Implementation of Quarkonium Production cross sections within Madgraph

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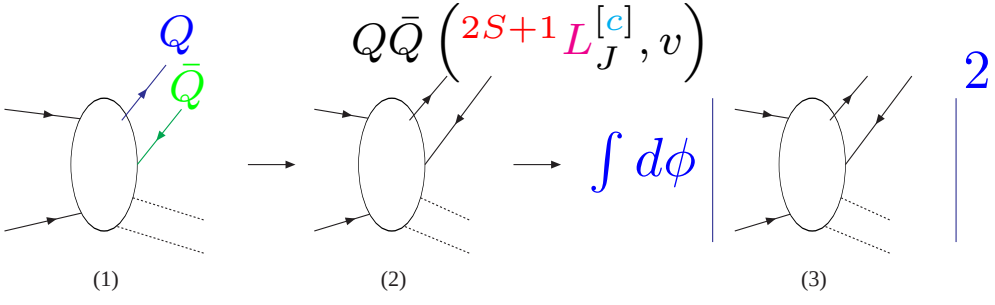
the purpose of MadOnia

- expression of cross sections within NRQCD:

$$\sigma(ij \to \mathcal{Q} + X) \quad = \quad \sum_n \hat{\sigma}(ij \to Q\bar{Q}(n) + X) \langle \mathcal{O}^{\mathcal{Q}}(n) \rangle_\Lambda$$

  - $\langle \mathcal{O}^{\mathcal{Q}}(n) \rangle$ is the long distance matrix element
  - $\hat{\sigma}(i + j \to Q\bar{Q}(n) + X)$ is the short distance cross section

- MadOnia: automatic tree-level computation of $\hat{\sigma}(ij \to Q\bar{Q}(n) + X)$



(1) open quark amplitude (MadGraph)

(2) projected amplitude (MadOnia)

(3) phase-space integration (unweighting $\longrightarrow$ MC event generator)

the purpose of MadOnia

- capabilities:
  - universality: MadOnia generates any helicity amplitude

$$\mathcal{M}\left(ij \to Q\bar{Q}\left({}^{2S+1}L_J^{[c]}\right) + X\right)$$

    at tree-level, for any model that can be implemented in MadGraph
  - it keeps track of quantum numbers on event-by-event basis $\longrightarrow$ events ready for showering and hadronization (in particular, calculation in terms of color-ordered amplitudes).
  - $Q\bar{Q}'$ production: the quark and the anti-quark can be of different flavour (such as B_c)
  - double quarkonium production (ex: $e^+e^- \to J/\psi\eta_c$)
  - relativistic corrections for S-wave state production can be computed