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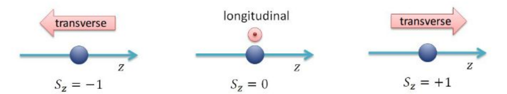
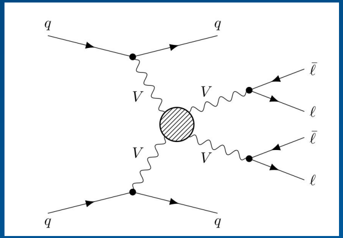


Dr. Z. Zinonos: Tests of the Standard Model of Particles. https://www.mpp.mpg.de/~zinonos/material/lecture10.pdf



Polarized cross sections for vector boson production with Sherpa

1st COMETA general meeting Izmir, February 29, 2024

based on the work published in arXiv: 2310.14803

Introduction

Why vector boson polarization?

Vector boson polarization measurements can probe the electroweak sector:

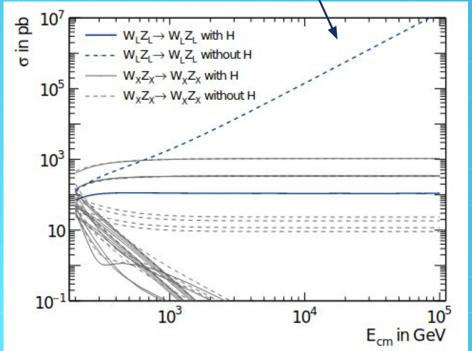
- concrete mechanism of EWSB ↔ longitudinal polarization
- EW gauge symmetry structure ↔ triple & quartic gauge couplings

How to measure vector boson polarization?

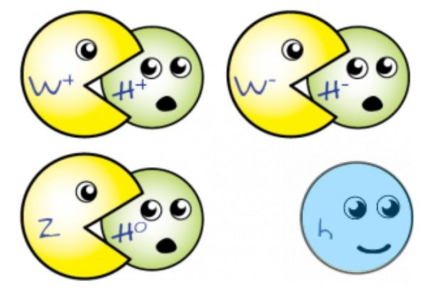
Fit with polarization templates from simulation

$$\frac{\mathrm{d}\sigma}{\mathrm{d}X} = f_L\frac{\mathrm{d}\sigma_L}{\mathrm{d}X} + f_R\frac{\mathrm{d}\sigma_R}{\mathrm{d}X} + f_0\frac{\mathrm{d}\sigma_0}{\mathrm{d}X}\left(+f_{int.}\frac{\mathrm{d}\sigma_{int.}}{\mathrm{d}X}\right)$$

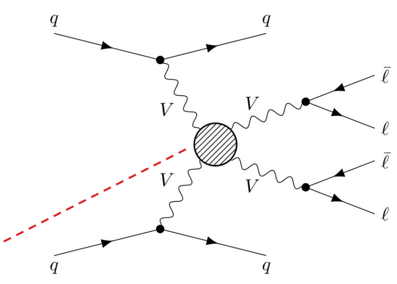
Unitarity violation

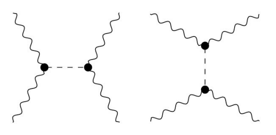


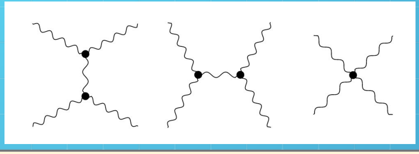
C.Bittrich, PhD TU Dresden 2020



J. Manjarrés Ramos, Talk at LHCP2022

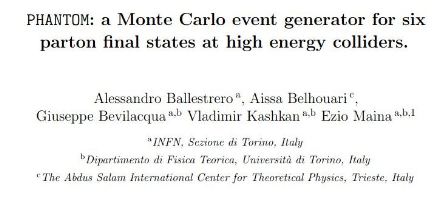






Generator landscape

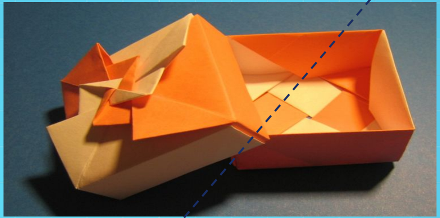
- **several private tools, see e.g. talk of Rene Poncelet**
- **public codes:**


PHANTOM: a Monte Carlo event generator for six parton final states at high energy colliders.

Alessandro Ballestrero[a], Aissa Belhouari[c],
Giuseppe Bevilacqua[a,b] Vladimir Kashkan[a,b] Ezio Maina[a,b,1]

[a] *INFN, Sezione di Torino, Italy*
[b] *Dipartimento di Fisica Teorica, Università di Torino, Italy*
[c] *The Abdus Salam International Center for Theoretical Physics, Trieste, Italy*

MADGRAPH5 aMC@NLO



DPA

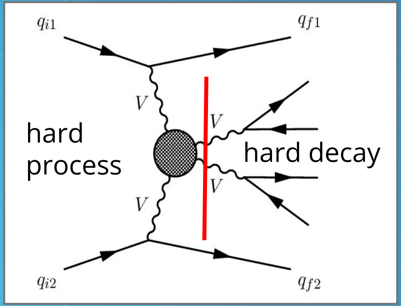
truncated propagator

NWA

  - ***PHANTOM***: 2->6 processes @ LO+PS [A. Ballestrero et al. 2008, 2017]
  - ***MG5_aMC@NLO***: arbitrary processes @ LO,
    PS matching, multi-jet merging [D. Buarque Franzosi et al. 2020]
  - ***POWHEG-BOX-RES*** : diboson processes @NLO QCD+PS [G. Pelliccioli, G. Zanderighi 2023]

  - ***Sherpa:*** arbitrary processes @nLO QCD, PS matching, multi-jet merging
    [MH, M. Schönherr, F. Siegert 2023]
    THIS TALK

Calculation of polarized cross sections



- **On-shell approximation: extended narrow-width approximation**

$$\boxed{\frac{1}{\left(q^2-m_V^2\right)^2+\Gamma_V^2 m_V^2} \rightarrow \frac{\pi\delta\left(q^2-m_V^2\right)}{\Gamma_V m_V}}$$

[Höche et al. 2014]

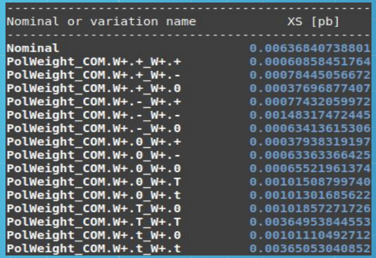
  - spin correlation algorithm [Richardson 2001] to preserve spin correlations between VB production & decay
  - off-shell effects via mass smearing of on-shell vector boson states

$$\left|\mathcal{M}^{pol}\right|^2_{\lambda_1\ldots\lambda_n;\,\lambda'_1\ldots\lambda'_n} \propto \mathcal{M}^{\mathcal{P}}_{\lambda_1\ldots\lambda_n}\mathcal{M}^{*\mathcal{P}}_{\lambda'_1\ldots\lambda'_n}\mathcal{M}^{\mathcal{D}}_{\lambda_1\ldots\lambda_n}\mathcal{M}^{*\mathcal{D}}_{\lambda'_1\ldots\lambda'_n}$$

- **Algorithm for polarized cross sections:**

[MH, M. Schönherr, F. Siegert 2023]

  - simulation essentially unpolarized in NWA
  - polarization fractions calculated on top
    - polarized amplitudes from spin correlation algorithm
    - keep whole amplitude tensor
    - multiplied by event XS
    - output as additional event weights



```
-------------------------------------------------------------
Nominal or variation name                    XS [pb]
-------------------------------------------------------------
Nominal                                   0.00636840738801
PolWeight_COM.W+.+_W+.+                   0.00060858451764
PolWeight_COM.W+.+_W+.-                   0.00078445056672
PolWeight_COM.W+.+_W+.0                   0.00037696877407
PolWeight_COM.W+.-_W+.+                   0.00077432059972
PolWeight_COM.W+.-_W+.-                   0.00148317472445
PolWeight_COM.W+.-_W+.0                   0.00063413615306
PolWeight_COM.W+.0_W+.+                   0.00037938319197
PolWeight_COM.W+.0_W+.-                   0.00063363366425
PolWeight_COM.W+.0_W+.0                   0.00065521961374
PolWeight_COM.W+.0_W+.T                   0.00101508799740
PolWeight_COM.W+.0_W+.t                   0.00101301685622
PolWeight_COM.W+.T_W+.0                   0.00101857271726
PolWeight_COM.W+.T_W+.T                   0.00364953844553
PolWeight_COM.W+.t_W+.0                   0.00101110492712
PolWeight_COM.W+.t_W+.t                   0.00365053040852
```

Features

Fully-realistic simulations for

- arbitrary processes with intermediate VBs

with

- all polarizations in one run using weights
- direct calculation of interference templates
- multiple polarization bases in one run
  - ✓ laboratory frame
  - ✓ center of mass frame of arbitrary combination of initial- / final state particles
  - ✓ parton-parton frame
  - ✓ easily extendable, if necessary

bluemoji.io

Including QCD effects matched to PS

- **based on Sherpa's MC@NLO** [S. Höche et al. 2012]

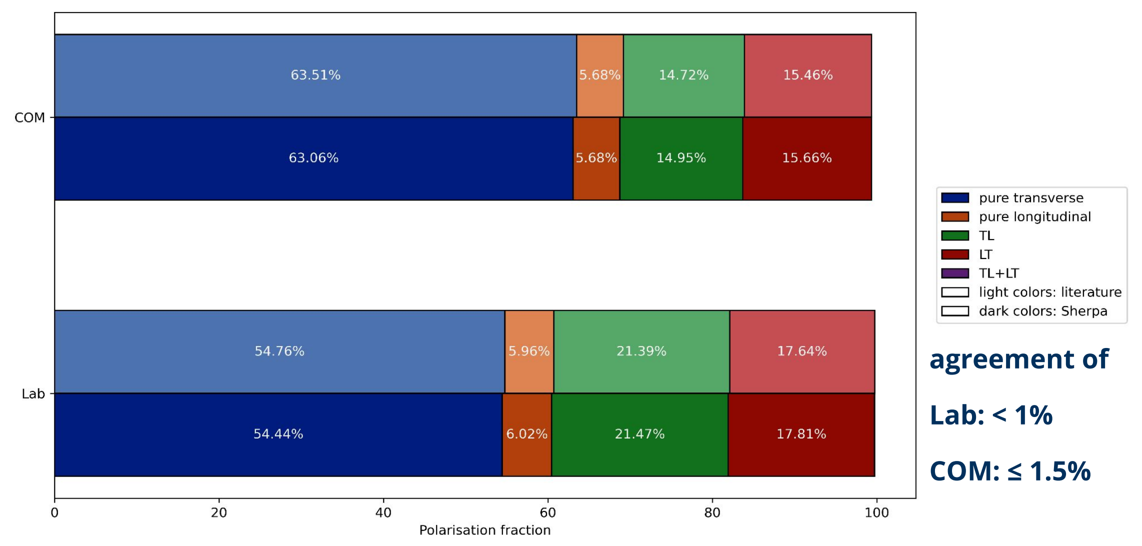
$$\sigma^{\mathrm{NLO}}_{\mathrm{MC@NLO}} = \underbrace{\int \mathrm{d}\tilde{\Phi}_n \bar{B}_n^{\mathcal{A}}(\tilde{\Phi}_n)\left[\bar{\Delta}^{\mathcal{A}}(t_0) + \int_{t_0} \mathrm{d}\tilde{\Phi}_1 \frac{D_n^{\mathcal{A}}(\tilde{\Phi}_{n+1})}{B_n(\tilde{\Phi}_n)}\bar{\Delta}^{\mathcal{A}}(t)\right]}_{=:\sigma_{\mathbb{S}}} + \underbrace{\int \mathrm{d}\tilde{\Phi}_{n+1} H_n^{\mathcal{A}}(\tilde{\Phi}_{n+1})}_{=:\sigma_{\mathbb{H}}}$$

- **unpolarized event XS fully NLO QCD accurate**
- **different amplitudes used for polarization fraction calculation in dependence of event type:**
    - ***H-events & resolved S-events:*** real-emission amplitude
    - ***Unresolved S-events:*** Born amplitude
      -> virtual, ultra-soft & ultra-collinear emission effects neglected for polarization fractions

dominant NLO effects captured through real emission MEs

nLO+PS vs. full fixed NLO – WZ-Diboson production

Comparison with NLO QCD fixed order calculation [A. Denner & G. Pelliccioli 2021]

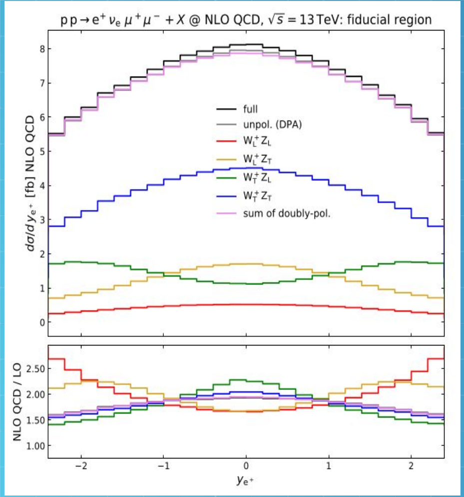


agreement of

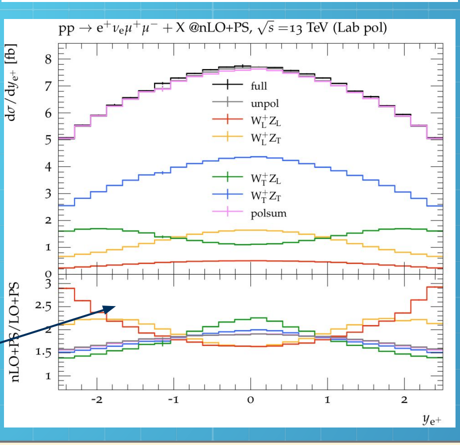
Lab: < 1%

COM: ≤ 1.5%

- **can reproduce even non-trival NLO effects!**



Literature



Sherpa

nLO+PS vs. full fixed NLO - WZ-Diboson production

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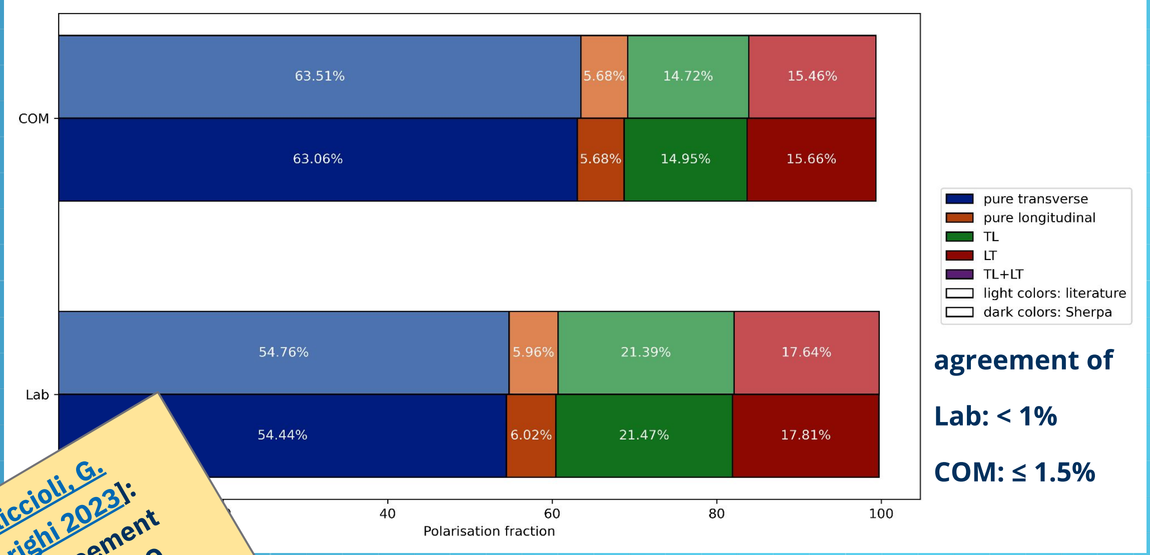


agreement of

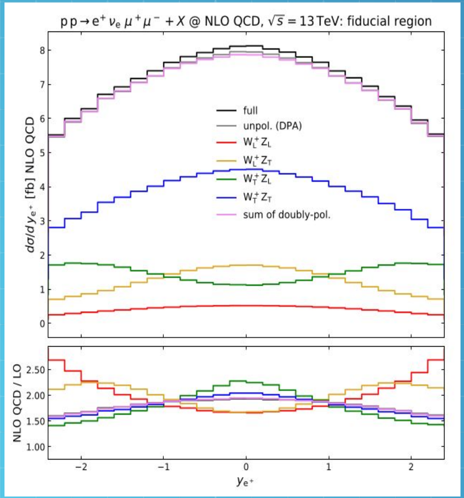
Lab: < 1%

COM: ≤ 1.5%

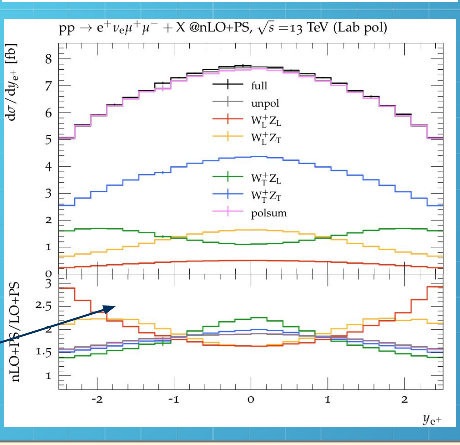
[G. Pelliccioli, G. Zanderighi 2023]: similar agreement compared to NLO QCD+PS with POWHEG+PYTHIA

➢ **can reproduce even non-trival NLO effects!**

Literature

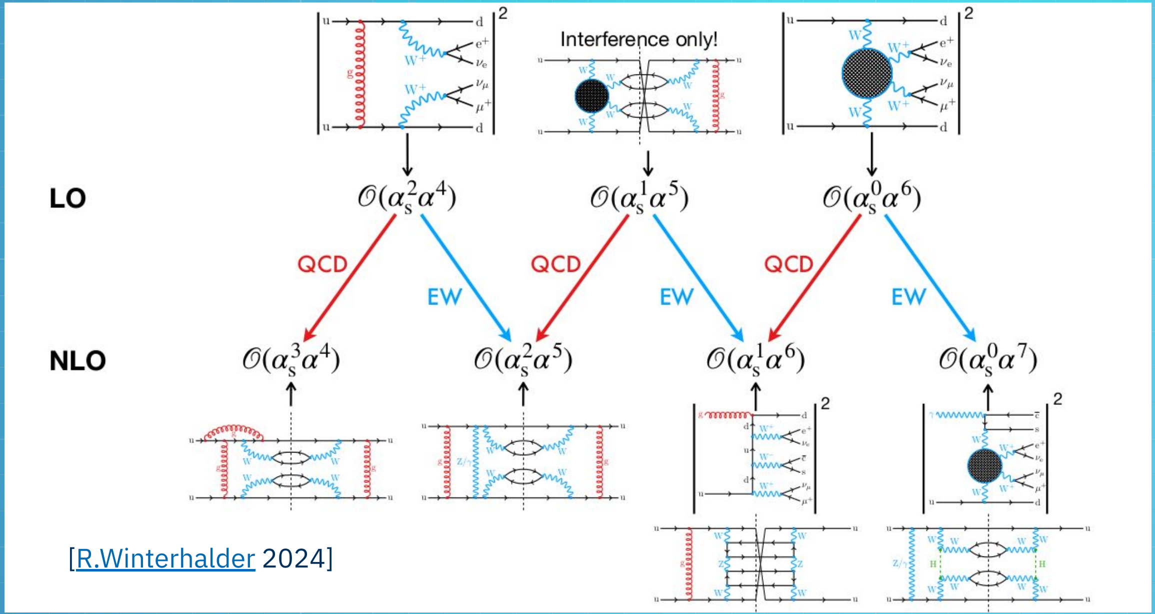


Sherpa



Higher order polarized cross sections for VBS processes

- **Calculation of full NLO effects to VBS processes very challenging:**



[R.Winterhalder 2024]

- currently only available at fixed order, unpolarized, e.g. [B. Biedermann et al. 2017, S. Dittmaier et al. 2023]
- polarized cross sections only @ LO [A. Ballestrero et al. 2020, 2017, 2019]

With the new framework
first study in **W^+W^+jj** :

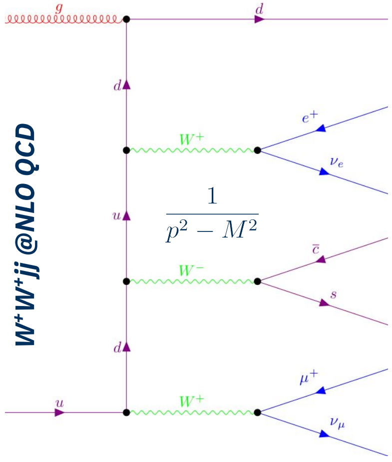
LO+1j merged calculation

First higher order polarized cross sections for W^+W^+jj

Preliminary results

	unpol [fb]	LL [fb]	Fraction [%]	LT+TL [fb]	Fraction [%]	TT [fb]	Fraction [%]
LO+PS	2.459	0.237	9.63	0.765	31.12	1.497	60.88
LO+1j VBS approx.	2.302	0.224	9.73	0.716	31.10	1.399	60.77

W^+W^+jj @NLO QCD

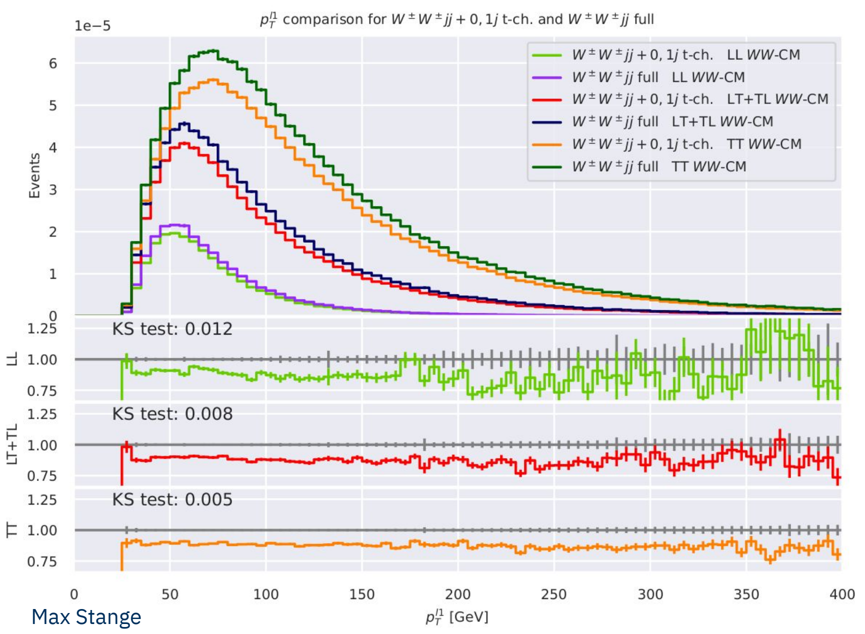


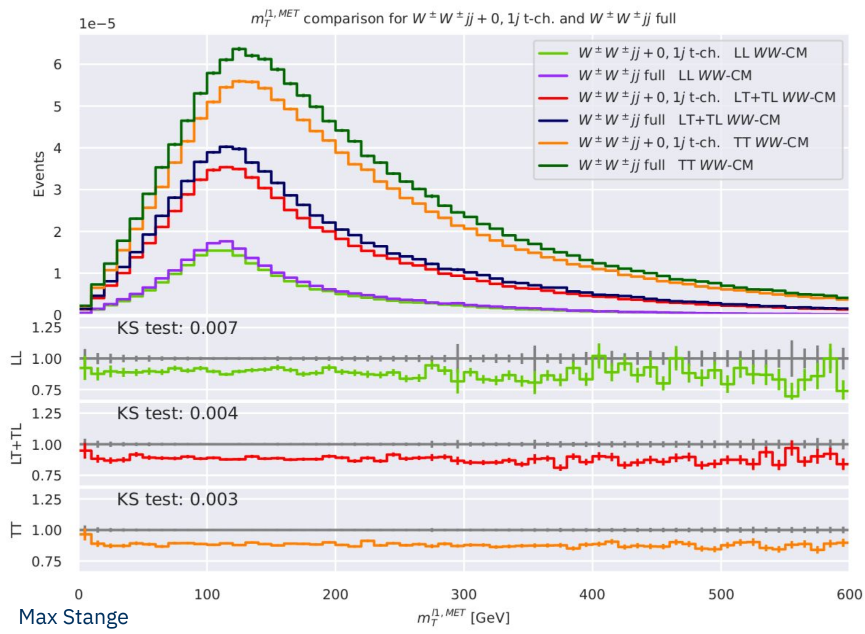
$\rightarrow \infty$ for $m_{jj} \rightarrow M_{\mathrm{VB}}$

Only sub-percent level effect of QCD corrections on integrated polarization fractions …

First higher order polarized cross sections for W^+W^+jj

Preliminary results





… differential polarization fractions!

Summary and Outlook

- ✓ first implementation of polarized cross sections in Sherpa
- ✓ higher order QCD corrections @nLO + PS & via multijet-merging
- ➔ first fully-realistic VB polarization samples including higher order QCD effects for VBS processes

https://www.zeppelinschule-speyer.de/ausblick-auf-die-zeit-nach-pfingsten/

What comes next ...

- ☐ Extension to NLO QCD and approximate NLO EW
- ☐ Applications in phenomenological analyses: BSM studies (UFO), full NLO effects for VBS processes

Summary and Outlook

- √ **first implementation of polarized cross sections in Sherpa**
- √ **higher order QCD corrections @nLO + PS & via multijet-merging**
- ➔ **first fully-realistic VB polarization samples including higher order QCD effects for VBS processes**

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What comes next ...

- ❏ Extension to NLO QCD and approximate NLO EW
- ❏ Applications in phenomenological analyses: BSM studies (UFO), full NLO effects for VBS processes

Thank you for your attention! Questions?

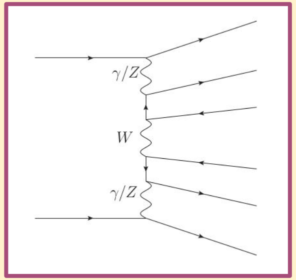
Backup

Polarized cross sections from fully exclusive events

Polarization templates

- Interference between different polarizations
- Polarization fractions are frame dependent
- Separation of polarization not for all diagrams

-> approximations necessary



non-resonant diagrams

$$\frac{\mathrm{d}\sigma}{\mathrm{d}X} = f_L \frac{\mathrm{d}\sigma_L}{\mathrm{d}X} + f_R \frac{\mathrm{d}\sigma_R}{\mathrm{d}X} + f_0 \frac{\mathrm{d}\sigma_0}{\mathrm{d}X} \left(+ f_{int.} \frac{\mathrm{d}\sigma_{int.}}{\mathrm{d}X} \right)$$

NWA

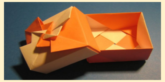
DPA

truncated propagator

LO+PS Tools

- ***PHANTOM***: 2->6 processes @ LO+PS [A. Ballestrero et al. 2008, 2017]
- ***MG5_aMC@NLO***: arbitrary processes @ LO, PS matching, multi-jet merging [D. Buarque Franzosi et al. 2020]

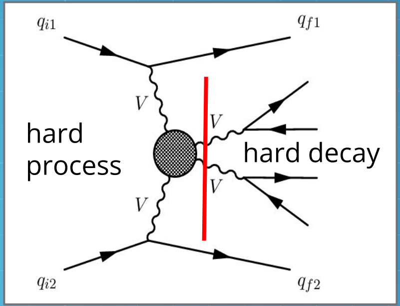
Higher orders



- ***POWHEG-BOX-RES***: diboson processes @NLO QCD+PS [G. Pelliccioli, G. Zanderighi 2023]
- ***SHERPA***: arbitrary processes @nLO QCD, PS matching, multi-jet merging [MH, M. Schönherr, F. Siegert 2023]

On-shell Approximation in Sherpa [S. Höche et al. 2014]

- **extended narrow-width approximation:**
  - spin correlations preserved
  - off-shell effects via mass smearing of on-shell vector boson states



01 Simulation of unpolarized production process

$$|\mathcal{M}^{\mathcal{P}}|^2 = \sum_{\lambda_1\dots\lambda_n} \mathcal{M}^{\mathcal{P}}_{\lambda_1\dots\lambda_n}\mathcal{M}^{*\mathcal{P}}_{\lambda_1\dots\lambda_n}$$

02 Recalculation of the production amplitude tensor

$$|\mathcal{M}^{\mathcal{P}}|^2_{\lambda_1\dots\lambda_n;\lambda'_1\dots\lambda'_n} = \mathcal{M}^{\mathcal{P}}_{\lambda_1\dots\lambda_n}\mathcal{M}^{*\mathcal{P}}_{\lambda'_1\dots\lambda'_n}$$

03 Spin correlation algorithm generates decay chain, decay matrices [Richardson 2001]

$$\mathcal{D}_{\lambda_A\lambda'_A} = \frac{1}{\mathcal{N}_{\mathcal{D}}}\mathcal{M}^{\mathcal{D}}_{\lambda_A}\mathcal{M}^{\mathcal{D}*}_{\lambda'_A}$$

04 Mass Smearing of the intermediate vector bosons according to Breit-Wigner distribution

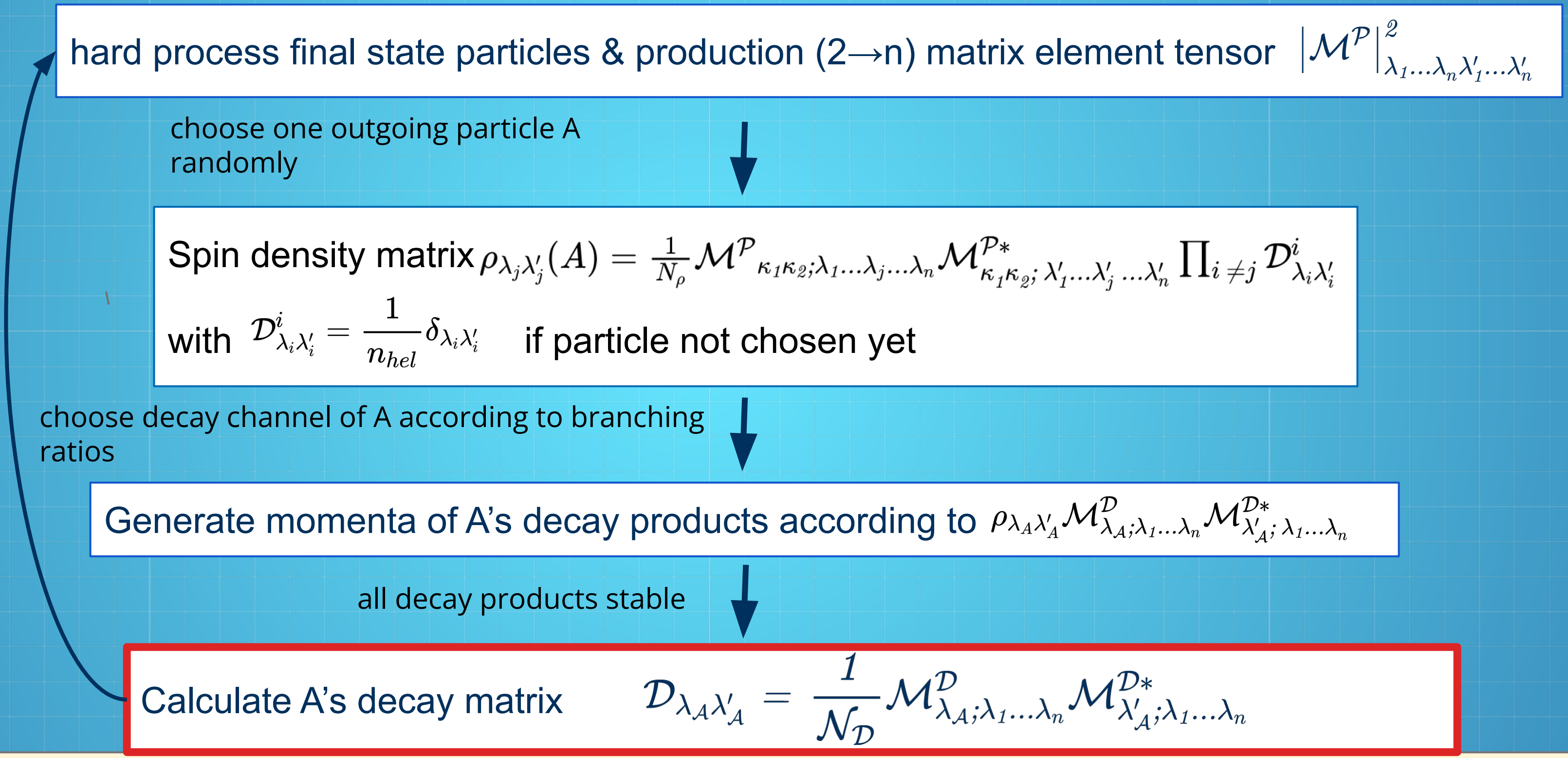
$$\mathrm{BW} \sim \frac{1}{(p^2 - M^2)^2 + \Gamma^2 M^2}$$

05 Reweighting of production cross section with decay branching ratio

$$|\mathcal{M}^{\mathrm{NWA}}|^2 = |\mathcal{M}^{\mathcal{P}}|^2 \times \mathrm{BR}$$

Spin-Correlation Algorithm

- **here only for VB decaying into stable leptons**



hard process final state particles & production (2→n) matrix element tensor $\left|\mathcal{M}^{\mathcal{P}}\right|^{2}_{\lambda_1\ldots\lambda_n\lambda'_1\ldots\lambda'_n}$

choose one outgoing particle A randomly

Spin density matrix $\rho_{\lambda_j\lambda'_j}(A) = \frac{1}{N_\rho}\mathcal{M}^{\mathcal{P}}{}_{\kappa_1\kappa_2;\lambda_1\ldots\lambda_j\ldots\lambda_n}\mathcal{M}^{\mathcal{P}*}_{\kappa_1\kappa_2;\,\lambda'_1\ldots\lambda'_j\,\ldots\lambda'_n}\prod_{i\neq j}\mathcal{D}^{i}_{\lambda_i\lambda'_i}$

with $\mathcal{D}^{i}_{\lambda_i\lambda'_i} = \dfrac{1}{n_{hel}}\delta_{\lambda_i\lambda'_i}$ if particle not chosen yet

choose decay channel of A according to branching ratios

Generate momenta of A's decay products according to $\rho_{\lambda_A\lambda'_A}\mathcal{M}^{\mathcal{D}}_{\lambda_A;\lambda_1\ldots\lambda_n}\mathcal{M}^{\mathcal{D}*}_{\lambda'_A;\,\lambda_1\ldots\lambda_n}$

all decay products stable

Calculate A's decay matrix $\mathcal{D}_{\lambda_A\lambda'_A} = \dfrac{1}{N_{\mathcal{D}}}\mathcal{M}^{\mathcal{D}}_{\lambda_A;\lambda_1\ldots\lambda_n}\mathcal{M}^{\mathcal{D}*}_{\lambda'_A;\lambda_1\ldots\lambda_n}$

Key part of the polarization framework: Transformation of the matrix elements

- Two ways to change polarization definition in matrix elements:
  - a priori: change polarization definition directly in matrix element generator
  - **a posteriori: transformation of calculated production tensor, decay matrices**
- change of basis = basis transformation of polarization vectors

$$\begin{pmatrix}\tilde\varepsilon^{0}_{+} & \tilde\varepsilon^{0}_{-} & \tilde\varepsilon^{0}_{0}\\ \tilde\varepsilon^{1}_{+} & \tilde\varepsilon^{1}_{-} & \tilde\varepsilon^{1}_{0}\\ \tilde\varepsilon^{2}_{+} & \tilde\varepsilon^{2}_{-} & \tilde\varepsilon^{2}_{0}\\ \tilde\varepsilon^{3}_{+} & \tilde\varepsilon^{3}_{-} & \tilde\varepsilon^{3}_{0}\end{pmatrix} = \begin{pmatrix}\varepsilon^{0}_{+} & \varepsilon^{0}_{-} & \varepsilon^{0}_{0}\\ \varepsilon^{1}_{+} & \varepsilon^{1}_{-} & \varepsilon^{1}_{0}\\ \varepsilon^{2}_{+} & \varepsilon^{2}_{-} & \varepsilon^{2}_{0}\\ \varepsilon^{3}_{+} & \varepsilon^{3}_{-} & \varepsilon^{3}_{0}\end{pmatrix} \begin{pmatrix} a_{++} & a_{-+} & a_{0+}\\ a_{+-} & a_{--} & a_{0-}\\ a_{+0} & a_{-0} & a_{00}\end{pmatrix}$$

transformation coefficients

matrix of new polarization vectors

matrix of default polarization vectors

- Transformation of matrix elements

$$|\mathcal{M}|^{2}_{\lambda_1\lambda_1'\dots\lambda_n\lambda_n'} = \sum_{\kappa_1\kappa_1'\dots\kappa_n\kappa_n'} a^{\text{part}1}_{\lambda_1\kappa_1}\, a^{\text{part}1*}_{\lambda_1'\kappa_1'} \cdots a^{\text{part}n}_{\lambda_n\kappa_n}\, a^{\text{part}n*}_{\lambda_n'\kappa_n'}\, |\mathcal{M}|^{2}_{\kappa_1\kappa_1'\dots\kappa_n\kappa_n'}$$

matrix element in new basis

linear combination coefficients

matrix element in default basis

Matching to parton shower: S-MC@NLO

[S. Höche et. al, 2012]
[S. Frixione & B.R. Webber, 2002]

***Idea:* Double counting eliminated by subtraction of the shower contribution at fixed order from contributions of the hard process at higher orders**

- Separation of real correction into IR-singular and IR-regular term:

$$R_n = D_n^{\mathcal{A}} + H_n^{\mathcal{A}}$$

- NLO QCD cross section:

$$\sigma^{\text{NLO}} = \int \mathrm{d}\tilde{\Phi}_n \bar{B}^{\mathcal{A}}(\tilde{\Phi}_n) + \int \mathrm{d}\tilde{\Phi}_{n+1} H^{\mathcal{A}}(\tilde{\Phi}_{n+1})$$

Born

virtual correction

integrated subtraction term

subtraction terms

$$\bar{B}^{\mathcal{A}}(\tilde{\Phi}_n) = B_n(\tilde{\Phi}_n) + \tilde{V}_n(\tilde{\Phi}_n) + I_n^{\mathcal{S}}(\tilde{\Phi}_n) + \int \mathrm{d}\tilde{\Phi}_1 \Big[D_n^{\mathcal{A}}(\tilde{\Phi}_{n+1}) - D_n^{\mathcal{S}}(\tilde{\Phi}_{n+1}) \Big]$$

matched NLO QCD cross section up to first emission:

$$\sigma^{\text{NLO}}_{\text{MC@NLO}} = \underbrace{\int \mathrm{d}\tilde{\Phi}_n \bar{B}_n^{\mathcal{A}}(\tilde{\Phi}_n) \Big[\bar{\Delta}^{\mathcal{A}}(t_0) + \int_{t_0} \mathrm{d}\tilde{\Phi}_1 \frac{D_n^{\mathcal{A}}(\tilde{\Phi}_{n+1})}{B_n(\tilde{\Phi}_n)} \bar{\Delta}^{\mathcal{A}}(t) \Big]}_{=:\sigma_{\mathbb{S}}} + \underbrace{\int \mathrm{d}\tilde{\Phi}_{n+1} H_n^{\mathcal{A}}(\tilde{\Phi}_{n+1})}_{=:\sigma_{\mathbb{H}}}$$

applied to expectation value of an IR-safe observable O

particles a_i with flavours f_i in the Born process with momenta p_i

S-event

$$\begin{aligned}
\langle O \rangle^{(\text{NLOMC})} = \sum_{\{\vec{f}\}} \int \mathrm{d}\Phi_B(\{\vec{p}\})\, \bar{\mathrm{B}}^{(\mathrm{A})}(\{\vec{a}\}) \Bigg[& \underbrace{\bar{\Delta}^{(\mathrm{A})}(t_0;\{\vec{a}\})}_{\text{unresolved}}\, O(\{\vec{p}\}) \\
& + \sum_{\{\widetilde{\imath\jmath},\tilde{k}\}} \sum_{F_i=q,g} \int \mathrm{d}\Phi_{R|B}^{ij,k}\, \Theta\big(t(\Phi_{R|B}^{ij,k}) - t_0\big)\; O\big(r_{\widetilde{\imath\jmath},\tilde{k}}(\{\vec{p}\})\big) \\
& \times \underbrace{\frac{1}{S_{ij}} \frac{S\big(r_{\widetilde{\imath\jmath},\tilde{k}}(F_i;\{\vec{f}\})\big)}{S(\{\vec{f}\})} \frac{\mathrm{D}_{ij,k}^{(\mathrm{A})}\big(r_{\widetilde{\imath\jmath},\tilde{k}}(F_i,\Phi_{R|B}^{ij,k};\{\vec{a}\})\big)}{\mathrm{B}(\{\vec{a}\})}\, \bar{\Delta}^{(\mathrm{A})}(t;\{\vec{a}\})}_{\text{resolved, singular}} \Bigg]
\end{aligned}$$

H-event

$$+ \sum_{\{\vec{F}\}} \int \mathrm{d}\Phi_R(\{\vec{P}\}) \underbrace{\Big[\mathrm{R}(\{\vec{A}\}) - \sum_{ij,k} \mathrm{D}_{ij,k}^{(\mathrm{A})}(\{\vec{A}\}) \Big]}_{\text{resolved, non-singular}} O(\{\vec{P}\})\,.$$

particles A_i with flavours F_i in the real process with momenta P_i

Sudakov factor

Polarized cross sections matched to PS - MC@NLO

[S. Höche et al. 2012]

Idea MC@NLO: Double counting eliminated by subtraction of the shower contribution at fixed order from contributions of the hard process at higher orders

$$\sigma^{\mathrm{NLO}}_{\mathrm{MC@NLO}} = \underbrace{\int \mathrm{d}\tilde{\Phi}_n \bar{B}_n^A(\tilde{\Phi}_n)\left[\bar{\Delta}^A(t_0) + \int_{t_0} \mathrm{d}\tilde{\Phi}_1 \frac{D_n^A(\tilde{\Phi}_{n+1})}{B_n(\tilde{\Phi}_n)}\bar{\Delta}^A(t)\right]}_{=:\sigma_{\mathbb{S}}} + \underbrace{\int \mathrm{d}\tilde{\Phi}_{n+1} H_n^A(\tilde{\Phi}_{n+1})}_{=:\sigma_{\mathbb{H}}}$$

Recalculation of the amplitude tensor in dependency of event type

Resolved S-events

- universal-soft-collinear radiation pattern in PS approximation above PS IR cutoff

- ***construction from complete real emission amplitude***

virtual, ultra-soft & ultra-collinear emission effects neglected for polarisation fractions

Unresolved S-events

- emissions below PS IR cutoff
- virtual corrections

- ***construction from Born amplitude***

H-events

- hard, well-separated emissions beyond PS starting scale
- process-specific corrections to universal soft-collinear emission pattern

- ***construction from complete real emission amplitude***

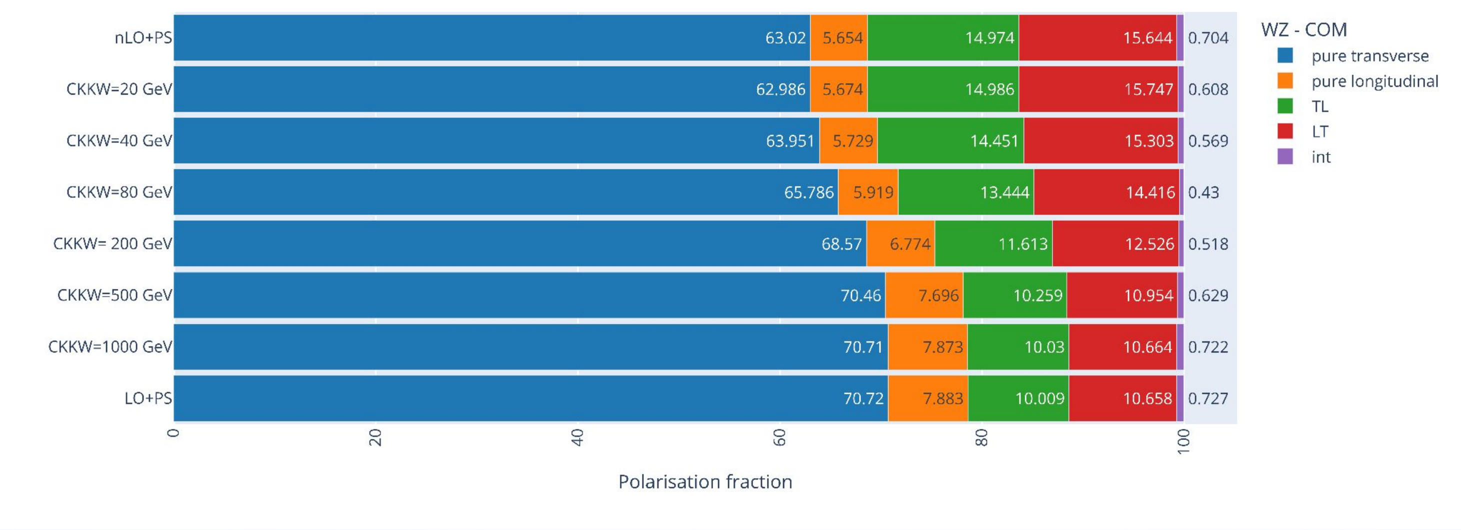
nLO+PS (Sherpa) vs. full NLO+PS (POWHEG+PYTHIA)

Literature: [G. Pelliccioli, G. Zanderighi 2023]

ZZ-Production

	$\sigma_{\mathrm{NLO+PS}}$ [fb]	Fraction [%]	$\sigma_{\mathrm{nLO+PS}}$ [fb]	Fraction [%]	$\frac{\mathrm{nLOPS}}{\mathrm{NLOPS}} - 1$[%]	
					XS	**Frac**
unpol	14.02(1)	100	14.017(17)	100	-0.0	
LL	0.819(1)	5.84	0.8404(12)	5.996(11)	+2.6	+2.7
LT + TL	3.565(3)	25.43	3.6177(39)	25.81(4)	+1.5	+1.5
TT	9.47(1)	67.52	9.370(14)	66.85(13)	-1.1	-1.0
int	0.171	1.28	0.1886(24)	1.345(17)	+10.3	+5.1

WZ - LO + 1jet merged with PS compared with (n)LO+PS - COM



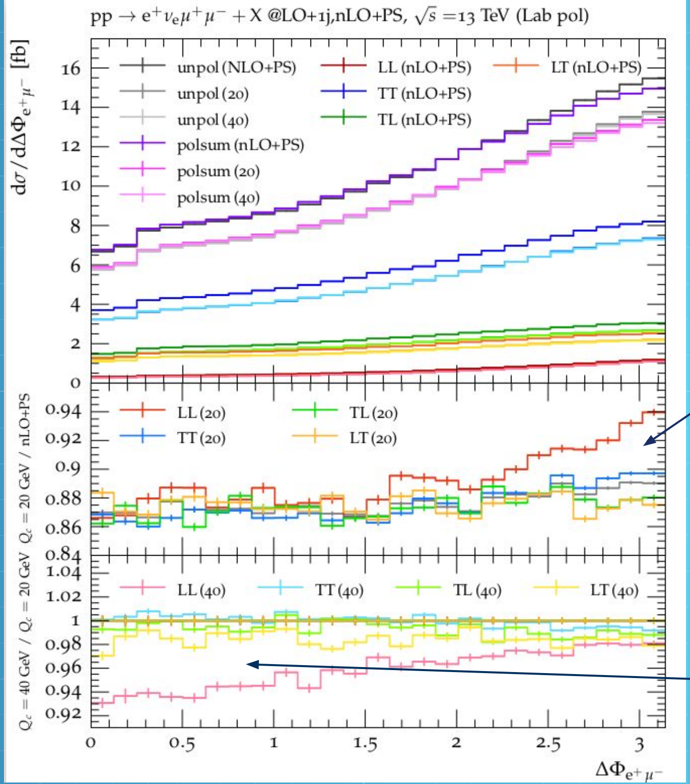
small merging scale (20-40 GeV):

- good approximation to nLO+PS result
- no large dependency on concrete scale value

larger merging scale:

- transition to LO behavior

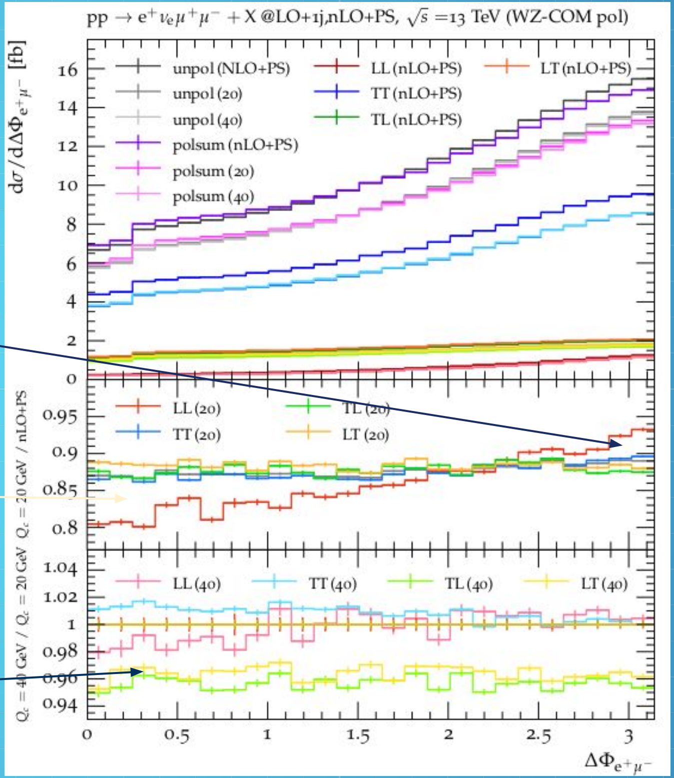
WZ - LO + 1jet merged with PS compared with (n)LO+PS



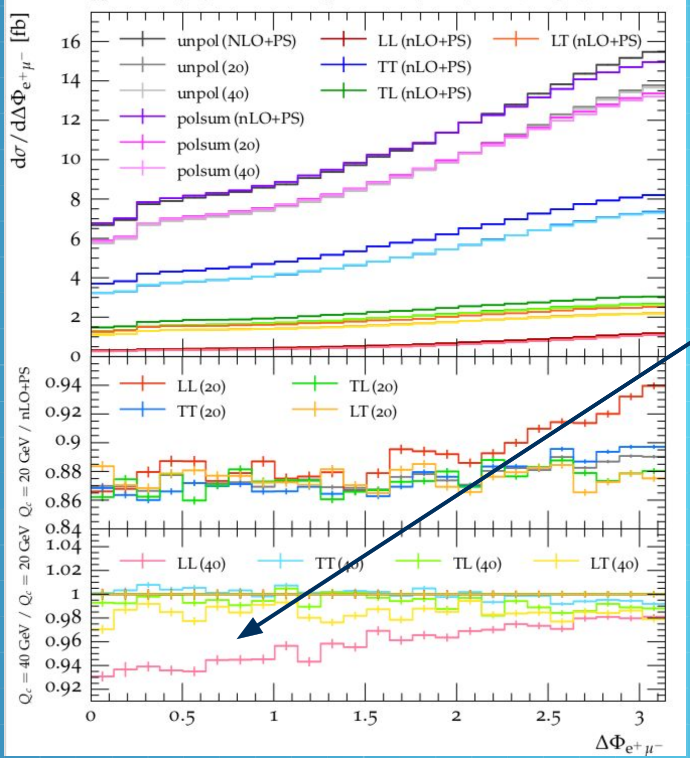
impact of very soft emissions below 20 GeV different on LL component

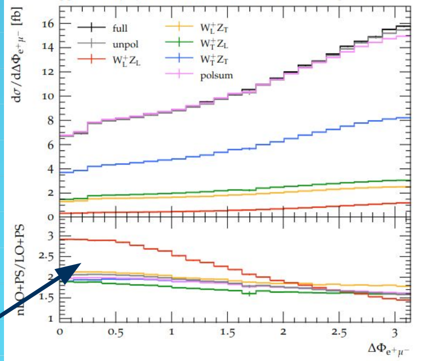
frame dependent effect

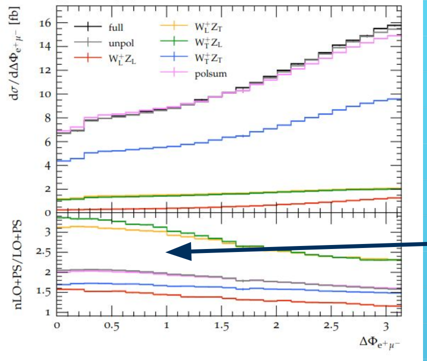
effect from emissions between 20 & 40 GeV extremely frame dependent

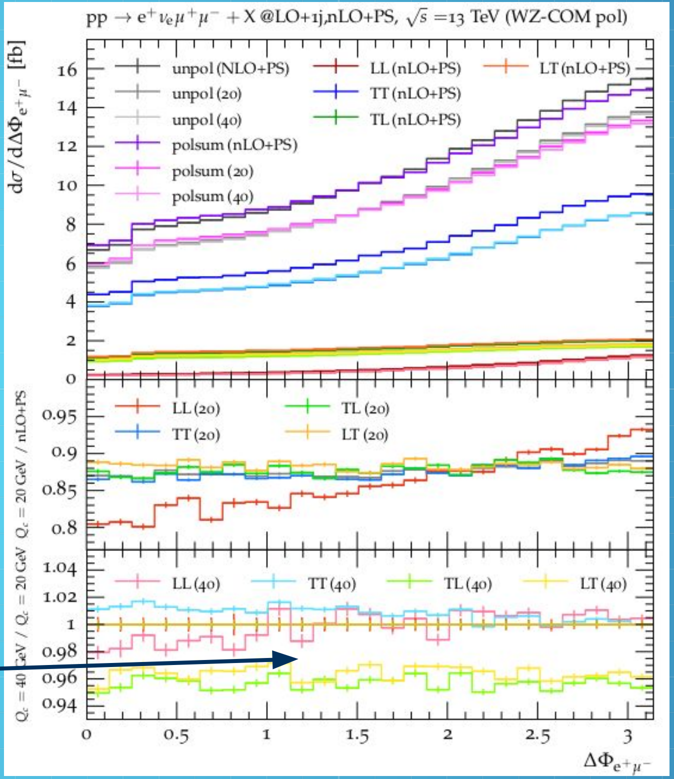


WZ - LO + 1jet merged with PS compared with (n)LO+PS

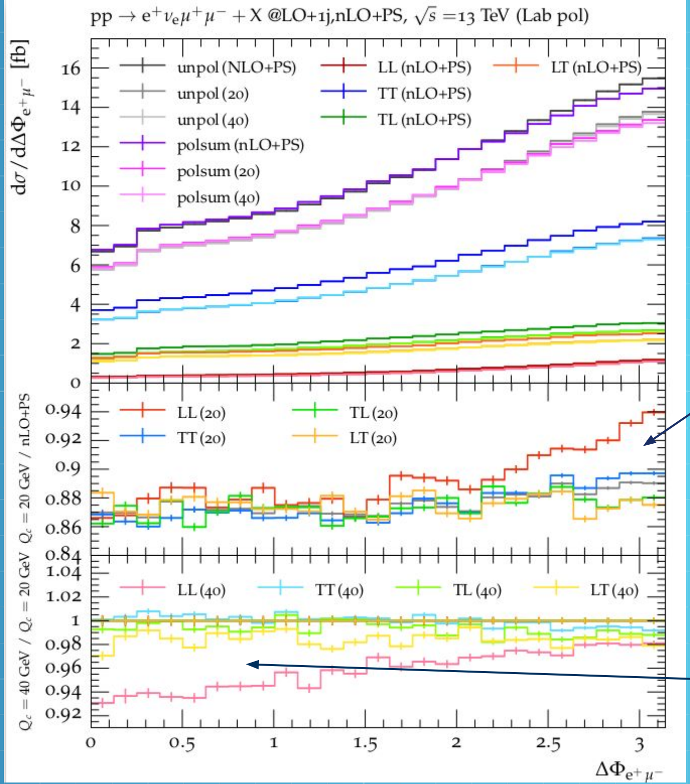








WZ - LO + 1jet merged with PS compared with (n)LO+PS



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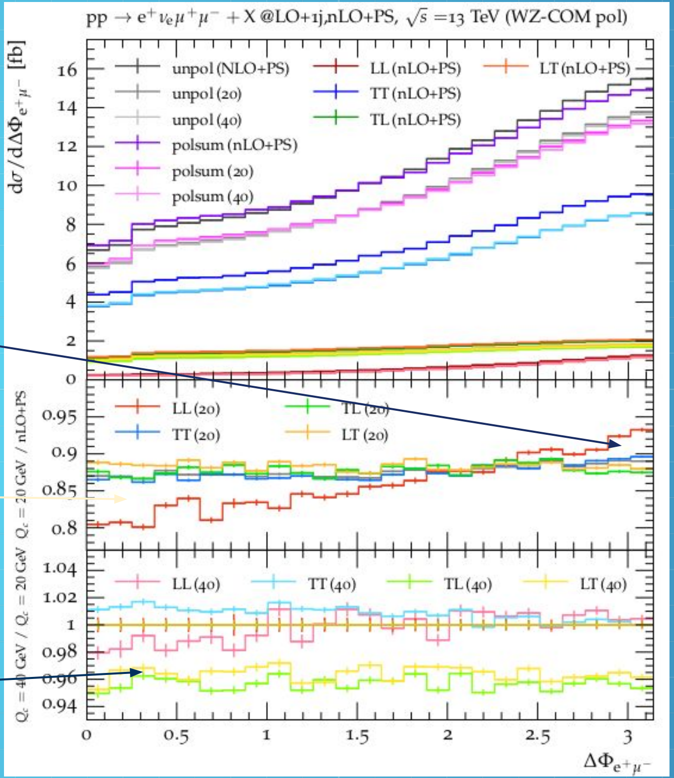
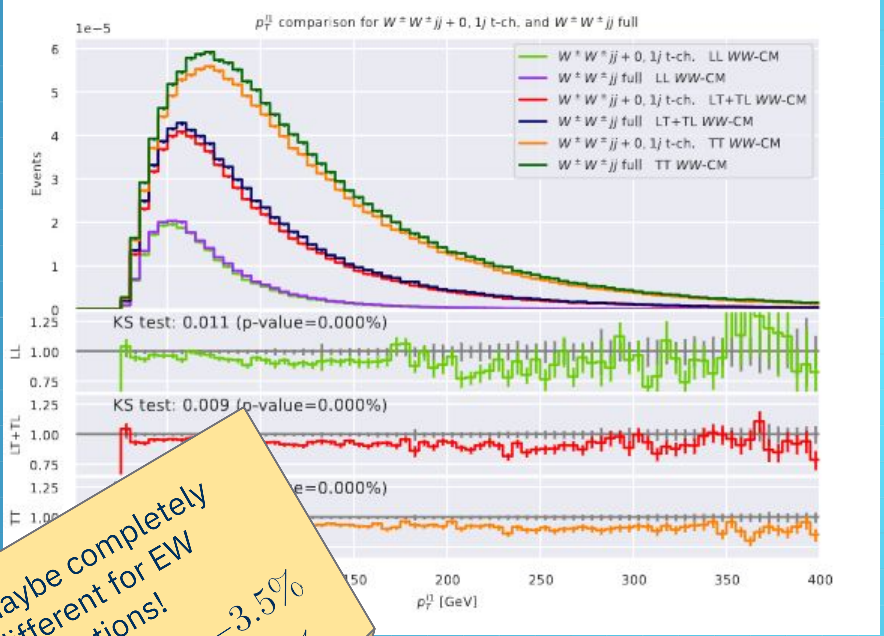
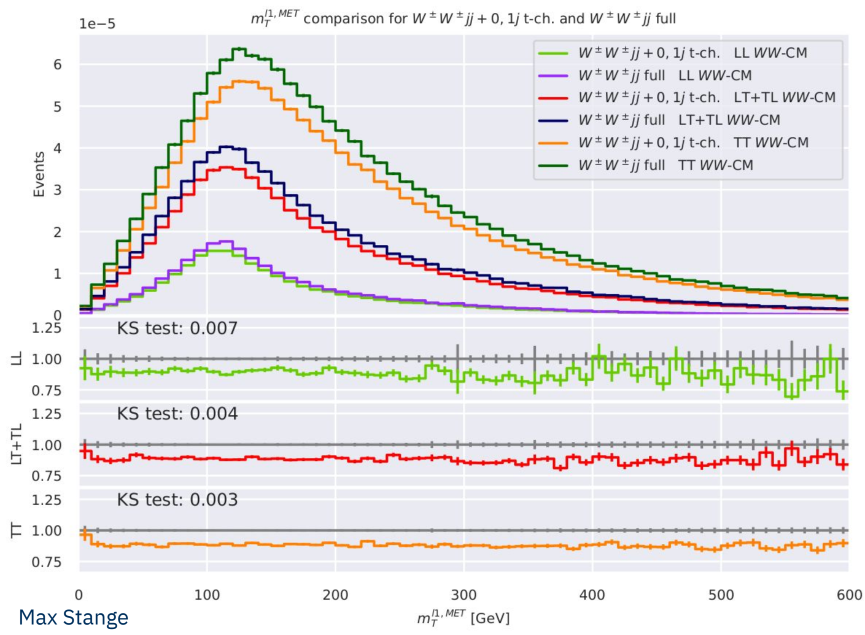


First higher order polarized cross sections for W^+W^+jj

Preliminary results





Max Stange

Maybe completely different for EW corrections!

$\mathcal{O}(\alpha^6 \alpha_S) = -3.5\%$

$\mathcal{O}(\alpha^7) = -13.2\%$

B. Biedermann et al. 2017

… differential polarization fractions!