ISR/FSR Uncertainties for Tevatron Studies

Theory versus Practice

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Outline

- What *IS* the parton shower
- How good is it?
- Uncertainties

Radioactive Decay Problem

$f(t) \equiv$ prob. 'something will happen' (a nucleus decay) at time t

something happens at t **only** *if it did not happen at $t' < t$*

Equation for nothing $\mathcal{N}(t)$ to happen *up to time t* is ($\mathcal{N}(0) = 1$):

$$-\frac{\mathrm{d}\mathcal{N}}{\mathrm{d}t} = f(t)\mathcal{N}(t) = \mathcal{P}(t)$$

$$\mathcal{N}(t) = \exp\left\{-\int_0^t f(t')\,\mathrm{d}t'\right\}$$

$$\mathcal{P}(t) = f(t)\exp\left\{-\int_0^t f(t')\,\mathrm{d}t'\right\}$$

- Naive answer modified by exponential suppression
- $\mathcal{N}(t) \Rightarrow$ Sudakov form factor

Toy Parton Shower

Consider a system that can emit a number of quanta (photons) with energy $z_0 < x < x_{\max}(x)$, $x_{\max}(1) = 1$

$$0 \leq Q(z) \leq 1, \quad \lim_{z \to 0} Q(z) = 1,$$

IF the prob. of one emission is $a\frac{Q(x)}{x}dx$
THEN the *Sudakov form factor* is

$$\Delta(x_2, x_1) = \exp\left[-a\int_{x_1}^{x_2} dz \frac{Q(z)}{z}\right],$$

Limit	Sudakov	# of Quanta
a $\ll 1$	$\Delta \sim 1 - a\frac{Q(x)}{x}dx$	few
a $\gg 1$	$\Delta \sim 0$	many

Constructing an "Event" Generator

Event $\equiv$ original system + emissions down to scale x_0

Take $Q(x) = 1$

To solve for the shower evolution:

1. Pick $r = \exp\left(-a \int_x^{x_2} dx/x \right) = (x/x_2)^a$
2. Solve $x = x_2 r^{(1/a)}$
3. Calculate remaining energy x_2
4. Continue until $x < x_0$

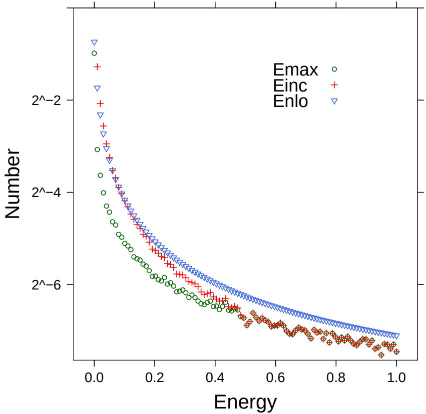
This generates an energy-ordered shower with multiple photon emissions

Example Event Record

Event listing (summary)

I	particle/jet	KS	KF	orig	E
1	e-	1	11	0	1.000
2	nu_e	1	12	0	0.000
3	(e-)	11	11	0	0.296
4	gamma	1	22	0	0.704
5	(e-)	11	11	3	0.285
6	gamma	1	22	3	0.011
7	(e-)	11	11	5	0.283
8	gamma	1	22	5	0.002
9	e-	1	11	7	0.282
10	gamma	1	22	7	0.001
		sum:	-1.00		1.000

Spectra



Real (NLO) spectrum =

$$\frac{d\sigma}{dx} = a\frac{R(x)}{x}$$

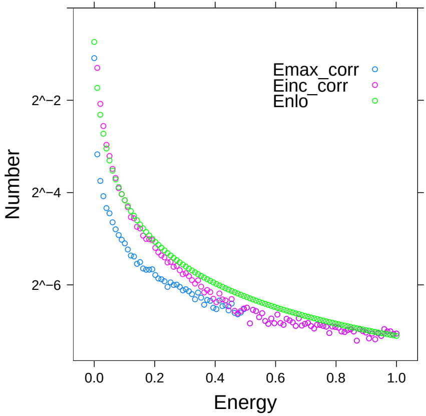
$R(x) \to Q(x)$ as $x \to 0$

Here: $R(x) = (1 + x/10)^2$

Enlo = Einc

Parton shower underestimates high x

Matrix Element Correction to Parton Shower



Assume the parton shower samples all of phase space and gives the hardest emission first

For the 1st emission, weight according to $\frac{R(x)}{Q(x)}$

Here: $(1 + x/10)^2 < 2$

Parton shower gets correct limit for large x and includes multiple photon emission

How Good Is The Parton Shower?

Extensive LEP Experience and Tuning

- In general, a fair number of parameters are fit to data
- Most of these are related to the phenomenological model of hadronization
- For a given choice of Parton Shower, most sensitive parameters deal with the shower-hadronization transition and scale used in α_s

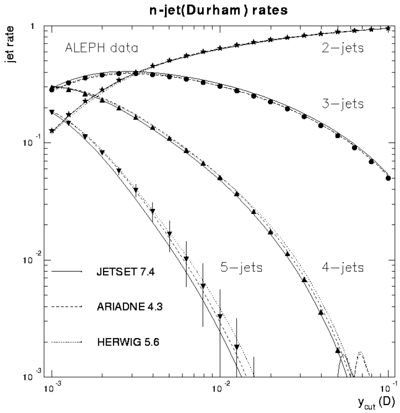
Range of $Q_0, \Lambda_{\rm LLA}$ gives approximate picture of our understanding of FSR in resonance production (numbers in GeV)

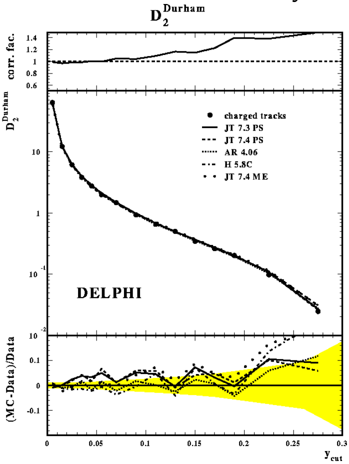
Parameter	Name	Default	Aleph	Delphi	L3	Opal
Shower $\Lambda_{\rm LLA}$	`PARJ(81)`	0.290	0.320	0.297	0.306	0.250
Shower Cutoff Q_0	`PARJ(82)`	1.00	1.22	1.56	1.0	1.9

Good description of complex topologies in e^+e^-

$R_2(y)$

$$D_2 = \frac{R_2(y) - R_2(\Delta y)}{\Delta y}$$





In general, `Ariadne` > `Pythia` > `Herwig`

Quality of fit

Pythia 6.3

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

- $\chi^2/\text{dof} > 1$
- "theory" T should have a systematic error qT
- $\chi^2 = \dfrac{(O - T)^2}{(\sigma_O^2 + (qT)^2)}$

q	0%	0.5%	1%
$\sum \chi^2$	523	364	234

for $q = .01$, $\chi^2/\text{dof} = 234/196 \sim 1 \Rightarrow$ generator good to 1%

except $p_{\perp\text{out}} > 0.7$ GeV (10%–20% error)

$p_{\perp\text{out}} \equiv$ one-particle inclusive $p_\perp$ spectrum out of the event plane

- problem for all generators

ISR Sudakov

DGLAP

$$\mathrm{d}\mathcal{P}_b = \frac{\mathrm{d}f_b(x,t)}{f_b(x,t)} = |\mathrm{d}t| \sum_{a,c} \int \frac{\mathrm{d}x'}{x'} \frac{f_a(x',t)}{f_b(x,t)} \frac{\alpha_{abc}}{2\pi} P_{a\to bc}\left(\frac{x}{x'}\right)$$

Summing up the cumulative effect of many small changes $\mathrm{d}t$, the probability for no radiation exponentiates:

$$\begin{aligned} S_b(x, t_{\max}, t) &= \exp\left\{ -\int_t^{t_{\max}} \mathrm{d}t' \sum_{a,c} \int \frac{\mathrm{d}x'}{x'} \frac{f_a(x',t')}{f_b(x,t')} \frac{\alpha_{abc}(t')}{2\pi} P_{a\to bc}\left(\frac{x}{x'}\right) \right\} \\ &= \exp\left\{ -\int_t^{t_{\max}} \mathrm{d}t' \sum_{a,c} \int \mathrm{d}z \, \frac{\alpha_{abc}(t')}{2\pi} P_{a\to bc}(z) \frac{x' f_a(x',t')}{x f_b(x,t')} \right\} \end{aligned}$$

Probability that a parton b remains at x from $t_{\max}$ to a $t < t_{\max}$.

Uncertainties

1. Shower physics included, but only approximately
   - LL $+ \alpha_s(p_T) + E - p \sim$ NLL
2. Shower physics not included
   - genuine NLL effects: $1 \rightarrow 3$ splittings
   - $2 \rightarrow 4$ "dipole" splittings (soft)
3. Beyond Shower Physics
   - Matrix Elements + Parton Shower

Plan

1. Estimate ME effects doing “matching” (hard emissions) or faking it
2. Vary logs with Q_{max} and $c \times p_T$ variations
   - changes range of Sudakov integration $\rightarrow$ prob. of no radiation
3. Use Tevatron data:
   - High Mass M_{bb}/M_{jj}
   - H_T distribution?
   - many fits, several parameters