Standard-Model Predictions for semi-leptonic VBS and tri-boson

Presented by
Daniele Lombardi

Joint COMETA WG1 + WG3 meeting (online)
Semi-leptonic decay channels in multi-boson production
November 20th, 2024

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- Consider process in all final states.
- Study complementary/overlapping signals.

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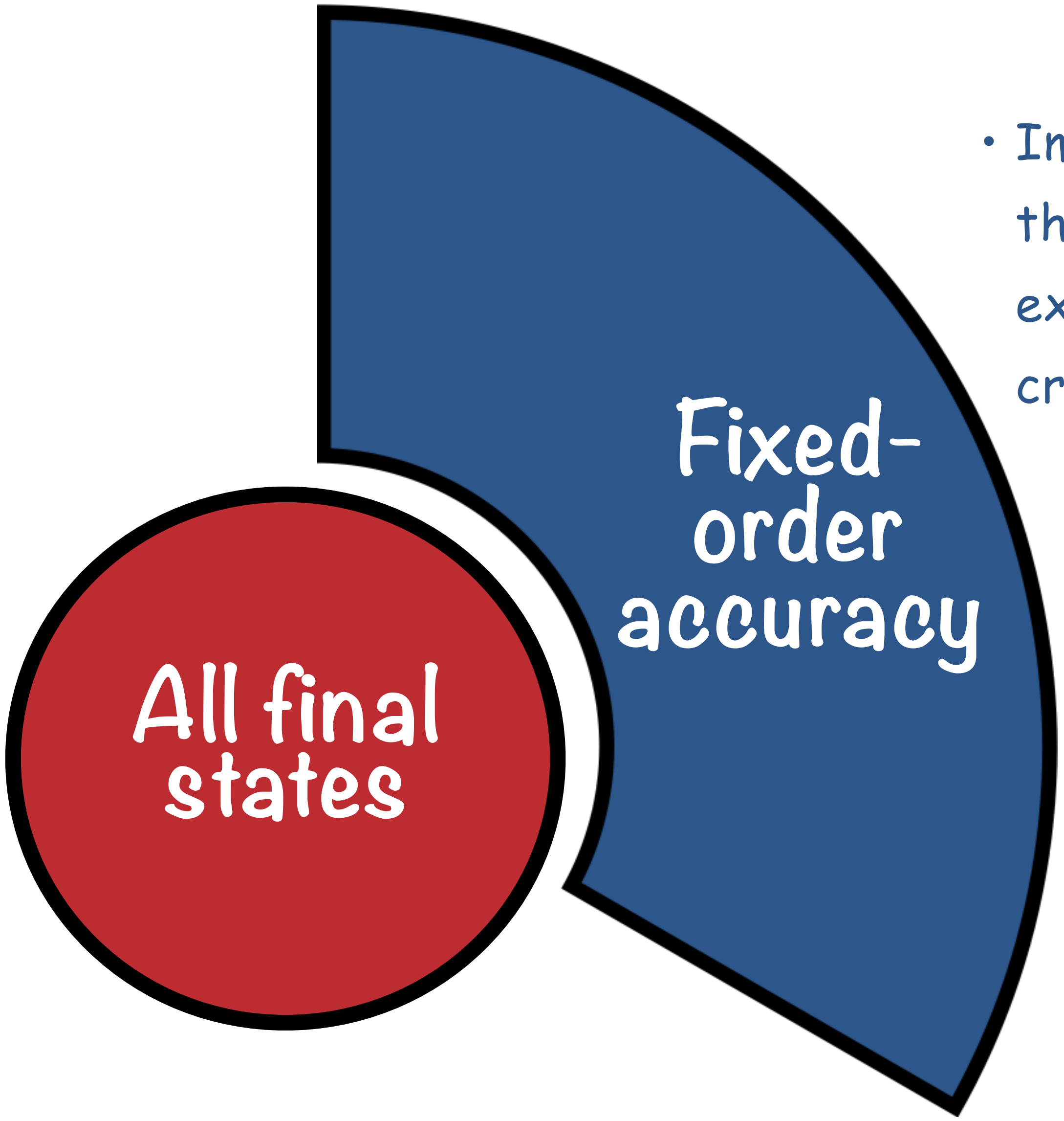

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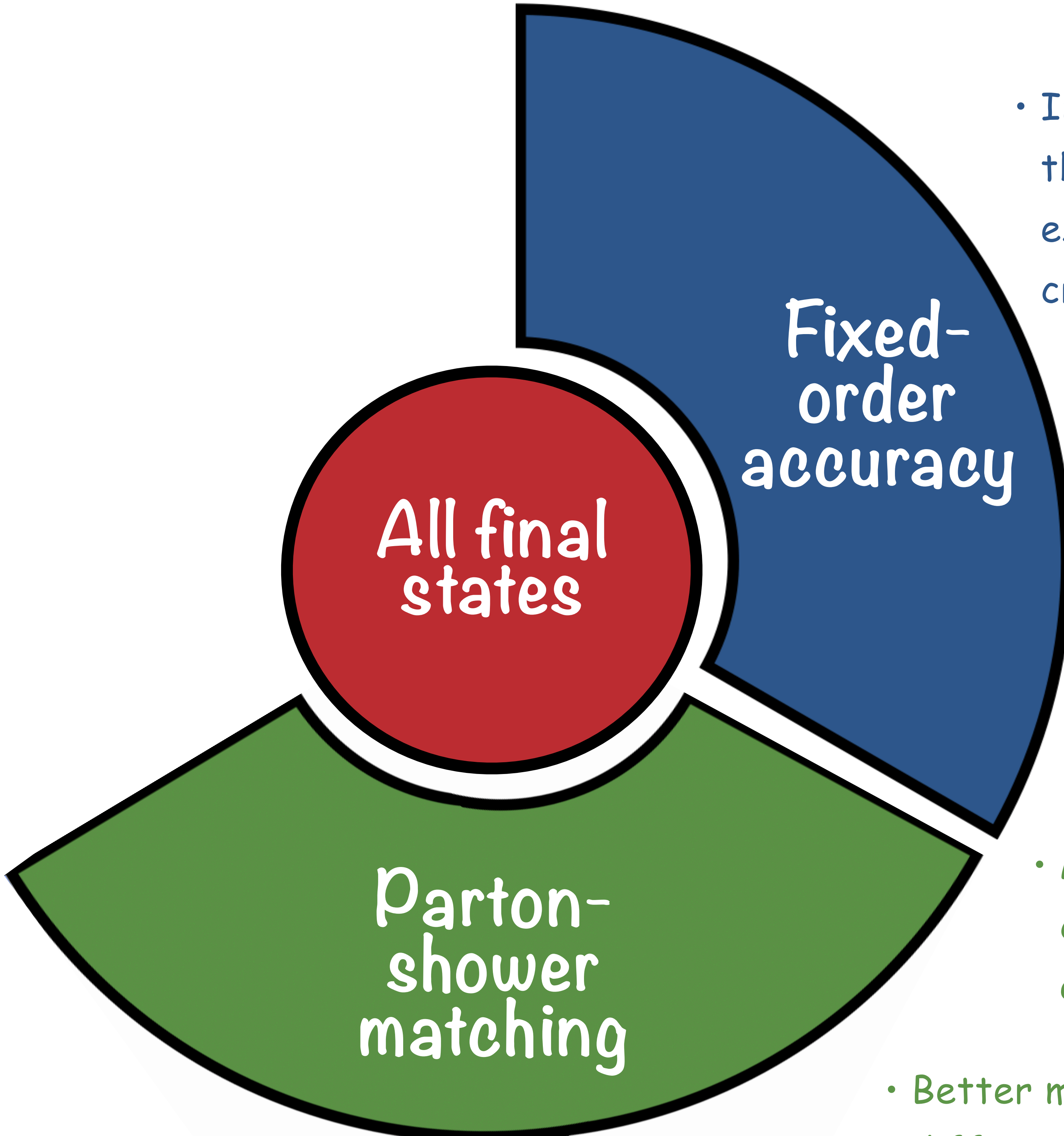

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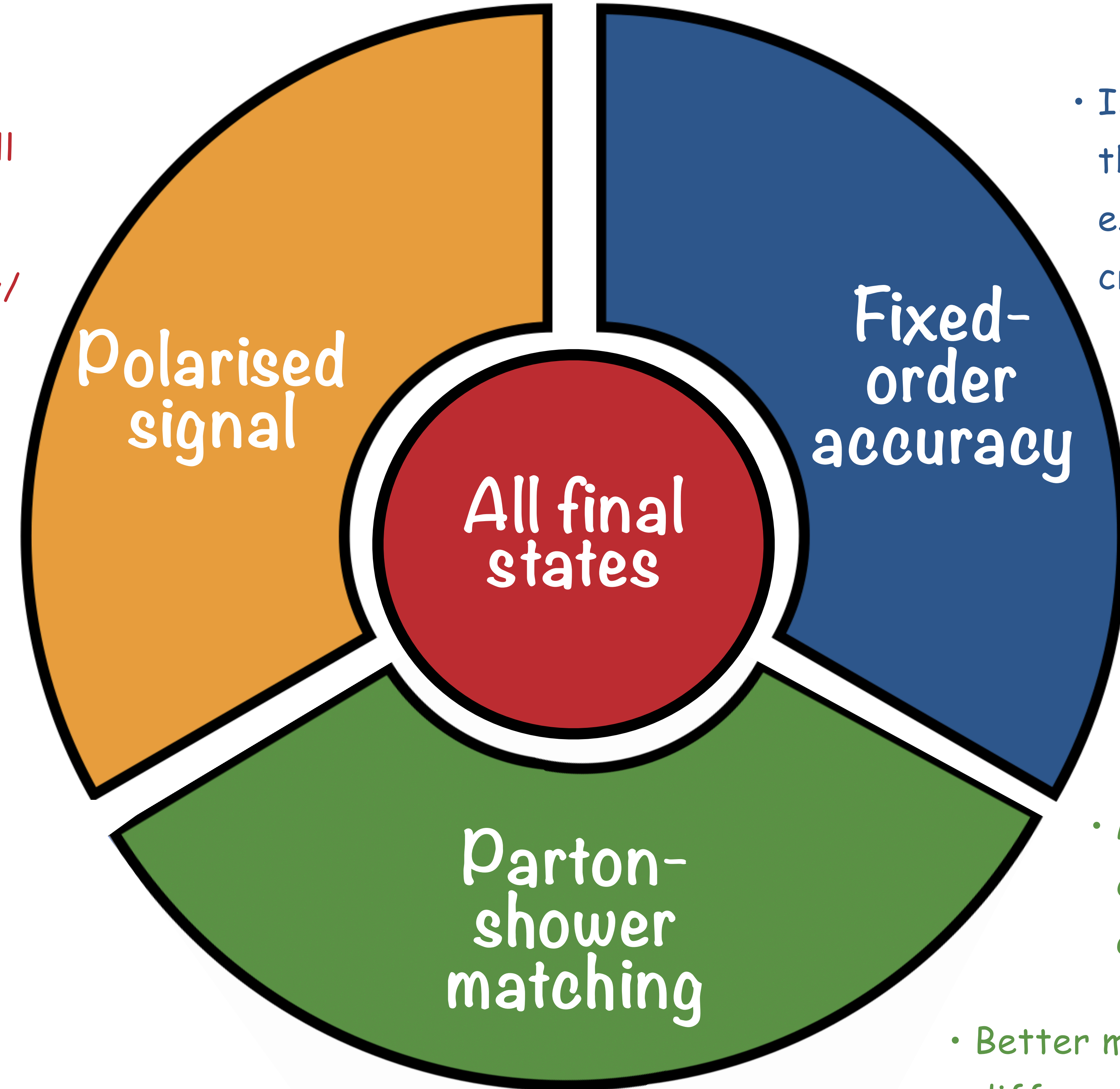
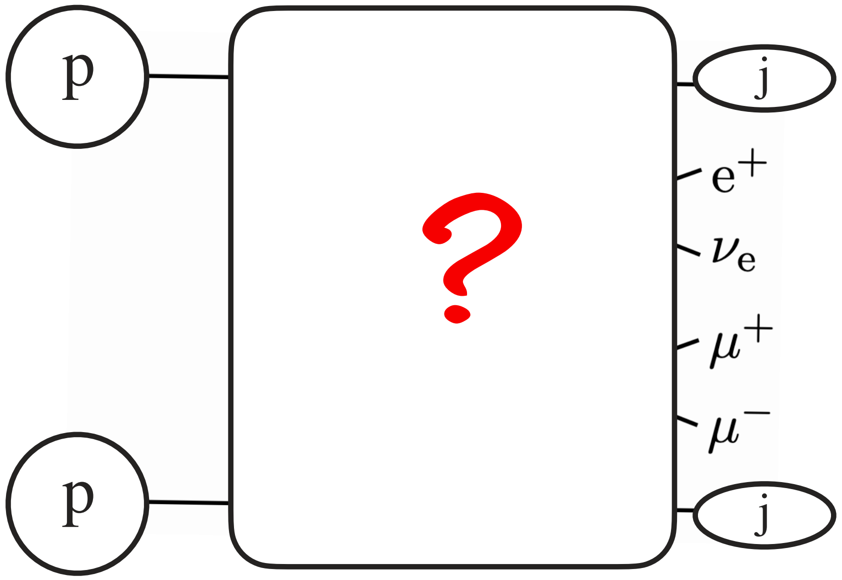


- Even more detailed information on the process by accessing polarisation states.

- Make theory results comparable to experiments.
- Better modelling of differential distributions.

Process definition



Experimental definition: only access to final states.

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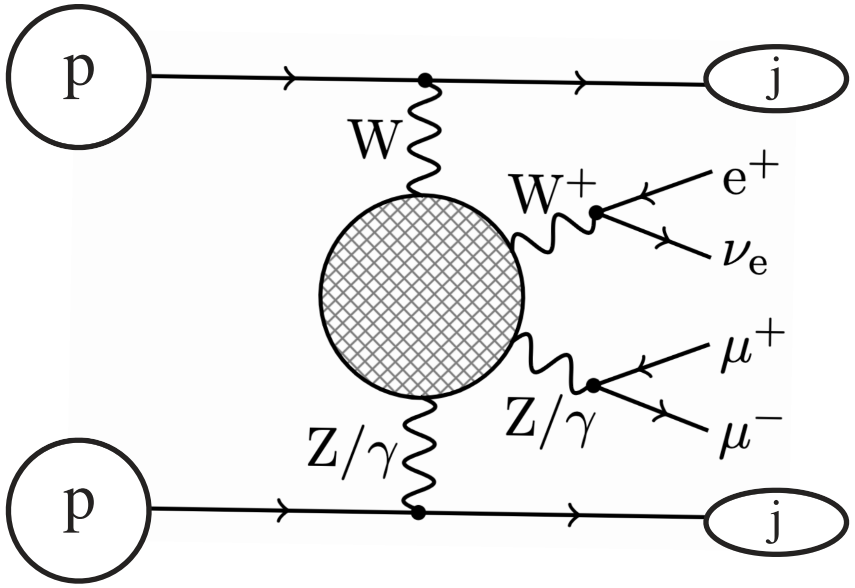

All final states

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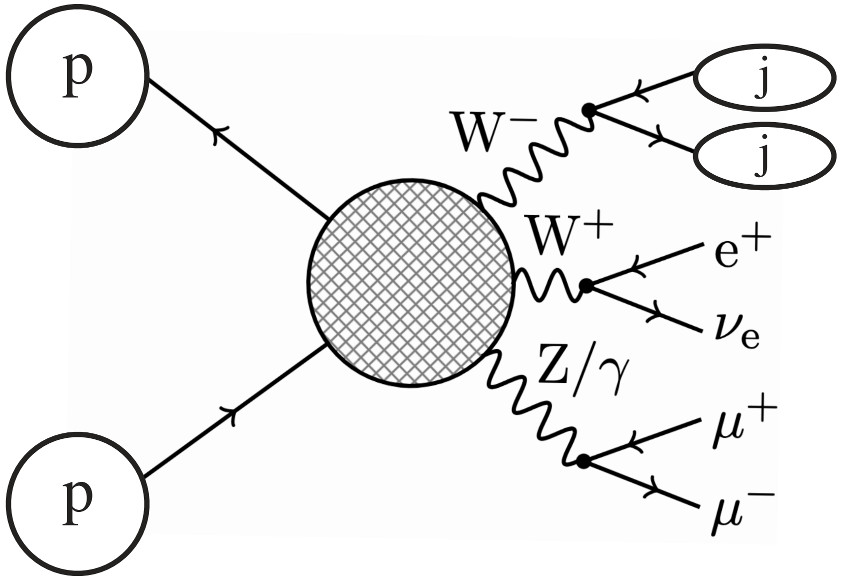
VBS

Process definition



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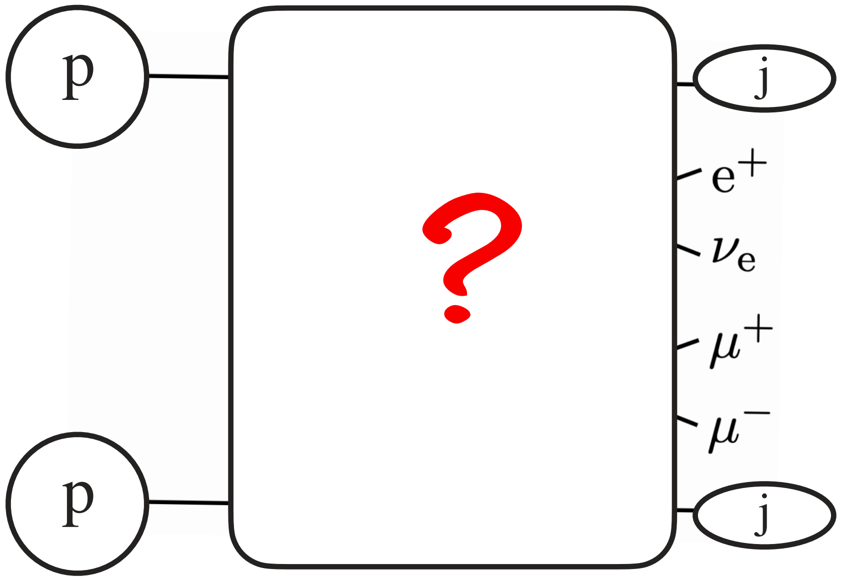
Tri-boson

Process definition



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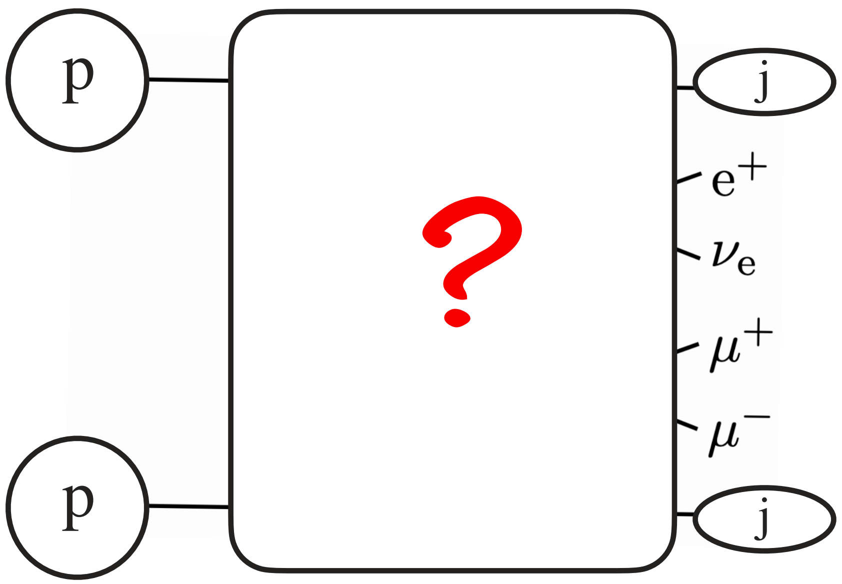

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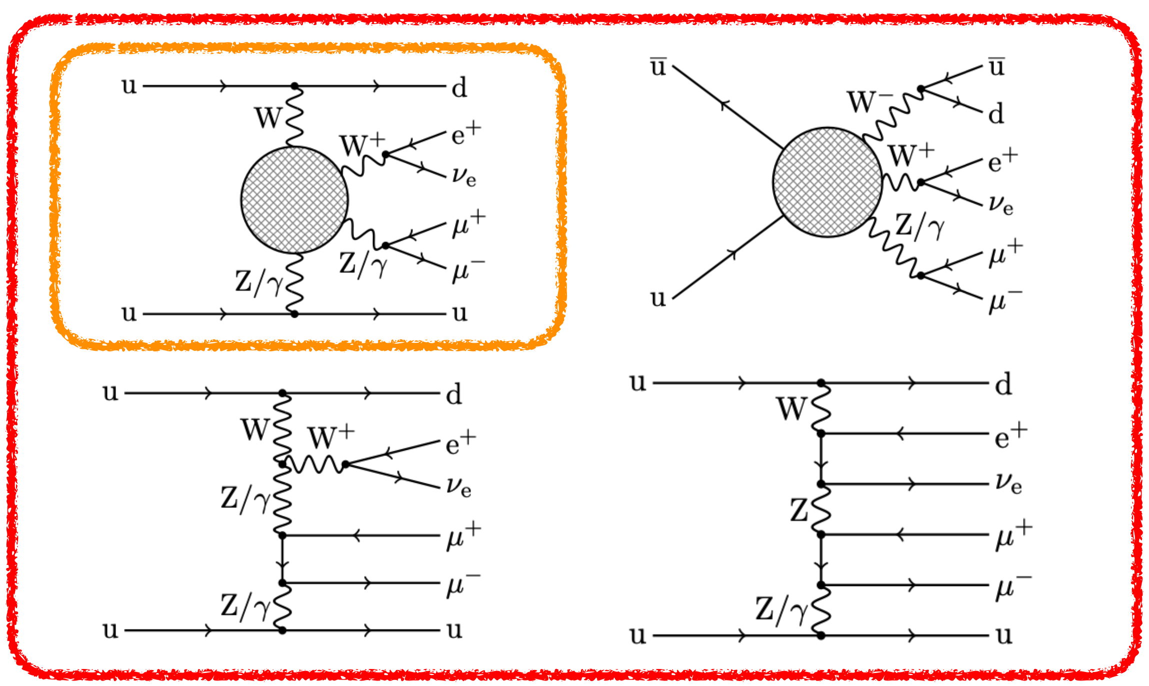
Example: fully-leptonic VBS at LO

LO EW

α^6



VBS-like topologies

Non-resonant contributions, tri-boson processes ...

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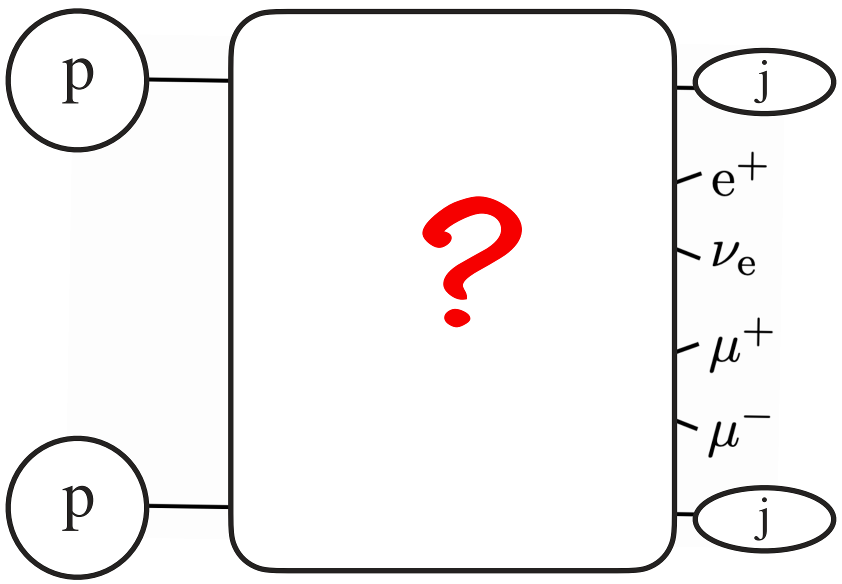

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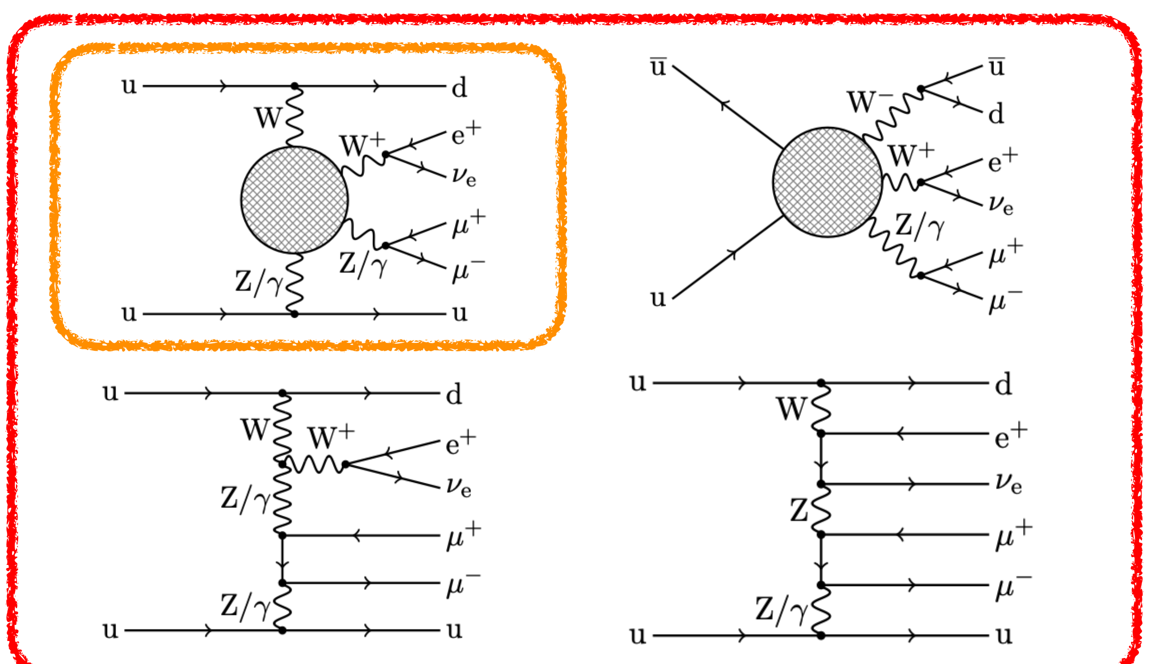

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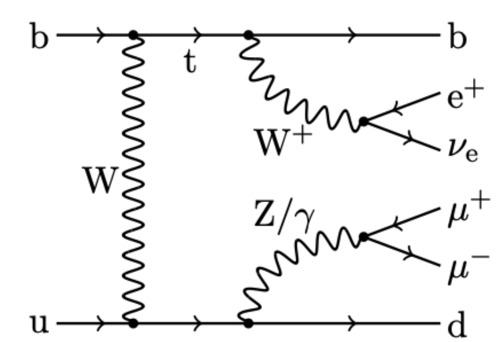
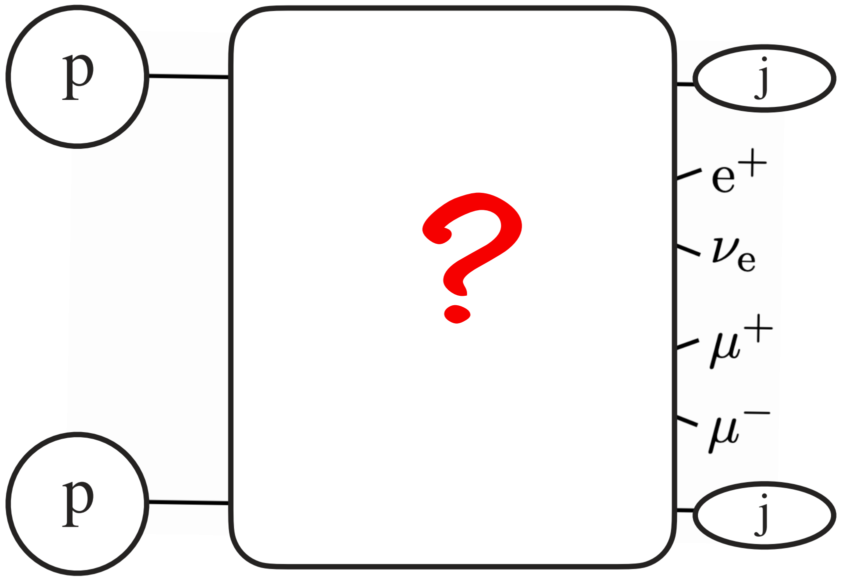
Top-quark background



Gauge-invariant set of diagrams that can be dropped (no b-initial states, perfect b-tagging/veto)

Process definition

All final states



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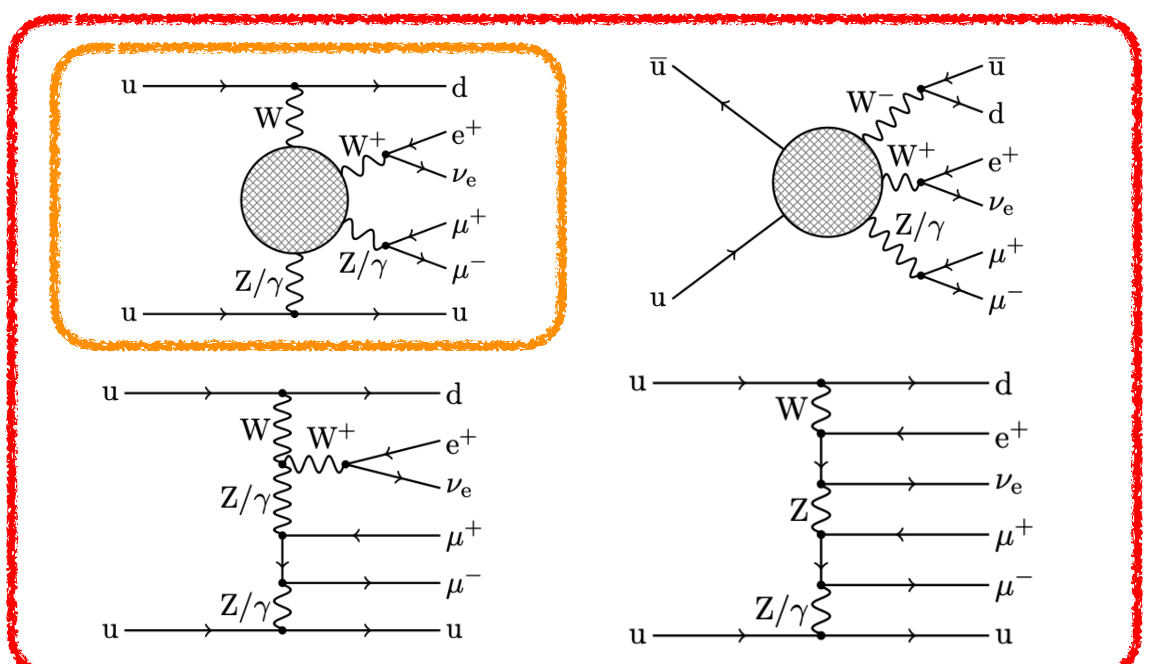
LO EW	Interference	QCD background
α^6	$\alpha_S\alpha^5$	$\alpha_S^2\alpha^4$



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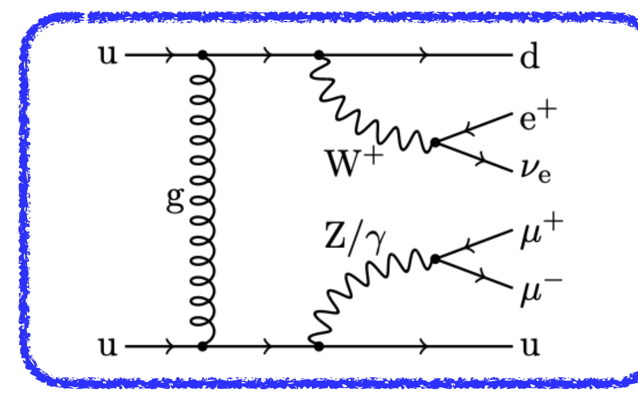

QCD-mediated processes

Semi-leptonic VBS

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Experimental issues:

✓ larger cross section;

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Theory issues: severe computational challenges.

LO EW	Interference 1	QCD background	Interference 2	Single W+jets
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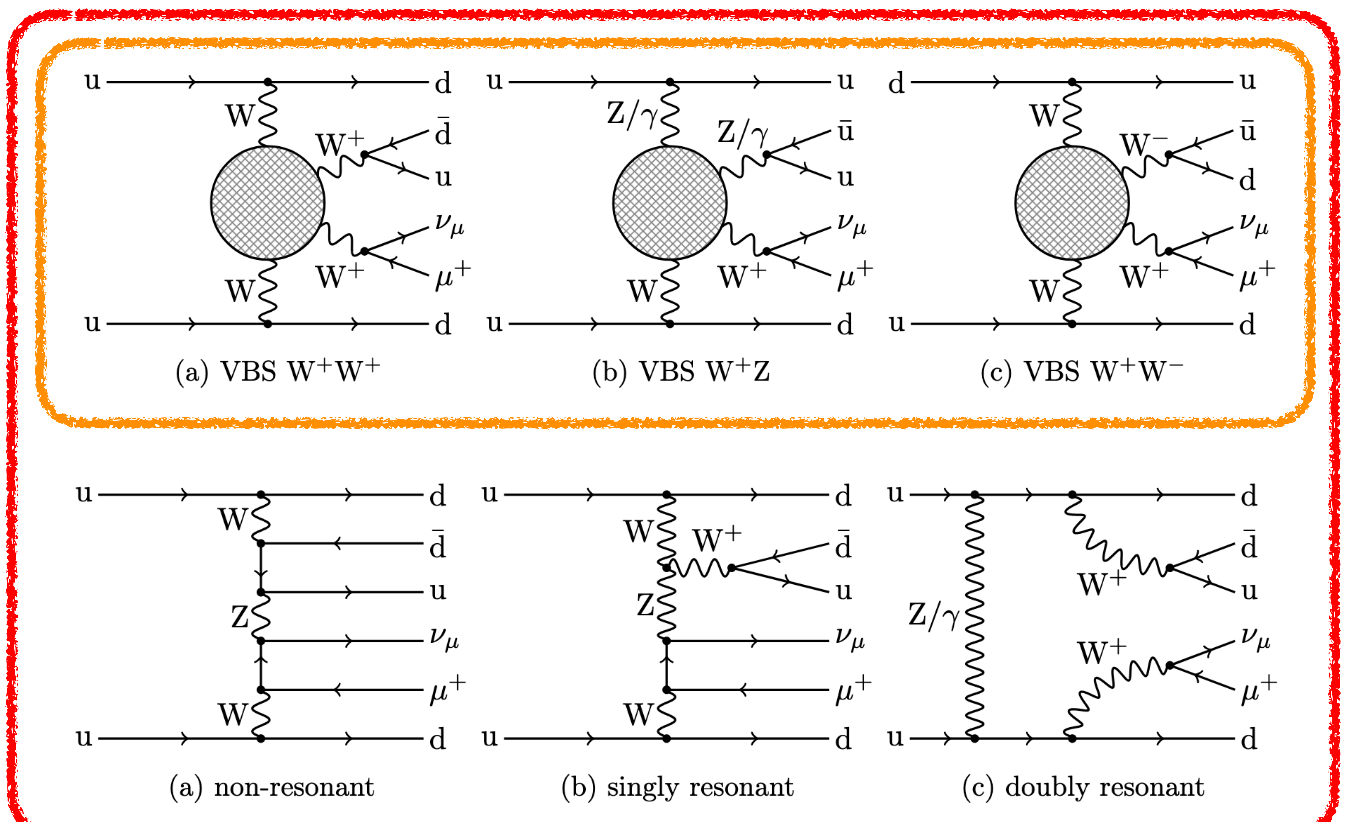

(a) VBS W⁺W⁺ (b) VBS W⁺Z (c) VBS W⁺W⁻

(a) non-resonant (b) singly resonant (c) doubly resonant

VBS-like topologies

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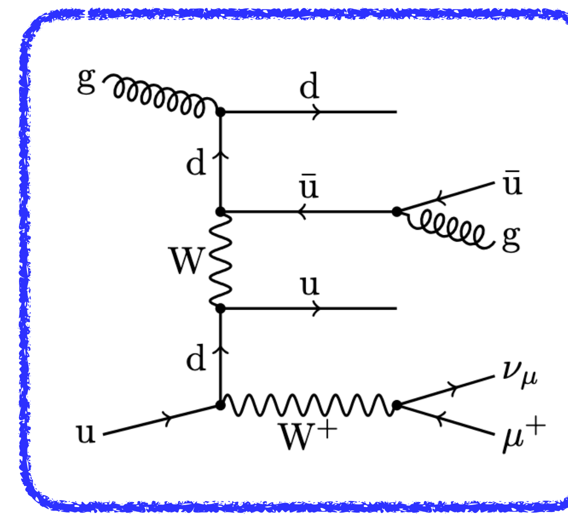
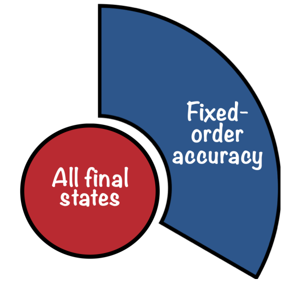


QCD-mediated processes

Fixed-order predictions for VBS



Fully-leptonic VBS

- ☑ **NLO QCD corrections** both to $\mathrm{LO_{EW}}$ and QCD background known and available in VBFNLO, POWHEG-BOX, Sherpa, MG5_aMC@NLO …
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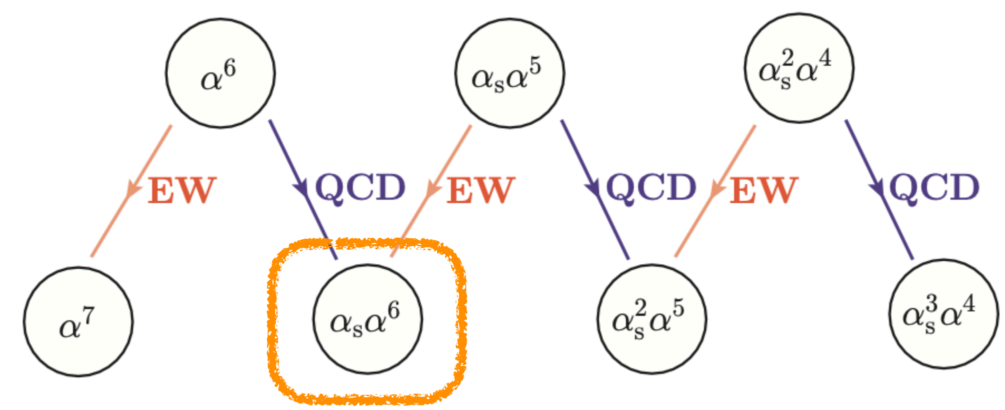

Fixed-order predictions for VBS

Fixed-order accuracy
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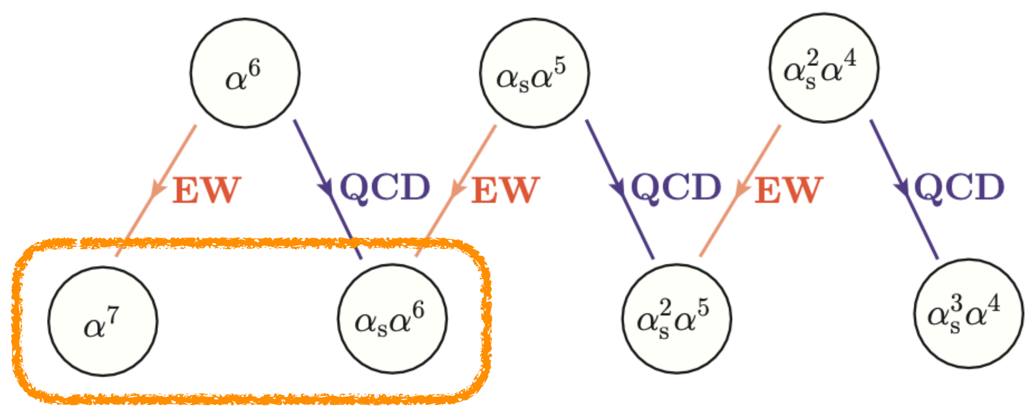

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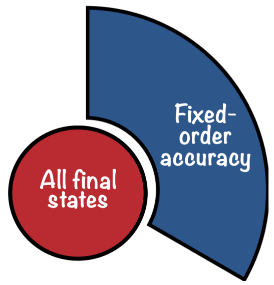

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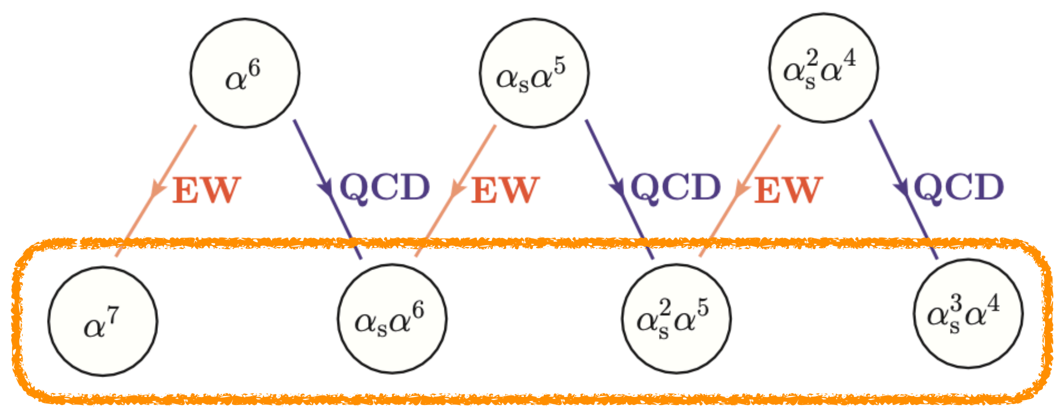

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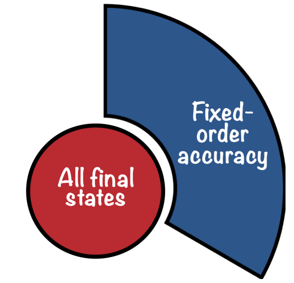

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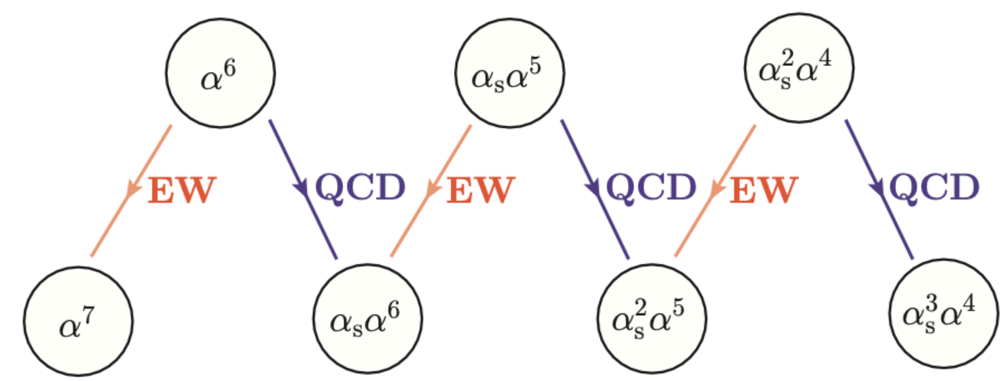

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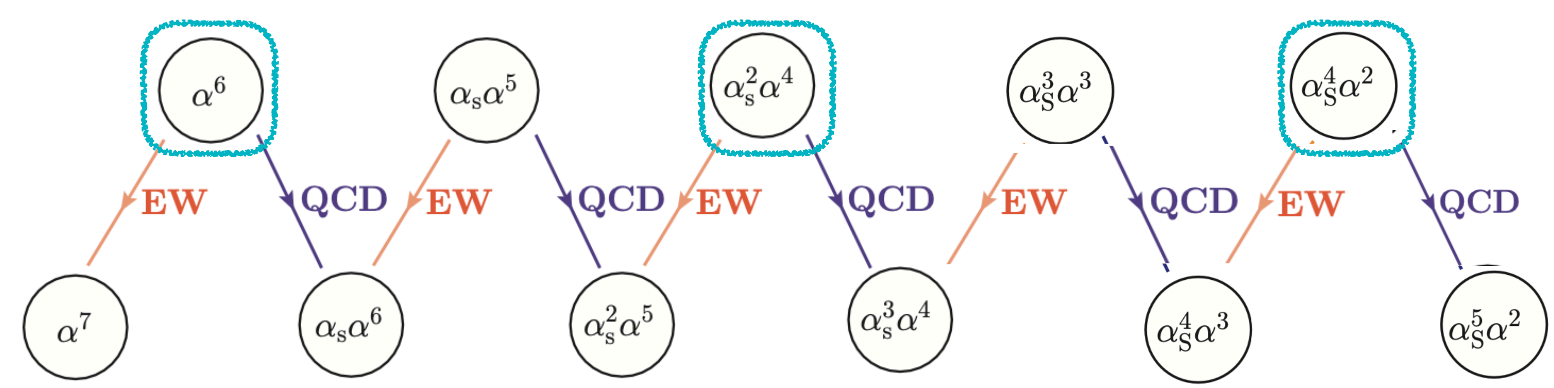

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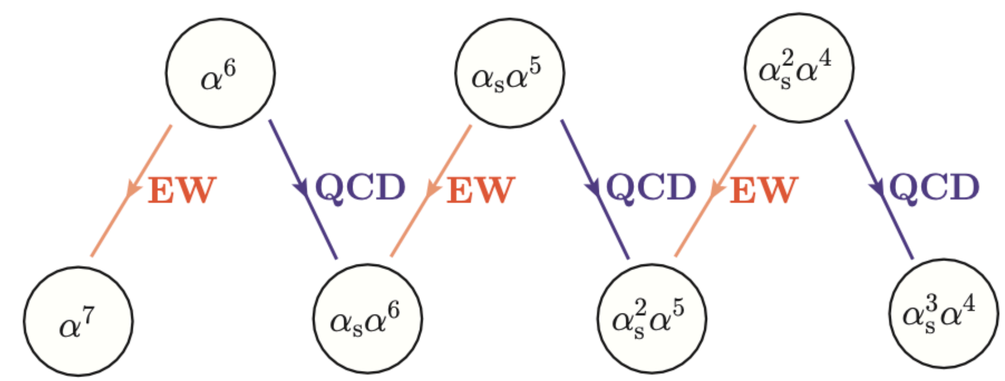

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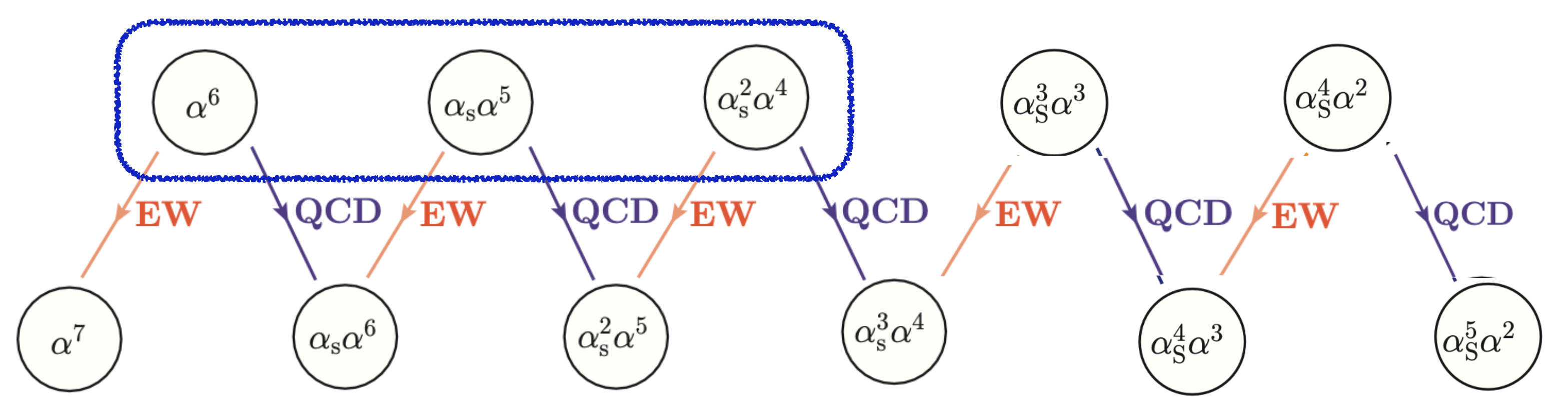

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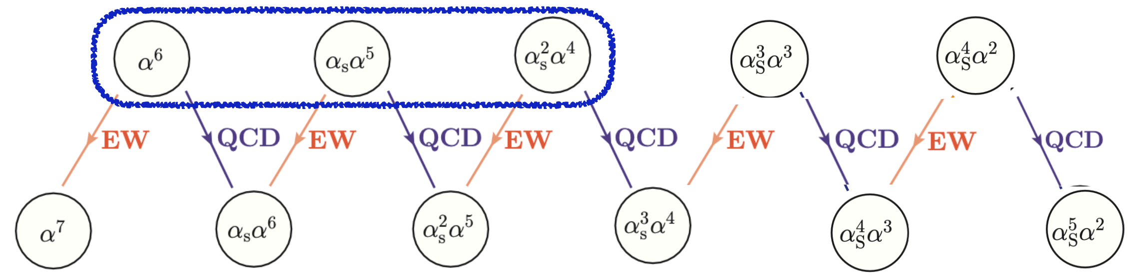

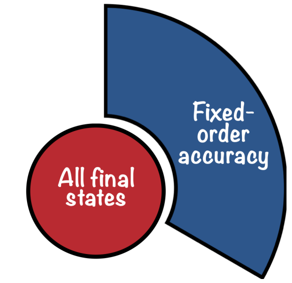

Calculation

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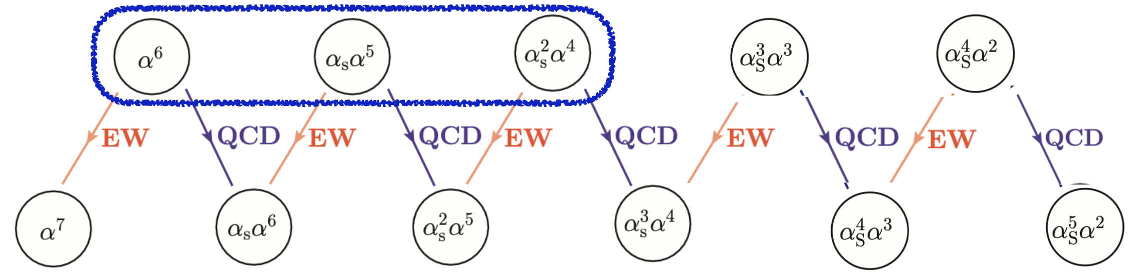

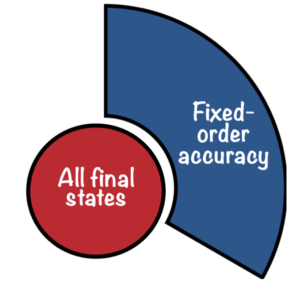

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Fiducial region inspired by CMS analysis [arXiv:2112.05259]

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  - AK4 jets: $R = 0.4$ with $p_{T,j_{AK4}} > 30\,\text{GeV}\,,\quad |y_{j_{AK4}}| < 4.7\,;$
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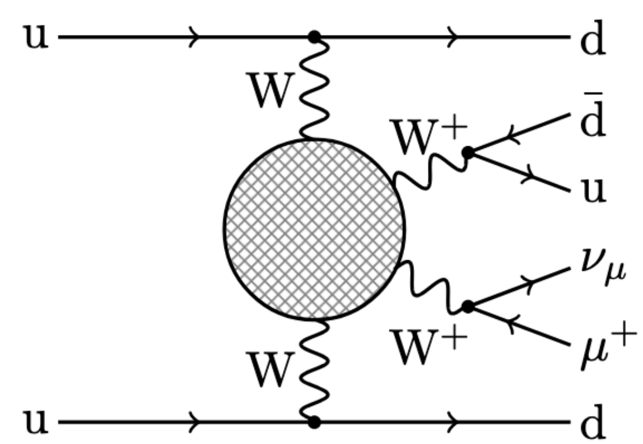

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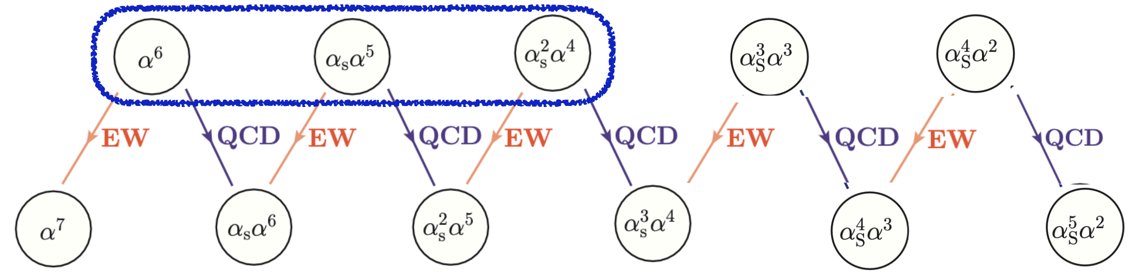

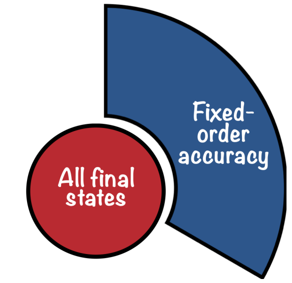

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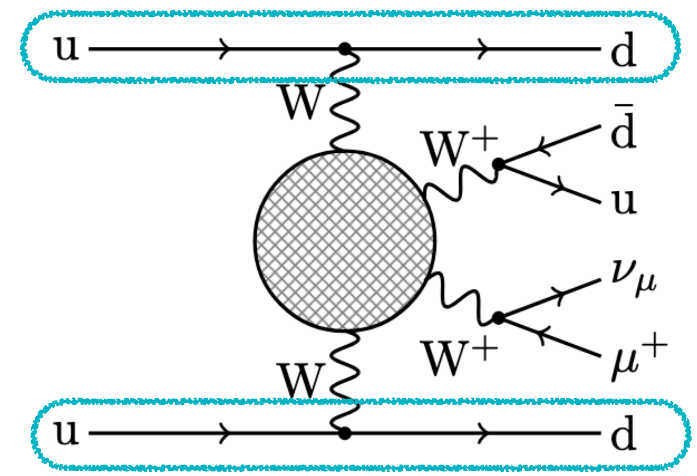

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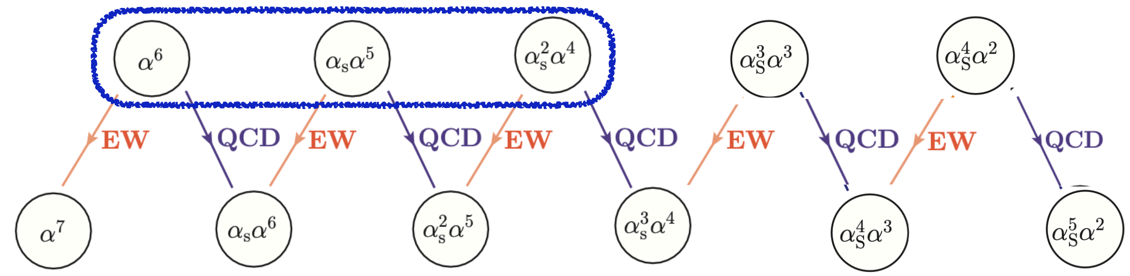

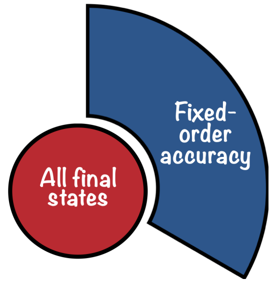

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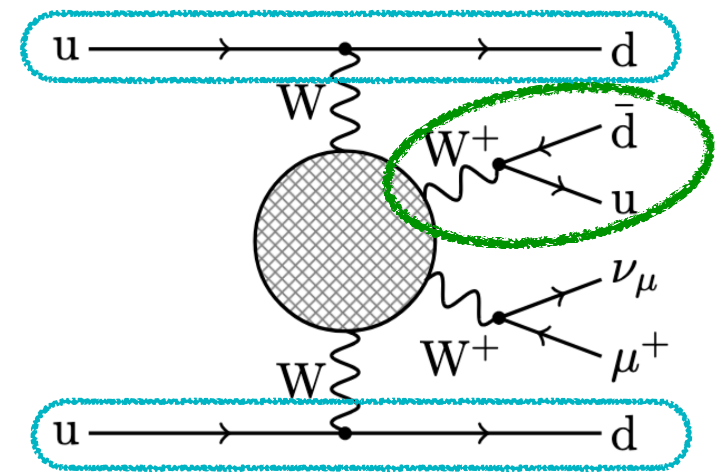

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- **Jet(s) from hadronically decaying W boson** j_V:
  - Resolved: the two non-tag AK4 jets with invariant mass the closest to $85\,\text{GeV} \rightarrow 65\,\text{GeV} < M_{j_V} < 105\,\text{GeV}$
  - Boosted: the AK8 jet $\rightarrow$ $70\,\text{GeV} < M_{j_V} < 115\,\text{GeV}$

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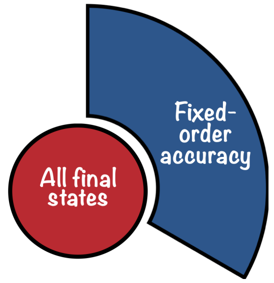


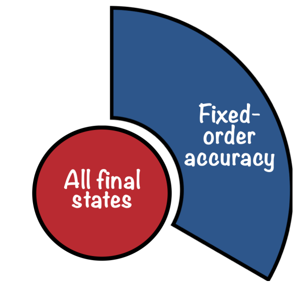
Integrated cross sections

Order	resolved-setup		boosted-setup	
	$\sigma_{\text{off shell}}$ [fb]	Δ [%]	$\sigma_{\text{off shell}}$ [fb]	Δ [%]
$\mathcal{O}(\alpha^6)$	$9.042(1)^{+9.0\%}_{-7.7\%}$	22.8	$2.5070(4)^{+11.6\%}_{-9.6\%}$	21.0
$\mathcal{O}(\alpha_s\alpha^5)$	$0.2952(1)^{+17.2\%}_{-13.5\%}$	0.7	$0.06920(5)^{+19.3\%}_{-14.9\%}$	0.6
$\mathcal{O}(\alpha_s^2\alpha^4)$	$30.334(5)^{+36.7\%}_{-24.7\%}$	76.5	$9.338(3)^{+39.1\%}_{-25.9\%}$	78.4
sum	$39.673(5)^{+30.2\%}_{-20.8\%}$	100.0	$11.914(3)^{+33.2\%}_{-22.4\%}$	100.0

Small ratio of **LO_{EW} (embedding signal)** over **QCD background** in both categories (between 21-23%).

Semi-leptonic VBS at LO

Denner, Lombardi, Schwan [arXiv:2406.12301]



Order	resolved-setup $\sigma_{\text{off shell}}$ [fb]	resolved-setup Δ [%]	boosted-setup $\sigma_{\text{off shell}}$ [fb]	boosted-setup Δ [%]
$\mathcal{O}(\alpha^6)$	$9.042(1)^{+9.0\%}_{-7.7\%}$	22.8	$2.5070(4)^{+11.6\%}_{-9.6\%}$	21.0
$\mathcal{O}(\alpha_s\alpha^5)$	$0.2952(1)^{+17.2\%}_{-13.5\%}$	0.7	$0.06920(5)^{+19.3\%}_{-14.9\%}$	0.6
$\mathcal{O}(\alpha_s^2\alpha^4)$	$30.334(5)^{+36.7\%}_{-24.7\%}$	76.5	$9.338(3)^{+39.1\%}_{-25.9\%}$	78.4
sum	$39.673(5)^{+30.2\%}_{-20.8\%}$	100.0	$11.914(3)^{+33.2\%}_{-22.4\%}$	100.0

Integrated cross sections

LO $= \mathcal{O}(\alpha^6)$ full off-shell

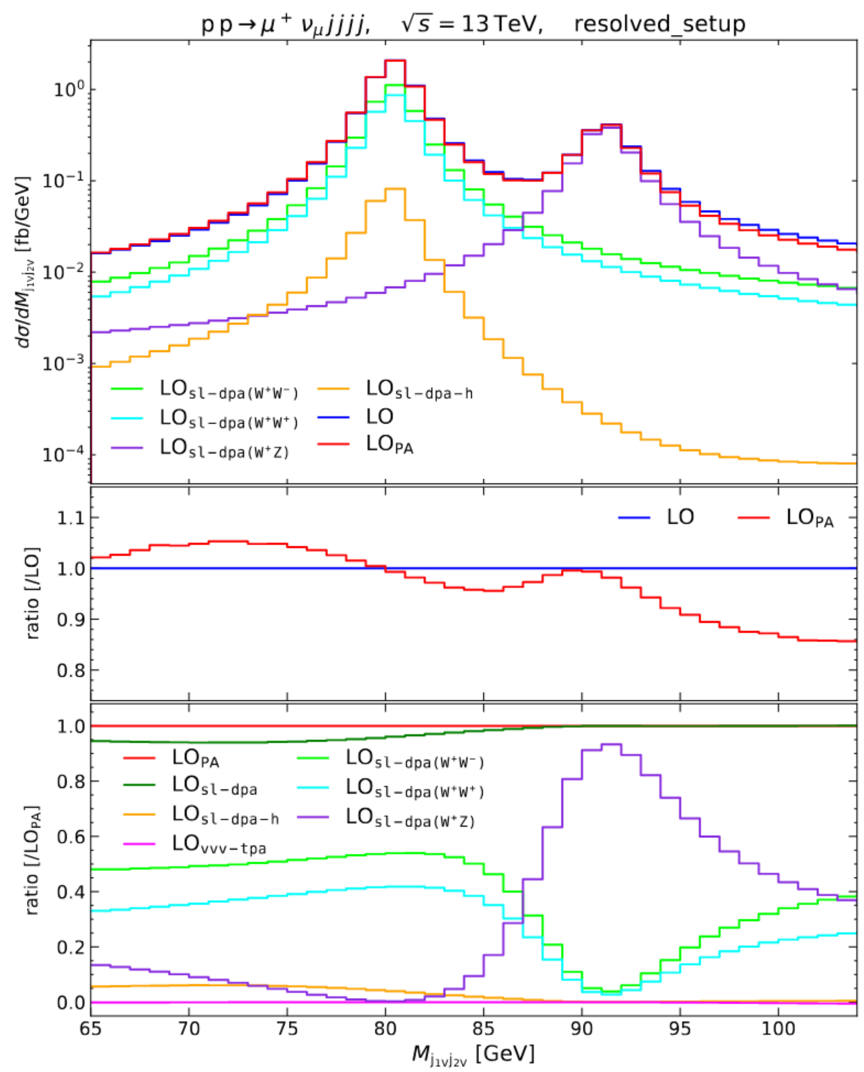
LO_{PA} $= \mathcal{O}(\alpha^6)$ in DPA

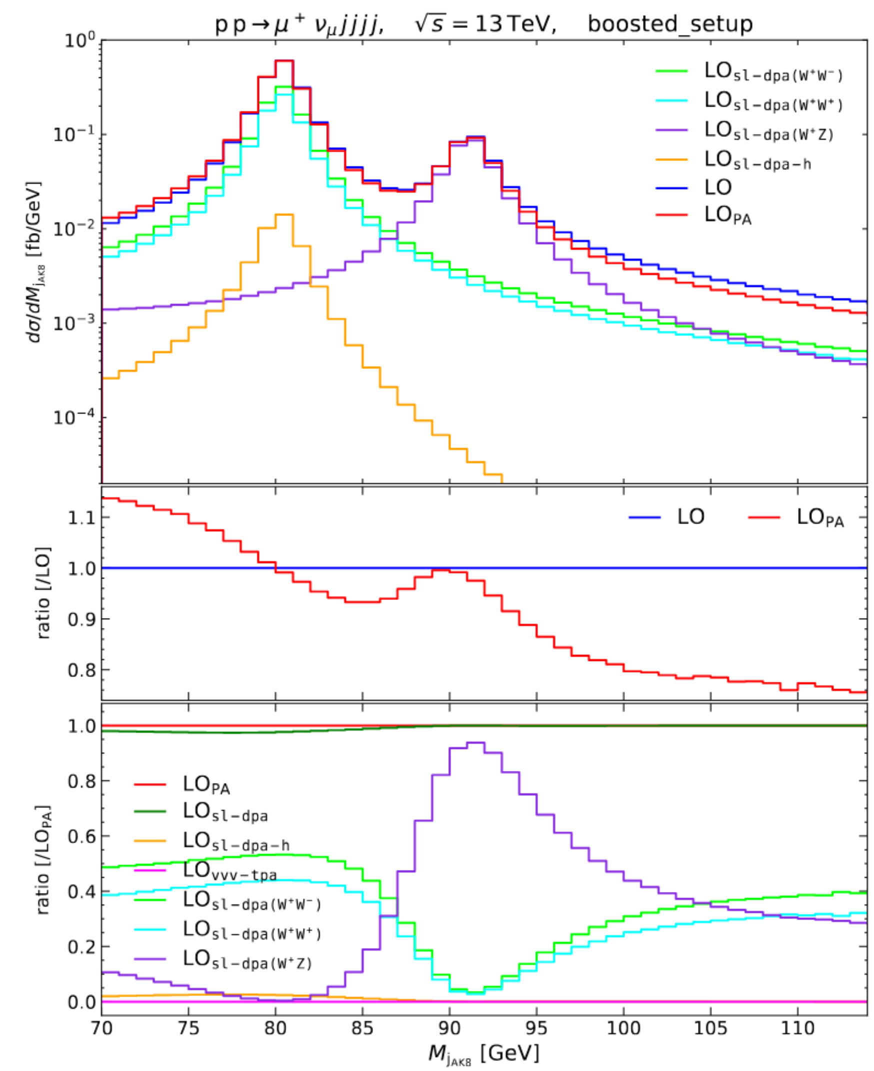
Quality of DPA at $\mathcal{O}(\alpha^6)$

Most of the physics captured by DPA for observables inclusive over decay products of resonances.

DPA fails in off-shell regions:

- overestimate of +5/15% below W peak;
- underestimate up to -20% above Z peak.

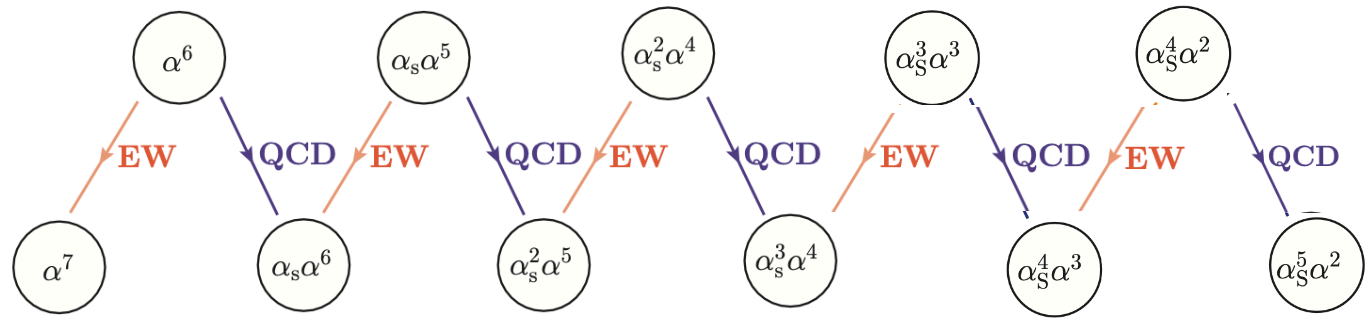




Semi-leptonic VBS: moving to NLO?

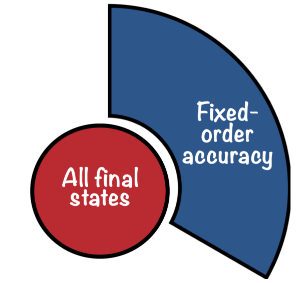
All final states
Fixed-order accuracy

Even if all ingredients in principle available, still a formidable task …



➡ Number of partonic channels to be evaluated explodes.

Semi-leptonic VBS: moving to NLO?



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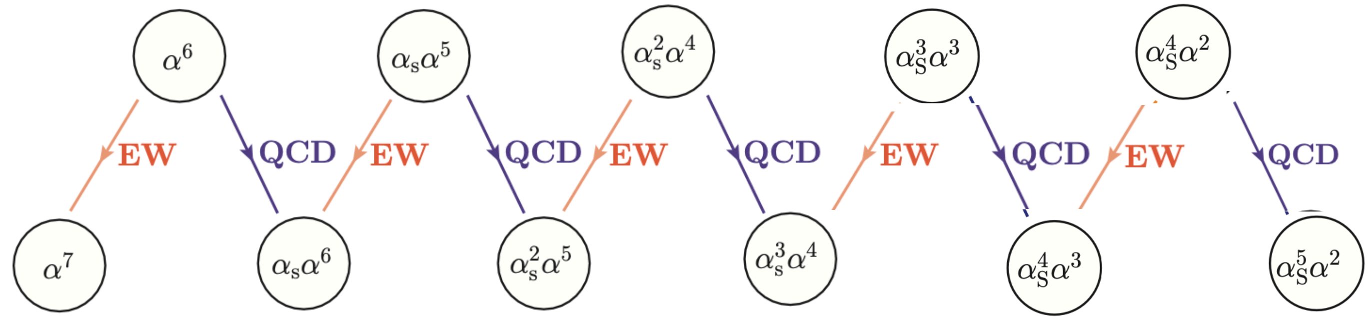

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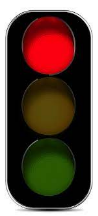

Approximate result using DPA?
Due to non-trivial resonance structure of semi-leptonic VBS process, DPA computation becomes extremely difficult already at $\mathcal{O}(\alpha^6)$.

Semi-leptonic DPAs with 1 → 2 decay

$\mathrm{pp} \to \mathrm{W}^+(\ell^+\nu_\ell)\mathrm{W}^+(\mathrm{jj})\mathrm{jj},$
$\mathrm{pp} \to \mathrm{W}^+(\ell^+\nu_\ell)\mathrm{Z}(\mathrm{jj})\mathrm{jj},$
$\mathrm{pp} \to \mathrm{W}^+(\ell^+\nu_\ell)\mathrm{W}^-(\mathrm{jj})\mathrm{jj},$

Fully hadronic DPAs with 1 → 2 decay

$\mathrm{pp} \to \ell^+\nu_\ell\mathrm{W}^-(\mathrm{jj})\mathrm{W}^+(\mathrm{jj}),$
$\mathrm{pp} \to \ell^+\nu_\ell\mathrm{W}^-(\mathrm{jj})\mathrm{Z}(\mathrm{jj}),$
$\mathrm{pp} \to \ell^+\nu_\ell\mathrm{W}^-(\mathrm{jj})\mathrm{W}^-(\mathrm{jj}),$
$\mathrm{pp} \to \ell^+\nu_\ell\mathrm{Z}(\mathrm{jj})\mathrm{Z}(\mathrm{jj}),$

Semi-leptonic DPAs with 1 → 4 decay

$\mathrm{pp} \to \mathrm{W}^+(\ell^+\nu_\ell)\mathrm{H}(\mathrm{jjjj}),$ $\mathrm{pp} \to \mathrm{W}^+(\ell^+\nu_\ell)\mathrm{Z}(\mathrm{jjjj}),$
$\mathrm{pp} \to \mathrm{W}^+(\ell^+\nu_\ell)\mathrm{W}^-(\mathrm{jjjj}),$
$\mathrm{pp} \to \mathrm{W}^+(\ell^+\nu_\ell\mathrm{jj})\mathrm{Z}(\mathrm{jj}),$
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Fully hadronic DPAs with nested 1 → 2 decay

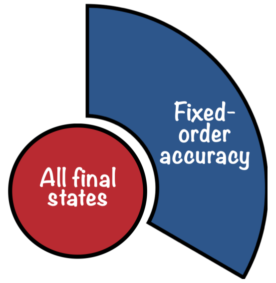
$\mathrm{pp} \to \ell^+\nu_\ell\mathrm{H}(\mathrm{W}^+(\mathrm{jj})\mathrm{jj}),$ $\mathrm{pp} \to \ell^+\nu_\ell\mathrm{Z}(\mathrm{W}^+(\mathrm{jj})\mathrm{jj}),$
$\mathrm{pp} \to \ell^+\nu_\ell\mathrm{H}(\mathrm{Z}(\mathrm{jj})\mathrm{jj}),$
$\mathrm{pp} \to \ell^+\nu_\ell\mathrm{H}(\mathrm{W}^-(\mathrm{jj})\mathrm{jj}),$ $\mathrm{pp} \to \ell^+\nu_\ell\mathrm{Z}(\mathrm{W}^-(\mathrm{jj})\mathrm{jj}).$

Semi-leptonic DPAs with nested 1 → 4 decay

$\mathrm{pp} \to \mathrm{H}(\mathrm{W}^+(\ell^+\nu_\ell)\mathrm{jj})\mathrm{jj},$ $\mathrm{pp} \to \mathrm{Z}(\mathrm{W}^+(\ell^+\nu_\ell)\mathrm{jj})\mathrm{jj}.$
$\mathrm{pp} \to \mathrm{H}(\ell^+\nu_\ell\mathrm{W}^-(\mathrm{jj}))\mathrm{jj},$ $\mathrm{pp} \to \mathrm{Z}(\ell^+\nu_\ell\mathrm{W}^-(\mathrm{jj}))\mathrm{jj},$

- Nested contributions.
- Subtraction of overcounting of triply-resonant contributions.
- …

Complementary signals: tri-boson production



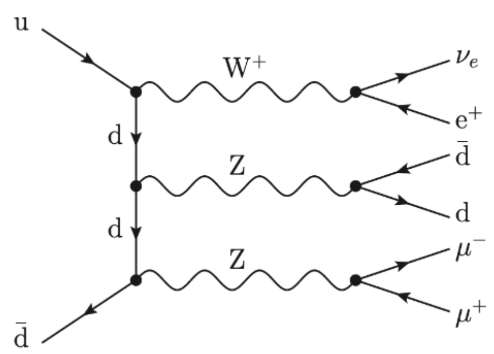
Fully-leptonic tri-boson production

- Rare (but clean) signature with small cross section.
- Simple structure of QCD corrections.

☑ **NLO QCD corrections** known and available in VBFNLO, Sherpa, …

☑ **NLO EW corrections** also computed and available in Madgraph, …

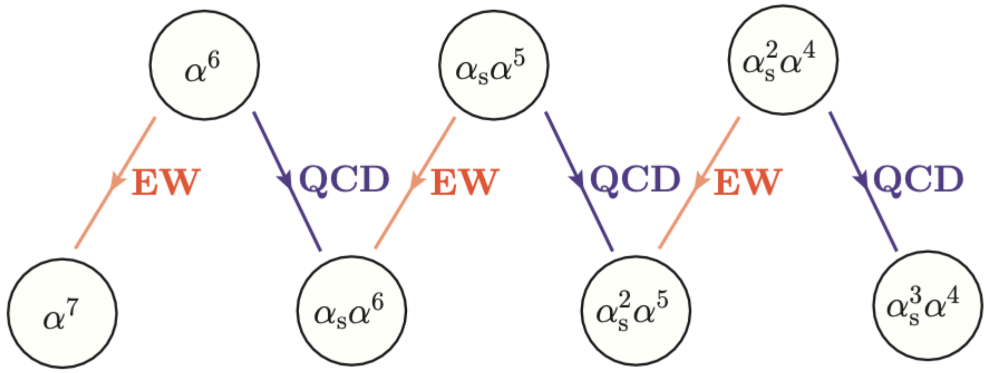
Tri-boson production with a hadronically decaying boson



- Larger cross section, but also numerous background sources.
- Overlap with fully-leptonic VBS, but different definition of fiducial volume.

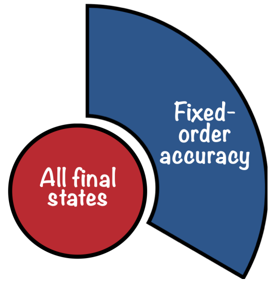
☑ **Only two results available with LO and NLO corrections obtained with full off-shell calculations.**

- WZ + jj production: all LO contributions + NLO corrections at $\mathcal{O}(\alpha^7)$ and $\mathcal{O}(\alpha_S\alpha^6)$. Denner et all . [arXiv:2407.21558]
- $W^{\pm}W^{\pm}$+ jj production: full set of LO and NLO contributions. Denner et all . [arXiv:2406.11516]



Tri-boson production: WZ + jj

Denner, Lombardi, Lopez, Pellicciolì [arXiv:2407.21558]



Integrated cross sections

	$\mathcal{O}(\alpha^6)$	$\mathcal{O}(\alpha_s\alpha^5)$	$\mathcal{O}(\alpha_s^2\alpha^4)$
σ_{LO} [ab]	50.230(2)	8.144(2)	847.7(5)
Δ_{tot} [%]	5.54	0.90	93.56

Overwhelming QCD **background**.

$\mathcal{O}(\alpha^6)$ [ab]	$\mathcal{O}(\alpha^7)$ [ab]	$\Delta^{(i)}_{\alpha^6}$ [%]	$\mathcal{O}(\alpha_s\alpha^6)$ [ab]	$\Delta^{(i)}_{\alpha^6}$ [%]
50.230(2)	−7.20(5)	−14.3	2.17(6)	4.3

Large **EW** corrections (Sudakov logarithms with $\langle\sqrt{s}\rangle \sim 750\,\text{GeV}$) and moderare **QCD** ones.

Tri-boson Phase space

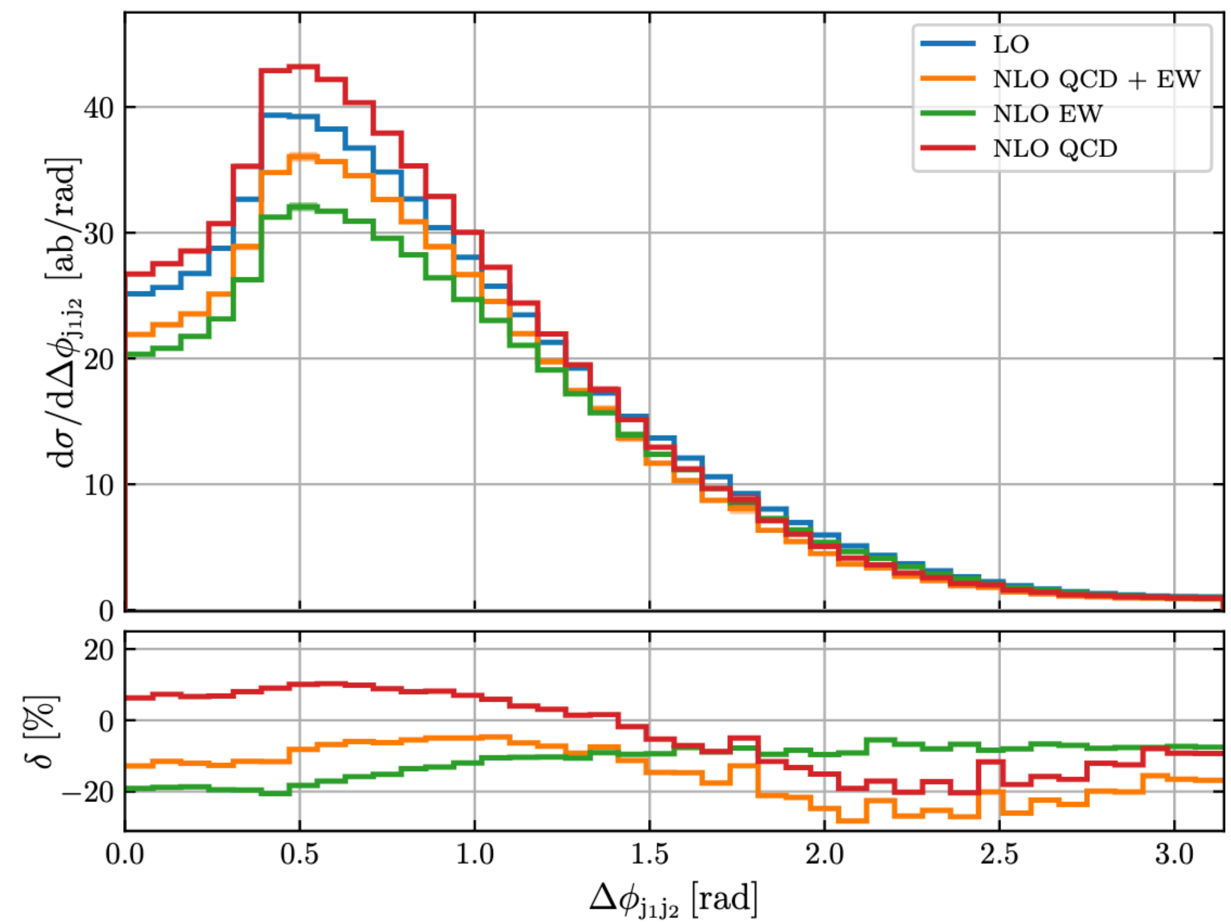
- Exactly two tag jets satisfying: $p_{T,\,j_{1/2}} > 40\,\text{GeV}\,, \quad |y_{j_{1/2}}| < 3$ → VETO on additional radiation
- Invariant-mass cut on tag jets: $50\,\text{GeV} < M_{j_1j_2} < 100\,\text{GeV}$

Differential results at NLO

- NLO QCD + EW $= \mathcal{O}(\alpha^6) + \mathcal{O}(\alpha^7) + \mathcal{O}(\alpha_s\alpha^6)$
- NLO EW $= \mathcal{O}(\alpha^6) + \mathcal{O}(\alpha^7)$
- NLO QCD $= \mathcal{O}(\alpha^6) + \mathcal{O}(\alpha_s\alpha^6)$

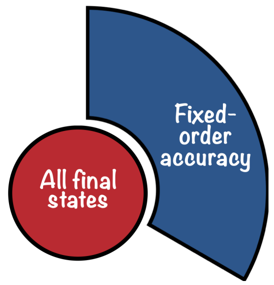
Non-trivial interplay between EW and QCD corrections:

- Dominance of negative **EW** corrections as compared to the positive **QCD** ones where the bulk of the cross section resides;
- Negative corrections in the tail.



Tri-boson production: $W^{\pm}W^{\pm}+jj$

Denner, Pellen, Schönherr, Schumann [arXiv:2406.11516]



Integrated cross sections

order	$\mathcal{O}(\alpha^6)$	$\mathcal{O}(\alpha_s\alpha^5)$	$\mathcal{O}(\alpha_s^2\alpha^4)$
$\sigma_{\rm LO}$[fb]	0.78549(9)	0.00732(1)	0.25925(3)
$\sigma/\sigma^{\rm sum}_{\rm LO}$[%]	74.7	0.7	24.6

QCD **background** larger than for VBS.

order	$\mathcal{O}(\alpha^7)$	$\mathcal{O}(\alpha_s\alpha^6)$	$\mathcal{O}(\alpha_s^2\alpha^5)$	$\mathcal{O}(\alpha_s^3\alpha^4)$
$\delta\sigma$[fb]	−0.035(1)	0.305(1)	−0.0032(3)	0.2260(3)
$\delta\sigma/\sigma^{\rm sum}_{\rm LO}$[%]	−3.4	29.0	−0.30	21.5

Smaller **EW** corrections compared to VBS.

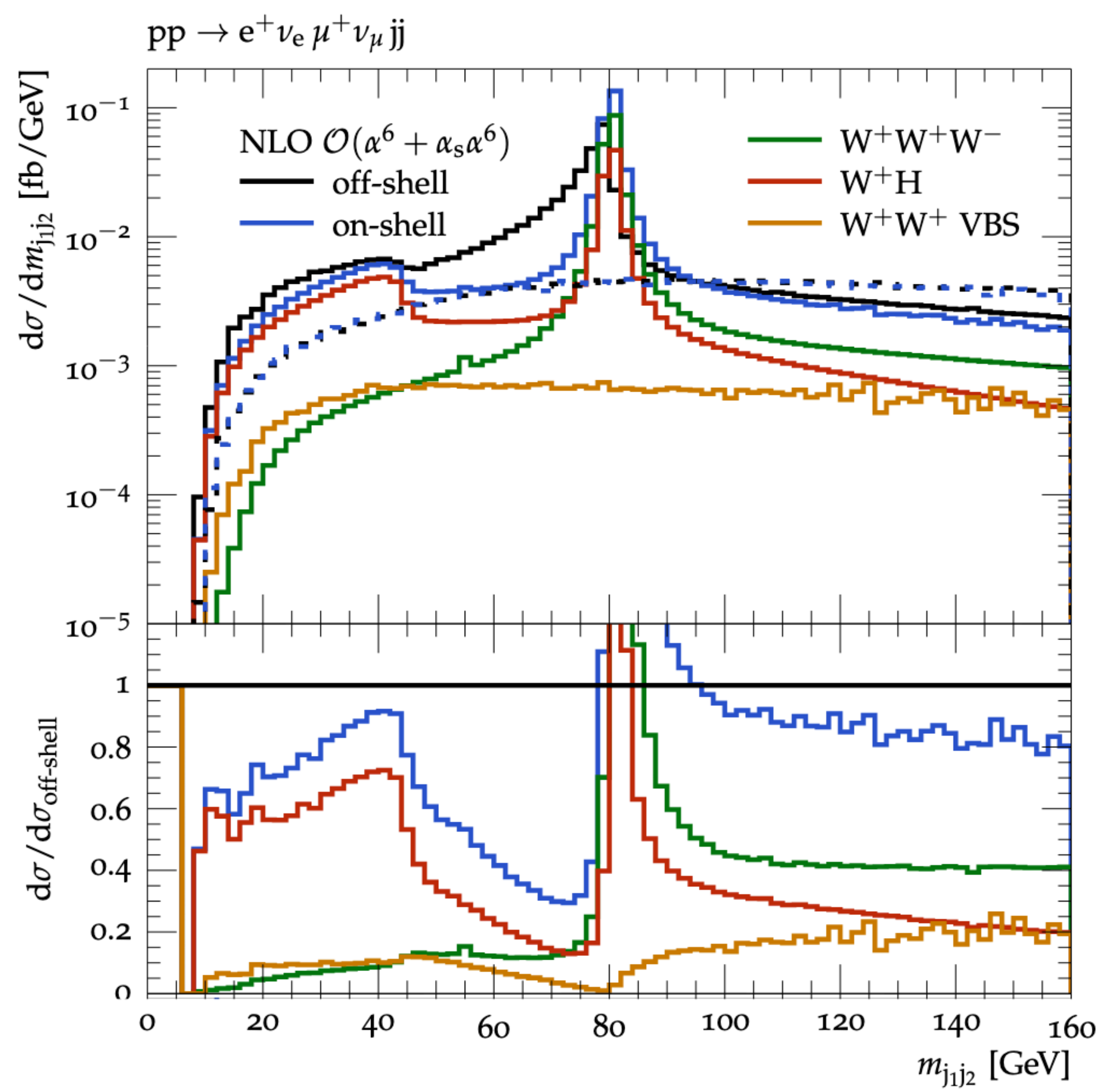
Tri-boson Phase space

- Arbitrary number of jets satisfying:
  $p_{T,j} > 20\,\text{GeV}\,, \quad |y_j| < 4.5$
- Two leading jets:
  $M_{j_1j_2} < 160\,\text{GeV} \quad |\Delta y_{j_1j_2}| < 1.5$

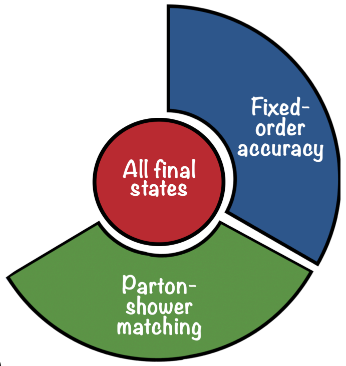
Off-shell effects

At **differential level**, large differences between off-shell and on-shell results:

- Enhancement at $M_{j_1j_2} \sim M_W$.
- Suppression for $M_H - M_W < M_{j_1j_2} < M_W$.
  - Missing contributions with additional W- or Higgs boson off-shell.
  - Additional QCD radiation from hadronically decaying W boson not included.



Parton-shower matching for VBS and tri-boson

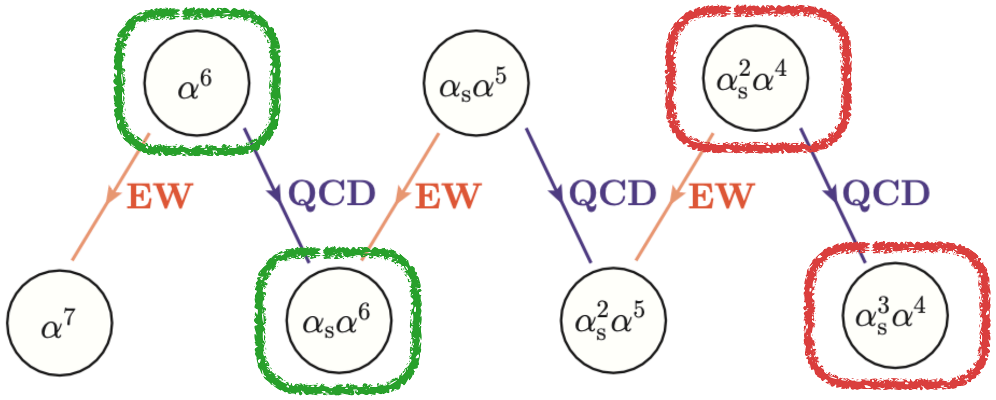


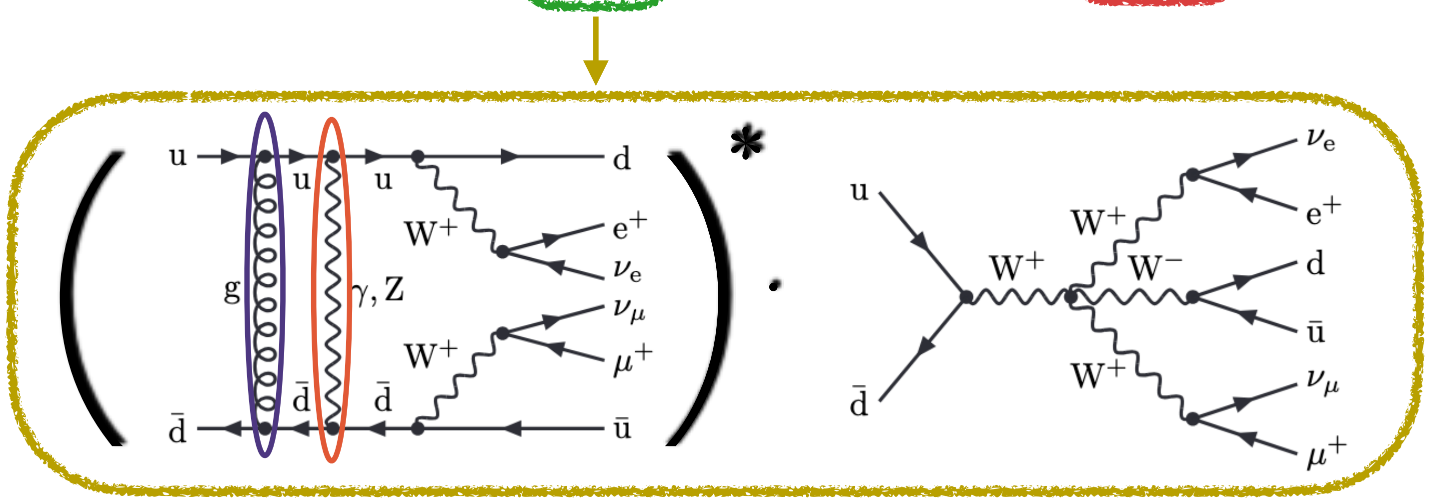
Fully-leptonic case

☑ **NLO QCD corrections:** matched to QCD Parton shower (PS) both for VBS and tri-boson production (fully-leptonic final states) and available in public tools like POWHEG-BOX, Sherpa, MG5_aMC@NLO …

- QCD-production mode for VBS.
- EW-production mode for VBS obtained within VBS approximation, where s-channels and t/u-channel interference neglected.

→ matching ambiguity





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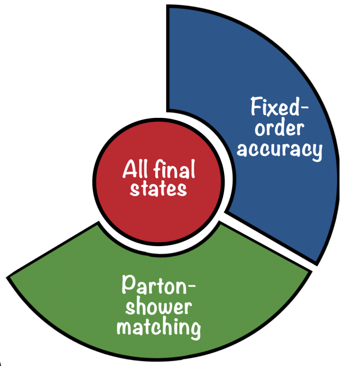

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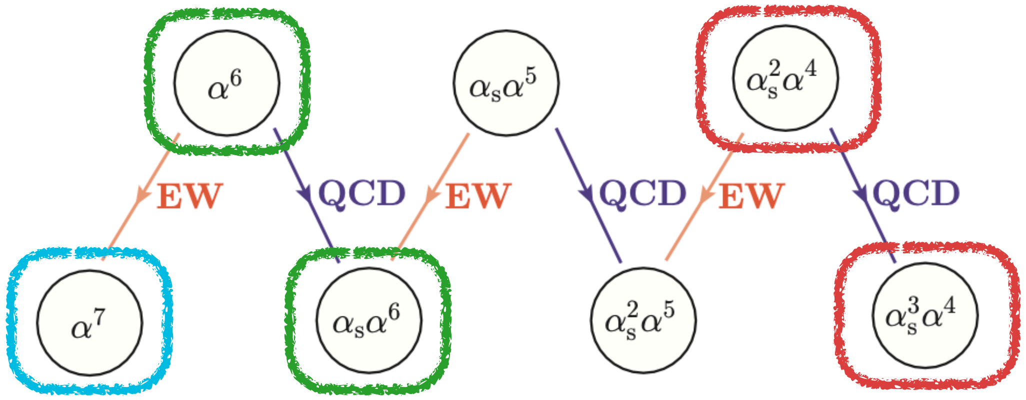


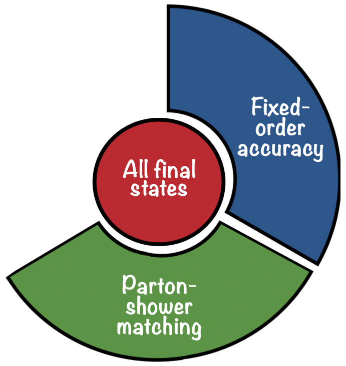
☑ **NLO EW corrections:** $\mathcal{O}(\alpha^6)$ + $\mathcal{O}(\alpha^7)$ for $W^\pm W^\pm$ VBS matched to QED PS and interfaced to QCD PS in POWHEG-BOX-RES. Chiesa et all . [arXiv:1906.01863]

Semi-leptonic case

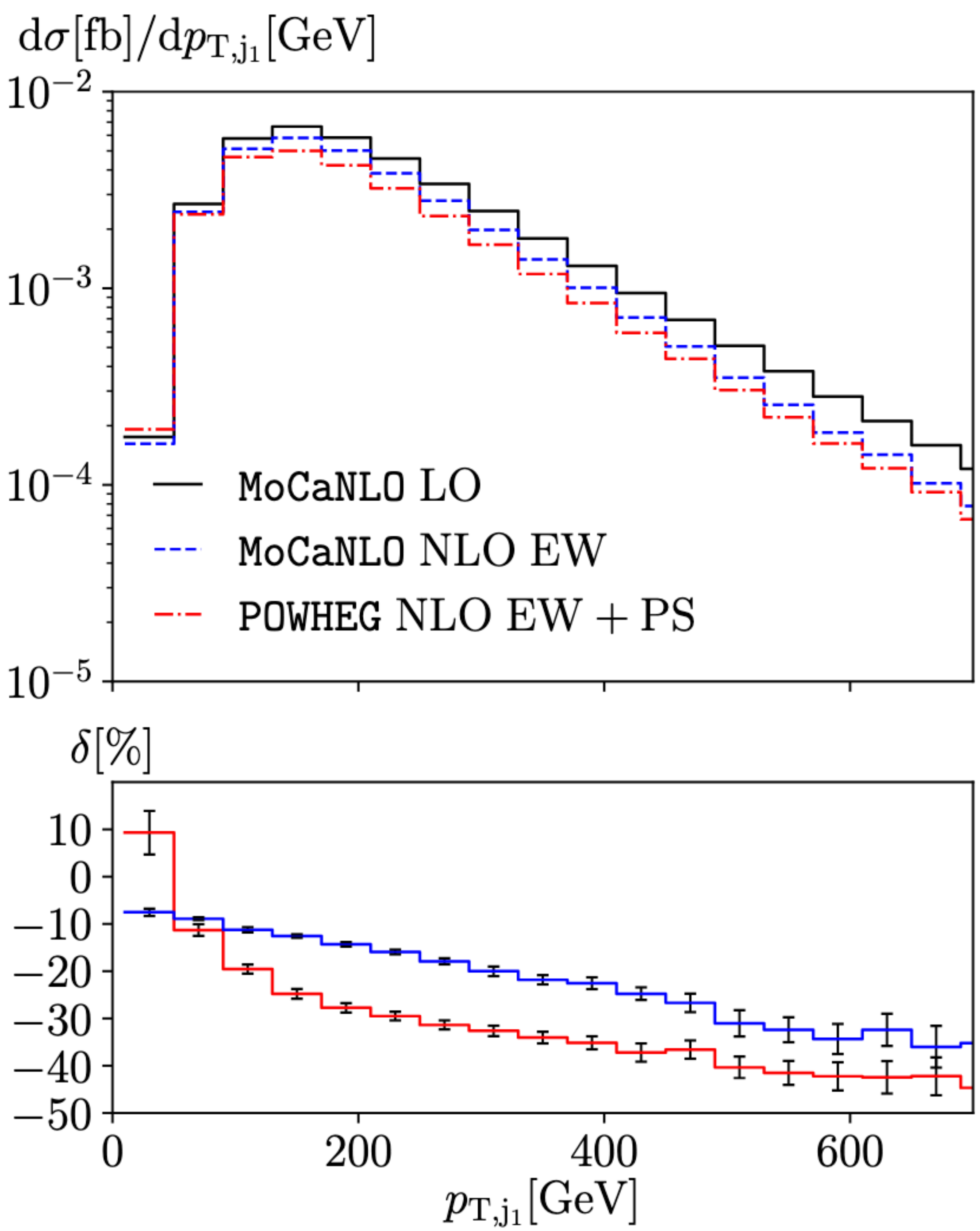
☑ **Only one result for** $W^\pm W^\pm$+ jj tri-boson production (complexity of fully-leptonic VBS): NLO QCD corrections matched to QCD and QED PS with approximate inclusion of NLO EW corrections at $\mathcal{O}(\alpha^7)$ in Sherpa. Denner et all . [arXiv:2406.11516]

Matching of NLO EW corrections

Chiesa, Denner, Lang, Pellen [arXiv:1906.01863]



Off-shell NLO EW corrections to fully-leptonic $W^{\pm}W^{\pm}$ VBS matched to QED and interfaced to QCD PYTHIA Parton shower.



POWHEG method used for the NLO matching, with PS starting scale set to $\sqrt{p_{\mathrm{T\,j_1}}\,p_{\mathrm{T\,j_2}}}$ instead of photon $p_{\mathrm{T}\,\gamma\,\mathrm{pow}}$ (scalup).

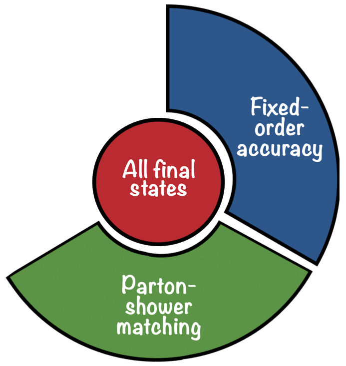
- Avoid unphysical suppression of QCD radiation.
- Veto QED radiation with $p_{\mathrm{T}\,\gamma} > p_{\mathrm{T}\,\gamma\,\mathrm{pow}}$ to prevent double counting.

Redistribution of events from high to low transverse momentum due to additional QCD/QED radiation from the PS.

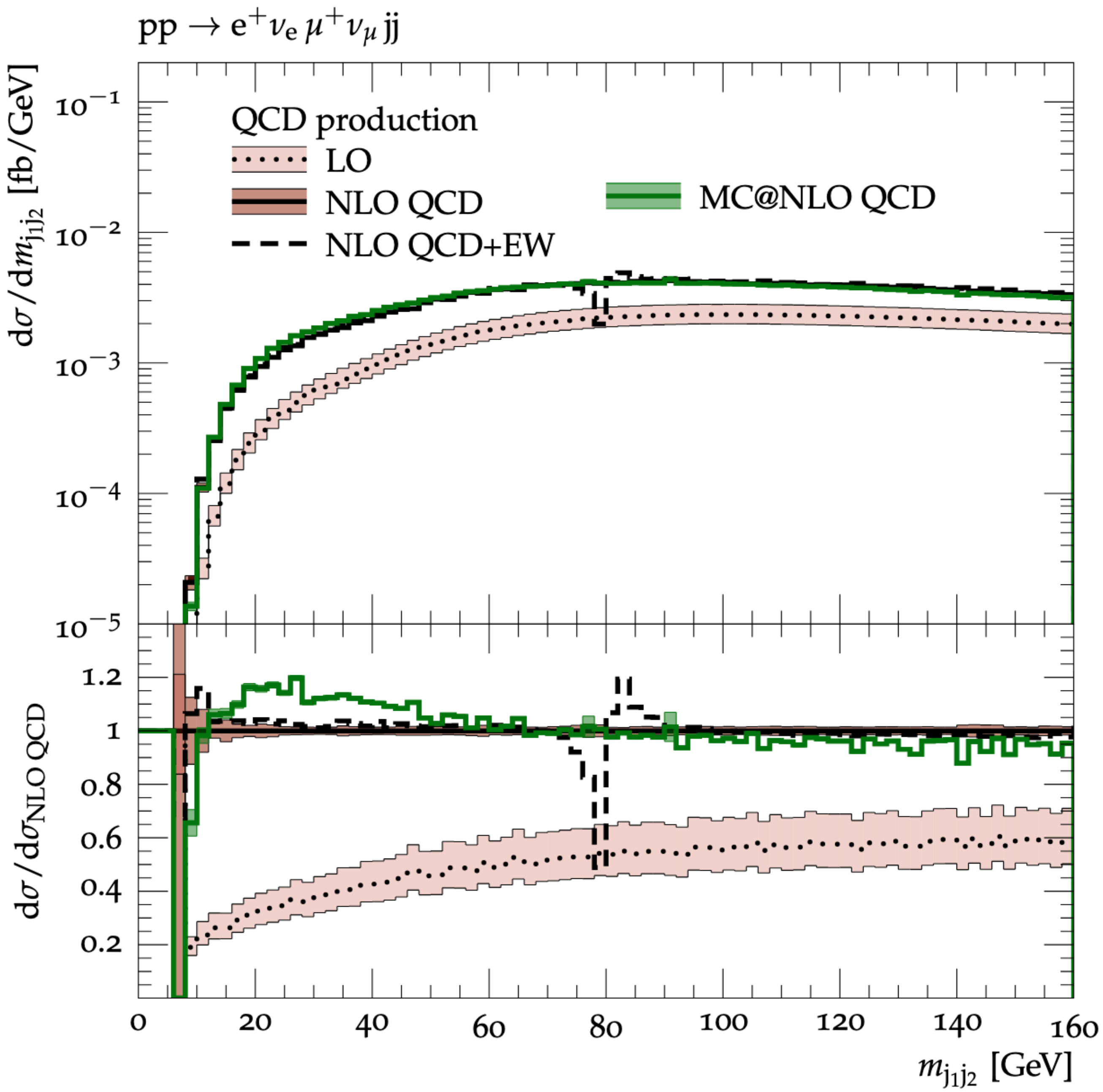
→ consistent with observed behaviour for $\mathcal{O}(\alpha_{\mathrm{s}}\alpha^6)$ correction.

NLO QCD matching with approximate QED/EW effects

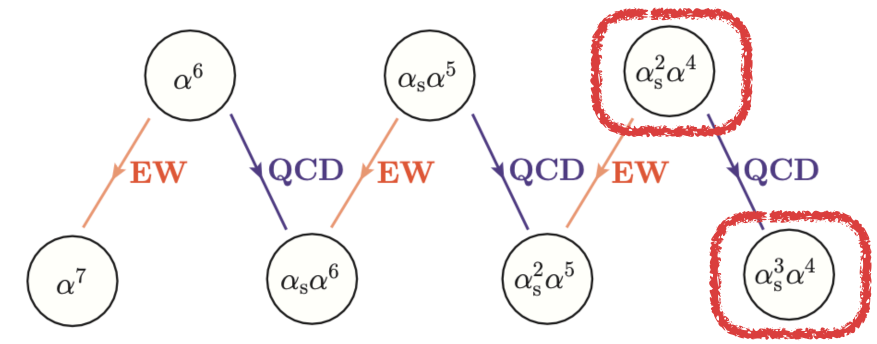
Denner, Pellen, Schönherr, Schumann [arXiv:2406.11516]



Off-shell corrections to tri-boson production in the $W^{\pm}W^{\pm}jj$ channel matched to Sherpa Parton shower with MC@NLO.



QCD production mode

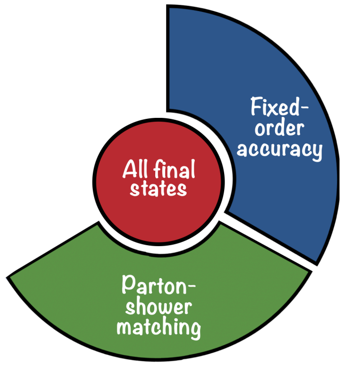


- QCD corrections at $\mathcal{O}(\alpha_S^3\alpha^4)$ matched to QCD PS.
- QED effects from final-state leptons via YFS soft-photon resummation.
- EW corrections not included.

  - Redistribution of events to lower $M_{j_1j_2}$.
  - Missing EW effects of $\mathcal{O}(\alpha_S^2\alpha^5)$ terms (especially around W mass).

NLO QCD matching with approximate QED/EW effects

Denner, Pellen, Schönherr, Schumann [arXiv:2406.11516]



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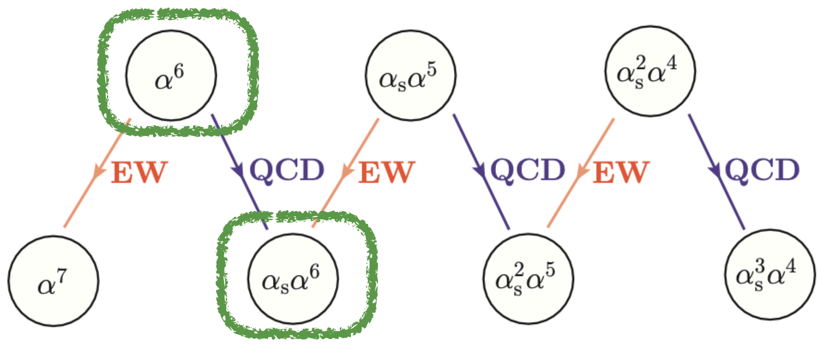
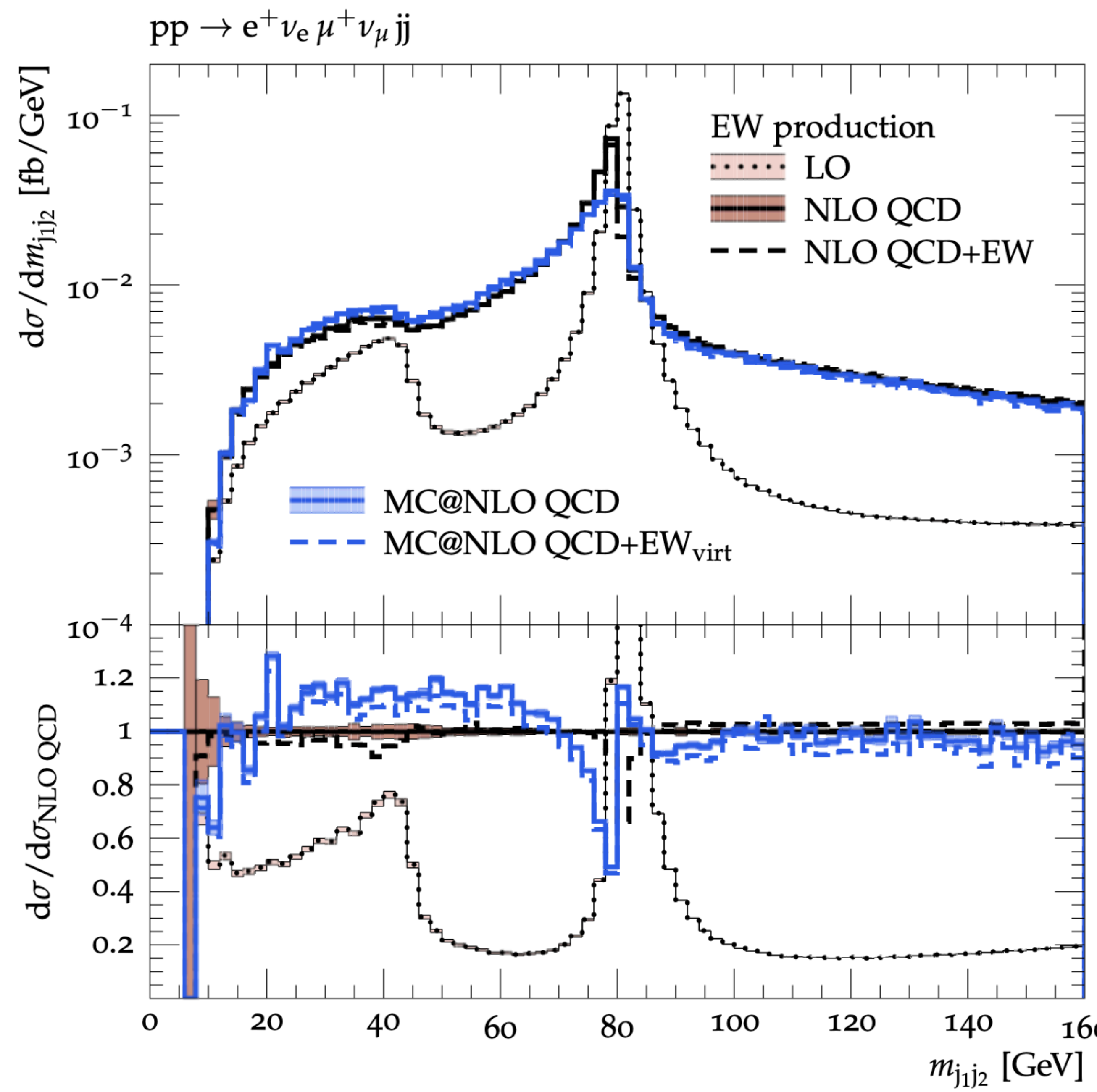
SHERPA

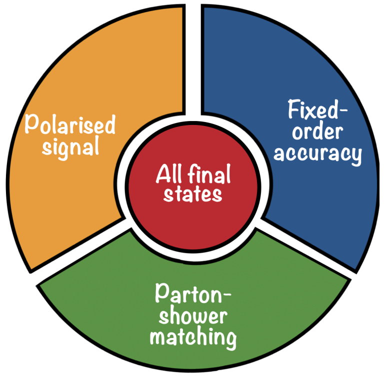
EW production mode



- $\mathcal{O}(\alpha^6)$ split into incoherent sum of s- and u/t-channel contributions → QCD PS matching well-defined.
- QED effects from final-state leptons via YFS soft-photon resummation.
- EW corrections included with EW_{virt} approximation (photon-induced channels excluded).
  - Redistribution of events to lower $M_{j_1j_2}$.
  - Negative EW corrections predicted for $M_{j_1j_2} > M_W$.



Accessing polarisation states in VBS

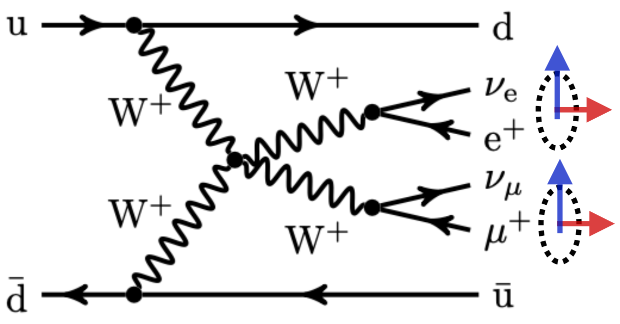


Measuring polarisation states of Vector Bosons can provide additional information on spontaneous EW Symmetry Breaking / Unitarity Restoration at high energies.

Experimental definition:

Only access to final states, not directly to resonances. Polarisation states extracted with:

- Machine-learning techniques;
- Polarised-template method.



T = transverse polarised
L = longitudinal polarised

Theory definition:

Non-trivial definition of cross section for two polarised vector bosons:

- Selection of doubly-resonant diagrams
  → DPA to preserve gauge invariance.

→ Separation of doubly-resonant contribution from singly-/non-resonant background:

$$\mathcal{M}_{\text{full}} \to \mathcal{M}_{\text{PA}}$$

- Definition of polarised signal via helicity projectors.

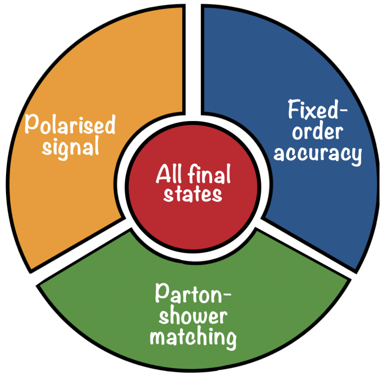
→ Separation of the four polarised signals ($\lambda \in \{LL, LT, TL, TT\}$) from interference contributions:

$$|\mathcal{M}_{\text{PA}}|^2 = \underbrace{\sum_{\lambda} |\mathcal{M}_{\text{PA}}^{\lambda}|^2}_{\text{Polarised signal}} + \underbrace{\sum_{\lambda \neq \lambda'} \mathcal{M}_{\text{PA}}^{\lambda,*} \mathcal{M}_{\text{PA}}^{\lambda'}}_{\text{Interference}}$$

Polarisation states depend on reference frame (usually set to CMS of vector bosons).

Polarised fully-leptonic $W^\pm W^\pm$ VBS at NLO

Denner, Haitz, Pellicciolì [arXiv:2409.03620]



- ☑ Results for polarised di-boson production known at **NLO QCD** and **EW**, also including **matching with PS**.
- ☑ Results for polarised fully-leptonic VBS only at **LO** and available in public codes like PHANTOM, Sherpa, MG5_aMC@NLO ...
- ☑ First result for polarised fully-leptonic $W^\pm W^\pm$ VBS at NLO QCD + EW.

→ Paving way to polarised semi-leptonic VBS.

	$\mathcal{O}(\alpha^6)$	$\mathcal{O}(\alpha^7)$	$\mathcal{O}(\alpha_s\alpha^6)$
state	σ_{LO} [fb]	δ_{EW}	δ_{QCD}
full	$1.4863(1)^{+9.2\%}_{-7.8\%}$	-0.140	-0.047
PA	$1.46455(9)^{+9.2\%}_{-7.8\%}$	-0.142	-0.050
LL	$0.14879(1)^{+8.3\%}_{-7.2\%}$	-0.101	-0.044
LT	$0.23209(2)^{+9.1\%}_{-7.8\%}$	-0.131	-0.042
TL	$0.23208(2)^{+9.1\%}_{-7.8\%}$	-0.131	-0.042
TT	$0.87702(7)^{+9.4\%}_{-8.0\%}$	-0.154	-0.054
int.	$-0.0254(1)^{-8.9\%}_{+10.6\%}$	-0.139	-0.007

$$|\mathcal{M}_{PA}|^2 = \sum_{\lambda} |\mathcal{M}^{\lambda}_{PA}|^2 + \sum_{\lambda\neq\lambda'} \mathcal{M}^{\lambda,*}_{PA}\mathcal{M}^{\lambda'}_{PA}$$

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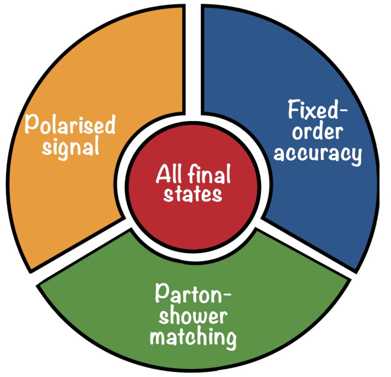

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- First result for polarised fully-leptonic $W^{\pm}W^{\pm}$ VBS at NLO QCD + EW. → Paving way to polarised semi-leptonic VBS.

state	σ_{LO} [fb] $\mathcal{O}(\alpha^6)$	δ_{EW} $\mathcal{O}(\alpha^7)$	δ_{QCD} $\mathcal{O}(\alpha_s\alpha^6)$
full	$1.4863(1)^{+9.2\%}_{-7.8\%}$	-0.140	-0.047
PA	$1.46455(9)^{+9.2\%}_{-7.8\%}$	-0.142	-0.050
LL	$0.14879(1)^{+8.3\%}_{-7.2\%}$	-0.101	-0.044
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$$\frac{(\sigma_{\mathrm{full}} - \sigma_{\mathrm{PA}})}{\sigma_{\mathrm{PA}}} \sim 1.5\,\%$$

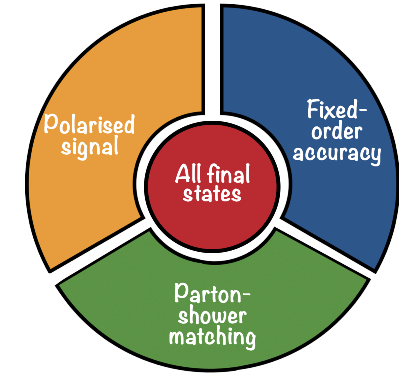
Non-doubly resonant **background**

$$|\mathcal{M}_{\mathrm{PA}}|^2 = \sum_{\lambda} |\mathcal{M}^{\lambda}_{\mathrm{PA}}|^2 + \sum_{\lambda \neq \lambda'} \mathcal{M}^{\lambda,*}_{\mathrm{PA}} \mathcal{M}^{\lambda'}_{\mathrm{PA}}$$

Interference $\sim -1.7\,\%$

Polarised fully-leptonic $W^\pm W^\pm$ VBS at NLO

Denner, Haitz, Pellicciol [arXiv:2409.03620]



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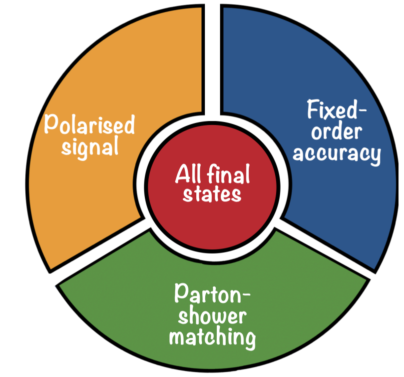
Polarised signal **Interference** $\sim -1.7\,\%$

- Dominance of TT contribution $\sim 60\% \cdot \sigma_{\text{PA}}$.
- δ_{EW} different in size among polarisation contributions (e.g $(\delta^{\text{TT}}_{\text{EW}} - \delta^{\text{LL}}_{\text{EW}})/\delta^{\text{TT}}_{\text{EW}} \sim 3\,\%$).
- δ_{QCD} small and mostly polarisation independent.

Polarised fully-leptonic $W^{\pm}W^{\pm}$ VBS at NLO

Denner, Haitz, Pellicciolì [arXiv:2409.03620]



Study suitable observables for polarisation extraction:

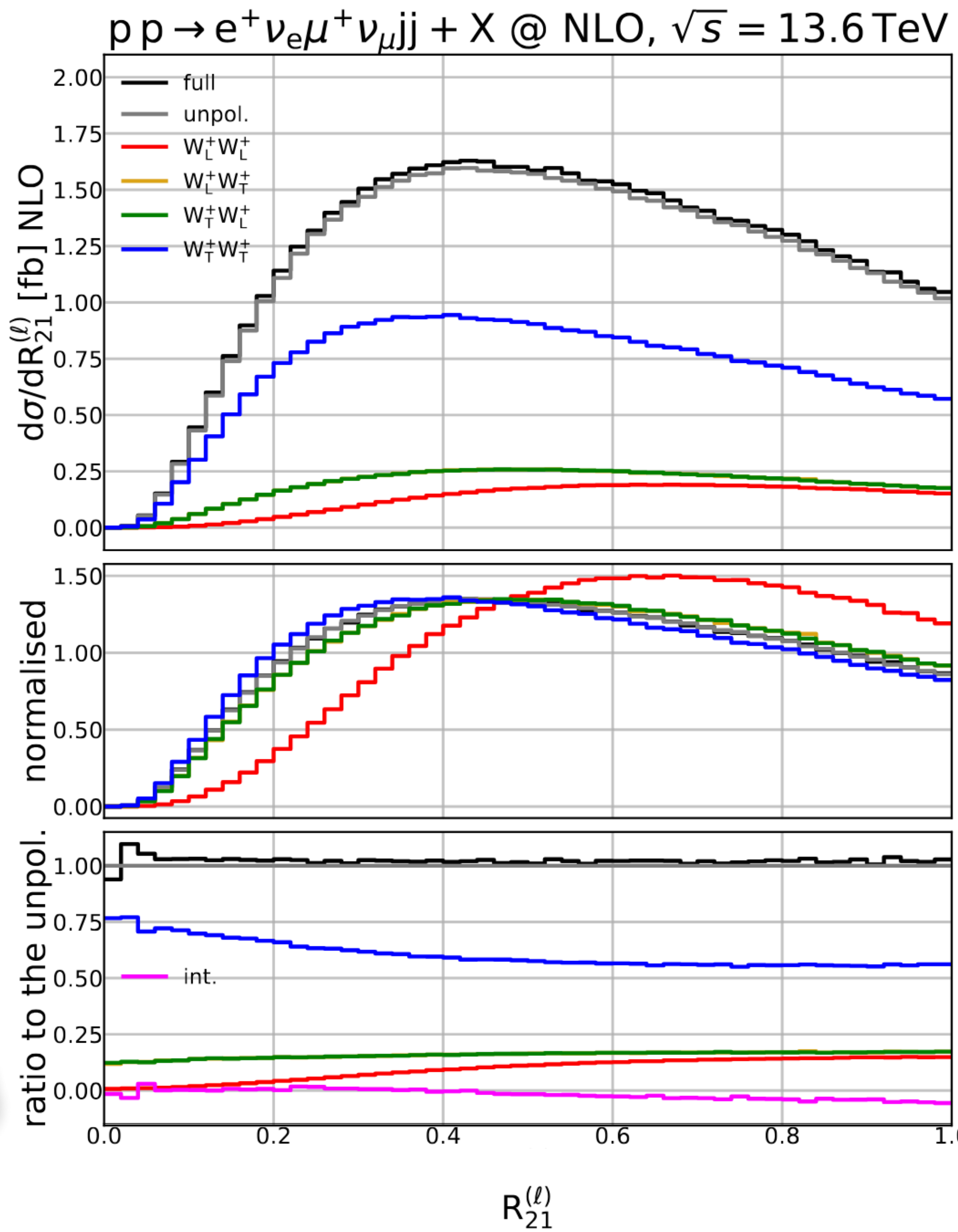
- The least model dependent;
- With the highest discrimination power.

→ E.g $R_{21}^{(\ell)} = \frac{p_{\mathrm{T},\ell_2}}{p_{\mathrm{T},\ell_1}}$

Differential behaviour

❖ Shape differences among polarised signals:

- Leptons tend to align to direction of T-polarised W.
- Leptons preferably orthogonal to direction of L-polarised W.



Lepton cuts

$p_{\mathrm{T}\,\ell_1} > 25\,\mathrm{GeV}$ $p_{\mathrm{T}\,\ell_2} > 20\,\mathrm{GeV}$

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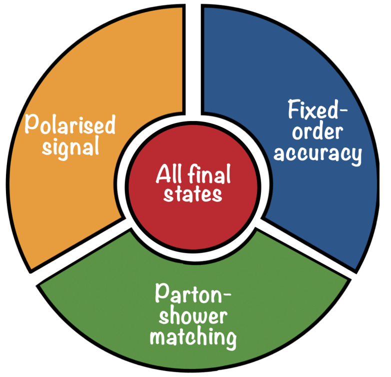

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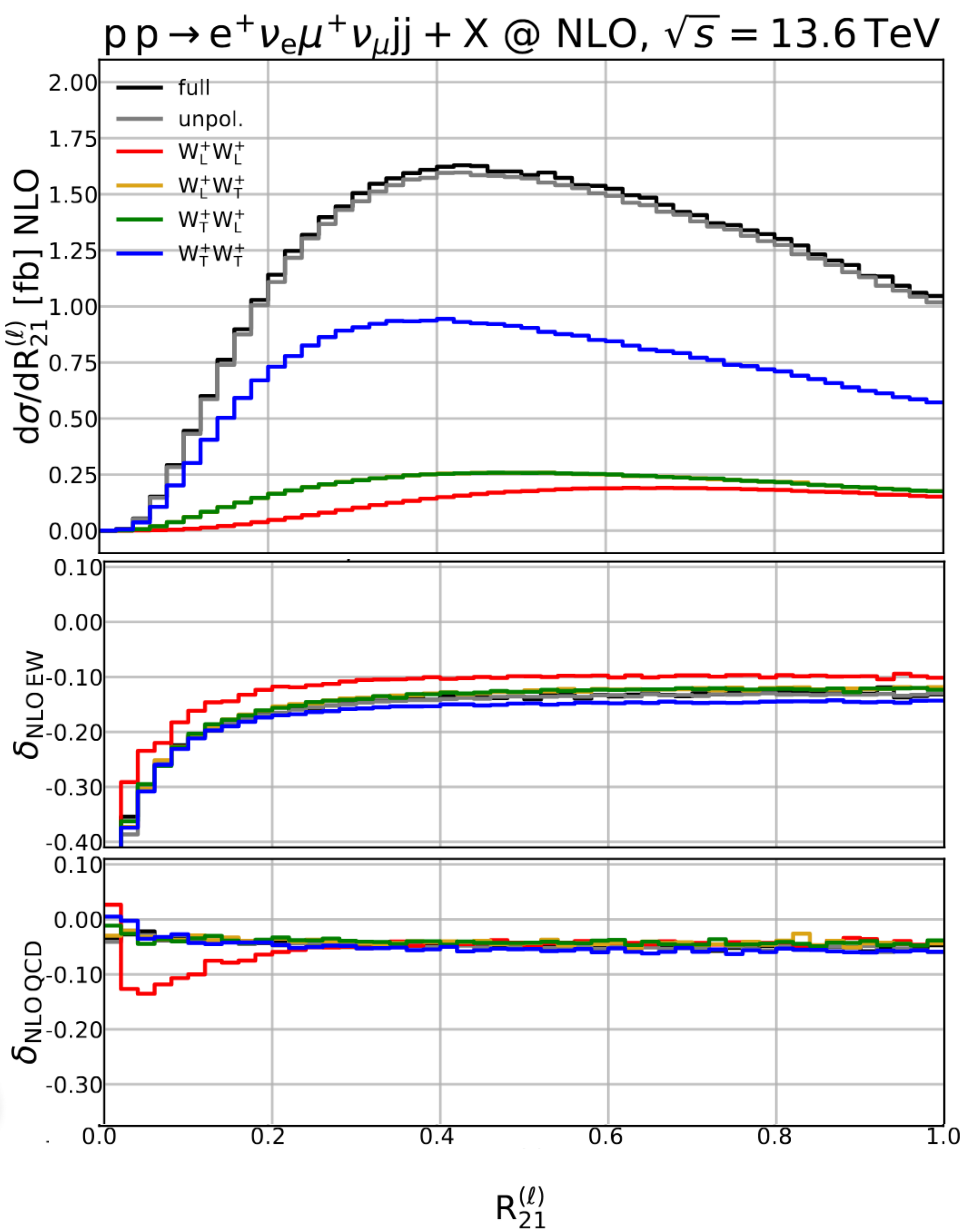
Differential behaviour

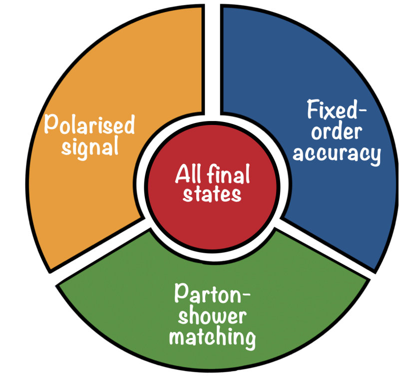
- Shape differences among polarised signals:
  - Leptons tend to align to direction of T-polarised W.
  - Leptons preferably orthogonal to direction of L-polarised W.
- Size of NLO corrections for $R_{21}^{(\ell)} < 0.2$:
  - Largest δ_{EW} for TT signal.
  - Sizeable and negative δ_{QCD} for LL signal.

Lepton cuts

$p_{T\,\ell_1} > 25\,\mathrm{GeV}$ $p_{T\,\ell_2} > 20\,\mathrm{GeV}$



Conclusions



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- Already for the fully-leptonic final state, the inclusion of EW corrections when matching to a QCD and a QED **parton shower** deserves further investigation + no PS-matched results for semi-leptonic VBS.

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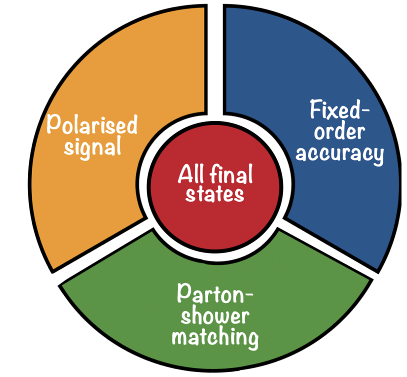

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Thank you for your attention