Quantum Entanglement at the ATLAS Experiment

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on behalf of the ATLAS Collaboration

Quantum Information with Top Quarks and Higgs Bosons
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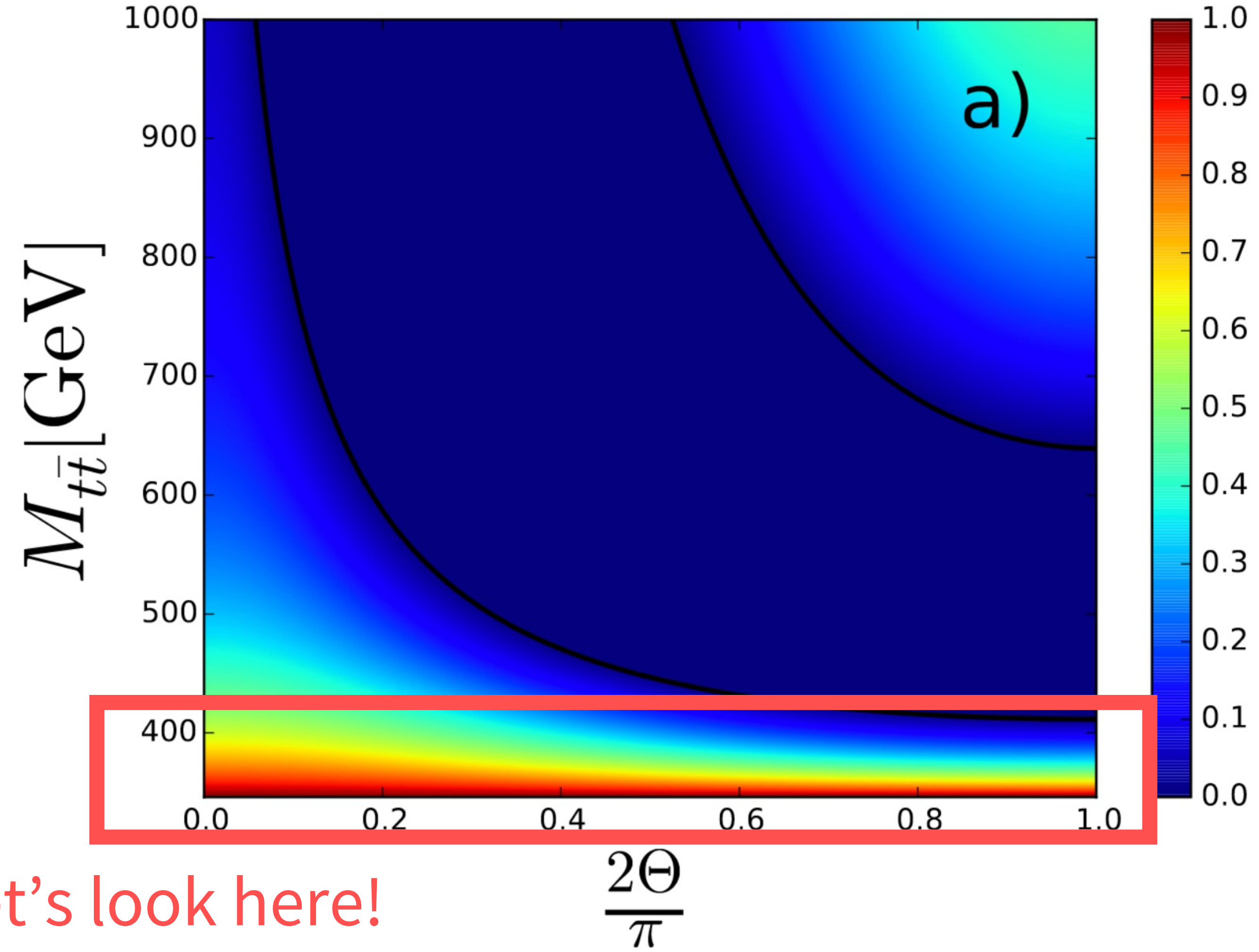
University of Glasgow

THE ROYAL SOCIETY

ATLAS EXPERIMENT

The Measurement

- Entanglement in $t\bar{t}$ pairs
- Bipartite quantum system
- Dileptonic decay channel



Let's look here!

Entanglement Observable

Define the observable

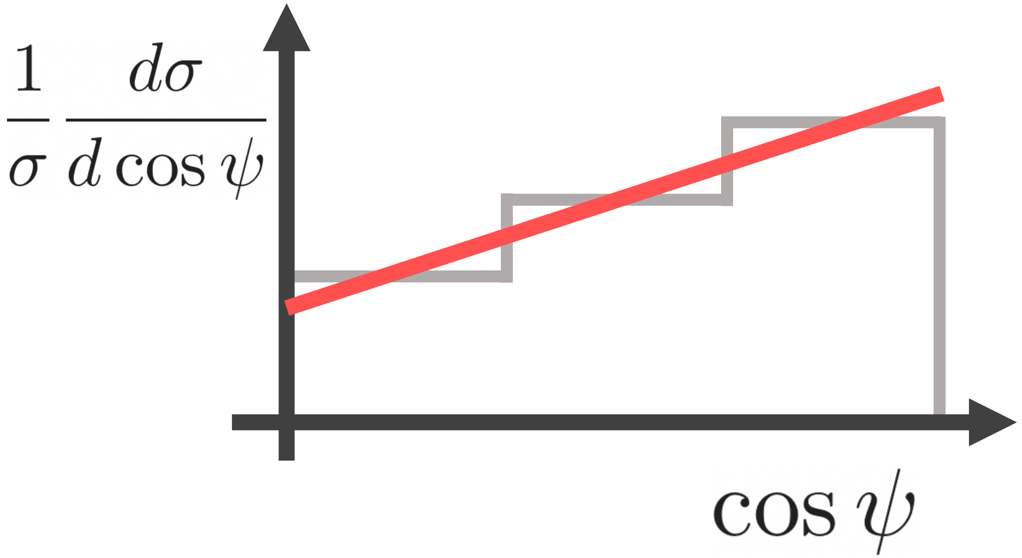
$$D = \frac{\mathrm{tr}[C]}{3} < -\frac{1}{3}$$

Access through:

$$\left.\frac{1}{\sigma}\frac{d\sigma}{d\cos\psi}\right|_{m_{t\bar{t}}<M} = \frac{1}{2}(1 - D\cos\psi)$$

Selecting events less than some mass cut

Angle between charged leptons (boosted into parent top's frame)



Method

1. Apply invariant mass cut.
2. Boost leptons into parent tops' frames.
3. Generate cos phi distribution.
4. Unfold to parton-level.
5. Extract D through linear fit.

Kinematic Reconstruction

Several top reconstruction techniques investigated:

- NeutrinoWeighting
- Sonnenschein method [0603011]
- Ellipse method [1305.1878]

The Ellipse method was selected (trade-off of accuracy and expediency)

Other methods implemented as back-ups for when Ellipse fails.

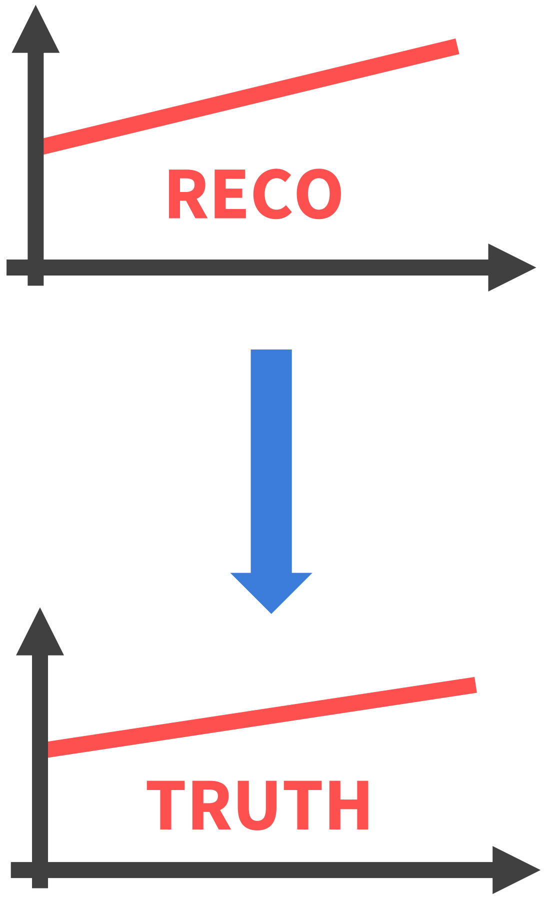
Unfolding Strategy

Unfolding techniques investigated:

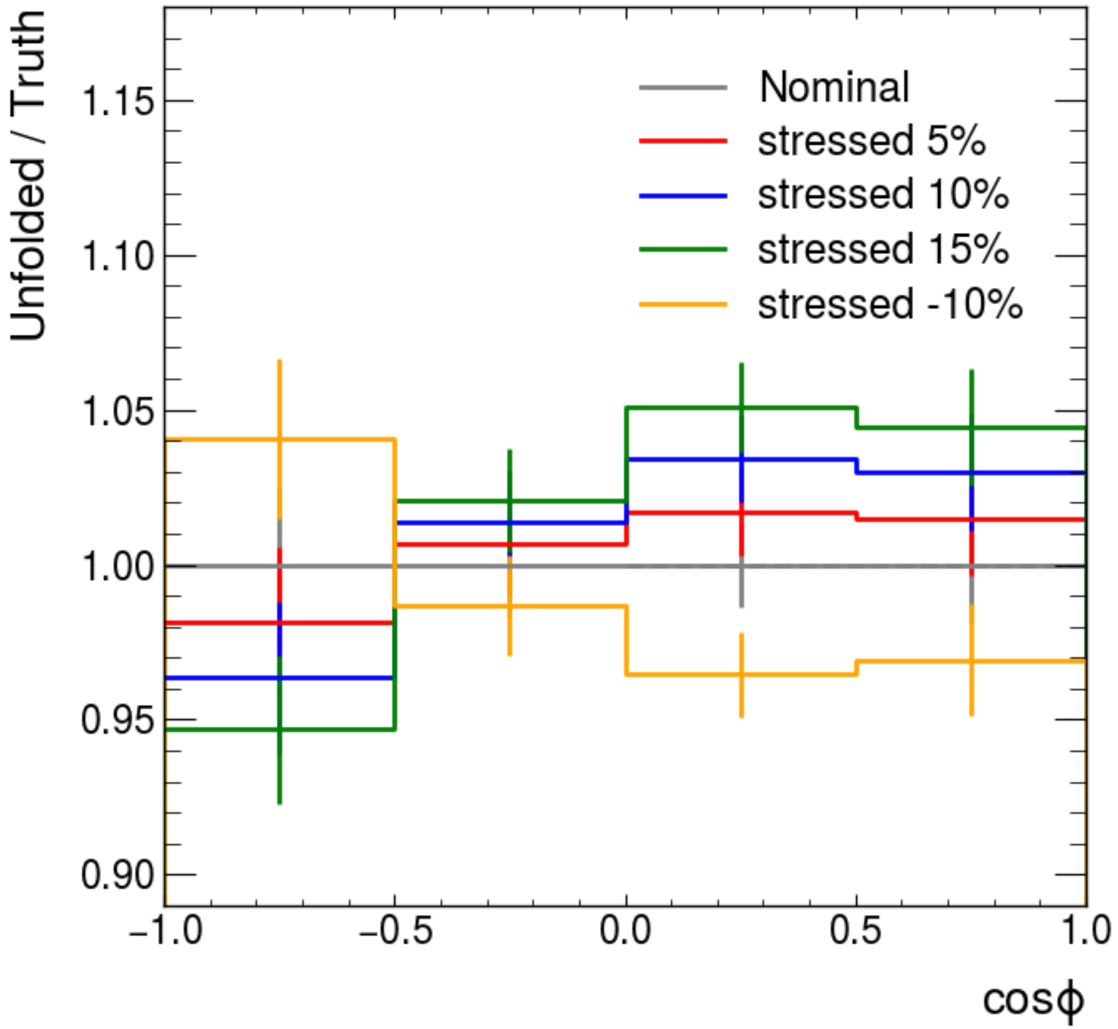
- Iterative Bayesian unfolding
- Profile likelihood unfolding
- SVD unfolding

Check unfolding not (too) biased to SM signal.

(Response matrix derived from SM Monte Carlo)



How things unfolded…



Inject a change in slope, and unfold this new distribution.

We were not able to unfold in an unbiased manner.

The Cause

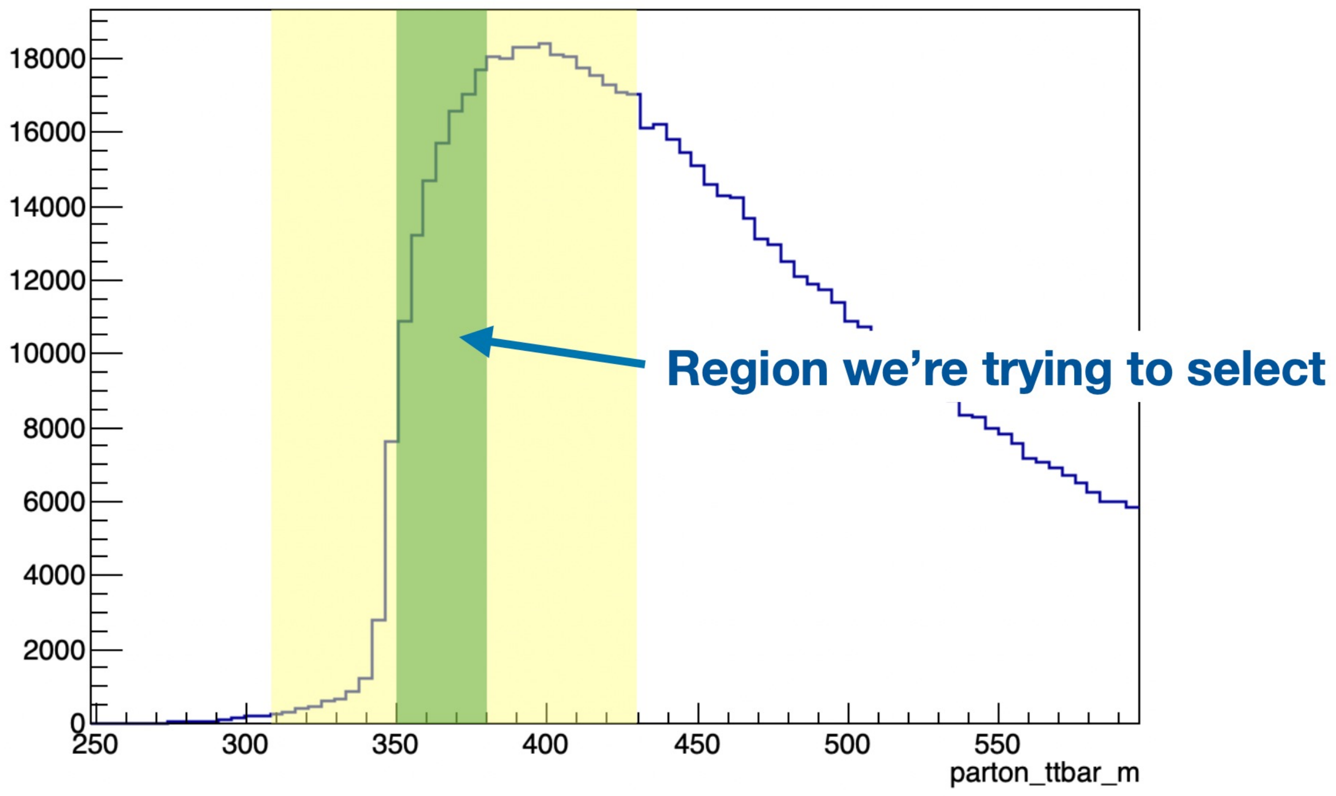
- Poor efficiencies:

Very few reco-level events have corresponding parton-level event

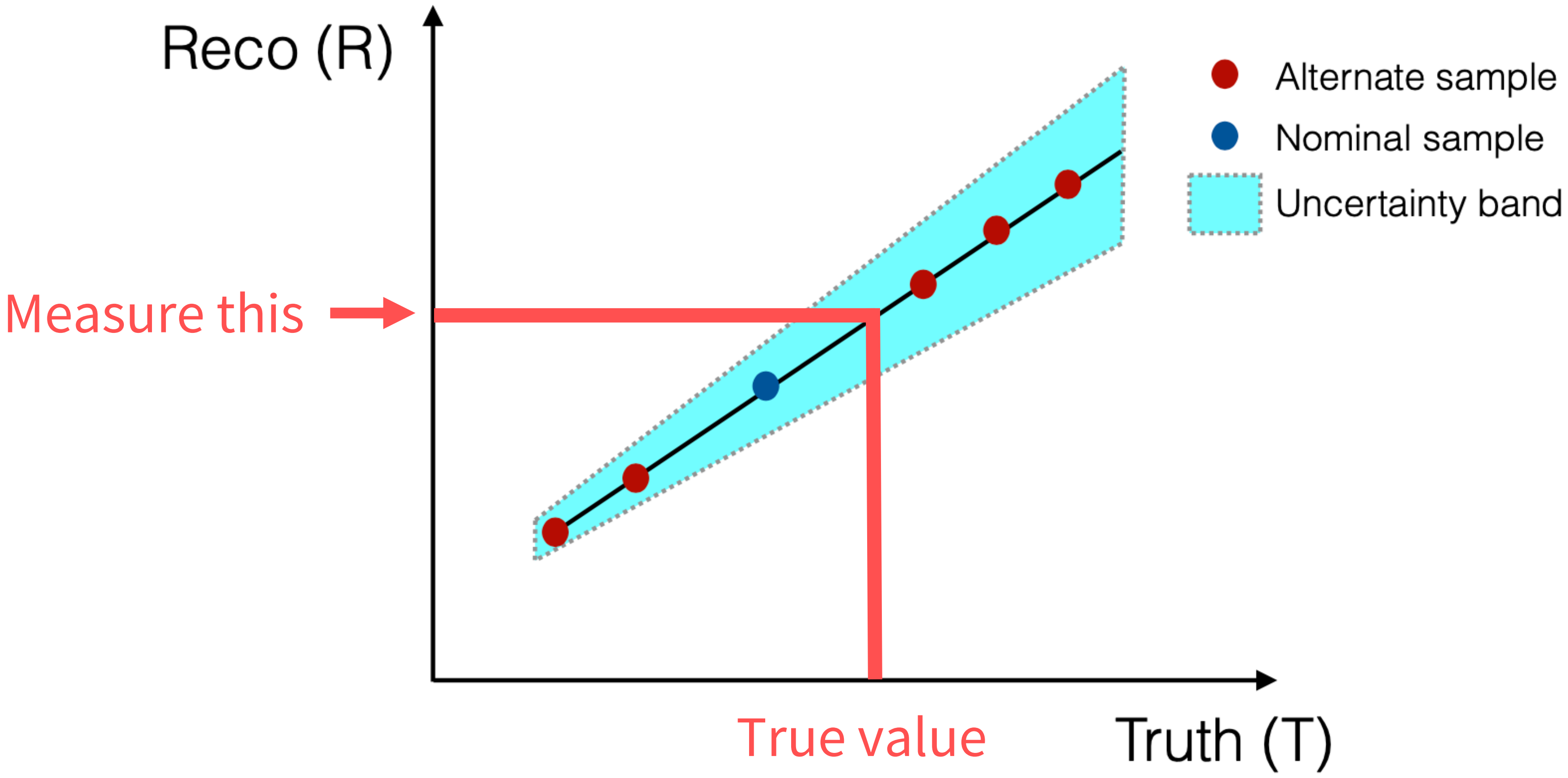
- Driven by poor top quark reconstruction resolution

Phase-space too narrow

- Strong requirement for better top quark reconstruction!!



Calibration Curve



Requires range of different MC samples with different values of D.

Calibration Curve

Positives:

+ Simple to implement
+ Robust method
+ Avoid unfolding issues

Negatives:

- How to generate alternative samples?
- No cosphi distribution
- No unfolding advantages, such as constrained statistical uncertainty.

Summary

- Simple observable from single differential cross-section.
- Phase-space too narrow to unfold successfully.
- Real requirement for superior top reconstruction.
- Use a calibration curve instead to “unfold” single parameter D.

Auxiliary Material

ATLAS Measurements

Pedigree in measuring top properties in dileptonic channels.

PRL **108,** 212001 (2012) PHYSICAL REVIEW LETTERS week ending 25 MAY 2012

Observation of Spin Correlation in $t\bar{t}$ Events from pp Collisions at $\sqrt{s} = 7$ TeV Using the ATLAS Detector

G. Aad *et al.**
(ATLAS Collaboration)
(Received 19 March 2012; published 24 May 2012)

A measurement of spin correlation in $t\bar{t}$ production is reported using data collected with the ATLAS detector at the LHC, corresponding to an integrated luminosity of 2.1 fb^{-1}. Candidate events are selected in the dilepton topology with large missing transverse energy and at least two jets. The difference in azimuthal angle between the two charged leptons in the laboratory frame is used to extract the correlation

PRL **114,** 142001 (2015) PHYSICAL REVIEW LETTERS week ending 10 APRIL 2015

Measurement of Spin Correlation in Top-Antitop Quark Events and Search for Top Squark Pair Production in pp Collisions at $\sqrt{s} = 8$ TeV Using the ATLAS Detector

G. Aad *et al.**
(ATLAS Collaboration)
(Received 16 December 2014; published 8 April 2015)

A measurement of spin correlation in $t\bar{t}$ production is presented using data collected with the ATLAS detector at the Large Hadron Collider in proton-proton collisions at a center-of-mass energy of 8 TeV, corresponding to an integrated luminosity of 20.3 fb^{-1}. The correlation between the top and antitop quark spins is extracted from dilepton $t\bar{t}$ events by using the difference in the azimuthal angle between the two charged leptons in the laboratory frame. In the helicity basis the measured degree of correlation corresponds to ... performed for pair ...

Eur. Phys. J. C (2020) 80:754
https://doi.org/10.1140/epjc/s10052-020-8181-6
THE EUROPEAN PHYSICAL JOURNAL C
Check for updates
Regular Article - Experimental Physics

Measurements of top-quark pair spin correlations in the $e\mu$ channel at $\sqrt{s} = 13$ TeV using pp collisions in the ATLAS detector

ATLAS Collaboration*
CERN, 1211 Geneva 23, Switzerland

Received: 19 March 2019 / Accepted: 23 June 2020 / Published online: 19 August 2020

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)
Submitted to: JHEP
CERN-EP-2022-166
26th August 2022

Evidence for the charge asymmetry in $pp \to t\bar{t}$ production at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration

Experimental Requirements

- High object-identification efficiencies
- Performant b-tagging
- Top kinematic reconstruction
- Correction of detector effects

But all in a narrow region of phase-space...