Measurements of R($D^{(*)}$) and other missing energy decays at Belle II

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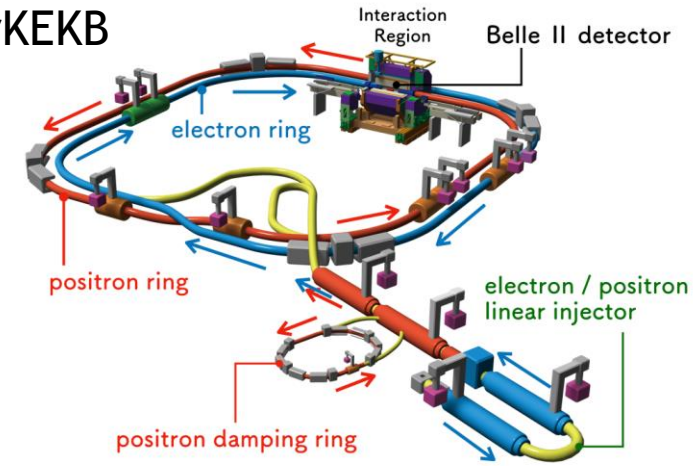
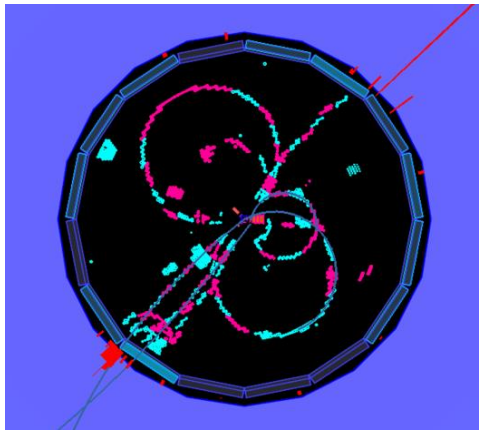
THE UNIVERSITY of ADELAIDE

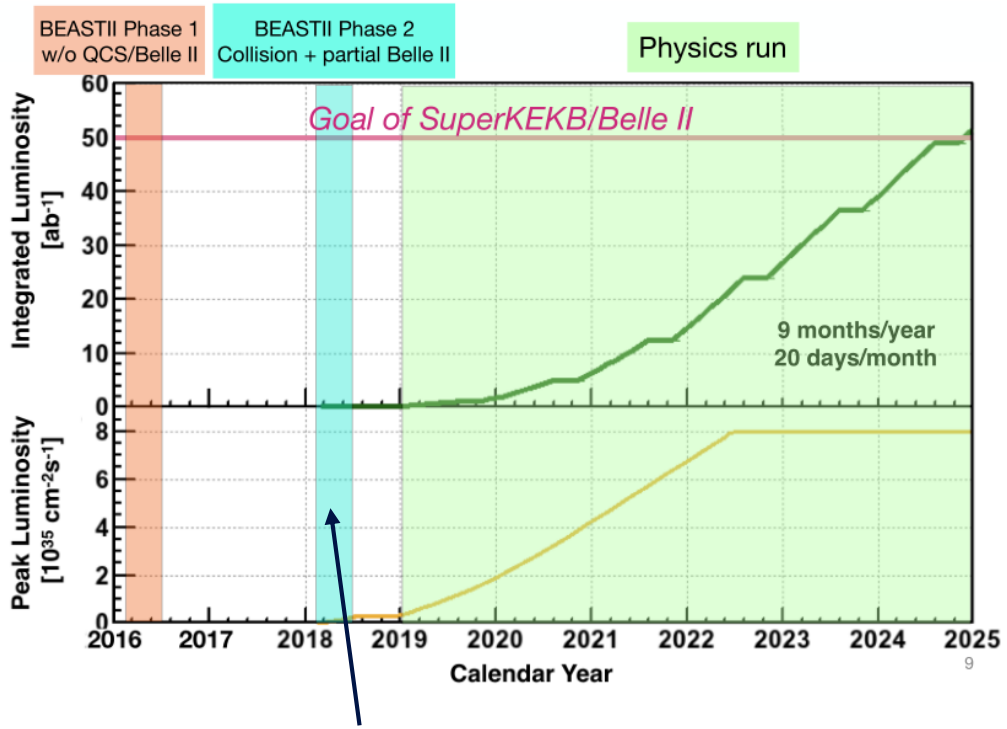
Overview of Belle II physics so far

- Belle II is an e^+e^- collider experiment operating primarily at the Y(4S) resonance
  - Produces $B\bar{B}$ and $\tau^+\tau^-$ pairs, as well as $q\bar{q}$ background
- Phase 2 is currently in progress:
  - All Belle II subdetectors except vertex detector
  - D and B meson "rediscovery" in progress

SuperKEKB



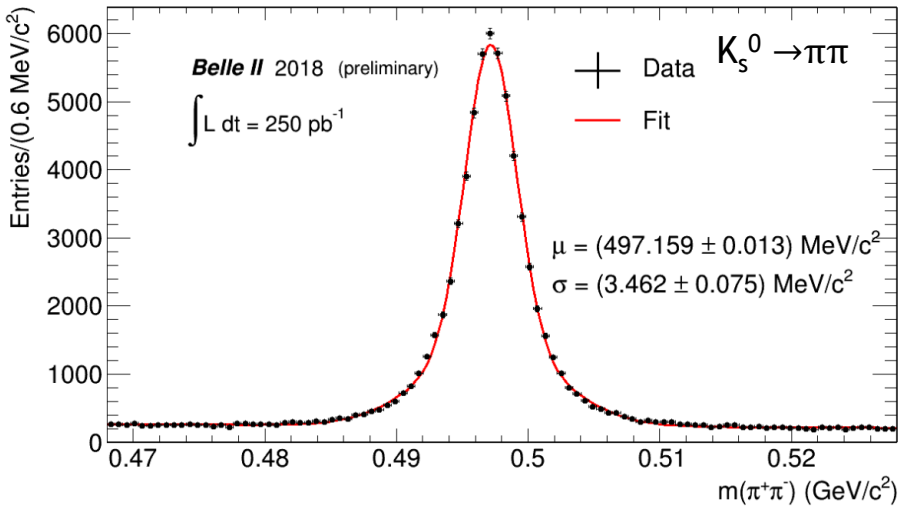


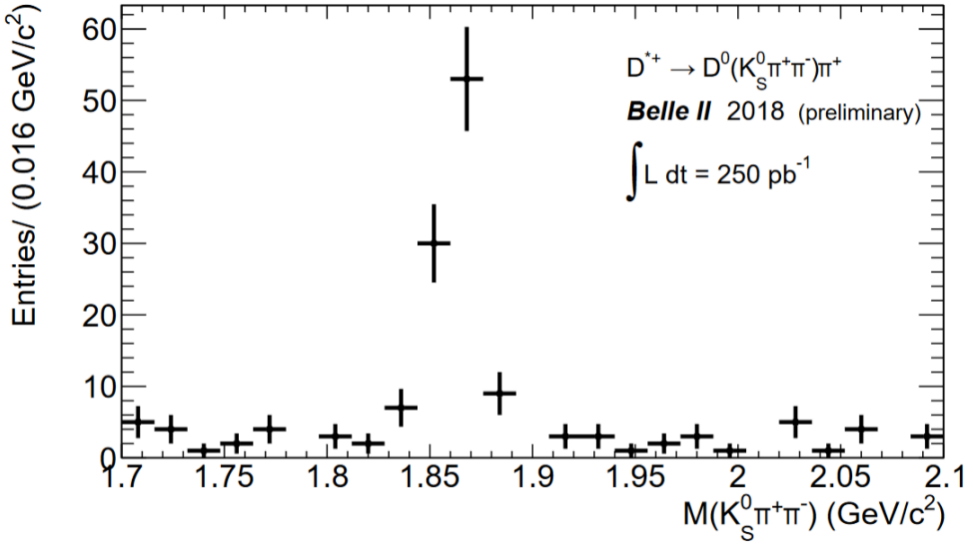


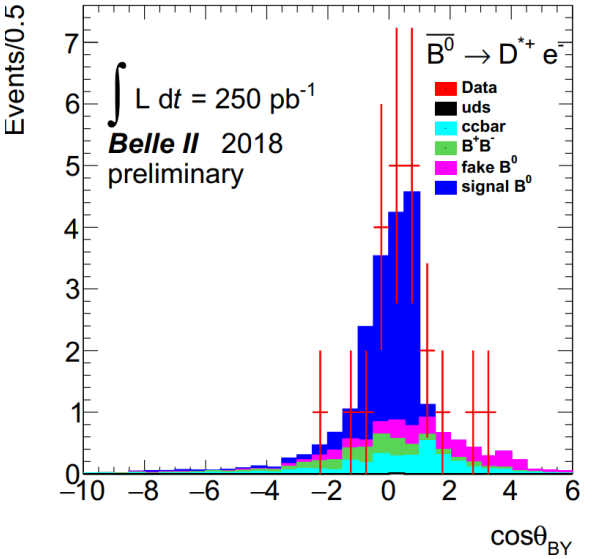
Phase 2 (in progress)

First collisions on 26th April
250 pb^{-1} so far

Overview of Belle II physics so far







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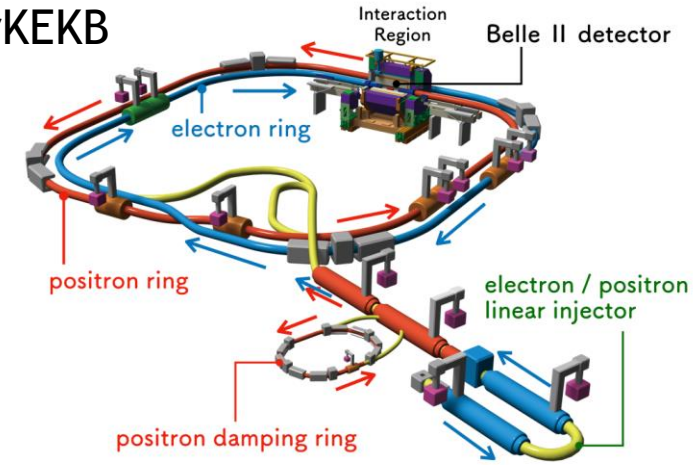
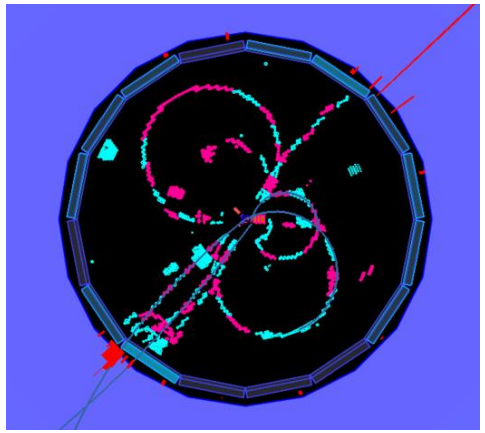
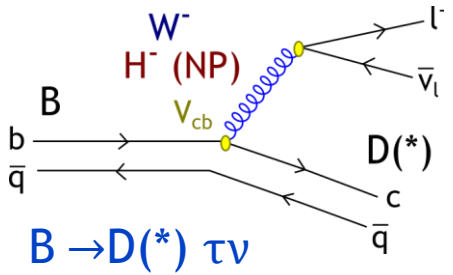


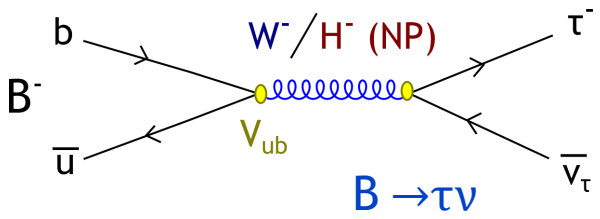


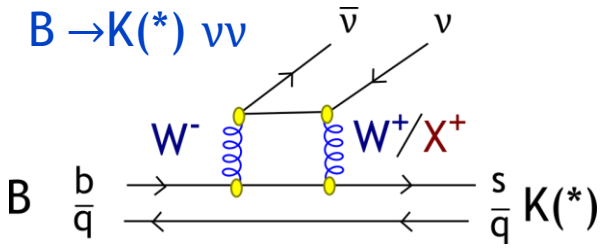
More information:

- "The Belle II experiment: status and prospects" [Detector R&D]
  Shuji Tanaka, 9:12am Saturday
- "Charm physics prospects at the Belle II experiment" [Quark and Lepton Physics]
  Hulya Atmacan, 4:50pm Friday

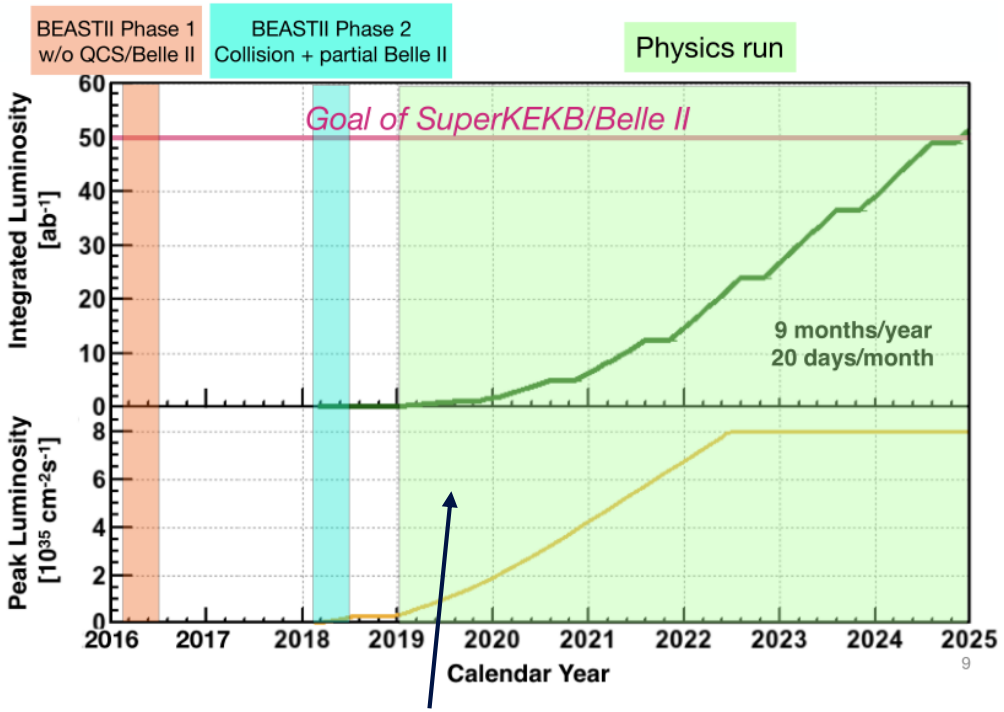
Belle II and new physics prospects







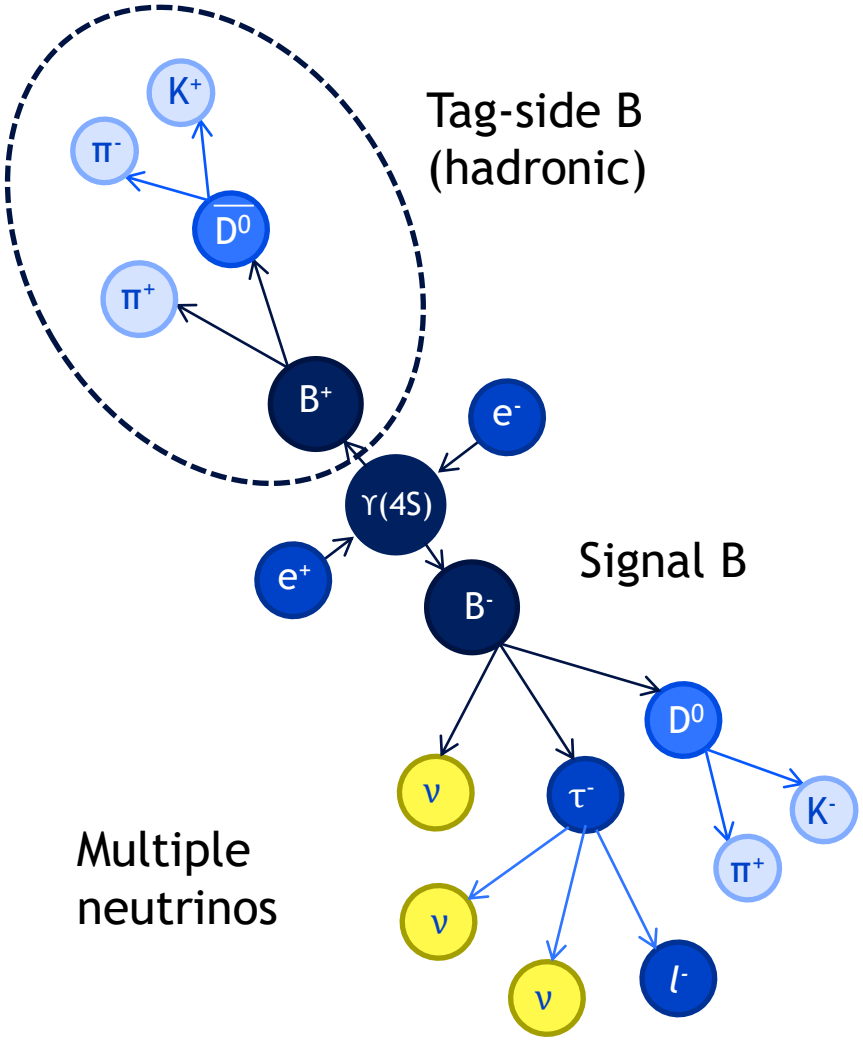
- In this talk: Phase 3 prospects for R(D$^{(*)}$) and missing energy
  - Improved vertex resolution
  - Higher statistics
- Belle II studies complementary to LHC high P_T direct searches
  - Different set of systematics for e^+e^- collider
  - Full reconstruction of all particles in an event allows effective calculation of missing energy/momentum to constrain signal



Phase 3 (Feb 2019)

Full detector
Target 40x Belle luminosity

Hadronic full reconstruction



- Reconstructing the event in full is very useful in missing energy studies to constrain the event and reduce backgrounds
- Multiple channels for tag-side B are used to increase efficiency
- Hadronic full reconstruction expected to be used for:
  - Semi-leptonic and semi-tauonic modes for $R(D^{(*)})$
  - $B \rightarrow \tau\nu$ decays
- These studies will use Belle II's new algorithm

Hadronic full reconstruction at Belle II

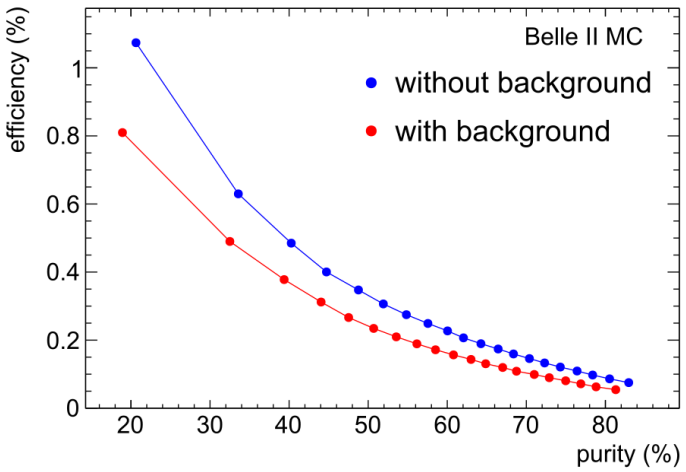
Particle	# channels (Belle)	# channels (Belle II)
$D^+/D^{*+}/D_s^+$	18	26
D^0/D^{*0}	12	17
B^+	17	29
B^0	14	26

Algorithm	MVA	Efficiency	Purity
Belle v1 (2004)	Cut based (Vcb)		
Belle v3 (2007)	Cut based	0.1	0.25
Belle NB (2011)	Neurobayes	0.2	0.25
Belle II FEI (2017)	Fast BDT	0.5	0.25

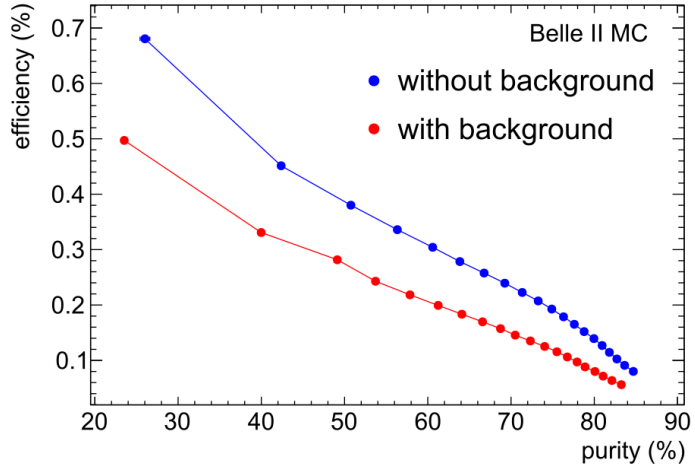
Improvement to tagging efficiency in Belle II

- More modes used for tag-side hadronic B than Belle, and multiple classifiers
- Good performance on Belle II predicted beam background conditions

Hadronic charged B



Hadronic neutral B



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D^0/D^{*0}	12
B^+	17
B^0	14

Coming soon:

- Paper on the new Belle II algorithm
- Studies of generic B mesons in Belle II Phase 2 data!

de hadronic
classifiers
II predicted
ns

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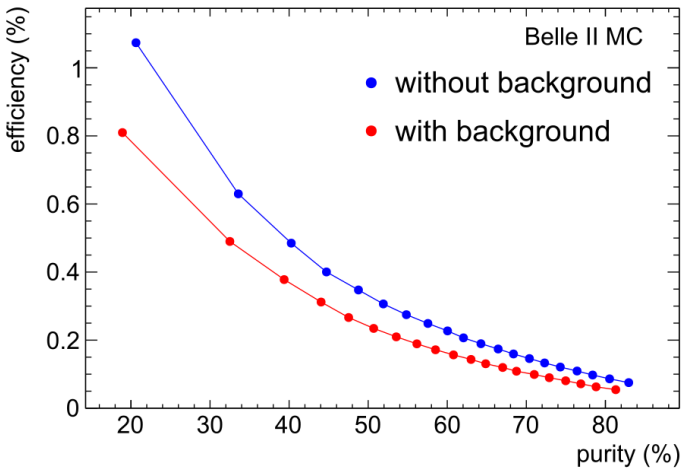

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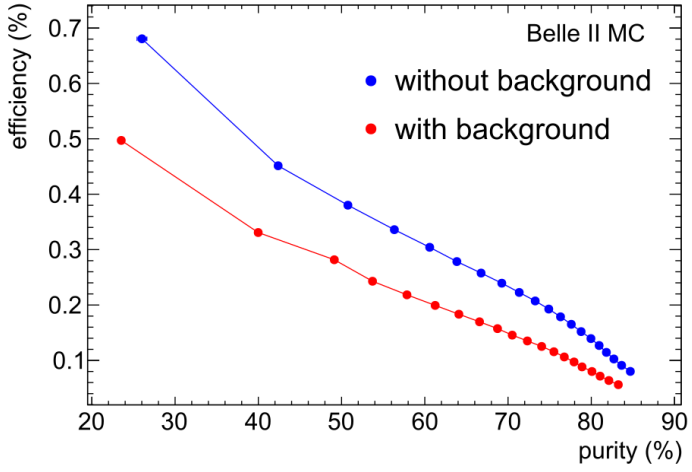
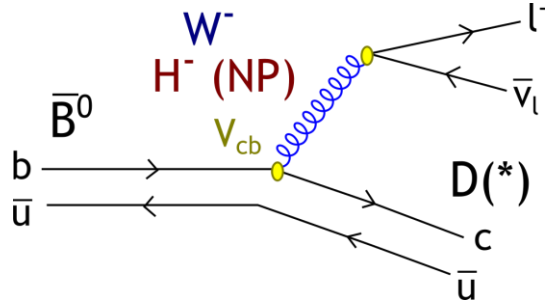
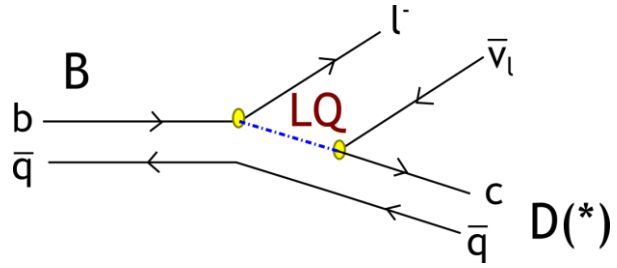


Search for new physics in $B \to D^{(*)} \tau\nu$

- In the Standard Model, $B \to D\tau\nu$ and $B \to Dl\nu$ are expected to differ only because of the mass of the tau lepton.
- The ratio of these decays is highly sensitive to new physics effects:
  - Possible models: 2HDM, leptoquarks…
- Additional observables to determine type of NP:
  - Measurements of the tau polarisation $P_\tau(D^*)$ can be combined with R(D*)
  - q^2 distribution
- Current world average combination for R(D), R(D*) is at 3.78σ tension with SM! (HFLAV summer 2018)
  - Next talk: Kodai Matsuoka, recent results from Belle





$$R_{D^{(*)}} = \frac{\mathrm{Br}(B \to D^{(*)}\tau\nu_\tau)}{\mathrm{Br}(B \to D^{(*)}\ell\nu_\ell)}$$

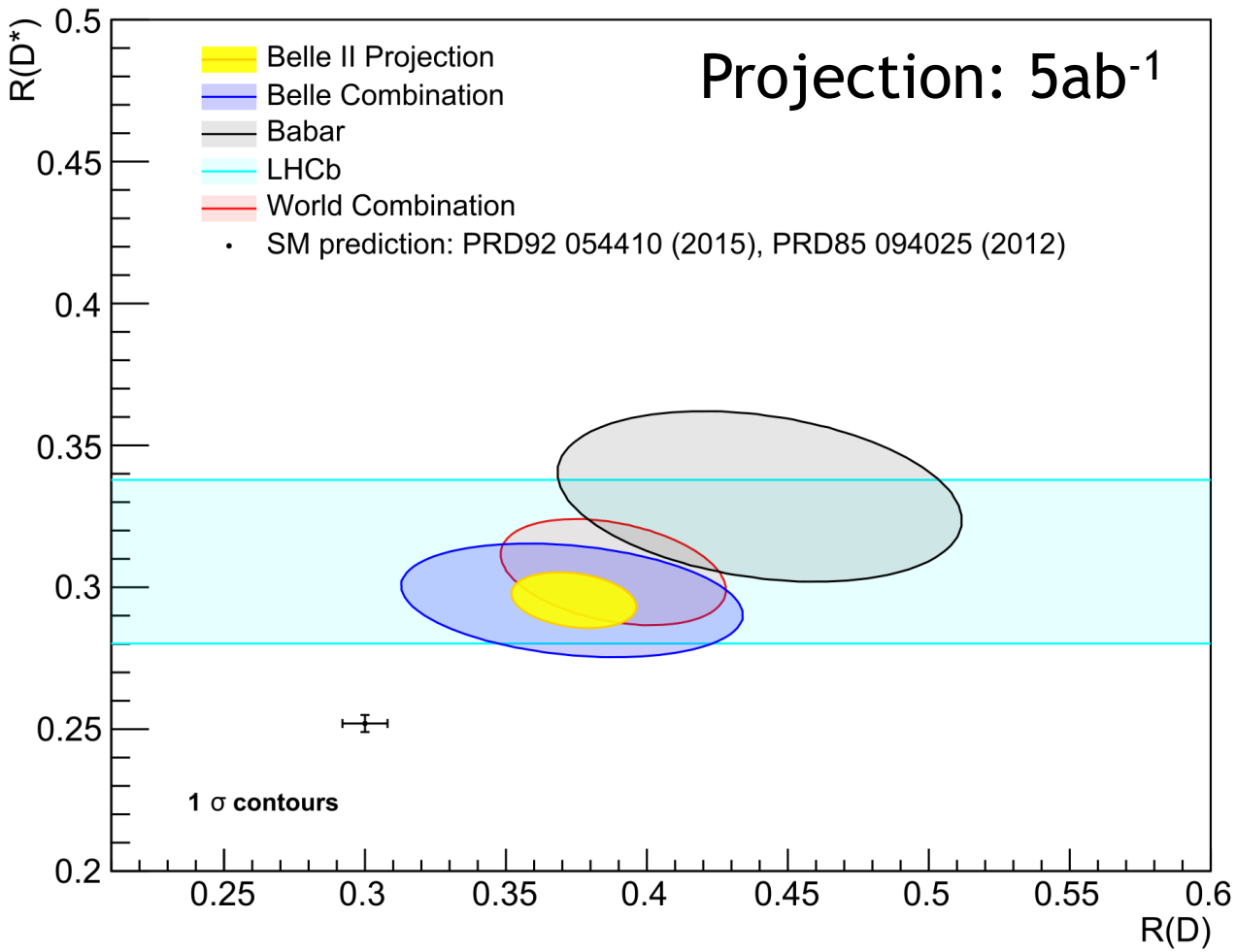
Projections for Belle II R(D$^{(*)}$)

- Predictions of uncertainty using hadronic full reconstruction:

	ΔR(D) [%]			ΔR(D*) [%]		
	Stat	Sys	Total	Stat	Sys	Total
Belle 0.7 ab^{-1}	14	6	16	6	3	7
Belle II 5 ab^{-1}	5	3	6	2	2	3
Belle II 50 ab^{-1}	2	3	3	1	2	2

- Systematic uncertainty dominated by D** and missed soft pions:
  - Studies of B→D** lν and B→D** τν planned
  - Branching ratios and decay modes from data

See Abi Soffer (this session): Improved studies of B→D(*) τν with vertexing at Belle II



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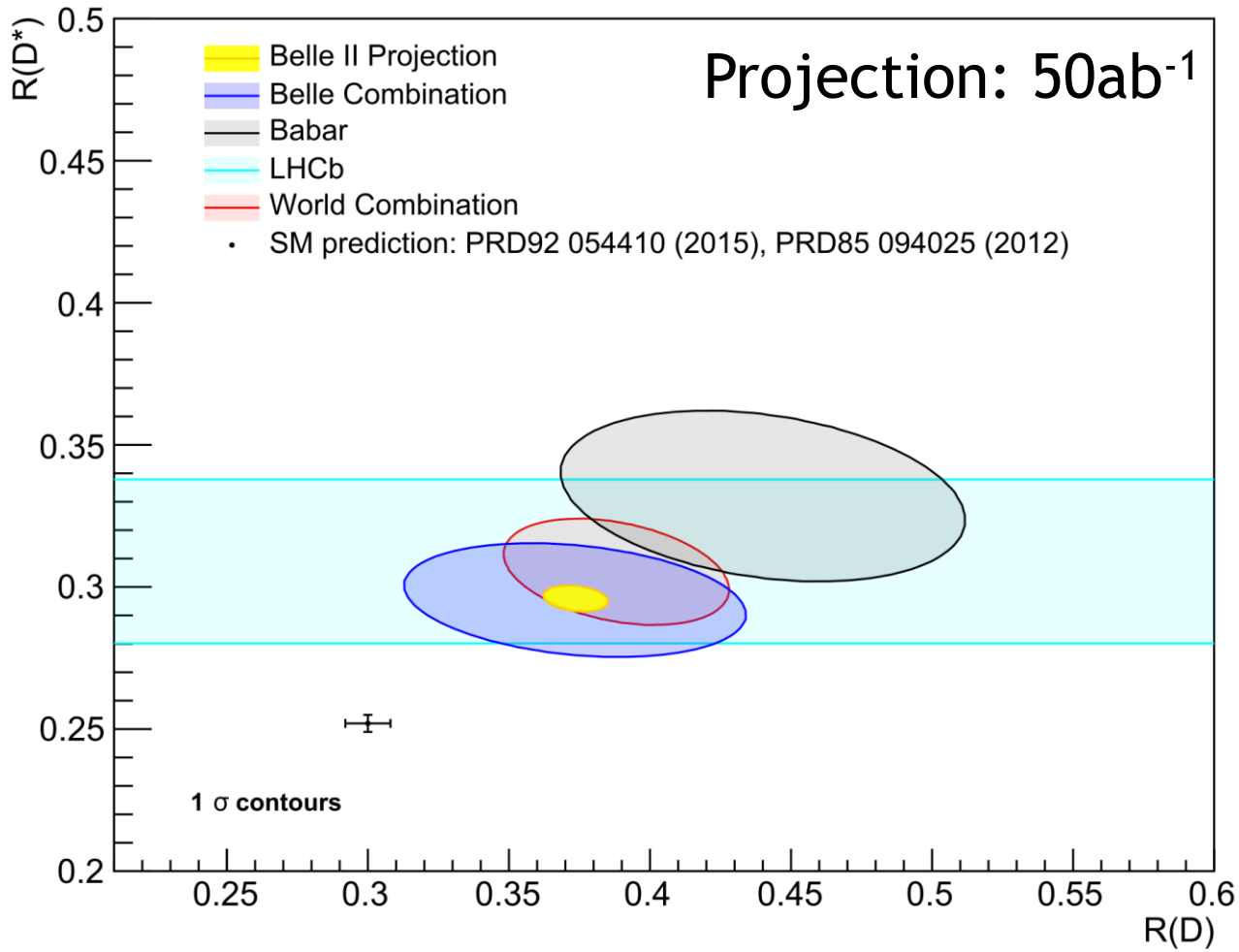

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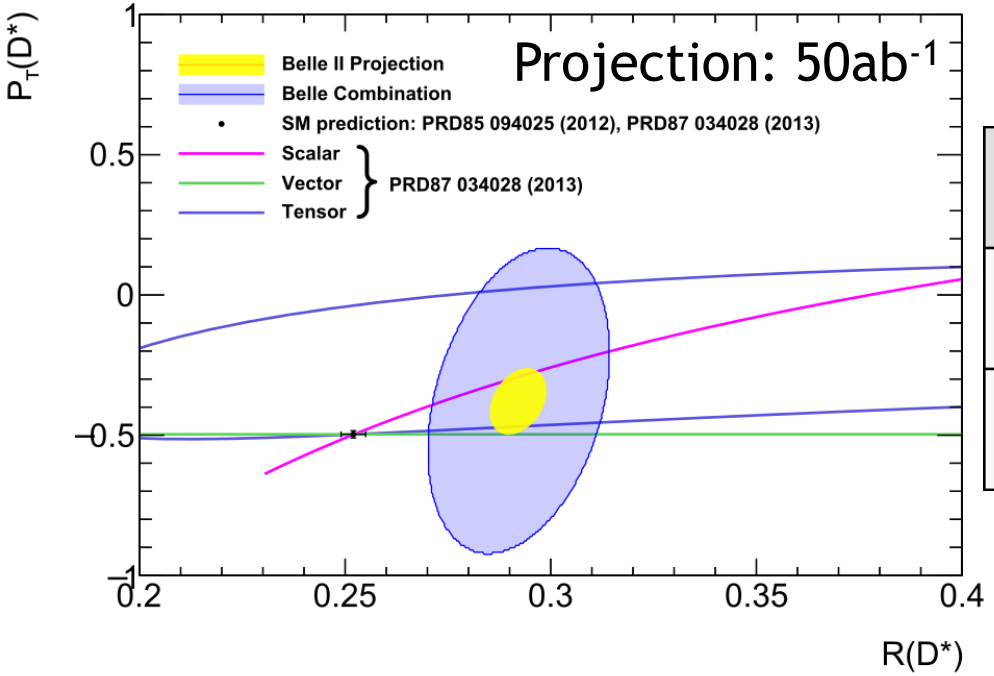
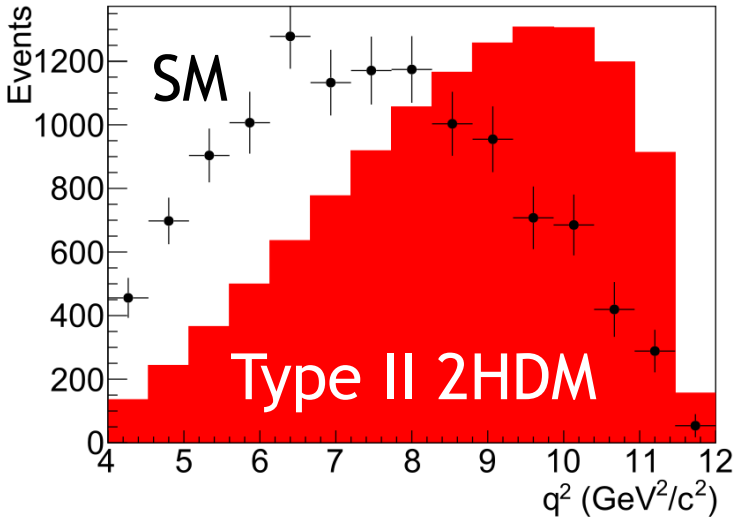
Other measurements from $B \to D^{(*)} \tau\nu$



Projections for $P_\tau(D^*)$ at Belle II

$P_\tau(D^*)$	Stat. uncertainty	Sys. uncertainty
at 5 ab^{-1}	0.18	0.08
at 50 ab^{-1}	0.06	0.04

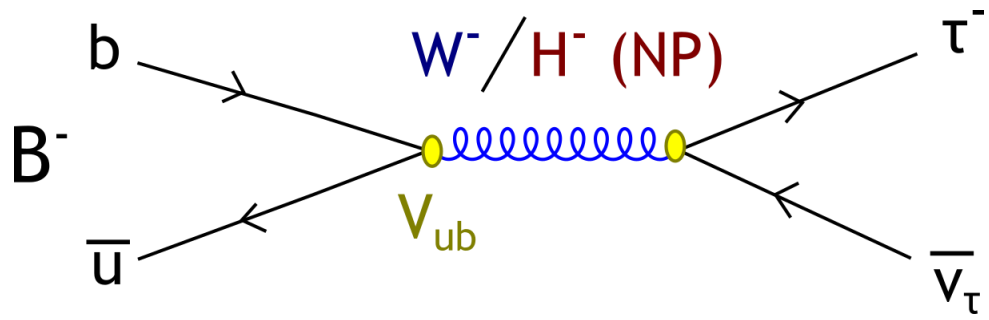
q^2 spectrum $B \to D^* \tau\nu$
50ab^{-1} projection



- Extra measurements like $P_\tau(D^*)$ and the q^2 distribution may be able to help describe possible new physics in detail.
- This will have the best discrimination with the full dataset, but hints may be available earlier

New Physics and B→τν

- Standard Model:
  - Helicity suppression means branching ratio depends strongly on lepton mass
  - B →τν allows direct measurement of f_B and $|V_{ub}|$
- New Physics:
  - Significant suppression or enhancement of branching ratio is possible (e.g. due to charged Higgs in 2HDM)
  - Reduced uncertainty needed to observe new physics!



$$\mathrm{Br}(B \to \tau\nu)_{\mathrm{SM}} = \frac{G_F^2 |V_{ub}|^2}{8\pi} \tau_B f_B^2 m_\tau^2 m_B \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2$$

$$\mathrm{Br}(B \to \tau\nu) = \mathrm{Br}_{\mathrm{SM}} \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)$$

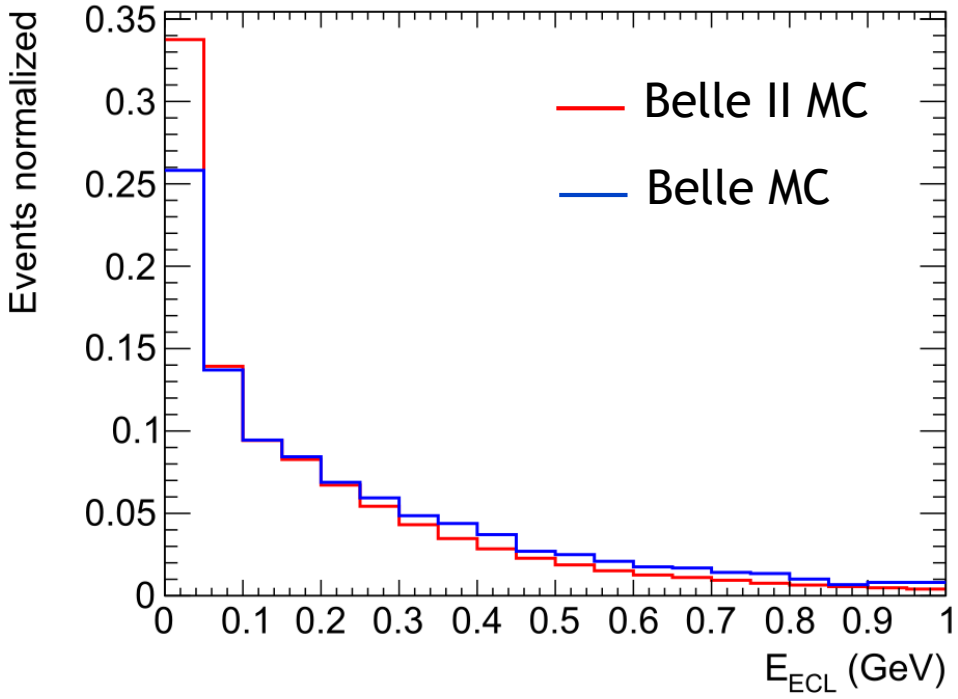
Current world average for Br(B →τν) ,HFLAV December 2017: (144 ± 31) x 10^{-6}

Belle I average: (91 ± 19 ± 11) x 10^{-6} (24 % uncertainty, 4.6σ total significance)

10.1103/PhysRevD.92.051102

Prospects for B →τν at Belle II

Extra energy in calorimeter (beam background included)



- Signal yields to be extracted from fit to extra neutral energy
  - The expected extra energy resolution for Belle II is better than for Belle, despite increased beam background.
  - Cluster timing information used to remove beam background in calorimeter

Comparison with Belle hadronic tag.
1 ab^{-1} equivalent statistics

E_{ECL}		< 0.25 GeV
Belle II	# background events	1348
	# signal events	136
	signal efficiency (‰)	1.6
Belle	# background events	365
	# signal events	60
	signal efficiency (‰)	0.7

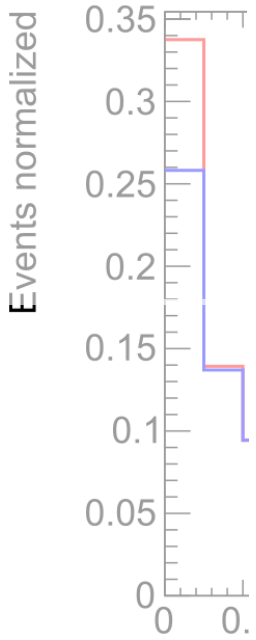
- First study will use:
  - 1-prong tau decay
  - Hadronic tag-side B for full reconstruction

Prospects for B →τν at Belle II

Extra energy in calorimeter (beam background included)

- Signal yields to be extracted from fit to extra neutral energy

Extrapolation at full Belle II statistics



	Integrated Luminosity (ab^{-1})	50
hadronic tag	statistical uncertainty (%)	4.1
	systematic uncertainty (%)	4.6
	total uncertainty (%)	6.2
semileptonic tag	statistical uncertainty (%)	2.7
	systematic uncertainty (%)	4.5
	total uncertainty (%)	5.3

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		0.25 GeV
		1348
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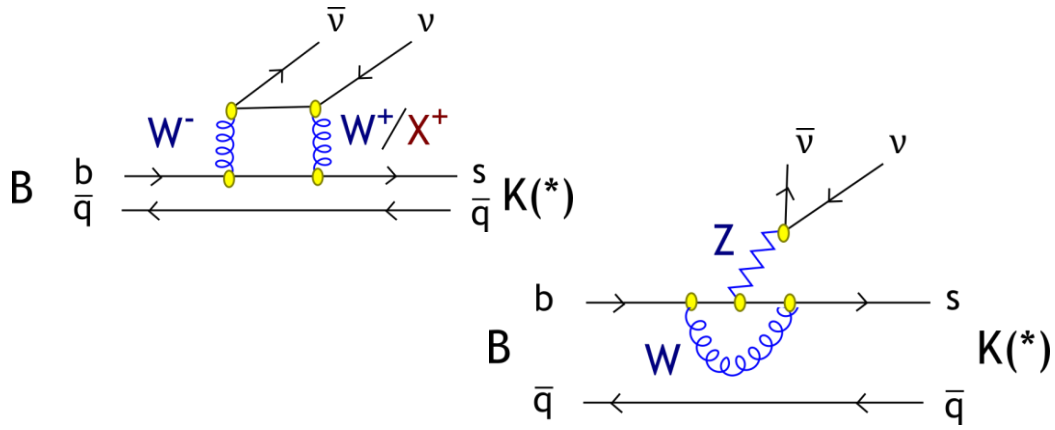
Semileptonic tag B studies also planned

$B \to K(*)\, \nu\bar{\nu}$ predictions

- Standard Model:
  - Flavour changing neutral current prohibited at tree level
  - Measurement of $B \to K(*)\, \nu\bar{\nu}$ would allow high accuracy extraction of $B \to K(*)$ form factors
  - SM estimate of branching fraction known to ~10% uncertainty
- New Physics:
  - Contribution from NP may be similar in size to SM contributions, decreasing time required to make discovery.
  - Light dark matter scenarios:
    - $B \to K\, \nu\bar{\nu}$ is identical in the detector to $B \to K$ + invisible searches for light dark matter
    - Increased $B \to K\, \nu\bar{\nu}$ branching ratio may suggest a light dark matter component



Projected precision on branching ratios at 50 ab^{-1} Belle II data, with FEI hadronic tag

Mode	Stat. uncertainty	Total uncertainty
$B^+ \to K^+\, \nu\bar{\nu}$	9.5%	10.7%
$B^+ \to K^{*+}\, \nu\bar{\nu}$	7.9%	9.3%
$B^+ \to K^{*0}\, \nu\bar{\nu}$	8.2%	9.6%

Standard model observations of these modes could be made with ~18 ab^{-1}

Summary of Belle II prospects

- New hadronic full reconstruction algorithm improves efficiency, improving time to discovery in Phase 3 physics prospects
- We calculate:
  - 5σ confirmation of $R(D^{(*)})$ anomalies at 5 ab^{-1}
  - 5σ significance of $B \to \tau\nu$ branching ratio at 1-3 ab^{-1}
  - SM observation of $B \to K(*)\ \nu\bar{\nu}$ at ~18ab^{-1}

Total uncertainty	5 ab-1 (2020)	50 ab-1 (2025)
R(D)	6%	3%
R(D*)	3%	2%
$B \to \tau\nu$ with hadronic tag full reconstruction	15%	6%
$B \to \tau\nu$ with semileptonic tag full reconstruction		5%
$B \to K(*)\nu\bar{\nu}$ modes (average)		10%