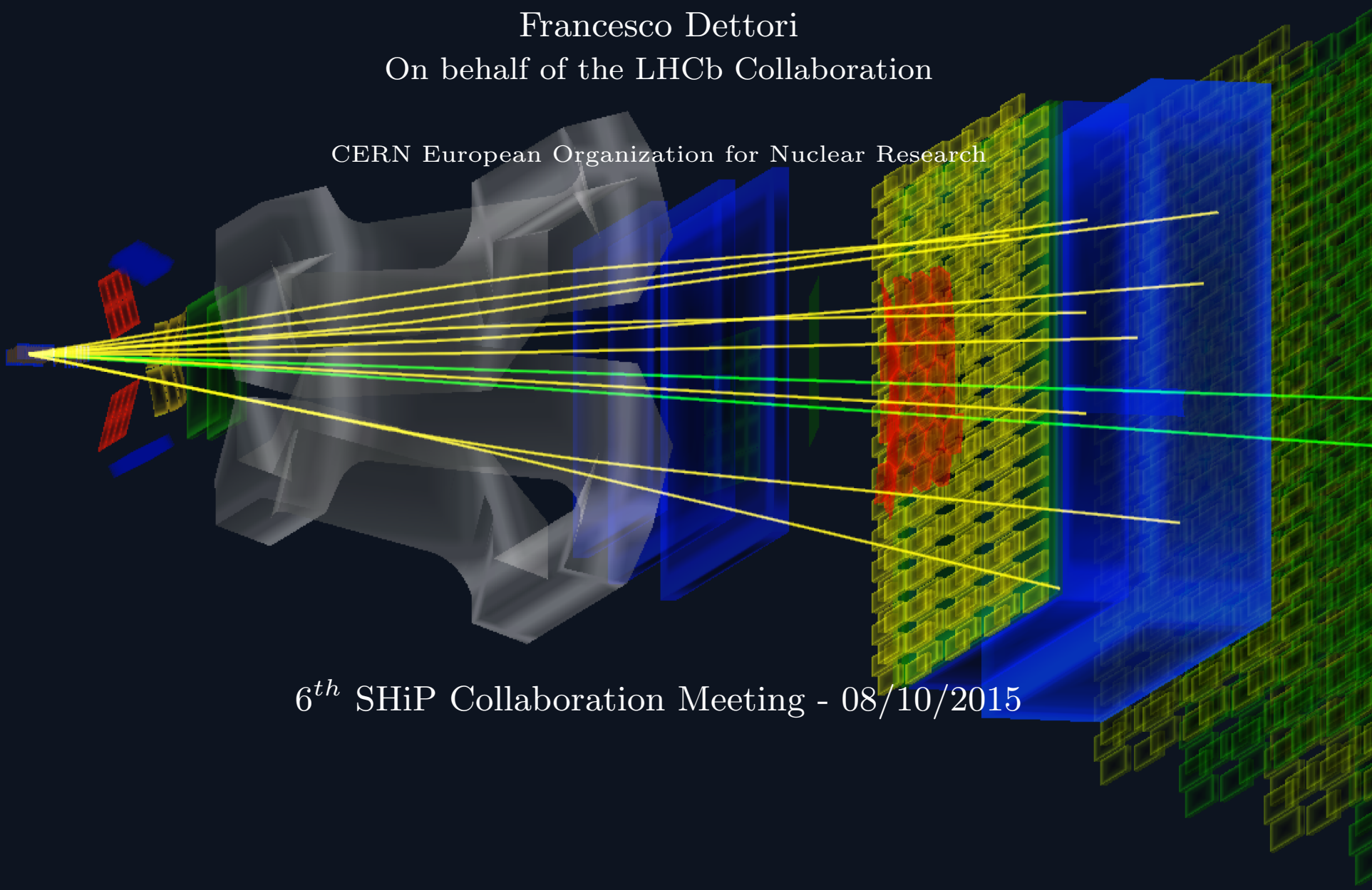
Searches for long lived particles at LHCb

Francesco Dettori
On behalf of the LHCb Collaboration

CERN European Organization for Nuclear Research

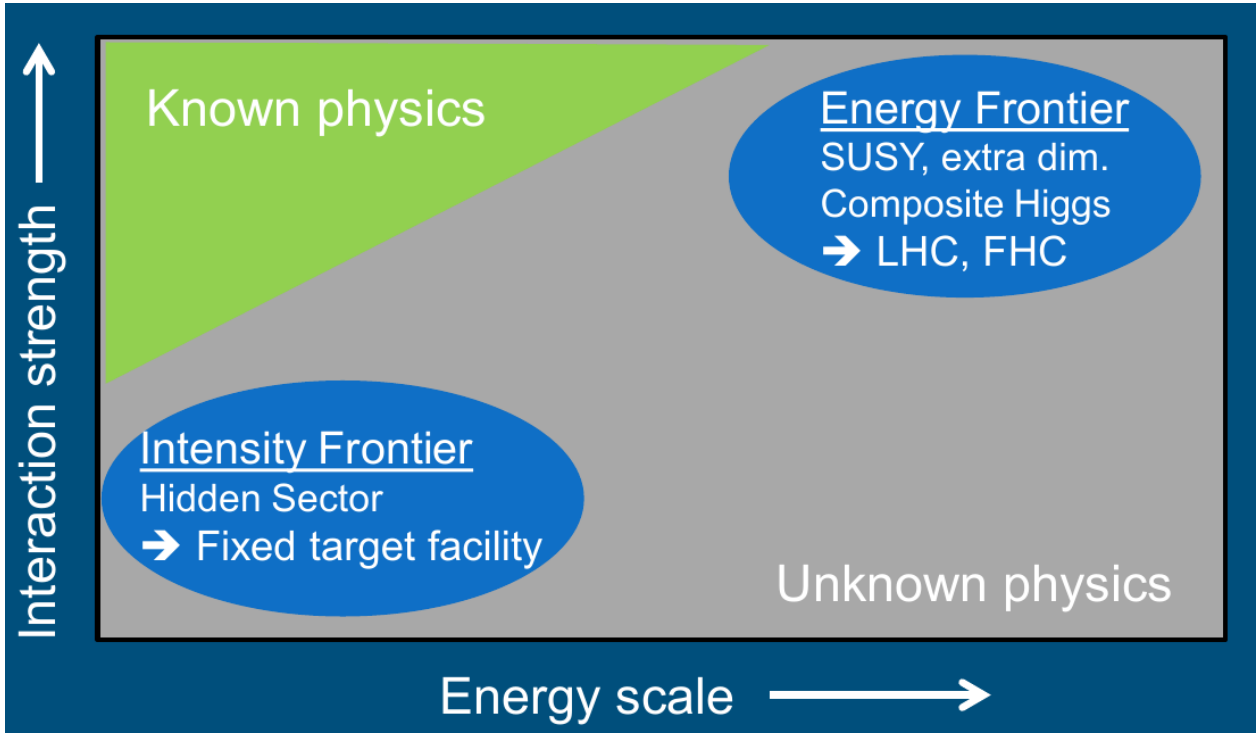


6^{th} SHiP Collaboration Meeting - 08/10/2015

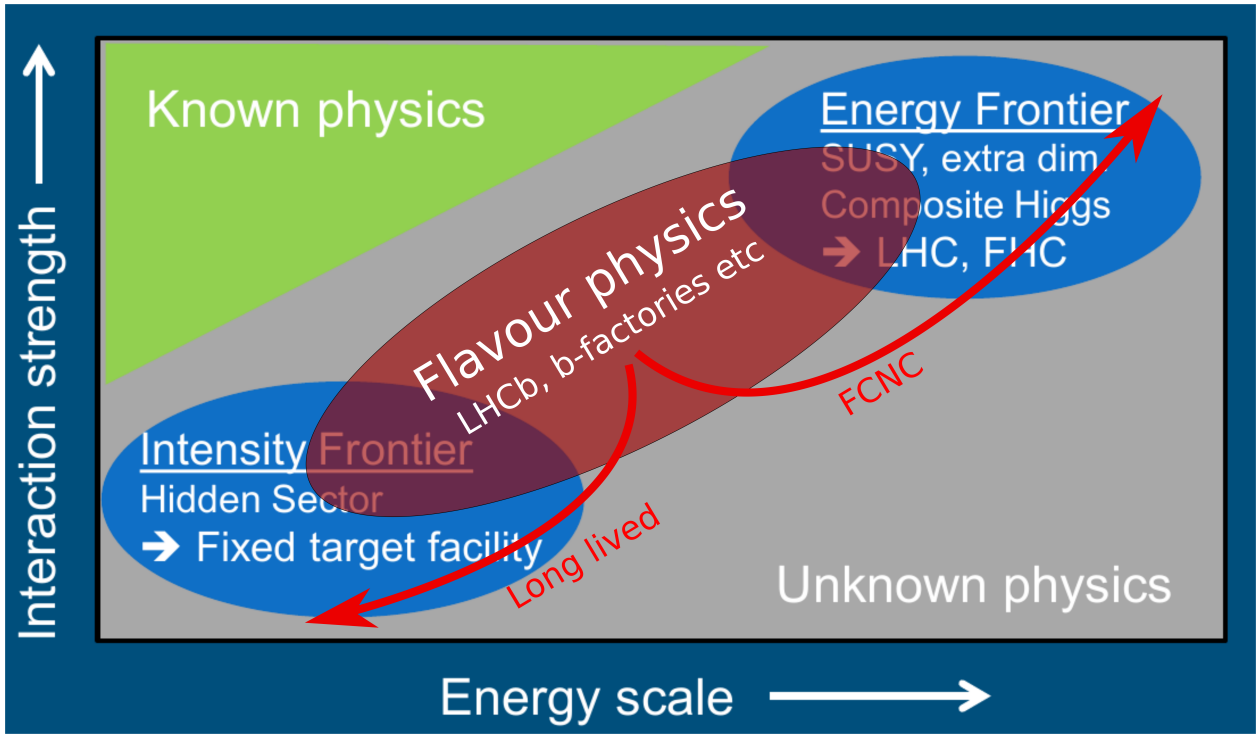
Outline

- LHCb for long lived particles
- Searches for Majorana neutrinos
- Search for long-lived particles decaying to jet pairs
- Search for hidden-sector bosons in $B_d^0 \to K^* \mu^+ \mu^-$ decays

Flavour as a tool for discovery



Flavour as a tool for discovery

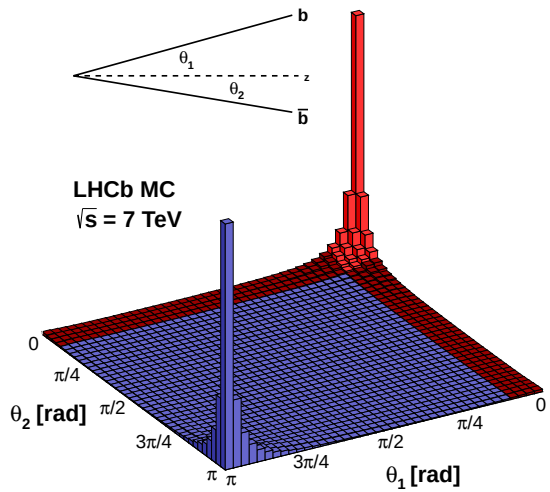


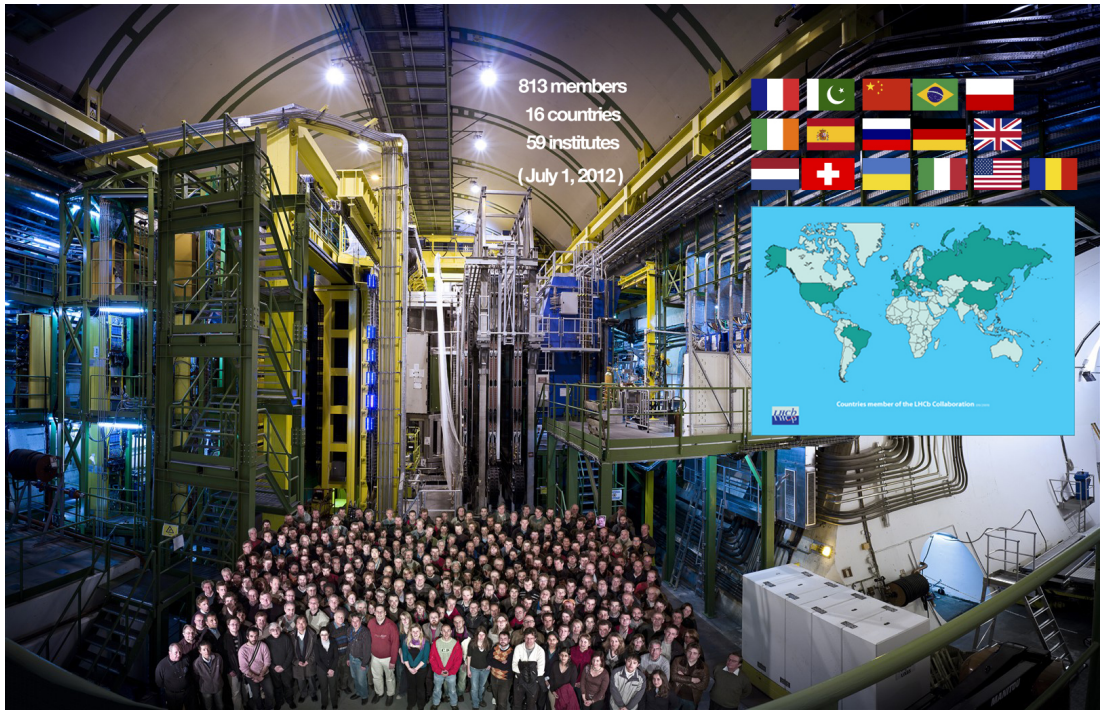
Between the intensity and energy frontiers there is the flavour land which rather than a frontier can be viewed as a tool to jump at the frontiers

The LHCb experiment

Large Hadron Collider
as flavour factory

- pp collisions at 7-8-13 TeV
- Large b-quark production in the forward region
- Full b-hadrons spectrum
- $\mathcal{L} = 3 - 4 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- $\int \mathcal{L} = 3.0 \mathrm{fb}^{-1}$ in Run I
  $\Rightarrow \mathcal{O}(10^{12})$ $b\bar{b}$ pairs

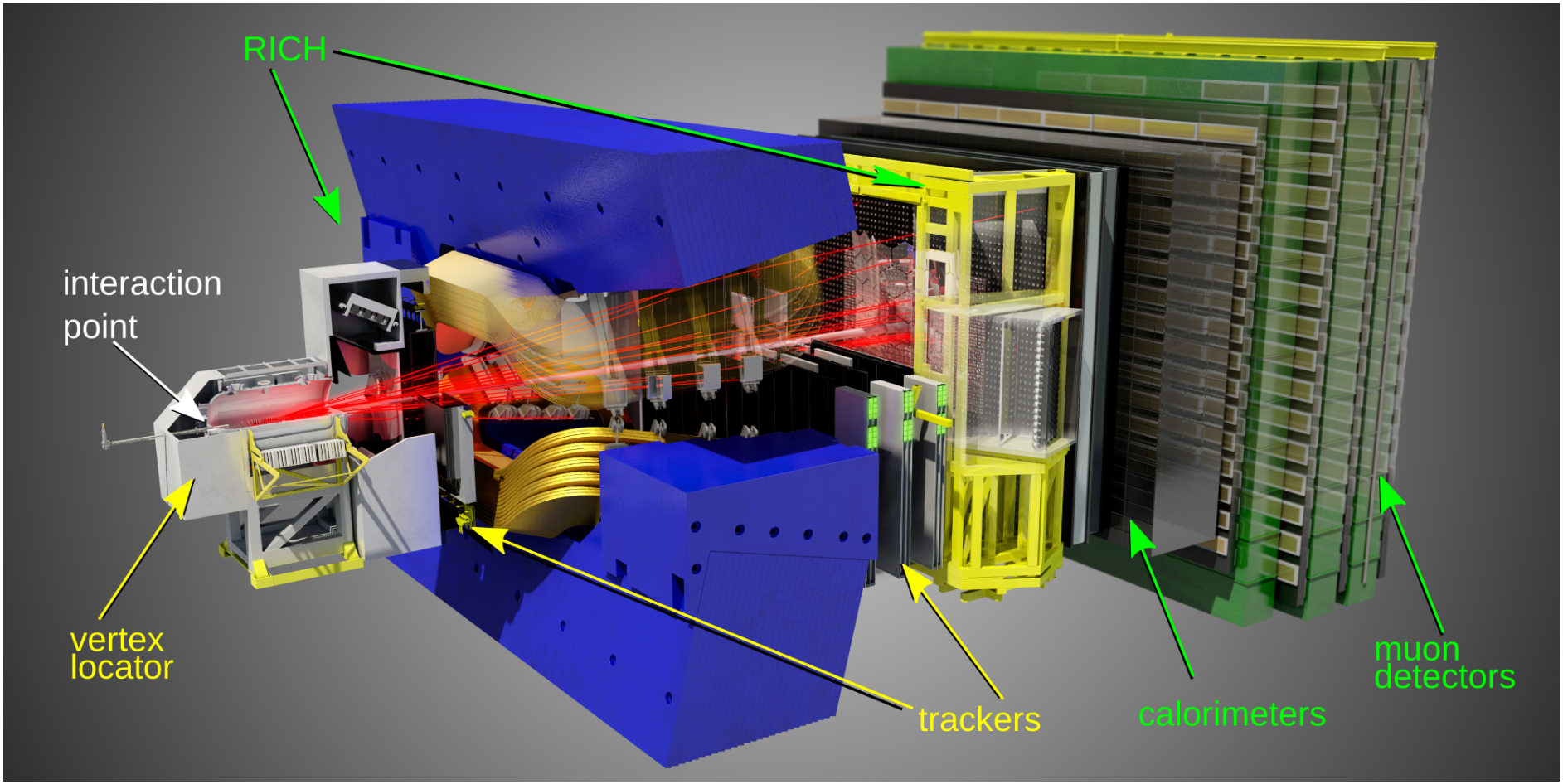




LHCb:

- Specialized B-physics experiment
- Forward single arm spectrometer
- Acceptance: $2 < \eta < 5$

The LHCb detector



Excellent vertex and IP resolution

- $\sigma(IP) \simeq 24\mu$m at $p_{\mathrm{T}} = 2$ GeV/c
- $\sigma_{\mathrm{BV}} \simeq 16\mu$m in x, y

Very good momentum resolution

- $\sigma(p)/p = 0.5\% - 0.8\%$ for $p \in (0, 100)$ GeV/c
- $\sigma(m_B) \sim 25$ MeV for two body decays

Muon identification

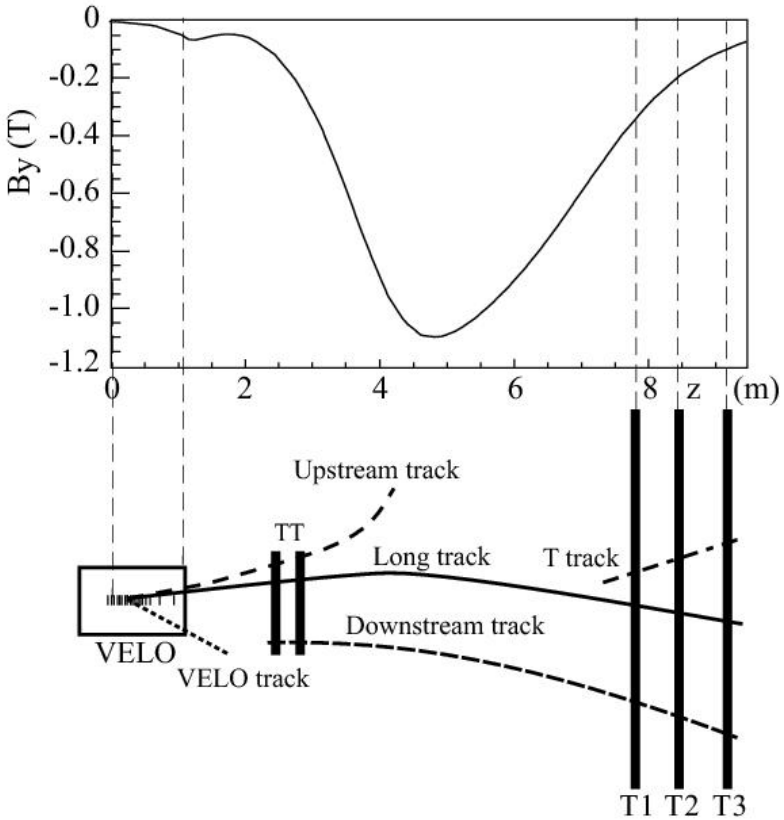
- $\varepsilon_\mu = 98\%$, $\varepsilon_{\pi\to\mu} = 0.6\%$, $\varepsilon_{K\to\mu} = 0.3\%$, $\varepsilon_{p\to\mu} = 0.3\%$

Trigger

- $\varepsilon_\mu = 90\%$

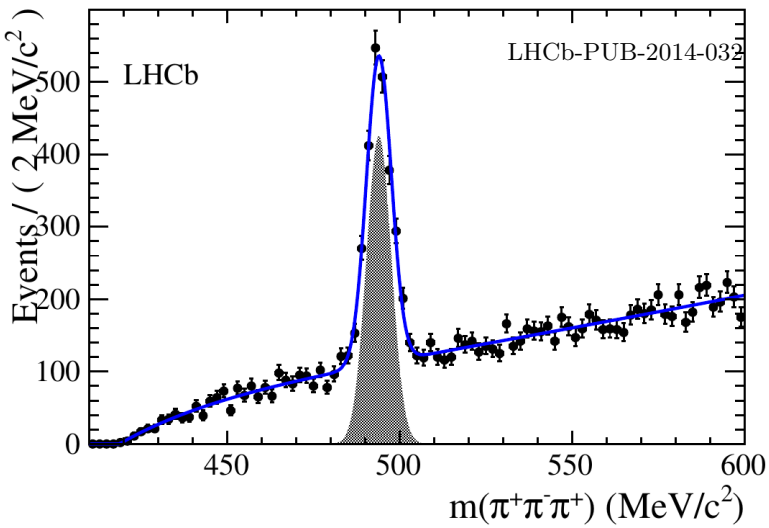
Int. J. Mod. Phys. A 30 (2015) 1530022

How long lived?



- Less than 1 meter of decay length for particles reconstructed with long tracks
- Up to about 2 meters for downstream tracks
- Sensitivity to lifetimes of the order of nanoseconds

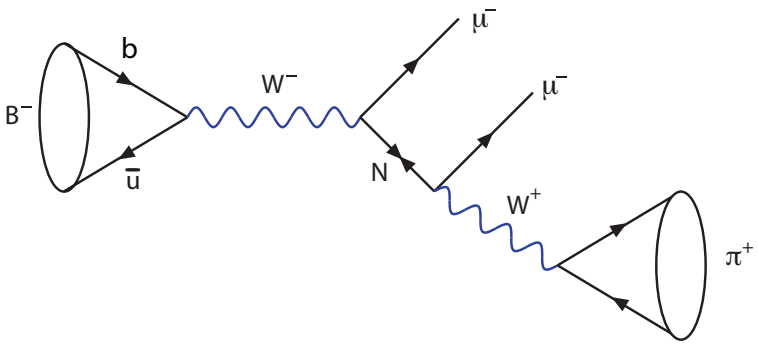
Example: $K^+ \to \pi^+\pi^-\pi^+$ decay reconstructed with downstream tracks.

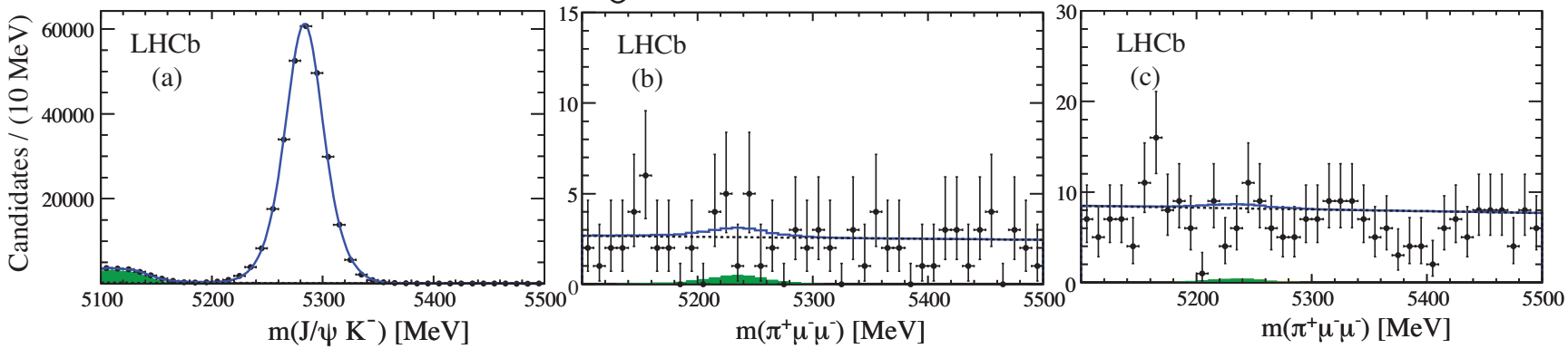


Search for Majorana neutrinos at LHCb: $B^- \to \pi^+\mu^-\mu^-$

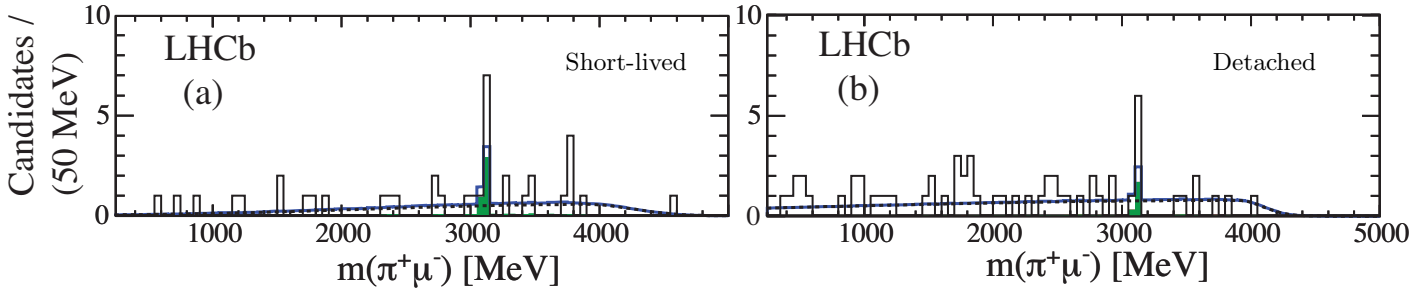
PRL 112, 131802 (2014)

- Search for Majorana neutrinos $B^- \to \mu^- N(\to \mu\pi)$
- Short and detached topologies (up to 1000 ps)
- No excess in the B mass: $\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 4.0 \cdot 10^{-9}$ (95%CL)

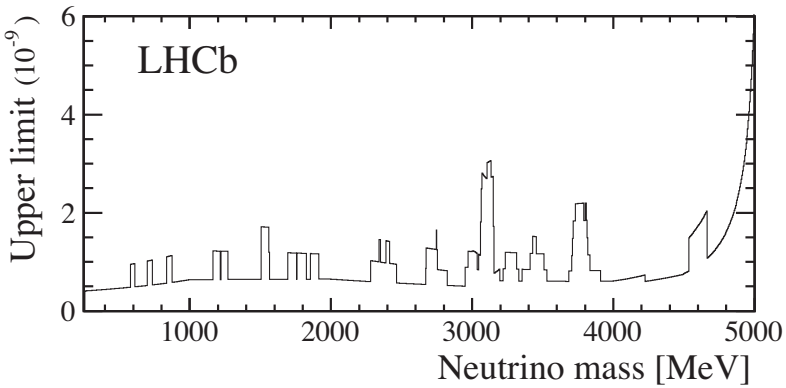


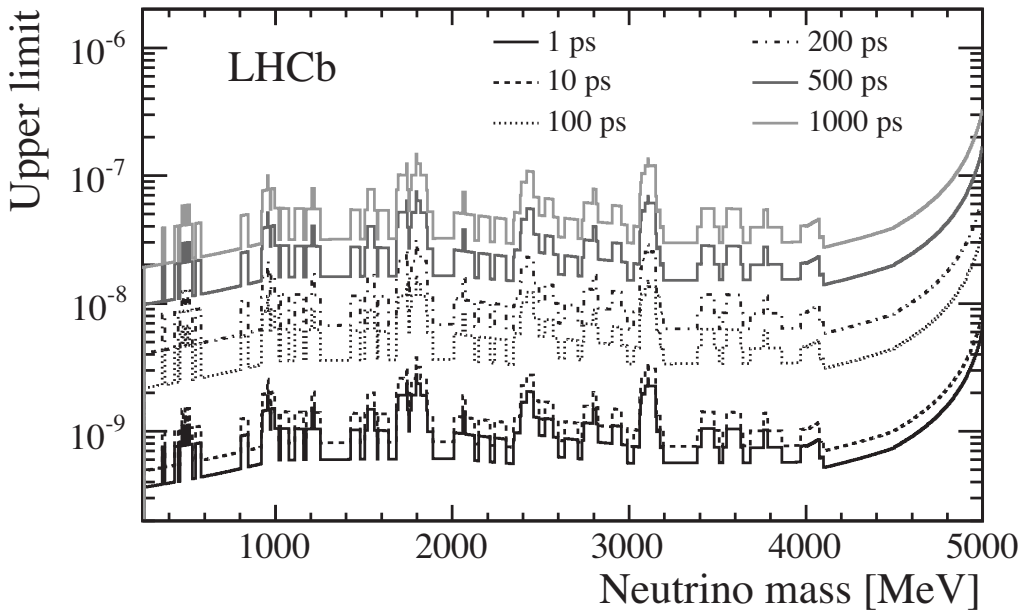


Search for Majorana neutrinos at LHCb: $B^- \to \pi^+ \mu^- \mu^-$



- Upper limit with CLs method
- Efficiency varies depending on τ_N
- Different upper limits as a function of τ_N



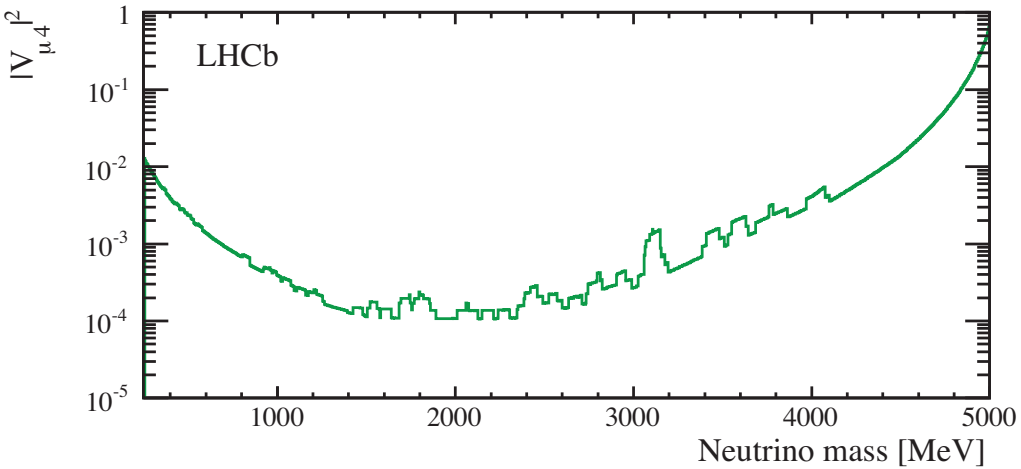


PRL 112, 131802 (2014)

Search for Majorana neutrinos at LHCb: $B^- \to \pi^+\mu^-\mu^-$

PRL 112, 131802 (2014)

- Upper limits on a fourth generation neutrino coupling $|V_{\mu 4}|$
- Model dependent limit versus m_N



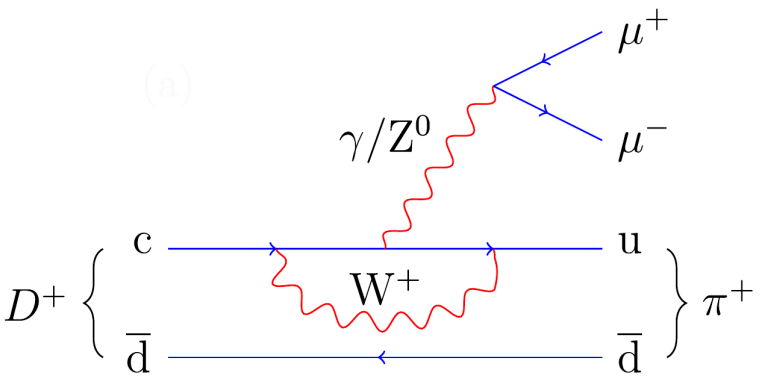
$$\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) = \frac{G_F^4 f_B^2 f_\pi^2 m_B^5}{128\pi^2\hbar}|V_{ub}V_{ud}|^2\tau_B\left(1-\frac{m_N^2}{m_B^2}\right)\frac{m_N}{\Gamma_N}|V_{\mu 4}|^4$$

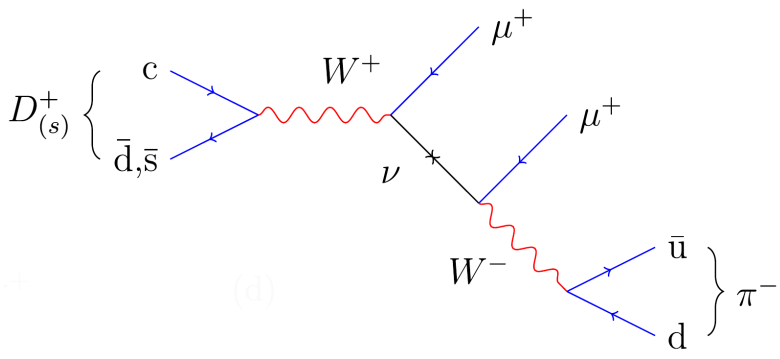
Total width parametrised as:
$\Gamma_N = f(m_N) \times |V_{\mu 4}|^2$

Search for Majorana neutrinos at LHCb: $D^+_{(s)} \to \pi^- \mu^+ \mu^+$

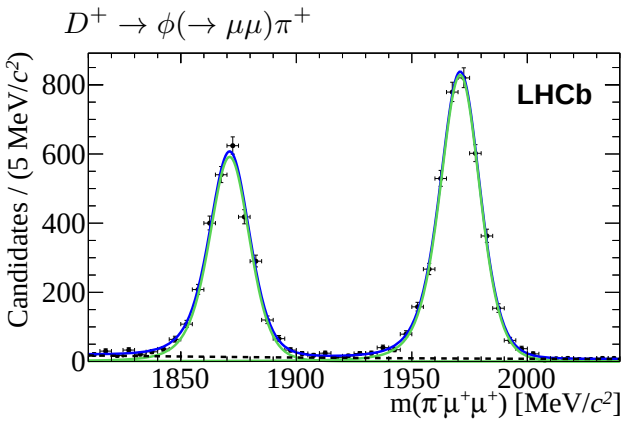
Phys. Lett. B 724 (2013) 203-212

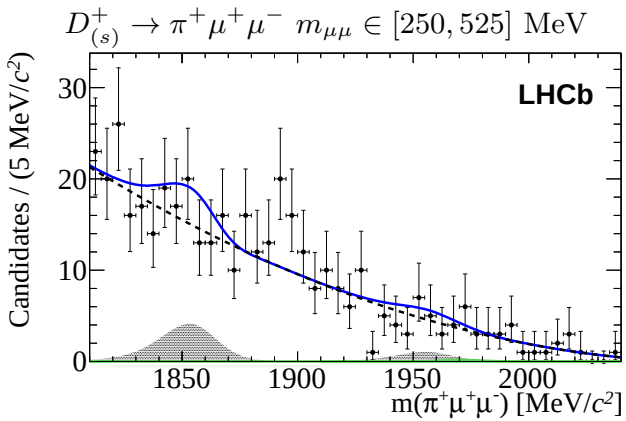
- Search for non-resonant $D^+_{(s)} \to \pi^+ \mu^+ \mu^-$ (FCNC)
- and LFV $D^+_{(s)} \to \pi^- \mu^+ \mu^+$ decays (Majorana neutrinos?)
- $\mathcal{L} = 1\text{fb}^{-1}$ at $\sqrt{s} = 7$ TeV
- Normalise to $D^+_{(s)} \to \phi(\to \mu\mu)\pi^+$
- No displacement allowed in this case

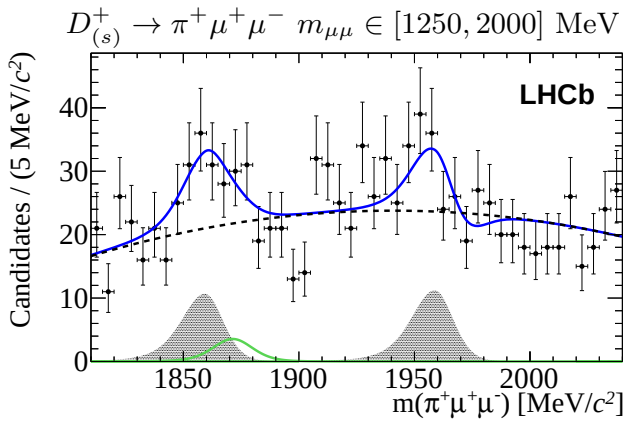




Search for Majorana neutrinos at LHCb: $D^+_{(s)} \to \pi^-\mu^+\mu^+$







Phys. Lett. B 724 (2013) 203-212

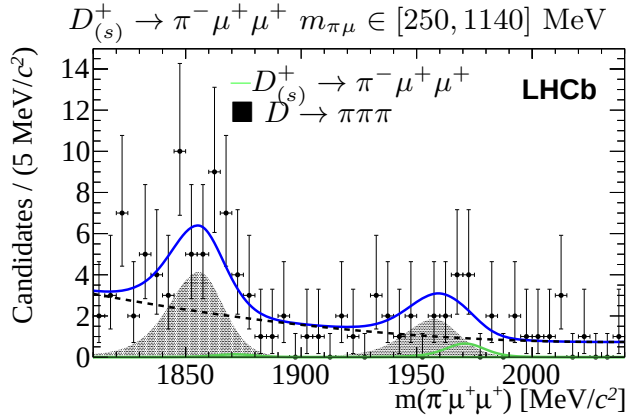
No signal observed, limit at 90%CL:
for FCNC:

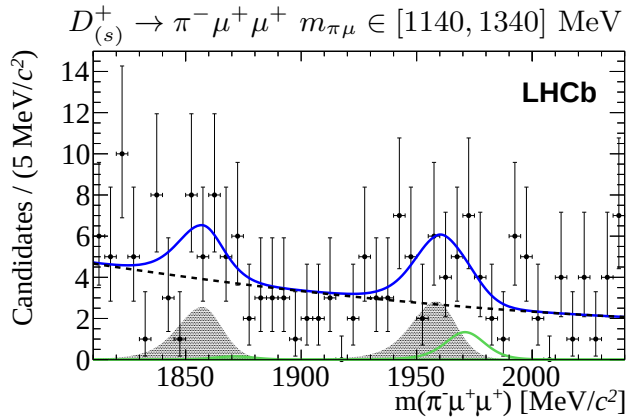
$$\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-) < 7.3 \cdot 10^{-8}$$
$$\mathcal{B}(D_s^+ \to \pi^+\mu^+\mu^-) < 4.1 \cdot 10^{-7}$$

for LFV:

$$\mathcal{B}(D^+ \to \pi^-\mu^+\mu^+) < 2.2 \cdot 10^{-8}$$
$$\mathcal{B}(D_s^+ \to \pi^-\mu^+\mu^+) < 1.1 \cdot 10^{-8}$$

Limits for different $m_{\pi\mu}$ also set

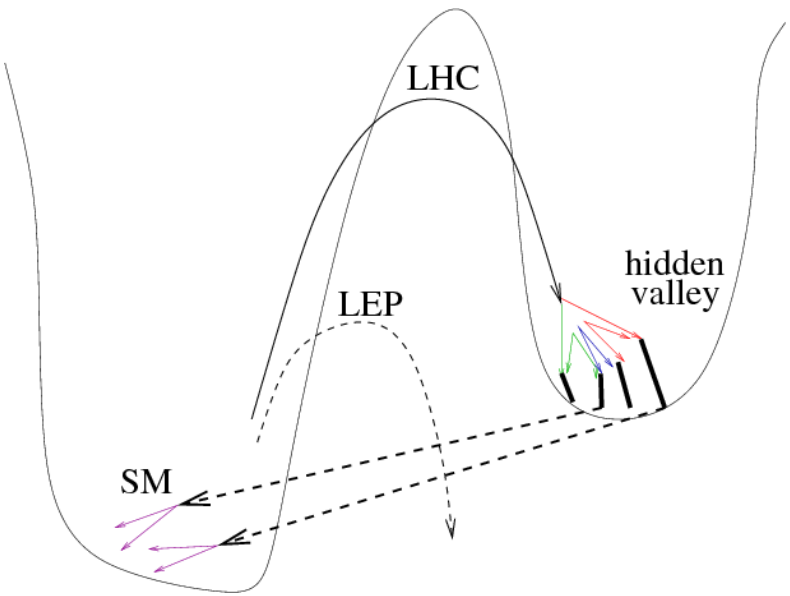




Search for long-lived particles decaying to jet pairs

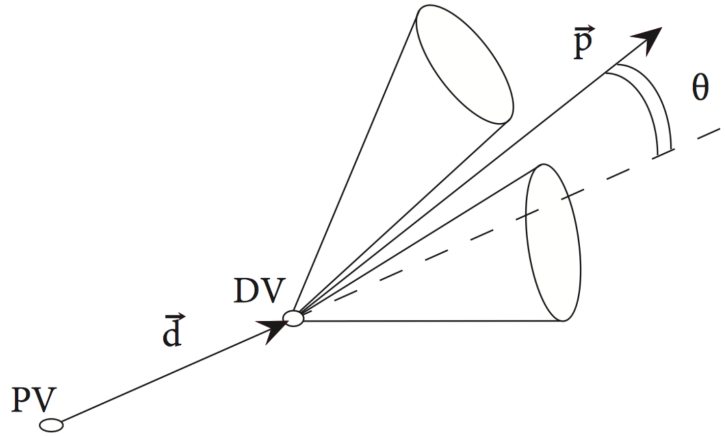
Motivation

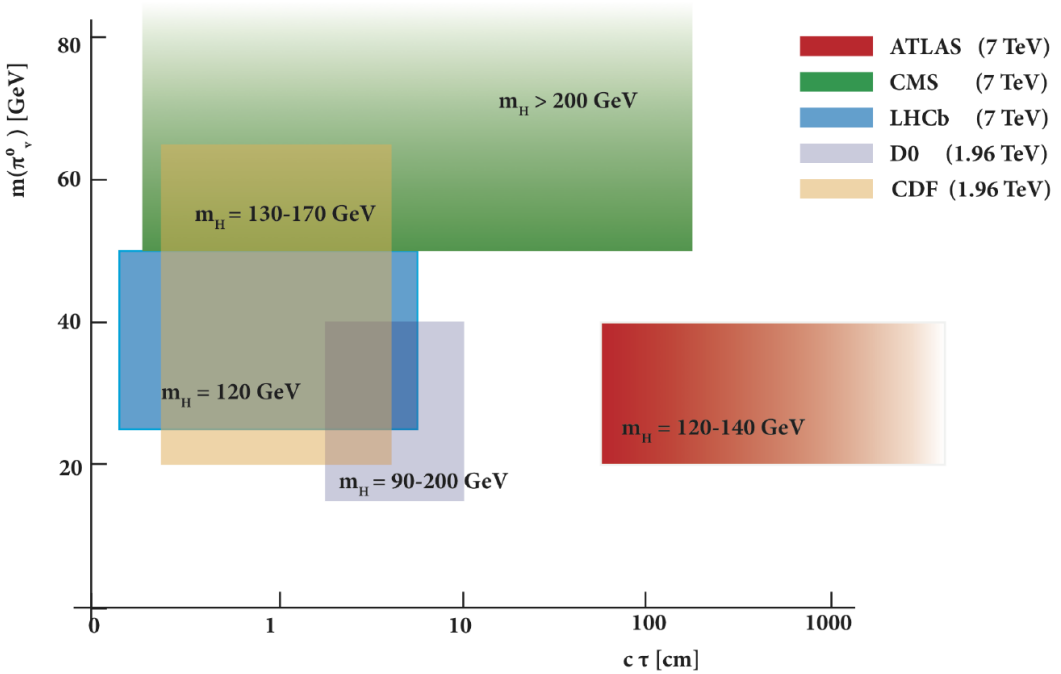
- Some SUSY models with long-lived neutralinos:
  $h^0 \to \chi\chi$, $\chi \to$ 3quarks
  Phys.Rev.Lett. 99 (2007) 211801, [hep-ph/0607204]
- Some Hidden Valley models
  $h^0 \to \pi_V \pi_V$, with $\pi_V \to b\bar{b}$ Phys.Lett. B651 (2007) 374379,[hep-ph/0604261]



Search for long-lived particles decaying to jet pairs

- Experimentally:
  a pair of jets coming from same vertex, displaced from the primary vertex
  (the second particle is undetected)
- Complementary phase space to other experiments

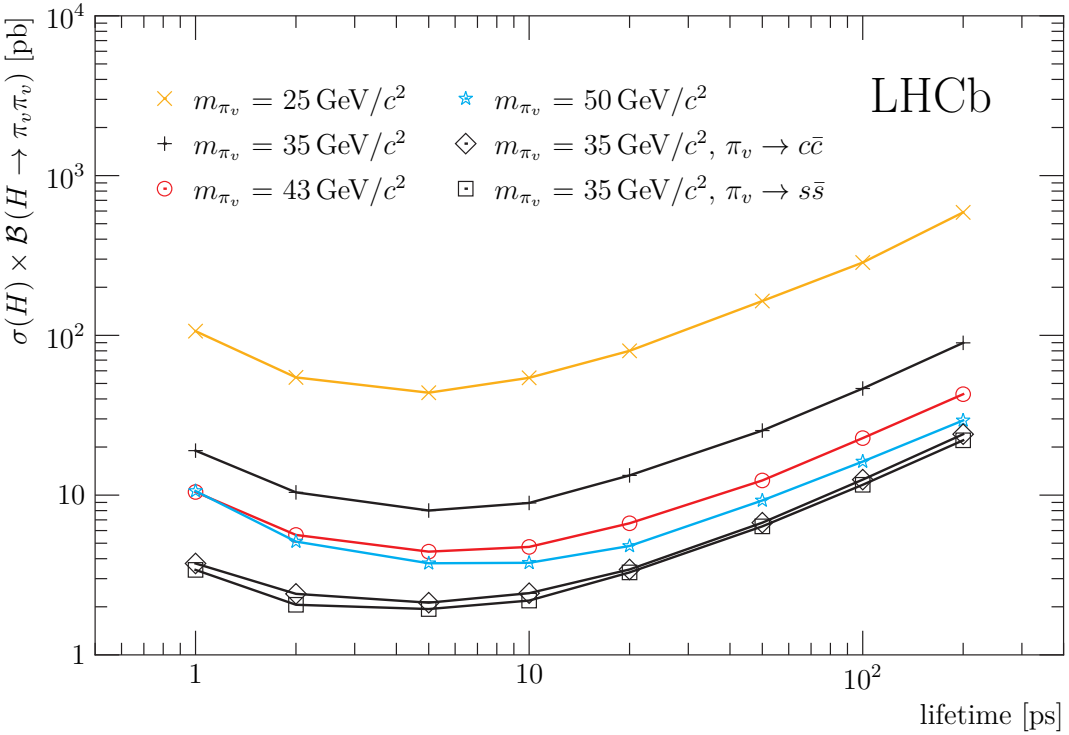


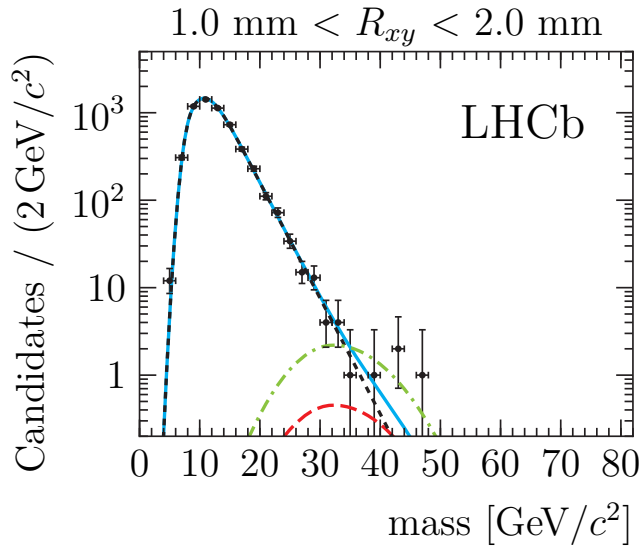


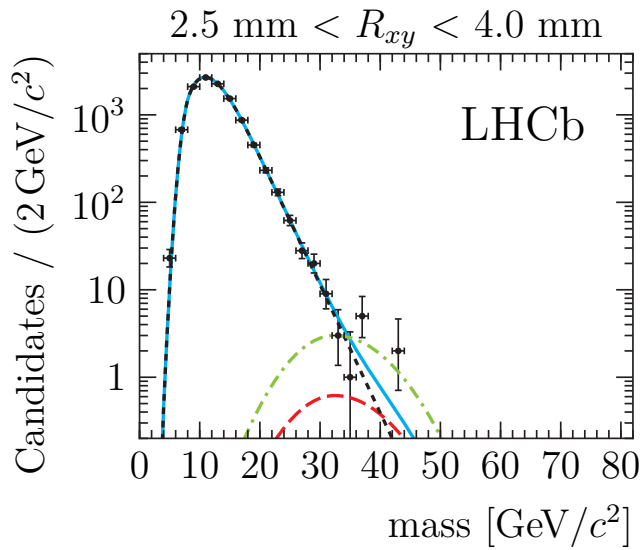
Eur. Phys. J. C75 (2015) 152

Search for long-lived particles decaying to jet pairs

- Jets reconstructed with particle flow
- Exploited 0.62fb^{-1} at 7 TeV
- Search in reconstructed mass and radial distance from the beam
- Limits for different π_V masses and lifetimes



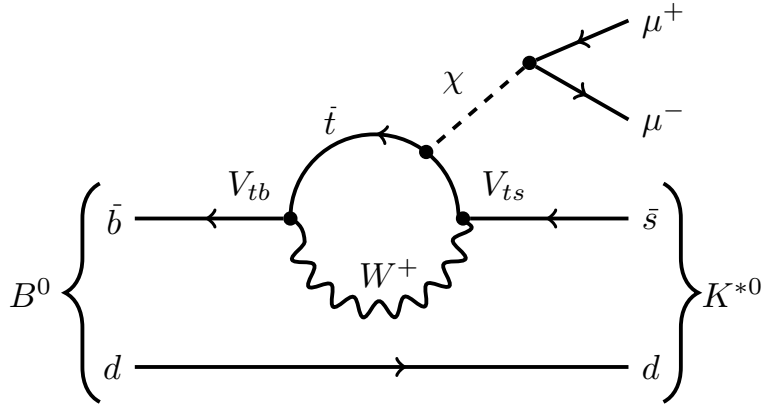


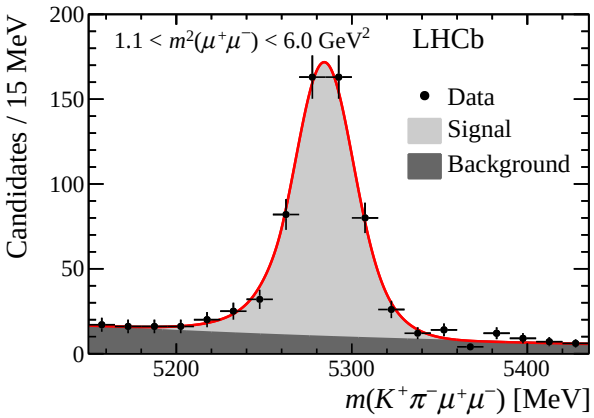


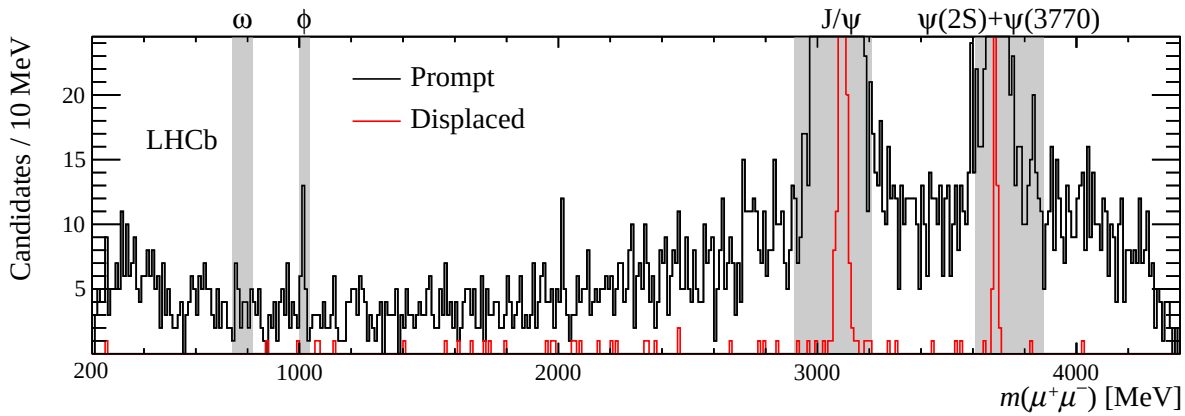
Eur. Phys. J. C75 (2015) 152

Search for hidden-sector bosons in $B^0_d \to K^*\mu^+\mu^-$ decays

- Search for $B^0_d \to K^*\chi$ with $\chi \to \mu\mu$
- Both prompt and displaced events searched for
- Standard selection
- Narrow resonances vetoed, others handled within profile likelihood
- Scan in mass and lifetime of χ
- Normalization to $B^0_d \to K^*\mu^+\mu^-$
- Limits with scan in mass (JINST 10 (2015) P06002)

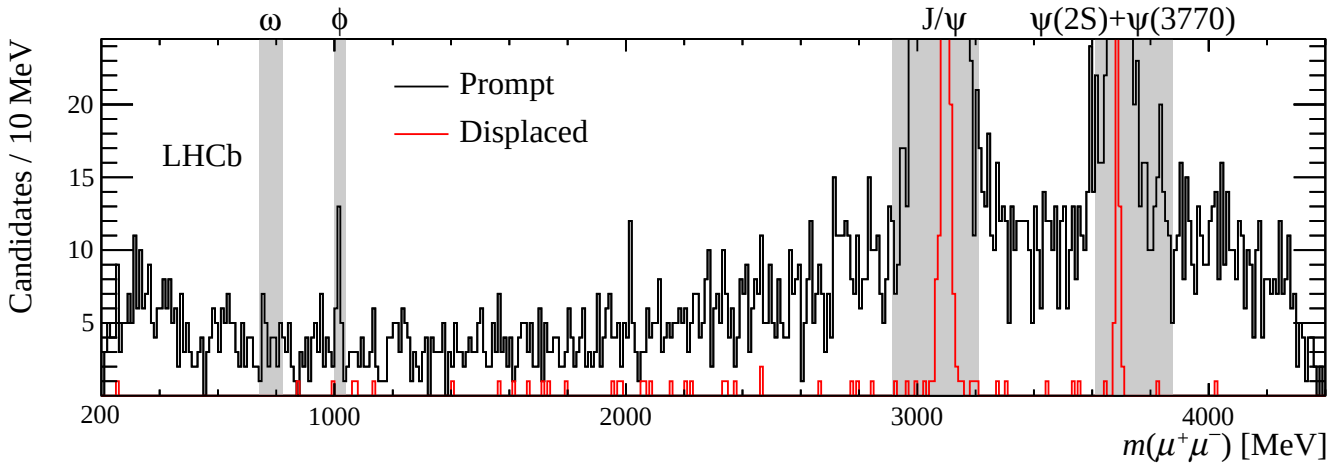


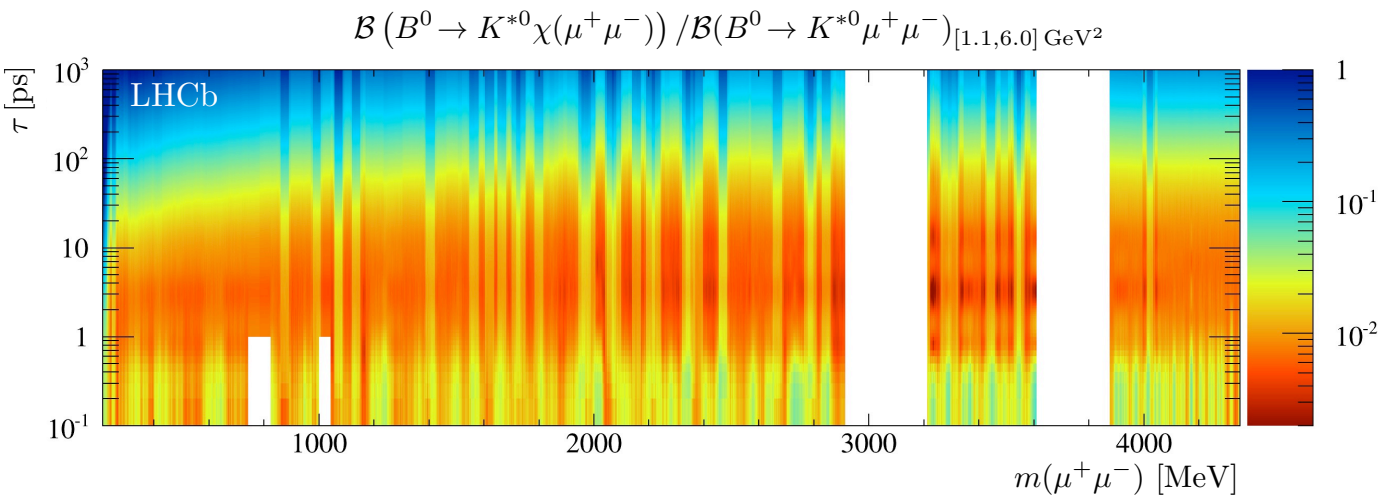




LHCb-PAPER-2015-036 - Accepted by PRL

Search for hidden-sector bosons in $B^0_d \to K^* \mu^+ \mu^-$ decays





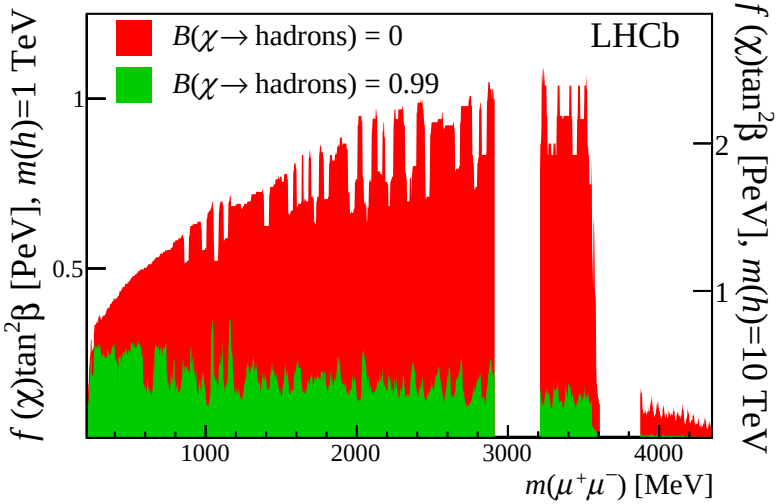
Limits set assuming spin = 0 for the hidden boson
Limits for different spin assumptions also provided

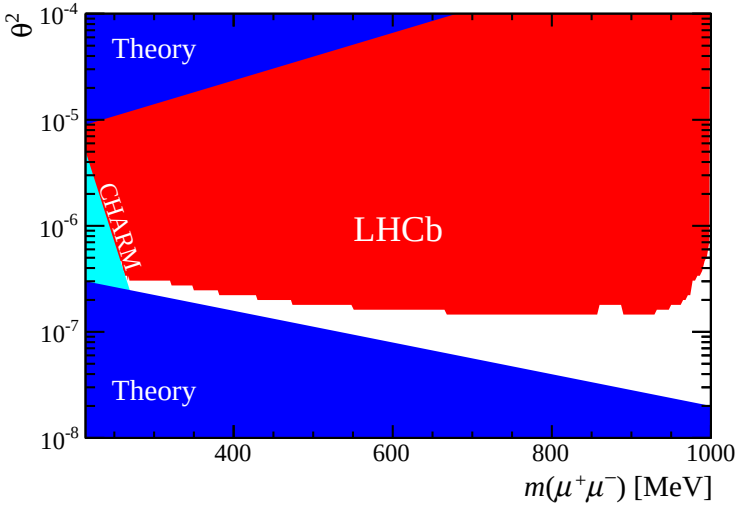
LHCb-PAPER-2015-036 - Accepted by PRL

Search for hidden-sector bosons in $B^0_d \to K^* \mu^+ \mu^-$ decays

Constrains on an

- Axion model (Freytsis et al. Phys.Rev.D81 034001 2010)
- Inflaton model (Bezrukov et al. Phys.Lett. B736 (2014) 494)

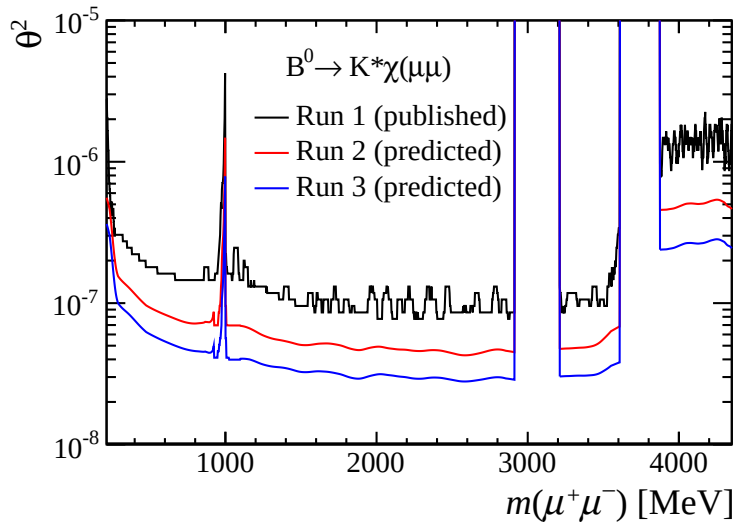




Where do we go from here?

- Data-taking restarted at 13 TeV
- About double cross-section for b and c hadrons
- LHCb will accumulate in Run II about 5 fb^{-1}
- LHCb Upgrade will improve the detector and collect higher luminosities (Run III about 15 fb^{-1}, for the full dataset $>$ 50fb^{-1} are expected)

- Extrapolation of $B^0_d \to K^* \chi(\mu^+\mu^-)$
- Limit on scalar mixing angle
- Addition of downstream $\mu\mu$ pairs

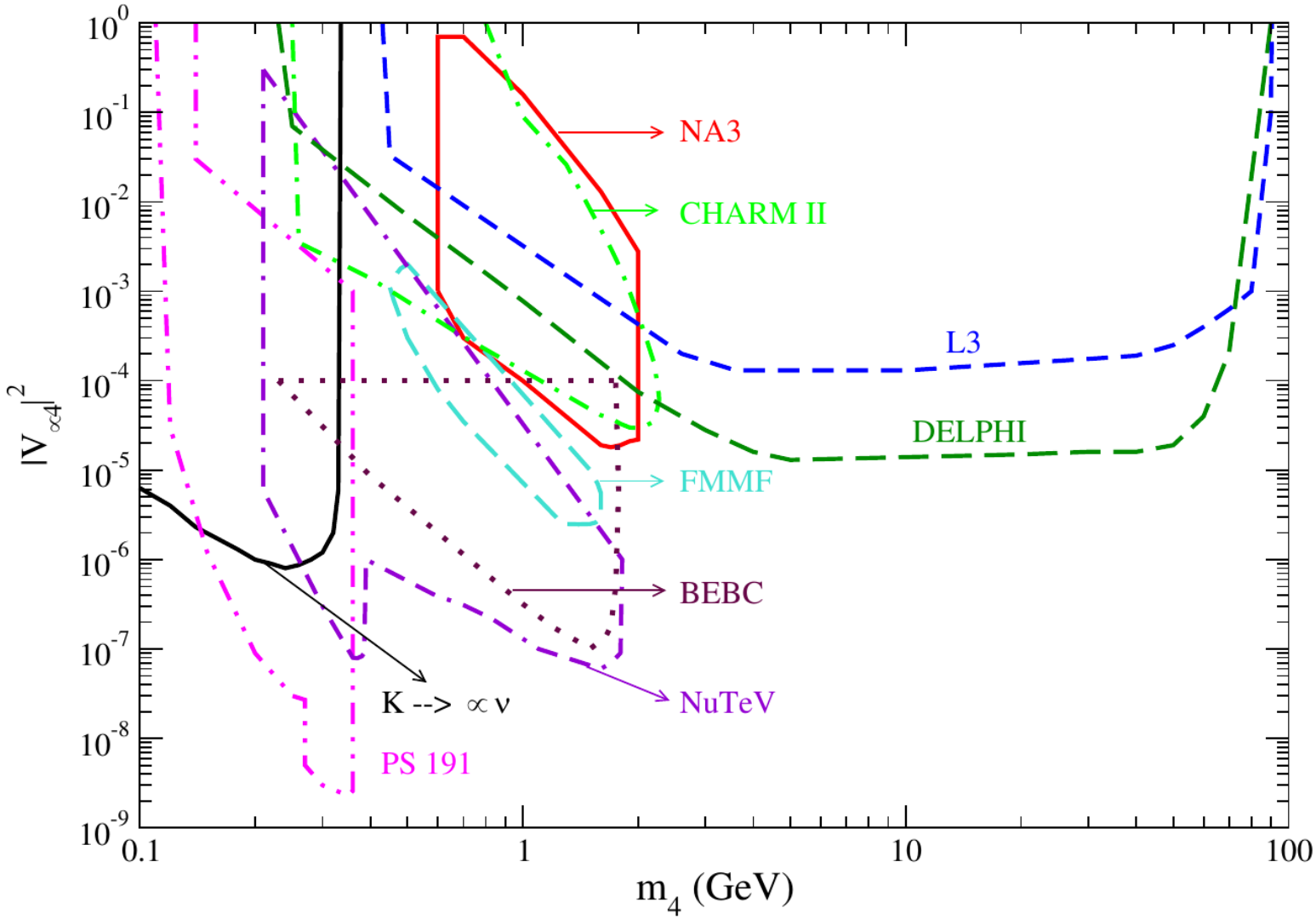


Conclusions and outlook

- LHCb has competitive performances for long-lived particles
- Long lived particles also studied with jets, complementary phase space to GPD
- Searches for Majorana neutrinos and dark bosons put world best limits

- Many new searches on their way with Run I data
- Run II data has improved trigger and larger cross-sections

Additional material


NA3
CHARM II
L3
DELPHI
FMMF
BEBC
NuTeV
K --> ∝ ν
PS 191
$|V_{\propto 4}|^2$
m_4 (GeV)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0.1
1
10
100