Displaced and Invisible Signatures of ALPs at Belle II

Ruth Schäfer

Heidelberg University

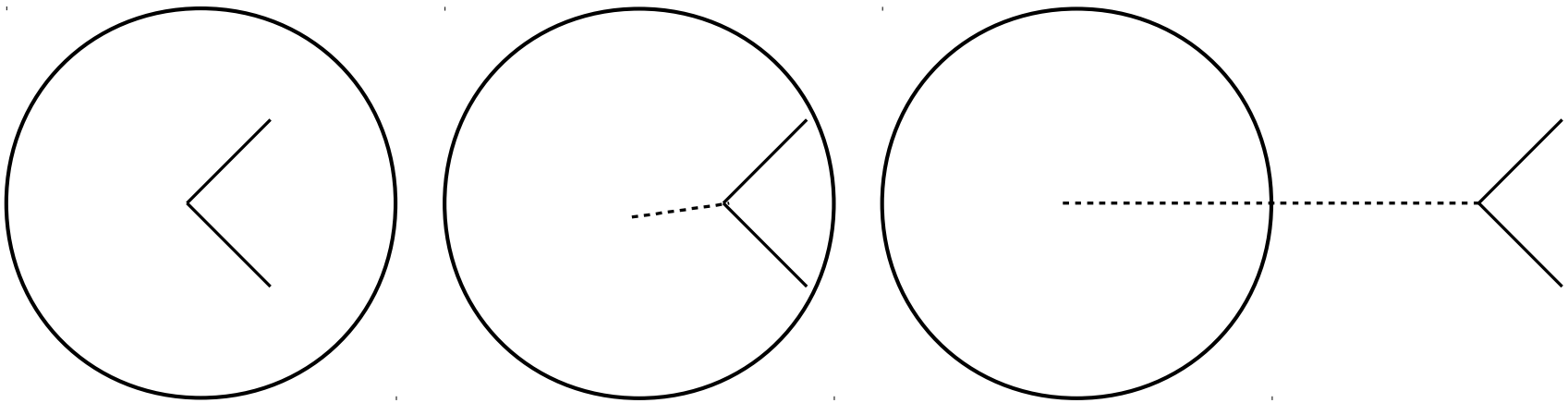
November 3rd 2021

Brookhaven Forum
Opening New Windows to the Universe

Based on an ongoing project with T. Ferber, A. Filimonova, RS, and S. Westhoff; RS supported by GRK 1940

Long-lived Particles

- Non-prompt decays
- Light or weakly coupled new physics
- Interesting detector signatures:
  - Displaced decays
  - Missing energy
  - More exotic signatures



Axion-like particles

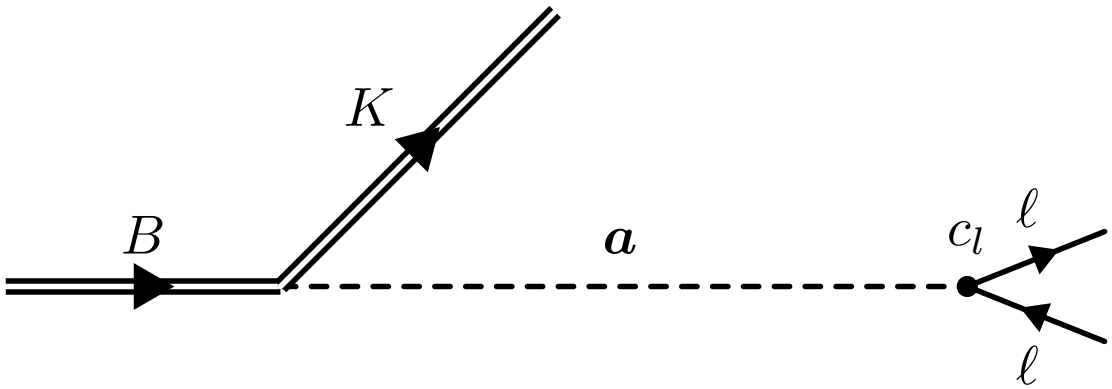
- Effective Model of Standard Model + ALP
- Couples in the UV to either fermions or W-bosons

$$\mathcal{L}_{\text{eff,UV}} = \sum_f \frac{c_{ff}(\mu)}{2} \frac{\partial^\mu a}{f_a} (\bar{f}\gamma_\mu\gamma_5 f) + c_{WW} \frac{a}{f_a} \frac{\alpha_2}{4\pi} W^A_{\mu\nu} \widetilde{W}^{\mu\nu,A}$$

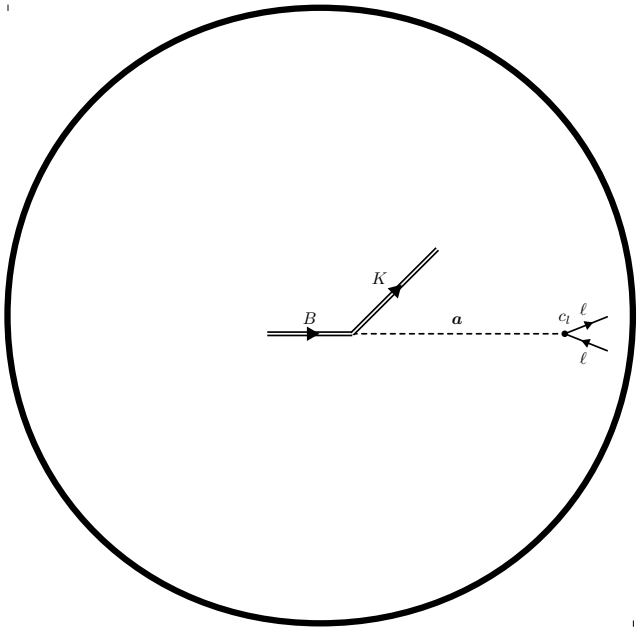
using Bauer, et al. [2012.12272]

ALPs at Belle II

- Belle II is an e^+e^--collider:
  - Small boost
  - Clean background
  - Optimised for rare B-decays
- We produce ALP in $B^+ \to K^+ a$



Displaced decays

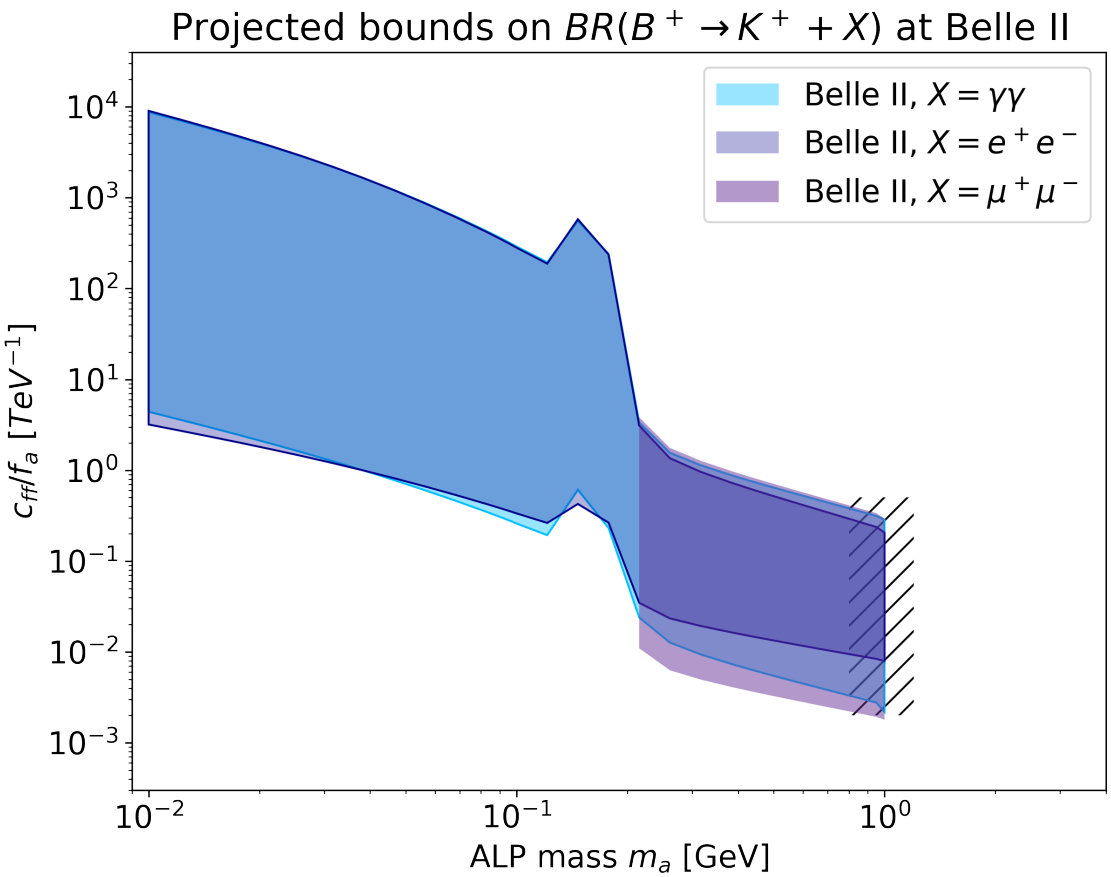


- The ALP decays into pair of visible particles
- Within the tracking system (CDC)

$$N_{disp} = N \times Br\left(B \to Ka\right) \times \left(e^{-\frac{d_{res}}{\gamma\beta c\tau}} - e^{-\frac{R}{\gamma\beta c\tau}}\right) \times Br\left(a \to f\bar{f}\right) \times \varepsilon$$

Displaced ALP decays

- $B^+ \to K^+ a$, $a \to \mu^+\mu^-, e^+e^-, \gamma\gamma$ displaced
- Simulated with EvtGen data
- Assume zero background

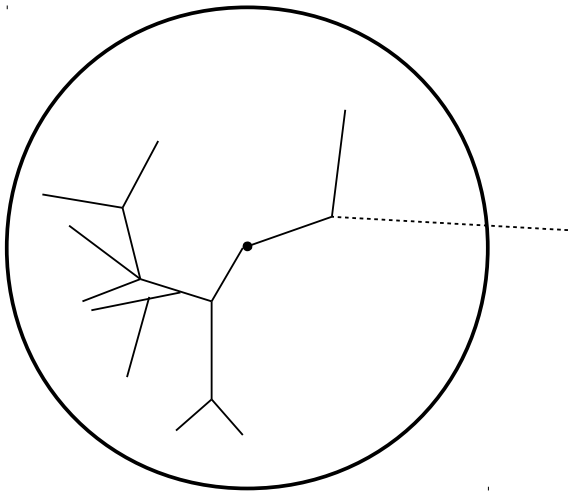


Preliminary

Invisible decays

- ALP decays outside of detector
- The other B decays generically
- Difficult to reconstruct
- Analysis of B- and continuum backgrounds

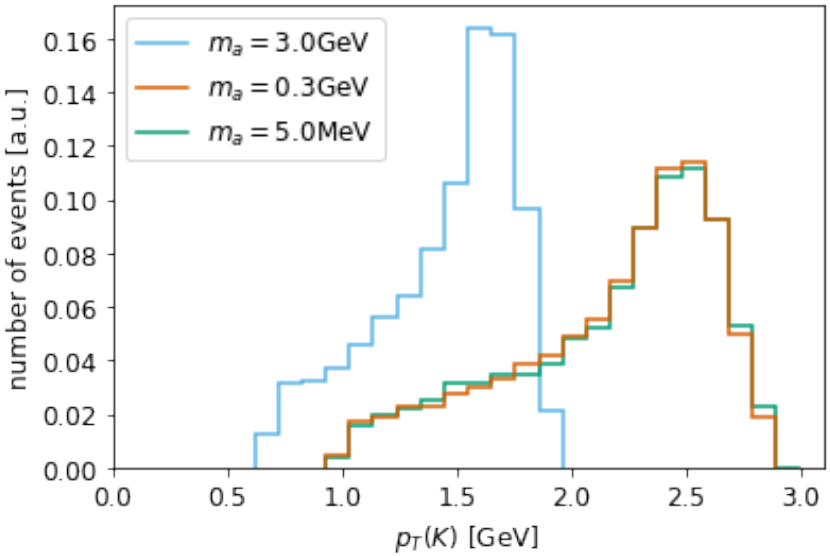
$$N_{inv} = N \times Br\,(B \to Ka) \times e^{-\frac{R}{\gamma\beta c\tau}} \times \varepsilon$$

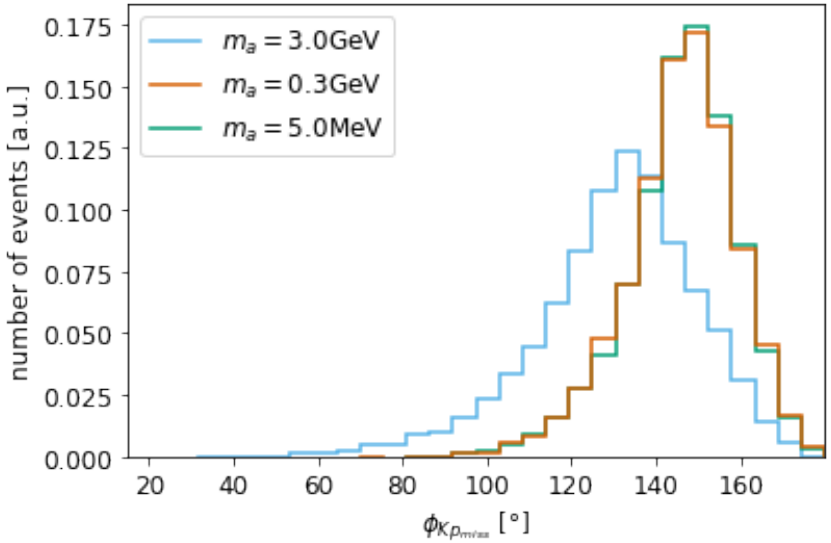


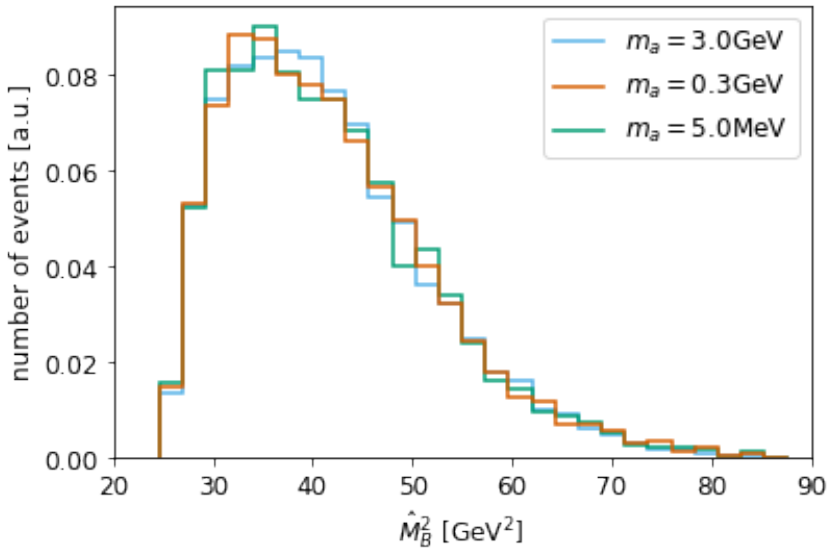
Kinematic variables of the system

- The decay $B \to Ka$ is given by its final state momenta
  - $p(K), p(a)$
  - $p(a)$ is not measurable
  - p_{miss} is measurable
- We choose the following variables to describe our system:
  - Kaon transverse momentum $p_T(K)$
  - Opening angle between kaon and missing momentum $\phi_{Kp_{miss}}$
  - Reconstructed B-meson mass $\hat{M}_B^2$ from $p(K), p_{miss}$

Kinetic variables in our signal samples

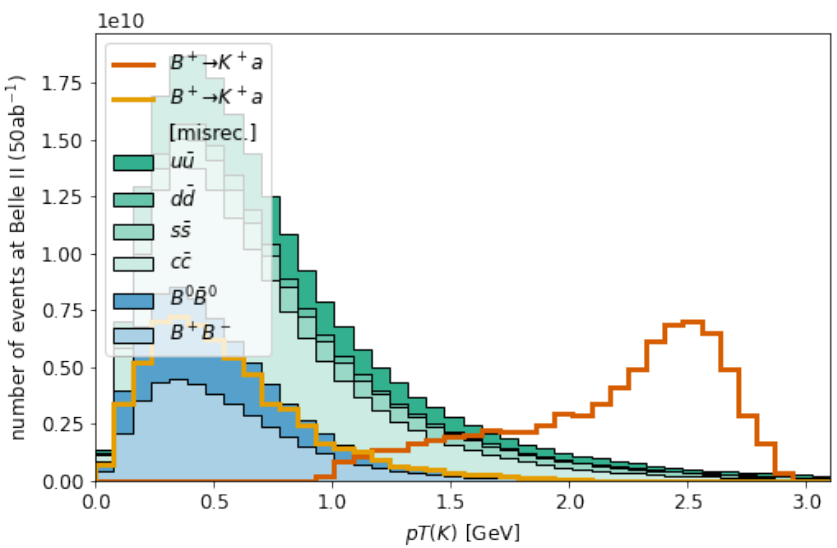


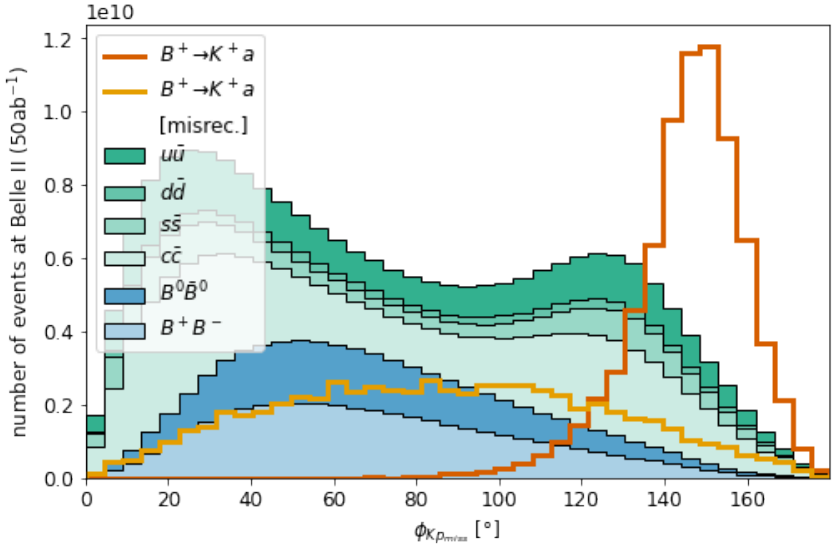


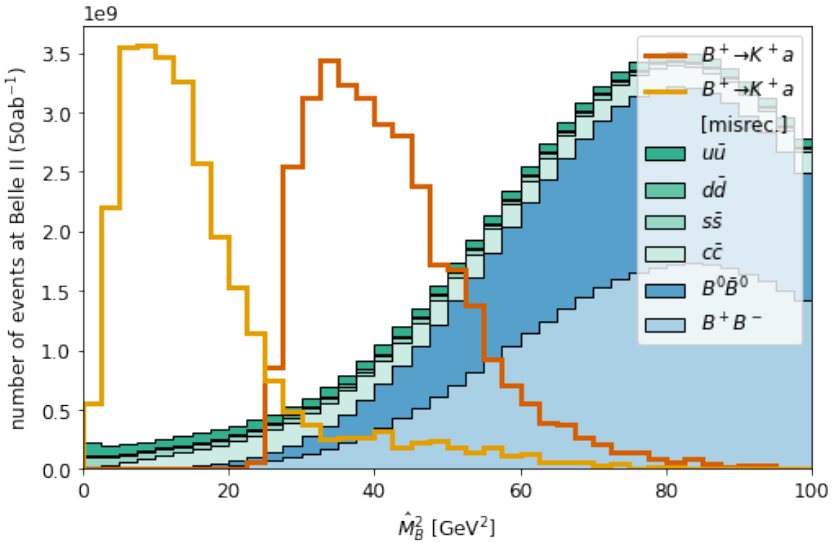


Preliminary

Kinetic variables in our backgrounds

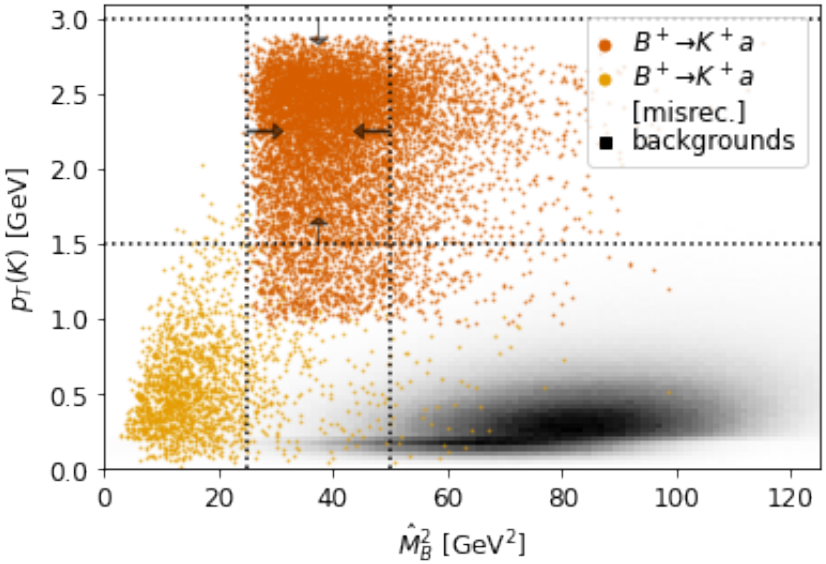


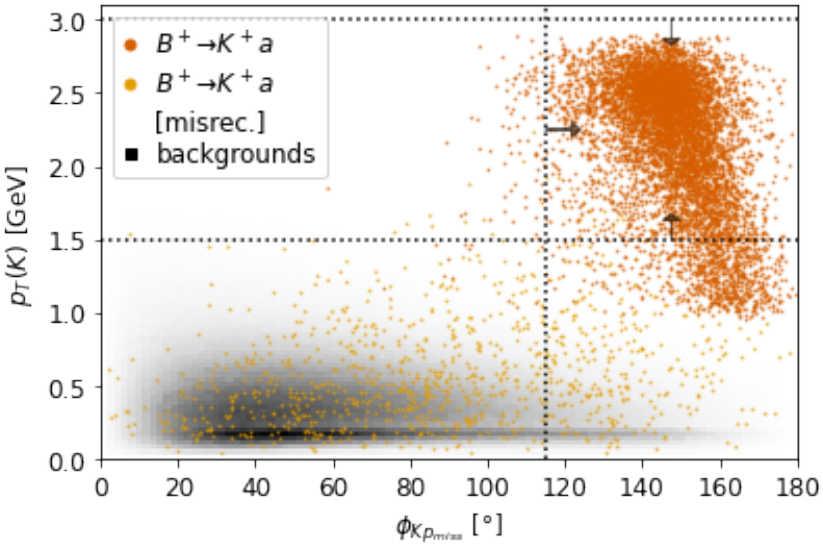


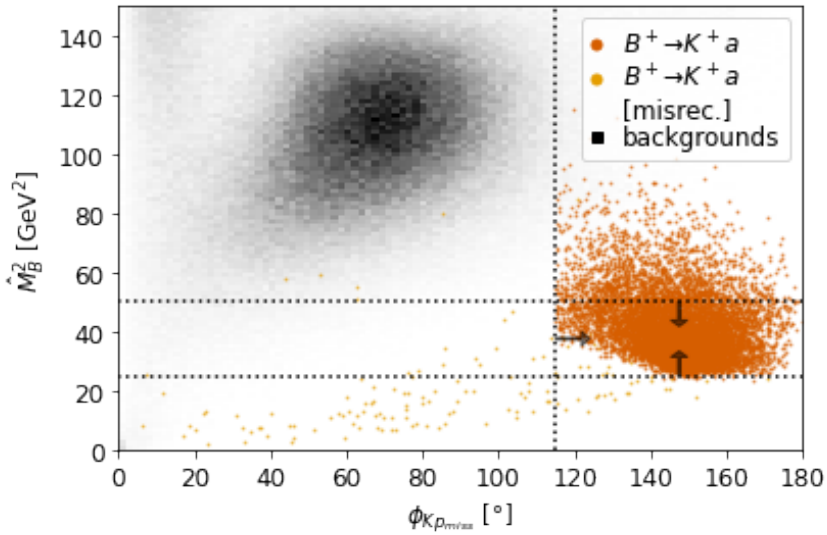


Preliminary

Placing cuts on the distributions

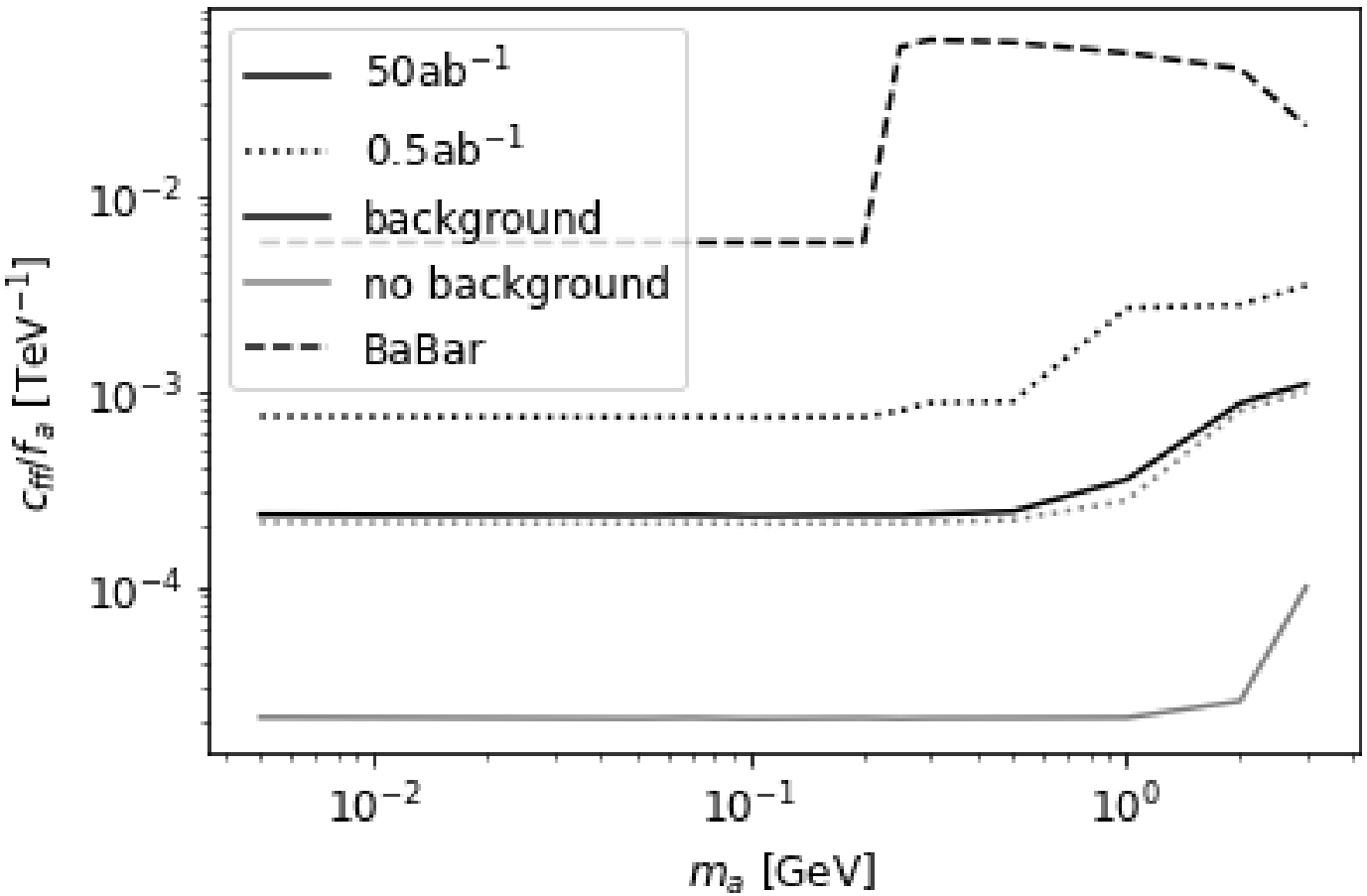






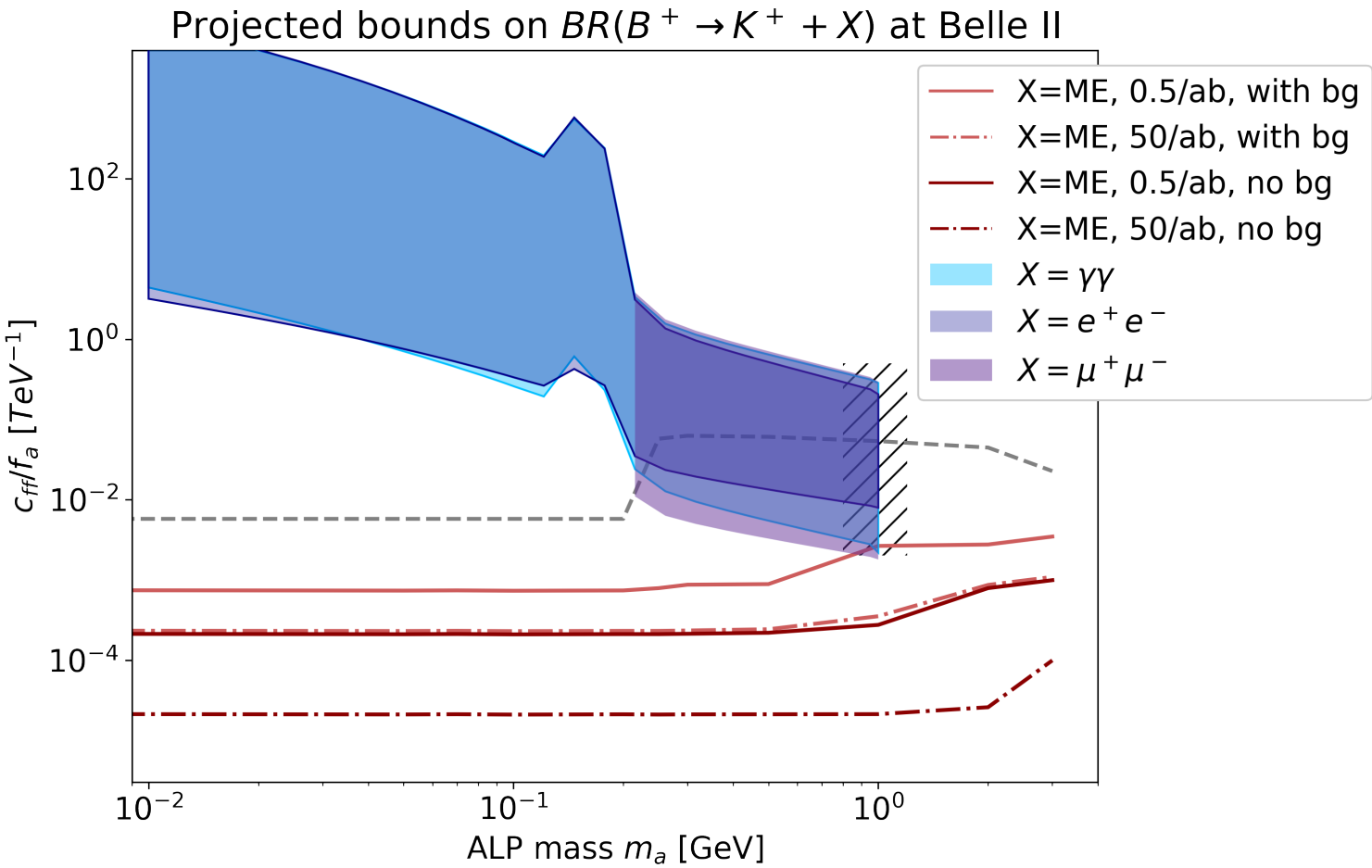
Preliminary

Bounds from invisible decays



Preliminary

Displaced or Invisible?



Preliminary

Conclusion

- Belle II is a good detector for long-lived particles
- Invisible searches are stronger than displaced ones
- This varies from model to model and detector to detector
- Searches for long-lived particles can greatly help us explore the ALP parameter space
- Displaced searches are useful for characterising LLPs