Physics potential of a linear collider in Higgs physics

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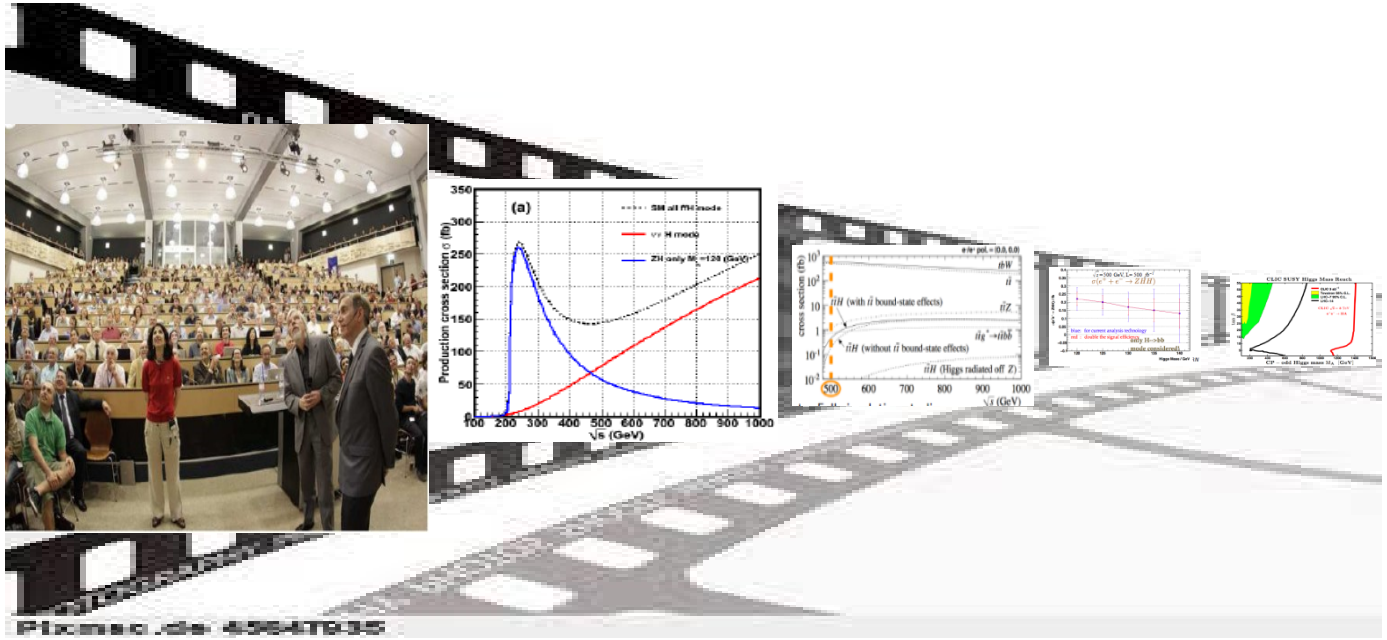


LINEAR COLLIDER COLLABORATION

What is the motivation?

- We have a Higgs! That's great.
- But does it really behave as Higgs/Brout/Englert want? Or are here hints for BSM?
- What are his talents and characters?
- Why is the Higgs so spectacular? Because that's the bridge between 'micro' and 'macro' cosmos.
- Which exp. set-ups are required to manifest its role?
- We have the LHC and the HL-LHC. That's great!
- Do we really also need the LC?

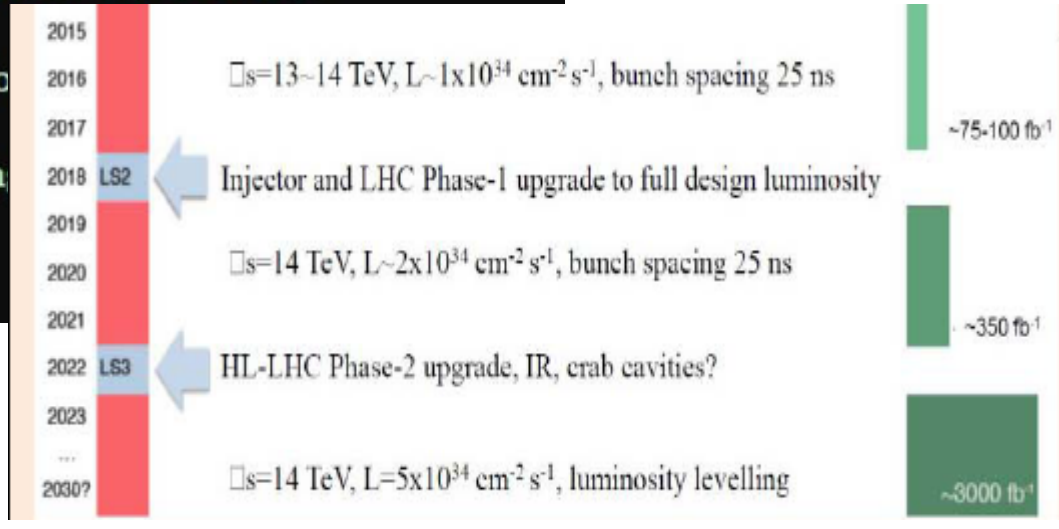
…a great chance might just be ahead….

Very encouraging politics!

Possible Timeline

- July 2013
  - Non-political evaluation of 2 Japanese candidate sites complete, followed by down-selecting to one
- End 2013
  - Japanese government announces its intent to bid
- 2013~2015
  - Inter-governmental negotiations
  - Completion of R&Ds, preparation for the ILC lab.
- ~2015
  - Inputs from LHC@14TeV, decisio
- 2015~16
  - Construction begins (incl. biddin
- 2026~27
  - Commissioning

LHC timeline



But is it justified by physics?

Preface

- **Discovery of a SM-like Higgs around m_H~125 GeV**
  - Is an absolute revolution!
  - Completely new type
  - Not clear whether a SM-Higgs

`The properties of the Higgs boson, to be discovered at the LHC, must be thoroughly investigated in a good condition at the ILC'
(K. Kawagoe, Feb 12)

- **In short -- some LC capabilities:**

As e.g. Δm_{top}~0.1 GeV, $coup_{tth}$~5%
H: BR's~ 1 (b)-7(c)% ,Γ_h~3%, $\Delta\lambda$~18%,
CP, mixed states

- **Very active: many new LC studies and reports….**
  - *ILC TDR (since June 12, 2013)*
  - *CLIC CDR 2012*
  - *Collection of LC notes (DESY123h) online*
  - *2 more LC reviews under work*

Focus of my talk
(in p. 1st article in Desy123h, 1210.0202)

The LC physics offer

- **A `staged' approach:**
  - **$\sqrt{s}$=250 GeV, `Higgs cross section, mass + couplings'**
  - **$\sqrt{s}$=350 GeV, `Higgs width + top mass'**
  - **$\sqrt{s}$=500 GeV, `Special Higgs- and top couplings+BSM'**
  - **($\sqrt{s}$=91 GeV, `Precision frontier + indirect BSM frontier')**
  - **$\sqrt{s}\geq$1000 GeV, `Closing the Higgs picture? '**
  - **High rates!**

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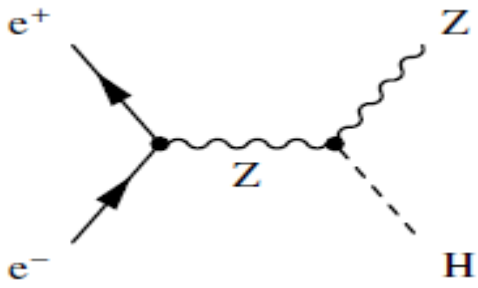
	250 GeV	350 GeV	500 GeV	1 TeV	1.5 TeV	3 TeV
$\sigma(e^+e^- \to ZH)$	240 fb	129 fb	57 fb	13 fb	6 fb	1 fb
$\sigma(e^+e^- \to H\nu_e\bar{\nu}_e)$	8 fb	30 fb	75 fb	210 fb	309 fb	484 fb
Int. $\mathcal{L}$	250 fb^{-1}	350 fb^{-1}	500 fb^{-1}	1000 fb^{-1}	1500 fb^{-1}	2000 fb^{-1}
# ZH events	60,000	45,500	28,500	13,000	7,500	2,000
# $H\nu_e\bar{\nu}_e$ events	2,000	10,500	37,500	210,000	460,000	970,000

- **Plus `new' features:**
  - **Precise energy, threshold scans, polarization, $\gamma\gamma$-option**

Higgs @ staged LC



- √s=250 GeV: dominant process
- Why crucial?
  - allows model-independent access!
  - Absolute measurement of Higgs cross section σ(HZ) and g_{HZZ}: crucial input for all further Higgs measurements !

$\sqrt{s}$	250 GeV
Int. $\mathcal{L}$	250 fb-1
$\Delta(\sigma)/\sigma$	2.5%
$\Delta(g_{HZZ})/g_{HZZ}$	1.3%

← Model independent!

  - Reconstructed recoil mass distributions (eeX, μμX): ΔmH=32 MeV
  - Model independent coupling measurement

- **$\sqrt{s}$=250 GeV: HZ production ~350 fb with (-.8,+0.3)**
  - **Determination of couplings to c, b,g,τ**

Δ(σ*BR)/(σ*BR)	250 GeV/250 fb^{-1} P = (-0.8,+0,3)	350 GeV/250 fb^{-1} P = (-0.8,+0,3)
H→bb	1.0%	1.0%
H→cc	6.9%	6.2%
H→gg	8.5%	7.3%
H->ττ	**4.2%**	

>factor 10 better than HL-LHC

LC unique

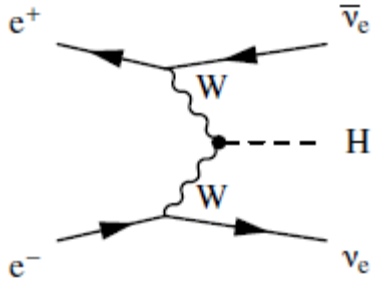
LC unique

[H.Ono, A: Miyamoto] EPJC (2013) 73

- **Scaling factor: $\sigma_{pol}/\sigma_{unpol} \sim (1-0.151\ P_{eff}) * L_{eff}/L$**
- **LC: unique sensitivity to invisible decay modes**
  - **Extending down to BR(inv) as low as 1% !**
- **Threshold scan:**
  - **Access to spin and CP-quantum numbers: O+, O- (*see talk K. Krueger)***
- **Estimate: about 3 years running time needed on $\sqrt{s}$=250 GeV**

Higgs width

- √s=350 GeV: Further improvement in Higgs couplings (see TDR)
- Access to Higgs total width :
  - Total width for mH=125 GeV: T_h^{tot} ~4 MeV!
  - Does need WW-fusion



	$\Delta T_h^{tot}/T_h^{tot}$
250 GeV:	13%
350 GeV:	~7%
500 GeV:	~5-6%
1 TeV:	~ 4%

Scaling factor:

$\sigma_{pol}/\sigma_{unpol} \sim (1 - P_{eff}) * L_{eff}/L$

- Higgs width crucial for absolute BR's, couplings and model discrimination!

Higgs CP-state

- A priori: observed Higgs can be mixed CP-even/odd
- HVV SM-coupling: only sensitive to CP-even states
  - CP-odd admixtures enters only at loop-level
  - Same problem for LHC as for LC
- At $\sqrt{s}$=350 GeV: use angular distributions, involving fermion coupling:

$$\Delta\mathcal{L} = -\frac{m_\tau}{v} h \bar{\tau}(\cos\alpha + i \sin\alpha \gamma^5)\tau$$

  - Construct CP-odd observable
- Exploit τ-decays: s-ps mixing-angle up to 6^0
- At $\sqrt{s}$=500: threshold of ttH also unqiue for CP-mixing

Top Yukawa coupling

- √s=500 GeV: top-Yukawa couplings:
  - At this energy: ttH is close to threshold
  - But thanks to threshold effects: σ enhancement by factor 2!
  - Key role in dynamics of ew symmetry-breaking
  - Yukawa couplings: g_{ttH}

E_{CM} = 500 GeV, L= 1 ab^{-1}, Pol= (-0.8,+ 0.3)

	500 GeV/ 1 ab^{-1}	1000 GeV/ 2 ab^{-1}
$\Delta g_{ttH}/g_{ttH}$	10%	4.6%

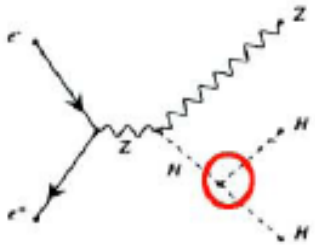
R. Yonamine, T. Tanabe, K. Fujii

LHC estimates: about Δg_{ttH}~10% at HL-LHC (14 TeV, 3000fb^{-1})

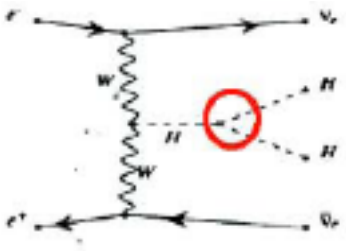
- √s=1000 GeV: beats HL-LHC result by factor 2!

√s=500GeV: Trilinear Higgs couplings

- **Very important for establishing Higgs mechanism!**
  - **LHC estimates:**
    - **about $\Delta\lambda_{HHH}$~32% at HL-LHC (14 TeV, 3000fb^{-1})**
  - **At LC: Very challenging (small rates , lots of dilution+backg.)**



dλ/λ = 1.8 dσ/σ



dλ/λ = 0.85 dσ/σ

500 GeV 2 ab^{-1} P=(-0,8,0,3)

	Δλ/λ
ILC 500/2ab^{-1}	44%
ILC 1000/2ab^{-1}	18%

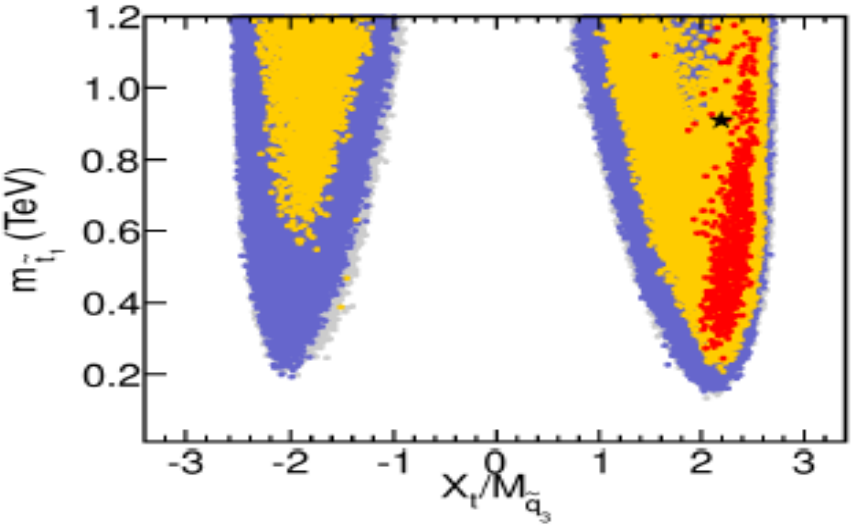
[J.Tian LC-REP-2013-003]

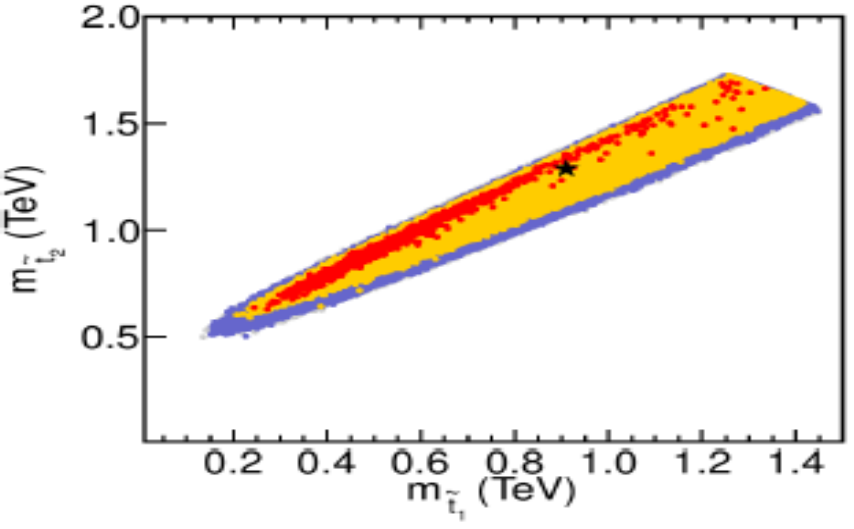
state-of-the-art today

  - **Further improvement with P_{e+}=55% instead of P_{e+}=30%:**
    - **Same scaling factors as given before**
    - **about 50% enhancement comp. to P_{e+}=0%**

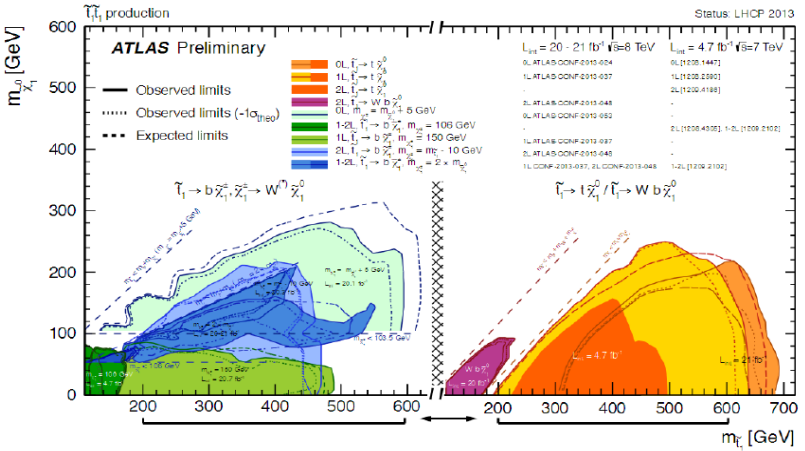
MSSM interpretation of light Higgs

- **Preferred values for stop masses from fits :**
  - **m_H no free parameter any more: $\Delta m^2_H \sim m^4_{top}$**





- **$M_h \sim 125$ GeV requires large stop mixing ~ large X_t**
  - **Rather large $X_t = A_t - \mu \cot \beta$**
- **But $m_{\tilde{t}}$ can still be light !**

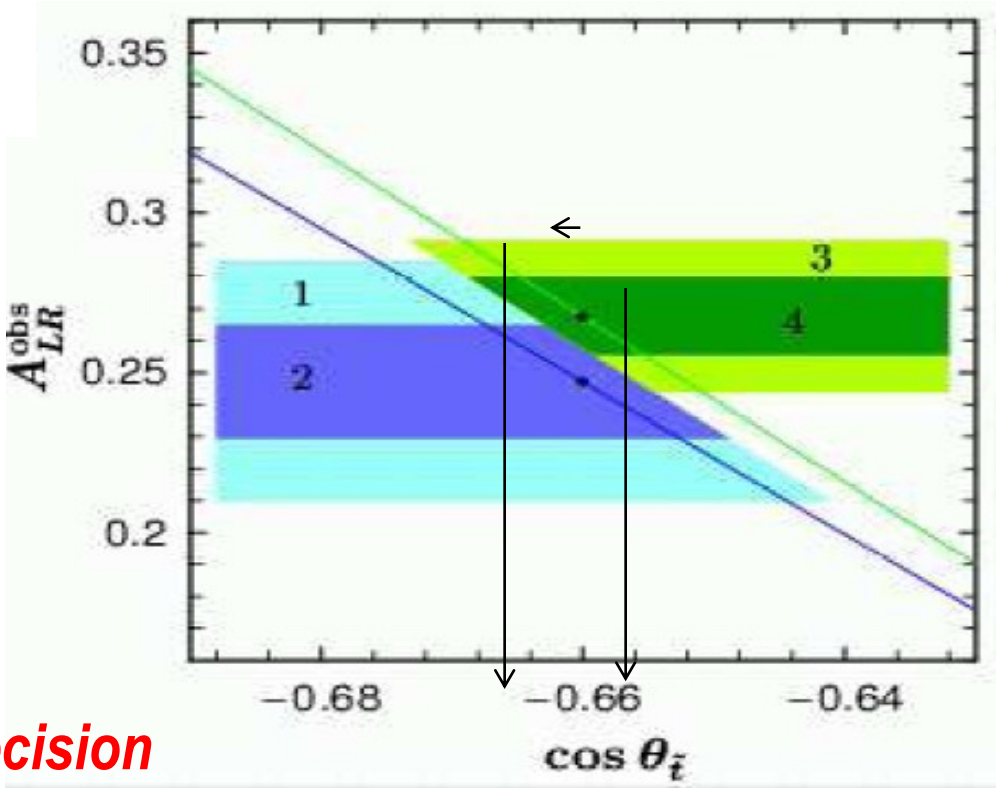


Start with stops: features at a LC

- **With polarized beams: A_{LR} applicable**

Eberl, Kraml,'05

$\mathcal{L}_{\rm int}$	P_{e^-}	P_{e^+}	$\Delta m_{\tilde{t}_1}$	$\Delta\cos\theta_{\tilde{t}}$
100 fb^{-1}	$\mp$0.9	0	1.1%	2.3%
500 fb^{-1}	$\mp$0.9	0	0.5%	1.1%
100 fb^{-1}	$\mp$0.9	$\pm$0.6	0.8%	1.4%
500 fb^{-1}	$\mp$0.9	$\pm$0.6	0.4%	0.7%



- **Mixing angle $\Delta\cos\theta_t$<1%**
  - **If ΔX_t±1%: Δm_h=±0.2GeV**

⟶ *matches long-term LHC precision*

  - **If ΔX_t±10%: Δm_h=±1.5GeV**

⟶ *Too big to check the consistency of the model!*

Conclusions

- **Rich phenomenology of 'Higgs@LC'** ***(often exceeding LHC)***
  - **Model-independent couplings, absolute BR's, cross section…**
  - **Staged energy approach allows to choose the suitable energy**

    As e.g. Δm_{top}~0.1 GeV, $coup_{tth}$~5%
    H: BR's~ 1 (b)-7(c)% ,Γ_h~3%, $\Delta\lambda$~18%,
    CP, mixed states
  - **flexible and still improvement potential: beam pol., tunable $\sqrt{s}$**
- **LC precision allows to reveal the Higgs secrets!**
- **Further undiscussed options(because of time):**
  - **Extended Higgs sector (heavy +light Higgs, NMSSM,….)**

    E.g. NMSSM could have mh<LEP-limit
  - **Further option: $\gamma\gamma$-option at high energy**

    beneficial for heavy Higgs and unique also for CP-couplings