Theoretical Uncertainties in W + Jets Production

Implications for BSM Searches with $\ell + \not{E}_T$ + Jets Signatures

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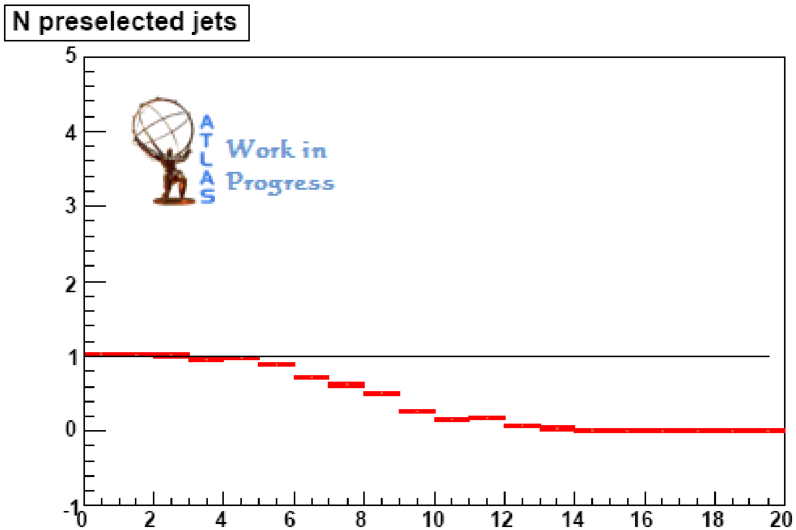
Introduction

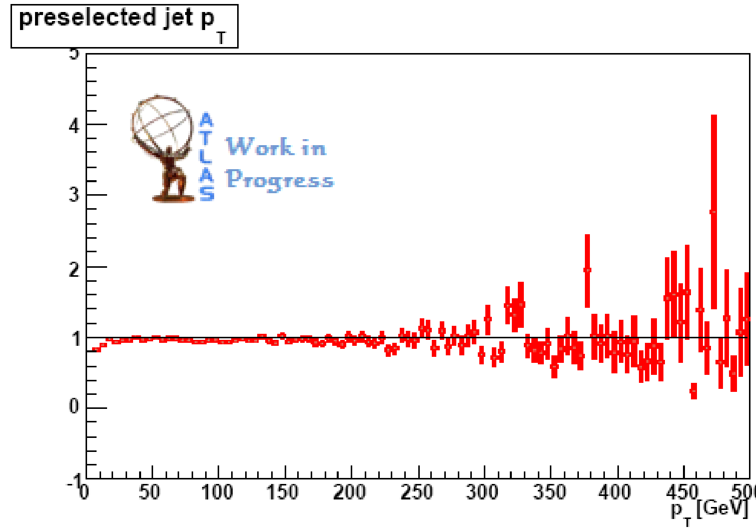
- W + Jets is an important background for BSM searches
  - AlpGen + Herwig with Jimmy is standard for ATLAS production
    - Cannot assume that this adequately represents reality
- Generate alternative sample using AlpGen + Pythia
  - Pythia may be a better choice for default shower MC
- Vary generation parameters from nominal Alpgen + Herwig
  - p_T cutoff in MLM matching (ptjmin/ ETCLUS)
  - Renormalization/Factorization functional form (iqopt)
  - Renormalization/Factorization Scale Factor (qfac)
  - α_s-reweighting scale (ktfac)
- Generate alternative samples with unrelated description
  - Sherpa chosen because it has many differences
    - All numbers of partons produced inclusively
    - ME generation, Shower MC and hadronization all distinct from AlpGen
    - CKKW matching

Method

- Generated many more events than official sample
  - 0-5 partons with all settings the same as official
  - Test that they are consistent
- Generate samples for the alternatives outlined on last slide
- Create ATLAS format with truth information from generation
  - Only objects built from truth quantities will be shown
    - Antikt4TruthJets used with truth particles as input
  - Detector effects should be equivalent between different generators
- Overlay various alternative MC
  - All samples normalized to nominal LO cross section (8623.81 pb)
    - Total cross section will be measured not taken from theory
  - Plots and numbers given for 10 pb^{-1}
- Look at ratio plots for variations relative to Nominal
  - Many more distributions investigated than will be shown

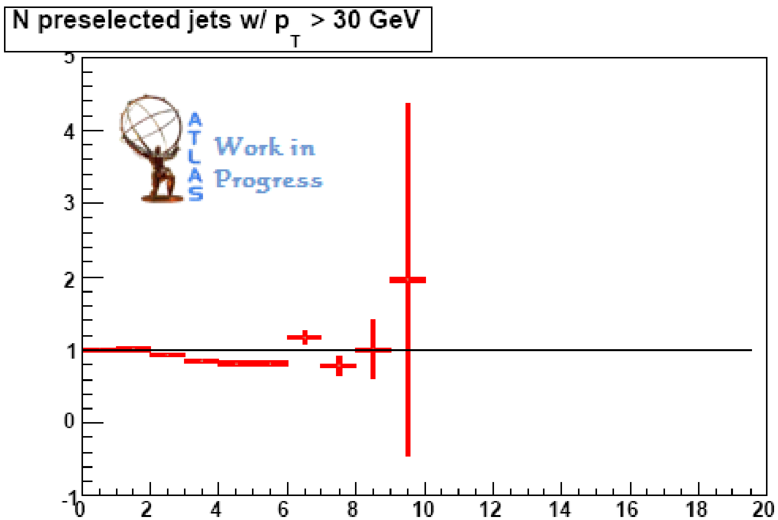
AlpGen Herwig vs Pythia

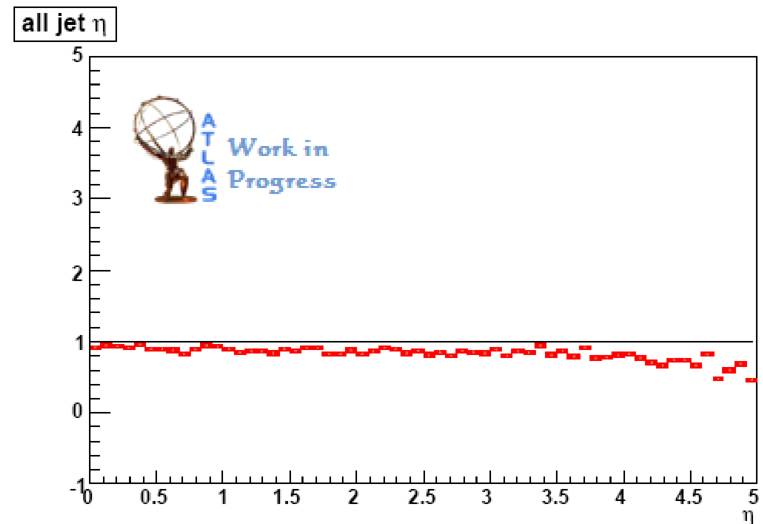




- AlpGen + Pythia done with AMBT1 tune
  - AMBT1 is a recent tune from ATLAS data
    - Could argue that you expect this to be more accurate than Herwig
- Clear difference in high jet multiplicity
  - Expected since these jets must be done by shower MC
- Discrepancy is at low p_T
  - Expected since shower MC affects the soft/collinear region

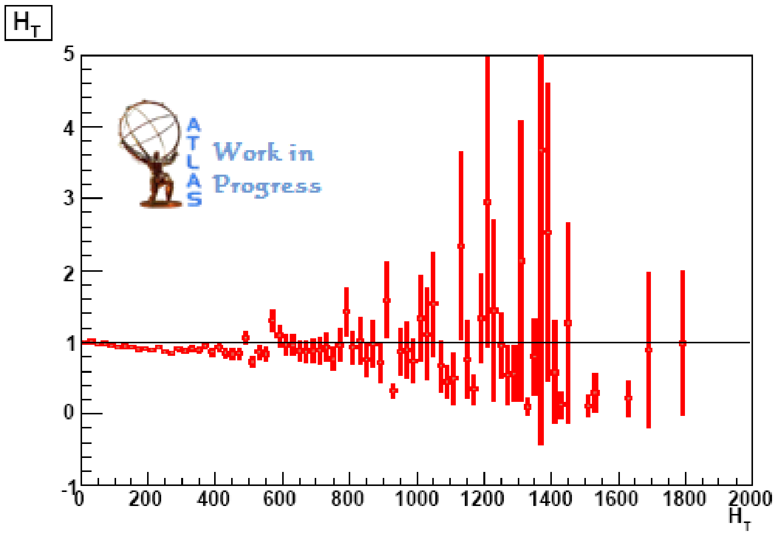
AlpGen Herwig vs Pythia

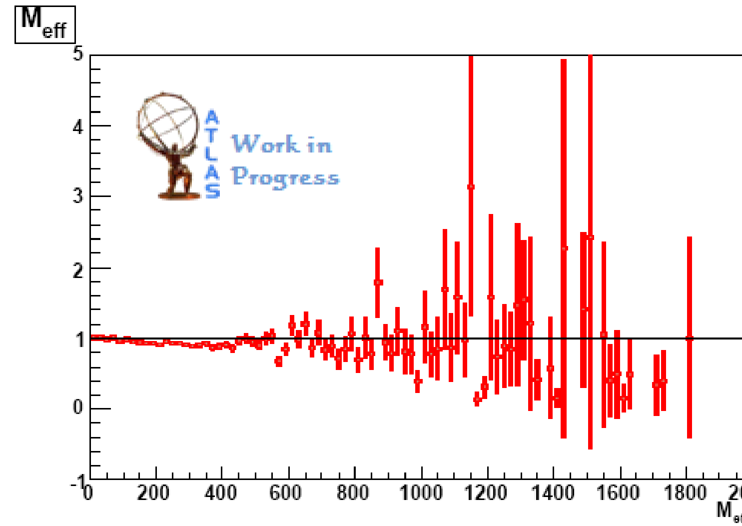




- AlpGen + Pythia differences reduced for jets with p_T > 30 GeV
- Leading jets only affected when they are done by shower MC
- η distribution shows overall shift
  - Shift comes from lower jet multiplicity
  - Some differences in forward region
    - Most searches do not use high η jets

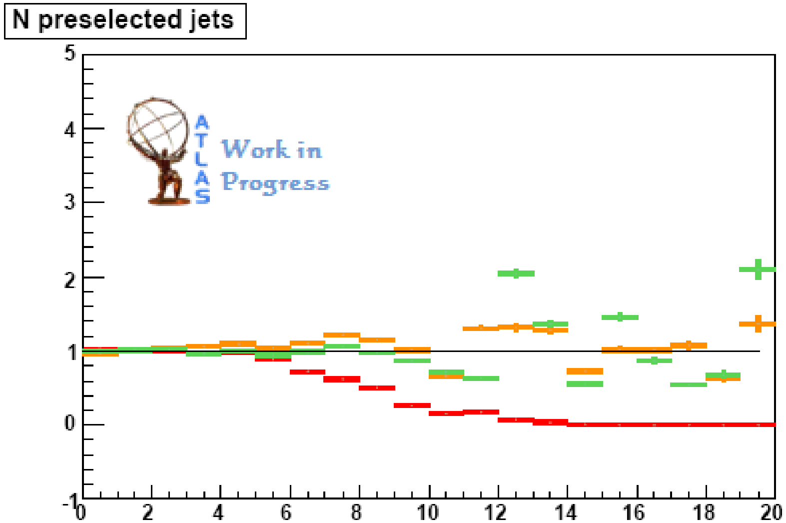
Herwig vs Pythia for SUSY

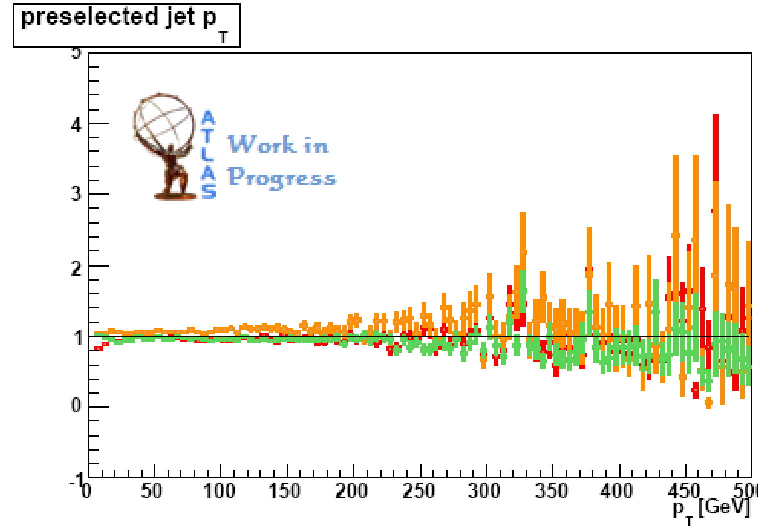




- Require at least 1 Jet with p_T > 30 GeV
  - 8909 ± 13 events for Herwig and 8845 ± 13 events for Pythia remain
- 2 jet W control region
  - 30GeV < $\not{E}_T$ < 50 GeV, 40 GeV < m_T < 80 GeV $m_T = \sqrt{(ME_T + p_T^\ell)^2 - (ME_x + p_x^\ell)^2 - (ME_y + p_y^\ell)^2}$
  - 368.1 ± 2.8 events for Herwig and 343.5 ± 2.8 events for Pythia remain
- 4 jet SUSY region
  - p_T>30 GeV, H_T > 340 GeV, $\not{E}_T$ > 120 GeV $H_T = \sum_{Jet} p_T$
  - 3.85 ± 0.15 events for Herwig and 3.20 ± 0.14 events for Pythia remain

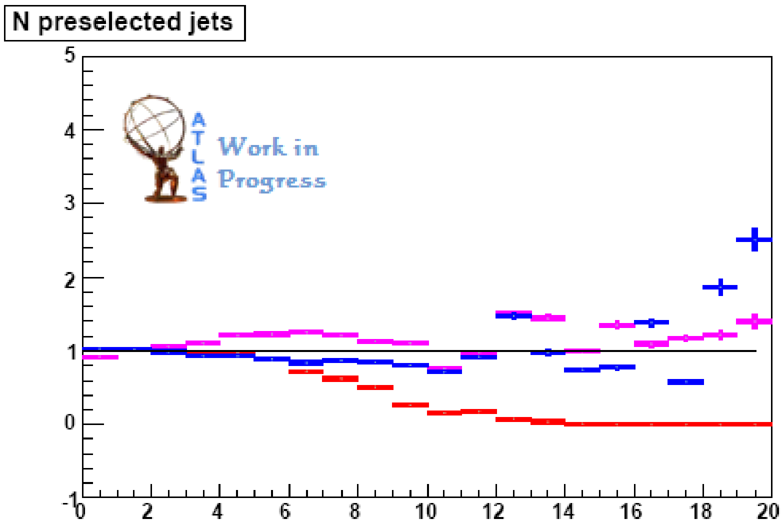
MLM Jet p_T Variation

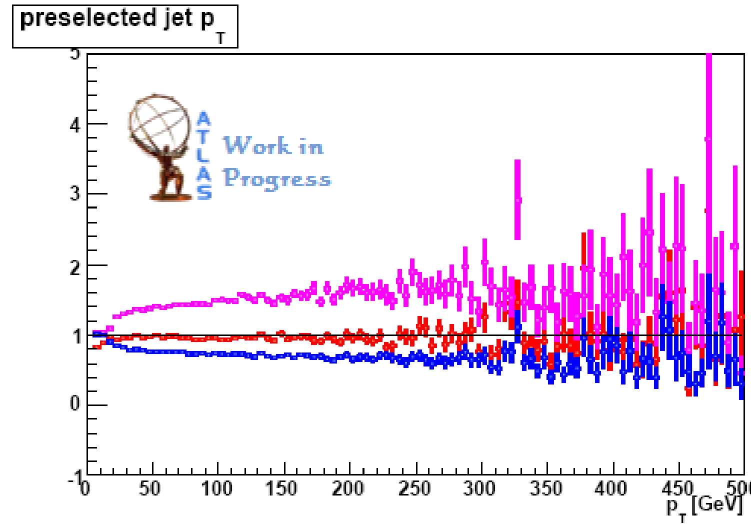




- p_T variables used in MLM matching
  - ptjmin ≡ Minimum p_T to meet the MLM definition of a hard parton
  - ETCLUS ≡ Minimum p_T to meet the MLM definition of a Jet
  - Nominal is ptjmin = 15 GeV with ETCLUS = ptjmin + 5 GeV
  - Varied to p_T=20 GeV and p_T = 10 GeV
  - SUSY cuts give 3.56 ± 0.09 for p_T=20 and 4.17 ± 0.33 for p_T=10
- Represents the robustness of MLM Matching
  - Should be small enough to ignore

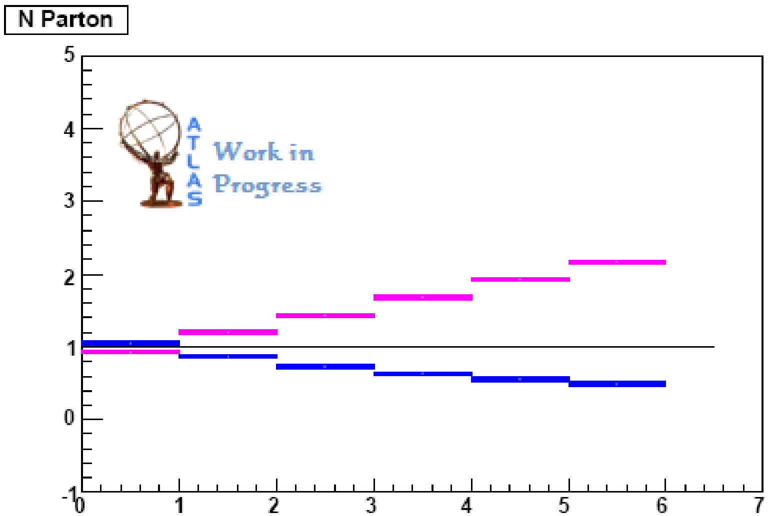
Scale Variations

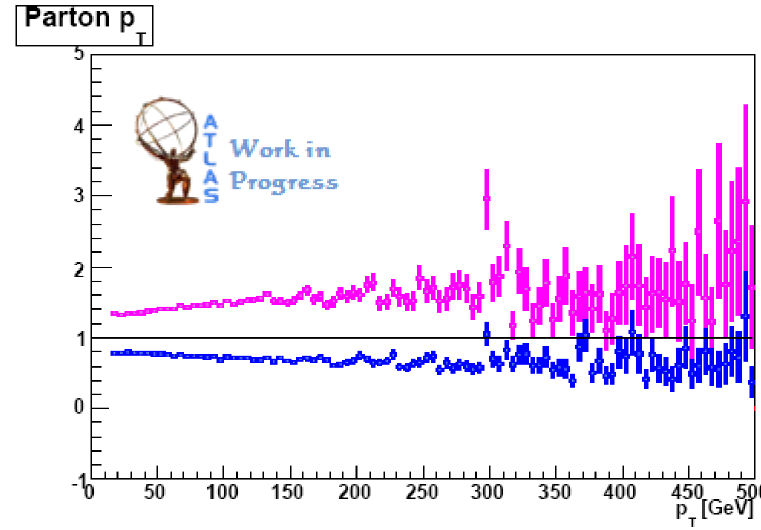


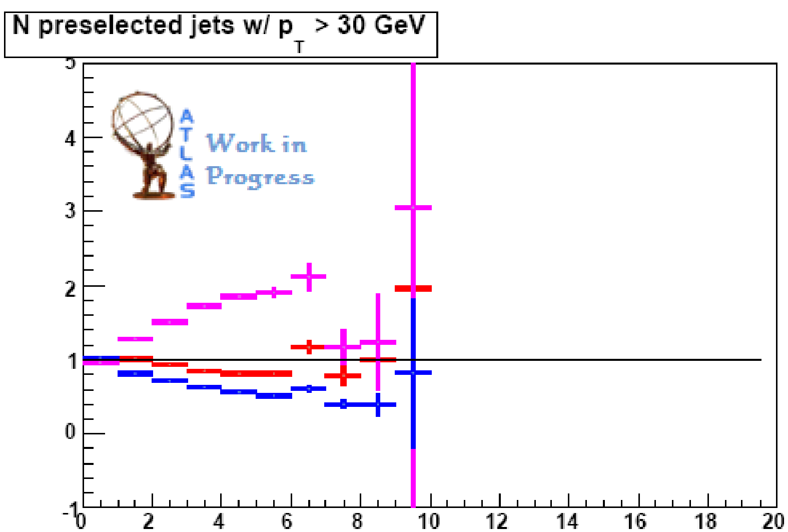


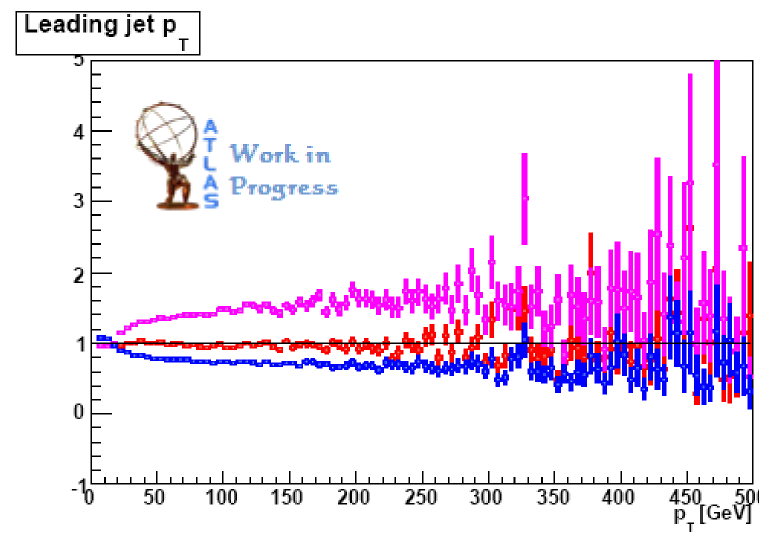
- qfac ≡ Multiplicitive factor to renormalization functional form
  - Factorization scale is determined from the Renormalization scale
- ktfac ≡ Factor to the appearance of the nodes in ME
- Vary both in tandem by factor of two
  - Scale down gives more and harder jets
  - Scale up gives less and softer jets
- Very different effect to that of AlpGen + Pythia

Partons from Scale Variations









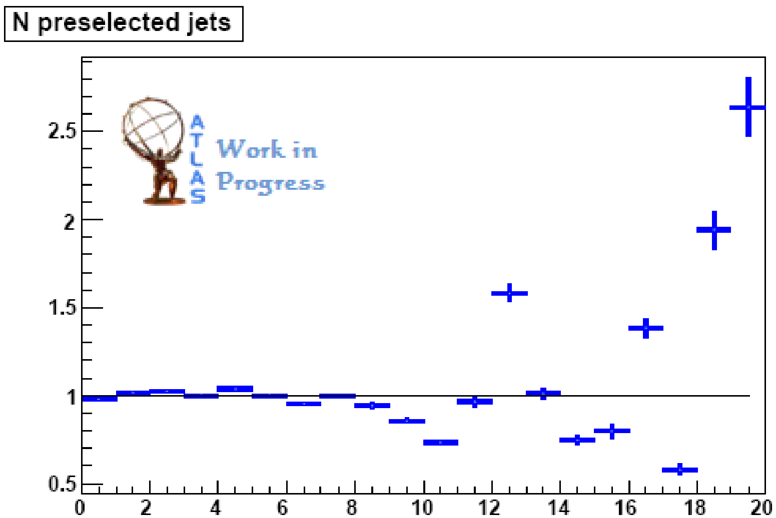
Scale Impact on SUSY Searches

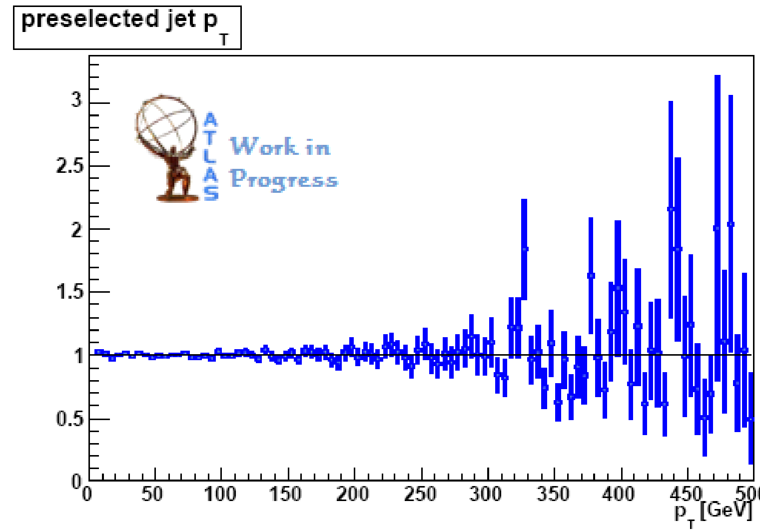
- Clearly this has a large effect on many distributions
  - Difficult to interpret how large a factor of two is
- Require at least 1 Jet with p_T > 30 GeV
  - Scale down gives 11,877 ± 17 and scale up gives 7022 ± 10 events
    - Recall 8909 events for Herwig and 8845 events for Pythia remained
- 2 jet W control region
  - Scale down gives 551.7 ± 4.2 and scale up gives 257.0 ± 2.0 events
    - Recall 368.1 events for Herwig and 343.5 events for Pythia remained
- 4 jet SUSY region
  - Scale down gives 7.25 ± 0.30 and scale up gives 2.099± 0.084 events
    - Recall 3.85 events for Herwig and 3.20 events for Pythia remained
- This is a systematic that must be taken into account
  - Do not want to make 2 more samples to run on

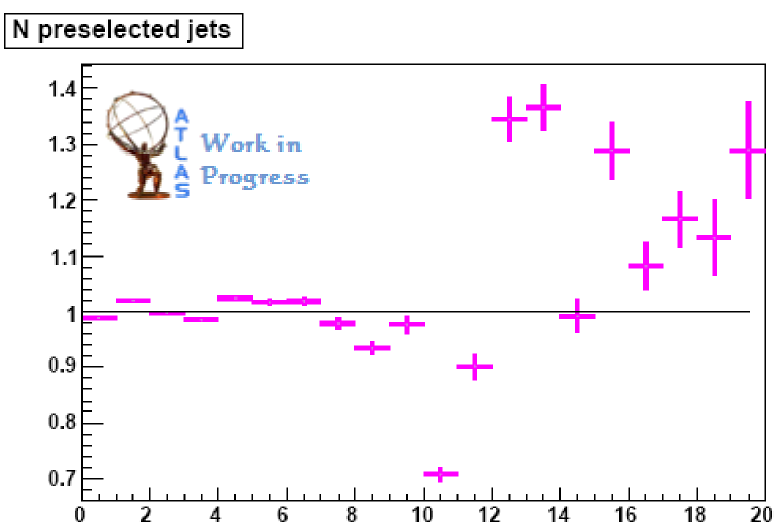
Reweighting Nominal Sample

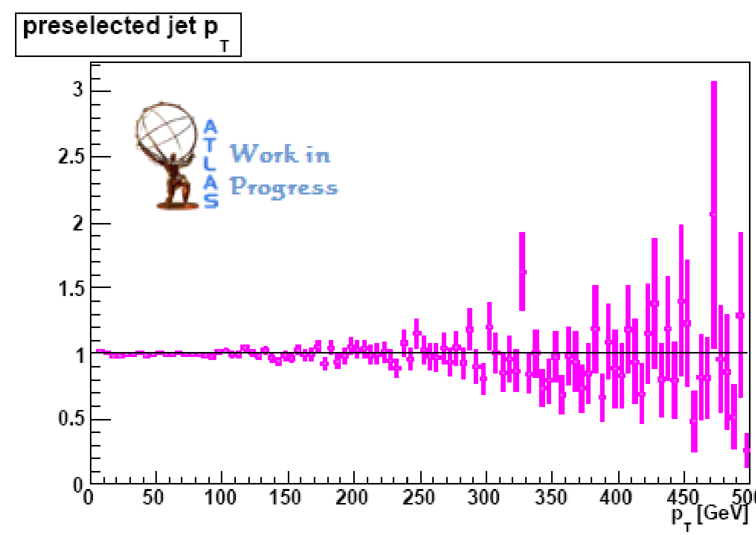
- How to take this uncertainty into account
  - The distributions in each parton bin do not change for differing scales
    - Other studies have shown that is true for qfac variations
  - Only the cross sections have changed so you can rescale the Nominal
- The difference between the cross sections is like a k-factor
  - Apply to nominal to retrieve Scaled down samples
    - d0= 0.922, d1 = 1.196, d2 = 1.428, d3 = 1.674, d4 = 1.926, d5 = 2.162
  - Apply to nominal to retrieve Scaled up samples
    - up0=1.049, up1=0.857, up2=0.730, up3=0.638, up4=0.554, up5=0.492
- Match in all control regions
  - Nominal scaled down gives 7.66 and up gives 2.08 events
    - Good match to 7.25 ± 0.3 and 2.10 ± 0.08
  - Many distributions also checked for consistency

Scale Reproduction

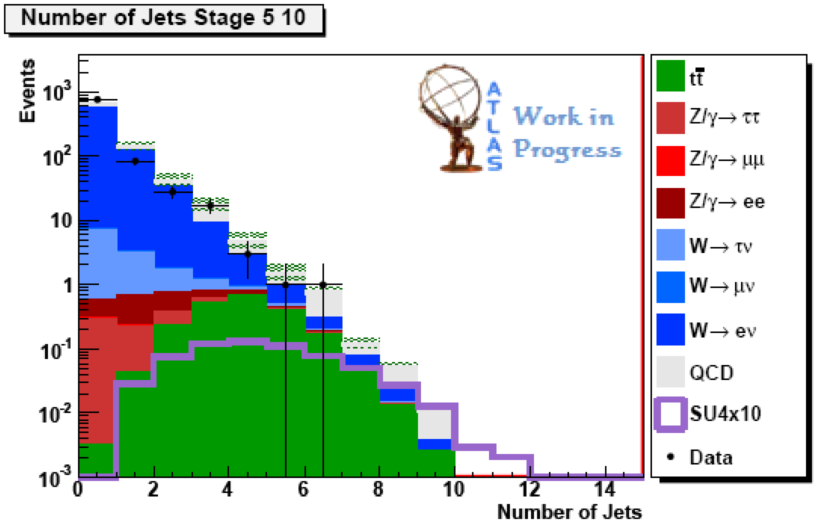


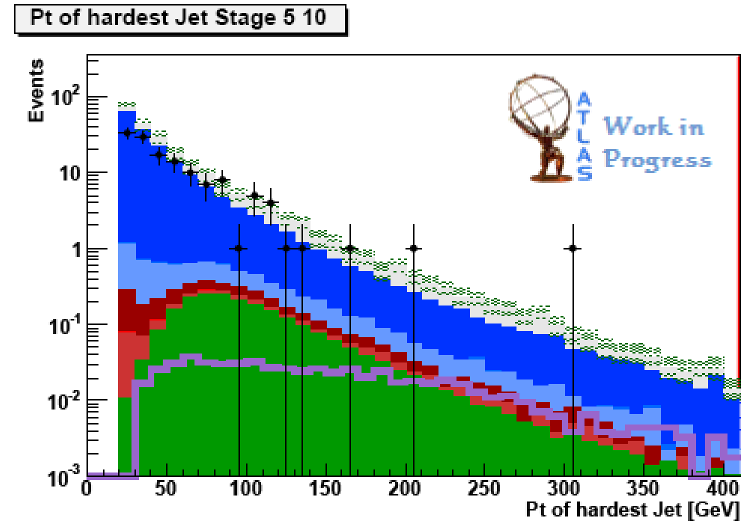






Applying Method to Data

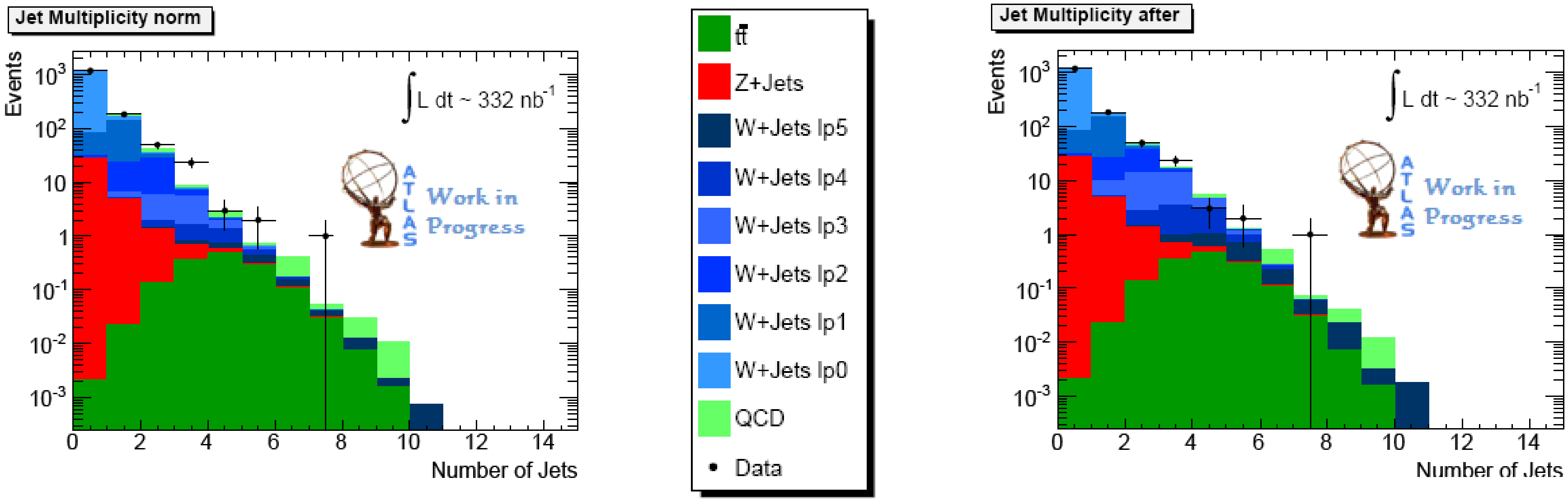




- Scale variation is a large systematic uncertainty
  - Scale down represents upper bound and scale up represents lower
- Apply the reweighting to the Nominal MC
- This systematic uncertainty is comparable to data uncertainty
- Can attempt to constrain these k-factors from data

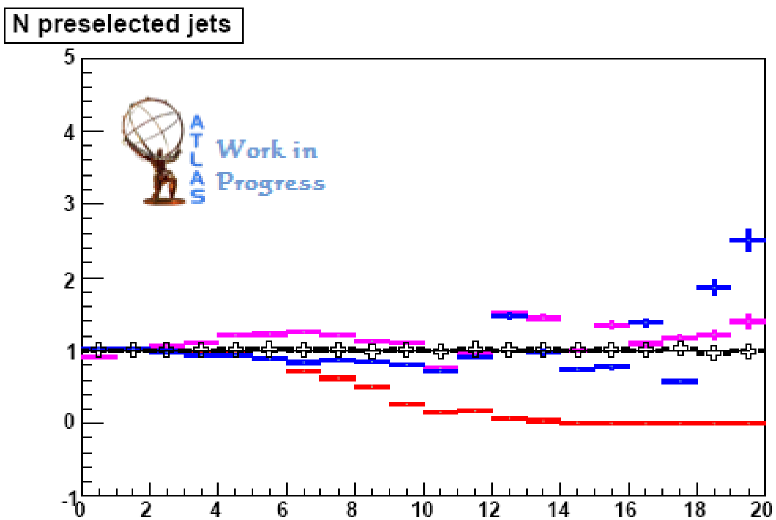
Constraining Scale Variation

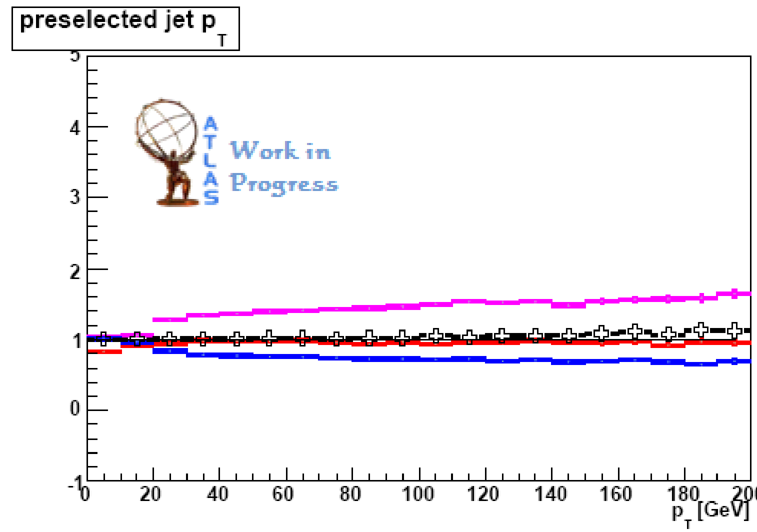
T. Müller



- Normalize MC to 332nb^{-1} of data in control regions
  - First normalize in QCD region, then W region
- The jet multiplicity distribution is sensitive to the ME parton
  - Allow the relative normalization of each parton sample to vary
    - Overall normalization fixed
    - K0 = 0.975±0.027, K1 = 1.02±0.13, K2 = 1.02±0.39, K345 = 2.87±0.83
- Low parton multiplicity is more constrained than qfac variation
  - High parton multiplicity suffers from statistical issues

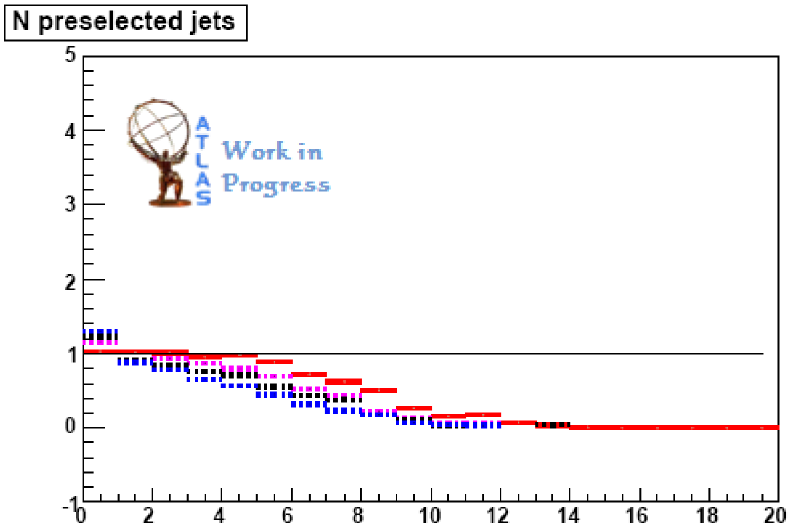
Variation of Functional Form

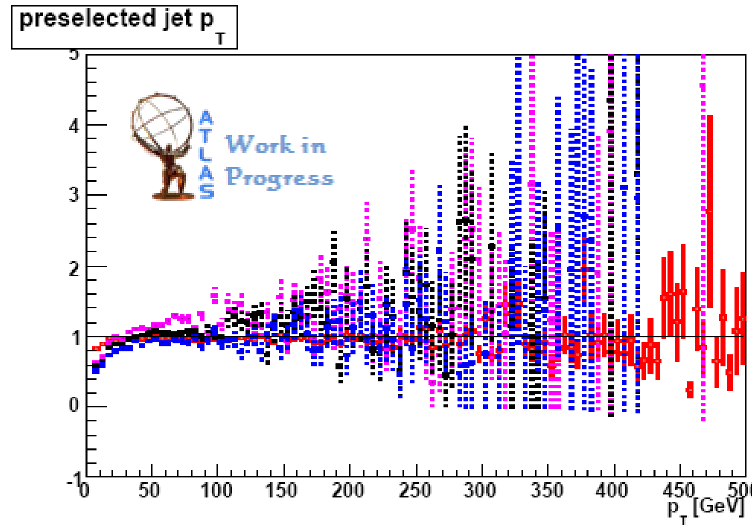




- The Renormalization scale is determined from a function
- Default is: $Q_o^2 = m_W^2 + \sum_{Partons} \left(m^2 + p_T^2\right)$
- Variation is: $Q_o^2 = m_W^2 + p_{TW}^2$ represented by ✚
  - All other settings are nominal
- Clearly a very small effect
- Predominantly only a change in the cross sections
  - As with the scale factor

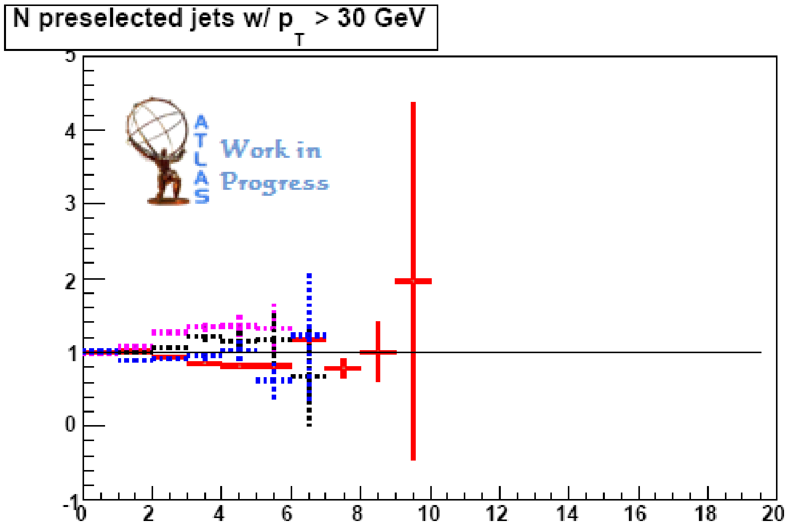
Sherpa vs AlpGen

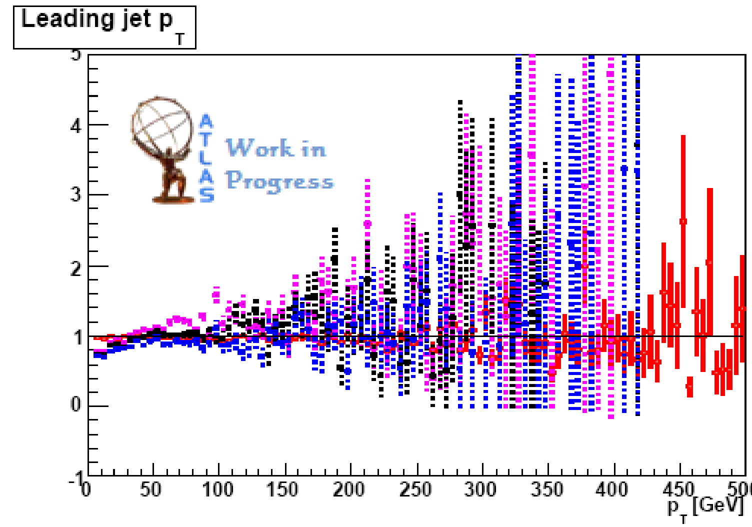




- Sherpa 1.1 used for W + 4 jets inclusive sample
  - Older version with Pythia like shower, Apacic
- Normalized to Nominal LO cross section (8623.81 pb)
  - Nominal, scale down and scale up are given dotted
- Clear shape difference from Nominal
  - Sherpa has similar behaviour to AlpGen + Pythia
- Scale variation has similar effect as in AlpGen

Sherpa vs AlpGen





- Sherpa can only generate up to W + 4 partons
  - High multiplicity bins have large statistical error
- 1 jet region
  - Nominal = 9017 ± 93, scale down = 9952 ± 93, scale up = 8041 ± 83
- 2 jet W control region
  - Nominal = 380 ± 19, scale down = 468 ± 20, scale up = 307 ± 16
- Statistically limited for looking in SUSY region

Effects from Control Regions

- The numbers previously given for SUSY cuts are naive
  - Should be normalized first in W control region
  - Normalization will reduce a significant portion of the systematic
    - Normalize to Nominal AlpGen + Herwig instead of data
    - Only the relative difference matters so normalization is irrelevant

Sample	SUSY Events	After Normalization
Herwig Nominal	3.85	3.85
Pythia Nominal	3.20	3.43
Herwig Scale up	2.10	3.00
Herwig Scale low	7.25	4.84

- As expected the variation is decreased

Conclusion

- Pythia has differing phenomenology to Herwig
  - All differences are expected
  - Pythia and Herwig will both be tuned to data
- MLM Jet p_T definitions have a relatively small effect
  - Should be able to ignore this
- Scale variation has a huge effect on distributions
  - There is a way to understand systematic effects without new MC
  - Strong possibility to constrain this systematic with data
    - Variation by factor of 2 has no metric for interpretation
  - Some of the variation eliminated by use of control regions
  - Want to vary Renormalization and Factorization scale independently
  - Change from different functional form is very small
    - Could try more unconventional forms
- Sherpa has a variety of differences
  - Expected since it uses completely distinct methods

End

- Back-up slides follow

Events Generated

	0 Partons	1 Partons	2 Partons	3 Partons	4 Partons	5 Partons
Herwig Nominal	2565300	904271	143200	48640	94329	18154
Pythia Nominal	2559400	940735	138883	43018	74452	14242
Herwig Scale up	2471851	867818	147455	55019	116353	21876
Herwig Scale low	2594300	979328	140018	49052	84013	12900
Herwig pT 20	2739700	2739700	186196	68988	164444	30024
Herwig pT10	2298300	628428	84660	27814	50774	7823

- 100,000 events generated for each Sherpa sample
  - Thanks to Christian Schmitt

Nominal AlpGen + Herwig + Jimmy

```
MODE             ! imode
PROCESS          ! label for files
0                ! start with: 0=new grid, 1=previous warmup grid, 2=previous generation grid
WARM 4         ! Nevents/iteration,  N(warm-up iterations)
EVENTS         ! Nevents generated after warm-up
*** The above 5 lines provide mandatory inputs for all processes
*** (Comment lines are introduced by the three asteriscs)
*** The lines below modify existing defaults for the hard process under study
*** For a complete list of accessible parameters and their values,
*** input 'print 1' (to display on the screen) or 'print 2' to write to file
njets JETS
ptjmin 15
drjmin 0.7
ih2 1                 ! LHC
ebeam 3500.0          ! E beam
ndns 9                ! PDF CTEQ6L1
iqopt 1               ! Qscale, 1 is generator default for all the processes
qfac  1               ! Qscale factor
ickkw 1               ! enable jet-parton matching, determine scale of alpha_s
ktfac 1               ! ckkw alphs scale
ptlmin 0.             ! lepton min pt
metmin 0.0            ! missing et cut
etajmax 6.0           ! parton max eta
etalmax 10.0          ! lepton max eta
drlmin 0.0            ! min delta r between leptons
iwdecmode 2           ! W decay mode (2: mu)
cluopt 1              ! kt scale option. 1:kt propto pt, 2:kt propto mt
iewop 3               ! EW parameter scheme, (3= mw=80.419, mz=91.188, GF=1.16639^-5 hard coded)
```