Asymmetric collisions in MadGraph5_aMC@NLO

Carlo Flore

Università di Cagliari & INFN - Sezione di Cagliari

Quarkonia as Tools 2025
Centre Paul Langevin, Aussois
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Outline

- Introduction

- NLO computations in MG5

- Implementation of asymmetric hadronic collisions at NLO in MG5

- Implementation of *ep* and *eA* collisions at NLO in MG5

- Conclusions and outlook

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    we have done it extending MG5

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Symmetric hadronic collisions in MG5 at NLO

CF, D. Kikoła, A. Kusina, J.-P. Lansberg, O. Mattelaer, A. Safronov, in preparation

$$d\sigma_{hh \to X} = \sum_{a,b} \int dx_a dx_b \, f_{a/h}(x_a, \mu_F; \mathtt{LHAID\_h}) \, f_{b/h}(x_b, \mu_F; \mathtt{LHAID\_h})$$
$$\times \, d\widehat{\sigma}_{ab \to X} \left(x_a, x_b, \mu_F, \alpha_S(\mu_R; \mathtt{LHAID\_h}) \right)$$

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E: Event, fully resolved configuration
S, *C*, *SC*: soft, collinear, soft-collinear limits of *E* (Counterevents)

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$$\times \, W^{(\alpha)}(x_a^{(\alpha)}, x_b^{(\alpha)}, \mu_F^{(\alpha)}, \alpha_S(\mu_R^{(\alpha)}; \text{LHAID\_h})) \, d\chi_{12} \, d\chi_{n+1}$$

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Symmetric hadronic collisions in MG5 at NLO

$$W^{(\alpha)} = g_S^{2b+2}(\mu_R^{(\alpha)}; \texttt{LHAID\_h}) \left[\widehat{W}_0^{(\alpha)} + \widehat{W}_F^{(\alpha)} \log \left(\frac{\mu_F^{(\alpha)}}{Q} \right)^2 + \widehat{W}_R^{(\alpha)} \log \left(\frac{\mu_R^{(\alpha)}}{Q} \right)^2 \right]$$
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- $\widehat{W}_B$ shares same kinematics of Soft Counterevents
- $\mu_F^{(\alpha)}$ may be different for Events and Counterevents
- output of a fixed-order NLO computation $\Rightarrow$ HwU files

$$N_{\mathrm{entr}} = \underbrace{4}_{\substack{\text{2 bin edges} \\ \text{1 cross section} \\ \text{1 MC error}}} + \underbrace{(3 + N_\mu)}_{\substack{\text{1 central value} \\ \text{2 min/max values} \\ N_\mu \text{ scale combinations}}} + \sum_{i=1}^{N_{\mathrm{LHAID}}} \underbrace{(3 + N_{\mathrm{mem}}^i)}_{\substack{\text{1 central value} \\ \text{2 min/max values} \\ N_{\mathrm{mem}} \text{ PDF members}}}$$

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Asymmetric hadronic collisions in MG5 at NLO
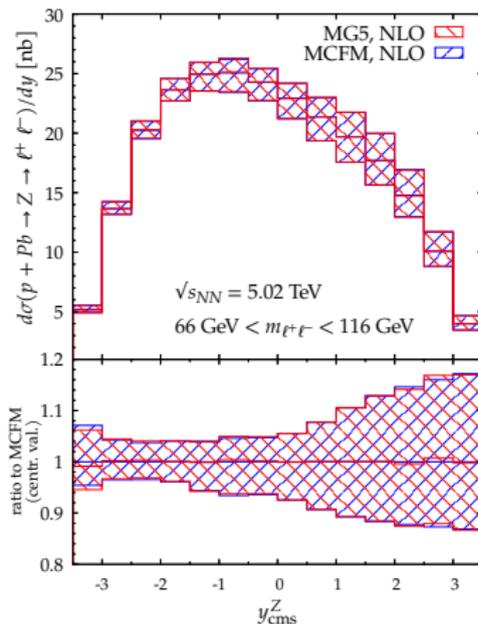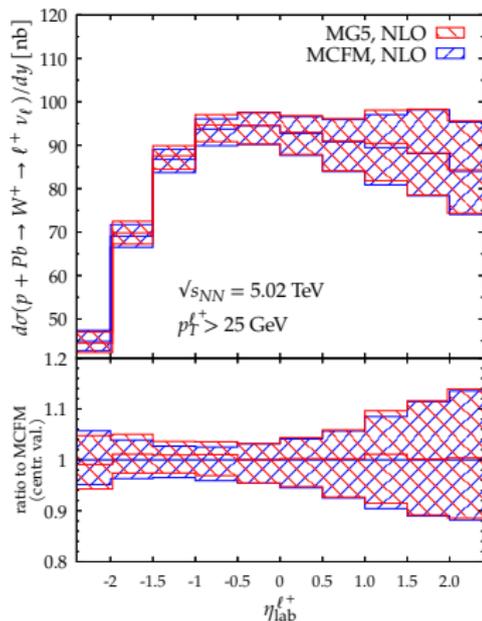
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- strong coupling constant from the LHAPDF set of hadron h_2
- for pA collisions, full consistency if corresponding proton baseline for nPDF is used

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  5. in general $N_{\text{entr}}^{\text{asym}} > N_{\text{entr}}^{\text{symm}}$, may also be $N_{\text{entr}}^{\text{asym}} \gg N_{\text{entr}}^{\text{symm}}$

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Validation - *pA*

- only nPDF uncertainty shown
- excellent agreemente with MCFM

Validation - πA

$\pi^- + W \to \mu^+ \mu^-$, $\sqrt{s} = 21.7$ GeV

- MG5 and JAM MC statistical uncertainties tend to grow in the most forward region
- MG5 and JAM results essentially identical and compatible with experimental data

Selection of results (I)

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CF, D. Kikoła, A. Kusina, J.-P. Lansberg, O. Mattelaer, A. Safronov, in preparation

Selection of results (I)

- nPDF uncertainty dominant at forward (pseudo)rapidity
- scale and NPDF uncertainties comparable in the backward region
- such predictions can be now obtained in a single run by indicating three LHAIDs in the run_card

Selection of results (II)

- nuclear modification factor: $R_{pPb} = \frac{1}{A_{Pb}} \frac{d\sigma_{pPb}}{d\sigma_{pp}}$

- approximation for uncertainty computation:

$$\delta(R_{AB}) = \frac{1}{A_A A_B} \frac{\delta(d\sigma_{AB})}{d\sigma_{pp}^{central}}$$

- *R_{pPb} automatically computed in a single run*

ep and *eA* collisions

We now focus on photoproduction:

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$$\sigma_{eh(A)\to C+X} = \sum_b \int dx_\gamma dx_b \, f_\gamma^e(x_\gamma, Q_{\max}^2)$$
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- fixed some bugs related to the WW distribution and modified the boost routines
- lab frame now default

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Inclusive photoproduction - validation at LO

- validation for $c\bar{c}$ (left) and $b\bar{b}$ photoproduction (HERA kinematics) at LO
- agreement $\mathcal{O}(1\%)$ with HELAC-Onia and $\sim 4\%$ with FMNR

Inclusive photoproduction - validation at NLO

- validation for $c\bar{c}$ (left) and $b\bar{b}$ photoproduction (HERA kinematics) at NLO
- very satisfactory agreement ($\mathcal{O}(1\%)$) with FMNR

Inclusive $b\bar{b}$ photoproduction - predictions

- NLO predictions for future ep colliders
- limited P_T range at EICC
- P_T spectrum extend to $P_T \sim 60$ GeV at LHeC and FCC-eh

Resolved contribution - validation at NLO

- ratio MG5 to FMNR with combined Monte Carlo uncertainties
- $\sim \mathcal{O}(2\%)$ agreement with FMNR

$b\bar{b}$ photoproduction at the EIC

- predictions for the EIC at $\sqrt{s_{ep}} = 45$ GeV (left) and $\sqrt{s_{ep}} = 140$ GeV (right)
- resolved contribution comparable with direct one around $P_T \sim 9 - 10$ GeV at $\sqrt{s_{ep}} = 45$ GeV
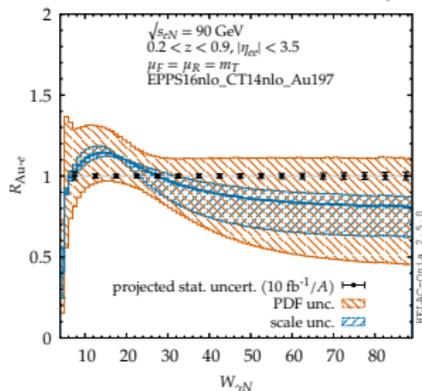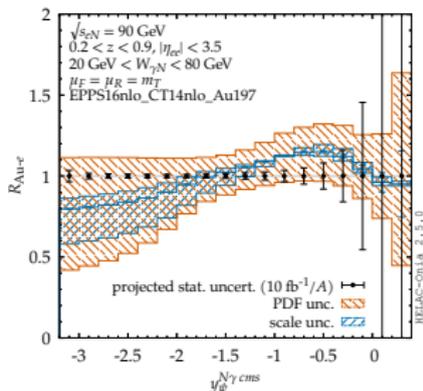- direct contribution dominant but resolved one not negligible at $\sqrt{s_{ep}} = 140$ GeV

R_{eAu} @ EIC $- \sqrt{s_{ep}} = 45$ GeV

R_{eAu} @ EIC − $\sqrt{s_{ep}} = 90$ GeV

Conclusions and outlook

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- validated and developed MG5 for asymmetric collisions
  - photoproduction in ℓh collisions
  - nuclear modification factors in pA, πA and AB collisions

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  - DIS implementation at (N)LO+PS
  - automation of onium production computations at (N)LO in MG5

    Alice's talk

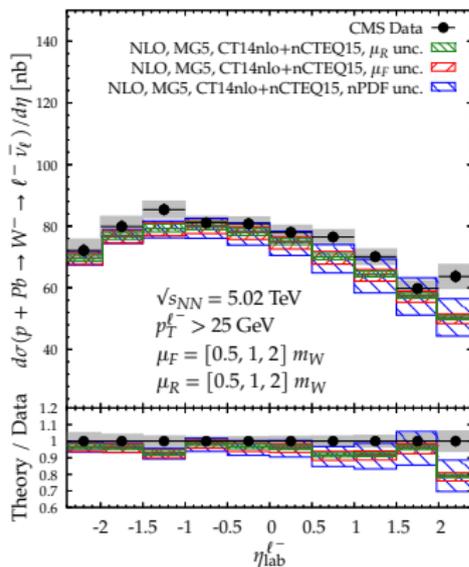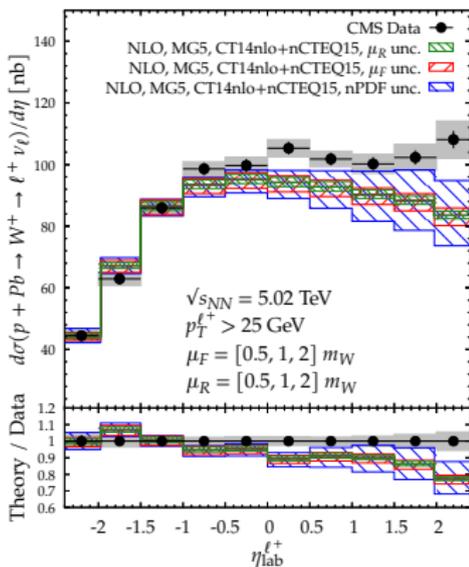 - automation of spin and transverse momentum effects for quarkonium production

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  - automation of spin and transverse momentum effects for quarkonium production

Thank you

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Backup

MG5 HwU output for asymmetric collisions

reweight_scale	reweight_PDF	No. of entries (symmetric): $N_{\mathrm{entr}}^{\mathrm{sym}}$	No. of entries (asymmetric): $N_{\mathrm{entr}}^{\mathrm{asym}}$
True	True	$4 + N_{\mathrm{LHAID}}\left(3+N_\mu\right) + \sum\limits_{i=1}^{N_{\mathrm{LHAID}}}\left(3+N_{\mathrm{mem}}^i\right)$	$N_{\mathrm{entr}}^{\mathrm{sym}} + 2(N_{\mathrm{LHAID}}-1)\left(3+N_\mu\right) + 2\sum\limits_{i=2}^{N_{\mathrm{LHAID}}}\left(3+N_{\mathrm{mem}}^i\right)$
True	False	$4 + N_{\mathrm{LHAID}}\left(3+N_\mu\right) + N_{\mathrm{LHAID}}\left(3+1\right)$	$N_{\mathrm{entr}}^{\mathrm{sym}} + 2(N_{\mathrm{LHAID}}-1)\left(3+N_\mu\right) + 2(N_{\mathrm{LHAID}}-1)\left(3+1\right)$
False	True	$4 + \sum\limits_{i=1}^{N_{\mathrm{LHAID}}}\left(3+N_{\mathrm{mem}}^i\right)$	$N_{\mathrm{entr}}^{\mathrm{sym}} + 2\sum\limits_{i=2}^{N_{\mathrm{LHAID}}}\left(3+N_{\mathrm{mem}}^i\right)$
False	False	$4 + N_{\mathrm{LHAID}}\left(3+1\right)$	$N_{\mathrm{entr}}^{\mathrm{sym}} + 2(N_{\mathrm{LHAID}}-1)\left(3+1\right)$

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Selection of results

- nPDF uncertainty dominant at forward (pseudo)rapidity
- scale and NPDF uncertainties comparable in the backward region
- such predictions can be now obtained in a single run by indicating three LHAIDs in the run_card
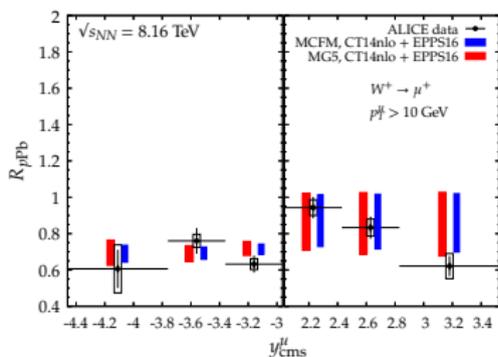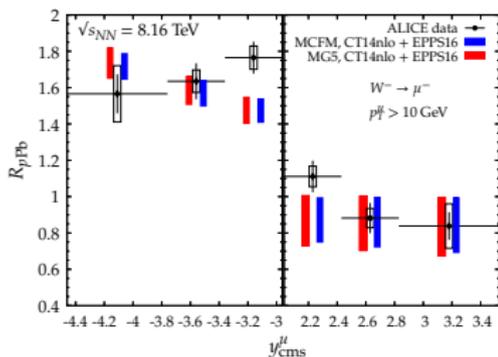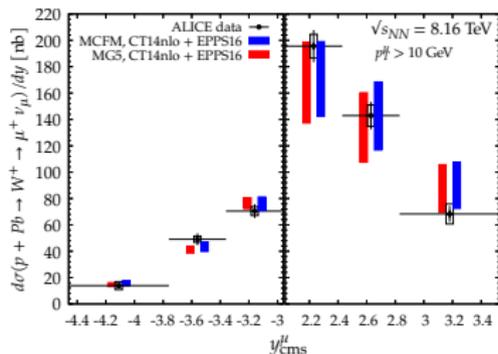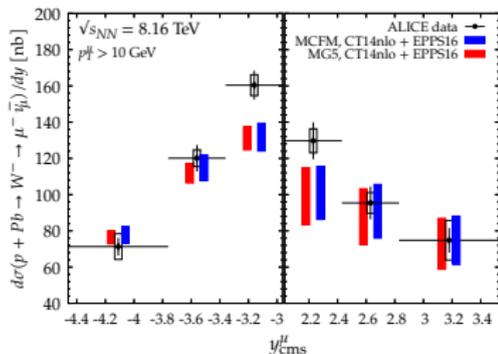
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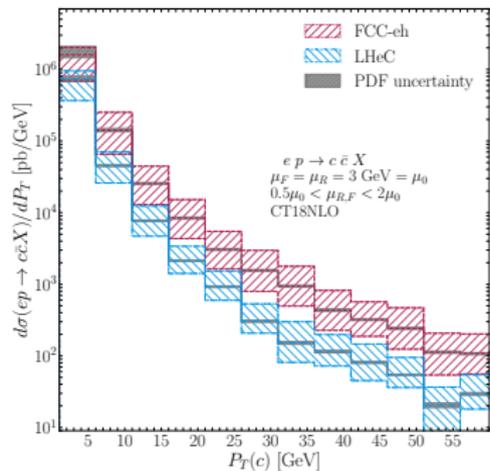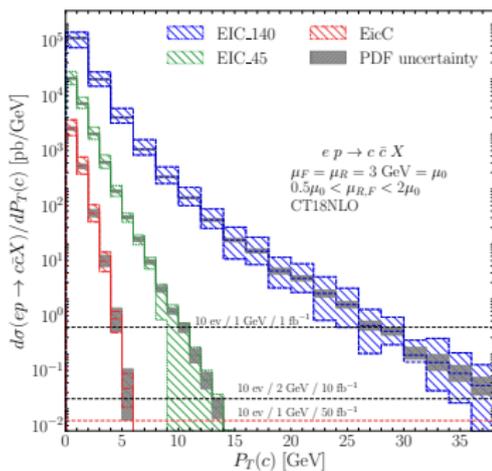
Selection of results

CF, D. Kikoła, A. Kusina, J.-P. Lansberg, O. Mattelaer, A. Safronov, in preparation

Selection of results

- NLO predictions for future *ep* colliders
- limited P_T range at EIcC
- P_T spectrum extend to $P_T \sim 60$ GeV at LHeC and FCC-eh