Examining the Noise to Find the Signal

Andre Bach
Mentors:
Steve Ellis
Matt Strassler

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High Energy Physics

- Aim: investigate basic laws of nature
- Do this by slamming tiny particles into each other at high speeds/energies
- Build large accelerators and detectors to do this
QuickTime™ and a Sorenson Video 3 decompressor are needed to see this picture.

Credit: atlasexperiment.org
What comes out of a collision

- Quarks decay into a shower of particles
- A **jet** is a collection of particles in a cone believed to have all come from one quark or gluon
- Example: t tbar production
Finding that W boson

- Finding W bosons at the LHC is important to discovering new physics
- Invariant mass of 2 particles: if 2 particles came from the decay of one, it’s the mass of that one
- Find invariant mass of each possible pair of jets and make a histogram
- Problem: whole lot of possible pairs!
My project

- Determine how bad this problem of combinatorics is in various situations
- Examine strategies for getting around it
How bad is it?

- What kind of background do we get from all those incorrect pairs of jets?
  - Given probability distributions for random jets
  - Use basic probability theory
  - Leads to multi-dimensional integrals over the phase space of the jets
Mmm, integrals

\[ P(\tilde{m}^2) = \int \int P_1(p_1)P_1(p_2) \delta(m^2(p_1, p_2) - \tilde{m}^2) \frac{d^3p_1}{E_1} \frac{d^3p_2}{E_2} \]

\[ P_1(p_1) = \frac{1}{4\pi b^2} e^{-r_1/b} \]

\[ P(\tilde{m}^2) = \left( \frac{1}{4\pi b^2} \right)^2 \int \int \int \int \int e^{-(r_1+r_2)/b} r_1 r_2 \sin(\theta_1) \sin(\theta_2) \delta(2r_1 r_2(1 - \cos(\Delta\theta)) - \tilde{m}^2) \, dr_1 d\theta_1 d\phi_1 \, dr_2 d\theta_2 d\phi_2 \]
Integrals, solved

\[ P(\tilde{m}) = 2\tilde{m} \quad P(\tilde{m}^2) = \frac{\tilde{m}^2}{2b^3} \quad K_1(\tilde{m}/b) \]
Conclusions from integrals

QuickTime™ and a
Animation decompressor
are needed to see this picture.
Stepping back from integrals

- Since the three kinds of wrong choices are roughly the same, lump them together
- Two things to look at
  - Ratio of signal to background as number of jets and purity of signal are varied
  - Number of events left after imposing constraints
- Balance between S/B and statistics
The behavior of S/B

\[ \frac{S}{B} = \frac{f}{\binom{n}{2} - f} \]

Purity $f$ and number of jets $n$ are functions of how many jets are tagged and the efficiency and false positive rates.
What we’ve learned & what remains

- Evaluated various fancy integrals to discover that the background is surprisingly simple in some cases
- Simple-minded rule of thumb: if you have any reason to reject jets, do so
- In the next week
  - Look at more realistic jet distributions, see if conclusions remain the same
  - Factor in effect of statistics
  - Write paper