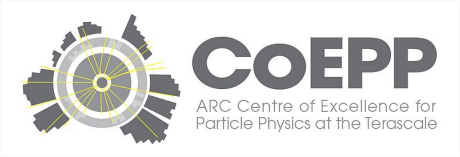


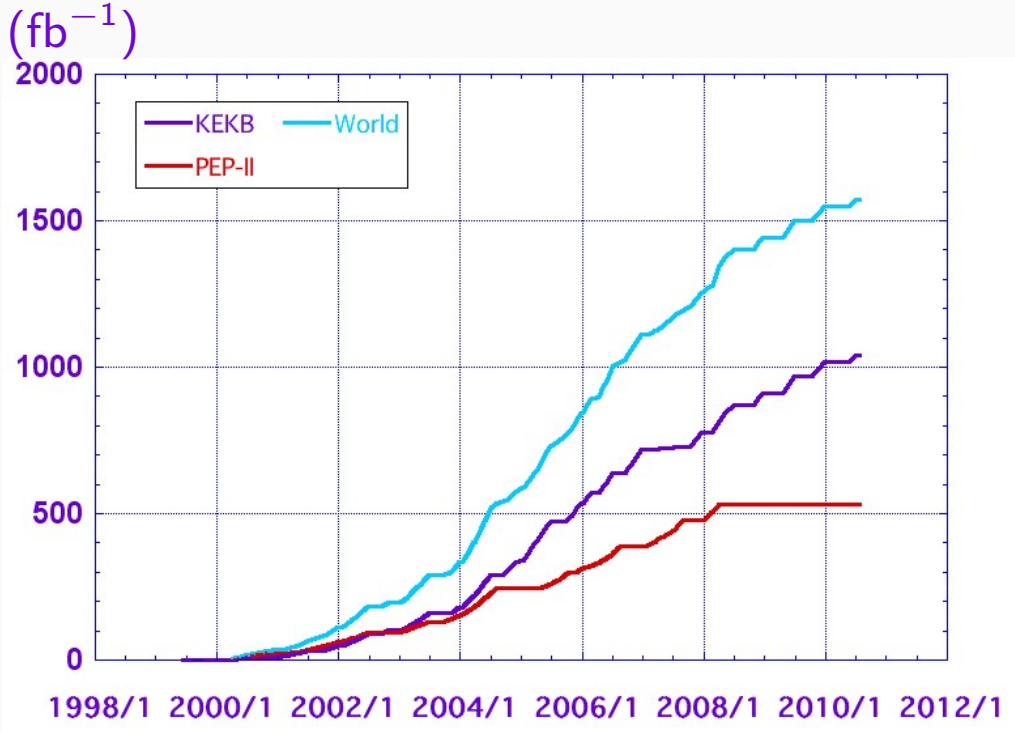
Studying leptonic and semileptonic B decays at the Belle II experiment

Ethan Cross, Chia-Ling Hsu and Kevin Varvell

USyd-UNSW Workshop 03-May-2019

Particle Physics Group,
The University of Sydney

The first decade of this century was the "Age of the B-factories"



PEP-II/BABAR

On resonances:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off reson./scan: 54 fb^{-1}

Total: 550 fb^{-1}

KEKB/Belle

On resonances:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

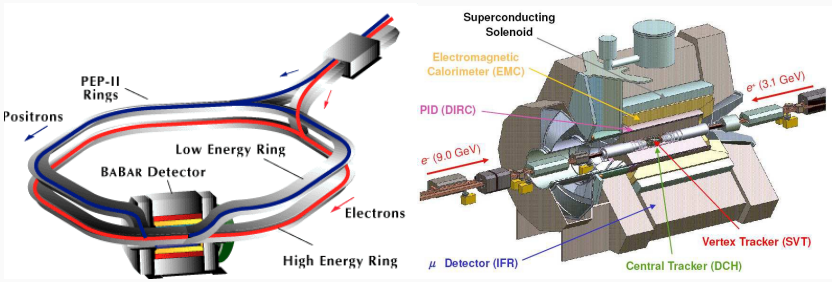
$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

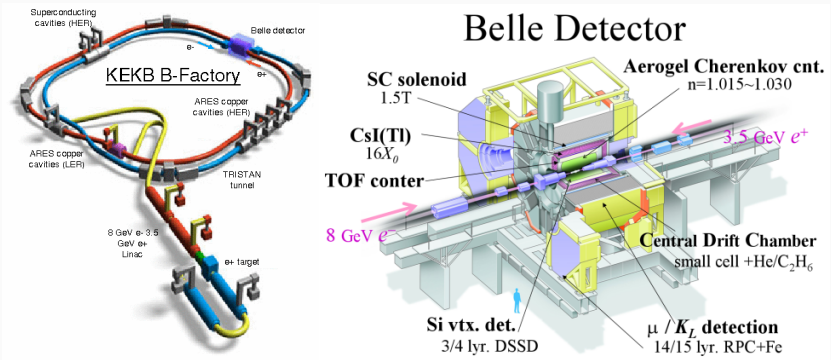
Off reson./scan: 100 fb^{-1}

Total: > 1 ab^{-1}

PEP-II/BABAR (1999-2008)



KEKB/Belle (1999-2010)



B-factories exploit the $\Upsilon(4S)$ resonance ($b\bar{b}$ bound state)

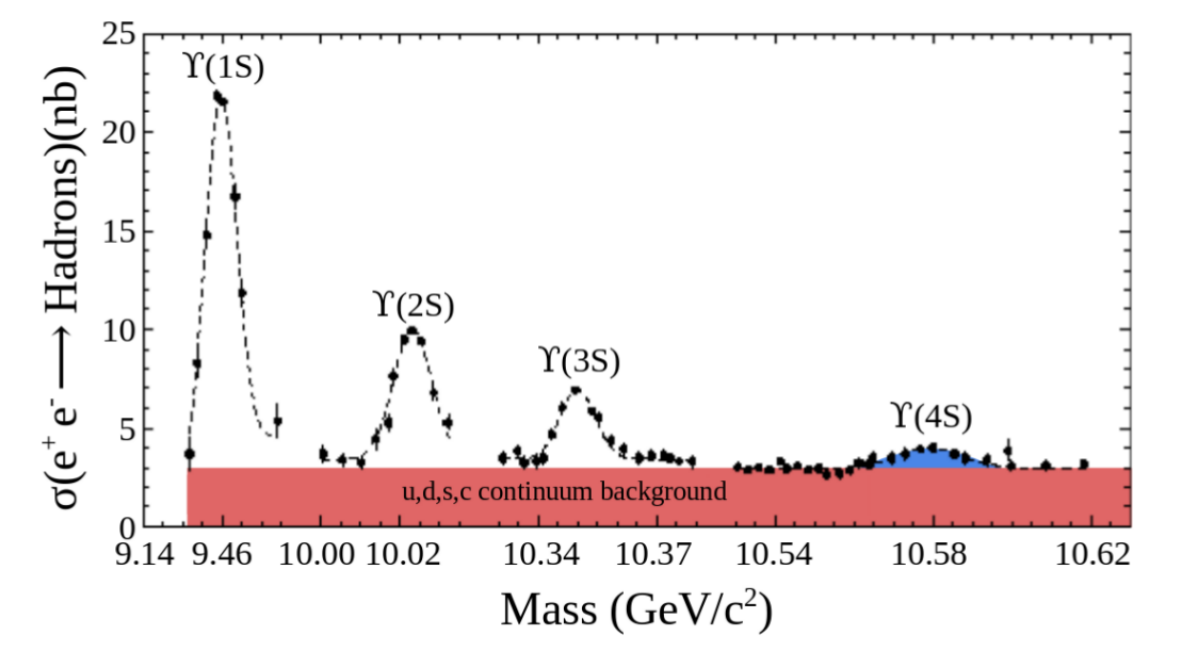


Image from arXiv:0901.1443 [hep-ex]

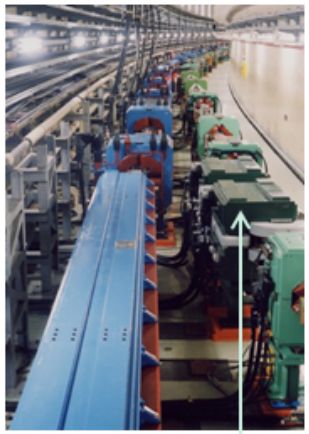
$$e^+ + e^- \rightarrow \Upsilon(4S) \rightarrow B^0 + \overline{B}^0 \qquad (51.4 \pm 0.6)\% \qquad (B^0 : d\bar{b})$$

$$e^+ + e^- \rightarrow \Upsilon(4S) \rightarrow B^+ + B^- \qquad (48.6 \pm 0.6)\% \qquad (B^+ : u\bar{b})$$

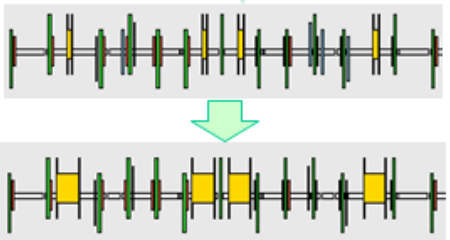
Belle : 772×10^6 $B\bar{B}$ pairs

Now in operation - SuperKEKB and Belle II

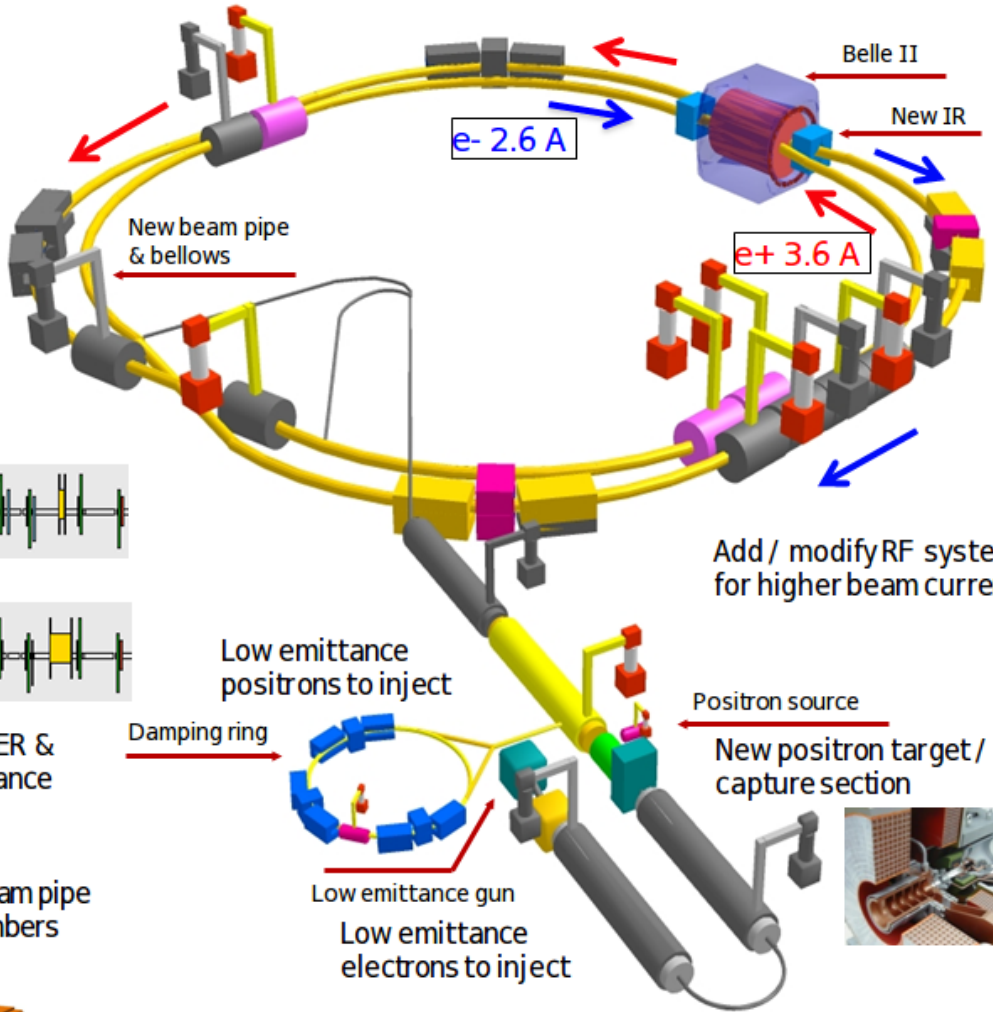
KEKB to SuperKEKB



Replace short dipoles with longer ones (LER)

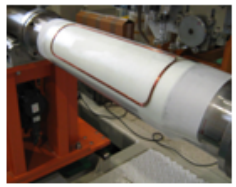


Redesign the lattices of HER & LER to squeeze the emittance



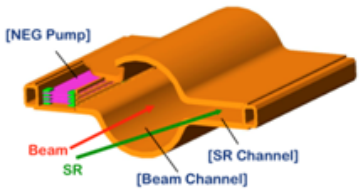
Colliding bunches

New superconducting /permanent final focusing quads near the IP



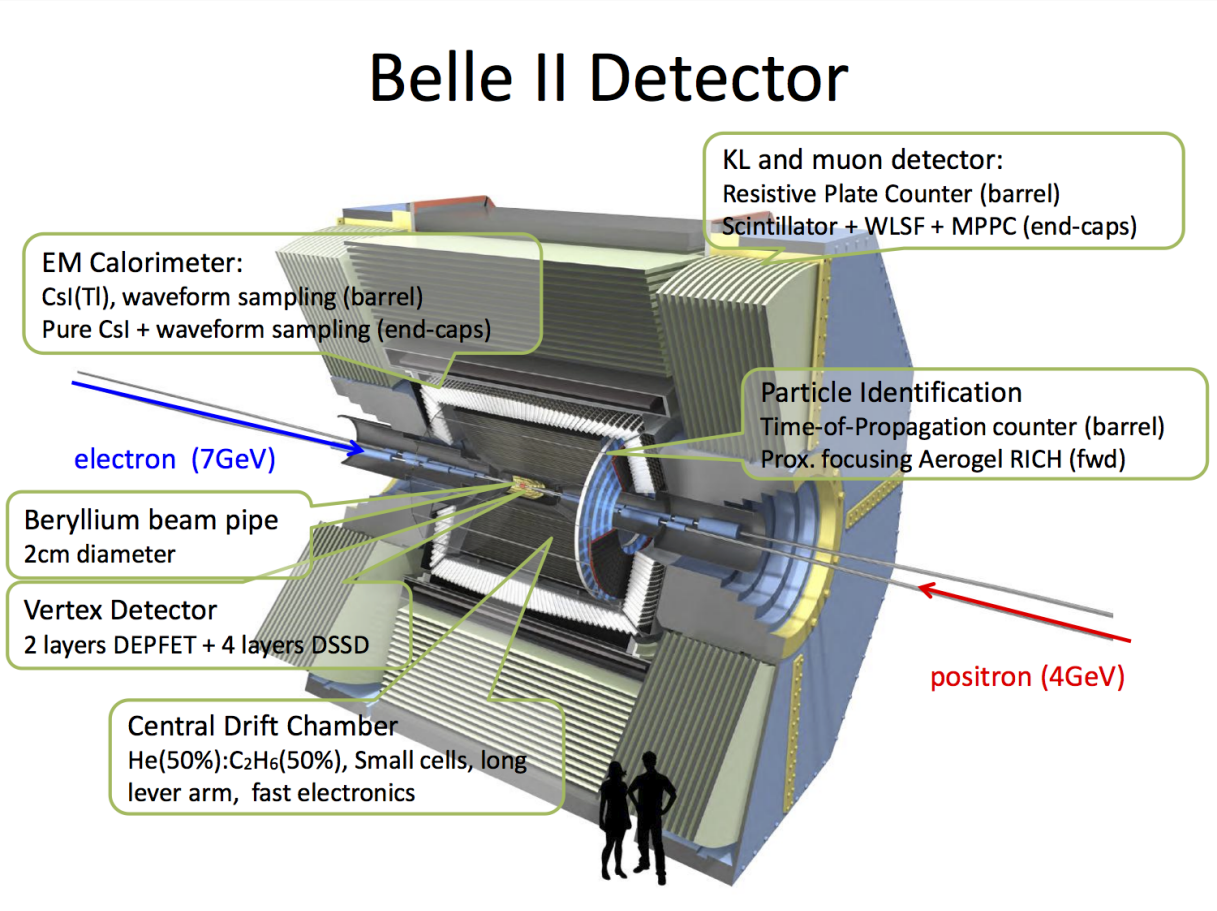
Add / modify RF systems for higher beam current

TiN-coated beam pipe with antechambers



To obtain x40 higher luminosity

Belle II is an improved version of Belle, largely to handle higher luminosity

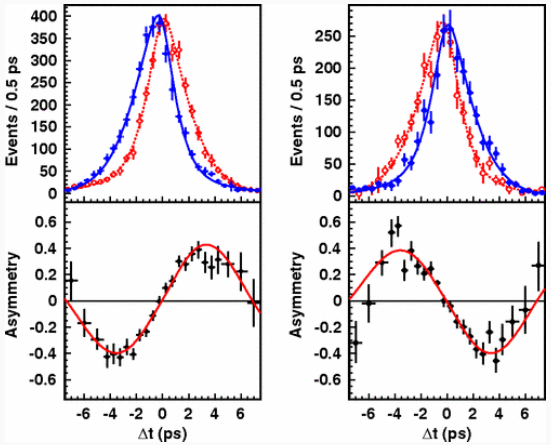


- Aiming for 50 ab^{-1} $= 50000\ \mathrm{fb}^{-1} \approx$ 50 $\times$ Belle data
- 2018: "Phase II" commissioning run - no vertex detector - 0.5 fb^{-1}
- 2019: "Phase III" full Physics run commenced

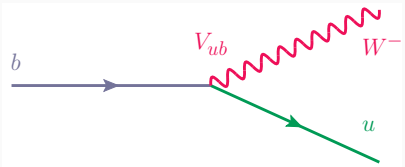
Belle II has a number of physics aims relating to "Flavour Physics"

Here are three:

- *CP* violation in *B* decays (continue the Belle legacy)

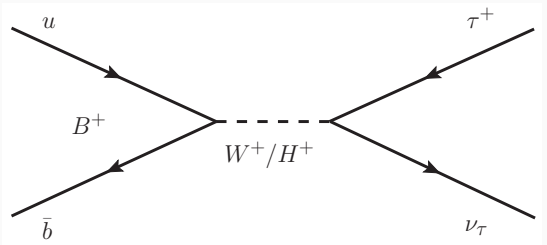


- Explore the CKM matrix governing weak transitions e.g. $B^0 \to \pi^- \ell^+ \nu_\ell$



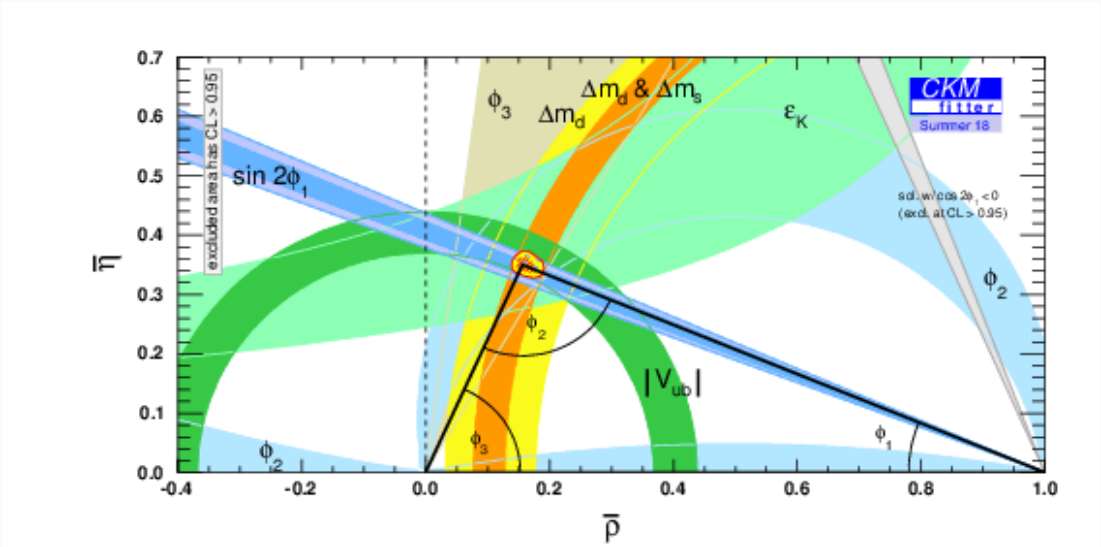
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Search for deviations from the Standard Model using rare *B* decays e.g. $B^+ \to \ell^+ \nu_\ell$, e.g. $B \to D^{(*)} \tau^+ \nu_\tau$

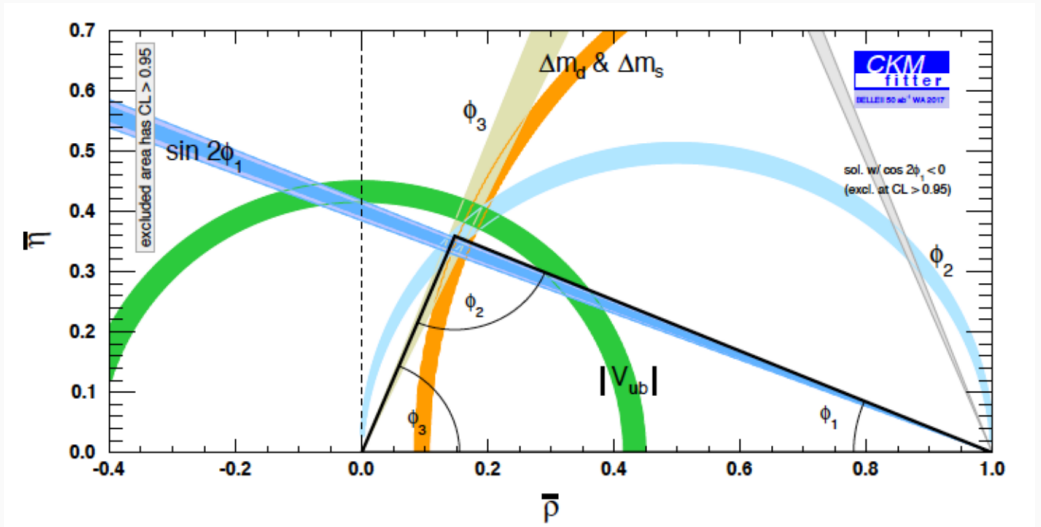


We would like to test unitarity of CKM matrix more precisely

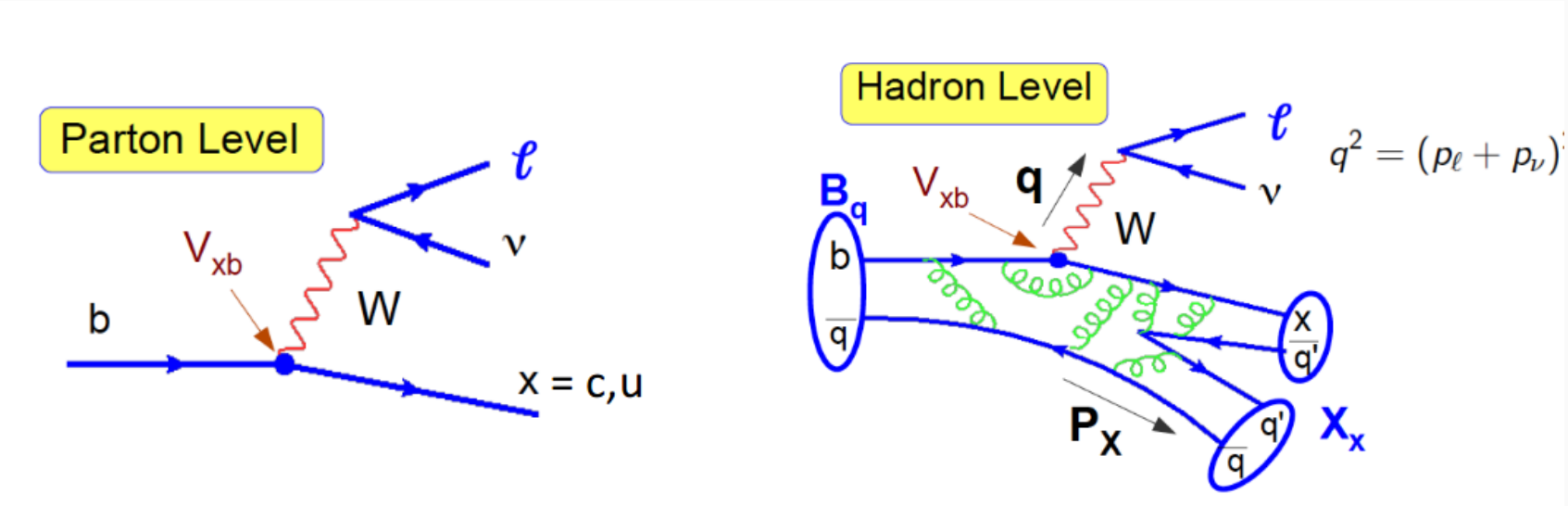
Currently



Belle II 50 ab^{-1}

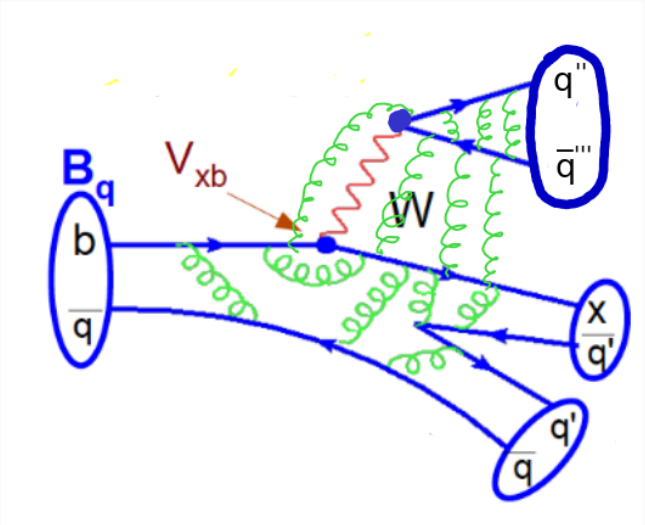


Leptonic and semileptonic decays are cleaner than hadronic decays, both theoretically and experimentally



From J. Dingfelder, FPCP 2018 talk

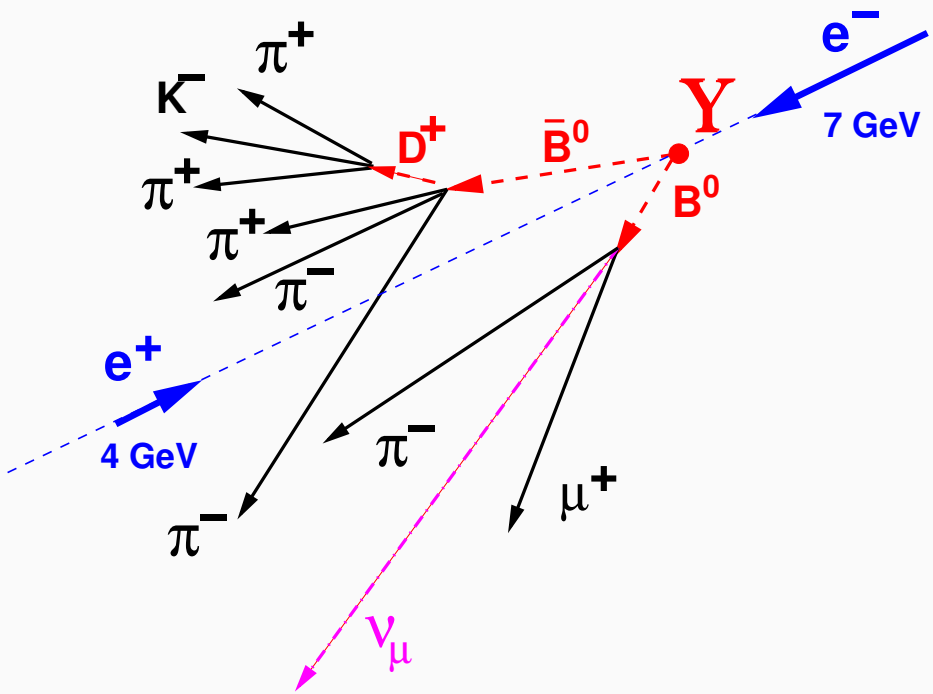
More complicated form factors ⇒



In many cases, ideally we would like a beam of B mesons . . .

. . . but

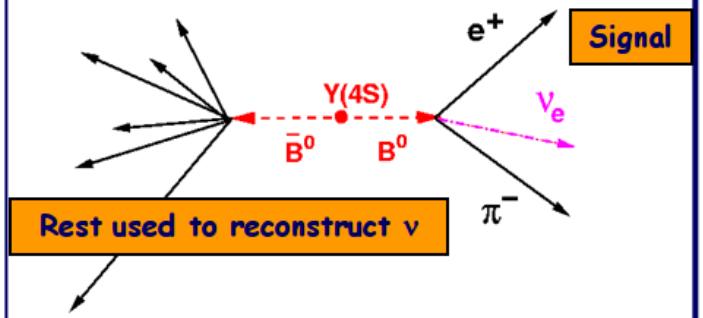
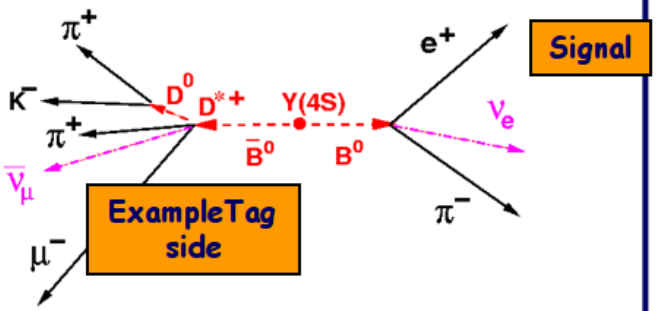
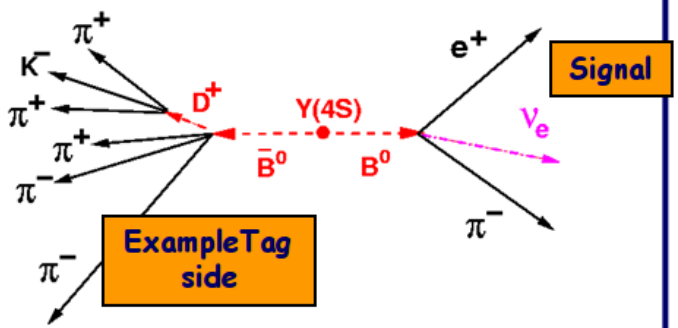
- not all collisions produce a $B\bar{B}$ pair
- we get two B mesons when they do - which decay products came from which?



- Use "tagging"

There are three approaches to "tagging"

Example signal: $B^0 \to \pi^- e^+ \nu_e$

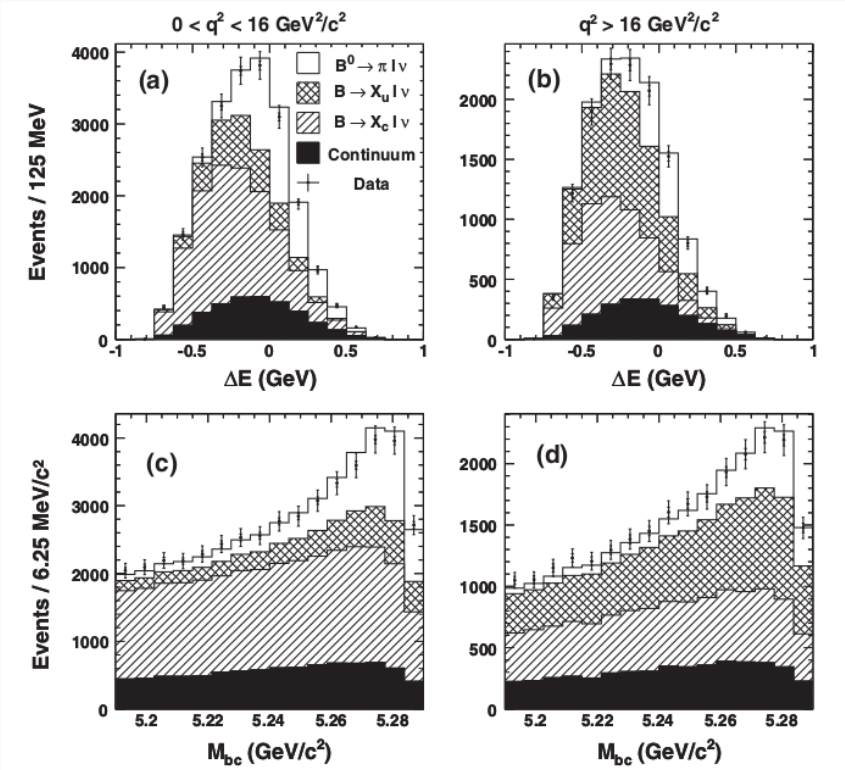
Untagged ▪ initial 4-momentum known ▪ missing 4-momentum = ν ▪ Reconstruct B → π^- ℓ ν cand using m_B (beam-constrained) and $\Delta E = E_B - E_{beam}$	**Pros** ▪ High efficiency **Cons** ▪ ν resolution problematic ▪ Rel. high backgrounds (rel. low purity)	
Semileptonic (SL) Tag ▪ One B reconstructed in a selection of $D^{(*)}$ ℓ ν modes ▪ Two missing ν in event Use kinematic constraints	**Pros** ▪ Lower backgrounds (higher purity) **Cons** ▪ Rel. low efficiency	
Full Recon Tag ▪ One B reconstructed completely in known e.g. b → c mode. Many modes used.	**Pros** ▪ Very good ν resolution ▪ Very low backgrounds **Cons** ▪ Very low efficiency	

Full Recon Tagging is cleaner

Example signal: $B^0 \to \pi^- \ell^+ \nu_\ell, \quad \ell = e, \mu$

Belle Untagged

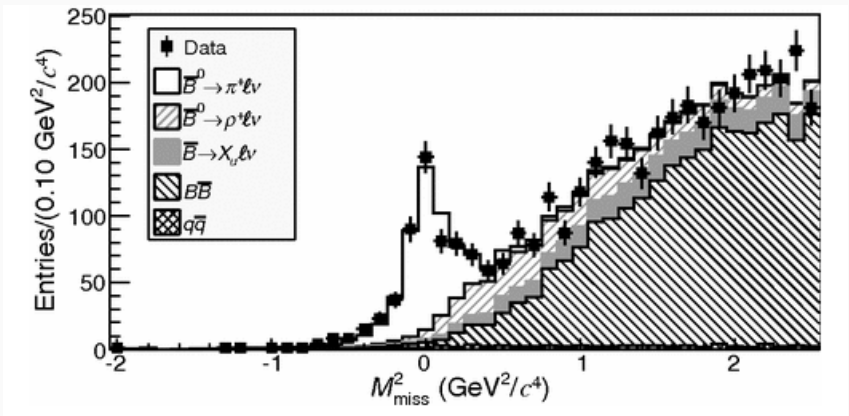
605 fb^{-1}



Phys. Rev. D83 (2011) 071101R

Belle Full Recon Tag (FR)

711 fb^{-1}



Phys. Rev. D88 (2013) 032005

The Belle II Full Recon scheme is called Full Event Interpretation (FEI)

Hierarchical reconstruction of tags using machine-learning techniques

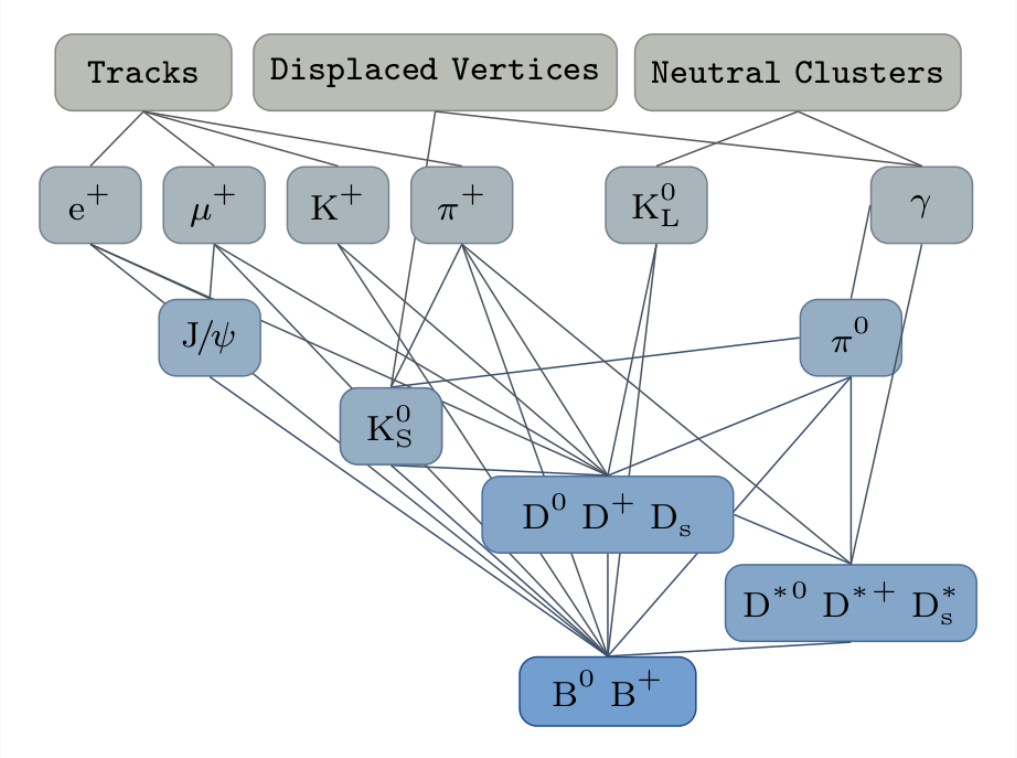


Image from arXiv:1807.08680 [hep-ex]

- Can do both hadronic and semileptonic tagging (Belle FR hadronic only)
- Provides a list of potential tags with associated "Signal Probability" which allows the purity of the selected decays to be controlled

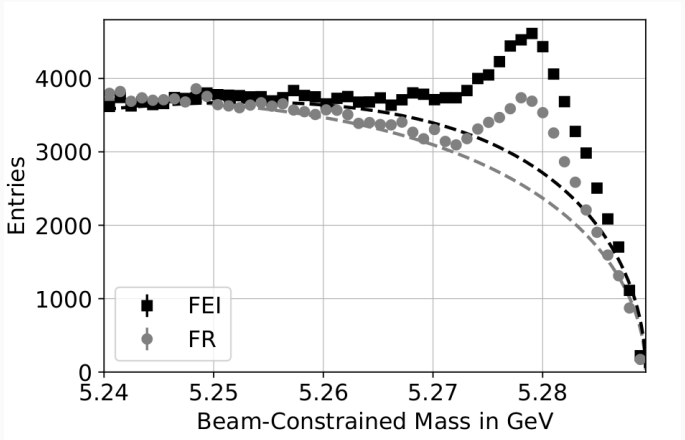
The FEI has been validated using Belle MC and data

Details can be found in Comput.Softw.Big Sci. 3 (2019) no.1, 6.

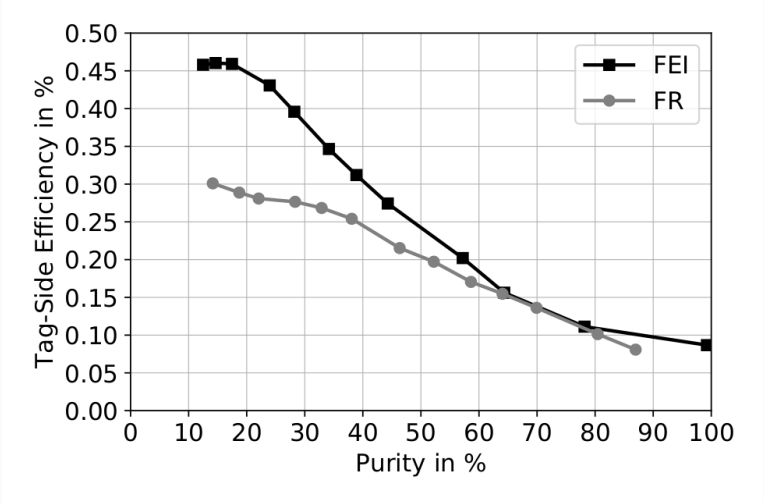
Maximum tag efficiency

	$B^{\pm}$	B^{0}
Hadronic		
FEI with FR channels	0.53 %	0.33 %
FEI	0.76 %	0.46 %
Semileptonic		
FEI	1.80 %	2.04 %

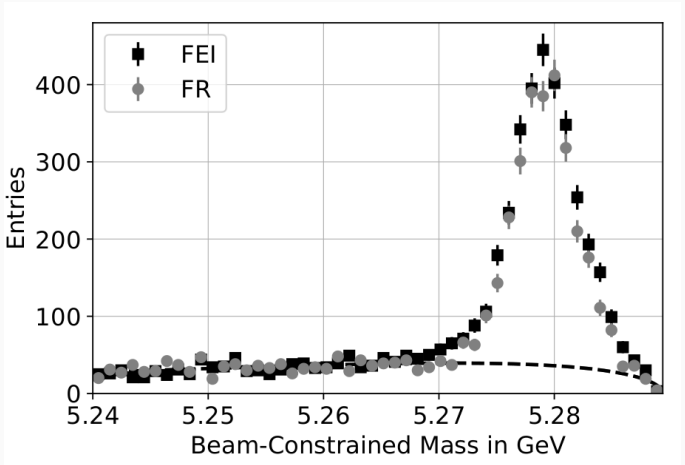
Low purity



Charged tags

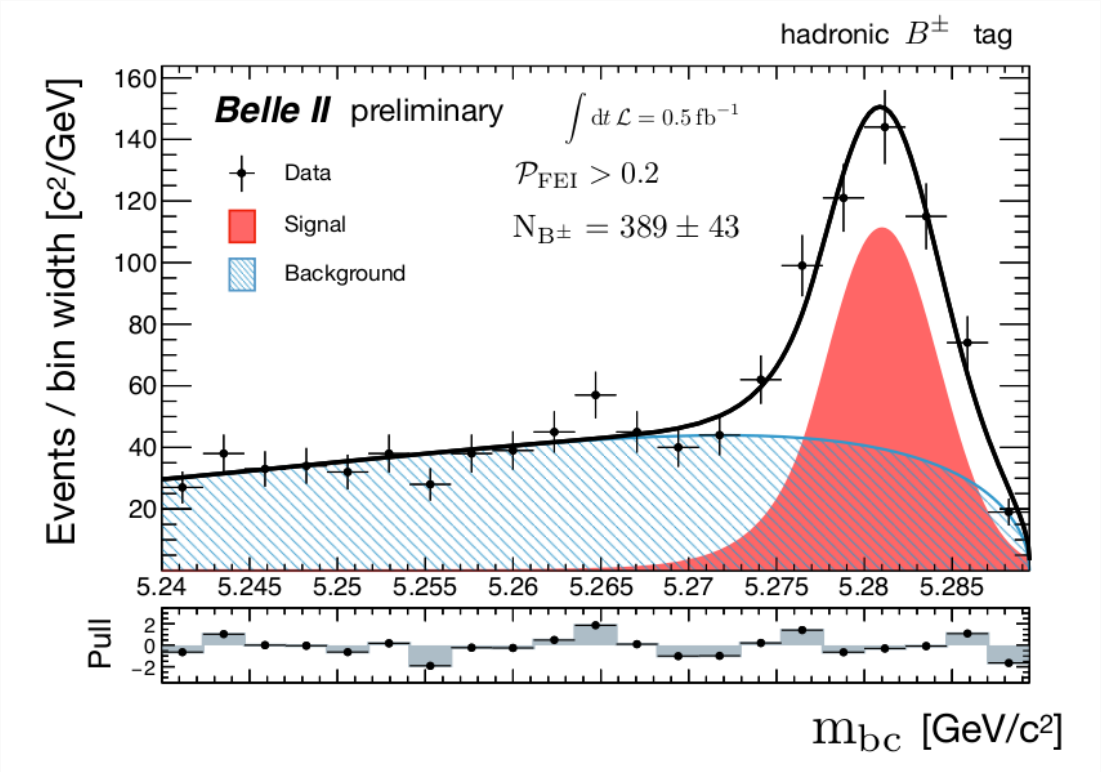


High purity



Belle II has "rediscovered" hadronic B decays in Phase II running using the FEI

Based on the Phase II dataset of 0.5 fb^{-1}

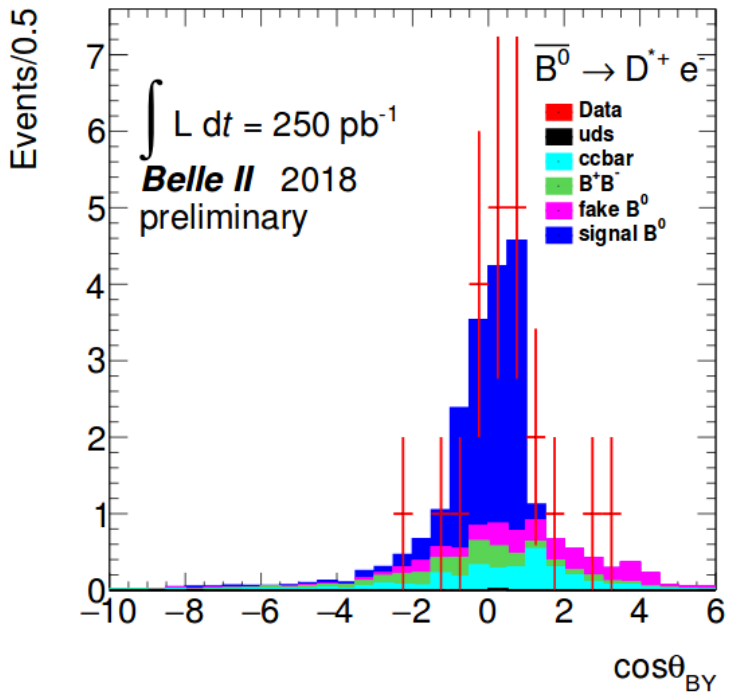


Ongoing work USyd/UAdel - validate FEI for semileptonic and hadronic tagging, early Phase III data

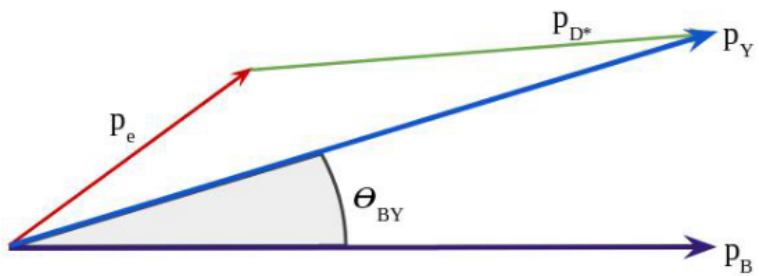
Ethan Cross, Philip Grace, Chia-Ling Hsu, Paul Jackson, Kevin Varvell

Semileptonic B decays can be extracted by exploiting kinematics

Example: $\overline{B^0} \to D^{*+} e^- \bar{\nu}_e$ based on 0.25 fb^{-1} of the Belle II Phase II dataset



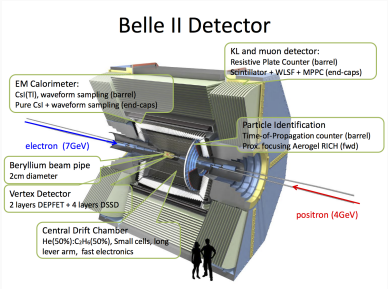
$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - m_B^2 - m_Y^2}{2p_B^* p_Y^*}$$



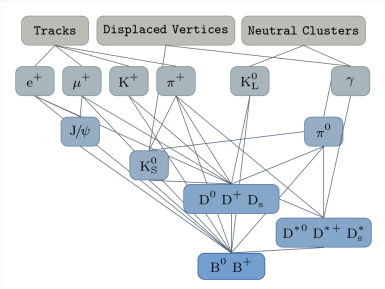
This result was verified by Bernanda Telalovic in a 2018 honours project.

Conclusions

- Belle II is commissioned, running and ready to study rare B-meson decays and Flavour Physics



- A superior method of tagging B-meson decays (Full Event Interpretation) has been developed



- Our focus is currently to validate the method and help to "rediscover" B-mesons using early Phase III data from Belle II