

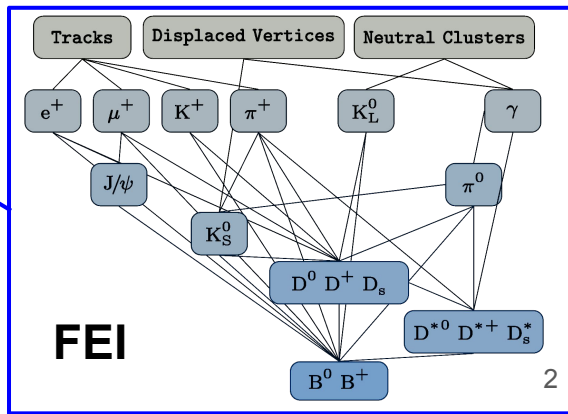
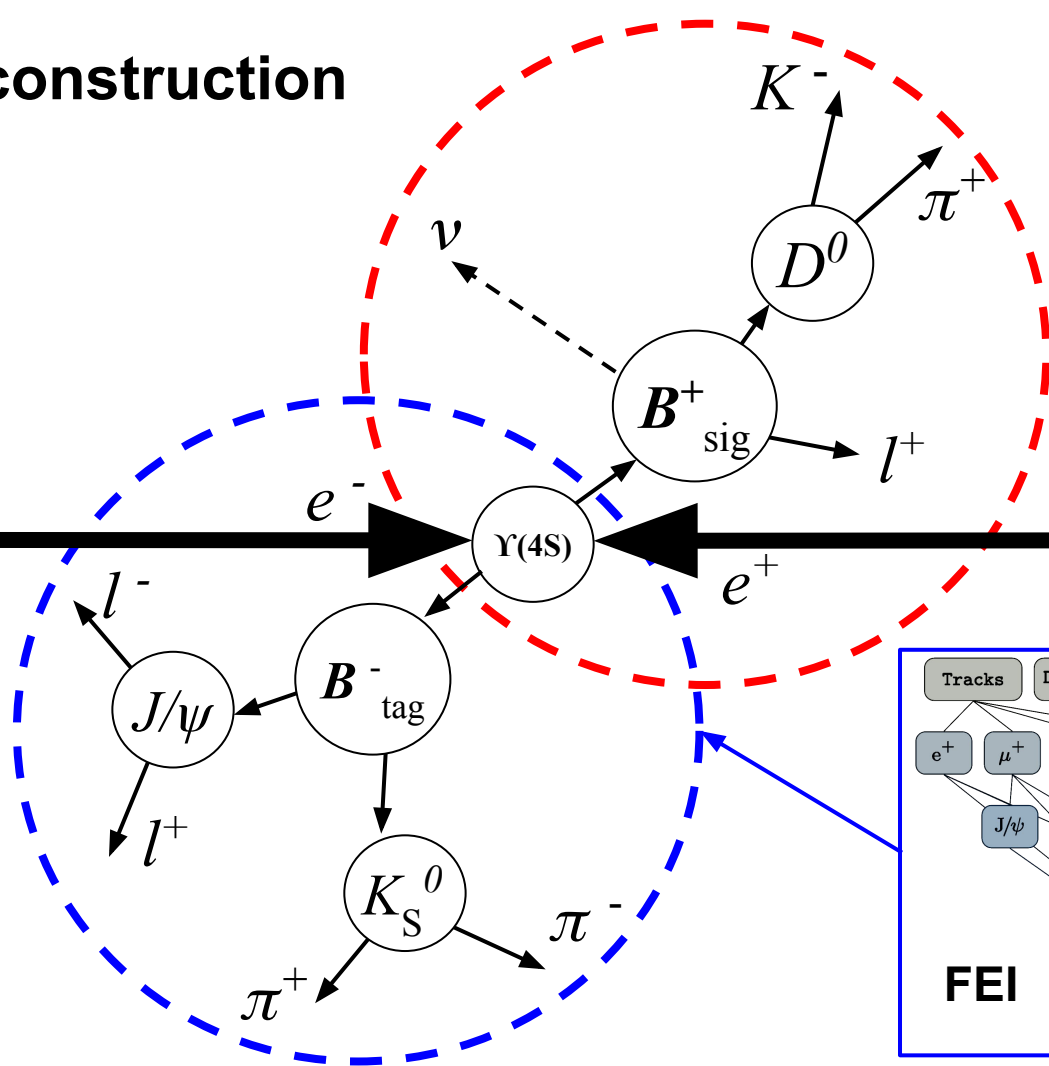
Full event reconstruction in charm

Krištof Špenko

Jožef Stefan Institute, Ljubljana, Slovenia

29. 9. 2026 – F9 Strategic Meeting, Krvavec

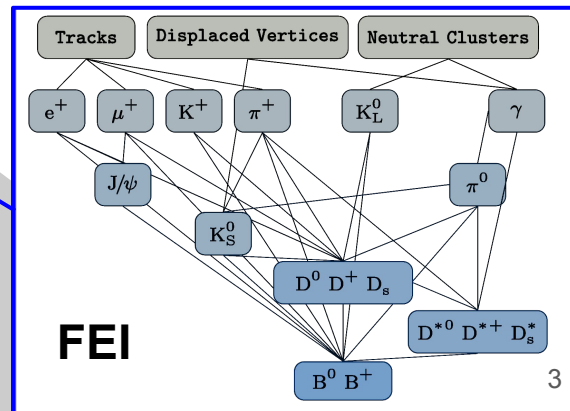
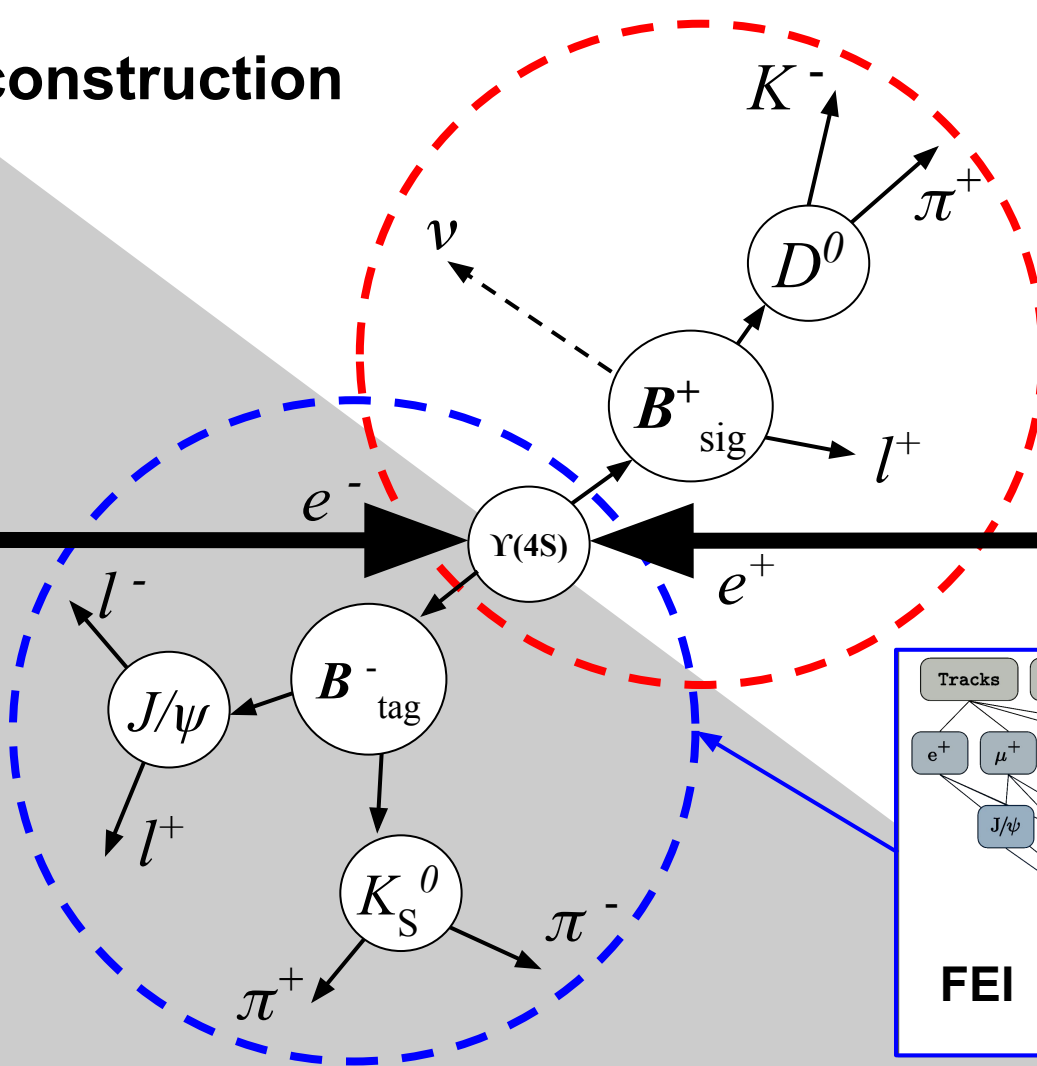
Full event reconstruction in B events:



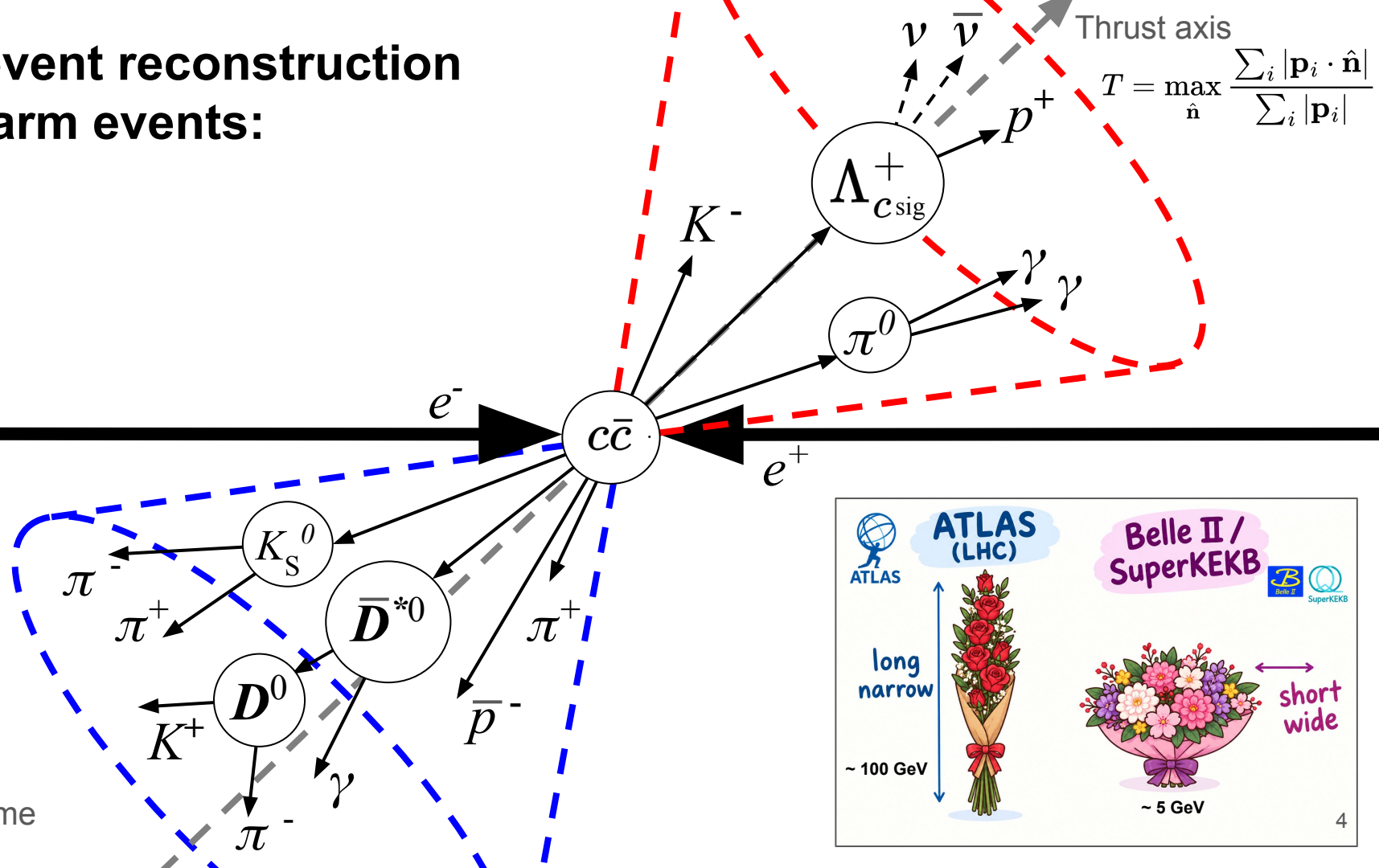
Full event reconstruction in B events:

TAG

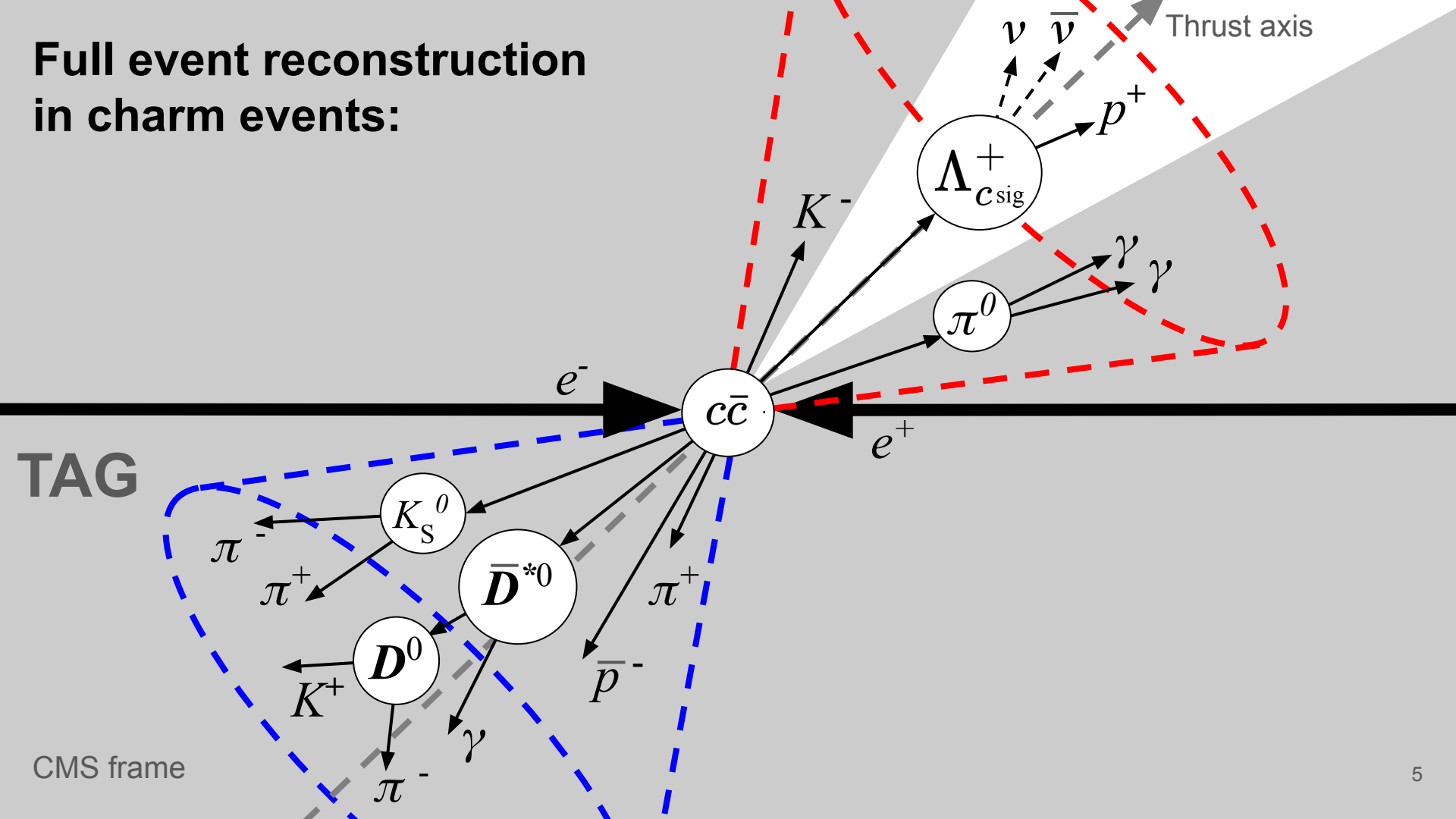
CMS frame



Full event reconstruction in charm events:



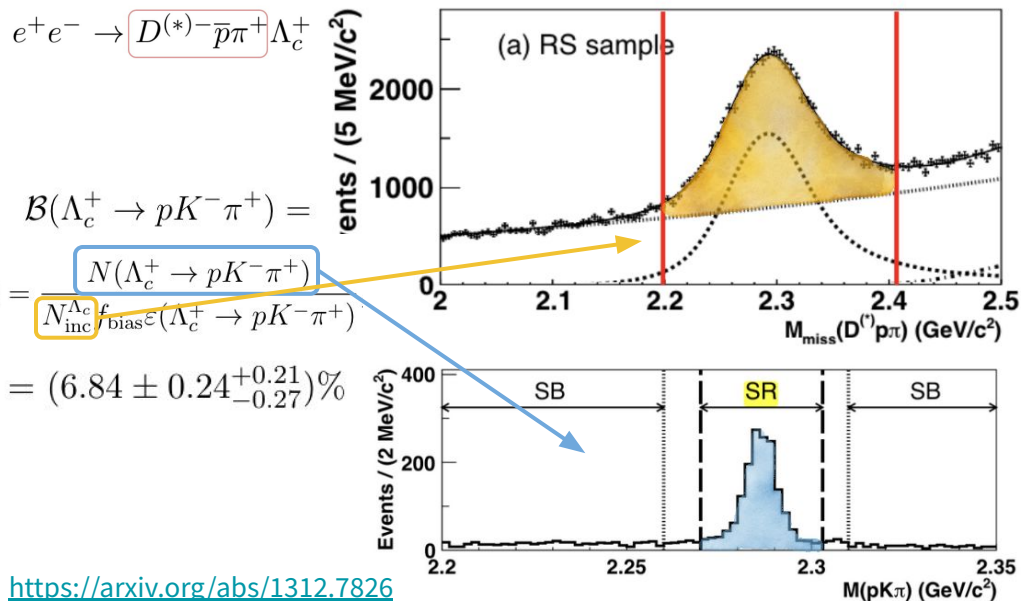
Full event reconstruction in charm events:



A bit of history & motivation ...

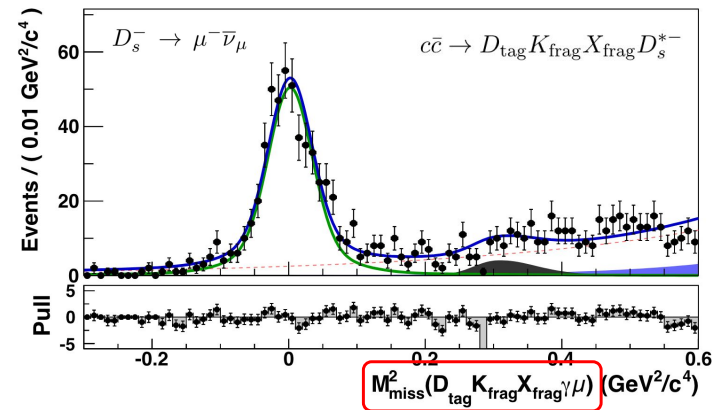
- Pioneering work by Anže Zupanc (IJS F9).
- Make an **inclusive** sample by cutting on missing/recoil mass: $M_{recoil} = \sqrt{p_{e^-} + p_{e^+} - p_{c\bar{c}tag}}/c^2$
- Allows to perform measurements of:

1) Absolute branching fractions:



<https://arxiv.org/abs/1312.7826>

2) Decays with missing energy:



$$\begin{aligned} \mathcal{B}(D_s^+ \rightarrow \mu^+ \nu_\mu) &= (5.31 \pm 0.28(\text{stat.}) \pm 0.20(\text{syst.})) \times 10^{-3}, \\ \mathcal{B}(D_s^+ \rightarrow \tau^+ \nu_\tau) &= (5.70 \pm 0.21(\text{stat.})^{+0.31}_{-0.30}(\text{syst.})) \times 10^{-2}, \\ \mathcal{B}(D_s^+ \rightarrow e^+ \nu_e) &< 1.0 \text{ (0.83)} \times 10^{-4} \text{ at 95 (90)\% C.L.} \end{aligned}$$

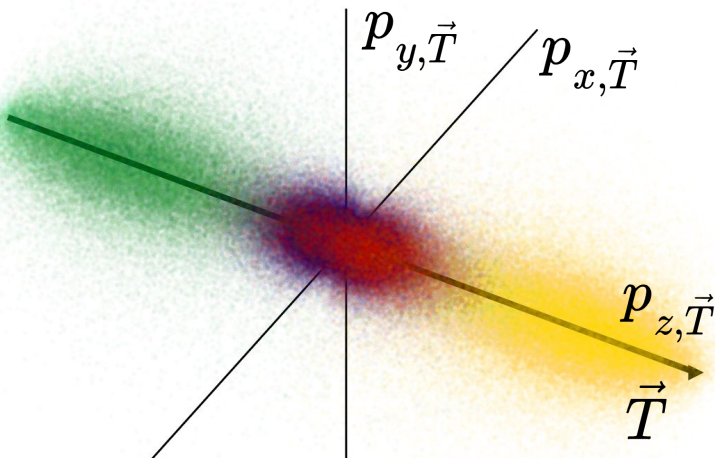
<https://arxiv.org/abs/1307.6240>

Development of ccbarFEI

$$e^+e^- \rightarrow c\bar{c} \rightarrow \Lambda_c^+ D_{tag} \bar{p} X_{frag}$$

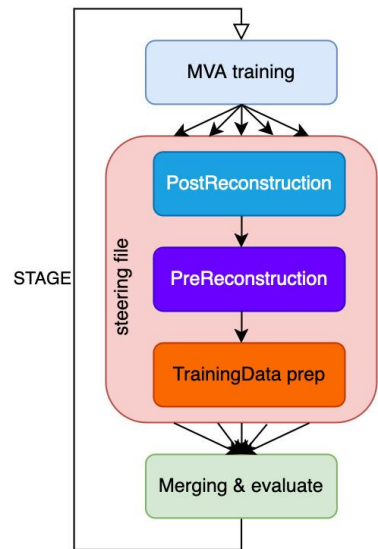
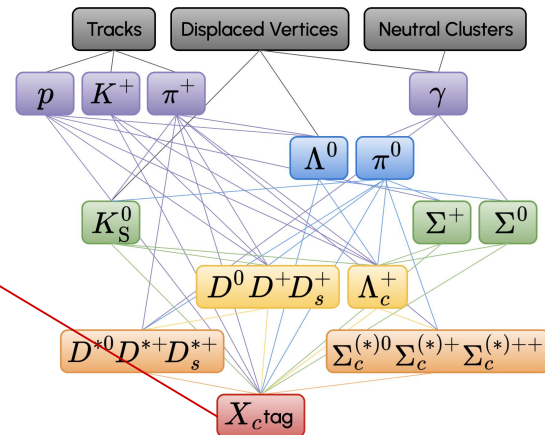
ccbarFEI specific:

- creating custom MC “truth matching” to use as the training **target**,
- identifying the best fragmentation **modes (85)** in MC included in the training,
- investigating **event topologies** to design crucial input variables for the BDTs.



General technical:

- exploiting FEI’s modular design to enable checkpoints & the ability to **retrain(rebase)**.
- **minimised storage** load,
- revised training evaluation to handle **weighted** samples.

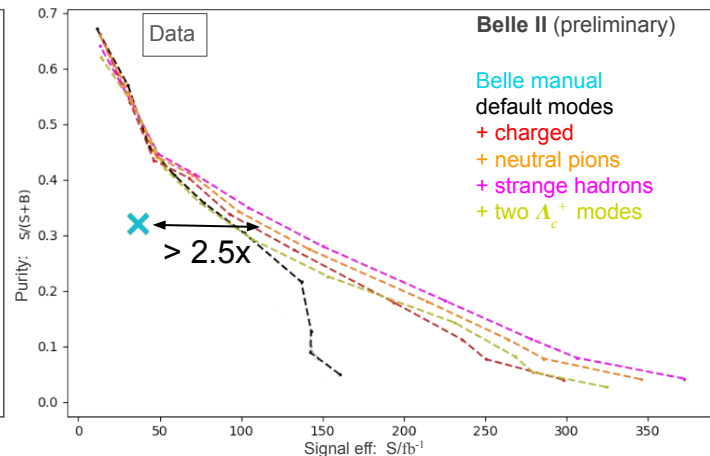
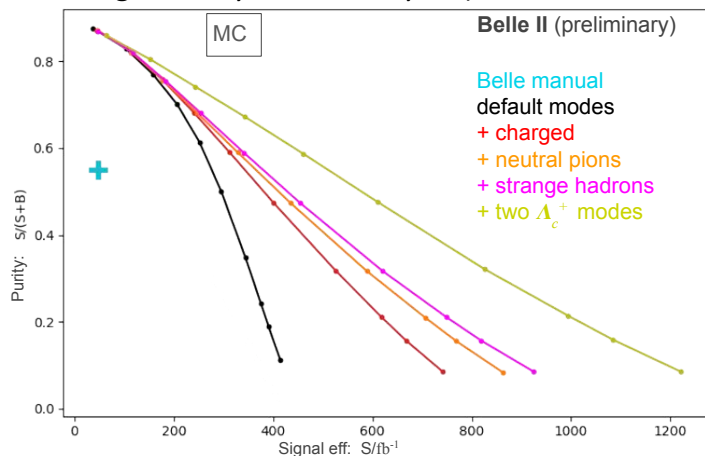
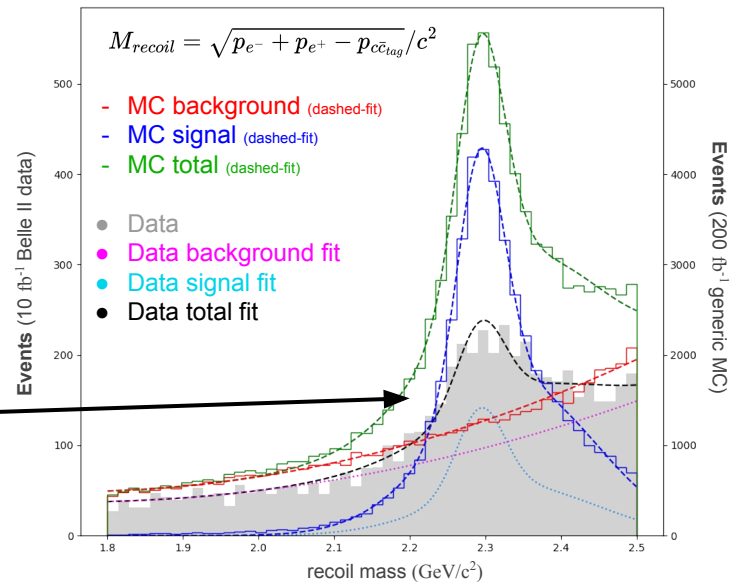


Performance of **ccbar** FEI

- Roughly 2.5 times higher efficiency (Belle A. Zupanc).
- Provides continuous score to optimize for analysis.

Main remaining challenges:

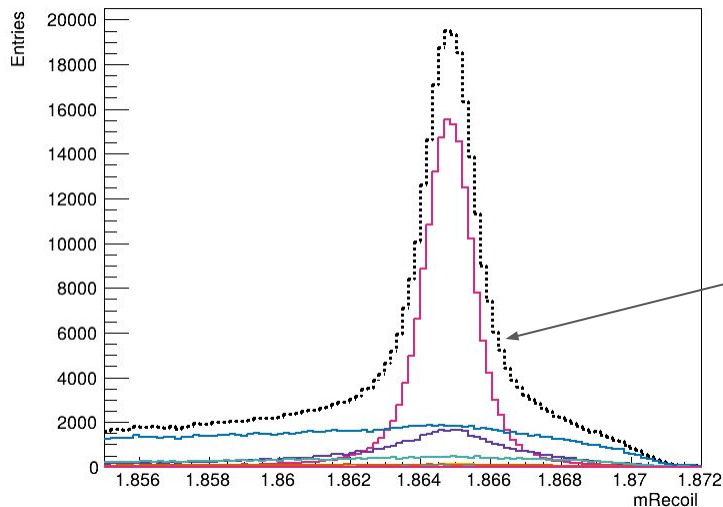
- Limited MC for less common frag. modes.
- Large fragmentation MC mis-modeling:
 - partially mitigated with calibration factors,
 - study and improve MC generators ...
 (Belle II recently started testing with Herwig 7.2 for generating orbitally excited baryons)



Extending **ccbar** FEI for D mesons:

D0 tagging payloads:

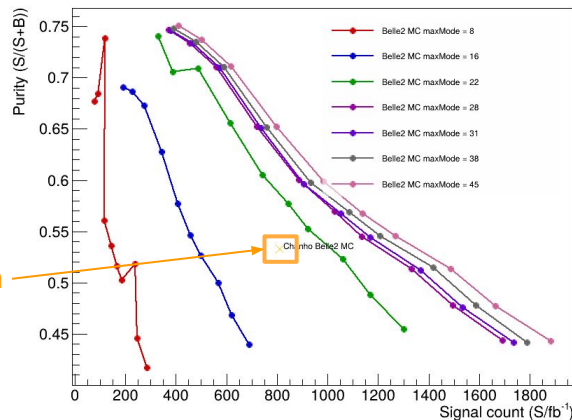
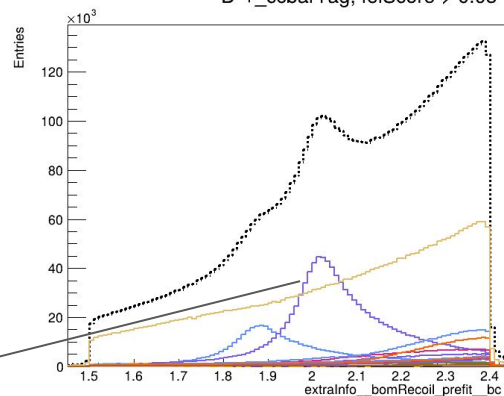
D0_ccbarTag2_1, feiScore > 0.03



- take D^{*+} tag and perform mass constrained fit,
- then add one more pion.
- ~2x improvement compared to manual approach

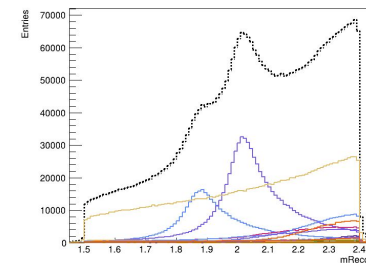
D $^{*+}$ tagging payloads:

D $^{*+}$ _ccbarTag, feiScore > 0.03



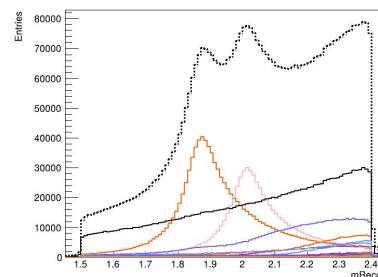
D+(prompt) tagging payloads:

D+_ccbarTag, feiScore > 0.03



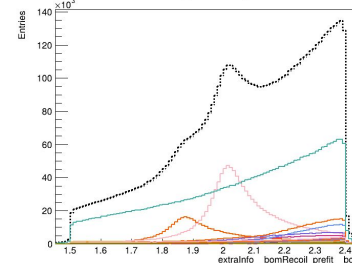
D0(prompt) tagging payloads:

D0_ccbarTag, feiScore > 0.03



D 0 tagging payloads:

D 0 _ccbarTag, feiScore > 0.03



Summary & future work:

Completed development of the **ccbarFEI** tool;

- opens up a plethora of new analysis,
- implementations have also direct impact on training and further development of preexisting **FEI**.

Next step:

- Employ **ccbarFEI** to conduct the **first search** for the rare FCNC decay: $\Lambda_c^+ \rightarrow p\nu\bar{\nu}$ at Belle II.

Long term outlook: (*personal opinion*)

- optimized trainings for D meson tagging,
- studying/improving fragmentation modeling.

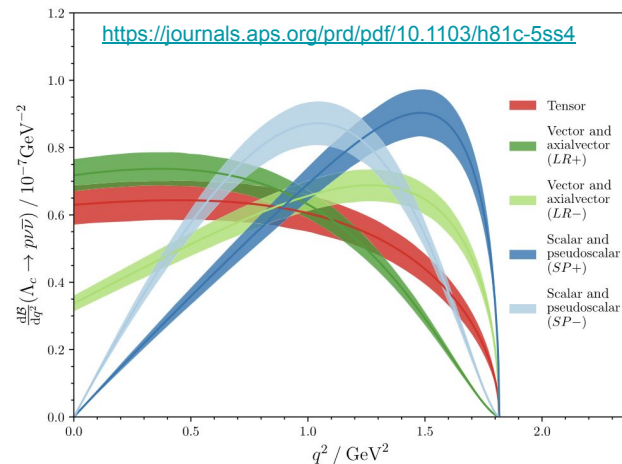
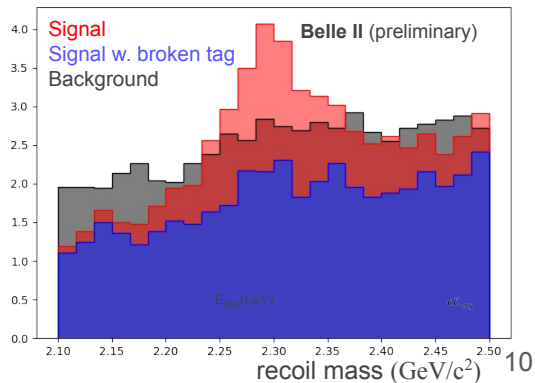
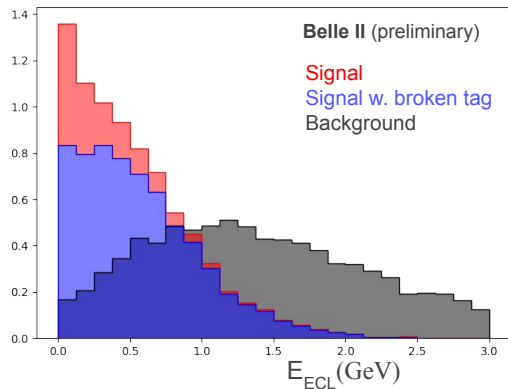
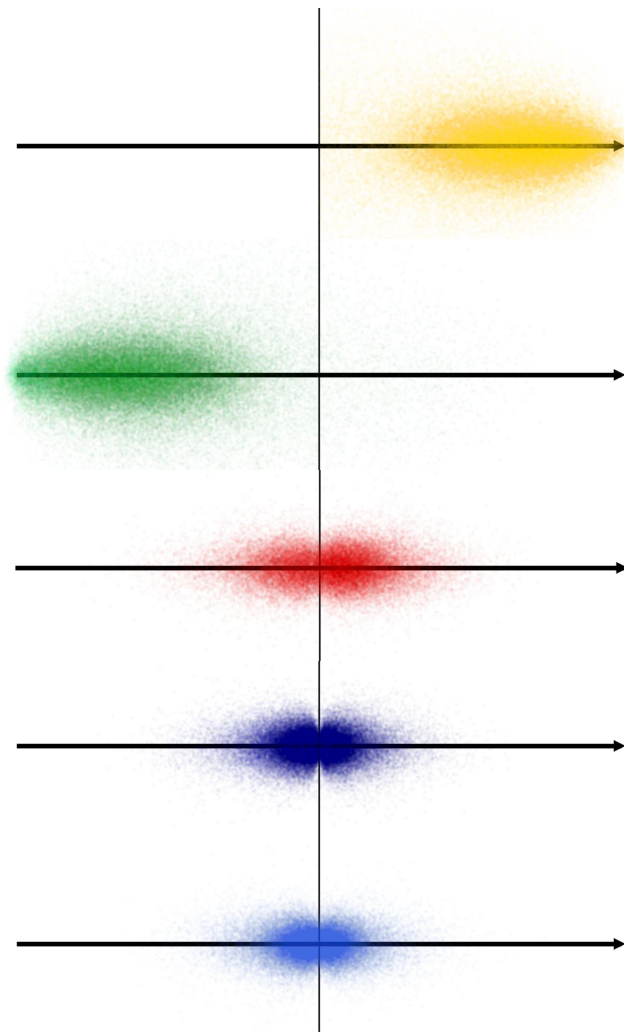
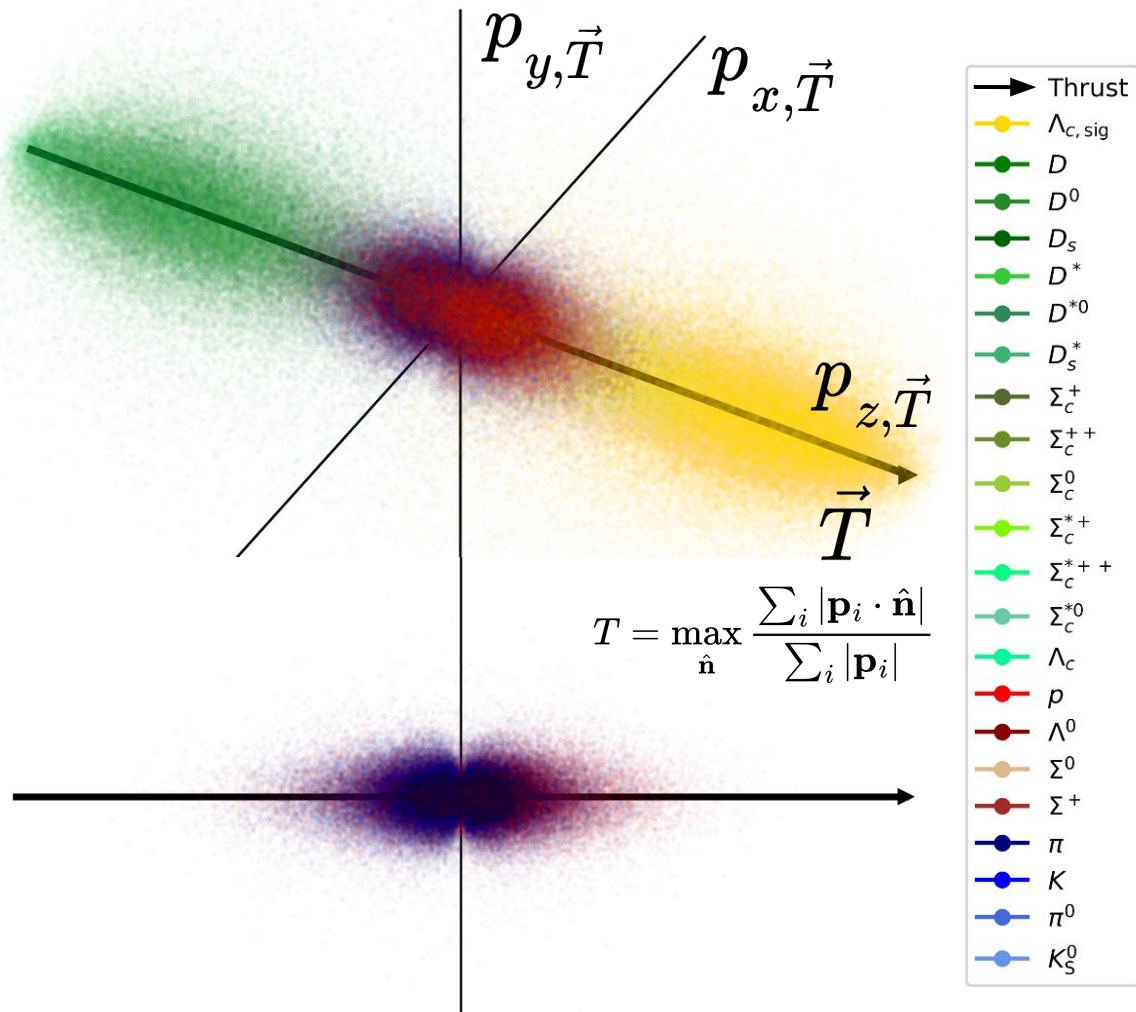


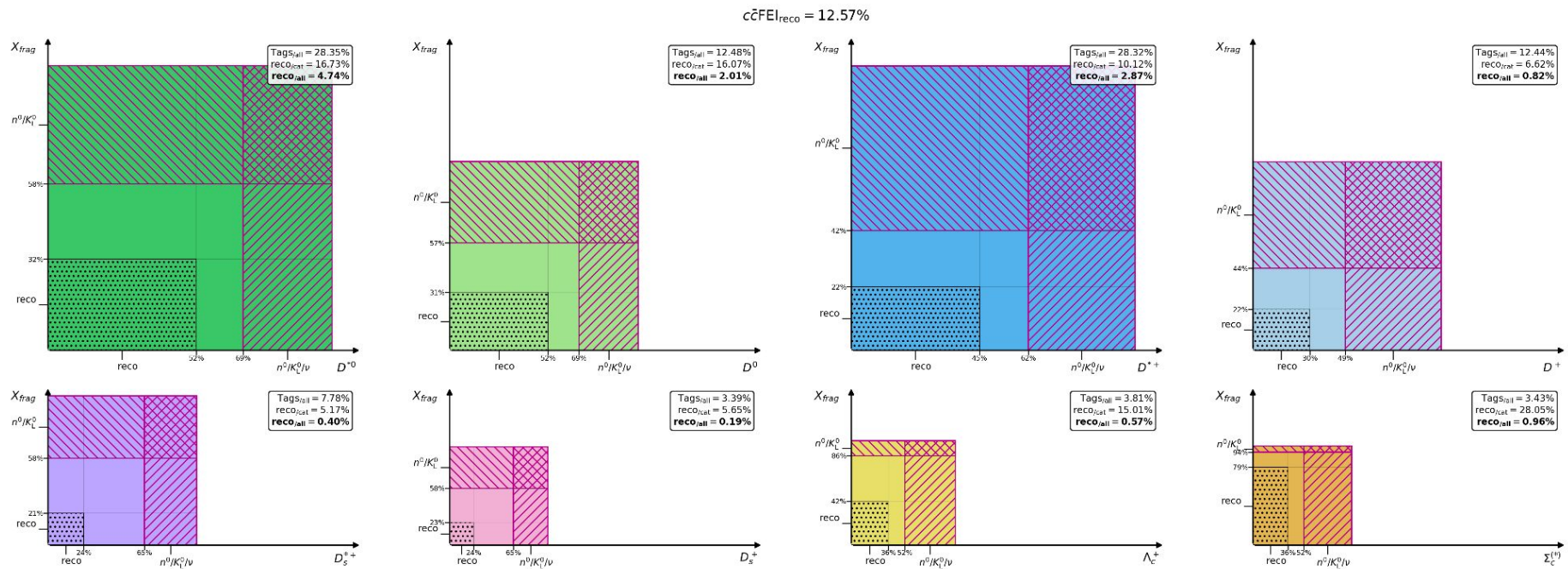
FIG. 3. The $d\mathcal{B}(\Lambda_c \rightarrow p\nu\bar{\nu})/dq^2$ distributions as functions of q^2 ; see Fig. 1. Central values are normalized to $\mathcal{B}(\Lambda_c \rightarrow p\nu\bar{\nu}) = 10^{-7}$. The uncertainty includes statistical and systematic errors of the form factors given in [49].



BACKUP



Composition of X_c tags:



MOTIVATION: FCNC - Flavour Changing Neutral Currents

- ❑ No FCNC at tree level in SM.
- ❑ Loop FCNC **highly suppressed**.
- ❑ Very sensitive to NP.
- ❑ **Charm** unique probe of up-type quark sector.
- ❑ Experimentally weakly explored → big opportunities for Belle II.

