ISR/FSR and underlying events: constraints and modeling

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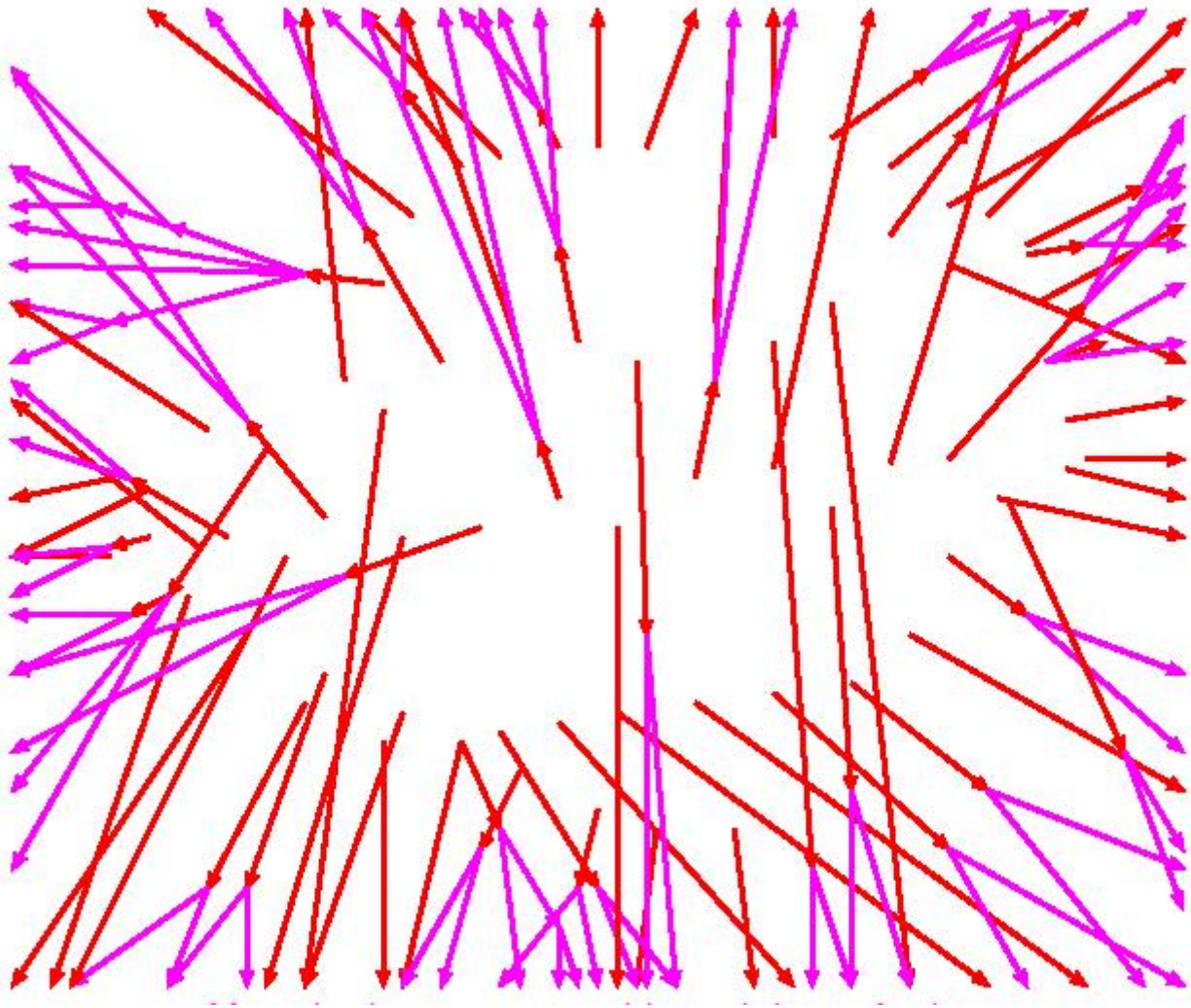
On behalf of the ATLAS collaboration

ATLAS experience:

- Underlying event
- ISR/FSR
- Validation procedures
- Future

What is what?



And these decay further….

Approximations to QCD

- Fixed order matrix elements: Truncated expansion in a_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.

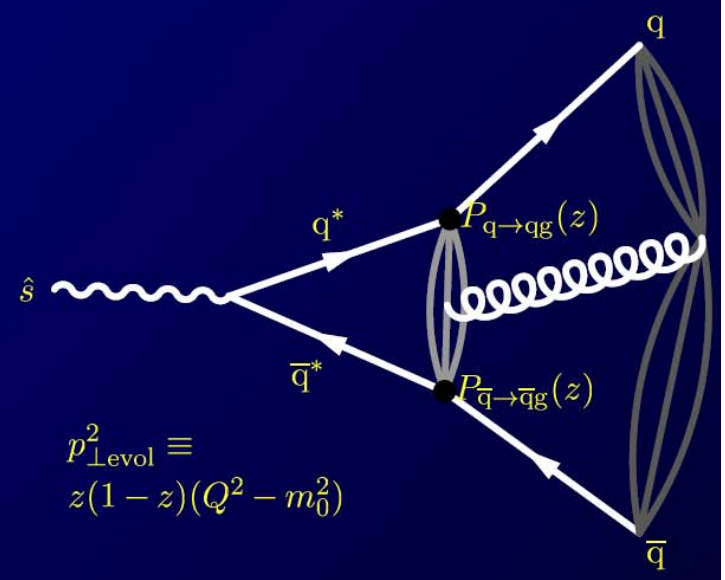
MC generators for shower (ISR/FSR) and multiple interactions/underlying event

- At ATLAS we are using two primary MC generators for showering description:
  - Pythia (currently v. 6.403 with patches)
    - NEW model for UE and ISR/FSR
  - Herwig (currently v. 6.510 with patches)
    - Jimmy (v. 4.2) used for UE description
- In addition, Sherpa has been validated and is used for a selection of processes.
- The MC base will of course expand:
  - Pythia 8
  - HERWIG++
  - Ariadne
  - ???

Pythia 6.3+ : p_T-ordered showers

Merged with X + 1 jet Matrix Elements (by reweighting) for:
h/γ/Z/W production, and for most EW, top, and MSSM decays!

Exclusive *kinematics* constructed inside dipoles based on Q^2 and z, assuming yet unbranched partons on-shell



Iterative application of Sudakov factors...

$\Rightarrow$ One combined sequence $p_{\perp\max} > p_{\perp 1} > p_{\perp 2} > \ldots > p_{\perp\min}$

NB: Choice of $p_{\perp\max}$ non-trivial and *very* important for hard jet tail
$\leftrightarrow$ wimpy vs power showers...

p_T-ordered showers: T. Sjöstrand & PS - Eur.Phys.J.C39:129,2005

Common validation procedures at ATLAS

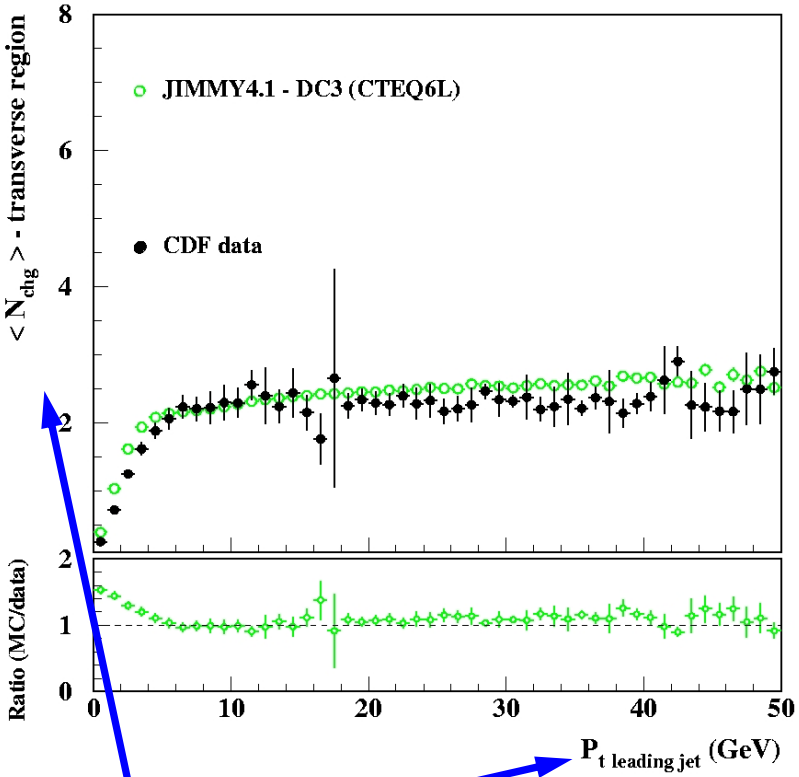
- There are in general two approaches:
  - We take into account the experience and results at the Tevatron (tunings) and/or we try to tune/check the generators using available Tevatron information ourselves.
  - We compare the results of different MC generators in the quantities where they should match (to a certain precision) either at the generator level or by performing full analysis studies.
- We intend to make use of CEDAR/JETWEB when it comes online.
  - Need contributions from TeVatron experiments!

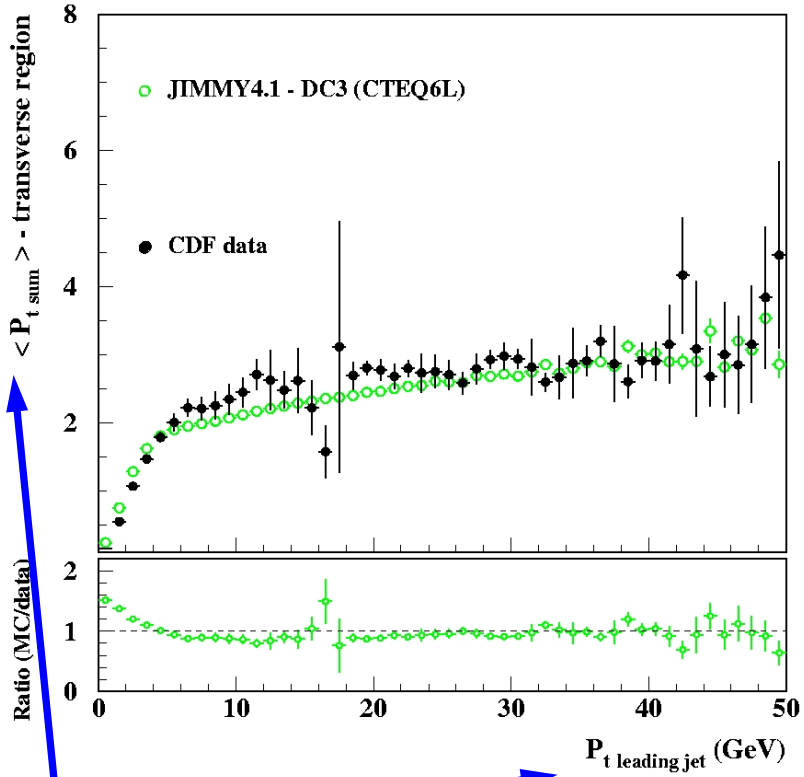
UE tunings: Jimmy CSC tuning

JIMMY4.1 & HERWIG6.507

CSC tuning		Default
CTEQ6LO (LO fit with LO α_s)	LHAPDF PDF set number: 10042	
JMUEO=1	QCD 2→2 (secondary 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

UE tunings: Jimmy validation using CDF data

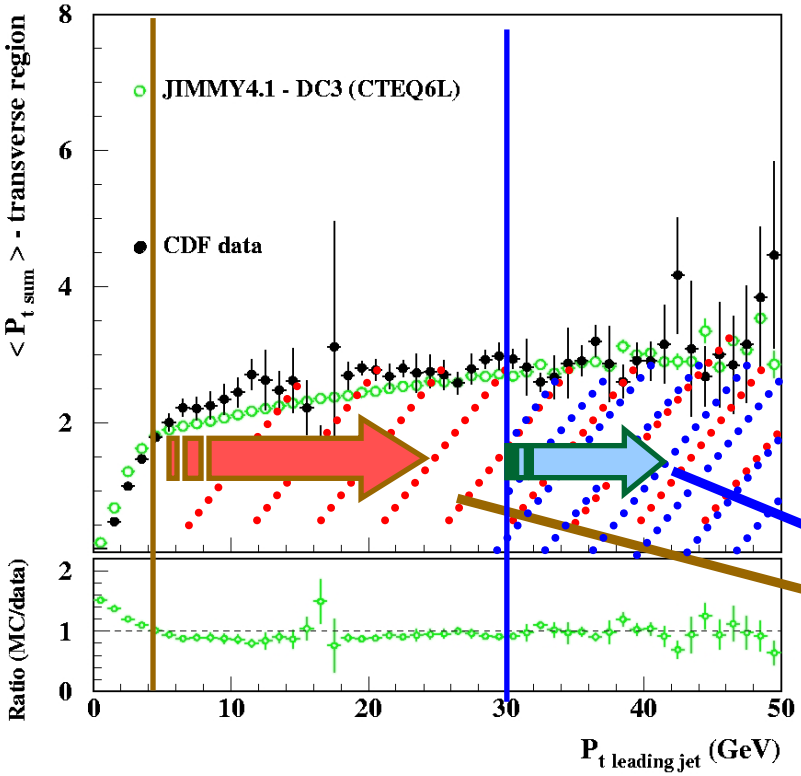




Average multiplicity of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

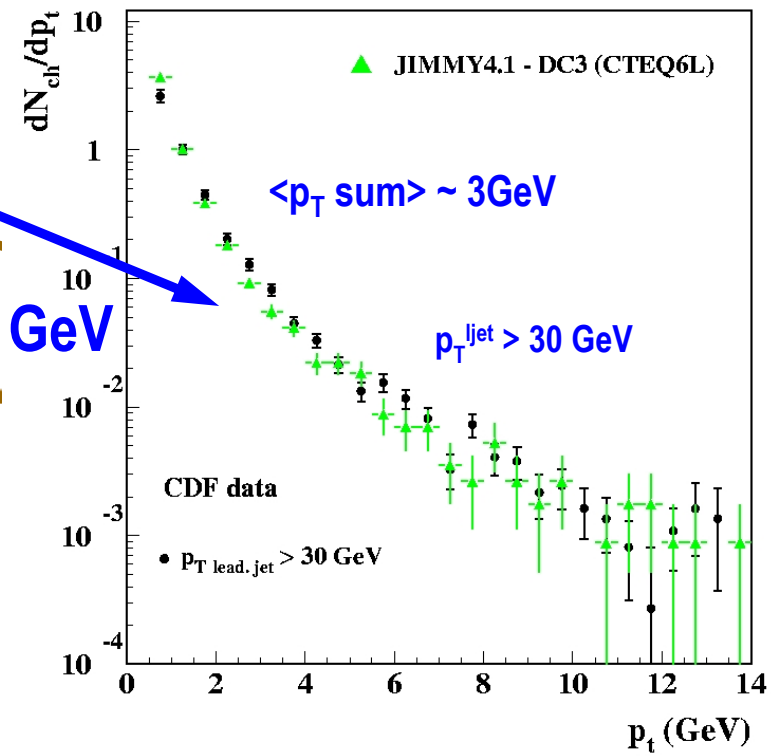
Average $\mathbf{p_T^{sum}}$ (GeV) of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

UE tunings: Jimmy validation using CDF data



p_T^{ljet} > 30 GeV

p_T^{ljet} > 5 GeV



UE measurement: MAX/MIN analysis

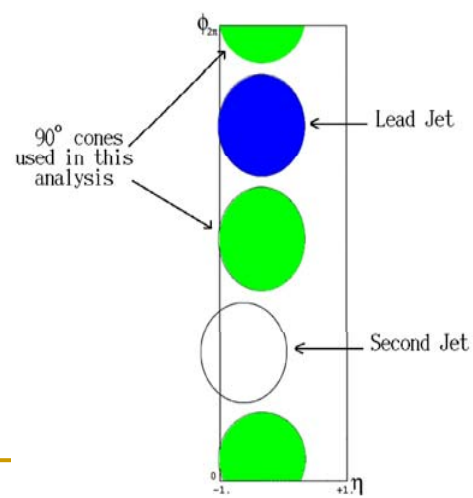
CDF analysis – Run I data

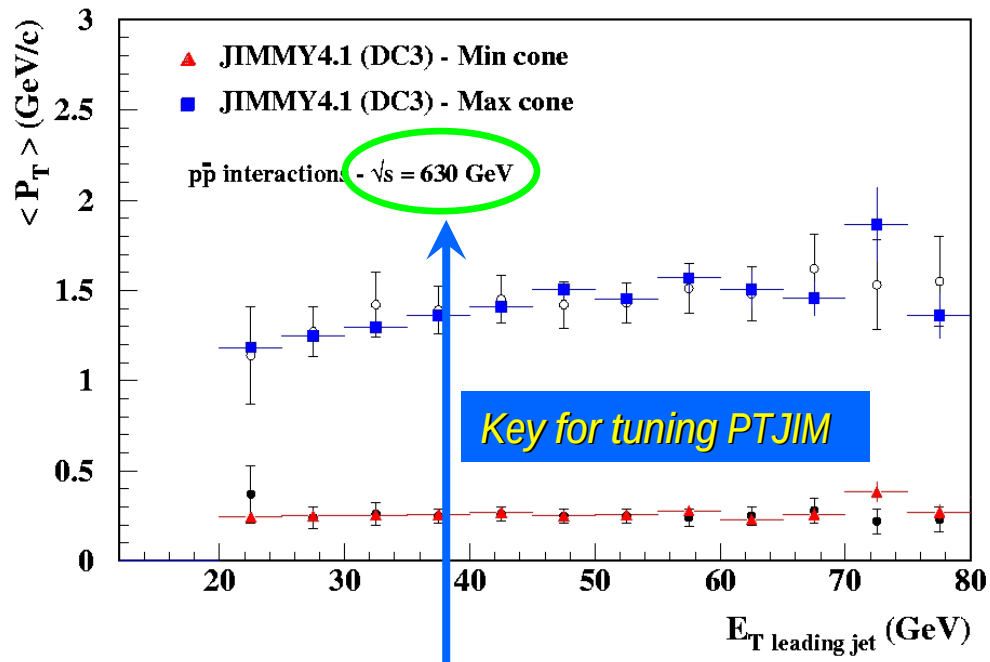
The underlying event in Hard Interactions at the Tevatron ppbar collider, CDF Collaboration, PRD 70, 072002 (2004).

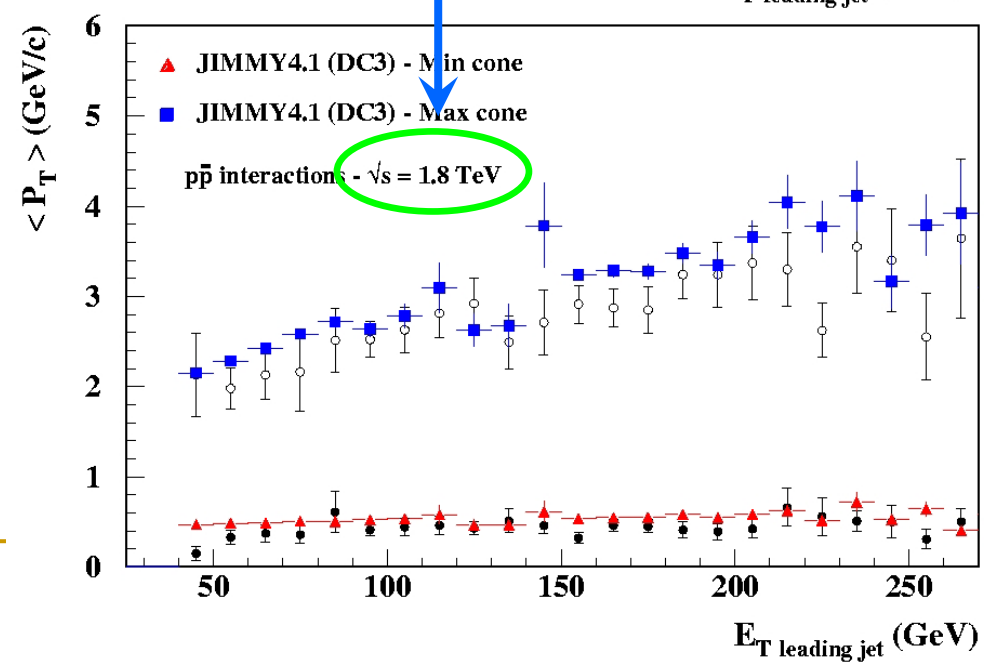
- **Two cones in $\eta-\phi$ space are defined:**

$\eta=\eta_{ljet}$ *(same as the leading jet)*
$\phi=\phi_{ljet} \pm 90°$
$R=0.7$

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



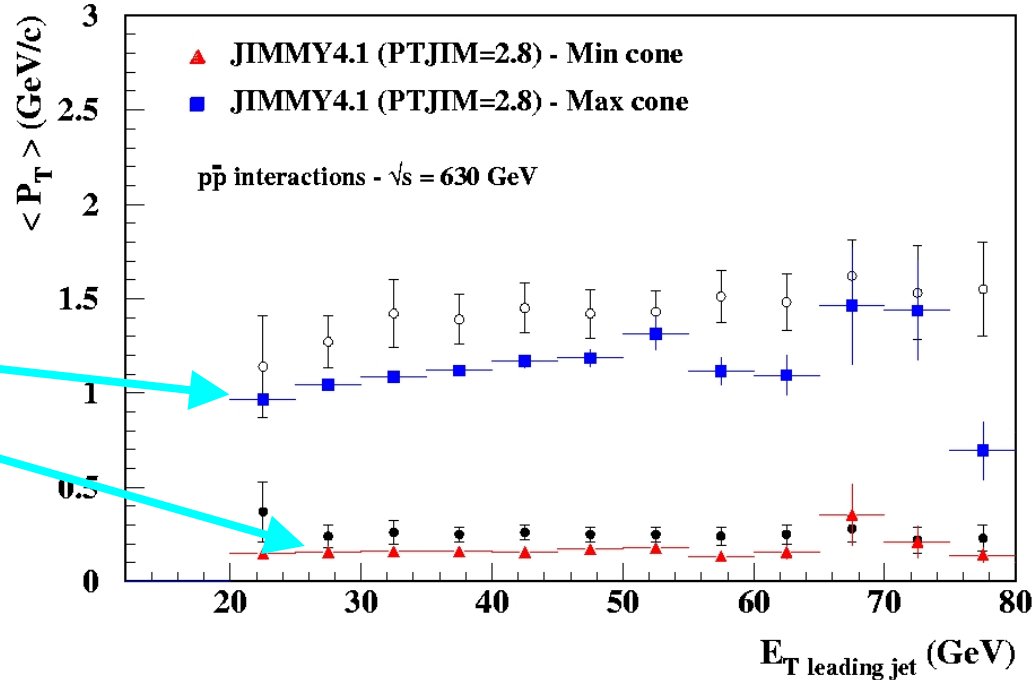




PTJIM energy dependence

PTJIM=2.8

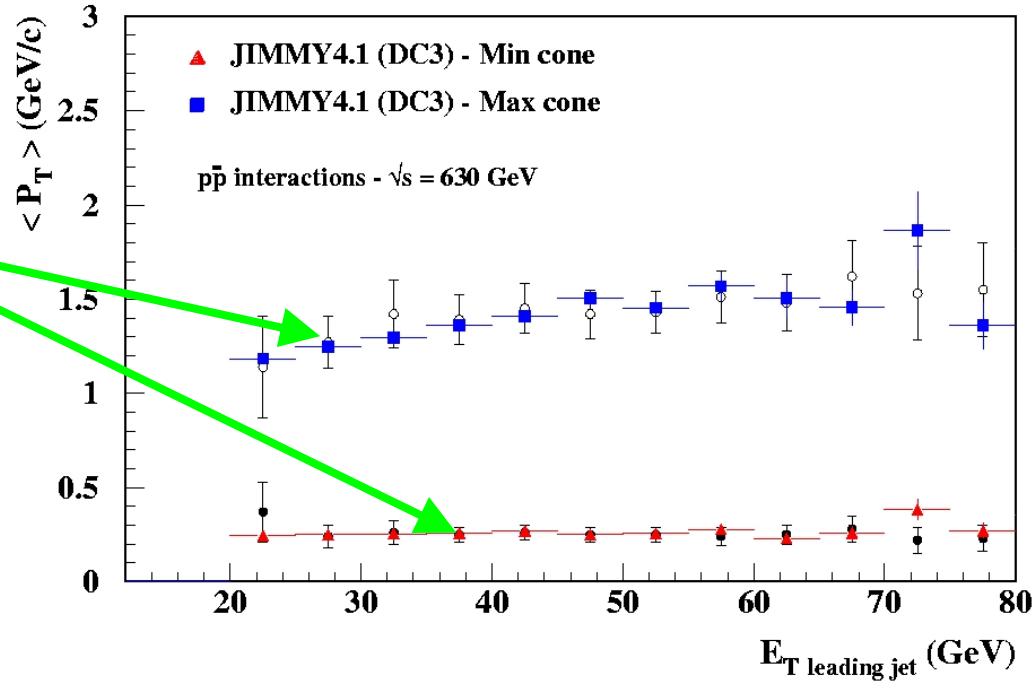
- same PTJIM obtained from comparisons to 1.8 TeV data!
- This underestimates the data.



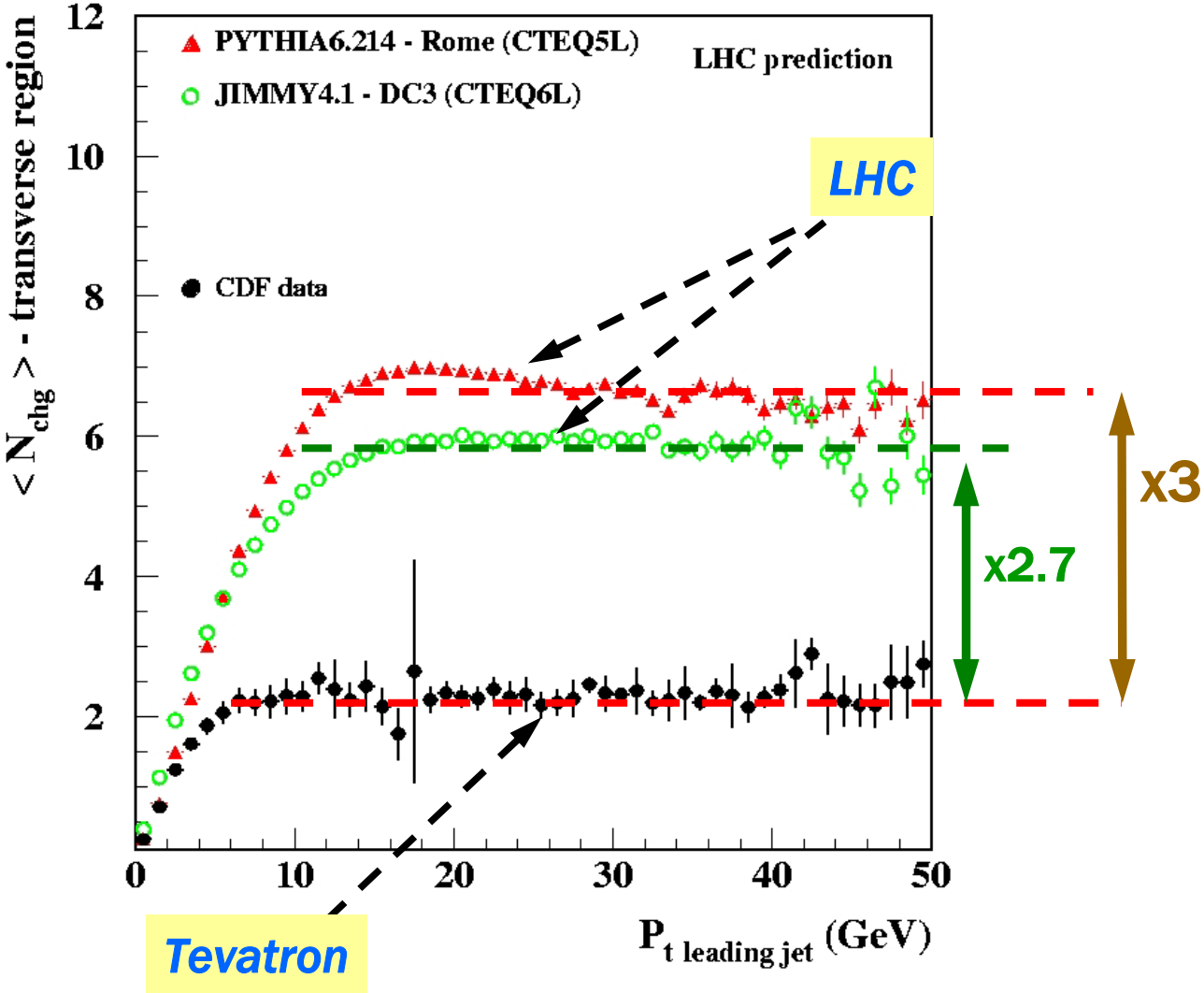
PTJIM=2.1

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

- introducing energy dependent factor we get a better agreement.



UE tunings: Pythia vs. Jimmy



PTJIM=4.9

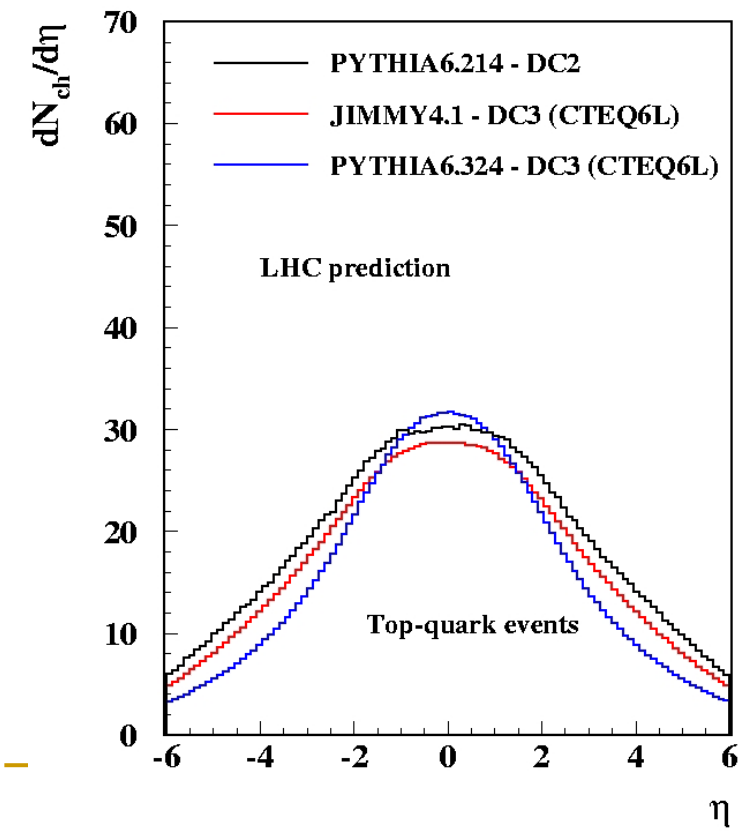
$= 2.8 \times (14 / 1.8)^{0.27}$

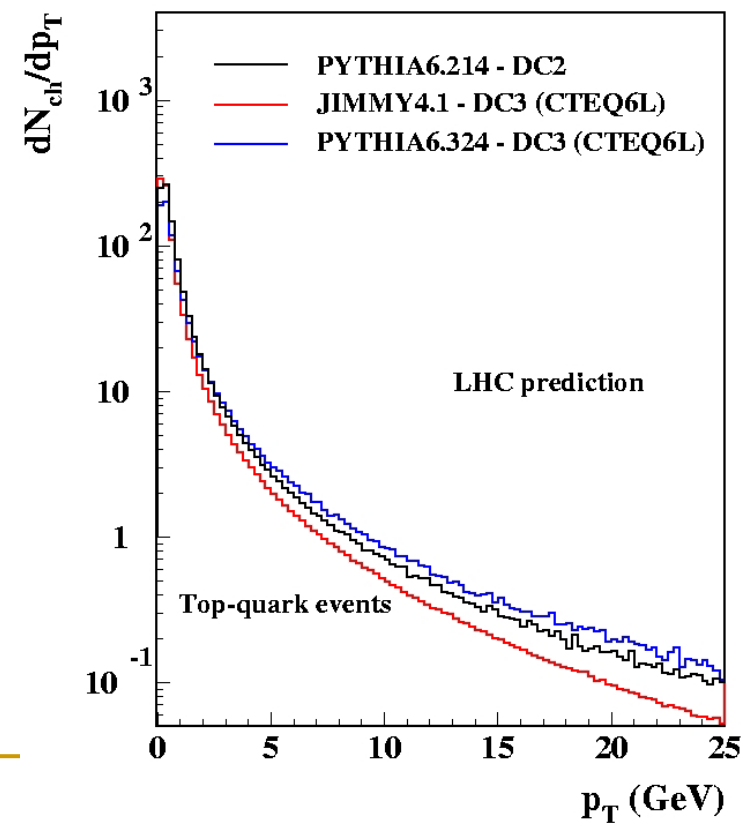
- **energy dependent PTJIM generates UE predictions similar to the ones generated by PYTHIA6.2 – ATLAS.**

Consistency check for CSC tuning: top-quark production

- ***2004 (Rome)tuning***:
  JIMMY was tuned to dN/dη for LHC tt̄ production generated by PYTHIA6.2 – ATLAS.

- ***2006 (CSC) tuning***: **tuning based on comparisons to UE data leads to a natural agreement to PYTHIA's prediction for particle density in tt̄ events at LHC.**





Tuning for CTEQ6M: used in MC@NLO events

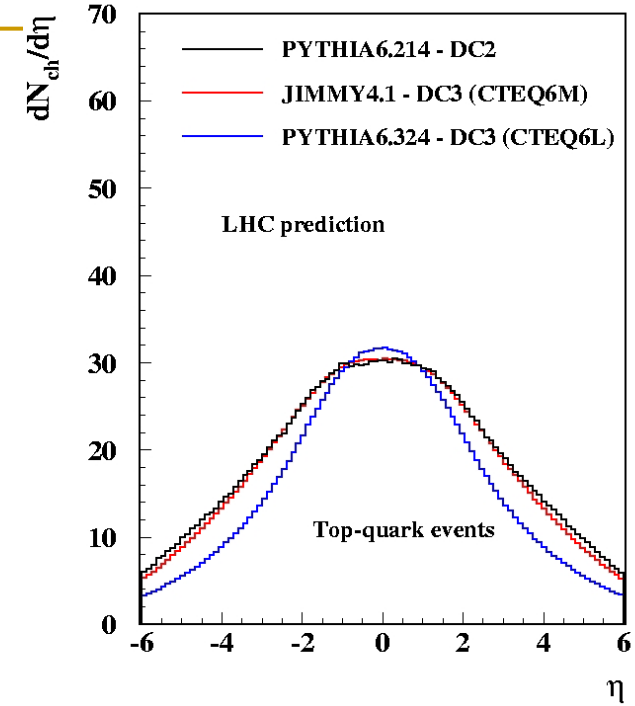
CTEQ6M → LHAPDF
PDF set number: 10000

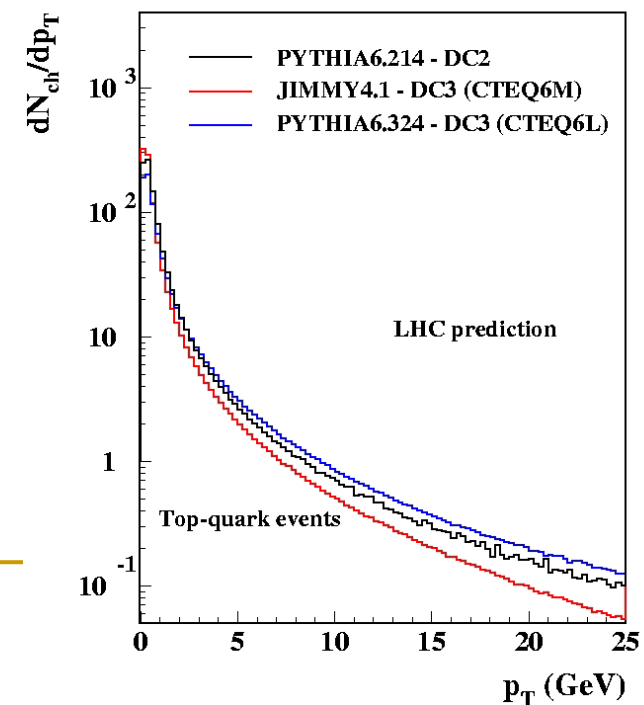
JMUEO=1

PTJIM=2.5 x $(\sqrt{s}/1.8\ \text{TeV})^{0.21}$ → PTJIM=2.8 x $(\sqrt{s}/1.8\ \text{TeV})^{0.27}$
(used for CTEQ6L)

JMRAD(73)=1.8

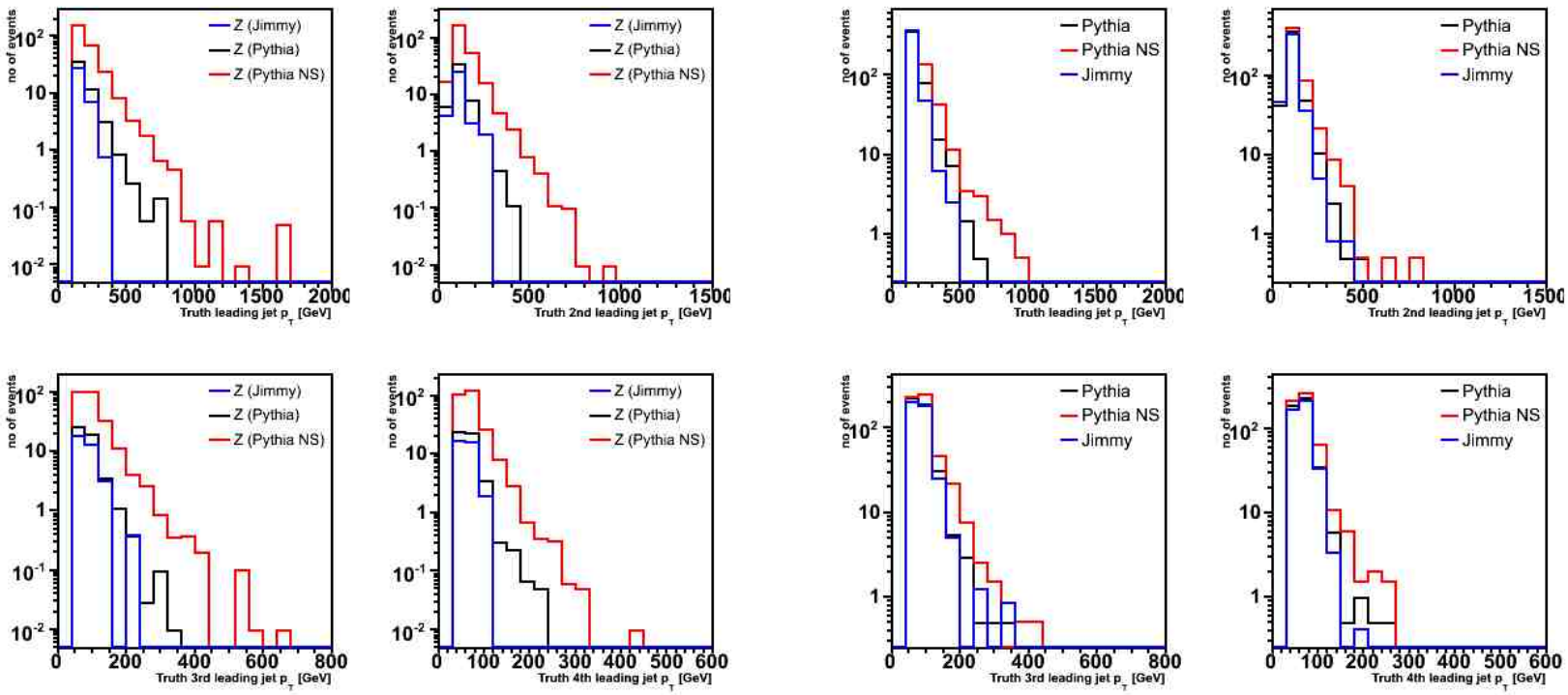
PRSOF=0.0





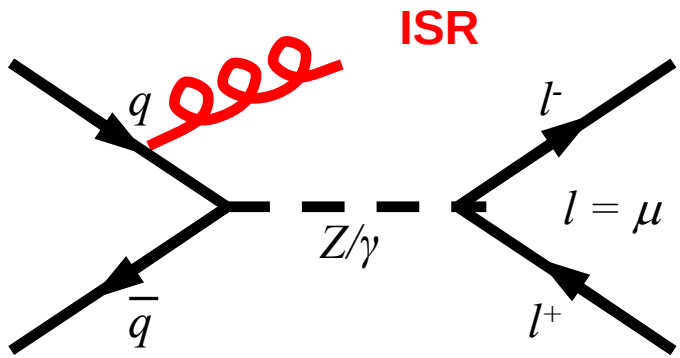
ISR/FSR showering studies

- The new pT-ordered ISR/FSR/UE introduced in Pythia 6.3:
  - The most striking difference from the 'old' results is the harder pT spectrum of jets – stronger ISR/FSR/UE activity:
  - Also quite harder than HERWIG/Jimmy..



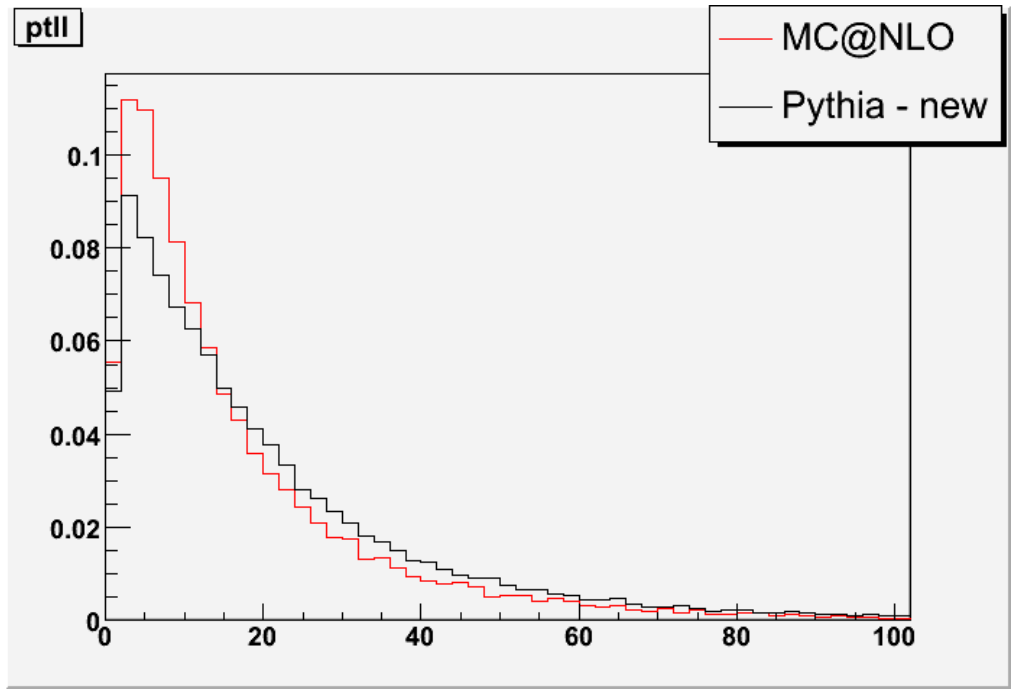
Drell Yan processes

- 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
- In the given studies the lepton FSR (Photos) was turned off to get the ideal picture.
- The comparison was made between MC@NLO/Herwig and Pythia Drell-Yan.



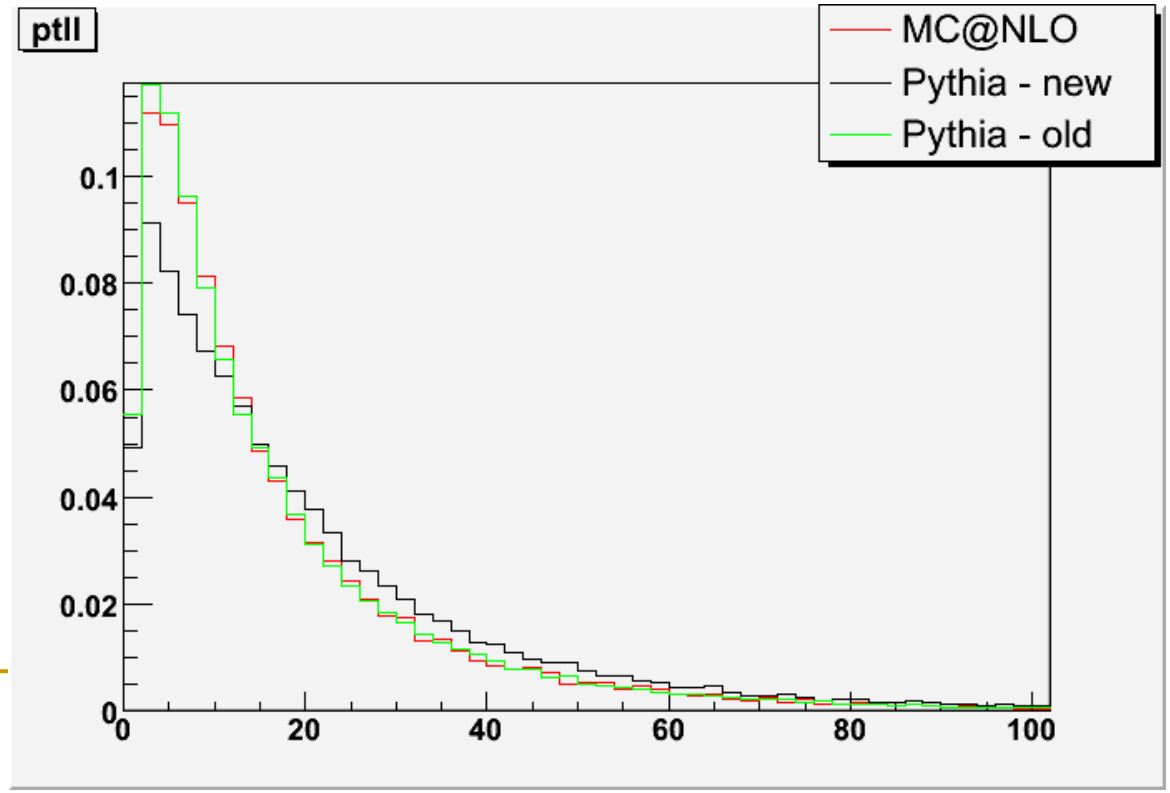
The P_T of the dilepton system

- It appears that the new Pythia showering actually gives a harder ISR spectrum – confirms what was already observed in many cases.
- 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.

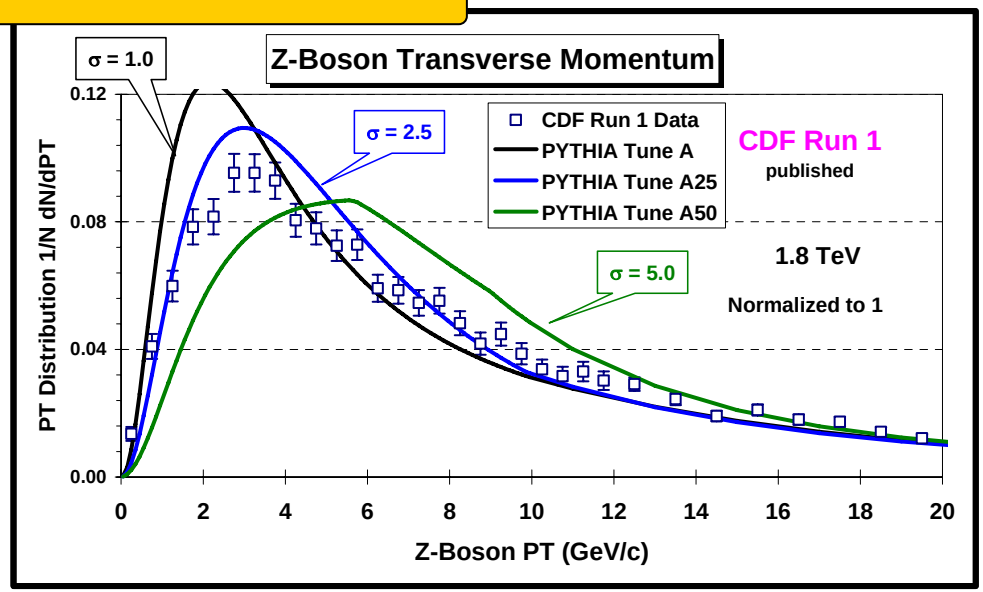
UE Parameters

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

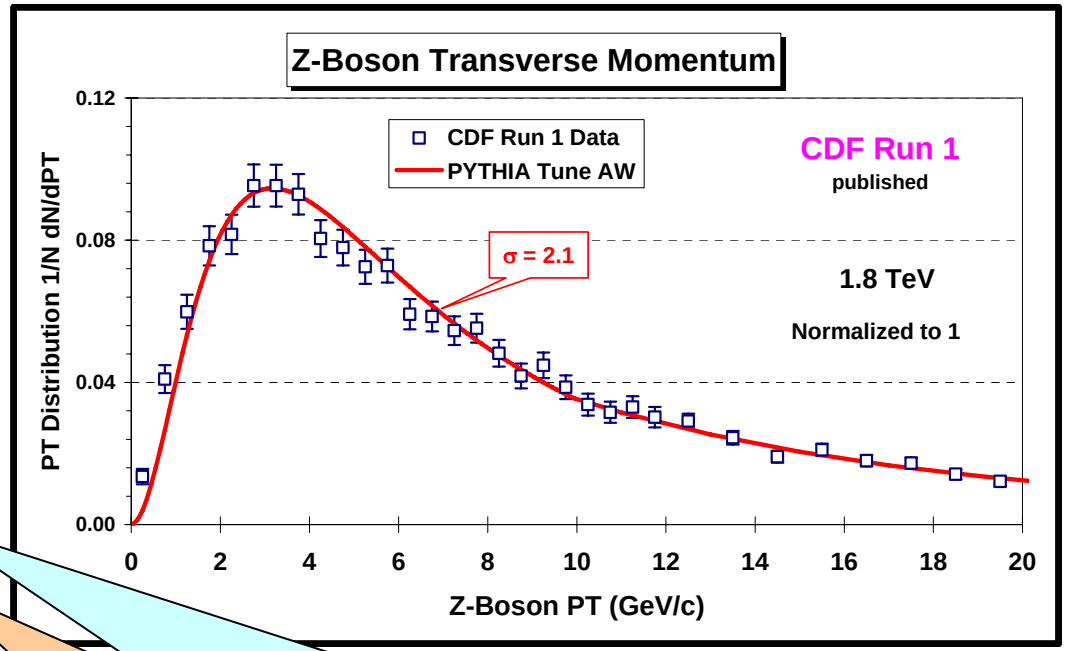
- However the R. Fields AW-tune does a much better job!

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

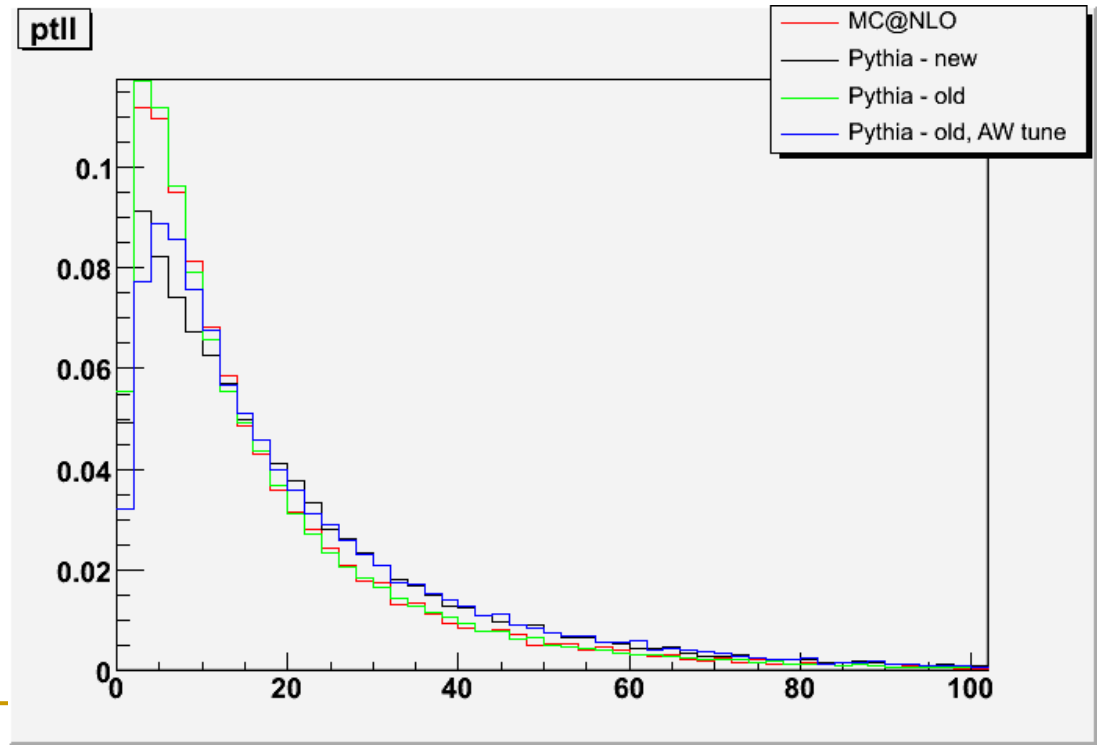


Effective Q cut-off, below which space-like showers are not evolved.

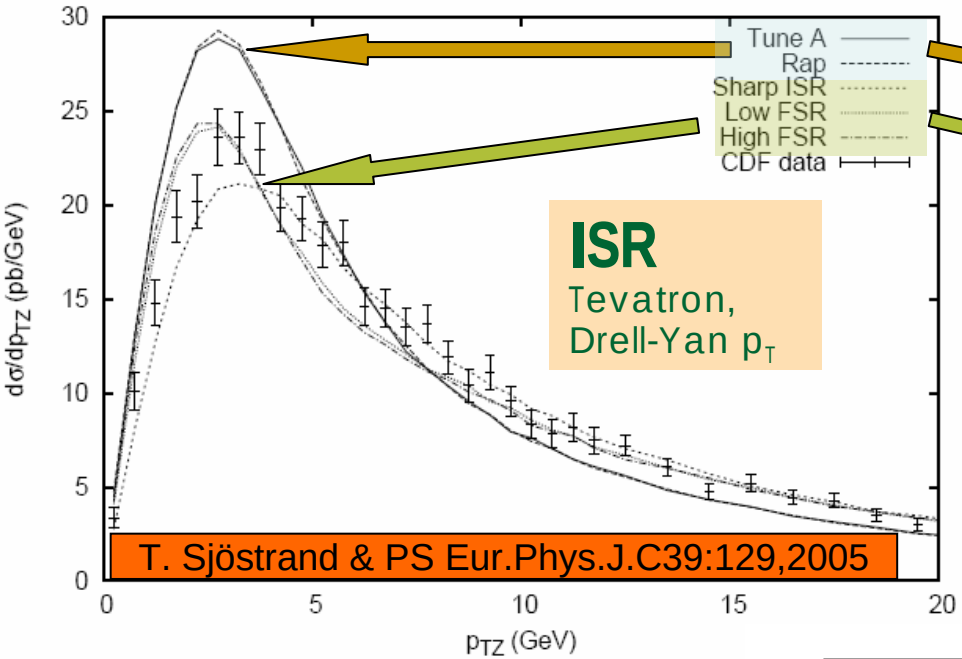
The $Q^2 = k_T^2$ in α_s for space-like showers is scaled by PARP(64)!

P_T of the dilepton system

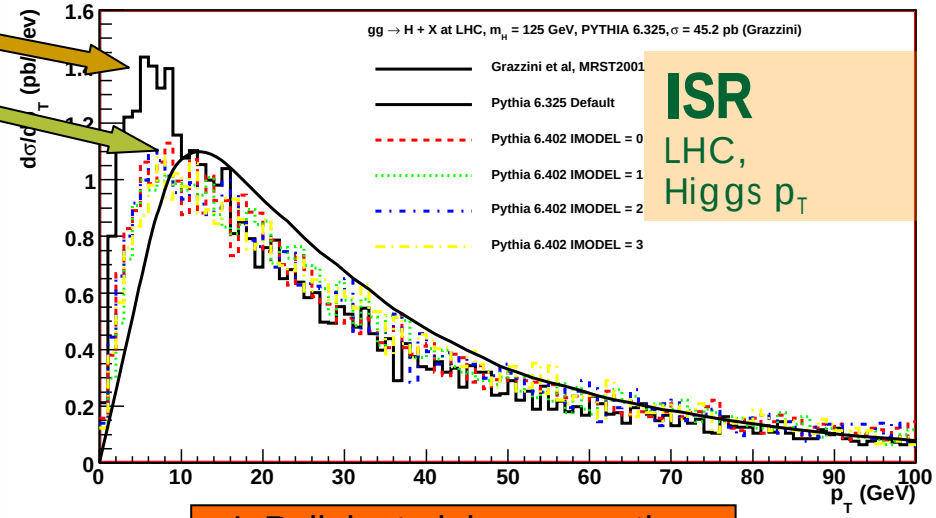
- The new AW tuning was ported to the ATLAS Pythia setup.The result is rather surprising, namely the AW-tuned 'old' Pythia showering seems to agree quite well with the new Pythia showering!
  - This would thus indicate that the new Pythia model works fine!
  - What it boils down to is that ISR/FSR tuning is of essence!
  - Sadly similar tests do not exist at CDF.. Need more info!



Pythia 6.3+ : p_T-ordered showers



T. Sjöstrand & PS Eur.Phys.J.C39:129,2005

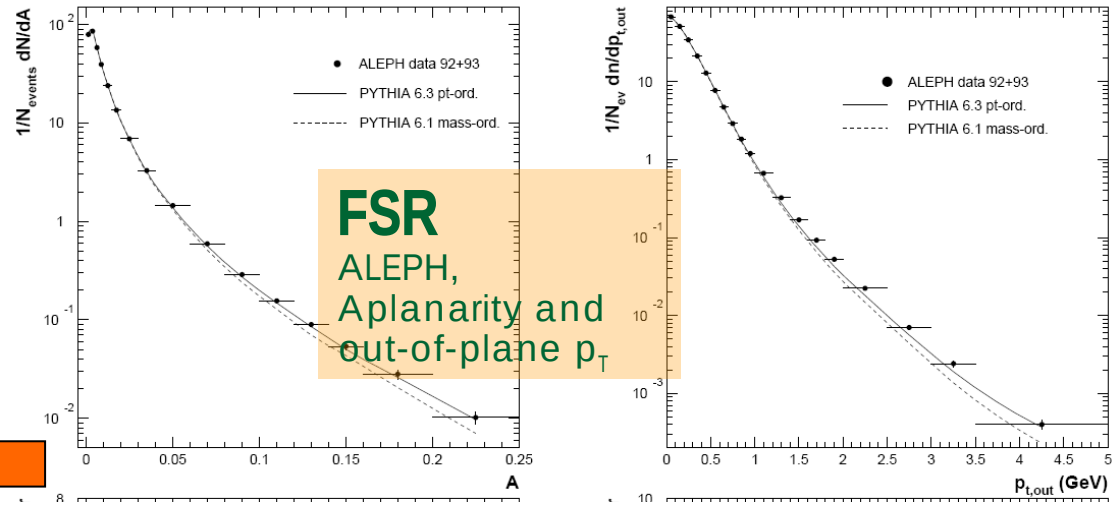


I. Puljak et al, in preparation

Sample tunes available as new subroutine: PYTUNE(ITUNE)

http://www.thep.lu.se/~torbjorn/pythia/main75.f (for Pythia 6.402+)

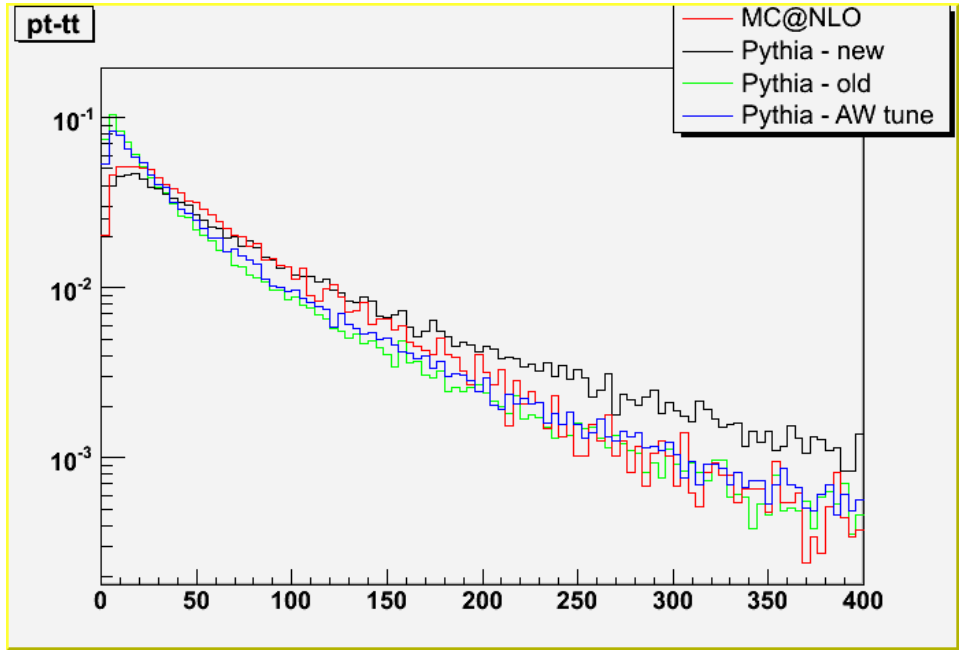
(incl. detailed comments on each tune)



G. Rudolph (ALEPH, 2004)

tt~ processes

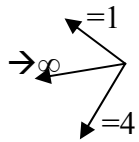
- Again the MC@NLO and Pythia (old and new showering) are compared, both initial states (qq~ and gg) are taken into account.
- The ISR-sensitive observable we looked at is the pT of the tt~ system – motivated by the Drell-Yan but hard to reconstruct.
- The first look gives again a somewhat surprising result: The new Pythia showers are substantially harder.
- We will need the data to tune and (in-)validate the different models..



To Quantify Further:

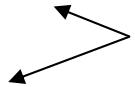
- Compare MadGraph for ttbar , with 0, 1, and 2 explicit additional jets to:

- 5 different shower approximations (Pythia):
  - 'Wimpy Q^2-ordered' (PHASE SPACE LIMIT < Q_F)
  - 'Power Q^2-ordered' (PHASE SPACE LIMIT = s)
  - 'Tune A' (Q^2-ordered) (PHASE SPACE LIMIT ~ Q_F)



PARP(67)

  - 'Wimpy p_T-ordered' (PHASE SPACE LIMIT = Q_F)
  - 'Power p_T-ordered' (PHASE SPACE LIMIT = s)



New in 6.3

NB: Renormalisation scale in p_T-ordred showers also varied, between $p_T/2$ and $3p_T$

Rainwater, Plehn & PS : hep-ph/0510144 + hep-ph/0511306

ttbar + jets @ Tevatron

Process characterized by:

- Threshold production (mass large compared to s)
- A 50-GeV jet is reasonably hard, in comparison with hard scale ~ top mass

SCALES [GeV]

$s = (2000)^2$

$Q^2_{Hard} \sim (175)^2$

$50 < p_{T,jet} < 250$

→ RATIOS

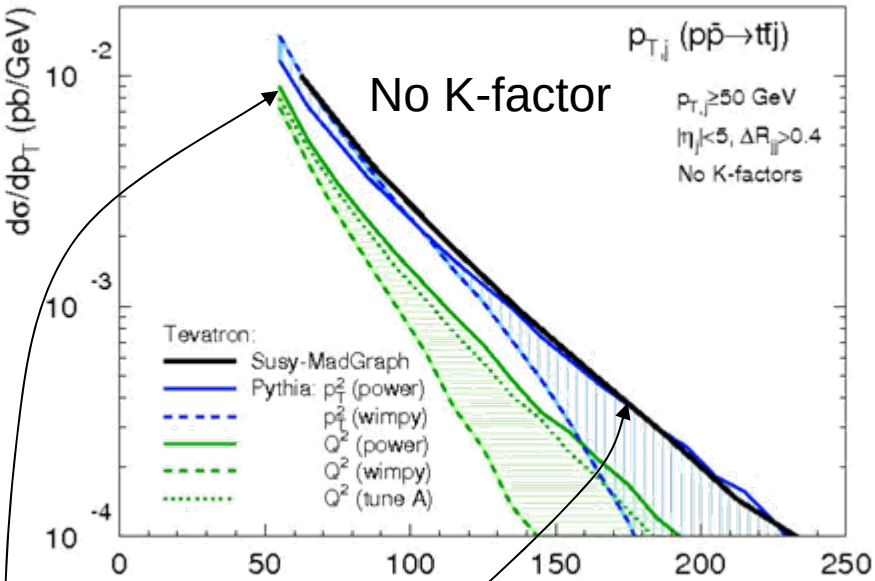
$Q^2_H/s = (0.1)^2$

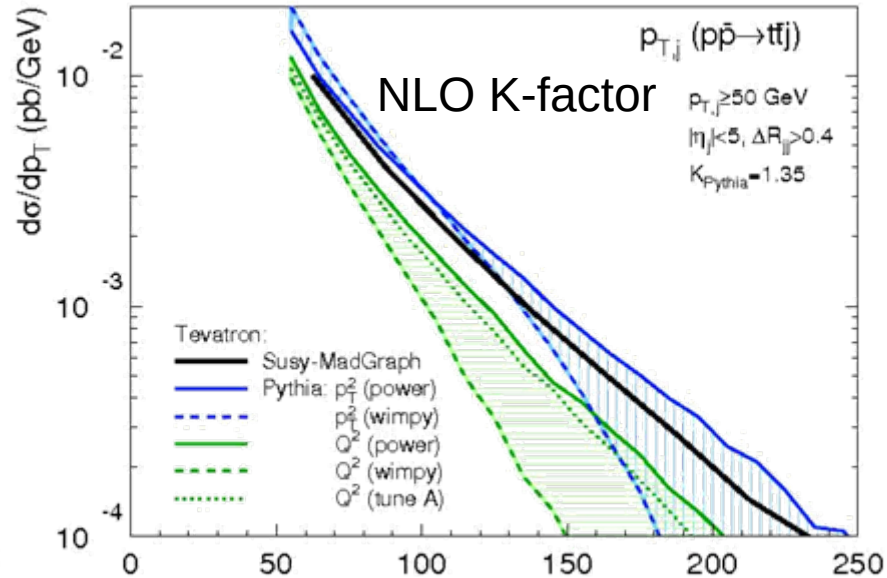
$1/4 < p_T / Q_H < 2$

SCALES [GeV]
$s = (2000)^2$
$Q^2_{Hard} \sim (175)^2$
$50 < p_{T,jet} < 250$

jets @ Tevatron

RATIOS
$Q^2_H/s = (0.1)^2$
$1/4 < p_T / Q_H < 2$





<u>Hard tails</u>:
- Power Showers (solid green & blue) surprisingly good (naively expect *collinear* approximation to be worse!)
- Wimpy Showers (dashed) drop rapidly around top mass.

<u>Soft peak</u>: logs large @ ~ mtop/6 ~ 30 GeV → fixed order <u>still good</u> for 50 GeV jets (did not look explicitly below 50 GeV yet)

ttbar + jets @ LHC

Process characterized by:

- Mass scale is small compared to s
- A 50-GeV jet is still hard, in comparison with hard scale ~ top mass, but is now soft compared with s.

SCALES [GeV]

$s = (14000)^2$

$Q^2_{Hard} \sim (175+\ldots)^2$

$50 < p_{T,jet} < 450$

RATIOS:

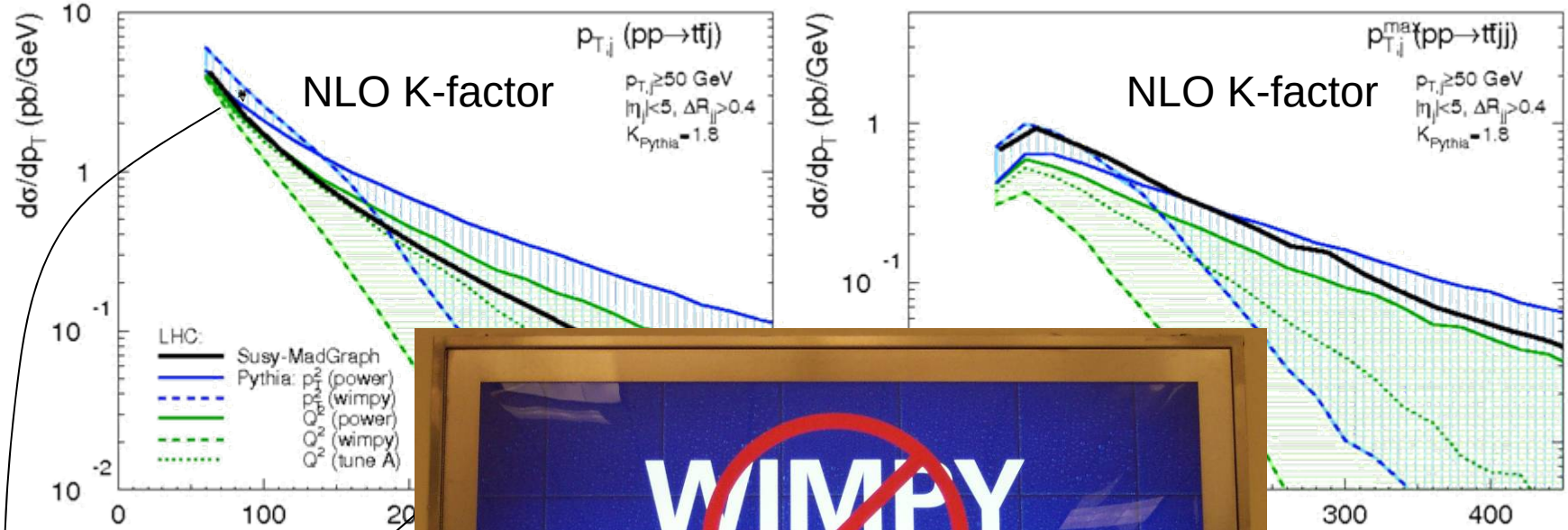
$Q^2_H/s = (0.02)^2$

$1/5 < p_T / Q_H < 2.5$

SCALES [GeV]
s = (14000)^2
Q^2_{Hard} ~ (175+…)^2
$50 < p_{T,jet} < 450$

jets @ LHC

RATIOS
$Q^2_H/s = (0.02)^2$
$1/5 < p_T / Q_H < 2.5$



Hard tails: More
- Power Showers
- Wimpy Showers ass.

- Soft peak: logs not threshold dominated here) - jets.

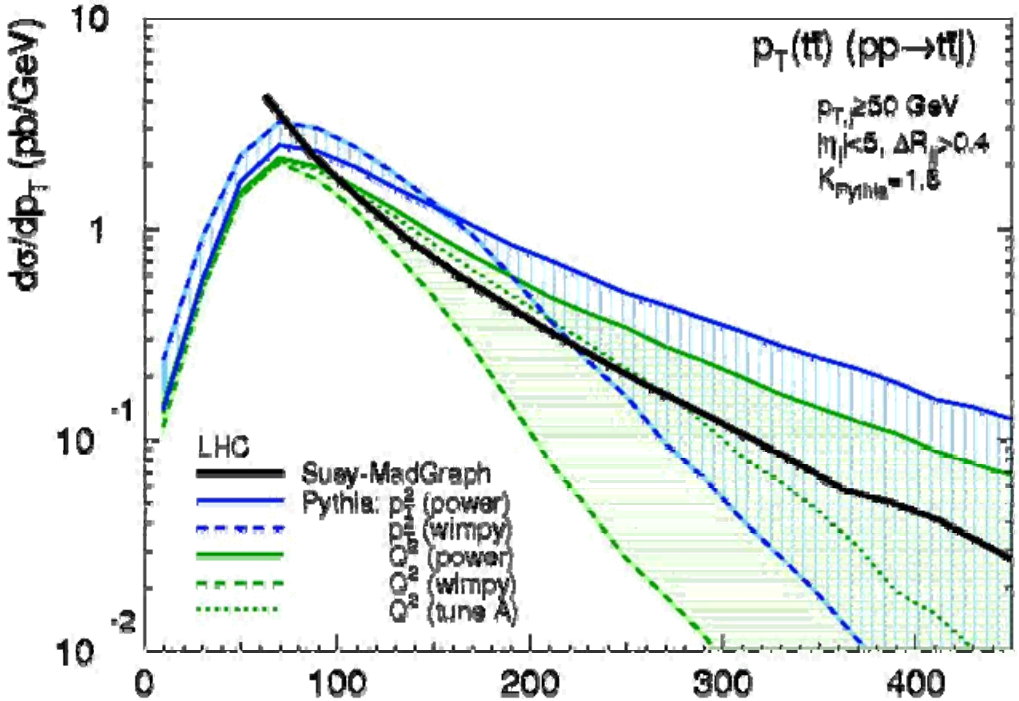
p_T of hard system
(Equivalent to $p_{T,Z}$ for Drell-Yan)

ttbar + 1 jet @ LHC

p_T of (ttbar) system

→ Resummation necessary

Bulk of cross section sits in peak sensitive to multiple emissions.

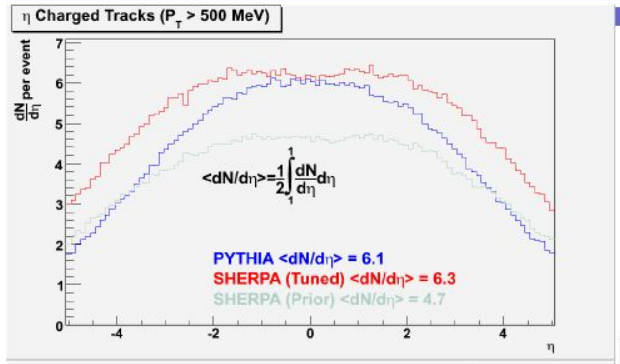


SHERPA studies

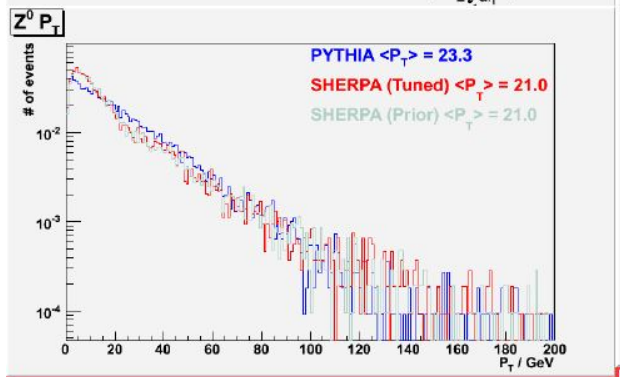
- Quite some effort on the ATLAS part to validate the SHERPA code and incorporate it into the ATLAS ATHENA framework,
  - We think using SHERPA is of essence because of the CKKW matching
  - useful to compare to ALPGEN MLM matching and PS models

Sherpa UE

Compare UE η & P_T distributions

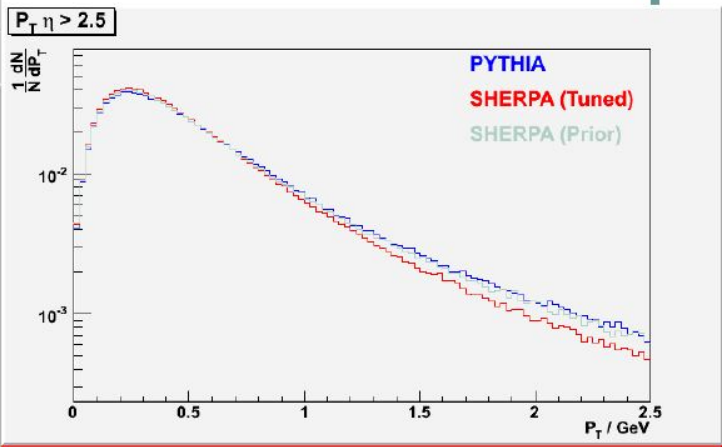


NORMALIZATION ACCOUNTS FOR BIN WIDTHS. $\langle dN/d\eta \rangle = \frac{1}{2}\int_{-1}^{1}\frac{dN}{d\eta}d\eta$



$P_T(\nu\,\bar{\nu})$. DISTRIBUTION NORMALIZED TO AREA

- Sherpa & Pythia agree in central region η<1
- Pythia drops off more dramatically between 2.5<η<4.5

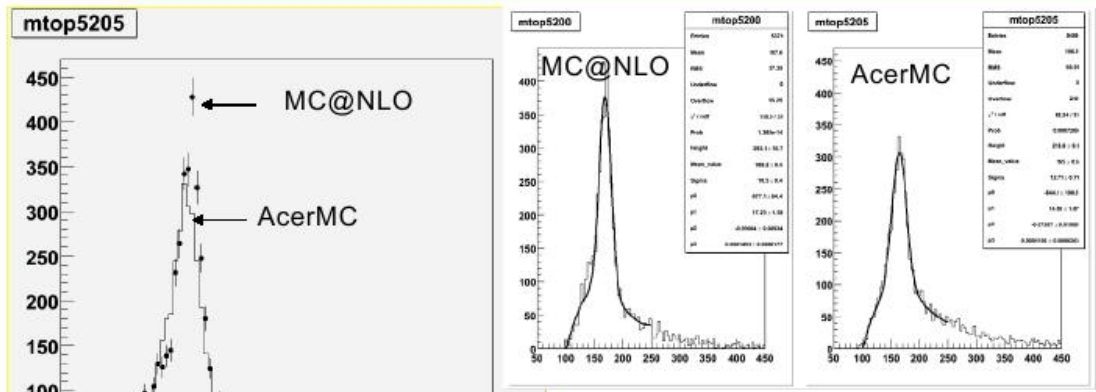


TRACK P_T DISTRIBUTION NORMALIZED TO AREA

Impact of different models

- Recently a study of top mass reconstruction using tt~ events by Jerome Schwindling was done using:
  - MC@NLO (Herwig+Jimmy)
  - AcerMC (Pythia – new model)
  - Full detector simulation

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!

Summary/Conclusions

- A lot of effort has been spent (but by no means wasted!) on incorporating different MC tools and models 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. Collaboration is of the essence!
  - We won't know what the right answer is until we get our own data to work on..
- All in all we believe to be in a good shape waiting for the first physics data!