sensitivity of anomalous HVV coupling @ ILC

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ongoing study, results are rather preliminary

outline

- methodology to measure anomalous HVV @ ILC
- sensitivity of aHZZ obtained by analysis based on full detector simulation @ ILC
- comparison with aHVV @ LHC
- summary and next plan

H(125): J=0 is now strongly favoured by LHC data

FIXED SPIN AND PARITY TESTS

(P. Savard@EPS-HEP2015)

Test alternative fixed spin and parity hypotheses relative to the SM 0^+ hypothesis

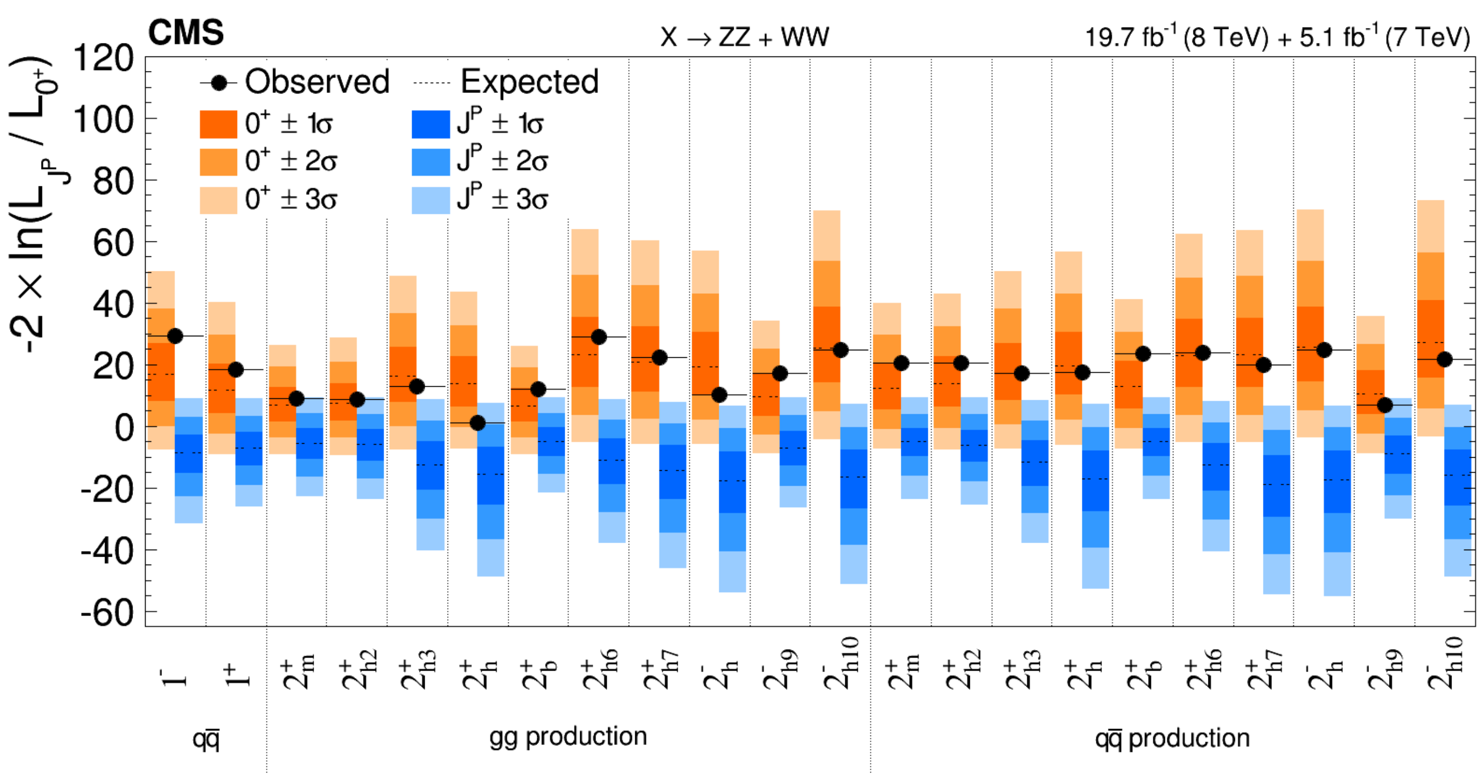
$$\tilde{q} = \log \frac{\mathcal{L}(J^P_{\mathrm{SM}}, \hat{\hat{\mu}}_{J^P_{\mathrm{SM}}}, \hat{\hat{\theta}}_{J^P_{\mathrm{SM}}})}{\mathcal{L}(J^P_{\mathrm{alt}}, \hat{\hat{\mu}}_{J^P_{\mathrm{alt}}}, \hat{\hat{\theta}}_{J^P_{\mathrm{alt}}})}$$

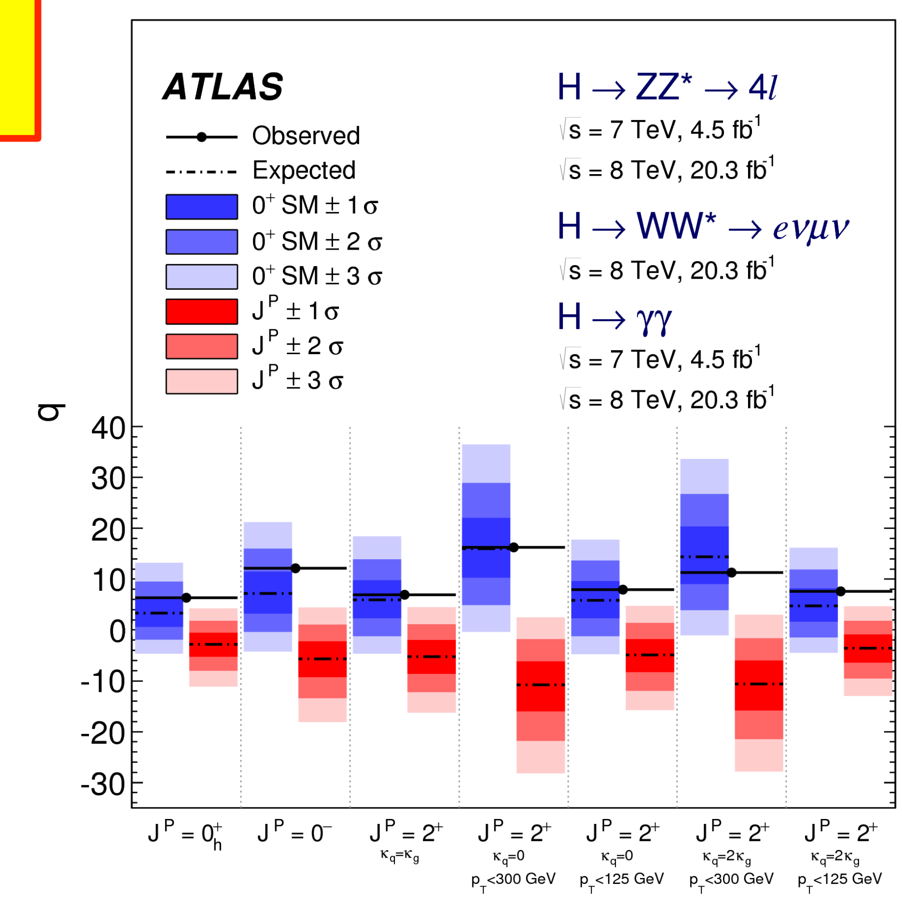
Results favour the spin 0^+ hypothesis

Alternatives: 0-, 1-, 1+, various spin 2 models are typically excluded at > 99.9% CL

Also Tevatron results:
PRL 114, 151802 (2015)

Large anomalous couplings are excluded. Next step: look for presence of smaller contributions





next: probe tensor structure of HVV coupling

$$L_{HVV} = 2M_V^2(\frac{1}{v} + \frac{a}{\Lambda})HV_\mu V^\mu + \frac{b}{\Lambda}HV_{\mu\nu}V^{\mu\nu} + \frac{\tilde{b}}{\Lambda}HV_{\mu\nu}\tilde{V}^{\mu\nu}$$

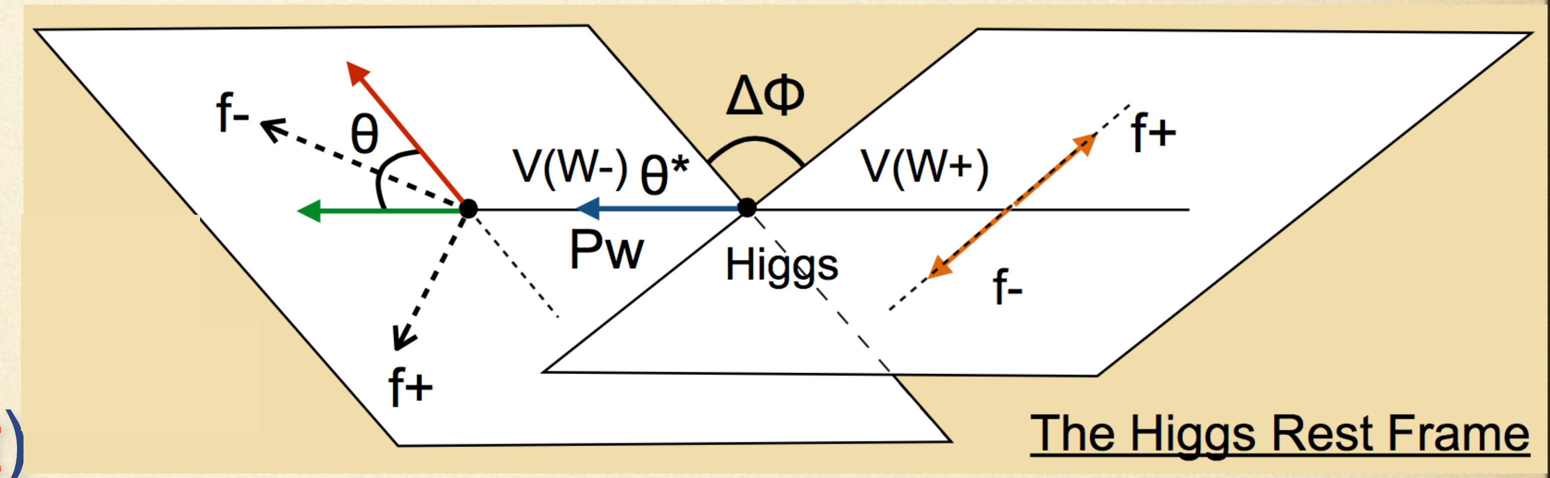
strategy we follow @ ILC:

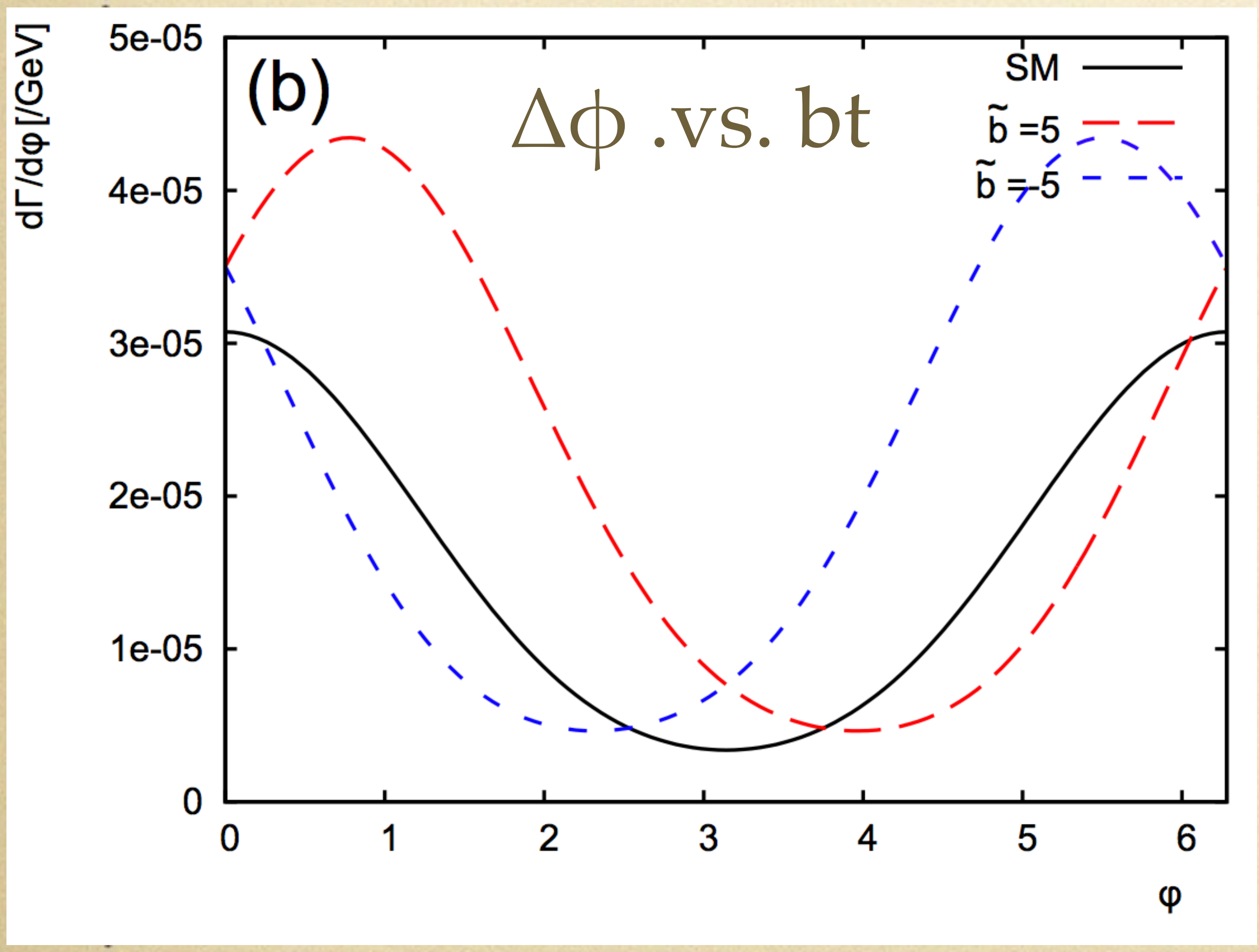
- effective field theory approach (dimension 5)
- *V*: W/Z; $V_{\mu\nu}$: field tensor; $\tilde{V}_{\mu\nu}$: dual tensor
- Λ: new physics scale (set to 1 TeV)
- *a*,*b*, $\tilde{b}$: anomalous coupling (dimensionless)
- a term: SM like, CP-even
- b term: "*B*· *B* - *E*· *E*" type, CP-even
- b-tilde term: "*E*· *B*" type, CP-odd

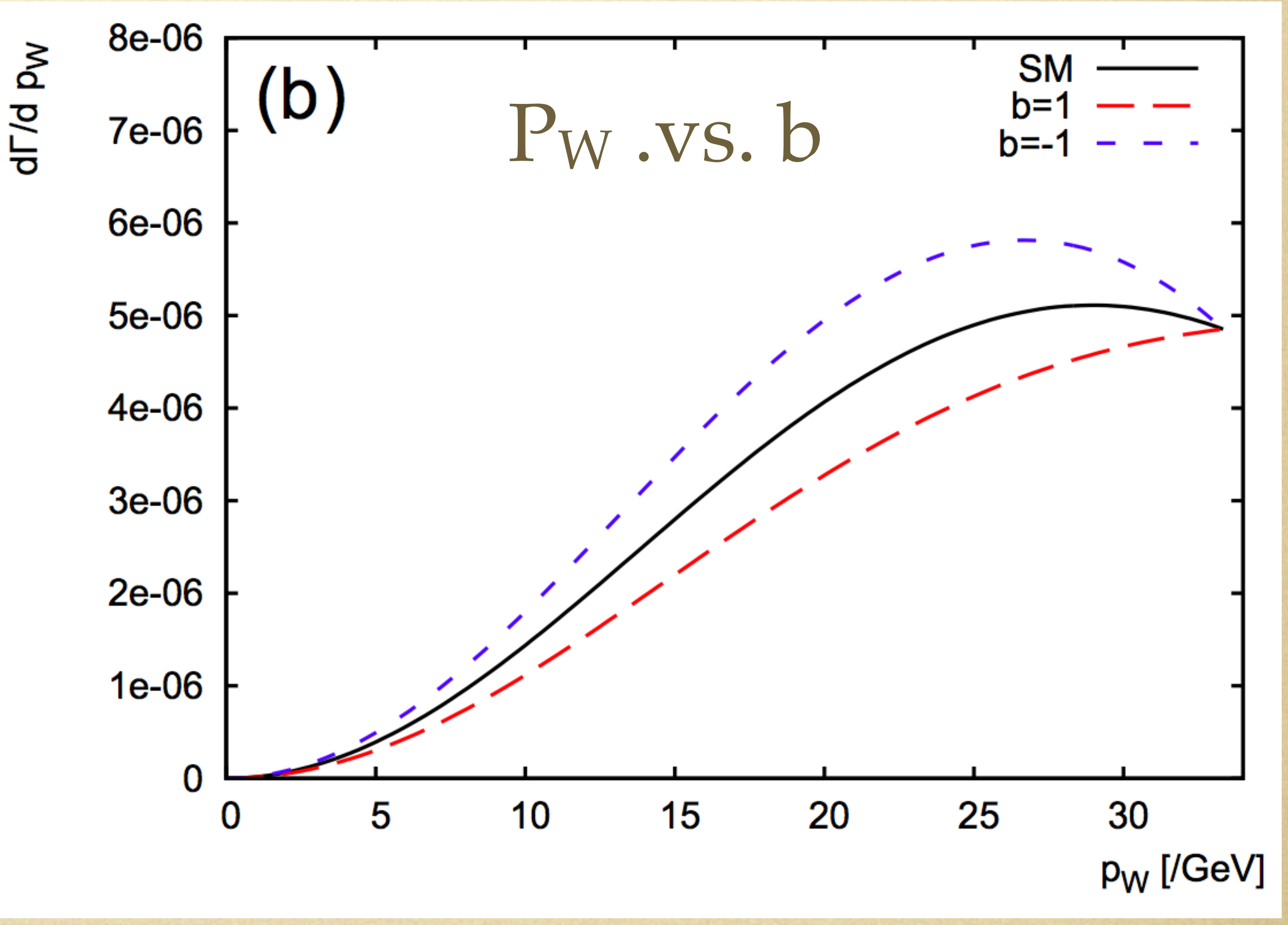
observables sensitive to anomalous couplings

- cross section (a,b,bt)
- angle between two decay planes (bt)
- V momentum (b,bt)
- helicity angle in V—>ff (b,bt)

example in H—>WW*

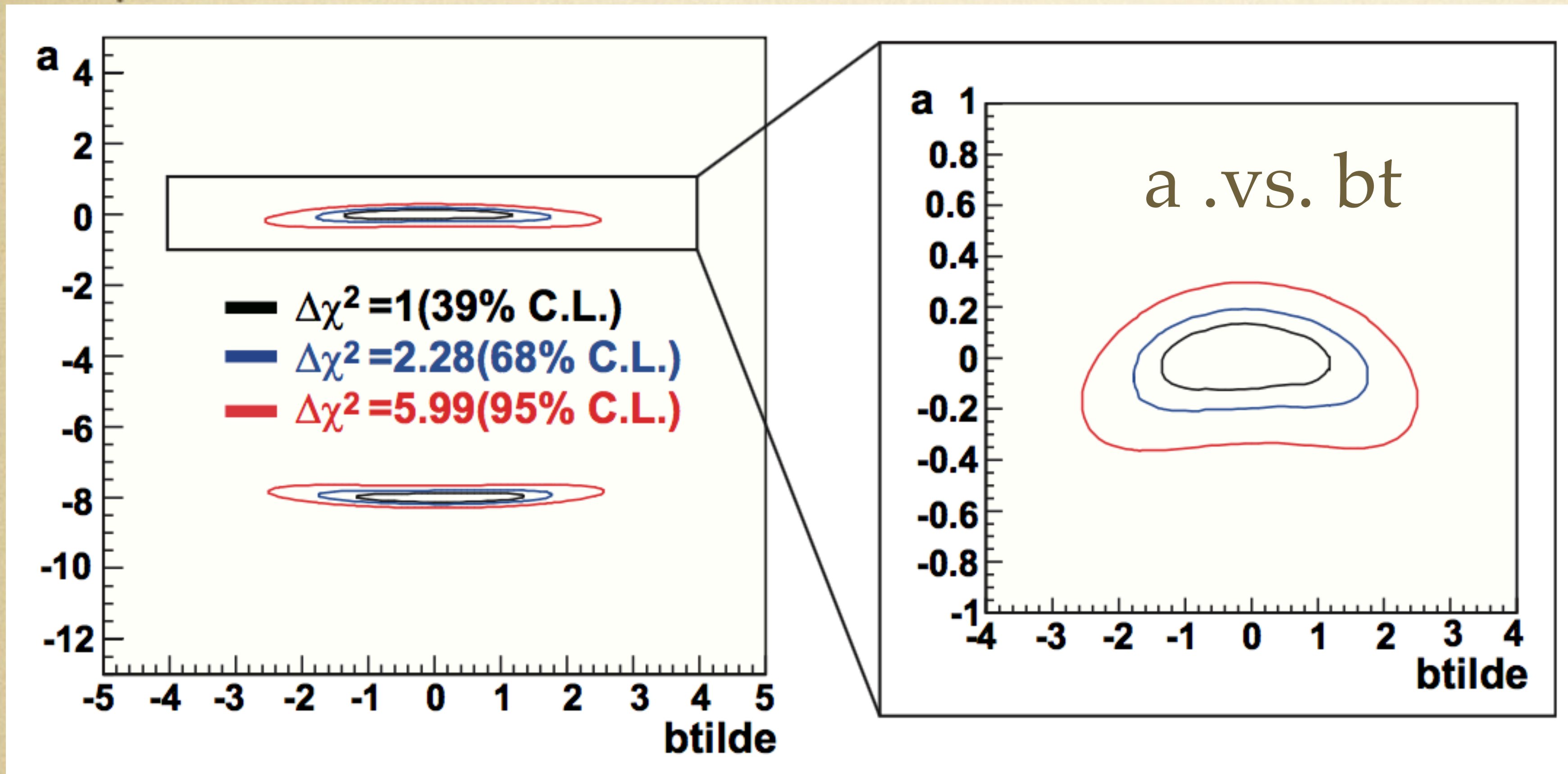


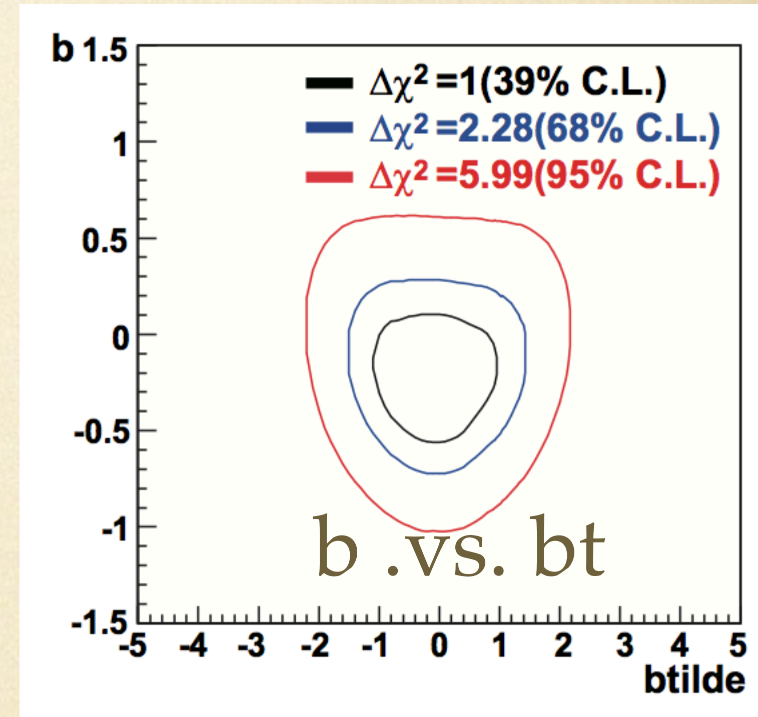


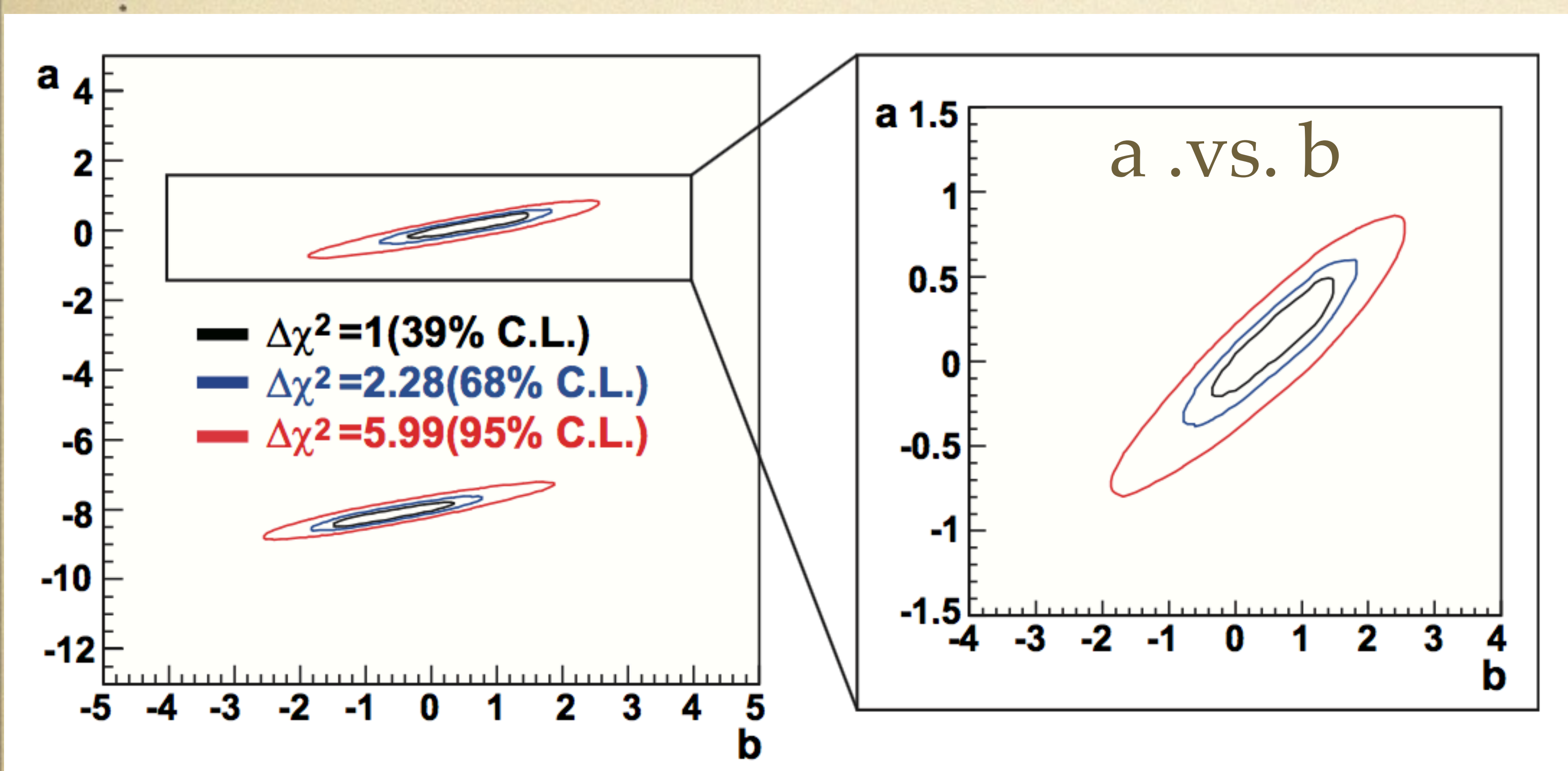


Y. Takubo et al, arxiv:1011.5805

previous study: use just e^+e^-—>ZH—>(νν)(WW*)





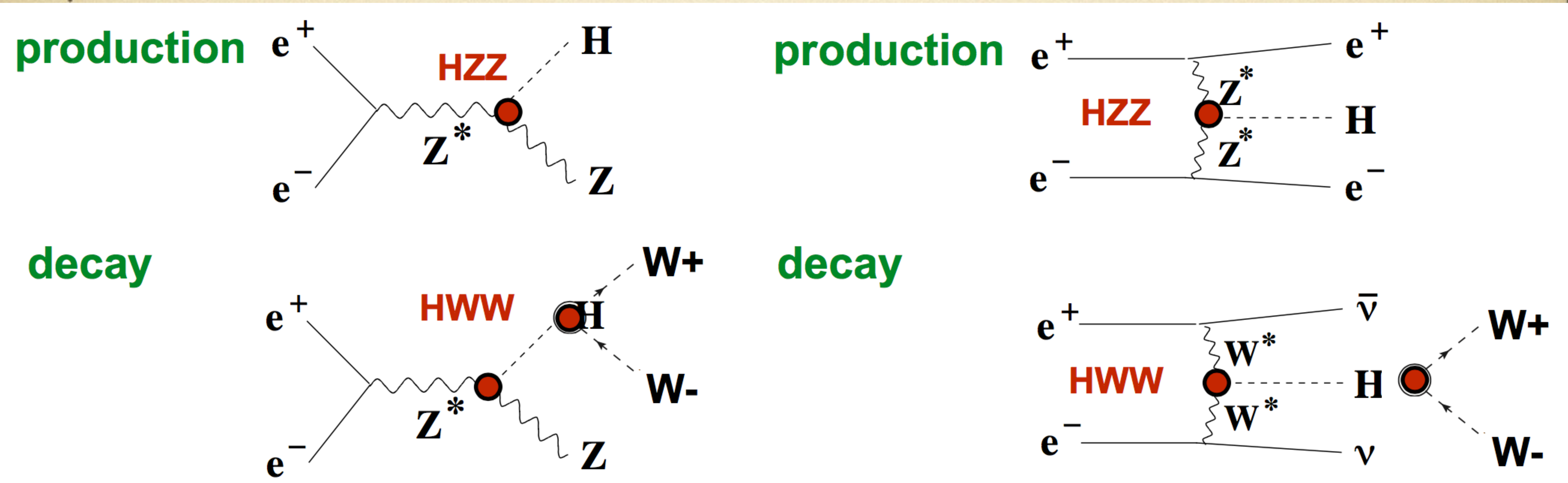


- O(1) constraints on b and b-tilde
- mainly limited by low efficiencies of c-tagging, in the case of soft jets from W*

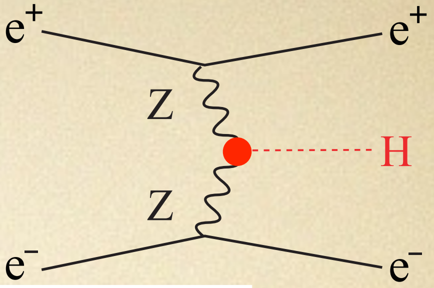
Y. Takubo et al, arxiv:1011.5805

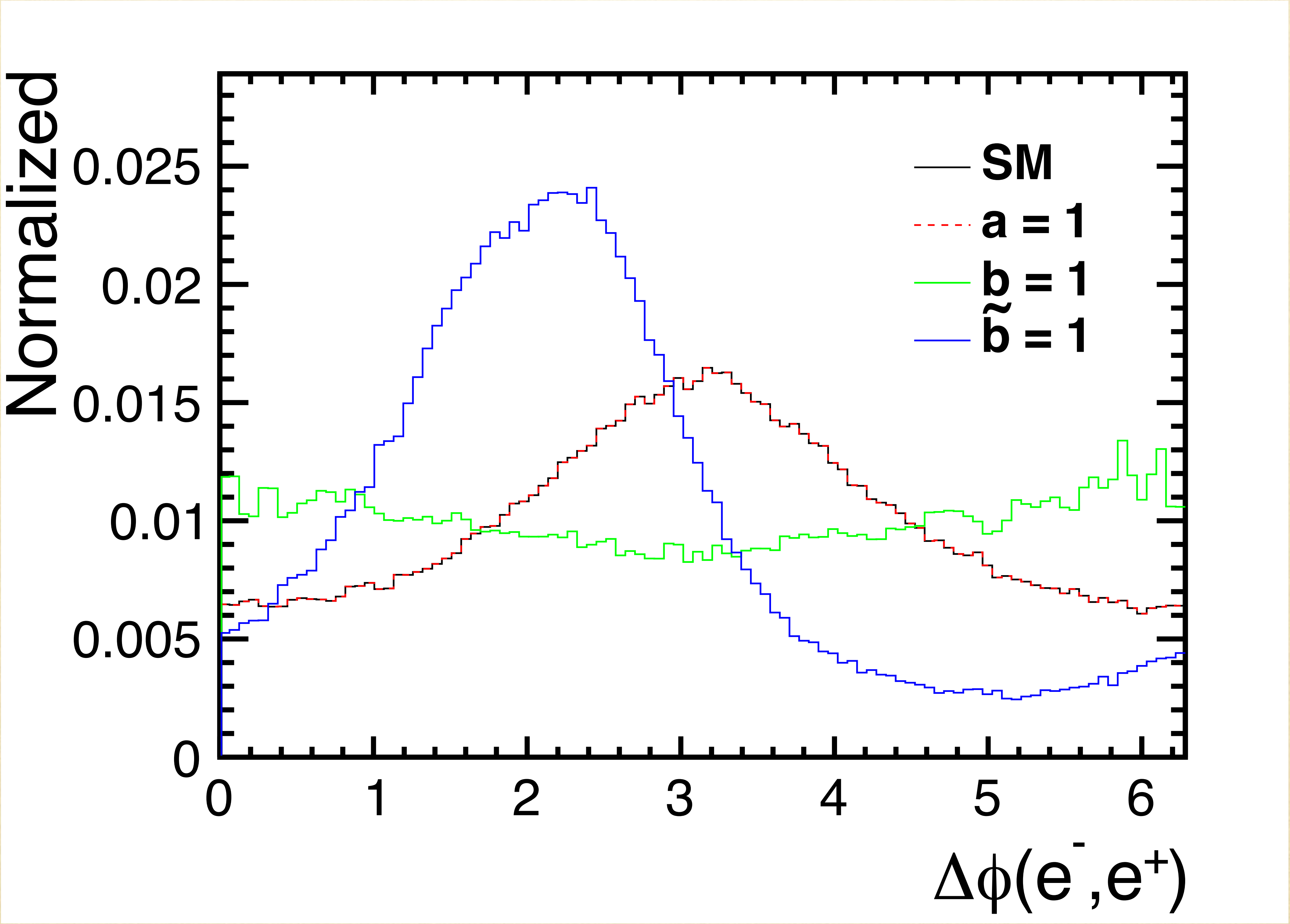
new study: more comprehensive channels

- exploit all production vertex at ILC, V*—>VH, V*V—>H, and all decay vertex H—>VV*
- interesting channels: e^+e^- —> e^+e^-H via ZZ-fusion, where Δϕ can be very well reconstructed (but cross section is not large)
- e^+e^- —>vvH via WW-fusion, where cross section is very large (but Δϕ is difficult due to missing neutrinos)
- e^+e^- —>ZH, using both Z—>ll or Z—>qq, where cross section is large and full kinematics are reconstructed (the most sensitive channel)



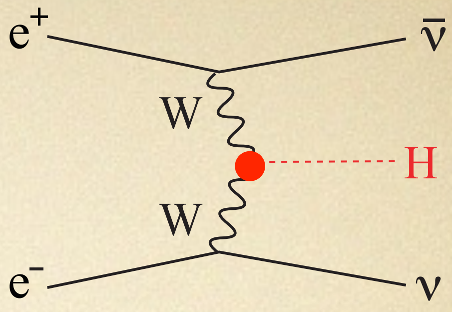
example in e^+e^- —> e^+e^-H via ZZ-fusion

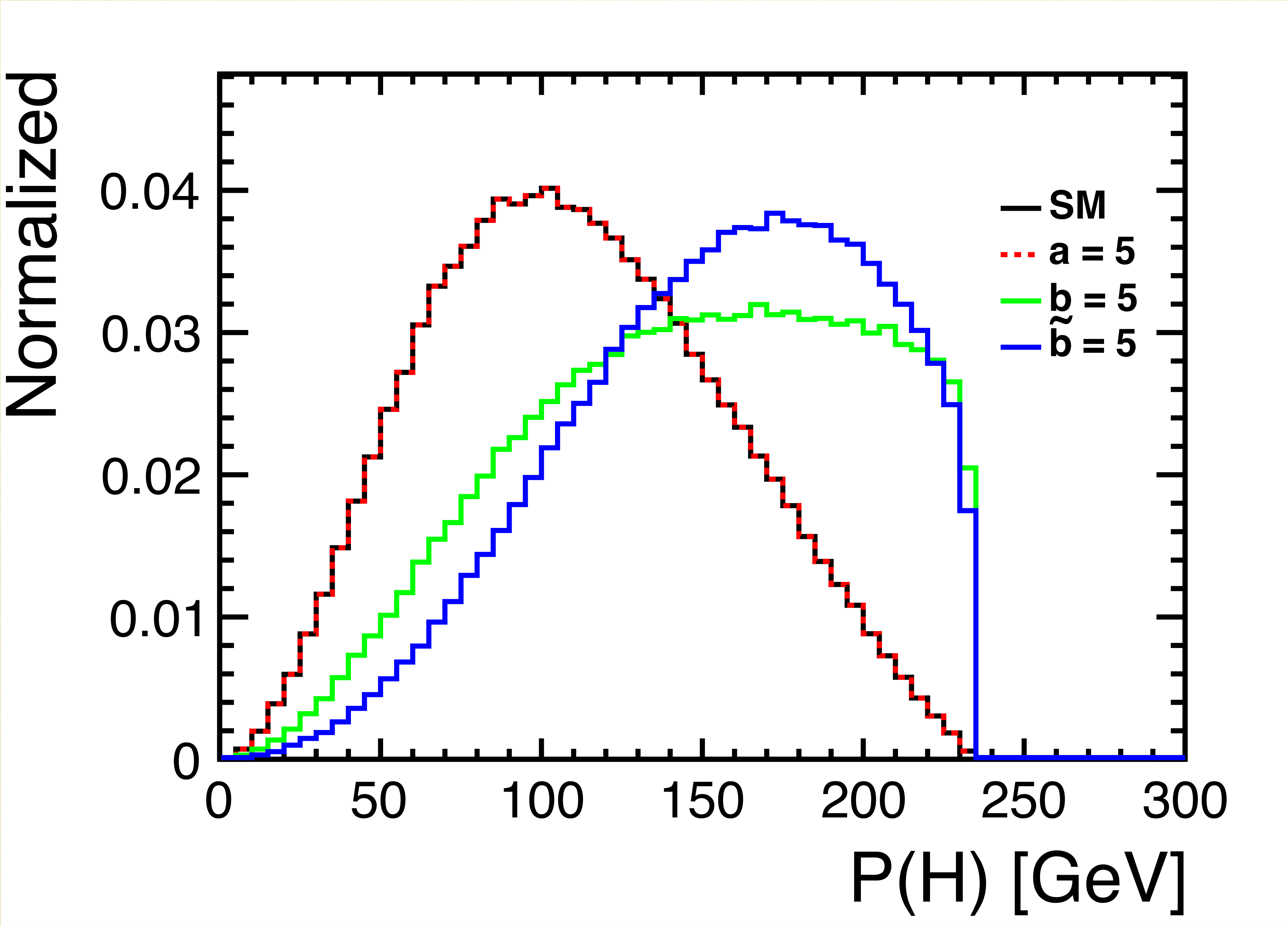




Δφ between two decay planes —> Δφ between final electron pairs

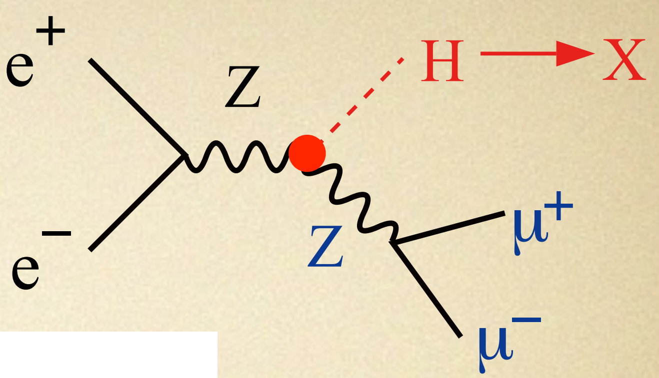
example in e^+e^- —> ννH via WW-fusion

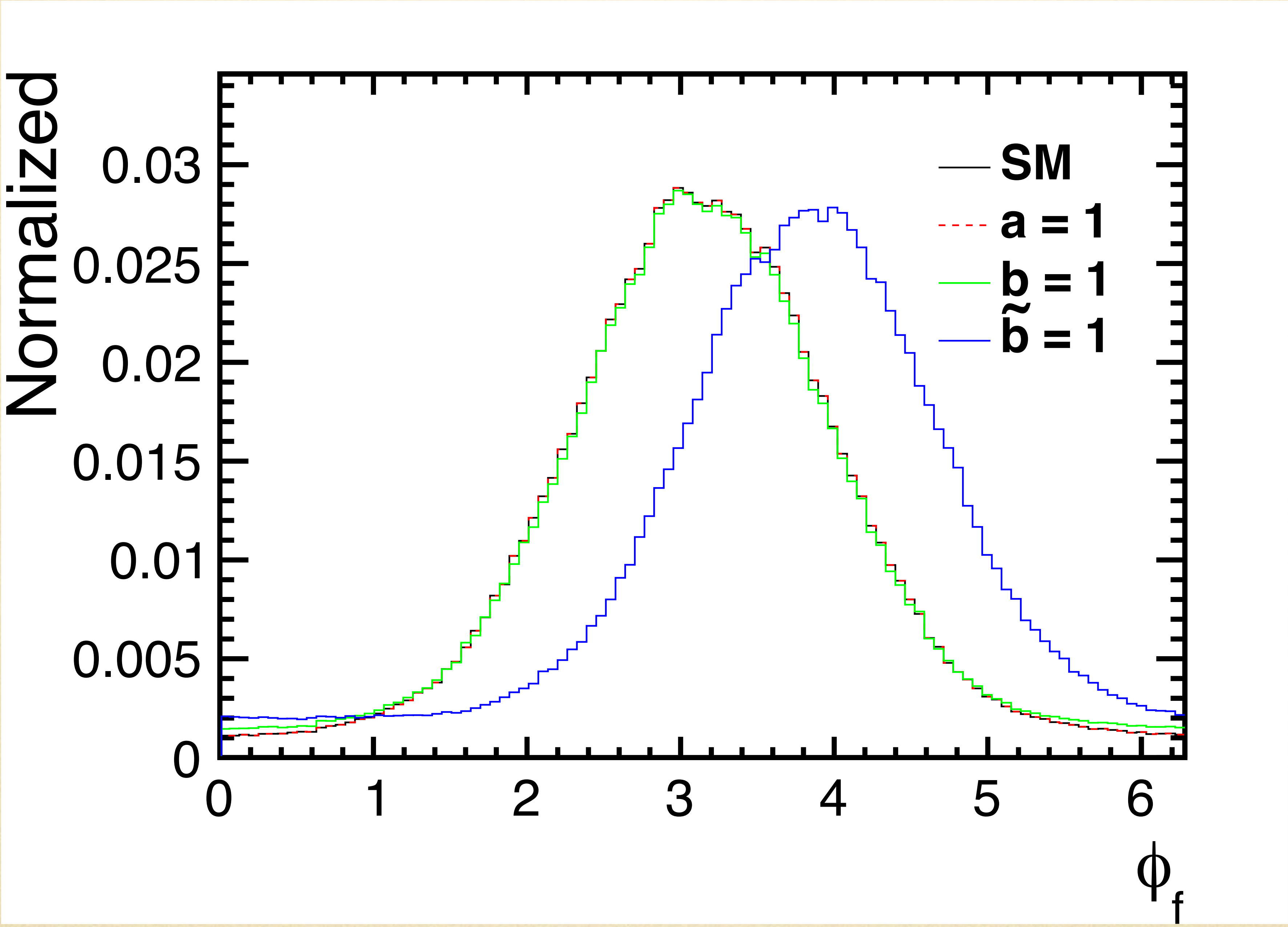




though Δφ can't be reconstructed, P_H is very useful

example in e^+e^- —> ZH, Z—>ll/qq





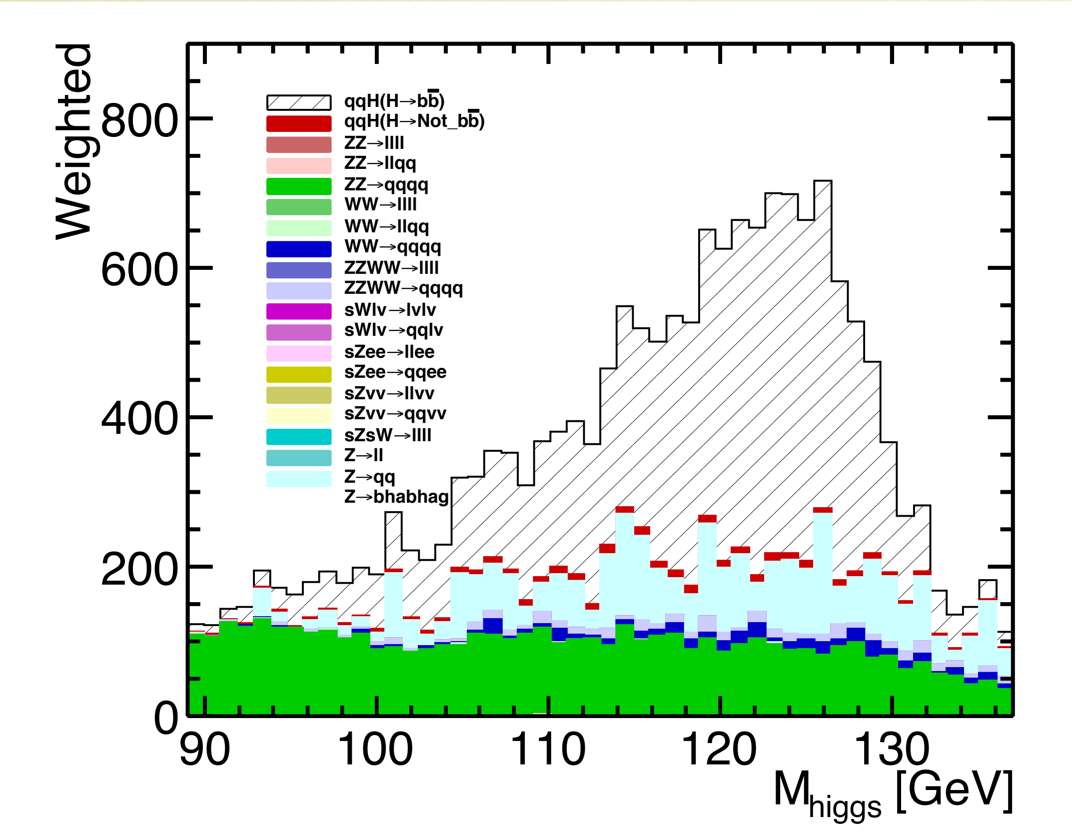
Z* is at rest —> Δφ can be simplified by Δφ between production plane and Z decay plane

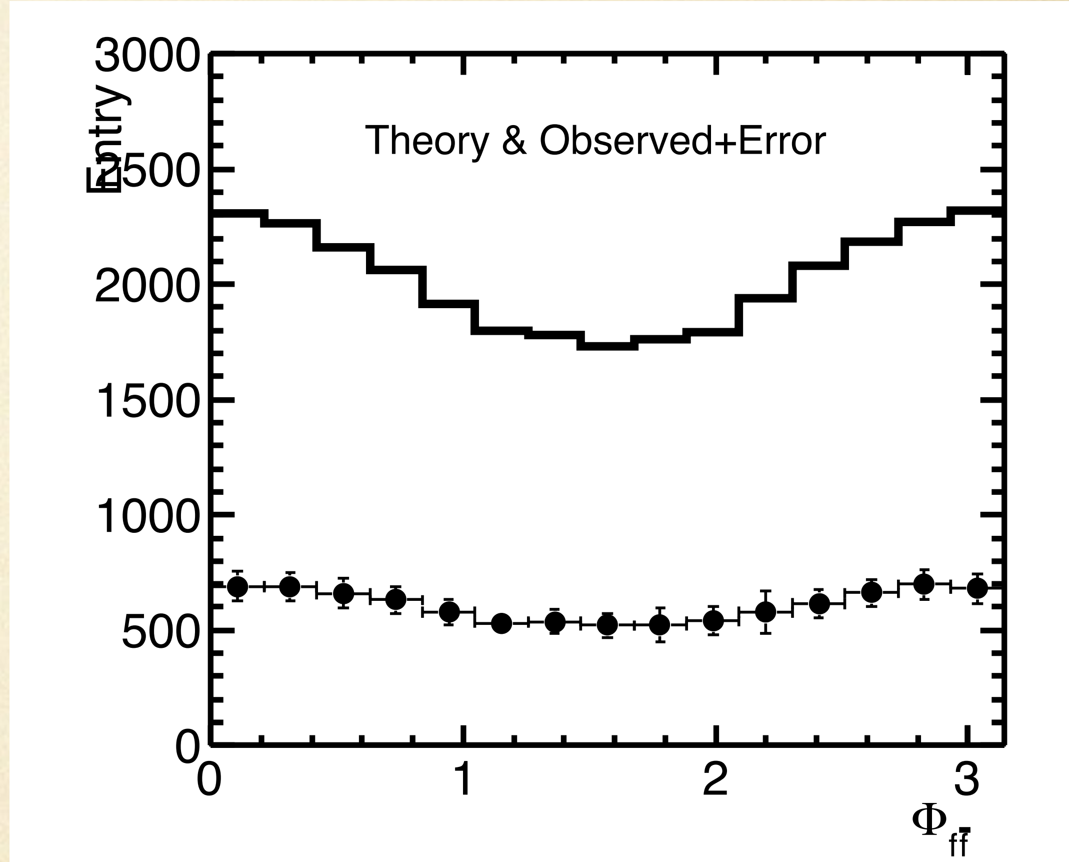
full simulation analysis probing anomalous HZZ @ ILC

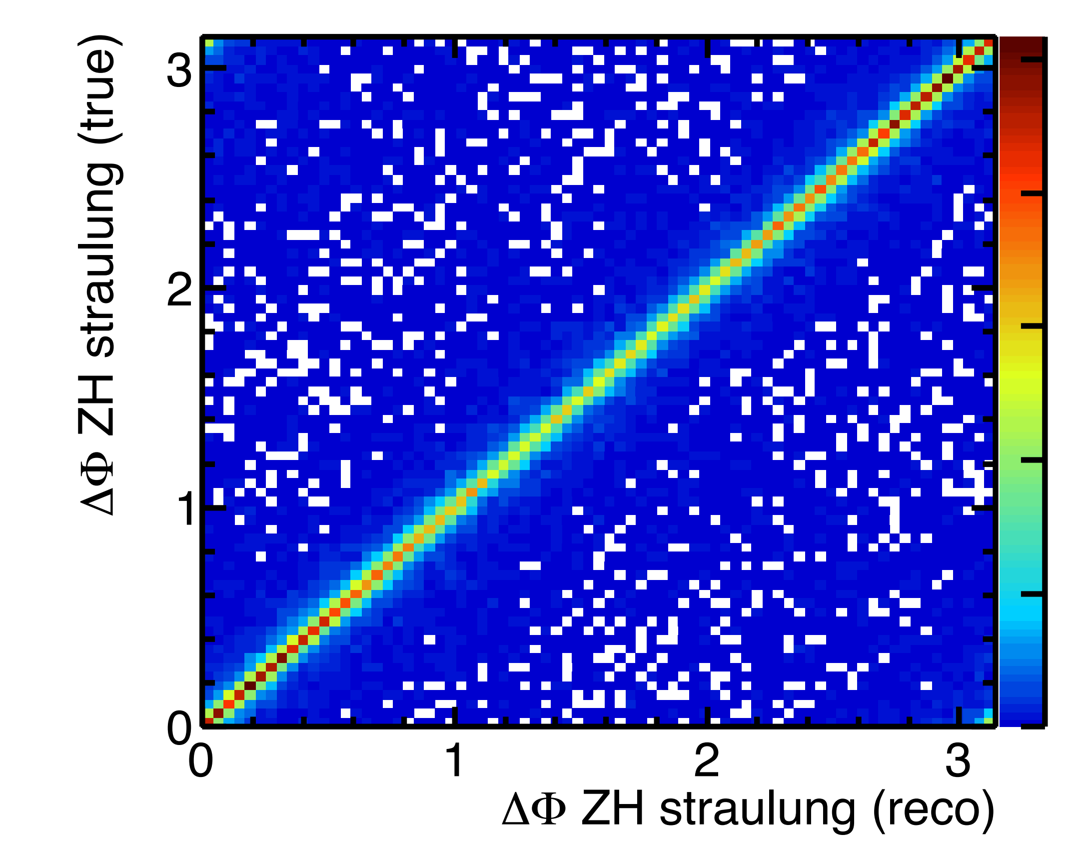
brief procedure:

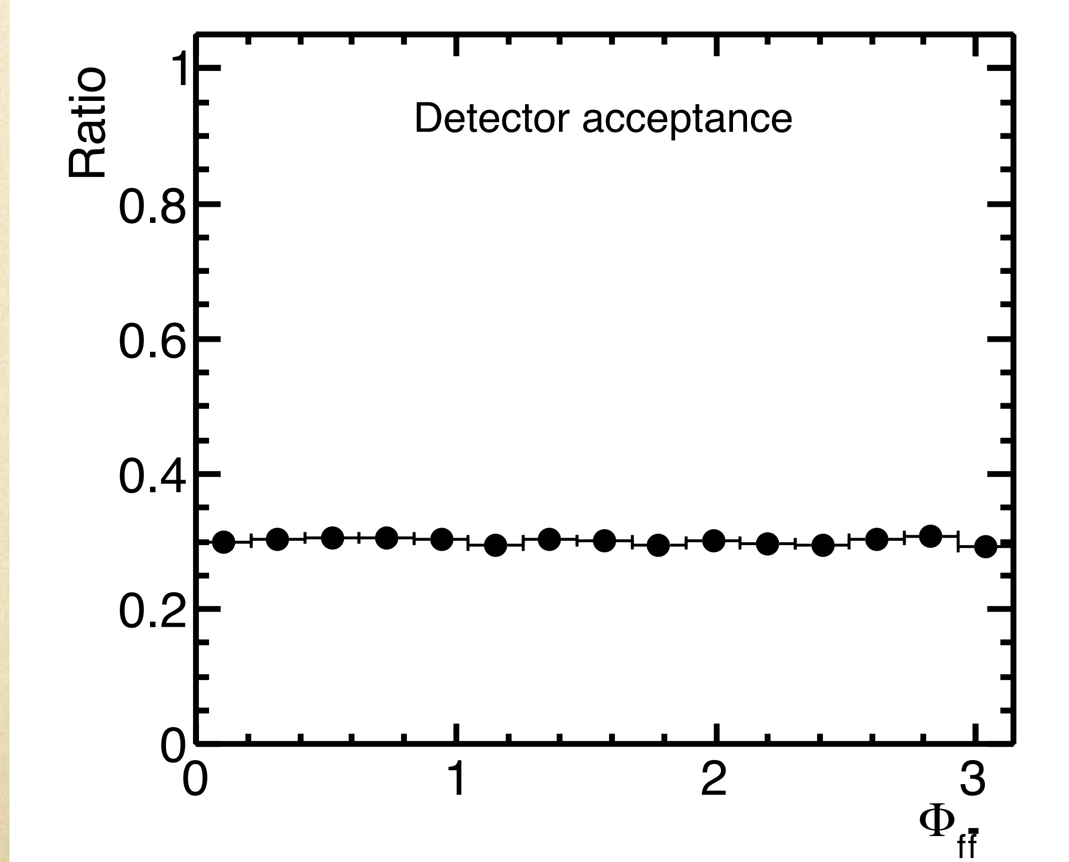
- produce SM signal and all SM background events based on full detector simulation
- do the “normal” analysis to suppress BG (not to bias the distribution of observables used for probing aHZZ)
- extract the observables for signals and get acceptance function by comparing to generator
- use the acceptance function to give the observables in case of any anomalous coupling
- compare the observables by SM events and anomalous events, to draw the sensitivity of aHZZ coupling

example in e+e- —> ZH —> qqbb

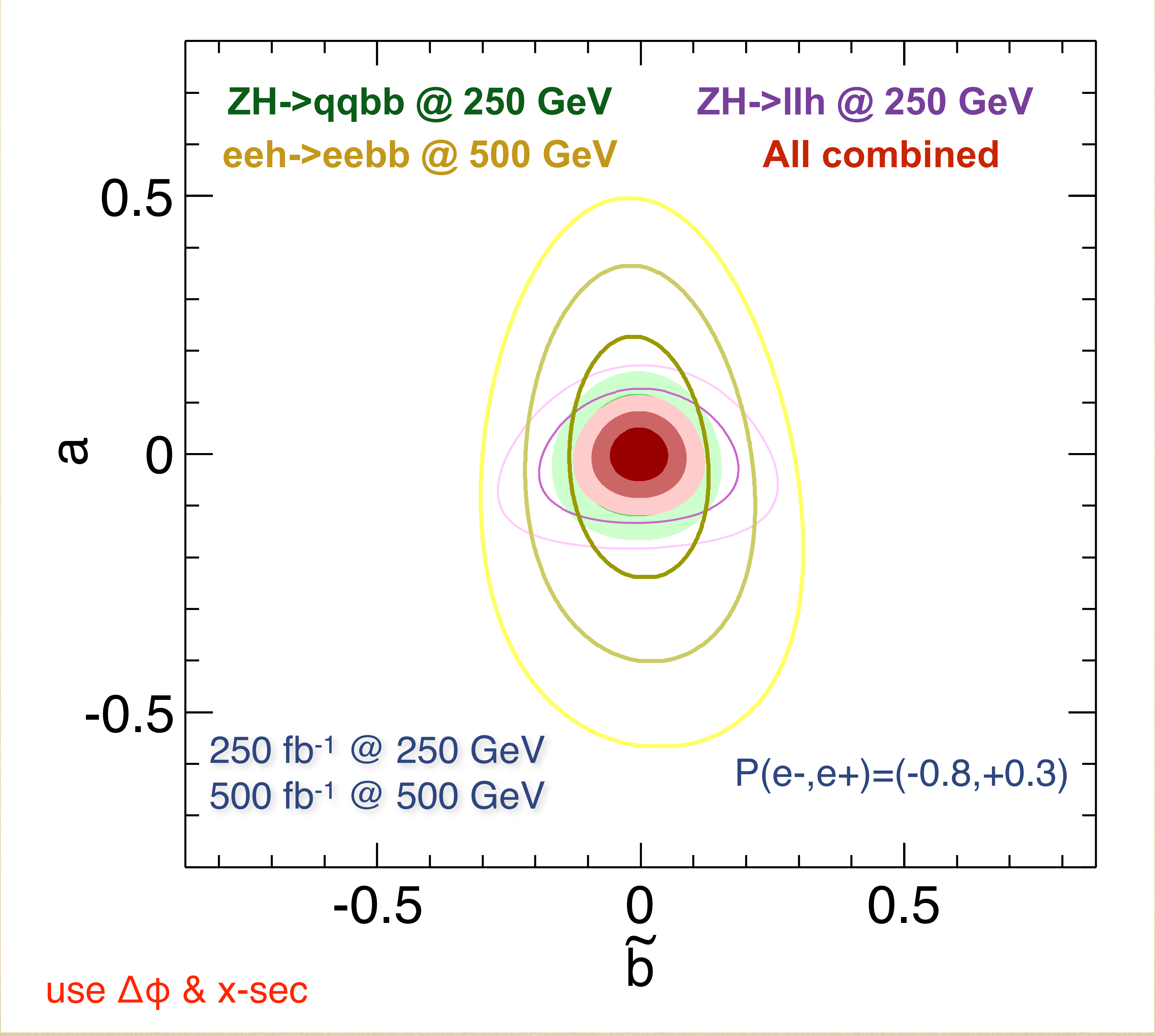






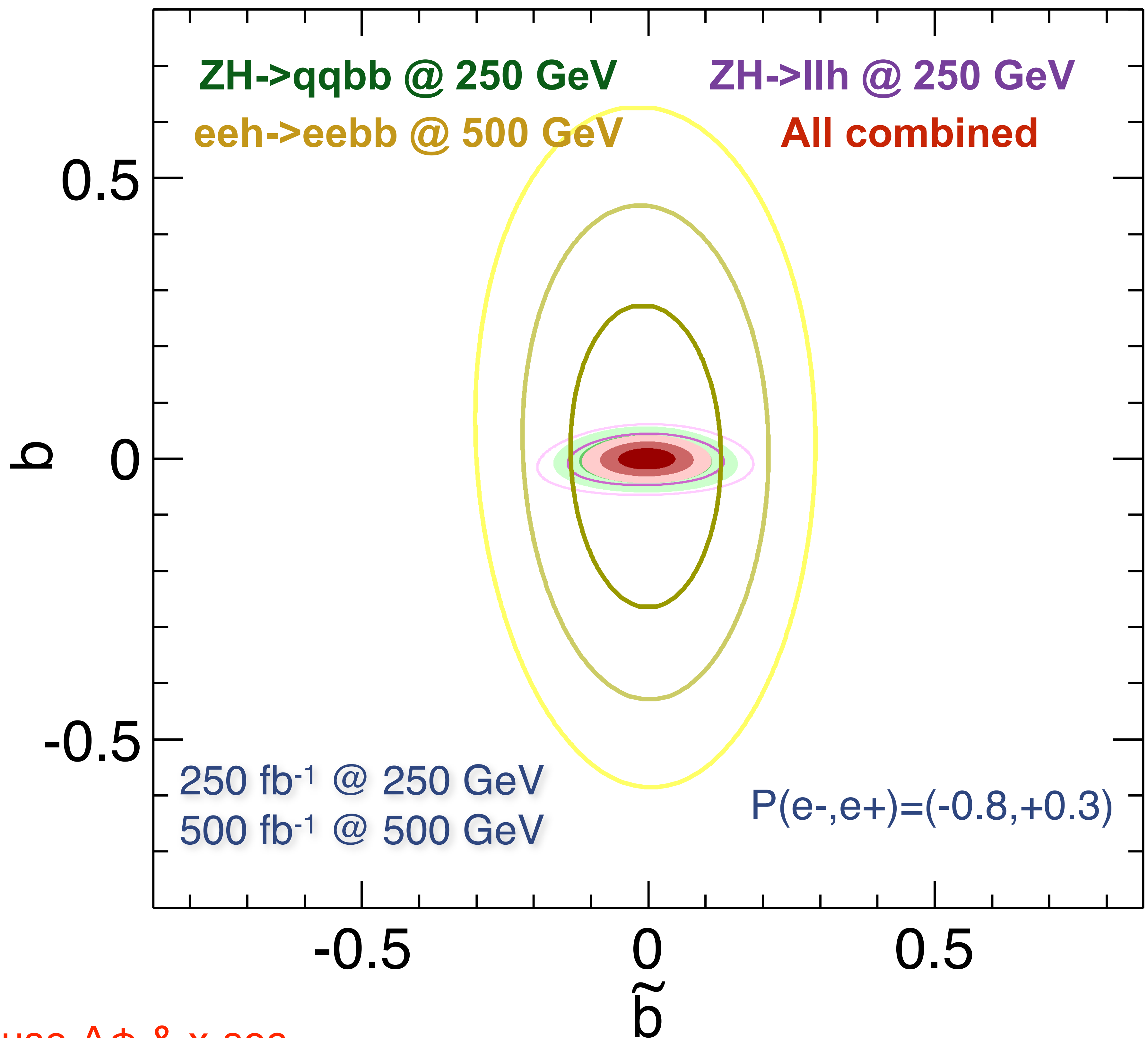


results of sensitivity of aHZZ @ ILC (a .vs. bt)



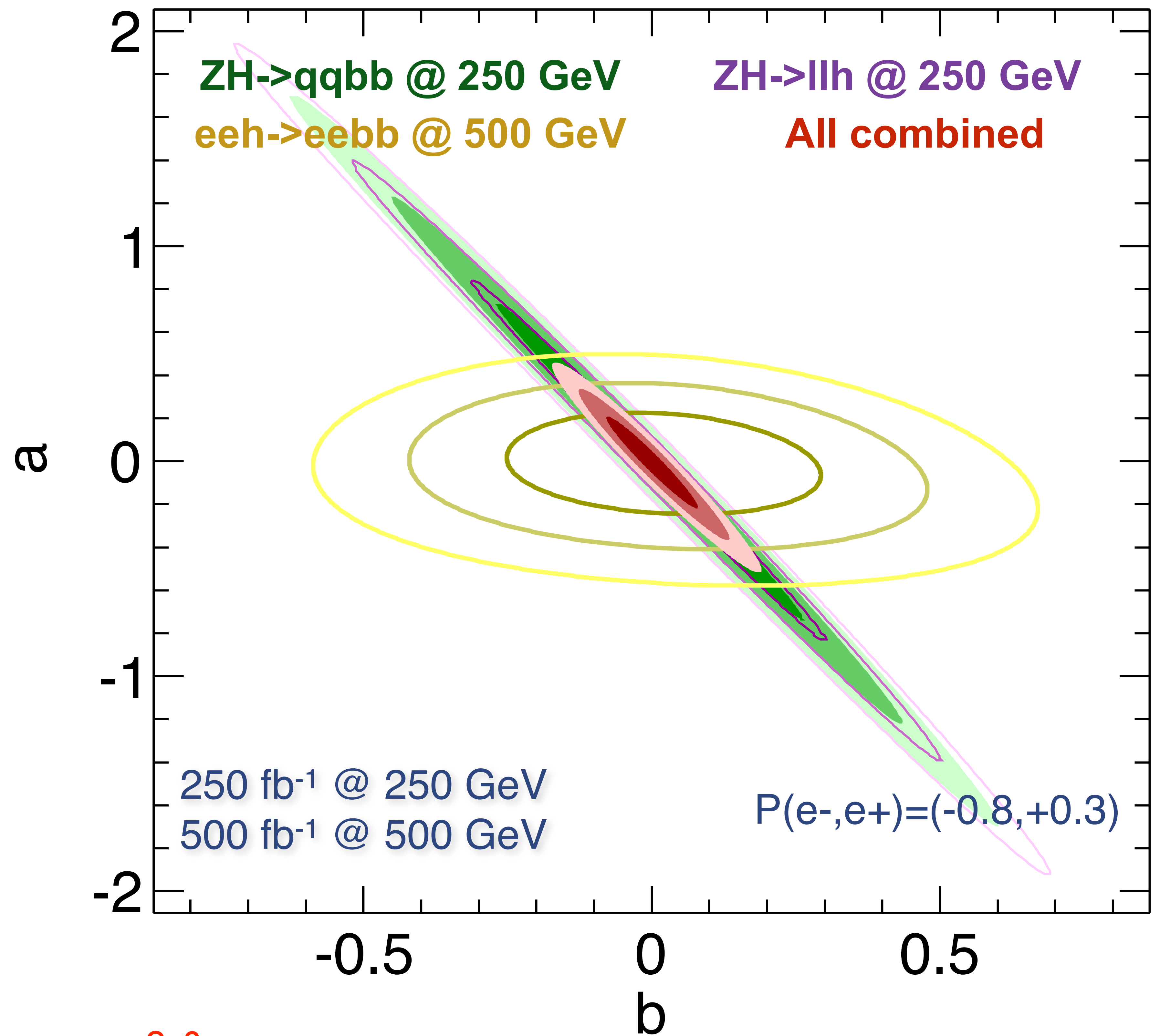
three contours for each color: 1σ/2σ/3σ constraints

results of sensitivity of aHZZ @ ILC (b .vs. bt)



use Δφ & x-sec

results of sensitivity of aHZZ @ ILC (a .vs. b)



use cosθ & x-sec

CMS CP Mixing Results

(P. Savard@EPS-HEP2015)

Probe potential CP-mixing and tensor structure of Higgs interactions

- Amplitude describing interaction between a spin 0 and two spin 1 particles:

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} \right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

$$f_{\Lambda 1} = \frac{\tilde{\sigma}_{\Lambda 1} / (\Lambda_1)^4}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1} / (\Lambda_1)^4 + \ldots}, \qquad \phi_{\Lambda 1},$$

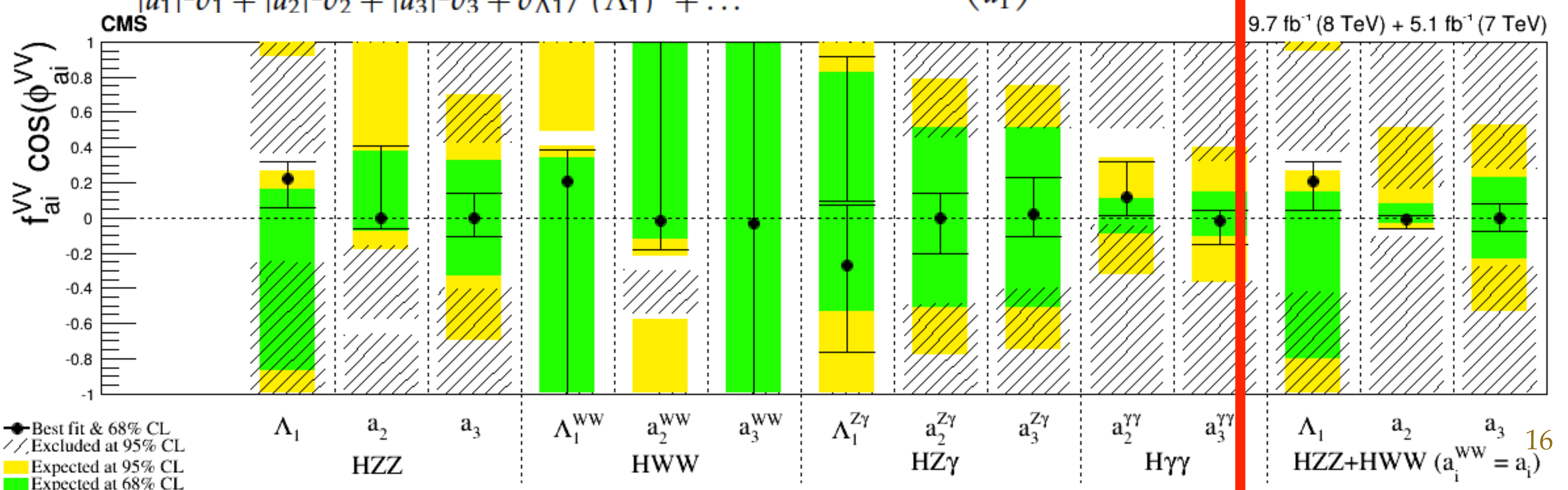
$$f_{a2} = \frac{|a_2|^2\sigma_2}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1} / (\Lambda_1)^4 + \ldots}, \qquad \phi_{a2} = \arg\left(\frac{a_2}{a_1}\right)$$

$$f_{a3} = \frac{|a_3|^2\sigma_3}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1} / (\Lambda_1)^4 + \ldots}, \qquad \phi_{a3} = \arg\left(\frac{a_3}{a_1}\right)$$

σ_i : xs for $a_i = 1$

$\Lambda_1 = 1$ TeV

Phys Rev D. 89.035007



ATLAS CP Mixing Results

(P. Savard@EPS-HEP2015)

Lagrangian describing interaction between a spin 0 and a pair of W or Z bosons (from JHEP 1311 (2013) 043):

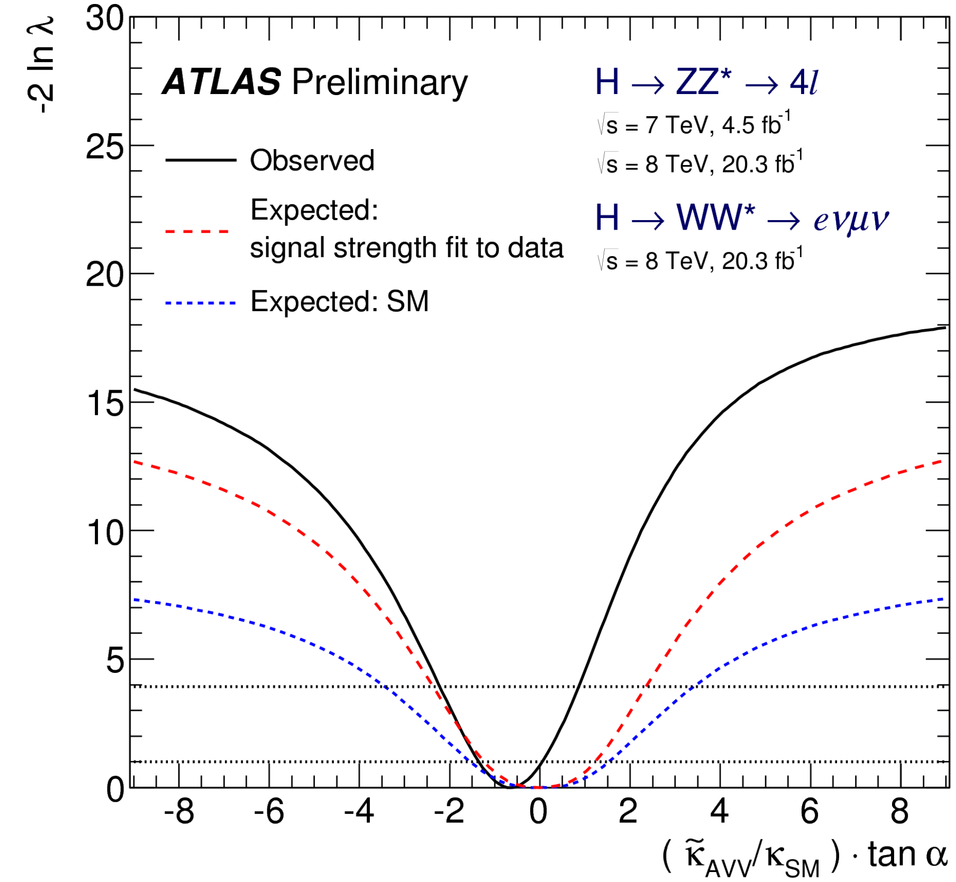
$$\mathcal{L}_0^V = \Big\{c_\alpha \kappa_{SM}\left[\tfrac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W^+_\mu W^{-\mu}\right] - \tfrac{1}{4}\tfrac{1}{\Lambda}\left[c_\alpha \kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu}\right] - \tfrac{1}{2}\tfrac{1}{\Lambda}\left[c_\alpha \kappa_{HWW} W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW} W^+_{\mu\nu} \tilde{W}^{-\mu\nu}\right]\Big\} X_0.$$

J^P	Model	Choice of tensor couplings			
		κ_{SM}	κ_{HVV}	κ_{AVV}	α
0^+	Standard Model Higgs boson	1	0	0	0
0^+_h	BSM spin-0 CP-even	0	1	0	0
0^-	BSM spin-0 CP-odd	0	0	1	$\pi/2$

CMS/ATLAS comparison (Michael Duehrssen)

No significant contributions from BSM terms are observed

ATLAS paper: JHEP 1311 (2013) 043



BSM CP-even (95% CL)

CMS $f_{a2}\cos(\phi_{a2}) \in [-0.11, 0.17]$

ATLAS $f_{a2} < 0.12$ for $\phi_{a2} = 0$

$f_{a2} < 0.16$ for $\phi_{a2} = \pi$

BSM CP-odd (95% CL)

CMS $f_{a3}\cos(\phi_{a3}) \in [-0.27, 0.28]$

ATLAS $f_{a3} < 0.090$ for $\phi_{a3} = 0$

$f_{a3} < 0.41$ for $\phi_{a3} = \pi$

comparison of aHVV in Snowmass

(arxiv: 1310.8361; 1309.4819)

convension: transalte f_{ai} at different collider, Ecm to f_{ai} in decay

$$A(X_{J=0} \to VV) = v^{-1} \left(a_1 m_V^2 \epsilon_1^* \epsilon_2^* + a_2 f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \right)$$

$$f_{CP} = \frac{|a_3|^2 \sigma_3}{\sum |a_i|^2 \sigma_i}$$

Collider	pp	pp	e^+e^-	e^+e^-	e^+e^-	e^+e^-	$\gamma\gamma$	$\mu^+\mu^-$	target
E (GeV)	14,000	14,000	250	350	500	1,000	126	126	(theory)
$\mathcal{L}$ (fb^{-1})	300	3,000	250	350	500	1,000	250		
spin-2^+_m	$\sim 10\sigma$	$\gg 10\sigma$	$>10\sigma$	$>10\sigma$	$>10\sigma$	$>10\sigma$			$>5\sigma$
$VVH^\dagger$	0.07	0.02	✓	✓	✓	✓	✓	✓	$< 10^{-5}$
$VVH^\ddagger$	$4\cdot10^{-4}$	$1.2\cdot10^{-4}$	$7\cdot10^{-4}$	$1.1\cdot10^{-4}$	$4\cdot10^{-5}$	$8\cdot10^{-6}$	–	–	$< 10^{-5}$
$VVH^\diamond$	$7\cdot10^{-4}$	$1.3\cdot10^{-4}$	✓	✓	✓	✓	–	–	$< 10^{-5}$

† estimated in $H \to ZZ^*$ decay mode

‡ estimated in $V^* \to HV$ production mode

◇ estimated in $V^*V^* \to H$ (VBF) production mode

translate our new result O(0.1) sensitivity on b-tilde at 250 GeV using 250 fb-1

—> $f_{CP} \sim 1.0\text{x}10^{-4}$, which is already improved by a factor of 7

—> $f_{CP} \sim 1.2\text{x}10^{-5}$, b-tilde ~ O(0.03), assuming 2 ab-1 in H20 scenario

—> $f_{CP} \sim 1.0\text{x}10^{-6}$, b-tilde ~ O(0.01), + 4 ab-1 @ 500 GeV in H20 scenario

summary and next plan

$$L_{HVV} = 2M_V^2(\frac{1}{v} + \frac{a}{\Lambda})HV_\mu V^\mu + \frac{b}{\Lambda}HV_{\mu\nu}V^{\mu\nu} + \frac{\tilde{b}}{\Lambda}HV_{\mu\nu}\tilde{V}^{\mu\nu}$$

- spin 0 is favoured for H(125), and CP-even fraction should be dominant; next experimental challenge is to probe a possible small CP-odd mixture
- d5 effective field theory approach is commonly adopted to study the tensor structure of HVV coupling
- at the ILC, taking advantage of the major Higgs production channels, HVV coupling can be precisely measured
- based on full simulation analysis, anomalous couplings, a/b/b-tilde, can be probed up to O(0.01) with Λ=1TeV at ILC assuming H20 operating scenario; what kind of BSM models can be tested?
- next step: finish remaining HZZ channels and move to HWW channels; combine individual observables to get better sensitivity, and eventually use optimal matrix element method

backup

Simulation Test

>. Procedure

>. What we want to do : Estimate the sensitivity to anomalous components with several parameters using $\chi 2$ test (MC simulation)

>. What we have to do : Estimate the detector acceptance for each sensitive parameter "θ* and Φ" with bias as less as possible (Full simulation)

multiply by the effect of detector acceptance

$$\chi^2 = \sum_{bin=1}^{Nbins} \left(\frac{y_{bin}^{SM-MC} - f_{\text{Theory model}}(x_{bin}; a, b, \tilde{b})}{\sigma_{bin}^{SM-MC}} \right)^2$$

Error of observed signals

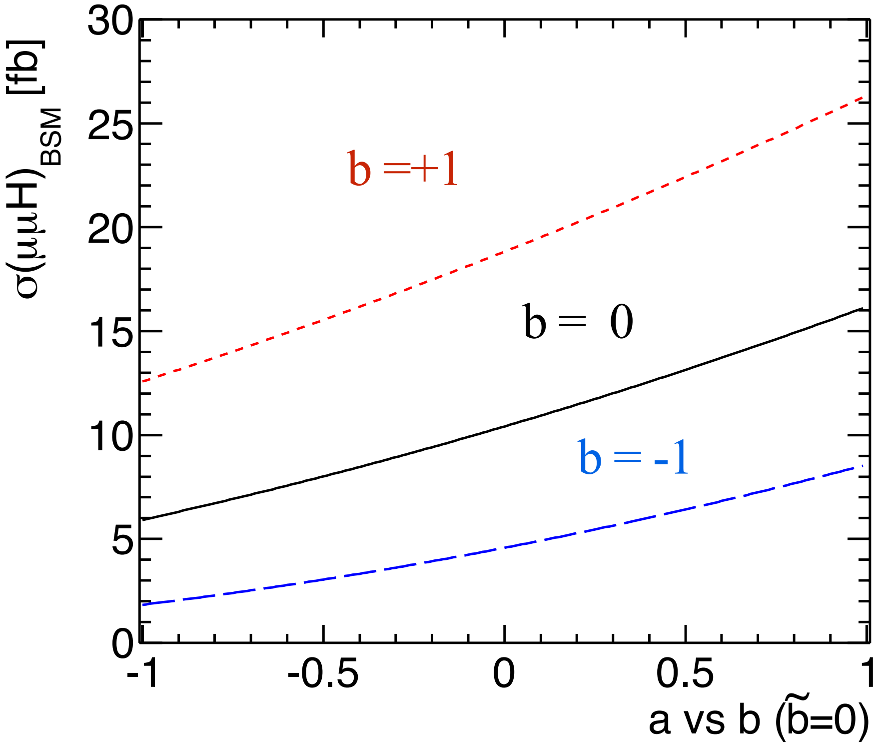
>. For less bias : Any angle cut (also related to angles) for Bkgs suppression should not be used.

>. For less error : Values of each cut variables for Bkgs suppression are set to take the maximum significance.

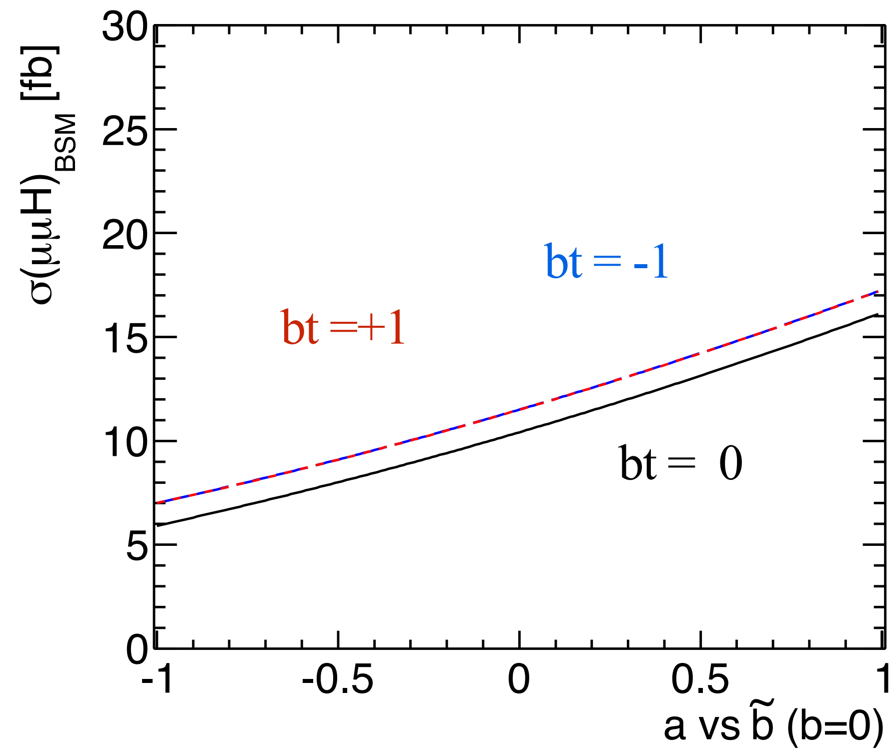
Difference of the Cross Section

>. 250GeV, Zh ➡ eeh/μμh (recoil analysis)

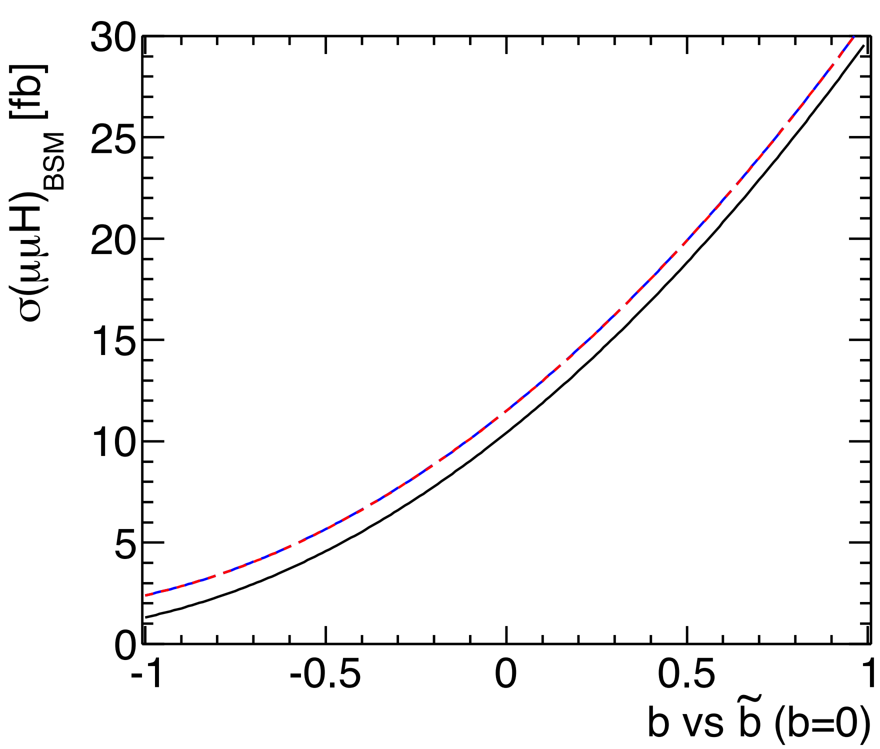
b affect σ strongly



x axis: a



x axis: a



x axis: b

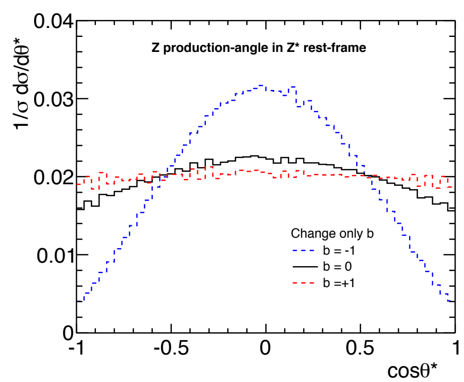
Difference of the Angle Distributions (calculation is based on Lab frame)

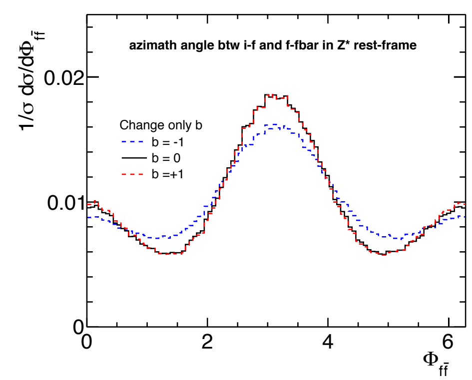
>. 250GeV, Zh ➡ eeh/μμh (recoil analysis)

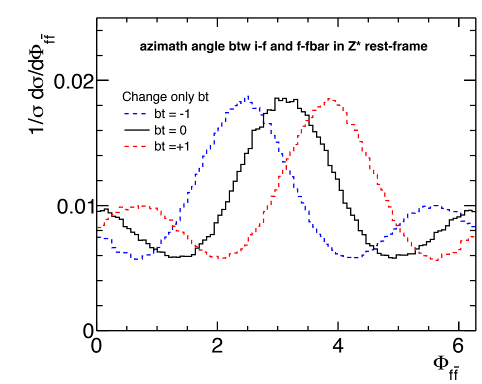
>. Parameter "b" is changed | **>. Parameter "b" is changed** | **>. Parameter "bt" is changed**

cosθ* | **Φ** | **Φ**

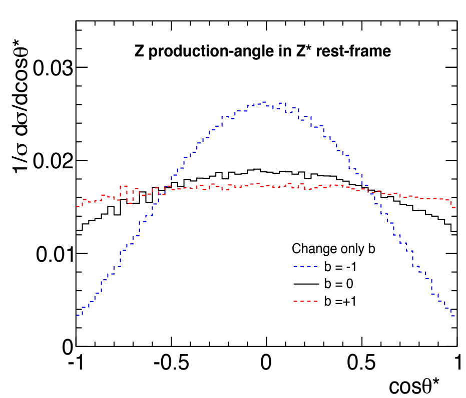
— **SM**
— **parameter: - 1**
— **parameter: +1**

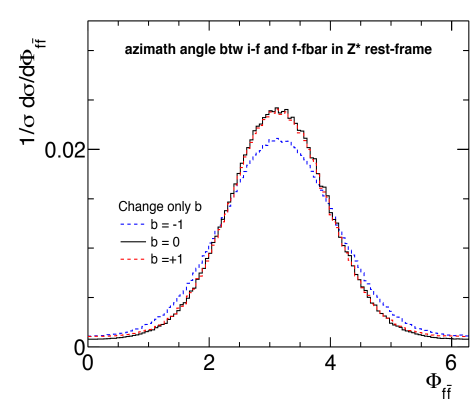


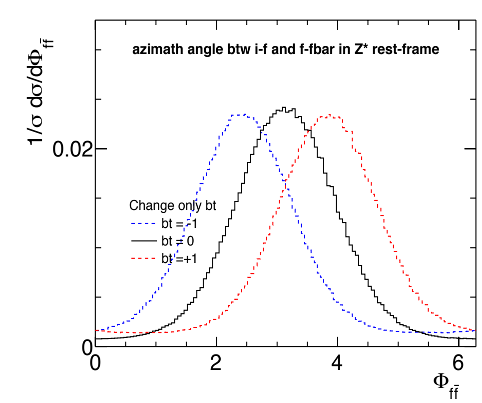




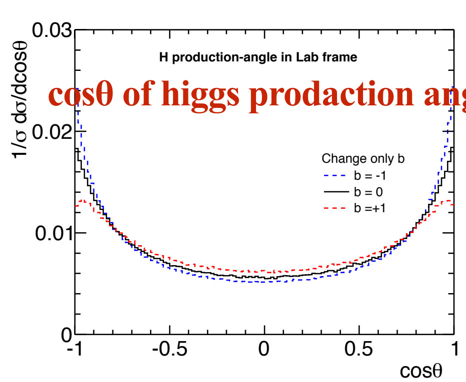
>. 250GeV, Zh ➡ qqbb (hadronic process)

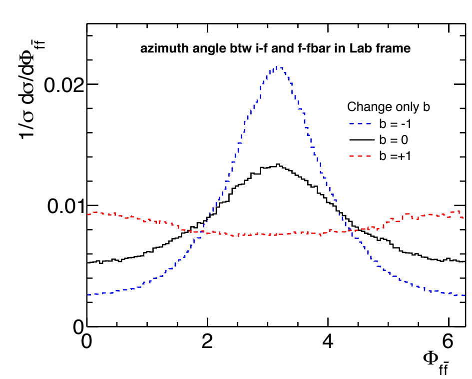






>. 500GeV, eeh ➡ eebb (ZZ-fusion)





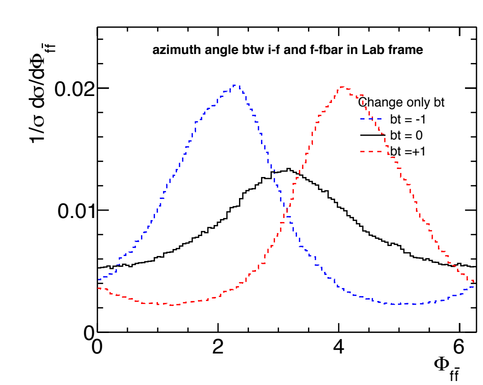


TABLE II: Description of processes used for HVV tensor structure measurements with the corresponding cross sections ratios, where σ_1, σ_2, or σ_4 corresponds to $g_1 = 1$, $g_2 = 1$, or $g_4 = 1$, respectively, and $\sigma_+ = \sigma_1$ ($g_+ = g_1$) for all processes except couplings to massless vector bosons ($Z\gamma, \gamma\gamma, gg$) where $\sigma_+ = \sigma_2$ ($g_+ = g_2$). MC simulation parameters used in studies are shown, where the generated coupling g_i values correspond to certain f_{a2} and f_{a3} values. The expected precision on the f_{a2} and f_{a3} parameters are quoted for 300 fb^{-1} (first row) and 3000 fb^{-1} (second row) scenarios on LHC and four energy scenarios on an e^+e^- machine, as discussed in Table I. This expected precision corresponds to about 3σ deviation from zero of the MC simulated values. The $f_{a2}^{\rm dec}$ and $f_{a3}^{\rm dec}$ values correspond to cross sections defined in decay.

process description					MC simulation parameters						expected precision			
collider	energy	mode	σ_2/σ_1	σ_4/σ_+	$\lvert g_2/g_1\rvert$	$\lvert g_4/g_+\rvert$	f_{a2}	$f_{a2}^{\rm dec}$	f_{a3}	$f_{a3}^{\rm dec}$	δf_{a2}	$\delta f_{a2}^{\rm dec}$	δf_{a3}	$\delta f_{a3}^{\rm dec}$
any	any	$H \to ZZ^*$	0.362	0.153	0	1.20	0		0.18		–		0.06	
					0	0.67	0		0.06		–		0.02	
					0.78	0	0.18		0		0.088		–	
					0.42	0	0.06		0		0.014		–	
any	any	$H \to WW^*$	0.776	0.322	0	1.76	0		0.50		–		–	
					1.13	0	0.50		0		–		–	
any	any	$H \to \gamma\gamma, gg$	N/A	1.0	N/A	1.0	0		0.50		–		–	
any	any	$H \to Z\gamma$	N/A	1.0	N/A	1.0	0		0.50		–		–	
pp	14 TeV	$gg \to H$	N/A	1.0	N/A	1.0	0	0	0.50	0.50	–		0.50	0.50
		$(H \to ZZ^*)$			N/A	1.0	0	0	0.50	0.50	–		0.16	0.16
pp	14 TeV	$V^*V^* \to H$	14.0	11.3	0	0.299	0	0	0.50	0.013	–		0.190	7×10^{-3}
		$(H \to ZZ^*)$			0	0.109	0	0	0.12	0.0018	–		0.036	6×10^{-4}
pp	14 TeV	$V^*V^* \to H$	14.0	11.3	0	0.109	0	0	0.12	0.0018	–		0.04	7×10^{-4}
		$(H \to \gamma\gamma)$			0	0.052	0	0	0.030	0.0004	–		0.009	1.3×10^{-4}
pp	14 TeV	$V^* \to VH$	76.1	46.8	0	0.145	0	0	0.50	0.0032	–		0.32	3×10^{-3}
	$(V \to q\bar{q}', H \to ZZ^*)$				0	0.095	0	0	0.30	0.0014	–		0.10	6×10^{-4}
pp	14 TeV	$V^* \to VH$	76.1	46.8	0	0.061	0	0	0.15	0.0006	–		0.09	4×10^{-4}
	$(V \to \ell^+\ell^-, H \to b\bar{b})$				0	0.049	0	0	0.10	0.0004	–		0.029	1.2×10^{-4}
e^+e^-	250 GeV	$Z^* \to ZH$	34.1	8.07	0	0.117	0	0	0.10	2×10^{-3}	–		0.032	7×10^{-4}
					0.057	0	0.10	1.2×10^{-3}	0	0	0.033	4×10^{-4}	–	
e^+e^-	350 GeV	$Z^* \to ZH$	84.2	50.6	0	0.0469	0	0	0.10	3×10^{-4}	–		0.031	1.1×10^{-4}
					0.025	0	0.05	2×10^{-4}	0	0	0.015	7×10^{-5}	–	
e^+e^-	500 GeV	$Z^* \to ZH$	200.8	161.1	0	0.0263	0	0	0.10	1.1×10^{-4}	–		0.034	4×10^{-5}
					0.024	0	0.10	2×10^{-4}	0	0	0.033	7×10^{-5}	–	
e^+e^-	1 TeV	$Z^* \to ZH$	916.5	870.8	0	0.0113	0	0	0.10	2×10^{-5}	–		0.037	8×10^{-6}
					0.014	0	0.15	7×10^{-5}	0	0	0.049	3×10^{-5}	–	