Using the W as a standard candle to reach the top

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NEW!

[arXiv:2311.02157], [Phys.Rev.D.107.114002 (2022)], [arXiv:2407.12900]

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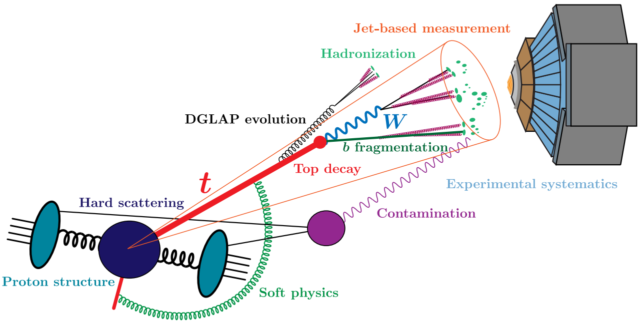
Challenges in top quark mass measurements

- Top quark measurements at hadron colliders are complicated!
- Hadronic initial states, pileup, underlying event, soft QCD, parton shower, hadronization



Challenges in top quark mass measurements

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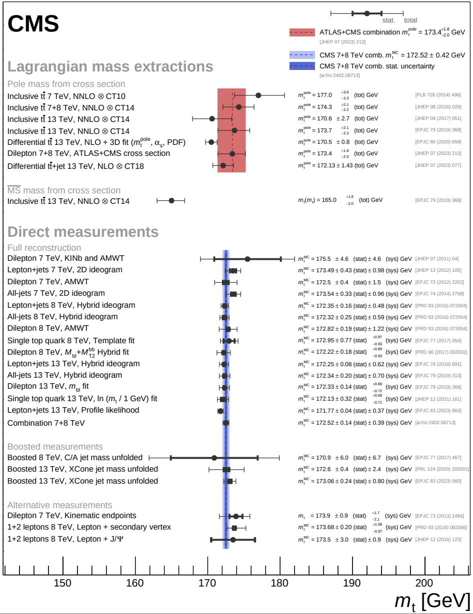


Multiple strategies to measure the top quark mass:

- **Direct** measurements: very precise but ambiguities in m_t^{MC}
- Extractions from **cross sections**: Less precise, often depend on definition of a stable top quark particle, $t\bar{t}$ threshold sensitive to non-trivial corrections
- **Boosted** measurements: defined at level of stable particles, high sensitivity to m_t, but theory and experimental phase space not compatible yet

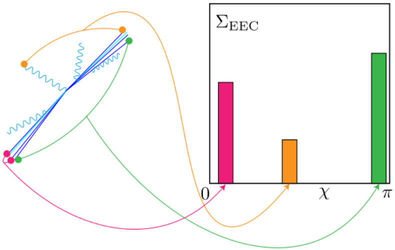
Energy correlators

Energy-Energy Correlatior: One of the very first event shapes and a QCD correlation observable:

Basham et al. 1978

$$\frac{\mathrm{d}\Sigma}{\mathrm{d}\cos\chi} = \sum_{ij} \int \frac{E_i E_j}{Q^2} \delta(\vec{n}_i \cdot \vec{n}_j - \cos\chi) \mathrm{d}\sigma$$

Multiple entries per event!



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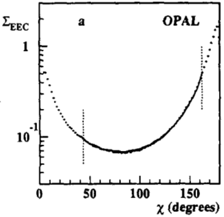


[Opal collboration, Z. Phys. C59 (1993) 21]

Well explored field, to be extended in top

[Basham, Brown, Ellis, Love, PRL 41, 1585 (1978)], [Schindler, Stewart, Sun, arXiv:2305.19311], [Lee, Pathak, Stewart, Sun, arXiv:2405.19396], ...

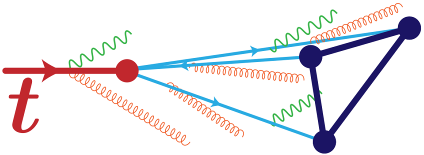
Energy correlators in the top decay

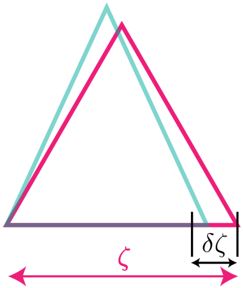
- Triplet energy correlator captures opening angle of top decay

$\rightarrow$ Sensitivity to boost (p_T) and mass m_t

1. Find all triplets of particles
2. For each triplet: entry at $\zeta = \frac{\sum \Delta R_{ij}^2}{3}$ with weight $w = \frac{(p_{\mathrm{T},1} p_{\mathrm{T},2} p_{\mathrm{T},3})^n}{p_{\mathrm{T,jet}}^n}$ (n: exponent of choice)

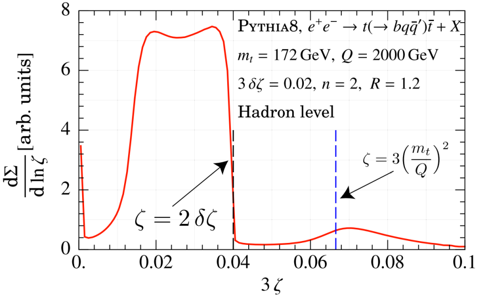
- Equilateral triangle configuration suppresses collinear contributions

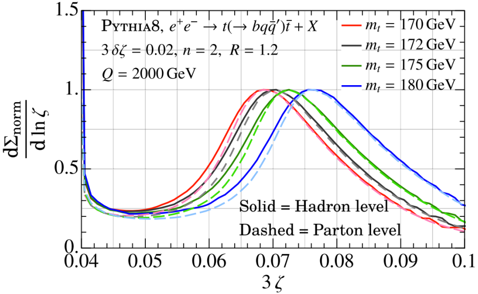




Example in ee collisions

- Example in $pp \to t\bar{t}$
- Here, replace $p_{T,jet}$ with $Q = \sqrt{s}$
- Peak at $\zeta \sim 3\left(\frac{m_t}{Q}\right)^2$
- Non-perturbative effects in the peak very small
- Sensitivity to m_t





Energy correlator in pp collisions

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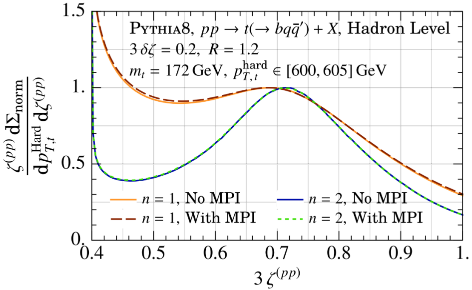
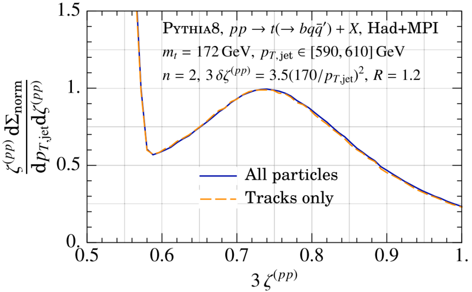
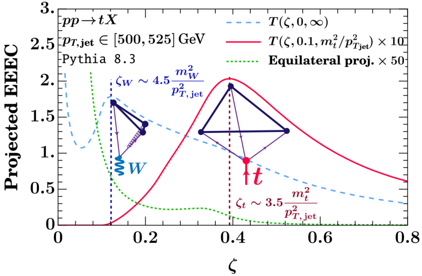


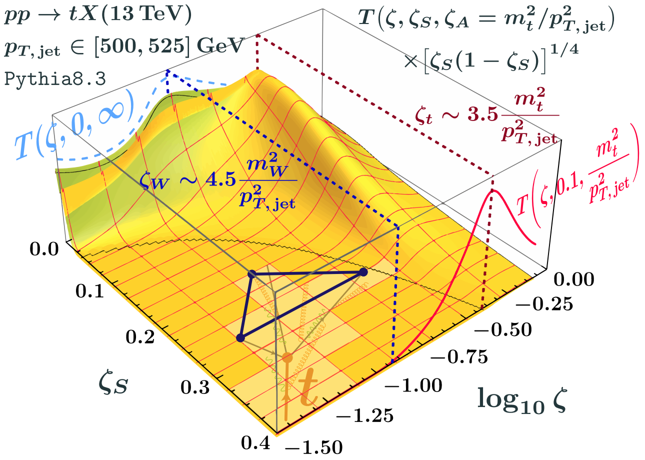


- In pp use top decays reconstructed in a single jet
- Energy scale is now jet p_T
- Robust against MPI
- Measurement can be performed using tracks only!
- But peak position still depends on jet p_T, which results in large uncertainties due to jet calibration

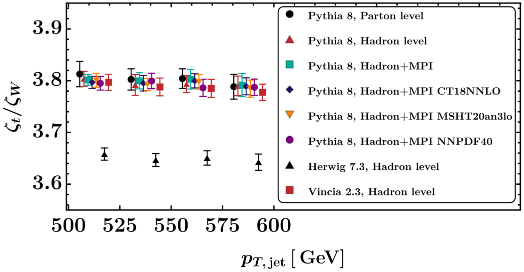
The W as a standard candle

- If we allow the shortest side of the triangle to be small, a W peak emerges



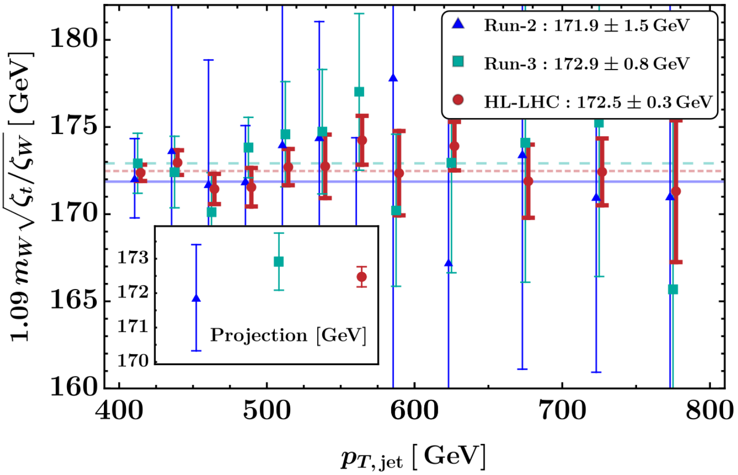


Ratio of top and W



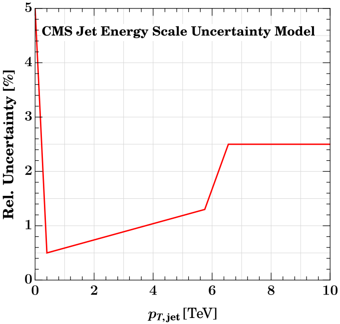
- For now, measure ratio of peak positions (with calculations available, the measurement would be performed using the full distributions)
- Jet p_T dependence eliminated in top to W ratio
- Non-perturbative effects very small
- Precise value of the ratio can be calculated. Here it differs between Pythia and Herwig because of different showers

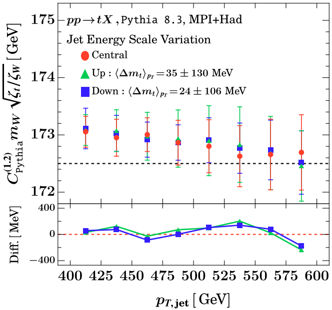
Statistical feasibility

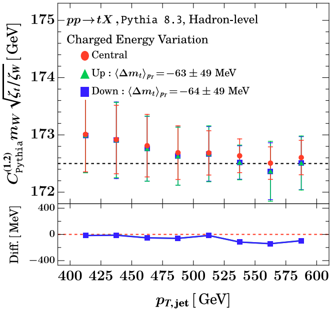


- Measurement experimentally feasible at HL-LHC!
- Statistical uncertainty $<$ 1 GeV already with Run 3

Systematic uncertainties - Jet energy scale

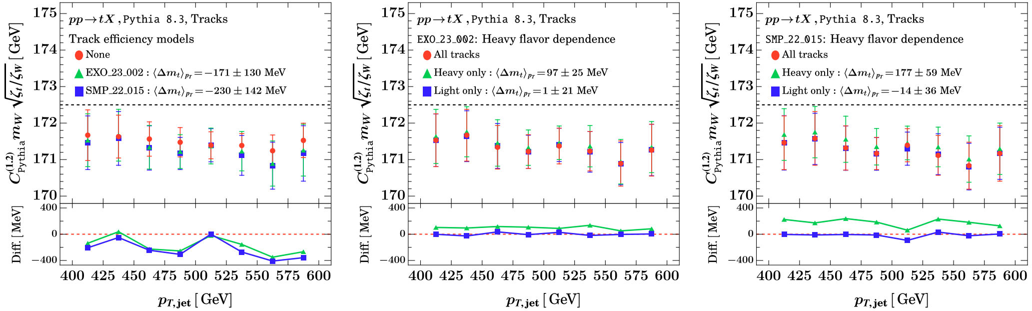






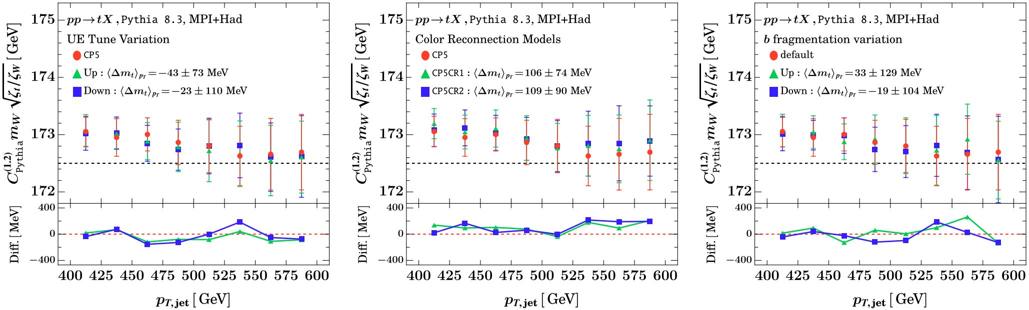
- Variations of jet p_T (oriented at CMS jet energy uncertainty) and constituent p_T lead to shifts well below 200 MeV

Systematic uncertainties - Track efficiency



- Vary tracking efficiency (constant 3% or p_T-dependent)
- Second model where we only vary the light/heavy tracking efficiency
- Estimates have larger uncertainties, still small effect

Systematic uncertainties - Modelling



- Also studied modelling parameters that enter via (simulation-based) unfolding
- Variations of UE tune, color reconnection, b fragmentation
- All smaller than 200 MeV

Summary

- Energy correlators exhibit high m_t sensitivity in the perturbative region
- Ratio of top and W make it robust against leading uncertainties in existing measurements
- Possibility of a high-precision m_t extraction in a well-defined mass scheme
- Paper with more studies (jet radius, ISR, FSR, PDFs, NLO matching,...) on arXiv since yesterday: [arXiv:2407.12900]!