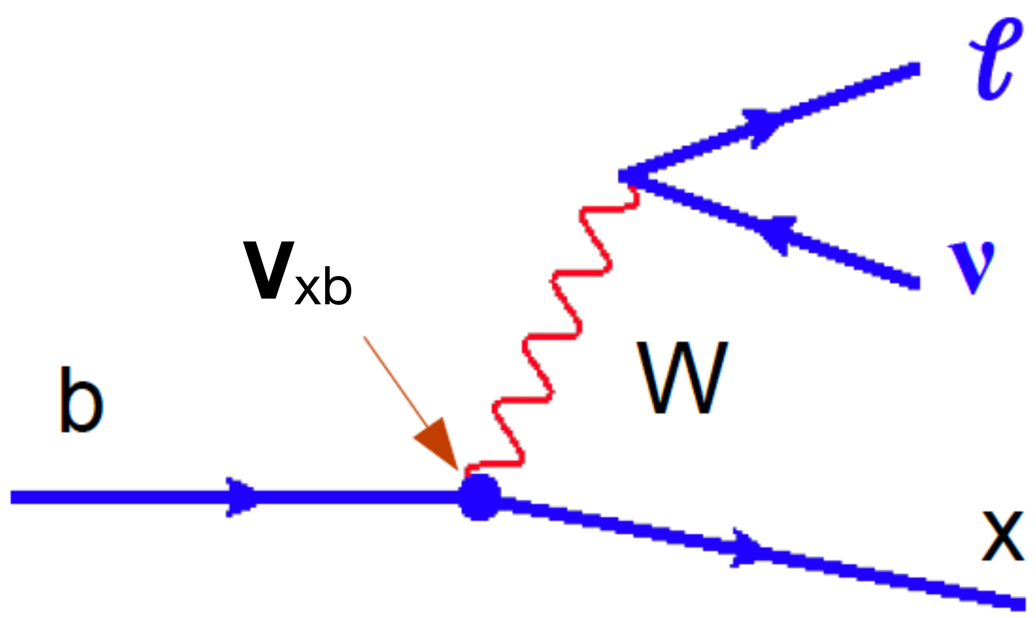
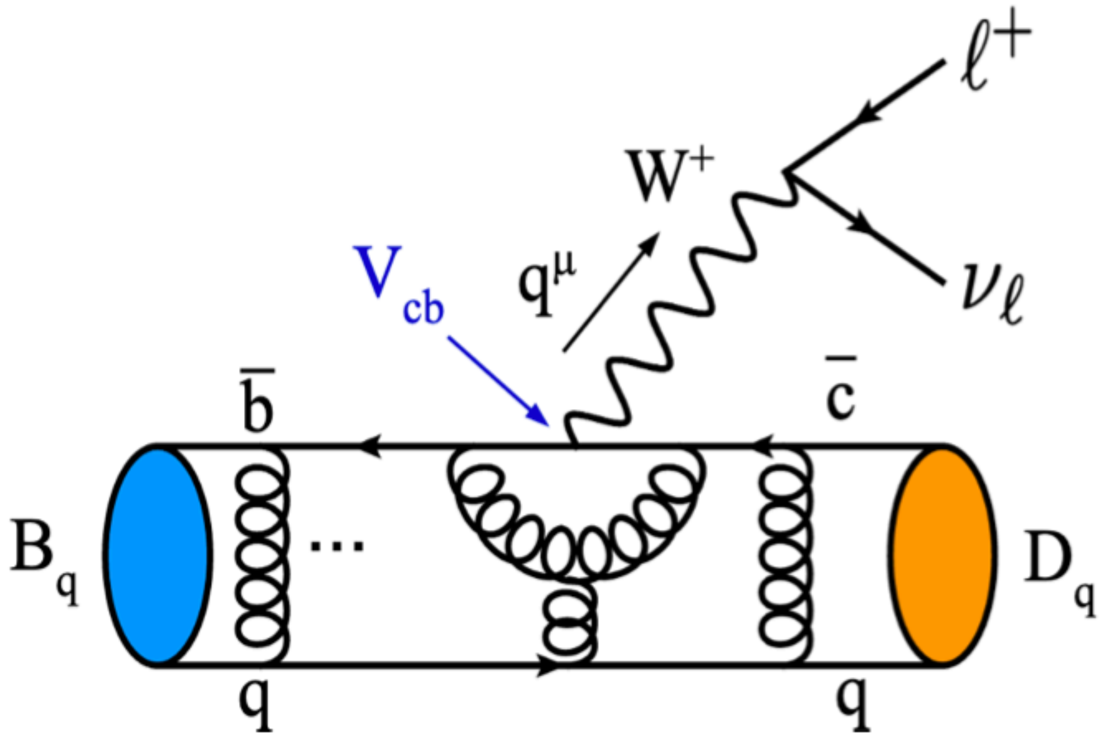
Semi-leptonic B decays at Belle II



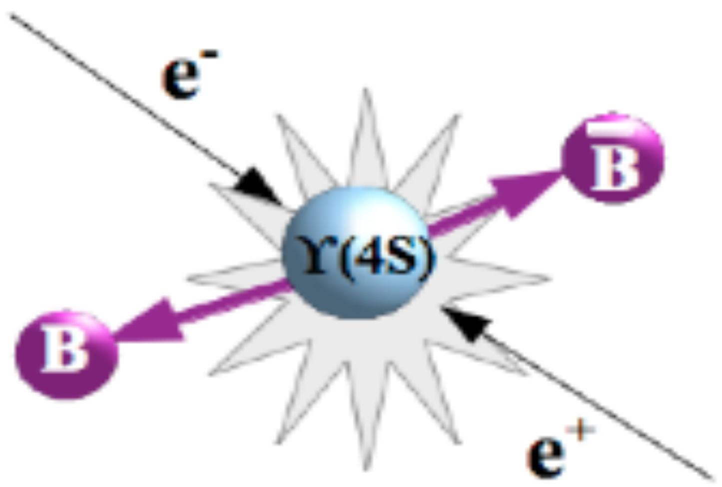
Racha Cheaib
DESY

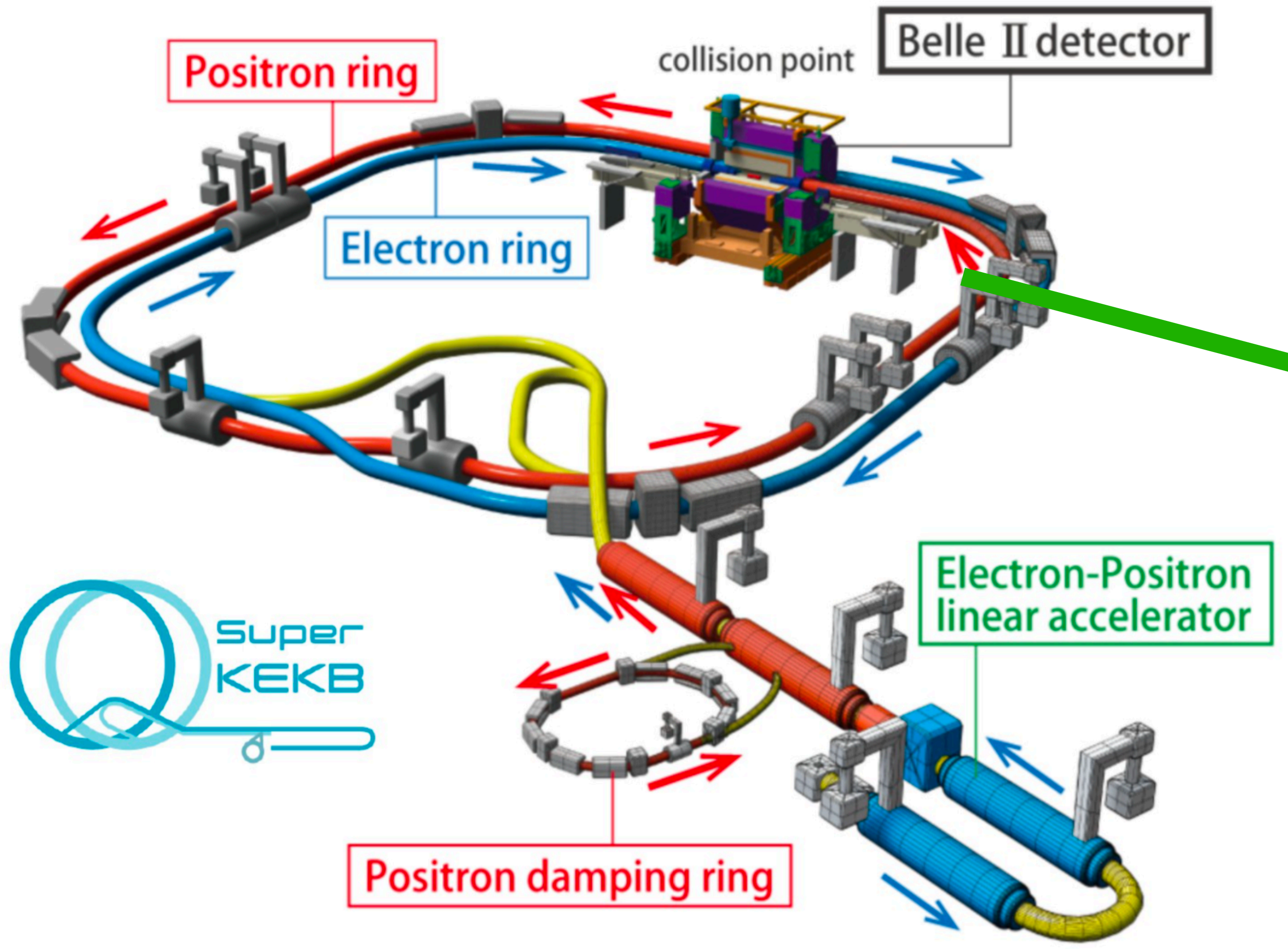
July 5th, 2021

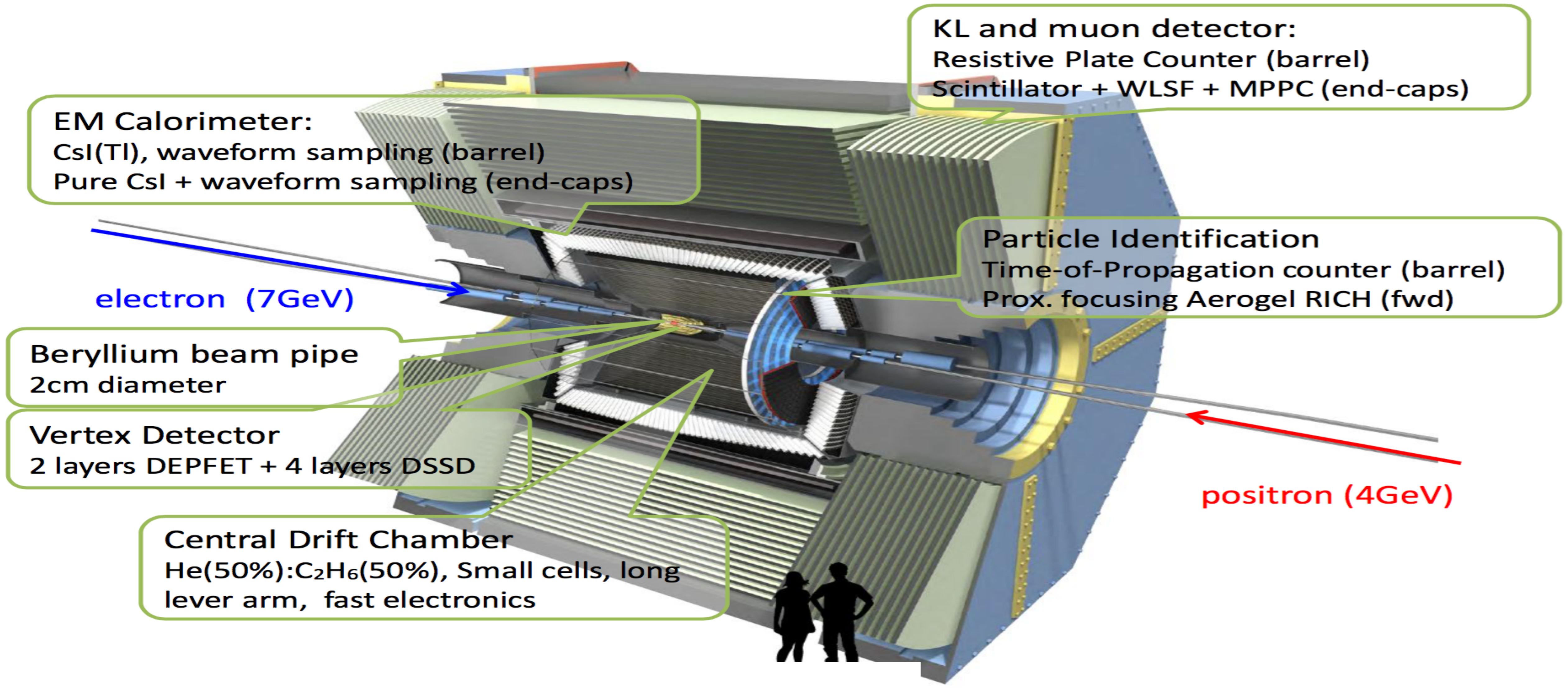


Belle II experiment

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

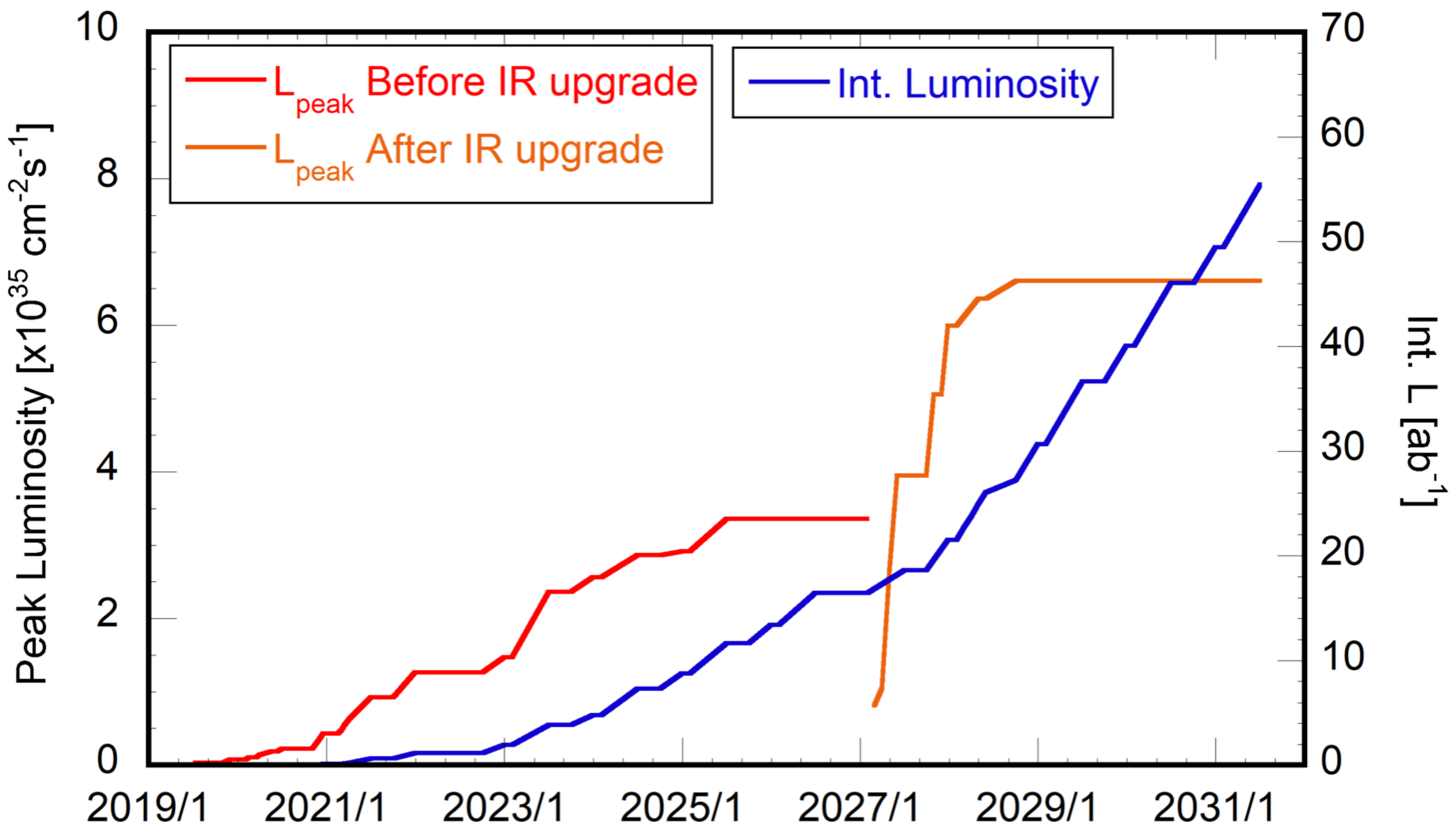






- Target luminosity: 50 ab^{-1}, 50x the Belle dataset.

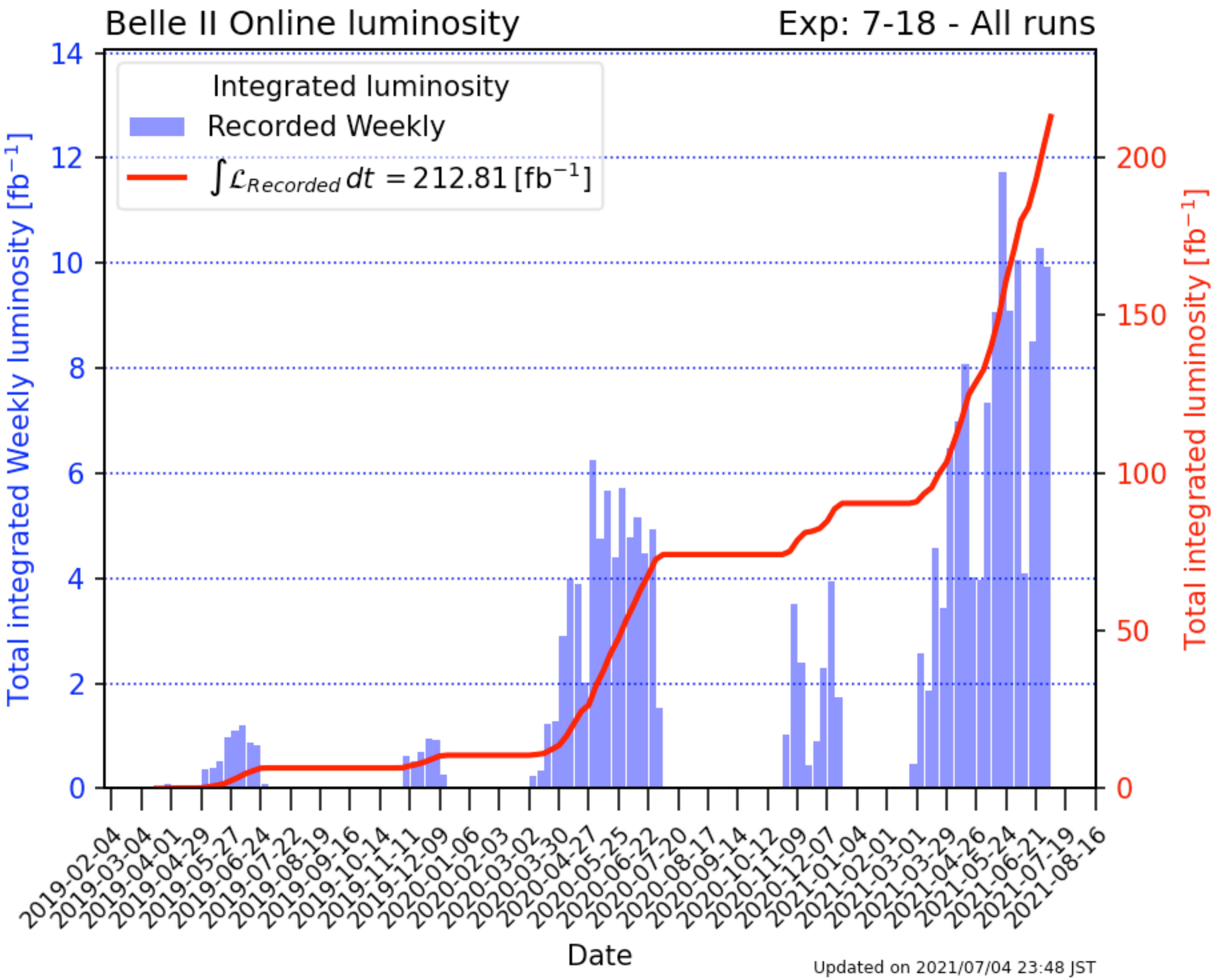
- a (Super) B-factory (~1.1 x 10^9 $B\bar{B}$ pairs per ab^{-1})
- a (Super) charm factory (~1.3 x 10^9 $c\bar{c}$ pairs per ab^{-1})
- a (Super) τ factory (~0.9 x 10^9 $\tau\bar{\tau}$ pairs per ab^{-1})



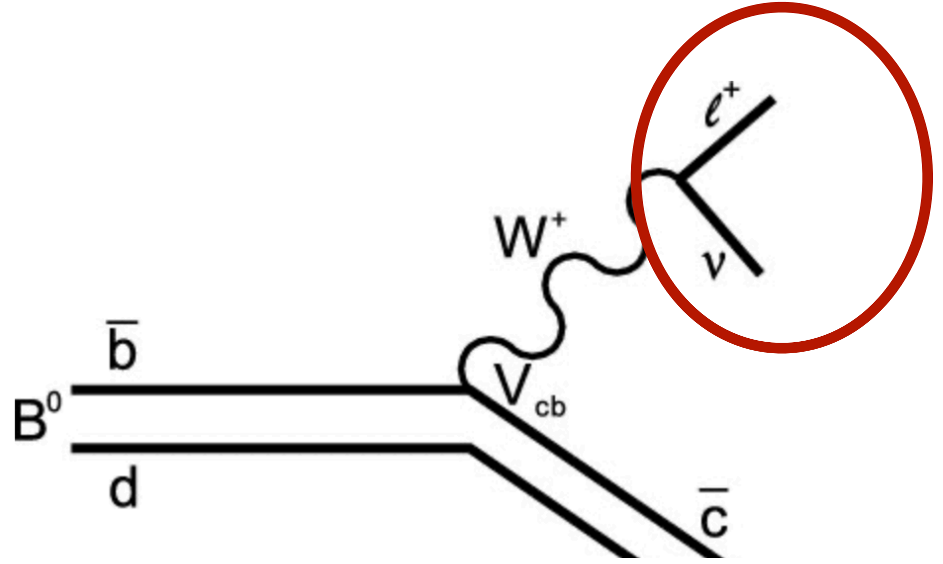
- B-physics:
  - CPV: B→ J/ψ K_S^0, ϕK^0
  - Rare B decays: B→Kνν, $K\tau^+\tau^-$
  - Semi-leptonic B decays
- Lepton flavour violation:
  - $\tau \to \mu\gamma$
- Charm Physics: D-mixing

Current Belle II dataset

Many results presented today with 34.6 or 68.2 fb^{-1} of reprocessed data.



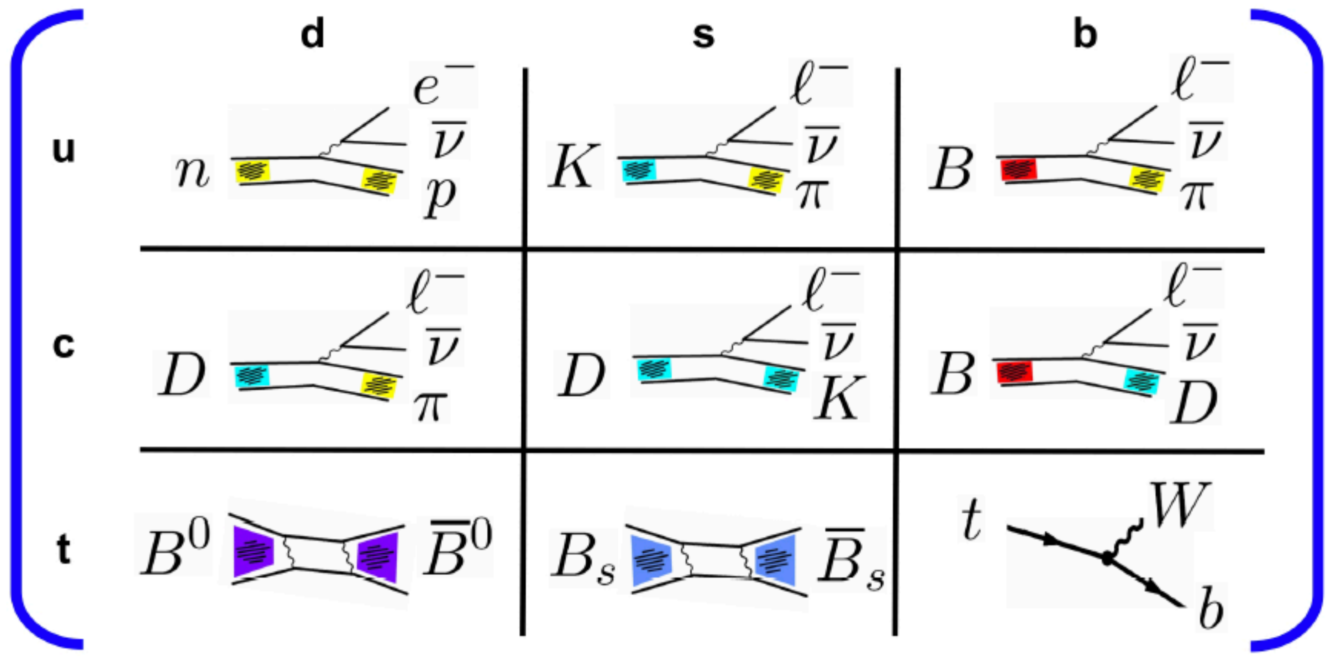
Semi-leptonic decays

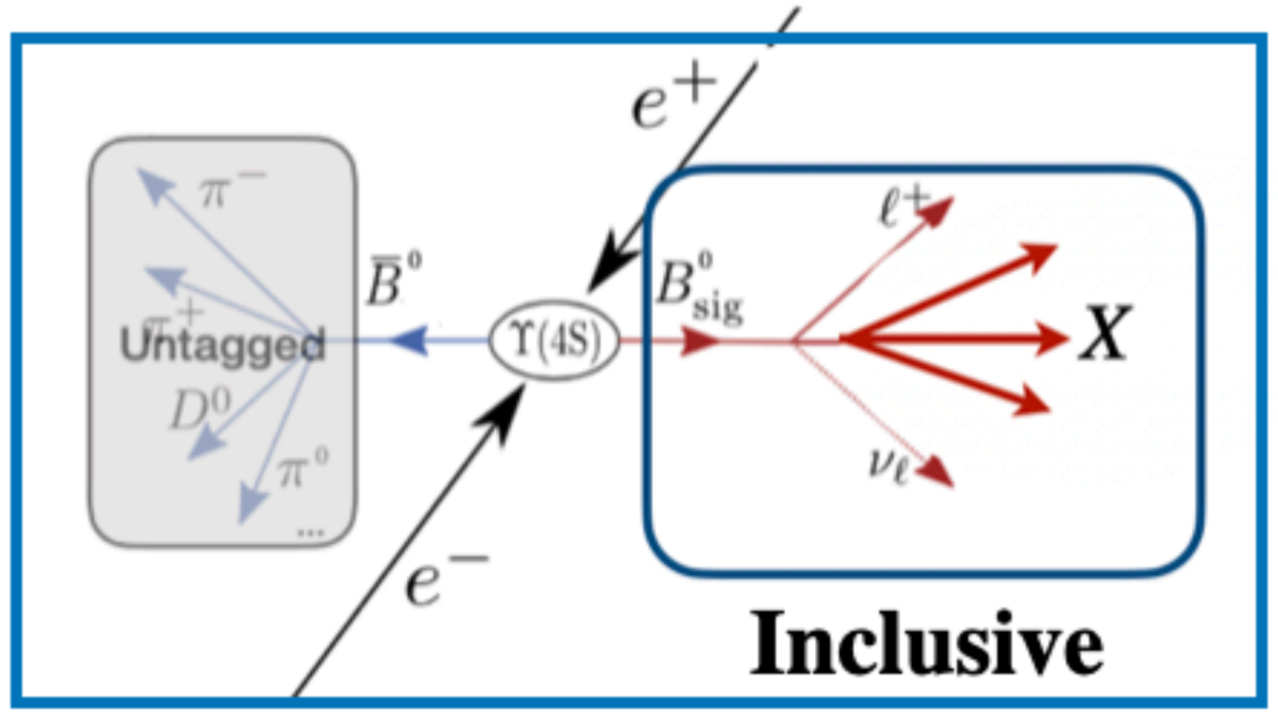


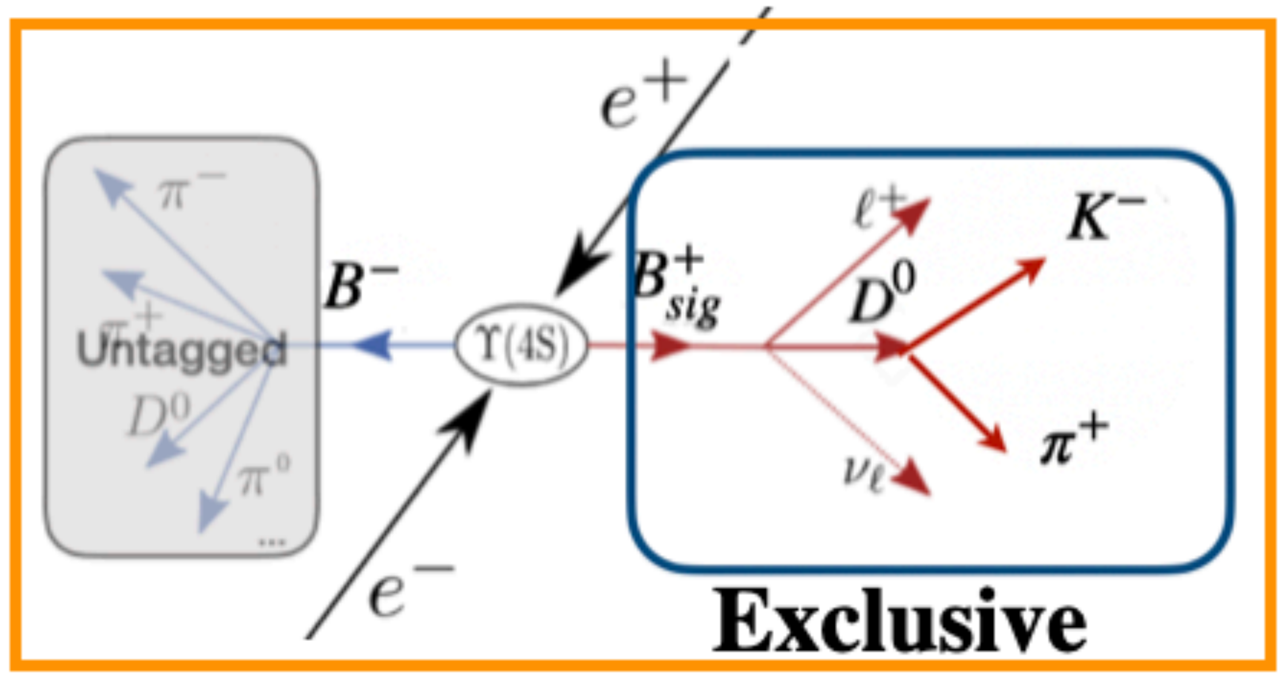
- Semi-leptonic decays involve neutrinos, which is inferred as missing energy in our detector.

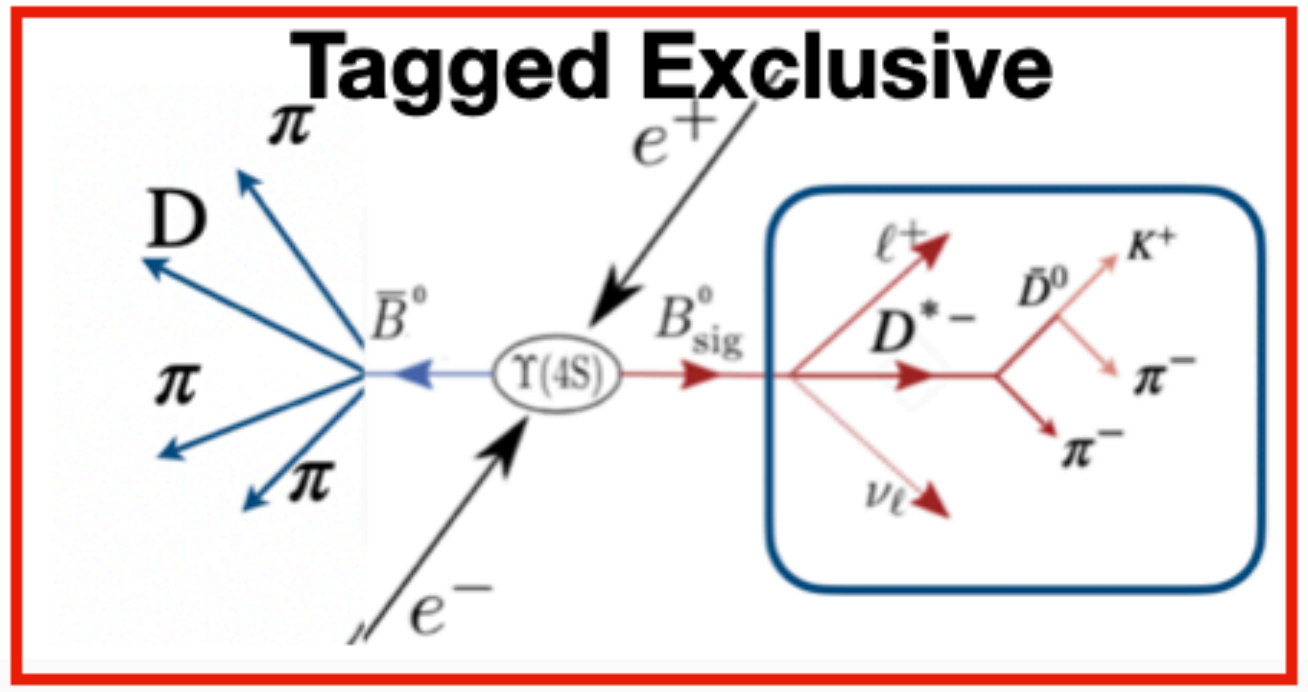
- Inclusive and exclusive $b \to u\ell\nu$ and $b \to c\ell\nu$ transitions are crucial for the determination of the CKM matrix elements $|V_{ub}|$ and $|V_{cb}|$.

V =

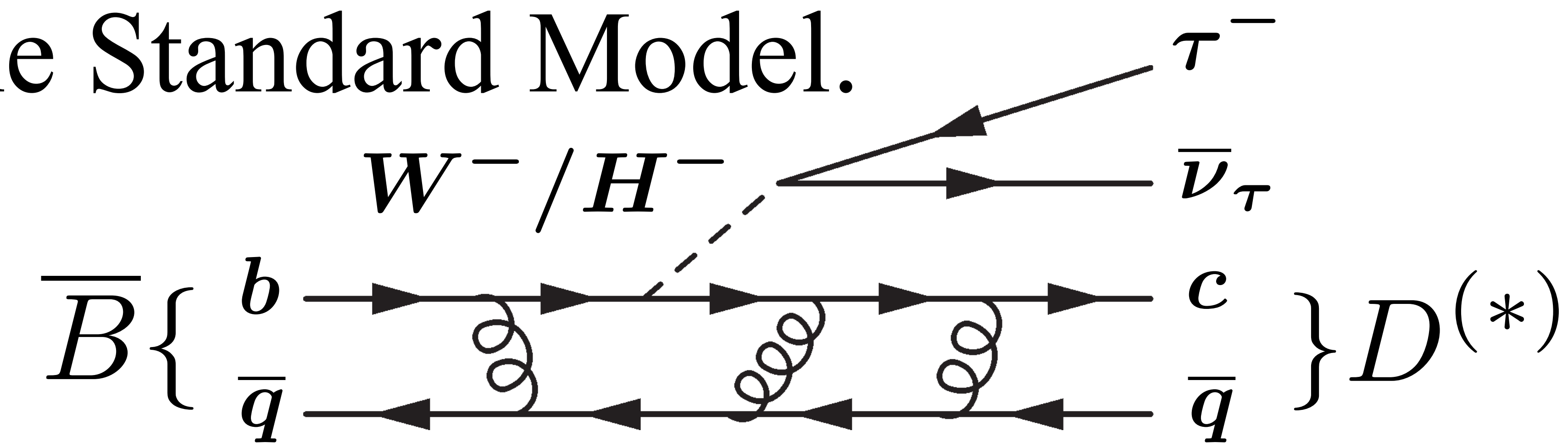




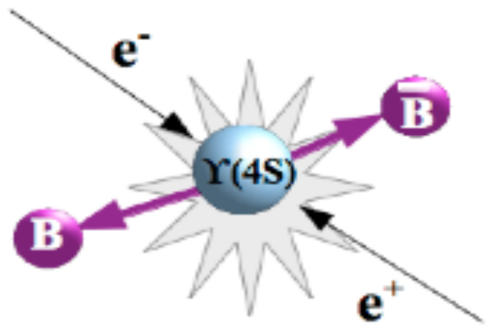




- Lepton Flavour Violation studies are an important probe for physics beyond the Standard Model.



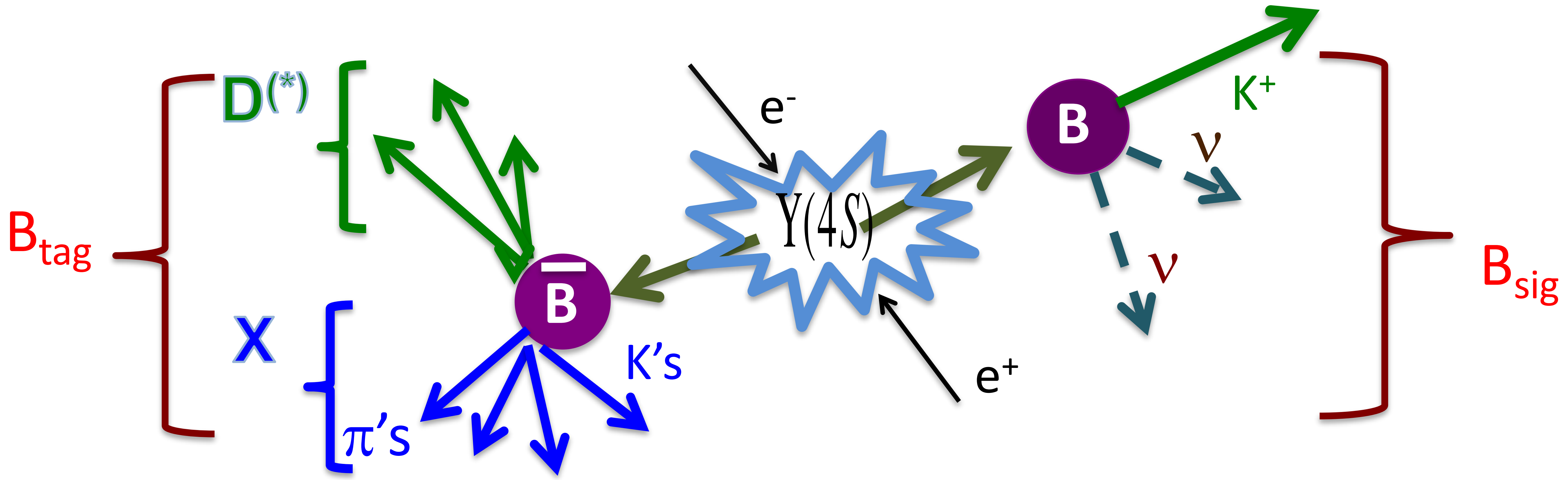
Full Event Interpretation

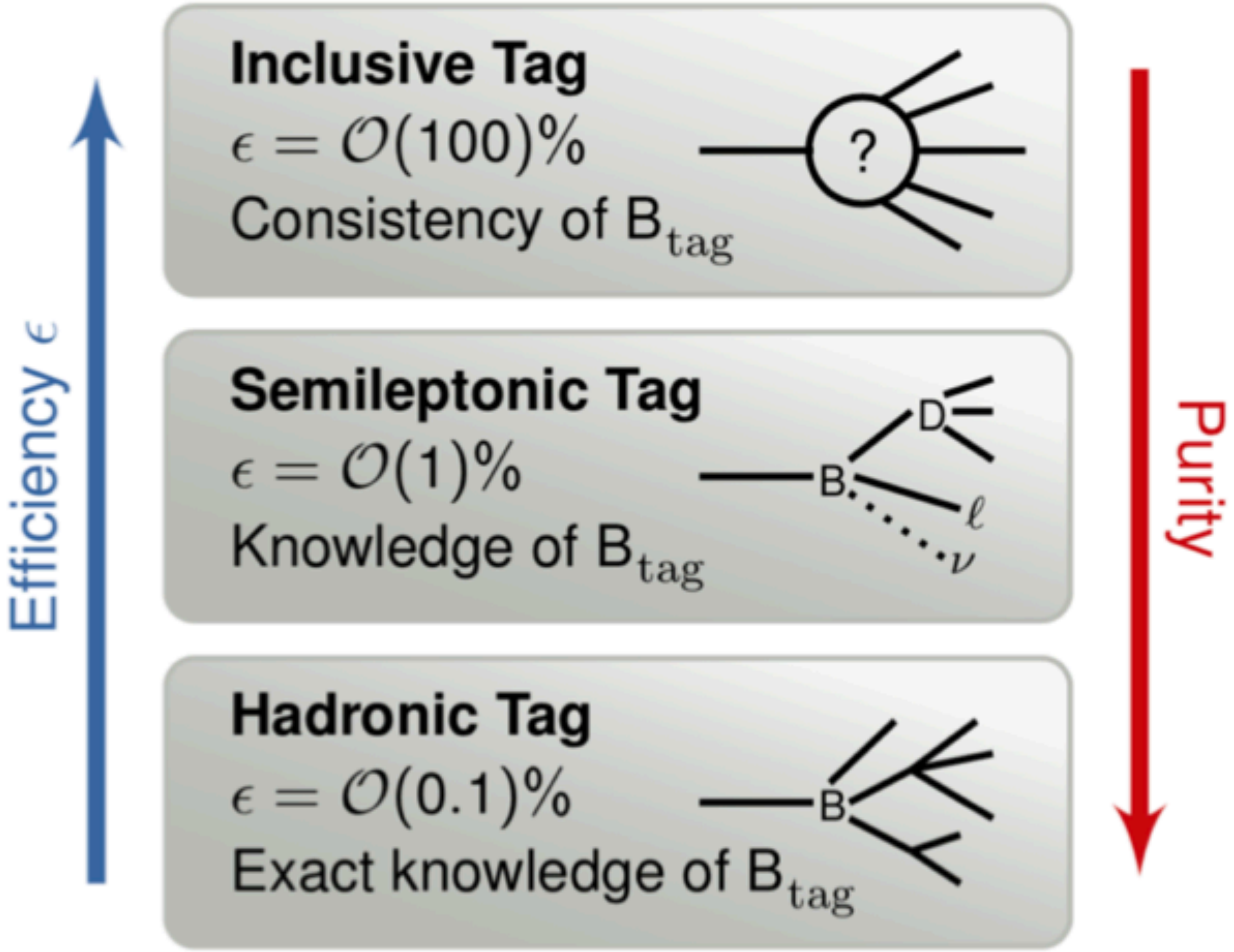


- Implement tagging, where one B referred to as B_{tag} is exclusively reconstructed using hadronic or semi-leptonic modes.

- The remaining tracks and clusters are then attributed to the signal B, B_{sig}, on which the search or measurement of a particular decay is done.

- Any missing energy is attributed to the B_{sig}.





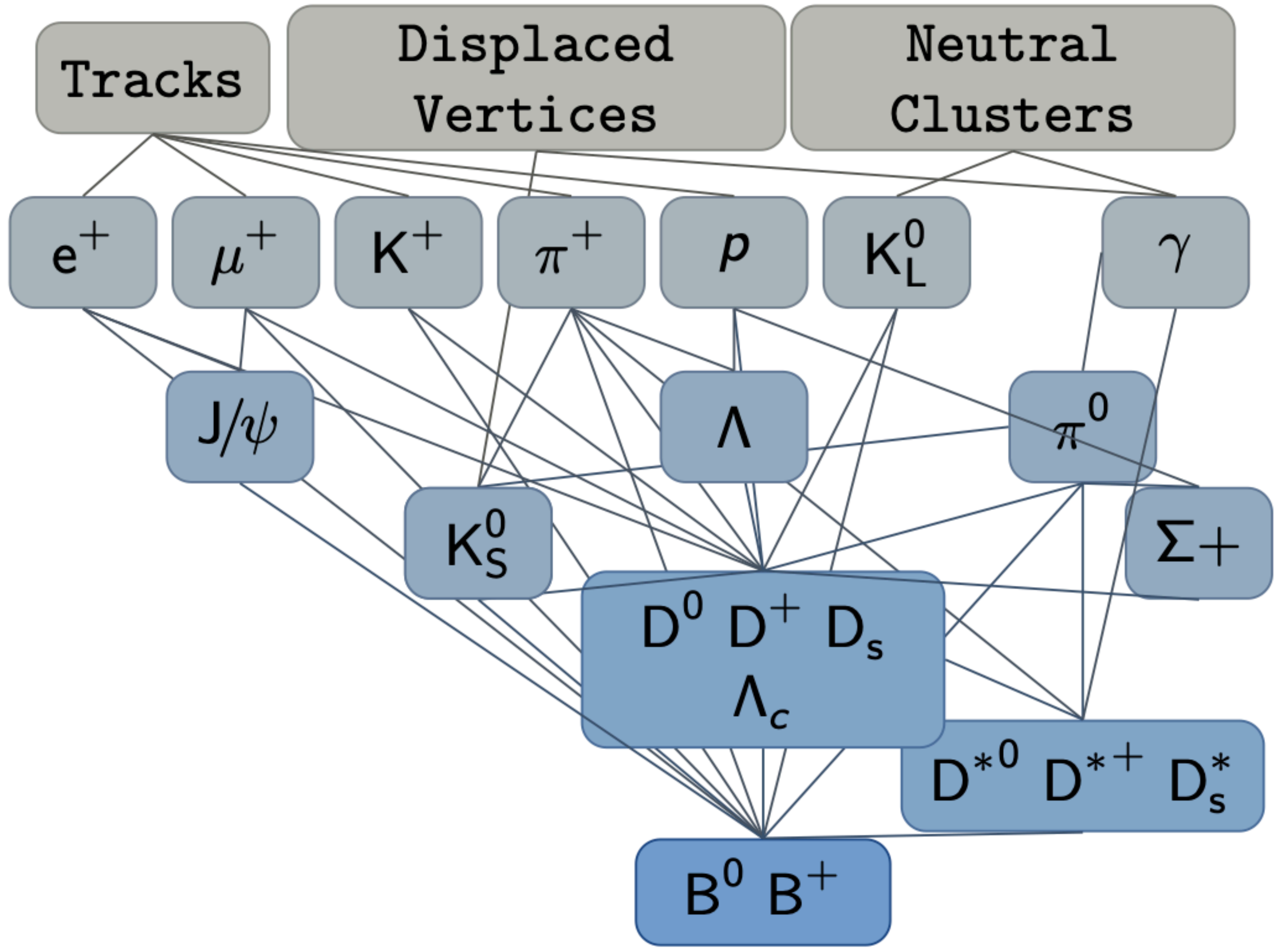
Infer momentum and direction of signal B candidate:

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

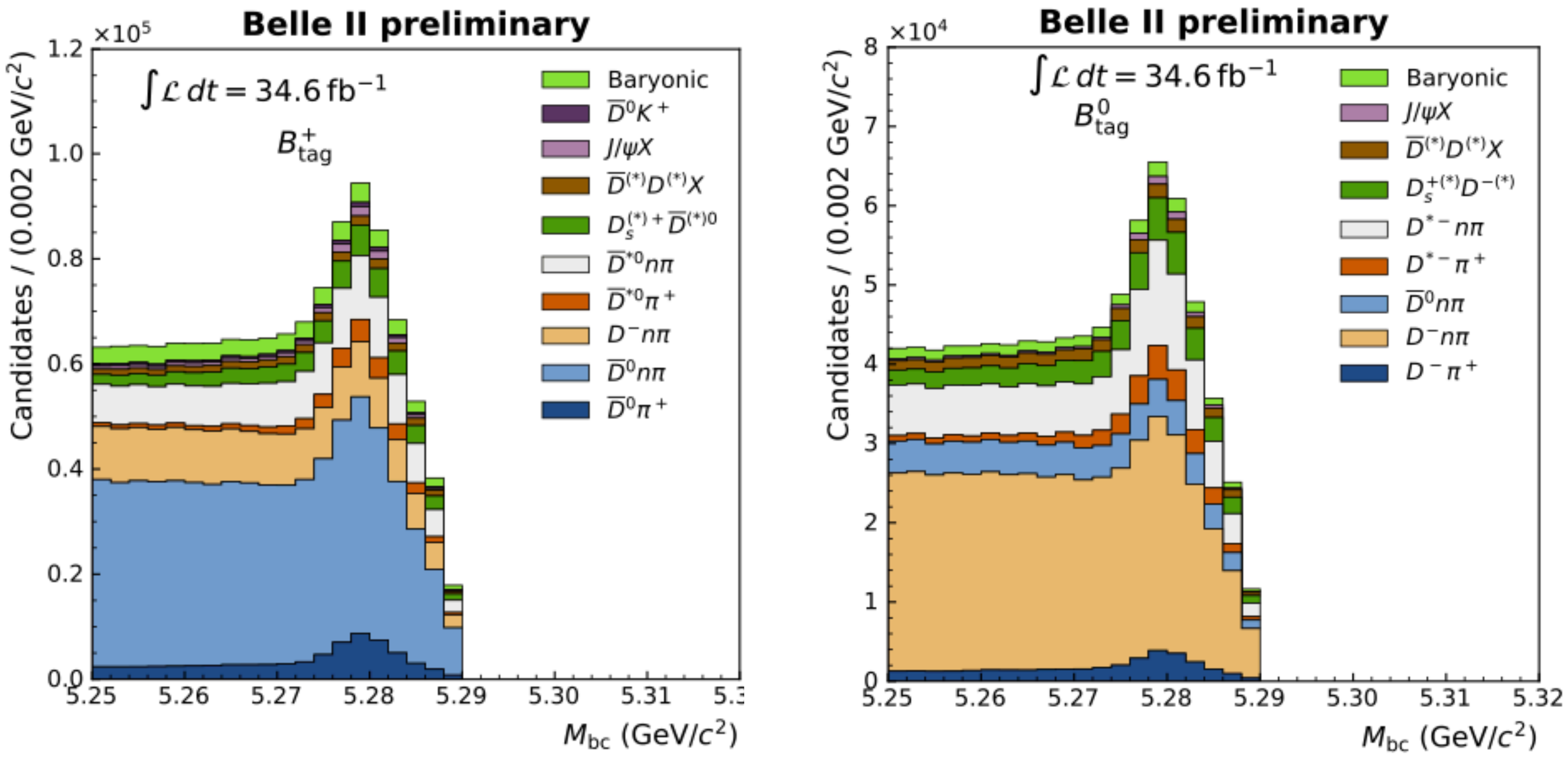
Ideal for decays with neutrinos, missing energy signatures!

Full Event Interpretation

- Multivariate algorithm with hierarchal approach



- Employs over 200 Boosted Decision Trees to reconstruct more than 10000 B decay modes.



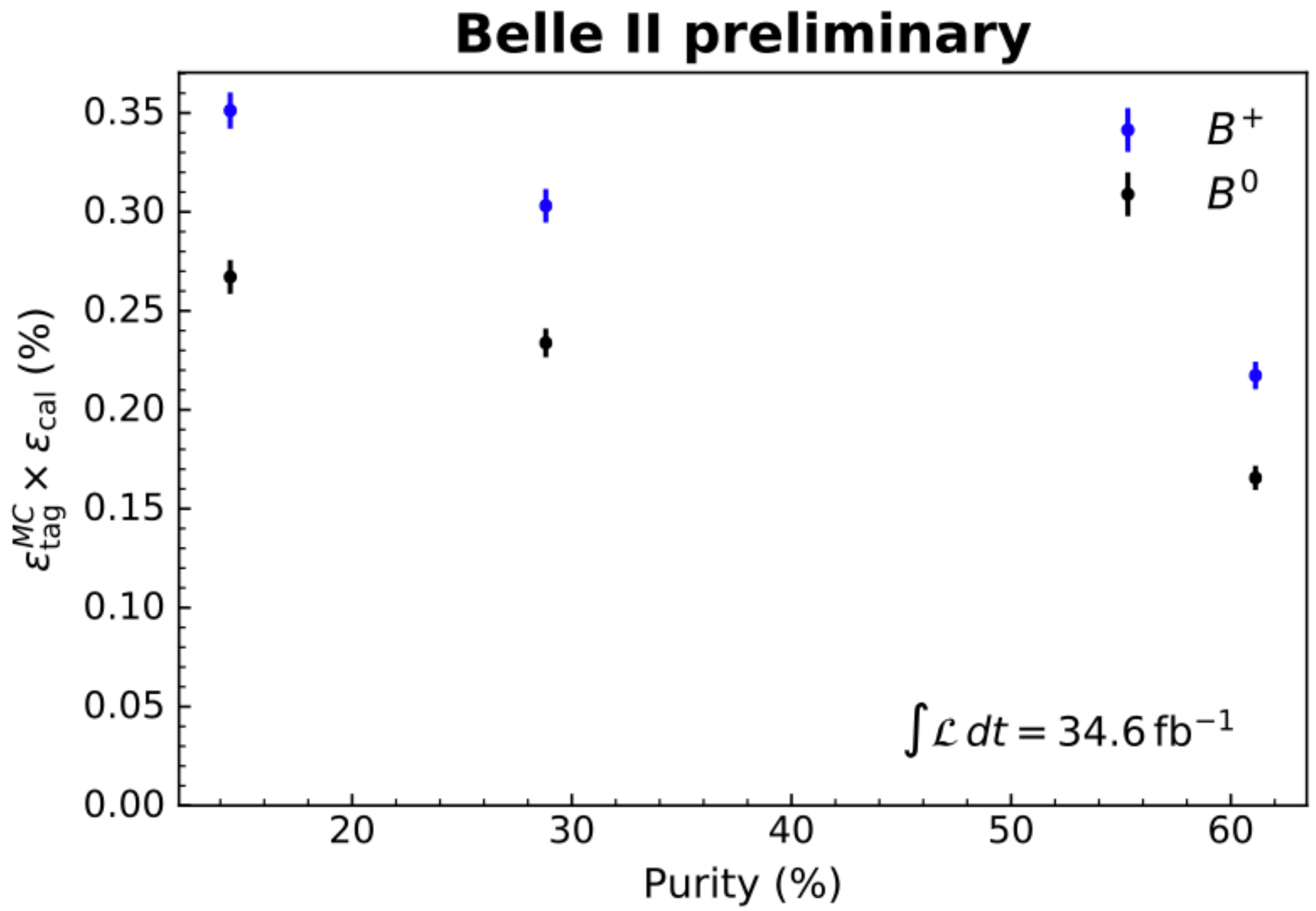
$$M_{bc} = \sqrt{E_{beam}^2/4 - (p_{B_{\mathrm{tag}}}^{\mathrm{cm}})^2}$$

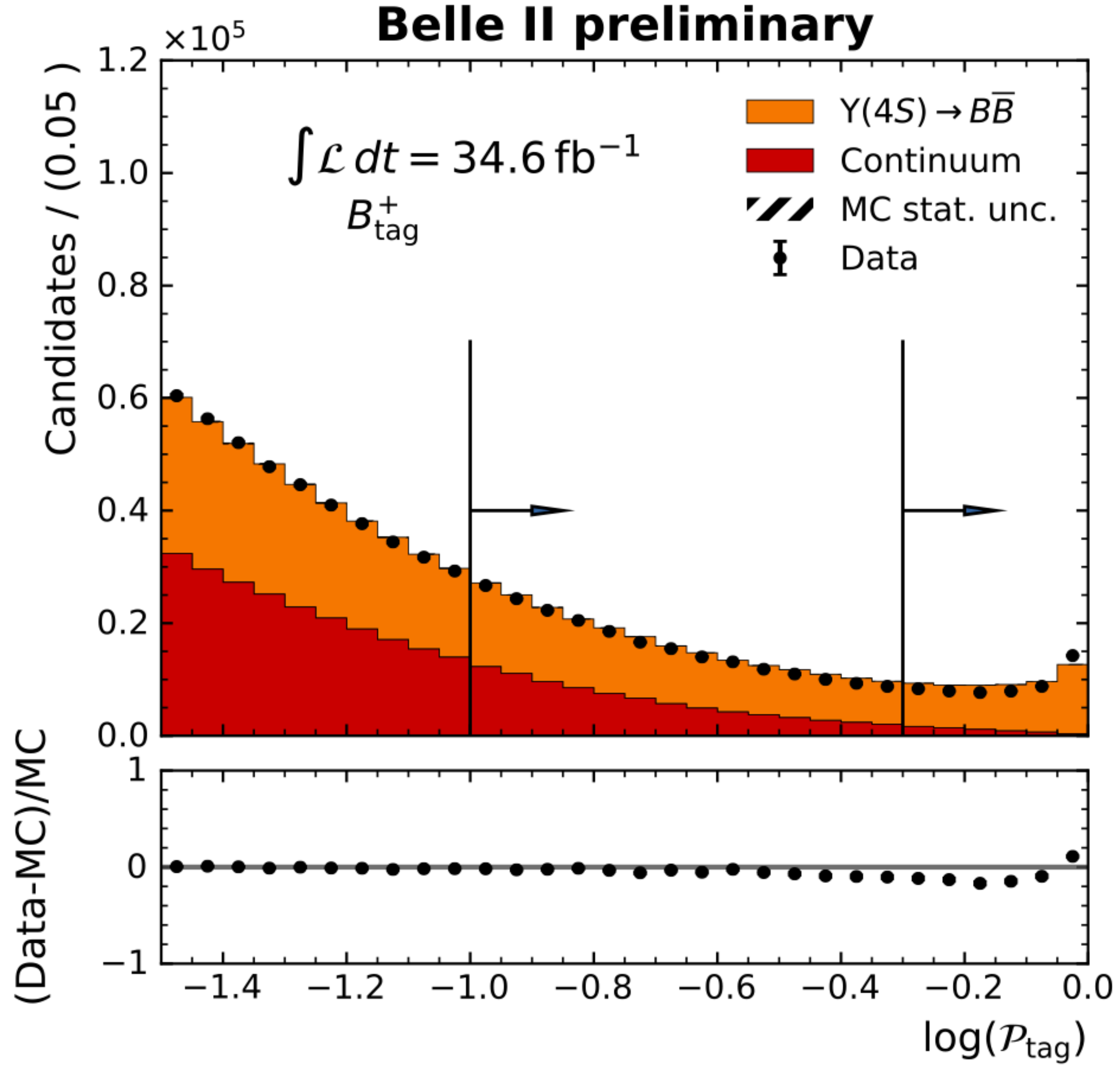
Tagging Algorithm	Had B+/B0	SL B+/B0
Full Reconstruction Belle	0.28/0.18	0.67/0.63
FEI Belle	0.78/0.46	1.80/2.04

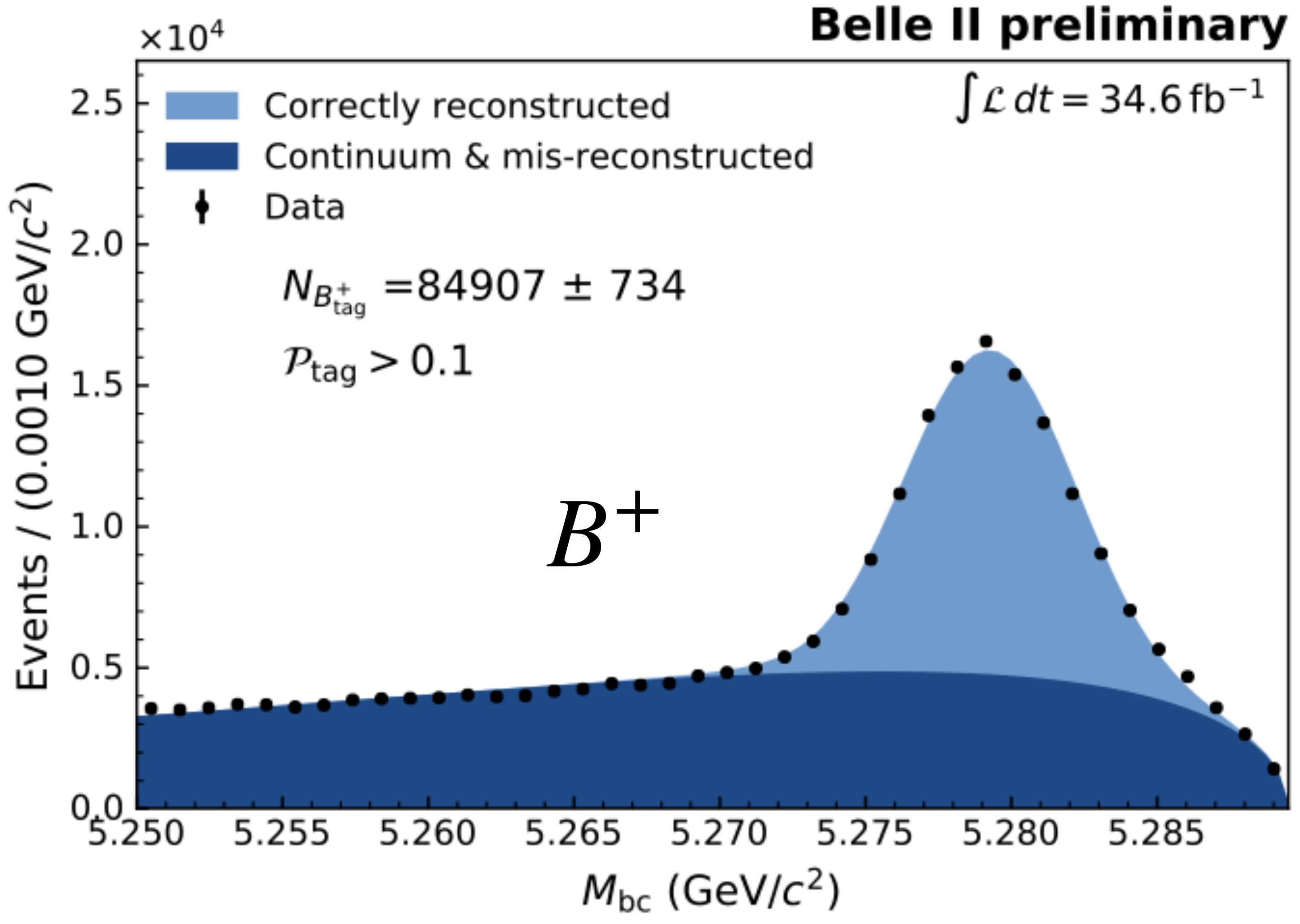
MC Tagging efficiency at 10% purity!

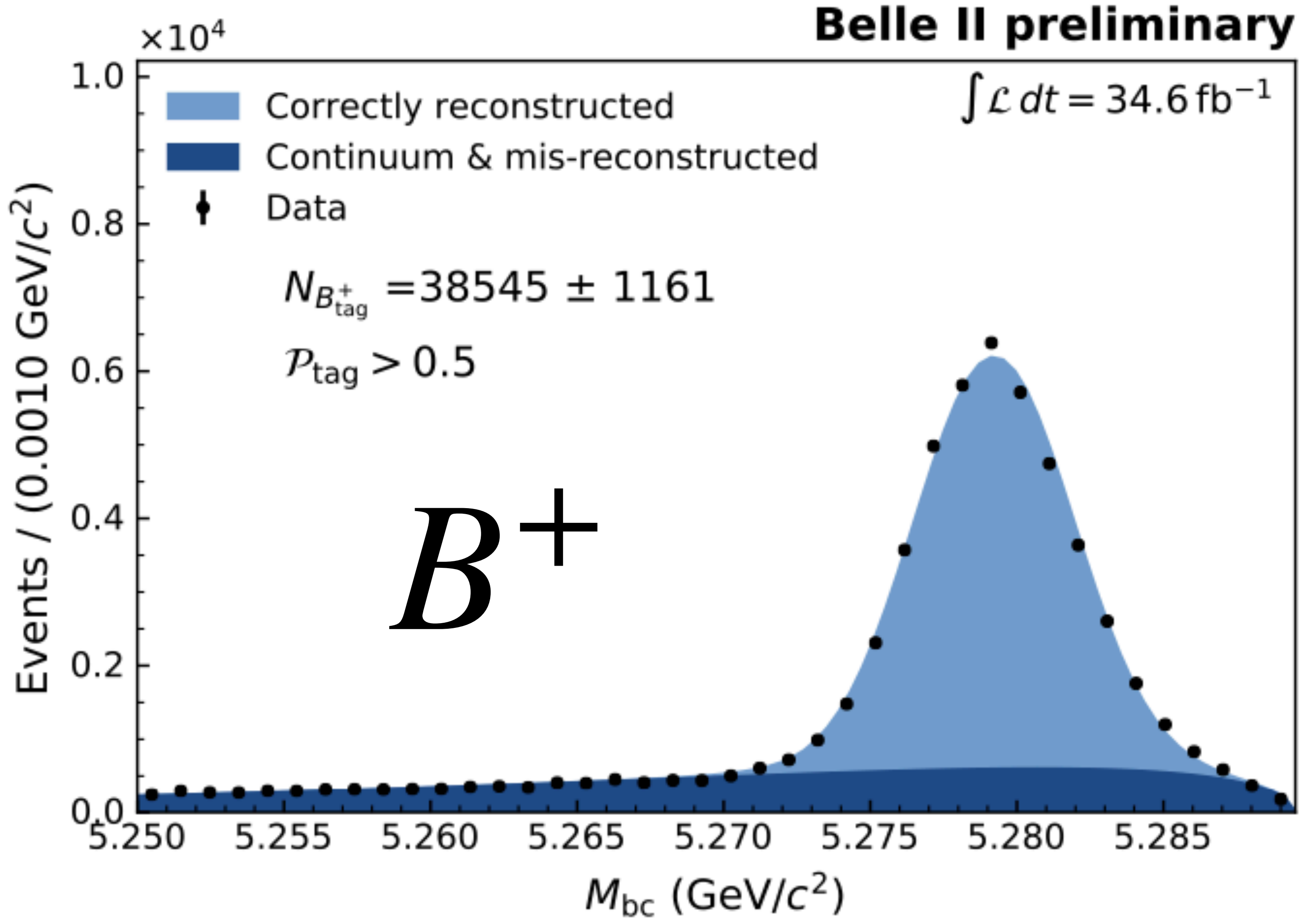
FEI signal probability

- Output of the FEI is a signal probability between 0 (mis-reconstructed) and 1 (properly reconstructed) **B**$_{tag}$ candidate.
- Purity and efficiency of B_{tag} sample varies with FEI signal probability cut.



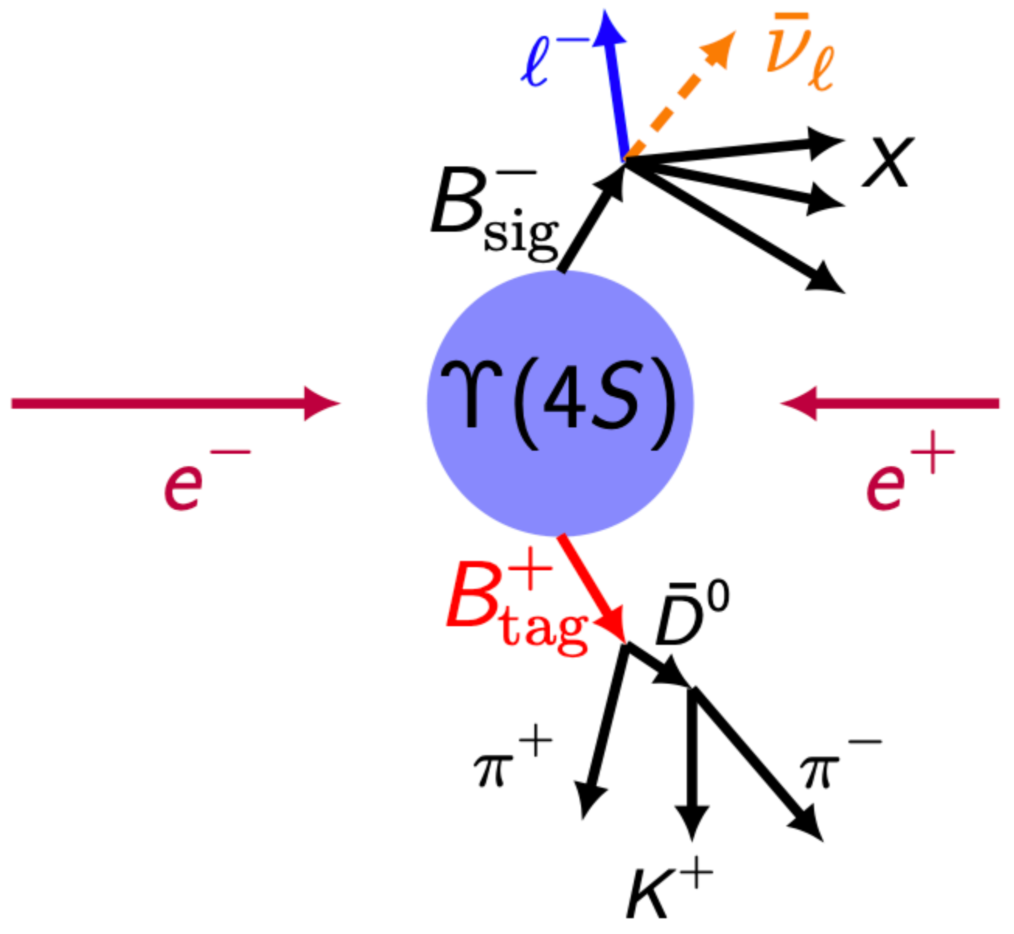






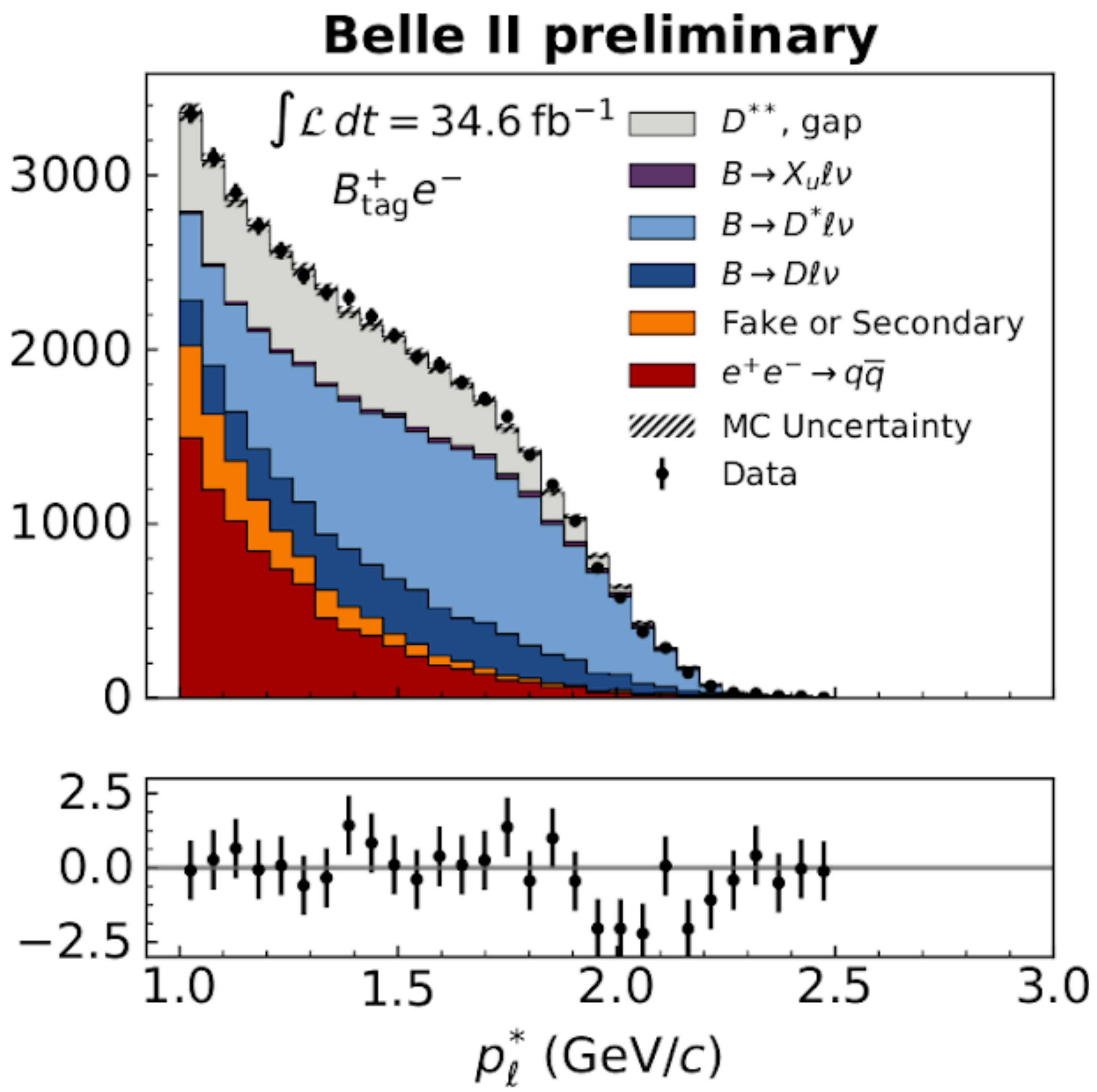
Hadronic FEI calibration

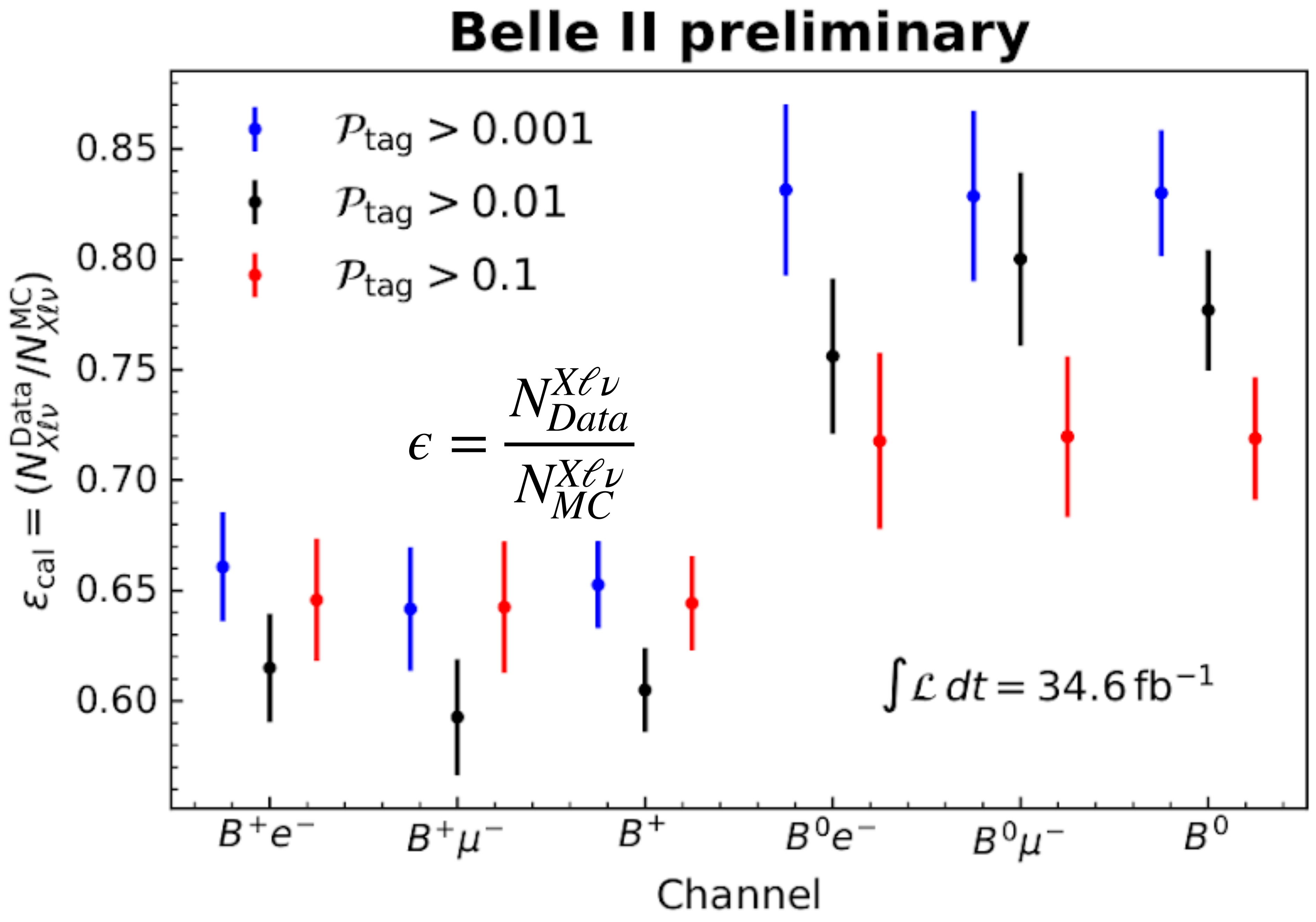
- calibration is required to account for data MC differences in the FEI algorithm.
- Using a signal side decay with a large branching fraction $B \to X\ell\nu$ (~20%), the efficiency of the FEI is compared between data and MC.



Require B_{tag} candidate with M_{bc} >5.27 GeV/c^2 and -0.15<ΔE<0.1 GeV.

Look for signal side lepton with momentum (in B_{sig} rest frame) >1 GeV/c.

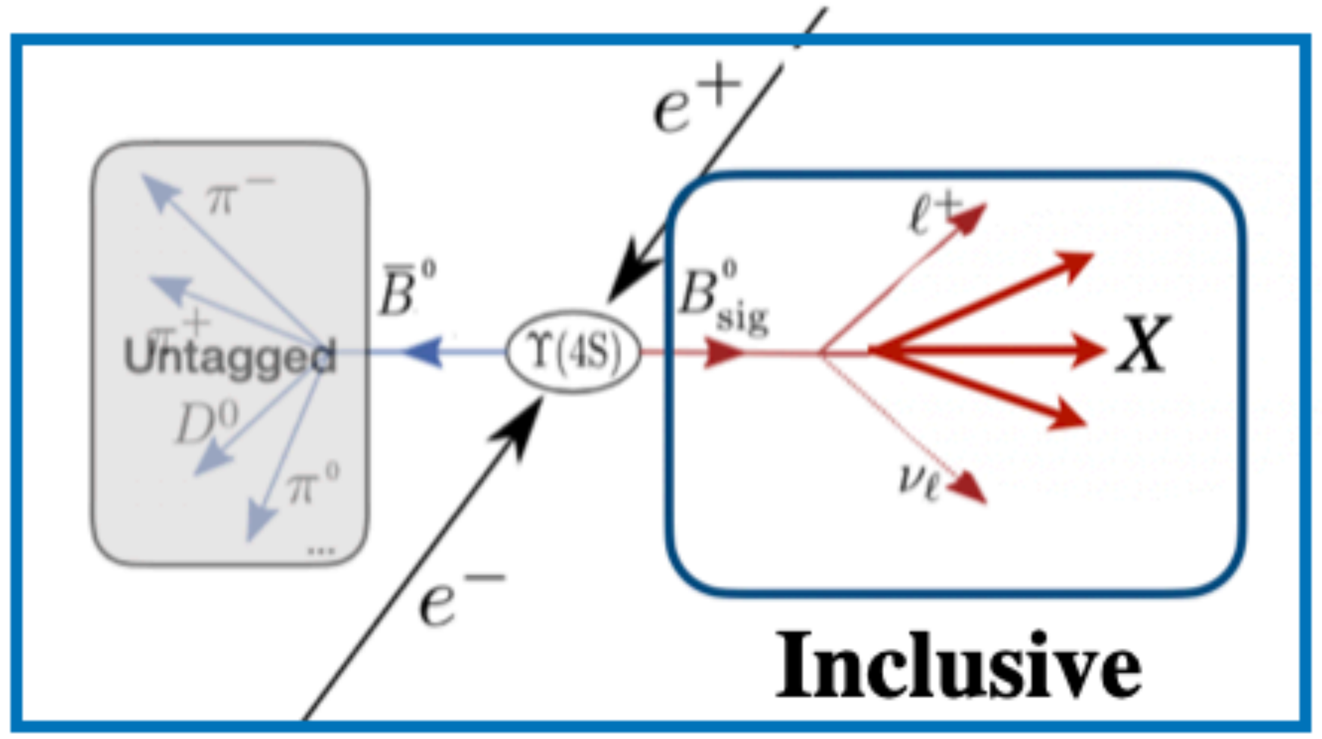


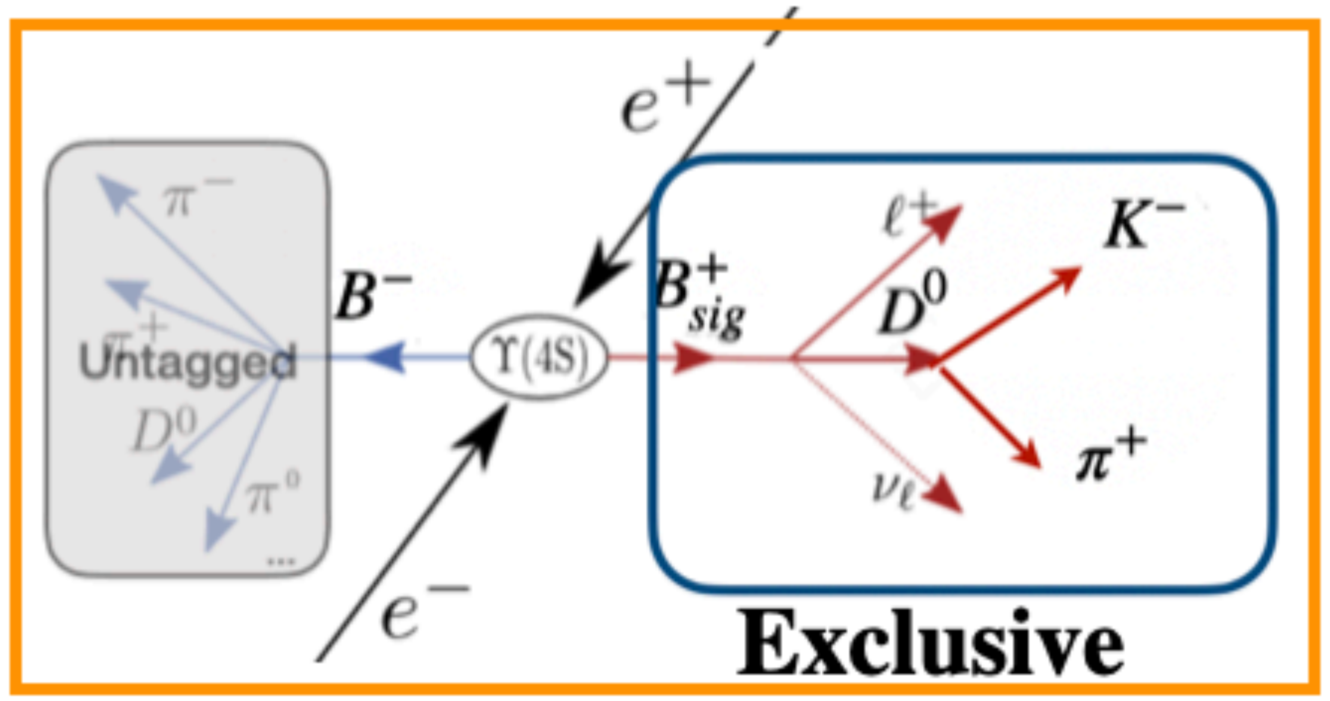


$\mathcal{P}_{B^+} >$	ϵ	% uncertainty
0.001	0.653 ± 0.020	3.02
0.01	0.605 ± 0.019	3.13
0.1	0.644 ± 0.021	3.30

$\mathcal{P}_{B^0} >$	ϵ	% uncertainty
0.001	0.830 ± 0.029	3.44
0.01	0.777 ± 0.027	3.51
0.1	0.719 ± 0.028	3.87

$b \to c\ell\nu$





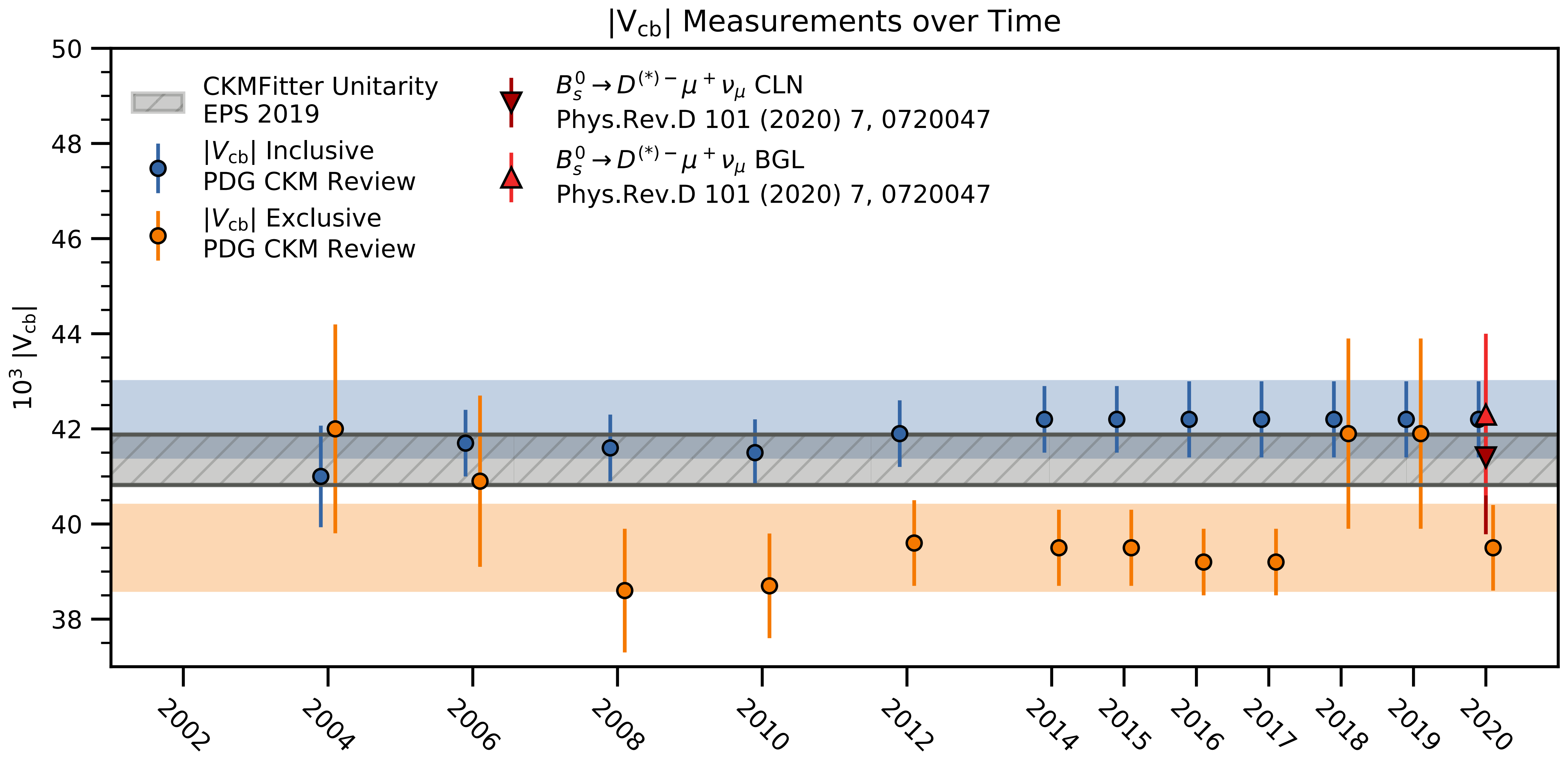
- $B \to X_c\ell\nu$: main channel for inclusive $|V_{cb}|$ determination.

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

  - Heavy Quark expansion of decay rate with non-perturbative matrix elements and perturbative coefficients.
  - Non-perturbative parameters determined using the lepton energy or hadronic mass moments of $B \to X_c\ell\nu$

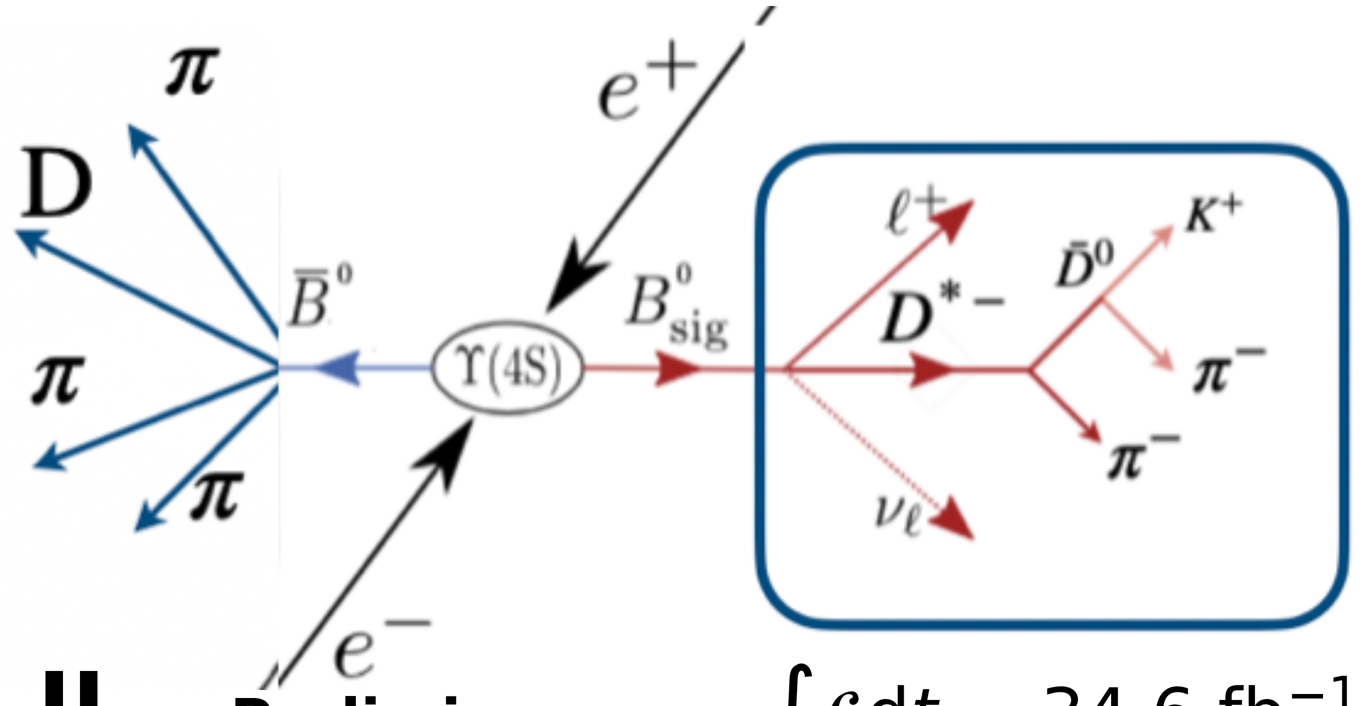
- $B \to D^{(*)}\ell\nu$: main channel for exclusive $|V_{cb}|$ determination:
  - Clean experimental modes with low background.
  - Decay rate requires input on the form factor parametrization.

$$|V_{cb}| = (42.2 \pm 0.8) \times 10^{-3}\ \text{(inclusive)}\quad \textbf{PDG value}$$
$$|V_{cb}| = (39.5 \pm 0.9) \times 10^{-3}\ \text{(exclusive)}\quad \textbf{PDG value}$$



Tension between exclusive and inclusive determinations.

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

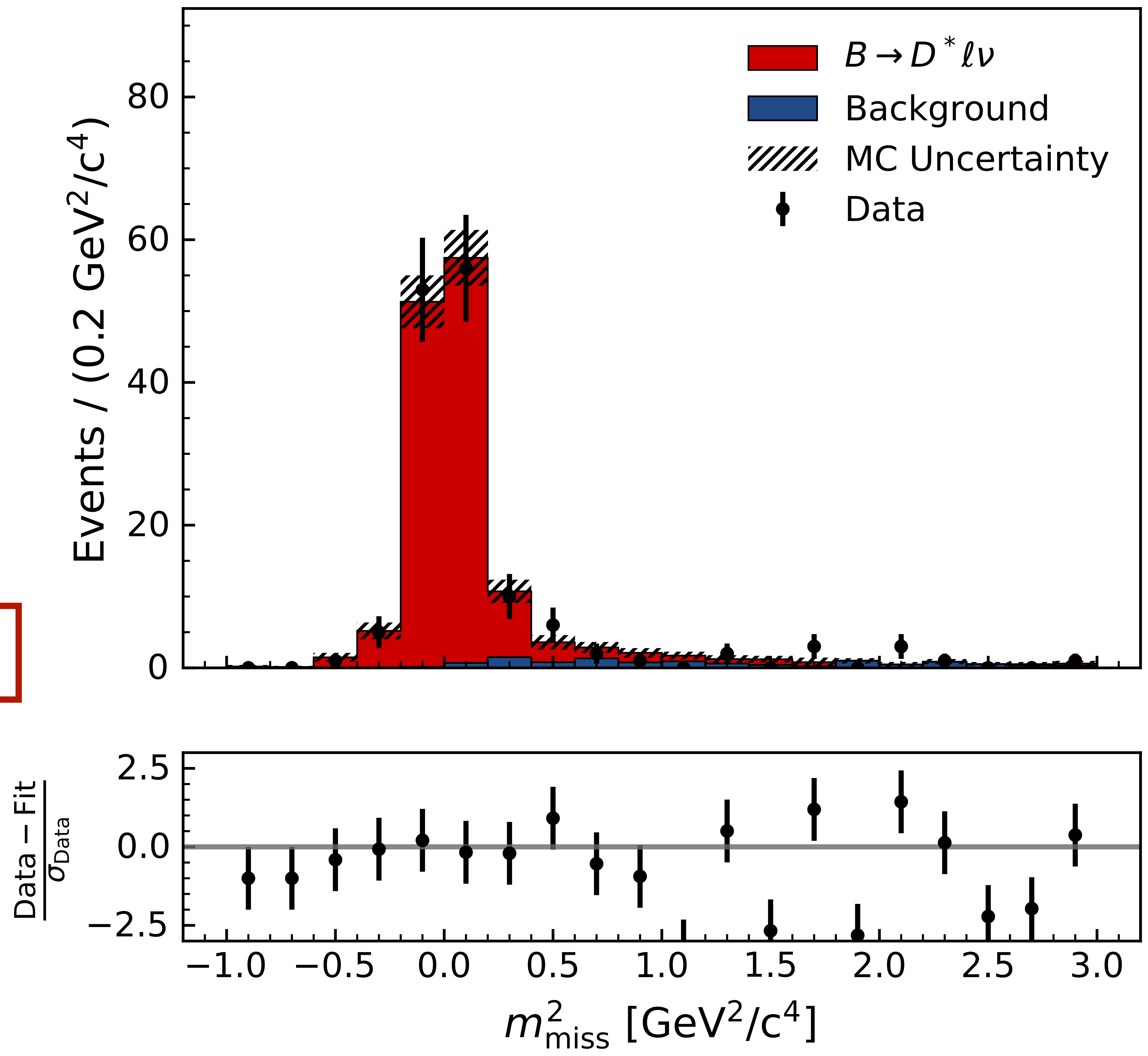


- Clean mode for testing FEI calibration and Belle II analysis chain.
- Identify B_{tag} candidate with M_{bc}>5.27 GeV/c^2 $-0.15 < \Delta E < 0.1$ and FEI signal probability >0.001.
- Reconstruct D^0 meson from oppositely charged tracks and form D^{*+} with $0.143 < \Delta M < 0.148$ GeV/c^2
- Identify high momentum lepton with $p_l^* > 1.0$ GeV and determine M^2_{miss}

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

- Extract signal yield using a fit to signal + background:

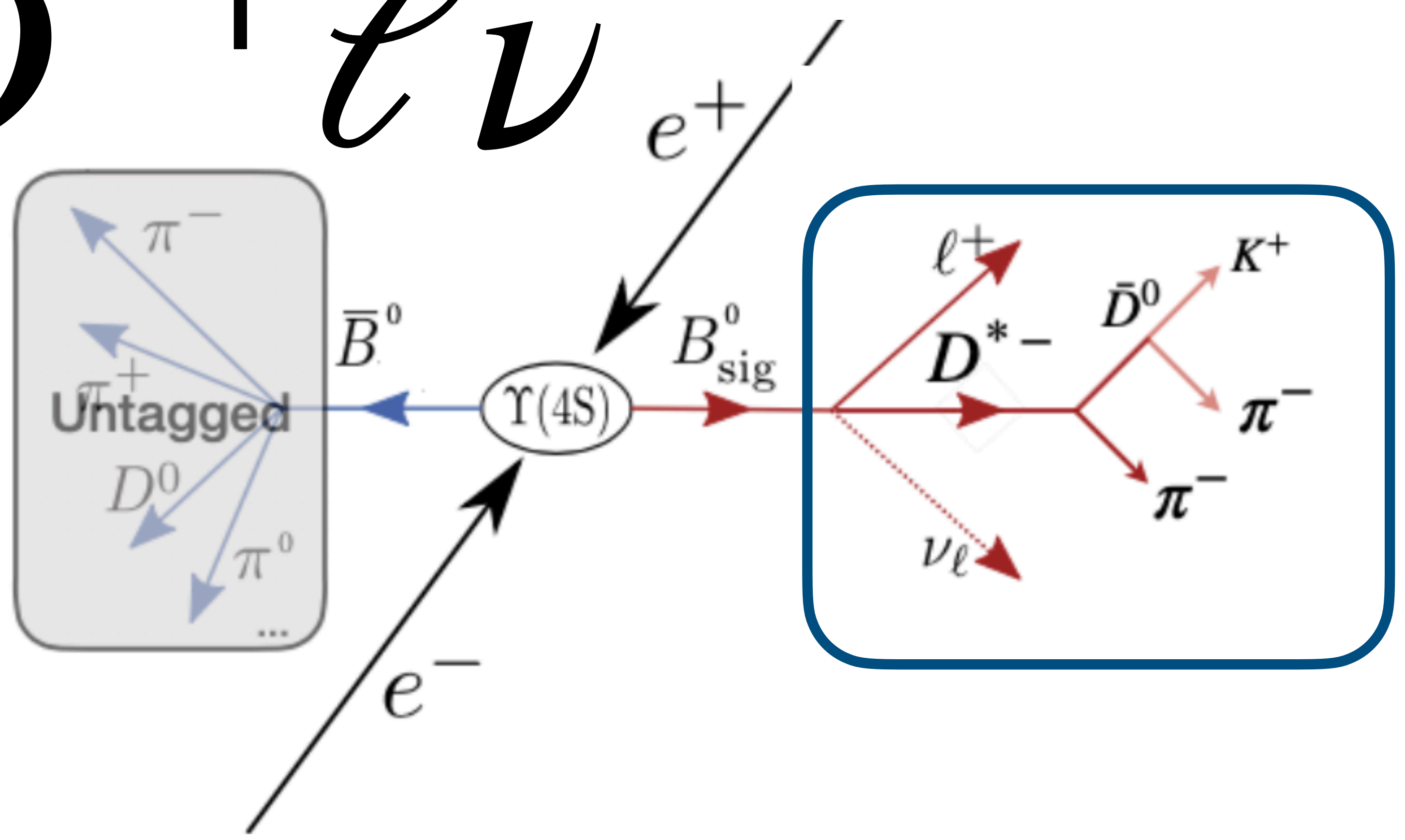
$$\boxed{\mathscr{B}(\bar{B}^0 \to D^{*+}\ell\nu_\ell) = (4.51 \pm 0.41_{stat} \pm 0.27_{syst} \pm 0.45_{\pi_s})\,\%}$$



In agreement with world average

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

Untagged Exclusive $B \to D^{*+}\ell\nu$



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.

Extract signal yield with a fit to $cos\theta_{BY}$, where Y= $D^*\ell$.

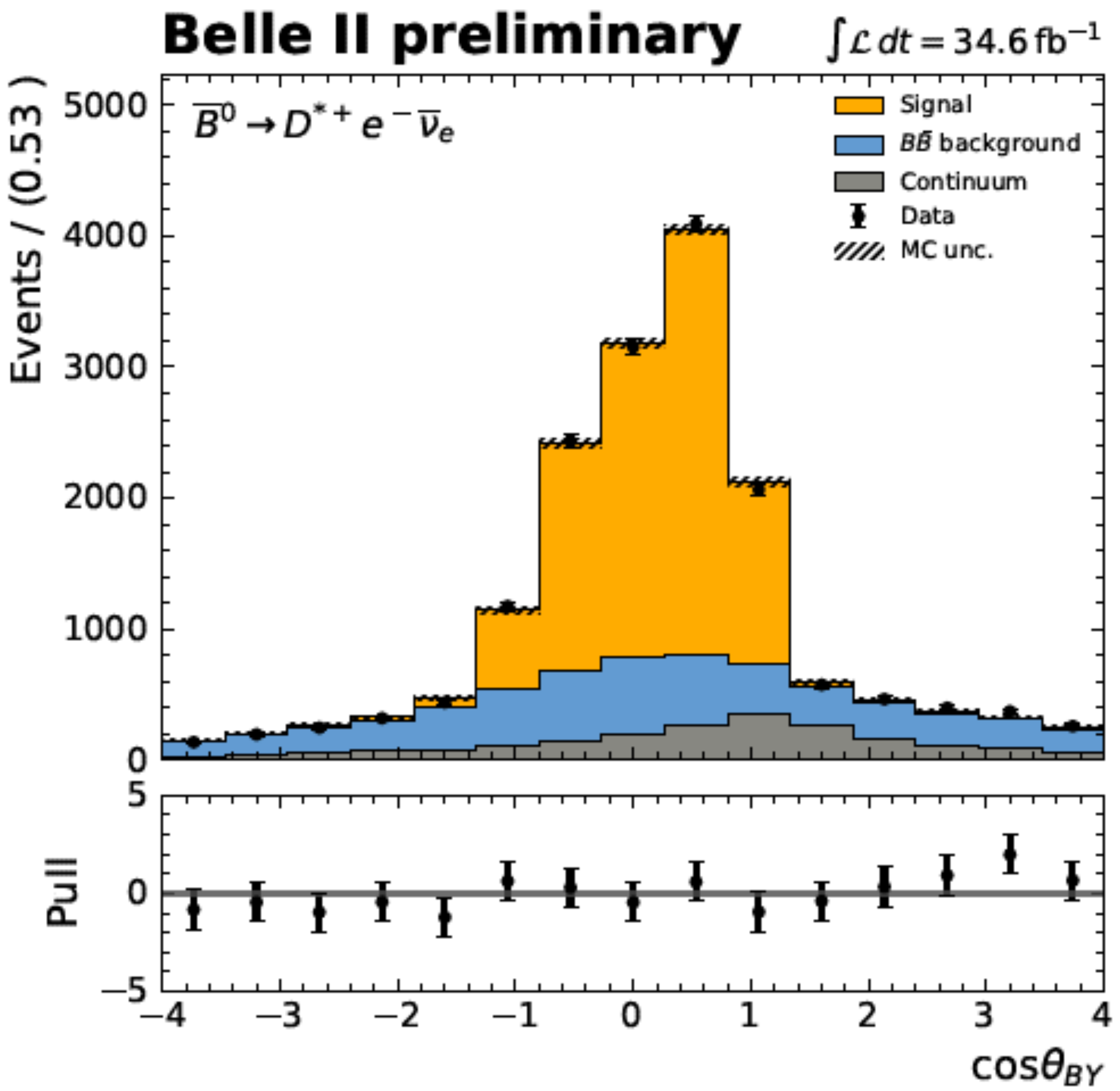
$$cos\theta_{BY} = \frac{2E_B^*E_Y^* - m_B^2 - m_Y^2}{2|p_B^*||p_Y^*|}$$

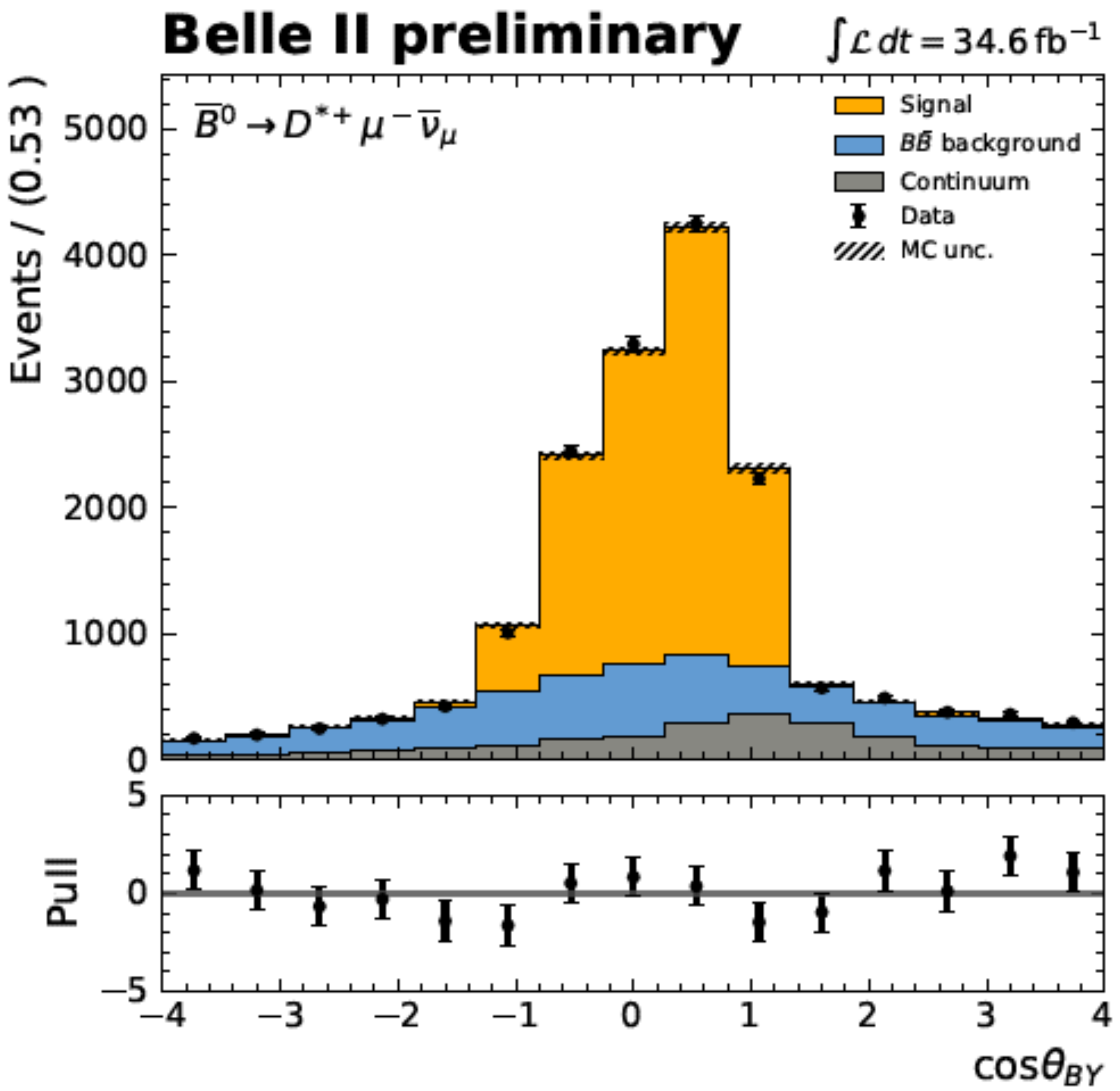
$\mathscr{B}(\bar{B}^0 \to D^{*+}\ell\bar{\nu}) = (4.60 \pm 0.05(stat) \pm 0.18(sys) \pm 0.45\pi_s)$ %

Compatible with current world average.

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

Expecting updated results with the full available Belle II dataset very soon.

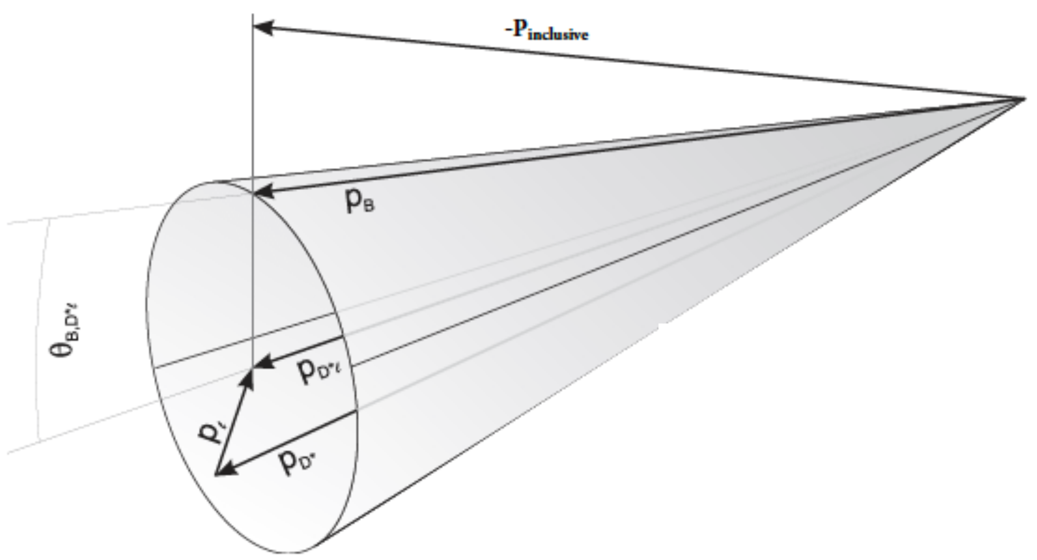


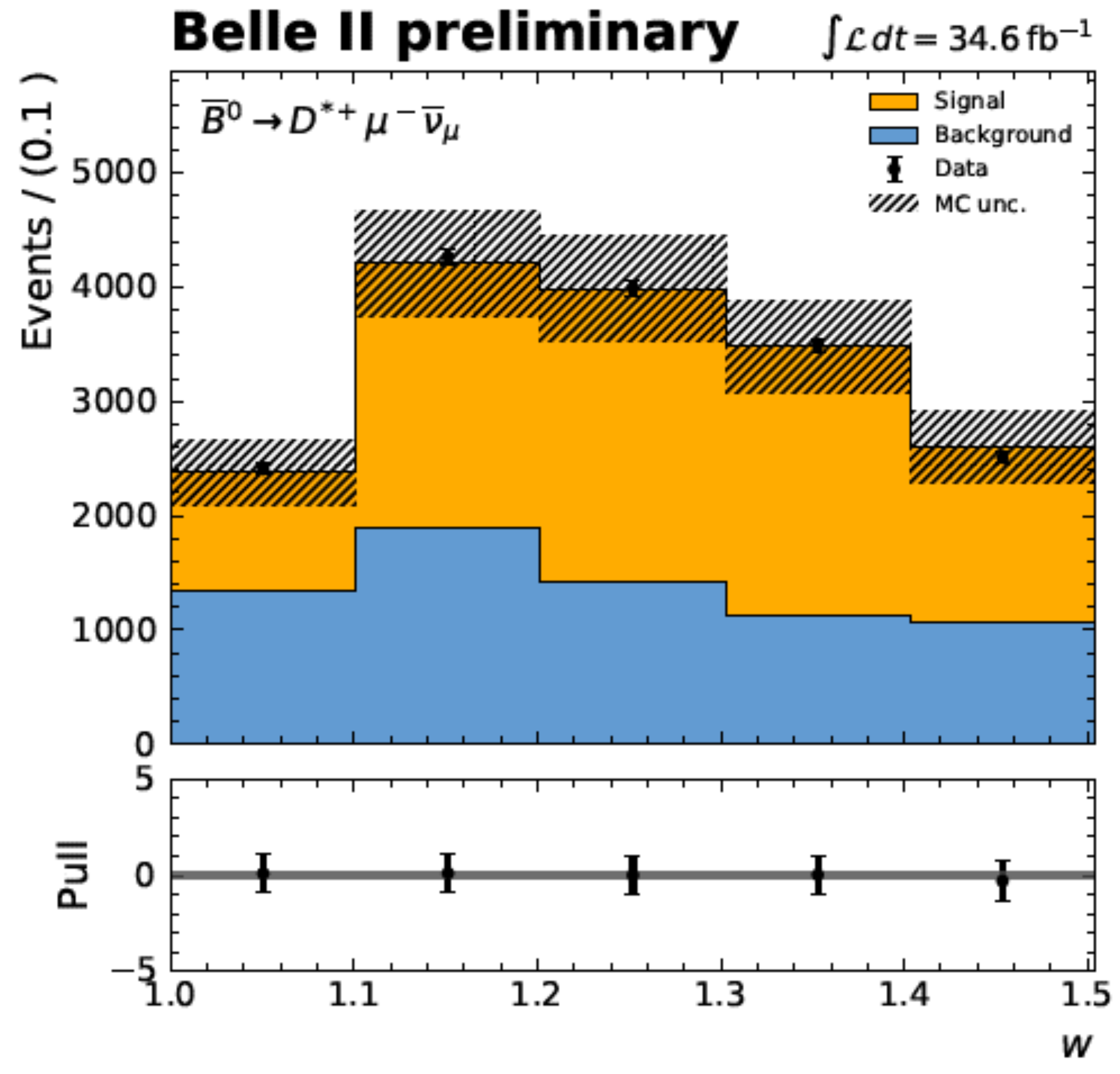


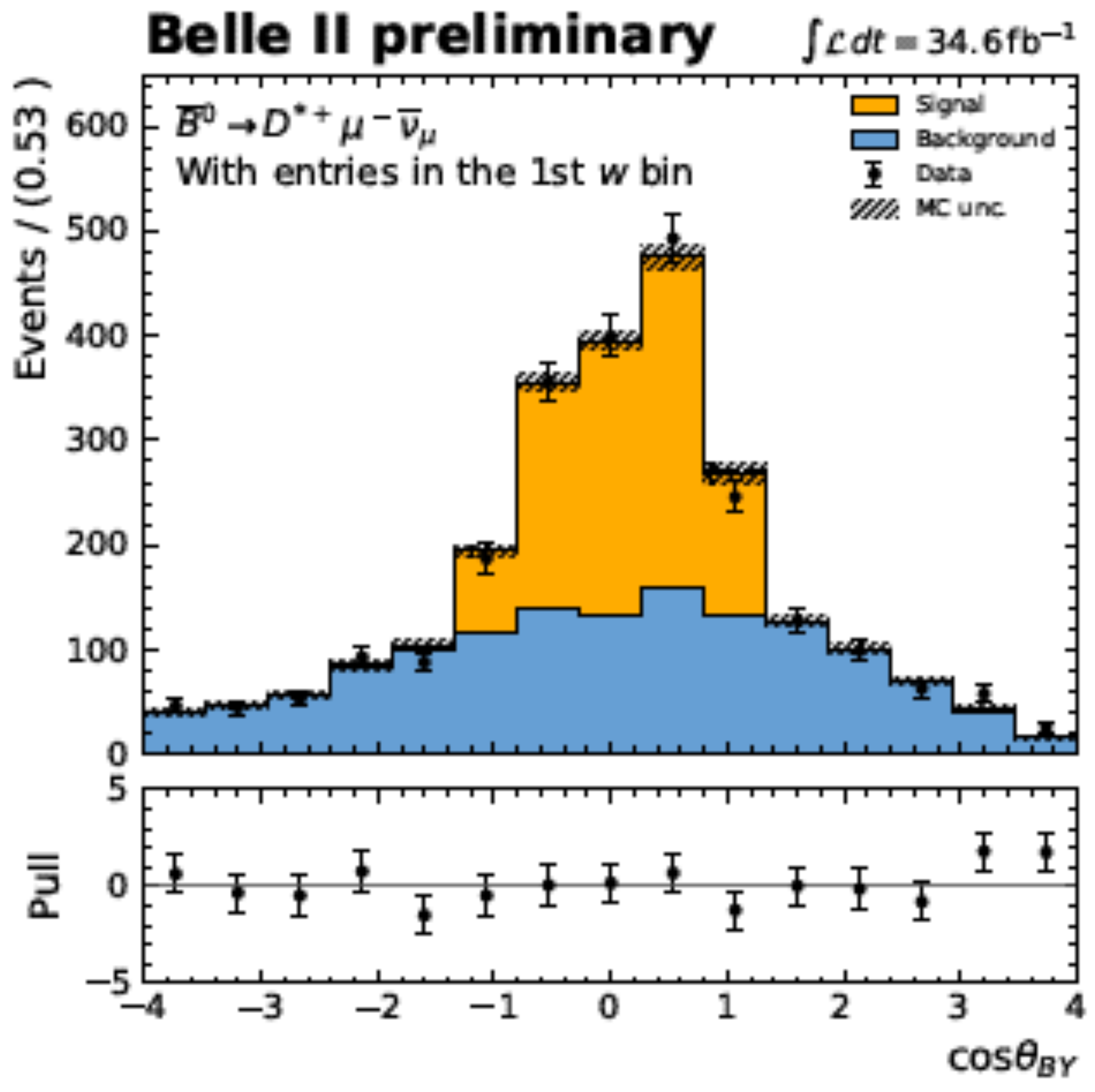
Untagged Exclusive $B \to D^{*+}\ell\nu$

Examine hadronic recoil parameter spectrum

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



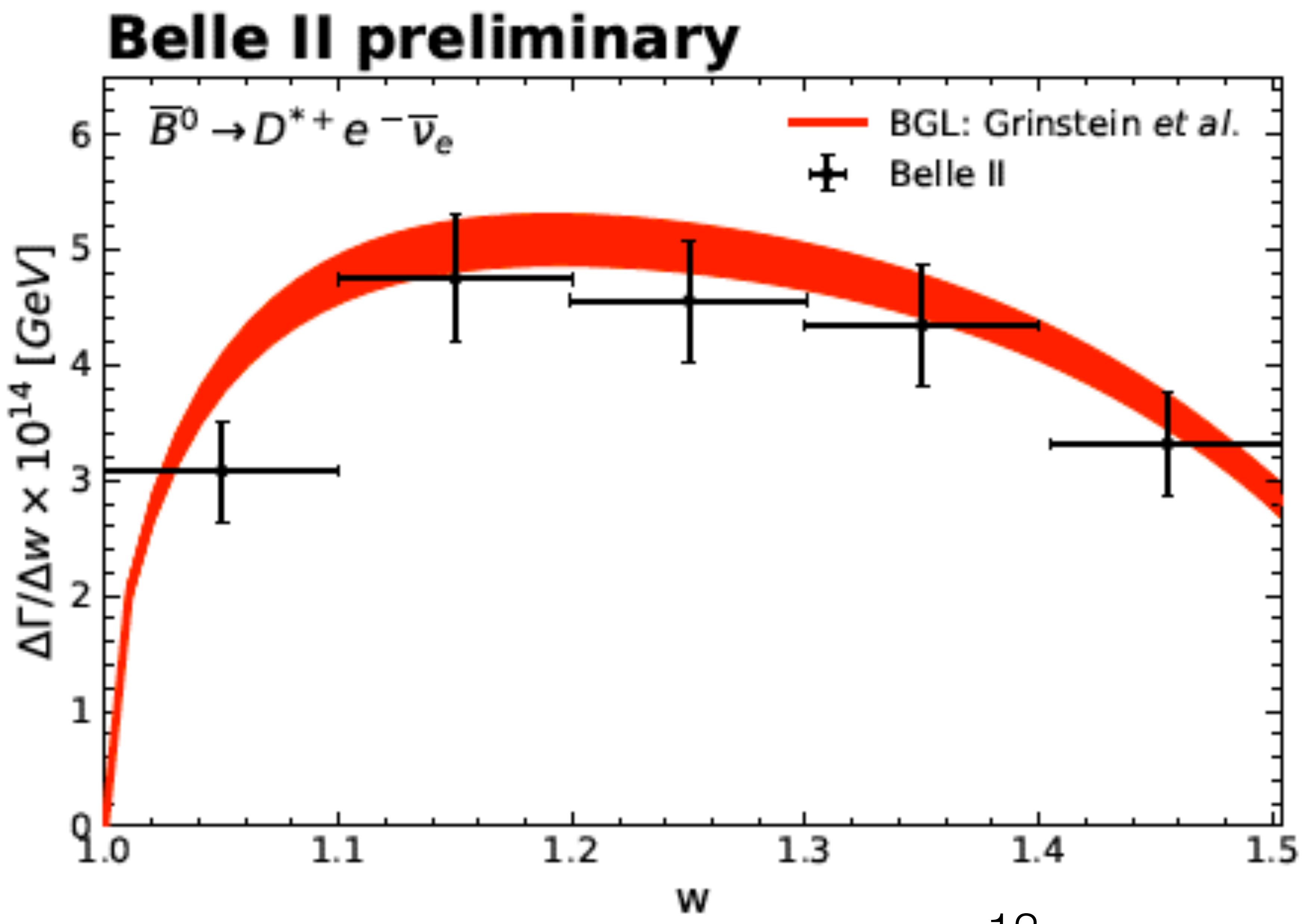


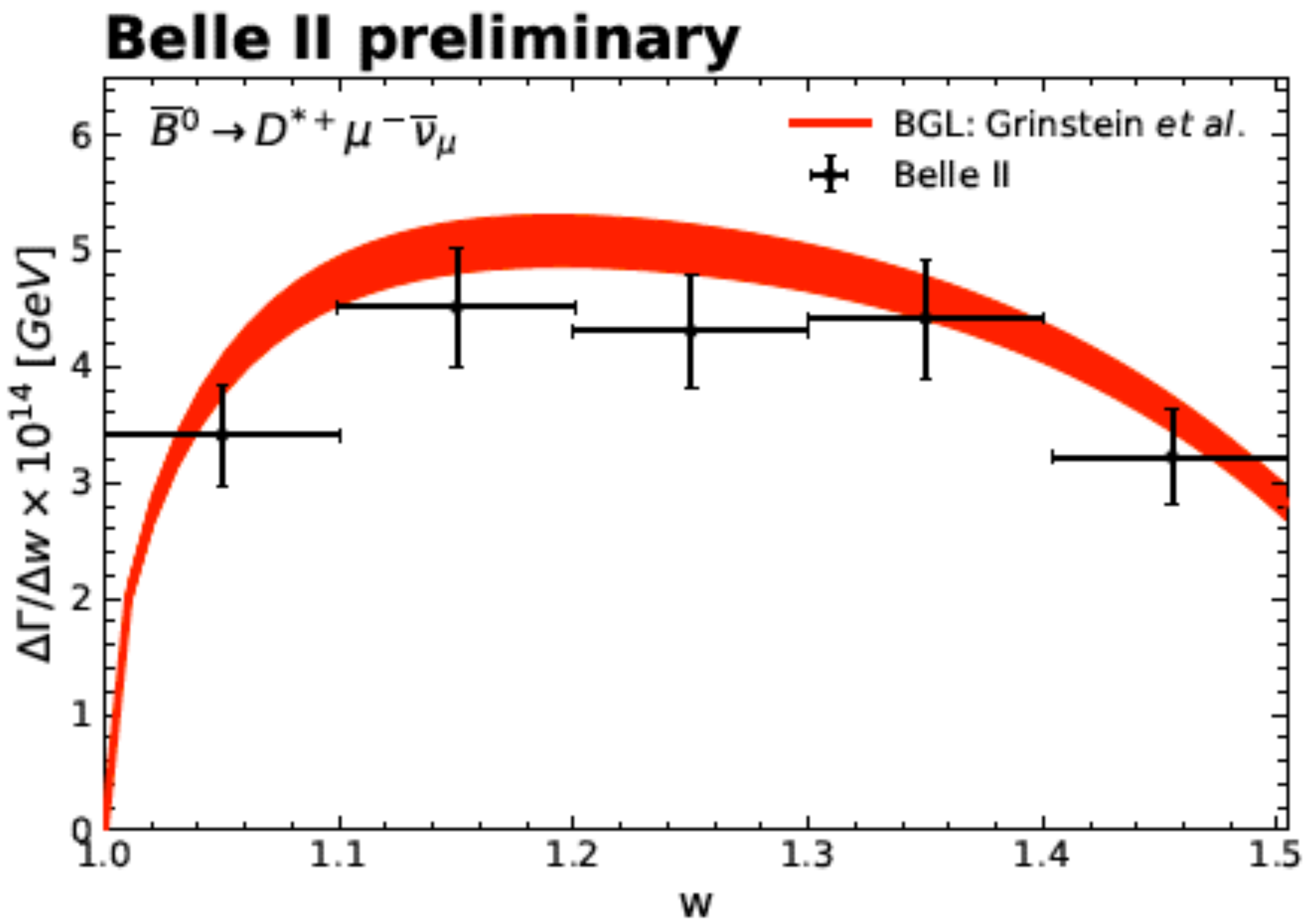


Divide spectrum into 5 equal bins of 0.1008 between w=1 and w_{max}=1.504.

Unfold the *w* spectrum to compare with BGL.

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





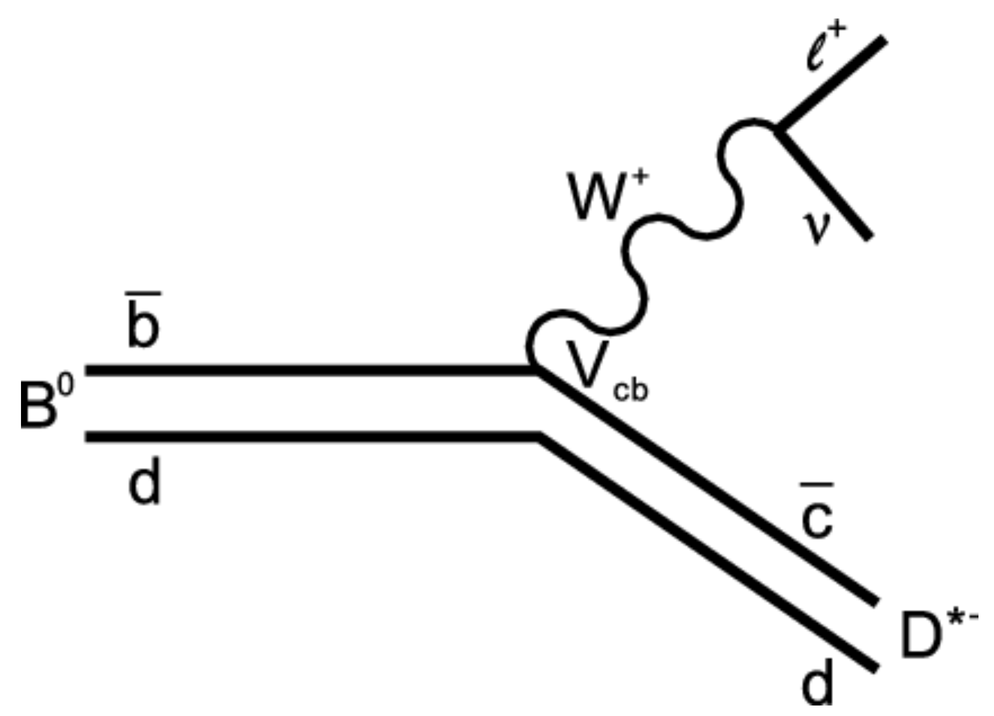
Phys. Rev. D **56**, 6895, 1997

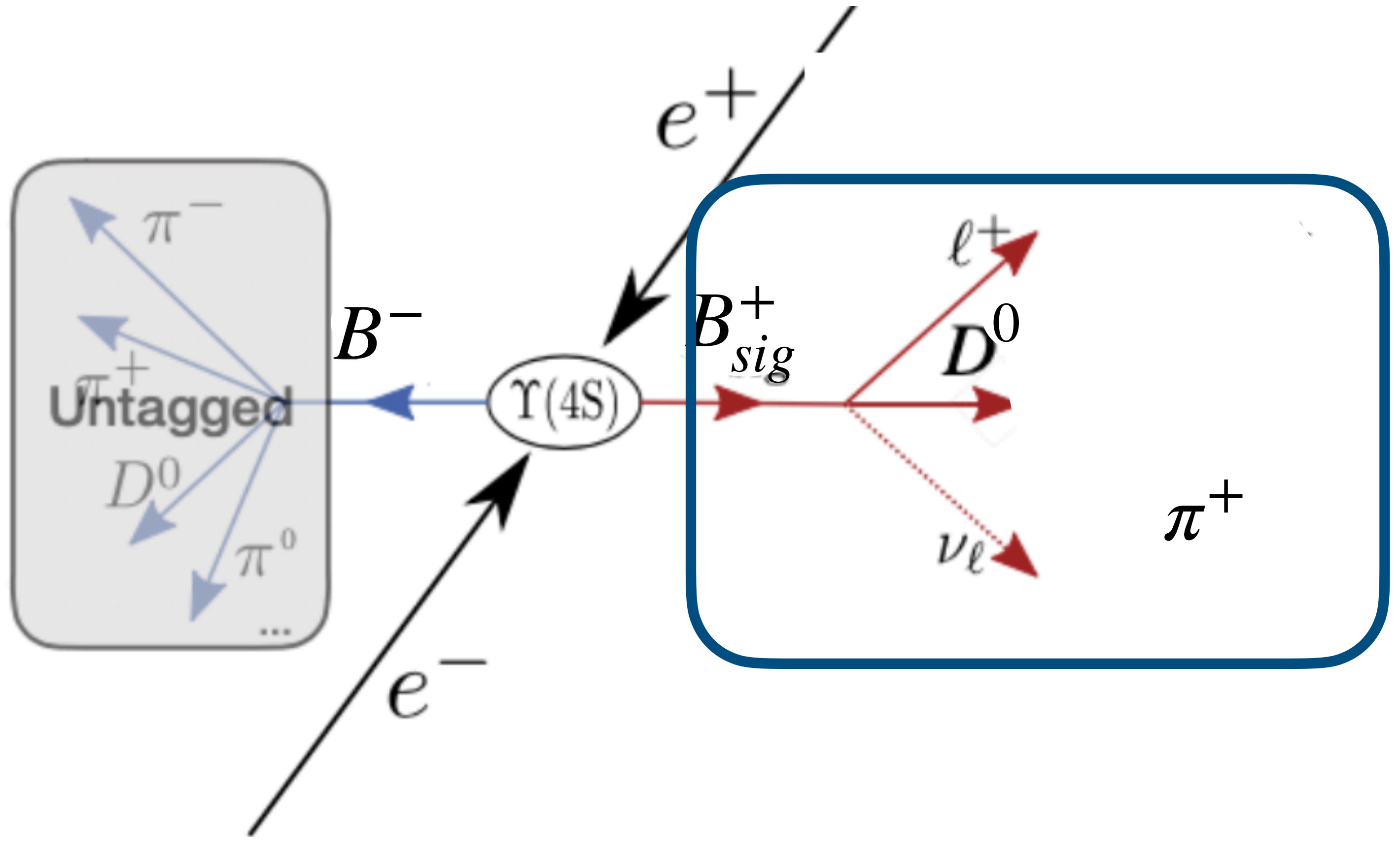
$B^- \to D^0 \ell \nu$

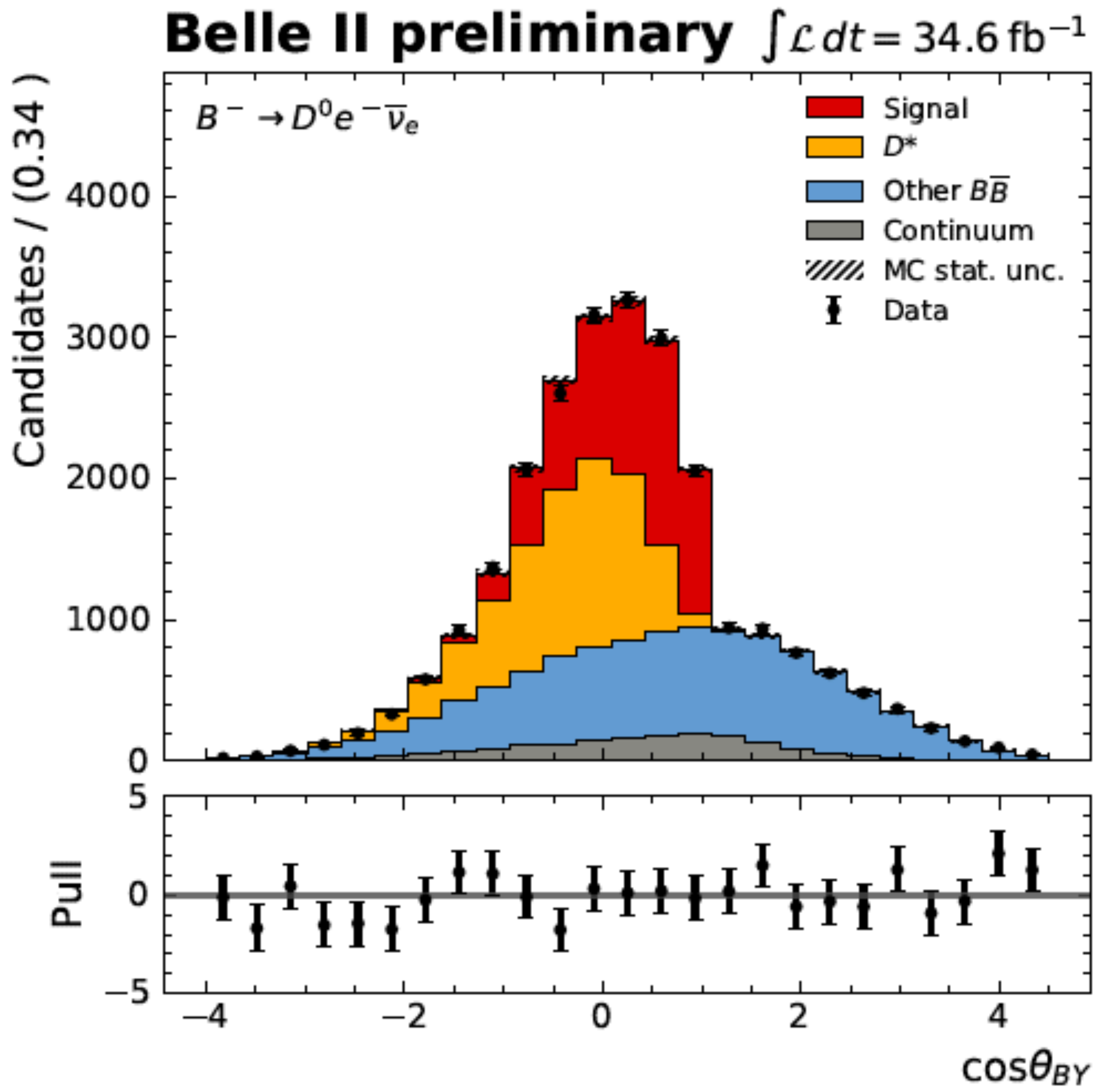
Flagship decay for exclusive V_{cb} measurements!

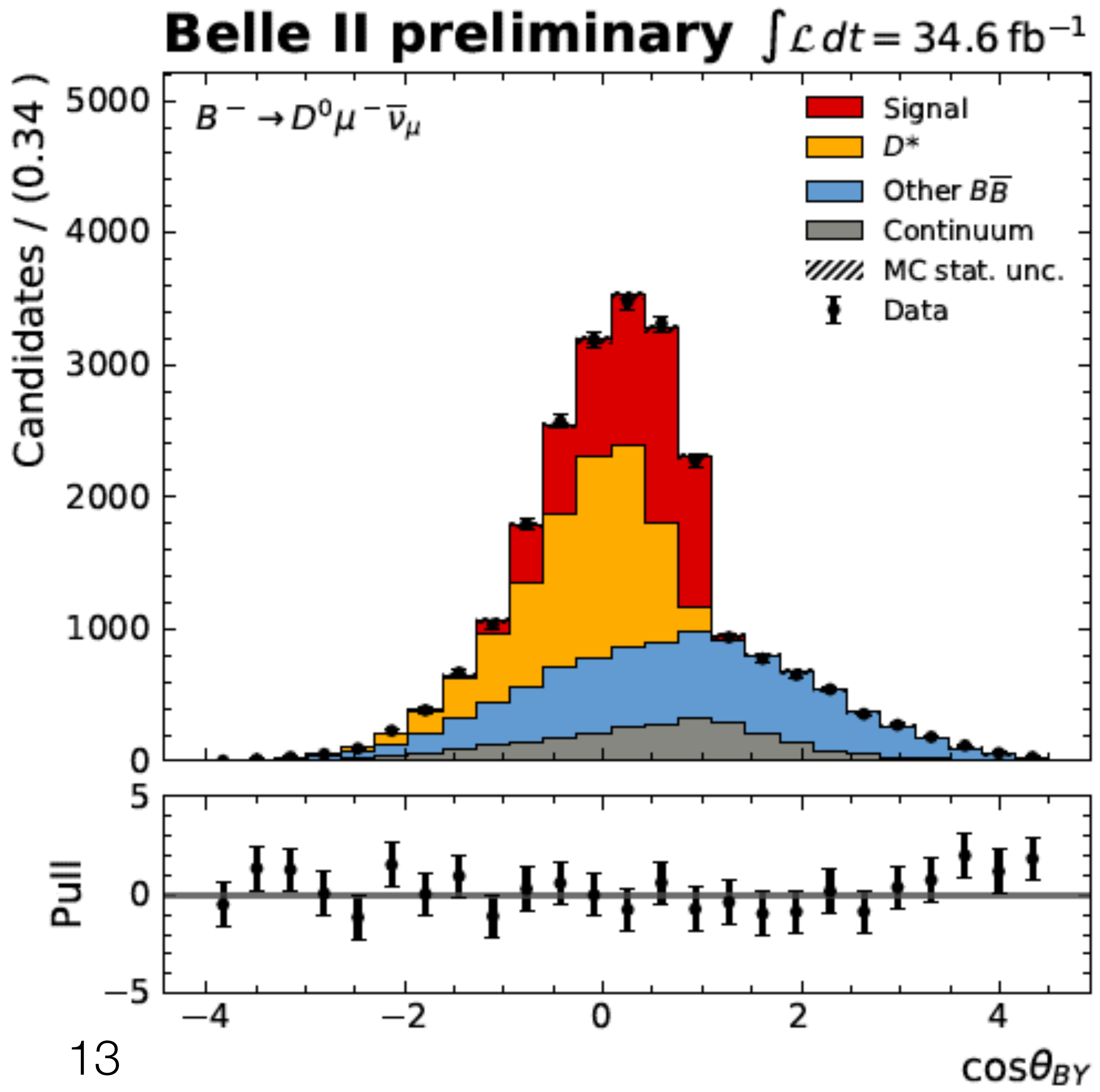
Reconstruct $D^0 \to K^- \pi^+$.
Identify lepton using PID algorithms.
Suppress $e^+e^- \to q\bar{q}$ events using p_{D^*}<2.4 GeV/c and R_2 <0.3

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 $B \to X_c \ell \nu$

- Heavy Quark Expansion (HQE) in powers of $1/m_b$
- Determine parameters of HQE using moments of the differential rate.

$$\langle E^n \rangle_{\mathrm{cut}} = \frac{\int_{E_\ell > E_{\mathrm{cut}}} dE_\ell \, E_\ell^n \, \frac{d\Gamma}{dE_\ell}}{\int_{E_\ell > E_{\mathrm{cut}}} dE_\ell \, \frac{d\Gamma}{dE_\ell}} \qquad \langle (M_X^2)^n \rangle_{\mathrm{cut}} = \frac{\int_{E_\ell > E_{\mathrm{cut}}} dM_X^2 \, (M_X^2)^n \, \frac{d\Gamma}{dM_X^2}}{\int_{E_\ell > E_{\mathrm{cut}}} dM_X^2 \, \frac{d\Gamma}{dM_X^2}} \qquad R^*(E_{\mathrm{cut}}) = \frac{\int_{E_\ell > E_{\mathrm{cut}}} dE_\ell \, \frac{d\Gamma}{dE_\ell}}{\int_0 dE_\ell \, \frac{d\Gamma}{dE_\ell}}$$

$$\mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3, m_b, (m_c)$$

- Using the branching fraction, determine $|V_{cb}|$

$$\mathrm{Br}(\bar{B} \to X_c \ell \bar{\nu}) \propto \frac{|V_{cb}|^2}{\tau_B} \left[\Gamma_0 + \Gamma_{\mu_\pi} \frac{\mu_\pi^2}{m_b^2} + \Gamma_{\mu_G} \frac{\mu_G^2}{m_b^2} + \Gamma_{\rho_D} \frac{\rho_D^3}{m_b^3} \right]$$

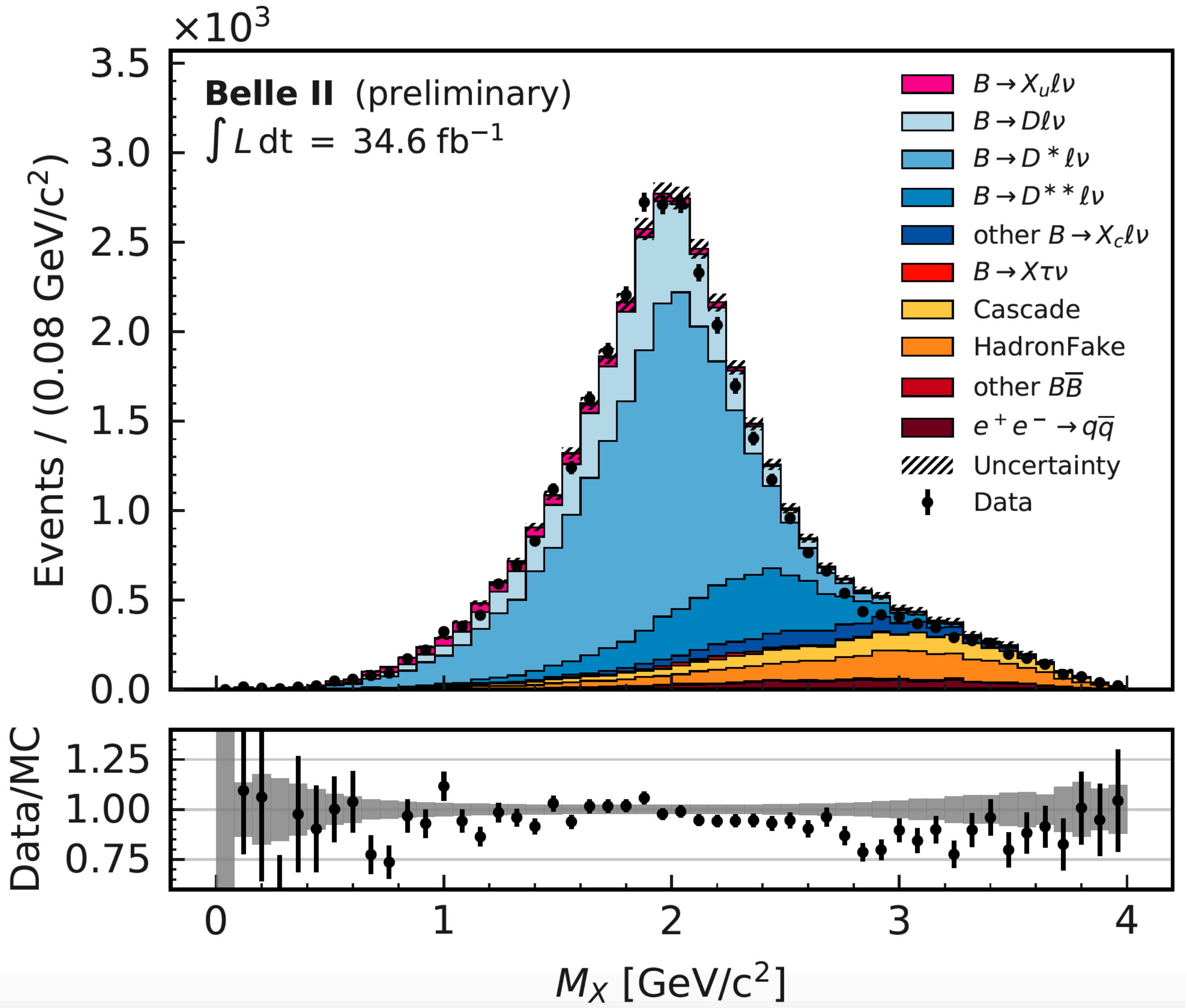
	Kinetic scheme	1S scheme
$O(1)$	m_b, m_c	m_b
$O(1/m_b^2)$	μ_π^2, μ_G^2	λ_1, λ_2
$O(1/m_b^3)$	ρ_D^3, ρ_{LS}^3	ρ_1, τ_{1-3}

JHEP 1109 055 (2011)
Phys. Rev. D **70**, 094017 (2004)

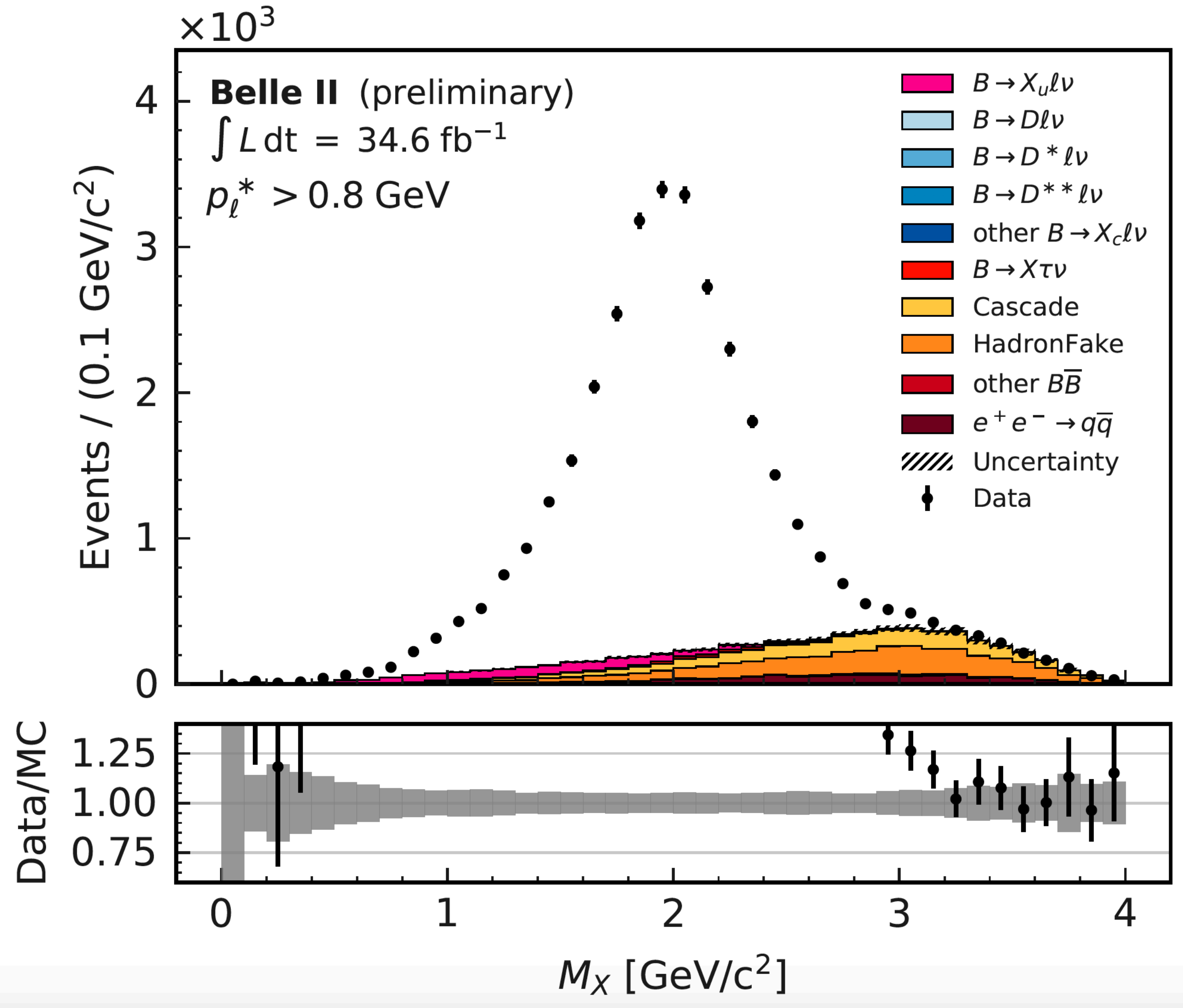
Hadronic Mass Moments of $B \to X_c \ell \nu_\ell$

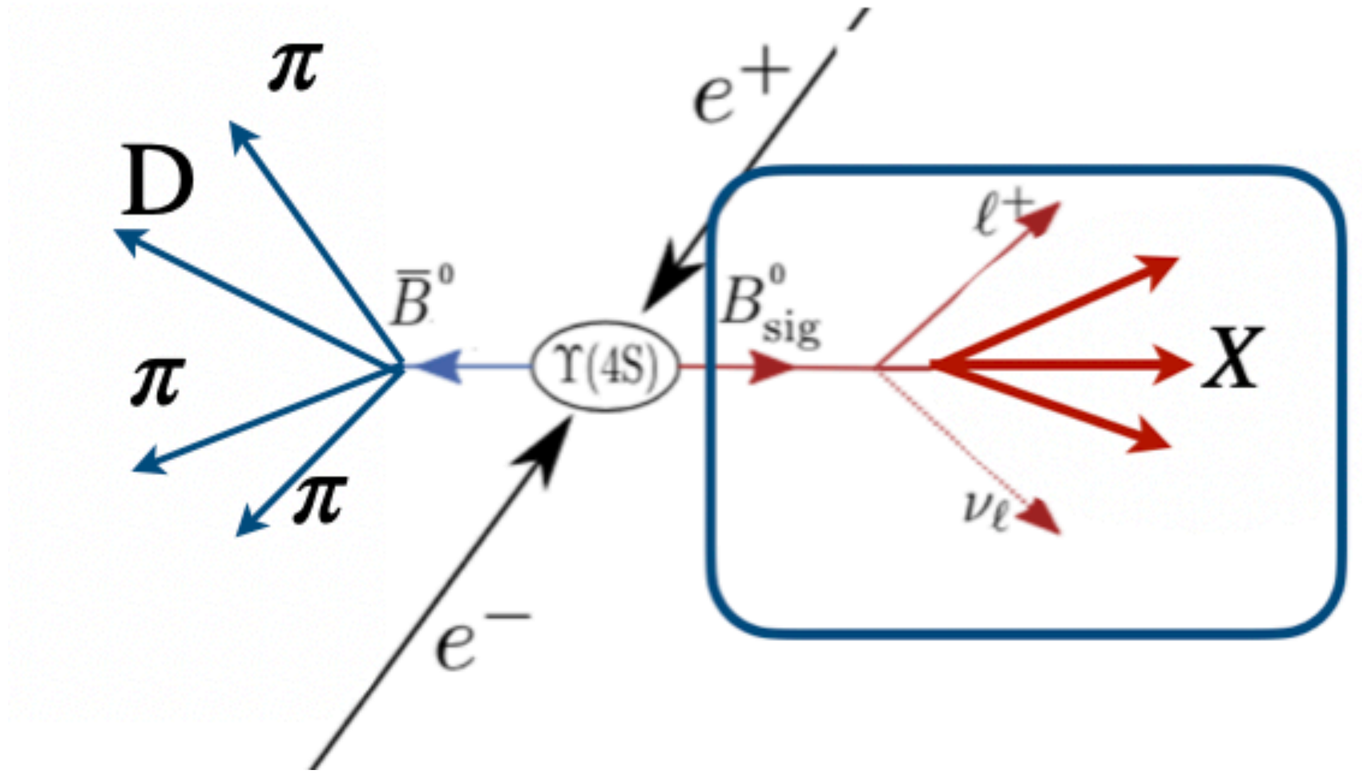
arXiv:2009.04493

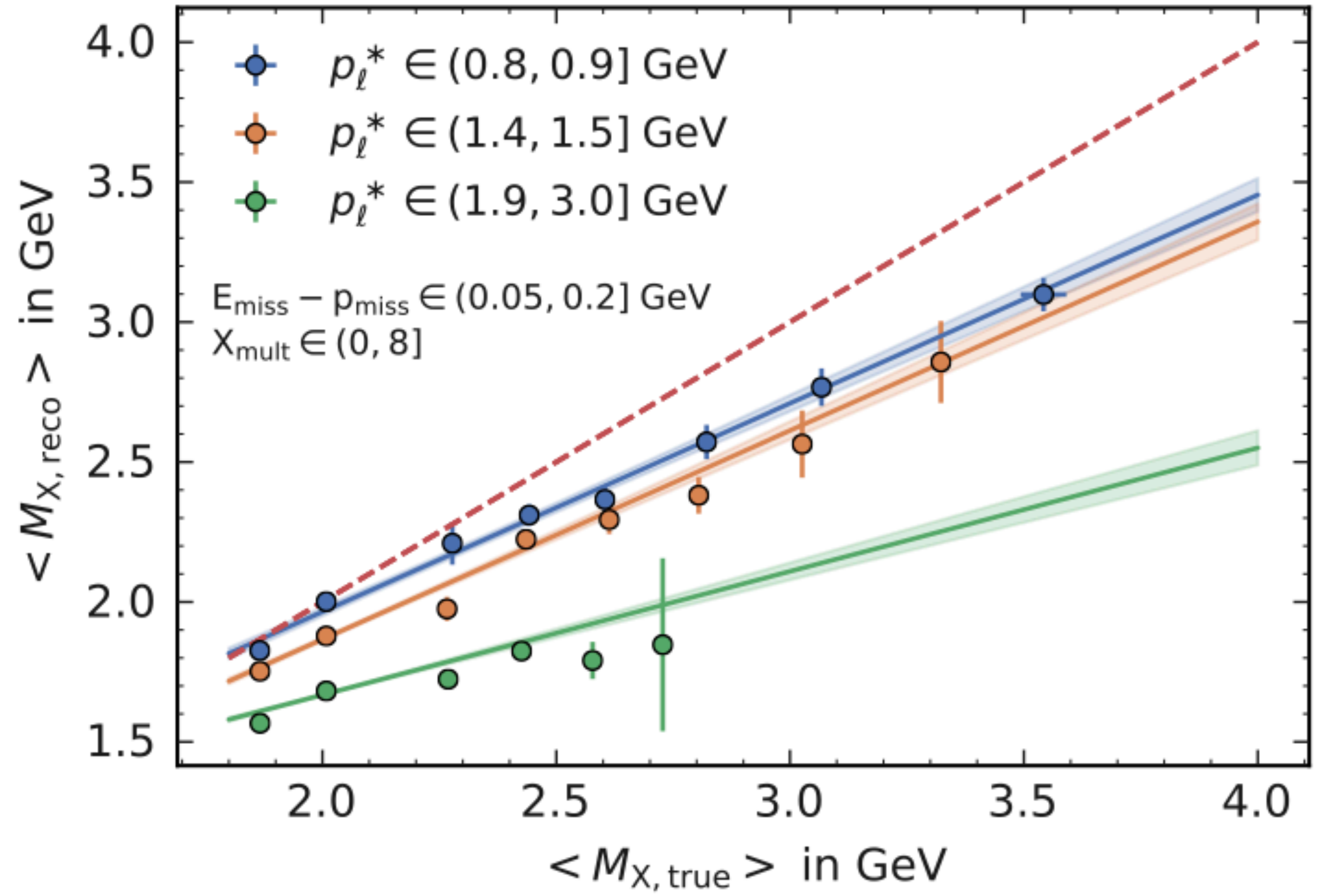
- Use hadronic FEI tagging and identify one lepton with $p^*_l > 0.8$ GeV/c.



Subtract background by assigning a signal probability to each event







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

Reconstruction bias

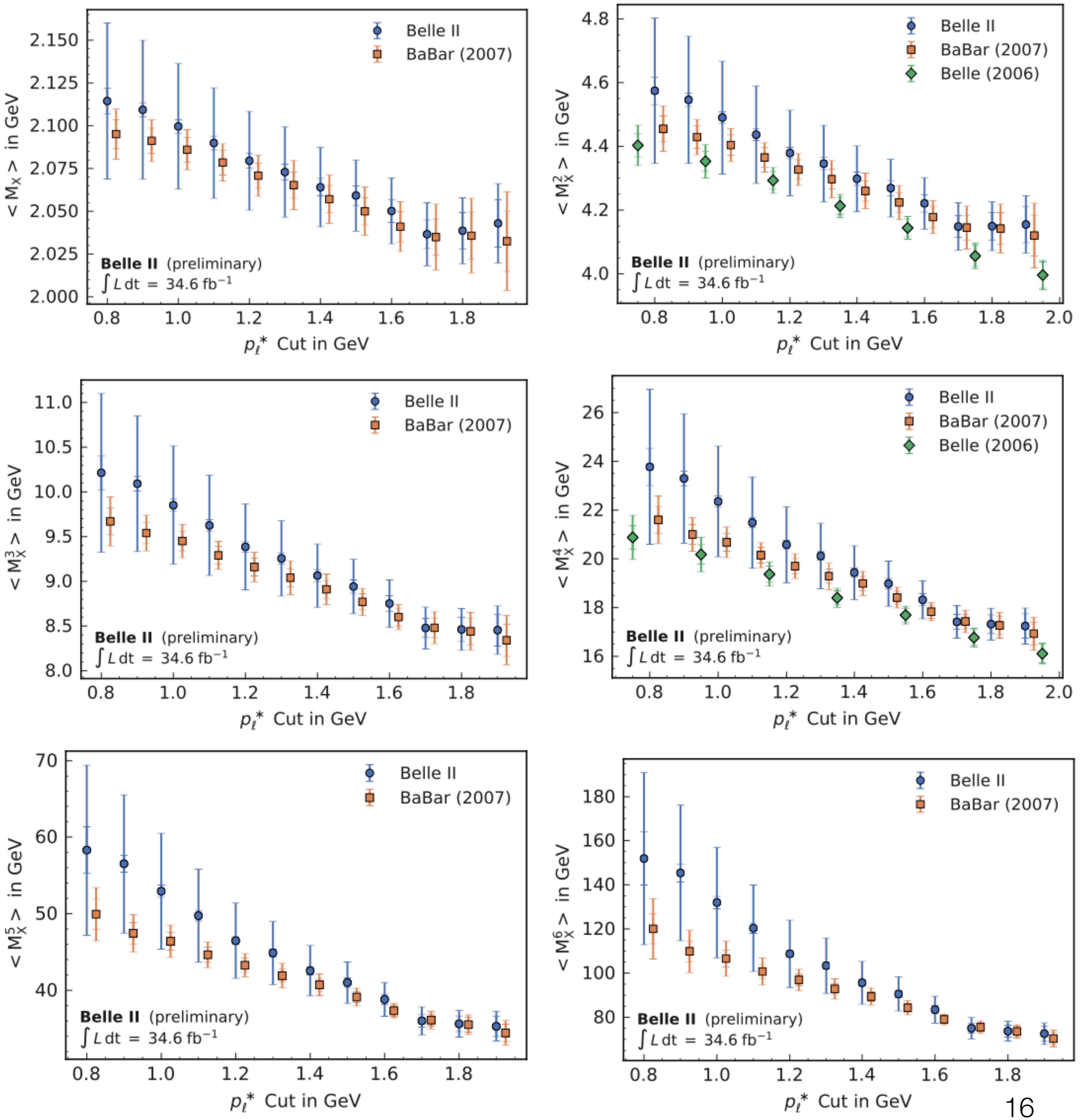
$$\langle M_X^n \rangle = \frac{\sum_i w_i(M_X) M_{X,\mathrm{calib},i}^n}{\sum_i w_i(M_X)} \times \mathcal{C}_{\mathrm{calib}} \times \mathcal{C}_{\mathrm{true}}$$

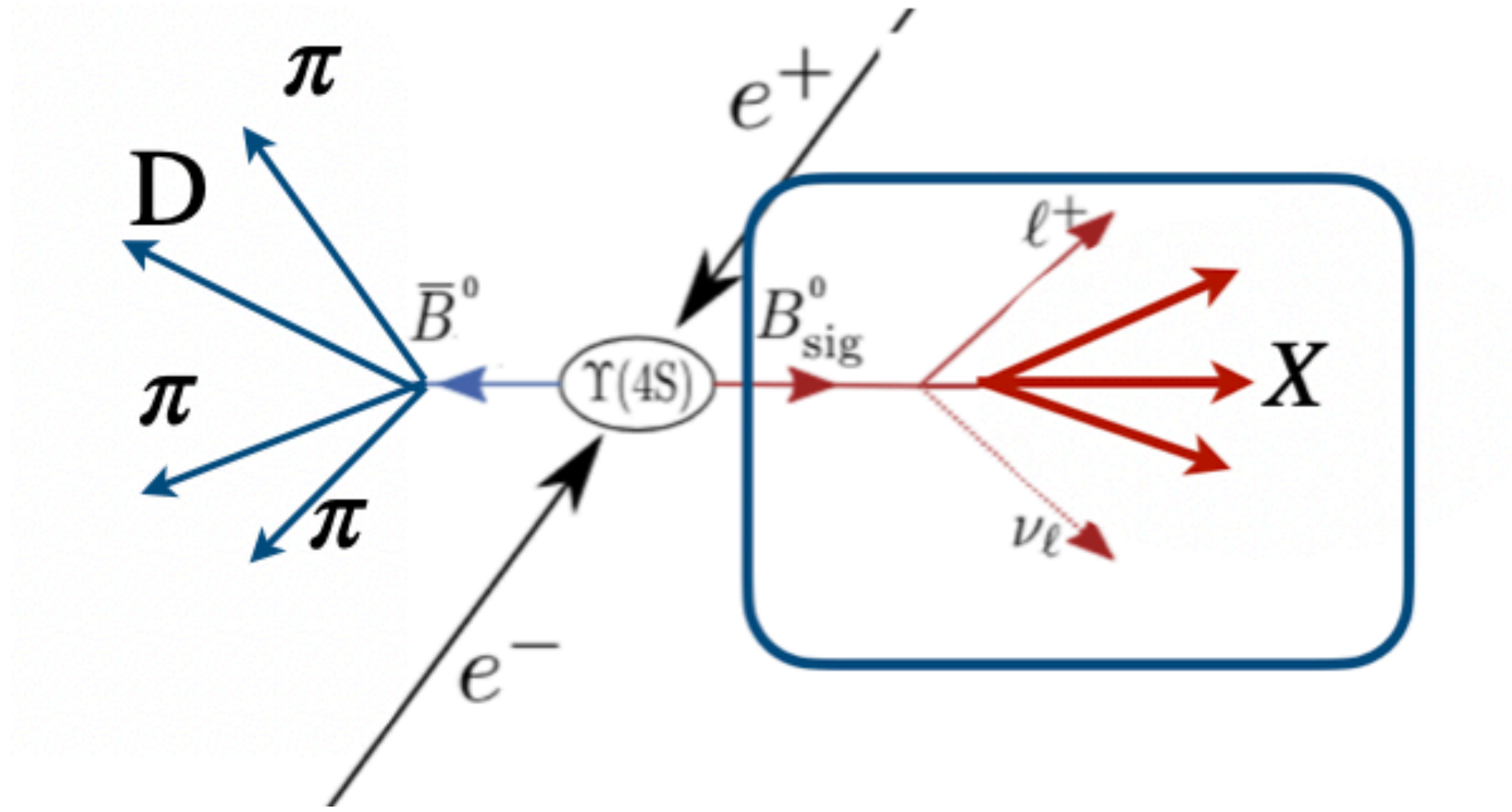
Calibration Bias

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

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

arXiv:2009.04493





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

Alternative Inclusive $|V_{cb}|$

- Achieve more precision by including higher order:

$$\Gamma \propto |V_{cb}|^2 m_b^5 \left[\Gamma_0 + \Gamma_0^{(1)} \frac{\alpha_s}{\pi} + \Gamma_0^{(2)} \left(\frac{\alpha_s}{\pi}\right)^2 + \frac{\mu_\pi^2}{m_b^2}\left(\Gamma^{(\pi,0)} + \frac{\alpha_s}{\pi}\Gamma^{(\pi,1)}\right) + \frac{\mu_G^2}{m_b^2}\left(\Gamma^{(G,0)} + \frac{\alpha_s}{\pi}\Gamma^{(G,1)}\right) + \frac{\rho_D^3}{m_b^3}\Gamma^{(D,0)} + \mathcal{O}\left(\frac{1}{m_b^4}\right) \cdots \right]$$

NOVEL APPROACH!!!

Fael, Mannel, Vos , JHEP 02 (2019) 177

- Number of parameters: 4 up to $1/m_b^3$, 13 up to $1/m_b^4$ and 31 up to $1/m_b^5$
- Use reparametrization invariance to link different orders of 1/mb and reduce the number of total parameters
- Requires RPI observables such as q²

8 parameters instead of 13 !

- $2M_B r_G^4 \equiv \frac{1}{2}\langle B|\bar{b}_v\,[iD_\mu, iD_\nu]\,[iD^\mu, iD^\nu]\,b_v|B\rangle \propto \langle \vec{E}^2 - \vec{B}^2\rangle$
- $2M_B r_E^4 \equiv \frac{1}{2}\langle B|\bar{b}_v\,[ivD, iD_\mu]\,[ivD, iD^\mu]\,b_v|B\rangle \propto \langle \vec{E}^2\rangle$
- $2M_B s_B^4 \equiv \frac{1}{2}\langle B|\bar{b}_v\,[iD_\mu, iD_\alpha]\,[iD^\mu, iD_\beta]\ (-i\sigma^{\alpha\beta})b_v|B\rangle \propto \langle \vec{\sigma}\cdot\vec{B}\times\vec{B}\rangle$

$$\langle (q^2)^n\rangle_{\mathrm{cut}} = \int_{q^2>q^2_{\mathrm{cut}}} dq^2\,(q^2)^n \frac{d\Gamma}{dq^2} \Big/ \int_{q^2>q^2_{\mathrm{cut}}} dq^2 \frac{d\Gamma}{dq^2}$$

$$R^*(q^2_{\mathrm{cut}}) = \int_{q^2>q^2_{\mathrm{cut}}} dq^2 \frac{d\Gamma}{dq^2} \Big/ \int_0 dq^2 \frac{d\Gamma}{dq^2}$$

- HQE expressed in higher order terms

$$\mathrm{Br}(\bar{B}\to X_c\ell\bar{\nu}) \propto \frac{|V_{cb}|^2}{\tau_B}\left[\Gamma_{\mu_3}\mu_3 + \Gamma_{\mu_G}\frac{\mu_G^2}{m_b^2} + \Gamma_{\tilde{\rho}_D}\frac{\tilde{\rho}_D^3}{m_b^3} + \Gamma_{r_E}\frac{r_E^4}{m_b^4} + \Gamma_{r_G}\frac{r_G^4}{m_b^4} + \Gamma_{s_B}\frac{s_B^4}{m_b^4} + \Gamma_{s_E}\frac{s_E^4}{m_b^4} + \Gamma_{s_{qB}}\frac{s_{qB}^4}{m_b^4}\right]$$

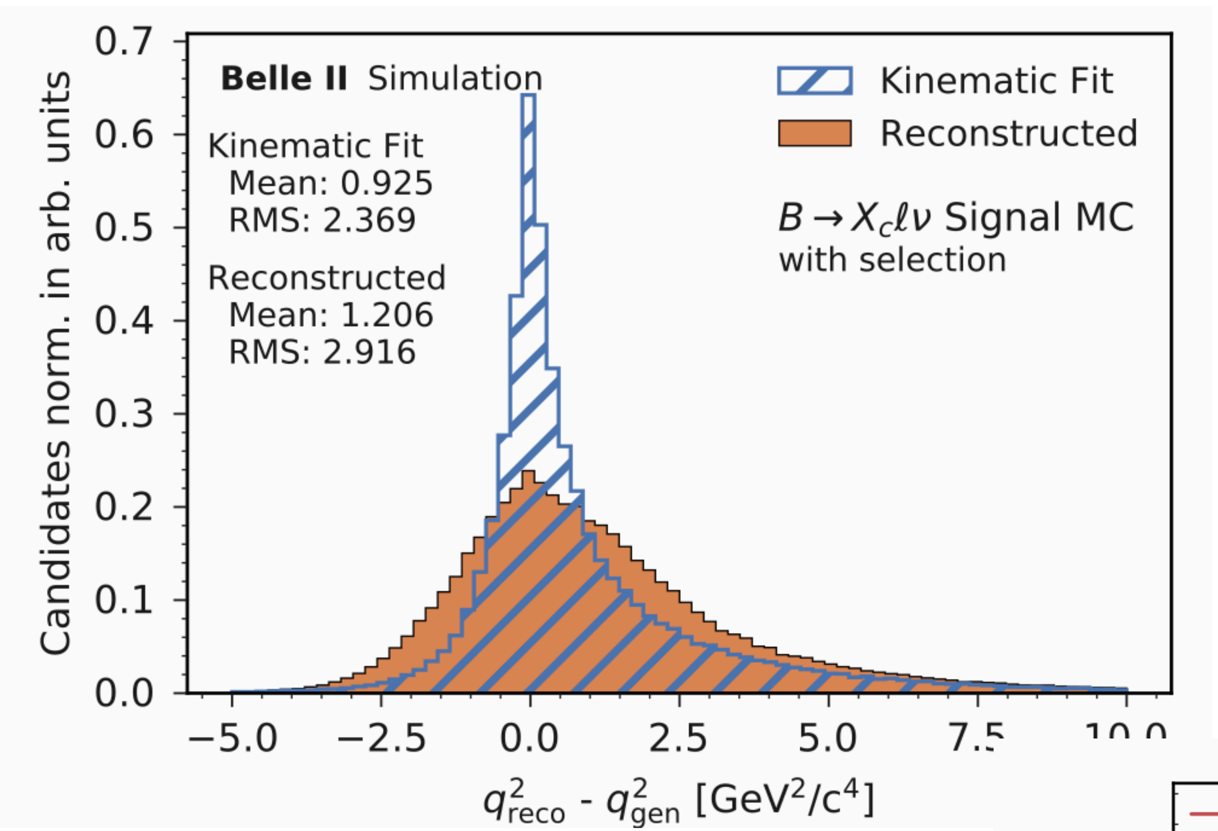
$\mu_3, \mu_G, \tilde{\rho}_D, r_E, r_G, s_E, s_B, s_{qB}, m_b, m_c$

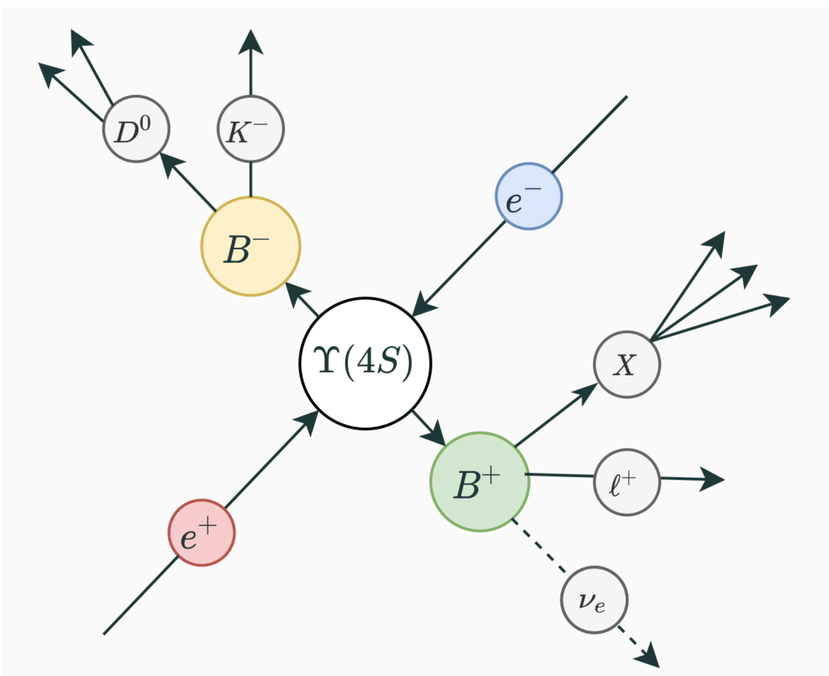
Determine moments and use it determine $|V_{cb}|$

q^2 moments from $B \to X_c \ell \nu$

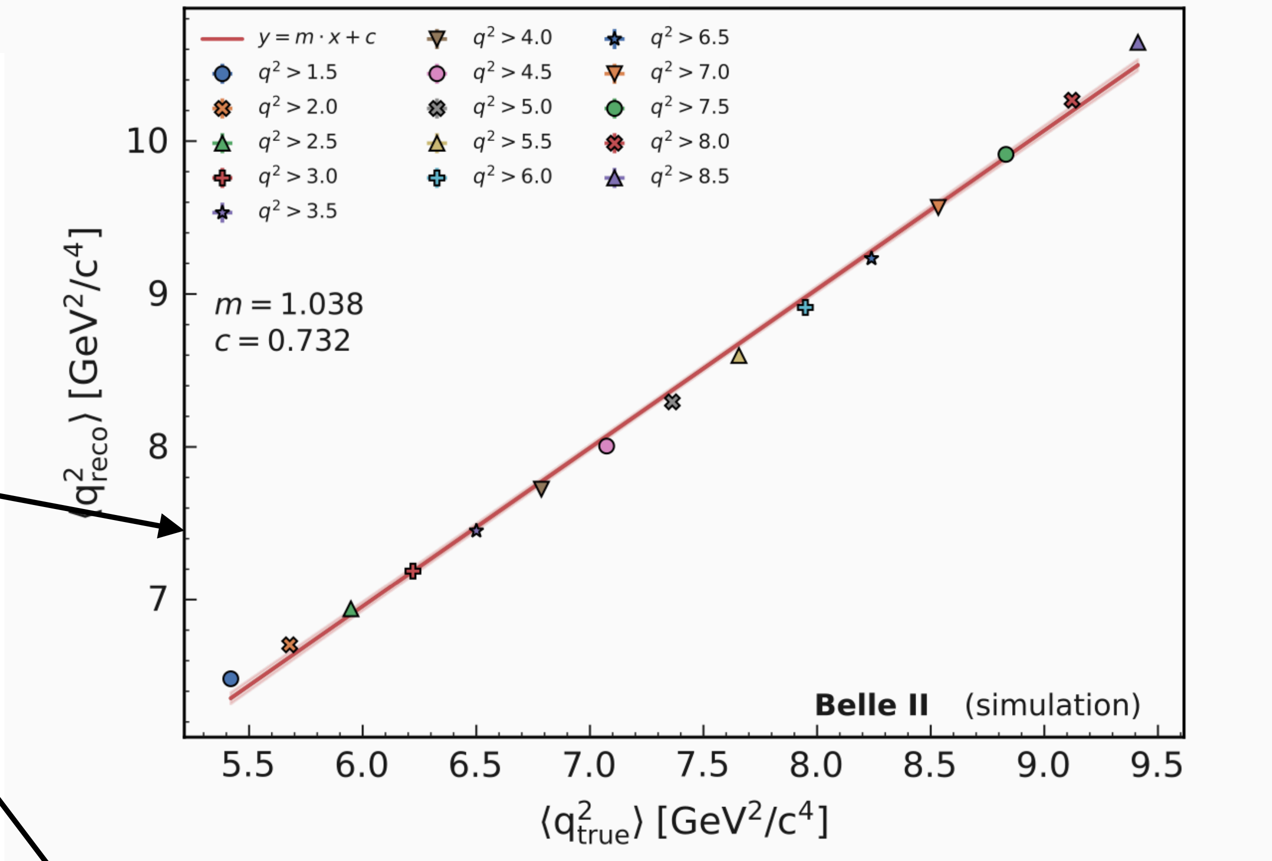
- Similar to m_X moments, use hadronic tagging and reconstruct X from rest-of-event (ROE).
- Apply kinematic fit with B mass constraint to improve the q^2 resolution.
- Fit to independent variable M_X in order to fix background normalization and determine signal probability

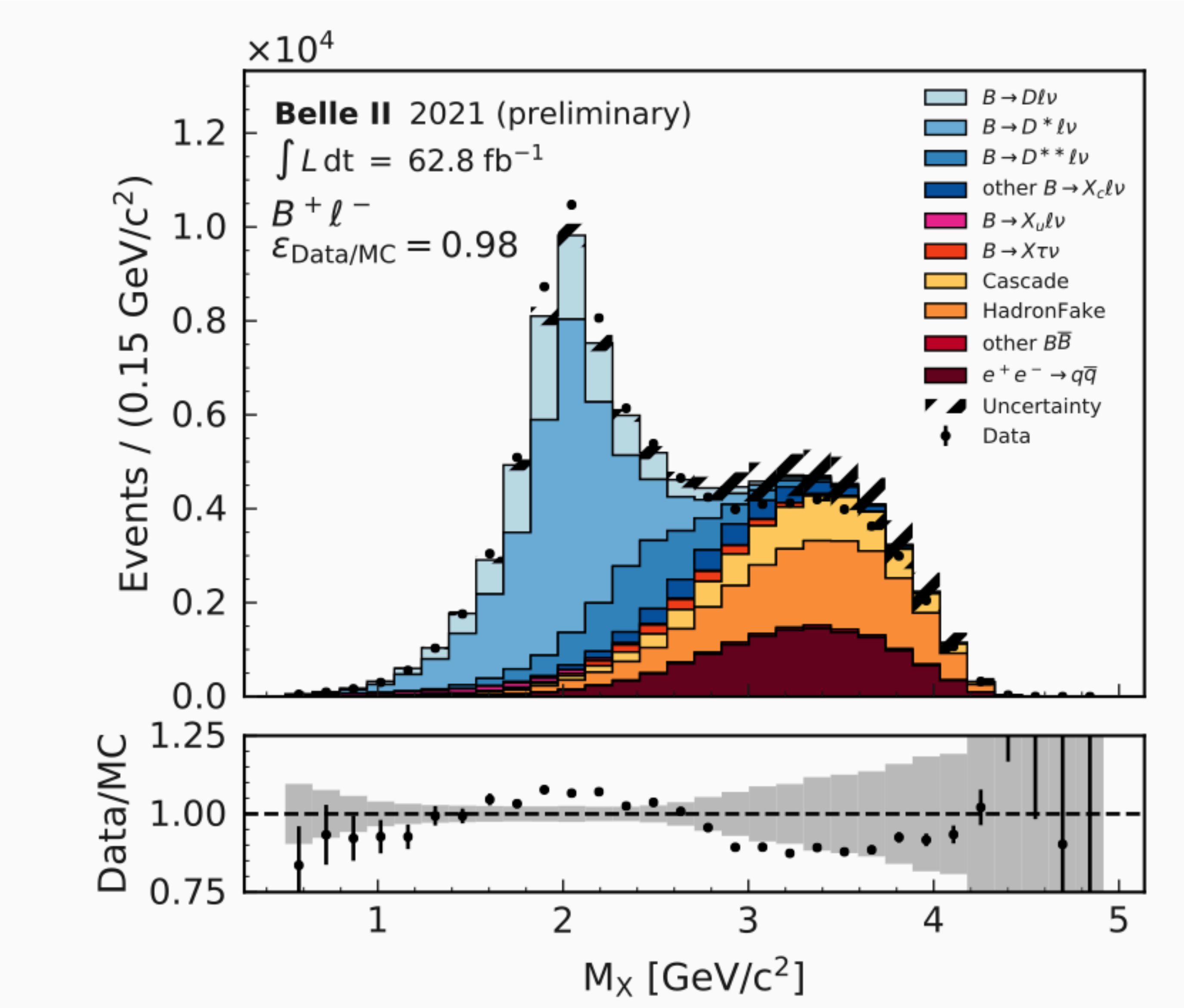
Paper draft in preparation.

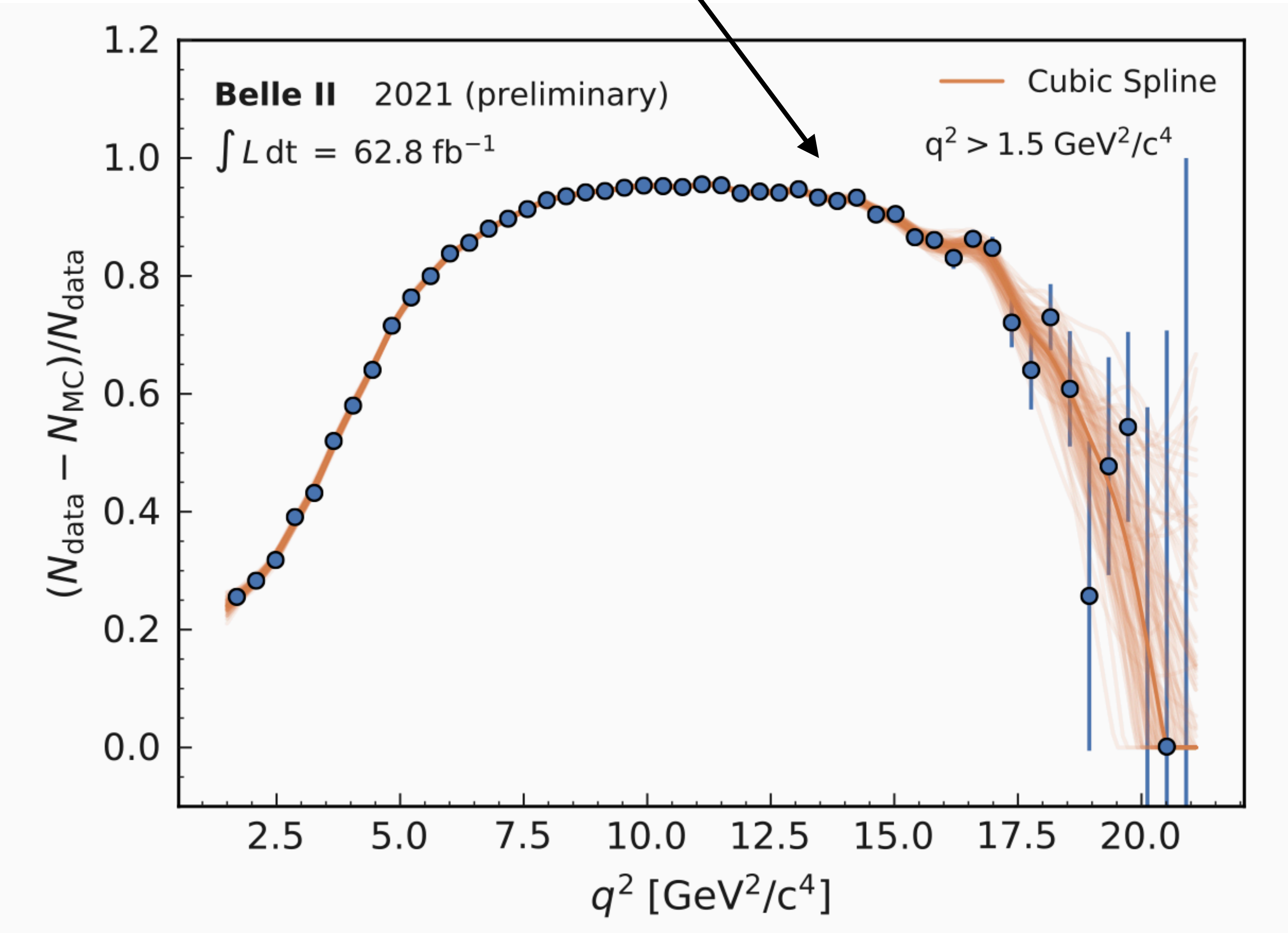


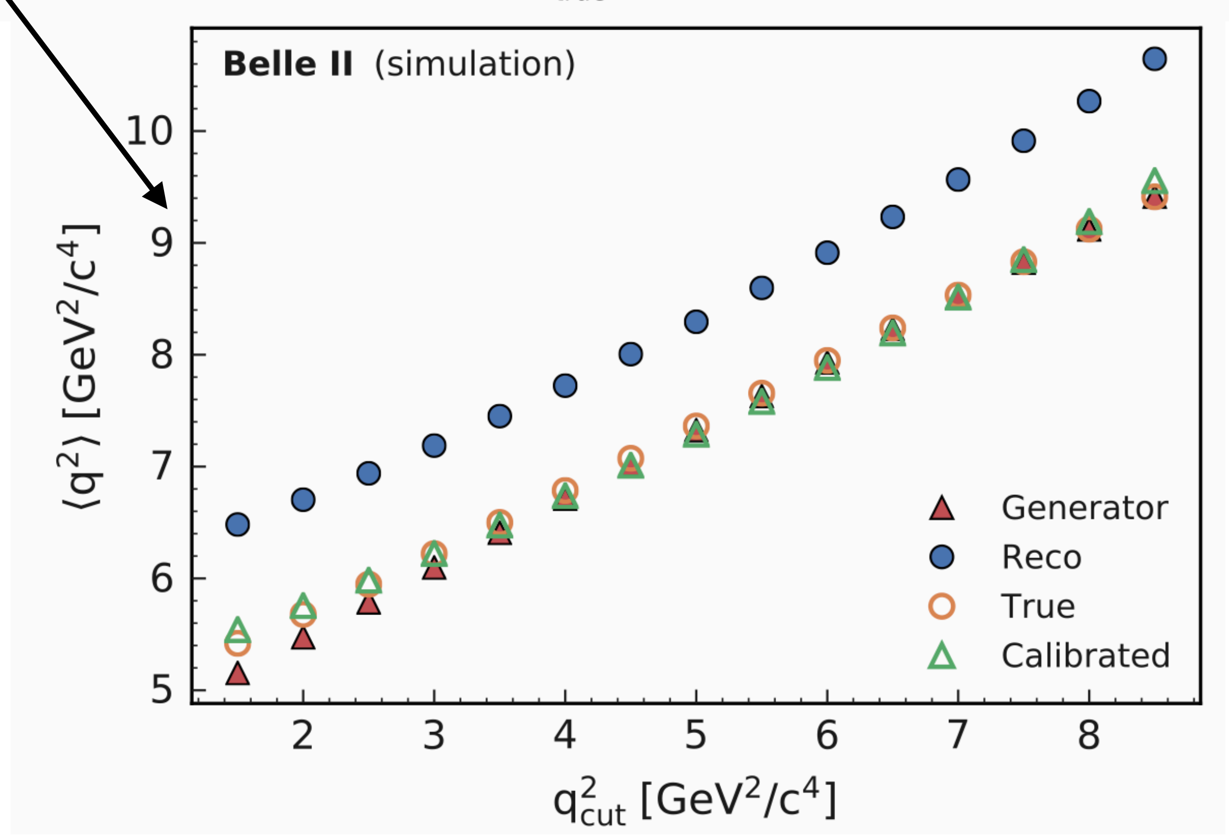


$$\langle q^{2^n} \rangle = \frac{\sum_i w_i(q^2) q^{2^n}_{\mathrm{calib},i}}{\sum_i w_i(q^2)} \times \mathcal{C}_{\mathrm{calib}} \times \mathcal{C}_{\mathrm{true}}$$









Untagged analysis in progress and targeting summer 2021.

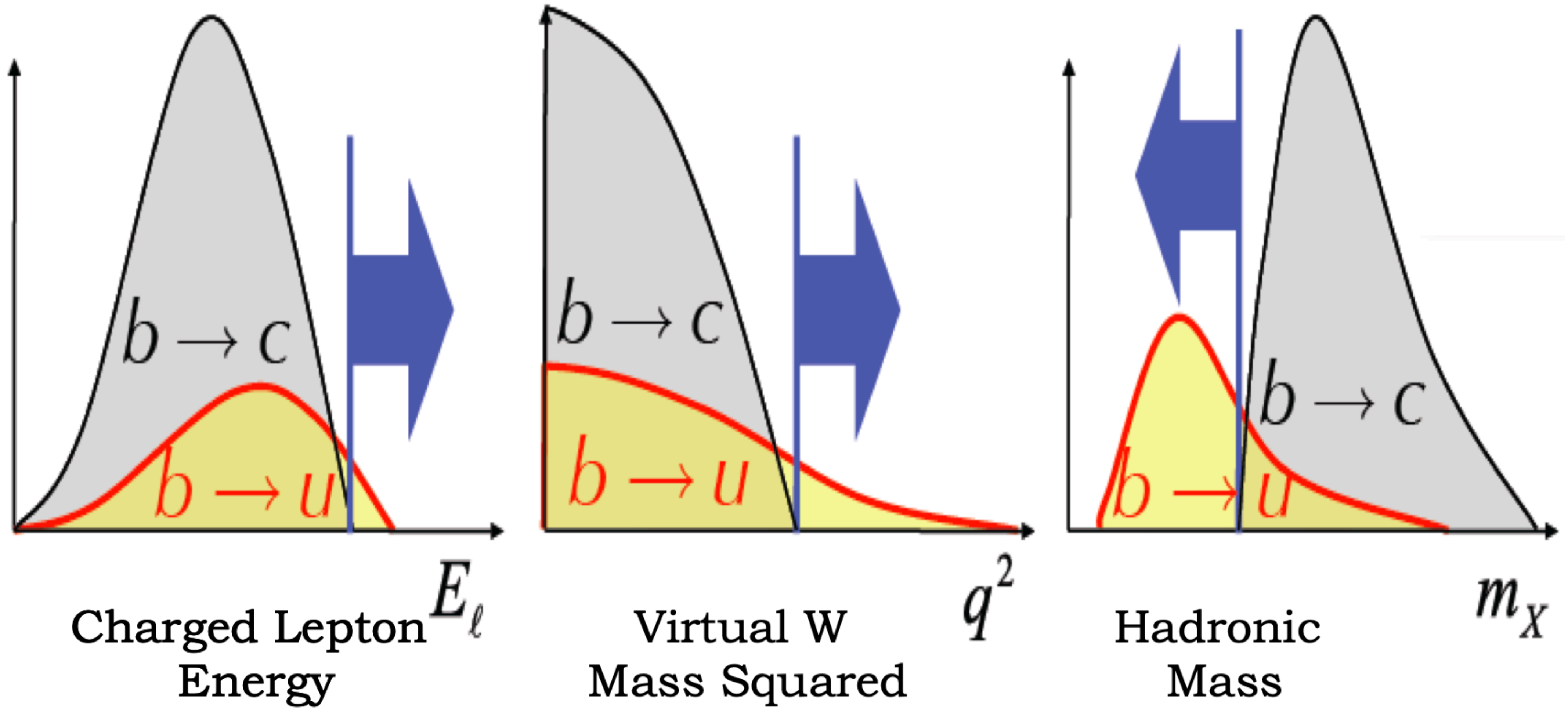
$b \to u\ell\nu$

- Experimentally challenging due to dominant $b \to c\ell\nu$ background.
- Only certain kinematic regions allow for clean separation: lepton momentum endpoint spectrum or low m_X.
- $B \to X_u\ell\nu$ is used for inclusive $|V_{ub}|$ measurement.
  - Precision of (~7%)
  - Operator Product Expansion (OPE) = Heavy Quark Expansion.
  - HQE breaks down and a non-perturbative shape function is

$$d\Gamma = d\Gamma_0 + d\Gamma_2\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)^2 + d\Gamma_3\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)^3 + d\Gamma_4\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)^4$$

- $B \to \pi\ell\nu$ is used for exclusive $|V_{ub}|$ measurement.
  - Most precise determination of $|V_{ub}|$ (~4%)
  - Requires form factor determination: non-perturbative from lattice QCD (high q^2) or LCSR (q^2~0) .

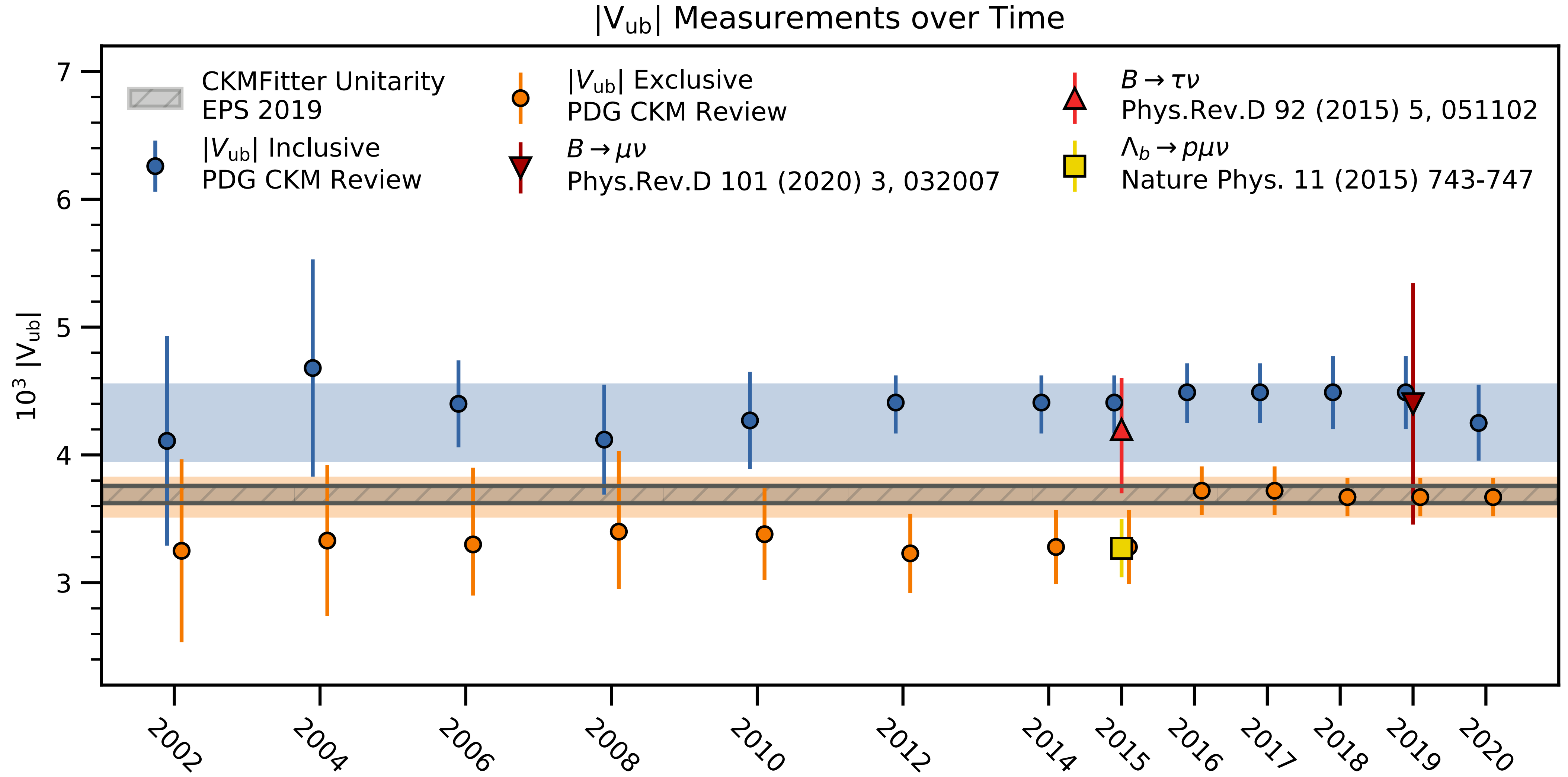
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{ub}|^2}{24\pi^3}|p_\pi|^3|f_+(q^2)|^2$$



Current ~3σ tension between inclusive and exclusive determinations

$$|V_{ub}| = (4.25 \pm 0.12^{+0.15}_{-0.14} \pm 0.23) \times 10^{-3}$$ **PDG inclusive**

$$|V_{ub}| = (3.70 \pm 0.10 \pm 0.12) \times 10^{-3}$$ **PDG exclusive**



Hybrid Modeling for $B \to X_u \ell \nu$

- Non-resonant component overestimated in generic Belle II MC
- Use hybrid modeling instead, where the non-resonant component is weighted down such that the total number of events matches the inclusive rate:

$$H_i = R_i + w_i I_i,$$

H_i: total number of hybrid events per bin
R_i: number of resonant events per bin
w_i: hybrid weight per bin
I_i: number of non-resonant events per bin

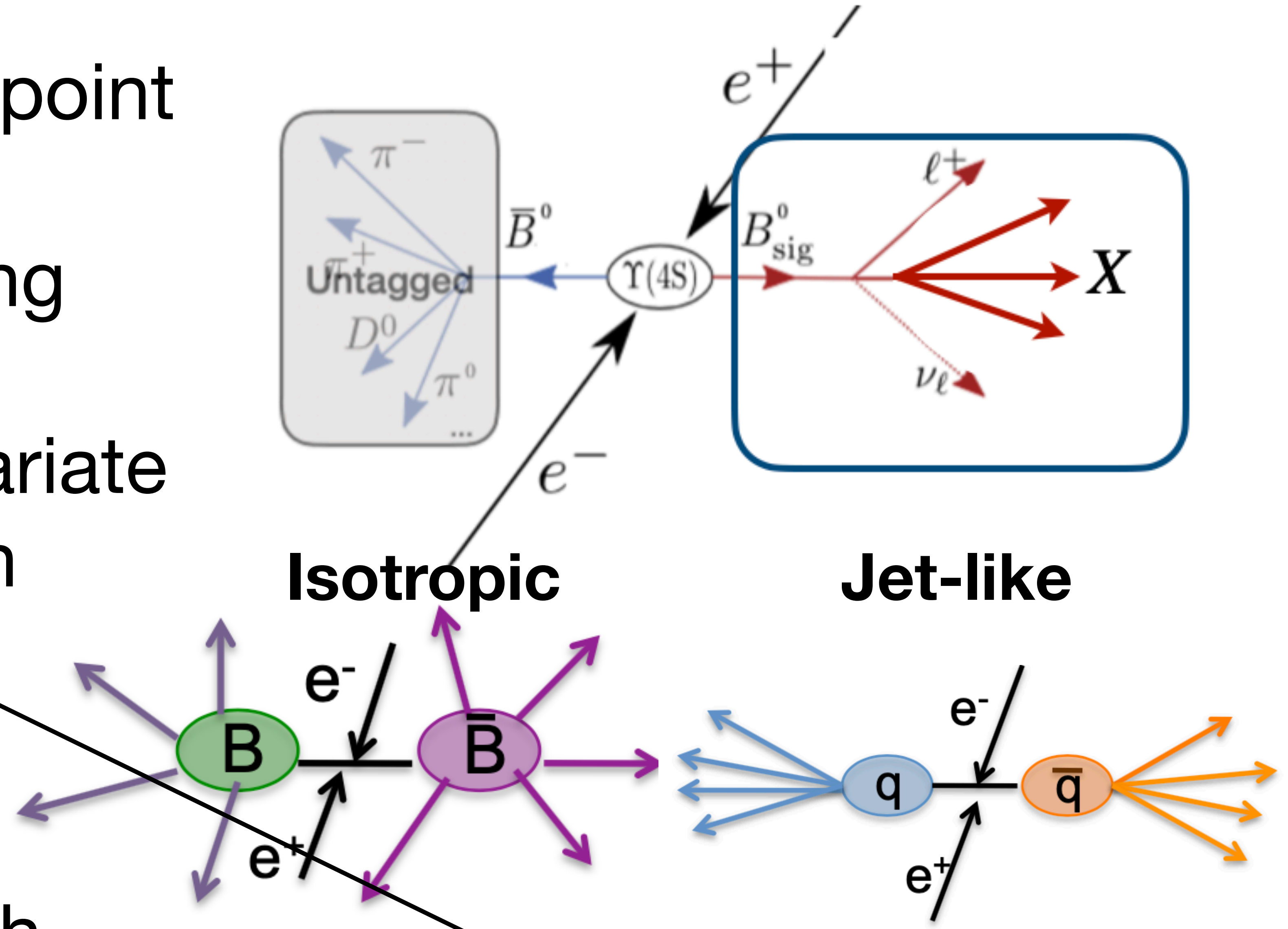
- Re-weighting done via eFFORT, in 3D bins of E_B, m_X, q^2
  - E_B :lepton energy in Bsig frame
  - M_X: mass of hadronic system X
  - q^2: 4-momentum transfer to leptonic system

Phys. Rev. D 41, 1496, 1990

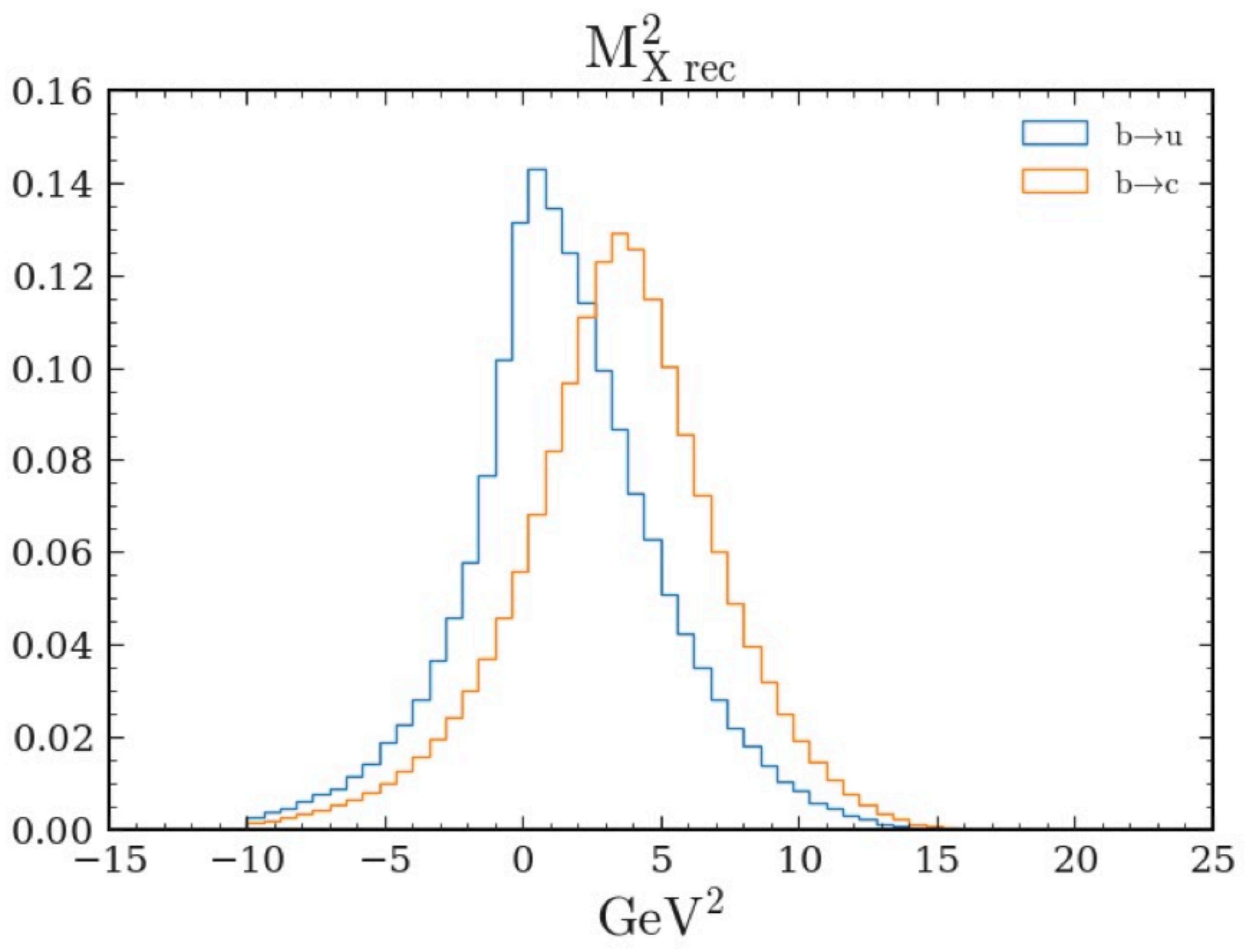
arXiv:2103.02629

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

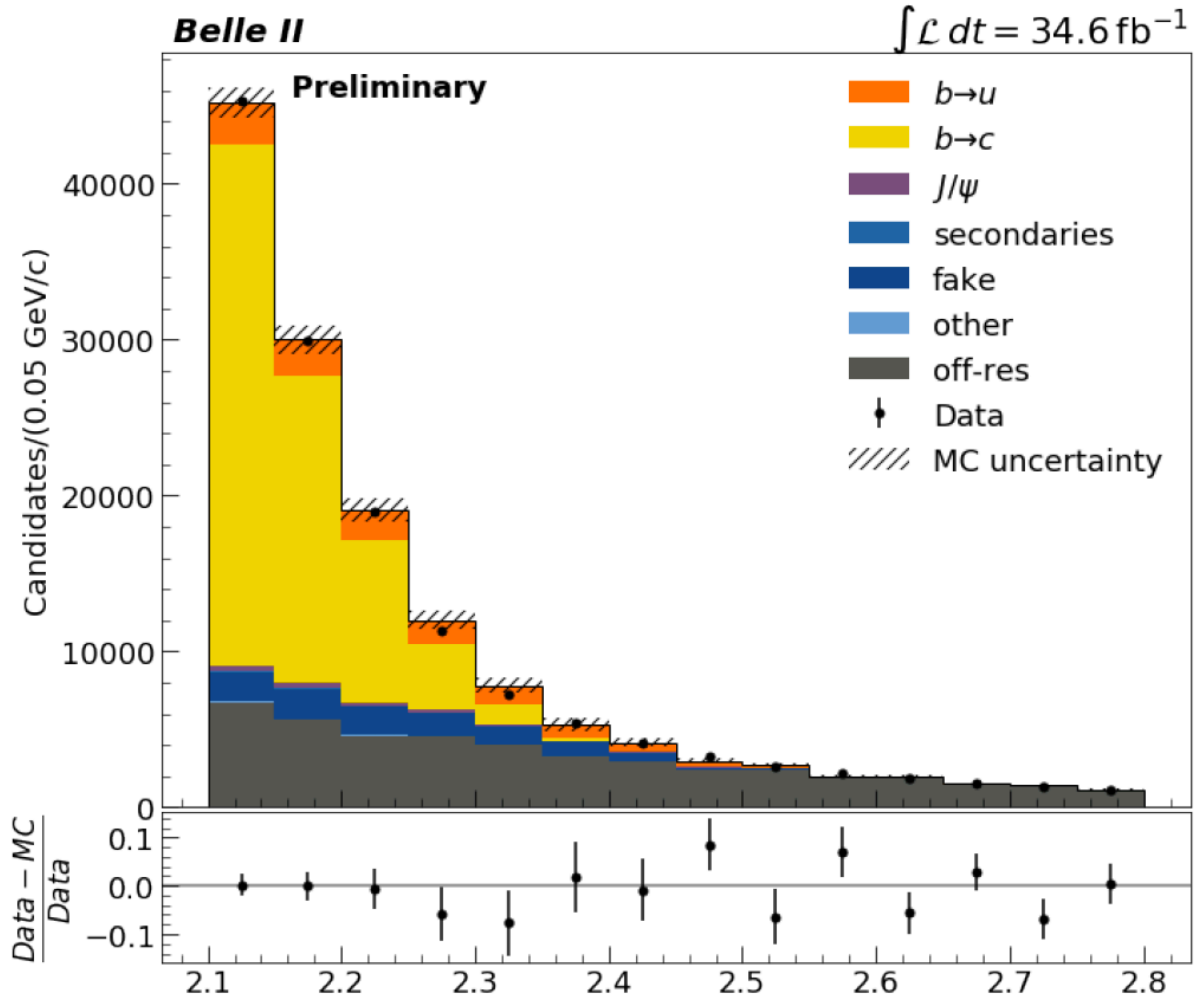
- Measurement of $|V_{ub}|$ in the lepton endpoint momentum spectrum.
  - Identify one lepton in the event using Particle Identification algorithms.
  - Suppress continuum using multi-variate Boosted Decision Tree trained with event shape variables.

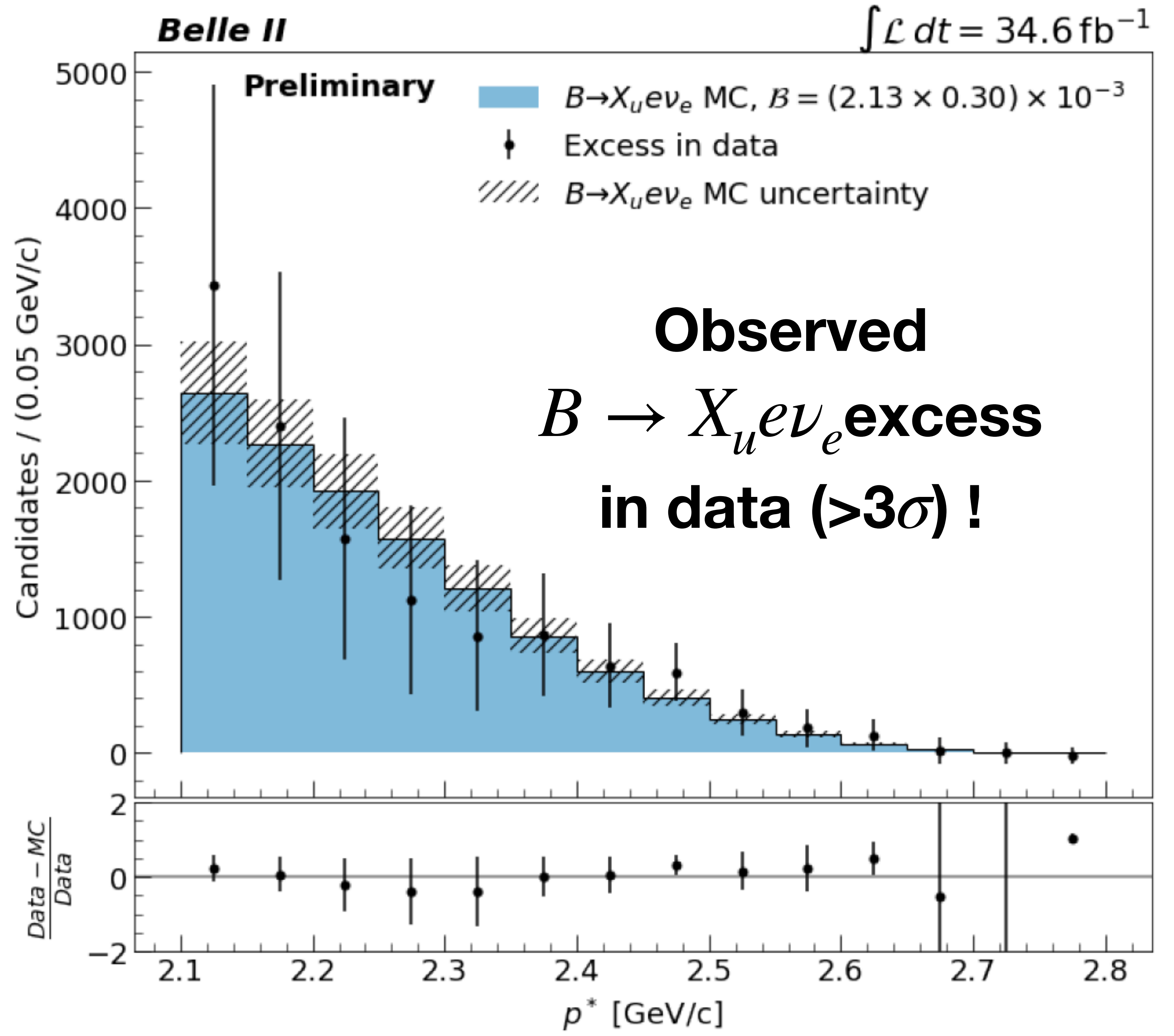


- In progress: train MVA to distinguish $b \to u$ from $b \to c$ events based on M_X^2 or rest-of-event variables.



Implement rest-of-event selection on remaining tracks and clusters to isolate neutrino 4-vector.

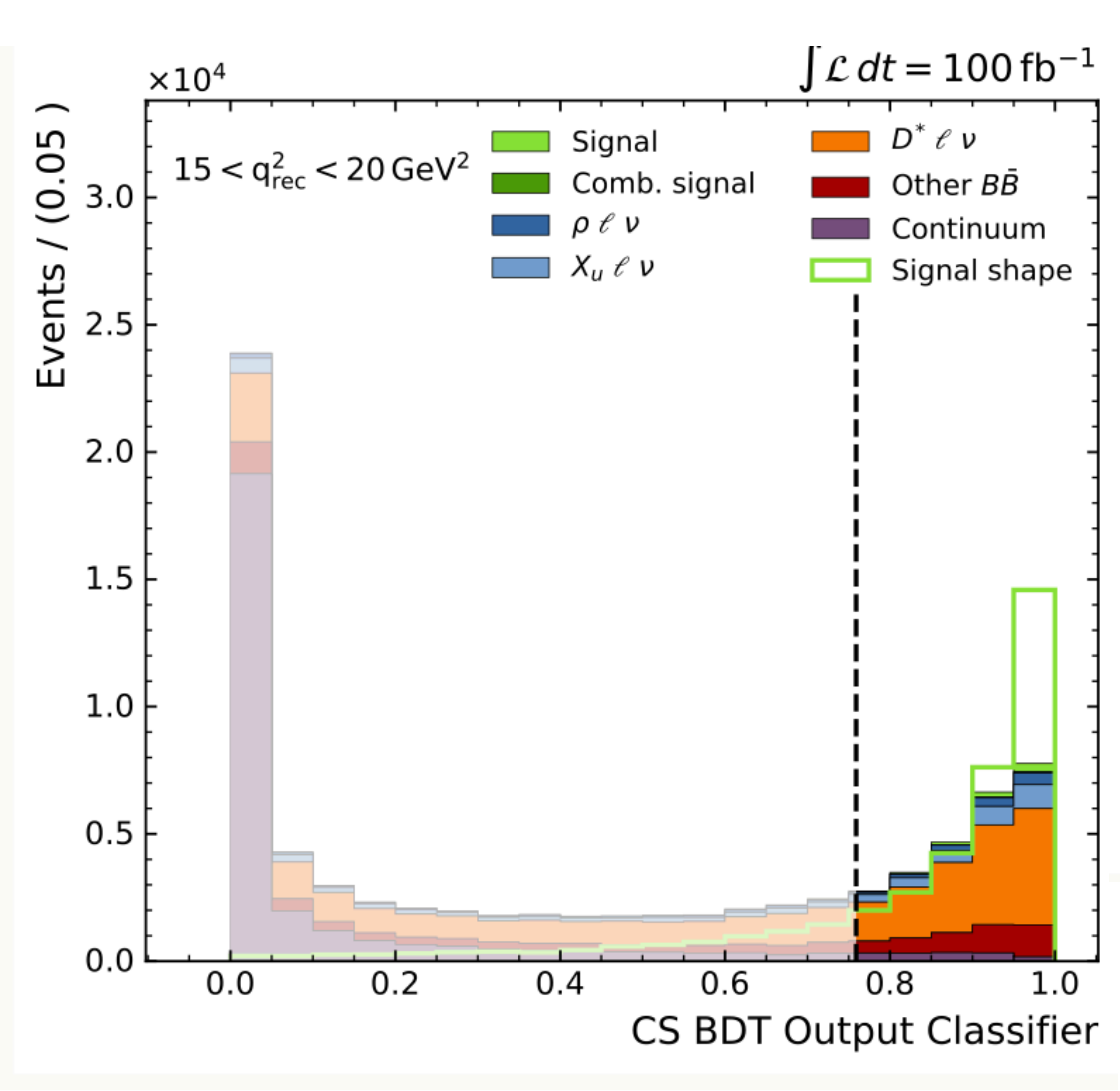


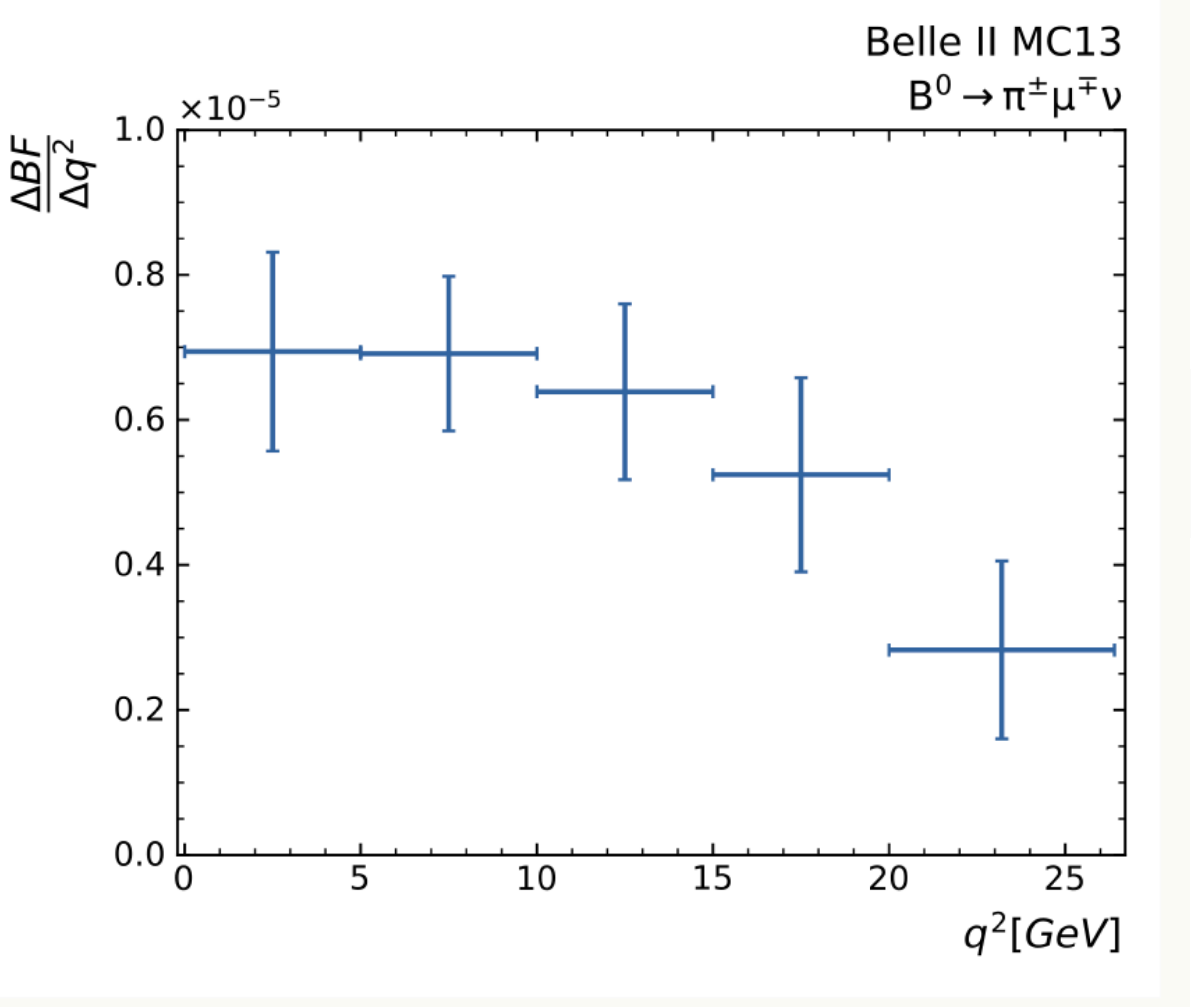


Observed $B \to X_u e \nu_e$ excess in data (>3σ) !

Untagged $B \to \pi \ell \nu$

- Measured in 5 bins of $q^2 = (p_B - p_\pi)^2$ to extract $|V_{ub}|$.
- Identify pion and lepton using PID algorithm with vertex fit to parent B.
- Suppress continuum using multivariate Boosted Decision Trees trained in each q^2 bin.
- Constrain background from simultaneous fit to p_l in sideband region.
- Signal extraction from a 3D fit to $\Delta E, M_{bc}, q^2$





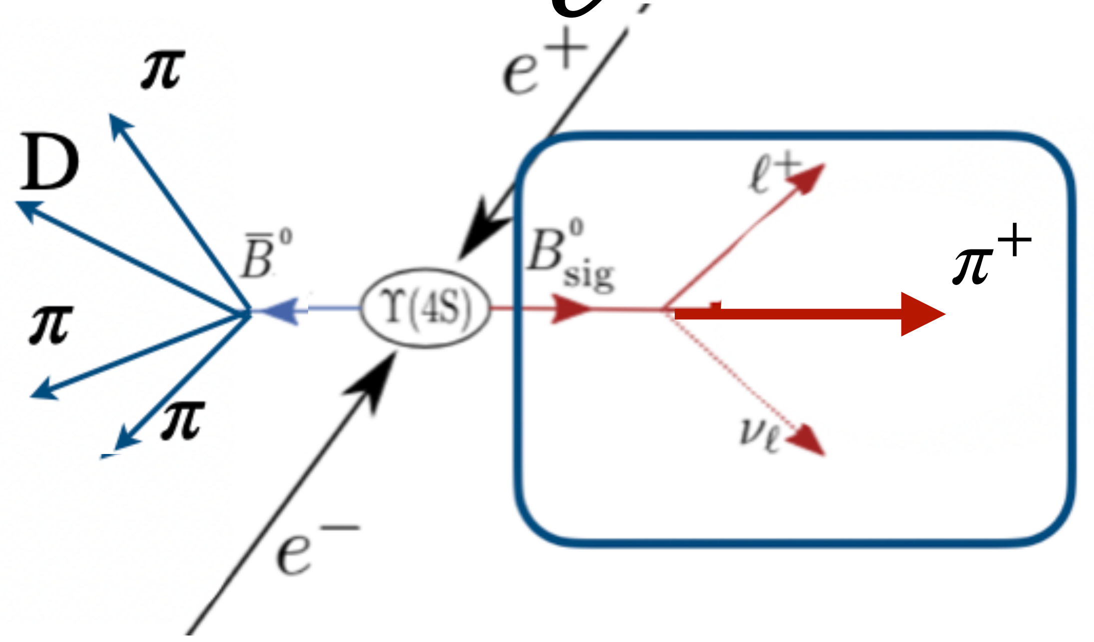
$$BF^i = \frac{N^i_{yield}}{2 \times \epsilon^i_{rec} \times f \times N_{BB}}$$

$$f = BF(\Upsilon(4S) \to B^0 \overline{B^0})$$

Signal Region: $|\cos\theta_{BY}| < 1.1$
Sideband: $1.2 < |\cos\theta_{BY}| < 2.4$

In progress !

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



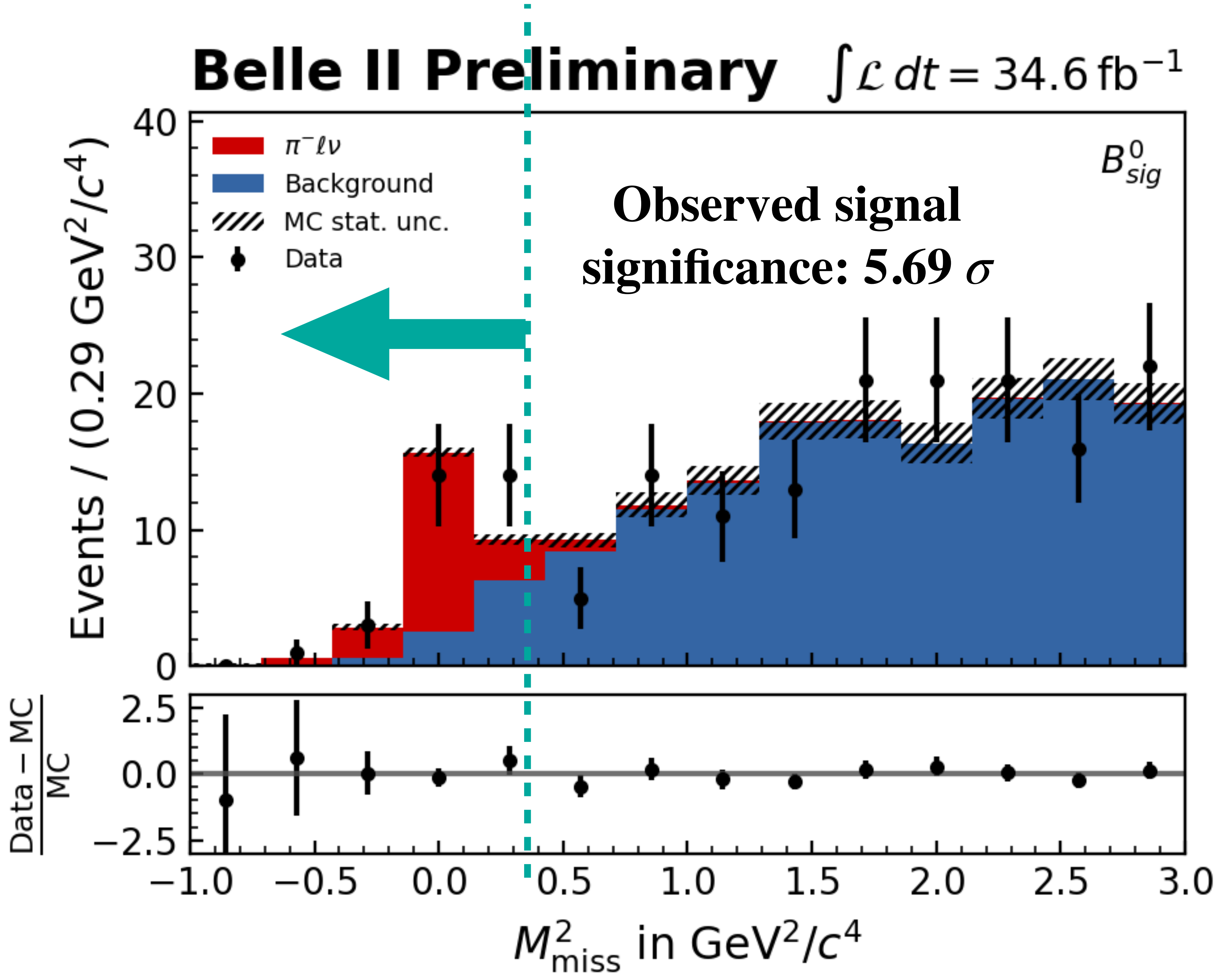
- FEI hadronic tagging to measure $\mathscr{B}(B^0 \to \pi^- \ell \nu)$.
- Identify oppositely charged lepton, $p_e > 0.3$and $p_\mu > 0.6$ GeV/c, and pion using PID algorithms.
- Suppress continuum using FoxWolfram moment R2.
- Apply $E_{miss}>0.3$ and $E_{residual}<1.0$ GeV.

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

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

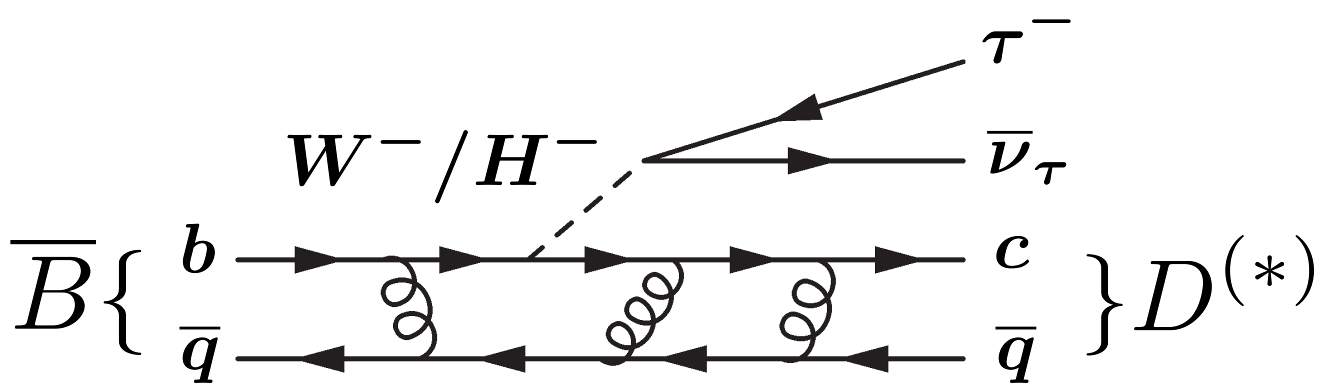
$\mathcal{B}(B^0 \to \pi^- \ell \nu)$	$(1.58 \pm 0.43_{\text{stat}} \pm 0.07_{\text{sys}}) \times 10^{-4}$

In agreement with world average.



Extract signal yields in bins of q^2 and determine $|V_{ub}|$.
Similar effort in channels: $B \to X \ell \nu, X = \pi^0, \rho^+ \rho^0$

R(D) and R(D*)



Persistent deviation from Standard Model prediction, measured by Belle, BaBar and LHCb.

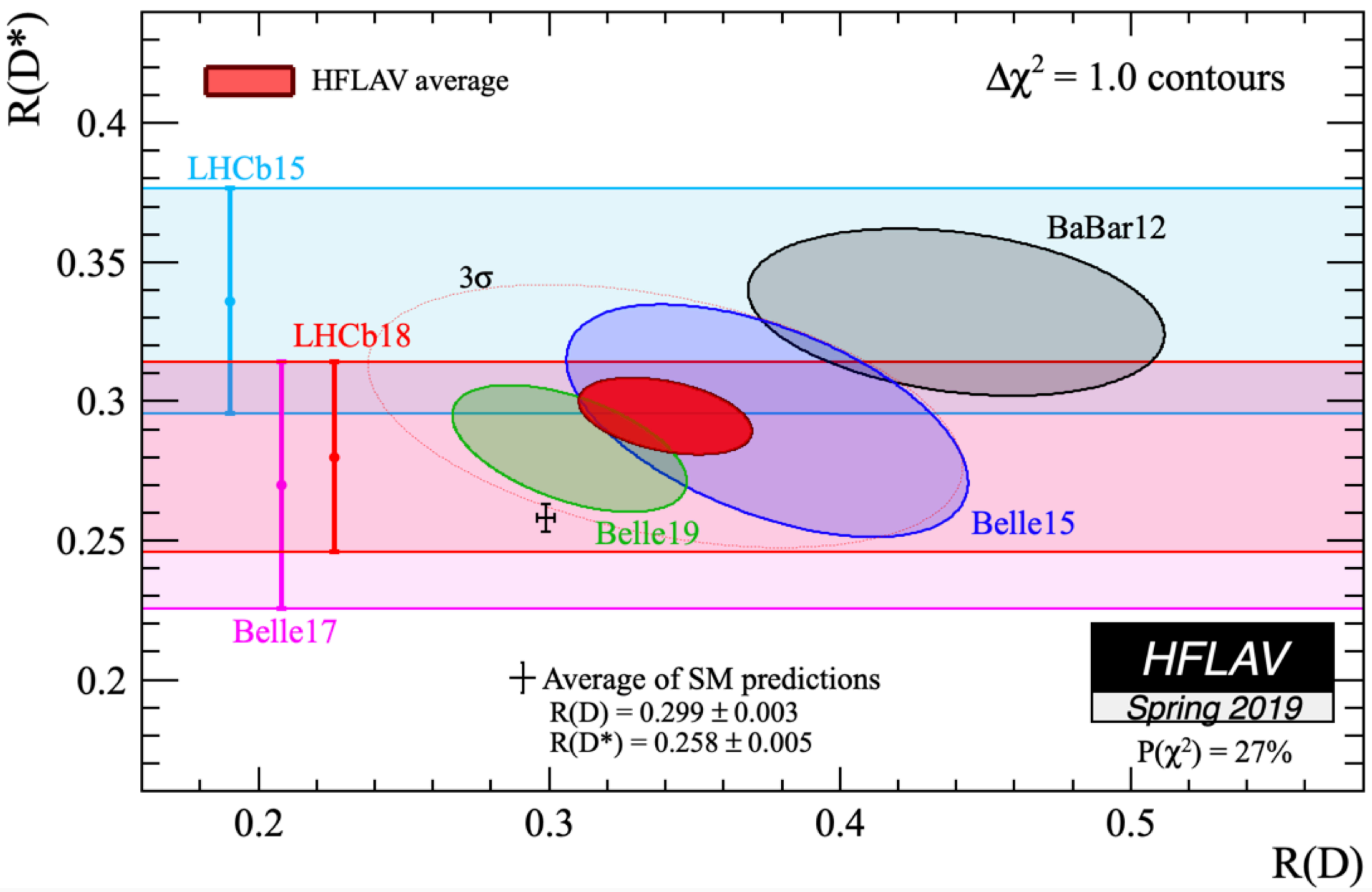
Signal Mode

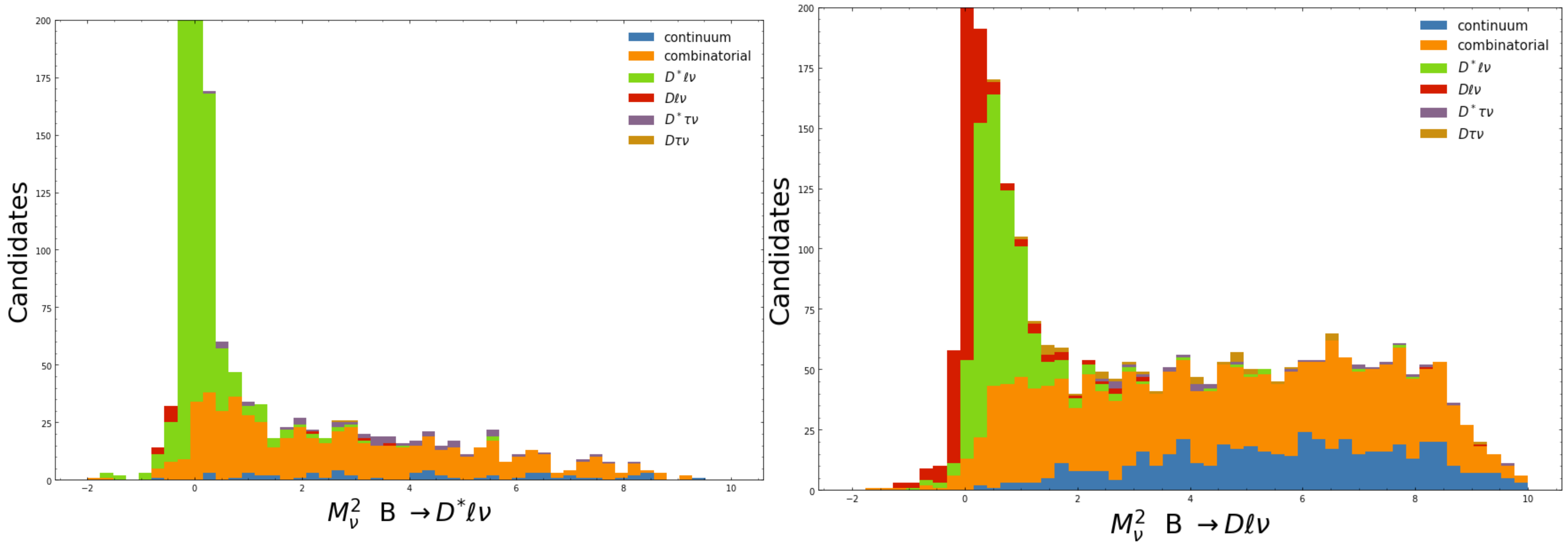
$$R(D) = \frac{\mathscr{B}(\bar{B} \to D^+\tau^-\bar{\nu}_\tau)}{\mathscr{B}(\bar{B} \to D^+\ell^-\bar{\nu}_\ell)} \qquad R(D^*) = \frac{\mathscr{B}(\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathscr{B}(\bar{B} \to D^{*+}\ell^-\bar{\nu}_\ell)}$$

Normalization Mode

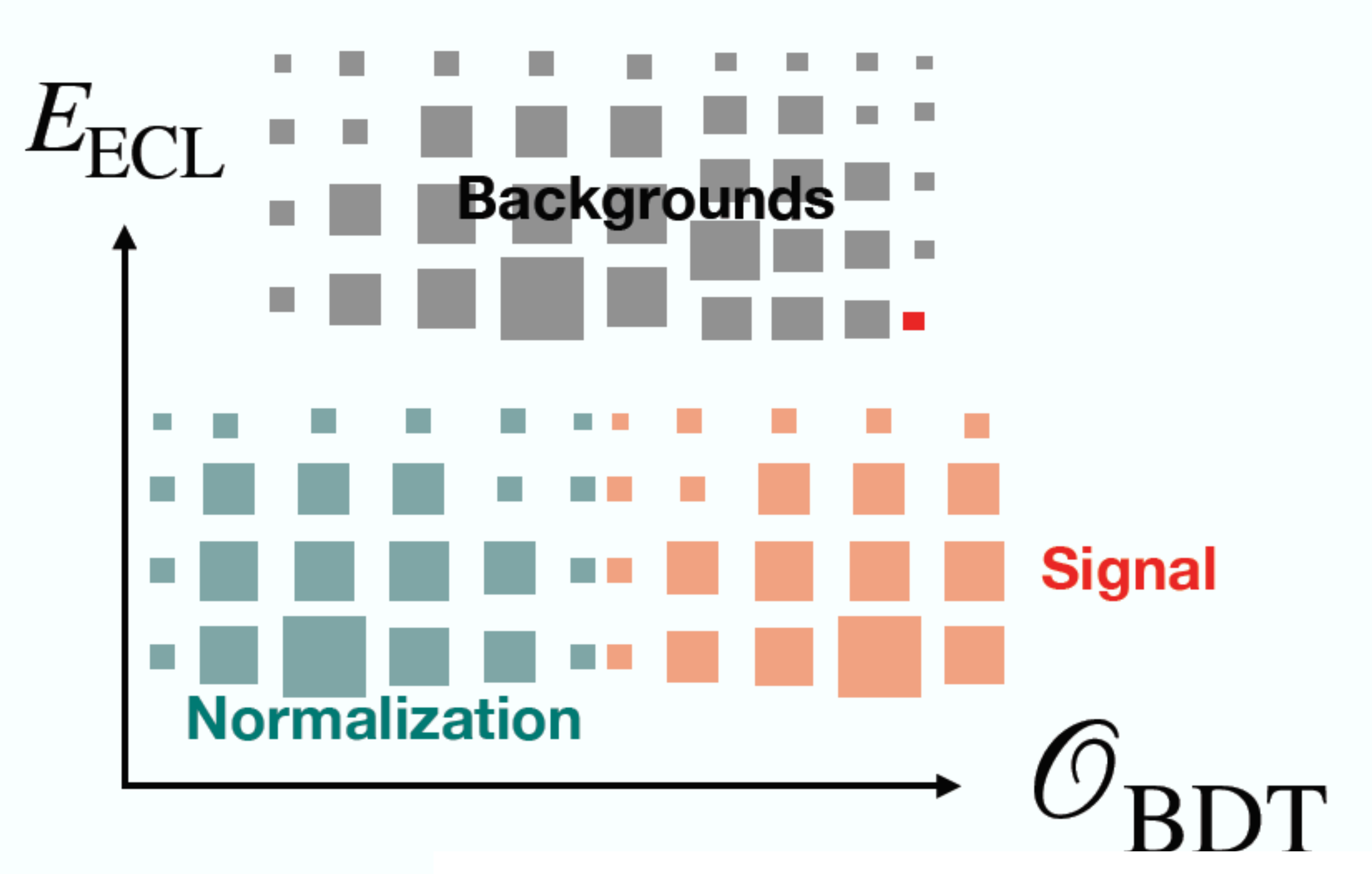
- Current ongoing analyses with FEI hadronic tagging:
  - Leptonic tau decays
  - Hadronic tau decays
  - Inclusive $B \to X\tau\nu$
- Analyses well established. Current effort to minimize background and optimize signal extraction.
- Initial plan: confirm anomaly with ~0.5 ab-1 of Belle II data.

$B^0 \to D^+\ell\nu$ $\qquad B^0 \to D^{(*+)}\ell\nu$

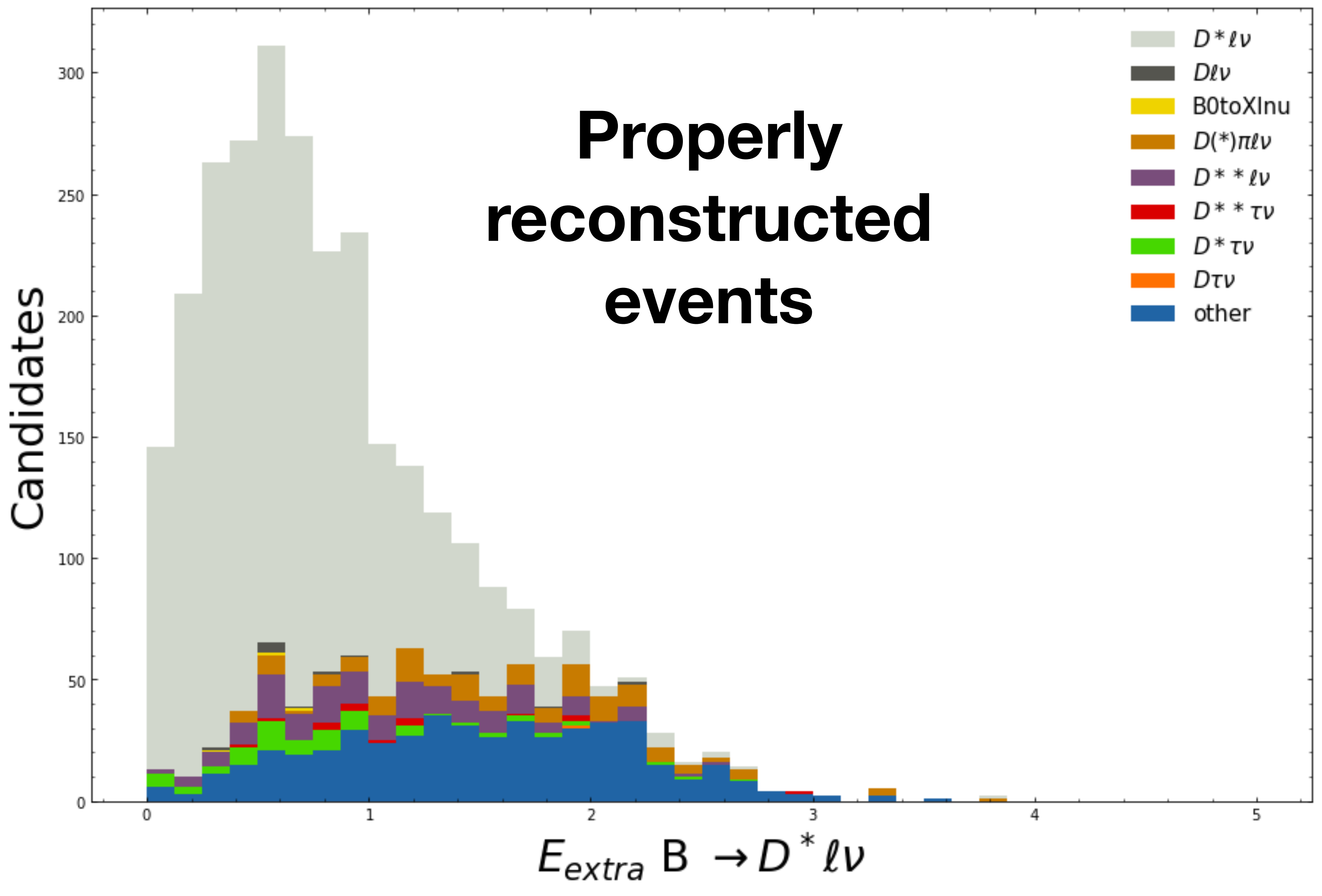




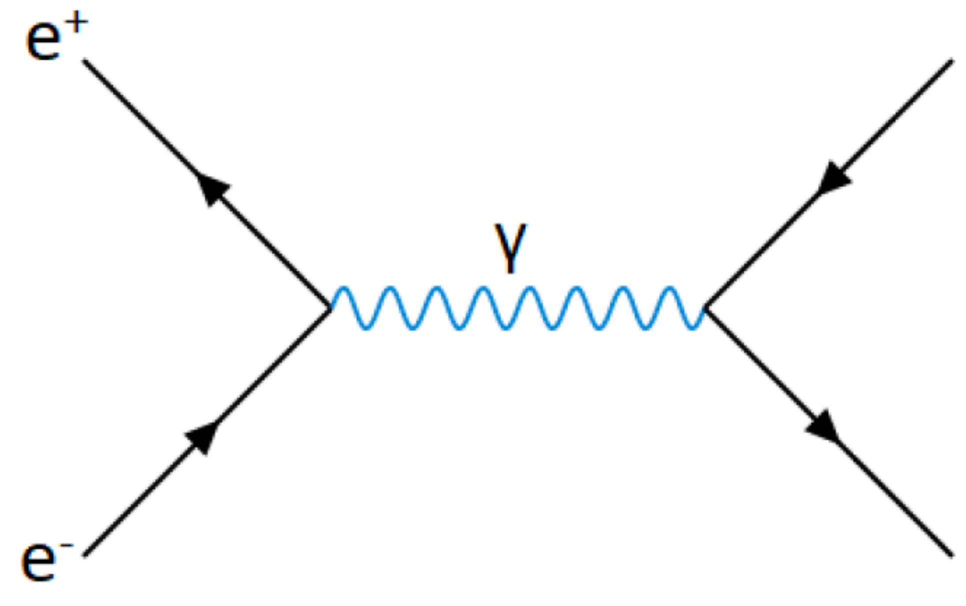
R(D) and R(D*)



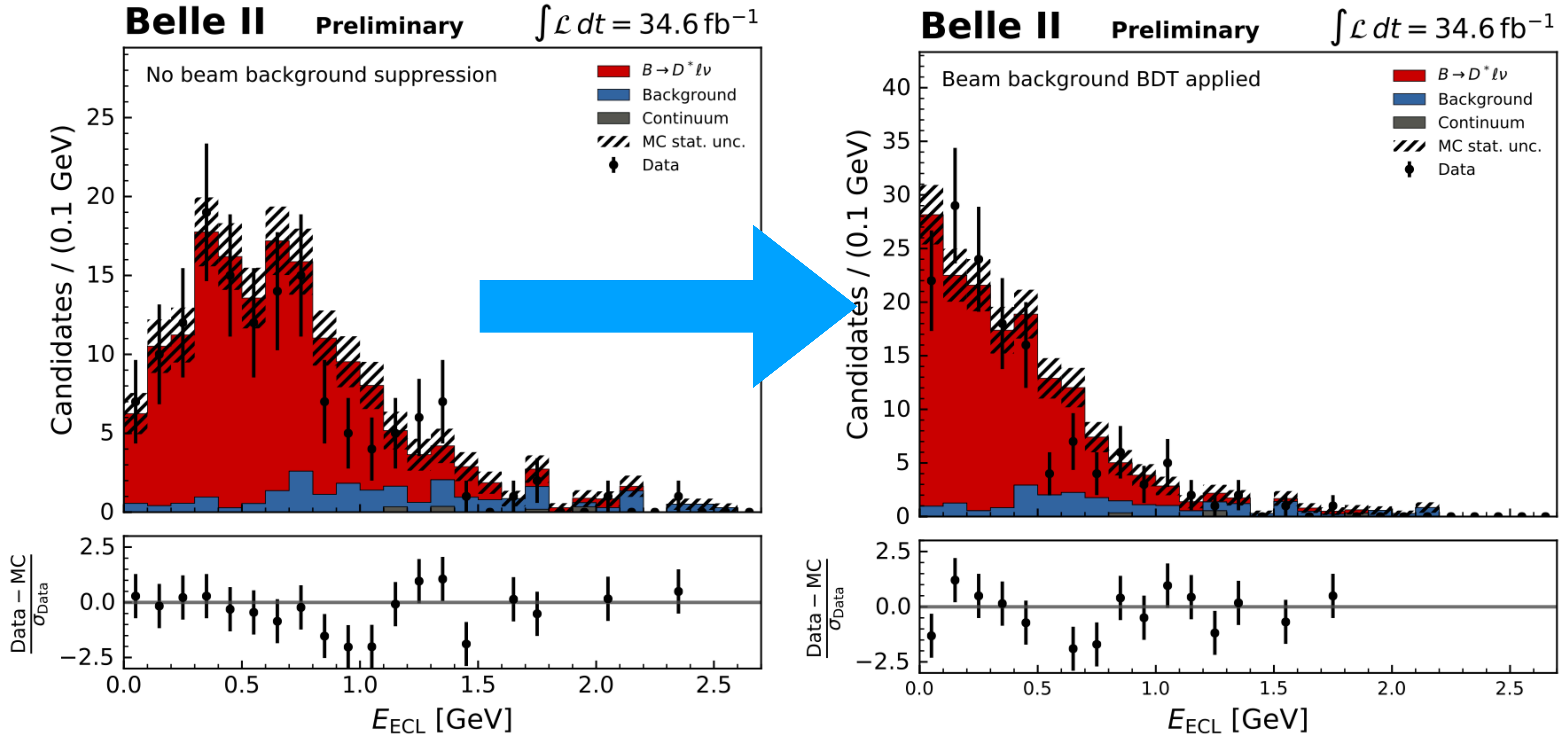
- Separation between signal, normalization and background modes can be established with E_{ECL}, sum energy of all neutral deposits in the event not related to the B_{sig} or B_{tag} reconstruction.
- At Belle II, beam backgrounds contribute to E_{ECL} and dilute separation between signal and background.



Use $e^+e^- \to \mu^+\mu^-$ data events and examine the cluster shape and energy distribution of energy deposits related to beam backgrounds.



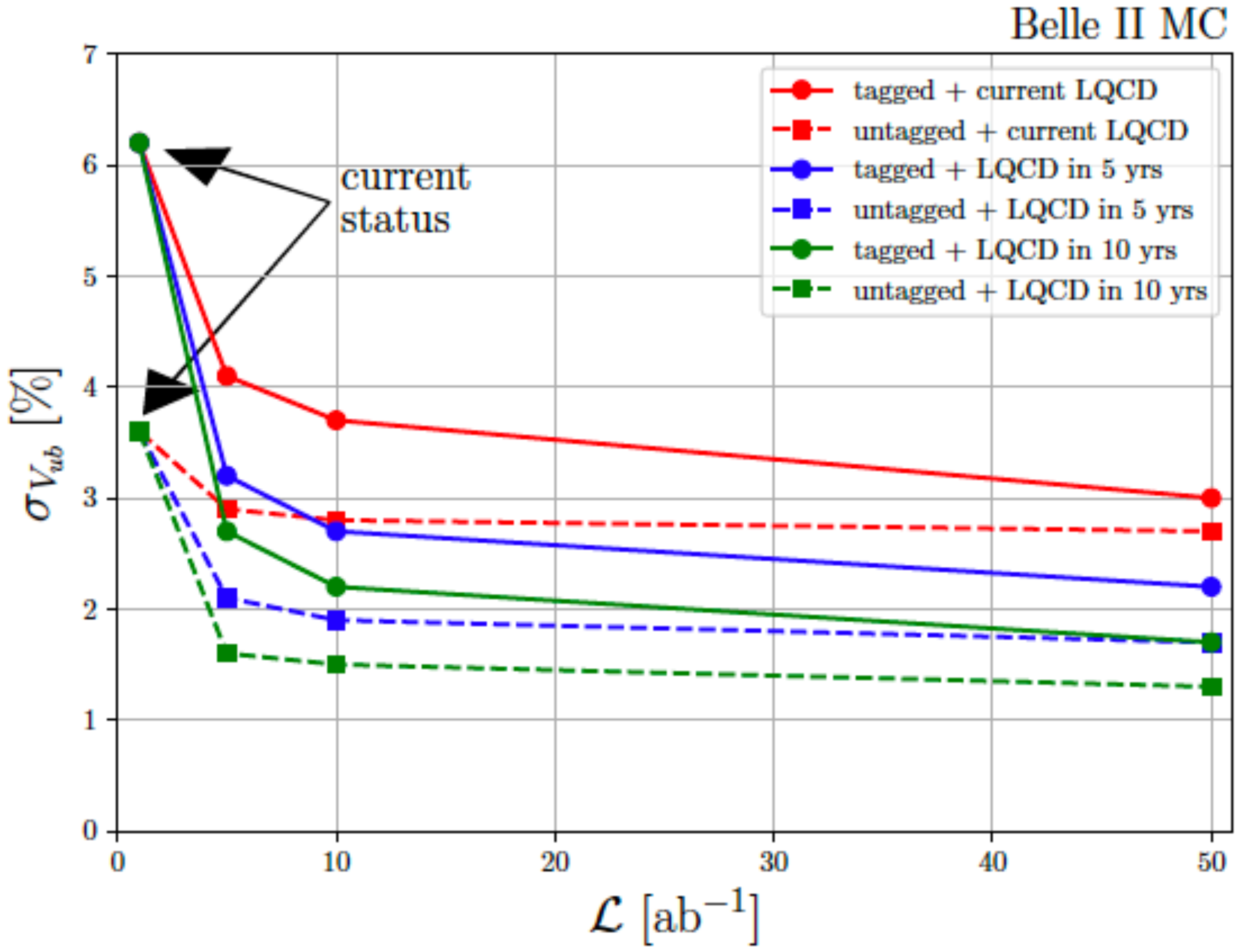
Train MVA to suppress beam background contributions in E_{ECL}.

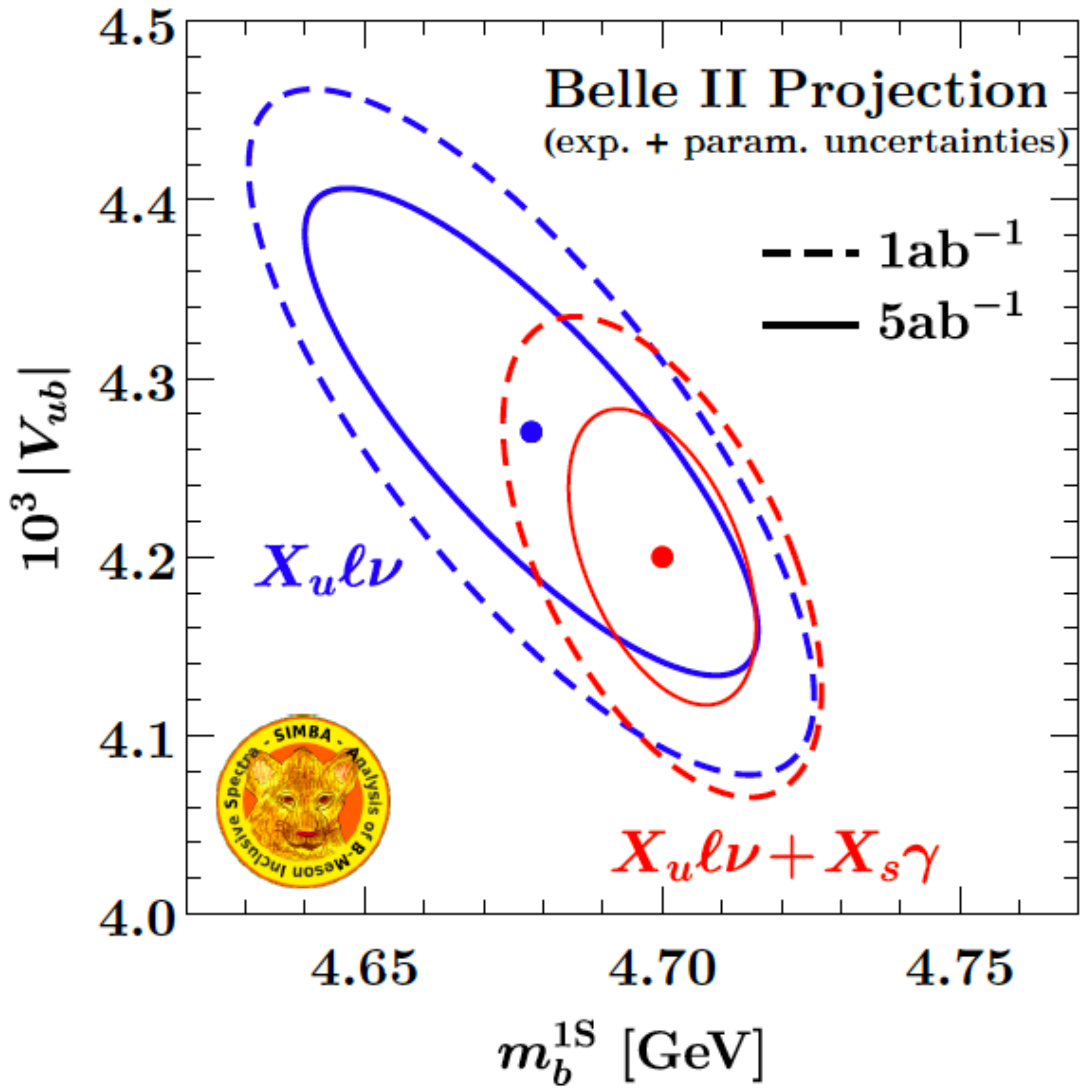


Work in progress for further optimization and suppression of hadronic split-offs as well.

$B \to X\ell\nu$ Prospects at Belle II

- With 1 ab^{-1} size dataset, the limitation will mainly be systematic.
  - Improved tracking, PID and vertexing tools.
- Improved tagging techniques Full Event Interpretation(see backup) is expected to increase efficiency by ~2%
- Improved measurements for $N_{B\bar{B}}$ and f^{+0}
- Achieve higher precision in the measurements of the moments for inclusive $|V_{cb}|$.
  - Valuable input for theory!
- Provide complementary kinetic information by measuring other single differential spectra, such as the hadronic energy or q^2.
  - Work already in progress.
- Improved measurements of $B \to D^{**}\ell\nu$ with 1 ab^{-1}
- For inclusive |Vub|, ,maximize shape function information by measuring a large number of differential spectra
- Global fit to the full spectrum, combining $B \to X_u\ell\nu$ and $B \to X_s\gamma$ with constraints on HQE parameters from $B \to X_c\ell\nu$ simultaneously.





	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ 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
$\lvert V_{ub}\rvert$ 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

Conclusion

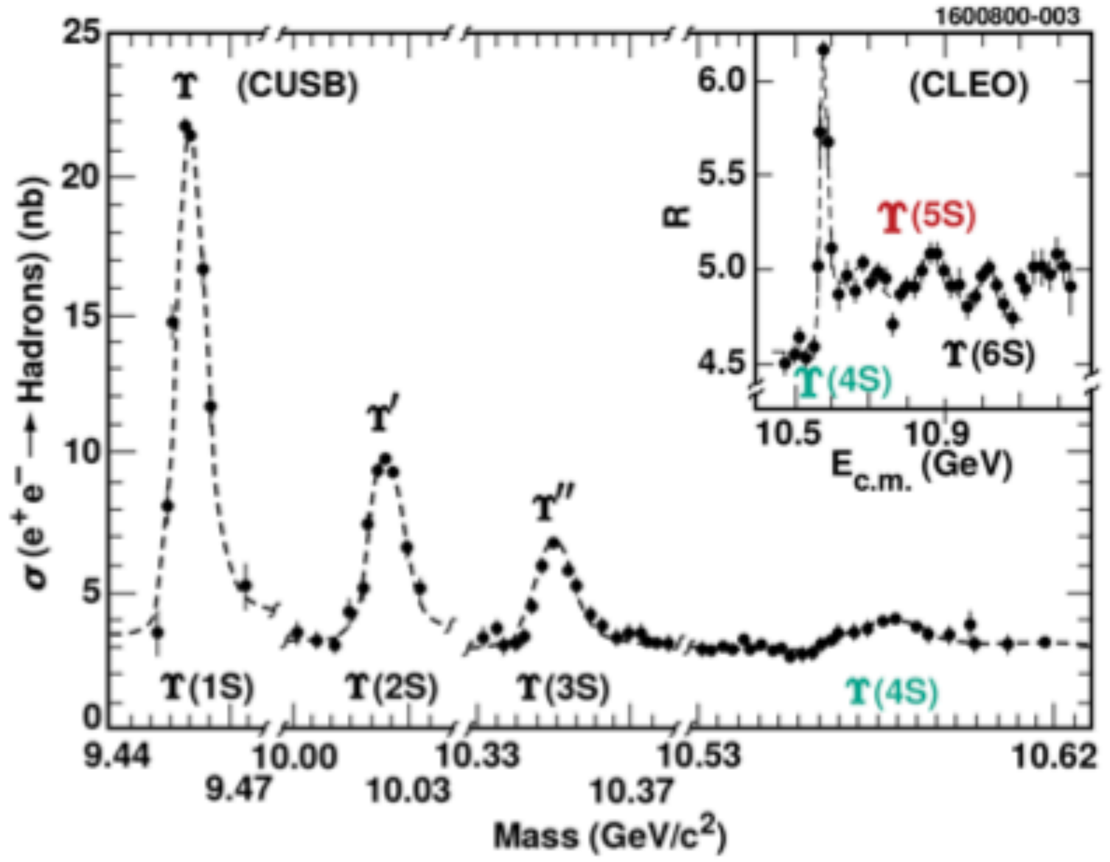
- $B \to D^{(*)}\ell\nu$ and exclusive $|V_{cb}|$:
  - Work in progress at Belle II for improved precision in $B \to D\ell\nu$ and $B \to D^*\ell\nu$ results.
  - Expected first |Vcb| measurement by EPS 2021 for untagged $B \to D^*\ell\nu$.
- $B \to X_c\ell\nu$ and inclusive $|V_{cb}|$:
  - Novel q^2 moments to be measured at Belle II using tagged and untagged approaches.
  - First results expected by EPS2021.
- $B \to \pi, \rho, \eta\ell\nu$ and exclusive $|V_{ub}|$
  - Upcoming results on untagged $B \to \pi\ell\nu$ for Fall 2021.
  - Work in progress at Belle II for improved precision in $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$, results by EPS 2021.
- $B \to X_u\ell\nu$ and inclusive $|V_{ub}|$:
  - Work in progress at Belle II for first results using lepton endpoint spectrum analysis.

Belle II

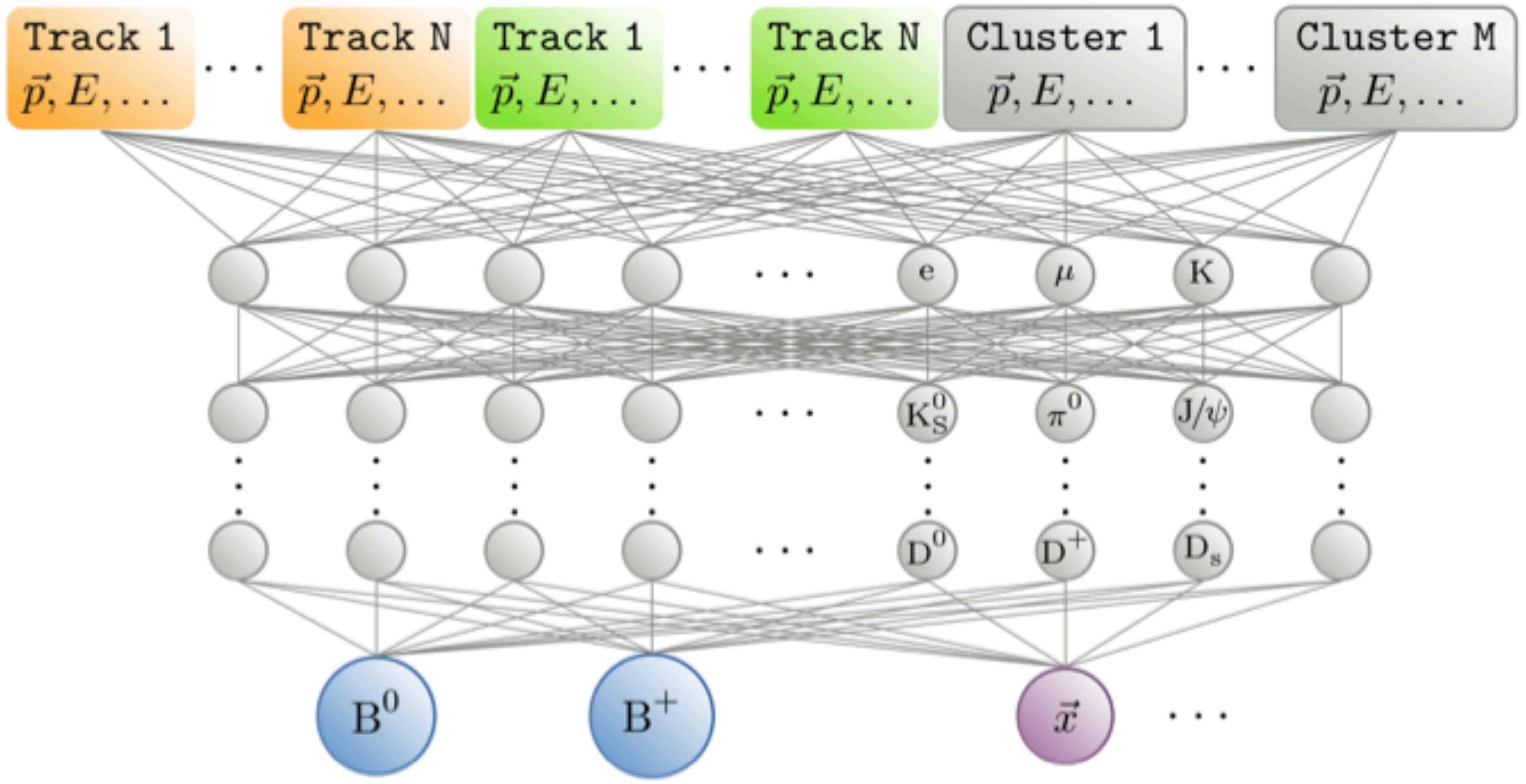
Back up

FEI prospects

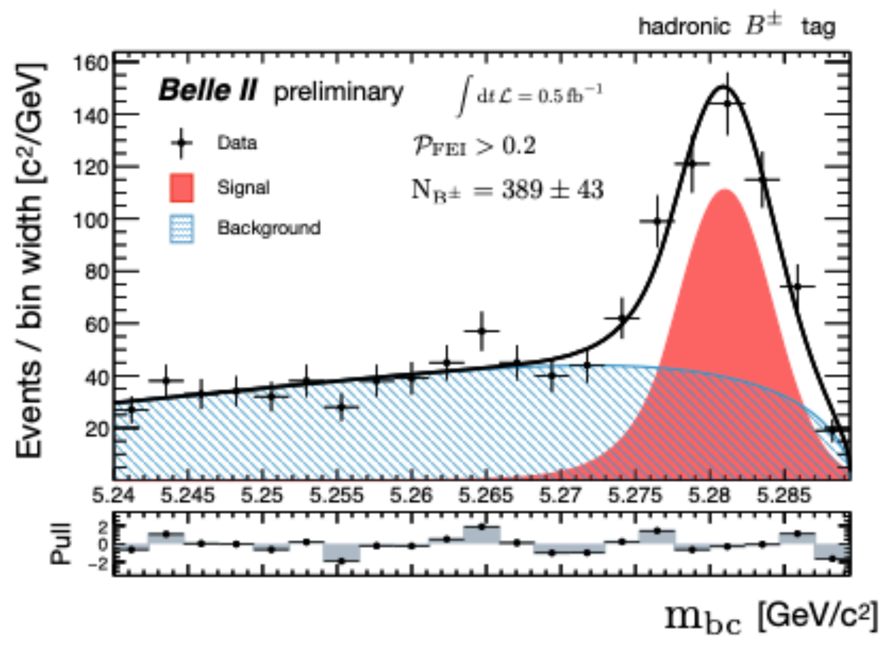
- Algorithm has been successfully applied to the $\Upsilon(5S)$ resonance.

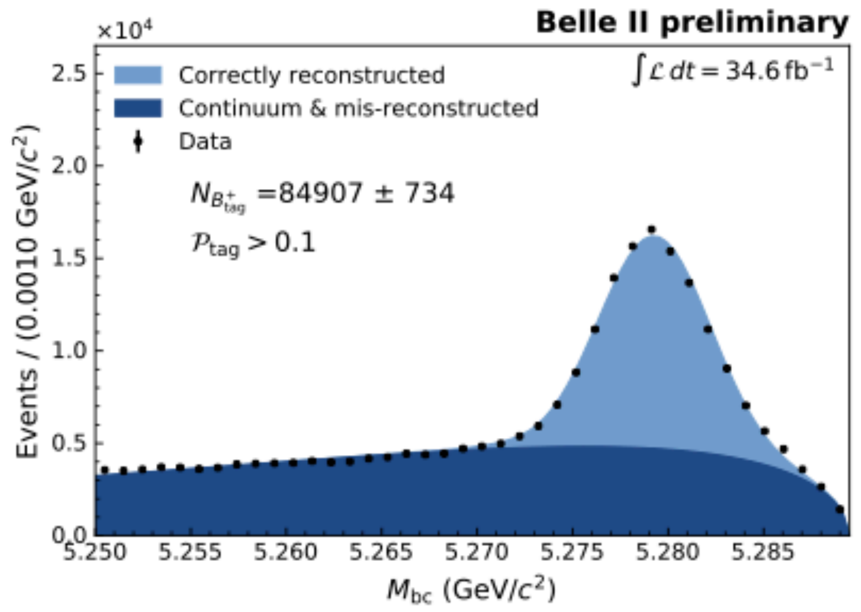


- Exploring deep extensions of the FEI.



- We can look forward to exciting physics results from the growing number of B tags at Belle II!



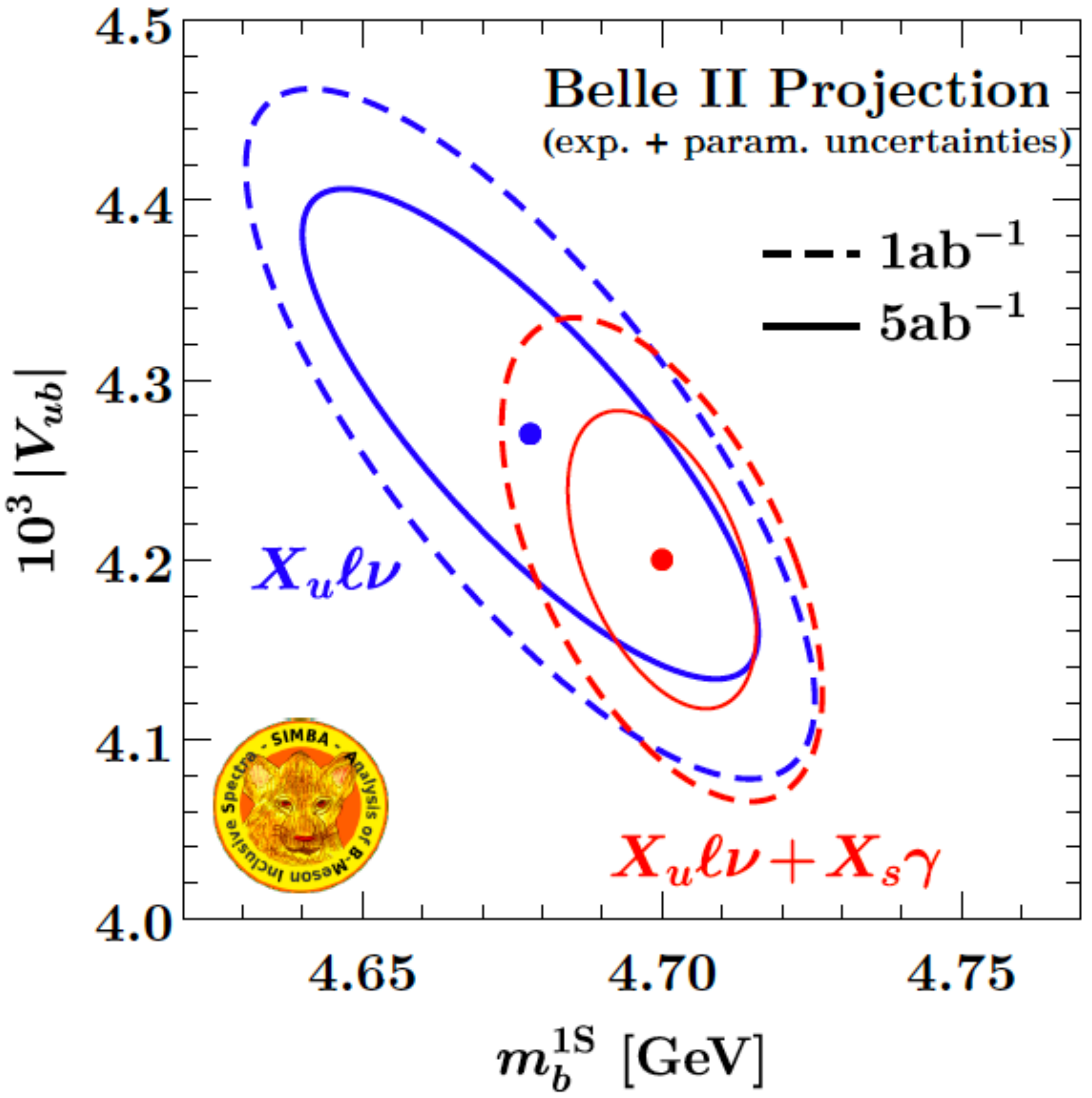


Inclusive $B \to X_u \ell \nu$ at Belle II

- Maximize shape function information by measuring a large number of differential spectra
- Global fit to the full spectrum, combining $B \to X_u \ell \nu$ and $B \to X_s \gamma$ with constraints on HQE parameters from $B \to X_c \ell \nu$ simultaneously
- This has been demonstrated by SIMBA, **A**nalysis of ***B***-Meson, **I**nclusive **S**pectra, group.

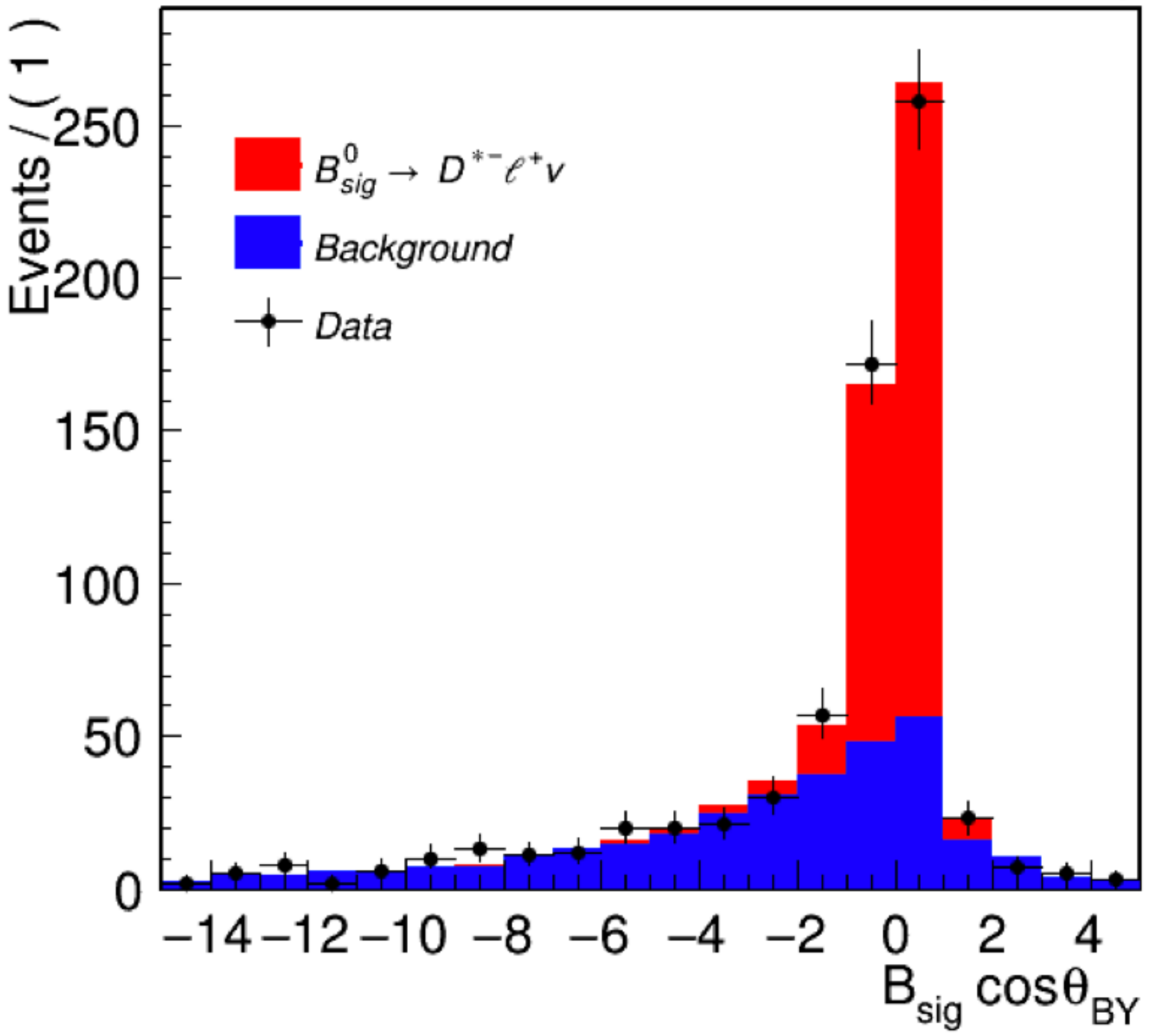
	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\|V_{ub}\|$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.7, 1.6)	6.0	2.5–4.5	6.5–7.5
5 ab^{-1}	1.1	(1.3, 1.6)	2.3	2.5–4.5	3.4–5.1
50 ab^{-1}	0.4	(0.4, 1.6)	1.7	2.5–4.5	3.0–4.8

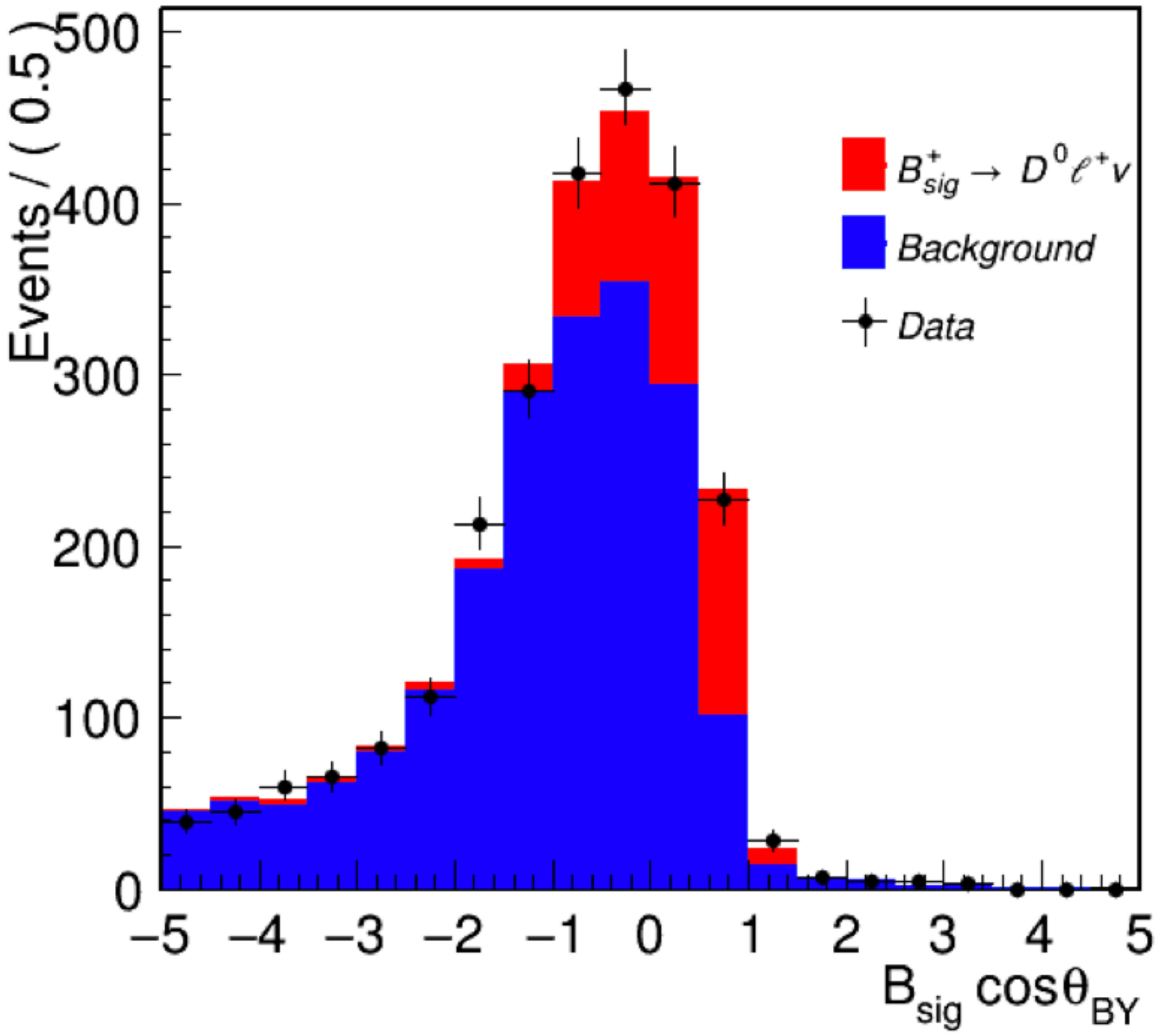
- Systematic uncertainties related to tracking and PID will be improved by Belle II upgrades:
  - New and improved PID in the barrel region (time of propagation counter)
  - Smaller drift chamber cell size .
  - Improved detector performance



Semi-leptonic FEI calibration

Will remove data **log(sigProb)>-1.0**



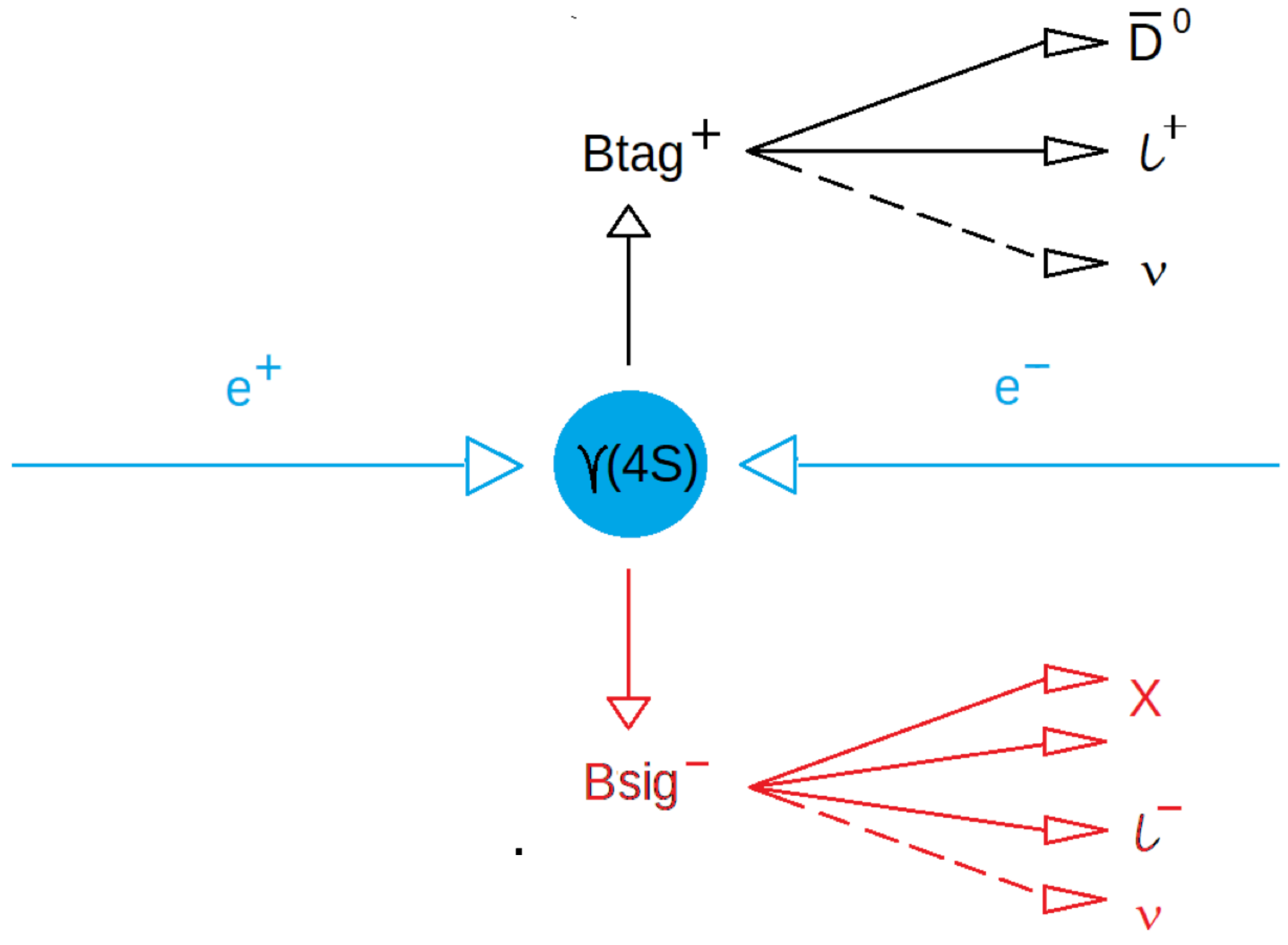


~5% purity

	B^+	B^0
FEI efficiency (%)	2.04	1.80
Full Reconstruction (%) Belle	0.34	0.31

Determined using simulated MC.

- Progress in the semi-leptonic FEI calibration .
- Currently two approaches:
  - $B \to X\ell\nu$: similar approach to hadronic calibration
  - $B \to D^{(*)}\ell\nu$: start with cleaner tag modes
- Effort to converge both approaches and unify procedure for summer 2021 analyses.
- Upcoming measurement of $B \to \pi\ell\nu$ with semi-leptonic tagging.



Hadronic FEI Systematics

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

Diamond Frame definition

– q^2 reconstructed using Diamond Frame method

– Takes a weighted average over four different possible configurations of the B direction

$$q^2 = (p_B - p_\pi)^2$$