“Tutorial” on Generator Usage in ATLAS

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(inc. slides from Borut Kersevan, Mike Seymour)

Artemis 1st Annual Meeting

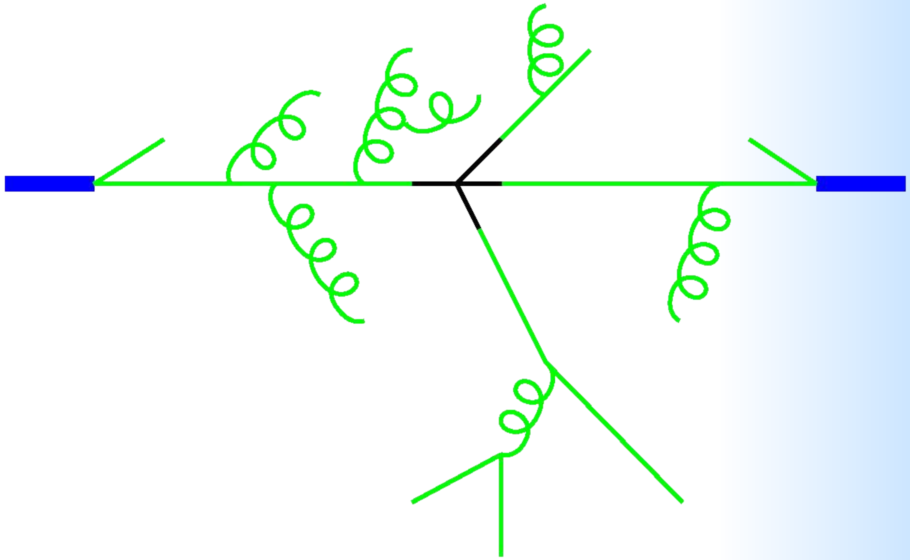
Chalkidiki, Thessalonka, 27th Sept 2007

Outline

- Some general features
- Why use generators?
- Generator usage in ATLAS
- Some examples of generator studies in ATLAS

The Physics of a complete event generator

1. Hard process



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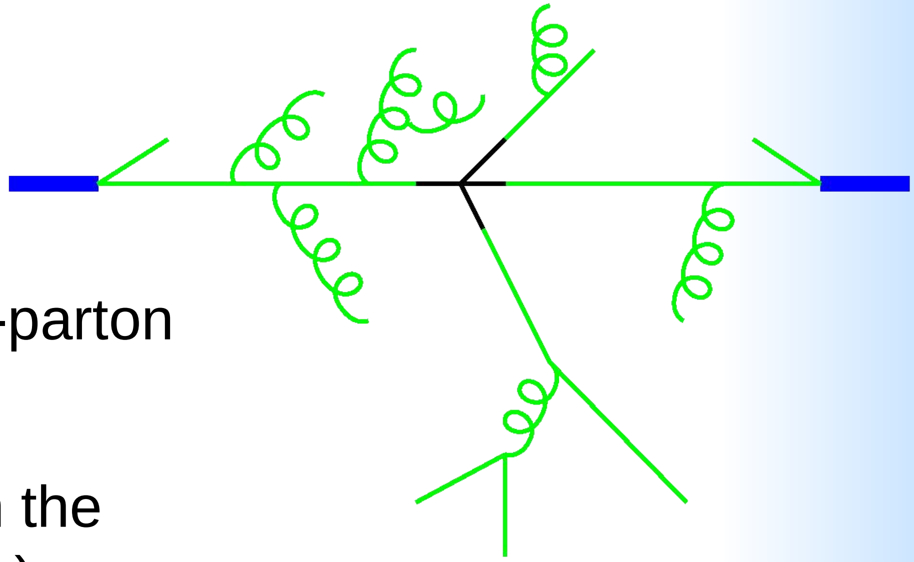

Matrix element parton-parton scattering.

Incoming partons from the proton structure (PDFs)

Essentially arbtrary separation between this and...

The Physics of a complete event generator

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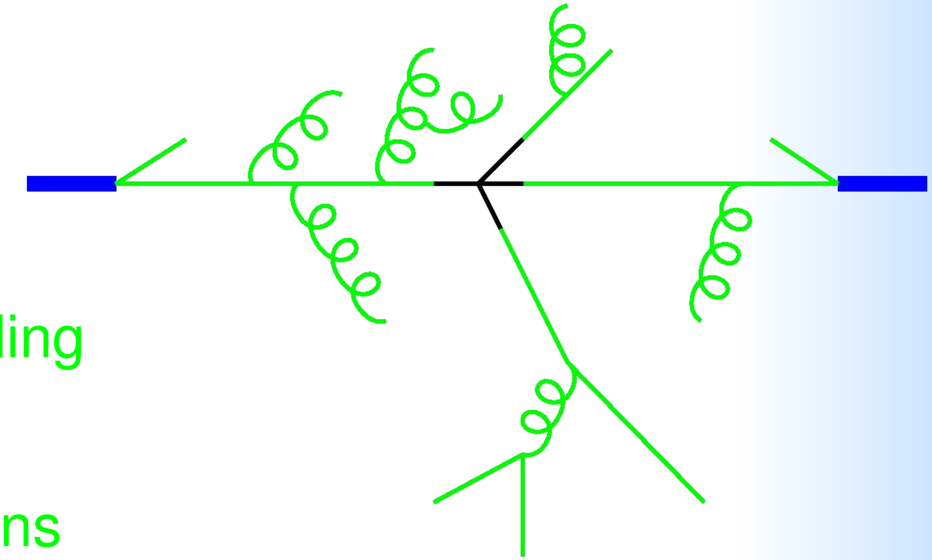
2. Parton Shower

Still in the small-coupling (perturbative) regime

Many final state partons

Works best in collinear region and/or when there is a big ratio of scales.



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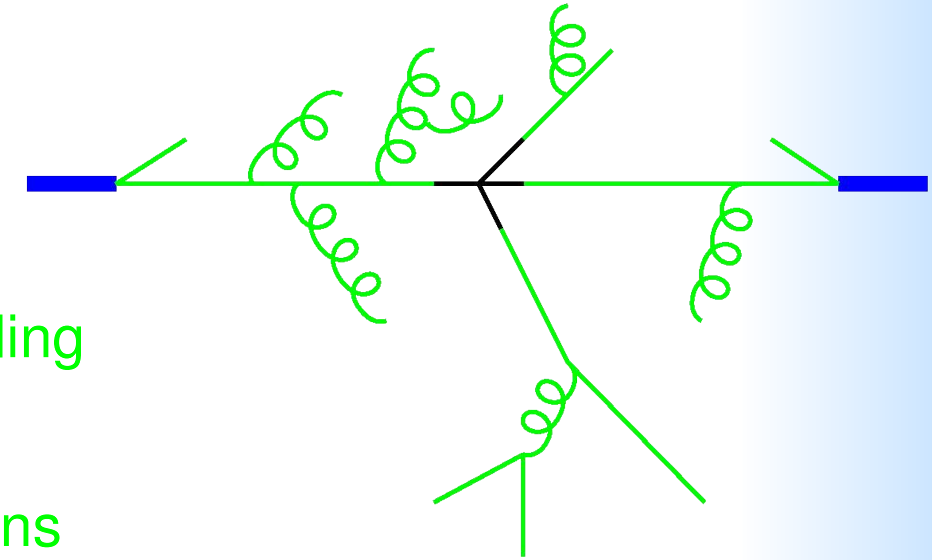


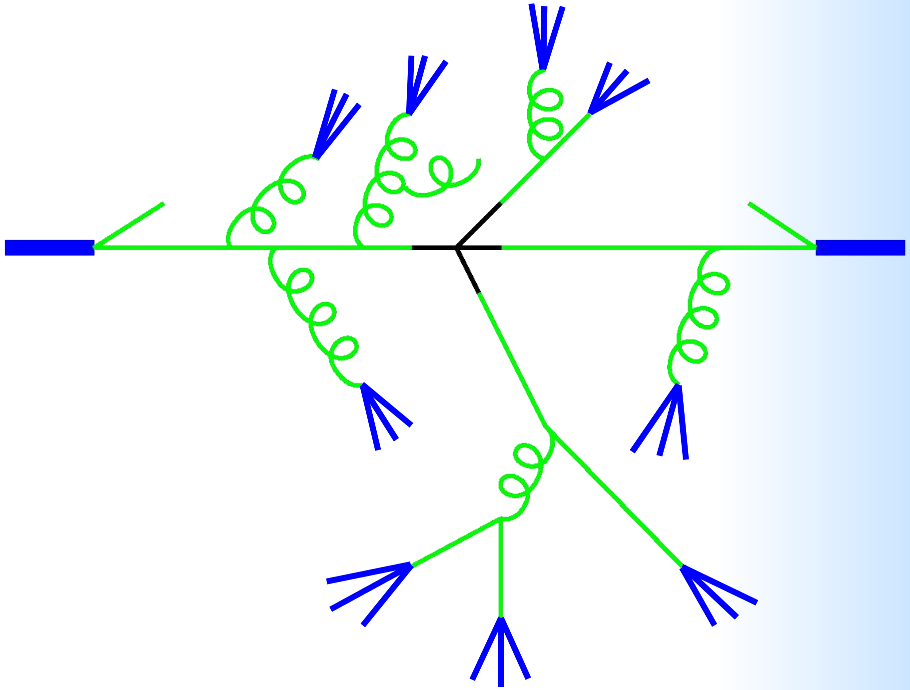
Needs to be a matching between N-leg matrix element and parton shower.

The Physics of a complete event generator

1. Hard process
2. Parton shower
3. Hadronization

Turn partons into physics objects.

Non-perturbative, tuned to data.



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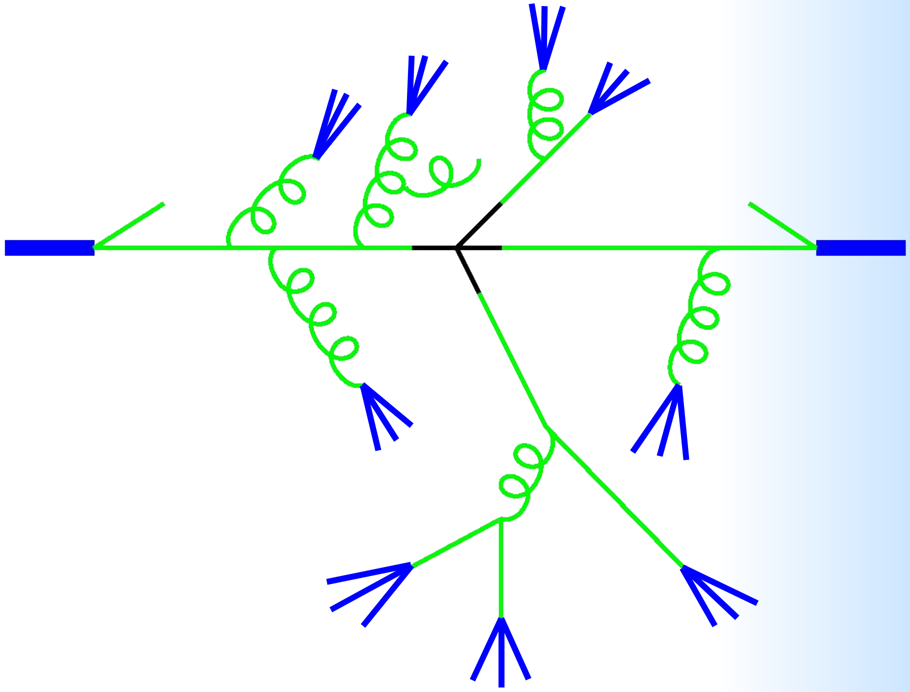
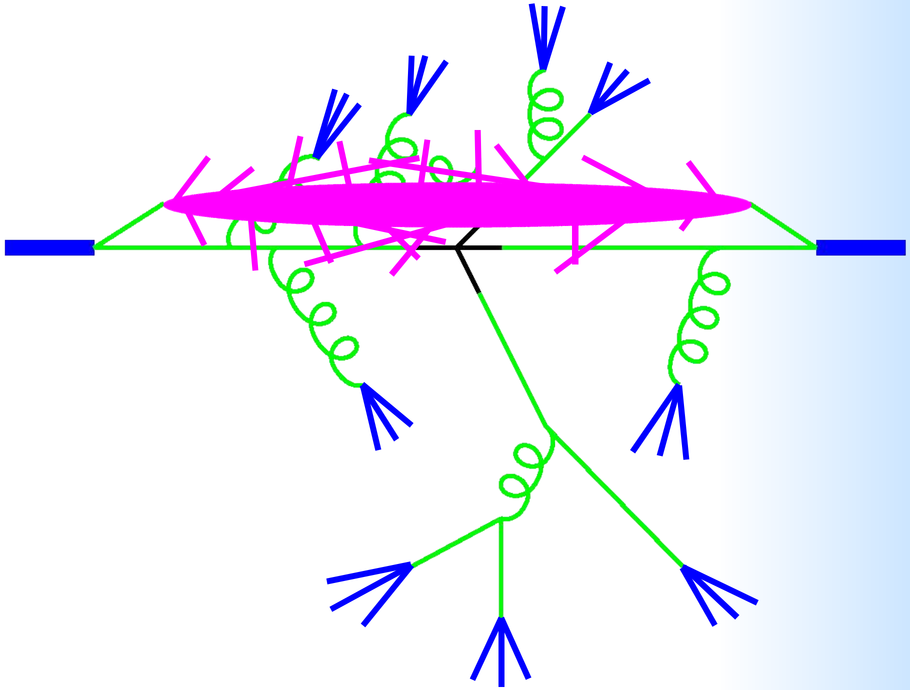


B-decays may initiate new parton showers

The Physics of a complete event generator

1. Hard process
2. Parton shower
3. Hadronization
4. Underlying event

Interactions between the rest of the protons (remnants)



May contain further hard processes.

When to use generators

- Estimate expectations from SM and new Physics
  - design detectors and triggers

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- Realistic input for detector simulations
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  – vary MC parameters to study the model dependence and other systematics.
- Practice analysis, stress-test software and computing
  – one of the main uses on ATLAS...

When to use generators

- In some cases, Monte Carlo generators actually provide the best theoretical model with with to compare the corrected data
  - better than (N)NLO in some areas
  - allow sophisticated cuts on final state which may reduce the accuracy of inclusive calculations.

When NOT to use generators

- Should not be used to attempt to compensate for inadequacies of experiment.
  - e.g. if your detector is not sensitive to muons below 10 GeV, you cannot use a generator to “correct” for this acceptance and get a total inclusive muon cross section.
  - you will simply recover the MC expectation for the dominant part of the cross section. The detector adds very little.

When NOT to use generators

- Should not (in general) be used to attempt to correct back to unphysical cross sections.
  - e.g. parton level jets, Z propagator etc.
  - in some cases it is justifiable if the theory corrections are very well understood (rarely the case if ever for QCD!)
  - often it is useful to aid interpretation of measurements which have been made at the particle/physical level. But make the measurement first, otherwise your “measurement” will have a shelf life determined by the MC version number.

Specifically at ATLAS...

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  - Lots of new phase space for SM processes (especially W, Z, top, Higgs?, Jets)
  - Possible new physics
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- What extrapolations or interpolations are involved?

LHC needs...

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- Therefore we need *general purpose generators* so we can cross-validate between processes where possible
  - 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, in production for some processes

What we are currently using

- AcerMC: Zbbbar, ttbar, single top, ttbarbbbar, Wbbar
- Alpgen (+ MLM matching): W+jets, Z+jets, QCD multijets
- Charbydis: Black holes..
- CompHep: Multijets..
- HERWIG+JIMMY: QCD multijets, Drell-Yan, SUSY (ISAWIG)...
- Hijing: Heavy Ions, Beam-gas..
- MadEvent: Z/W+jets...
- MC@NLO: ttbar, 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
- PHOJET: Needs reviving

Interfaces needed soon...

HERWIG++

Pythia 8

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, HERA, LEP etc and/or we try to tune/check the generators using available 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.

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..).

Beginning to make use of Jetweb/Rivet (www.cedar.ac.uk). Validation framework and database, experiment independent, also used by generator authors (MCnet). (www.montecarlonet.org) - see next session.

Validation Procedures

Detailed checks when switching versions of the same MC tool.

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

Alex Richards (GeneratorsRTT)

Brinick Simmons (overall RTT)

Use LCG Generator Services release where possible, and profit from their validation (which also uses Rivet, see later).

NB – need to move to GENSER HepMC release.

ATLAS Organisation

- ATLAS MC Generators physics group (coordinated by JMB, Borut Kersevan until 30 Sept, Osamu Jinnouchi from 1 Oct)
  - liaise with generator authors on enhancements & fixes
  - provide, document & maintain the ATLAS interfaces
  - look for gaps in ATLAS capability & try to fill them
  - coordinate & support effort within and between physics groups
  - make sure things once validated stay validated (standardise tests for the most important generators and channels)

ATLAS Organisation

- ATLAS generator software maintenance
  - Until rel 13, Ian Hinchliffe, Georgos Stavropolos
  - From rel 14 on Judith Katzy, new DESY + Gottingen group
  - Work closely with coordinators, experts, LCG
- LCG Generator Services (LHC-wide)
  - Witek Pokorski (also ATLAS member)
  - Distribute and validate generators on the important platforms

Communication

- Hypernews forum
  - https://hypernews.cern.ch/HyperNews/Atlas/get/Generators.html
- Wiki
  - https://twiki.cern.ch/twiki/bin/view/Atlas/MonteCarloWorkingGroup
- Meetings
  - Next ATLAS MC Generators one 8 Oct
  - http://indico.cern.ch/categoryDisplay.py?categId=3l977
- Bug tracking
  - https://savannah.cern.ch/bugs/?group=atlasgener&func=browse&set=open

Some Software Details

- Generators are modified as little as possible
  - "symbolic" packages in Externals, which simply contain a requirements file pointing to the LCG distribution.
- Generators are interfaced to Athena
  - Generators area contains interface packages, e.g. Herwig_i, Pythia_i etc...
  - Any urgent bug fixes, before they propagate to an official LCG distribution, are contained in the interface (overwrite routines on linking)
  - Random numbers service is unified
  - STOP statements in code are removed!
  - "ATLAS defaults" are hardwired in the code
    - (can be changed in joboptions)

Some Software Details

- The general purpose fortran generators (Pythia, HERWIG) are wrapped in C++ interfaces
  - same for the add/decay packages (Photo, EvtGen, Jimmy)
- HepMC is used as the standard event format in memory, and can also be written & read.
- The Matrix-Element level MC generators written in FORTRAN interfaced through the LesHouches-compliant event files
  - The event samples themselves produced offline and validated

Some ATLAS Achievements

Illustrate what is going on in the ATLAS MC activities, some slides on some efforts at understanding the QCD activity:

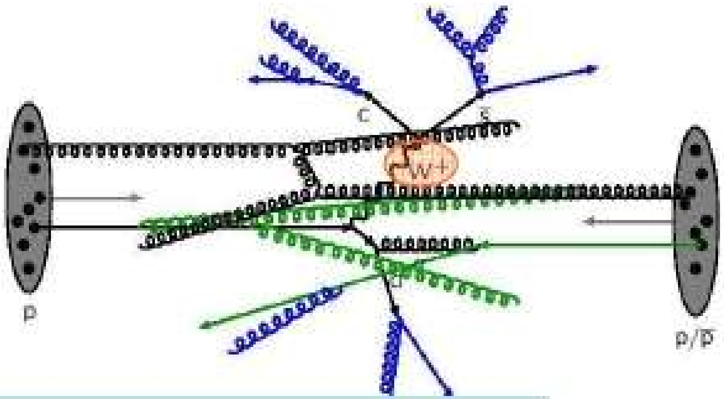
Underlying Event tuning: Pythia (two models) and Jimmy

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!

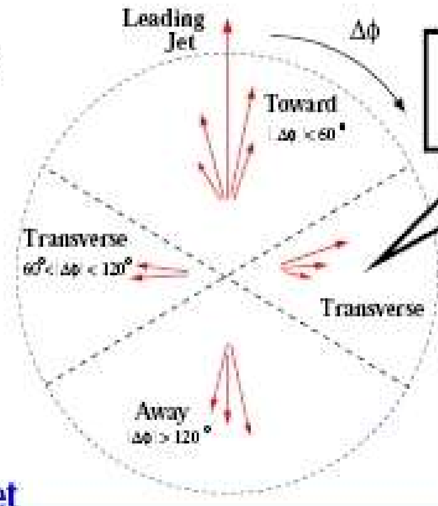


CDF analysis: QCD dijets

- 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 pbar 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.

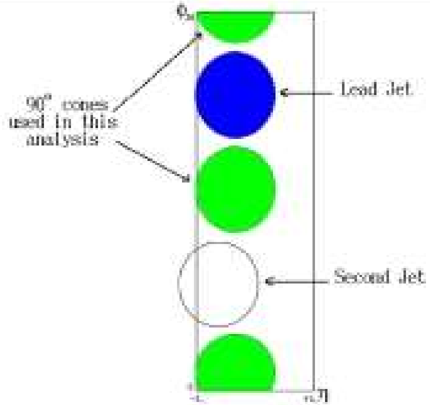
- Two cones in $\eta-\phi$ space are defined:

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

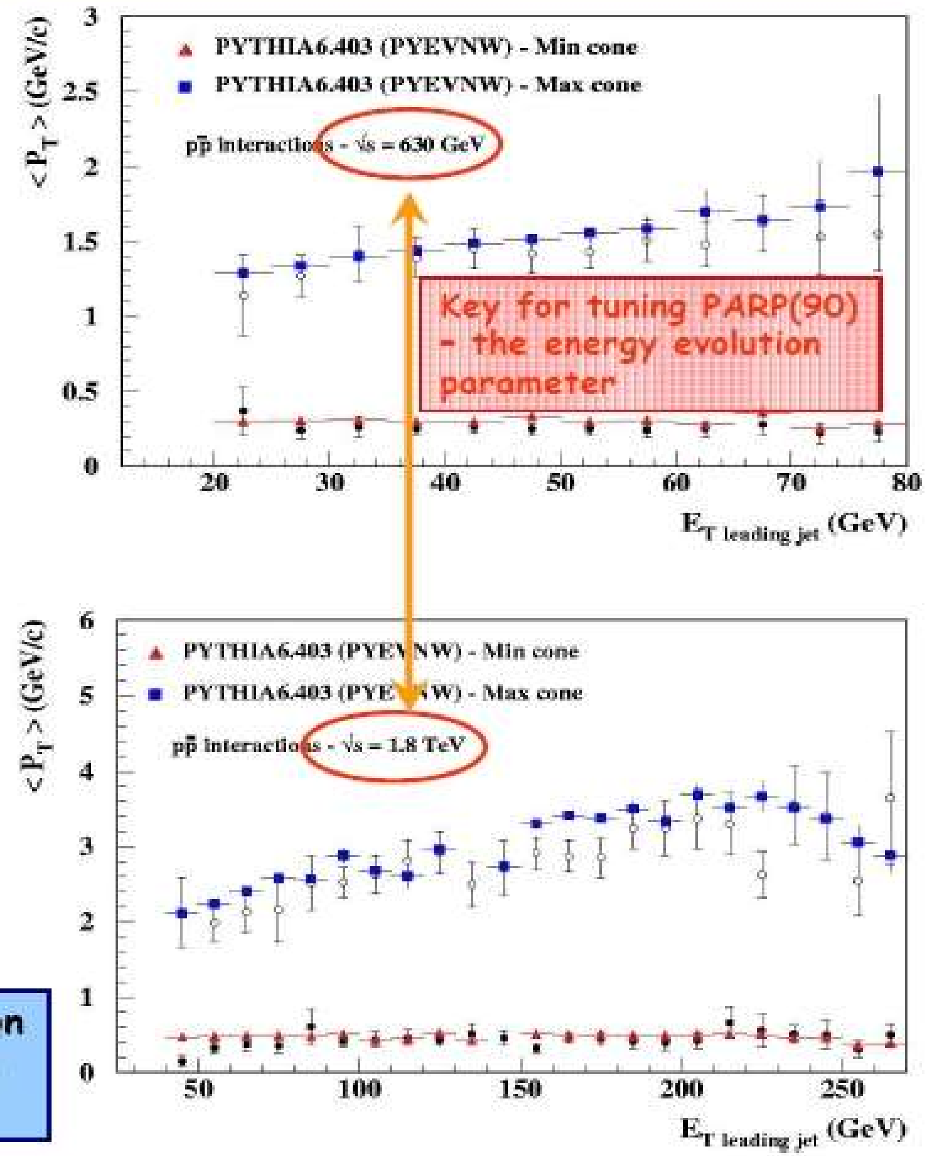
$\phi=\phi_{ljet} \pm 90°$

R=0.7

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



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



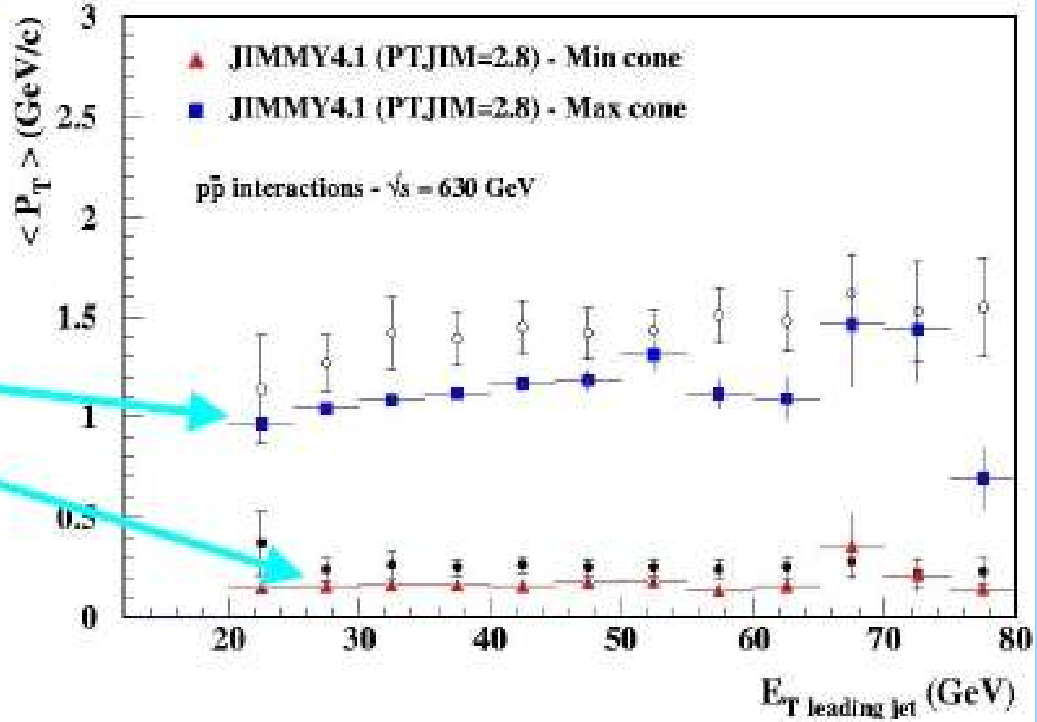
Underlying event tune to CDF data

- JIMMY
  - CTEQ 6LO (LHAPDF 10042)
  - PTJIM=2.8 x $(\sqrt{s}/1.8\ \mathrm{TeV})^{0.27}$ (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

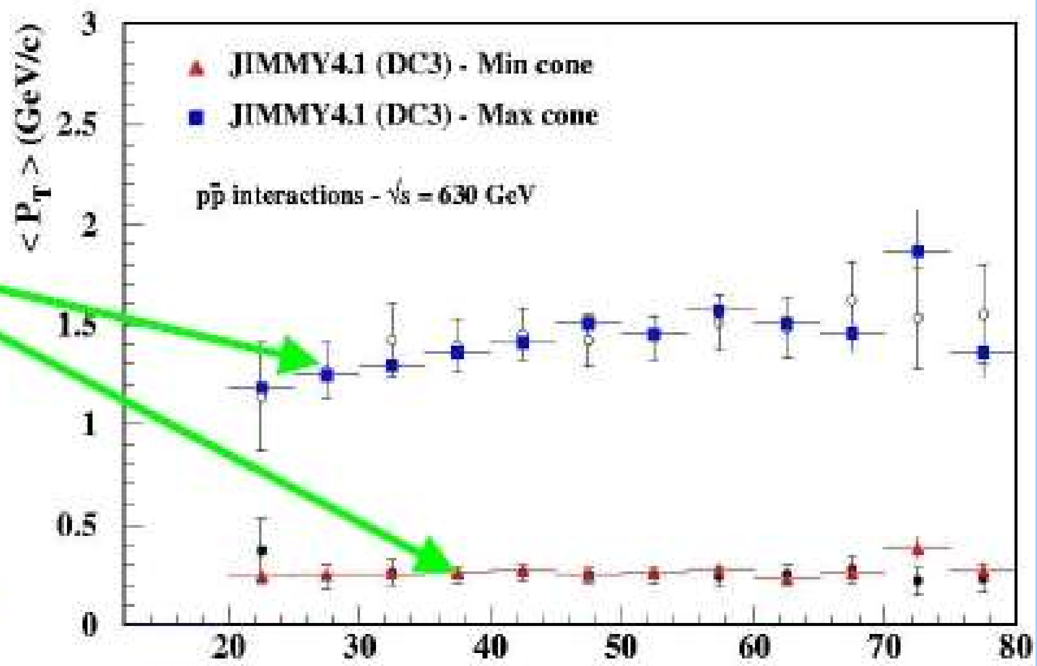
- same PTJIM obtained from comparisons to 1.8 TeV data!
- This underestimates the data.



PTJIM=2.1

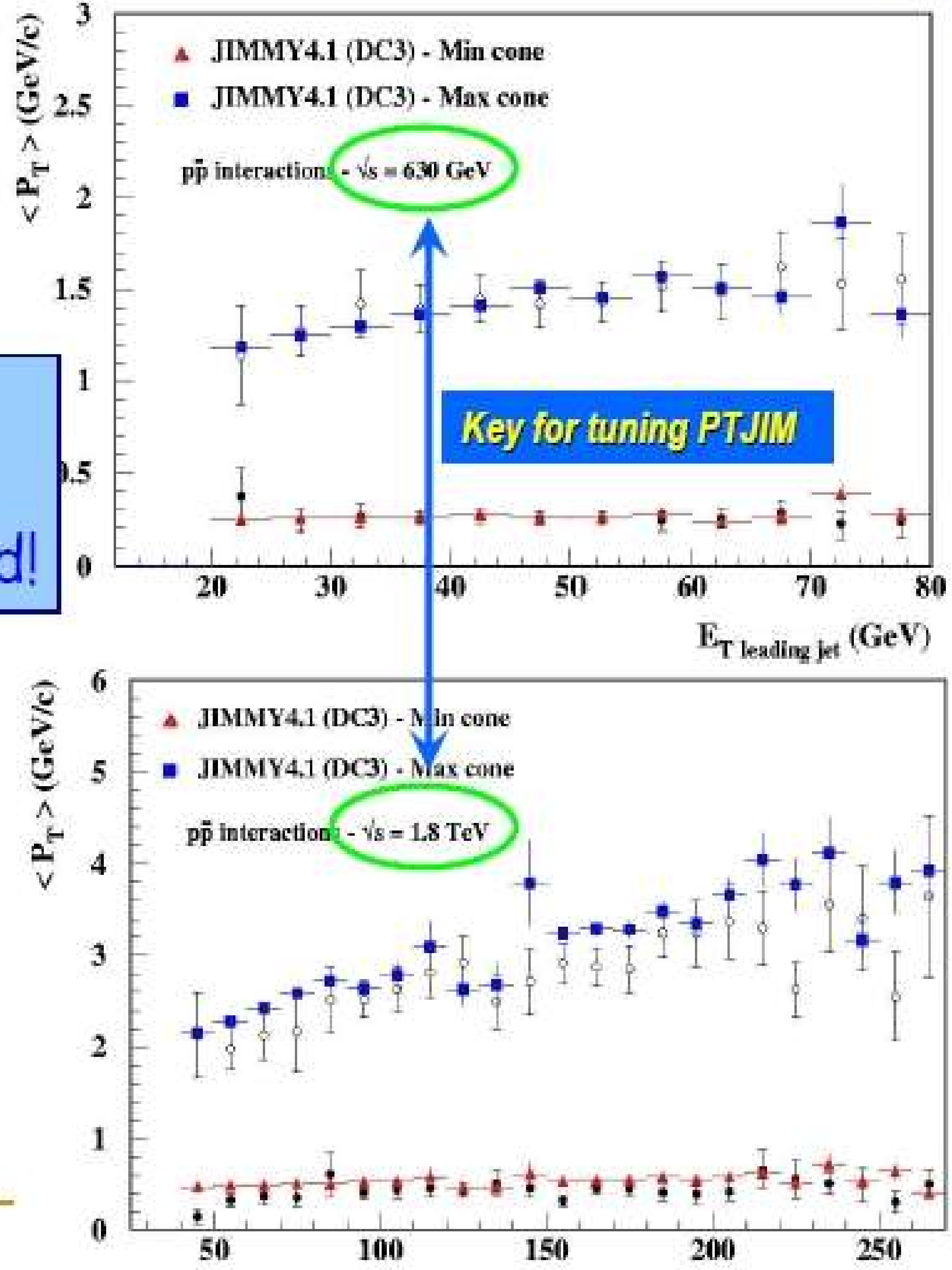
$= 2.8 \times (0.63 / 1.8)^{0.27}$

- introducing energy dependent factor we get a better agreement.

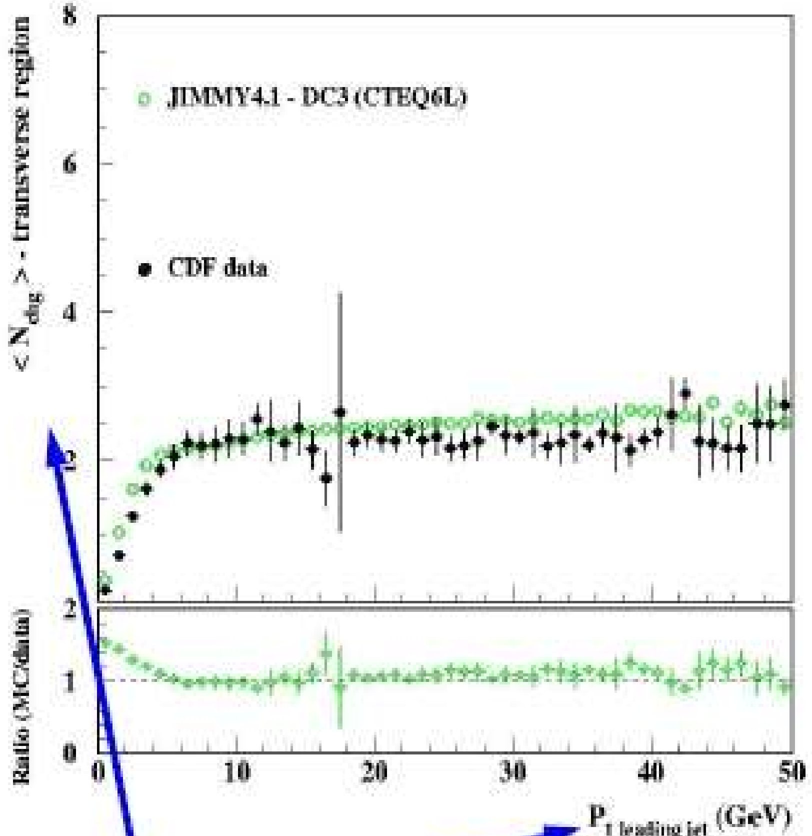


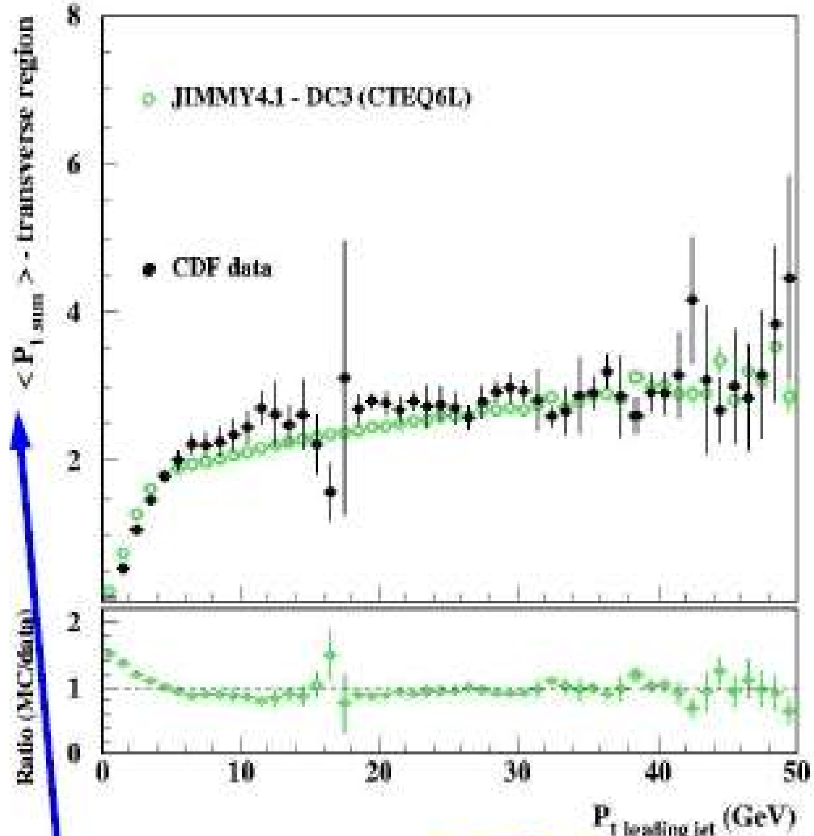
MAX/MIN analysis with Jimmy

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



UE tunings: Jimmy validation using CDF data

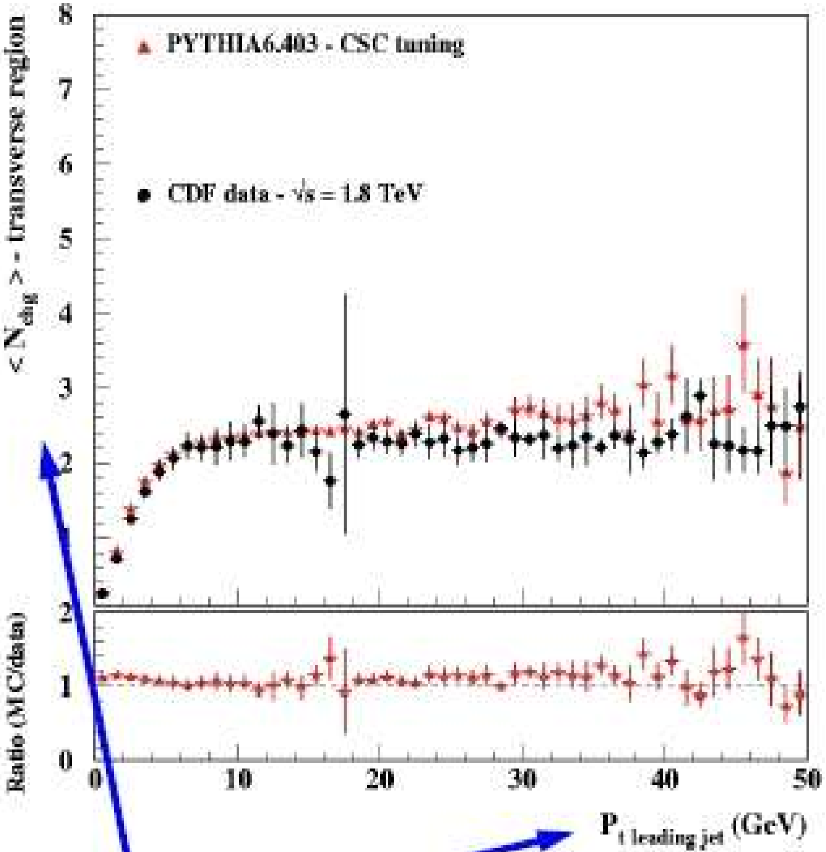


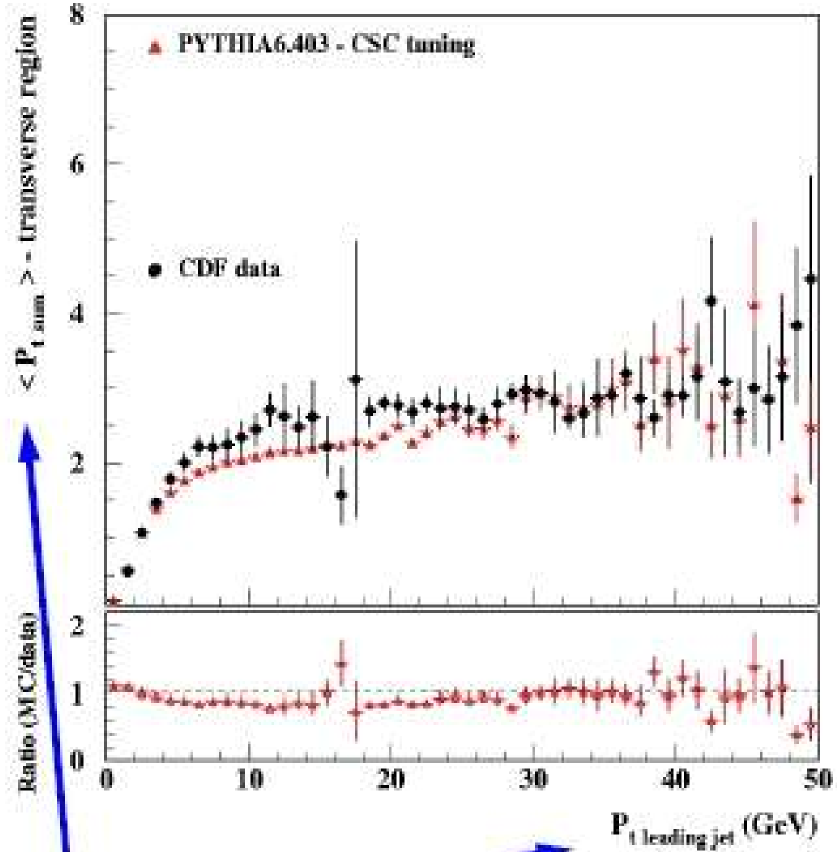


Average multiplicity of charged particles in the underlying event associated to a leading jet with P_t^{ljet} (GeV).

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





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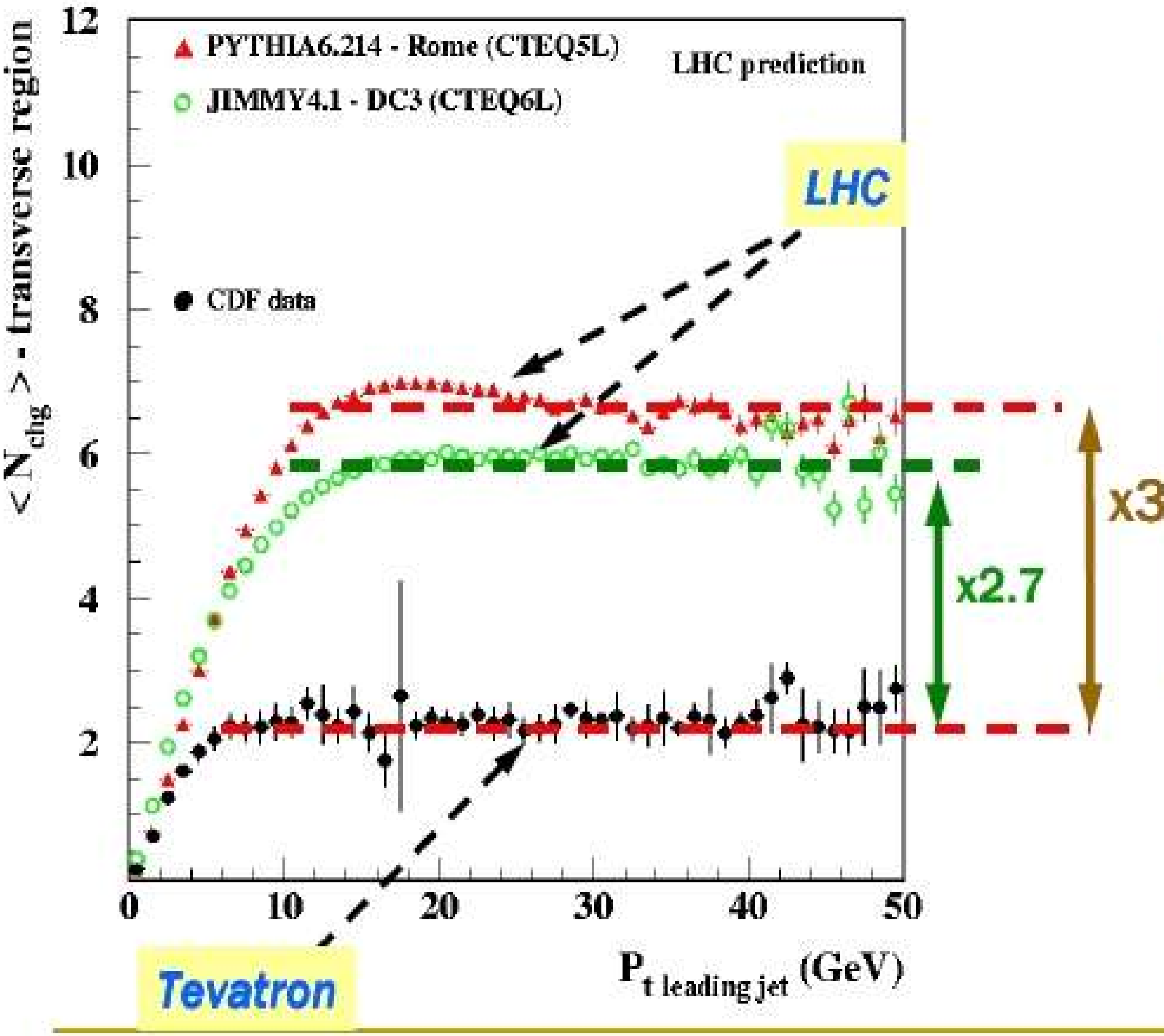
UE tunings: Pythia vs. Jimmy



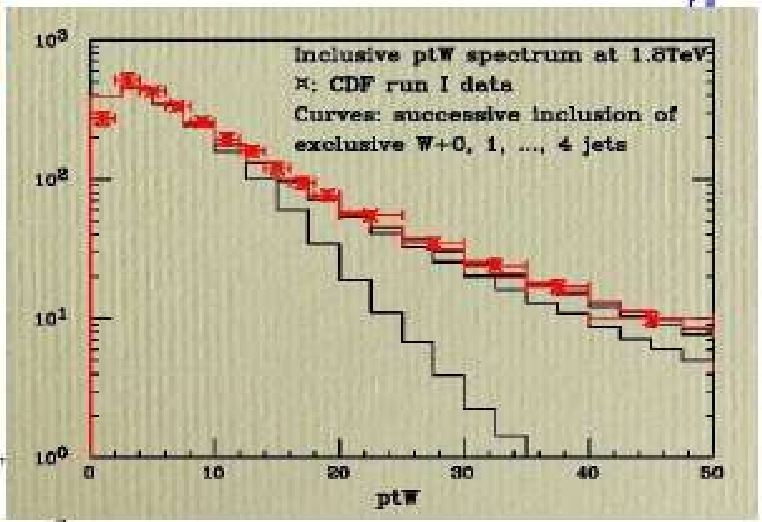
Energy dependent PTJIM generates UE predictions similar to the ones generated by PYTHIA; the difference used to be a factor two!

ME/PS Matching

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

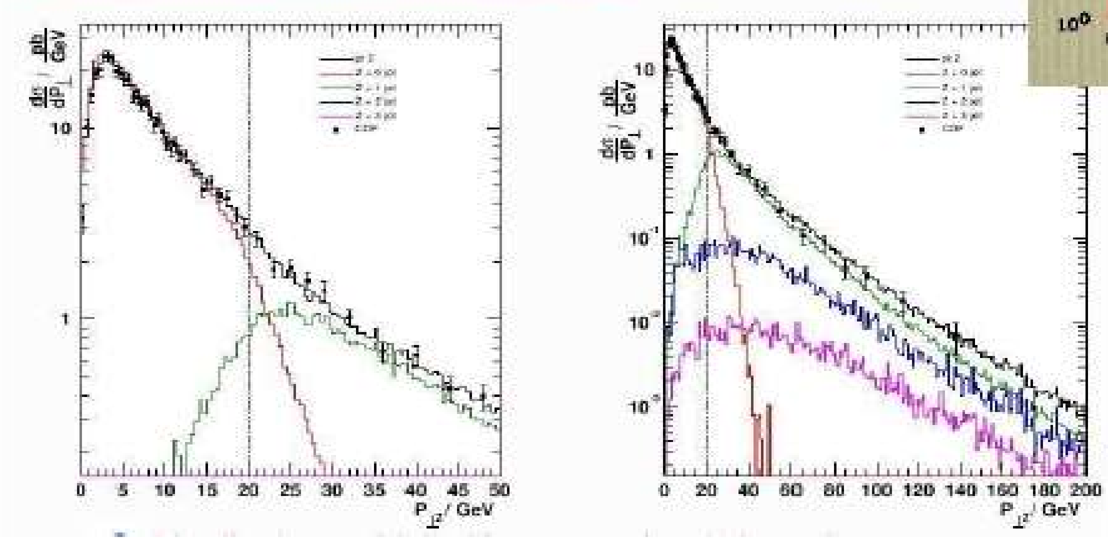
Alpgen

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



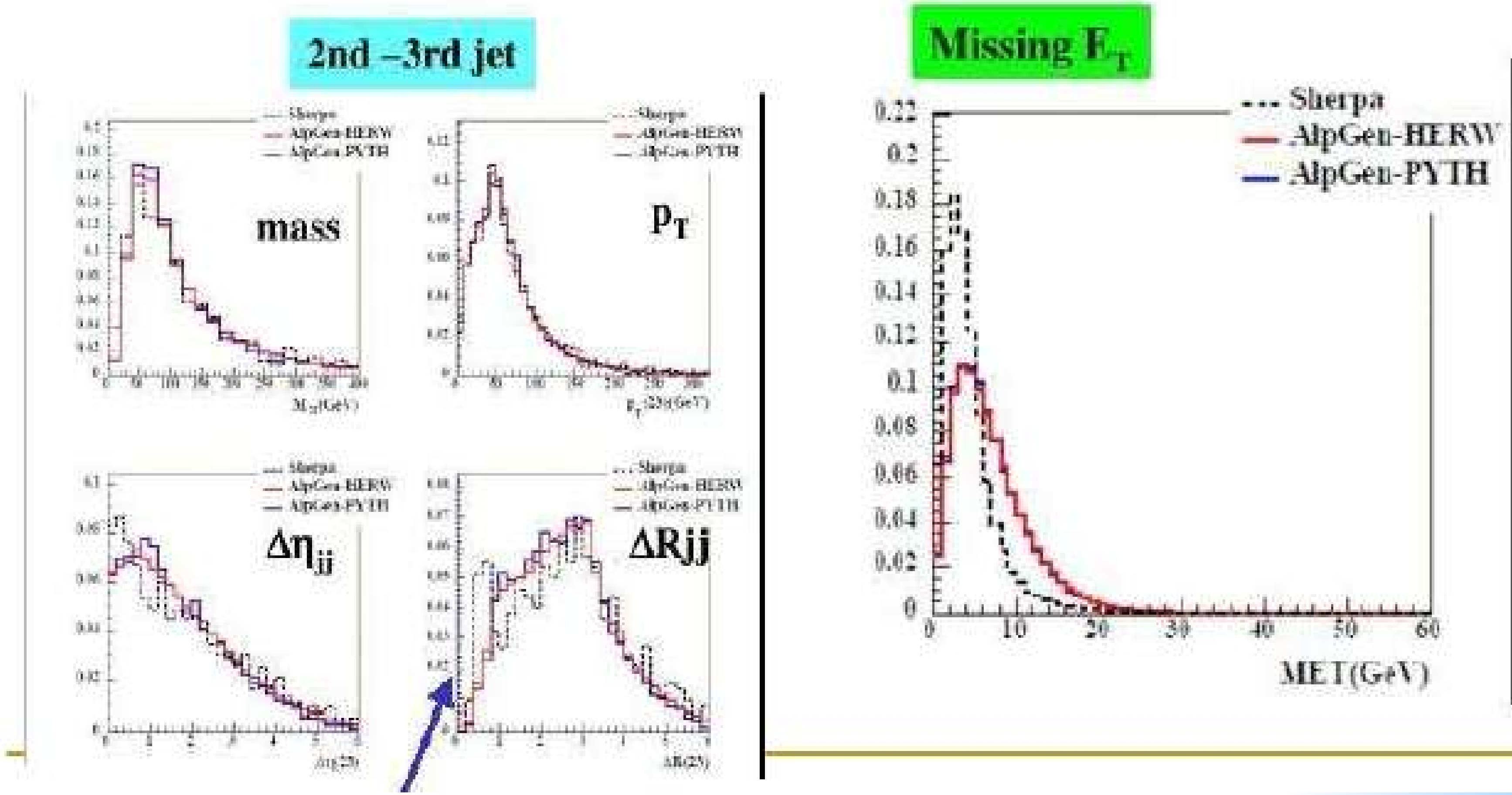
Sherpa

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



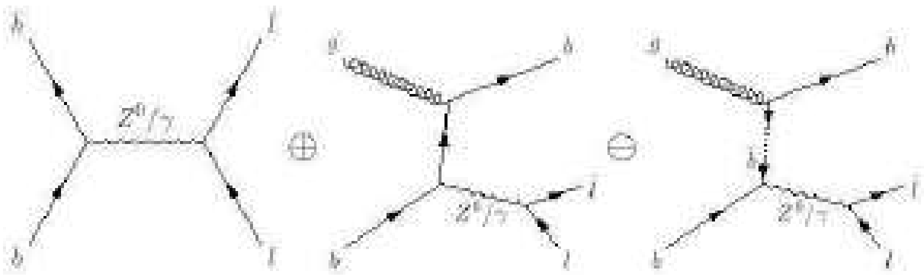
ME/PS Matching

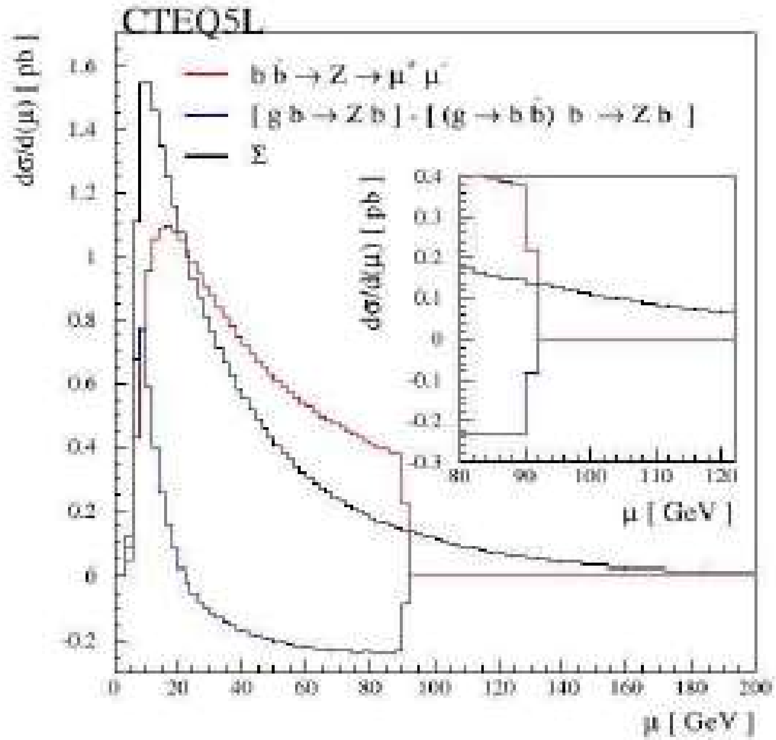
- Differences between Sherpa and AlpGen seen in e.g. in Z+n jet studies at LHC energy.

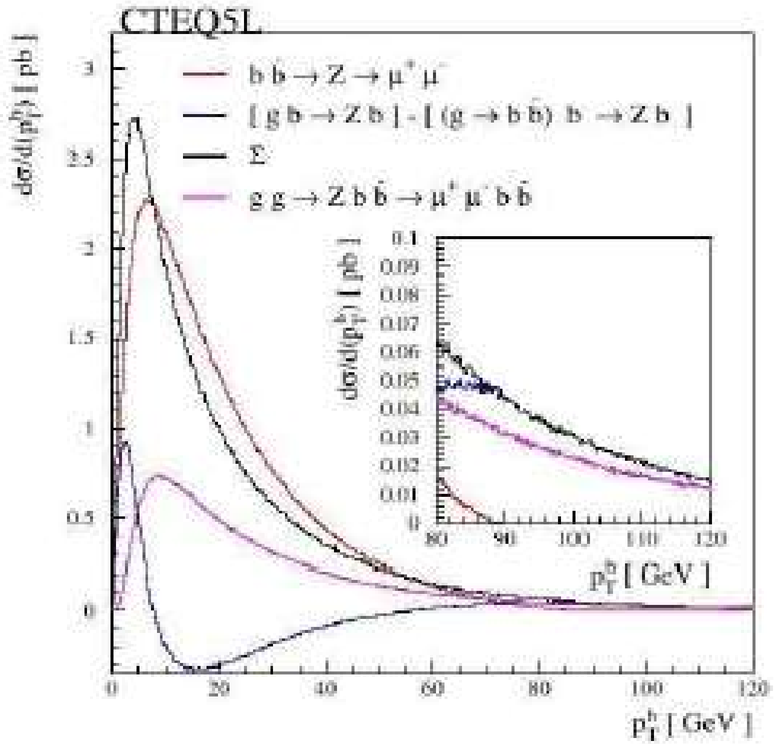


AcerMC heavy quark matching

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

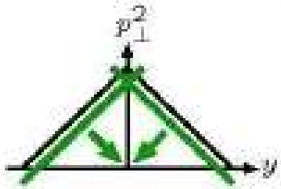
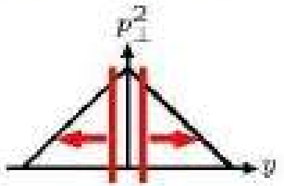




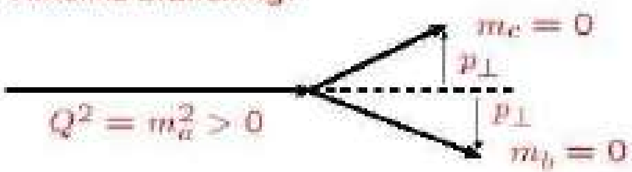


Parton showering: Pythia and Herwig

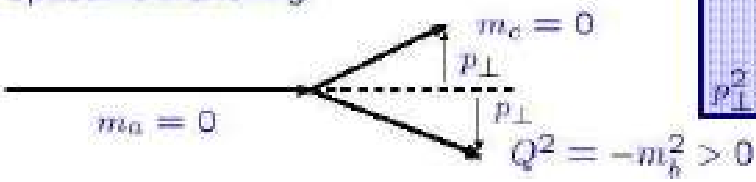
- Pythia introduced a new parton-shower model with version 6.3+, using the pT in the splitting as the Sudakov evolution parameter:
  - At ATLAS we decided to use it as default (the first ones to do it!)
  - The showering activity increases substantially in the new model!

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

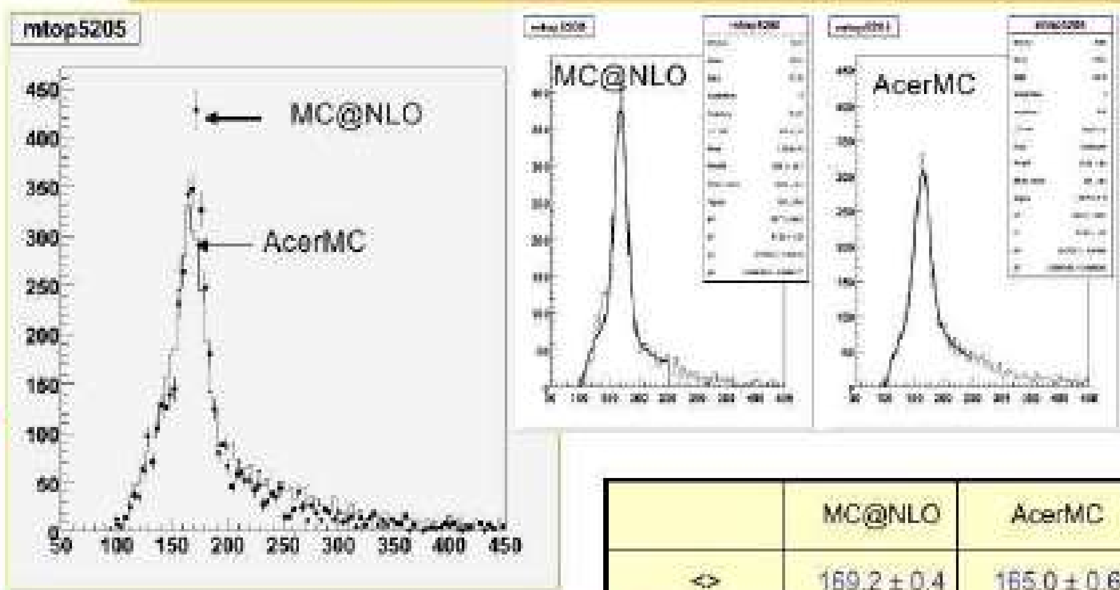
$$p_\perp^2 = z(1-z)Q^2$$

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

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



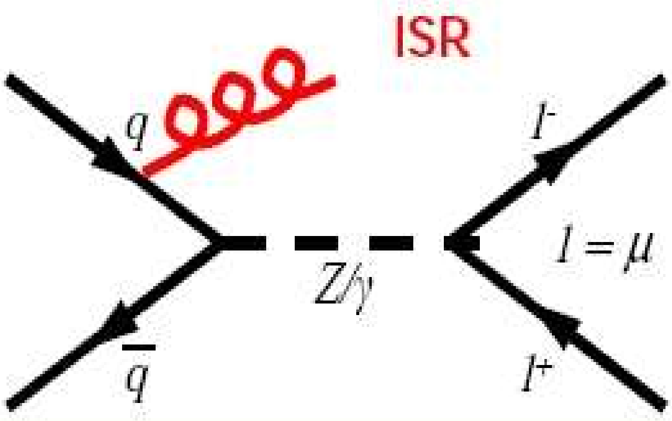
	MC@NLO	AcerMC
<>	169.2 ± 0.4	165.0 ± 0.6
σ	10.5 ± 0.4	12.7 ± 0.7

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

We do cannot know offhand which answer is correct!

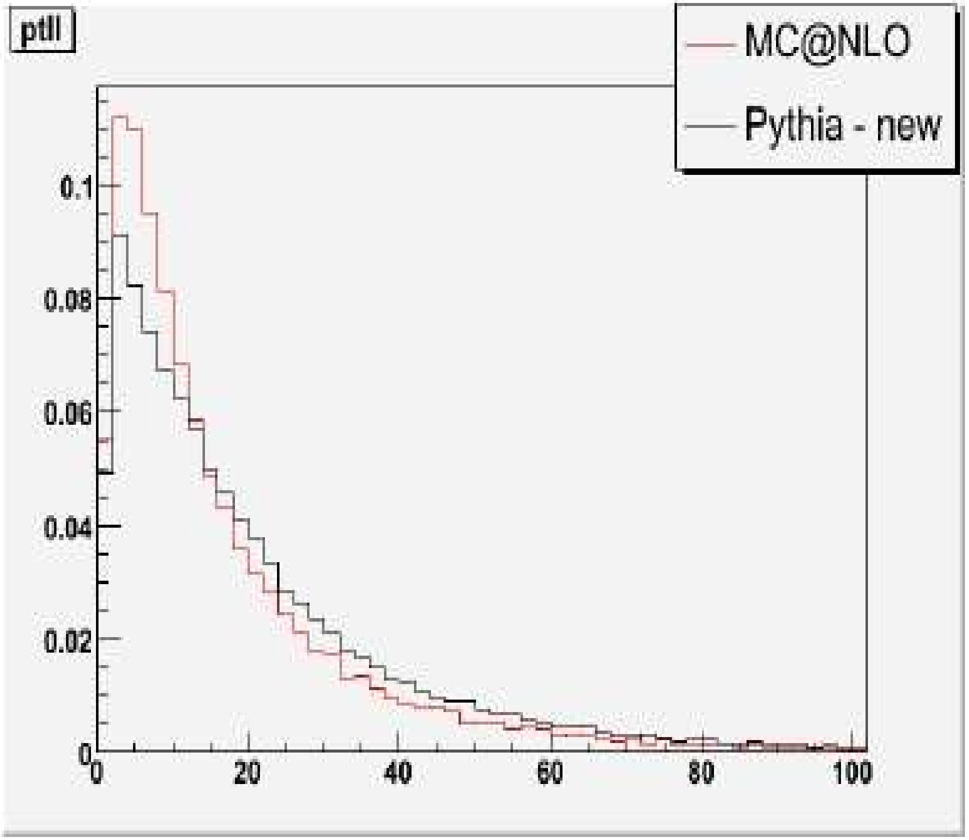
Drell Yan processes

- 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.



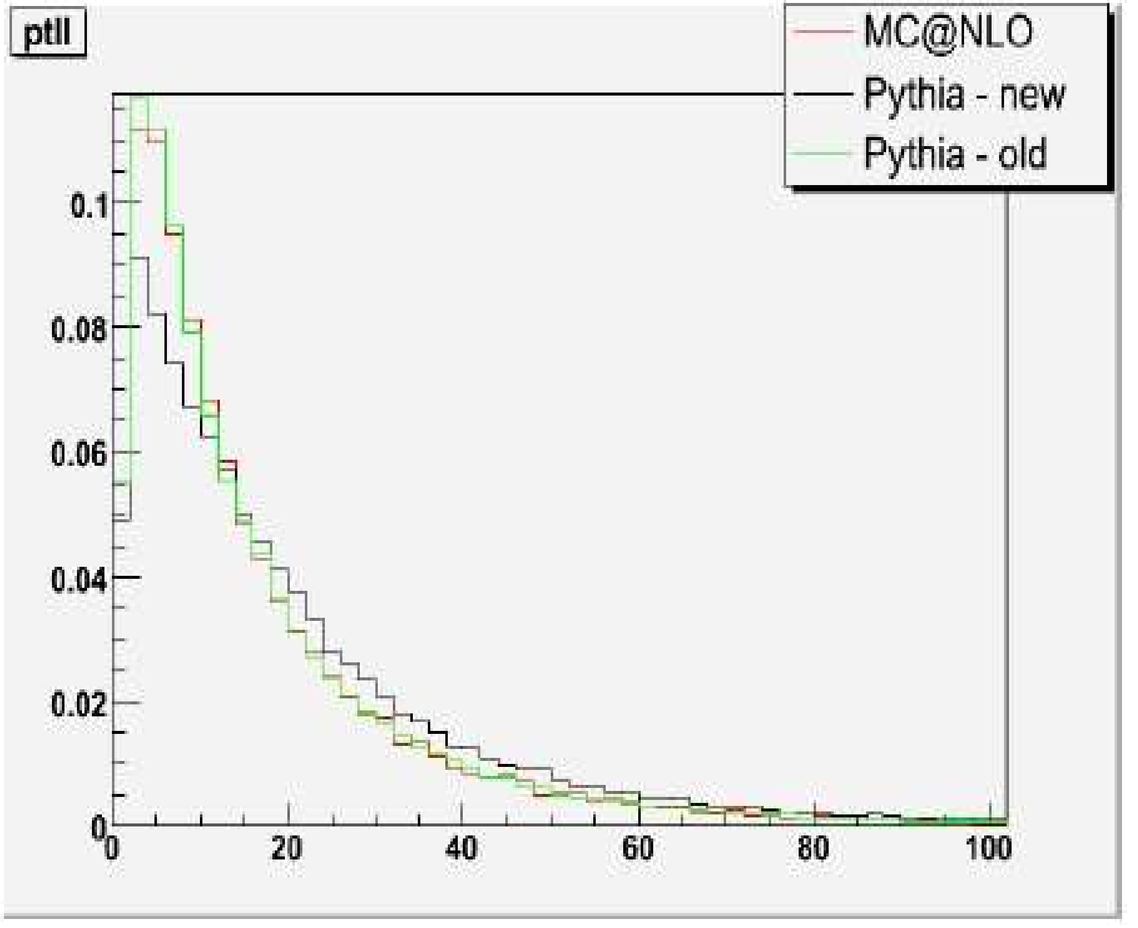
The P_T of the dilepton system

- 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!



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.

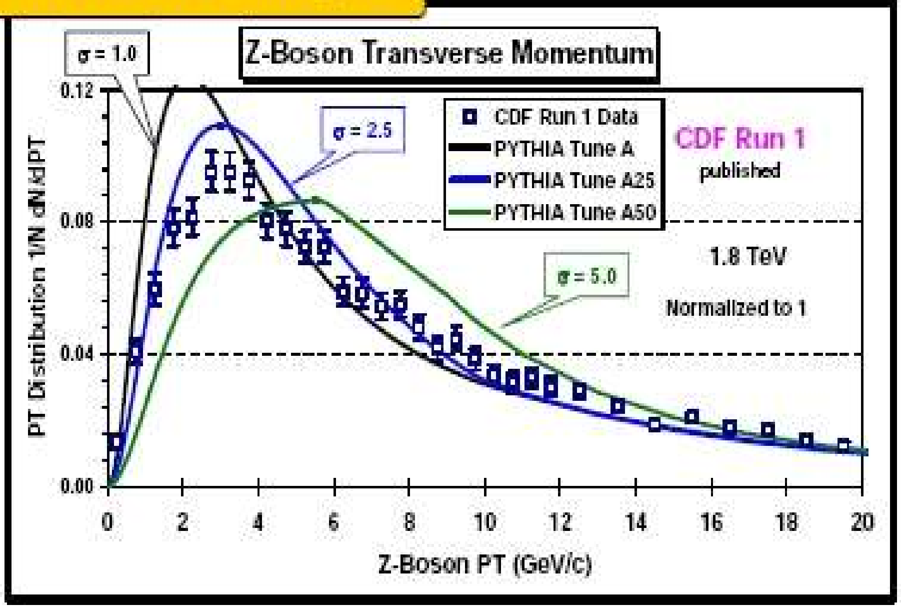
UE Parameters

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

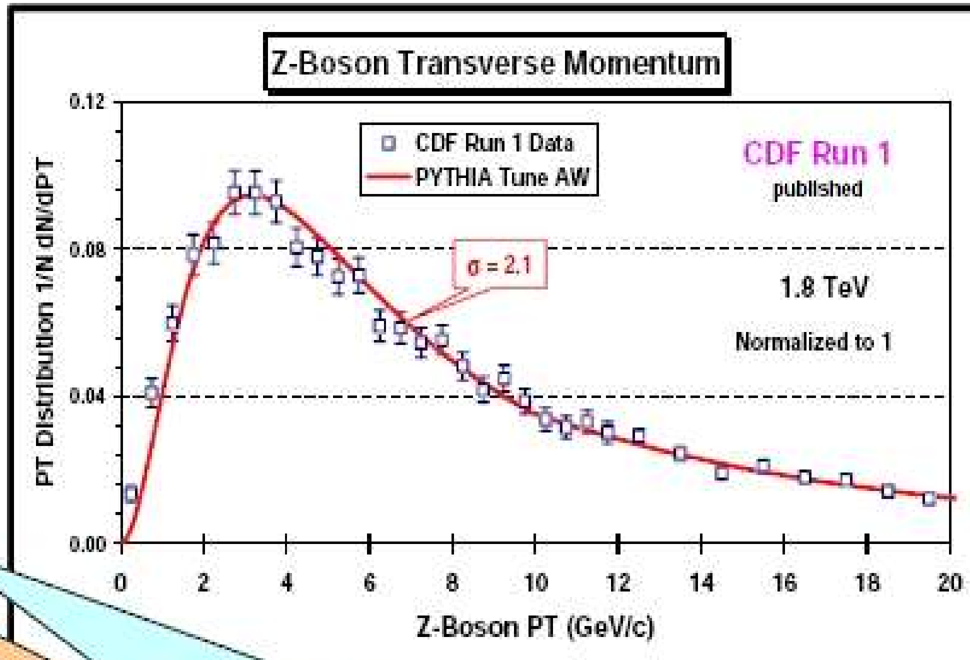
- However the R. Fields AW-tune does a much better job!

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

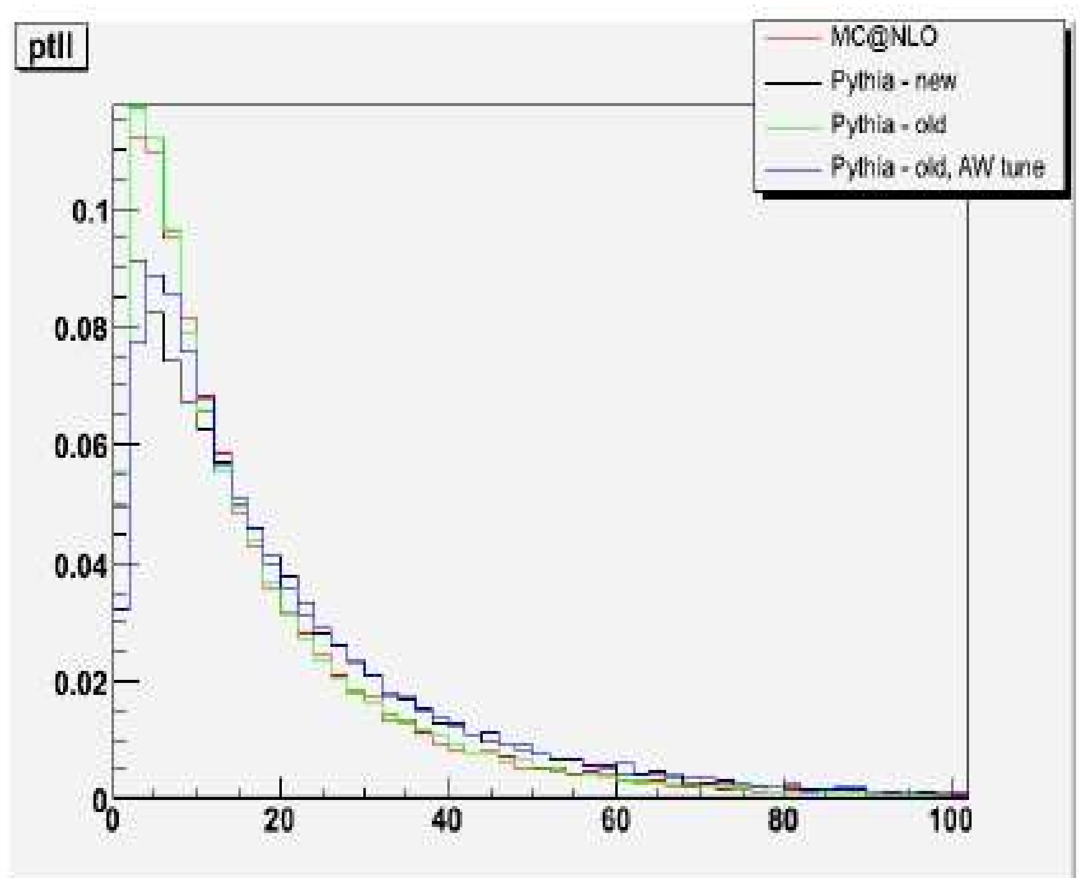


Effective Q cut-off, below which space-like showers are not evolved.

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!



Summary

- Lots of work done within ATLAS to make use of the 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.
- Some discussion within Artemis of what our priorities are?