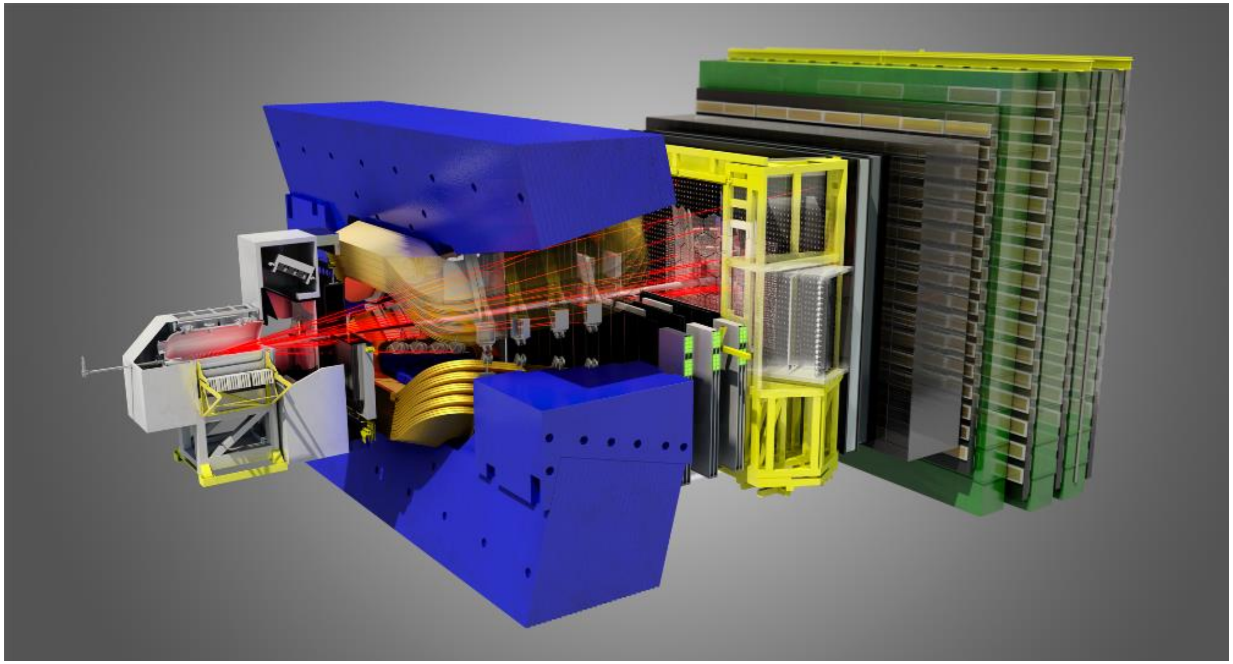
Rare B decays with taus at LHCb

Justine Serrano

on behalf of the french tau addicts (and LHCb collaboration)

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE

CPPM



LFV/LFU why and how ?

Outline

- Search for the rare decay $B_{(s)} \to \tau^+\tau^-$
  - Kristof De Bruyn, Jérôme Charles, Julien Cogan, Giampiero Mancinelli, Alessandro Mordá, Justine Serrano

Preliminary results shown at TAU2016
LHCb-CONF-2016-011

- Search for the LFV decay $B_{(s)} \to \tau\mu$
  - Joan Arnau, Julien Cogan, Giampiero Mancinelli

- Search for the rare decay $B \to K^*\tau\tau$
  - Jérôme Charles, Andrey Tayduganov, Giampiero Mancinelli

- Search for the LFV decay $B \to K^*\tau\mu$
  - Andrea Mogini, Francesco Polci, Justine Serrano

- About $\tau^- \to \pi^- \pi^+ \pi^- \nu$ decay models $\Rightarrow$ Julien's Talk

$B_{(s)} \to \tau^+\tau^-$: why ?

Using EFT approach, the time integrated BR is predicted to be:

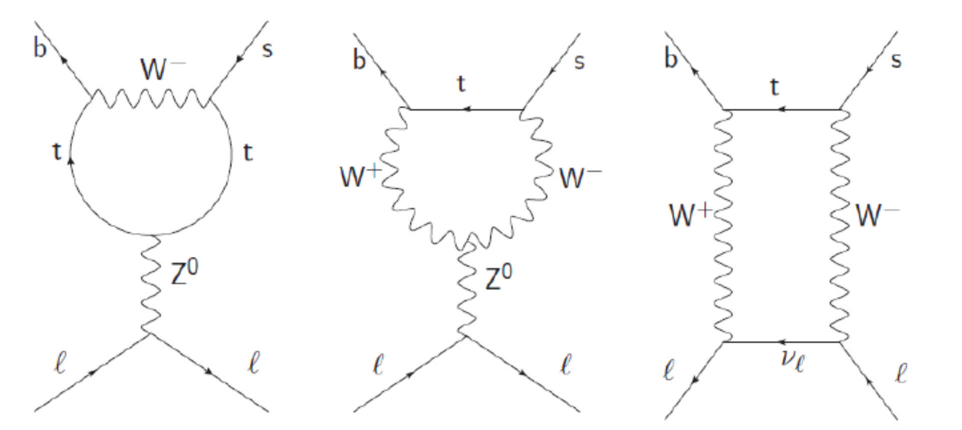
$$\mathcal{BR}(B_q^0 \to \ell^+\ell^-) = \frac{\tau_{B_q} G_F^4 M_W^2 \sin^4\theta_W}{8\pi^5} \times |V_{tb}^\star V_{tq}|^2 f_{B_q}^2 M_{B_q} m_\ell^2 \beta_{m_\ell} \times (|\mathcal{P}|^2 + |\mathcal{S}|^2) \times \frac{1 + y_q \mathcal{A}_{\Delta\Gamma}^{\ell\ell}}{1 - y_q^2}$$

$$\beta_{m_\ell} \equiv \sqrt{1 - \frac{4m_\ell^2}{M_{B_q^0}^2}}$$

SM

$$\mathcal{P} = (\mathcal{C}_{10}^\ell - \mathcal{C}_{10}^{\prime\ell}) + \frac{M_{B_q}^2}{2m_\ell}\frac{m_b}{m_b + m_q}(\mathcal{C}_P^\ell - \mathcal{C}_P^{\prime\ell})$$

$$\mathcal{S} = \beta_{m_\ell}\frac{M_{B_q}^2}{2m_\ell}\frac{m_b}{m_b + m_q}(\mathcal{C}_S^\ell - \mathcal{C}_S^{\prime\ell}) .$$



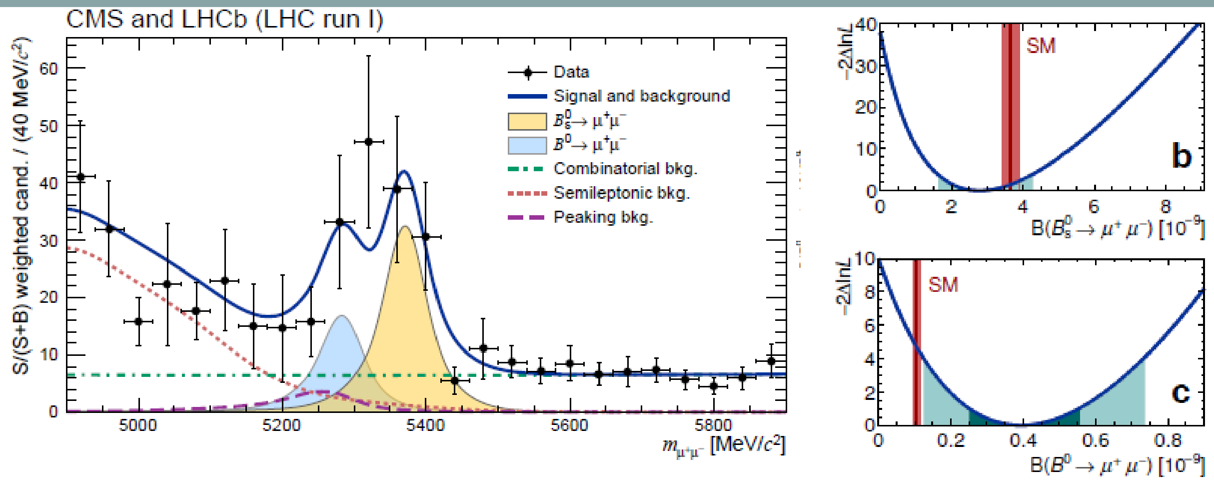
SM predictions:

	ee	μμ	ττ
B^0	$(2.48\pm0.21)\ 10^{-15}$	$(1.06\pm0.09)\ 10^{-10}$	$(2.22\pm0.19)\ 10^{-8}$
B_s	$(8.54\pm0.55)\ 10^{-14}$	$(3.65\pm0.23)\ 10^{-9}$	$(7.73\pm0.49)\ 10^{-7}$

$B_{(s)} \to \tau^+\tau^-$: why ?

Best experimental results so far (UL at 90%CL) :

	ee	μμ	ττ
B^0	$< 8.3\ 10^{-8}$ (CDF)	$3.9^{+1.6}_{-1.4}\ 10^{-10}$ (LHCb+CMS)	$< 4.1\ 10^{-3}$ (Babar)
B_s	$< 2.8\ 10^{-7}$ (CDF)	$2.8^{+0.7}_{-0.6}\ 10^{-9}$ (LHCb+CMS)	-



First observation (at 6.2 σ) for B_s and first evidence (at 3.2 σ) for B^0

Results compatible with SM predictions at 1.2 σ for B_s and 2.2 σ for B_d

NP in $B_{(s)} \to \tau^+\tau^-$

- Experimental measurements indirectly constrain the BR to 3% (Bobeth, Haish, *Acta Phys. Polon. 225 B44 (2013) 127*)
- Can be enhanced in NP scenarios up to % level (e.g J. Cline, *arXiv:1512.02210, R. Alonso et al, arXiv:1505.05164*)

- Could even help in distinguishing leptoquark from vector boson models (Bhattacharya et al, *arXiv:1609.09078*)

$$VB \quad : \quad \mathcal{B}(B_s^0 \to \tau^+\tau^-)|_{\rm max} = 2.3 \times 10^{-5} \ ,$$
$$U_1 \quad : \quad \mathcal{B}(B_s^0 \to \tau^+\tau^-)|_{\rm max} = 5.3 \times 10^{-4} \ .$$

  - Also true for K*tautau

$$VB \quad : \quad \mathcal{B}(B \to K^{(*)}\tau^+\tau^-)|_{\rm max} = 5.0 \times 10^{-6} \ ,$$
$$U_1 \quad : \quad \mathcal{B}(B \to K^{(*)}\tau^+\tau^-)|_{\rm max} = 1.1 \times 10^{-4} \ .$$

Most useful tau decays (for LHCb)

Leptonic:

- BR($\tau^- \to \mu^- \nu\nu$) = 17.41 ± 0.04 %
- BR($\tau^- \to e^- \nu\nu$) = 17.83 ± 0.04 %

Hadronic:

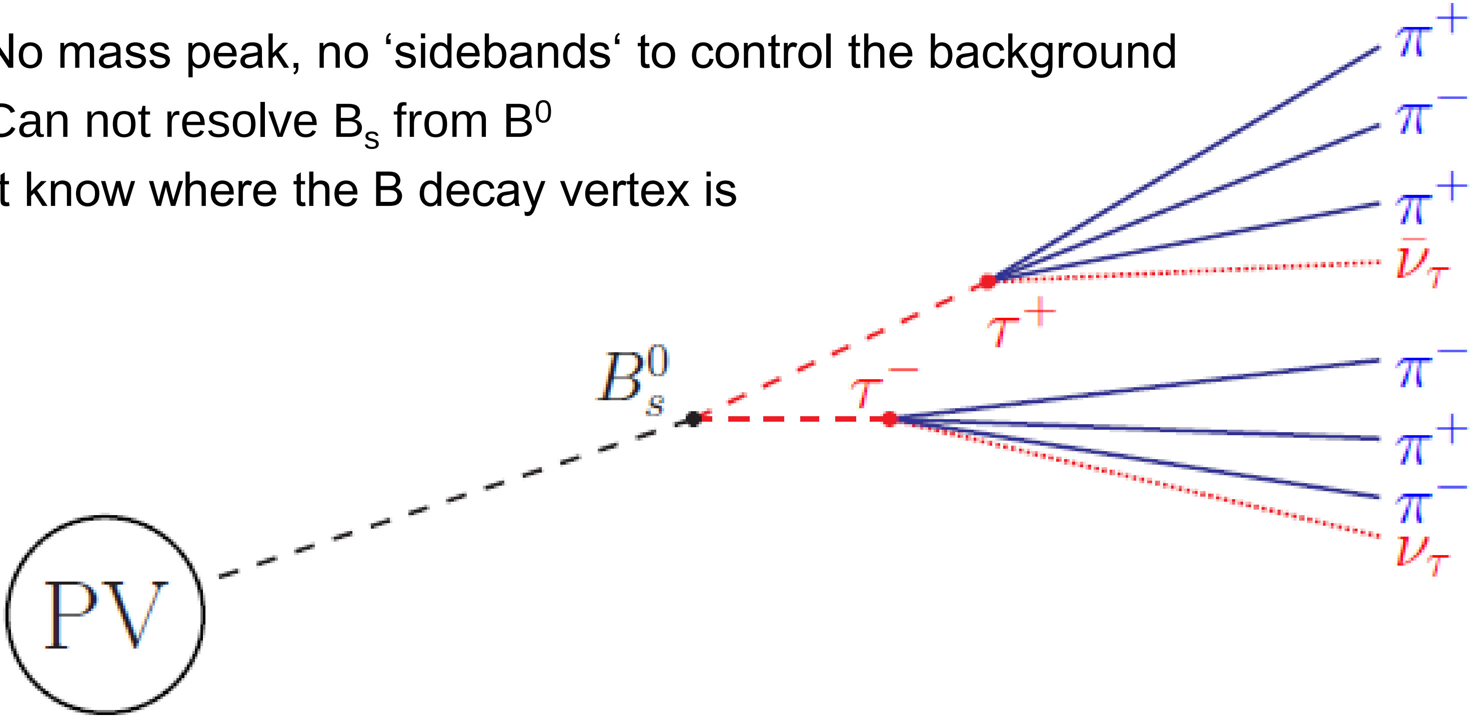
- BR($\tau^- \to \pi^- \nu$) = 10.83 ± 0.06 %
- BR($\tau^- \to \pi^- \pi^0 \nu$) = 25.52 ± 0.09 %
- BR($\tau^- \to \pi^- \pi^0 \pi^0 \nu$) = 9.30 ± 0.11 %
- BR($\tau^- \to \pi^- \pi^+ \pi^- \nu$) = 9.31 ± 0.06 %
- BR($\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu$) = 4.62 ± 0.06 %

- Which decay mode is best depends on the analysis

$B_{(s)} \rightarrow \tau^+\tau^-$: how ?

Analyze Run1 data with the 6 pions final state.
The challenge:

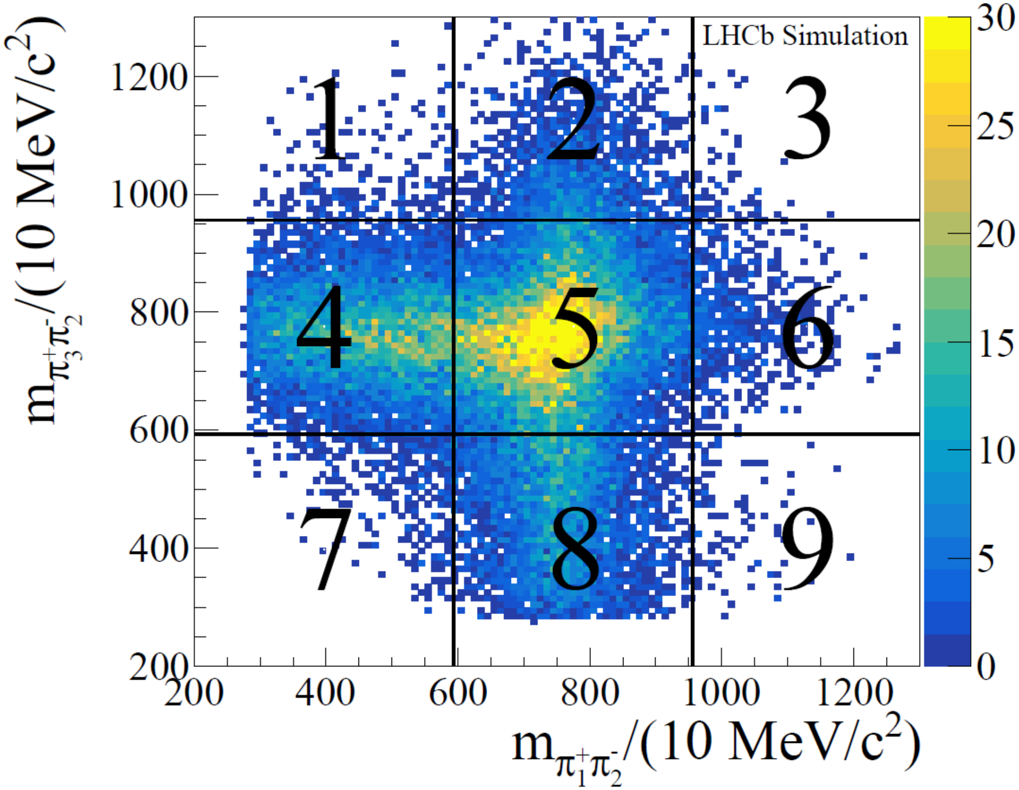
- 6 pions in final state
  - Low efficiency
  - high combinatorial background
- 2 neutrinos in final state
  - No mass peak, no ‘sidebands‘ to control the background
  - Can not resolve B_s from B^0
- Don’t know where the B decay vertex is



But..

- We can take advantage of intermediate resonances:

$$\tau^- \to a_1^-(1260)\nu_\tau \to \rho^0(770)\pi^-\nu_\tau$$



- Signal region: both τ in 5
- Control region: one τ in (4,5,8) and the other in (4,8)
- Background region: at least one τ in (1,3,7,9)

Selection

- Usual kinematic and geometrical variables : lifetimes, masses, p_T, IP…
- Isolation variables :
  - Track isolation
  - Vertex isolation
  - Neutral isolation
- Variables coming from the full reconstruction of $B \rightarrow \tau^+\tau^-$, developed by A. Mordá and J. Charles (CERN-THESIS-2015-264)

⇒ Used in preselection cuts and Neural Network

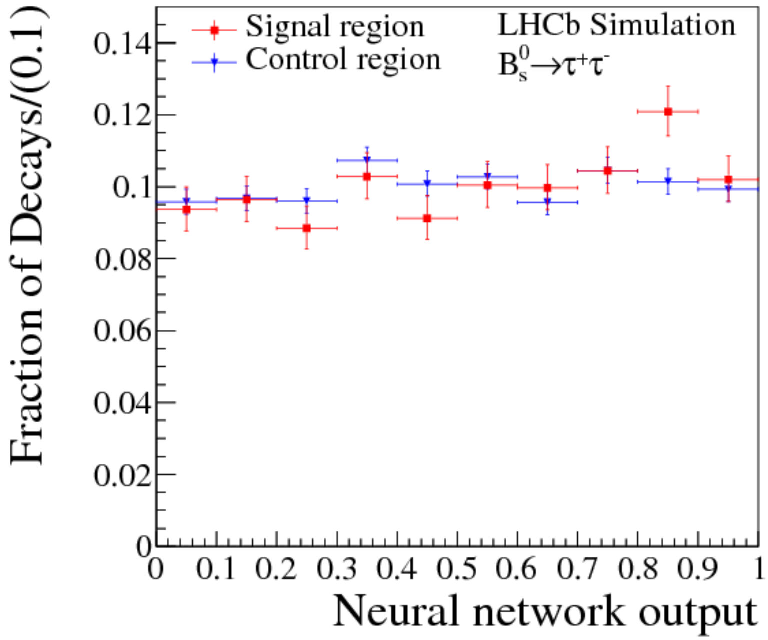
⇒ Pass from 18M events to ~10k events in signal region with a signal efficiency of ~3 10^{-5}. Assuming SM, expect 0.02 signal event

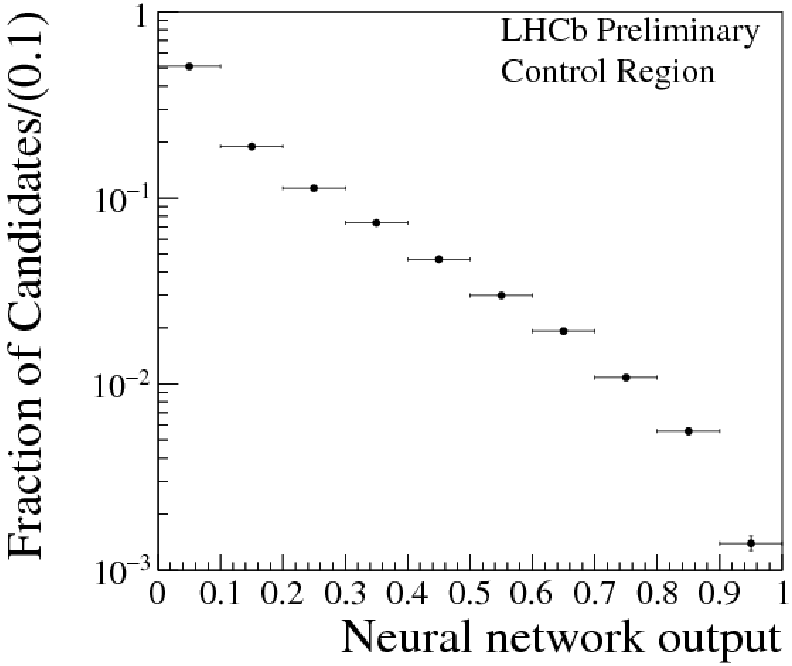
- Percentage of event in each region:

	SR	CR	BR
Signal	17	55	11
Data	4.8	44	41

Fit

- Build a second Neural network that is the discriminating variable to be fitted
  - Used 29 input variables
  - Trained on signal MC and data from background region
  - Output in [0,1], region >0.7 blinded until analysis completion

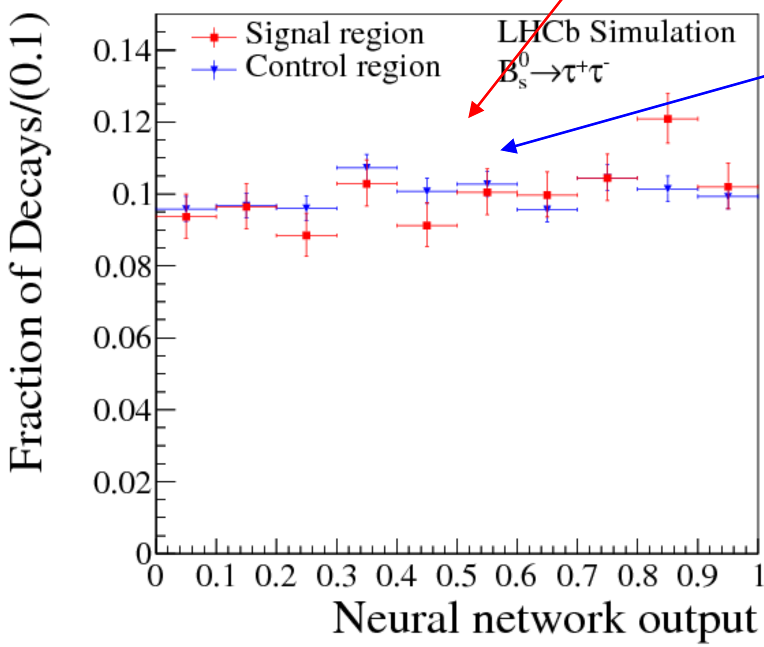


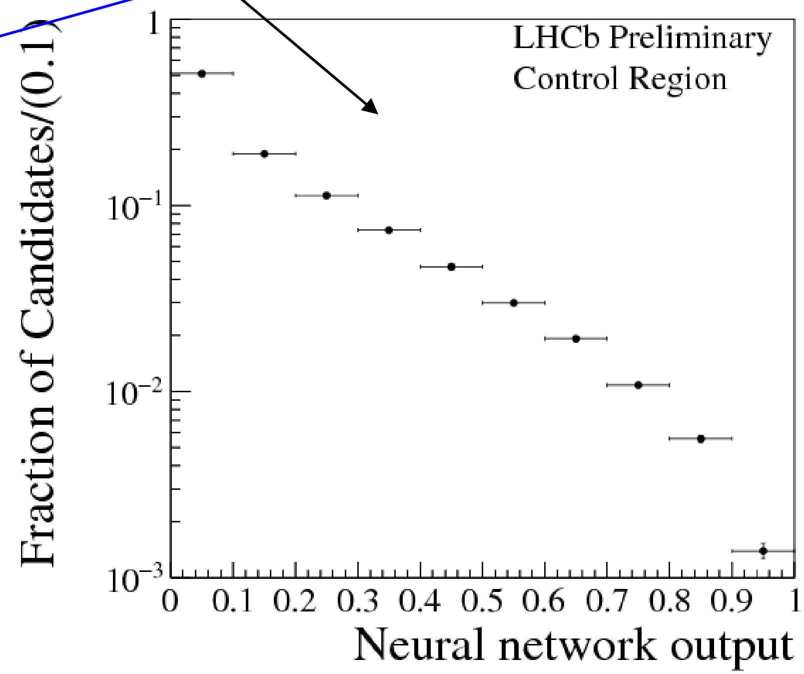


Fit

- Binned fit of the NN output in the signal region
- Signal PDF from simulation
- Background PDF from control region, subtracting signal contribution

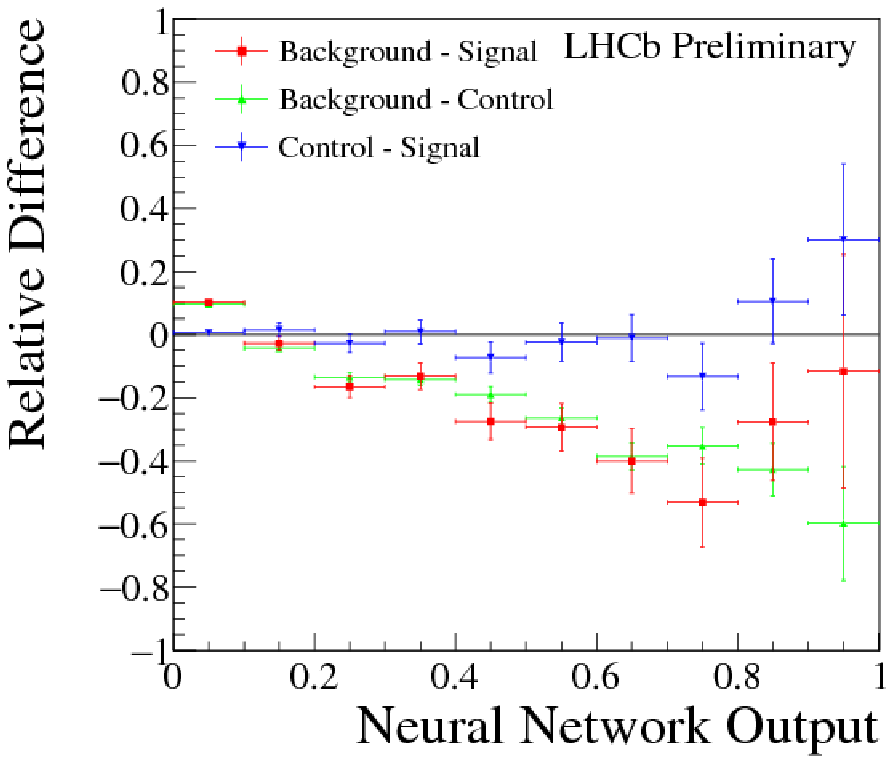
$$\mathrm{NN}^{\mathrm{SR}}_{\mathrm{data}} = s \times \widehat{\mathrm{NN}}^{\mathrm{SR}}_{\mathrm{sim}} + f_b \times \left(\mathrm{NN}^{\mathrm{CR}}_{\mathrm{data}} - s \cdot \frac{\varepsilon^{\mathrm{CR}}}{\varepsilon^{\mathrm{SR}}} \widehat{\mathrm{NN}}^{\mathrm{CR}}_{\mathrm{sim}} \right)$$





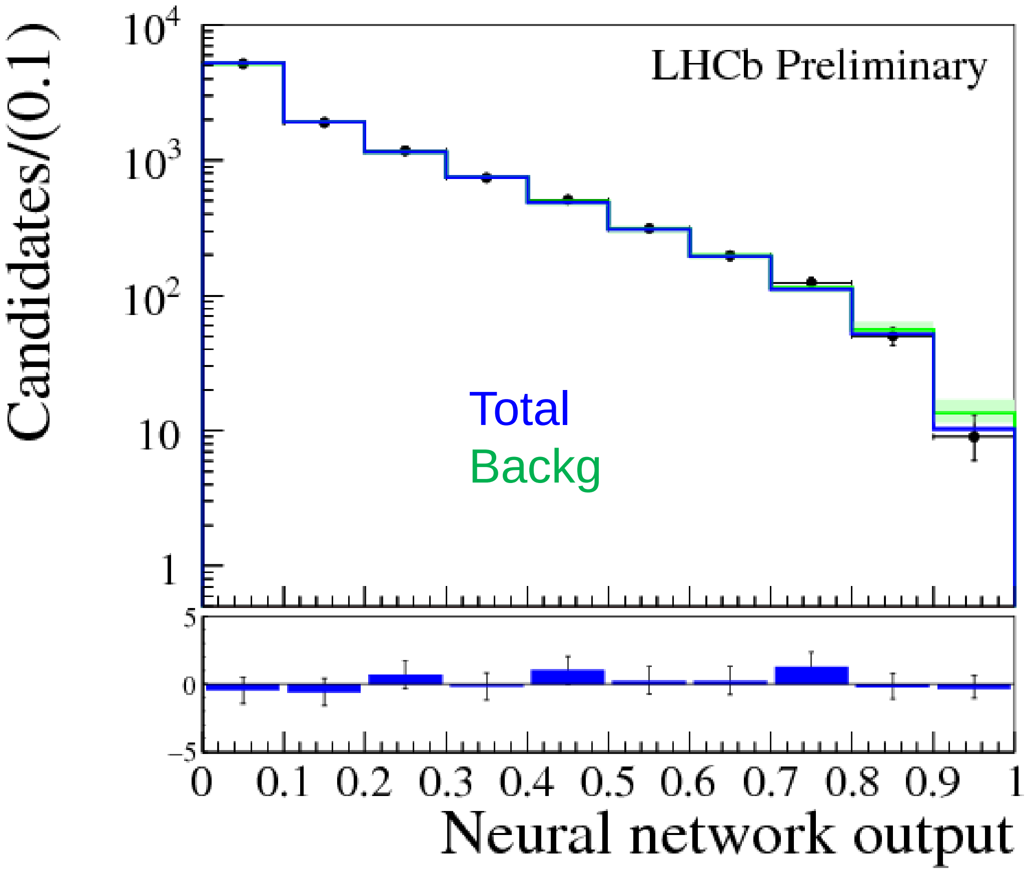
Crosschecks

- Background shapes compared in
  - signal and control data region (for NN<0.7 before unblinding)
  - Exclusive MC samples (e.g $B \to D3\pi$, $D \to \pi\pi^0$)
  - Inclusive MC sample (all b hadron decays)

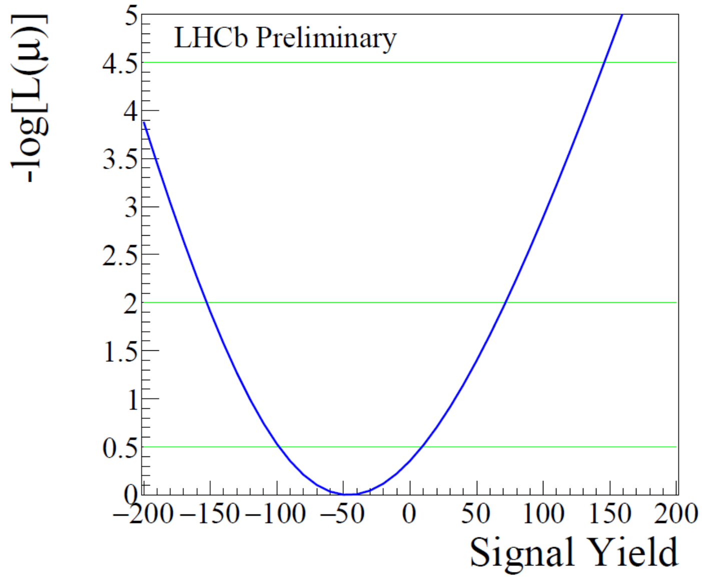


Fit result

Assuming signal fully dominated by B_s decays :



s = - 46 ± 51

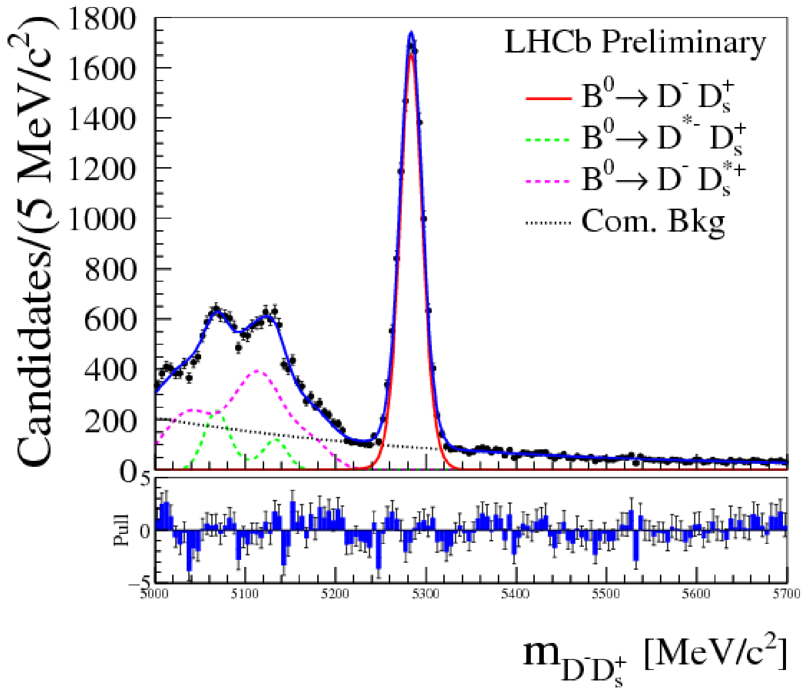


Normalization : $B^0 \to D^+ D_s^-$

$$\mathcal{B}(B_s^0 \to \tau^+\tau^-) = \alpha_s \cdot s \ ,$$

$$\alpha_s = \frac{\epsilon^{D^- D_s^+} \cdot \mathcal{B}(B^0 \to D^+ D_s^-) \cdot \mathcal{B}(D^+ \to K^- \pi^+ \pi^+) \cdot \mathcal{B}(D_s^+ \to K^+ K^- \pi^+)}{N^{\rm obs}_{D^- D_s^+} \cdot \epsilon^{\tau^+\tau^-} \cdot [\mathcal{B}(\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau)]^2} \cdot \frac{f_d}{f_s} \ ,$$

$$\alpha_s = (3.16 \pm 0.43) 10^{-5}$$



Limit for $B_s \to \tau\tau$

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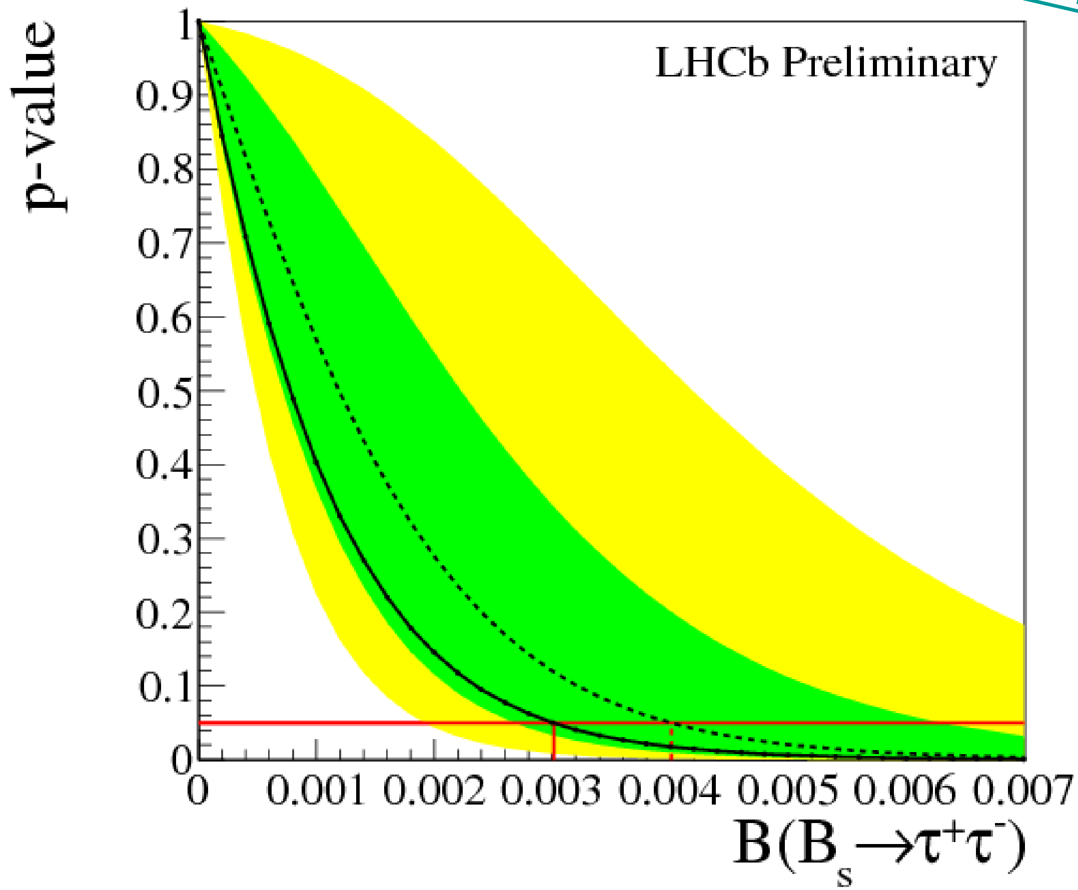

$B(B_s \to \tau\tau) < 2.4(3.0)\ 10^{-3}$ at 90 (95)% CL

First experimental limit!

Result for $B^0 \to \tau\tau$

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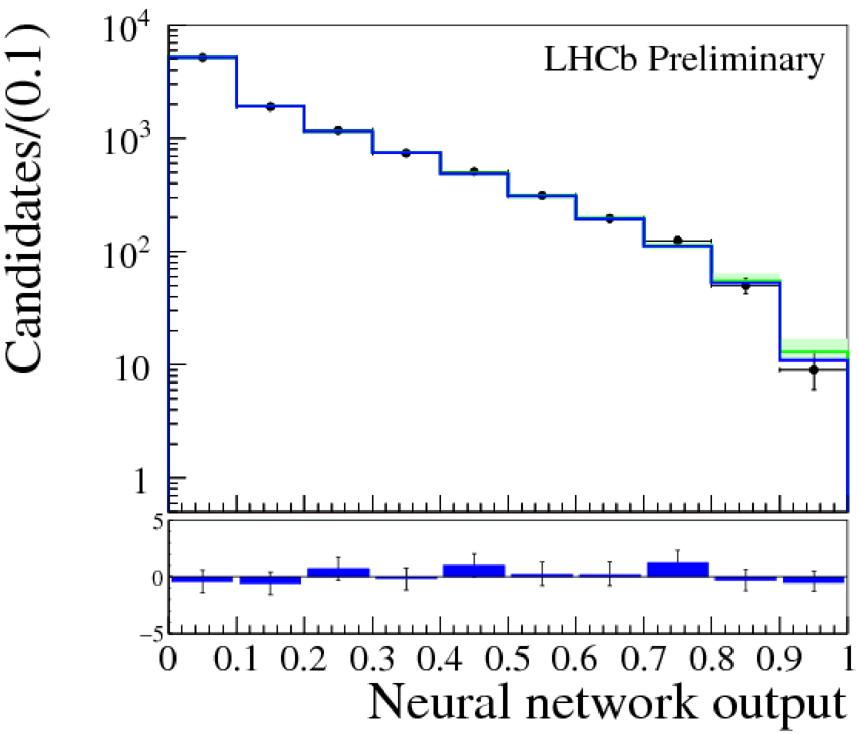
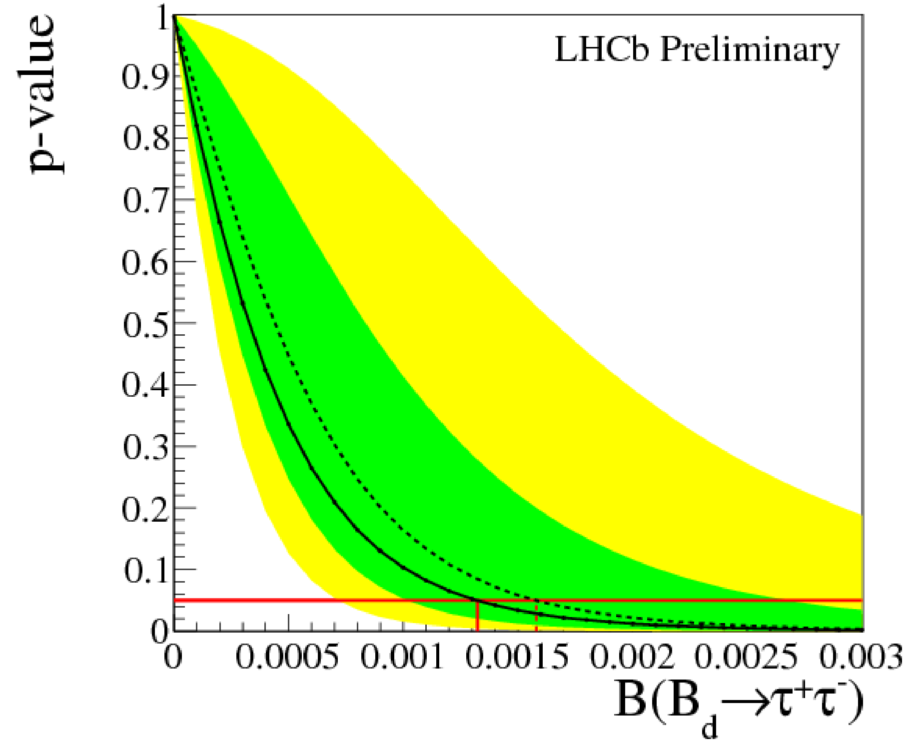
Assuming signal fully dominated by B^0 decays :

s = - 39 ± 65

$\alpha_d = (0.94 \pm 0.16) 10^{-5}$





$B(B^0 \to \tau\tau) < 1.0(1.3)\ 10^{-3}$ at 90 (95)% CL

Factor ~4 improvement wrt Babar result!

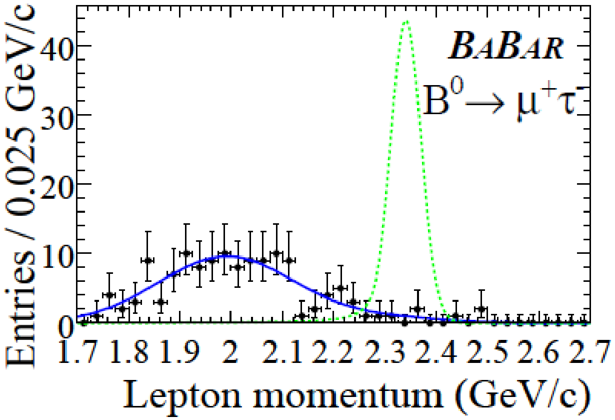
But…

- These results are based on MC generated with the EVTGEN model of $\tau^- \to \pi^- \pi^+ \pi^- \nu$ decays

- This is not satisfactory since we know other models that describe better the data, available in TAUOLA → see Julien's talk

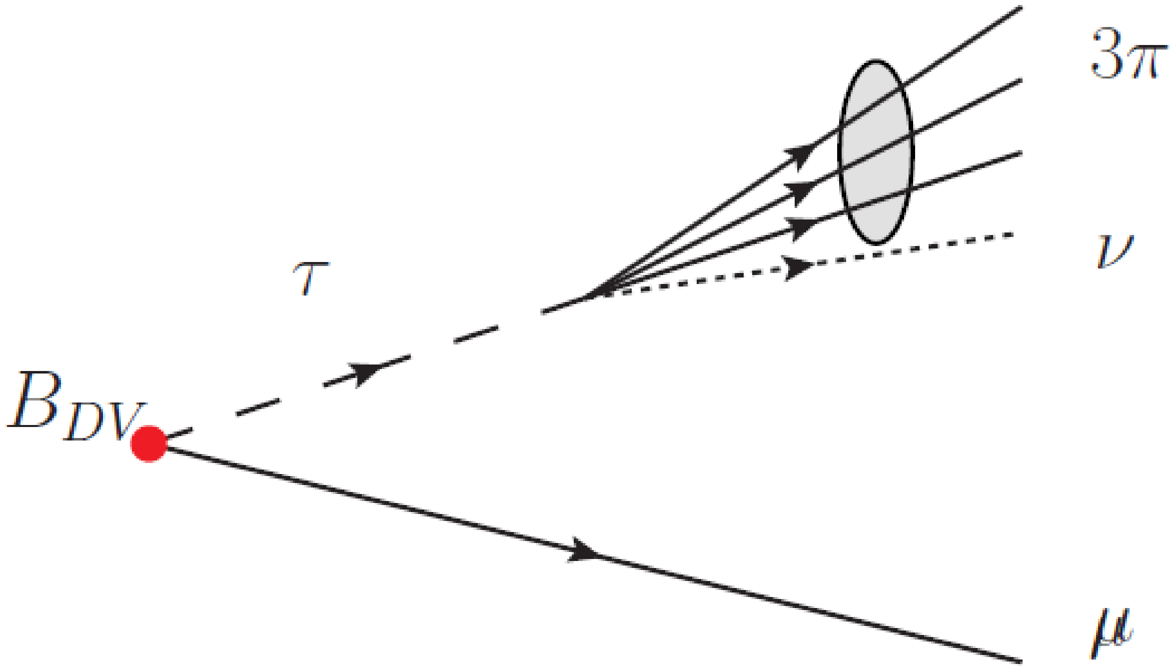
$B_{(s)} \to \tau\mu$: why?

- (Almost) forbidden in the SM
- Visible BR in several BSM theories (e.g, in generic Z' models $BR(B_s \to \tau\mu) \sim 10^{-6}$, *A. Crivellin et al arXiv:1504.07928*)
- Only experimental result from Babar : $BR(B^0 \to \tau\mu) < 2.2\ 10^{-5}$ @90%CL
- No result for the B_s channel so far



$B_{(s)} \to \tau\mu$: how?

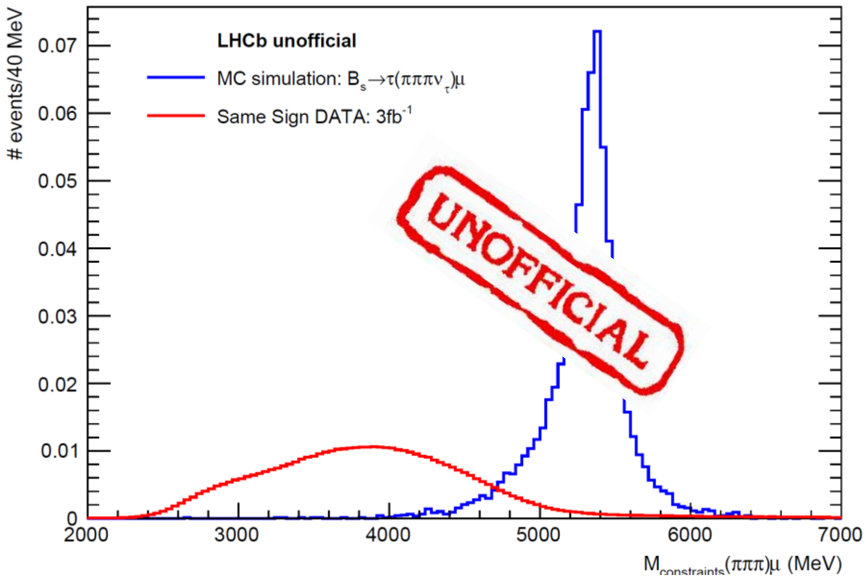
- Use $\tau^- \to \pi^- \pi^+ \pi^- \nu$ channel
- Larger efficiency thanks to the muon
- Smaller missing energy
- Less handle (only one Dalitz plane available)
- Large background from semileptonic B decays



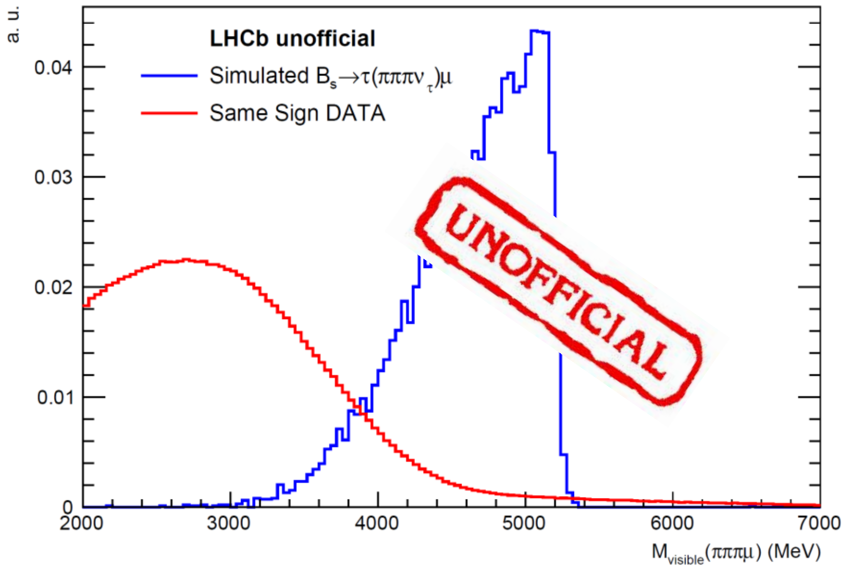
$B_{(s)} \to \tau\mu$: how?

- Can use kinematical contraints to refine the reconstructed B mass
- Blind the signal region
- Suppress background using boosted decision trees
- Fit the reconstructed mass, taking background shape from same sign data / Dalitz external regions / simulation
- Normalize to $B^0 \to D^+\pi^-$

$B_s \to \tau(\pi\pi\pi\nu_\tau)\mu$ mass with kinematic constraints



$B_s \to \tau(\pi\pi\pi\nu_\tau)\mu$ visible mass



$B \to K^* \tau\tau$: why ?

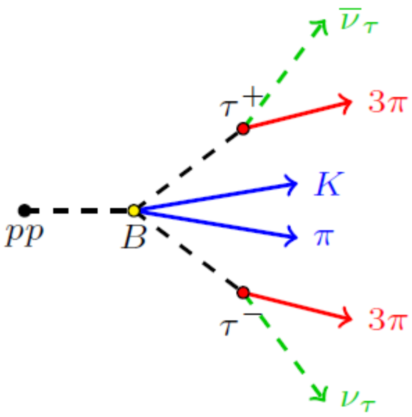
- Complementary to $B \to K^* \mu\mu$ and $B \to K^* ee$:
  - The sizable τ mass allows to test both right-handed and left-handed couplings
  - τ decay into measurable products leads to a variety of angular observables, related to the τ polarization
  - Comparison with $B \to K^* \mu\mu$ and $B \to K^* ee$ allow stringent tests of LFU

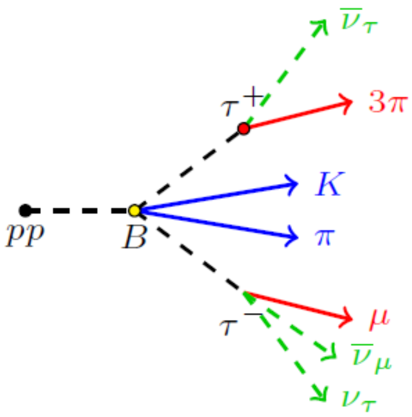
$$\frac{d\Gamma_\tau}{dq^2} = \left(1 - \frac{m_\tau^2}{q^2}\right) \frac{d\Gamma_\ell}{dq^2}\bigg|_{m_\ell = 0} + \frac{3m_\tau^2}{q^2} \left(\sum_{\lambda = \perp, \|, 0} 2\mathcal{R}e[A_\lambda^L A_\lambda^{R*}] + |A_t|^2 \right)$$

- Expected BR in the SM $\sim 10^{-7}$
- No existing experimental results
- Experimental goal: obtain a first limit / measure the integrated BR
- Phenomenological study of new observables that vanish for the light lepton modes, as well as variables sensitive to the τ polarization
- This requires a careful theoretical analysis of the full differential decay rate $\Rightarrow$ work in collaboration with CPT

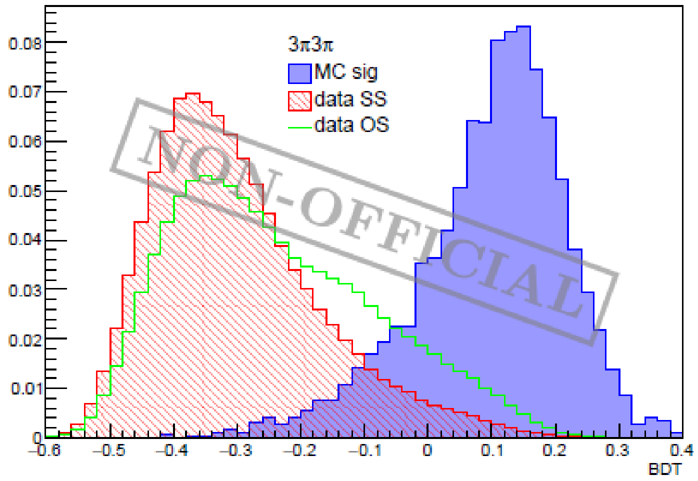
B→K*ττ: how ?

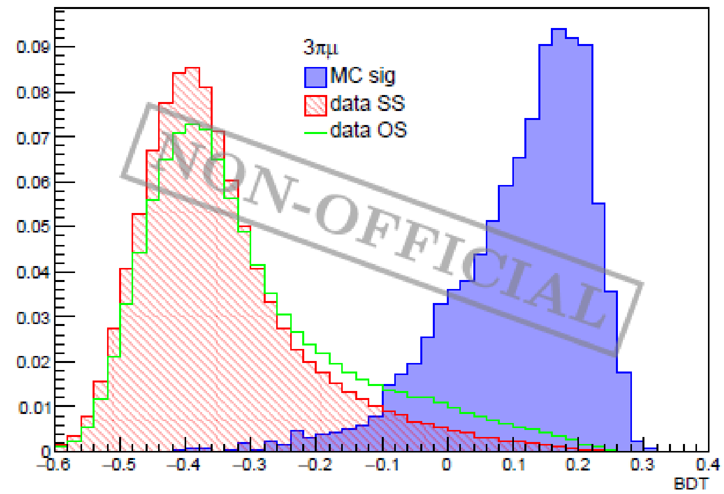
- Use both (3π,3π) and (3π,μ) final state





- Adapt tools already developed for $B_{(s)} \to \tau^+\tau^-$, analytic mass reconstruction using hadronic and leptonic decay modes, selection with BDT





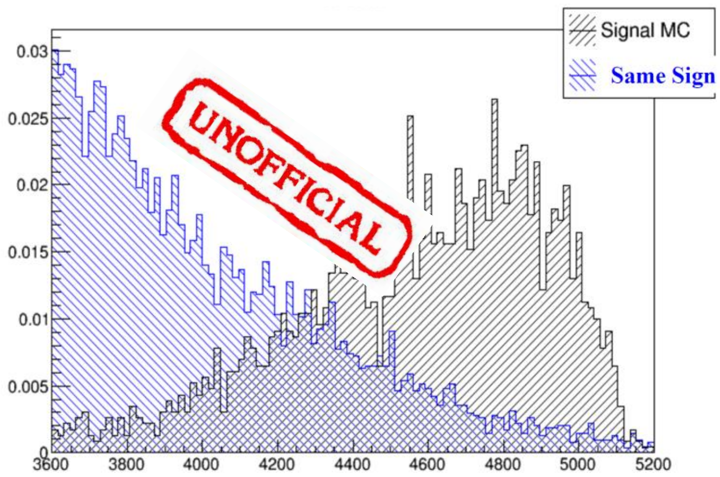
B→K*τμ

- No experimental result yet, work ongoing in LHCb

- Visible BR in several BSM theories (e.g, in generic Z' models BR(B→K*τμ) ~10^{-6} , *A. Crivellin et al* arXiv:1504.07928)

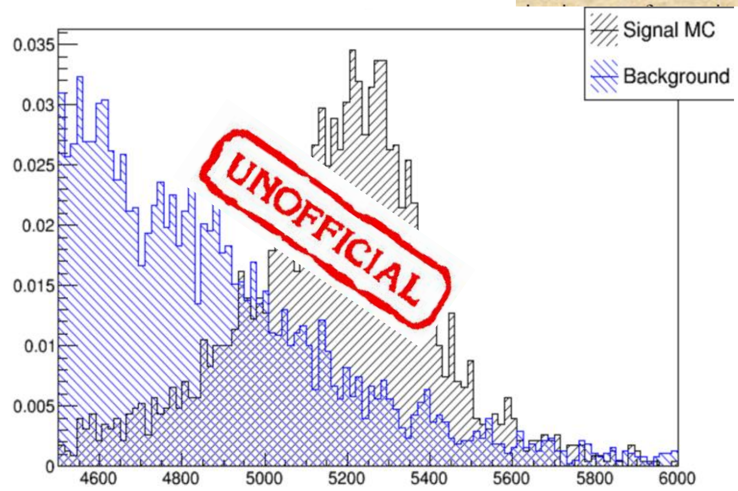
- Use both $\tau^- \to \pi^- \pi^+ \pi^- \nu$ and $\mu\nu\nu$ channel

Visible mass



corrected mass

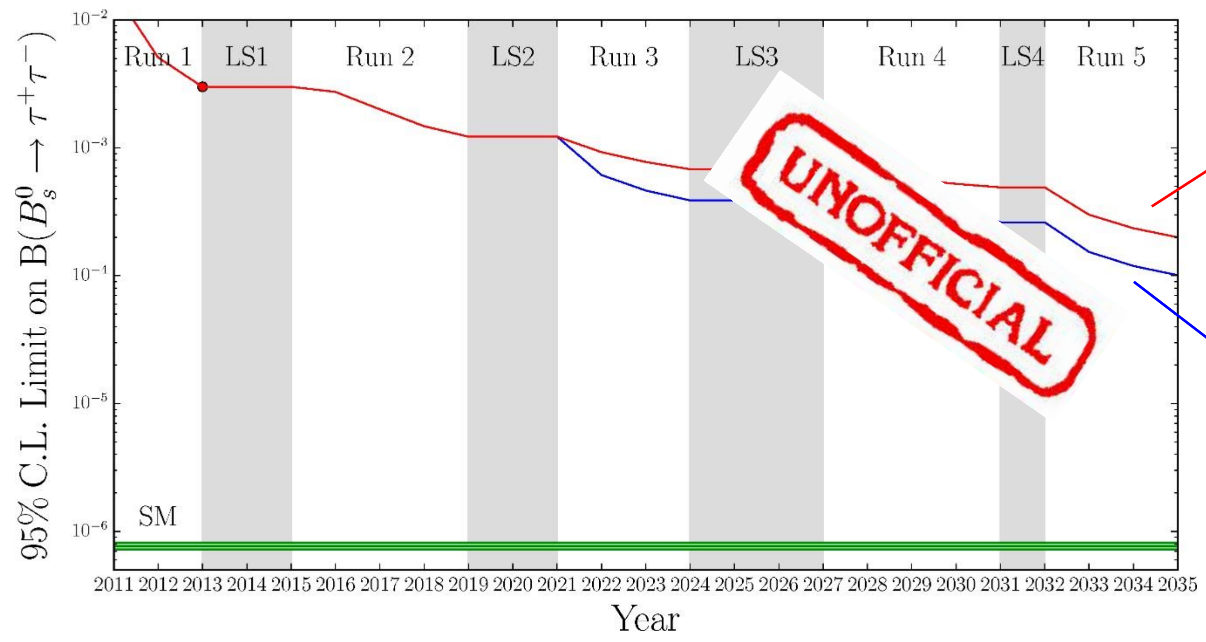
$$B_{CM} = \sqrt{p_{\perp}^2 + B_{MM}^2} + p$$



- B →Kτμ also under study

Conclusion and prospects

- $B_{(s)} \to \tau\tau$:
  - First experimental result on B_s, competitive with Babar on B^0
  - Proof of concept that rare B decay with taus decaying hadronically are doable at LHCb!
  - Next step: study the impact of different tau decay models
    $\Rightarrow$ publish final results with Run 1 data
  - Improve limit adding muonic mode, more data…and new ideas



Only luminosity gain

Adding muonic mode and improved upgrade trigger

Conclusion and prospects

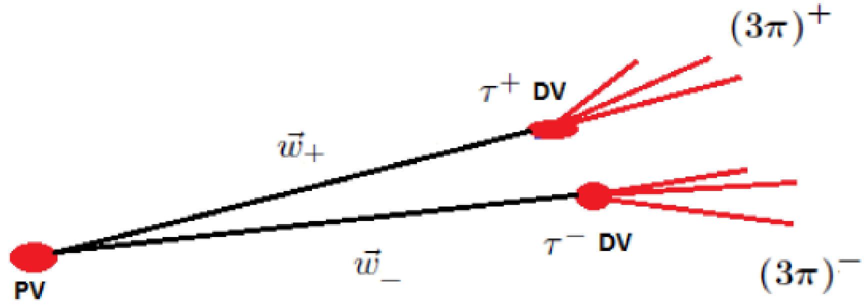
- New results expected soon for
  - $B_{(s)} \to \tau\mu$
  - $B \to K^{*}\tau\mu$
  - $B \to K^{*}\tau\tau$

Backup

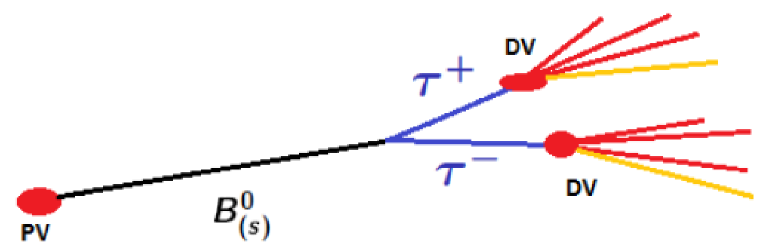
Reconstruction method

In the reconstructed events the following quantities are known:

- B origin vertex
- 3D sides of triangle $\vec{w}_\pm$
- 4-momenta $p^\mu_\pm$ of $(3\pi)_\pm$ system



How to access the tau momenta ?



Reconstruction method

Solving (momentum conservation along the decay chain):

$$W = H \cdot P$$

$$W \equiv (w_+^\mu, w_-^\mu) \qquad P \equiv (p_+, p_-)$$

$$H \equiv \begin{pmatrix} \frac{t_B}{m_B} + \frac{t_{\tau+}}{m_\tau} & \frac{t_B}{m_B} \\ \frac{t_B}{m_B} & \frac{t_B}{m_B} + \frac{t_{\tau-}}{m_\tau} \end{pmatrix}$$

Decay time t_i unknown

Using on-shell and flight direction constraints, this equation is equivalent to solving

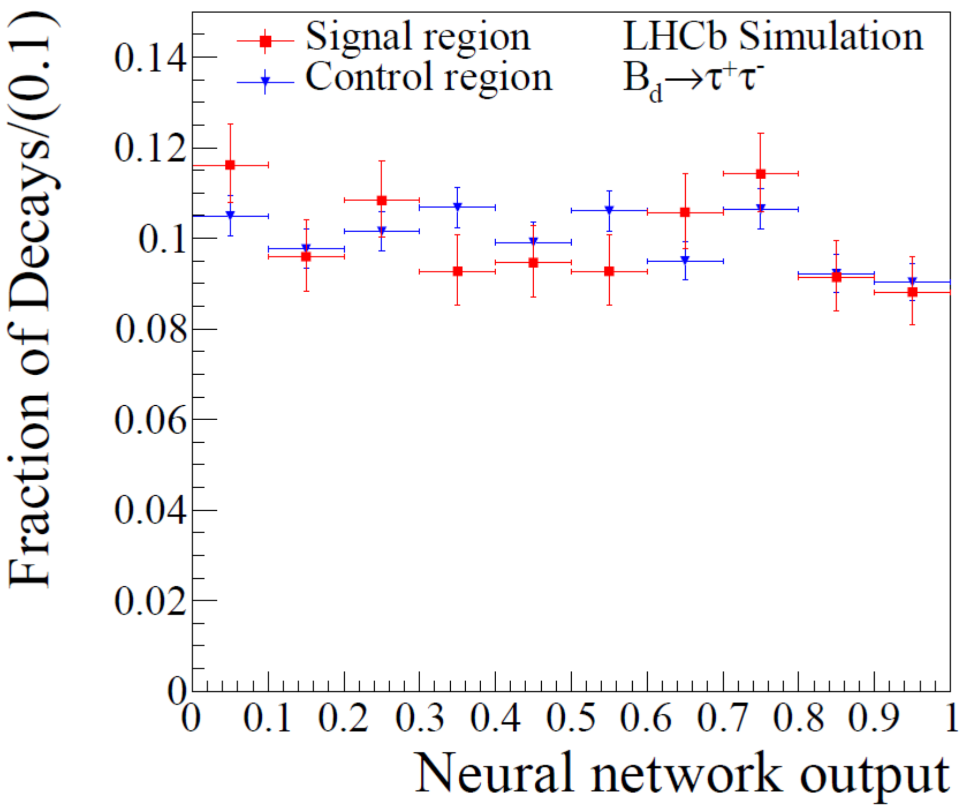
$$\mathcal{P}^{(4)}(\xi) = \sum_{i=0}^{4} a_i(\theta)\xi^i = 0$$

⇒ 4 complex solutions

θ is sensitive to the symmetry of the triangle formed by the PV and tau DVs, can be approximated

Several new variables appear in the reconstruction process and have discriminating power, although not being ‘physical’

$B^0 \to \tau\tau$



Signal region
Control region
LHCb Simulation
$B_d \to \tau^+\tau^-$
Fraction of Decays/(0.1)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Neural network output