Tuning of ISR/FSR and underlying event in MC generators
TeVatron-ATLAS top physics workshop

L. Mijović[1], B.P. Krševan[1,2]

[1]FMF, University of Ljubljana

[2]Jožef Stefan Institute

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Talk overview

Goal: present current status of ISR/FSR and UE modeling and tuning at LHC (ATLAS) and TeVatron.
Note: focus on ISR/FSR at ATLAS, $t\bar{t}$ and UE and ISR/FSR (Pythia) parameters interplay - my work.

Topics to be covered:

- **UE and ISR/FSR tuning at TeVatron:**
  - CDF: work done by R. Field *et. al*: dijets and Drell-Yan,
  - CDF: ISR/FSR in $t\bar{t}$ events, D$\emptyset$: ISR in dijet events,
  - other studies ?
- **ISR/FSR tuning at ATLAS ($t\bar{t}$):**
  - MC study, goals: modeling uncertainty - ttbar observables (top mass), find relevant tunable ISR/FSR parameters, observables for tuning (data).
  - comments on ISR/FSR effects on other top physics observables.
- **UE tuning at ATLAS:**
  - work done by A. Moraes,
- **ISR/FSR and UE tuning interplay:**
  - common Pythia parameters, TeVatron (data and Monte Carlo) and ATLAS.

UE and ISR/FSR tuning at TeVatron

Main ideas of the studies to be presented :

- **UE and ISR/FSR in high-pt jets events and Drell-Yan:**
  - CDF, Run II study by R. Field *et. al*,
  - study activity in different $\eta - \Phi$ regions wrt. highest-pt jet and Z boson.
  - Pythia (tuning), Herwig.

- **ISR/FSR tuning using Dijet Azimuthal Decorrelations:**
  - D0, Run II study by Begel, Wobisch and Zielinski,
  - study azimuthal angle difference of the 2 highest-pt jets in event,
  - Pythia (tuning), Herwig.

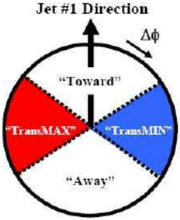
- **ISR/FSR in $t\bar{t}$ at TeVatron:**
  - CDF, Run II study
  - extrapolate Drell-Yan ISR to $t\bar{t}$: does not work for LHC and ATLAS.
  - Pythia.

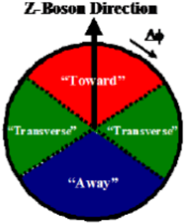
Note: at TeVatron old (pre-6.3) Pythia is used.

UE and ISR/FSR in high-pt jets events and Drell-Yan

- R. Field., *Run 2 Monte Carlo Tunes* in M. G. Albrow *et al.* [TeV4LHC QCD Working Group], *Tevatron-for-LHC report of the QCD working group*, 2006.
- D. Kaar, R. Field, *Using Drell-Yan to Probe the UE in Run 2 at CDF*, CDF/PUB/CDF/PUBLIC/9351.

- TransMAX(MIN): transverse region with largest(smallest) N of charged particles [1], definition applies to QCD 2 → 2 and Drell-Yan processes.





QCD 2 → 2 process	Drell-Yan
TransMAX region: hardest ISR/FSR	TransMAX region: hardest ISR/FSR
TransMIN: beam-beam UE component	Transverse region: clean UE probe
TransMAX - TransMIN: ISR/FSR probe	Toward region pt Z: ISR sensitive

- Different scales of QCD high-pt jets and Drell-Yan; UE description universal?

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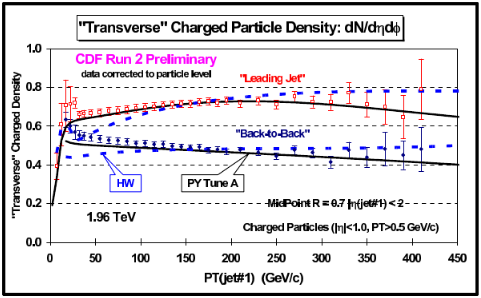
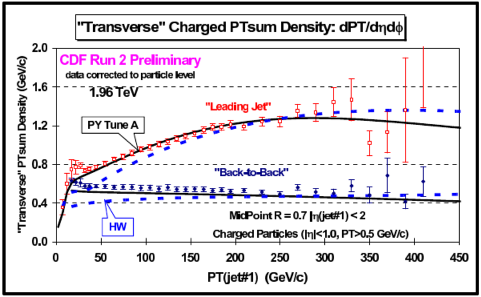
[1] or scalar *pt* sum, CDF/PUB/CDF/PUBLIC/9351

UE and ISR/FSR in high-pt jets events: Run 1 → Run 2





- R. Field., *Run 2 Monte Carlo Tunes*, 2006.

Definitions:

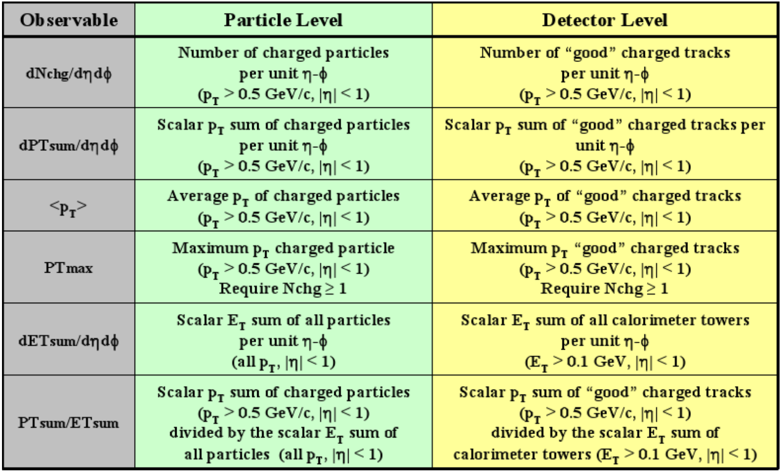
- **leading jet:** no restrictions on jet#2 and jet#3.
- **back-to-back:** $|\Delta\Phi| < 150^\circ$, pt(jet#2)/pt(jet#1)>0.8, pt(jet#3)<15 GeV
- **Tune A:** Run 1 dijets data.

Note:

- *old* Pythia,
- Herwig: no MPI,
- in the next slides: *new* Pythia and Herwig + Jimmy plots.

UE and ISR/FSR in high-pt jets events: quantities and observables

R. Field, *Fourth Hera-LHC Workshop*, May 2008.

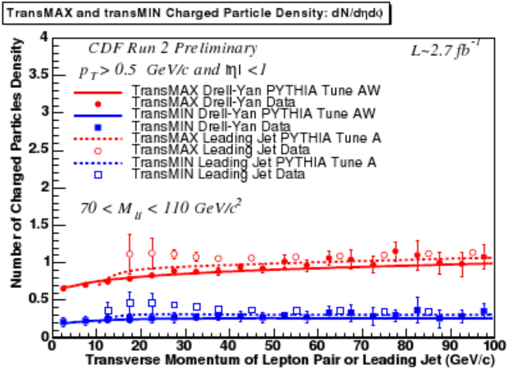


Observable	Particle Level	Detector Level
$dNchg/d\eta d\phi$	Number of charged particles per unit η-ϕ ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$)	Number of "good" charged tracks per unit η-ϕ ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$)
$dPTsum/d\eta d\phi$	Scalar p_T sum of charged particles per unit η-ϕ ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$)	Scalar p_T sum of "good" charged tracks per unit η-ϕ ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$)
$\langle p_T \rangle$	Average p_T of charged particles ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$)	Average p_T of "good" charged tracks ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$)
PTmax	Maximum p_T charged particle ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$) Require $Nchg \geq 1$	Maximum p_T "good" charged tracks ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$) Require $Nchg \geq 1$
$dETsum/d\eta d\phi$	Scalar E_T sum of all particles per unit η-ϕ (all p_T, $\|\eta\| < 1$)	Scalar E_T sum of all calorimeter towers per unit η-ϕ ($E_T > 0.1$ GeV, $\|\eta\| < 1$)
PTsum/ETsum	Scalar p_T sum of charged particles ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$) divided by the scalar E_T sum of all particles (all p_T, $\|\eta\| < 1$)	Scalar p_T sum of "good" charged tracks ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$) divided by the scalar E_T sum of calorimeter towers ($E_T > 0.1$ GeV, $\|\eta\| < 1$)

Also include the leading jet mass (new)!

UE and ISR/FSR in high-pt jets and Drell-Yan: recent results

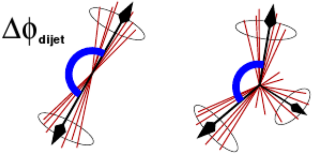
- D. Kaar, R. Field, CDF/PUB/CDF/PUBLIC/9351, Jul. 2008.



- Note: UE universality (but needs to be checked for e.g. top).

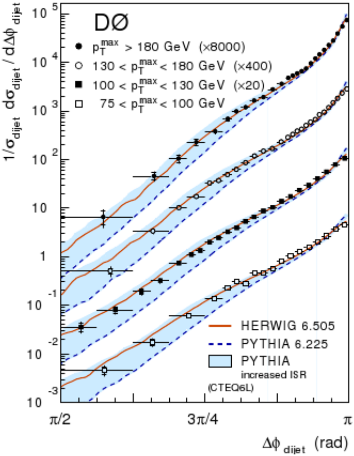
ISR/FSR tuning using Dijet Azimuthal Decorrelations

- V. M. Abazov *et al.*, [The DØ Collaboration], Phys. Rev. Lett. **94**, 2005.



PYTHIA tuning:

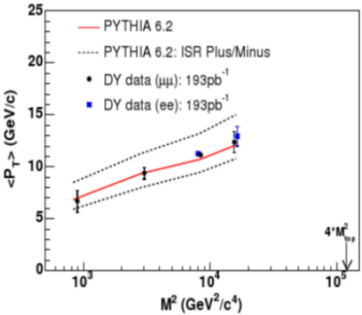
- **ISR:** PARP(64) and PARP(67)
- **FSR:** PARP(71)
- **parton kt:** PARP(91)
- **cut-off:** PARP(93)

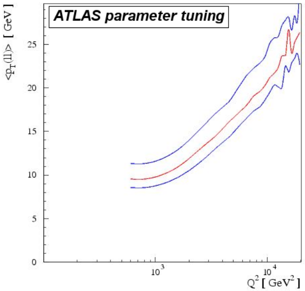


- Found: PARP(67) is the only relevant parameter,
- better description of the data obtained if: PARP(67)=1 → PARP(67)=4.

ISR/FSR in $t\bar{t}$ at TeVatron

- A. Abulencia *et al.*, [The CDF Collaboration], Phys. Rev. **D73**, 2006.
- Drell-Yan: $pt(ll) \propto \ln(Q^2)$, $t\bar{t}$ mostly produced in $q\bar{q}$ processes ($\sim 85\%$),
- define more/less active ISR systematics samples and extrapolate.

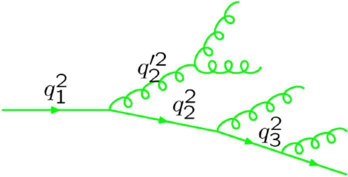




- The very nice idea cannot be used for LHC and ATLAS:
- $t\bar{t}$ mostly produced in gg processes ($\sim 90\%$),
- $pt(ll) \propto \ln(Q^2)$ not true for the new Pythia.

Pythia Parton Showers from TeVatron to ATLAS

Paron shower = ordered:

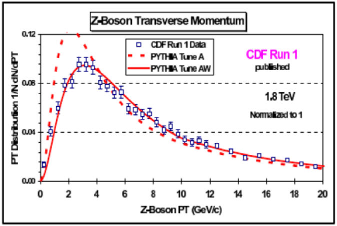


M. Seymour:
Introduction to Event Generators,
2008 MCNet-CTEQ Summer School
http://zorro.atomki.hu/~zoltan/CTEQ/cteq.html

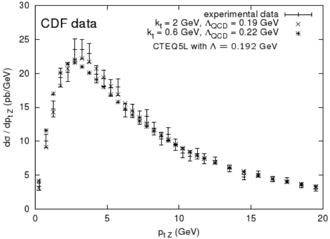
$$q_1^2 > q_2^2 > q_3^2 > \dots$$
$$q_1^2 > q_2'^2 \dots$$

Old Pythia (TeVatron): $q^2 = (-)m^2$:   New Pythia (ATLAS): $q^2 = p_t^2$:

arXiv:hep-ph/0610012



T. Sjostrand:
New pT-ordered Showers and Interleaved Multiple Interactions
http://home.thep.lu.se/~torbjorn/



ISR/FSR tuning at ATLAS ($t\bar{t}$)

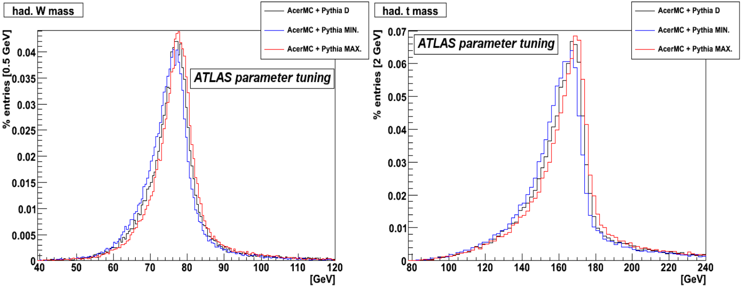
- **What we have: ISR/FSR uncertainty from MC (t mass, x-sect.,...)**
- **Determination Procedure:**
  1.) check MC generator 1 vs MC generator 2 diff. (Herwig + MCNLO and Pythia + AcerMC, also checked: Herwig + MCNLO $\sim$ Herwig + AcerMC).
  2.) vary MC generator 1 and MC generator 2 tunable ISR/FSR parameters
    - (Pythia has plenty, Herwig not so many).
  3.) The biggest difference for an observable = MC uncertainty.
- **If observable = top mass (semileptonic $t\bar{t}$, truth-matched):**
  - biggest difference: Pythia tunable parameters variation.
- **Summary of most relevant parameters + effects** (D=ATLAS default)**:**

Pythia parameter description		if ⇑, t mass:	max. mass sample	min. mass sample
ISR regularization scheme	MSTP(70)			
	MSTP(70)=0, PARP(62)	⇓	D-0.5D	D+0.5D
	MSTP(70)=1, PARP(81)	⇓		
	MSTP(70)=2, PARP(82)	⇓		
ISR Λ_{QCD}	PARP(61)	⇑	2D	0.5D
ISR evolution factor	PARP(64)	⇓		
FSR Λ_{QCD} (extern. process)	PARJ(81)	⇓	0.5D	2D

ISR/FSR at ATLAS: semileptonic $t\bar{t}$ mass

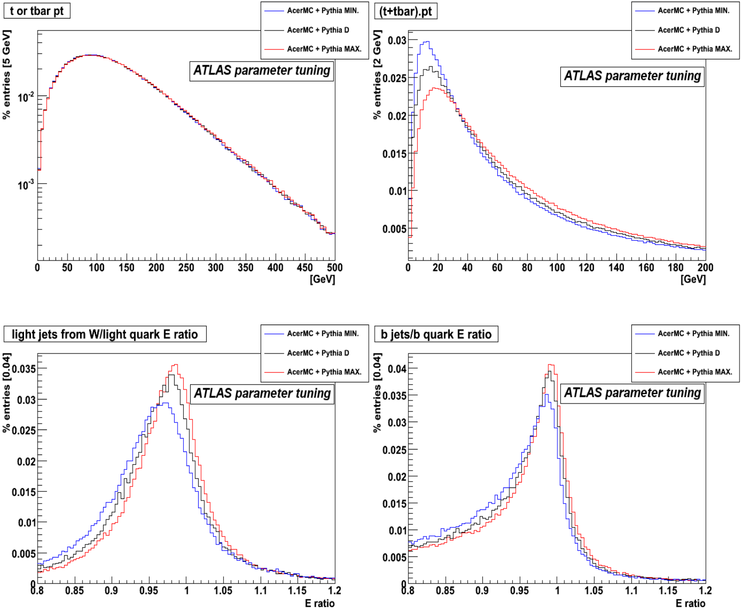
Analysis details:

- AcerMC + Pythia (new showering), $\sim$ 1M events, gen. level,
- semileptonic decay channel,
- !1 lepton (el., μ), pt $>$ 20 GeV, $|\eta|$ <2.5,
- $\geq$ 4(3) jets, pt $>$ 20(40) GeV, $|\eta|$ <2.5,
- using cone 0.4 truth jets,
- use truth-matching for t reconstruction.

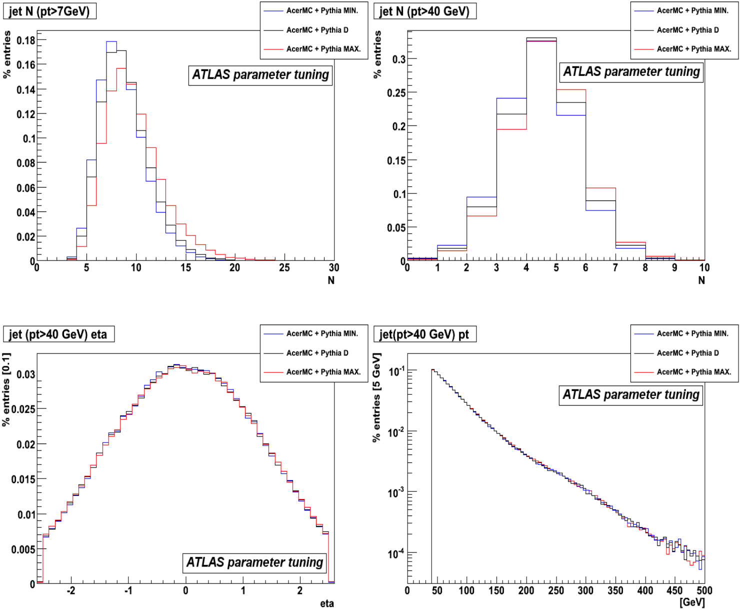


- Max. and Min. mass samples do their job - effect not small (gen. level).

ISR/FSR at ATLAS: semileptonic $t\bar{t}$ properties



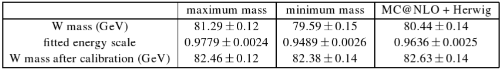
ISR/FSR at ATLAS: semileptonic $t\bar{t}$ (truth) jets



ISR/FSR at ATLAS: CSC studies 1

Expected Performance of the ATLAS Experiment,Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.

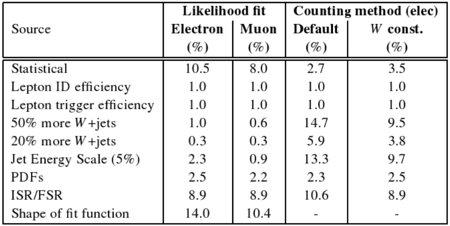
- **Min. and Max. mass samples at reco level:**



	maximum mass	minimum mass	MC@NLO + Herwig
W mass (GeV)	81.29 ± 0.12	79.59 ± 0.15	80.44 ± 0.14
fitted energy scale	0.9779 ± 0.0024	0.9489 ± 0.0026	0.9636 ± 0.0025
W mass after calibration (GeV)	82.46 ± 0.12	82.38 ± 0.14	82.63 ± 0.14

(is-situ) calibration reduces ISR/FSR effects.

- **$t\bar{t}$ x-section**



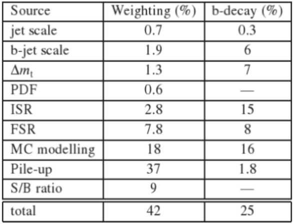
	Likelihood fit		**Counting method (elec)**	
Source	**Electron** (%)	**Muon** (%)	**Default** (%)	***W* const.** (%)
Statistical	10.5	8.0	2.7	3.5
Lepton ID efficiency	1.0	1.0	1.0	1.0
Lepton trigger efficiency	1.0	1.0	1.0	1.0
50% more W+jets	1.0	0.6	14.7	9.5
20% more W+jets	0.3	0.3	5.9	3.8
Jet Energy Scale (5%)	2.3	0.9	13.3	9.7
PDFs	2.5	2.2	2.3	2.5
ISR/FSR	8.9	8.9	10.6	8.9
Shape of fit function	14.0	10.4	-	-

ISR/FSR: x-section: $\sim$ 10% effect, also important for other t properties.

ISR/FSR at ATLAS: CSC studies Cont'd, Comments

Expected Performance of the ATLAS Experiment,Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.

- **top charge**

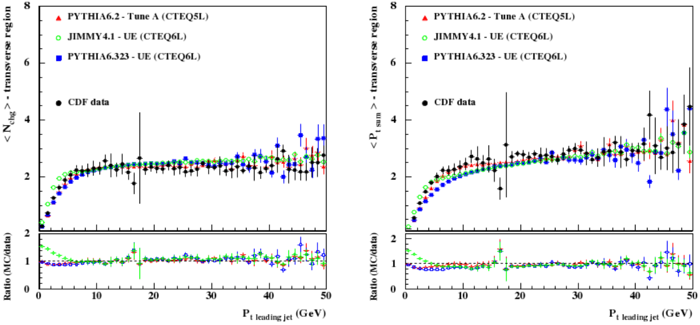


Source	Weighting (%)	b-decay (%)
jet scale	0.7	0.3
b-jet scale	1.9	6
Δm_t	1.3	7
PDF	0.6	—
ISR	2.8	15
FSR	7.8	8
MC modelling	18	16
Pile-up	37	1.8
S/B ratio	9	—
total	42	25

- **Comments:**
- Min. and Max. **mass** samples not optimized for an arbitrary $t\bar{t}$/single t study ⇒ define additional (replacement) samples (for example):
  - min./max. jet multiplicity,
  - jet energy(cone04)/jet energy(cone07).
- ISR/FSR sensitive observables: t mass peak, shape, jet N, jet E distribution.
- But: ISR+FSR+UE dependant + first data: want more robust variables.

UE tuning at ATLAS

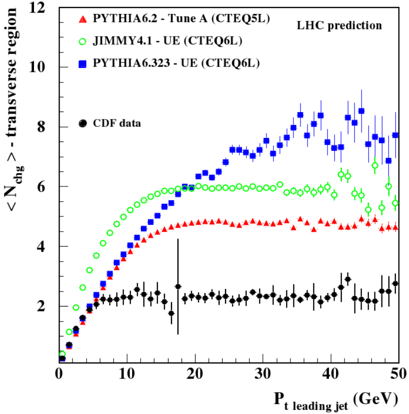
- A. Moraes, *Underlying Event Tunes for the LHC* in M. G. Albrow *et al.* [TeV4LHC QCD Working Group], *Tevatron-for-LHC report of the QCD working group*, 2006.
- since Pythia 6.3 new UE model available ⇒ modify CDF tunes accordingly
- other ATLAS vs CDF diffs (PDF...)



- Jimmy 4.1+Herwig 6.507, Pythia 6.2 and Pythia 6.323 can be **tuned** to describe the CDF data.
- at ATLAS Pythia tunes have recently been updated (Pythia 6.416).

UE at the LHC

- A. Moraes, *Underlying Event Tunes for the LHC* in M. G. Albrow *et al.* [TeV4LHC QCD Working Group], *Tevatron-for-LHC report of the QCD working group*, 2006.

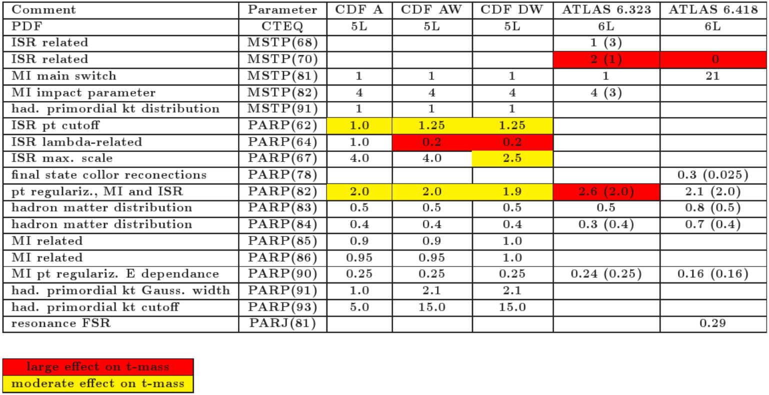


Parameter	Default	UE	Comment
MSTP(51) MSTP(52)	7 (5L)	10042 (6L) 2	CTEQ PDF
MSTP(68)	3	1	max. virtuality scale and ME matching for ISR
MSTP(70)	1	2	regul. scheme for ISR
MSTP(82)	3	4	complex scenario and double Gaussian matter distribution
PARP(82)	2.0	2.6	$p_{t_{min}}$ parameter
PARP(84)	0.4	0.3	hadronic core radius (only for MSTP(82)=4)
PARP(89)	1.8	1.8	energy scale (TeV) used to calculate $p_{t_{min}}$
PARP(90)	0.25	0.24	power of the $p_{t_{min}}$ energy dependence

- Note: MC describes UE at TeVatron $\not\Rightarrow$ MC describes UE at LHC.

ISR/FSR and UE tuning interplay

- UE tuning Pythia parameters, most important for ISR/FSR
- compiled from: R. Field., *Run 2 MC Tunes*, latest ATLAS production jo, May MC meeting talk by A. Moraes and Pythia Manual 6.4.



Comment	Parameter	CDF A	CDF AW	CDF DW	ATLAS 6.323	ATLAS 6.418
PDF	CTEQ	5L	5L	5L	6L	6L
ISR related	MSTP(68)				1 (3)	
ISR related	MSTP(70)				2 (1)	0
MI main switch	MSTP(81)	1	1	1	1	21
MI impact parameter	MSTP(82)	4	4	4	4 (3)	
had. primordial kt distribution	MSTP(91)	1	1	1		
ISR pt cutoff	PARP(62)	1.0	1.25	1.25		
ISR lambda-related	PARP(64)	1.0	0.2	0.2		
ISR max. scale	PARP(67)	4.0	4.0	2.5		
final state collor reconections	PARP(78)					0.3 (0.025)
pt regulariz., MI and ISR	PARP(82)	2.0	2.0	1.9	2.6 (2.0)	2.1 (2.0)
hadron matter distribution	PARP(83)	0.5	0.5	0.5	0.5	0.8 (0.5)
hadron matter distribution	PARP(84)	0.4	0.4	0.4	0.3 (0.4)	0.7 (0.4)
MI related	PARP(85)	0.9	0.9	1.0		
MI related	PARP(86)	0.95	0.95	1.0		
MI pt regulariz. E dependance	PARP(90)	0.25	0.25	0.25	0.24 (0.25)	0.16 (0.16)
had. primordial kt Gauss. width	PARP(91)	1.0	2.1	2.1		
had. primordial kt cutoff	PARP(93)	5.0	15.0	15.0		
resonance FSR	PARJ(81)					0.29

🟥 large effect on t-mass

🟨 moderate effect on t-mass

Summary - 1

Covered topics:

- **UE and ISR/FSR tuning at TeVatron:**
  - many results useful for ATLAS, especially work done by R. Field *et. al*: dijets and Drell-Yan; used for ATLAS UE tuning by A. Moraes.
  - some results/methods can not be (directly) used for ATLAS;
  - reasons: MC (Pythia version) or physics($t\bar{t}$ gg production) diferences.
- **ISR/FSR tuning at ATLAS**
  - **top physics:**
    - studies of MC predictions of ISR/FSR systematics effects: top mass, x-section and more.
    - systematics effects evaluation: different MCs, Pythia systematics samples,
    - ongoing work/recent activities:
      - strategy of evaluation with the (early) data,
      - UE interplay.
  - **ATLAS SM group has been active in ISR/FSR systematics evaluation.**
  - **ATLAS top group: single top program for ISR/FSR systematics.**

Summary - 2

Covered topics Cont'd:

- **UE tuning at ATLAS:**
  - work done by A. Moraes, linked to work done at TeVatron,
  - *new* Pythia is tuned to reproduce TeVatron data/tunes.
- **ISR/FSR and UE tuning interplay:**
  - TeVatron:
  - ISR/FSR and UE tuning parameters overlap - example: dijets and Drell-Yan: UE tuning successfully adjusted to high-pt physics results.
  - ATLAS:
  - UE and high-pt physics ISR/FSR tuning coupled, e.g. t and $t\bar{t}$ physics,
  - some common Pythia parameters have been identified,
  - (how) can we extract UE info from top events (preferably for early data)?
  - Currently active research, more results to come in the next weeks/months.

Backup slides

Minimum Bias at ATLAS

Expected Performance of the ATLAS Experiment,Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.

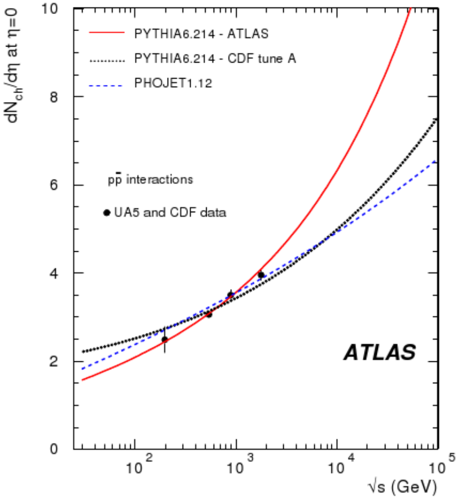
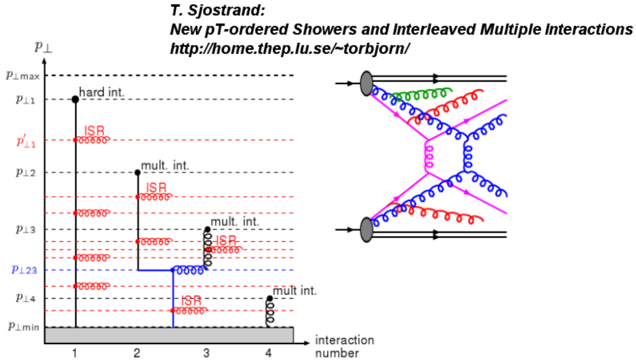


Figure: Extrapolation uncertainty of the central charged particle density for non-single diffractive inelastic $p\bar{p}$ collisions.

Multiple Interactions, Pythia > 6.3



T. Sjostrand:
New pT-ordered Showers and Interleaved Multiple Interactions
http://home.thep.lu.se/~torbjorn/

"Evolution" equation, only Multiple Interactions:

$$\frac{\mathrm{d}\mathcal{P}}{\mathrm{d}p_\perp} = \frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p_\perp} \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p'_\perp}\mathrm{d}p'_\perp\right)$$

Evolution equation, only Initial State Radiation:

$$\frac{\mathrm{d}\mathcal{P}}{\mathrm{d}p_\perp} = \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p_\perp} \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p'_\perp}\mathrm{d}p'_\perp\right)$$

Evolution equation, MI + ISR, with competition for PDF and phase space:

$$\frac{\mathrm{d}\mathcal{P}}{\mathrm{d}p_\perp} = \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p_\perp}\right) \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p'_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p'_\perp}\right) \mathrm{d}p'_\perp\right)$$