# Top reconstruction and spin correlations

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# How to observe top quark spin?

Spin state = behaviour under rotation → angles of decay products

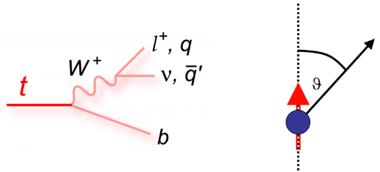
**The Top quark** decays before hadronization:

- spin information transmitted to decay products ($W$, $b$)
- secondary decay products only ($\ell, \nu, b$) are detected

**Angle of decay products** in the top rest-frame, a proxy to spin state:

$$\frac{1}{\Gamma_t}\frac{d\Gamma_t}{d\cos\theta} = \frac{1}{2}(1 + A\cos\theta)$$

$A_{\ell,q} = 1$, $A_{\nu,q'} = -0.31$, $A_b = -0.41$



# How to observe top quark spin correlations?

Spin state = behaviour under rotation $\rightarrow$ angles of decay products

**Cross-section as function of lepton directions:**

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\hat{\ell}_1 \mathrm{d}\hat{\ell}_2} \propto \left(1 + B_1 \cdot \hat{\ell}_1 + B_2 \cdot \hat{\ell}_2 - \hat{\ell}_1 \cdot C \cdot \hat{\ell}_2\right)$$

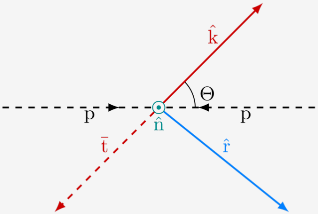
($\hat{\ell}_i \equiv$ unity vector aligned with the lepton $i$ direction)

15 observables for 2 quarks and 3 axes

- polarizations: $B_i$ ($2 \times 3$-vectors)
- correlations: $C$ ($3 \times 3$ matrix)

Arbitrary choices of (quantization) axes

1. lab-frame axes ($\vec{x}, \vec{y}, \vec{z}$): *beam basis*
2. ZMF of top quarks ($\vec{k}, \vec{r}, \vec{n}$): *helicity basis*




[plot from PRD 100 072002]

# Top reconstruction: motivation, challenge & methods

Spin observables $\sim$ angles in top quark rest-frame

- what we need: $\vec{p}^{\,\nu}$, $\vec{p}^{\,\ell}$ and $\vec{p}^{\,b}$
- what we get: $E_T^{\text{miss}}$, $\vec{p}^{\,\ell}$ and $\{\vec{p}^{\,j}, b\text{-tag}\}$

**Two difficulties:** neutrinos *v.s.* missing energy ($2\ell$) & jets combinatorics

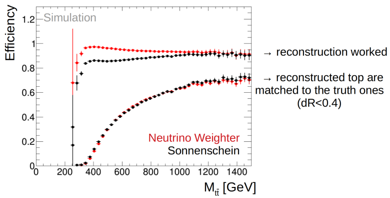
**Two tested strategies** to handle $\vec{p}_\nu$'s ambiguity

1. scan kinematics ($\eta_\nu$'s) and weight each configuration based on $E_T^{\text{miss}}$ resolution, keep the highest weight kinematics. **$\nu$Weighter** method [PRD 80 092006]
2. resolve analytically the equations $\rightarrow$ 0, 2 or 4 solutions, keep the lowest $m_{t\bar{t}}$ solution. **Sonnenschein** and **Ellipse** methods [PRD 78 079902, NIMA 2013 10 039]

**Trying different kinematics** for jet combinatorics but not only ...

- $\nu$Weighter: intrinsic to the method, considering on top several jets combinations
- analytics: smear object kinematics (and jet comb.) to reduce 0-solution cases

# Top reconstruction performances - simulation

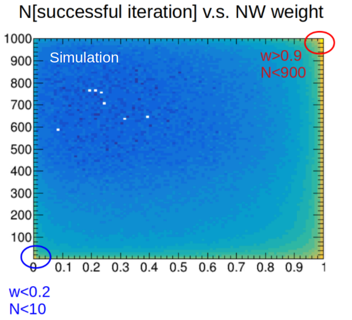


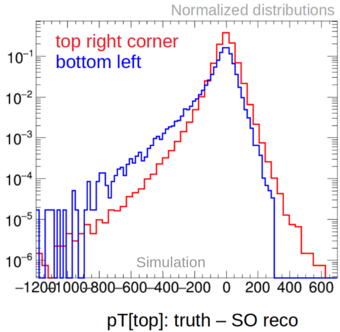

## Two main aspects:

1. efficiency (left)
2. quality (bottom)

$w \equiv$ weight from $\nu$W (high = better)

$N \equiv$ number of smeared kinem with a solution



# Detector response for one spin observable - simulation

**Correlations between two top axes:** defining $c_{kk} \equiv \cos\theta_+^k \cos\theta_-^k$, and $A$ the correlation, integrating $\frac{\mathrm{d}^2\sigma}{\mathrm{d}\hat{\ell}_1 \mathrm{d}\hat{\ell}_2}$ over all the other angles:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}c_{kk}} = \frac{\sigma}{4}\left(1 - A\, c_{kk}\right) \quad \rightarrow \quad A = -9\,\langle c_{kk} \rangle$$

$c_{kk}$ distribution should be well reconstructed, ideally a purely diagonal migration matrix