Sensitivity to New Physics in $B \to VV$ Polarization, or

Have we seen new physics in $B \to \phi K^*$?

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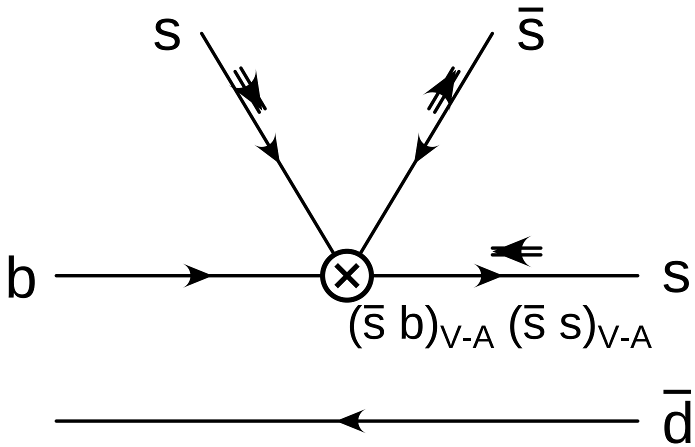
Outline

- $B \to VV$ Polarization in the Standard Model for light vectors
  e.g., ϕK^*, $K^*\rho$, $\rho\rho$
  - Naive Factorization
  - Power Counting for Non-Factorizable amplitudes
- Sensitivity to New Physics, Comparison with data
  - $R_T \sim R_0 \Rightarrow$ new Dirac Structure
  - $R_\perp \gg R_\parallel \Rightarrow$ RH Currents
- Which new operators are the most interesting?
  A few surprises!

Also see AK, SSI 02; SLAC workshops; WIN 03

Polarization in the SM: Naive Factorization (NF)

- Eg, $\bar{B}^{0,-} \to \phi K^{*0,-}$ helicity amplitudes
  - $A^{0,-,+} \equiv \phi,\ K^*$ longitudinal, negative, positive helicities



$$\mathcal{A}^0 = O(1), \quad \mathcal{A}^- = O(1/m), \quad \mathcal{A}^+ = O(1/m^2)$$

- $\mathcal{A}^-/\mathcal{A}^0 = \mathcal{O}(m_\phi/m_B)$, helicity of $\bar{s}$ in ϕ flipped
  - twist-3 ϕ projection
- $\mathcal{A}^+/\mathcal{A}^- = \mathcal{O}(\Lambda_{QCD}/m_b)$, helicity of s in K^* flipped
  - form factor suppression -use large energy form factor relations of Charles et al

Large energy form factor relations and SCET

- Large energy relations for soft form factor contribns Charles et al

$$\frac{m_B}{m_B+m_V} V(q^2) = \frac{m_B+m_V}{2E} A_1(q^2) \equiv \zeta_\perp(E)$$

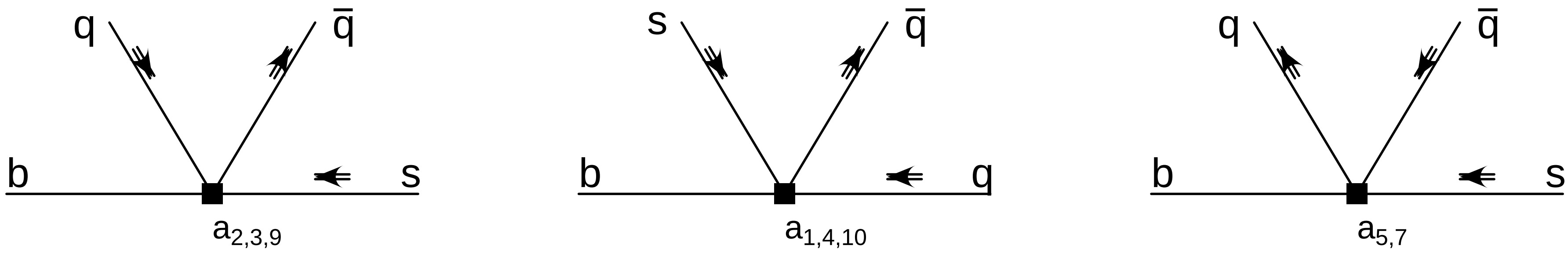
$$\frac{m_V}{E} A_0(q^2) = (1+\frac{m_V}{m_B}) A_1(q^2) - (1-\frac{m_V}{m_B}) A_2(q^2) \equiv \zeta_\|(E)$$

- Soft form factors receive negligible Sudakov suppresion in SCET Lange, Neubert
- SCET power corrections start at $O(1/m)$ Beneke, Feldmann

$$\Longrightarrow A_1 - V = O(\frac{1}{m_b})$$

- Corrections from $\mathcal{O}(\alpha_s)$ form factor contribns
  - negligible for $A_0/A_1/A_2$ relation Beneke, Feldmann
  - vanish for A_1/V and T_1/T_2 relations Burdman, HIller

Implications for $\bar{B} \to V_1 V_2$ amplitudes in NF



V_2: two upward lines, V_1: Form factor vector meson

- contributions to the helicity amplitudes, $\mathcal{A}^h(V_1V_2)$:

$$\mathcal{A}^0(V_1V_2) \;\propto\; f_{V_2}\, m_B^2\, \zeta_{\|}^{V_1} = O(1)$$

$$\mathcal{A}^-(V_1V_2) \;\propto\; -2 f_{V_2}\, m_{V_2}\, m_B\, \zeta_{\perp}^{V_1} = O\left(\frac{1}{m}\right)$$

$$\mathcal{A}^+(V_1V_2) \;\propto\; -f_{V_2}\, m_{V_2}\, m_B \times O(\zeta_{\perp}^{V_1} \frac{\Lambda_{QCD}}{m_b}) = O\left(\frac{1}{m^2}\right)$$

- $\mathcal{A}^-$: quark helicity-flip costs one unit of twist or $1/m$

- $\mathcal{A}^+$: additional helicity-flip $\Longrightarrow$ form factor suppression $1/m$

Transversity Basis

Transverse amplitudes in transversity basis:

$$A_{\perp,\parallel} \equiv (A^- \pm A^+)/\sqrt{2}$$

- In naive factorization, rates satisfy

$$\frac{\Gamma_\perp}{\Gamma_\parallel} = 1 + O\left(\frac{1}{m_b}\right)$$

- Total transverse rate, $\Gamma_T = \Gamma_\perp + \Gamma_\parallel$, satisfies

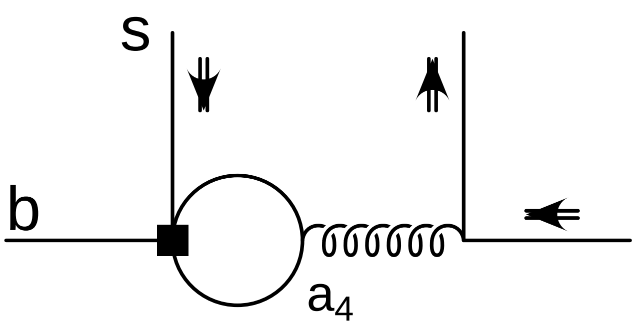
$$\frac{\Gamma_{\mathrm{T}}}{\Gamma_0} = O\left(\frac{1}{m_b^2}\right)$$

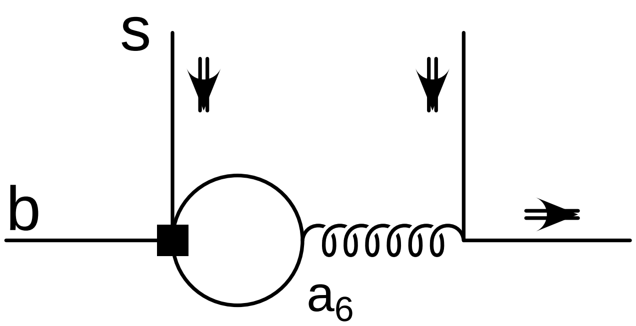
- Is power counting preserved by non-factorizable effects? Can address in QCD factorization
  - penguin contractions, vertex corrections, spectator interactions, annihilation graphs, $(q\bar{q}g)$ states

Non-factorizable helicity amplitudes in QCD factorization

previous work: Cheng, Yang; Li, Lu, Yang

1) Penguin contractions: charm quark, up quark loops



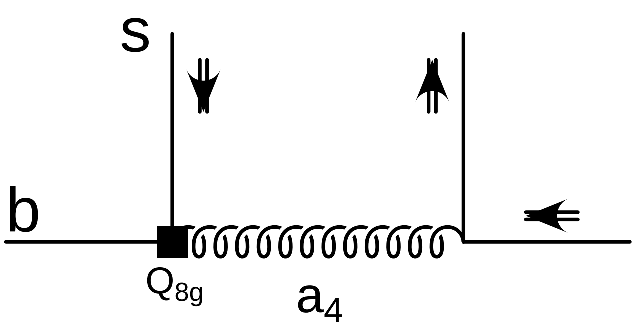


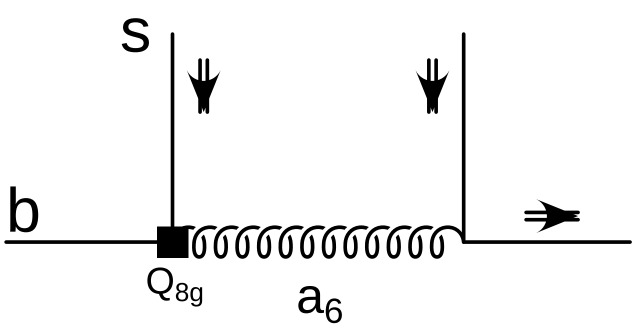
V_2: two upward lines, V_1: Form factor vector meson

	$\mathcal{A}^0$	$\mathcal{A}^-$	$\mathcal{A}^+$
a_4	$O(1)$	$O\left(\frac{1}{m_b}\right)$ twist-3^{V_2}	$O\left(\frac{1}{m_b^2}\right)$ twist-3^{V_2} $\times$ FF^{V_1}
a_6	$O\left(\frac{1}{m_b}\right)$ twist-3^{V_2}	—	—

Each helicity-flip costs $\frac{1}{m}$: one unit of twist or FF suppression

2) Penguin contractions: chromomagnetic dipole operator Q_{8g}





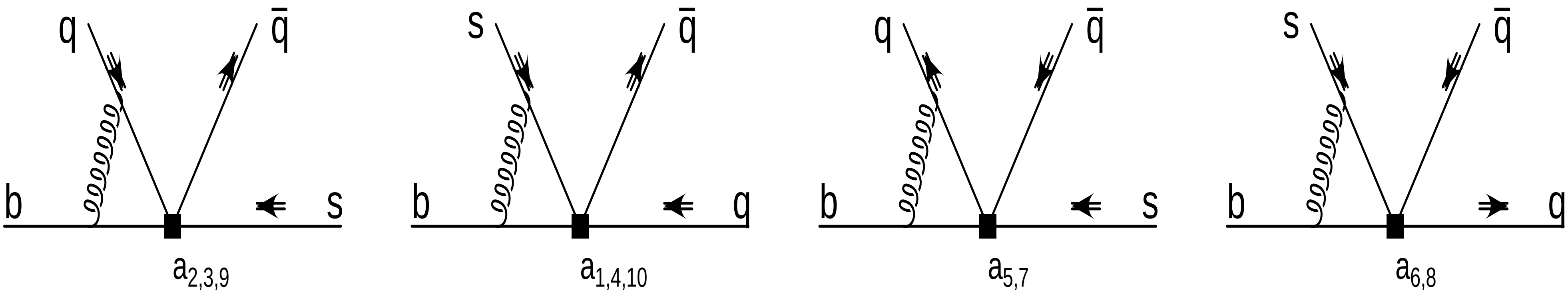
Contribution of a_4^0 to $\mathcal{A}^0$ is $O(1)$. All other contributions vanish!

- Physical reason? would require coupling to longitudinal component of gluon but:

  dipole operator tensor current only couples to transverse component

- Important implications for NEW PHYSICS

3) Vertex corrections:

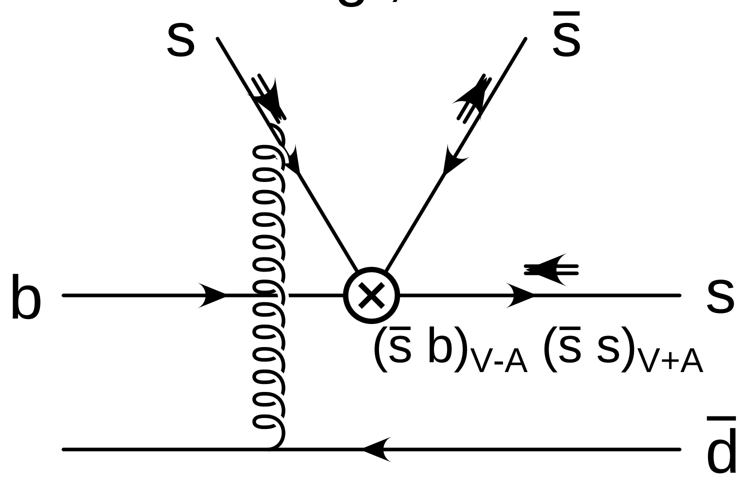


V_2: two upward lines, V_1: Form factor vector meson

	$\mathcal{A}^0$	$\mathcal{A}^-$	$\mathcal{A}^+$
$a_{1,..,4,9,10}$	$O(1)$	$O\left(\frac{1}{m_b}\right)$ twist-3^{V_2}	$O\left(\frac{1}{m_b^2}\right)$ twist-3$^{V_2} \times$ FF^{V_1}
$a_{1,..,4,9,10}$	$O(1)$	$O\left(\frac{1}{m_b}\right)$ twist-3^{V_2}	$O\left(\frac{1}{m_b^2}\right)$ twist-3$^{V_2} \times$ FF^{V_1}
$a_{6,8}$	$O\left(\frac{1}{m_b}\right)$ twist-3^{V_2}	$\leq O\left(\frac{1}{m_b^3}\right)$ twist-4$^{V_2} \times$ FF^{V_1}	$\leq O\left(\frac{1}{m_b^2}\right)$ twist-4^{V_2}

Each helicity-flip costs $\frac{1}{m}$: one unit of twist or FF suppression

4) Spectator interactions: e.g.,



$$A^0 = O(1), \qquad A^- = O\left(\frac{1}{m}\ln\frac{m}{\Lambda_h}\right), \qquad A^+ = O\left(\frac{1}{m^2}\ln\frac{m}{\Lambda_h}\right)$$

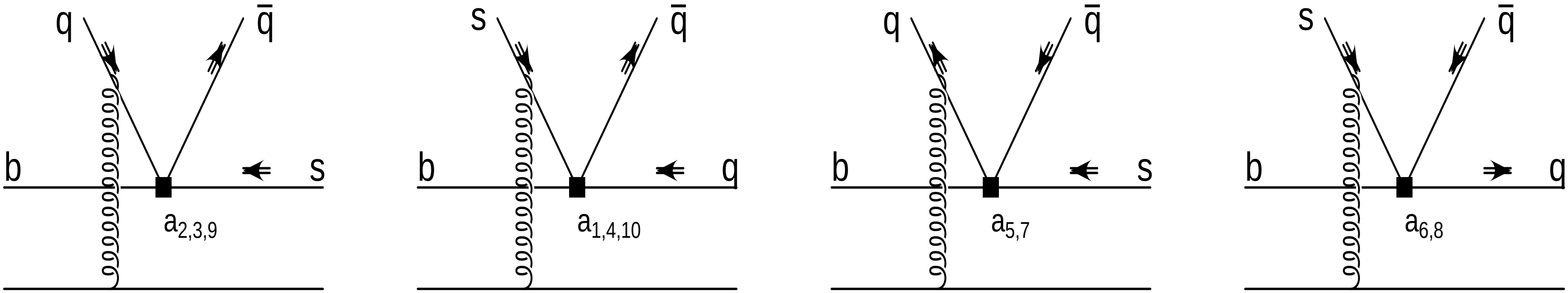
- Soft spectator limit in $V_1 \Longrightarrow$

  Log divergences at $\geq$ twist-3, phys cutoff $\Lambda_h \sim \Lambda_{QCD}$

- In SCET expect same power counting but:

  Log divergences $\Rightarrow$ non-perturbative universal parameters

Spectator interaction summary:



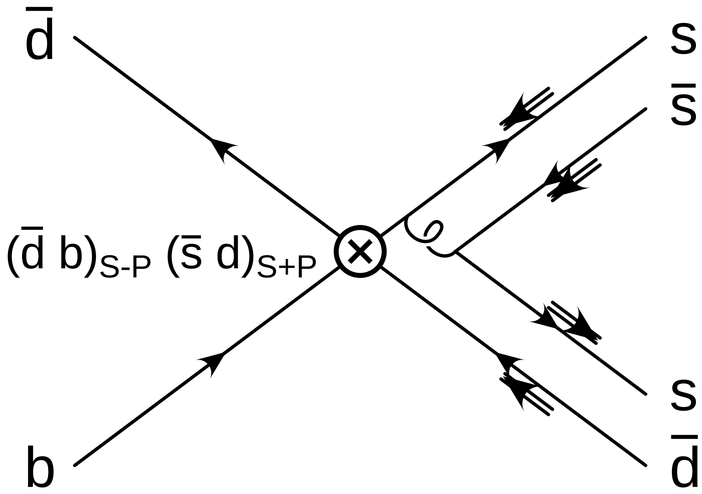
V_2: two upward lines, V_1: Form factor vector meson

	$\mathcal{A}^0$	$\mathcal{A}^-$	$\mathcal{A}^+$
$a_{1,..,4,9,10}$	$O(1)$	$O\left(\frac{1}{m}\ln\frac{m}{\Lambda_h}\right)$ twist-3^{V_2}	$O\left(\frac{1}{m^2}\ln\frac{m}{\Lambda_h}\right)$ twist-3$^{V_1}\times$ twist-3^{V_2}
$a_{5,7}$	$O(1)$	$O\left(\frac{1}{m}\ln\frac{m}{\Lambda_h}\right)$ twist-3^{V_2}	$O\left(\frac{1}{m^2}\ln\frac{m}{\Lambda_h}\right)$ twist-3$^{V_1}\times$ twist-3^{V_2}
$a_{6,8}$	—	$O\left(\frac{1}{m}\ln\frac{m}{\Lambda_h}\right)$ twist-3^{V_1}	$O\left(\frac{1}{m^2}\ln\frac{m}{\Lambda_h}\right)$ twist-4^{V_2}

$\times$ overall parametric suppression: $\frac{C_F}{N_c^2}\frac{f_B}{m_B\zeta} \approx .02$

- Each helicity-flip costs one unit of twist

5) Annihilation graphs: e.g., $a_6 < (\bar{d}b)_{S-P} \times (\bar{s}d)_{S+P} >$



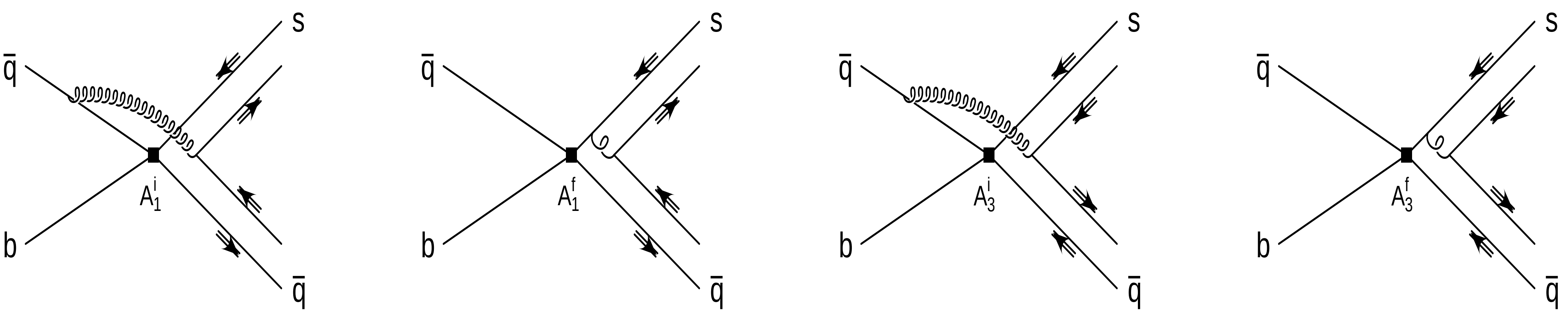
$$\mathcal{A}^0,\ \mathcal{A}^- = O\left(\frac{1}{m^2}\ln\frac{m}{\Lambda_h}\right), \qquad \mathcal{A}^+ = O\left(\frac{1}{m^4}\ln\frac{m}{\Lambda_h}\right)$$

- annihilation topology $\Longrightarrow$ overall $1/m$
- helicity-flips $\Longrightarrow$ rest of $1/m$ factors, or twists:

$\mathcal{A}^0$, $(\mathcal{A}^-)$ = twist-3$^{\phi(K^*)}$ $\times$ twist-2$^{K^*(\phi)}$ + twist-3$^{K^*(\phi)}$ $\times$ twist-2$^{\phi(K^*)}$

$\mathcal{A}^+$ = twist-4$^{\phi}$ $\times$ twist-3$^{K^*}$ + twist-4$^{K^*}$ $\times$ twist-3$^{\phi}$

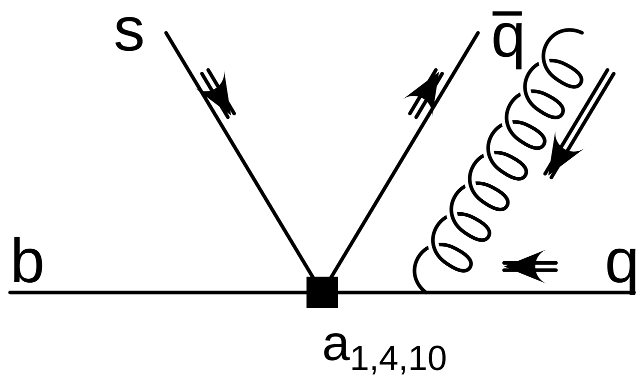
Annihilation summary:



	$\mathcal{A}^0$	$\mathcal{A}^-$	$\mathcal{A}^+$
A_1^i	$\frac{1}{m}\ln\frac{m}{\Lambda_h}$	$\frac{1}{m^3}$ (lin div) $\sim \frac{1}{m^2}$	$\frac{1}{m^3}\ln\frac{m}{\Lambda_h}$
A_1^f	—	$\frac{1}{m^3}\ln\frac{m}{\Lambda_h}$	$\frac{1}{m^3}\ln\frac{m}{\Lambda_h}$
$A_3^{i,f}$	$\frac{1}{m^2}\ln^2\frac{m}{\Lambda_h}$	$\frac{1}{m^2}\ln^2\frac{m}{\Lambda_h}$	$< \frac{1}{m^3}$
Totals	$\frac{1}{m}\ln\frac{m}{\Lambda_h}$	$\frac{1}{m^2}\ln^2\frac{m}{\Lambda_h}$	$\frac{1}{m^3}\ln\frac{m}{\Lambda_h}$

- NF power counting $(1, \frac{1}{m}, \frac{1}{m^2})$ preserved
- Each helicity-flip $\Longrightarrow$ one unit of twist, $\frac{1}{m}$

6) Higher Fock states with collinear gluons: e.g.,



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- $V_2(q\bar{q}g)$ has negative helicity but:

  $\phi(q\bar{q}g)$ distribution amplitudes are twist-3 $\Rightarrow \frac{1}{m}$

  $$\Longrightarrow \mathcal{A}^- \sim O(1/m)$$

- $\mathcal{A}^+$ could be obtained via, e.g.,

  $V_2(q\bar{q}g)$ + V_1 $(q\bar{q}g)$ $\Longrightarrow \mathcal{A}^+ \sim O(1/m^2)$

- $(q\bar{q}g)$ states preserve NF power counting!

Standard Model / Experiment Summary

- NF power-counting maintained in QCD factorization:

$$\frac{\Gamma_\perp}{\Gamma_\parallel} = 1 + O\left(\frac{1}{m}\right)$$

$$\frac{\Gamma_T}{\Gamma_0} = O\left(\frac{1}{m^2}\right)$$

Numerical analysis coming soon!

- Experimental situation ($R_{0,\perp,\parallel} \equiv \Gamma_{0,\perp,\parallel}/\Gamma_{\rm total}$):

$R_0(B^0 \to \phi K^{*0})$=0.58 ± 0.10, $R_0(B^+ \to \phi K^{*+}) = 0.46 \pm 0.12$

$$R_0(\bar{B} \to \phi K^*)_{\rm AVG} = 0.53 \pm 0.08$$

$$R_0(B^+ \to \rho^0 K^{*+}) = 0.96 \pm 0.16, \qquad R_0(B^+ \to K^{*0}\rho^+) = ?$$

$$R_0(B^+ \to \rho^+\rho^0) = 0.96 \pm 0.07, \qquad R_0(B^0 \to \rho^+\rho^-) = 0.99 \pm 0.08.$$

$R_\perp(B^0 \to \phi K^{*0}) = 0.41 \pm 0.11$, $R_\parallel(B^0 \to \phi K^{*0}) = 0.01 \pm 0.15$

New Physics in Polarization

$$\Gamma_{\mathrm{T}} \sim \Gamma_0 \quad \Longrightarrow \quad \text{Non}-\text{standard Dirac structure operators}$$

$$\Gamma_{\perp} \gg \Gamma_{\|} \quad \Longrightarrow \quad \text{right}-\text{handed (RH) currents}$$

- Tensor $\times$ Tensor operators:

$$\frac{G_F}{\sqrt{2}}\,\kappa\,\bar{s}\,\sigma_{\mu\nu}(1 \pm \gamma_5)b\,\bar{q}\,\sigma_{\mu\nu}\,q$$

$\mathcal{A}^{\mp}$ leading power, $\mathcal{A}^{0}$ subleading !

$$\kappa \sim \frac{C_4^{\mathrm{SM}}}{8} \Longrightarrow \Gamma_{\mathrm{T}} \sim \Gamma_0^{\mathrm{SM}}$$

- Tensor operators from conventional NP scenarios? Unlikely.

  $\mathrm{SUSY} + (\tan\beta \gg 1) + (m^2_{A^0} \neq m^2_{H^0}) \Rightarrow\ (S{+}P)\,(S{+}P)$ operators

  Fierz $\Longrightarrow$ tensor operators. But:

  $\kappa \propto \frac{1}{8N_c}$ (Fierz) + $B_s \to \mu\mu$ $\Longrightarrow$ negligible effects.

- Tensor operators from gluino / squark box graphs ?
  Borzumati et al

- Exciting: Flavor changing graviton / string-resonance tensor couplings in large extra dimension / low scale string models!

- $\Gamma_\perp \sim \Gamma_\parallel$ may be realized with ‘standard’ opposite chirality 4-quark operators, $\tilde{Q}_i$ $(b \to s_R)$, e.g., $(V-A)\,(V+A)$

  TREE-LEVEL operators favored!

  - dependence on SM, NP Wilson coefficients:

$$A_{0,\parallel} \propto C_i^{\rm SM} + C_i^{\rm NP} - \tilde{C}_i^{\rm NP}, \qquad A_\perp \propto C_i^{\rm SM} + C_i^{\rm NP} + \tilde{C}_i^{\rm NP}$$

  - need LARGE $\tilde{C}_i^{\rm NP}$ to beat $O(1/m)$ in $\mathcal{A}^+$
  - $\mathcal{A}_\perp$: constructive interference

    $\mathcal{A}^0$: destructive interference. Alternatively,
  - parity invariance: $C_i^{\rm NP} = \tilde{C}_i^{\rm NP} \Rightarrow \mathcal{A}_\perp$ enhanced, no effect in $\mathcal{A}^0,\ \mathcal{A}_\perp$

- $\Gamma_\perp \gg \Gamma_0 \Rightarrow$ opposite-chirality RH operators, e.g., tensor or ‘standard’ opp. chirality ops
  - $\tilde{Q}_i$: inverted hierarchy, $A^+/A^- = \mathcal{O}(1/m)$. Recall

$$A_{\perp,\parallel} \equiv (A^- \pm A^+)/\sqrt{2}$$