Herwig++ Status Report

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(for the collaboration)
University of Manchester

SM@LHC
11th-14th April 2011, IPPP Durham

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Herwig++ main features

- Built-in framework for new physics based on Feynman rules/diagrams
- Many Powhegs and some MC@NLOs built in
- CKKW matching built in
- New angular-ordered parton shower algorithm
  - particular care on flavour-dependence
- Truncated showers
- Cluster hadronization model with improved treatment of baryons/excited mesons

Herwig++ main features

- Underlying event/inclusive soft physics models based on hard+soft eikonal multi-parton interaction model
- Colour reconnection model
- Sophisticated secondary hadron/tau decays
  - including off-shell effects/matrix elements/spin correls.
- Secondary QED radiation

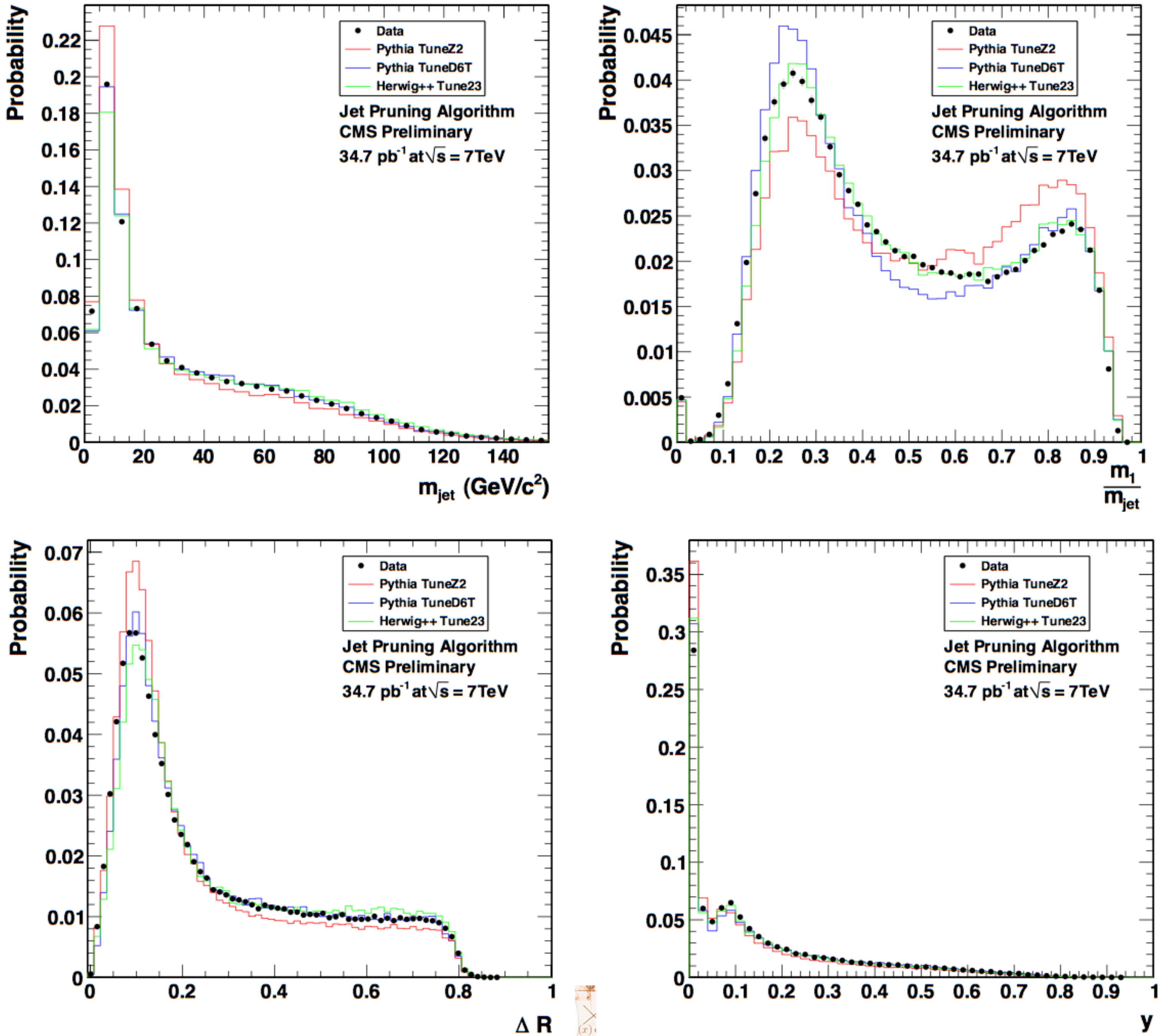
Herwig++ 2.5.0 – February 8th 2011

- new leading-order matrix elements for hadron-hadron and lepton-lepton collisions and photon-initiated processes
- additional models of physics beyond the Standard Model
- new next-to-leading order matrix elements (Powhegs) including weak boson pair production
- new colour reconnection model
- diffractive processes

New parton shower algorithm

Study of Jet Substructure in pp Collisions at 7 TeV in CMS

- Jet pruning/filtering designed to isolate new physics through hard internal jet structure
- Also a good probe of final state parton shower



Probability
Data
Pythia TuneZ2
Pythia TuneD6T
Herwig++ Tune23
Jet Pruning Algorithm
CMS Preliminary
34.7 pb^{-1} at $\sqrt{s}$ = 7TeV
m_{jet} (GeV/c^2)
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$\frac{m_1}{m_{jet}}$
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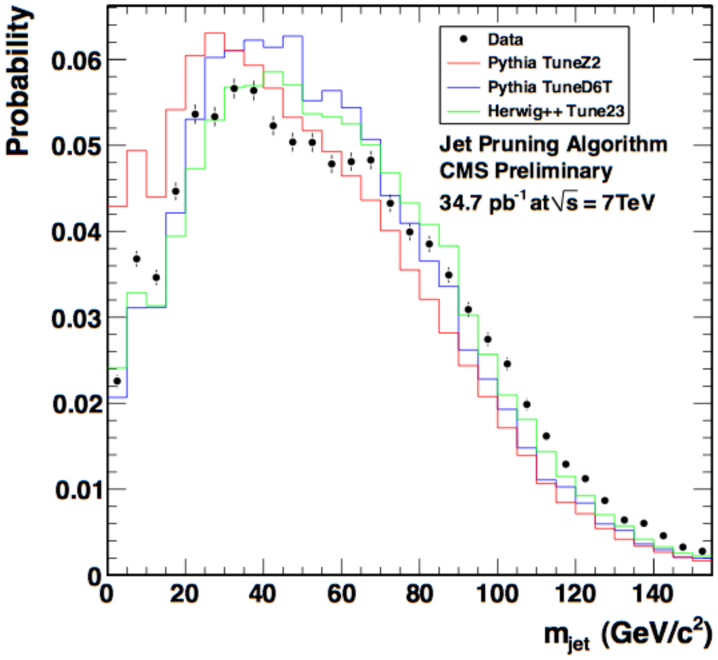

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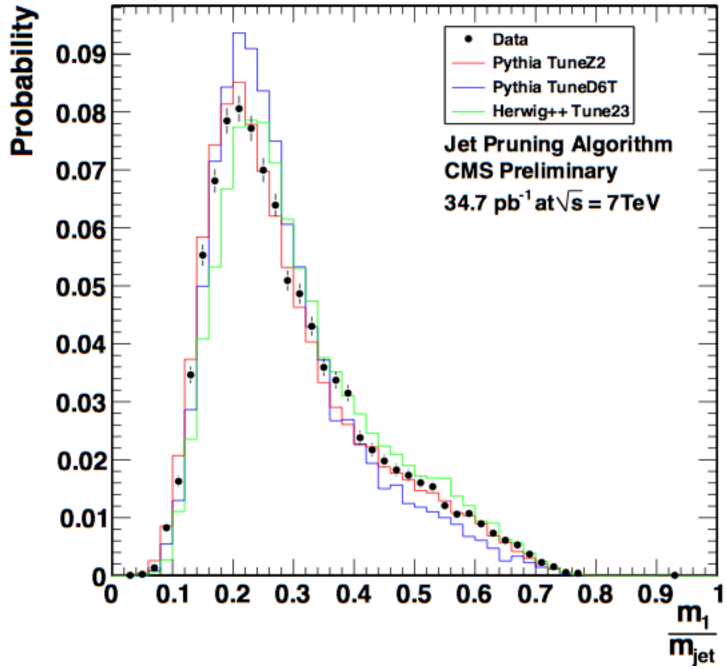

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$\frac{m_1}{m_{jet}}$

Implementation of new physics models

Matthew J. Dolan, David Grellscheid, Joerg Jaeckel,
Valentin V. Khoze, Peter Richardson

arXiv:1104.0585

“New Constraints on Gauge Mediation and Beyond from LHC SUSY Searches at 7 TeV”

New Constraints on Gauge Mediation and Beyond from LHC SUSY Searches at 7 TeV

- New physics model → Herwig++ → Rivet implementation of ATLAS analysis → exclusion

Consistency check: do the same as ATLAS, get the same result as ATLAS →

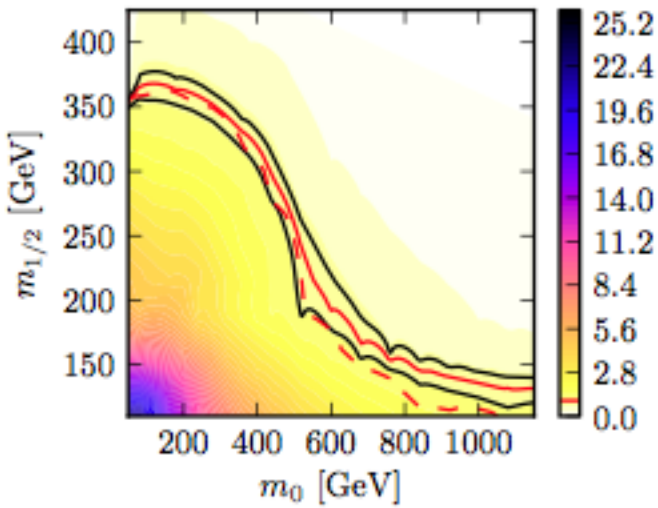


Figure 3: 95% confidence level exclusion limit in the $(m_0, m_{\frac{1}{2}})$ plane for $\tan\beta = 3$, $A_0 = 0$ and $\mu > 0$ in the CMSSM. The solid red line is the result using our signal simulations (the solid black lines show the effect of varying the factorization and renormalisation scales used to calculate the next-to-leading order SUSY production cross sections by a factor of $\frac{1}{2}$ and 2), whereas the dashed red line is the limit obtained by ATLAS in [3]. The colour scale shows the expected number of signal events normalised to the exclusion limit.

Then automate and repeat…

Benchmark point	mediation scenario	σ/pb				status
		A	B	C	D	ATLAS 35pb^{-1}
ATLAS Limits		1.3	0.35	1.1	0.11	
sps1a [12]	CMSSM	2.031	0.933	1.731	0.418	A,B,C,D
sps1b [12]	CMSSM	0.120	0.089	0.098	0.067	allowed
sps2 [12]	CMSSM	0.674	0.388	0.584	0.243	B,D
sps3 [12]	CMSSM	0.123	0.093	0.097	0.067	allowed
sps4 [12]	CMSSM	0.334	0.199	0.309	0.144	D
sps5 [12]	CMSSM	0.606	0.328	0.541	0.190	D
sps6 [12]	CMSSM (non-universal $m_{\frac{1}{2}}$)	0.721	0.416	0.584	0.226	B,D
sps7 [12]	GMSB ($\tilde{\tau}_1$ NLSP)	0.022	0.016	0.023	0.015	allowed
sps8 [12]	GMSB ($\tilde{\chi}_1^0$ NLSP)	0.021	0.011	0.022	0.009	allowed
sps9 [12]	AMSB	0.019*	0.004*	0.006*	0.002*	A,B,C,D
SU1 [13]	CMSSM	0.311	0.212	0.246	0.143	D
SU2 [13]	CMSSM	0.009	0.002	0.010	0.001	allowed
SU3 [13]	CMSSM	0.787	0.440	0.637	0.258	B,D
SU4 [13]	CMSSM	6.723	1.174	7.064	0.406	A,B,C,D
SU6 [13]	CMSSM	0.140	0.101	0.115	0.074	allowed
SU8a [13]	CMSSM	0.251	0.174	0.197	0.120	D
SU9 [13]	CMSSM	0.060	0.046	0.053	0.040	allowed
LM0 [14]	CMSSM	6.723	1.174	7.064	0.406	A,B,C,D
LM1 [14]	CMSSM	2.307	1.108	1.808	0.458	A,B,C,D
LM2a [14]	CMSSM	0.303	0.201	0.241	0.139	D
LM2b [14]	CMSSM	0.260	0.180	0.205	0.123	D
LM3 [14]	CMSSM	1.155	0.504	1.113	0.270	B,C,D
LM4 [14]	CMSSM	0.783	0.432	0.699	0.260	B,D
LM5 [14]	CMSSM	0.202	0.138	0.179	0.109	allowed
LM6 [14]	CMSSM	0.127	0.094	0.099	0.068	allowed
LM7 [14]	CMSSM	0.062	0.013	0.072	0.006	allowed
LM8 [14]	CMSSM	0.189	0.099	0.194	0.082	allowed
LM9a [14]	CMSSM	0.238	0.029	0.358	0.015	allowed
LM9b [14]	CMSSM	0.075	0.017	0.088	0.009	allowed
LM10 [14]	CMSSM	0.003	0.000	0.003	0.000	allowed
LM11 [14]	CMSSM	0.358	0.223	0.311	0.166	D
LM12 [14]	CMSSM	0.037	0.008	0.043	0.004	allowed
LM13 [14]	CMSSM	2.523	0.904	2.289	0.331	A,B,C,D
PGM1a [11]	pure GGM ($\tilde{\chi}_1^0$ NLSP)	0.351	0.030	0.570	0.009	allowed
PGM1b [11]	pure GGM ($\tilde{\chi}_1^0$ NLSP)	0.373	0.032	0.625	0.014	allowed
PGM2 [11]	pure GGM ($\tilde{\tau}_1$ NLSP)	0.008*	0.005*	0.009*	0.003*	allowed
PGM3 [11]	pure GGM ($\tilde{\tau}_1, \tilde{\chi}_1^0$ co-NLSP)	0.140	0.103	0.121	0.086	allowed
PGM4 [11]	pure GGM ($\tilde{\tau}_1$ NLSP)	0.000	0.000	0.000	0.000	allowed

Table 1: Status of SUSY benchmark points. For each point the columns labelled A,B,C and D give the cross section for each of the signal regions used in the ATLAS analysis [3]. The last column shows which of the four regions the point is excluded by using the new data. In the GMSB scenerio the NLSP was taken to be stable on collider time scales. The starred cross sections are computed at leading-order values whereas all the other values are NLO.

Then automate and repeat…

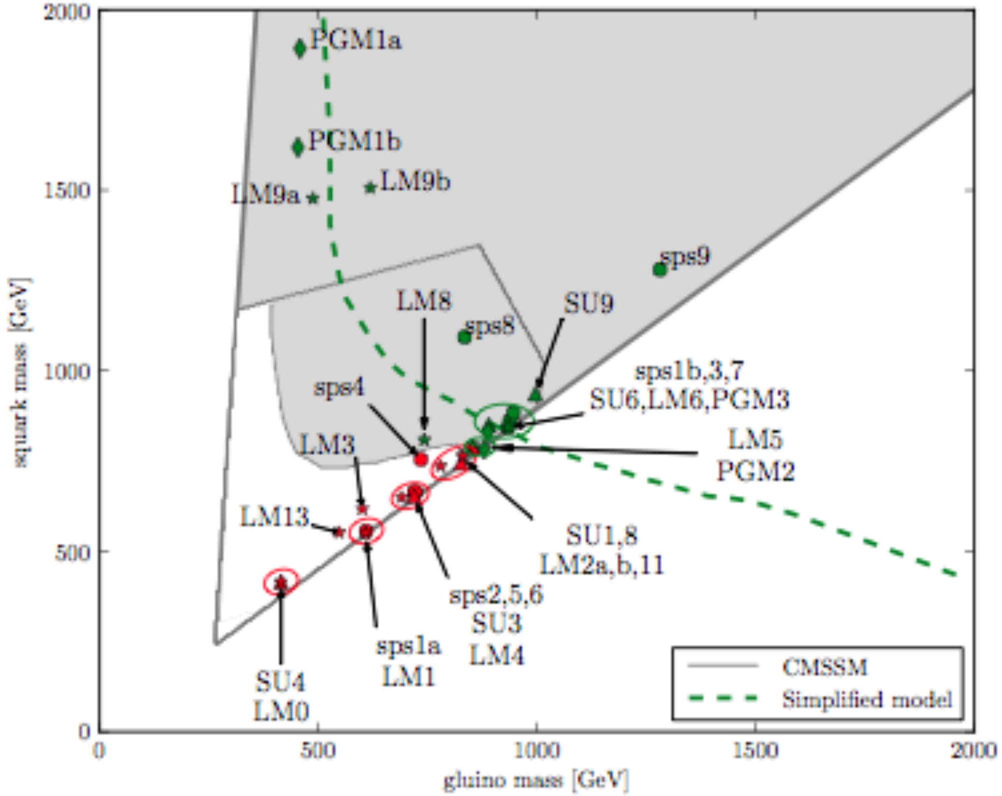
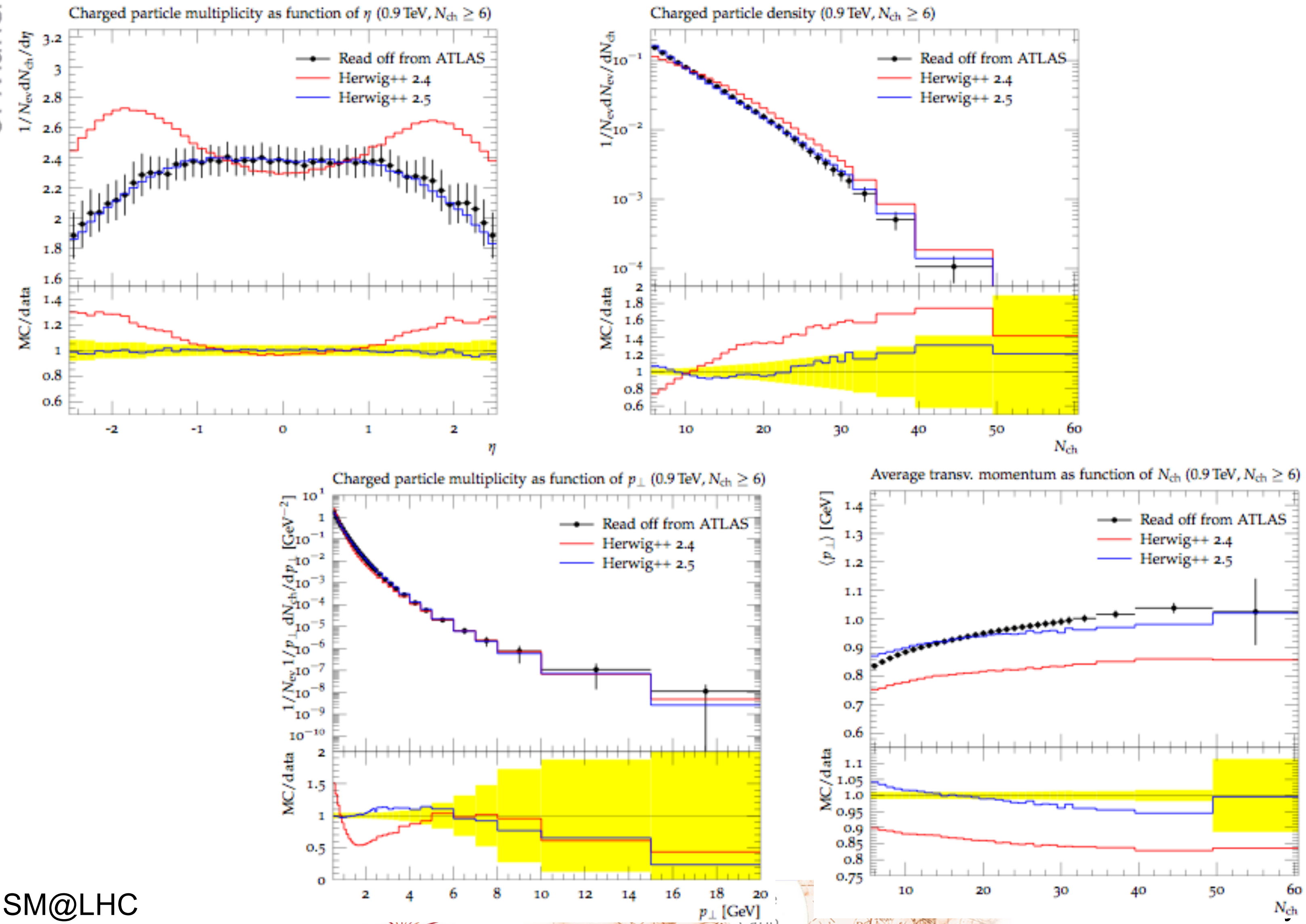


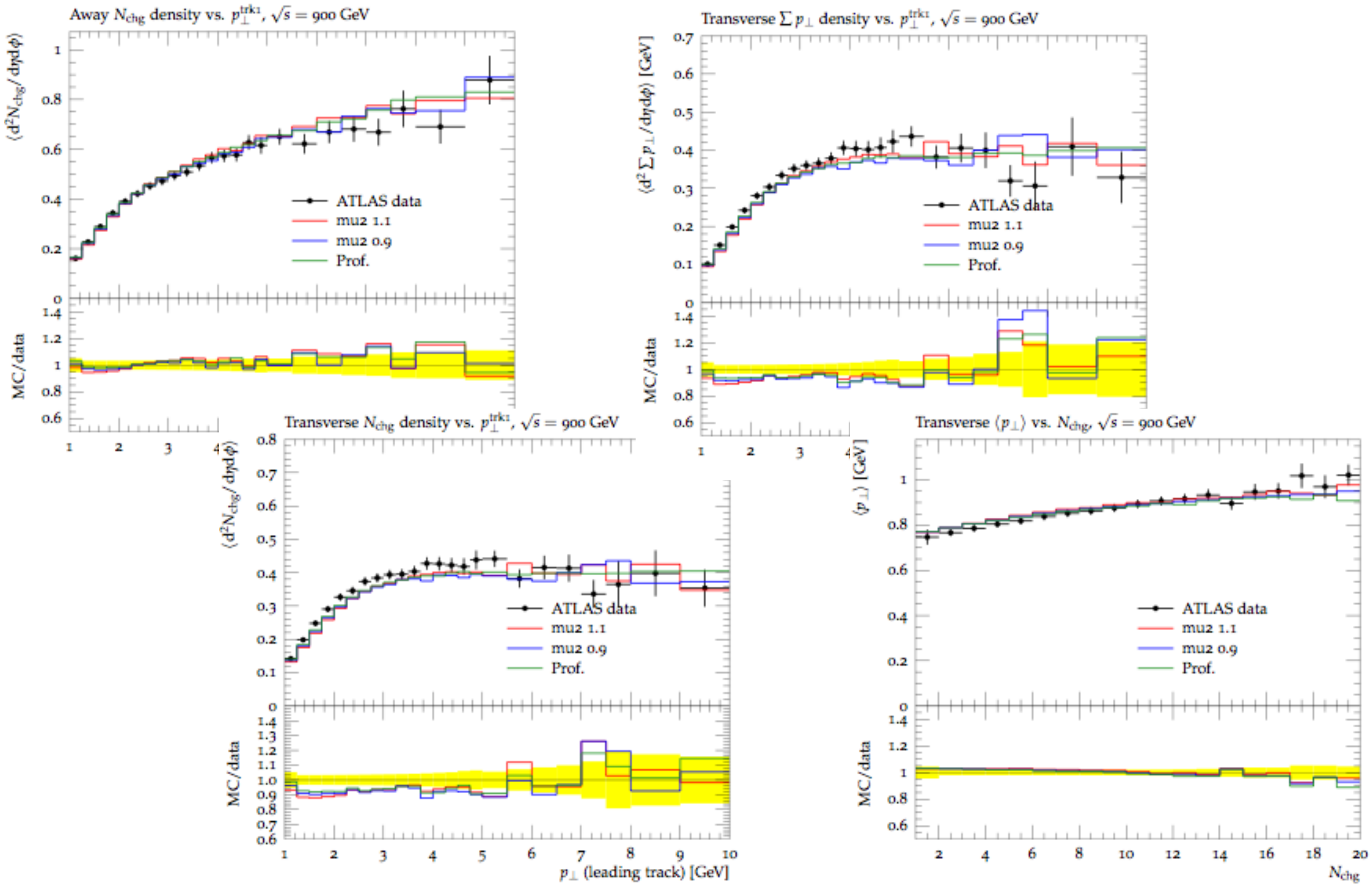
Figure 5: This plot shows constraints on the CMSSM for $\tan\beta = 3$, $A_0 = 0$ and $\mu > 0$ mapped into the plane of the physical squark (average of first generation) and gluino masses. The kite-shaped area shows the same region of parameter space as in Fig. 3. The grey area is still allowed, whereas the white region inside the kite is now excluded by the ATLAS measurements [3]. The region below the diagonal $m_{\tilde{g}} \lesssim m_{\tilde{q}}$ is not part of the CMSSM parameter space due to the influence of the gluino mass on the squark masses during the RG evolution. The dashed green line gives the constraints obtained from a simplified model (containing only squarks and gluinos and a massless neutralino) in [3]. The reduced sensitivity in the CMSSM is mainly due to the non-negligible neutralino mass. The labelled points are the benchmark points of Tab. 1. Red points are now excluded whereas green points are still viable.

Colour reconnection model/
MPI tuning

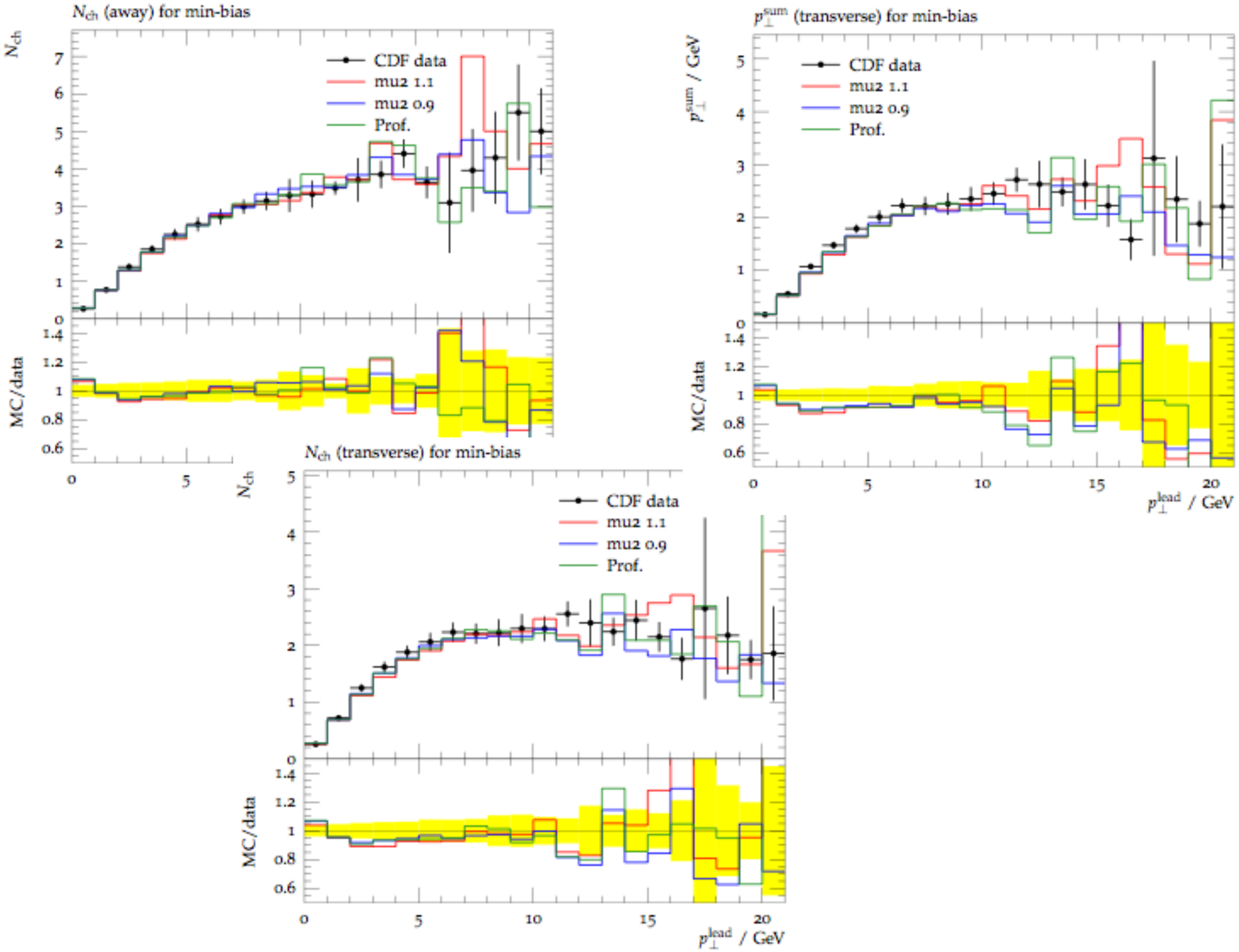
Colour reconnection model/MPI tuning



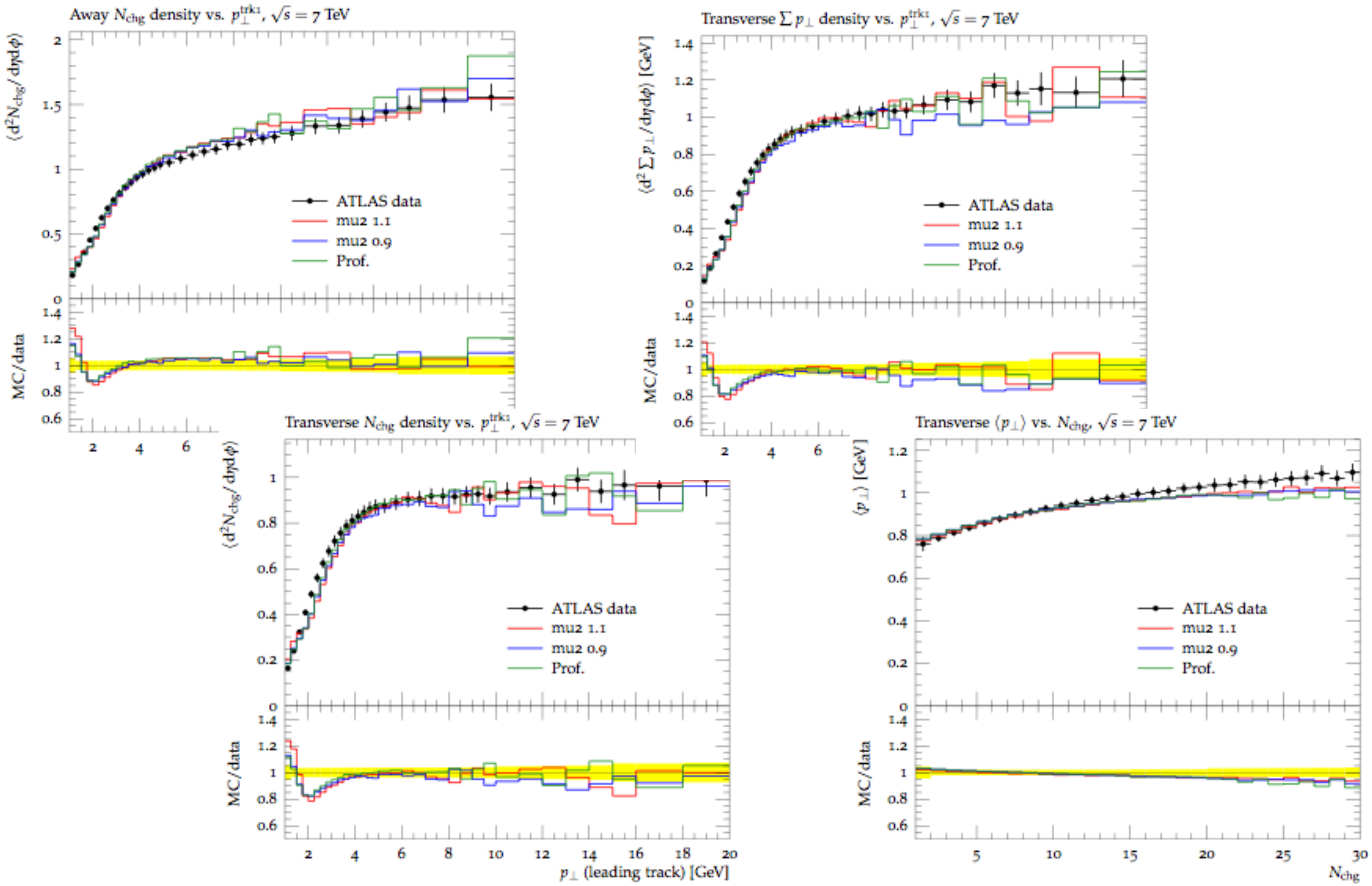
Underlying event at 900 GeV



Underlying event at 1800 GeV



Underlying event at 7000 GeV



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Tuning conclusion

- Not possible to fit with energy-independent parameters
- Possible to fit with energy-dependent $p_{t,min}$ and all else energy-independent
- e.g.

For μ^2=	1.1 GeV^2	0.9 GeV^2
and $\sqrt{s}$=	PTMIN=	PTMIN=
900	2.34	2.17
1800	3.09	2.80
2760	3.31	2.92
7000	4.02	3.36

Prediction/ Recommendation

Tuning conclusion

- Public version: 2.5.0, released 8th Feb 2011
  - does not come with latest tuned values
    - check http://projects.hepforge.org/herwig/trac/wiki/MB_UE_tunes for updates

POWHEG implementations

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Herwig++ POWHEGs

Shipping with the current release HW++ 2.5

- hh $\rightarrow \gamma$ / Z / W / H / ZH / WH [KH, Richardson, Tully]
- hh $\rightarrow$ WW / ZZ / WZ [KH]
- H $\rightarrow$ Q $\bar{\mathrm{Q}}$ [Richardson, Winn]
- Spin correlations in decays [also for real emissions]
- QCD coherence via Nason's truncated shower idea

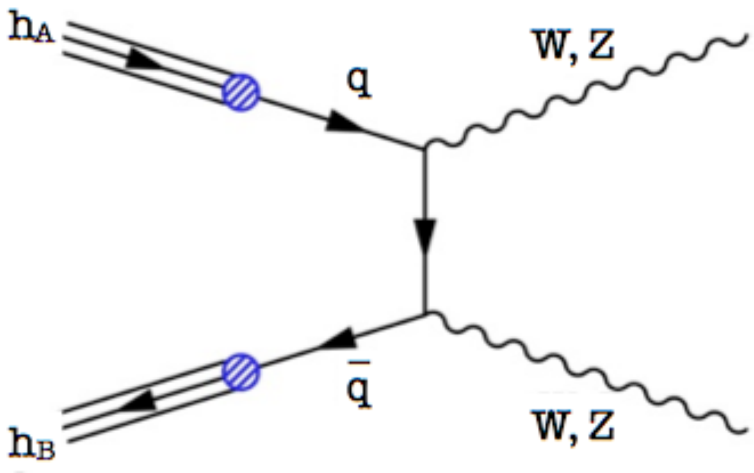
Herwig++ POWHEGs

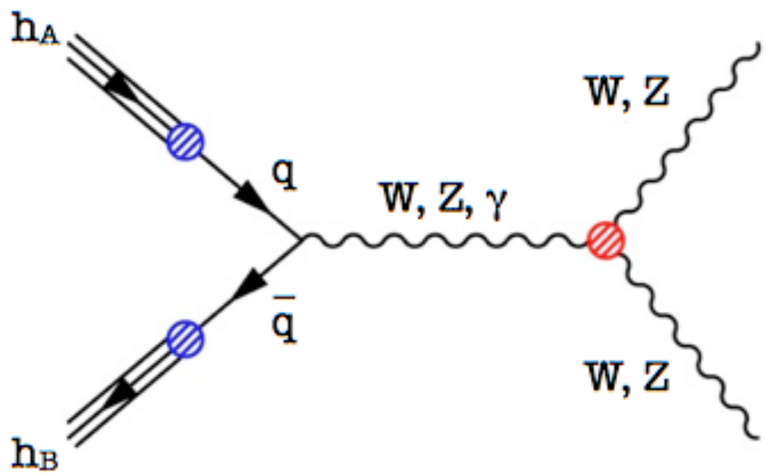
Just finishing ...

- VBF [D'Errico, Richardson]
- hh $\rightarrow \gamma\gamma$
- hh $\rightarrow \tilde{l}\tilde{l}$ / $\chi^0\chi^0$/ $\chi^+\chi^-$/ $\chi^\pm\chi^0$ [Fridman-Rojas, Richardson]

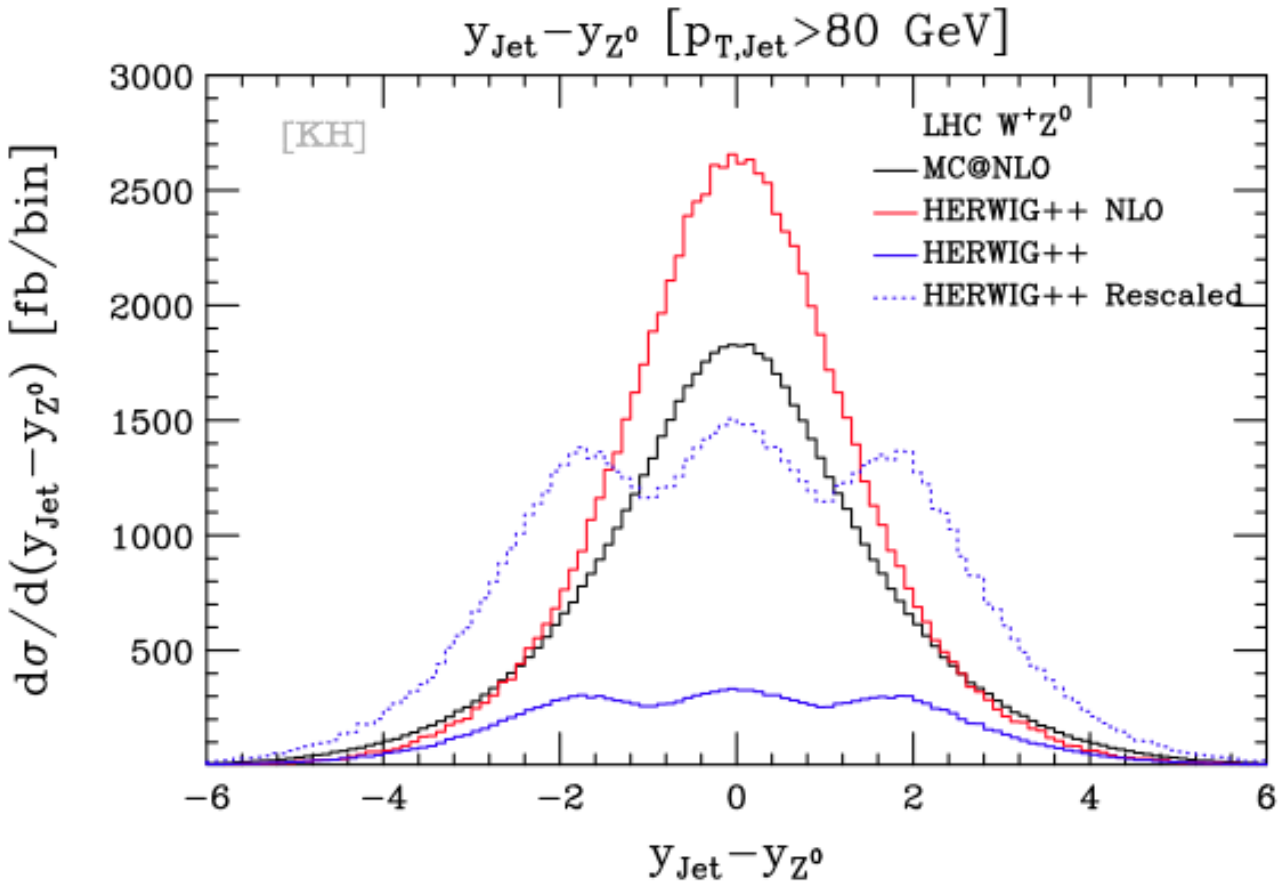
Results

Resonant diboson production



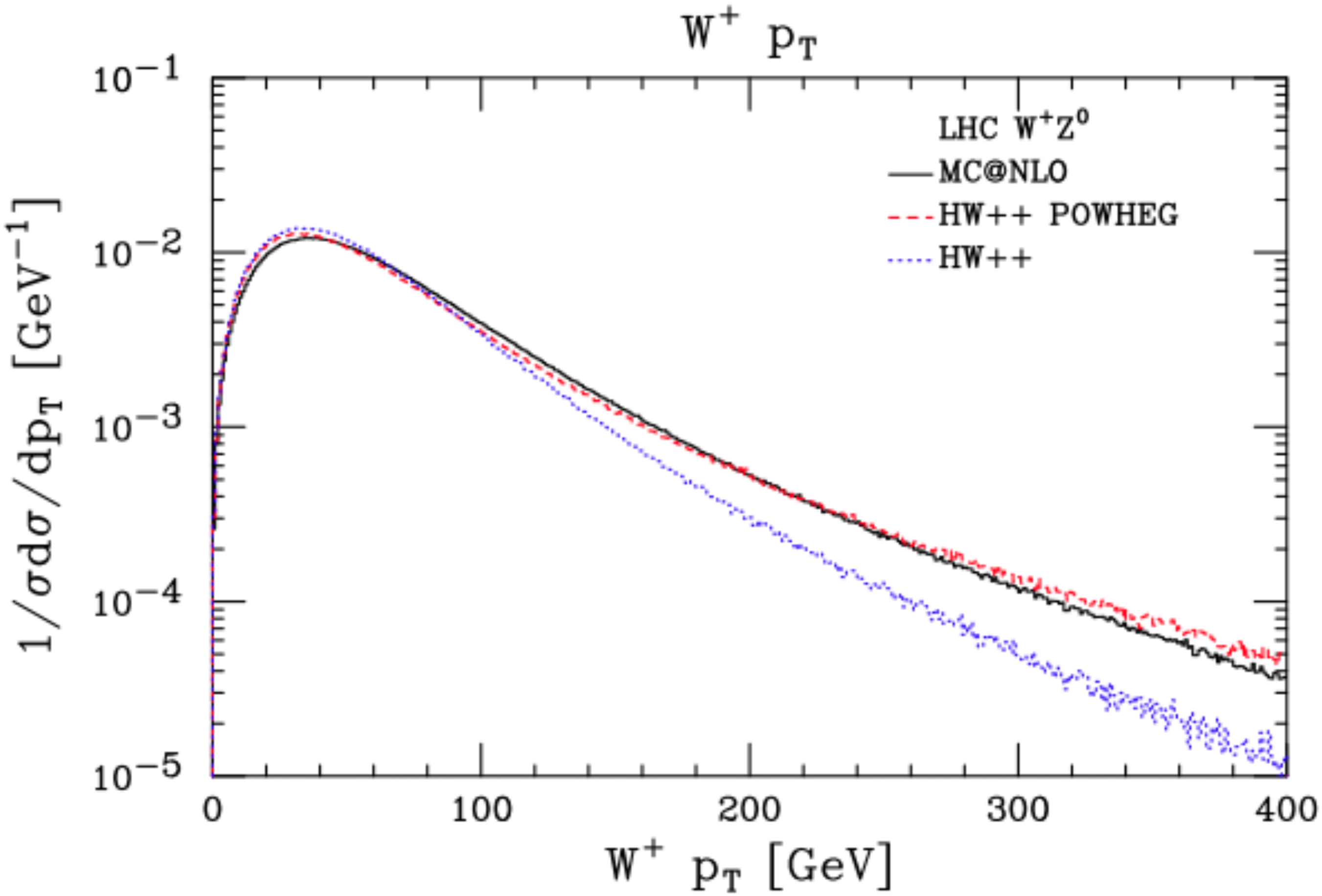


Resonant diboson production



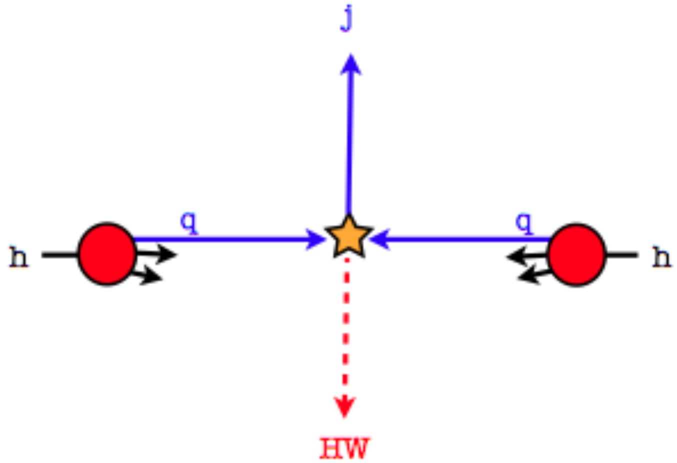
- LO total inclusive cross section
- PS has half as many 80 GeV jet events [LL approx]
- Direction of hard jets not like the NLO real correction

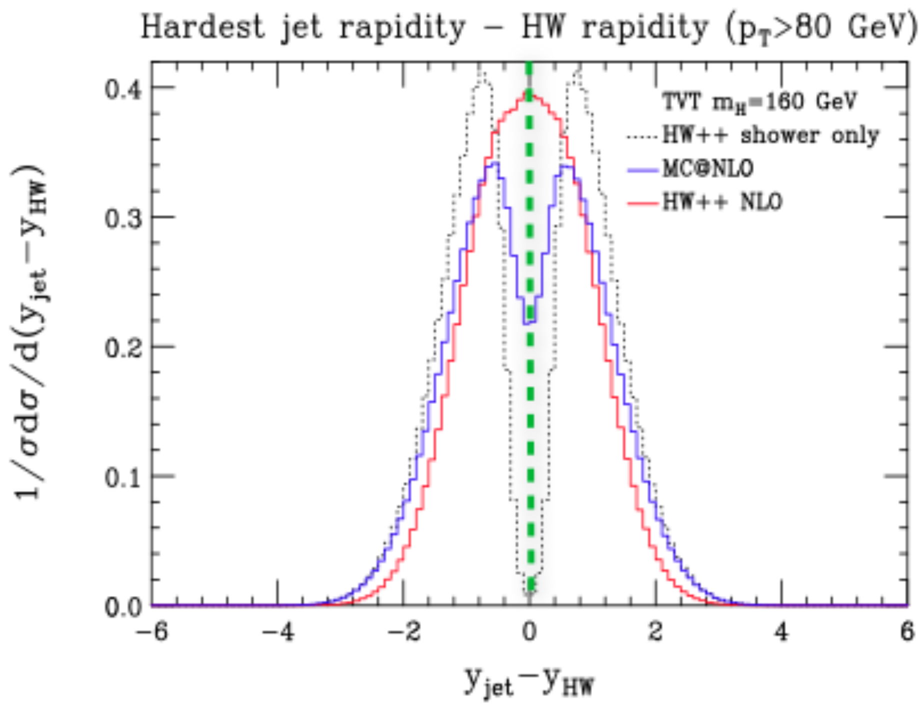
Resonant diboson production



- Factor of 3 enhancement in NLO distribution!
- Really "soft" W emission from hard quark $qg \rightarrow qZ \rightarrow qWZ$
- Also big enhancement due to incident gluon flux [Frixione et al]

Higgs-strahlung ($q\bar{q} \to HW^-$)





[KH, Richardson, Tully]

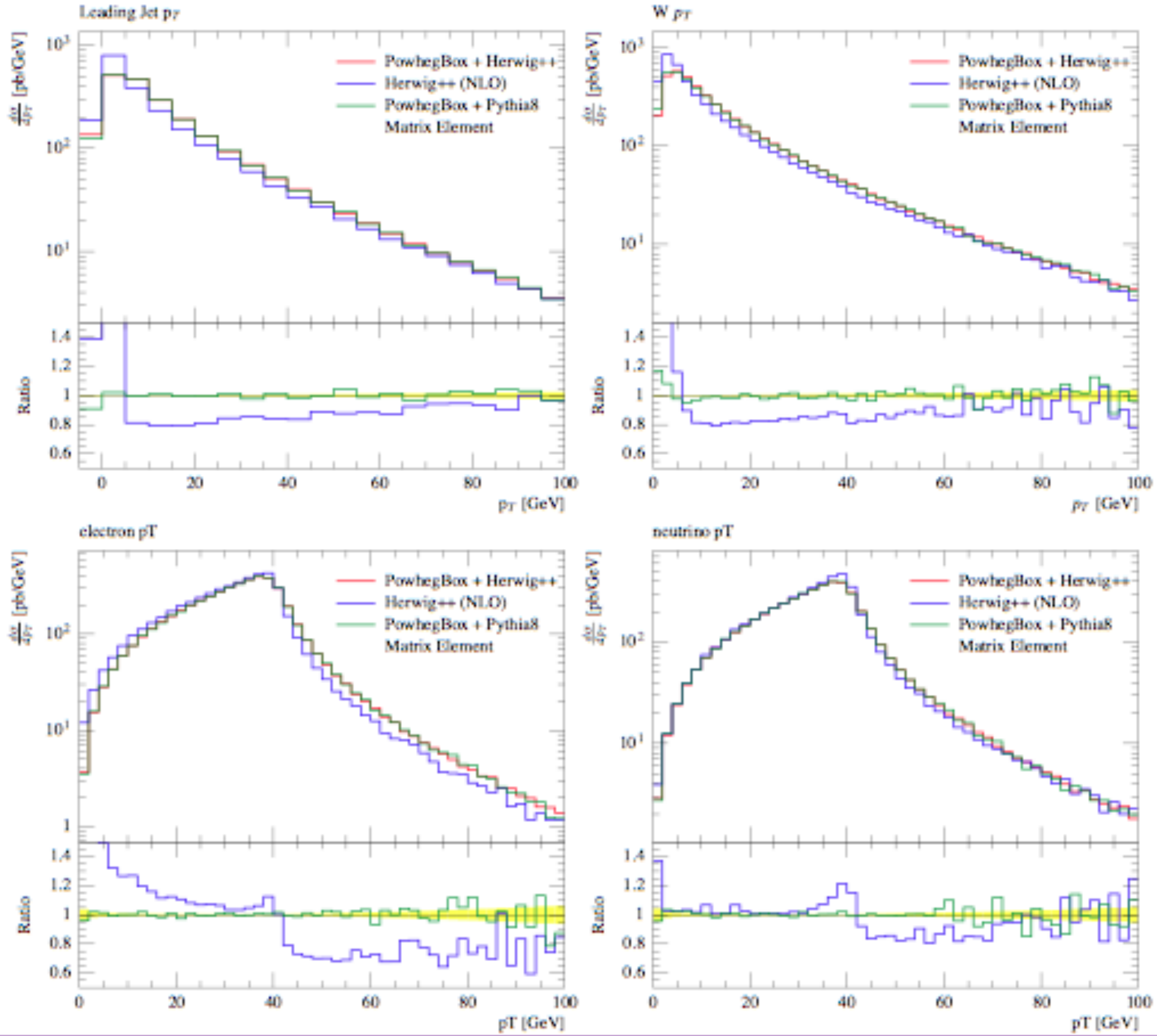
Internal vs external POWHEGs

POWHEG Validation with Herwig++ and Pythia8

Kiran Joshi, Andy Pilkington, Mike Seymour

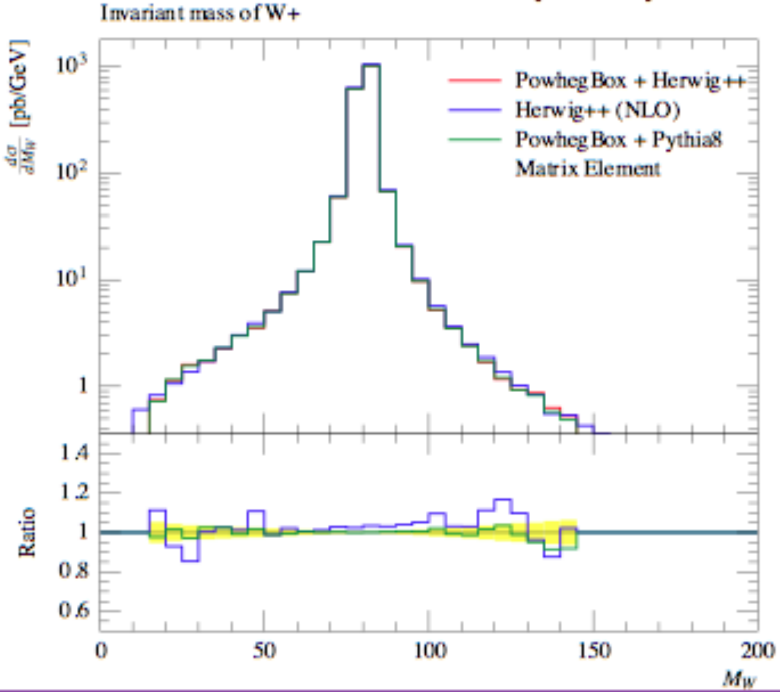
University of Manchester

Matrix Element level



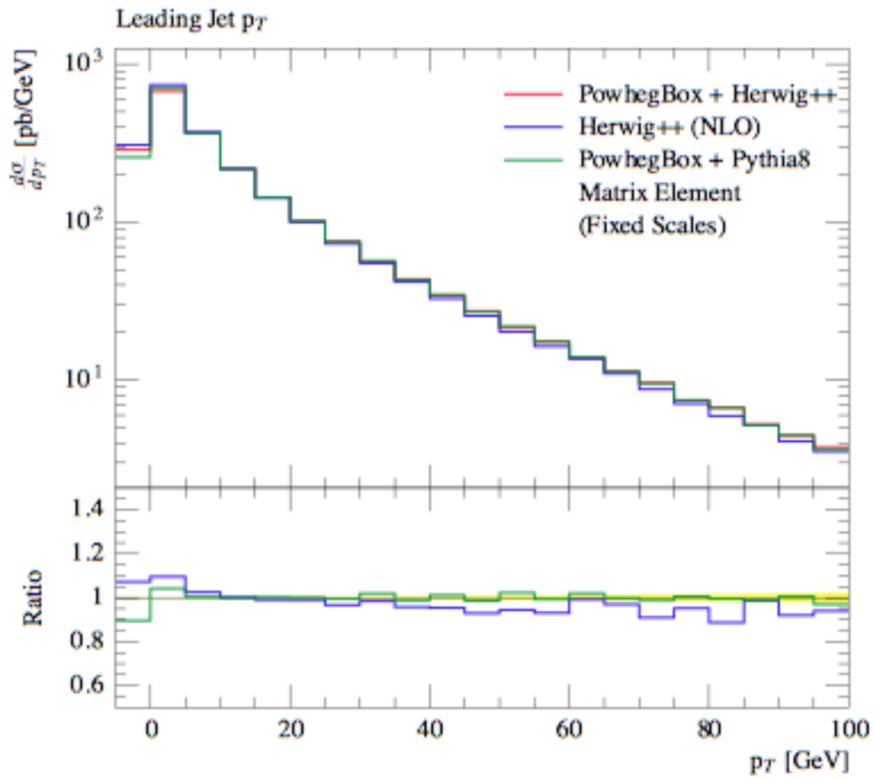
Matrix Element level

- Difference in M_W due to QED radiation
  - Turned on by default in Herwig++ NLO and Pythia8, but not when showering Powheg-Box with HW++
  - Turn QED radiation off in HW++ (NLO) and Pythia8:



Matrix Element level

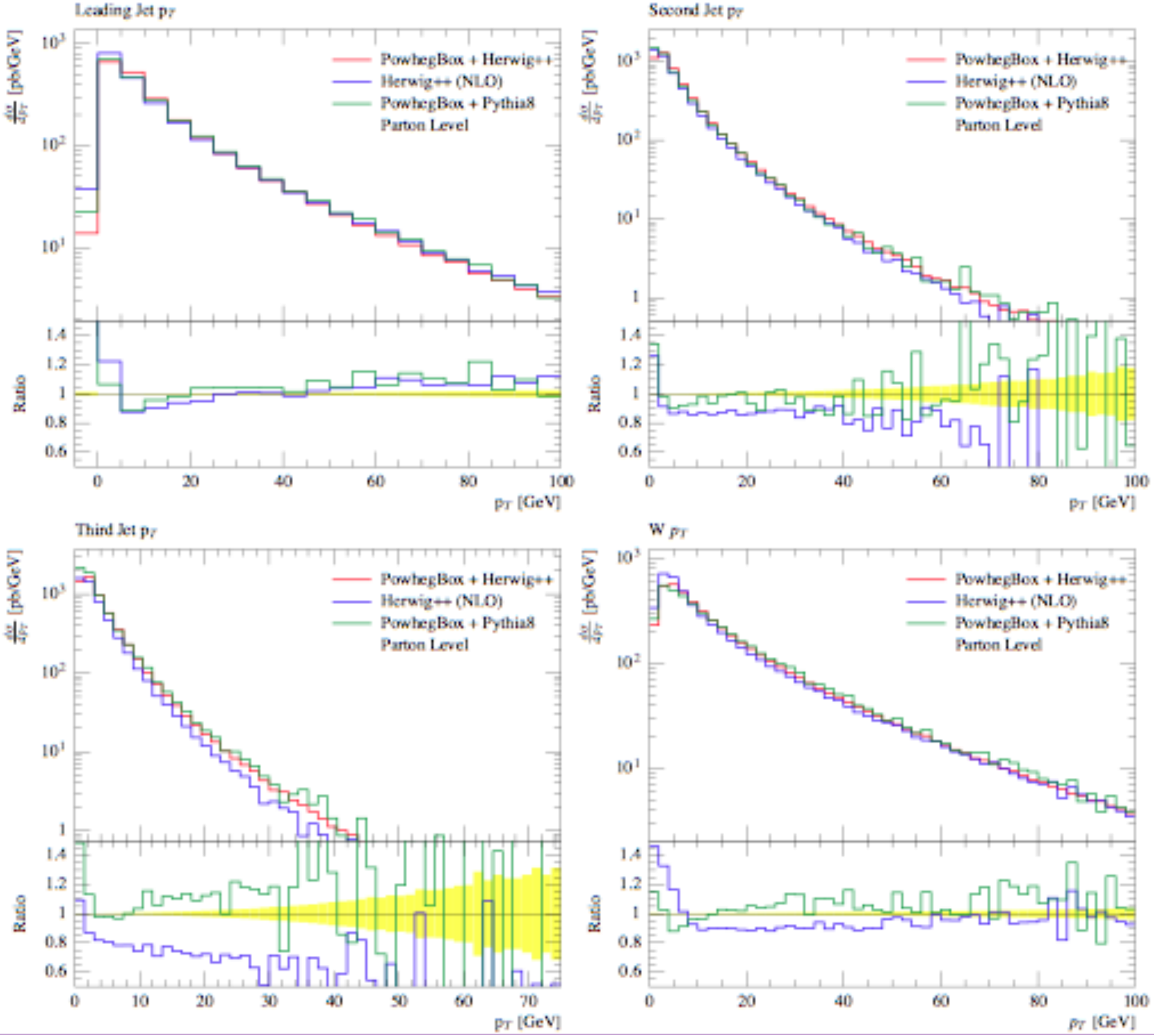
- Difference in p_T distributions due to different scale choices.
  - Powheg-Box default = p_T
  - HW++ default = M_T



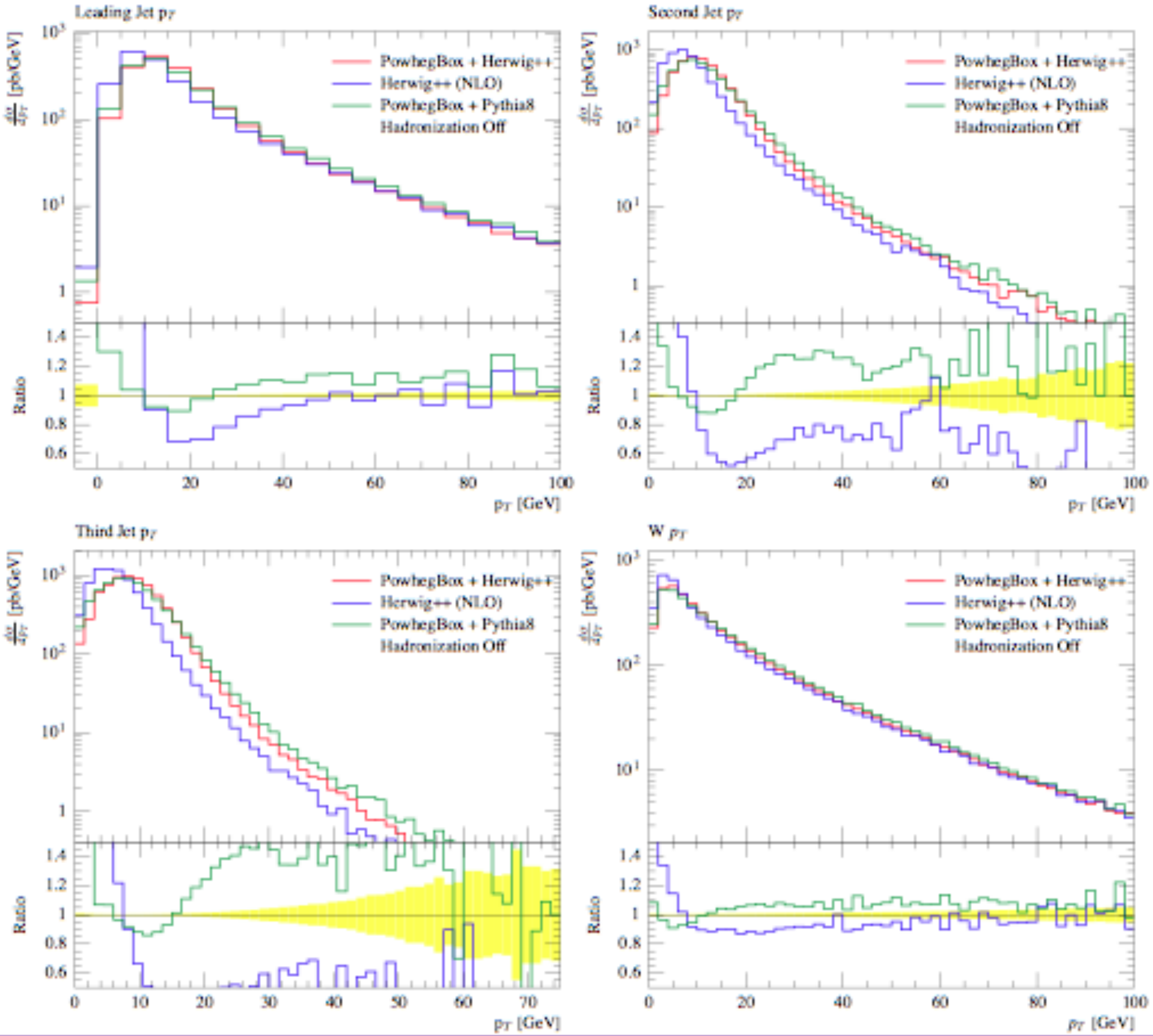
- Force both to use the same (fixed) scale:

  (nearly)

Parton level

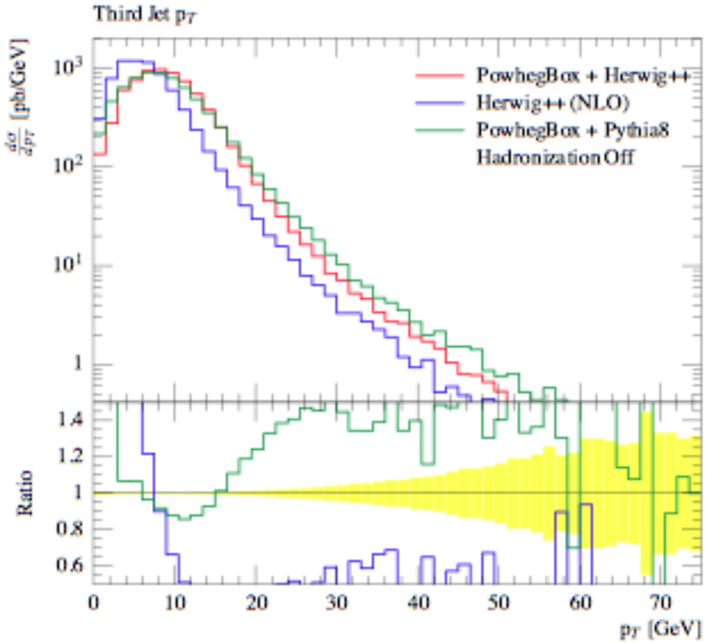


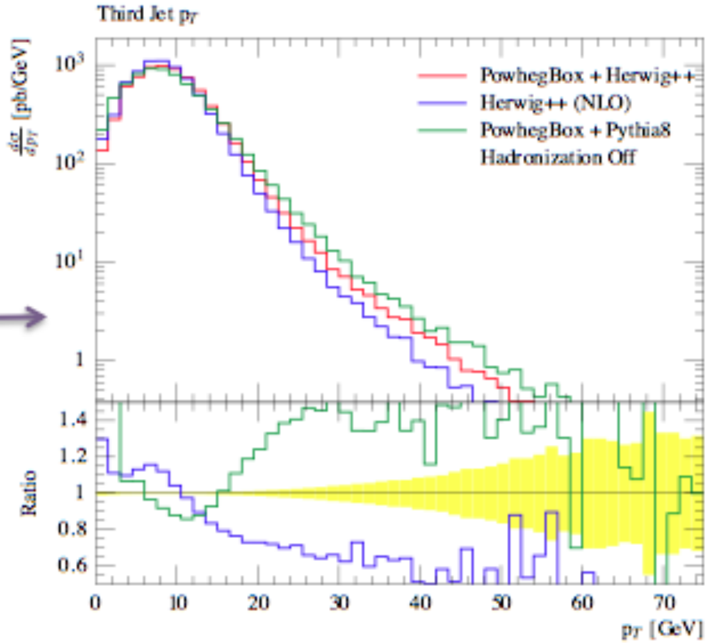
Hadronization Off



Hadronization Off

- pT shift partially caused by different default PDFs
  - In HW++ (NLO), PDF used in the hard process is also used for MPI.
  - Powheg-Box + HW++ uses the default LO PDF for MPI.
- Setting the same PDFs (NLO for hard process, LO** for MPI):





POWHEG validation conclusion

- Internal/external Powheg should be ~identical
- By default they are as different as Pythia
- Still haven't identified all differences

Simulation of gap-between-jets events

Alex Schofield & MHS,
arXiv:1103.4811

"Jet vetoing and Herwig++"

- Colour partner treatment for gluons in fHERWIG and Herwig++…

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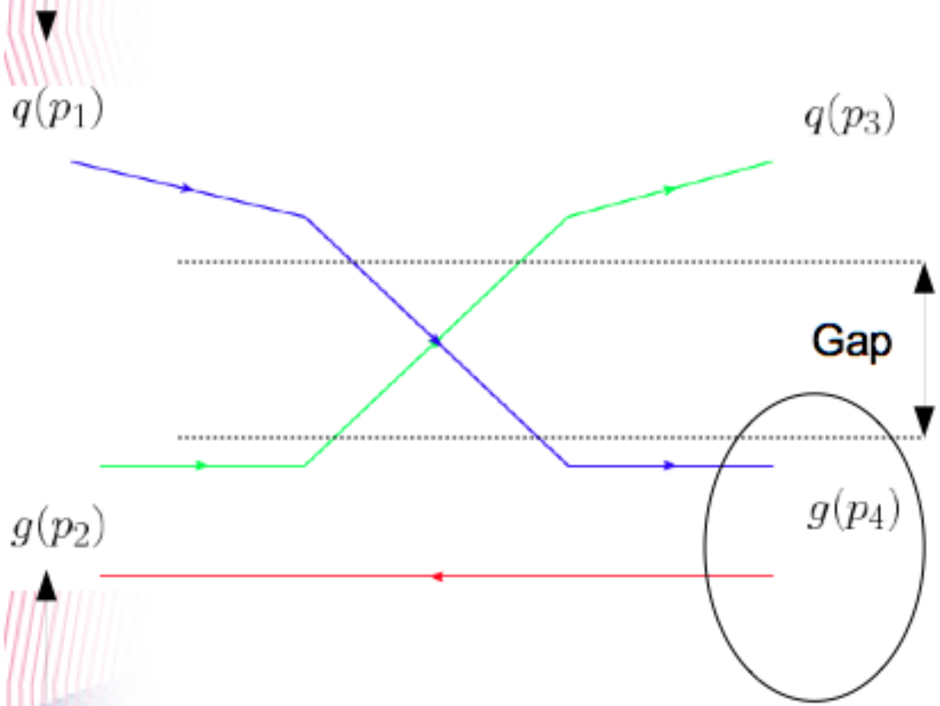
Colour partners

Partner one:
Across the gap



Partner two: Same side of the gap

Analytical model

Gluon evolution (Both partners across the gap)

$\mathrm{Exp}[-\Gamma_g]$

Gluon evolution (Only one partner across the gap)

$\frac{1}{2}\,(1 + \mathrm{Exp}[-2\Gamma_g])$

Partner on the same side of the gap

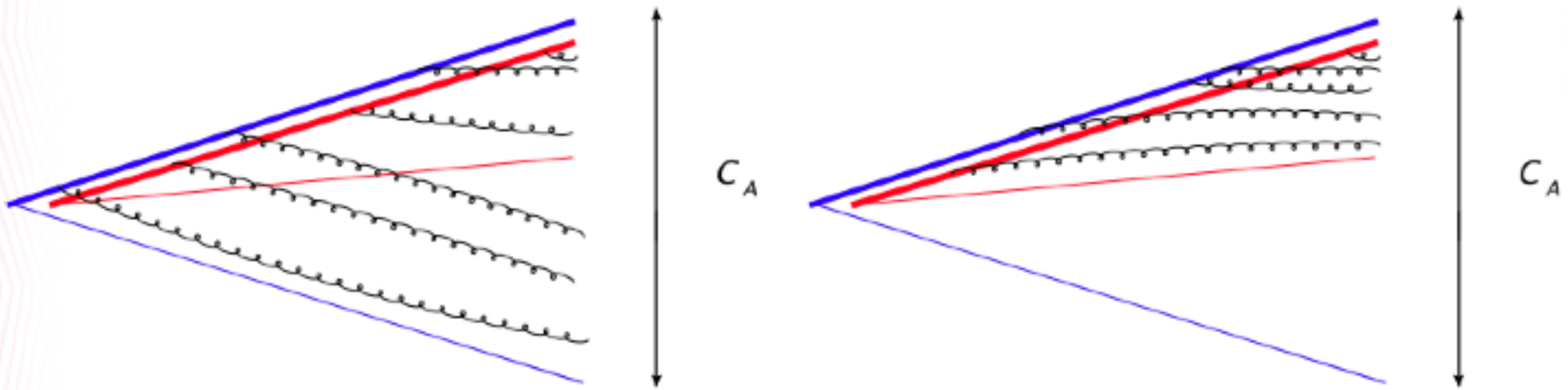
Partner is across the gap

Quark evolution is unchanged

Parton shower chooses one of the two colour partners with 50-50 chance

For gg->gg this can lead to “singlets”

Colour partners - Radiation



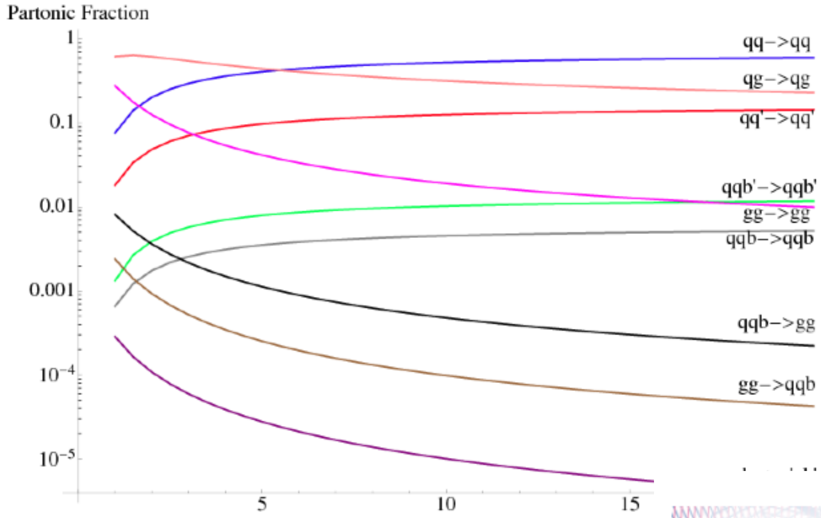
Wide angle partner chosen:
Radiation throughout the whole of phase space with colour factor C_A.

Small angle partner chosen:
Only small angle radiation with colour factor C_A.

In both cases, radiation is attached randomly to one of the gluon's two colour lines. This doesn't change the behaviour of the shower, but it does cause problems when hadronization is taken into account.

Y=5
Q=500GeV
S=14TeV

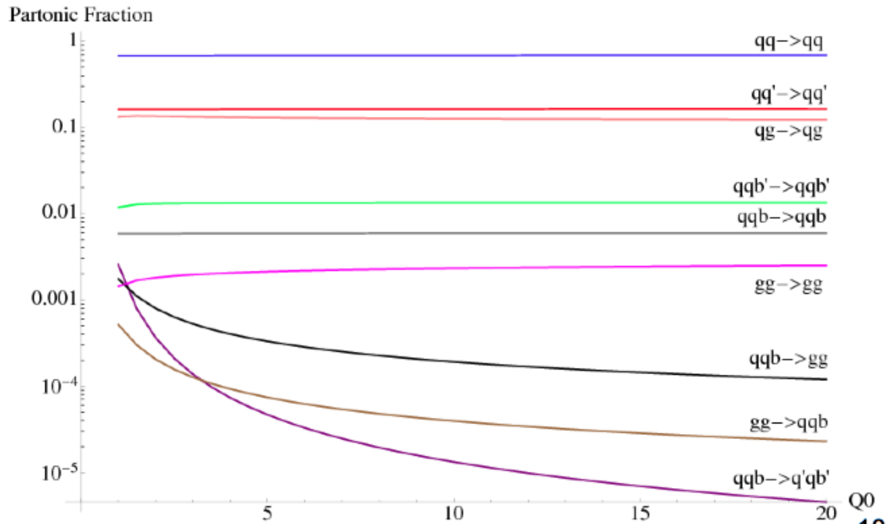
Partonic Fractions



"HERWIG++" - qg->qg, gg->gg dominates for low Q0

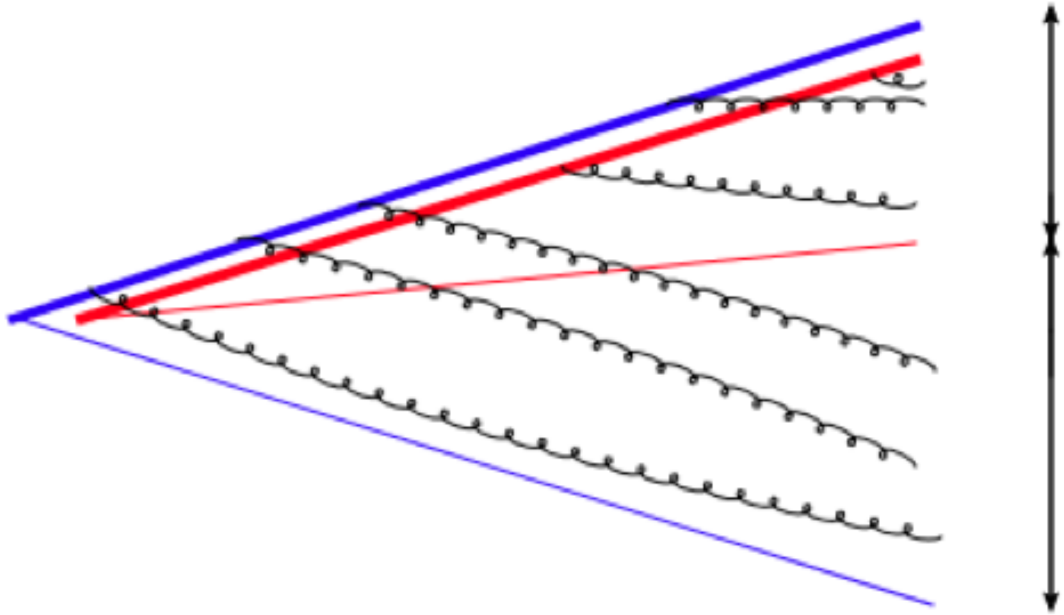
Y=5
Q=500GeV
S=14TeV

Partonic Fractions



Analytical without interferences – qq type interactions dominate

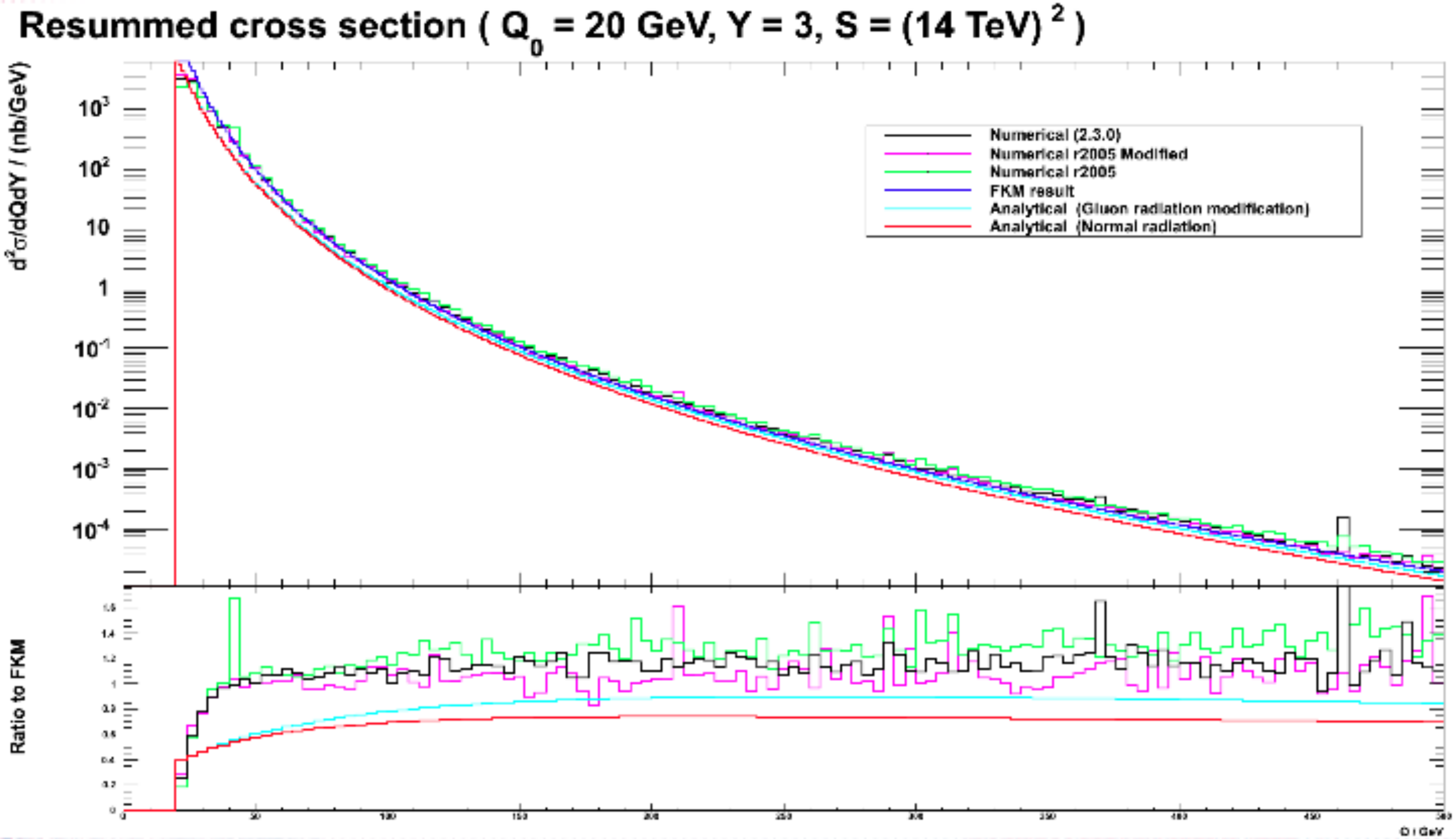
Modifications to shower



The correct colour factor is now used for wide angle radiation.

Wide angle radiation is now only attached to the wide angle colour line. This generates the correct hadronization behaviour.

Cross section results



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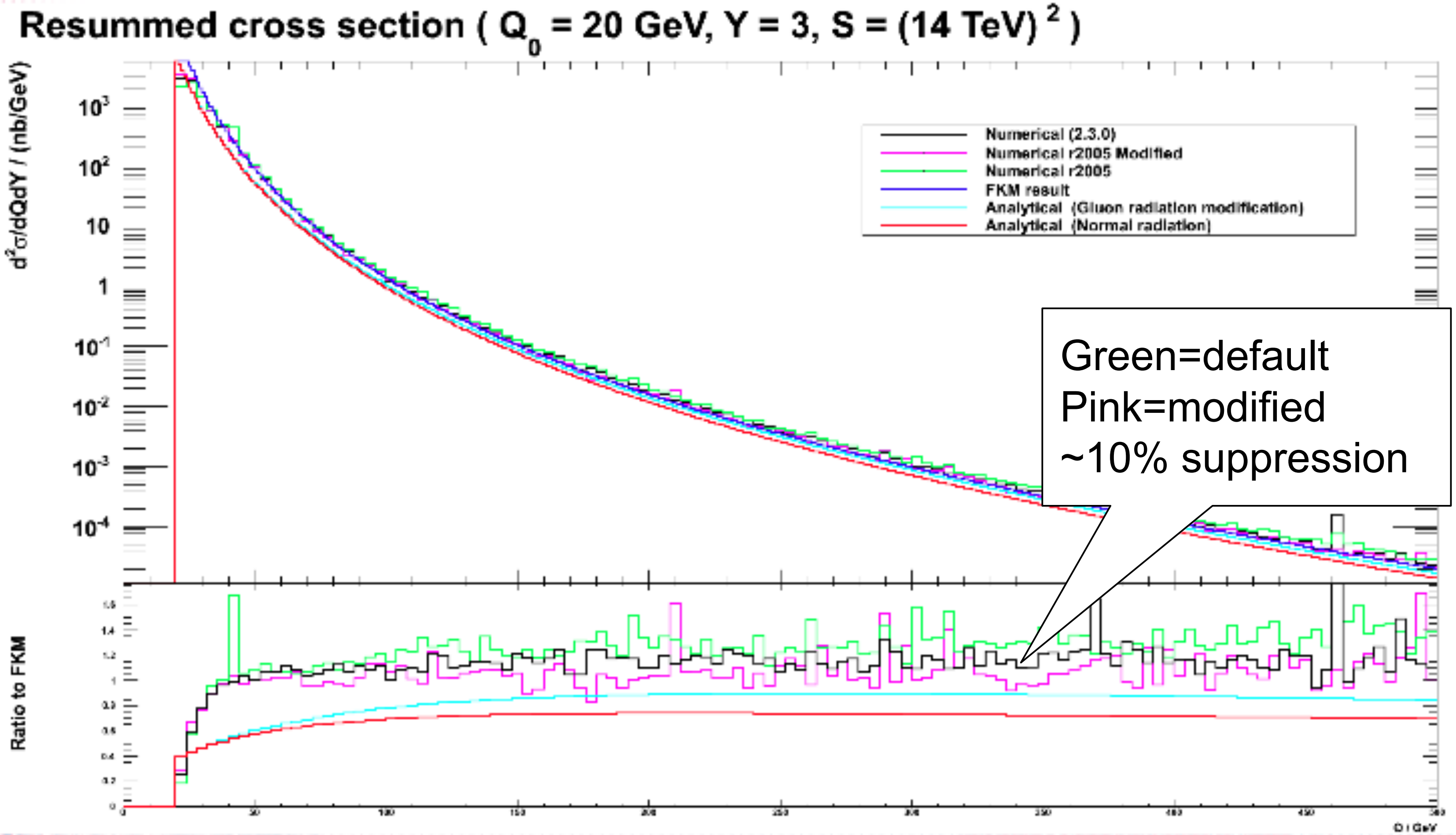
Cross section results



Green=default
Pink=modified
~10% suppression

Summary

Summary

- http://projects.hepforge.org/herwig/