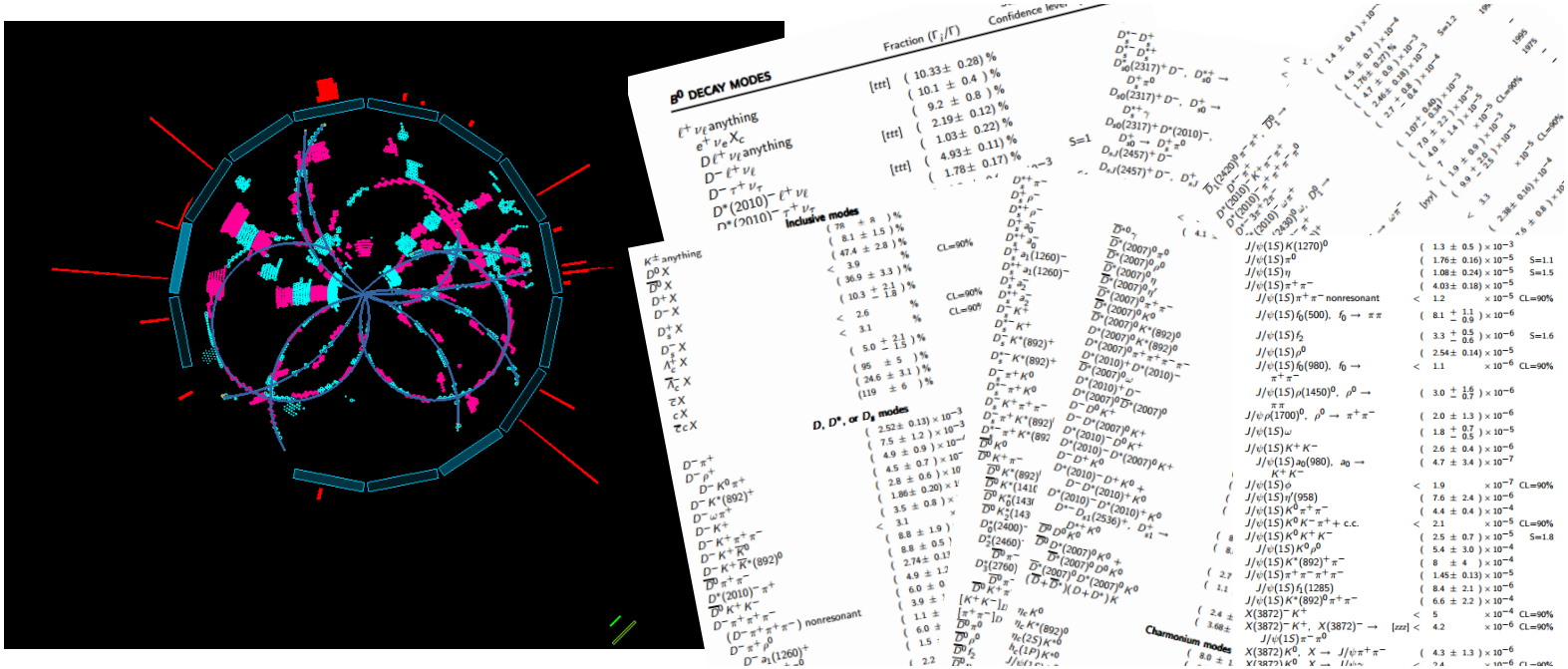
Full Event Interpretation at Belle II



Belle II

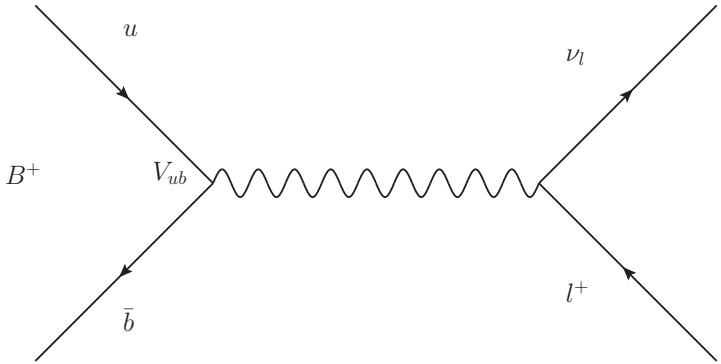
ICHEP 2020 | PRAGUE
40th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
VIRTUAL CONFERENCE
28 JULY - 6 AUGUST 2020
PRAGUE, CZECH REPUBLIC

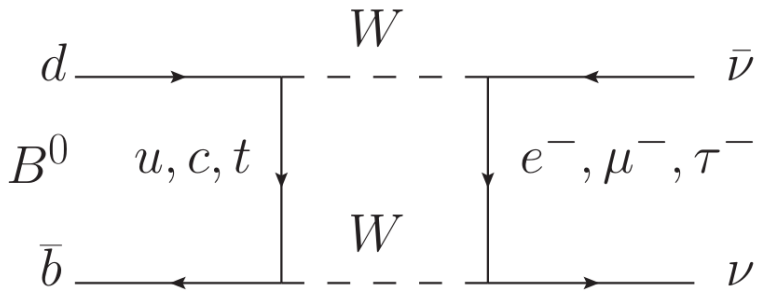
Alexander von Humboldt
Stiftung/Foundation

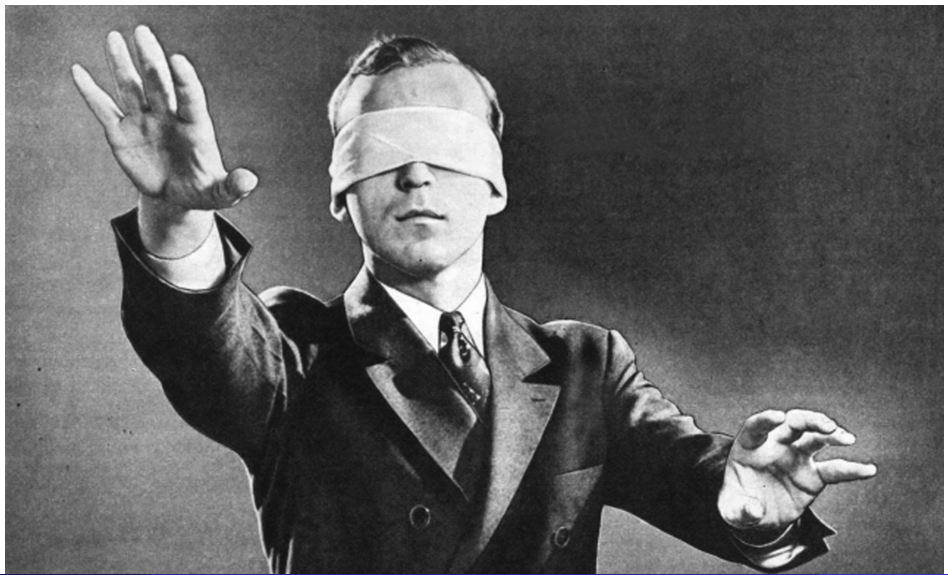
UNIVERSITÄT BONN

Why we need Full Event Interpretation?

- Interesting physics can be obtained from several challenging modes with missing neutrinos ($B \to D^{(*)}\tau\nu$, $B \to \ell\nu$, $B \to X_u\ell\nu$, $B \to h\nu\bar{\nu}$.)







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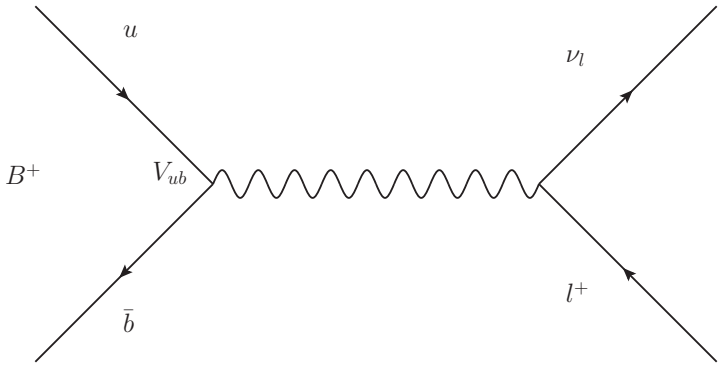
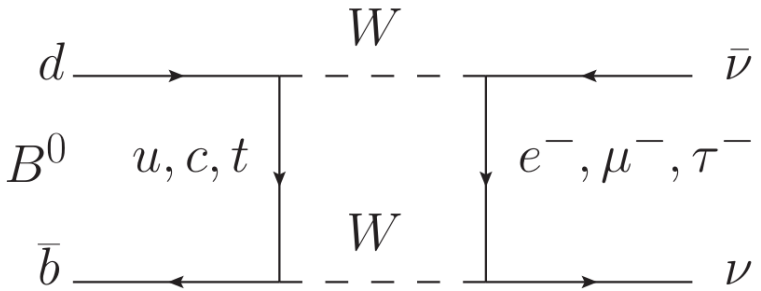
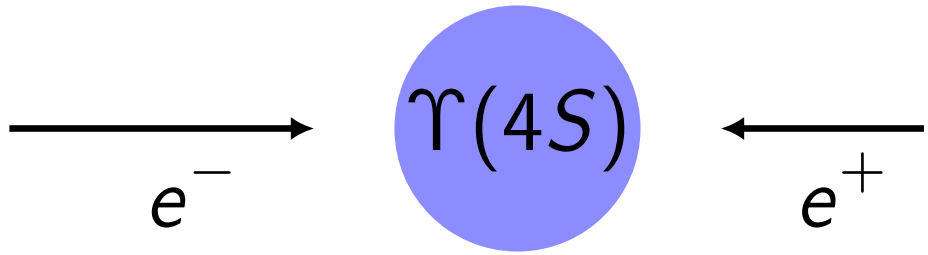




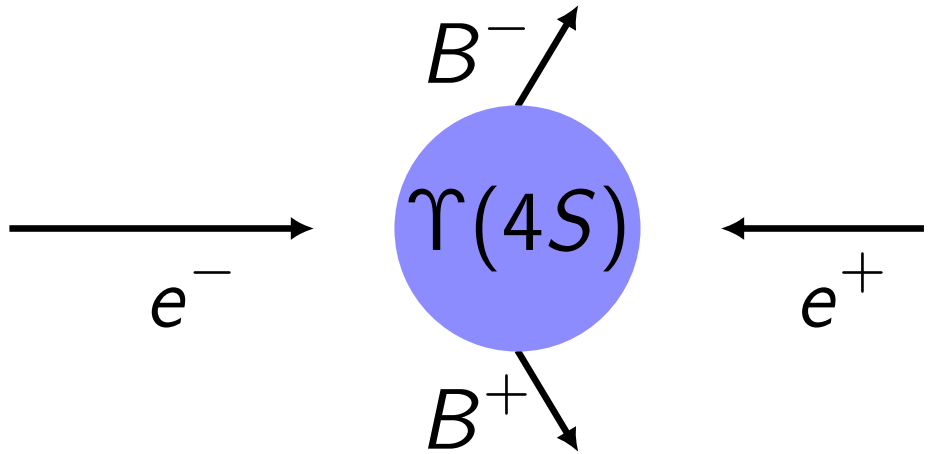
Tag-side B reconstruction

- Collide e^+ and e^- at the energy to make $\Upsilon(4S)$ particles.



Tag-side B reconstruction

- Collide e^+ and e^- at the energy to make $\Upsilon(4S)$ particles.
- $\Upsilon(4S)$ decays to B^+B^- and $B^0\bar{B}^0$ over 96% of the time.



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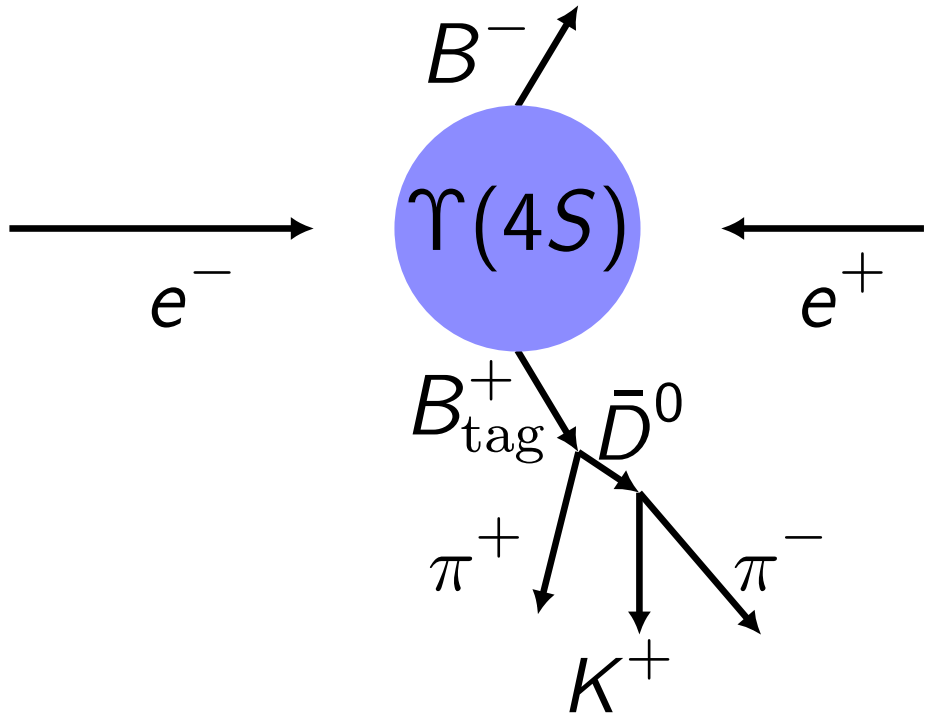

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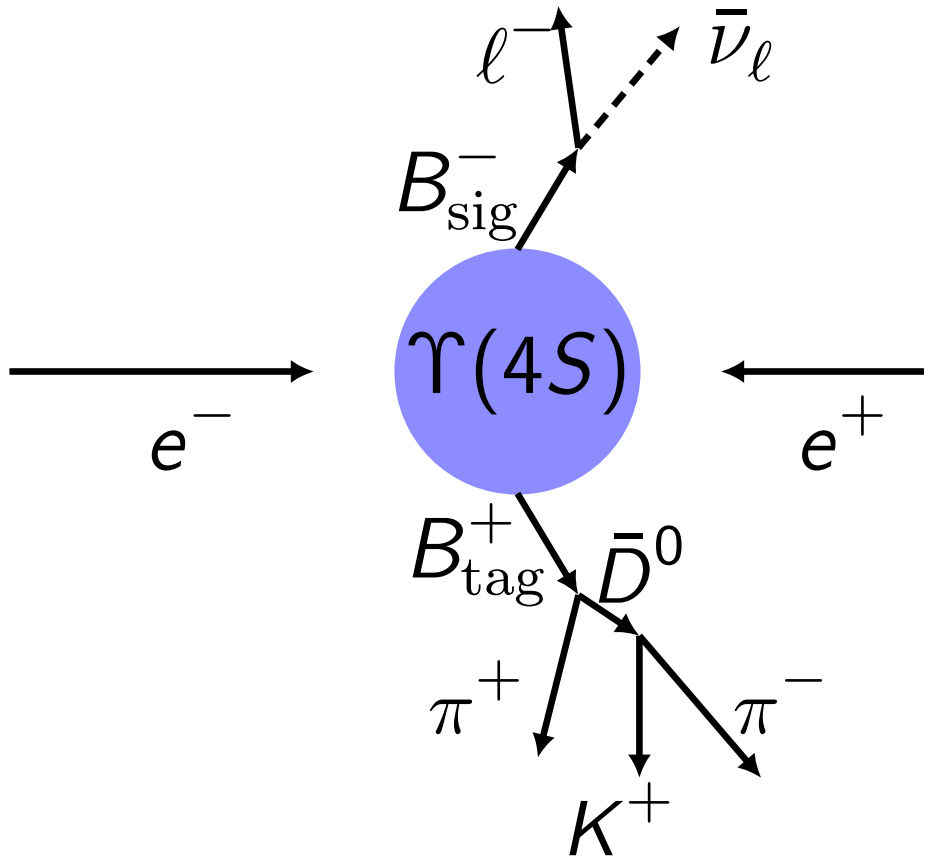

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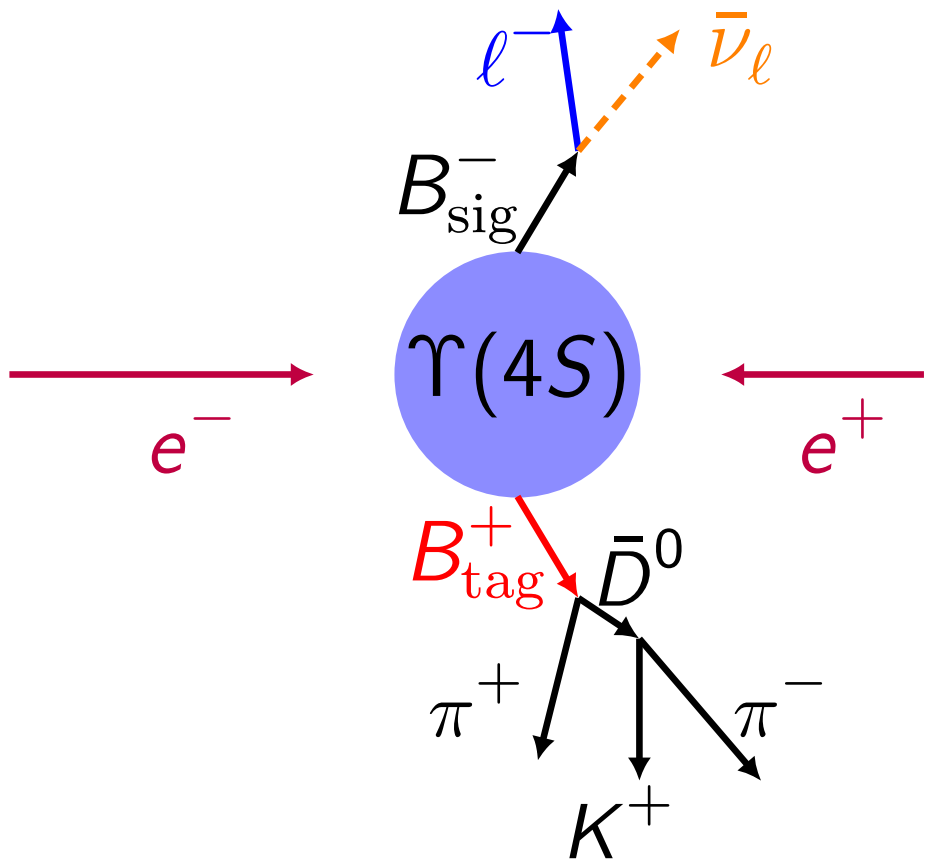
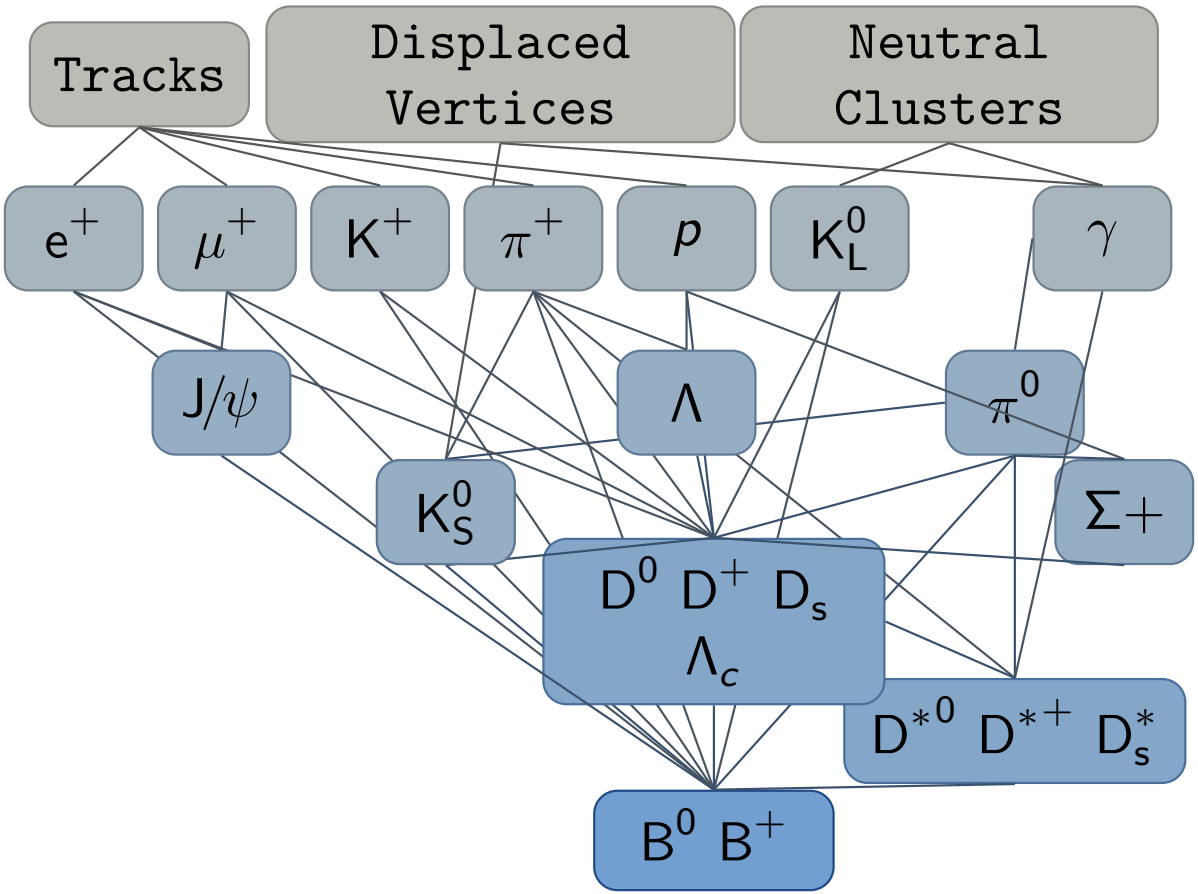
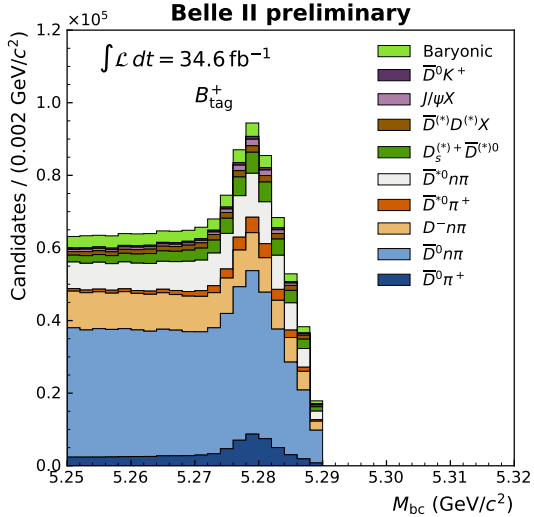
- Reconstruct one B meson as tag-side (B_{tag}) hadronic or SL.
- Study remaining B meson as signal (B_{sig}).
- Flavour constraints:
  $B^+_{\text{tag}} \implies B^-_{\text{sig}}$
  Kinematic constraints:
  $p_\nu = p_{e^+e^-} - p_{\ell^-} - p_{B^+}$

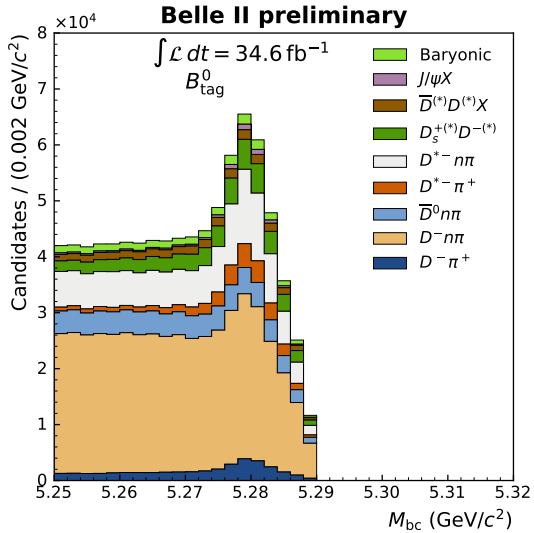


The Full Event Interpretation

- Employs over 200 BDTs to reconstruct 10000 B decay chains.
- Baryonic decays recently added.





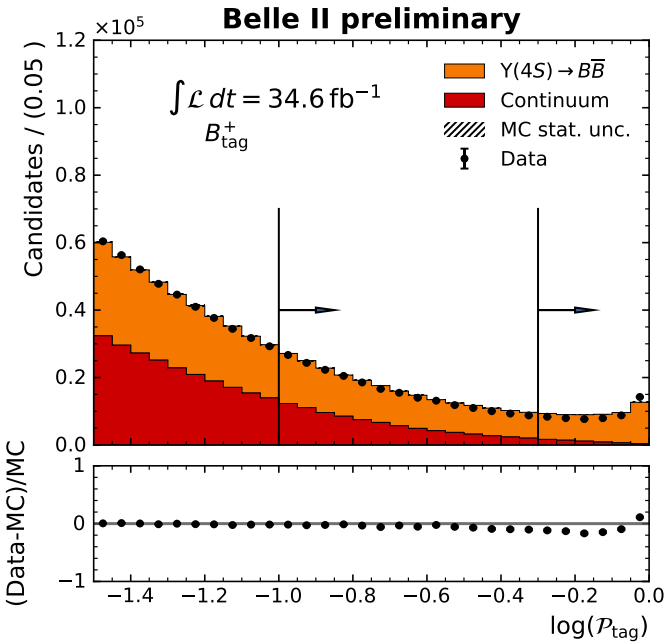


Keck, T. et al. Comput Softw Big Sci (2019) 3: 6.

$$M_{bc} = \sqrt{E^2_{beam}/4 - (p^{\text{cm}}_{B_{\text{tag}}})^2}$$

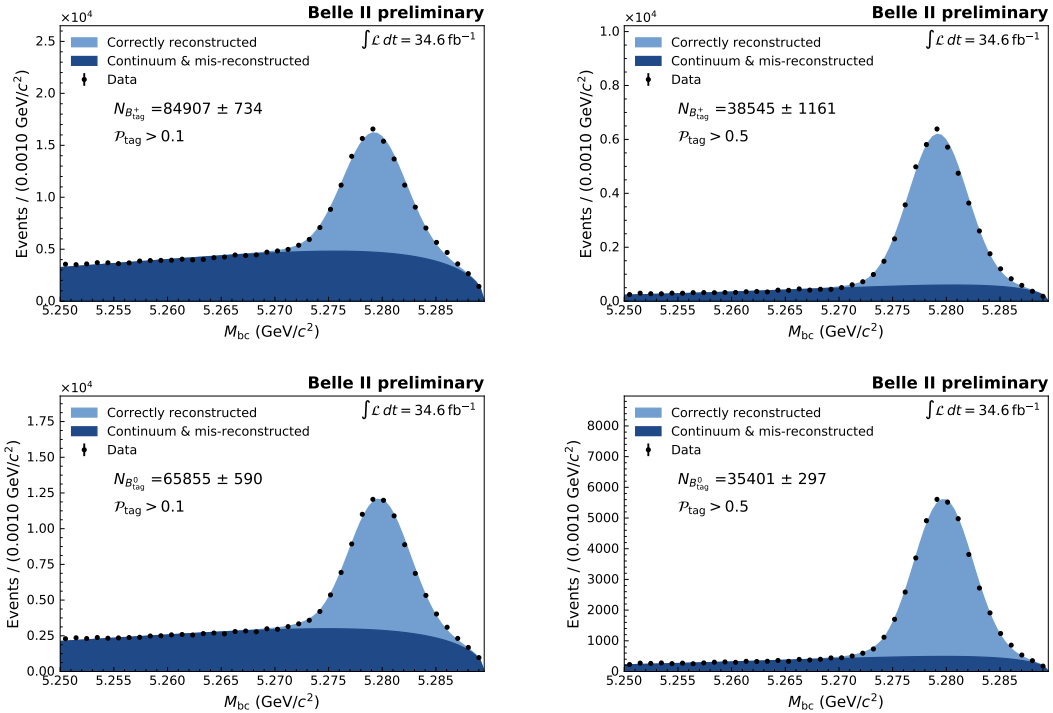
Role of the tag-side B classifier.

- B classifier value, $\mathcal{P}_{\text{tag}}$, discriminates correctly reconstructed tag-sides from background.



- Select a high purity sample by cutting on $\mathcal{P}_{\text{tag}}$.

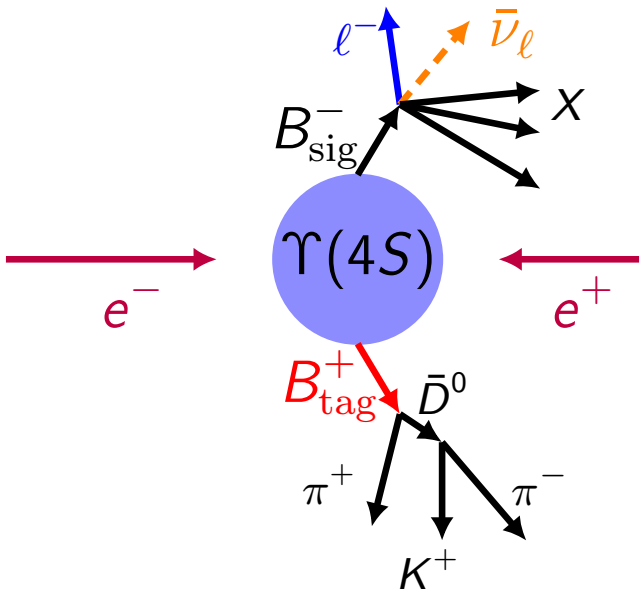
- Determine the correctly reconstructed tag-side yield by fitting M_{bc}.



- Efficiency of the algorithm differs between simulation and data due to the complexity.

Calibrating the FEI

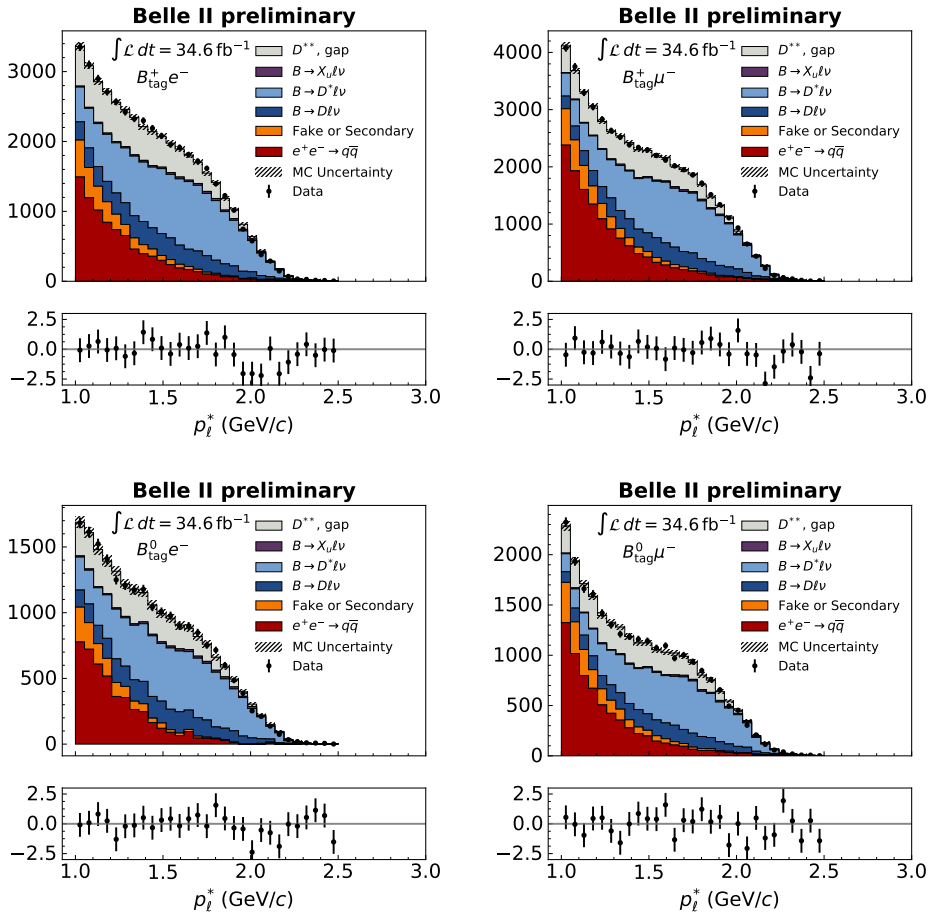
- Can calibrate the FEI by measuring a signal-side.
- Use $B \to X l \nu$ given the large branching fraction ($\sim$20%).



- $M_{bc} > 5.27$ GeV/c^2, $\mathcal{P}_{\text{tag}} > 0.001$, 0.01, 0.1, Lepton ID, $p^*_\ell > 1$ GeV/c

* $\implies$ B Rest Frame

- Calibration factor, $\epsilon_{cal} = N^{X\ell\nu}_{Data} / N^{X\ell\nu}_{MC}$



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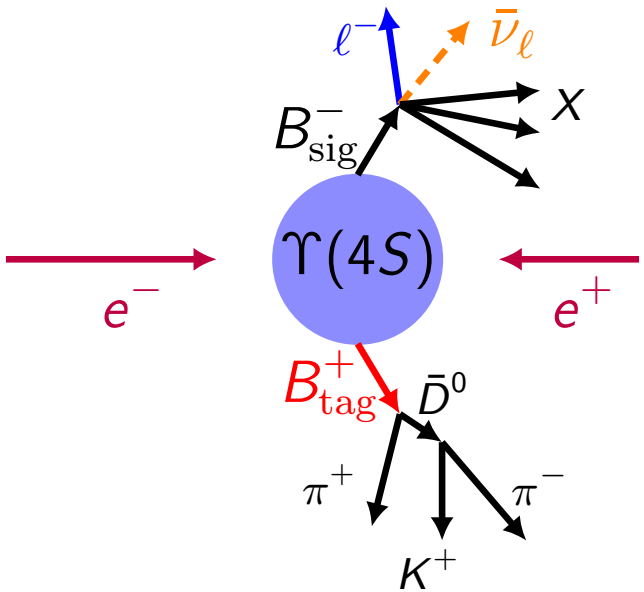

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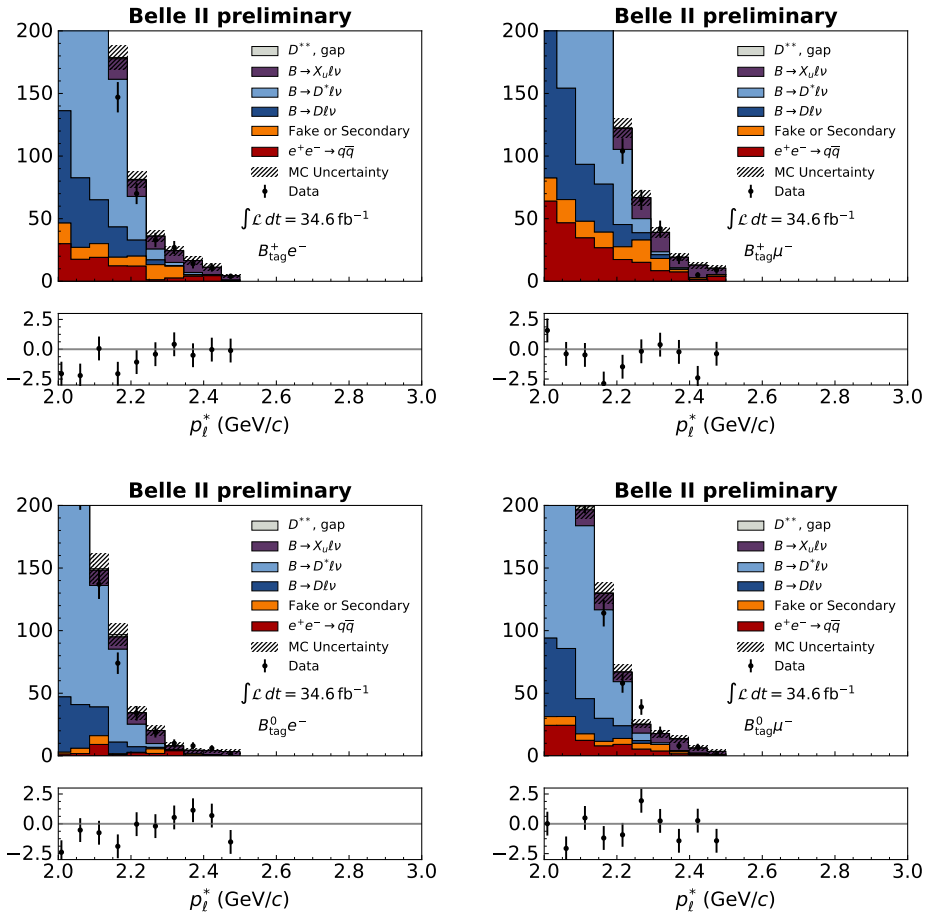

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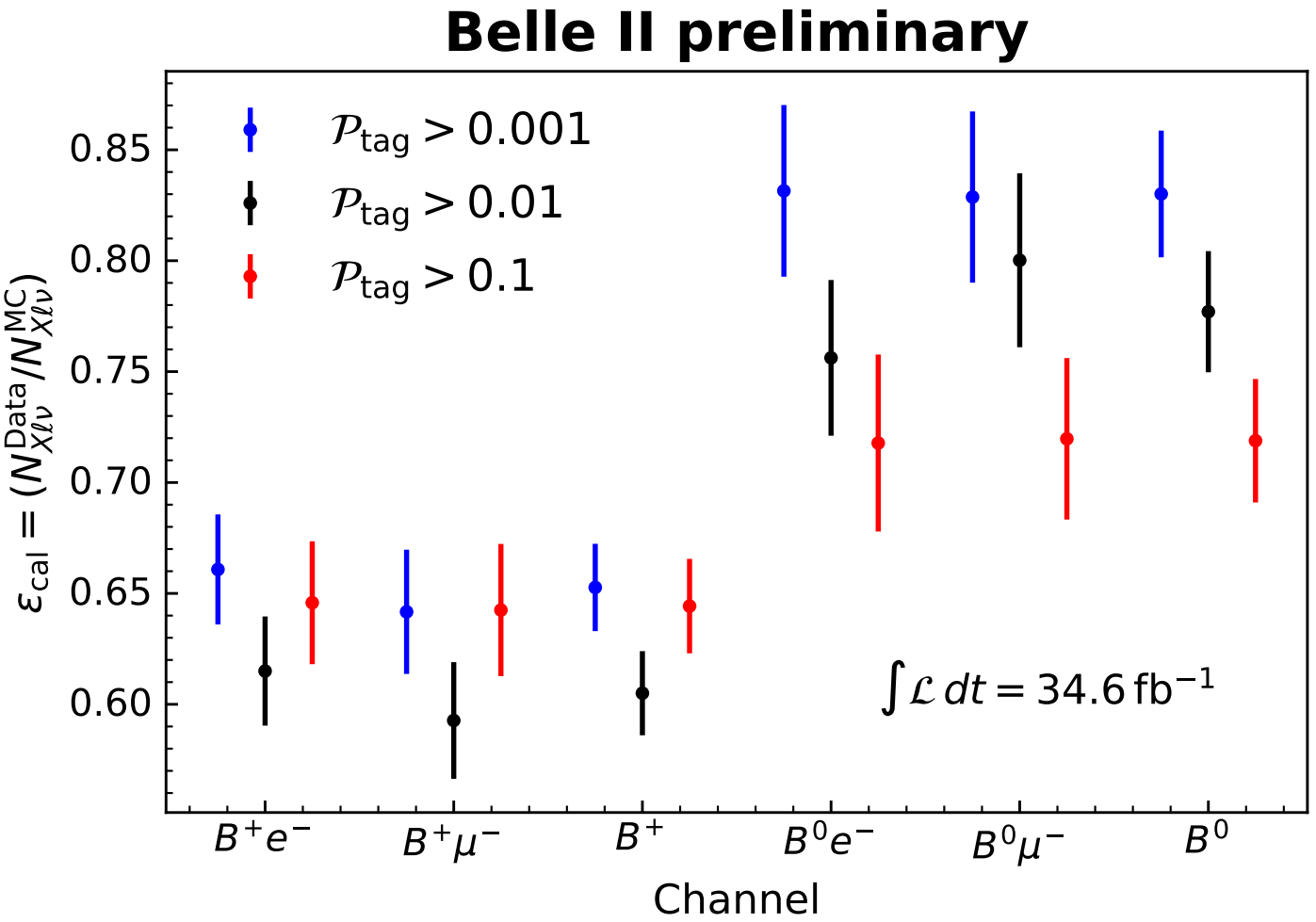
Calibration results



Calibration results

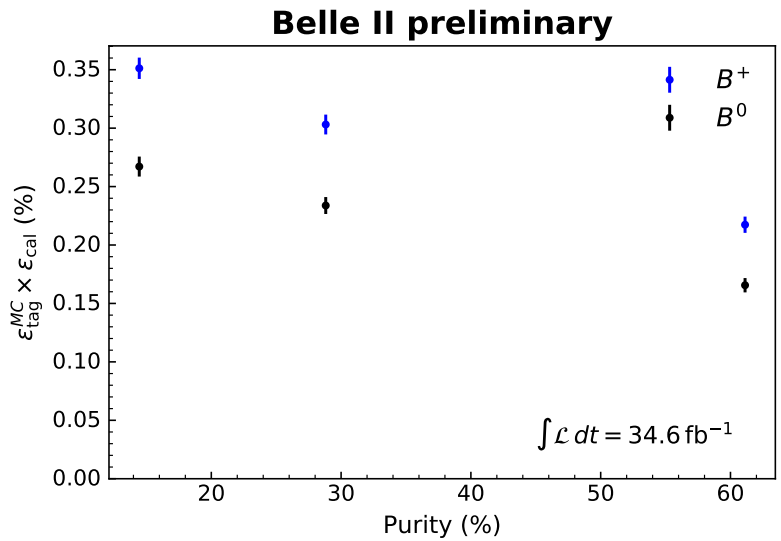
$\mathcal{P}_{B^+} >$	ϵ	% uncertainty
0.001	0.653 ± 0.020	3.02
0.01	0.605 ± 0.019	3.13
0.1	0.644 ± 0.021	3.30

$\mathcal{P}_{B^0} >$	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

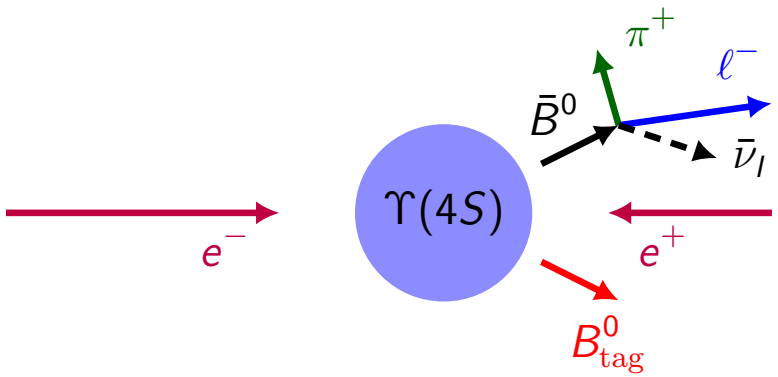
Sources of uncertainty in %

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

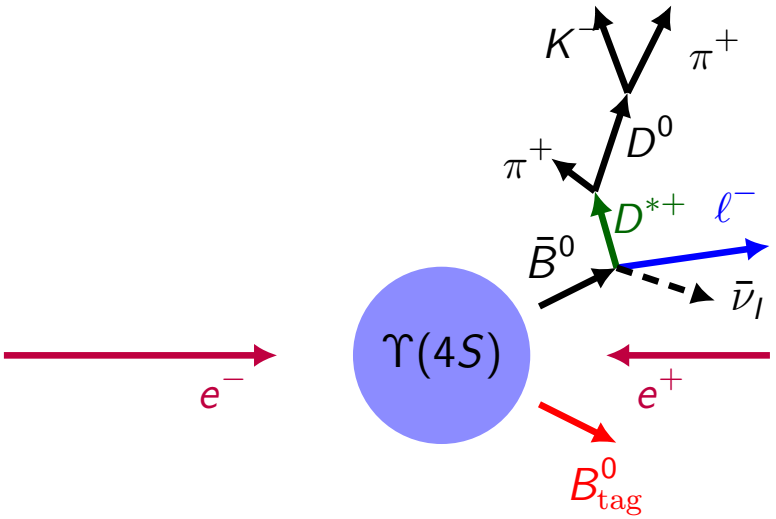
- Tag-side efficiency in simulation against purity corrected by ϵ_{cal}.
- Tag-side efficiency = No. of events with a correctly reconstructed tag-side (N_{corr}) / No. of $\Upsilon(4S) \to B\bar{B}$
- Purity = N_{corr} / No. of events with a tag-side



Rediscovering $B \to \pi \ell \nu$ and $B \to D^* \ell \nu$ with tagging

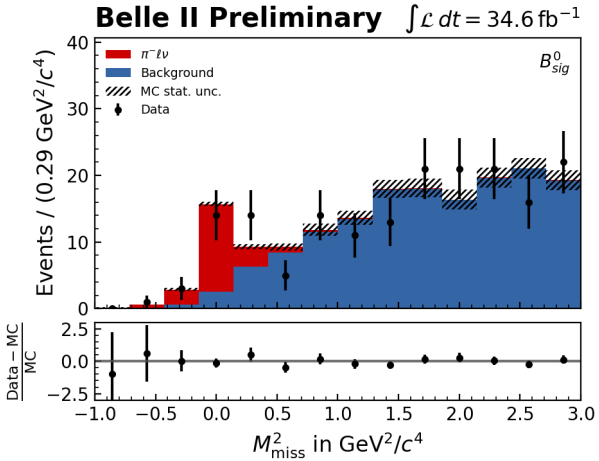


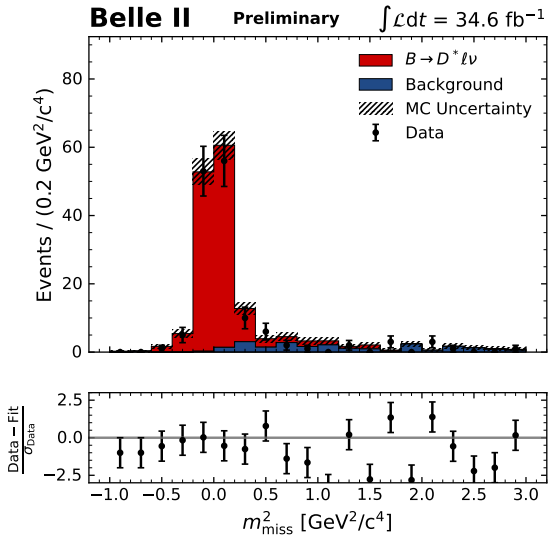
$$m^2_{\text{miss}} = (p_{e^+e^-} - p_{B_{\text{tag}}} - p_\ell - p_{\pi/D^*})^2$$



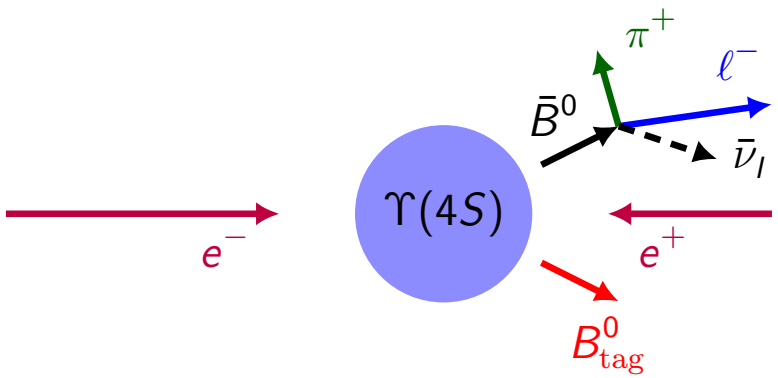
See Racha Cheaib's V_{ub} and V_{cb} talk

- Data-simulation comparisons with the calibration applied.



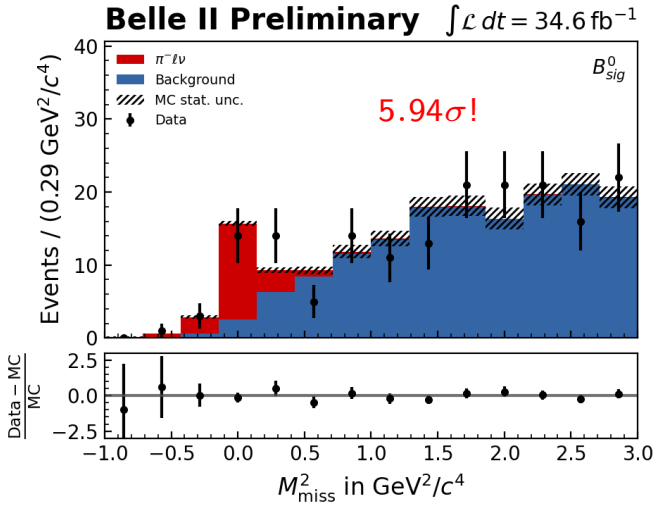


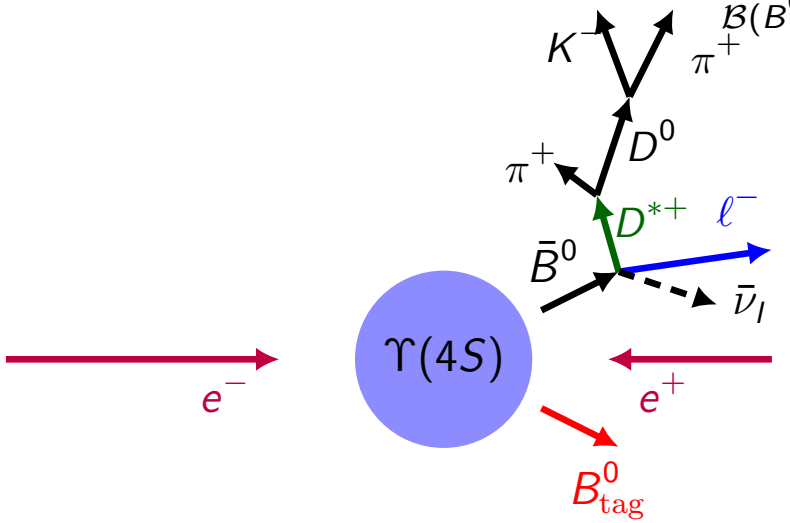
Rediscovering $B \to \pi\ell\nu$ and $B \to D^*\ell\nu$ with tagging



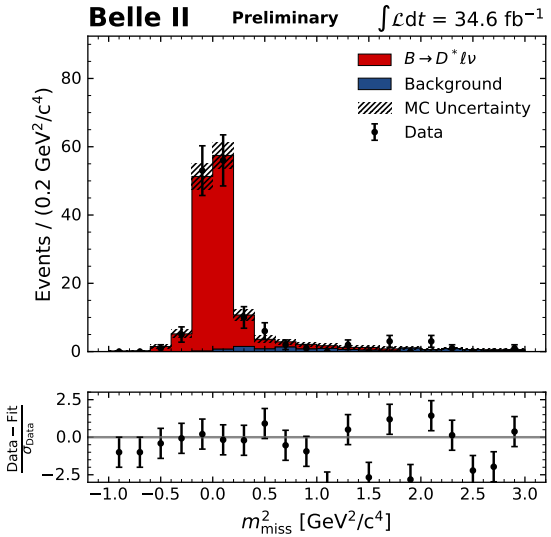
$$m^2_{\text{miss}} = (p_{e^+e^-} - p_{B_{\text{tag}}} - p_\ell - p_{\pi/D^*})^2$$

$$\mathcal{B}(B \to \pi\ell\nu) = (1.62 \pm 0.42(\text{stat}) \pm 0.07(\text{sys})) \times 10^{-4}$$





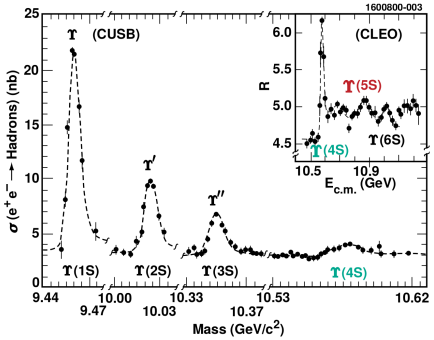
$$\mathcal{B}(B^0 \to D^{*+}\ell\nu) = (4.45 \pm 0.41(\text{stat}) \pm 0.27(\text{sys}) \pm 0.45(\pi_s)) \times 10^{-2}$$



See Racha Cheaib's V_{ub} and V_{cb} talk

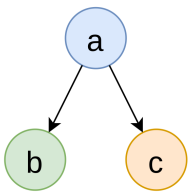
FEI Developments and the Future

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



- Graph networks naturally suit particle decays.

Input graph



Adjacency matrix

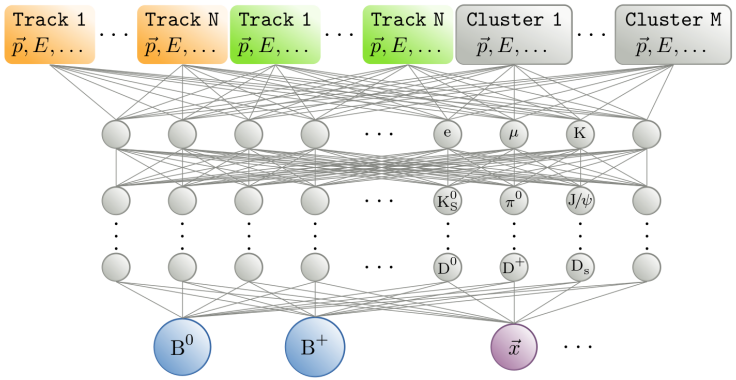
	a	b	c
a	0	1	1
b	1	0	0
c	1	0	0

Feature matrix

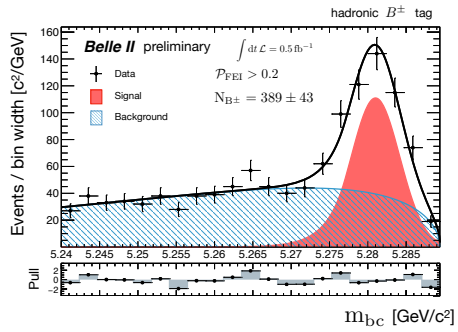
a0	a1
b0	b1
c0	c1

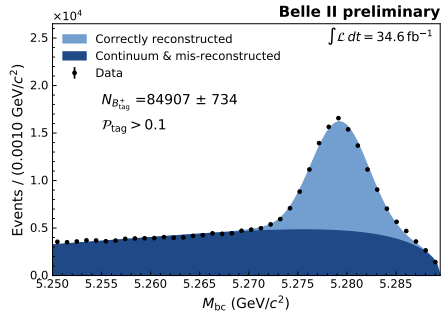
Figure: Example of matrices fully defining a graph.

- Exploring deep extensions of the FEI.



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





Conclusion

- The FEI is performing well in early Belle II data.
- A first calibration of the FEI has been performed with $B \to X\ell\nu$.
- For a loose tag-side classifier selection the values of the calibration factors are 0.65 ± 0.02 (B^+) and 0.83 ± 0.03 (B^0).
- The decays $B \to \pi\ell\nu$ and $B \to D^*\ell\nu$ have been rediscovered with tagging.
- We are exploring deep learning extensions of the current algorithm.
- More physics with tagging to come soon!