First Results on V_{ub} and V_{cb} with the Belle II experiment

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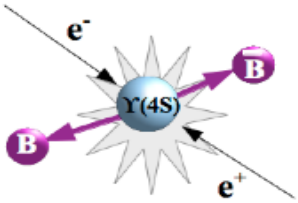
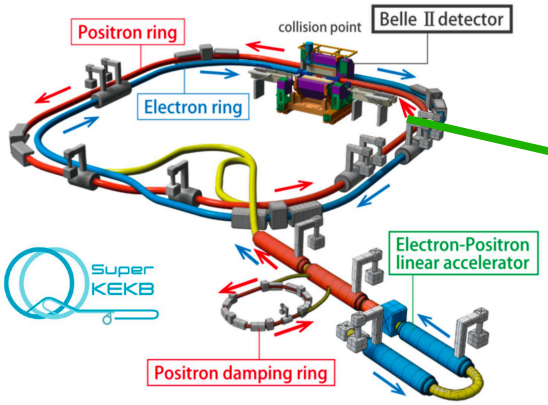
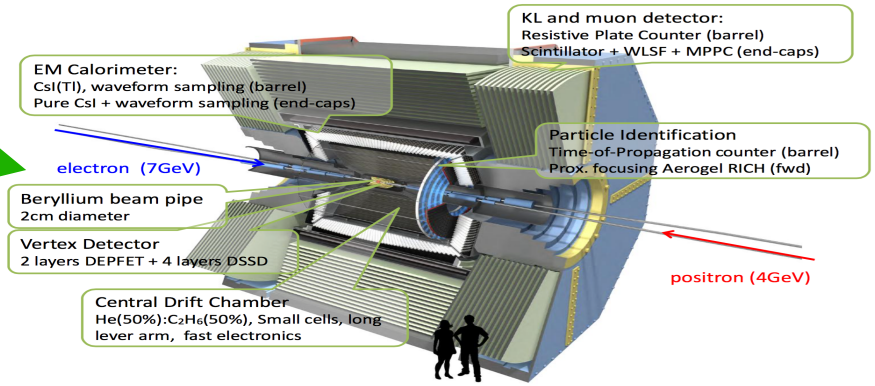
On behalf of the Belle II Collaboration

Belle II experiment

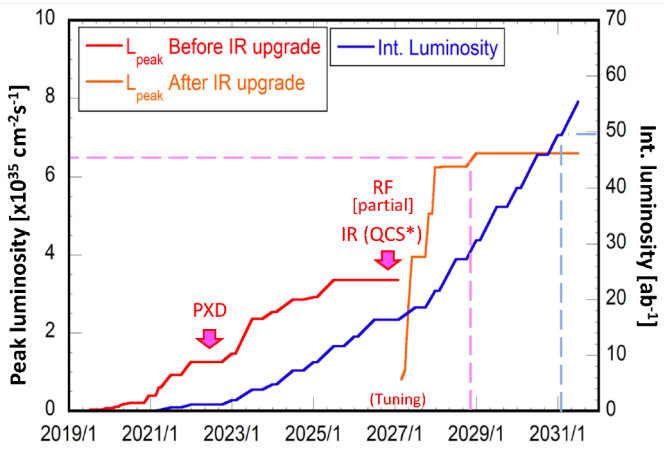
- A *B* meson factory in Tsukuba, Japan based on the SuperKEKB accelerator complex.
- Upgrade of its predecessor Belle and KEKB.







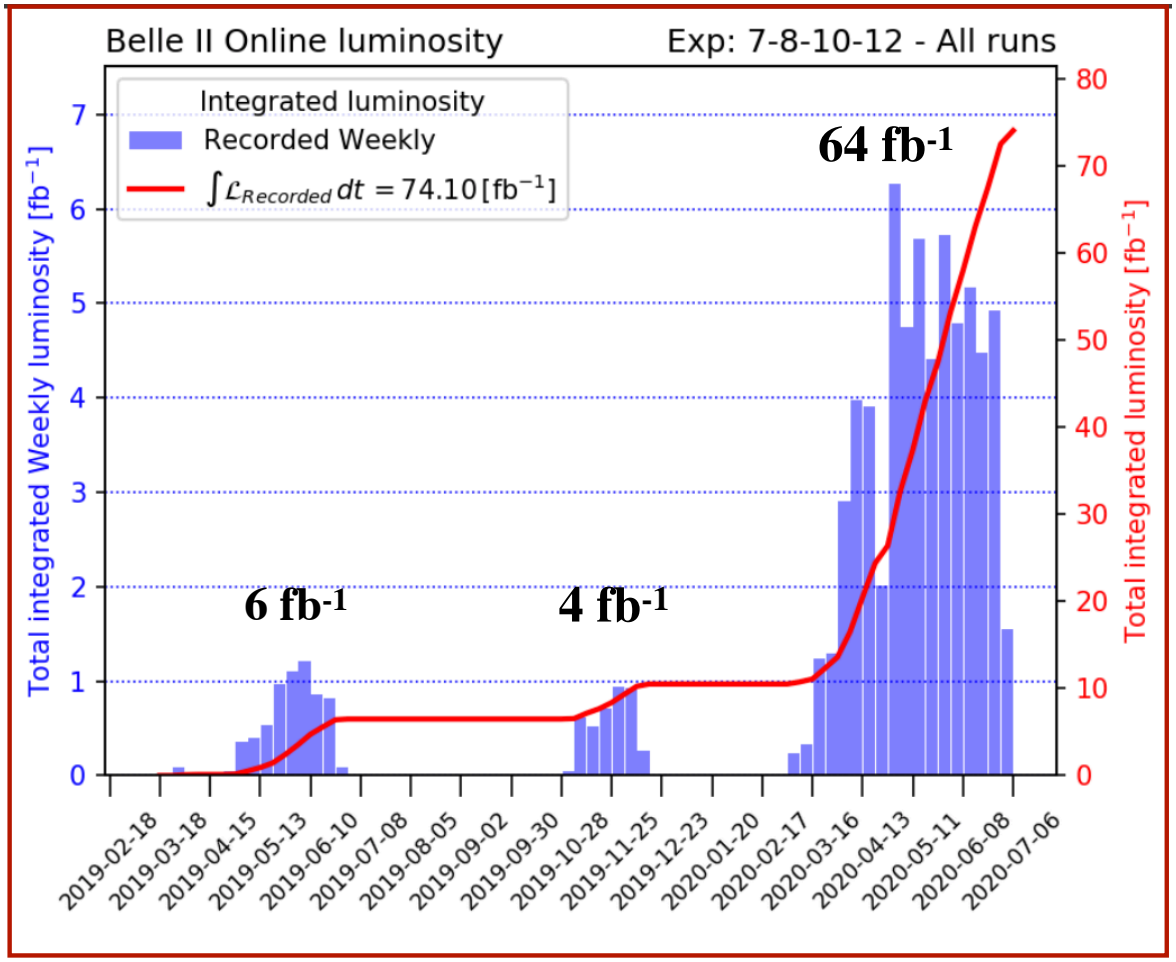
- Target luminosity: 50 ab^{-1}, 50 x the Belle dataset.
  - a (Super) B-factory (~1.1 x 10^9 BB pairs per ab-1)
  - a (Super) charm factory (~1.3 x 10^9 cc pairs per ab-
  - a (Super) τ factory (~0.9 x 10^9 ττ pairs per ab-1)



- B-physics:
  - CPV: B→ J/ψ K_S^0, ϕK^0
  - Rare B decays: B→Kνν, $K\tau^+\tau^-$
  - Semi-leptonic B decays
- Lepton flavour violation:
  - τ→μγ
- Charm Physics: D-mixing

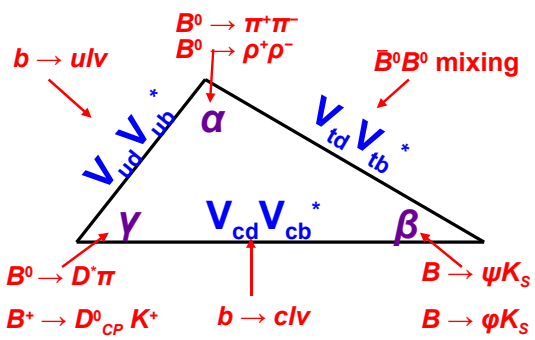
Current Belle II dataset

Results presented today with 34.6 fb^{-1} of reprocessed data.

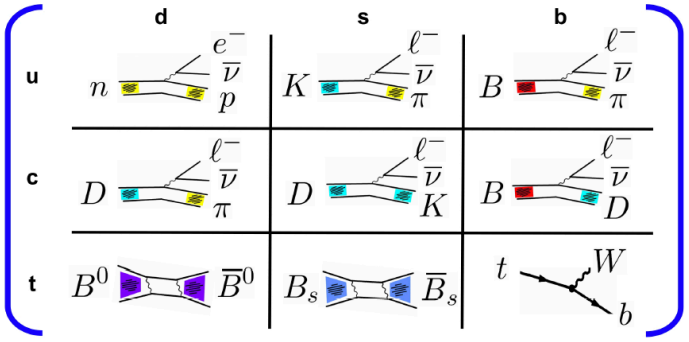


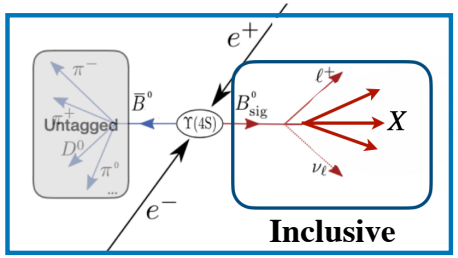
V_{cb} and V_{ub}

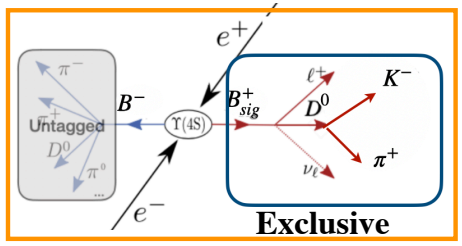
Precision measurements of CKM matrix at the core of the Belle II physics program.

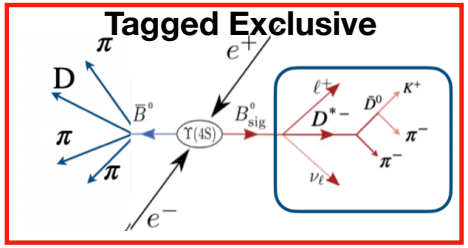


$V =$

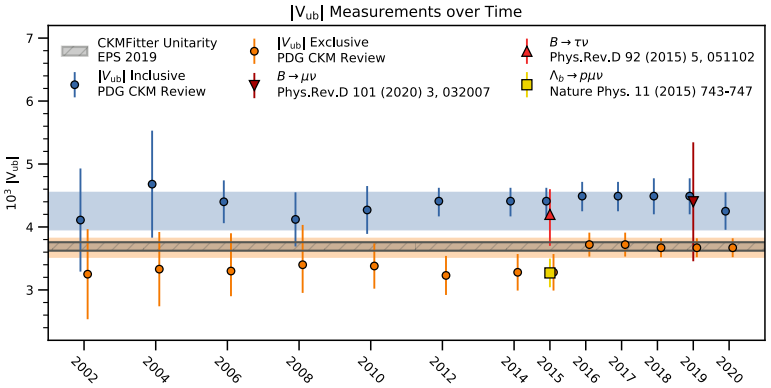


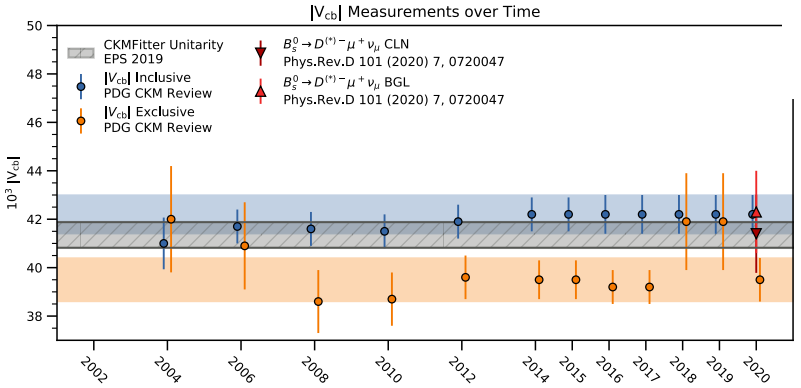






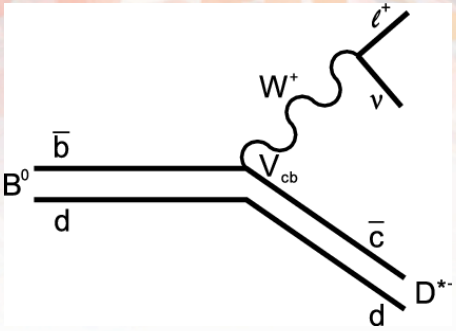
V_{ub} and V_{cb} mainly from semileptonic decays of B mesons





Tension between exclusive and inclusive V_{ub} and V_{cb} measurements along with other related B -anomalies .

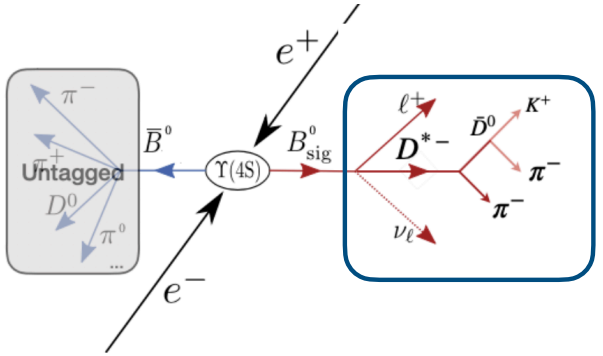
Exclusive $B^0 \to D^{*+} \ell \nu_\ell$



Exclusive $\bar{B}^0 \to D^{*+}\ell\nu_\ell$

Flagship decay for exclusive V_{cb} measurements!

Reconstruct $D^0 \to K^-\pi^+$ and $D^{*+} \to D^0\pi_s$.
Identify lepton using PID algorithms.
Suppress $e^+e^- \to q\bar{q}$ events using p_{D^*}<2.4 GeV/c and R_2 <0.3.



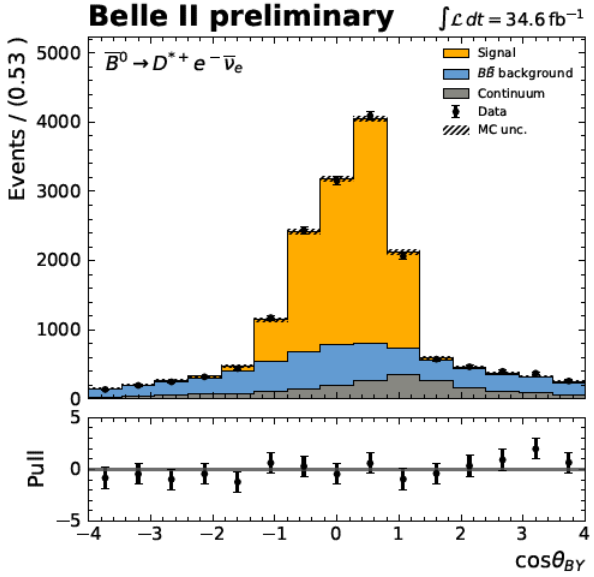
$$cos\theta_{BY} = \frac{2E_B^* E_Y^* - m_B^2 - m_Y^2}{2|p_B^*||p_Y^*|}$$

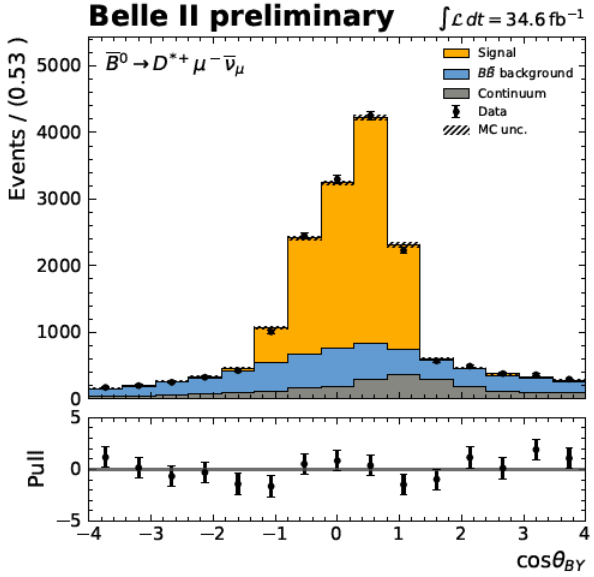
Extract signal yield with a fit to $cos\theta_{BY}$.

$\mathcal{B}(\bar{B}^0 \to D^{*+}\ell\bar{\nu}) = (4.60 \pm 0.05(stat) \pm 0.18(sys) \pm 0.45\pi_s)\,\%$

Compatible with current world average!

$$R_{e\mu} = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}e^-\bar{\nu}_e)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)} = 0.99 \pm 0.03\,,$$

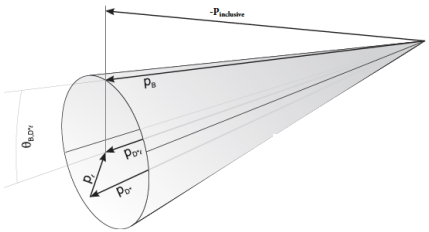




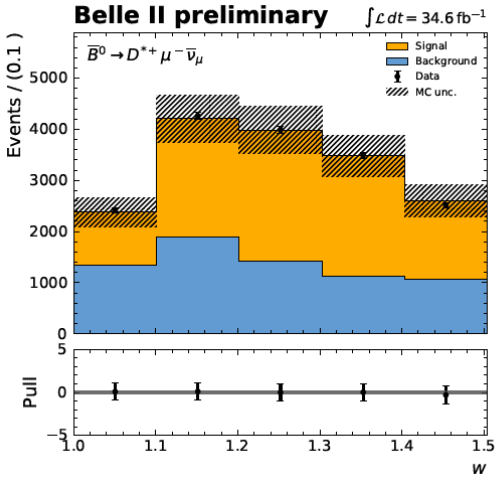
$\bar{B}^0 \to D^{*+}\ell\nu_\ell$

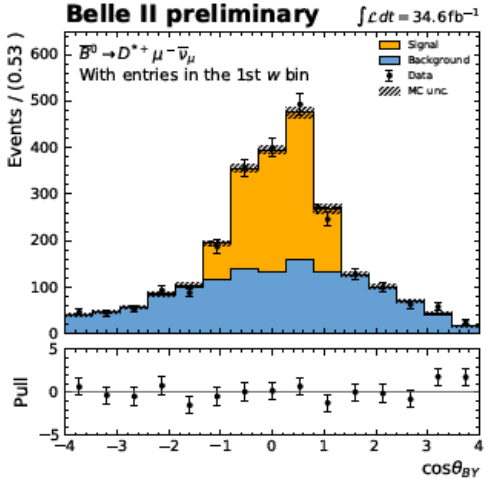
Examine hadronic recoil parameter spectrum

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



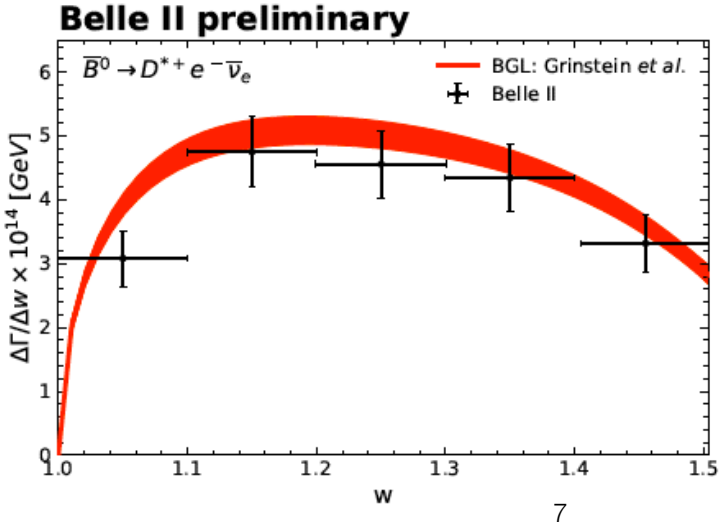
Divide spectrum into 5 equal bins of 0.1008 between w=1 and w_{max}=1.504.

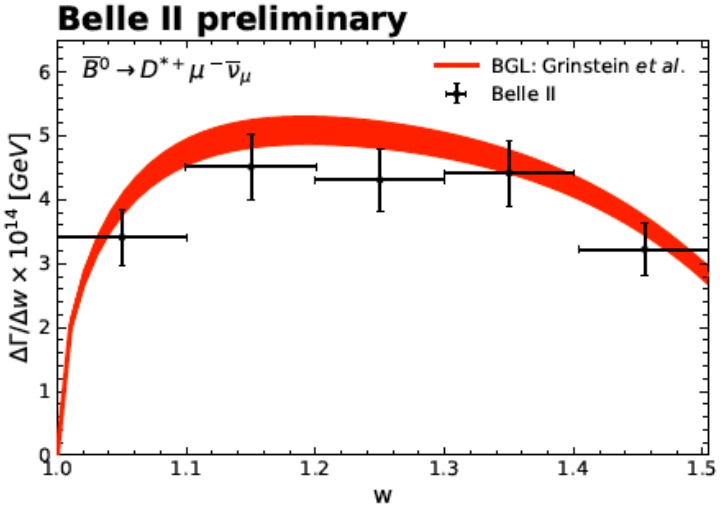




Unfold the *w* spectrum to compare with BGL.

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





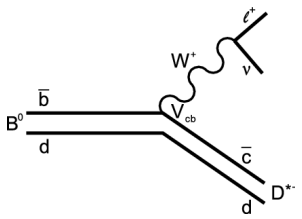
Phys. Lett. B 771, 359 (2017)

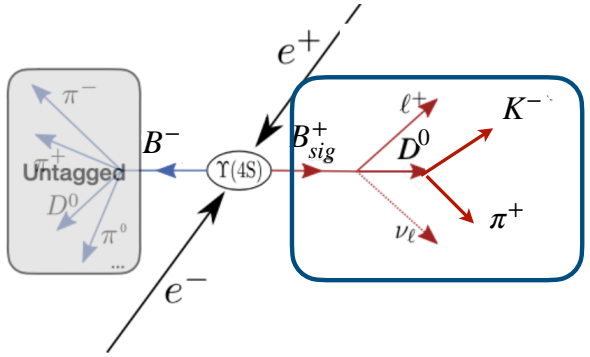
$B^- \to D^0 \ell \nu_\ell$

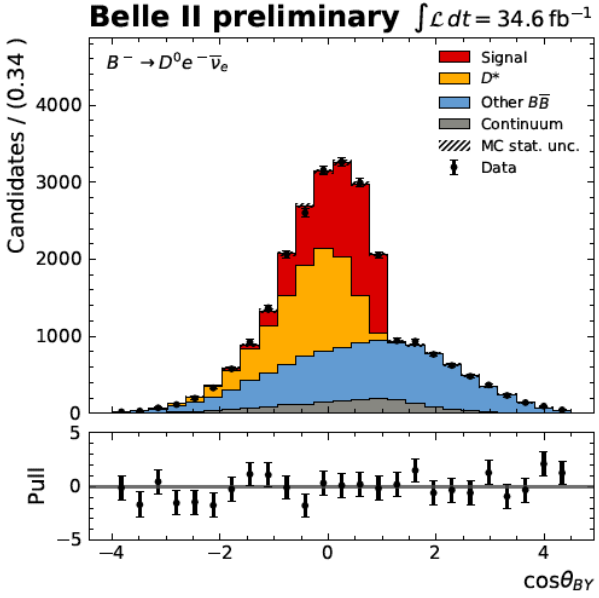
Flagship decay for exclusive V_{cb} measurements!

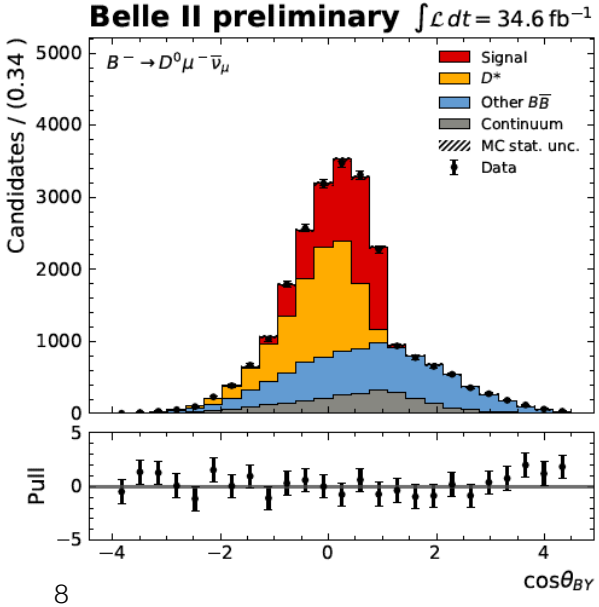
Reconstruct $D^0 \to K^- \pi^+$.
Identify lepton using PID algorithms.
Suppress $e^+e^- \to q\bar{q}$ events using p_{D^*}<2.4 GeV/c and R_2 <0.3

Apply D* veto by combining D candidates with:
π_s^+ and exclude $\Delta m \in$ [0.144,0.148] GeV/c²
γ, π_s^0 and exclude $\Delta m \in$ [0.141,0.146] GeV/c²



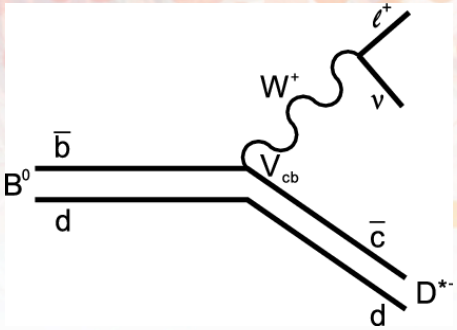






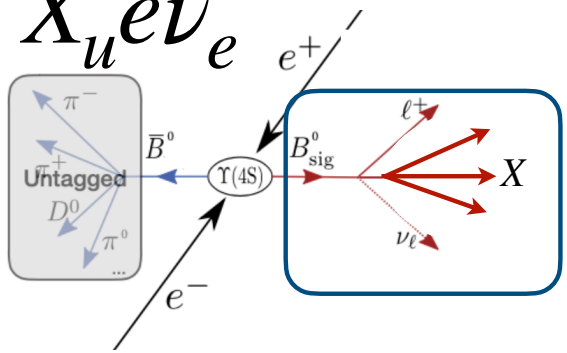
First measurement at Belle II !

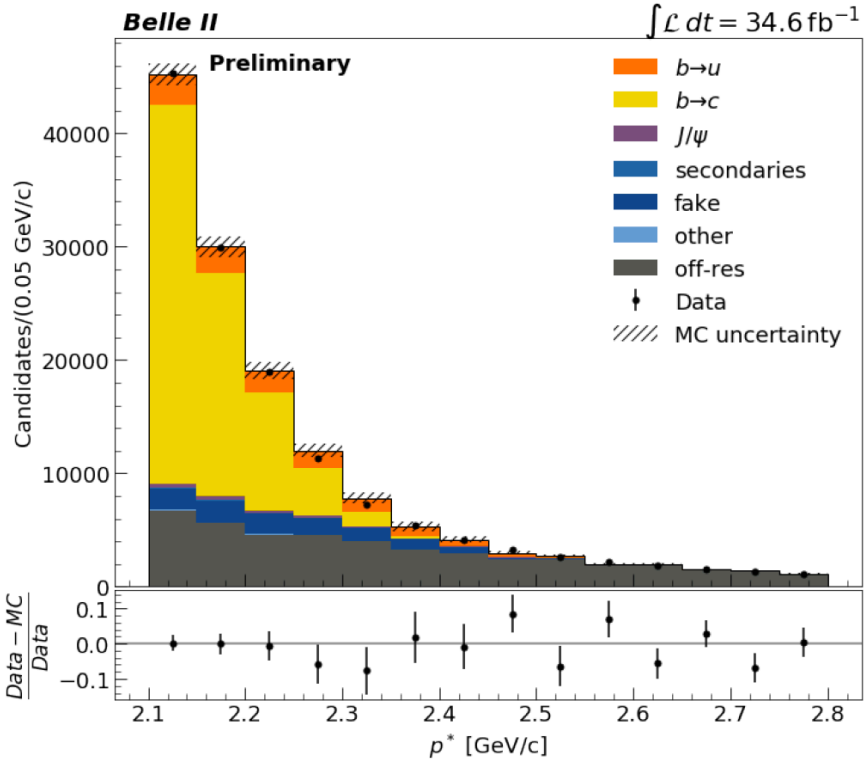
Inclusive $B \to X \ell \nu_\ell$

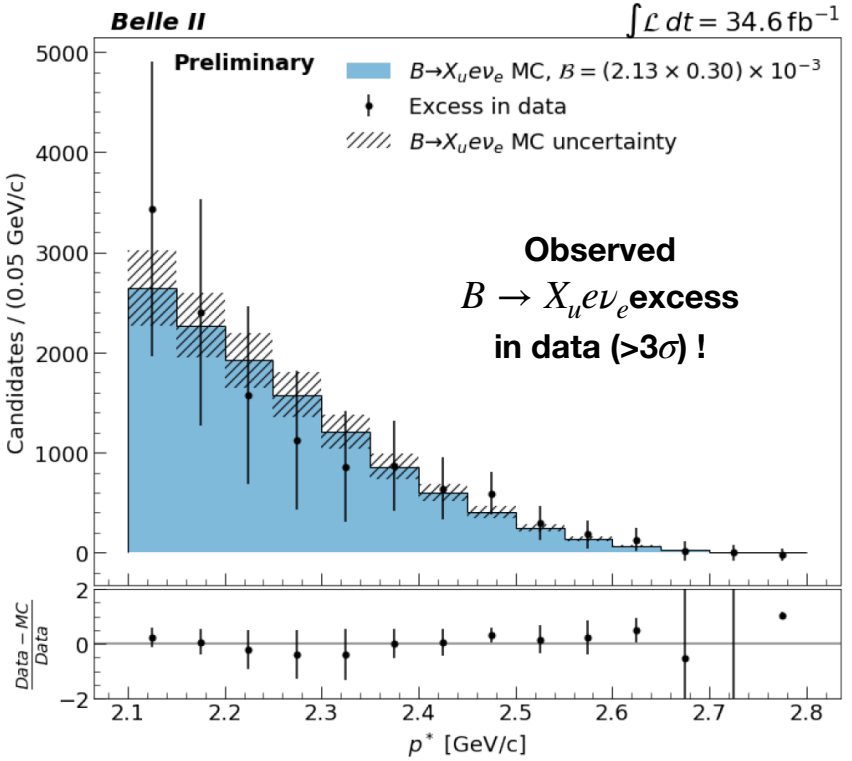


Inclusive $B \to X_u e \bar{\nu}_e$

- Measurement of V_{ub} in the lepton endpoint momentum spectrum.
  - Identify one lepton in the event using PID algorithms.
  - Suppress continuum using MVA trained with event shape variables.
  - Subtract continuum and other $B\bar{B}$ contributions.





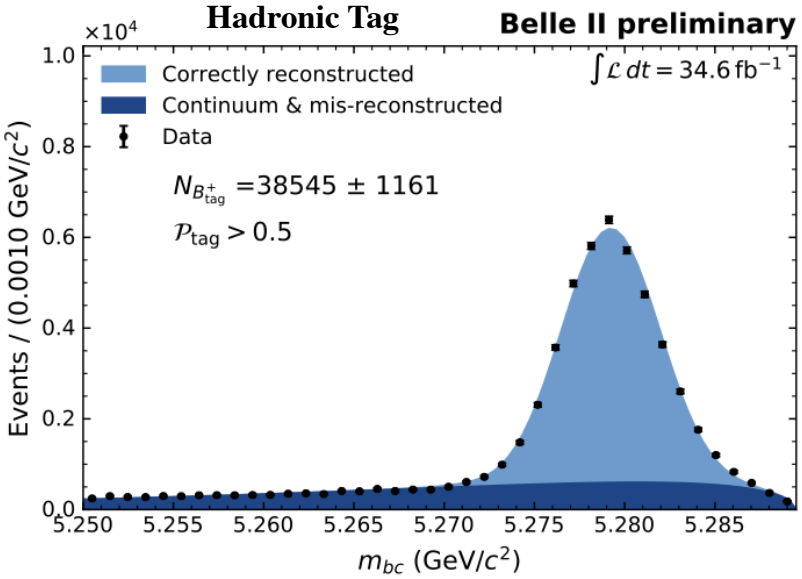


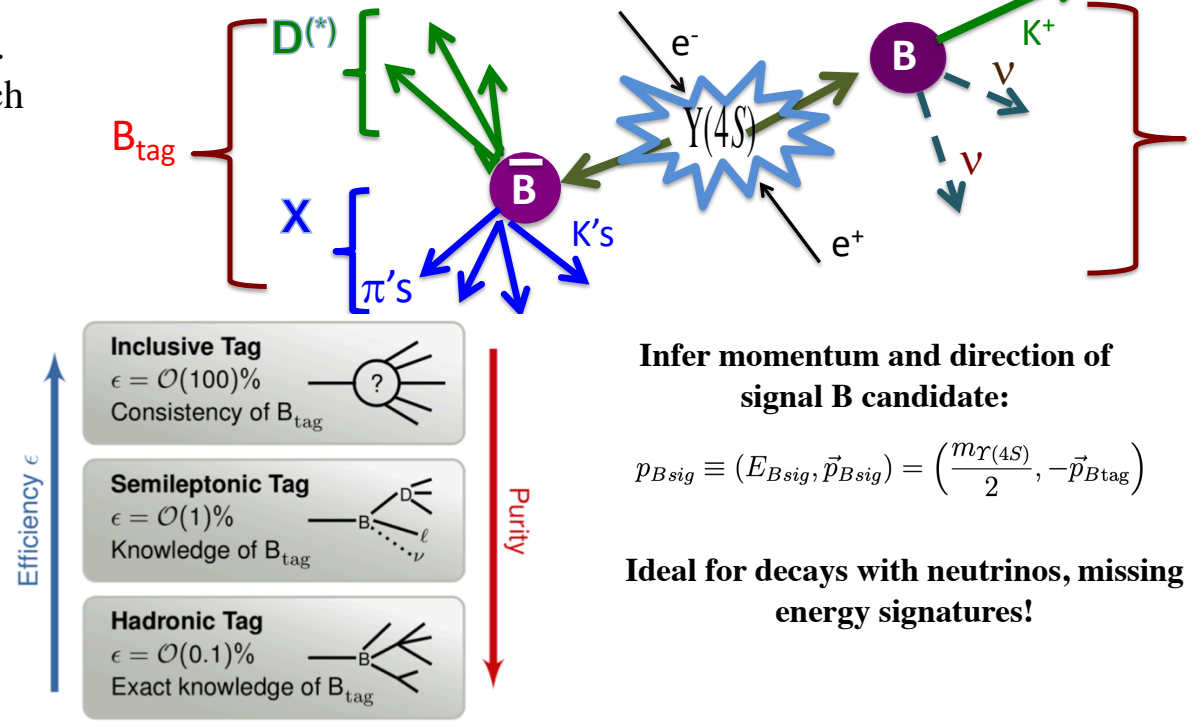
Tagged Exclusive $B^0 \to \pi^+ \ell \nu_\ell$

FEI reconstruction

See talk by William Sutcliffe

- Exclusive reconstruction of hadronic B modes.
- Multivariate algorithm with hierarchal approach





Infer momentum and direction of signal B candidate:

$$p_{Bsig} \equiv (E_{Bsig}, \vec{p}_{Bsig}) = \left(\frac{m_{\Upsilon(4S)}}{2}, -\vec{p}_{B\text{tag}}\right)$$

Ideal for decays with neutrinos, missing energy signatures!

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

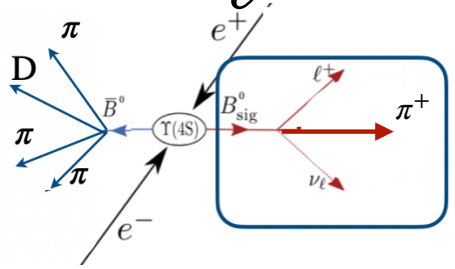
MC Tagging efficiency at 10% purity!

Tagged Exclusive $B^0 \to \pi^- \ell \nu_\ell$

- FEI hadronic tagging to measure $\mathcal{B}(B^0 \to \pi^- \ell \nu)$ with
- Identify oppositely charged lepton, $p_e > 0.3$and $p_\mu > 0.6$ GeV/c, and pion using PID algorithms.
- Suppress continuum using FoxWolfram moment R2.
- Apply E_{miss}>0.3 and $E_{residual}$<1.0 GeV.

$$p_{miss} \equiv (E_{miss}, \vec{p}_{miss}) = p_{Bsig} - p_Y$$

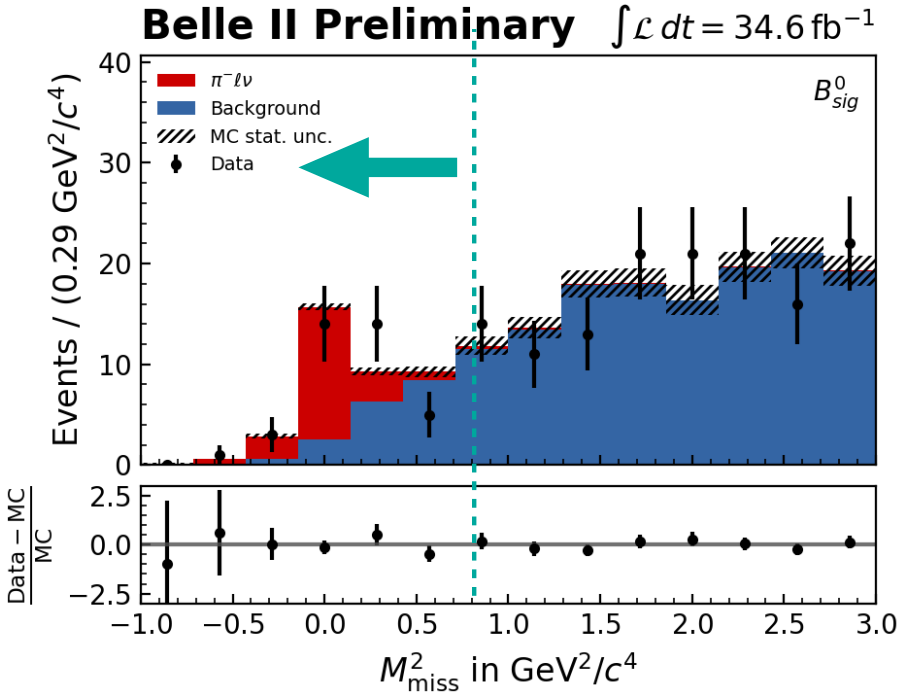
- Analysis performed blinded in the signal region $M^2_{miss} \leq 1$ GeV²/c⁴.



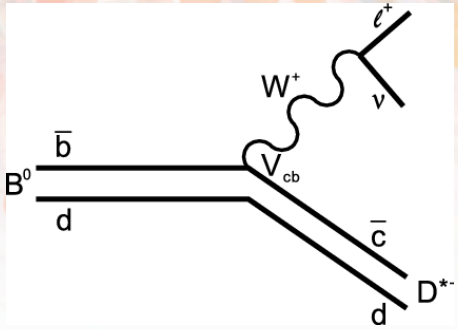
$N_{\text{sig}}^{\text{data}}$	20.79 ± 5.68
f_{+0}	1.058 ± 0.024
CF_{FEI}	0.8301 ± 0.0286
$N_{B\bar{B}}$	$(37.711 \pm 0.602) \times 10^6$
ϵ	$(0.216 \pm 0.001)\%$
$\mathcal{B}(B^0 \to \pi^- \ell \nu)$	$(1.58 \pm 0.43_{\text{stat}} \pm 0.07_{\text{sys}}) \times 10^{-4}$

In agreement with world average!

Observed signal significance: 5.69 σ



Tagged Exclusive $B^0 \to D^{*+}\ell\nu_\ell$



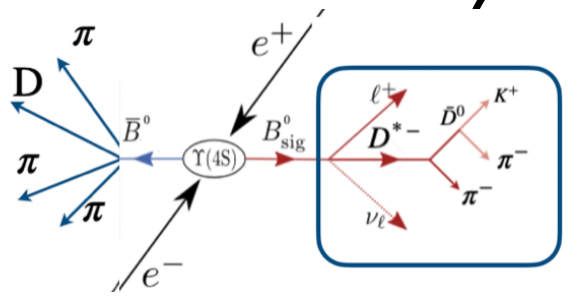
Tagged Exclusive $B^0 \to D^{*+}\ell\nu_\ell$

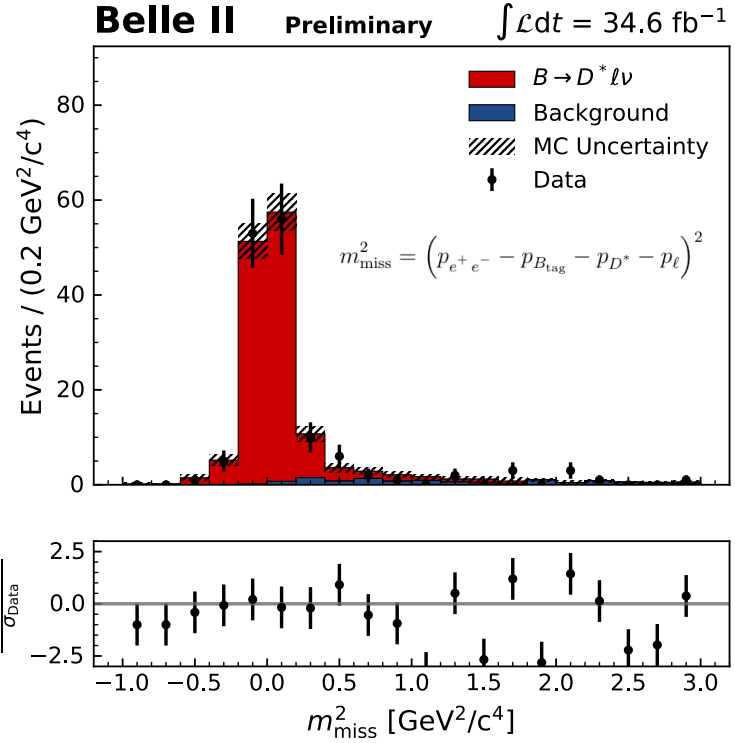
- Identify B_{tag} candidate with M_{bc}>5.27 GeV/c² $-0.15 < \Delta E < 0.1$ and FEI signal probability >0.001.
- Reconstruct D^0 meson from oppositely charged tracks with $1.858 < M_D < 1.878$ GeV/c² .
- Combine D^0 and π_s to form D^{*+} with $0.143 < \Delta M < 0.148$ GeV/c²
- Identify high momentum lepton with $p_l^* > 1.0$ GeV and combine with D*+ .
- Apply E_{miss}>0.3 GeV and determine M^2_{miss}
- Extract signal yield using a fit to signal + background:

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

In agreement with world average!

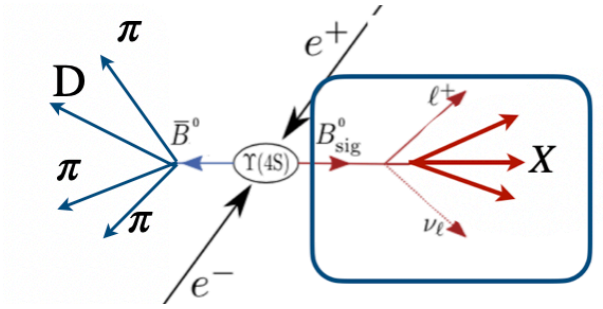
$$\mathcal{B}(\bar{B}^0 \to D^{*+}\ell\nu_\ell) = (5.05 \pm 0.14)\,\%$$

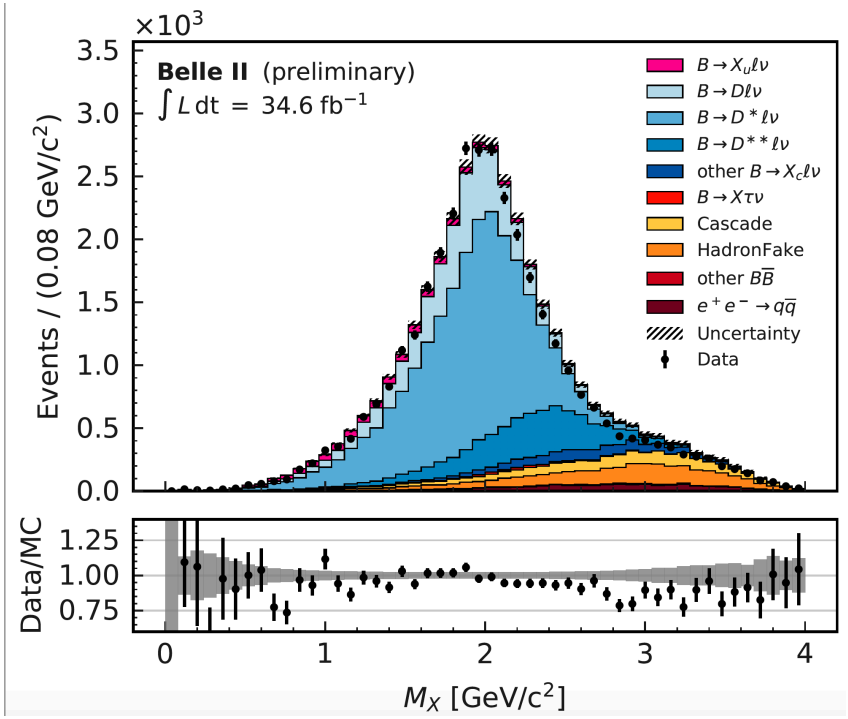




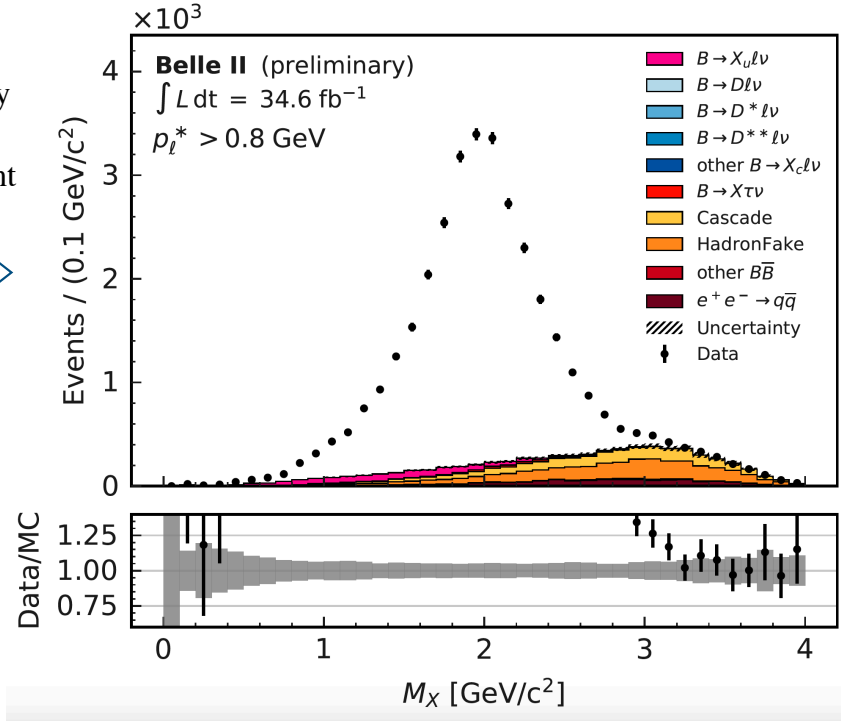
Hadronic Mass Moments of $B \to X_c \ell \nu_\ell$

- Moments used to determine V_{cb} and the mass of the b quark in HQE.
- Use hadronic FEI tagging and identify one lepton with $p^*_l > 0.8$ GeV/c and PID likelihood >0.9.
- 6 signal channels $B^0\ell^\pm, B^+\ell^-$ and two control $B^+\ell^+$ to estimate N^i_{bkg}
- Identify X_c system using remaining tracks and clusters in the $\Upsilon(4S)$ rest of event.
- Suppress continuum and require E_{miss} and p_{miss}>0.5 GeV.



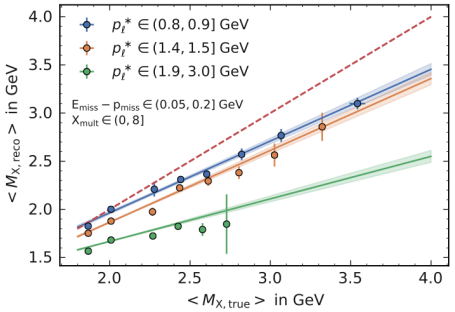


Subtract background by assigning a signal probability to each event



Hadronic Mass Moments of $B \to X_c \ell \nu_\ell$

Determine calibration functions, in bins of p_l, to correct for experimental effects on M_X^n .



$$M^n_{\mathrm{X,calib}} = \frac{M^n_{\mathrm{X}} - c(E_{\mathrm{miss}} - p_{\mathrm{miss}}, \mathrm{X_{mult}}, p^*_\ell)}{m(E_{\mathrm{miss}} - p_{\mathrm{miss}}, \mathrm{X_{mult}}, p^*_\ell)}$$

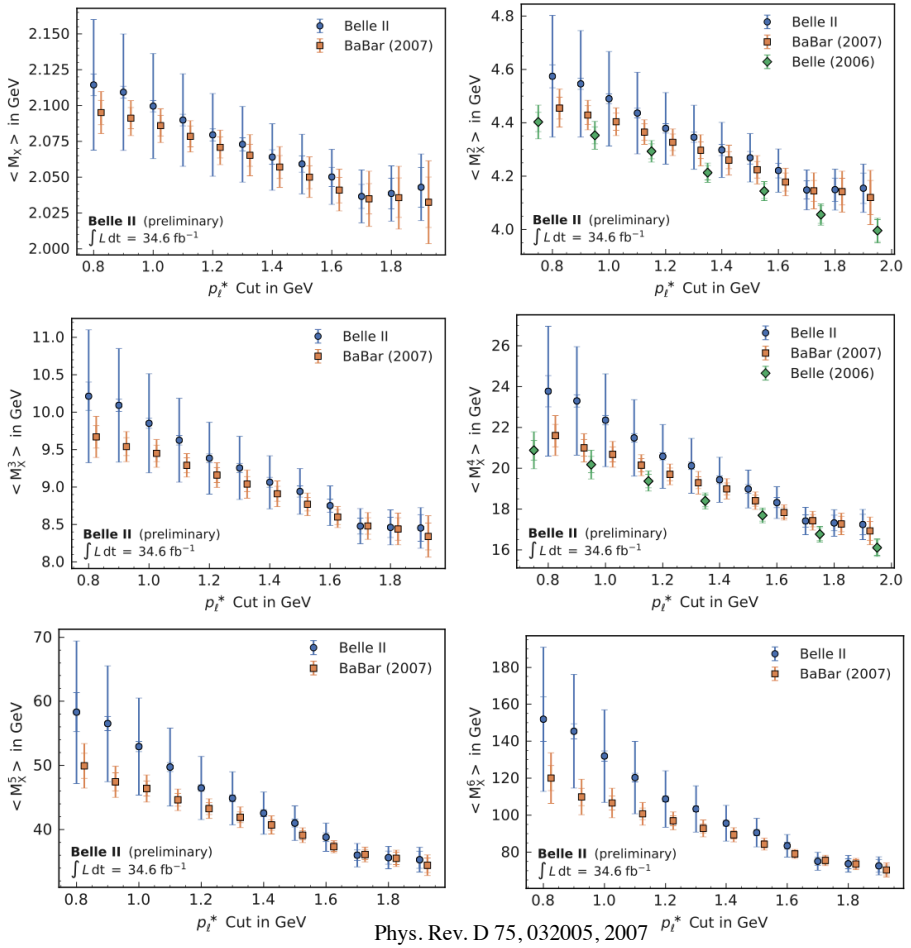
Extract hadronic mass moments as a weighted average using the following:

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

Reconstruction bias

Calibration Bias

In agreement with previous measurements!



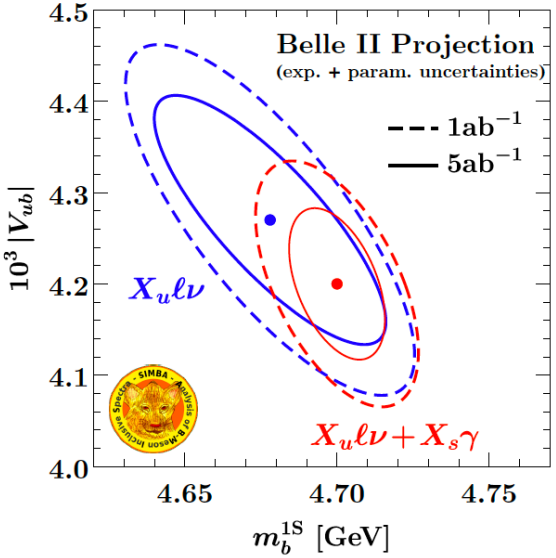
Phys. Rev. D 75, 032005, 2007
BABAR-CONF-07/003 arXiv:0707.2670

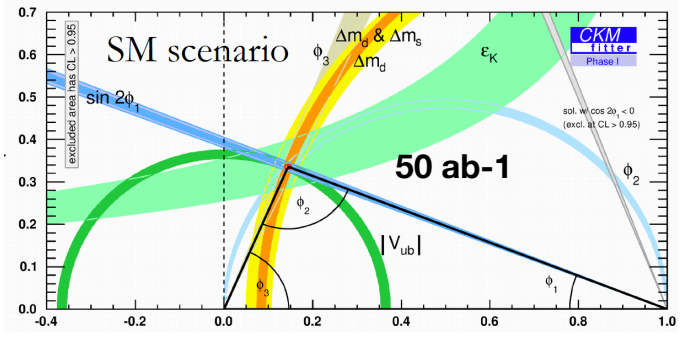
Towards higher luminosities

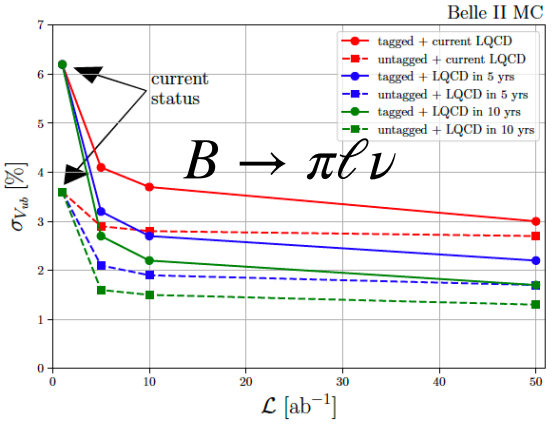
Future prospects

Expect significant improvement with higher luminosities and better understanding of the detector's performance.

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%







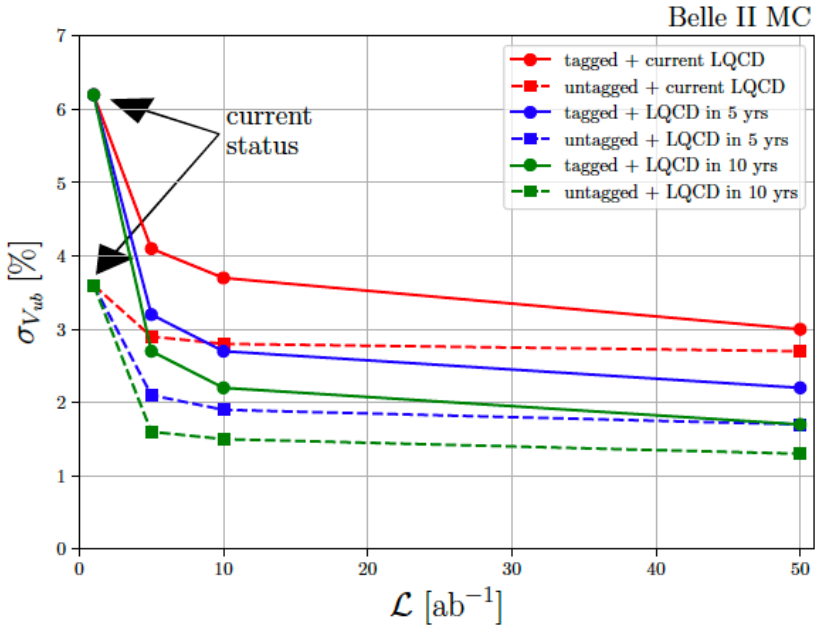
Summary

- First measurements for tagged and untagged $\mathscr{B}(\bar{B}^0 \to D^{*+}\ell\bar{\nu}_\ell)$ at the Belle II experiment:
  - Untagged: $\mathscr{B}(\bar{B^0} \to D^{*+}\ell\bar{\nu}_\ell) = (4.60 \pm 0.05(stat) \pm 0.18(sys) \pm 0.45\pi_s)\,\%$
  - Tagged:$\mathscr{B}(\bar{B}^0 \to D^{*+}\ell\bar{\nu}_\ell) = (4.51 \pm 0.41_{stat} \pm 0.27_{syst} \pm 0.45_{\pi_s})\,\%$
- First measurement of hadronic tagged $\mathscr{B}(B^0 \to \pi^-\ell\bar{\nu}_\ell) = (1.58 \pm 0.43_{stat} \pm 0.07_{sys}) \times 10^{-4}$ and evidence of non-zero V_{ub} in the lepton momentum endpoint in $\mathscr{B}(B \to X_u\ell\nu)$ at the Belle II experiment.
- First measurement of the hadronic moments in $\mathscr{B}(B \to X_c\ell\nu)$ at the Belle II experiment.
- Agreement with world average and previous experimental measurements .

More to come with increased luminosity!

BACK UP

$B^0 \to \pi^+ \ell \nu_\ell$

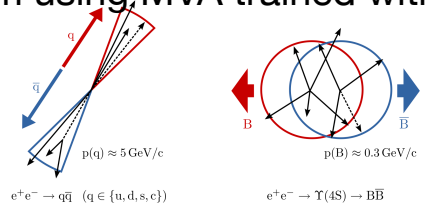


B to X l nu MC modeling

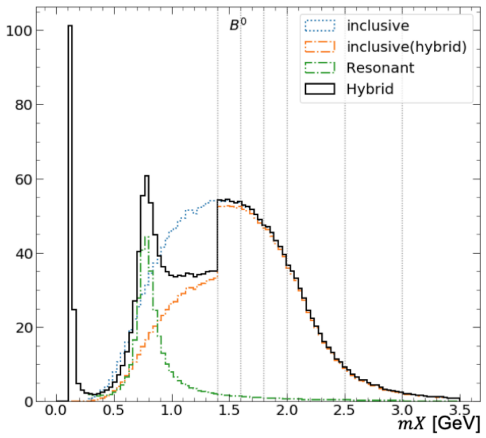
$\mathcal{B}$	Value B^+	Value B^0
$B \to D\,\ell^+\,\nu_\ell$	$(2.3 \pm 0.1) \times 10^{-2}$	$(2.1 \pm 0.1) \times 10^{-2}$
$B \to D^*\,\ell^+\,\nu_\ell$	$(5.5 \pm 0.1) \times 10^{-2}$	$(5.1 \pm 0.1) \times 10^{-2}$
$B \to D_1\,\ell^+\,\nu_\ell$ $(\hookrightarrow D^*\pi)$	$(4.5 \pm 0.3) \times 10^{-3}$	$(4.2 \pm 0.3) \times 10^{-3}$
$B \to D_1\,\ell^+\,\nu_\ell$ $(\hookrightarrow D\pi\pi)$	$(3.2 \pm 1.0) \times 10^{-3}$	$(2.8 \pm 0.9) \times 10^{-3}$
$B \to D_2^*\,\ell^+\,\nu_\ell$ $(\hookrightarrow D^*\pi)$	$(1.5 \pm 0.1) \times 10^{-3}$	$(1.4 \pm 0.1) \times 10^{-3}$
$B \to D_2^*\,\ell^+\,\nu_\ell$ $(\hookrightarrow D\pi)$	$(2.2 \pm 0.2) \times 10^{-3}$	$(2.1 \pm 0.2) \times 10^{-3}$
$B \to D_0^*\,\ell^+\,\nu_\ell$ $(\hookrightarrow D\pi)$	$(3.9 \pm 0.8) \times 10^{-3}$	$(3.6 \pm 0.7) \times 10^{-3}$
$B \to D_1'\,\ell^+\,\nu_\ell$ $(\hookrightarrow D^*\pi)$	$(4.3 \pm 0.8) \times 10^{-3}$	$(4.0 \pm 0.8) \times 10^{-3}$
$B \to D\pi\,\ell^+\,\nu_\ell$	$(1.5 \pm 0.6) \times 10^{-3}$	$(1.5 \pm 0.6) \times 10^{-3}$
$B \to D^*\pi\,\ell^+\,\nu_\ell$	$(1.5 \pm 1.0) \times 10^{-3}$	$(1.5 \pm 1.0) \times 10^{-3}$
$B \to D\pi\pi\,\ell^+\,\nu_\ell$	$(0.5 \pm 0.5) \times 10^{-3}$	$(0.5 \pm 0.5) \times 10^{-3}$
$B \to D^*\pi\pi\,\ell^+\,\nu_\ell$	$(2.6 \pm 1.0) \times 10^{-3}$	$(2.4 \pm 1.0) \times 10^{-3}$
$B \to D\eta\,\ell^+\,\nu_\ell$	$(2.0 \pm 2.0) \times 10^{-3}$	$(2.2 \pm 2.2) \times 10^{-3}$
$B \to D^*\eta\,\ell^+\,\nu_\ell$	$(2.0 \pm 2.0) \times 10^{-3}$	$(2.2 \pm 2.2) \times 10^{-3}$
$\mathrm{B} \to \mathrm{X_c}\ell\nu_\ell$	$(10.8 \pm 0.4) \times 10^{-2}$	$(10.0 \pm 0.4) \times 10^{-2}$

Inclusive $B \to X_u e \bar{\nu}_e$

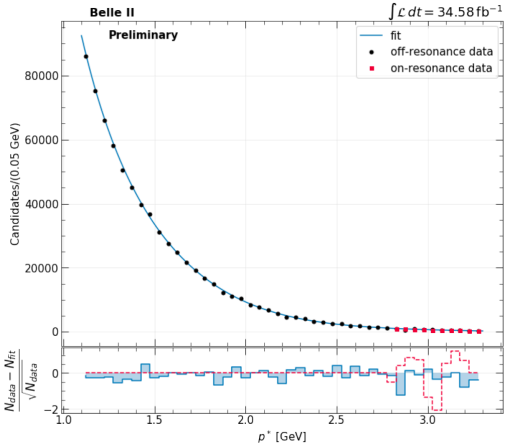
- Measurement of Vub in the lepton endpoint momentum spectrum.
  - Identify one lepton in the event using PID algorithms.
  - Suppress continuum using MVA trained with event shape variables.

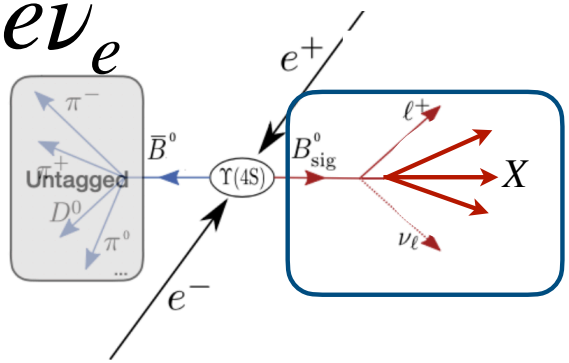


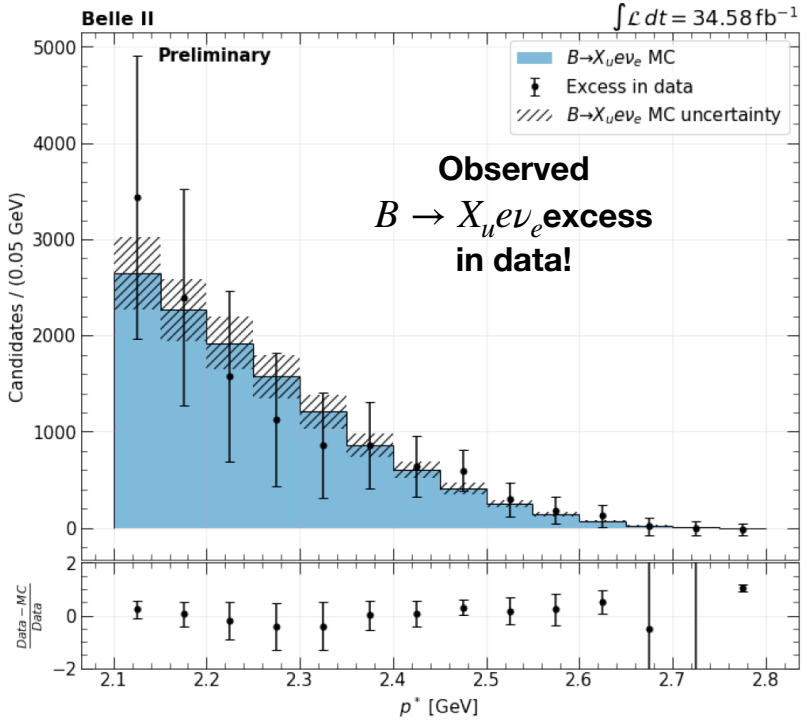
  - Subtract continuum and other BB contributions from data.



Use hybrid model weighting in MC

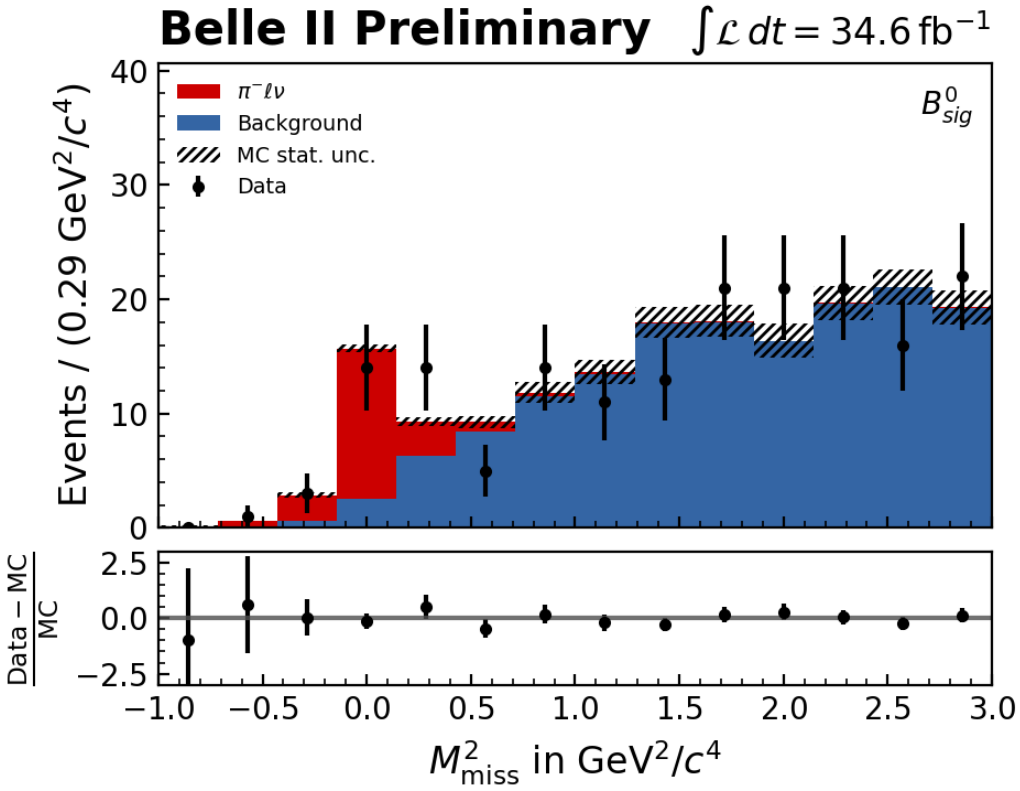


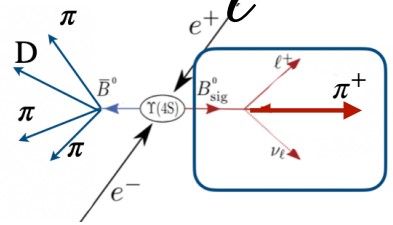




Tagged Exclusive $B^0 \to \pi^+ \ell \nu_\ell$

- Extract signal yield using a fit with two templates: signal +background.

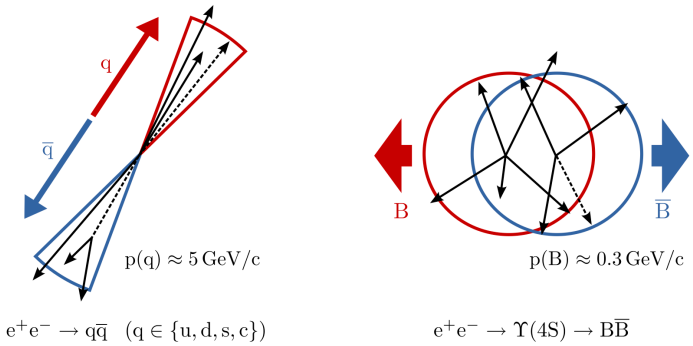


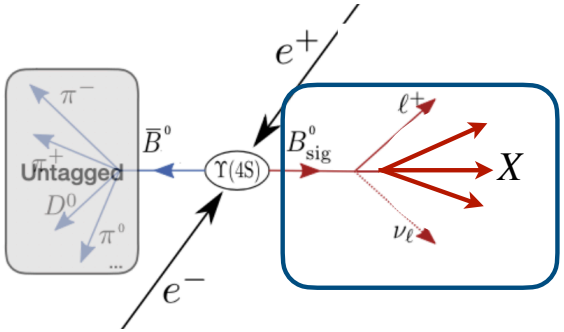


$$\mathcal{B}(B^0 \to \pi^-\ell\nu) = \frac{N_{\mathrm{sig}}^{\mathrm{data}}(1+f_{+0})}{4 \times \mathrm{CF}_{\mathrm{FEI}} \times N_{B\bar{B}} \times \epsilon}$$

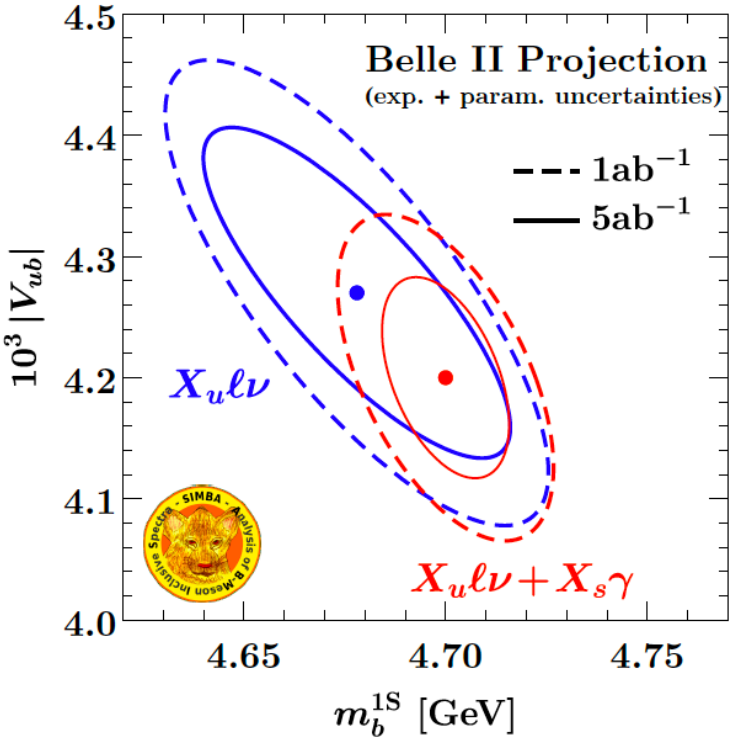
$N_{\mathrm{sig}}^{\mathrm{data}}$	20.79 ± 5.68
f_{+0}	1.058 ± 0.024
$\mathrm{CF}_{\mathrm{FEI}}$	0.8301 ± 0.0286
$N_{B\bar{B}}$	$(37.711 \pm 0.602) \times 10^6$
ϵ	$(0.216 \pm 0.001)\%$
$\mathcal{B}(B^0 \to \pi^-\ell\nu)$	$(1.58 \pm 0.43_{\mathrm{stat}} \pm 0.07_{\mathrm{sys}}) \times 10^{-4}$

$B \to X_u e \bar{\nu}_e$



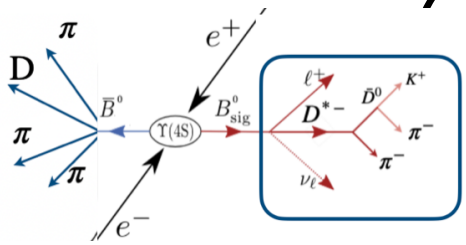


Global Vub fit to the full spectrum using all available experimental and theoretical information: Constraints on HQE parameters such as mb and the shape functions.



Tagged Exclusive $B^0 \to D^{*+}\ell\nu_\ell$

- Examine beam background contributions to Eres, the sum of energy deposits for all neutral clusters after Bsig+Btag reconstruction, in the Belle II environment.



- Suppress beam backgrounds using MVA trained with cluster shower shape variables.