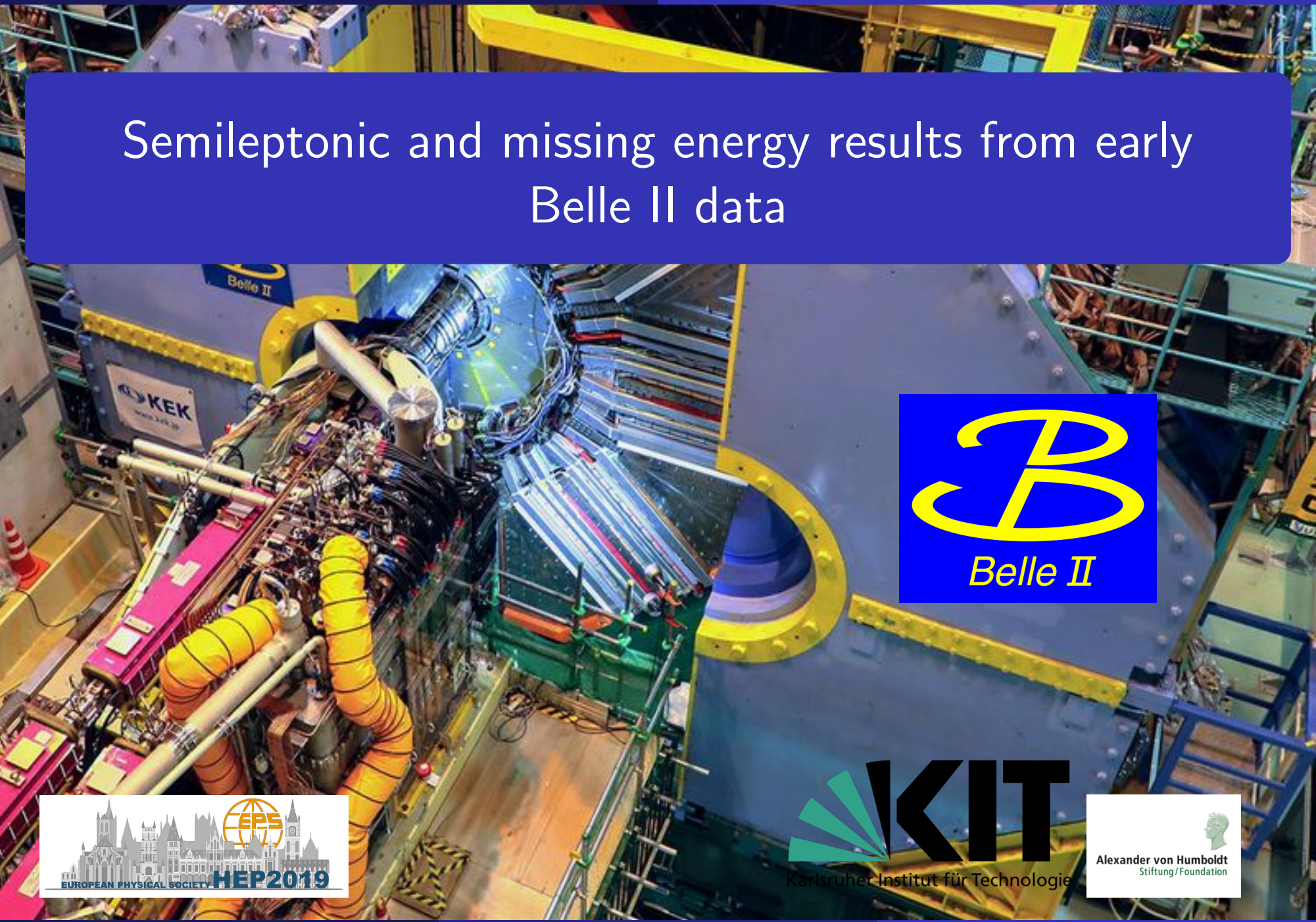
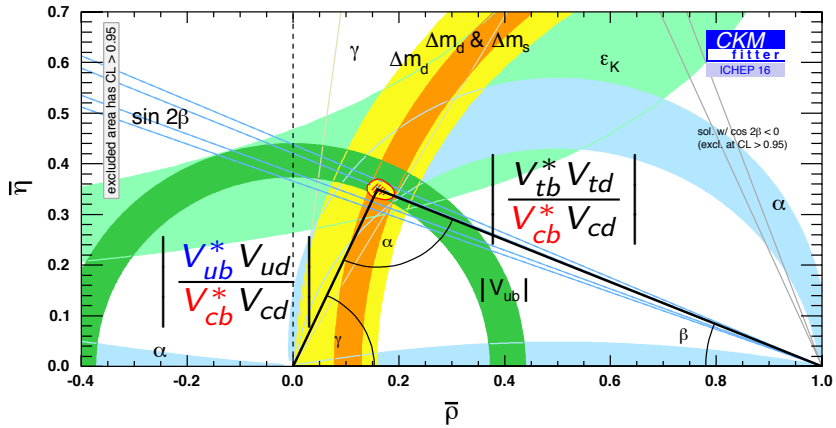
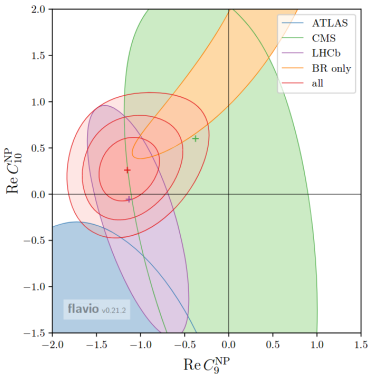
Semileptonic and missing energy results from early Belle II data

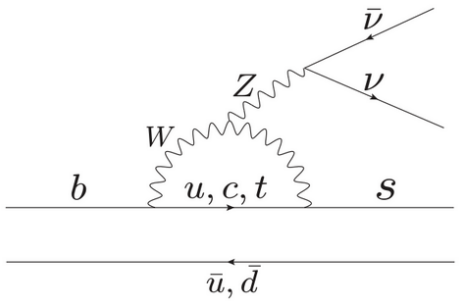


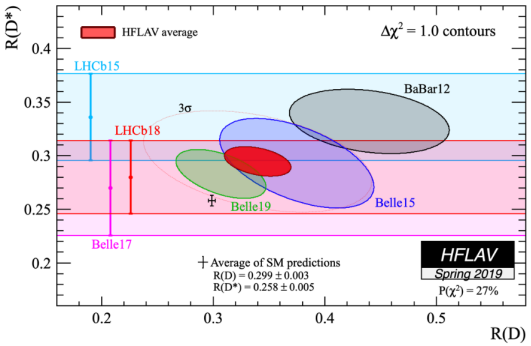
Why semileptonic / missing energy decays?

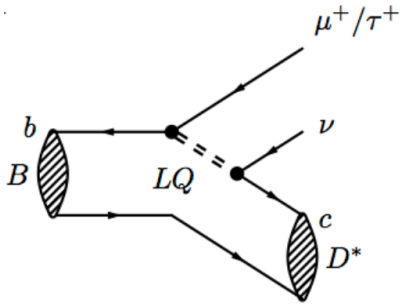
- Precision measurements of the SM:
  - Semileptonic decays are used to determine CKM matrix elements which are essential in global fits for the CKM parameters.
- Excellent probe of new physics:
  - Potential NP in $B \to D^* \tau \nu_\tau$.
  - NP hints in $b \to s\ell\ell$ should be seen in $b \to s\nu\bar{\nu}$

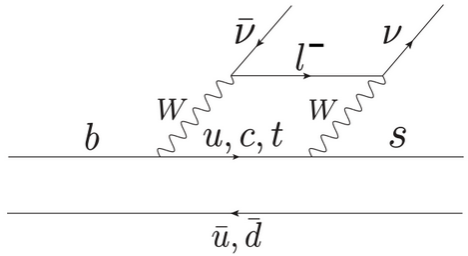












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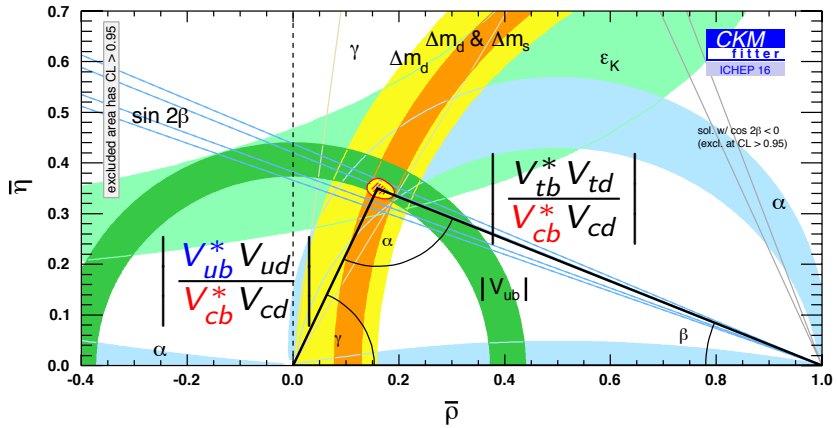
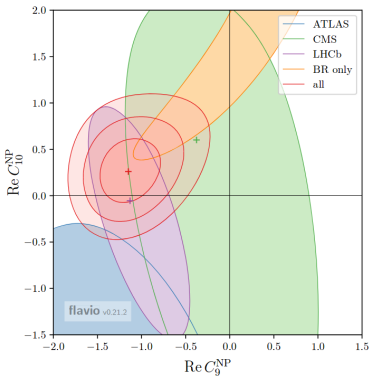
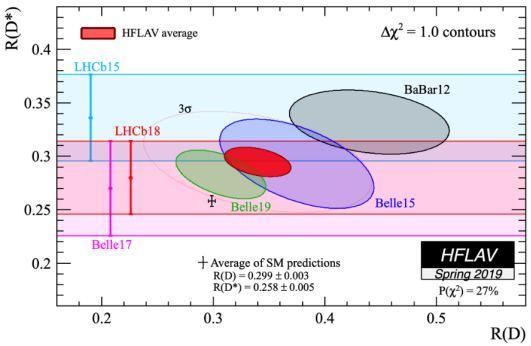
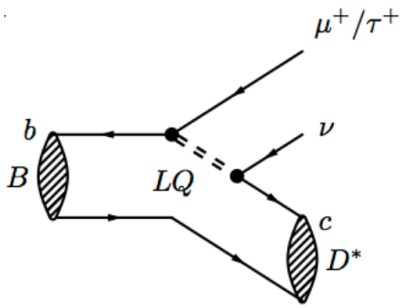
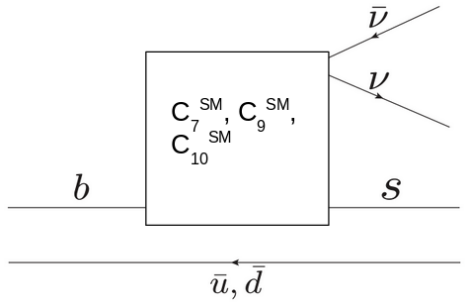
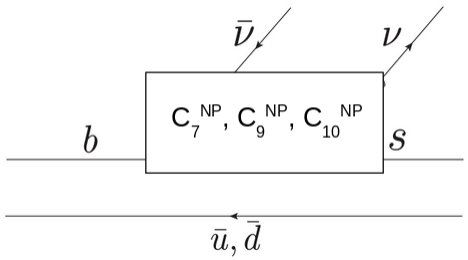




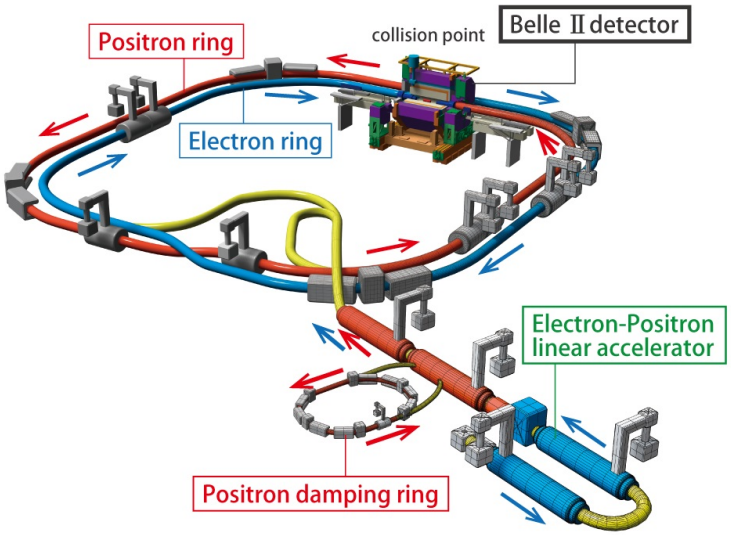


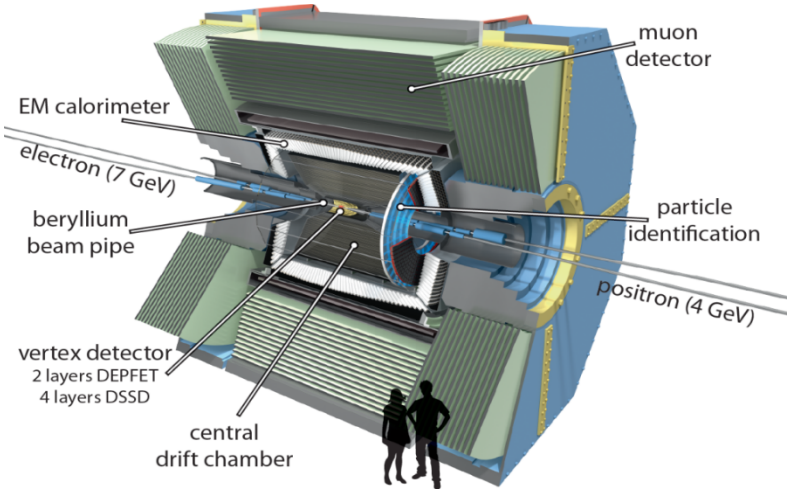


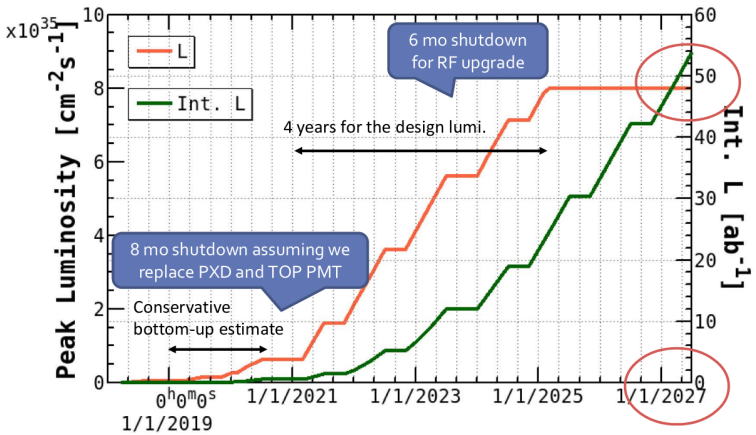


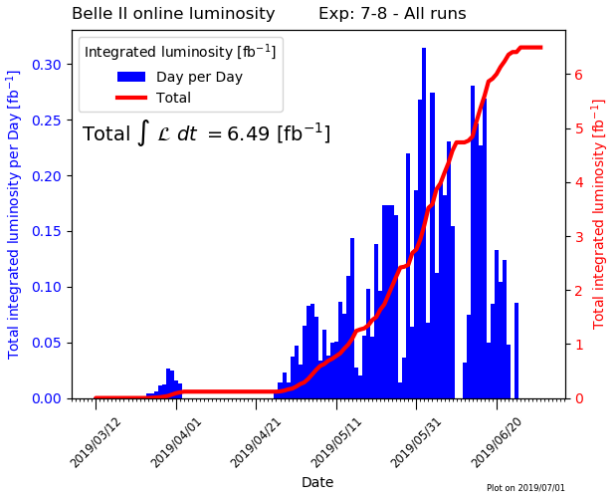


The Belle II experiment





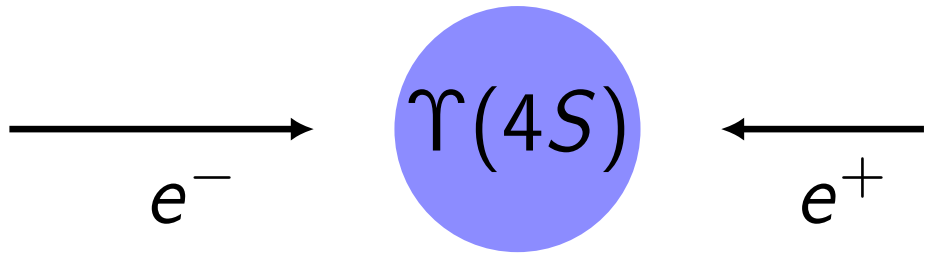




- Results here will use only 0.41fb^{-1}

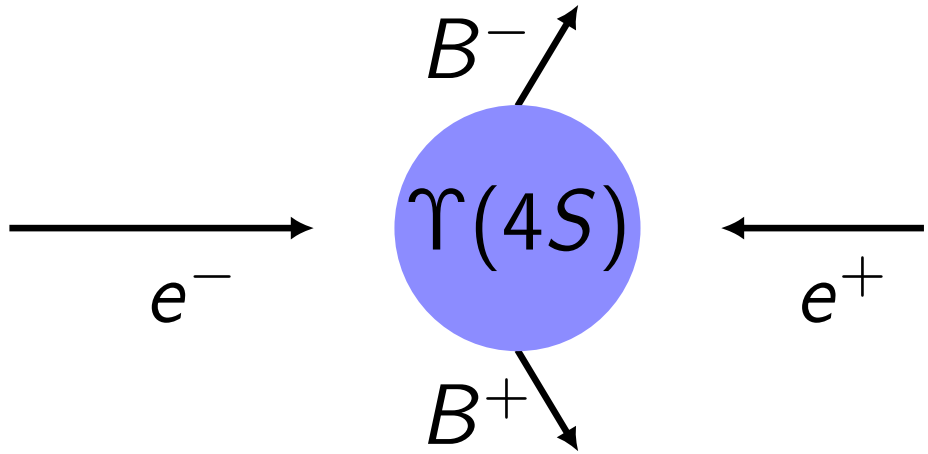
Semileptonic B reconstruction

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



Semileptonic B reconstruction

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



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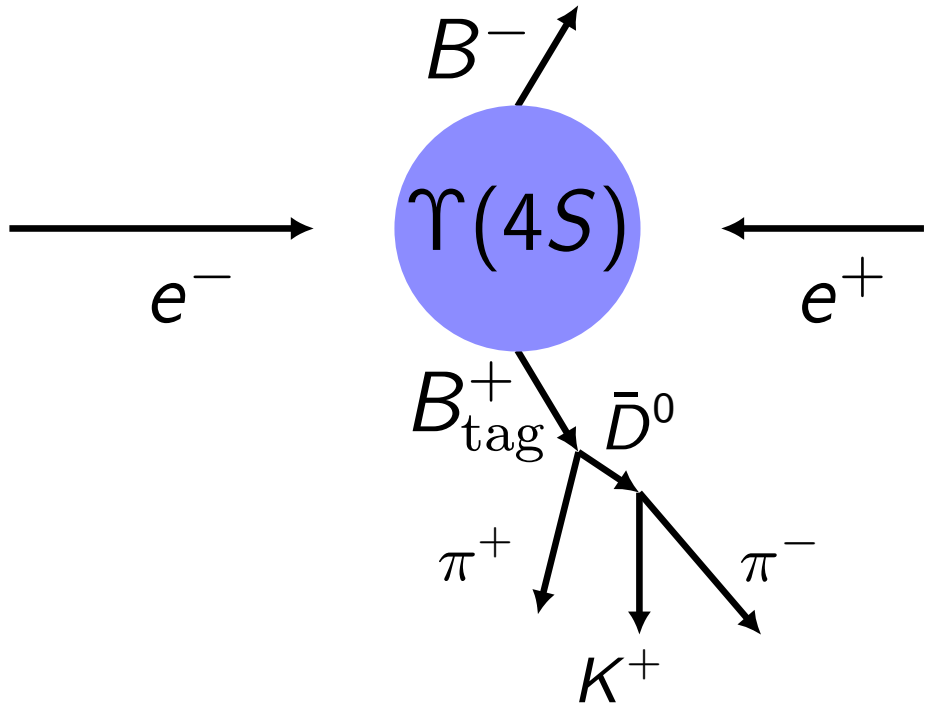

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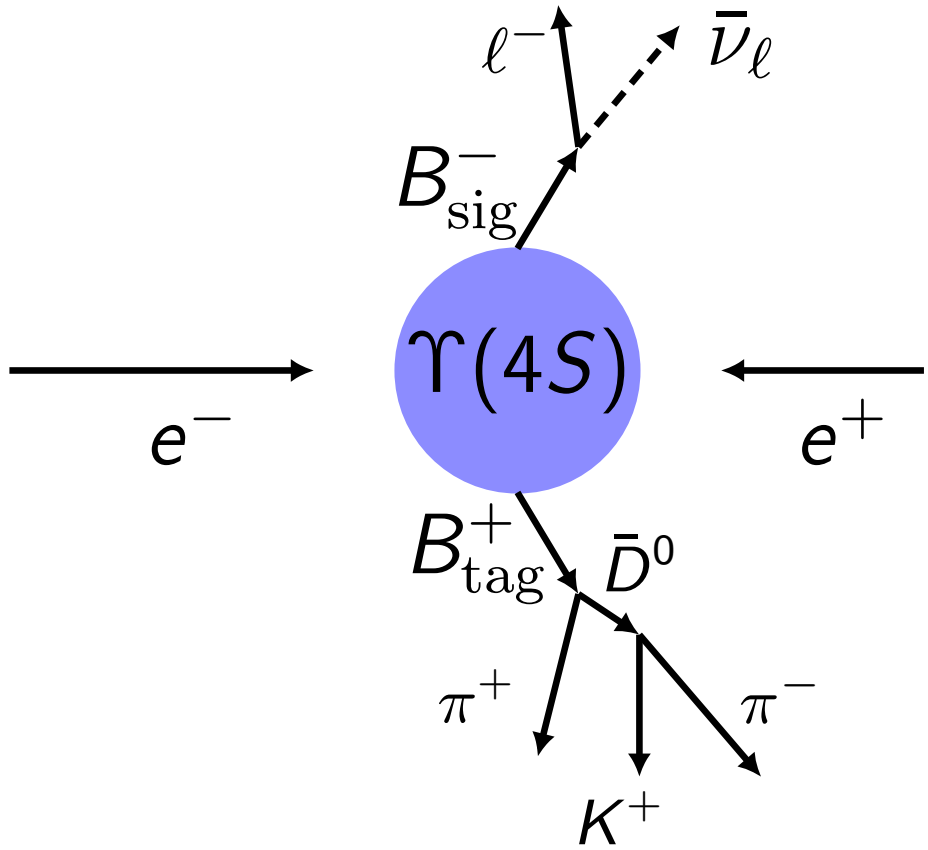

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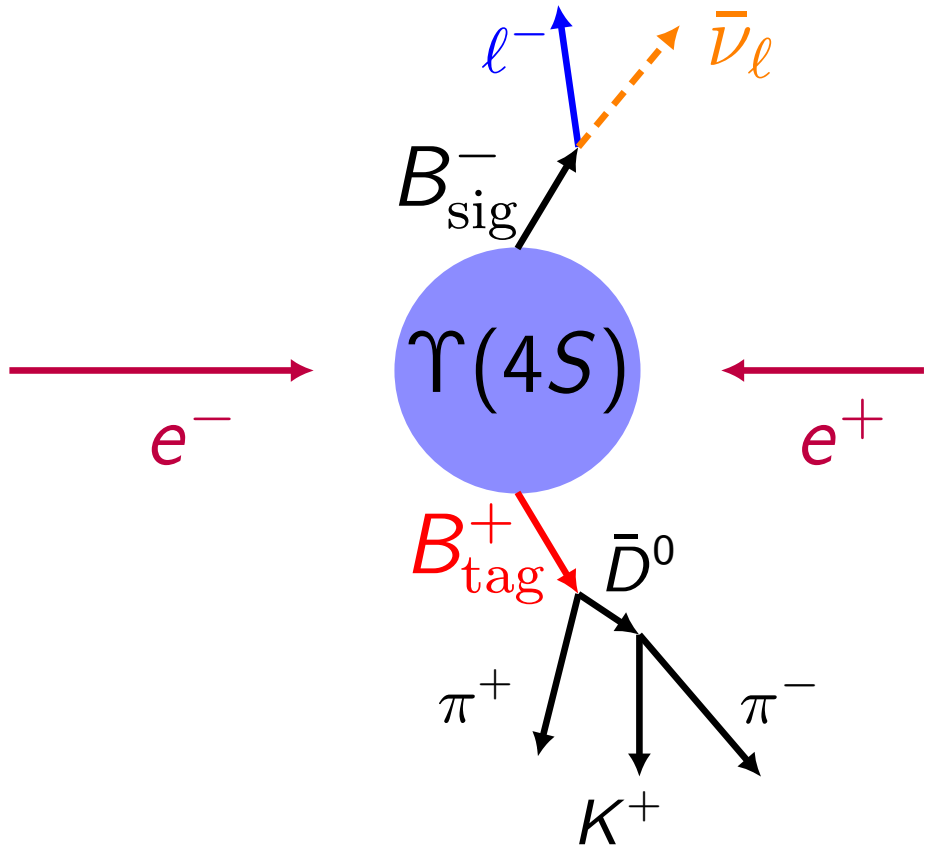
$p_\nu = p_{e^+e^-} - p_{\ell^-} - p_{B^+}$



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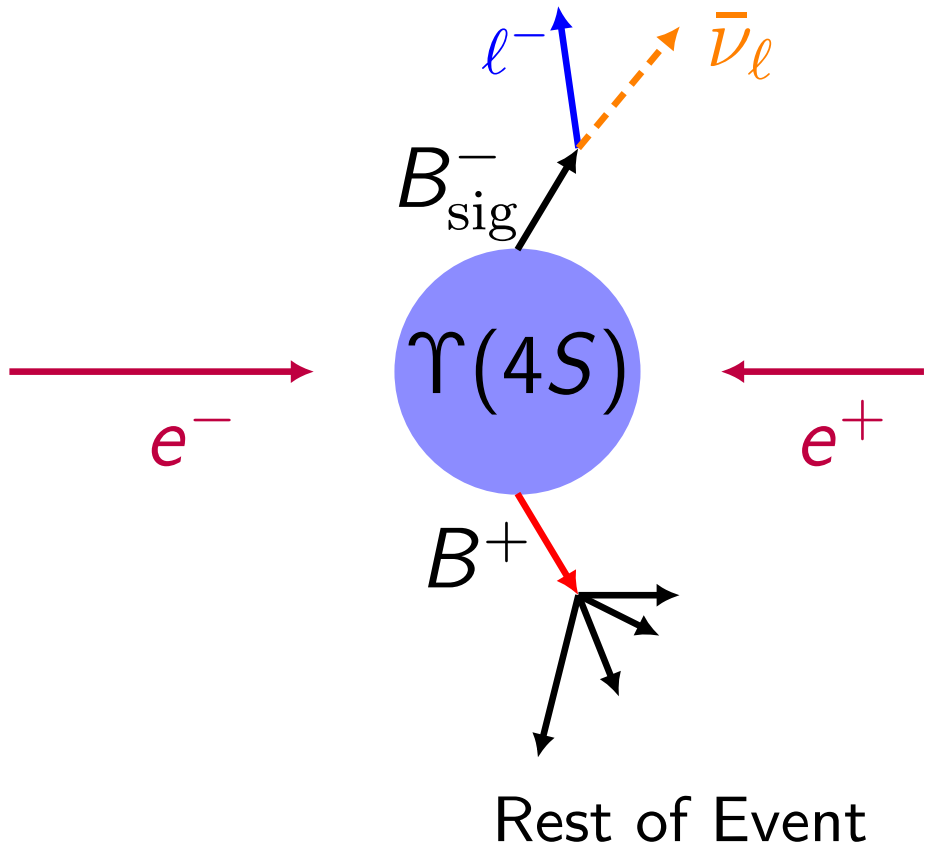

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- Untagged approach:
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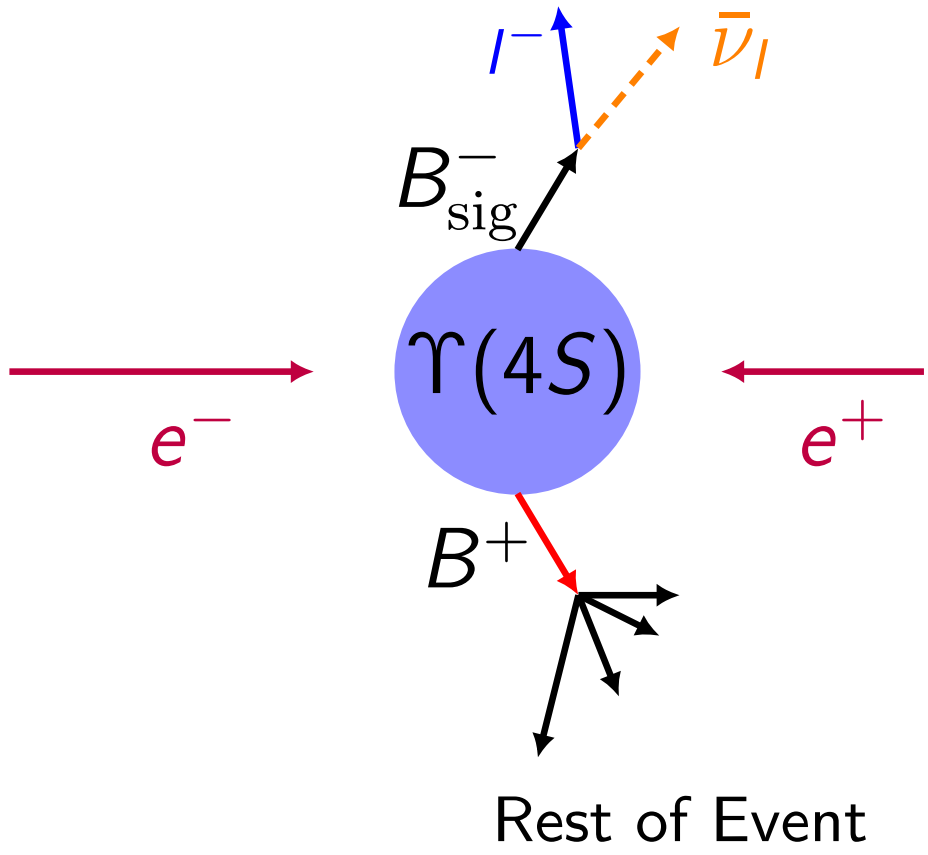
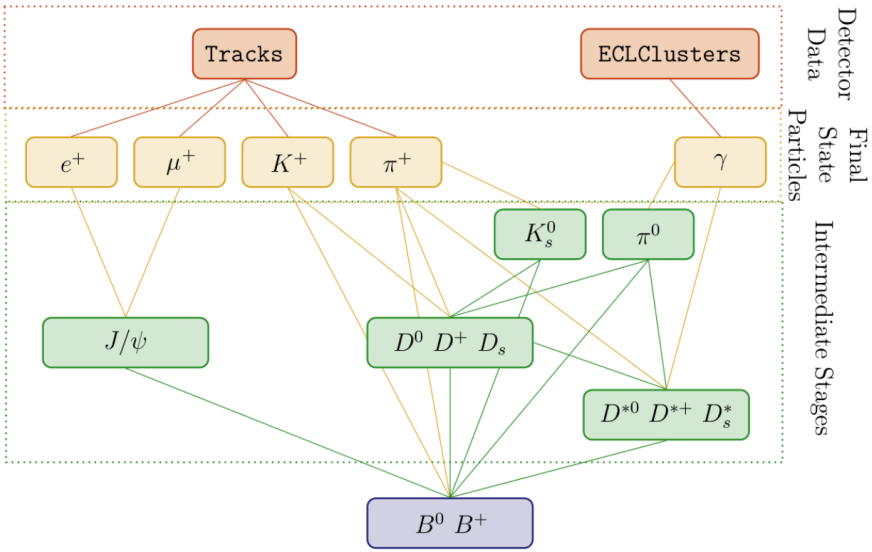
  - Inclusively sum over all tracks and clusters in remaining event or use signal only information e.g p^*_ℓ.



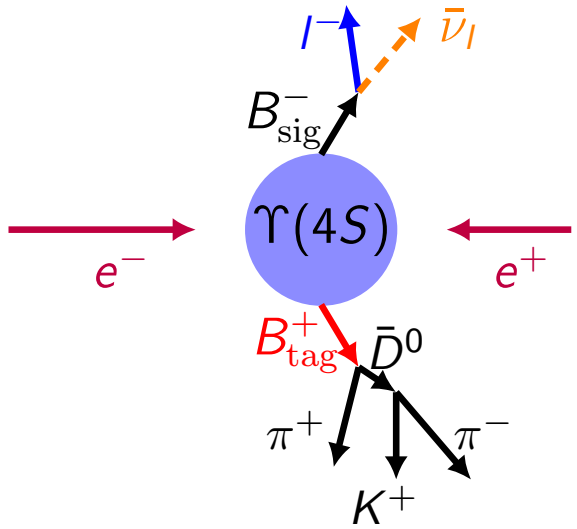
Full Event Interpretation

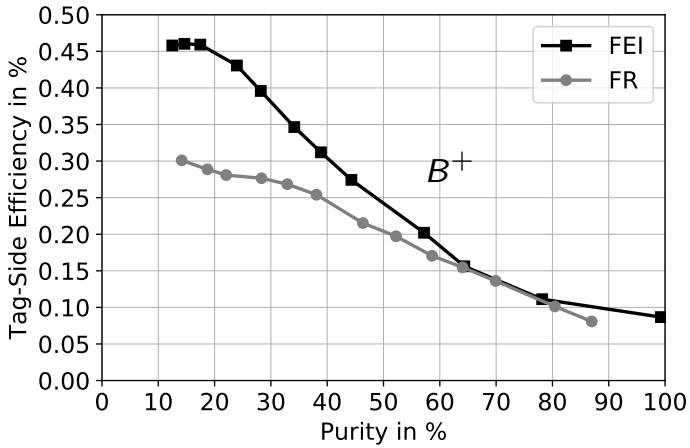
- Trains $\mathcal{O}(200)$ decay channel classifiers.
- Classifiers are used in a hierarchical reconstruction of order $\mathcal{O}(10,000)$ B meson decay chains.



- FEI outperforms predecessor algorithm Full Reconstruction.

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

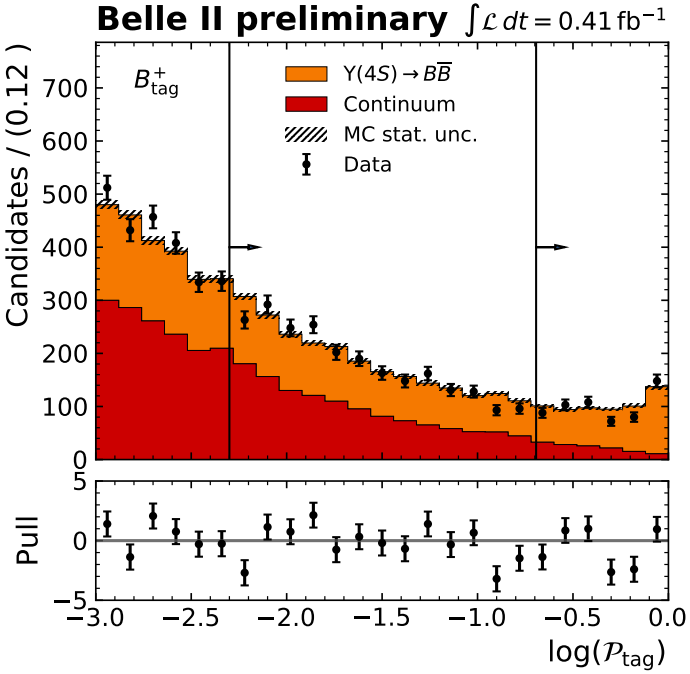




Produced with Belle data

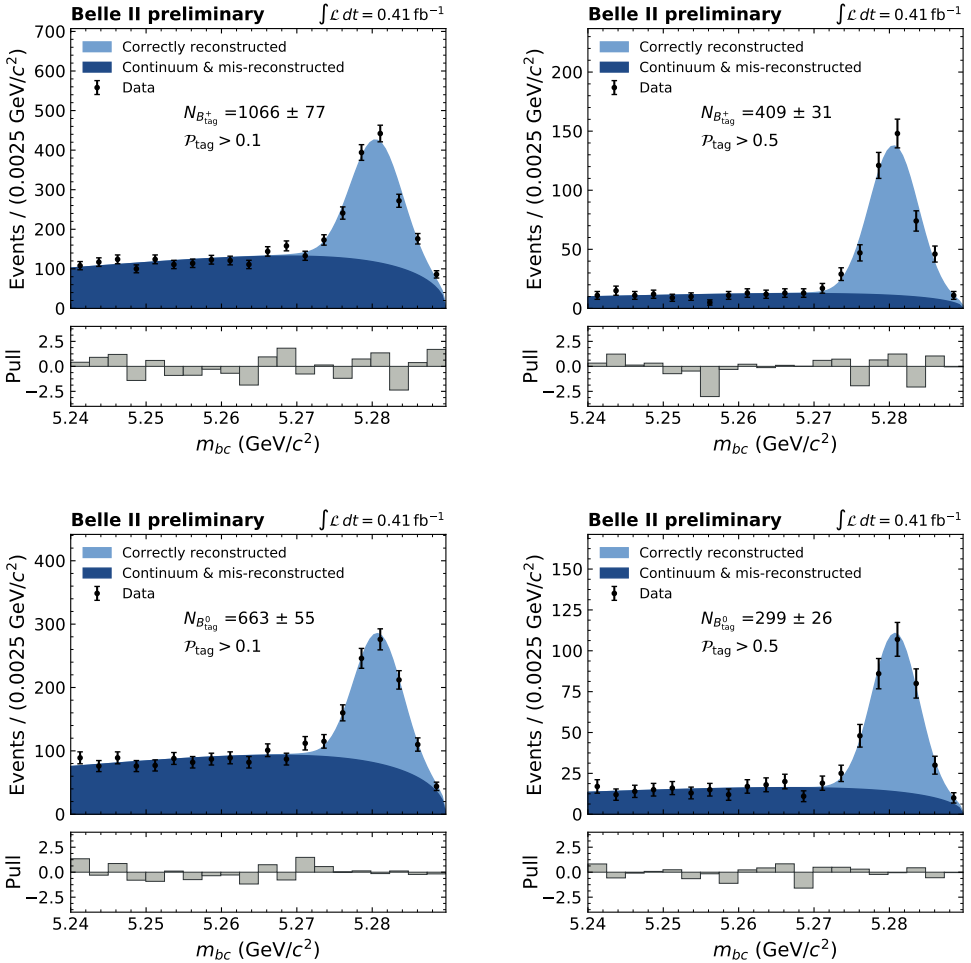
Hadronic tag-side reconstruction in early data

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



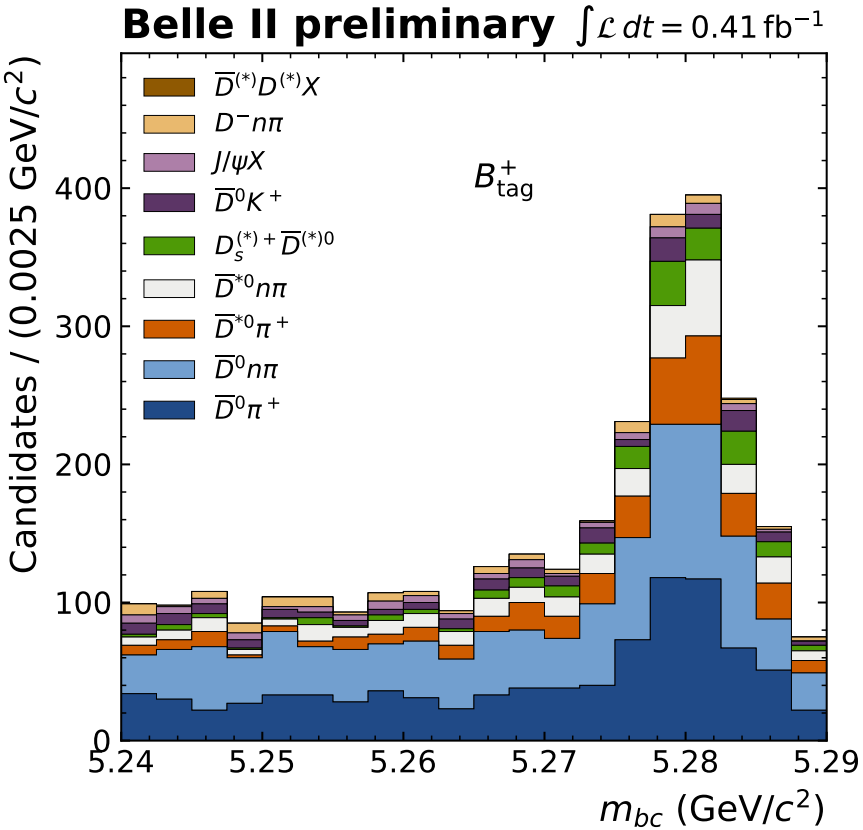
- Select a high purity sample using a selection on $\mathcal{P}$.

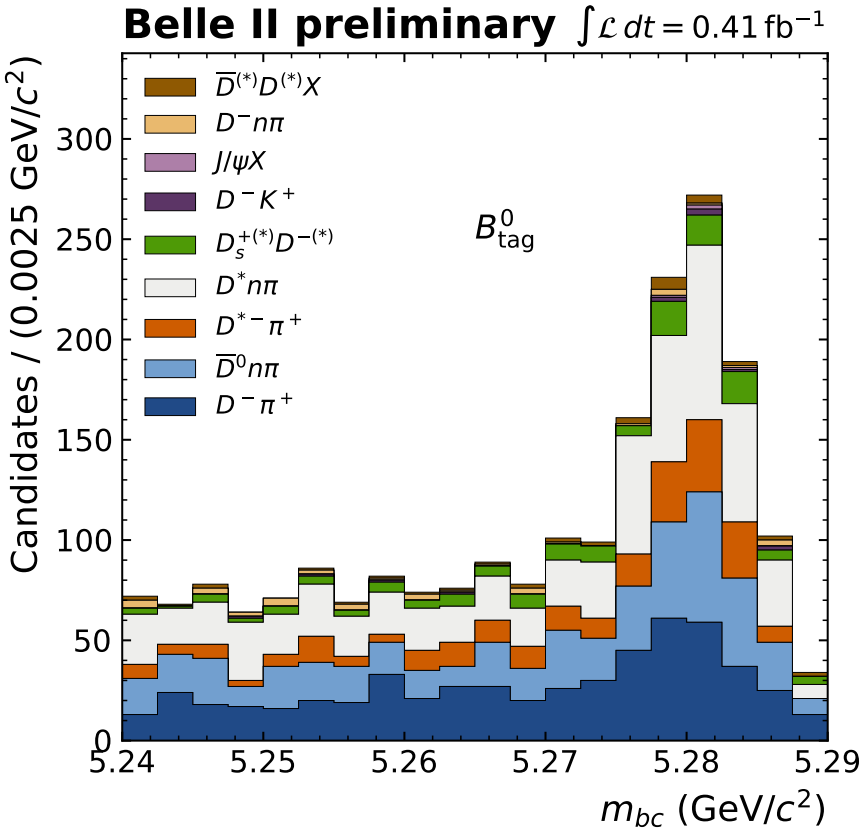
Determine the correctly reconstructed tag-side yield by fitting $m_{bc} = \sqrt{E^2_{beam}/4 - p^{*2}_{B_{\text{tag}}}}$.



Hadronic tag-sides by decay mode

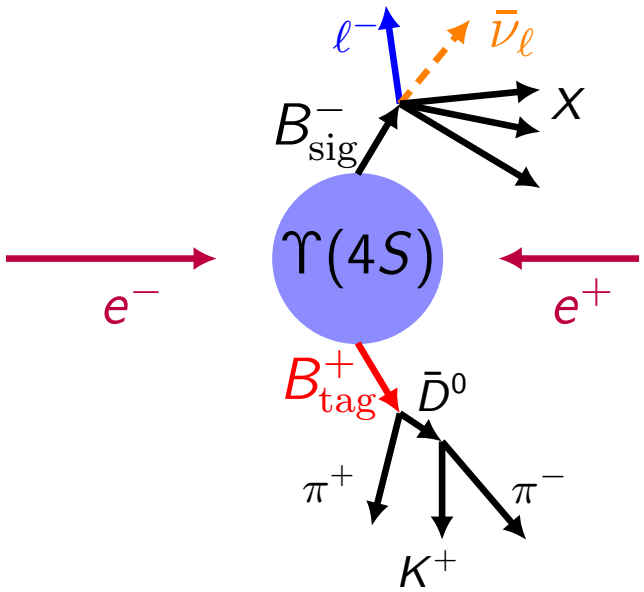
- 29 and 26 hadronic B^+ and B^0 tag-side decay modes are reconstructed.
- Contribution of different categories of modes are shown for data below.





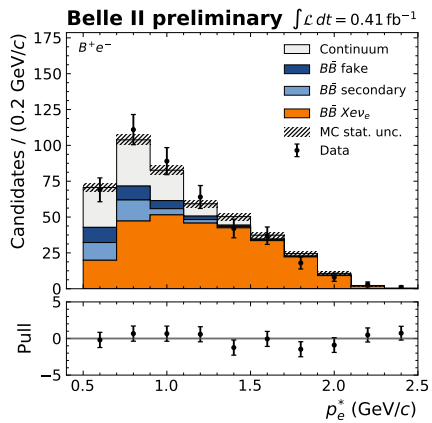
First look at $B \to X l \nu$ decays using hadronic tagging

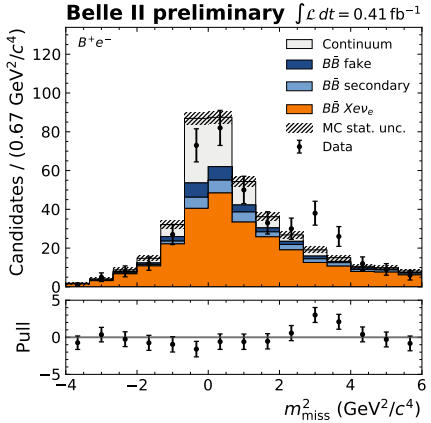
- Perform first Belle II signal side reconstruction with tagging.
- Study $B \to X l \nu$ given the large branching fraction (∼20%)

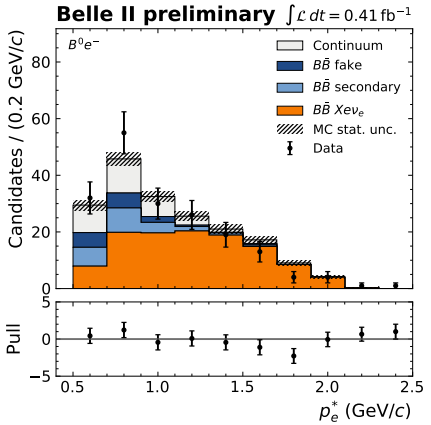


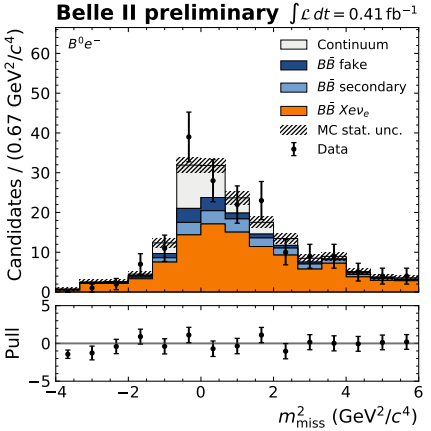
- Highest p^*_ℓ lepton selected with $p^*_\ell > 0.6$ GeV/c, $M^{\text{tag}}_{bc} > 5.27 GeV/c$

$$m^2_{\text{miss}} = (p^*_{e^+e^-} - p^*_{B_{\text{tag}}} - p^*_\ell - p^*_X)^2$$









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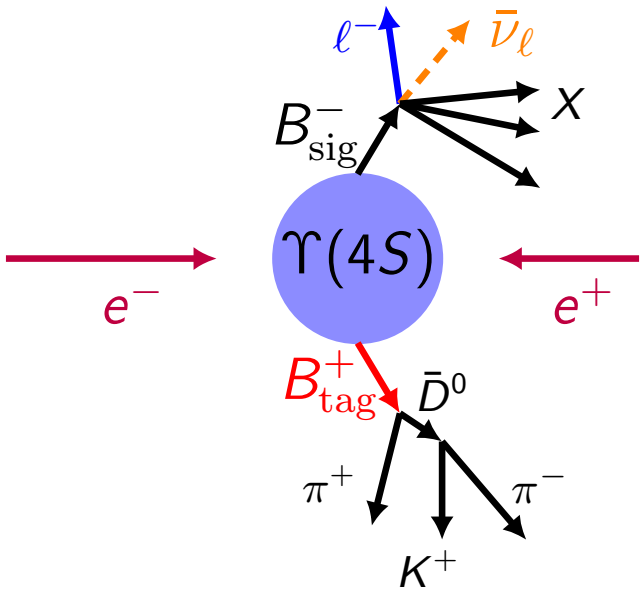

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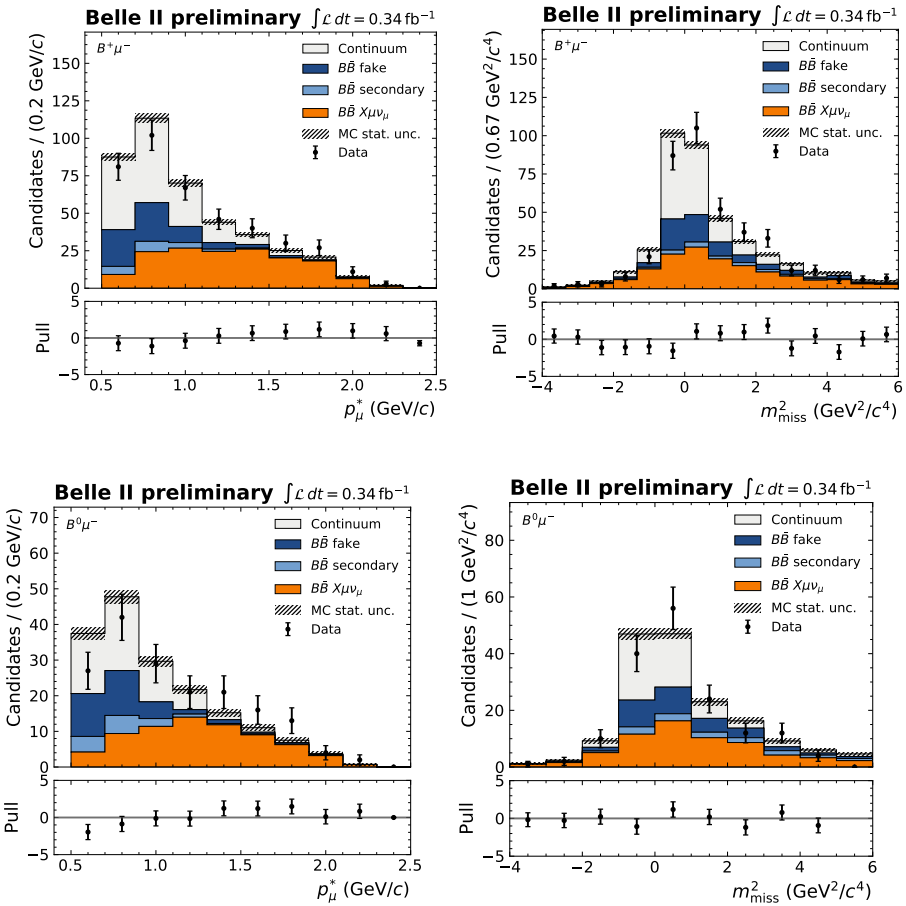
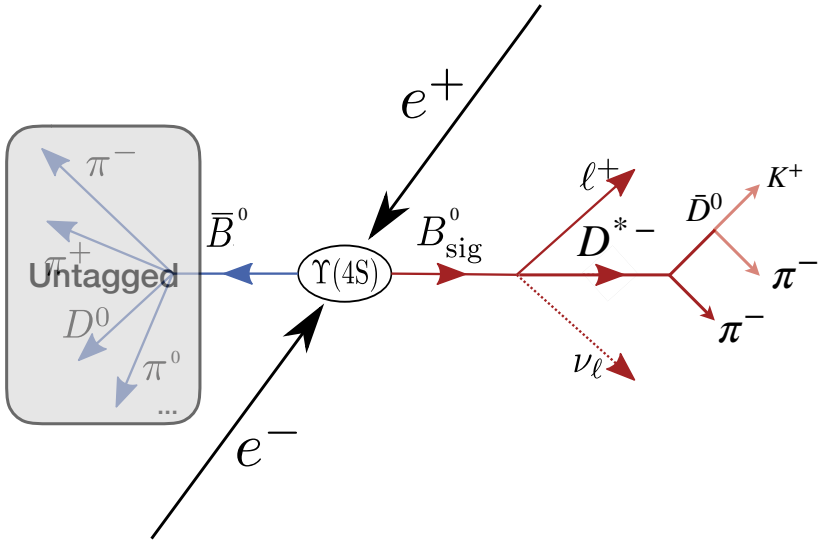


Untagged $B^0 \to D^{-*} l^+ \nu$ selection

- Reconstruct $D^* l\nu$ decays in early phase III data.
- An essential test of tracking and PID for leptons.
- The mode will be used in $|V_{cb}|$ and $R(D^*)$ measurements.



- Selection outlined below.

Particle	Selection
Tracks	IP in $z < 2$ cm
Tracks	IP in r-ϕ plane < 0.5 cm
ℓ	$1.2 < p^*_\ell < 2.4$ GeV/c
e	Electron likelihood > 0.85
μ	Muon likelihood > 0.9
slow π	$p^*_\pi < 0.5$ GeV/c
D^0	$1.85 < M_D < 1.88$ GeV/c^2
D^*	$0.144 < M_{D^*} - M_D < 0.148$ GeV/c^2
D^*	$p_{D^*} < 2.5$ GeV/c

IP = Impact Parameter

- In addition, suppression of $e^+e^- \to q\bar{q}$ using Fox-Wolfram moments.

$B^0 \to D^{-*} l^+ \nu$ reconstruction

- It is possible to compute $\cos\theta_{BY}$ in the CoM frame (*).
- For signal this physically constrained to lie in the region (-1,1).

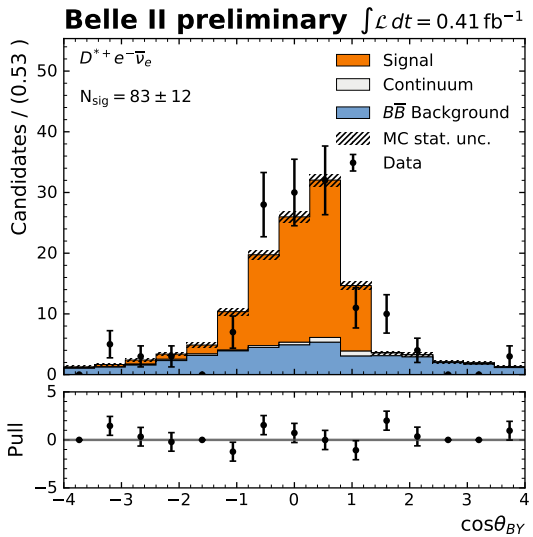
Starting from

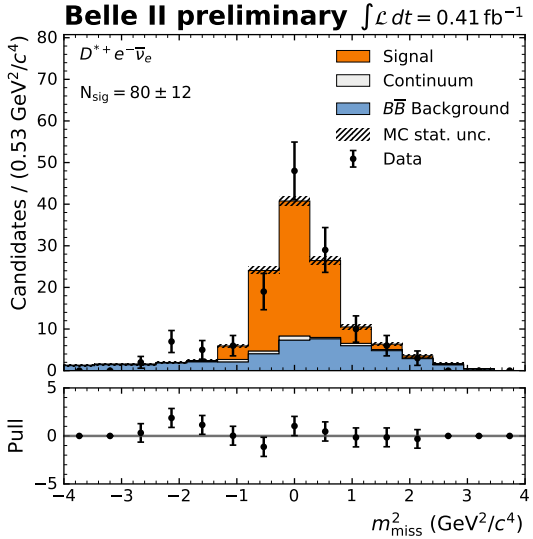
$$0 = p_\nu^2 = (p_B^* - p_Y^*)^2$$

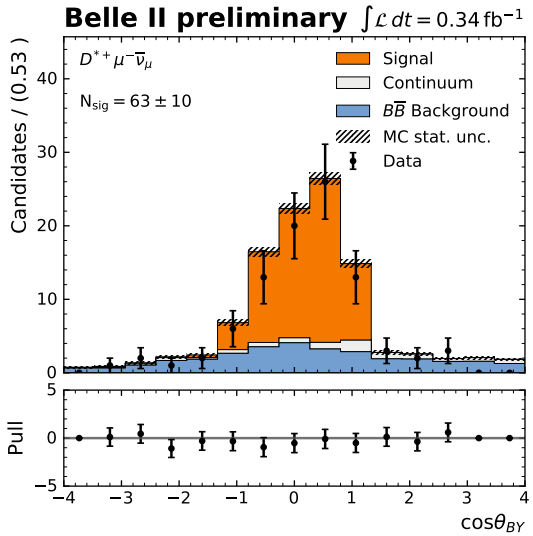
one can derive:

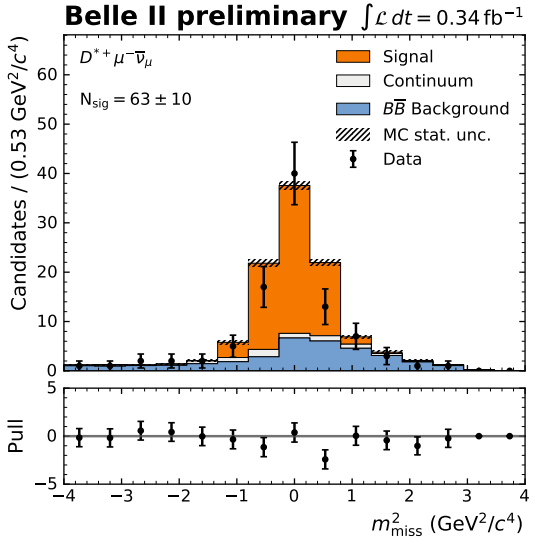
$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - m_B^2 - m_Y^2}{2|\vec{p}_B^*||\vec{p}_Y^*|}$$

- Alternatively use $m^2_{\text{miss}} = ((E_{\text{beam}}/2, 0, 0, 0) - p_Y^*)^2$
- $\implies$ B mesons assumed at rest in the CM frame.









Prospects for the future

- There are a number of semileptonic measurements for which Belle II is essential.

Observables	Belle (2017)	Belle II 5 ab^{-1}	Belle II 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%

- In addition, the measurement of rare $b \to s\nu\bar{\nu}$ will provide a critical orthogonal probe to $b \to sll$ decays. Prospects for golden channels below.

Observables	Belle (2017)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$	$< 40 \times 10^{-6}$	25%	9%
$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$	$< 19 \times 10^{-6}$	30%	11%

Belle II physics book [arXiv1808.10567]

Conclusion

- First measurements of $B \to D^* l \nu$ and $B \to X l \nu$ decays with the full Belle II detector.
- Tag-side reconstruction, a critical Belle II technique, is performing well in early data.
- We plan to calibrate the tag-side reconstruction with $B \to X l \nu$ decays.
- Only have shown results here for 0.41 fb^{-1} we will update soon to the early dataset of 6.43 fb^{-1}.
- Exciting semileptonic and missing energy results to come with more Belle II data!