Theoretical Physics

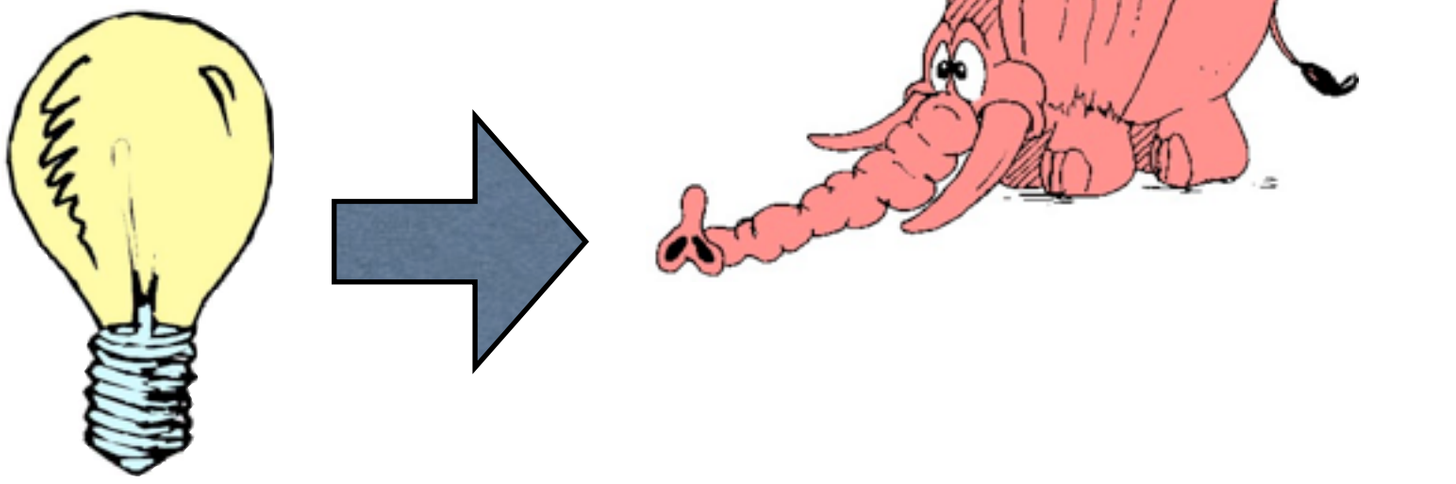
Monte Carlo Development and Tuning

P. Skands (PPD/TH, now at CERN)

Event Generators

Comparisons to Collider observables

Theoretical Idea



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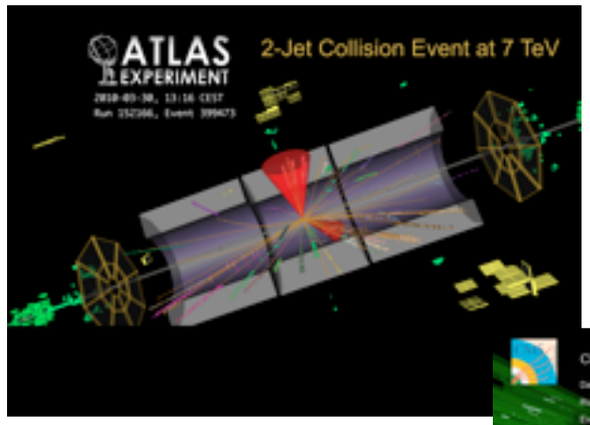

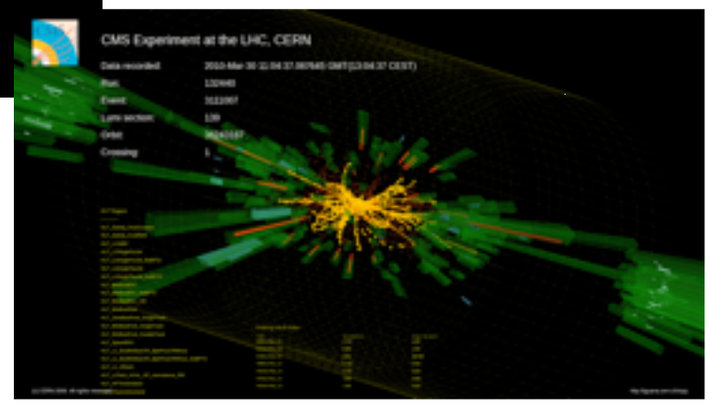

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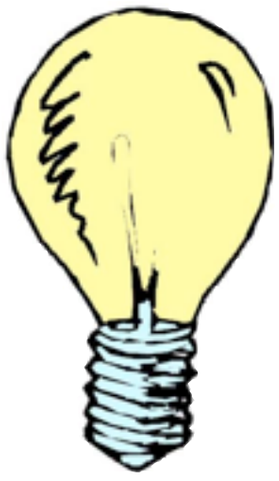

Event Generator (+ detector sim)

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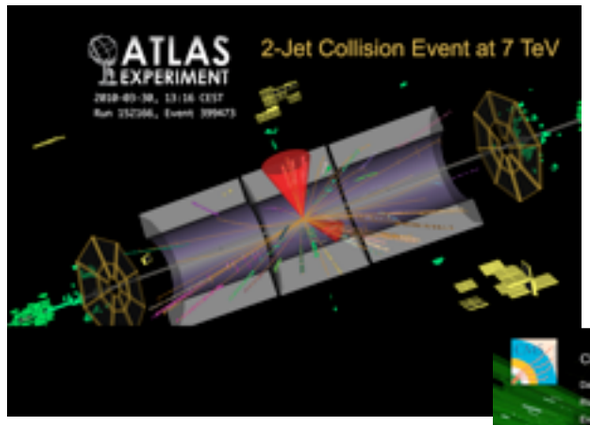

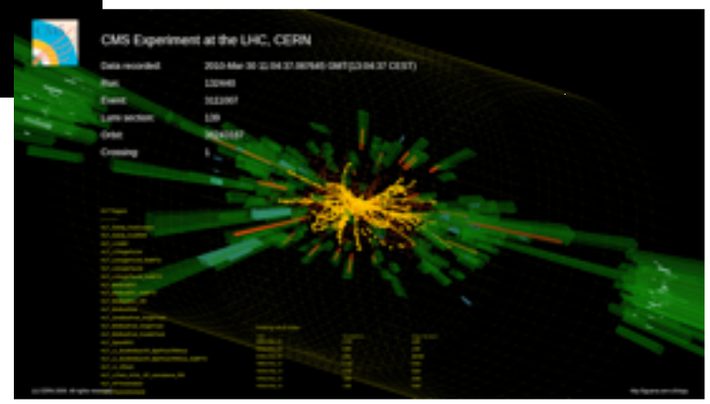

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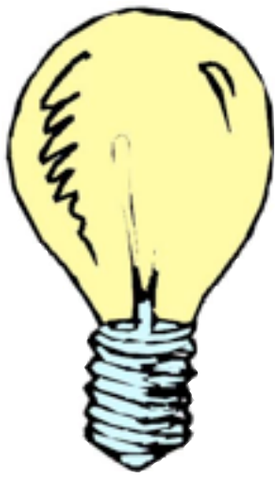

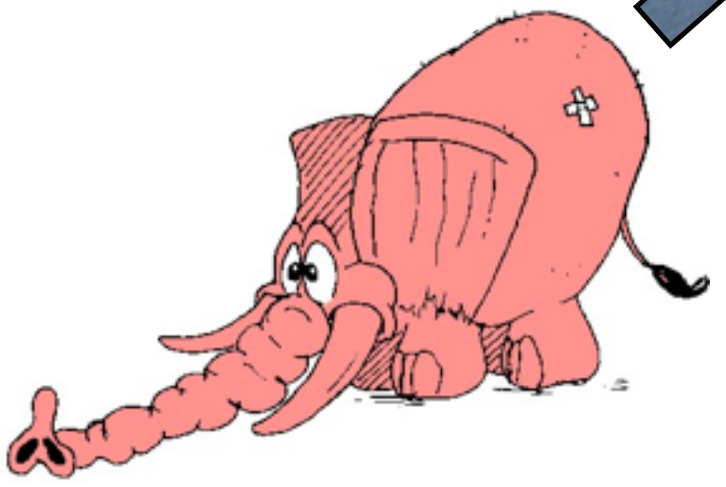

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A) Theoretical Idea is wrong

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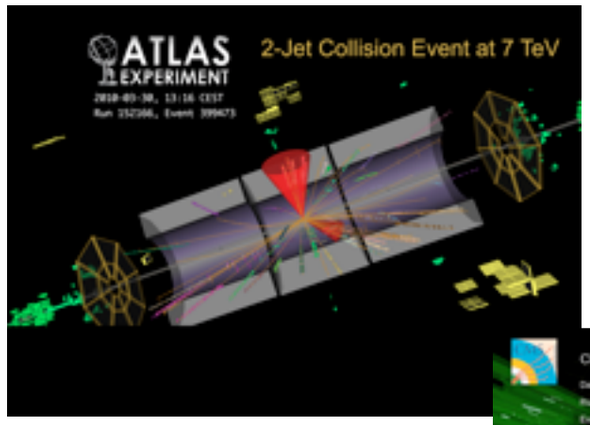

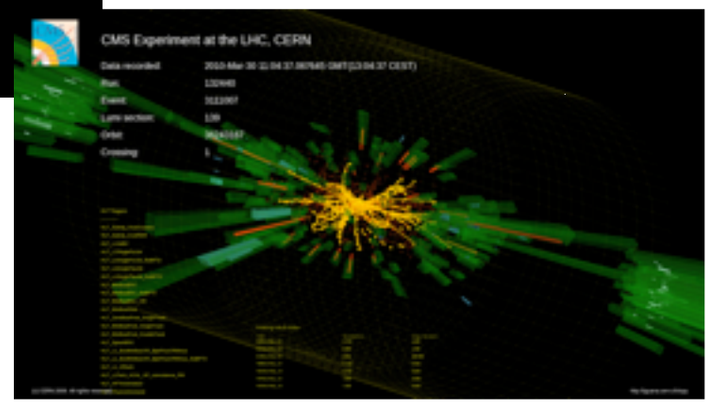

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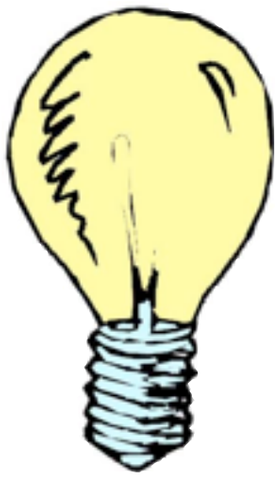

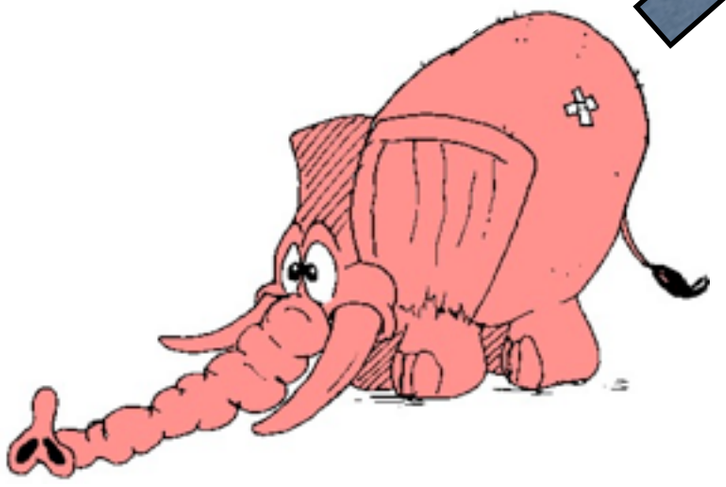

Event Generator (+ detector sim)

A) Theoretical Idea

B) Event Generator Model is wrong

Event Generators

- **Based on Random Number Generator**
  - Use Random Numbers to sample from quantum mechanical probability distributions
  - Factorize complete hadron collision event into sub-steps (MANY substeps) each of which has a fundamental quantum probability to occur
    - Hard Scattering Process ~ a few elementary particles
    - Resonance decays ~ tens of particles
    - Bremsstrahlung (spacelike and timelike) ~ several tens of particles
    - Confinement → (string) hadronization ~ hundreds of hadrons
    - Beam Remnants, Hadron Decays (e.g., $\pi^0 \to \gamma\gamma$) , … + hundreds of photons
  - Put the steps together → Generate completely simulated full-fledged hadron collider physics events

Requirements

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- **1. Write a good event generator**
  - Development Work: Include all known physics (in as good an approximation as possible)
    - Mostly on paper, then on your desktop, debugging, more desktop, finally on cluster or farm to look at tails (many distributions fall off exponentially)
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- **2. Tune the generator**
  - Some (most) free parameters of the generator correspond to things that *cannot* be calculated from first principles theory
    - I.e., finished generator has knobs which are a priori not fixed
    - Must be constrained by comparison to data ⇒ **TUNING**

Generator Tuning

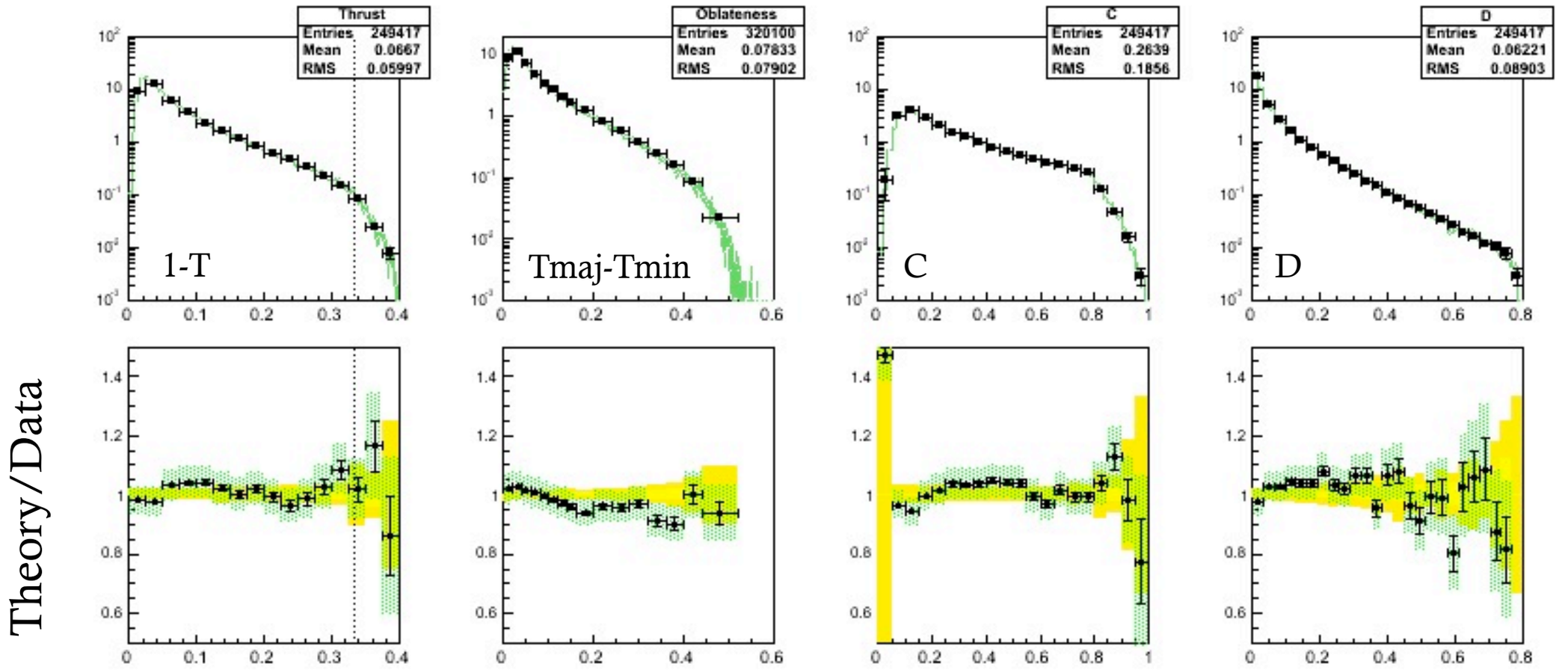
(and validation)

- **After Development** (once physics model itself is ~ finished)
  - Compare to large set of collider measurements
    - Adjust parameters until "best fit" obtained
      - → need to run the generator MANY times, with slightly different parameters, and for different measurements
      - Need GOOD statistics to distinguish fluctuations from physical behavior for rare events
      - **Rare events important!** (most likely to mistake for new physics)
- **Long runs**
  - Repeated long run cycles during tuning
  - Single long run for validating a new version (frozen tuning)

Example: PYTHIA 8

- After run:

In this case looking at:
event shapes at LEP



Tells you how well the generator is reproducing known physics

Tuning & Development

- **Tuning is a developing field**
  - **New distributions** are added → new runs
  - **New lessons** are learned about which distributions are important → new runs
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  - **Physics Models and other inputs** (e.g., proton structure functions) updated → new runs
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Constant demand for up-to-date tunes (and uncertainty evaluations) from the experiments → never 'done'

Size and Scaleability

- **The indivisible quantum is 1 event**
  - Typically ~ 1 - 10 ms on a "standard" CPU
  - Negligible memory requirements (~ 10M)
- **Number of events needed for tuning**
  - Typically from 100k events (low stats)
  - to 100M events (high stats)
  - For each collider (~ 10 from LEP to Tevatron, LHC)
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- **On my desktop**
  - 2 cores: ~ 1 year **PER ITERATION!**

Results

- **Major Tuning & Physics Reference Web Site** (~ 10000 plots)
  - http://home.fnal.gov/~skands/leshouches-plots/
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