WHIZARD 3.0: Status and News

Pascal Stienemeier

Linear Collider Workshop, 18 March 2021

Table of Contents

1 About WHIZARD

2 Lepton collisions with WHIZARD

3 WHIZARD 3.0: Status and News

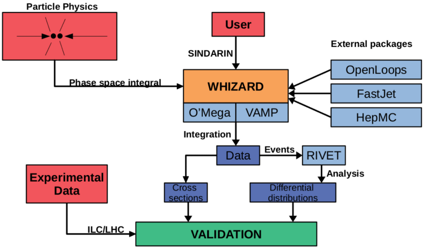
4 Summary

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

About WHIZARD

The code

WHIZARD is a **multi-purpose Monte Carlo event generator** for **hadron** and **lepton** colliders providing all parts of event generation



References:

WHIZARD (main): EPJ C71 (2011) 1742
O'Mega (ME generator): LC-TOOL (2001) 040
VAMP (MC integrator): CPC 120 (1999) 13
VAMP2 (MC integrator): EPJ C79 (2019) 4.344
CIRCE (beamstrahlung): CPC 101 (1997) 269
NLO QCD capabilities: JHEP 1612 (2016) 075
POWHEG matching: EPS-HEP (2015) 317

Programming languages

Languages:	Fortran2008 (gfortran $\geq$ 5.4.0, $\approx 250k$ lines of code)
	OCaml ($\geq$ 4.02.3, $\approx 100k$ lines of code)
Tests:	136 unit tests, 316 functional tests, CI at Uni Siegen

About WHIZARD

the team

The team

Wolfgang Kilian, **Thorsten Ohl**, **Jürgen R. Reuter**,
Simon Brass, Pia Bredt, Nils Kreher, Vincent Rothe, Pascal Stienemeier, Tobias Striegl

Information and contact

- Main web page: https://whizard.hepforge.org/
- Public GitLab: https://gitlab.tp.nt.uni-siegen.de/whizard/public
- Launchpad (User support): https://launchpad.net/whizard
- E-mail contact: `whizard@desy.de`

Recent versions

WHIZARD 2.8.5: UFO support

WHIZARD 3.0.0β: NLO QCD

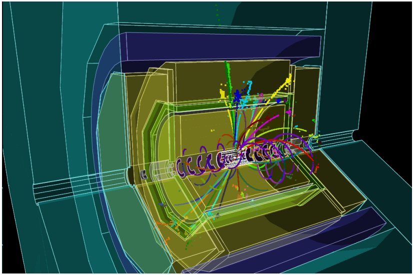
Table of Contents

1 About WHIZARD

2 Lepton collisions with WHIZARD

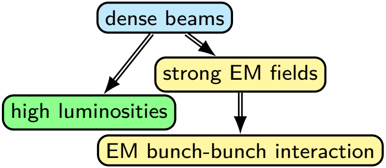
3 WHIZARD 3.0: Status and News

4 Summary

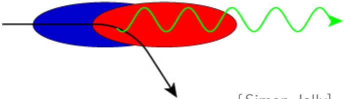


$e^+e^- \rightarrow Zh \rightarrow q\bar{q}h$ at 250 GeV ILC

☑ Beamstrahlung



$$L = \frac{n \cdot N_1 \cdot N_2 \cdot f}{4\pi\sigma_x\sigma_y}$$

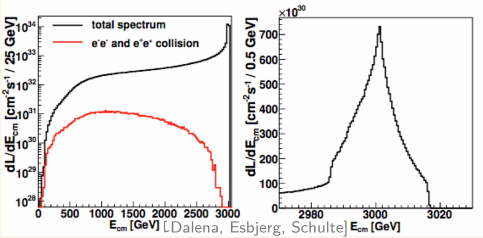


[Simon Jolly]

CIRCE

CIRCE1: 6 or 7 parameter fit to GuineaPig

CIRCE2: smoothed 2D histogram fit to GuineaPig spectrum



[Dalena, Esbjerg, Schulte]

Lepton collisions with WHIZARD

Features – Bremsstrahlung

- ☑ Beamstrahlung
- ☑ Bremsstrahlung

Bremsstrahlung

ISR photon emission important due to small electron mass

$$\epsilon = \frac{\alpha}{\pi} e^2 \ln \left(\frac{s}{m_e^2} \right)$$

$\Longrightarrow$ soft/collinear photon resummation required

Implementation

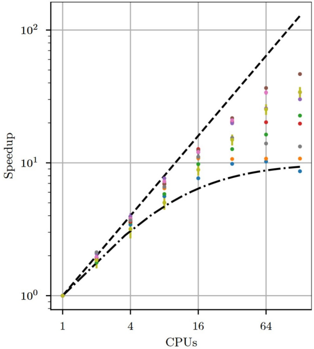
cross sections: LL resummation in the strict *collinear limit* [Skrzypek/Jadach 1990]
event generation: *One photon per beam* added. p_T and recoil via `isr_handler`

- ☑ Beamstrahlung
- ☑ Bremsstrahlung
- ☑ Beam polarisation
  - ☑ circular polarisation
  - ☑ longitudinal polarisation
  - ☑ transversal polarisation
  - ☑ arbitrary axes
  - ☑ arbitrary density matrices
  - ☑ arbitrary polarisation fractions

E.g. for an ILC-like setup:

```
beams = e1, E1
beams_pol_density = @(-1), @(+1)
beams_pol_fraction = 80%, 30%
```

- ☑ Beamstrahlung
- ☑ Bremsstrahlung
- ☑ Beam polarisation
- ☑ Parallel phase space integration



VAMP

VEGAS AMPlified: doubly adaptive multi-channel Monte Carlo integrator

VAMP2

Fully MPI-parallelized version of VAMP with speedups of 10–30 and saturation at $\mathcal{O}(100)$ tasks

[Simon Brass]

- ☑ Beamstrahlung
- ☑ Bremsstrahlung
- ☑ Beam polarisation
- ☑ Parallel phase space integration
- ☑ Many event formats

Event formats

internal: `StdHEP`, `LHA`, `LHEF2&3`, `ascii`, ...

external: `LCIO`, `HepMC2&3` $\to$ `ROOT`

Conclusion

`WHIZARD` is ideally suited for large scale lepton colliders

Table of Contents

1 About WHIZARD

2 Lepton collisions with WHIZARD

3 WHIZARD 3.0: Status and News

4 Summary

☑ NLO QCD corrections for **lepton** collisions

3.0.0α

Process	MadGraph σ_{LO} [fb]	MadGraph σ_{NLO} [fb]	MadGraph K	WHIZARD σ_{LO} [fb]	WHIZARD σ_{NLO} [fb]	WHIZARD K	σ^{std}_{NLO}
$e^+e^- \to jj$	622.70(5)	639.30(12)	1.027	622.737(8)	639.39(5)	1.027	0.69
$e^+e^- \to jjj$	340.4(7)	317.3(8)	0.932	340.6(5)	317.8(5)	0.933	0.53
$e^+e^- \to jjjj$	104.09(20)	103.67(26)	0.996	105.0(3)	104.2(4)	0.992	1.11
$e^+e^- \to jjjjj$	22.35(5)	24.65(4)	1.103	22.33(5)	24.57(7)	1.100	0.99
$e^+e^- \to jjjjjj$	–	–	–	3.583(17)	4.46(4)	1.245	–
$e^+e^- \to t\bar{t}$	166.32(11)	174.5(3)	1.049	166.37(12)	174.55(20)	1.049	0.14
$e^+e^- \to t\bar{t}j$	47.95(9)	53.336(10)	1.112	48.12(5)	53.41(7)	1.110	1.05
$e^+e^- \to t\bar{t}jj$	8.608(18)	10.515(19)	1.222	8.592(19)	10.526(21)	1.225	0.39
$e^+e^- \to t\bar{t}jjj$	1.0371(21)	1.415(4)	1.364	1.035(4)	1.405(5)	1.357	1.56
...	...	...	...	...	...	...	...

☑ NLO QCD corrections for **hadron** collisions

3.0.0α

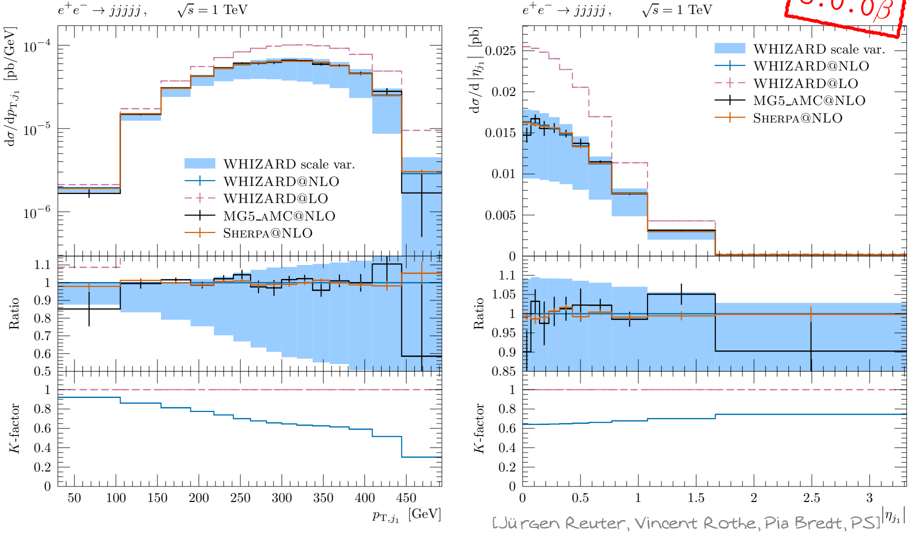
Process	MadGraph σ_{LO} [fb]	MadGraph σ_{NLO} [fb]	MadGraph K	WHIZARD σ_{LO} [fb]	WHIZARD σ_{NLO} [fb]	WHIZARD K	σ^{std}_{NLO}
$pp \to jj$	$1.1593(23) \cdot 10^9$	$1.6040(29) \cdot 10^9$	1.384	$1.162(4) \cdot 10^9$	$1.601(5) \cdot 10^9$	1.378	0.10
$pp \to jjj$	$8.940(21) \cdot 10^7$	$7.619(19) \cdot 10^7$	0.852	$9.01(4) \cdot 10^7$	$7.46(9) \cdot 10^7$	0.828	1.73
$pp \to t\bar{t}$	$4.584(3) \cdot 10^5$	$6.746(14) \cdot 10^5$	1.472	$4.589(9) \cdot 10^5$	$6.740(10) \cdot 10^5$	1.469	0.35
$pp \to t\bar{t}j$	$3.133(5) \cdot 10^5$	$4.095(8) \cdot 10^5$	1.307	$3.123(6) \cdot 10^5$	$4.087(9) \cdot 10^5$	1.309	0.66
$pp \to t\bar{t}jj$	$1.363(3) \cdot 10^5$	$1.784(3) \cdot 10^5$	1.309	$1.360(4) \cdot 10^5$	$1.775(7) \cdot 10^5$	1.305	1.18
$pp \to t\bar{t}t\bar{t}$	4.505(5)	9.076(13)	2.015	4.485(6)	9.070(9)	2.022	0.38
$pp \to t\bar{t}W^\pm$	$3.777(3) \cdot 10^2$	$5.668(18) \cdot 10^2$	1.501	$3.775(5) \cdot 10^2$	$5.674(5) \cdot 10^2$	1.503	0.32
$pp \to t\bar{t}W^\pm j$	$2.352(3) \cdot 10^2$	$3.434(8) \cdot 10^2$	1.460	$2.356(7) \cdot 10^2$	$3.427(8) \cdot 10^2$	1.455	0.62
$pp \to t\bar{t}Zj$	$3.953(4) \cdot 10^2$	$5.079(14) \cdot 10^2$	1.285	$3.943(14) \cdot 10^2$	$5.069(17) \cdot 10^2$	1.286	0.45
$pp \to t\bar{t}ZZ$	1.349(14)	1.843(4)	1.366	1.3590(29)	1.842(3)	1.355	0.20
$pp \to HZ$	$6.468(8) \cdot 10^2$	$7.693(19) \cdot 10^2$	1.189	$6.474(11) \cdot 10^2$	$7.679(12) \cdot 10^2$	1.186	0.62
...	...	...	...	...	...	...	...

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

[Jürgen Reuter, Vincent Rothe, PS]

☑ NLO QCD corrections for arbitrary hadron and lepton collider events

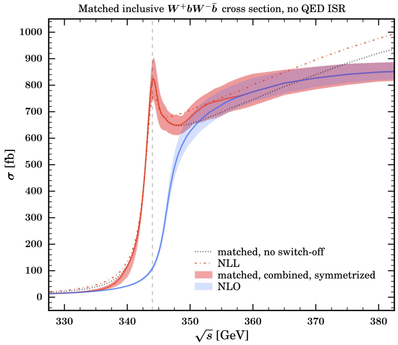
3.0.0β

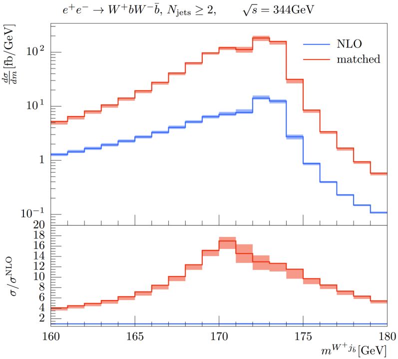


[Jürgen Reuter, Vincent Rothe, Pia Bredt, PS]

Top-threshold in WHIZARD

WHIZARD provides special model for NRQCD top-threshold resummation matched to NLO QCD for exclusive final states [JHEP 1803(2018)184]





(ongoing project by FCC-ee Straßbourg)

[Jürgen Reuter, Bijan Chokoufé, Christian Weiss]

Internal hard-coded models

Model type	Model name
Yukawa test model	`Test`
QED with e, μ, τ, γ	`QED`
QCD with d, u, s, c, b, t, g	`QCD`
Standard Model	`SM, SM_CKM`
SM with anomalous gauge couplings	`SM_ac, SM_ac_CKM`
SM with Hgg, $H\gamma\gamma$, $H\mu\mu$, He^+e^-	`SM_Higgs, SM_Higgs_CKM`
SM with bosonic dim-6 operators	`SM_dim6`
SM with charge 4/3 top	`SM_top`
SM with anomalous top couplings	`SM_top_anom`
SM with anomalous Higgs couplings	`SM_rx/NoH_rx/SM_ul`
SM extensions for VV scattering	`SSC/AltH/SSC_2/SSC_AltT`
SM with Z'	`Zprime`
Two-Higgs Doublet Model	`THDM, THDM_CKM`
MSSM	`MSSM, MSSM_CKM`
MSSM with gravitinos	`MSSM_Grav`
NMSSM	`NMSSM, NMSSM_CKM`
extended SUSY models	`PSSSM`
Littlest Higgs	`Littlest`
Littlest Higgs with ungauged $U(1)$	`Littlest_Eta`
Littlest Higgs with T parity	`Littlest_Tpar`
Simplest Little Higgs (anomaly-free)	`Simplest`
Simplest Little Higgs (universal)	`Simplest_univ`
SM with graviton	`Xdim`
UED	`UED`
"SQED" with gravitino	`GravTest`
Augmentable SM template	`Template`

External UFO models

FeynRules/SARAH

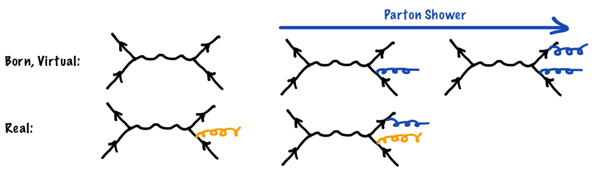
↓ UFO

WHIZARD

- ☑ Spin $0, 1/2, 1, 3/2, 2, 3, 4, 5$ — 2.8.5
- ☑ Arbitrary Lorentz structures
- ☑ 5- and 6-point vertices
- ☑ arbitrary color structures
- ☑ BSM SLHA input
- ☑ Many technical bug fixes
- ☐ Majorana statistics — 3.0.0

[Thorsten Ohl]

Problem: double counting



POWHEG matching: the idea

- Take **hard** emissions from the **matrix element**
- Take **soft** emissions from the **parton shower**
- Use the NLO Born and real matrix elements as emission probability $\mathcal{R}/\mathcal{B}$

POWHEG matching: pros and cons

+ No double counting: $\sigma_{\mathtt{POWHEG}} = \sigma_{\mathrm{NLO}}$
+ Fits well to FKS subtraction scheme
+ No negative event weights

− dependence on damping parameter h_{damp}

[PS]

From NLO QCD to NLO EW

- ☑ gluon emission → photon emission
- ☑ EW couplings and splittings
- ☑ photon content in proton PDFs for hadron collisions
- ☑ electron-photon recombination
- ☐ electron PDFs for lepton collisions
- ☐ infrastructure for mixed coupling expansions

Process	MadGraph		WHIZARD			
	σ_{LO} [fb]	σ_{NLO} [fb]	σ_{LO} [fb]	σ_{NLO} [fb]	$\sigma_{\mathrm{NLO}}/\sigma_{\mathrm{LO}}$	$\sigma^{\mathrm{std}}_{\mathrm{NLO}}$
$pp \to ZZZ$	$1.0761(1) \cdot 10^1$	$0.9741(1) \cdot 10^1$	$1.0752(8) \cdot 10^1$	$0.9727(9) \cdot 10^1$	0.905	1.00
$pp \to \nu_e \overline{\nu}_e$	$3.2947(4) \cdot 10^6$	$3.3136(4) \cdot 10^6$	$3.2949(10) \cdot 10^6$	$3.3138(10) \cdot 10^6$	1.006	0.02
$pp \to e^+ \nu_e$	$1.78224(13) \cdot 10^7$	$1.77598(15) \cdot 10^7$	$1.78224(21) \cdot 10^7$	$1.77621(21) \cdot 10^7$	0.997	0.93

☑ first cross sections

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
[Pia Bredt]

Table of Contents

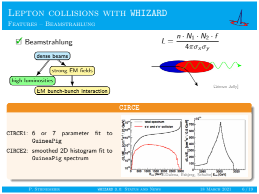
1 About WHIZARD

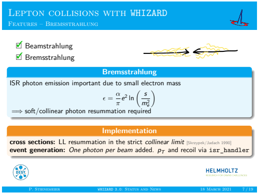
2 Lepton collisions with WHIZARD

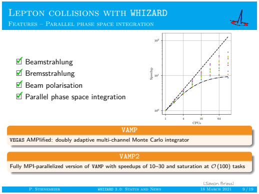
3 WHIZARD 3.0: Status and News

4 Summary

Summary

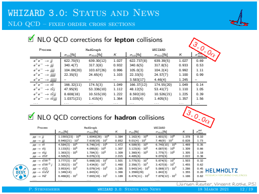


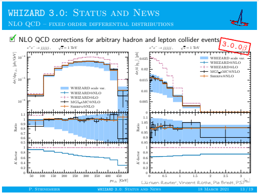


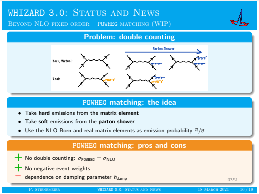


Summary

1. WHIZARD is well suited for simulations at future lepton colliders
2. Fixed order NLO QCD is validated and released
3. Full UFO support will be available from WHIZARD 3.0.0 onwards
4. Work in progress: POWHEG matching and NLO EW corrections







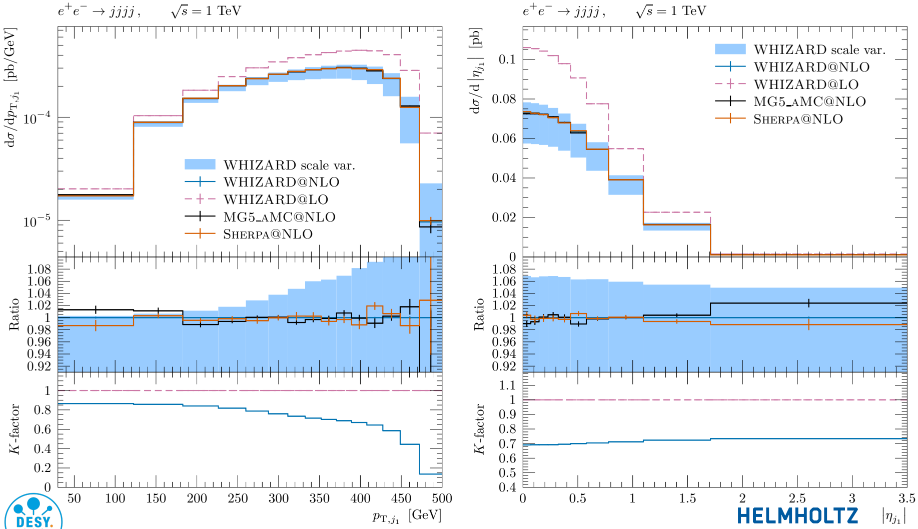
Thanks!

Questions?

Backup Slides

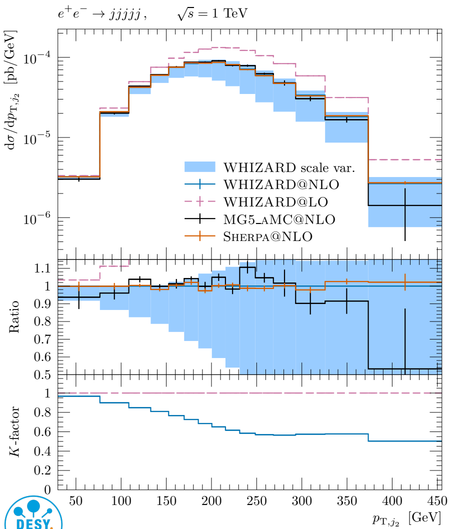
Backup

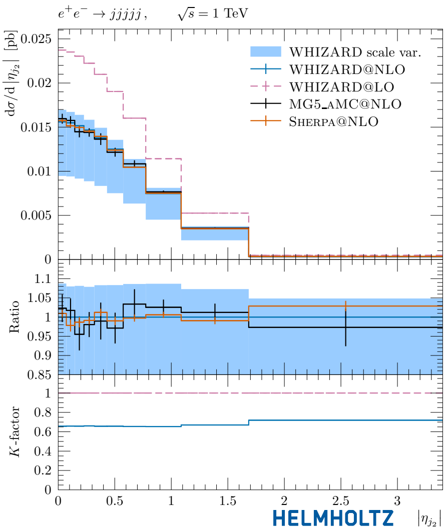
NLO QCD – fixed order differential distributions: $e^+e^- \to jjjj$



Backup

NLO QCD – fixed order differential distributions: $e^+e^- \to jjjjj$

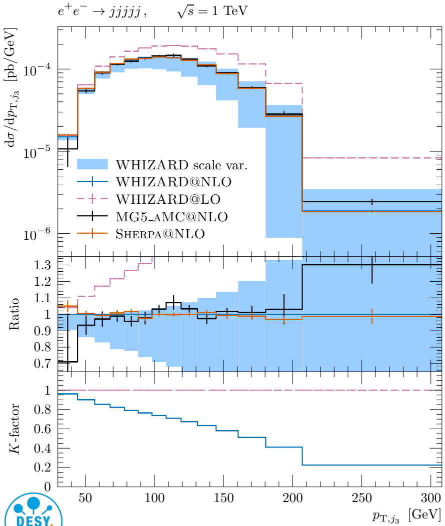


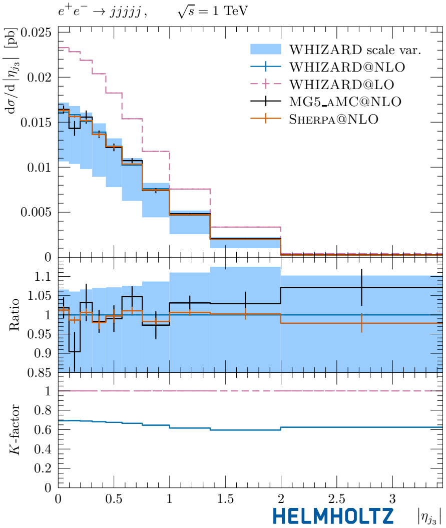


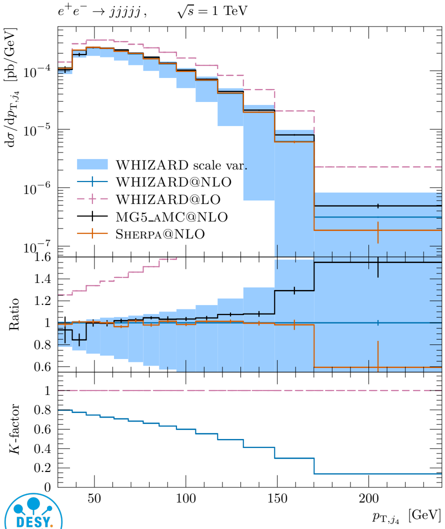
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

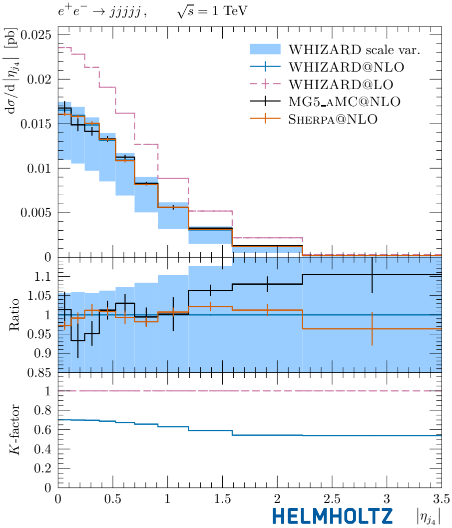
Backup

NLO QCD – fixed order differential distributions: $e^+e^- \to jjjjj$





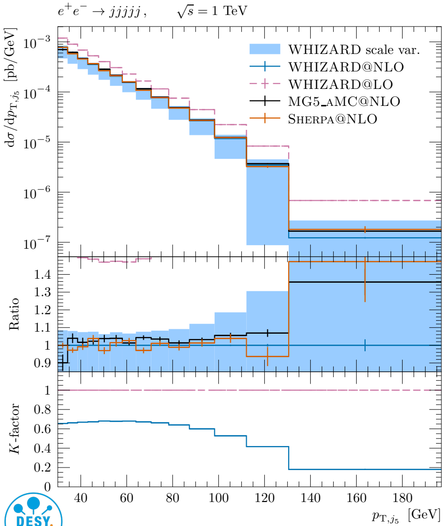


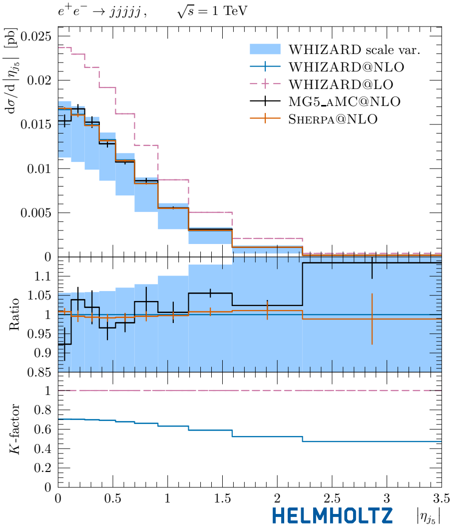


HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Backup

NLO QCD – fixed order differential distributions: $e^+e^- \to jjjjj$





Backup

NLO QCD – fixed order differential distributions: $e^+e^- \to jjjjj$