Uses of Transversely Polarized e^+e^- Colliding Beams to Uncover New Physics

(JHEP 02 (2003) 008)

- 'Transverse' polarization? Why?
- Potential for NP study - unexplored
- Sensitivity to special NP types - Extra Dimensions, Anomalous Couplings...
- Background, Analyses + reaches → comparisons
- Outlook + Conclusions

⇒ Spin rotators with near 100% efficiency can take longitudinally polarized beams + make them transversely polarized... SO?

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3/03

Consider

$e^+e^- \to \bar{f}f, W^+W^-$ are the dominant processes at the LC ... symbolically, the spin (final) averaged matrix elements (squared) can be written as:

(Σ - symbols suppressed here)

$$|\bar{\mathcal{M}}|^2 = \frac{1}{4}(1 - P_L P_L')(|T_+|^2 + |T_-|^2) + (P_L - P_L')(|T_+|^2 - |T_-|^2)$$
$$+ \; (2 P_T P_T')[\cos 2\phi \; Re(T_+ T_-^*) - \sin 2\phi \; Im(T_+ T_-^*)],$$

- $P_{L,T}^{(\prime)}$ are the $e^-(e^+)$ longitudinal + transverse polarizations
- $T_\pm$ = complex helicity amplitudes $\left\{ \begin{array}{l} T_+ = M_{+-} \\ T_- = M_{-+} \end{array} \right\}$
- ϕ = ∢ between e^- polarization + plane of final state particles

$\Rightarrow$ IF $P_T^{(\prime)} = 0$ only $|T_\pm|^2$ can be probed by experiment:

$\sigma \sim |T_+|^2 + |T_-|^2$, $A_{LR} \sim \dfrac{|T_+|^2 - |T_-|^2}{|T_+|^2 + |T_-|^2}$

BUT

IF P_T, P_T' both are $\neq 0$

$\rightarrow$ Re, Im $(T_+ T_-^*)$ probed.

Note unlike A_{LR}, we need Both beams polarized to form asymmetries (for A_{LR}, $P_L' = 0$ is ok)

A unique reason for 2 beam polarization

IF $P_T^{(\prime)}$ were available, what new Physics BSM can be probed using transverse polarization asymmetries ??

GOAL: Discovery new physics ...

IDENTIFY IT ... (Model ?)

Explore IT in all detail ...

The more tools, the better we will do!

Over the years, very little work has been done on e^+e^- collisions w/ transverse polarized beams both in the SM + BSM:

R. Budny, Phys. Rev. **D14**, 2969 (1976); H.A. Olsen, P. Osland and I. Overbo, Phys. Lett. **B97**, 286 (1980); K. Hikasa, Phys. Rev. **D33**, 3203 (1986); C.P. Burgess and J.A. Robinson, Int. J. Mod. Phys. **A6**, 2709 (1991); A. Djouadi, F.M. Renard and C. Verzegnassi, Phys. Lett. **B241**, 260 (1990); F.M. Renard, Z. Phys. **C44**, 75 (1989); J.L. Hewett and T.G. Rizzo, Z. Phys. **C44**, 75 (1987) and Z. Phys. **C36**, 209 (1987); J. Fleischer, K. Kolodziej and F. Jegerlehner, Phys. Rev. **D49**, 2174 (1994); for a recent discussion of this option at the LC, see K. Desch, talk given at the *International Workshop on the Linear Collider, LCWS2002*, Jeju Island, Korea, Aug. 2002.

Here we will ask if P_T helps to probe for New Physics (exchange) in $e^+e^- \to f\bar{f}$, ... etc

– Unexplored

(Yes!)

If we are lucky NP will be seen directly by new particle production, e.g. SUSY

- But, perhaps, NP will be <u>indirectly</u> observed through deviations in σ, asymmetries... etc revealed by precision measurements : LC

  e.g, Contact interactions

- <u>Lots</u> of NP → CI's : ⟺ <u>Mass Scale</u>

Λ	· compositeness (spin-1)
$m_{\tilde{\nu}}$	· $\tilde{\nu}$ Exchange, SUSY $\not{R}$ (spin-0)
$M_{Z'}$	· Z' (spin-1)
M_c	· gauge KK (spin-1)
m_{LQ}	· LQ / BL
M_H	· Gravity in Extra dims { ADD*, RS† } <u>(spin-2)</u>

⋮ ⋮ ⋮

<u>etc</u>

* Arkani-Hamed, Dimopoulos + Dvali – many small resonances > 10^6/GeV

† Randall-Sundrum ~ big resonances with ~100's of GeV separation

Consider $e^+e^- \to f\bar{f}$ $(m_f = 0)$

- We can easily obtain all the amplitudes in the SM { Z′, gauge KK, cont. int's... } and in the ADD case

→ When spin-2 is present, the amplitudes contain higher powers of $z = \cos\theta$ than in the case of the SM, Z′..... Unique

Transverse Polarization Asymmetry :

$$\frac{1}{N}\frac{dA}{dz} = \frac{\int_+ \frac{d\sigma}{dz\,d\phi} - \int_- \frac{d\sigma}{dz\,d\phi}}{\int_{ALL} d\sigma} \quad \leftarrow \text{note}$$

($\int_\pm$ = integrate regions where $\cos 2\phi$ is $\pm$)

isolates the $\mathrm{Re}(T_+ T_-^*)$ part of $|\bar{M}|^2$

(These are small #'s - normalized to full σ !)
(not unique !)

Charges

Z-couplings

$$
\begin{aligned}
f_{LL} &= Q_e Q_f + g_Z(v_e - a_e)(v_f - a_f)P \\
f_{RR} &= Q_e Q_f + g_Z(v_e + a_e)(v_f + a_f)P \\
f_{LR} &= Q_e Q_f + g_Z(v_e - a_e)(v_f + a_f)P \\
f_{RL} &= Q_e Q_f + g_Z(v_e + a_e)(v_f - a_f)P ,
\end{aligned}
$$

{ + ... }

Weak coupling

$$g_Z = \frac{G_F M_Z^2}{2\sqrt{2}\pi\alpha},$$

For Z′, gauge KK, cont. int's f_{LL}'s augmented etc only

Z- prop.

$$P = \frac{s}{s - M_Z^2 + iM_Z\Gamma_Z}.$$

$e^+e^- \to f\bar{f}$ ($m_f = 0$) Amplitudes

$$
\begin{aligned}
T^{+-}_{+-} &= f_{LL}(1+z) - f_g(z + 2z^2 - 1) \\
T^{-+}_{+-} &= f_{LR}(1-z) - f_g(z - 2z^2 + 1) \\
T^{+-}_{-+} &= f_{RL}(1-z) - f_g(z - 2z^2 + 1) \\
T^{-+}_{-+} &= f_{RR}(1+z) - f_g(z + 2z^2 - 1).
\end{aligned}
$$

spin-2

ADD → $f_g = \frac{\lambda s^2}{4\pi\alpha M_H^4}.$

$\lambda = \pm 1$

M_H = cut-off scale in Hewett notation

$$\left(f_g = \frac{\lambda s^2}{4\pi\alpha M_H^4}\left[1 - i\frac{\pi M_H^4(\sqrt{s})^{\delta-2} S_{\delta-1}}{16 M_D^{\delta+2}}\right]. \right)$$

$z = \cos\theta$

In the SM **AND** in **all** models with new

s-channel spin(-0 or) 1 exchanges ...

$$\frac{1}{N}\frac{dA}{dz} \sim (1-z^2)$$

(almost everything but gravity)

∴ non-$\sin^2\theta$ behavior (for all f) signals

spin-2 exchange !!

[Fig.]

⇒ How to probe deviations from $(1-z^2)$?

- Note the interference between spin-1 + 2 exchange induces a z-odd term in $N^{-1}\, dA/dz$ ...

(i) $$A_{FB} = \frac{1}{N}\left\{ \int_{z>0} dz\, \frac{dA}{dz} - \int_{z<0} dz\, \frac{dA}{dz} \right\}$$

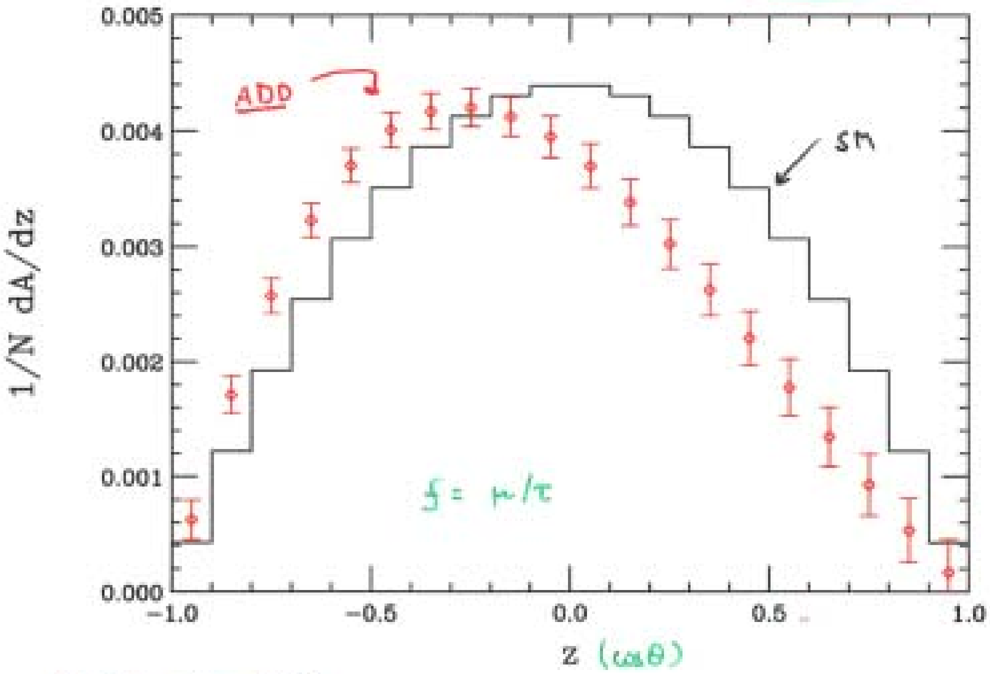
(= 0 for spin-0, -1)

(ii) $$\langle P_n \rangle = \frac{1}{N}\int dz\; P_n(z)\, \frac{dA}{dz} \qquad (n = 1,2,3)$$

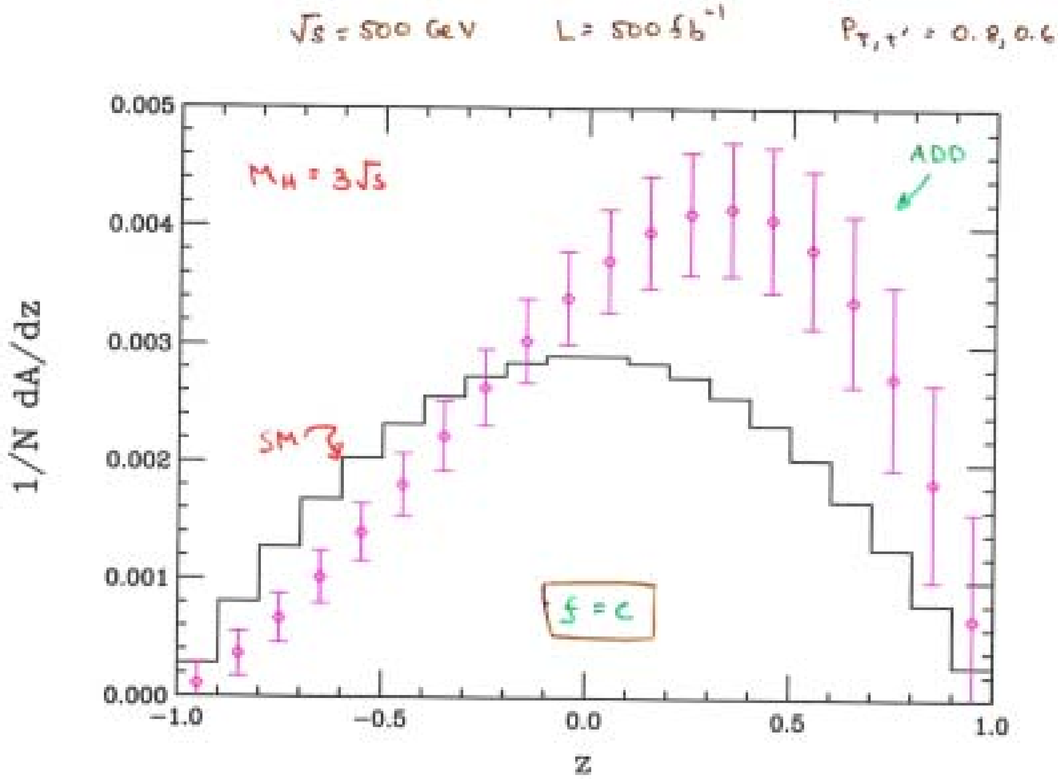
$\langle P_{1,3} \rangle \neq 0$ for gravity

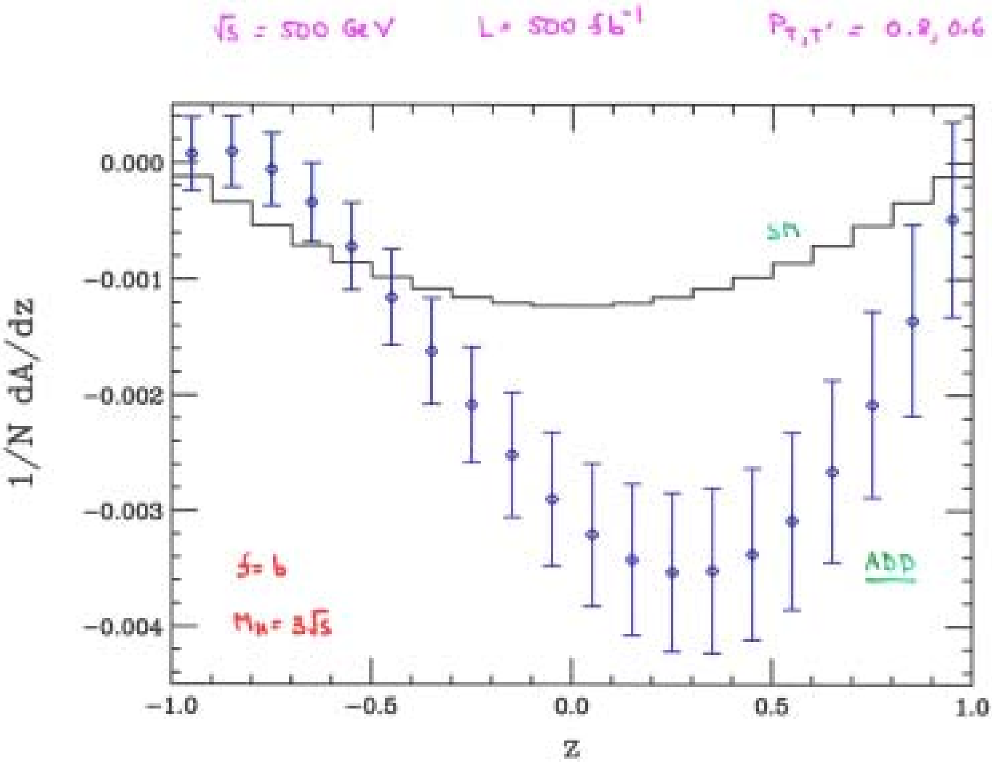
$\sqrt{s}$ = 500 GeV   L = 500 fb^{-1} P_T = 0.8 P_T' = 0.6

$M_H = 3\sqrt{s}$



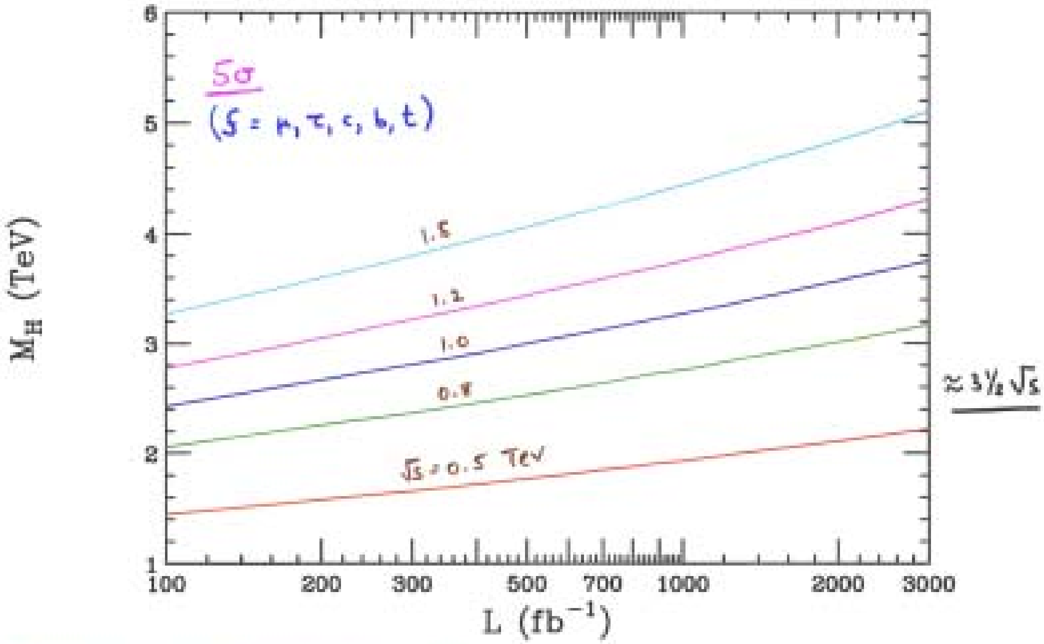
Note asymmetry around z=0 ...


√s = 500 GeV
L = 500 fb⁻¹
P_{ℓ,ℓ'} = 0.8, 0.6
M_H = 3√s
ADD
SM
f = c
1/N dA/dz
z
0.005
0.004
0.003
0.002
0.001
0.000
−1.0
−0.5
0.0
0.5
1.0



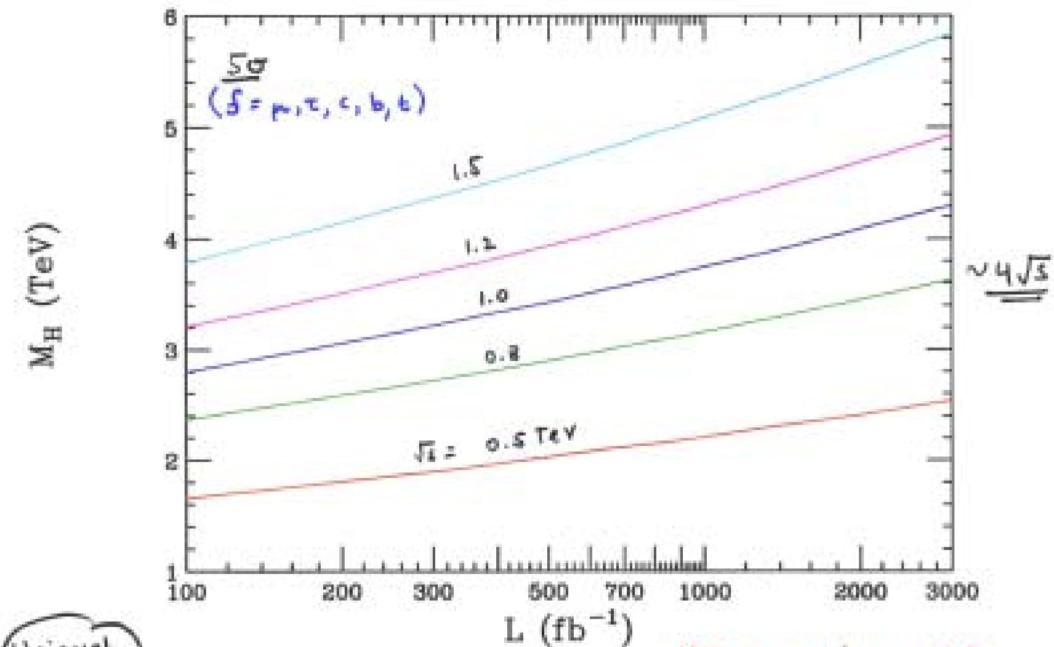
√s = 500 GeV
L = 500 fb⁻¹
P_{T,T'} = 0.8, 0.6
1/N dA/dz
z
SM
ADD
f = b
M_H = 3√s
0.000
−0.001
−0.002
−0.003
−0.004
−1.0
−0.5
0.0
0.5
1.0

$\langle P_n \rangle$ sensitivity for $M_H \neq \infty$



Unique signal for spin-2/graviton exchange

A_{FB} sensitivity to $M_H \neq \infty$



Uniquely Signals graviton exchange

NOT as good as ⟨P_n⟩ method using P_L's only
≃ 6√s

Can we do better? <u>Yes</u>

- Try to **force** a fit of the form for each final fermion f

$$\left\{ \begin{array}{l} \frac{1}{N}\frac{dA}{dz} = C_i\,(1-z^2) \\ C_i = \text{arbitrary} \end{array} \right.$$

Ask: for what M_H is the CL of fits below CL for $5\sigma \simeq 5.7 \cdot 10^{-5}$?

[ID Reach]

$\Rightarrow$ Low quality of fit signals deviations from simple $\sim \sin^2\theta$ behavior...

Furthermore ...

Ask: for what M_H do I agree w/ SM at 95% CL

ie, what is the 95% CL lower bound on M_H from any deviation?

Find: for lumi's in the $\simeq \frac{1}{2} - 2\ ab^{-1}$ range the bounds are systematics dominated...

E_{CM} (GeV)	Reach (TeV) reach 95%CL	ID reach Reach (TeV)
500	10.2	5.4
800	17.0	8.8
1000	21.5	11.1
1200	26.0	13.3
1500	32.7	16.7
	$\approx 21\sqrt{s}$	$\approx 11\sqrt{s}$!

For lumi's above ~ ½ ab^{-1} the variation in these bounds is ≲ 10% ... ⇒ **x2** 'old' results

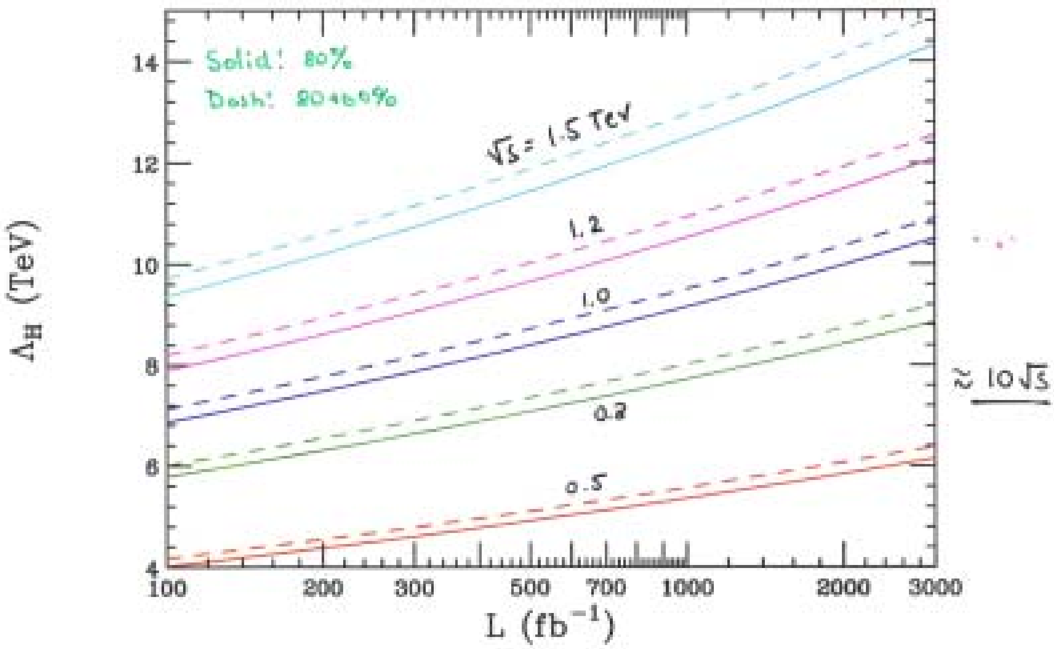
WARNING !! THEORIST at WORK !!

Since these bounds are systematics dominated they should be CAREFULLY re-examined by an experimenter ...

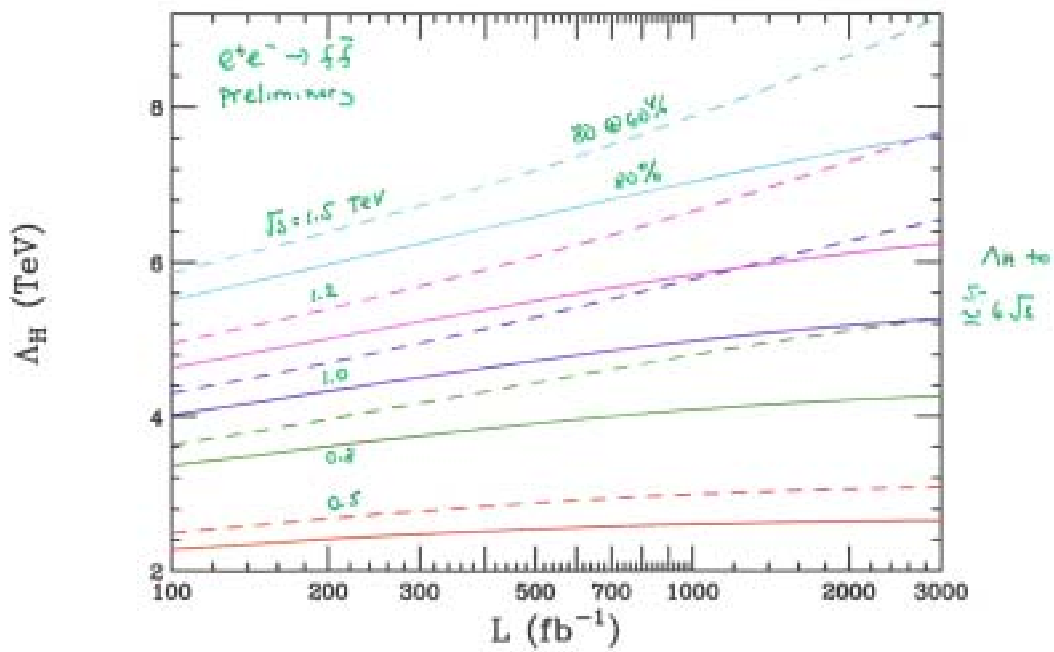
BUT

⇒ Likely that P_T significantly improves ADD sensitivity.

'Standard' 95% CL reach for ADD



5σ ID Reach (moments P_n)



USUAL :
ADD :

$$f_g = \frac{\lambda s^2}{4\pi\alpha M_H^4}$$

RS : $\frac{\lambda}{M_H^4} \to -\frac{1}{8\Lambda_\pi^2} \sum_n \frac{1}{s - m_n^2 + i m_n \Gamma_n}$

↑ TeV-scale gravitons

Below resonance production they look the same... (for $\sqrt{s}$ fixed!)

- Datta, Gabrielli + Mele :

$$f_g = \frac{\lambda s^2}{4\pi\alpha M_H^4} \left\{ 1 - i \, \frac{\pi M_H^4 (\sqrt{s})^{\delta-2} S_{\delta-1}}{16 M_*^{\delta+2}} \right\}$$

↗ imaginary, sub-leading term in ADD from graviton continuum (usually neglected)

M_* = 4+δ-dim Planck scale ~ M_H

$S_{\delta-1}$ = area of δ-sphere (a number)

∴ ADD $\mathrm{Im}(T_+ T_-^*) \neq 0$ everywhere

RS $= 0$ away from resonances!

To probe $\text{Im}(T_+ T_-^*)$ ...

$$\frac{1}{N}\frac{dA_i}{dz} = \frac{\int_+ \frac{d\sigma}{dz\,d\phi} - \int_- \frac{d\sigma}{dz\,d\phi}}{\int_{ALL} d\sigma}$$

$= 0$ in SM, RS + all spin-1 exchange NP model

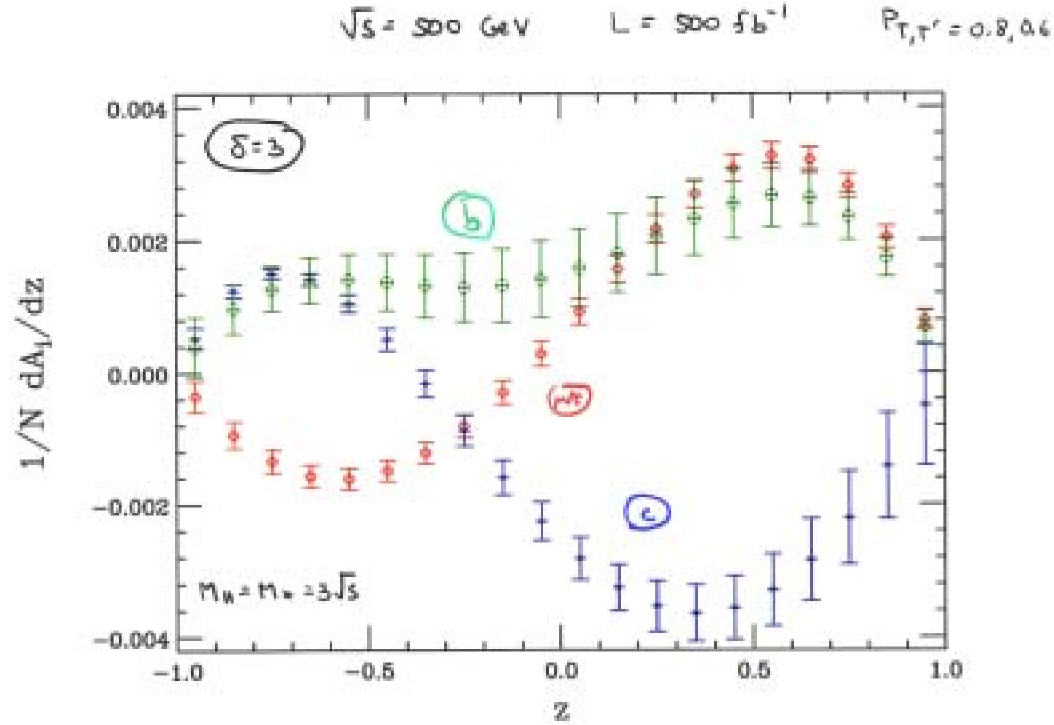
But now $\pm$ are regions where $\sin 2\phi$ is $\pm$ ...

$$\rightarrow N^{-1}\, dA_i/dz \begin{cases} = 0 & \text{in RS (away from reson.)} \\ \neq 0 & \text{in ADD} \end{cases}$$

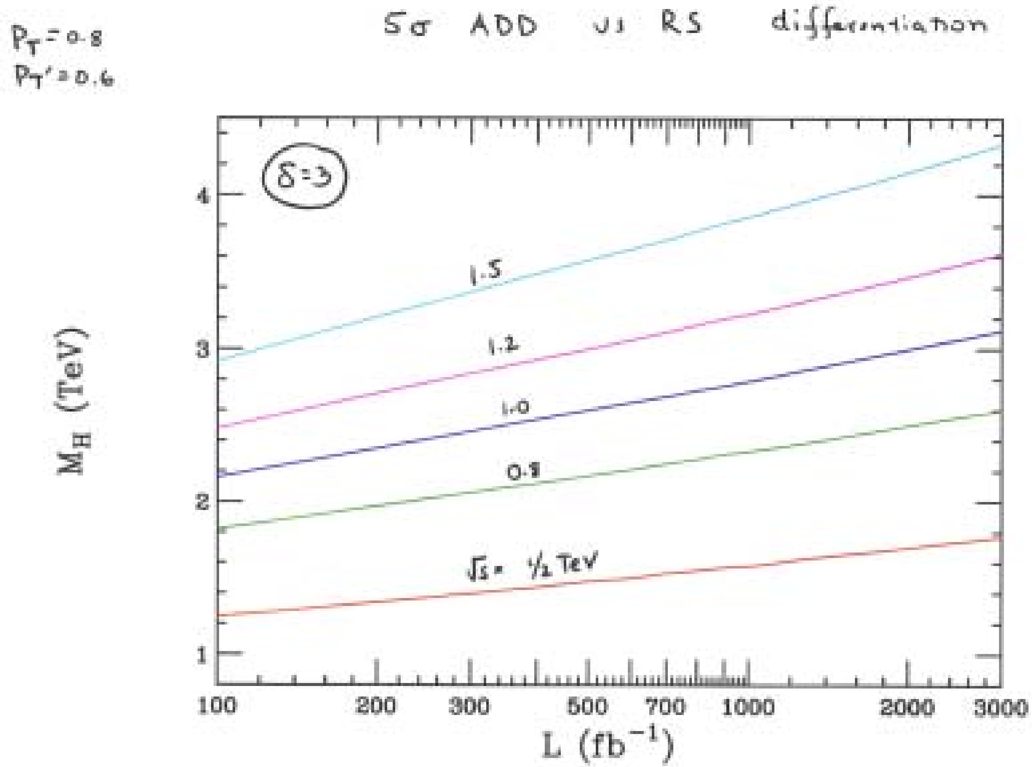
Ask: Up to what M_H ($= M_s$) can I tell $N^{-1}\, dA_i/dz \neq 0$ at 5σ for different δ?

$\Rightarrow$ This tells us the M_H for which ADD + RS can be distinguished....

Expect: as δ grows the reach decreases due to $(\sqrt{s}/M)^{\delta}$ dependence....



√s = 500 GeV
L = 500 fb⁻¹
P_{τ,τ'} = 0.8, 0.6
δ=3
b
μτ
c
M_H = M_* = 3√s
1/N dA_1/dz
z



$P_T = 0.8$
$P_T' = 0.6$
5σ ADD vs RS differentiation
δ=3
1.5
1.2
1.0
0.8
√s = 1/2 TeV
M_H (TeV)
L (fb^{-1})
1
2
3
4
100
200
300
500
700
1000
2000
3000

What else has beem done?

- very little -

Transverse beam polarization in $e^+e^- \to W^+W^-$*

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Katowice, Poland

Fred Jegerlehner

DESY Zeuthen

Plan

- Why polarization?
- Polarized W-pair production cross sections.
- Transverse beam polarization.
- Standard Model results including $\mathcal{O}(\alpha)$ virtual corrections and bremsstrahlung.
- Conclusions and outlook.

– Extended ECFA/DESY Workshop –

– Prague, November 2002 –

* Based on work: J. Fleischer, K. Kołodziej, F. Jegerlehner, Phys. Rev. D49 (1994) 2174.

Why polarization?

Direct tests at LEP2 and indirect tests through loop effects at LEP1 of the triple gauge coupling of the $SU(2)_L \times U(1)_Y$ group $\Longrightarrow$ no expectation for large deviations from the SM at a linear collider.

Renormalizability $\Longrightarrow$ experimentally well established $W l \nu_l$ coupling uniquely fixes the triple gauge coupling. How to disentangle the triple gauge couplings if there is fine tuning among them?

Problems

- form factors measurable only for low momentum transfer, i.e., in "classical limit", or, at resonance, where a process is dominated by a single process of one-particle exchange.
- $e^+e^- \to W^+W^-$ is measured far above the Z resonance, electroweak unification is at work $\Longrightarrow$ not possible to disentangle the photon from the Z, except for mass effects and different properties under parity.

Polarization allows to discriminate between the γ and Z s-channel contributions. The s-channel contributions suppressed at the W-pair threshold grow fast with energy.

Why polarization?

Observed is the process

$$e^+e^- \to 4f,$$

but sufficiently above the threshold

$$e^+e^- \to W^+W^- \to 4f,$$

with both W's at resonance dominates.

The most interesting processes are

$$e^-e^+ \to W_L^- W_L^+$$

and

$$e_R^- e^+ \to W^- W^+.$$

These modes are very much suppressed with respect to the dominant transverse–transverse polarization mode with two opposite W helicities.

A high luminosity is required.

Transverse beam polarization may help to disentangle different contributions.

In e^+e^- storage rings transverse polarization is natural. How about the linear collider?

Polarized W-pair production

The differential W-pair production cross section is given by

$$\frac{\mathrm{d}\sigma(h_e;\lambda,\bar\lambda)}{\mathrm{d}\cos\theta} = \frac{\beta_W}{32\pi s}\left|\sum_{i=1}^{6} X_i^{(h_e)} M_{X_i}(h_e;\lambda,\bar\lambda)\right|^2 .$$

At the tree level

$$M_0(-;\lambda,\bar\lambda) = S^{(-)}_{1(0)} M_{S_1}(-;\lambda,\bar\lambda) + T^{(-)}_{1(0)} M_{T_1}(-;\lambda,\bar\lambda),$$
$$M_0(+;\lambda,\bar\lambda) = S^{(+)}_{1(0)} M_{S_1}(+;\lambda,\bar\lambda),$$

where in the high energy limit, $s \to \infty$,

$$S^{(+)}_{1(0)} = -\frac{e^2}{s}\left(1 - \frac{1}{1-\frac{M_Z^2}{s}}\right) \longrightarrow 0,$$
$$S^{(-)}_{1(0)} = S^{(+)}_{1(0)} - \frac{g^2}{2s}\frac{1}{1-\frac{M_Z^2}{s}} \longrightarrow -\frac{g^2}{2s},$$
$$T^{(-)}_{1(0)} = \frac{g^2}{s}\frac{1}{\frac{1+\beta_W^2}{2} - \beta_W\cos\theta} \longrightarrow \frac{g^2}{s}\frac{1}{1-\cos\theta}.$$

Moreover,

$$\frac{M_{T_1}(h_e;\lambda,\bar\lambda)}{M_{S_1}(h_e;\lambda,\bar\lambda)} \longrightarrow \frac{1-\cos\theta}{2}$$

and we see that the gauge cancellations are at work.

The longitudinal beam polarization allows to study the relative weight of γ and Z couplings to W-bosons.

Transverse beam polarization

With unpolarized beams we can measure $|M_-|^2 + |M_+|^2$ through the total cross section σ

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} = \frac{1}{2}\left(\frac{\mathrm{d}\sigma_L}{\mathrm{d}\cos\theta} + \frac{\mathrm{d}\sigma_R}{\mathrm{d}\cos\theta}\right) = \frac{\beta_W}{64\pi s}\left(|M_-|^2 + |M_+|^2\right),$$

with longitudinally polarized beams we can measure $|M_-|^2 - |M_+|^2$ through the left-right asymmetry A_{LR}

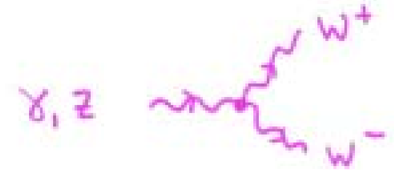
$$\frac{\mathrm{d}(\sigma A_{LR})}{\mathrm{d}\cos\theta} = \frac{1}{2}\left(\frac{\mathrm{d}\sigma_L}{\mathrm{d}\cos\theta} - \frac{\mathrm{d}\sigma_R}{\mathrm{d}\cos\theta}\right) = \frac{\beta_W}{64\pi s}\left(|M_-|^2 - |M_+|^2\right)$$

and with transverse polarized beams we can measure $\mathrm{Re}\left(M_+ M_-^*\right)$ from the azimuthal asymmetry A_T defined by

$$\frac{\mathrm{d}(\sigma A_T)}{\mathrm{d}\cos\theta} = \int_0^{2\pi} \frac{\mathrm{d}^2\sigma}{\mathrm{d}\cos\theta \mathrm{d}\cos\phi_W} \cos 2\phi_W \mathrm{d}\phi_W = \frac{\beta_W}{64\pi s} 2\mathrm{Re}\left(M_+ M_-^*\right).$$

(This is different from the asymmetry defined in the $e^+e^- \to f\bar{f}$ study by an overall factor)

Tri-linear gauge boson couplings are completely fixed in the SM:



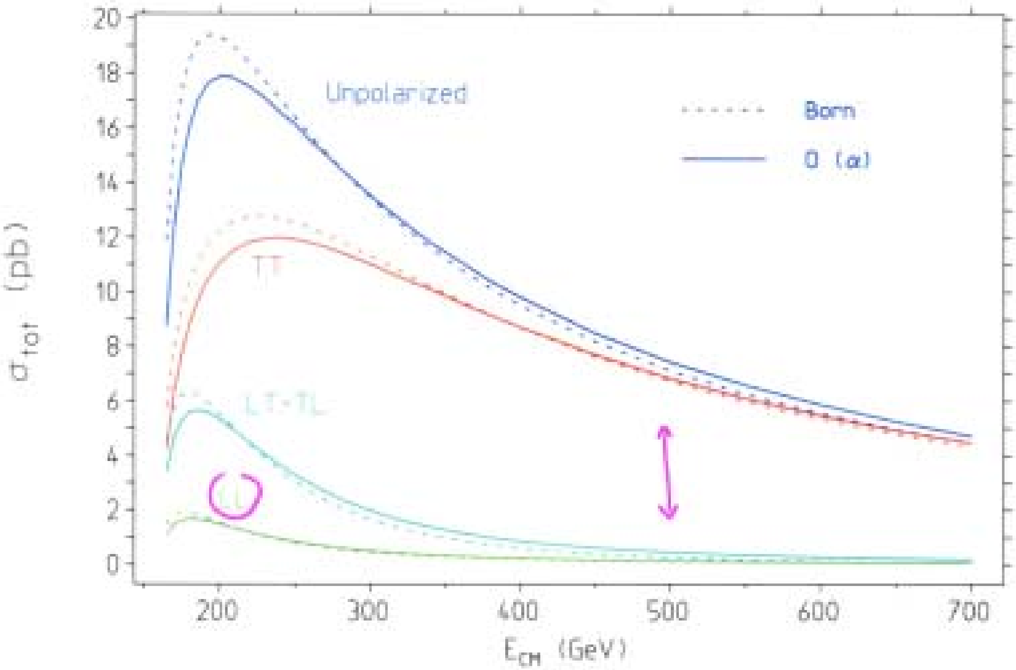
But: if some 'funny' NP is present "anomalous" couplings can arise ....

- LC is particularly good at probing for AC through P_L + precision measurements

- $W_L^+ W_L^-$ can be particularly interesting in this regard...

$\Rightarrow$ But $e^+e^- \to W_L^+ W_L^-$ is only a small part of the cross section - hard to isolate ...

at $\sqrt{s} = 500$ GeV the W's are mostly transverse



Unpolarized
Born
O (α)
TT
LT+TL
LL
σ_{tot} (pb)
E_{CM} (GeV)
(FKJ 1994)

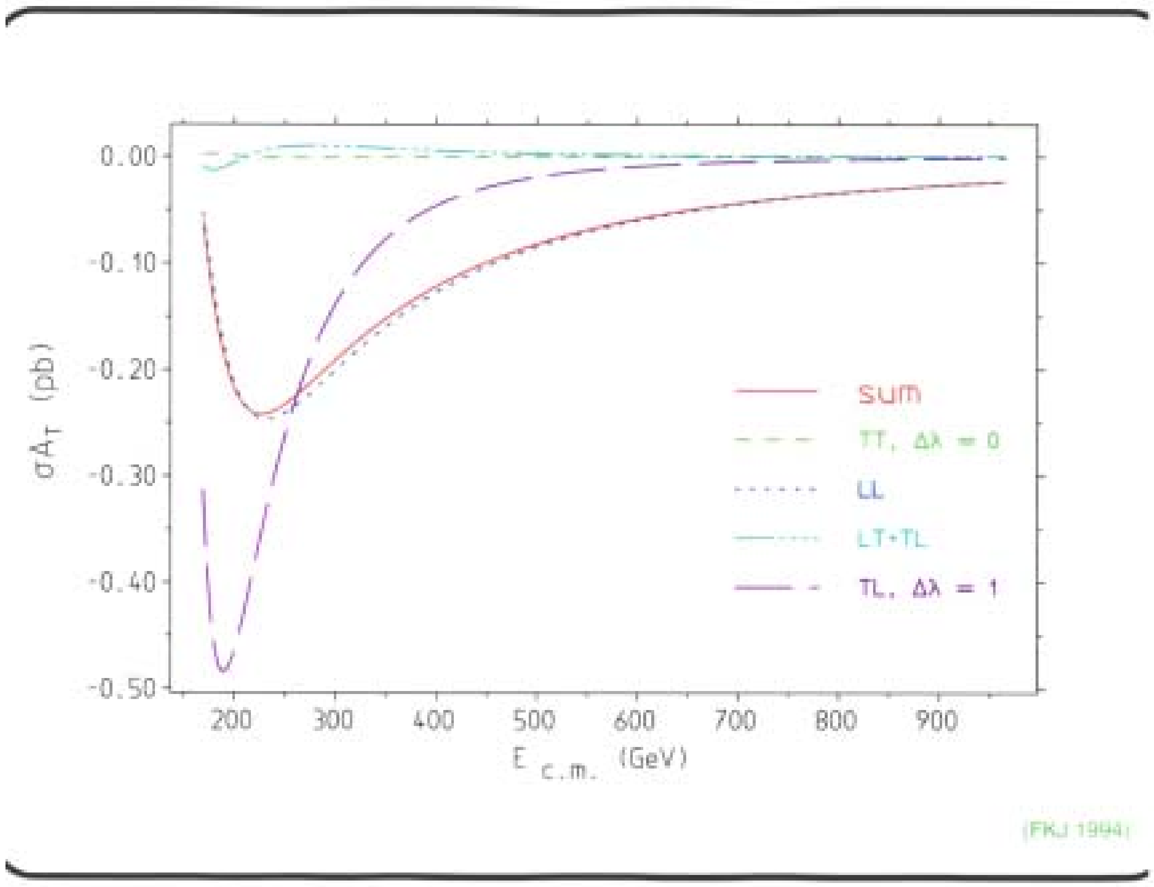
Main features of σA_T

- no TT $|\Delta\lambda| = 2$ final state contribution
  as $M(+;\pm\mp) = 0$
- !!! sum over final state spins: almost pure LL
  (see Fig σA_T)
- TL and LT large but cancel in sum
- rather small at 1% level
  (size similar to σ_R; probe different physics)
- note $\sigma A_{LR} \simeq \sigma_L/2 \simeq \sigma_{tot}^{\text{unpol}}$
  dominated by TT; probe different physics

transversal polarization provides an important tool for investigation of $W_L W_L$ physics, probing electroweak symmetry breaking; clean, no background !

without transversal polarization: $W_L W_L$ is small contribution which can only be dug out by angular cutting (background problem).

- A_T here comes (almost completely) from the LL final state ... changes in A_T probe changes in LL cross section + properties


0.00
-0.10
-0.20
-0.30
-0.40
-0.50
200
300
400
500
600
700
800
900
σA_T (pb)
E c.m. (GeV)
sum
TT, Δλ = 0
LL
LT+TL
TL, Δλ = 1
(FKJ 1994)

HOW TO DISENTANGLE TRIPLE GAUGE COUPLINGS

The dependence of the cross section on the VWW form–factors shows up directly in the helicity amplitudes:

$$M(-;\lambda,\bar{\lambda}) = \sqrt{2}\beta_W\gamma^{2-|\lambda|-|\bar{\lambda}|}\, d^{J_0}_{\Delta\sigma,\Delta\lambda}(\theta)$$
$$\left\{e^2\,(H_i^\gamma - \frac{H_i^Z}{1-M_Z^2/s}) + \frac{g^2}{2}\frac{H_i^Z}{1-M_Z^2/s}\right.$$
$$\left. - \quad \frac{\hat{M}_{T_1}(-;\lambda,\bar{\lambda})}{\beta_W}\,\frac{g^2}{\frac{1+\beta_W^2}{2} - \beta_W\cos\theta}\right\}$$

$$M(+;\lambda,\bar{\lambda}) = \sqrt{2}\beta_W\gamma^{2-|\lambda|-|\bar{\lambda}|}\, d^{J_0}_{\Delta\sigma,\Delta\lambda}(\theta)$$
$$\left\{e^2\,(H_i^\gamma - \frac{H_i^Z}{1-M_Z^2/s})\right\}$$

with the correspondence

amplitude	state	
H_l^V	LL	
H_0^V	TT	; $\Delta\lambda = 0$
H_{-1}^V	TL, LT	; $\Delta\lambda = -1$
H_{+1}^V	TL, LT	; $\Delta\lambda = +1$

Radiative corrections:

$$
\begin{aligned}
H_l^V &= (2+\gamma^{-2})A_1^V + 2A_2^V - \beta_W^2 A_3^V \\
H_0^V &= A_1^V \\
H_{-1}^V &= 2A_1^V + A_2^V + \beta_W A_4^V \\
H_{+1}^V &= 2A_1^V + A_2^V - \beta_W A_4^V \quad .
\end{aligned}
$$

With A_i^V vertex corrections ($V = \gamma,\ Z$).

Anomalous couplings:

$$
\begin{aligned}
H_l^V &= 2\{(1+\tfrac{2M_W^2}{s})\delta_V + \delta\kappa_V + (1-\tfrac{M_W^2}{s})\lambda_V\} \\
H_0^V &= \delta g_V + \tfrac{s}{2\Lambda^2}\lambda_V \\
H_\mp^V &= 2\delta_V + \delta\kappa_V + \lambda_V \mp \beta_W \tfrac{s}{\Lambda^2}\xi_V \quad .
\end{aligned}
$$

Conclusions and outlook

- Transverse beam polarization at a high-luminosity linear collider allows one to study longitudinal W physics without analyzing final state polarizations.
- A_T provides information on the Higgs mechanism.
- The program for transverse polarization effects in $e^+e^- \to W^+W^-$ still exists.
- The transverse beam polarization can be implemented into MC programs for $e^+e^- \to 4f$.

Nice

But a quantitative study is lacking!

What about graviton exchange in $e^+e^- \to W^+W^-$?

Unfortunately, it is not as beneficial as in $e^+e^- \to \bar{f}f$ ....

[Fig]

For $\sqrt{s} = 500$ GeV $\to$ 95% CL search reach is

L	M_H
0.1	2.77
0.5	3.39
1.0	3.69
ab^{-1}	TeV

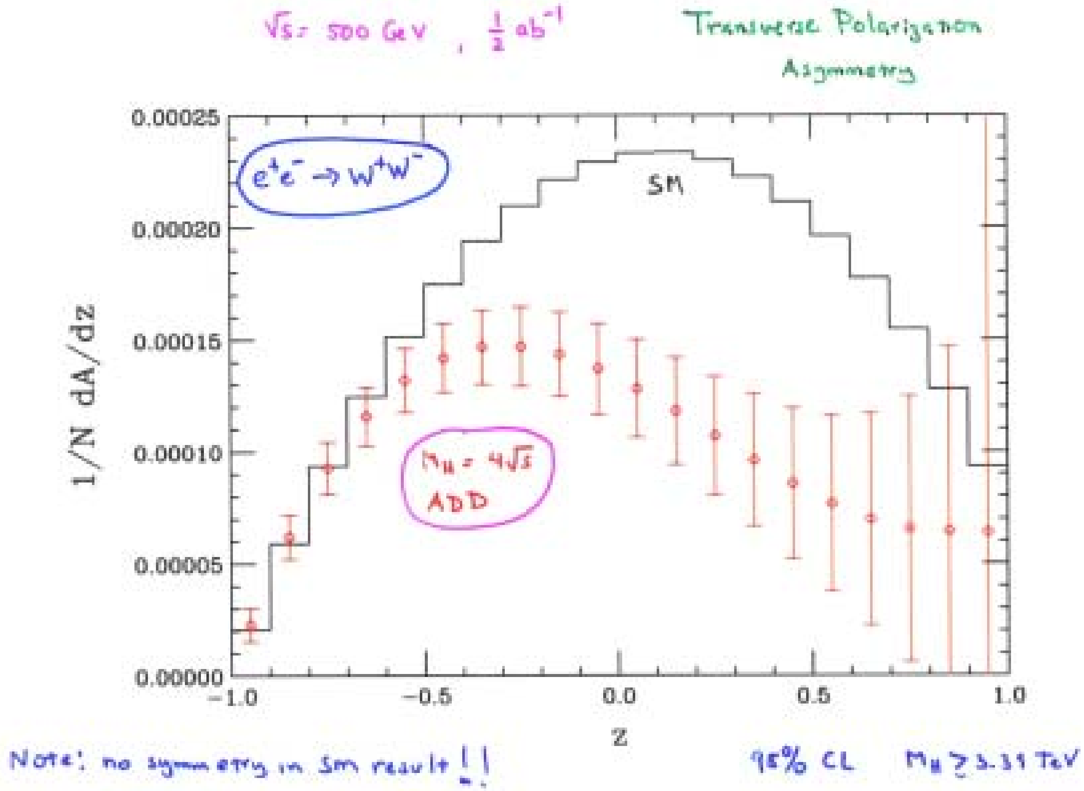
$\approx 7\sqrt{s}$

not bad for only one observable ...

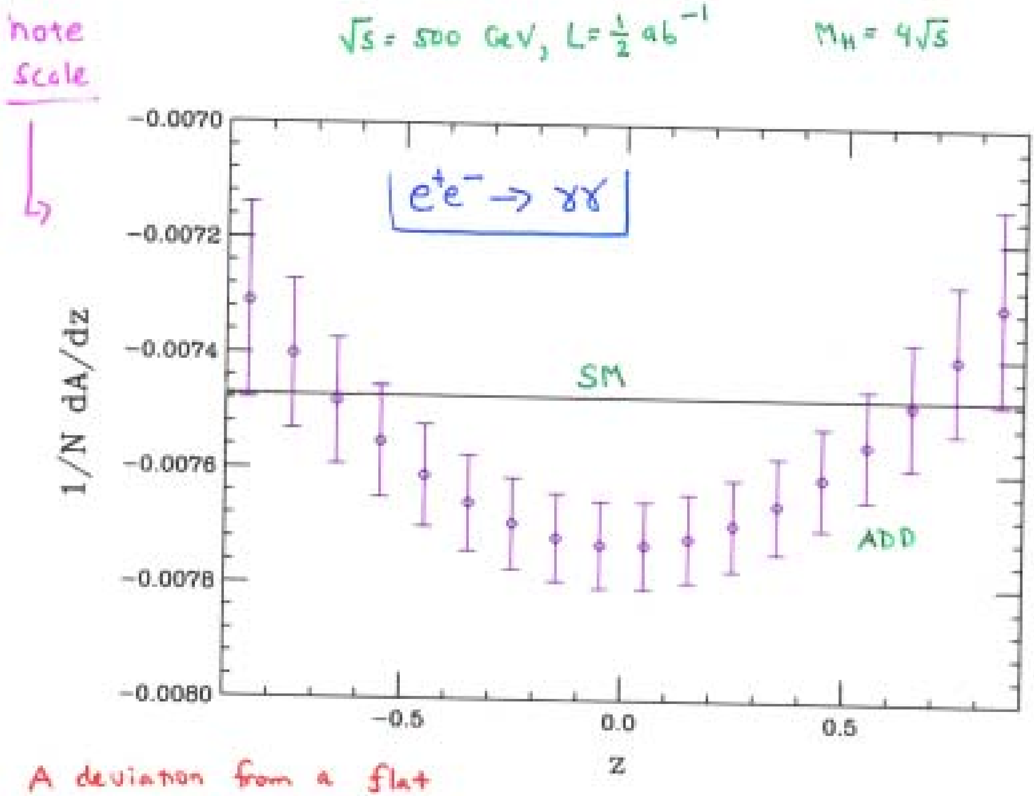
For other processes, e.g, $e^+e^- \to 2\gamma$, P_T is even less sensitive to graviton exchange ...

($\to$ for $L = \frac{1}{2} ab^{-1}$ $M_H > 3.09$ TeV) [Fig]

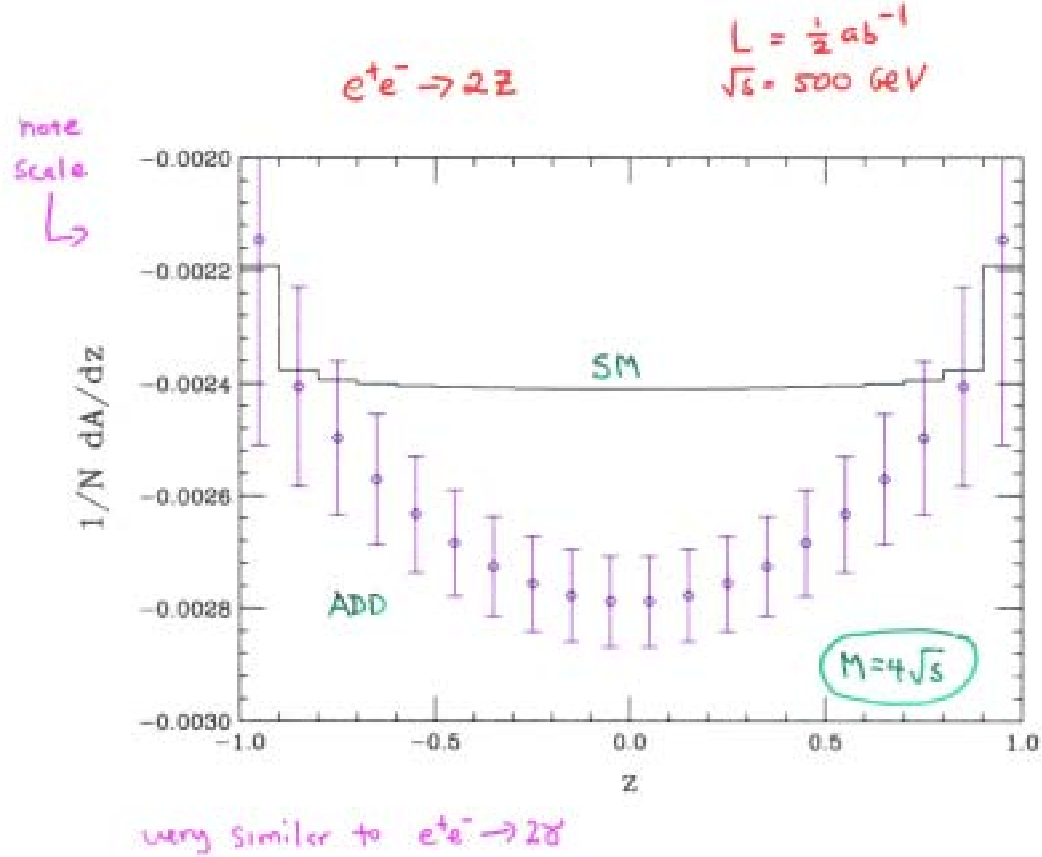
Ditto for $e^+e^- \to 2Z$ ... [Fig]



√s = 500 GeV , ½ ab⁻¹
Transverse Polarization Asymmetry
e⁺e⁻ → W⁺W⁻
SM
M_H = 4√s
ADD
1/N dA/dz
z
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
−1.0
−0.5
0.0
0.5
1.0
Note: no symmetry in SM result !!
95% CL



A deviation from a flat line signals new physics



$e^+e^- \to 2Z$
$L = \frac{1}{2} ab^{-1}$
$\sqrt{s} = 500$ GeV
note scale
−0.0020
−0.0022
−0.0024
−0.0026
−0.0028
−0.0030
1/N dA/dz
SM
ADD
$M = 4\sqrt{s}$
−1.0
−0.5
0.0
0.5
1.0
z
very similer to $e^+e^- \to 2\gamma$

Outlook + Conclusions

- Transverse polarization's potential for LC physics has gotten too little attention ...

  THIS NEEDS TO CHANGE !!

→ Is IT only useful for some few cases of interest (gravity, TGV's ...) or are there wider uses ? Requires investigation ...

This study: P_T can be used to both probe for graviton exchange + to differentiate it from other NP possibilities - about twice as good as 'classic' methods (Beware systematic errors !)

- To some extent, P_T can even differentiate extra dim models : ADD vs RS

- More work is needed in other channels