First Measurements of Spin Correlation Using Semi-leptonic $t\bar{t}$ Events at ATLAS

Why Top?

- Top quarks decay before hadronization
- Allows to study spin of a bare quark

Why Spin?

- Involves $t\bar{t}$ production and decay
- Perfect probe of SM/BSM physics

Why Lepton+Jets?

- BSM effects different for jets/leptons
- Challenging reconstruction

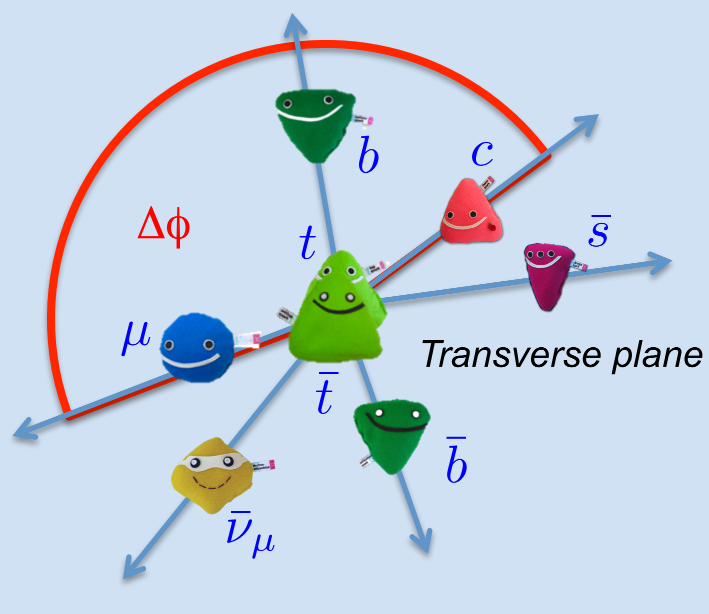
Summary

- In SM: $t\bar{t}$ pairs unpolarized, but with correlated spins (via strong production)
- Correlation measurement tests spin, production and decay of $t\bar{t}$ pairs
- First LHC measurement of $t\bar{t}$ spin correlation in the lepton+jets channel
- Reconstruction using explicit u/d type quark separation
- High sensitivity of used Δϕ distribution to $t\bar{t}$ modeling
- Combination of two hadronic analyzers reduces uncertainties significantly

Combined fit result:

f_{SM} = 1.12 ± 0.11 (stat.) ± 0.22 (syst.)
(SM: f_{SM} = 1.0)

Observable



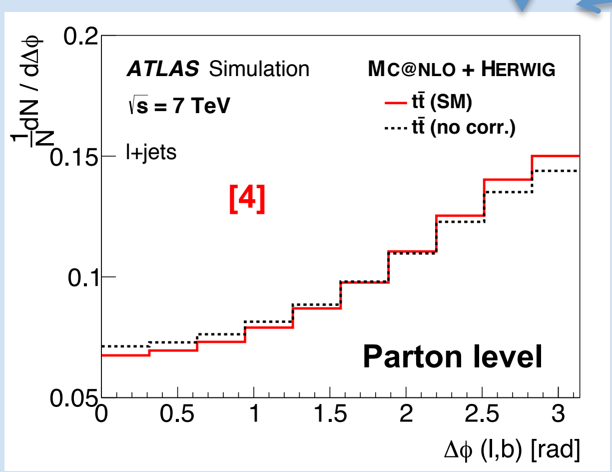
Δϕ(a_1, a_2) in the lab frame

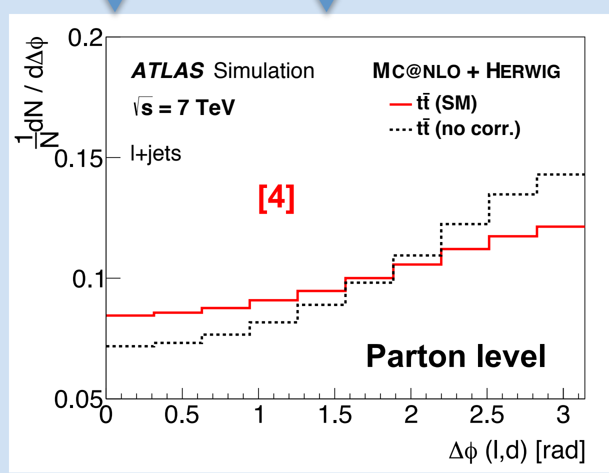
- Chosing one analyzer a_i for each top
- No full event reconstruction needed
- Sensitive to *gg* fusion production [1]

Spin Analyzers

Two spin analyzers needed. Spin analyzing power determines separation power between correlated and uncorrelated $t\bar{t}$ samples

Spin analyzing power [2]	b quark	W⁺	l⁺	d/s quark	u/c quark
α_i (NLO)	-0.390	0.390	0.998	0.930	-0.31





b quark:
+ Easy to reconstruct
− Low analyzing power

down type quark:
+ High analyzing power
− Hard to reconstruct

Dataset and Selection

- 4.6 fb^{-1} at 7 TeV
- e or μ + ≥4 jets (≥1 b-tag)
- e+jets: E_T^{miss} > 30 GeV, m_T^W > 60 GeV
- μ+jets: E_T^{miss} > 20 GeV, m_T^W+E_T^{miss} > 60 GeV

	e+jets	μ+jets
W+jets (DD/MC)	2320	4840
Z+jets (MC)	450	480
Fake leptons (DD)	840	1830
Single top (MC)	1190	1980
Diboson (MC)	50	70
Total (non $t\bar{t}$)	4830	9200
$t\bar{t}$ (MC)	**17220**	**28330**
Total Expected	22100	37500
Total Observed	21770	37645

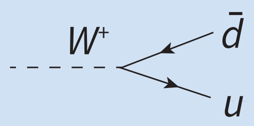
Reconstruction of Hadronic Analyzers via KLFitter [3]

- Maximizing likelihood for each of the 4!=24 parton/jet permutations

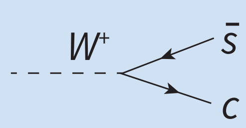
$$\mathcal{L} = \prod_{\mathrm{W,\,t}} B\left(m_{\mathrm{reco}} \mid m_{\mathrm{true}}\right) \cdot \prod_{\mathrm{jets}} W\left(E_{\mathrm{jet}} \mid E_{\mathrm{parton}}\right) \cdot$$

$$W\left(\tilde{E}_{\mathrm{x}}^{\mathrm{miss}} \mid p_{x,\nu}\right) \cdot W\left(\tilde{E}_{\mathrm{y}}^{\mathrm{miss}} \mid p_{y,\nu}\right) \cdot \begin{cases} W\left(\tilde{E}_{\ell} \mid E_{\ell}\right), & e\text{+jets channel} \\ W\left(\tilde{p}_{\mathrm{T},\ell} \mid p_{\mathrm{T},\ell}\right), & \mu\text{+jets channel} \end{cases}$$

- Breit-Wigner mass constraints (B) + transfer functions (W) for detector response
- Extended likelihood (incl. p_T and b-tag weight distributions) for u/d type quark separation
- Separation power mainly via c/s pairs:

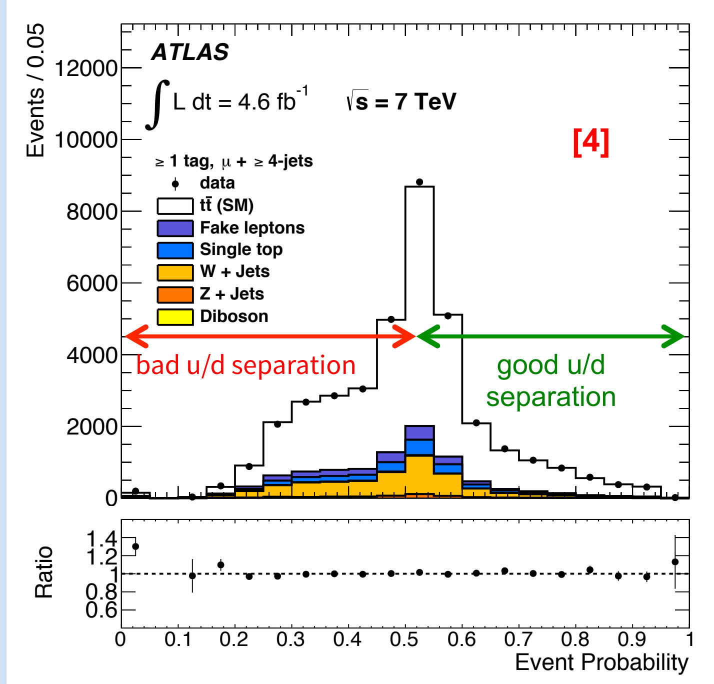


(50%, only p_T difference)



(50%, b-tag weight [c quark] + p_T difference)

- Picking permutation with highest *event probability* (normalized extended likelihood)



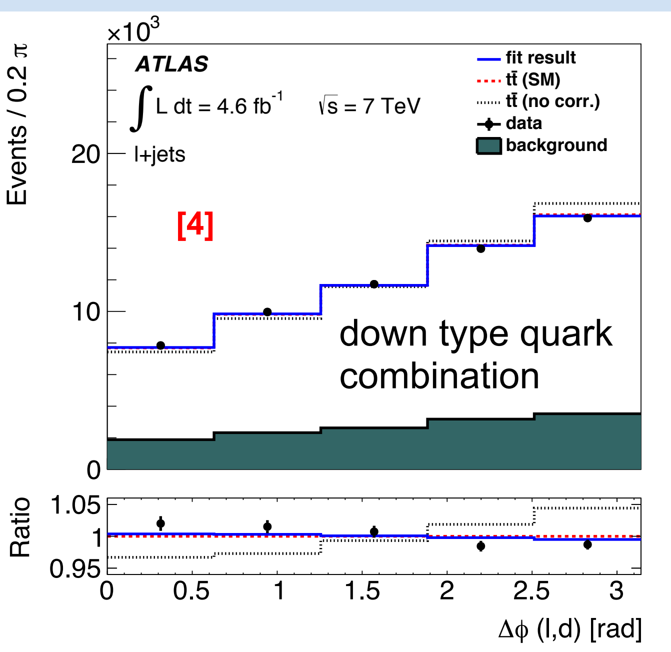
Fit and Results

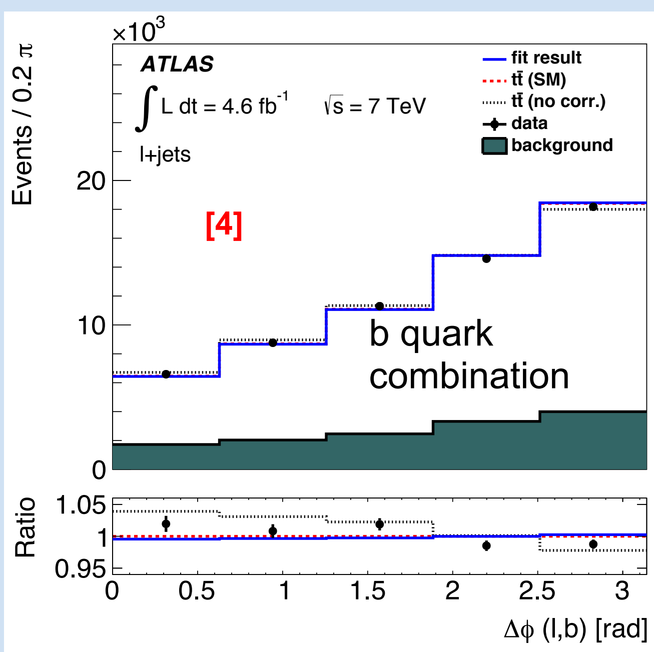
- $t\bar{t}$ signal fitted as composition of SM correlation $t\bar{t}$ sample and uncorrelated $t\bar{t}$ pairs:

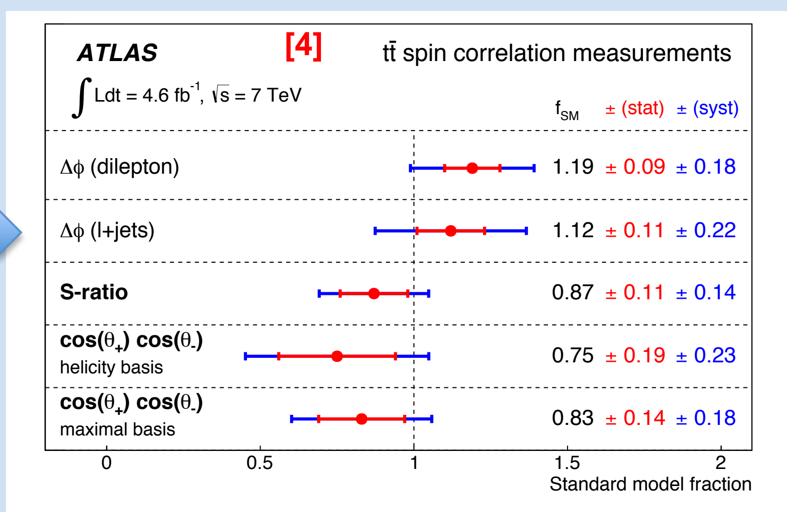
$$n_{t\bar{t}}^{\mathrm{exp.}} = s \cdot \left(f \cdot n_{t\bar{t}}^{A=SM} + (1-f) \cdot n_{t\bar{t}}^{A=0}\right)$$

s: relative scale of cross section (w.r.t. SM)
f: fraction of events with SM spin correlation
A: spin correlation

- Combined fit of Δϕ in 16 channels to take advantage of different $t\bar{t}$ purity: [e,μ]x[4, ≥5 jets]x[1, ≥2-btags]x[down type quark, b quark]

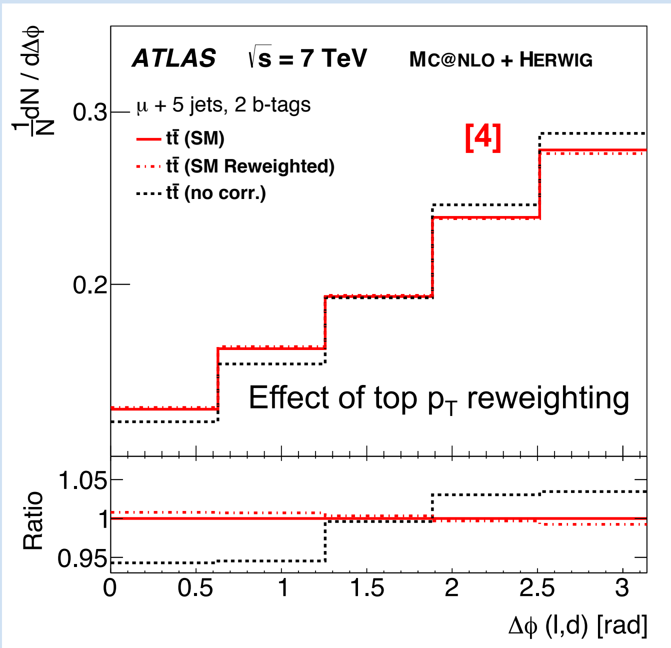






Systematic Uncertainties

- Uncertainties dominated by $t\bar{t}$ modeling
- Nuisance parameters used where applicable
- Anticorrelated effects of systematic uncertainties on the two Δϕ distributions
  - Constrained by the combination
  - Example: top quark p_T reweighting leads to a more flat distribution, interpreted by the fit as larger (smaller) spin correlation by the down-type quark (b quark)



Detector Modeling I	± 0.09
Detector Modeling II	± 0.02
Renormalization/Factorization Scale	± 0.06
Parton Shower and Fragmentation	± 0.16
ISR/FSR	± 0.07
Underlying Event	± 0.05
Color Reconnection	± 0.01
PDF Uncertainty	± 0.02
MC Statistics	± 0.05
Top p_T Reweighting	± 0.02
Total Systematic Uncertainty	**± 0.22**
Data Statistics	**± 0.11**

References

[1] G. Mahlon and S. J. Parke, Phys. Rev. D 81, 074024 (2010)
[2] M. Jezabek and J. H. Kühn, Phys.Lett. B329 (1994) 317
A. Brandenburg, Z. Si, and P. Uwer, Phys.Lett. B539 (2002) 235
[3] J. Erdmann et al., Nucl.Instrum.Meth. A748 (2014) 18
[4] ATLAS Collaboration, arXiv:1407.4314 [hep-ex]. Submitted to Phys. Rev. D.

Poster and references:

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