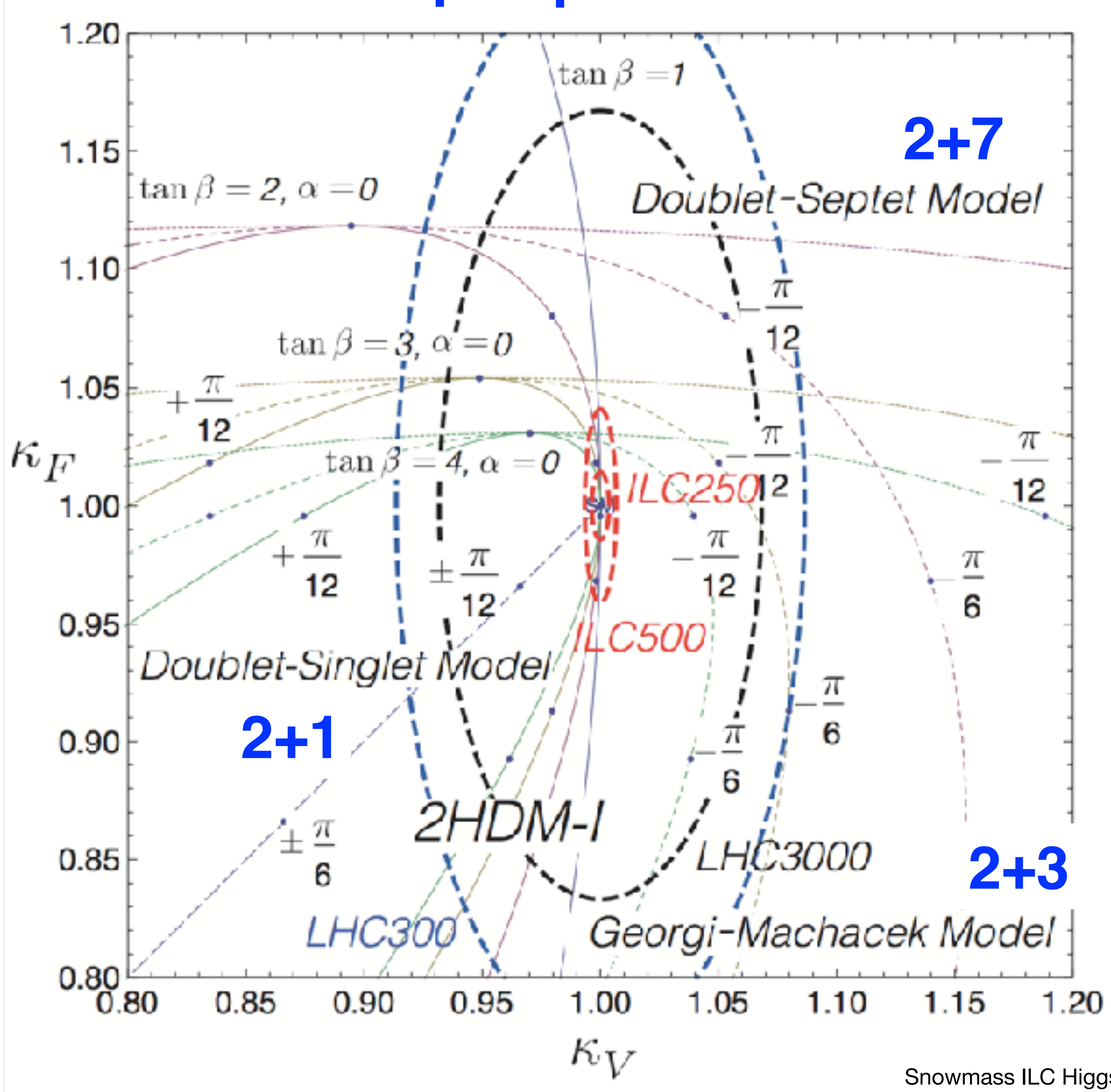
Multiplet Structure

Other ρ=1 possibilities



Snowmass ILC Higgs White Paper (arXiv: 1310.0763)

Kanemura et al (arXiv: 1406.3294)

Figure 1.18. The scaling factors in models with universal Yukawa coupling constants.

arXiv 1502.03959

Footprints of Supersymmetry on Higgs Decay

Motoi Endo[(a,b)], Takeo Moroi[(a,b)], and Mihoko M. Nojiri[(b,c,d)]

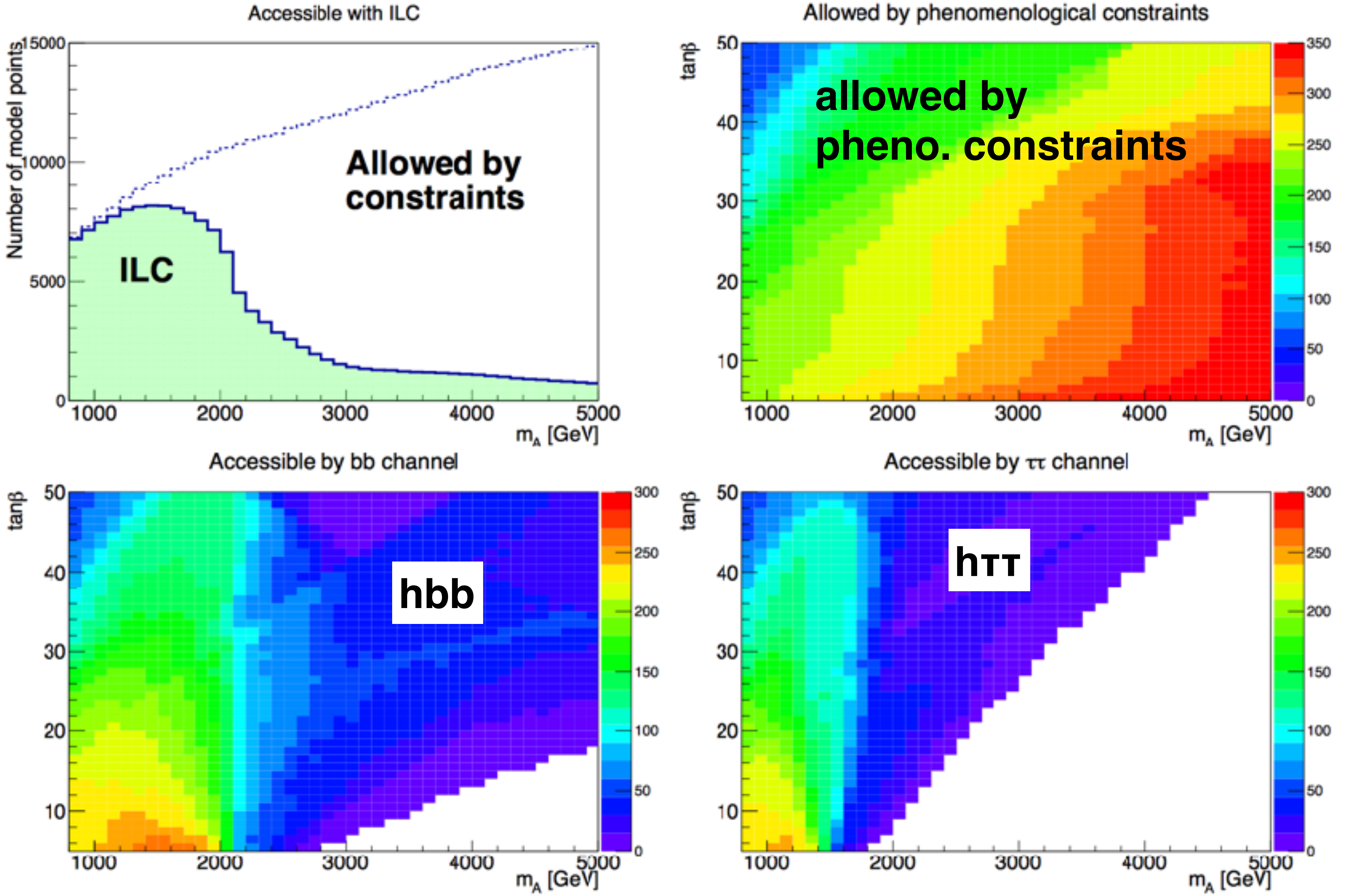


Figure 8: Upper-left: The number of model points accessible with ILC by at least one decay mode of h as a function of m_A (green histogram), as well as that of model points allowed by the phenomenological constraints (dotted histogram). Upper-right: The number of model points allowed by the phenomenological constraints on m_A vs. $\tan\beta$ plane. Lower-left: The number of model points accessible with ILC by $h \to \bar{b}b$. Lower-right: The number of model points accessible with ILC by $h \to \bar{\tau}\tau$.

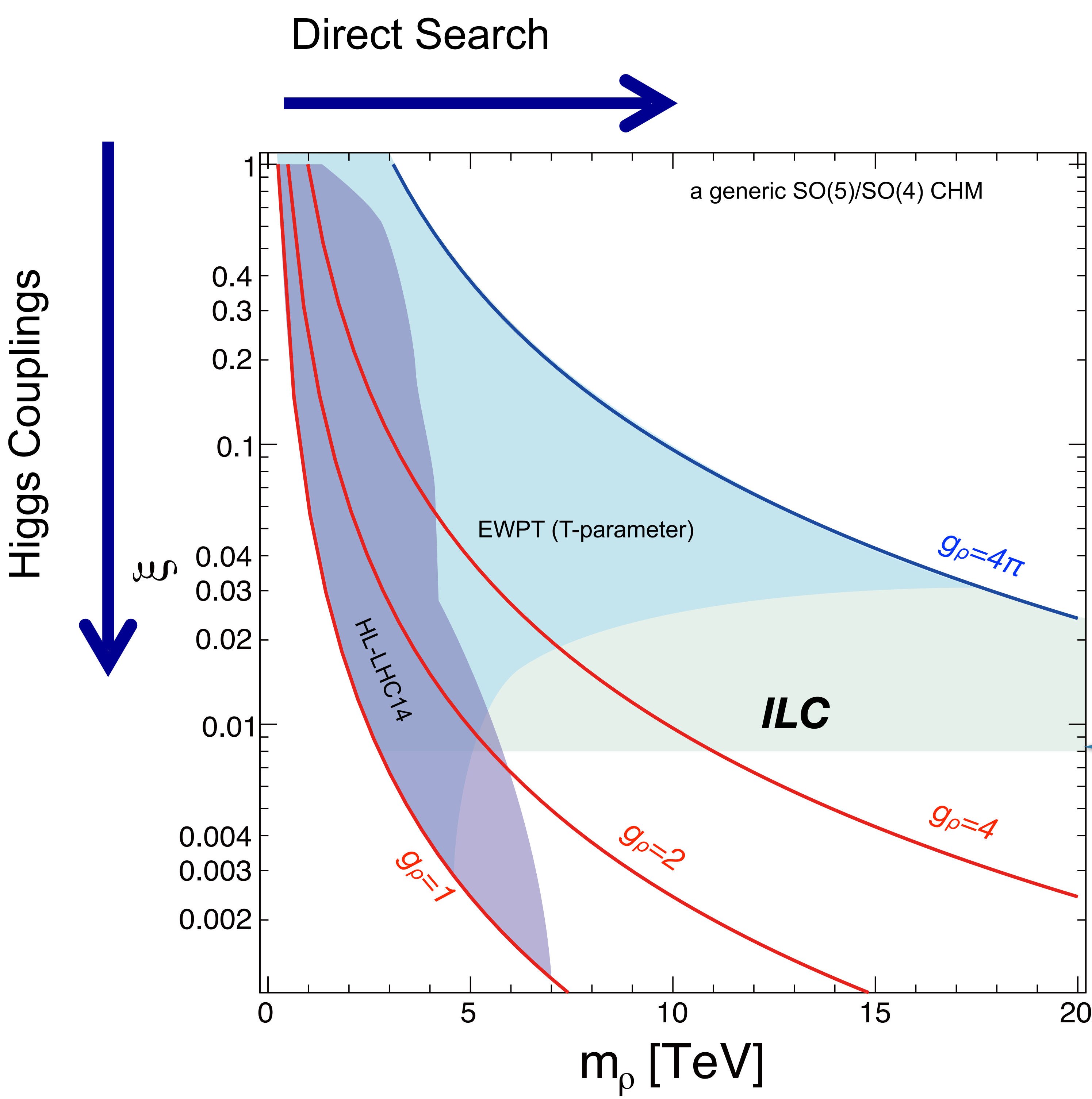
Composite Higgs: Reach

Complementary approaches to probe composite Higgs models

- Direct search for heavy resonances at the LHC
- Indirect search via Higgs couplings at the ILC

Comparison depends on the coupling strength (g_*)

Based on Contino, et al, JHEP 1402 (2014) 006
Torre, Thamm, Wulzer 2014
Grojean @ LCWS 2014



$$\xi = \frac{g_\rho^2}{m_\rho^2} v^2 = \frac{v^2}{f^2}$$

$$\frac{g_{hVV}}{g_{h_{\rm SM}VV}} = \sqrt{1-\xi}$$

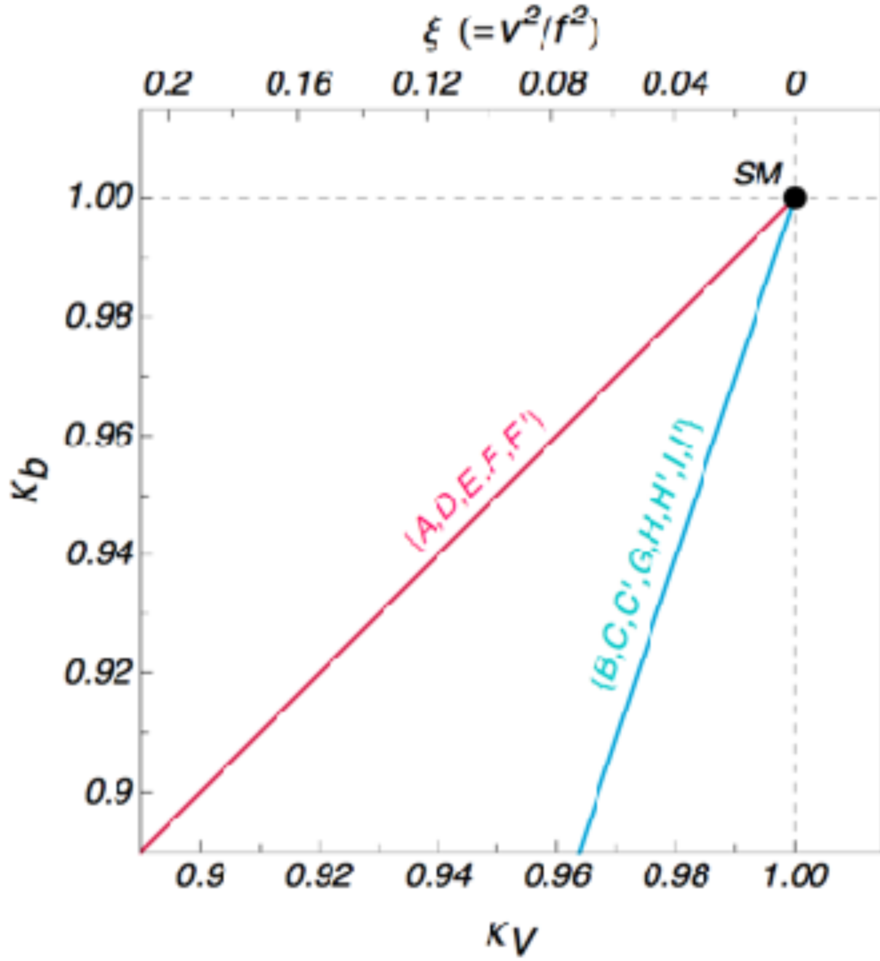
ILC (250+500 LumiUP)

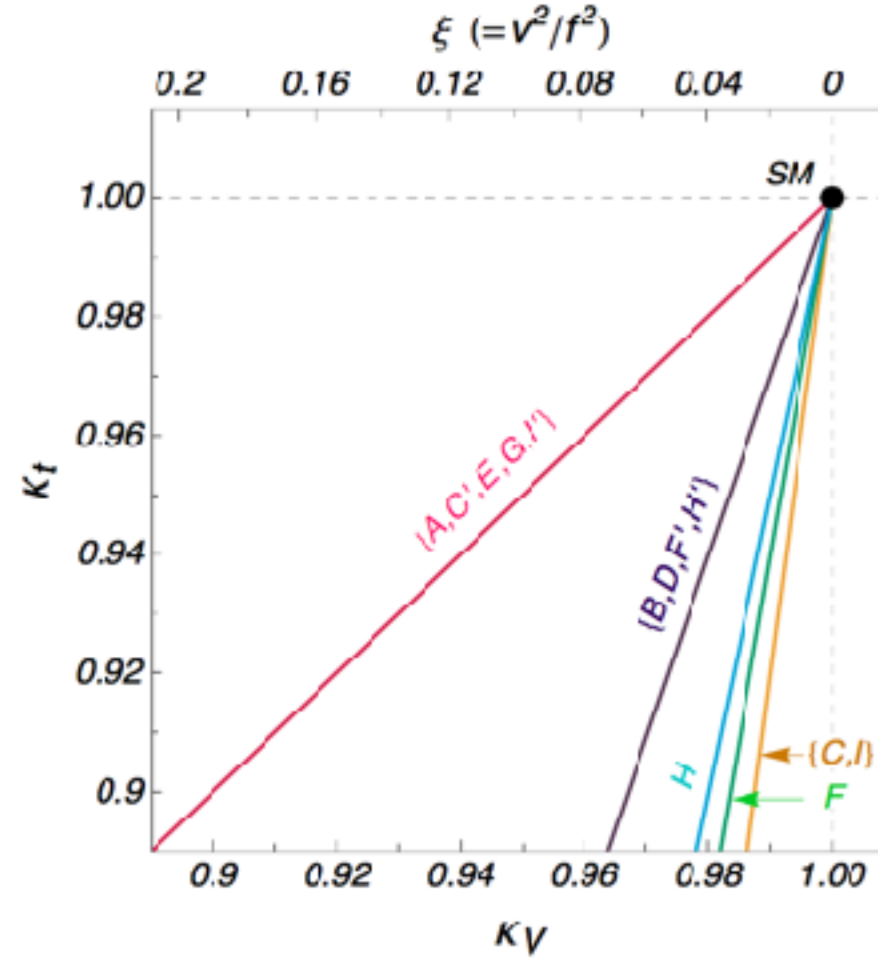
$$\Delta \frac{g_{hVV}}{g_{hVV}} = 0.4\%$$

New resonance scale and fingerprint identification in minimal composite Higgs models

Shinya Kanemura,[1] Kunio Kaneta,[2] Naoki Machida,[1] and Tetsuo Shindou[3]

arXiv 1410.8413





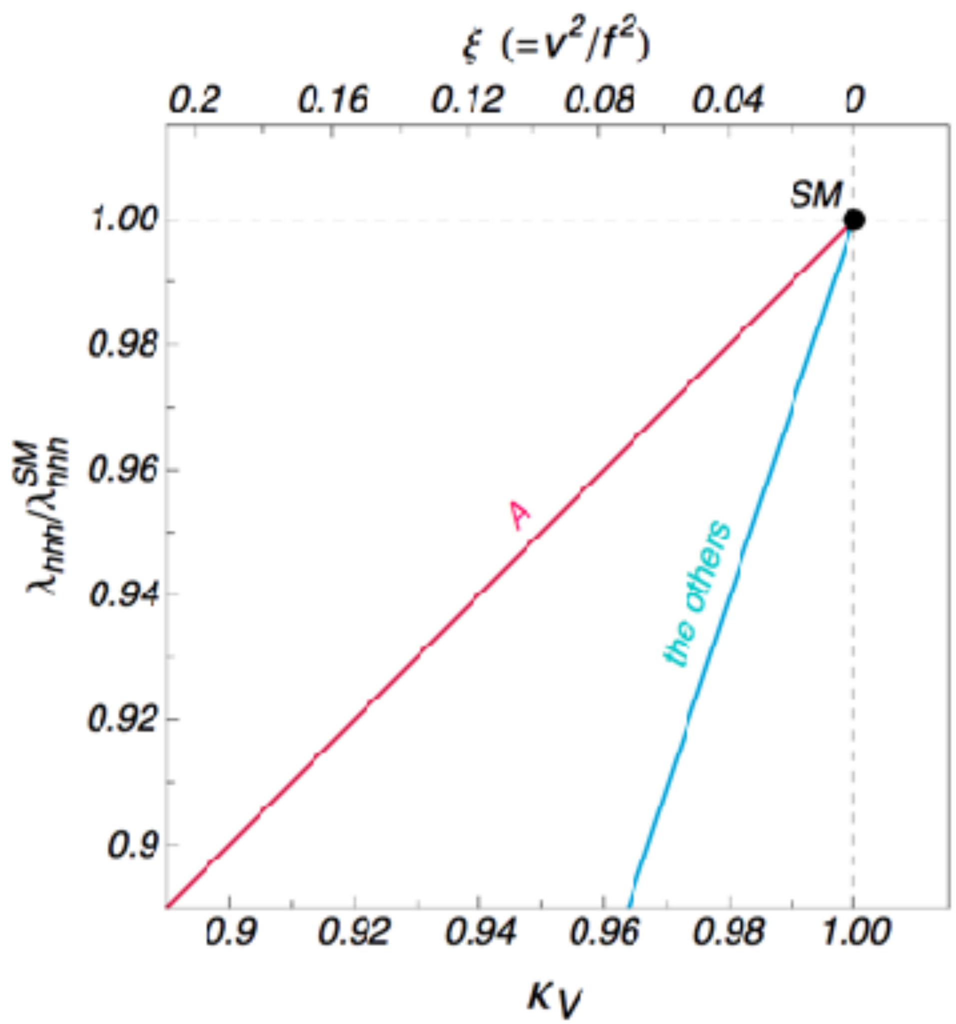


TABLE I: Scale factors for MCHMs with various matter representations. The labels are used in Fig. 7, where C, H and I are the case of $M_1^t \to 0$, and C', H' and I' are the case of $M_2^t \to 0$.

Label	Model	κ_V	c_{hhVV}	κ_{hhh}	c_{hhhh}	κ_t	κ_b	c_{hhtt}	c_{hhbb}
A	$MCHM_4$	$\sqrt{1-\xi}$	$1-2\xi$	$\sqrt{1-\xi}$	$1-\frac{7}{3}\xi$	$\sqrt{1-\xi}$	$\sqrt{1-\xi}$	$-\xi$	$-\xi$
B	$MCHM_5$	$\sqrt{1-\xi}$	$1-2\xi$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-28\xi/3+28\xi^2/3}{1-\xi}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	-4ξ	-4ξ
B	$MCHM_{10}$	$\sqrt{1-\xi}$	$1-2\xi$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-28\xi/3+28\xi^2/3}{1-\xi}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	-4ξ	-4ξ
C, C'	$MCHM_{14}$	$\sqrt{1-\xi}$	$1-2\xi$	H_1	H_2	F_3	$\frac{1-2\xi}{\sqrt{1-\xi}}$	F_6	-4ξ
D	$MCHM_{5\text{-}5\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-28\xi/3+28\xi^2/3}{1-\xi}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\sqrt{1-\xi}$	-4ξ	$-\xi$
E	$MCHM_{5\text{-}10\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-28\xi/3+28\xi^2/3}{1-\xi}$	$\sqrt{1-\xi}$	$\sqrt{1-\xi}$	$-\xi$	$-\xi$
F, F'	$MCHM_{5\text{-}14\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	H_1	H_2	F_5	$\sqrt{1-\xi}$	F_8	$-\xi$
G	$MCHM_{10\text{-}5\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-28\xi/3+28\xi^2/3}{1-\xi}$	$\sqrt{1-\xi}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$-\xi$	-4ξ
B	$MCHM_{10\text{-}14\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	H_1	H_2	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	-4ξ	-4ξ
B	$MCHM_{14\text{-}1\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-28\xi/3+28\xi^2/3}{1-\xi}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	-4ξ	-4ξ
H, H'	$MCHM_{14\text{-}5\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	H_1	H_2	F_4	$\frac{1-2\xi}{\sqrt{1-\xi}}$	F_7	-4ξ
B	$MCHM_{14\text{-}10\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	H_1	H_2	$\frac{1-2\xi}{\sqrt{1-\xi}}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$	-4ξ	-4ξ
I, I'	$MCHM_{14\text{-}14\text{-}10}$	$\sqrt{1-\xi}$	$1-2\xi$	H_1	H_2	F_3	$\frac{1-2\xi}{\sqrt{1-\xi}}$	F_8	-4ξ

Composite Higgs: Reach

σ_{Zh} in EFT → Composite Scale

The size comes from the scale of an EFT operator:

$$\mathcal{L} \supset \left(\frac{c_H}{\Lambda^2}\right)\frac{1}{2}\left(\partial_\mu |H|^2\right)^2$$

$$\to \left(\frac{2C_H v^2}{\Lambda^2}\right)\frac{1}{2}\left(\partial_\mu h\right)^2$$

250GeV

ILC direct Zh

(Yan et al. 1604.07524)

$\sqrt{s}$	250 GeV		350 GeV		500 GeV	
	$\int \mathcal{L}dt$	$\Delta\sigma_{ZH}/\sigma_{ZH}$	$\int \mathcal{L}dt$	$\Delta\sigma_{ZH}/\sigma_{ZH}$	$\int \mathcal{L}dt$	$\Delta\sigma_{ZH}/\sigma_{ZH}$
$e^-_L e^+_R$	1350 fb^{-1}	1.1%	115 fb^{-1}	5.0%	1600 fb^{-1}	2.9%
$e^-_R e^+_L$	450 fb^{-1}	2.2%	45 fb^{-1}	9.8%	1600 fb^{-1}	3.1%

My naive ILC combo: $\delta\sigma_{Zh}/\sigma_{Zh}$=0.88%

$$c_H \frac{v^2}{\Lambda^2} < 0.0044$$

$\Lambda > 2.6$ TeV ($c_H = 1$)

"r_H< 0.076 am"

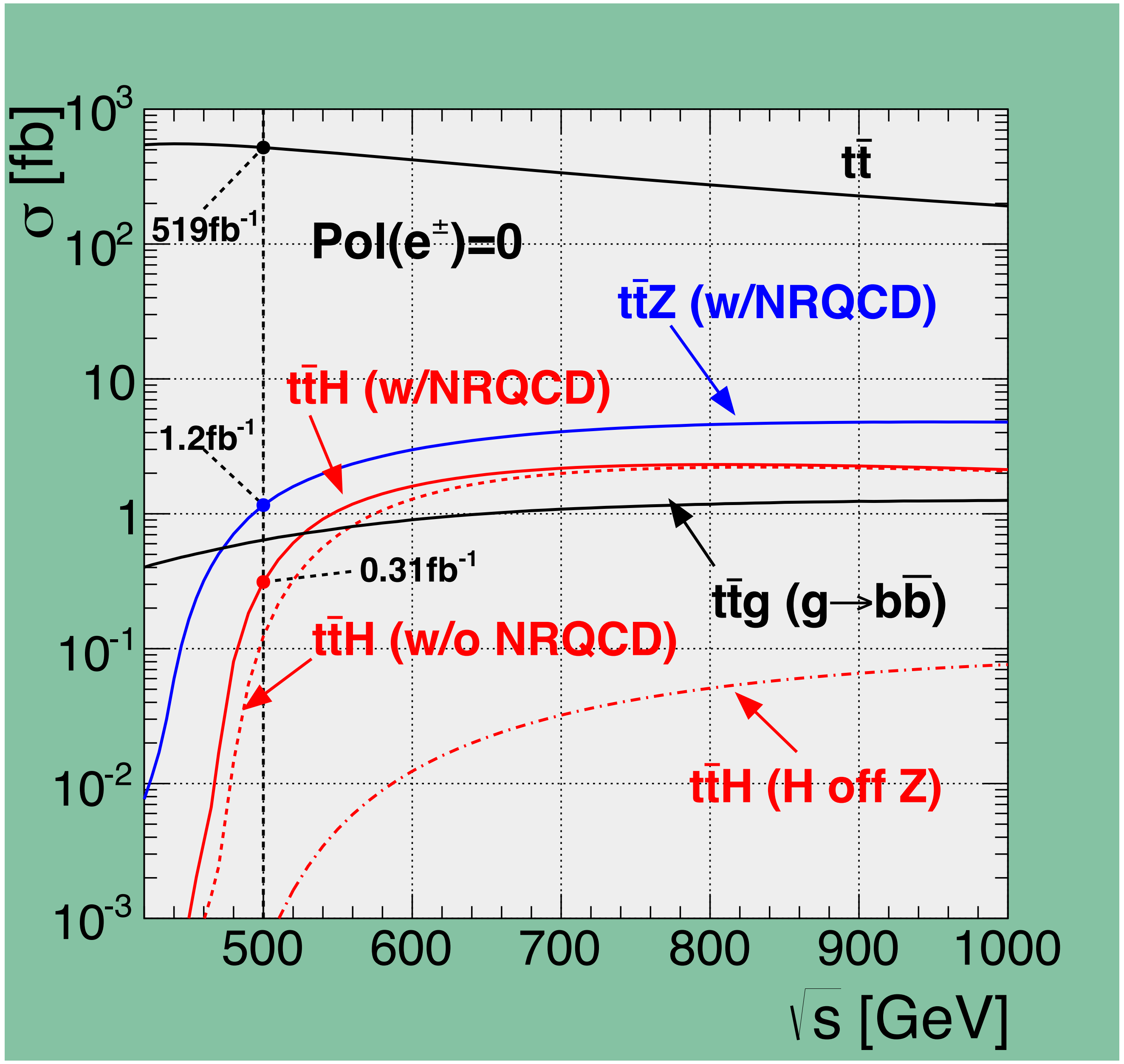
This ***requires the absolute value, not ratio***.

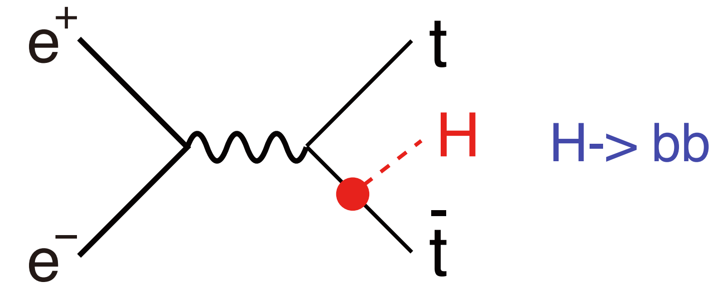
→ **recoil mass technique essential** → e^+e^- colliders.

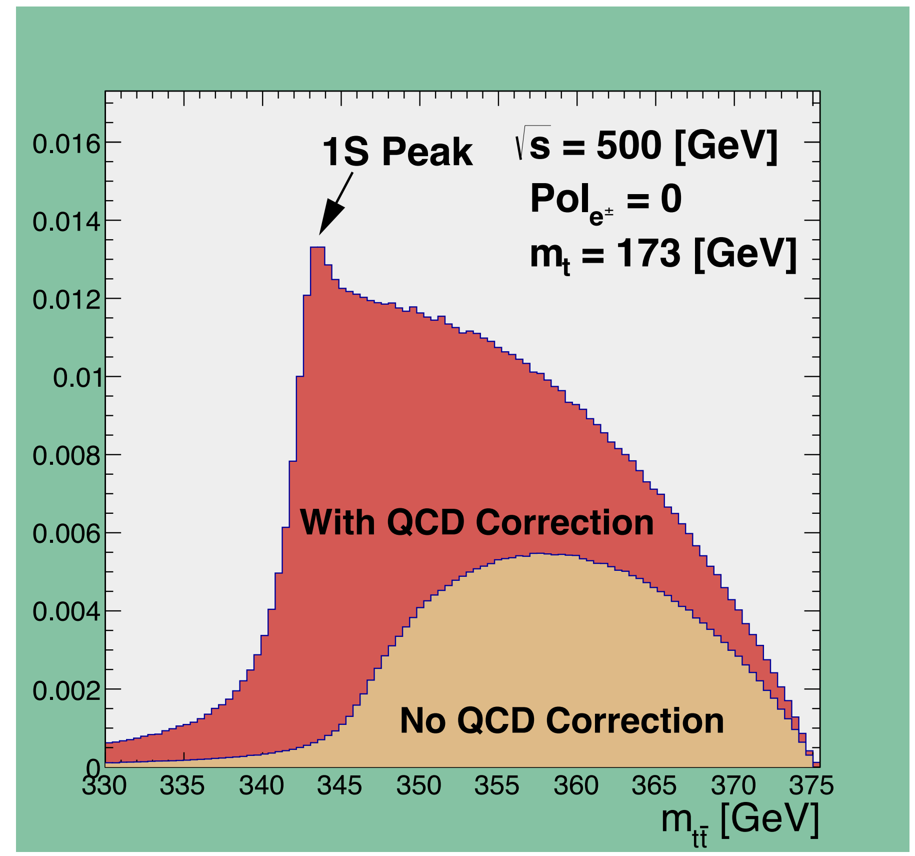
N. Craig, LCWS16 in Morioka

Top Yukawa Coupling

The largest among matter fermions, but not yet directly observed







A factor of 2 enhancement from QCD bound-state effects

Cross section maximum at around Ecm = 800GeV

Philipp Roloff, LCWS12

Tony Price, LCWS12

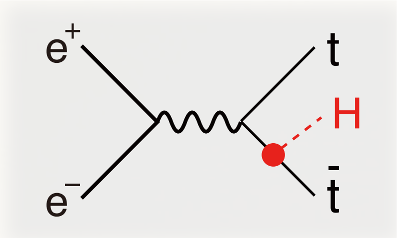
DBD Full Simulation

$$1\,\mathrm{ab}^{-1}@500\,\mathrm{GeV} \qquad m_H = 125\,\mathrm{GeV}$$

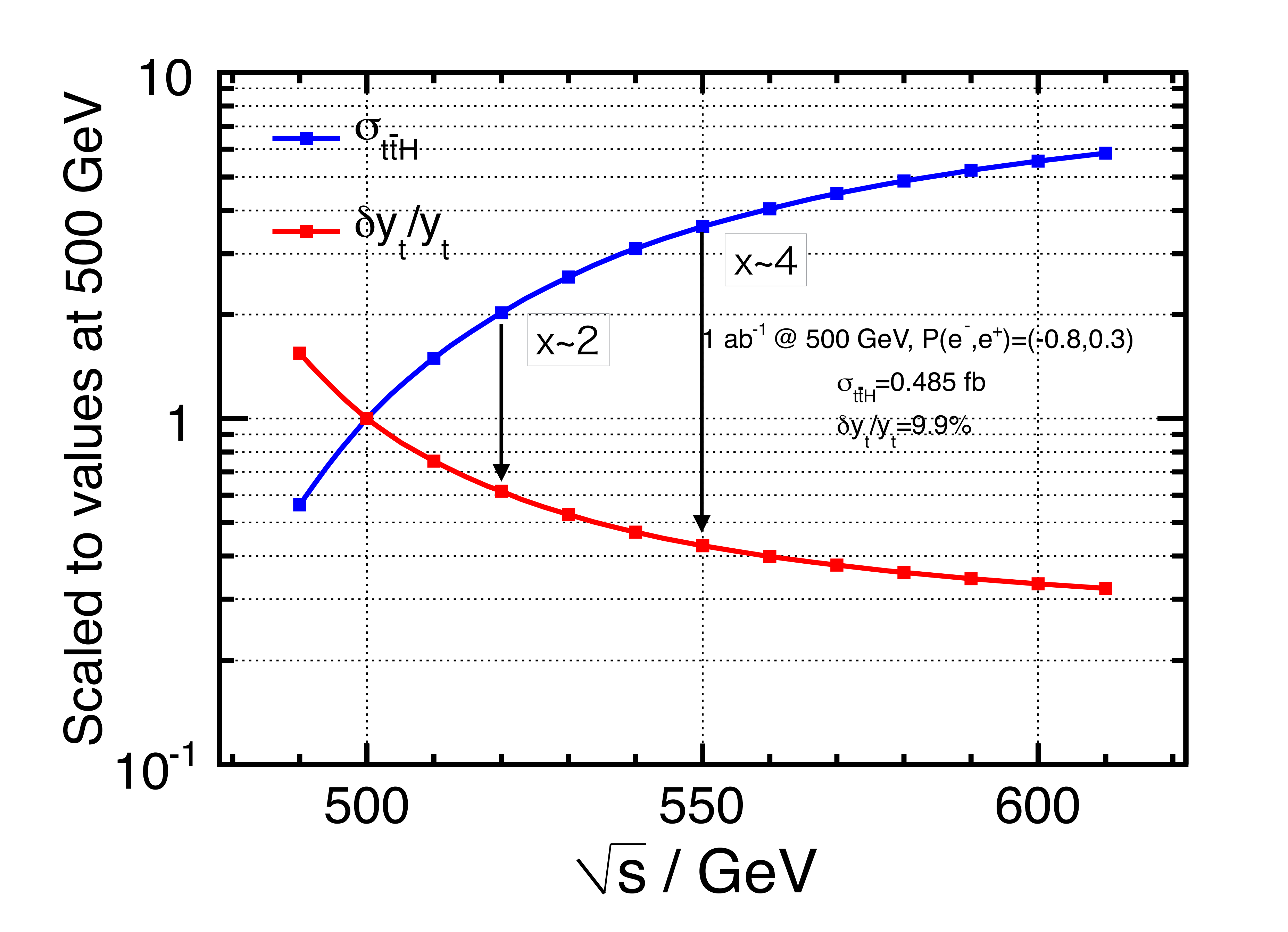
$$\Delta g_Y(t)/g_Y(t) = 9.9\%$$

Tony Price, LCWS12 scaled from mH=120 GeV

Notice σ(500+20GeV)/σ(500GeV) ~ 2
Moving up a little bit helps significantly!



Top Yukawa coupling



Y. Sudo

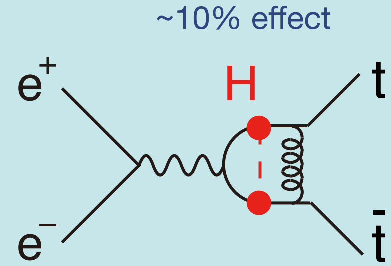
Slight increase of E_{max} is very beneficial!

Areas of Current Activities

Key quantities: mt, tth and ttZ couplings

Top at Threshold

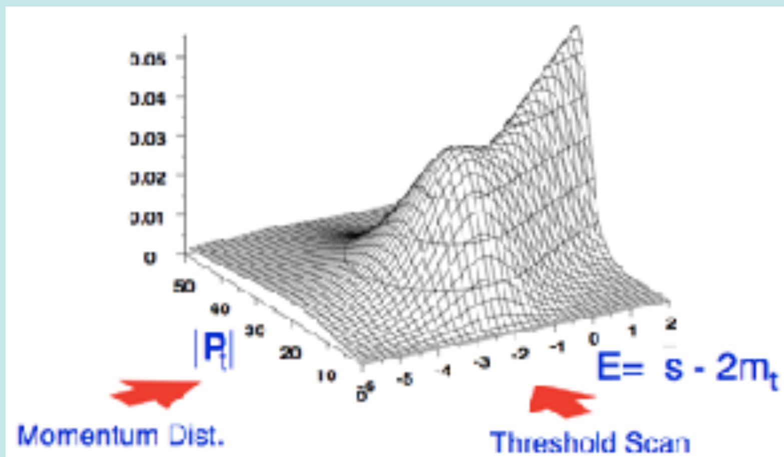
$m_t = g_{tth}\, v$



tth

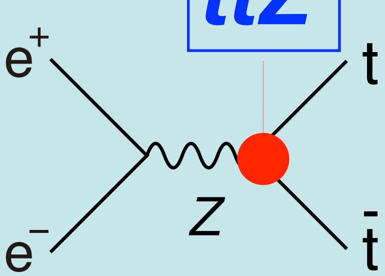
The top mass is crucial to decide the fate of the SM vacuum!

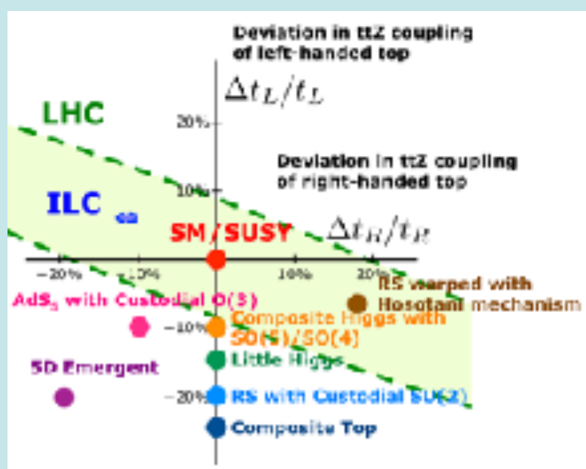
Strong team of QCD experts in Japan



Open Top Region

ttZ





Strong analysis team of both theorists and experimentalists in France.

GRACE *Sizable EW 1-loop effects!*

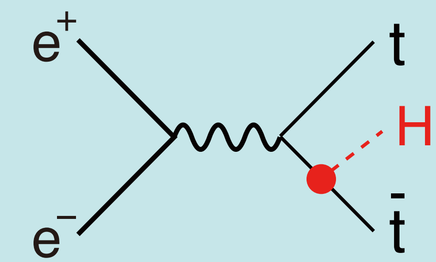
Higher order EW correction essential for BSM detection !

GRACE experts in Japanese Team!

Open Top Region

tth

Japanese analysis team working on the tth coupling



Development of Analysis Techniques

Matrix Element Method

$$e^+e^- \to t\bar{t} \to \mu^+\mu^- b\bar{b}\nu_\mu\bar{\nu}_\mu$$

$$|\mathcal{M}|^2$$

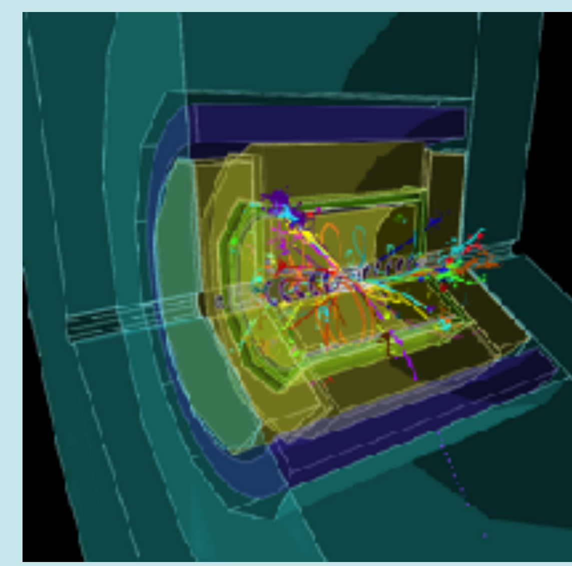
Full reconstruction of 2L+2b final states
→ full exploitation of available information

Expert in Matrix Element Method in French team

b-tagging and b-charge ID

Final state reconstruction uses all detector aspects

Proper top charge ID is essential, for which b-charge ID is very powerful if realized



In all of these analyses b-tagging and b-charge measurement essential !

Analysis experts in France

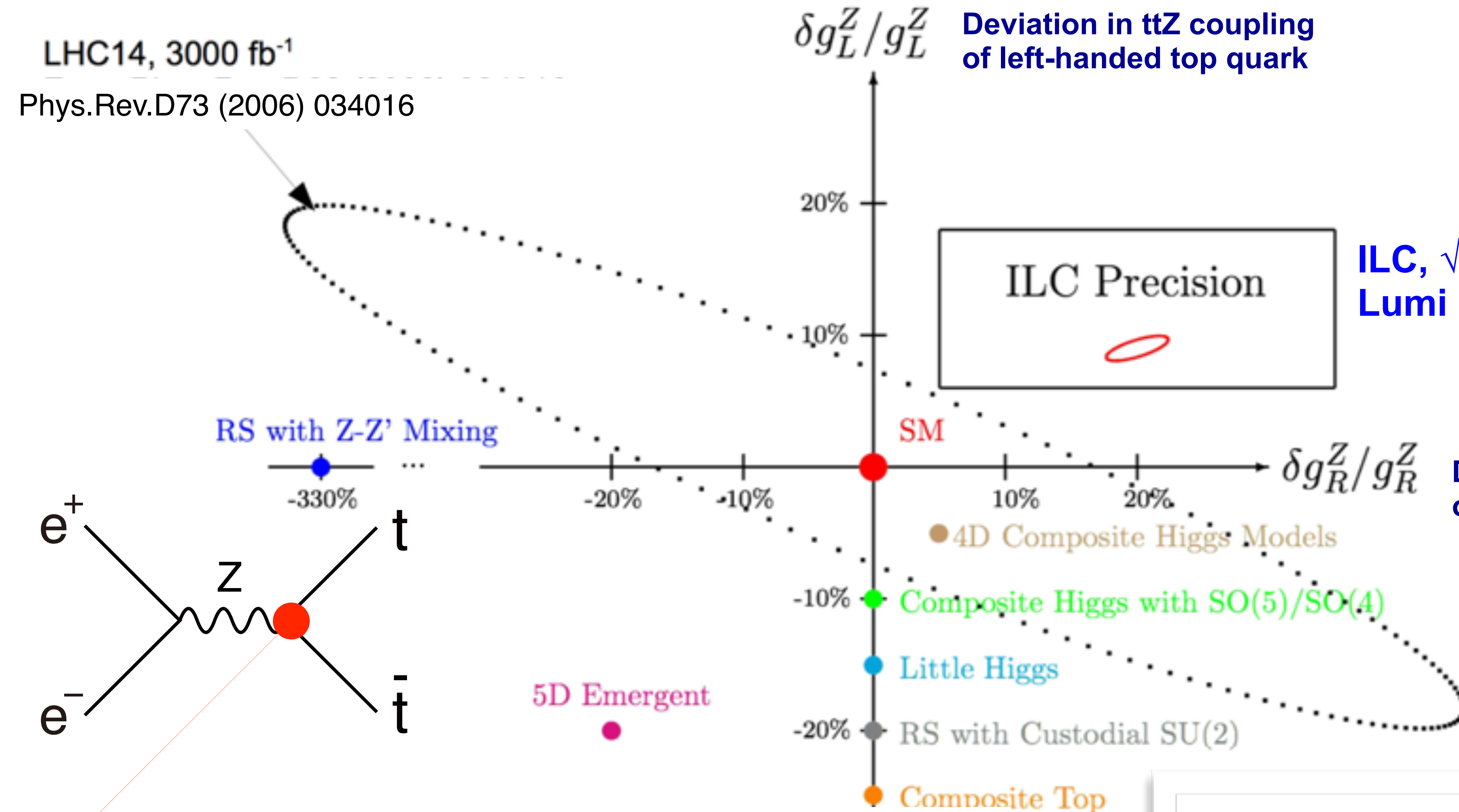
Experts of flavor tagging (LCFIPlus) in Japan

Search for Anomalous tZZ Couplings

Top: **Heaviest in SM**→Must couple **strongly to the EWSB sector (source of $\mu^2<0$)!**

→ ***Specific deviation pattern*** *expected in* ***ttZ form factors*** *depending on new physics.*

→ ***Beam polarization essential* to separate L- and R-couplings (Strength of ILC)**



Deviation in ttZ coupling of left-handed top quark

ILC, $\sqrt{s}$ = 500 GeV
Lumi = 500 fb^{-1}

Deviation in ttZ coupling of right-handed top quark

$$\Gamma_\mu^{ttX}(k^2, q, \bar{q}) = ie\left\{\gamma_\mu\left(\tilde{F}_{1V}^X(k^2) + \gamma_5 \tilde{F}_{1A}^X(k^2)\right) + \frac{(q-\bar{q})_\mu}{2m_t}\left(\tilde{F}_{2V}^X(k^2) + \gamma_5 \tilde{F}_{2A}^X(k^2)\right)\right\}$$

ILC is sensitive to ***M_{KK} up to ~25TeV*** for typical RS scenarios (even up to ~80 TeV in extreme cases)!

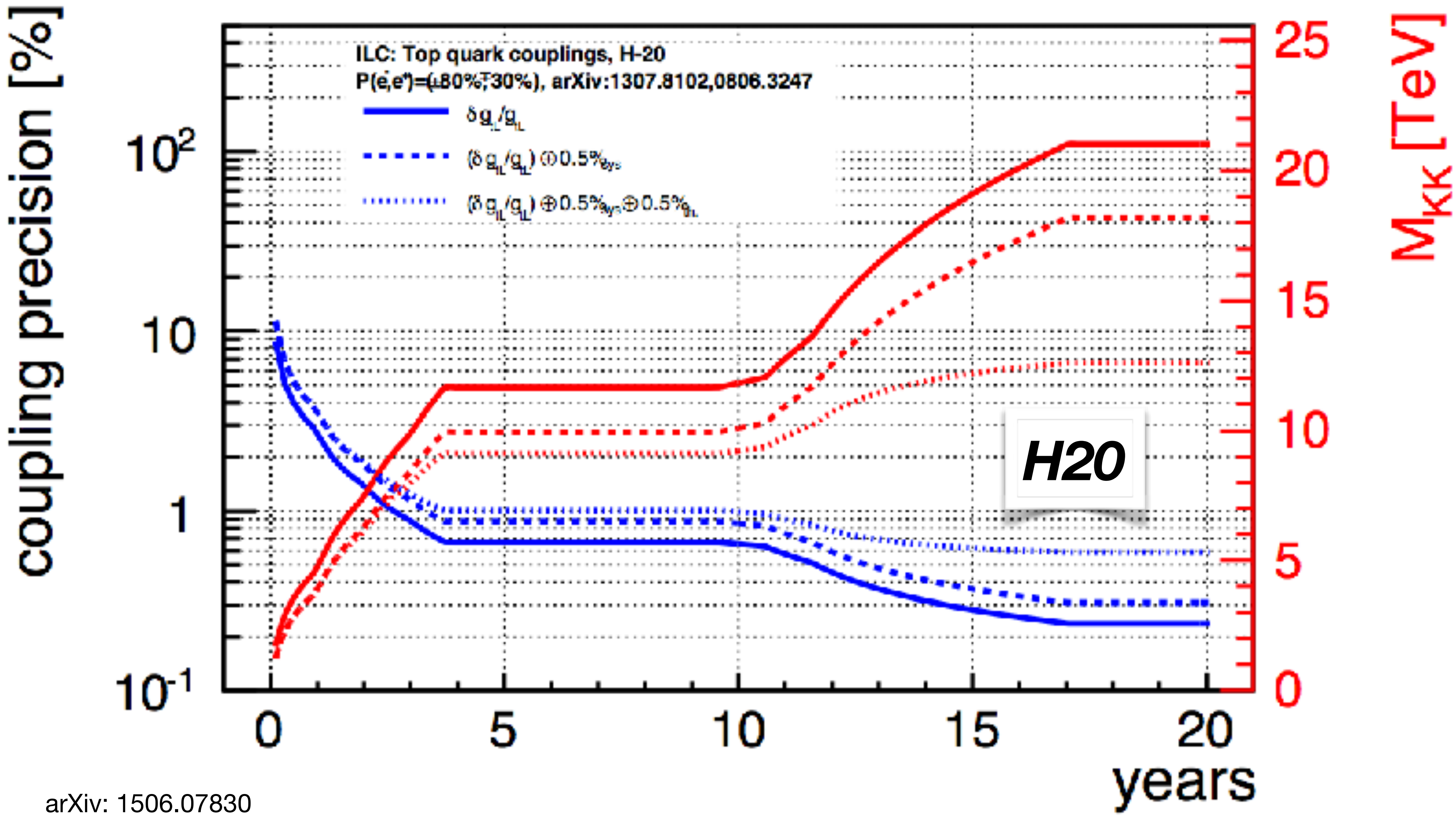
Deviation expected for various new physics models (new physics scale ~1 TeV)
arXiv:1505.06020

3rd Effect: ***Modifications of the EW couplings of top***

Large overlap of t_R wave function with the Higgs (to explain $m_t >> m_q$)

→ partial compositeness of the top quark

→ ***shifts in ttZ couplings (with different size for t_L and t_R)***



arXiv: 1506.07830

→ ILC H20 would be ***sensitive to even a 20 TeV KK W/Z bosons***

250 GeV is below ttbar threshold, so at the initial stage, we need to use something else.
→Use bbar instead
→arXiv: 1709.04289

arXiv: 1709.04289

Measurement of b quark EW couplings at ILC

S. Bilokin, R. Pöschl and F. Richard.

Laboratoire de l'Accélérateur Linéaire (LAL), Centre Scientifique d'Orsay, Université Paris-Sud XI, BP 34, Bâtiment 200, F-91898 Orsay CEDEX, France

ILD full simulation

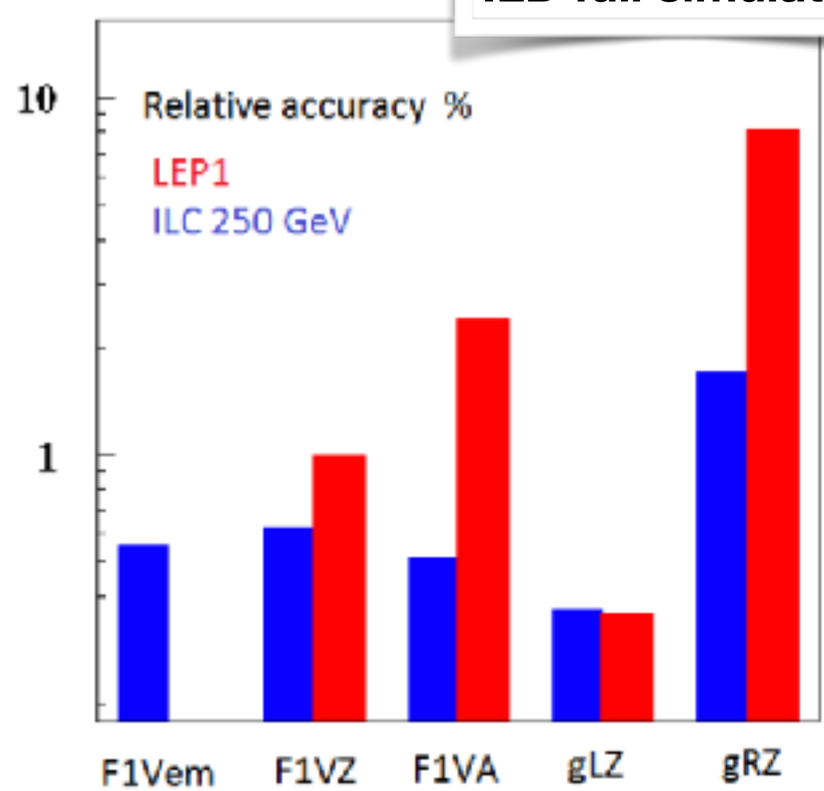


Figure 6: Comparison of relative accuracies achieved at LEP1 (in red) and those predicted for ILC (in blue) for a luminosity of 500 fb-1.

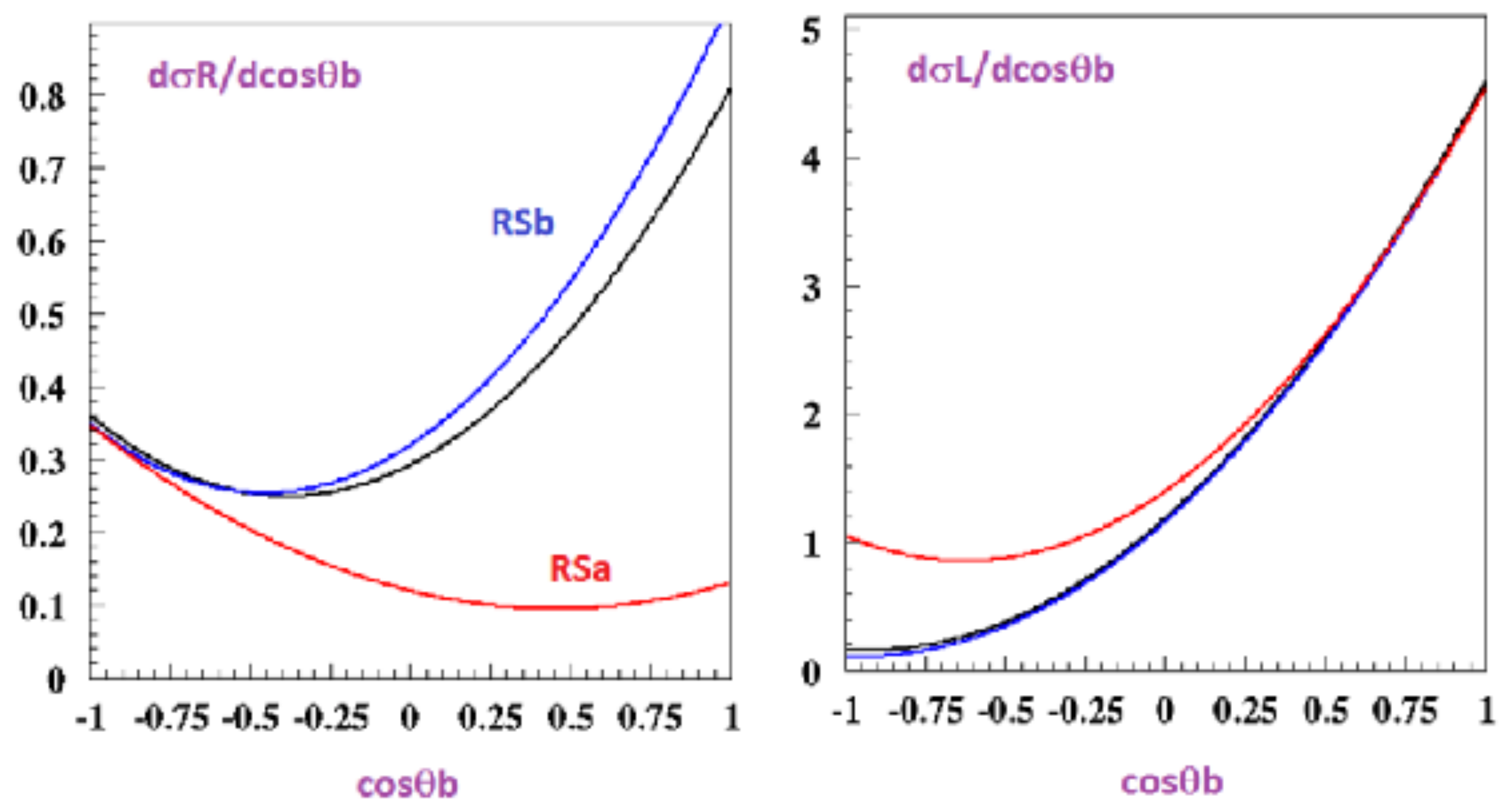


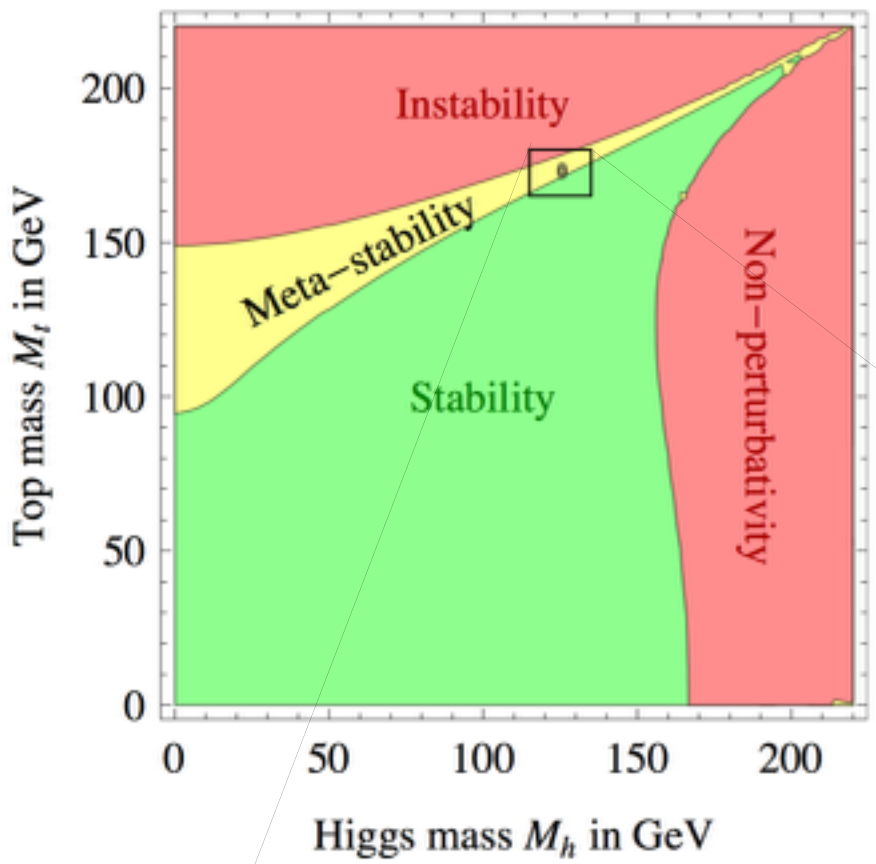
Figure 7: Predicted angular distributions for ee->bb for the SM (black), the RSb solution (blue) and the RSa solution deduced from the LEP1 anomaly. Left is for e^-_R and right is for e^-_L.

ILC will resolve the long outstanding LEP anomaly in $A_{FB}(b)$

What if we could see no deviation from the SM in Higgs and Top couplings?

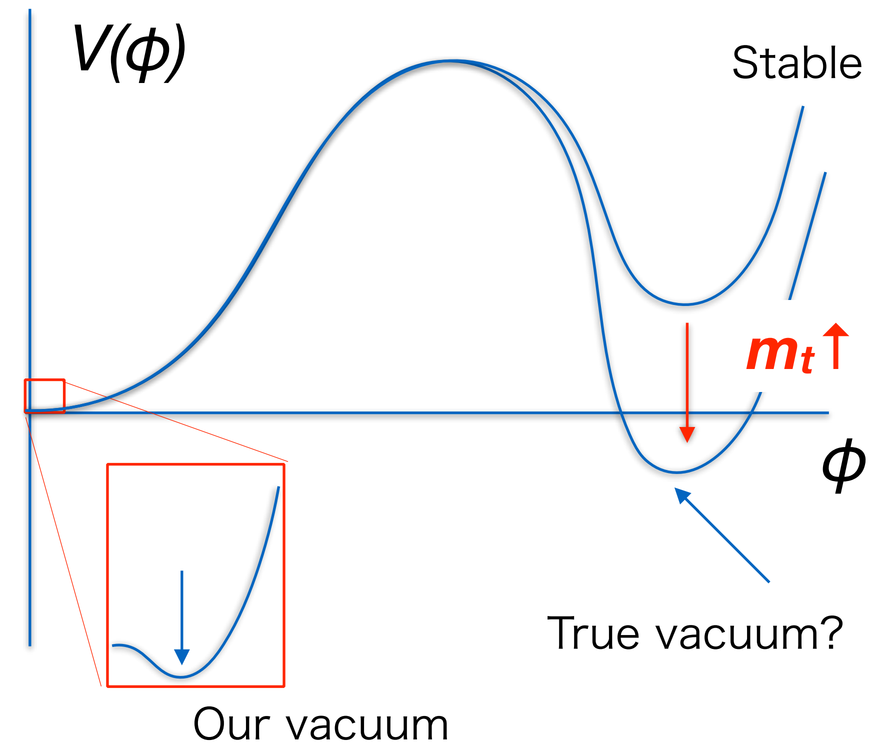
Clarify the Range of Validity of SM

Stability of SM Vacuum



Top Yukawa coupling drives the 4-point Higgs coupling (λ) to negative!

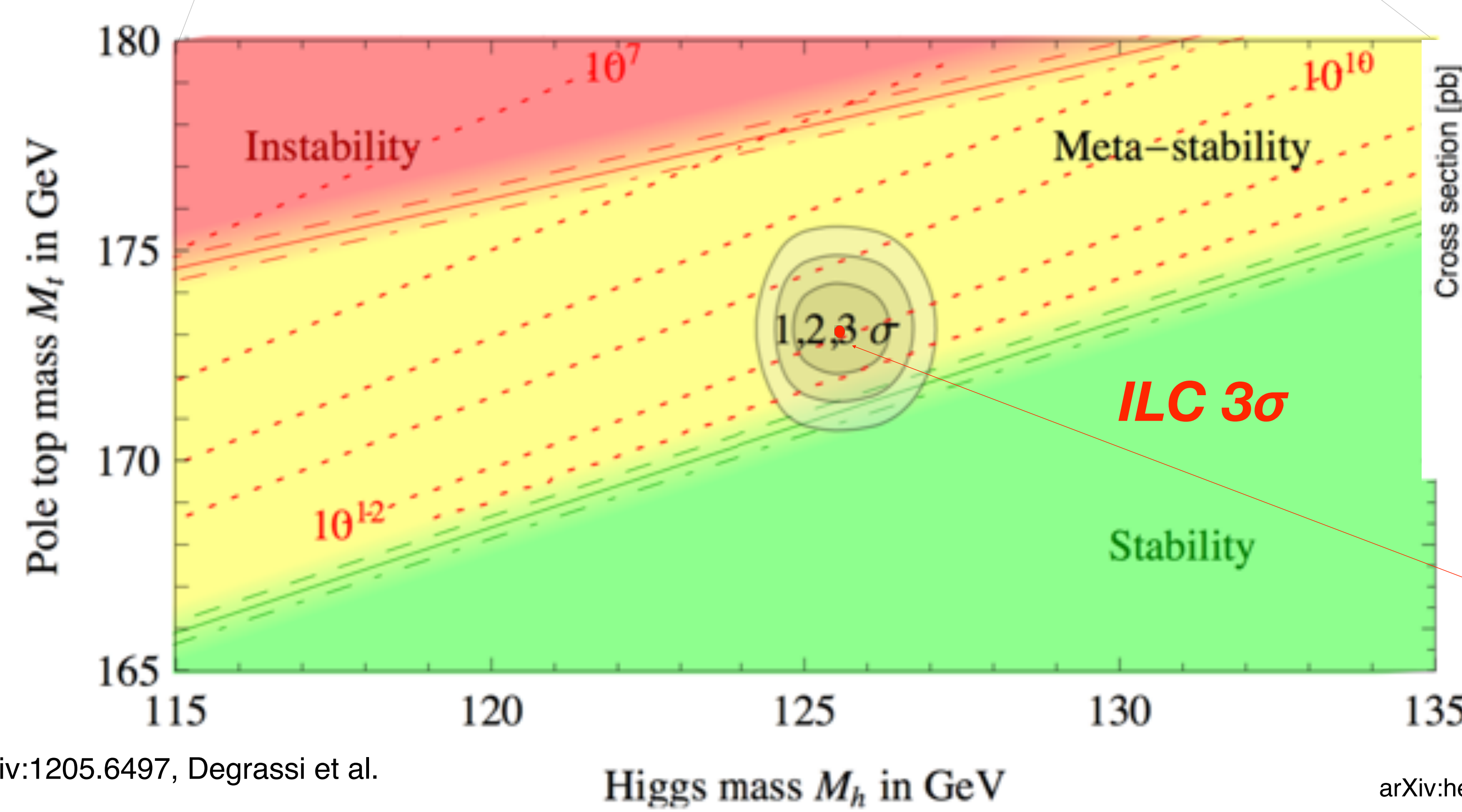
The current values of mt and mh:
Subtle point of meta-stability!



Does λ go to negative below Λ_P? or $\lambda(\Lambda_{Pl}) = 0$?

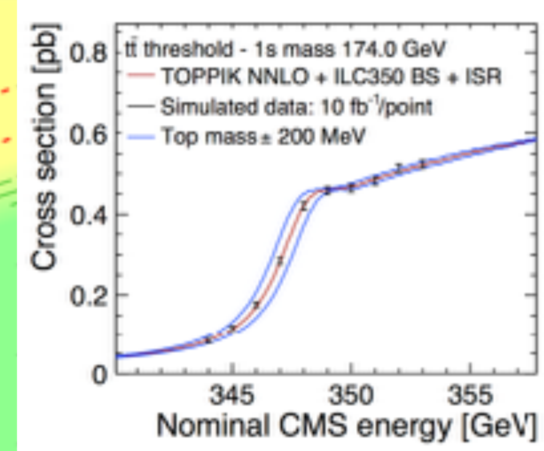
To answer this, we need precision m_t measurement!

At LHC, theory error limits the precision to ~250MeV.

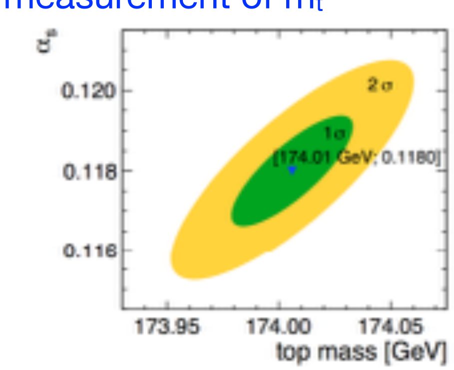


arXiv:1205.6497, Degrassi et al.

TTbar Threshold Scan @ILC



Theoretically very clean measurement of m_t



$$\Delta m_t(\overline{MS}) \lesssim 50\,\mathrm{MeV}$$
$$\Delta m_H = 15\,\mathrm{MeV}$$

ILC pinpoints the vacuum location

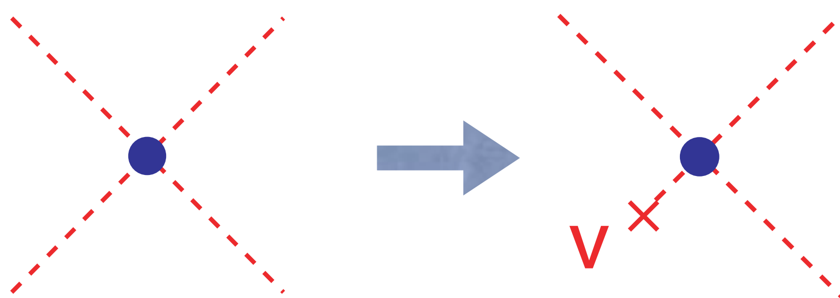
arXiv:hep-ph/1502.01030: Quark mass relation to 4-loop order
arXiv:hep-ph/1506.06864: NNNLO QCD
arXiv:hep-ph/1506.06542: possibility of MSbar mass to 20MeV

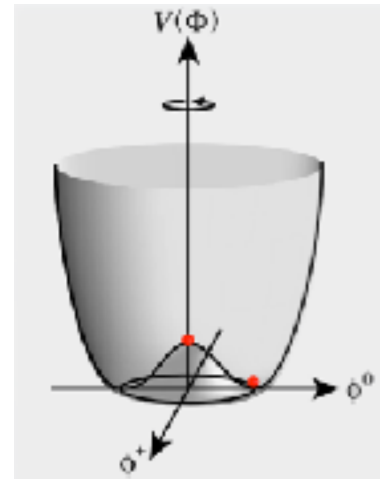
Higgs Self-Coupling

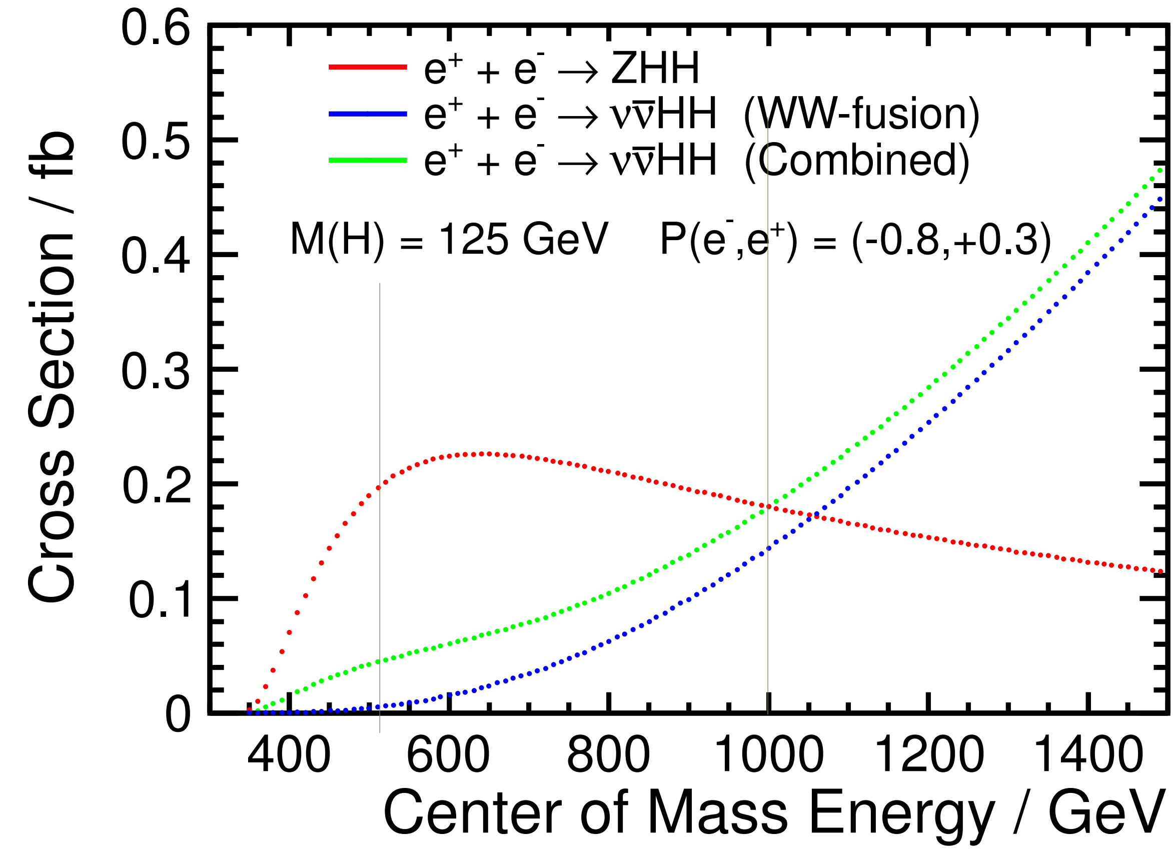
This could be the only coupling with observable large deviation from the SM!

Higgs Self-Coupling

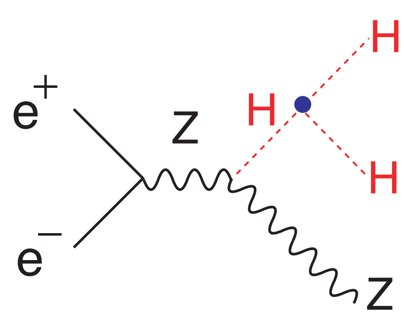
The ***Higgs cubic self-coupling*** is at the heart of EWSB, so should be measured in its own right!

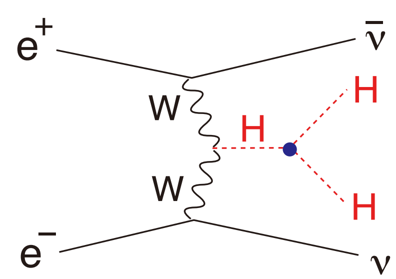






There are ***two ways to measure it*** at ILC





Challenging even at ILC because of

- Small cross section
- ***Presence of irreducible BG diagrams that dilute the self-coupling contribution!***

ILC

	500 GeV	+ 1 TeV
Snowmass	46%	13%
H20	**26%**	**10%**

H20 arXiv: 1506.07870

J. Tian, LC-REP-2013-003

C. Dürig @ ALCW16

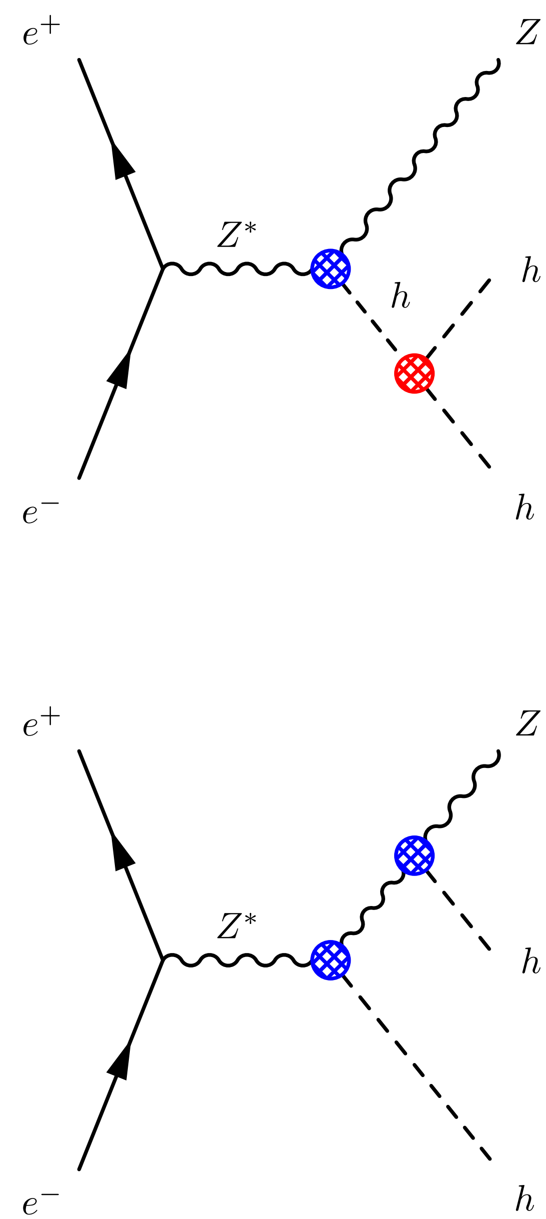
M. Kurata, LC-REP-2014-025

CLIC

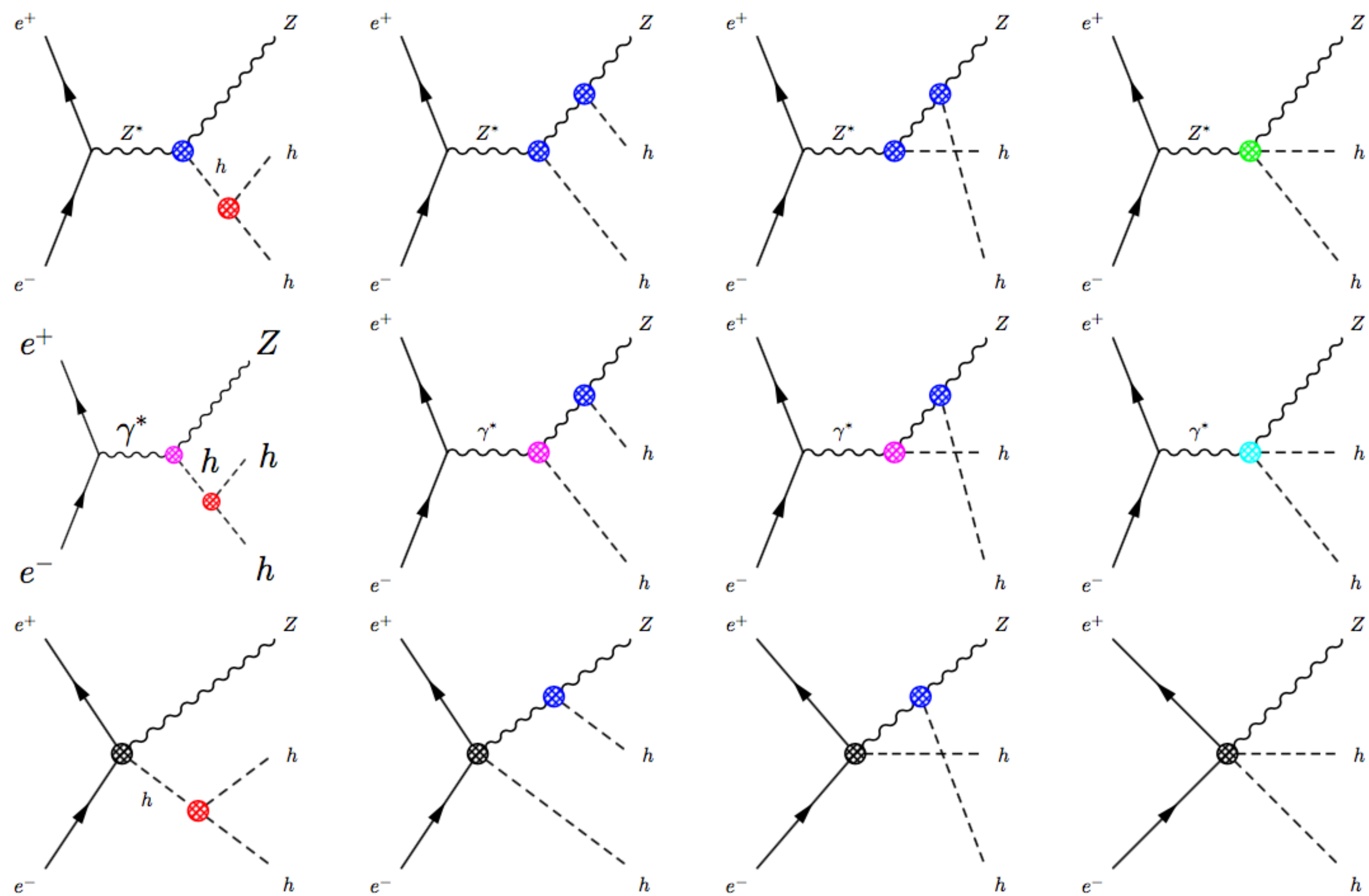
1.4 TeV (1.5 ab^{-1})	+3 TeV (2 ab^{-1})
21%	10%

(arXiv: 1307.5288)

Ongoing analysis improvements ***towards O(10)% measurement*** question 1: how can we determine λ_{hhh} if there are anomalous hhVV, hVV, hhh couplings?



answer to Q1: determine λ_{hhh} in EFT



Uncertainties in other EFT coefficients contribute only a 5% systematic error to the anomalous cubic coupling (C6)

Jumping Tian New Higgs WG, Aug. 18-19, 2017

EW Baryogenesis?

The answer is no in the Standard Model.

Strong 1st order EW phase transition

to bring the universe out of equilibrium

→ Large deviation of Higgs cubic self-coupling

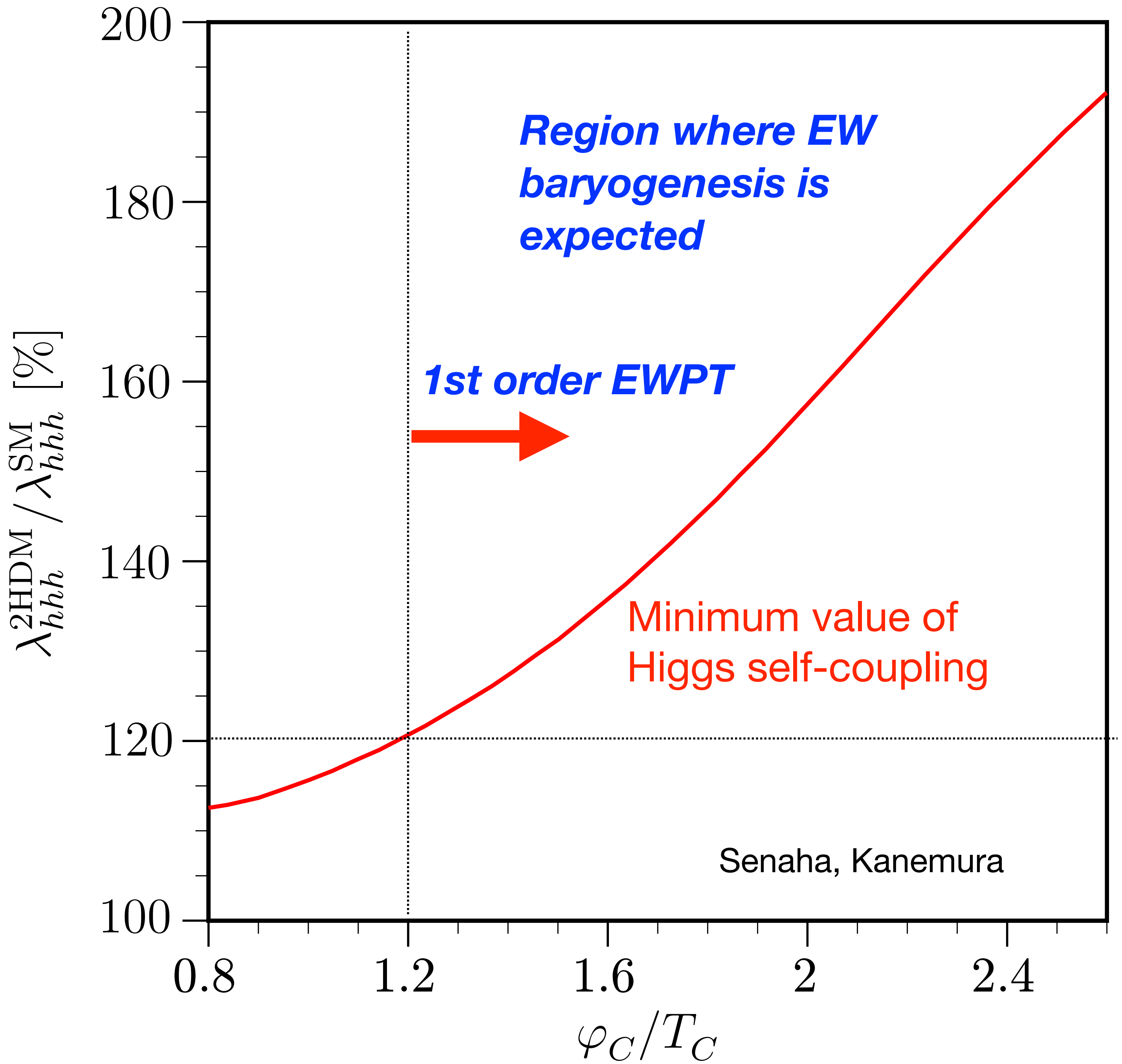
Enough CPV (δ_{KM} too small)

→ CPV source in Higgs sector

→ Extended Higgs sector

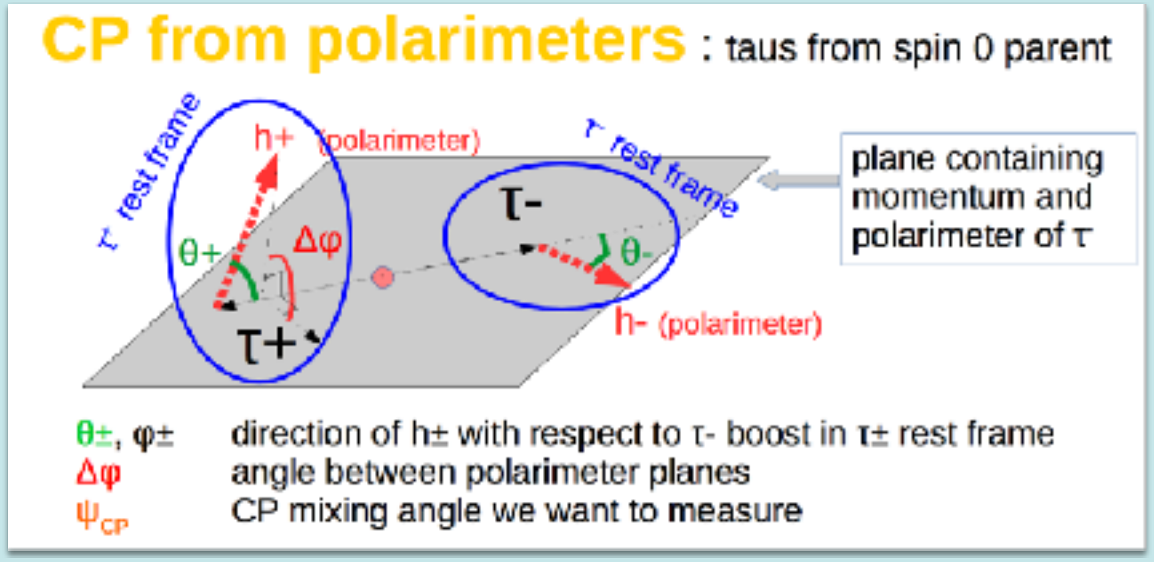
Electroweak Baryogenesis?

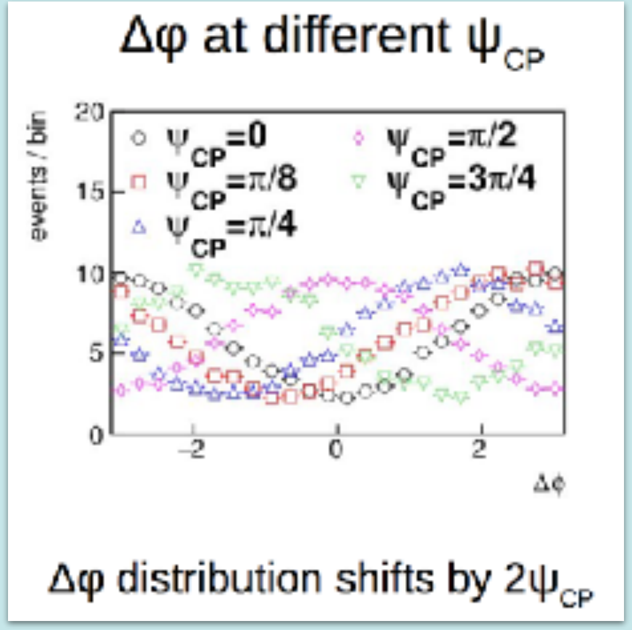
Example: ***2 Higgs Doublet Model (2HDM)***



Measuring CP in H → τ+τ- at ILC

$$\mathcal{L}_{h\tau\tau} = g\bar{\tau}\left(\cos\Psi_{\text{CP}} + i\gamma_5 \sin\Psi_{\text{CP}}\right)\tau\, h$$





2ab^{-1} @ 250 GeV

$$\langle \delta\Psi_{\text{CP}} \rangle \simeq 3.8^\circ$$

(preliminary)

D. Jeans, LCWS16

Self-coupling Measurement at ILC

Constructive interference between signal and BG diagrams @500GeV

→ ***if +100% deviation, then Δλ/λ=14% expected!***

ILC can address the idea of ***baryogenesis occurring at the electroweak scale***.

Strong 1st Order Phase Transition

Example: ***Doublet-Singlet Mixing Model (HSM)***

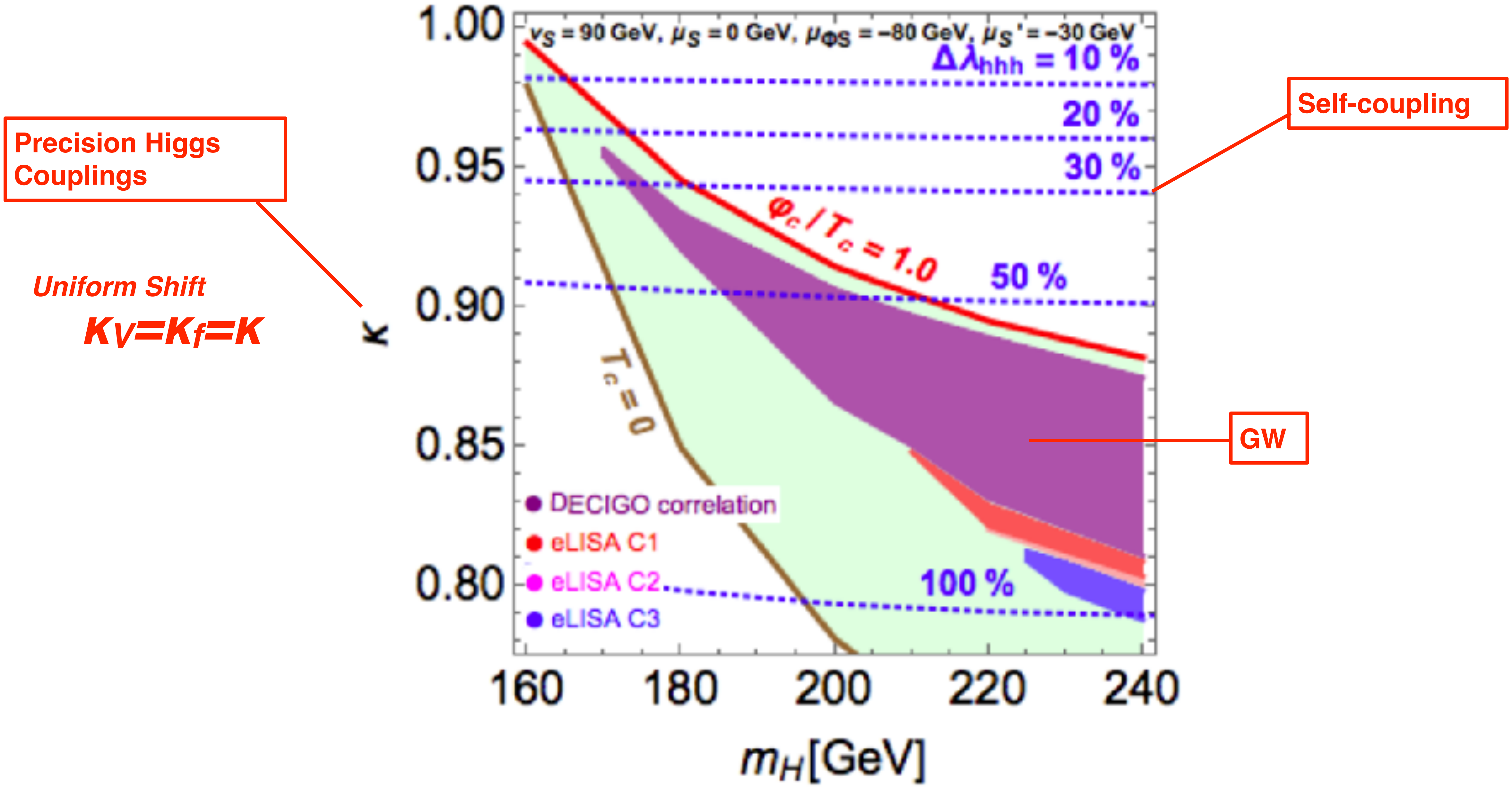


FIG. 2: The detectability of GWs and the contours of the deviations in the hhh coupling $\Delta\lambda_{hhh}$ in the m_H-κ plane. The projected region of a higher sensitive detector design is overlaid with that of weaker one. The region which satisfies both $\varphi_c/T_c > 1$ and $T_c > 0$ is also shown for a reference. The input parameters and legends are same as in Fig. 1

Fuyuno, Senaha: arXiv: 1406.0433

Hashino, Kakizaki, Kanemura, Matsui, Ko: arXiv 1609.00297

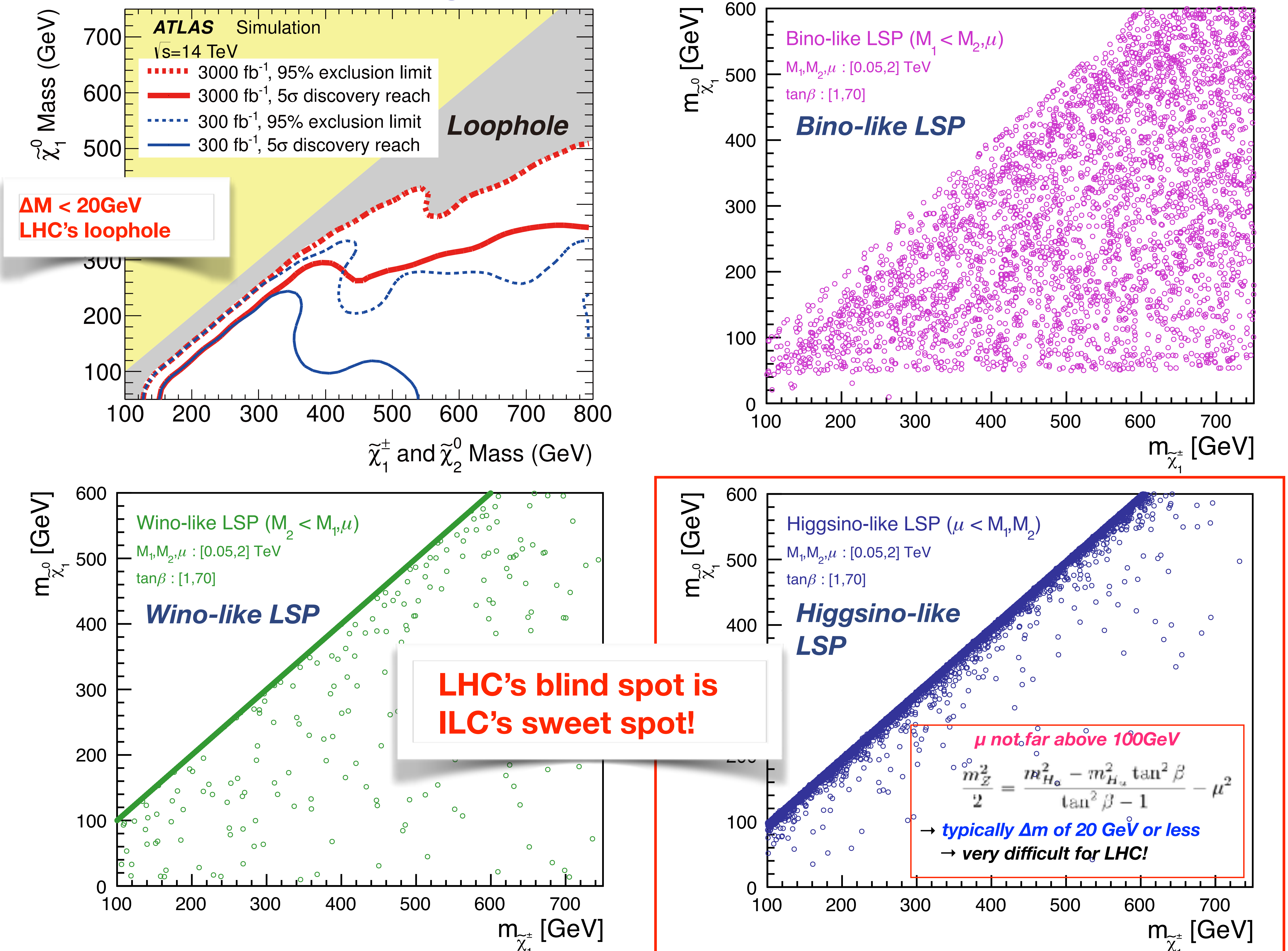
Direct Searches for New Particles

ILC, too, is an energy frontier machine!

It will enter ***uncharted waters of e^+e^- collisions***

Thanks to well-defined initial states,
clean environment w/o QCD BG, and polarized beams
ILC can cover blind spots of LHC

Chargino / Neutrarino Searches

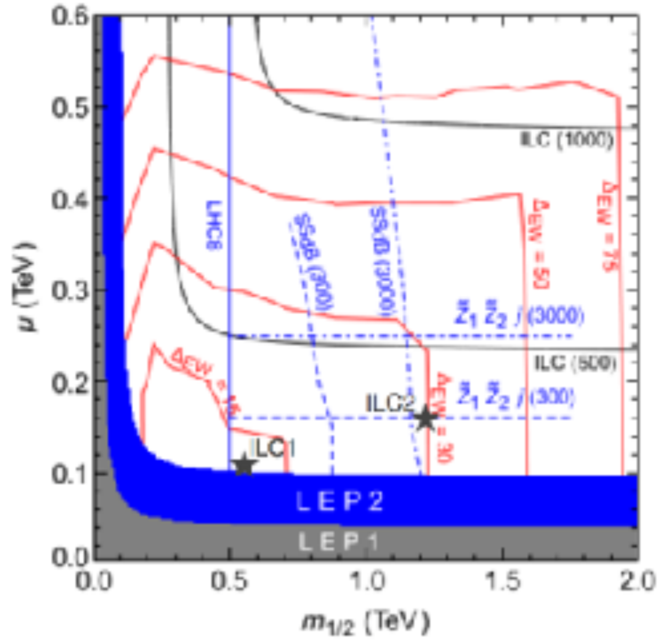


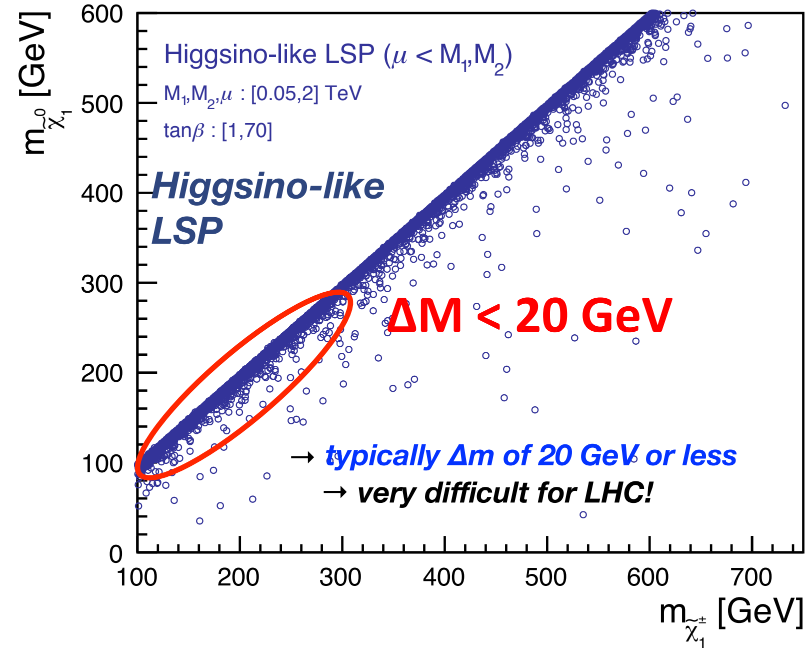
Higgsinos

Radiatively driven Natural SUSY

μ not far above 100GeV

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - \mu^2$$





Chargino & Neutralino Productions

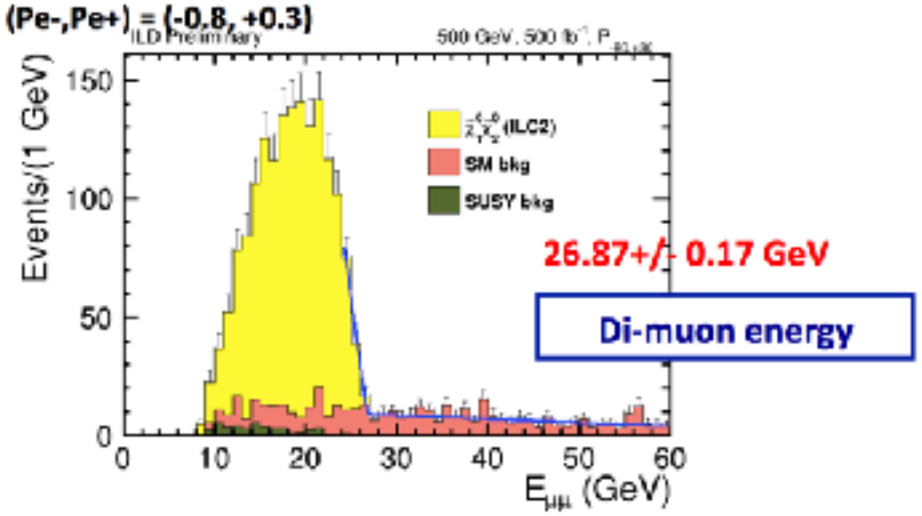
Neutralino mixed production with leptonic decay

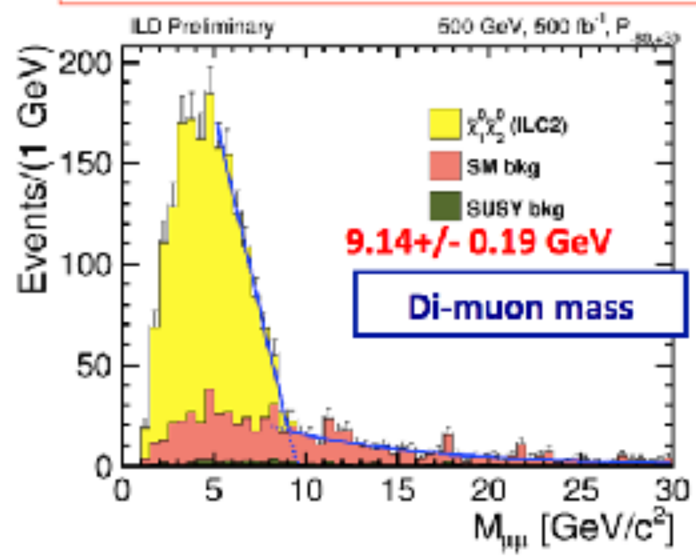
$$e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$$

ILC2, μμ

Edge precisions assuming 500 fb^{-1}
0.5-1 %, for Eμμ , 2-2.5% for Mμμ

(Pe-,Pe+) = (-0.8,+0.3)



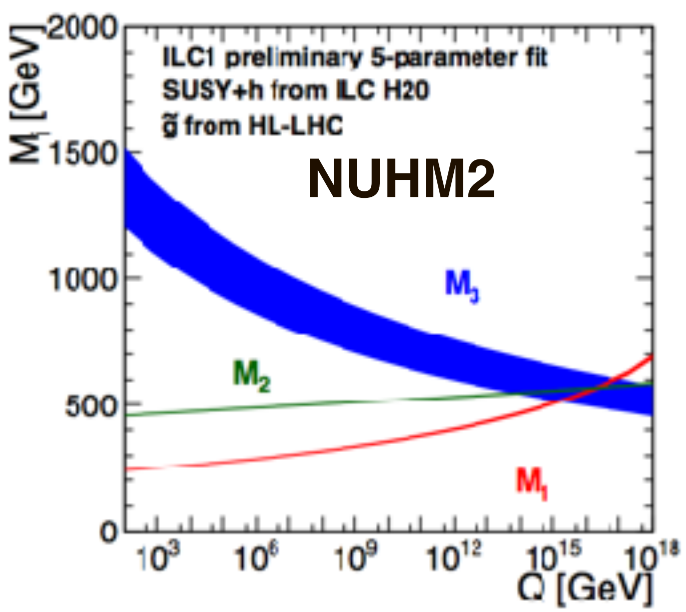


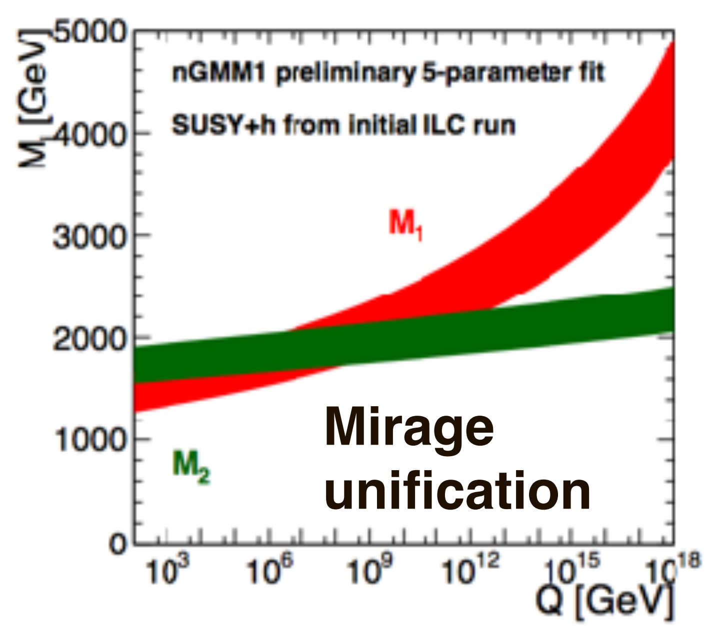
J. Yan : LCWS2016

End points → M_X

"ILC2 benchmark": ΔM∼ 10GeV
σ_M / M < 1% (H20)

500GeV → ***ILC1: 250GeV***
ILC2: 350GeV





S. Lehtinen : LCWS2016

Power of Beam Polarization for Higgsino-Gaugino decomposition

Left: **Test of gaugino mass unification**

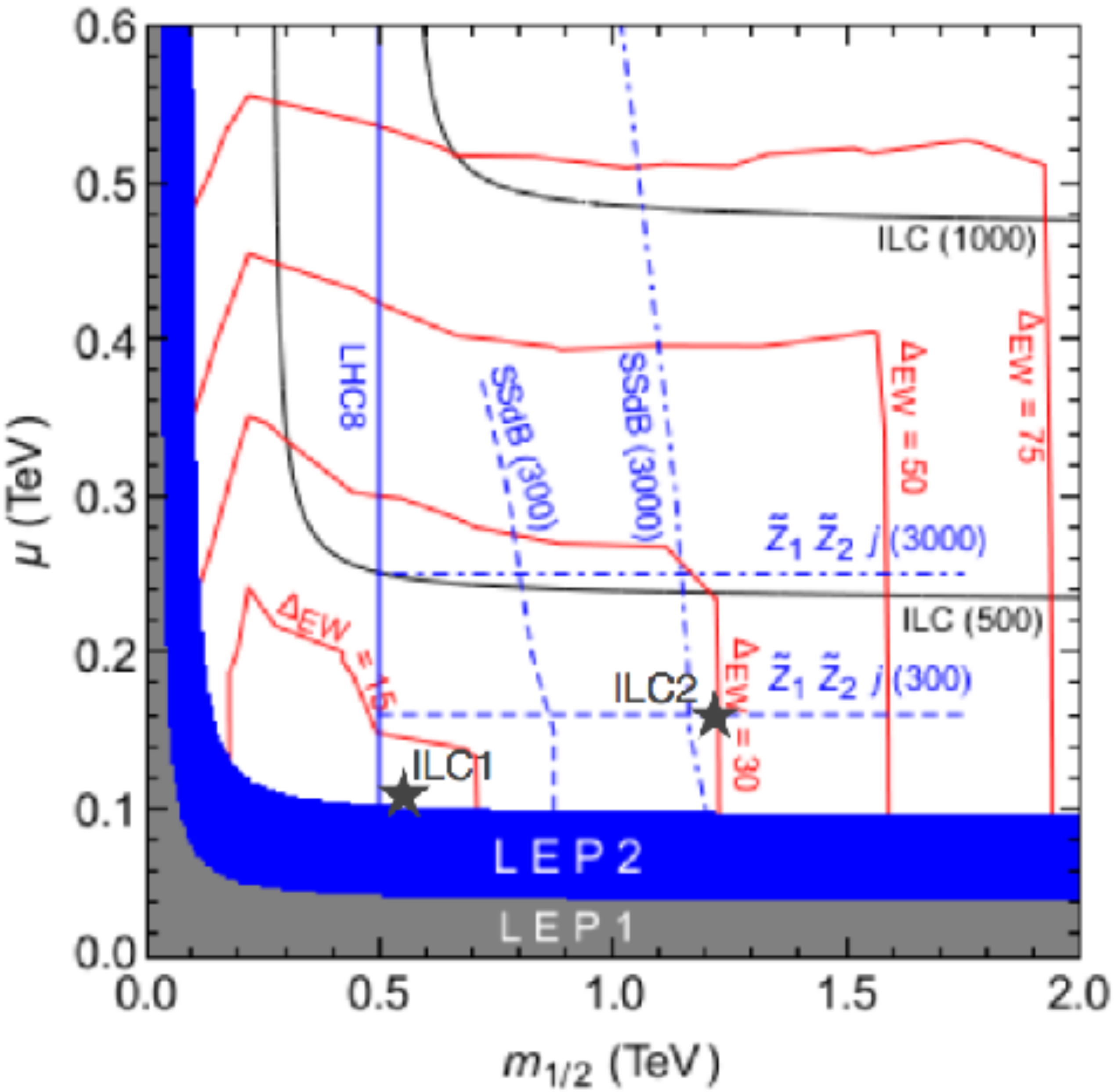
Right: **Select SUSY breaking models** (gravity mediated SUSY breaking vs mirage unification)

Higgsinos

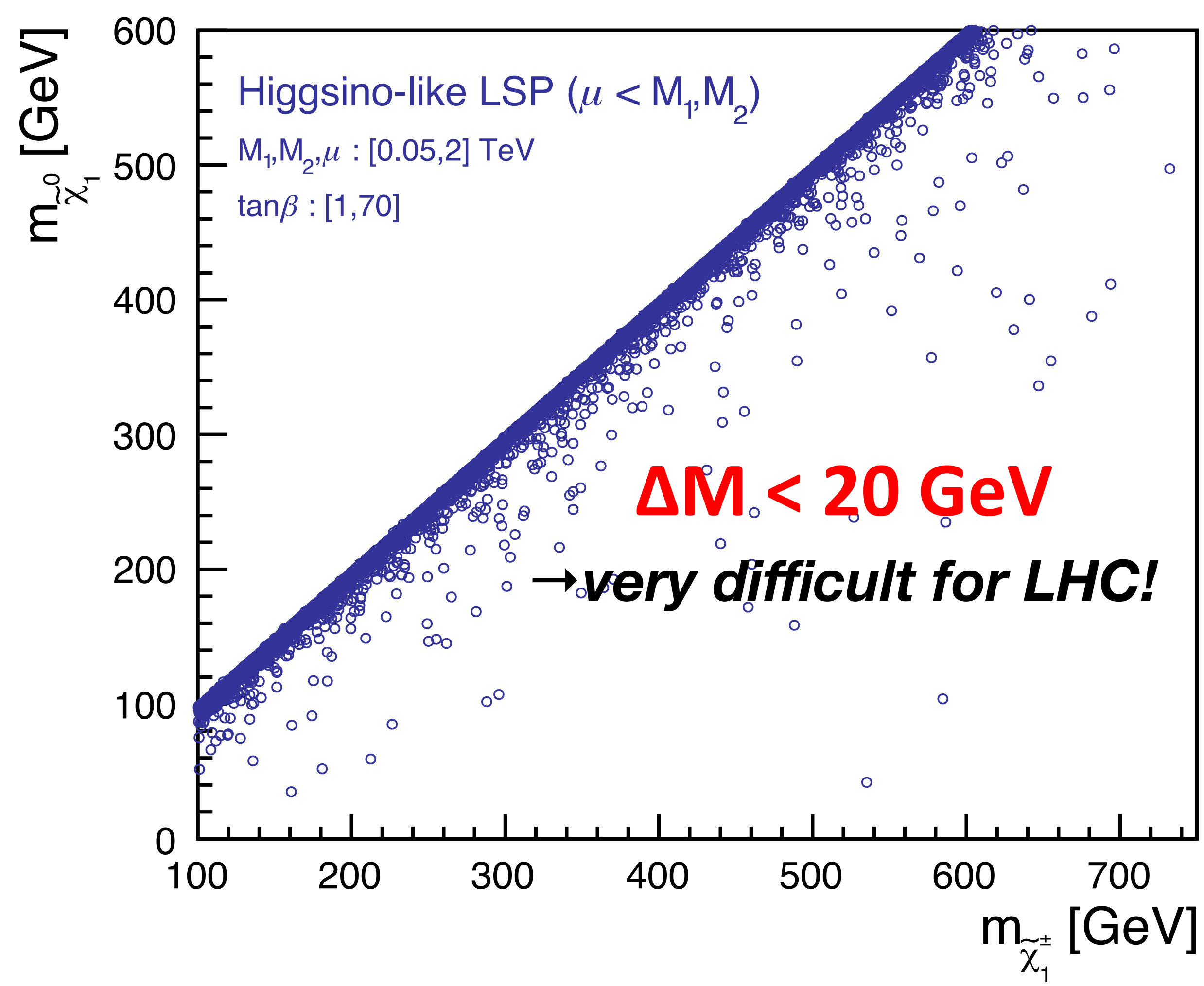
Radiatively driven Natural SUSY

μ not far above 100GeV

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - \mu^2$$



Higgsino-like LSP

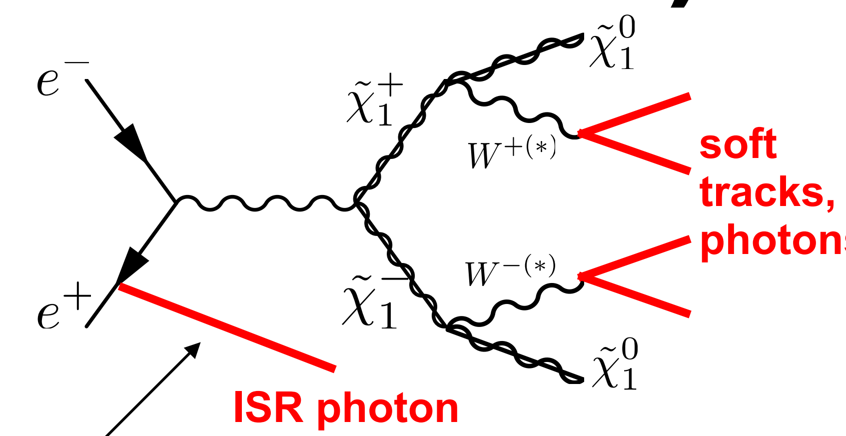


Higgsinos in Natural SUSY (ΔM<a few GeV)

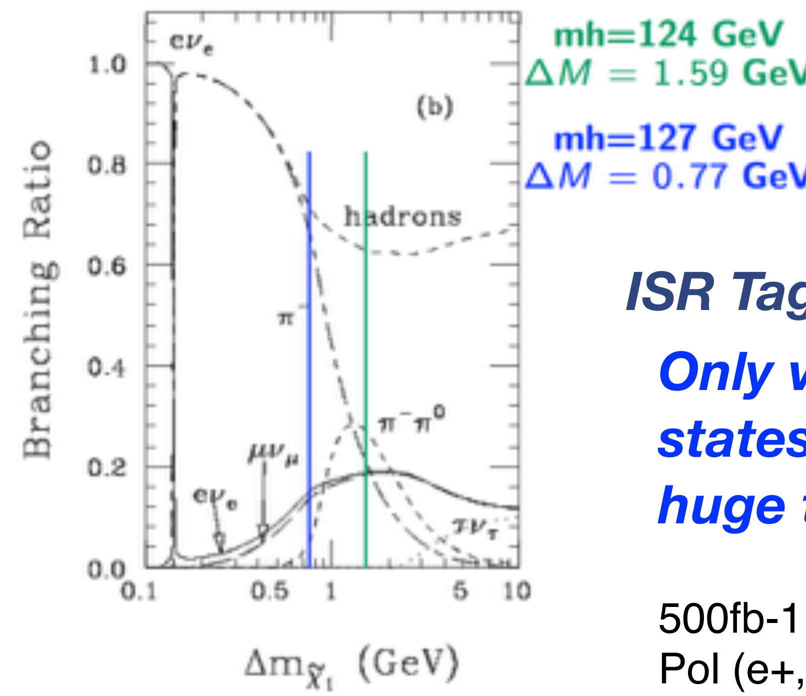
ISR Tagging

ILC as a Higgsino Factory

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$$
$$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_1^0\gamma$$



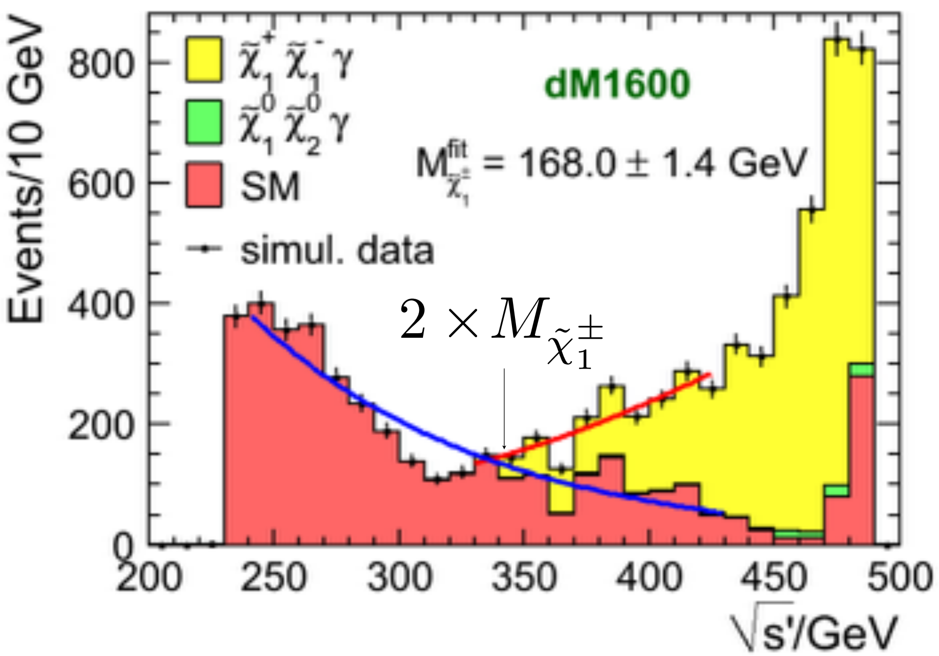
Ref: C.-H. Chen et al. hep-ph:9512230

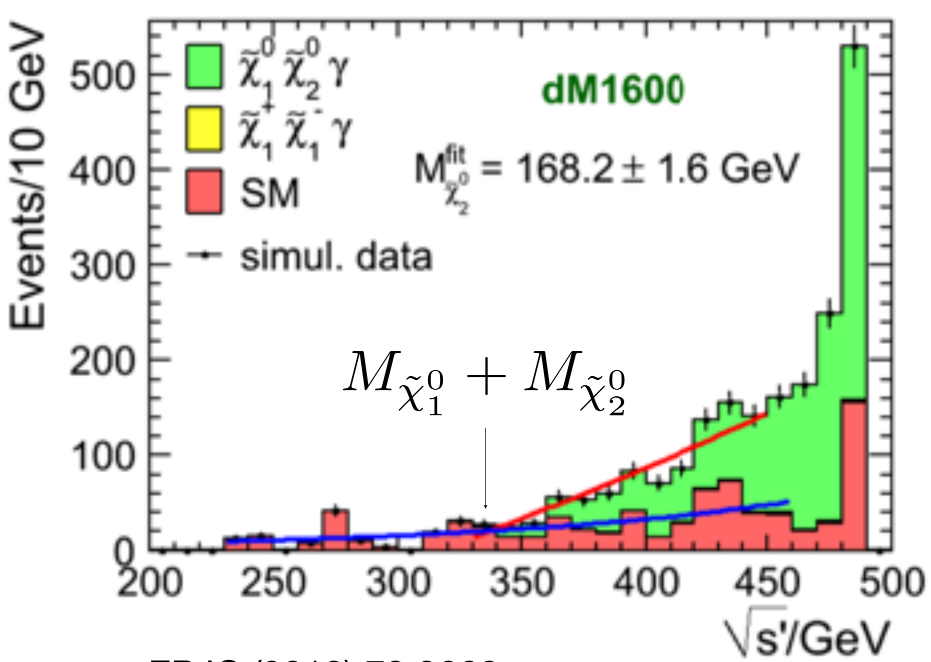


ISR Tagging

Only very soft particles in the final states → Require a hard ISR to kill huge two-photon BG!

500fb-1 @ Ecm=500GeV
Pol (e+,e-) = (+0.3,-0.8) and (-0.3,+0.8)





EPJC (2013) 73:2660

dm1600

Mass Spectrum

Particle	Mass (GeV)
h	124
$\tilde{\chi}_1^0$	164.17
$\tilde{\chi}_1^\pm$	165.77
$\tilde{\chi}_2^0$	166.87
H's	$\sim 10^3$
$\tilde{\chi}$'s	$\sim 2-3\times10^3$

$\Delta M(\tilde{\chi}_1^\pm,\tilde{\chi}_1^0) = 1.59$ GeV

$$\delta(\sigma\times BR)\simeq 3\%$$
$$\delta M_{\tilde{\chi}_1^\pm}(M_{\tilde{\chi}_1^0})\simeq 2.1(3.7)\,\mathrm{GeV}$$
$$\delta\Delta M(\tilde{\chi}_1^\pm,\tilde{\chi}_1^0)\simeq 70\,\mathrm{MeV}$$

dm770

Mass Spectrum

Particle	Mass (GeV)
h	127
$\tilde{\chi}_1^0$	166.59
$\tilde{\chi}_1^\pm$	167.36
$\tilde{\chi}_2^0$	167.63
H's	$\sim 10^3$
$\tilde{\chi}$'s	$\sim 2-3\times10^3$

$\Delta M(\tilde{\chi}_1^\pm,\tilde{\chi}_1^0) = 0.77$ GeV

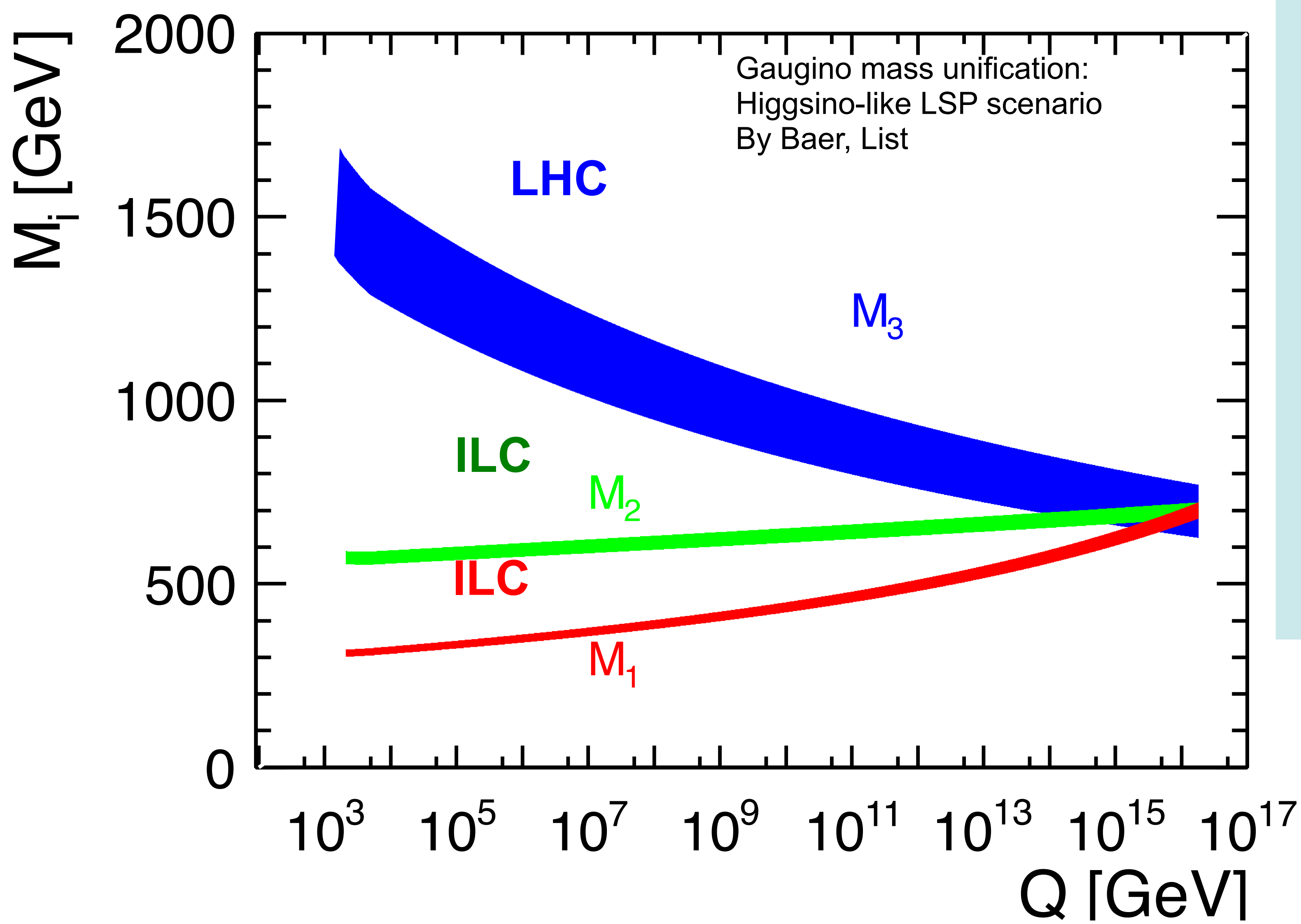
$$\delta(\sigma\times BR)\simeq 1.5\%$$
$$\delta M_{\tilde{\chi}_1^\pm}(M_{\tilde{\chi}_1^0})\simeq 1.5(1.6)\,\mathrm{GeV}$$
$$\delta\Delta M(\tilde{\chi}_1^\pm,\tilde{\chi}_1^0)\simeq 20\,\mathrm{MeV}$$

GUT Scale Physics

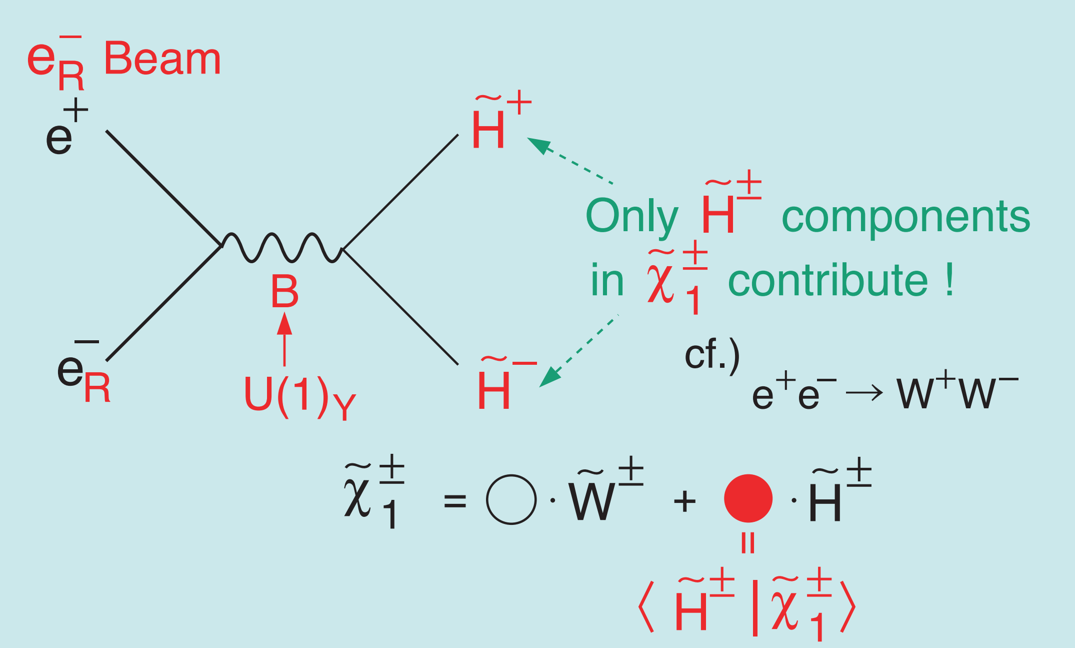
If we are lucky and the gluino is in LHC's mass reach and the lighter chargino and the neutralinos are in ILC's mass reach, ***we will be able to test the gaugino mass unification!***

LHC: gluino discovery
→ mass determination

ILC: Higgsino-like EWkino discovery
→ M1, M2 via mixing between Higgsino and Bino/Wino



Chargino decomposition



Beam polarization is essential *to decompose the EWkinos to bino, wino, and higgsino and extract M_1 and M_2.*

WIMP Dark Matter Search @ ILC

Weakly Interacting Massive Particle

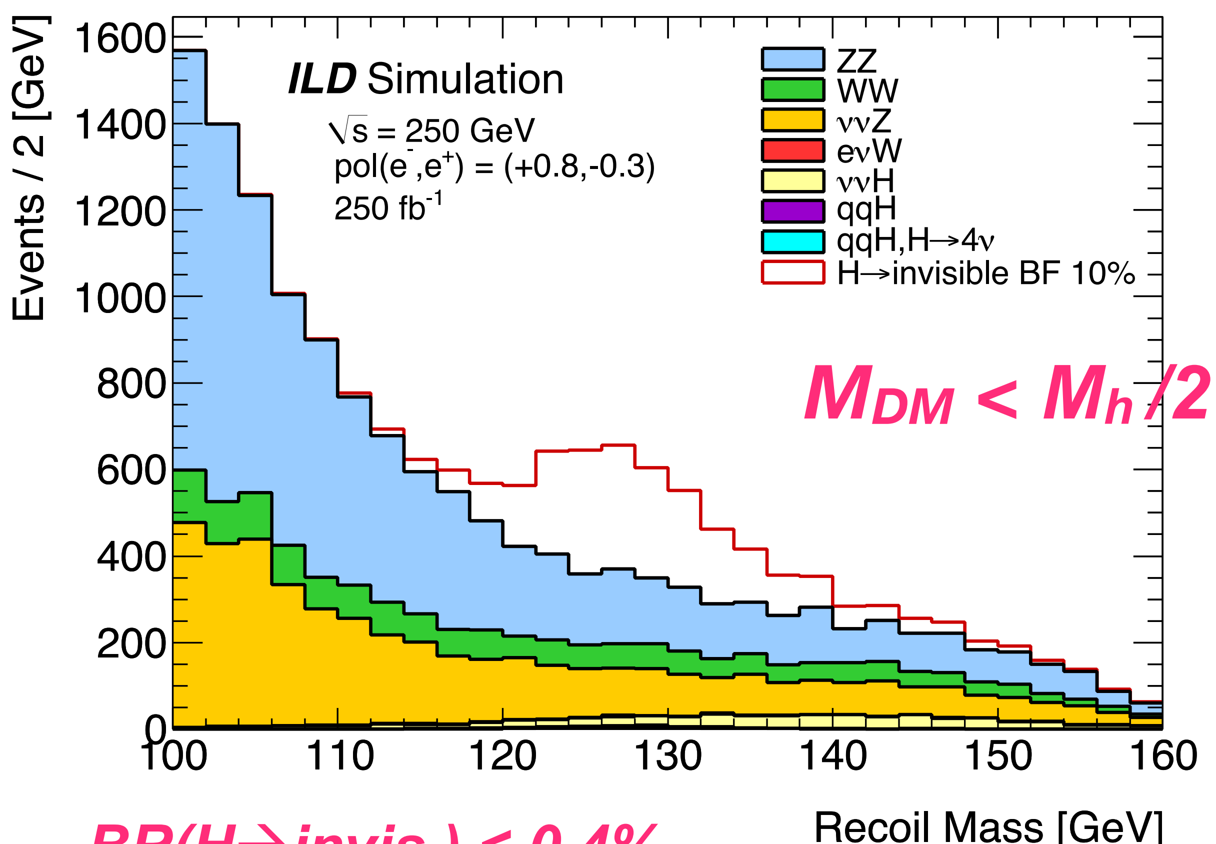
1. Decay of a new particle to Dark Matter (DM)

DM has a charged partner in many new physics models.

SUSY: The Lightest SUSY Particle (LSP) = DM → Its partner decays to a DM.

- Events with missing Pt (example: light chargino: see the previous page)

2. Higgs Invisible Decay

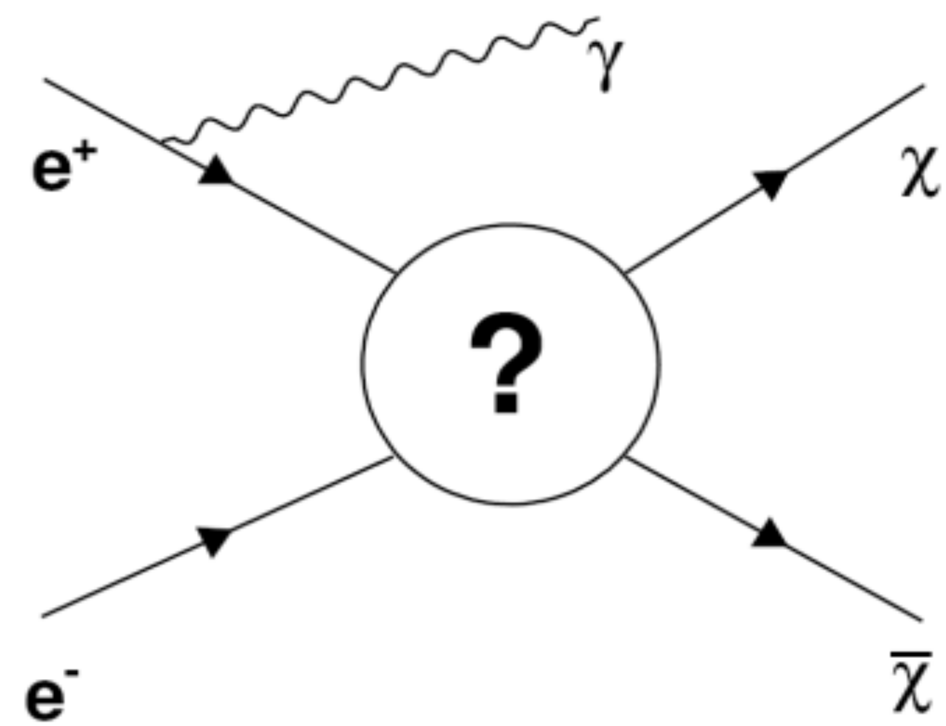


BR(H→invis.) < 0.4%

at 250 GeV, 1150 fb^{-1} ***(<0.3% at 95%CL: H20)***

Possible to access BR_{inv} to 0.3%!

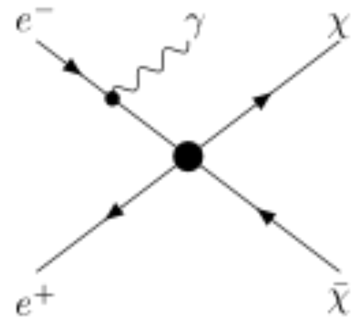
3. Mono-photon Search



→ ***M_{DM} reach ~ $E_{cm}/2$***

Possible to access DM to ~$E_{cm}/2$!

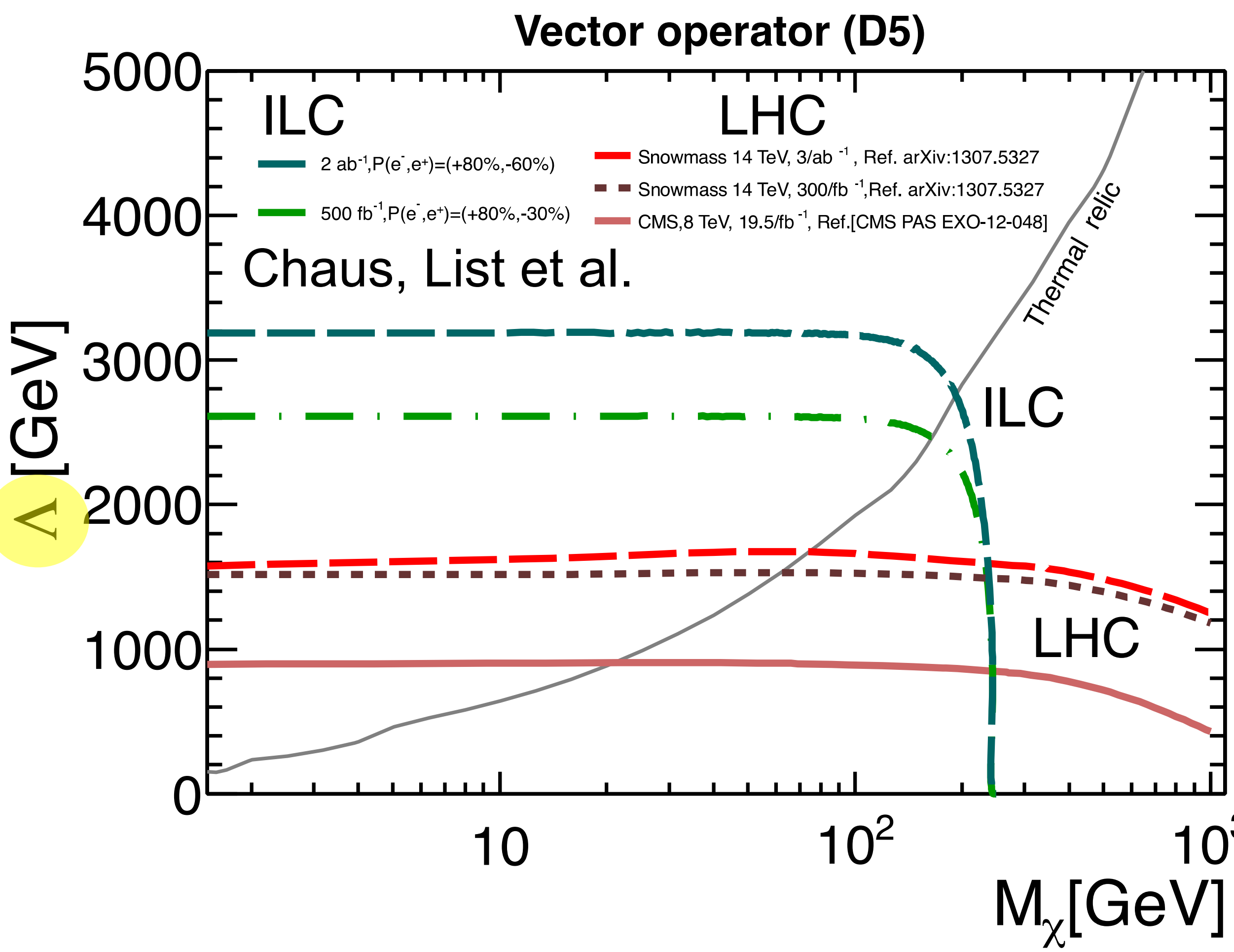
DM: Effective Operator Approach

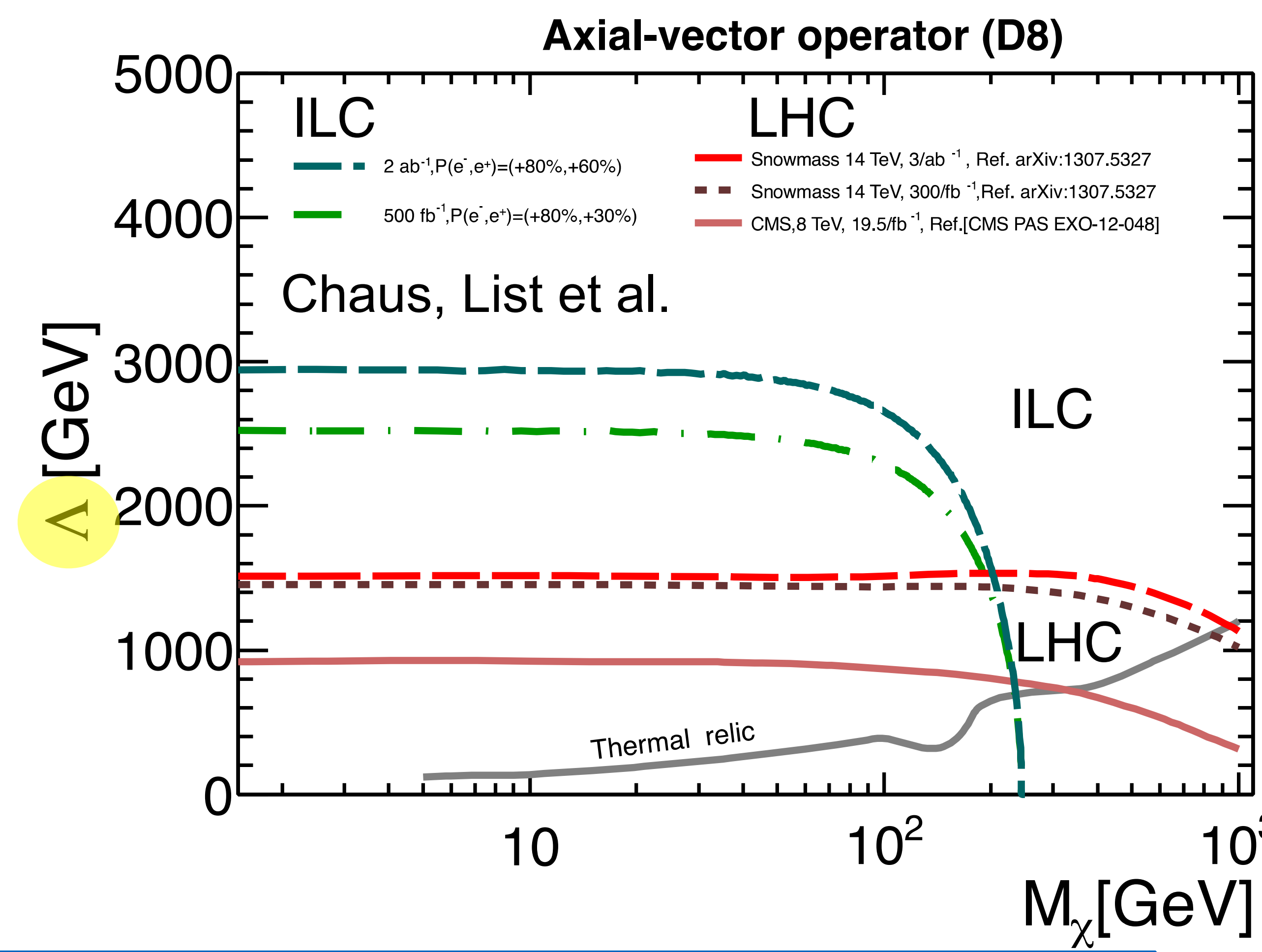


$$\mathcal{L}_{\rm int} = \frac{1}{\Lambda^2}\mathcal{O}_i$$

$$\mathcal{O}_V = (\overline{\chi}\gamma_\mu\chi)(\bar{\ell}\gamma^\mu\ell)$$

$$\mathcal{O}_A = (\overline{\chi}\gamma_\mu\gamma_5\chi)(\bar{\ell}\gamma^\mu\gamma^5\ell)$$



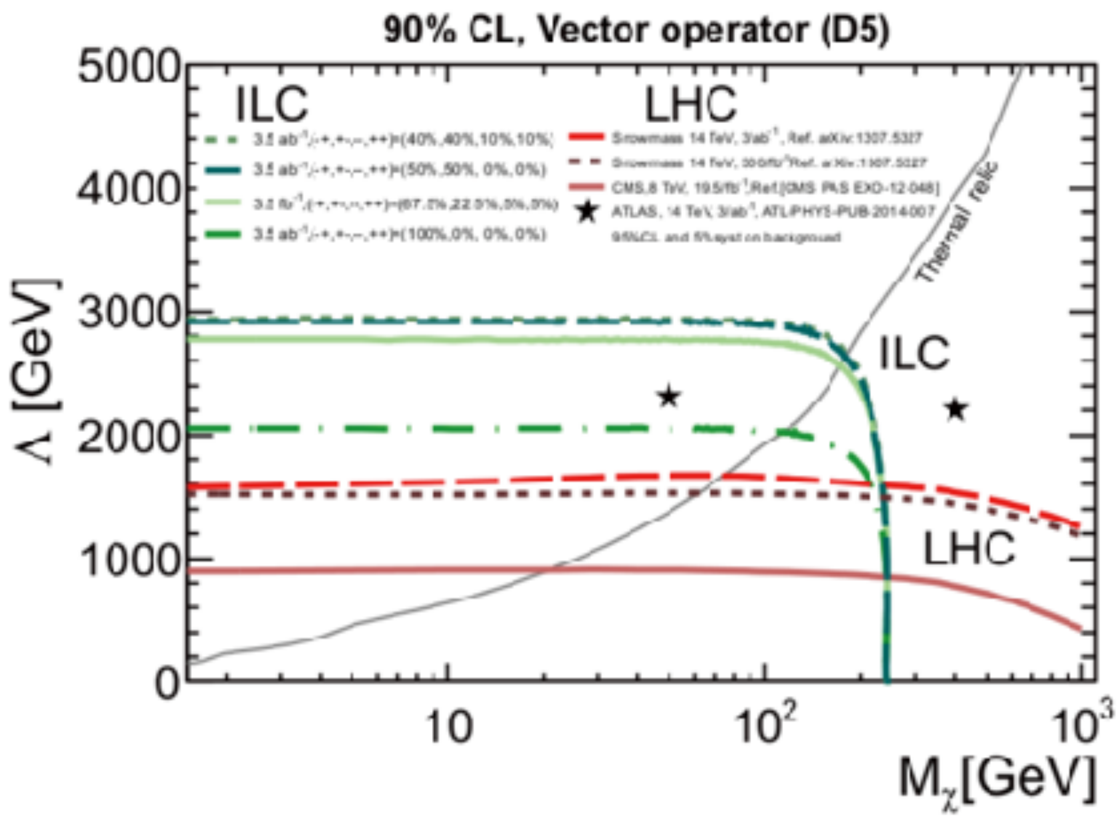


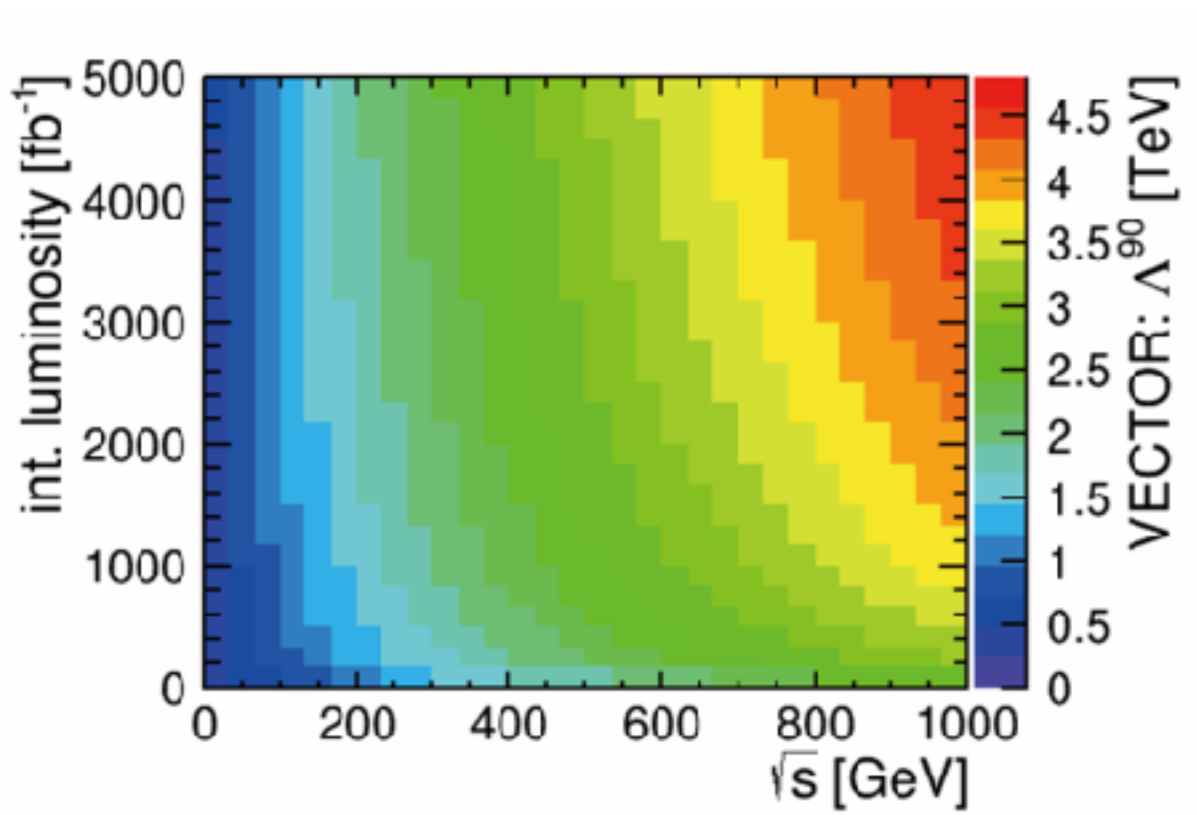
LHC sensitivity: Mediator mass up to Λ~1.5 TeV for **large DM mass**

ILC sensitivity: Mediator mass up to ***Λ~3 TeV*** for ***DM mass up to ~√s/2***

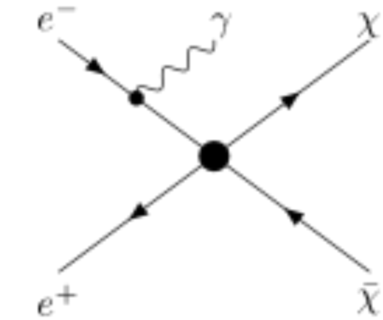
⇒ ***LHC-ILC synergy!***

DM: Effective Operator Approach





Previous result



LHC-ILC Comparison [A. Chaus]

$$\mathcal{L}_{\rm int} = \frac{1}{\Lambda^2}\mathcal{O}_i$$

Example: Vector operator

- LHC sensitive to higher mass
- ILC sensitive to higher Λ

LHC-ILC synergy!

Recent result

Extrapolation to other √s [M. Habermehl]

- ILC reach of Λ at different CM energies and integrated luminosities
- for small M_χ (< 100 GeV)
- Allows study of run scenarios

ILC's H20 run scenario allows us to access Λ up to 3 ~ 4 TeV

T. Tanabe, LCWS16

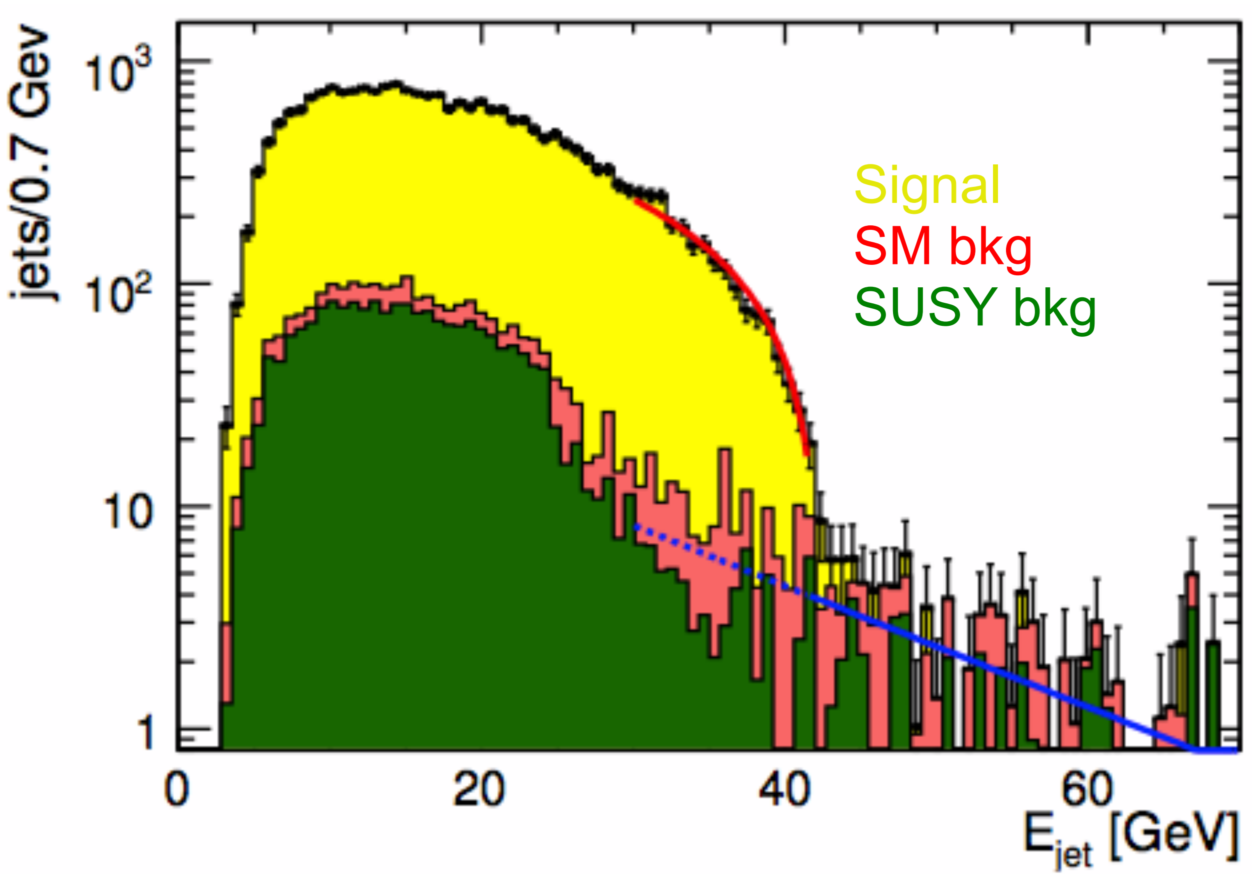
Slepton decays to DM with small mass differences

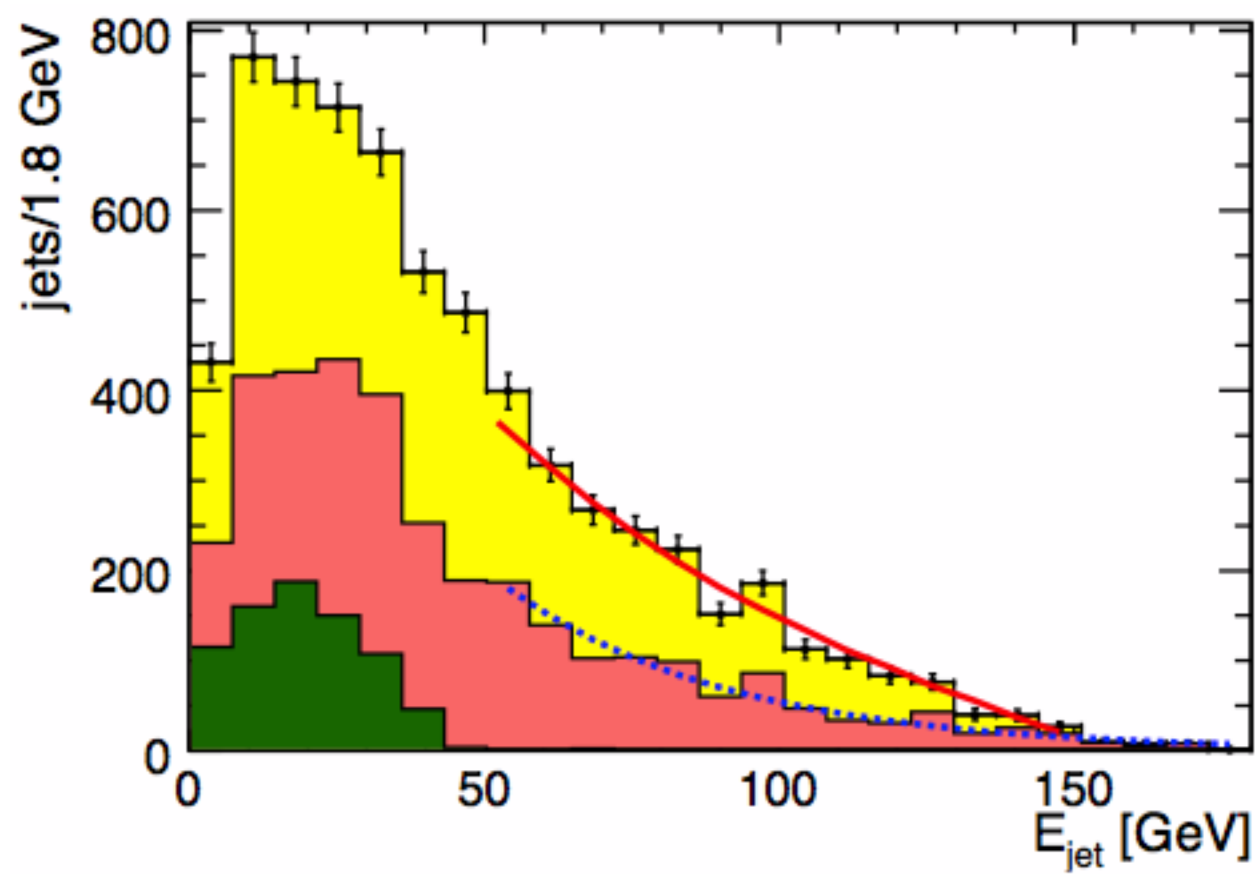
Study of stau pair production at the ILC
Observation of lighter and heavier stau states with decay to DM + hadronic tau

Benchmark point: m(LSP) = 98 GeV, m(stau1) = 108 GeV, m(stau2) = 195 GeV

$$\sigma(e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^-) = 158 \text{ fb}$$
$$\sigma(e^+e^- \to \tilde{\tau}_2^+\tilde{\tau}_2^-) = 18 \text{ fb}$$

Bechtle, Berggren, List, Schade, Stempel, arXiv:0908.0876, PRD82, 055016 (2010)



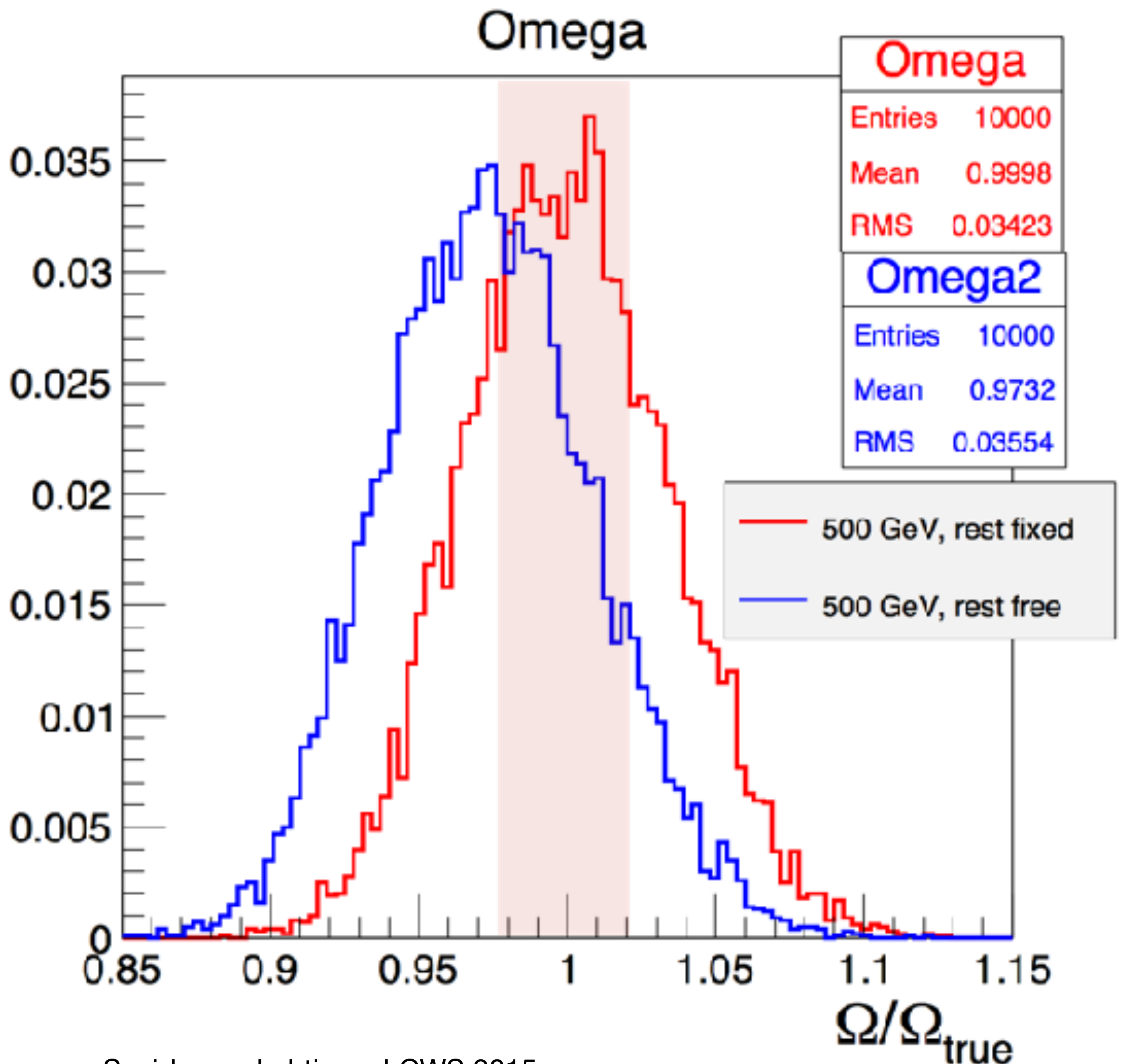


√s=500 GeV, Lumi=500 fb-1, P(e-,e+)=(+0.8,-0.3)
Stau1 mass ~0.1%, Stau2 mass ~3% → LSP mass ~1.7%

DM Relic Abundance

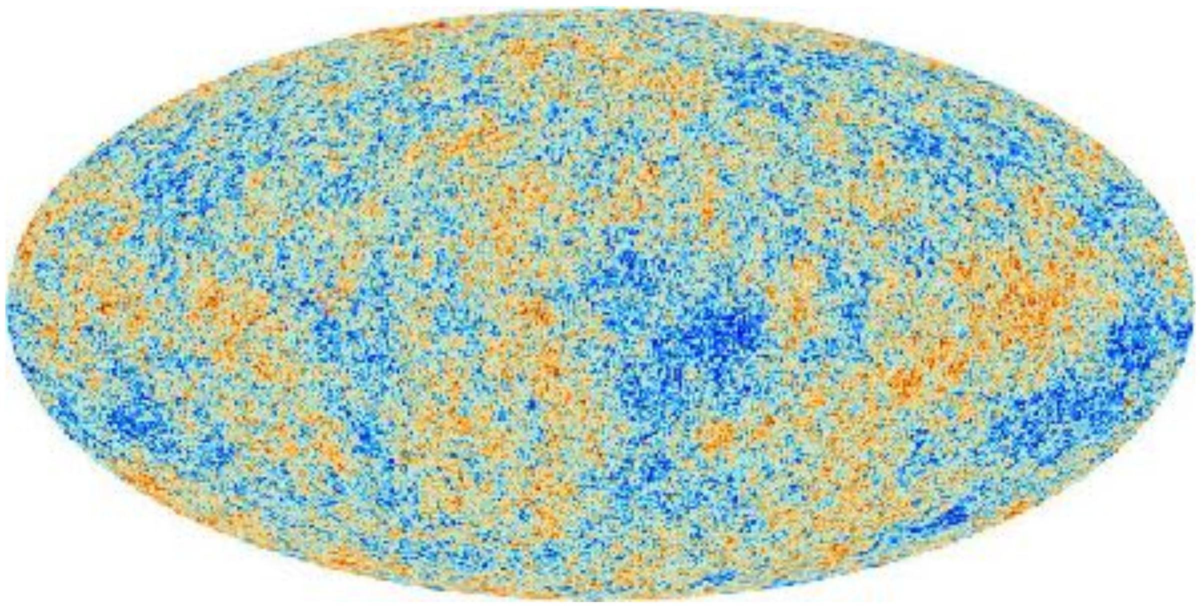
WMAP/Planck (68% CL)

$$\Omega_c h^2 = 0.1196 \pm 0.0027$$



Suvi-Leena Lehtinen, LCWS 2015

ESA/Planck



Once a DM candidate is discovered, crucial to check the consistency with the measured DM relic abundance.

Mass and couplings measured at ILC
→ DM relic density to compare with the CMB data