Overview of Lepton Flavour Violation and Lepton Number Violation Measurements at LHCb

Murilo Rangel
on behalf of the LHCb Collaboration

SUSY 2014

MANCHESTER 1824
The University of Manchester

LHCb

Instituto de Física 50 ANOS
Universidade Federal do Rio de Janeiro

Outline

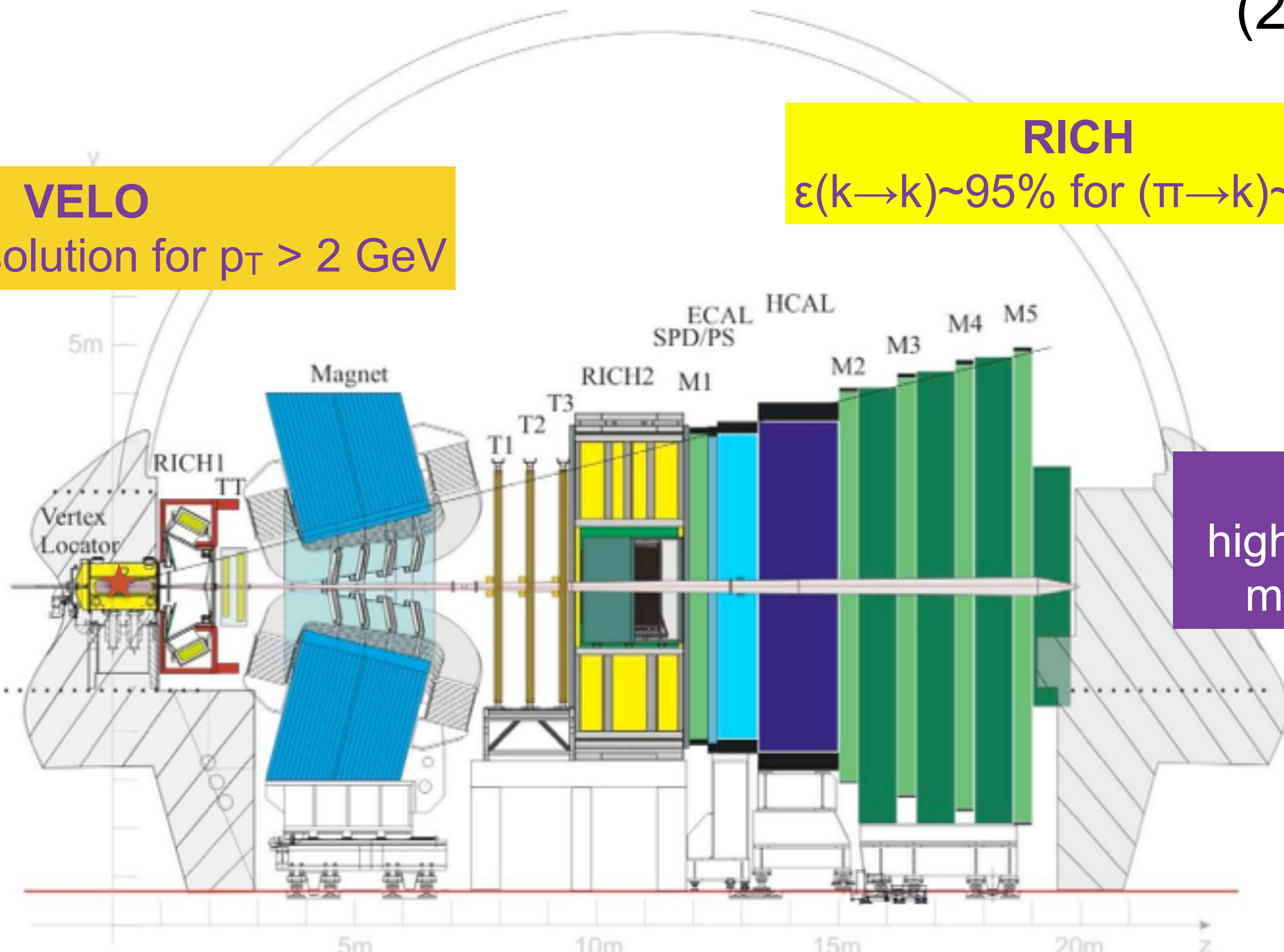
- **LHCb Experiment**
- **Searches**
  - **Majorana neutrinos in $B^- \to \pi^+ \mu^- \mu^-$**
  - **Lepton Flavour Violation in $\tau^- \to \mu^- \mu^+ \mu^-$**
  - **LPV and BNV in $\tau^- \to p \mu^+ \mu^-$ / $\tau^- \to p \mu^- \mu^-$**
- **Summary**

LHCb Experiment

LHCb is a single arm spectrometer fully instrumented in the forward region $(2.0<\eta<5.0)$

VELO
~20μm IP resolution for p_T > 2 GeV

RICH
$\varepsilon(k\rightarrow k)\sim95\%$ for $(\pi\rightarrow k)\sim5\%$

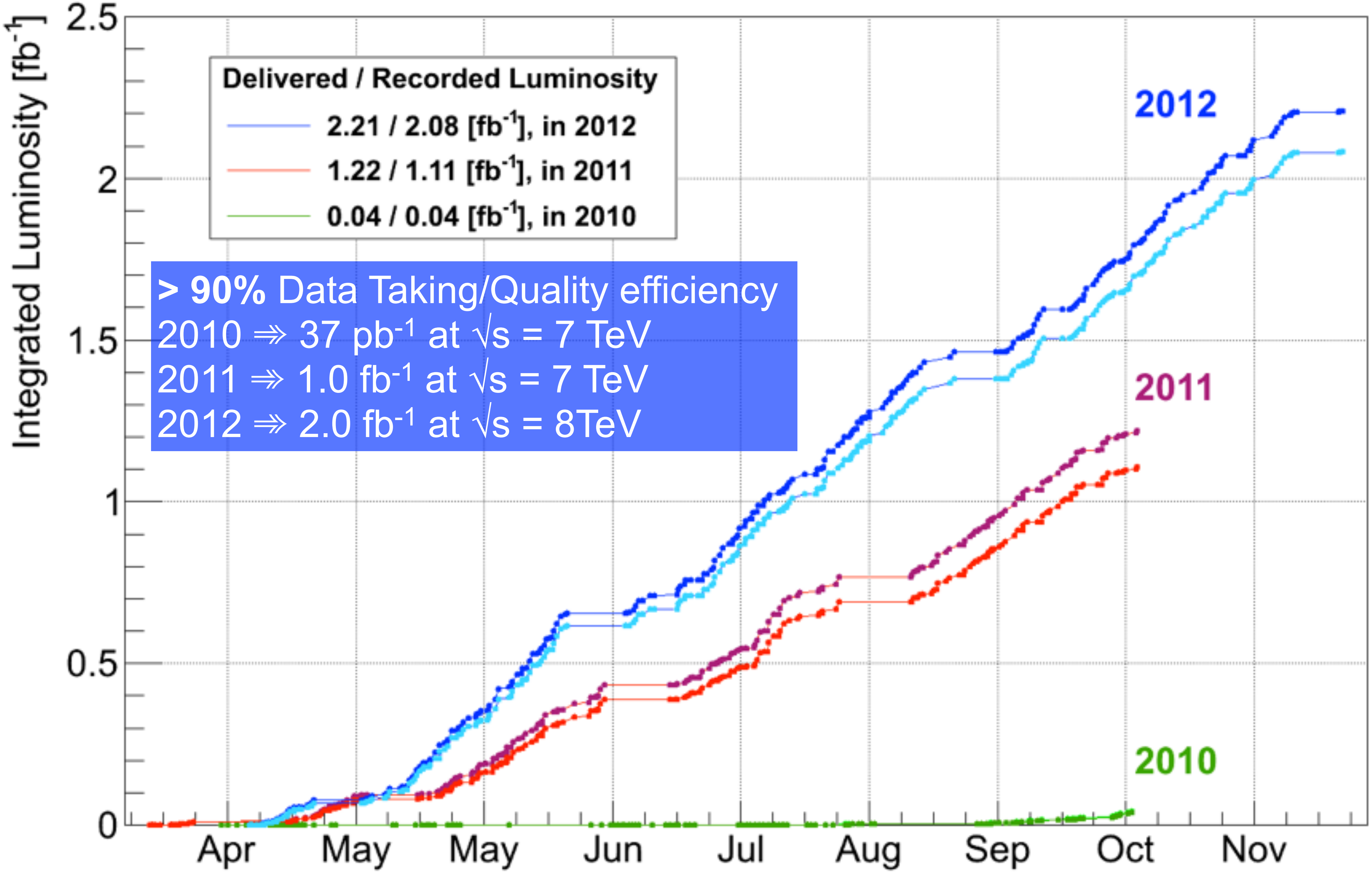


Trigger
high efficiency for muon triggers

TRACK
0.4%-0.6% momentum resolution

MUON
Muon Identification ε~97% misID~2%

Data



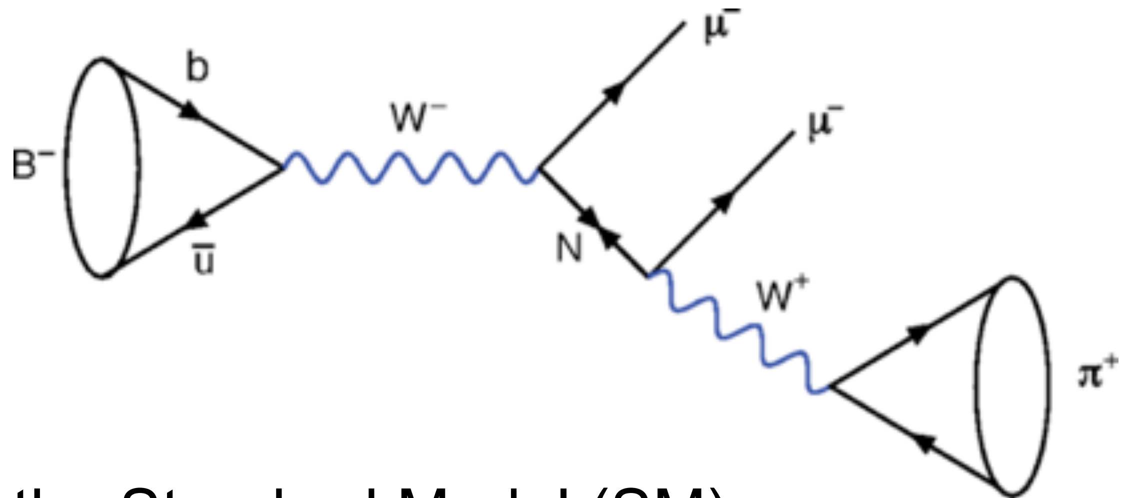
> 90% Data Taking/Quality efficiency

2010 ⇛ 37 pb^{-1} at $\sqrt{s}$ = 7 TeV

2011 ⇛ 1.0 fb^{-1} at $\sqrt{s}$ = 7 TeV

2012 ⇛ 2.0 fb^{-1} at $\sqrt{s}$ = 8TeV

$B^- \to \pi^+ \mu^- \mu^-$

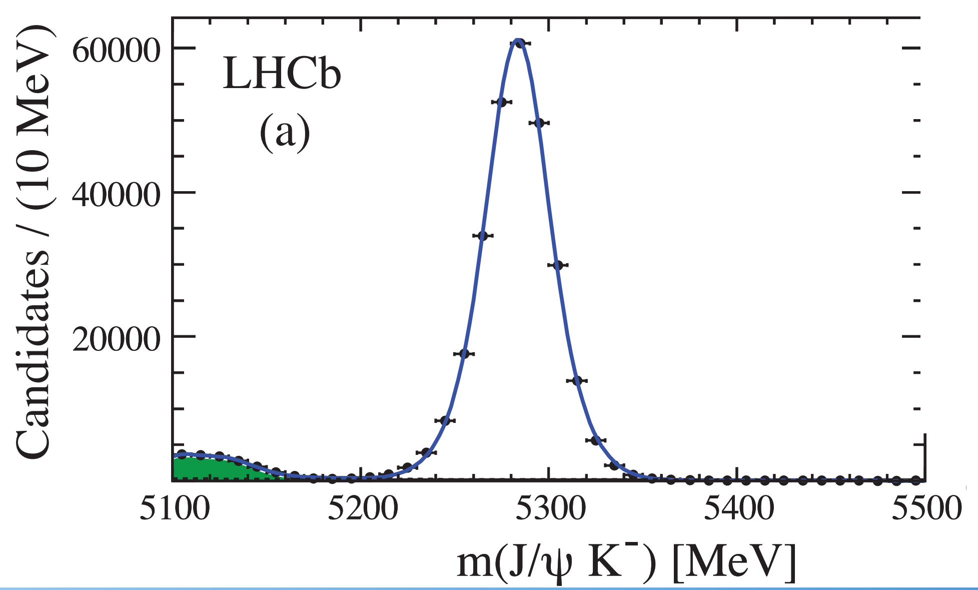


Motivation

- Forbidden decay in the Standard Model (SM) ⇒ can proceed via Majorana neutrinos
- This decay is the most sensitive search channel for Majorana neutrinos
- Complementary to double β decays

Analysis Strategy

- Using 2011+2012 data, 3 fb^{-1} of data collected at $\sqrt{s}$=7(8) TeV
- Trigger on muon and secondary vertex
- Optimised selection for two ranges of lifetime (τ_N) - improvement since previous results
- **Control sample** ($B^- \to K^- J/\psi(\mu^+\mu^-)$) for normalisation



$B^- \to \pi^+\mu^-\mu^-$

Signal Samples

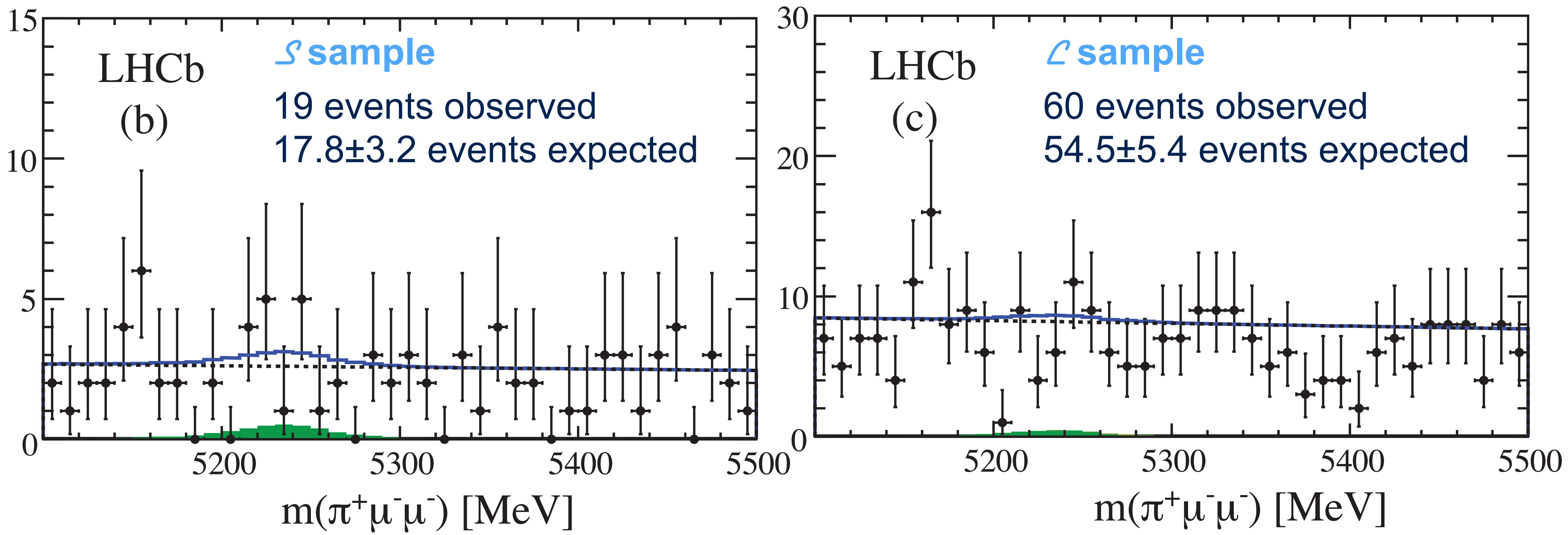
$\mathcal{S}$ sample - short τ_N up 1ps
same vertex from B

$\mathcal{L}$ sample - long τ_N from 1ps up to 1000 ps
detached $\pi^+\mu^-$ vertex from B vertex

Background

dominated by combinatorial background

peaking background shapes and normalization fixed using exclusive reconstruction



$B^- \to \pi^+\mu^-\mu^-$

I) at 95% CL, we set a limit for **τ_N < 1ps**

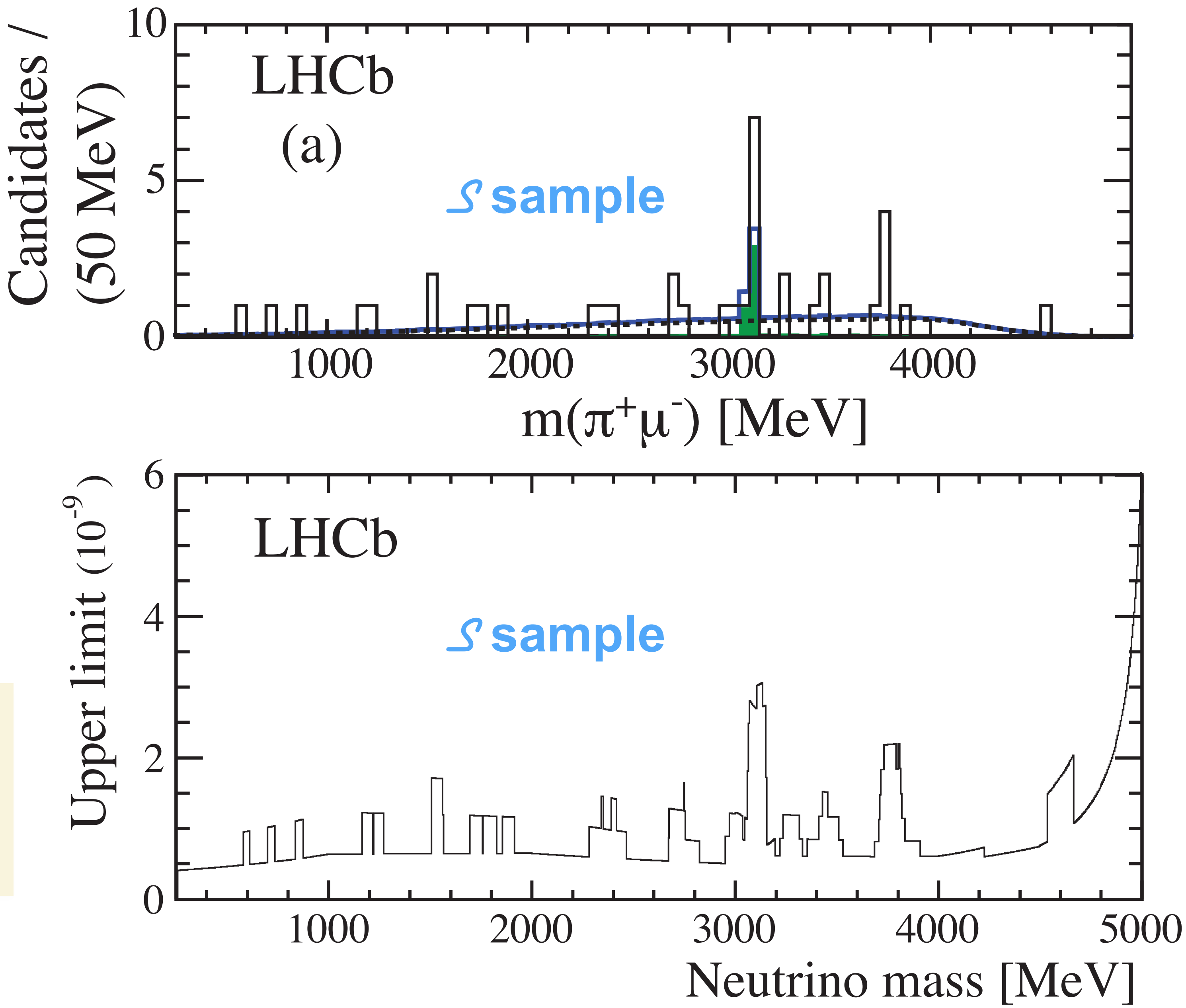
$$\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 4.0 \times 10^{-9}$$

This is the best limit up to date

For a mass dependent search,
the $\pi^+\mu^-$ invariant mass is used

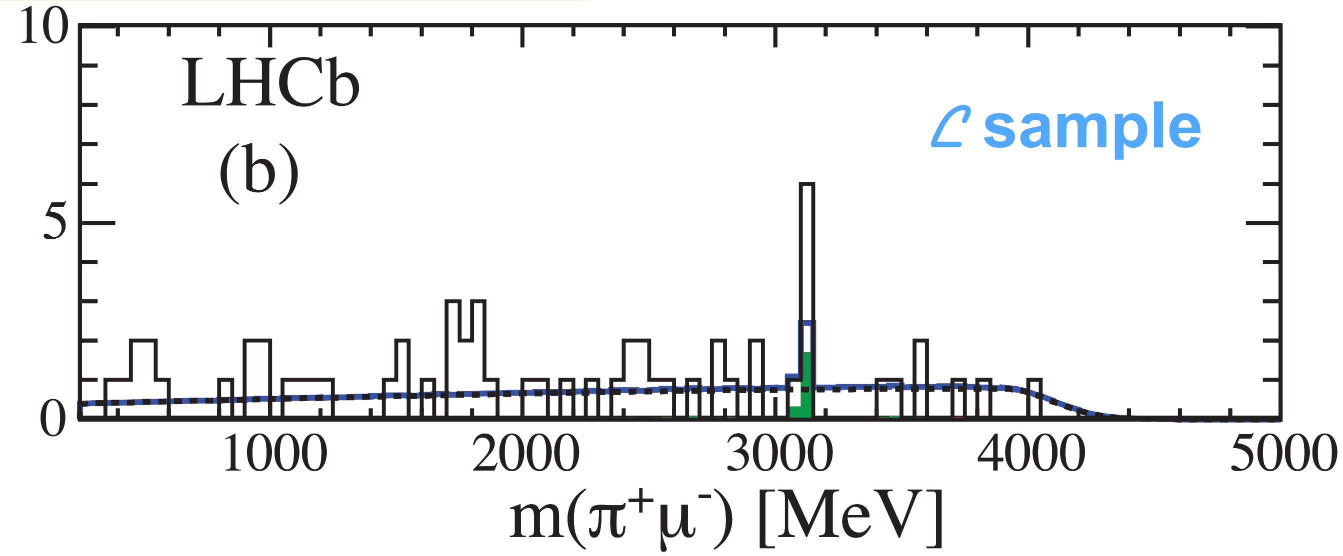
— combinatorial background derived by fitting events from sidebands of B peak
— peaking backgrounds estimated from simulation

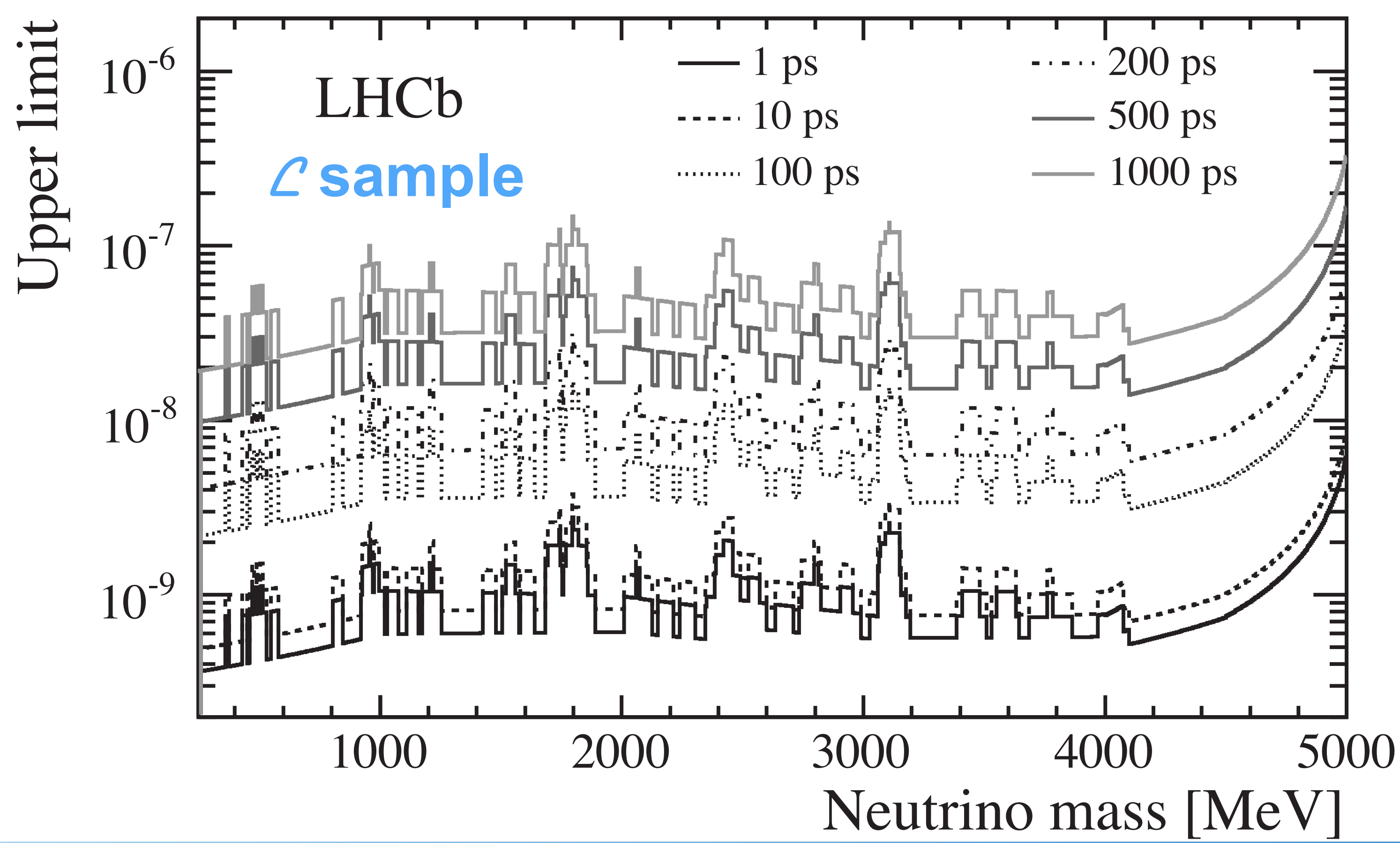
II) No signal excess is observed in $\mathcal{S}$ sample, then we set limits at 95% CL



$B^- \rightarrow \pi^+\mu^-\mu^-$

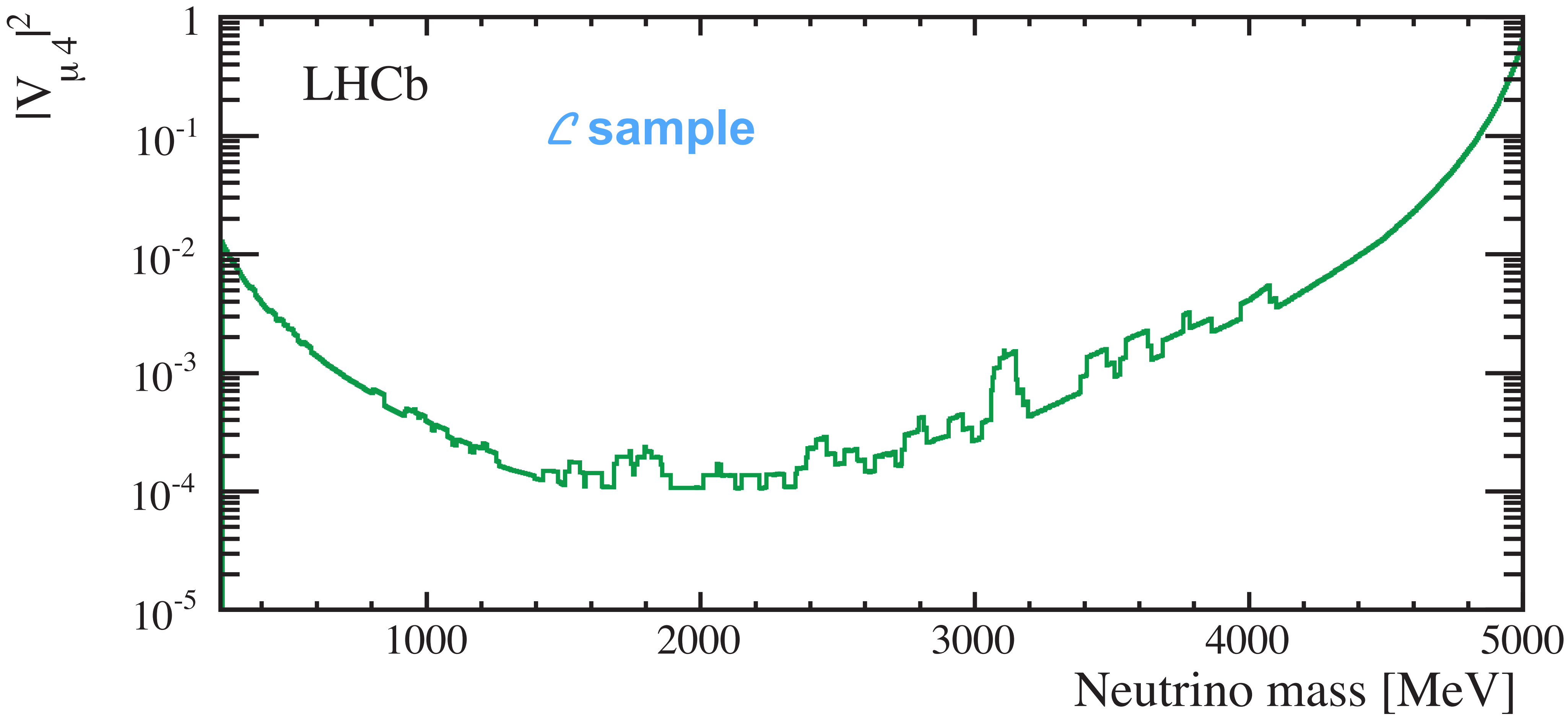
III) No signal excess is observed in $\mathcal{L}$ sample
we set limits at 95% CL for individual τ_N



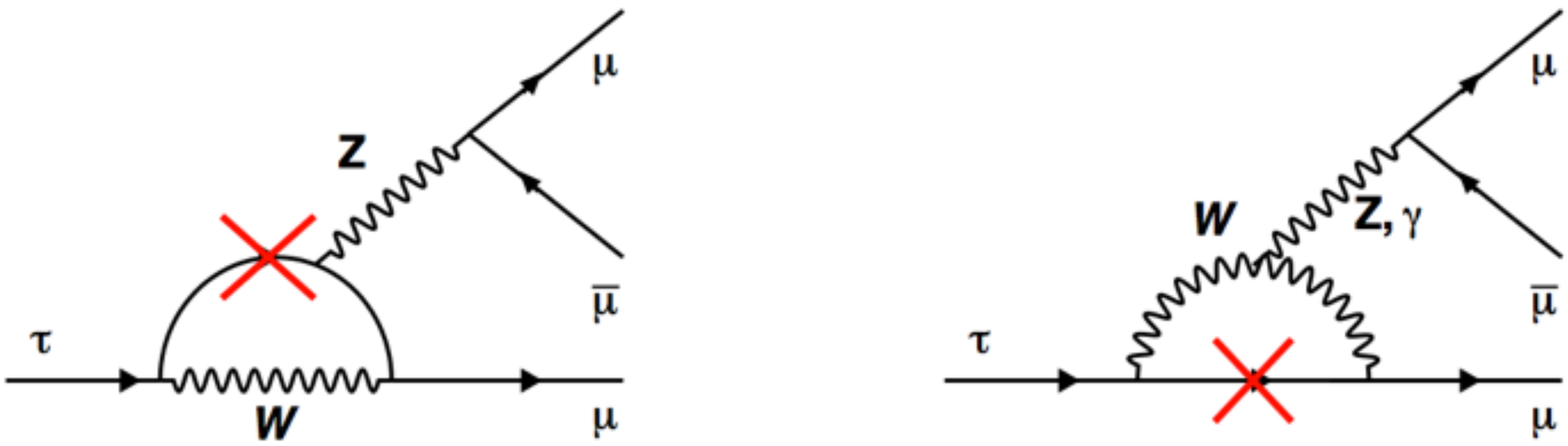


$B^- \to \pi^+ \mu^- \mu^-$

IV) Model dependent limits on the coupling of single 4th generation Majorana neutrino to muons can be calculated



$\tau^- \to \mu^-\mu^+\mu^-$



Motivation

- Neutrino oscillations imply that Lepton Flavour Violation (**LFV**) exists in the charged sector, but $BR_{SM} < 10^{-40}$

⇒ Observation will be clear sign of beyond SM physics.

Analysis Strategy

- 1.0 fb^{-1} of data collected in 2011 at $\sqrt{s}$=7 TeV
- Trigger on muon and secondary vertex
- Multivariate analysis to discriminate signal and background
- Control sample ($D_s^- \to \phi(\mu^+\mu^-)\pi^-$) for normalisation and calibration

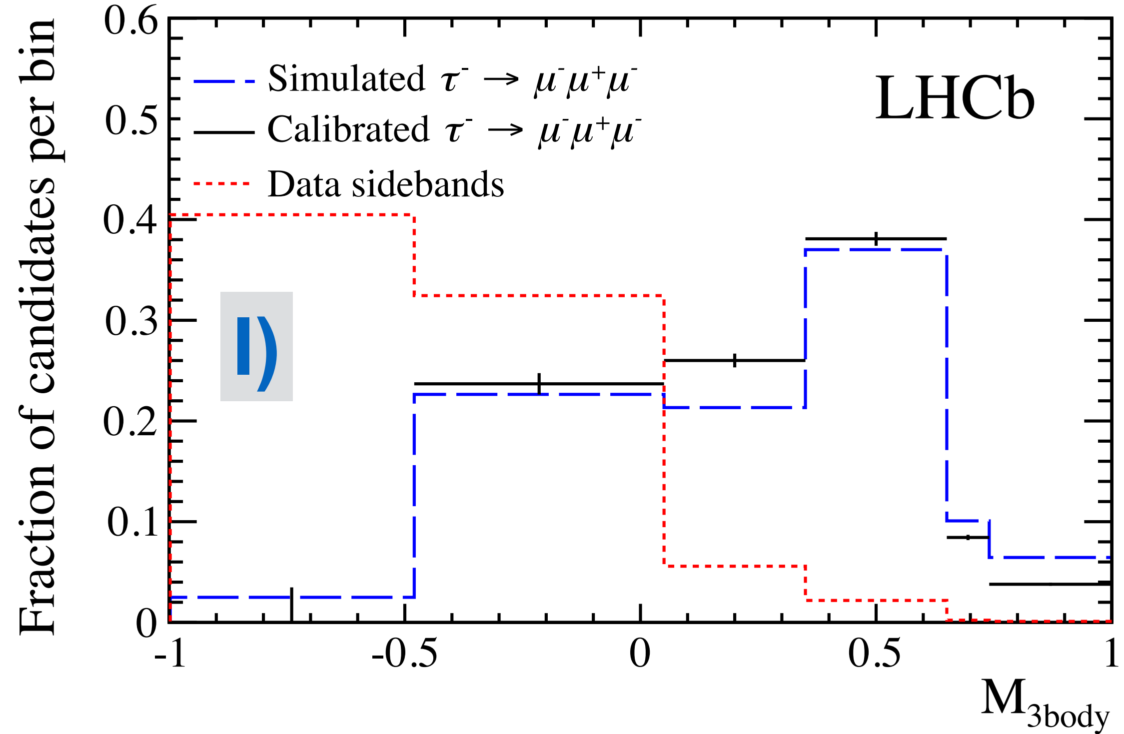
$\tau^- \rightarrow \mu^-\mu^+\mu^-$

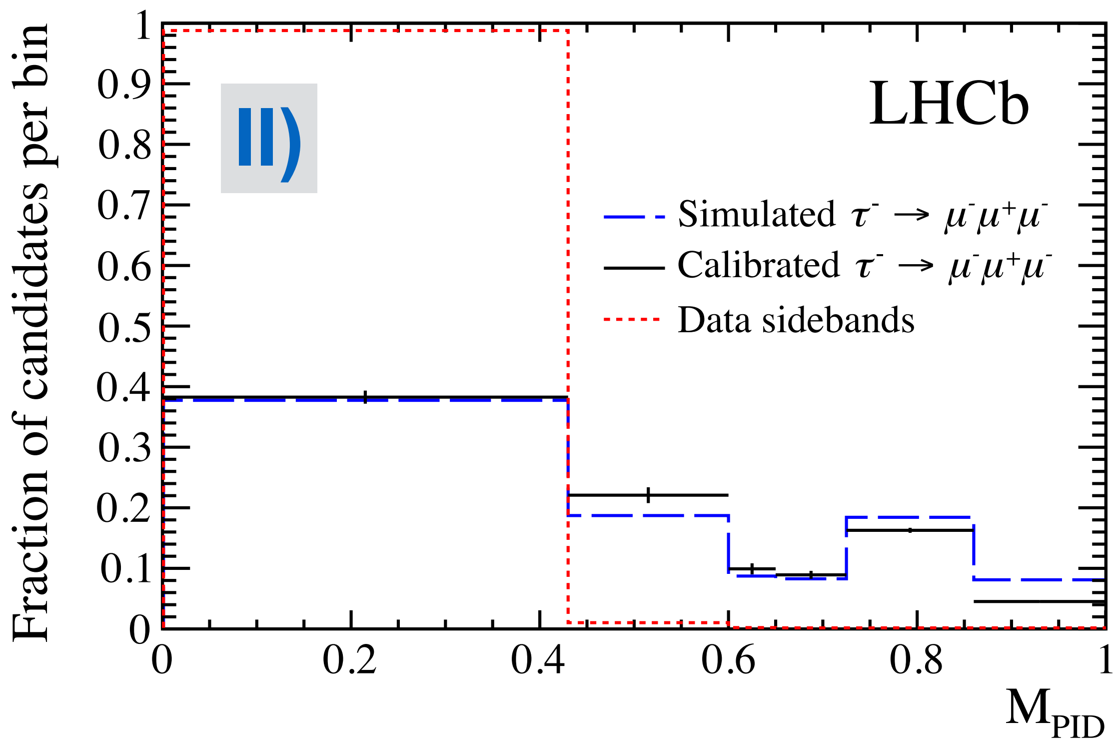
Three likelihoods are used to give a probability for the candidate to be signal or background

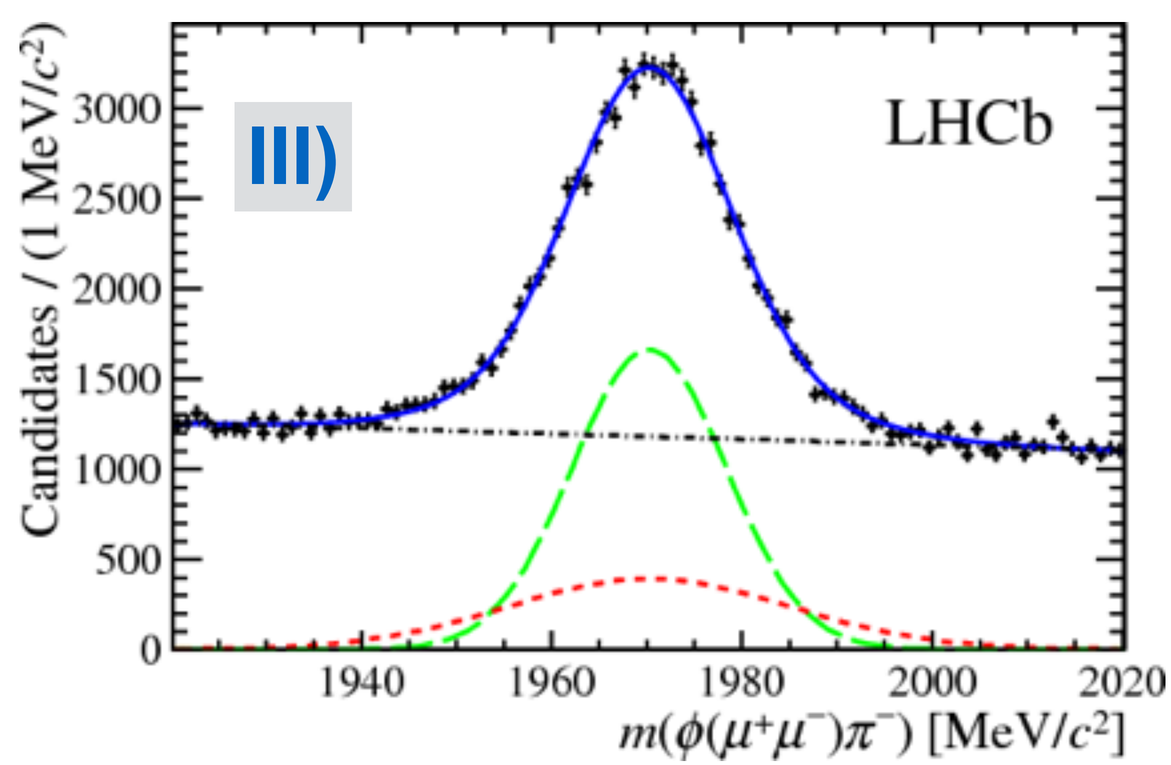
I) M_{3body} discriminates signal from B/D decays
II) M_{PID} is used to improve muon mis-identification
III) $M_{3\mu}$ shape is taken from simulation

- M_{3body} (M_{PID}) are BDT (NN) trained using simulated samples of signal and background and calibrated in data

- $M_{3\mu}$ calibrated by fit of the invariant mass of control sample ($D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$)





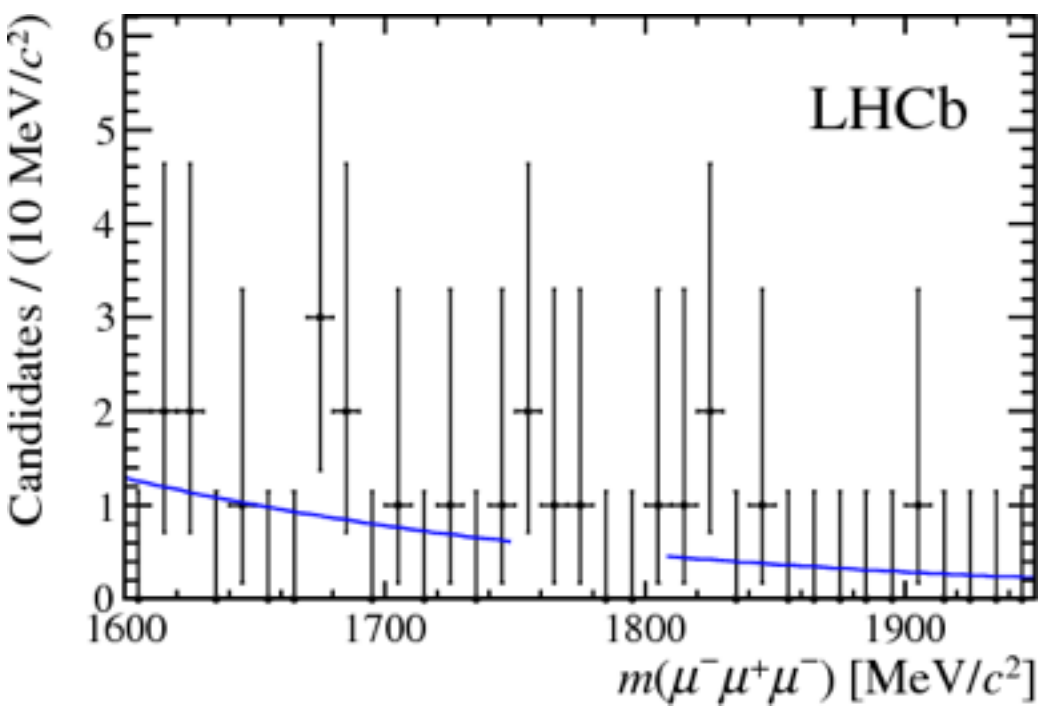


$\tau^- \to \mu^-\mu^+\mu^-$

Normalisation using control sample $D_s^- \to \phi(\mu^+\mu^-)\pi^-$

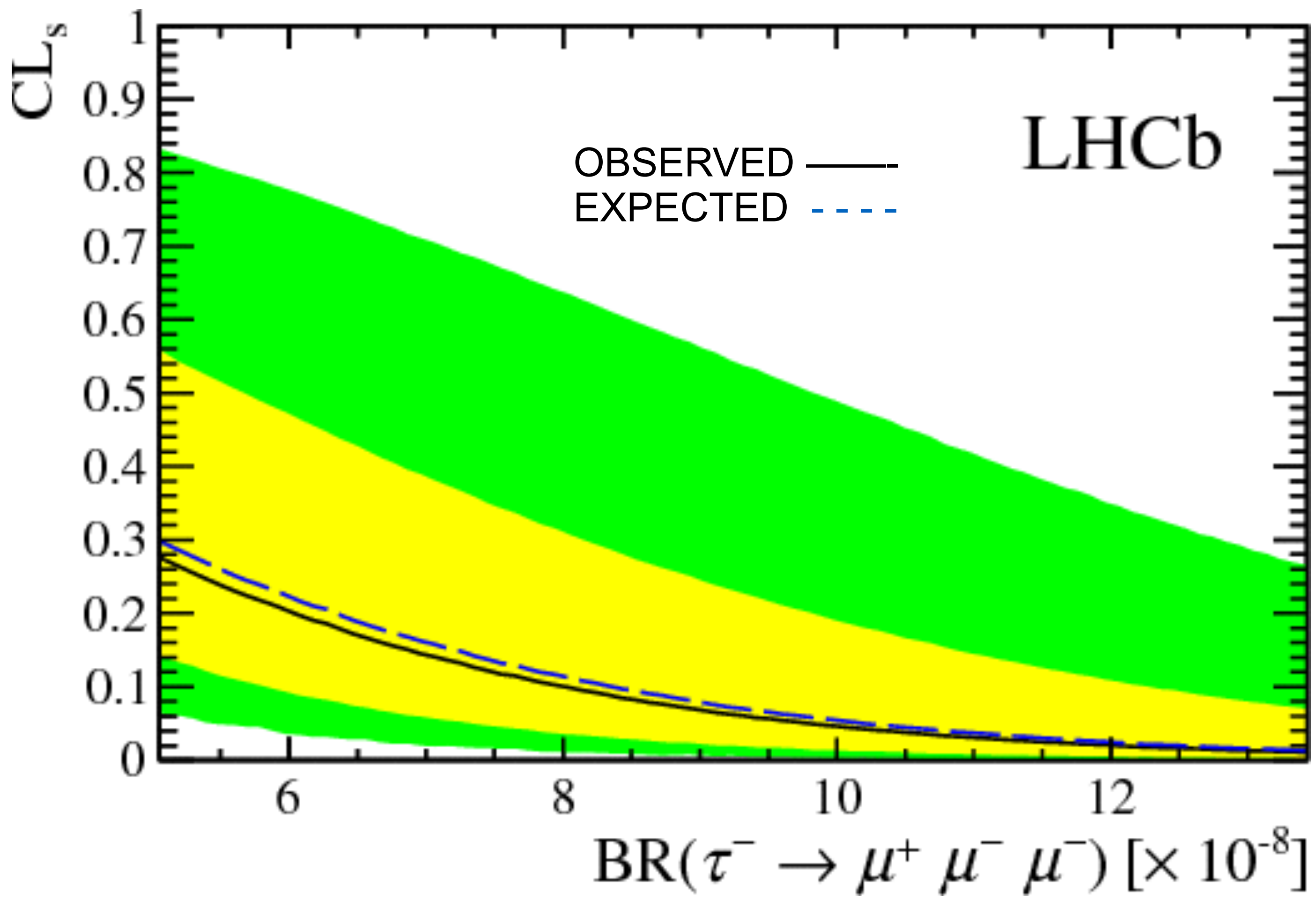
$$\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-)$$
$$= \mathcal{B}(D_s^- \to \phi(\mu^+\mu^-)\pi^-) \times \frac{f_\tau^{D_s}}{\mathcal{B}(D_s^- \to \tau^-\bar{\nu}_\tau)}$$
$$\times \frac{\epsilon_{\text{cal}}^{\text{REC\&SEL}}}{\epsilon_{\text{sig}}^{\text{REC\&SEL}}} \times \frac{\epsilon_{\text{cal}}^{\text{TRIG}}}{\epsilon_{\text{sig}}^{\text{TRIG}}} \times \frac{N_{\text{sig}}}{N_{\text{cal}}}$$
$$= \alpha \times N_{\text{sig}},$$

Background dominated by random combination of one (two) muon with two (one) mis-identified muons



$\tau^- \rightarrow \mu^-\mu^+\mu^-$

Limits calculated using the CLs method in bins of the three likelihood discriminants



Expected Limits at 90% (95%) CL

$$\mathcal{B}(\tau^- \rightarrow \mu^-\mu^+\mu^-) < 8.3\ (10.2) \times 10^{-8}$$

Observed Limits at 90% (95%) CL

$$\mathcal{B}(\tau^- \rightarrow \mu^-\mu^+\mu^-) < 8.0\ (9.8) \times 10^{-8}$$

First limits at hadron colliders
(best limit from Belle 2.1×10^{-8} at 90%CL)

Full statistics limit update soon

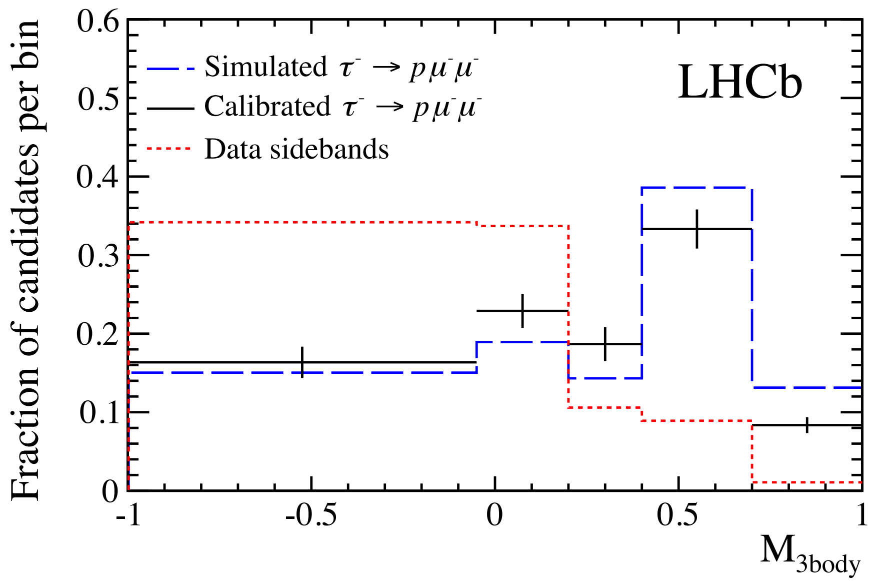
$\tau^- \to \bar{p}\mu^+\mu^-$ / $\tau^- \to p\mu^-\mu^-$

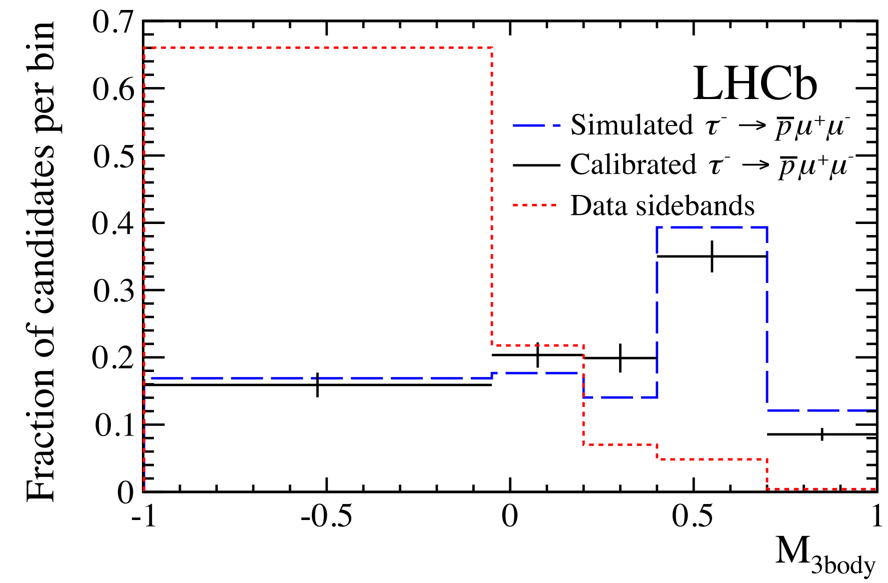
Motivation

- First search on LFV and Baryon number violation (BNV)

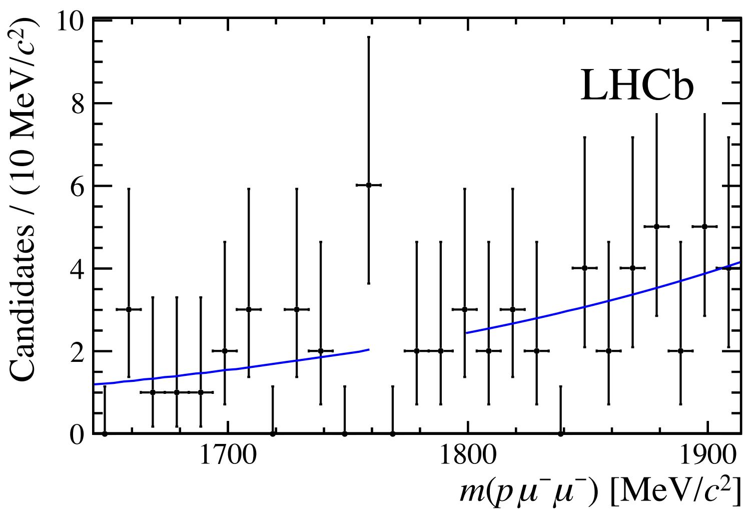
Analysis Strategy

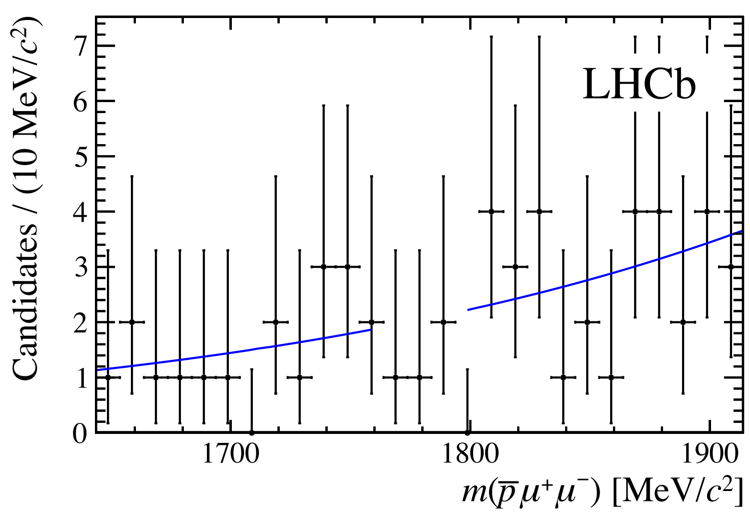
- same data and similar strategy than $\tau^- \to \mu^-\mu^+\mu^-$
- M_{PID} is replaced by cuts on PID variables of the decay products





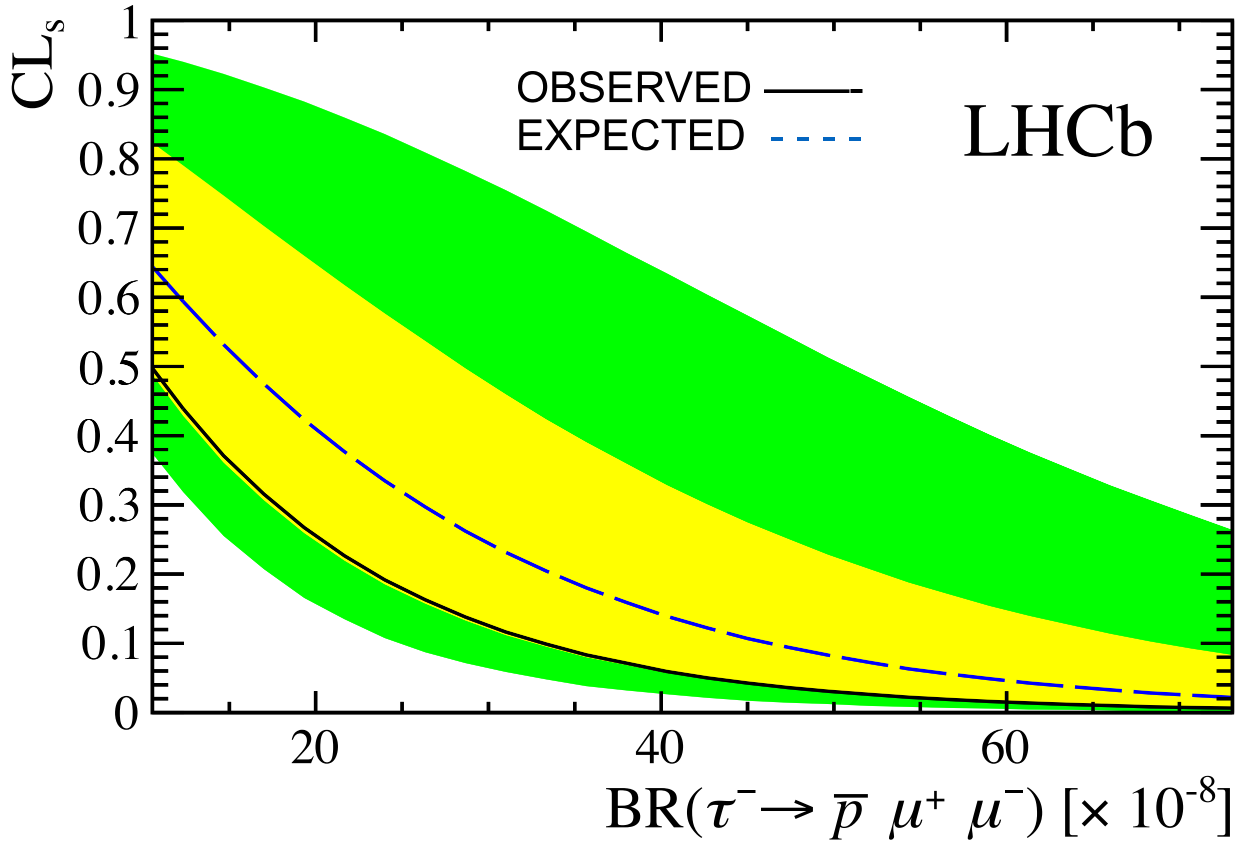
Background dominated by random combination - no peaking backgrounds expected

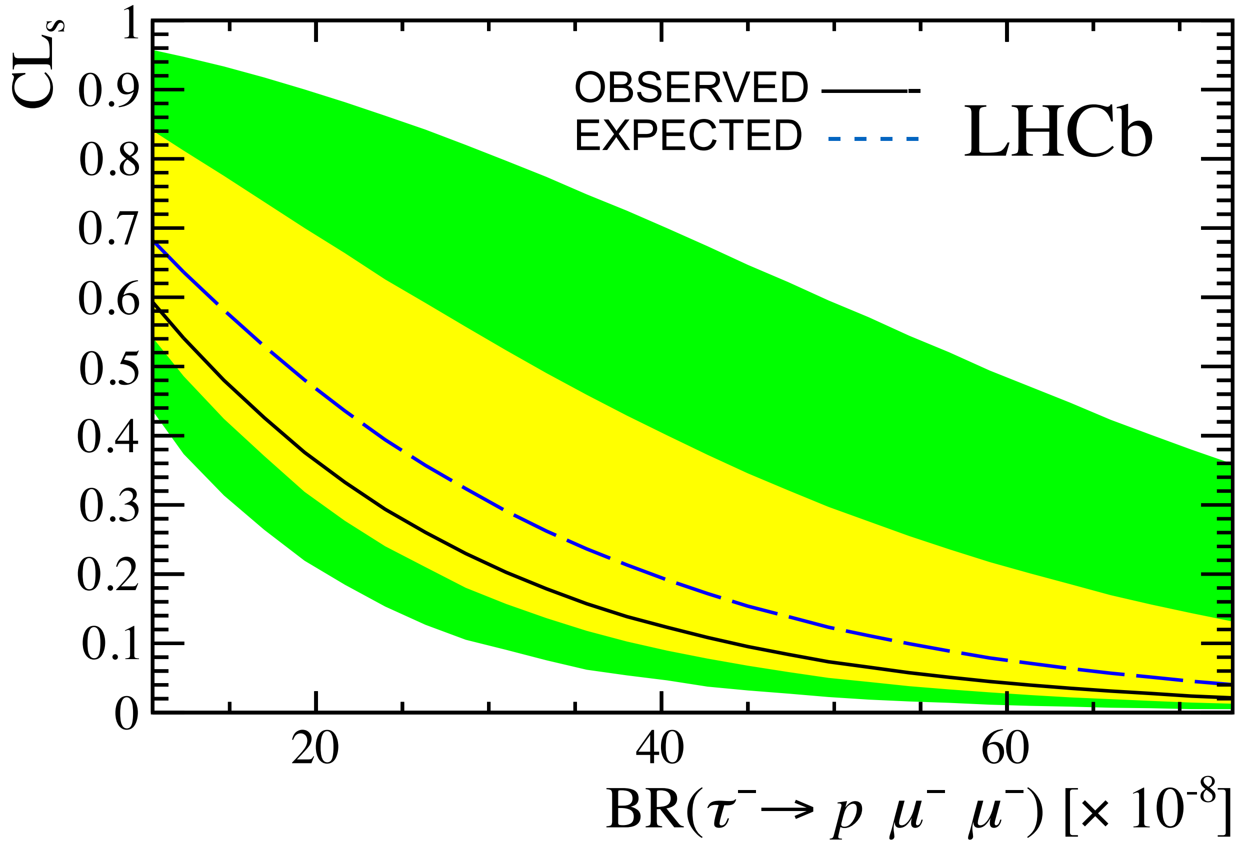




$\tau^- \to \bar{p}\mu^+\mu^-$ / $\tau^- \to p\mu^-\mu^-$

Limits calculated using the CLs method in bins of the two likelihood discriminants





Expected Limits at 90% (95%) CL

$$\mathcal{B}(\tau^- \to \bar{p}\mu^+\mu^-) < 4.6\ (5.9) \times 10^{-7},$$

$$\mathcal{B}(\tau^- \to p\mu^-\mu^-) < 5.4\ (6.9) \times 10^{-7},$$

Observed Limits at 90% (95%) CL

$$\mathcal{B}(\tau^- \to \bar{p}\mu^+\mu^-) < 3.3\ (4.3) \times 10^{-7},$$

$$\mathcal{B}(\tau^- \to p\mu^-\mu^-) < 4.4\ (5.7) \times 10^{-7}.$$

First limits for these decays

Summary

- presented searches for
  Majorana Neutrinos / LFV / BNV

- non-observation of signal ⇒ NP constrained (1,2)

BR	at 95% CL	
$B^- \to \pi^+ \mu^- \mu^-$ (3 fb^{-1}) PRL 112, 131802(2014)	4×10^{-9}	World's Best
$\tau^- \to \mu^- \mu^+ \mu^-$ (1.0 fb^{-1}) PLB 724, 36(2013)	9.8×10^{-8}	Competitive with Belle
$\tau^- \to \bar{p} \mu^+ \mu^-$ (1.0 fb^{-1}) $\tau^- \to p \mu^- \mu^-$ (1.0 fb^{-1}) PLB 724, 36(2013)	5.7×10^{-7} 4.3×10^{-7}	World's First