Examining the Noise to Find the Signal

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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

Credit:
atlasexperiment.org

QuickTime™ and a
Sorenson Video 3 decompressor
are needed to see this picture.

What comes out of a collision

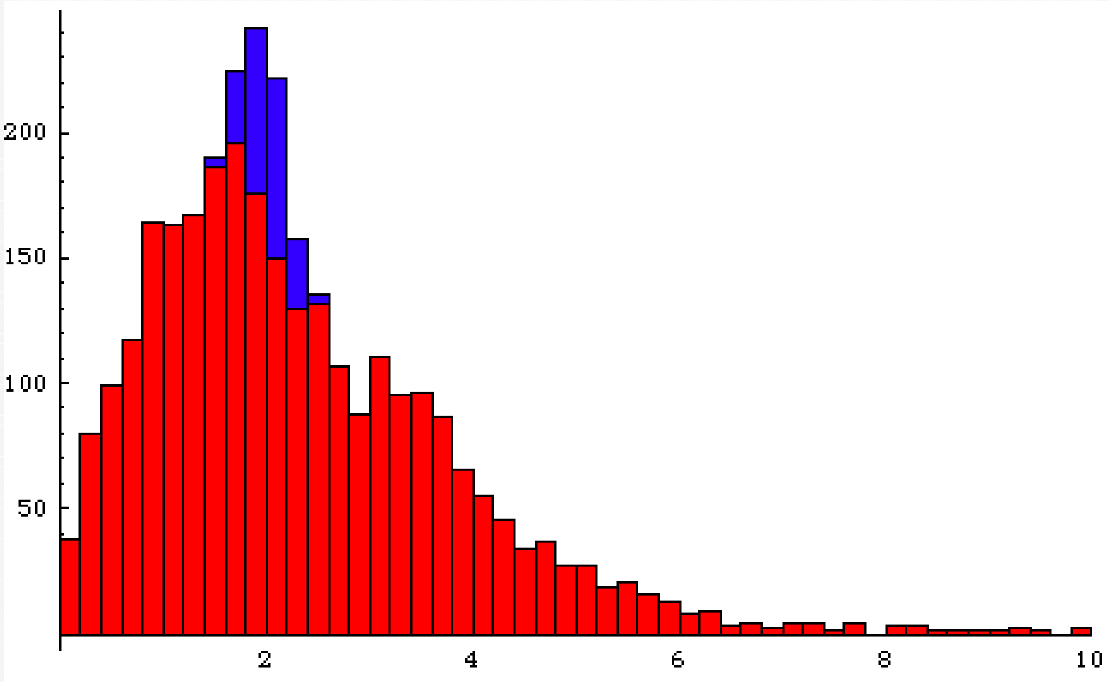
- Quarks decay into a shower of particles
- A jet is a collection of particles in a cone believed to have all come from one quark or gluon
- Example: t tbar production

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

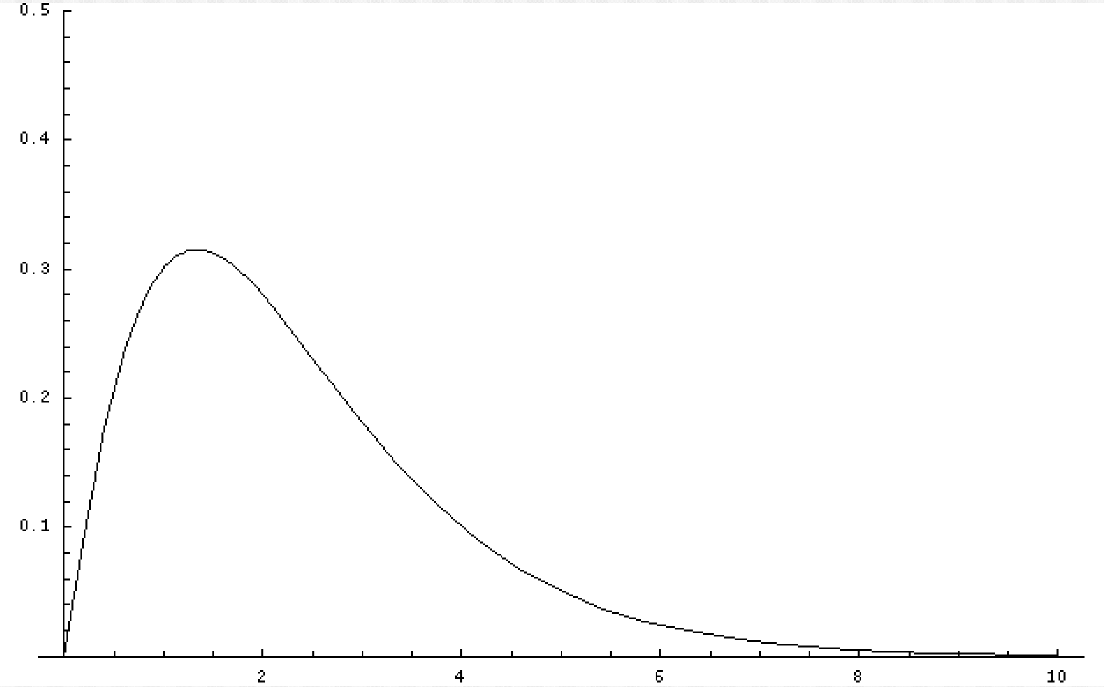
$$P(\widetilde{m}^2) = \int\int P_1(\mathbf{p}_1)P_1(\mathbf{p}_2)\,\delta(m^2(\mathbf{p}_1,\mathbf{p}_2) - \widetilde{m}^2)\,\frac{d^3p_1}{E_1}\,\frac{d^3p_2}{E_2}$$

$$P_1(\mathbf{p}_1) = \frac{1}{4\pi b^2}\,e^{-r_1/b}$$

$$P(\widetilde{m}^2) = \left(\frac{1}{4\pi b^2}\right)^2 \int\int\int\int\int\int e^{-(r_1+r_2)/b}\,r_1 r_2 \sin(\theta_1)\sin(\theta_2)\,\delta\big(2r_1r_2(1-\cos(\Delta\theta)) - \widetilde{m}^2\big)\;dr_1 d\theta_1 d\phi_1\;dr_2 d\theta_2 d\phi_2$$

Integrals, solved

$$P(\widetilde{m}) = 2\widetilde{m}\ P(\widetilde{m}^2) = \frac{\widetilde{m}^2}{2b^3}\ K_1(\widetilde{m}/b)$$



Conclusions from integrals

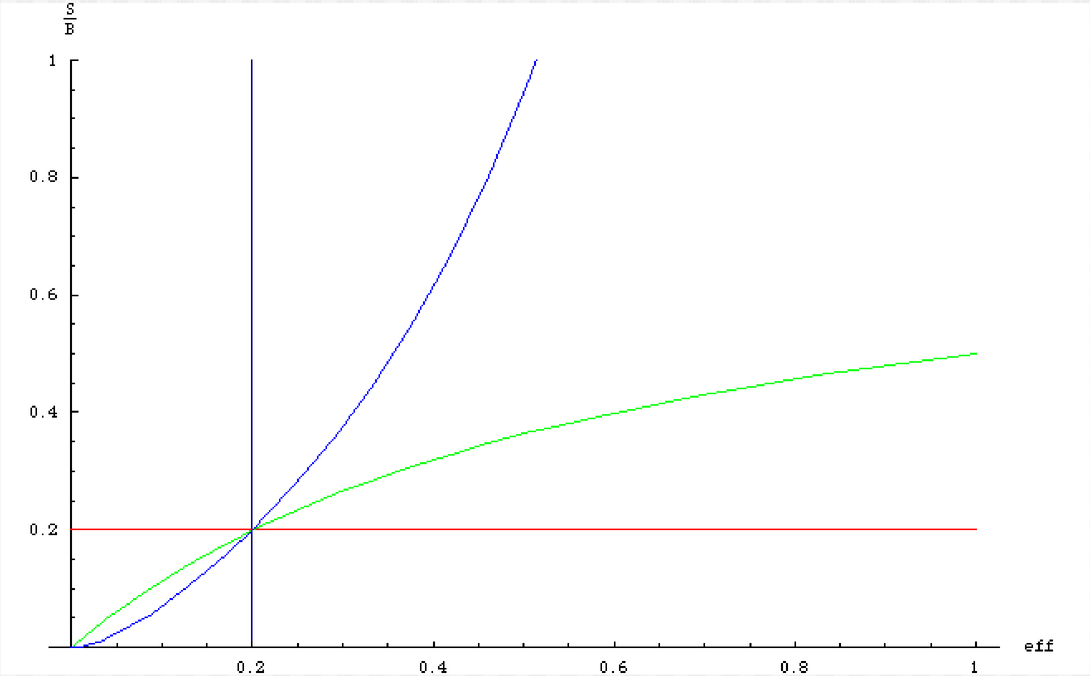
QuickTime™ and a
Animation decompressor
are needed to see this picture.

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