

# Implementation of Quarkonium Production cross sections within Madgraph

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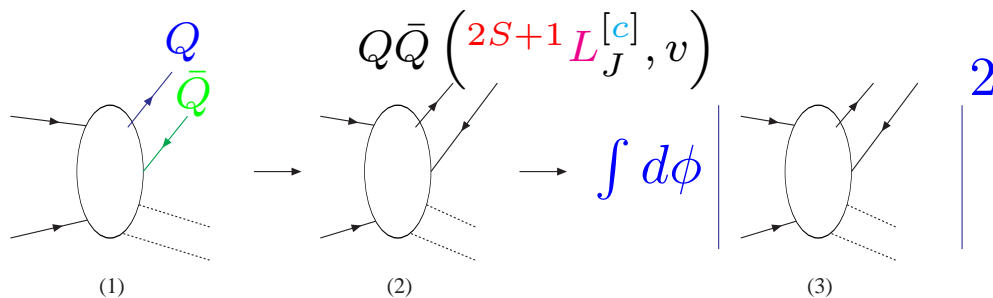
# the purpose of MadOnia

- expression of cross sections within NRQCD:

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

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

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



(1) open quark amplitude  
(MadGraph)

(2) projected amplitude  
(**MadOnia**)

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

# the purpose of MadOnia

● capabilities:

- **universality**: MadOnia generates any helicity amplitude

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

at tree-level, for any model that can be implemented in MadGraph

- it keeps track of **quantum numbers** on event-by-event basis → 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:  $e^+e^- \rightarrow J/\psi\eta_c$ )
- **relativistic corrections** for  $S$ -wave state production can be computed