NLO in Herwig7 - Matching and Merging

in collaboration with the Herwig Collaboration
Johannes Bellm (IPPP) | 5.4.2016

MCnet meeting Göttingen

Outline

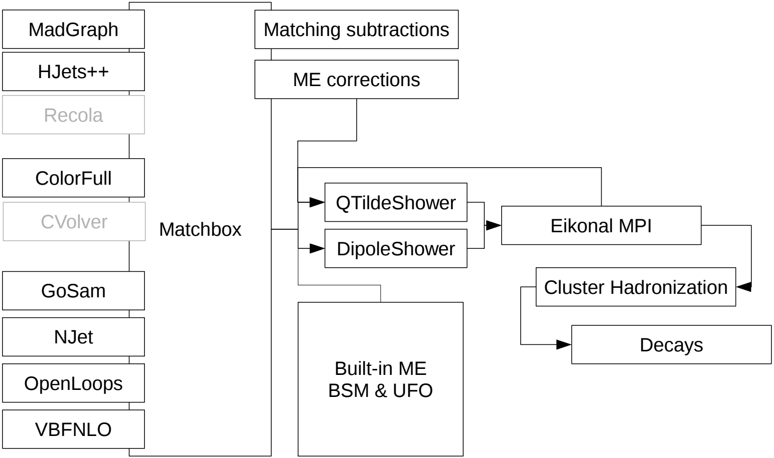
- Herwig 7
  - automatised NLO in Herwig.
  - How to use.
  - Changing parameters.
- Next Steps and Herwig 7.1
  - Upcoming Features and Improvements.
  - Merging @ NLO.
- Summary and Outlook

Herwig 7

It's there!

- **NLO matched to parton showers as default** in the hard process
- Two showers: The default **Angular-ordered** and **Dipole** shower
- **Spin correlations** and **QED-radiation** in the angular ordered shower
- implementation of various parameters to quantify the **parton shower uncertainties**.
- Additional contributions like: EW corrections to di-boson production, more build in matrix elements, multiple weight support for LHE files....
- Vastly **improved documentation, usage** and **installation** and last but not least new tunes.

Under the hood



by S. Plätzer

Use Herwig

1. Install: **./herwig-bootstrap /where/to/install**
2. Activate **source /where/to/install/bin/activate**
3. Modify Input:
   cp $HERWIG_ENV/share/Herwig/LHC-Matchbox.in .
   vi LHC-Matchbox.in ...
   (see herwig.hepforge.org for documentation)
4. Build:
   Herwig build LHC-Matchbox.in –max-jobs=10
5. Integrate:
   for i in $(seq 0 9);
   do Herwig integrate -n$i LHC-Matchbox.run & done
6. Run:
   Herwig run LHC-Matchbox.run -j10 -x setup-file.in

setup-file.in

Uncertainties estimations with **setup-file.in** $\rightarrow$ **Graemes talk**

setup-file.in

```
cd /Herwig/DipoleShower/
set DipoleShowerHandler:RenormalizationScaleFactor 1.
set DipoleShowerHandler:FactorizationScaleFactor 1.
set DipoleShowerHandler:HardScaleFactor 1.

cd /Herwig/Shower/
set ShowerHandler:RenormalizationScaleFactor 1.
set ShowerHandler:FactorizationScaleFactor 1.
set ShowerHandler:HardScaleFactor 1.

cd /Herwig/MatrixElements/Matchbox/
set Factory:RenormalizationScaleFactor 1.
set Factory:FactorizationScaleFactor 1.
```

Upcoming Features (near future)

- **extended UFO-Model** support. (JB, Grellscheid)
  - For now up to $2 \rightarrow 2$ is build in with decays in the showering process.
  - With Matchbox facilities and MadGraph this is easily extensible to $2 \rightarrow N$ at LO. (in test phase)
  - For NLO UFO models it needs (current) work.
- **Reweighing** for uncertainties with weights vectors in HepMC-files (JB, Plätzer, Richardson, Siódmok, Webster)
  - Modified weights in veto algorithm.
  - $\rightarrow$ see **Stephens talk**.

Upcoming Features (next to near future)

- Improved top decay in dipole shower.
  (Webster, Richardson, Plätzer)
- Merging for high energy jets interfaced to HEJ.(JB, Plätzer)
- NLO merging as a defining criterion of Herwig 7.1.
  (JB, Gieseke, Plätzer)
  - Based on uniterised merging idea.
  - Strong reduction of negative weights (in preparation).
  - Alternative to:
    - MEPS@NLO [JHEP 01 (2013) 144, JHEP 04 (2013) 027]
    - UNLOPS [JHEP 03 (2013), 166]
    - FxFx [JHEP 12 (2012), 061]
    - MINLO+POWHEG [JHEP 1305 (2013) 082]

Parton shower

$\mathcal{P}_{Prod.}(Q)$	$\mathcal{P}_{PS}(Q \to \mu)$		
B_0	$\cdot\Delta^0_\mu$		no emission
	$P_1\Delta^0_1 B_0$	$\cdot\Delta^1_\mu$	exactly one emission
		$P_2\Delta^1_2 P_1\Delta^0_1 B_0$	at least two emissions

- Cross section for B_0 is conserved
- Approximation: factorised, universal functions for splitting $P(z)$, from collinear and infrared limits
- Evolution is then:

$$1 = \Delta^Q_\mu + \int_{\mu^2}^{Q^2} \frac{\mathrm{d}q^2}{q^2} \int \mathrm{d}z \frac{\alpha_s(q)}{2\pi} P(z) \Delta^Q_q$$

Parton shower: Merging

B_0	$\cdot\Delta^0_\mu$	
	$P_1\Delta^0_1 B_0$	$\cdot\Delta^1_\mu$
		$P_2\Delta^1_2 P_1\Delta^0_1 B_0$

1 = no emission

+ exactly one Emission

+ at least two emissions

B_0	$\cdot\Delta^0_\mu$	
	$\Delta^0_1 B_1$	$\cdot\Delta^1_\mu$
		$\Delta^1_2\Delta^0_1 B_2$

Modify the emissions with weighted matrix elements

[Catani et. al., JHEP 0111 (2001) 063]

[Lönnblad, JHEP 0205 (2002) 046]

B_0	$-\int \Delta^0_1 B_1$	
	$\Delta^0_1 B_1$	$-\int \Delta^1_2\Delta^0_1 B_2$
		$\Delta^1_2\Delta^0_1 B_2$

Subtract the same expressions to conserve cross section

[Plätzer, JHEP 1308 (2013) 114]

[Prestel, Lönnblad, JHEP 1302 (2013) 094]

A 'merging' scale ρ is introduced to produce stable and efficient results.

Parton Shower: Matching

born	virt. & real & subtr.		
B_0	$\bar{V}_0 + IPK_0$	$-\int D_1$	no emission
	B_1		one emission

Problem:

- Same expressions already in the parton shower (approximated).
- Simple inclusion would lead to double counting.

Solution:

- Expand parton shower to $\mathcal{O}(\alpha_s) \rightarrow$ new $\mathcal{P}_{Prod.}(Q)$:

B_0	$\bar{V}_0 + IPK_0$	$\int (P_1 B_0 - D_1)$
	$B_1 - P_1 B_0$	

$\mathcal{O}(\alpha_s)$ of PS

[Frixione, Webber, JHEP 0206 (2002) 029][P. Nason, JHEP 11 (2004), 040]

NLO Merging: Correction to B_0

Unitarized merging (with merging scale):

B_0	$-\int \Delta_1^0 B_1 \theta_{PS} \theta_{ME}$	$\cdot \Delta_\mu^V$	
	$P_1 \Delta_1^{0,V} B_0 \not\theta_{ME}$	$P_1 \Delta_1^{0,V} (-\int \Delta_1^0 B_1 \theta_{ME}) \theta_<$	in $\not\theta_{ME}$
	$\Delta_1^0 B_1 \theta_{ME}$		in θ_{ME}

Problem:

- As in NLO matching: double counting

Solution:

- Expand parton shower to $\mathcal{O}(\alpha_s) \to$ Addition to $\mathcal{P}_{Prod.}(Q)$:

$\bar{V}_0 + IPK_0$	$\int (B_1 \theta_{PS} - D_1) \theta_{ME}$	$\int (P_1 B_0 - D_1) \not\theta_{ME}$
	$(B_1 - P_1 B_0) \not\theta_{ME}$	

$\mathcal{O}(\alpha_s)$ of PS in $\not\theta_{ME}$

compare to [Plätzer, JHEP 1308 (2013) 114] or [Prestel, Lönnblad, JHEP 1302 (2013) 094]

NLO Merging: Correction to B_1

$(\bar{V}_1 + IPK_1 - (\partial^1_{\alpha_s}\Delta^0_1)B_1)\theta^1_{ME}$	$\int(B_2 - D_2)\theta^2_{ME}\theta^1_{ME}$	$\int(P_2 B_1 - D_2)\not\theta^2_{ME}\theta^1_{ME}$
	$(B_2\Theta - P_2 B_1)\not\theta^2_{ME}\theta^1_{ME}$	

$\mathcal{O}(\alpha_s)$ expansion of parton shower weights

cuts on multiple emissions

Goal:

- NLO corrections in matrix element region θ^n_{ME}

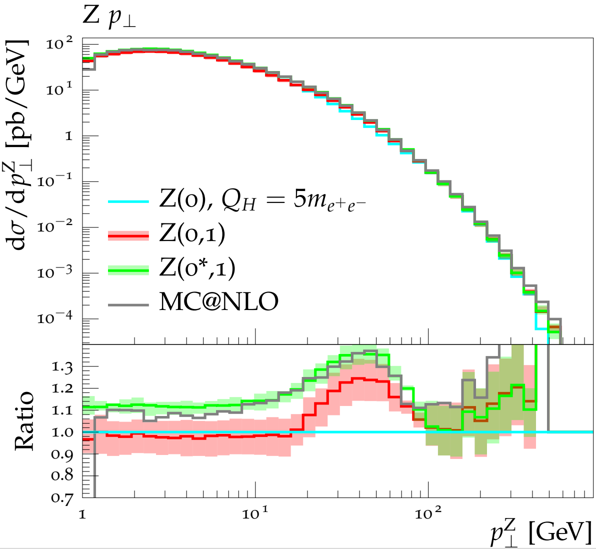
Problems:

- double counting and multiple singular regions
- PS-weights: $\Delta^0_n = 1 + \alpha_s f(Q, q_1, z...)$ $\rightarrow$ same order in α_s
- change of NLO cross section

Solutions:

- expand the PS in α_s (also the PS-weights)
- define ME regions for multiple emissions
- unitarize the additional expressions

Example: $pp \to e^+e^- + X$



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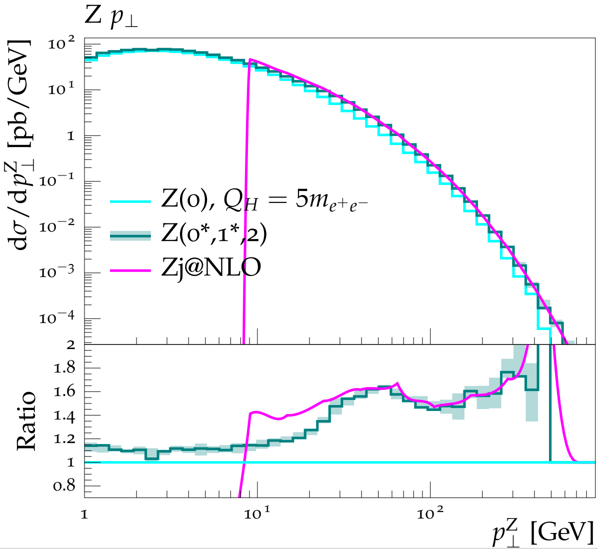

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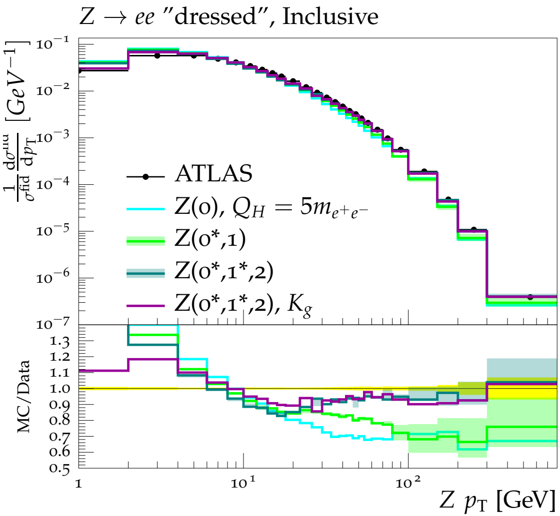
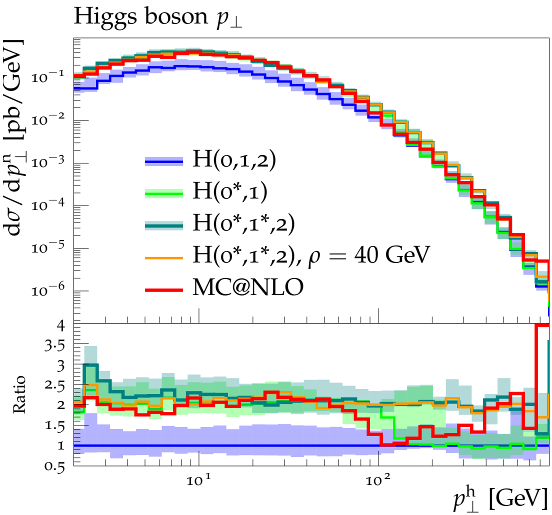


[ATLAS Collaboration, JHEP 1409 (2014) 145]

LHC: Higgs



- Higgs Produktion in HEFT ($m_t \to \infty$)
- Vgl. zu MC@NLO
- see also **Peters talk**

Conclusion

- Herwig7 is there!
- Automated matching to both Herwig showers.
- Easy to use!
- Automated linking of external programs for NLO corrections in Herwig 7.
- Outlook on upcoming features.
- Alternative algorithm to include multiple NLO corrections to LO merging.
- Showed typical examples.
- See the next talks for more Herwig topics.

Simple Scale

```
create Herwig::MatchboxScale WWScale
set WWScale:JetFinder /Herwig/Cuts/JetFinder
# Set a path to compile:
set WWScale:ScalePath /Users/.../test/
# scale function.
```

do WWScale:Function (lepton[0]+lepton[1]+lepton[2]+lepton[3]).m2()

```
set Factory:ScaleChoice WWScale
```

Inclusive one jet

$$B_1 \Delta_1^0 \theta_{ME} = f_1(Q_f)\alpha_s^n(Q_r)\tilde{B}_1 \cdot \Delta_{q_1}^0 \frac{\alpha_s(q_1)}{\alpha_s(Q_r)} \frac{f_0(Q_f)}{f_0(q_1)} \frac{f_1(q_1)}{f_1(Q_f)} \theta_{ME}$$

- $\Delta_1^0 = 1 + \alpha_s f(PS_0, Q_h, Q_r, Q_f, q_1) + \mathcal{O}(\alpha_s^2)$
- $\Delta_{q_1}^0 = 1 - \sum_i \frac{\alpha_s}{2\pi} \int_{q_1}^{Q_h} d\Phi_{PS}^i P_i + \mathcal{O}(\alpha_s^2)$
- $\frac{\alpha_s(q_1)}{\alpha_s(Q_r)} = 1 - \frac{\alpha_s}{2\pi} \cdot \beta_0 \ln\left(\frac{q_1^2}{Q_r^2}\right) + \mathcal{O}(\alpha_s^2)$
- $\frac{f_0(Q_f)}{f_0(q_1)} = 1 - \frac{\alpha_s}{2\pi} \cdot \ln\left(\frac{q_1^2}{Q_r^2}\right) \int_x^1 dz P_+^{0j}(z) \frac{f_j(x/z)}{f_0(x)} + \mathcal{O}(\alpha_s^2)$
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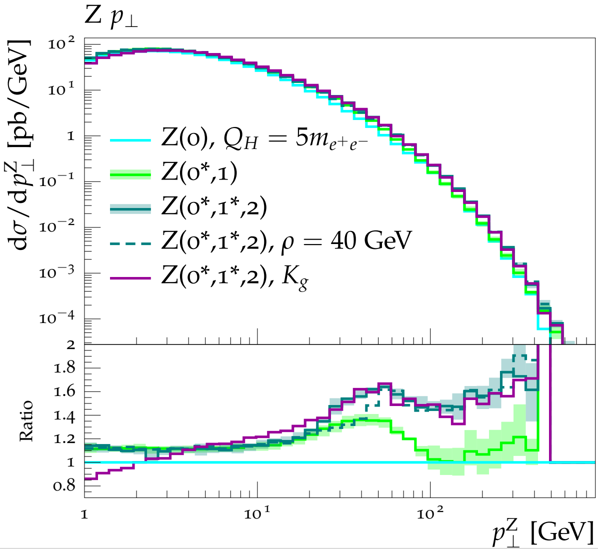
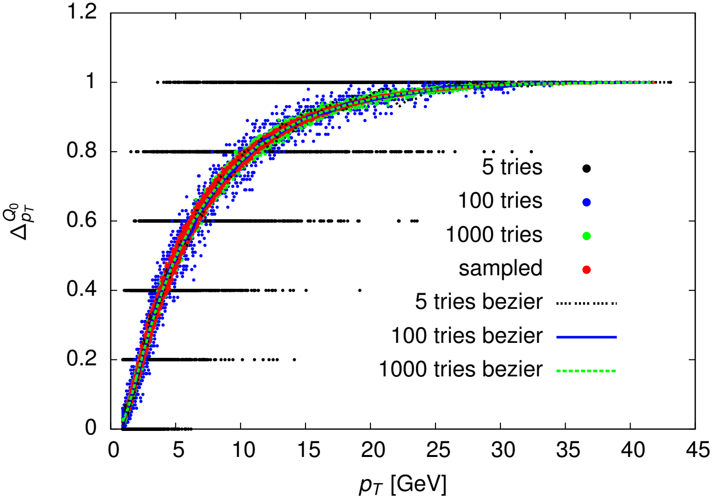
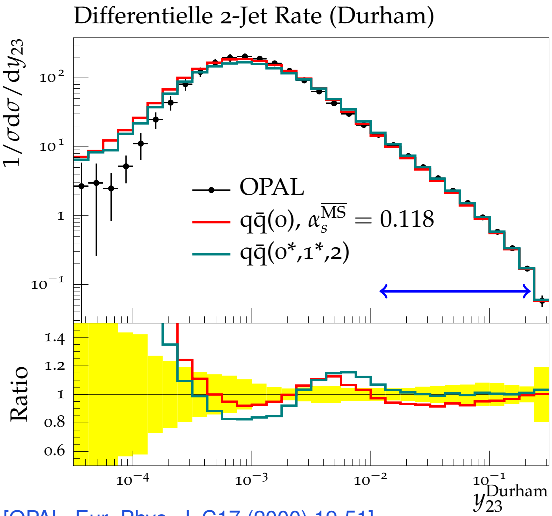
Beispiel: $pp \to e^+e^- + X$



Sudakov suppression



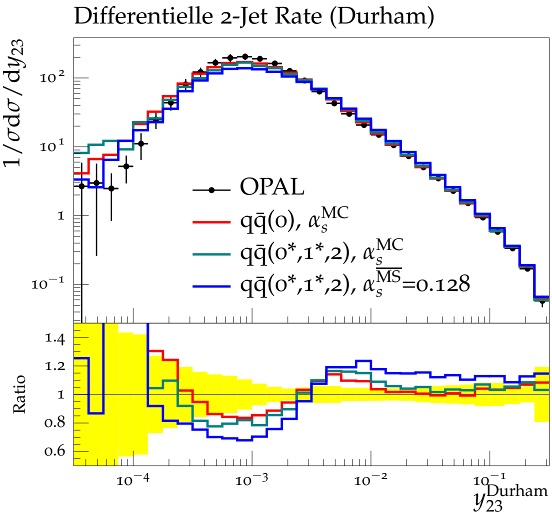
Ergebnisse: LEP: $e^+e^- \rightarrow$ Jets



[OPAL, Eur. Phys. J. C17 (2000) 19-51]

- Jets durch Durham Algorithmus
- y_{23} = Auflösung drei Jets
- $q\bar{q}(0^*, 1^*, 2)$
- Perturbative Region: $\rightarrow \alpha_s$ Messung durch Vgl. mit NLL
- Unitarisierung
- Tuning von α_s in PS

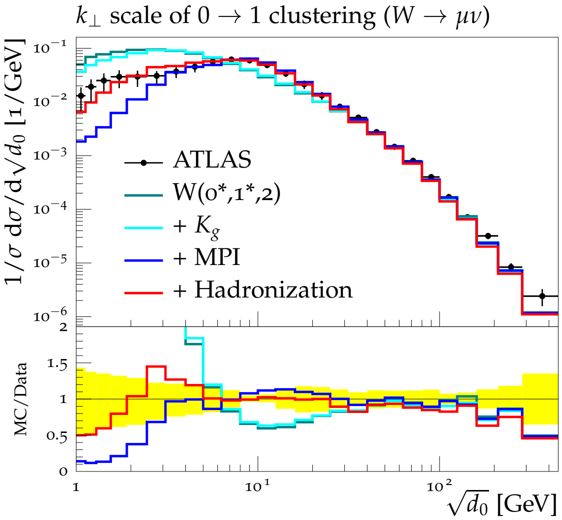
Ergebnisse: Choice of α_s



[OPAL, Eur. Phys. J. C17 (2000) 19-51]

- Gute Beschreibung $q\bar{q}(0)$ und $q\bar{q}(0^*, 1^*, 2)$
- Naives $\alpha_s^{MS} = 0.128$ $\rightarrow$ Schlechte Beschreibung.
- Terme sind formal $\alpha_s^2 L^2$ also NNLL.

LHC: $W^{\pm} \to \mu^{\pm}\nu$



[ATLAS, Eur. Phys. J. C73 (2013) 2432]

Beispiel: $pp \to e^+e^- + X$