Imperial College London

Searches for light exotics at LHCb

Federico Leo Redi, on behalf of the LHCb collaboration.

31 VIII 2015

LHCP-2015, Санкт-Петербург.

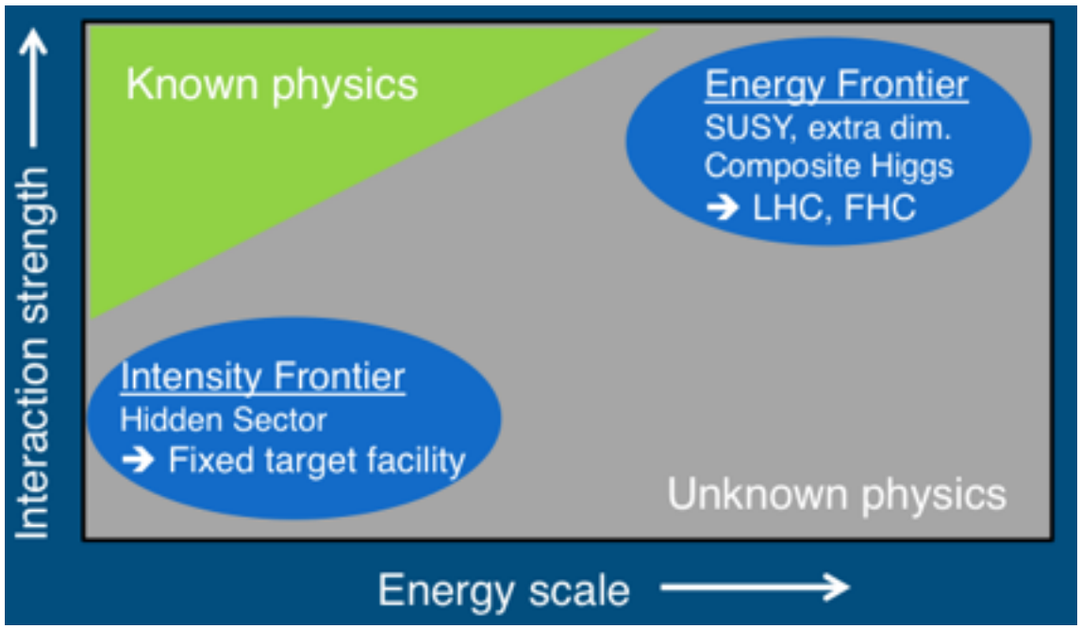
Outline

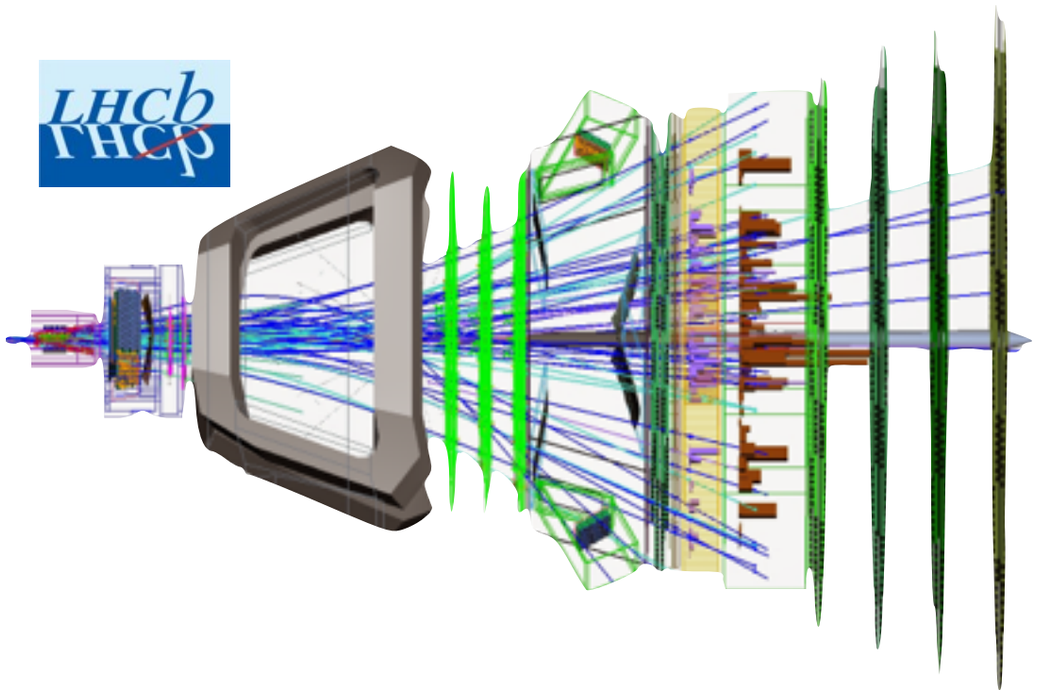
- LHCb can exploit its unique features to search for exotic phenomena in different ways

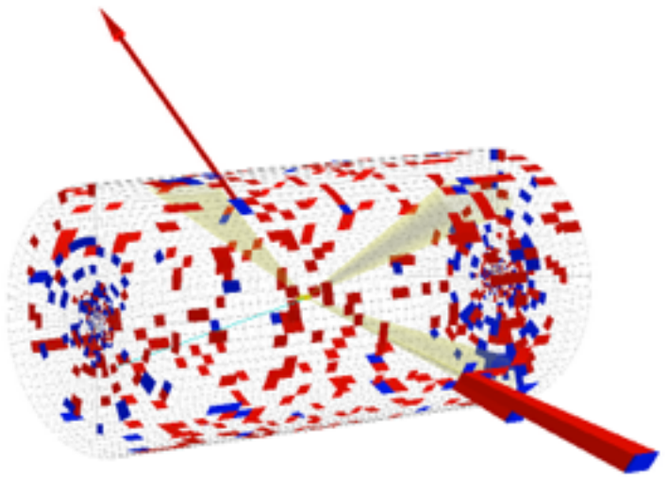
  - Exotic hadronic structure
    see Mikhail Shapkin's talk in the HF parallel session
    and Giovanni Veneziano's "Results on Rare Decays" talk.

  - **Very rare decays**

Introduction





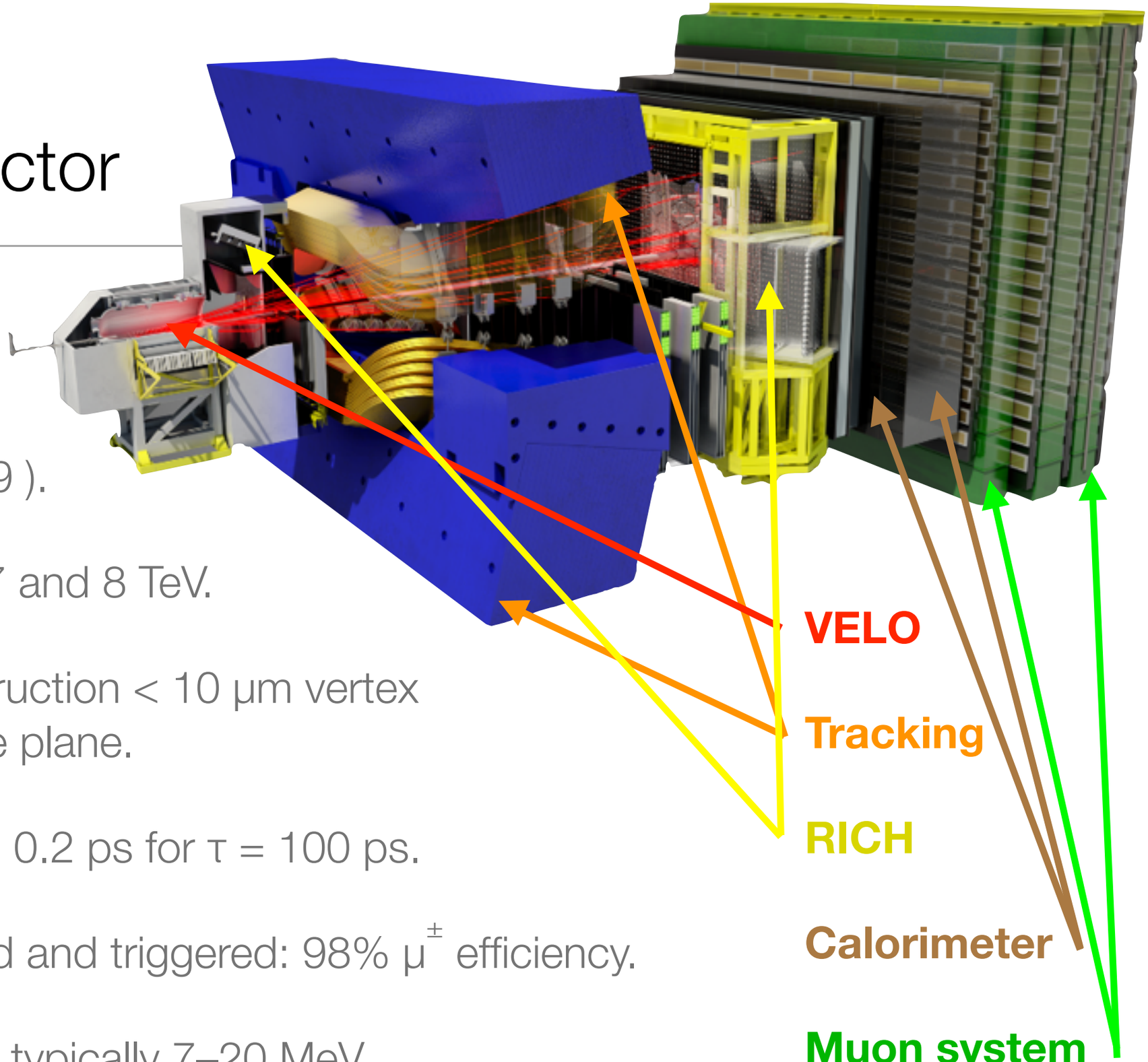


CMS Experiment at LHC, CERN
Data recorded: Sat Nov 17 17:23:56 2012 IST
Run/Event: 207454 / 1095163126
Lumi section: 771

https://indico.cern.ch/event/386054/

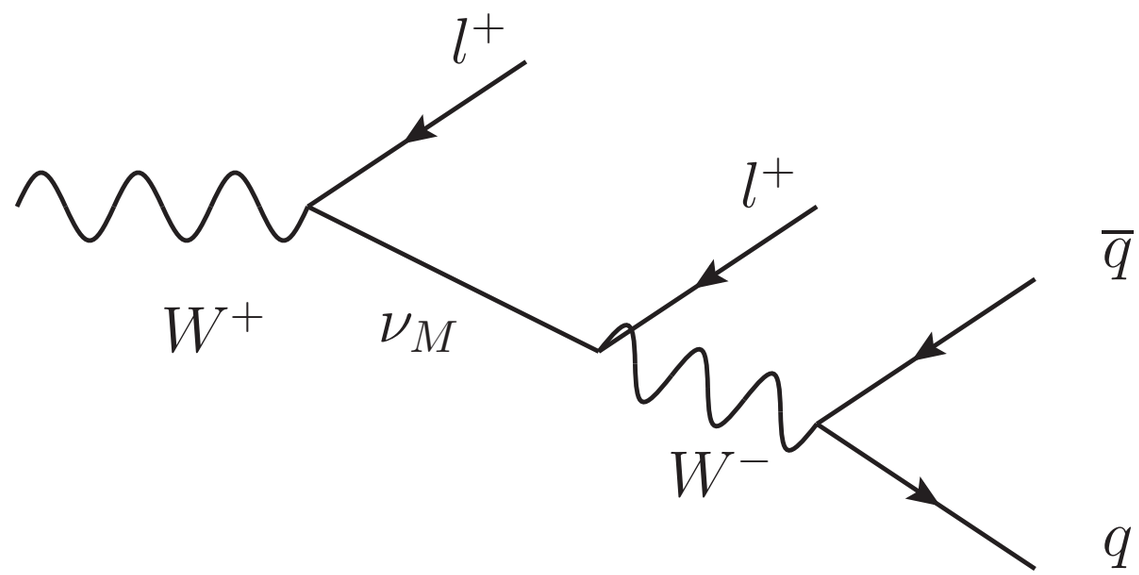
The LHCb detector

- LHCb is a dedicated flavour experiment in the forward region at the LHC ($1.9 < \eta < 4.9$).
- 3.0 fb^{-1} from Run1 at 7 and 8 TeV.
- Precise vertex reconstruction < 10 μm vertex resolution in transverse plane.
- Lifetime resolution of ~ 0.2 ps for $\tau = 100$ ps.
- Muons clearly identified and triggered: 98% $\mu^{\pm}$ efficiency.
- Great mass resolution: typically 7–20 MeV.
- Low p_T trigger means low masses accessible. Ex: $p_{T\mu} > 1.5$ GeV.



Majorana neutrinos at LHCb

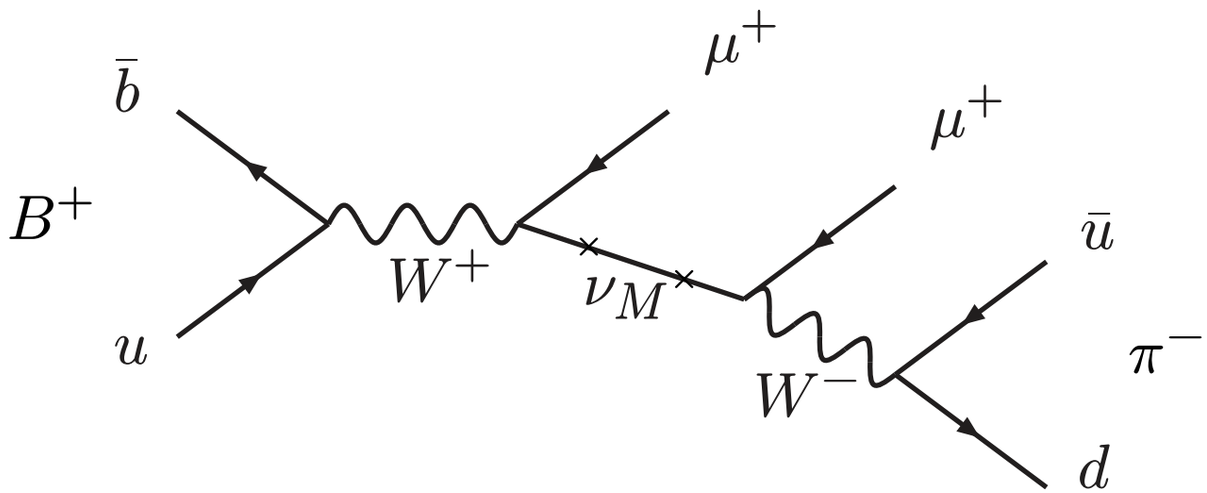
- Searches for the decays of heavy mesons to final states with two same sign leptons.
  - Complementary to other searches, such as in neutrino-less double β decay (only coupling to *e*).
  - LHCb searches (will) constrain models like the type-I seesaw model with three right-handed neutrinos.
- Very stringent limits are possible for rare B and D decays.
  - Particularly true for on- and off-shell Majorana Neutrinos in B and D decays.

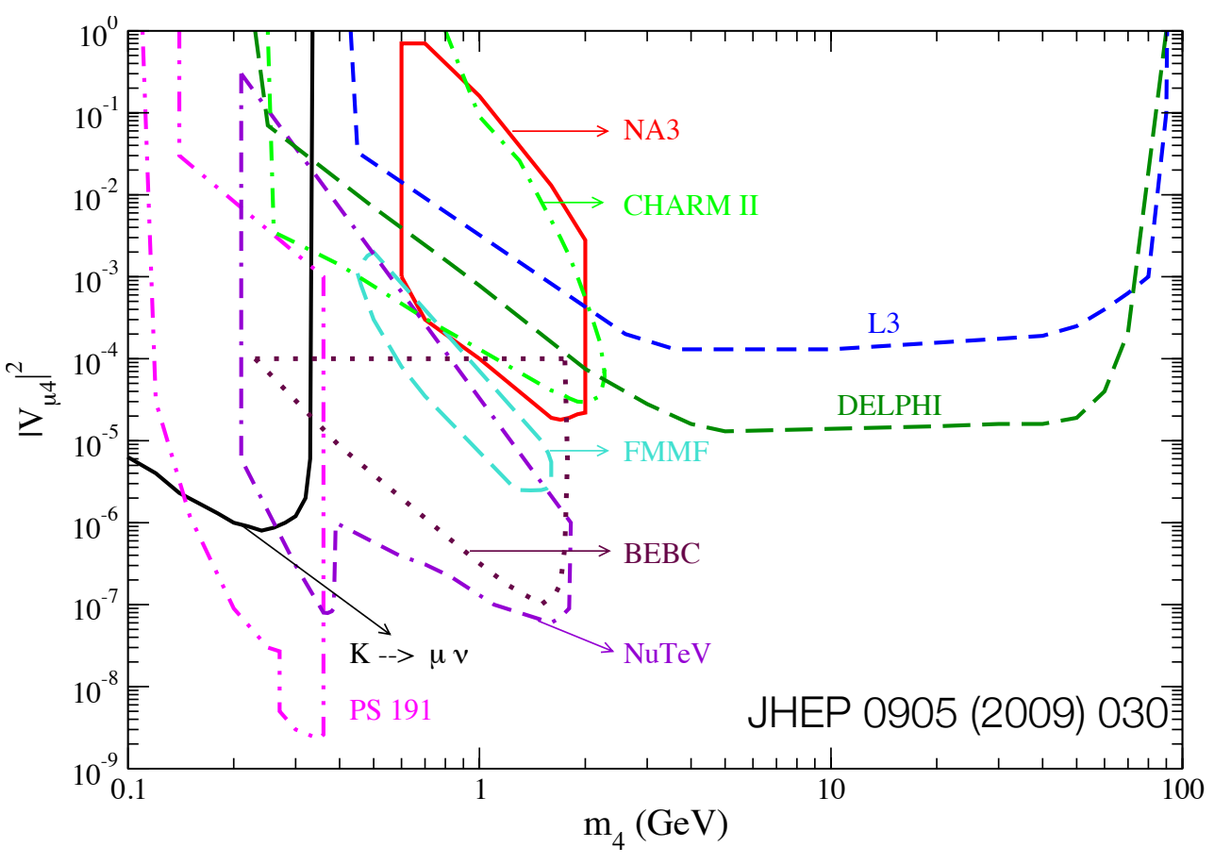


- A. Phys.Rev.Lett. 112 (2014) 131802: $h^{\mp} = \pi^{\mp}$, with 3.0 fb^{-1} (7 TeV and 8 TeV).
- B. Phys.Rev. D85 (2012) 112004: $h^{\mp} = D^{\mp}$, $D^{*\mp}$, $D_s{}^{\mp}$ and $D^0\pi^{\mp}$, with ~40 pb^{-1} (7 TeV).
- C. Phys.Rev.Lett. 108 (2012) 101601: $h^{\mp} = K^{\mp}$ or $\pi^{\mp}$, with ~36 pb^{-1} (7 TeV).

Searches for same sign muons from B decays

- LHCb uses $B^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ with 3.0 fb^{-1} (7 TeV and 8 TeV).
- m_N window of 250 – 5000 MeV and lifetimes from zero to 1000 ps are probed.
- The existing experimental limits for the mixing parameter $|V_{\mu 4}|$ as a function of the mass of the Majorana neutrino m_4 shows that LHCb could play a significant role in the region above 2 GeV.



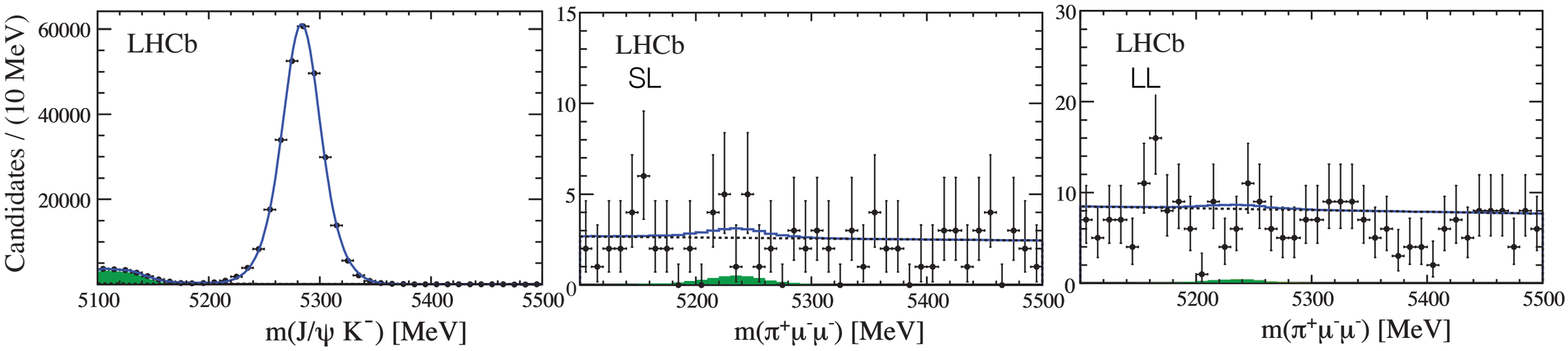


Majorana neutrino at LHCb

- Split into Short (SL) (one vertex) and Long (LL) (two vertices) neutrino lifetimes. For LL the $\pi^{\mp}\mu^{\pm}$ vertex can be displaced.

- Channel is normalised to $B^+ \rightarrow J/\psi K^+$ and with charmonium backgrounds (**green**) estimated from data.

- The search is performed in a 2σ window around B^+ mass using CLs method to set upper limits using a p-value of 5%.



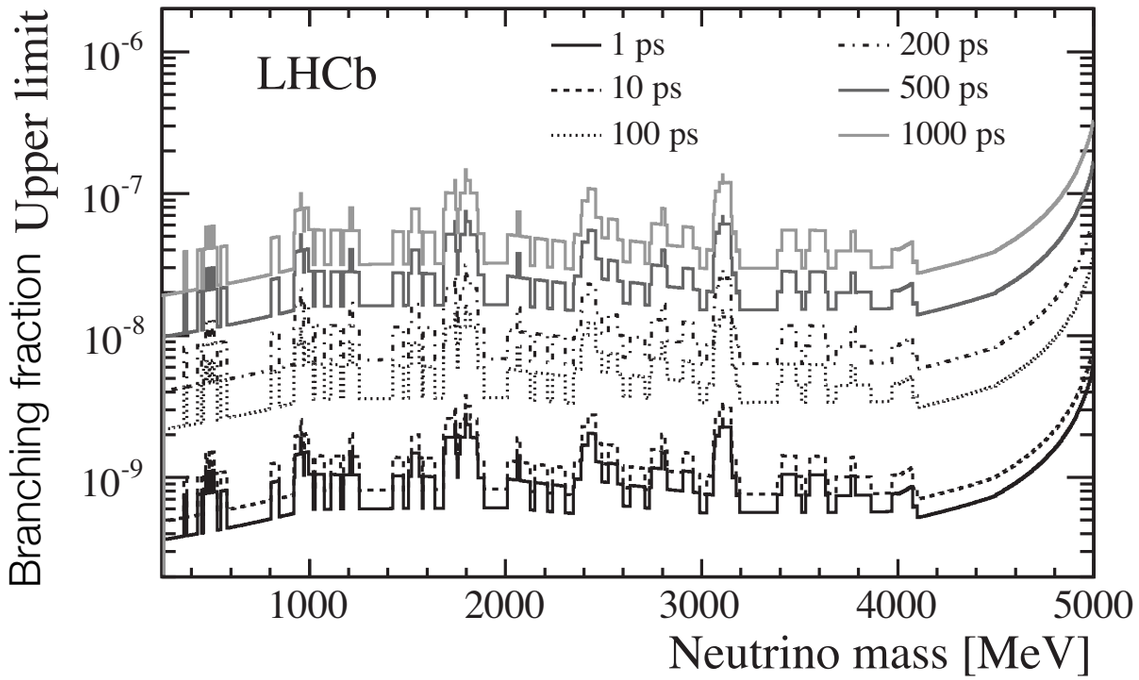
Phys.Rev.Lett. 112 (2014) 131802

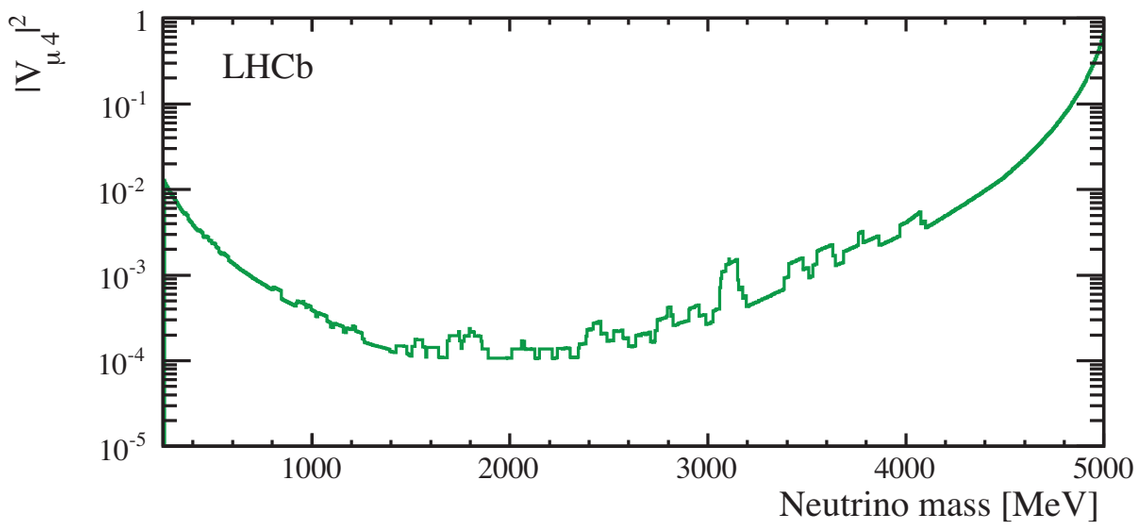
Limits

- The efficiency is highest for τ_N of a few ps, it decreases rapidly until about 200 ps when it levels off until about 1000 ps and beyond it vanishes as $\pi^{\mp}\mu^{\pm}$ vertex is outside VELO.

- The τ_N dependence is taken into account by using different efficiencies for each lifetime step.

- Limits on the fourth generation coupling $|V_{\mu 4}|^2$ as a function of neutrino mass are extracted as function of m_N.

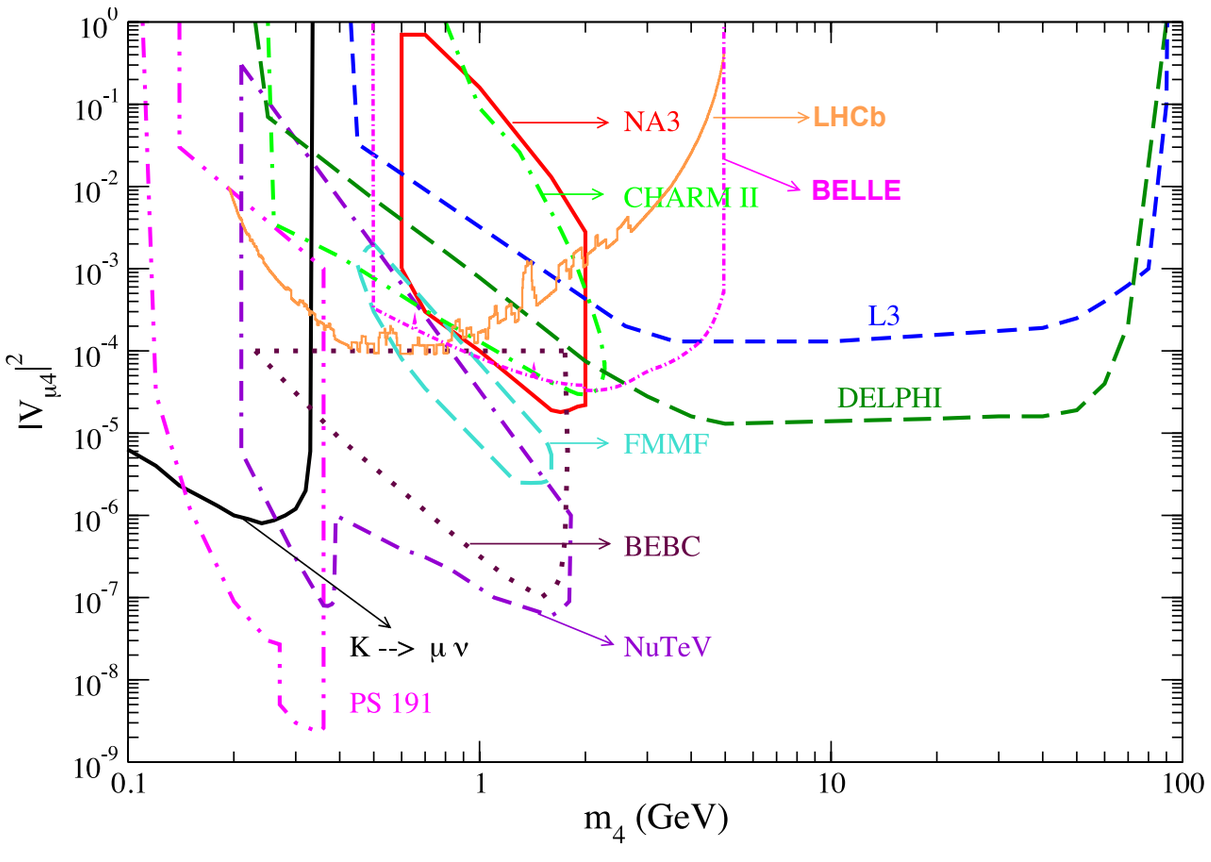




Phys.Rev.Lett. 112 (2014) 131802

Review of results

- Phys.Rev. D87 (2013) 071102
- Performs direct search for $N \to l^{\pm}\pi^{\mp}$ using $B \to lXN$ with $X = D^{(*)}$, light meson or nothing and $l = e,\mu$
- Set upper limits on both $|V_{e4}|^2$, and $|V_{\mu 4}|^2$.



- BaBar Phys.Rev. D89 (2014) 011102
- Performs direct search $B^+ \to X^- l^+ l'^+$ with $l,l'=e,\mu$.
- Limits on the ρ^-, π^- and K^- modes are an order of magnitude improvement on previous results.

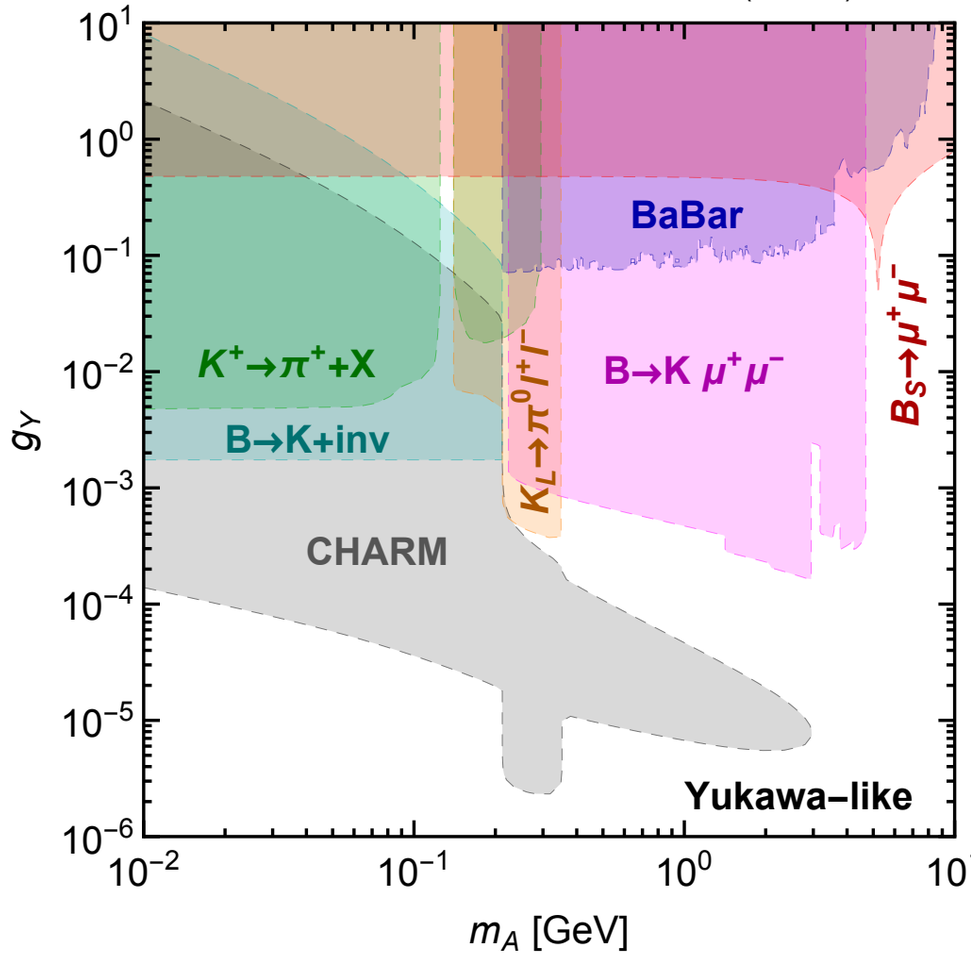
Channel	$\mathcal{B}_{UL}(\times 10^{-7})$
$B^+ \to K^{*-} e^+ e^+$	4.0
$B^+ \to K^{*-} e^+ \mu^+$	3.0
$B^+ \to K^{*-} \mu^+ \mu^+$	5.9
$B^+ \to \rho^- e^+ e^+$	1.7
$B^+ \to \rho^- e^+ \mu^+$	4.7
$B^+ \to \rho^- \mu^+ \mu^+$	4.2
$B^+ \to D^- e^+ e^+$	26
$B^+ \to D^- e^+ \mu^+$	21
$B^+ \to D^- \mu^+ \mu^+$	17
$B^+ \to K^- e^+ \mu^+$	1.6
$B^+ \to \pi^- e^+ \mu^+$	1.5

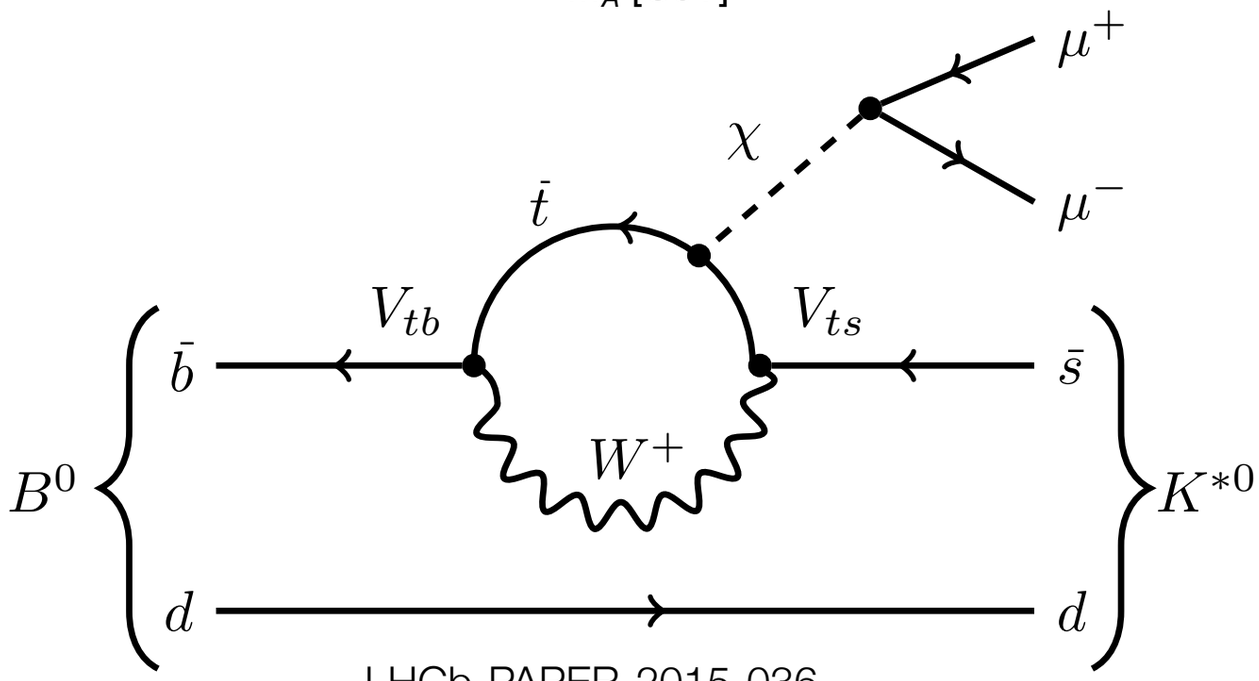
JHEP 0905 (2009) 030 including LHCb and BELLE

Low mass dark boson

- Higgs discovered is so far consistent with SM Higgs boson. It could still couple to exotic particles: inflaton (LL), dark matter mediator (SL), axion-like (SL), etc.
    - LL: Long lifetime: Displaced vertex kills most of background; lower reconstruction efficiency.
    - SL: Short lifetime Prompt decay: contamination from SM. Higher reconstruction efficiency.
- The blinded analysis uses the decay signature $B \to K^{*}(K\pi)\chi(\mu\mu)$: large top-quark Yukawa coupling and fully reconstructing the B^0.
- Dimuon vertex can be displaced from the K^{*} vertex.

JHEP 1503 (2015) 171

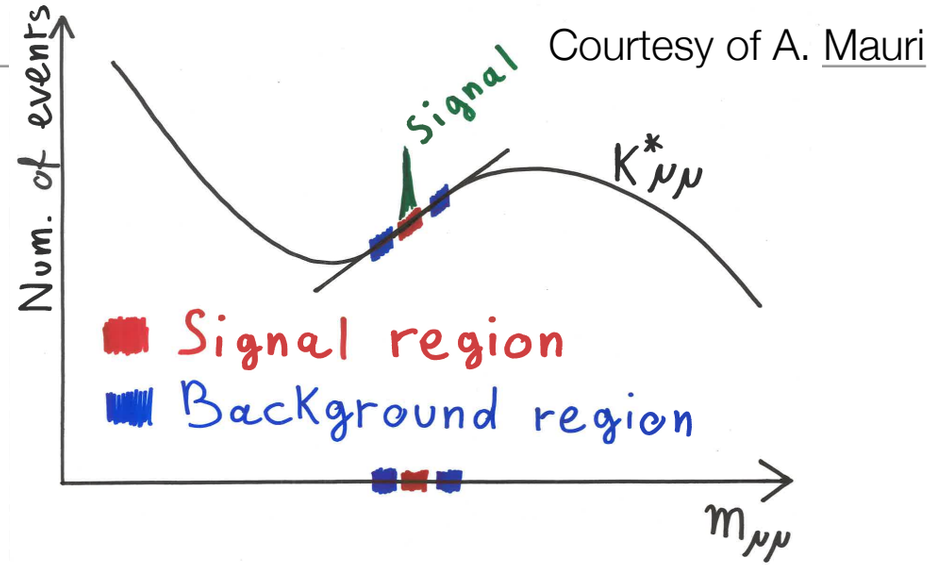




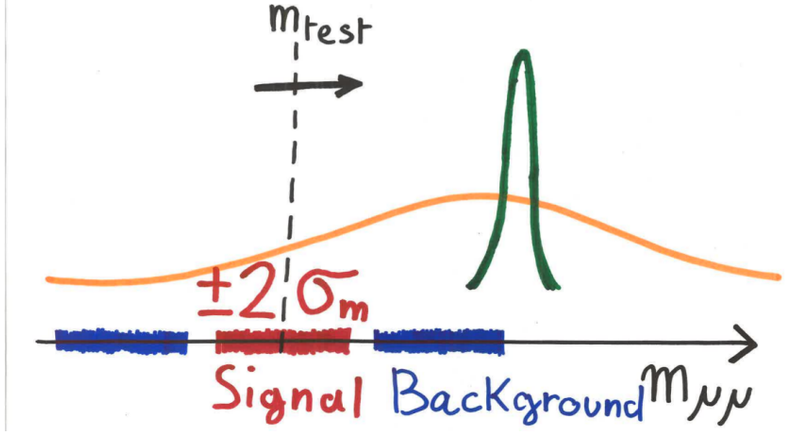
LHCb-PAPER-2015-036

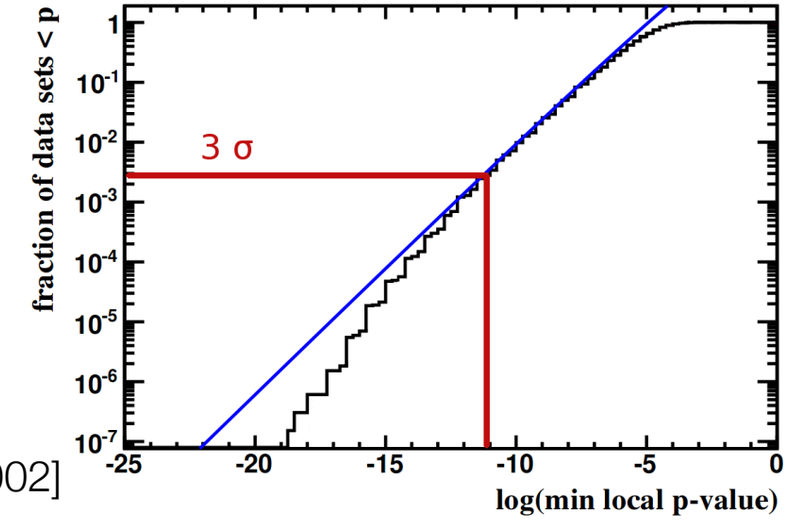
Strategy of the search for dark bosons

- We are looking for di-muon resonance:
- Scan dimuon mass spectrum.
- Do this with a set of m_{test} in steps of 1/2 σ_m where σ_m = 1 ÷ 7 MeV is the dimuon mass resolution.
    - Wide resonances are safe. but narrow resonances must be vetoed.
- Test statistic performed for each m_{test}.
- A global p-value is assigned from the minimum local p-value observed.
    - fraction of toys that have a minimum local p-value less than the observed in data.
    - Takes count of the Look Elsewhere Effect.



Courtesy of A. Mauri

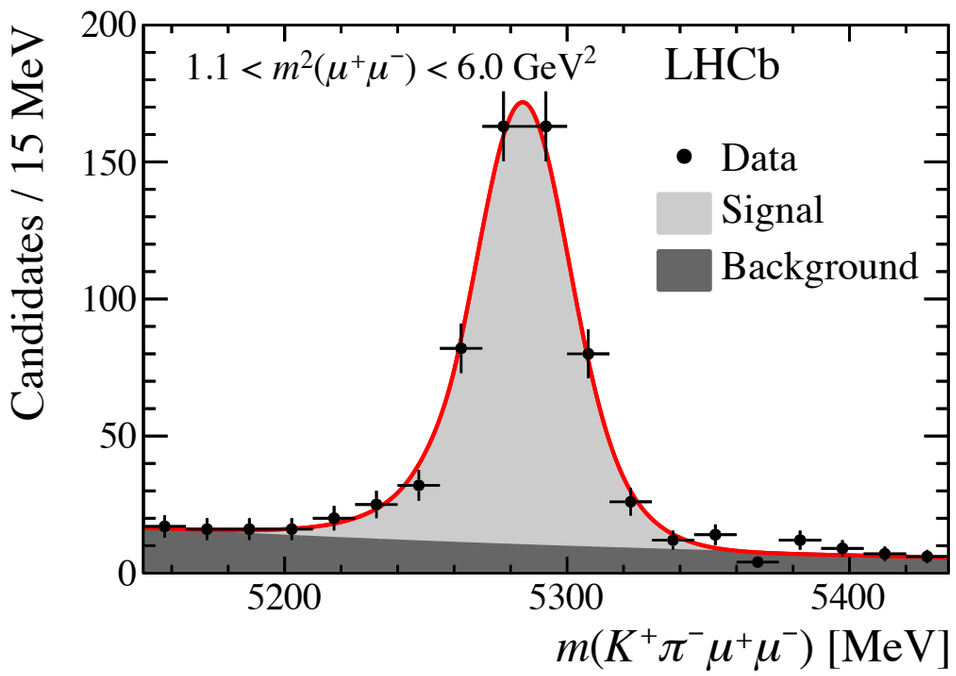


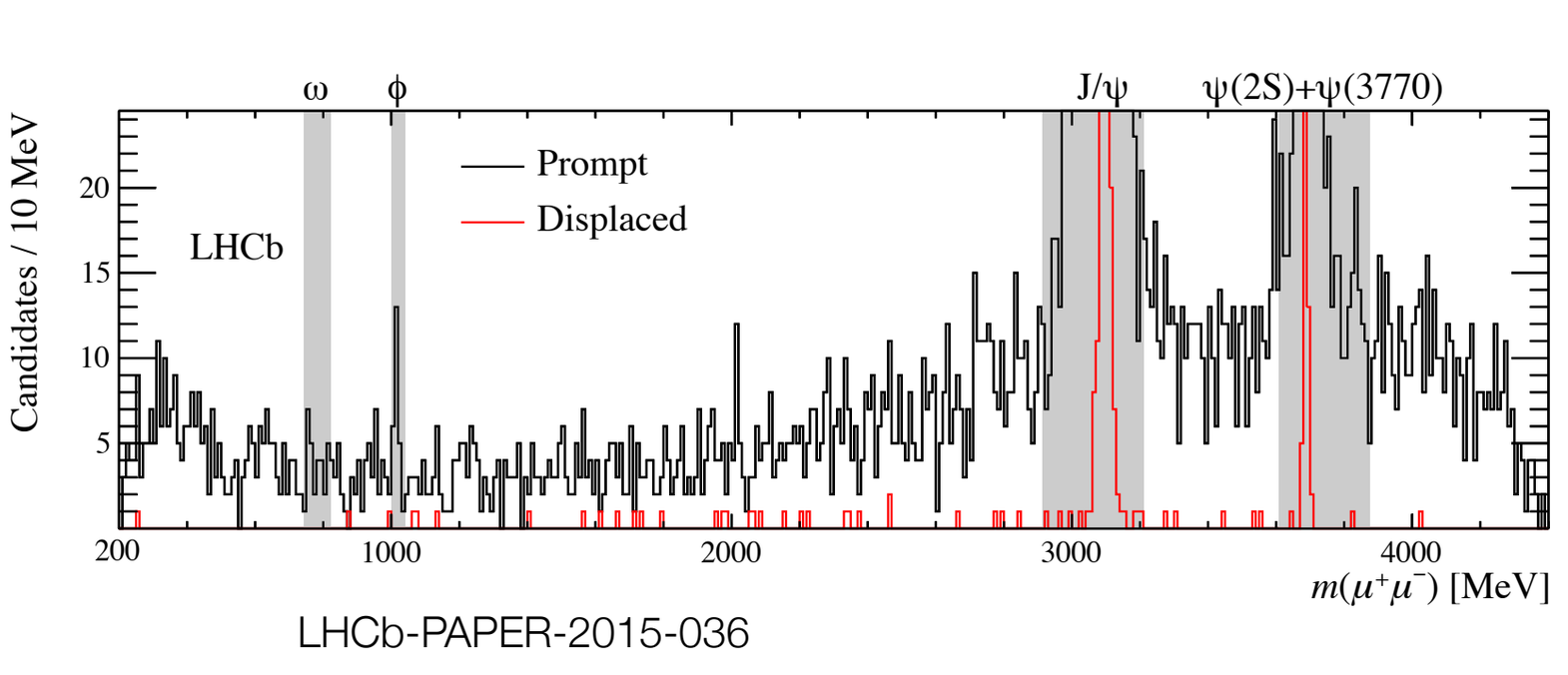


[M.Williams JINST 10(2015)P06002]

Unblinded fit results

- The decay B→K*μμ is used as normalisation mode in the region 1.1<q2<6.0 GeV2. Same final state allow to cancel many systematic errors.
- Selection triggers on muons factorising lifetimes into two separate components: prompt and displaced.
- A dedicated multi variate analysis (uBDT) is used. The performance is (nearly) independent of the mass and lifetime of χ [JINST 8(2013) P12013].
- Unblinded dimuon mass (for candidates in the B mass window) shows no evidence of a dark boson. Local p-value of 0.02.

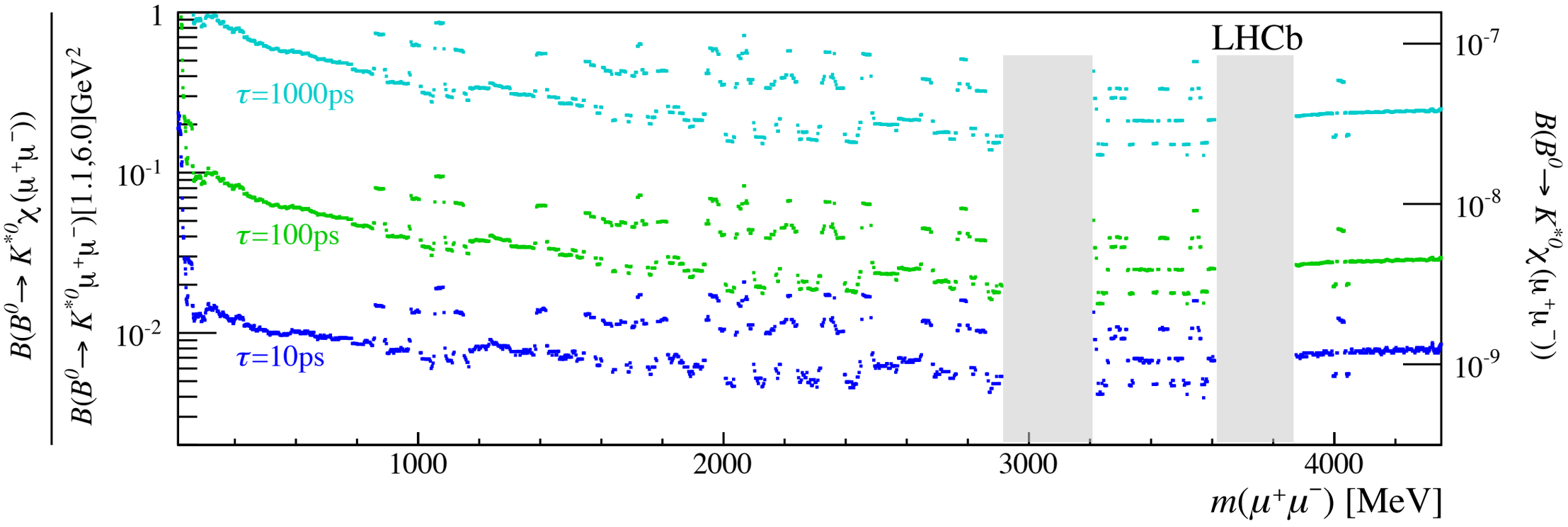




LHCb-PAPER-2015-036

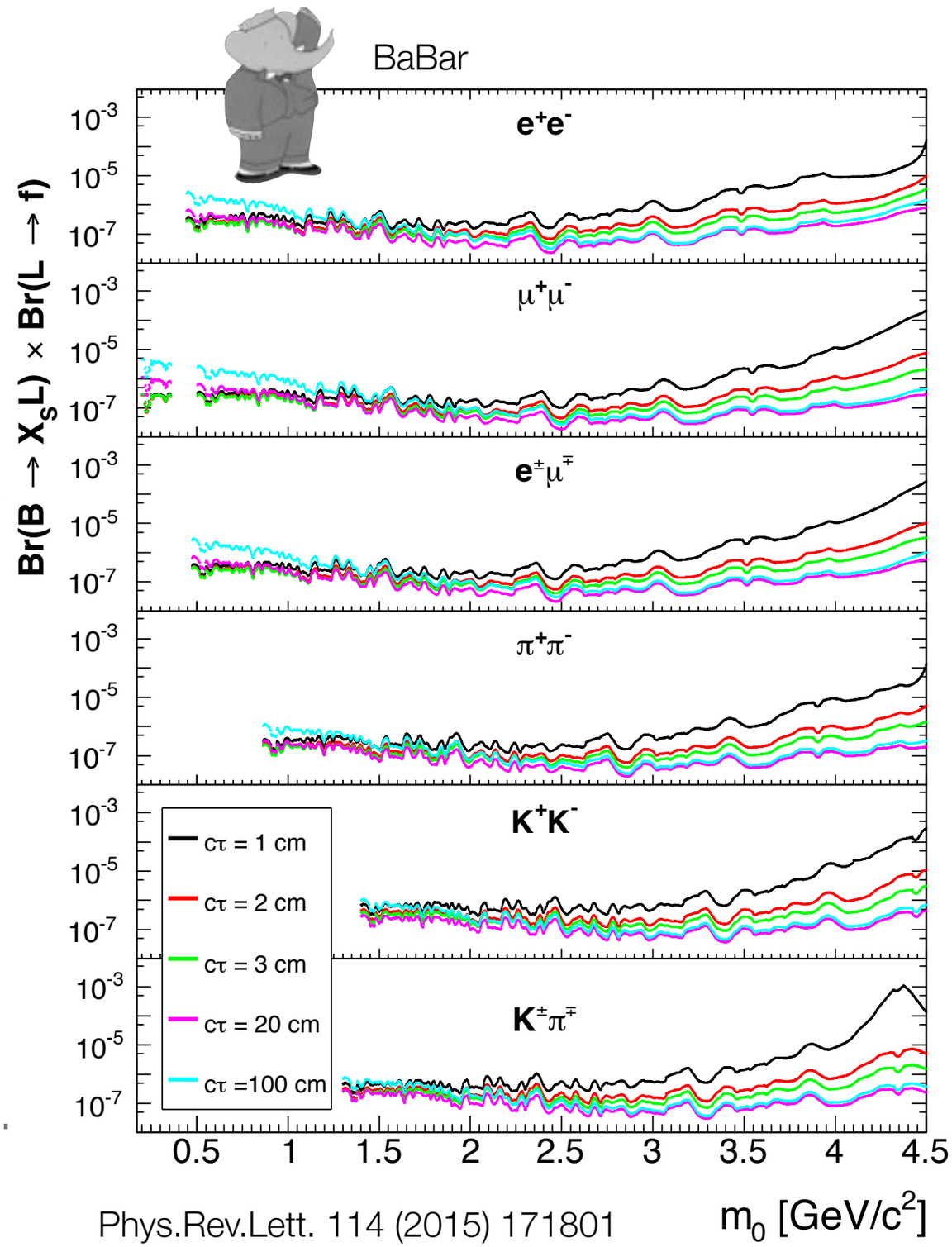
Limits

- No deviation-from background is observed.
- Can set model independent limits (LHS axis) using a 95% CL upper limit as function of mass and lifetime for a new χ, in the range studied.
- Assuming new particle is scalar we can set limits to BF (RHS axis).
- Best limits are $O(10^{-9})$ for $\tau < \sim 10$ ps. Less stringent for larger lifetime (due to loss of reconstruction efficiency). Vetoed regions are visible as before.



Review of results

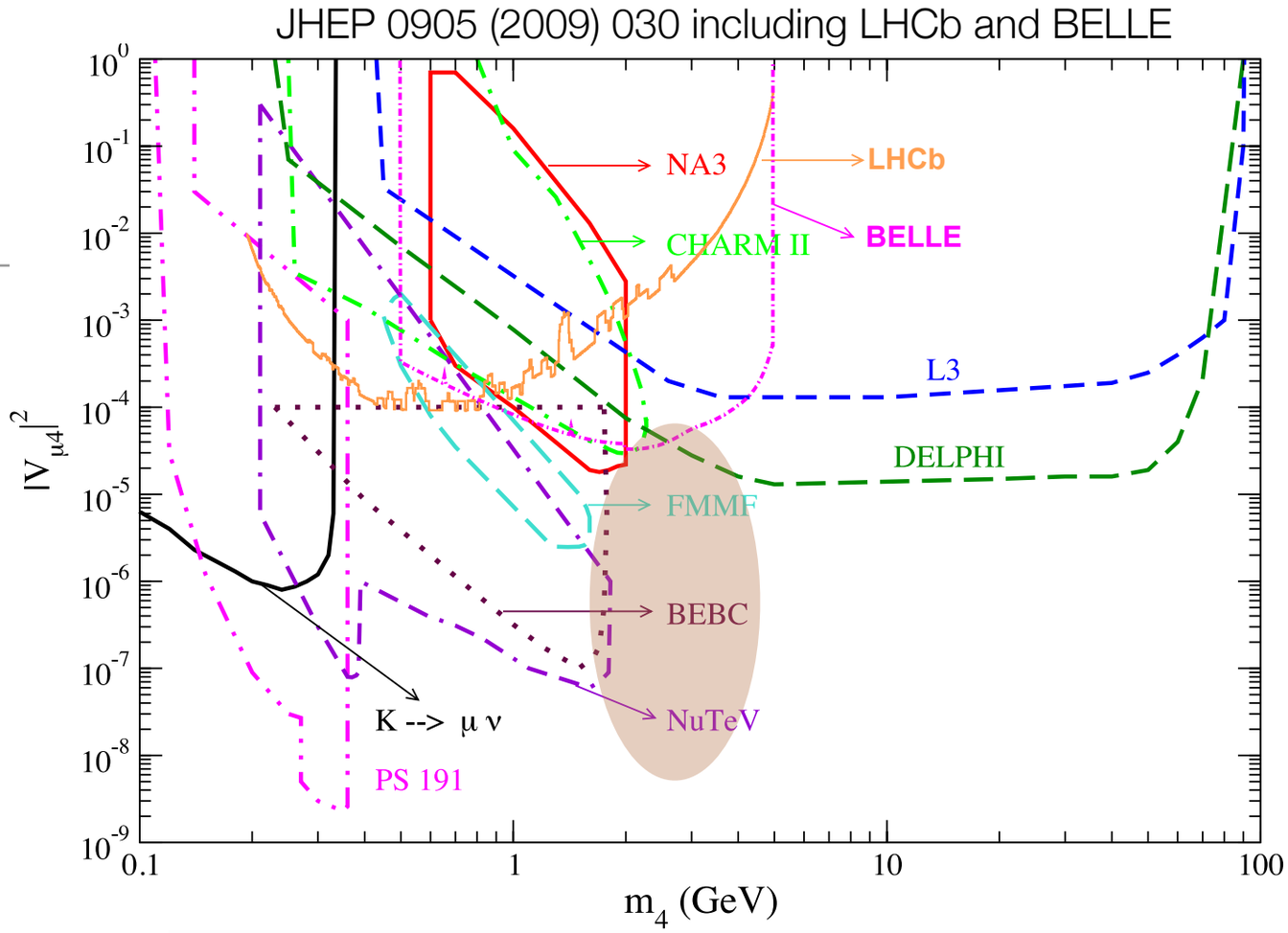
- Model dependent and model independent. Showing here model dependent for $B \rightarrow X_s L$, where X_s is a strange hadron (S=−1) and $_+L_-$ is a long-lived neutral particle decaying to f=*l l'* l = (e, μ, K).
- Requirements: displaced L vertex and two body decay kinematics. No additional specific requirements on the reaction.
- Search performed by fitting L mass distribution.
- W.r.t. LHCb is more general but also larger background.
  - No attempt to set limits for $\tau_L < 30$ps.
  - Where limits are set, LHCb is more stringent.

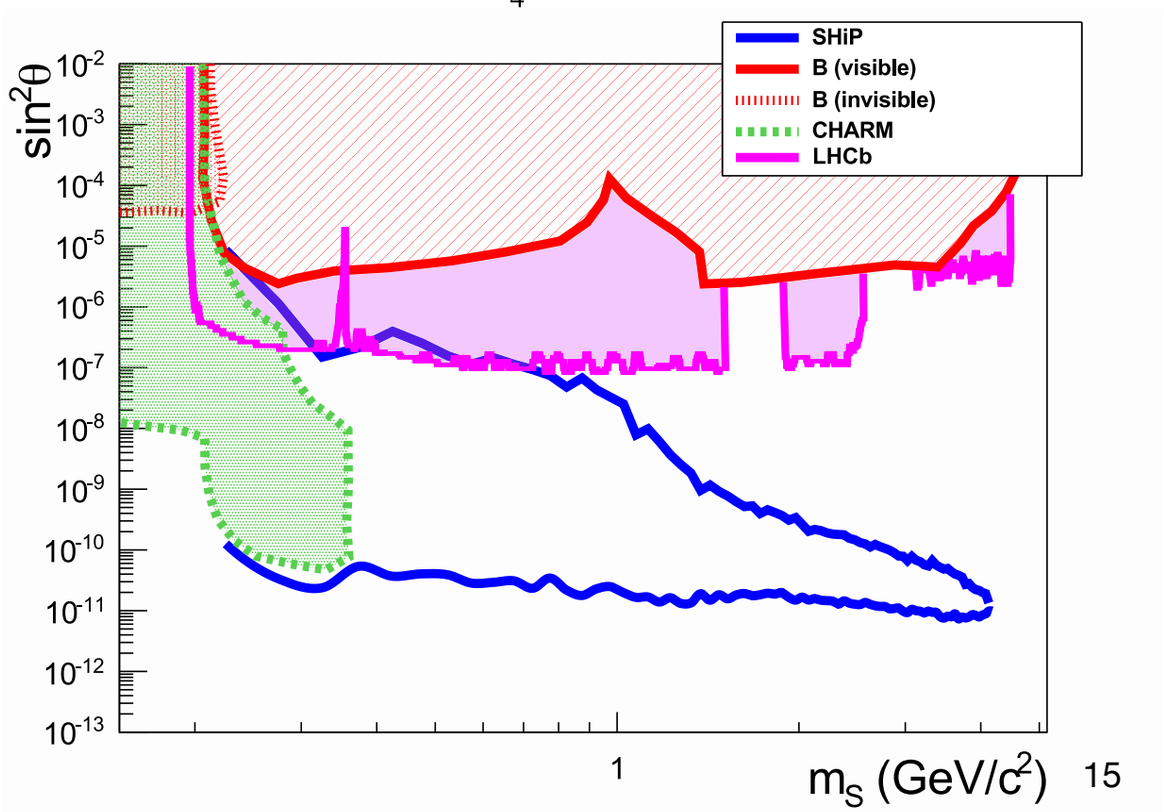


Phys.Rev.Lett. 114 (2015) 171801

Conclusions

- A number of new results on searches for low mass in heavy flavour hadron decay.
- Majorana neutrino and dark bosons are most recent results, LHCb plays a key role in the game.
- World's best limits on several branching fractions, possibility to set world's best limits on fourth generation coupling in phase space above charm threshold.
- B factories continue to exploit their dataset and will come back with BELLEII, until then it is up to the LHC.
- New results from LHCb are to be expected both with new and old data.





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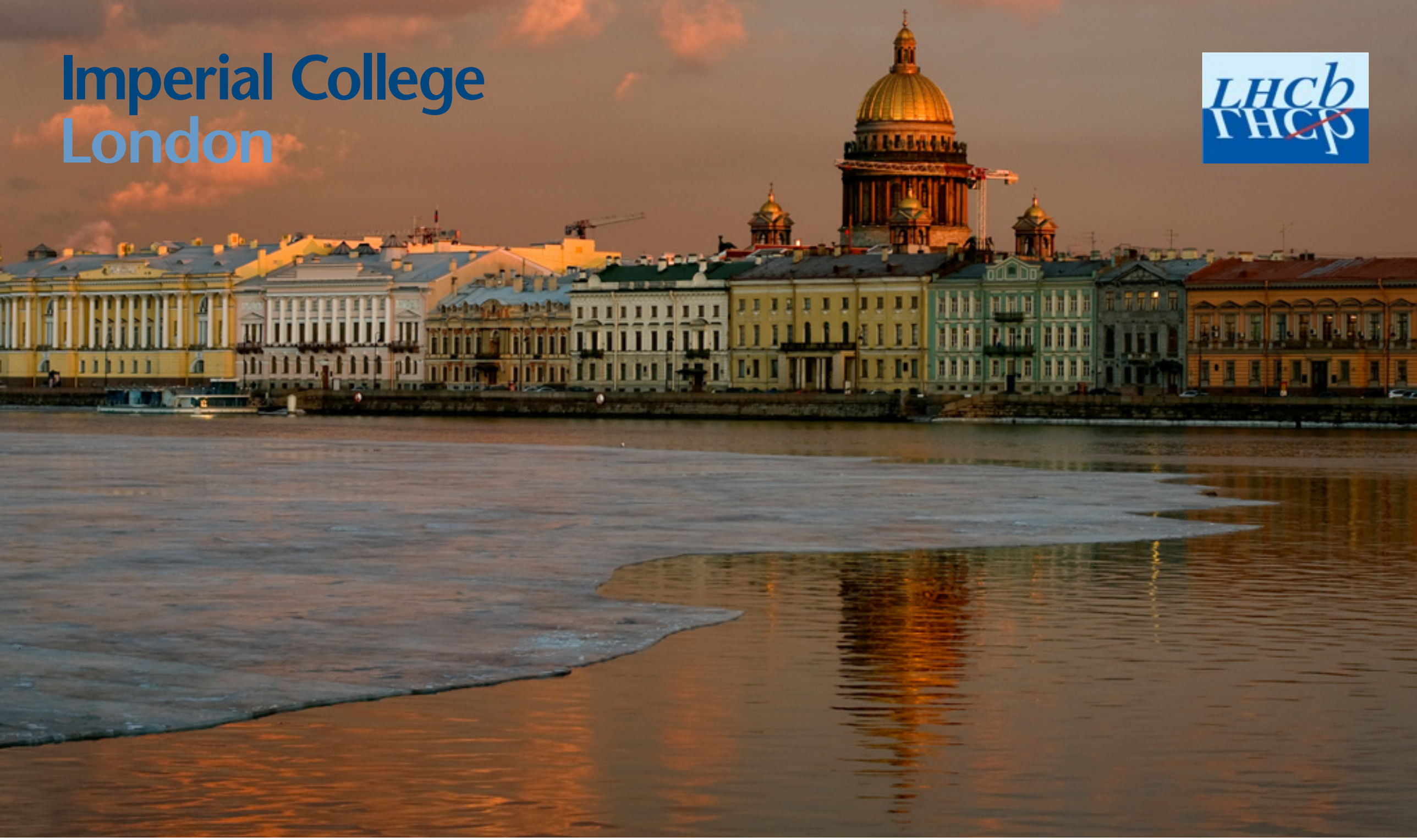
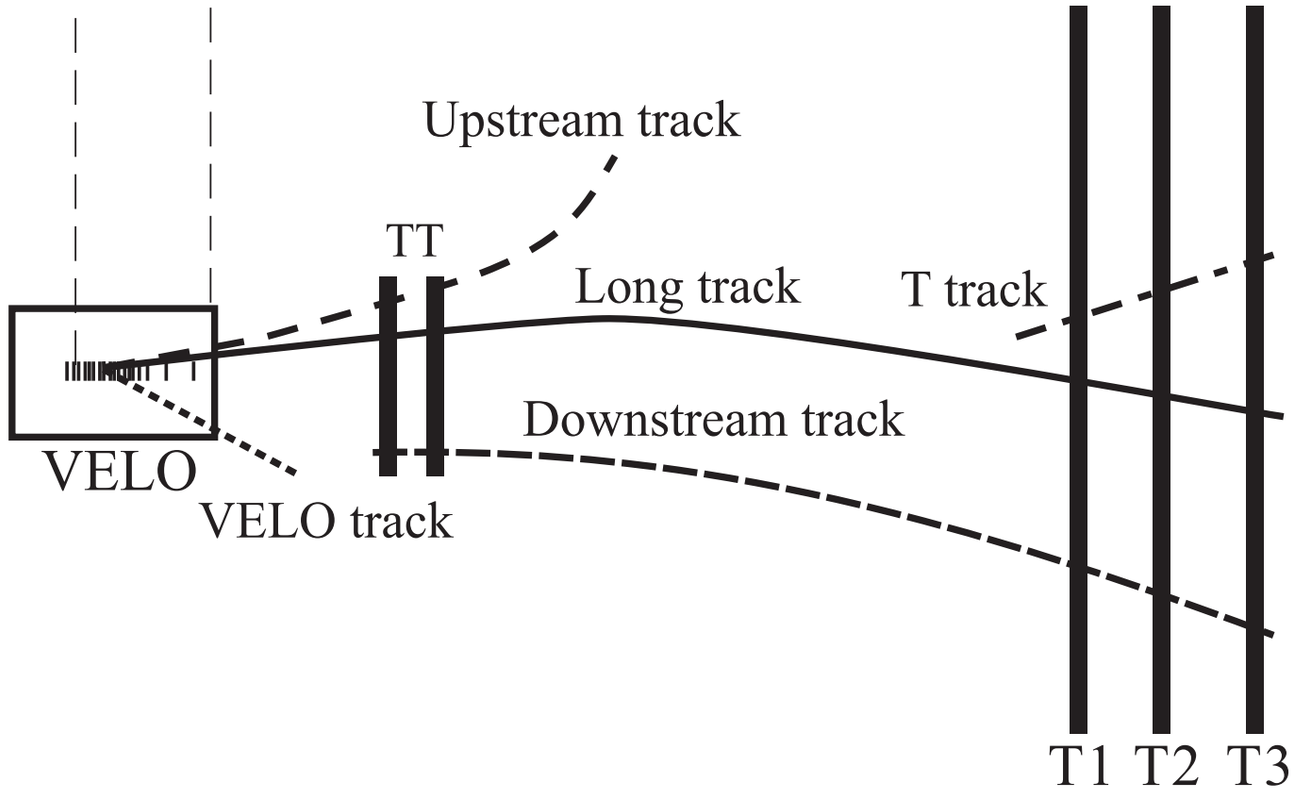


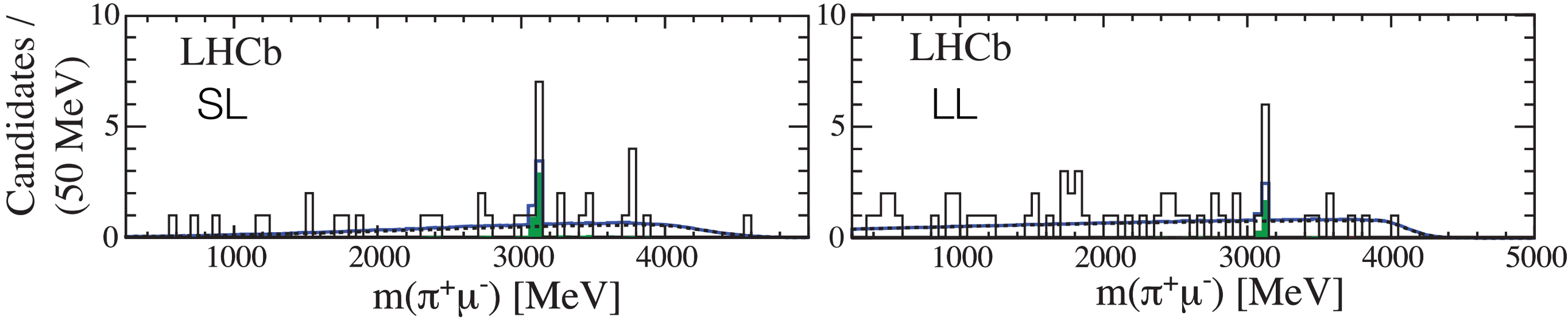
Thanks | Federico Leo Redi

LHCb track types



Bkp \ Scan in m_N for Majorana in LHCb

- No evidence for a signal, upper limits are set by scanning across the mN window.
- At every 5 MeV step beginning at 250 MeV and ending at 5000 MeV we define a ±3σ search region, where σ ranges from approximately 3 MeV at low mass to 24 MeV at high mass.
- The fitted background is then subtracted from the event yields in each interval. The upper limit at 95% C.L. of Bf($B^- \to \pi^+ \mu^- \mu^-$) at each mass value is computed using the CLs method.



Phys.Rev.Lett. 112 (2014) 131802

Limits from LHCb together with BaBar for Majorana neutrino

Channel	$\mathcal{B}_{UL}$ 95% CL
$B^+ \to K^- \mu^+ \mu^+$	5.4×10^{-8}
$B^+ \to D^- \mu^+ \mu^+$	6.9×10^{-7}
$B^+ \to D^{*-} \mu^+ \mu^+$	2.4×10^{-6}
$B^+ \to \pi^- \mu^+ \mu^+$	4.0×10^{-9}
$B^+ \to D_s^- \mu^+ \mu^+$	5.8×10^{-7}
$B^+ \to D^0 \pi^- \mu^+ \mu^+$	1.5×10^{-6}

Channel	$\mathcal{B}_{UL}(\times 10^{-7})$
$B^+ \to K^{*-} e^+ e^+$	4.0
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Production and decay of Majorana neutrino at BELLE