Charged Lepton Flavour Violation Searches in B decays at LHCb

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Outline of the talk

- **Motivation & experimental overview**
- **LFV searches in B decays at LHCb**
  - Search for LFV $B^0 \to K^{*0} e^{\pm} \mu^{\mp}$ and $B^0_s \to \phi e^{\pm} \mu^{\mp}$
  - Search for LFV $B^0 \to K^{*0} \tau^{\pm} \mu^{\mp}$ decay
  - Search for LFV $B^0_s \to \phi \tau^{\pm} \mu^{\mp}$ decay
- **Summary**

Motivation and experimental overview

- **LFV occurs in the SM only via neutrino oscillations**
- **Highly suppressed** ($\Delta m^2/M_W^2$), expected BR in charged sector **~O(10^{-50})**
- **Any observation constitutes a clear probe of New Physics (NP)**
- Some NP models, e.g. LQ, predicts BRs close to current experimental limit and are sensitive to the lepton families coupling
- **B factories** and **LHCb** set stringent LFV bounds

DISCUSSED TODAY

Leptons	Decay	Limit (90% C.L.)	Integrated luminosity	Experiment
$e\mu$	$B^0 \to e^\mp\mu^\pm$	1.0×10^{-9} [89]	$3fb^{-1}$	LHCb
	$B_s^0 \to e^\mp\mu^\pm$	5.4×10^{-9} [89]	$3fb^{-1}$	LHCb
	$B^0 \to \pi^0 e^\mp\mu^\pm$	1.4×10^{-7} [90]	472M BB ($426fb^{-1}$)	BaBar
	$B^+ \to \pi^+ e^\mp\mu^\pm$	1.7×10^{-7} [90]	472M BB ($426fb^{-1}$)	BaBar
	$B^0 \to K^0 e^\mp\mu^\pm$	3.8×10^{-8} [91]	772M BB ($771fb^{-1}$)	Belle
	$B^0 \to K^{*0} e^\mp\mu^\pm$	10.1×10^{-9} [12]	$9fb^{-1}$	LHCb
	$B^0 \to K^{*0} e^-\mu^+$	5.7×10^{-9} [12]	$9fb^{-1}$	LHCb
	$B^0 \to K^{*0} e^+\mu^-$	6.8×10^{-9} [12]	$9fb^{-1}$	LHCb
	$B^+ \to K^+ e^\mp\mu^\pm$	7.0×10^{-9} [92]	$3fb^{-1}$	LHCb
	$B^+ \to K^+ e^-\mu^+$	6.4×10^{-9} [92]	$3fb^{-1}$	LHCb
	$B^+ \to K^{*+} e^-\mu^+$	9.9×10^{-7} [93]	472M BB ($426fb^{-1}$)	BaBar
	$B^+ \to K^{*+} e^+\mu^-$	1.3×10^{-6} [93]	472M BB ($426fb^{-1}$)	BaBar
	$B^+ \to D^- e^+\mu^+$	1.8×10^{-6} [94]	772M BB ($771fb^{-1}$)	Belle
	$B_s^0 \to \phi e^\pm\mu^\mp$	1.6×10^{-8} [12]	$9fb^{-1}$	LHCb
$\tau\mu$	$B^0 \to \tau^\mp\mu^\pm$	1.4×10^{-5} [95]	$3fb^{-1}$	LHCb
	$B_s^0 \to \tau^\mp\mu^\pm$	4.2×10^{-5} [95]	$3fb^{-1}$	LHCb
	$B^+ \to \pi^+\tau^+\mu^-$	4.5×10^{-5} [90]	472M BB ($426fb^{-1}$)	BaBar
	$B^+ \to \pi^+\tau^-\mu^+$	2.45×10^{-5} [90]	472M BB ($426fb^{-1}$)	BaBar
	$B^0 \to K^{*0}\tau^+\mu^-$	1.0×10^{-5} [96]	$9fb^{-1}$	LHCb
	$B^0 \to K^{*0}\tau^-\mu^+$	9.8×10^{-6} [96]	$9fb^{-1}$	LHCb
	$B^+ \to K^+\tau^+\mu^-$	5.9×10^{-6} [97]	772M BB ($771fb^{-1}$)	Belle
	$B^+ \to K^+\tau^-\mu^+$	2.45×10^{-5} [97]	772M BB ($771fb^{-1}$)	Belle
	$B_s^0 \to \phi\tau^\pm\mu^\mp$	1.0×10^{-5} [98]	$9fb^{-1}$	LHCb

Searches for $B^0 \to K^* e\mu$ and $B^0_s \to \phi e\mu$

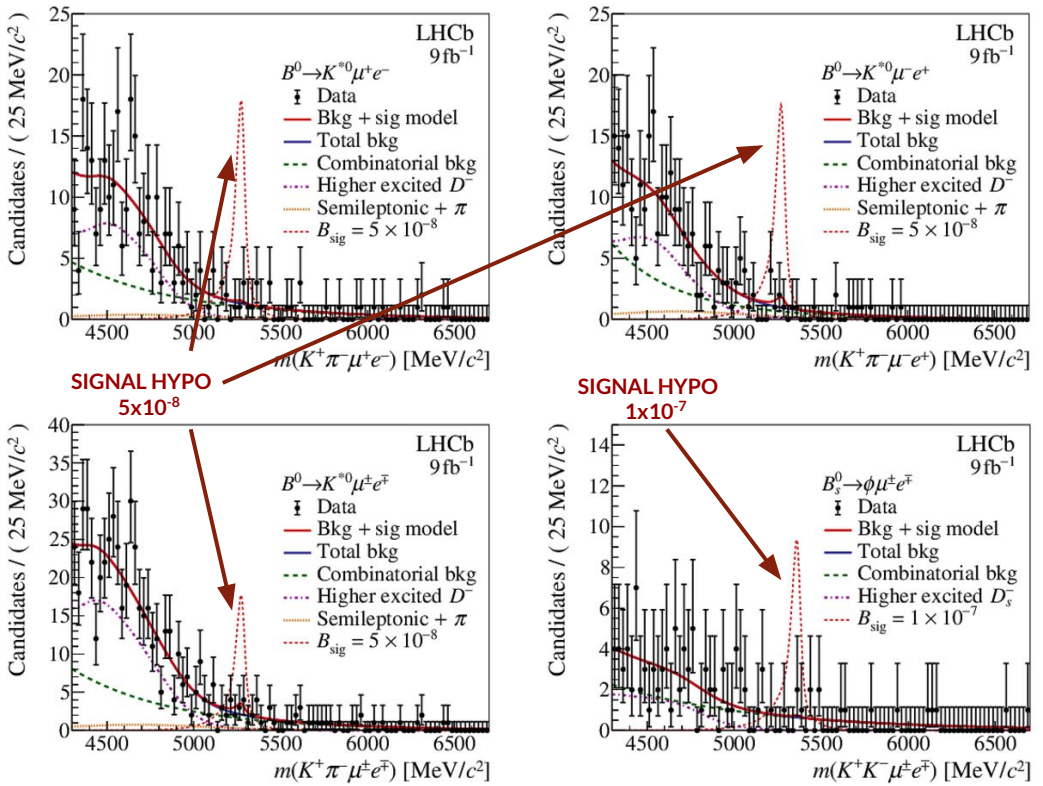
JHEP 06 (2023), 073

- Full Run 1+2 LHCb datasets (**9fb^{-1}**)
- First result ever for $B^0_s \to \phi\mu^\pm e^\mp$
- *Final states*:

  $K^*(\to K^+\pi^-)\mu^\pm e^\mp$ and $\phi(\to K^+K^-)\mu^\pm e^\mp$
- *Normalization samples*:

  $B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-)$ and

  $B^0_s \to \phi J/\psi(\to \mu^+\mu^-)$
- **$B^0 \to K^{*0}\mu^+e^-$ and $B^0 \to K^{*0}\mu^-e^+$ charge combinations treated separately**
  - different background components/NP predictions



Fit on data of invariant mass distributions

Searches for $B^0 \to K^* e\mu$ and $B^0_s \to \phi e\mu$: Results

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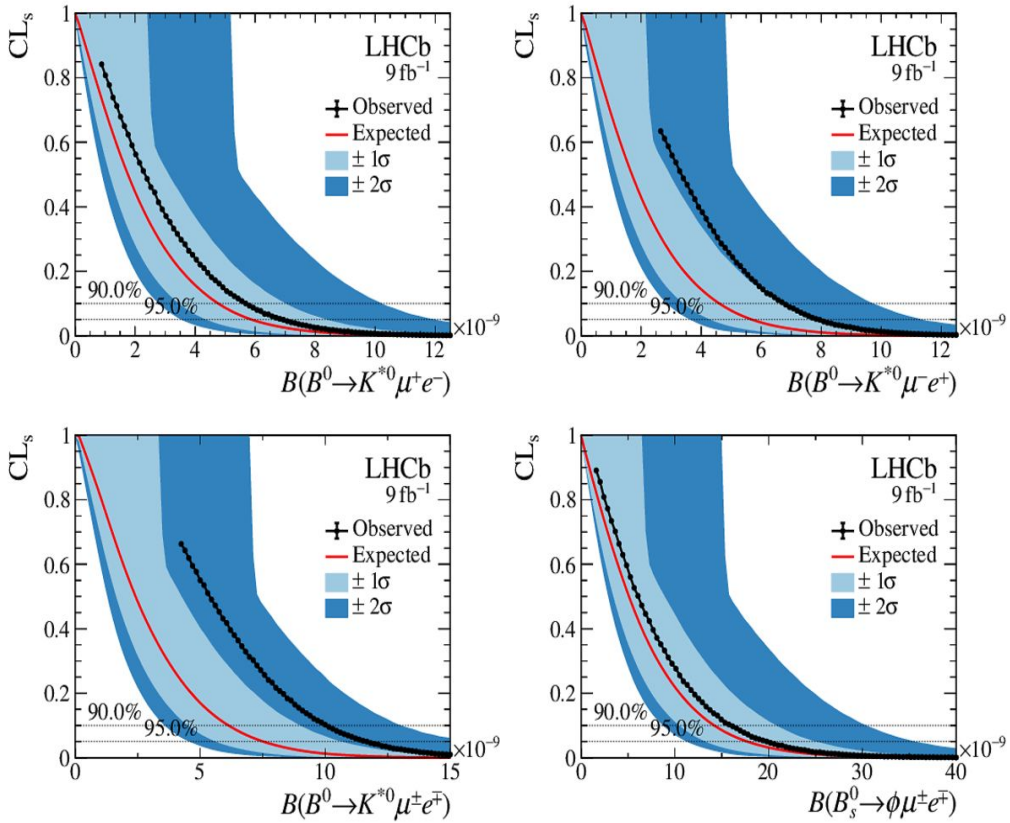
- **No significant signal observed**
- Upper limits at 90 (95)% CLs

$$\mathcal{B}(B^0 \to K^{*0} e^+ \mu^-) < 6.8(7.9) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to K^{*0} e^- \mu^+) < 5.7(6.9) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to K^{*0} e^\pm \mu^\mp) < 10.1(11.7) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \phi e^\pm \mu^\mp) < 16.9(19.8) \times 10^{-9}$$

- Limits set assuming **uniform phase space**
- Evaluated in **different NP models**

channel	PHSP	left-handed	scalar
$\mathcal{B}(B^0_s \to \phi\mu^\pm e^\mp)$	16.0 (19.8)	16.5 (20.5)	18.8 (23.1)
$\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp)$	10.1 (11.7)	12.0 (13.9)	14.7 (17.0)
$\mathcal{B}(B^0 \to K^{*0}\mu^- e^+)$	6.8 (7.9)	8.0 (9.5)	9.9 (11.5)
$\mathcal{B}(B^0 \to K^{*0}\mu^+ e^-)$	5.7 (6.9)	6.7 (8.3)	8.4 (10.2)



Search for $B^0 \to K^{*}\tau\mu$

- Full Run 1+2 LHCb datasets (**9fb^{-1}**)
- First search for $B^0 \to K^{*0}\tau^{\pm}\mu^{\mp}$
- *Final states:*

  $K^{*0}(\to K^{+}\pi^{-})\ \tau^{\pm}(\to \pi^{\pm}\pi^{\pm}\pi^{\mp}(\pi^{0})\nu_{\tau})\ \mu^{\mp}$
- *Normalization sample*:

  $B^0 \to D^{-}(\to K^{+}\pi^{-}\pi^{-})D_s^{+}(\to K^{+}K^{-}\pi^{+})$
- **$B^0 \to K^{*0}\mu^{-}\tau^{+}$ and $B^0 \to K^{*0}\mu^{+}\tau^{-}$ charge combinations treated separately**
- **Missing ν_{τ} momentum** from τ decay

$$m_{corr} = \sqrt{p_T^2 + M^2} + p_T$$

Invariant mass of the final states

Missing momentum in the transverse plane

Background shape parameterized by control sample extracted from data

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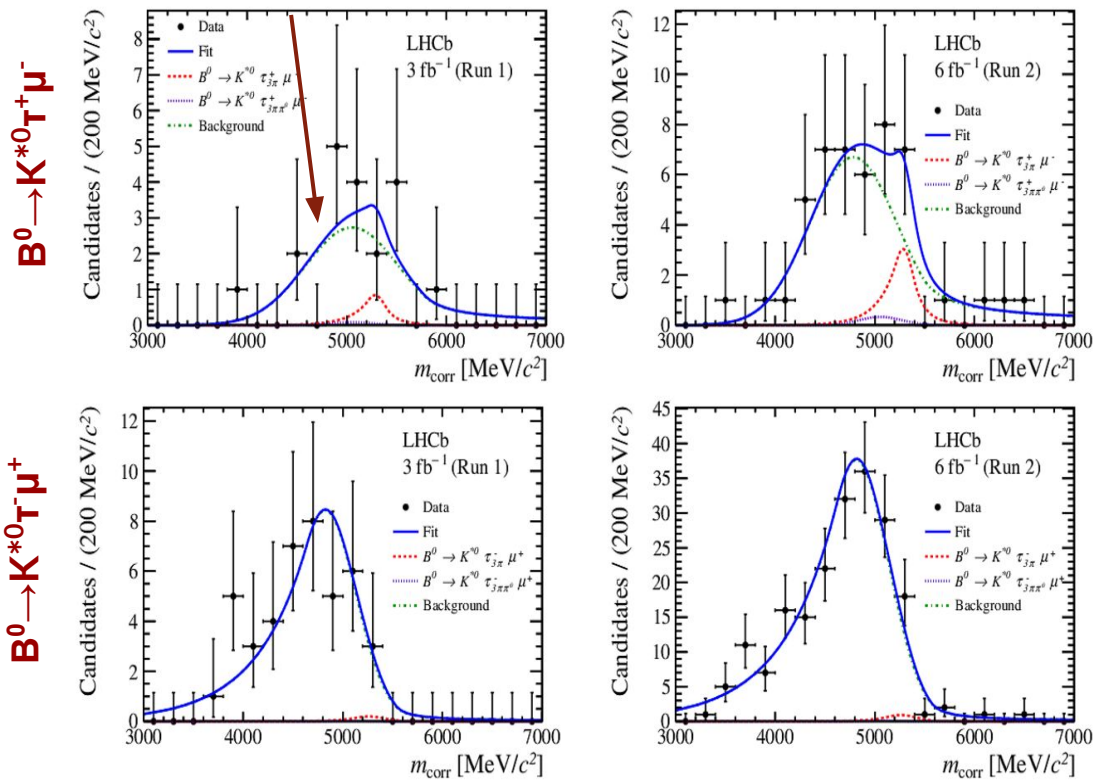

Fit on data of corrected mass distributions

Search for $B^0 \to K^{*}\tau\mu$: Results

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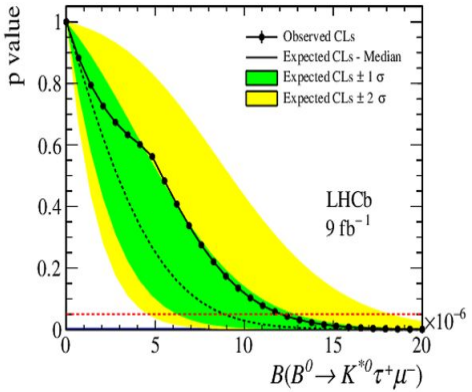
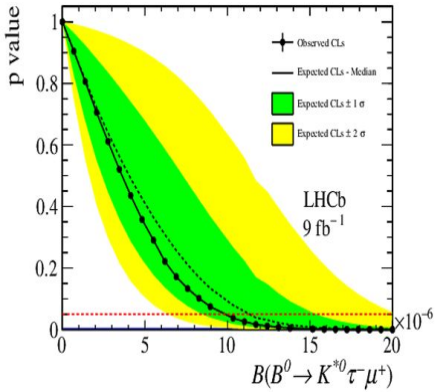
- **No significant signal observed**
- Upper limits at 90 (95)% CLs

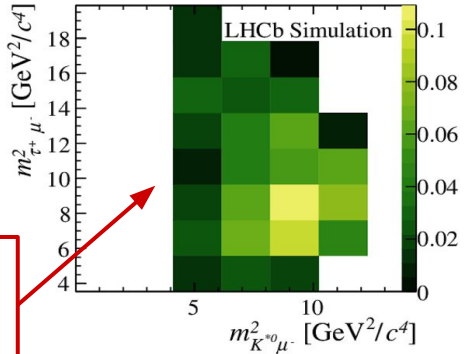
$$B(B^0 \to K^{\star 0}\tau^+\mu^-) < 1.0(1.2) \times 10^{-5}$$
$$B(B^0 \to K^{\star 0}\tau^-\mu^+) < 8.2(9.8) \times 10^{-6}$$

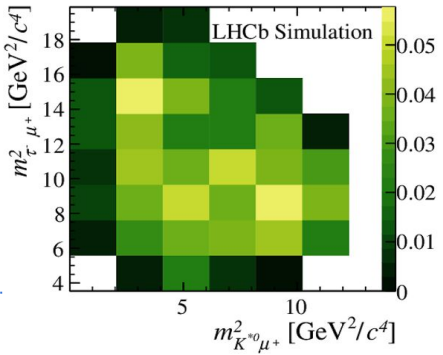
- Limits set assuming **uniform phase space**
- **Efficiencies maps** on invariant mass squared of K*μ and τμ provided, allowing to **reweight wrt a specific model**





Veto on **m(K⁺μ⁻)>1885 MeV/c²** to reject $B^0 \to D^{(*)-}\tau^+\nu_\tau$ bkg





Search for $B^0_s \to \phi\tau\mu$

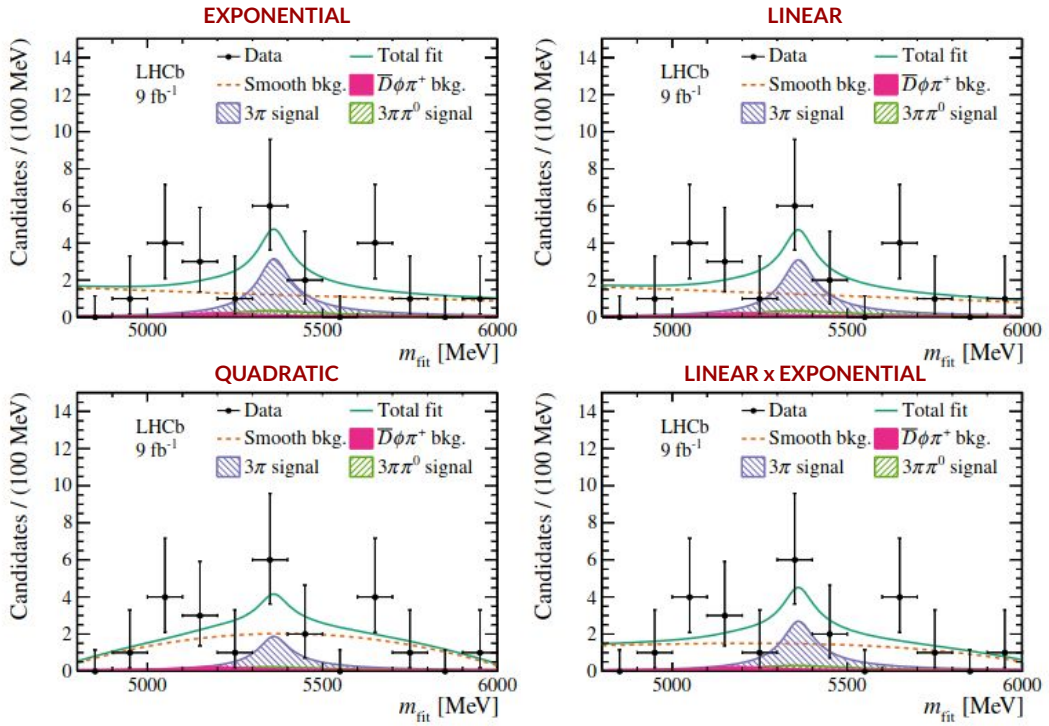
NEW

https://arxiv.org/abs/2405.13103

- Full Run 1+2 LHCb dataset (**9fb^{-1}**)
- First search for $B^0_s \to \phi\tau^{\pm}\mu^{\mp}$
- *Final states:*

  $\phi(\to K^+K^-)\ \tau^{\mp}(\to \pi^{\pm}\pi^{\pm}\pi^{\mp}(\pi^0)\nu_\tau)\ \mu^{\mp}$
- *Normalization sample*:

  $B^0_s \to \psi(2s)(\to J/\psi(\to \mu^+\mu^-)\pi^+\pi^-)\phi(\to K^+K^-)$
- **Indistinguishability of ϕ meson** does not allow to separate $B^0 \to \phi\tau^{\pm}\mu^{\mp}$ from $\overline{B}^0 \to \phi\tau^{\pm}\mu^{\mp}$
- **Mass refitted** including missing neutrino momentum and kinematic constraints



Fit on data of refitted mass distributions

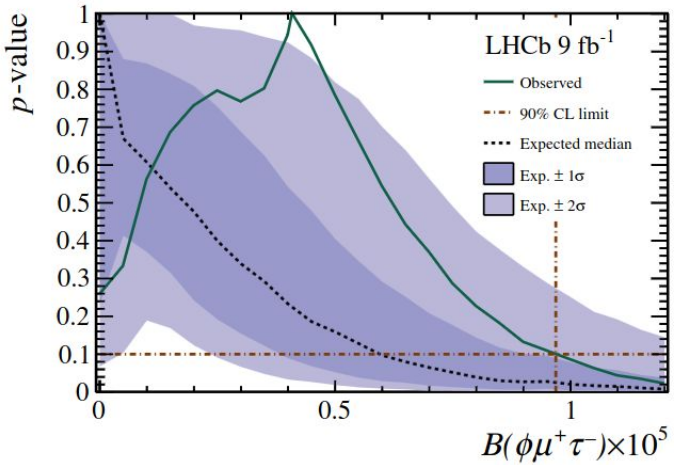
Search for $B^0_s \to \phi\tau\mu$: Results

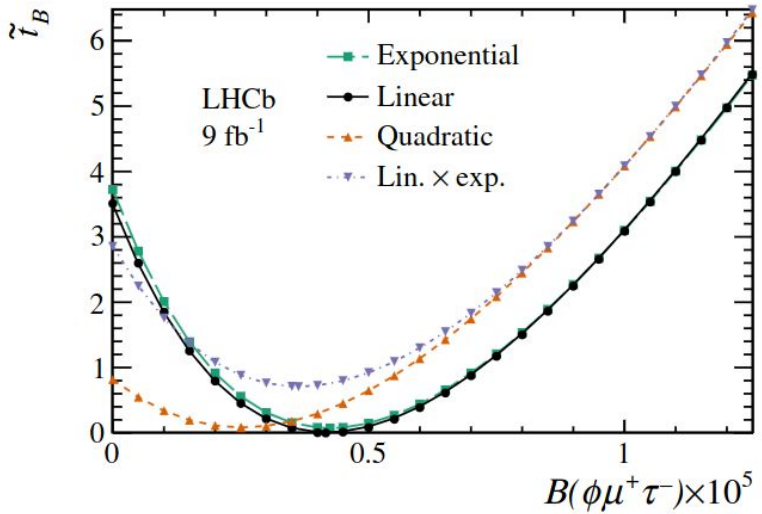
NEW

https://arxiv.org/abs/2405.13103

- **Four different background shapes** considered
- For a particular value of *BR*, the lowest of the four test-statistics is $\tilde{t}_{\mathcal{B}}$
- Upper limits at 90 (95)% confidence level using Feldman-Cousins method

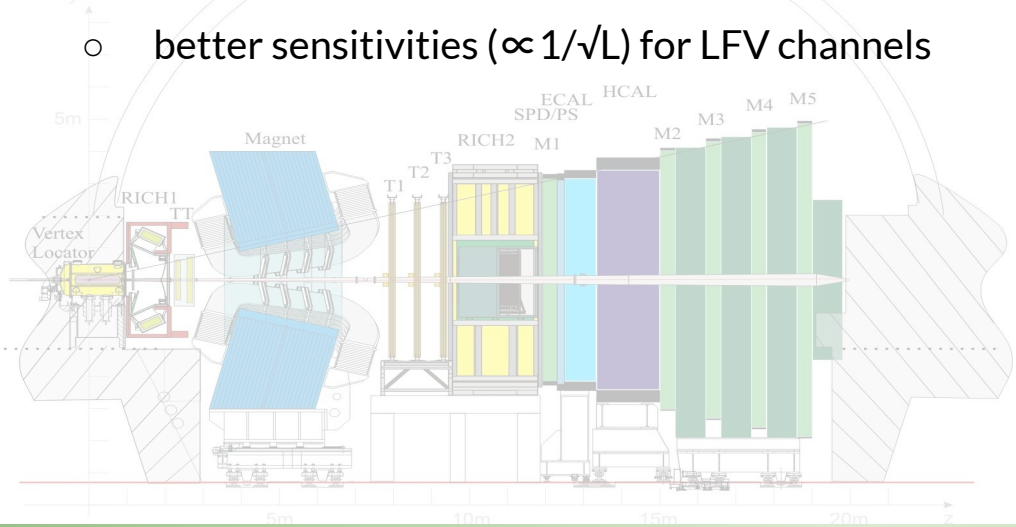
$$\mathcal{B}(B_s^0 \to \phi\tau^{\pm}\mu^{\mp}) < 1.0(1.1) \times 10^{-5}$$

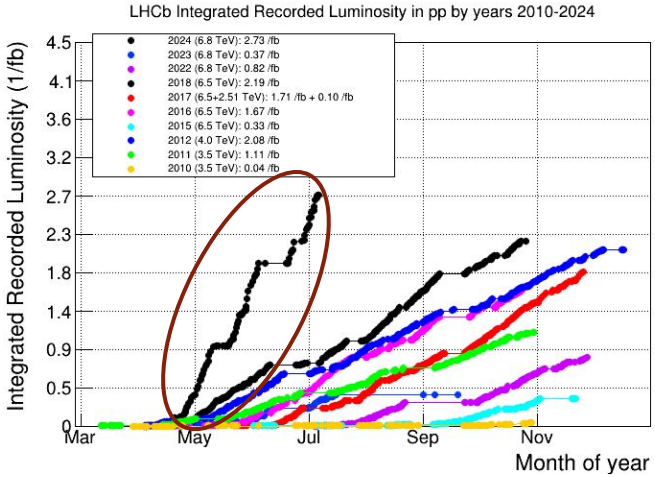




Summary

- **Most recent LFV searches in B decays @ LHCb presented**
- Search ongoing also in τe sector from B decays with Run 2 data
- Not only LFV in B decays @ LHCb: also in **charm, baryon and Higgs sector** and direct searches in **τ decays** (τ→3μ, τ→ϕμ, τ→pμμ)
- Run 3 ongoing, lot of data taken and foreseen
  - better sensitivities ($\propto 1/\sqrt{L}$) for LFV channels





https://lbgroups.cern.ch/online/OperationsPlots/index.html


thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
спасибо
Баярлалаа
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bedankt
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kop khun krap
go raibh maith agat
mochchakkeram
merci
grazie
arigatō
takk
dakujem
мерси
terima kasih
감사합니다
ありがとう
ευχαριστώ
tapadh leat
dank je
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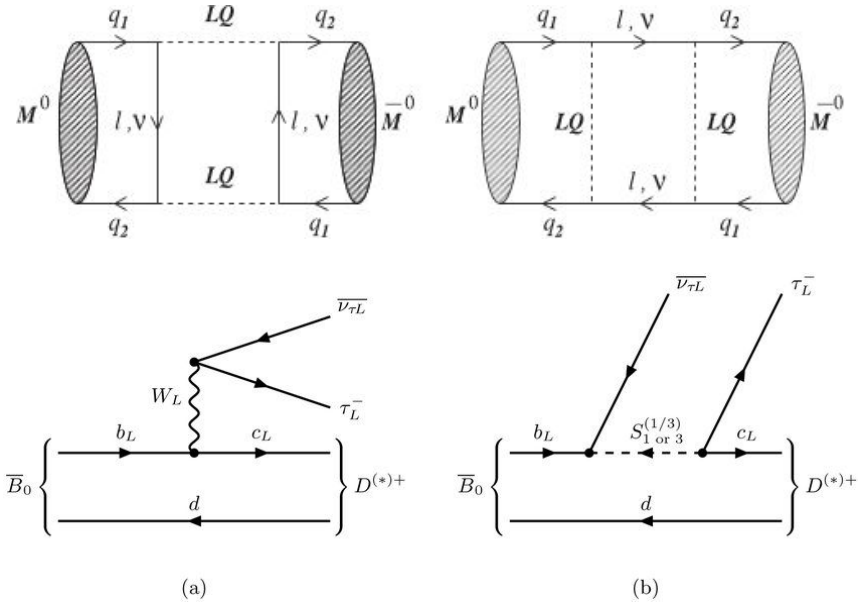
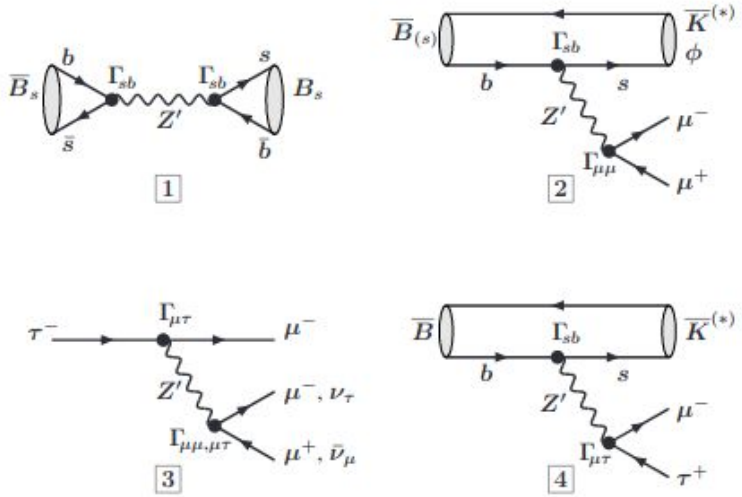
BACKUP

Theoretical models

New Physics scenario with Leptoquark (LQ)



New Physics scenario with Z' mediator



Selection and Normalization for $B^0 \to K^* e\mu$ and $B^0_s \to \phi e\mu$

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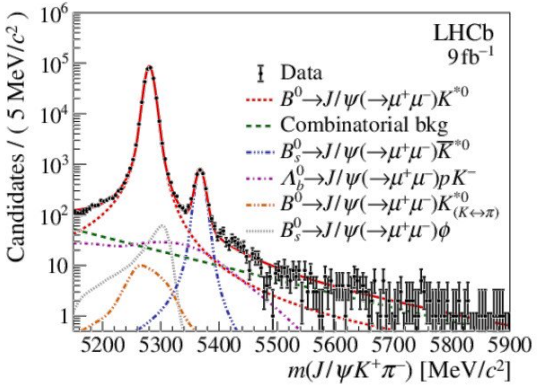
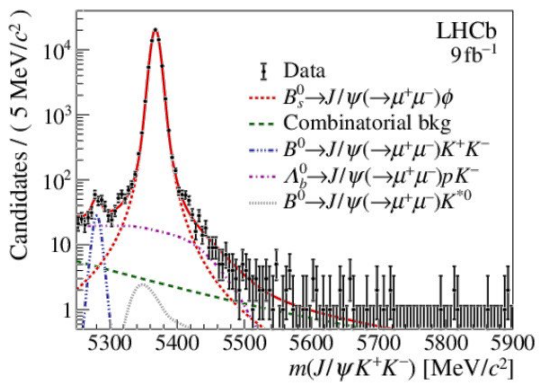
- Signal region in **[4300, 6700] MeV/c²**
- PID requirements on final state hadrons and leptons to suppress double mis-ID bkg $B^0_{(s)} \to K^{*0}(\phi)\,\pi^\pm\,\pi^\mp$
- Mass window of **invariant mass for $K^+\pi^-$ and K^-K^+** with width respectively **100 MeV/c²** for K^* and **12 MeV/c²** for ϕ, centered on PDG mass value
- **Vetoes** for rejecting background for **J/ψ and ψ(2s) resonances** and **semileptonic cascade involving D mesons** ($b \to c(\to s l'^+ \nu_{l'}) l^- \bar{\nu}_l$ decays)
- Separate BDT for each of the two signal decay to remove combinatorial background
- **Fit on normalization sample**





Background for $B^0 \to K^* e\mu$ and $B^0_s \to \phi e\mu$

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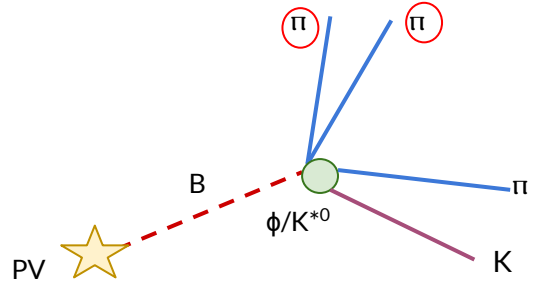
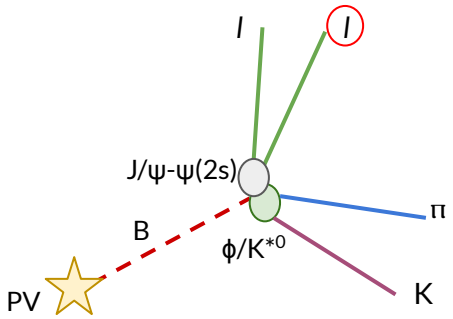
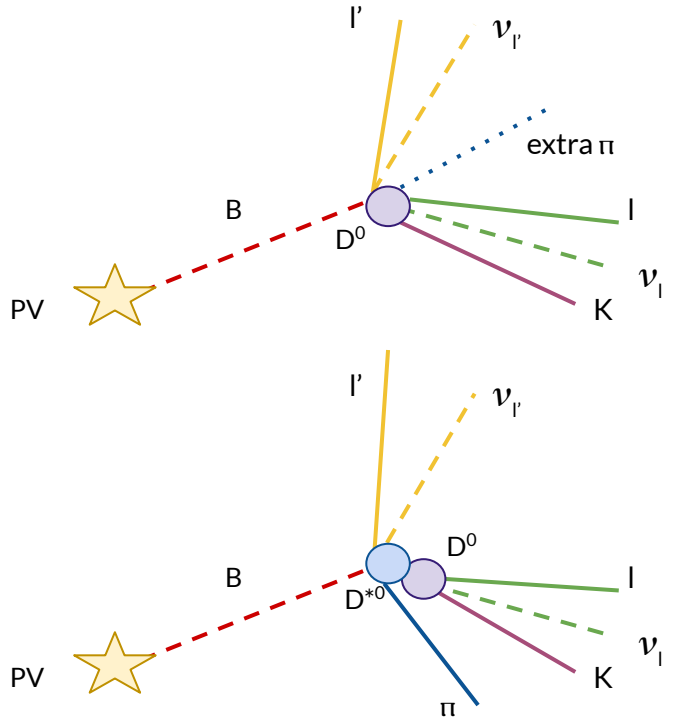


Double mis-ID $B^0_{(s)} \to K^{*0}(\phi)\,\pi^\pm\pi^\mp$



Lepton mis-ID $B^0_{(s)} \to K^{*0}(\phi)\,J/\psi$ or $B^0_{(s)} \to K^{*0}(\phi)\,\psi(2s)$



$b \to c l \nu_l$ cascades with same final states as signal

NP models for $B^0 \to K^* e\mu$ and $B^0_s \to \phi e\mu$

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- Limit set assuming **uniform phase space**
- Distributions differs significantly in NP models

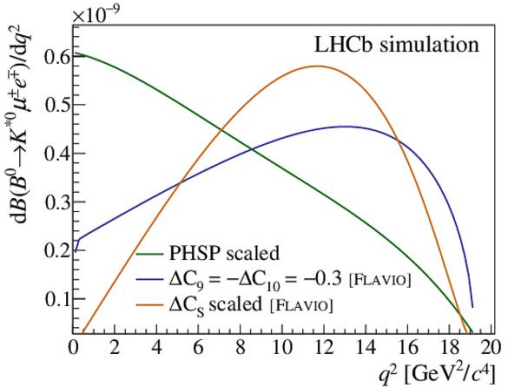
Scalar model $C_S^{\mu e} \neq 0$

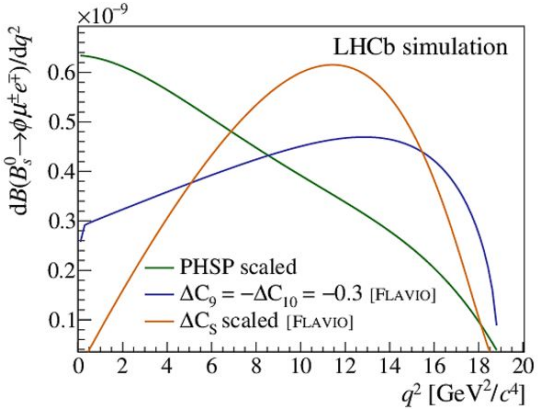
$$B(B^0 \to K^{\star 0} e^+ \mu^-) < 9.9(11.5) \times 10^{-9}$$
$$B(B^0 \to K^{\star 0} e^- \mu^+) < 8.4(10.2) \times 10^{-9}$$
$$B(B^0 \to K^{\star 0} e^\pm \mu^\mp) < 14.7(17.0) \times 10^{-9}$$
$$B(B^0 \to \phi e^\pm \mu^\mp) < 18.8(23.1) \times 10^{-9}$$

Left-handed model

$C_9^{\mu e} = -C_{10}^{\mu e} \neq 0$

$$B(B^0 \to K^{\star 0} e^+ \mu^-) < 8.0(9.5) \times 10^{-9}$$
$$B(B^0 \to K^{\star 0} e^- \mu^+) < 6.7(8.3) \times 10^{-9}$$
$$B(B^0 \to K^{\star 0} e^\pm \mu^\mp) < 12.0(13.9) \times 10^{-9}$$
$$B(B^0 \to \phi e^\pm \mu^\mp) < 16.5(20.5) \times 10^{-9}$$





Background for $B^0 \to K^* \tau\mu$

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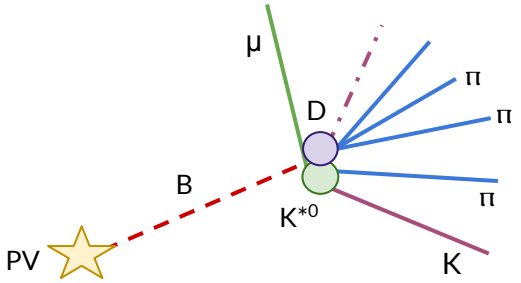
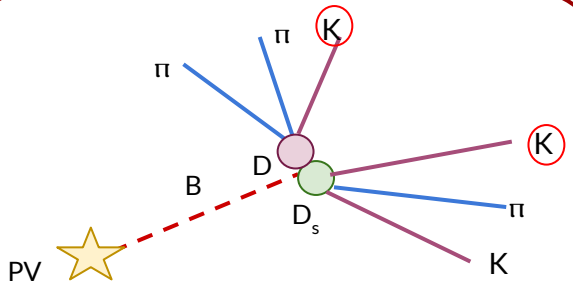
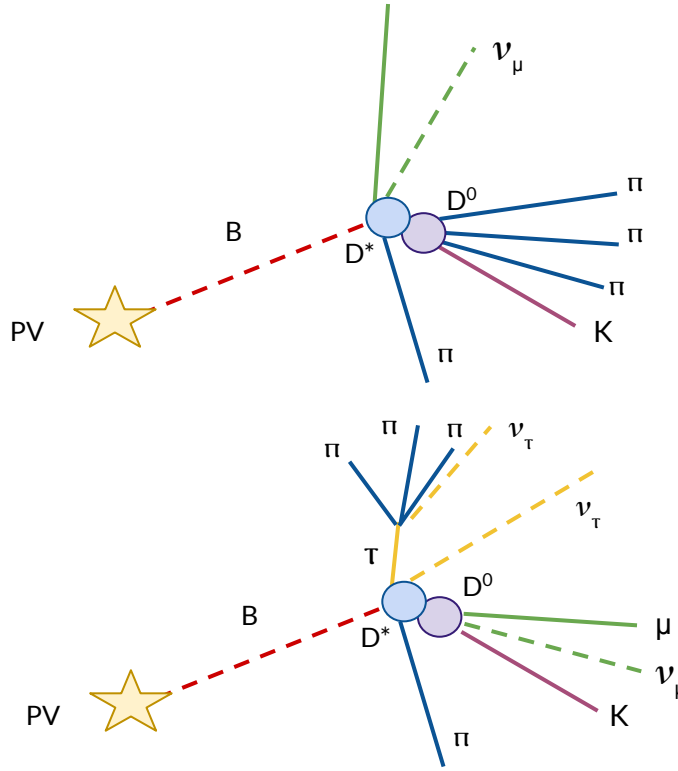


Partial reconstructed decay



Double mis-ID $B \to D_s D$



$b \to c l \nu_l$ cascades with same final states as signal

Selection and Normalization for $B^0 \to K^{*}\tau\mu$

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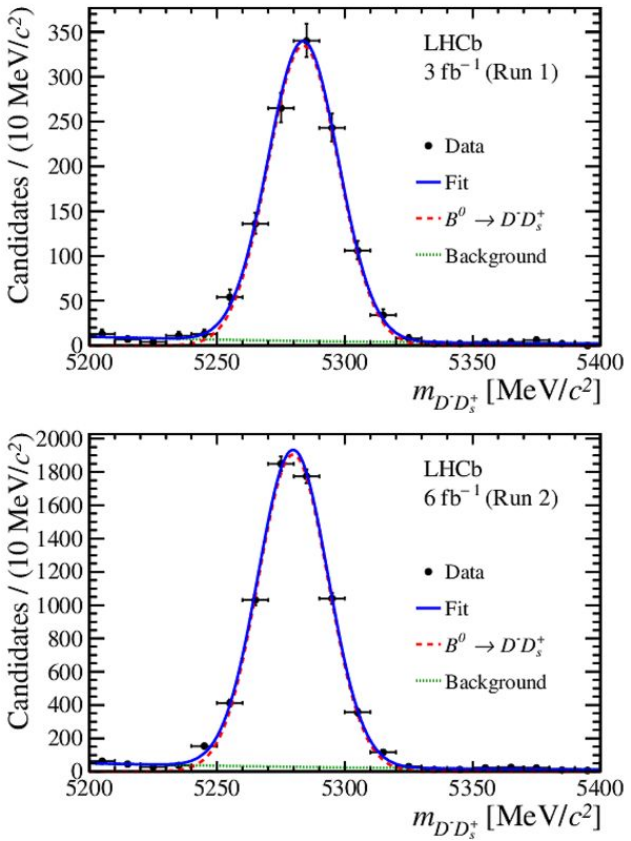
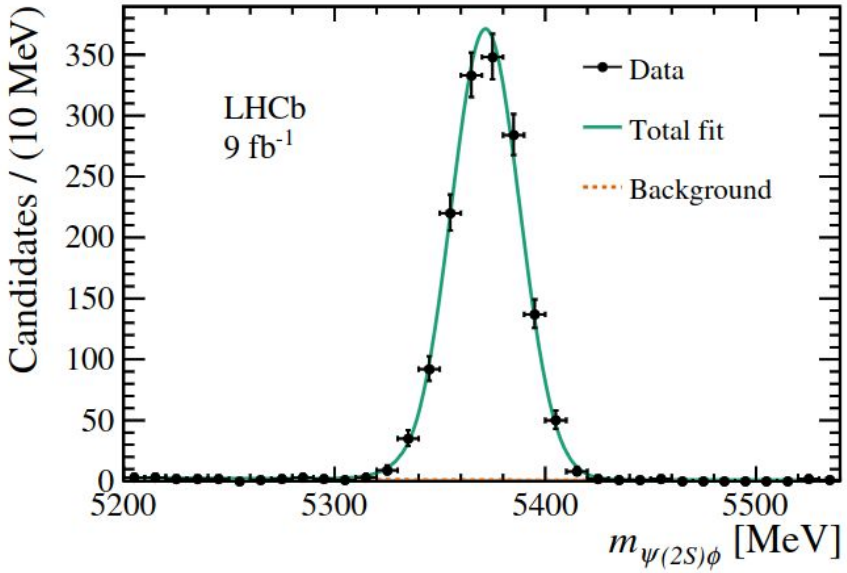
- Signal region in **[4600, 6400] MeV/c^2**
- **PID requirements** on final state hadrons and leptons
- BDT to suppress **combinatorial background**
- BDT to suppress **charmed meson contributions** in τ reconstruction
- Fisher discriminant using **isolation** information of the candidates to remove **part. reconstructed bkg**
- Specific **vetoes for D^0/D^+ mesons**
- **Fit on normalization sample**



Selection and normalization for $B^0_s \to \phi\tau\mu$

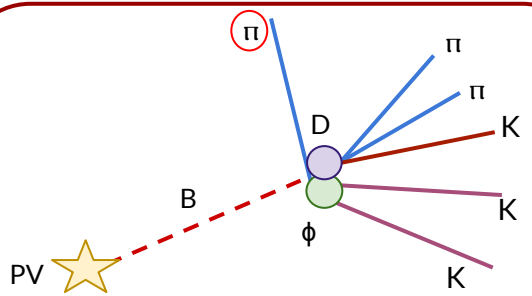
https://arxiv.org/abs/2405.13103

- **PID requirements** on final state hadrons and lepton and **vertex requirements** on quality of reconstruction and separation from PVs
- Mass window of **invariant mass for K^-K^+** with width **8 MeV/c^2** for ϕ, centered on PDG mass value
- Mass thresholds on final state combinations
- **Refit constraints on B and τ directions and τ mass**
- Specific **vetoes for charm mesons**
- Two BDTs to remove combinatorial and part. reco background from B decays
- **Fit on normalization sample**

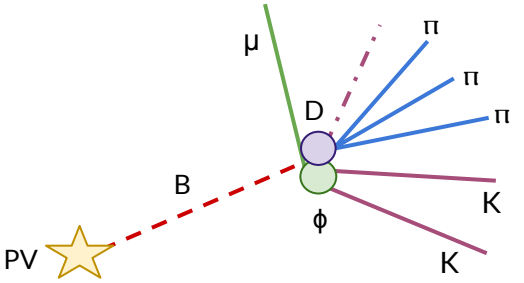


Background for $B^0_s \to \phi\tau\mu$

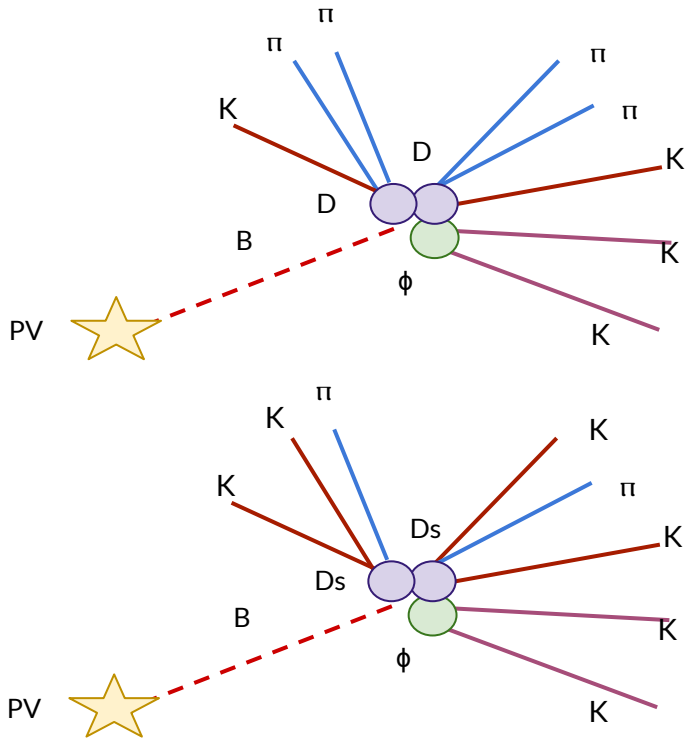
https://arxiv.org/abs/2405.13103



Mis-ID $B_s \to D\phi\pi$



Partially reconstructed decays



$B \to DD\phi$ and $B \to D_s D_s \phi$