Herwig

-

Matching and Merging

1. Overview
2. Matching
3. Merging
4. How to use it…
5. Current Study (V+J, JJ)

J. Bellm (Lund U.), EW-WG, CERN, 30.10.2018

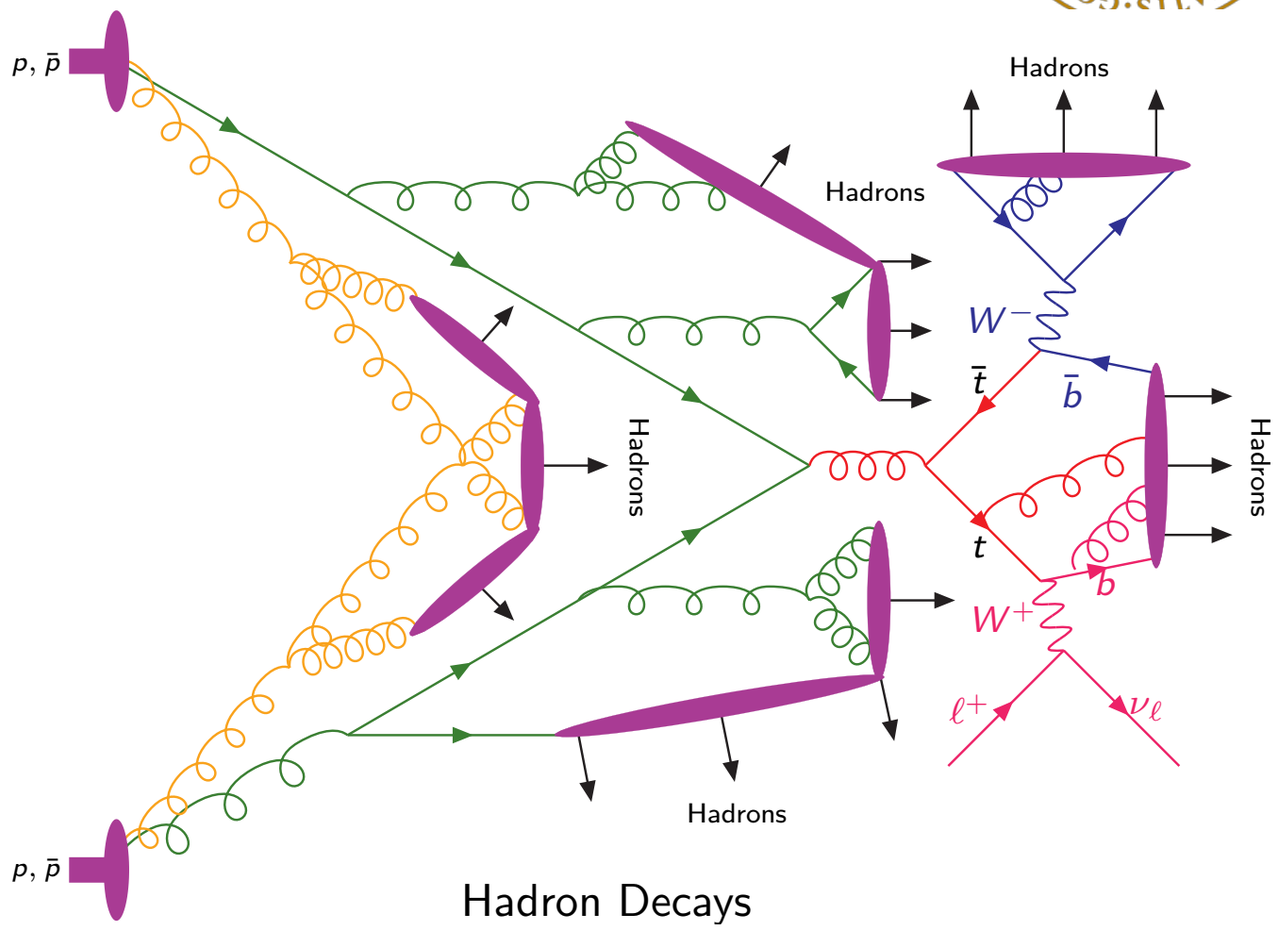
Herwig(_/++/7) – Brief History

Key features:
- Angular Ordering
- Cluster Model

HERWIG – Fortran
63940 lines ~400 Routines –> 1 file

Herwig++ (2000 – 2015)
– new development in C++

Herwig7 (+ ThePEG) (~1200 header)
- 7.0 : overcome HERWIG with automatized NLO Matching
  and many documented features
- 7.1 : merging, soft model, impr. jet evolution and impr. mass effects



Hadron Decays

Picture from P. Richardson

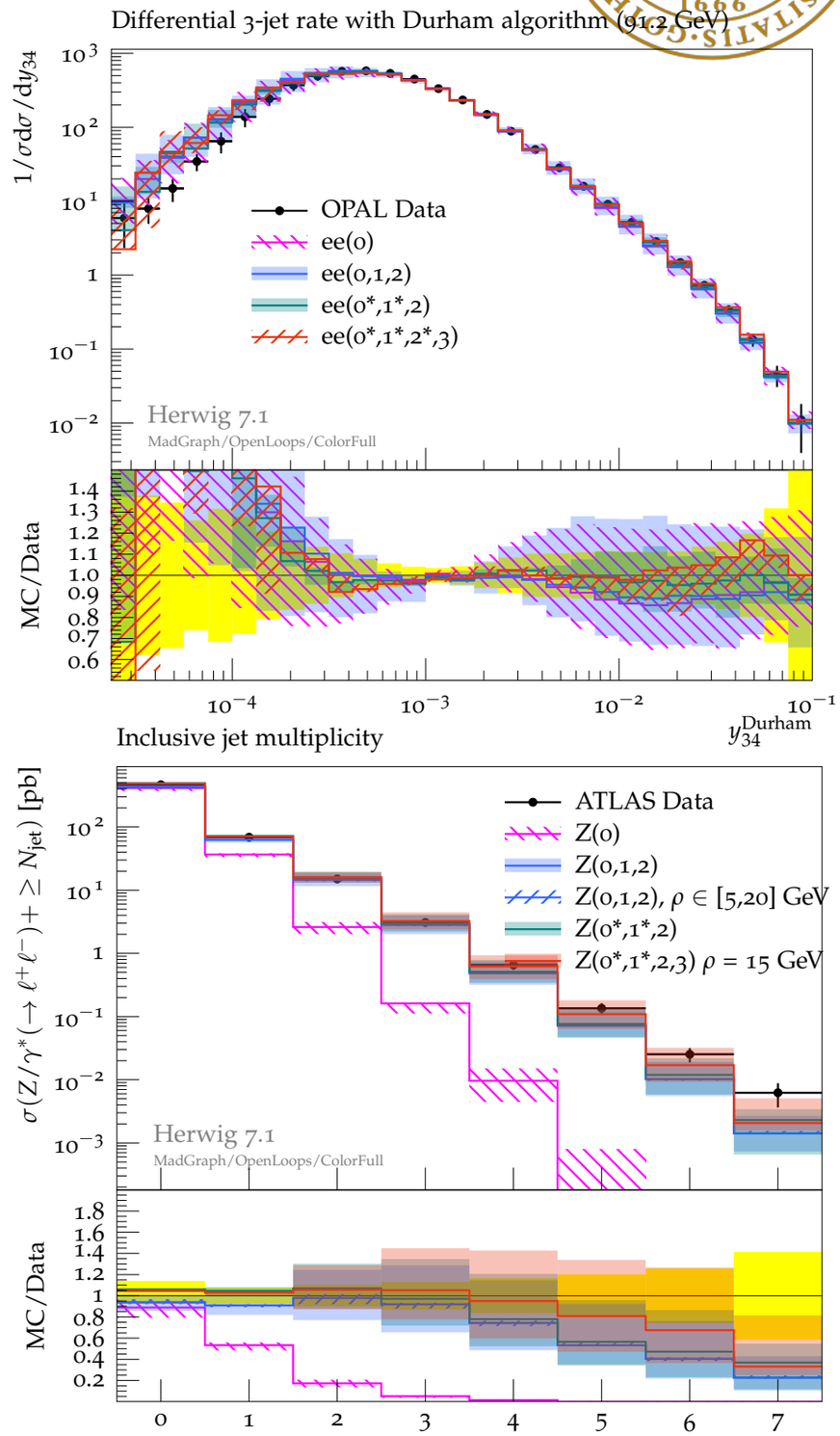
Herwig7 – Brief Features

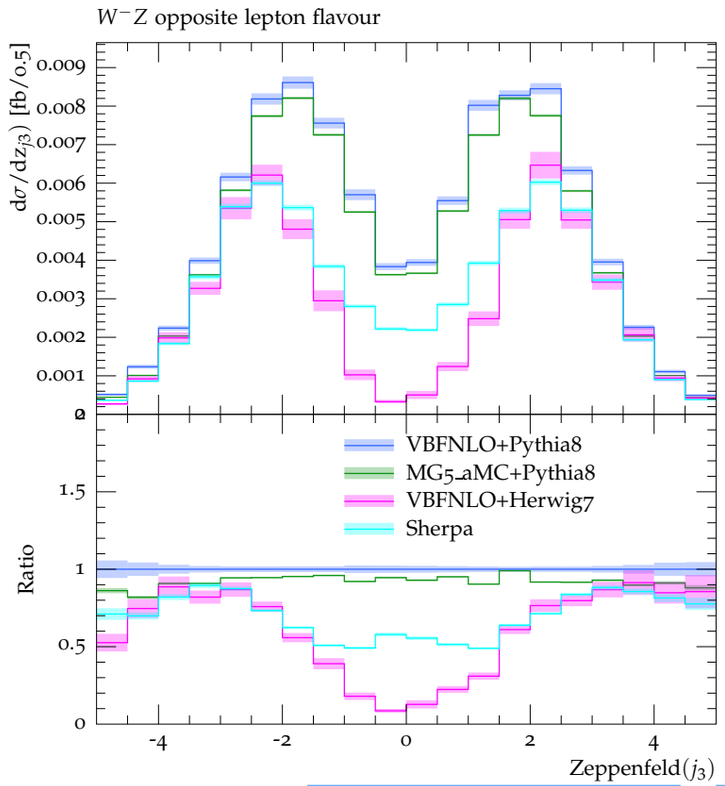
- Two Showers (Angular Ordered and Dipole shower)
- Two matching schemes to both parton showers
- NLO merging
- Spin correlations
- QED radiation in shower
- Parton shower reweighting for uncertainties
- Developments at the soft front
- Vastly improved documentation and usability
- many more…

Matching and Merging

The Herwig Matchbox builds the foundation for Matching and Merging higher orders.

Stress testing the simulations and data comparisons are mandatory.





Les Houches 2017

Bellm, Plätzer, Gieseke EPJC 78 (2018) no.3, 244

Matching

Virtual **Int. Subt.** **Shower "Virtual"** **Subtraction**

$$d\sigma_0^0 + (d\sigma_0^1 + d\sigma_0^0 \oplus \mathcal{I}_1) + d\sigma_0^0 \int dq_1 \{P_1(q_1)\theta(Q - q_1) - D_1\}\mathcal{O}(\phi_X)$$

$$d\sigma_1^0 - d\sigma_0^0 \qquad P_1(q_1)\theta(Q - q_1)\mathcal{O}(\phi_{X+1})$$

Real **Shower "Real"**

Matching

Factory:BornContributions

Based on CS-Subtraction

Shower Subtraction for both showers.

Virtual **Int. Subt.** **Shower "Virtual"** **Subtraction**

$$d\sigma_0^0 + (d\sigma_0^1 + d\sigma_0^0 \oplus \mathcal{I}_1) + d\sigma_0^0 \int dq_1 \{P_1(q_1)\theta(Q-q_1) - D_1\}\mathcal{O}(\phi_X)$$

$$d\sigma_1^0 - d\sigma_0^0 \qquad P_1(q_1)\theta(Q-q_1)\mathcal{O}(\phi_{X+1})$$

Real **Shower "Real"**

Factory:VirtualContributions

Factory:RealContributions

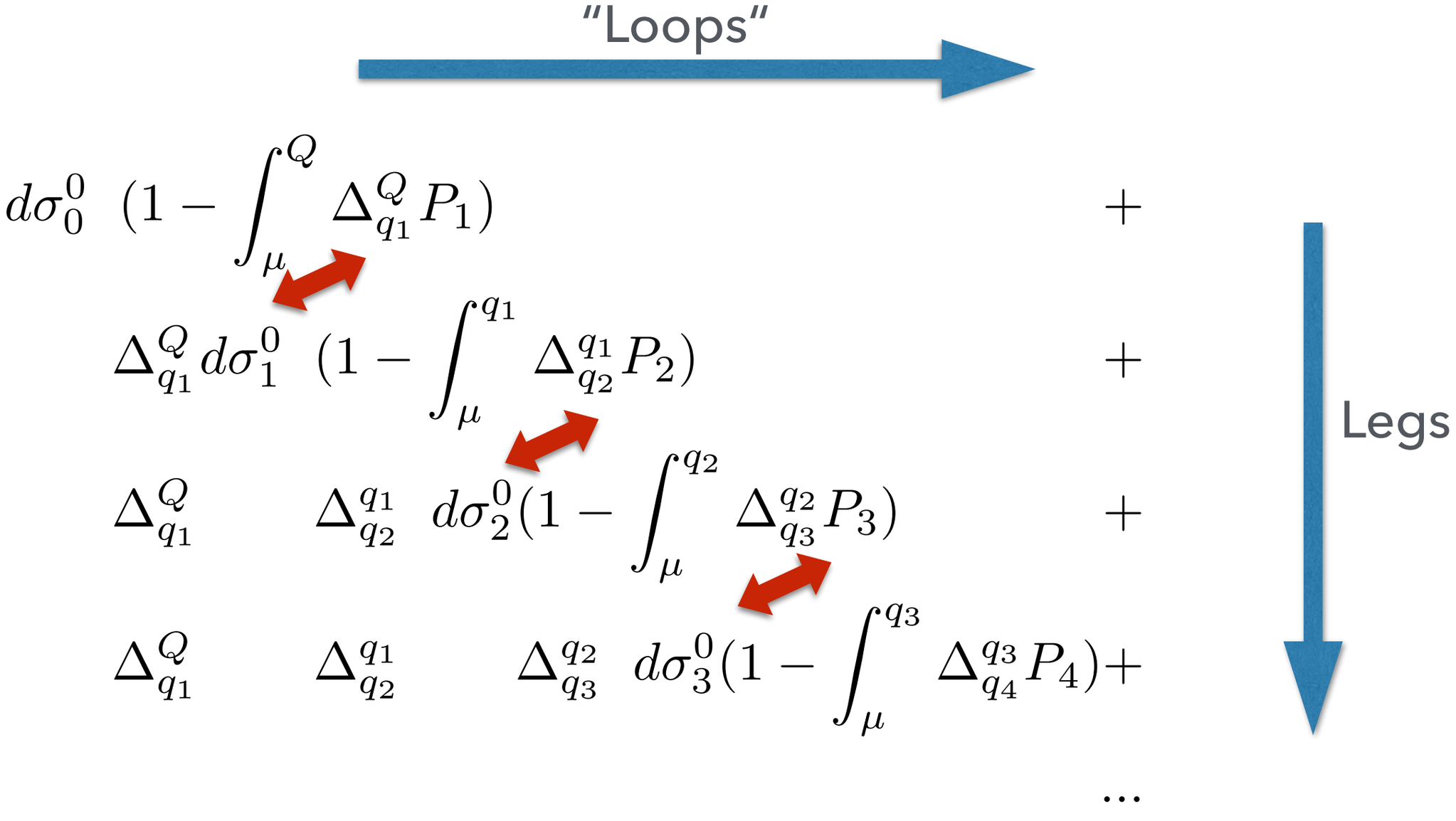
Input file:

```
# read Matchbox/MCatNLO-DefaultShower.i
# read Matchbox/Powheg-DefaultShower.in
## use for strict LO/NLO comparisons
# read Matchbox/MCatLO-DefaultShower.in
## use for improved LO showering
# read Matchbox/LO-DefaultShower.in

# read Matchbox/MCatNLO-DipoleShower.in
# read Matchbox/Powheg-DipoleShower.in
## use for strict LO/NLO comparisons
# read Matchbox/MCatLO-DipoleShower.in
## use for improved LO showering
# read Matchbox/LO-DipoleShower.in

# read Matchbox/NLO-NoShower.in
# read Matchbox/LO-NoShower.in
```

LO Merging



Mismatch between emission and no-emission!

LO Merging

Unitariesed LO merging:

"Loops"

$$
\begin{aligned}
&(d\sigma_0^0 - \int_\mu^Q \Delta_{q_1}^Q d\sigma_1^0) && + \\
&\Delta_{q_1}^Q (d\sigma_1^0 - \int_\mu^{q_1} \Delta_{q_2}^{q_1} d\sigma_2^0) && + \\
&\Delta_{q_1}^Q \Delta_{q_2}^{q_1} (d\sigma_2^0 - \int_\mu^{q_2} \Delta_{q_3}^{q_2} d\sigma_3^0) && + \\
&\Delta_{q_1}^Q \Delta_{q_2}^{q_1} \Delta_{q_3}^{q_2} (d\sigma_3^0 - \int_\mu^{q_3} \Delta_{q_4}^{q_3} d\sigma_4^0) && + \\
&\dots
\end{aligned}
$$

Legs

Replace no-emission with (1 – emission)

NLO Merging

NLO cross section

$$\boxed{(d\sigma_0^1 + \int_\mu^Q dq_1 \quad d\sigma_1^0)} - \int_\mu^Q dq_1 \Delta_{q_1}^Q (d\sigma_1^1 + \int_\mu^{q_1} dq_2 \quad d\sigma_2^0) +$$

$$\Delta_{q_1}^Q (d\sigma_1^1 + \int_\mu^{q_1} dq_2 \quad d\sigma_2^0 - \int_\mu^{q_1} dq_2 \Delta_{q_2}^{q_1} (d\sigma_2^1 + \int_\mu^{q_2} dq_3 \quad d\sigma_3^0)) +$$

$$\Delta_{q_1}^Q \quad \Delta_{q_2}^{q_1} (d\sigma_2^1 + \int_\mu^{q_2} dq_3 \quad d\sigma_3^0 - \int_\mu^{q_2} dq_3 \Delta_{q_3}^{q_1} (d\sigma_3^1 + \int_\mu^{q_3} dq_4 \quad d\sigma_4^0)) +$$

$$\Delta_{q_1}^Q \quad \Delta_{q_2}^{q_1} \quad \Delta_{q_3}^{q_2} (d\sigma_3^1 + \int_\mu^{q_3} dq_4 \quad d\sigma_4^0 - \int_\mu^{q_3} dq_4 (d\sigma_4^1 + \int_\mu^{q_4} dq_5 \quad d\sigma_5^0)) +$$

$$\ldots$$

– Red and blue (…) parts cancel in inclusive cross section.
– NLO cross section restored.
– Subtraction not discussed here (makes it really messy).
– Expansion of shower scale dependent quantities also suppressed.
– Real emission corrects Shower below merging scale.

How to use it…

Input card structure:

Various examples in share folder.

But also in src-folder (build our test-files):

> cd Tests

> make Rivet-input-files

Process:

```
cd /Herwig/MatrixElements/Matchbox
set Factory:OrderInAlphaS 0
set Factory:OrderInAlphaEW 2
do Factory:Process p p -> e+ e-
# Choose Tree/Loop provider (MadGraph/OpenLoops/GoSam/NJets/HJet/VBFNLO)
read Matchbox/MadGraph-OpenLoops.in
```

Merging:

```
Replace Factory with MergingFactory
add  [j , j]  for LO merged jets
set MergingFactory:NLOProcesses 2   # for X and X+J at NLO
```

How to use it…

Scale Choice:

Various scale objects defined:

FixedScale, HTPrimeScale, HTScale, LeptonPairMassScale, LeptonPairPtScale, LeptonQ2Scale, MaxJetPtScale, SHatScale, TopPairIndividualMTScale, TopPairLinearMTScale, TopPairMTScale, TopPairMassScale, TriVecScale

If not enough (recipe):

1. Take any scale e.g. MatchboxHtScale.cc form MatrixElement/Matchbox/Scales .
2. Rename class name. :%s/MaxJetPtScale/MyScale/g
3. Implement scale:
   renormalizationScale()
   factorizationScale()
   showerScale(). //-> shower starting scale (by default returns factorizationScale(), but can be modified)
4. And put „.so“ name in describe, e.g.:
   DescribeClass<MyScale,MatchboxScaleChoice>
   describeHerwigMyScale("Herwig::MyScale", „MyScale.so“); // So Herwig knows where to search
5. g++ --shared -o MyScale.so -fPIC -I/home/jbellm/opt/include/ MyScale.cc
6. Put path to .so in LD_LIBRARY_PATH or *.so local in run-folder.
7. Put lins in in-file:
   cd /Herwig/MatrixElements/Matchbox
   create Herwig::MatchboxHtHatScaleShowerNoMZ Myscale MyScale.so
   set /Herwig/MatrixElements/Matchbox/Factory:ScaleChoice Myscale   # for matching
   set /Herwig/Merging/MergingFactory:ScaleChoice Myscale   # for merging (first born state)

How to use it…

Cuts:

Various cut objects defined:

BottomQuarkCut, ChargedCurrentCut, ChargedLeptonCut , ChargedLeptonDeltaRCut, ChargedLeptonPairMassCut, FirstJet, FourthJet, HiggsBosonCut, IdentifiedParticleCut, InvariantMassCut, LeptonCut , LeptonDeltaRCut, LeptonPairMassCut, MassCut, MatchboxDeltaRCut, MatchboxJetMatcher, MinBiasCuts, MissingPtCut, NJetsCut, NeutralCurrentCut, PhotonCut, PhotonIsolationCut, SecondJet, ThirdJet, TopQuarkCut, WBosonCut, ZBosonCut

If not enough:

Similar recipe as for Scales.

Difference:

– Cuts in Herwig are ThePEG classes.

– different cuts for single vs. two-particle vs. multi particles

–> Start with cut definition that is close to what you want

Warning: Treat rapidity as in: ThePEG/Cuts/JetRegion.cc (for lab frame).

Issue:

FirstJet vs. SecondJet is ill defined for Dijet production: (clear FirstJet:Accepts)

Same issue:

When we did the comparison between (N)LO FO Herwig vs. Sherpa we needed to randomize the Jet-input in Rivet to get comparable results. Otherwise first-jet and second-jet are tilded.

How to use it…

Bias event generation:

Add:

```
cd /Herwig/MatrixElements/Matchbox
create Herwig::MergingReweight MyPreWeight HwDipoleShower.so
insert Factory:Preweighters 0  MyPreWeight
set MyPreWeight:MaxPTPower 3
```

To in-file to bias event generation to higher pts.
(pre-weighters can be written and used as the scale example.)

Not fully unweighting:

Add:

```
set Sampler:Kappa 0.1
```

To in-file to produce unweighted events to 1/10 of maxweight.

How to use it…

Preparation:

Small processes:

```
Herwig read LHC-Matchbox.in
Herwig run LHC-Matchbox.run
```

More complicated processes:

```
Herwig build LHC-Matchbox.in
```

helpful options:

-z1 split up integration runs to contain 1 subprocess each

-y4 split up integration runs into 4 sub integrations dividing the subprocesses

```
Herwig integrate --jobid=$i LHC-Matchbox.run
```

can easily be pushed to farm

wait for integration to finish:

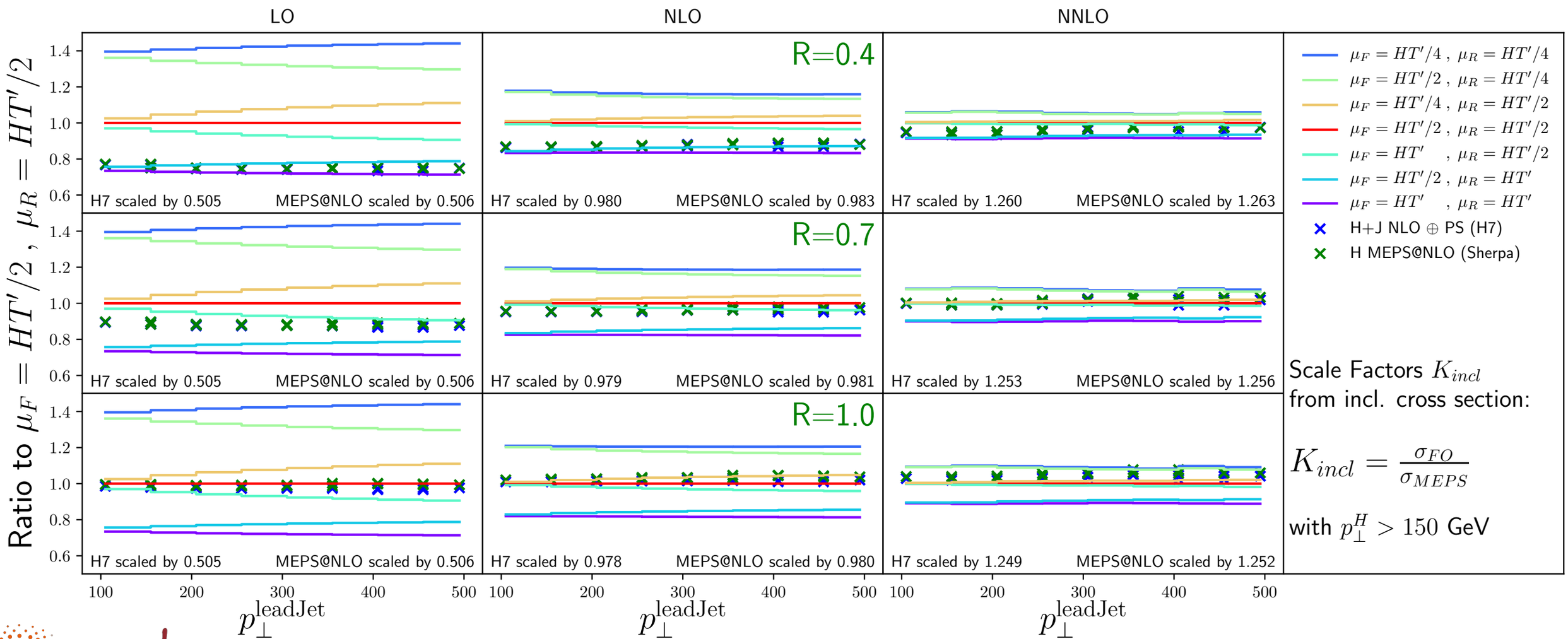
```
Herwig run LHC-Matchbox.run -j20 -N100000
```

LH 17 – FO vs. PS

Les Houches 2017

Questions: How does the PS jet size compare against FO jet size?

Start of a broader study on jet sizes comparing NNLO to PS+NLO predictions. Observable: leading Jet in Higgs production



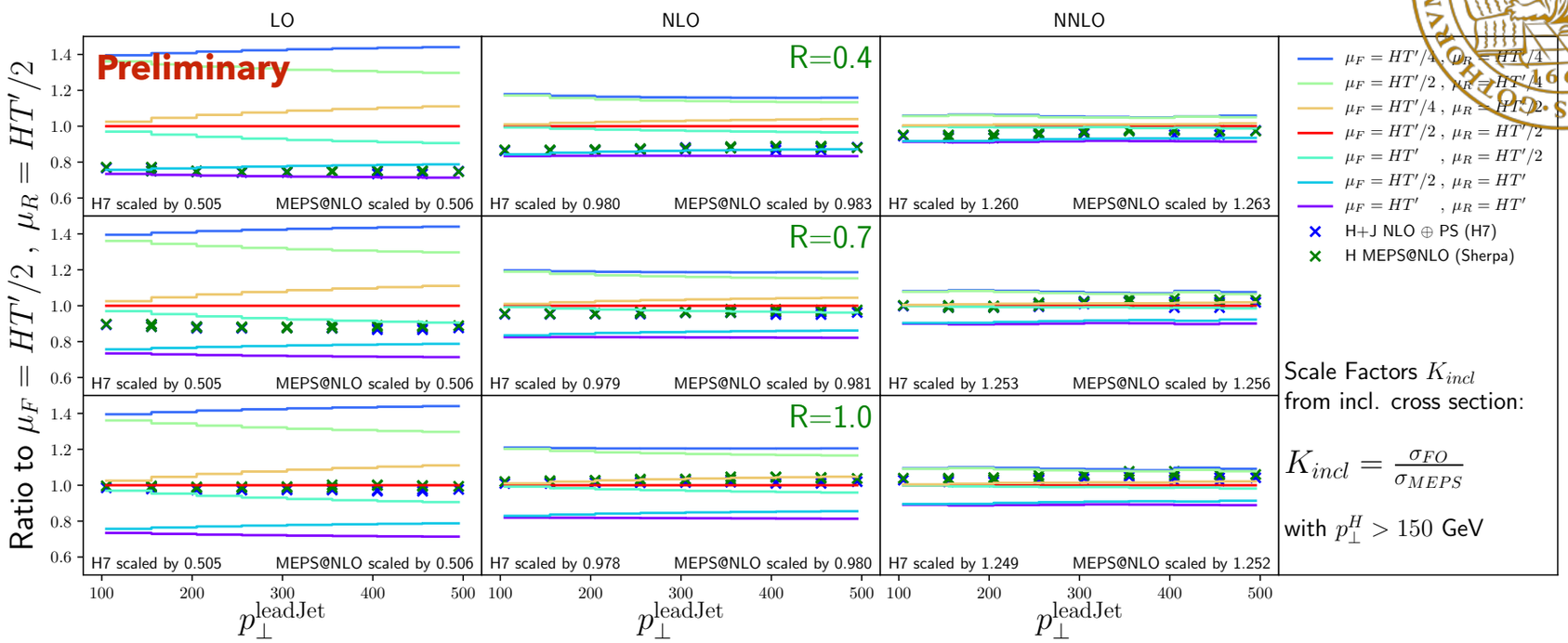
Scale Factors K_{incl} from incl. cross section:

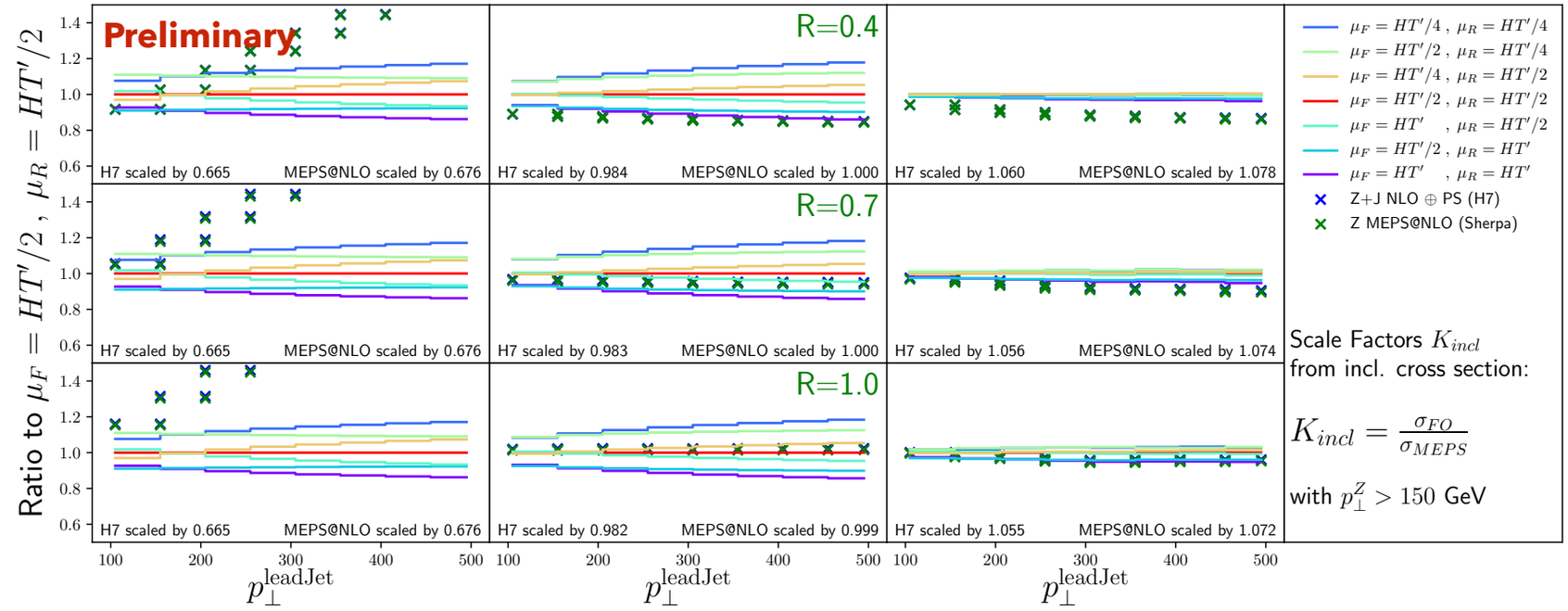
$$K_{incl} = \frac{\sigma_{FO}}{\sigma_{MEPS}}$$

with $p_\perp^H > 150$ GeV

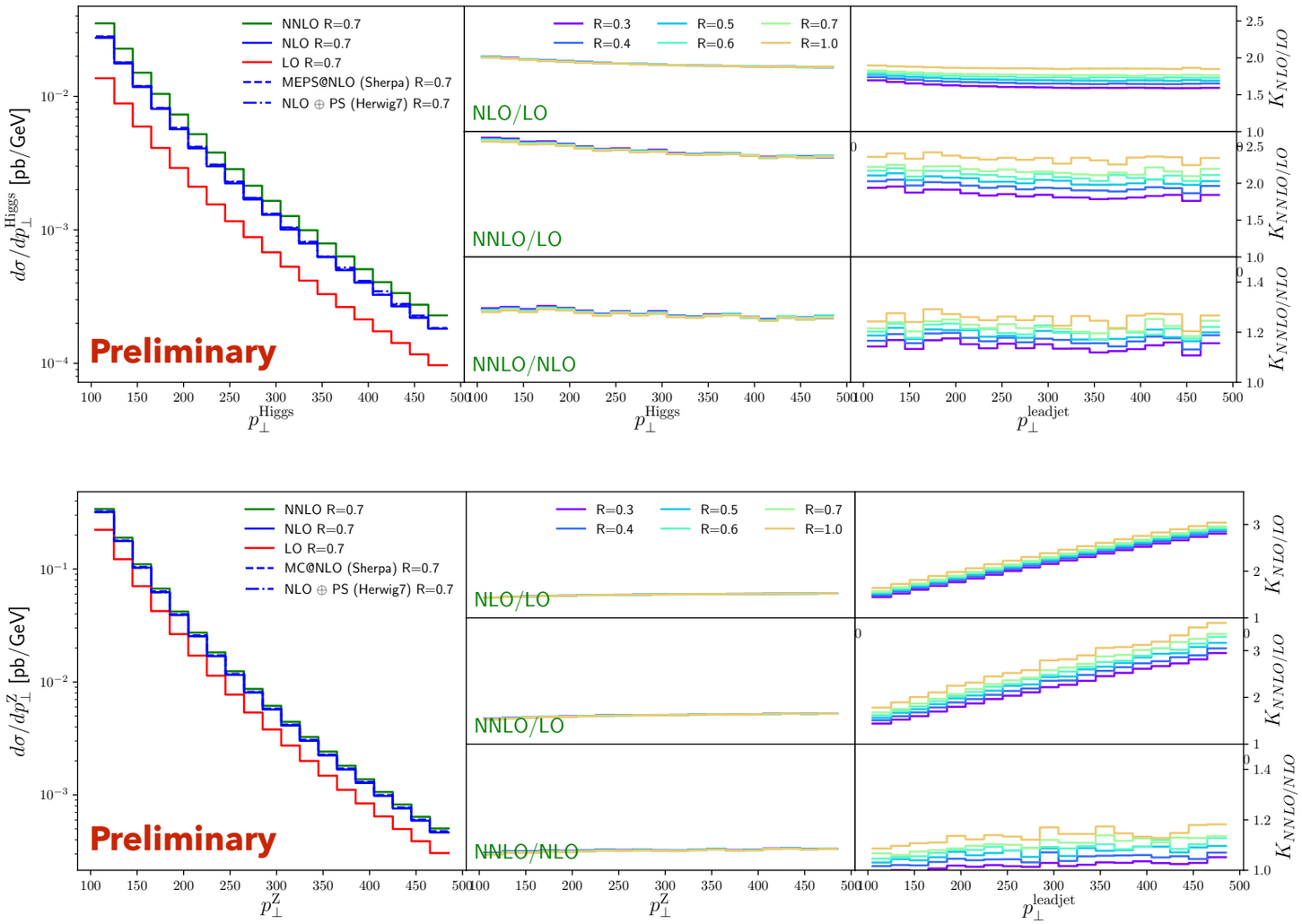
J. Bellm (Lund U.), EW-WG, CERN , 30.10.2018

FO vs. PS


LO
NLO
NNLO
Preliminary
R=0.4
R=0.7
R=1.0
H7 scaled by 0.505
MEPS@NLO scaled by 0.506
H7 scaled by 0.980
MEPS@NLO scaled by 0.983
H7 scaled by 1.260
MEPS@NLO scaled by 1.263
H7 scaled by 0.505
MEPS@NLO scaled by 0.506
H7 scaled by 0.979
MEPS@NLO scaled by 0.981
H7 scaled by 1.253
MEPS@NLO scaled by 1.256
H7 scaled by 0.505
MEPS@NLO scaled by 0.506
H7 scaled by 0.978
MEPS@NLO scaled by 0.980
H7 scaled by 1.249
MEPS@NLO scaled by 1.252
Ratio to $\mu_F = HT'/2$, $\mu_R = HT'/2$
$p_\perp^{\text{leadJet}}$
$\mu_F = HT'/4$, $\mu_R = HT'/4$
$\mu_F = HT'/2$, $\mu_R = HT'/4$
$\mu_F = HT'/4$, $\mu_R = HT'/2$
$\mu_F = HT'/2$, $\mu_R = HT'/2$
$\mu_F = HT'$, $\mu_R = HT'/2$
$\mu_F = HT'/2$, $\mu_R = HT'$
$\mu_F = HT'$, $\mu_R = HT'$
H+J NLO ⊕ PS (H7)
H MEPS@NLO (Sherpa)
Scale Factors K_{incl} from incl. cross section:
$K_{incl} = \frac{\sigma_{FO}}{\sigma_{MEPS}}$
with $p_\perp^H > 150$ GeV


LO
NLO
NNLO
Preliminary
R=0.4
R=0.7
R=1.0
H7 scaled by 0.665
MEPS@NLO scaled by 0.676
H7 scaled by 0.984
MEPS@NLO scaled by 1.000
H7 scaled by 1.060
MEPS@NLO scaled by 1.078
H7 scaled by 0.665
MEPS@NLO scaled by 0.676
H7 scaled by 0.983
MEPS@NLO scaled by 1.000
H7 scaled by 1.056
MEPS@NLO scaled by 1.074
H7 scaled by 0.665
MEPS@NLO scaled by 0.676
H7 scaled by 0.982
MEPS@NLO scaled by 0.999
H7 scaled by 1.055
MEPS@NLO scaled by 1.072
Ratio to $\mu_F = HT'/2$, $\mu_R = HT'/2$
$p_\perp^{\text{leadJet}}$
$\mu_F = HT'/4$, $\mu_R = HT'/4$
$\mu_F = HT'/2$, $\mu_R = HT'/4$
$\mu_F = HT'/4$, $\mu_R = HT'/2$
$\mu_F = HT'/2$, $\mu_R = HT'/2$
$\mu_F = HT'$, $\mu_R = HT'/2$
$\mu_F = HT'/2$, $\mu_R = HT'$
$\mu_F = HT'$, $\mu_R = HT'$
Z+J NLO ⊕ PS (H7)
Z MEPS@NLO (Sherpa)
Scale Factors K_{incl} from incl. cross section:
$K_{incl} = \frac{\sigma_{FO}}{\sigma_{MEPS}}$
with $p_\perp^Z > 150$ GeV

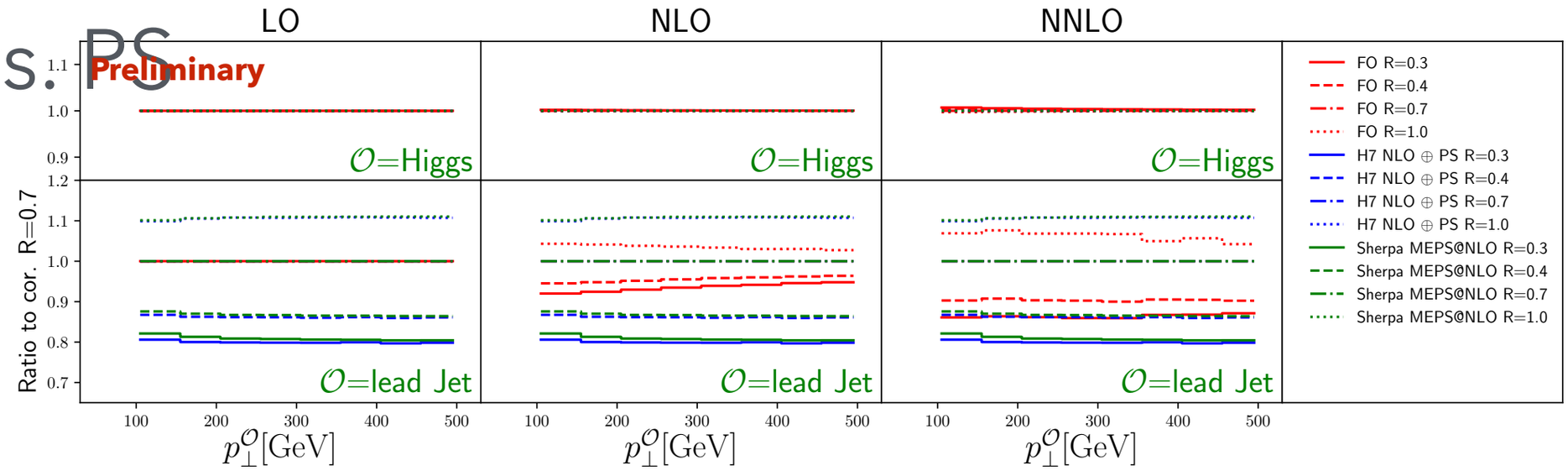
FO vs. PS

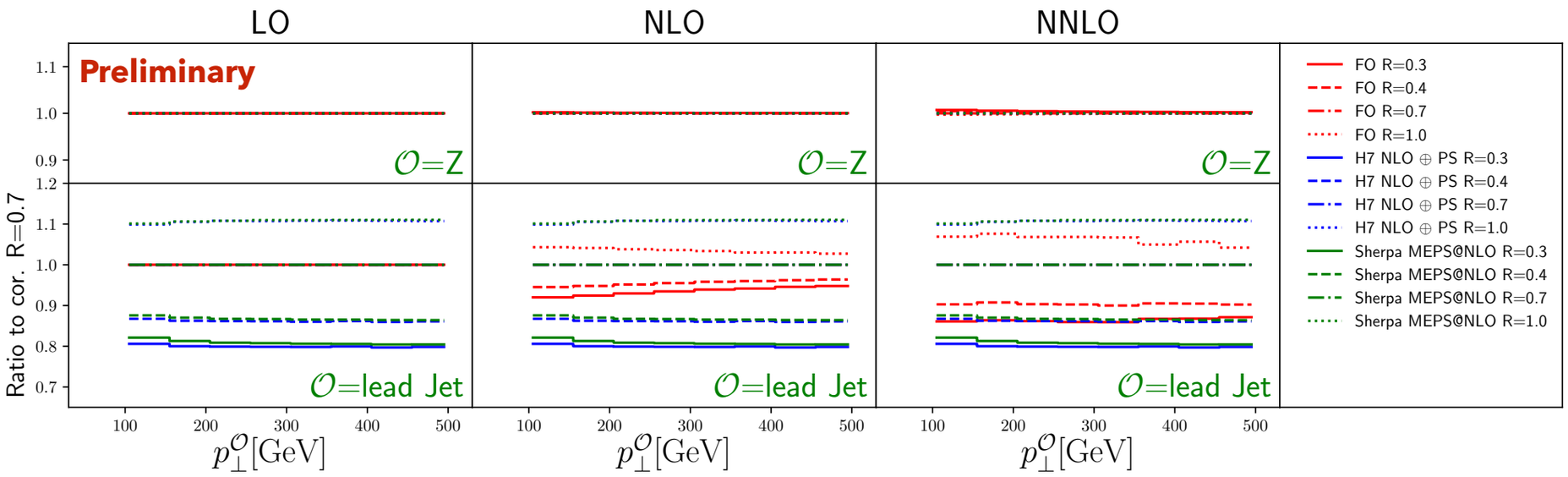

NNLO R=0.7
NLO R=0.7
LO R=0.7
MEPS@NLO (Sherpa) R=0.7
NLO ⊕ PS (Herwig7) R=0.7
R=0.3
R=0.4
R=0.5
R=0.6
R=0.7
R=1.0
NLO/LO
NNLO/LO
NNLO/NLO
Preliminary
$d\sigma/dp_\perp^{\mathrm{Higgs}}$ [pb/GeV]
$p_\perp^{\mathrm{Higgs}}$
$p_\perp^{\mathrm{leadjet}}$
$K_{NLO/LO}$
$K_{NNLO/LO}$
$K_{NNLO/NLO}$

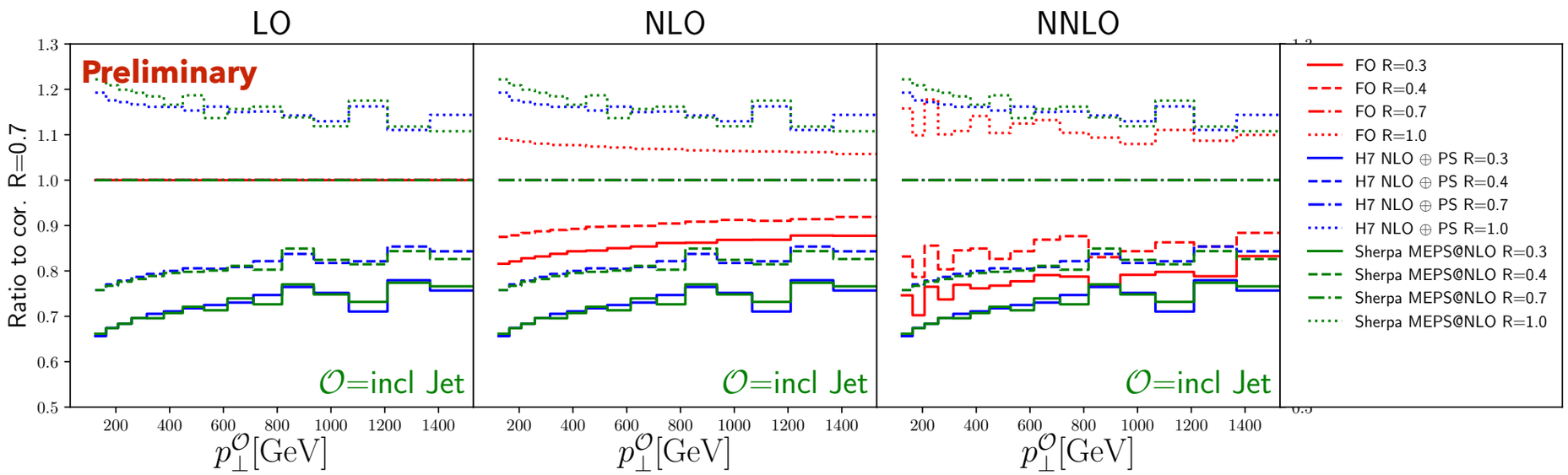
NNLO R=0.7
NLO R=0.7
LO R=0.7
MC@NLO (Sherpa) R=0.7
NLO ⊕ PS (Herwig7) R=0.7
R=0.3
R=0.4
R=0.5
R=0.6
R=0.7
R=1.0
NLO/LO
NNLO/LO
NNLO/NLO
Preliminary
$d\sigma/dp_\perp^{\mathrm{Z}}$ [pb/GeV]
$p_\perp^{\mathrm{Z}}$
$p_\perp^{\mathrm{leadjet}}$
$K_{NLO/LO}$
$K_{NNLO/LO}$
$K_{NNLO/NLO}$

NNLO R=0.7
NLO R=0.7
LO R=0.7
MC@NLO (Sherpa) R=0.7
NLO ⊕ PS (Herwig7) R=0.7
1.5<|y|<3.5
0<|y|<1.5
R=0.3
R=0.4
R=0.5
R=0.6
R=0.7
R=1.0
NLO/LO
NNLO/LO
NNLO/NLO
Preliminary
$d\sigma/dp_\perp^{\mathrm{incljet}}$ [pb/GeV]
$p_\perp^{\mathrm{incljet}}$
$p_\perp^{\mathrm{incljet}}\ 1.5 < |y| < 3.5$
$p_\perp^{\mathrm{incljet}}\ 0 < |y| < 1.5$
$K_{NLO/LO}$
$K_{NNLO/LO}$
$K_{NNLO/NLO}$

FO vs. PS


LO
NLO
NNLO
Preliminary
$\mathcal{O}$=Higgs
$\mathcal{O}$=lead Jet
Ratio to cor. R=0.7
$p_\perp^{\mathcal{O}}$[GeV]
FO R=0.3
FO R=0.4
FO R=0.7
FO R=1.0
H7 NLO ⊕ PS R=0.3
H7 NLO ⊕ PS R=0.4
H7 NLO ⊕ PS R=0.7
H7 NLO ⊕ PS R=1.0
Sherpa MEPS@NLO R=0.3
Sherpa MEPS@NLO R=0.4
Sherpa MEPS@NLO R=0.7
Sherpa MEPS@NLO R=1.0


LO
NLO
NNLO
Preliminary
$\mathcal{O}$=Z
$\mathcal{O}$=lead Jet
Ratio to cor. R=0.7
$p_\perp^{\mathcal{O}}$[GeV]
FO R=0.3
FO R=0.4
FO R=0.7
FO R=1.0
H7 NLO ⊕ PS R=0.3
H7 NLO ⊕ PS R=0.4
H7 NLO ⊕ PS R=0.7
H7 NLO ⊕ PS R=1.0
Sherpa MEPS@NLO R=0.3
Sherpa MEPS@NLO R=0.4
Sherpa MEPS@NLO R=0.7
Sherpa MEPS@NLO R=1.0


LO
NLO
NNLO
Preliminary
$\mathcal{O}$=incl Jet
Ratio to cor. R=0.7
$p_\perp^{\mathcal{O}}$[GeV]
FO R=0.3
FO R=0.4
FO R=0.7
FO R=1.0
H7 NLO ⊕ PS R=0.3
H7 NLO ⊕ PS R=0.4
H7 NLO ⊕ PS R=0.7
H7 NLO ⊕ PS R=1.0
Sherpa MEPS@NLO R=0.3
Sherpa MEPS@NLO R=0.4
Sherpa MEPS@NLO R=0.7
Sherpa MEPS@NLO R=1.0

Developments

- Matching:
  - Cormier, Plätzer, Reuschle, Richardson, Webster:
    Parton Shower and Matching Uncertainties in **Top Quark Pair Production** with Herwig 7, 1810.06493
  - Campanario, Figy, Plätzer, Rauch, Schichtel, Sjödahl:
    Stress testing the **vector-boson-fusion approximation** in multijet final states Phys.Rev. D98 (2018) no.3, 033003
  - LH17:
    Precision comparisons of predictions for Higgs boson + jet production at the LHC as a function of jet size
- Spin and (sub)leading N:
  - Bellm:
    Colour Rearrangement for Dipole Showers , Eur.Phys.J. C78 (2018) no.7, 601
  - Richardson, Webster:
    Spin Correlations in Parton Shower Simulations, 1807.01955
  - Martínez, De Angelis, Forshaw, Plätzer, Seymour
    Soft gluon evolution and non-global logarithms
  - Plätzer, Sjodahl, Thorén:
    Color matrix element corrections for parton showers, arXiv:1808.06770
- MPI, Hadronisation:
  - Gieseke, Kirchgaeßer , Plätzer:
    Baryon production from cluster hadronisation ,Eur.Phys.J. C78 (2018) no.2, 99
- Studies on the crosstalk between perturbative and non-perturbative modeling:
  - Hoang, Plätzer, Samitz:
    On the **Cutoff Dependence of the Quark Mass** Parameter in Angular Ordered Parton Showers , 1807.06617
  - Gieseke, Kirchgaeßer, Plätzer, Siodmok:
    Colour Reconnection from Soft Gluon Evolution, 1808.06770
- Heavy Ion modeling:
  - Bellm, Bierlich: **PISTA**: Posterior Ion STAcking, 1807.01291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Thank you!


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