HELAC-Onia

Hua-Sheng Shao
Peking University
PH-TH, CERN

Charmonium Workshop, LAL-Orsay

06 March 2013

arXiv:1212.5293

http://helac-phegas.web.cern.ch/helac-phegas

erdissshaw@gmail.com

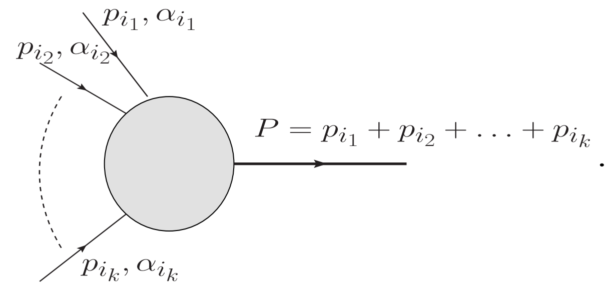
HELAC-Onia framework

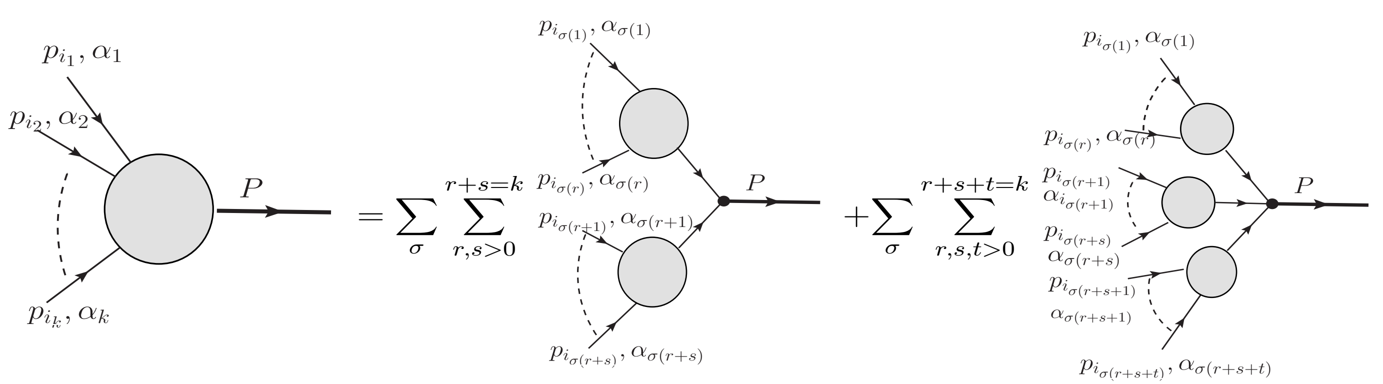
HELAC-Onia in a nutshell

- HELAC generates the QCD and EW amplitudes at the partonic level based on Dyson-Schwinger equations. *A. Kanaki, C.G.Papadopoulos (2000)* *C.G.Papadopoulos, M.Worek (2006)*
- PHEGAS generates partonic level events with multi-channel techniques. *C.G.Papadopoulos (2000)*
- Onia generates hadronic (or quarkonium) level helicity amplitudes and physical observables based on the factorization of non-relativistic quantum chromodynamics.

recursion relation

$$\mathcal{J}(\{p_{i_1},\ldots,p_{i_k}\};\{\alpha_{i_1},\ldots,\alpha_{i_k}\}) \equiv$$

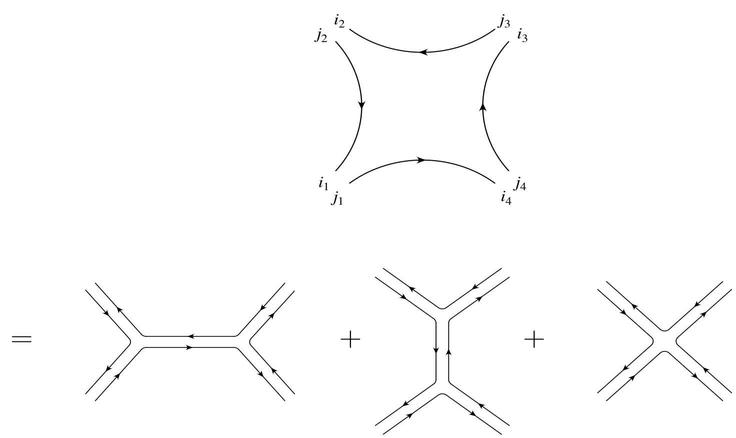


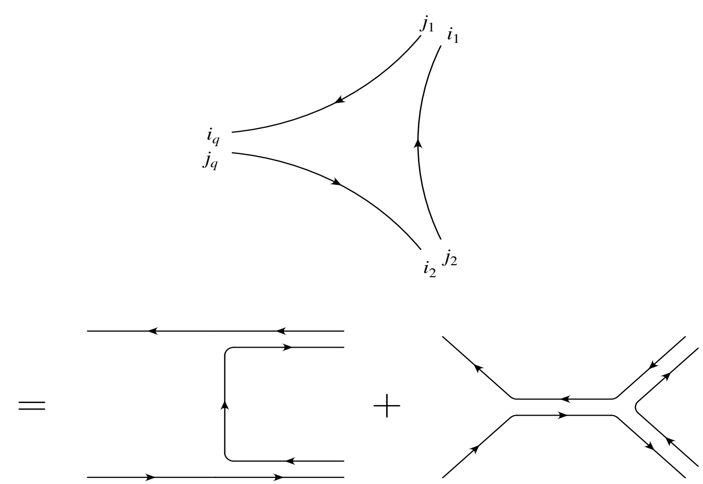


Generalization of Berends-Giele recursion relation !!!

color decomposition

- N particle amplitudes can be decomposed as, $A_N = \sum C_i A_N^i$, where $C_i = \delta_1^{\sigma_i(1)} \delta_2^{\sigma_i(2)} \cdots \delta_n^{\sigma_i(n)} (n \le N)$. The final color matrix is $M_{ij} = \sum C_i C_j$, and the final square of amplitudes is $A_N A_N^* = \sum_{i,j} M_{ij} A_N^i A_N^{j*}$ (color flow basis).
- For illustration:1)g g > g g 2) q q~ > g g





Quarkonium amplitudes

- In NRQCD factorization,

$$\sigma(pp \to \mathcal{Q} + X) = \sum_{i,j,n} \int \mathrm{dx_1 dx_2} f_{\mathrm{i/p}}(\mathrm{x_1}) f_{\mathrm{j/p}}(\mathrm{x_2}) \hat{\sigma}(\mathrm{ij} \to \mathrm{Q\bar{Q}[n] + X}) \langle \mathcal{O}_{\mathrm{n}}^{\mathcal{Q}} \rangle,$$

- Projection method is used to constrain the spin and color quantum number of heavy quark pair in its short distance coefficient.
- P-wave currents are introduced in order to calculate helicity amplitudes of P-wave fock states.

More technical details are presented in arXiv:1212.5293

What could HELAC-Onia do ?

- Multi heavy quarkonium, including Bc system, production at the pp(p~) and e+e- colliders.
- Multi P-wave heavy quarkonium production at the pp(p~) and e+e- colliders.
- Fully differential distributions calculations.
- Spin density matrix elements in helicity frame, Collins-Soper frame, Gottfried-Jackson frame and target frame.
- EW particles with complex mass scheme and jets with inclusive kT clustering procedure.
- LHE files can be generated with modified PHEGAS.

→ **First step to full NLO automation !!!**

Benchmark processes

arXiv:1212.5293

- Bc meson production at the LHC.
- Charmonium production at B factories. Single charmonium and double charmonium production.
- Double quarkonia production at hadron colliders.
- Hadroproduction of quarkonia in association with a heavy quark pair.
- Spin density matrix and polarization.

Application

How to use HELAC-Onia?

- 1.Specify input parameters in user.inp following the format in default.inp.
- 2.Provide process information in process.inp.
- 3.Compile with the command line:

  > make
- 4.Run with the command line:

  > ./Helac-Onia
- 5.If one wants to remove the output files, object files and exectuable files, run the command line:

  > make clean

An example

- If we want to calculate

$$e^- e^+ > \eta_c({}^1S_0^{[1]})ggg$$

- Specify the process information in process.inp:

```
6
2 -2 441001 35 35 35
# nhad
...
```

- 6 ← Total number of external legs nhad=6
- 2 -2 441001 35 35 35 ← Ids for the process
- # nhad, ... ← comments

An example

- Choose input parameters in user.inp:

```
colpar 3  # 1=pp,2=ppbar,3=e+e-
energy 10.6d0 # cms energy
qcd 4  # qcd and qed
alphasrun 0 # running alphas (1) or not (0)
cmass 1.5d0 # mass of charm quark
# e+e- cutoff
cutoffe 1.0d-10 # cutoff (e+e- case)
minenl 0d0 # minimum lepton energy
mineng 0d0 # minimum quark energy
minangll 0d0 # minimum angle l-l
minanglq 0d0 # minimum angle l-q
minangqq 0d0 # minimum angle q-q
minmqqe 0d0  # minimum mass q-q (e+e-)
unwgt T       # unweighting on/off
alphas2 0.26d0 # fixed value of alphas
alphaem 0.00729927d0 # alphaem value
```

```
preunw 10000 # n. of pre-unw events
unwevt 100000 # n. of unw events
nmc  100000  # number of MC interation
nopt  10000  # opti parameteter
nopt_step  10000 # opti parameter
optf 1 # opti parameter
maxopt 8 #opti parameter
noptlim 100000 # opti parameter
iopt 1 # opti parameter
alimit 0 #  lower limit of alpha(i) in mul-cha
gener 0 # 0 PHEGAS 1 RAMBO 3 VEGAS
ranhel 3 # MC over helicities
ptdisQ F # don't calculate pt distribution
Scale 0 # 0=fixed scale
FScaleValue 5.3d0 # the value of fixed scale
LDMEcc1S01 0.0645d0 # 0.387/2/Nc
```

An example

- Run ./Helac-Onia. Two useful output files generated: RESULT_eebaretac1ggg.out,sampleeebaretac1ggg.lhe (only when unwgt=1 and gener=0).

RESULT_eebaretac1ggg.out

```
...
average estimate :   0.373070D-05
                  +\-   0.200429D-07
 variance estimate:   0.401719D-15
                    +\-   0.559955D-17
out of       100000        100001  points have been used
and        100001  points resulted to =/= 0 weight
whereas            0  points to 0 weight
-----------------------------------
total sigma (nb) =   0.373070D-05   +\-   0.200429D-07
-----------------------------------
% error:   0.537244D+00
-----------------------------------
lwri: number of points have used   8931.0000000000000
The Timing Consuming in Phase Space Integration is:
0  h;          4  m;          11  s;          38  centi s
```

sampleeebaretac1ggg.lhe

```
<LesHouchesEvents version="1.0">
<!--
File generated with HELAC_PHEGAS_ONIA
 -->
<init>
11    -11  5.300000E+00  5.300000E+00  -1  -1\
  -1    -1    3    1 3.7306977547E-03 2.004293\
5975E-05    1.0000000000E+00    81
</init>
<event>
...
```

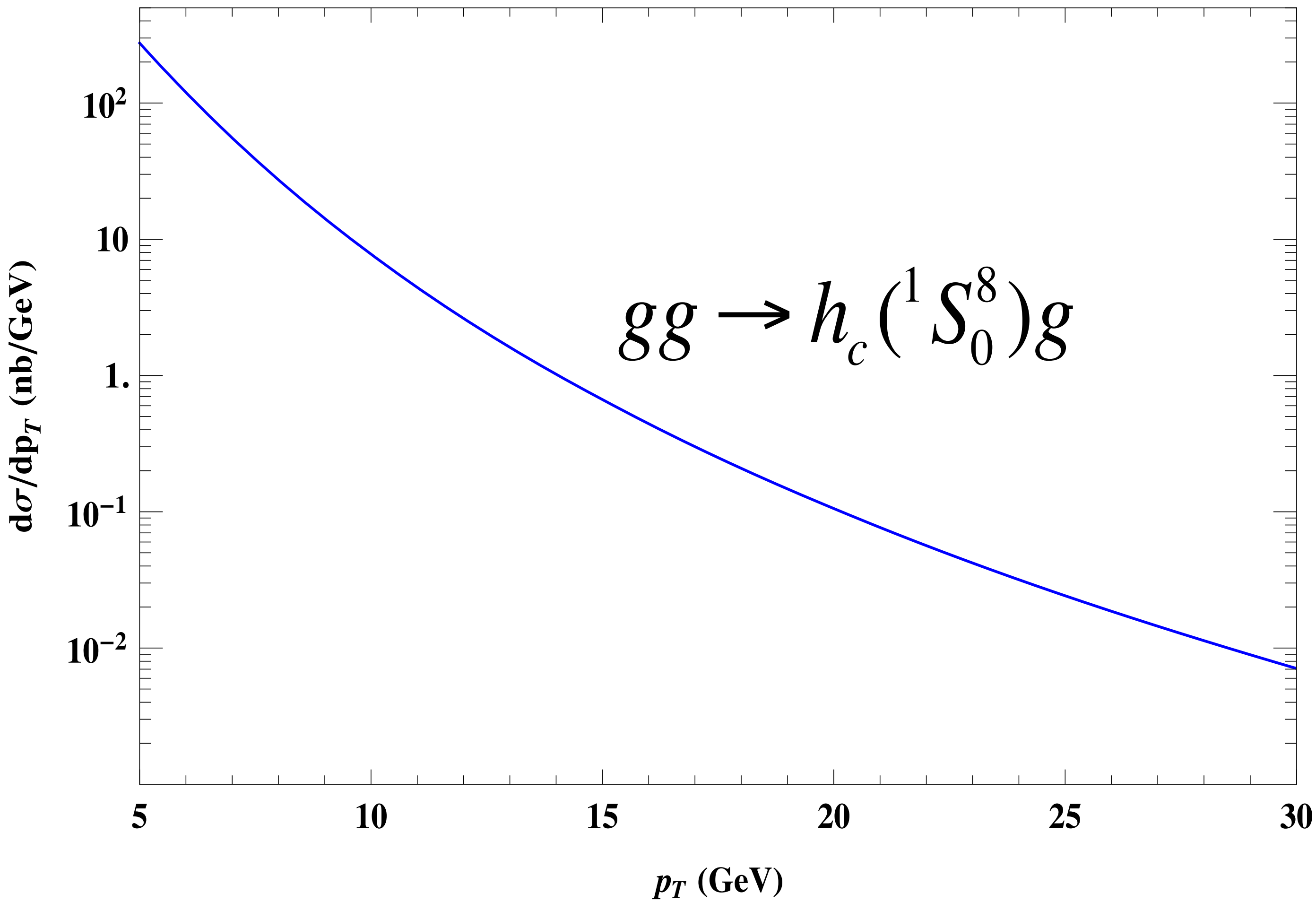
ηc and hc

- From above example, it is quite easy for one to calculate ηc and hc production rate at the LHC. The fock states up to O(v^7) for ηc are ${}^1S_0^{[1/8]}, {}^3S_1^{[8]}, {}^1P_1^{[8]}$, and for hc are ${}^1S_0^{[8]}, {}^1P_1^{[1]}$.
- For example, I recalculated the dominant sub-channel $gg \to h_c({}^1S_0^8)g$ use the the same input parameters (except using CTEQ6L1) as in arXiv:0904.0726 (others see C.-F.Qiao's talk),

$$m_c = 1.78GeV, \mu = \sqrt{4m_c^2 + p_T^2}, |\eta(h_c)| < 2.2,$$

$$\langle O^{h_c}({}^1S_0^{[8]})\rangle = 9.8 \times 10^{-3} GeV^3, CTEQ6L1$$

ηc and hc



$gg \rightarrow h_c(^1S_0^8)g$
dσ/dp_T (nb/GeV)
10^2
10
1.
10^-1
10^-2
5
10
15
20
25
30
p_T (GeV)

Close words

- The program is available at http://helac-phegas.web.cern.ch/helac-phegas .
- If you have any questions about HELAC-Onia, please don't hesitate to contact me:

erdissshaw@gmail.com

- **Thanks for your attention !!!**