# MC Generators for LHC at ATLAS

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On behalf of the ATLAS collaboration

ATLAS experience:
- Generators used
- Validation procedures
- Interesting examples

# Focus of interest/concern

- The LHC environment is going to be extremely 'busy' from physics point of view:
  - Many different processes: Standard Model (cum Higgs), SUSY, New Physics (new gauge bosons…black holes…)
    - Someone's 'signal' is another one's 'background'
  - Everything 'wrapped up' in QCD: High jet activity
    - Believing the Factorisation theorem these can be sub-divided:
      - QCD radiation from initial state/colliding partons,
      - QCD radiation from final state partons,
      - Underlying event/Multiple interactions from beam remnants.

How certain are we of the predictions we have?
What can we use from data in an unbiased way?

# Focus of interest/concern cont'd

- In order to tackle these questions we of course need 'bleeding edge' theoretical predictions, preferably in form of Monte-Carlo generators:
  - We need to adequately incorporate detector effects!
- In more detail we need:
  - t)

**A lot of effort has been invested and impressive progress has been made by the theorists in the recent years!**

  - Getting the QCD activity 'under control', i.e. having tools which describe the jet production over all/most of the available phase space.
    - Commonly often referred to as the Matrix element and Parton shower matching.

# MC Generators used at ATLAS

- What we have available (i.e. stable/interfaced to ATLAS software etc):
  - Several parton level 'ME' MC generators,
  - Latest HERWIG 6.5 and Pythia 6.4 for the jet production in terms of QCD/QED parton showering/fragmentation..
  - Jimmy 4.2 and Pythia 6.4 models for multiple interactions/underlying event simulation.
  - Several 'addon'/decay packages are used.
  - ME and PS matching in several versions (MLM, CKKW).

- We try to use as many generators as reasonable:
  - The final answer which is best will be given only by the data.
  - Need some overlap: different generators for the same processes.

# ME level MC tools used at ATLAS

- The list is 'longish' but we are still adding to it:
  - AcerMC: Zbb~, tt~, single top, tt~bb~, Wbb~
  - Alpgen (+ MLM matching): W+jets, Z+jets, QCD multijets
  - Charbydis: Black holes..
  - CompHep: Multijets..
  - HERWIG: QCD multijets, Drell-Yan, SUSY (ISAWIG)...
  - Hijing: Heavy Ions, Beam-gas..
  - MadEvent: Z/W+jets...
  - MC@NLO: tt~, Drell-Yan, boson pair production
  - Pythia: QCD multijets, B-physics, Higgs production...
  - Sherpa: W+jets/Z+jets...
  - WINHAC: W production and decay
- The MC base will of course expand:
  - Pythia 8
  - HERWIG++
  - ???

# Addon/decay packages

- TAUOLA:
  - Interfaced to work with Pythia, Herwig and Sherpa,
    - Native ATLAS effort/patches present..
- PHOTOS:
  - Interfaced to work with Pythia, Herwig and Sherpa,
    - Also native ATLAS effort present..
- EvtGen:
  - Used in B-physics channels.
    - An ongoing effort to validate it...

# Common validation procedures at ATLAS

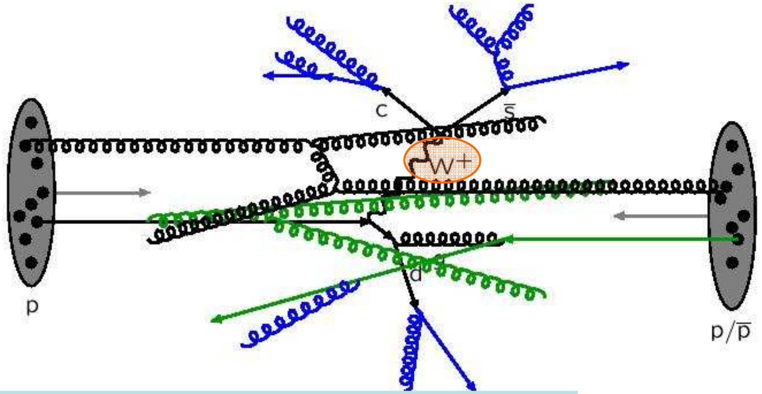
- There are in general two approaches:
  - We take into account the experience and results at the Tevatron (tunings) and/or we try to tune/check the generators using available Tevatron information ourselves.
  - We compare the results of different MC generators in the quantities where they should match (to a certain precision) either at the generator level or by performing full analysis studies.
- We intend to make use of CEDAR/JETWEB.
- In all cases we of course check the obvious parameters (masses, resonance shapes, angular (a)symmetries etc.)
- We also check the stability of the algorithms and their sensitivity to parameter changes (e.g. cutoff parameters in MLM matching algorithm etc..).
- Detailed checks when switching versions of the same MC tool.

# Some ATLAS achievements

- To illustrate what is going on in the ATLAS MC activities I will show some of our major efforts in terms of understanding the QCD activity:
  - UE tuning: Pythia (two models) and Jimmy
  - Covering the full QCD phase space: PS and ME matching:
    - Alpgen + MLM matching validation
    - Sherpa studies & implementation
    - Heavy quarks in the initial state: AcerMC solution..
  - Parton showering: Pythia and Herwig showering models..

# Undelying event tunings using CDF data

- All particles from a single particle collision except the process of interest.
- Semi-phenomenological models, tunable parameters!
- Most important is the energy extrapolation to LHC energies!



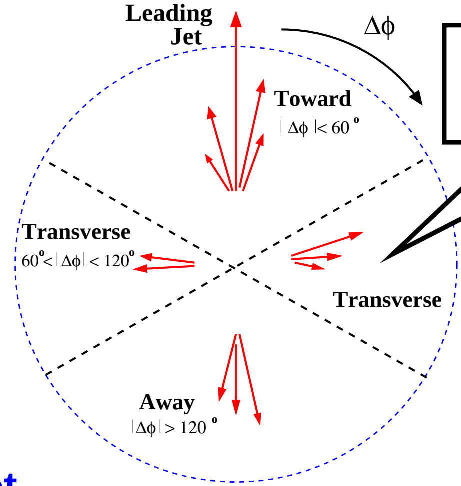

**CDF analysis: QCD dijets**

- charged particles:

$p_t$>0.5 GeV and $|\eta|<1$

- **cone jet finder:**

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.7$$




UE is defined as the Transverse Region

$\Delta\phi = \phi - \phi_{ljet}$

*The underlying event in Hard Interactions at the Tevatron ppbar collider, CDF Collaboration, PRD 70, 072002 (2004).*

# Max/Min analysis:Pythia

- The underlying event is measured for jet events at two different colliding energies: 630 GeV and 1800 GeV.

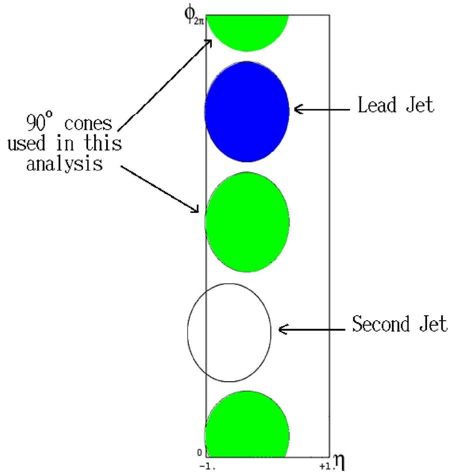
- Two cones in η–φ space are defined:

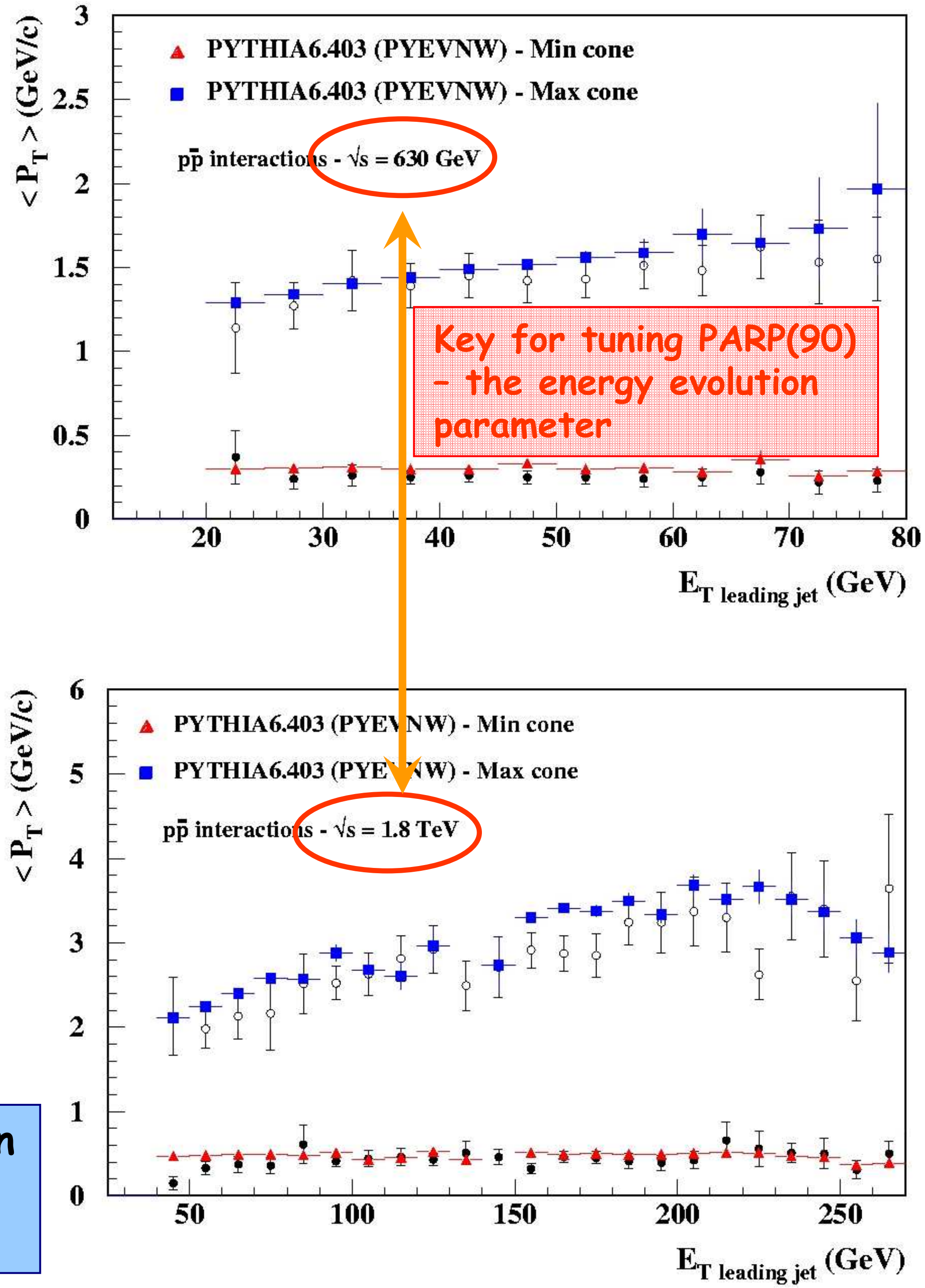
$\eta=\eta_{ljet}$ *(same as the leading jet)*

$\phi=\phi_{ljet} \pm 90°$

R=0.7

$P_T^{90max}$ and $P_T^{90min}$




- This provides important information on how to model the energy extrapolation in UE models.

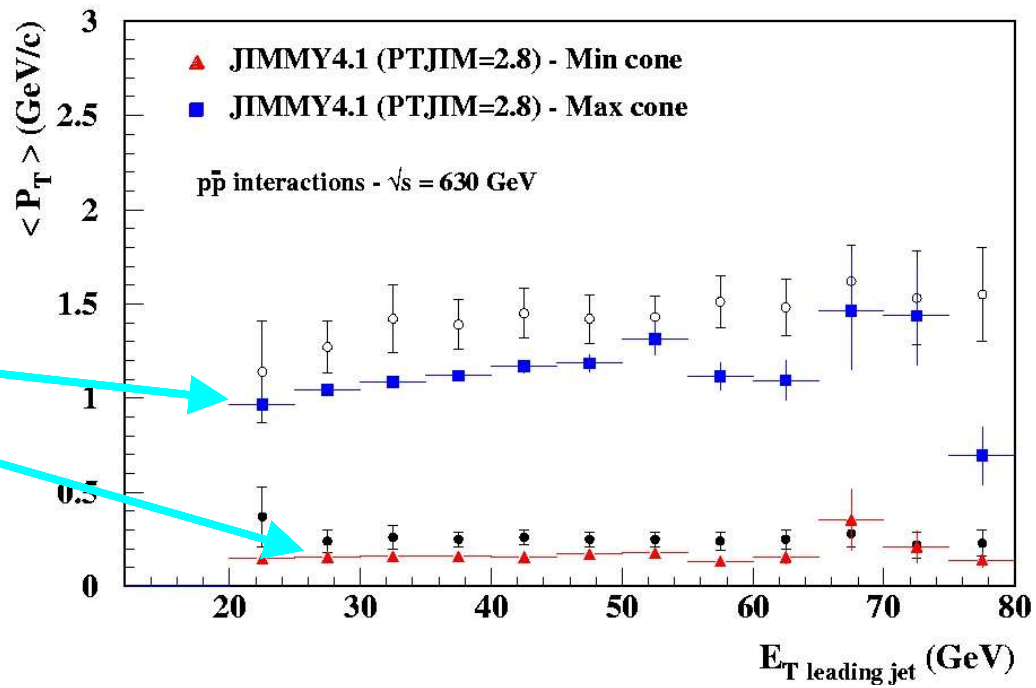
# UE tunings: Jimmy ATLAS tuning

**JIMMY4.1 & HERWIG6.507**

| ATLAS tuning | | | Default |
|---|---|---|---|
| CTEQ6LO (LO fit with LO $\alpha_s$) | LHAPDF | | |
| JMUEO=1 | scattering $p_T$ limited by PTJIM) | | JMUEO=1 |
| PTJIM=2.8 x $(\sqrt{s}/1.8\ \text{TeV})^{0.27}$ | minimum $p_T$ for secondary scatterings | → | PTJIM=3.0 |
| JMRAD(73)=1.8 | inverse proton-radius squared | → | JMRAD(73)=0.71 |
| PRSOF=0.0 | probability of a soft underlying event | → | PRSOF=1.0 |

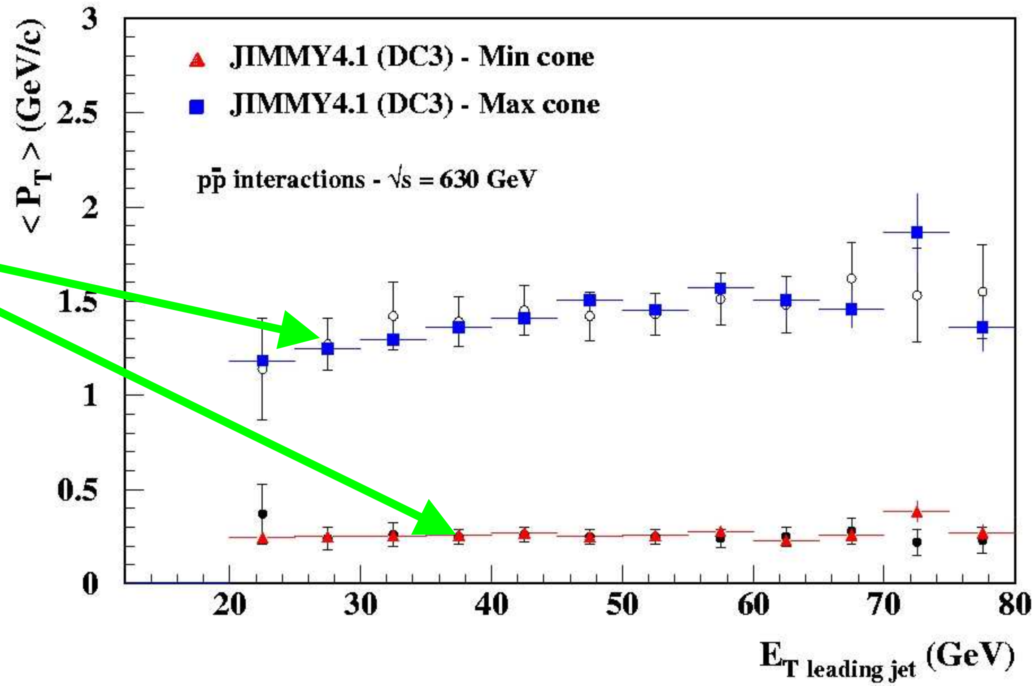
At ATLAS we introduced an energy-dependent factor similar to Pythia PARP(90)

# PTJIM energy dependence




**PTJIM=2.8**

- same PTJIM obtained from comparisons to 1.8 TeV data!
- This underestimates the data.



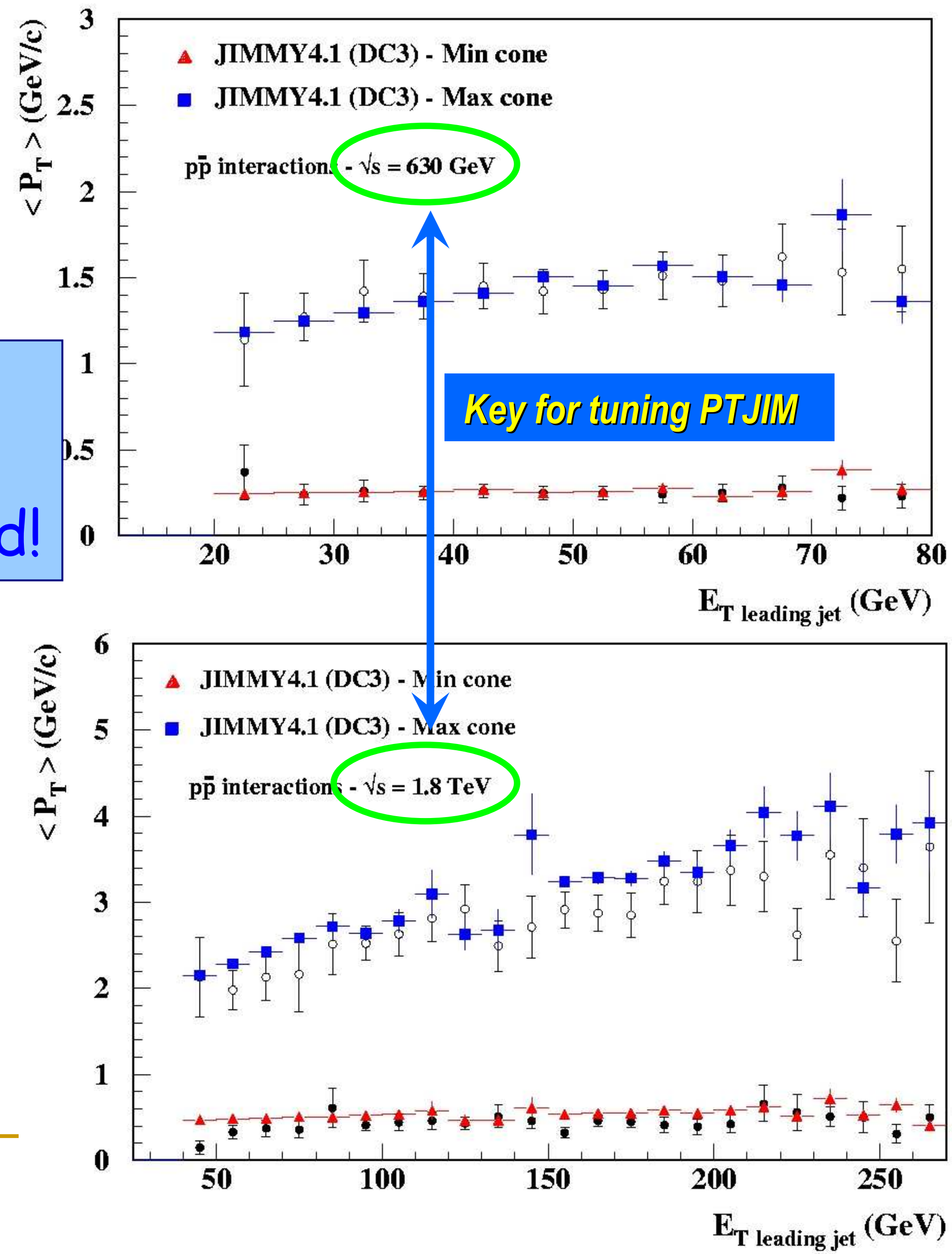

**PTJIM=2.1**

$= 2.8 \times (0.63 / 1.8)^{0.27}$

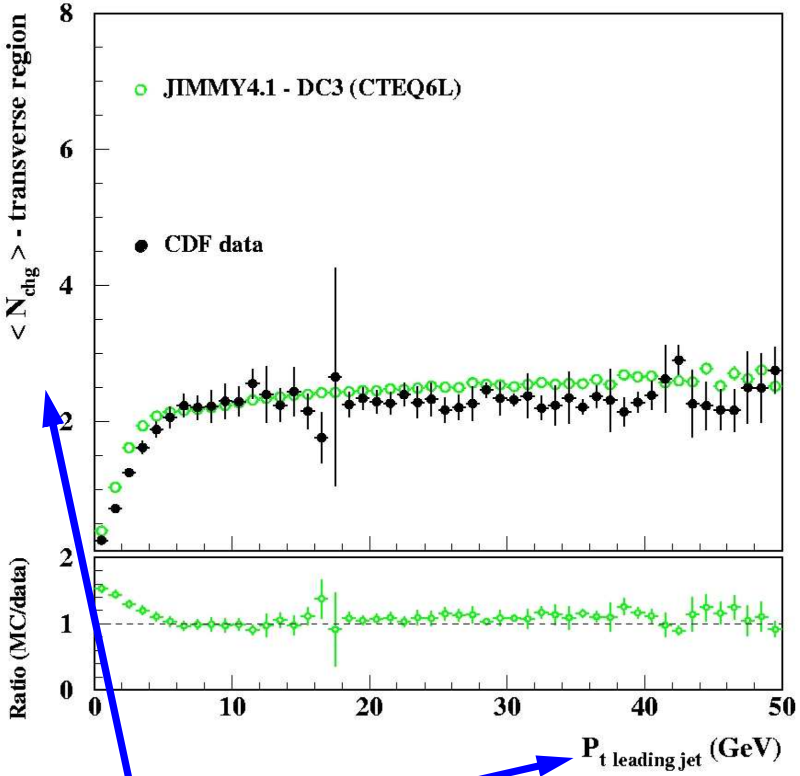
- introducing energy dependent factor we get a better agreement.

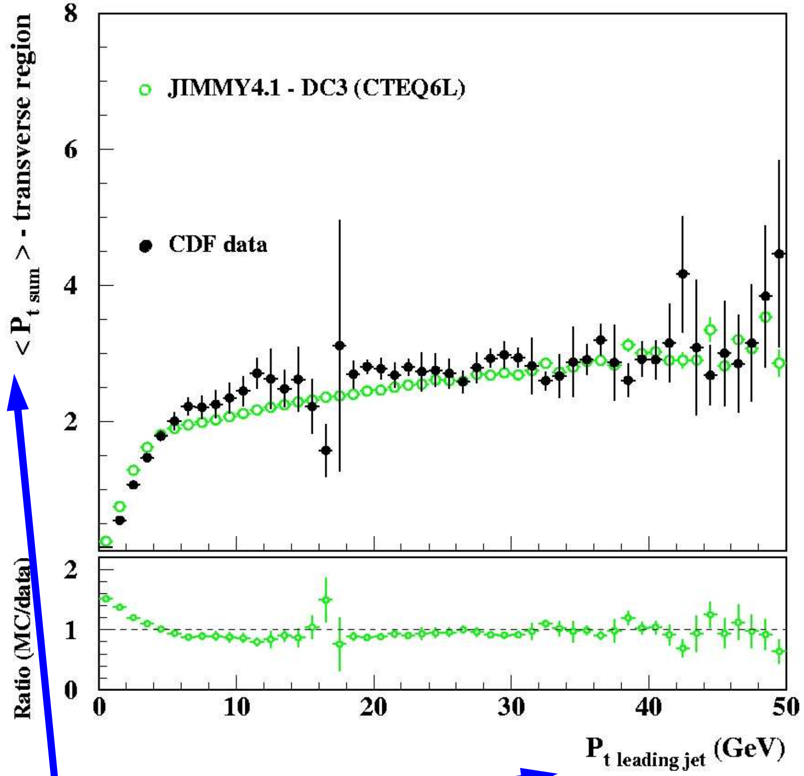
MAX/MIN analysis with Jimmy

With the introduction of this energy scaling a good agreement is again reached!



# UE tunings: Jimmy validation using CDF data

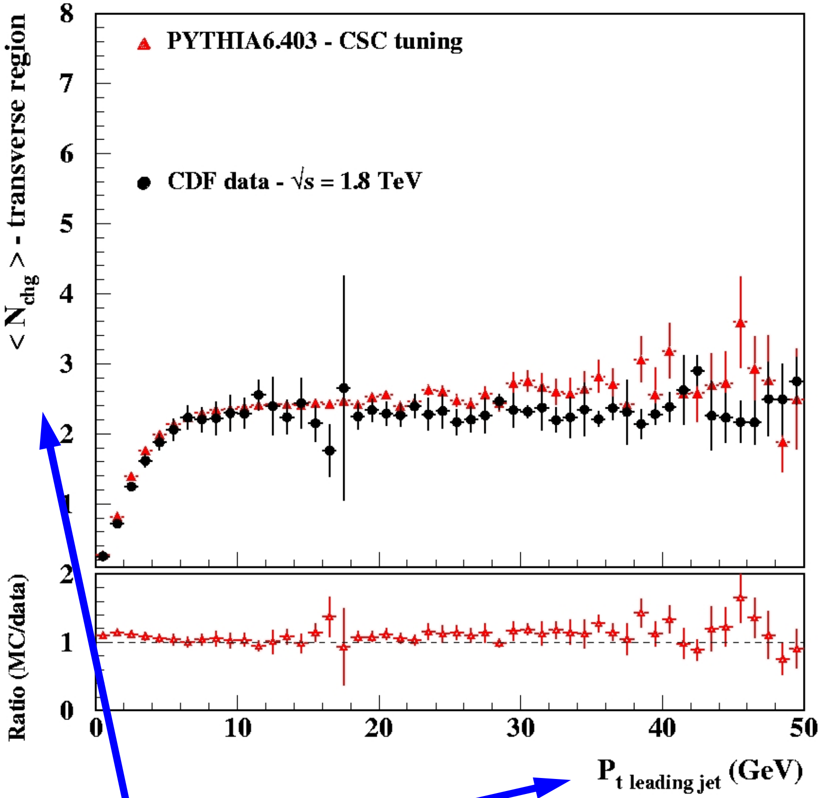


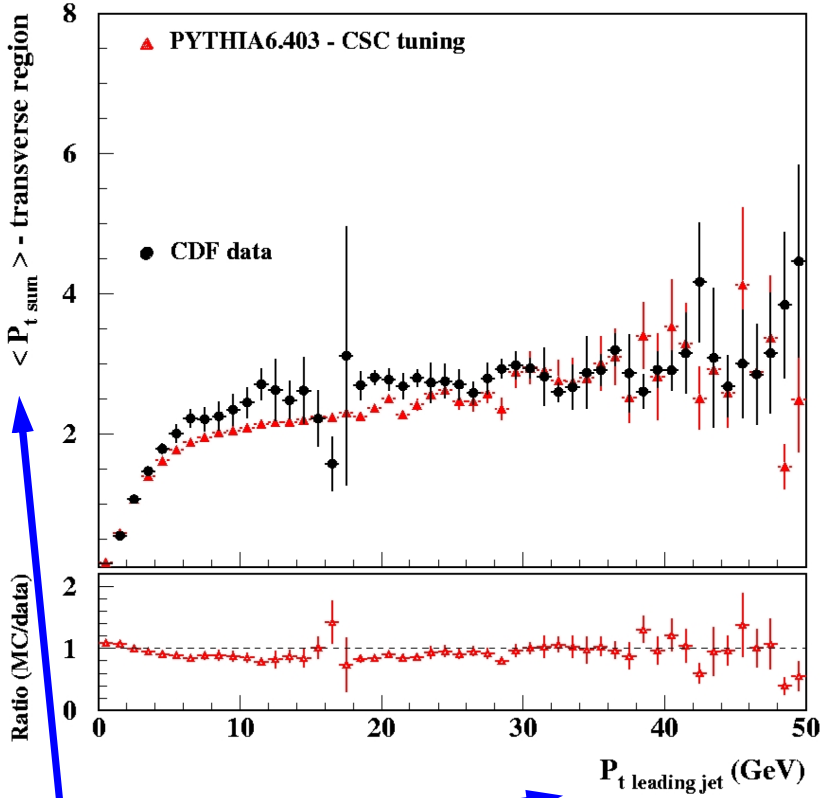




**Average multiplicity** of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

**Average** $\mathbf{p_T^{sum}}$ (GeV) of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

# UE tunings: Pythia 6.4 validation using CDF data

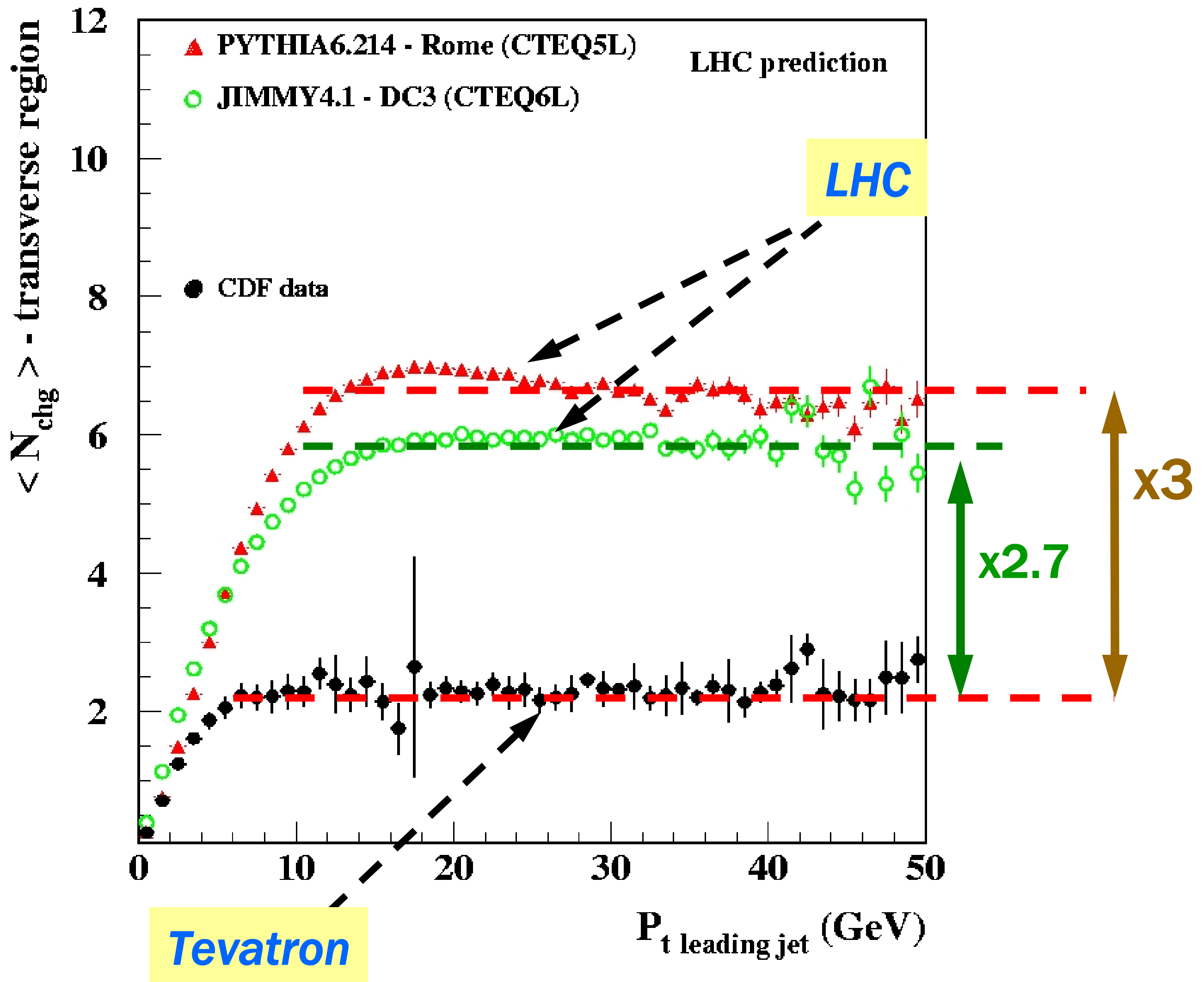



**Average multiplicity** of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

**Average** $\mathbf{p_T^{sum}}$ (GeV) of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

# UE tunings: Pythia vs. Jimmy




Energy dependent PTJIM generates UE predictions similar to the ones generated by PYTHIA; the difference used to be a factor two!

# Parton shower and Matrix element matching: Approximations to QCD

- Fixed order matrix elements: Truncated expansion in $\alpha_S$ →
  - Full intereference and helicity structure to given order.

- Matrix Elements correct for 'hard' jets
- Parton Showers correct for 'soft' ones.
- The question remains what is hard and what soft?
  - To what extent is it realistic to construct/tune showers and match them to hard radiation?

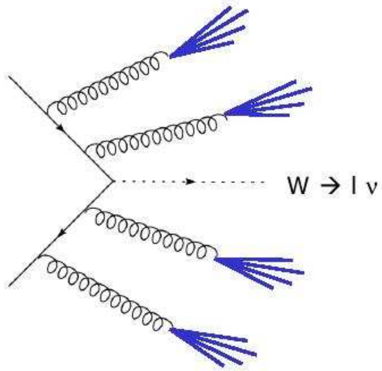
  - Interference terms neglected + simplified helicity structure + ambiguous phase space → large uncertainties away from singular regions.

# MLM and L-CKKW approaches

- At ATLAS we use two available answers:
  - The MLM matching implemented inside Alpgen MC generator,
  - The L-CKKW matching implemented in the Sherpa MC generator.
- Inclusive W+n jets and Z+n jets samples wanted by e.g. the Top and SUSY physics WG for background studies:
  - Quite a lot of effort went into setting up the system and validating it.
    - Huge CPU requirements involved..

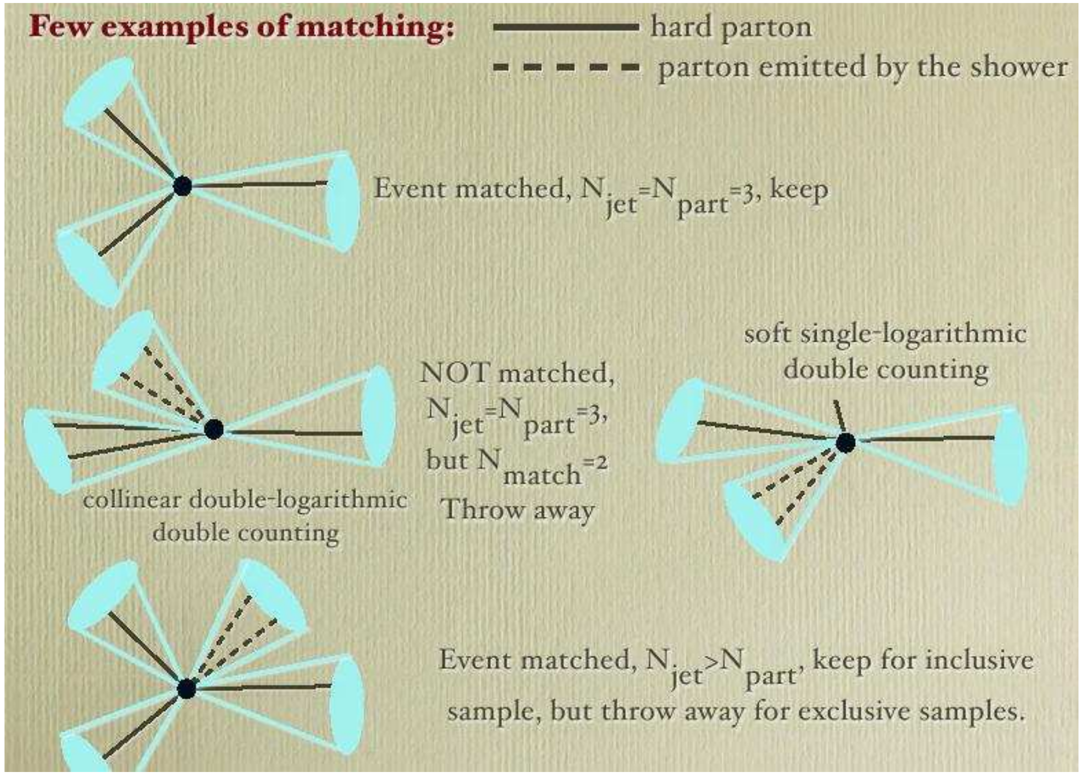
# MLM and L-CKKW approaches cont'd

- I don't have the time to describe the two methods in detail, for a nice overview see the paper by P. Skands and P. Richardson (hep-ph/0312274) but in brief, taking W-production as an example:
  - Both approaches begin with W+n(=0-5) parton matrix elements and generate parton-level events accordingly.
  - The addition of Sudakov (parton) showering introduces additional partons which would 'double-count' the ME events.
  - In order to remove this double counting two different approaches are used...



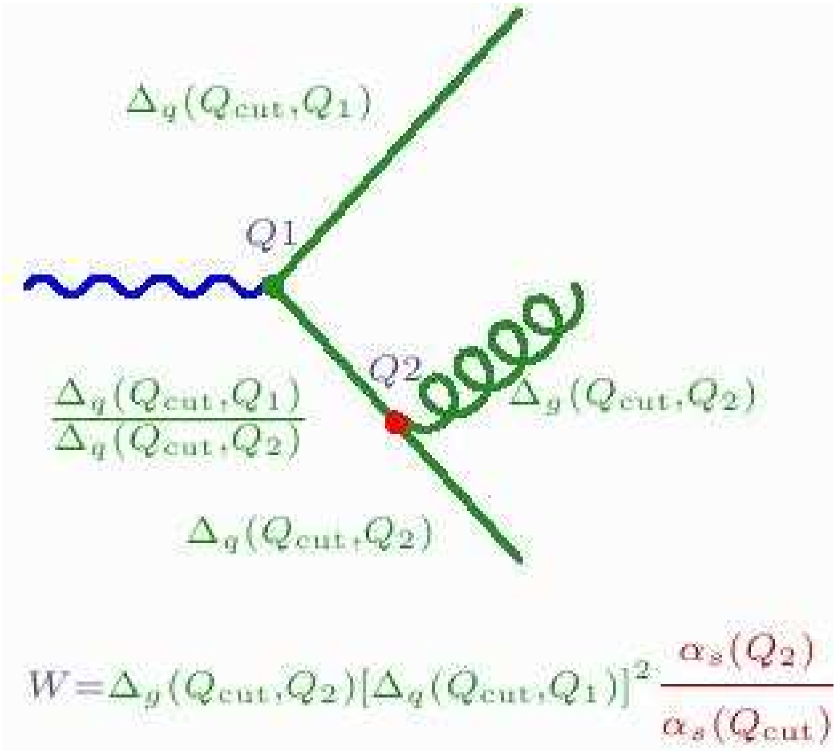
# MLM and L-CKKW approaches cont'd

- In MLM the number and topology of (semi-experimental) produced jets must match the partons in each of the ME used with the exception of the highest 'n'/multiplicity



# MLM and L-CKKW approaches cont'd

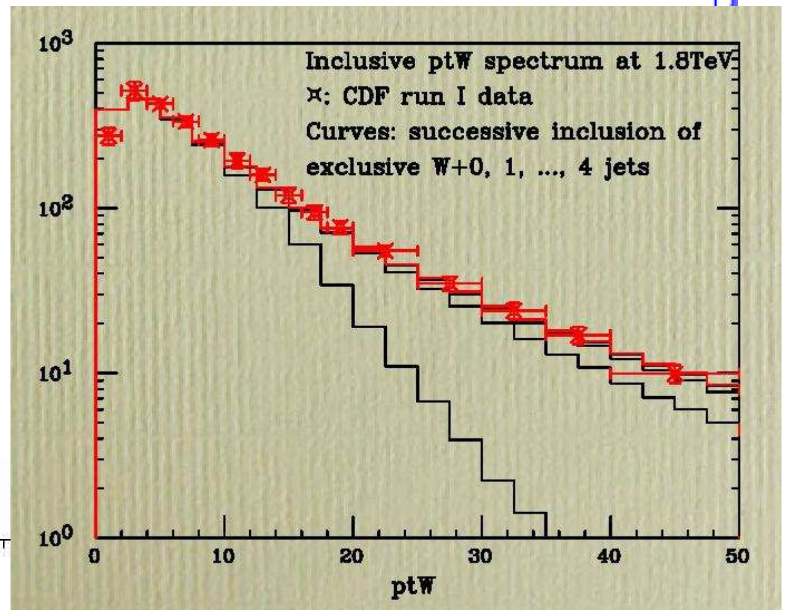
- In L-CKKW the ME events are reweighted with assigned Sudakov weights and the parton shower procedure is veto-ed accordingly.
  - An 'interpolation' scheme between ME and PS regions of validity.



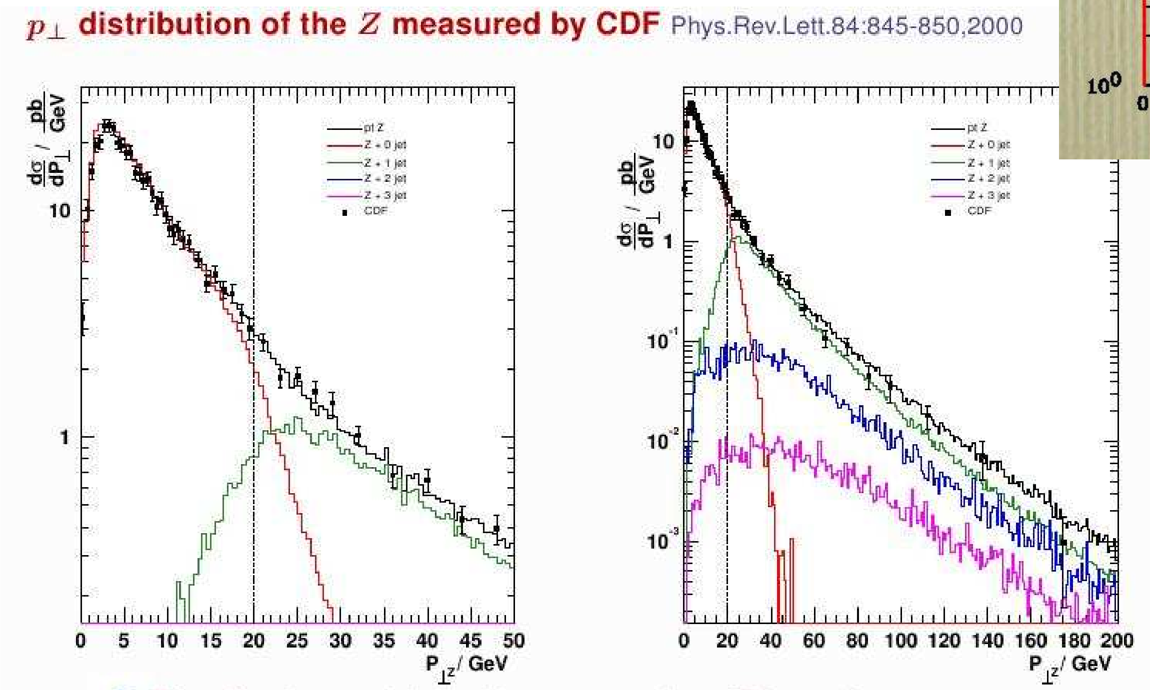
# MLM and L-CKKW approaches cont'd

- The (experimental) bottom line is that both seem to be doing a good job at the TeVatron!

Alpgen




Sherpa



# ALPGEN and MLM: Stability checks

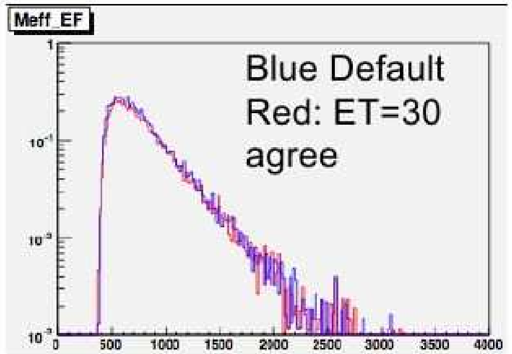
- A nice example is the check of the stability of the MLM matching procedure using Alpgen W+n jets process:
  - The default ET and cone values of the semi-experimental jets were shifted by about 30%
  - The plot shows checks done in a SUSY analysis after the selection cuts were performed

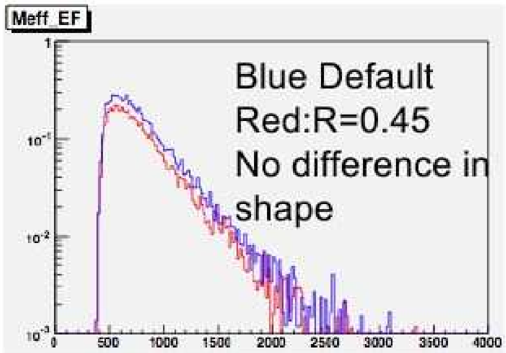
| | Default | ET(THS)=30GeV | R=0.45 |
|---|---|---|---|
| W+2parton | 0.29 | 0.19 | 0.12 |
| W+3parton | 2.20 | 1.60 | 1.64 |
| W+4parton | 2.67 | 2.19 | 2.12 |
| W+5parton | 1.65 | 2.34 | 1.39 |
| Sum | 6.84 | 6.32 | 5.27 |

σ*Br after MLM matching

SUSY CUT

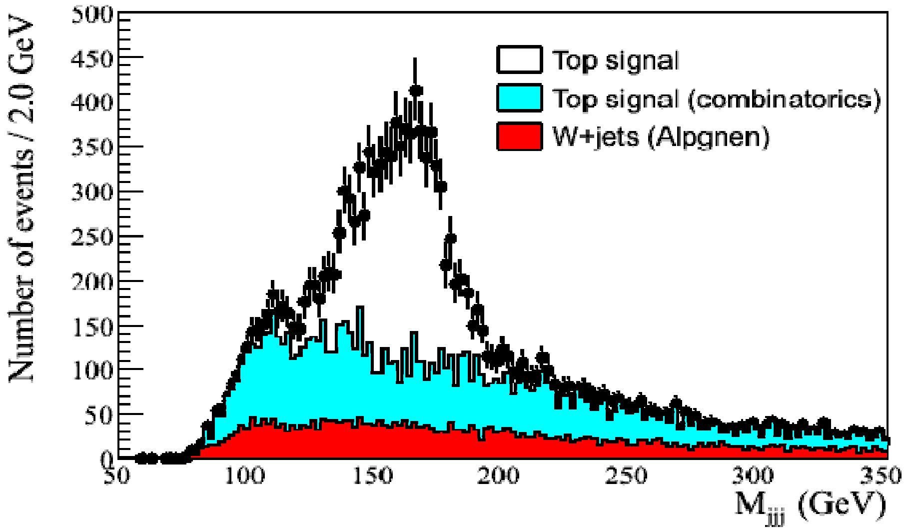
(-20% difference)



# ALPGEN and MLM: Stability checks

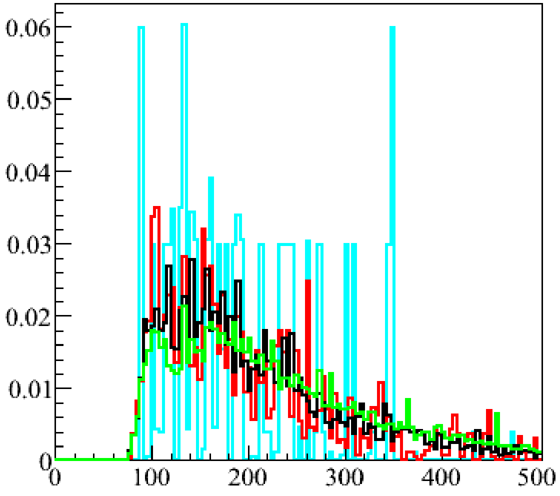
- A similar check was performed in the tt~ semi-leptonic analysis where W+4jets is assumed to be the dominant background:

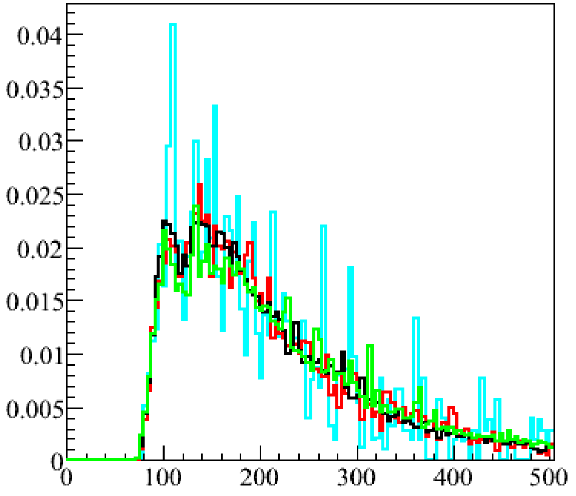


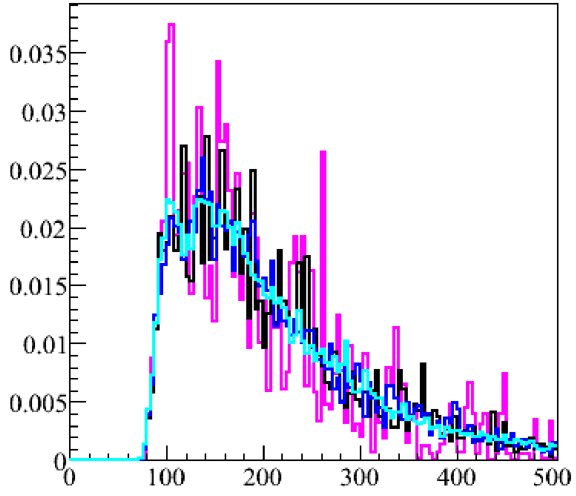

**3 jets with pT>40 + 1 jet with pT>20 && 1 lepton pT>20**

# Stability checks

- After the selection cuts the event shapes are consistent and agree with other observations

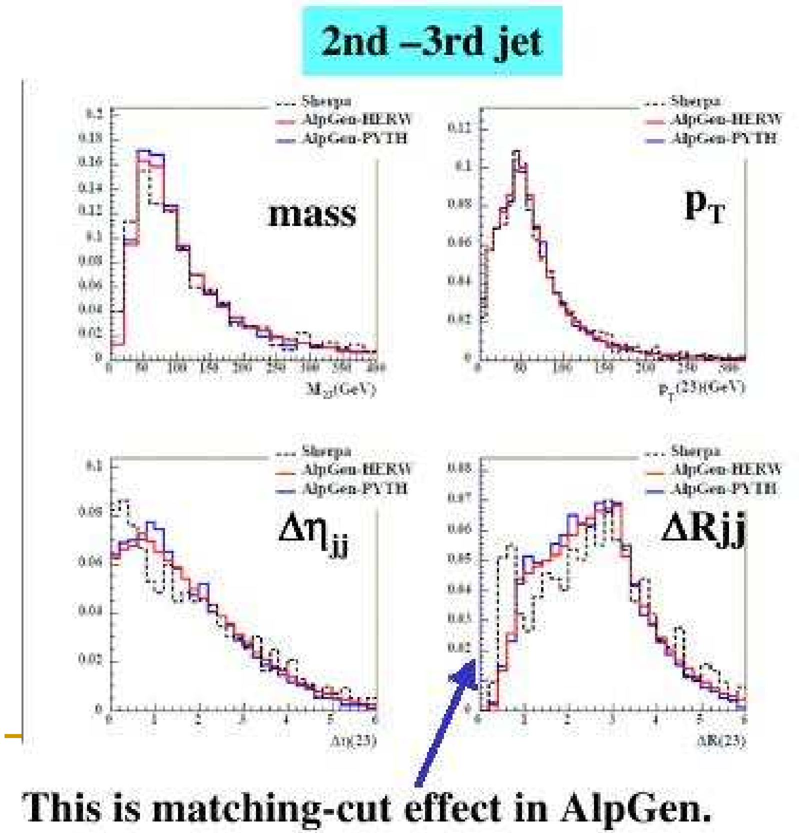


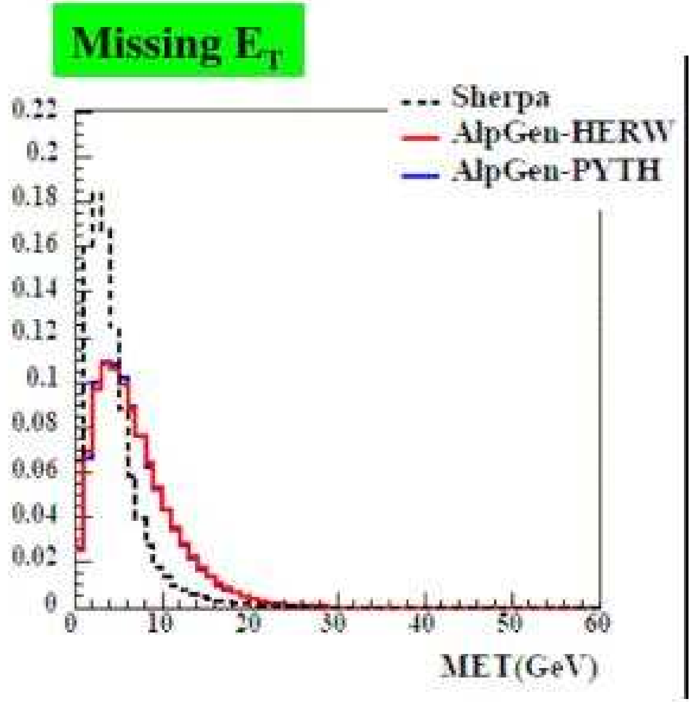



# Comparison with Sherpa

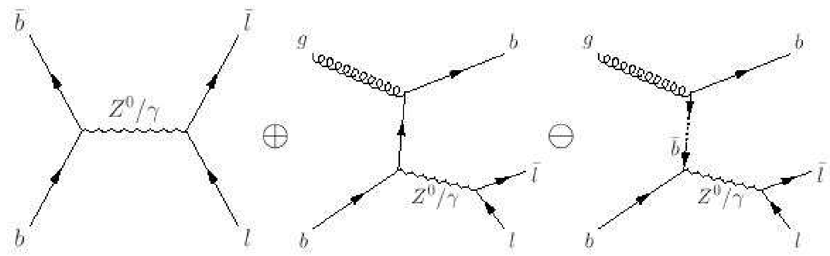
- There are however observable differences when comparing the Alpgen +MLM and Sherpa (L-CKKW) predictions.. Still under study.. Example from Z+n-jet study:

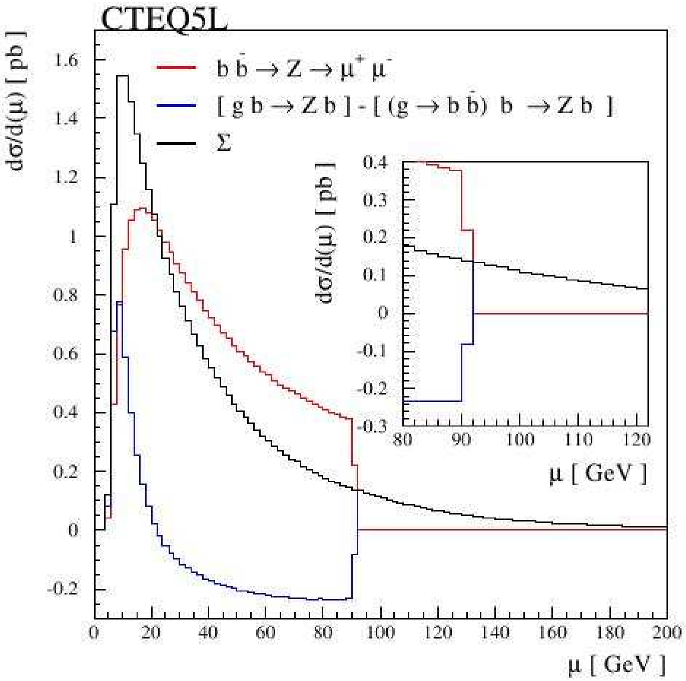


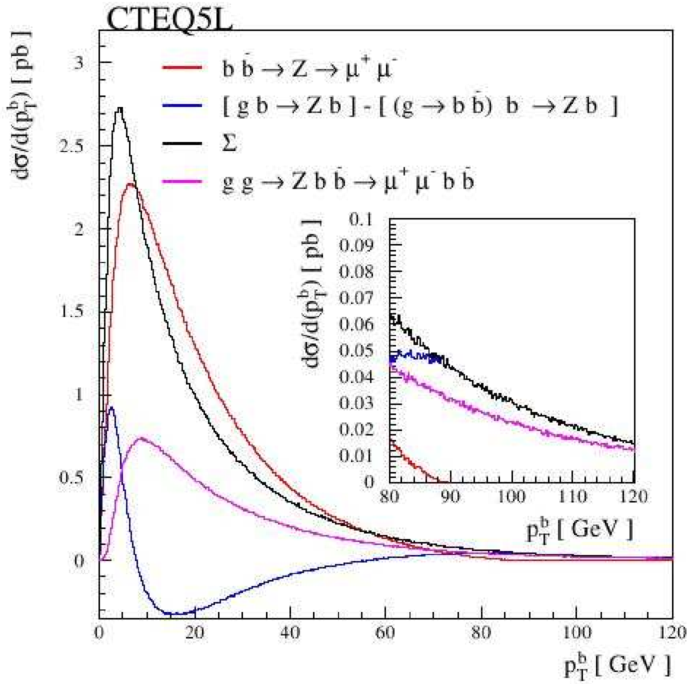



# AcerMC heavy quark matching

- I will just flash this, details in JHEP09(2006)033



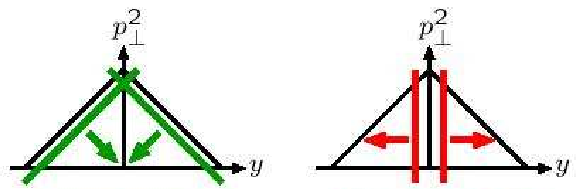


# Parton showering: Pythia and Herwig

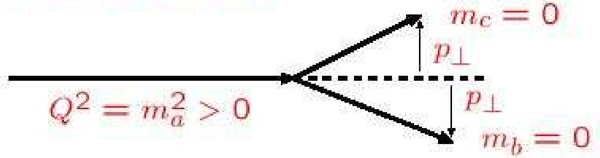
- Pythia introduced a new parton-shower model with version 6.3+, using the pT in the splitting as the Sudakov evolution parameter:
  - At ATLAS we decided to use it as default (the first ones to do it!)
  - The showering activity increases substantially in the new model!

| PYTHIA: $Q^2 = m^2$ | HERWIG: $Q^2 \sim E^2\theta^2$ |
|---|---|

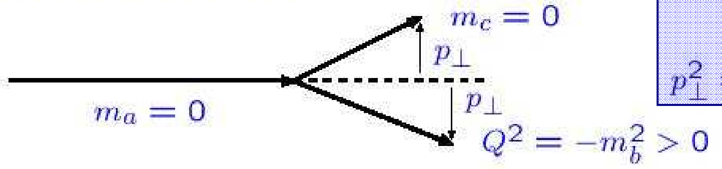



| PYTHIA | HERWIG |
|---|---|
| large mass first | large angle first |
| ⇒ "hardness" ordered | ⇒ **hardness not ordered** |
| **coherence brute force** | coherence inherent |
| covers phase space | **gaps in coverage** |
| ME merging simple | **ME merging messy** |
| g → q$\overline{\text{q}}$ simple | g → q$\overline{\text{q}}$ simple |
| **not Lorentz invariant** | **not Lorentz invariant** |
| no stop/restart | no stop/restart |
| ISR: $m^2 \to -m^2$ | ISR: $\theta \to \theta$ |

Timelike branching:




Spacelike branching:




**New evolution variables**

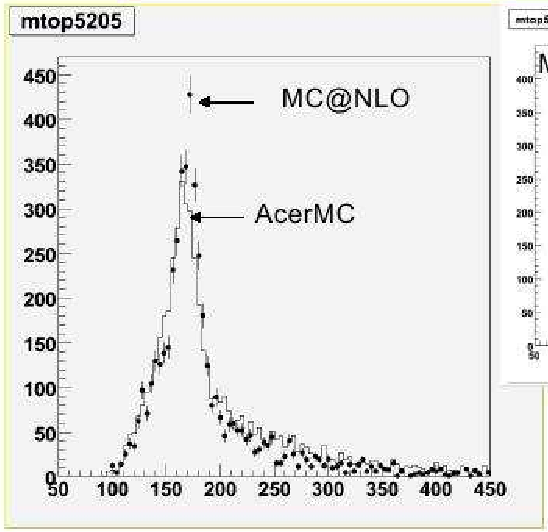
$$p_\perp^2 = z(1-z)Q^2$$

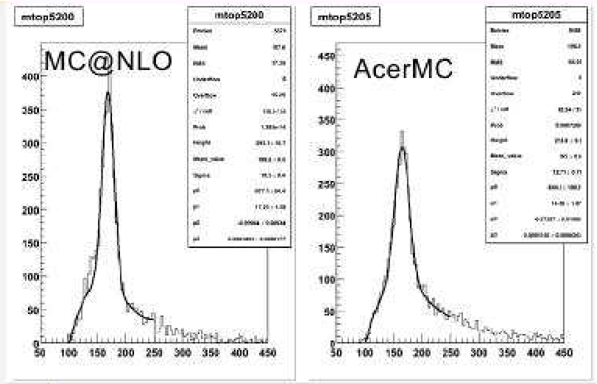
$$p_\perp^2 = (1-z)Q^2$$

# Impact of different models

- Recently a study of top mass reconstruction using tt~ was done using:
  - MC@NLO (Herwig+Jimmy)
  - AcerMC (Pythia – new model)
  - Full detector simulation
  - The observed discrepancy caused quite a few raised eyebrows..

AcerMC versus MC@NLO



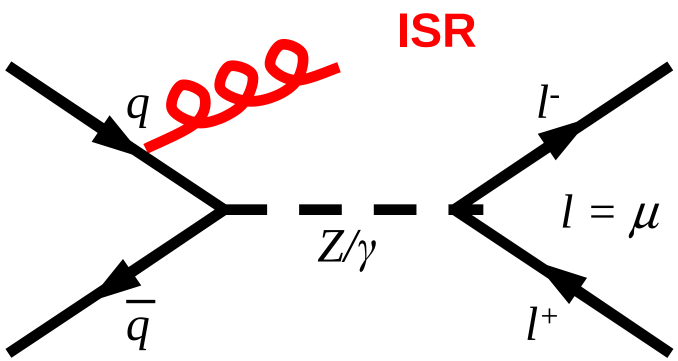

| | MC@NLO | AcerMC |
|---|---|---|
| <> | 169.2 ± 0.4 | 165.0 ± 0.6 |
| σ | 10.5 ± 0.4 | 12.7 ± 0.7 |

We do cannot know offhand which answer is correct!

- Distributions not compatible
- Fit (gaussian + P3) → 4 GeV difference !!

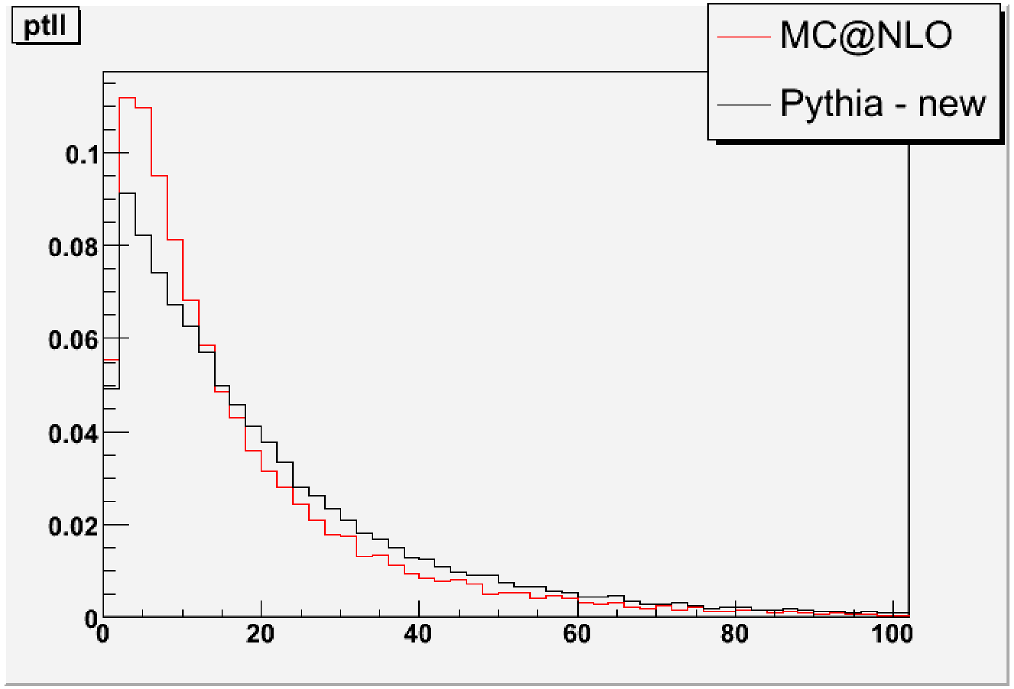
# Drell Yan processes

- In order to compare the different showering models a simpler example was used, motivated by the TeVatron approach to showering systematics in tt~ events.
  - The relevant observable for the ISR effect was observed to be the $P_T$ of the dilepton system
  - Measures the recoil of the Z due to ISR
- The comparison was made between MC@NLO/Herwig and Pythia Drell-Yan.



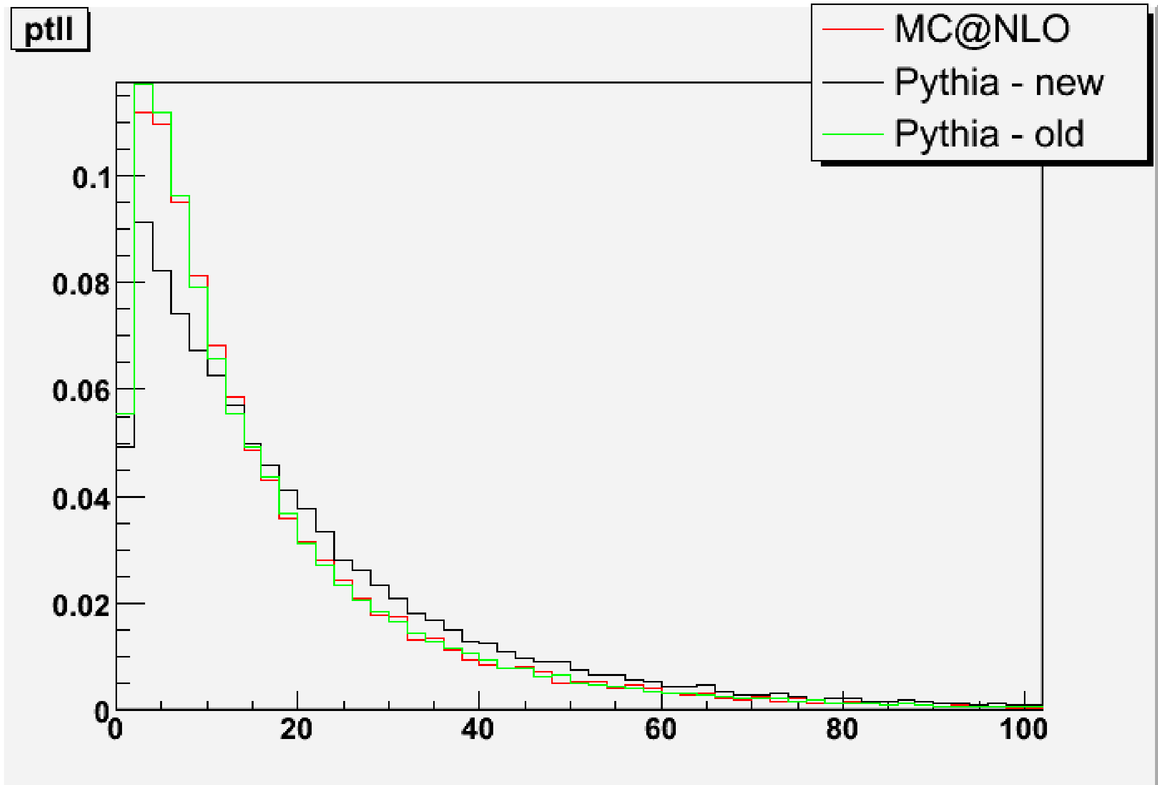
# The $P_T$ of the dilepton system

- It appears that the new Pythia showering actually gives a harder ISR spectrum – confirms what was already observed
  This seems surprising:
  - MC@NLO should in principle get at least the first ISR gluon harder than Pythia?
  - Actually, not entirely true: The MC@NLO 'extra jet' part is actually LO – same as Pythia's ME corrections in the Drell-Yan case.
  - The observed difference therefore strictly ISR related!



# $P_T$ of the dilepton system

- The situation becomes quite worrying if one superimposes the Drell-Yan with the old Pythia showering:
  - Seems to agree quite well with MC@NLO!
  - One would thus assume that the new showering is 'problematic' ...
  - Of course there is a however..



# $P_T$ of the dilepton system

- The present 'old' Pythia defaults are quite close to Rick Field's 'tune A' for UE settings.

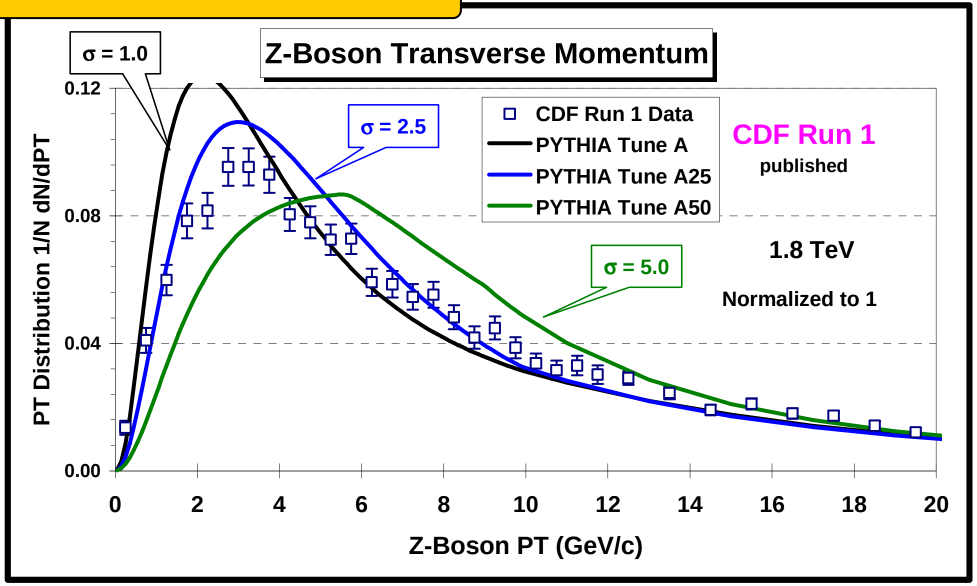
UE Parameters

ISR Parameter

Intrinsic KT

| Parameter | Tune A | Tune A25 | Tune A50 |
|---|---|---|---|
| MSTP(81) | 1 | 1 | 1 |
| MSTP(82) | 4 | 4 | 4 |
| PARP(82) | 2.0 GeV | 2.0 GeV | 2.0 GeV |
| PARP(83) | 0.5 | 0.5 | 0.5 |
| PARP(84) | 0.4 | 0.4 | 0.4 |
| PARP(85) | 0.9 | 0.9 | 0.9 |
| PARP(86) | 0.95 | 0.95 | 0.95 |
| PARP(89) | 1.8 TeV | 1.8 TeV | 1.8 TeV |
| PARP(90) | 0.25 | 0.25 | 0.25 |
| PARP(67) | 4.0 | 4.0 | 4.0 |
| MSTP(91) | 1 | 1 | 1 |
| PARP(91) | 1.0 | 2.5 | 5.0 |
| PARP(93) | 5.0 | 15.0 | 25.0 |

PYTHIA 6.2 CTEQ5L




- PARP(67) =1 in 'old' model Pythia defaults!

# $P_T$ of the dilepton system

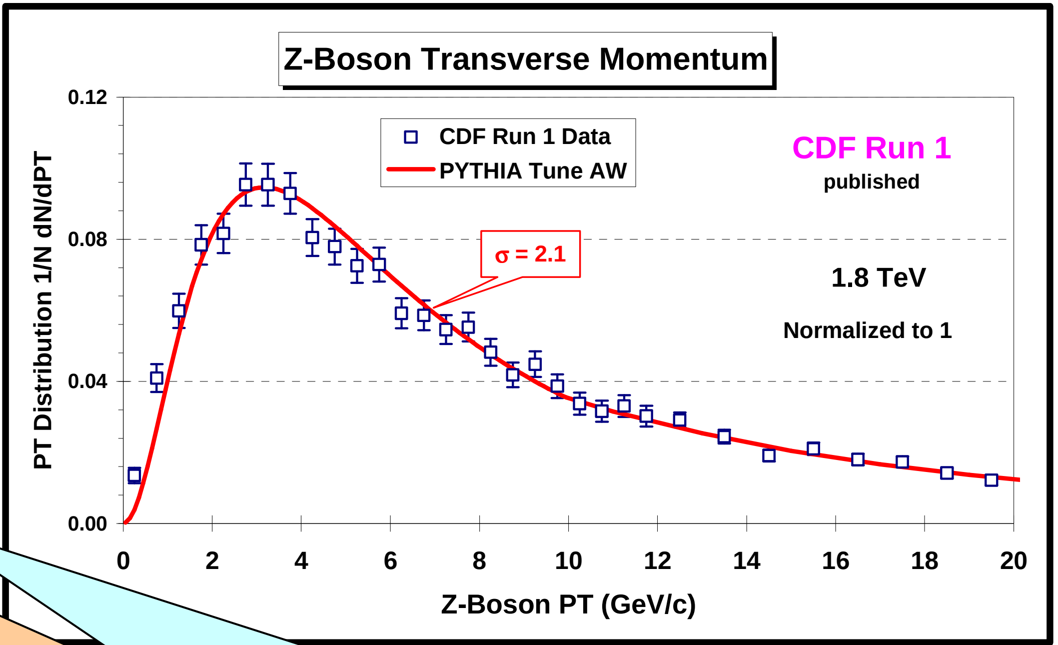
- However the R. Fields AW-tune does a much better job!

| Parameter | Tune A | Tune AW |
|---|---|---|
| MSTP(81) | 1 | 1 |
| MSTP(82) | 4 | 4 |
| PARP(82) | 2.0 GeV | 2.0 GeV |
| PARP(83) | 0.5 | 0.5 |
| PARP(84) | 0.4 | 0.4 |
| PARP(85) | 0.9 | 0.9 |
| PARP(86) | 0.95 | 0.95 |
| PARP(89) | 1.8 TeV | 1.8 TeV |
| PARP(90) | 0.25 | 0.25 |
| PARP(62) | 1.0 | 1.25 |
| PARP(64) | 1.0 | 0.2 |
| PARP(67) | 4.0 | 4.0 |
| MSTP(91) | 1 | 1 |
| PARP(91) | 1.0 | 2.1 |
| PARP(93) | 5.0 | 15.0 |

UE Parameters (MSTP(81) – PARP(90))

ISR Parameters (PARP(62) – PARP(67))

Intrinsic KT (MSTP(91) – PARP(93))

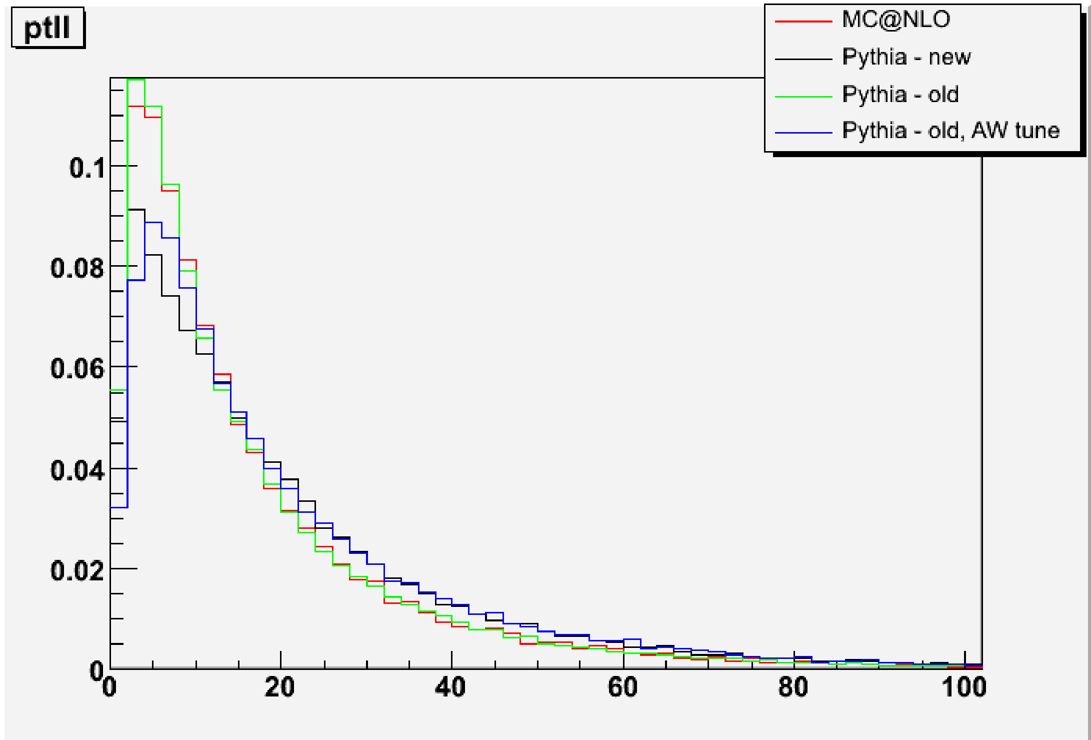



Effective Q cut-off, below which space-like showers are not evolved.

The $Q^2 = k_T^2$ in $\alpha_s$ for space-like showers is scaled by PARP(64)!

# $P_T$ of the dilepton system

- The new AW tuning was ported to the ATLAS Pythia setup. The result is rather surprising, namely the AW-tuned 'old' Pythia showering seems to agree quite well with the new Pythia showering!
  - This would thus indicate that the new Pythia model works fine!
  - What it boils down to is that ISR/FSR tuning is of essence!
  - These results are of course very preliminary studies, need work!



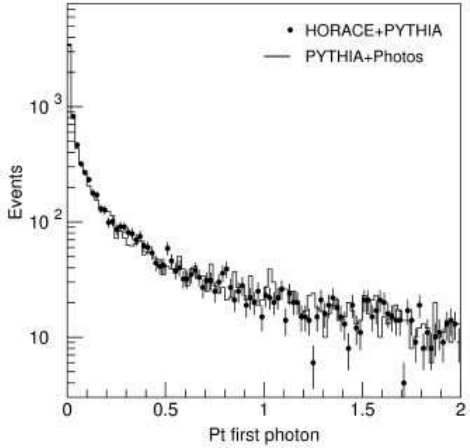
# A successful validation example (since I'm in Cracow)

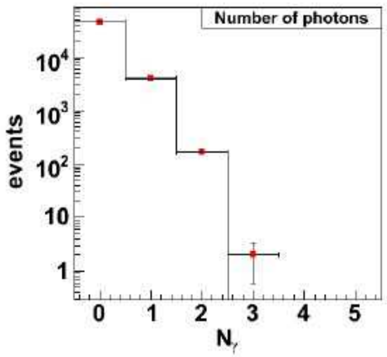
- Comparison between PHOTOS (supposed to be an approximate algorithm in principle) and HORACE (exact QED DGLAP solution):
  - Turns out that PHOTOS is doing an excellent job!

## HORACE vs Photos (3)

- Photon multiplicity and transverse momentum spectrum done with standalone generators (outside Athena)

perfect agreement for all $p_T$ range




with cut $p_T(\gamma)$ > 500 MeV perfect agreement also in Athena iterfaced version to third hard photon

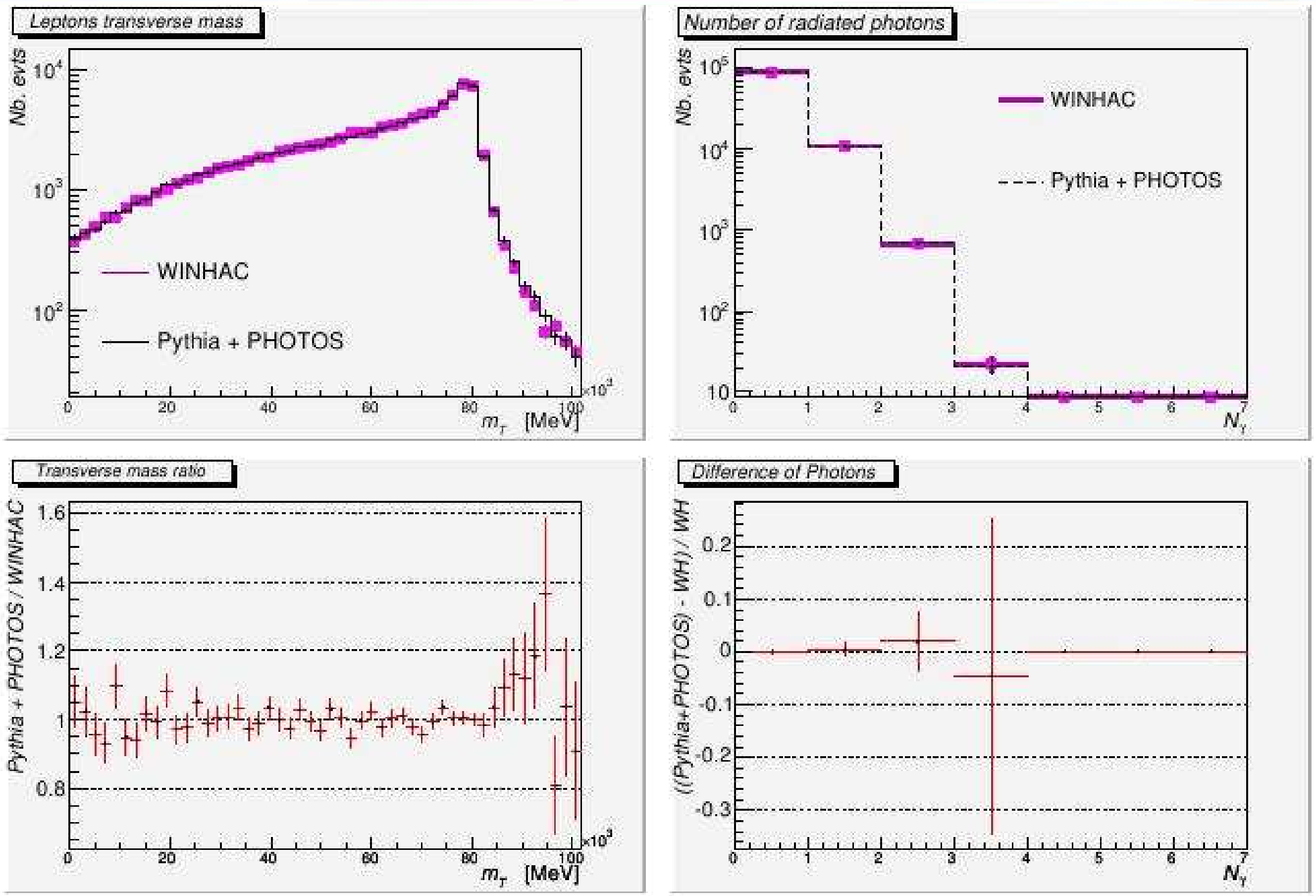
Pythia + HORACE

Pythia + Photos

# And another one..

WINHAC (6/9)
└3. Latest validation results

## Tuned comparison with PYTHIA+PHOTOS

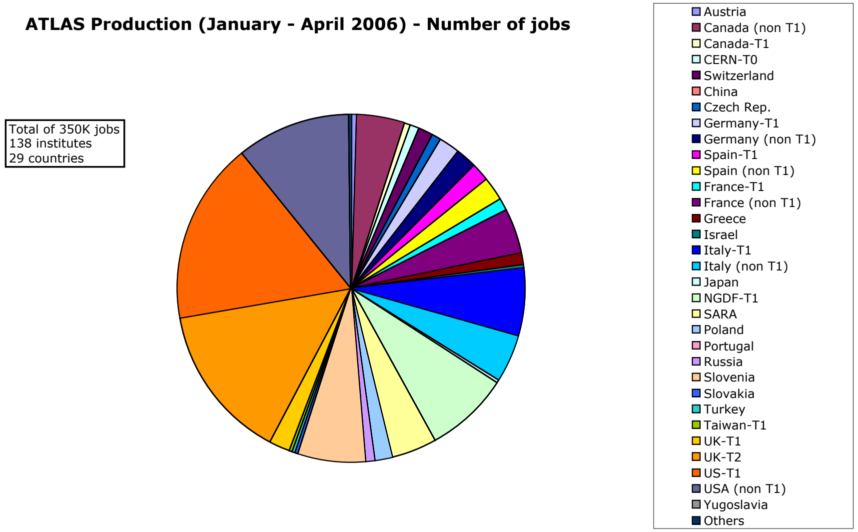


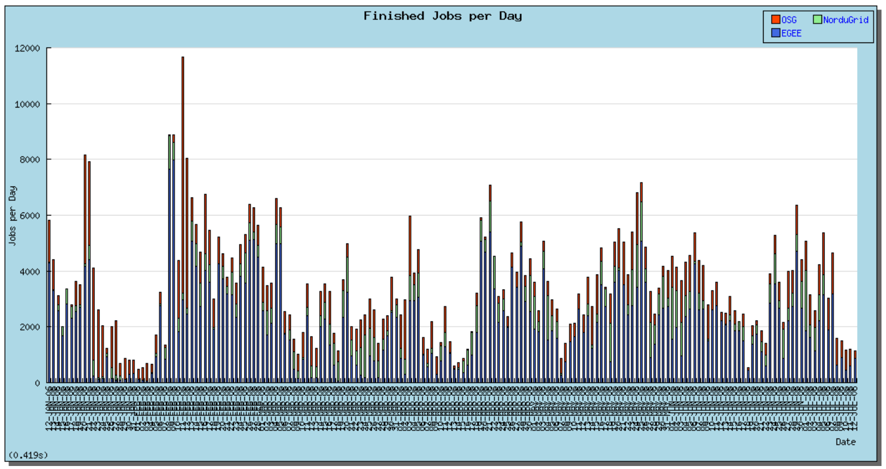
# Summary/Conclusions

- A lot of effort has been spent (but by no means wasted!) on incorporating the wide range of MC tools into the ATLAS software framework and validating them.
  - The validation and use of new tools/versions that appear on the HEP 'marketplace' will of course continue.
- Some issues still need work..
  - e.g. Tuning MC tools using Tevatron (and other) experience/results
- All in all we believe to be in a good shape waiting for the first physics data!

# ATLAS CSC

- The latest large-scale MC production is ongoing within the ATLAS Computing System Comissioning program:
  - 30M+ fully simulated MC events produced.
  - A wide range of MC generators used.
  - CSC done within the grid infrastructure, 3 grid flavors used (OSG, LCG and NorduGrid)



# ATLAS interface to MC generators

- MC generators interfaced to the ATLAS ATHENA (C++/Python) framework:
  - The ME level MC generators written in FORTRAN interfaced through the LesHouches-compliant event files:
    - The event samples themselves produced offline and validated
  - The PS/UE/MI generators (Pythia and Herwig) are linked into the ATHENA infrastructure using suitable C++ wrappers
  - The same is done with the addon/decay packages (Photos, EvtGen...)
  - We rely on GENSER where available.
- HepPDT, HepMC, LHAPDF used as generic tools.
  - What we have also done is to unify the (pseudo)random number service.