Unique Graviton Exchange Signatures

at LC's

Many new physics scenarios lead to contact-int.-like deviations in e^+e^- processes....

- Z', $\tilde{\nu}$, LQ, DL, extra dim's, string excitations, ...

- If deviations <u>ARE</u> seen, how do we know which [if any of the above] it is ?

- Try fits to various hypotheses ... $\boxed{\text{OR}}$

- Look for something <u>unique</u> for graviton exchange ...., at a <u>single</u> $\sqrt{s}$ [dim-~~6 vs~~ dim 8]

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Unique Graviton Exchange Signatures :

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

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \frac{3}{8}\left[1 + \cos^2\theta + \frac{8}{3}A_{FB}\cos\theta\right]$$

in the SM, Z' or $\overset{\text{any}}{\text{contact}}$ int cases

$$= a_0 P_0 + a_2 P_2 + a_1 P_1$$

$P_n \equiv P_n(\cos\theta)$

Legendre Poly's

$$\left| \int_{-1}^{1} dz \; P_n P_m = \frac{2}{n+1}\delta_{nm} \right|$$

$$\langle P_n \rangle \equiv \int_{-1}^{1} \frac{1}{\sigma}\frac{d\sigma}{dz} P_n(z)\, dz \qquad [z = z = \cos\theta]$$

$$\to \begin{cases} \langle P_0 \rangle \equiv 1 \qquad \langle P_1 \rangle = 2/3\, A_{FB} \qquad \langle P_2 \rangle = 1/10 \\ \qquad \langle P_{n>2} \rangle = 0 \end{cases}$$

- Z' / contact int $\qquad \langle P_1 \rangle \neq \langle P_1 \rangle_{SM}$
- $\tilde{\nu}$ / $\cancel{R}$ $\qquad \langle P_1 \rangle, \langle P_2 \rangle \neq$ SM values

<u>**But**</u> $\langle P_{n>2} \rangle$ still $= 0$!

$$\frac{d\sigma}{dz} = N_c \frac{\pi\alpha^2}{s} \left\{ \tilde{P}_{ij} \left[A^e_{ij} A^f_{ij} (2P_0 + P_2)/3 + B^e_{ij} B^f_{ij} \cdot P_1 \right] \right.$$

$$- \frac{\lambda s}{2\pi\alpha\Lambda_H^4} \tilde{P}_i \left[(2\underline{P_3} + 3P_1)/5 \; v^e_i v^f_i + a^e_i a^f_i P_2 \right]$$

$$\left. + \frac{s^4}{16\pi^2\alpha^2\Lambda_H^8} \left[16\underline{P_4} + 5P_2 + 14P_0 \right]/35 \right\}$$

- $\langle P_3 \rangle$ at order $s/\pi\alpha\Lambda_H^4$
- $\langle P_4 \rangle$ at order $(\quad " \quad)^2$

$\rightarrow$ $\langle P_3 \rangle \neq 0$ will be <u>dominant</u>

$$A_{LR}(z) \equiv \frac{\tilde{P}_{ij} \left[B^e_{ij} A^f_{ij} (P_2 + 2P_0)/3 + A^e_{ij} B^f_{ij} \cdot P_1 \right] - \frac{\lambda s}{2\pi\alpha\Lambda_H^4} \tilde{P}_i \left[(2\underline{P_3} + 3P_1)/5 \; a^e_i v^f_i + P_2 v^e_i a^f_i \right]}{\{ \text{above} \}}$$

For the Normalized Distribution 0.375(1+z**2), what are the Legendre Poly Moments as we increase nbins??

NBINS	P_2 MOMENT	P_4 MOMENT
0.1000000000D+02	0.9004000000D-01	-0.2675850000D-01
0.2000000000D+02	0.9750250000D-01	-0.6828453125D-02
0.5000000000D+02	0.9960006400D-01	-0.1098806944D-02
0.2000000000D+03	0.9997500025D-01	-0.6874533861D-04
0.1000000000D+04	0.9999900000D-01	-0.2749992541D-05
	this is 0.1 in the cont. lim.	this iz 0 in the cont. limit

NOW WE KEEP NBINS=20 & CHANGE THE ANGLE CUT

CUT(MR)	COS(CUT)	P_2	P_4
0.0	0.1000000000D+01	0.9750250000D-01	-0.6828453125D-02
.01	0.9999500004D+01	0.9742830551D-01	-0.6898110097D-02
.05	0.9987502604D+00	0.9565225028D-01	-0.8559000078D-02
0.1	0.9950041653D+00	0.9015889880D-01	-0.1361589379D-01
0.2	0.9800665778D+00	0.6903092903D-01	-0.3189468450D-01

OR IN MORE DETAIL FOR a 0.375(1+z**2)+z distribution which gives P_1=2/3 and P_3=0 in the cont limit..still for 20 bins & angle cuts as above

P_2	P_4	P_1	P_3
0.9750250000D-01	-0.6828453125D-02	0.6650000000D+00	-0.5818750000D-02
0.9742830551D-01	-0.6898110097D-02	0.6649002557D+00	-0.5915603692D-02
0.9565225028D-01	-0.8559000078D-02	0.6625098141D+00	-0.8230135856D-02
0.9015889880D-01	-0.1361589379D-01	0.6550819162D+00	-0.1534061274D-01
0.6903092903D-01	-0.3189468450D-01	0.6260036782D+00	-0.4197362741D-01

"real" LC $\sqrt{s} = 500$ GeV $\theta \geq 50$ mr (SM)

	$\langle P_2 \rangle$	$\langle P_4 \rangle$	$\langle P_1 \rangle$	$\langle P_3 \rangle$
μ, τ	0.9583178524D-01	-0.8575064935D-02	0.3193237706D+00	-0.3966851446D-02
b	0.9583178524D-01	-0.8575064935D-02	0.4194039034D+00	-0.5210113163D-02
c	0.9583178524D-01	-0.8575064935D-02	0.4073311326D+00	-0.5060137206D-02
t	0.4408526168D-01	-0.6871751178D-02	0.2691767856D+00	-0.3343892374D-02

Unpol. cross-section

μ, τ	0.9583178524D-01	-0.8575064935D-02	0.4978149864D+00	-0.6184187587D-02
b	0.9583178524D-01	-0.8575064935D-02	0.4194039034D+00	-0.5210113163D-02
c	0.9583178524D-01	-0.8575064935D-02	0.4073311326D+00	-0.5060137206D-02
t	0.4408526168D-01	-0.6871751178D-02	0.2691767856D+00	-0.3343892374D-02

$\dfrac{d\sigma^+ - d\sigma^-}{dz}$

Note $\langle P_2 \rangle_{t\bar{t}} << 0.1$ due to finite m_t^2/s terms

- $\langle P_2 \rangle \simeq 0.1$ + $\langle P_{3,4} \rangle$ small for massless guys as before

- $\langle P_3 \rangle$ appears flavor dependent... leaks in from $\langle P_1 \rangle$ since A_{FB} is sensitive to final f couplings

Now what if we bring Λ_H from ∞ (SM) to 2 TeV ?

$\sqrt{s} = 500$ GeV $\qquad \Lambda_H = 2$ TeV

	$\langle P_2 \rangle$	$\langle P_4 \rangle$	$\langle P_1 \rangle$	$\langle P_3 \rangle$
μ, τ	0.8404986807D-01	-0.8032733352D-02	0.2858088512D+00	-0.1268972869D-01
b	0.5409391190D-01	-0.6653835427D-02	0.3761896817D+00	-0.1604285987D-01
c	0.1176024162D+00	-0.9004093559D-02	0.4479671249D+00	0.5926959655D-02
t	0.5450228551D-01	-0.7144569407D-02	0.2829118150D+00	0.3915261996D-03

$$\frac{d\sigma^+ + d\sigma^-}{dz}$$

	$\langle P_2 \rangle$	$\langle P_4 \rangle$	$\langle P_1 \rangle$	$\langle P_3 \rangle$
μ, τ	0.8235699163D-01	-0.8131522069D-02	0.4841933136D+00	-0.9767800563D-02
b	0.5409391190D-01	-0.6653835427D-02	0.3761896817D+00	-0.1604285987D-01
c	0.1176024162D+u0	-0.9004093559D-02	0.4479671249D+00	0.5926959655D-02
t	0.5450228551D-01	-0.7144569607D-02	0.2829118150D+00	0.3915261996D-03

$$\frac{d\sigma^+ - d\sigma^-}{dz}$$

$\langle P_3 \rangle$ shifted substantially from SM case

perform fit to $\langle P_{3,4} \rangle$ deviations ...

$$\frac{1}{\sigma}\frac{d\sigma}{dz}\bigg|_{sm+grav} = \sum_{n=0}^{4} a_n P_n \quad !!$$

$\therefore \quad \langle P_{3,4}\rangle \neq 0 \implies$ graviton exchange!

not so simple in Real World ...

(i) finite bin width + N_{bins}

(ii) cuts near beam pipe remove full $\cos\theta$ range [orthogonality]

⋮

e.g. SM $\quad N_{bin} = 20 \quad \theta^{cut} = 50\,mr$

$\langle P_2\rangle = 0.0957$ (0.1) $\quad \langle P_4\rangle = -8.56\cdot 10^{-3}$ (0)

$\langle P_3\rangle = -8.23\cdot 10^{-3}$ (0)

$$\langle P_n\rangle = \int_{-1}^{1}\frac{1}{\sigma}\frac{d\sigma}{dz}P_n(z)\,dz \implies \sum_n\left[\int_{bin}\frac{1}{\sigma}\frac{d\sigma}{dz}dz\right]P_n(z_{bin})$$

Real World Effects induce spurios contributions to moments which need to be "background subtracted"

Look at $\frac{1}{\sigma}\frac{d\sigma}{dz} \sim \frac{d\sigma^+ + d\sigma^-}{dz}$

and $\sim p\,\frac{d\sigma^+ - d\sigma^-}{dz}$

{stat, lumi, pol, ...

$$\chi^2 = \sum_{\text{dist}} \sum_f \sum_{n=3,4} \left(\langle P_n \rangle - \langle P_n \rangle_{SM} \right)^2 / \text{err}_{nf}^2$$

$\gtrsim 25$ $\quad$ ($\chi^2_{SM} = 0$ by definition)

$\delta L/L = 0.25\%$, $\delta P/P = 0.3\%$ etc

→ $e^+e^- \to f\bar{f}$ ID reach for gravity [Plot]

→

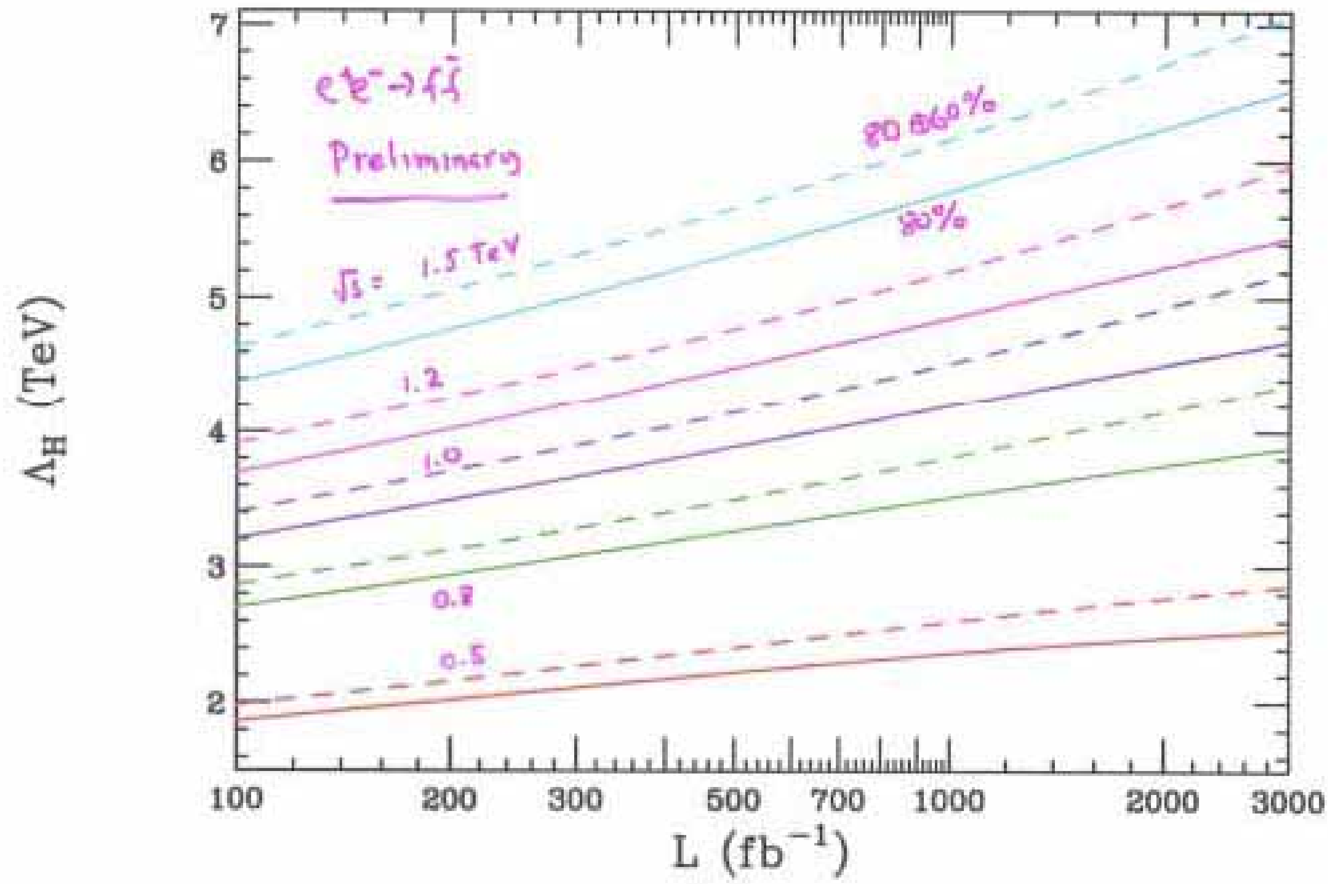
- This method will work for processes w/o u- or t-channel poles ...

(→ they contain all P_n, e.g.,)

$\times\; e^+e^- \to e^+e^-,\ \gamma\gamma,\ ZZ \qquad e^-_L e^+_{(R)} \to W^+W^- \;\times$

However $\quad e^-_R e^+_{(L)} \to W^+W^-$ is pure s-channel :

$\to\ \frac{1}{\sigma}\frac{d\sigma}{dz} = a_0 P_0 + a_2 P_2 \quad$ in SM {or Z'...}



$e^+e^- \to f\bar{f}$
Preliminary
$\sqrt{s}$ = 1.5 TeV
1.2
1.0
0.8
0.5
80 & 60%
80%
Λ_H (TeV)
L (fb^{-1})

note

again, Gravity induces $\left\{ \begin{array}{l} \langle P_1\rangle \\ \langle P_3\rangle, \langle P_4\rangle \neq 0 \end{array}\right.$

For ALL final state W^+W^- polarizations

$\rightarrow$ not Z' or contact int $\left[\sim \bar{e}e\, W_{\mu\nu}W^{\mu\nu}\right]$

($\langle P_2\rangle$ deviation only)

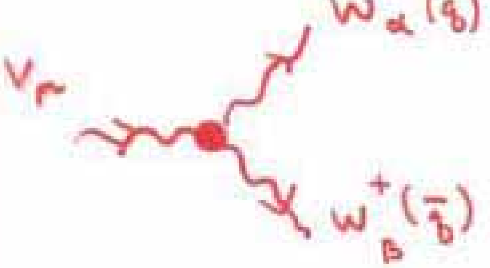
But anomalous couplings do induce $\left\{ \begin{array}{l} \langle P_1\rangle, \\ \langle P_{3,4}\rangle \neq 0 \ldots \end{array}\right.$

$$\frac{d\sigma}{dz} = \frac{\pi\alpha^2}{2s}\,\beta\left(\Sigma_{TT} + \Sigma_{TL+LT} + \Sigma_{LL}\right) \qquad (e^-_R e^+_L)$$

$$\Sigma_{TT} = 2\beta^2 F_1^2 (1-z^2)$$

$$\Sigma_{LL} = (1-z^2)\frac{\beta^2 s^2}{4m_W^4}\left\{F_3 - (1-2m_W^2/s)F_1 + \frac{\beta^2 s}{2m_W^2}F_2\right\}^2$$

$$\Sigma_{LT+TL} = \frac{s\beta^2}{2m_W^2}\Big\{(F_3+\beta z F_5)^2(1+z^2) + F_5^2(1-z^2)^2 + 2(F_3+\beta z F_5)\,z\,(1-z^2)F_5\Big\}$$



$$F_5 \sim g_5^V \epsilon^{\mu\alpha\beta\rho}(q-\bar{q})_\rho \quad (\not{C}, \not{P})$$

(appears at 1-loop in SM)$_{VVA}$

BUT $\langle P_1\rangle, \langle P_{3,4}\rangle \neq 0$ only for TL+LT final state

$\Rightarrow \langle P_{1,3,4} \rangle \neq 0$ in $e^-_R e^+ \to W^+W^-$

Excludes Z' + contact int's AND

$\langle P_{1,3,4} \rangle \neq 0$ in TT/LL modes

Excludes g_5^V-type couplings as source!

IF a pure RH e^- beam were available ...

χ^2 w/ $\langle P_{1,3} \rangle \neq$ only $\longrightarrow$ [Fig]

However .. we don't have 100% RH e^- ....

Best case w/ $P_{e^+} = 60\%$ is to combine $d\sigma$'s

w/ diffrent P_{e^-,e^+} signs to extract $d\sigma_{e^-_R}$

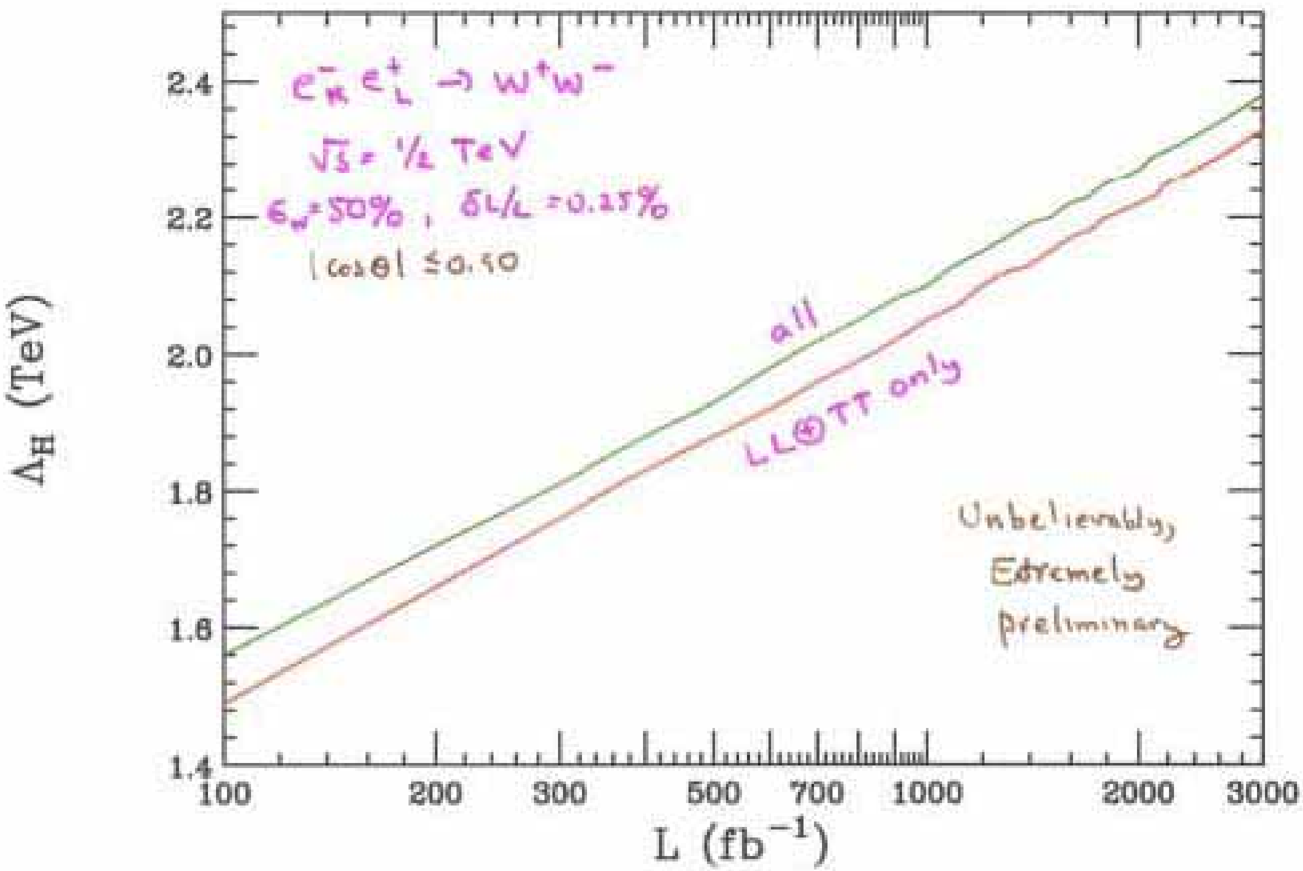
- recall $d\sigma_{e^-_R} \ll d\sigma_{e^-_L}$ — lots of systematics

... First pass analysis .. [Fig]

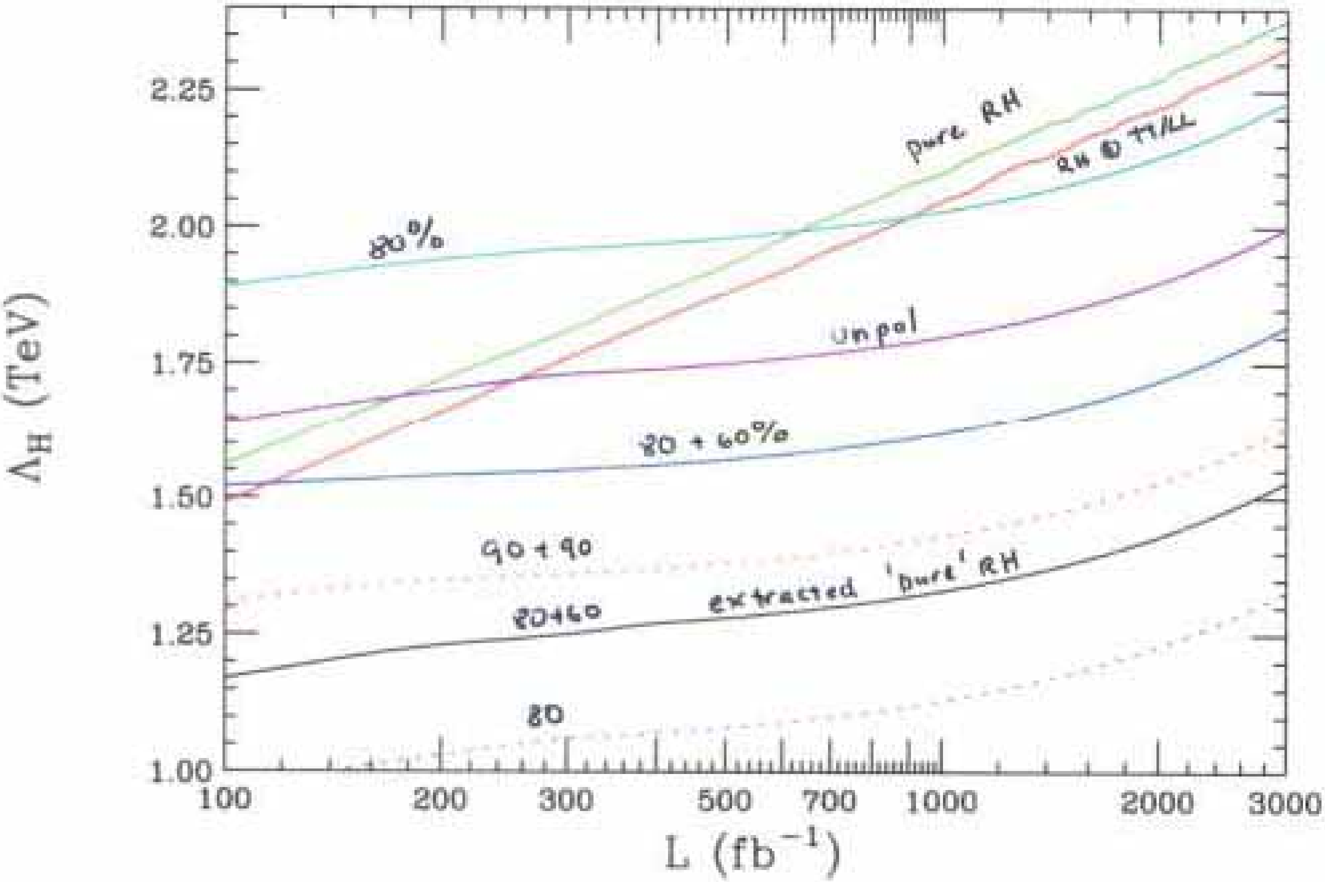
$\rightarrow$ Seems like poor reach in comparison to

$\rightarrow$ $e^+e^- \to f\bar{f}$

5σ ID reach

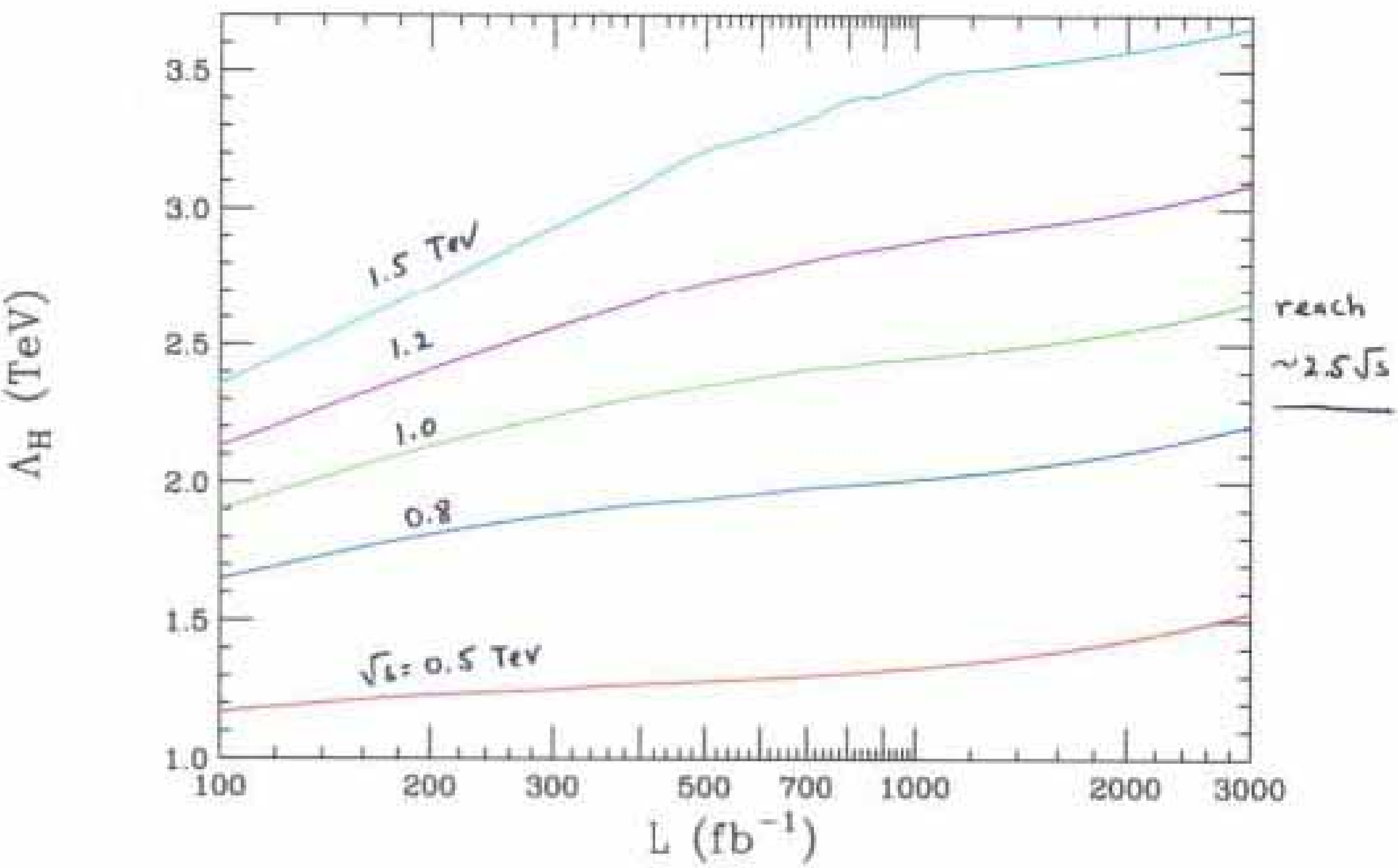


$e^-_R e^+_L \to W^+W^-$
$\sqrt{s} = 1/2$ TeV
$\epsilon_W = 50\%$, $\delta L/L = 0.25\%$
$|\cos\theta| \leq 0.90$
all
LL⊕TT only
Unbelievably, Extremely preliminary
Λ_H (TeV)
L (fb^{-1})
1.4
1.6
1.8
2.0
2.2
2.4
100
200
300
500
700
1000
2000
3000



pure RH
RH ⊗ TT/LL
80%
unpol
80 + 60%
90 + 90
extracted 'pure' RH
80+60
80
Λ_H (TeV)
L (fb^{-1})

fit to $e_R^- e^+ \to W^+ W^-$; extracted



Conclusions

- Graviton exchange signatures can be $\boxed{\text{uniquely}}$ ID'd in $e^+e^- \to f\bar{f}$ and, possibly, $e^-_R e \to W^+W^-$
- More work needs to be done to really understand how well this can be done