




# CDF/D0 PYTHIA Tutorial

Fermilab, December 7, 2004

## Physics News in PYTHIA 6.3

Peter Skands, Fermilab

### Part I:

-  New underlying event framework
-  New  $p_{\perp}$ -ordered parton showers
-  Overview of relevant parameters

### Part II:

-  The SUSY Les Houches Accord

# New UE Framework: WHY BOTHER?

- 📍 QCD point of view: hadron collisions are highly complex, while present descriptions are not.  
Should be possible to gain further physics insight.
- 📍 LHC point of view: any reliable extrapolation will require such insight.  
Simple parametrizations are not sufficient.
- 📍 New Physics and precision point of view: random and systematic fluctuations in the underlying activity can impact measurements:  
More reliable understanding is needed.
- 📍 Obvious point of view: Lots of fresh data from Tevatron:  
Great topic for phenomenology right now

# New Parton Shower: WHY BOTHER?

- Some common approaches to showers:  
Parton Showers (e.g. HERWIG, PYTHIA)  
and Dipole Showers (e.g. ARIADNE).  
Each has pros and cons.
- Idea was to combine the virtues of each of these while  
avoiding the vices.

# News in PYTHIA 6.3

PYTHIA 6.3 includes new ISR and FSR parton showers, based on a  $p_{\perp}$ -ordered sequence of  $1 \rightarrow 2$  parton splittings.

It also includes a new model for multiple parton–parton interactions (for underlying events and min-bias).

Further, the description of parton showers and the underlying event has been unified in a common  $p_{\perp}$ -ordered ‘interleaved evolution’ of the event as a whole.

(The PYTHIA 6.2 shower and underlying-event framework remains in PYEVNT, while the new options are obtained by using PYEVNW instead.)

# THE NEW FRAMEWORK



Interactions



+ showers



+ remnants

# New Multiple Interactions: Some Details



## Correlated PDF's:

- Momentum and Energy in parent hadron conserved.
- Sum rules for valence quarks respected.  
(Can't kick the same quark out twice!)
- Sea quarks knocked out → 'companion quarks'.



## Hadronization:





- Possible to have composite objects in the beam remnants, e.g. diquarks.
- Addressing 'baryonic' colour topologies → 'string junctions' in the colour confinement field.








## Colour Correlations:

- The big question! Seems Nature likes a *very* high degree of correlation (cf. 'Tune A' of old model!).
- Several possibilities investigated, so far without success.

# New $p_{\perp}$ -ordered parton showers

-   $p_{\perp}$  ordering  $\Rightarrow$  coherence inherent, while kinematics still simple and Lorentz invariant  
(cf. quite messy kinematics and LI in HERWIG, coherence not inherent and slightly messy kinematics in “old” PYTHIA).
-   $p_{\perp}$  ordering  $\Rightarrow$  Merging with Matrix Elements also simple  
(cf. complicated in HERWIG — “dead zone”)
-  It's still a parton shower, so  $g \rightarrow q\bar{q}$  not principally different from other branchings and ISR no problem  
(cf. ‘artificial’ in ARIADNE)
-  showers can be stopped and restarted at any  $p_{\perp}$  scale  
( $\Rightarrow$  well suited for ME/PS matching)

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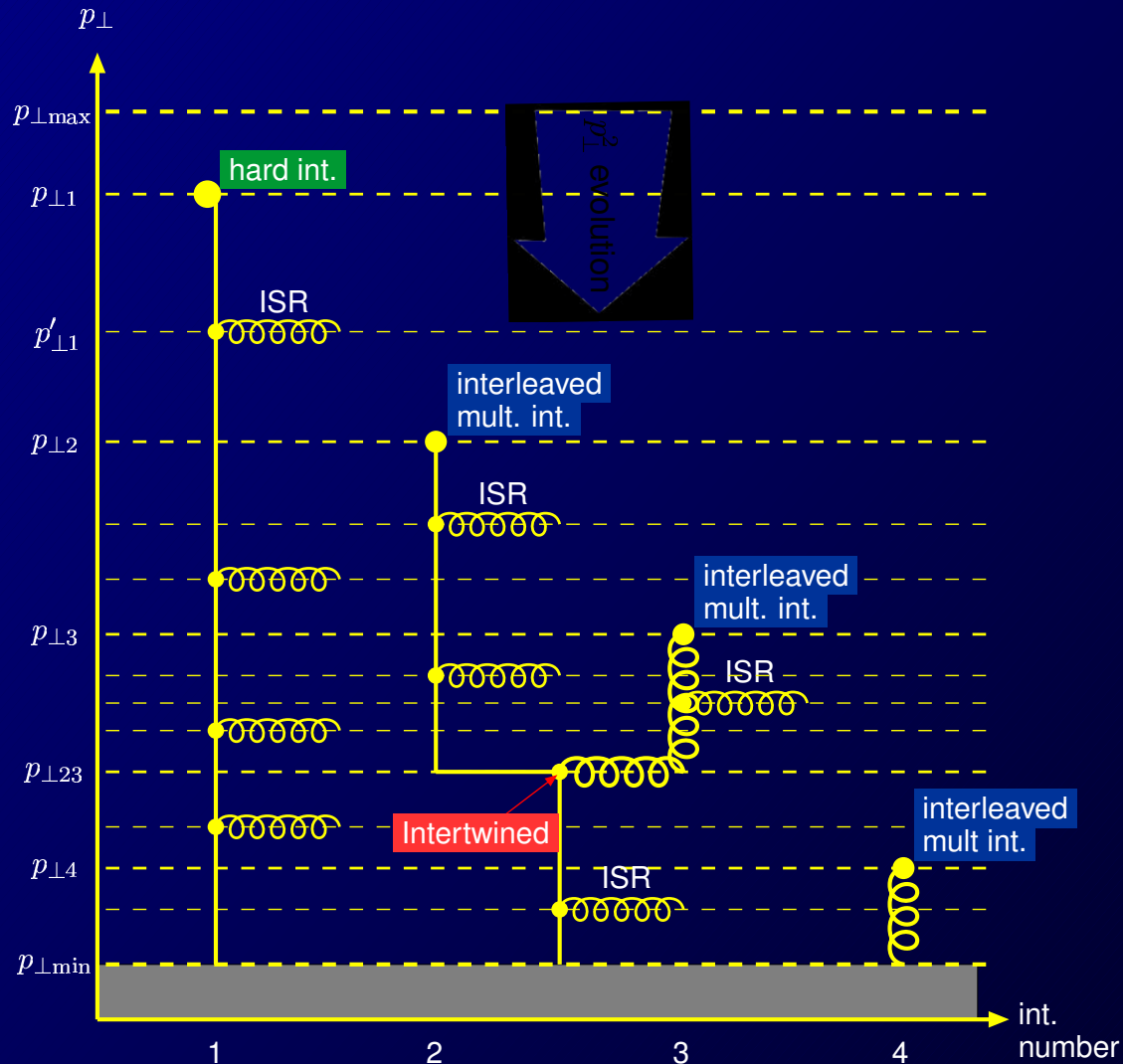
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-  showers can be stopped and restarted at any  $p_{\perp}$  scale  
( $\Rightarrow$  well suited for ME/PS matching)
-   $p_{\perp}$  evolutions of showers and multiple interactions can be combined  $\rightarrow$  *common evolution of ISR, FSR, and MI!*

**$\equiv$  ‘Interleaved Multiple Interactions’**



# Interleaved Evolution, what is that?

The new picture: start at the most inclusive level,  $2 \rightarrow 2$ .  
Add exclusivity progressively by evolving *everything* downwards.



# The New Framework

## The building blocks:

- 🎱  $p_{\perp}$ -ordered multiple interactions. ✓
- 🎱  $p_{\perp}$ -ordered initial-state parton showers. ✓
- 🎱  $p_{\perp}$ -ordered final-state parton showers. ✓
- 🎱  $p_{\perp}$  used as scale in  $\alpha_s$  and in PDF's. ✓
- 🎱 (Model for) correlated multi-parton densities. ✓
- 🎱 Beam remnant hadronization model. ✓
- 🎱 Model for initial state colour correlations. (✓)
- 🎱 Other phenomena? (e.g. colour reconnections (✓), ...)
- 🎱 Realistic tunes to data (so far only for FSR...)

# Model Tests: FSR

## FSR algorithm.

- Tested on ALEPH data (G. Rudolph).

Distribution of	nb.of interv.	$\sum \chi^2$ of model	
		PY6.3 $p_{\perp}$ -ord.	PY6.1 mass-ord.
Sphericity	23	25	16
Aplanarity	16	23	168
1-Thrust	21	60	8
Thrust <sub>minor</sub>	18	26	139
jet res. $y_3(D)$	20	10	22
$x = 2p/E_{cm}$	46	207	151
$p_{\perp in}$	25	99	170
$p_{\perp out} < 0.7 \text{ GeV}$	7	29	24
$p_{\perp out}$	(19)	(590)	(1560)
$x(B)$	19	20	68
sum	$N_{dof} =$ 190	497	765

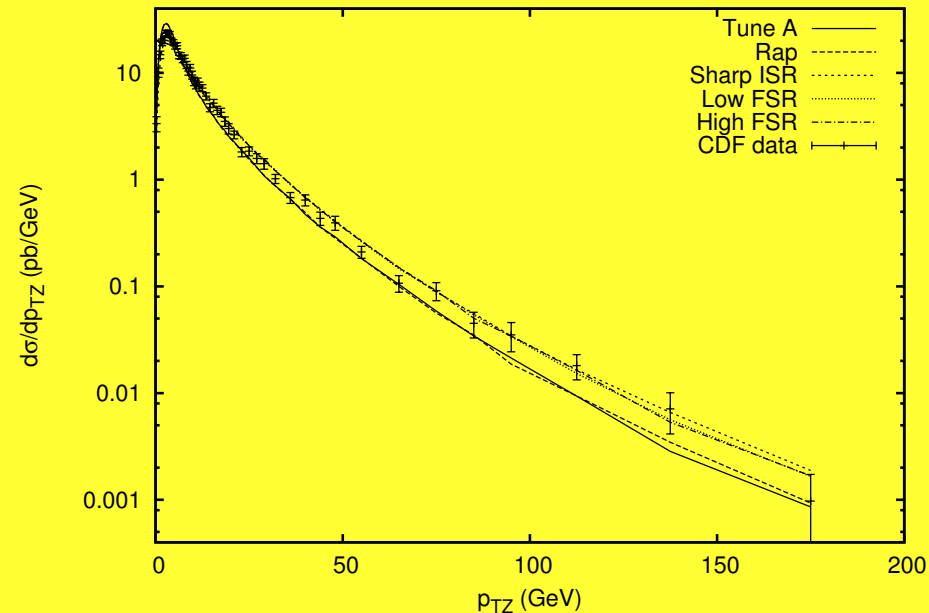
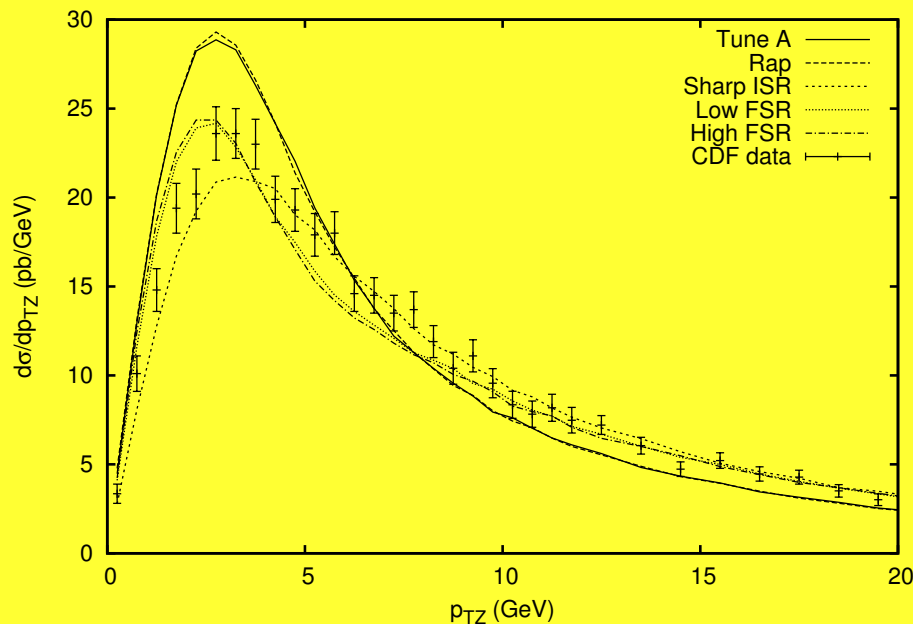
- (Also, generator is not perfect. Adding 1% to errors  $\Rightarrow \sum \chi^2 = 234$ . i.e. generator is 'correct' to  $\sim 1\%$ )

# Model Tests: ISR



## ISR algorithm.

- Less easy to test. We looked at  $p_{\perp}$  of  $Z^0$  at Tevatron.
- Compared “Tune A” with an ‘intermediate scenario’ (“Rap”), and three rough tunes of the new framework.
- Description is improved (but there is still a need for a large primordial  $k_{\perp}$ ).

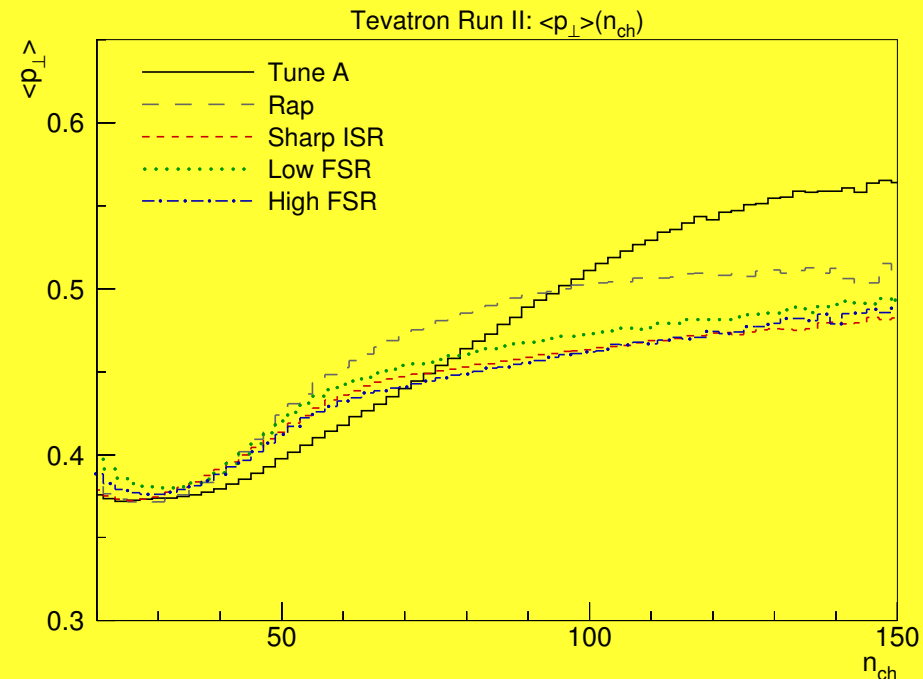
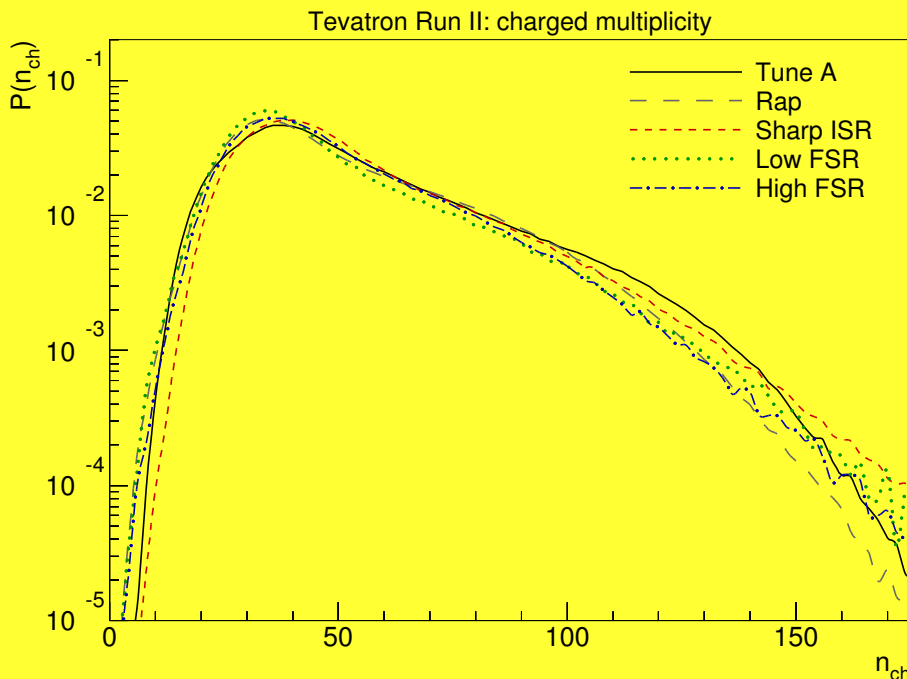


# Model Tests



## Whole framework.

- The rough tunes were made to 'Tune A' at the Tevatron, using charged multiplicity distribution and  $\langle p_{\perp} \rangle(n_{ch})$ , the latter being highly sensitive to the colour correlations.
- Similar overall results are achieved (not shown here), **but**  $\langle p_{\perp} \rangle(n_{ch})$  **still difficult**.
- Anyway, these were only *rough* tunes...



# Outlook

- 🟡 New complete framework for hadron collisions has been developed. Includes  $p_{\perp}$ -ordered *interleaved* parton showers and multiple interactions, correlated remnant parton distributions, impact parameter-dependence, extended (junction) string fragmentation model, etc.
- 🟡 It's all in PYTHIA 6.316 (24 Nov 2004).
- 🟡 Good overall performance, though still only primitive studies/tunes carried out, except for FSR.
- 🟡 Colour correlations still a headache. Still unclear what role *intertwining* may play.

# Outlook



Butch Cassidy and the Sundance Kid. Copyright: Twentieth Century Fox Films Inc.

Conclusion: our picture of hadron collisions is becoming more complex...

# PYTHIA 6.3

## OVERVIEW OF RELEVANT PARAMETERS










# PYTHIA 6.3 Parameter Overview: Switches

- MSTP (61) Master switch for initial–state radiation. Default is on.
- MSTP (71) Master switch for final–state radiation. Default is on.
- MSTP (81) Master switch for multiple interactions and beam remnant framework.
- MSTP (70) Selects regularization scheme for ISR when  $p_{\perp} \rightarrow 0$ . Default is sharp cutoff at the regularization scale used for MI.
- MSTP (72) Selects maximum scale for radiation off FSR dipoles stretched between ISR partons. Default is  $p_{\perp}$  scale of radiating parton.
- MSTP (82) Selects which functional form to assume for the impact-parameter dependence of the matter overlap between two beam particles.
- MSTP (84) Selects whether initial–state radiation is turned on or off for subsequent interactions (i.e. interactions after the main one). Default is on.
- MSTP (85) Selects whether final–state radiation is turned on or off for subsequent interactions (i.e. interactions after the main one). Default is on.
- MSTP (89) Controls how initial–state parton shower initiators are colour–connected to each other. Default is to assume a rapidity ordering.
- MSTP (95) Selects whether colour reconnections are allowed or not. Default is on.

# PYTHIA 6.3 Parameter Overview: Parameters

- PARP (82) Regularization scale,  $p_{\perp 0}$ , for multiple interactions, at reference energy PARP (89). Default is 2 GeV.
- PARP (89) Reference energy for energy rescaling of  $p_{\perp 0}$  cutoff, i.e. the energy scale at which  $p_{\perp 0}$  is equal to PARP (82). Default is 1800 GeV.
- PARP (90) Power of energy rescaling used to determine the value of  $p_{\perp 0}$  at scales different from the reference scale PARP (89).
- PARP (83 : 84) Shape parameters, controlling the assumed matter distribution or overlap profile, as applicable (i.e. depending on MSTP (82)).
- PARP (78) Controls the amount of colour reconnection in the final state.
- PARP (79) Enhancement factor for  $x$  values of composite systems (e.g. di-quarks) in the beam remnant.
- PARP (80) Suppression factor for initial–state colour connections that would break up the beam remnant.

# More information on PYTHIA 6.3

-  The PYTHIA 6.3 manual: [hep-ph/0308153](http://hep-ph/0308153)
-  “Notes on using PYTHIA 6.3”: on my homepage:  
<http://home.fnal.gov/~skands/>
-  Physics descriptions of the new ISR/FSR/MI framework:
  -  TS+PS, “Transverse-Momentum-Ordered Showers and Interleaved Multiple Interactions”, [hep-ph/0408302](http://hep-ph/0408302).
  -  TS, “New Showers with transverse-momentum-ordering”, [hep-ph/0401061](http://hep-ph/0401061).
  -  TS+PS, “Multiple Interactions and the Structure of Beam Remnants”, JHEP 0403 (2004) 053.
-  + Slides like these.

(See “Slides/Talks” on my homepage for a complete list)