Input from Top to Accelerator Parameters Group

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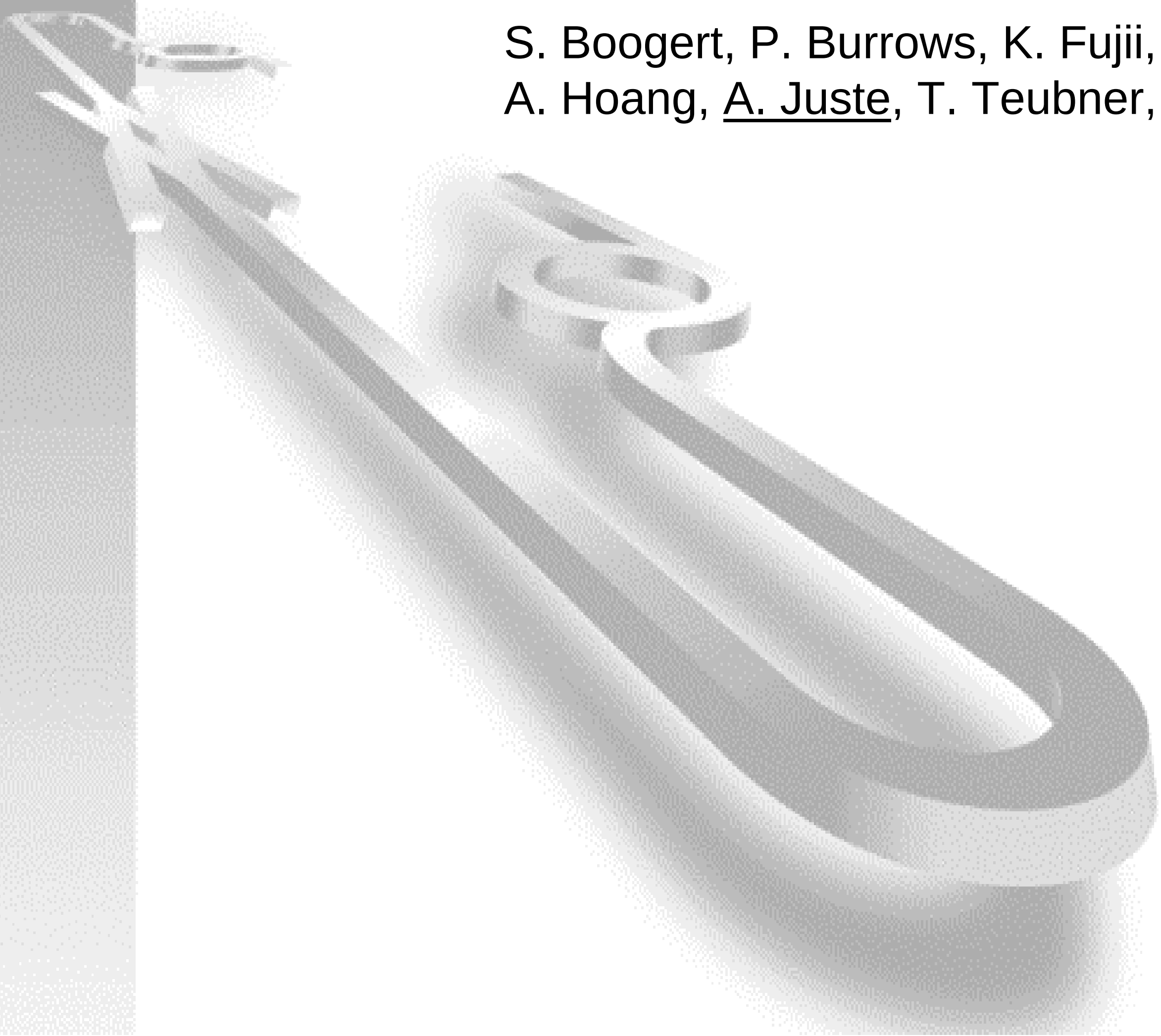


Request from Parameters Group

- Accelerator Baseline Document:

  http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

- ILCSC (in close collaboration with WWS and GDE) has re-activated the "Parameters Group" to revisit the Baseline Design taking into account new insights and development as well as provide cost versus performance guidance.

  ⇒ needed for the finalization of the RDR and preparation for the TDR.

  ⇒ goal is have results presented to the WWS and GDE at the ECFA meeting in Valencia.

- Input requested from different physics working group regarding dependence of physics performance with respect to accelerator parameters: energy, luminosity and polarization.

- Question for Top working group:

  What is the achievable precision for the top mass measurement? Please provide information for two energies: a) threshold scan, b) 500 GeV

  How much luminosity is needed to reach the expected level of theoretical uncertainties?

- Additional questions to be addressed:
  - Is there any impact of decreasing (increasing) beamstrahlung by a factor of two relative to the standard parameters, i.e. trading off luminosity vs background?
  - Is there any benefit from electron plus positron polarisation (80 and 60%) or from increased electron polarisation in the absence of positron polarisation?
  - Are there other accelerator parameters strongly influencing this measurement?

Impact of a Precise m_t Measurement

- Important ingredient for EW precision analyses at the quantum level.
- ILC precision on m_t will be needed to match future experimental/experimental accuracy on M_W and $\sin^2\theta_{eff}$.

Experimental	Today	Tevatron/LHC	ILC	GigaZ
$\delta \sin^2\theta_{\mathrm{eff}} (\times 10^5)$	16	14–20	–	1.3
δM_W [MeV]	34	15	10	7

Intrinsic theoretical: δM_W = 4 MeV, $\delta\sin^2\theta_{eff} = 4.9\times10^{-5}$

Parametric theoretical:

δm_t = 4.3 GeV $\Rightarrow$ δM_W = 26 MeV, $\delta\sin^2\theta_{eff} = 14\times10^{-5}$

LHC: = 1.5 GeV $\Rightarrow$ δM_W = 9 MeV, $\delta\sin^2\theta_{eff} = 4.5\times10^{-5}$

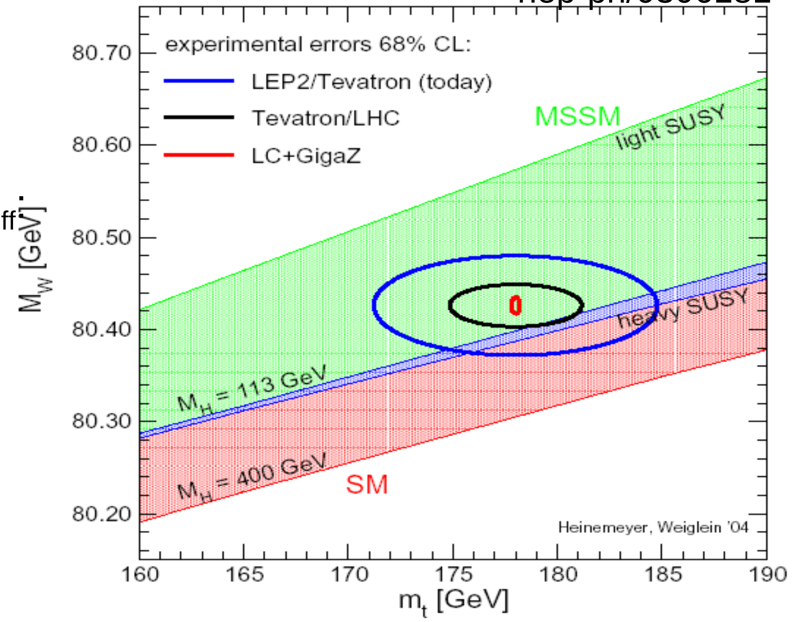
ILC: = 0.1 GeV $\Rightarrow$ δM_W = 1 MeV, $\delta\sin^2\theta_{eff} = 0.3\times10^{-5}$

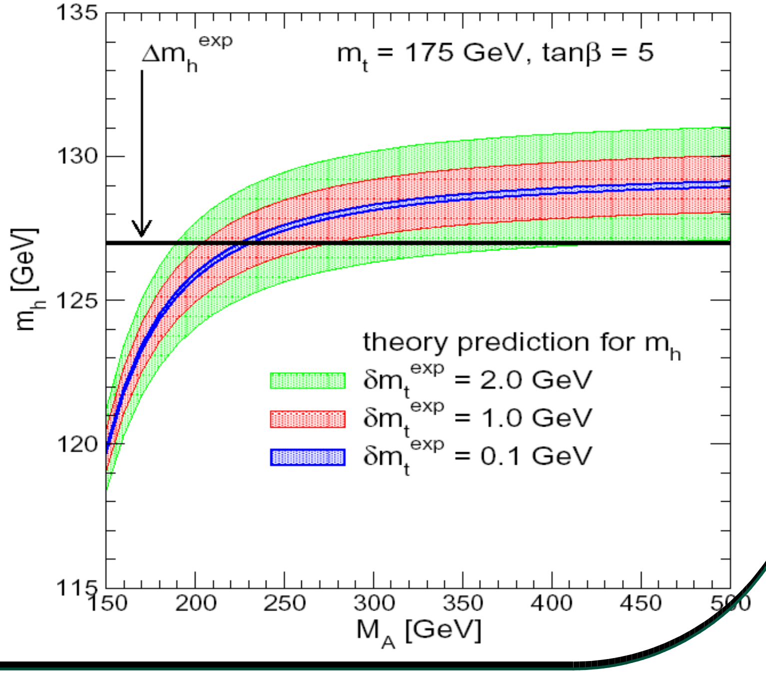
- M_H depends sensitively on m_t in all models where M_H can be predicted (e.g. MSSM).

  Need LC precision on m_t in order to exploit LHC (and LC) precision on Higgs sector measurements.

- Other examples:
  - RGE running to higher scales
  - …

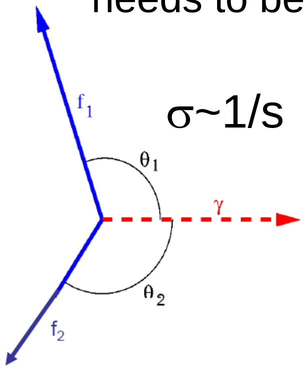
hep-ph/0306181





Beam Energy

- Precise detemination of absolute beam energy critical for many physics measurements:
    - Top mass: 200 ppm (Δm_t = 35 MeV)
    - Higgs mass: 200 ppm (ΔM_H = 60 MeV for M_H = 120 GeV)
    - Giga-Z program: 50 ppm
- Main methods envisioned:
    - Accelerator diagnostics: pre-IP and post-IP energy spectrometers. Can achieve 10^{-4} precision but will be dominated by systematics and don't measure luminosity-weighted bunch energy.
    - $e^+e^- \to \mu^+\mu^-(\gamma)$ events: measure what's needed but statistics-limited and full analysis still needs to be performed to understand real potential.

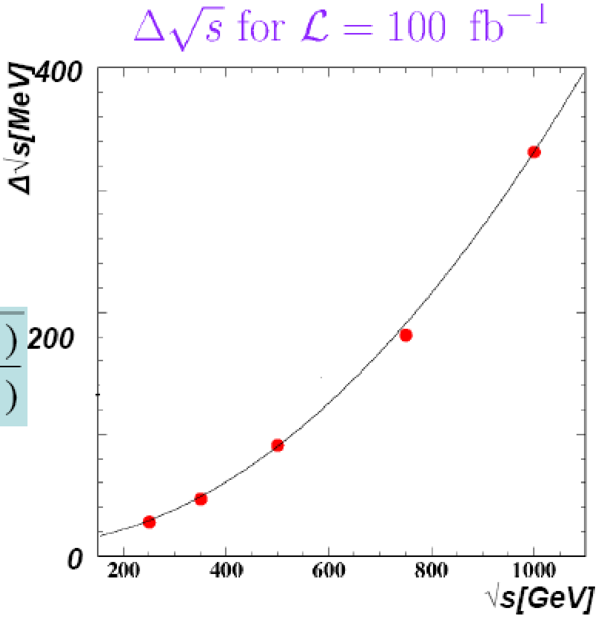


$\sigma \sim 1/s$

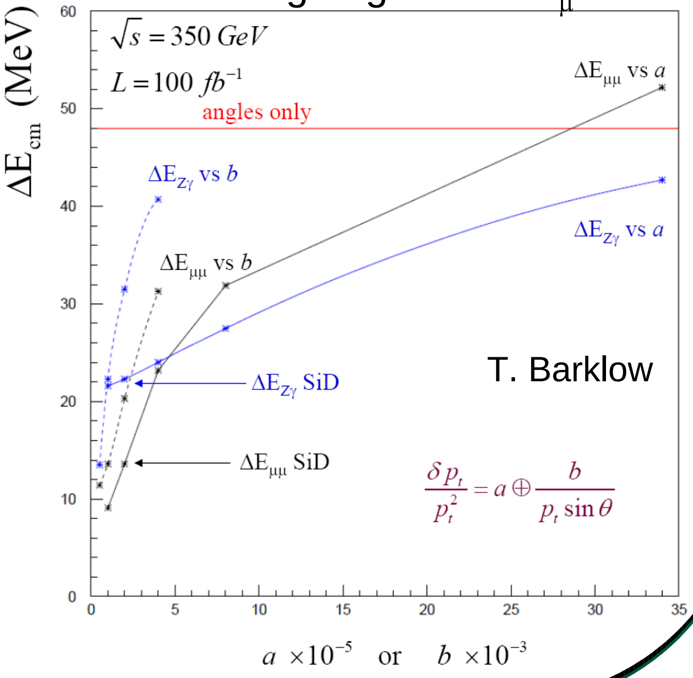
$$\sqrt{s} = M_Z \sqrt{\frac{\sin\theta_1 + \sin\theta_2 + \sin(\theta_1+\theta_2)}{\sin\theta_1 + \sin\theta_2 - \sin(\theta_1+\theta_2)}}$$

H.J. Schreiber and K. Moning

Using angles-only:



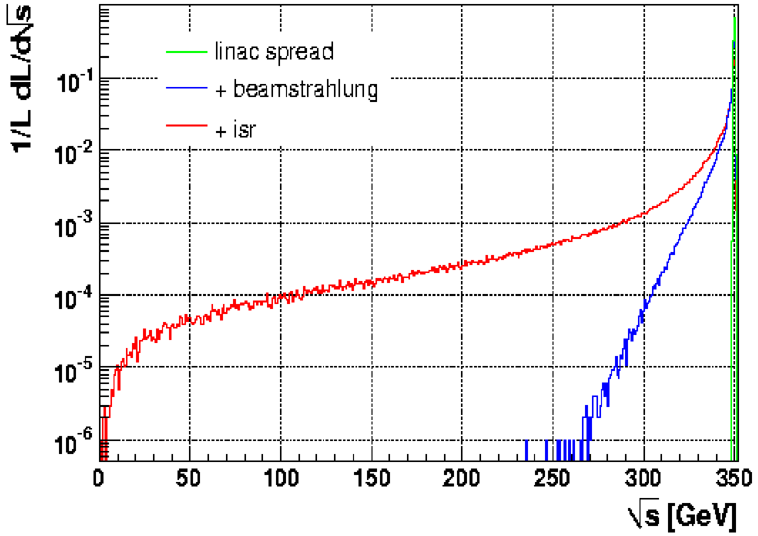
Using angles and E_μ:



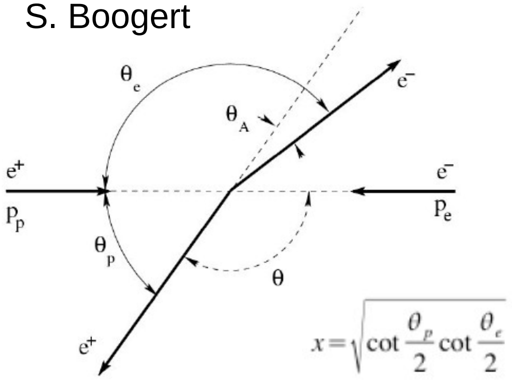
T. Barklow

Luminosity Spectrum

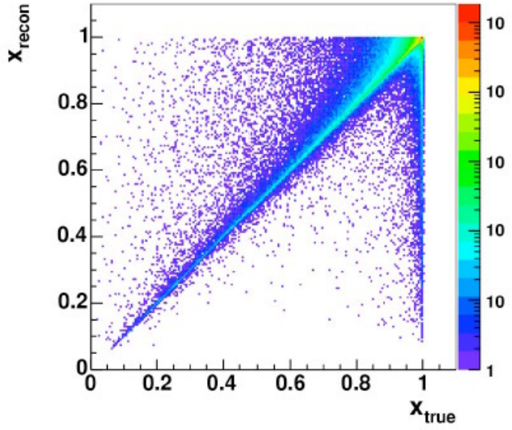
- Luminosity spectrum not a Delta function:
  - Beam energy spread: ~0.1%
  - Bremsstrahlung (ISR): can be calculated accurately
  - Beamstrahlung: ~0.7% @ 350 GeV (Baseline) coherent radiation due to beam-beam interactions. Must be measured precisely: acollinearity in Bhabha events (targets forward tracker)



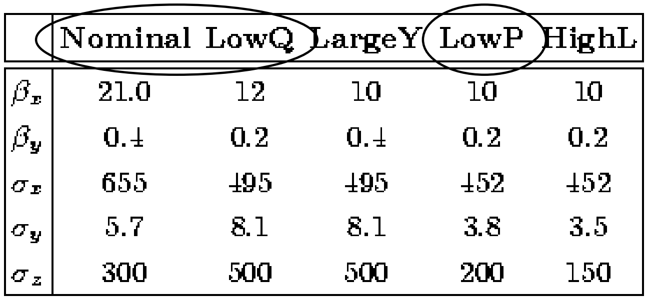
S. Boogert



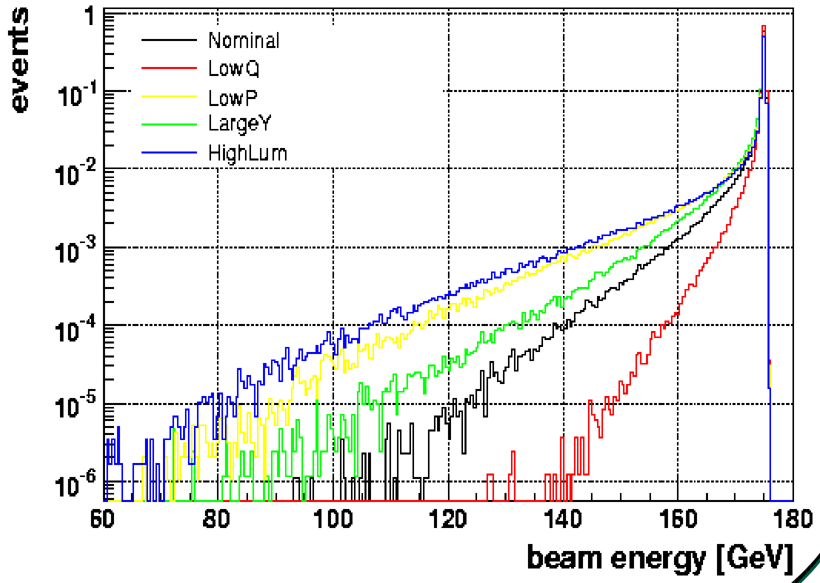
$$x = \sqrt{\cot\frac{\theta_p}{2}\cot\frac{\theta_e}{2}}$$



- Beamstrahlung simulated using GUINEA PIG for five different accelerator parameter sets:



	Nominal	LowQ	LargeY	LowP	HighL
β_x	21.0	12	10	10	10
β_y	0.4	0.2	0.4	0.2	0.2
σ_x	655	495	495	452	452
σ_y	5.7	8.1	8.1	3.8	3.5
σ_z	300	500	500	200	150



Beam Polarization

- Baseline machine: $|P(e^-)| \sim 0.8$
  Option: in addition to electron polarization, $|P(e^+)| \sim 0.6$

- In the case of tt+X, 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:

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

Unpolarized cross section

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

Effective polarization

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

Left-right asymmetry

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

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

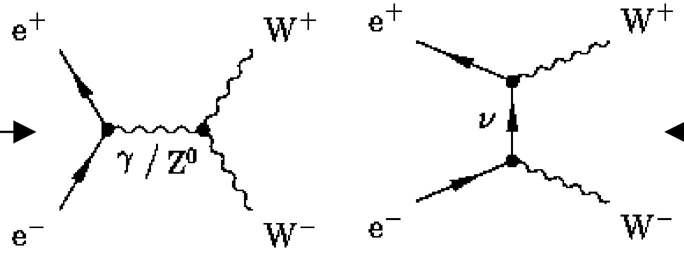
$(1 - P_{e^+}P_{e^-})$: requires to have BOTH beams polarized

$[1 - P_{\text{eff}}\ A_{\text{LR}}]$: 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 √s), driven by the Z exchange.

- Measurement of luminosity-weighted polarization can be performed e.g. using W^+W^- events

Sensitive to TGCs →



← Sensitive to polarization
Targets forward tracker+calorimeter

Top Pair Production at Threshold

- Large Γ_t: cutoff for non-perturbative QCD effects
  - Top decays before top-flavored hadrons or tt-quarkonium bound states can form.
  - Use non-relativistic pQCD to compute σ_{tt} near threshold.
- Remnants of toponium S-wave resonances induce a fast rise of σ_{tt} near threshold.

  Basic parameters: σ_{tt} (m_t, α_s, Γ_t)

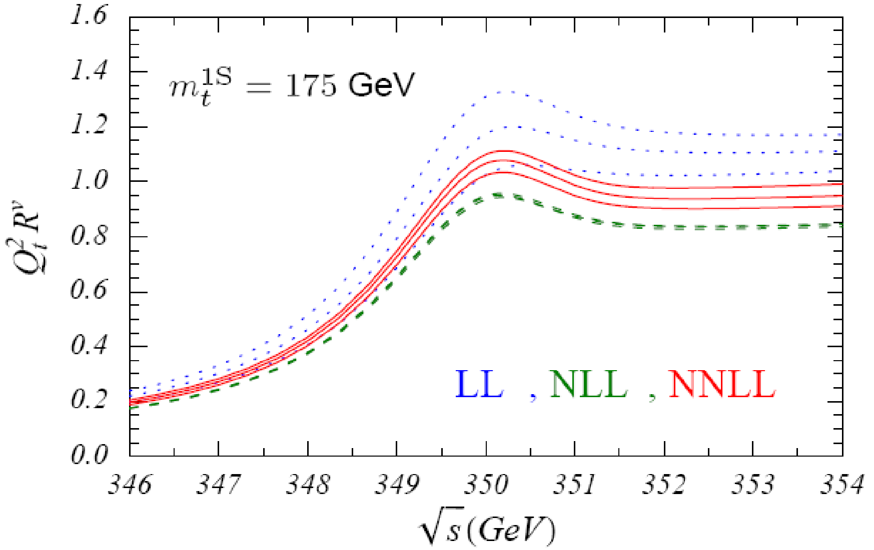
  ⇒ high precision expected (color singlet system, counting experiment,…)
- Convergence of calculation sensitive to m_t definition used: pole mass is not IR-safe

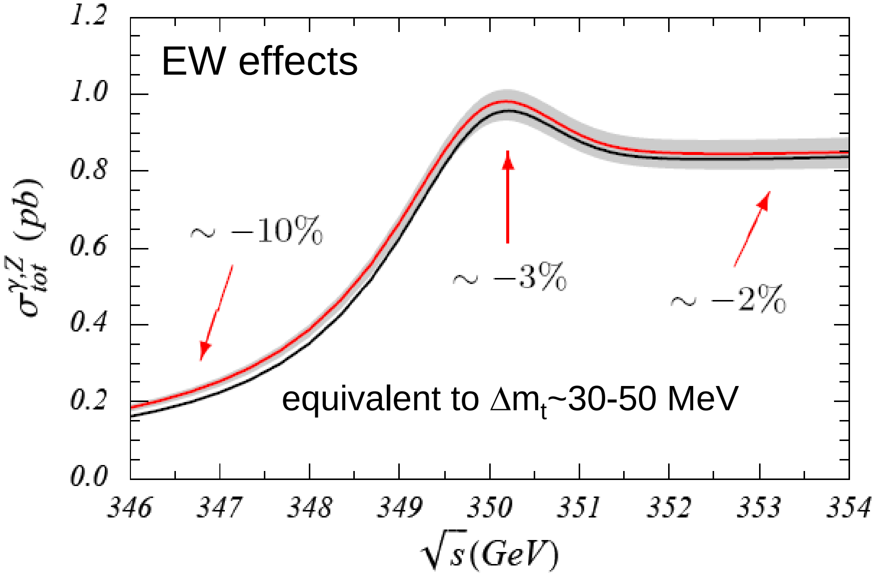
  ⇒ σ_{tt}^{peak} not stable vs √s

  Solution is to use threshold masses: e.g. 1S mass (=1/2 the mass of the lowest tt bound state in the limit $\Gamma_t \to 0$).

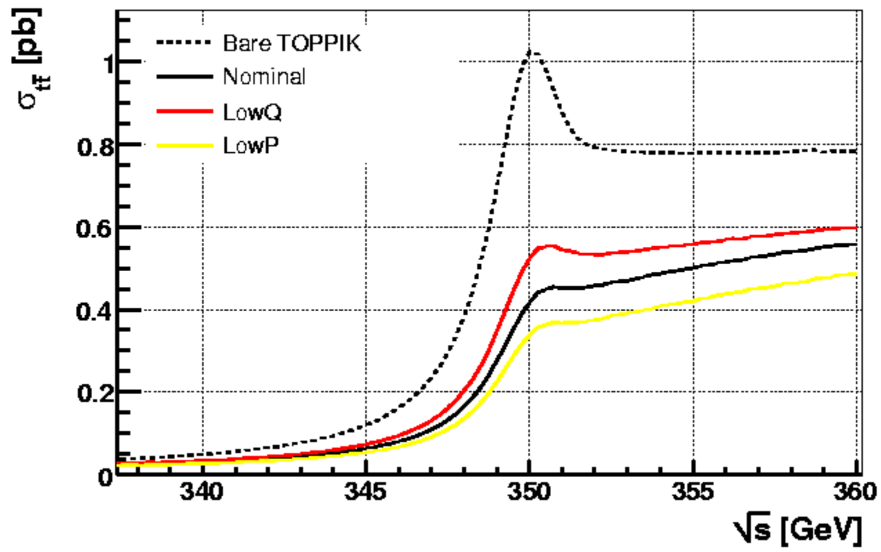
  High accuracy in absolute normalization requires velocity resummation.

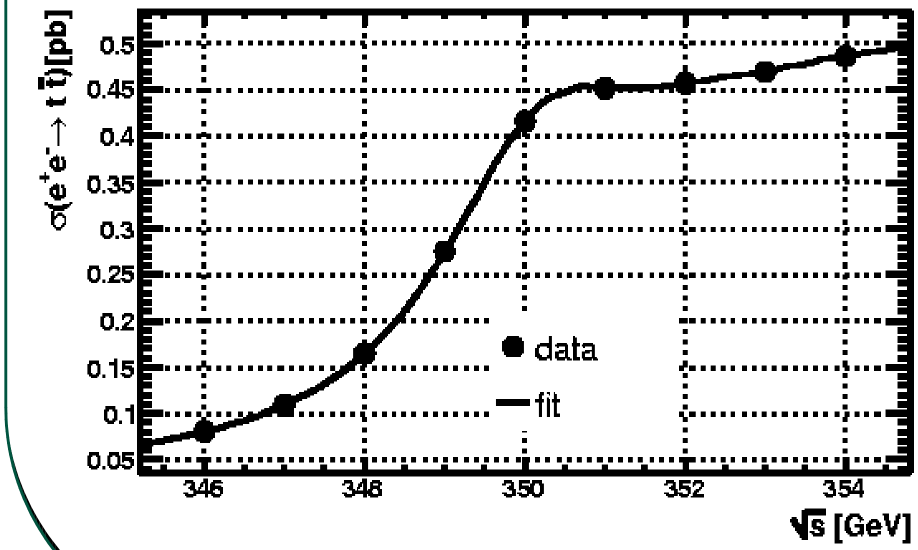
  State of the art (NNLL): $(\Delta\sigma_{tt})_{QCD}$~6%
- Goal: 3% ⇒ important to take into account previously neglected %-level effects: EW corrections (Γ_t +non-resonant W^+bW^-b background, QED), non-factorizable QCD corrections,… ⇒ a lot of work ahead!





Top Mass Measurement at Threshold (I)





- Lineshape significantly distorted by luminosity spectrum:

$$\sigma^{\mathrm{obs}}(\sqrt{s}) = \frac{1}{L_0}\int_0^1 L(x)\,\sigma(x\sqrt{s})\,\mathrm{d}x$$

- Precise determination of dL/d√s and <√s> critical.
- Consider only Nominal, LowQ and LowP parameter sets.

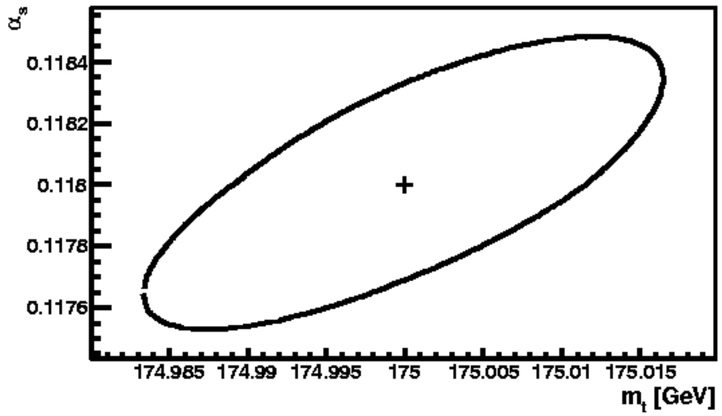
- Perform scan in √s around the threshold region and compare measurement of various observables to theoretical predictions as a function of model parameters.

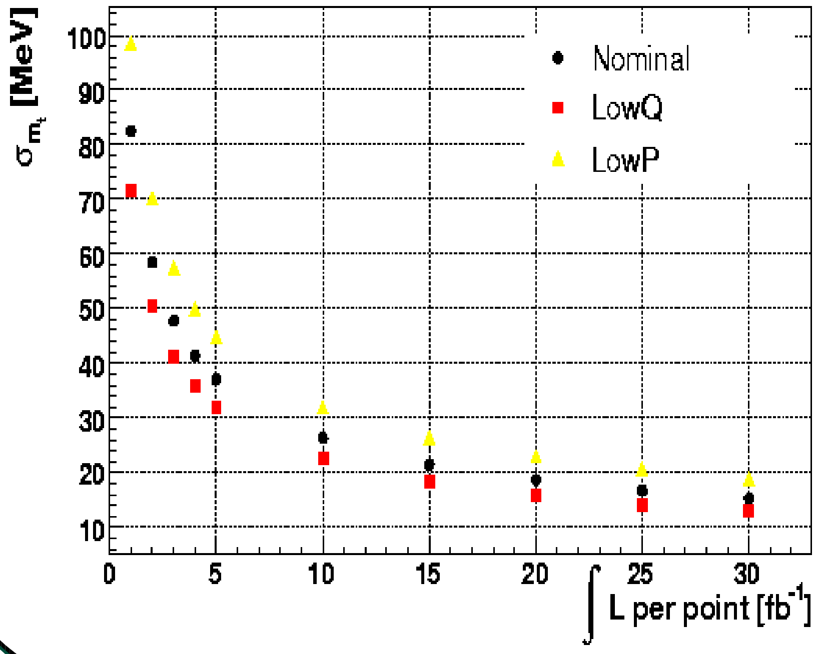
Following hep-ph/0207315:

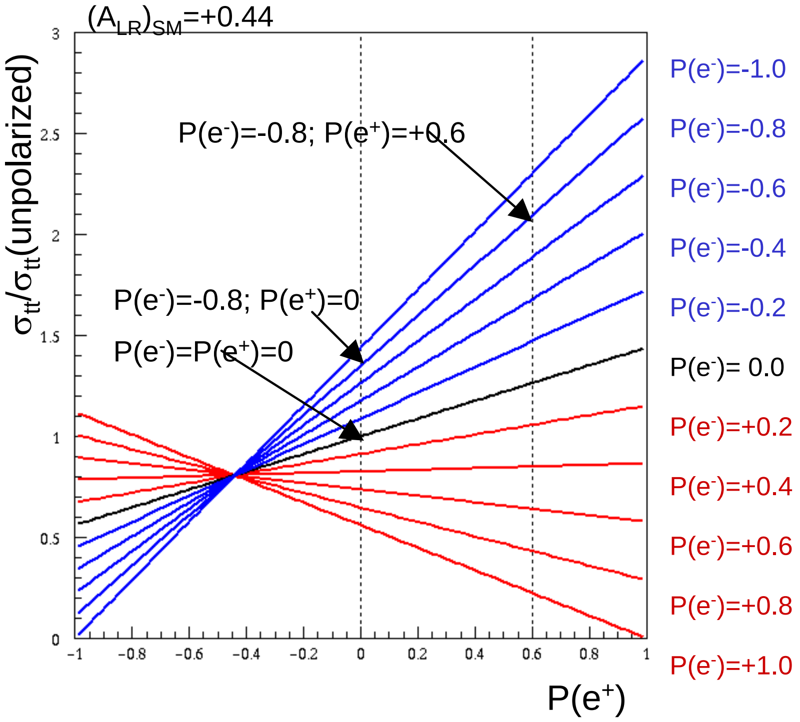
  - 10 uniformly distributed scan points, one of them well below the threshold to measure the background. Same luminosity per scan point. Scan strategy not optimized.
  - Consider lepton+jets and all-jets final states: ε_{tt}~41%, no background assumed

Top Mass Measurement at Threshold (II)

- Perform simultaneous measurement of m_t^{1S} and α_S considering only σ_{tt} observable.
- Statistical uncertainty:
  - Scales like 1/√(L/point).
  - Improves as effective luminosity increases for parameter sets with smaller beamstrahlung.
  - Can be further improved by making use of polarized beams: i.e. can reduce total L invested in scan.
  - It’s not the whole story…



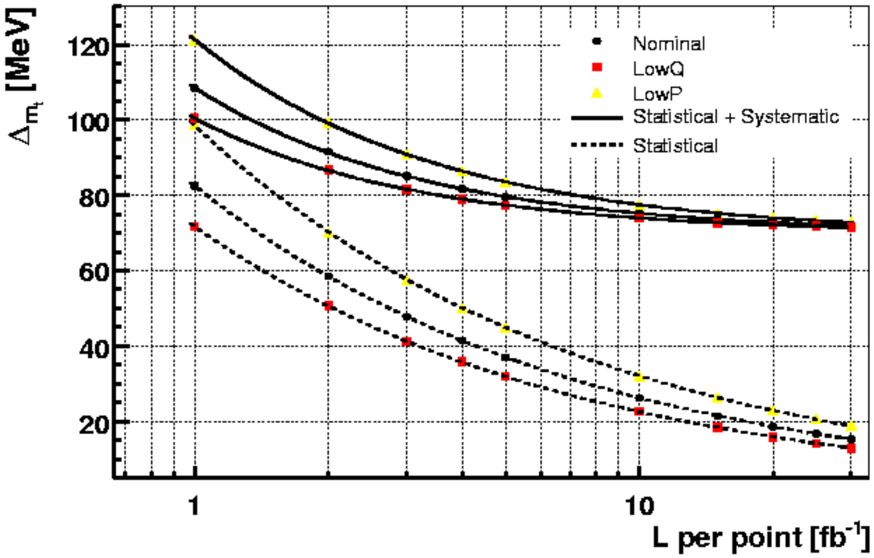




Top Mass Measurement at Threshold (III)

- Systematic uncertainties (only ones considered in this study):
  - Detemination of absolute beam energy: assume 35 MeV
  - Determination of luminosity spectrum: assume 50 MeV independent of parameter set.

    A-priori expect performance (an systematic uncertainties) of acollinearity method to degrade if both beams radiate significantly. More realistic estimate underway.
  - Theoretical uncertainty on σ_{tt} (6%): 35 MeV



- Conversion from 1S to MSbar mass definition involves an additional systematic uncertainty.

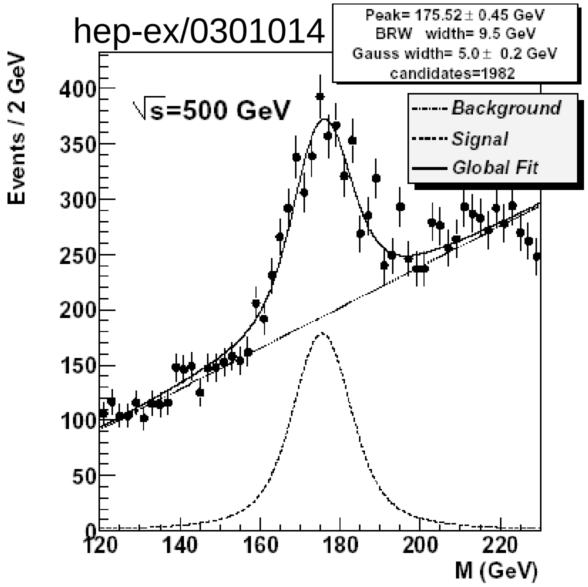
$$\delta\overline{m}_t(\overline{m}_t) = \delta m_t^{1S} \pm 70\ \mathrm{MeV(pert)} \pm x \cdot 70\ \mathrm{MeV}(\alpha_s)$$

- Tentative conclusion: total uncertainty on MSbar m_t ~120 MeV relatively independent of accelerator parameters (within LowQ to LowP range) for L/point ≥ 5 fb^{-1}.
- Caveat: this doesn’t include a study of the impact of beam-beam backgrounds.

Top Mass Measurement in the Continuum

- Direct reconstruction can yield competitive statistical uncertainties:
  Fully hadronic decay channel: Δm_t(stat)~100 MeV, L=300 fb^{-1}

  Force event to 6 jets
  Reduced set of cuts: $|M_{123} - M_{456}| < 40\,GeV, |\vec{P}_{123} - \vec{P}_{456}| < 20\,GeV$
  No kinematic fitting orb-tagging.



hep-ex/0301014

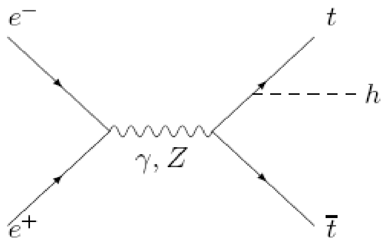
- Better understanding of experimental systematic uncertainties needed. Preliminary estimates:
  - Fragmentation+hadronization modeling: ~250-400 MeV
  - Bose-Einstein correlations: 100-250 MeV
  - Color reconnections: O(100) MeV

- In addition, what's being determined is the pole mass(?).
  Conversion to m_t(MSbar) suffers from large renormalon ambiguity:Δm_t(theo)~O(Λ_{QCD})

- Expected total uncertainty: ≥500 MeV, systematics-dominated and independent of the accelerator parameters.

- Caution: top mass measurement is only a small fraction of the Top Physics program. Other equally-important measurements are definitely more sensitive to accelerator parameters!.

Example: Top-Higgs Yukawa Coupling



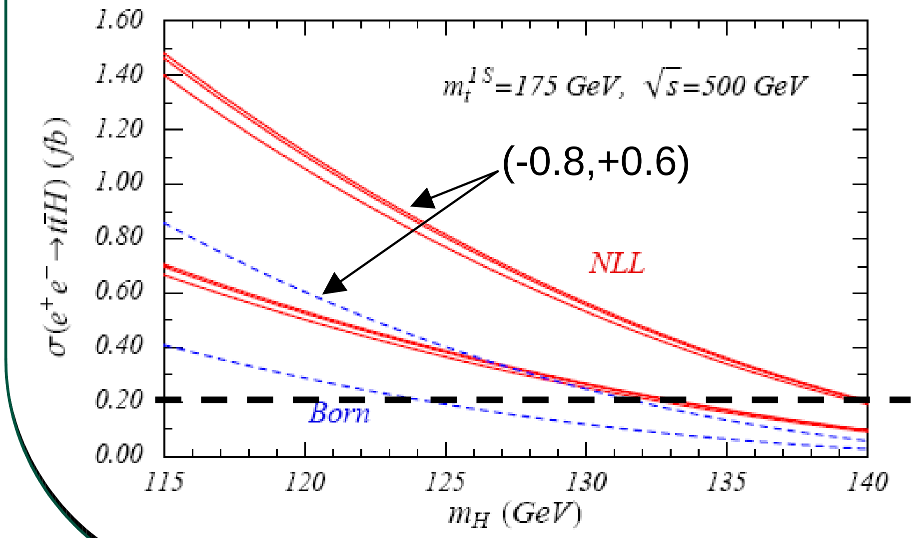
- The top-Higgs Yukawa coupling is the largest coupling of the Higgs boson to fermions. Precise measurement important since the top quark is the only “natural” fermion from the EWSB standpoint.
- Can be determined via cross section measurement: $\sigma_{tth} \propto g^2_{tth}$
- σ_{tth}(Born) ~ 0.2(2.5) fb at √s=500(800) GeV for m_h=120 GeV
- Previous study:
  √s=800 GeV, L=1 ab^{-1}, $\Delta g_{ttH}/g_{tth}$ ~ 6(10)% for m_H=120(190) GeV

  ⇒ What are the prospects at √s=500 GeV?

  First estimate: $\Delta g_{ttH}/g_{tth}$~23% for m_H=120 GeV, L=1 ab^{-1} [AJ, 2002]

hep-ph/9910301
hep-ph/0604034

- However, at √s=500 GeV the tt dynamics is non-relativistic
  ⇒ use vNRQCD as in the tt threshold



Considering σ_{tth} enhancement due to:

- QCD resummation effect: x2.4 (m_h=120 GeV)
- ($P(e^-)$,$P(e^+)$) = (-0.8,+0.6): x2.1

Anticipate: $(\Delta g_{ttH}/g_{tth})_{stat}$~10% for m_H=120 GeV, L=1 ab^{-1} (measurement potentially possible up to m_H~140 GeV!!)

- Large sensitivity to beamstrahlung: cross section reduced by~40% (m_h=120 GeV)
- An unrelated benchmarking question: dominant background is tt+jets. Is the measurement completely killed as soon as one considers minijets from beam-related backgrounds?

Conclusions

- Tentative (minor) conclusion: the top quark mass measurement seems to place only mild constraints on accelerator parameters.

- Main conclusion:

  A comprehensive program of benchmarking measurements must be established as soon as possible, including an increasingly more realistic description of the detector, reconstruction algorithms and backgrounds (both physics and beam-related).

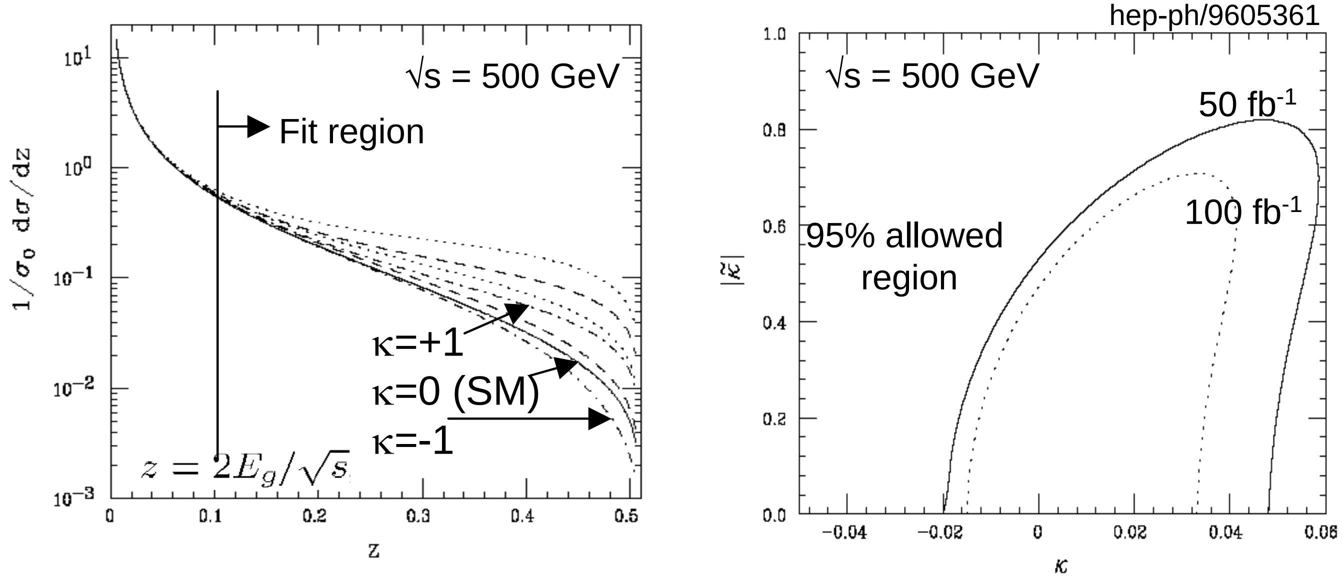
  - Crucial to design and optimize the detector towards the CDR.

  - Critical to ensure we are in a position to provide accurate and complete information on the impact on the physics from engineering/cost-related decisions that will unavoidably be taken on both accelerator and detector fronts.

Backup

Top Couplings to Gauge Bosons: g

- At the ILC, the main observable explored so far is the energy spectrum of the gluon in $e^+e^- \to t\bar{t}g$.



hep-ph/9605361

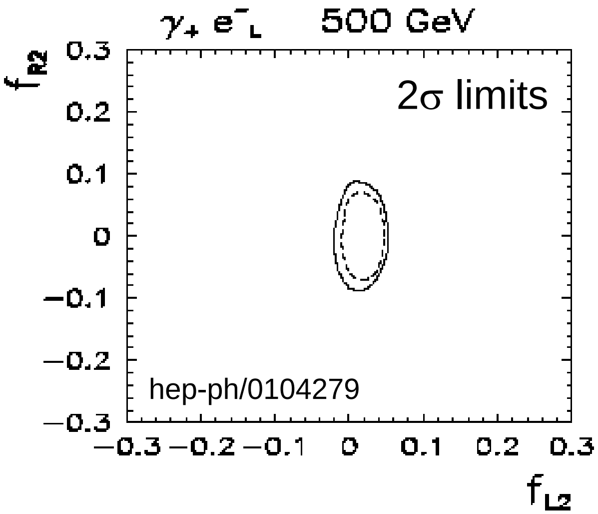
- Reach in chromo-electric dipole moment ($\tilde{\kappa}$) improves by ~x2 for same integrated luminosity at √s = 1 TeV.
- A-priori it should be possible to find additional observables to increase sensitivity, particularly to the chromo-electric dipole moment.
- Caveat: a global analysis at ILC is needed since the gluon energy spectrum is simultaneously sensitive to electroweak dipole moments (from $tt\gamma$ and ttZ vertices)

- Nice complementarity between LHC and ILC which should be exploited:
  - LHC more sensitive to chromo-electric dipole moment.
  - ILC more sensitive to chromo-magnetic dipole moment.

Top Couplings to Gauge Bosons: W

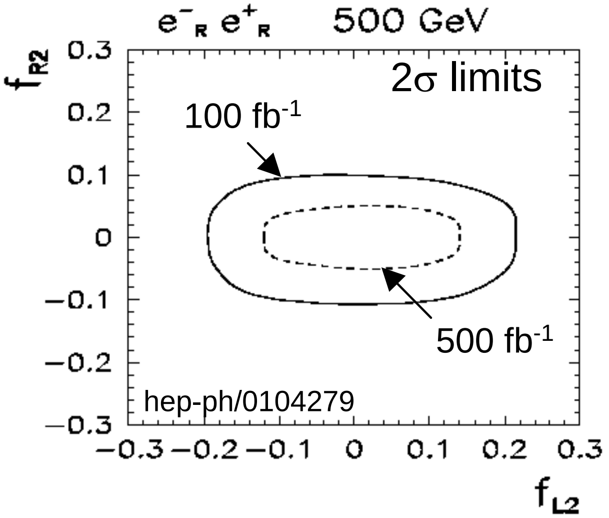
ILC

- Most promising approach is single top quark cross section in polarized γe collisions:
  $\sigma_{\gamma e}$~30-100 fb, no tt background vs σ_{e+e-}~ few fb, large tt background
- Significant sensitivity also from asymmetries in $e^+e^- \to$ tt.



2σ limits

hep-ph/0104279



2σ limits

100 fb^{-1}

500 fb^{-1}

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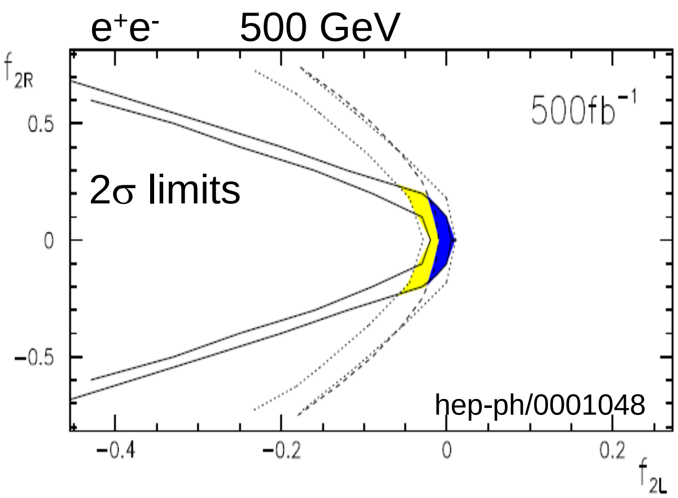


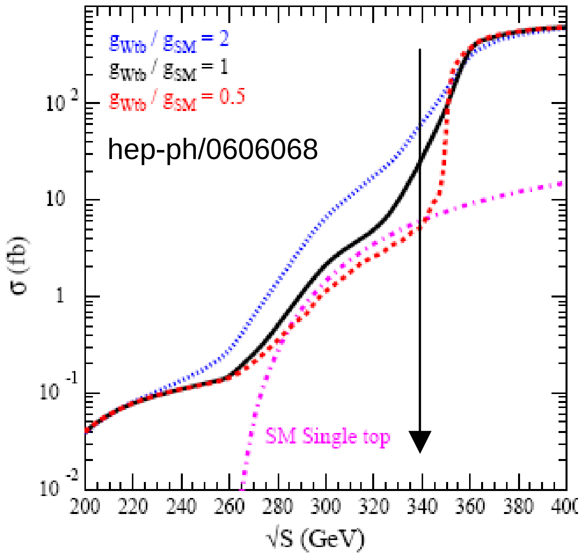
2σ limits

hep-ph/0001048

- Another possibility might be the measurement of σ_{tt} just below threshold, in conjunction with the precise Γ_t measurement from the tt threshold scan:

$\sqrt{s}$=340 GeV, L=100 fb^{-1}

$\Delta g_{tbW}/g_{tbW}$ ~2%



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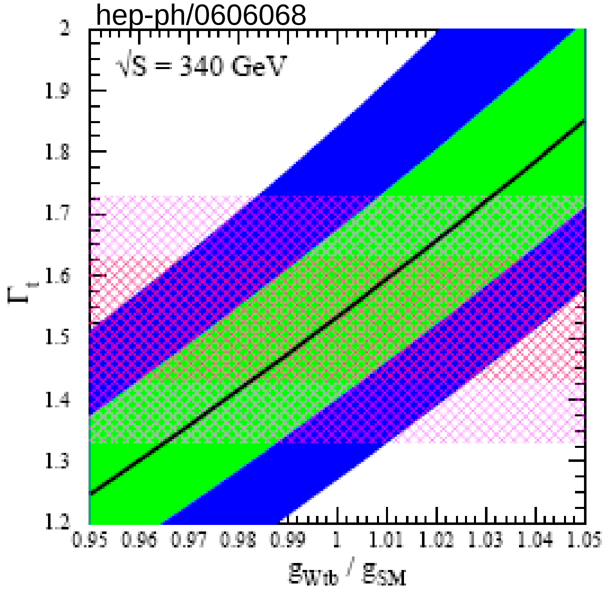

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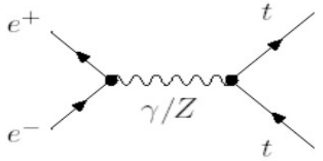
Top Couplings to Gauge Bosons: γ and Z

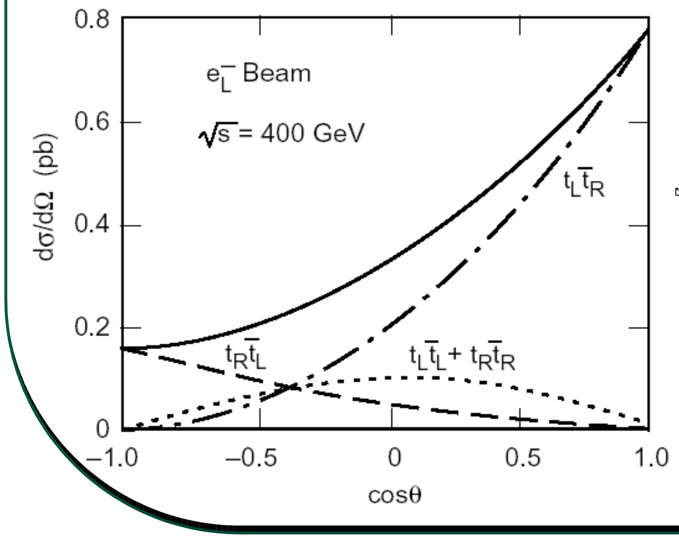
- ILC: the top pair production rate is directly sensitive to BOTH t-t-γ and t-t-Z vertices.

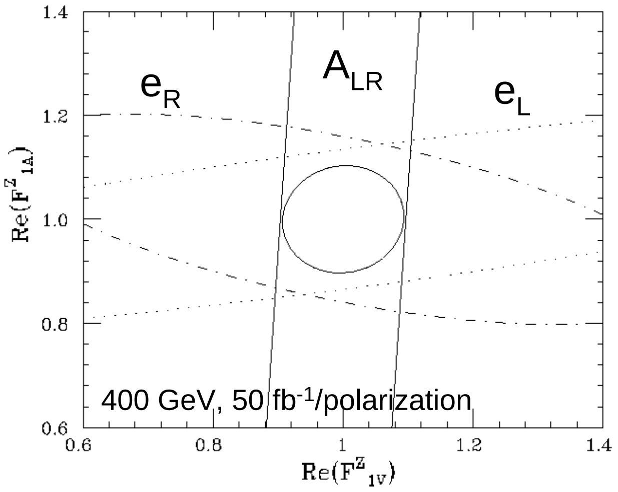


- Polarization is an important tool to disentangle among different couplings:
  - High sensitivity both at threshold (highly polarized top quarks) and continuum
  - Inclusive polarization observables: e.g. $A_{LR} = (\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$
  - Angular distributions of final state products

hep-ex/0106057

coupling	e^+e^-		LHC, 300 fb^{-1}
$\Delta\widetilde{F}^{\gamma}_{1V}$	$+0.047$ -0.047	200 fb^{-1}	$+0.043$ -0.041
$\Delta\widetilde{F}^{\gamma}_{1A}$	$+0.011$ -0.011	100 fb^{-1}	$+0.051$ -0.048
$\Delta\widetilde{F}^{\gamma}_{2V}$	$+0.038$ -0.038	200 fb^{-1}	$+0.038$ -0.035
$\Delta\widetilde{F}^{\gamma}_{2A}$	$+0.014$ -0.014	100 fb^{-1}	$+0.16$ -0.17
$\Delta\widetilde{F}^{Z}_{1V}$	$+0.012$ -0.012	200 fb^{-1}	$+0.34$ -0.72
$\Delta\widetilde{F}^{Z}_{1A}$	$+0.013$ -0.013	100 fb^{-1}	$+0.079$ -0.091
$\Delta\widetilde{F}^{Z}_{2V}$	$+0.009$ -0.009	200 fb^{-1}	$+0.26$ -0.34
$\Delta\widetilde{F}^{Z}_{2A}$	$+0.052$ -0.052	100 fb^{-1}	$+0.35$ -0.35





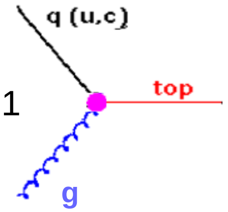
- LHC competitive with ILC for most t-t-γ couplings.
- A-priori precision t-t-Z couplings only possible at ILC.
- Caveat: multi-parameter fits will be required at the ILC to disentangle effects at t-t-γ and t-t-Z vertices (no realistic analysis available).

Top Couplings to Gauge Bosons: FCNC

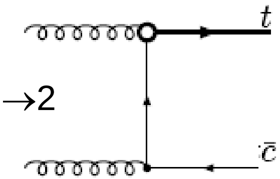
LHC

- tqg: via anomalous single top production

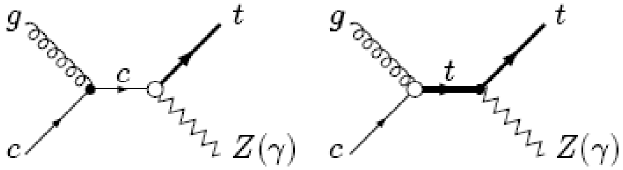
2→1



2→2

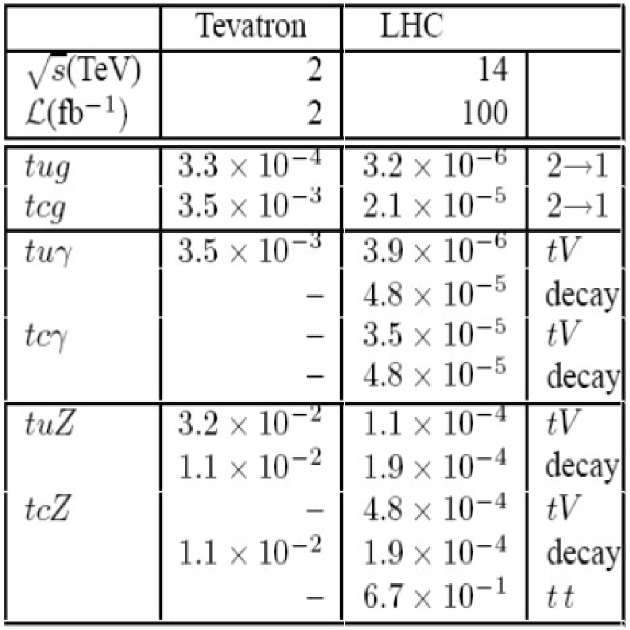


- tqγ/Z: via anomalous tV production and t →Vq in tt events.



Best 3σ discovery limits
(hep-ph/0003033)

95% upper limits
(ATL-PHYS-PUB-2005-009)

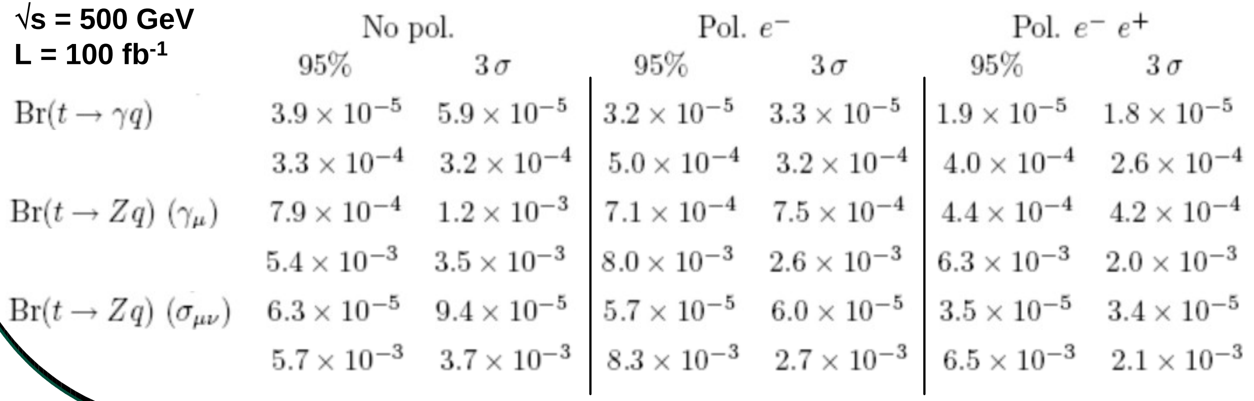


	Tevatron	LHC		95% upper limits
$\sqrt{s}$(TeV)	2	14		
$\mathcal{L}$(fb^{-1})	2	100		100
tug	3.3×10^{-4}	3.2×10^{-6}	2→1	4.3 x 10^{-4} (decay)
tcg	3.5×10^{-3}	2.1×10^{-5}	2→1	4.3 x 10^{-4} (decay)
$tu\gamma$	3.5×10^{-3}	3.9×10^{-6}	tV	
	–	4.8×10^{-5}	decay	1.8 x 10^{-5} (decay)
$tc\gamma$	–	3.5×10^{-5}	tV	
	–	4.8×10^{-5}	decay	1.8 x 10^{-5} (decay)
tuZ	3.2×10^{-2}	1.1×10^{-4}	tV	
	1.1×10^{-2}	1.9×10^{-4}	decay	6.5 x 10^{-5} (decay)
tcZ	–	4.8×10^{-4}	tV	
	1.1×10^{-2}	1.9×10^{-4}	decay	6.5 x 10^{-5} (decay)
	–	6.7×10^{-1}	$t\,t$	

ILC: both anomalous production (e^+e^-→tq) and decay (e^+e^- →tt; t→Vq) can be explored.

hep-ph/0102197

√s = 500 GeV
L = 100 fb^{-1}



	(P(e$^-$),P(e$^+$)) = (0,0) No pol.		(P(e$^-$),P(e$^+$)) = (-0.8,0) Pol. e^-		(P(e$^-$),P(e$^+$)) = (-0.8,+0.45) Pol. e^- e^+		
	95%	$3\,\sigma$	95%	$3\,\sigma$	95%	$3\,\sigma$	
$\mathrm{Br}(t \to \gamma q)$	3.9×10^{-5}	5.9×10^{-5}	3.2×10^{-5}	3.3×10^{-5}	1.9×10^{-5}	1.8×10^{-5}	tq
	3.3×10^{-4}	3.2×10^{-4}	5.0×10^{-4}	3.2×10^{-4}	4.0×10^{-4}	2.6×10^{-4}	decay
$\mathrm{Br}(t \to Zq)$ (γ_μ)	7.9×10^{-4}	1.2×10^{-3}	7.1×10^{-4}	7.5×10^{-4}	4.4×10^{-4}	4.2×10^{-4}	tq
	5.4×10^{-3}	3.5×10^{-3}	8.0×10^{-3}	2.6×10^{-3}	6.3×10^{-3}	2.0×10^{-3}	decay
$\mathrm{Br}(t \to Zq)$ $(\sigma_{\mu\nu})$	6.3×10^{-5}	9.4×10^{-5}	5.7×10^{-5}	6.0×10^{-5}	3.5×10^{-5}	3.4×10^{-5}	tq
	5.7×10^{-3}	3.7×10^{-3}	8.3×10^{-3}	2.7×10^{-3}	6.5×10^{-3}	2.1×10^{-3}	decay

- Sensitivity better from production than from decay since, despite the lower S/B, σ is larger.
- Beam polarization very useful to improve limits from production.
- γγ→tc would allow to study FCNC with higher σ (~x100) and lower SM bckg.

LHC/ILC complementarity