LC top physics above threshold – a sampler

– R. Frey, oregon

Moral: Very interesting physics.
But studies very unsophisticated.
(compared to threshold)

→ opportunity to make important contributions, perhaps in context of realistic simulations for detector studies.

* Basics

* Couplings

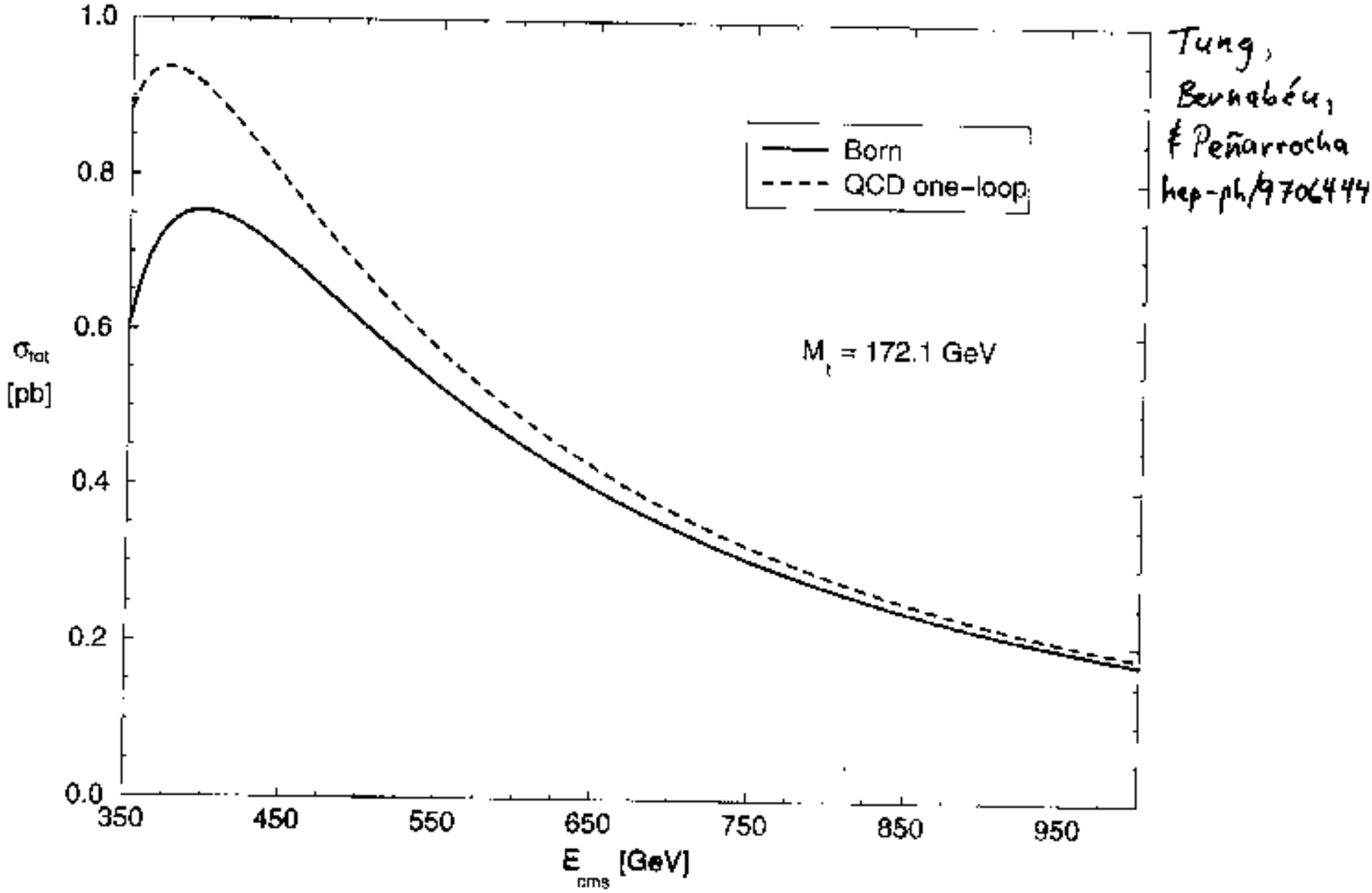
* Yukawa couplings

* V_{tb} (V_{ts})

[* $dL/d\sqrt{s}$]

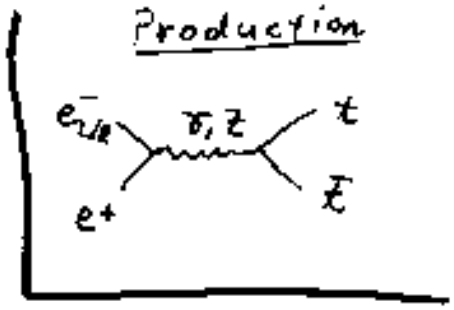
* Note: $e^+e^- \to \nu\bar{\nu}\, t\bar{t}$ at large $\sqrt{s}$ (strong coupling test)

Talks by Barklow and/or Peskin in EW/strong int. subgroup



Tung, Bernabéu, & Peñarrocha hep-ph/9706444

Top Decay in S.M.



- $BR(t \to bW) \simeq 1$
- $\Gamma(t \to bW) \simeq (0.18\,\text{GeV}) \cdot \left(\frac{m_t}{m_W}\right)^3$

$\Rightarrow$ In $e^+e^- \to \bar{t}t$, t decays in ≈ 0.01 fm

before hadronization can occur

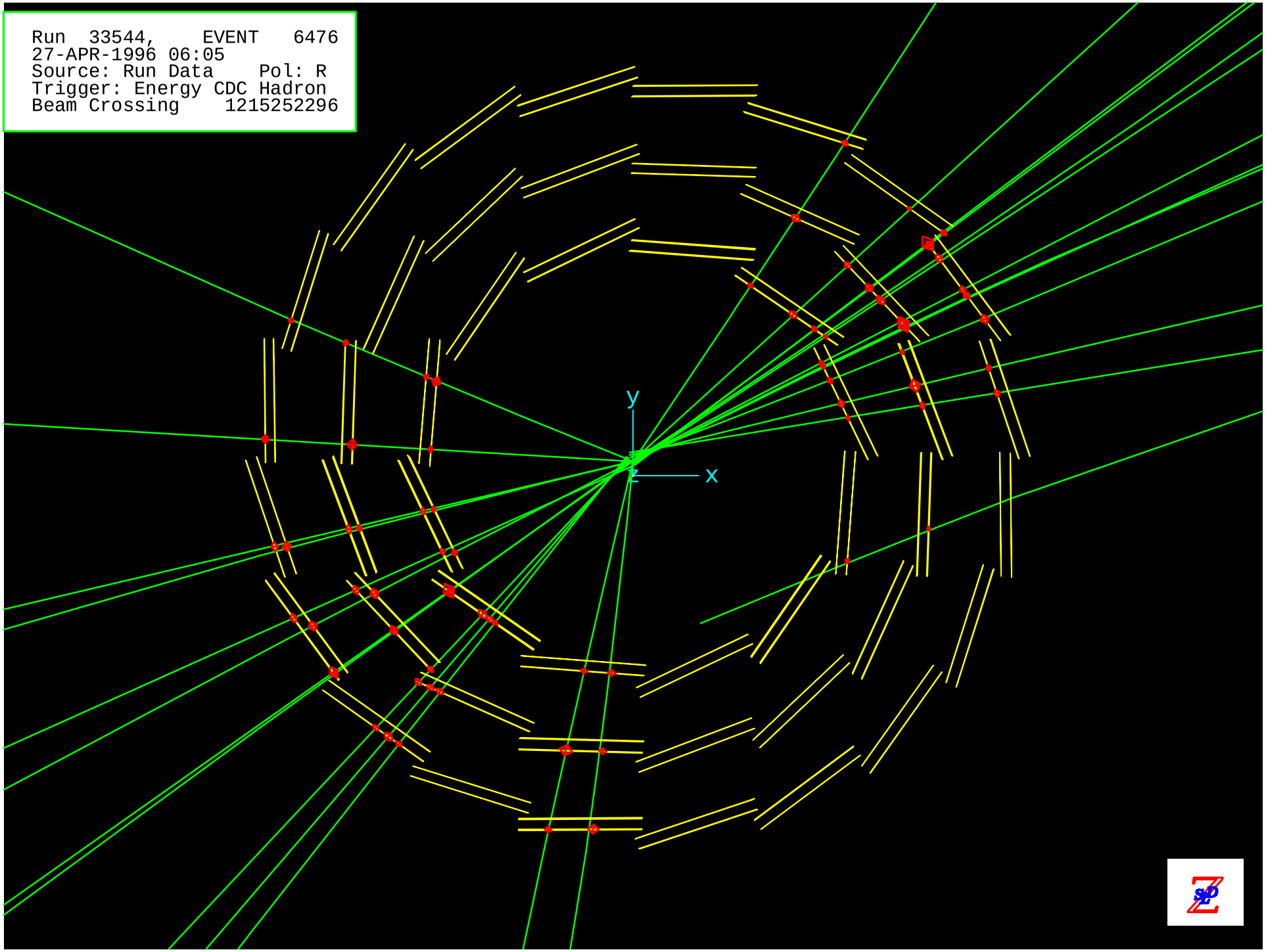
$e^+e^- \to t\bar{t}$
$t \to \bar{b}W$
$\bar{t} \to bW$

- parton level
- color string joins b-$\bar{b}$
- top helicity $\to bW$
- no IR gluons from t

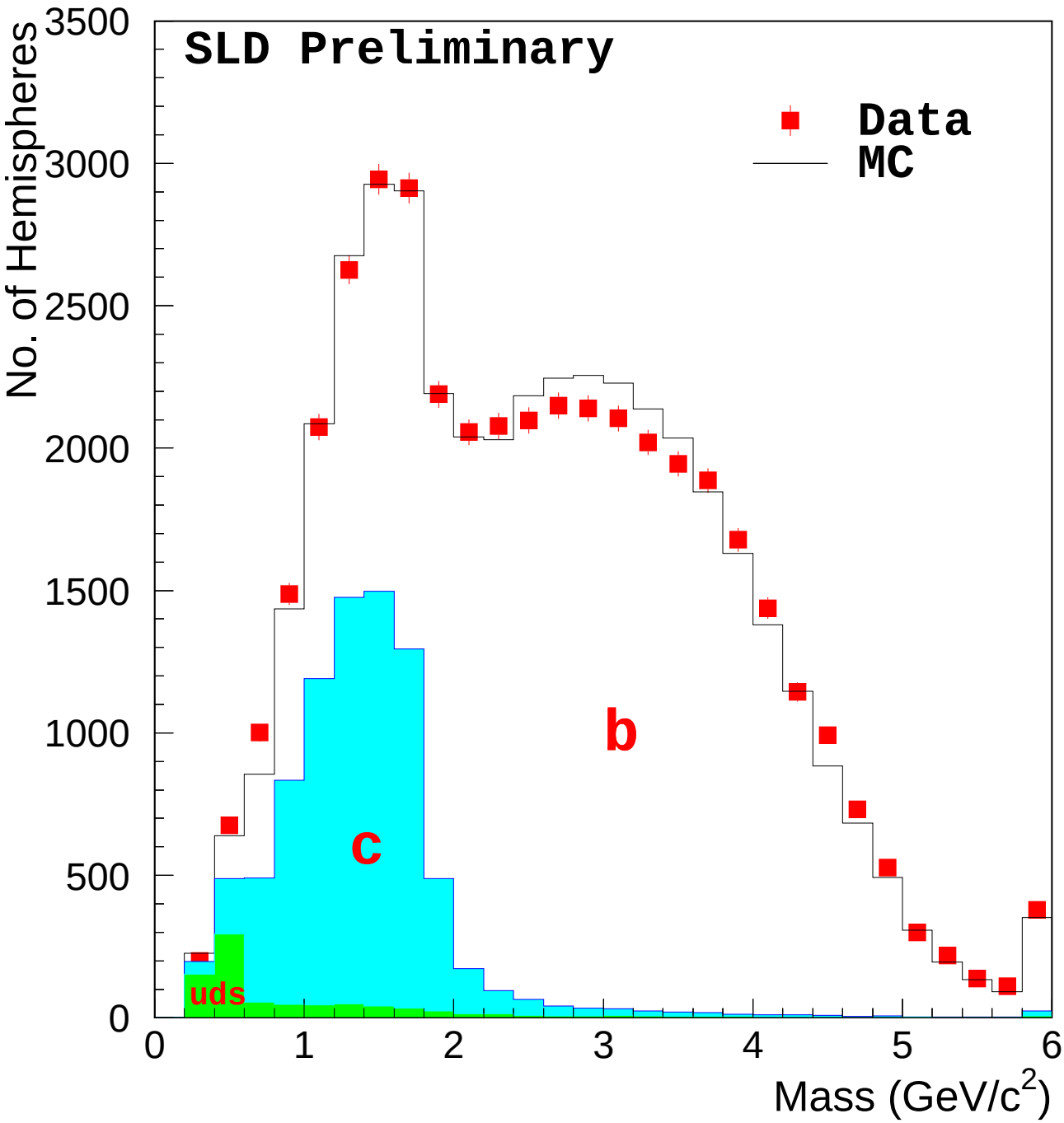
Large $m_t \Rightarrow W$ mostly longitudinally polarized

Final states:

$t\bar{t} \to$	$b\bar{b}\,4q$	45%
$\to$	$b\bar{b}\,2q\,l\nu$	44%
$\to$	$b\bar{b}\,2(l\nu)$	11%


Run 33544, EVENT 6476
27-APR-1996 06:05
Source: Run Data Pol: R
Trigger: Energy CDC Hadron
Beam Crossing 1215252296
y
x
z

P_t Corrected Mass (VXD3 97-98)



Top Form Factor Studies

aka top couplings,
anomalous moments

New physics ⇒ top couplings which depart from SM

(cf Wudka – Eff. Th. approach)

NB: Since top does not hadronize,

helicity information preserved in decay.

$e^+e^- \longrightarrow t\bar{t}$

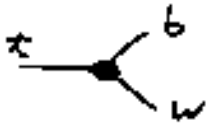
$t \longrightarrow \bar{b} W^-$

$t \longrightarrow b W^+$

NC

NLC only

CC



NLC/LHC/FNAL

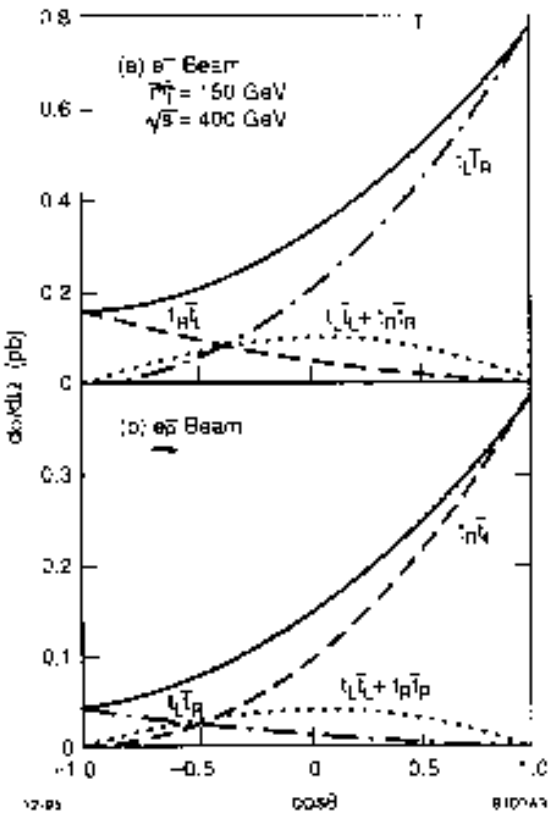
Top Production

$$\mathcal{M}^{\gamma,Z} = e\gamma^\mu \left[Q_f^{\gamma,Z} F_{1V}^{\gamma,Z} + Q_A^{\gamma,Z} F_{1A}^{\gamma,Z}\gamma_5\right] - \frac{ie}{2m_t}\sigma^{\mu\nu}k_\nu \left[Q_f^{\gamma,Z} F_{2V}^{\gamma,Z} - Q_A^{\gamma,Z} F_{2A}^{\gamma,Z}\gamma_5\right]$$

$(Q_f^\gamma = Q_f^1 = \frac{4}{3}, Q_f^Z = (1-\frac{8}{3}\sin^2\theta_W)/(4\sin\theta_W\cos\theta_W), Q_A^Z = -1/(4\sin\theta_W\cos\theta_W))$

In SM: $F_{1V}^\gamma = F_{1V}^Z = F_{1A}^Z$ 1. with all others zero.

$$\frac{d\sigma}{d\cos\theta} = \frac{\beta_t}{32\pi s}\left[c_0\sin^2\theta + c_+(1+\cos\theta)^2 + c_-(1-\cos\theta)^2\right]$$



$c_0, c_\pm$ functions of form factors

Ladinsky & Yuan

Peskin & Schmidt

Soni & Atwood

F_{2V} : EW "magnetic" dipole $\sim \alpha_s/\pi$ in SM

F_{2A} : EW EDM : SM : $\not{CP}$ thru 2 loops ($\not{CP}$)

e.g. 2HDM $\Rightarrow |F_{2A}| \sim 10^{-21}$ e-m

Top Decay

$$\mathcal{M}^{t\to W} = \frac{g}{\sqrt{2}}\gamma^\mu \left[P_L F_{1L}^W + P_R F_{1R}^W\right] + \frac{ig}{2\sqrt{2}\,m_t}\sigma^{\mu\nu}k_\nu \left[P_L F_{2L}^W + P_R F_{2R}^W\right]$$

($P_{L,R}$ are the left-right projectors)

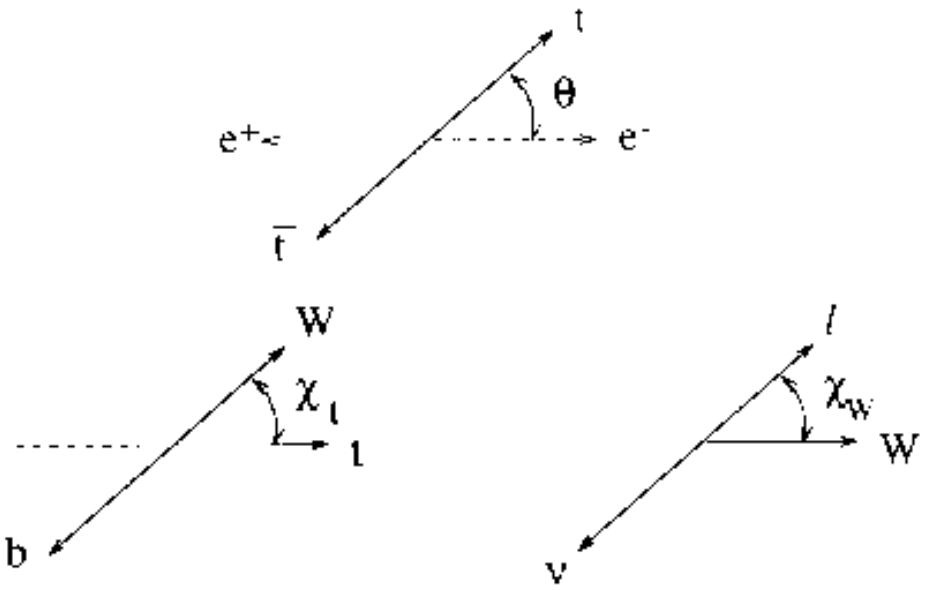
In SM: $F_{1L}^W = 1$ and all others zero.

- $t\bar{t} \rightarrow b W^+ \bar{b} W^- \rightarrow b\bar{b}\, q\bar{q}'\, \underline{\ell}^{\pm}\, \nu_\ell$

  tags t vs $\bar{t}$ hemisphere

- Complete event reconstruction (use m_W, m_t constraints)

  $\Rightarrow$ helicity angles θ, χ_t, χ_W



- Form Liklihood for $\{\theta, \chi_t, \chi_W\}$ as function of form factors

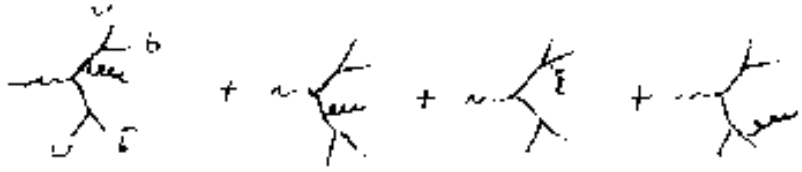
* event generation

* $e^+e^- \to t\bar{t}(g) \to b\ell^+\nu\,\bar{b}\ell^-\bar{\nu}(g)$

monte carlo by Carl Schmidt, MSU

[Schmidt
Schmidt & Peskin

- complete helicity correlations ;
- optional full $t\bar{t}(g)$ at $O(\alpha_s)$



- e^- beam polarization

* apply parameterized detector effects :

ℓ : $\Delta E/E = 0.15/\sqrt{E}$

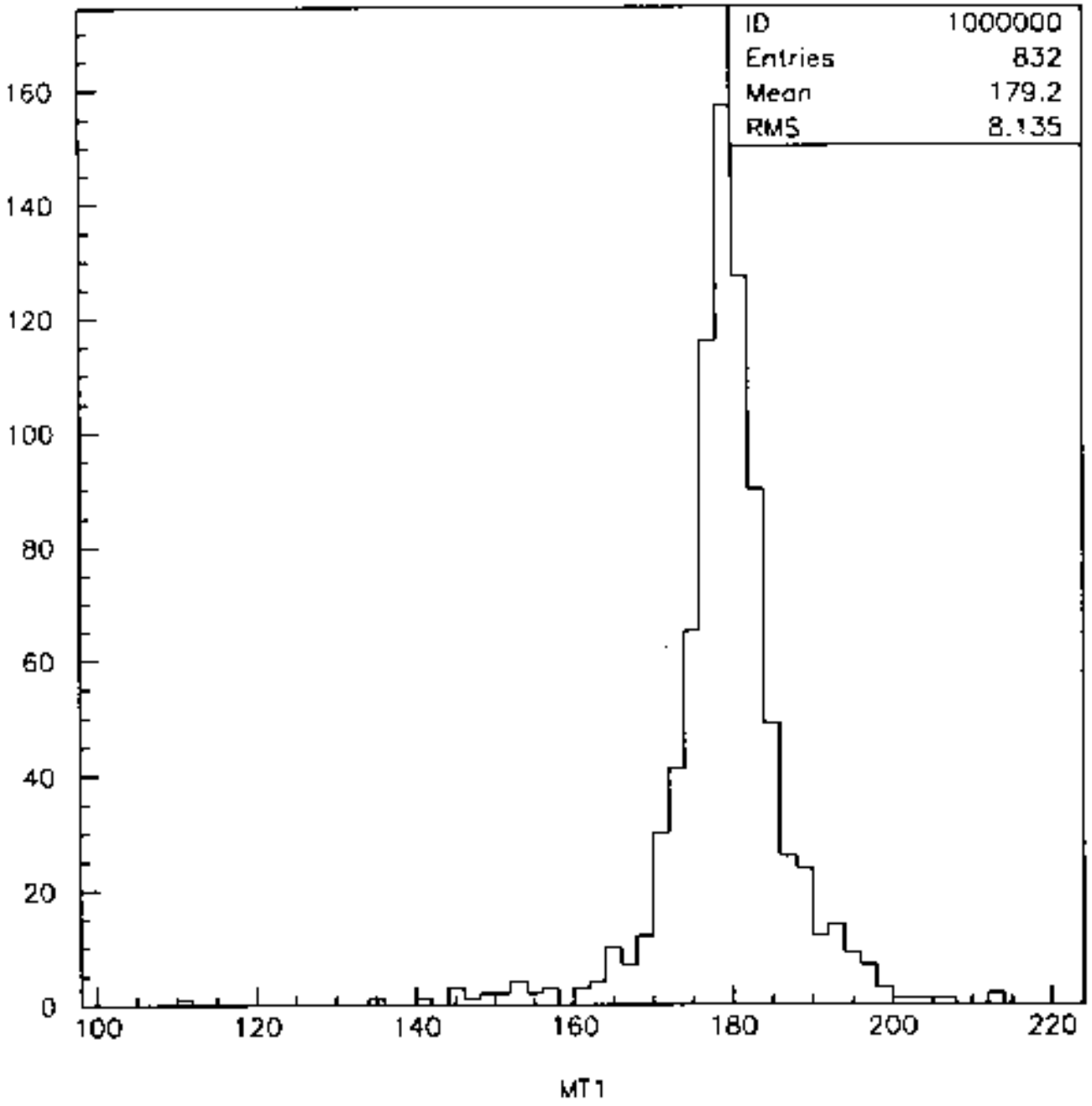
j : $\Delta E/E = 0.40/\sqrt{E}$

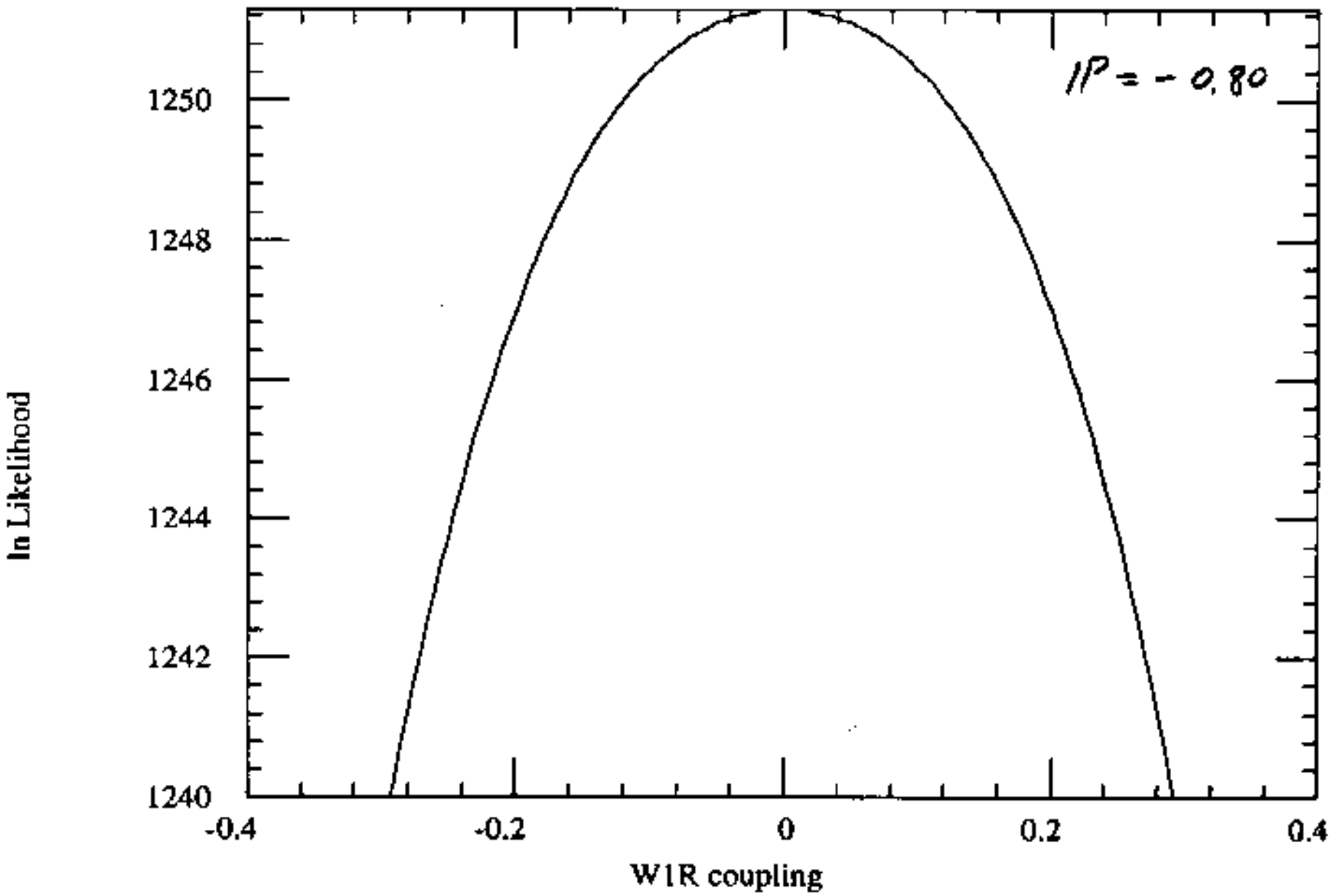
$\theta_{lab} > 10^\circ$ ($\approx 3\%$ inefficiency)

$m_t = 180$ GeV

$\sqrt{s} = 500$ GeV

e^- beam polarization = $\pm 80\%$, (0 %)


ID 1000000
Entries 832
Mean 179.2
RMS 8.135
160
140
120
100
80
60
40
20
0
100
120
140
160
180
200
220
MT1


$P = -0.80$
1250
1248
1246
1244
1242
1240
ln Likelihood
-0.4
-0.2
0
0.2
0.4
W1R coupling

Generate $t\bar{t}(g)$ to $\mathcal{O}(\alpha_s)$ using complete helicity amplitudes

C. Schmidt-(9

(gluon emitted before or after top decay ?)

$\sqrt{s} = 500$ GeV

$m_t = 180$ GeV/c^2 total effic. $\simeq 18\%$

10 fb^{-1}

Sampling of Results

Form Factor	SM Value (Lowest Order)	Limit 68% CL	Limit 90% CL
$F_{1R}^{\gamma}(P=0)$	0	± 0.13	± 0.18
$F_{1R}^{\gamma}(P=80\%)$	0	± 0.06	± 0.10
F_{1A}^{Z}	1	1 ± 0.08	1 ± 0.13
F_{1V}^{Z}	1	1 ± 0.10	1 ± 0.16
F_{2A}^{γ}	0	± 0.05	± 0.08
F_{2V}^{γ}	0	± 0.07	$^{+0.13}_{-0.11}$
F_{2A}^{Z}	0	± 0.09	± 0.15 *
F_{2V}^{Z}	0	± 0.07	± 0.10
$\Im(F_{2A}^{Z})$	0	± 0.06	± 0.09

* $\sim 8 \times 10^{-20}$ e-m

- Measuring the top-Higgs Yukawa coupling an important element of the physics program at NLC.

$\lambda_t^2 = \left(\frac{175}{250}\right)^2 = 0.5$, $\lambda_b = 4 \times 10^{-4}$

- At $t\bar{t}$ threshold, 50 fb^{-1} $\Rightarrow$ $\frac{\Delta\lambda_t}{\lambda_t} \sim 5\%$ $\quad m_t = 175$ GeV, $m_H \cong 100$ GeV

Studies: Scan optimization.

Error as fn. of m_H

- For $\sqrt{s} \gtrsim 500$ GeV

  - Light Higgs $\Rightarrow$ Higgs-strahlung process

    $\rightarrow$ $\frac{\Delta\lambda_t}{\lambda_t} \sim 10\%$ for 50-100 fb^{-1}

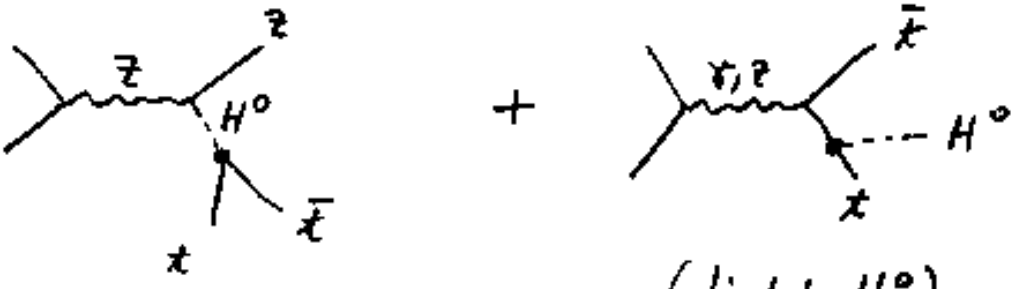
    8 jets (4b) $\Rightarrow$ signal/bkgd optimization

  - Heavy Higgs: $e^+e^- \rightarrow Z^* H$, $H \rightarrow t\bar{t}$

    Studies need updating for m_t as measured.

- Multi-Higgs doublet models $\rightarrow$ CP in Higgs-strahlung which can be large and measureable.

Direct Search for Top Yukawa Couplings



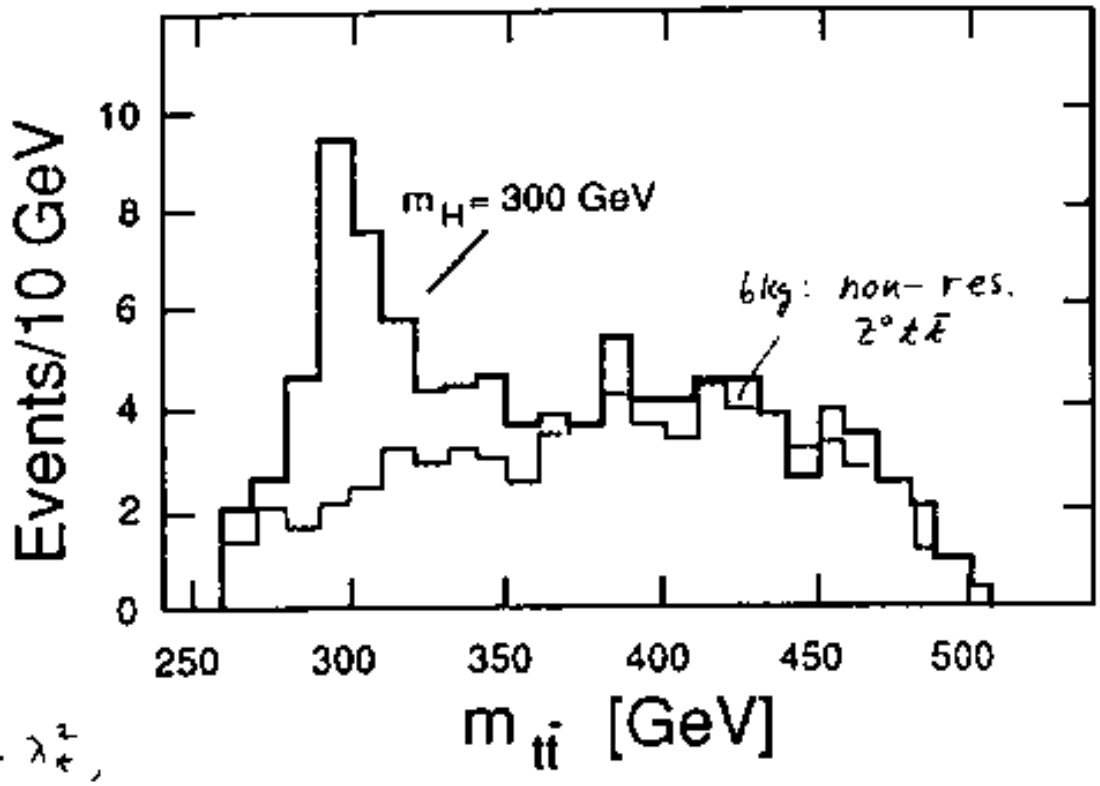
$(m_H > 2m_t)$ Small σ

(light H°) →

Goal: check $\lambda_t^2 = \sqrt{2}\, G_F m_t^2$

$\lambda_t^2 \simeq 0.5$; $\lambda_b^2 \simeq 4 \times 10^{-4}$

$60\,fb^{-1}$; $m_t = 130$ GeV; 8-jet final state ↓



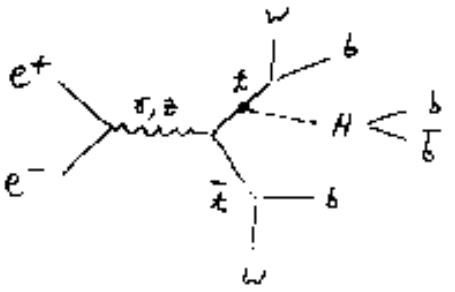
Fujii

$S \propto \lambda_t^2$,

$S/\sqrt{B} = \frac{27}{\sqrt{91}} \Rightarrow \frac{\Delta\lambda_t}{\lambda_t} \simeq 10\%$

Measuring Higgs-strahlung

$e^+e^- \to t\bar{t}H$



8 Jets (4 b-jets) 38%

6 Jets + lν (4 b-jets) 37%

Background $e^+e^- \to t\bar{t}Z$

Same as above when $Z \to b\bar{b}$.

(I.) Fujii ('95 SSI)

Require:

6 or 8 jets

$N(b\text{-tags}) > 2$

$M(2\text{-jets}) \approx M_W$ or M_H

$M(3\text{-jets}) \approx M_t$

E_{vis}, p balance

$\Rightarrow$

$\varepsilon_{t\bar{t}H} = 0.51$

$\varepsilon_{t\bar{t}Z} = 0.18$

$S/\sqrt{B} = \frac{183}{\sqrt{79}} = 20$

$\to \frac{\Delta\lambda_t}{\lambda_t} = 10\%$

$m_t = 170$ GeV

$M_H = 100$ GeV

$\sqrt{s} = 700$ GeV

$100\ fb^{-1}$

(II.) European Working Group (LCWS95)

Different selection

$m_t = 180$ GeV

$50\ fb^{-1}$

$\sqrt{s} = 750$ GeV

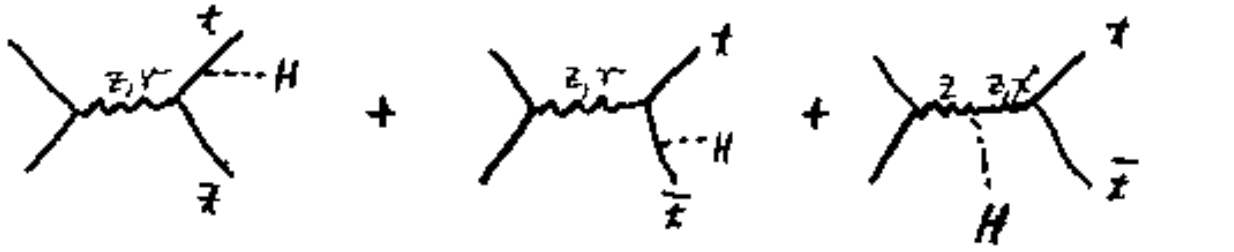
$\Rightarrow \frac{S}{\sqrt{B}} = \frac{47}{\sqrt{28}} = 9 \to \frac{\Delta\lambda_t}{\lambda_t} \approx 20\%$

Bar-Shalom, Atwood, Eilam, Mendel, / Soni =
(PRD 57 (1998) 1167)

2-Higgs doublet models

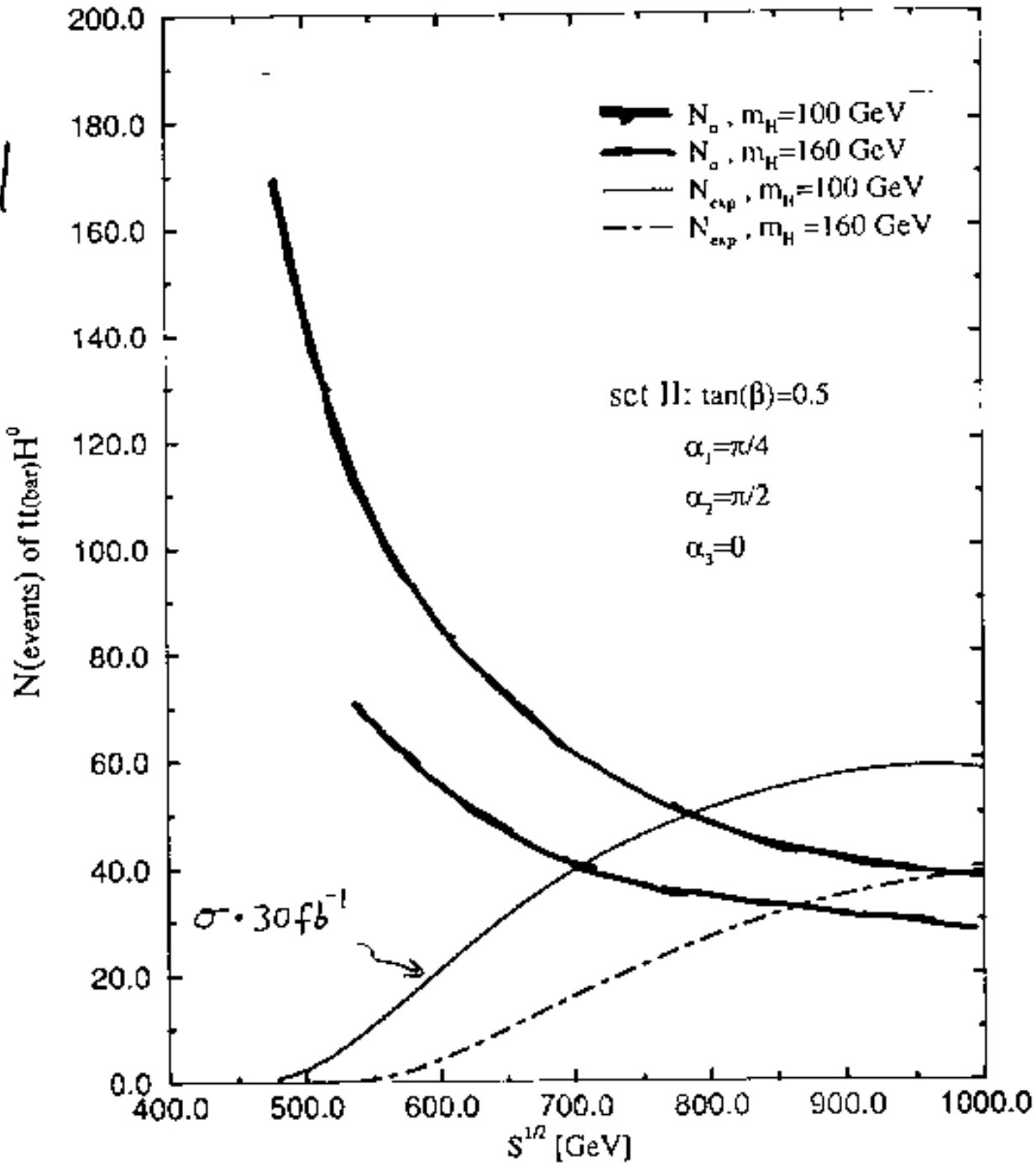
$\Rightarrow$ CP violation for

$e^+e^- \to t\bar{t}H^\circ$



Asymmetry in $\vec{p}_e \cdot (\vec{p}_t \times \vec{p}_{\bar{t}}) \,/\, s^{3/2}$

Bar-Shalom, et al.

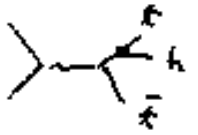


N : # events required to see 1σ CP

Gunion and He

Snowmass 96

hep-ph/9609453



$e^+e^- \to t\bar{t}h$ where h is lightest neutral Higgs boson

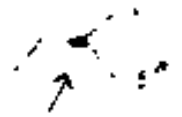
$t\bar{t}h$: $\quad -\bar{t}(a+ib\gamma_5)t\,\frac{g m_t}{2 m_w}$

SM : $a = 1$, $b = 0$

2HDM : $\quad a = -\frac{\sin\alpha_1 \cos\alpha_2}{\sin\beta}$

$b = \sin\alpha_1 \sin\alpha_2 / \tan\beta$

Measure $\bar{t}th$ & $e^+e^- \to Zh$:



$\Rightarrow$ distinguish Higgs models. fn. of α_i, β

Can do accurately for $m_h \sim 100$ GeV

with $\sqrt{s} = 1$ TeV, $500\,fb^{-1}$

V_{tb} and V_{ts}

J. Jaros
Snowmass 96

$$\Gamma_{t\to bW} = |V_{tb}|^2 \frac{G m_t^3}{8\sqrt{2}\pi}\left[1-\left(\frac{m_W}{m_t}\right)^2\right]\left[1+2\left(\frac{m_W}{m_t}\right)^2\right]\eta_{QCD}$$

$\eta_{QCD} \uparrow 0.92$

$$= B(t\to bW)\,\Gamma_{TOT}$$

Γ_{TOT} → Direct measurement from threshold scan ($\frac{\delta\Gamma}{\Gamma}\sim 5\%$)

$B(t\to bW)$ → (1) measure $\sigma^{THEORY}_{t\bar{t}} \cdot B^2(t\to bW)\cdot\varepsilon$

$\Delta\varepsilon/\varepsilon \sim 5\%$

(2) $\bar{t}t$ → tag via $t\to b\ell\nu$ ← isolated ℓ, correct charge

↑ vertex tag

measure $B(\bar{t}\to \bar{b}W)$

50 fb^{-1} ⇒ Expect $\frac{\delta V_{tb}}{V_{tb}} \simeq 3\%$

For V_{ts}, need to tag s, exclude b. Need ~300 rejection factor

At SLC: $\varepsilon_s \cong 0.9$, $\varepsilon_b \cong 0.2$ using vertexing.

Need particle ID to tag $K^\pm$ → $\varepsilon_b \sim 10^{-2}$

Difficult w/o particle ID. New ideas?