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New physics searches in leptonic decays of B mesons

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Overview

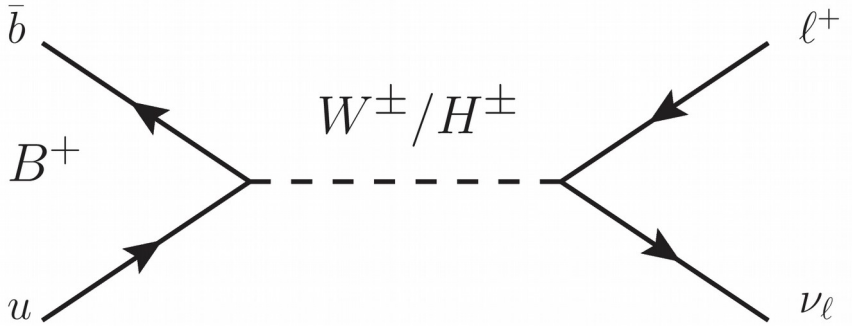
- Motivation for B → l nu (l = tau, mu, e) decays.
- B → l nu (l = mu, e) with hadronic tag.
- **B → tau nu with semileptonic tag**
  – Update first time shown in public.

Motivation for B → l nu (l = tau, mu, e)

- Reasonably well possible to calculate assuming annihilation via W-Boson:

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- In addition there can be coherent interference with other processes, that would allow to mediate such a process, e.g. H^+.



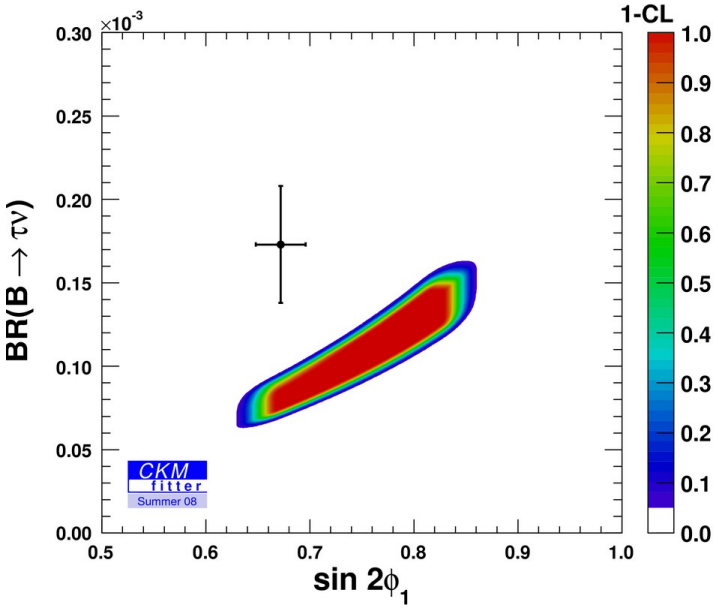
- Some new physics models (e.g. non MFV) could as well affect B → mu nu in a different way than B → tau nu.

Motivation

- In 2008 a tension emerged for V_{ub} from B → tau nu vs. CKM full triangle fit (excluding direct measurements of **V_{ub}**).

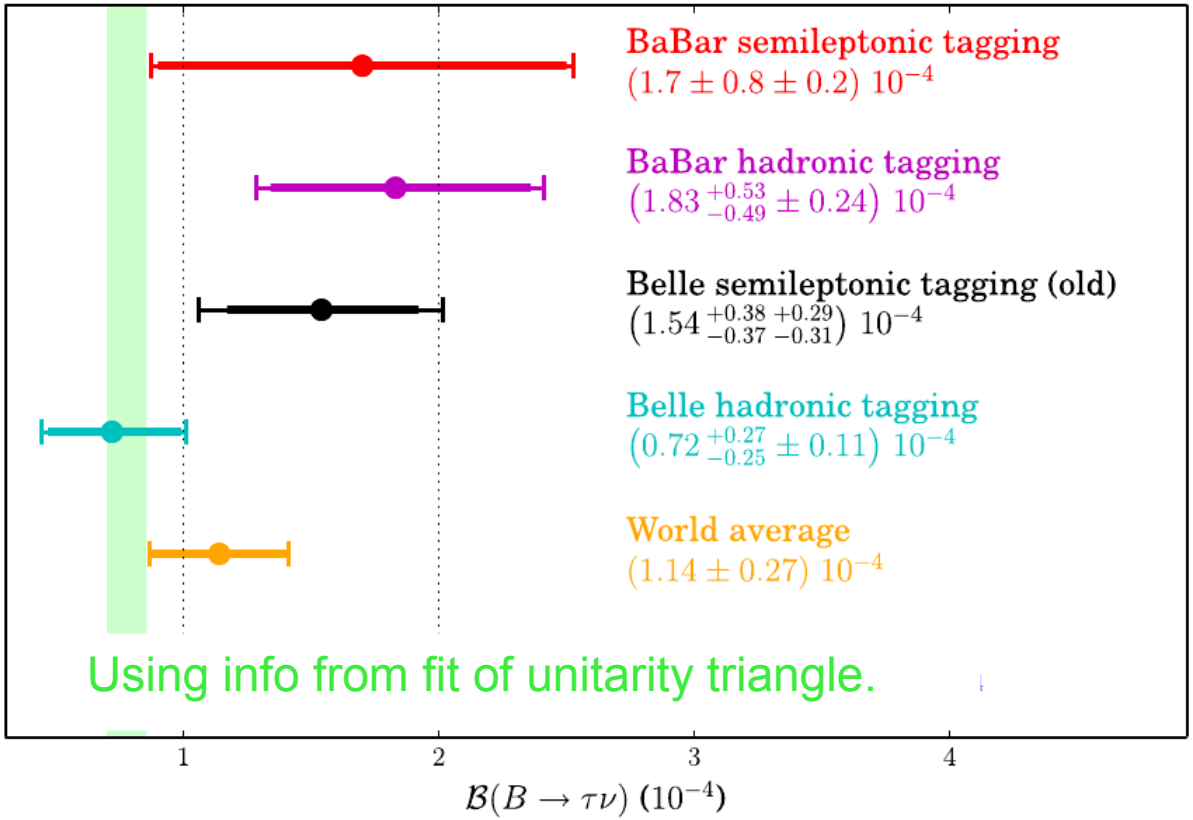
- Is the BR too high?
  Is there New Physics causing this?

  In this case B → tau nu can as well be taken as measurement of **V_{ub}** and the New Physics could be in the sin(2 phi_1) measurement.



Tensions Easing Later

- Belle Analysis with new tracking and new hadronic tag reduced the average and thereby tensions considerably:



But now to the current measurements!

Experimental Situation of B → l nu

- BR (B → e nu) < 9.8 * 10**(-7)
- BR (B → mu nu) < 1.0 * 10**(-6)

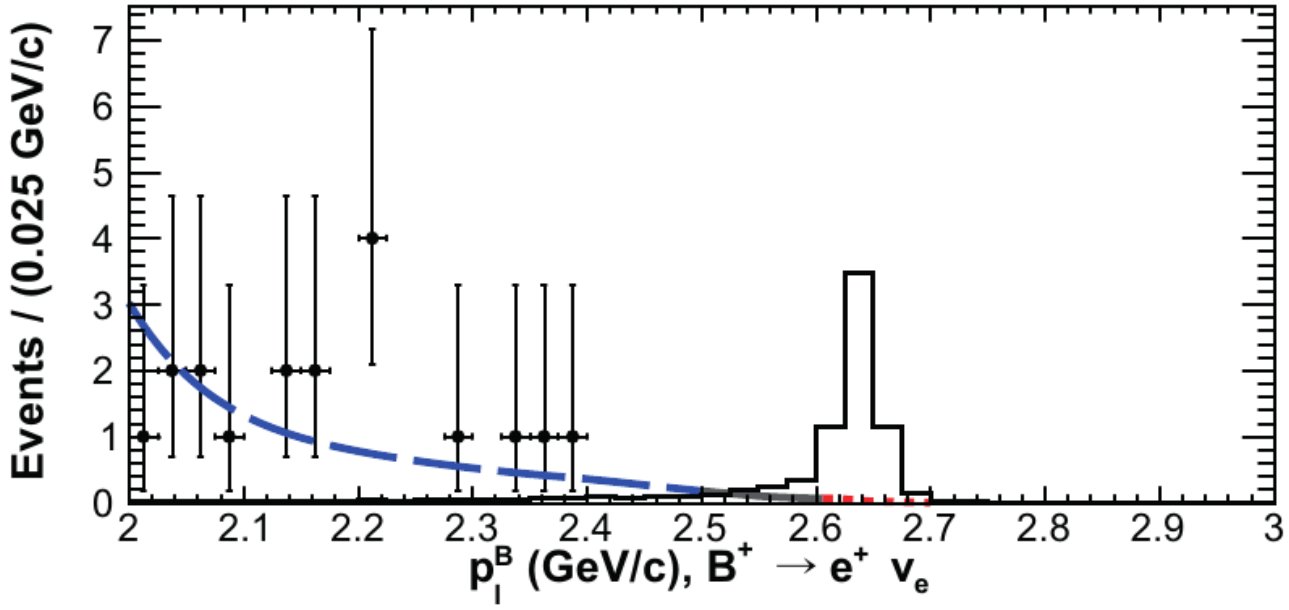
- These limits were done with an inclusive tag, taking first the high momentum lepton and then summing up the rest of the event and check, if there is a reasonable B with minimal criteria.
  - This method suffers from high background, but has very large statistics.

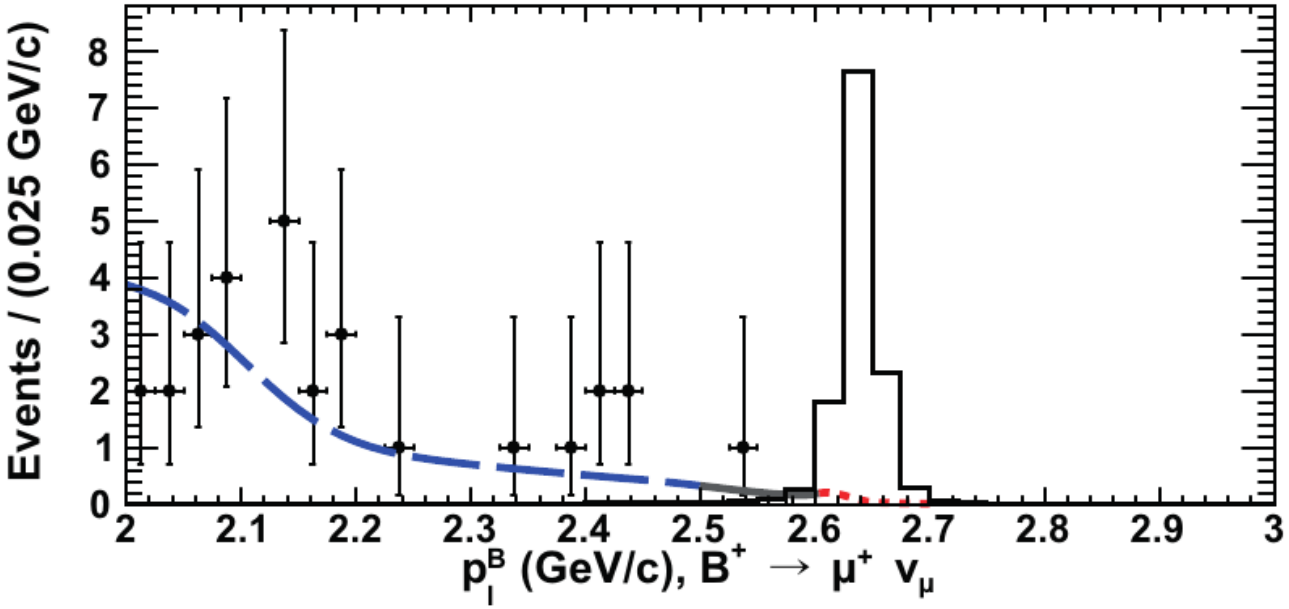
- Alternatively, the entire reconstruction of the tag side can be performed to gain a very clean sample.
  - Limits from that methods are currently ~5 times worse.
  - Factor will become smaller with higher statistics (~linear vs. square root)
    → Is this the way to go in Belle II?

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Reconstruction Information

- Full Belle Data Set
- Full Hadronic Tag (efficiency for signal MC: ~ 0.3%, based on semileptonic calibration channel).
- Reasonable lepton.
- No additional tracks.
- Limited (0.5 GeV) rest energy in the calorimeter after all used particles are subtracted.
- Thrust Axis requirement to suppress continuum background.





Signal displayed as 40 times Standard Model for muonic mode.

Results

TABLE II: Summary of multiplicative systematic uncertainties related to $N_{B\bar{B}} \times \epsilon_{sig}$ calculation, in percent.

Source	$B^+ \to e^+\nu_e$	$B^+ \to \mu^+\nu_\mu$
$N_{B\bar{B}}$	1.4	1.4
$B_{\rm tag}$ correction	4.2	4.2
Lepton ID	1.0	1.0
Tracking efficiency	0.35	0.35
MC statistics	1.6	1.5
p_ℓ^B Shape	13.8	13.8
Total	14.6	14.6

Mode	$\epsilon_{\rm s}$ [%]	$N_{\rm obs}$	$N_{\rm exp}^{\rm bkg}$	$\mathcal{B}^{90\%\ \rm C.L.}$
$B^+ \to e^+\nu_e$	0.092	0	$0.10^{+0.05}_{-0.04}$	$< 3.5 \times 10^{-6}$
$B^+ \to \mu^+\nu_\mu$	0.109	0	$0.26^{+0.10}_{-0.08}$	$< 2.7 \times 10^{-6}$

Comments

- We scaled the results as well to Belle II full statistics.
  - Without additional effort (which is very well possible), the inclusive method still looks better.
  - We have to see, if it is possible to have some kind of more inclusive full event interpretation in Belle II compared with the exclusive reconstruction of the tag side and still retain most of the Y(4S) decay information.

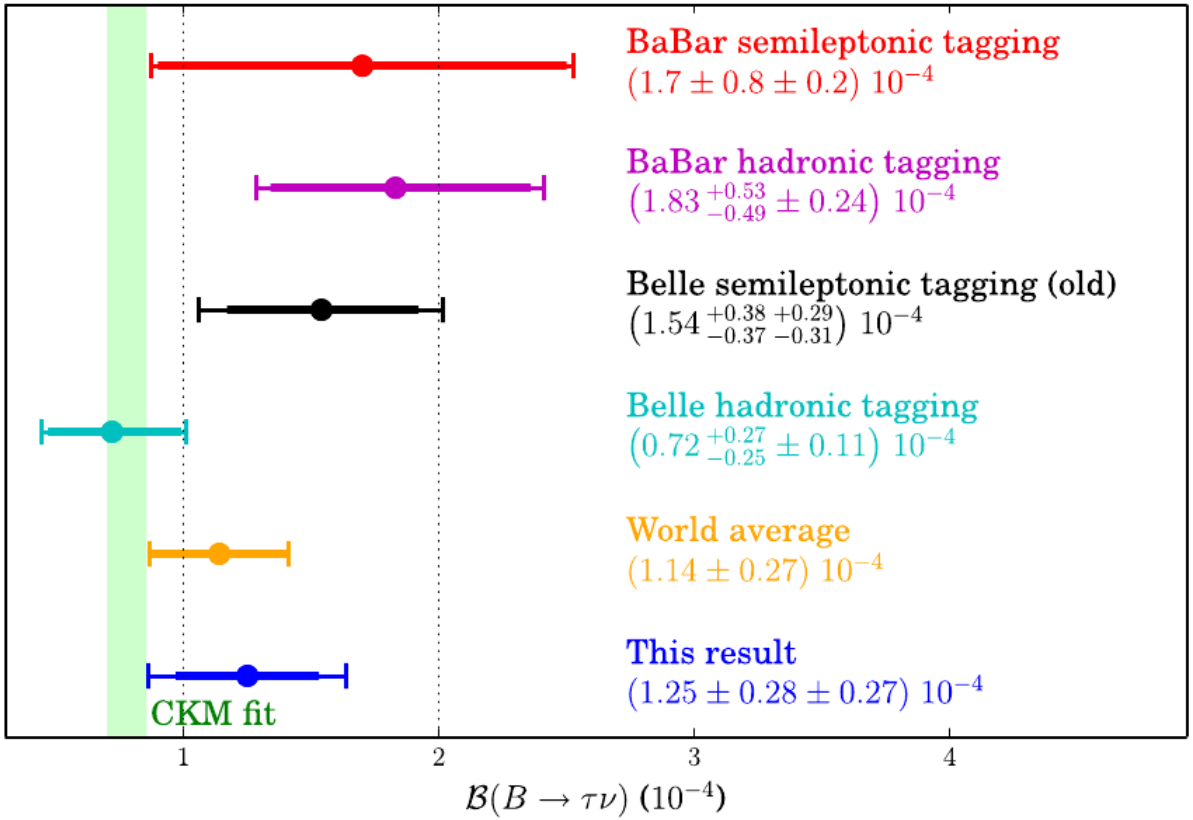
  - Paper is now on arxiv (submitted to PRD): http://arxiv.org/abs/1406.6356

B → tau nu

- Update analysis with semileptonic tag
  - with full Belle data set (20% more than before),
  - new tracking and new multi-variate tag reconstruction with more D-decays,
  - reevaluation for all other cuts, especially now with a dedicated continuum background reduction,
  - including tau → rho nu as new tau decay channel, (now considered:
    - tau → mu nu nu,
    - tau → e nu nu,
    - tau → pi nu,
    - tau → rho nu)
  - using two fit dimensions:
    - extra energy in the ECL,
    - momentum of the non-neutrinos (NEW) in the Y(4S)-restframe.

Results

$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.25 \pm 0.28 \pm 0.27) \times 10^{-4}$$



Cross-checks

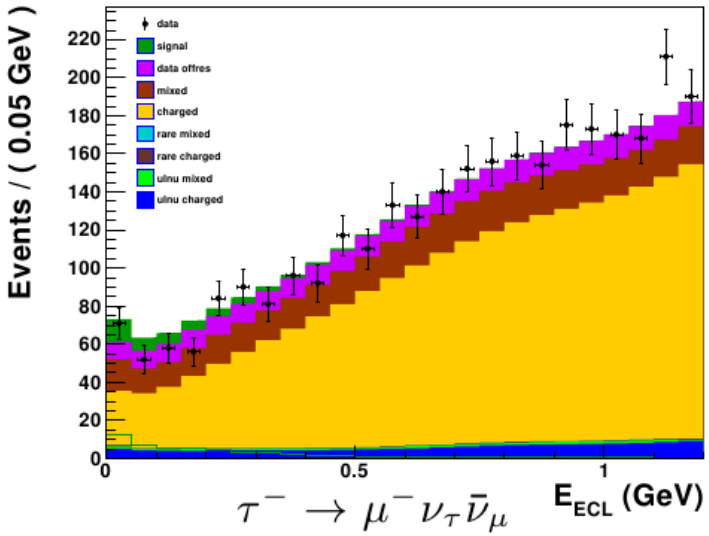
- Channels are consistent (p-value of 20%)

Divided by τ decay channel

$\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$	0.34 ± 0.55
$\tau^- \to e^- \nu_\tau \bar{\nu}_e$	0.90 ± 0.47
$\tau^- \to \pi^- \nu_\tau$	1.82 ± 0.68
$\tau^- \to \rho^- \nu_\tau$	2.16 ± 0.60

Errors are statistical only!

Plots


data
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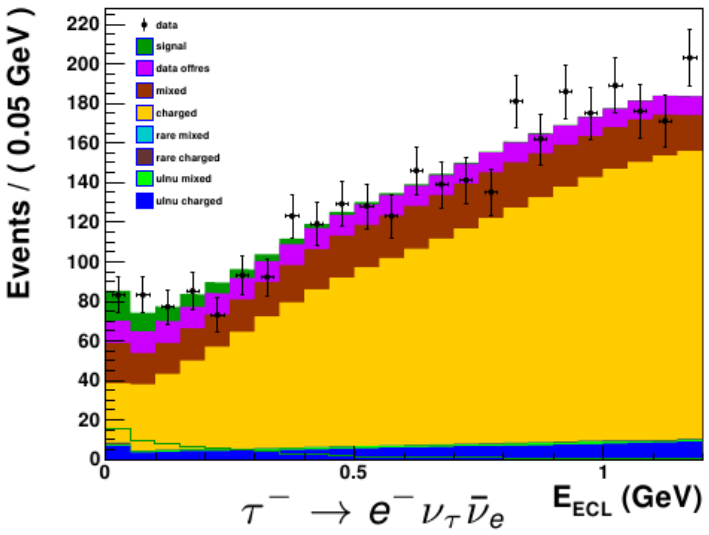
data offres
mixed
charged
rare mixed
rare charged
ulnu mixed
ulnu charged
Events / (0.05 GeV)
E_ECL (GeV)
$\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$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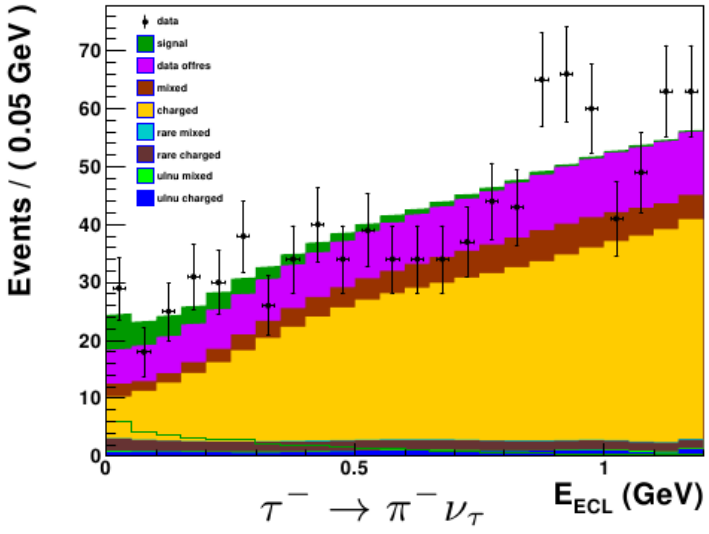
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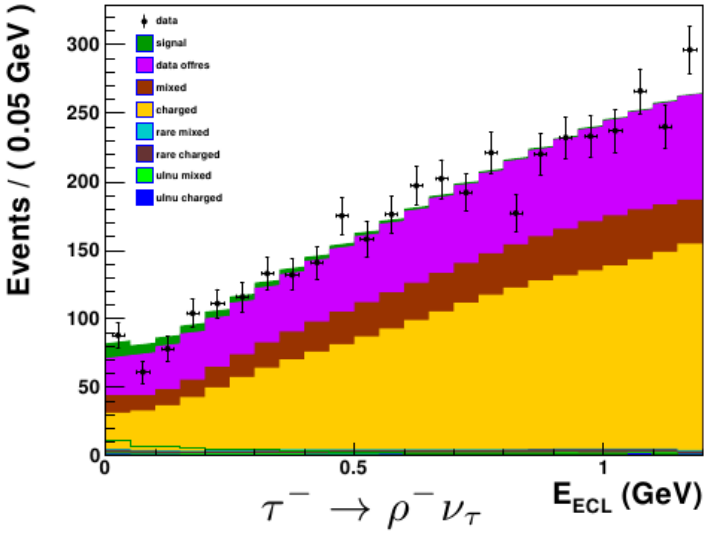
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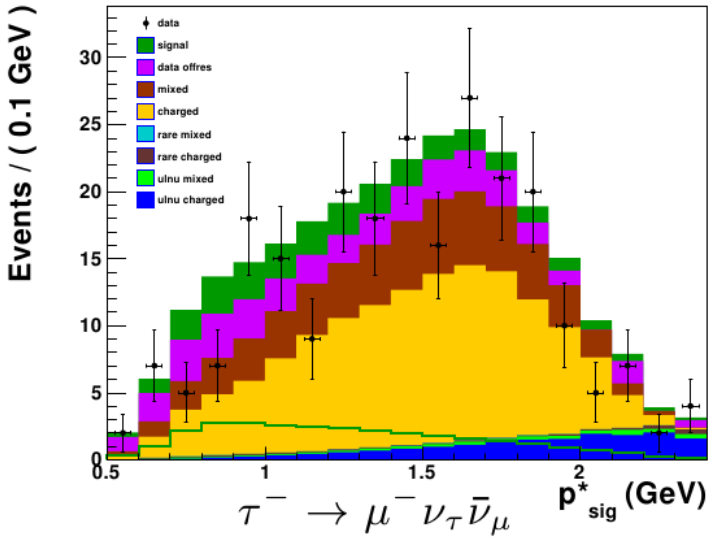
More Plots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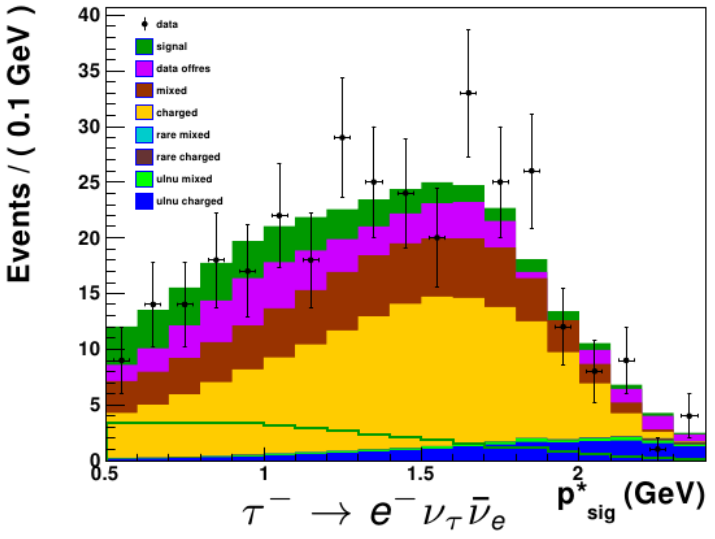
Events / (0.1 GeV)
$\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$
p^*_{sig} (GeV)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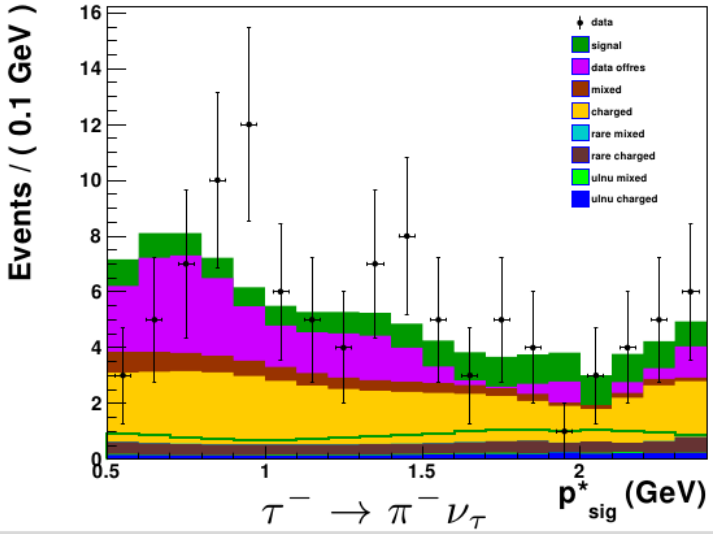
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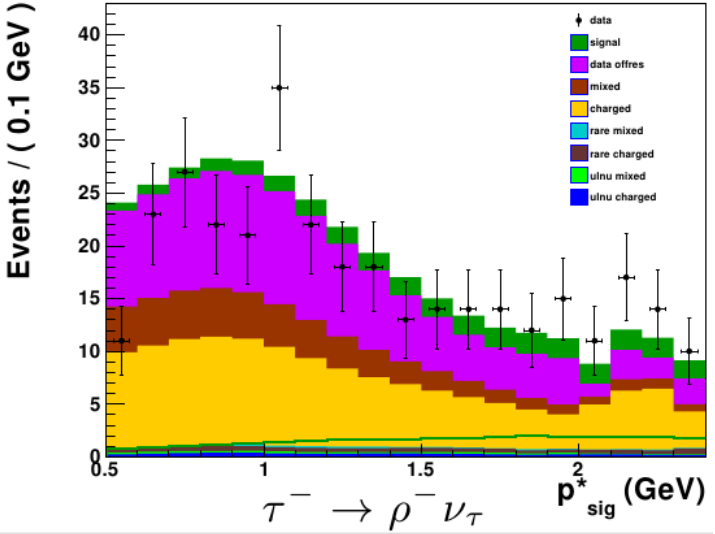
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p^*_{sig} (GeV)

Correlations between the two Fitting Variables

- Shapes are mostly uncorrelated, so the Fit-Function factorizes.
- Exception: signal contributions for
  - pi nu
  - rho nu
  - Reason: if neutral pion of rho decay is missed, this ends up in the pion channel, but with lower momentum and higher extra energy.
    As this happens only for the signal contributions, it is possible to generate enough MC to make use of a 2D-Histogram.

Systematics

Source	Relative Uncertainty (%)
Histogram PDF shapes	8.5
Continuum description	14.1
Signal reconstruction efficiency	0.6
Background branching fractions	3.1
Efficiency correction	12.6
τ decay branching fractions	0.2
Best candidate selection	0.4
Tracking efficiency	0.4
π^0 reconstruction efficiency	1.1
Efficiency of *PID* cut	0.5
Charged track veto	1.9
Number of $B\bar{B}$ pairs	1.4
Total	22.0

Conclusion B → lepton neutrino

- Reanalysis of B → tau nu has basically eliminated the tensions between the UT fit and this BR.
- To make elaborate tagged analysis of B → l nu (l = mu, e) competitive with the more inclusive approach is hard work even for Belle II.