Herwig 7.1

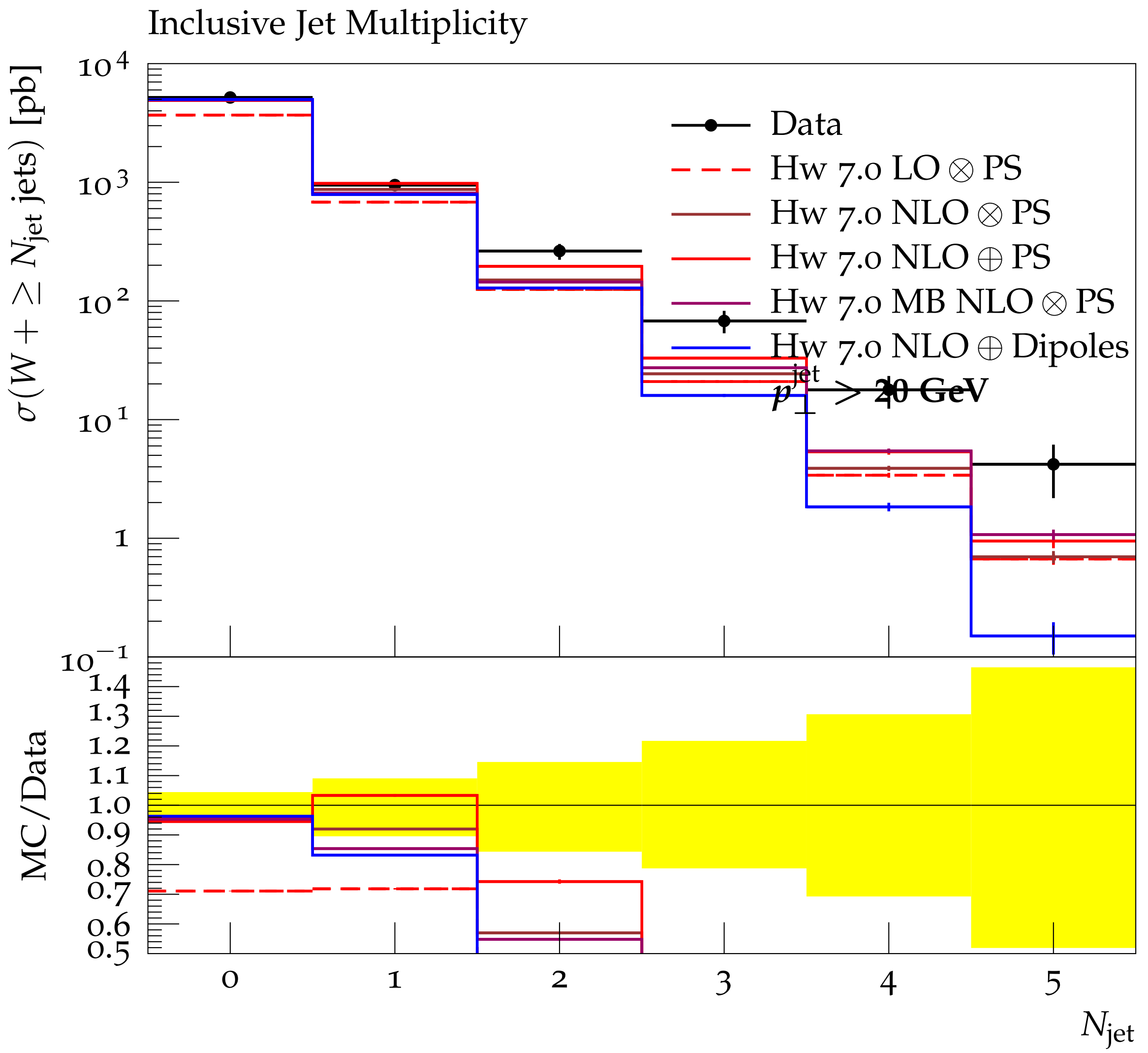
– Multijet Matching –

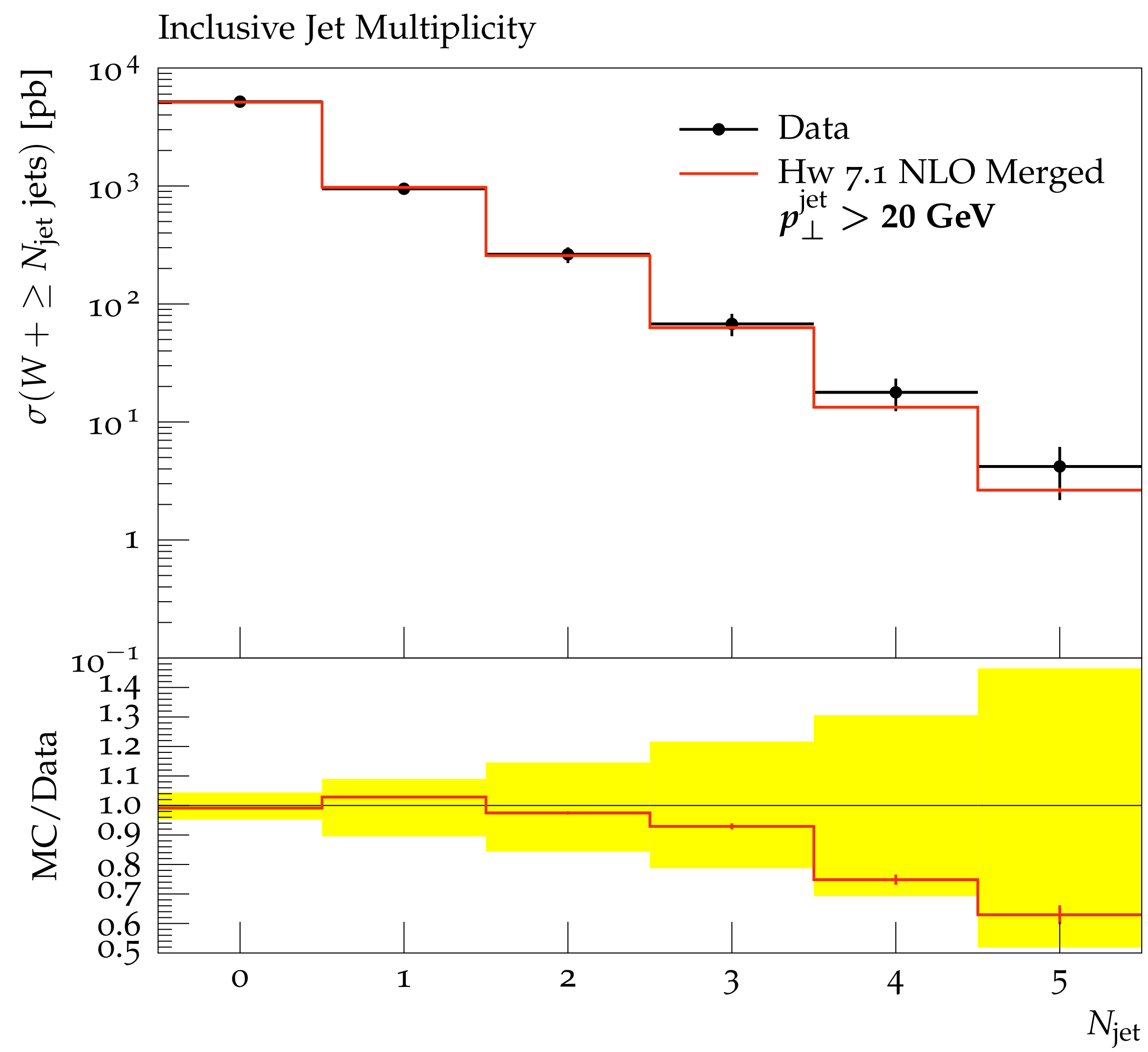
Johannes Bellm

IP3

ATLAS-CMS MC workshop
@ CERN 2017

Motivation


Inclusive Jet Multiplicity
Data
Hw 7.0 LO ⊗ PS
Hw 7.0 NLO ⊗ PS
Hw 7.0 NLO ⊕ PS
Hw 7.0 MB NLO ⊗ PS
Hw 7.0 NLO ⊕ Dipoles
$p_\perp^{jet} > 20$ GeV
$\sigma(W + \geq N_{jet}$ jets) [pb]
MC/Data
N_{jet}


Inclusive Jet Multiplicity
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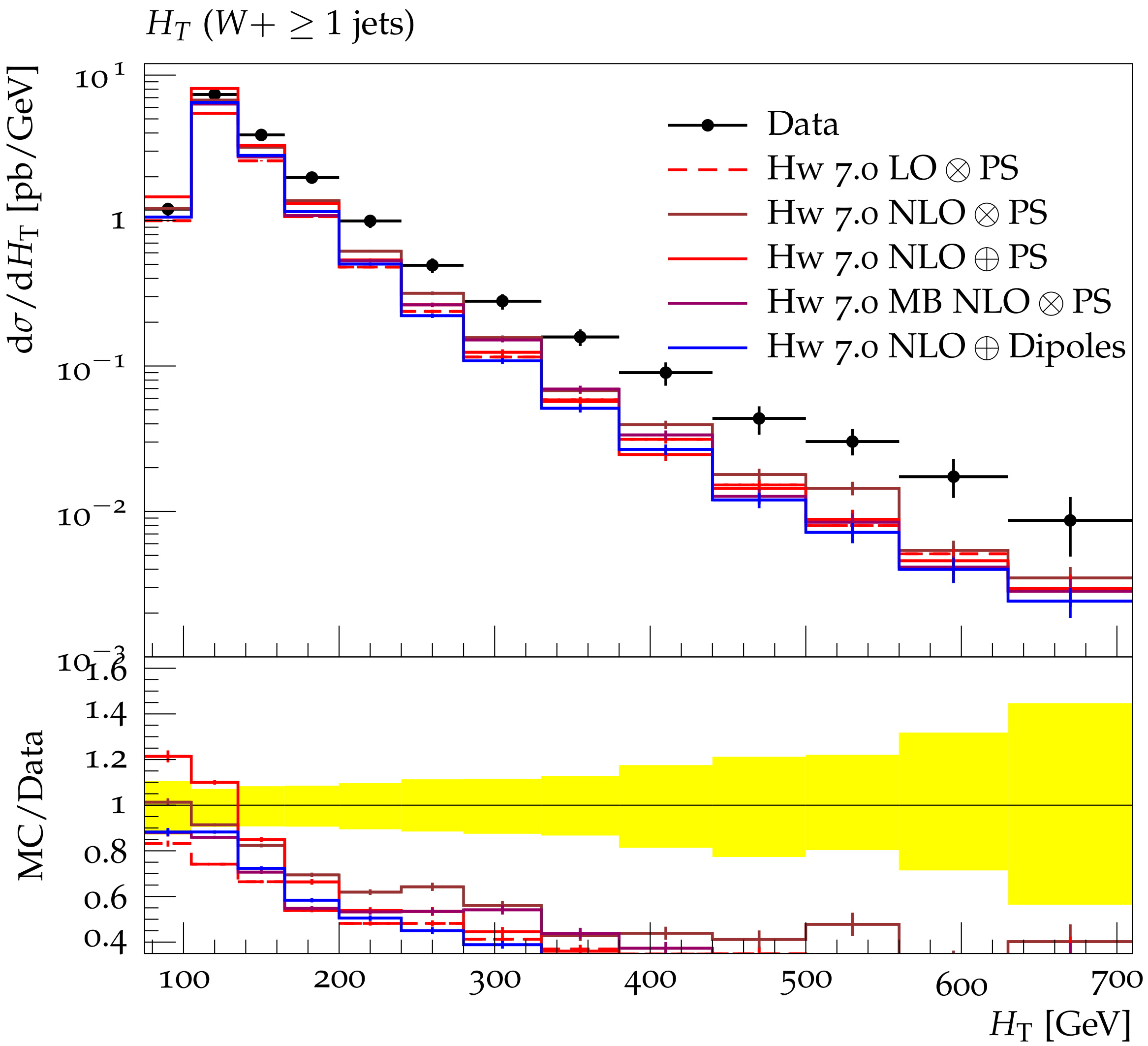

H_T ($W+\geq 1$ jets)
Data
Hw 7.0 LO ⊗ PS
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dσ/dH_T [pb/GeV]
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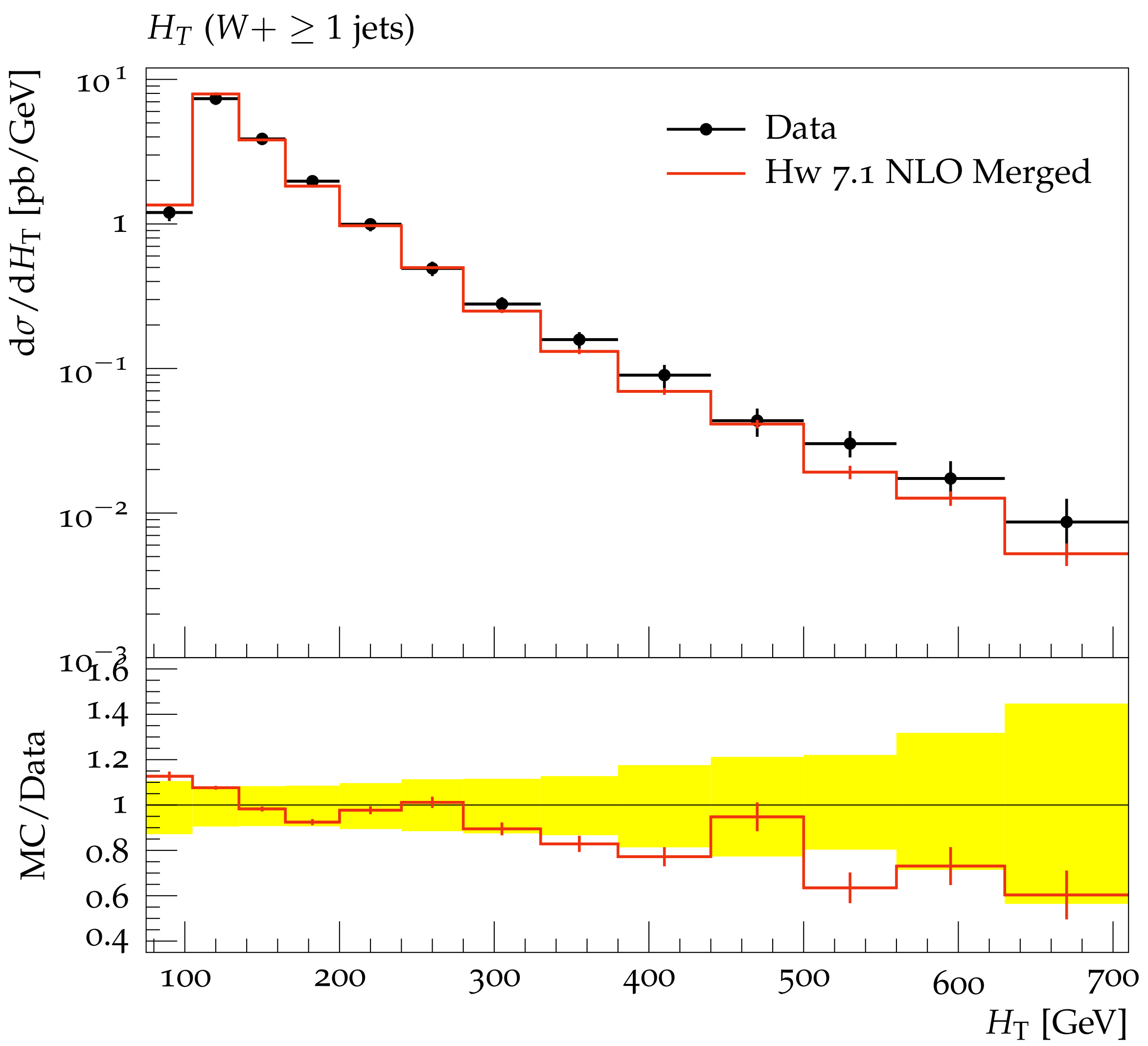
H_T [GeV]



H_T ($W+\geq 1$ jets)
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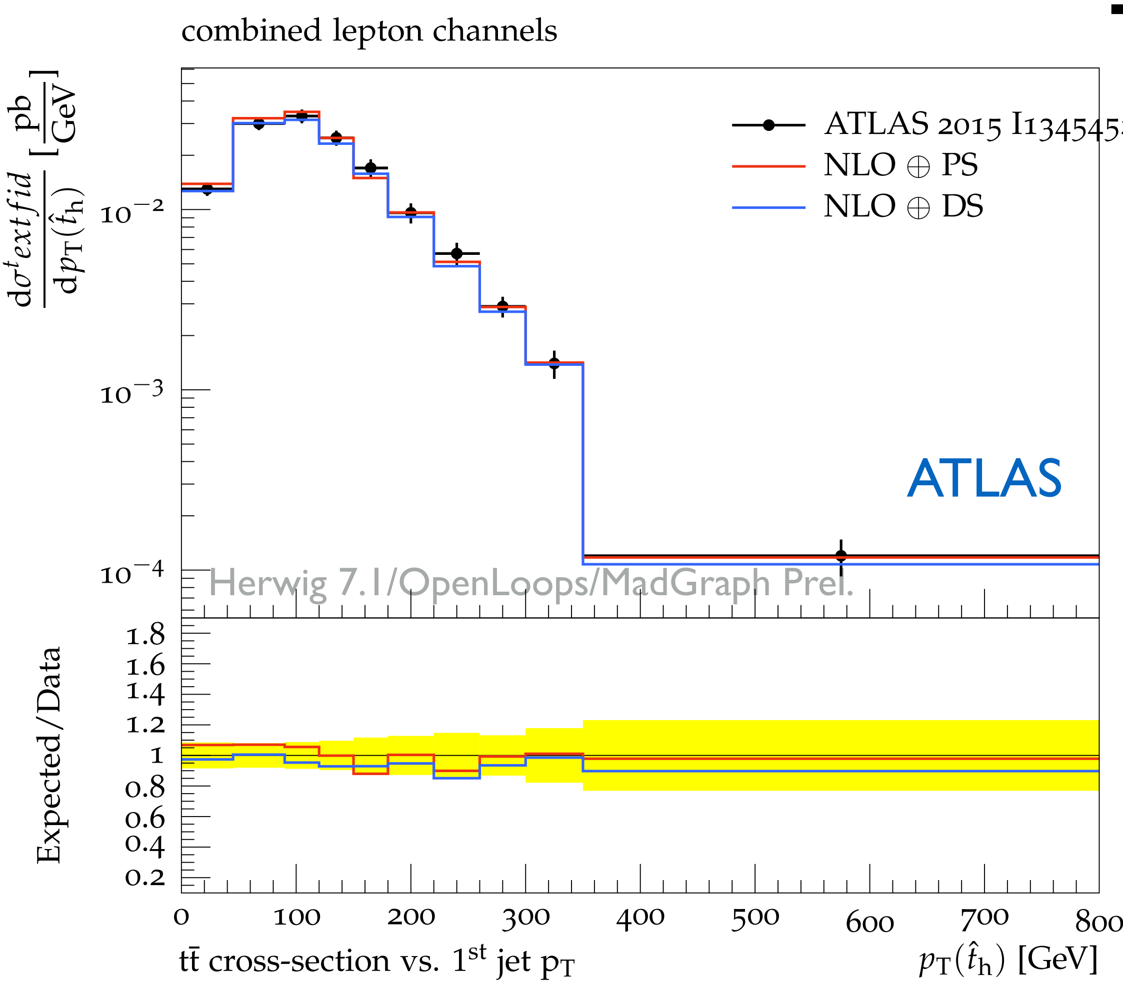
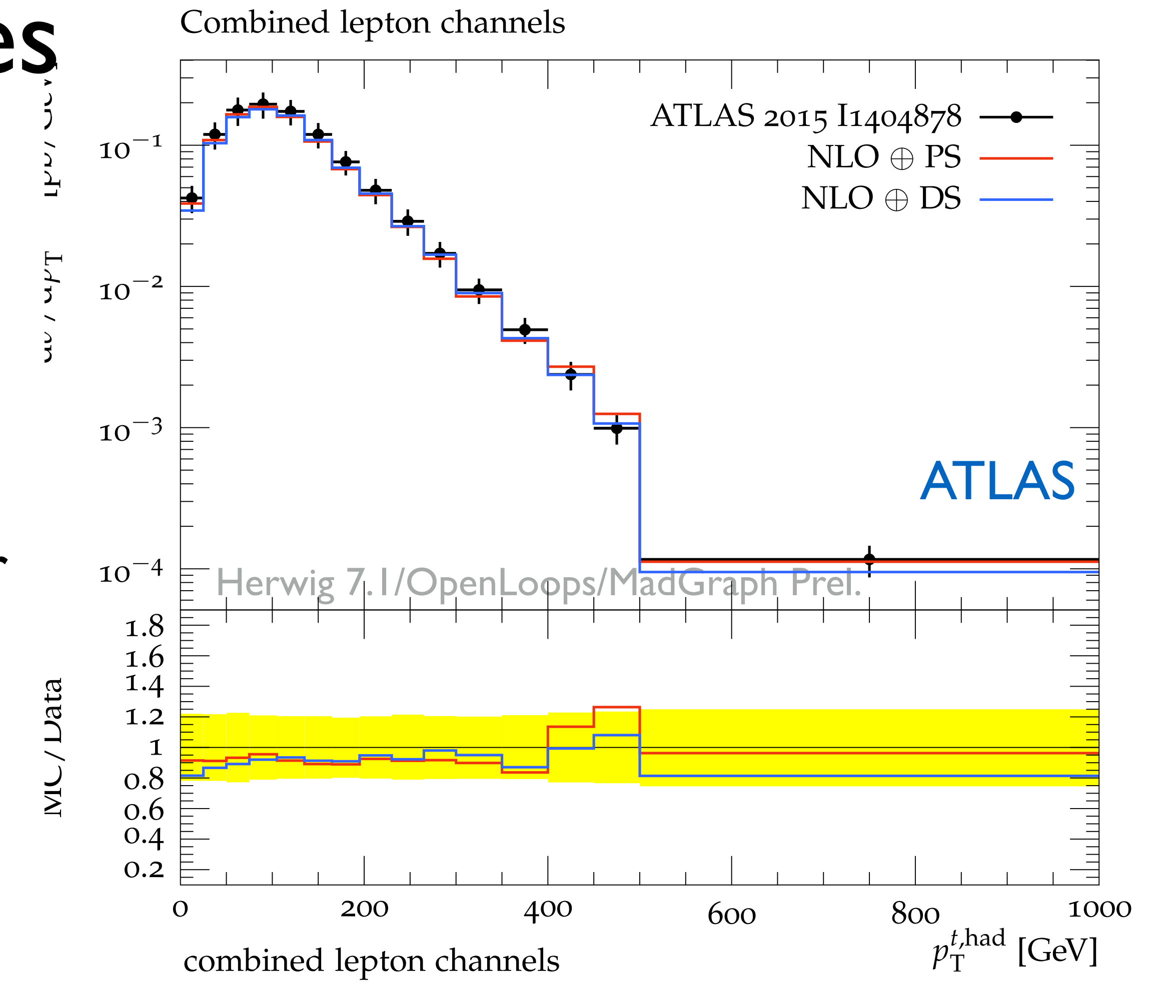
dσ/dH_T [pb/GeV]
MC/Data
H_T [GeV]

Outline

- update on tops
- a bit theory
- how to use
- validation and data comparisons

Top studies





NNLO K Factor

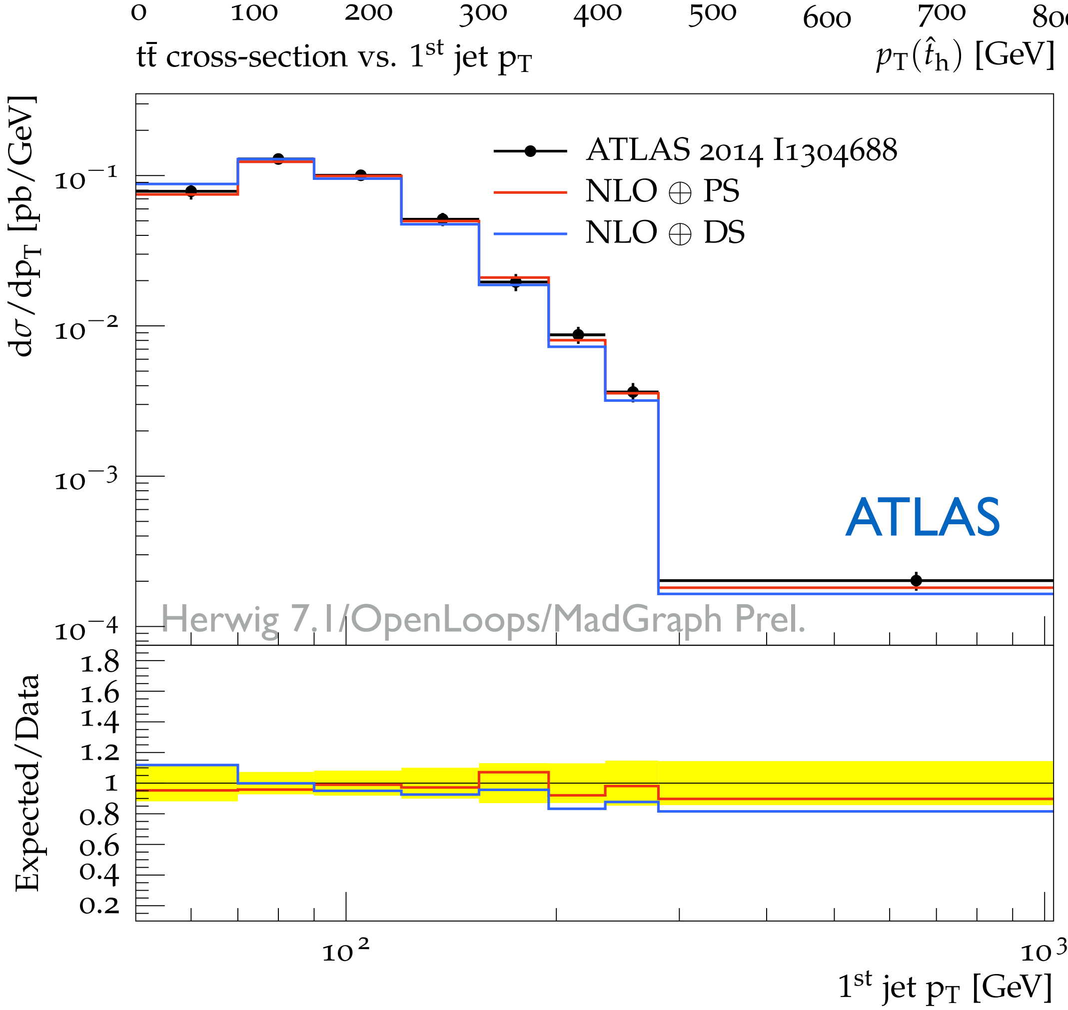
Top decays with NLO corrections for dipole shower

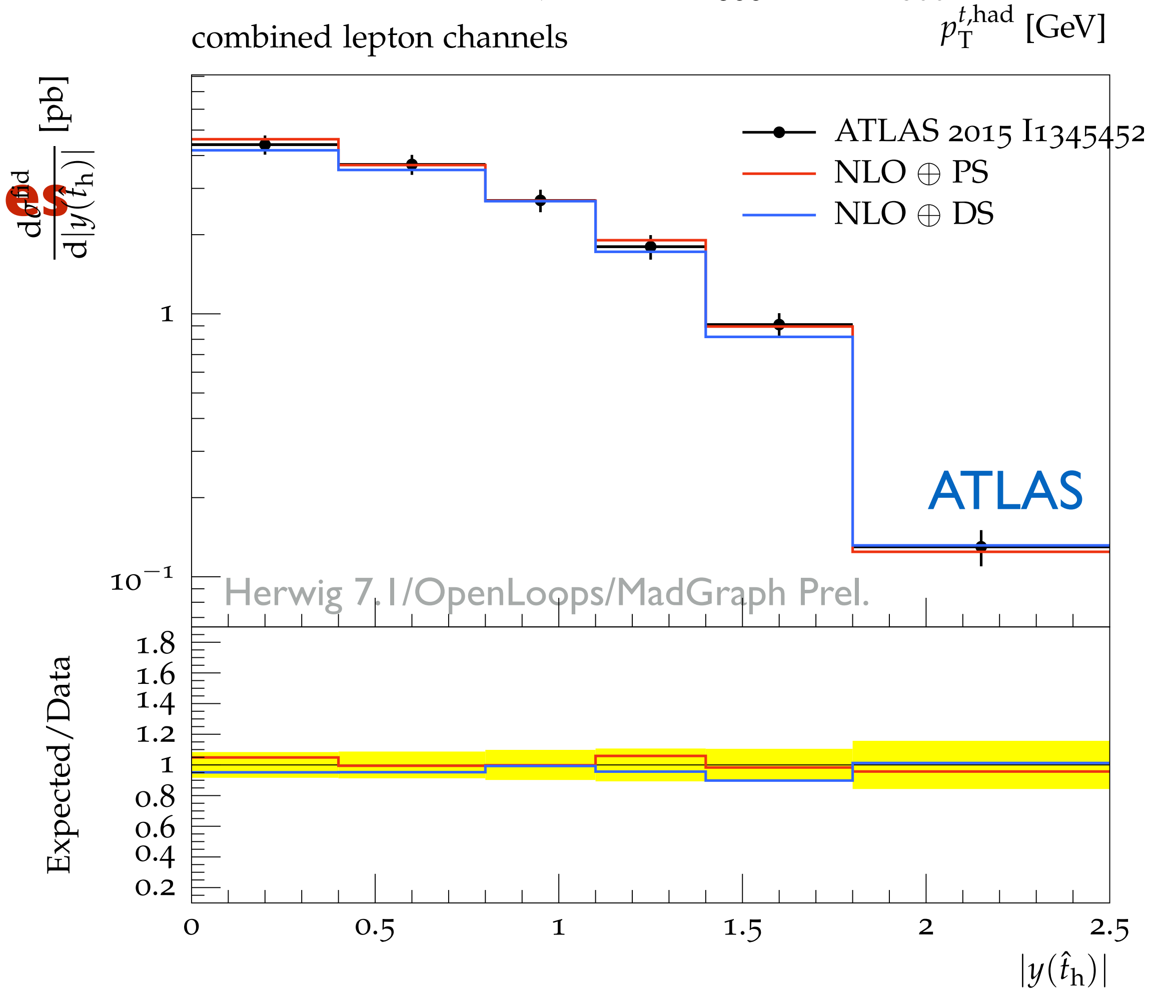
Various Scale Choices tested

Improved Kinematics

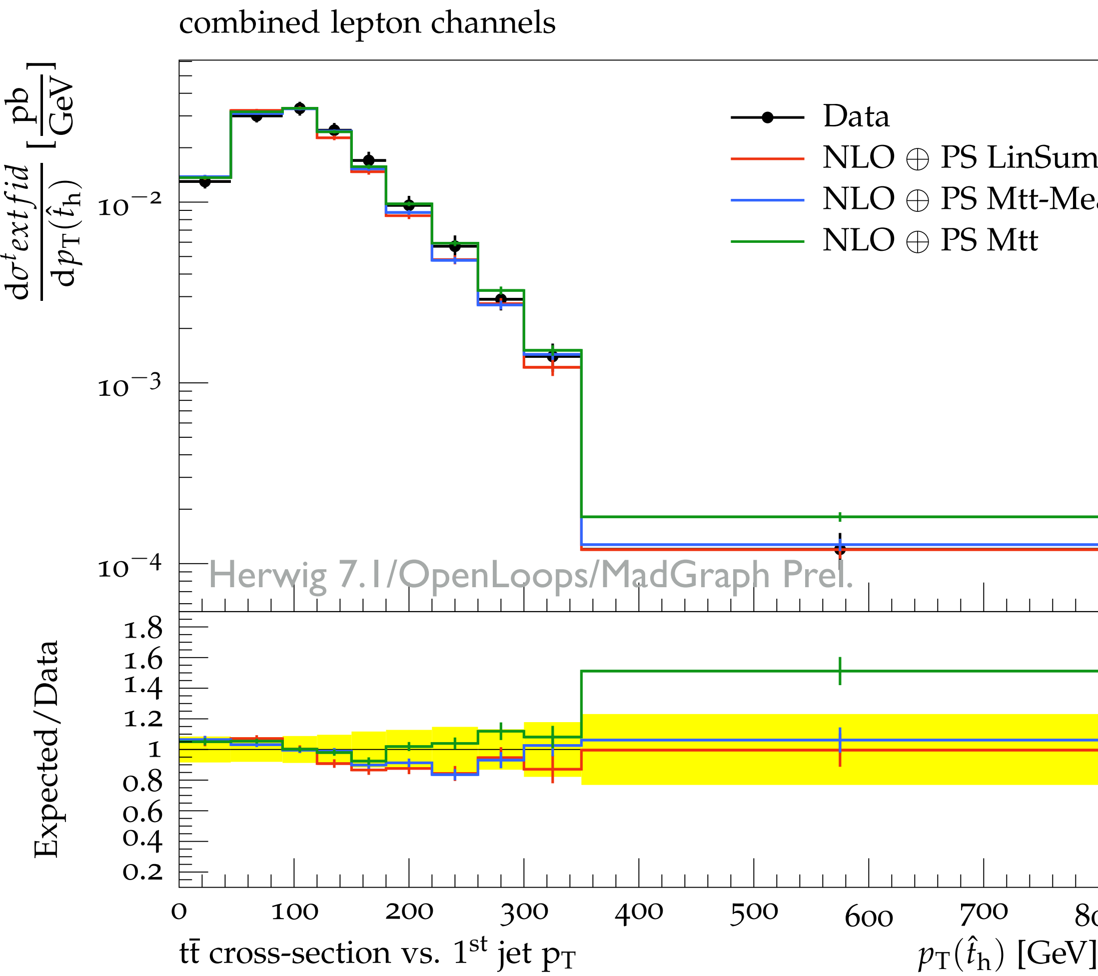
Ongoing studies

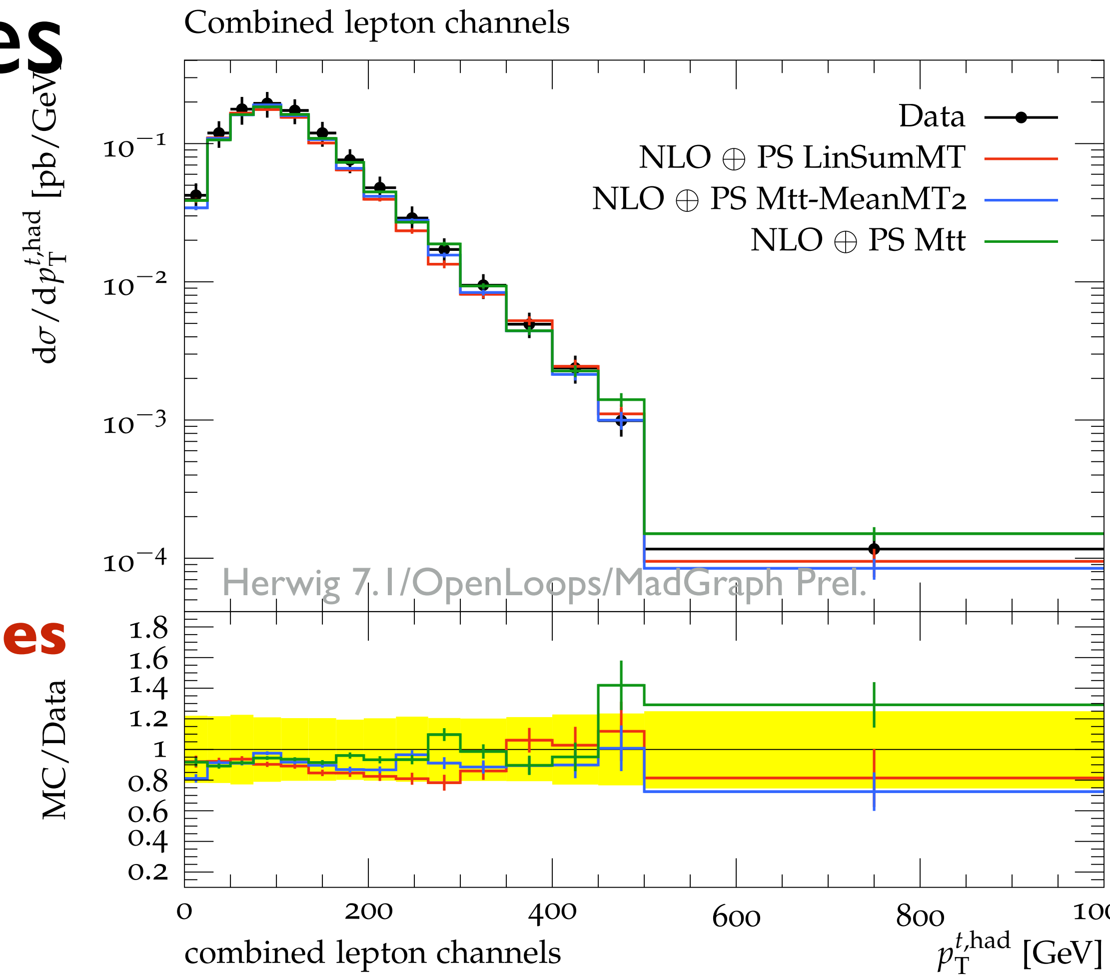
S. Plätzer,
P. Richardson,
S. Webster





Top studies





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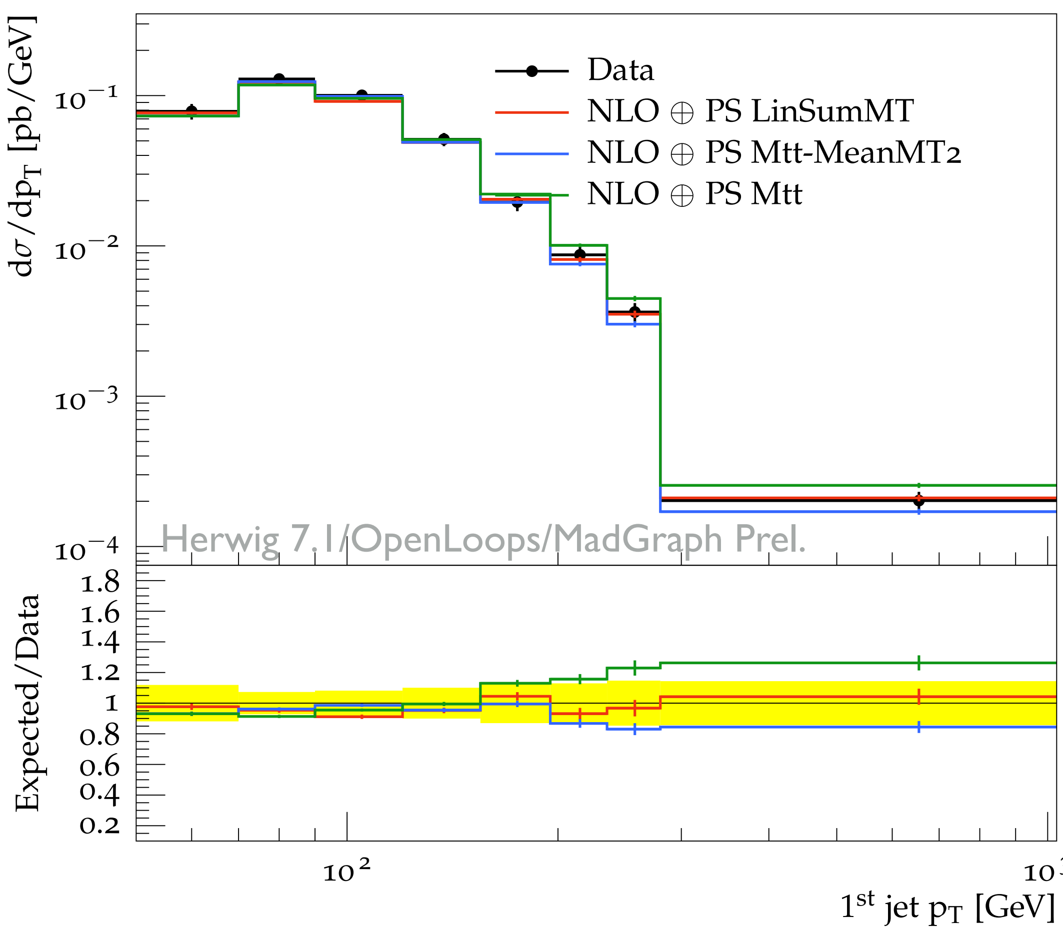
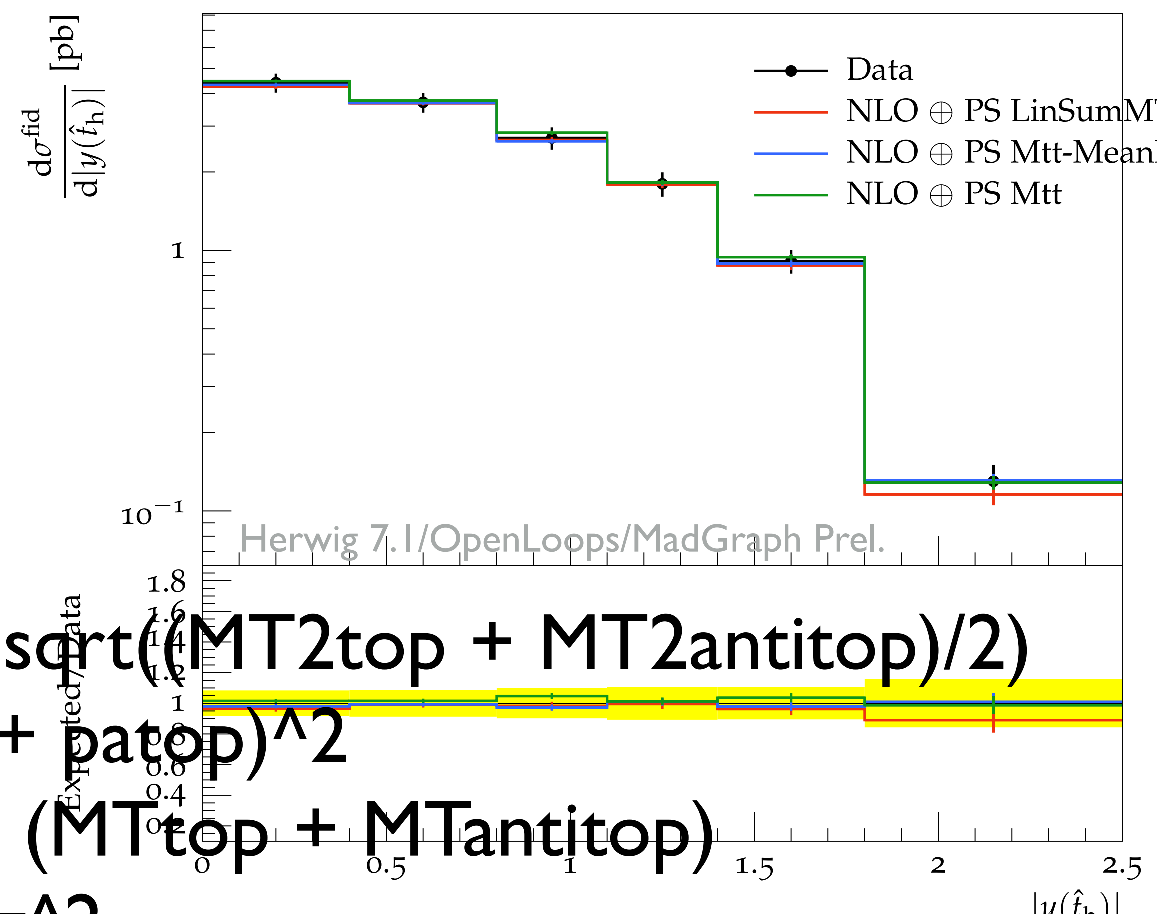




S. Plätzer,
P. Richardson,
S. Webster

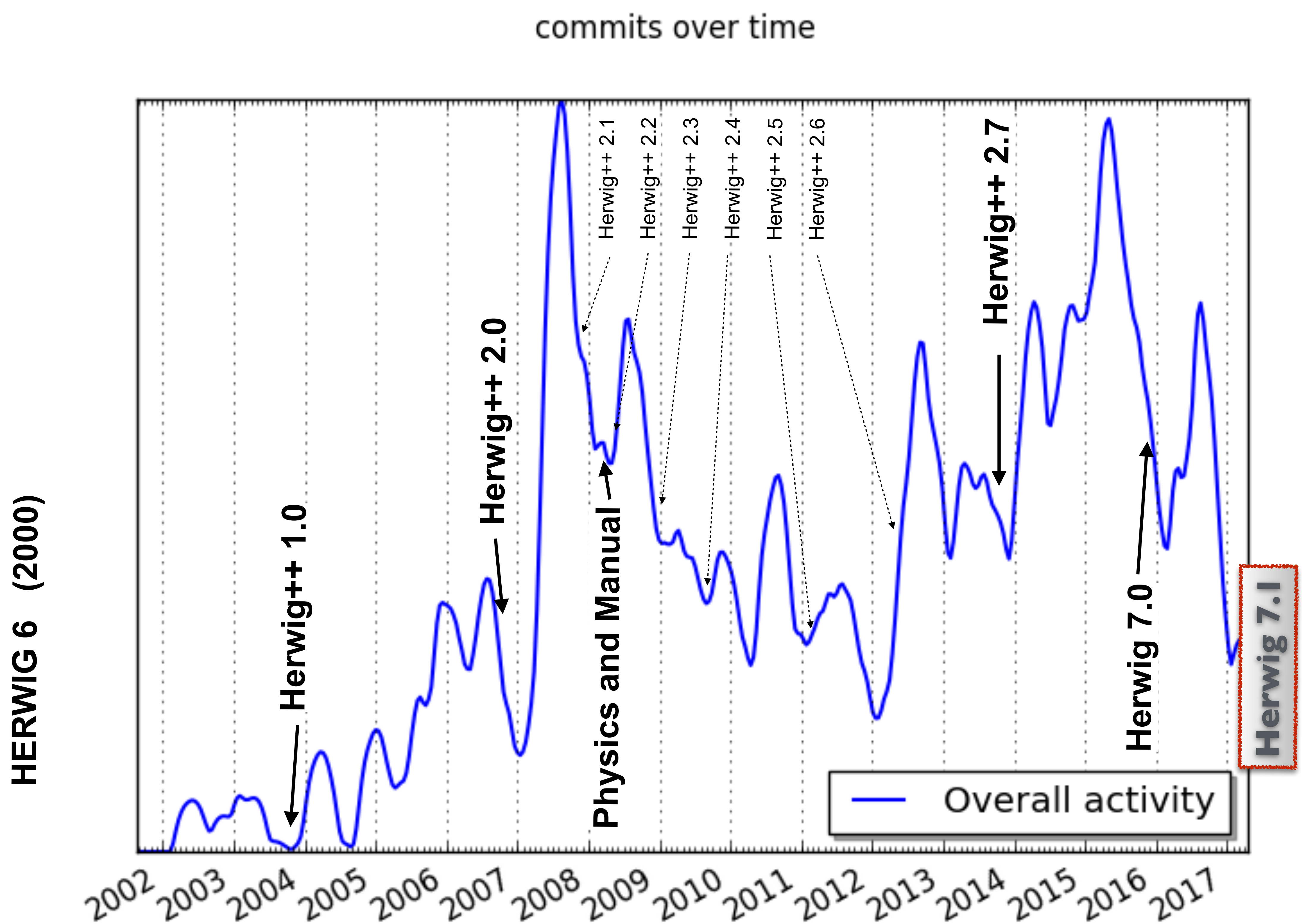
MeanMT2 = sqrt((MT2top + MT2antitop)/2)

Mtt = (ptop + patop)^2

LinSumMT = (MTtop + MTantitop)

MT2= E^2 - z^2

The Release Wave Pattern



Herwig 7.1

JHEP 1308 (2013) 114

EVTGen

New Soft Model

Improved Massive DS

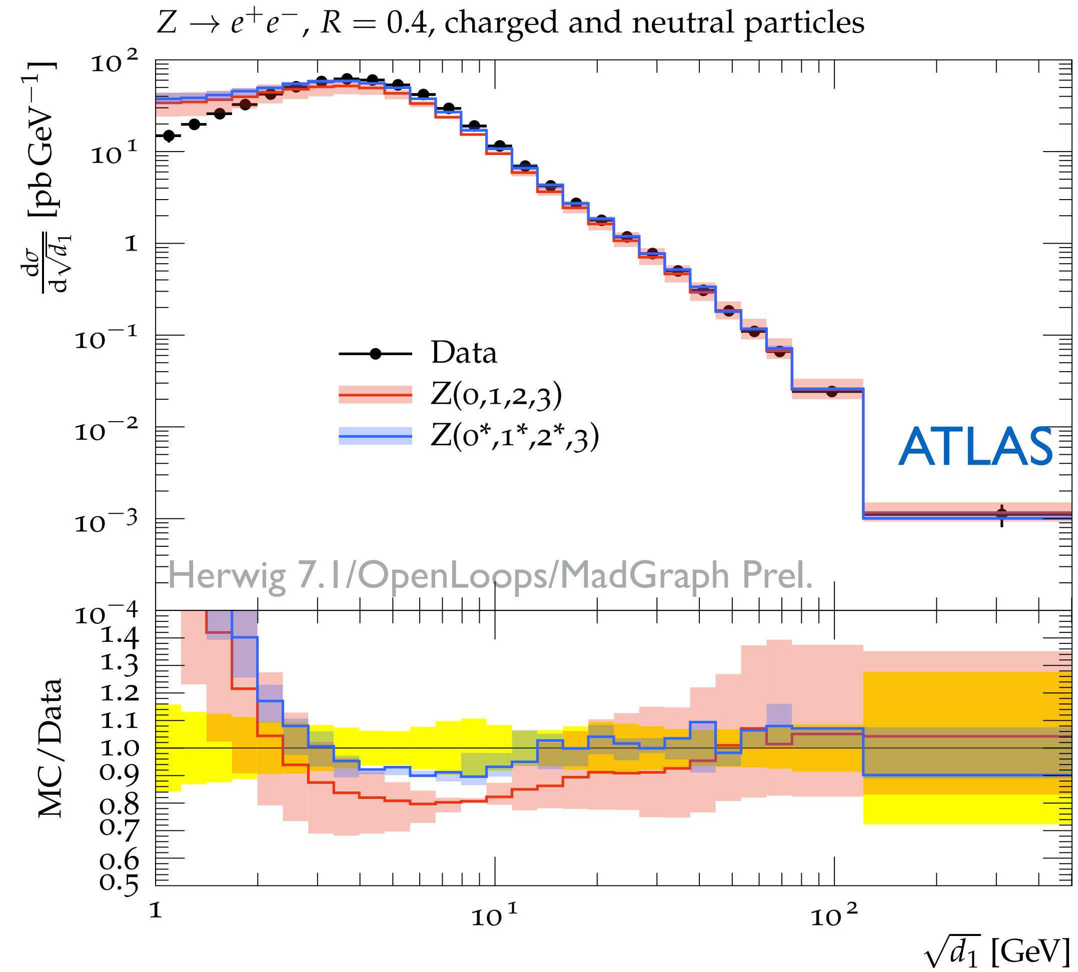
NLO Merging with DS

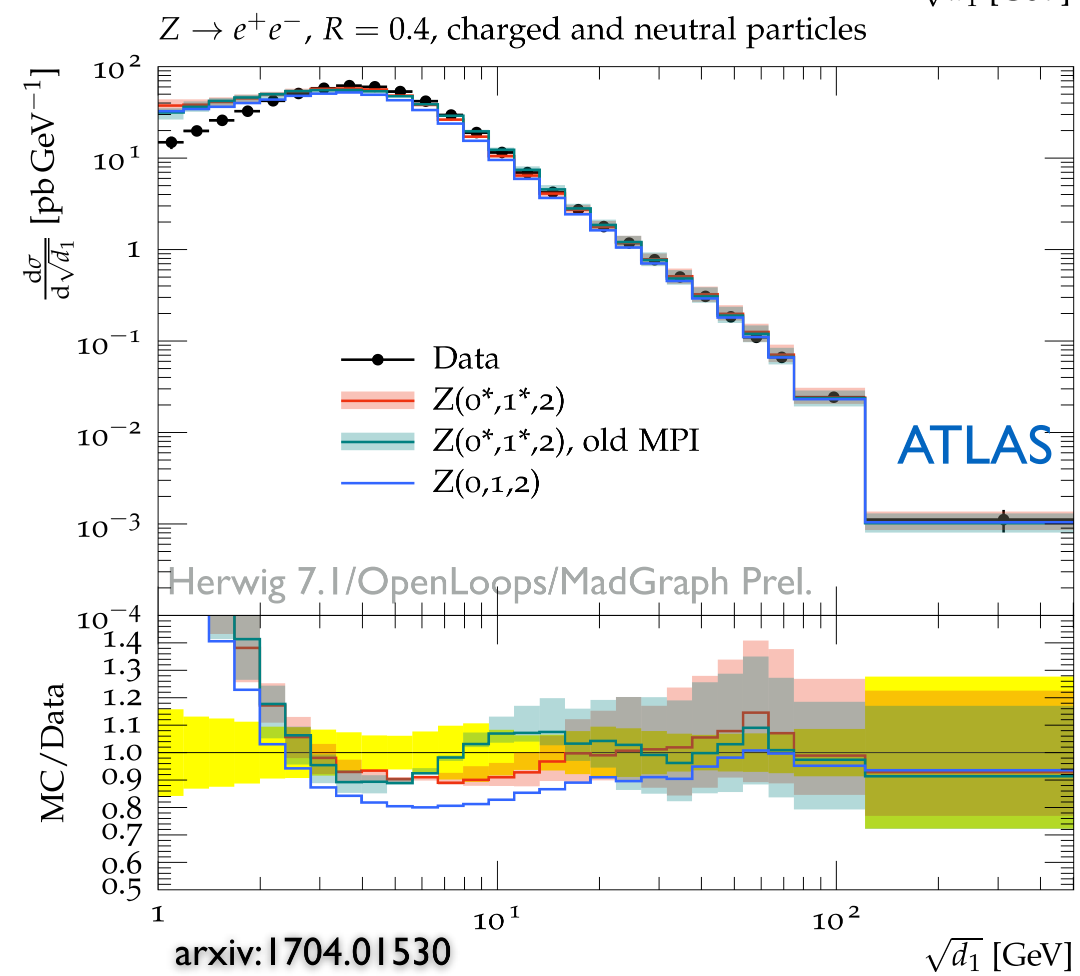
JB, S. Gieseke, S. Plätzer

KrkNLO Matching

New Tunes

- Based on unitised merging idea
- Not fully unitarised
- Various schemes to estimate uncertainties
- Simple input file structure:
  do MF:Process p p -> e+ e- [j j j]
  do MF:NLOProcesses 3





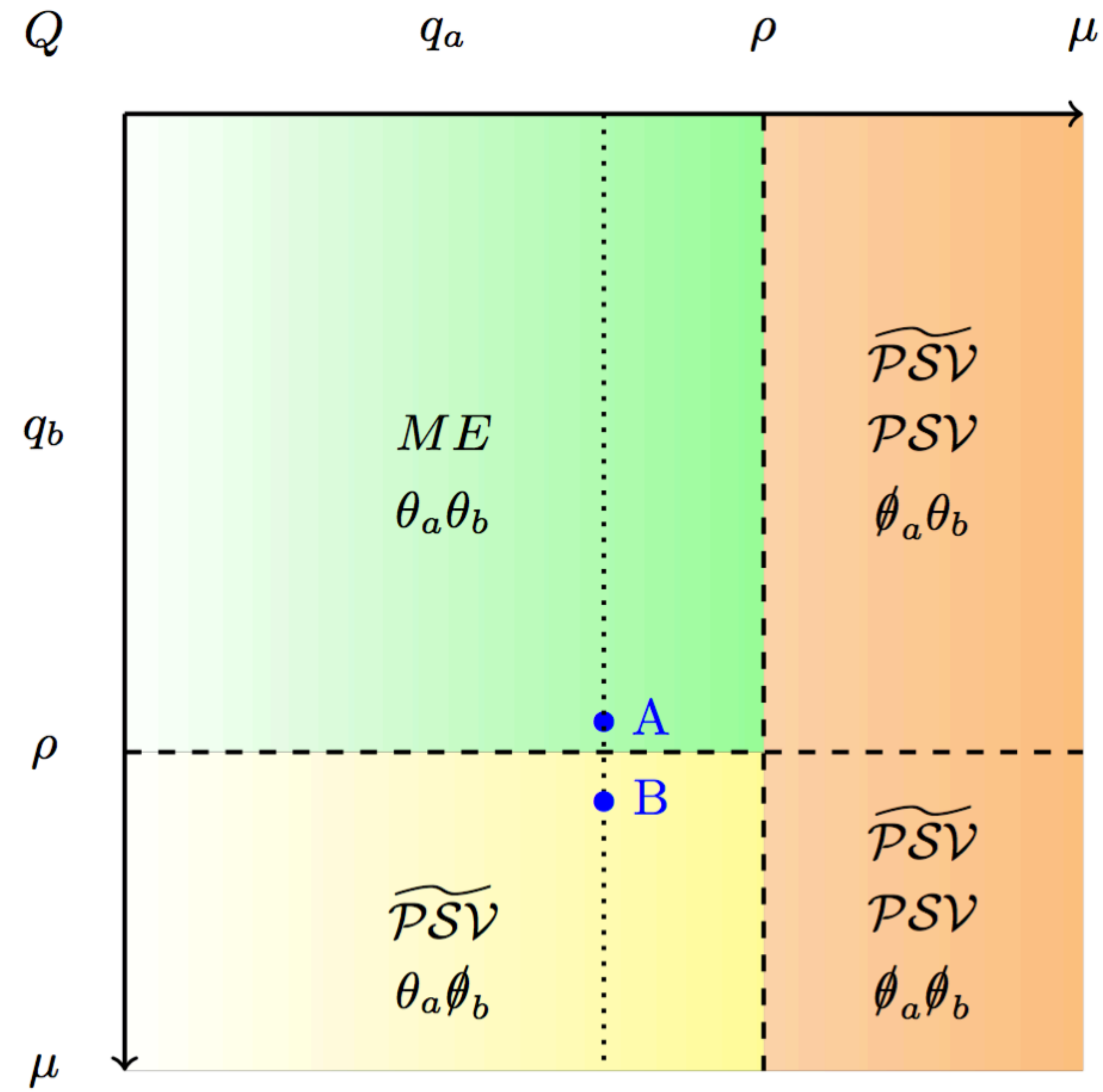
arxiv:1704.01530

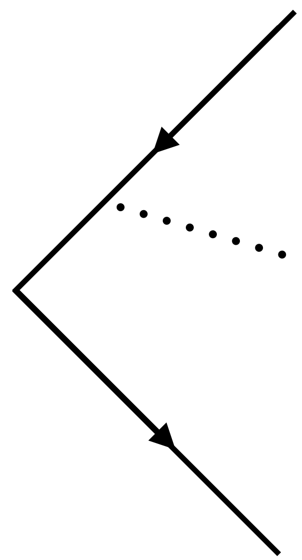
Merging

Basic Idea:
Divide the phase space into ME and PS regions.

$$\mathcal{PS}_\mu[u(\phi_n,Q)] = \widetilde{\mathcal{PSV}}_\mu[\widetilde{\mathcal{PS}}_\rho[u(\phi_n,Q)]]$$

Overlapping phase spaces produce dead regions if not treated properly.



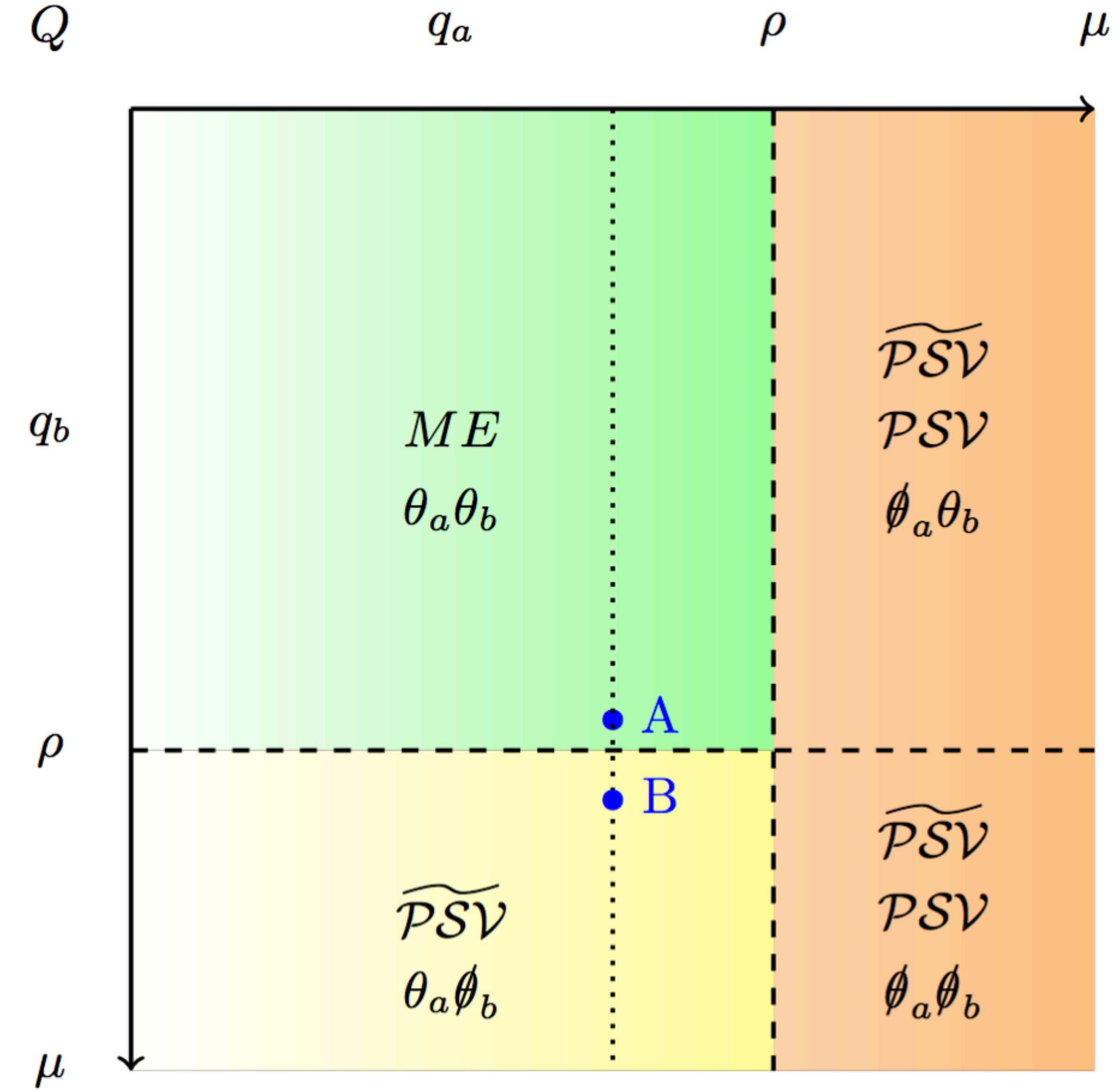


Simple example:

- Start with two kernels with overlapping phase spaces.
- ME region defined by clustering algorithm.
- Both scales q_a and q_b must be above merging scale
- Assume emission in shower region from kernel P_a
- Simple veto PS would produce point A but not B

Merging

$$\mathcal{PS}_{\mu}[u(\phi_n,Q)] = \widetilde{\mathcal{PSV}}_{\mu}[\widetilde{\mathcal{PS}}_{\rho}[u(\phi_n,Q)]]$$



Now replace $\widetilde{\mathcal{PS}}_{\rho}[u(\phi_n,Q)]$
with expressions from the ME calculation weighted with shower history:

$$w_I^k = \sum_{\alpha} \frac{w^k_{C,\alpha}}{\sum_s w^k_{C,\beta}} \frac{\alpha_S(q_k)}{\alpha_S(\mu_R)} \cdot \underbrace{\frac{f_k^{(1,2)}(\eta_{k-1},q_{k-1})}{f_k^{(1,2)}(\eta_{k-1},q_k)} \Pi^{(1,2)}(q_{k-1}|q_k)}_{\approx \Delta(q_{k-1}|q_k)} \prod_f \Delta(q_{k-1}|q_k)$$

Merging

$$d\sigma_n u(\phi_n, q_n) w_H^n - \int_\rho^{q_n} dq \sum_\alpha \frac{w_{C,\alpha}}{\sum_\beta w_{C,\beta}} u(\phi_n^\alpha, q_n^\alpha) d\sigma_{n+1} w_H^{n+1}$$

$$+ d\sigma_{n+1} u(\phi_{n+1}, q_{n+1}) w_H^{n+1}$$

Unitarized LO and NLO merging now adds and subtracts the same parts. Here only if the cluster history is produced.

In order to add NLO corrections the history and the additional emissions need to be expanded to order α_S in the ME and the PS region

$$d\sigma_n u(\phi_n, q_n) \left. \frac{\partial w_H^n}{\partial \alpha_S} \right| - \int_\rho^{q_n} dq \sum_\alpha \frac{w_{C,\alpha}}{\sum_\beta w_{C,\beta}} u(\phi_n^\alpha, q_n^\alpha) d\sigma_{n+1}$$

$$+ d\sigma_{n+1} u(\phi_{n+1}, q_{n+1})$$

Merging

For example $$\prod_i \frac{\alpha_S(q_i)}{\alpha_S(\mu)} = 1 - \sum_i b_0 \frac{\alpha_S(\mu)}{\pi} \log\left(\frac{q_i}{\mu}\right) + \mathcal{O}(\alpha_S^2)$$

Together with LO weights the expansion needs to produce the form

$$d\sigma_n^B (1 + \mathcal{O}(\alpha_S^2))$$

but e.g.

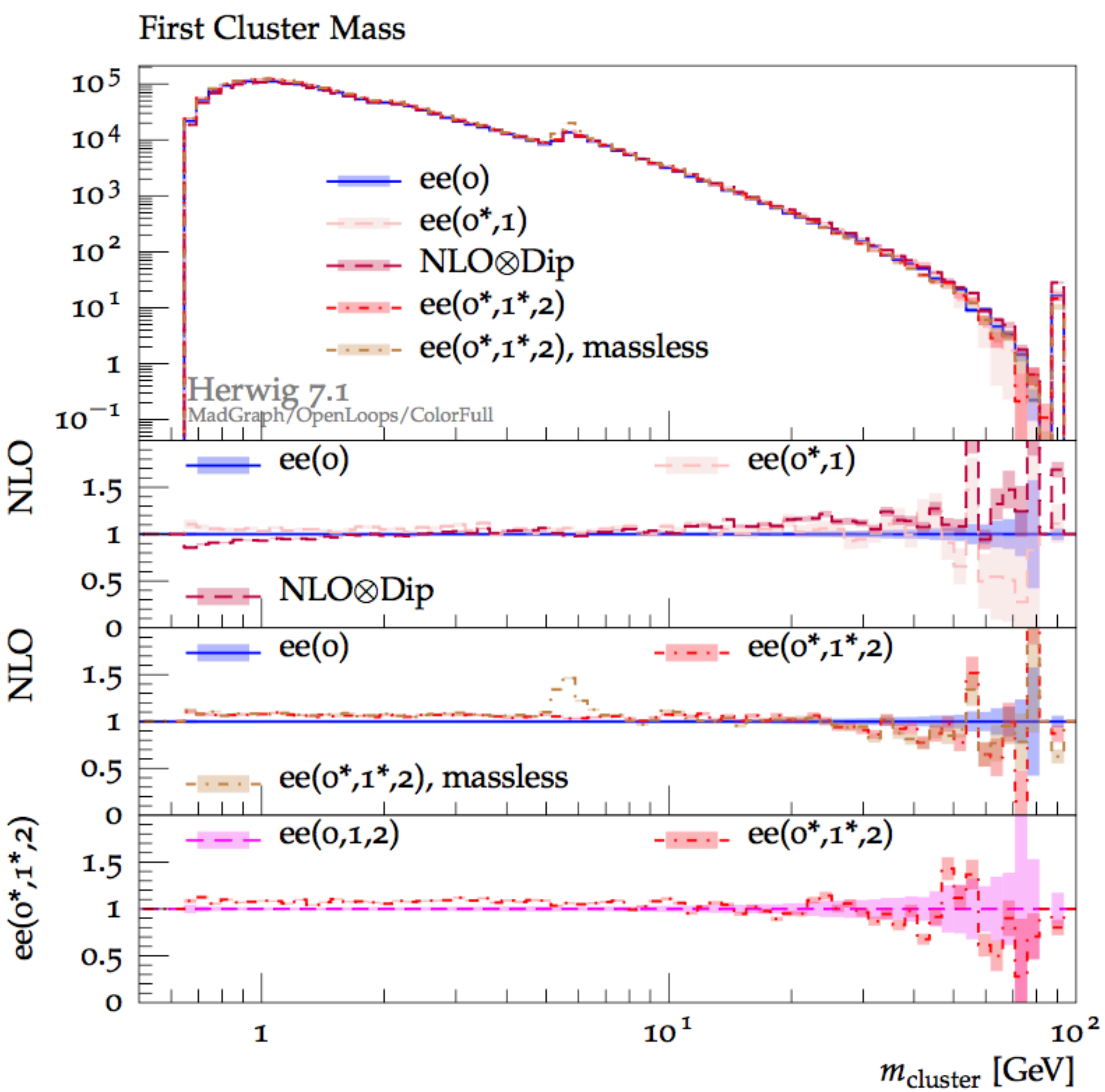
$$d\sigma_n^B \prod_i \left(\left[1 - \sum_X \alpha_S w^i_{\partial X} \right] \prod_X w^i_X \right) \quad \text{and} \quad d\sigma_n^B \prod_i \left(\left[\prod_X w^i_X - \sum_X \alpha_S w^i_{\partial X} \right] \right)$$

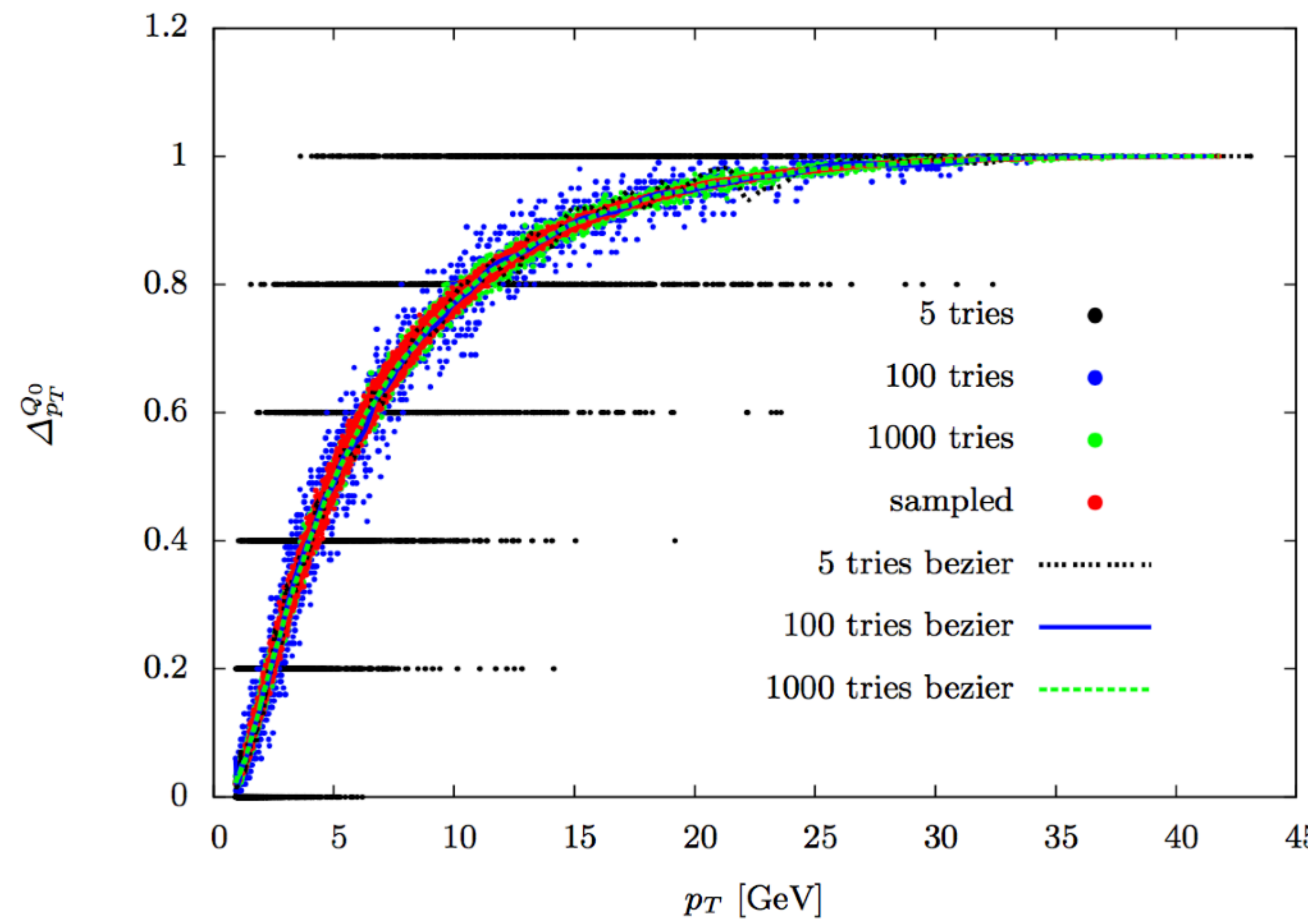
both fulfil the criterion above.

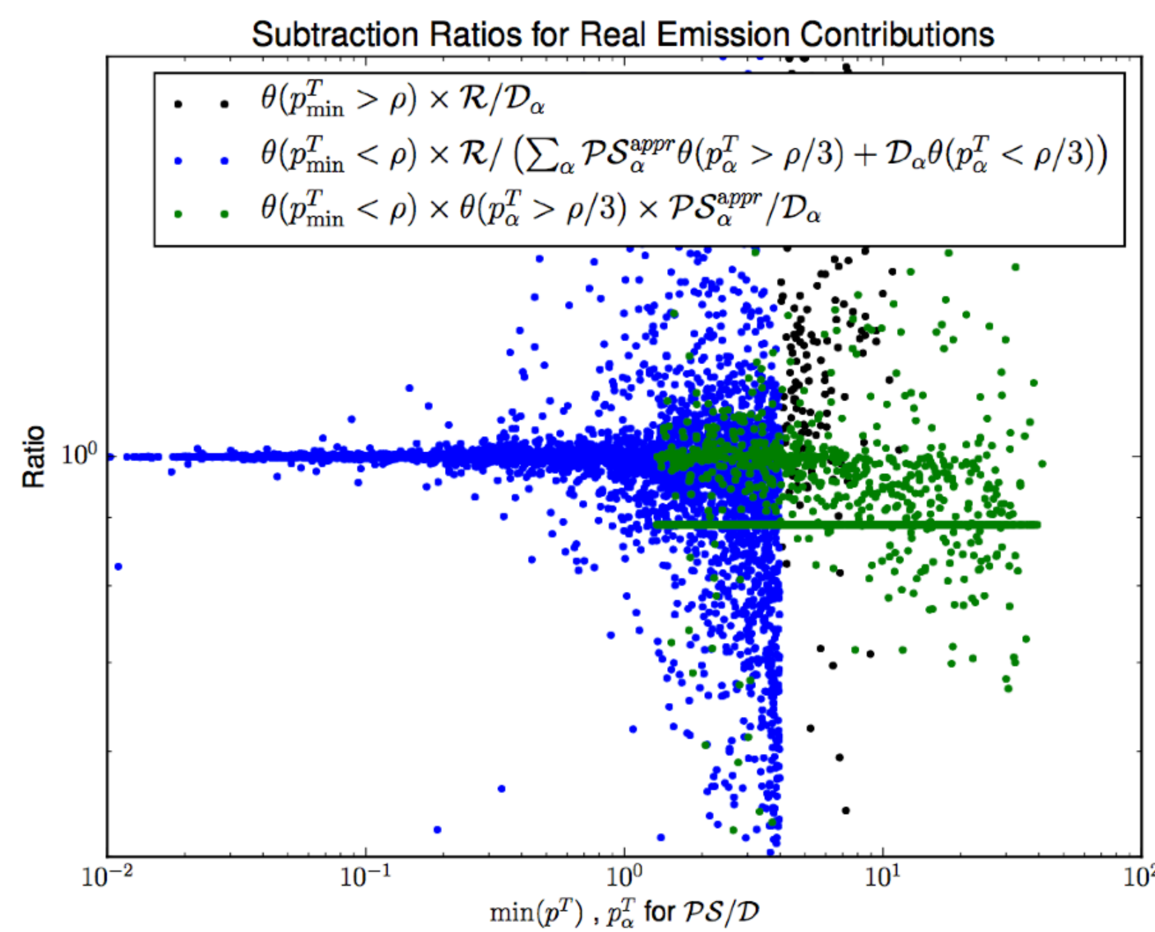
Can be used as uncertainty as difference tests higher orders.

Sanity Checks

- Sudakov sampling
- Subtraction plots
- Cluster mass spectra







Example Input File

```
# -*- ThePEG-repository

##################################################
## Herwig/Merging example input file
##################################################

##################################################
## Collider type
##################################################

read snippets/DipoleMerging.in
read snippets/PPCollider.in
read snippets/MonacoSampler.in

##################################################
## Beam energy sqrt(s)
##################################################

cd /Herwig/EventHandlers
set EventHandler:LuminosityFunction:Energy 13000*GeV

##################################################
## Process selection
##################################################

## Note that event generation may fail if no matching matrix element has
## been found.  Coupling orders are with respect to the Born process,
## i.e. NLO QCD does not require an additional power of alphas.

## Model assumptions
read Matchbox/StandardModelLike.in
read Matchbox/DiagonalCKM.in

## Set the order of the couplings
cd /Herwig/Merging
set MergingFactory:OrderInAlphaS 0
set MergingFactory:OrderInAlphaEW 2

## Select the process
## You may use identifiers such as p, pbar, j, l, mu+, h0 etc.

do MergingFactory:Process p p -> e+ e- [ j j ]

set MergingFactory:NLOProcesses 2

# Set the merging scale dividing the parton shower
# from the matrix element region in phase space.
set Merger:MergingScale 15.*GeV
set Merger:MergingScaleSmearing 0.1

# The following lines control a preweighter,
# that can be used to force more events in higher
# HT or pt regions. The unweighted events are accepted
# with a enhanced probability W, that is divided fron the
# event weight once the event is accepted.
# W = ((HT/scale)^HTPower + (pt_max/scale)^MaxPTPower)
# with scale = MZ (can be changed)
# Note that the weights will therefore differ from "1"
# if the powers are not zero.
set MPreWeight:HTPower 0
set MPreWeight:MaxPTPower 0
set MPreWeight:OnlyColoured No


# The next line can switch of hadronization
# and MPI modelling. Use with care!!
# read Matchbox/PQCDLevel.in



## Special settings required for on-shell production of
## unstable particles
## enable for on-shell top production
# read Matchbox/OnShellTopProduction.in
## enable for on-shell W, Z or h production
# read Matchbox/OnShellWProduction.in
# read Matchbox/OnShellZProduction.in
# read Matchbox/OnShellHProduction.in
# Special settings for the VBF approximation
# read Matchbox/VBFDiagramsOnly.in

##################################################
## Matrix element library selection
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## Select a generic tree/loop combination or a
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# read Matchbox/MadGraph-GoSam.in
# read Matchbox/MadGraph-MadGraph.in
# read Matchbox/MadGraph-NJet.in
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# read Matchbox/HJets.in
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## Uncomment this to use ggh effective couplings
## currently only supported by MadGraph-GoSam and
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# read Matchbox/HiggsEffective.in
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Setup your collider

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Biased Production

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## Select a generic tree/loop combination or a
## specialised NLO package

# read Matchbox/MadGraph-GoSam.in
# read Matchbox/MadGraph-MadGraph.in
# read Matchbox/MadGraph-NJet.in
# read Matchbox/MadGraph-OpenLoops.in
# read Matchbox/HJets.in
# read Matchbox/VBFNLO.in

## Uncomment this to use ggh effective couplings
## currently only supported by MadGraph-GoSam and
## MadGraph-Openloops

# read Matchbox/HiggsEffective.in
```

Example Input File

```
##################################################
## Cut selection
## See the documentation for more options
##################################################

set /Herwig/Cuts/ChargedLeptonPairMassCut:MinMass 60*GeV
set /Herwig/Cuts/ChargedLeptonPairMassCut:MaxMass 120*GeV

cd /Herwig/MatrixElements/Matchbox/Utility
insert DiagramGenerator:ExcludeInternal 0 /Herwig/Particles/gamma

## cuts on additional jets

# read Matchbox/DefaultPPJets.in

# insert JetCuts:JetRegions 0 FirstJet
# insert JetCuts:JetRegions 1 SecondJet
# insert JetCuts:JetRegions 2 ThirdJet
# insert JetCuts:JetRegions 3 FourthJet

##################################################
## Scale choice
## See the documentation for more options
##################################################

cd /Herwig/MatrixElements/Matchbox/Scales/
set /Herwig/Merging/MergingFactory:ScaleChoice LeptonPairMassScale

##################################################
## Scale uncertainties
##################################################

# read Matchbox/MuDown.in
# read Matchbox/MuUp.in

##################################################
## Shower scale uncertainties
##################################################

# read Matchbox/MuQDown.in
# read Matchbox/MuQUp.in

##################################################
## CMW - Scheme
##################################################
read Merging/Merging-Dipole-FactorCMWSchemeTune.in

### Use factor in alpha_s argument: alpha_s(q) -> alpha_s(fac*q)
### with fac=exp(-(67-3pi^2-10/3*Nf)/(33-2Nf))
read Merging/FactorCMWScheme.in

### Linear CMW multiplication:
### alpha_s(q) -> alpha_s(q)(1+K_g*alpha_s(q)/2pi )
# read Merging/LinearCMWScheme.in


##################################################
## PDF choice
##################################################

read Matchbox/FiveFlavourNoBMassScheme.in
read Matchbox/MMHT2014.in

##################################################
## Analyses
##################################################

cd /Herwig/Analysis
insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 Rivet
# insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 HepMC


# Here we collected a various Rivet analysis for Zs at LHC
# at the 8 TeV. (The collection might not be complete.)
read Merging/LHC7-Z-Analysis.in


##################################################
## Save the generator
##################################################

do /Herwig/Merging/MergingFactory:ProductionMode

set /Herwig/Generators/EventGenerator:IntermediateOutput Yes

cd /Herwig/Generators

saverun LHC-Z-Merging EventGenerator
```

Example Input File

```
##################################################
## Cut selection
## See the documentation for more options
##################################################

set /Herwig/Cuts/ChargedLeptonPairMassCut:MinMass 60*GeV
set /Herwig/Cuts/ChargedLeptonPairMassCut:MaxMass 120*GeV

cd /Herwig/MatrixElements/Matchbox/Utility
insert DiagramGenerator:ExcludeInternal 0 /Herwig/Particles/gamma

## cuts on additional jets

# read Matchbox/DefaultPPJets.in

# insert JetCuts:JetRegions 0 FirstJet
# insert JetCuts:JetRegions 1 SecondJet
# insert JetCuts:JetRegions 2 ThirdJet
# insert JetCuts:JetRegions 3 FourthJet

##################################################
## Scale choice
## See the documentation for more options
##################################################

cd /Herwig/MatrixElements/Matchbox/Scales/
set /Herwig/Merging/MergingFactory:ScaleChoice LeptonPairMassScale

##################################################
## Scale uncertainties
##################################################

# read Matchbox/MuDown.in
# read Matchbox/MuUp.in

##################################################
## Shower scale uncertainties
##################################################

# read Matchbox/MuQDown.in
# read Matchbox/MuQUp.in
```

Cut Selection

```
##################################################
## CMW - Scheme
##################################################
read Merging/Merging-Dipole-FactorCMWSchemeTune.in

### Use factor in alpha_s argument: alpha_s(q) -> alpha_s(fac*q)
### with fac=exp(-(67-3pi^2-10/3*Nf)/(33-2Nf))
read Merging/FactorCMWScheme.in

### Linear CMW multiplication:
### alpha_s(q) -> alpha_s(q)(1+K_g*alpha_s(q)/2pi )
# read Merging/LinearCMWScheme.in


##################################################
## PDF choice
##################################################

read Matchbox/FiveFlavourNoBMassScheme.in
read Matchbox/MMHT2014.in

##################################################
## Analyses
##################################################

cd /Herwig/Analysis
insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 Rivet
# insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 HepMC


# Here we collected a various Rivet analysis for Zs at LHC
# at the 8 TeV. (The collection might not be complete.)
read Merging/LHC7-Z-Analysis.in


##################################################
## Save the generator
##################################################

do /Herwig/Merging/MergingFactory:ProductionMode

set /Herwig/Generators/EventGenerator:IntermediateOutput Yes

cd /Herwig/Generators

saverun LHC-Z-Merging EventGenerator
```

Example Input File

```
##################################################
## Cut selection
## See the documentation for more options
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set /Herwig/Cuts/ChargedLeptonPairMassCut:MinMass 60*GeV
set /Herwig/Cuts/ChargedLeptonPairMassCut:MaxMass 120*GeV

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insert DiagramGenerator:ExcludeInternal 0 /Herwig/Particles/gamma

## cuts on additional jets

# read Matchbox/DefaultPPJets.in

# insert JetCuts:JetRegions 0 FirstJet
# insert JetCuts:JetRegions 1 SecondJet
# insert JetCuts:JetRegions 2 ThirdJet
# insert JetCuts:JetRegions 3 FourthJet

##################################################
## Scale choice
## See the documentation for more options
##################################################

cd /Herwig/MatrixElements/Matchbox/Scales/
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##################################################
## Scale uncertainties
##################################################

# read Matchbox/MuDown.in
# read Matchbox/MuUp.in

##################################################
## Shower scale uncertainties
##################################################

# read Matchbox/MuQDown.in
# read Matchbox/MuQUp.in
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Scale Selection

```
##################################################
## CMW - Scheme
##################################################
read Merging/Merging-Dipole-FactorCMWSchemeTune.in

### Use factor in alpha_s argument: alpha_s(q) -> alpha_s(fac*q)
### with fac=exp(-(67-3pi^2-10/3*Nf)/(33-2Nf))
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### Linear CMW multiplication:
### alpha_s(q) -> alpha_s(q)(1+K_g*alpha_s(q)/2pi )
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##################################################
## PDF choice
##################################################

read Matchbox/FiveFlavourNoBMassScheme.in
read Matchbox/MMHT2014.in

##################################################
## Analyses
##################################################

cd /Herwig/Analysis
insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 Rivet
# insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 HepMC

# Here we collected a various Rivet analysis for Zs at LHC
# at the 8 TeV. (The collection might not be complete.)
read Merging/LHC7-Z-Analysis.in


##################################################
## Save the generator
##################################################

/Herwig/Merging/MergingFactory:ProductionMode

set /Herwig/Generators/EventGenerator:IntermediateOutput Yes

cd /Herwig/Generators

saverun LHC-Z-Merging EventGenerator
```

Example Input File

```
##################################################
## Cut selection
## See the documentation for more options
##################################################

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set /Herwig/Cuts/ChargedLeptonPairMassCut:MaxMass 120*GeV

cd /Herwig/MatrixElements/Matchbox/Utility
insert DiagramGenerator:ExcludeInternal 0 /Herwig/Particles/gamma

## cuts on additional jets

# read Matchbox/DefaultPPJets.in

# insert JetCuts:JetRegions 0 FirstJet
# insert JetCuts:JetRegions 1 SecondJet
# insert JetCuts:JetRegions 2 ThirdJet
# insert JetCuts:JetRegions 3 FourthJet

##################################################
## Scale choice
## See the documentation for more options
##################################################

cd /Herwig/MatrixElements/Matchbox/Scales/
set /Herwig/Merging/MergingFactory:ScaleChoice LeptonPairMassScale

##################################################
## Scale uncertainties
##################################################

# read Matchbox/MuDown.in
# read Matchbox/MuUp.in

##################################################
## Shower scale uncertainties
##################################################

# read Matchbox/MuQDown.in
# read Matchbox/MuQUp.in
```

```
##################################################
## CMW - Scheme
##################################################
read Merging/Merging-Dipole-FactorCMWSchemeTune.in

### Use factor in alpha_s argument: alpha_s(q) -> alpha_s(fac*q)
### with fac=exp(-(67-3pi^2-10/3*Nf)/(33-2Nf))
read Merging/FactorCMWScheme.in

### Linear CMW multiplication:
### alpha_s(q) -> alpha_s(q)(1+K_g*alpha_s(q)/2pi )
# read Merging/LinearCMWScheme.in
```

CMW Schemes

```
##################################################
## PDF choice
##################################################

read Matchbox/FiveFlavourNoBMassScheme.in
read Matchbox/MMHT2014.in

##################################################
## Analyses
##################################################

cd /Herwig/Analysis
insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 Rivet
# insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 HepMC


# Here we collected a various Rivet analysis for Zs at LHC
# at the 8 TeV. (The collection might not be complete.)
read Merging/LHC7-Z-Analysis.in


##################################################
## Save the generator
##################################################

do /Herwig/Merging/MergingFactory:ProductionMode

set /Herwig/Generators/EventGenerator:IntermediateOutput Yes

cd /Herwig/Generators

saverun LHC-Z-Merging EventGenerator
```

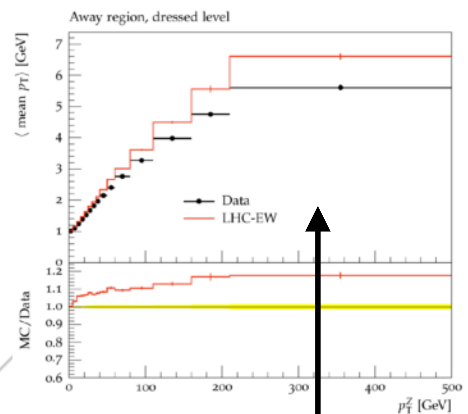
Herwig 7.1 - Release Status / Testing

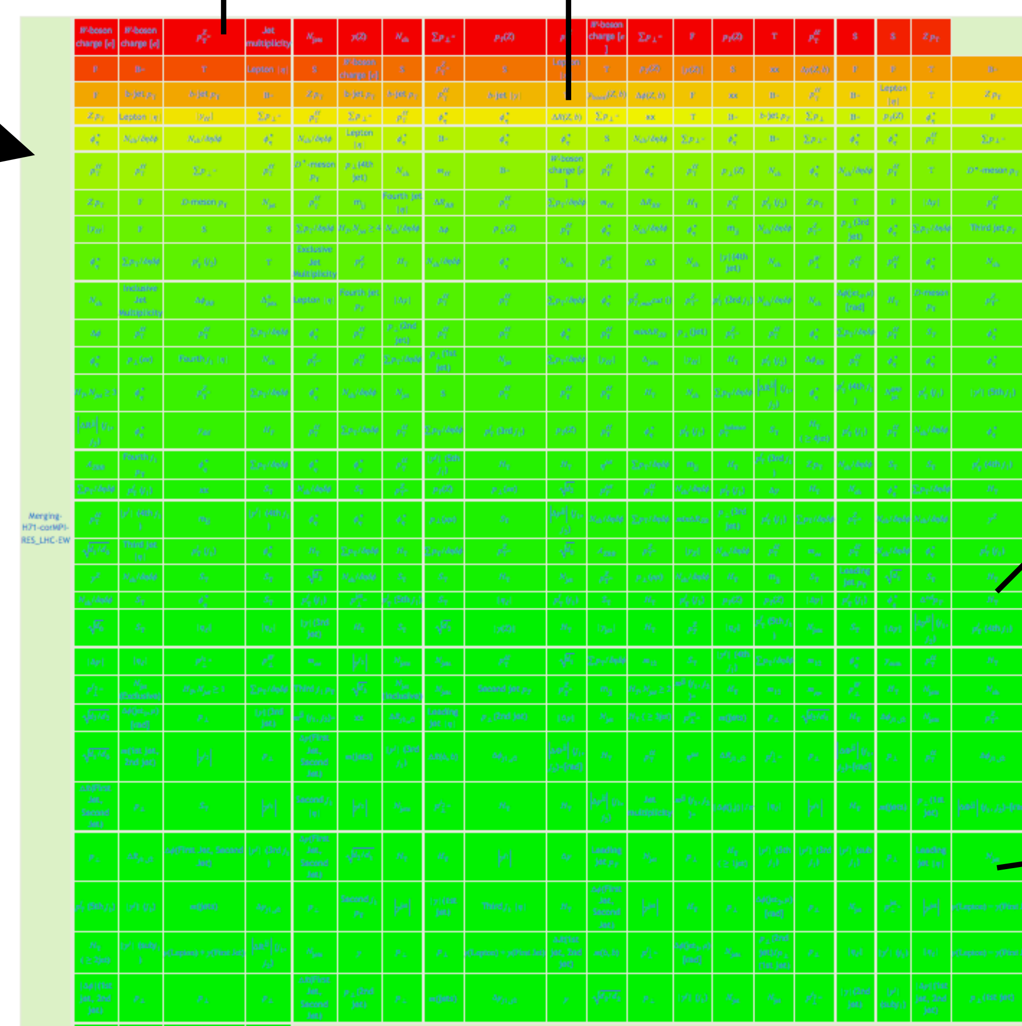
Currently ~20000 observables

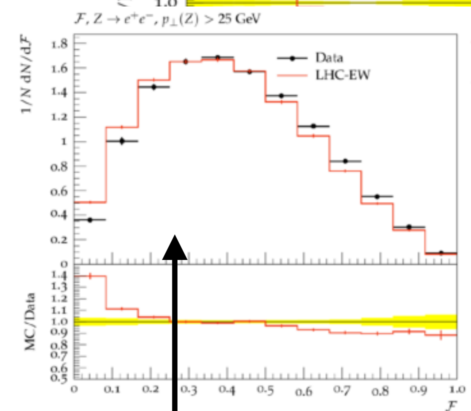
Need a way to structurally filter results.

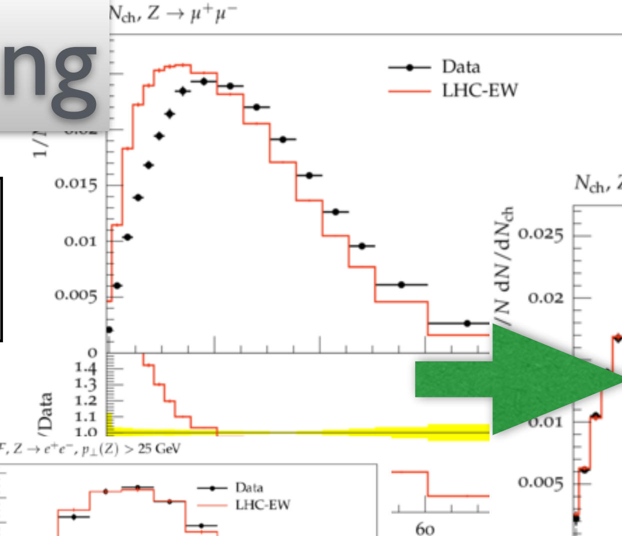
JB, S. Webster, P. Richardson

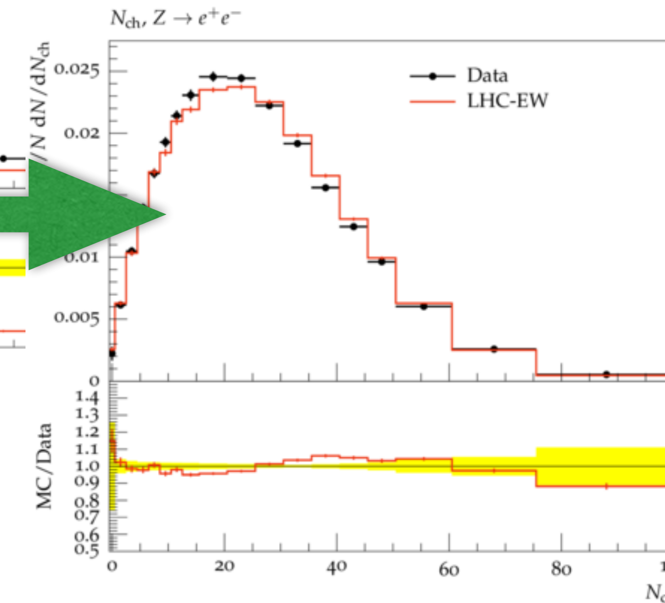
Revisions	BFactory	TVT-Photon	LHC-EW	LHC-Photon	DIS-NoME	LHC-Jets	LEP	SppS	TVT-WZ	TVT-Jets	DIS
Merging-H71-corMPI-RES	---	---	0.1[illegible]	---	---	0.35	---	---	---	---	---
MB-QT-H71-5B-RES	---	---	1.66	---	---	0.41	0.71	---	[illegible]	0.57	5.38
POW-QT-H71-0B-RES	---	---	---	---	---	---	0.76	---	1.48	---	1.37
MB-POW-QT-H71-0B-RES	---	---	---	---	---	---	1.04	---	---	---	3.40
LO-H71-0B-RES	0.84	0.87	1.33	0.81	0.86	0.82	0.80	0.67	1.83	0.76	1.43
POW-QT-H71-5B-RES	---	---	2.07	---	---	0.57	0.71	---	0.72	0.53	1.13
MB-QT-H71-0B-RES	---	---	---	---	---	---	0.82	---	---	---	3.57
LO-H70-RES	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
LO-H71-5B-RES	0.99	0.87	1.11	0.80	1.22	0.85	0.69	0.68	0.94	0.86	1.25
MB-POW-QT-H71-5B-RES	---	---	2.07	---	---	0.57	1.04	---	0.81	0.53	5.77
Merging-H71-RES	---	---	0.16	---	---	0.35	0.94	---	0.67	0.89	2.14

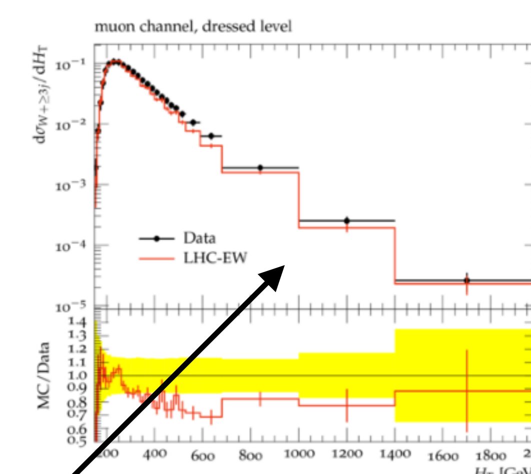


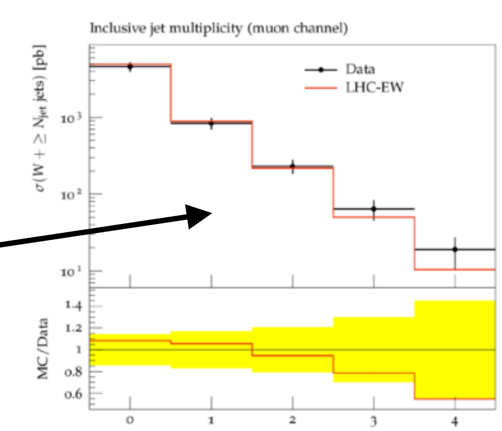




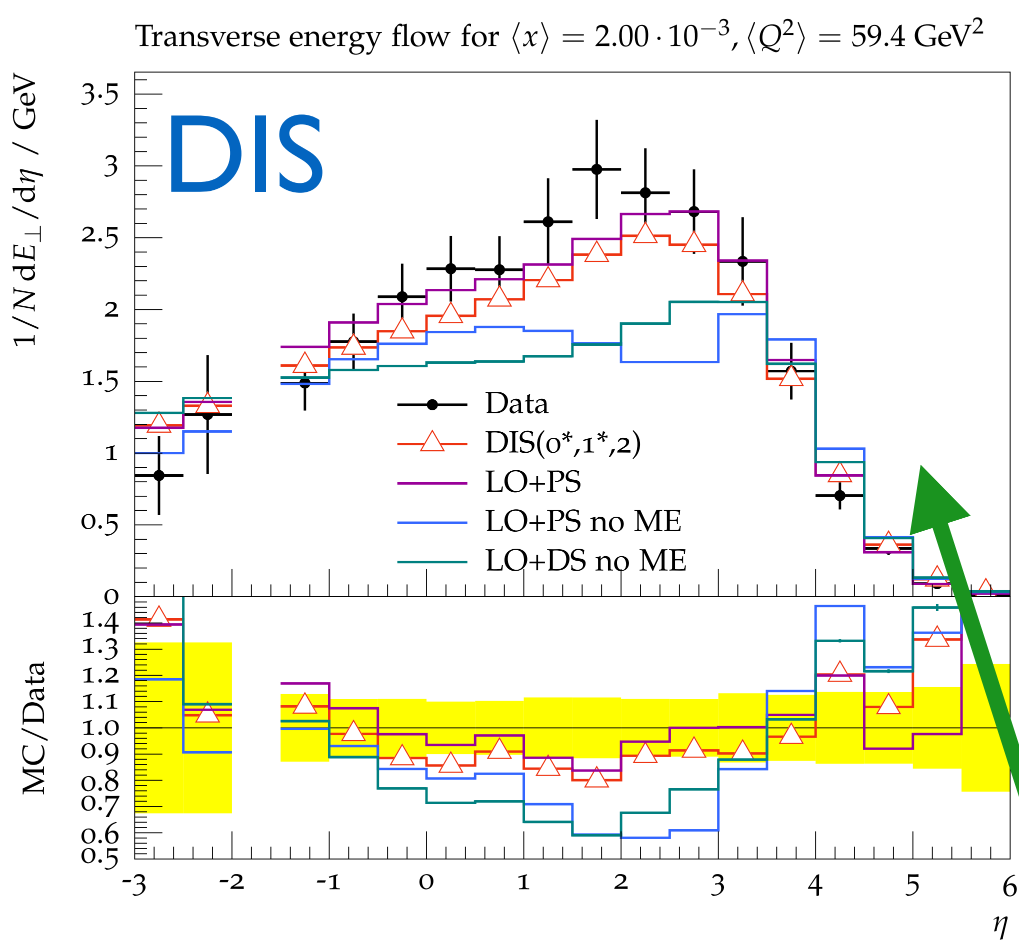


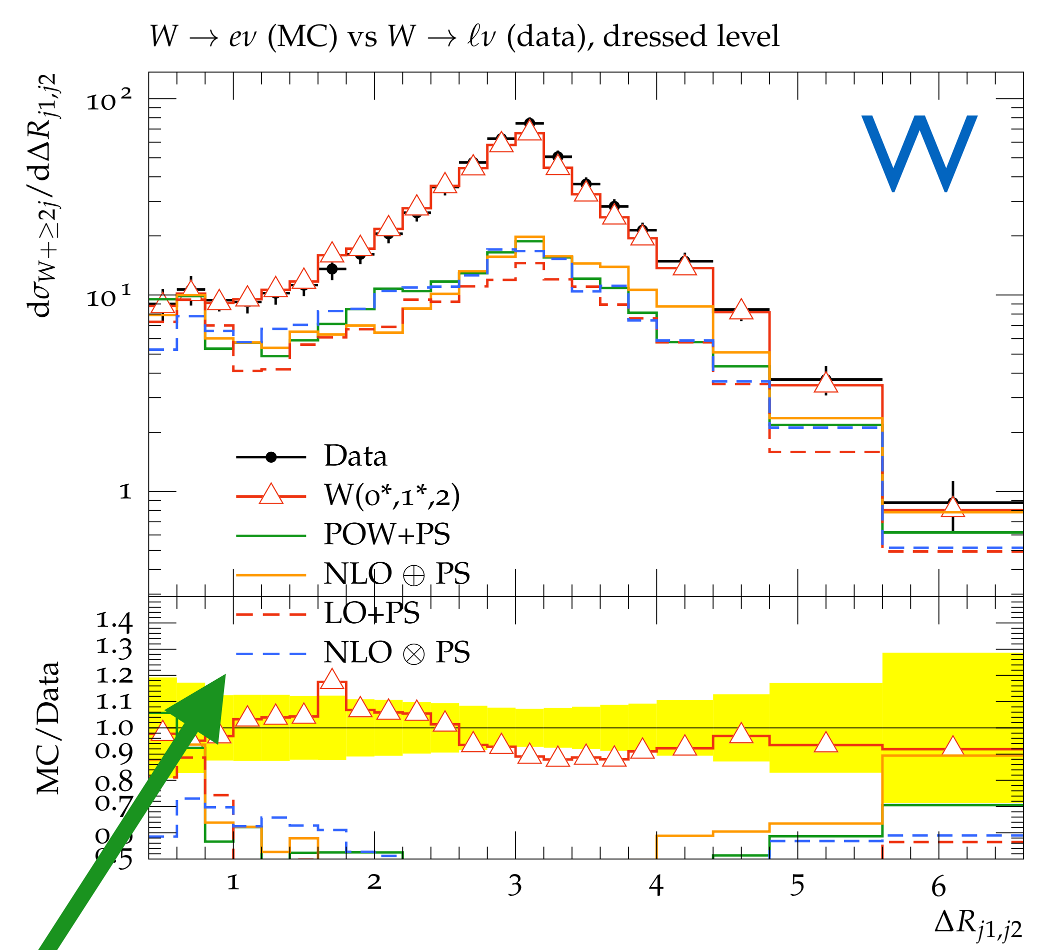






Test Results





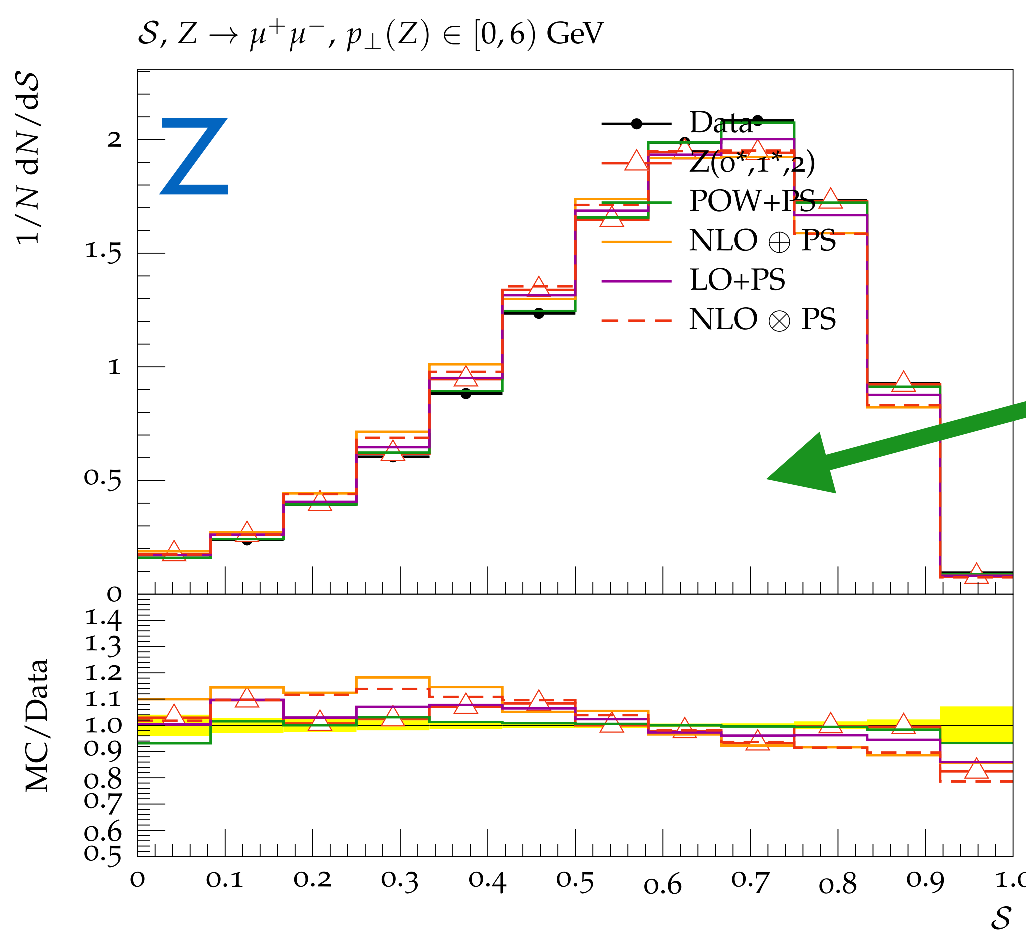
One tune to rule them all…

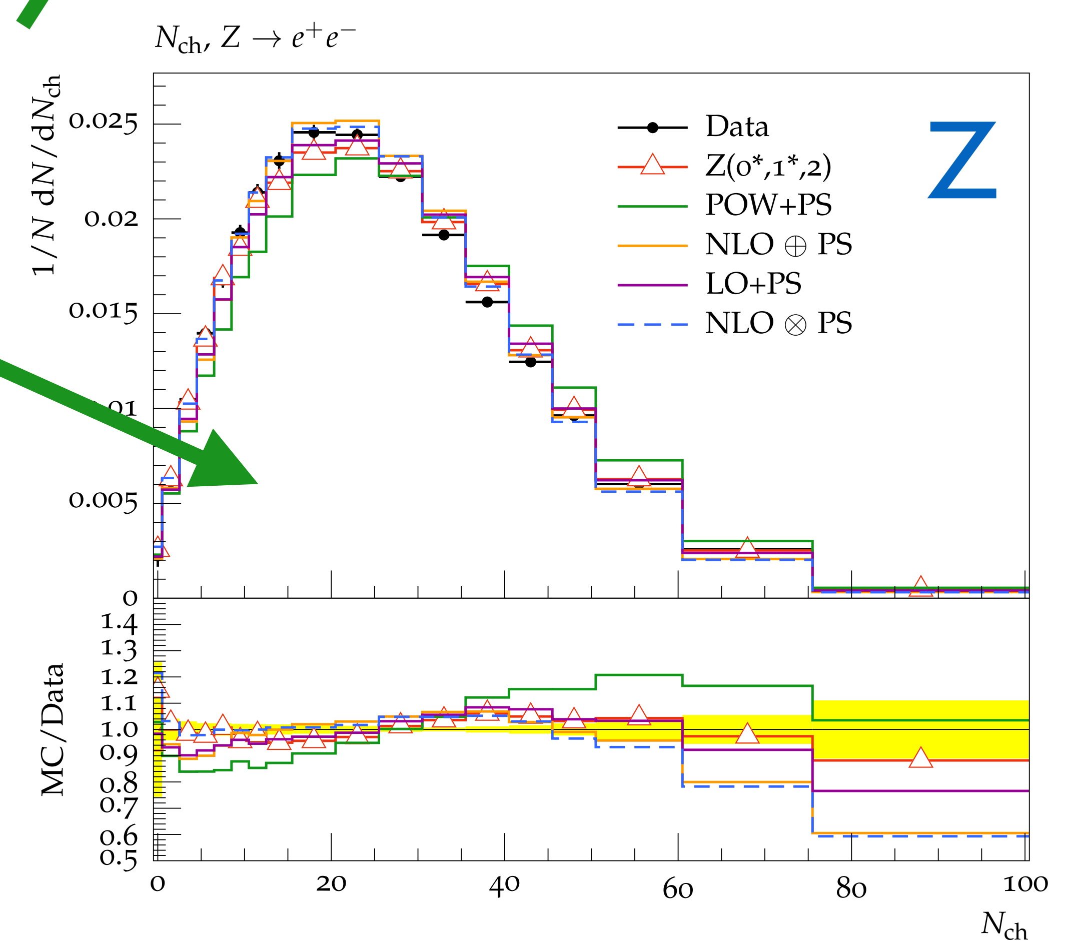
LEP is fine

DIS tested

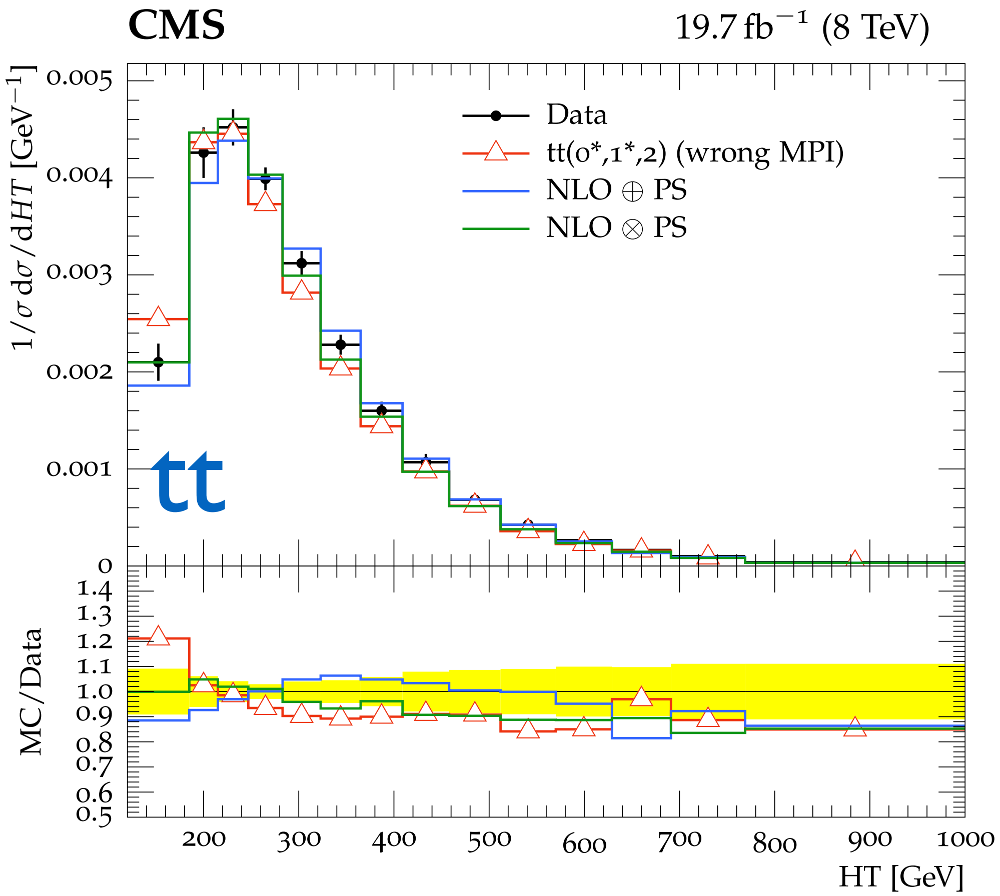
DY hard emissions

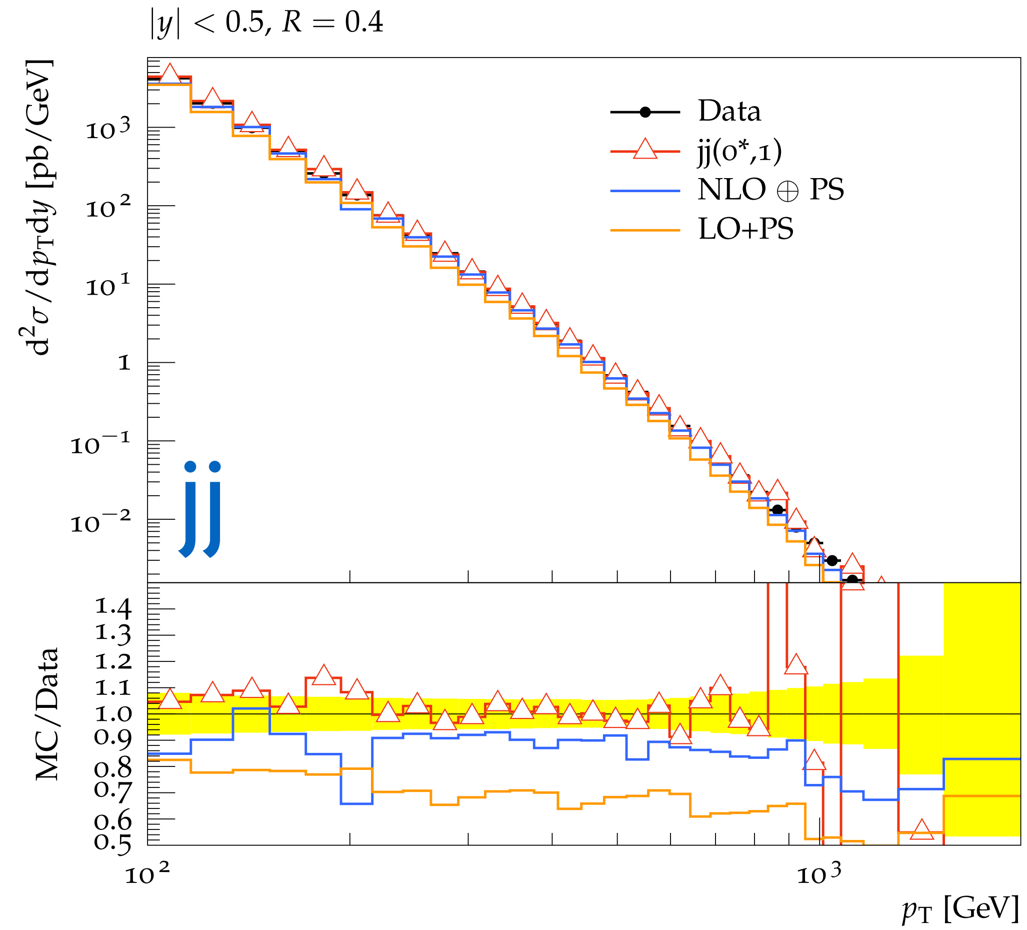
Interplay with MPI needs testing





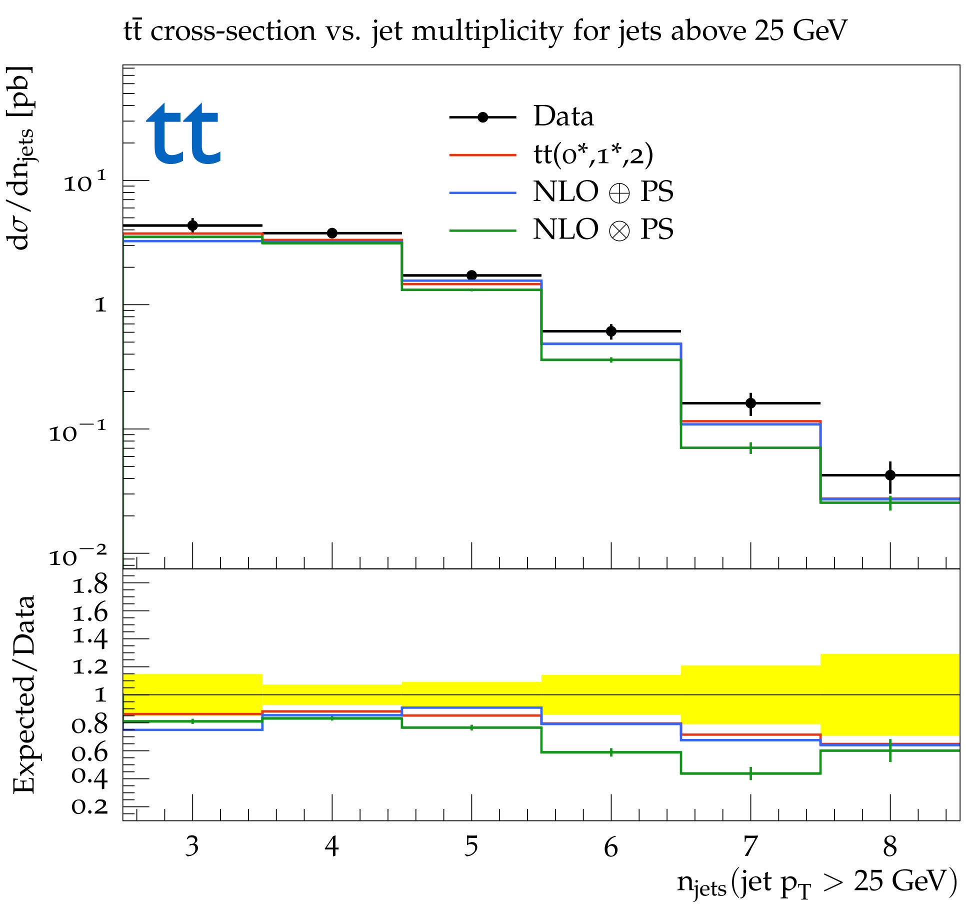
Test Results

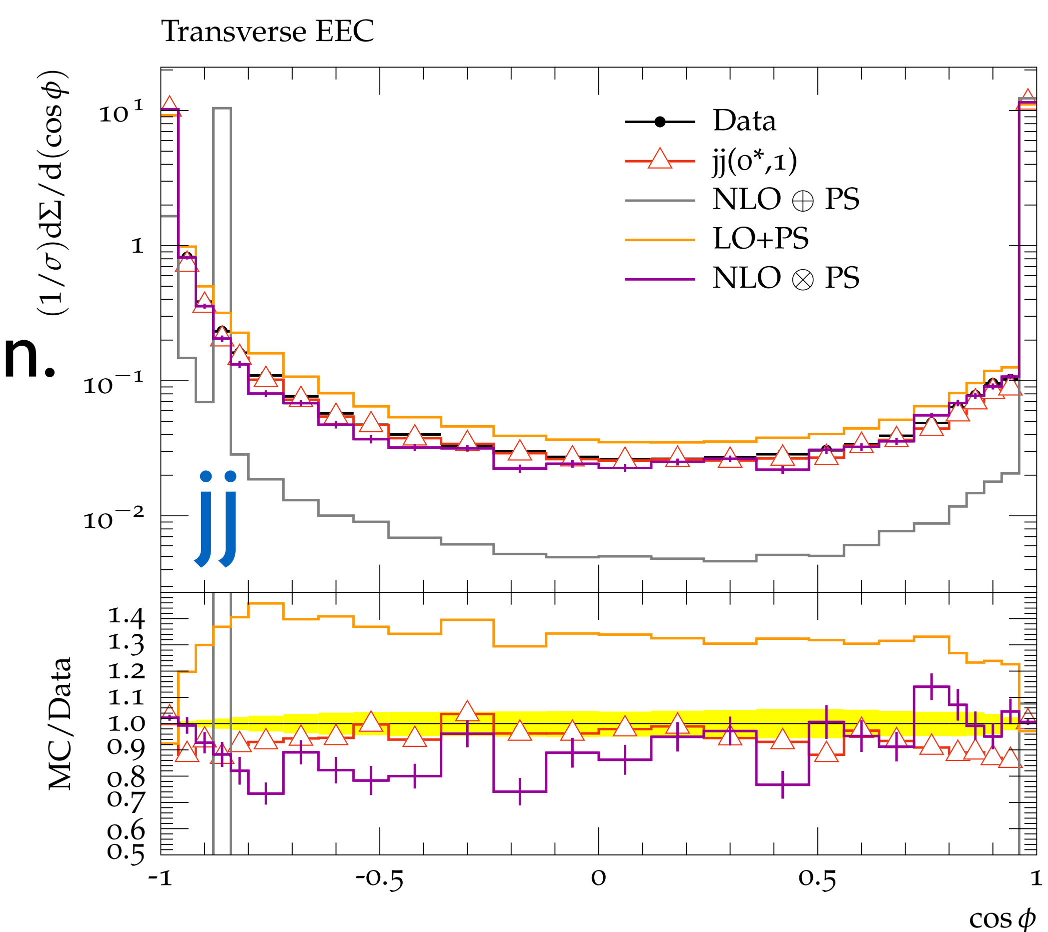




Tops in progress but nothing to worry

Jets need lots of memory. Here only one NLO correction.





Summary and Outlook

- ✦ Close to Release
- ✦ Merging in Herwig
- ✦ Lots of testing
- ✦ well described Z/W/tops and jets physics

Thank You!