More Precision, Less Work

Assisting precision calculations with Monte Carlo sampling
OR
Assisting Monte Carlo sampling with precision calculations

David Farhi (Harvard University)

Work in progress with Ilya Feige, Marat Freytsis, Matthew Schwartz

Boston Jets Workshop, 1/21/2014

Importance of Precision QCD

* New physics searches -- need precise calculations of QCD backgrounds
* Jet observables like jet mass, n-subjettiness, …

Monte Carlo

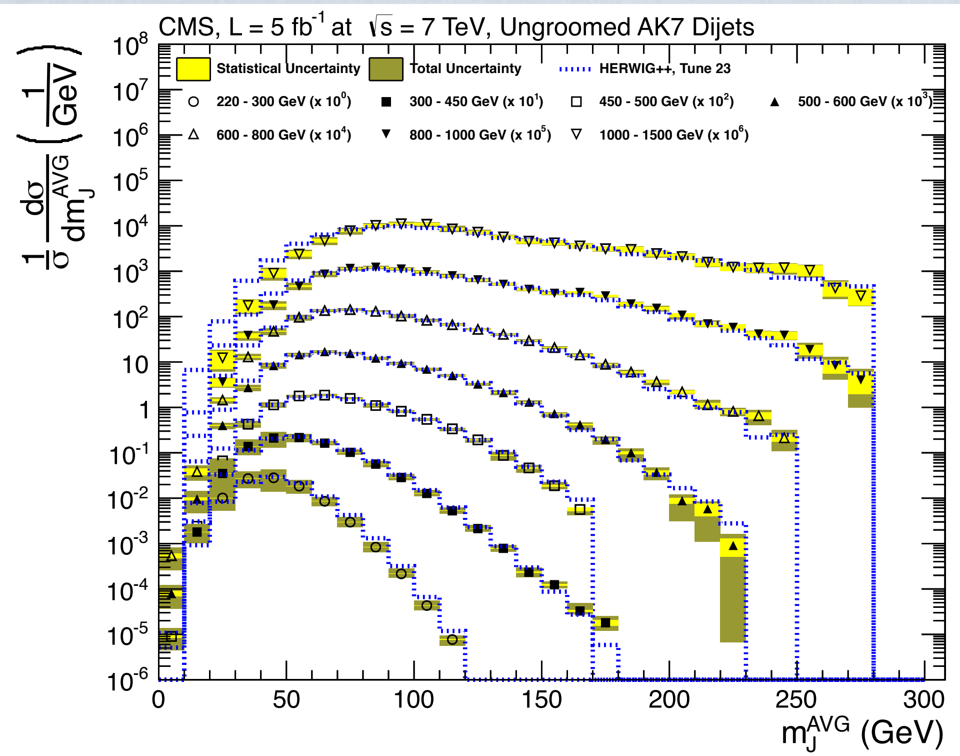
- Automated
- Widely applicable
- Generally excellent agreement with data

Analytic methods (e.g. SCET)

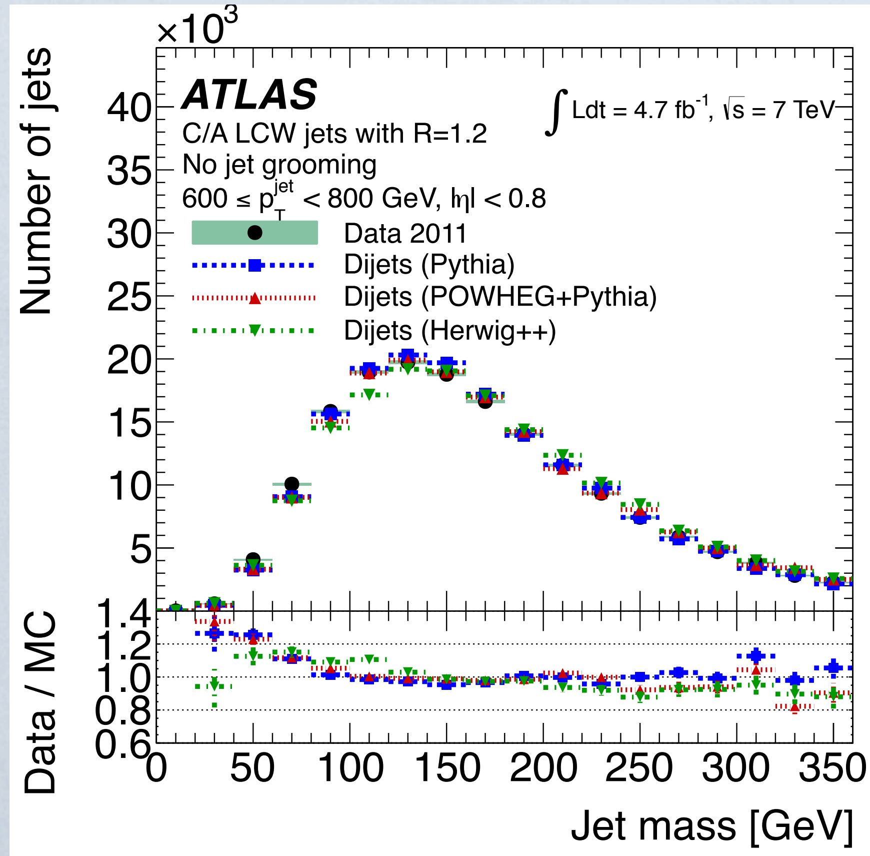
- Systematically improvable
- Well-understood imprecision

Monte Carlo Methods Work Well

CMS “Studies of jet mass”; arxiv 1303.4811



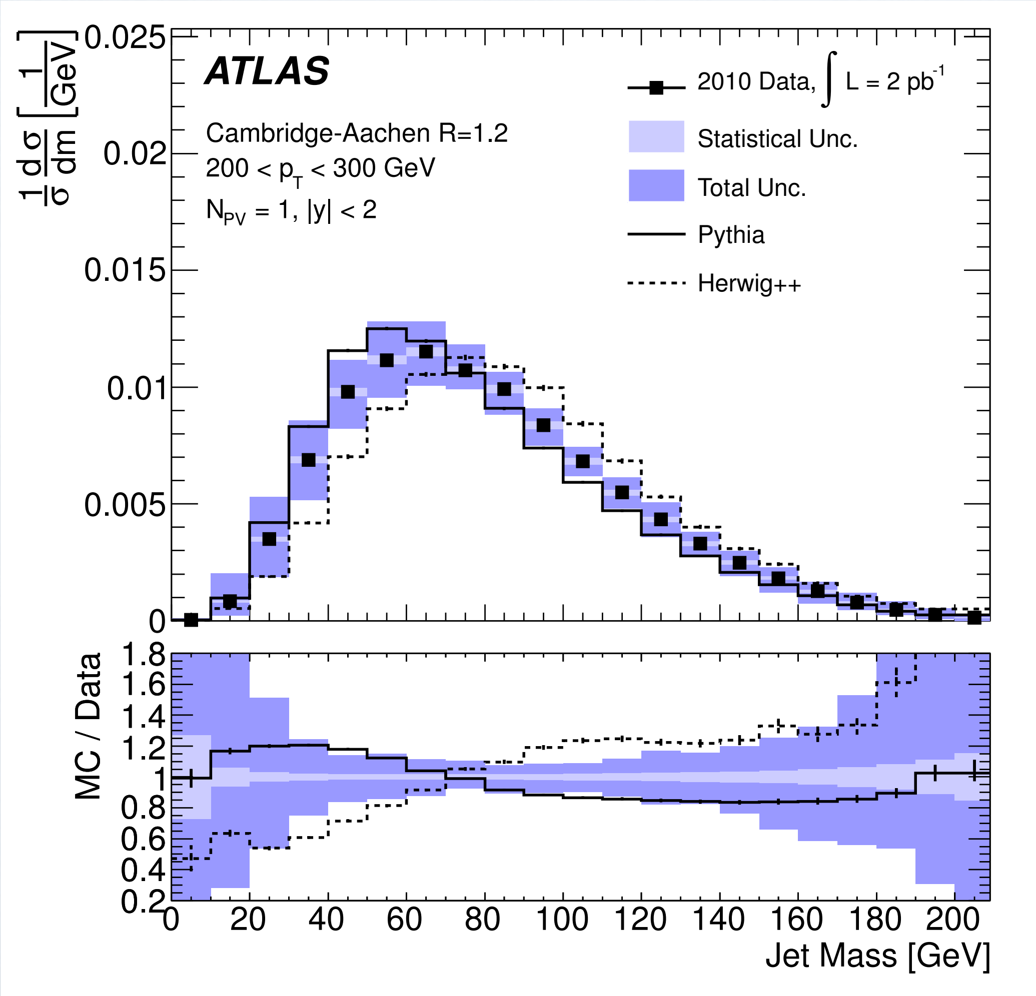
ATLAS “Performance of jet substructure techniques”; arxiv 1306.4945



… but why?

Monte Carlo issues:

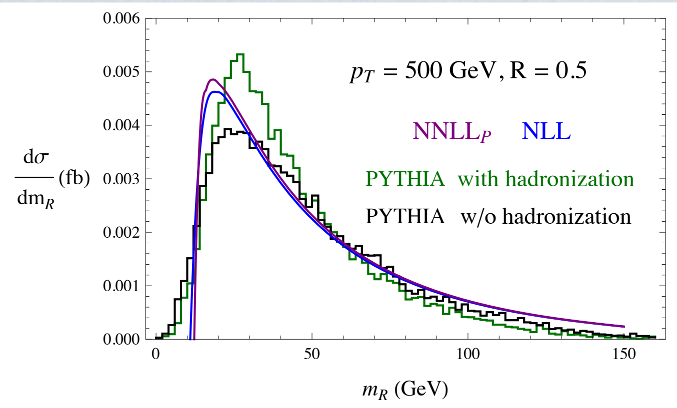
- ⋆ Technically only include leading logs
- ⋆ Tuned to data
- ⋆ Precision poorly understood
- ⋆ Disagreement (Pythia or Herwig?)



Plot from "Jet mass and substructure of inclusive jets"; arxiv 1203.4606

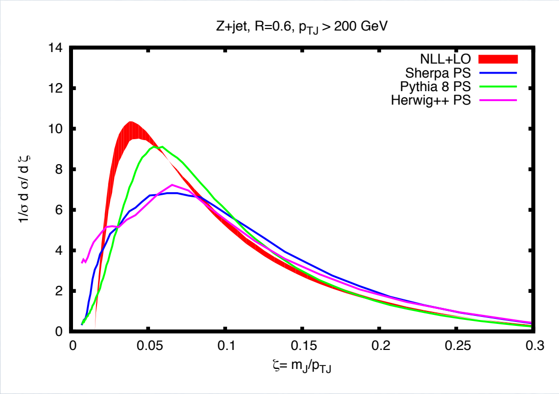
Analytic Methods Work Well

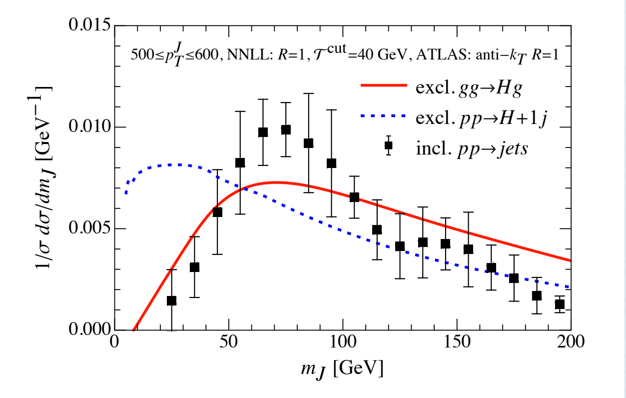
- SCET, pQCD compute distributions analytically
- Precision under analytic control
- Systematically improvable



Chien, Kelley, Schwartz, Zhu
Photon +jet

Dasgupta, Khelifa-Kerfa,
Marzani, Spannowsky; Z+jet



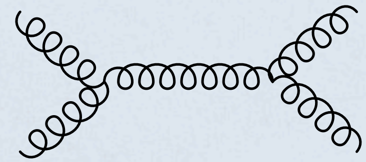


Jouttenus, Stewart, Tackmann,
Waalewijn; H+j

But so far, precision jet mass calculations only in boson+ 1 jet events!

… but faces practical challenges.

- ⋆ Jet mass so far only for boson+jet events
  (or single phase space point for dijets)



- ⋆ But jet mass data is primarily from dijets
- ⋆ τ_2/τ_1 starts at pp->jj+X

9 Color Structures
Color mixing in operator evolution:

$$\begin{pmatrix} C_A(U-2T) & 0 & 0 & 0 & 0 & 0 & -T & U-T & 0 \\ 0 & -C_AT & 0 & 0 & 0 & 0 & 0T-U & -U & \\ 0 & 0 & C_A(U-2T) & 0 & 0 & 0 & -T & U-T & 0 \\ 0 & 0 & 0 & C_A(U-T) & 0 & 0 & T & 0 & U \\ 0 & 0 & 0 & 0 & -C_AT & 0 & 0 & T-U & -U \\ 0 & 0 & 0 & 0 & 0 & C_A(U-T) & T & 0 & U \\ U-T & 0 & U-T & U & 0 & U & 2C_A(U-t) & 0 & 0 \\ -T & -U & -T & 0 & -U & 0 & 0 & -2C_AT & \\ 0 & T-U & 0 & T & T-U & T & 0 & 0 & 0 \end{pmatrix}$$

Why no dijets?

- Precision calculations difficult and tedious
- Must be recomputed for every observable.

Phase space integrals sometimes include perturbatively singular regions; require multiple subtractions

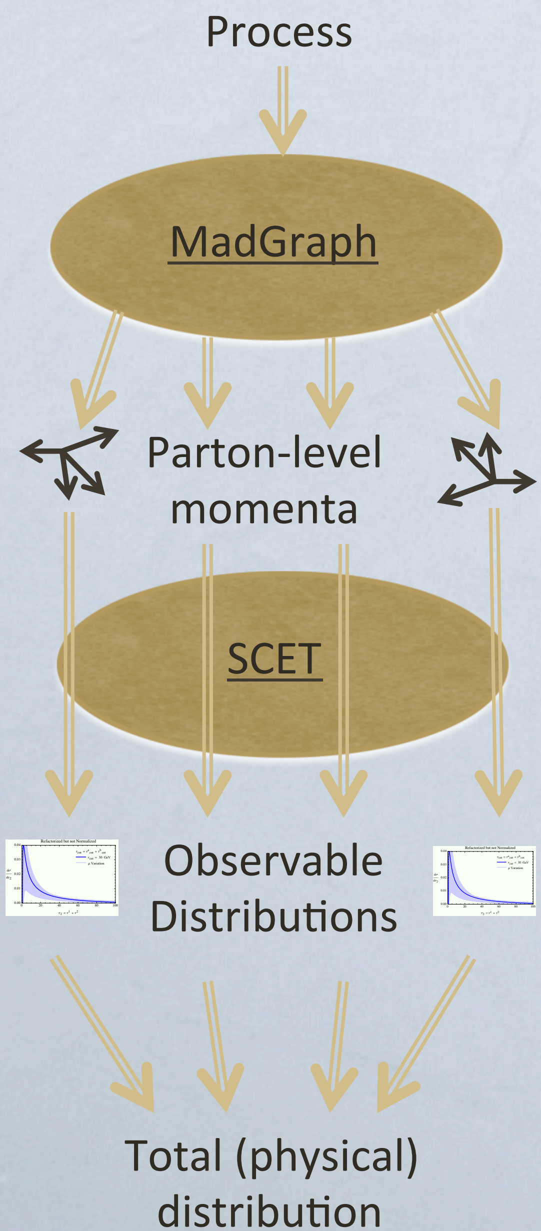
Now go to V+2j:
2 to 3 phase space with mass!

We'd like to use existing tools to simplify calculations and move forward.

Monte Carlo vs Analytic Methods

Factorization	Monte Carlo	Analytic Methods (e.g. SCET)
Hard Interaction	e.g. Madgraph • Exact tree level matrix elements • Monte Carlo sampling phase space • Systematically improvable (NLO…)	Hard function • Different for each process • Phase space integrals tedious even at tree-level • Color structures subtle
Showering, Hadronization, etc	e.g. Pythia, Herwig • LL Resummation • Precision hard to understand • Not systematically improvable	Jet, Soft functions • Systematically improvable, for inclusive enough observables • Mostly universal functions • Mostly universal integrals

Using Monte Carlo in SCET



Part 1: MadGraph

- Gives weighted/unweighted sampling of phase space
- Hard function computed.
- Color structure usually marginalized, but can be extracted

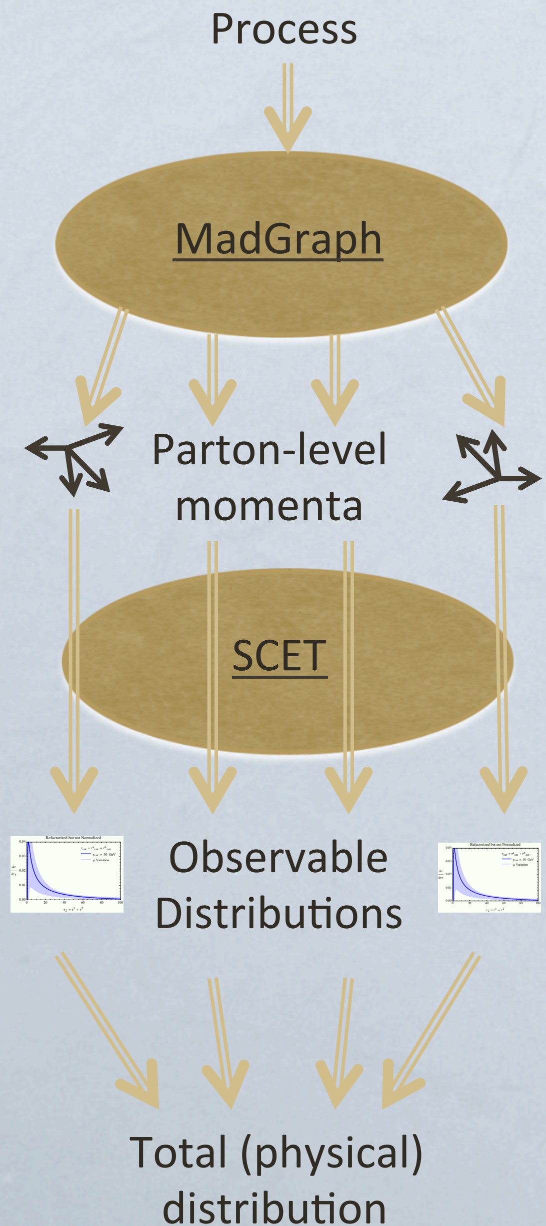
Part 2: SCET

- Generate distribution for each MadGraph phase space pt
- For given phase space, integrals tractable

Part 3: Sum

- Sum distributions across phase space points
- Use weights from MadGraph
- Does hard integral (numerically)

Using Monte Carlo in SCET

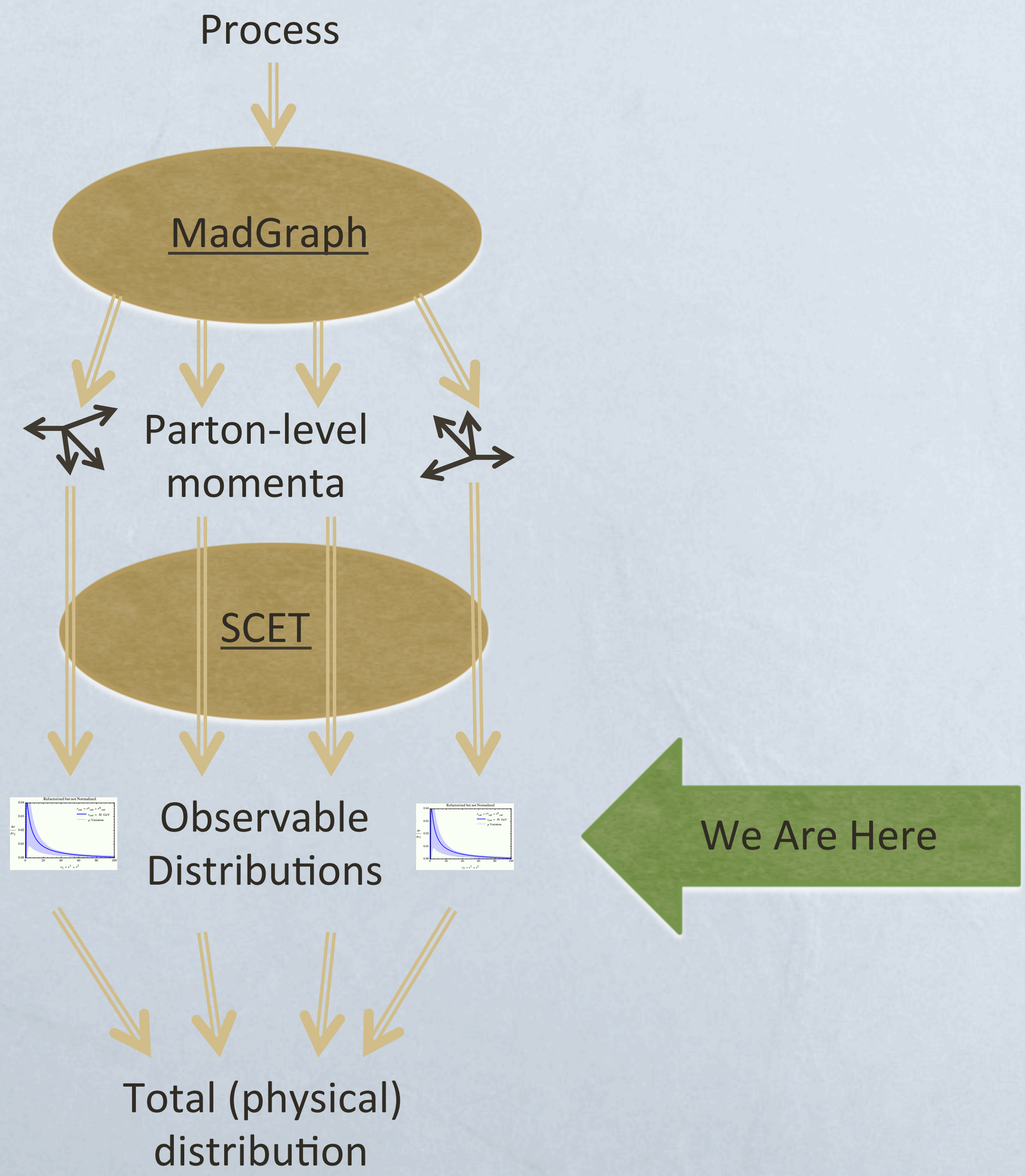


For Monte Carlo Enthusiasts	For SCET Enthusiasts
1. Generate events (e.g. MadGraph) 2. Compute analytic distribution for each each event 3. Sum appropriately	1. Factorization theorem: $\sigma = \int HJJS$ 2. Compute jet, soft pieces analytically 3. Compute hard function and phase space integral numerically (with MadGraph)
• Alternative to Pythia with less tuning • Semi-analytic method provides imprecision control	• Just using MadGraph to numerically evaluate difficult integrals. • Semi-automatic method provides extensibility

Potential Reach

- Could be used for lots of observables:
  - Dijet events (e.g. in pp->Wjj) :
    - Jet mass
    - 2-subjettiness (not τ_2/τ_1)
  - Multi-jet events
- Set up machinery once, get results for many observables with less additional work
- Explore subtle QCD effects (e.g. color mixing)
- Can be systematically improved to NNLL (up to NGLs) with improved Monte Carlo generators

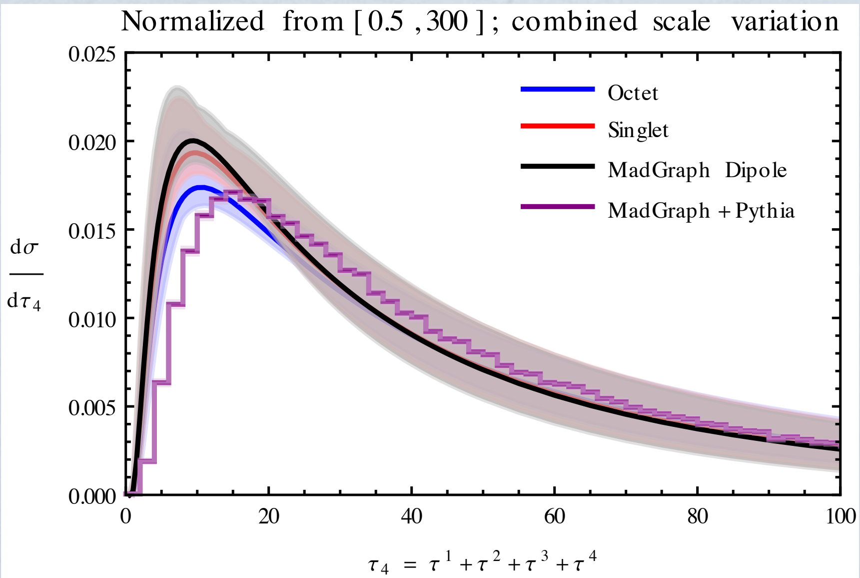
Preliminary Results



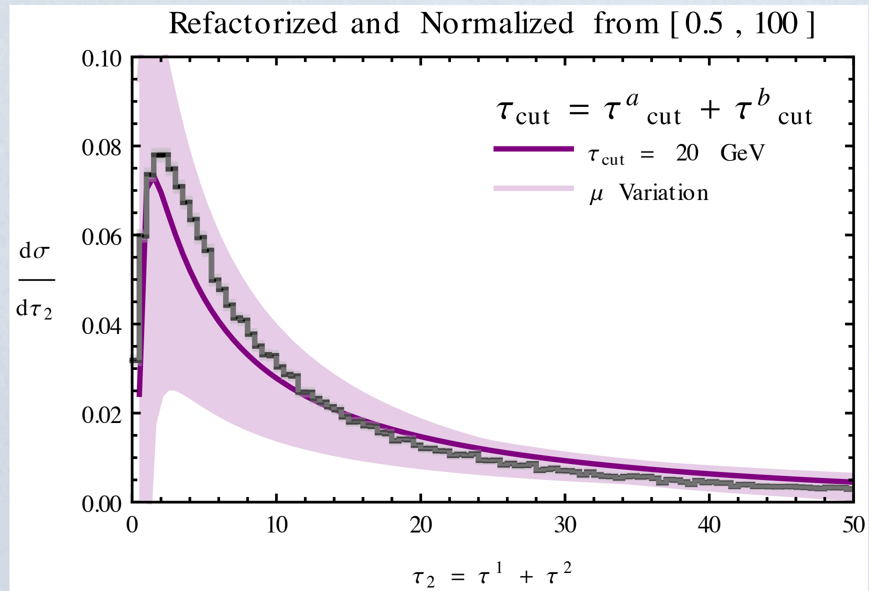
Preliminary Results

(Work-in-progress)

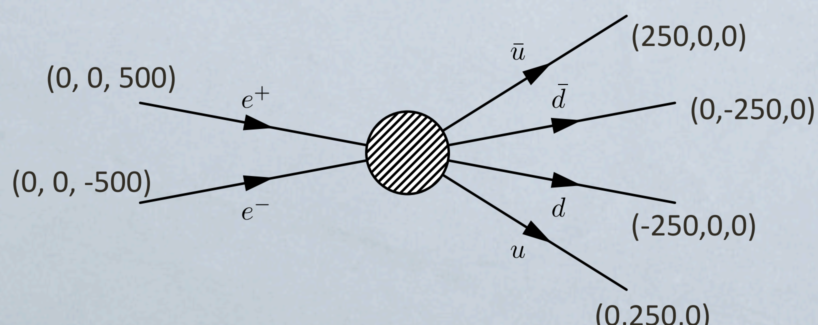
4-jettiness in ee



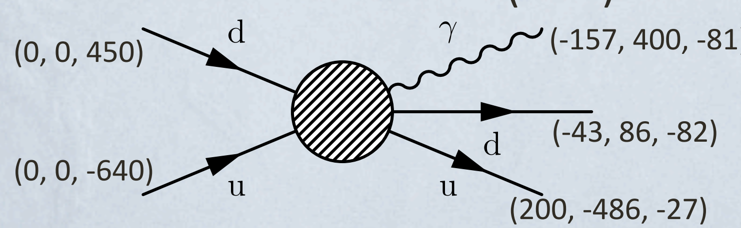
2-jettiness at LHC



Channel & momenta (GeV)



Channel & momenta (GeV)



12

Conclusions

* Monte Carlo generators can help simplify tedious and non-universal parts of precision calculations
* Combining MadGraph and SCET allows semi-numerical, semi-analytic computation of various distributions
* Precision and accuracy analytically controlled; can be systematically improved
* Non-universal pieces automated; can be extended to different processes
* Example applications:
  * Jet mass in dijet events,
  * n-subjettiness in boson+jj events.

Thank you

Comparison

	Comparison to Monte Carlo	Comparison to SCET
Pros of hybrid method	• Semi-analytic; imprecision understood	• Semi-automatic; easier to compute many different observables
Cons of hybrid method	• Only semi-automatic; takes more work • Less universally applicable; only valid when logs exponentiate	• Only semi-analytic; no analytic formula at the end • Requires Monte Carlo generators