Spin Correlations in Top Quarks @ CDF

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on behalf of CDF collaboration
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Talk Outline

- Introduction and motivation.
- Measuring spin correlation in $t\bar{t}$ data
  - Result in dilepton channel. First measurement using Run II data!
  - Prospects in l+jets events.
- Conclusion and outlook.

Introduction

- Top pairs produced through a spin 1 gluon
- Conservation of angular momentum implies:
  - top pairs from $q\bar{q}$ annihilation tend to be produced in unlike spin states
  - gluon fusion prefers like-spin tops
- Top pairs @Tevatron produced mostly (85%) by $q\bar{q}$ annihilation $\Rightarrow$ polarized top pairs
- BSM Top models would affect this property

Top "Bare Necessities"

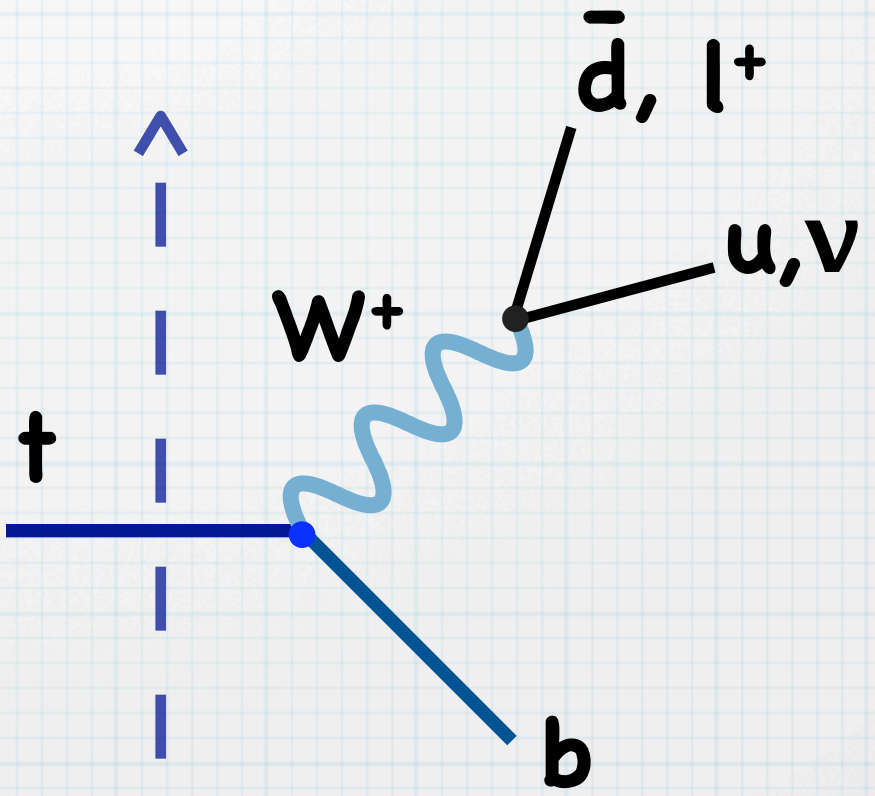
- A light quark undergoes hadronization process on the time scale of 3×10^{-24} s and "gets dressed" as meson or barion
- Huge mass shortens top quark lifetime to 4×10^{-25} s as it decays to W+b prior any hadronization. Top is always bare.
- Spin of top propagated to final states!

Top Decay Analyzers

Look at angles θ_i between top spin axis and decay momenta

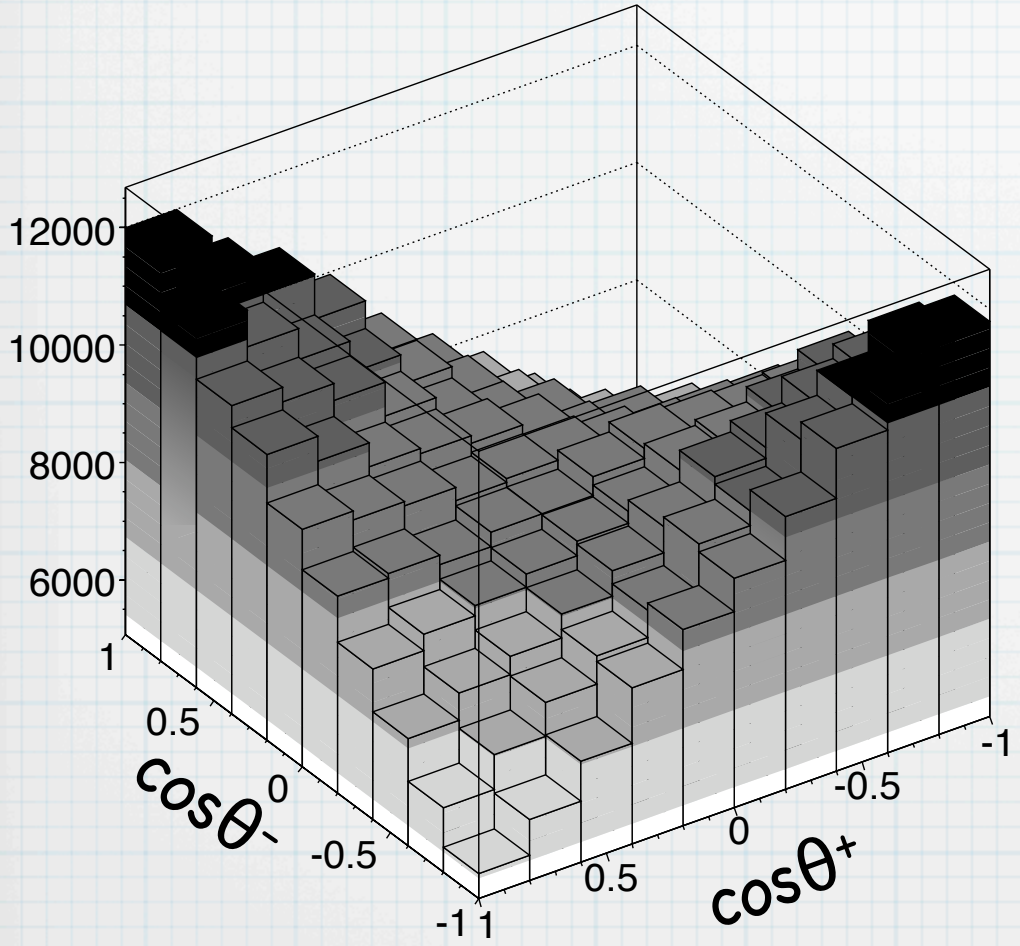
$$\frac{1}{\Gamma}\frac{d\Gamma}{dcos\theta_i} = \frac{1}{2}(1+\alpha_i cos\theta_i)$$

- α_l = -1.0 for leptons and down-quarks
- α_b = 0.47 for b-jets
- α_ν = 0.31 for up-quarks and neutrino



Correlations in $t\bar{t}$ Pair

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_i^+ d\cos\theta_i^-} = \frac{1}{4}(1+\alpha_i^+\alpha_i^- k\,\cos\theta_i^+\cos\theta_i^-)$$



we wish to measure **k** correlation coefficient

$$k = \frac{N_{||} - N_{\times}}{N_{||} + N_{\times}}$$

where $N_{||}$ is number of events when both tops have same spins (or opposite for $N_{\times}$)

Frames and Basis

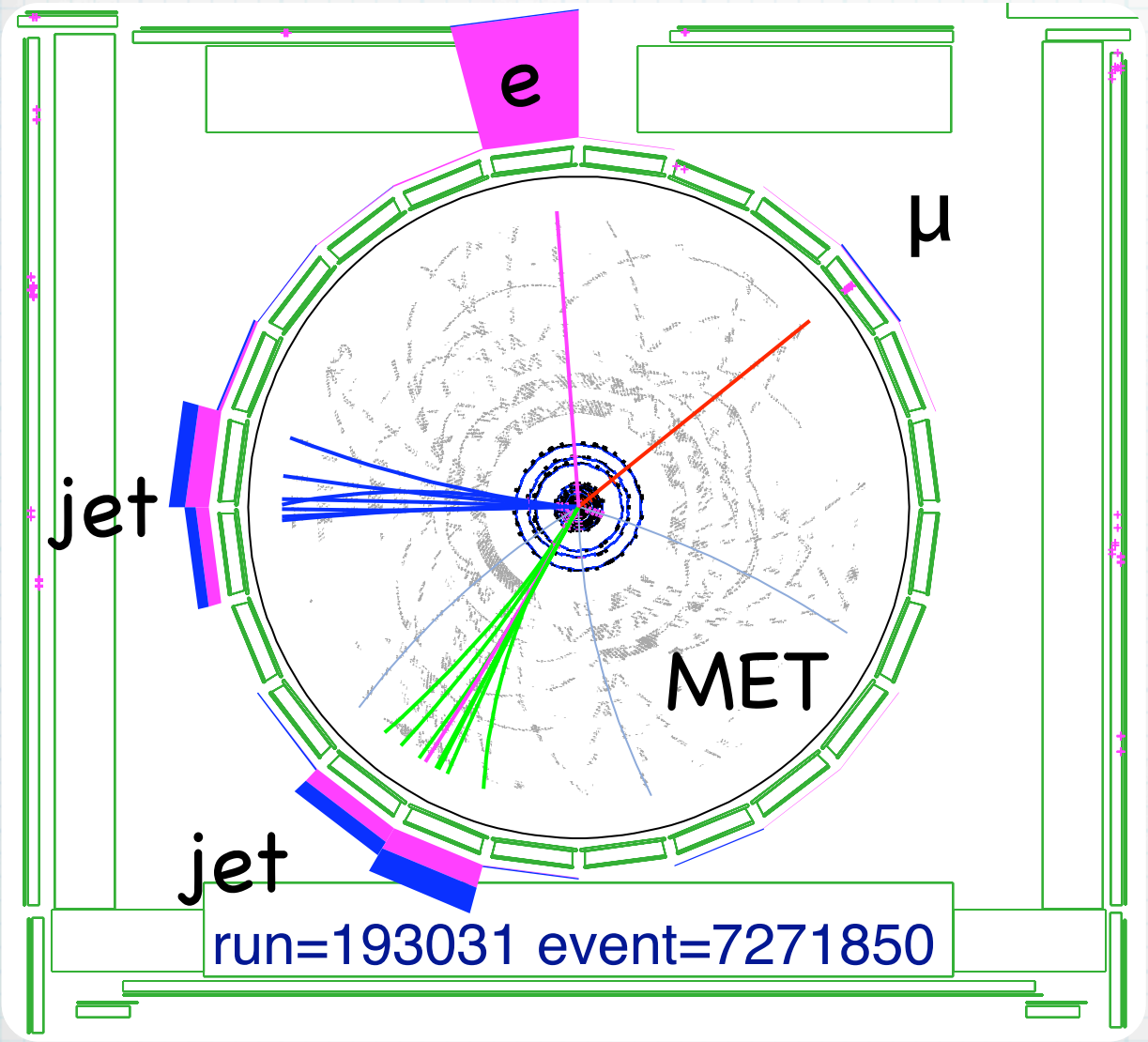
- In $t\bar{t}$ rest frame we define spin axis, used for measuring angles in $t,\bar{t}$ ZMF
- If spin axis coincide with top moment direction, we call it "helicity basis". For SM top pair production k_{hel}=-0.35
- In "off-diagonal" basis the choice for axis is to maximize spin asymmetry. For SM top pair production k_{off}=0.78

Dilepton Measurement
First Run II result !

Small yet Significant

- Dilepton sector of top pair production amounts to only 5% of all events, **but**
- This channel provides cleanest top sample with S:B≈2:1 prior to b-jet ID
- Dilepton channel is the natural choice for angular correlations study, since lepton is the best analyzer of top spin

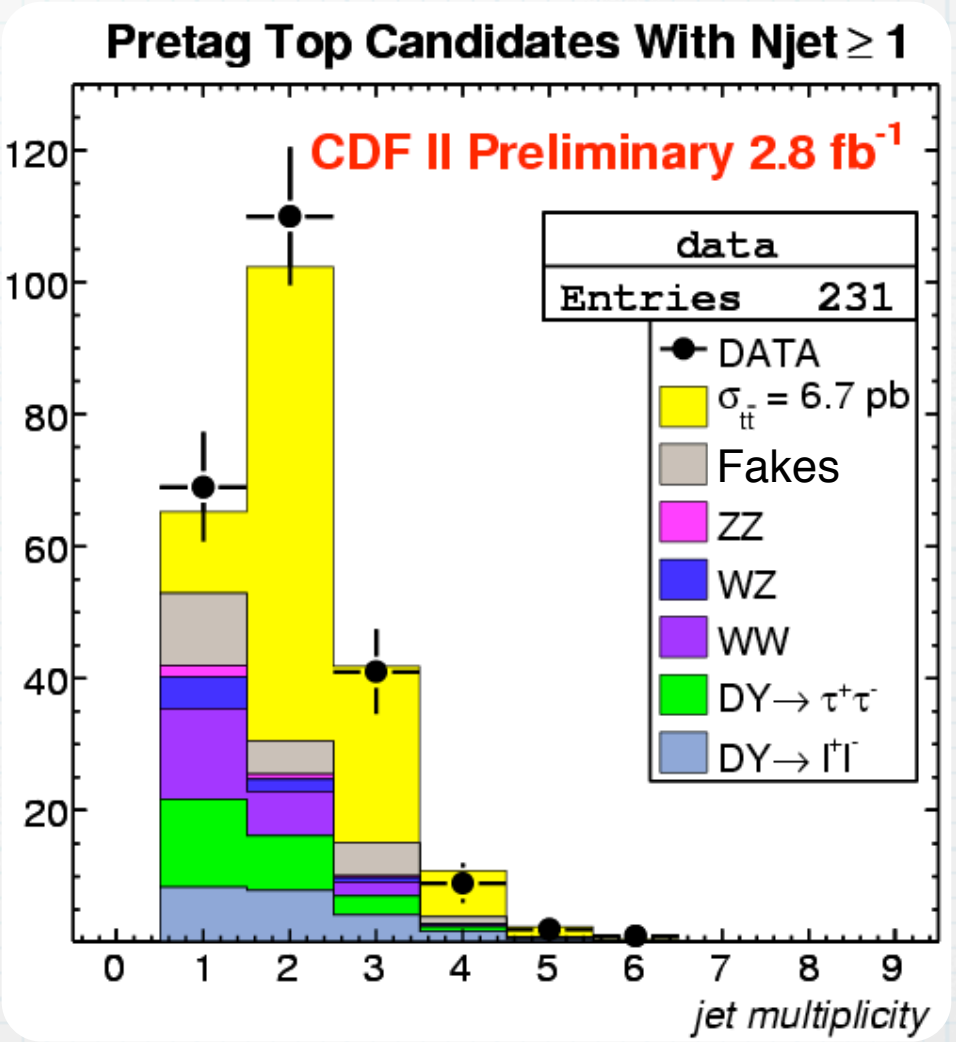
Dilepton Signature



- Two e,μ identified leptons P_T>20 GeV
- At least two jets P_T>15 GeV, |η|<2.4
- Missing energy MET>25 GeV

Selected Events in 2.8 fb^{-1}

Source	Events
DY→ ee, μμ	14.6
DY→ ττ	12.0
ZZ	1.46
WW	10.2
WZ	2.91
Fakes	10.8
Background	51.9
$t\bar{t}$ (6.7 pb)	110.6
Total sum	**162.5 ± 4.5**
Data	162



Dilepton Kinematics

- Full event reconstruction is tough:
  - 6 unknowns from missing neutrinos, jet combinatorics and b ambiguity
  - 6 constraints from m_t, m_W, MET
- Most likely kinematics per event is picked out of 8 possible solutions

Dilepton Likelihood

- Additional constraints driven mostly by $t\bar{t}$ production: $P_Z(t\bar{t})$, $P_T(t\bar{t})$, $M(t\bar{t})$

$$\mathcal{L}(\vec{p_\nu},\ \vec{p_{\bar{\nu}}},\ E_b^{guess},\ E_{\bar{b}}^{guess}) = P(p_z^{t\bar{t}}) \times P(p_T^{t\bar{t}}) \times P(M_{t\bar{t}}) \times$$

$$\frac{1}{\sigma_x^{MET}} exp\left[-\frac{1}{2}\left\{ \frac{\not{E}_x^{meas} - \not{E}_x^{guess}}{\sigma_x^{MET}} \right\}\right] \times \frac{1}{\sigma_y^{MET}} exp\left[-\frac{1}{2}\left\{ \frac{\not{E}_y^{meas} - \not{E}_y^{guess}}{\sigma_y^{MET}} \right\}\right]$$

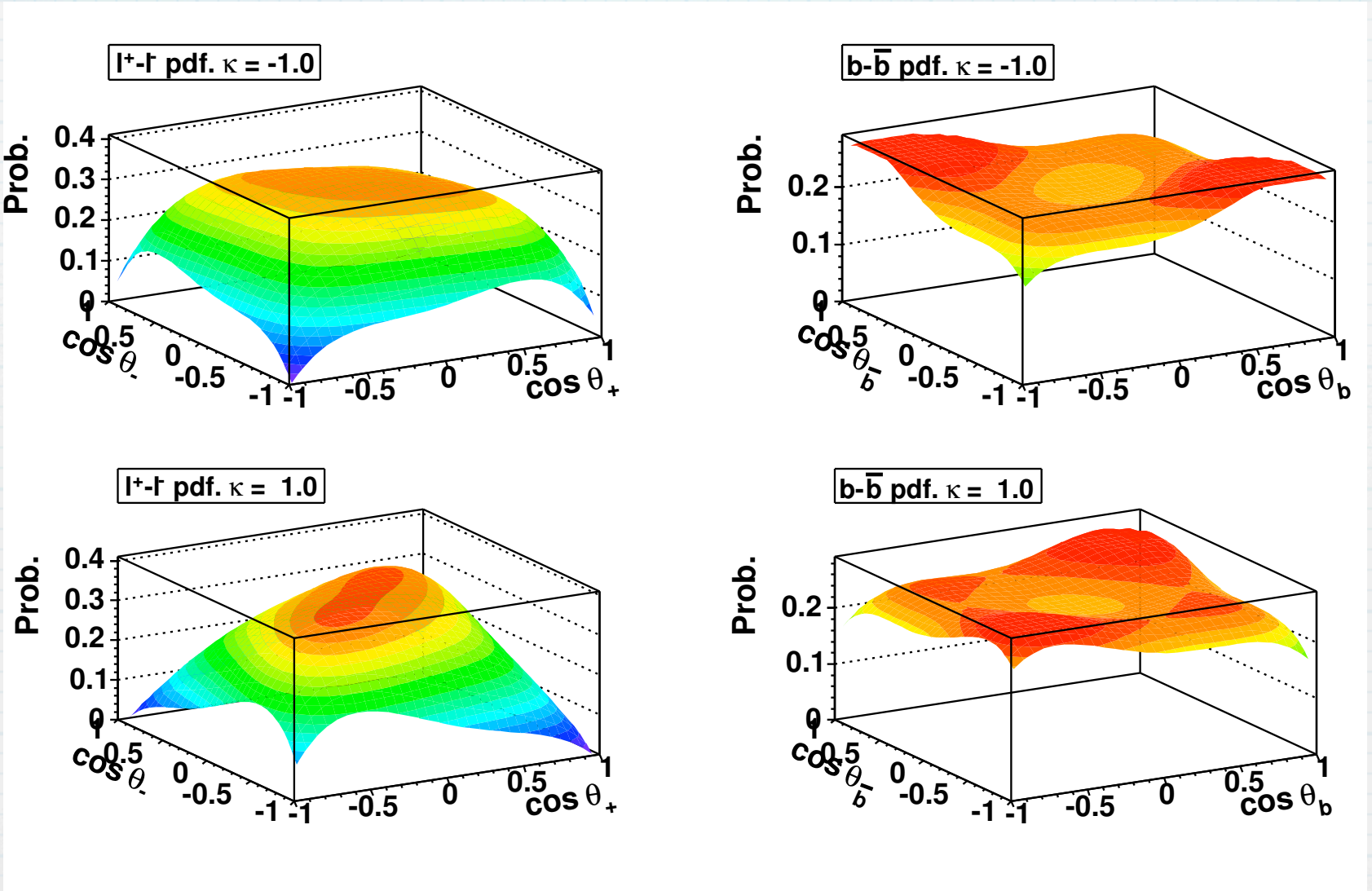
$$\frac{1}{\sigma_{jet}} exp\left[-\frac{1}{2}\left\{ \frac{E_{jet1}^{meas} - E_{jet1}^{guess}}{\sigma_{jet}} \right\}\right] \times \frac{1}{\sigma_{jet}} exp\left[-\frac{1}{2}\left\{ \frac{E_{jet2}^{meas} - E_{jet2}^{guess}}{\sigma_{jet}} \right\}\right]$$

- MET and Jet resolutions incorporated

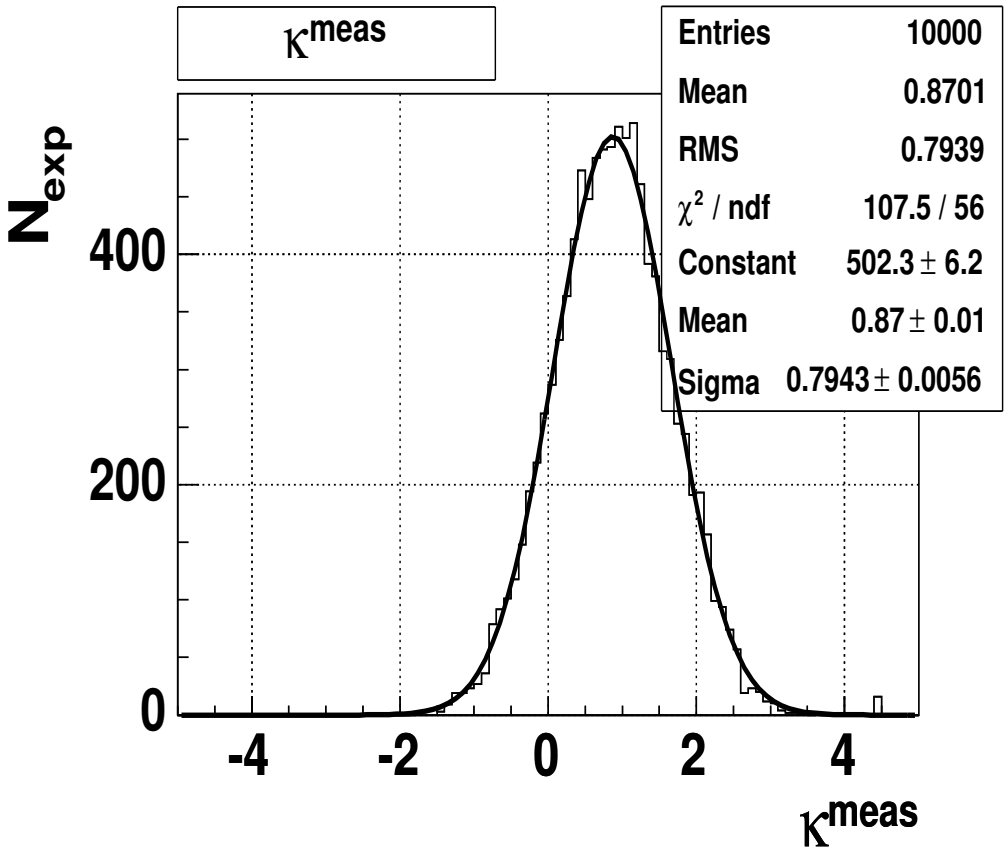
Performing the Measurement

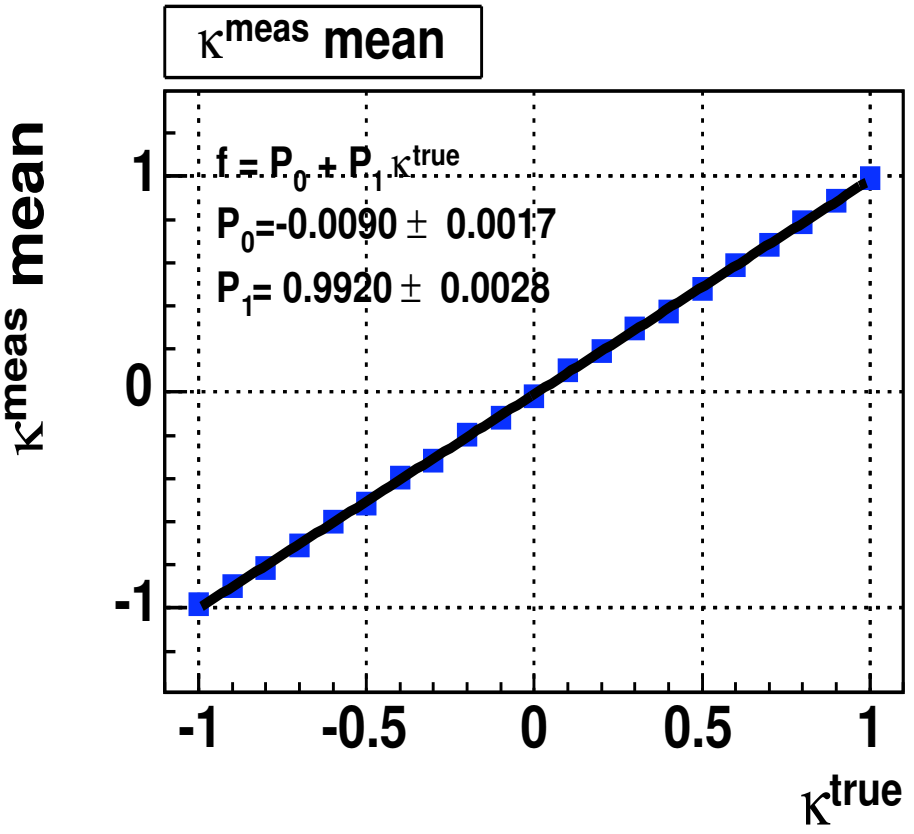
- In "off diagonal basis" create $\cos\theta^+$ vs $\cos\theta^-$ histogram for pairs of leptons and b
- Construct template function by fitting simulation distributions for various **k**
- Use unbinned likelihood method and test it by running pseudo-experiments
- Carry out the measurement on the data

Template Fit Function

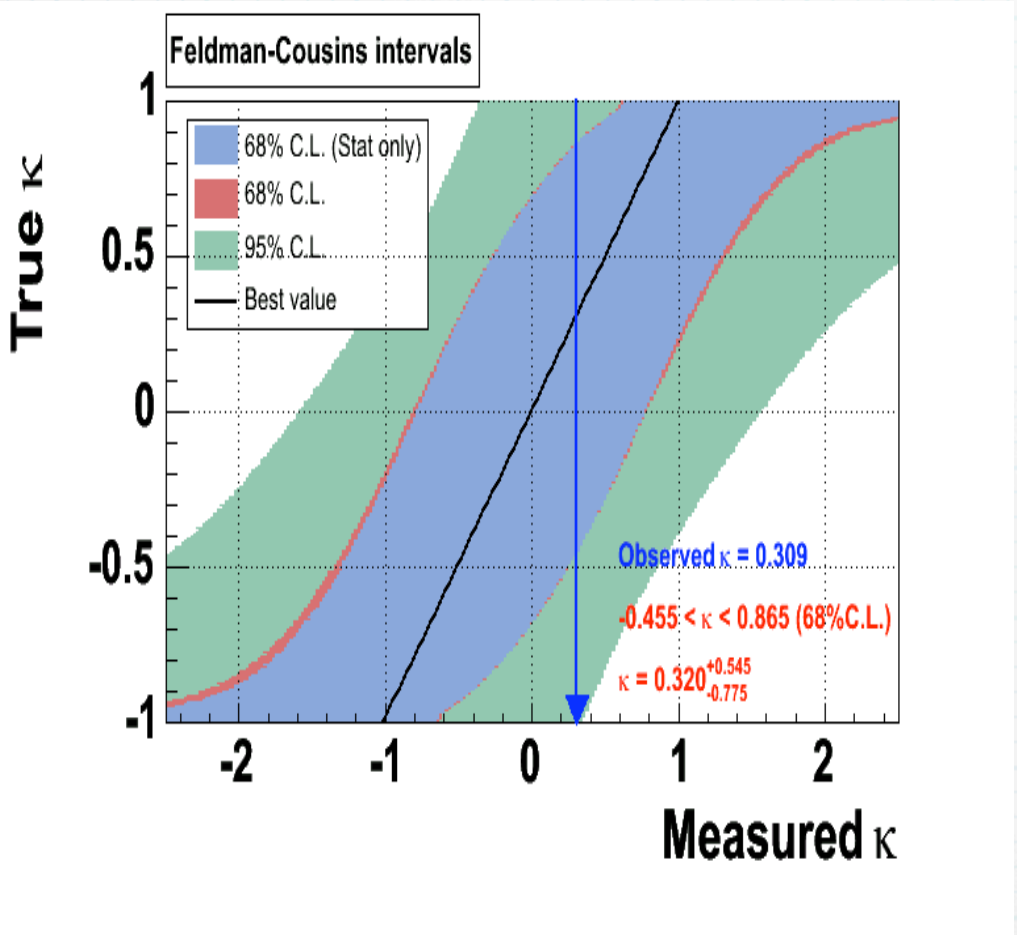


Checking P.E. & Linearity





The First Run II Result !



- 68% C.L. band $-0.455 < k < 0.865$ edges $k_{SM}=0.78$
- Result limited by statistics
- Most systematics due to PDF and backgrounds

$$k=0.320^{+0.545}_{-0.775}$$

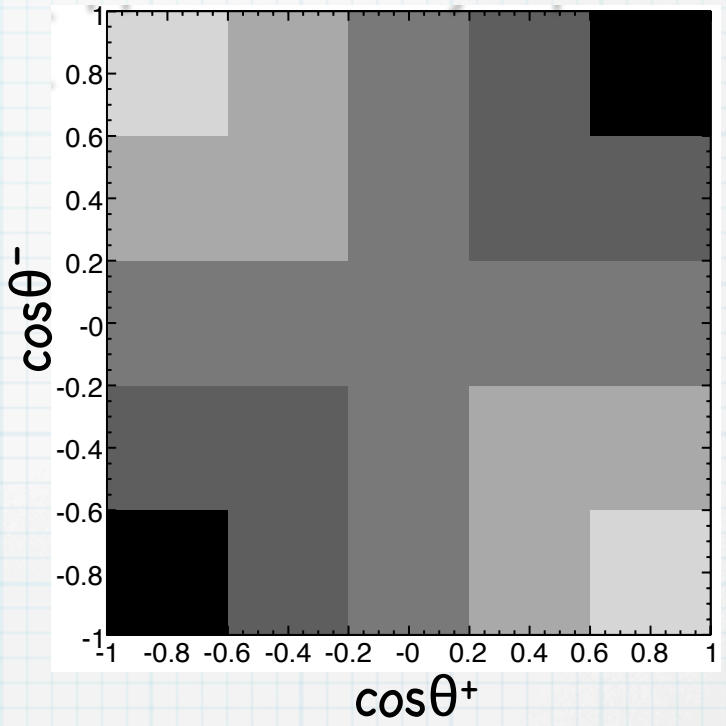
Exploring Lepton+Jets: Prospect For Another Measurement

Golden Top Sample

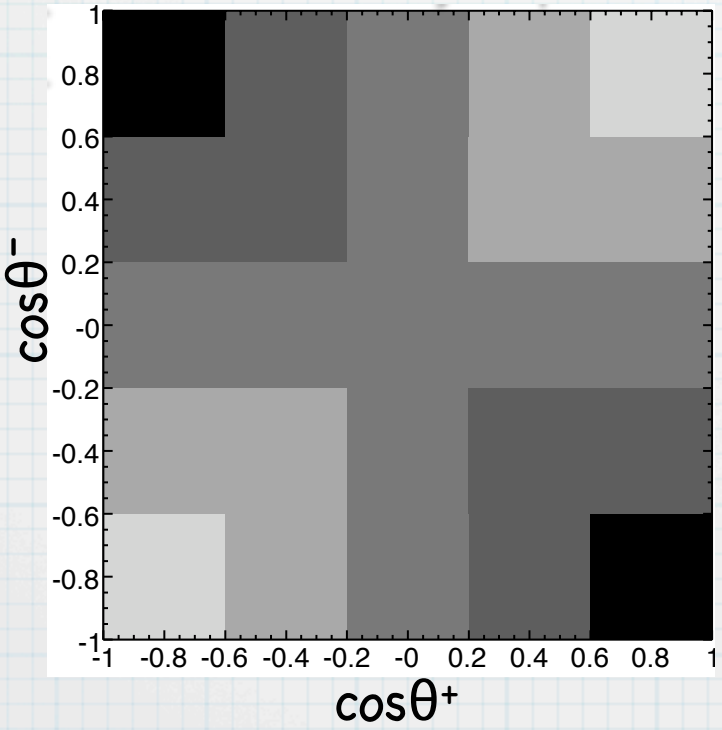
- Lepton+Jets events outscore statistics of dilepton channel by a factor of 5!
- Event kinematics is well constrained, no info on quark flavor from W decay
- For measuring spin correlation we use two basis templates in helicity frame

Split signal into two basis templates: top pairs with aligned and opposite spins

Same Spin Top Pairs

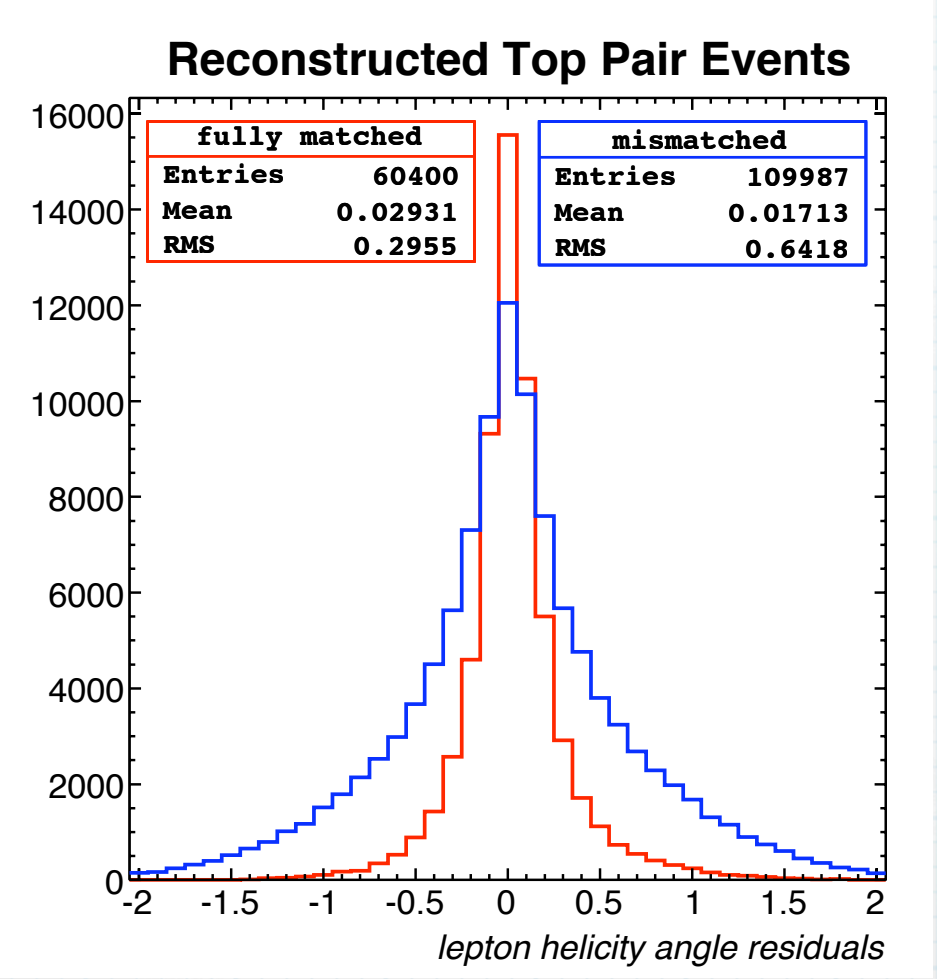


Opposite Spin Top Pairs



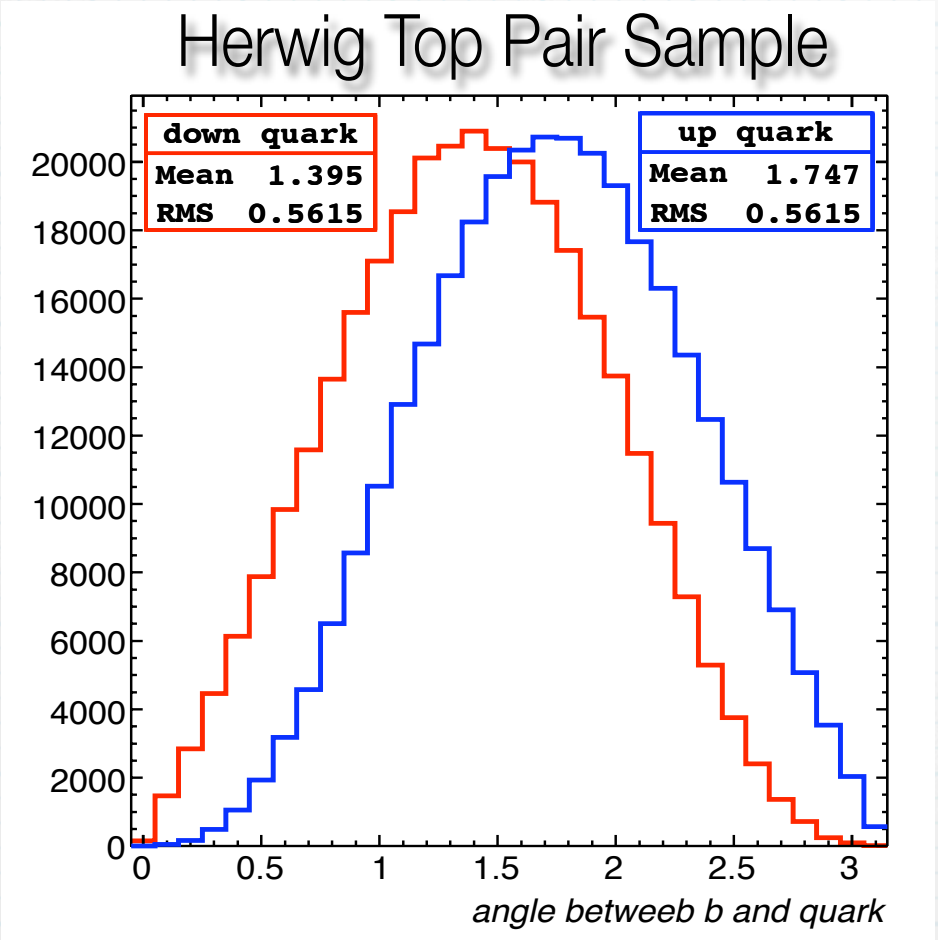
Fit data for fractions of two basis templates using binned likelihood method

Kinematic Fitter



- Need at least 4 reconstructed jets
- Jets match quarks for 33% of events
- Identifying down-quark jet further reduces efficiency

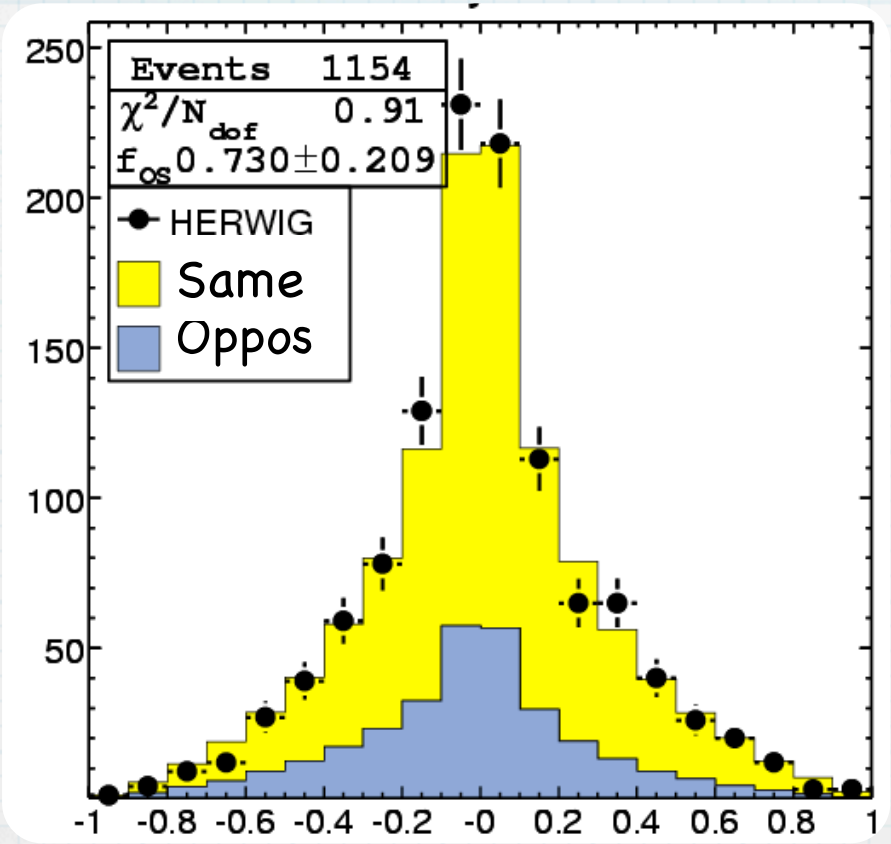
Determining d-Quark



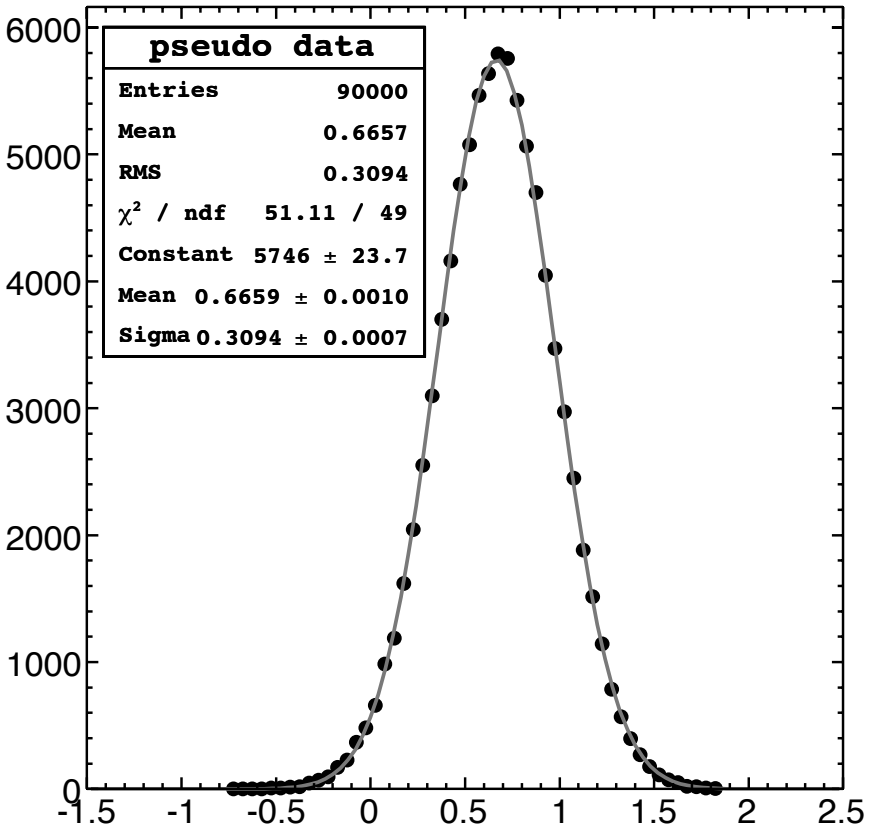
- Get to hadronic W rest frame
- closest jet to the b-quark direction is 60% likely the d-type quark

Pseudo Data Analysis

Pseudo Data Fit for HERWIG



Pseudo Data Ensembles F_{OS}=0.67



Lepton+Jets Outlook

- Statistical uncertainties of lepton+jet measurement looks to be much better relative to dilepton result
- Predicted overall systematics will not be dominating by background model
- Public result using lepton+jets data not yet available, but expected soon

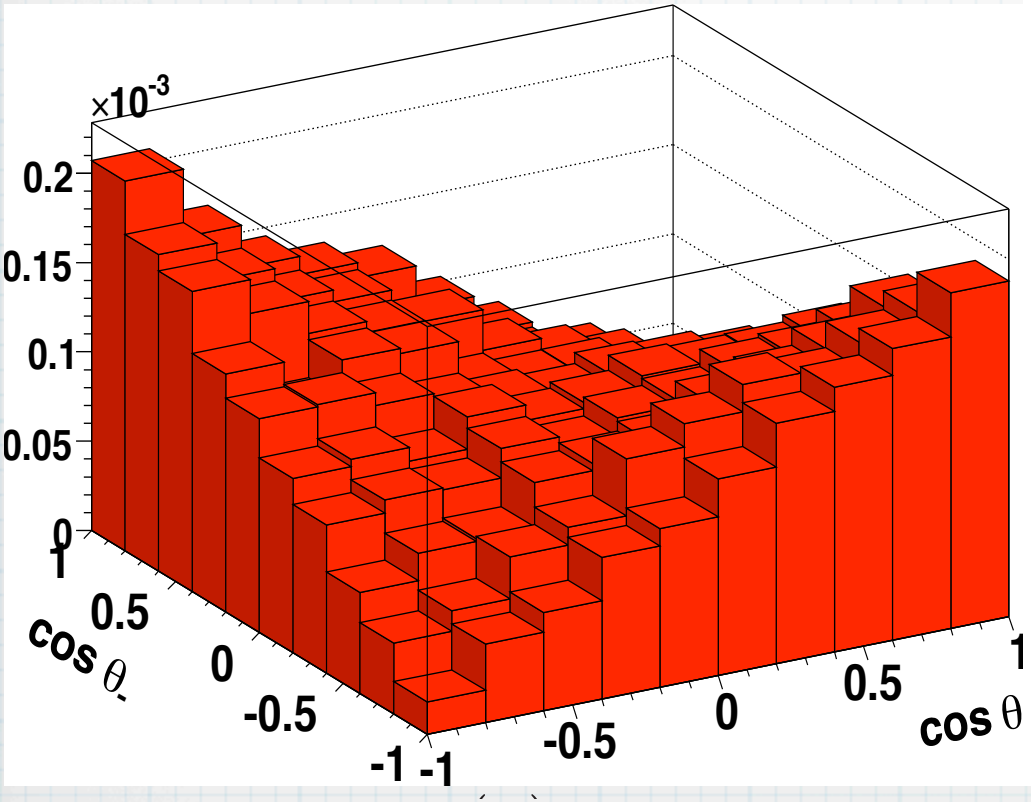
Summary

- CDF produced first spin correlation result using dilepton $t\bar{t}$ events in 2.8 fb^{-1} of Run II data
- Another measurement in independent lepton+jets channel is underway
- Combination of two measurements will provide a very powerful result

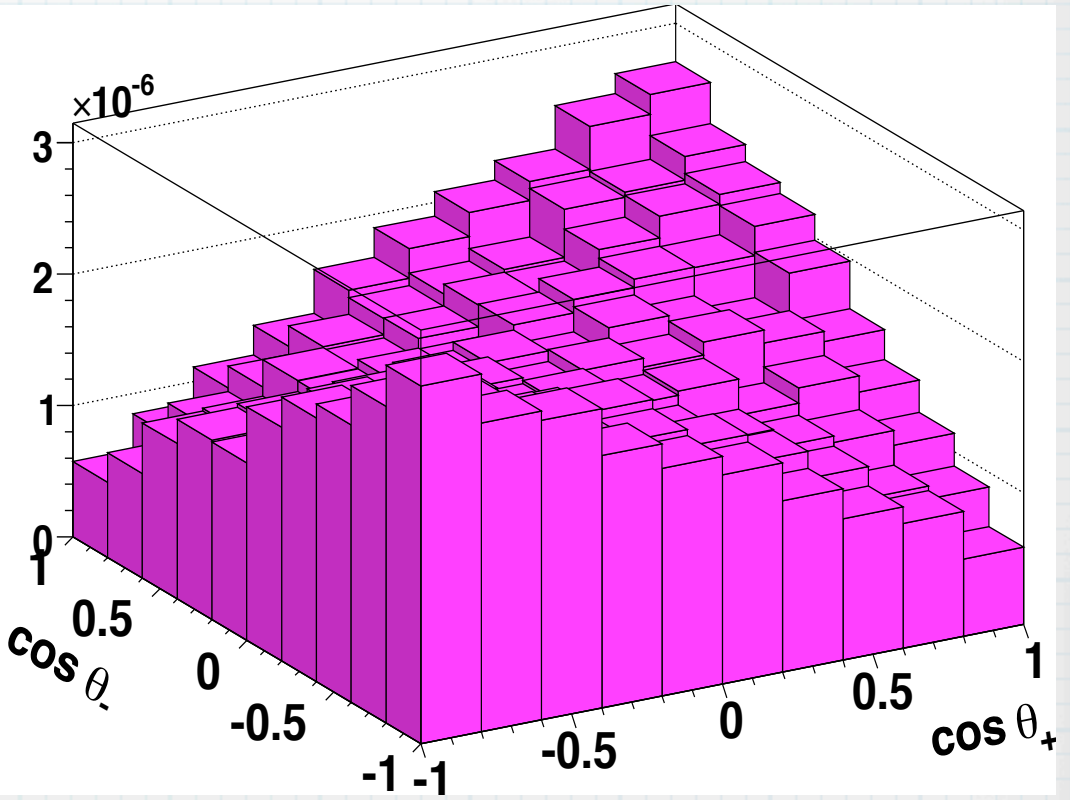
Backup Slides

BSM Top Scenarios

top pairs mediated by J=0



top pairs mediated by J=2



R. Frederix, F. Maltoni arXiv:0712.2355