MAX-PLANCK-INSTITUT
FÜR PHYSIK

Precise predictions for doubly polarised ZZ @ LHC and (close) future perspectives in COMETA

Outline

- Integrated results
- Differential results at FO
- Plan for PS-matched predictions
- CMS & ATLAS input
- Future polarisation-related plans in COMETA

COMETA project on polarisation

Started in March 2024.

Involved all MC tools available on the market and all experts in the field:

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code	OS approx.	LO	loop-ind.	NLOQCD	NNLOQCD	NLOEW	LOPS	NLOPS
MoCaNLO	DPA	✓	✓	✓	✗	✓	✗	✗
STRIPPER	DPA	✓	✓	✓	✓	✗	✗	✗
MulBos	DPA	✓	✓	✓	✗	✓	✗	✗
BBMC	DPA	✓	✗	✓	✗	✓	✗	✗
Sherpa	NWA	✓	✗	(✓)	✗	✗	✓	(✓)
MadGraph	NWA	✓	✓	✗	✗	✗	✓	✗
PowHeg-Box	DPA	✓	✗	✓	✗	✗	✓	✓

Setup(s)

Process: $pp \to e^+e^-\mu^+\mu^- + X$ @ 13TeV

Accuracy: NLO EW $[\mathcal{O}(\alpha^5)]$, N$^{1(2)}$LO QCD $[\mathcal{O}(\alpha_s^{1(2)}\alpha^4)]$, gg loop-induced $[\mathcal{O}(\alpha_s^2\alpha^4)]$.

Details: $N_F = 5$, G_μ-scheme for α, Complex-Mass-Scheme for EW bosons.

PDFs: NNPDF3.1 at NNLO with $\alpha_s(M_Z) = 0.118$.

Ren. and fact. scale: $\mu_R = \mu_F = M_Z$.

Fiducial selections from ATLAS measurement [ATLAS [2310.04350]]:

- $p_{T,e^\pm} > 7\,\text{GeV}$, $p_{\mu^\pm} > 5\,\text{GeV}$, $p_{\ell_{1(2)}} > 20\,\text{GeV}$
- $\Delta R_{\ell\ell'} > 0.05$, $|\eta_{e^\pm}| < 2.47$, $|\eta_{\mu^\pm}| < 2.7$
- $M_{4\ell} > 180\,\text{GeV}$, $|M_{\ell^+\ell^-} - M_Z| < 10\,\text{GeV}$

Anti-k_T QCD jets with $R = 0.4$, photon recombination if $\Delta R_{\ell\gamma} < 0.1$.

Integrated cross sections

Fiducial cross sections at LO

Tree-level:

code	OS approx.	full	unpol.	LL	LT	TL	TT
MoCaNLO	DPA	11.336(1)	11.242(1)	0.6574(1)	1.3332(2)	1.3370(2)	7.7874(8)
STRIPPER	DPA	11.3357(4)	11.2451(2)	0.6560(0)	1.3326(0)	1.3365(0)	7.7925(1)
MulBos	DPA	–	11.2393(3)	0.6572(0)	1.3329(1)	1.3366(1)	7.7846(2)
BBMC	DPA	11.3372(4)	11.2424(3)	0.6574(0)	1.3333(1)	1.3372(1)	7.7872(2)
Sherpa	NWA	11.363(6)	11.513(4)	0.6767(4)	1.3538(6)	1.3734(6)	7.952(3)
MadGraph	NWA	11.38(2)	11.29(2)	0.660(1)	1.335(2)	1.338(2)	7.81(1)
PowHeg-Box	DPA	11.335(1)	11.245(1)	0.6575(1)	1.3333(1)	1.3374(1)	7.7885(8)

Loop-induced:

code	OS approx.	full	unpol.	LL	LT	TL	TT
MoCaNLO	DPA	1.6968(6)	1.6978(6)	0.0914(0)	0.0360(0)	0.0356(0)	1.5360(5)
STRIPPER	DPA	1.682(7)	1.700(2)	0.0912(1)	0.0360(0)	0.0357(0)	1.538(2)
MulBos	DPA	–	1.6981(9)	0.0913(1)	0.0360(0)	0.0357(0)	1.5363(8)
MadGraph	NWA	1.699(6)	1.697(6)	0.0902(3)	0.0355(1)	0.0359(1)	1.539(6)

Fiducial cross sections at NLO

NLO QCD:

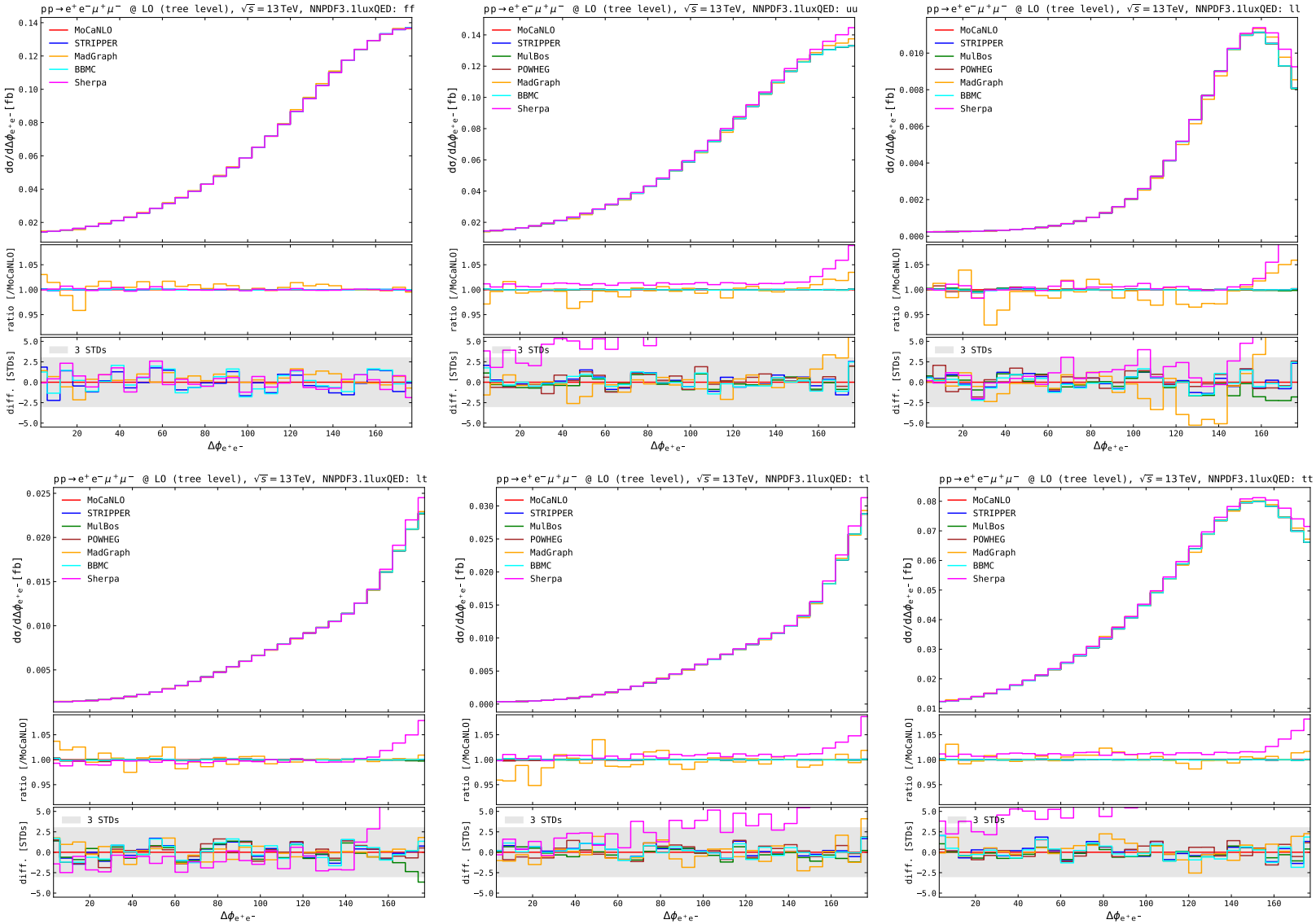
code	OS approx.	full	unpol.	LL	LT	TL	TT
MoCaNLO	DPA	15.282(1)	15.158(2)	0.8899(3)	1.9313(5)	1.9243(2)	10.2095(9)
STRIPPER	DPA	15.284(3)	15.159(1)	0.8899(1)	1.9305(1)	1.9241(1)	10.2098(7)
MulBos	DPA	–	15.1575(9)	0.88997(6)	1.9305(1)	1.9240(1)	10.2106(6)
BBMC	DPA	15.284(1)	15.158(1)	0.8898(1)	1.9306(2)	1.9240(2)	10.2085(7)
PowHeg-Box	DPA	15.280(2)	15.156(2)	0.8909(2)	1.9306(4)	1.9239(5)	10.206(1)
Sherpa	NWA	15.304(4)	15.441(5)	0.9266(5)	2.093(1)	2.041(1)	10.289(4)

NLO EW:

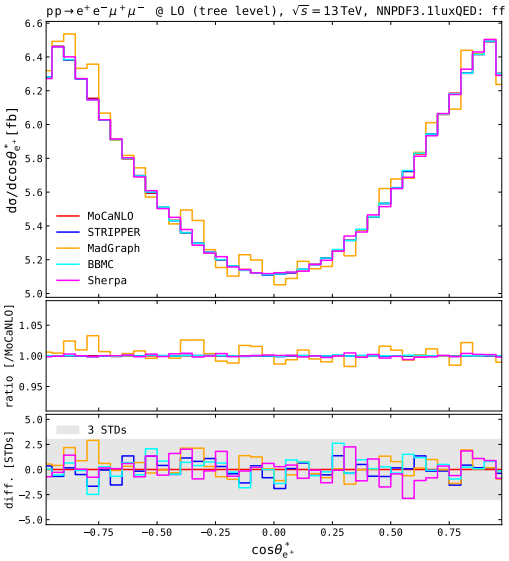
code	OS approx.	full	unpol.	LL	LT	TL	TT
MoCaNLO	DPA	10.080(2)	10.0213(8)	0.59068(9)	1.1994(1)	1.20293(9)	6.9129(3)
MulBos	DPA	–	10.0203(3)	0.59058(2)	1.19926(4)	1.20294(4)	6.9121(3)
BBMC	DPA	10.082(2)	10.0203(4)	0.59057(4)	1.19949(6)	1.20308(9)	6.9125(3)

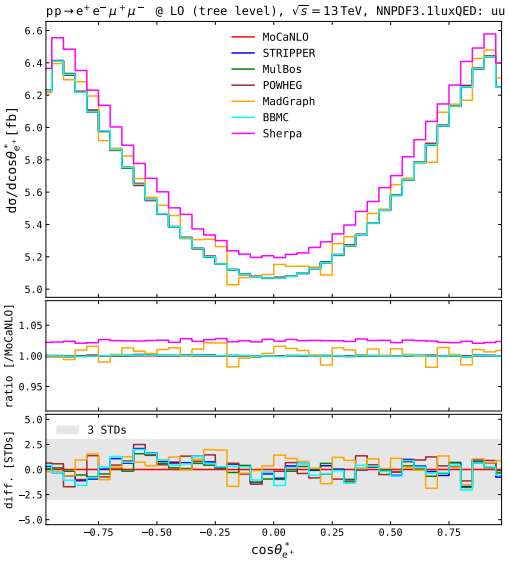
LO (tree level)

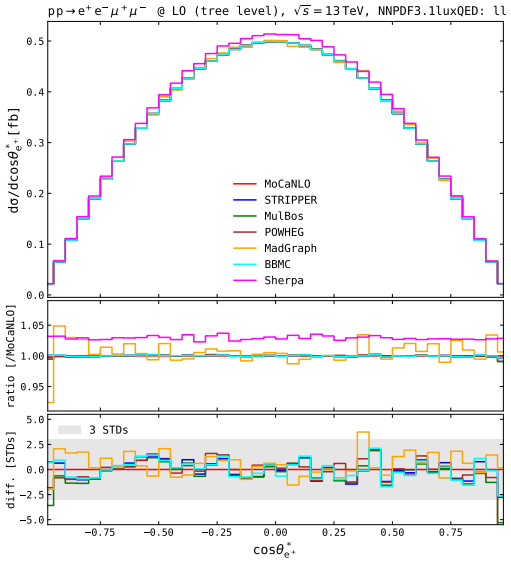
LO (tree): e^+e^- azimuthal separation

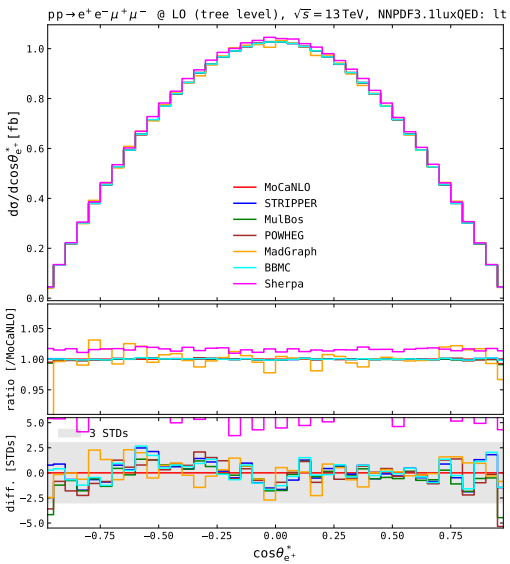


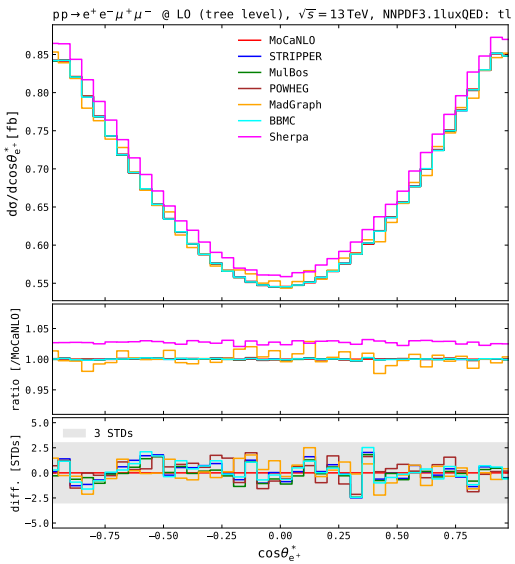
LO (tree): e^+ decay angle

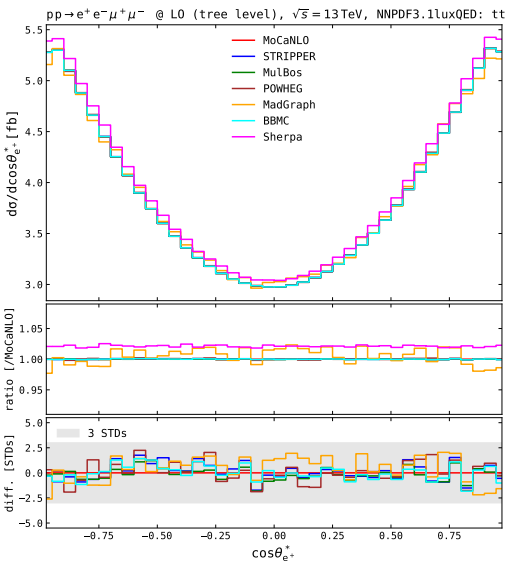




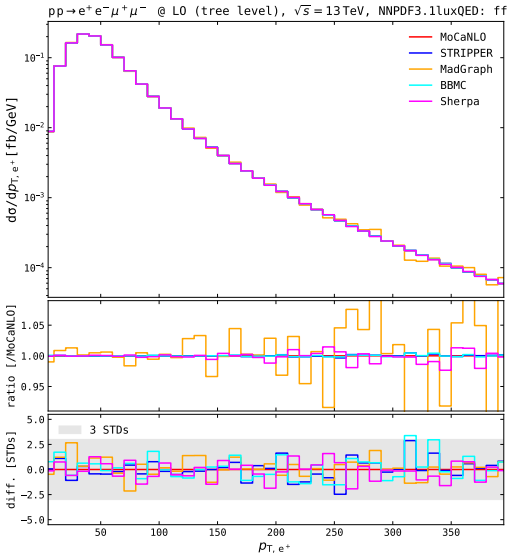


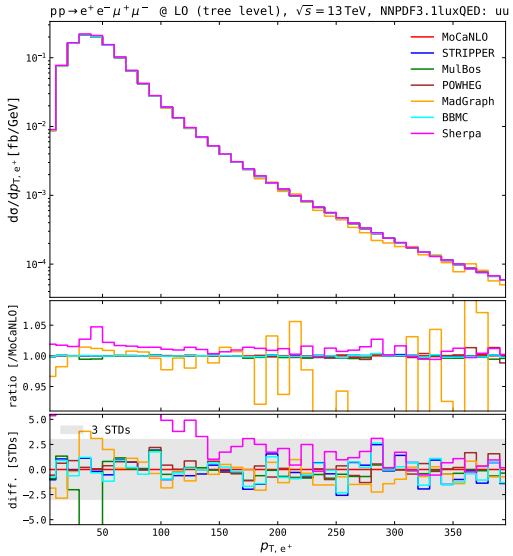


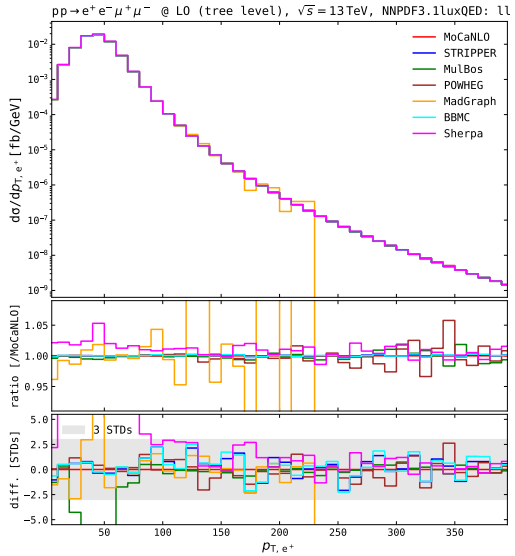


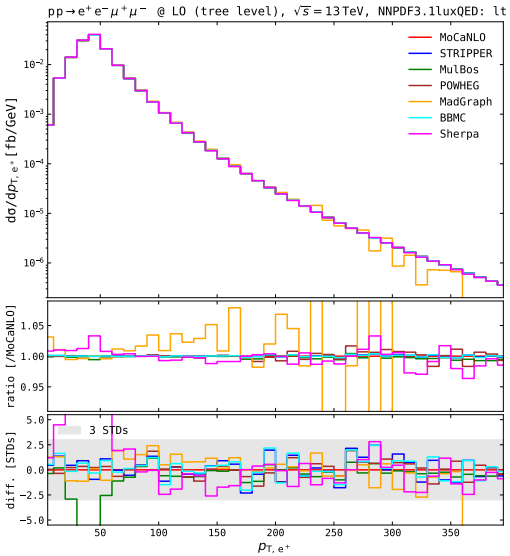


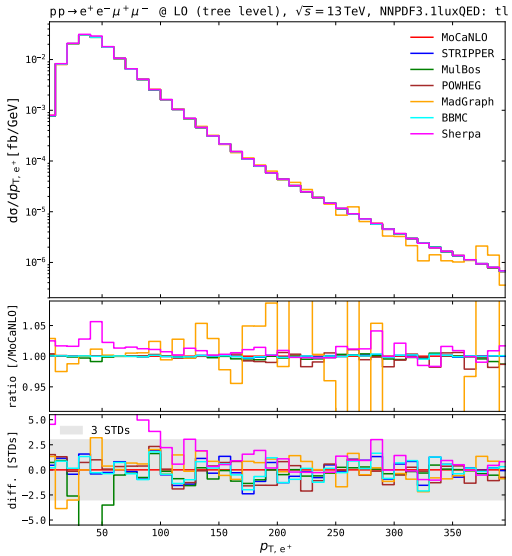
LO (tree): e^+ transverse momentum

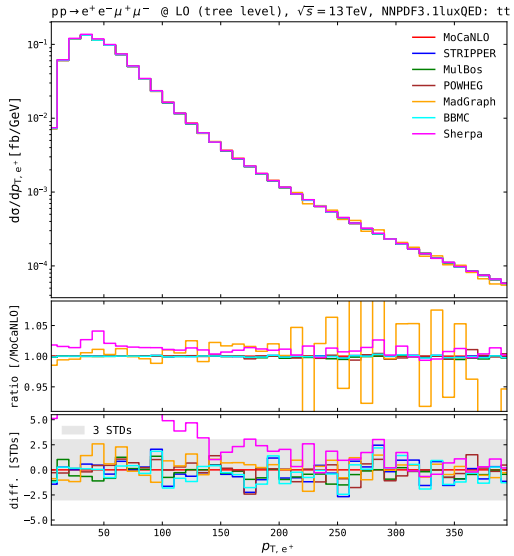




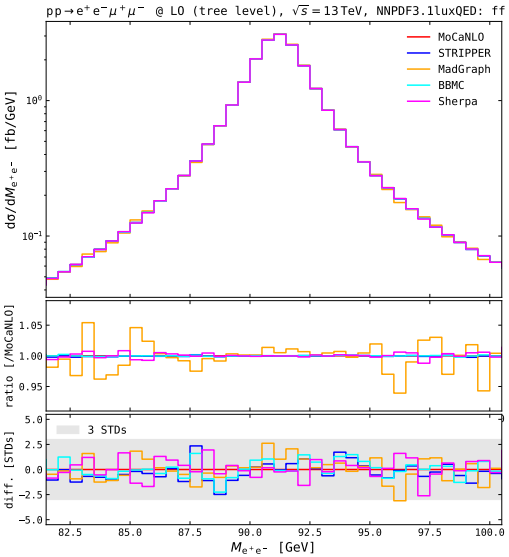


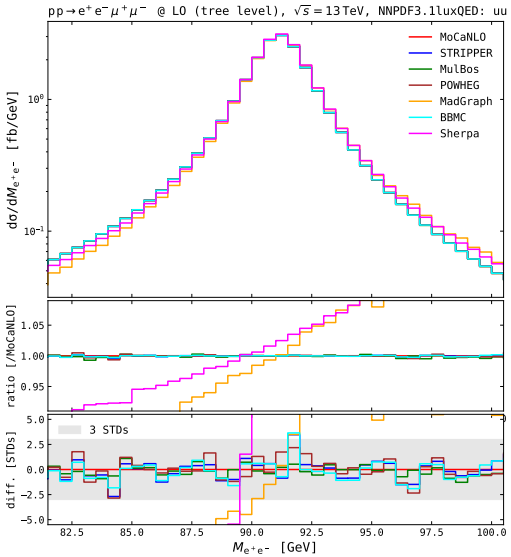


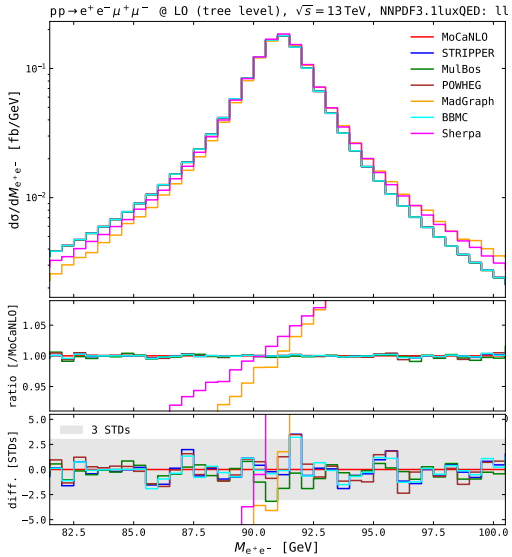


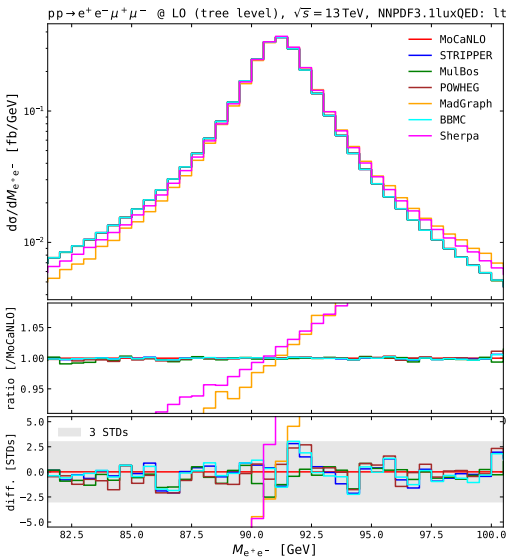


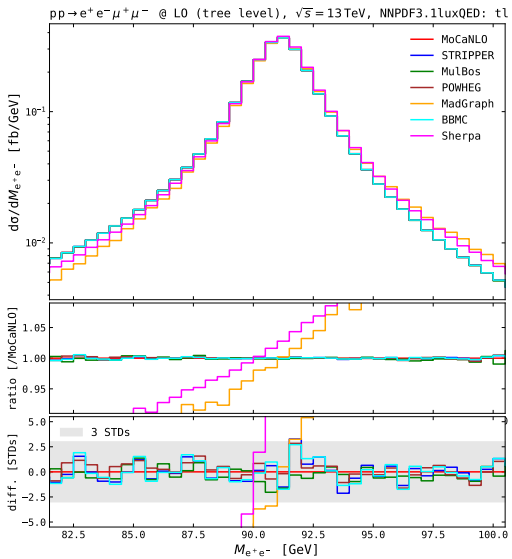
LO (tree): e^+e^- invariant-mass

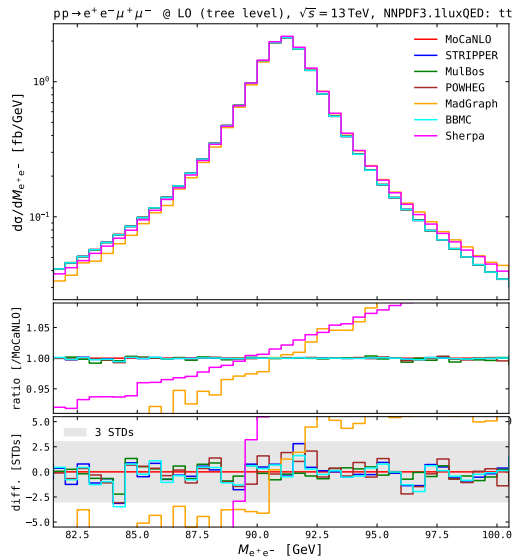






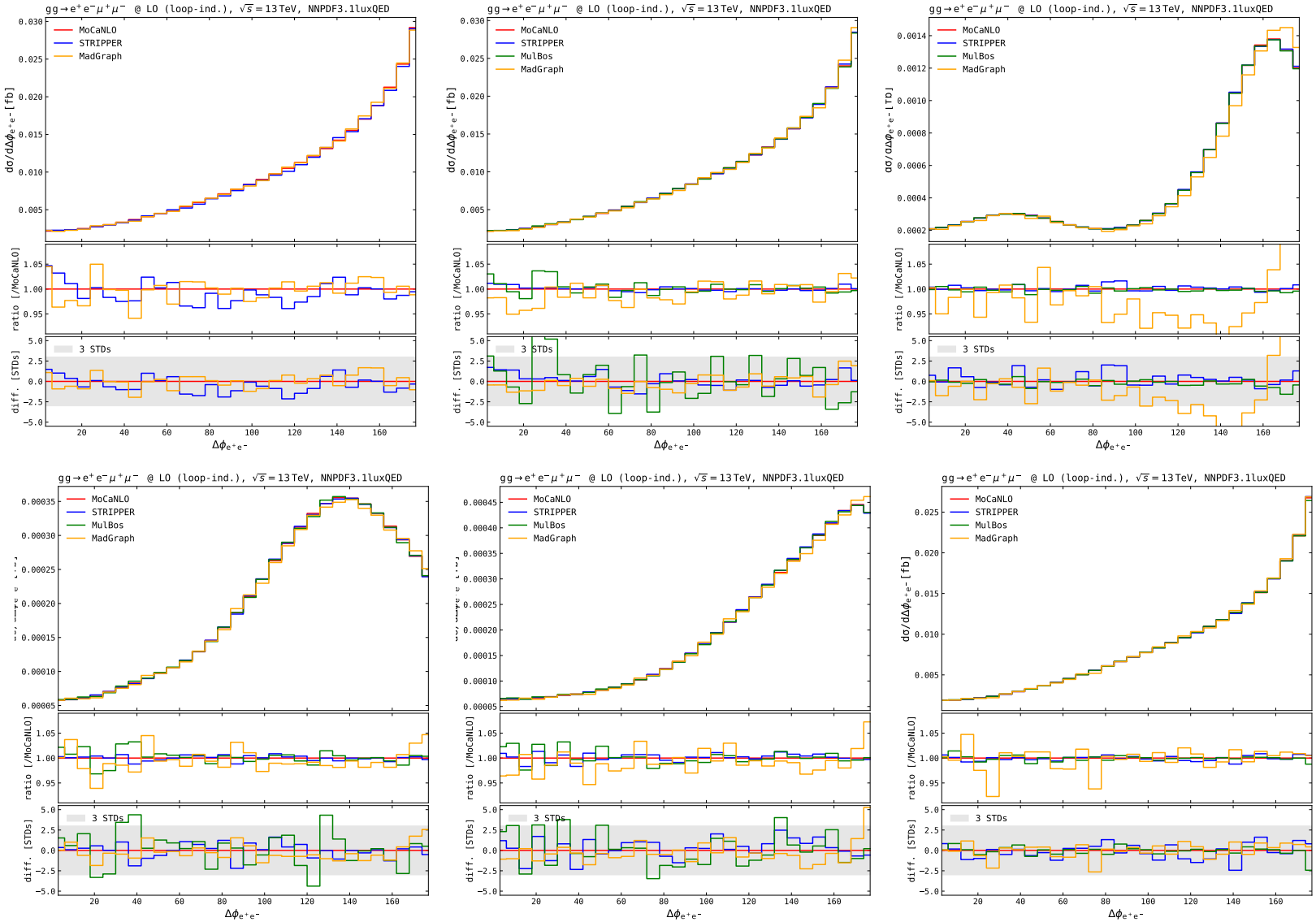




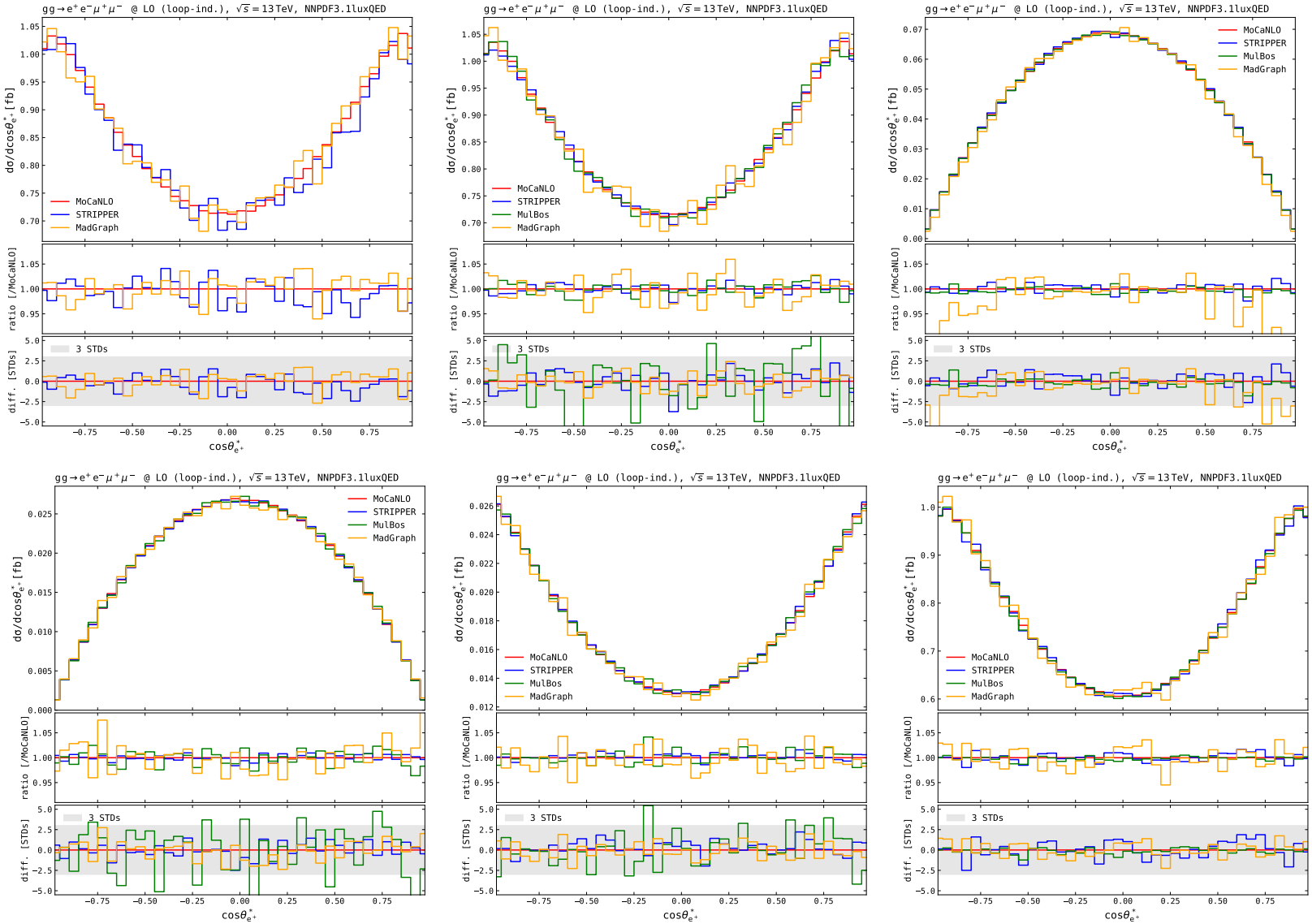


LO (loop induced)

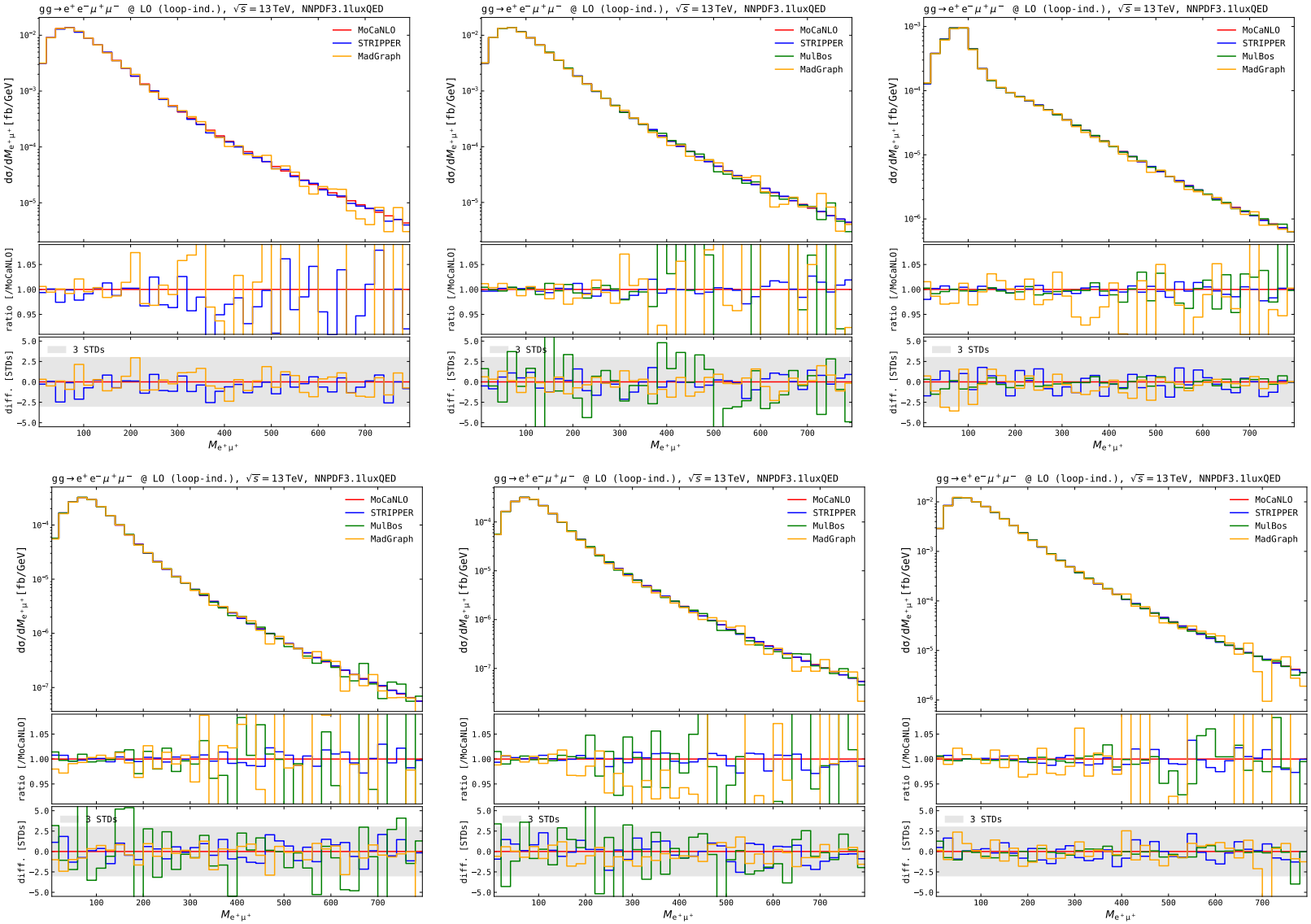
LO (loop-ind.): e^+e^- azimuthal separation



LO (loop-ind.): e^+ decay angle

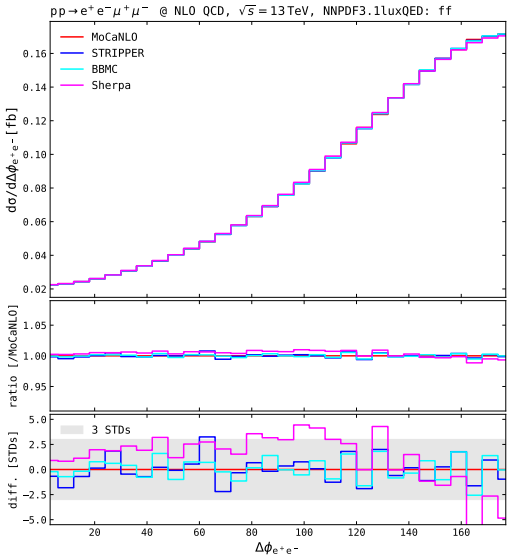


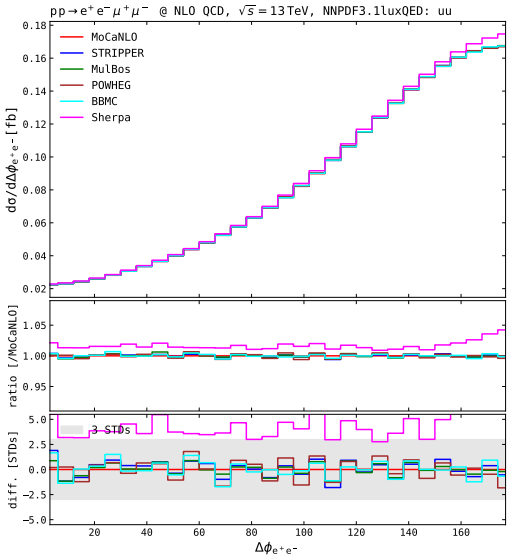
LO (loop-ind.): $e^+\mu^+$ invariant-mass

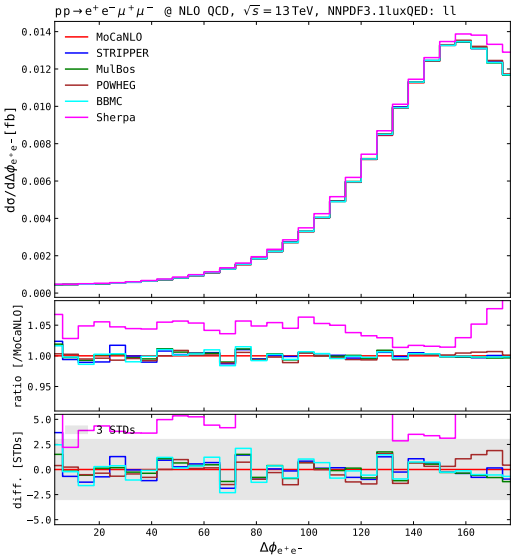


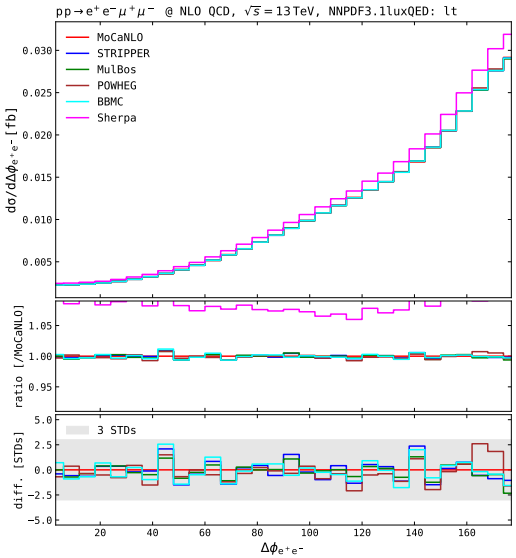
NLO QCD

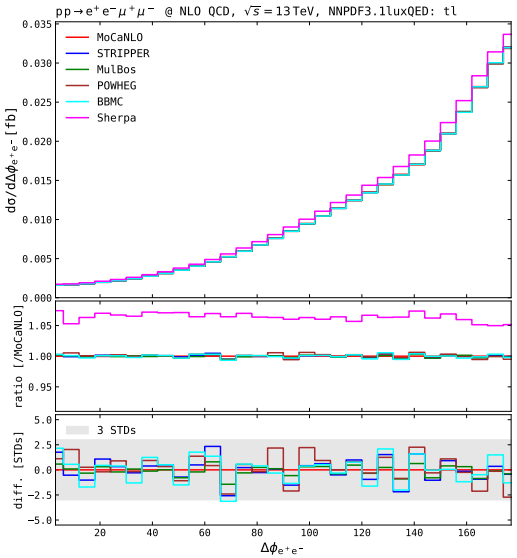
NLO QCD: e^+e^- azimuthal separation

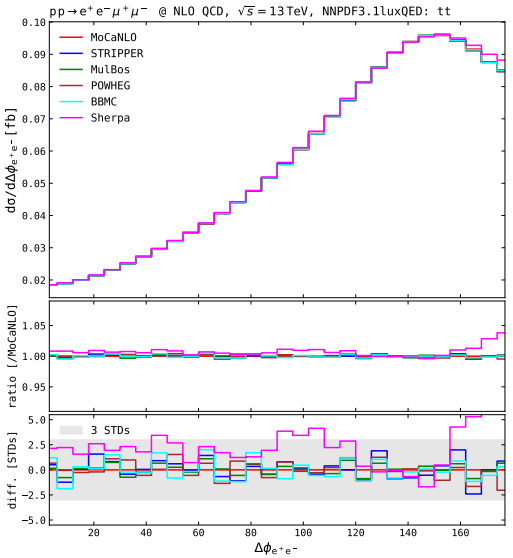




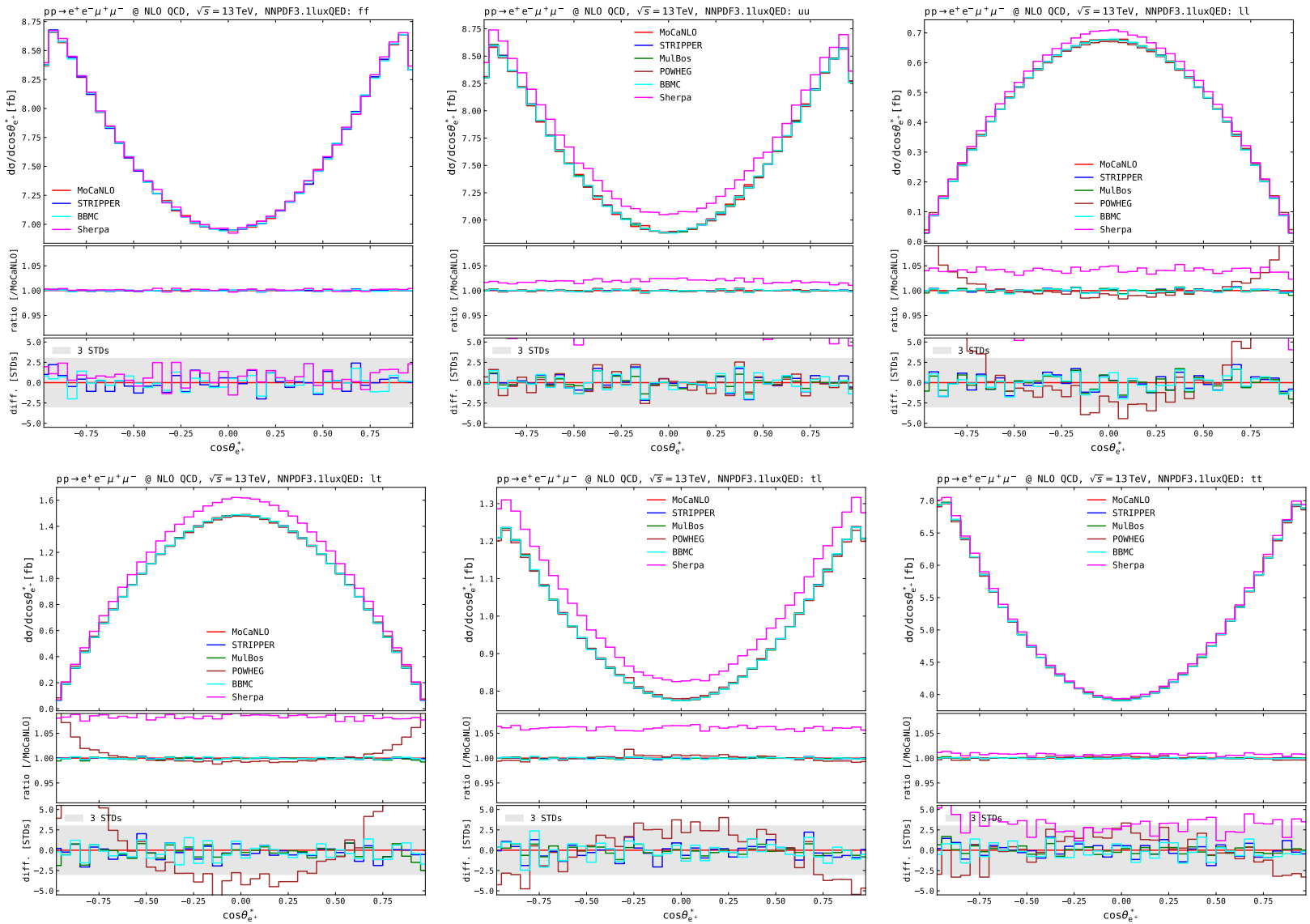




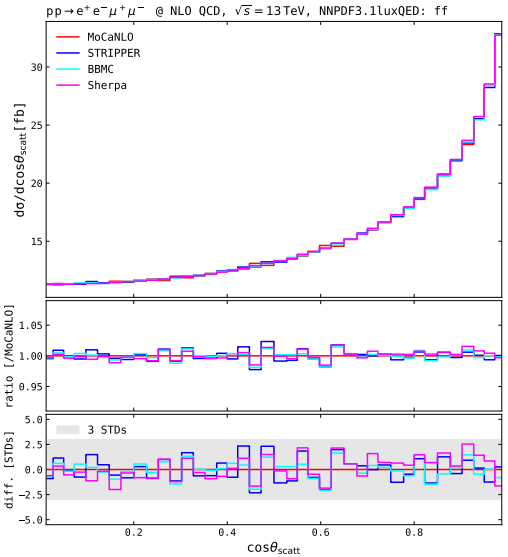


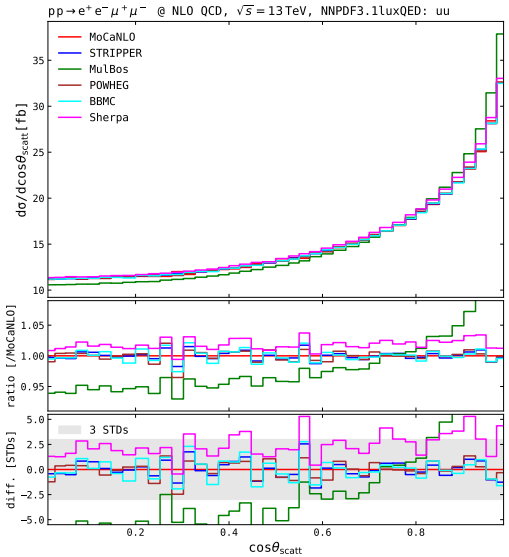


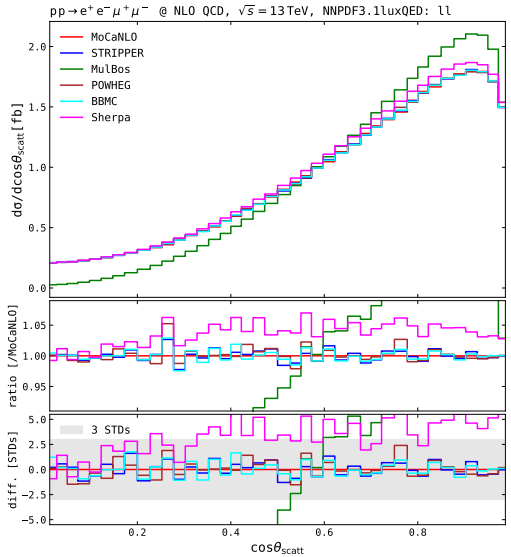
NLO QCD: e^+ decay angle

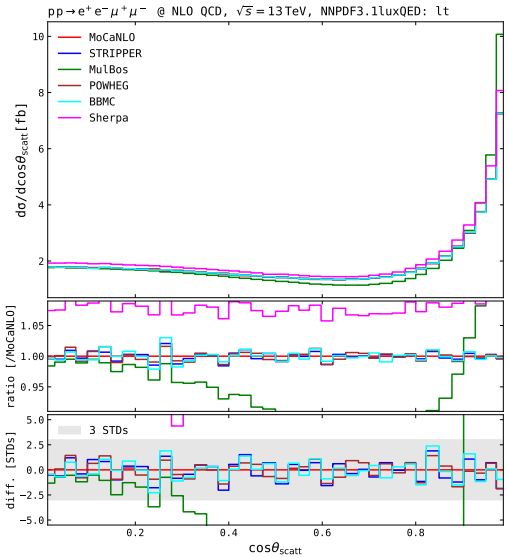


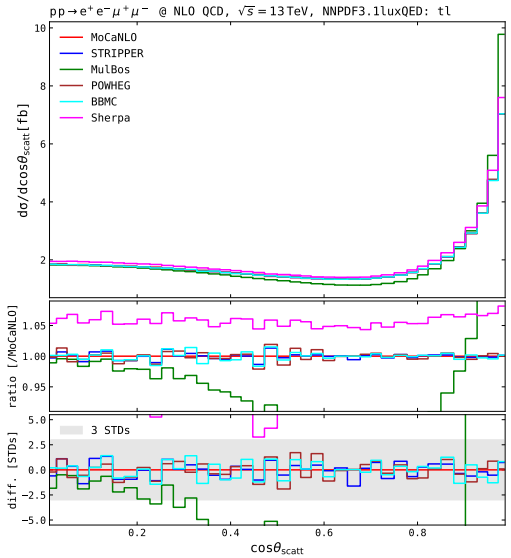
NLO QCD: scattering angle

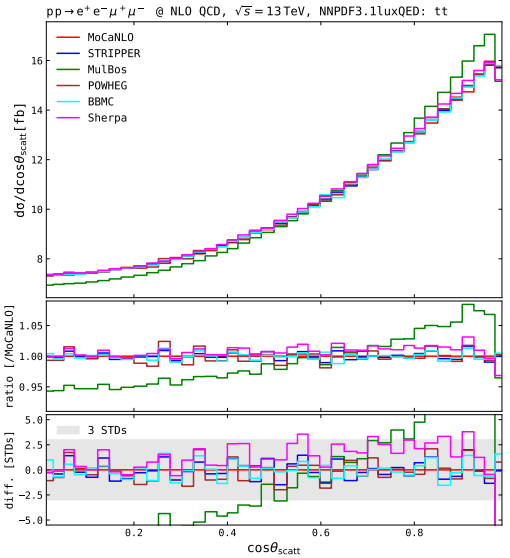




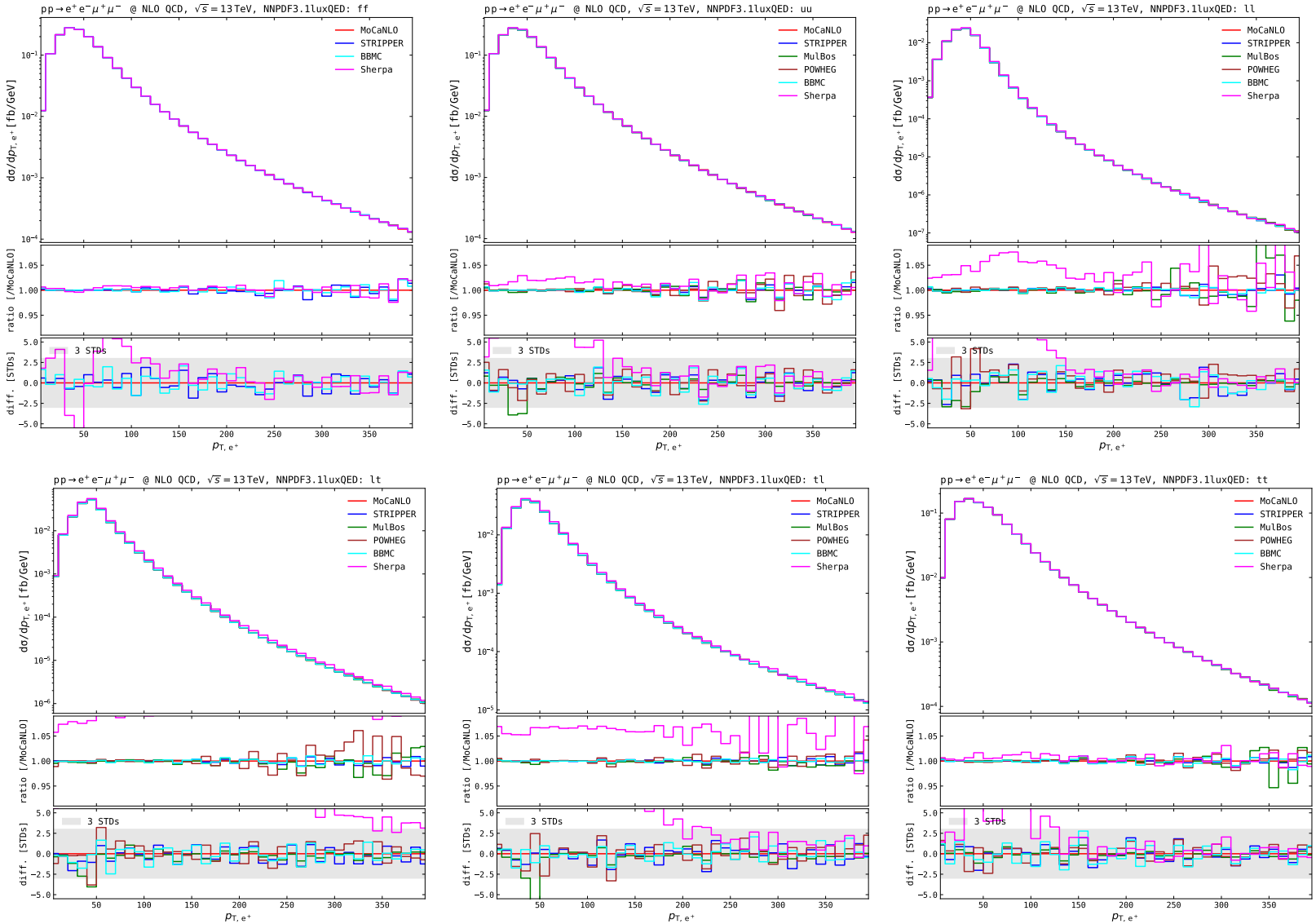






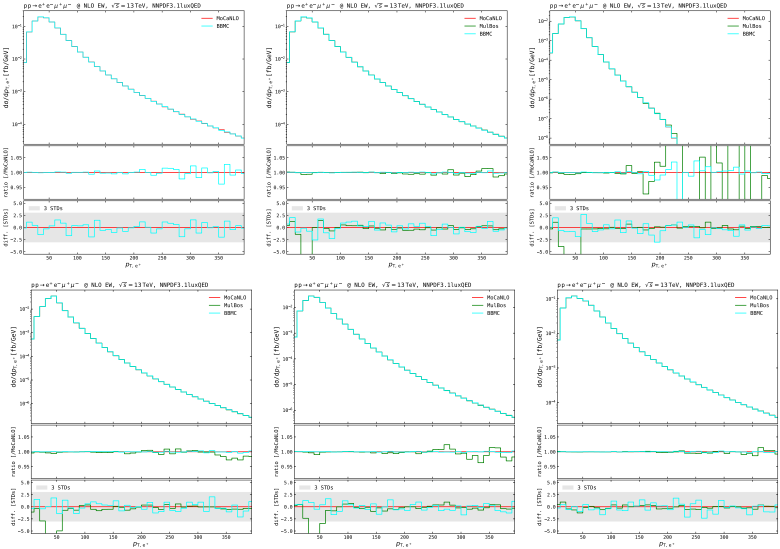


NLO QCD: e^+ transverse momentum

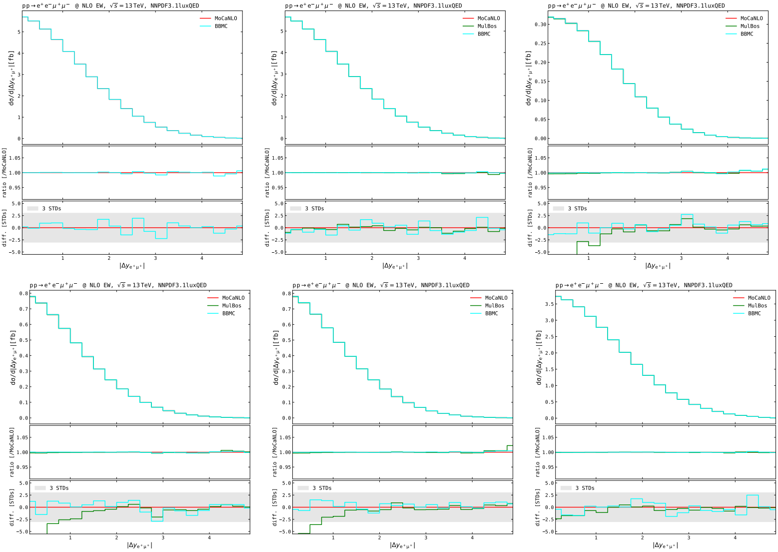


NLO EW

NLO EW: e^+ transverse momentum



NLO EW: $e^+\mu^+$ rapidity separation



Strategy for PS-matched predictions

(N)LO PS settings

Should agree on PS settings:

- QED shower on/off? If on: $\gamma \to f\bar{f}$ splitting off?
- Hadronisation on/off?
- MPI on/off?
- Other?

Input from CMS & ATLAS

- Multijet-merged (LO) results coming in.
- What to compare?

Future plans in COMETA

Future polarisation-oriented plans

- Polarisation tagger for leptonic decays
- Re-weighting vs sampling
- ML strategies ($\rightarrow$ WG2)
- Polarisation tagger for hadronic decays
- Jet-substructure observables unavoidable?
- More ideas?