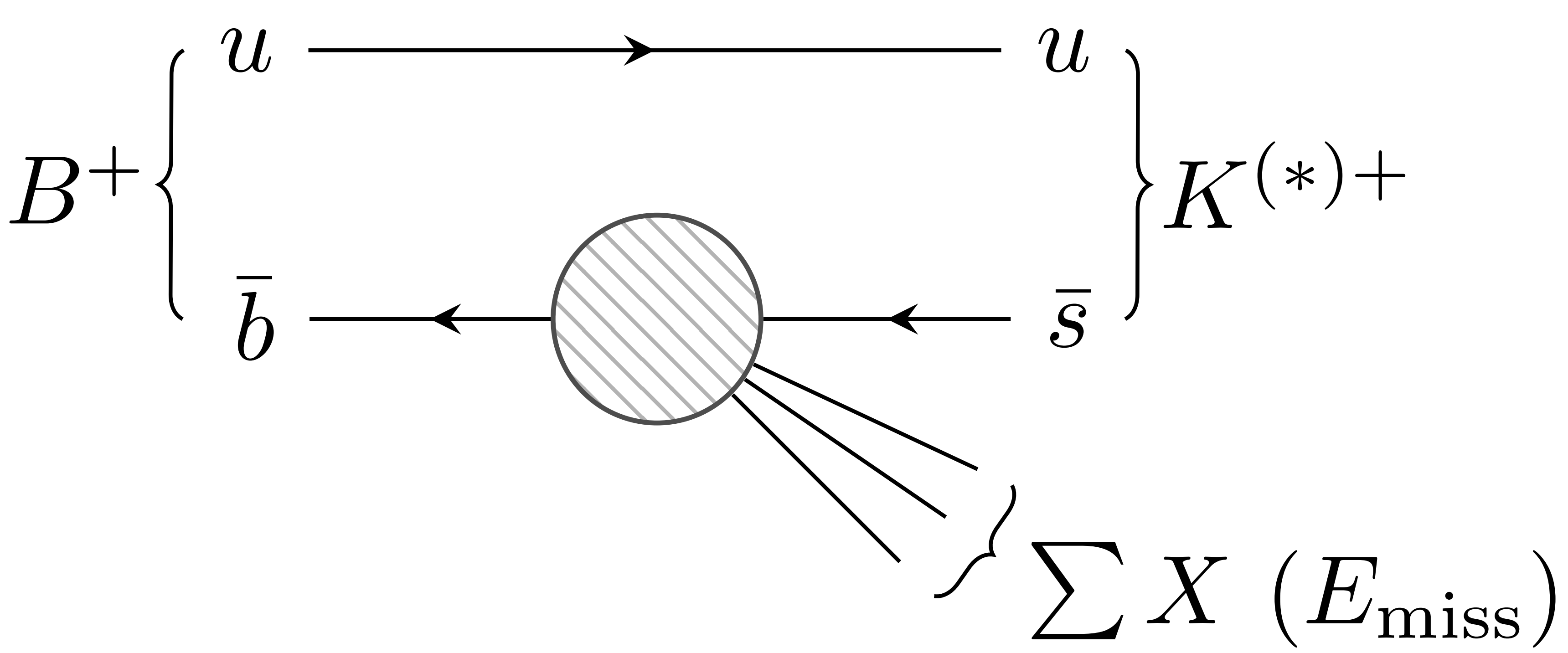

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Impact of New Invisible Particles on $B \to K^{(*)} E_{\rm miss}$

Based on: arXiv:2403.13887, arXiv:2503.19025

Patrick D. Bolton, Svjetlana Fajfer, Jernej F. Kamenik and Martín Novoa-Brunet

Belle II Physics Week, KEK, Tsukuba

Outline

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Part I

- Light NP interpretations of the Belle II $B^+ \to K^+\nu\bar{\nu}$ ($E_{\rm miss}$) inclusive tagging analysis (ITA)
- Weak effective theory (WET) couplings to $b \to s$
- Best-fit masses and couplings (including constraints from *BABAR* + LEP)

Part II

- Impact of light NP scenarios on $B \to K^* E_{\rm miss}$ observables
- Integrated and differential branching fractions $\mathscr{B}$ and longitudinal polarisation fraction F_L

Part III

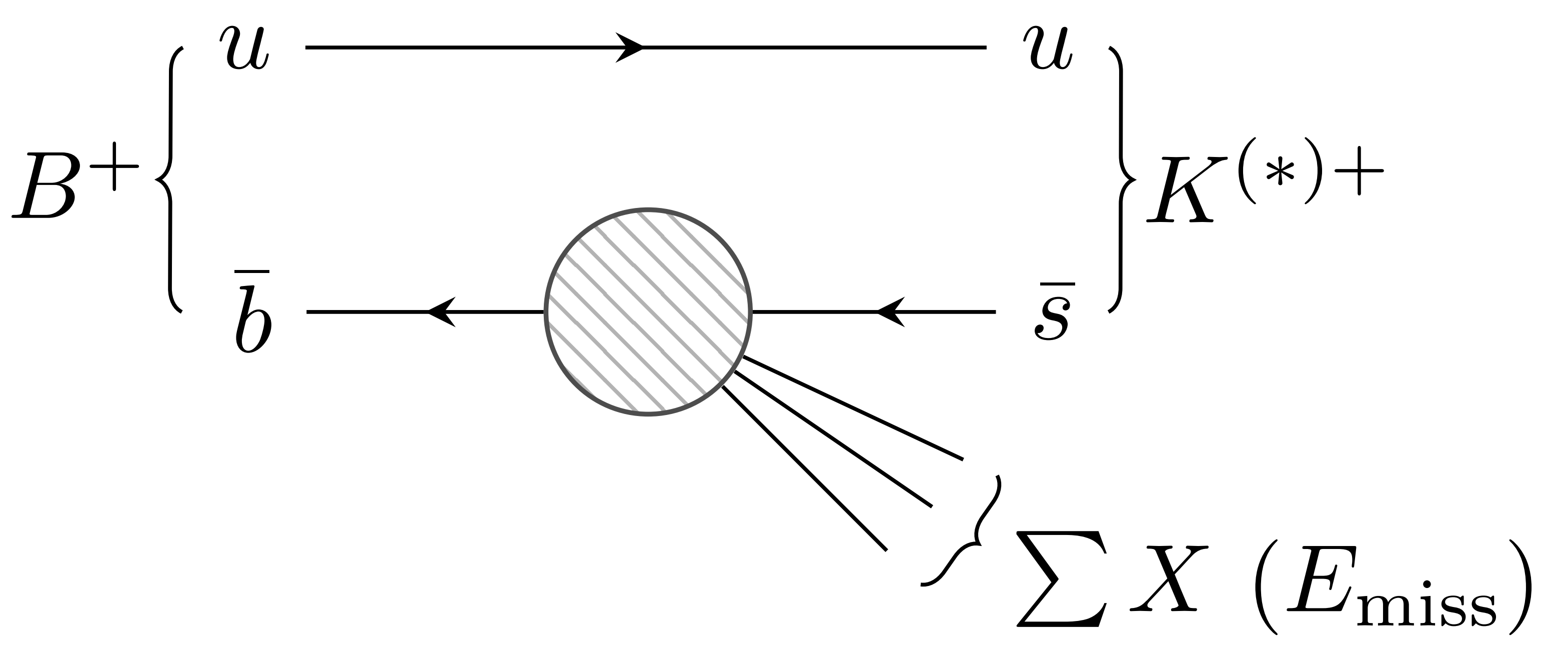
- Semi-realistic UV realisation of $B^+ \to K^+ X$ with $X = Z'$
- Constraints on model from theory and experiment (collider, electroweak, missing energy…)
- Possible connection to dark matter (DM)

Light NP Interpretations for $B^+ \to K^+ E_{\rm miss}$

$$\mu = \frac{\mathcal{B}(B^+ \to K^+ \nu\bar{\nu})}{\mathcal{B}(B^+ \to K^+ \nu\bar{\nu})\big|_{\rm SM}} = 5.4 \pm 1.0\ (\text{stat}) \pm 1.1\ (\text{syst})$$ (ITA)

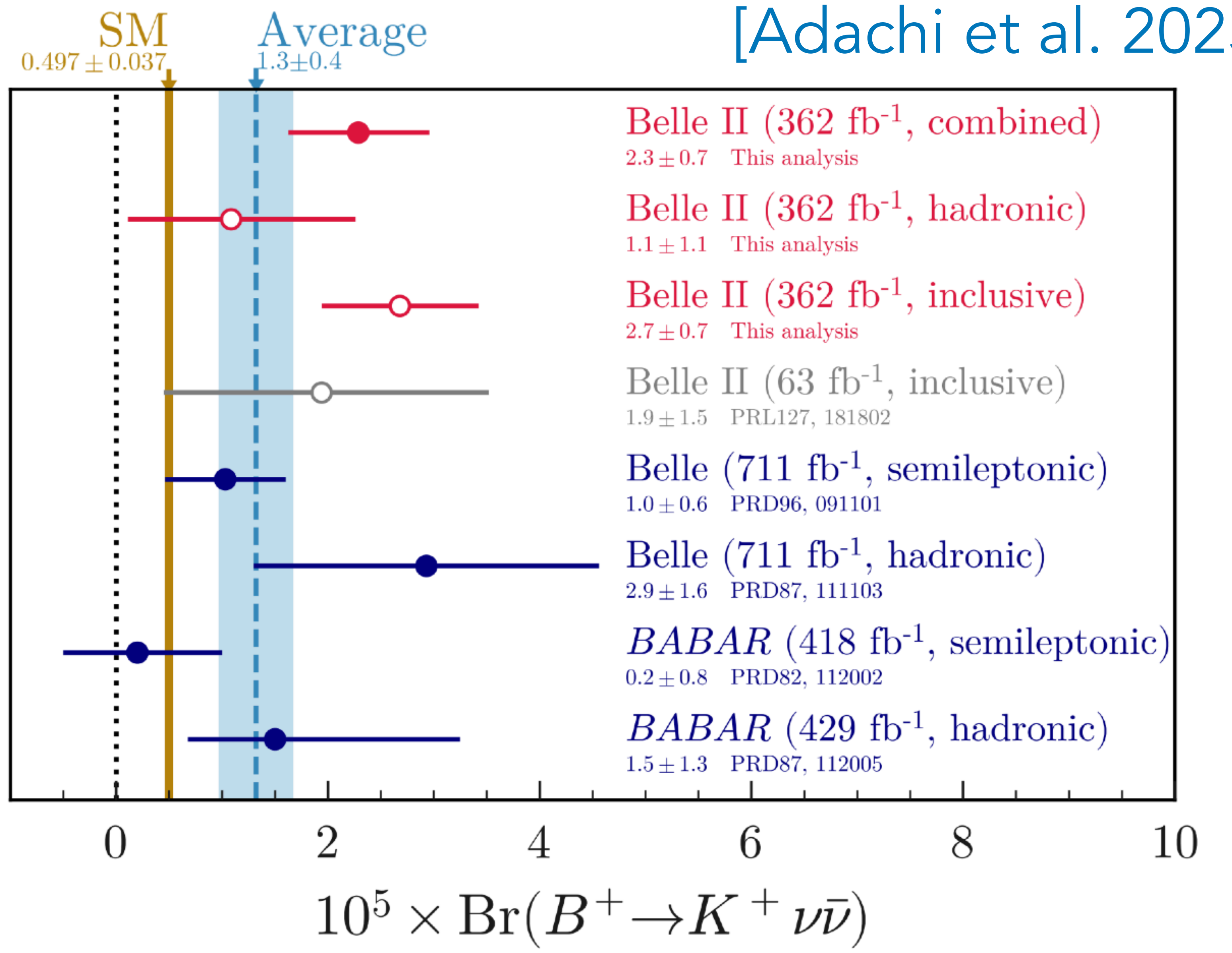
Parametric + form factor uncertainties well understood

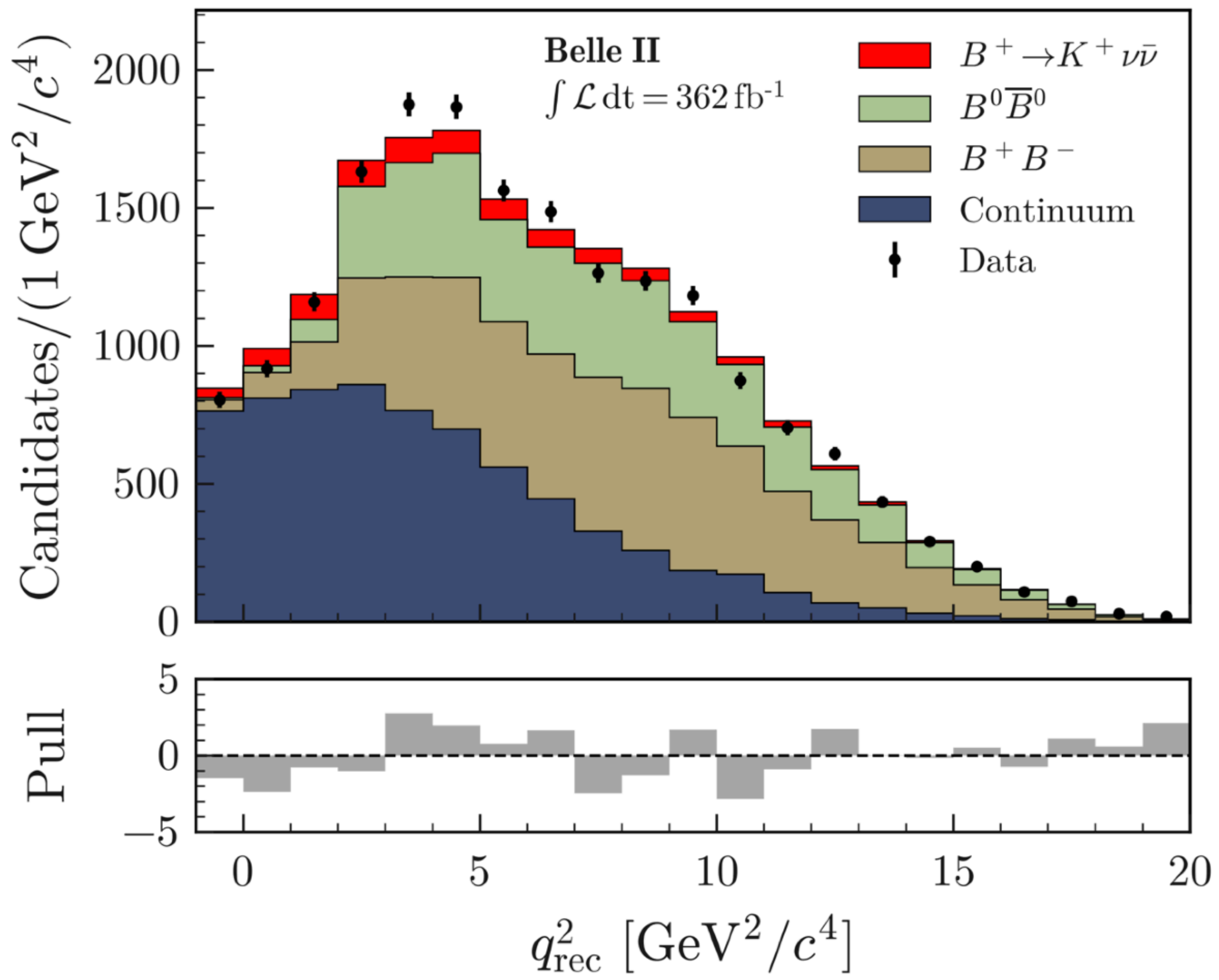
Interpret excess as $E_{\rm miss}$ = new light degrees of freedom



- Possible spin $J = \{0, 1/2, 1, 3/2\}$
- Distinct kinematic signatures due to spin, mass and multiplicity
- Intriguing possible connection to dark matter (DM)

[Adachi et al. 2023]





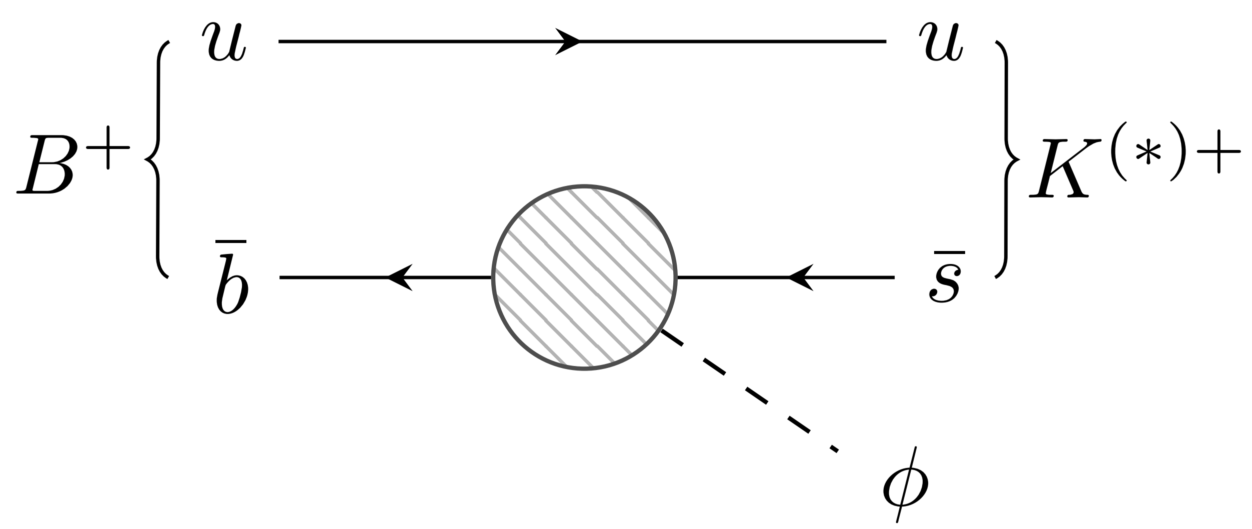
Light New Physics Scenarios

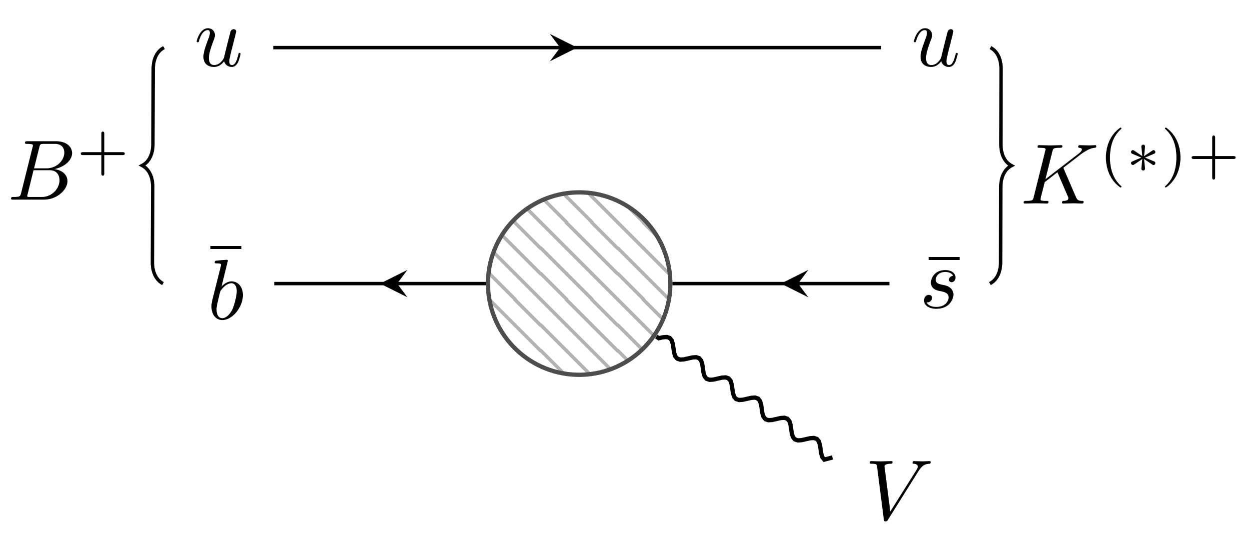
With generic $J = \{0, 1/2, 1, 3/2\}$ fields $X \in \{\phi, \psi, V_\mu, \Psi_\mu\}$, we may have

Scenarios

Two-body:

$B^+ \to K^+ X$



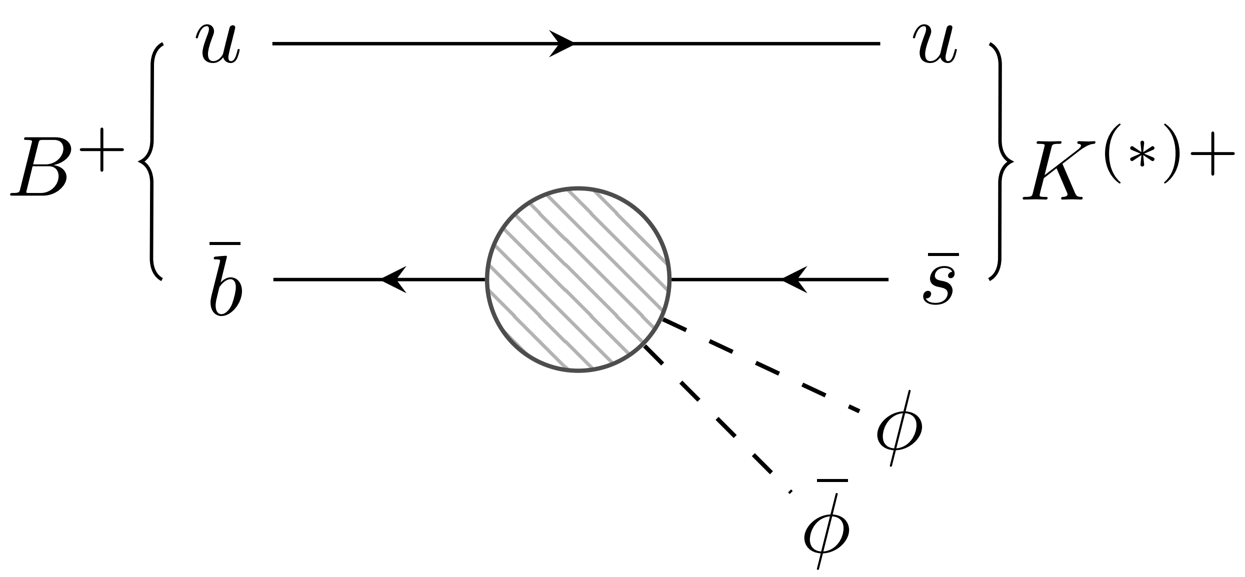


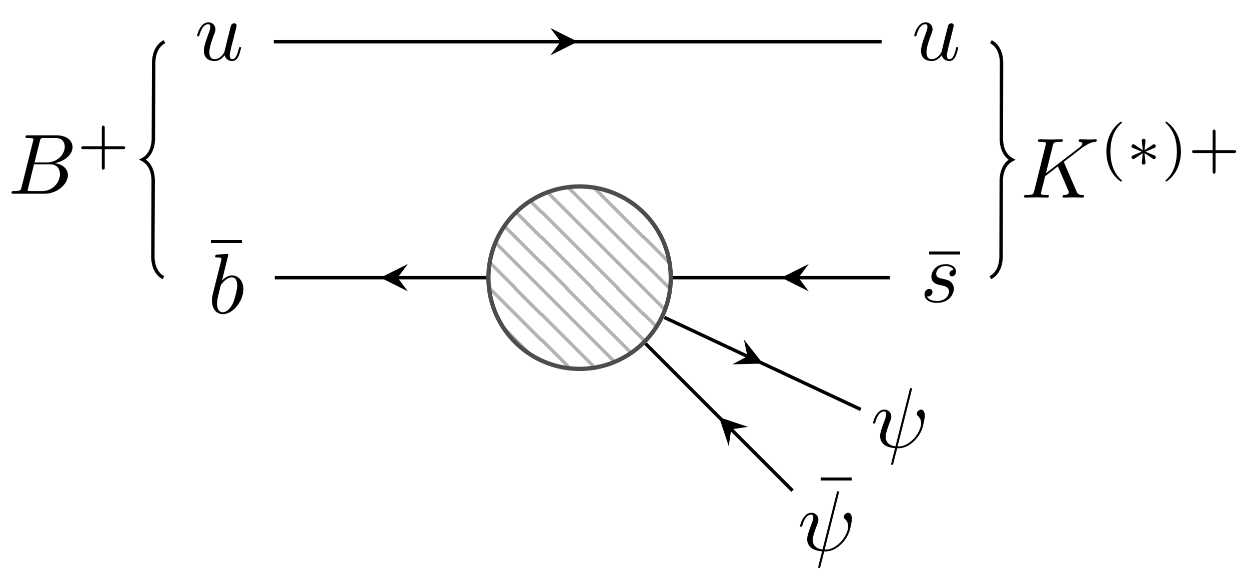
Axion-like particle (ALP)

Light Z' (dark photon)

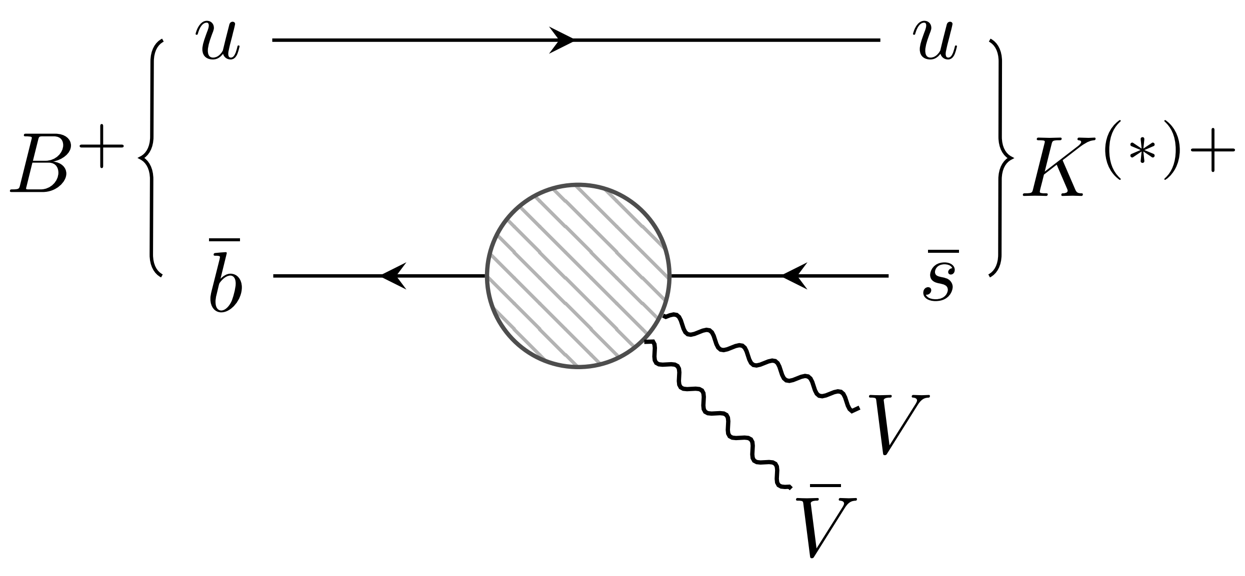
Three-body:

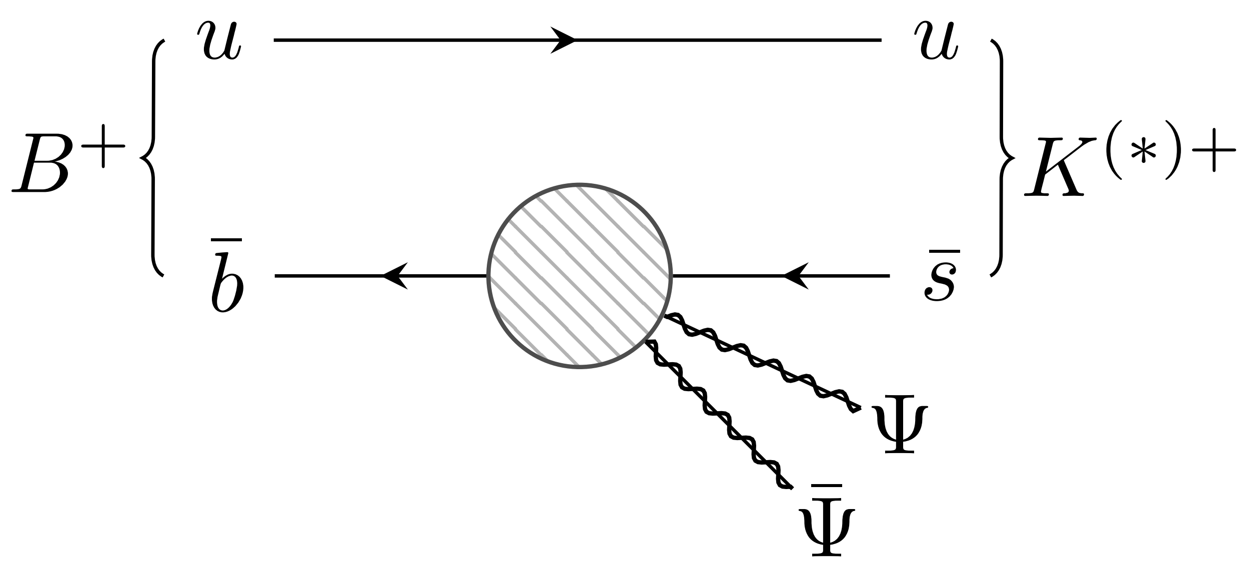
$B^+ \to K^+ X X$





Heavy Neutral Lepton (connection to ν masses?)





Gravitino

Composite models

Effective Couplings - Parity Basis

New fields are assumed to have effective WET(+X) couplings to the $b \to s$ transition quark current

e.g. vector $b \to s$ current

$$\mathcal{H}_{\text{eff}}^{V(A)} \supset \bar{b}\gamma_\mu\gamma_5 s\left[\underbrace{\frac{g_V}{\Lambda}\partial^\mu\phi + \frac{g_{VV}}{\Lambda^2}i\phi^\dagger\overleftrightarrow{\partial}^\mu\phi}_{\text{Spin-0}} + \underbrace{\frac{f_{VV}}{\Lambda^2}\bar{\psi}\gamma^\mu\psi + \frac{f_{VA}}{\Lambda^2}\bar{\psi}\gamma^\mu\gamma_5\psi}_{\text{Spin-1/2}} + \underbrace{h_V V^\mu}_{\text{Spin-1}} + \underbrace{\frac{F_{VV}}{\Lambda^2}\bar{\Psi}^\rho\gamma^\mu\Psi_\rho + \frac{F_{VA}}{\Lambda^2}\bar{\Psi}^\rho\gamma^\mu\gamma_5\Psi_\rho}_{\text{Spin-3/2}}\right]$$

[Kamenik, Smith, 2011]

$$\langle K|\,\bar{b}\gamma_\mu s\,|B\rangle = P_\mu f_+(q^2) + \frac{m_B^2 - m_K^2}{q^2}q_\mu\left[f_0(q^2) - f_+(q^2)\right]$$

$$\langle K|\,\bar{b}\gamma_\mu\gamma_5 s\,|B\rangle = 0$$

- $B^+ \to K^+ E_{\text{miss}}$ is sensitive only to parity (P) even operators, use the 'parity' basis

$\Rightarrow$ Basis of operators using chiral quark fields more natural from UV (SMEFT) perspective

Effective Couplings - Parity Basis

Also WET(+X) couplings to scalar and tensor $b \to s$ current

$$\mathcal{H}_{\text{eff}}^{S(P)} \supset \bar{b}\gamma_5 s\Big[\underbrace{g_S\phi + \frac{g_{SS}}{\Lambda}\phi^\dagger\phi}_{\text{Spin-0}} + \underbrace{\frac{f_{SS}}{\Lambda^2}\bar{\psi}\psi + \frac{f_{SP}}{\Lambda^2}\bar{\psi}\gamma_5\psi}_{\text{Spin-1/2}} + \underbrace{\frac{h_S}{\Lambda}V_\mu^\dagger V^\mu}_{\text{Spin-1}} + \underbrace{\frac{F_{SS}}{\Lambda^2}\bar{\Psi}^\rho\Psi_\rho + \frac{F_{SP}}{\Lambda^2}\bar{\Psi}^\rho\gamma_5\Psi_\rho}_{\text{Spin-3/2}}\Big]$$

$$\mathcal{H}_{\text{eff}}^{T(\tilde{T})} \supset \bar{b}\sigma_{\mu\nu}\gamma_5 s\Big[\underbrace{\frac{f_{TT}}{\Lambda^2}\bar{\psi}\sigma^{\mu\nu}\psi}_{\text{Spin-1/2}} + \underbrace{\frac{h_T}{\Lambda}V^{\mu\nu}}_{\text{Spin-1}} + \underbrace{\frac{F_{TS}}{\Lambda^2}\bar{\Psi}^{[\mu}\Psi^{\nu]} + \frac{F_{TP}}{\Lambda^2}\bar{\Psi}^{[\mu}\gamma_5\Psi^{\nu]} + \frac{F_{TT}}{\Lambda^2}\bar{\Psi}^\rho\sigma^{\mu\nu}\Psi_\rho}_{\text{Spin-3/2}}\Big]$$

- Rates proportional $f_+(q^2)$, $f_0(q^2)$ and $f_T(q^2)$. All FFs taken from BSZ fit of [Gubernari et al. 2023]
- ψ may be unrelated to neutrinos (no $\bar{L}\tilde{H}\psi$ if ψ is charged under dark U(1) or odd under Z_2).

$\Rightarrow$ We can consider scalar + tensor operators in $m_\psi \to 0$ limit with no neutrino mass/$0\nu\beta\beta$ bounds

New Physics Contributions to $B^+ \to K^+ E_{\mathrm{miss}}$

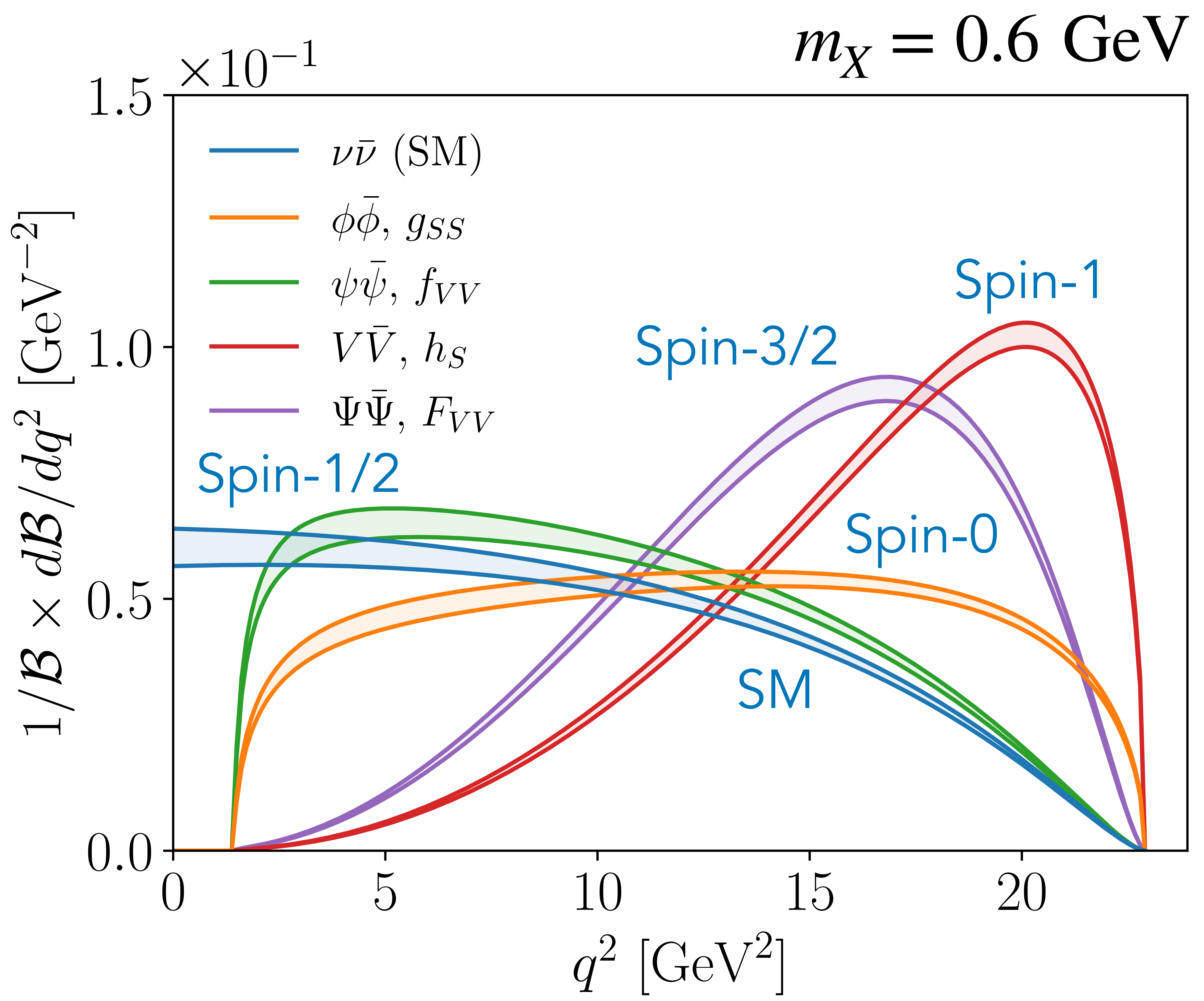
Two-body kinematics:

- q^2 fixed at mass of ϕ or V

Three-body kinematics:

- Smooth q^2 distribution
- Kinematic threshold at $q^2 = 4m_X^2$
- Different q^2 shapes for ϕ, ψ, V, Ψ

Unbiased NP interpretations require fit to reconstructed q^2_{rec} spectrum



[PDB, Fajfer, Kamenik, Novoa-Brunet 2024]

⇒ Belle II likelihood (reweighting method) now public

[Gärtner et al. 2024]

[Abumusabh et al. 2025]

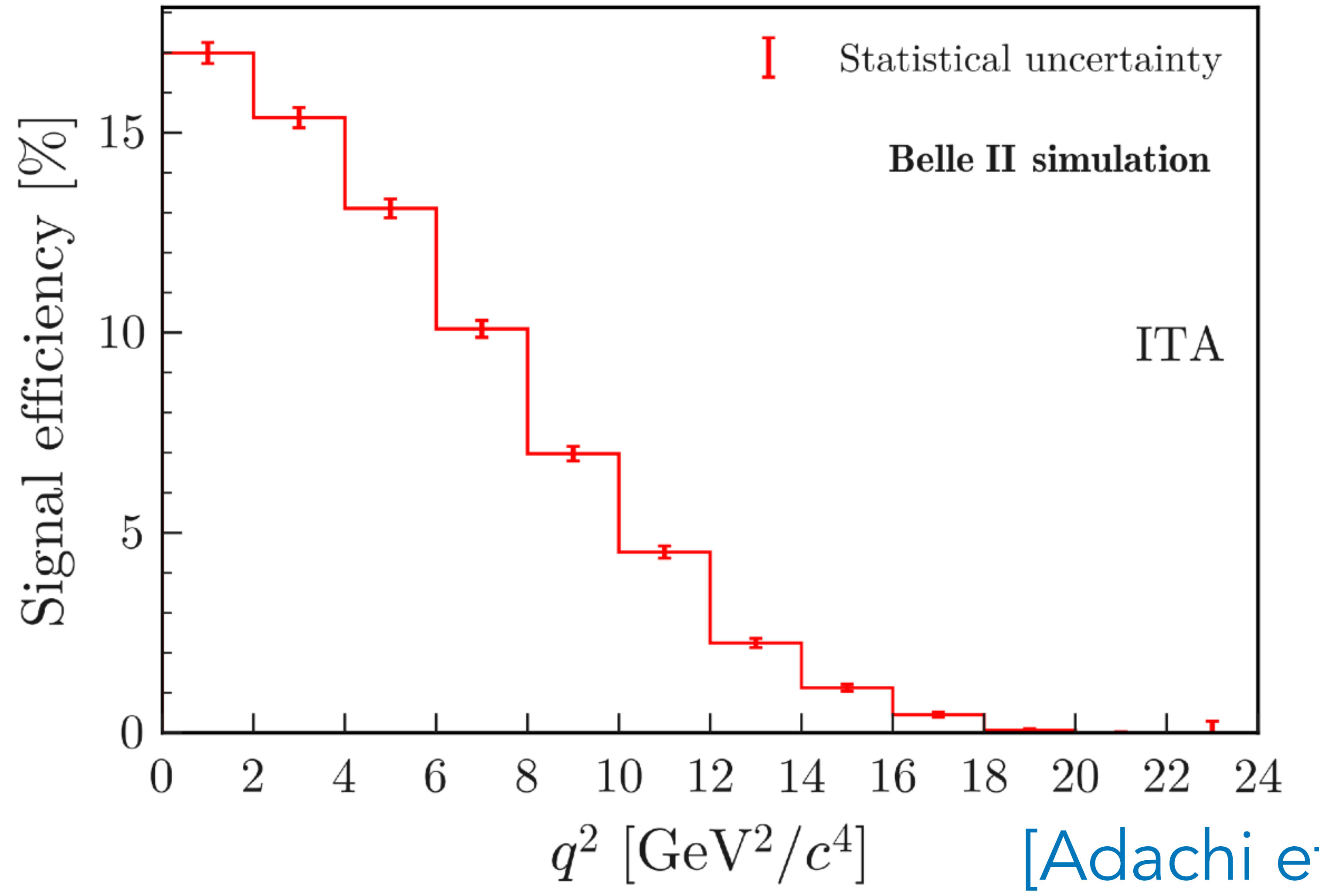
Reinterpreting the Belle II ITA Results

Before the Belle II likelihood release, our approach was to:

Construct differential event rate in the reconstructed q^2_{rec}:

$$\frac{dN_{\mathsf{SM}(X)}}{dq^2_{\text{rec}}} = N_B \int dq^2 \, f_{q^2_{\text{rec}}}(q^2) \, \epsilon(q^2) \, \frac{d\mathcal{B}_{\mathsf{SM}(X)}}{dq^2}$$

Smearing of q^2_{rec} Detector efficiency



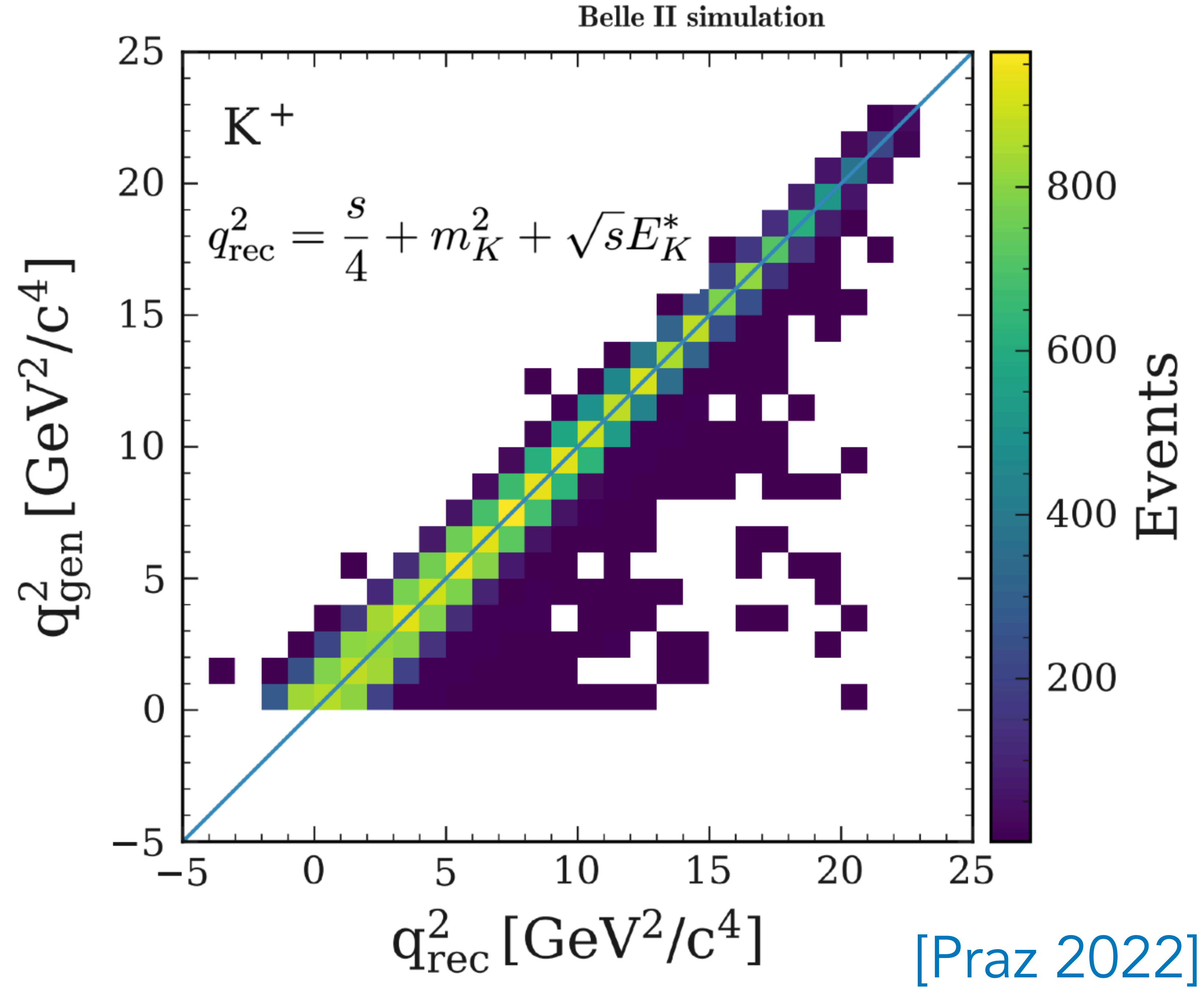
[Adachi et al. 2023]

Construct total event count in bin i:

$$n_i = \mu(1+\theta_i^{\text{SM}})s_i^{\text{SM}} + (1+\theta_i^X)s_i^X + \sum_b \tau_b(1+\theta_i^b)b_i \, ,$$

$$s_i^{\text{SM}(X)} = \int_{q_i^2}^{q_j^2} dq^2_{\text{rec}} \frac{dN_{\text{SM}(X)}}{dq^2_{\text{rec}}}$$

$b_i \Rightarrow B^+B^-$, $B^0\bar{B}^0$ and continuum bkgs.



[Praz 2022]

Nuisance parameters: μ, θ_i and τ_b

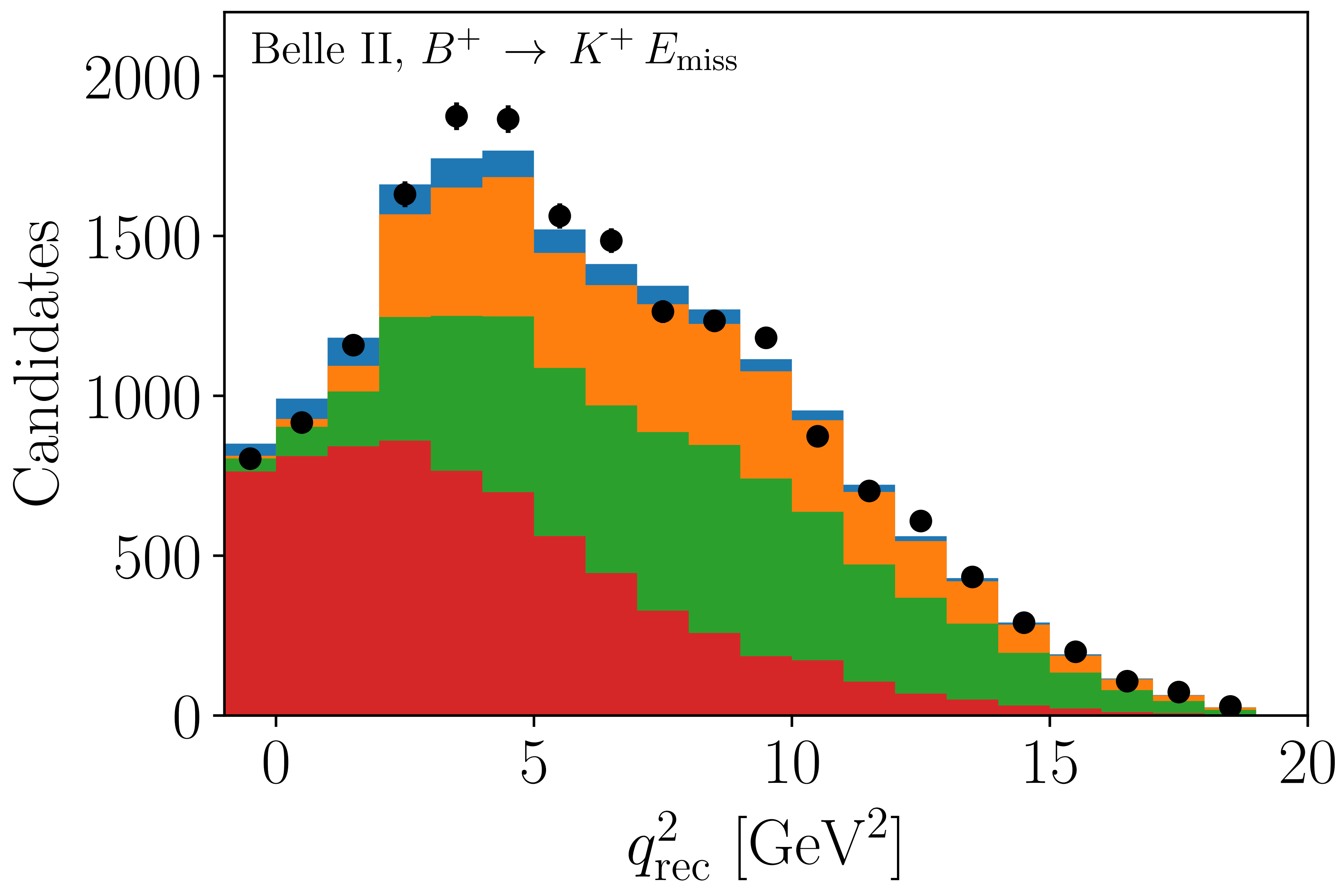
Reinterpreting the Belle II ITA Results

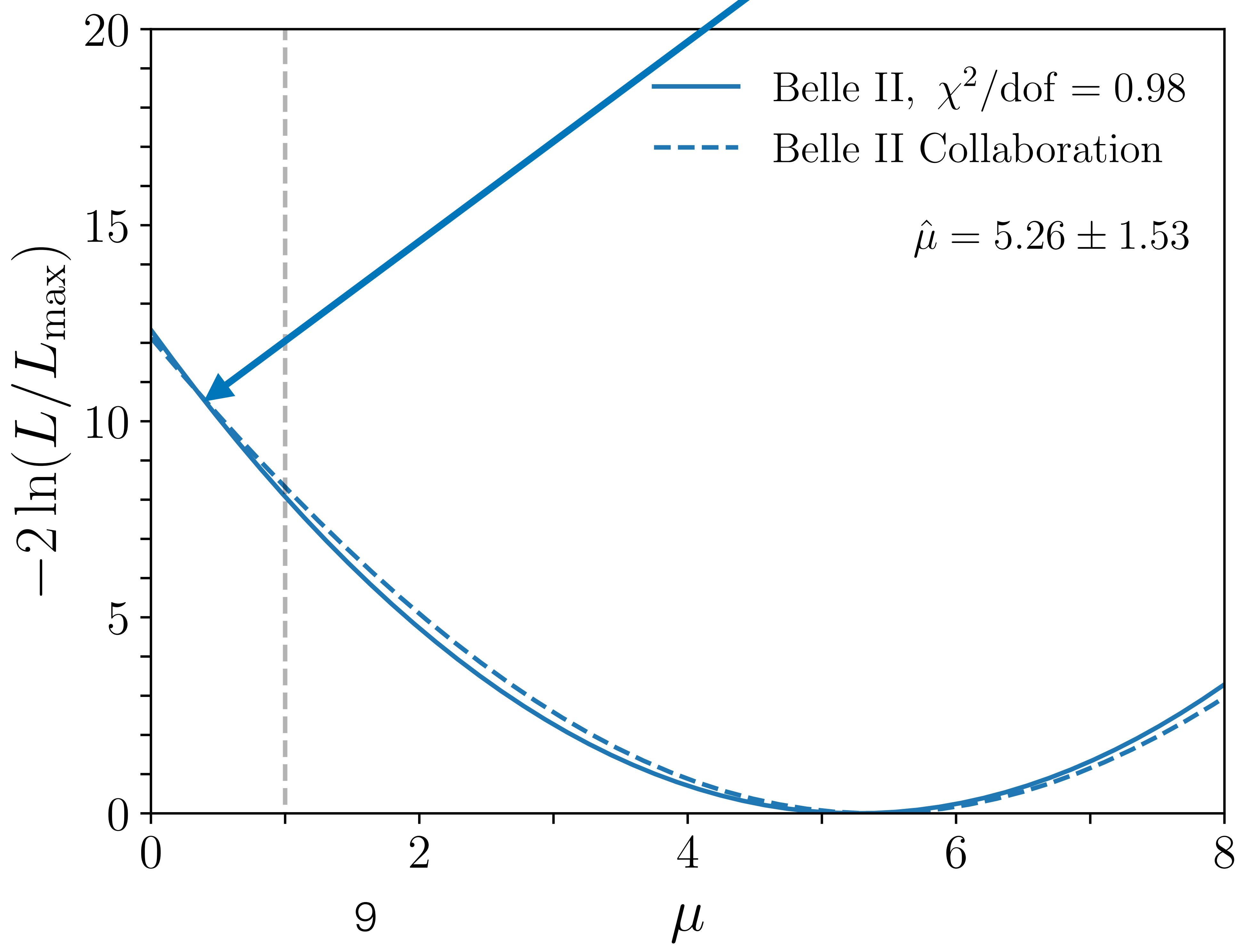
Construct binned likelihood: $L^{\text{Belle II}}_{\text{SM}+X} = \prod_{i,x,b} P\left(n_i^{\text{obs}}, n_i\right) \mathcal{N}\left(\boldsymbol{\theta}^x; \Sigma^x\right) \mathcal{N}\left(\tau_b; \sigma_b^2\right)$ $\quad x = \text{SM}, X, b$

Σ^x : Covariances accounting for signal theory uncertainties and background MC statistical errors for ITA

σ_b : Overall background normalisation uncertainty, fixed to obtain agreement with Belle II profile likelihood

[Adachi et al. 2023]





n_i^{obs} : $\eta(\text{BDT}_2) > 0.92$
q^2_{rec} data

Fit varying μ and θ, assuming SM only

SM + NP Signal Hypothesis

We perform a fit to the SM ($\mu = 1$) + NP for all effective couplings C_X

$\Rightarrow$ Vary light new particle mass m_X and marginalise over C_X and all nuisance parameters

Two-body $B^+ \to K^+X$ Three-body $B^+ \to K^+XX$

[PDB, Fajfer, Kamenik, Novoa-Brunet 2024]

Favoured Scenarios

Viable scenarios (better fit w.r.t to the re-scaled SM):

Two-body:

$B \to K\phi$ or $B \to KV$ with $m_{\phi/V} = (2.1 \pm 0.1)$ GeV

Three-body:

$B \to K\psi\bar{\psi}$ for vector couplings with $m_\psi = 0.60^{+0.11}_{-0.14}$ GeV

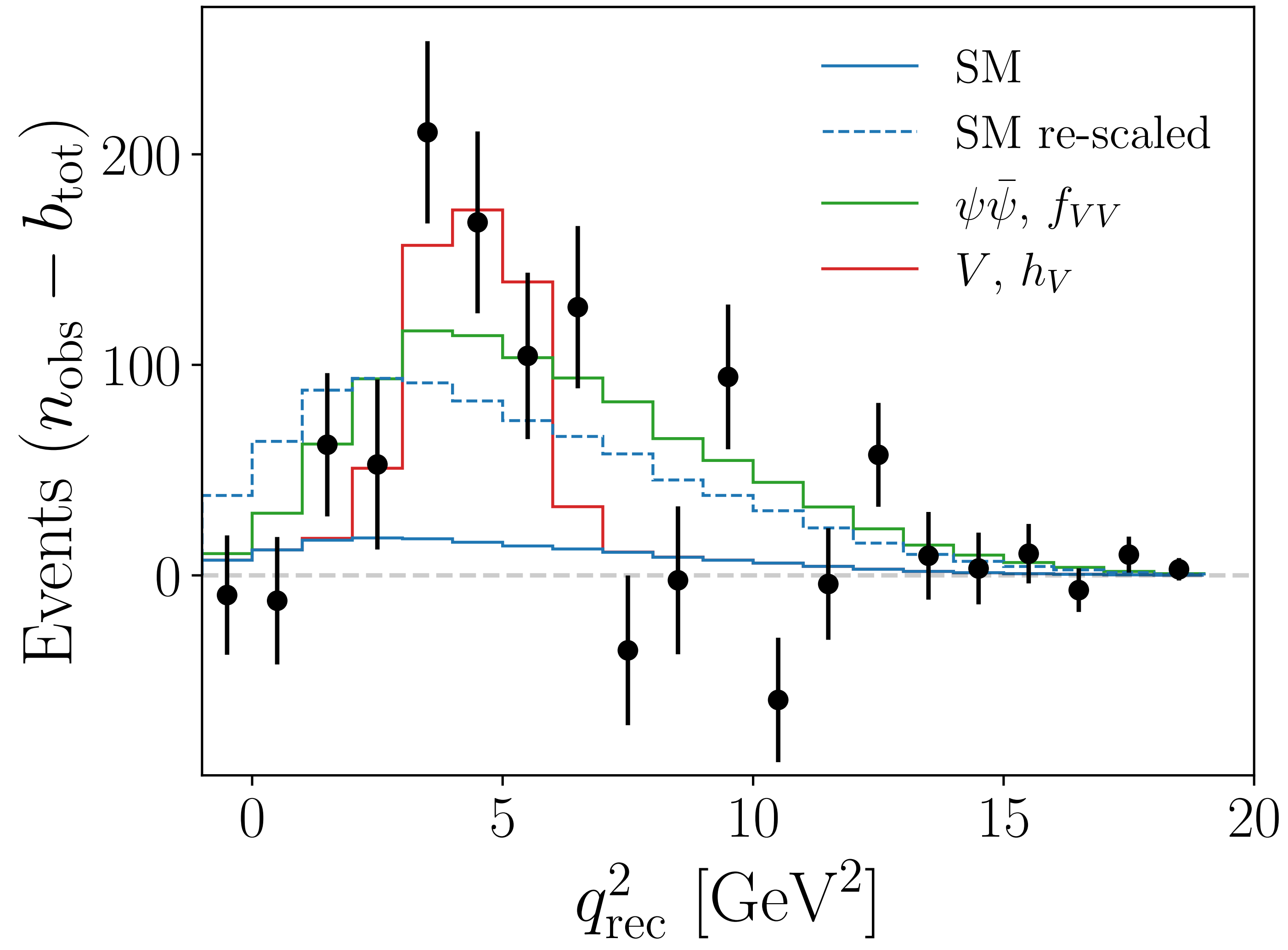
$B \to K\phi\bar{\phi}$ for vector couplings with $m_\phi = 0.38^{+0.13}_{-0.15}$ GeV

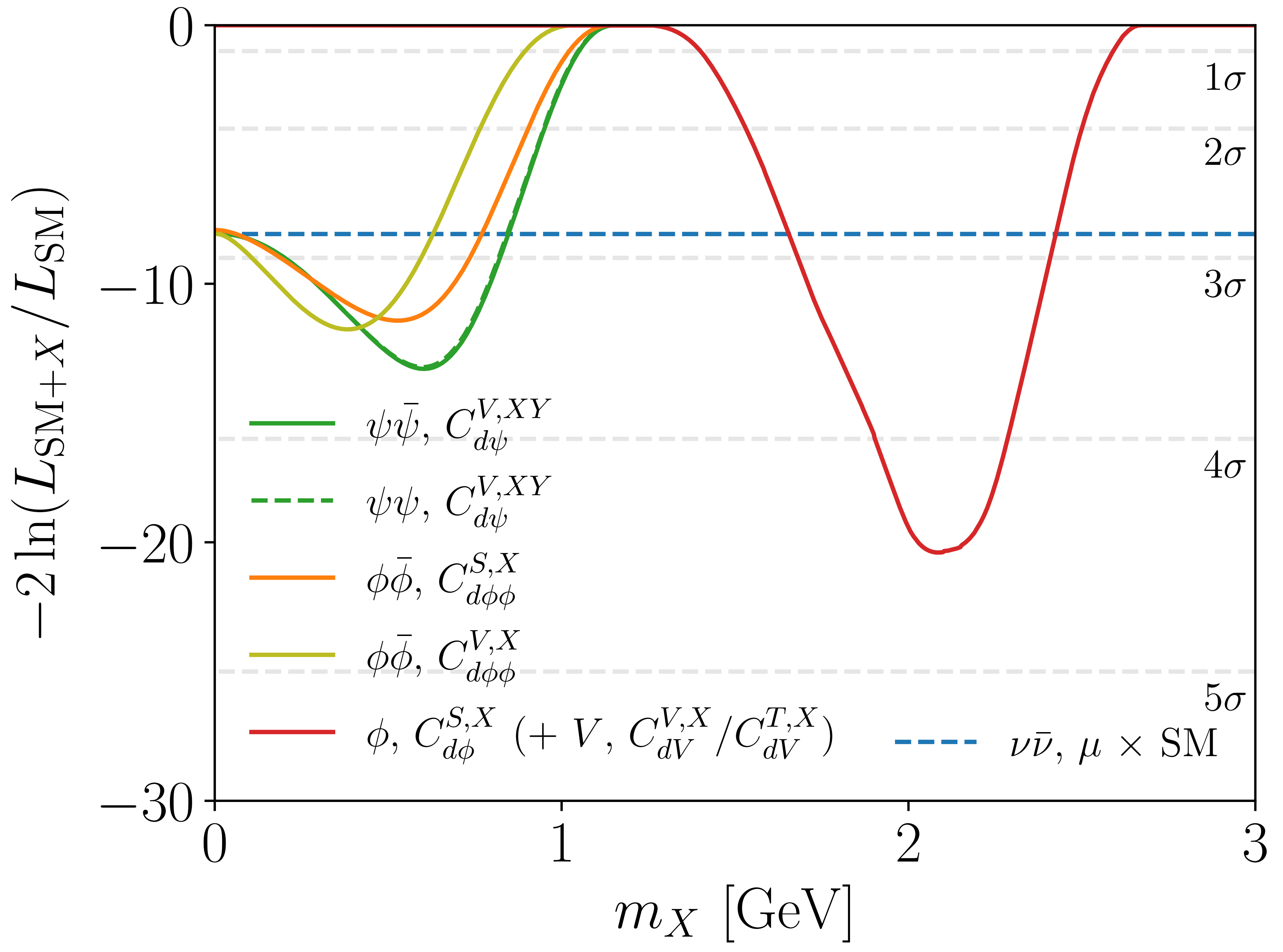
scalar couplings with $m_\phi = 0.52^{+0.11}_{-0.14}$ GeV

Non-viable scenarios (worse fit w.r.t to the re-scaled SM:

- $B \to K\psi\bar{\psi}$ for scalar and tensor couplings
- $B \to KVV/\Psi\bar{\Psi}$ for all couplings

$\Rightarrow$ Kinetics cannot accommodate excess at $q^2_{\text{rec}} \sim 4\ \text{GeV}^2$





Scalar Boson (Two-body) Scenario

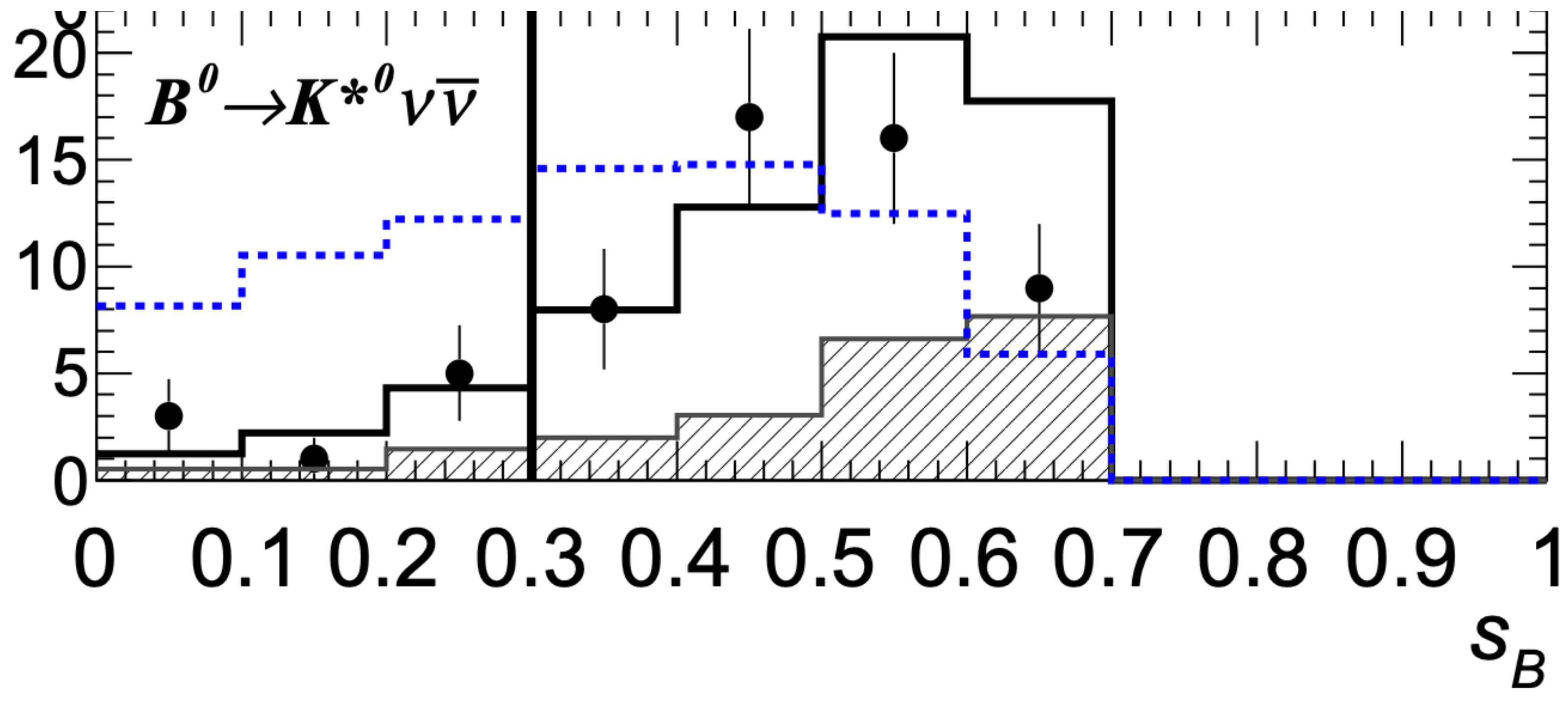
Next, we investigate the favoured couplings for the best-fit scalar mass values $\Rightarrow$ profile likelihood

We allow *P* even and *P* odd couplings,

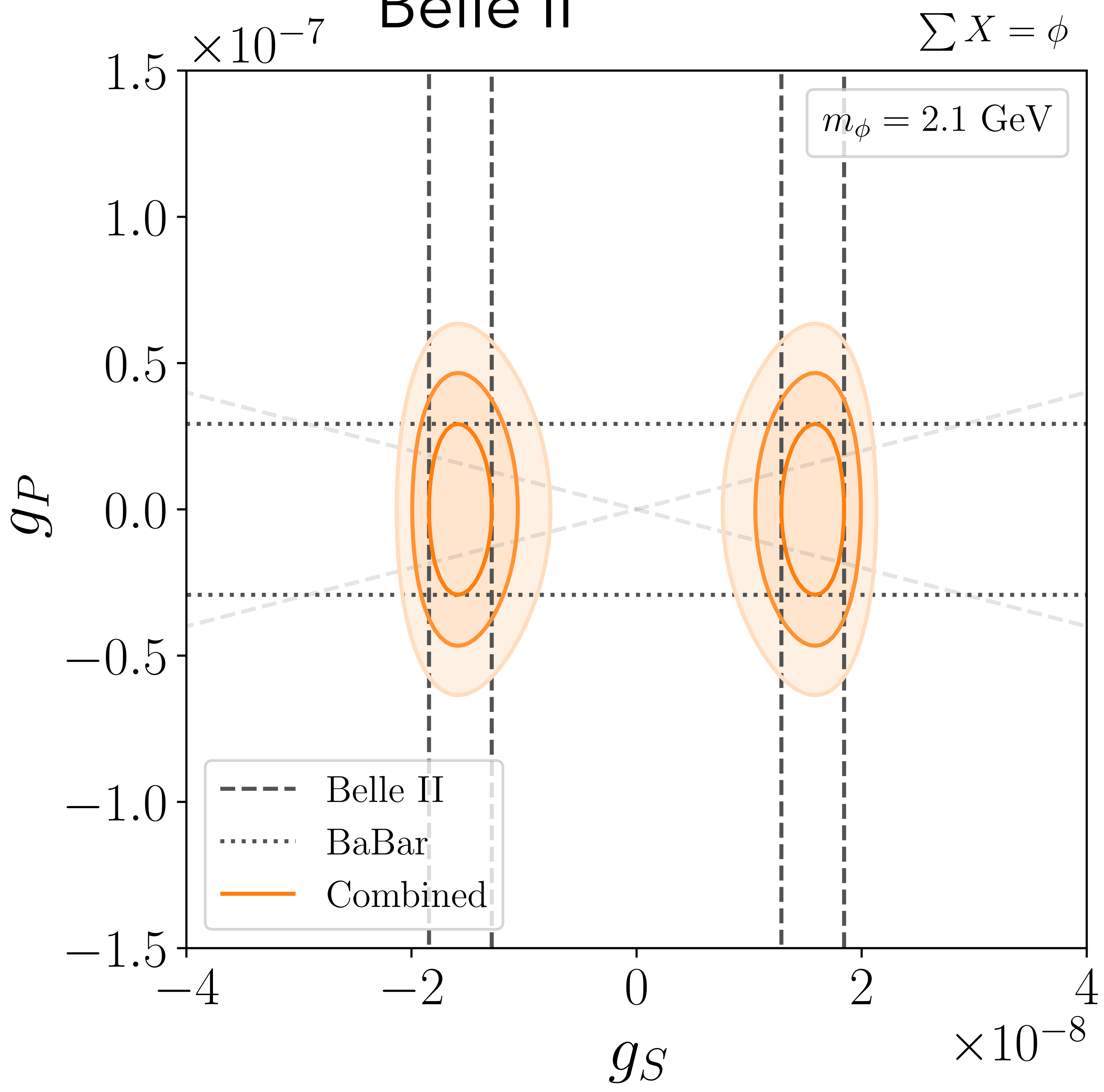
$$g_S(\bar{b}s)\phi + g_P(\bar{b}\gamma_5 s)\phi$$

P odd couplings can be constrained by the *BABAR* $B \to K^* E_{\text{miss}}$ upper bound (most recent q^2 distribution):

$$\mathcal{B}(B \to K^* E_{\text{miss}}) < 11 \times 10^{-5}$$



[Lees et al. 2013]



BABAR

See also: [Altmannshofer et al. 2023] [McKeen et al. 2023] [Hati et al. 2024]

Vector Boson (Two-body) Scenario

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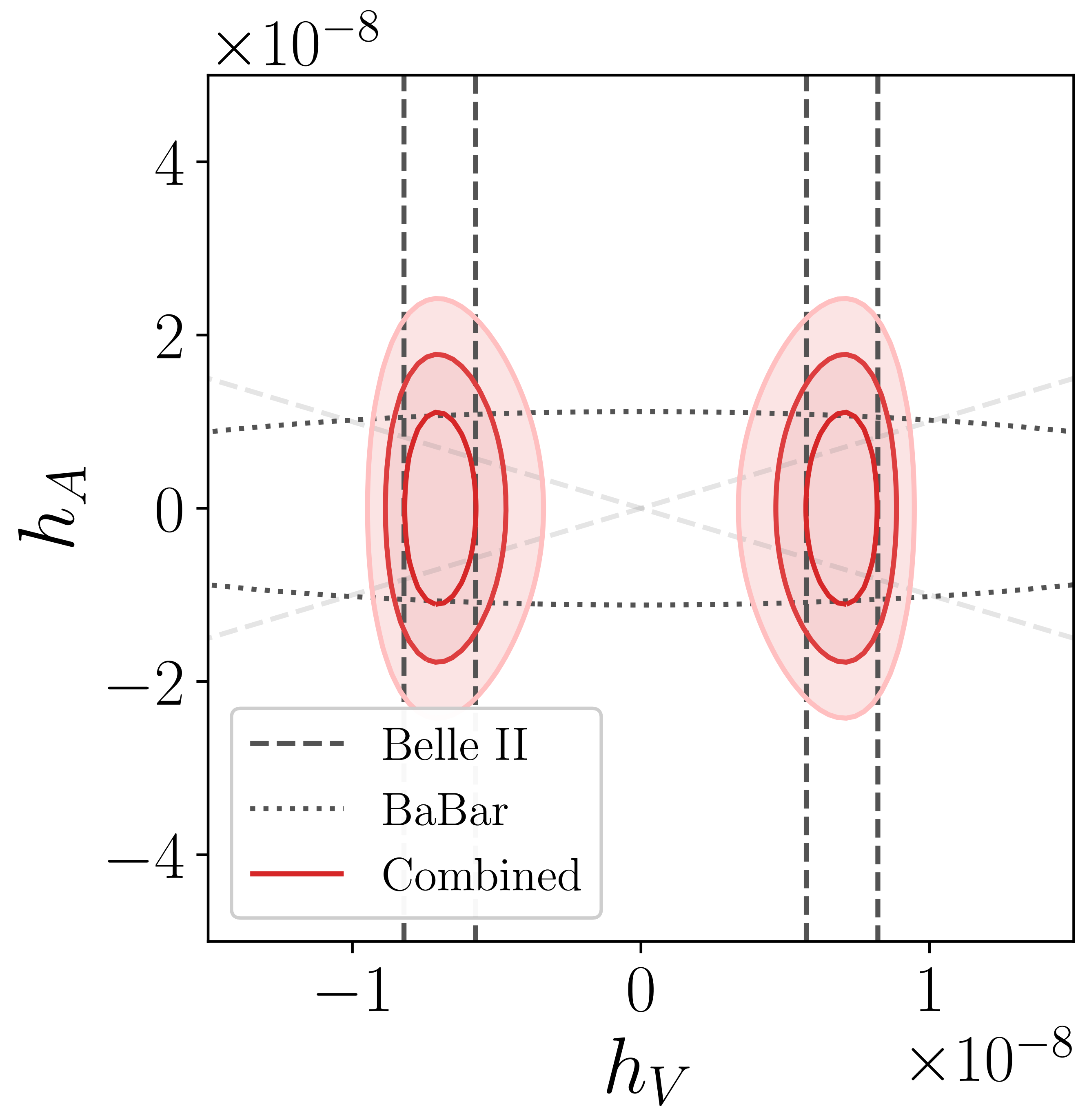
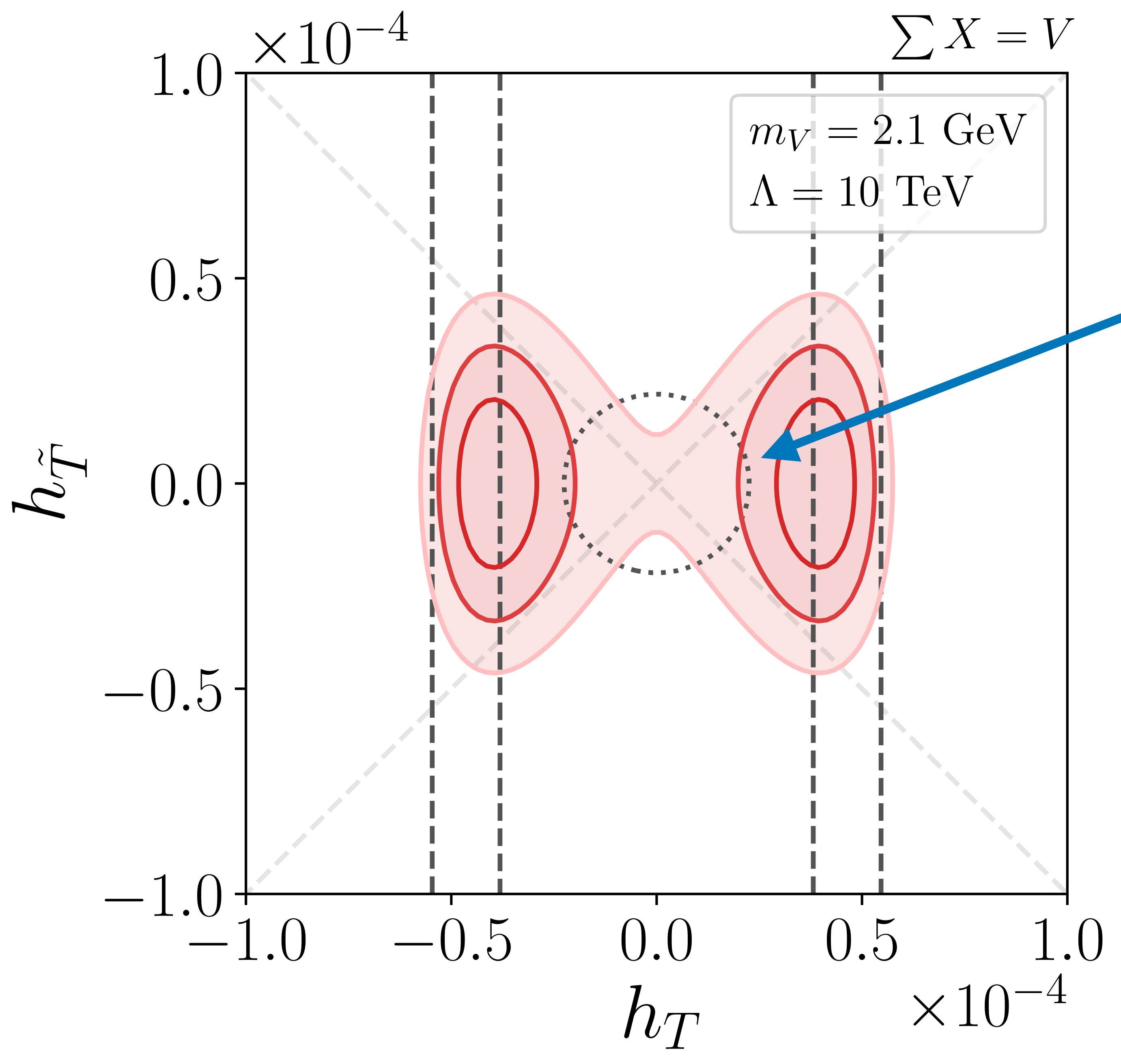
Favoured vector and tensor couplings for the vector boson scenario



$$h_V(\bar{b}\gamma_\mu s)V^\mu + h_A(\bar{b}\gamma_\mu\gamma_5 s)V^\mu$$



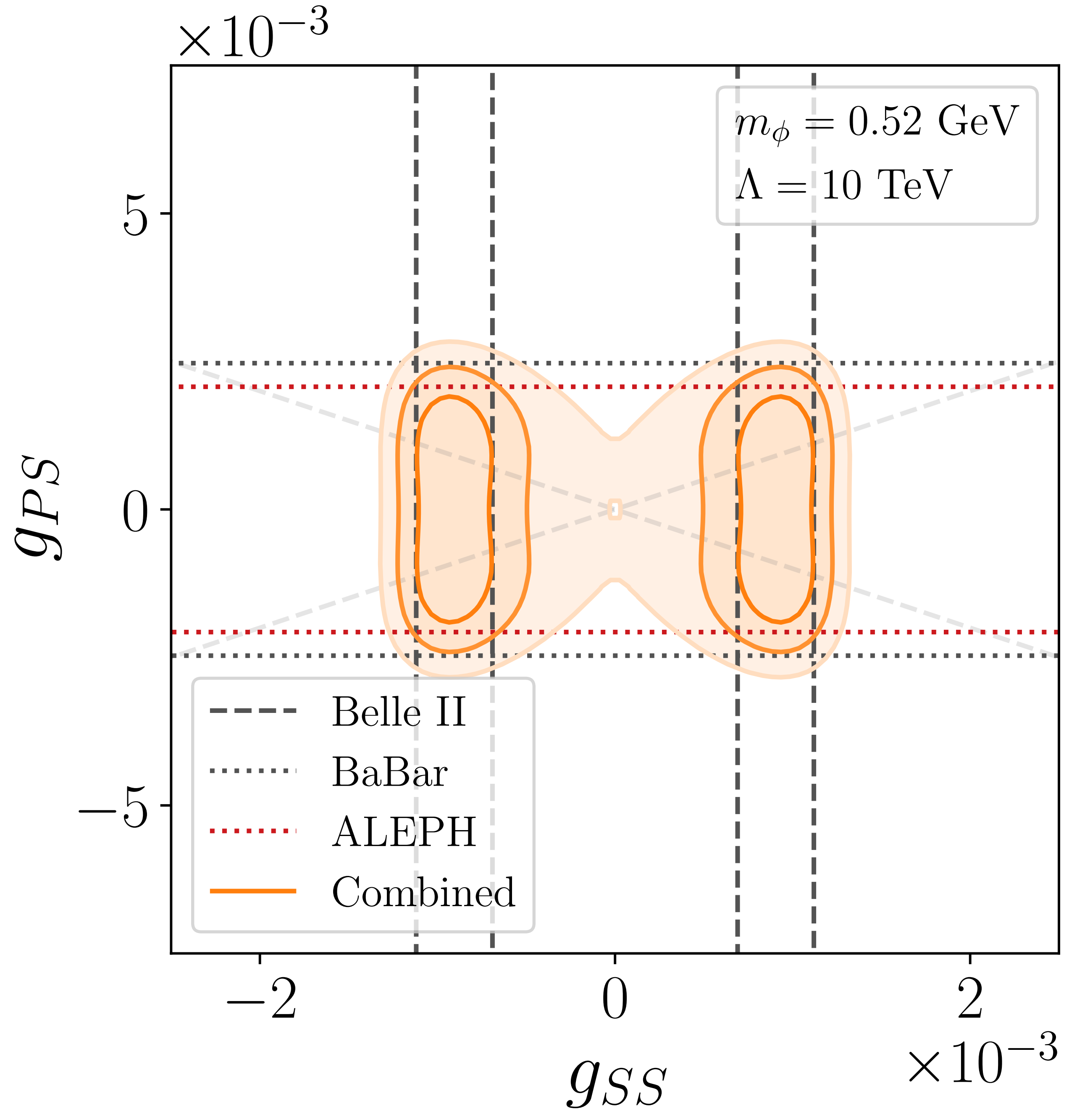
$$\frac{h_T}{\Lambda}(\bar{b}\sigma_{\mu\nu}s)V^{\mu\nu} + \frac{h_{\tilde{T}}}{\Lambda}(\bar{b}\sigma_{\mu\nu}\gamma_5 s)V^{\mu\nu}$$

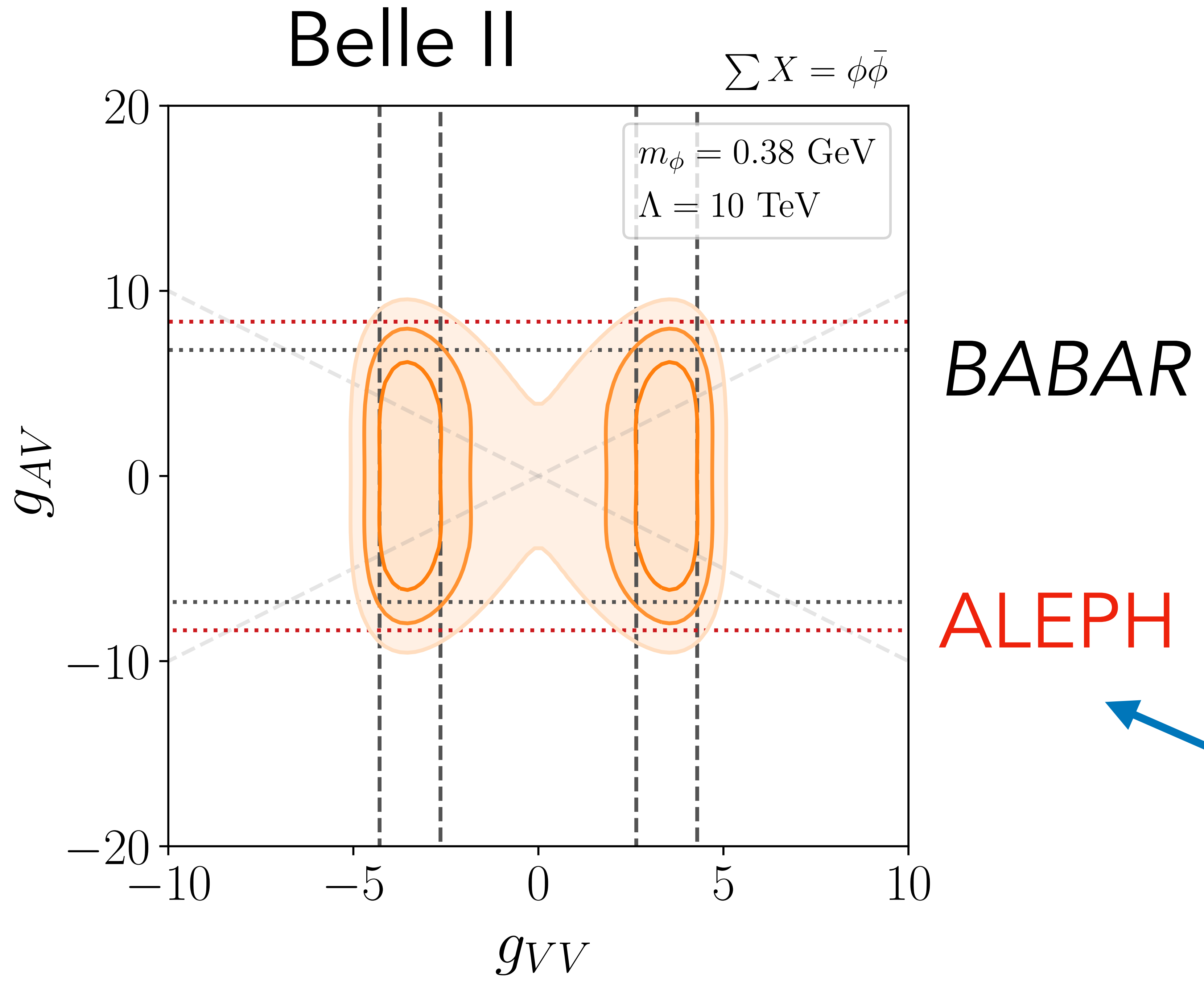
BABAR upper bound on $B \to K^* V$ in tension with favoured Belle II h_T coupling

See also: [Altmannshofer et al. 2023] [Gabrielli et al. 2023]

Scalar Boson (Three-body) Scenario

Favoured scalar and vector couplings for the scalar boson three-body scenario

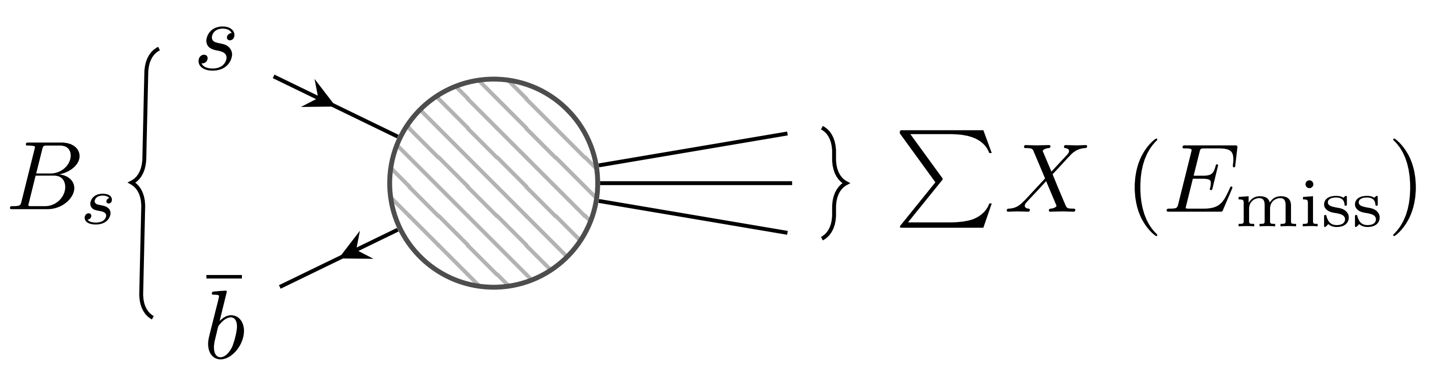




$B_s \to \phi\phi$ upper bound from recent ALEPH recast

$$\mathcal{B}(B_s \to E_{\text{miss}}) < 5.4 \times 10^{-4}$$

[Alonso-Álvarez, Escudero 2023]



$$\frac{g_{SS}}{\Lambda}(\bar{b}s)\phi\phi + \frac{g_{PS}}{\Lambda}(\bar{b}\gamma_5 s)\phi\phi \qquad \frac{g_{VV}}{\Lambda^2}(\bar{b}\gamma_\mu s)(i\phi^* \overleftrightarrow{\partial}^\mu \phi) + \frac{g_{AV}}{\Lambda^2}(\bar{b}\gamma_\mu\gamma_5 s)(i\phi^* \overleftrightarrow{\partial}^\mu \phi)$$

See also: [Bird et al. 2004]
[He et al. 2024]

Fermion Scenario

Favoured vector couplings for the fermion scenario

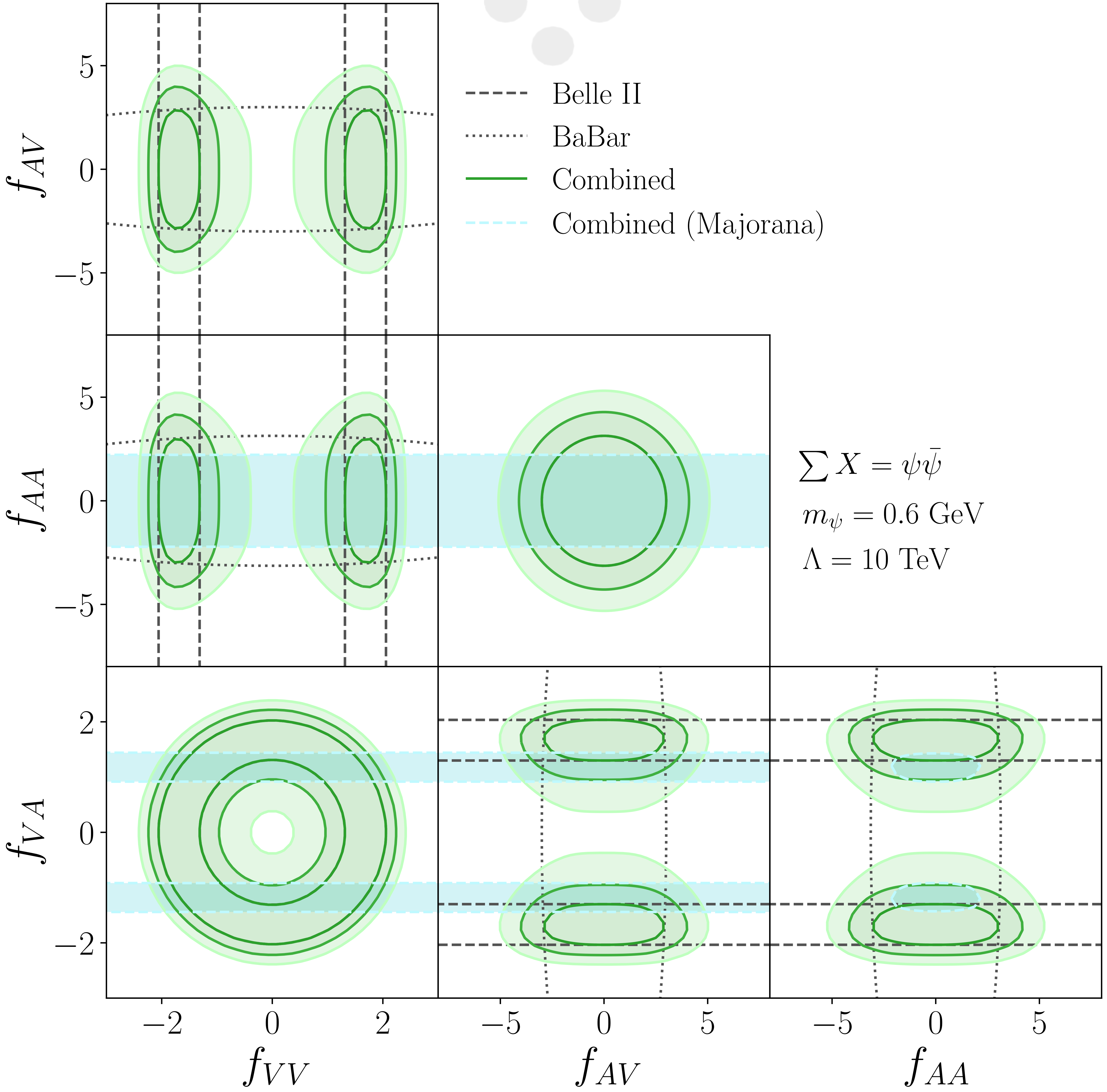
$$\frac{f_{VV}}{\Lambda^2}(\bar{b}\gamma_\mu s)(\bar{\psi}\gamma^\mu\psi) + \frac{f_{VA}}{\Lambda^2}(\bar{b}\gamma_\mu s)(\bar{\psi}\gamma^\mu\gamma_5\psi) + \frac{f_{AV}}{\Lambda^2}(\bar{b}\gamma_\mu\gamma_5 s)(\bar{\psi}\gamma^\mu\psi) + \frac{f_{AA}}{\Lambda^2}(\bar{b}\gamma_\mu\gamma_5 s)(\bar{\psi}\gamma^\mu\gamma_5\psi)$$

We consider Dirac and Majorana ψ

$\Rightarrow f_{VV}$ and f_{AV} vanish for Majorana ψ: $\bar{\psi}\gamma_\mu\psi = 0$

Only other relevant constraint (on P odd) operators from $B \to K^*\psi\bar{\psi}$

$B_s \to \psi\bar{\psi}$ is helicity suppressed



See also: [Fridell et al. 2024]

Implications for Future Measurements

With $\gtrsim 10\ \mathrm{ab}^{-1}$ of data, observation of $B \to K E_{\mathrm{miss}}$ and $B \to K^* E_{\mathrm{miss}}$ is possible

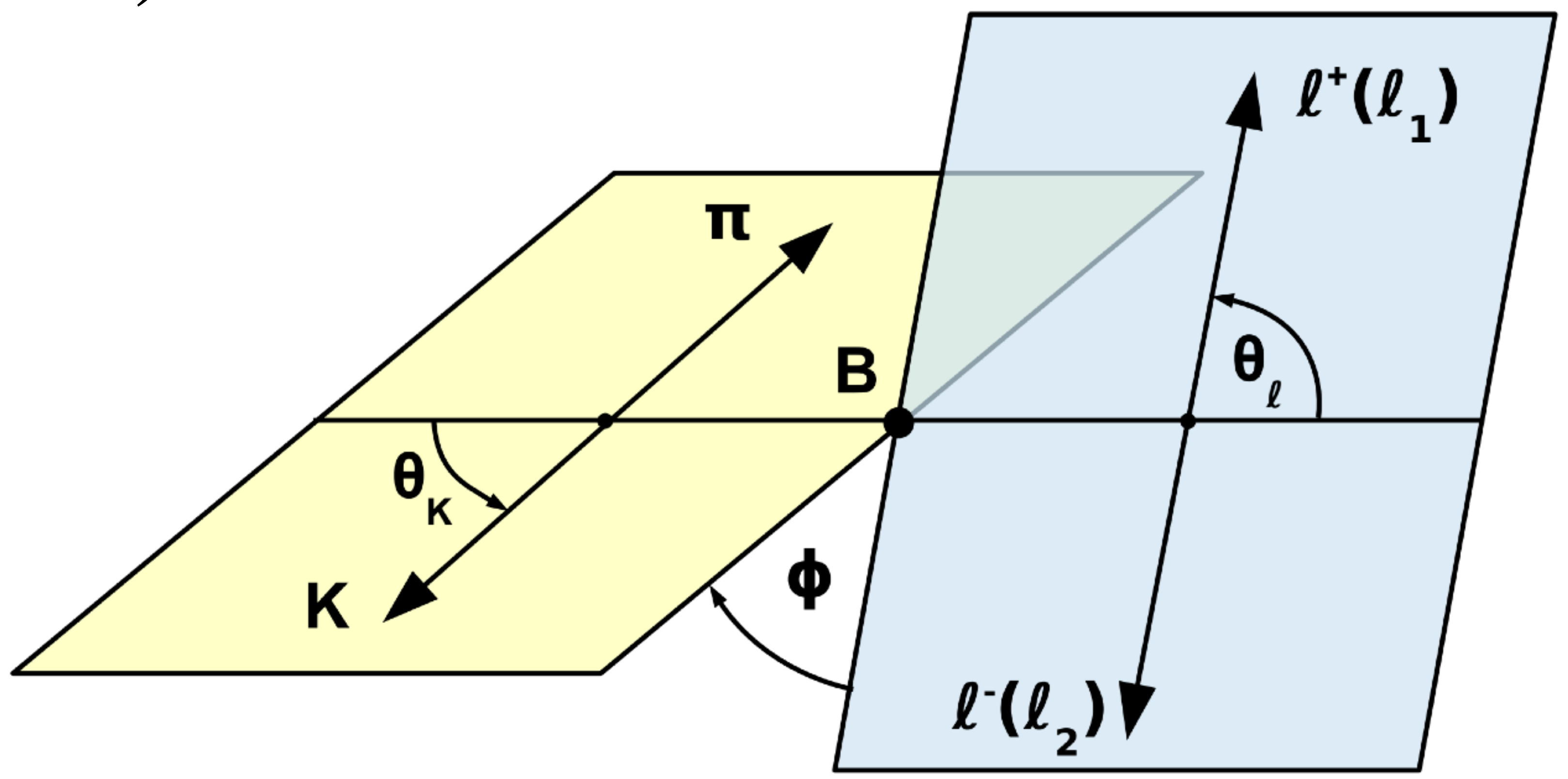
[Belle II Physics Book 2018]

$\Rightarrow$ $B \to K^*(\to K\pi) E_{\mathrm{miss}}$ is fully described by the differential rate

$$\frac{d^2\Gamma}{dq^2 d\cos\theta_K} = \frac{1}{2}\frac{d\Gamma}{dq^2}\left(1 + (3F_L - 1)D^2_{0,0}\right) \qquad D^2_{0,0} = \frac{1}{2}(3\cos^2\theta_K - 1)$$

Two observables:

$$\frac{d\Gamma}{dq^2} = \frac{d\Gamma_T}{dq^2} + \frac{d\Gamma_L}{dq^2}, \qquad F_L = \frac{d\Gamma_L}{dq^2} \Big/ \frac{d\Gamma}{dq^2}$$



[Gratex et al. 2016]

$\Rightarrow$ F_L: longitudinal polarisation fraction of K^*

$\Rightarrow$ Integrated and differential (i.e. binned) forms of observables

Effective Couplings - Chiral Basis

Given the NP explanations of the Belle II excess, what is expected for $B \to K^* E_{\text{miss}}$?

$\Rightarrow$ We consider the chiral basis to maximise correlations between $B \to K E_{\text{miss}}$ and $B \to K^* E_{\text{miss}}$

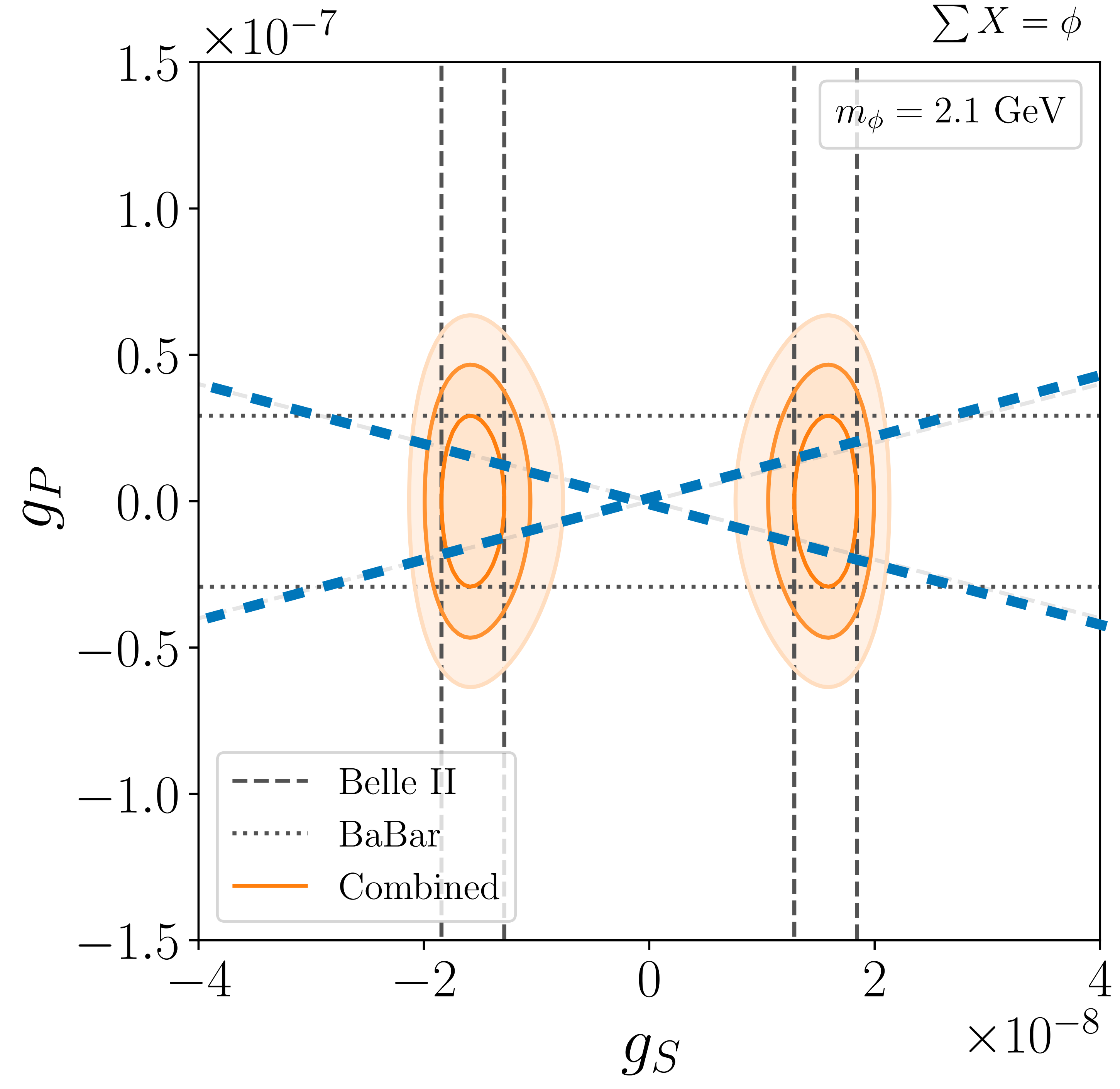
$$\mathcal{H}_{\text{eff}}^{V,L(R)} \supset C_i(\bar{b}\gamma_\mu P_{L(R)} s) \times \left[\text{light fields}\right]$$

$$\mathcal{H}_{\text{eff}}^{S,L(R)} \supset C_i(\bar{b} P_{L(R)} s) \times \left[\text{light fields}\right]$$

$$\mathcal{H}_{\text{eff}}^{T,L(R)} \supset C_i(\bar{b}\sigma_{\mu\nu} P_{L(R)} s) \times \left[\text{light fields}\right]$$

e.g.

$$\frac{v}{\sqrt{2}} C_{d\phi}^{S,L} = g_S - g_P \qquad \frac{v}{\sqrt{2}} C_{d\phi}^{S,R} = g_S + g_P$$



$$C_{d\phi}^{S,L} = 0$$

$$C_{d\phi}^{S,R} = 0$$

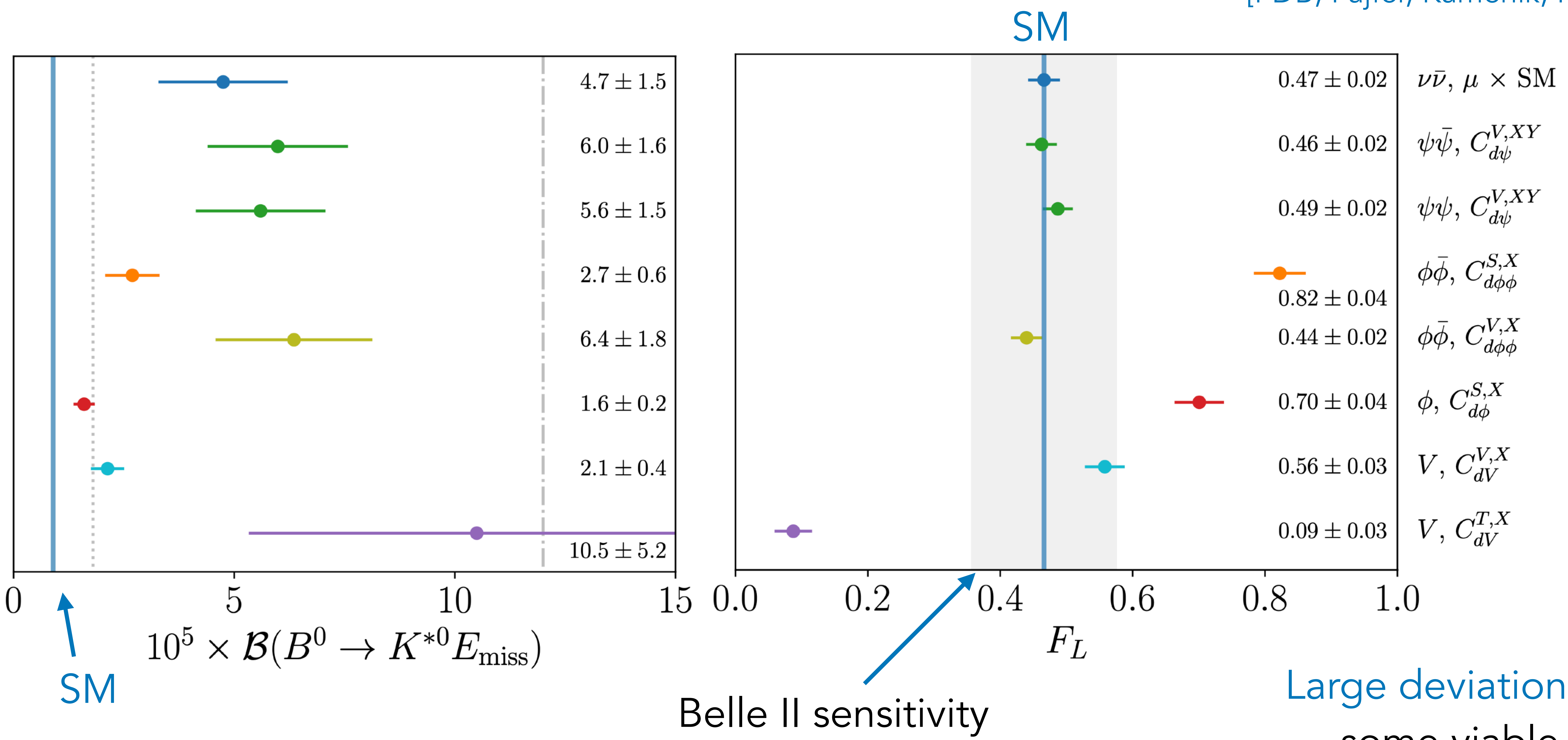
$\Rightarrow$ Add factors of Higgs vev expected from SM-invariant EFT

$$\bar{Q}Hd \to \frac{v}{\sqrt{2}} \bar{b}_L s_R$$

Implications for Future Measurements

Predictions for integrated observables, e.g. $\langle F_L \rangle = \int dq^2 F_L(q^2)$

[PDB, Fajfer, Kamenik, Novoa-Brunet 2025]



Large deviations from SM in some viable scenarios

Implications for Future Measurements

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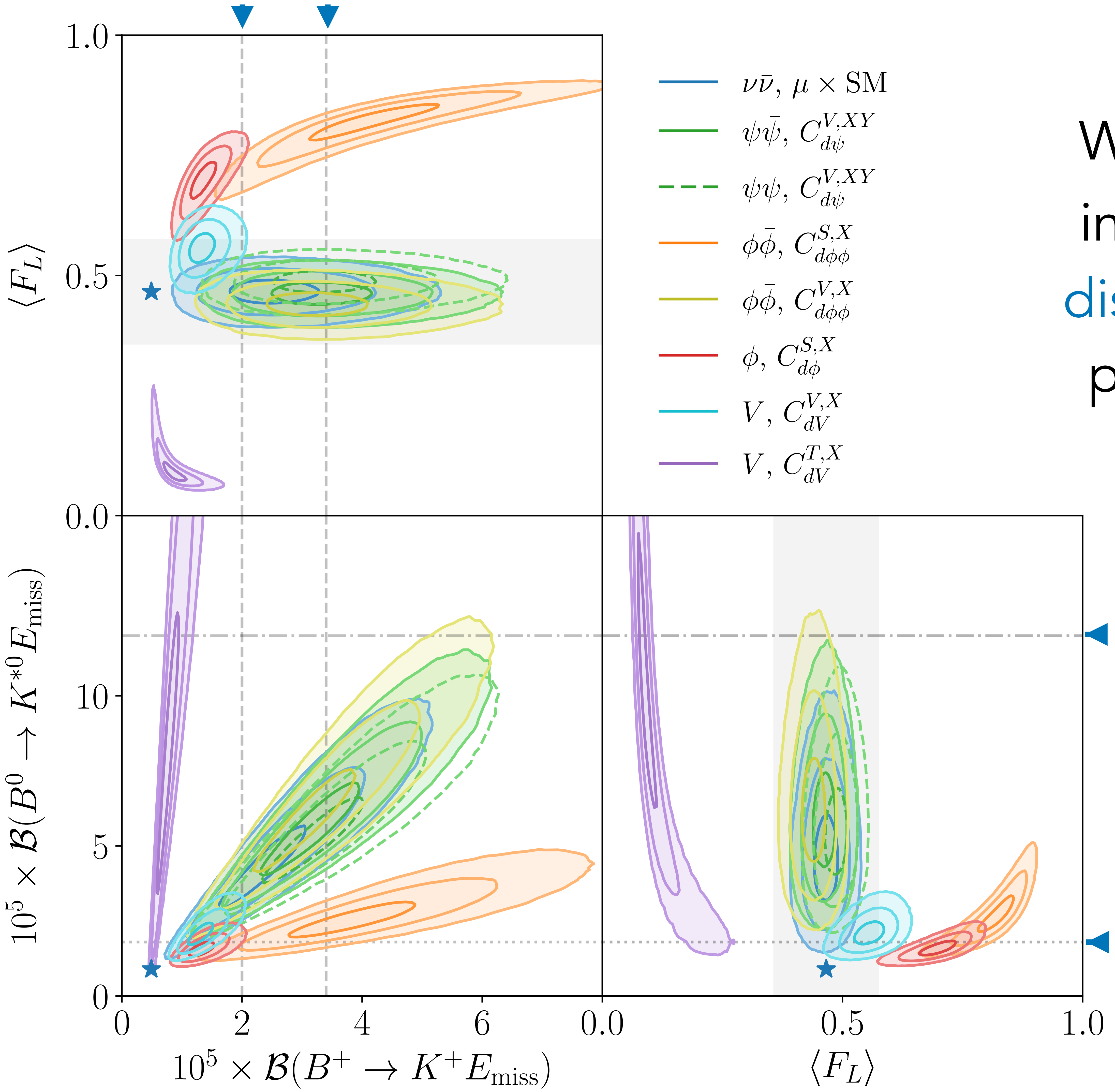
Belle II @ 68% CL (assuming SM) [Adachi et al. 2023]



BaBar @ 90% CL [Lees et al. 2013]

Belle @ 90% CL [Grygier, 2017]

Combined fit to Belle II, *BABAR* and ALEPH data

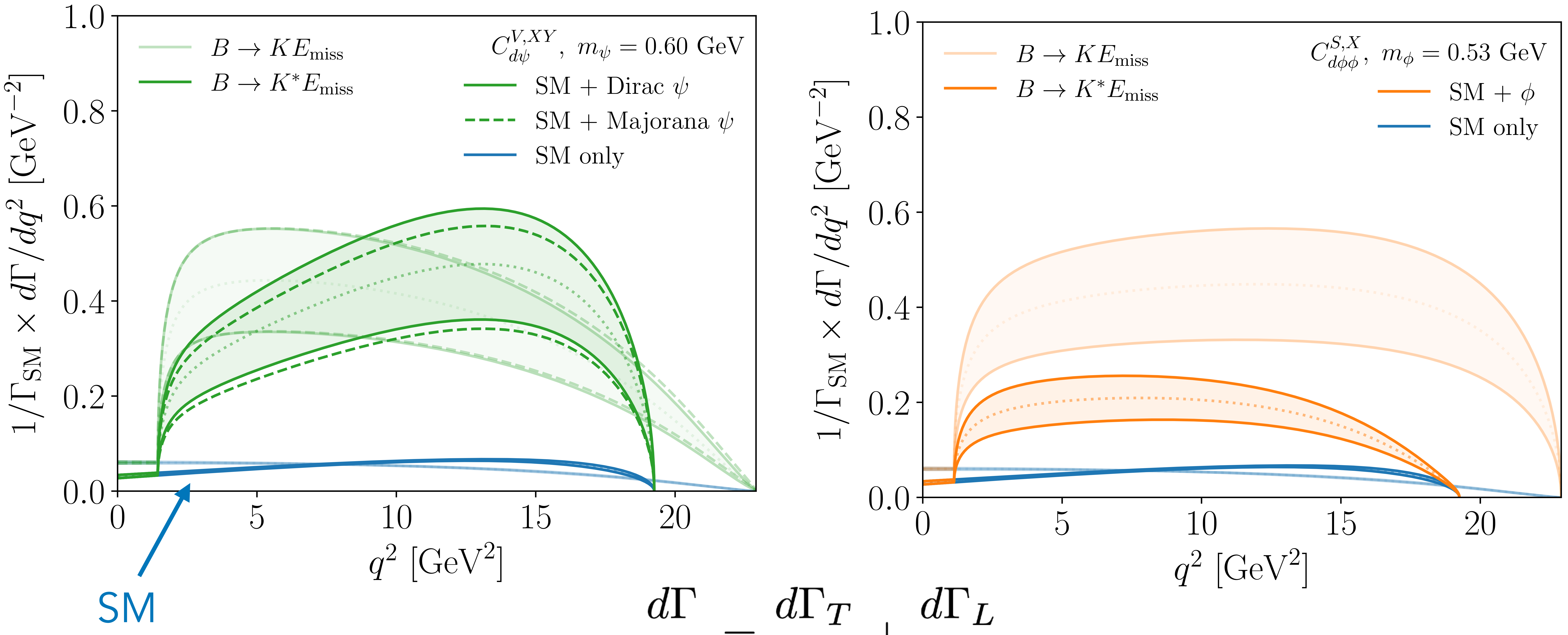
With $\mathcal{O}(10\%)$ sensitivities to integrated BRs and F_L clear distinction of some scenarios possible (mostly two-body)

[PDB, Fajfer, Kamenik, Novoa-Brunet 2025]

Implications for Future Measurements

Differential (binned) observables, e.g. branching fractions:

$\Rightarrow$ For chiral couplings, large $\mathscr{B}(B \to K^* E_{\rm miss})$ is expected for large $\mathscr{B}(B \to K E_{\rm miss})$



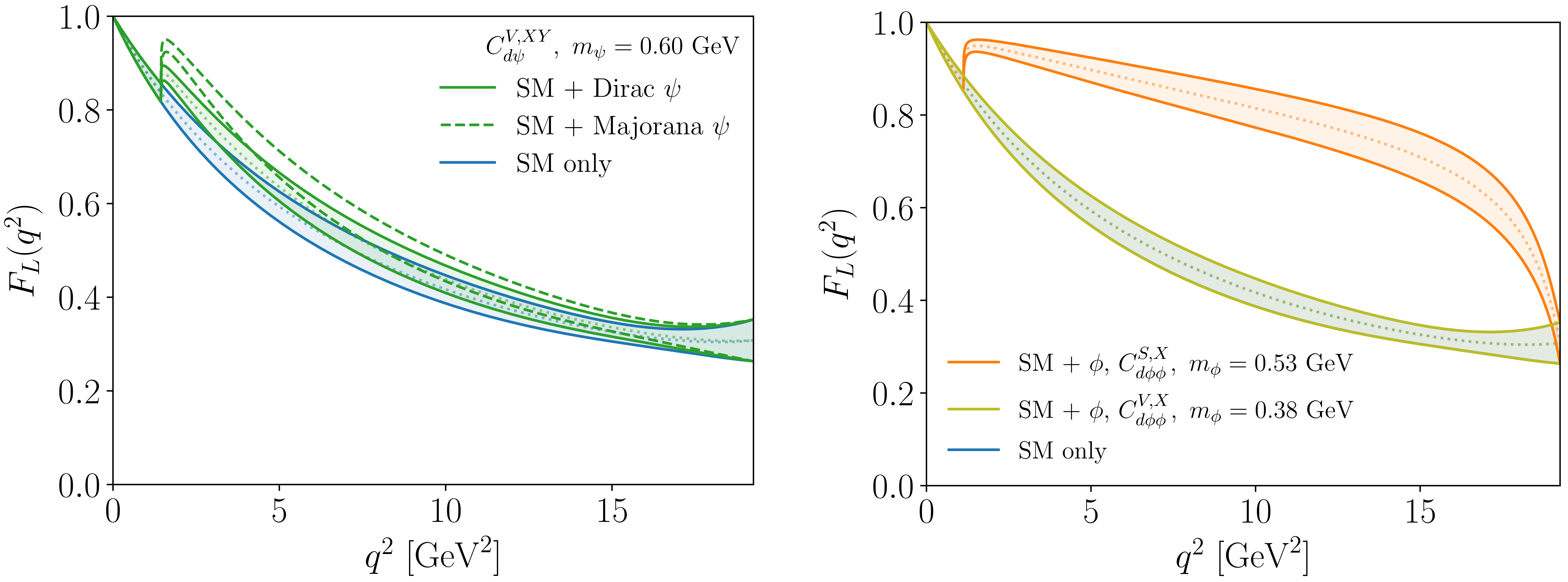
$$\frac{d\Gamma}{dq^2} = \frac{d\Gamma_T}{dq^2} + \frac{d\Gamma_L}{dq^2}$$

[PDB, Fajfer, Kamenik, Novoa-Brunet 2025]

Implications for Future Measurements

Differential (binned) observables, e.g. $F_L(q^2)$

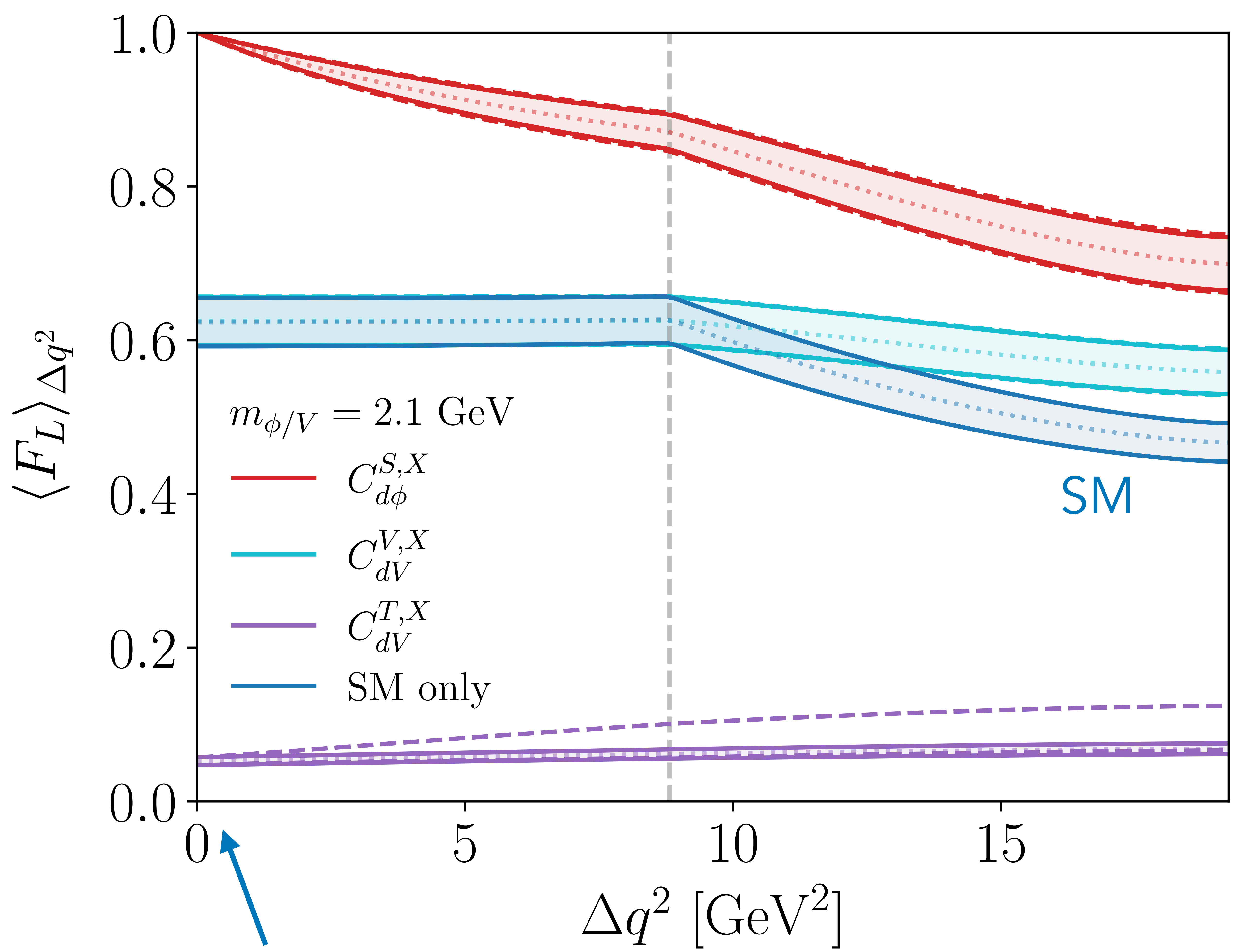
⇒ Further discrimination (e.g. around NP thresholds) for the three-body scenarios



$$F_L = \frac{d\Gamma_L}{dq^2} \Big/ \frac{d\Gamma}{dq^2}$$

[PDB, Fajfer, Kamenik, Novoa-Brunet 2025]

Implications for Future Measurements



Width of q^2 bin centred on m_X^2

Deviations in F_L for two-body scenarios can benefit from either:

a) Measuring F_L around $q^2 = m_X^2$ peak

b) Integrating over whole q^2 range

Binned F_L:

$$\langle F_L \rangle_{\Delta q^2} = \left(\int_{q_i^2}^{q_j^2} dq^2 \frac{d\Gamma_L}{dq^2} \right) \Big/ \left(\int_{q_i^2}^{q_j^2} dq^2 \frac{d\Gamma}{dq^2} \right)$$

[PDB, Fajfer, Kamenik, Novoa-Brunet 2025]

Model Building Implications - Light Z′

The light vector with mass ~ 2.1 GeV can be identified as a light Z′

See Also: [Altmannshofer et al. 2023]
[Gabrielli et al., 2024]
[Calibbi, Li, Mukherjee, Schmidt, 2025]
[di Luzio, Nardecchia, Toni, 2025]

Many UV theory model building directions. Naturally interesting to connect with dark matter (DM)

We consider the minimal aligned U(1)′ model from [Kamenik, Soreq, Zupan, 2018]

$$\begin{aligned}\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4}B'_{\mu\nu}B'^{\mu\nu} - \frac{\epsilon_B}{2}B_{\mu\nu}B'^{\mu\nu} + \left|D_\mu\Phi\right|^2 \\ + \bar{T}'(i\not{D} - M_T)T' + \bar{X}(i\not{D} - m_X)X \\ - \left[Y_T^r\bar{T}'\Phi u'_{Rr} + \text{h.c.}\right] - V(H,\Phi)\,,\end{aligned}$$

T': Vector-like top partner $(3,1,2/3,q')$
X: Vector-like dark fermion $(1,1,0,q'_X)$
Φ: Dark scalar $(1,1,0,q')$

⇒ Naturally implements MFV U(2) flavour symmetry structure

[PDB, Kamenik, Novoa-Brunet, work in progress]

Model Building Implications - Light Z′

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For Z′ see also: [Altmannshofer et al., 2023] [Gabrielli et al., 2024] [Calibbi, Li, Mukherjee, Schmidt, 2025] [di Luzio, Nardecchia, Toni, 2025]

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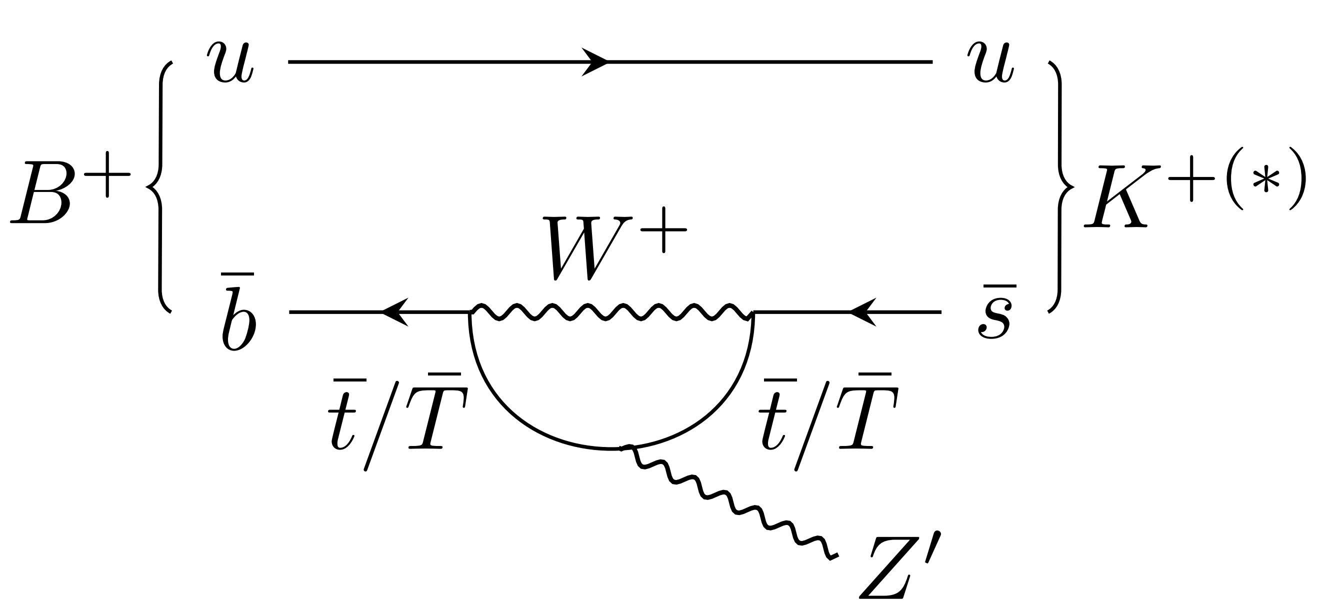

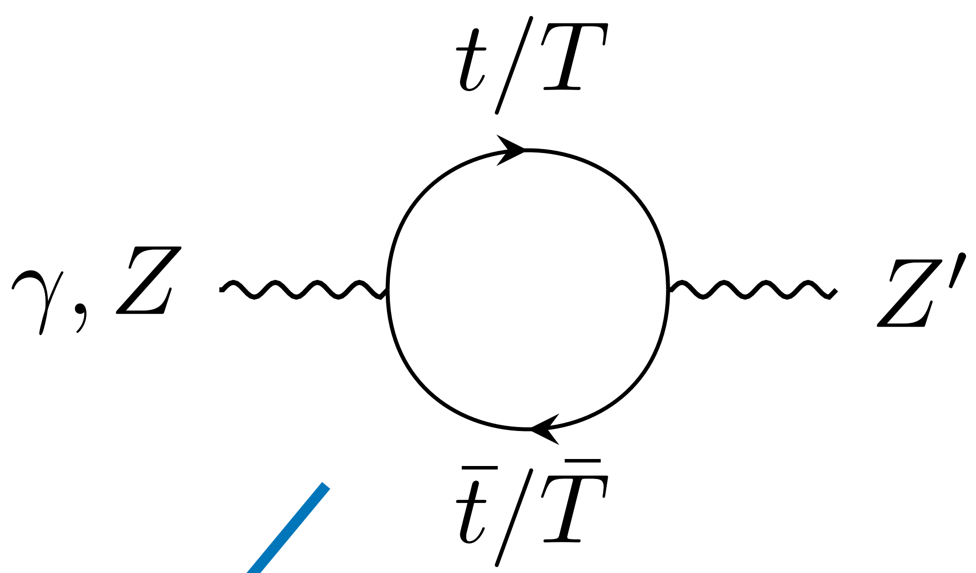

$$\boxed{-\frac{\epsilon_A}{2}F_{\mu\nu}Z'^{\mu\nu} - \frac{\epsilon_Z}{2}Z_{\mu\nu}Z'^{\mu\nu} - m^2_{ZZ'}Z_\mu Z'^\mu}$$

⇒ Z′ coupling to vector $b \to s$ current at one-loop. Also need $Z' \to \text{inv}$

[PDB, Kamenik, Novoa-Brunet, work in progress]

Model Building Implications - Light Z′

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We consider the minimal aligned U(1)′ model

$$
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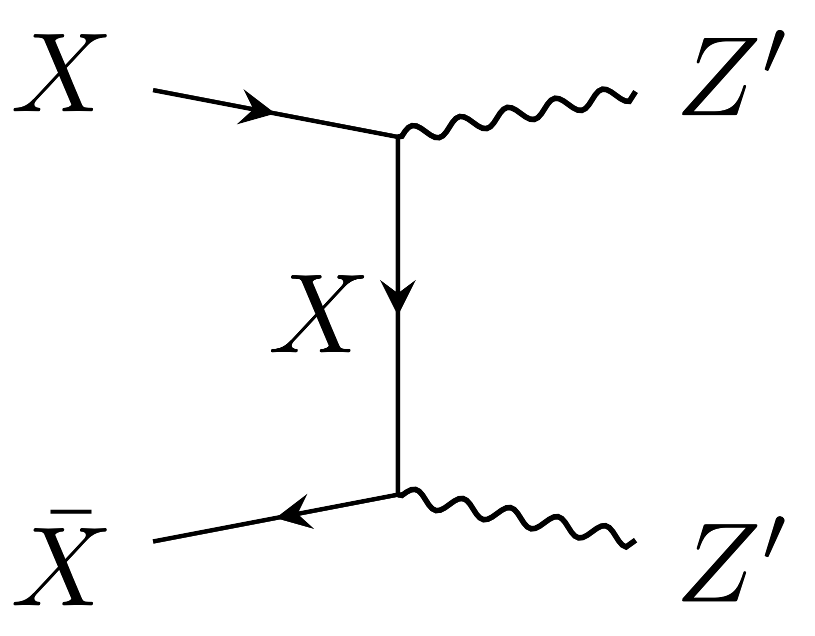
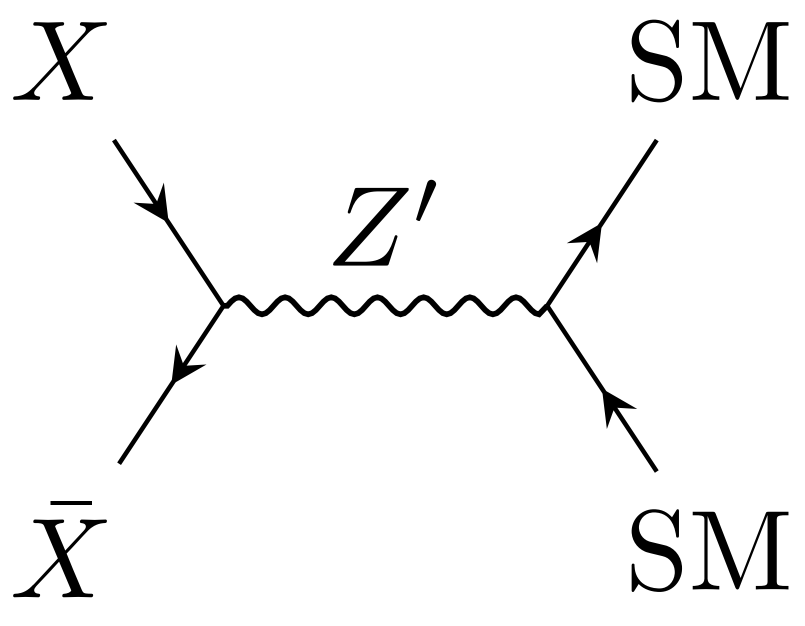
&- \left[Y_T^r \bar{T}'\Phi u'_{Rr} + \text{h.c.}\right] - V(H,\Phi)\,,
\end{aligned}
$$



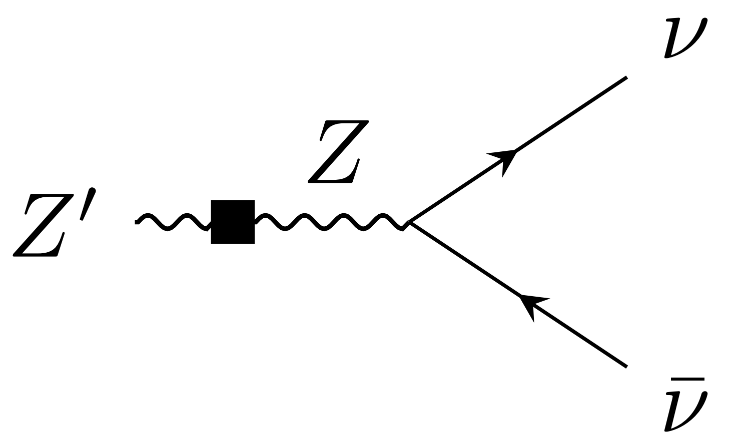


⇒ Z′ coupling to dark fermion X can allow freeze-out production of DM

[PDB, Kamenik, Novoa-Brunet, work in progress]

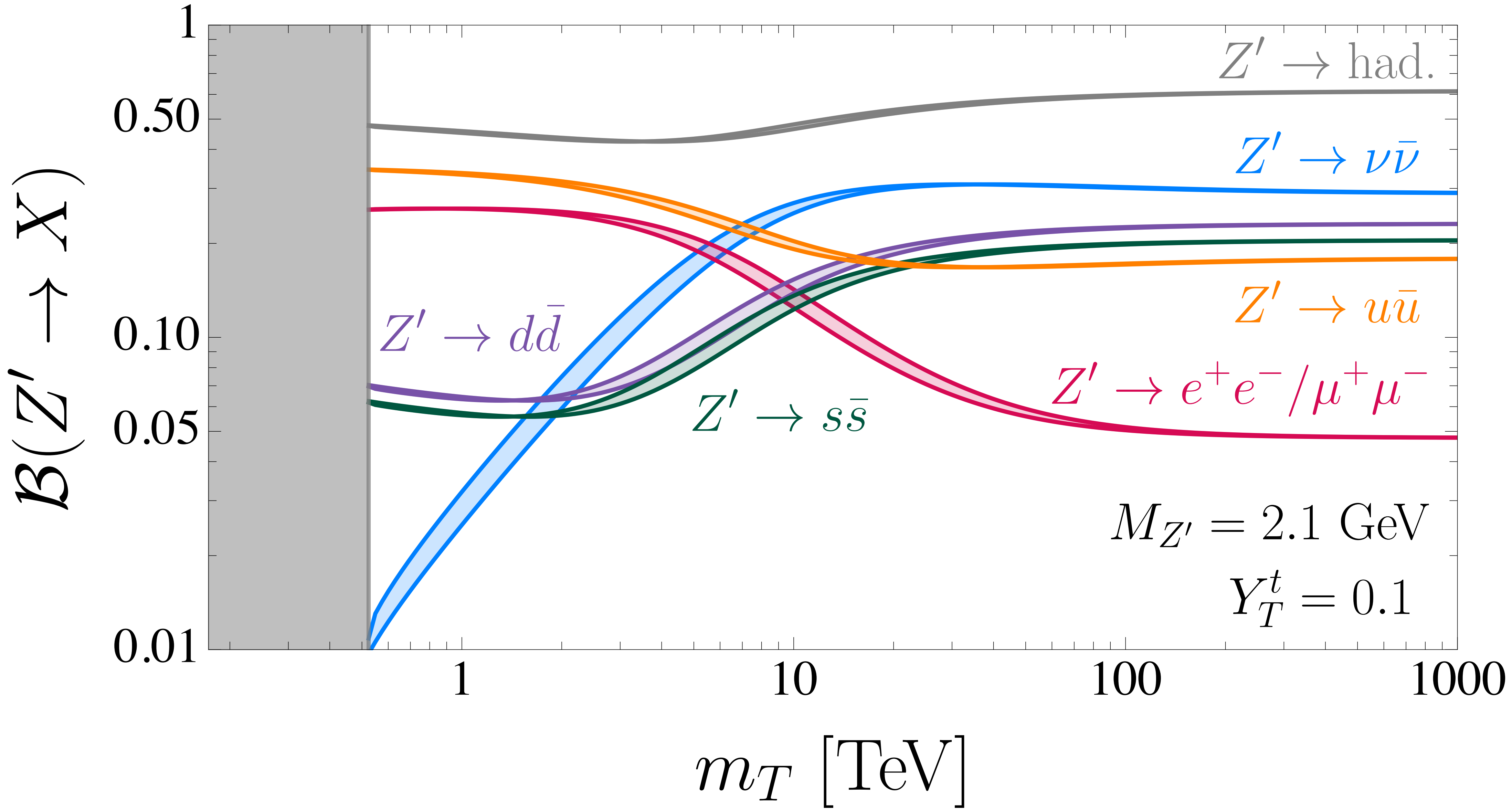
How do we get missing energy?

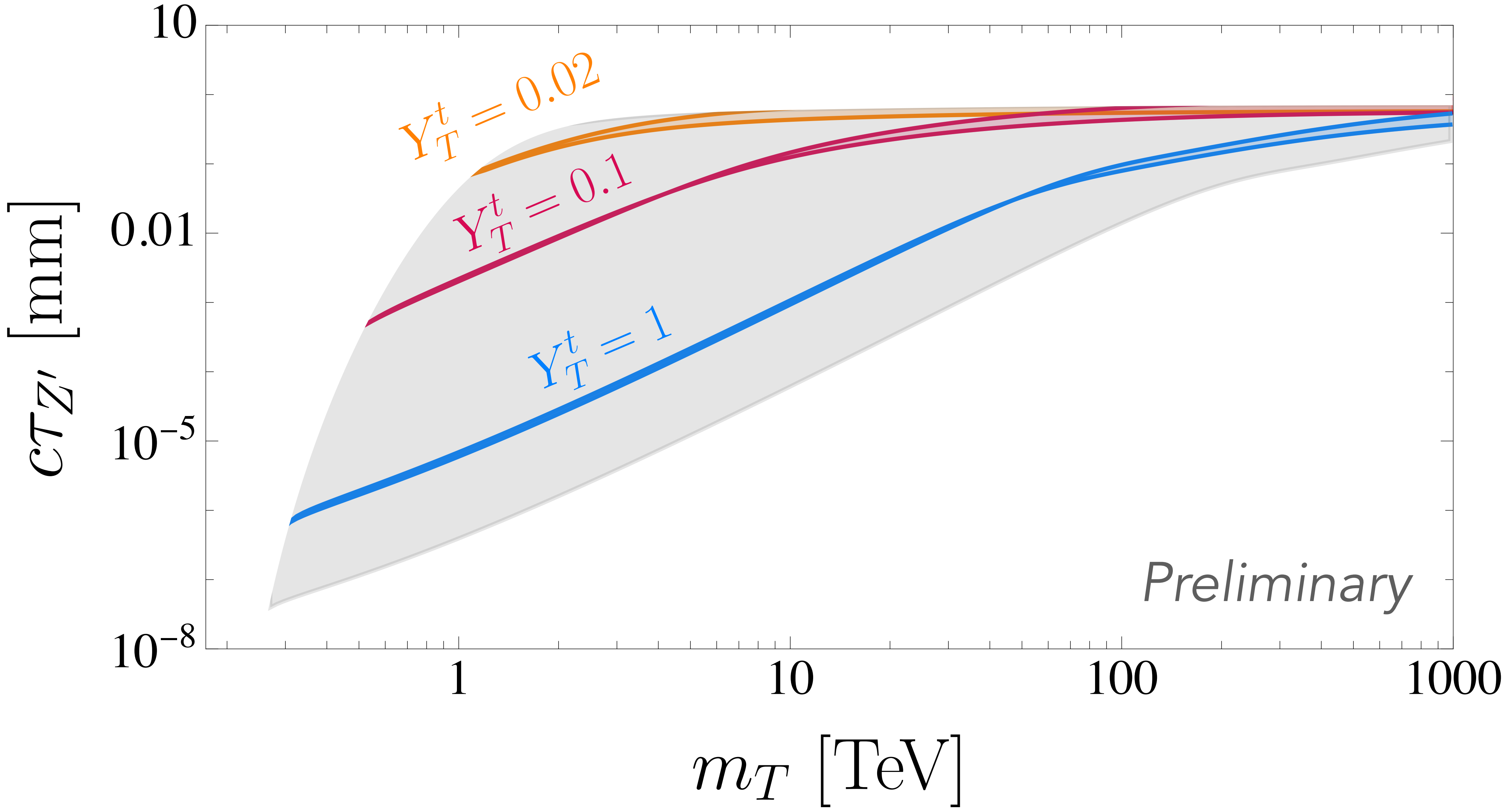
Consider heavy DM ($2m_X > M_{Z'}$), can have $E_{\text{miss}} = \nu\bar{\nu}$ via kinetic mixing



Dark photon-like

Z boson-like





But $Z' \to \ell^+\ell^-$ branching fraction large $\Rightarrow$ Excluded by $B^+ \to K^+\ell^+\ell^-$ at e.g., Belle, LHCb

[Aaij, 2014]

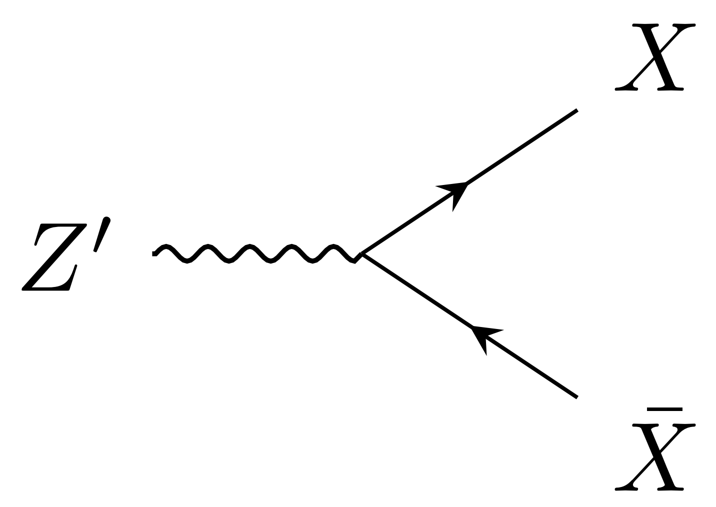
[Choudhury, 2019]

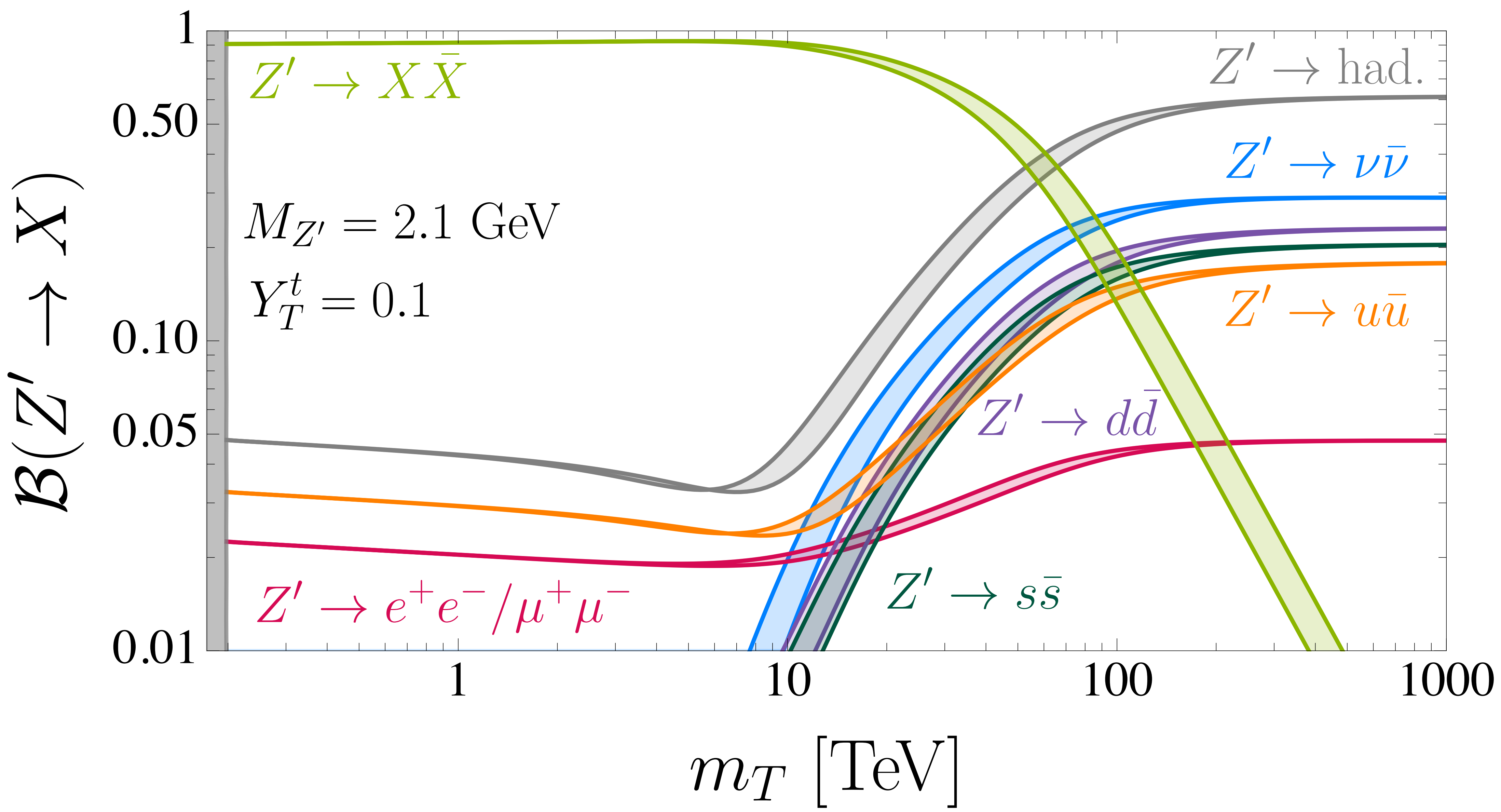
[PDB, Kamenik, Novoa-Brunet, 2025]

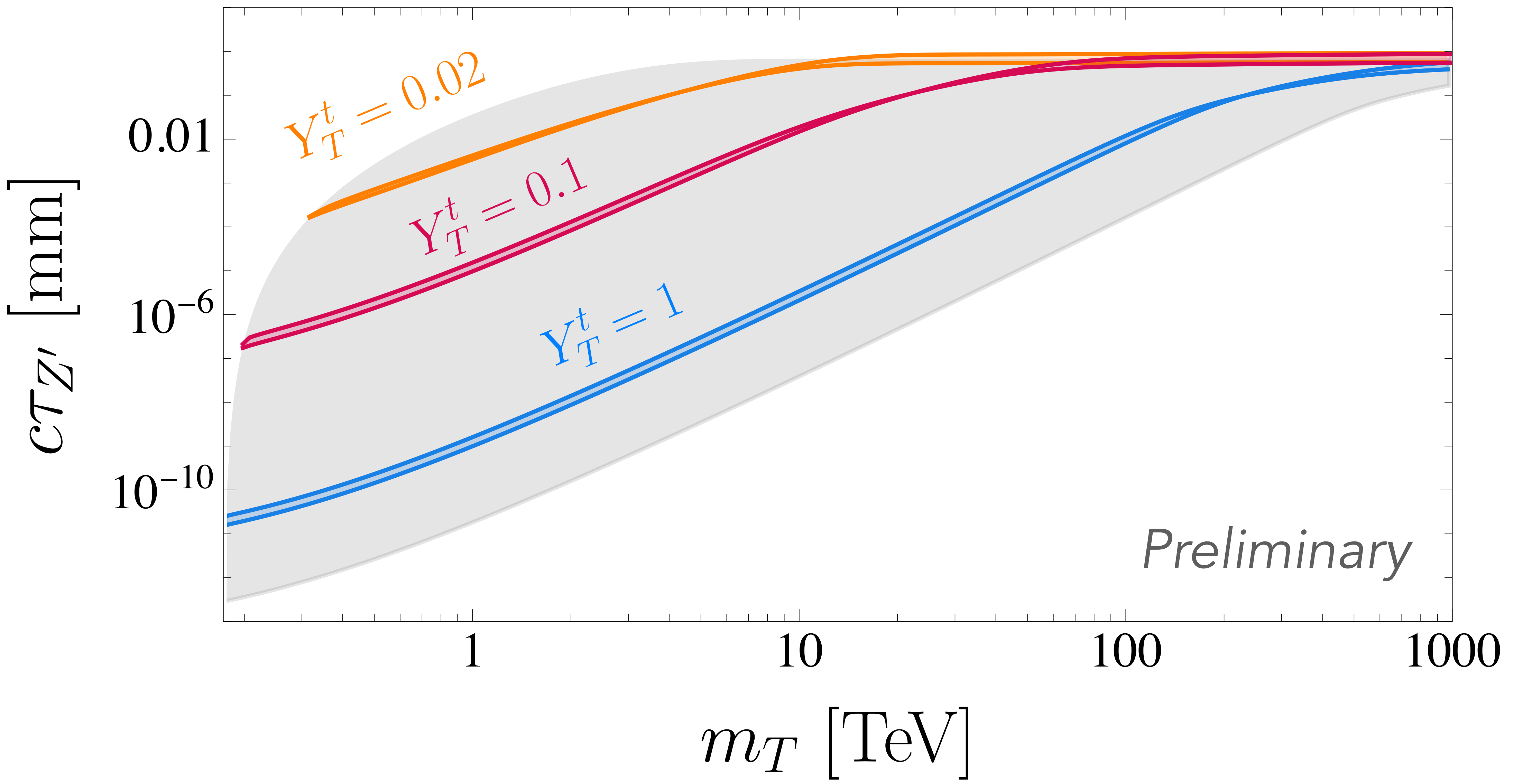
How do we get missing energy?

How about light DM ($2m_X < M_{Z'}$)? Can have $E_{\text{miss}} = X\bar{X}$

$\Rightarrow$ Depends on ratio q'_X/q'







For $q'_X = q'$, still excluded by $B^+ \to K^+\ell^+\ell^-$. Need $q'_X/q' \gtrsim 6$ to suppress $\mathscr{B}(Z' \to \ell^+\ell^-)$

[PDB, Kamenik, Novoa-Brunet, 2025]

Minimal Aligned U(1)′ Constraints

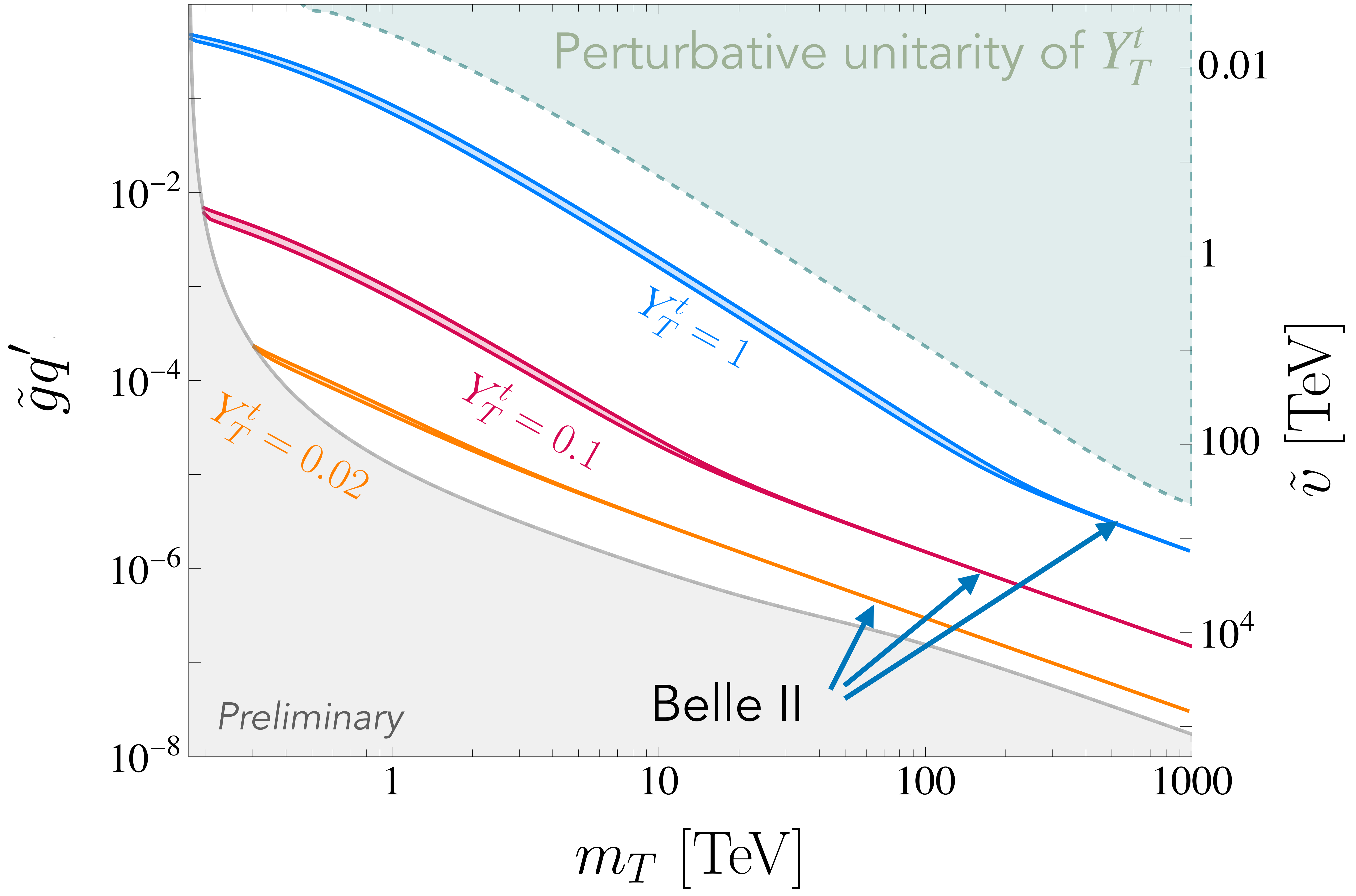
For benchmark choice $q'_X = 1$, $q' = \frac{1}{6}$, following regions explain Belle II $B^+ \to K^+ E_{\text{miss}}$ ITA signal

$$\tilde{g}q' = \frac{M_{Z'}}{\tilde{v}}$$

~ 2.1 GeV

Vacuum expectation value of dark U(1)′

Charge of dark U(1)′



[PDB, Kamenik, Novoa-Brunet, 2025]

Minimal Aligned U(1)′ Constraints

But, bounds also apply from collider, electroweak precision, direct Z' searches

$pp \to T\bar{T}$ @ ATLAS, CMS

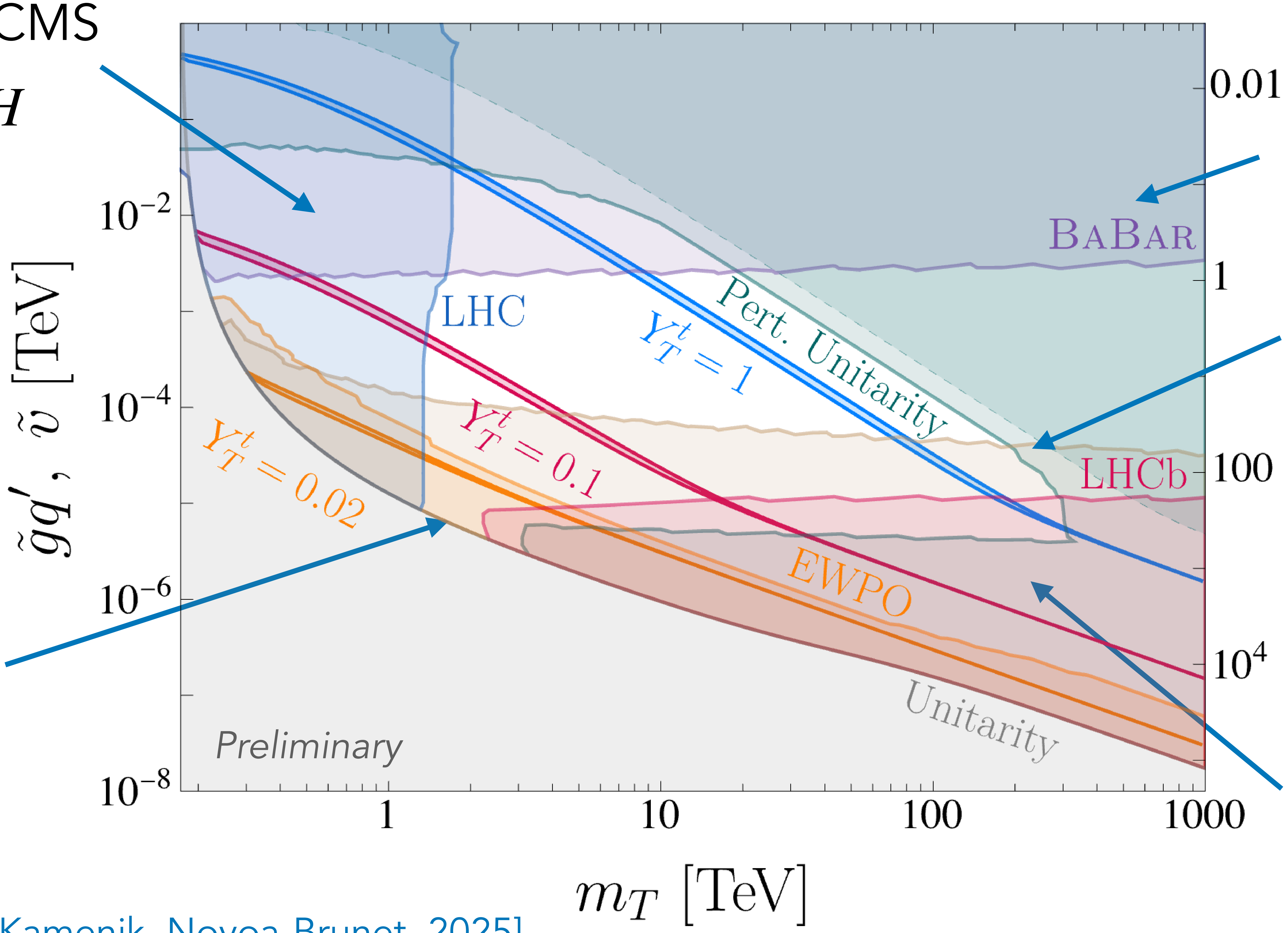
$T \to tZ', bW^+, tZ, tH$

[ATLAS, 2024]

$$\rho = \frac{M_W^2}{M_Z^2 c_w^2} \approx 1 + \alpha T$$

(EW precision)

[PDG, 2024]



[PDB, Kamenik, Novoa-Brunet, 2025]

$e^+e^- \to \gamma + \text{inv}$ @ *BABAR*

[Lees, 2017]

$\kappa_t = Y_t / Y_t|_{SM}$ @ CMS

[CMS, 2021]

$B \to K\ell^+\ell^-$ @ LHCb, Belle

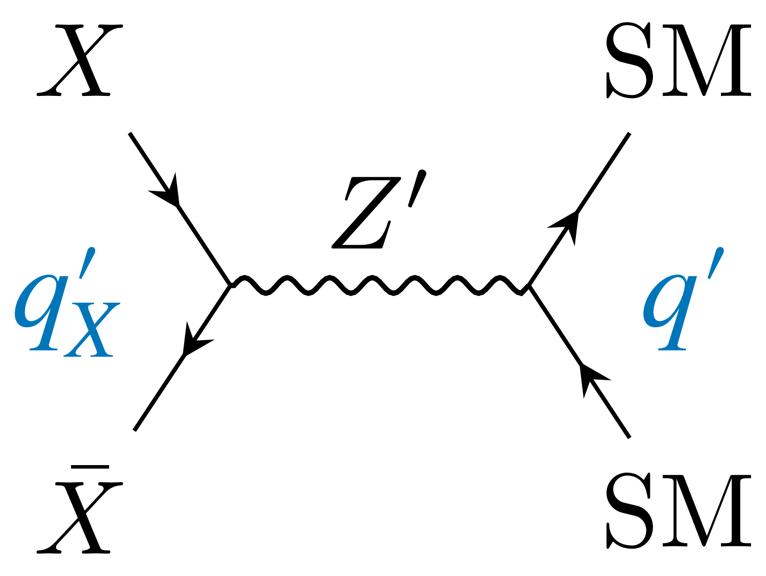
[Aaij, 2014]

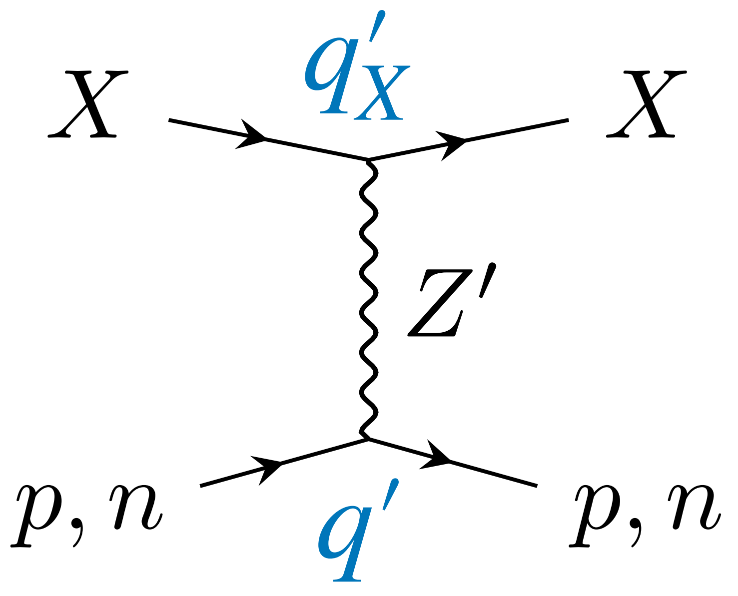
[Choudhury, 2019]

GeV Scale DM

For the allowed window, is correct DM relic abundance (Ω_X) possible? Yes!

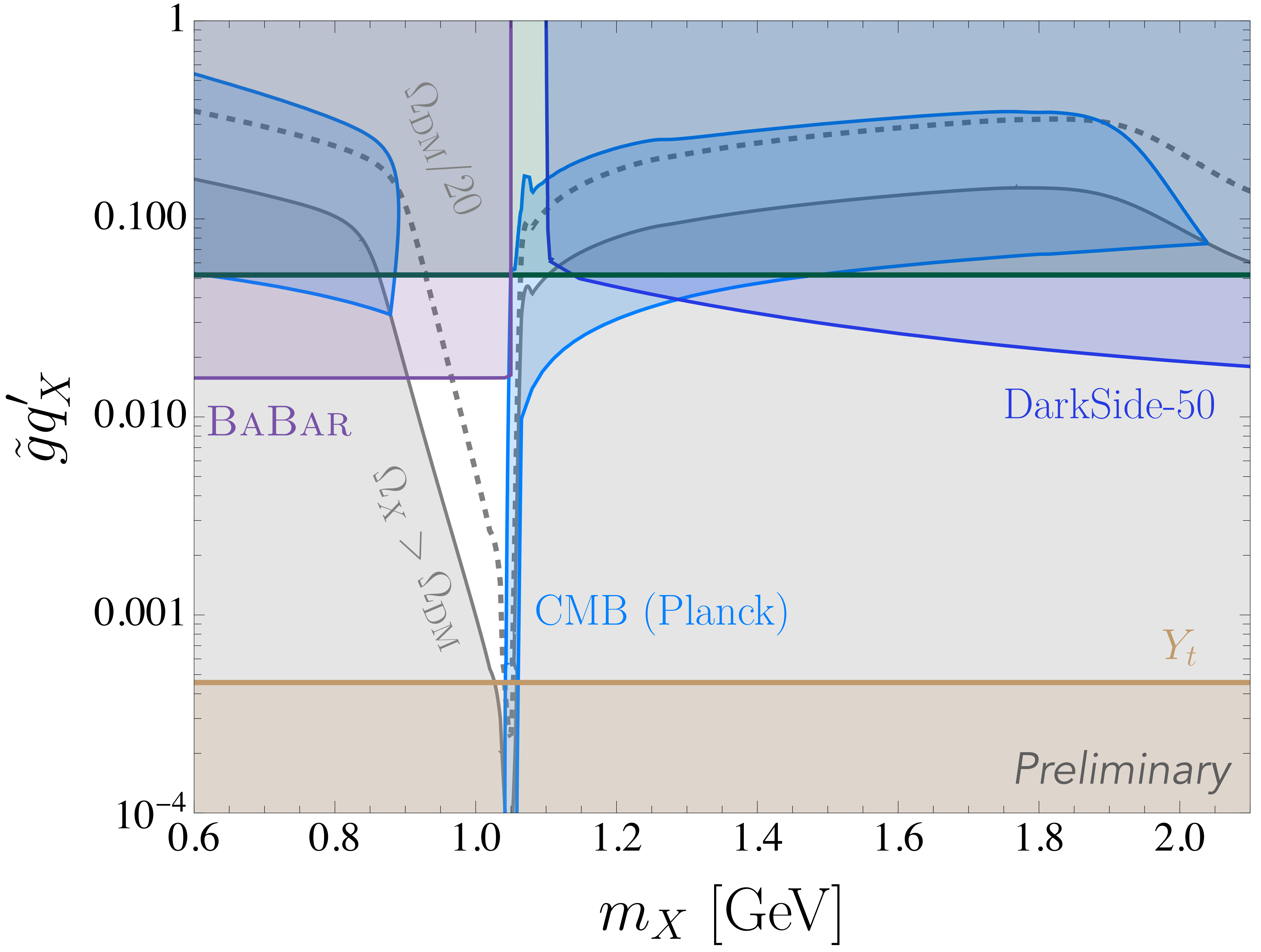
Resonant enhancement of $\langle \sigma v \rangle$ for $2m_X \sim M_{Z'}$





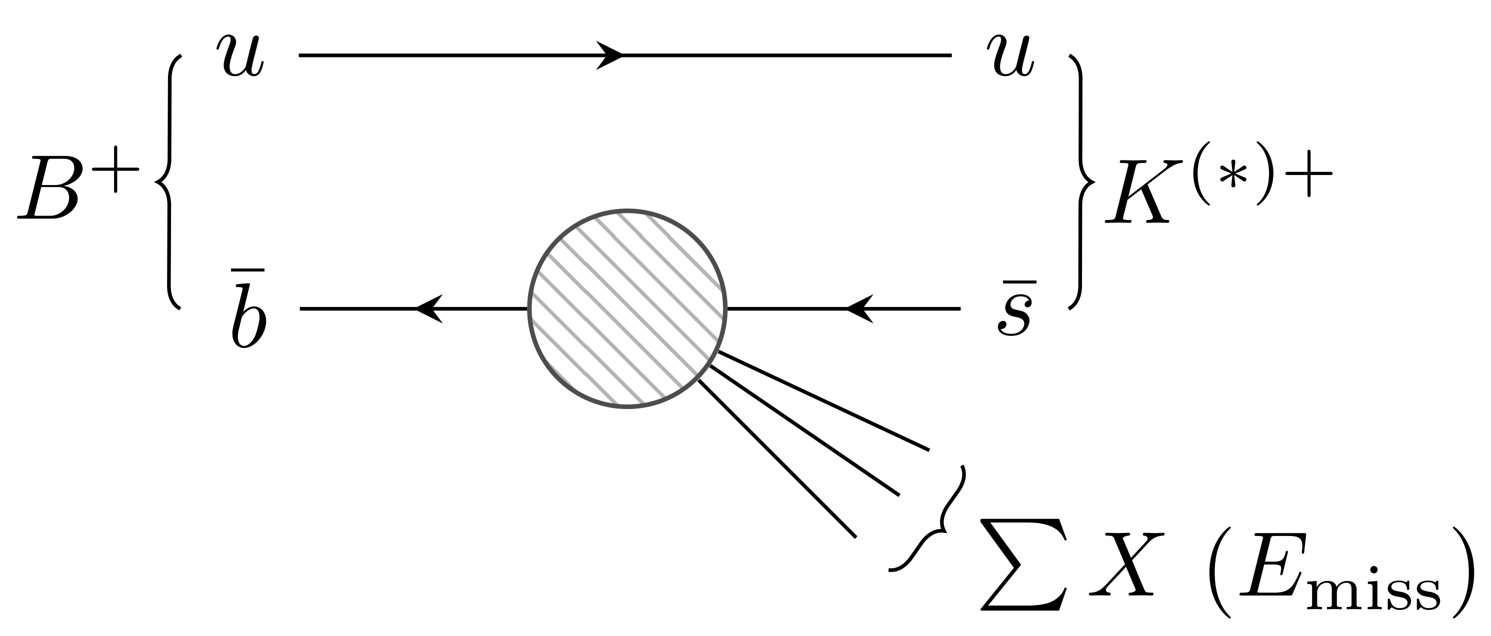
Mass range $0.9\ \mathrm{GeV} \lesssim m_X \lesssim 1\ \mathrm{GeV}$ gives correct Ω_X and evades bounds from direct (DarkSide-50) and indirect (CMB) detection

$$q'_X = 1,\ q' = \frac{1}{6} \qquad m_T = 10\ \mathrm{TeV}$$



[PDB, Kamenik, Novoa-Brunet, 2025]

Conclusions



FCNC + missing energy decays are excellent probes of NP

Light NP interpretation of current Belle II $B^+ \to K^+ \nu\bar{\nu}$ ITA data

- Two-body decays with scalar or vector (4.5σ), m_X ~ 2 GeV
- Three-body decays with scalars (3.4σ) or fermions (3.7σ), m_X ~ 0.4-0.5 GeV

[PDB, Fajfer, Kamenik, Novoa-Brunet 2024 + 2025]

Await future Belle II measurements of $B \to K^{(*)} E_{\rm miss}$ to exclude and/or discriminate scenarios

- Model-agnostic inference essential, supported by recent release of Belle II likelihood

[Abumusabh et al. 2025]

The minimal aligned U(1)′ model is predictive and tightly constrained

- Z′ with mass 2.1 GeV, coupled to light dark fermion, can give $B \to K E_{\rm miss}$ and avoid other bounds
- DM with $m_X \sim 0.9 - 1$ GeV can provide all of the required DM, $\Omega_X = \Omega_{\rm DM}$

Thank you for your attention!