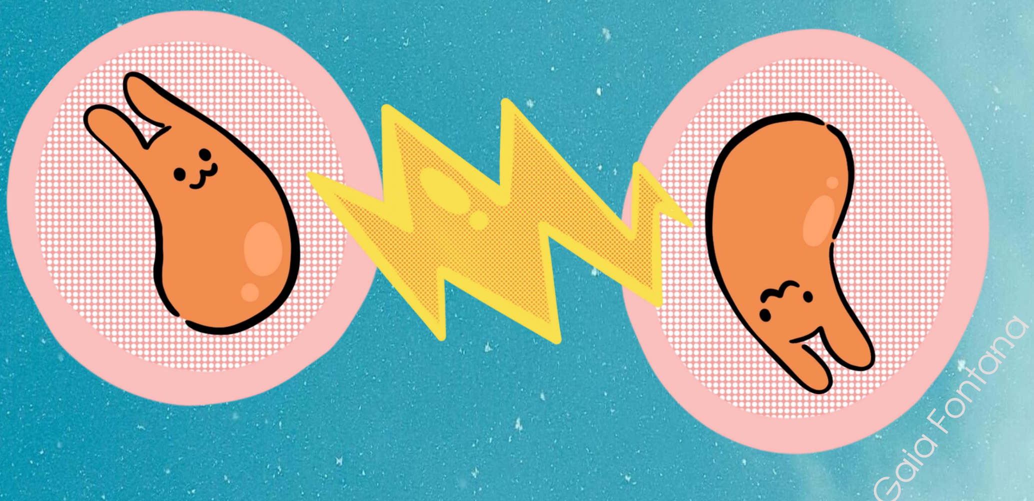
Quantum tops at the LHC

with C.Degli Esposti, F. Maltoni, M.Sioli, E.Vryonidou,
2110.10112, 2210.09330

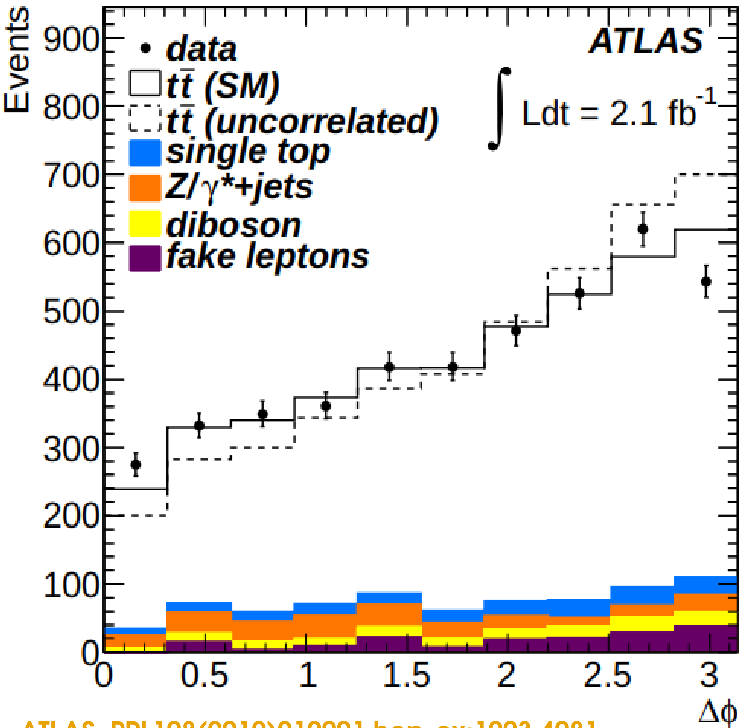


7/11/23 Claudio Severi - University of Manchester

Top spin correlations

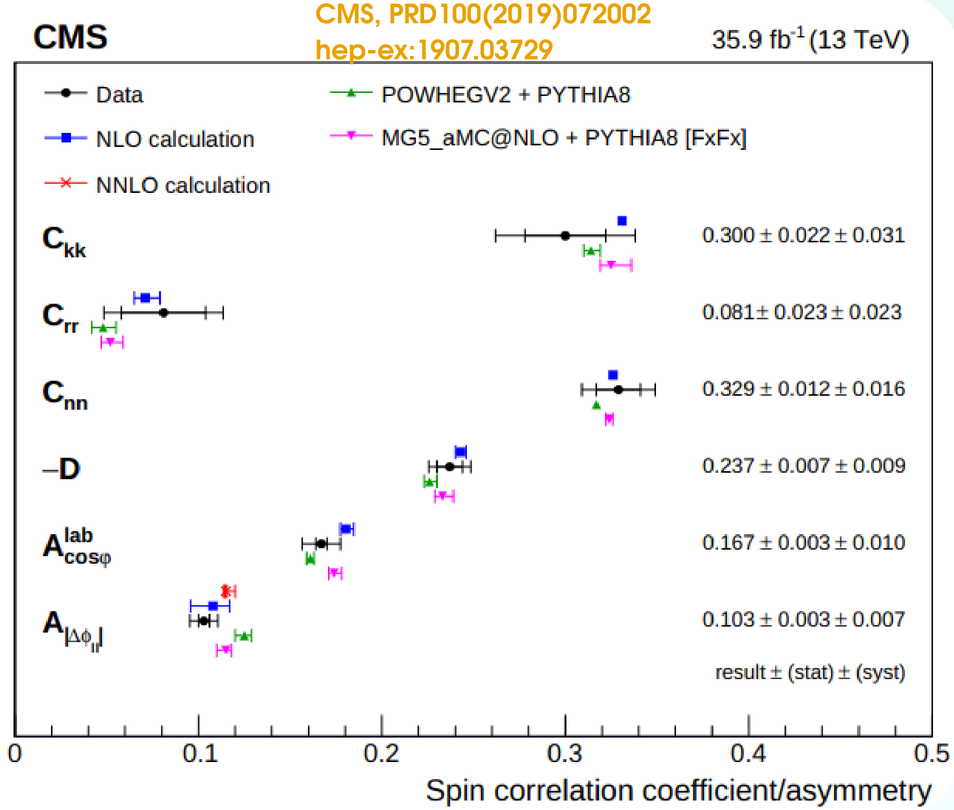
Top-antitop pairs are produced in colliders with correlated spins.

Top spin correlations have been discovered at the LHC and measured with Run 1 and early Run 2 data.



ATLAS, PRL108(2012)212001 hep-ex:1203.4081

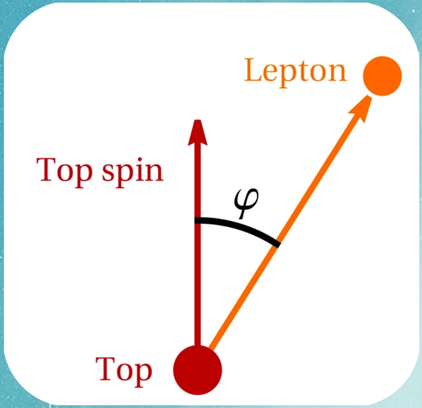
CMS, PRD100(2019)072002
hep-ex:1907.03729



Spin correlations are visible through the decay products.

The EW decay of tops leaves an imprint of their spin state in the direction of flight of their daughters.

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\varphi} = \frac{1+\alpha\cos\varphi}{2}$$



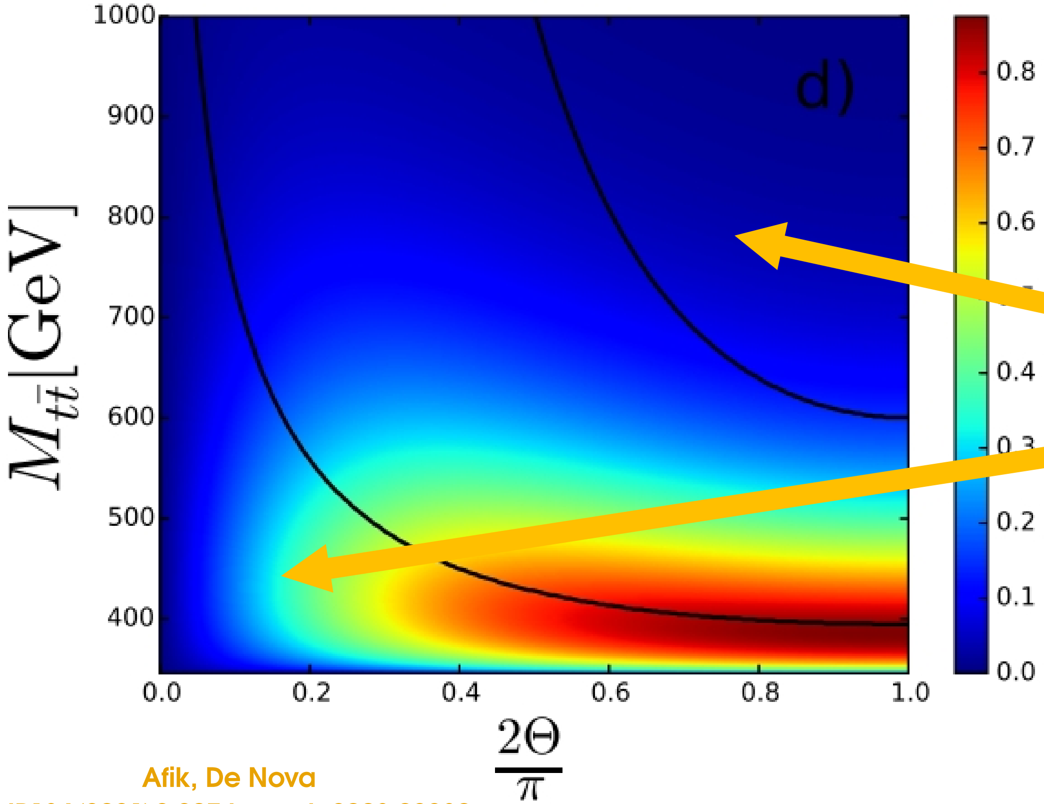
This makes the tt~ spin density matrix experimentally observable:

$$\rho = \frac{1}{4}\left(\mathbb{1}\otimes\mathbb{1} + \sum_{i,j=1}^{3} C_{ij}\,\sigma_i\otimes\sigma_j\right)$$

The spin density matrix can then be interpreted in the context of quantum information.

Quantum tops

Spin correlations in tt pairs are so strong they signal the presence of *quantum entanglement* between tops.



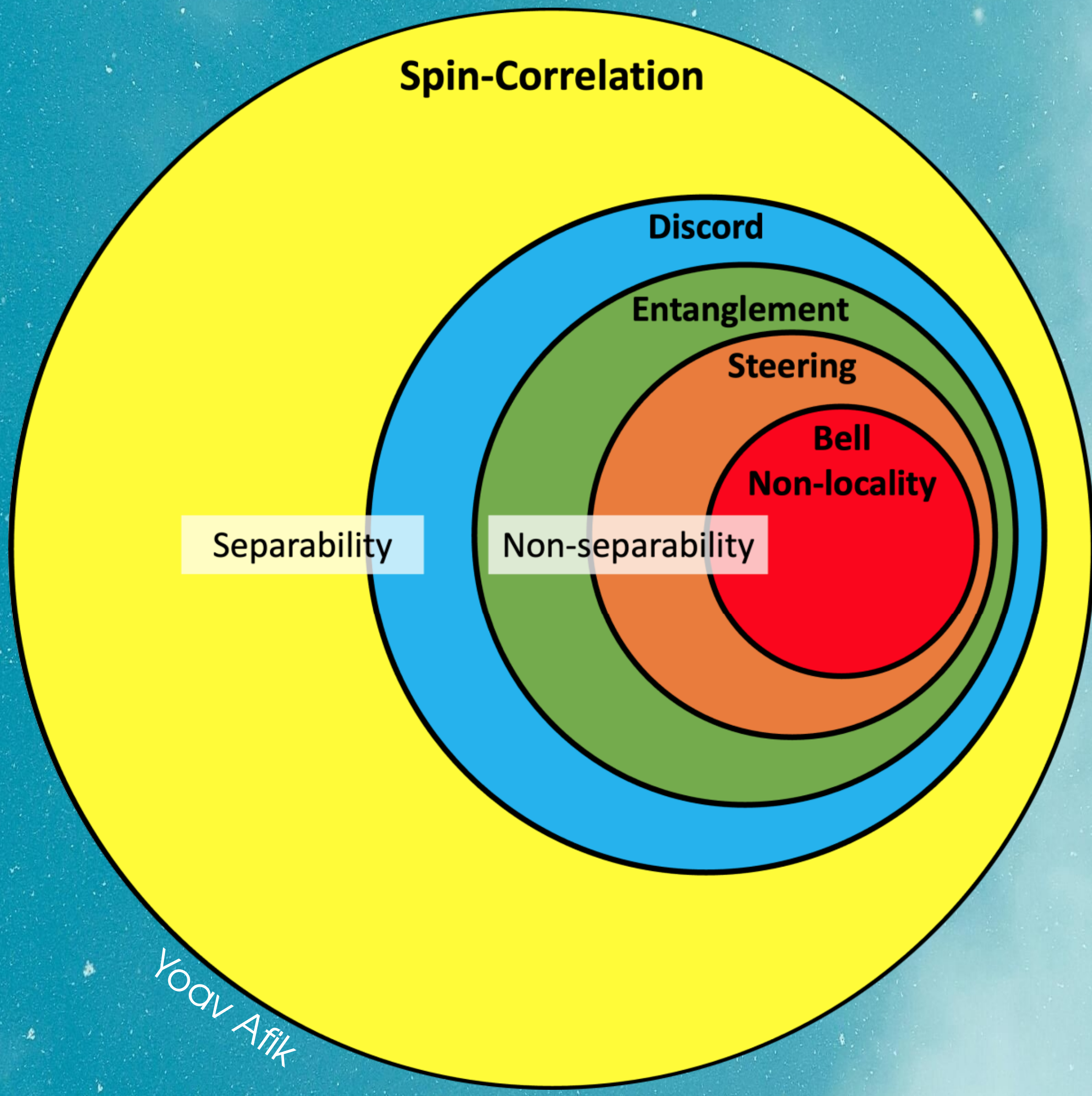
Afik, De Nova
EPJP136(2021)9,907 hep-ph:2003.02280

Entangled regions

1. High p_T
2. Threshold & forward

Quantum information with tops

There is a whole hierarchy of “quantum” observables for 2-qbit systems then can be applied to top pairs.



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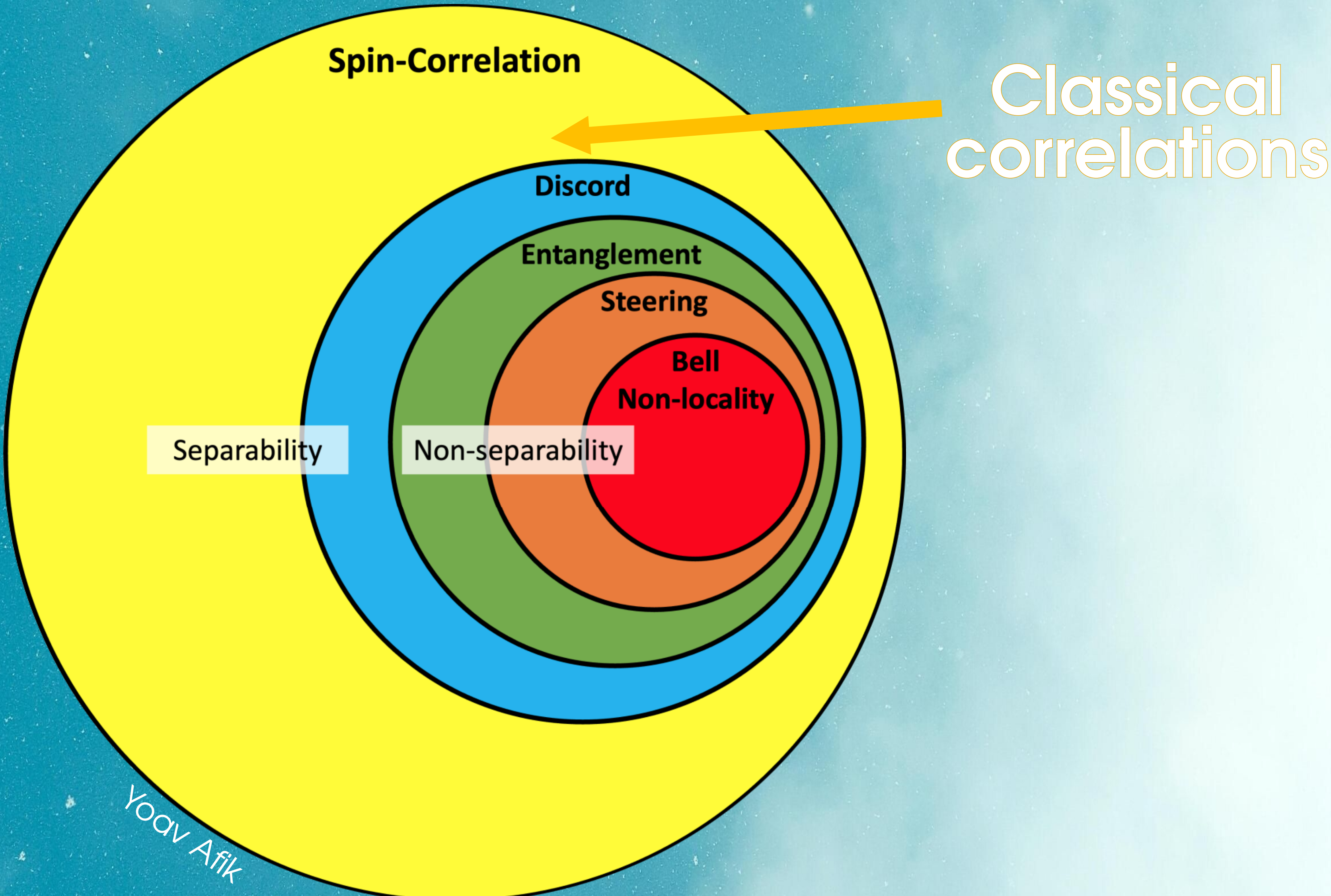

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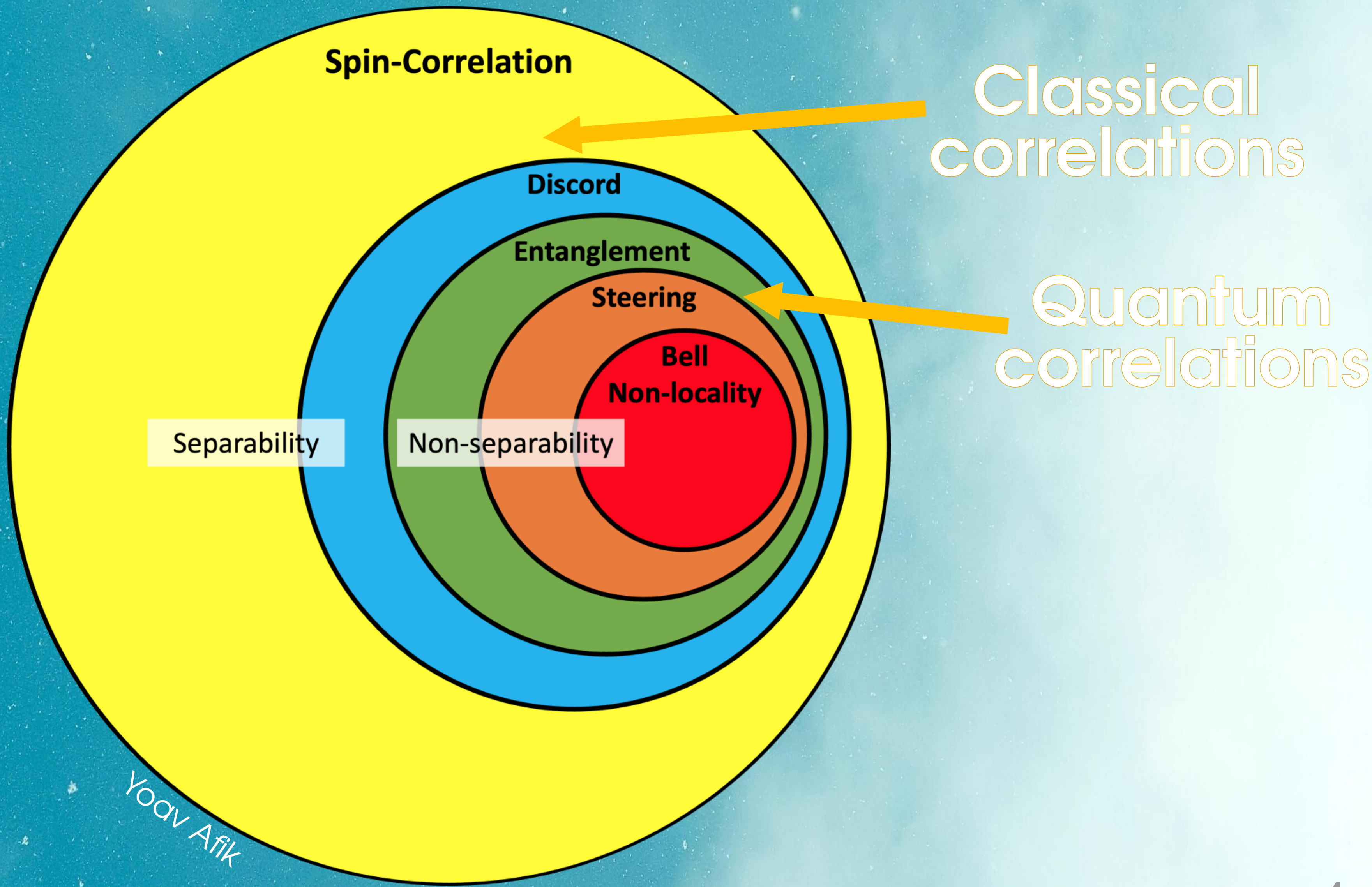

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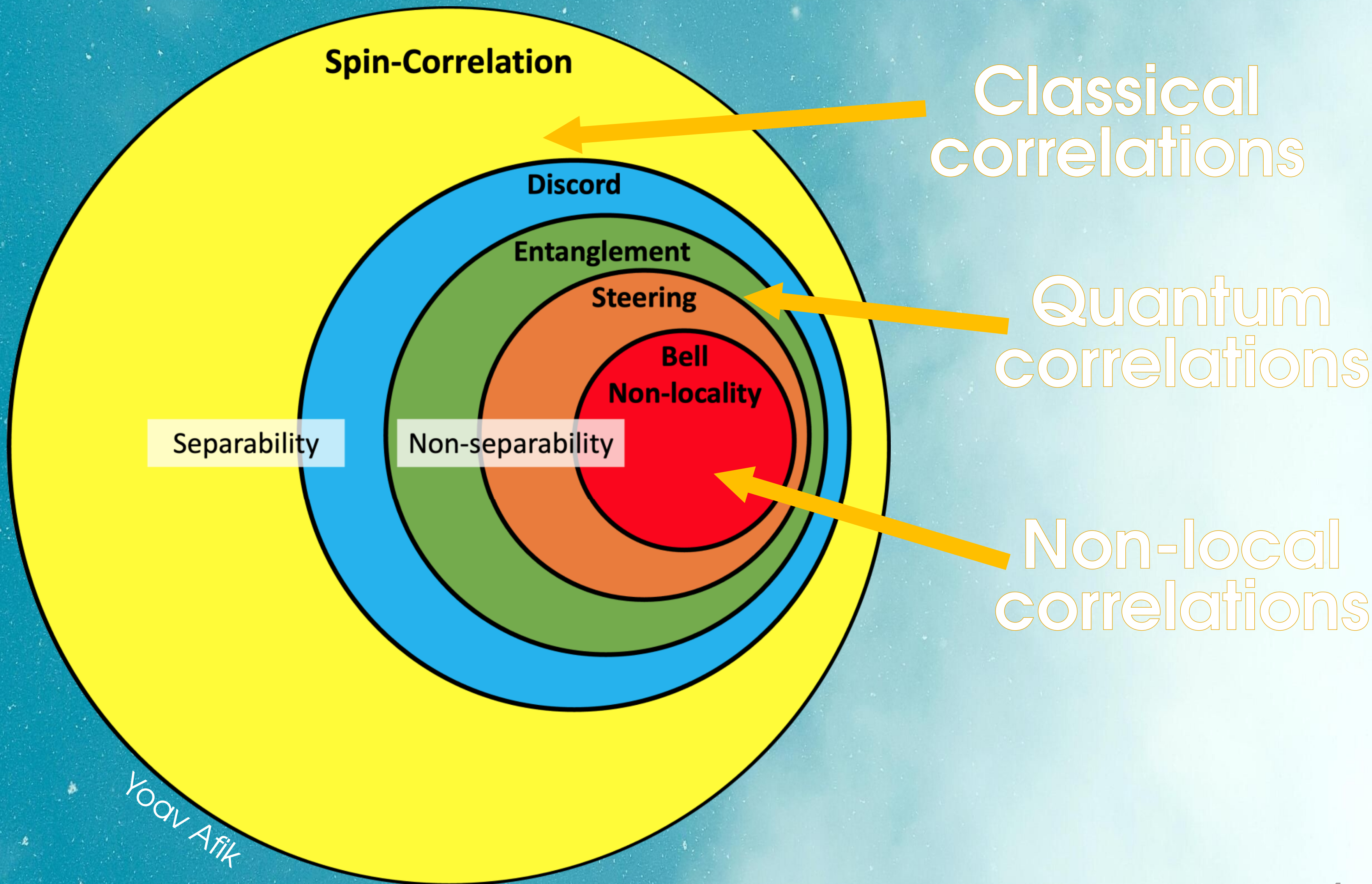


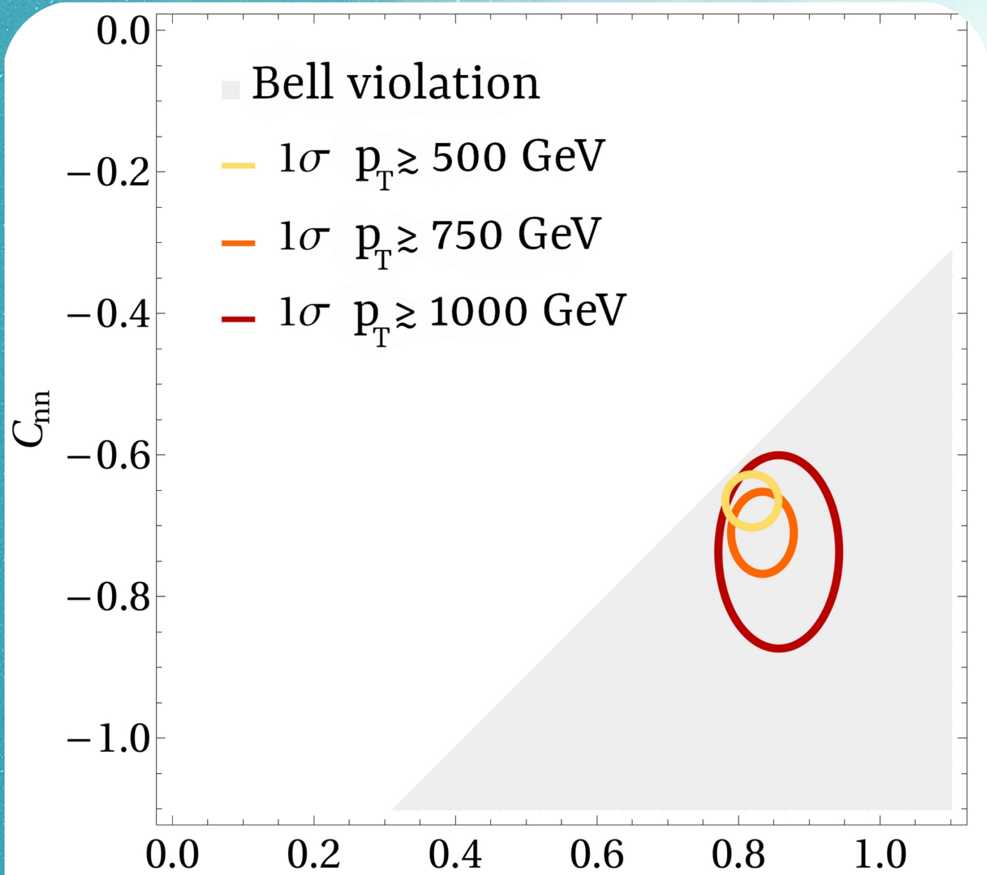
Bell non-locality with tops

Observing a Bell violation is the ultimate signal of non classicality.

At parton level, tops do violate Bell inequalities in extreme regions of phase space.

Our simulations suggest evidence for Bell violations can be reached at HL-LHC at 2/3σ.

Several improvements have since been suggested, 5σ significance may eventually be realistic.



Boschi, Maltoni, CS, Sioli
EPJC82(2022)4,285 hep-ph:2110.10112

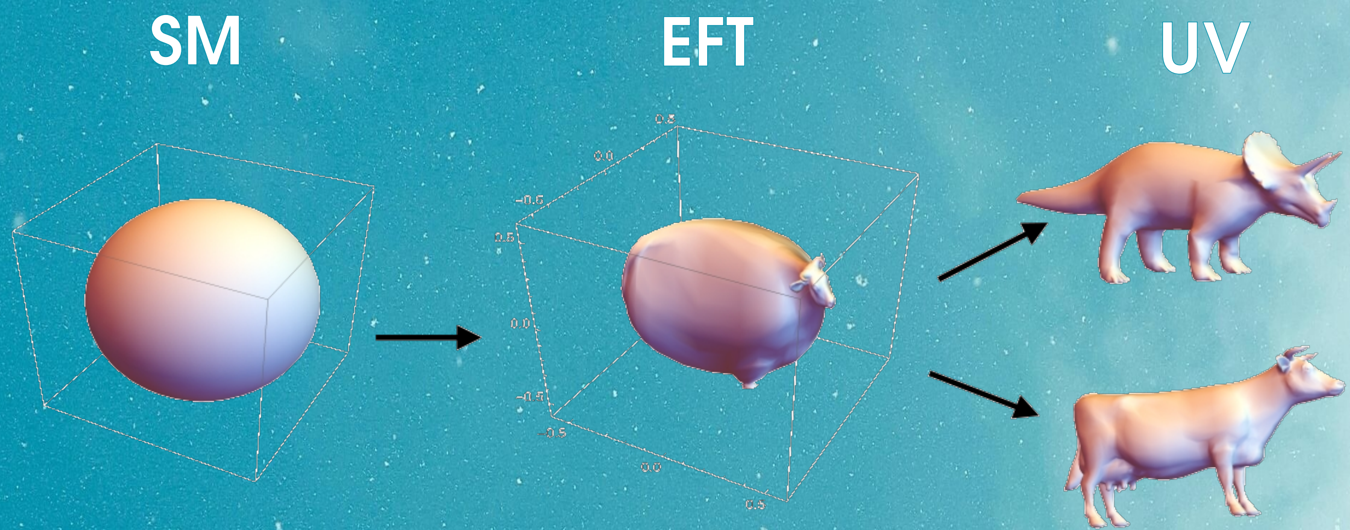
New physics in spin correlations

Spin correlations provide a novel window on top physics, whose exploration only started recently.

Several new physics scenarios predict different spin correlations, while keeping the more conventional observables within experimental bounds.

Quantum observables are an additional tool whose use has not been explored yet.

SM EFT in spin correlations

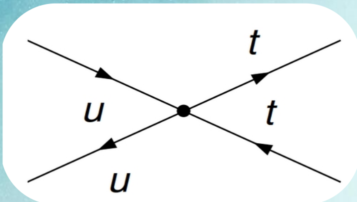


There are 15 dimension 6 operators entering spin correlations: 14 four-quark operators and the top chromo dipole O_{tG}.

Remarkably, no electroweak operator enters, even if spin measurements involve EW decays.

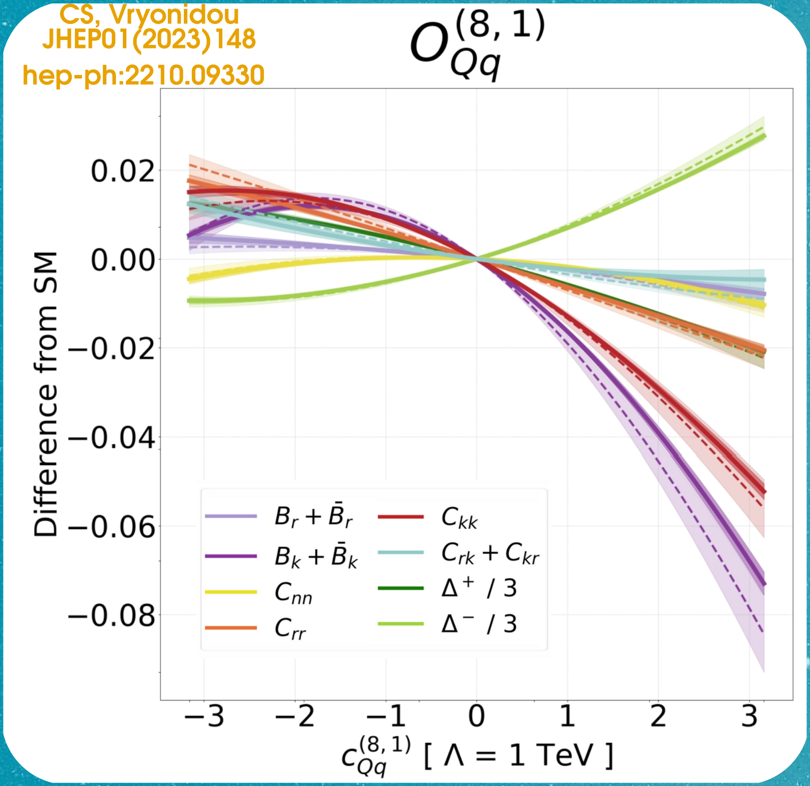
Impact on NP searches

Example: contact interaction between light quarks and tops.



Inclusive measurement

CS, Vryonidou
JHEP01(2023)148
hep-ph:2210.09330



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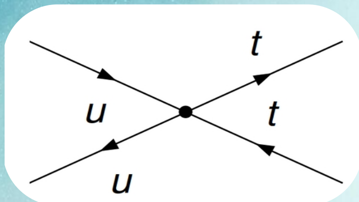

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CS, Vryonidou
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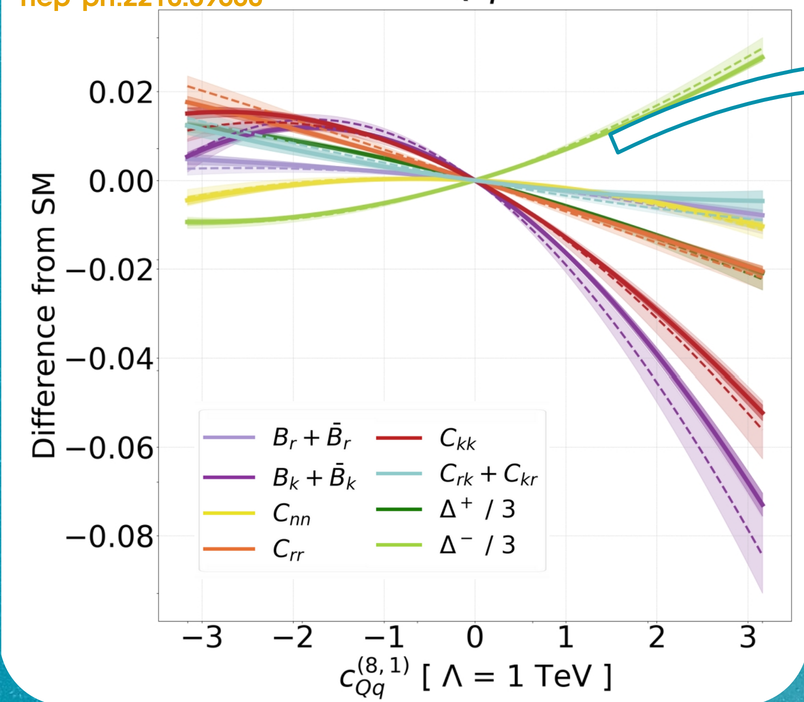
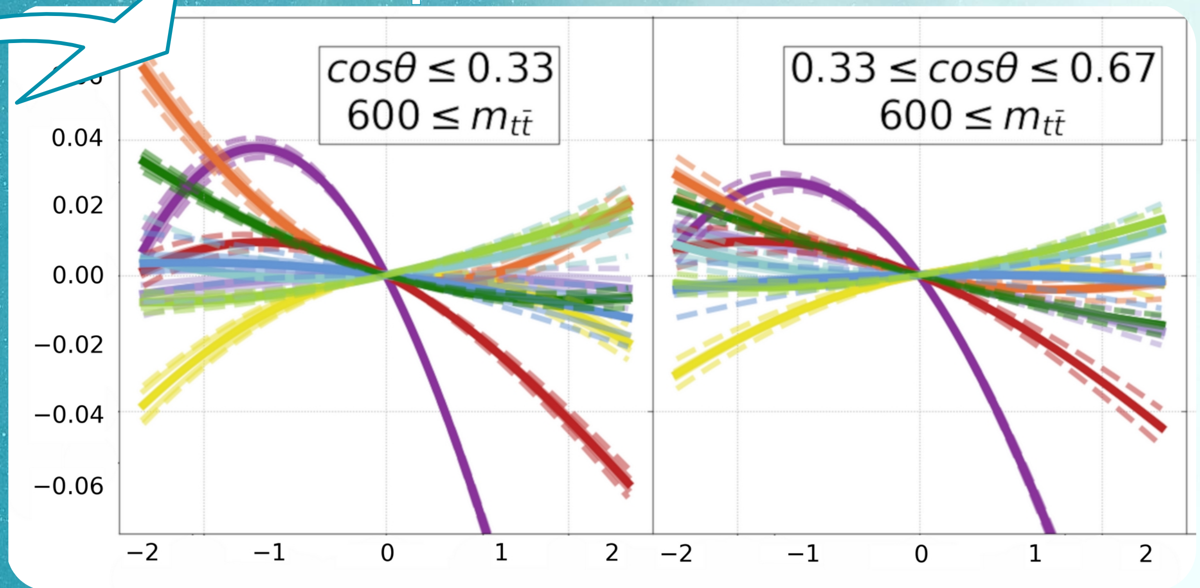


Measurement with p_T cuts



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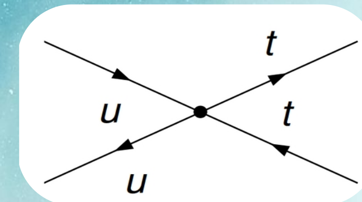

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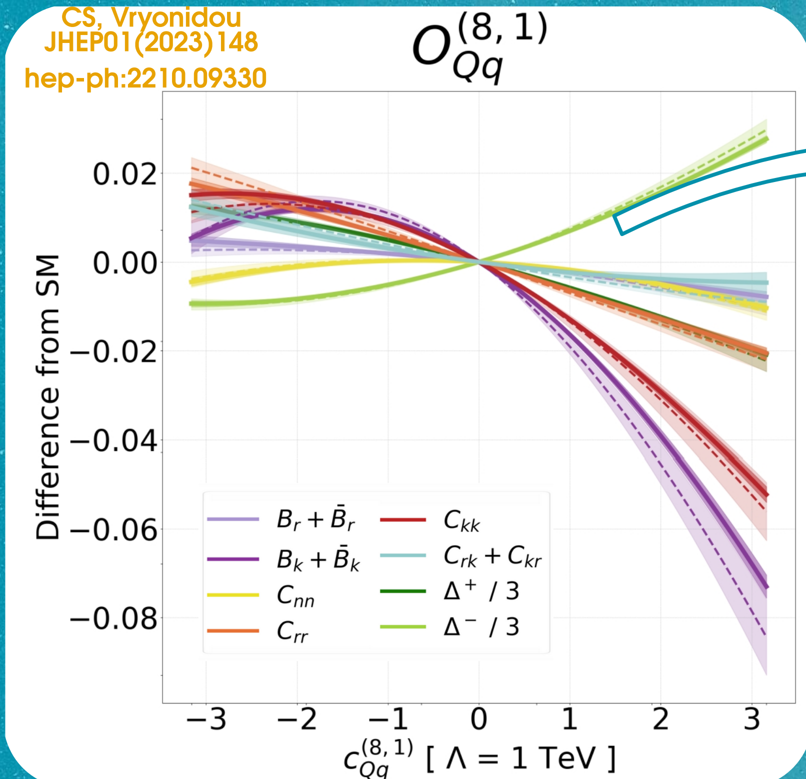

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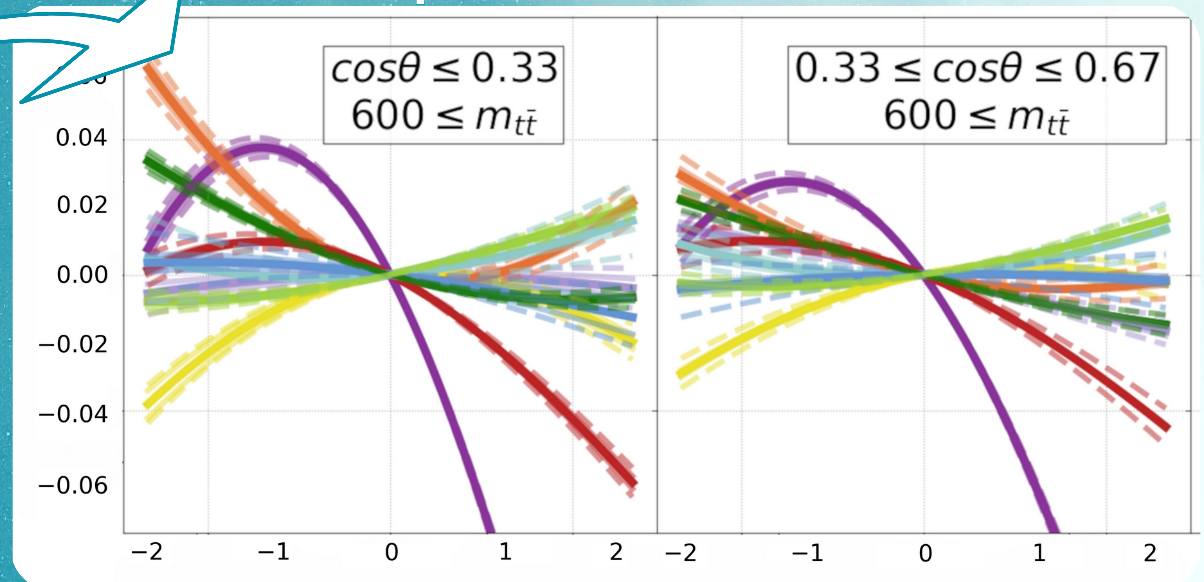

Our simulations [2210.09330] show that one differential measurement will be competitive with the global fits to all top data.

Operator	Run III Projection 300 fb^{-1} Differential	Current Global Fit
$\mathcal{O}_{Qu}^{8}$	$[-0.7, 0.6]$	$[-1.0, 0.5]$
$\mathcal{O}_{Qd}^{8}$	$[-0.9, 0.8]$	$[-1.6, 0.9]$
$\mathcal{O}_{Qq}^{(1,8)}$	$[-0.4, 0.3]$	$[-0.4, 0.3]$
$\mathcal{O}_{Qq}^{(3,8)}$	$[-1.1, 0.8]$	$[-0.5, 0.4]$

Conclusions

The phenomenal performance of the LHC opens new roads. It is now possible to do quantum information studies with the spin of tt pairs.

There is a variety of observables related to spin, ranging in theoretical cleanliness and experimental accessibility.

These new observables explore new corners of top physics, and carry a remarkable discovery potential.

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These new observables explore new corners of top physics, and carry a remarkable discovery potential.

More works (and measurements) are coming, stay tuned!