

Exploring Heavy-Quarkonium Fragmentation at the Electron-Ion Collider (EIC) via NRFF1.0

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NRFF1.0: A New Generation of FFs

NRFF1.0 is a public set of collinear Fragmentation Functions (FFs) for quarkonium production at moderate to large p_T .

https://github.com/FGCeliberto/Collinear_FF

- **Improvement over ZCW19+**: Systematically accounts for heavy quark thresholds during DGLAP evolution via the **HF-NRevo** scheme.

F. G. Celiberto and M. Fucilla, Eur. Phys. J. C 82, 929 (2022), 2202.12227.

$$D_a^Q(z, \mu_{F,0}) = \sum_{[n]} D_a^Q(z, [n]) \langle \mathcal{O}^Q[n] \rangle$$

Key Features

- **Framework:** Built on the single-parton fragmentation approximation in a Variable Flavor Number Scheme (VFNS).
- **Consistency:** First set to include **all partonic channels** with consistent flavor threshold treatments.
- **Pseudoscalar Sector:** Construction for η_c and η_b uses fully NLO-accurate NRQCD inputs.

Fock State Expansion and Color Mechanism

NRQCD Factorization: The $Q\bar{Q}$ pair is produced at short distances in a Fock state $n = {}^{2S+1}L_J^{[a]}$, where $a = 1$ (Singlet) or $a = 8$ (Octet).

- **Transition:** Intermediate CO states evolve into physical CS quarkonia via *non-perturbative* soft gluon emission.
- **Limit:** As $v \rightarrow 0$, NRQCD recovers the Color Singlet Model (CSM) for S -wave states.

Table: Leading velocity scaling of LDMEs

State	$^1S_0^{(1)}$	$^3S_1^{(1)}$	$^1S_0^{(8)}$	$^3S_1^{(8)}$	$^3P_0^{(8)}$	$^3P_1^{(8)}$	$^3P_2^{(8)}$
η_c, η_b	1	–	v_Q^4	v_Q^3	v_Q^4	v_Q^4	v_Q^4
$J/\psi, \Upsilon$	–	1	v_Q^3	v_Q^4	v_Q^4	v_Q^4	v_Q^4

The HF-NRevo Scheme: Bridging the Thresholds for η_c

HF-NRevo for $\eta_c[{}^1S_0^{(1)}]$ collinear fragmentation

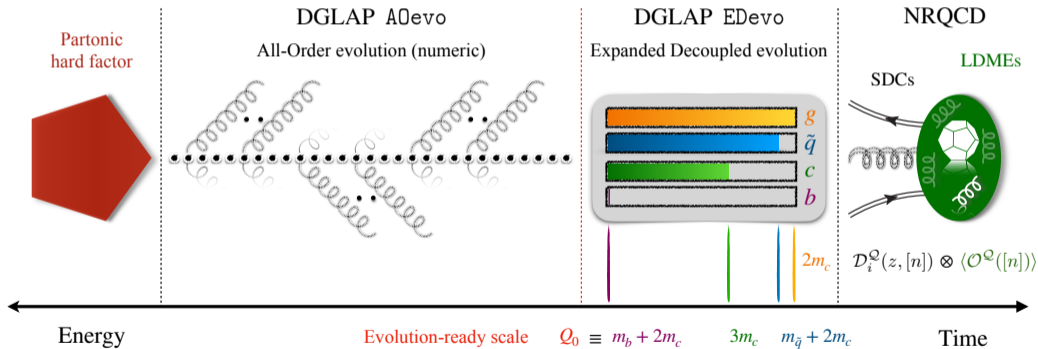


Figure: Evolution workflow within the HF-NRevo scheme

The HF-NRevo Scheme: Bridging the Thresholds for η_b

HF-NRevo for $\eta_b[{}^1S_0^{(1)}]$ collinear fragmentation

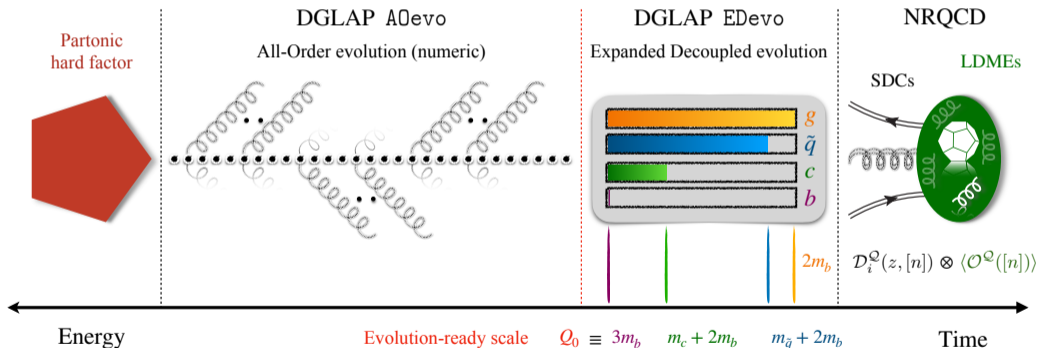


Figure: Evolution workflow within the HF-NRevo scheme

Hybrid Factorization (HyF) Framework

Concept: Combines High-Energy (BFKL) and Collinear factorization to describe processes at NLL/NLO+ accuracy.

- **High-Energy Resummation:** Incorporates BFKL Green's functions with singly off-shell emission functions (forward production impact factors).

The differential cross section is expressed as a Fourier expansion:

$$\frac{(2\pi)^2 d\sigma}{dy_1 dy_2 d|\vec{q}_{T1}| d|\vec{q}_{T2}| d\phi_1 d\phi_2} = C_0 + 2 \sum_{n=1}^{\infty} \cos(n\phi) C_n \quad (1)$$

where $\phi \equiv \phi_1 - \phi_2 - \pi$.

High-Energy Factorization

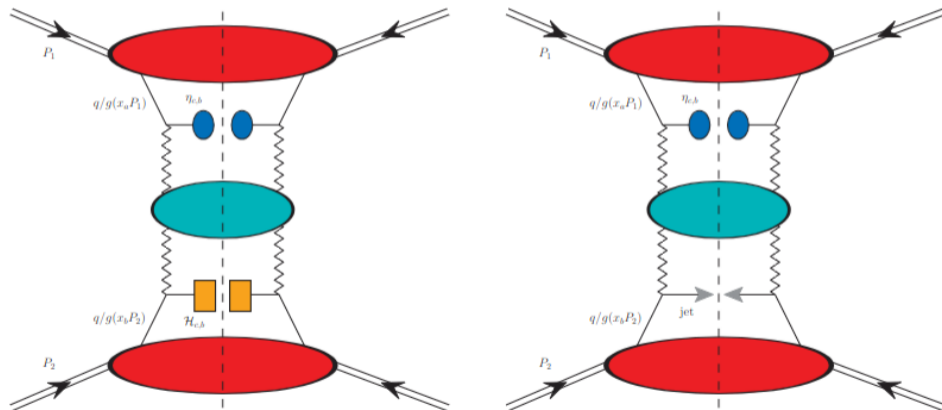
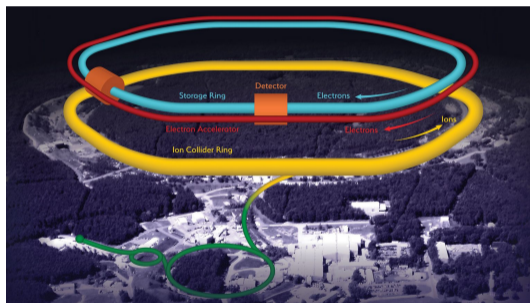


Figure: Hybrid factorization for the semi-inclusive hadroproduction

Outlook: The Next Generation

- **Vector States:** The HF-NRevo scheme is currently being extended to J/ψ and Υ , where the color-octet contributions are more complex.
- **TMD Evolution & Matching:** Future work involves moving beyond collinear factorization to Transverse Momentum Dependent (TMD) fragmentation.
- **Exotic States:** This framework provides the consistent basis for studying the fragmentation of tetraquarks and other exotics.
- Investigating how **intrinsic charm** manifests itself in high-energy hadronic processes.
- The HyF framework can be extended to cover **single-inclusive emissions of quarkonium states**
- We plan to further develop the NRFF1.0 sets by performing a **systematic uncertainty analysis**

THANK YOU!



BACK UP



Phenomenological Analysis

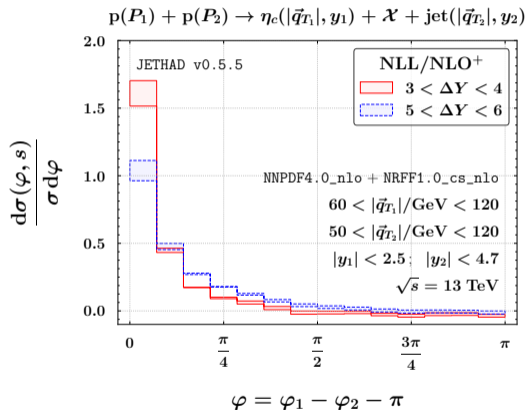


Figure: Angular multiplicities for the semi-inclusive hadroproduction

Phenomenological Analysis

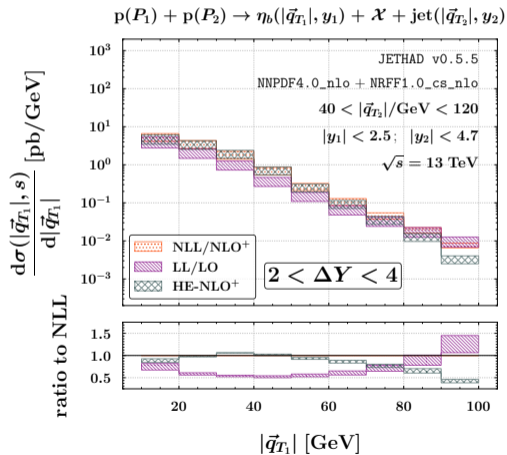


Figure: Transverse momentum distributions for the semi-inclusive hadroproduction