FEI and $B \to X_s ll$

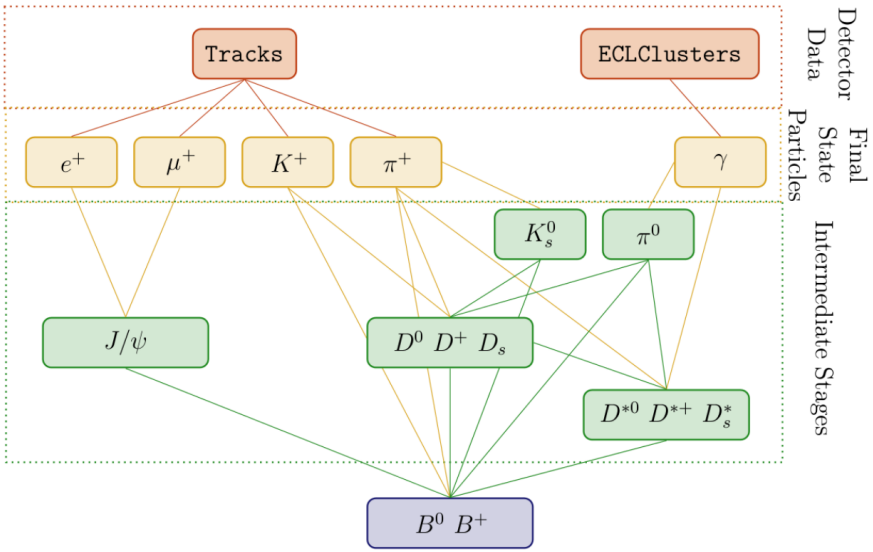
Past and ongoing research interests / tasks

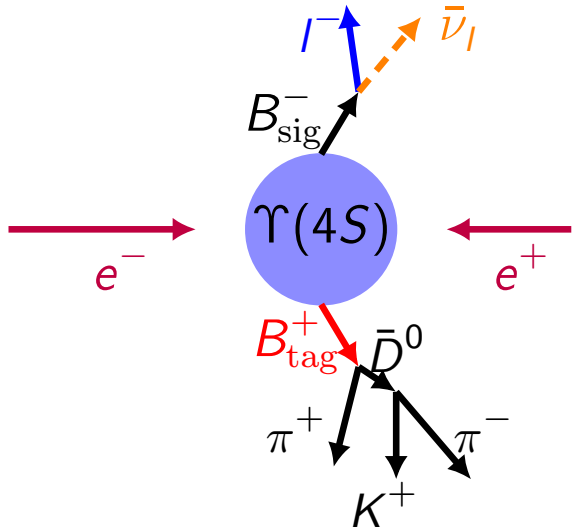
- Past:
  - Determination of $|V_{ub}|$ from $\Lambda_b \to p\ell\nu_\ell$ decays [PhD thesis + Nature Physics 11 (2015) 743]
  - HQET based fits combining LHCb measurements for $\Lambda_b \to \Lambda_c\ell\nu_\ell$ decays with LQCD predictions to better determine the form factors with Florian, Zoltan and Dean [Phys. Rev. D96 (2018) 112005, Phys. Rev. D 99 (2019) 055008]

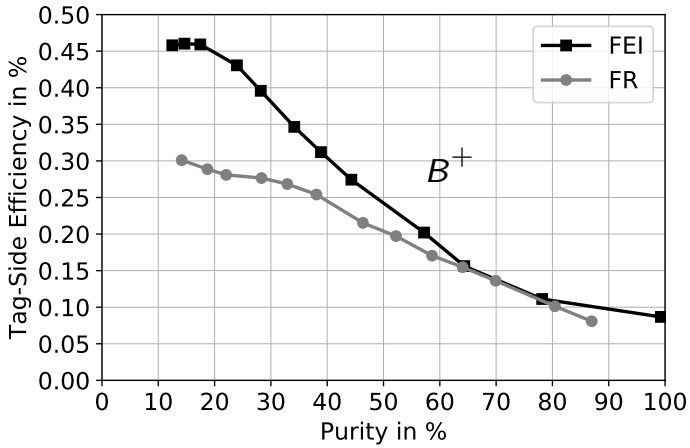
- Ongoing:
  - FEI maintenance (performing trainings, responding to issues, documentation) [Keck, T. et al. Comput Softw Big Sci (2019) 3: 6.]
  - FEI development (e.g. baryonic modes and exploring Deep learning alternatives)
  - $b \to ul\nu$ worked mainly on the BDT, $D^{(*)}$ FFs, M_{bc} fitting and fitting in general
  - $b \to sll$ (will be dedicating more time to this in future + PhD Student, data would be helpful too)

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.







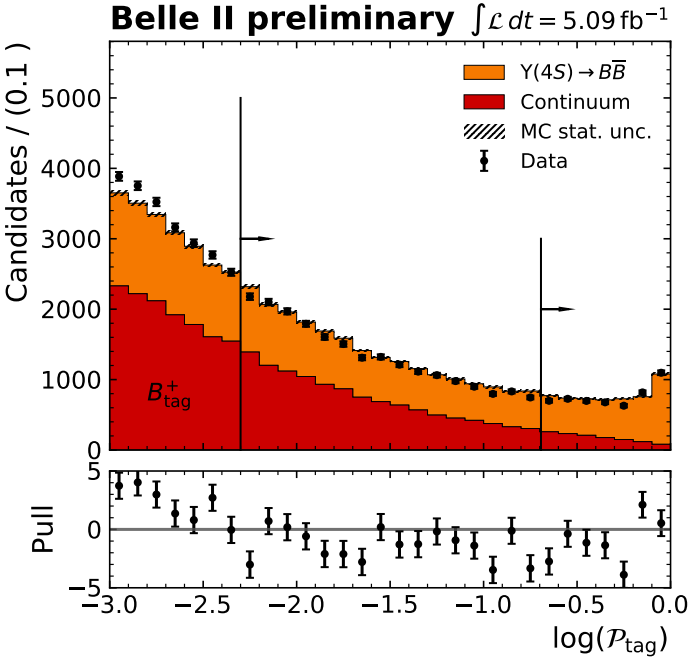
Produced with Belle data

- FEI outperforms predecessor algorithm Full Reconstruction.

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

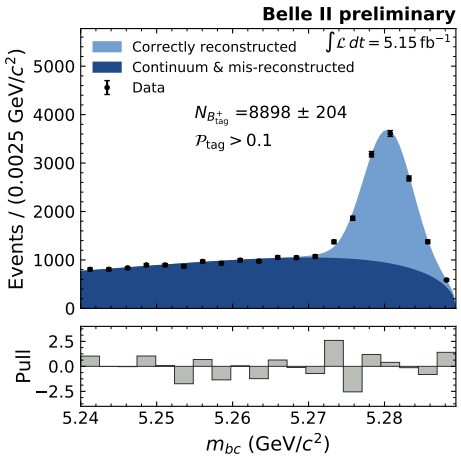
Hadronic tag-side reconstruction in early data

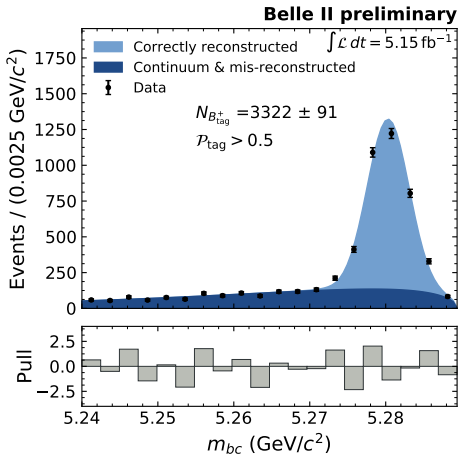
- See note BELLE2-NOTE-PL-2019-030
- B classifier value, $\mathcal{P}$, discriminates correctly reconstructed tag-sides from background.

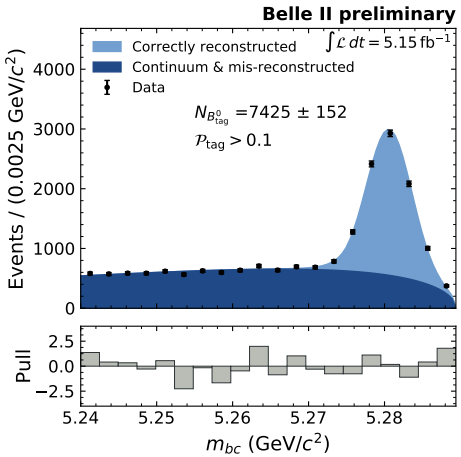


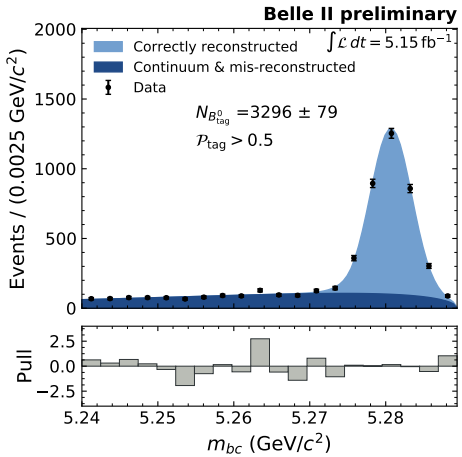
- Select a high purity sample using a selection on $\mathcal{P}$.

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



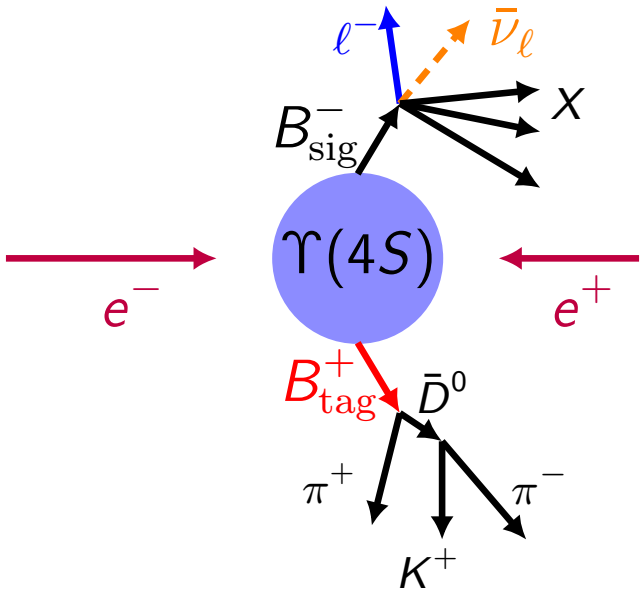






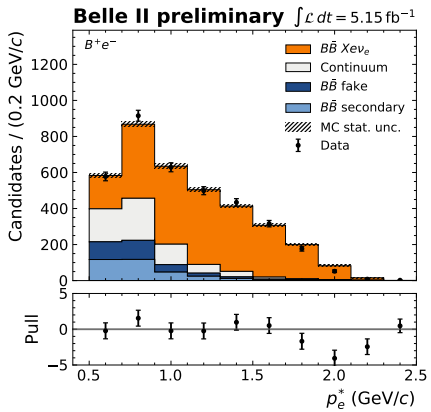
$B \to Xl\nu$ decays using hadronic tagging

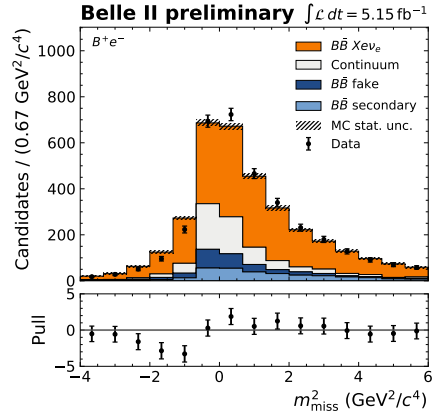
- Perform first Belle II signal side reconstruction with tagging.
- Study $B \to Xl\nu$ given the large branching fraction ($\sim$20%)

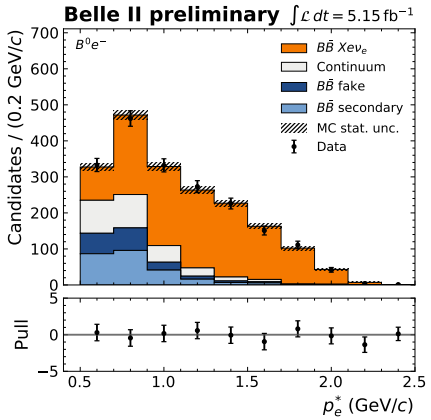


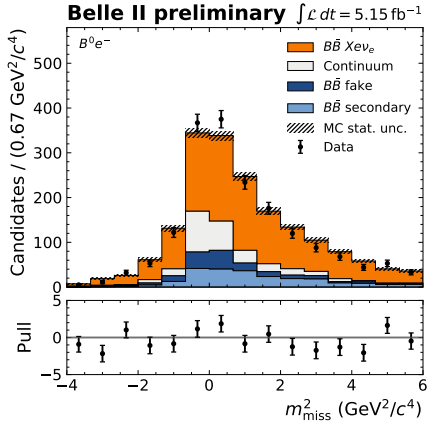
- Highest p^*_ℓ lepton selected with $p^*_\ell > 0.6$ GeV/c, $M^{\text{tag}}_{bc} > 5.27 GeV/c$. eID > 0.85 or muID > 0.9

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









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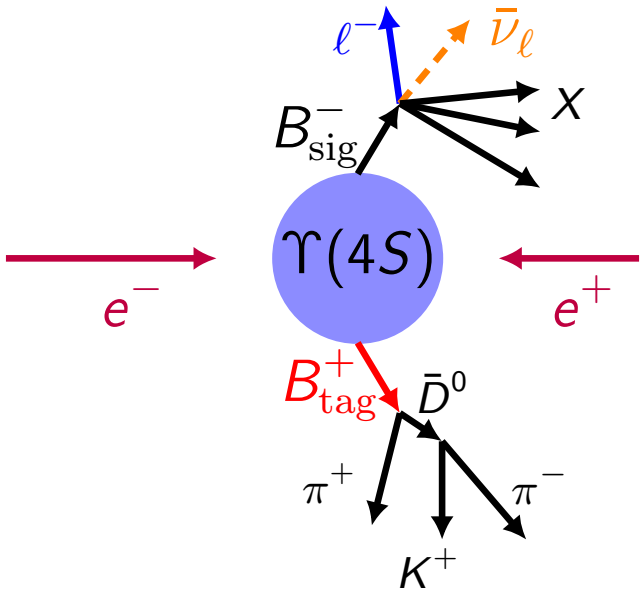

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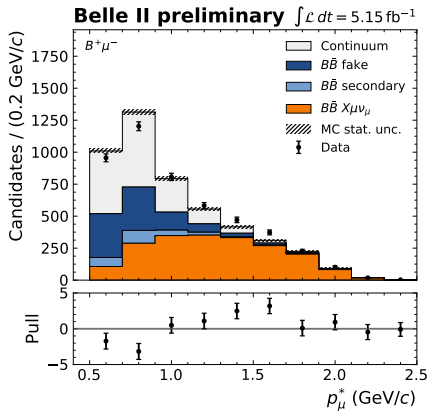
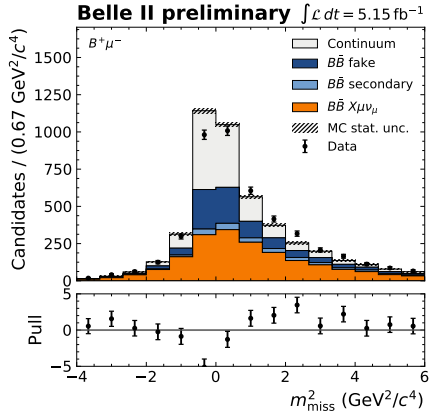
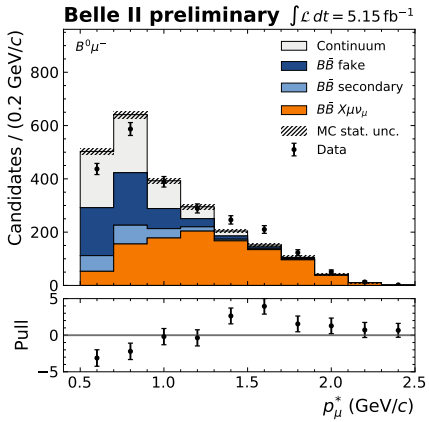
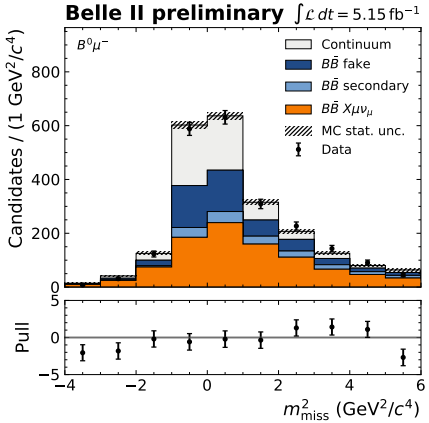




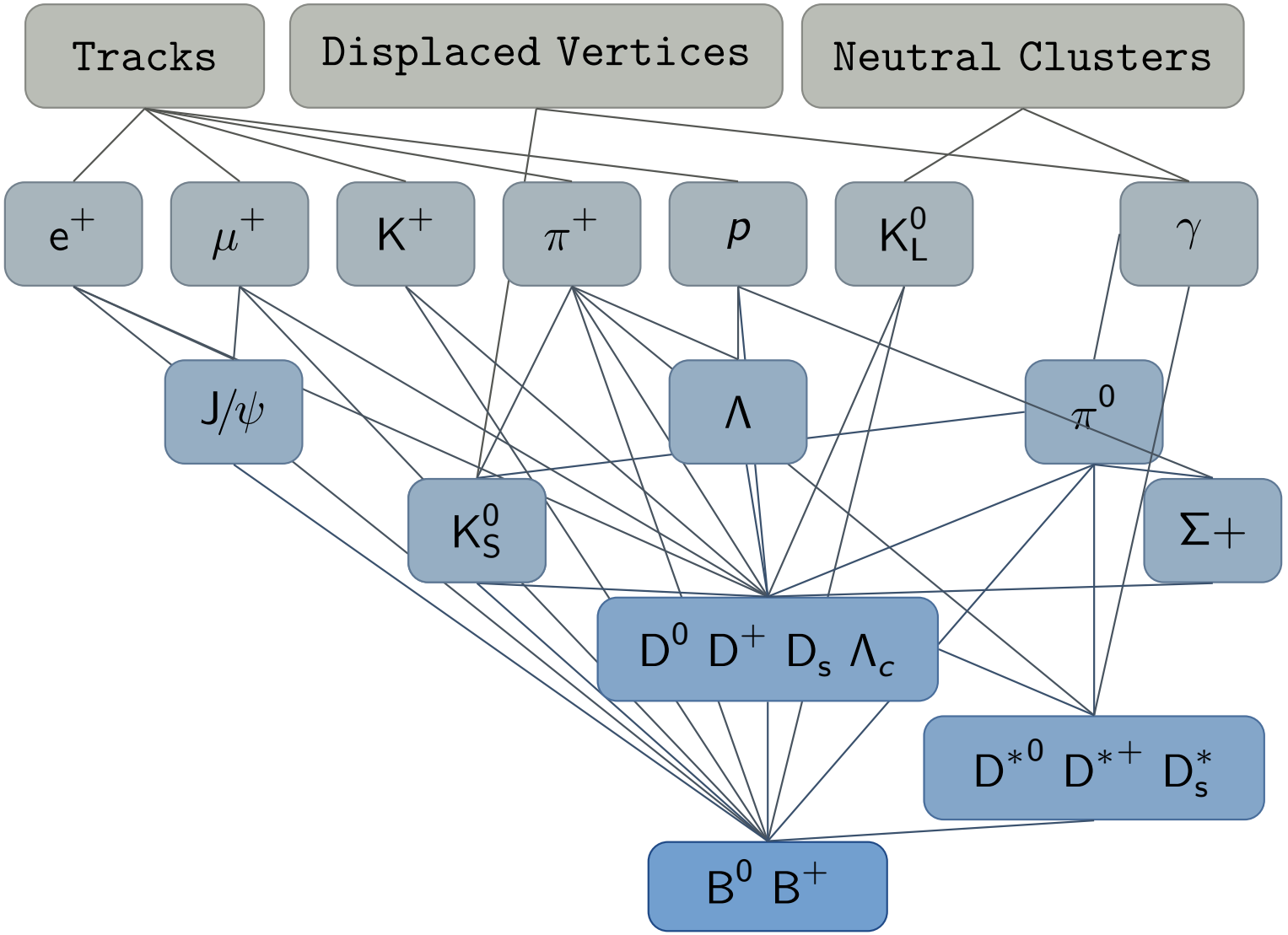




Addition of FEI modes with baryons

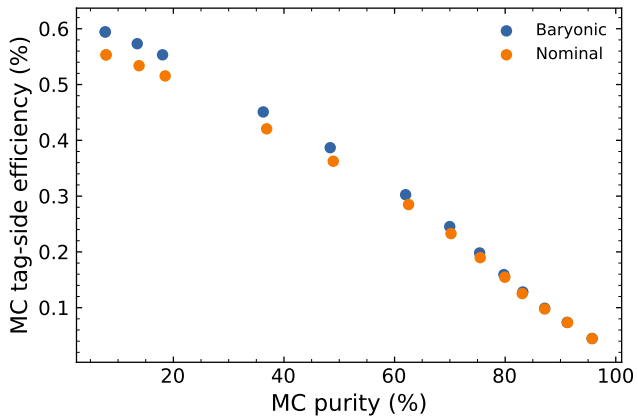
- Performed a baryonic training (O(100M) events) with 36 additional modes:
  - Protons
  - $\Lambda \to p\pi^+$
  - $\Sigma \to p\pi^0$
  - Λ_c (20 modes, $\sim$ 30% $\mathcal{B}$ coverage)
  - 6 (B^0) + 7 (B^+) modes with protons and Λ_c baryons
- Apply the training to 1M MC events for results here.
- Pull request https://stash.desy.de/projects/B2/repos/software/pull-requests/4632/overview

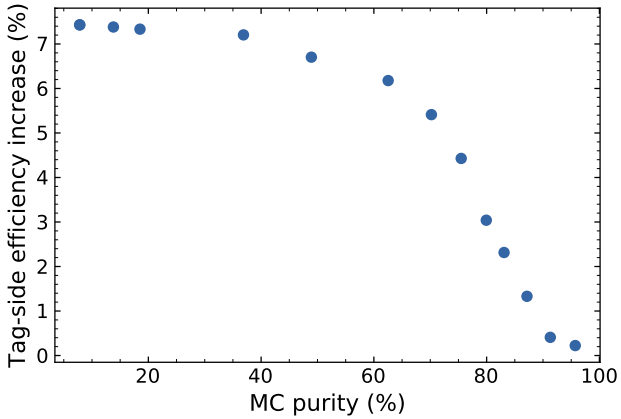
Hierarchy of the FEI with baryons

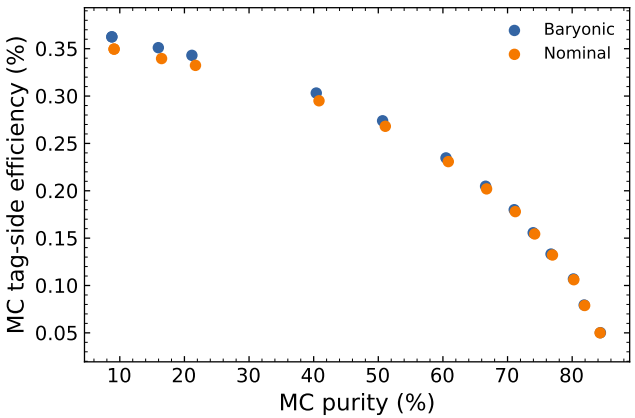


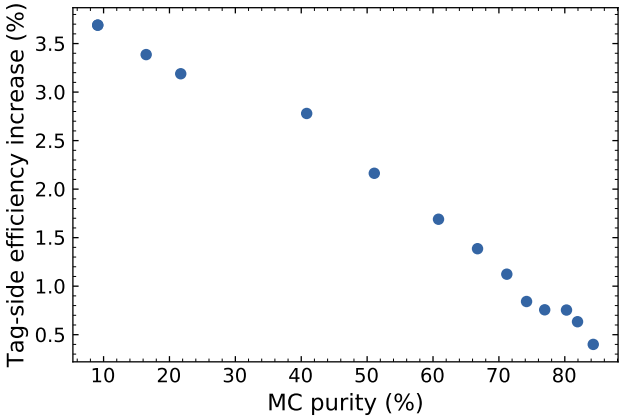
Performance impact

- Look at the tag-side efficiency vs purity for baryonic FEI compared to the nominal FEI.



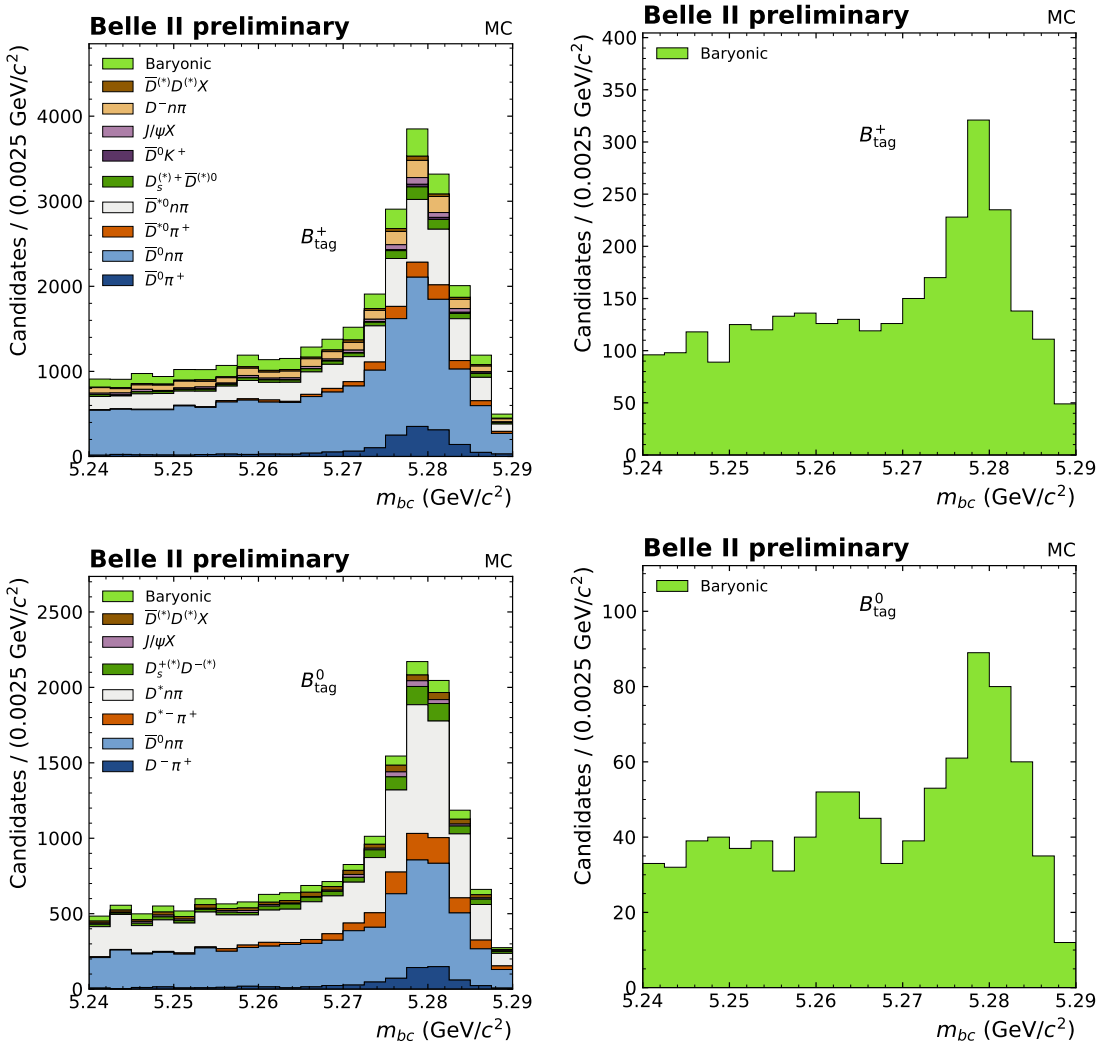






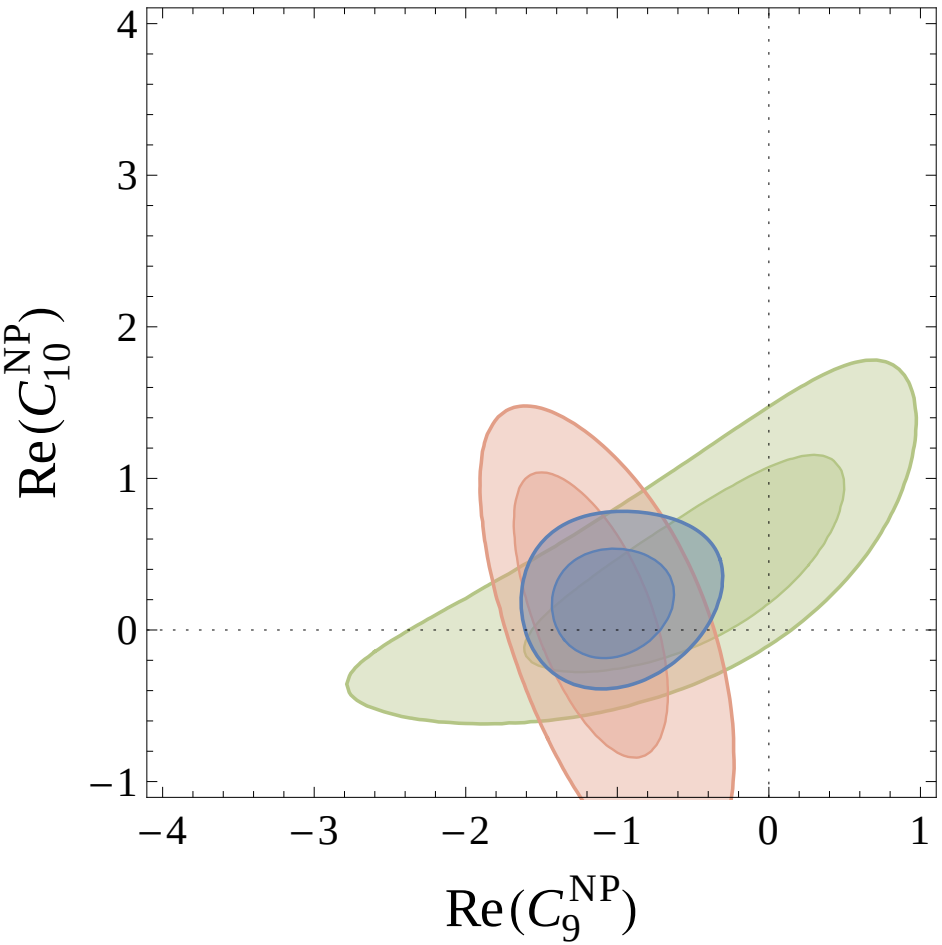
Performance impact

- Look at m_{bc} and the contribution from baryonic modes.



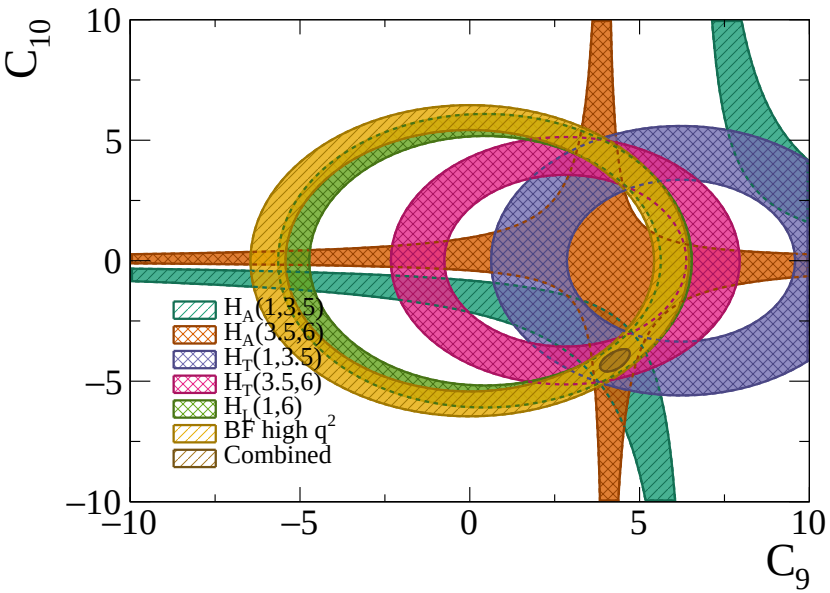
Motivation and Idea: $b \to s\ell\ell$

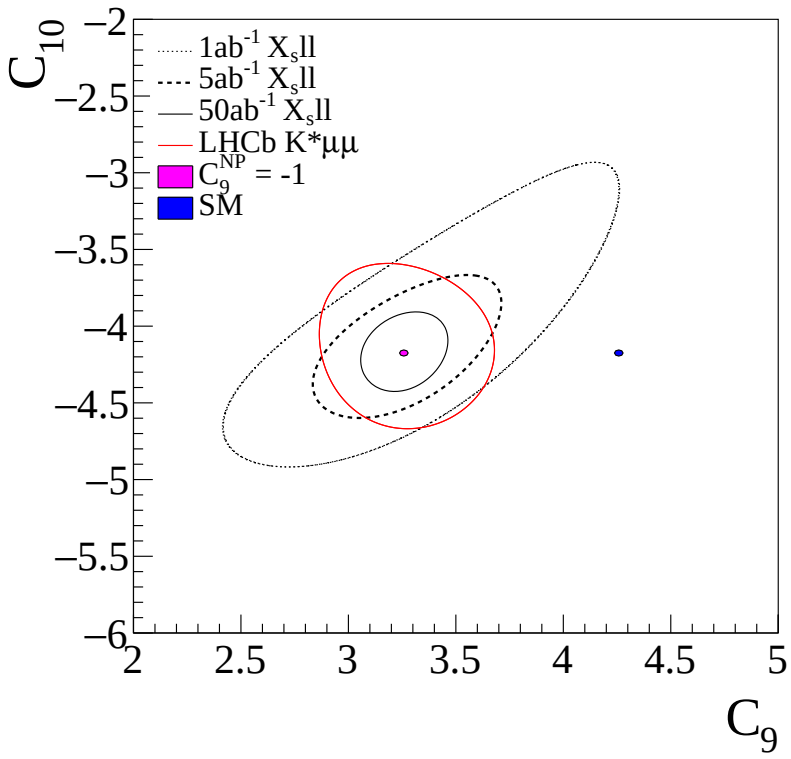
- No fully inclusive measurement of $b \to s\ell\ell$ decays.
- A variety of discrepencies with SM seen in exclusive $b \to s\ell\ell$ decays.



Motivation and Idea: $b \to sll$

$$\frac{d^2\Gamma}{dq^2 \cos\theta} = \frac{3}{8}\left[(1+\cos^2\theta)H_T(q^2) + 2\cos\theta H_A(q^2) + 2(1-\cos^2\theta)H_L(q^2)\right]$$





Strategy: $b \to sll$

- Three approches: Sum of exclusive modes (SEM), Tagged or purely a dilepton reconstruction (use PV?).
- Need flavour of B to determine θ (Flavour tagger or FEI)
- Ideally will used a tagged (SL + had) approach so one can reconstruct X_s
- Apply FEI + select dilepton. X built from RoE.
- Expect background from $e^+e^- \to q\bar{q}$, $B \to X(J/\psi \to l^+l^-)$, $B \to X(\psi(1s) \to l^+l^-)$ and $B \to D^{(*,**)}l\nu$ decays
- Can use $B \to X(J/\psi \to l^+l^-)$, $B \to X\mu^+e^-$ and $B \to Xe^+\mu^-$ as control samples.
- Ultimately reconstruct θ and fit signal in bins of this variable for chosen q^2 integrals.
- Finally fit unfolded angular distribution to extract helicity amplitudes.

Challenges

- $\mathcal{B}(B \to X_s ll) = 6 \times 10^{-6}$

	$N(B \to X_s ll)$	$\epsilon = 1\%$
711 fb^{-1}	18,504	185
5 ab^{-1}	130,126	1300
50 ab^{-1}	1,301,265	13,000

- Problems with K_L reconstruction if X_s reconstructed.
- If SEM used or selections on M_X (to suppress D bkg) angular distribution is harder to extract and theory is sensitive to the Shape Function in the latter case.

Conclusion

- Work maintaining the FEI and investigating new features / developments (e.g. baryonic modes)
- Focussed on looking a the hadronic FEI performance in early data.
- For the future I would like to focus on early FEI calibrations, $b \to sll$, $ul\nu$ fitting efforts and fitting in general and early FEI calibrations.

Areas of work in the $b \to u l \nu$ analysis

- In the analysis BDTs used to seperate $c l \nu$ and $u l \nu$
- M_{bc} fits in bins of kinematics.
- Subsequently χ^2 fit to continuum + bad tag subtracted data.
- Interested here in the development of fitting frameworks using numpy / tensor flow (easy to utilise a fully vectorised solutions).
- Started here Max's from framework.
- Ideal features: parameter handling, fully vectorised (calculation purely matrix operations), bin pars + single parameter systematic variations, gaussian constraints, sub templates/pdfs possible