Top Polarization from New Physics

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J. Shelton, `arXiv:0811.0569`

work in progress with D. Krohn, L.T. Wang

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Tops and new physics at the LHC

- **The LHC will be a top factory:** $\sigma(pp \to t\bar{t}) = 830$ pb
  - Nearly 1 SM top pair per second at low design luminosity
  - Precision characterization of SM top system a key part of the physics program
- **Beyond the SM, new physics responsible for EWSB must have large couplings to the top**
  - Anticipate relatively large cross-section for associated production of top and new physics
- **New physics will couple differently to t_L, t_R**
  - $\Rightarrow$ net polarization of tops from new physics
  - polarization will depend on kinematics and chiral couplings
- **Top polarization a window into chiral structure of new physics**

SM top decays

- **Top quarks decay before hadronization dilutes information about initial polarization**
  - angular distributions of decay products contain information about parent top polarization
  - direct probe of couplings at NP vertices
- **Angular distribution of daughter particles in top decays:**

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_f} = \frac{1}{2}\left(1 + \mathcal{P}_t\,\kappa_f \cos\theta_f\right)$$

- **'spin analyzing power' κ_f depends on particle identity:**
  - $\kappa_b = -\frac{m_t^2 - 2m_W^2}{m_t^2 + 2m_W^2} \simeq -0.4$
  - $\kappa_W = -\kappa_b$
  - $\kappa_\ell = 1, \qquad \kappa_\nu \simeq -0.3$

$t\bar{t}$ from a resonance

- **A well-studied scenario: $X \to t\bar{t}$**
  - Semi-leptonic events most promising channel for studying top polarization, just as in SM top pair spin correlations
  - reduce (combinatoric) backgrounds
  - exploit large spin analyzing power of ℓ
- **Reconstruct missing p_ν (up to quadratic ambiguity) $\Rightarrow$ reconstruct parent leptonic top**
  - can form distribution $\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell}$ and fully utilize maximal correlation of lepton
- **Any additional particles in final state complicate the story**
  - If event contains multiple sources of missing energy, this technique can't be applied.
  - Event reconstruction requires assumptions about event topology. Not necessarily desirable, especially in initial phases

Hadronic Tops

- **Hadronic tops are completely reconstructable without information from rest of event**
  - trade reduced spin analyzing power for versatility, top ID
  - best choice for tops coming from cascade decays with NP missing energy (e.g., SUSY cascades)
  - depending on event selection, may wish to use either b-jet or reconstructed W
- **Another potentially useful object can be constructed from the light quark jets**
  - cannot distinguish $\bar{d}$ jet from u jet, but on average, $\bar{d}$ less energetic than u in top rest frame
  - $\Rightarrow$ form angular distribution of the softer light quark jet j
  - $\kappa_j \simeq 0.5$ (Jezabek)

Boosted tops

- **Tops from very massive new physics will be highly boosted, and their decay products will be collimated**
  - Boosted top ID requires novel techniques: an active field of study

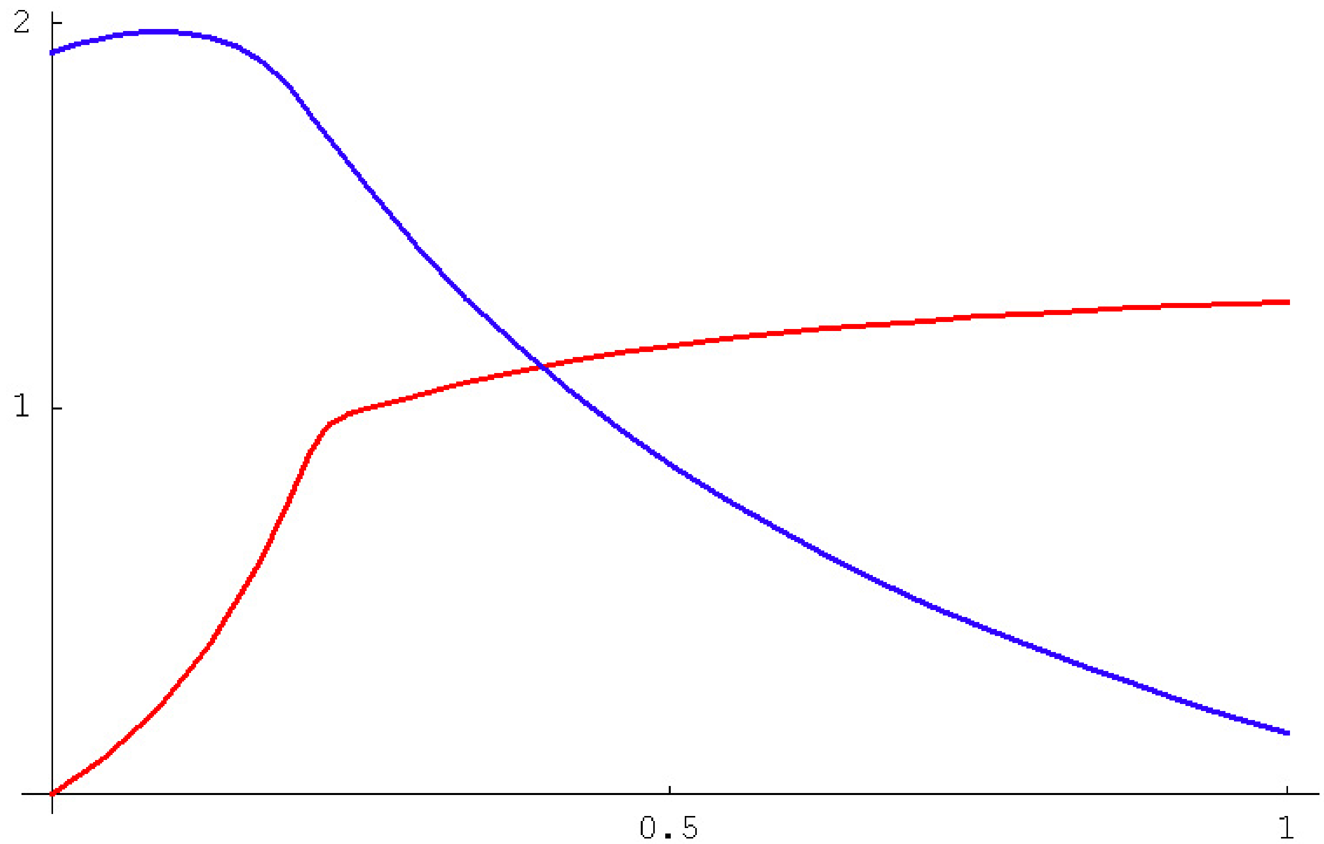
    (Kaplan, Rehermann, Schwartz, Tweedie; Thaler, Wang; Almeida, Lee, Perez, Sung, Virzi)

- **Can construct variables which become independent of the top rest frame in the collinear limit**
  - compare τs

- **Leptonic tops: natural variable is fraction of visible lab frame energy carried by the lepton,**

$$u = \frac{\mathcal{E}_\ell}{\mathcal{E}_\ell + \mathcal{E}_b}$$

Boosted leptonic tops



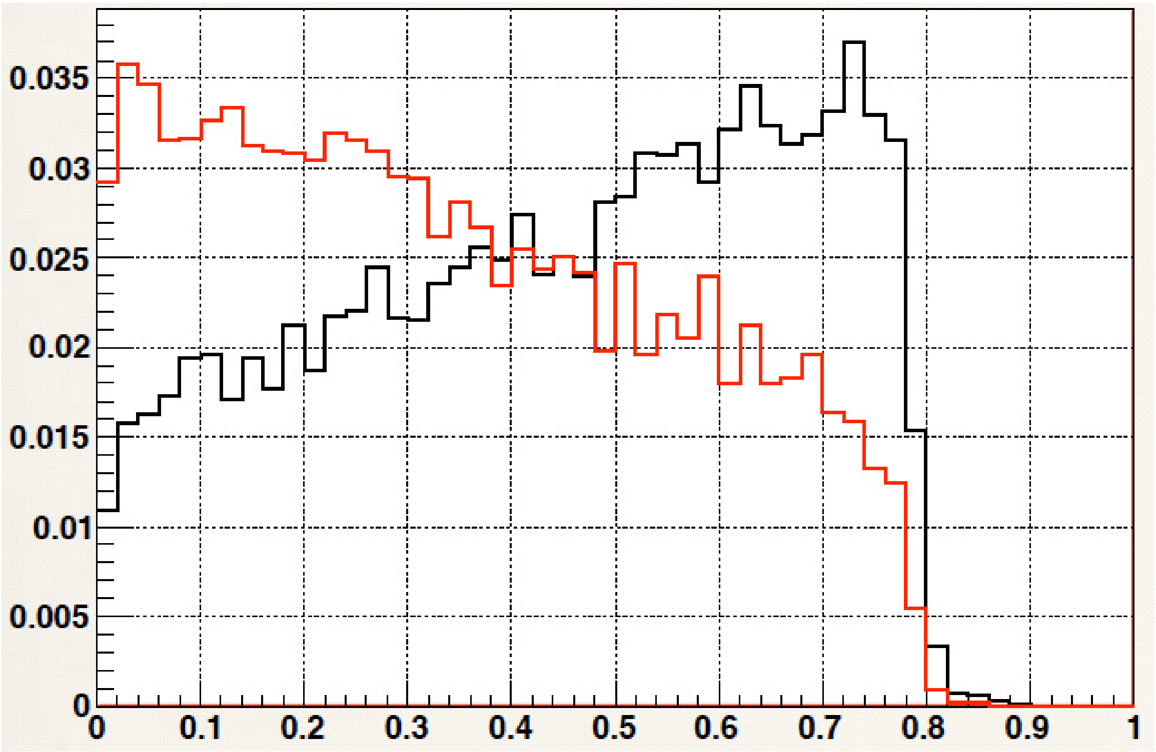
Distribution of u for positive (red) and negative (blue) helicity tops.

- Measurable distribution a linear combination of positive and negative helicity distributions according to degree of polarization $\langle \mathcal{P}_D \rangle$

Boosted hadronic tops

- **Parton level: natural variables are energy fractions of b (or other final state parton):**

$$z \equiv \frac{\mathcal{E}_b}{\mathcal{E}_t} = \frac{E_b}{m_t}(1 + \cos\theta_b)$$



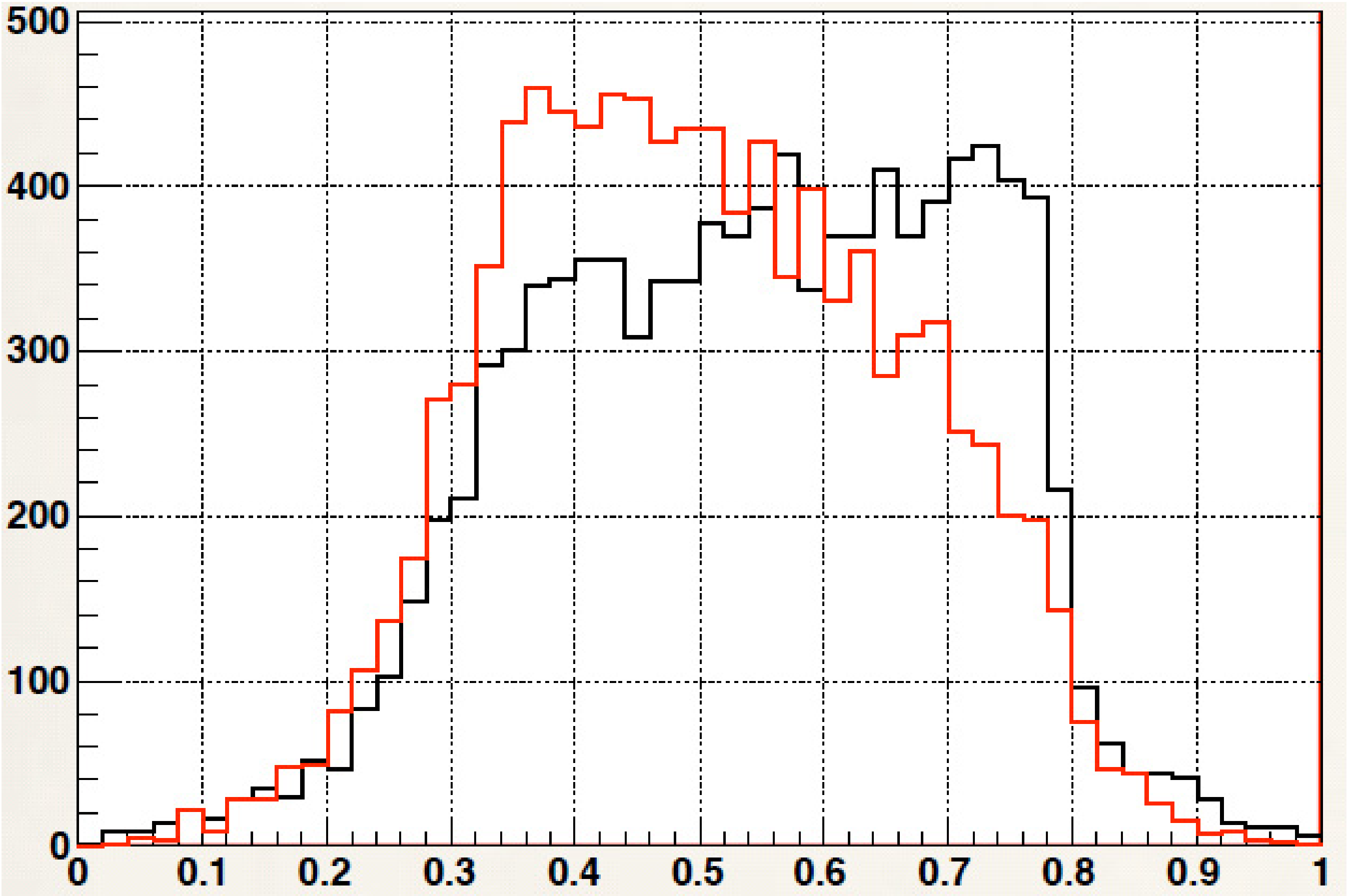
Distribution of z for positive (red) and negative (blue) helicity tops.

Boosted hadronic tops

- **From partons to hadrons: (work in progress with D. Krohn, L.-T. Wang)**
  - look at energy fractions of subjets within top-tagged fat jet
  - key question: how to choose subjet
- **Avoid reliance on b- or W-tagging**
  - b-tagging efficiencies suffer at high energy
  - W mass window a poor W tagger
- **Instead, select candidate jet based on k_T distances between subjets: more robust to showering**
  - Candidate algorithm selects jet correlated with b:
  - unwind top jet to obtain 3 hard subjets
  - choose pair with minimum separation under k_T metric
  - select the harder of the two jets.

Boosted hadronic tops

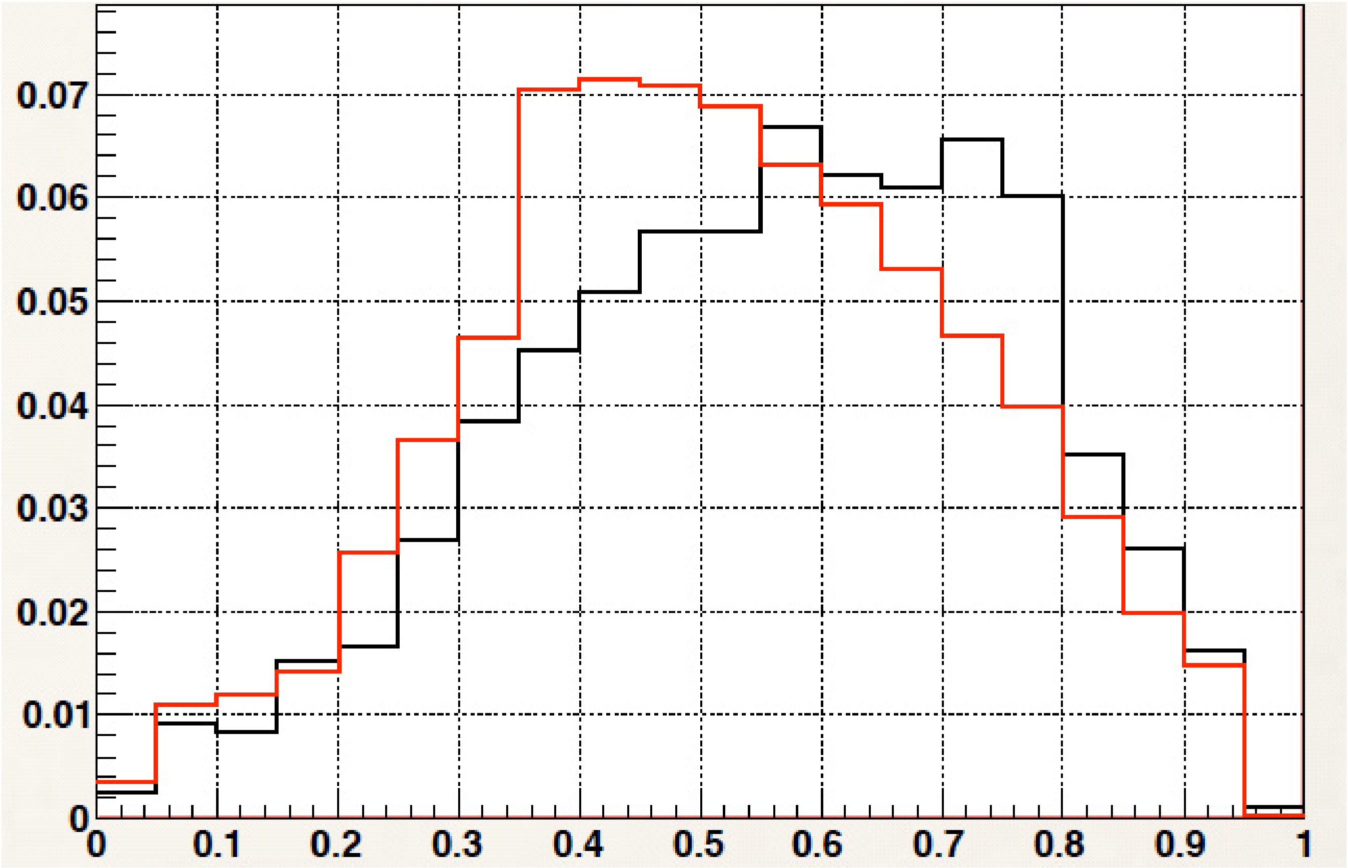
- **Plot the energy fraction of this jet:**



Parton level. Red = right, Black = left.

Boosted hadronic tops

- **Plot the energy fraction of this jet:**

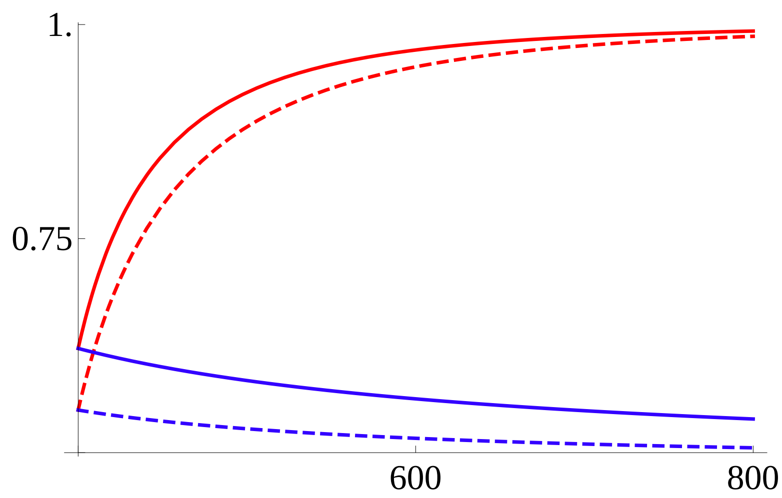


With ISR/FSR, hadronization, cell binning.

Red = right, Black = left.

Polarization from cascade decays

- **Many well-motivated models feature cascade decays of the form (top partner) $\rightarrow t +$ (vector boson partner)**
  - decay produces polarized tops due to chiral couplings λ_L, λ_R
  - can compute net production polarization $\langle \mathcal{P}_P \rangle$ as a function of particle masses



Net top quark polarization $\langle \mathcal{P}_P \rangle$ for couplings to pure t_L.

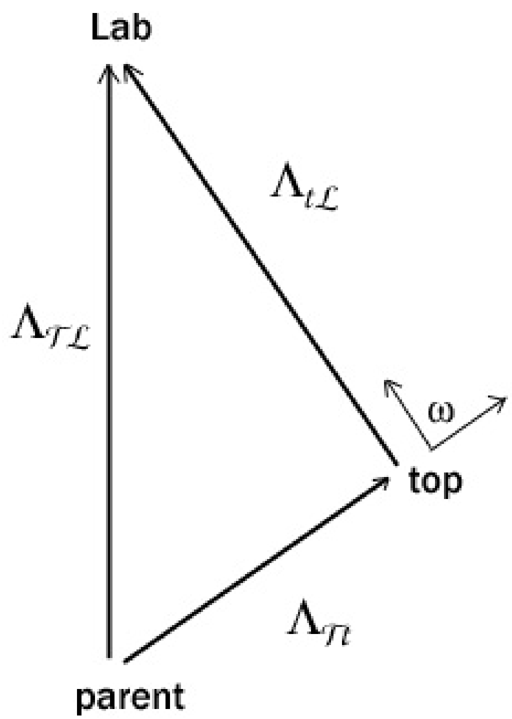
Red: fixed vector boson partner mass of 200 GeV

Blue: vector boson partner mass of (top partner mass)$-$200 GeV

Solid (dashed) lines: opposite- (same-) spin partners

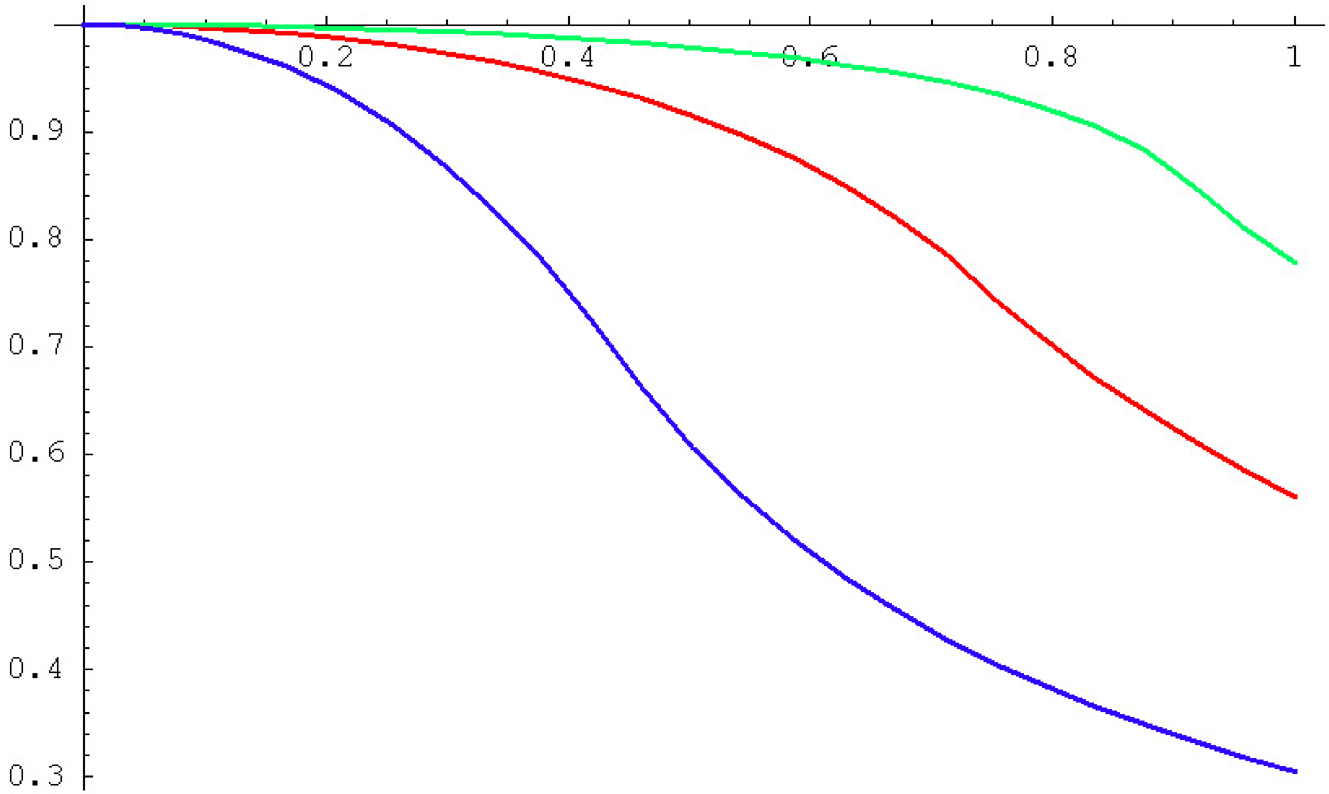
From production to detection

- **Cascades give net polarization $\langle \mathcal{P}_P \rangle$ along direction of motion in the *parent* rest frame. Not directly observable!**



  - Observable polarization is reduced: $\langle \mathcal{P}_D \rangle = \langle \mathcal{P}_P \rangle \cos\omega$
  - $\cos\omega$: calculable function of particle masses, production dynamics

Wigner suppression



- $\cos\omega$ **as a function of parent top partner boost** β
  - Red: $(M_T, M_V) = (500 \text{ GeV}, 150 \text{ GeV})$
  - Green: $(M_T, M_V) = (900 \text{ GeV}, 300 \text{ GeV})$
  - Blue: $(M_T, M_V) = (900 \text{ GeV}, 700 \text{ GeV})$

Conclusions

- **Top polarization is a key to unraveling the chiral structure of new physics at the EWSB**
  - finite m_t complicates the story, but detailed quantitative predictions are possible
  - many uses: measure detailed properties of new physics, separate signal from SM background,...
- **Tops from new physics may show up in many different guises; need a variety of tools**
- **Utility of hadronic tops: as complement to leptonic tops, and in their own right**
  - higher branching ratios and potentially higher top ID efficiency may compensate for reduced spin analyzing power
  - cascade decays and non-reconstructable events