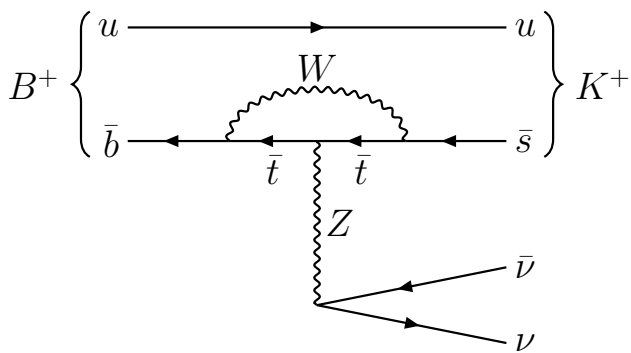
A Model-Independent Approach to $B^+ \to K^+ +$ Invisible

Flavor Physics Workshop 2026 (Toyama)

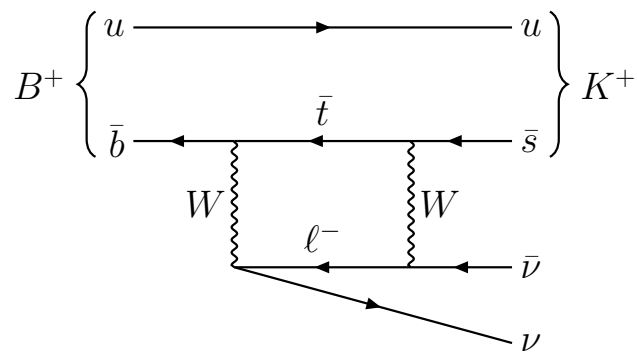
Jun Miyamoto (UTokyo, ICRR, M2)

Work in Progress

➢ B to K nu nu excess

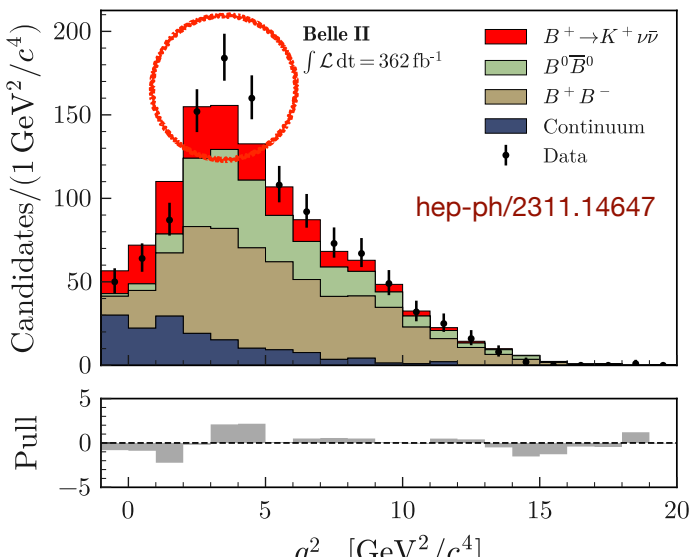


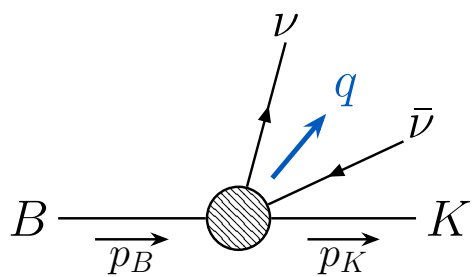
Z penguin



W box

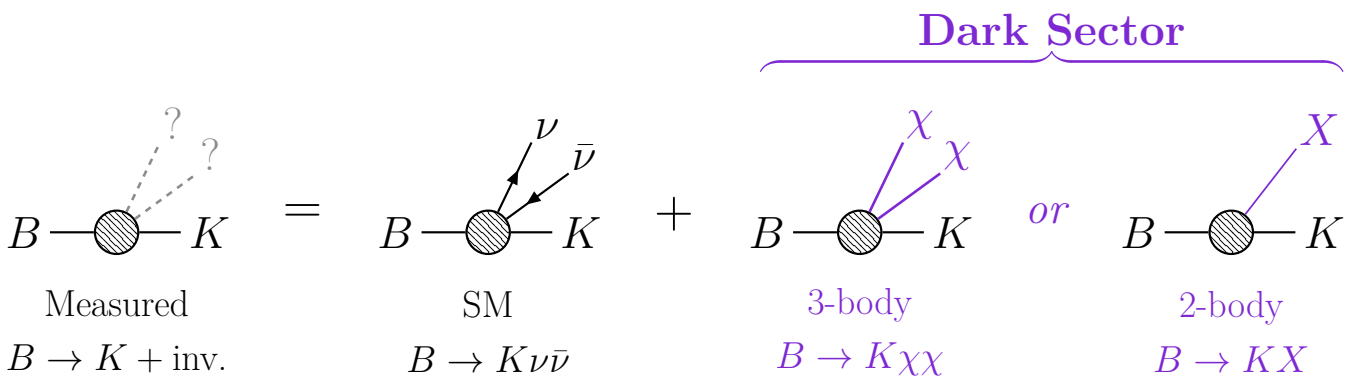
➢ B to K nu nu excess





$$q = p_B - p_K = p_\nu + p_{\bar{\nu}}$$

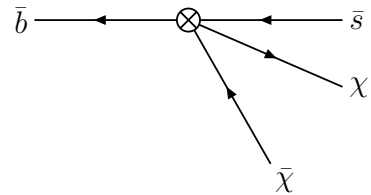
➢ B to K + Invisible



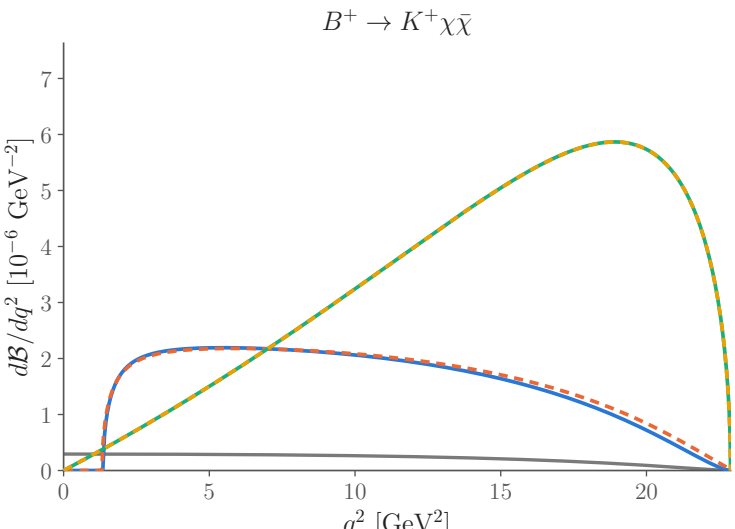
$$\mathcal{L} \supset \frac{C_V^\chi}{\Lambda^2}(\bar{s}\gamma_\mu b)(\bar{\chi}\gamma^\mu\chi) + \frac{C_S^\phi}{\Lambda}(\bar{s}b)\,\phi^\dagger\phi + \frac{C_S^V}{\Lambda}(\bar{s}b)\,V_\mu^\dagger V^\mu + g_S\,(\bar{s}b)\,S + \cdots + \text{h.c.}$$

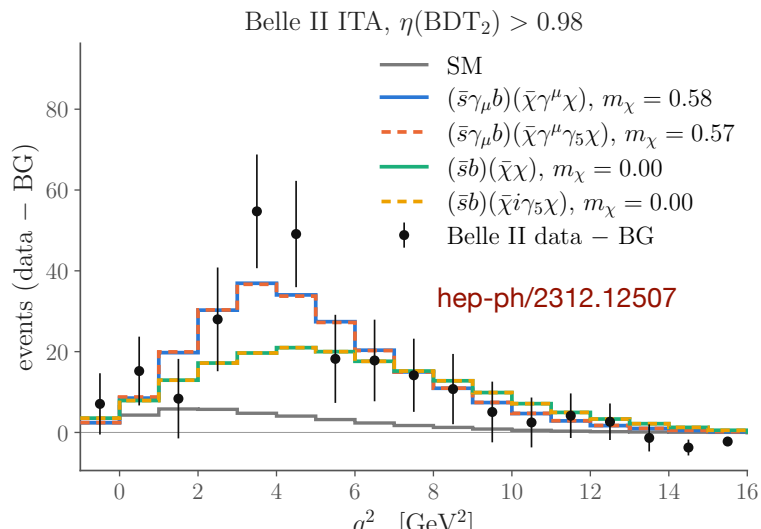
Wilson係数 と **暗黒粒子の質量 + α** が 理論の Parameter

➢ q-square distribution

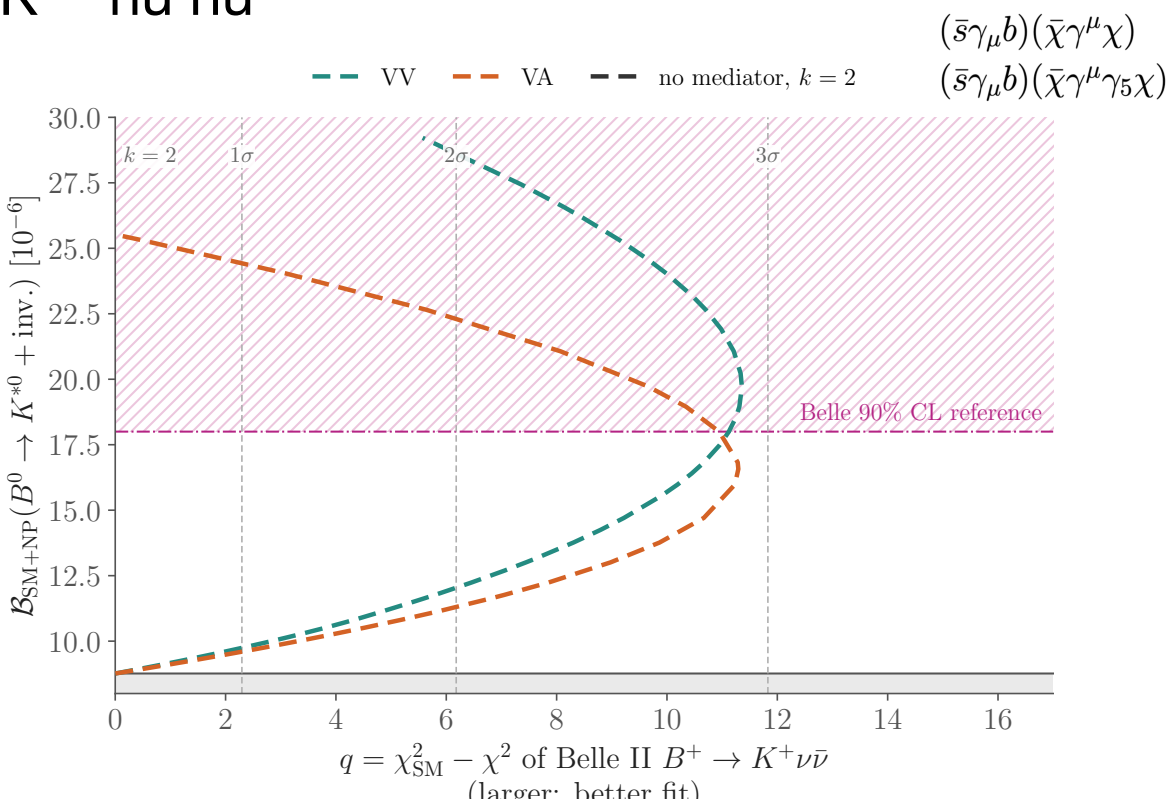


$$\mathcal{L} \supset \frac{C}{\Lambda^2}(\bar{s}\,\Gamma_q\,b)(\bar{\chi}\,\Gamma_\chi\,\chi)$$

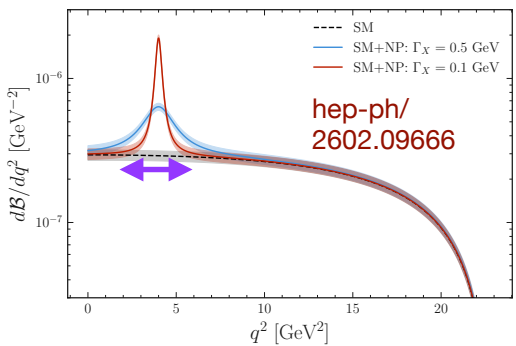


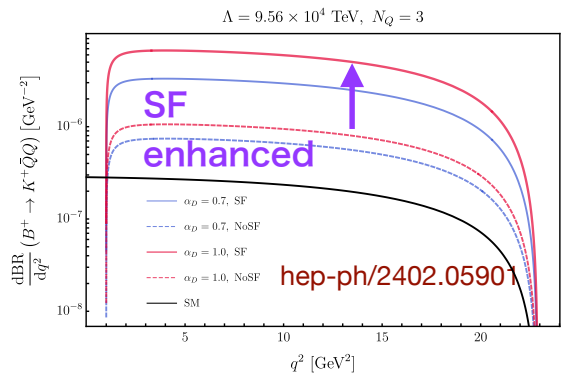


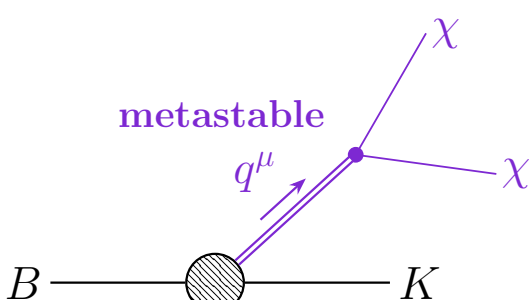
➢ B to K^* nu nu

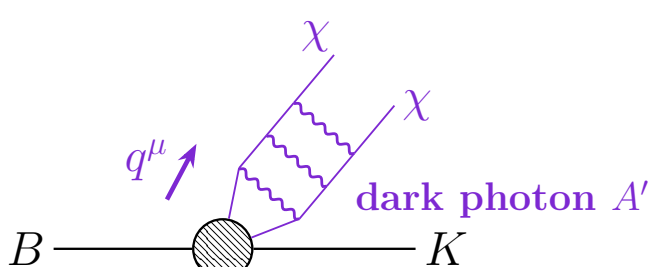

$(\bar{s}\gamma_\mu b)(\bar{\chi}\gamma^\mu\chi)$
$(\bar{s}\gamma_\mu b)(\bar{\chi}\gamma^\mu\gamma_5\chi)$
VV
VA
no mediator, $k = 2$
$k = 2$
1σ
2σ
3σ
Belle 90% CL reference
$\mathcal{B}_{\mathrm{SM+NP}}(B^0 \to K^{*0} + \mathrm{inv.})\ [10^{-6}]$
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
0
2
4
6
8
10
12
14
16
$q = \chi^2_{\mathrm{SM}} - \chi^2$ of Belle II $B^+ \to K^+\nu\bar{\nu}$
(larger: better fit)

➢ Metastable State/ Sommerfeld Effect









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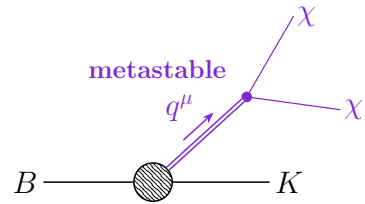
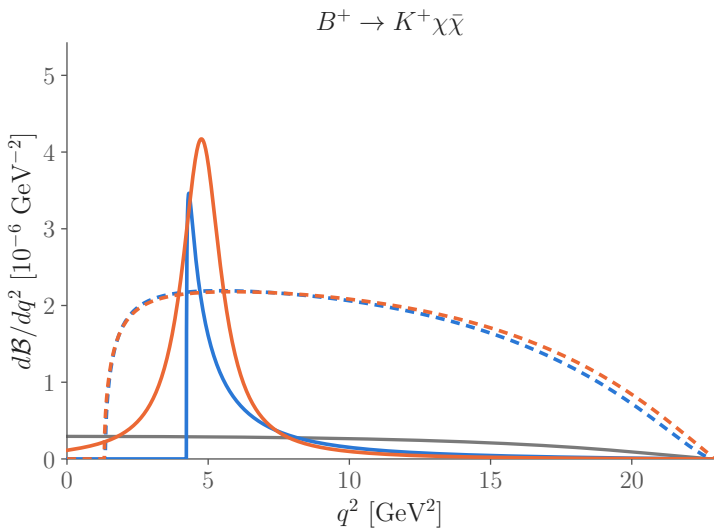
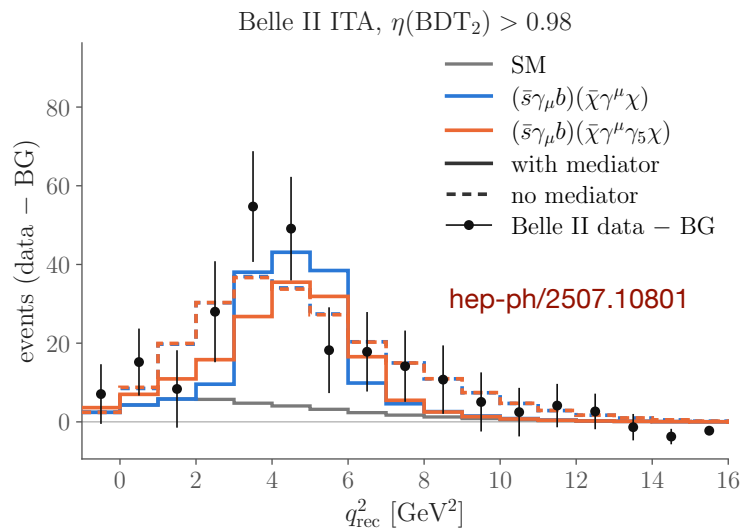
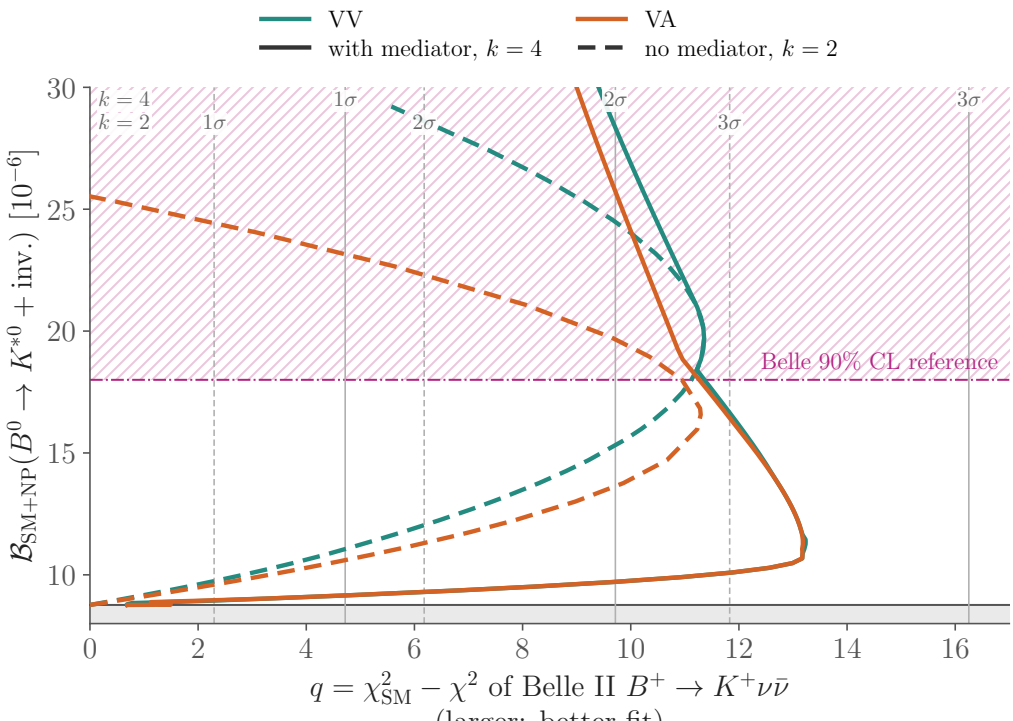






➢ B to K^* nu nu


VV
with mediator, $k = 4$
VA
no mediator, $k = 2$
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Belle 90% CL reference
$\mathcal{B}_{\mathrm{SM+NP}}(B^0 \to K^{*0} + \mathrm{inv.})\ [10^{-6}]$
$q = \chi^2_{\mathrm{SM}} - \chi^2$ of Belle II $B^+ \to K^+ \nu\bar{\nu}$
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➢ Dark Sector Interaction

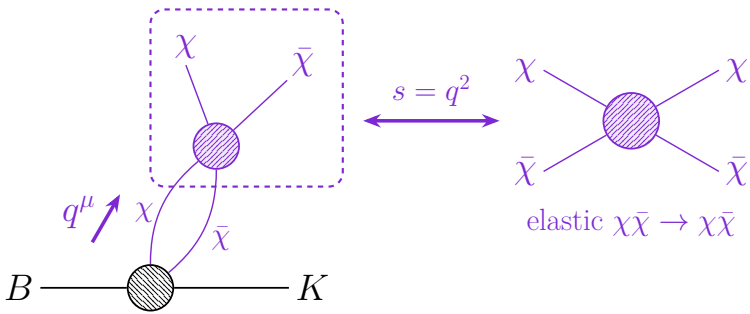
現状

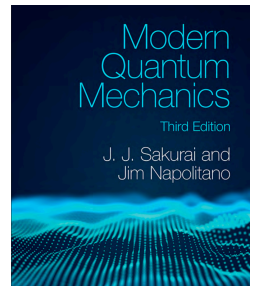
- 暗黒セクター相互作用がないモデルは $B \to K^* \nu\nu$ から強く制限
- 暗黒セクター相互作用によりスペクトルを修正できる
- 特に、Excess が見えている 4~5 GeV あたりの閾値補正が重要

課題

- 統一的に議論できる方法はないか？
- 強い相互作用だとしても有限個のパラメータでスペクトルを制御したい
- Excess を説明するパラメータを他の物理 (e.g. DM) へ応用したい

➢ Effective Range Expansion





$$\sigma_{\text{tot}} = \sigma_{l=0} = 4\pi \lim_{k\to 0} \left| \frac{1}{k\cot\delta_0 - ik} \right|^2$$

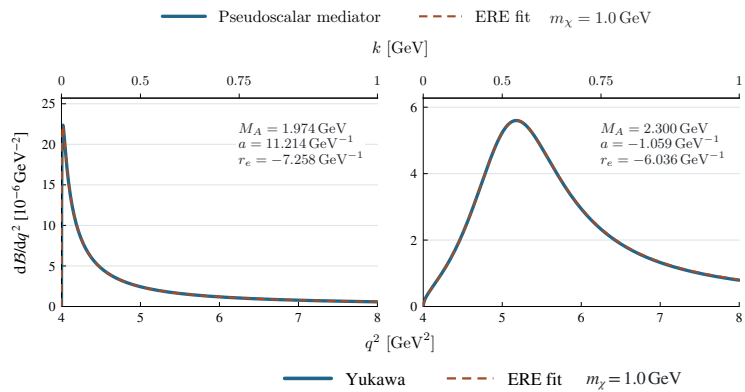
$$\frac{d\mathcal{B}_{\text{cont}}}{dq^2} \propto \left(\frac{d\mathcal{B}}{dq^2}\right)_{\text{free}} \times \underbrace{\frac{\left|1 + c_2\, k^2\right|^2}{\left(-1/a + \frac{1}{2} r_e k^2\right)^2 + k^2}}_{\text{ERE factor}} .$$

$$k\,\cot\,\delta_0 = -\frac{1}{a} + \frac{1}{2} r_0 k^2$$

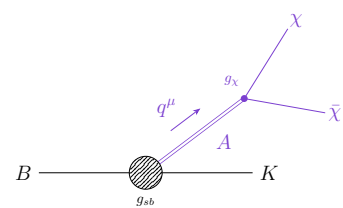
$$k^2 = \frac{q^2}{4} - m_\chi^2$$

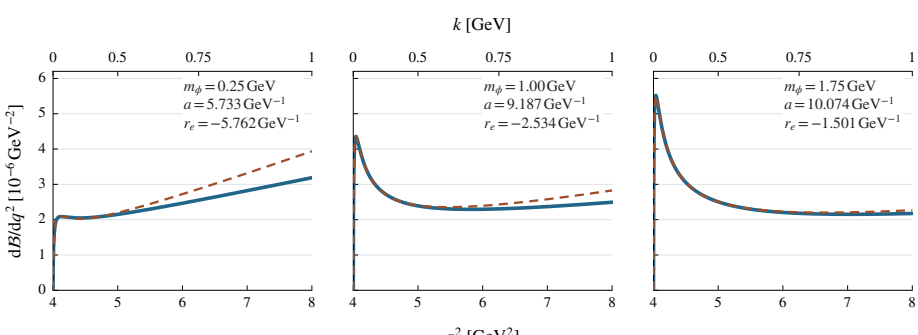
PhysRev.88.1163

➢ Accuracy of Effective range expansion



$$\mathcal{L}_{\rm int} = -g_\chi\, A\, \bar{\chi}\, i\gamma_5 \chi - \left(g_{sb}\, A\, \bar{s} b + \text{h.c.}\right).$$





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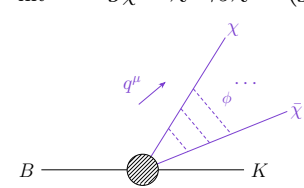
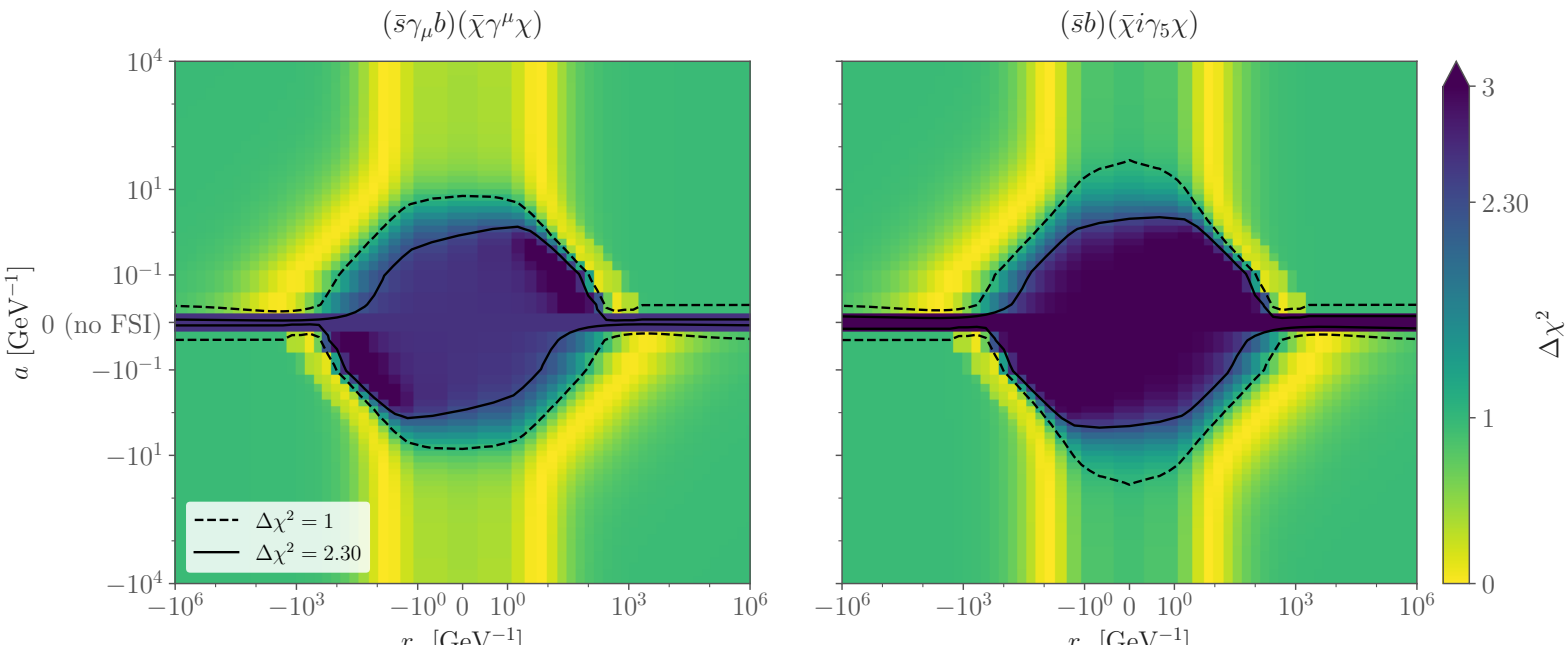
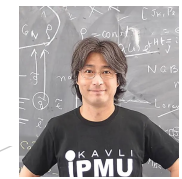


➢ Result


$(\bar{s}\gamma_\mu b)(\bar{\chi}\gamma^\mu\chi)$
$(\bar{s}b)(\bar{\chi}i\gamma_5\chi)$
a [GeV^{-1}]
r_e [GeV^{-1}]
10^4
10^1
10^{-1}
0 (no FSI)
-10^{-1}
-10^1
-10^4
-10^6
-10^3
-10^0 0 10^0
10^3
10^6
$\Delta\chi^2 = 1$
$\Delta\chi^2 = 2.30$
3
2.30
1
0
$\Delta\chi^2$

➢ Application: SIDM

hep-ph/1908.06067v3

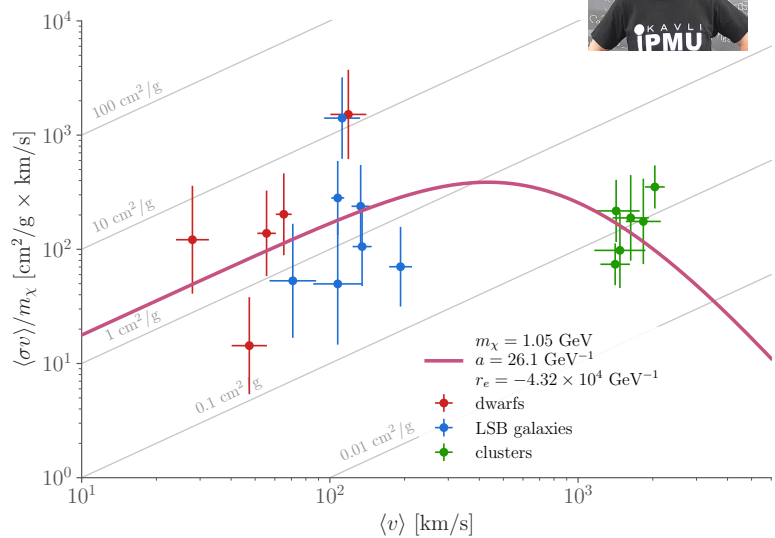


- CDM と観測の DM ハロー分布が異なる
(矮小銀河, LSB)

- DM の自己相互作用を入れる

- SIDM (Self interacting dark matter)

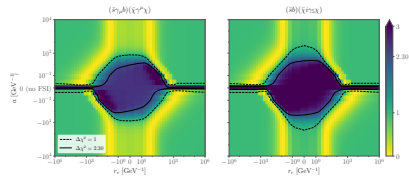
ERE のパラメータで性質が決まる



➢ Summary

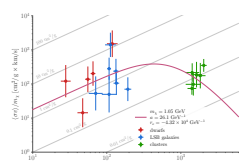
- モデルに依存せず、閾値効果を取り入れる方法を提案した

- 終状態相互作用がある方が好まれる



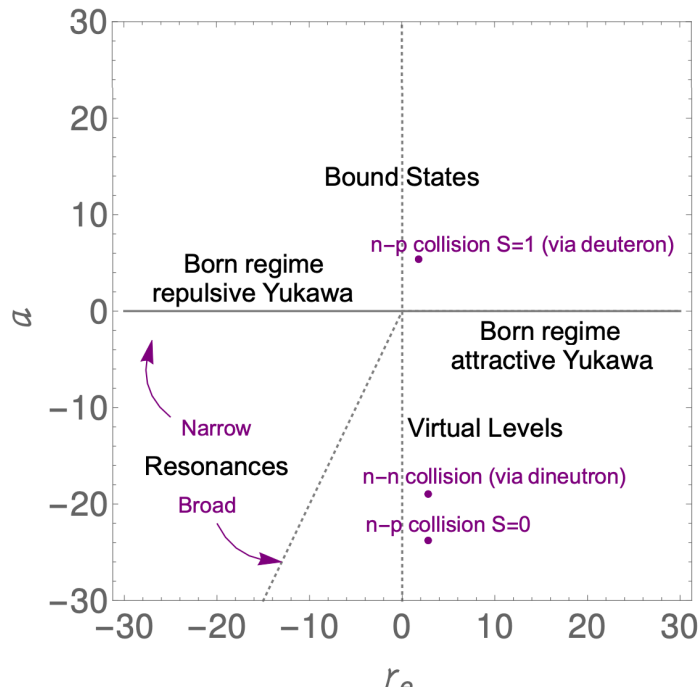
- B to K^* が SM あたりで測定されると暗黒セクター間の相互作用が必要

- SIDM と整合する パラメータ領域がある (この解析で見つけた)



- より詳細な q^2 分布が手に入れば、より暗黒セクターの特徴を絞れる

Backup



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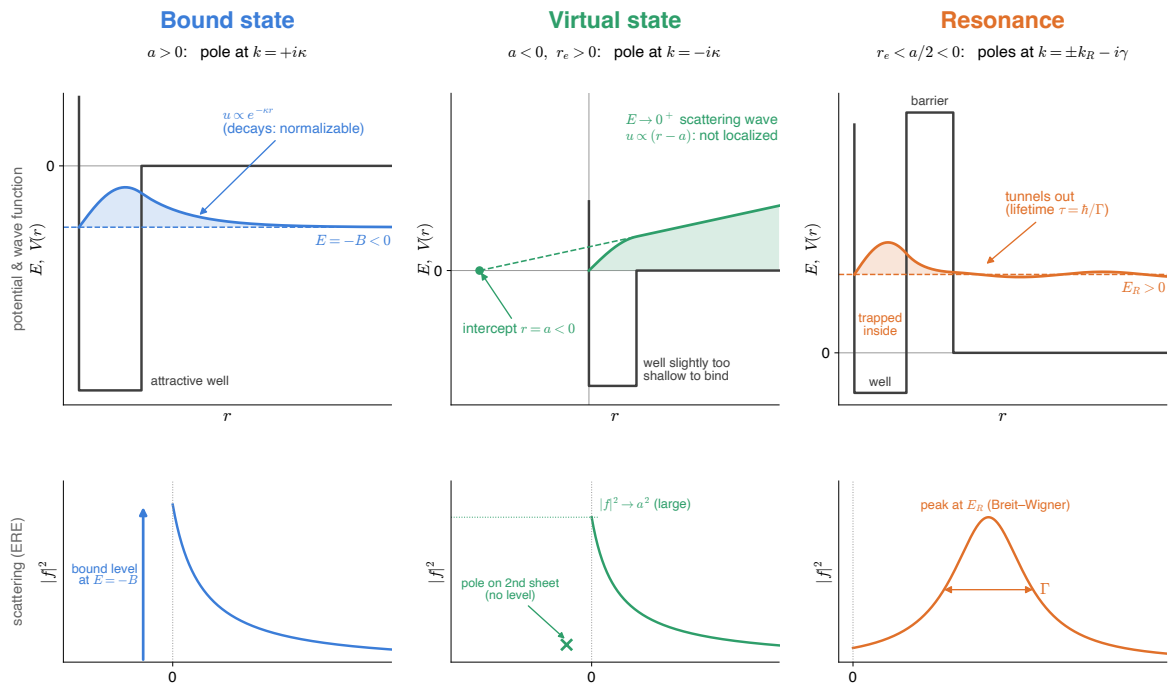
Bound state
$a > 0$: pole at $k = +i\kappa$
Virtual state
$a < 0,\ r_e > 0$: pole at $k = -i\kappa$
Resonance
$r_e < a/2 < 0$: poles at $k = \pm k_R - i\gamma$
potential & wave function
$E,\ V(r)$
$u \propto e^{-\kappa r}$
(decays: normalizable)
$E = -B < 0$
attractive well
r
$E \to 0^+$ scattering wave
$u \propto (r - a)$: not localized
intercept $r = a < 0$
well slightly too
shallow to bind
barrier
tunnels out
(lifetime $\tau = \hbar/\Gamma$)
$E_R > 0$
trapped
inside
well
scattering (ERE)
$|f|^2$
bound level
at $E = -B$
E
$|f|^2 \to a^2$ (large)
pole on 2nd sheet
(no level)
peak at E_R (Breit–Wigner)
Γ

$$\rho(E) = -\tfrac{1}{\pi}\,\mathrm{Im}\,T(E+i0)\text{:}\quad \rho = \tfrac{1}{\pi}\,k\,|f(k)|^2 \text{ for } E>0,\quad f = \left(-\tfrac{1}{a} + \tfrac{r_e}{2}k^2 - ik\right)^{-1}$$

