CFT 5: Light NP

Slavomira Stefkova and Emmanuel Stamou
RA2 kick-off Meeting
28.4.2026

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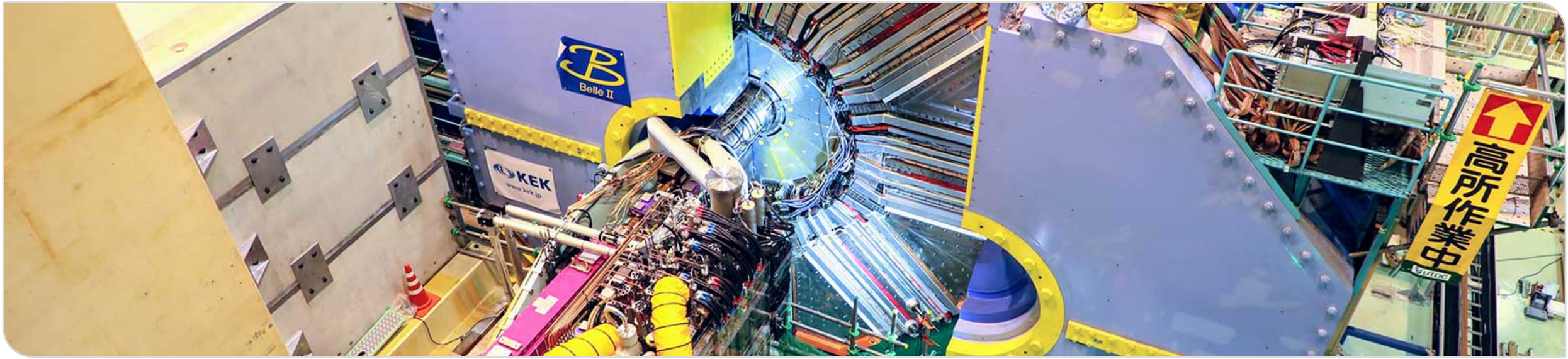


Light NP in Rare *B*- and *D*-decays

CFT5 Ongoing and Future Project Overview:

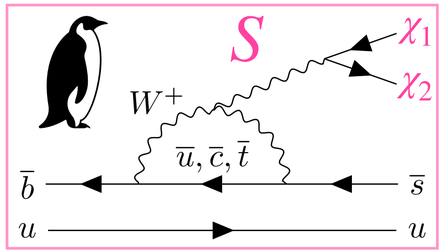
1. Search for SM $B \to K^{(*)}\nu\bar{\nu}$ decays with semileptonic tagging **(exp)**
   Proponents: Georgios Alexandris, Slavomira Stefkova + other Belle II collaborators
2. Search for SM $B \to K^{(*)}\nu\bar{\nu}$ decays with inclusive tagging **(exp)**
   Proponents: Valerio Bertacchi, Slavomira Stefkova + other Belle II collaborators
3. Search for SM $B \to \rho\nu\bar{\nu}$ **(exp)**
   Proponents: Other Belle II collaborators
4. Prediction for $B \to X_s\nu\bar{\nu}$ **(theory)**
   Proponents: Jack Jenkins
5. **RA2-17:** Search for $B \to K^{(*)}/D/p \ldots + X,$ **(exp + theory)**
   Flavor Structure in Axion models and generic extension with light NP
   Proponents: Feldmann, Stamou, Stefkova: **1 experimental PhD position to be filled**
6. **RA2-15:** Charm with Invisibles **(exp + theory)**
   Proponents: Hiller, Stefkova

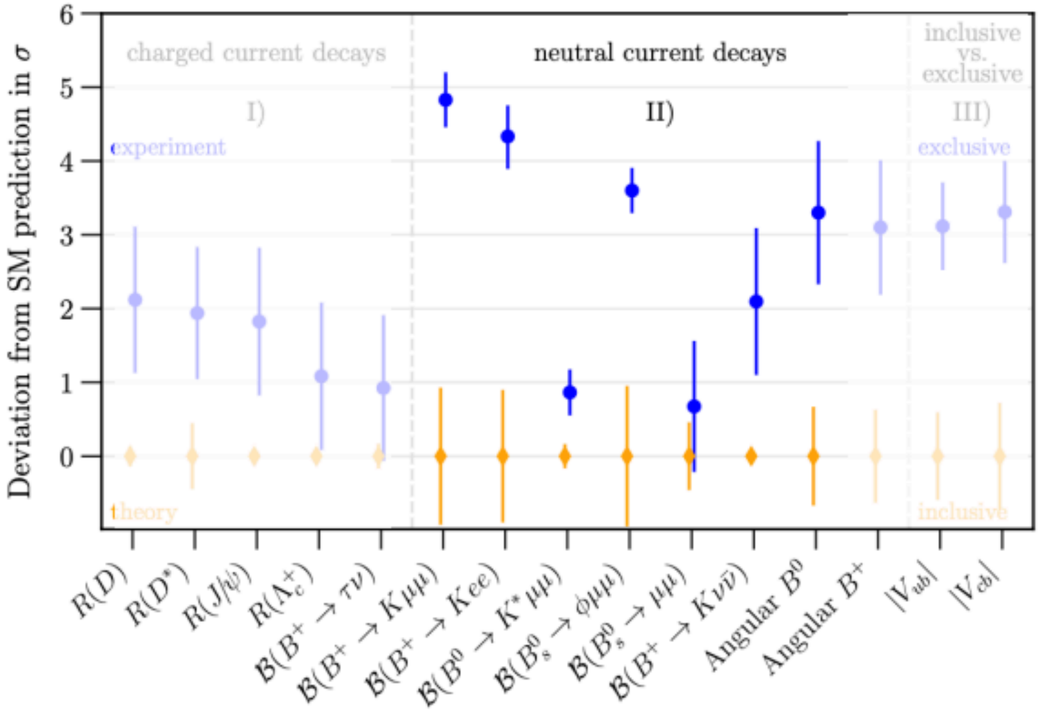
If you know of anyone in your groups working on light NP searches (theory + experiment), let us know!

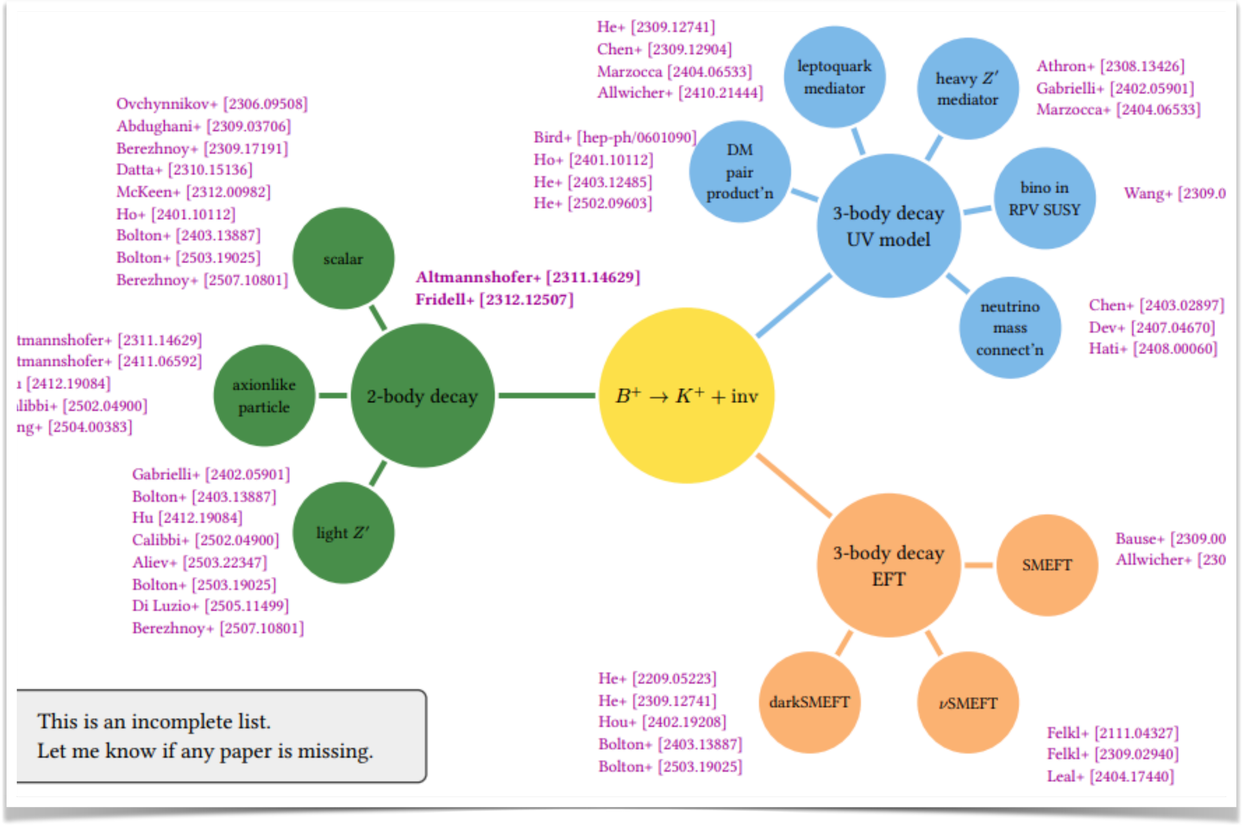
Light NP in rare B-decays

Rare B decays:

- GIM suppressed flavour changing neutral currents (FCNC) $[b \to s/d(\gamma)]$, e.g $B^+ \to K^+\nu\bar{\nu}$

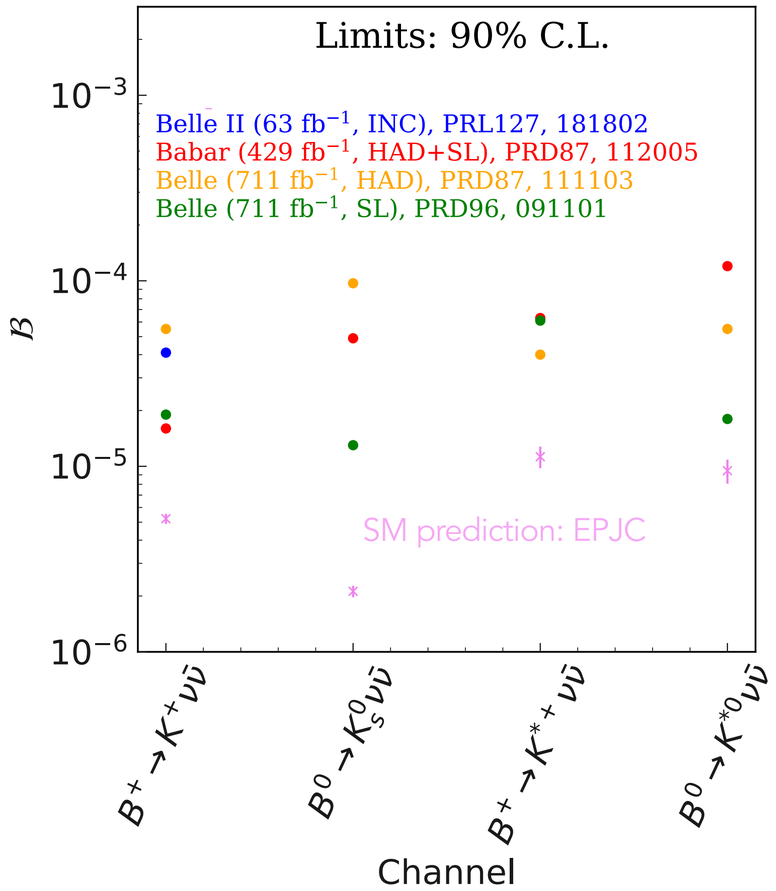






$B \to K^{(*)}\nu\bar{\nu}$ Measurements Overview

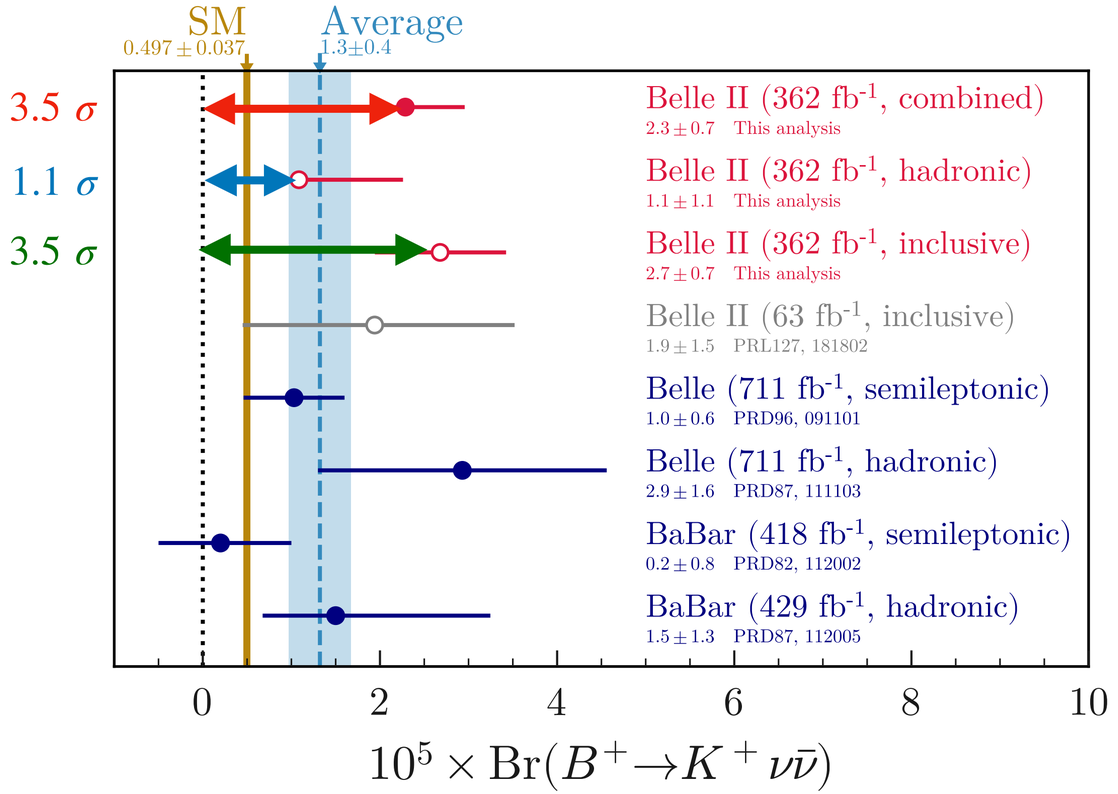
Pre-summer 2023



Post-summer 2023

PRD 109, 112006

→ first evidence of the $B^+ \to K^+\nu\bar{\nu}$

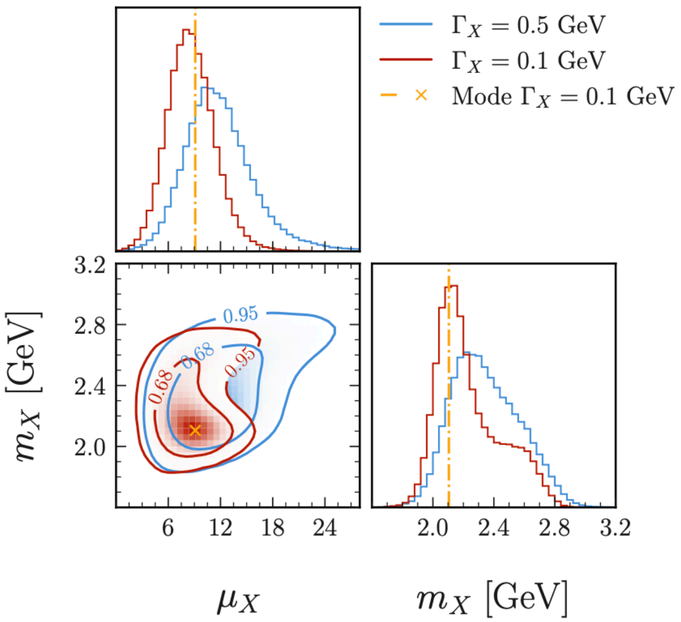


Probing Light NP in $B^+ \to K^+\nu\bar{\nu}$ Measurements

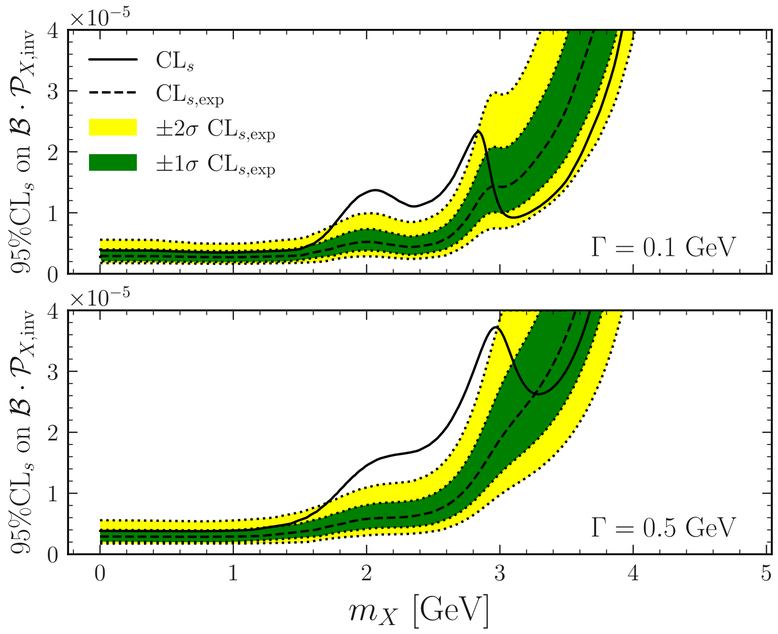
arXiv:2602.09666, submitted to PRD

We performed both Bayesian and frequentist analysis to obtain constraints on $B^+ \to K^+X$ parameters

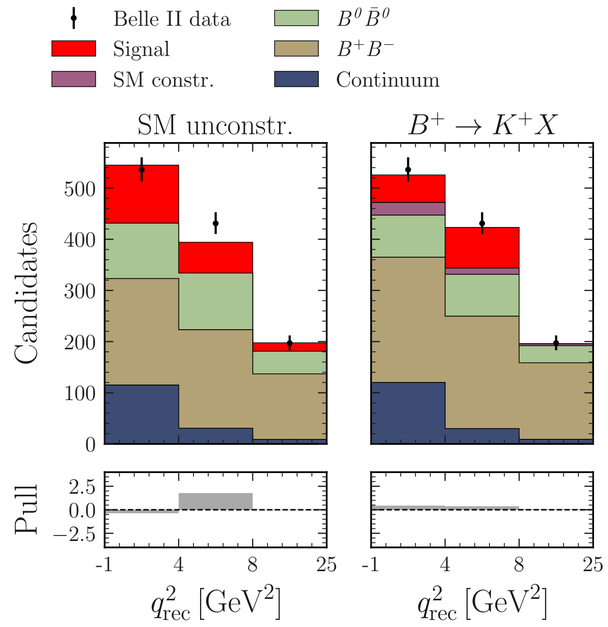
Marginalised posterior distributions



95% C.L limits on $\mathscr{B}(B^+ \to K^+X) \cdot \mathscr{P}_{X,\mathrm{inv}}$



Best-fit projections



Belle II data strongly prefers the resonance hypothesis, with a posterior mode for the mass

$m_X = 2.1^{+0.2}_{-0.1}$ GeV and a branching fraction of $\mathscr{B}(B^+ \to K^+X) \cdot \mathscr{P}_{X,\mathrm{inv}} = 9.2^{+1.8}_{-3.4} \cdot 10^{-6}$

Search for $B \to K^+X$

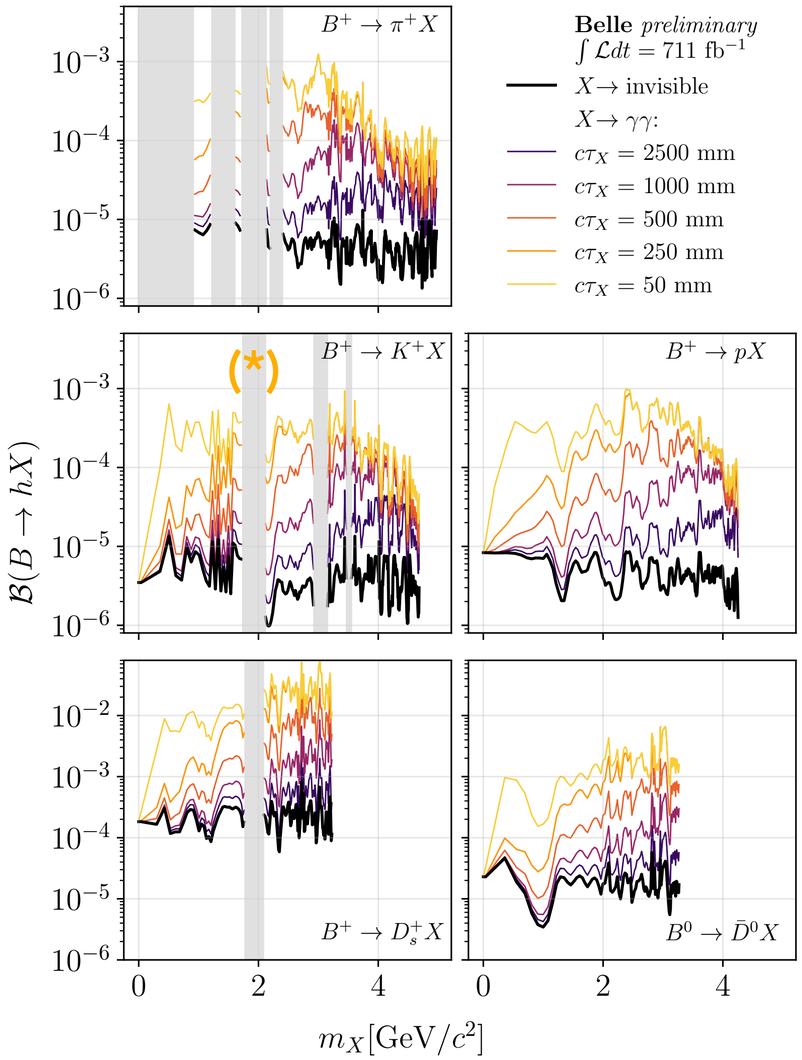
[arxiv:2601.07104]
Submitted to PRL

Belle performed first direct search for
$B^\pm \to hX(\to inv), h = \pi^\pm, K^\pm, D_s^\pm, p$ **and**
$B^0 \to D^0X(\to inv)$

- Sensitive to ALPS, dark scalars and dark baryons *(B-mesogenesis models)*

The most stringent upper upper limit to date @ 90 % CL set to date, to be done with Belle II data

Predecessor for RA2-17



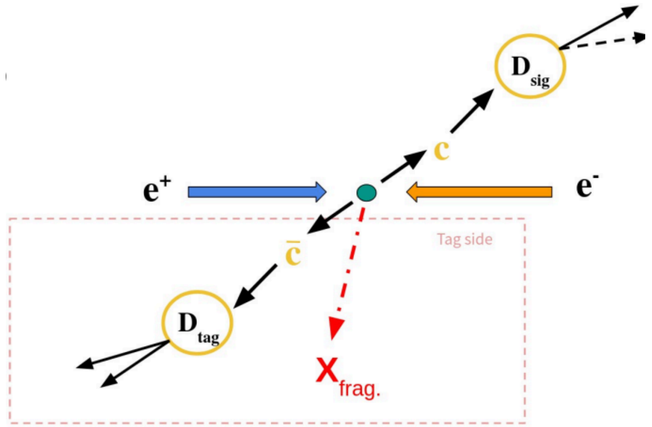
Physics case: Extensions of the SM that predict light particles that interact feebly with with the SM particles are phenomenologically attractive given the current lack of clear NP signatures from heavy, new particles. In fact such extensions can give insights into open questions in particle physics, i.e., the strong CP problem, the nature of Dark Matter, or be the lightest particles associated to a whole tower of much heavier NP particles, e.g., Goldstone bosons of spontaneous broken global symmetries, dark photons, or light dark Higgs'. Such extensions of the SM, e.g., axion-like particles (ALPs) or light gauge bosons with non-universal SM charges, typically also allow for —or even predict— new flavour-specific couplings to quarks and leptons. The flavour phenomenology of such setups strongly varies depending on both the when searching for concrete realisations. The goal of this project is to identify self-consistent flavour benchmark scenarios in models with ALPs and light vectors and confront them with state-of-the-art experimental measurements from precision flavour observables. The benchmarks shall provide examples for the aforementioned distinct phenomenology and would point towards gaps in current or future-planned experiments and thus inform future target measurements/interpretations.

Rare charm-decays with missing energy

RA2-15: Predict & measure $c \to u$ + missing energy:

- **This avenue is largely experimentally unexplored and CmF perfect platform to study such decays**
  - Charm tagging & FEI @ Belle II provides an interesting sample to study such decays e.g $D \to \pi\nu\bar{\nu}$ …

$D \to F$	A_+ $[10^{-8}]$	A_- $[10^{-8}]$
$D^0 \to \pi^0$	0.9	0
$D^+ \to \pi^+$	3.6	0
$D^0 \to \pi^0\pi^0$	0	0.2
$D^0 \to \pi^+\pi^-$(*)	0	0.4
$D^0 \to X$	2.2	2.2
$D^+ \to X$	5.6	5.6



- Only experimental information so far from $D^0 \to$ invisible (Belle, $\mathcal{C}_{S,P}$) and $D^0 \to \pi^0\nu\bar{\nu}$ (BESIII, $\mathcal{C}_{L,R,S,P}$):

$$\mathcal{B}(D^0 \to \text{invisible}) < 9.4 \times 10^{-5} \quad (90\%\ \text{C.L.}),$$
$$\mathcal{B}(D^0 \to \pi^0\nu\bar{\nu}) < 2.1 \times 10^{-4} \quad (90\%\ \text{C.L.}).$$

D^0: 6×10^8 $(\to 10^{11})$	
$D^+_{(s)}$: 10^8 $(\to 10^{10})$	
Λ_c^+: 10^7 $(\to 10^9)$	$\mathcal{O}$(1-10%)

  - optimised

Backup

How does it work?

What about charm

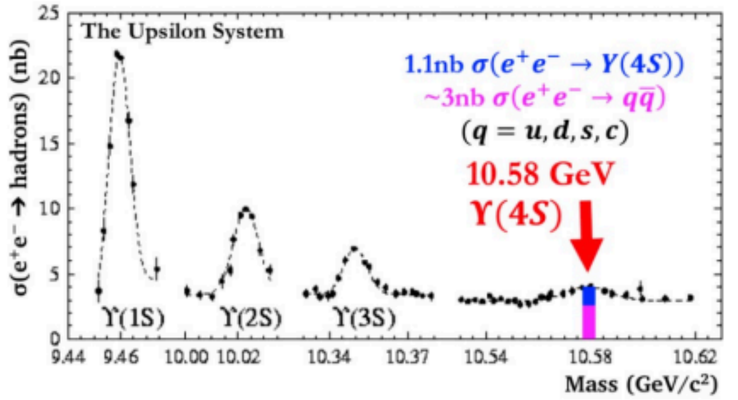
→ @ Belle II charmed hadrons are produced in B decays and in $e^+e^- \to c\bar{c}$ $(\sigma \sim 1.3\text{nb})$

→ while charm from B can also be used for charm studies ccbar events are our interest $e^+e^- \to c\bar{c}$

→ following the B tagging idea let's consider

$$e^+e^- \to c\bar{c} \to X_{\text{tag}} D_{\text{sig}}$$

need to reconstruct



→ if X_{tag} is correctly reconstructed in its RestOfEvent we will find only decay products of $D_{sig} \to f$ along with kinematic constraint $\vec{p}_{D_{sig}} = \vec{p}_{miss}$ $(\vec{p}_{miss} = \vec{p}_{e^+} + \vec{p}_{e^-} - \vec{p}_{X_{tag}})$

→ if we do not put any requirement on RestOfEvent and look at

$M_{miss} = \sqrt{p^2_{miss}}$ $(p_{miss} = p_{e^+} + p_{e^-} - p_{X_{tag}})$ correctly reconstructed events will peak at $M(D_{sig})$

→ the number of peaking events give the total number of D_{sig}'s in the sample (inclusive) which can is then used for absolute branching fraction calculation

Charm FEI

ccbarFEI

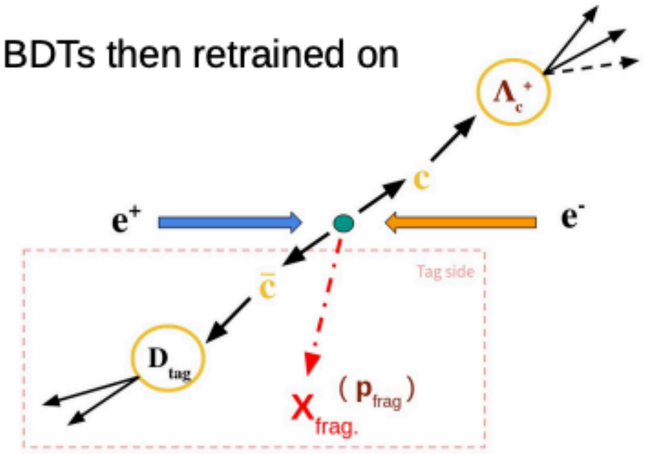
→ FEI is existing tool that is trained to efficiently reconstruct hadronic B decays.

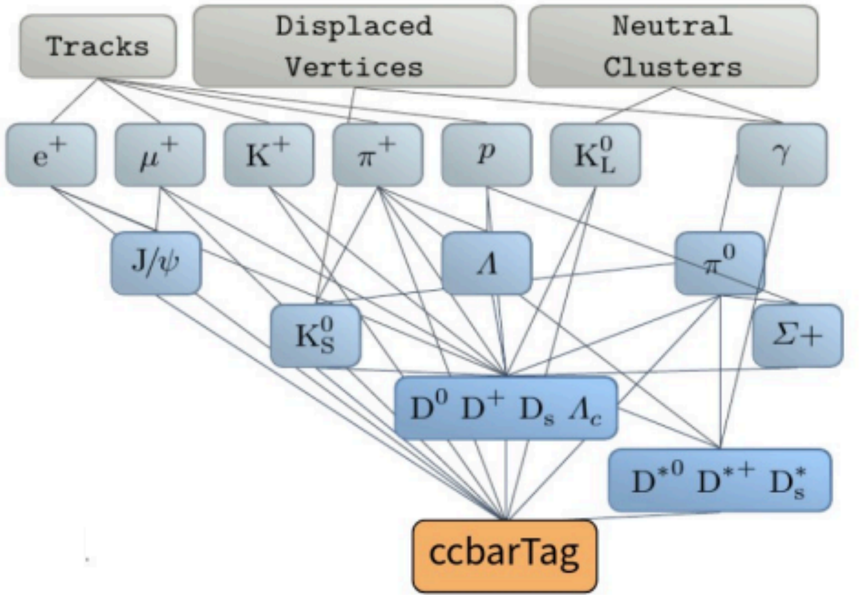
→ in the chain it is already reconstructing various charm states

→ idea of ccbarFEI is to adjust FEI to reconstruct charm tags (the recoil of which is a single $D_{(s)}, \Lambda_c,$ etc.)

→ target B modes in the last step of FEI are replaced with a list of target ccbar tags (specific for $D_{(s)}, \Lambda_c,$ etc. inclusive samples)

→ all stages of BDTs then retrained on ccbar events





Charm Datasets

Experiment	Machine	Operation	C.M.	Luminosity	N_{prod}	Efficiency	Characters
BESIII	BEPC-II (e^+e^-)	2010-2011 (2021-) 2016-2019 2014+2020	3.77 GeV 4.18-4.23 GeV 4.6-4.7 GeV	2.9 ($8 \to 20$) fb^{-1} 7.3 fb^{-1} 4.5 fb^{-1}	$D^{0,+}$: $10^7(\to 10^8)$ D_s^+: 5×10^6 Λ_c^+ : 0.8×10^6 ★☆	∼ 10-30% ★★★	☺ extremely clean environment ☺ quantum coherence ☺ pure D-beam, almost no background ☹ no CM boost, no time-dept analyses
Belle II	SuperKEKB (e^+e^-)	2019-	10.58 GeV	0.4 ($\to 50$) ab^{-1}	D^0: 6×10^8 ($\to 10^{11}$) $D^+_{(s)}$: 10^8 ($\to 10^{10}$) Λ_c^+: 10^7 ($\to 10^9$)	$\mathcal{O}$(1-10%)	☺ clear event environment ☺ high trigger efficiency ☺ good-efficiency detection of neutrals ☺ time-dependent analysis ☹ smaller cross-section than LHCb
BELLE	KEKB (e^+e^-)	1999-2010	10.58 GeV	1 ab^{-1}	D: 10^9 Λ_c^+: 10^8 ★★☆	★★	
LHCb	LHC (pp)	2011,2012 2015-2018 (2022-2025,2029-)	7+8 TeV 13 TeV	1+2 fb^{-1} 6 fb^{-1} ($\to 23 \to 50$)	5×10^{12} 10^{13} ★★★★	$\mathcal{O}$(0.1%) ★	☺ very large production cross-section ☺ large boost ☺ excellent time resolution ☹ dedicated trigger required

→ each of experiments has their advantages for different charm studies

→ at present BESIII may be hard to compete in many missing energy measurements

→ nonetheless, even at present (and especially in near future) Belle II has a great potential to produce competitive and leading results (especially with clever ideas and novel reconstruction techniques)