ATLAS Generator Usage and Tuning

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(most slides from Borut Kersevan, Cracow meeting Jan 2007, with minor updates)

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Outline

- Set the scene...
- Generators used
- Tuning/Validation
- Some examples

Scene-setting

- LHC environment will be very busy
  - Lots of new phase space for SM processes (especially W, Z, top, Higgs?, Jets)
  - Possible new physics
  - QCD everywhere
- One person's signal is is another one's background
  - need validated understanding of many processes even for some simple searches/measurements.
- Where do we have solid predictions?
- Where can we test these against data?

Scene-setting

- Therefore we need *general purpose generators* so we can cross-validate between processes
  - eg. QCD radiation, hadronisation...
- But we need state-of-the art custom simulation for specific aspects where available
  - e.g. NLO QCD; tau decays; multi-object final states

What we are currently using

- Several parton level Matrix Element generators
- Pythia 6.411
- Herwig 6.510 + Jimmy 4.31
- Sherpa interfaced, being validated

What we are currently using

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

DPEMC: Forward/elastic physics

The MC base will of course expand:

Pythia 8

HERWIG++

Add on/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.

Validation Procedures

Take into account experience and results at the Tevatron and elsewhere, and/or we try to tune/check the generators using available Tevatron information ourselves.

Compare the results of different MC generators in the quantities where they should agree (to a certain precision) either at the generator level or by performing full analysis studies.

Intend to make use of Jetweb/Rivet

In all cases we of course check the obvious parameters (masses, resonance shapes, angular (a)symmetries etc.)

Validation Procedures

Also check 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.

Nightly “Run Time Tester” (RTT) for regression/change tracking.

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:

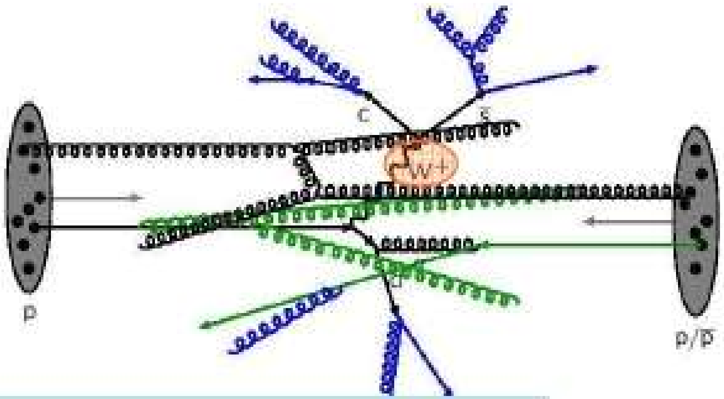
UE tuning: Pythia (two models) and Jimmy

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..

Underlying event tune 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!



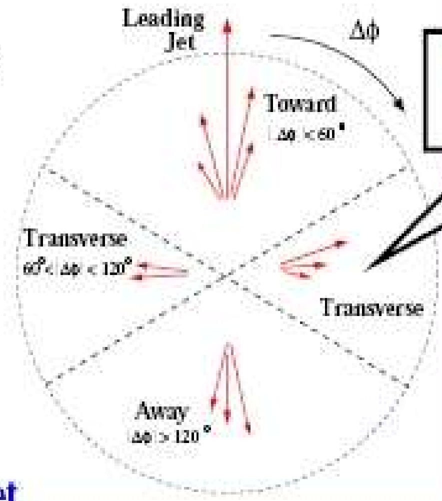
CDF analysis: QCD dijets

- charged particles:

p_t>0.5 GeV and |η|<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).***

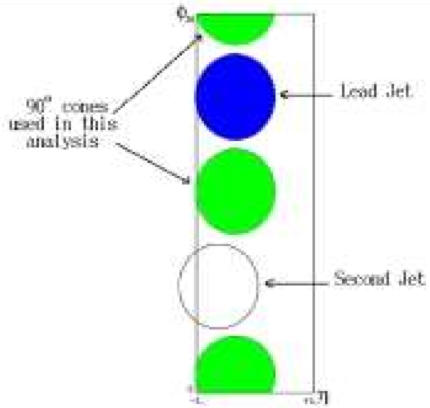
Underlying event tune using CDF data

Max/Min analysis:Pythia

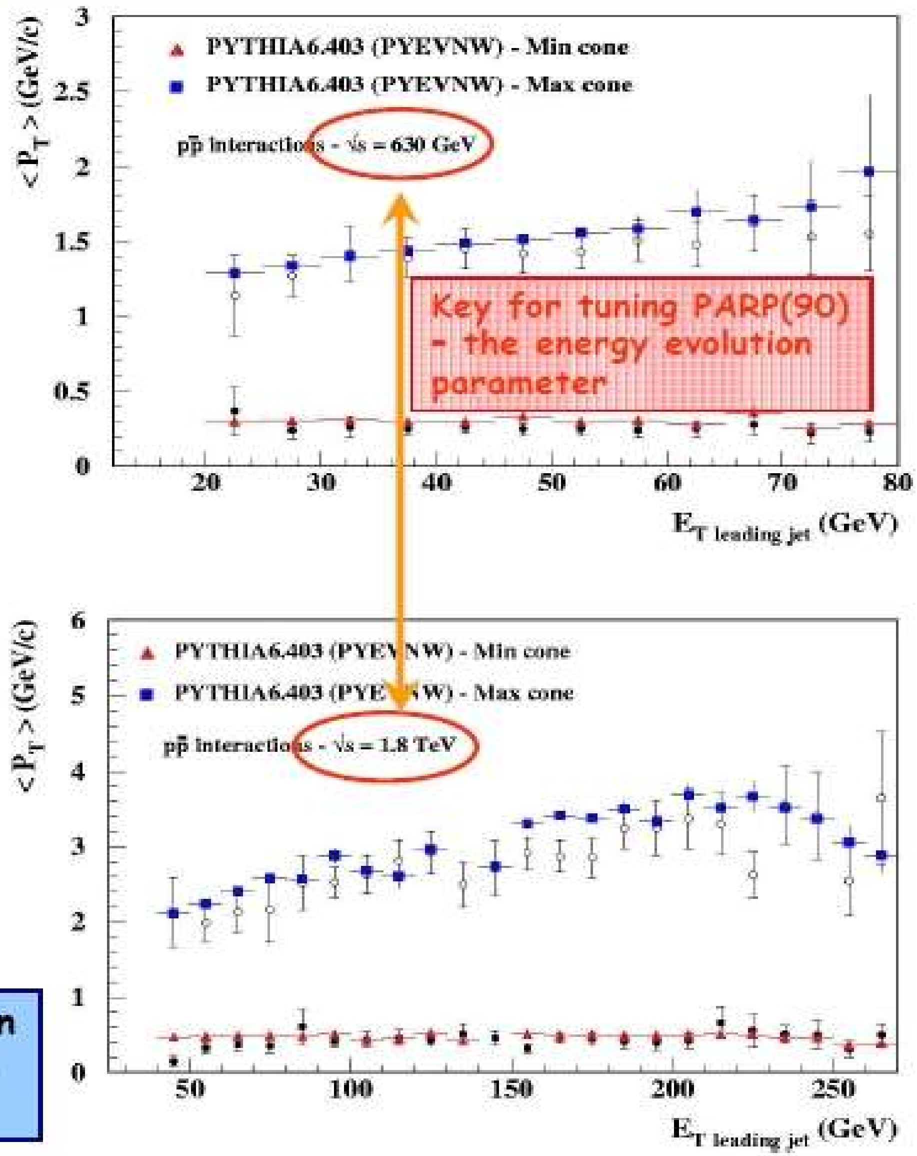
- The underlying event is measured for jet events at two different colliding energies: 630 GeV and 1800 GeV.

- 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.



Underlying event tune to CDF data

- JIMMY
  - CTEQ 6LO (LHAPDF 10042)
  - PTJIM=2.8 x $(\sqrt{s}/1.8\ \text{TeV})^{0.27}$ (default has no energy dependence)
  - JMRAD(73) = 1.8 (inverse proton radius squared, default 0.73)
  - PRSOF=0.0 (turn off Herwig soft underlying event)

PTJIM energy dependence

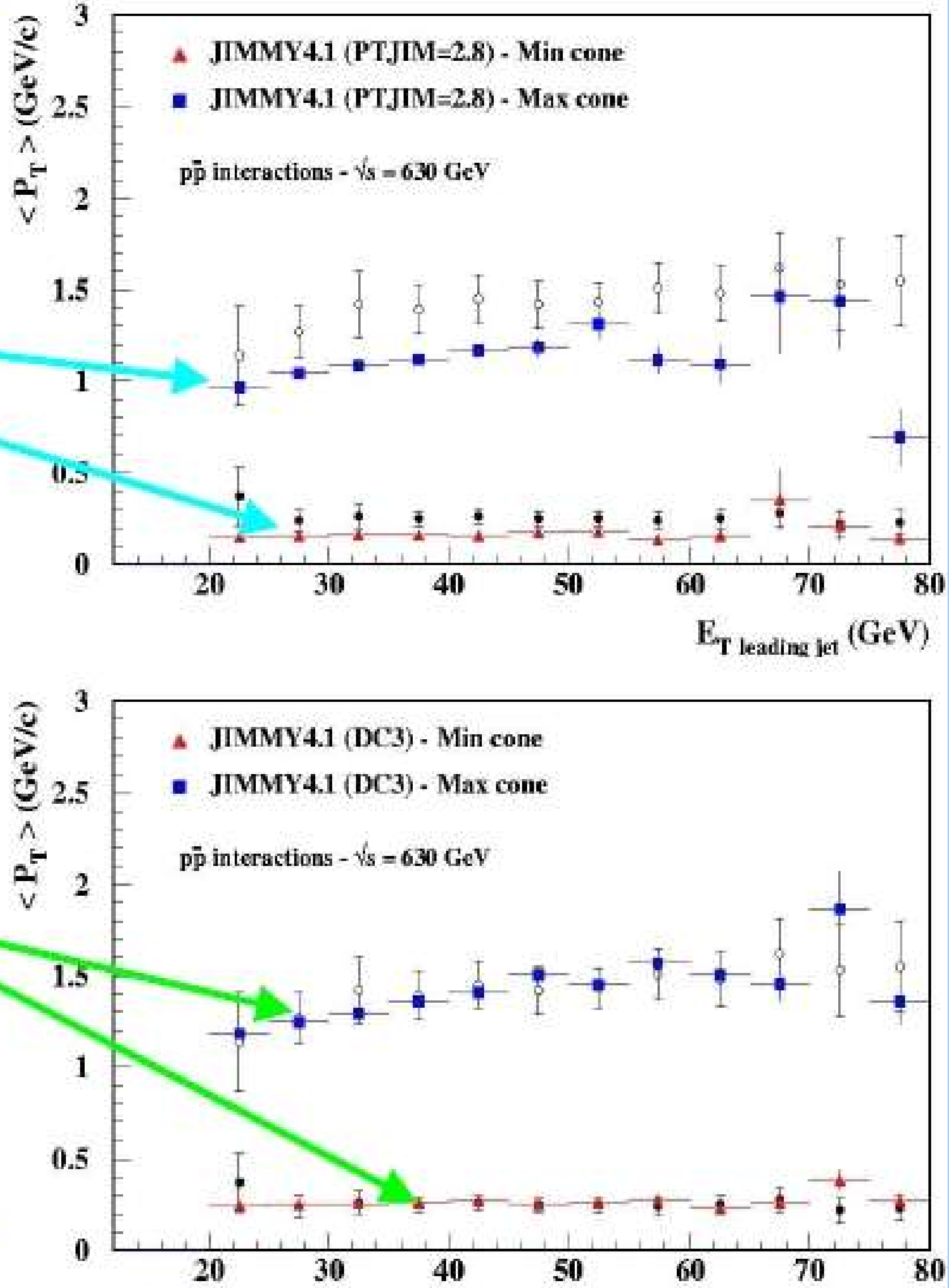
PTJIM=2.8

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

PTJIM=2.1

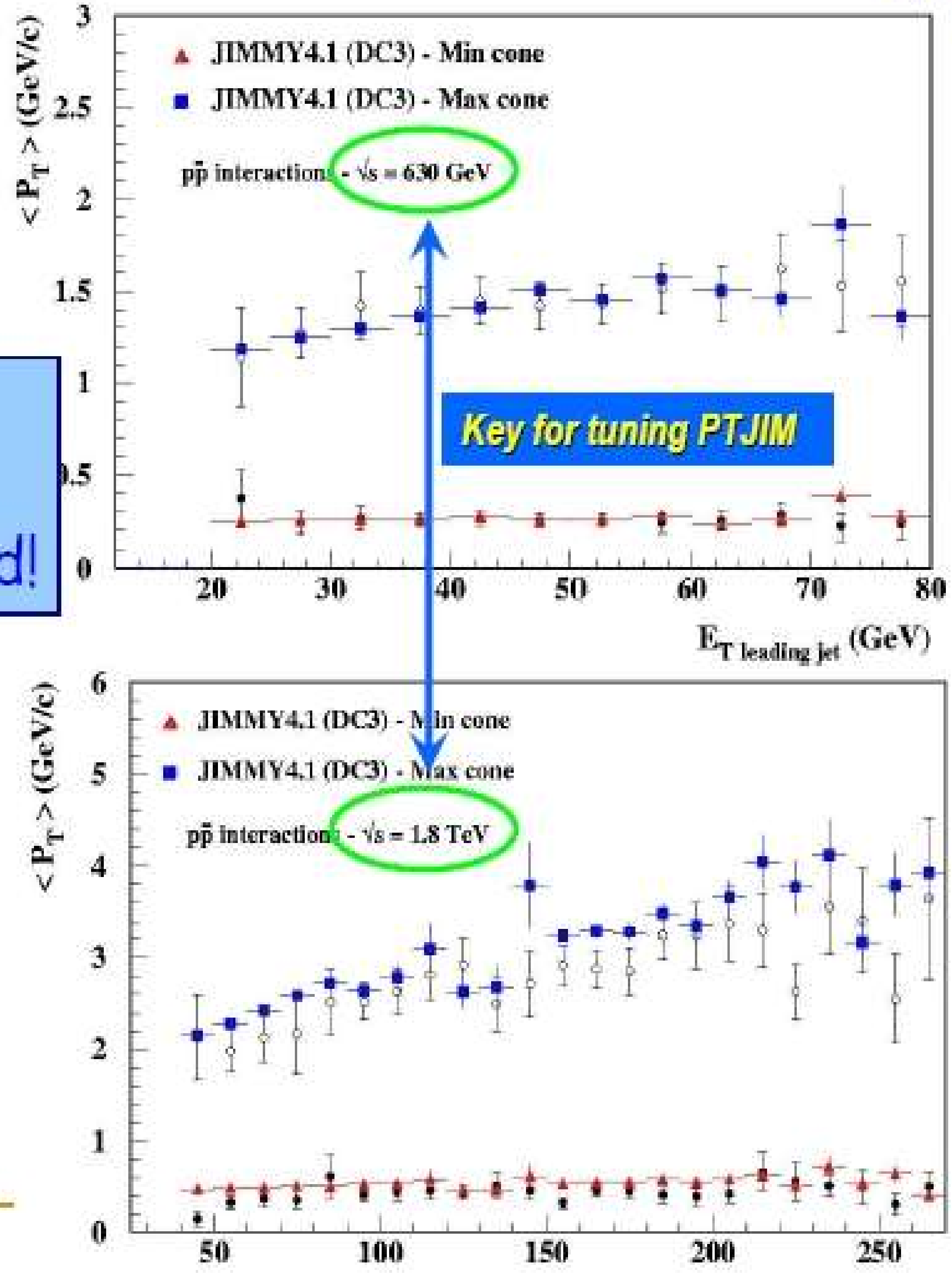
$= 2.8 \times (0.63 / 1.8)^{0.27}$

- introducing energy dependent factor we get a better agreement.

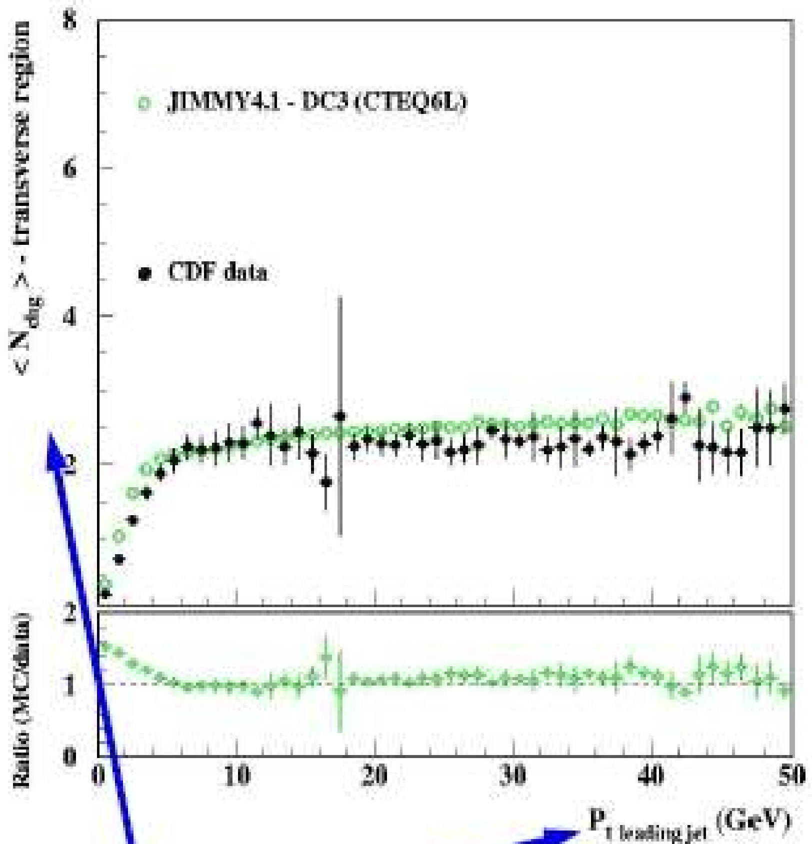


MAX/MIN analysis with Jimmy

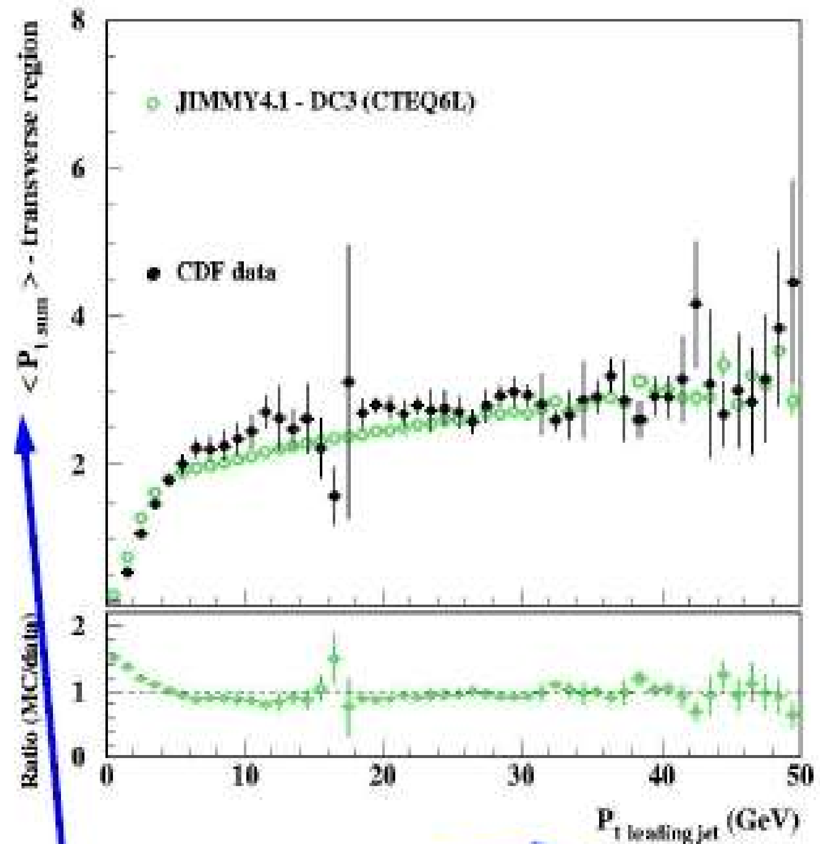
With the introduction of this energy scaling a good agreement is again reached!



UE tunings: Jimmy validation using CDF data

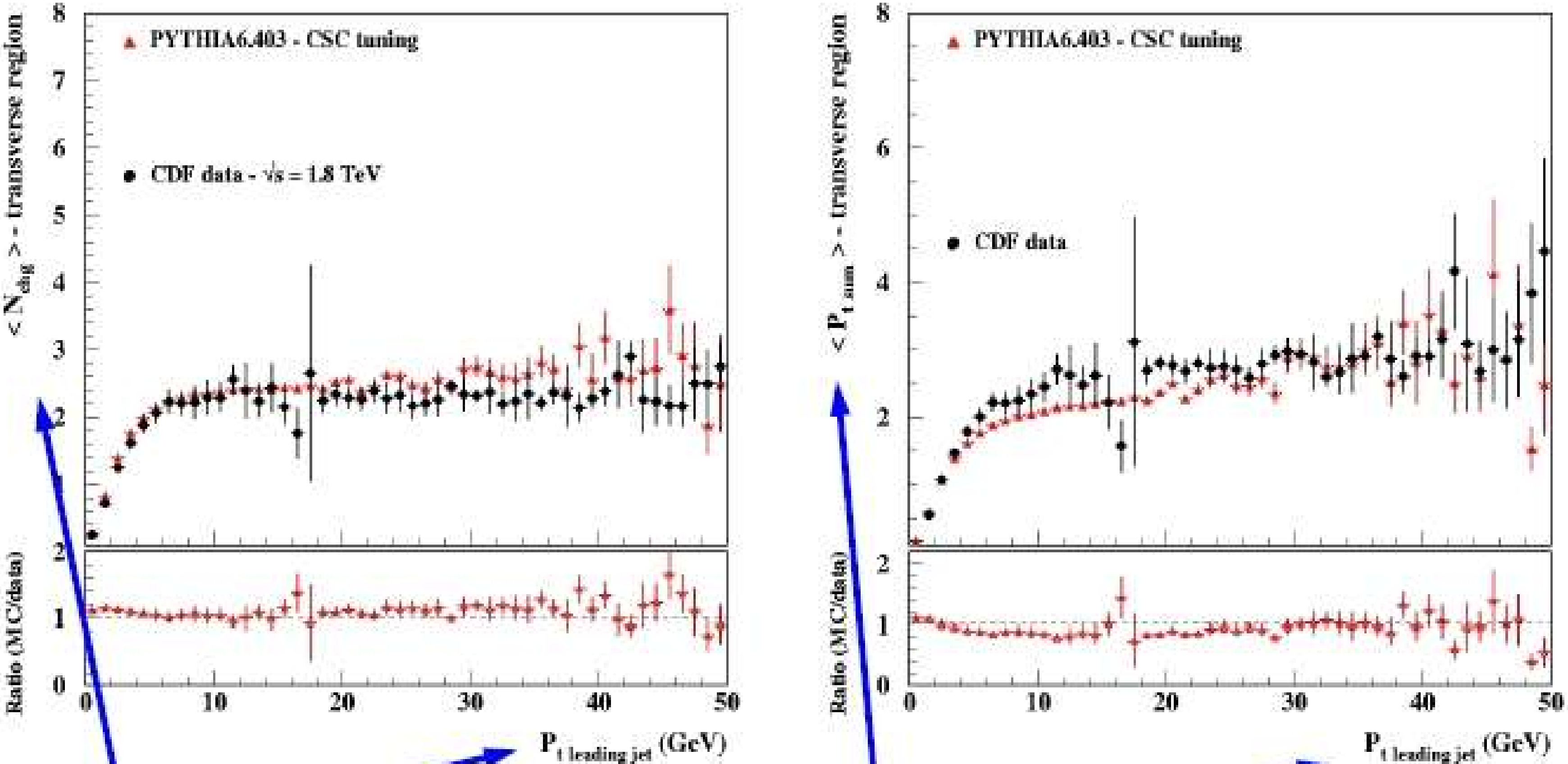


Average multiplicity of charged particles in the underlying event associated to a leading jet with P_t^{ljet} (GeV).



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

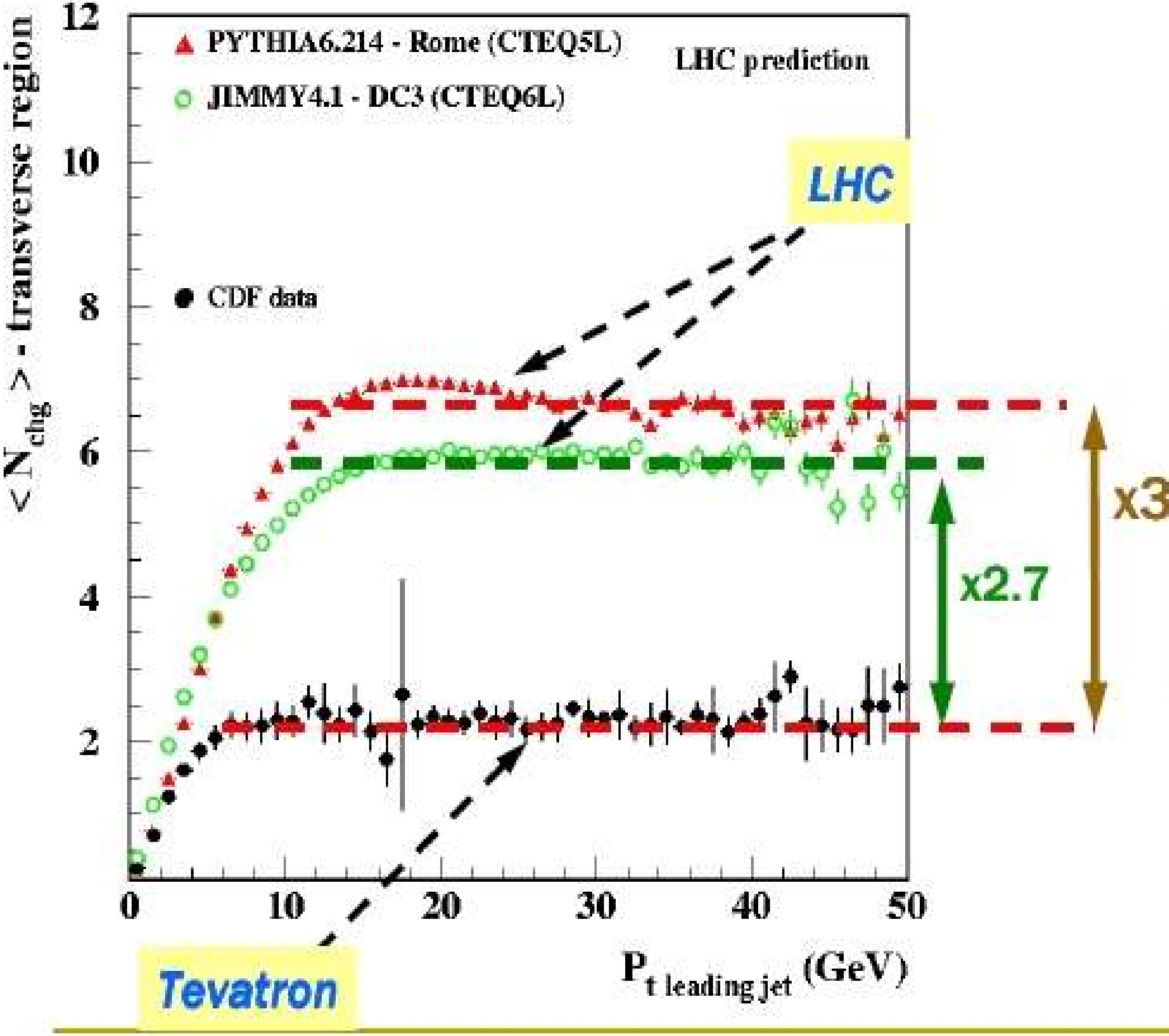
UE tunings: Pythia 6.4 validation using CDF data



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

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

UE tunings: Pythia vs. Jimmy



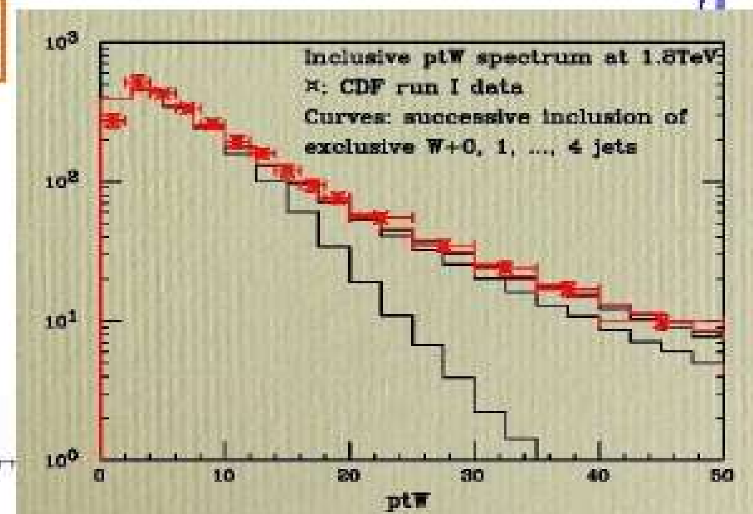
Energy dependent PTJIM generates UE predictions similar to the ones generated by PYTHIA; the difference used to be a factor two!

ME/PS Matching

- Experience on ATLAS with AlpGen (MLM) and Sherpa (L-CKKW), mainly for inclusive W+n jet and Z+n jet samples.

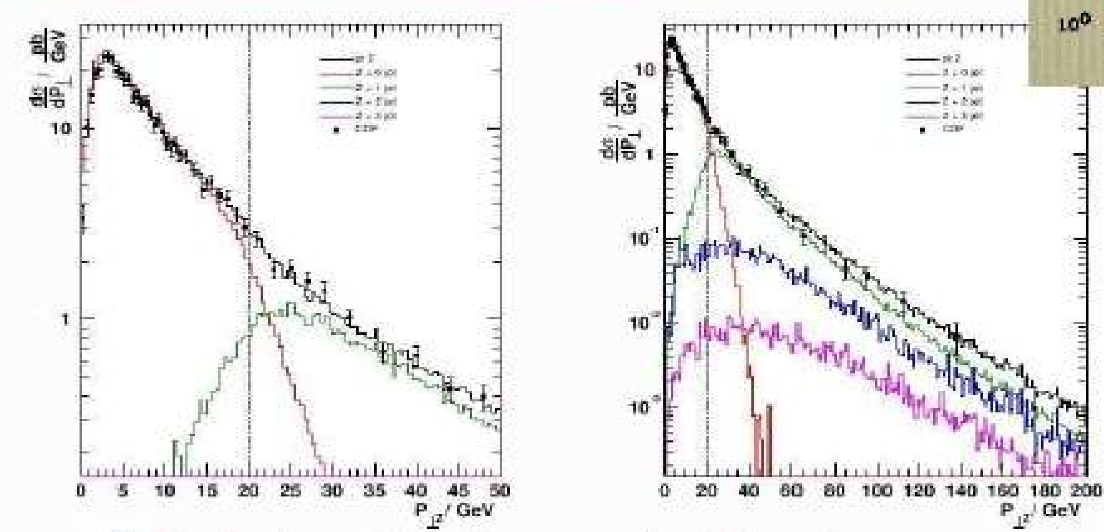
Alpgen

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



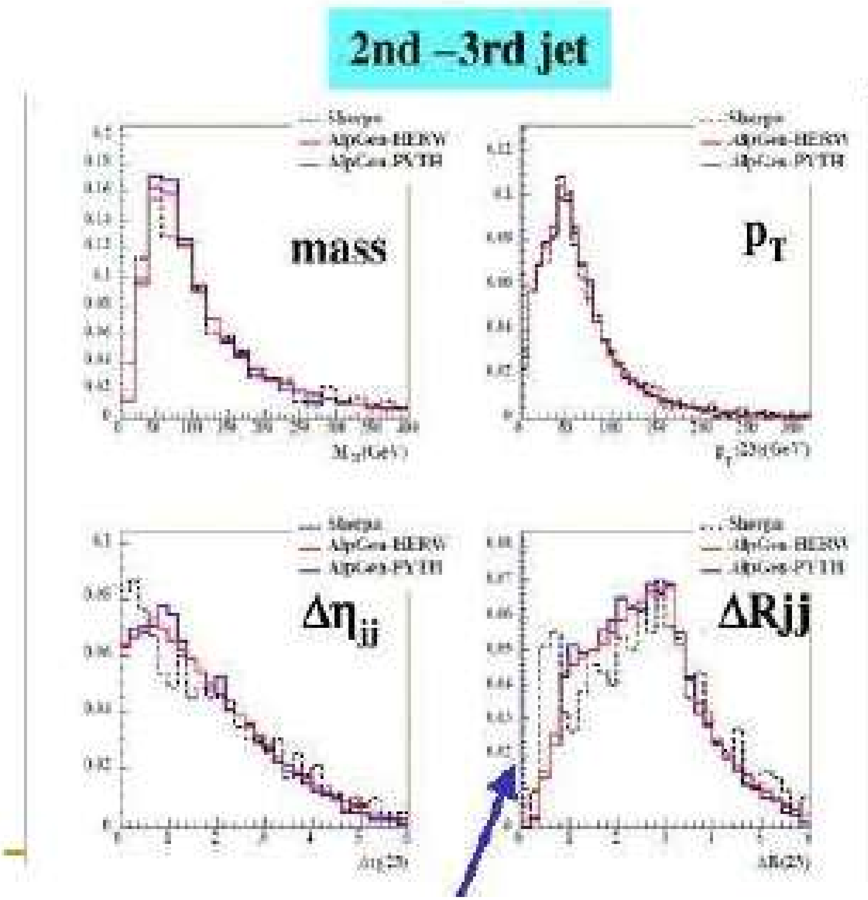
Sherpa

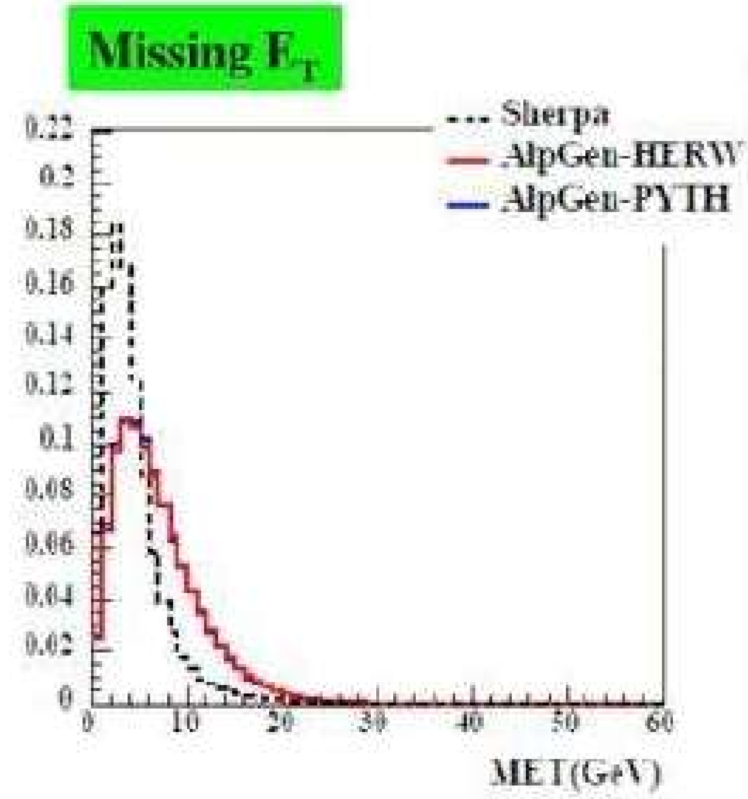
$p_\perp$ distribution of the Z measured by CDF Phys.Rev.Lett.84:845-850,2000



ME/PS Matching

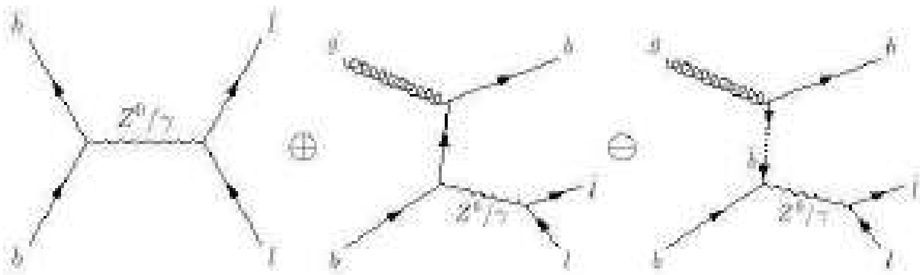
- Differences between Sherpa and AlpGen seen in e.g. in Z+n jet studies at LHC energy.

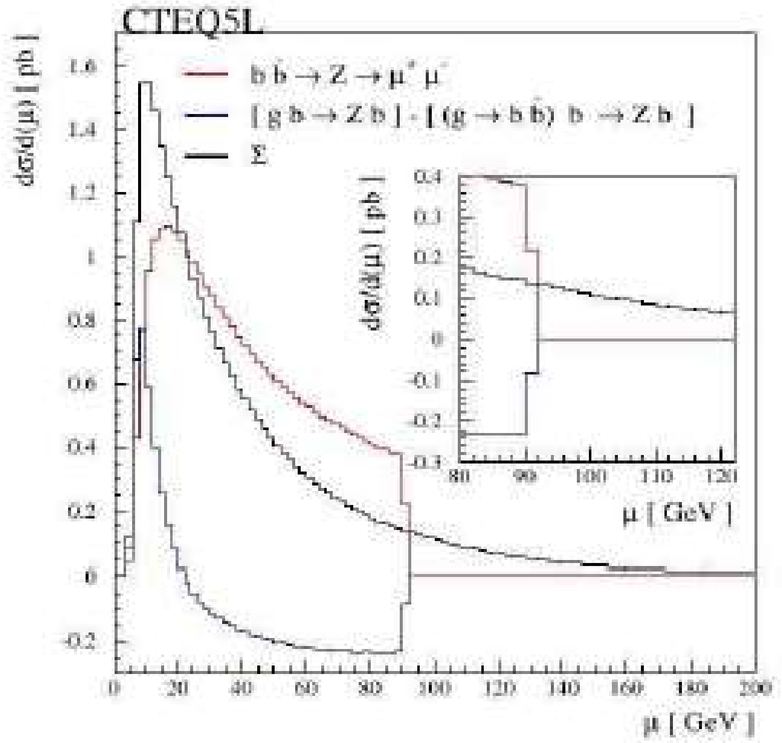


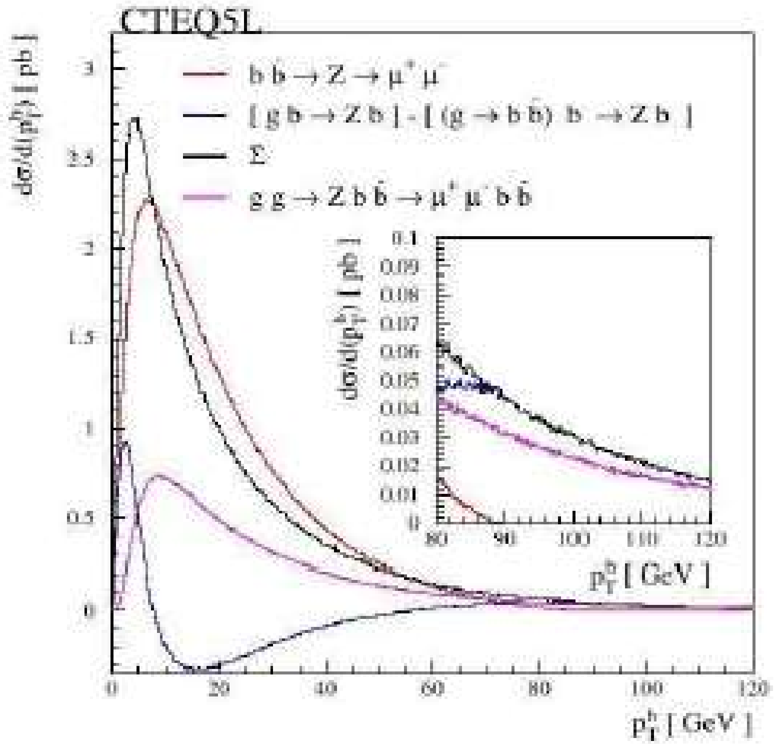


AcerMC heavy quark matching

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



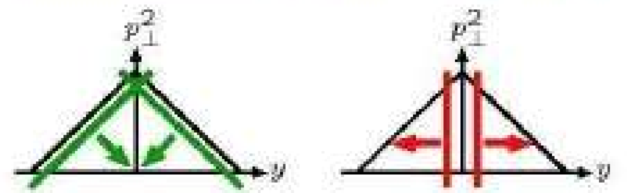




Parton showering: Pythia and Herwig

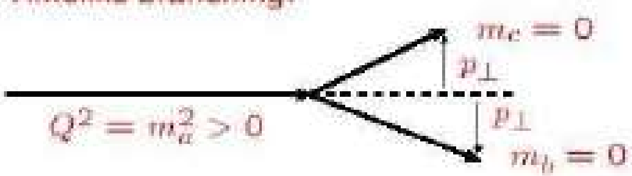
- Pythia introduced a new parton-shower model with version 6.3+, using the pT in the splitting as the Sudakov evolution parameter:
    - At ATLAS we decided to use it as default (the first ones to do it!)
    - The showering activity increases substantially in the new model!

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

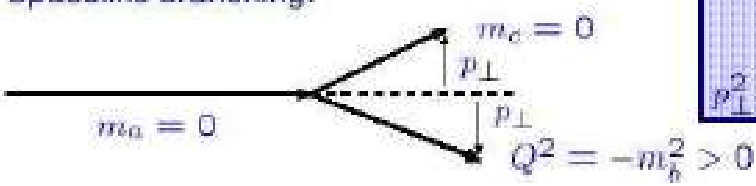


PYTHIA	HERWIG
large mass first	large angle first
⇒ "hardness" ordered	⇒ **hardness not ordered**
coherence brute force	coherence inherent
covers phase space	**gaps in coverage**
ME merging simple	**ME merging messy**
$g \to q\bar{q}$ simple	$g \to q\bar{q}$ simple
not Lorentz invariant	**not Lorentz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

Timelike branching:



Spacelike branching:



New evolution variables

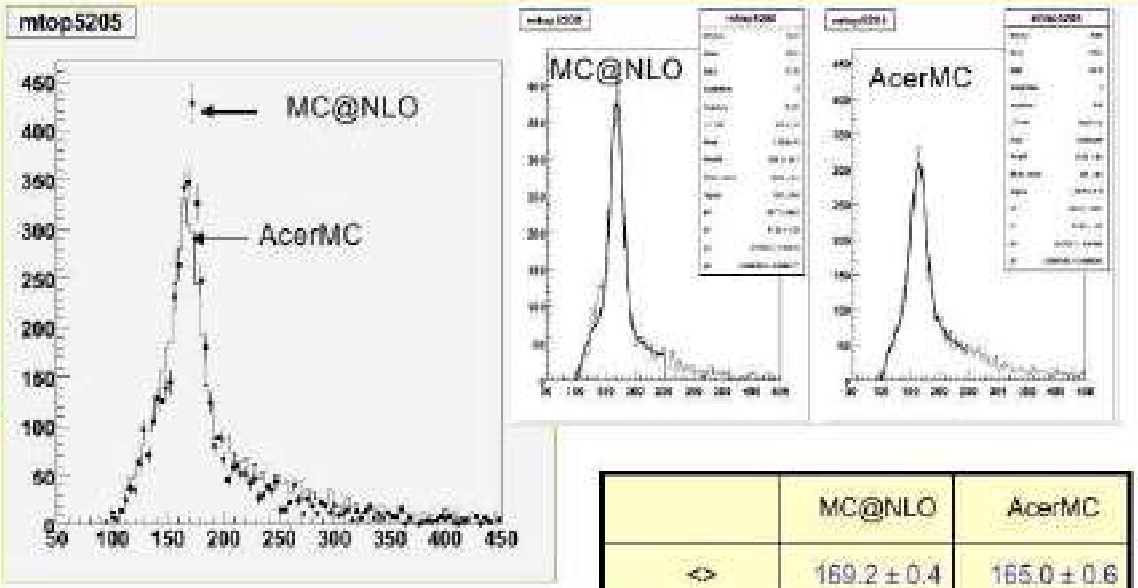
$$p_\perp^2 = z(1-z)Q^2$$

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

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



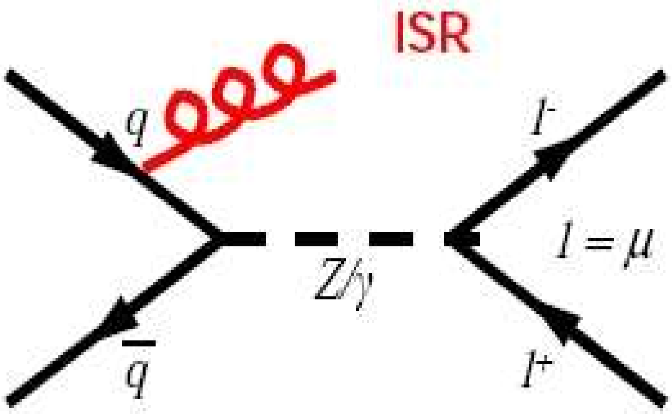
	MC@NLO	AcerMC
<>	169.2 ± 0.4	165.0 ± 0.6
σ	10.5 ± 0.4	12.7 ± 0.7

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

We do cannot know offhand which answer is correct!

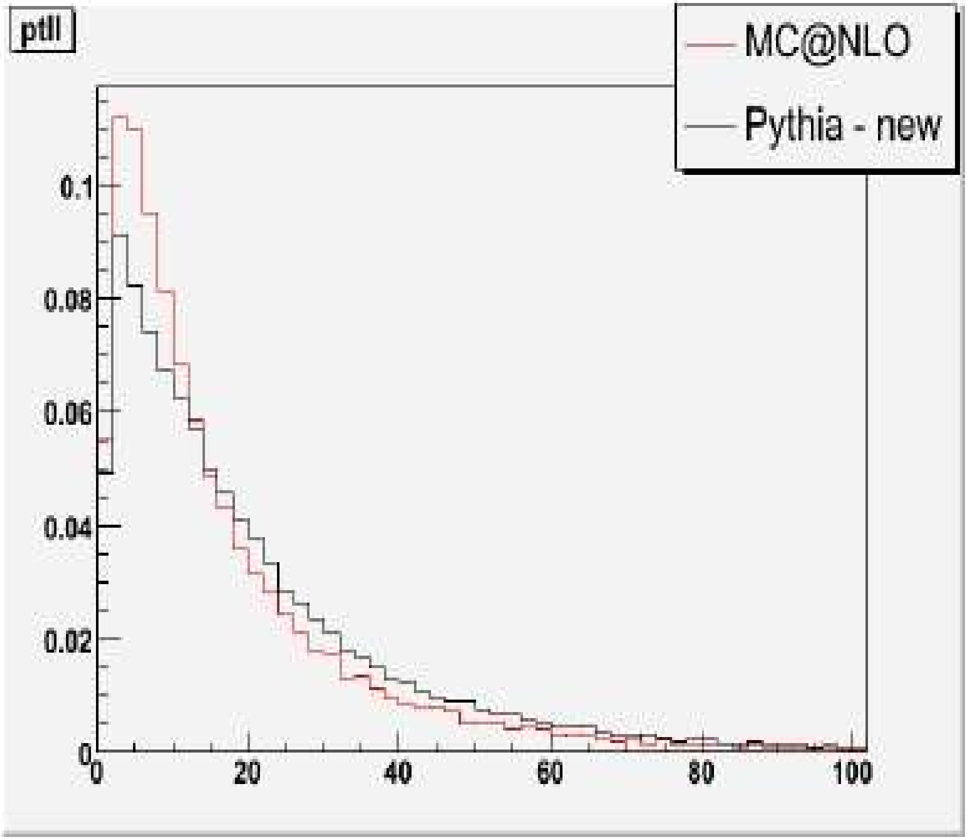
Drell Yan processes

- 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

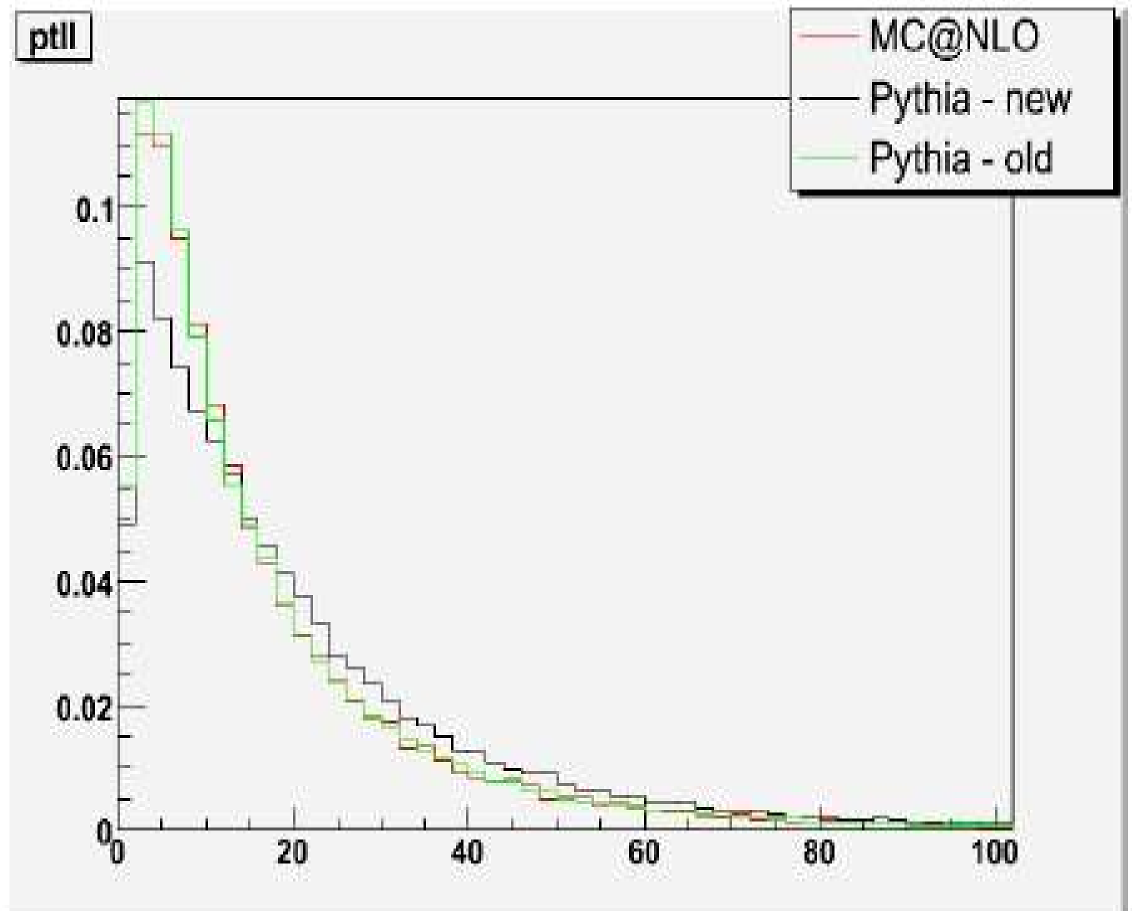
- It appears that the new Pythia showering actually gives a harder ISR spectrum - confirms what was already observed
  This seems surprising:
  - MC@NLO should in principle get at least the first ISR gluon harder than Pythia?
  - Actually, not entirely true: The MC@NLO 'extra jet' part is actually LO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



Jon B

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..



Jon B

P_T of the dilepton system

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

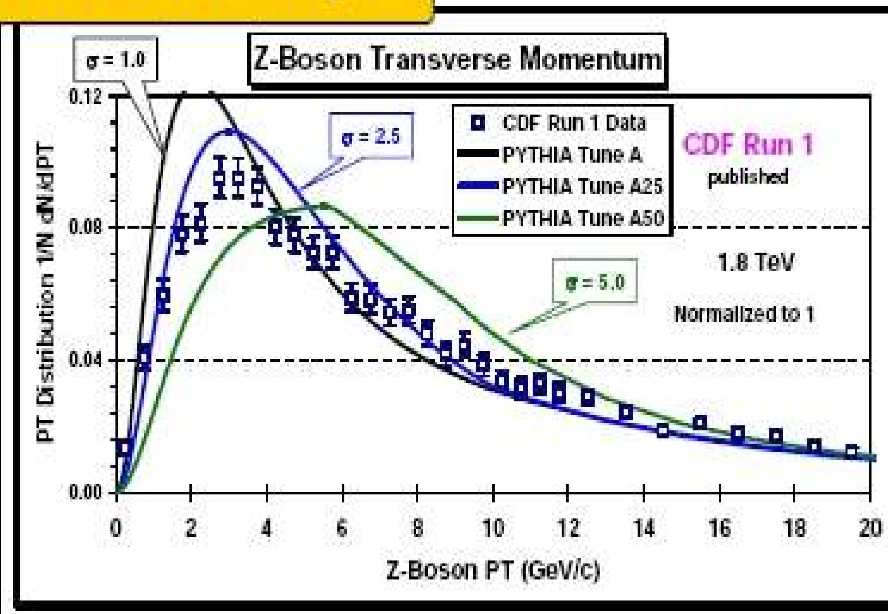
UE Parameters

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

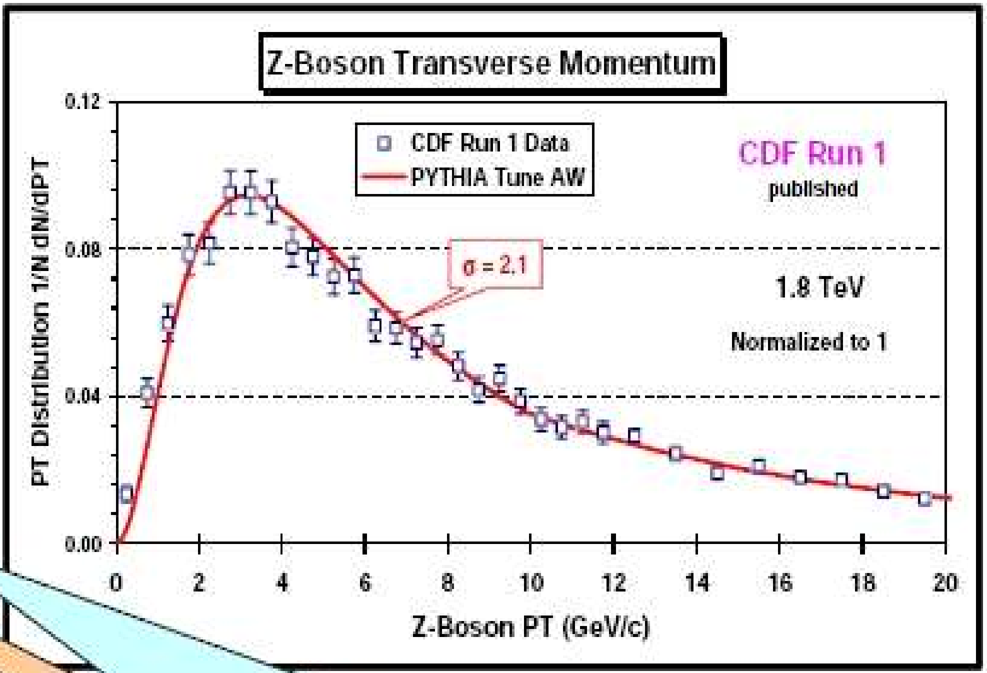
- However the R. Fields AW-tune does a much better job!

UE Parameters

ISR Parameters

Intrinsic KT

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

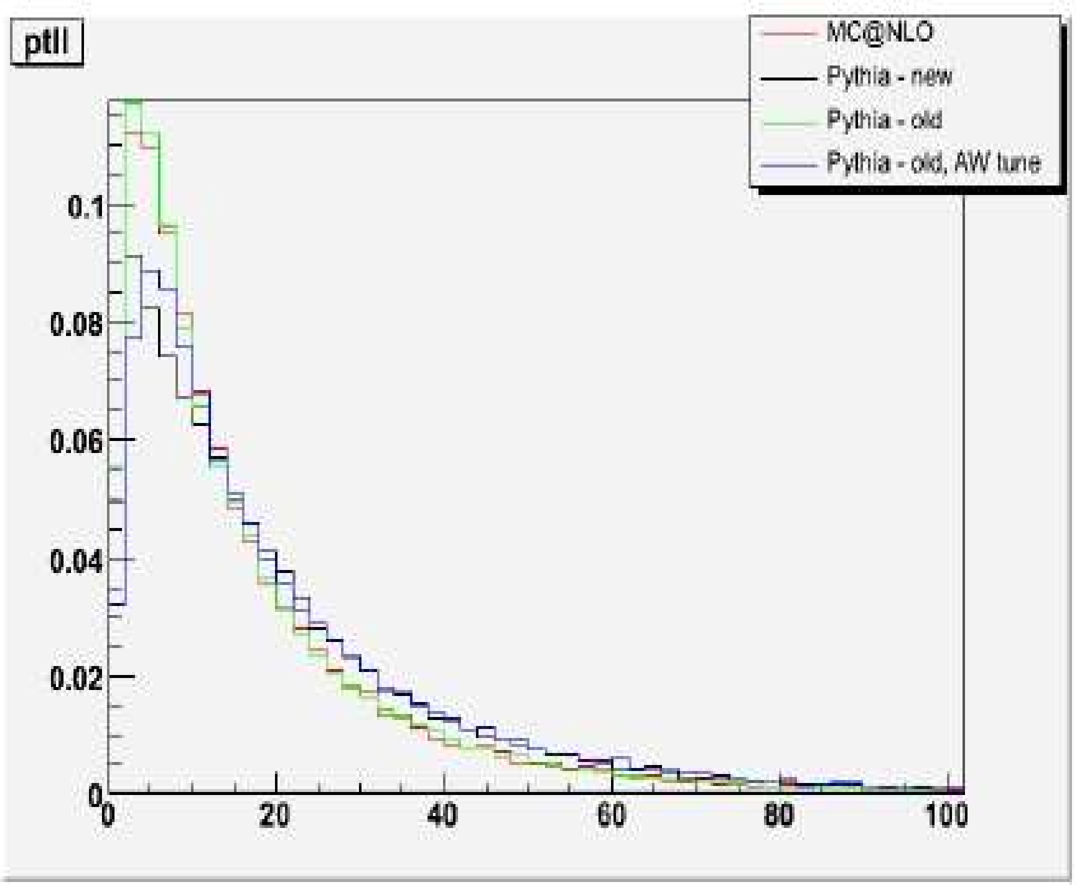


Effective Q cut-off, below which space-like showers are not evolved.

The $Q^2 = k_T^2$ in α_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!



Some technical SW details

MC generators are 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 (and where we have had time to make the switch!)
HepPDT, HepMC, LHAPDF used as generic tools.

Have unified the (pseudo)random number service.

Summary

- Lots of work done within ATLAS to make use of the great tools provided by the Generator authors.
- Benefiting now from GENSER, hope to move further in this direction (Sherpa, Herwig++, Pythia8, HepMC...)
- Lots of validation done. Next big task is to systematise this so we can respond rapidly to data and new models.