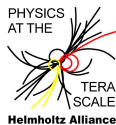


# Herwig++ and Matchbox $\Rightarrow$ Herwig 7

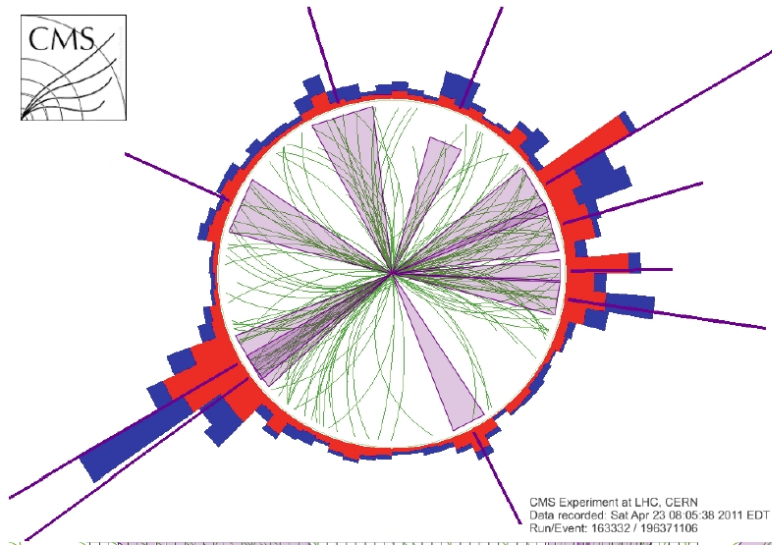
Stefan Gieseke

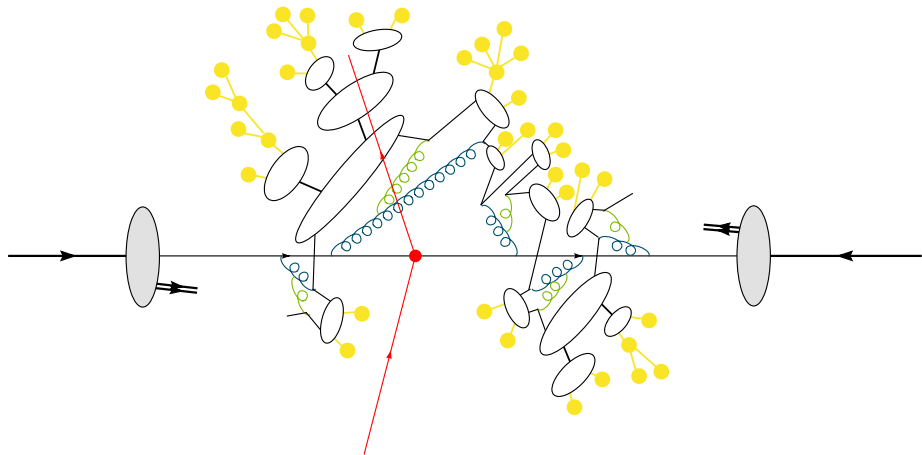
*Institut für Theoretische Physik  
KIT*

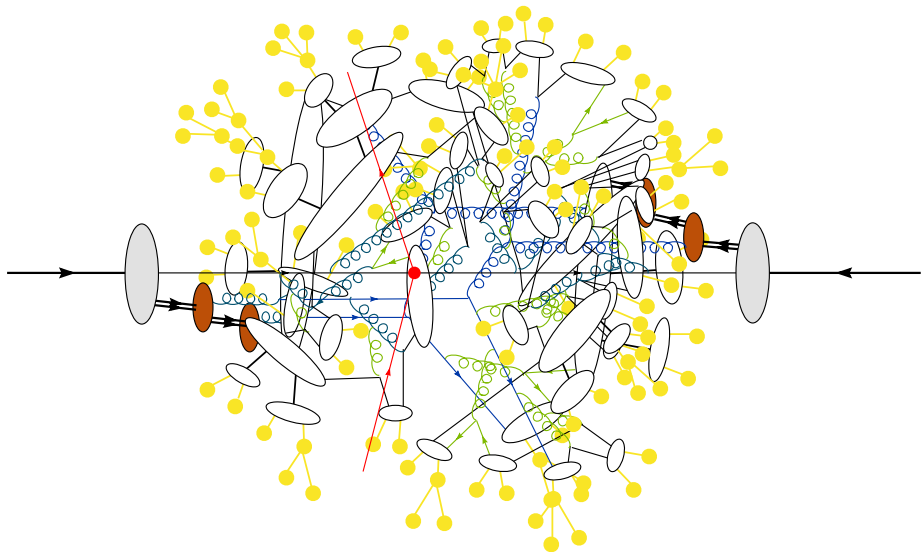
HA Annual Meeting, DESY HH, 17 Nov 2015



# Motivation: jets (at LHC of course)







# Recent History of Herwig

- HERWIG 6.5 last Fortran version, minor updates 2013.

[Corcella et.al., hep-ph/0204123]

- Herwig++ 1.0. First C++ version,  $e^+e^-$  only.

[SG, A. Ribon, P. Stephens, M.H. Seymour, B.R. Webber, JHEP 0402 (2004) 005]

- Herwig++ 2.0 $\beta$ – Herwig++ 2.7

[SG et.al., Herwig++ 2.0  $\beta$  Release Note, hep-ph/060206]

[SG et al., Herwig++ 2.0 Release Note, hep-ph/0609306]

[M. Bähr et al., Herwig++ 2.1 Release Note. 0711.3137]

[M. Bähr et al., Herwig++ 2.2 Release Note. 0804.3053]

[M. Bähr et al., Herwig++ 2.3 Release Note. 0812.0529]

[SG et al., Herwig++ 2.5 Release Note. 1102.1672]

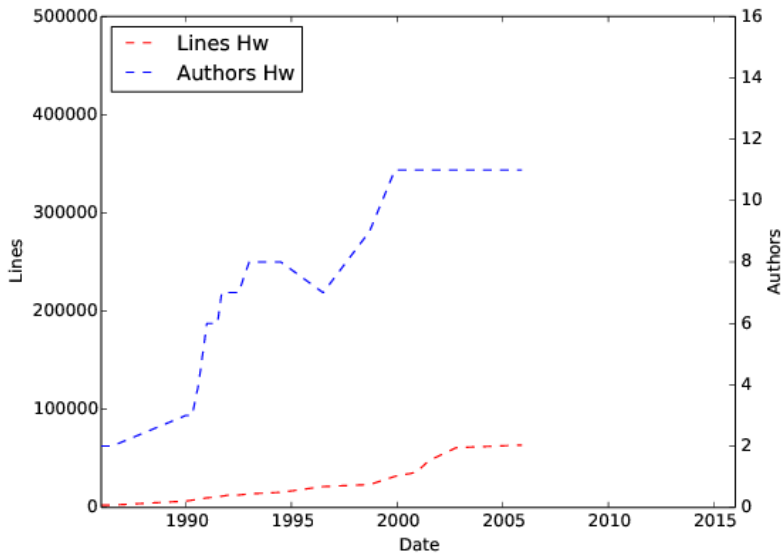
[J. Bellm et al., Herwig++ 2.7 Release Note. 1310.6877]

from simple  $pp$  collisions up to fully-fledged LHC event generation. Many 'in-house' NLO matched calculations.

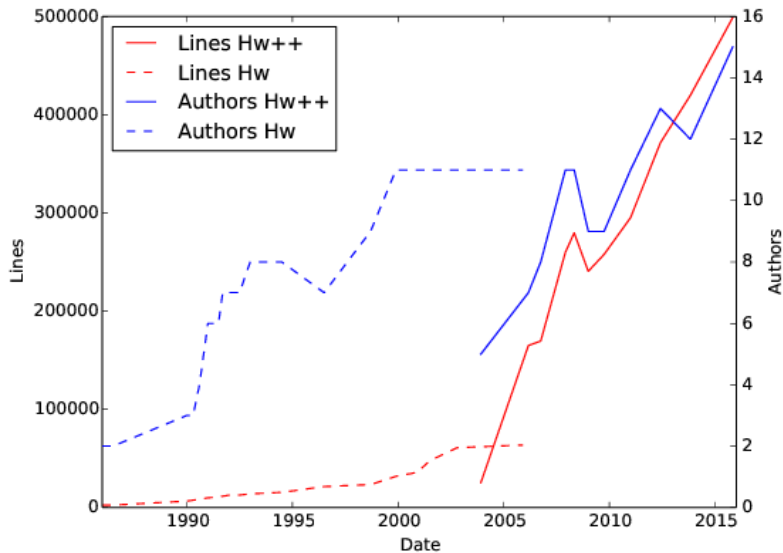
- Now,

$$\tau(\text{HERWIG}) \approx \tau(\text{Herwig++}) \gtrsim 15 \text{ years} .$$

# Recent History of Herwig



# Recent History of Herwig





New major release Herwig++ 3.0 aka Herwig 7.

Evolution of fHERWIG/Herwig++ subsumed as “7 > 6.5”.  
“Better than fHERWIG in any aspect plus more”.

“NLO for all hard processes.”





- Working horse of all NLO efforts in Herwig 7.  
Lead by S. Plätzer.
- Interfaces to various programs.
- Formalism and code to generate matched/merged events.

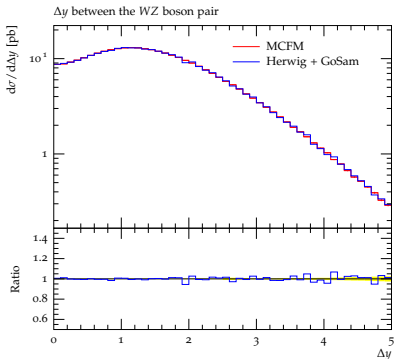
- Matching/merging formalism completely generic.
- Two showers
  - Angular ordered shower.
  - Catani–Seymour dipoles.
- Two matching formalisms
  - MC@NLO like.
  - POWHEG like.
- Many interfaces to (automatic) NLO programs.
- Automatic CS subtraction terms.
- Improved phase space.

- Amplitude level
  - Hand-coded MEs
  - Hjet++ [F. Campanario, T. Figy, S. Plätzer, M. Sjödhahl]
  - MadGraph5 [MadGraph, SG, S. Plätzer, J. Bellm]
  - Colour correlations with ColourFull [S. Plätzer, M. Sjödhahl]
- Squared amplitude level
  - GoSam [GoSam & J. Bellm, SG, S. Plätzer, C. Reuschle]
  - OpenLoops [OpenLoops & J. Bellm, SG, S. Plätzer]
  - NJet [NJet & S. Plätzer]
  - VBFNLO [VBFNLO & J. Bellm, SG, S. Plätzer ]

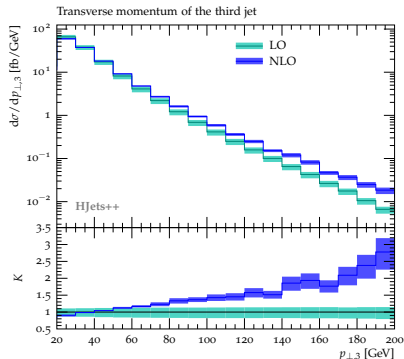
**Big validation effort**, see e.g. below.

# Processes at the parton level

E.g.  $WZ$  production,  $H + 3$  jets (EW) as more complicated example. Many processes tested.



[N. Fischer, KIT 2013]

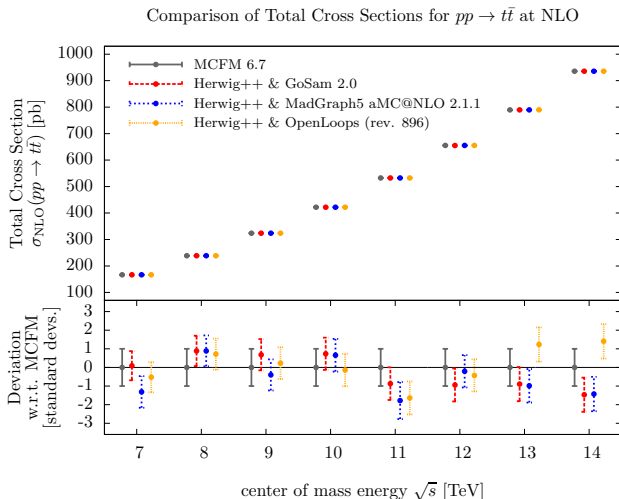


[F. Campanario, T. Figy, S. Plätzer, M. Sjö Dahl,

PRL 111 (2013) 211802]

All SM  $2 \rightarrow 2$  processes validated in detail. Plus more.

## Test of various NLO ME providers via Matchbox interface.

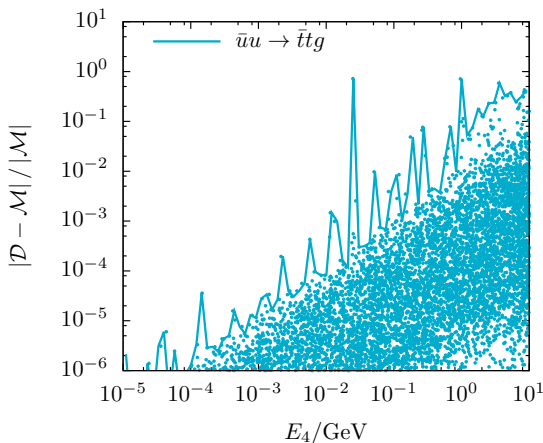


Accuracy of any calculation  $< 10^{-5}$ .

[Daniel Rauch, Master thesis KIT 2014]

$t\bar{t}$  subtraction check

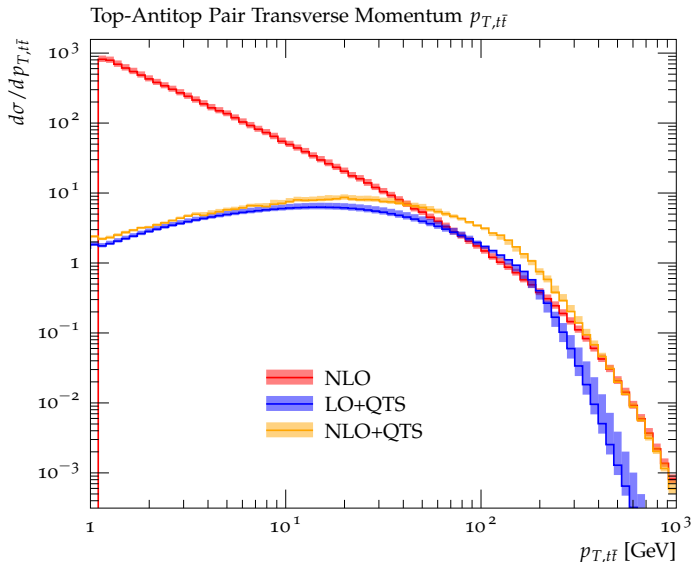
## Cancellation of soft divergence



[Daniel Rauch, Master thesis KIT 2014]

Convergence as expected.

# $t\bar{t}$ Matched with parton shower



[Daniel Rauch, Master thesis KIT 2014]

[work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]

Many processes validated.

Tunes for dipole and default showers.

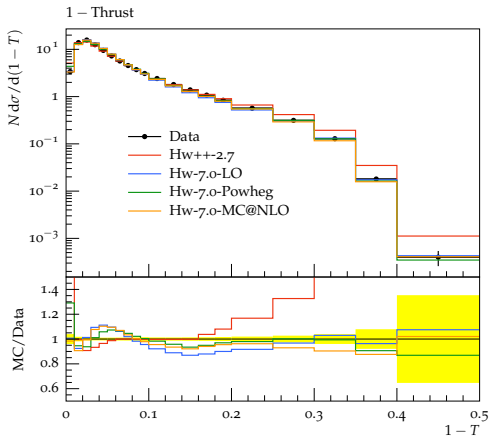
[A. Siodmok, P. Richardson]

Scrutinization based on tremendous RIVET effort.

Practically all analyses that are available are used to monitor.

Only few examples, both showers, mostly MC@NLO like matching.

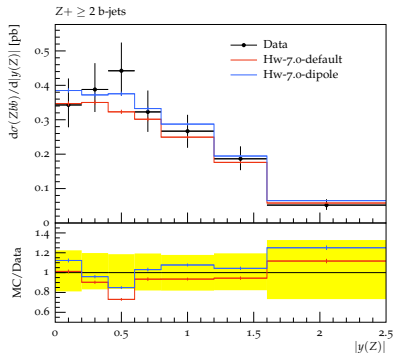
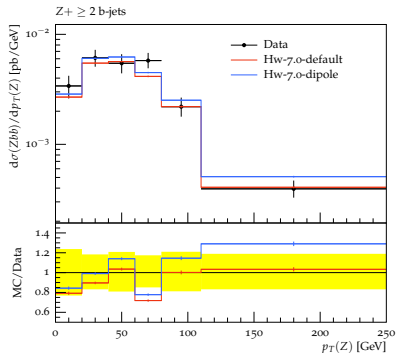




[Z.Phys.C73:11-60,1996]

$e^+e^- \rightarrow \text{hadrons}$

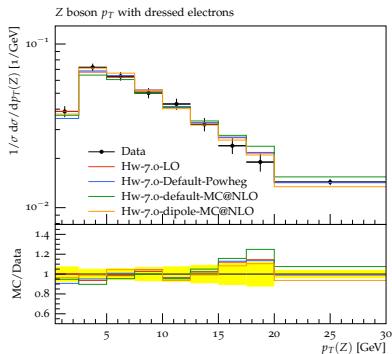
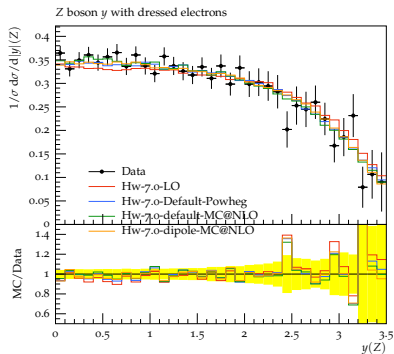
[work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]



[ATLAS, JHEP 1410 (2014) 141]

MC@NLO for  $Zb\bar{b}$ ,  $\tilde{q}$  and dipole showers  
(Madgraph+OpenLoops)

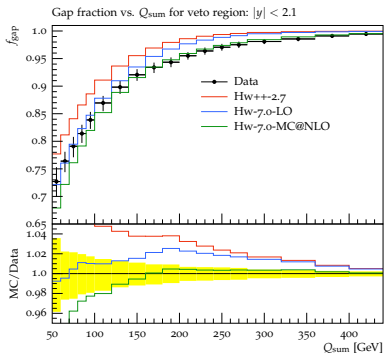
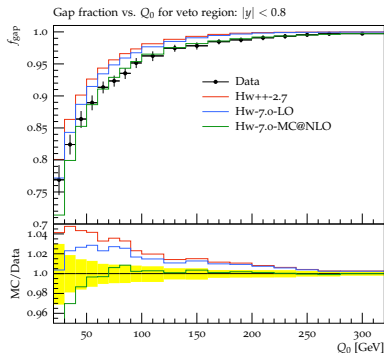
[work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]



[CMS, Phys.Rev. D85 (2012) 032002]

## Z production at CMS.

[work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]

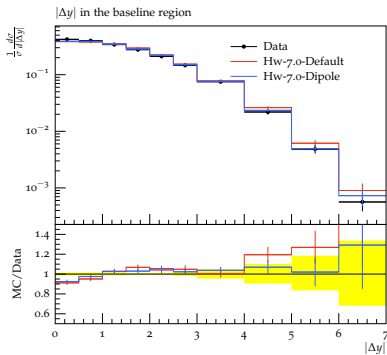
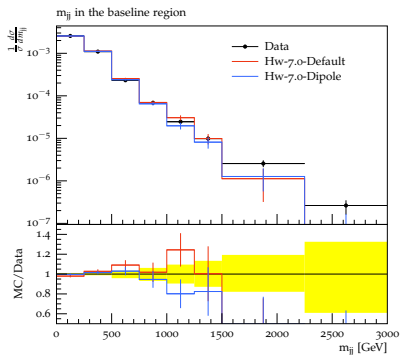


[ATLAS, Eur.Phys.J. C72 (2012) 2043]

$t\bar{t}$  production with a central jet veto.

$Q_0$ ,  $Q_{\text{sum}}$ : veto on first jet/all jets scalar  $p_{\perp}$  sum.

[work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]

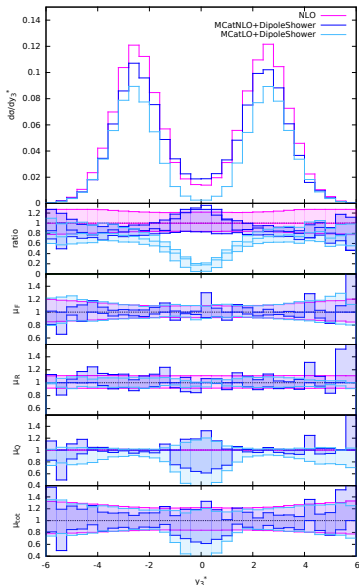


[ATLAS, JHEP 1404 (2014) 031]

$Z_{jj}$ , MC@NLO matching,  $\tilde{q}$  and dipole showers.

# Herwig 7 preliminary results

[work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]



$W^+W^- + 2\text{jets NLO}$   
(VBFNLO+Herwig 7):

- $y^* = y_3 - \frac{y_1+y_2}{2}$
- Shower mostly forward.
- $\mu_R, \mu_F$  ren./factorization scales.
- $\mu_Q$  shower scale.
- All varied by factor 2.

Extrapolation between central  
(hard) and forward (shower)  
region.

New approach in Herwig++/Matchbox.

[S. Plätzer, 1211.5467]

Idea: Approximation of Sudakov “ $\Delta \approx 1 - \int BP$ ” violates parton shower unitarity. Replace  $BP$  by full LO matrix element also in reweighting of events.

Leads to unified NLO matching and (LO/NLO)-merging prescription.

[J. Bellm, SG, S. Plätzer]

# Unitarized Matching/Merging

Consider parton shower acting on Born ME,

$$PS[B_0] = \Delta_\mu^0 B_0 + PS[P_1 \Delta_0^1 B_0] ,$$

iterate once,

$$PS[B_0] = \Delta_\mu^0 B_0 + \Delta_\mu^1 P_1 \Delta_1^0 B_0 + PS[P_2 \Delta_2^1 P_1 \Delta_1^0 B_0] ,$$

replace

$$P_1 B_0 \rightarrow \frac{\alpha_S(q_1)}{\alpha_S(q_0)} B_1 ,$$

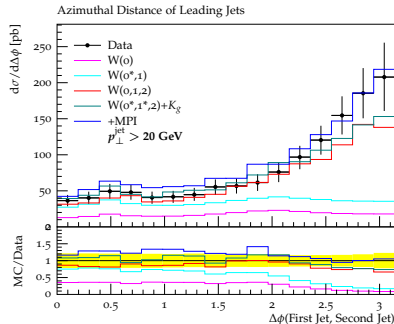
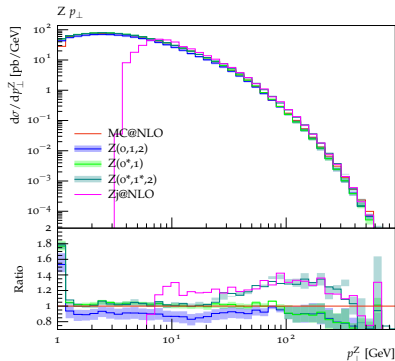
etc., but induces unitarity violation in Sudakov weights, so

$$\Delta_\mu^1 \approx 1 - P_1 B_0 \rightarrow 1 - \frac{\alpha_S(q_1)}{\alpha_S(q_0)} B_1 .$$



# Unitarized Matching/Merging

Z+jets, W+jets.

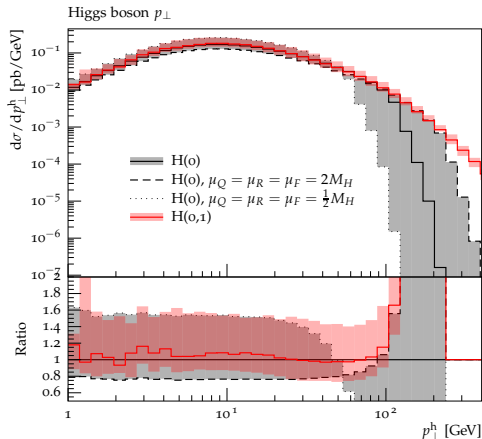


[J. Bellm, SG, S. Plätzer]

$Z(0^*,1^*,2) \rightarrow Z_j@NLO$  in hard region. Soft region very stable.  
 $W(0^*,1^*,2)$  describes jet correlations. Still large MPI content.

# Unitarized Matching/Merging

$H$ +jets. LO  $\rightarrow$  NLO merging.

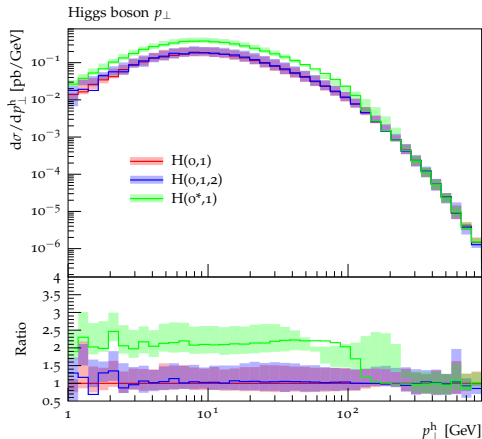


[J. Bellm, SG, S. Plätzer]

Shower starting scale dependence.  $H(0,1)$  for large  $p_{\perp}$ .

# Unitarized Matching/Merging

$H$ +jets. LO  $\rightarrow$  NLO merging.

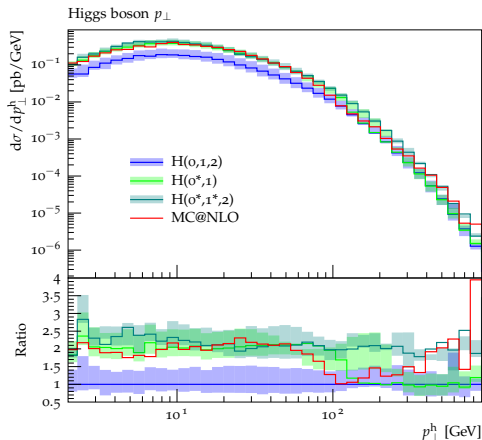


[J. Bellm, SG, S. Plätzer]

$H(0^*,1)$  gives  $K$  factor in shower region. Large step.

# Unitarized Matching/Merging

$H$ +jets. LO  $\rightarrow$  NLO merging.



[J. Bellm, SG, S. Plätzer]

$H(0^*,1^*,2)$  corrects and stabilizes high  $p_{\perp}$  region.

Today's event generators are very sophisticated tools.

Herwig 7 ready to be released.

Herwig 7/Matchbox offer many new possibilities to simulate processes at NLO.

NLO for systematic improvements of higher jet observables well under control. Should be available with next minor release.

# Monte Carlo

## training studentships



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