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Uncertainties in bH Production from ISR/FSR

A typical new physics signature (studied by experimentalists) is simulated as LO $(2 \to 2)\ d\sigma \oplus$ (N)LL parton showers $\oplus$ non-perturbative physics models

Q: What is the theory uncertainty?

A: (commonly):

- $\delta d\sigma \sim$ vary μ_R, μ_F from a NLO prediction + loop over 41 CTEQ6M PDF's
- δ(PS) $\sim$ average over no ISR/FSR
- δ(NP) $\sim$ 0
- δ(Total) $= \sqrt{\sum_i \delta_i^2}$

Is this conservative/liberal/enough/reasonable?

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Deconstructing the Prediction

$\boxed{d\sigma}$

- Hard physics characterized by a hard scale
- Proper description of *inclusive* quantities, such as total rate
- Not a good description of very exclusive quantities or kinematics much lower than hard scale

$\boxed{\text{PS}}$

- DGLAP evolution of PDFs and fragmentation functions as dictated by the factorization theorem
- Valid to scales where perturbation theory is still valid ~ 1 GeV
- Resolves structure of inclusive cross section

Deconstructing the Prediction

NP

- Models and parameterizations of physics below 1 GeV
- Important to connect to what experimentalists see

  i.e., predicts kinematics of B mesons
- Begins where PS leaves off – interconnected[a]

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[a] In principle, a change in PS cutoff requires a retuning of NP physics. Don't know exactly how important this is in practice – see next slides.

Uncertainties

$\boxed{d\sigma}$

- All you have to play with is scales and PDFs

$\boxed{\text{PS}}$

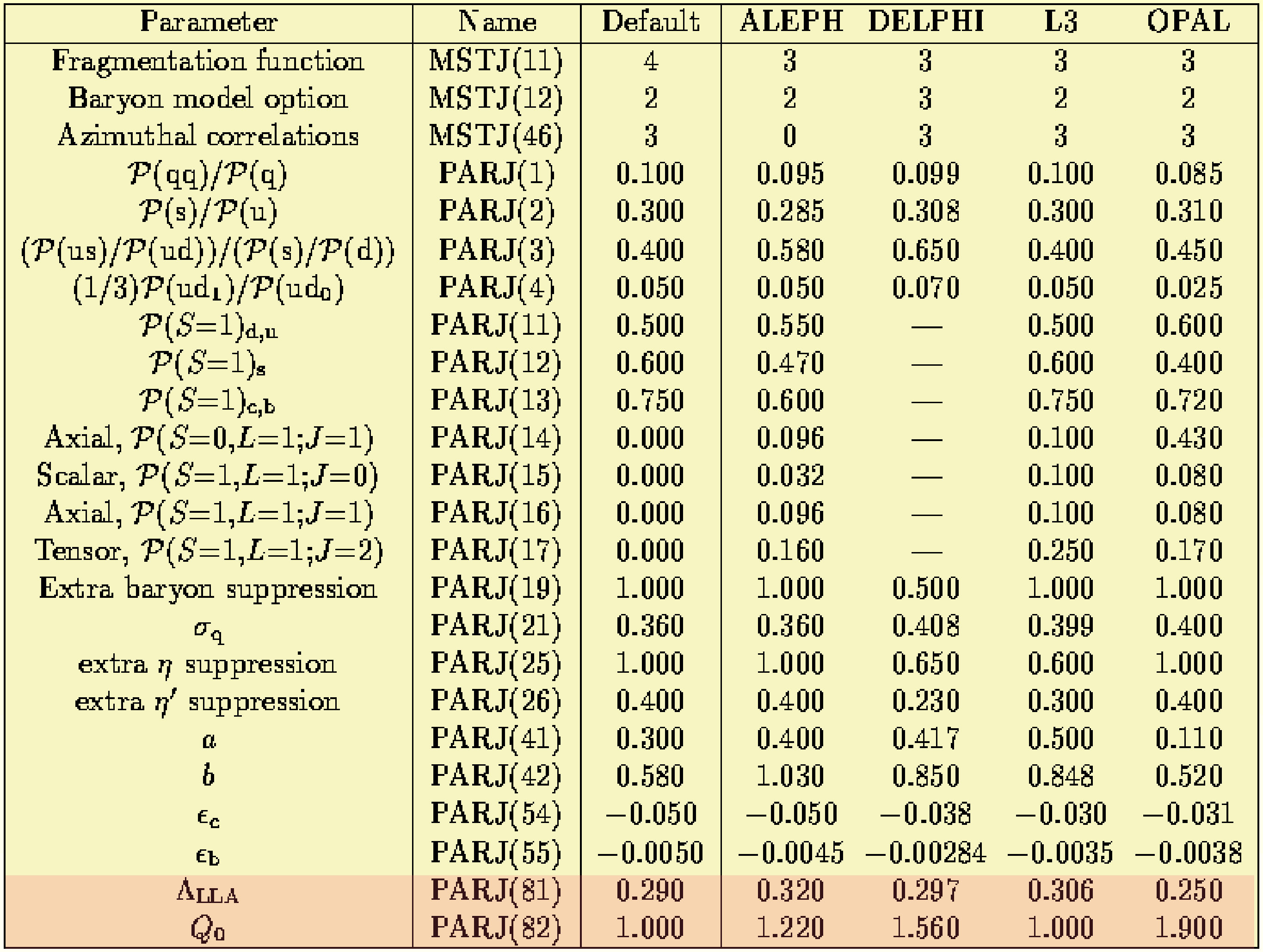
- Turning off radiation is a bad idea
- Assumes that the NP physics is tuned to a high scale, and works univerally when applied to a high scale
- Rather, want to vary PS within its range of validity, i.e. play with resummed logarithms

$\boxed{\text{NP}}$

- Not independent of the rest (look at RF's UE tunes)
- It is hard work to do this right – but we must evolve in this direction
- For now, assume models are robust

FSR

Final state radiation well-tested at LEP



Parameter	Name	Default	ALEPH	DELPHI	L3	OPAL
Fragmentation function	MSTJ(11)	4	3	3	3	3
Baryon model option	MSTJ(12)	2	2	3	2	2
Azimuthal correlations	MSTJ(46)	3	0	3	3	3
$\mathcal{P}(\mathrm{qq})/\mathcal{P}(\mathrm{q})$	PARJ(1)	0.100	0.095	0.099	0.100	0.085
$\mathcal{P}(\mathrm{s})/\mathcal{P}(\mathrm{u})$	PARJ(2)	0.300	0.285	0.308	0.300	0.310
$(\mathcal{P}(\mathrm{us})/\mathcal{P}(\mathrm{ud}))/(\mathcal{P}(\mathrm{s})/\mathcal{P}(\mathrm{d}))$	PARJ(3)	0.400	0.580	0.650	0.400	0.450
$(1/3)\mathcal{P}(\mathrm{ud}_1)/\mathcal{P}(\mathrm{ud}_0)$	PARJ(4)	0.050	0.050	0.070	0.050	0.025
$\mathcal{P}(S{=}1)_{\mathrm{d,u}}$	PARJ(11)	0.500	0.550	—	0.500	0.600
$\mathcal{P}(S{=}1)_{\mathrm{s}}$	PARJ(12)	0.600	0.470	—	0.600	0.400
$\mathcal{P}(S{=}1)_{\mathrm{c,b}}$	PARJ(13)	0.750	0.600	—	0.750	0.720
Axial, $\mathcal{P}(S{=}0,L{=}1;J{=}1)$	PARJ(14)	0.000	0.096	—	0.100	0.430
Scalar, $\mathcal{P}(S{=}1,L{=}1;J{=}0)$	PARJ(15)	0.000	0.032	—	0.100	0.080
Axial, $\mathcal{P}(S{=}1,L{=}1;J{=}1)$	PARJ(16)	0.000	0.096	—	0.100	0.080
Tensor, $\mathcal{P}(S{=}1,L{=}1;J{=}2)$	PARJ(17)	0.000	0.160	—	0.250	0.170
Extra baryon suppression	PARJ(19)	1.000	1.000	0.500	1.000	1.000
σ_{q}	PARJ(21)	0.360	0.360	0.408	0.399	0.400
extra η suppression	PARJ(25)	1.000	1.000	0.650	0.600	1.000
extra η' suppression	PARJ(26)	0.400	0.400	0.230	0.300	0.400
a	PARJ(41)	0.300	0.400	0.417	0.500	0.110
b	PARJ(42)	0.580	1.030	0.850	0.848	0.520
ϵ_{c}	PARJ(54)	−0.050	−0.050	−0.038	−0.030	−0.031
ϵ_{b}	PARJ(55)	−0.0050	−0.0045	−0.00284	−0.0035	−0.0038
Λ_{LLA}	PARJ(81)	0.290	0.320	0.297	0.306	0.250
Q_0	PARJ(82)	1.000	1.220	1.560	1.000	1.900

Range of $Q_{\mathrm{min}}, \Lambda_{\mathrm{LLA}}$ gives approximate picture of our understanding of FSR in resonance production

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Estimating FSR Uncertainties

Q_0 (the shower cutoff) is intimately related to the hadronization model – leave alone

$\Lambda_{\rm LLA}$ is more sensitive to the dynamics of the PS

Branching Probability

$$\mathrm{d}\mathcal{P}_a = \sum_{b,c} \frac{\alpha_s(c\ p_T^2)}{2\pi} P_{a\to bc}(z)\,\mathrm{d}t\,\mathrm{d}z$$

$$\mathcal{I}_{a\to bc}(t) = \int_{z_-(t)}^{z_+(t)} \mathrm{d}z\, \frac{\alpha_s(c\ p_T^2)}{2\pi} P_{a\to bc}(z)$$

Resummation of large logarithms $\Rightarrow \alpha_s(c\ p_T^2)$

$c \sim 1$

LL: $\alpha_s(p_T^2/\Lambda^2) \propto 1/\ln(p_T^2/\Lambda^2)$

PYTHIA: `PARJ(81)=.145-.580` $\Rightarrow c = 4 - \frac{1}{4}$

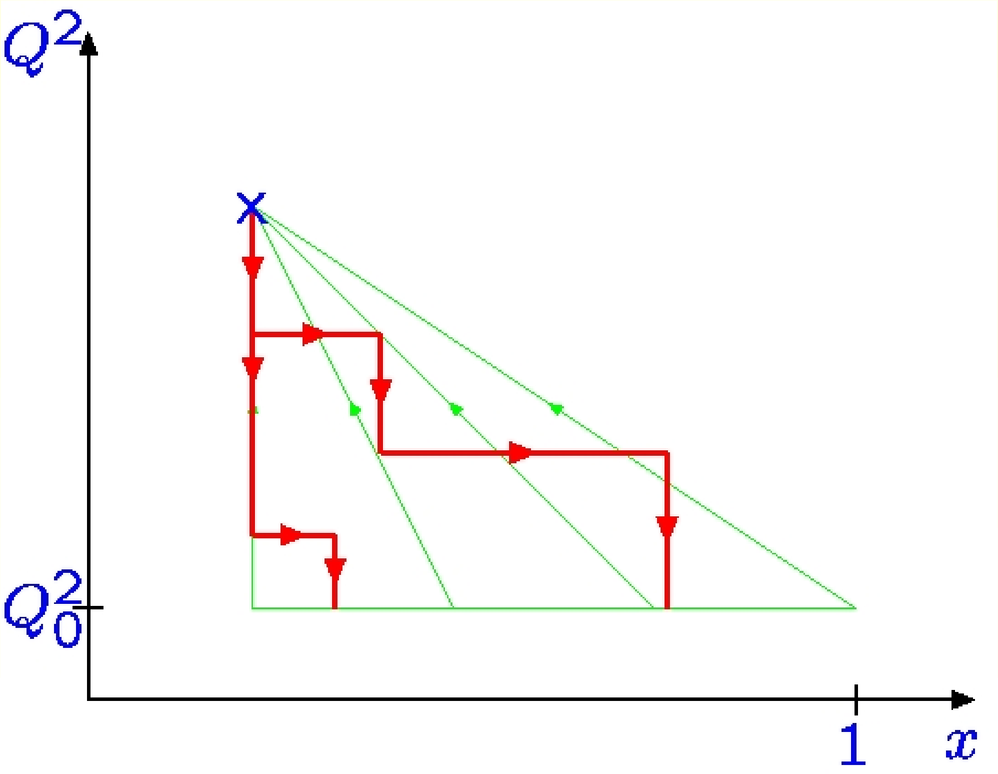
Initial State Radiation

In hadronic collisions, incoming partons can also radiate

$$p_1 \to p_2 + k, p_1^2 = p_2^2 = 0 \Rightarrow k^2 = (p_1 - p_2)^2 = -2p_1 \cdot p_2 < 0$$

Backwards (from hard scatter) evolution of partons with virtualities increasing $\to 0$

Since backwards, must normalize to the incoming flux of partons (PDF)



- Collinear parton shower obeys DGLAP evolution
- Weight Sudakov: $\frac{f_i(x,Q^2_{\rm lo})}{f_i(x,Q^2_{\rm hi})}$

ISR Uncertainties

Similar to FSR, can vary prefactor of p_T^2 in α_s, PDF's

PYTHIA: `PARP(64)=.25-4.0`

- $\Lambda_{\rm ISR}$ initially taken from PDF

PDF dependence?

- PS *is* based on DGLAP, but there is more physics in the PS than in PDF fits (i.e. exact kinematics, coherence)
- For each step in the PS, the denominator cancels the PDF dependence of the previous step
- Overall dependence is on the x and Q^2 values of the first (last in the backwards evolution) partons

Never seen this fully investigated

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Alternative Approach: PS Corrections to ME

Several methods have been suggested to match multi-legged ME predictions with PS's

ad hoc approaches have been used for some time (using, e.g., the external event machinery inside PYTHIA)

Note: ME expressions for emissions reduce to the PS ones in the soft/collinear limit (without Sudakov form factors)

Matching Schemes correspond to interpolation strategies between the kinematic regimes where ME's or PS's are valid – varying how this is done constitutes an error estimate

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How does this work?

Method boils down to generating, e.g. $W + 0, 1, 2, \cdots$ at parton level with cutoffs and using PS to reweight and add them

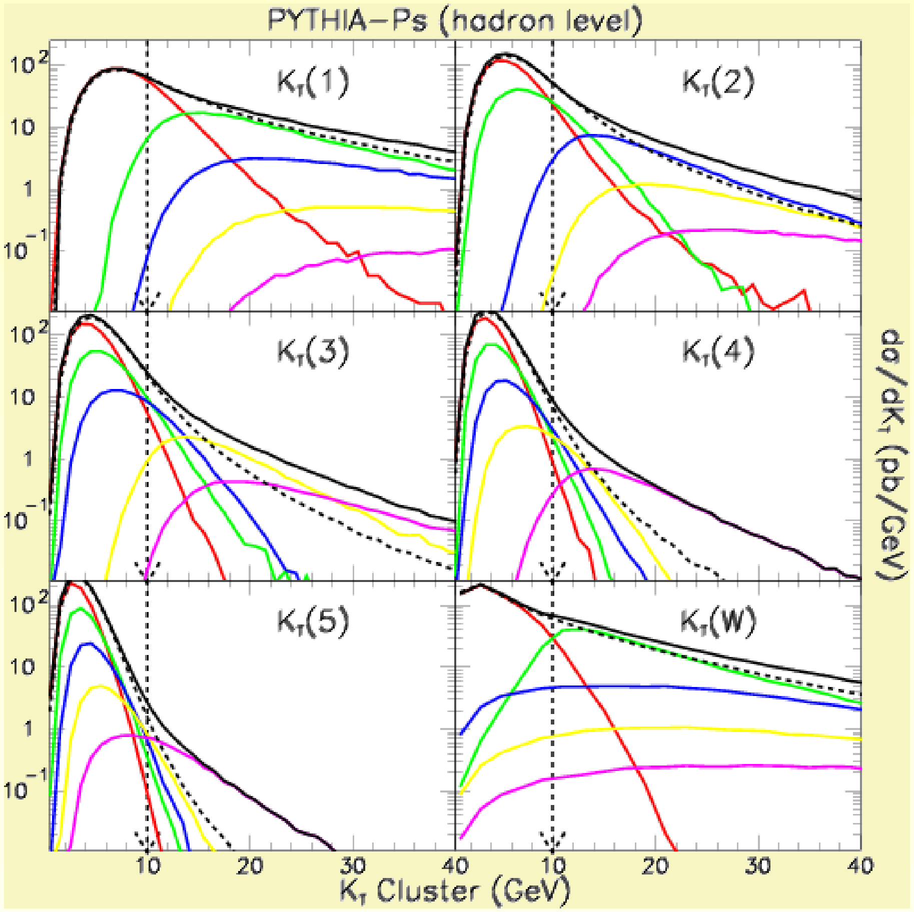
Each individual sample has a well-defined kinematic delineation

- (a) $W + 0$ k_T-jets> cutoff + any number below cutoff
- (b) $W + 1$ and only 1 k_T-jet> cutoff + any number below
- (c) *etc.*

Vetoing an event with a hard emission is like reweighting by the Sudakov form factor on external lines

Internal lines are harder and would have Sudakov weights that are closer to 1

W+0 $\oplus \cdots \oplus$ W+4 hard partons



Dashed is `Pythia` with default (ME) correction

Solid is Pseudoshower result

Combines ME contributions (0, 1, 2, 3, 4 partons)

Important issues for bH

Kinematics of the “spectator” b

PS scale choice for $g \longrightarrow b\bar{b}$ as compared to that for light QCD partons

We “know” little about the b and g PDF’s, and how they affect the PS