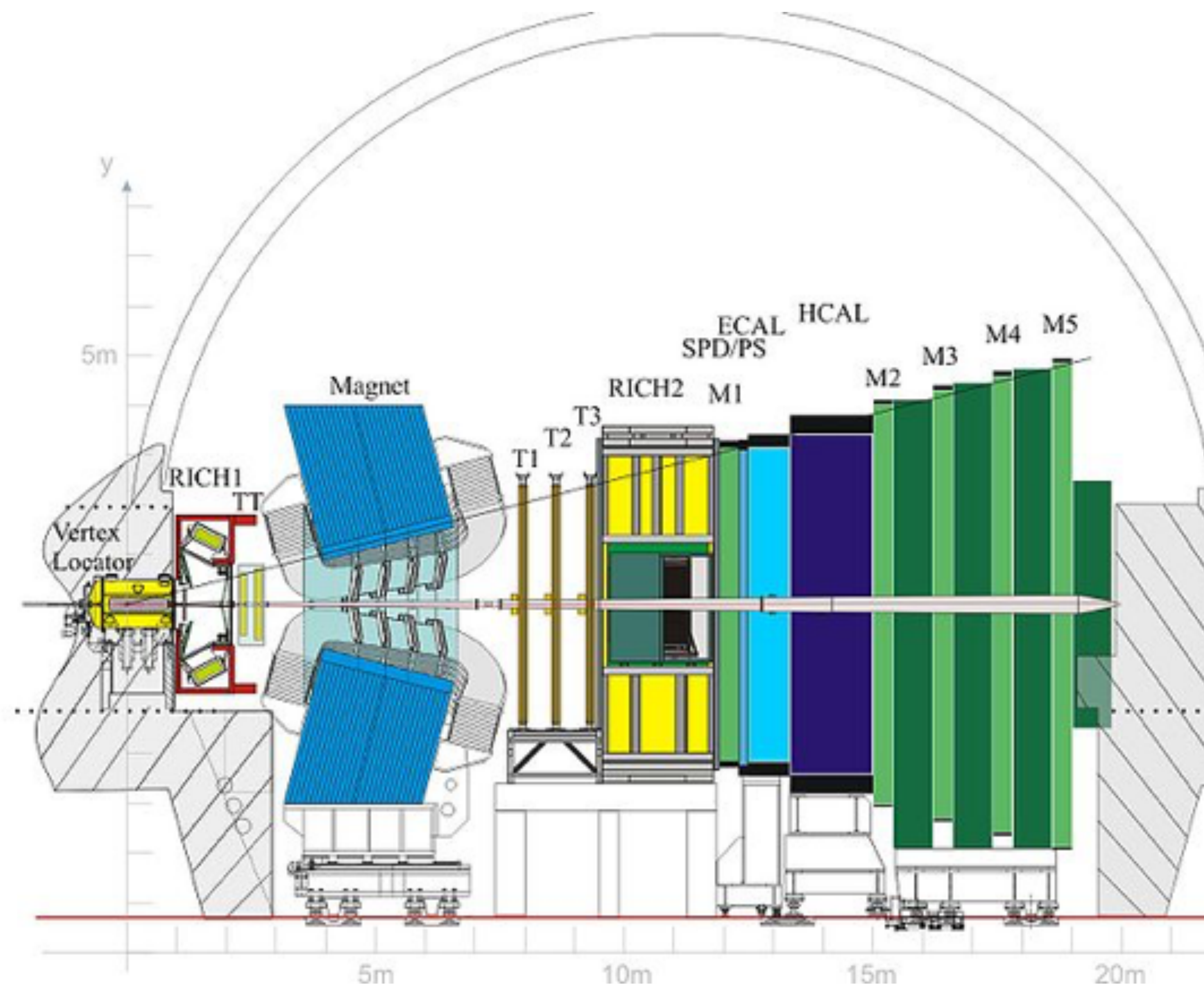


arXiv:1504.04855
arXiv:1504.04956

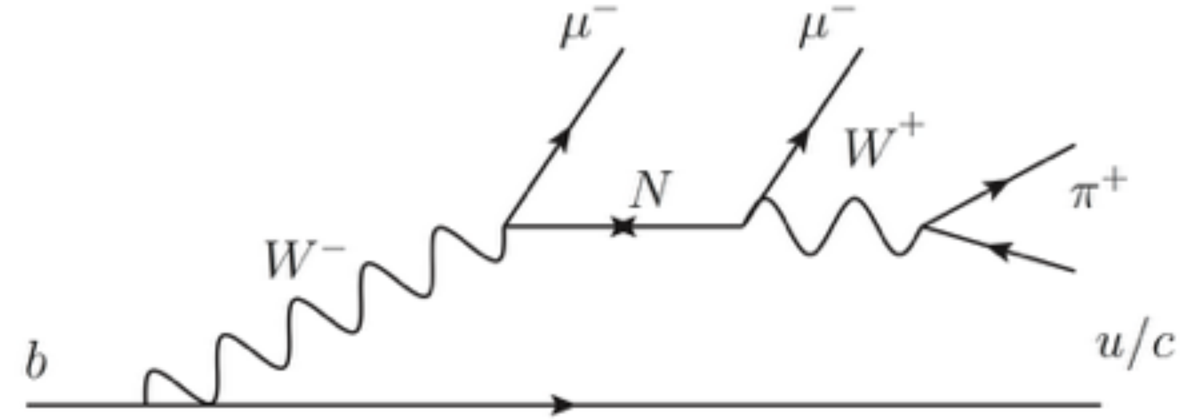
The LHCb detector

- **LHCb** is a dedicated flavour experiment in the forward region at the **LHC** ($1.9 < \eta < 4.9$).
  - Down to 10 μm vertex reconstruction precision.
  - 98% μ id efficiency.
- Collected *3.0 fb*$^{-1}$ from **Run1** at *7* and *8* TeV *pp* collisions.
- **Run2** is ongoing expected *5.0 fb*$^{-1}$ at *13* TeV (double the cross section).





Analysis strategy/1



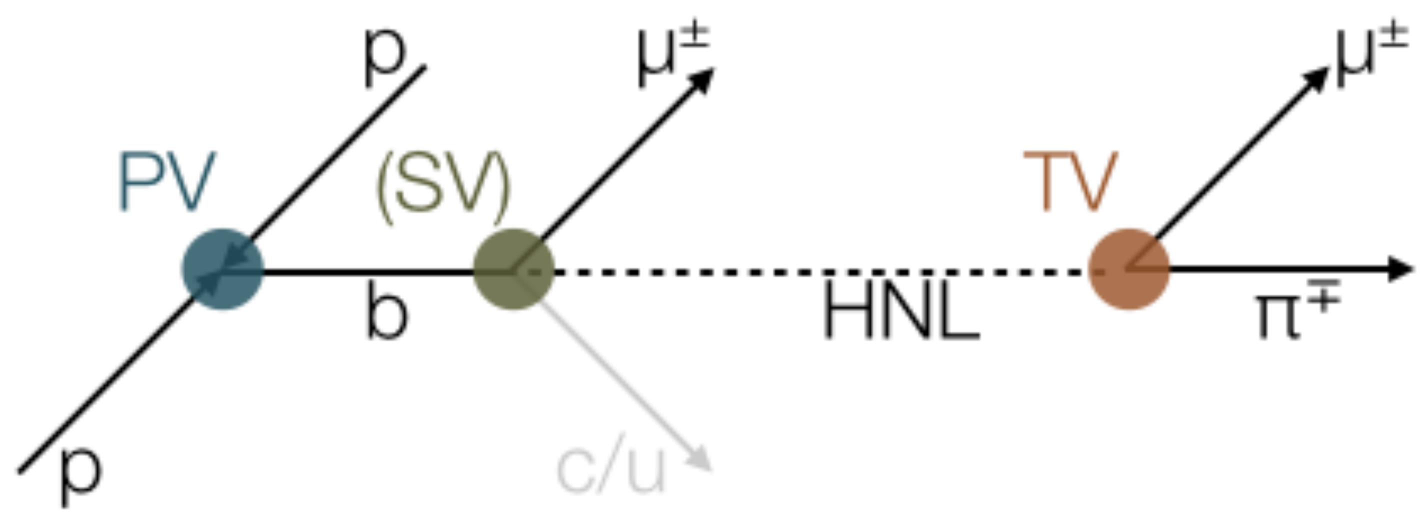
- Previously in **LHCb** we have looked at specific *B* (*D*) decays into Majorana neutrinos: final states peaking at *B* (*D*) mass.

- Our analysis considers **all *B* hadron** decays that can produce a Majorana neutrino.

- This approach should naively be stronger by a factor of *O(1000)* wrt exclusive approach.

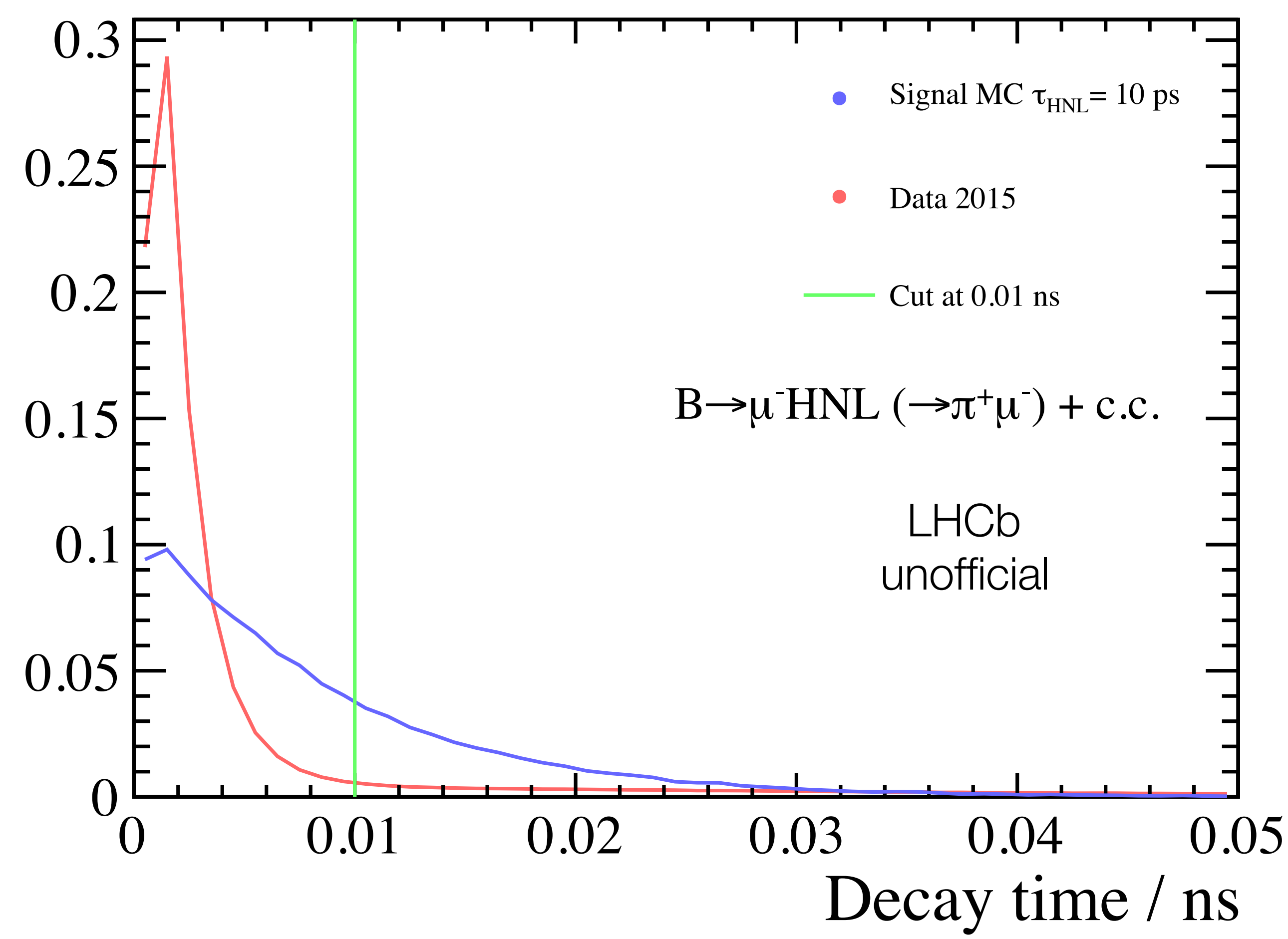
Analysis strategy/2

- **Different topology** from previous analysis.
- Selection.
- Efficiency correction.
- Calculation of coupling limit.



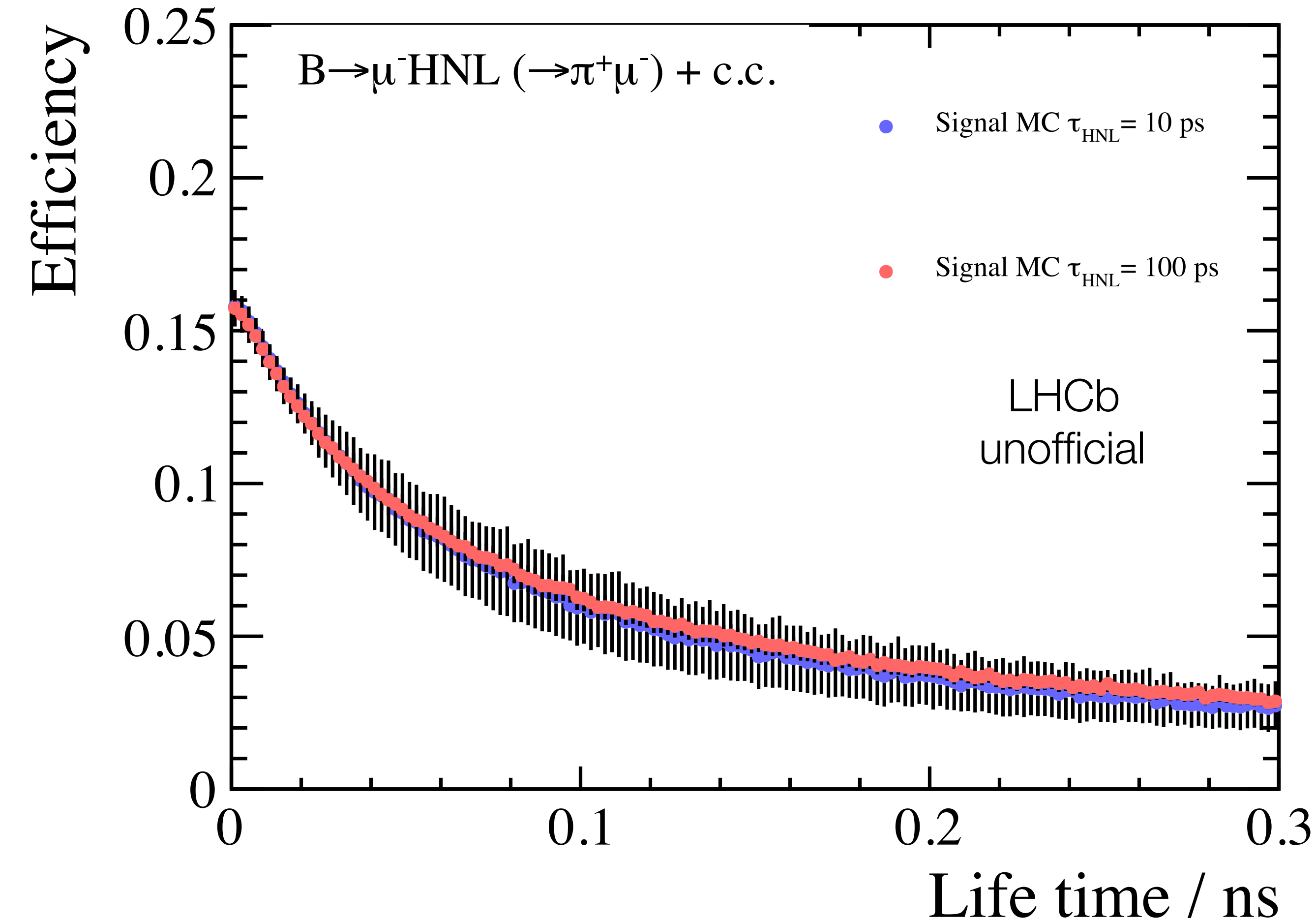
Selection

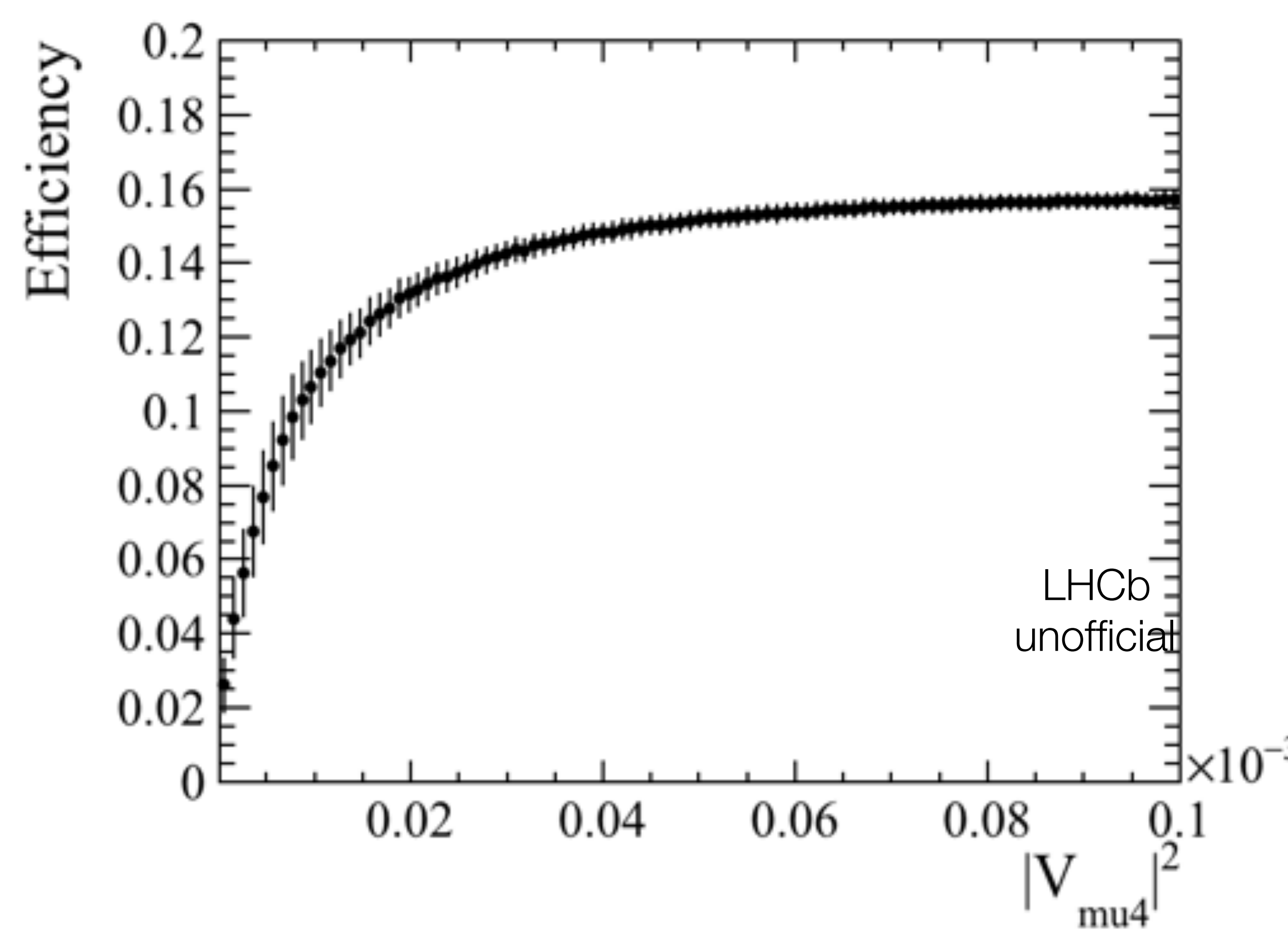
- Two μ must be of the same sign - help to reduce the background.
- Split data sample in **two**: one for prompt and the other for displaced candidates.
- Some kinematic variables can be used for cut based selection, some others can be fed into an **MVA**.



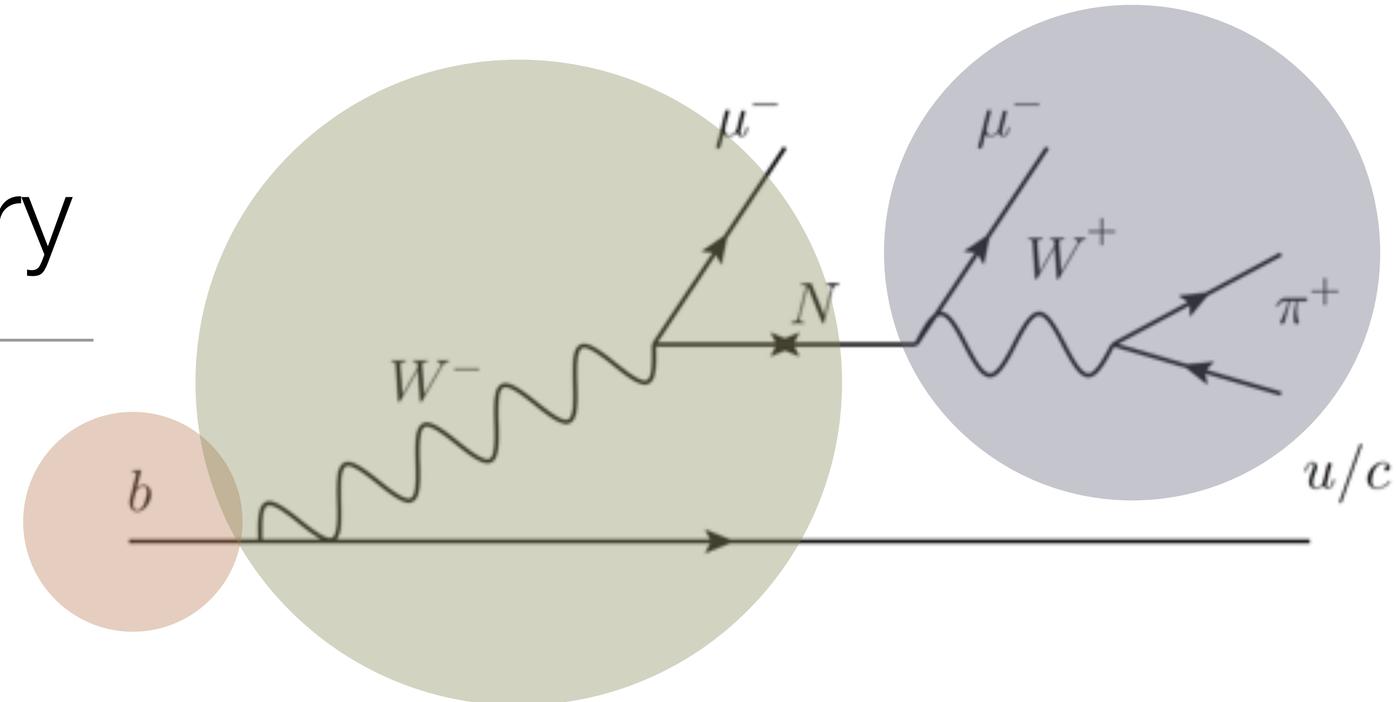
Efficiency studies

- Calculate efficiency as a function of lifetime and coupling.
- Do this for each value of Majorana mass.
- Lifetime inversely proportional to coupling.





Sensitivity studies theory

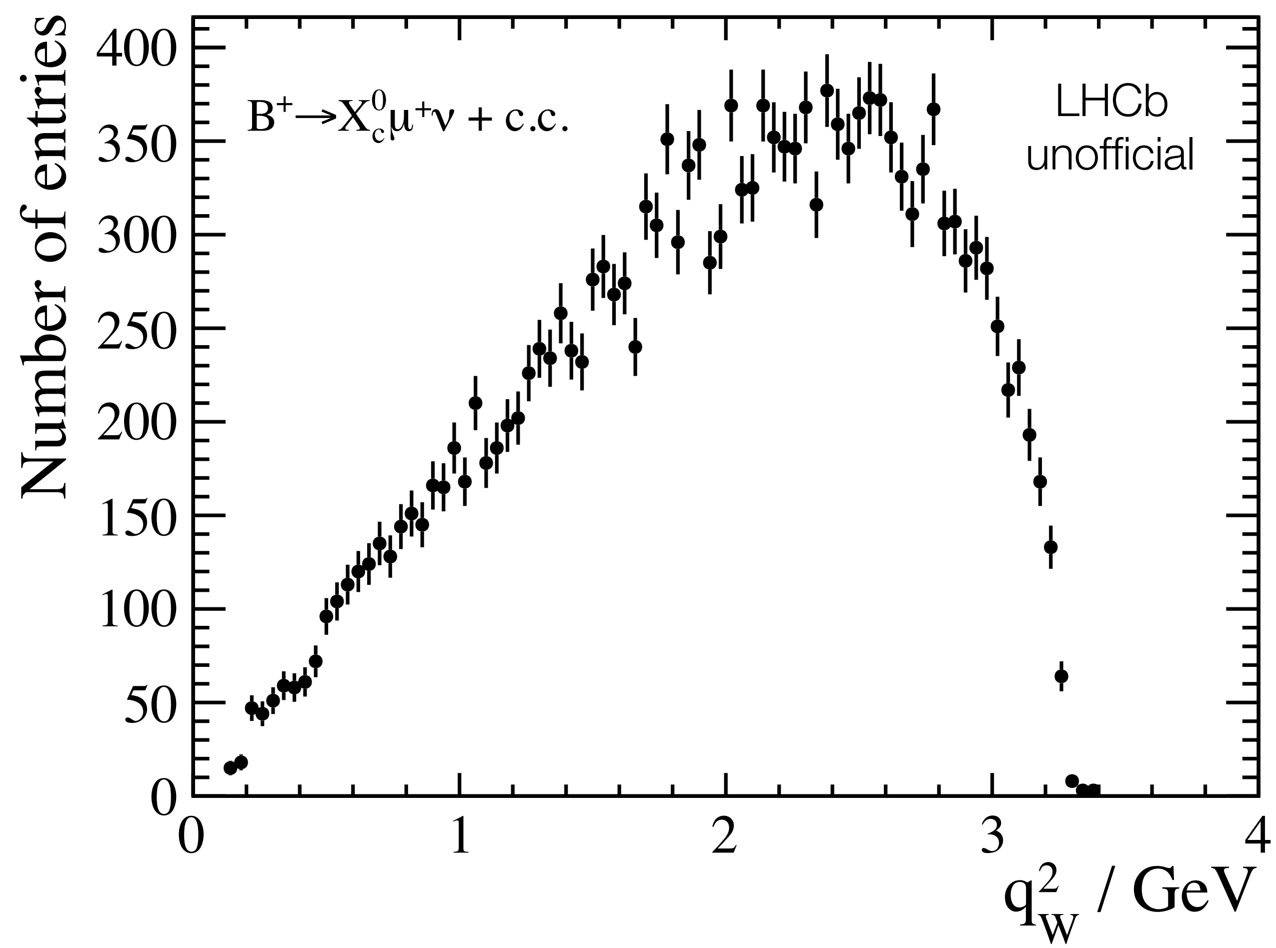


- Production of b.
- Production and decay of W corrected by ratio of decay of BSM to SM of W.
- Exclusive decay of *N* to *πμ*.

$$\text{detected events} = \mathcal{L} \times \sigma(b\bar{b}) \times \text{eff} \times \mathcal{B}(X_b \to X\mu\nu) \times \mathcal{B}(W \to \mu\text{N})/\mathcal{B}(W \to \mu\nu) \times \mathcal{B}(\text{N} \to \mu\pi)$$

Sensitivity studies/2

- Need q^2 (invariant mass of final state particles) distribution of *W* because of off-shell production.
- In addition to *b->c* transitions we include *b->u* transition, B_c annihilation, etc.
- Future steps involve the finalisation of the background studies and analysis of the possible systematic uncertainties.



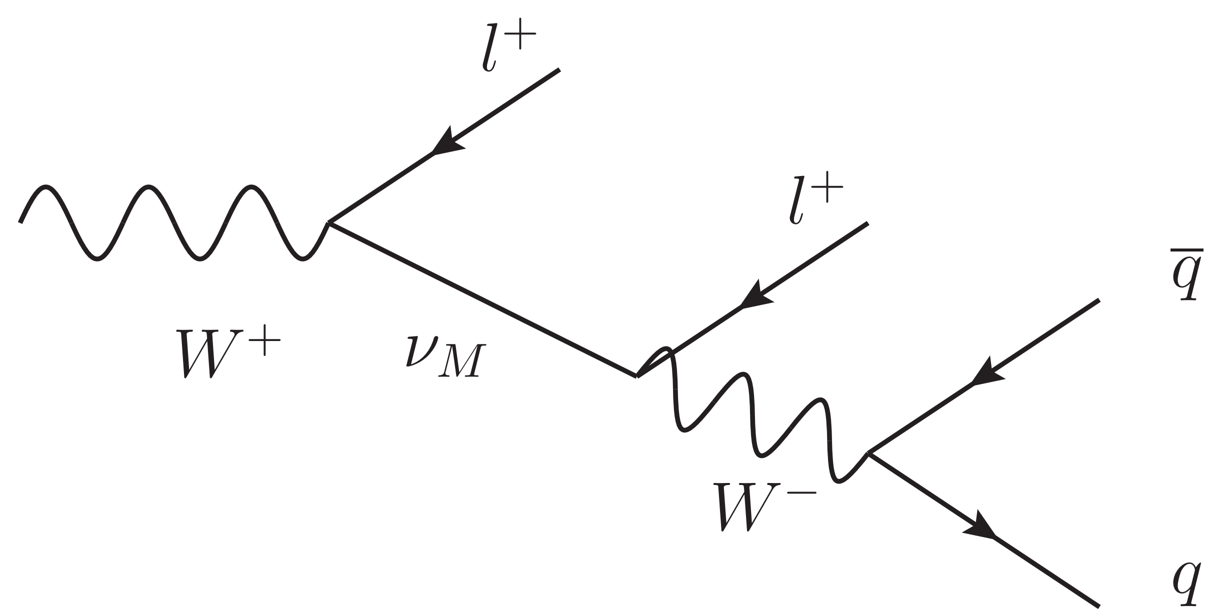
Conclusion

- We have shown complementarity of heavy right handed neutrinos in *b* decays wrt neutrinoless double beta decay.
- Different experiments can cover different phase space regions for Majorana mass.
- Analysis strategy will allow improvement on past results.
- Sensitivity studies completed, next steps involve background studies and systematic uncertainties.

Thanks. | *Federico Leo Redi.*

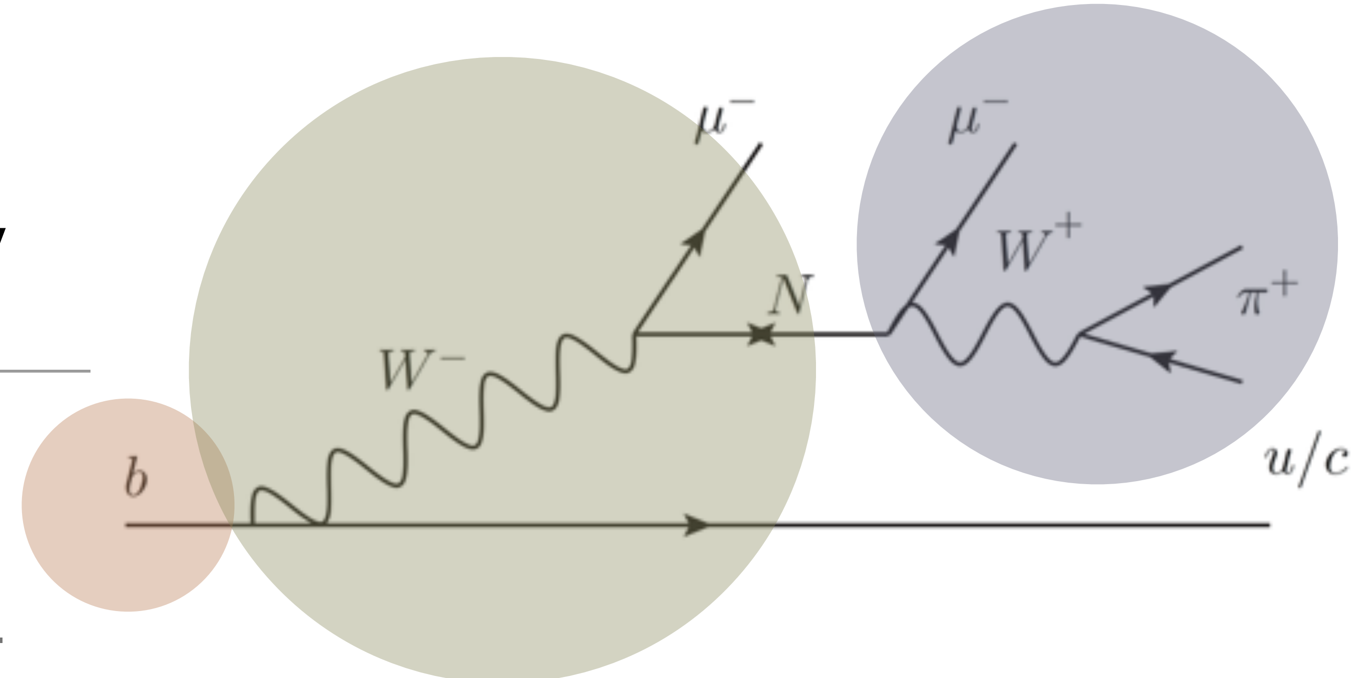
Majorana neutrinos at LHCb

- Searches for the decays of heavy mesons to final states with two same sign leptons.
    - Complementary to other searches, such as in neutrino-less double β decay (only coupling to *e*).
    - LHCb searches (will) constrain models like the type-I seesaw model with three right-handed neutrinos.



- Very stringent limits are possible for rare B and D decays.
    - Particularly true for on- and off-shell Majorana Neutrinos in B and D decays.
- A. Phys.Rev.Lett. 112 (2014) 131802: $h^{\mp} = \pi^{\mp}$, with 3.0 fb^{-1} (7 TeV and 8 TeV).
- B. Phys.Rev. D85 (2012) 112004: $h^{\mp} = D^{\mp}$, $D^{*\mp}$, $D_s^{\mp}$ and $D^0\pi^{\mp}$, with ~40 pb^{-1} (7 TeV).
- C. Phys.Rev.Lett. 108 (2012) 101601: $h^{\mp} = K^{\mp}$ or $\pi^{\mp}$, with ~36 pb^{-1} (7 TeV).

Sensitivity studies theory



- **Production of b**
- **Production and decay of W**: taken from the PDG.
  - **Corrected by ratio of decay of BSM to SM of W**: here we used the ratio of SM to BSM W production:
    - From PhysRevD.29.2539 we take the BSM part of the equation, namely:

$$B(W \to l + \bar{N}) \simeq 0.08\,|U|^2 \left[1 - \frac{M_N{}^2}{M_W{}^2}\right]^2 \left[1 + \frac{M_N{}^2}{2M_W{}^2}\right],$$

    - Where we have used the q2 distribution of the daughters of the off-shell W.
- **Exclusive decay of N to πμ**. To do this we take the same model as the one used in a previous analysis (LHCb-PAPER-2013-064) which was based upon arXiv:0901.3589.

$$\Gamma^{\ell P} \equiv \Gamma(N_4 \to \ell^- P^+) = \frac{G_F^2}{16\pi} f_P^2\, |V_{q\bar{q}'}|^2\, |V_{\ell 4}|^2\, m_4^3,$$

$$\Gamma_N = \left[3.95 m_N^3 + 2.00 m_N^5 (1.44 m_N^3 + 1.14)\right] 10^{-13} |V_{\mu 4}|^2,$$

- Which therefore gives:

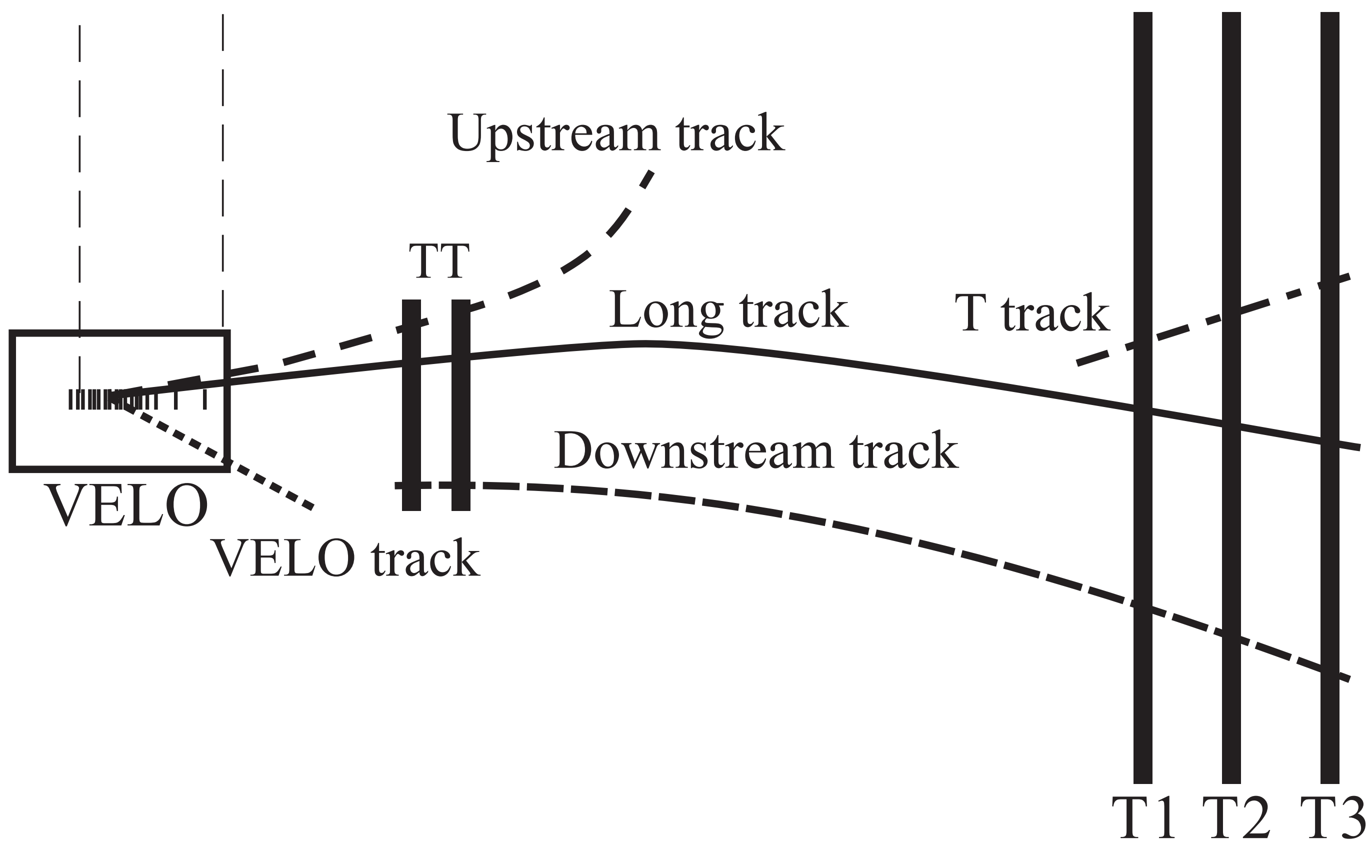
$$\text{detected events} = \mathcal{L} \times \sigma(b\bar{b}) \times \text{eff} \times \mathcal{B}(X_b \to X\mu\nu) \times \mathcal{B}(W \to \mu\text{N})/\mathcal{B}(W \to \mu\nu) \times \mathcal{B}(\text{N} \to \mu\pi)$$

Stripping cuts

B cuts		**μ cuts**	
m	$\in [1500, 6500]$ MeV	Track χ^2/dof	< 4
Vertex χ^2/dof	< 4	p	> 3000
DIRA	< 0.99	p_T	> 250
$(\Lambda^0$ vertex $- B$ vertex$)_z$	> 0 mm	Track ghost probability	< 0.5
Λ^0 cuts		PIDμ-PIDπ	> 0
Λ^0 *parameters*		PIDμ-PIDp	> 0
$(\Lambda^0$ vertex $- PV)\chi^2$	> 100	PIDμ-PIDK	> 0
m	> 1500MeV	min IP χ^2	> 12
p_T	> 700MeV		
Vertex χ^2/dof	< 10		
π *parameters*			
p	> 2000 MeV		
p_T	> 250 MeV		
Track χ^2/dof	> 4		
min IP χ^2	> 10		

- Timing is low, rate is low at ~ 0.05 % even with no tight cuts applied: thanks to same sign muon signature.
- Will be able to adjust the cuts when tested on 14 TeV data.
- Will be run also on 3 invfb of data for the incremental restripping.

LHCb track types



Limits in case of no background

	$1-\alpha$ =90%		$1-\alpha$ =95%	
n	$\nu_{\rm lo}$	$\nu_{\rm up}$	$\nu_{\rm lo}$	$\nu_{\rm up}$
0	–	2.30	–	3.00
1	0.105	3.89	0.051	4.74
2	0.532	5.32	0.355	6.30
3	1.10	6.68	0.818	7.75
4	1.74	7.99	1.37	9.15
5	2.43	9.27	1.97	10.51
6	3.15	10.53	2.61	11.84
7	3.89	11.77	3.29	13.15
8	4.66	12.99	3.98	14.43
9	5.43	14.21	4.70	15.71
10	6.22	15.41	5.43	16.96