Models ↔ Experiment
Bridging the Gap

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Outline

- Anatomy of an Event
- Parton Shower MC
- Matrix Element Corrections
- Current Tools
- Outlook
A Top Quark Event
Anatomy of an Event

1. High-Q Scattering
2. Parton Shower
3. Hadronization
4. Underlying Event
Hard Scattering

1. High-Q Scattering

Where new physics lies

process dependent

first principles description

it can be systematically improved

2. Parton Shower

3. Hadronization

4. Underlying Event
1. High-Q Scattering

QCD - "known physics"
universal/ process independent

3. Hadronization

4. Underlying Event
Hadronization

1. High-Q Scattering
2. Parton Shower
3. Hadronization
4. Underlying Event

universal/ process independent
model dependent

low $Q^2$ physics
Underlying Event

1. High-Q Scattering
2. Parton Shower
   - low Q physics
   - energy and process dependent
   - model dependent
3. Hadronization
4. Underlying Event
Building Bridges

Local Parton Hadron Duality
Parton Shower MC
HERWIG / Pythia

Start with Hard Process\(^*\) then allow to radiate

ME involving \( q \rightarrow q\ g \) (or \( g \rightarrow gg \)) are strongly enhanced when they are close in the phase space:

\[
\frac{1}{(p_q + p_g)^2} \sim \frac{1}{2E_q E_g (1 - \cos \theta)}
\]

Collinear factorization:

\[
|M_{p+1}|^2 d\Phi_{p+1} \sim |M_p|^2 d\Phi_p \frac{dt}{t} \frac{\alpha_s}{2\pi} P(z) dz d\phi
\]
Building Bridges

Modelling

HERWIG / PYTHIA

Experiment

Feynman Diagrams

Phenomenology

Showering

Hadroniz...

Underlying
Tevatron to LHC

- Backgrounds
  - Multi-parton (tt)
  - Study first
  - Key to Signal
- Require better event generators
Improve Hard Scattering

1. Identify all subprocesses (gg→ ggg, gq → ggq, etc) in

   \[
   \sigma(pp \rightarrow 3j) = \sum_{ijk} \int f_i(x_1) f_j(x_2) \hat{\sigma}(ij \rightarrow k_1 k_2 k_3)
   \]

   Easy

2. For each one calculate amplitude

   \[
   A(\{p\}, \{h\}, \{c\}) = \sum_i D_i
   \]

   Hard

3. Square amplitude, sum over spins & color, integrate over phase space

   \[
   \hat{\sigma} = \frac{1}{2 \hat{s}} \int d\Phi_P \sum_{h,c} |A|^2
   \]

   Very hard
Building Bridges

HERWIG / PYTHIA

Models  Phenomenology  Experiment

Matching

Showering  Hadroniz.  Underlying
M.E. / Shower Matching

Approaches are complementary!
But double-counting has to be avoided!
Avoid Double Counting

Jet-parton matching

Event matched, $N_{\text{jet}} = N_{\text{part}} = 3$
- Keep event
1. The most inclusive observable.
2. All parton multiplicities contribute.
3. Excellent agreement with TeV data (validation)
Building Bridges

Models
Feynman Diagrams

Phenomenology
CKKW, MLM

Experiment
HERWIG / PYTHIA

Showering
Hadroniz.
Underlying
Available Tools

- **Showering/Hadronization**
  - HERWIG
  - Pythia
  - SHERPA

- **Hard Scattering**
  - Alpgen (Multi parton)
  - AMEGIC (SHERPA integration)
  - Comphep/Calchep (User Interface)
  - MadGraph/MadEvent (see next slide)
Code can be generated either by:

I. Fill the form:
   * Model: [SM] Particle names
   * Input Process: [Examples]
   * Max QCD Order: [99]
   * Max QED Order: [99]
   * $p$ and $j$ definitions: [Definition]
   * Sum over leptons: [Lepton Sum]
   * Submit

II. Upload the proc_card.dat
   Process card examples
   Choose File, no file selected and send it to the server.
Structure

Model

particles.dat
interactions.dat
couplings.f

Calculator

proc_card
param_card
run_card
pythia_card
pgs_card

MG

H. Feyn. diags.
HELAS
amplitudes

ME

Parton-level events

Pythia

Hadron-level events

PGS

Reconstructed
events

ROOT

plot_card

Parton-level rootfile
Plots

Pythia rootfile
Plots

PGS rootfile
Plots
Models in MadGraph

- **Standard Model**

- **MSSM**
  Rainwater+Plehn+Alwall

- **General 2 Higgs Doublet Model (including CPV)**
  Herquet, De Visscher

- **Higgs EFT**
  Frederix

- **New**: General framework for user-defined models
MadGraph/Sherpa/Whizard SUSY comparison

~500 processes to check all Feynman rules (CP and R-conserving, CKM=MSN=1)

- $e^+e^-$, $e^-ar{\nu}_e$, $e^-e^-$, $\tau^+\tau^-$, $\tau^-\bar{\nu}_\tau$, $u\bar{u}$, $d\bar{d}$, $u\bar{u}$, $d\bar{d}$, $b\bar{b}$, $b\bar{b}$,
- $W^+W^-$, $W^-Z$, $W^-\gamma$, $ZZ$, $Z\gamma$, $\gamma\gamma$, $gW^-$, $gZ$, $g\gamma$, $gg$, $ug$, $dg$.

[Hagiwara et al. 2005]
Coming Soon

- New Tools for Adding New Models
- Decay Chains
Summary

- Accurate simulation of SM backgrounds and New Physics is essential for LHC
- Significant progress has been made in last 5 years
- New era in communication between Model builders and experimentalists