Understanding Top and Its Backgrounds

A Phenomenological Overview

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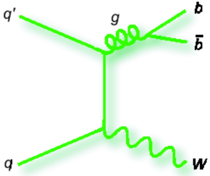
with *thanks to P. Skands and T. Sjostrand*

Top Mass Summit 2005

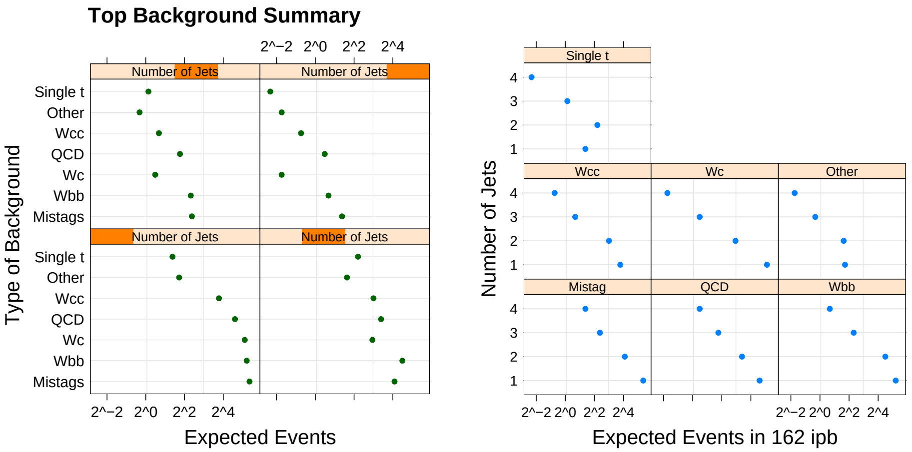


How the Top quark was discovered

Counting

- Primary analysis based on:
  - S≡"LL" event generator `Isajet` without coherence and using Feynman-Field hadronization
  - B≡Tree-level `VECBOS` + data
  - Supplemented with `Herwig` for cross checks and detailed kinematic analysis of top decays
- $M_t = 176 \pm 8 \pm 10$ GeV, $\sigma = 6.8^{+3.6}_{-2.4}$ pb
- $$(S+B)/B = (27/7 = 3.9, 23/15 = 1.5, 6/1.3 = 4.6)$$
  $$= (SVX, SLT, \ell\ell)$$
  - The convincing evidence was the kinematic reconstruction
- Discovery "easy", interpretation harder

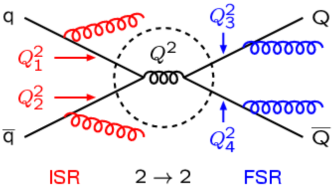
Non-Top Cocktail: CDF PRD with 162 pb^{-1}



Complicated; Correlated: is it right? can it be improved?

ISR/FSR basics: Parton Shower Approach

$$2 \to n \;=\; (2 \to 2) \oplus \text{ISR} \oplus \text{FSR}$$



FSR = Final-State Rad.;
timelike shower
$Q_i^2 \sim m^2 > 0$ decreasing

ISR = Initial-State Rad.;
spacelike shower
$Q_i^2 \sim -m^2 > 0$ increasing

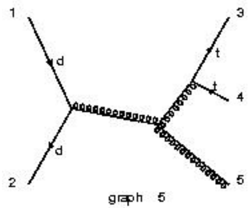
$2 \to 2$ = hard scattering (on-shell):

$$\sigma = \iiint \mathrm{d}x_1\, \mathrm{d}x_2\, \mathrm{d}\hat{t}\; f_i(x_1, Q^2)\, f_j(x_2, Q^2)\, \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}\hat{t}}$$

Shower evolution is viewed as a probabilistic process,
which occurs with unit total probability:
the cross section is not directly affected,
but indirectly it is, via the changed event shape

"Missing Diagrams"

- parton shower "generates Feynman diagrams" like a fixed-order calculation
- only includes those enhanced in the soft or collinear limit [DGLAP]
- may exclude some hard effects ($\sim Q_F$)
    - analyzing diagrams is gauge dependent!
- Where does the difference become important?



- hard momentum flows through propagators
- *No* singularity

Leading Log and Beyond

(Truncated) rate for one gluon emission is:

$$\mathcal{P}_{q\to qg} \sim \int \frac{dQ^2}{Q^2} \int dz d\phi \frac{\alpha_s}{2\pi} \frac{4}{3} \frac{1+z^2}{1-z}$$

$$\sim \alpha_s \ln\left(\frac{Q^2_{\max}}{Q^2_{\min}}\right) \frac{8}{3} \ln\left(\frac{1-z_{\min}}{1-z_{\max}}\right)$$

$\mathcal{P}_{q\to qg} \Rightarrow \alpha_s \ln^2$
Rate for n emissions:

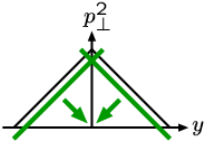
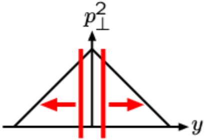
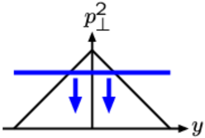
$$\mathcal{P}_{q\to q+ng} \sim \mathcal{P}^n_{q\to qg} \sim \alpha_s^n \ln^{2n}$$

NLL includes also: $\alpha_s^n \ln^{2n-1}$
Part of NLL is included in PS through:

- energy-momentum conservation
- coherent gluon emission ("angular ordered")
- $\alpha_s(cp_T^2)$
- "All order" $\sim$ "Fixed order"

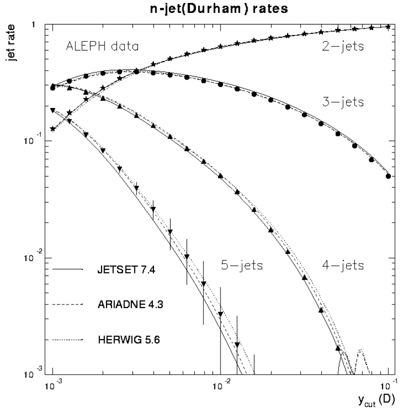
$$\alpha_s(m_t) \simeq \alpha_s(p_T) \ln^2\left(\frac{m_t}{p_T}\right) \Rightarrow p_T = 70 \text{ GeV}$$

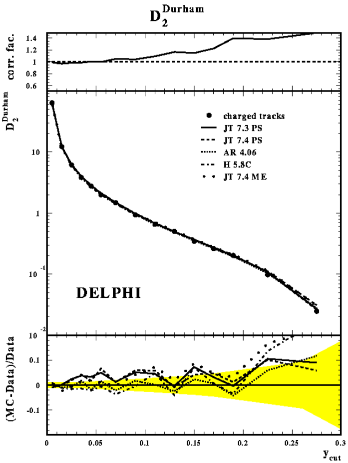
OLD $\sim$ **NEW Pythia**

PYTHIA: $Q^2 = m^2$	HERWIG: $Q^2 \sim E^2\theta^2$	ARIADNE: $Q^2 = p_\perp^2$
		
large mass first	large angle first	large $p_\perp$ first
$\Rightarrow$ "hardness" ordered	$\Rightarrow$ **hardness not ordered**	$\Rightarrow$ "hardness" ordered
coherence brute force	coherence inherent	coherence inherent
covers phase space	**gaps in coverage**	covers phase space
ME merging simple	**ME merging messy**	ME merging simple
g $\to$ q$\bar{\text{q}}$ simple	g $\to$ q$\bar{\text{q}}$ simple	**g $\to$ q$\bar{\text{q}}$ messy**
not Lorentz invariant	**not Lorentz invariant**	Lorentz invariant
no stop/restart	no stop/restart	can stop/restart
ISR: $m^2 \to -m^2$	ISR: $\theta \to \theta$	**ISR: more messy**

$\Rightarrow$ **Partons are different things in different generators** $\Leftarrow$

Generators describe data well

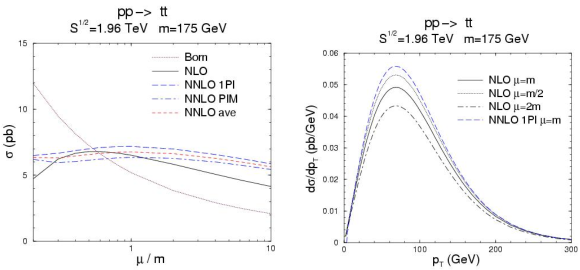




Parton level differences are "artificial"

Other NLO Issues

Kidonakis, *et al.*



Is there a *large* correlation between NLO and PS uncertainty?

- No, mostly top is produced at threshold and dominated by soft and virtual
- soft kinematics is important; this is the root of theoretical uncertainty
  - 1PI = kinematics of top recoil at threshold
  - PIM = kinematics of top pair recoil at threshold
- variations $\alpha_s(cp_T^2)$ affect detailed shapes (H_T?)

MC@NLO

Advantages

correct NLO normalisation and the first hard jet right

Disadvantages

shower ansatz and hence the resummation procedure cannot be varied

- be alert for observables and cuts which are sensitive to this, e.g. peak of the $t\bar{t}$ p_T spectrum

- "matched sample" with a K-factor is at the same level of precision, if not better, for *distributions*
- need to vary the shower ansatz in a well-considered way
- `http://home.fnal.gov/~skands/slides/high-shat_aug05.ppt`
  - shower gets the first hard jet correct to a good approximation
  - agrees with a first look at matched $t\bar{t}$,$t\bar{t}j$,$t\bar{t}jj$

"Jet" showering/fragmentation/hadronization

b-parton showering $\sim$ light parton except near shower cutoff

- "Large" virtuality involved in top decay
- Mapping back to parton level is more complicated for b-jets
- like looking at a parton distribution at two different scales

must tune *generator* fragmentation

- $\Rightarrow$ *not* the same as NLO (NLL?) fits

Caveat

- generators fit copious LEP data "correctly"
- we do not have a 'proof' of jet universality
- *e.g.*, breakdown from color reconnections

Mixing the Non-Top Cocktail

Method 2

Monte Carlo ratio
$R = (W + b - jets)/(W + jets)$

Measure $W + jets$ (no b-tag)

data(W+b-jets) $= R \times$data(W+jets)

Wcj/Wbb from Monte Carlo

Compare to predictions from MCFM

Campbell & Ellis
(see also Campbell & Huston)

MLM Method

Parton shower and hadronization are essential for studying b-jets

- Parton shower W+Npartons but reject emissions that are too hard
- Build up *inclusive* or *exclusive* samples
- R supplemented by phenomenological factor 1.5

$\delta R/R \sim$25-30%

Method 2 at Tree Level

Madevent (Stelzer and Maltoni)

Graph	Cross Sect(fb)
Sum (Wbb)	8.934
Sum (Wjj)	1061.627
ug→e^+vedg	327.810
udx→e^+vegg	257.060
gdx→e^+veuxg	137.300
dxg→e^+veuxg	48.591
uux→e^+veuxd	47.425
udx→e^+veddx	36.644
gu→e^+vedg	34.445
udx→e^+veuux	29.816
...	...

$R \times 1.5$ =1.3% (MLM = 1.4%)

$\langle R \rangle$ roughly the same

Many different topologies

Dominant ones not $q\bar{q}$

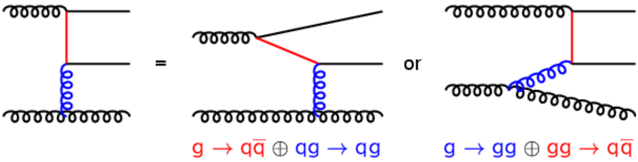
$$P_{qq}(z) = \frac{1}{2}(z^2 + (1-z)^2)$$

Different topologies parton shower and hadronize differently

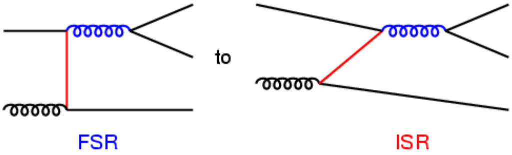
Many effects have to be modelled well to have a reliable prediction

Double Counting (Need for Matching)

A $2 \to n$ graph can be "simplified" to $2 \to 2$ in different ways:



or deform



Do not doublecount: $2 \to 2$ = most virtual = shortest distance

Conflict: theory derivations often assume virtualities strongly ordered; interesting physics often in regions where this is not true!

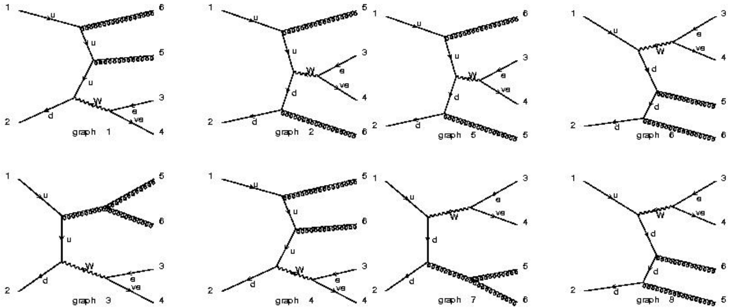
Fact. and Renorm. Scales

Factorization

Factorization Theorem allows for a separation of the hard process from the soft/collinear physics of $f(x)$ and $D(z)$ at the scale Q_F.

Renormalization

Renormalization introduces a residual scale dependence Q_R typical of the average virtuality.



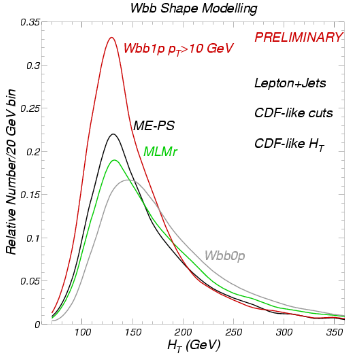
$\Rightarrow$ Averaged scales $\sim \sqrt{p_{TW}^2 + M_W^2}$

Impact of scale choice

- Assume $Q_F = Q_R$, normalize rate to data
- Choice matters, especially if p_{Tj} enters observable
- $H_T = \sum_i p_{Ti}$
- PS implies that p_{Tj} (for ISR, relative p_{Tjj} for FSR) is a good choice, but note dependence $\alpha_s(cp_T^2)$
- CKKW-like matching gives a prescription for choosing scales that seems quite reasonable (see SM and P. Richardson)
  - Since choice represents $\sim$ average virtuality of internal lines, it is close to BLM prescription

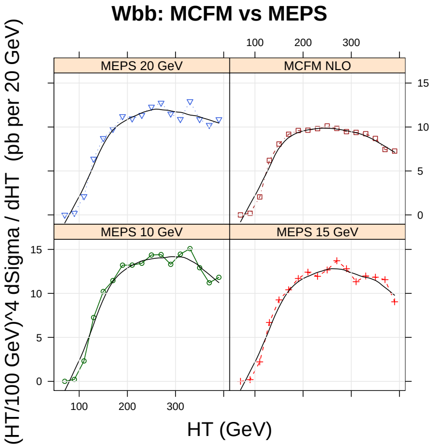
Matrix Element-Parton Shower Matching

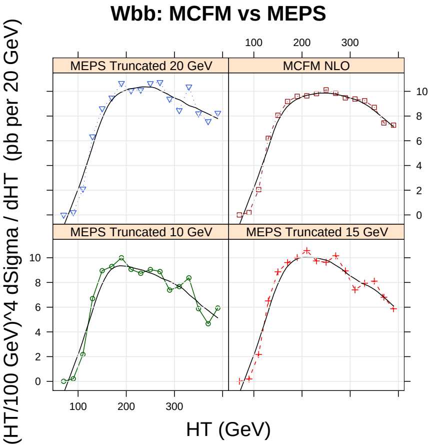
SM, PR *JHEP 0405:040,2004*



Testing Different Predictions

- Matching scheme needed to make inclusive predictions with hard emissions
- Pseudoshower Method (ME-PS) reweights matrix elements to look like parton showers where they should. Motivated by Catani et al., but more flexible and tuned to Pythia, Herwig, etc.

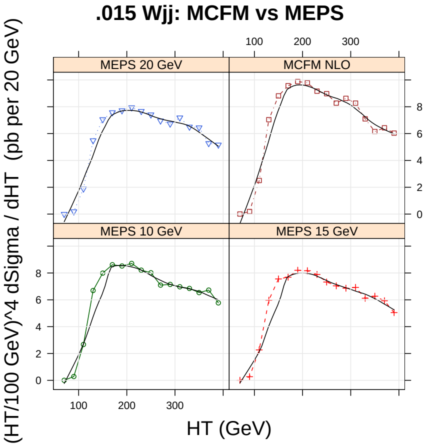




Matched Datasets have a systematically larger rate and different shape

Truncated Datasets contain only $Wb\bar{b} + Wb\bar{b}j$

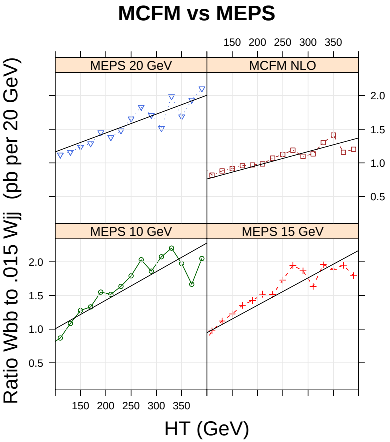
HO topologies modify shape

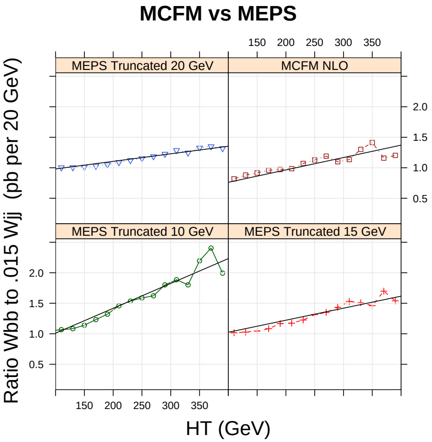


Wjj Matched Datasets have less variation with cutoff

Matched normalization here is smaller (no skipped Sudakov)

Stiffer shape (HO topologies)





Matched Datasets have consistently steeper slopes (note: MCFM steeper than LO)

Truncated Datasets contain only $Wb\bar{b} + Wb\bar{b}j$

Slopes more consistent with MCFM