HELAC-Onia: An Automatic Matrix Element/Event Generator For Heavy Quarkonium Physics

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Thursday, November 13, 14

ME/EVENT GENERATORS ON MARKET

w/o onia	w/ onia

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LO • Alpgen **Mangano, Moretti, Piccinini, Pittau, Polosa** • MG5/ME5 **Alwall, Herquet, Maltoni, Mattelaer, Stelzer** • HELAC-PHEGAS **Cafarella, Kanaki, Papadopoulos, Worek** • Sherpa ... **Gleisberg, Hoche, Krauss, Schaelicke, Schumann, Winter**	

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HELAC-Onia

Helac-Onia

HELAC-Onia is an automatic matrix element generator for the calculation of the heavy quarkonium helicity amplitudes in the framework of NRQCD factorization. The program is able to calculate helicity amplitudes of multi P-wave quarkonium states production at hadron colliders and electron-positron colliders by including new P-wave off-shell currents. Besides the high efficiencies in computation of multi-leg processes within the Standard Model, HELAC-Onia is also sufficiently numerical stable in dealing with P-wave quarkonia and P-wave color-octet intermediate states.

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People

Hua-Sheng Shao

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Compilers:

- gfortran

:: top ::

Software Download

NEW **HELAC-Onia Curent Version 1.1.2** (17 June 2013): HELAC-Onia-1.1.2.tar.gz

HELAC-Onia Version 1.0.0 (10 January 2013): HELAC-Onia-1.0.tgz

:: top ::

- **First version released on 10 Jan 2013.**
- **Download from** http://helac-phegas.web.cern.ch/helac-phegas/helac-onia.html
- **More and more functionalities are adding ...**

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HELAC-Onia: An automatic matrix element generator for heavy quarkonium physics☆

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ABSTRACT

By the virtues of the Dyson–Schwinger equations, we upgrade the published code HELAC to be capable to calculate the heavy quarkonium helicity amplitudes in the framework of NRQCD factorization, which we dub HELAC-Onia. We rewrote the original HELAC to make the new program be able to calculate helicity amplitudes of multi P-wave quarkonium states production at hadron colliders and electron–positron colliders by including new P-wave off-shell currents. Therefore, besides the high efficiencies in computation of multi-leg processes within the Standard Model, HELAC-Onia is also sufficiently numerical stable in dealing with P-wave quarkonia (e.g. $h_{c,b}$, $\chi_{c,b}$) and P-wave color-octet intermediate states. To the best of our knowledge, it is a first general-purpose automatic quarkonium matrix elements generator based on recursion relations on the market.

Program summary

Program title: HELAC-Onia.

Catalogue identifier: AEPR_v1_0

Program summary URL: http://cpc.cs.qub.ac.uk/summaries/AEPR_v1_0.html

Program obtainable from: CPC Program Library, Queen's University, Belfast, N. Ireland

BASICS

- Based on off-shell recursion relations, i.e. Dyson-Schwinger equation.
- Closed fermion chain between QQ is cutted again to form new effective wavefunctions.
- P-wave currents are introduced to avoid numerical instablity issue in P-wave production helicity amplitudes.

4 Benchmark processes

4.1 B_c meson production at the LHC

OVERVIEW OF (EARLY) BENCHMARKS

4 Benchmark processes

4.1 B_c meson production at the LHC

process	HELAC-Onia(nb)	MADONIA(nb)
$gg \to B_c^+(^1S_0^{[1]})b\bar{c}$	39.3994 ± 0.0958382	39.4
$gg \to B_c^+(^3S_1^{[1]})b\bar{c}$	98.3109 ± 0.287252	98.3
$gg \to B_c^+(^1P_1^{[1]})b\bar{c}$	5.21131 ± 0.0144431	5.20
$gg \to B_c^+(^3P_J^{[1]})b\bar{c}$	16.7341 ± 0.0589108	16.72
$gg \to B_c^+(^1S_0^{[8]})b\bar{c}$	0.411671 ± 0.00169734	0.411
$gg \to B_c^+(^3S_1^{[8]})b\bar{c}$	1.78657 ± 0.00624756	1.79
$gg \to B_c^+(^1P_1^{[8]})b\bar{c}$	0.11816 ± 0.000754526	0.117
$gg \to B_c^+(^3P_J^{[8]})b\bar{c}$	0.305862 ± 0.0011841	0.3051
$q\bar{q} \to B_c^+(^1S_0^{[1]})b\bar{c}$	0.137782 ± 0.000896985	0.137
$q\bar{q} \to B_c^+(^3S_1^{[1]})b\bar{c}$	0.83905 ± 0.00524885	0.834
$q\bar{q} \to B_c^+(^1P_1^{[1]})b\bar{c}$	$0.0296125 \pm 0.000154919$	0.0295
$q\bar{q} \to B_c^+(^3P_J^{[1]})b\bar{c}$	0.111259 ± 0.000839535	0.1105
$q\bar{q} \to B_c^+(^1S_0^{[8]})b\bar{c}$	$0.00103294 \pm 4.44716 \cdot 10^{-6}$	0.00103
$q\bar{q} \to B_c^+(^3S_1^{[8]})b\bar{c}$	$0.00707624 \pm 0.0000459292$	0.00703
$q\bar{q} \to B_c^+(^1P_1^{[8]})b\bar{c}$	$0.000253678 \pm 2.19206 \cdot 10^{-6}$	0.000251
$q\bar{q} \to B_c^+(^3P_J^{[8]})b\bar{c}$	$0.000826534 \pm 5.16988 \cdot 10^{-6}$	0.0008207

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4.2 Charmonia production at the B factory

process	HELAC-Onia(fb)	Refs.[32, 3](fb)
$e^+e^- \to \gamma^* \to \eta_c({}^1S_0^{[1]})c\bar{c}$	58.7938 ± 0.154193	58.7
$e^+e^- \to \gamma^* \to \eta_c({}^1S_0^{[1]})ggg$	3.72893 ± 0.0063512	3.72
$e^+e^- \to \gamma^* \to J/\psi({}^3S_1^{[1]})c\bar{c}$	147.864 ± 0.305001	148
$e^+e^- \to \gamma^* \to J/\psi({}^3S_1^{[1]})gg$	266.037 ± 0.247366	266

process	HELAC-Onia(fb)	Ref.[33](fb)
$e^+e^- \to \gamma^* \to J/\psi({}^3S_1^{[1]})\eta_c({}^1S_0^{[1]})$	3.78154 ± 0.00338108	3.78
$e^+e^- \to \gamma^* \to h_c({}^1P_1^{[1]})\eta_c({}^1S_0^{[1]})$	0.308533 ± 0.000198459	0.308
$e^+e^- \to \gamma^* \to J/\psi({}^3S_1^{[1]})\chi_{cJ}({}^3P_J^{[1]})$	3.47635 ± 0.00453553	3.47
$e^+e^- \to \gamma^* \to h_c({}^1P_1^{[1]})\chi_{cJ}({}^3P_J^{[1]})$	0.328299 ± 0.000392734	0.328

process	HELAC-Onia(fb)	Ref.[34](fb)
$e^+e^- \to \eta_c({}^1S_0^{[1]})c\bar{c}$	61.6802 ± 0.0854359	–
$e^+e^- \to J/\psi({}^3S_1^{[1]})c\bar{c}$	166.499 ± 0.175318	–
$e^+e^- \to J/\psi({}^3S_1^{[1]})J/\psi({}^3S_1^{[1]})$	6.64805 ± 0.0123474	6.65
$e^+e^- \to J/\psi({}^3S_1^{[1]})h_c({}^1P_1^{[1]})$	$0.00606923 \pm 6.84416 \cdot 10^{-6}$	0.0061

4 Benchmark processes

4.1 B_c meson production at the LHC

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4.3 Double quarkonia production at the Tevatron and the LHC

Final States	HELAC-Onia(nb)	Ref.[35](nb)
$2\eta_c(^1S_0^{[1]})$	$3.316 \cdot 10^{-3} \pm 3.705 \cdot 10^{-6}$	$3.32 \cdot 10^{-3}$
$2J/\psi(^3S_1^{[1]})$	$0.05631 \pm 4.437 \cdot 10^{-5}$	0.0563
$2\eta_b(^1S_0^{[1]})$	$1.866 \cdot 10^{-5} \pm 2.385 \cdot 10^{-8}$	$1.87 \cdot 10^{-5}$
$2\Upsilon(^3S_1^{[1]})$	$1.226 \cdot 10^{-4} \pm 1.489 \cdot 10^{-7}$	$1.23 \cdot 10^{-4}$
$B_c(^1S_0^{[1]})\overline{B}_c(^1S_0^{[1]})$	$3.854 \cdot 10^{-3} \pm 9.529 \cdot 10^{-6}$	$3.86 \cdot 10^{-3}$
$B_c(^1S_0^{[1]})\overline{B}_c(^3S_1^{[1]})$	$1.001 \cdot 10^{-3} \pm 2.492 \cdot 10^{-6}$	$1.00 \cdot 10^{-3}$
$B_c(^3S_1^{[1]})\overline{B}_c(^3S_1^{[1]})$	$8.226 \cdot 10^{-3} \pm 9.531 \cdot 10^{-6}$	$8.23 \cdot 10^{-3}$

OVERVIEW OF (EARLY) BENCHMARKS

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4.4 Hadroproduction of J/ψ and Υ in association with a heavy-quark pair

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4.5 Spin density matrix and polarization

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One or more S-wave and P-wave quarkonium(a) tree-level helicity amplitudes in NRQCD

4.3 Double quarkonia production at the Tevatron and the LHC

4.4 Hadroproduction of J/ψ and Υ in association with a heavy-quark pair

4.5 Spin density matrix and polarization

NEW DEVELOPMENTS IN VERSION 2.0

- More user-friendly interface

MadGraph5_aMC@NLO Alwall, Frederix, Frixione, Hirschi, Maltoni, Mattelaer, HSS, Stelzer, Torrielli, Zaro (2014)	HELAC-Onia 2.0
./bin/mg5 > generate p p > t t~ [QCD] > output pp2ttx > launch	./ho_cluster > generate g g > cc~(3S11) cc~(3S11) > launch

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./bin/mg5	./ho_cluster
> generate p p > t t~ [QCD]	> generate g g > cc~(3S11) cc~(3S11)
> output pp2ttx	> launch
> launch	

Good life only costs 2-3 commands !

NEW DEVELOPMENTS IN VERSION 2.0

- Decay module
  - Guarantee spin-correlations in heavy quarkonium decay chains.
  - For example, $\chi_c \to J/\psi + \gamma \to \ell^+\ell^- + \gamma$

- Considering the helicity amplitude for the decay process is $\mathcal{A}(\mathbf{x})$, where $\mathbf{x}$ is the set of variables to characterize the kinematics.
- The maximal weight of $|\mathcal{A}(\mathbf{x})|^2$ is W_{max}.
- Randomly generate a phase space point $\mathbf{x}$.
- Uniformly generate a random number $r \in [0, 1]$. If $|\mathcal{A}(\mathbf{x})|^2 > r \times W_{\mathrm{max}}$, the event corresponding to $\mathbf{x}$ is retained. Otherwise, go to the former step.

NEW DEVELOPMENTS IN VERSION 2.0

- Shower module
  - Interface to external parton shower Monte Carlo programs.

HELAC-Onia + QEDPS

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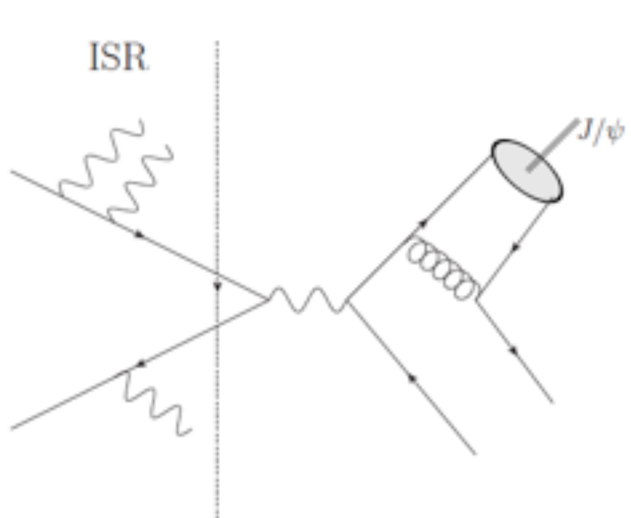
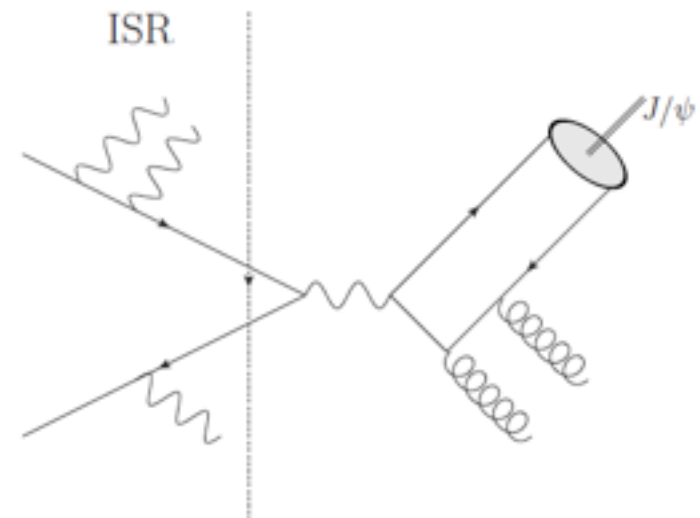
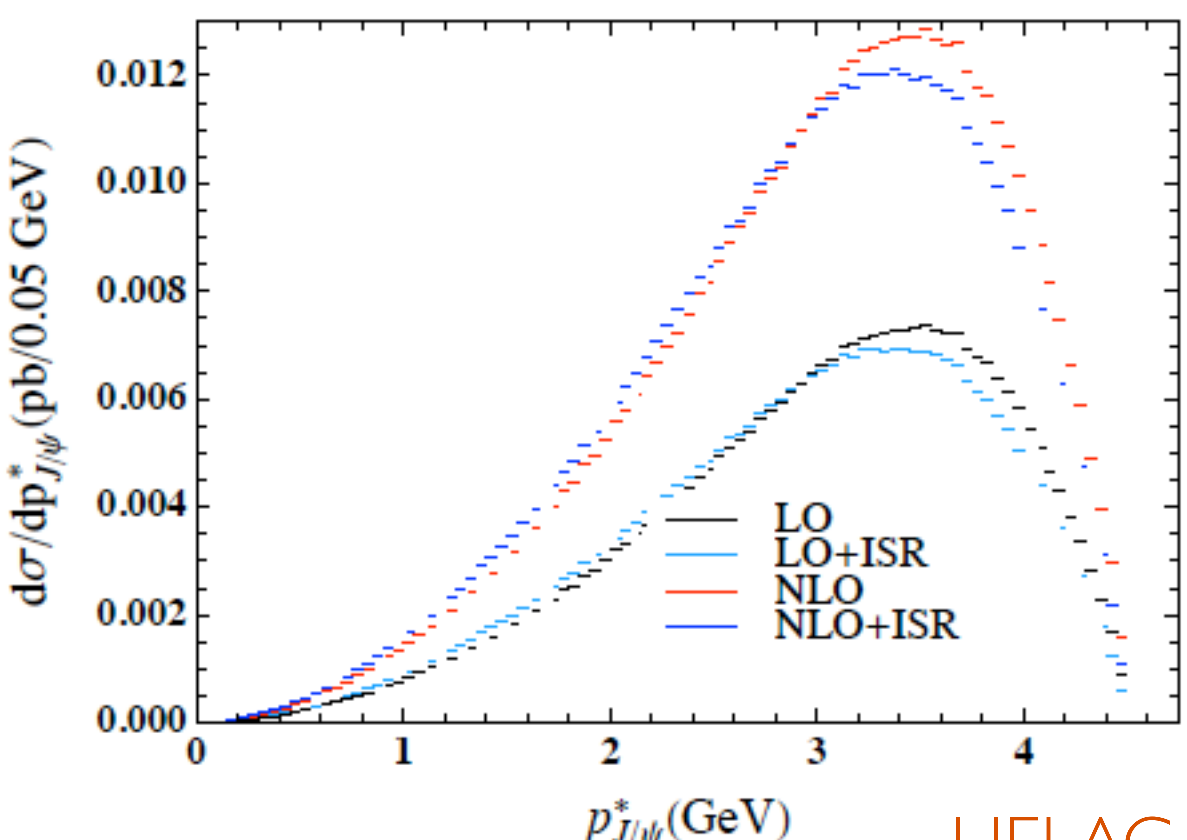
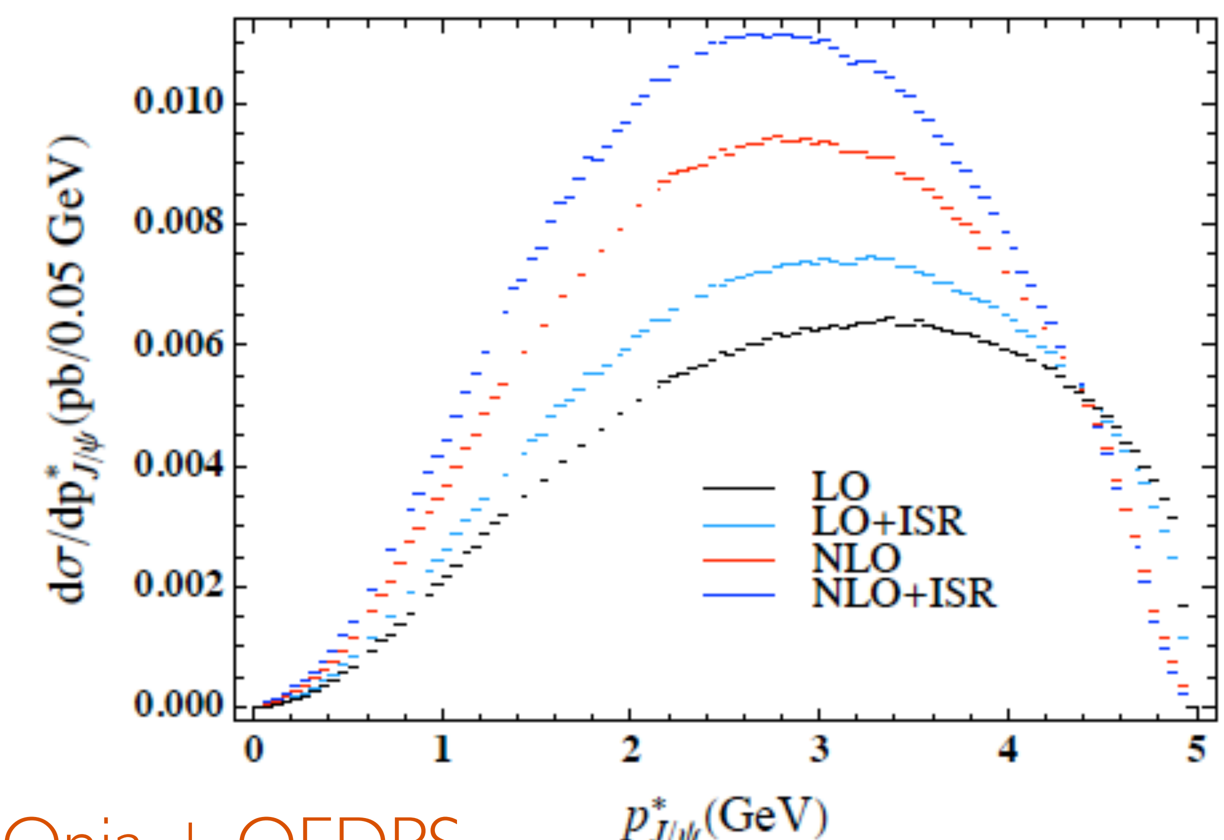
HSS (2014)









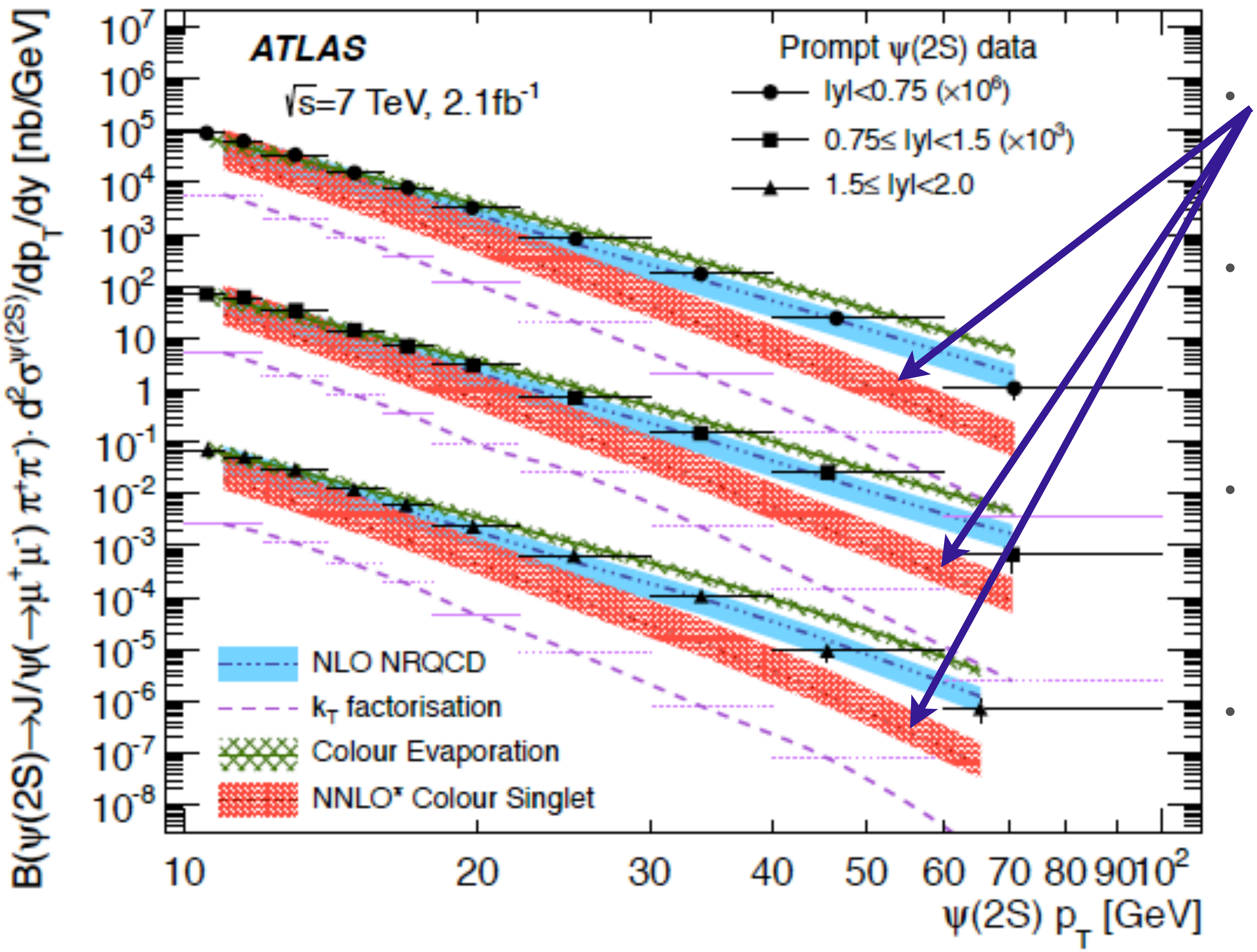
HELAC-Onia + QEDPS

NEW DEVELOPMENTS IN VERSION 2.0

- Analysis module
  - Generating topdrawer, gnuplot, root files on the fly. One-dimensional or two-dimensional distributions.
- Reweighting method is applied to estimate scale and PDF uncertainties on the fly.
- Addon codes
  - For example, double parton scattering for double psi production.
- In plan:
  - Fragmentation function module
  - TMD module etc

HIGHEST-MULTIPLICITY PROCESSES: NNLO* QCD CORRECTIONS

ATLAS Collaboration (2014)



- NNLO* QCD correction.
- First done by MadOnia [Artoisenet, Lansberg, Maltoni (2007)].
- The first 2 > 4 process with at least one quarkonium.
- HELAC-Onia reproduce the MadOnia result between 10-40 GeV.

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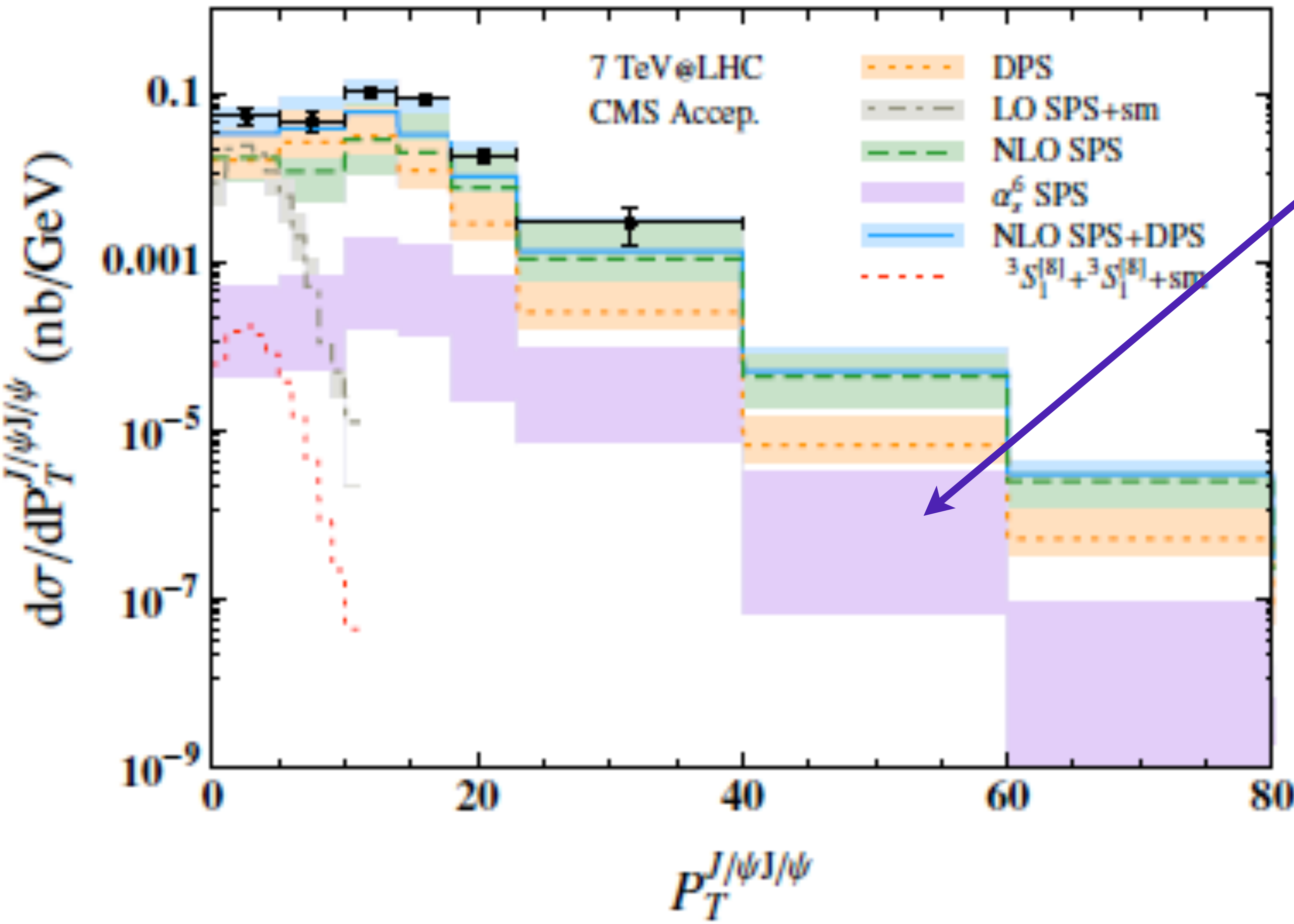
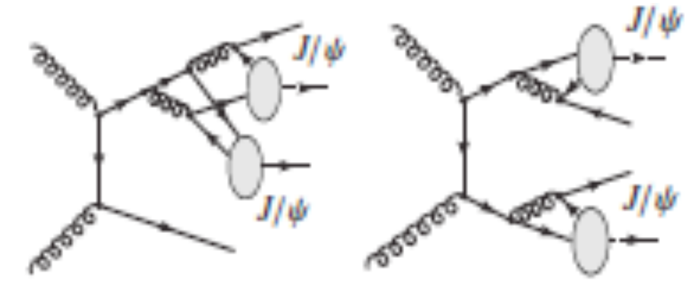
HIGHEST-MULTIPLICITY PROCESSES: P P > PSI+PSI+CC

Lansberg, HSS (2014)





- NNLO level process for double psi production.
- The first 2 > 4 process with at least two quarkonia.
- Satisfactory accuracy achieved for all plots within one week on single core.

CONCLUSION

- HELAC-Onia is an user-friendly public tool to study heavy quarkonium physics in an automatically way.
- Based on recursion relation, it can be applied to high-multiplicity processes with relatively lower computational cost.
- It provides a simulation tool for one or more S-wave and/or P-wave heavy quarkonia production based on tree-level helicity amplitudes.
- To do:
    - Ongoing developments to meet various application purposes.
    - Generalize to higher-order (e.g. NLO QCD correction).