Karlsruher Institut für Technologie

Recent results of B decays from Belle

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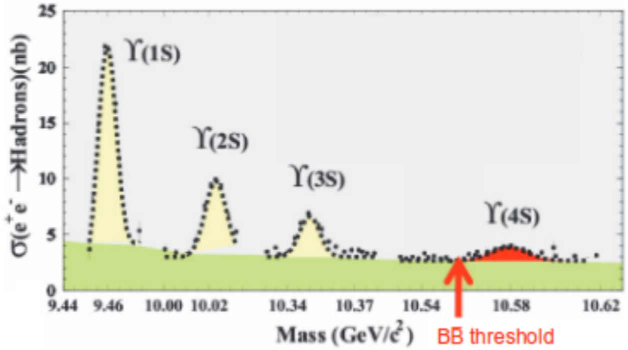
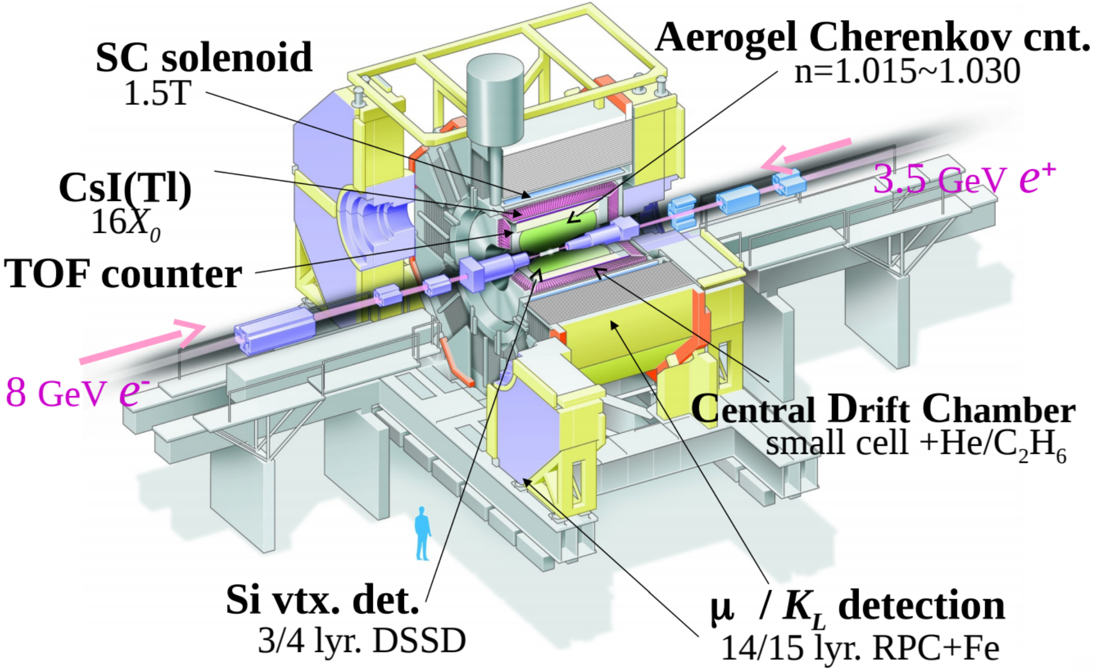
Overview

- key characteristics of Belle
- $B \to D^* \tau \nu$ - new measurement of τ polarization and $R(D^*)$
- $B \to K^* l^+ l^-$ - lepton-flavour-dependent angular analysis
- other recent results on rare B decays
  - $B \to h^{(*)} \nu \nu$
  - $B^+ \to \mu^+ \nu$
- summary & outlook

Key Characteristics of Belle

- asymmetric electron-positron collider at Y(4S)-energy
- 772 million $B\bar{B}$ pairs
- Running: 1999 - 2010

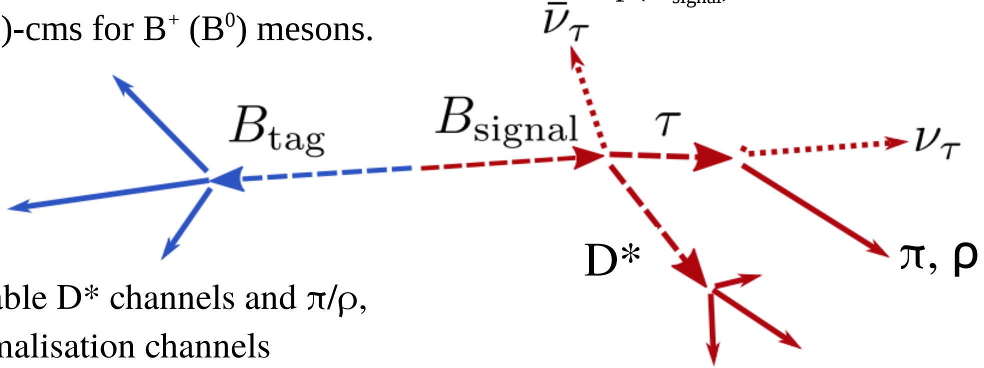




$B \rightarrow D^* \tau \nu$ - Polarization and R(D*)

Phys. Rev. Lett. 118, 211801

- strategy:
  - recombine one of the B mesons of the Υ(4S) - for this analysis, hadronic tagging is used, as it delivers a better resolution for $p(B_{signal})$, which is ~ 331 (326) MeV/c in the (~known) Υ(4S)-cms for B^+ (B^0) mesons.

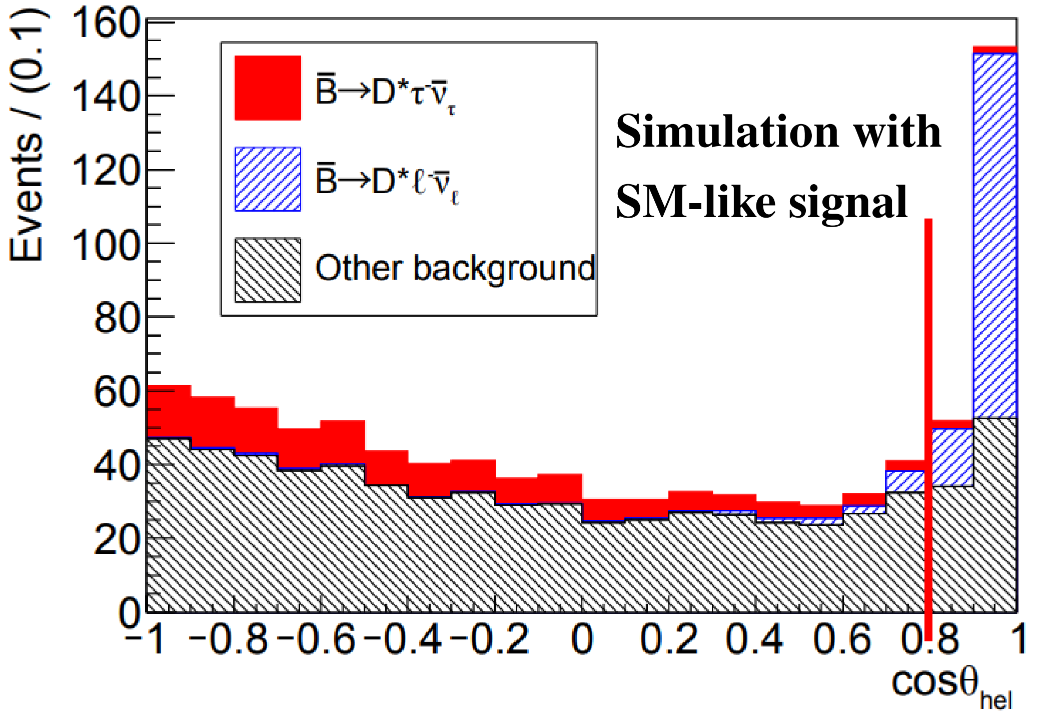


  - recombine signal side in all reasonable D* channels and π/ρ, light leptons instead of π/ρ for normalisation channels
  - Require kinematics of signal events to be consistent with the signal as well as no additional tracks, no additional good π^0, less than 1.5 GeV of energy in the ECL left.

$B \to D^* \tau \nu$ - Polarization

- Due to our knowledge of B_{signal} momentum, we can calculate the helicity angle
  $\cos \theta_{hel}$:
  angle between the τ-daughter momentum and the opposite of the momentum of the τ ν system in the τ rest frame

  Only $\cos \theta_{hel}$ between -1 and 0.8 is used, for further analysis, sample is divided into two categories:
  $\cos \theta_{hel}$ larger or smaller than zero

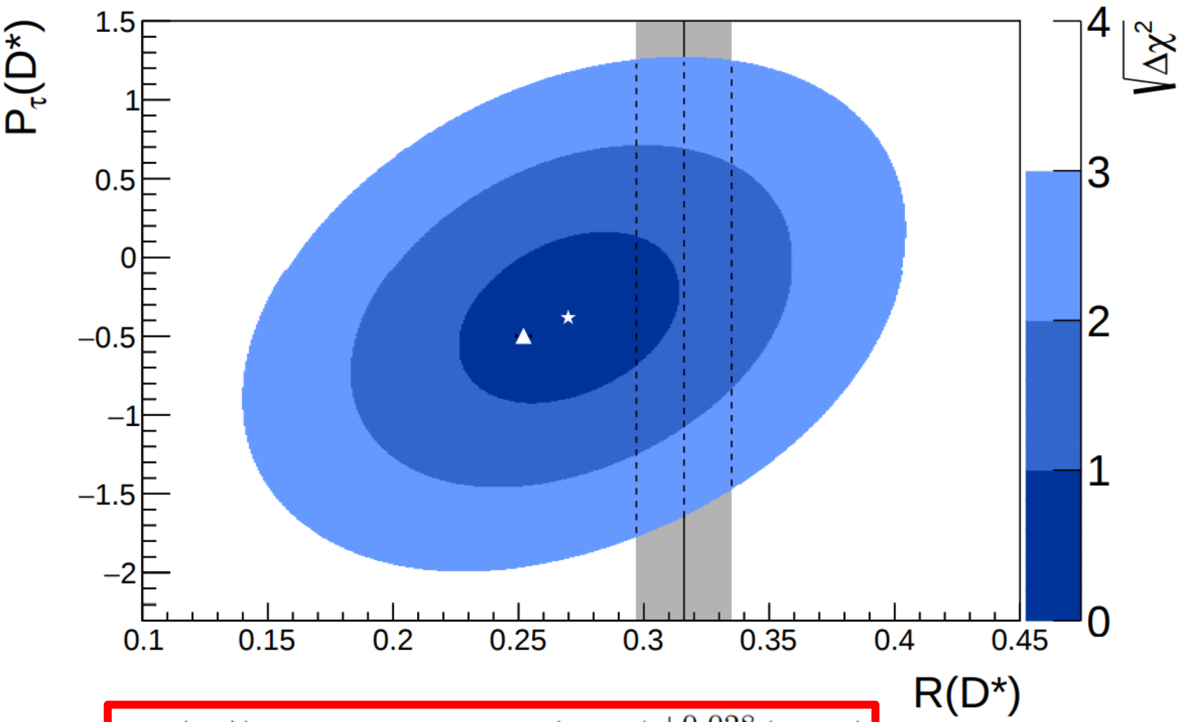


$B \rightarrow D^* \tau \nu$ - Results

$$P_\tau(D^*) = [2(N^{\rm F}_{\rm sig} - N^{\rm B}_{\rm sig})]/[\alpha(N^{\rm F}_{\rm sig} + N^{\rm B}_{\rm sig})]$$

- F(orward) denotes events with $\cos\theta_{hel} > 0$
- B(ackward) denotes events with $\cos\theta_{hel} < 0$
- α denotes a factor for the sensitivity of the respective final state $\alpha = 1$ for π, $\alpha = 0.45$ for ρ
- SM prediction for polarization: (Tanaka et al., PRD 87. 0.4028)

$$P_\tau(D^*) = -0.497 \pm 0.013$$

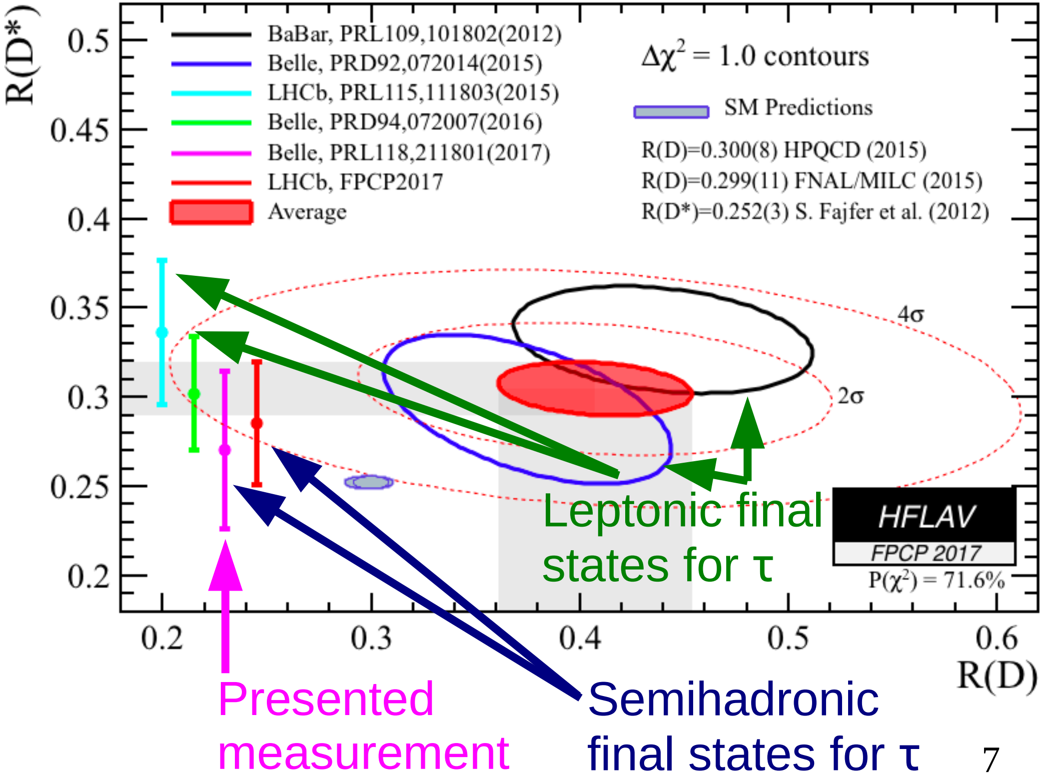


$$R(D^*) = 0.270 \pm 0.035({\rm stat.})^{+0.028}_{-0.025}({\rm syst.})$$

$$P_\tau(D^*) = -0.38 \pm 0.51({\rm stat.})^{+0.21}_{-0.16}({\rm syst.})$$

$B \rightarrow D^* \tau \nu$ - BR Overview

- world average differs by ~4 σ from theory predictions
- when thinking about New Physics solutions to the discrepancy, take into account, that we might not actually see τs, but perhaps light leptons + missing mass/energy



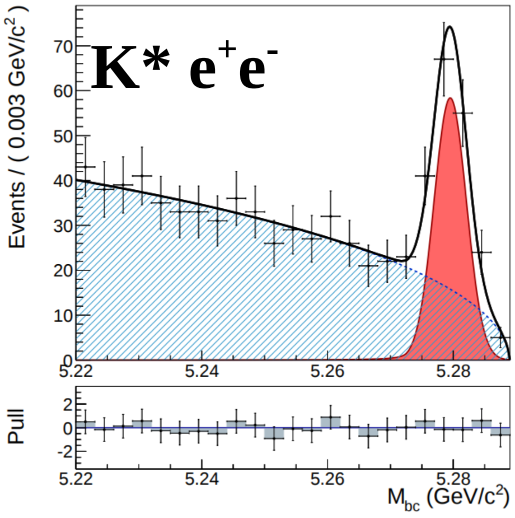
$B \to K^* l^+ l^-$ - angular analysis for μ/e

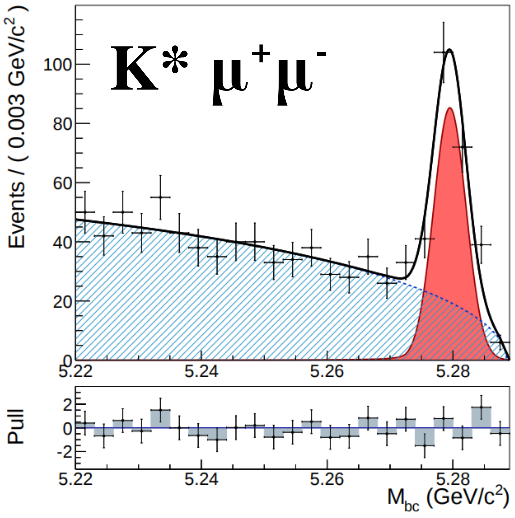
Phys. Rev. Lett. 118, 111801

- strategy:
  - reconstruct B mesons (B^+/B^0) in $\mathbf{K^*}[K^+ \pi^- / K^+ \pi^0 / K_S \pi^+]$ $\mathbf{l^+ l^-}$ ($l = \mu/e$)
  - Extract observables P'_i (explanation see later)

$B \to K^* l^+ l^-$ - m_{bc} signal extraction

- Most backgrounds don't peak in the beam constraint mass $M_{bc} = \sqrt{E^2_{beam}/c^4 - |\vec{p}_B|^2/c^2}$
- background distributions in the observables estimated from sideband
- Small peaking backgrounds are evaluated on MC to be very small

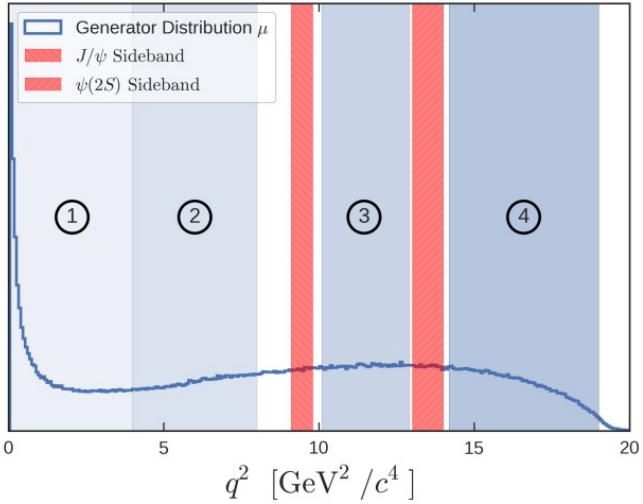




B → K* l+ l- - Differential Decay Rate, P'i

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi$$
$$+ S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

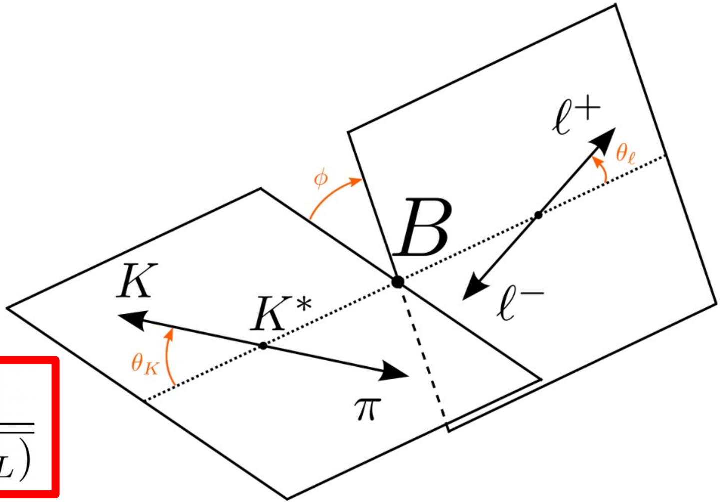
square of invariant mass of lepton pair



F_L, S_i functions only dependent on q^2

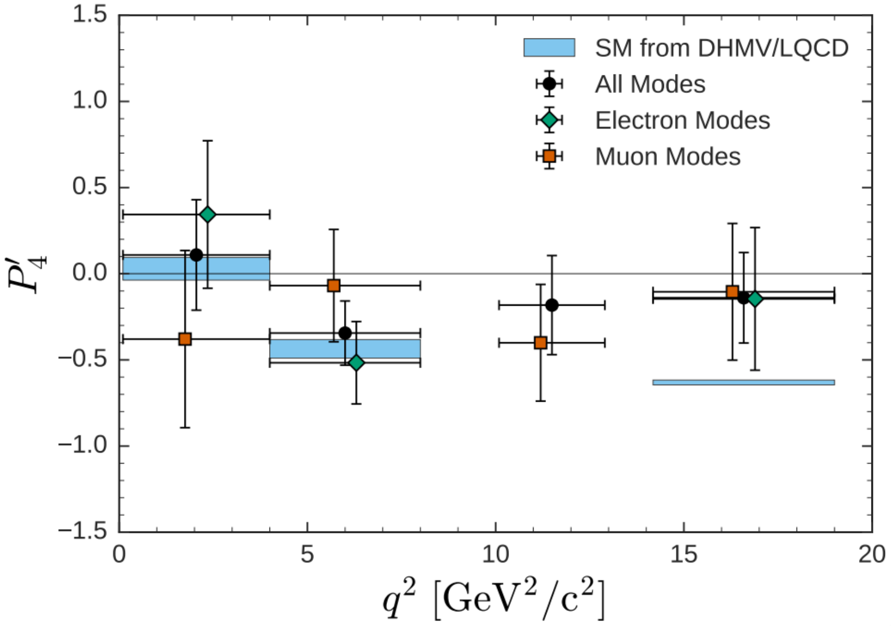
Believed to be largely free from Form Factor uncertainties:

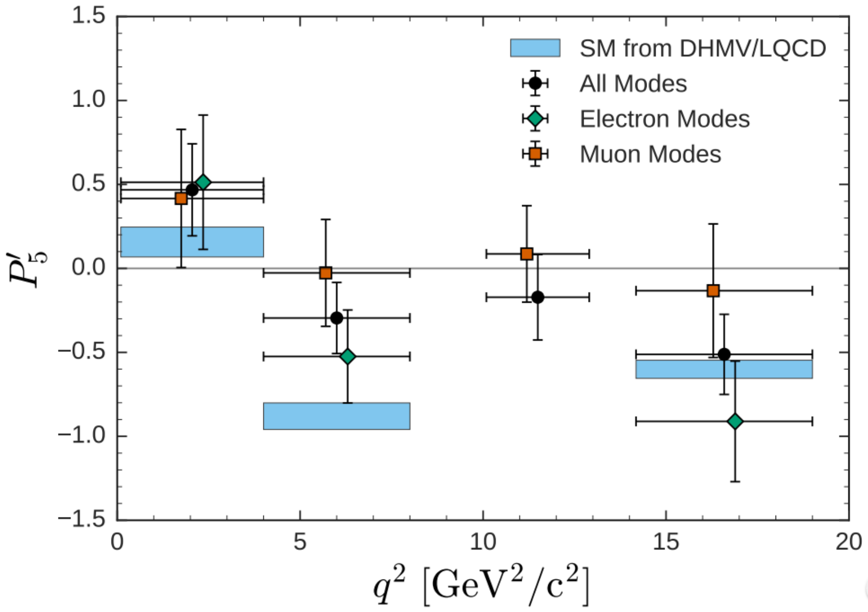
$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$



$B \rightarrow K^* l^+ l^-$ - Results

- Fit results for P’$_4$ and P’$_5$ for all decay channels and separately for the electron and muon modes. The first uncertainties are statistical and the second systematic.



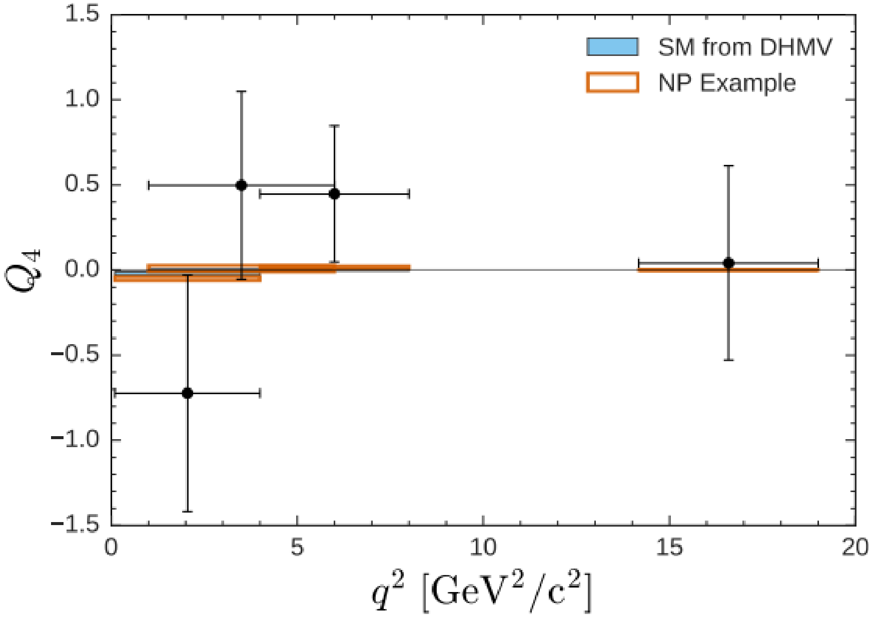


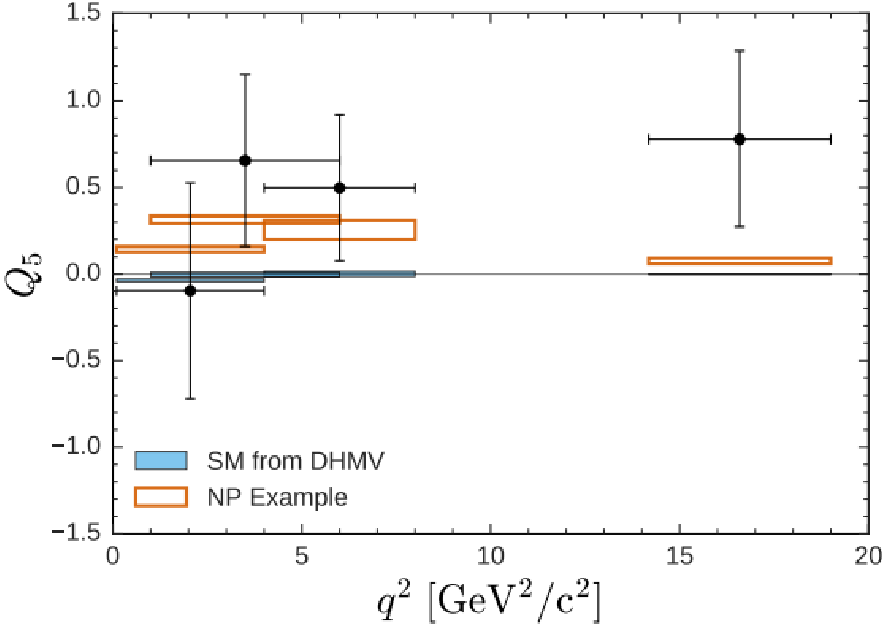
$B \rightarrow K^* l^+ l^-$ - Results in Numbers

q^2 in GeV^2/c^2	P_4'	$P_4^{e\prime}$	$P_4^{\mu\prime}$	P_5'	$P_5^{e\prime}$	$P_5^{\mu\prime}$
[1.00, 6.00]	$-0.45^{+0.23}_{-0.22} \pm 0.09$	$-0.72^{+0.40}_{-0.39} \pm 0.06$	$-0.22^{+0.35}_{-0.34} \pm 0.15$	$0.23^{+0.21}_{-0.22} \pm 0.07$	$-0.22^{+0.39}_{-0.41} \pm 0.03$	$0.43^{+0.26}_{-0.28} \pm 0.10$
[0.10, 4.00]	$0.11^{+0.32}_{-0.31} \pm 0.05$	$0.34^{+0.41}_{-0.45} \pm 0.11$	$-0.38^{+0.50}_{-0.48} \pm 0.12$	$0.47^{+0.27}_{-0.28} \pm 0.05$	$0.51^{+0.39}_{-0.46} \pm 0.09$	$0.42^{+0.39}_{-0.39} \pm 0.14$
[4.00, 8.00]	$-0.34^{+0.18}_{-0.17} \pm 0.05$	$-0.52^{+0.24}_{-0.22} \pm 0.03$	$-0.07^{+0.32}_{-0.31} \pm 0.07$	$-0.30^{+0.19}_{-0.19} \pm 0.09$	$-0.52^{+0.28}_{-0.26} \pm 0.03$	$-0.03^{+0.31}_{-0.30} \pm 0.09$
[10.09, 12.90]	$-0.18^{+0.28}_{-0.27} \pm 0.06$	-	$-0.40^{+0.33}_{-0.29} \pm 0.09$	$-0.17^{+0.25}_{-0.25} \pm 0.01$	-	$0.09^{+0.29}_{-0.29} \pm 0.02$
[14.18, 19.00]	$-0.14^{+0.26}_{-0.26} \pm 0.05$	$-0.15^{+0.41}_{-0.40} \pm 0.04$	$-0.10^{+0.39}_{-0.39} \pm 0.07$	$-0.51^{+0.24}_{-0.22} \pm 0.01$	$-0.91^{+0.36}_{-0.30} \pm 0.03$	$-0.13^{+0.39}_{-0.35} \pm 0.06$

B → K* l⁺ l⁻ - Lepton Universality Test

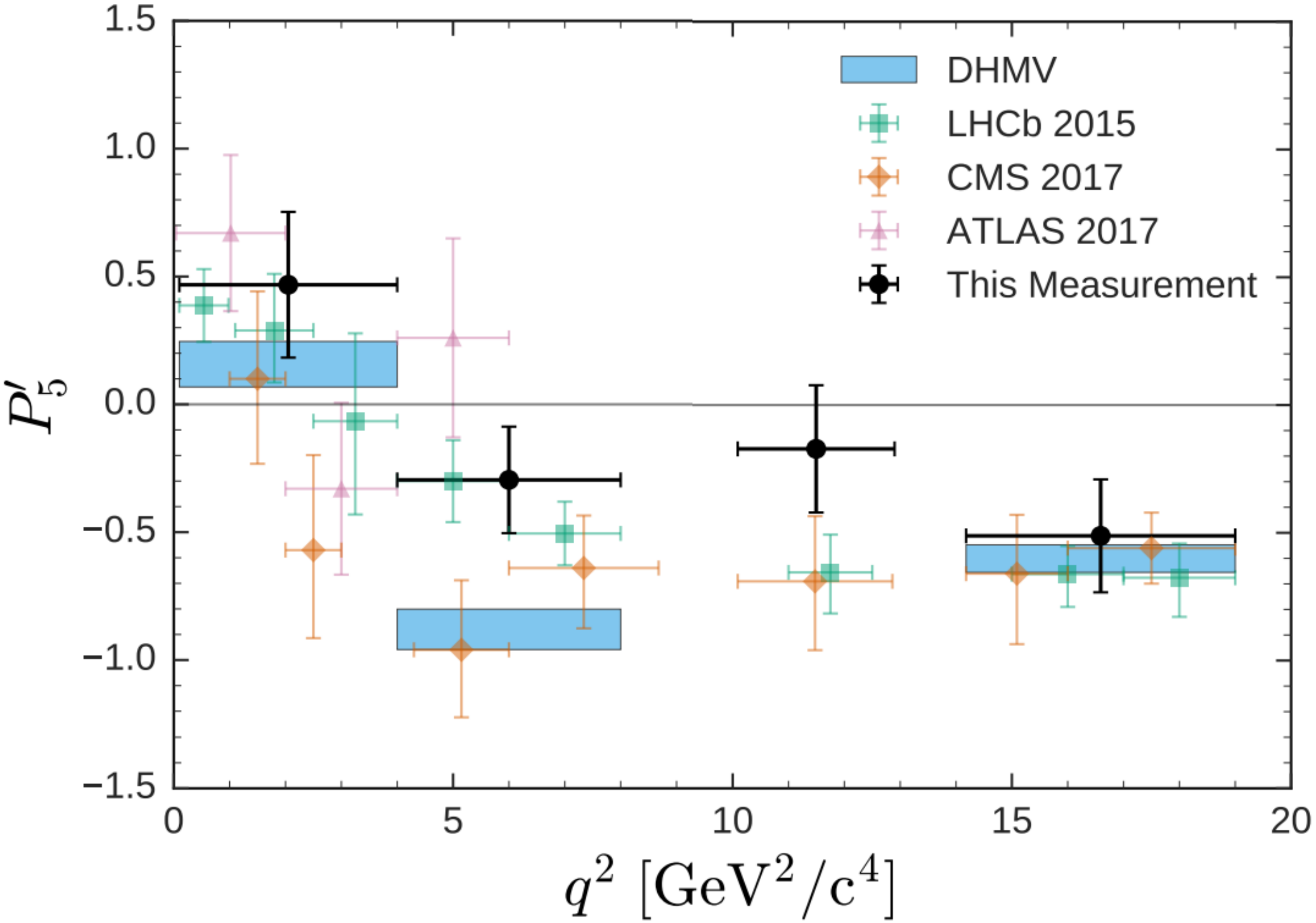
$$Q = P^{\mu} - P^{e}$$





Good agreement with measurements from LHC experiments.

Note: This is the combined e/μ value from Belle. Discrepancy with SM is bigger when taking P'^{μ}_5.

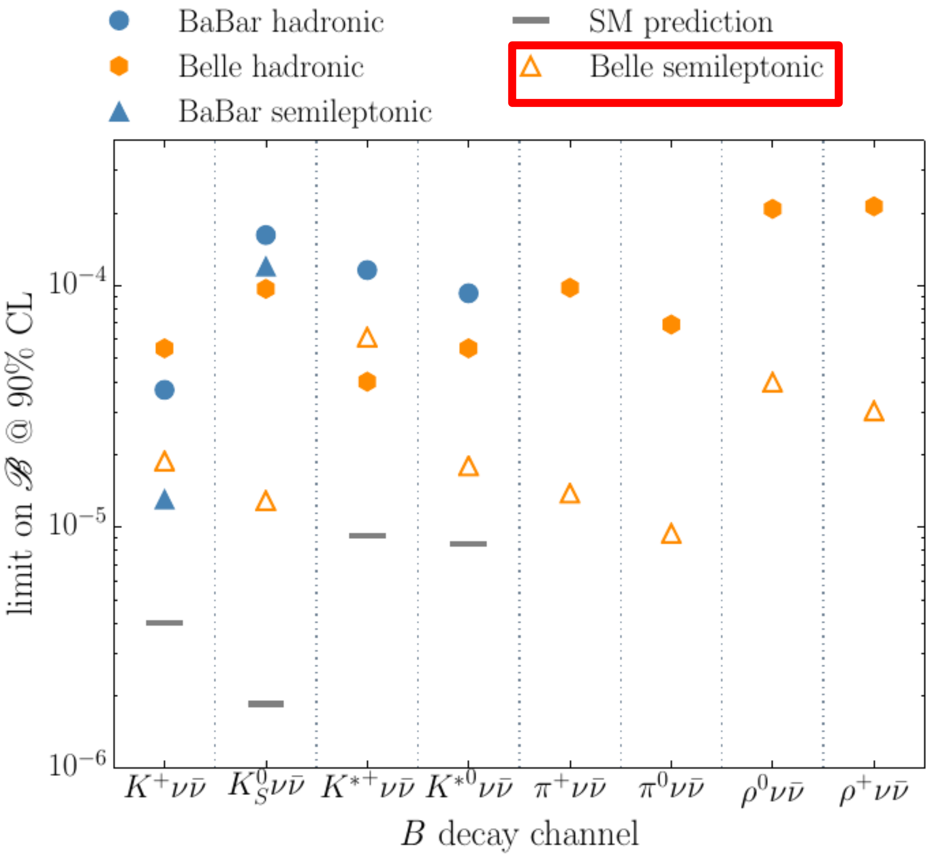


$B \to h^{(*)} \nu \nu$

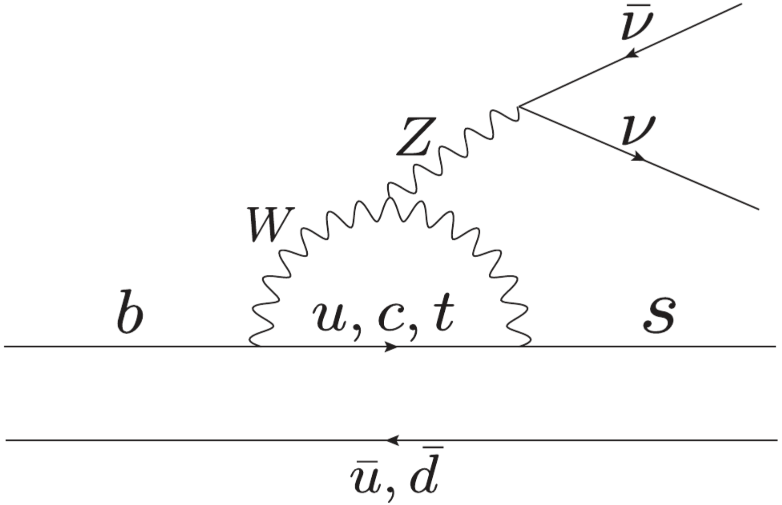
PRD accepted, https://arxiv.org/abs/1702.03224

- could be an alternative way to see the same kind of New Physics, that might be in $B \to K^* l^+ l^-$
- basic strategy similar to $B \to D^* \tau \nu$:
  - recombine one of the B mesons of the Υ(4S) -
    using ***semileptonic tag-side decays*** in the most recent measurement
  - select the $h^{(*)}$
  - veto any additional tracks, neutral pions/kaons
  - fit the amount of energy remaining in the calorimeter for the remaining events

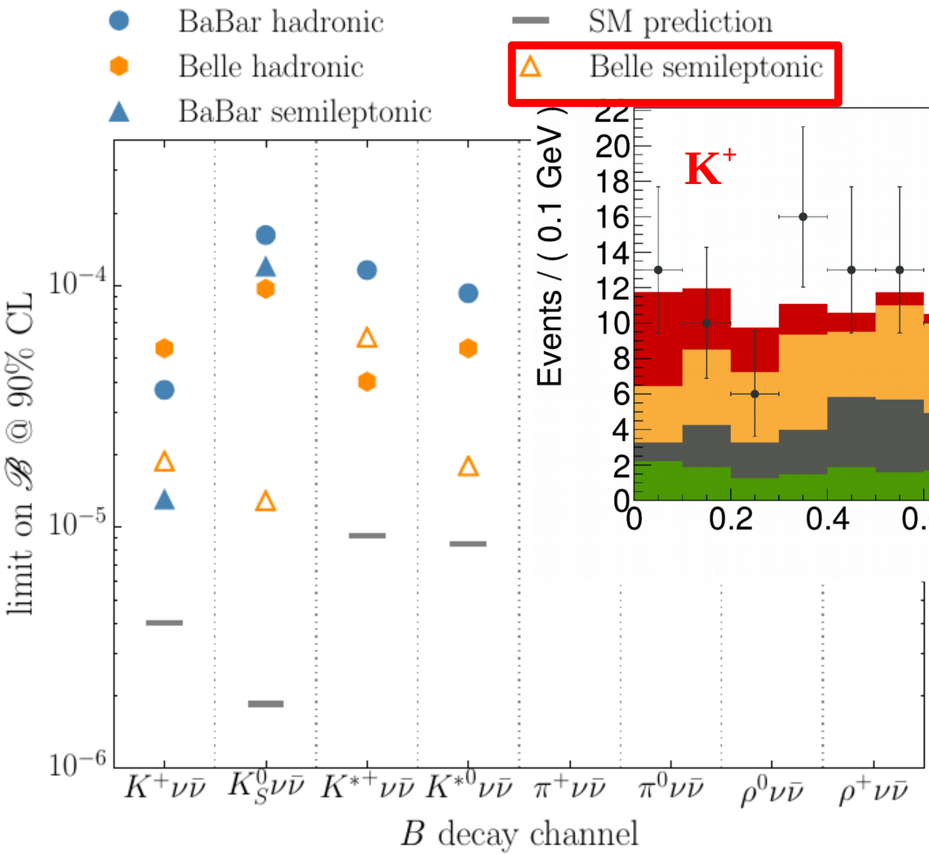
$B \to h^{(*)} \nu \nu$ - Limits Overview

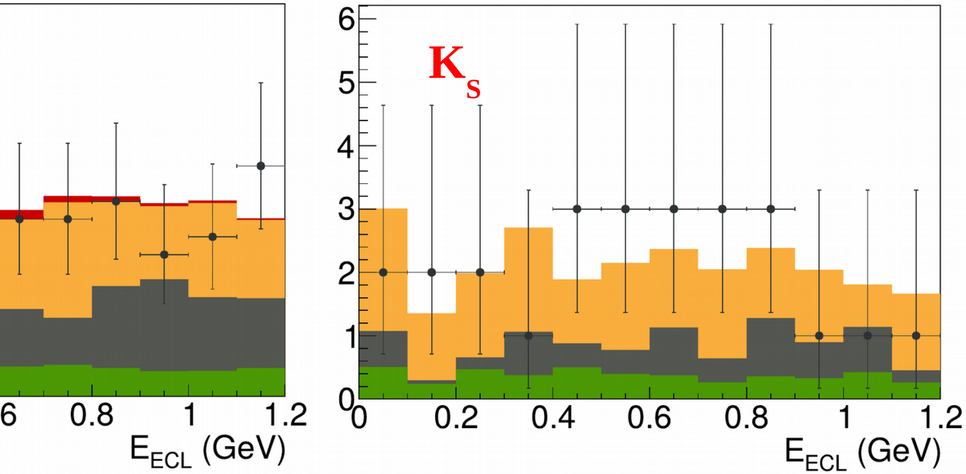


- Better sensitivity than hadronically tagged analysis



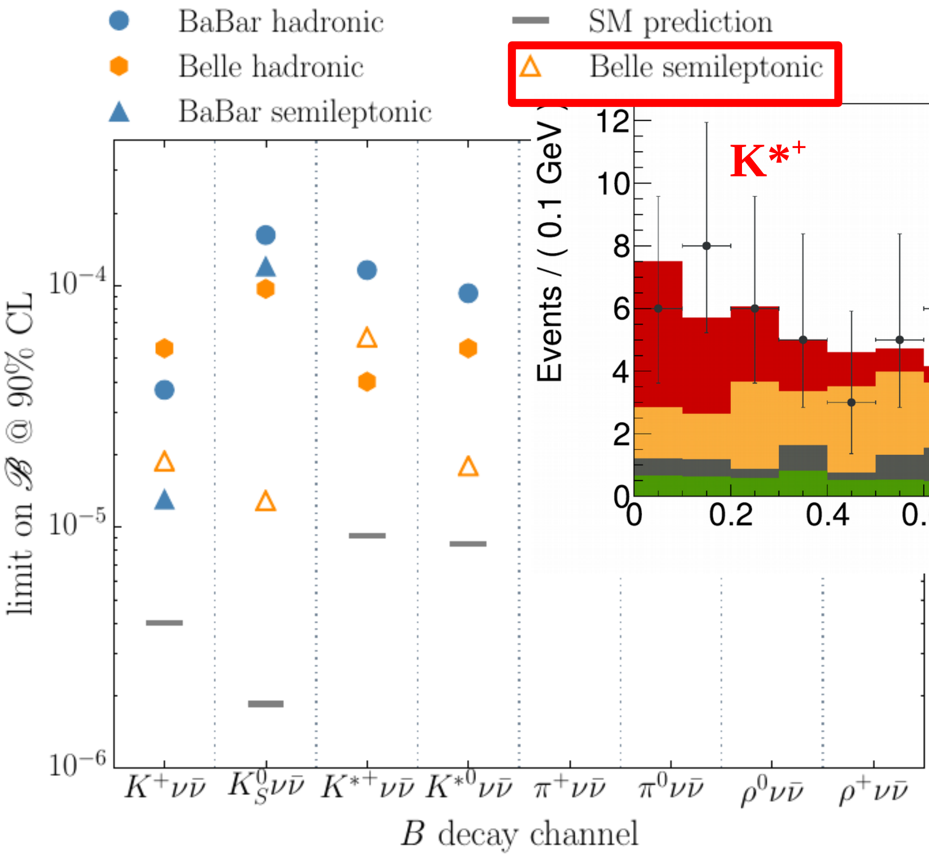
B → h^(*) ν ν - Limits Overview

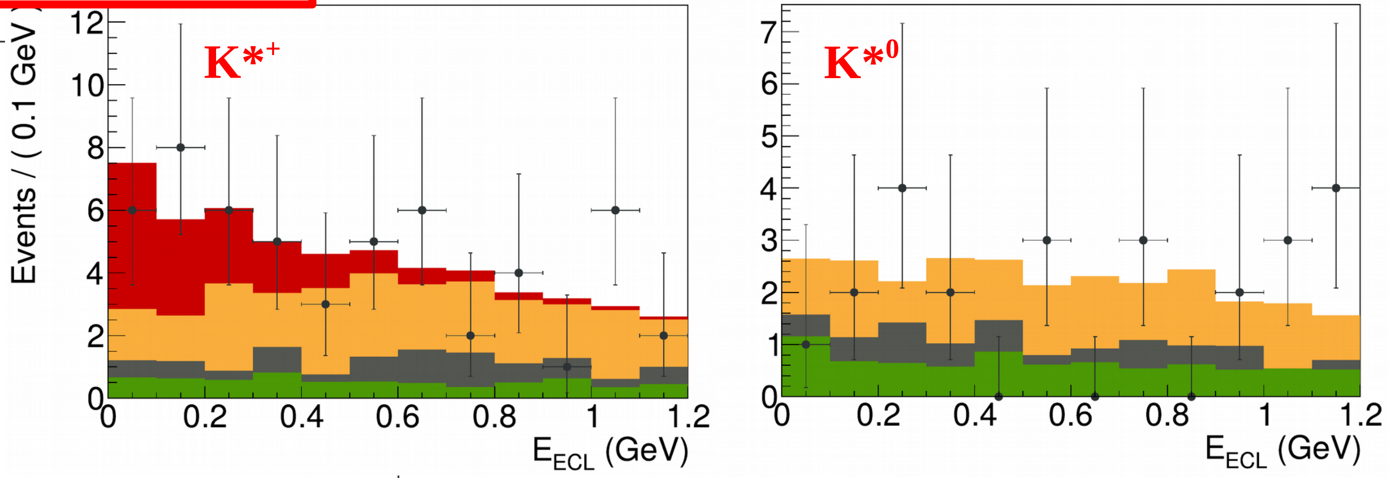




Channel	Observed signal yield	Significance
$K^+\nu\bar{\nu}$	$17.7 \pm 9.1 \pm 3.4$	$1.9\,\sigma$
$K_S^0\,\nu\bar{\nu}$	$0.6 \pm 4.2 \pm 1.4$	$0.0\,\sigma$

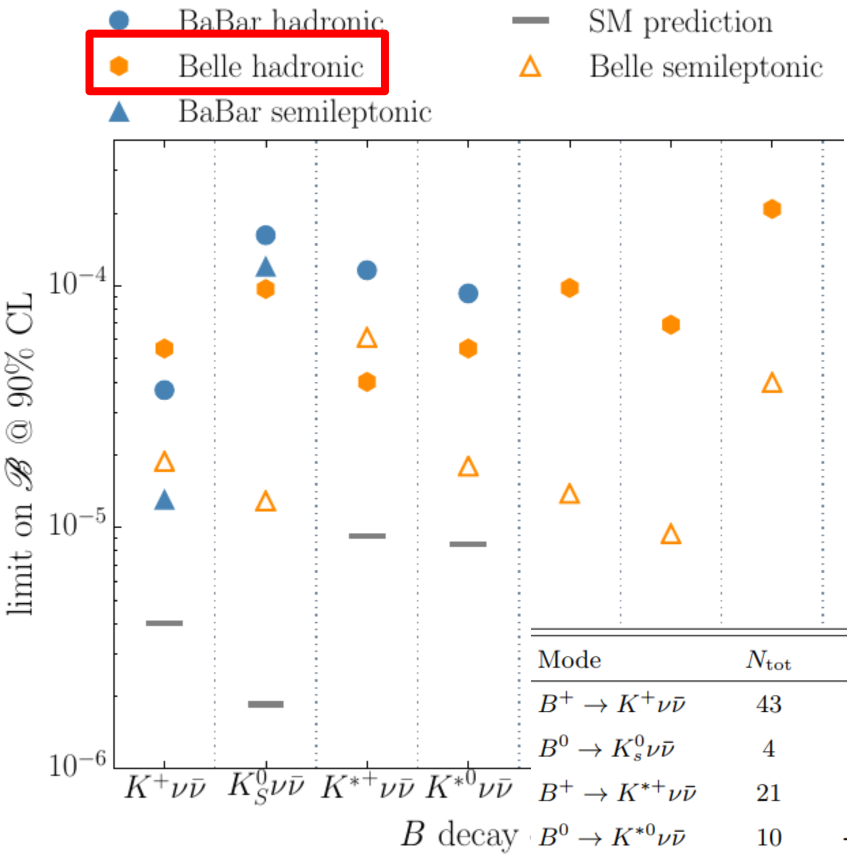
B → h$^{(*)}$ ν ν - Limits Overview

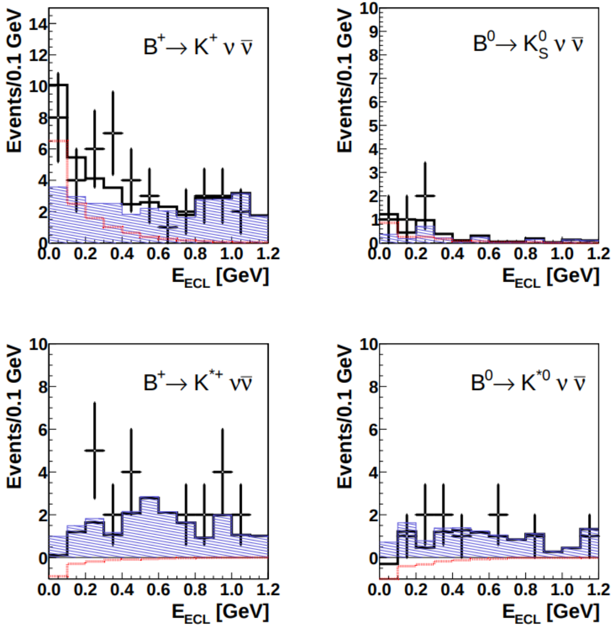




Channel	Observed signal yield	Significance
$K^{*+}\nu\bar{\nu}$	$16.2 \pm 7.4 \pm 1.8$	$2.3\,\sigma$
$K^{*0}\nu\bar{\nu}$	$-2.0 \pm 3.6 \pm 1.8$	$0.0\,\sigma$

$B \to h^{(*)} \nu \nu$ - Limits Overview





For comparison: Hadronically tagged analysis
(Phys. Rev. D 87 (2013) 111103)

→ Both are worth doing

Mode	N_{tot}	N_{sig}	Significance	$\epsilon, 10^{-4}$	Upper limit	Expected limit
$B^+ \to K^+\nu\bar{\nu}$	43	$13.3^{+7.4}_{-6.6}(\text{stat}) \pm 2.3(\text{syst})$	2.0σ	5.68	$< 5.5 \times 10^{-5}$	2.2×10^{-5}
$B^0 \to K^0_s\nu\bar{\nu}$	4	$1.8^{+3.3}_{-2.4}(\text{stat}) \pm 1.0(\text{syst})$	0.7σ	0.84	$< 9.7 \times 10^{-5}$	7.3×10^{-5}
$B^+ \to K^{*+}\nu\bar{\nu}$	21	$-1.7^{+1.7}_{-1.1}(\text{stat}) \pm 1.5(\text{syst})$	–	1.47	$< 4.0 \times 10^{-5}$	5.8×10^{-5}
$B^0 \to K^{*0}\nu\bar{\nu}$	10	$-2.3^{+10.2}_{-3.5}(\text{stat}) \pm 0.9(\text{syst})$	–	1.44	$< 5.5 \times 10^{-5}$	4.6×10^{-5}

$B^+ \to \mu^+ \nu$

publication in preparation

- strategy:
  - Identify a muon
  - Fit the muon momentum in the Υ(4S) rest frame and the output of an multivariate classifier

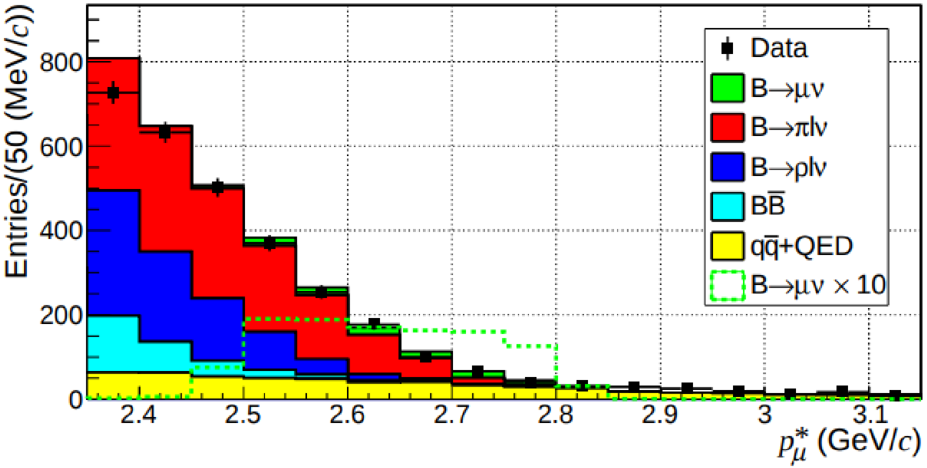
$B^+ \rightarrow \mu^+ \nu$

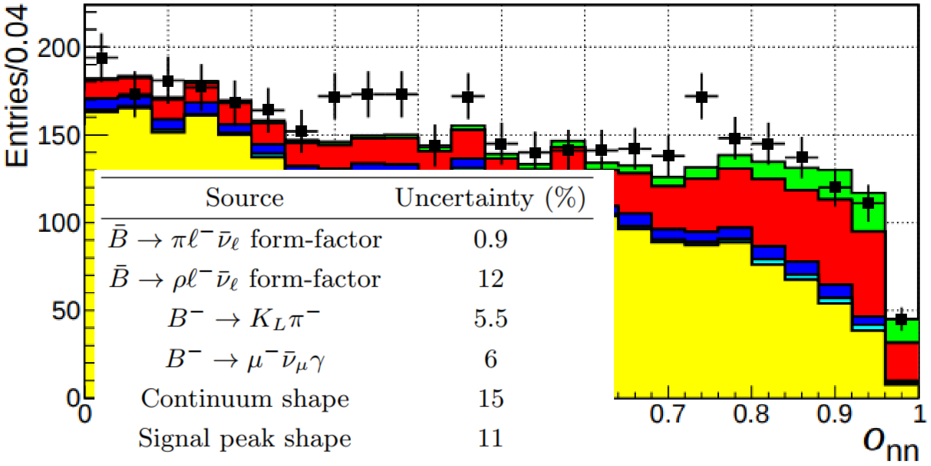
- 2.4 σ significance.

$\mathcal{B}(B^- \rightarrow \mu^- \bar{\nu}_\mu) \in [2.9, 10.7] \times 10^{-7}$ at the 90% C.L.

- Two sided limit compatible with SM value of $(3.80 \pm 0.31) \times 10^{-7}$ (value debatable due to V_{ub} situation)

- Extensive studies of u l ν backgrounds





Source	Uncertainty (%)
$\bar{B} \rightarrow \pi \ell^- \bar{\nu}_\ell$ form-factor	0.9
$\bar{B} \rightarrow \rho \ell^- \bar{\nu}_\ell$ form-factor	12
$B^- \rightarrow K_L \pi^-$	5.5
$B^- \rightarrow \mu^- \bar{\nu}_\mu \gamma$	6
Continuum shape	15
Signal peak shape	11
Trigger	8
$\mathcal{B}(\bar{B} \rightarrow \pi \ell^- \bar{\nu}_\ell)$	3.4
Total	24.6

Summary & Outlook

- Polarisation & R(D*) in yet another Belle analysis of **$B \rightarrow D^* \tau \nu$** using hadronic final states for τs is well compatible with the Standard Model.

- Belle's analysis of **$K^* l^+ l^-$** confirms, there is reason for excitement.

- **$B \rightarrow h^{(*)} \nu \nu$** limits are less than an order of magnitude away from the Standard Model, future experiments will likely observe strange final states.

- **$B^+ \rightarrow \mu^+ \nu$** is almost within reach and will be seen either by Belle or very early in future flavour experiments.