Towards first $|V_{ub}|$ and $|V_{cb}|$ measurements at Belle II

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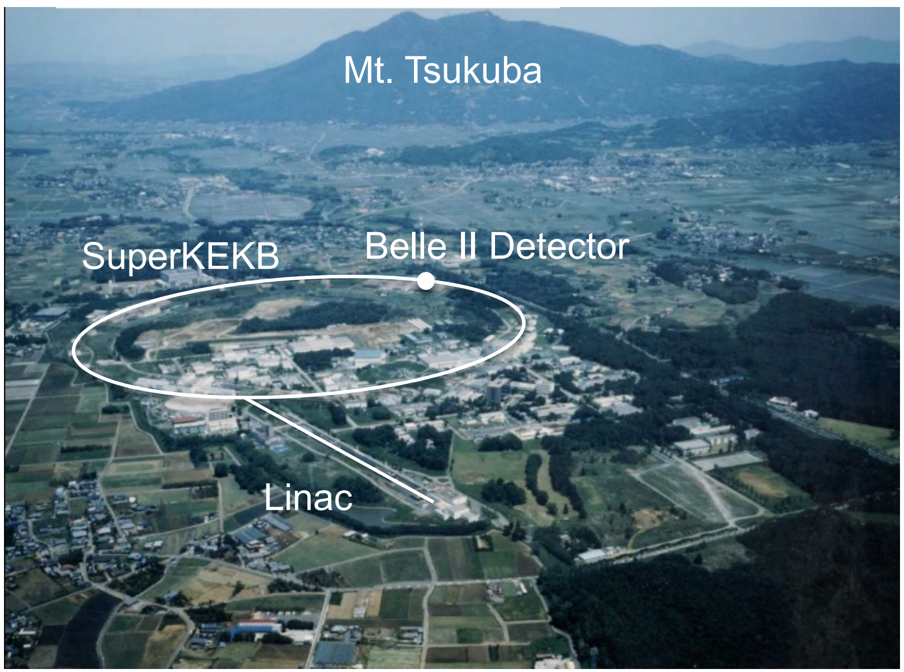
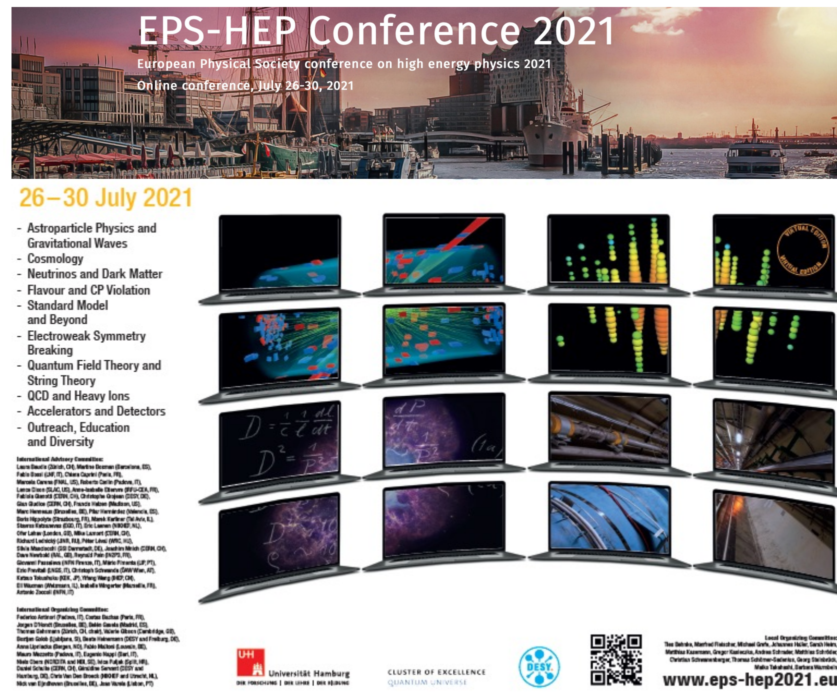
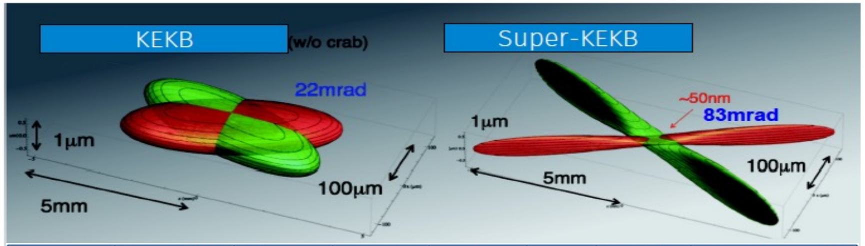
On behalf of the Belle II Collaboration

EPS-HEP 2021, July 26-30, 2021





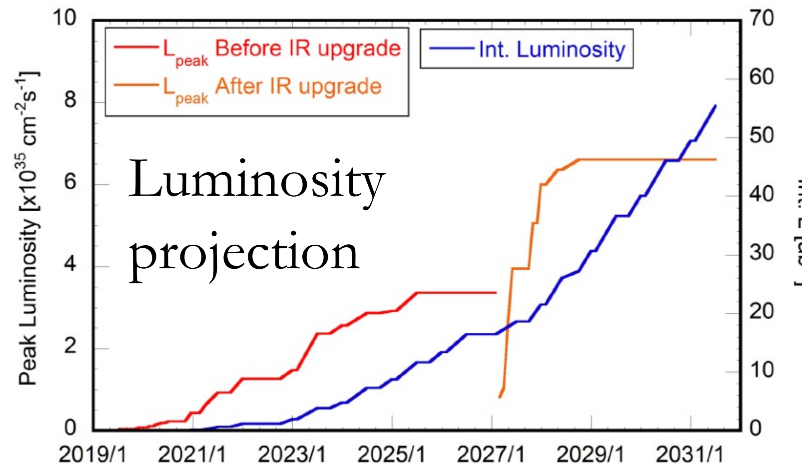
From KEKB/Belle to SuperKEKB/Belle II



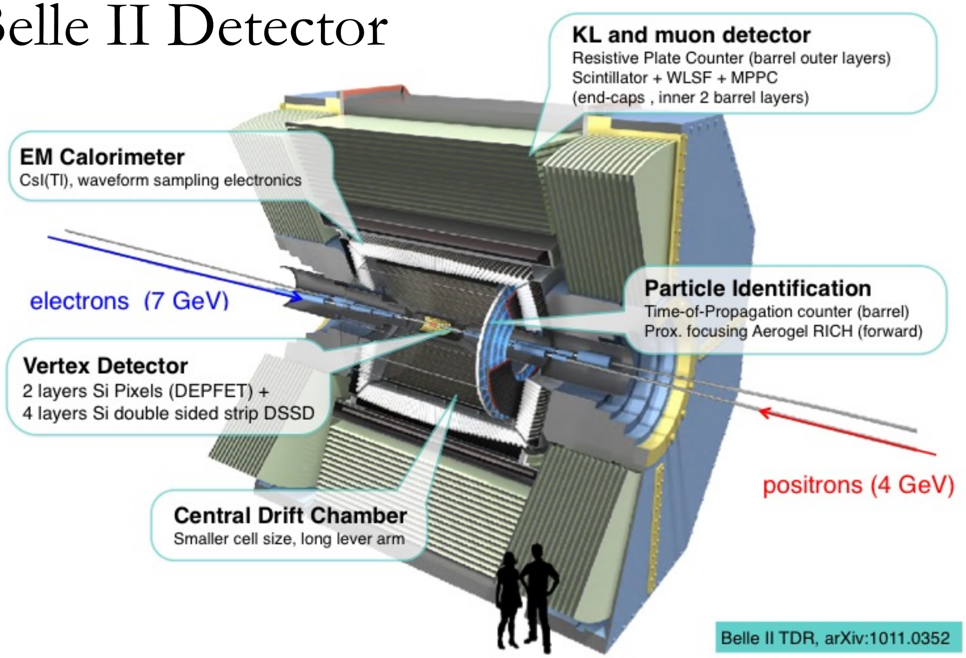
	Energy (GeV) LER/HER	β_y^* (mm) LER/HER	ε_x (nm) LER/HER	ξ_y LER/HER	φ (mrad)	I_{beam} (A) LER/HER	Luminosity ($cm^{-2}s^{-1}$) x 10^{34}
KEKB Achieved	3.5/8.0	5.9/5.9	18/24	0.13/0.09	11	1.6/1.2	2.11
SuperKEKB	4.0/7.0	0.27/0.3	3.2/2.4	0.09/0.09	41.5	2.8/2.0	65

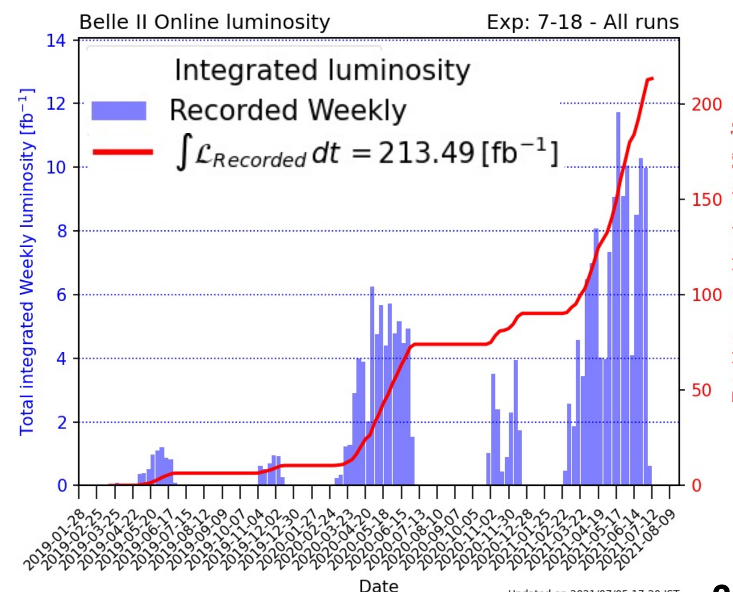
factor 20 factor 1.5

Factor ~30 in the luminosity

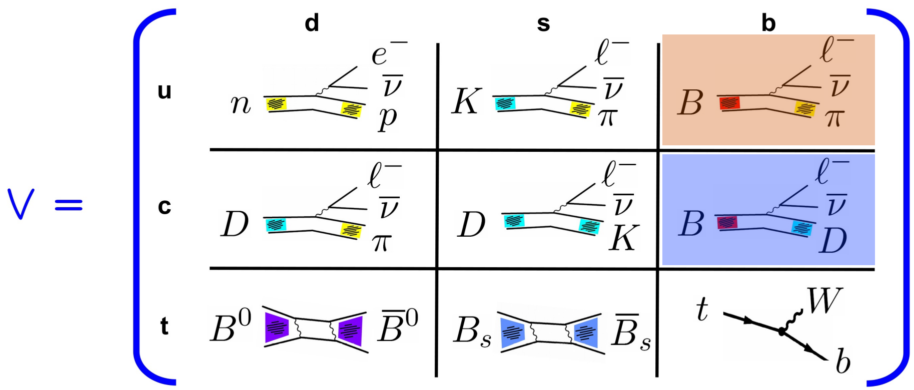


Belle II Detector





$|V_{ub}|$ and $|V_{cb}|$ determinations



CKM matrix elements $|\mathbf{V_{ub}}|$ and $|\mathbf{V_{cb}}|$ probed via semileptonic B decays with missing energy (neutrinos)

Both CKM matrix elements can be measured via inclusive or exclusive B decays:

- $|V_{ub}|$: $B \to X_u \ell \nu,\ B \to \pi(\rho, \eta)\ell\nu$
- $|V_{cb}|$: $B \to X_c \ell \nu,\ B \to D^{(*)}\ell\nu$

Belle II physics reach projections summarized in the Belle II Physics Book (PTEP 2019 (2019) 12, 123C01, https://doi.org/10.1093/ptep/ptaa008)

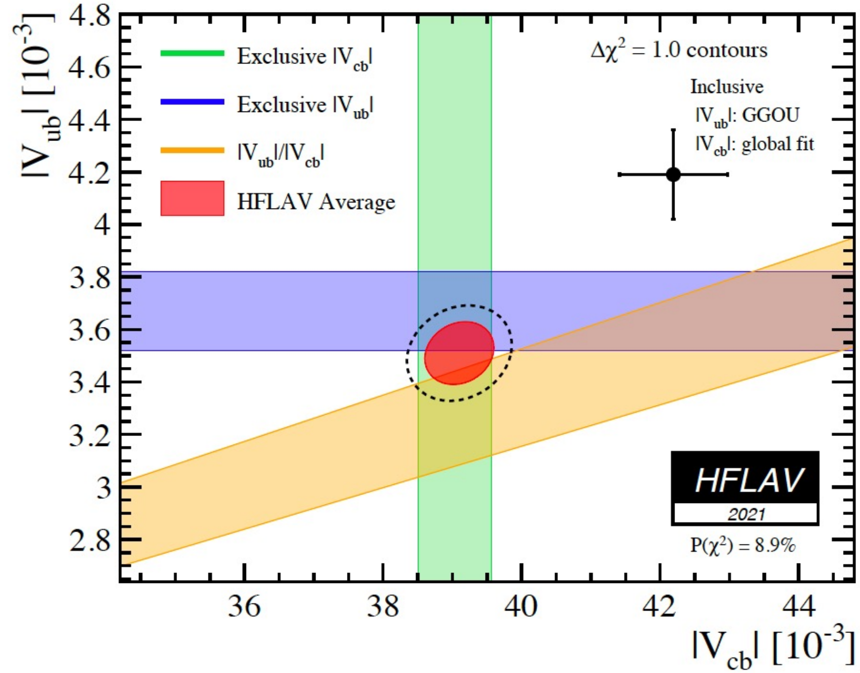
Semileptonic decays: $B \to X\ell\nu$

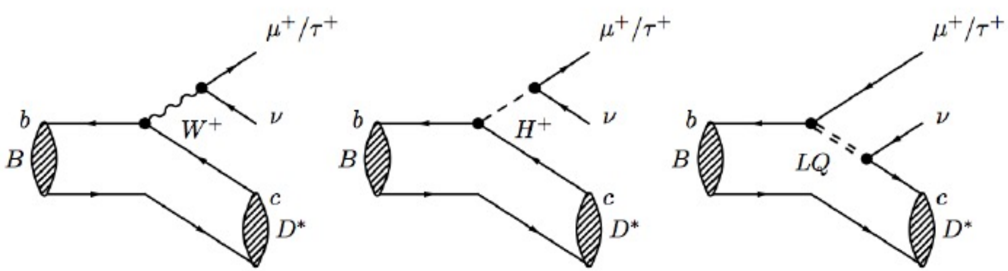
- Current precision is **1-2% on $|V_{cb}|$** and **3-4% on $|V_{ub}|$**

- **Tension** between inclusive and exclusive determinations: ~3.3σ for both $|V_{cb}|$ and $|V_{ub}|$

- $X_c l\nu$ decays are a clear test of the SM LFU: **NP** (charged Higgs in 2HDM models or Leptoquarks) **can affect the BF and $|V_{cb}|$**

hflav.web.cern.ch



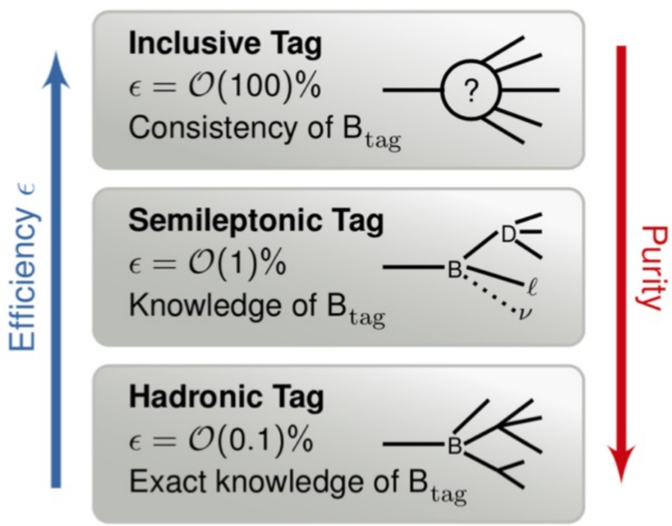


- Complementary to the R(D)/R(D*) measurements

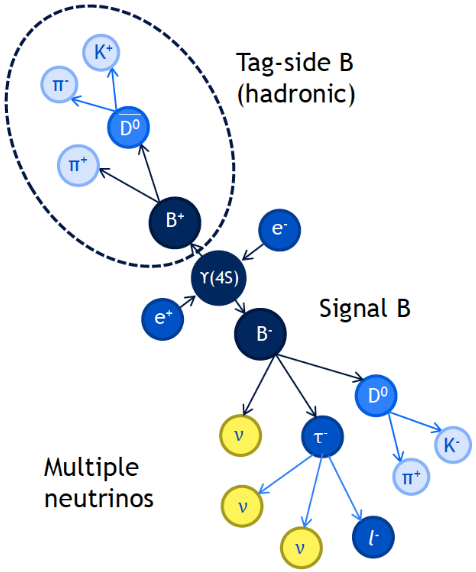
$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)} \quad (\ell = e, \mu)$$

Reconstruction of events with missing energy: Full Event Interpretation (FEI)

- Reconstruct one B ($\mathbf{B_{tag}}$) and constrain the 4-momentum of the other B ($\mathbf{B_{sig}}$)



- The FEI uses a multivariate technique to reconstruct the B-tag side (semileptonic or hadronic) through $O(10^3)$ decay modes in a Υ(4S) decay.



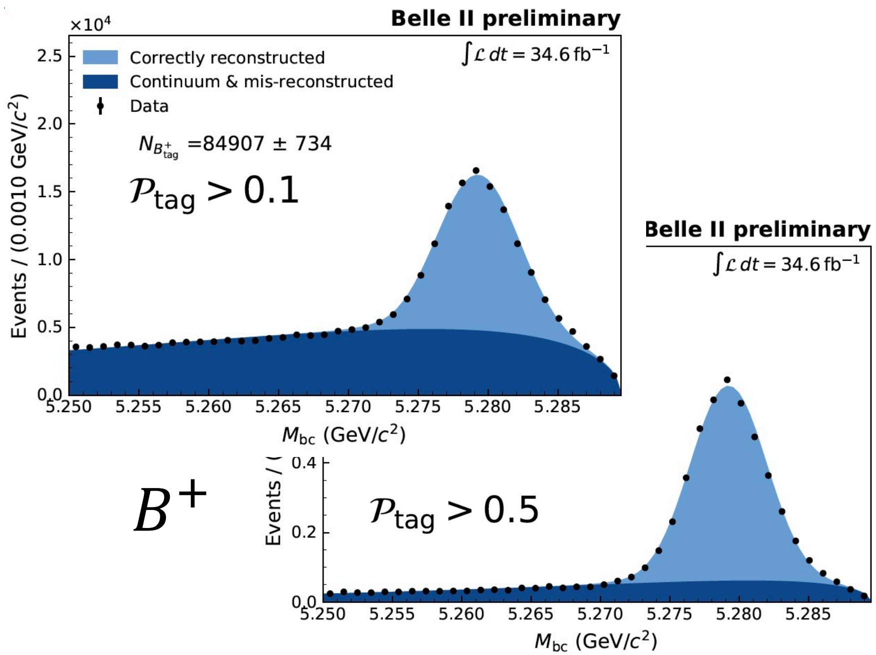
Tagging efficiency (evaluated on Belle MC) @10% purity

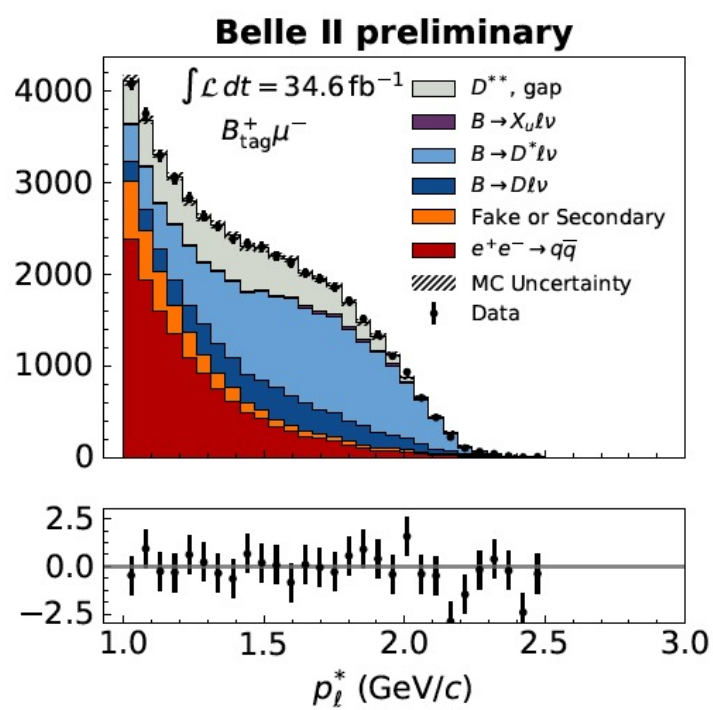
Tagging Algorithm	Had B^+/B^0 (%)	SL B^+/B^0 (%)
Full Reconstruction Belle	0.28/0.18	0.67/0.63
FEI Belle	0.78/0.46	1.80/2.04

Belle algorithm: NIM A 654, 432-440 (2011)
Belle II FEI: Keck, T., Abudinén, F., z, F.U. et al. Comput Softw Big Sci (2019) 3: 6. https://doi.org/10.1007/s41781-019-0021-8

FEI on Belle II data

arXiv:2008.06096v2





- Output of the FEI is a signal probability (P_{tag}) between 0 (mis-reconstructed) and 1 (properly reconstructed) B_{tag} candidate.
- **Tag side** reconstructed in hadronic modes

$$M_{bc} = \sqrt{s/4 - (p_B^*)^2}$$

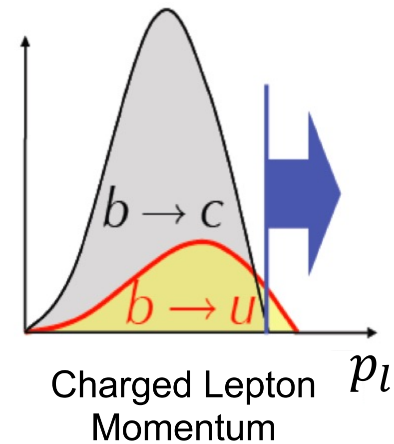
- Look for signal side lepton with momentum (in B_{sig} rest frame) > 1 GeV/c
- Check consistency with the well-known $\mathbf{B \to X\ell\nu}$
- Used to calibrate FEI

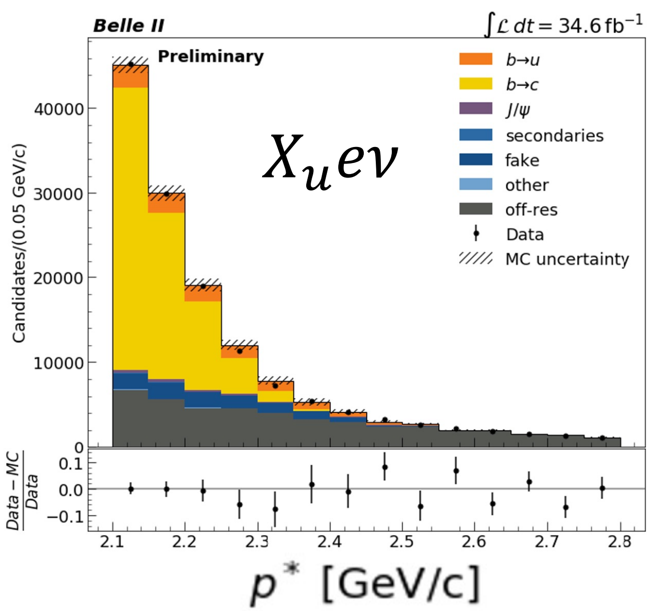
Inclusive $B \to X_u \ell \nu$

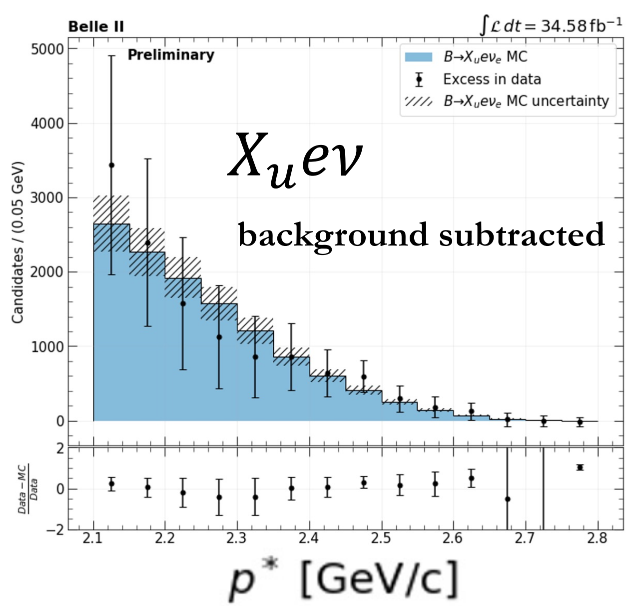
arXiv:2103.02629

BELLE2-NOTE-PL-2020-026

- Challenging due to the dominant $b \to c l \nu$ background
- Exploit the lepton momentum endpoint where the $b \to c$ component becomes negligible
- Identify one electron with particle identification criteria
- Suppress $q\bar{q}$ background with multi-variate algorithm, exploiting event shape variables







First observation at ~3σ level

Exclusive $B \to \pi \ell \nu$

arXiv:2008.08819
PRD 91, 074510 (2015)
arXiv:2102.07233

Measurement in bins of q^2 used to extract $|V_{ub}|$

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} |p_\pi|^3 |f_+(q^2)|^2$$

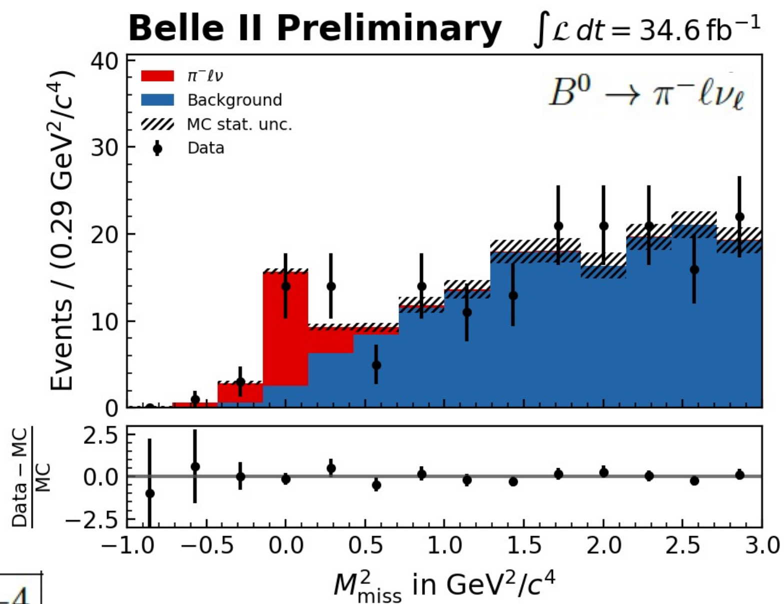
Form factors f computed with LQCD (high q^2) or LCSR ($q^2 \leq 0$)

FEI hadronic tagged analysis (untagged analysis in progress)

- Exploits missing energy and extra energy in the calorimeter
- Fit to M^2_{miss} distribution to measure the BF

$$M^2_{\rm miss} \equiv p^2_{\rm miss} = (p_{B_{\rm sig}} - p_Y)^2$$

Y is the $\pi\ell$ system

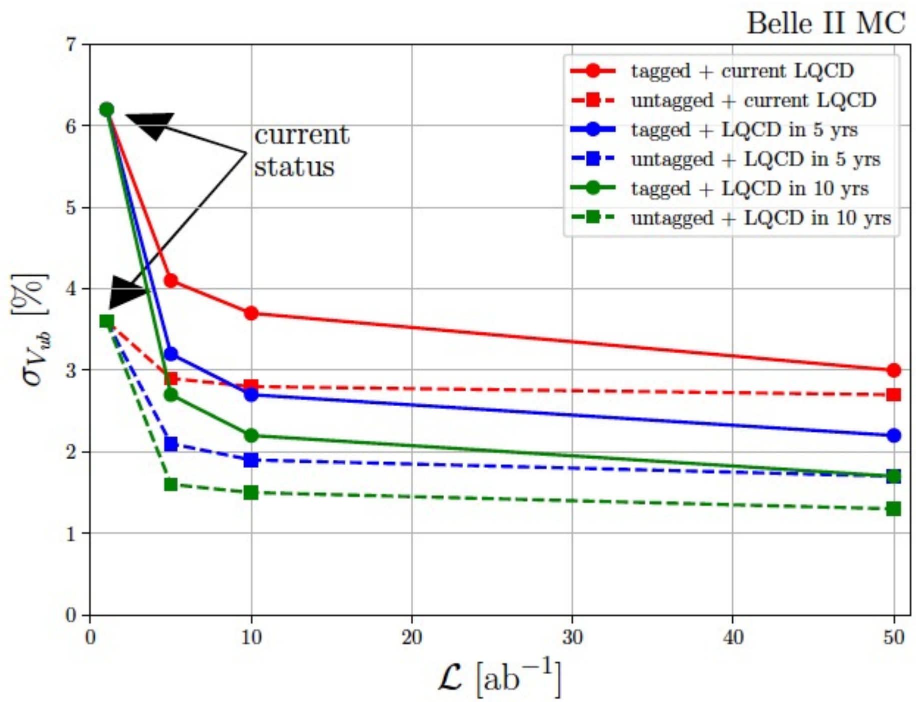


$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell)$	$(1.58 \pm 0.43_{\rm stat} \pm 0.07_{\rm sys}) \times 10^{-4}$

Observation with significance > 5σ

$|V_{ub}|$ projections

Belle II Physics Book



- Projection of $|V_{ub}|$ uncertainties from $\mathbf{B^0} \to \boldsymbol{\pi \ell \nu}$ decay

- Takes advantage from improvements in LQCD

- Precision of ~1% with full Belle II dataset

$\vert$Vub$\vert$ uncert.	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})
Exclusive	(1.2 ⊕1.7)%	(0.9 ⊕ 0.9)%
Inclusive	(2.3 ⊕ 2.5-4.5)%	(1.7 ⊕ 2.5-4.5)%

Projected errors: (experiment ⊕ theory)

Inclusive $B \to X_c \ell \nu$

JHEP02(2019)177

- Total decay rate expressed as expansion of non-perturbative matrix elements (heavy quark expansion, HQE)

$$\Gamma = \frac{G_F^2 m_b^5}{192\pi^2}|V_{cb}|^2\left(1 + \frac{c_5(\mu)\langle O_5\rangle(\mu)}{m_b^2} + \frac{c_6(\mu)\langle O_6\rangle(\mu)}{m_b^3} + \mathcal{O}(\frac{1}{m_b^4})\right)$$

- Measure the **spectral moments** (moments of lepton energy or hadronic mass) in order to simultaneously determine the non perturbative elements and $|V_{cb}|$ (see Kevin Olschewsky's talk for the determination using q^2 moments)
- Belle II performed both the **untagged** and the **hadronic tagged** analyses

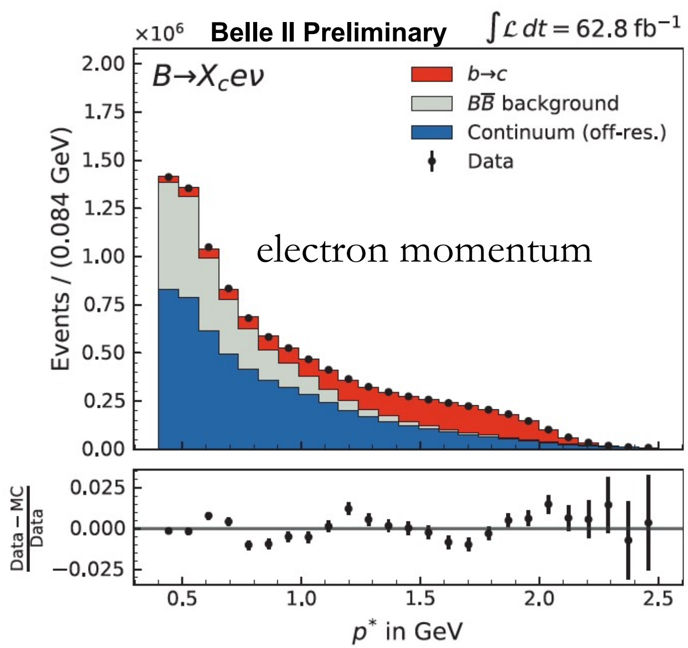
Untagged analysis

- Require one well identified lepton
- Exploit missing mass and momentum to reject backgrounds
- Measure the BF with a fit to p^*

$$\mathcal{B}(B \to X_c \ell \nu) = (9.75 \pm 0.03(stat) \pm 0.47(syst))\%$$

(average of muon and electron channels)

Main uncertainty is the knowledge of $B \to X_c \ell \nu$ branching fractions



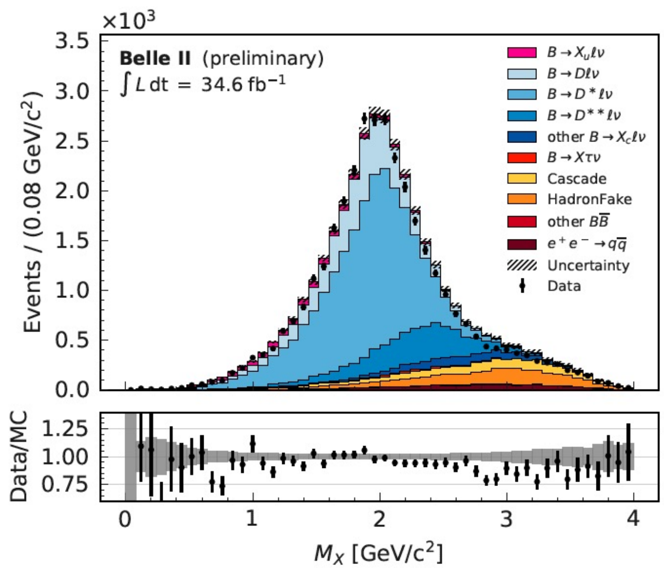
Hadronic mass moments from $B \to X_c \ell \nu$

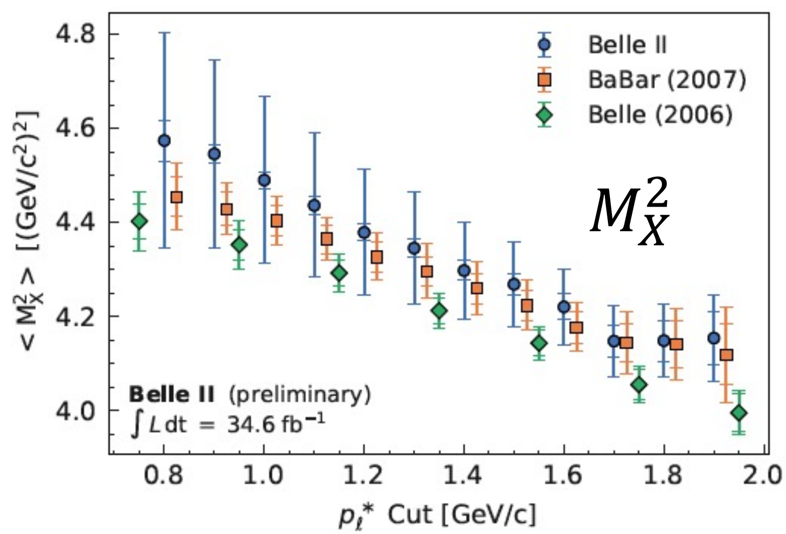
arXiv:2009.04493
Phys. Rev. D 75, 032005, 2007
BABAR-CONF-07/003,
arXiv:0707.2670

Tagged analysis

- Measure the hadronic mass moments

$$\langle M_X^n \rangle = \frac{\sum_i w_i(M_X) M_{X,\mathrm{calib}\,i}^{\;n}}{\sum_i w_i(M_X)} \times \mathcal{C}_{\mathrm{calib}} \times \mathcal{C}_{\mathrm{true}}$$



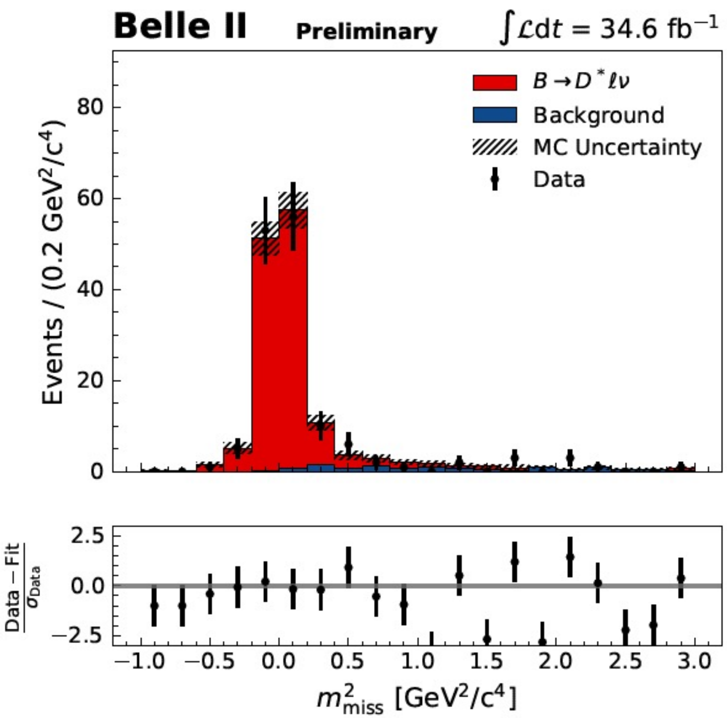


- Main systematics: knowledge of $B \to X_c \ell \nu$ composition and bias correction ($\mathcal{C}_{true}$)
- $|V_{cb}|$ determination from q^2 moments in progress

Exclusive $B \to D^{(*)}\ell\nu$

arXiv:2008.10299

- FEI hadronic tagged and untagged approaches explored
- Decays reconstructed in the channels $D^{*+} \to D^0\pi_s^+, D^0 \to K\pi$



$$m^2_{\text{miss}} = \left(p_{e^+e^-} - p_{B_{\text{tag}}} - p_{D^*} - p_\ell\right)^2$$

Tagged analysis ($\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$)

- Almost background free after tag and signal selection (D^*, D^0 invariant masses, $p_l^* > 1GeV$)

$$\mathcal{B}(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_l) = (4.51 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_s})\ \%$$

- Main systematics: tracking of π_s and MC modelling
- In agreement with world average

$$\mathscr{B}(\bar{B}^0 \to D^{*+}\ell\nu_\ell) = (5.05 \pm 0.14)\ \%$$

Exclusive $B \to D^{(*)}\ell\nu$

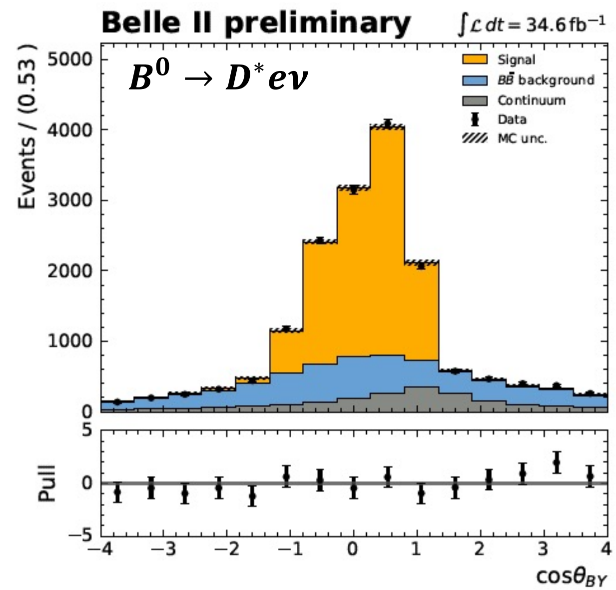
BELLE2-CONF-PH-2020-008

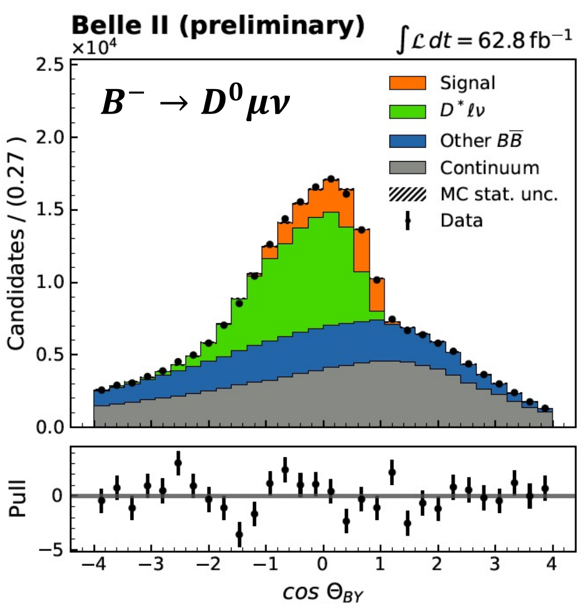
Untagged analysis

- θ_{BY} angle between the B flight direction and the direction of the $D^*\ell$ or $D^0\ell$ system (Y):

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

- Fit to $\cos\theta_{BY}$ distribution in data to measure the branching fraction





$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = (4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\pi_s})\,\%$$

$$\mathcal{B}(B^- \to D^0\ell^-\overline{\nu}_l) = (2.29 \pm 0.05_{\text{stat}} \pm 0.08_{\text{syst}})\%$$

(average of muon and electron channels)

consistent with the SM within 1σ

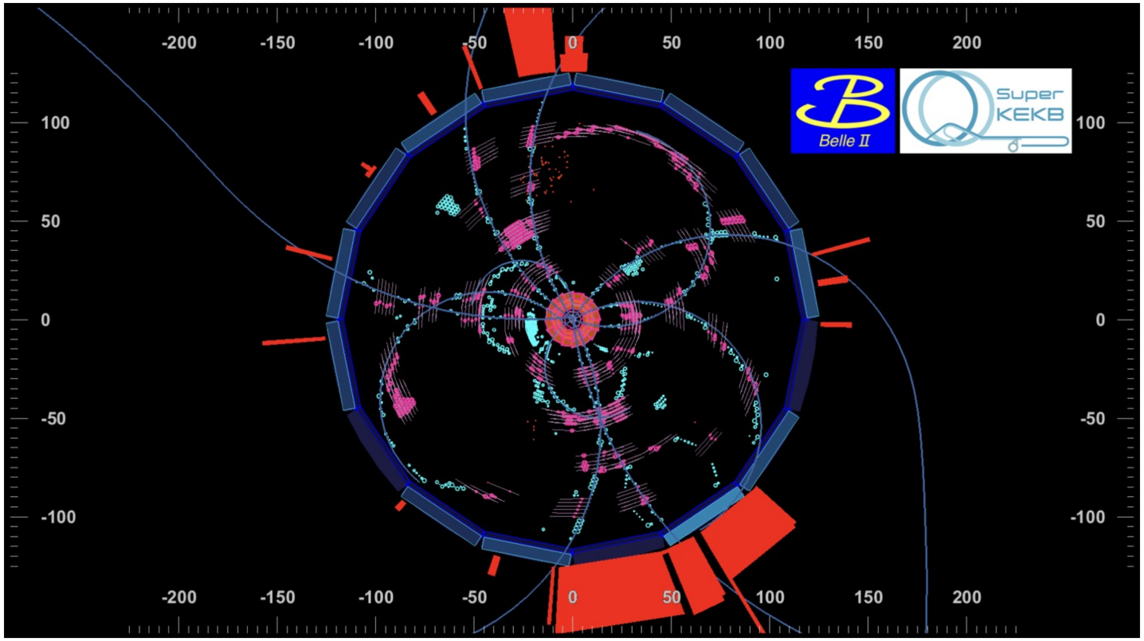
In progress: extraction of $|V_{cb}|$ from partial branching fractions in bins of hadron recoil parameter spectrum

Summary

- Within the next years Belle II will be able to address the **inclusive/exclusive $|V_{cb}|/|V_{ub}|$ tension** by precisely measuring semileptonic B decays with missing energy
- With about 1/4 of the current dataset, Belle II has been able to measure extensively inclusive and exclusive semileptonic B decays, adopting untagged approaches and exploiting the Full Event Interpretation algorithm for tagged analyses

Channel	Result presented in the talk	$\vert V_{xb}\vert$ measurement in progress
$B \to X_u \ell \nu$	3σ observation (untagged)	
$B^0 \to \pi^- \ell \nu$	$BF = (1.58 \pm 0.43_{stat} \pm 0.07_{syst}) \times 10^{-4}$ (FEI hadronic)	$\vert V_{ub}\vert$ from partial branching fraction in q^2 bins
$B \to X_c \ell \nu$	$BF = (9.75 \pm 0.03_{stat} \pm 0.47_{syst})\%$ (untagged) Hadronic mass moments (FEI hadronic)	$\vert V_{cb}\vert$ from q^2 spectral moments (novel approach)
$\bar{B}^0 \to D^{*+} \ell^- \nu$	$BF = (4.60 \pm 0.05_{stat} \pm 0.48_{syst})\%$ (untagged) $BF = (4.51 \pm 0.41_{stat} \pm 0.52_{syst})\%$ (FEI hadronic)	$\vert V_{cb}\vert$ from partial branching fractions in hadronic recoil parameter bins
$B^- \to D^0 \ell^- \nu$	$BF = (2.29 \pm 0.05_{stat} \pm 0.08_{syst})\%$ (untagged)	

Thanks !



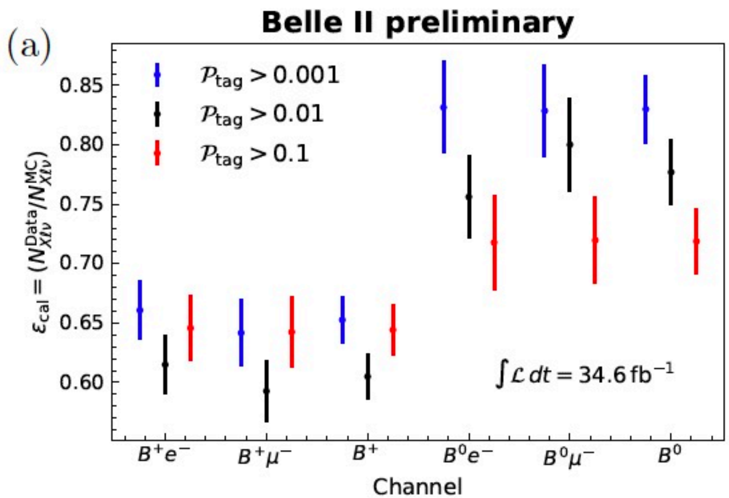
Summary talk on highlights from Belle II experiment by Carsten Niebuhr on Friday

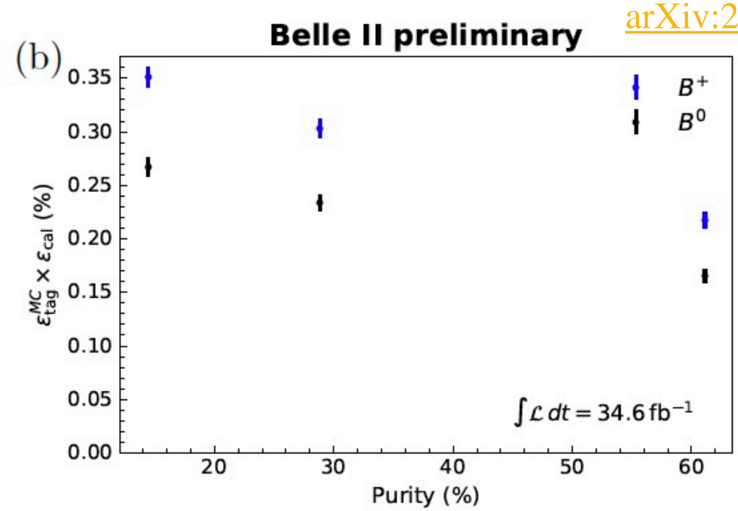
Backup

- FEI Calibration (17)
- B –> $\pi l\nu$ decay (18-19)
- B –> $X_c l\nu$ untagged (20)
- B –> $X_c l\nu$ hadronic mass moments(21-22)
- B –> $D^* l\nu$ and $|V_{cb}|$ (23)
- B –> $D^{(*)} l\nu$ (24)
- R(D),R(D*) (25)

FEI Calibration

arXiv:2008.06096v2





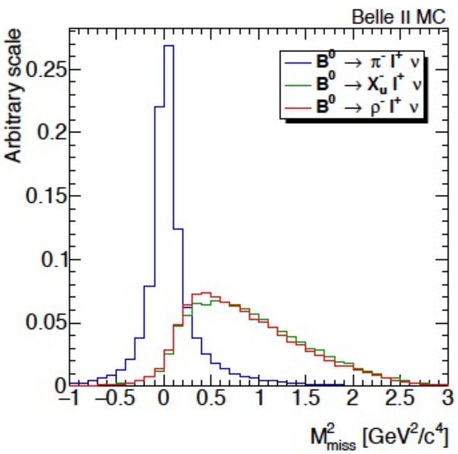
Channel	$N^{\rm MC}_{X\ell\nu}$	$N^{\rm Data}_{X\ell\nu}$	ϵ
Sig. Prob. > 0.001			
B^+e^-	$(4.46 \pm 0.11) \times 10^4$	$(2.94 \pm 0.08) \times 10^4$	0.66 ± 0.02
$B^+\mu^-$	$(4.78 \pm 0.11) \times 10^4$	$(3.10 \pm 0.10) \times 10^4$	0.65 ± 0.03
B^0e^-	$(1.75 \pm 0.04) \times 10^4$	$(1.46 \pm 0.07) \times 10^4$	0.83 ± 0.04
$B^0\mu^-$	$(1.85 \pm 0.06) \times 10^4$	$(1.54 \pm 0.05) \times 10^4$	0.83 ± 0.04
Sig. Prob. > 0.01			
B^+e^-	$(2.65 \pm 0.07) \times 10^4$	$(1.63 \pm 0.05) \times 10^4$	0.62 ± 0.02
$B^+\mu^-$	$(2.88 \pm 0.09) \times 10^4$	$(1.71 \pm 0.05) \times 10^4$	0.59 ± 0.03
B^0e^-	$(1.11 \pm 0.03) \times 10^4$	$(0.84 \pm 0.04) \times 10^4$	0.76 ± 0.04
$B^0\mu^-$	$(1.18 \pm 0.04) \times 10^4$	$(0.94 \pm 0.03) \times 10^4$	0.80 ± 0.04
Sig. Prob. > 0.1			
B^+e^-	$(1.10 \pm 0.03) \times 10^4$	$(0.71 \pm 0.03) \times 10^4$	0.65 ± 0.03
$B^+\mu^-$	$(1.21 \pm 0.04) \times 10^4$	$(0.78 \pm 0.04) \times 10^4$	0.64 ± 0.03
B^0e^-	$(0.60 \pm 0.02) \times 10^4$	$(0.43 \pm 0.02) \times 10^4$	0.72 ± 0.04
$B^0\mu^-$	$(0.64 \pm 0.02) \times 10^4$	$(0.46 \pm 0.02) \times 10^4$	0.72 ± 0.04

TABLE III. Results for $N_{X\ell\nu}$ as determined from the fits to data and simulation together with total uncertainties. The corresponding calibration factors computed from the ratio of these yields are also shown for each channel.

Channel	MC Stat.	$\mathcal{B}(B^{0/+} \to X\ell\nu)$	Tracking	$D\ell\nu$ FF	Lepton ID	$D^*\ell\nu$ FF	Fit Stat.	Fit Model
B^+e^-	0.39	2.09	0.91	0.06	0.76	0.41	0.93	2.67
$B^+\mu^-$	0.37	2.1	0.91	0.06	2.13	0.38	0.86	2.93
B^0e^-	0.62	2.1	0.91	0.07	0.73	0.43	1.22	3.72
$B^0\mu^-$	0.6	2.09	0.91	0.06	2.13	0.41	1.19	3.17

TABLE I. Itemisation of the percentage contribution from the sources of uncertainty on the calibration factors for the selection $\mathcal{P}_{\rm tag} > 0.001$.

Semileptonic decay: $B^0 \to \pi l \nu$



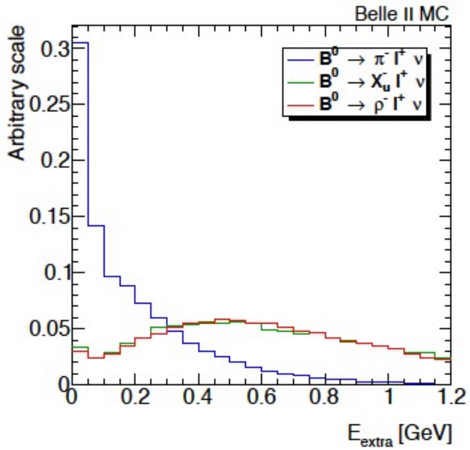


Table 53. Summary of systematic uncertainties on the branching fractions of $B^0 \to \pi^- \ell^+ \nu_\ell$ decays in hadronic tagged and untagged Belle analyses with 711 fb^{-1} [84] and 605 fb^{-1} [299] data samples, respectively. The estimated precision limit for some sources of systematic uncertainties is given in parentheses.

Source	Error (limit) [%]	
	Tagged	Untagged
Tracking efficiency	0.4	2.0
Pion identification	—	1.3
Lepton identification	1.0	2.4
Kaon veto	0.9	—
Continuum description	1.0	1.8
Tag calibration and $N_{B\bar{B}}$	4.5 (2.0)	2.0 (1.0)
$X_u \ell \nu$ cross-feed	0.9	0.5 (0.5)
$X_c \ell \nu$ background	—	0.2 (0.2)
Form factor shapes	1.1	1.0 (1.0)
Form factor background	—	0.4 (0.4)
Total	5.0	4.5
(reducible, irreducible)	(4.6, 2.0)	(4.2, 1.6)

LQCD: current is the world avergage by FLAG group

- 5 yr w/o EM: We assume a factor of 2 reduction of the lattice QCD uncertainty in the next five years and that the uncertainty of the EM correction is negligible (e.g. for processes insensitive to the EM correction).
- **5 yr w/ EM:** The lattice QCD uncertainty is reduced by a factor of 2, but we add in quadrature 1% uncertainty from the EM correction.
- 10 yr w/o EM: We assume a factor of 5 reduction of the lattice QCD uncertainty in the next ten years. It is also assumed that the EM correction will be under control and its uncertainty is negligible.
- **10 yr w/ EM:** We assume lattice QCD uncertainties reduced by a factor of 5, but add in quadrature 1% uncertainty from the EM correction.

$B \to \pi l \nu$

Source of systematic uncertainty	% of $\mathcal{B}$
f_{+0}	1.17
FEI calibration	3.45
$N_{B\bar{B}}$	1.60
Reconstruction efficiency ϵ	0.46
Tracking	1.60
Lepton ID	1.05
Total	4.44

TABLE IV: Sources of systematic uncertainties and their percentages of the total measured branching fraction.

Untagged $B \to X_c \ell \nu$

TABLE V. Estimated relative systematic uncertainty on the $B \to X_c \ell \nu$ branching fraction measurement in the two modes.

Contribution	Relative uncertainty [%]	
	Electron mode	Muon mode
Tracking	0.69	0.69
$N_{B\bar{B}}$	1.1	1.1
Lepton ID corrections	1.64	2.33
f_0/f_+, B lifetime	1.2	1.2
branching fractions	2.65	2.15
form factors	1.11	1.11
$B\bar{B}$ background model	0.24	0.34
Off-resonance data model	0.34	2.91
Sum	3.77	4.79

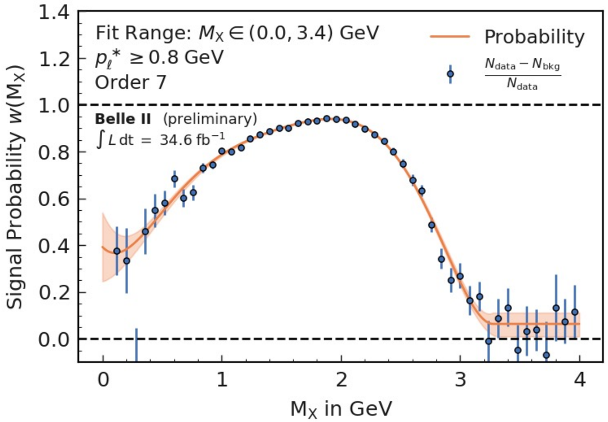
Hadronic mass moments from $B \to X_c \ell \nu$

arXiv:2009.04493

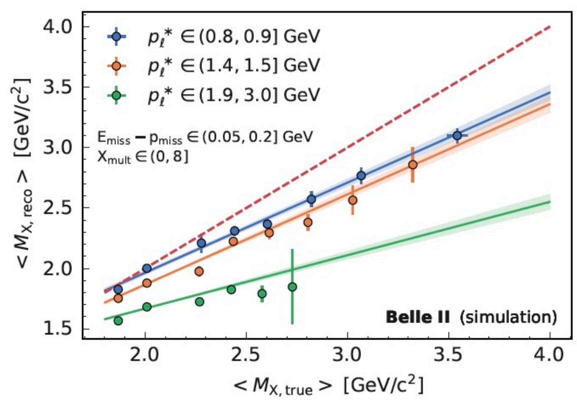
$$\langle M_X^n \rangle = \frac{\sum_i w_i(M_X) M_{X,\mathrm{calib}\,i}^{\;n}}{\sum_i w_i(M_X)} \times \mathcal{C}_{\mathrm{calib}} \times \mathcal{C}_{\mathrm{true}}$$

$$M_{X,\mathrm{calib}}^n = \frac{M_X^n - c(E_{\mathrm{miss}} - p_{\mathrm{miss}}, \mathrm{X}_{\mathrm{mult}}, p_\ell^*)}{m(E_{\mathrm{miss}} - p_{\mathrm{miss}}, \mathrm{X}_{\mathrm{mult}}, p_\ell^*)}$$

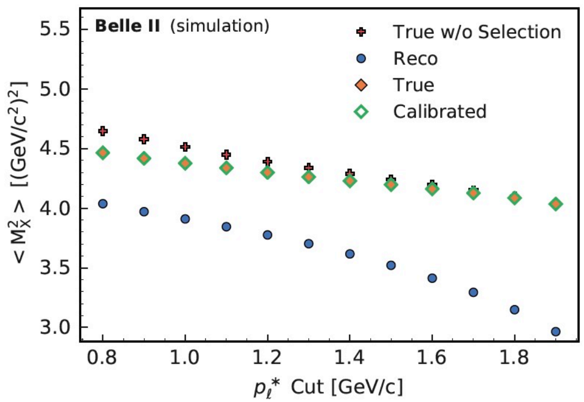
- w is the event-wise signal probability (obtained from background subtracted data)
- $\mathcal{C}_{calib}$ is a correction for the calibration bias and is obtained with the ratio of true generated and calibrated moments $\mathcal{C}_{\mathrm{calib}} = \langle M_{X,\mathrm{true}}^n \rangle / \langle M_{X,\mathrm{calib}}^n \rangle$
- $\mathcal{C}_{true}$ is a correction for reconstruction and detector acceptance and is the ratio of generated moments without and with event selection applied $\mathcal{C}_{\mathrm{true}} = \langle M_{X,\mathrm{true,signal}}^n \rangle / \langle M_{X,\mathrm{true}}^n \rangle$



w_i



$\mathcal{C}_{calib}$



$\mathcal{C}_{true}$

Hadronic mass moments from $B \to X_c \ell \nu$

arXiv:2009.04493

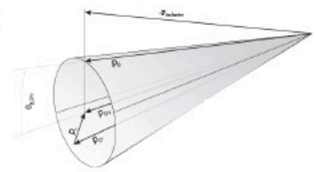
TABLE IV: Summary of statistical and systematic uncertainties for the measurement of $\langle M_X^2 \rangle$. All values are given in $(\mathrm{GeV}/c1)^2$ if not stated otherwise. The calculation of the uncertainties is described in Section 5 5.2.

p_ℓ^* Cut in GeV/c	0.8	0.9	1.0	1.1	1.2	1.3
$\langle M_X^2 \rangle$ in $(\mathrm{GeV}/c1)^2$	4.5743	4.5459	4.4902	4.4365	4.3790	4.3458
Stat. error (data)	0.0146	0.0151	0.0157	0.0165	0.0175	0.0189
Stat. error (signal prob.)	0.0405	0.0140	0.0092	0.0071	0.0017	0.0003
Stat. error (total)	0.0431	0.0206	0.0182	0.0180	0.0176	0.0189
Calib. function error	0.0473	0.0447	0.0427	0.0410	0.0393	0.0380
FEI eff..	0.0340	0.0201	0.0118	0.0060	0.0014	0.0005
PID eff.	0.0476	0.0210	0.0164	0.0109	0.0060	0.0046
$B \to X_u \ell \nu_\ell$ BF	0.0168	0.0157	0.0151	0.0150	0.0153	0.0160
Bias corr. (stat)	0.0115	0.0112	0.0110	0.0110	0.0112	0.0116
Bias corr. (model)	0.2099	0.1902	0.1687	0.1446	0.1254	0.1106
Sys. error (total)	0.2239	0.1985	0.1762	0.1519	0.1329	0.1187
Total error	0.2280	0.1996	0.1771	0.1530	0.1340	0.1202

p_ℓ^* Cut in GeV/c	1.4	1.5	1.6	1.7	1.8	1.9
$\langle M_X^2 \rangle$ in $(\mathrm{GeV}/c1)^2$	4.2980	4.2691	4.2209	4.1483	4.1493	4.1547
Stat. error (data)	0.0208	0.0235	0.0274	0.0337	0.0426	0.0553
Stat. error (signal prob.)	0.0011	0.0017	0.0026	0.0054	0.0088	0.0137
Stat. error (total)	0.0208	0.0236	0.0275	0.0341	0.0435	0.0570
Calib. function error	0.0366	0.0355	0.0339	0.0296	0.0310	0.0303
FEI eff..	0.0020	0.0038	0.0050	0.0065	0.0092	0.0134
PID eff.	0.0037	0.0032	0.0035	0.0041	0.0051	0.0070
$B \to X_u \ell \nu_\ell$ BF	0.0171	0.0200	0.0228	0.0283	0.0358	0.0503
Bias corr. (stat)	0.0123	0.0135	0.0154	0.0184	0.0230	0.0303
Bias corr. (model)	0.0920	0.0764	0.0621	0.0483	0.0328	0.0185
Sys. error (total)	0.1013	0.0878	0.0761	0.0664	0.0629	0.0703
Total error	0.1034	0.0909	0.0810	0.0746	0.0765	0.0905

$|V_{cb}|$ from D*lnu

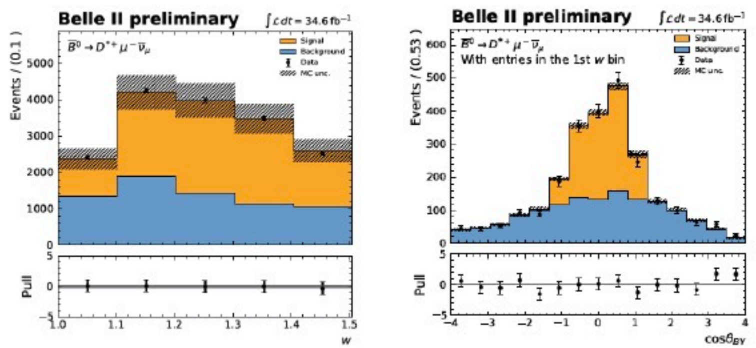
Examine hadronic recoil parameter spectrum



$$w = \frac{m_B^2 + m_{D^{*+}}^2 - q^2}{2 m_B m_{D^{*+}}}$$

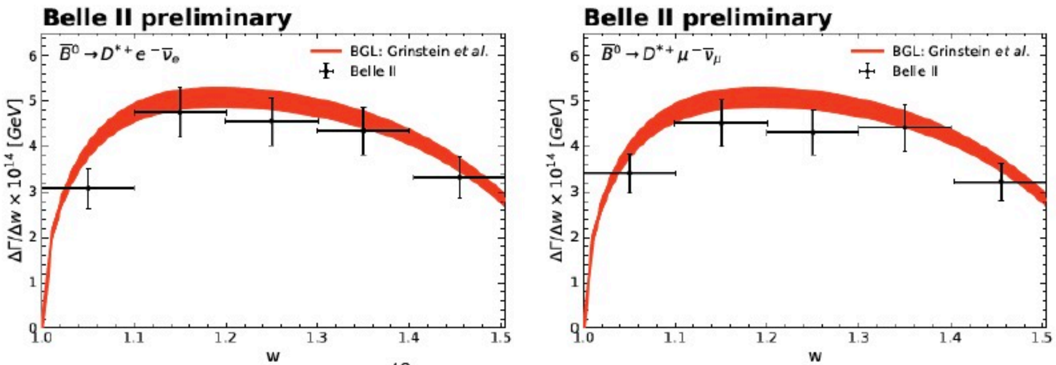
$$q^2 = (p_B - p_{D^{*+}})^2$$

Divide spectrum into 5 equal bins of 0.1008 between w=1 and w_{max}=1.504.



Unfold the *w* spectrum to compare with BGL.

Partial branching fractions in bins of *w* are a key step to determine $|V_{cb}|$.



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|Vcb| uncert.	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})
Exclusive	1.8%	1.4%

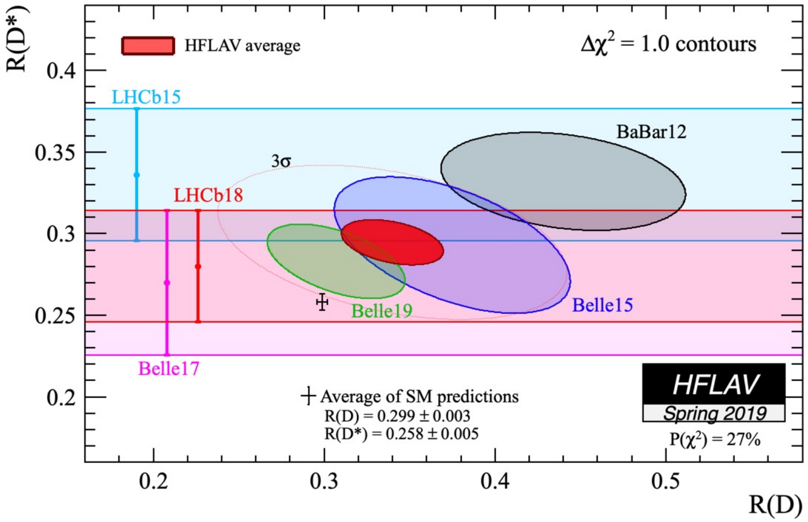
D*lnu and Dlnu

Source	Relative uncertainty (%)	
	$\overline{B}^0 \to D^{*+} e^- \overline{\nu}_e$	$\overline{B}^0 \to D^{*+} \mu^- \overline{\nu}_\mu$
PDF shape uncertainties	0.7	0.6
$\mathcal{B}(\bar{B} \to D^{**} \ell \bar{\nu})$	0.1	< 0.1
Lepton-ID	0.4	1.9
MC statistics, efficiency	< 0.1	< 0.1
Tracking of K, π, ℓ	2.4	2.4
Tracking of π_s	9.9	9.9
N_{B^0}	2.0	2.0
Charm branching fractions	1.1	1.1
$\overline{B}^0 \to D^{*+} \ell^- \overline{\nu}_l$ Form Factors	1.1	1.1
Total	10.5	10.7

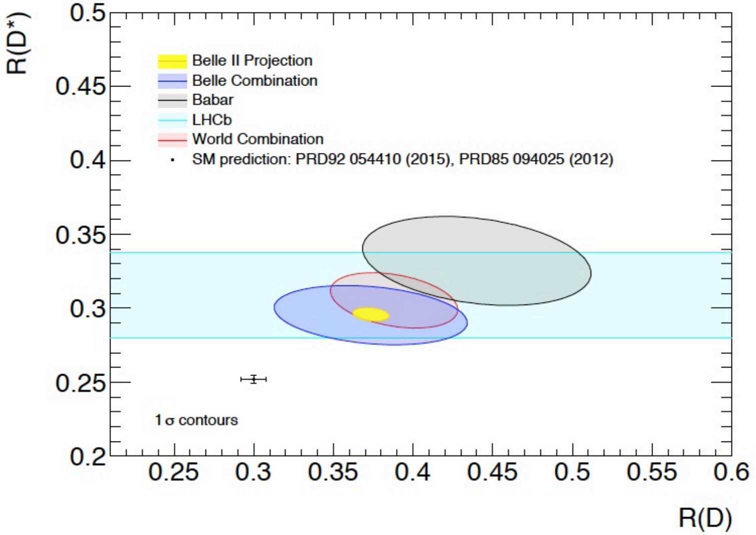
Source	Relative uncertainty [%]	
	$B^- \to D^0 e^- \overline{\nu}_e$	$B^- \to D^0 \mu^- \overline{\nu}_\mu$
$N_{B^\pm}$	1.61	1.61
$\mathcal{B}(D^0 \to K^- \pi^+)$	0.78	0.78
Tracking	2.07	2.07
Lepton identification	1.41	2.38
MC efficiency (statistical)	0.09	0.09
$D \ell \nu$ form-factor	0.15	0.15
$D^* \ell \nu$ form-factor	0.44	0.44
Continuum shape	0.37	0.37
Sum	3.14	3.68

R(D), R(D*)

World average



Belle II projection



	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

Main systematics: D** modelling, soft pions, yield of fake D* candidates. **Studies of $B \to D^{**}l\nu$ and $B \to D^{**}\tau\nu$ planned**