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Physics WG Concluding Mini-Plenary 08/25/2005

Towards a precise measurement of the Top-Higgs Yukawa coupling at 500 GeV

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Top Coupling to Scalars: Higgs

- The top-Higgs Yukawa coupling is the largest coupling of the Higgs boson to fermions (g_{ttH} ~ 0.7 vs g_{bbH} ~ 0.02). Precise measurement very important since the top quark is the only "natural" fermion from the EWSB standpoint.

<u>Indirect measurement</u> (from tt threshold scan)

- Yukawa potential: $V_{tth} = -\frac{g_{tth}^2}{4\pi}\frac{e^{-m_h r}}{r}$
- Sensitivity almost exclusively from σ_{tt}.
- Multiparameter fit to threshold observables and assuming $\Delta\sigma_{tt}$(theory)~1%(!):

hep-ph/0207315

9+1 scan points, 30 fb^{-1}/point
Multiparameter fit: m_t, Γ_t, g_{ttH}; $\Delta\alpha_s$=0.001 (constraint)
Δg_{ttH} ~ +35 -65% for m_H=120 GeV
Large correlation with m_t (+80%)

<u>Direct measurement</u>

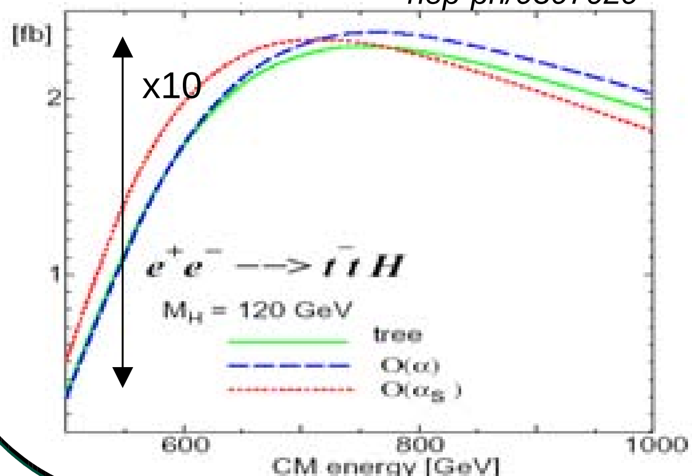
$m_H < 2m_t$: via $\sigma(e^+e^- \rightarrow ttH)$

- Spectacular signature: 4b+4q, 4b+2q+l+ν.
- Use of b-tagging and sophisticated multivariate selections crucial.

A. Juste and G. Merino (hep-ph/9910301)
A. Gay et al (4th ECFA/DESY Workshop)

$\sqrt{s}$ = 800 GeV, L = 1000 fb^{-1}
Δg_{ttH} ~ 6(10)% for m_H=120(190) GeV

hep-ph/0307029

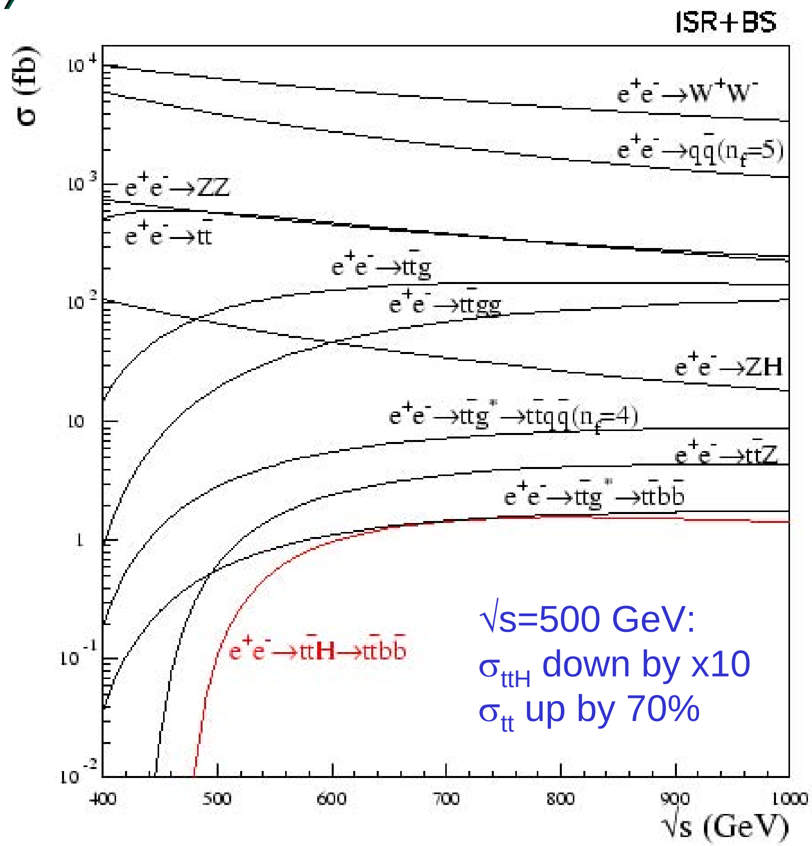


How well can the top-Higgs Yukawa coupling be measured at $\sqrt{s}$ = 500 GeV? What is the impact of available higher order calculations (EW, QCD, tt threshold effects)?

What kind of requirements on energy flow (and thus calorimeter design) and flavor tagging performances are imposed by e.g. the 8-jet channel, to maximize the potential for a competitive measurement?

What can be learned about anomalous t-t-H coupling?

g_{ttH} at $\sqrt{s}$=500 GeV (I)



A. Juste, Chicago LC Workshop, January 7-9, 2002

- $\sqrt{s}$=500 GeV; ISR (SF approach) and Beamstrahlung (CIRCE-NLC/JLC 2001) included
- m_t=175 GeV, m_h=120 GeV
- Detailed simulation of interfering and non-interfering backgrounds. 2→8 calculation for dominant tt+jets background.
- Fragmentation, hadronization and particles' decays handled by PYTHIA.
- Fast simulation of the response of a "Large Detector" for NLC (SIMDET v3.1).
- B-tagging algorithm kept simple so that success of the analysis doesn't depend on detector details. Rather "standard performance" ε_b ~ 50%, ε_{uds} ~ 1%

  ** Potential for improvement **
- Focus on semileptonic decay channel (expect ~70 events for L=1 ab^{-1}).

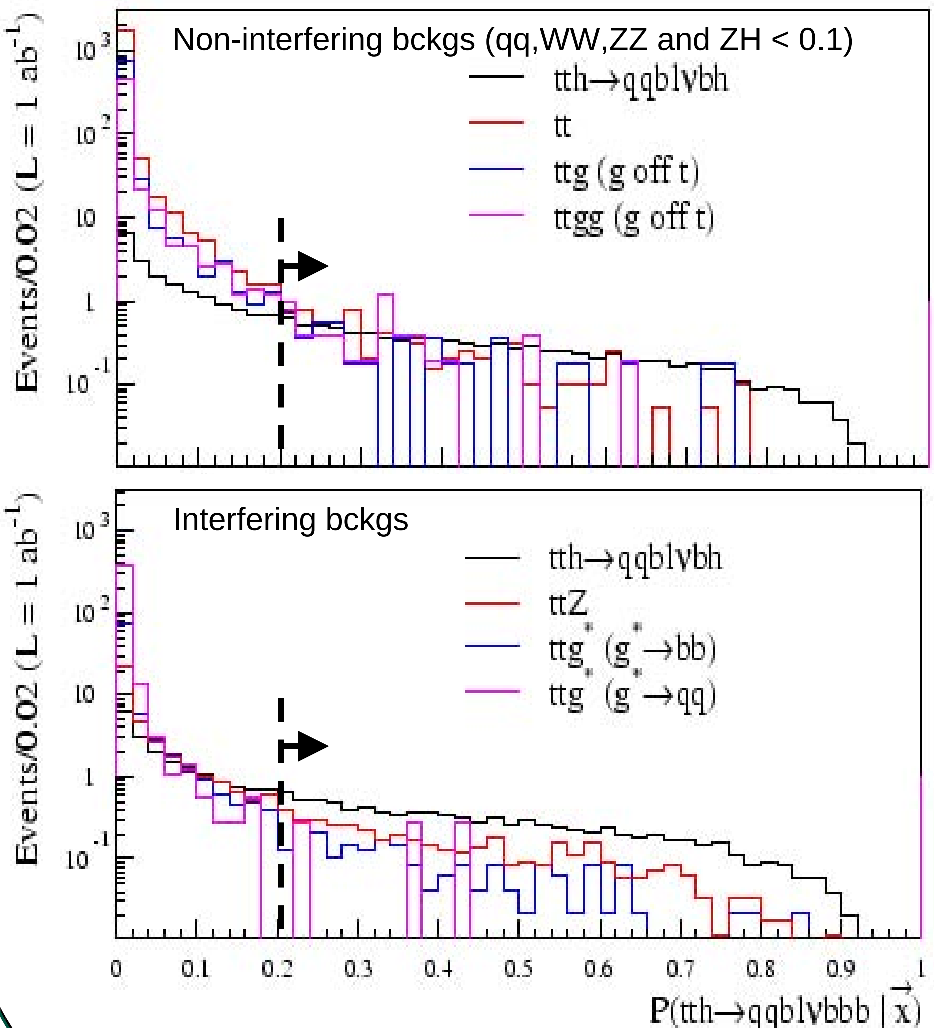
Approach:

- Apply soft preselection: ε~44%, S:B~1:100. Background completely dominated by tt+jets.
- Multivariate analysis: NN using 23 variables.

  [Analysis not optimized to fully exploit invariant mass information, angular distributions, etc.]

  ** Potential for improvement **

g_{ttH} at √s=500 GeV (II)



- Optimal discriminant cut: >0.2
- Expected uncertainty for semileptonic channel:

$$\left(\frac{\Delta g_{tth}}{g_{tth}}\right)_{semilept} \approx 33\%(stat) \oplus 7\%(syst)$$

m_H=120 GeV
√s=500 GeV, L = 1 ab^{-1}

- Assuming hadronic channel reduces statistical uncertainty by √2 (was essentially true at 800 GeV):

$$\boxed{\left(\frac{\Delta g_{tth}}{g_{tth}}\right) \approx 24\%}$$

m_H=120 GeV
√s=500 GeV, L = 1 ab^{-1}

- Reminder: improvements possible regarding b-tagging, use of kinematic information, adding channels, etc.

Impact of tt Threshold Effects

- Recent theoretical developments regarding the impact of v-resummation near the ttbar threshold in ttH events predict a sizeable cross section enhancement in this region.

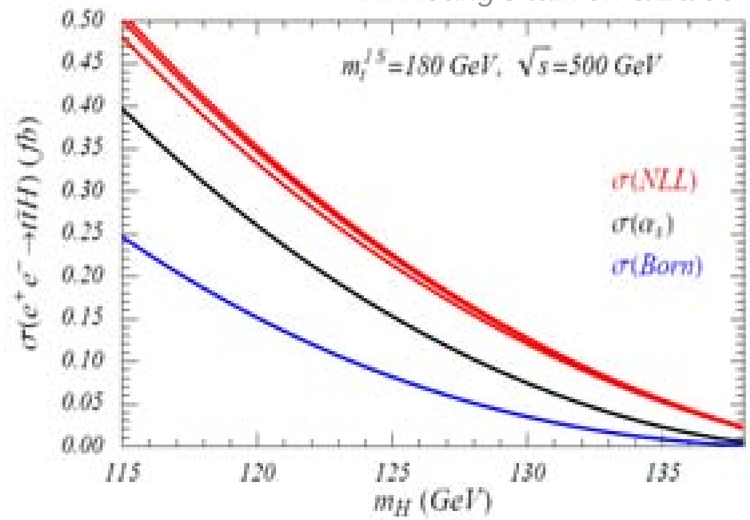
  ⇒ At √s=500 GeV and for $m_h \geq 120$ GeV, this region is dominant!

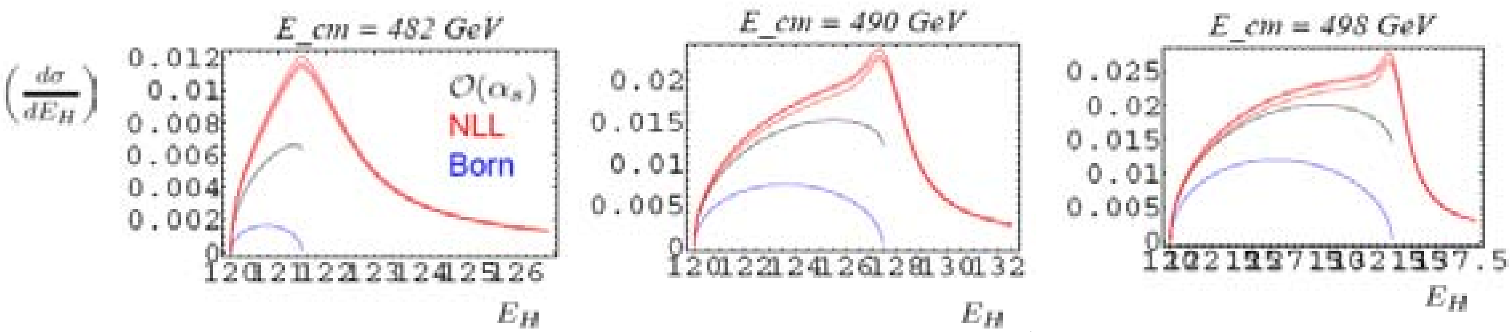
A. Hoang's talk on 8/16/05

$m_H = 120$ GeV

$\sigma(\text{NLL}) \equiv \sigma(\alpha_s)[v > 0.2] + \sigma(\text{NLL})[v < 0.2]$

$\sqrt{s}$ [GeV]	σ(Born) [fb]	$\sigma(\alpha_s)$ [fb]	σ(NLL) [fb]	$\frac{\sigma(\text{NLL})}{\sigma(\alpha_s)}$
500	0.151	0.263	0.357(20)	1.359
550	0.984	1.251	1.342(37)	1.073
600	1.691	1.939	2.005(30)	1.034
700	2.348	2.454	2.485(13)	1.012
800	2.428	2.427	2.442(5)	1.006
900	2.290	2.229	2.237(6)	1.004
1000	2.087	1.997	2.002(8)	1.003





$m_t^{1S} = 180$ GeV

$m_H = 120$ GeV

For a given m_H, the enhancement is larger at smaller √s.

⇒ Relevant to implement radiative effects in the initial state (ISR, Beamstralung), since they lower the effective center of mass energy

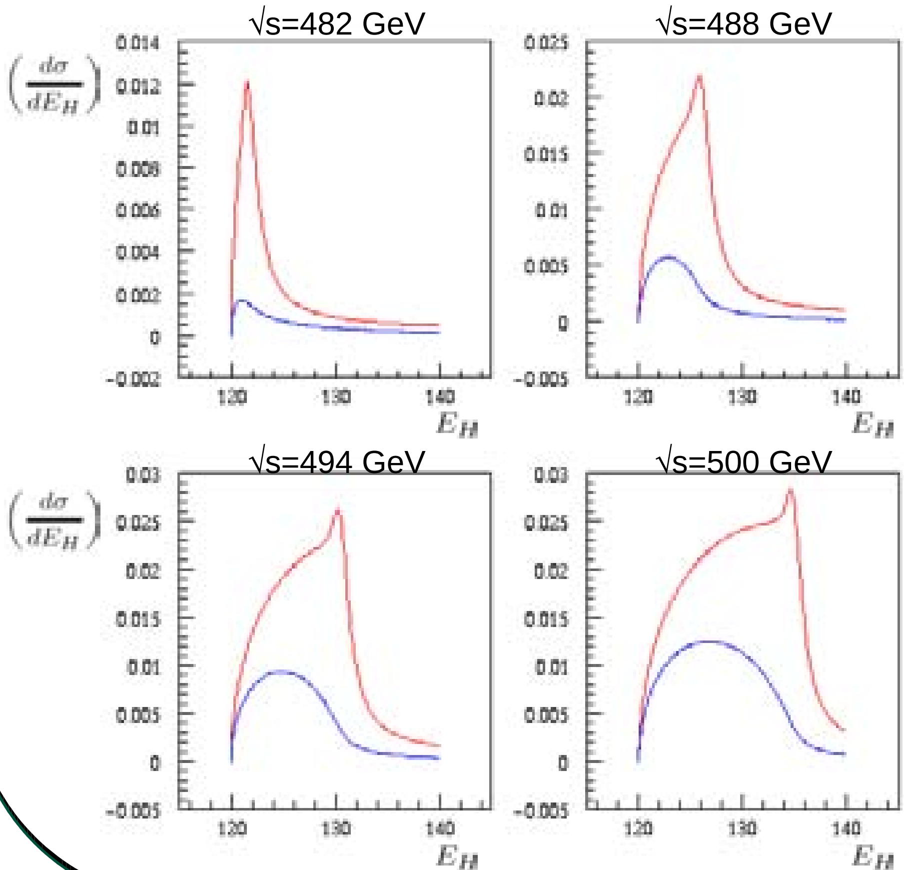
Implementation of ttbar Threshold Effects (I)

- Compute K-factor as a function of E_H:

$$K(E_H, s) = \frac{(d\sigma / dE_H)^{NLL}}{(d\sigma / dE_H)^{LO}}$$

From A. Hoang

From MADGRAPH ME-based $e^+e^- \to ttH \to W^+bW^-bH$ calculation



$$m_t^{1S} = 180\,\mathrm{GeV}$$
$$\mathrm{m_H} = 120\,\mathrm{GeV}$$

- Important to take into account off-shellness of the top quark for the LO prediction (since the NLL calculation is for off-shell top).

- NLL prediction only defined in the region:

$$\sqrt{s} \in [482{,}500]\,\mathrm{GeV}$$
$$\mathrm{E_H} \in [120, E_H^{\max}]\,\mathrm{GeV}$$

where E_h^{max} depends on √s and corresponds to a cut on top velocity β<0.2 in the on-shell approximation.

Outside this region I take K=1 (could actually use the O(α_S) prediction, but not done yet).

Implementation of ttbar Threshold Effects (II)

- Compute cross section taking into account ISR+BS effects as well as the K-factor:

$$\sigma_{ttH}(s) = \int dx_1 dx_2 dE_H \cdots \frac{d^{13}\sigma_{ttH}}{dE_H \cdots} f_{ISR+BS}(x_1, s) f_{ISR+BS}(x_2, s) K(E_H, s x_1 x_2)$$

MADGRAPH ME-based $e^+e^- \to ttH \to W^+bW^-bH$ calculation

σ_{ttH}(fb)		Born	Born w/ K-factor	Enhancement
no ISR/BS		0.157(1)	0.357(2)	2.27
BS	-48%	0.106(1)	0.252(3)	2.38
ISR+BS	-44%	0.0735(8)	0.179(2)	2.44

$\sqrt{s} = 500\,\mathrm{GeV}$

$m_t^{1S} = 180\,\mathrm{GeV}$

$\mathrm{m_H} = 120\,\mathrm{GeV}$

⇒ Radiative effects in the initial state (ISR,BS) VERY large: a factor of 2 decrease in cross section! Need to control related systematic uncertainties to the % level!

⇒ Would benefit from low BS accelerator operating point, but what would be the impact in luminosity?

⇒ Resummation effects lead to an increase by x2.4 increase in signal cross section with respect to the Born prediction! (Should evaluate expected enhancement in ttZ as well).

Promising! Can we further increase the signal cross section?

Effect of Beam Polarization (I)

- So far, all feasibility studies have neglected making use of beam polarization.
  Baseline machine: $|P(e^-)| \sim 0.8$
  Option: in addition to electron polarization, $|P(e^+)| \sim 0.6$

- In the case of ttH, mediated by γ,Z, only the two J=1 configurations for helicity of the e^- and e^+, σ_{RL} and σ_{LR}, contribute. The cross section for arbitrary longitudinal beam polarization can be expressed as:

$$\sigma_{P_{e^-}P_{e^+}} = (1 - P_{e^+}P_{e^-})\ \sigma_0\ [1 - P_{\mathrm{eff}}\ A_{\mathrm{LR}}]$$

Unpolarized cross section

$$\sigma_0 = \frac{\sigma_{\mathrm{RL}} + \sigma_{\mathrm{LR}}}{4}$$

Effective polarization

$$P_{\mathrm{eff}} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^+}P_{e^-}}$$

Left-right asymmetry

$$A_{\mathrm{LR}} = \frac{\sigma_{\mathrm{LR}} - \sigma_{\mathrm{RL}}}{\sigma_{\mathrm{LR}} + \sigma_{\mathrm{RL}}}$$

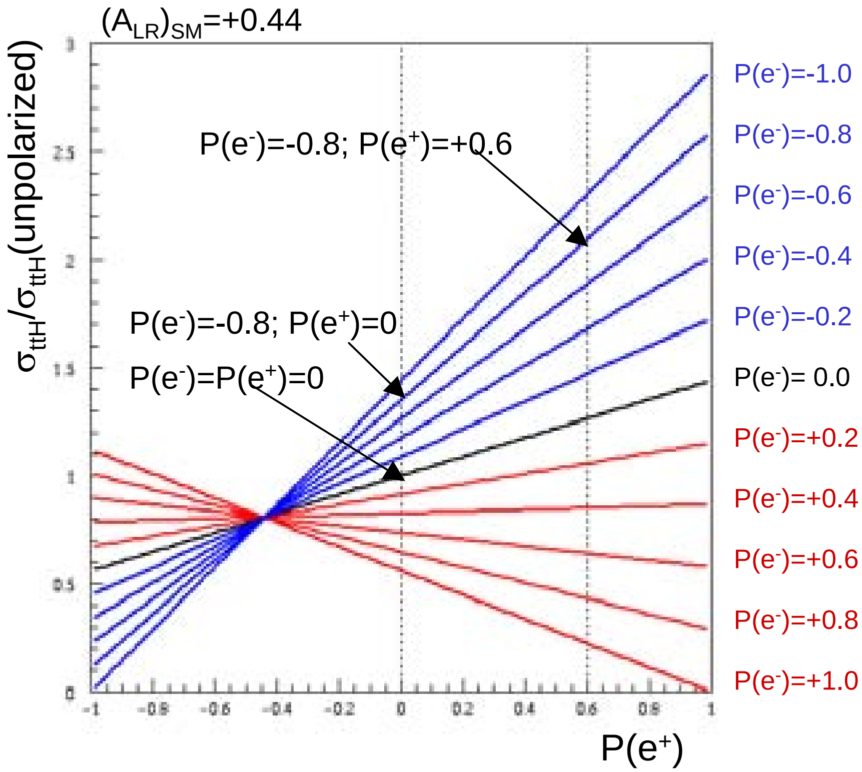
$\Rightarrow$ Two potential enhancement factors with respect to σ_0

$(1 - P_{e^+}P_{e^-})$: requires to have BOTH beams polarized

$[1 - P_{\mathrm{eff}}\ A_{\mathrm{LR}}]$: requires to have $A_{LR} \neq 0$ AND to choose the signs of P_{e+} and P_{e-} such that sign(P_{eff} A_{LR})<0

Within the SM, A_{LR}~+0.44 (essentially independent of $\sqrt{s}$~0.5-1 TeV), driven by the Z exchange.

Effect of Beam Polarization (II)



LHC (300 fb^{-1})

$$-0.05 \le \Delta F_{1V}^{\gamma} \le +0.05$$

$$-0.05 \le \Delta F_{1A}^{\gamma} \le +0.05$$

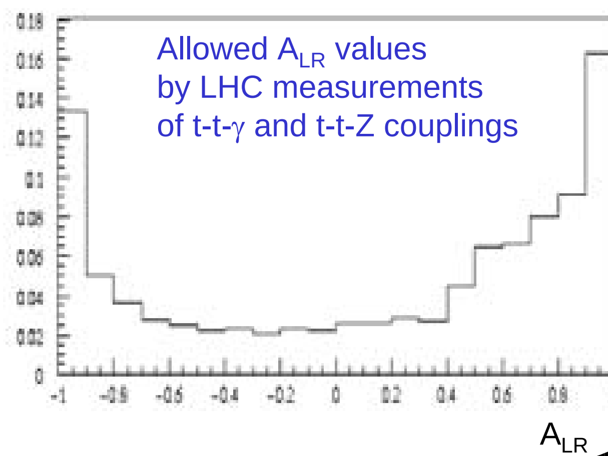
$$-0.45 \le \Delta F_{1V}^{Z} \le +0.85$$

$$-0.15 \le \Delta F_{1A}^{Z} \le +0.15$$

My approximate 68% intervals. Assume uncorrelated measurements and neglect F_2 couplings.

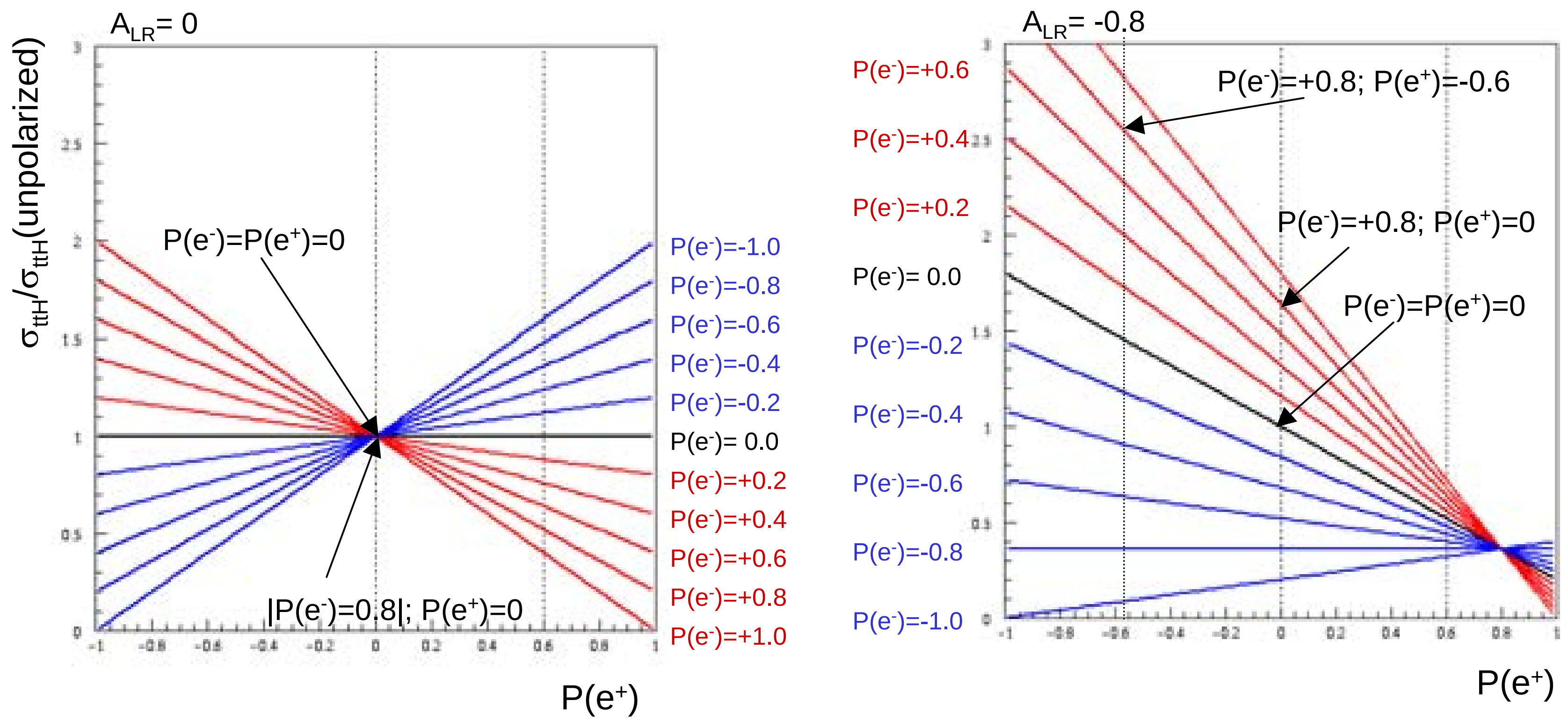
U. Baur et al, PRD 71 (2005) 054013 [hep-ph/0412021]

- Optimal (realistic) beam polarization: $(P_{e-},P_{e+}) = (-0.8,+0.6)$
  $\Rightarrow$ increase in cross section relative to the unpolarized case by x2.1 (valid for the SM). Strong case for having P_{e+} in the baseline.
- DISCLAIMER: choice of signs of P_{e-} and P_{e+} can only be done once the sign of A_{LR} is known. If A_{LR}<0 because of anomalous t-t-γ or t-t-Z couplings, then the optimal is $(P_{e-},P_{e+}) = (+0.8,-0.6)$.
- The LHC won't provide any stringent constraints on A_{LR}, because of the poor sensitivity to F_{1V}^{Z}.



Effect of Beam Polarization (III)

- Some examples of beam-polarization dependence for non-SM A_{LR}:



A possible plan for the ILC:

- Determine sign(A_{LR}) using tt events. This fixes the desired sign for P_{e-} and P_{e+}. Magnitude should be the largest possible.
- Top-Higgs Yukawa coupling measurement requires %-level and model-independent determination of t-t-γ and t-t-Z couplings. This typically benefits from changing beam polarization. Optimize strategy trying to maintain cross section enhancement for ttH while meeting precision goal for anomalous couplings.

Summary and Outlook

- Old preliminary estimate of precision on Top-Higgs Yukawa coupling measurement at √s=500 GeV:

$$\left(\frac{\Delta g_{tth}}{g_{tth}}\right) \approx 24\% \qquad \text{For } m_H=120 \text{ GeV, } L = 1 \text{ ab}^{-1}$$

- Recent theoretical developments regarding the impact of v-resummation near the ttbar threshold in ttH events predict a sizeable cross section enhancement (by x2 or more) with respect to the Born calculation.
- Another factor of 2 can be gained by exploiting beam polarization, in particular P_{e+}.

- Next step: redo feasibility study making a more optimal use of b-tagging and kinematic information.

- There is a good chance that uncertainties ≤10% can be achieved for m_H values in the vicinity of 120 GeV and assuming $L=1\ ab^{-1}$. Stay tunned!!!