Groomed jet mass

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Physics Seminar — Senior Thesis Talks

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2 Quantum chromodynamics

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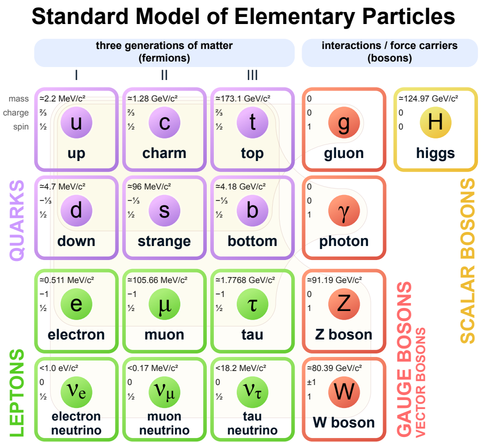
The Standard Model



Searching for new physics

- Direct particle searches
  - Resonance searches
  - Low-background detectors

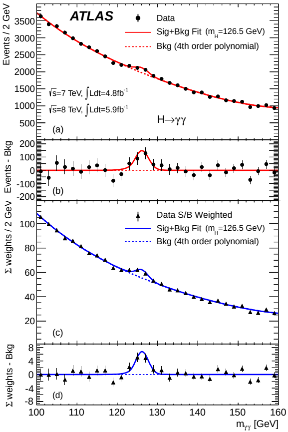


Figure: Higgs boson discovery by ATLAS, from [1]

Searching for new physics

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  - Resonance searches
  - Low-background detectors
- **Precisions measurements**

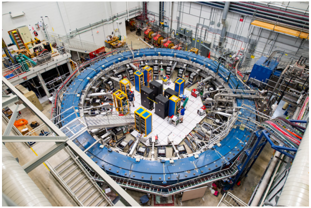
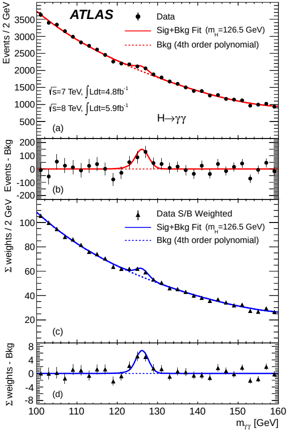


Figure: Muon $g-2$ experiment, from https://vms.fnal.gov/gallery/view?id=41



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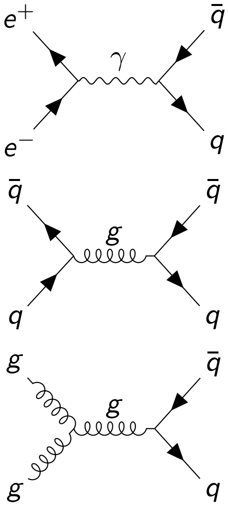
Quantum chromodynamics (QCD)

- Theory of the strong force
- Like the electric force
  - Particles have **color charge**
  - QCD version of photon is the **gluon**
- Interesting nonlinear dynamics:
  - Self-coupling
  - Scale-invariance
  - Confinement



Jets

- High-energy quarks and gluons $\rightarrow$ collimated sprays of hadronic particles in detector
- These sprays are called **jets**
- Rich substructure can be used to probe Standard Model
  - **Jet mass**, number of particles, number of 'prongs', etc
  - Would like, e.g., to measure strong coupling constant α_s

Jet example

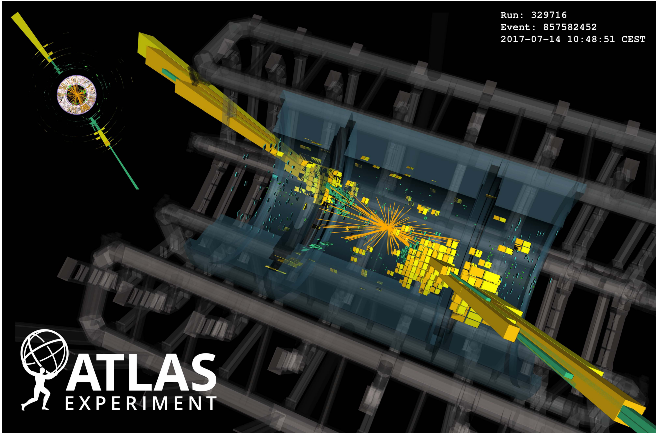


Figure: Dijet (two-jet) event captured by ATLAS in 2017. From https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Physics

Experimental problems with jets

- Other events in the detector might contaminate measurements

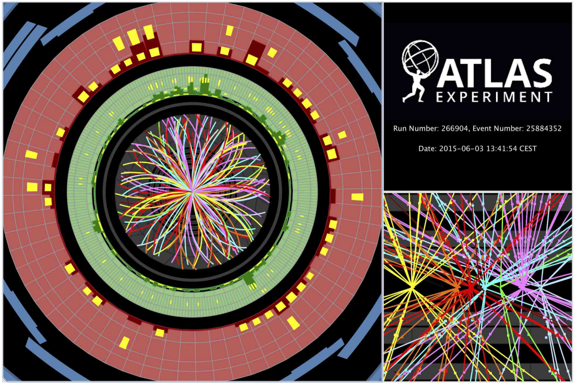


Figure: Collision event with significant 'pile-up' at ATLAS in 2015. From https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Collisions

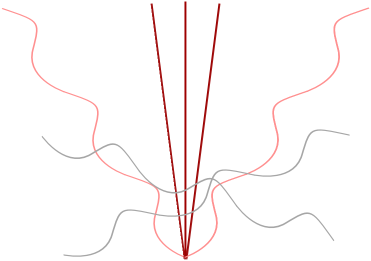
Theoretical problems with jets

- Very difficult to characterize corrections to jet substructure from out-of-jet radiation
  - Hadronization is complicated
- Separation between energy scale of jet and energy scale of background causes problems
  - Produces large so-called 'non-global logarithms' [2]
- If we have two scales ω_1 and ω_2 with $\omega_1 \ll \omega_2$, might find large terms like

$$\log \frac{\omega_1}{\omega_2}$$

Solution: jet grooming

- **Idea:** clear away low-energy (**soft**) radiation below some threshold z_{cut}
  - We lose some jet events, but mostly background events



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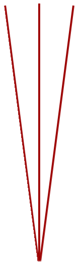
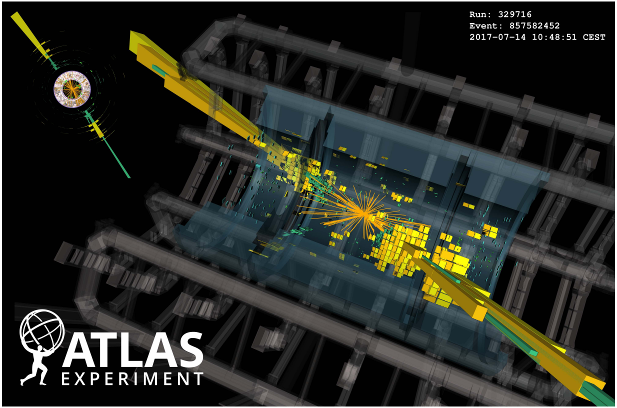


Observable of choice

- We want to look at $e^+e^- \rightarrow$ hemisphere jets events
- Measure the mass of the heavier hemisphere



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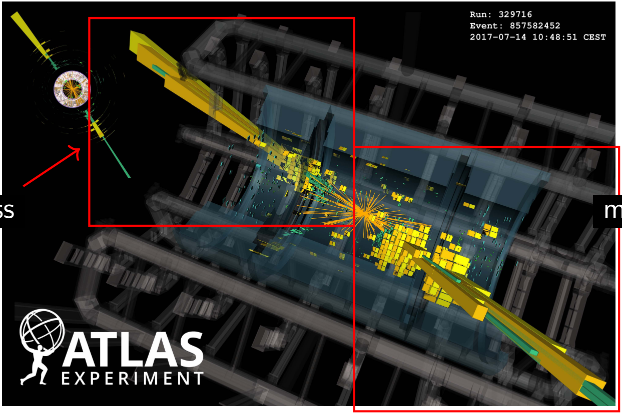
measure mass



measure mass

Recent experimental measurement

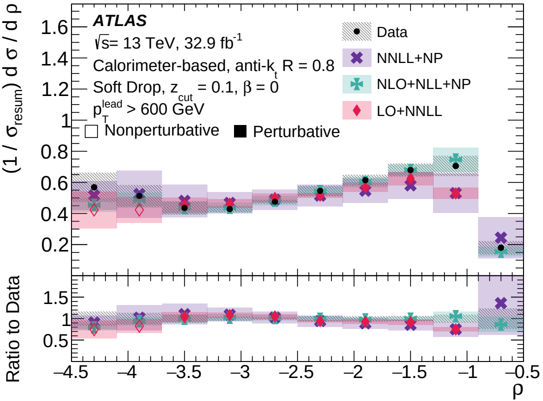


Figure: (Dimensionless) groomed jet mass measurement by ATLAS in 2020. (Note: this is not heavy hemisphere mass). From [3]

Recent theoretical results

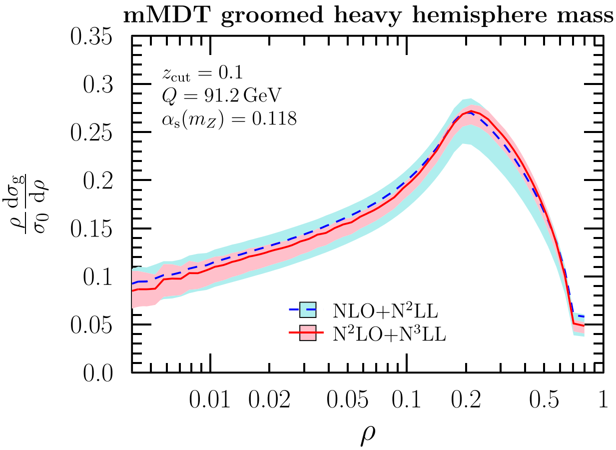
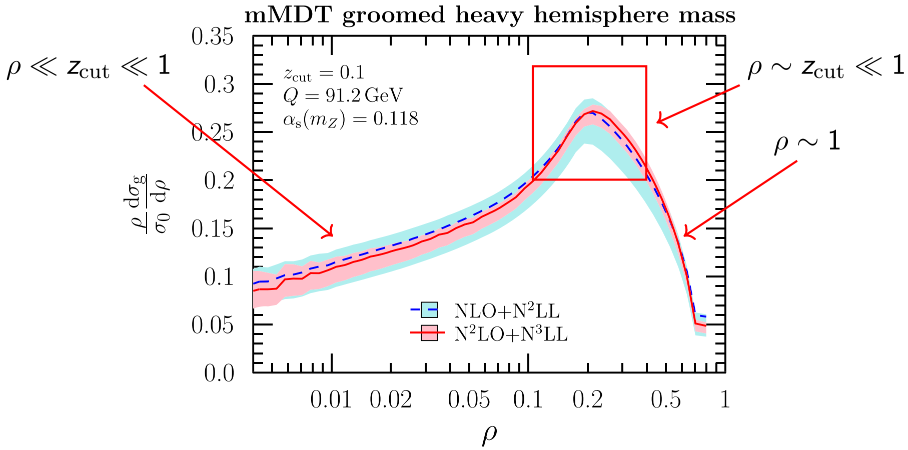


Figure: Most precise theoretical calculation of groomed jet mass to date by Kardos, Larkoski, and Tròcsànyi. From [2]

Recent theoretical results



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My thesis: calculating the cusp region

- Calculations in QCD often must be done as a Taylor expansion
- **Goal:** perform an 'all-orders' calculation in the cusp region
  - Overall expression which describes all terms of the expansion in terms of an integral
  - Accuracy can be increased by calculating higher-order terms of integrand
- Terms take the form [4]

$$
\begin{aligned}
F(\mu) = F(\mu_0) \exp \Bigg[2 \int_{\alpha_s(\mu_0)}^{\alpha_s(\mu)} \frac{d\alpha}{\beta(\alpha)} \Gamma_F(\alpha) \int_{\alpha_s(\mu_0)}^{\alpha} \frac{d\alpha'}{\beta(\alpha')} \\
+ \int_{\alpha_s(\mu_0)}^{\alpha_s(\mu)} \frac{d\alpha}{\beta(\alpha)} \gamma_F(\alpha) \\
+ \log \frac{\mu_0^2}{\mu_1^2} \int_{\alpha_s(\mu_0)}^{\alpha_s(\mu)} \frac{d\alpha}{\beta(\alpha)} \Gamma_F(\alpha) \Bigg]
\end{aligned}
$$

Day-to-day work

- Many weird, big integrals
- Lots of fun mathematical trickery involved for the curious
- Working in $4 - 2\epsilon$ dimensions so that we can calculate divergent integrals

$$\int d^4p\, f(p) = \infty$$

$$\int d^{4-2\epsilon}p\, f(p) < \infty$$

- And more!

References

[1] ATLAS Collaboration. Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC. *Phys. Lett. B*, 716(1):1–29, September 2012.

[2] Adam Kardos, Andrew J. Larkoski, and Zoltán Trócsányi. Groomed jet mass at high precision. *Physics Letters B*, 809:135704, October 2020.

[3] ATLAS Collaboration. Measurement of soft-drop jet observables in pp collisions with the ATLAS detector at $\sqrt{s} = 13$ TeV. *Phys. Rev. D*, 101(5):052007, March 2020.

[4] Christopher Frye, Andrew J. Larkoski, Matthew D. Schwartz, and Kai Yan. Factorization for groomed jet substructure beyond the next-to-leading logarithm. *J. High Energ. Phys.*, 2016(7):64, July 2016.