陽子・反陽子衝突実験でのトップクォーク対生成における
スピン偏極度相関の測定

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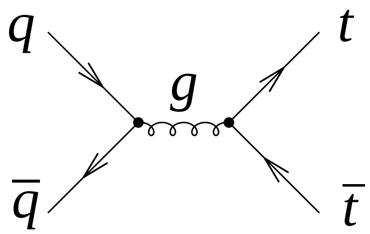
Mar. 30, 2004

Outline

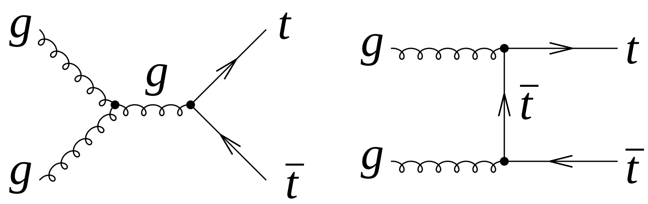
- Introduction
- Analysis
  - Event Selection
  - Event Reconstruction
- Monte Carlo Simulation with CDF-II Detector
  - Sensitivity Prospect
- Summary & Future Plan

Introduction

- $t\bar{t}$ productions in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$



$q\bar{q}$ annihilation
$\sim 85\%$

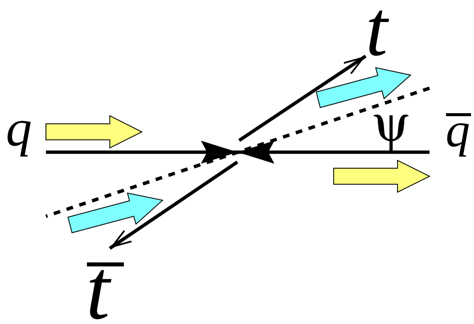


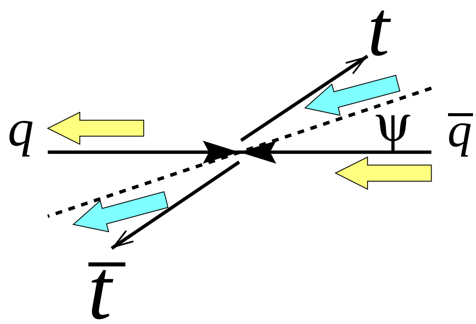
gluon fusion
$\sim 15\%$

  - Spin-flip time $O(m_t/\Lambda^2_{\mathrm{QCD}}) \simeq (1.3\,\mathrm{MeV})^{-1}$
  - Width: $\Gamma_t \simeq 1.42\,\mathrm{GeV}$
  - $O(m_t/\Lambda^2_{\mathrm{QCD}}) \gg 1/\Gamma_t$

  $\rightarrow$ Top quark decays before losing the spin information at the production.

- Spin configurations at production

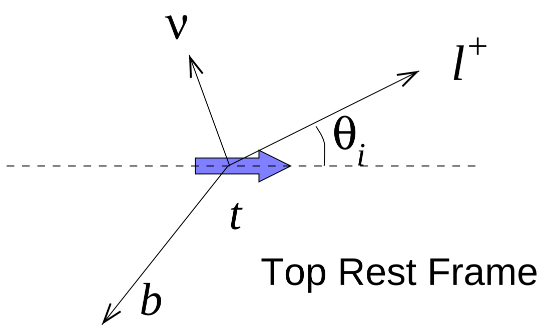




  - In tree-level $q\bar{q}$ annihilation, intermediate state gluon is polarized along Z-axis due to helicity conservation.

  $\rightarrow$ obtain only like-spin combinations (100% correlations), if take a proper basis so-called "off-diagonal".

Decay of Polarized Top Quark



Particle	α_i
ℓ^+	1
ν	-0.32
W^+	0.40
b	-0.40

$$\frac{1}{\Gamma}\cdot\frac{d\Gamma}{d\cos\theta_i}=\frac{1+\alpha_i\cos\theta_i}{2}$$

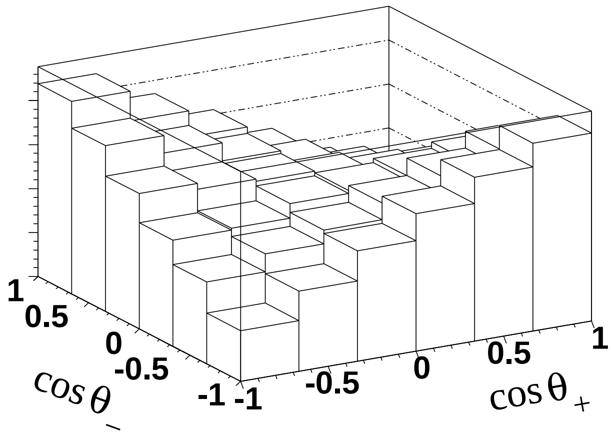
- $\theta_+(\theta_-)$: Angle of $\ell^+(\ell^-)$ flight direction w.r.t. quantization basis(off-diagonal basis) in $t(\bar{t})$ rest frame.
- $t\bar{t}$ spin correlations can be seen as angular correlations of leptons:

$$\frac{1}{\sigma}\cdot\frac{d^2\sigma}{d\cos\theta_+\,d\cos\theta_-}=\frac{1-\kappa\cos\theta_+\cos\theta_-}{4}$$

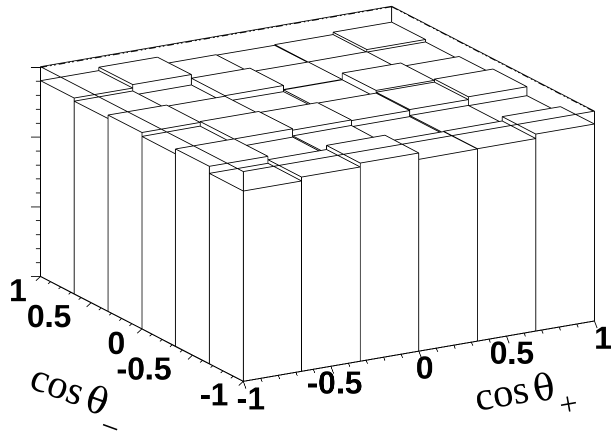
κ : correlation parameter (~ 0.81 in SM)

$0 \rightarrow 0\%$ correlated $\qquad 1 \rightarrow 100\%$ correlated

- Angular distributions from Herwig event generator:



w/ spin correlations



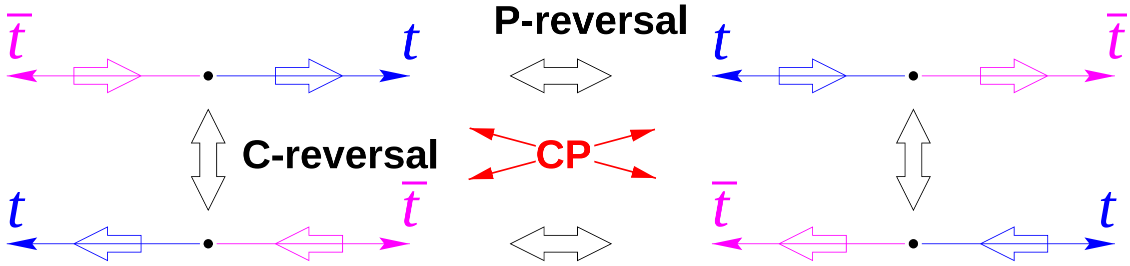
Null correlation

Physics Topics

- Direct proof of $1/\Gamma_t \ll O(m_t/\Lambda^2_{\rm QCD})$

  $\rightarrow$ Lower bound on Γ_t

- Probe to $\not{P}$ and $\not{C}P$ at $t\bar{t}$ production



Experimental Status

- No result from CDF Run I

- D∅ Run I result based on 6 dilepton candidates:

  - $\kappa > -0.25$ (68%CL) $\Leftrightarrow$ $\kappa \simeq 0.9$(SM)

Analysis Strategy

- Use dilepton channel $(t\bar{t} \to \ell^+ b \nu \ell^- \bar{b} \bar{\nu})$

  Pros

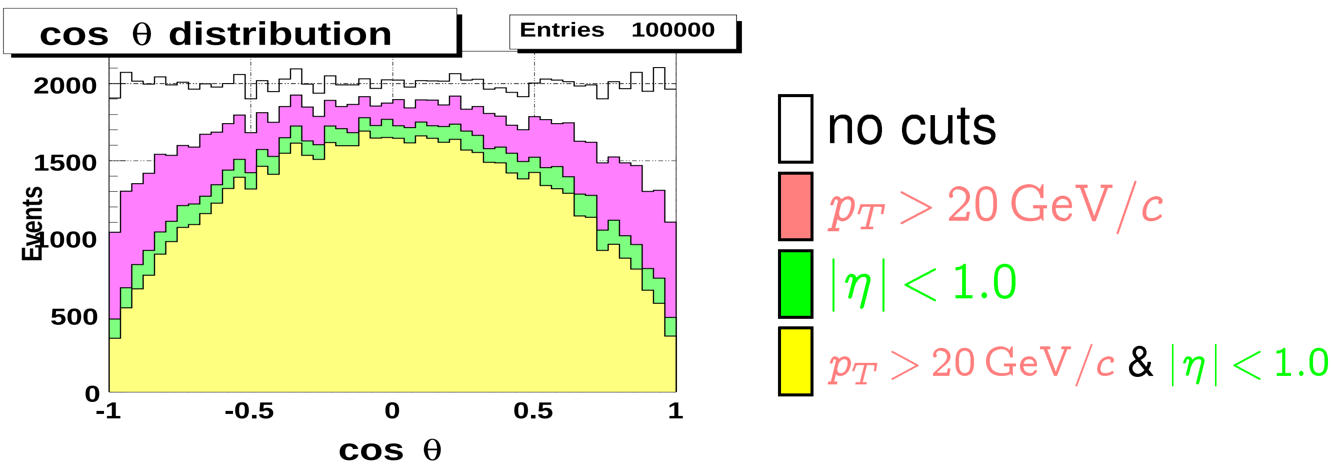
  - Leptons have the maximum analyzing power to $t(\bar{t})$ spins.
  - Clean and simple, comparing to lepton+jets channels.

  Cons

  - Small branching fraction (5%: ee, $e\mu$, $\mu\mu$).
  - How can we extract $\cos\theta_\pm$ w/o neturino?
  - Two possible combinations as to b-jets.

$\cos\theta_\pm$ Acceptance

- Effects on $\cos\theta_\pm$ by p_T and $|\eta_\ell|$ cuts:

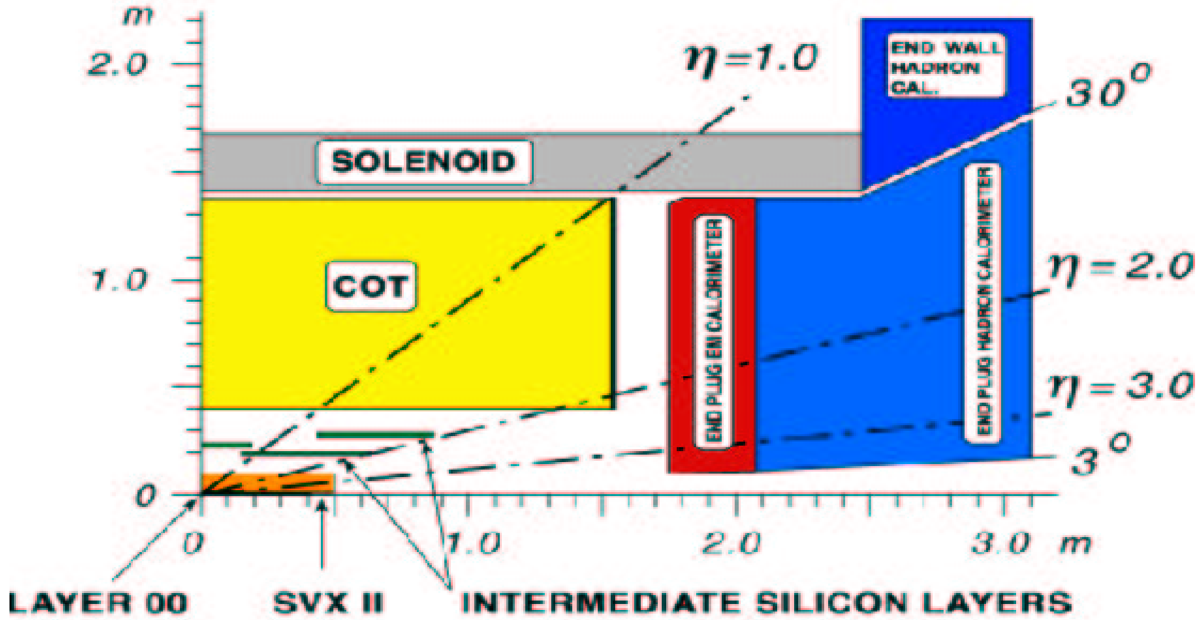


$\rightarrow$ p_T and/or $|\eta|$ cuts for leptons drop events sensitive to spin correlations.

Used samples

- $t\bar{t}$ inclusive MC sample only
  - Herwig event generator with CDF-II detector simulation.
  - Pythia event generator with CDF-II detector simulation.

Event Selection

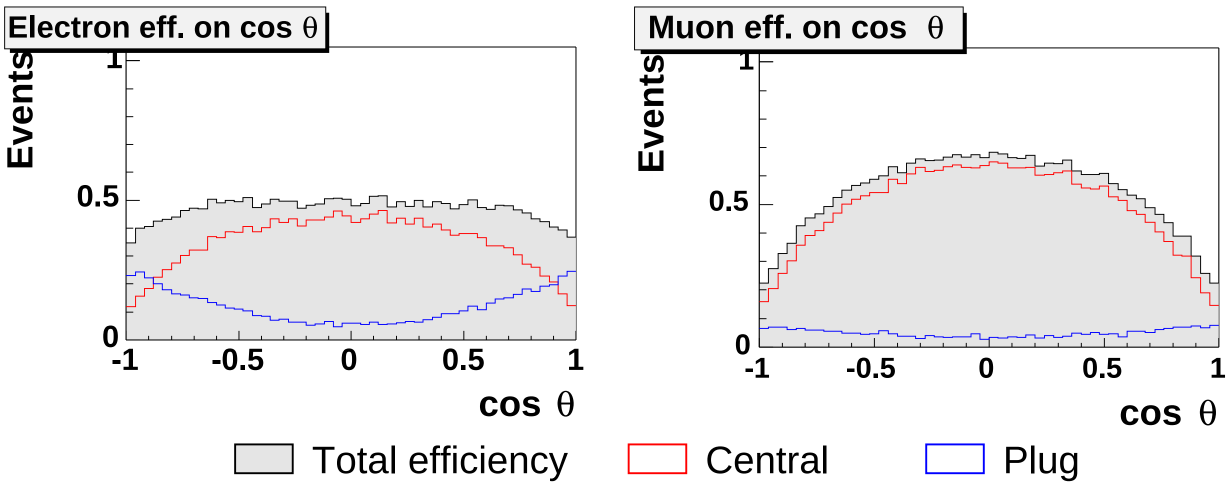


- Exact 2 leptons
  - Opposite charge
  - At least one central($|\eta| < 1.0$) lepton
  - Z^0 Veto ($76.0 < M_{ee}, M_{\mu\mu} < 106.0\,\mathrm{GeV}/c^2$)
- N(jets) $\geqslant 2$
  - Use leading 2 jets if more than two.
- $\not{E}_T > 25\,\mathrm{GeV}$
- $\Delta\varphi(\not{E}_T, \text{nearest } e \text{ or jet}) < 10^\circ$

Dilepton Event Acceptance

	w/ correlations	w/o correlations
Generate	80000	80000
2 lepton	20751	20625
Z^0 veto	17970	17817
$N_{\text{jets}} \geqslant 2$	15589	15345
$\not{E}_T$	13756	13551
$\Delta\varphi$	12386(15.5%)	12184(15.2%)

- Lepton ID efficiency as a function of $\cos\theta_\ell$



Event Reconstruction

- To reconstruct $\cos\theta_\ell$
  - ○ Assign two jets to b- and $\bar{b}$-jet.
  - ○ Guess momenta of two neutrinos on an under-constraint system.
    - — 6 unknowns against 4 constraints (m_W, $m_{\rm top}$)

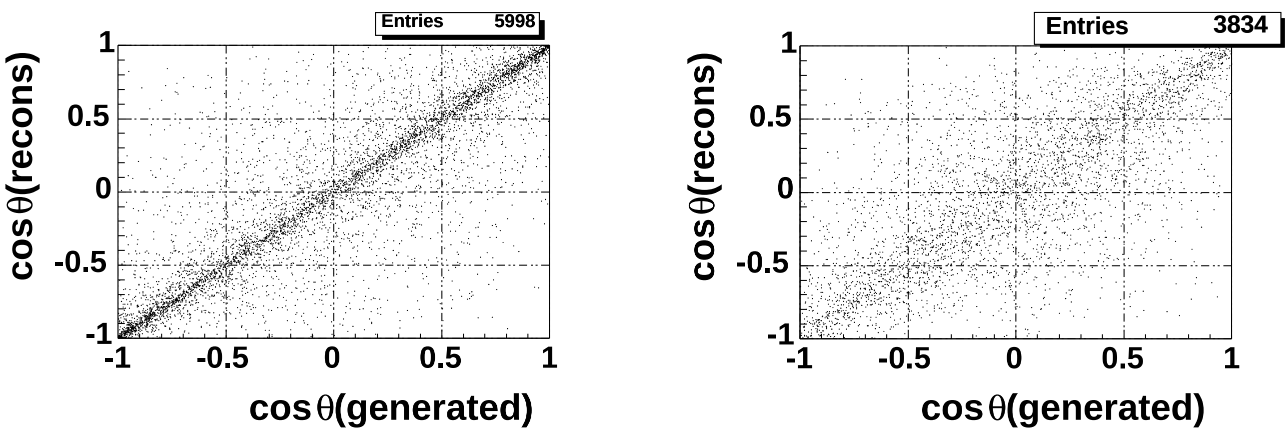
  $\rightarrow$ $t\bar{t}$ system can be written by two parameters: φ_+, φ_-

  $p_{t\bar{t}}(\varphi_+, \varphi_-)$

  $\rightarrow$ Scan all points in (φ_+, φ_-) space and choose one which gives maximum probability in 4-momentum $p_{t\bar{t}}$ distribution assumed to be known.

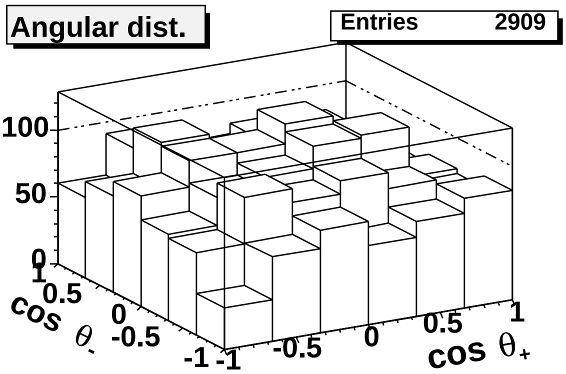
- Methodology check
  - ○ Plot generated $\cos\theta$ v.s. $\cos\theta$ reconstructed from p_{ℓ^+}, p_{ℓ^-}, p_{b_1}, p_{b_2} in Lab frame.

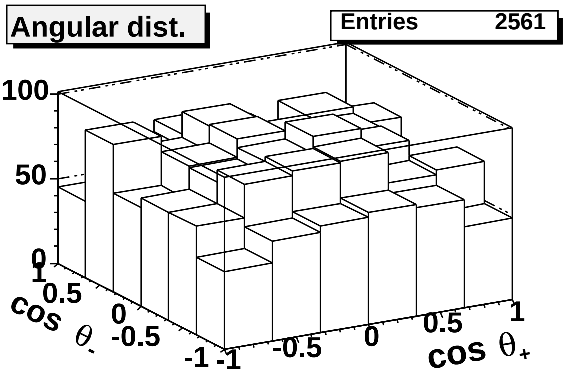
Before detector simulation After detector simulation

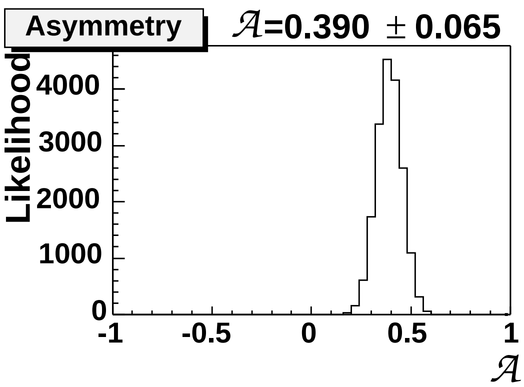


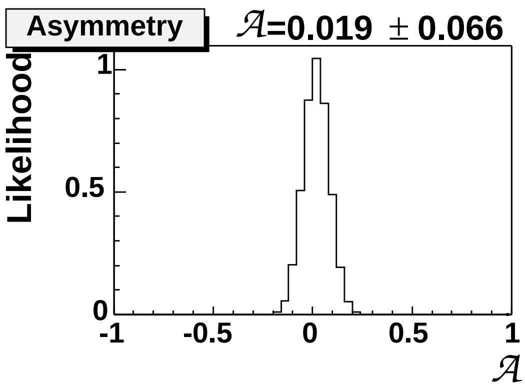
MC simulations with CDF-II detector

- MC samples
  - Herwig (w/ spin correlations)
    378K $t\bar{t}$ inclusive ($\int \mathcal{L}dt = 56.4\,\mathrm{fb}^{-1}$)
  - Pythia (w/o spin correlations)
    398K $t\bar{t}$ inclusive ($\int \mathcal{L}dt = 59.4\,\mathrm{fb}^{-1}$)
- Reconstructed angular distributions after event selection:









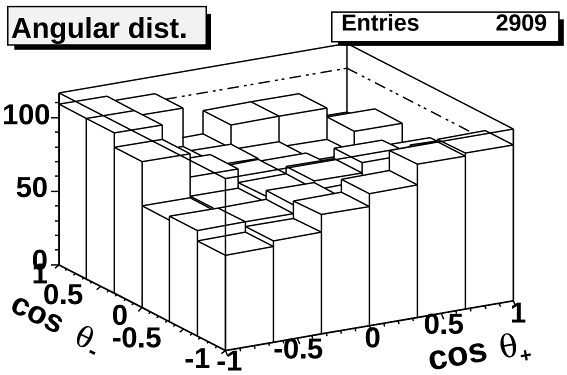
Herwig

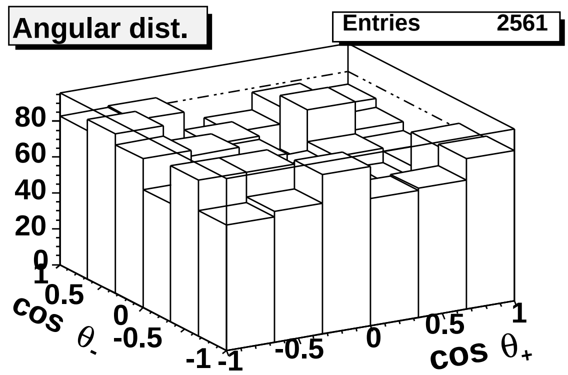
Pythia

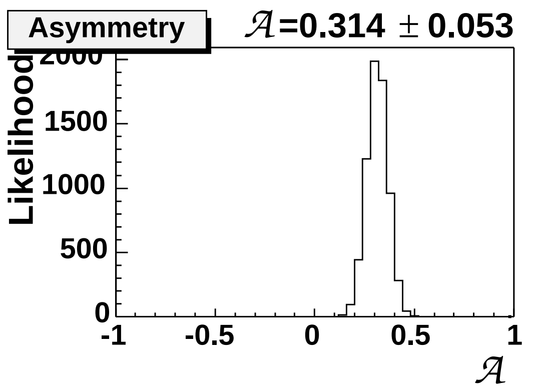
- $d\sigma \propto \eta(\cos\theta_+, \cos\theta_-)(1 - \kappa\cos\theta_+\cos\theta_- + C)$
  η: acceptance
  Assume $\eta(\cos\theta_+, \cos\theta_-) = \eta(\pm\cos\theta_+, \pm\cos\theta_-)$

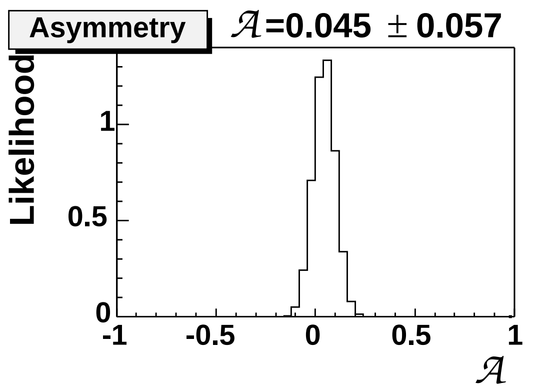
  $\rightarrow$ extract $\mathcal{A} = \kappa/(1 + C)$

- Angular distribution of b- and $\bar{b}$-jets



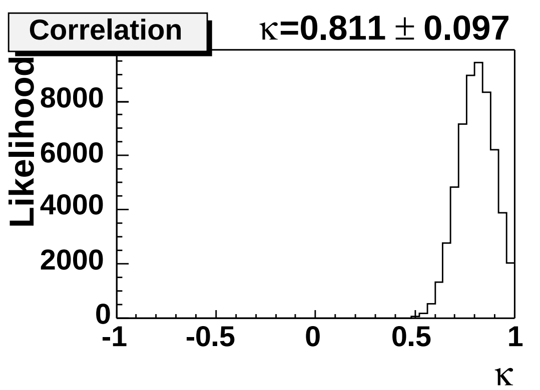


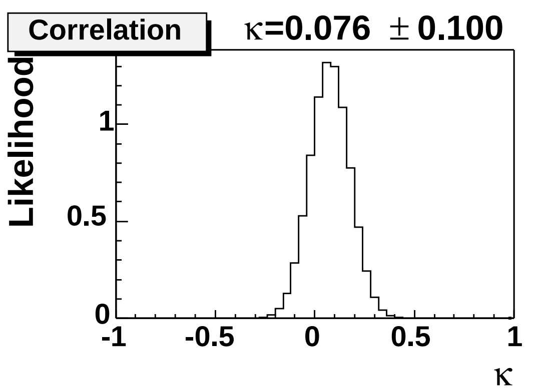




Herwig Pythia

- Re-scaling these asymmetries, obtain



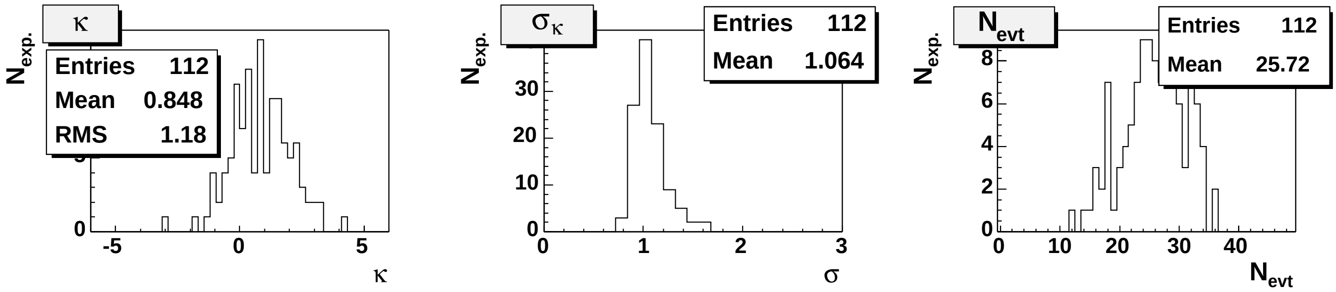


Herwig Pythia

$\kappa = 0.811 \pm 0.097$ using $\int \mathcal{L}dt = 56.4\,\mathrm{fb}^{-1}$

Sensitivity Prospect from Pseudo-experiments

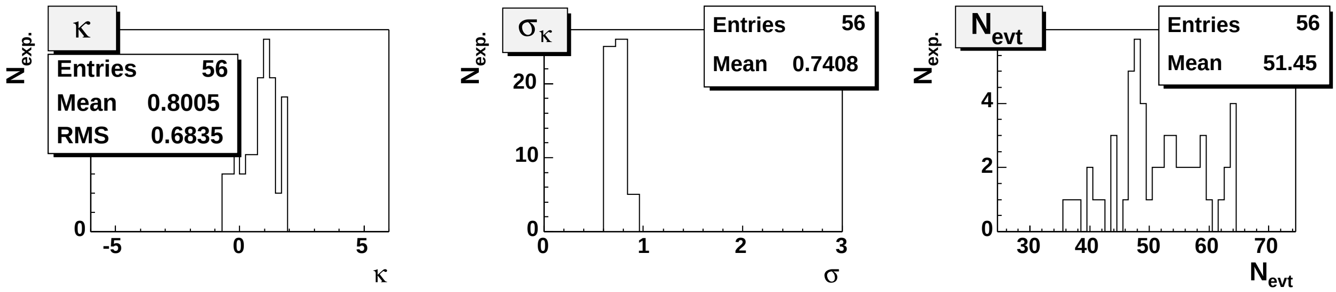
- $\int \mathcal{L} dt = 500\,\mathrm{pb}^{-1}$



$\langle \kappa \rangle = 0.848$ RMS $= 1.18$ $\langle \sigma_\kappa \rangle = 1.06$ $\langle N \rangle = 25.7$

Hopefully, can set lower limit $\kappa > -0.7$ (90%CL)

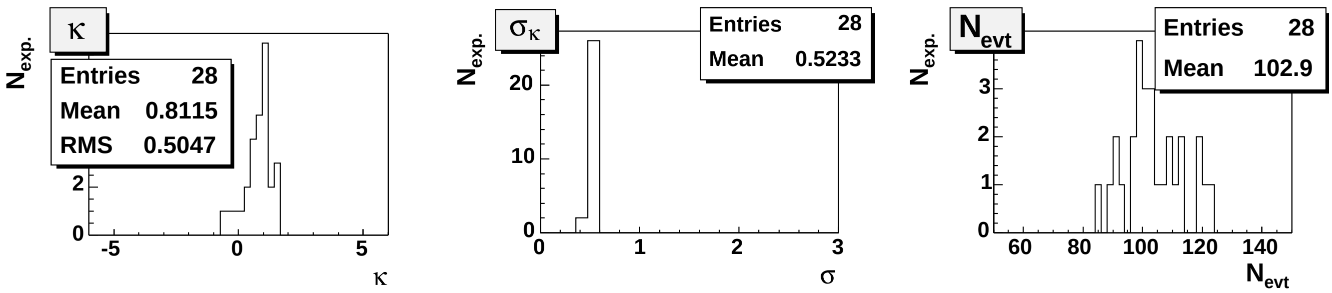
- $\int \mathcal{L} dt = 1\,\mathrm{fb}^{-1}$



$\langle \kappa \rangle = 0.801$ RMS $= 0.684$ $\langle \sigma_\kappa \rangle = 0.741$ $\langle N \rangle = 51.5$

Lower limit $\kappa > -0.06$(90%CL)

- $\int \mathcal{L} dt = 2\,\mathrm{fb}^{-1}$



$\langle \kappa \rangle = 0.812$ RMS $= 0.505$ $\langle \sigma_\kappa \rangle = 0.523$ $\langle N \rangle = 102.9$

Lower limit $\kappa > 0.16$(90%CL)
$\kappa > -0.02$(95%CL)

Summary & Future Plan

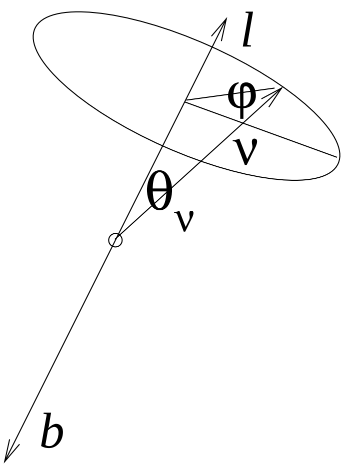
- In the $t\bar{t}$ pair production at the Tevatron, top quark spin correlations can be observed because of its extreamly short lifetime.
  - Approach to the top quark features (Γ_t, $\cdots$).
  - Clue to a new physics.
- Developed an analysis method for top spin correlations.
- Performed estimation of sensitivity to correlation parameter κ using the detector simulation.
  - $\langle \sigma_\kappa \rangle = 1.1 (500\,\mathrm{pb}^{-1}) \quad 0.74 (1\,\mathrm{fb}^{-1}) \quad 0.52 (2\,\mathrm{fb}^{-1})$

Future Plan

- Include backgrounds
  - diboson (WW, WZ)
  - $Z \to \tau\bar{\tau}$
  - Drell-Yan
  - QCD fakes
- Confirm null correlation using backgrounds events.
- $\ell + \mathrm{jets}$ channel?

Parameterization of $t\bar{t}$ system

In $\ell + b$ rest frame,



$$(p_\ell + p_\nu)^2 = m_W^2$$
$$(p_\ell + p_\nu + p_b)^2 = m_t^2$$
$$\Downarrow$$
$$p_\nu = \frac{m_t^2 - m_{\ell b}^2}{2\, m_{\ell b}}$$
$$p_\nu \cos\theta = \frac{m_t^2 - m_W^2 - m_{\ell b}^2}{2\, m_{\ell b}}$$

Momentum distribution of $t\bar{t}$ system