Karlsruhe Institute of Technology

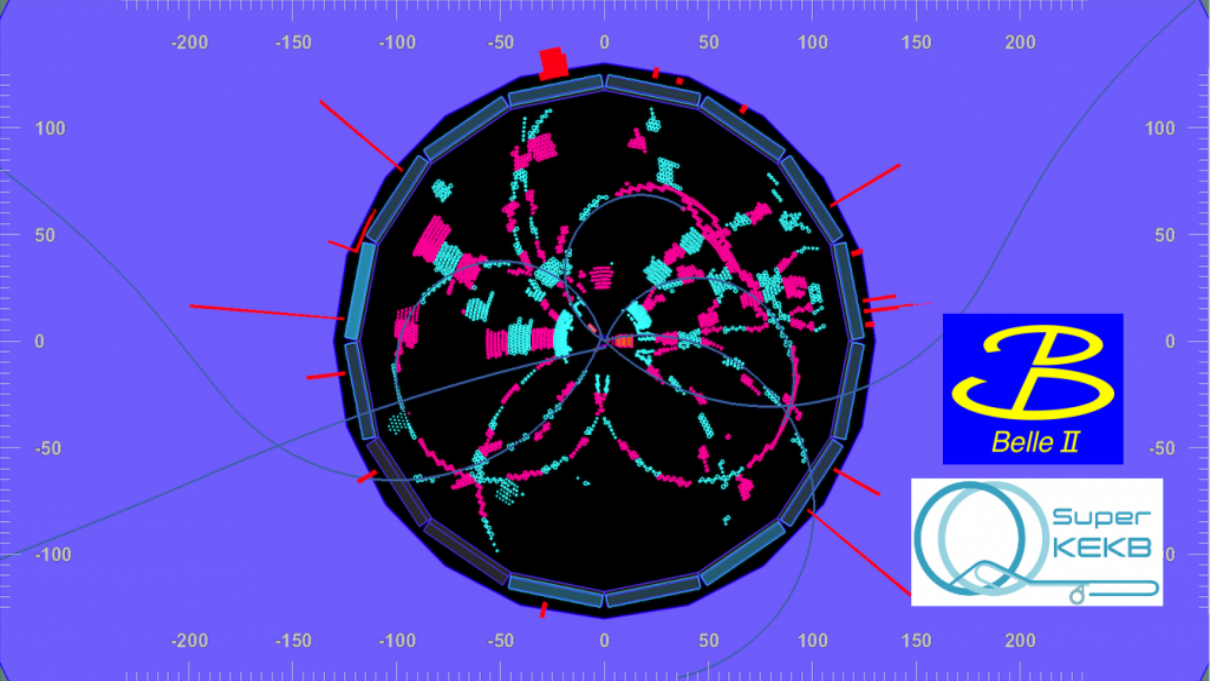
Belle II

Semileptonic and Leptonic B Decay Results from early Belle II Data

FPCP 2019

Markus Prim on behalf of the Belle II Collaboration | 8th May 2019

INSTITUT FÜR EXPERIMENTELLE TEILCHENPHYSIK (ETP)


-200
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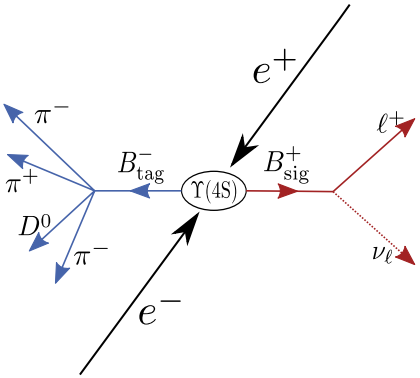
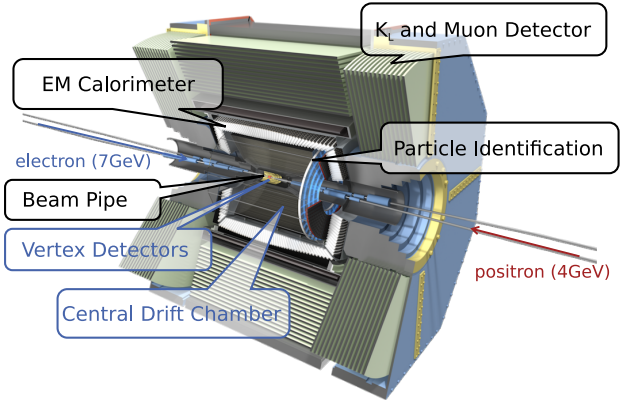
Belle II
Super
KEKB

The Belle II Experiment

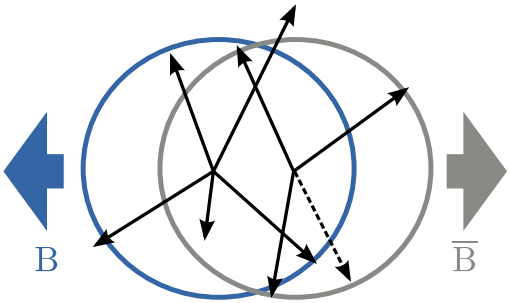




Belle II Recorded data on the $\Upsilon(4S)$ Resonance:
Commissioning Run 2018: $\mathcal{L} \approx 0.5\,\text{fb}^{-1}$
Physics Run 2019: $\mathcal{L} > 0.1\,\text{fb}^{-1}$

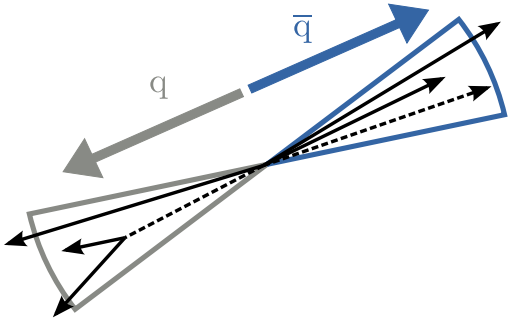
Event Topology at Belle II

$\Upsilon(4S)$ Event



Isotropic Momentum Distribution

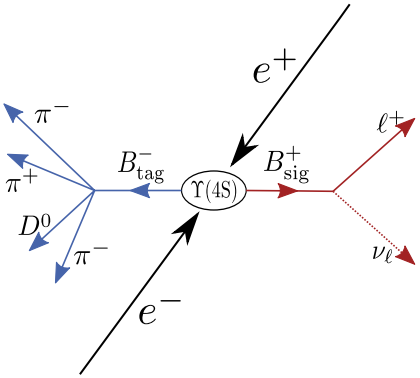
Non-Resonant Event

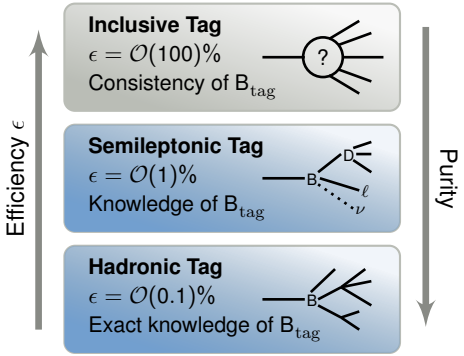


Back-To-Back Momentum Distribution

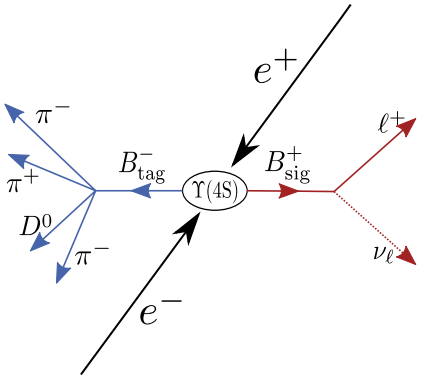
Discrimination by a Ratio of Fox-Wolfram Moments R2.

B-Tagging at Belle II

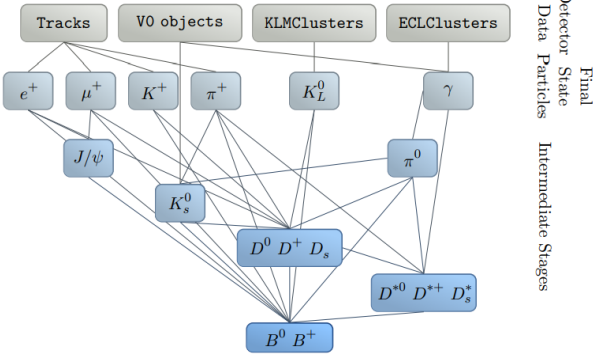




B-Tagging at Belle II



Exclusive Tagging:
The Full Event Interpretation (FEI)
Keck, T., et al. Comput Softw Big Sci (2019)



$\Rightarrow$ **Signal Probability**

FEI Performance

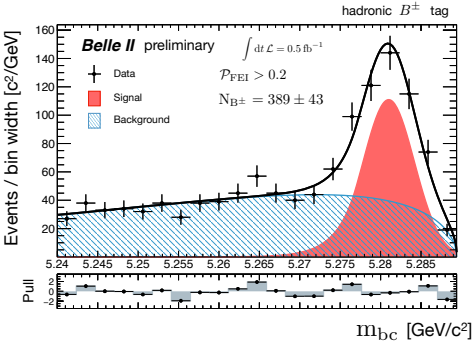
FEI Performance: Strategy

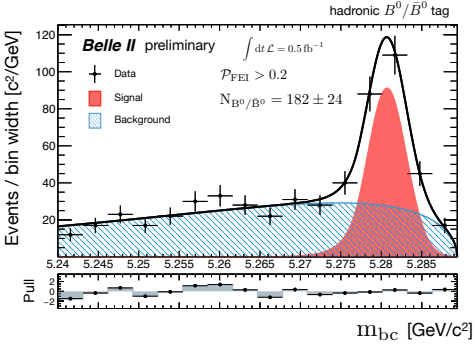
- The performance analysis used
  - the commissioning run data sample of $0.5\,\mathrm{fb}^{-1}$.
  - only hadronically reconstructed tag-side B mesons.

- Suppress continuum background using R2.
- Retrieve number of B candidates by fitting $m_{\mathrm{bc}} = \sqrt{s/4 - \left|\vec{p}^{\,*}_{\mathrm{B_{tag}}}\right|^2}$.

- Determine tag-side efficiency and purity:
  - Efficiency: $N_{\mathrm{B}}^{\mathrm{correct}} / N_{\Upsilon(4S)}^{\mathrm{total}}$
  - Purity: $N_{\mathrm{B}}^{\mathrm{correct}} / N_{\mathrm{B}}^{\mathrm{all}}$

FEI Performance: Results I





FEI Signal Probability $\mathcal{P} > 0.2$.

FEI Performance: Results II

	Candidates	Efficiency	Purity
	FEI Signal Probability $\mathcal{P} > 0.01$		
Charged Candidates	937±126	0.17%	24%
Neutral Candidates	394± 59	0.09%	25%
	FEI Signal Probability $\mathcal{P} > 0.2$		
Charged Candidates	389± 43	0.07%	63%
Neutral Candidates	182± 24	0.03%	73%

The FEI was successfully deployed on the first Belle II data.

Analysis of Inclusive Semileptonic $B \to Xe\nu$ Decays

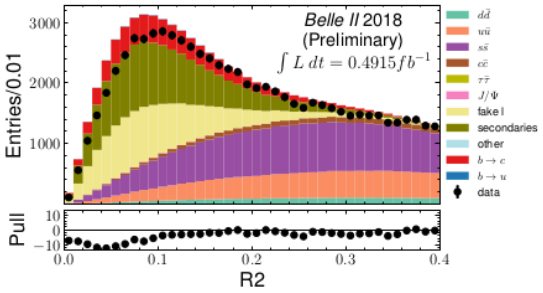
$B \to Xe\nu$: Strategy

- The analysis used
  - the commissioning run data sample of $0.5\,\mathrm{fb}^{-1}$.
  - lepton identification via $E_{\mathrm{ECL}}/p_{\mathrm{tracking}}$.
  - the electron momentum spectrum.

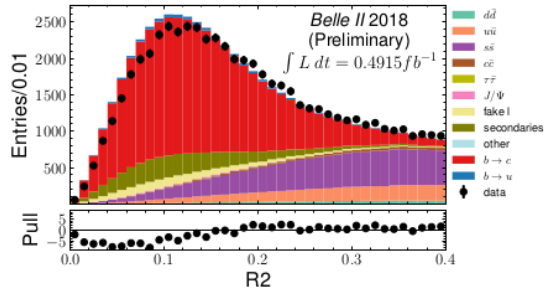
- Suppress continuum background using R2.
- Veto J/ψ candidates.

$B \to X e \nu$: Results I

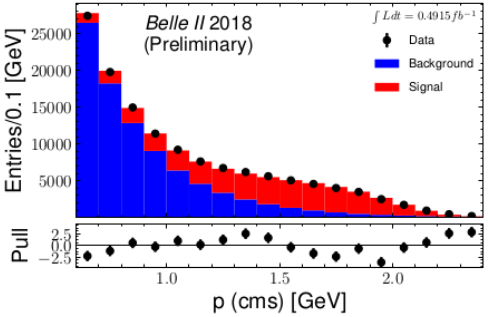
$p_e < 1\,\mathrm{GeV}$



$p_e > 1\,\mathrm{GeV}$



$B \to X e \nu$: Results II



- We observe 42191 ± 304 signal events.
- We expected 40209 ± 200 signal events.

Successful observation!

- No statements about $|V_{cb}|$, $|V_{ub}|$ or branching fractions possible, yet.

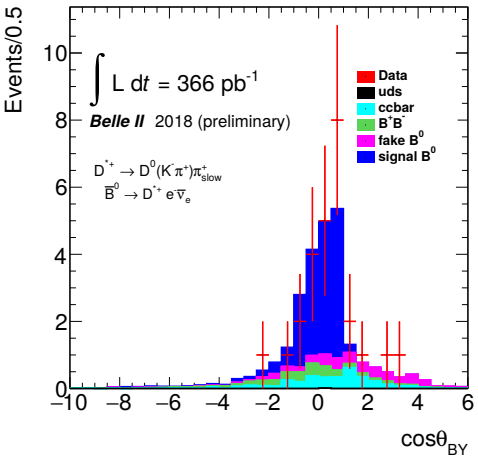
Analysis of Exclusive Semileptonic $B \to D^* e \nu$ Decays

Semileptonic B $\rightarrow$ D*eν Decays: Strategy

- The rediscovery used
  - a data sample of 366 pb^{-1} from the commissioning run.
  - the decay channel B $\rightarrow$ D*eν with D* $\rightarrow$ D$^0(\rightarrow \mathrm{K}\pi)\pi_{\mathrm{slow}}$.
  - lepton identification via $E_{\mathrm{ECL}}/p_{\mathrm{tracking}}$.

- Suppress continuum background using R2.
- Use the variable $\cos\Theta_{\mathrm{BY}} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$.
- Correctly reconstructed candidates peak in $\cos\Theta_{\mathrm{BY}} \in [-1, 1]$.

Semileptonic B $\rightarrow$ D*eν Decays: Results



- After final selection, we observe 22 events.
- 15 of these events are in the signal region $-1 < \cos\Theta_{BY} < 1$.
- 13 events are expected to be signal.

Successful Search!

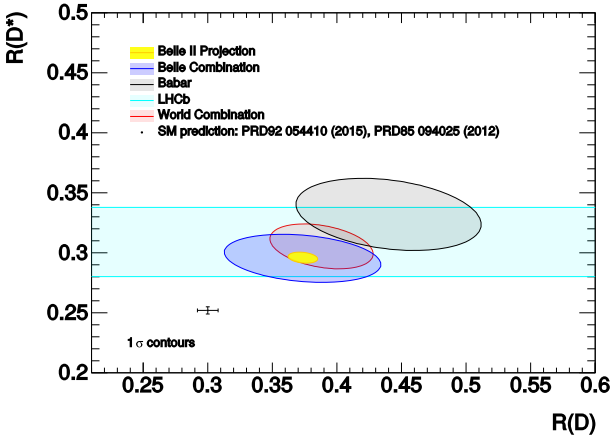
Summary & Outlook I

- First looks into data from the commissioning run have been successful:
  - Successful FEI application.
  - Observation for $B \to X e \nu$ decays.
  - Evidence for $B \to D^{*} e \nu$ decays.

- With the upcoming physics run data we will have a look at:
  - Untagged $B \to X_{u,c} \ell \nu$ decays.
  - Untagged $B \to \pi \ell \nu$ and $B \to \rho \ell \nu$ decays.
  - FEI performance studies and calibration.
  - Tagged (hadronic and semileptonic) $B \to X \ell \nu$ decays.
  - Tagged (hadronic) $B \to D^{(*)} \ell \nu$ decays.
  - And much more!

Summary & Outlook II

- Long term prospect $R(D^{(*)})$:



Summary & Outlook III

- Long term prospect $|V_{ub}|$:

	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\|V_{ub}\|$ exclusive (had. tagged)					
711 fb^{-1}	3.0	(2.3, 1.0)	3.8	7.0	8.0
5 ab^{-1}	1.1	(0.9, 1.0)	1.8	1.7	3.2
50 ab^{-1}	0.4	(0.3, 1.0)	1.2	0.9	1.7
$\|V_{ub}\|$ exclusive (untagged)					
605 fb^{-1}	1.4	(2.1, 0.8)	2.7	7.0	7.5
5 ab^{-1}	1.0	(0.8, 0.8)	1.2	1.7	2.1
50 ab^{-1}	0.3	(0.3, 0.8)	0.9	0.9	1.3
$\|V_{ub}\|$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.7, 1.6)	6.0	2.5−4.5	6.5−7.5
5 ab^{-1}	1.1	(1.3, 1.6)	2.3	2.5−4.5	3.4−5.1
50 ab^{-1}	0.4	(0.4, 1.6)	1.7	2.5−4.5	3.0−4.8
$\|V_{ub}\|$ $B \to \tau\nu$ (had. tagged)					
711 fb^{-1}	18.0	(7.1, 2.2)	19.5	2.5	19.6
5 ab^{-1}	6.5	(2.7, 2.2)	7.3	1.5	7.5
50 ab^{-1}	2.1	(0.8, 2.2)	3.1	1.0	3.2
$\|V_{ub}\|$ $B \to \tau\nu$ (SL tagged)					
711 fb^{-1}	11.3	(10.4, 1.9)	15.4	2.5	15.6
5 ab^{-1}	4.2	(4.4, 1.9)	6.1	1.5	6.3
50 ab^{-1}	1.3	(2.3, 1.9)	2.6	1.0	2.8

$|V_{ub}|$ uncertainty @ Belle II

exclusive ~1.5%

inclusive ~ 4%

leptonic ~ 3%

Summary & Outlook IV

Exciting times are ahead!

Backup

From The Belle II Physics Book (1808.10567)

Observables	Belle	Belle II	
	(2017)	5 ab^{-1}	50 ab^{-1}
$\|V_{cb}\|$ incl.	$42.2 \cdot 10^{-3} \cdot (1 \pm 1.8\%)$	1.2%	–
$\|V_{cb}\|$ excl.	$39.0 \cdot 10^{-3} \cdot (1 \pm 3.0\%_{\text{ex.}} \pm 1.4\%_{\text{th.}})$	1.8%	1.4%
$\|V_{ub}\|$ incl.	$4.47 \cdot 10^{-3} \cdot (1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$	3.4%	3.0%
$\|V_{ub}\|$ excl. (WA)	$3.65 \cdot 10^{-3} \cdot (1 \pm 2.5\%_{\text{ex.}} \pm 3.0\%_{\text{th.}})$	2.4%	1.2%
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$91 \cdot (1 \pm 24\%)$	9%	4%
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%
$R(B \to D\tau\nu)$ (Had. tag)	$0.374 \cdot (1 \pm 16.5\%)$	6%	3%
$R(B \to D^*\tau\nu)$ (Had. tag)	$0.296 \cdot (1 \pm 7.4\%)$	3%	2%

From The Belle II Physics Book (1808.10567) I

Observables	Expected the. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	LHCb/Belle II
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb
CP Violation			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb

From The Belle II Physics Book (1808.10567) II

Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K^0_S\pi^0\gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***	20%	Belle II
$R(B \to K^*\ell\ell)$	***	0.03	Belle II/LHCb
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$A_{CP}(D^0 \to K^0_S\pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\lvert q/p\rvert(D^0 \to K^0_S\pi^+\pi^-)$	***	0.03	Belle II
$\phi(D^0 \to K^0_S\pi^+\pi^-)$ $[^\circ]$	***	4	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***	< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***	< 3	Belle II/LHCb