e+e- summary/updates on Higgs spin and CP

- overview of relevant studies
- spin-parity from threshold scan
  - details of previous analysis
  - update for mH = 125 GeV

Katja Krüger

Snowmass: Seattle Energy Frontier Workshop,
Higgs Session

1 July 2013

HELMHOLTZ ASSOCIATION

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(detector level) studies on Higgs spin and CP

following J. List's talk at BNL:

- Spin-Parity from threshold scan

  → more information and update in this talk

- CP even/odd mixing in hZZ coupling (i.e. bosonic)

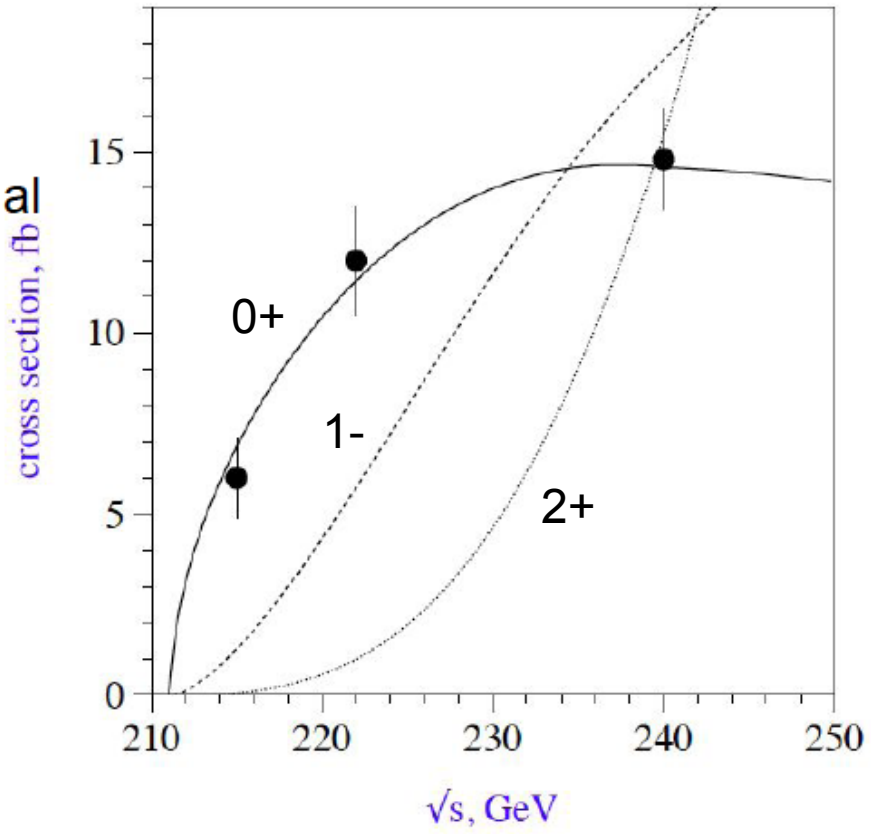
  → no news, see Jenny's BNL talk for more details

- CP even/odd mixing in decays to tau-leptons (ie. fermionic)

  → detailed phenomenological study, see next talk by S. Berge

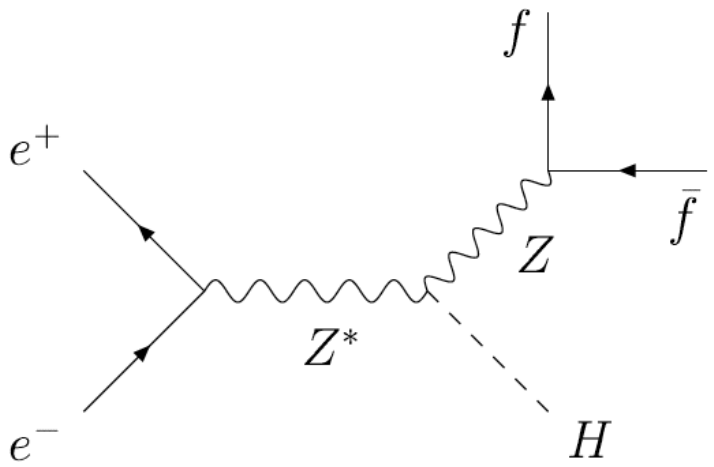
Higgs Spin-Parity from threshold scan: status BNL meeting

- J^P determination from shape of threshold
- Status: from TESLA TDR, cf. LC-PHSM-2001-055, Lohmann et al
- M_H = 120 GeV
- 20 fb^{-1} / point
- Discrimination of J^P= 0^+, 1^-, 2^+ on 10^{-5} level
- Would we learn something important from an update?

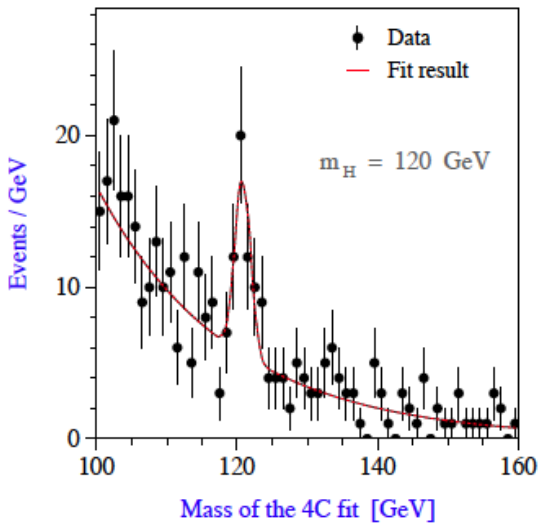


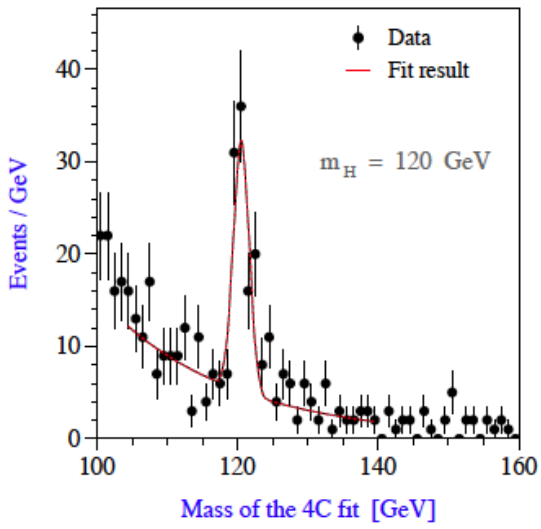
Higgs Spin-Parity from threshold scan: questions

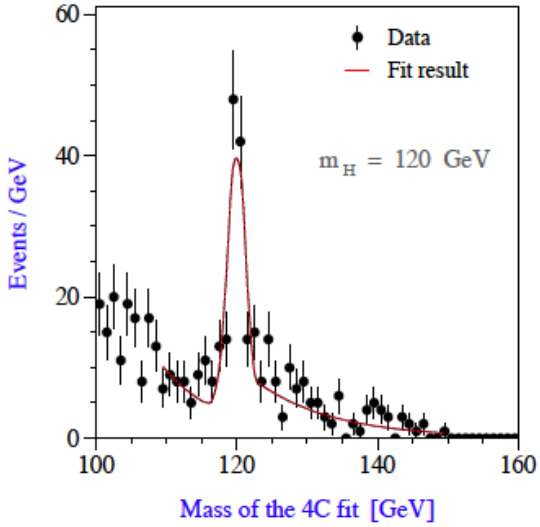
- How is the analysis done?
- How do we get to the numbers?
- Are the results still valid for current detector and collider parameters?
- What happens for M_H = 125 GeV?
- Can we say something about other models?
- Can this be optimized?



Higgs Spin-Parity from threshold scan: analysis details







- uses ee → ZH → ll jet jet
- 20 fb^{-1} per point
- determine cross section from fit of jet-jet invariant mass distributions
- fix background in fit to MC prediction
- relative uncertainties ~20% at 215 GeV and ~10% at 240 GeV

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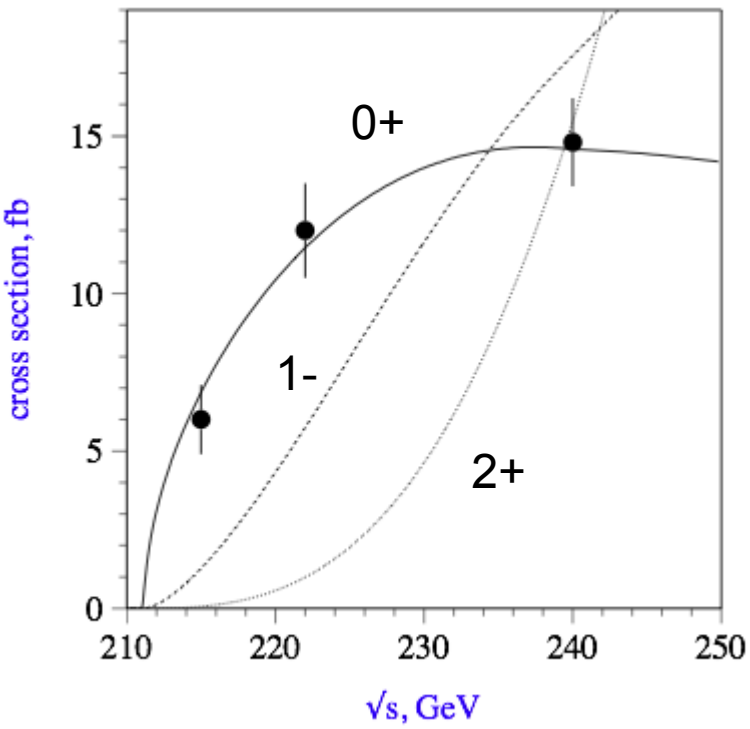
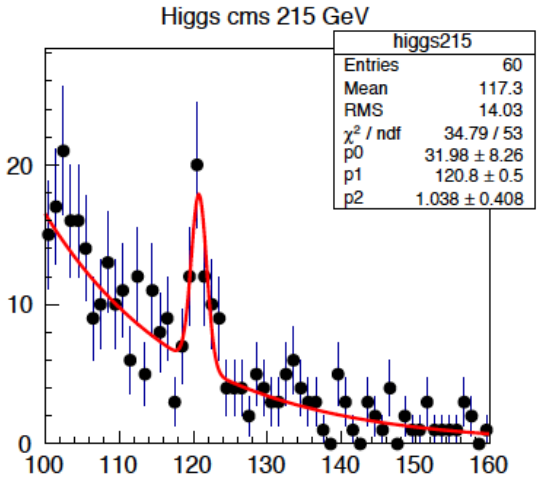
Higgs Spin-Parity from threshold scan: analysis details

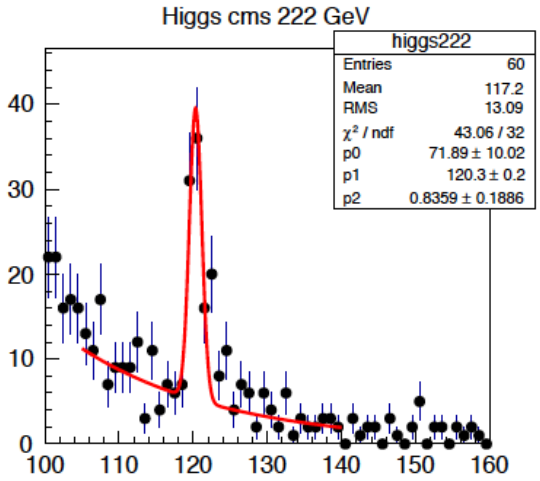


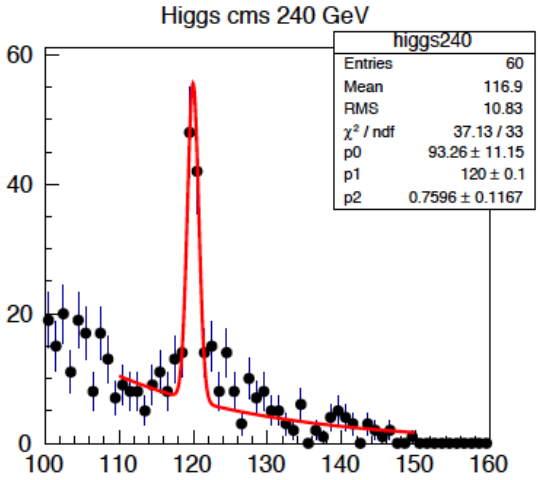
- theory predictions for 0+, 1-, 2+ from D.J. Miller, S.Y. Choi, B. Eberle, M.M. Mühlleitner and P. Zerwas, hep-ph/0102023
- corrected for initial state bremsstrahlung and beamstrahlung with PYTHIA
- fits with free normalisation
- 0+ has good χ^2 probability, "other fits have a χ^2 probability of less than 10^{-5}"

- footnote: "There are particular scenarios for s=1 and 2 which show a threshold behaviour similar in shape to the s=0 one. This can be disentangled using angular information in addition."

Higgs Spin-Parity from threshold scan: relative uncertainty







- my refit of histograms in Lohmann et al.
- fit function: Gauss + exponential
- background parameters fixed
- reasonable χ^2
- uncertainties:

  26% at 215 GeV

  14% at 222 GeV

  12% at 240 GeV

  (would be 0.4-0.8% larger for free background norm.)

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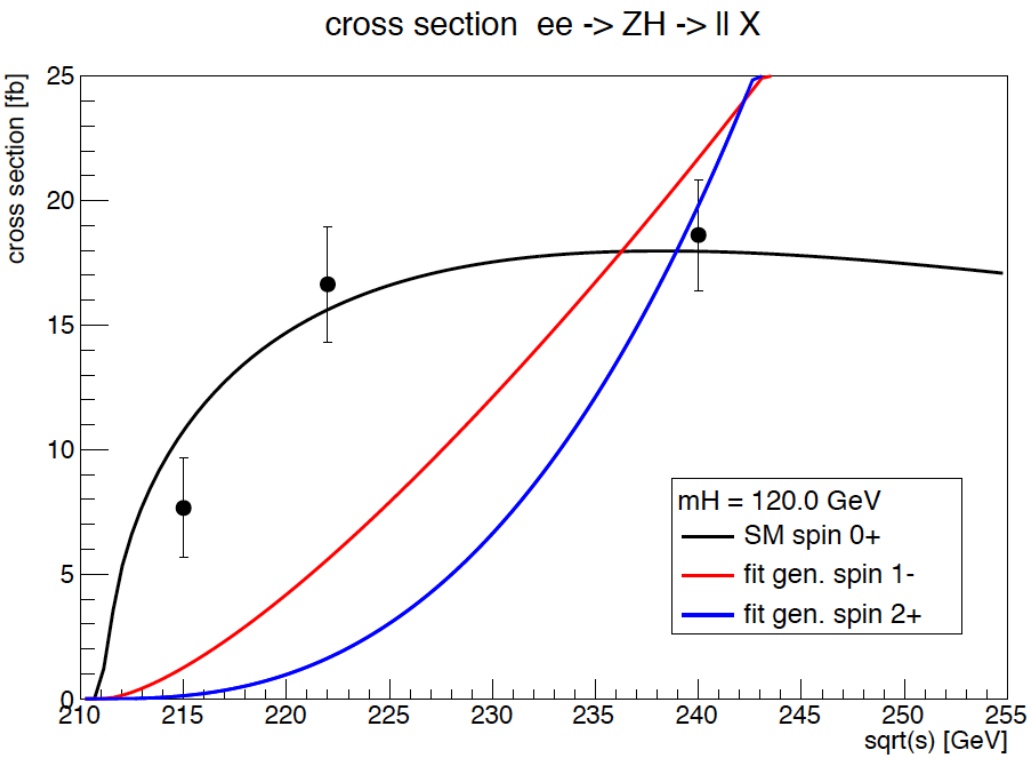
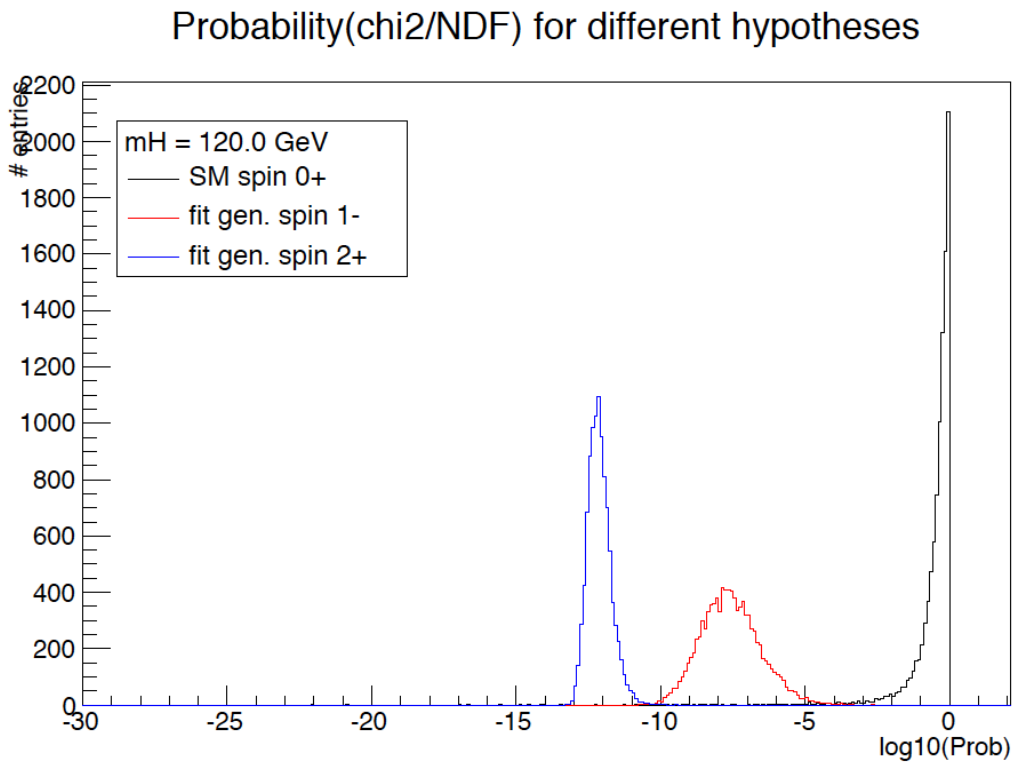
Higgs Spin-Parity from threshold scan: xsection fit



- same theory predictions for 0+, 1-, 2+ , not corrected for initial state bremsstrahlung and beamstrahlung
- fits with free normalization
- only one free parameter for each curve

Higgs Spin-Parity from threshold scan: probability



- generated 10000 sets of “cross section measurements” according to SM cross section with “my” relative uncertainties
- fitted the models with free normalization to the “data”
- distribution of the probabilities for the χ^2 and NDF of the fits

→ χ^2 probability of less than 10^{-5} for other fits confirmed

More details on theory predictions

J^P	Z^*ZH Coupling	Helicity Amplitudes	Threshold
Even Normality $n_H = +$			
0^+	$a_1 g_\perp^{\mu\alpha} + a_2 k_\perp^\mu q^\alpha$	$\Gamma_{00} = (-a_1 E_Z - \frac{1}{2} a_2 s^{3/2} \beta^2)/M_Z$	1
		$\Gamma_{10} = -a_1$	1
1^-	$b_1 g^{\alpha\beta} k_\perp^\mu + b_2 q^\alpha q^\beta k_\perp^\mu + b_3 (q^\alpha g_\perp^{\mu\beta} - q^\beta g_\perp^{\mu\alpha}) + b_4 (q^\alpha g_\perp^{\mu\beta} + q^\beta g_\perp^{\mu\alpha})$	$\Gamma_{00} = \beta [-b_1 (s - M_Z^2 - M_H^2) - \frac{1}{2} b_2 s^2 \beta^2 + b_3 s - b_4 (M_Z^2 - M_H^2)] \sqrt{s}/(2 M_Z M_H)$	β
		$\Gamma_{10} = \beta (b_3 - b_4) s/(2 M_H)$	β
		$\Gamma_{01} = \beta (b_3 + b_4) s/(2 M_Z)$	β
		$\Gamma_{11} = \beta \sqrt{s}\, b_1$	β
2^+	$c_1 (g^{\alpha\beta_1} g_\perp^{\mu\beta_2} + g^{\alpha\beta_2} g_\perp^{\mu\beta_1}) + c_2 g_\perp^{\mu\alpha} q^{\beta_1} q^{\beta_2} + c_3 (g_\perp^{\mu\beta_1} q^{\beta_2} + g_\perp^{\mu\beta_2} q^{\beta_1}) q^\alpha + c_4 (g^{\alpha\beta_1} q^{\beta_2} + g^{\alpha\beta_2} q^{\beta_1}) k_\perp^\mu + c_5 k_\perp^\mu q^\alpha q^{\beta_1} q^{\beta_2}$	$\Gamma_{00} = \frac{\sqrt{2/3}}{M_Z M_H^2} \{ c_1 E_H (s - M_Z^2 - M_H^2) - \frac{1}{8} c_5 s^{7/2} \beta^4 - \frac{1}{4} s^2 \beta^2 [c_2 E_Z - 2 c_3 E_H + 2 c_4 (s - M_Z^2 - M_H^2)/\sqrt{s}] \}$	1
		$\Gamma_{10} = \sqrt{2/3} (-c_1 - c_2 s^2 \beta^2/(4 M_H^2))$	1
		$\Gamma_{01} = (2 c_1 (s - M_Z^2 - M_H^2) + c_3 s^2 \beta^2)/(2\sqrt{2} M_Z M_H)$	1
		$\Gamma_{11} = (-c_1 E_H + \frac{1}{2} c_4 s^{3/2} \beta^2) \sqrt{2}/M_H$	1
		$\Gamma_{12} = -2 c_1$	1

- threshold behaviour governed by lowest order in β
- for 2+ case c1 leads to same behaviour as SM, so set =0 for fits
- always 1 non-zero parameter in fits, other parameters give even worse χ^2

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Current collider and detector parameters, mH = 125 GeV

no update of threshold scan analysis with more recent detector simulation or other Higgs mass available

similar analysis: determination of mH and cross section from recoil spectrum

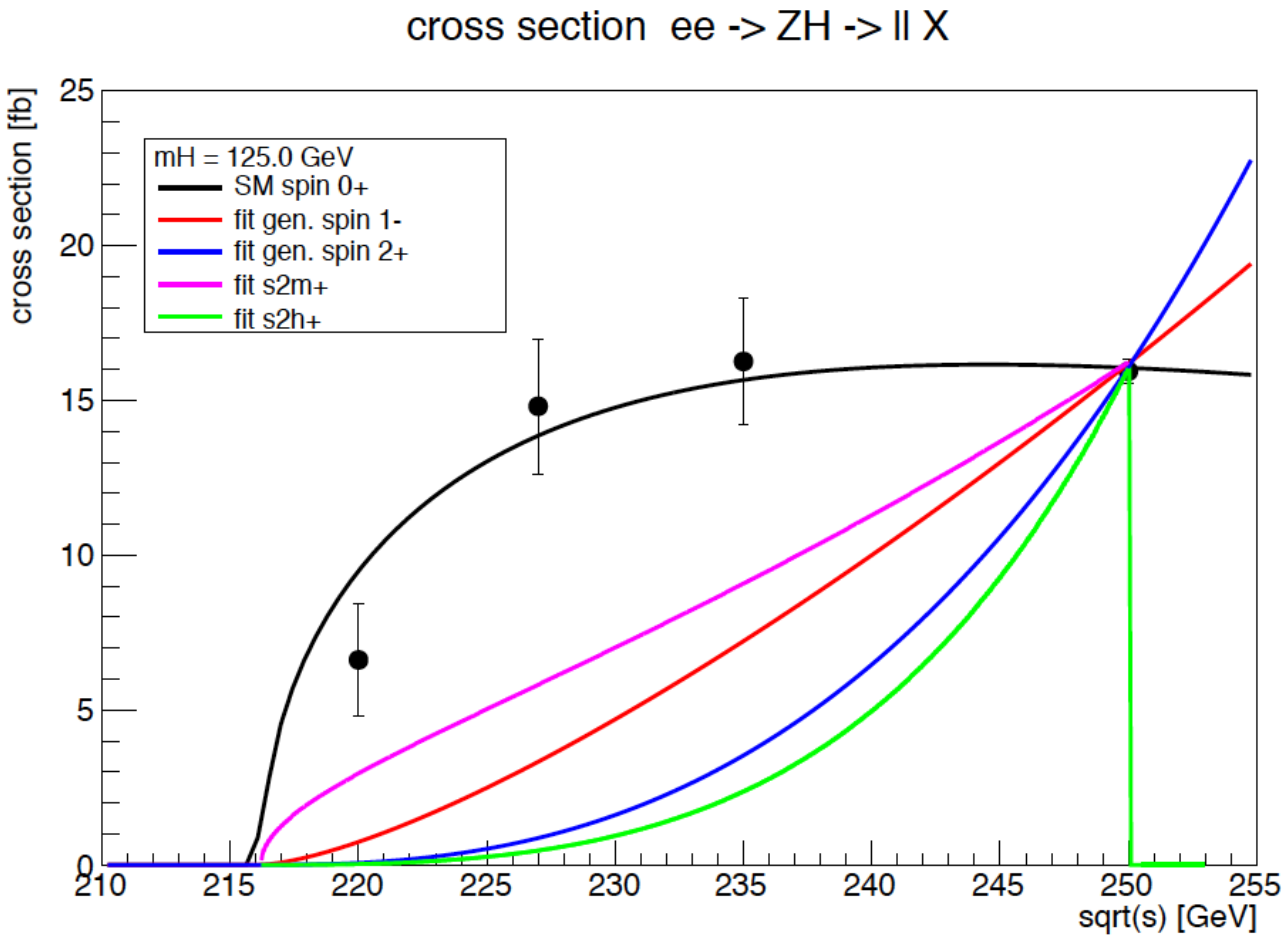
- both analyses use Z → ee and Z → mu mu
- threshold scan used H→ jet jet (BR about 70% for mH in the range of 120 to 125 GeV), recoil analysis allows all H decays: more statistics in recoil analysis, easier mass reconstruction in threshold scan
- recoil analysis was done for TESLA TDR (2001) for mH=120 GeV at √s=350 GeV, same detector as threshold scan
- recoil analysis has been repeated for ILD LOI (2009) for mH=120 GeV at √s=250 GeV and recently been updated/cross checked for mH=125 GeV, results are consistent with TESLA TDR
- scaling of uncertainties of the recoil analysis with luminosity and BR gives a bit lower uncertainties in threshold region than “my” uncertainties

→ “my” relative uncertainties should be conservative for current collider and detector parameters

Analysis for mH=125 GeV

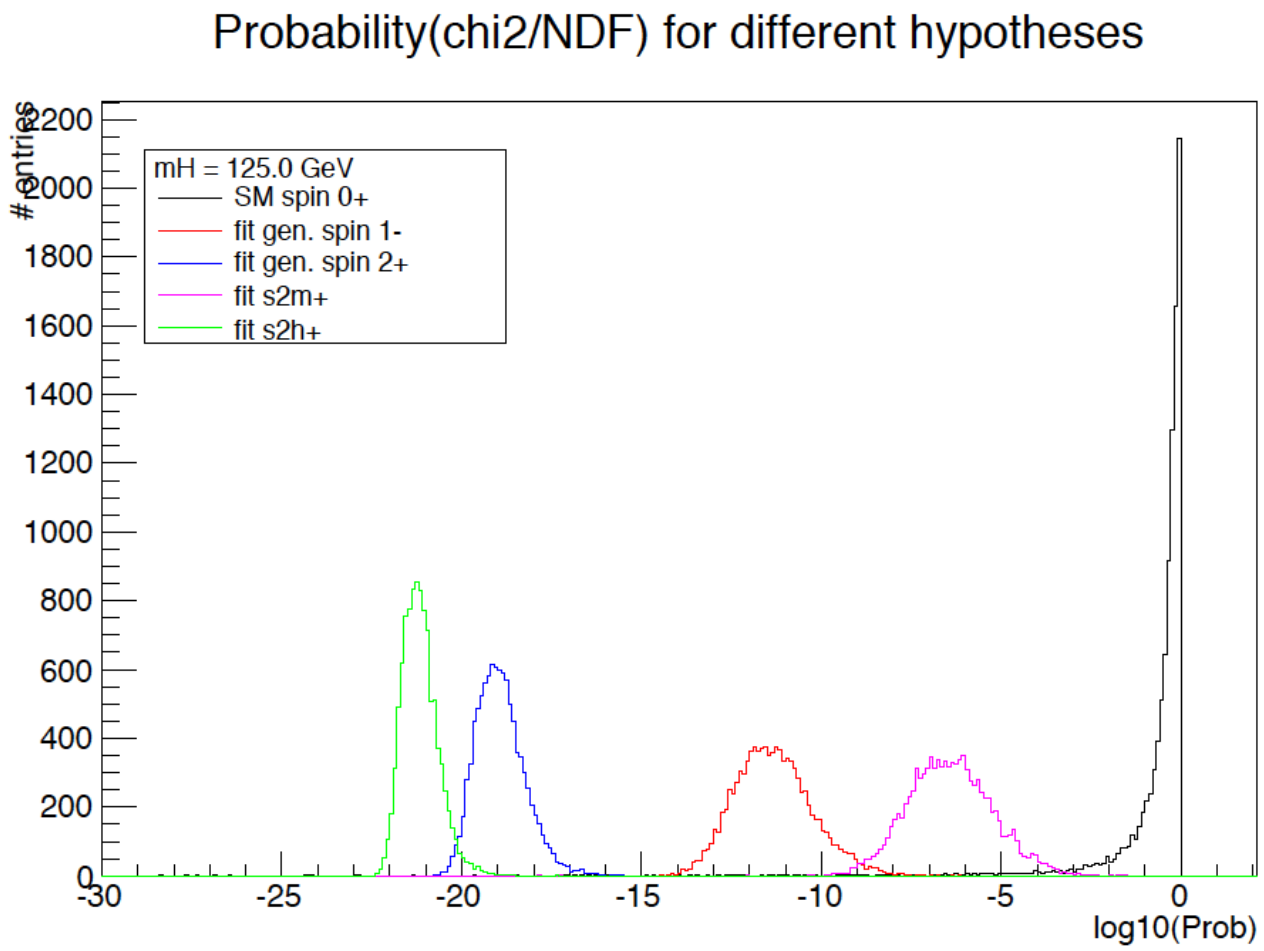
- shift √s up by 5 GeV to have same distance to threshold
- add one high-statistics point at √s = 250 GeV (2.5% unc.) since foreseen in ILC running scenarios, adjust √s of 3rd point
- uncertainties scaled up by 5% to account for ~10% smaller cross section
- theory predictions from Miller et al. adjusted to mH = 125 GeV
- additional predictions from A. Gritsan (S. Bolognesi et al., arXiv:1208.4018), free normalization parameter:
  - 1- : in agreement with Miller et al.
  - 2m+ : graviton-like tensor with minimal couplings, corresponds to c1≠0 in 2+ prediction of Miller et al.
  - 2h+ : tensor with higher-dimension operators

Analysis for mH=125 GeV: xsections



- technicality: additional predictions at the moment only up to √s = 250 GeV
- additional point at √s = 250 GeV provides strong normalization constraint

Analysis for mH=125 GeV: probabilities



- additional point at √s = 250 GeV reduces probabilities for non-SM considerably, even 2m+ has a typical probability of 10^{-6}

Summary

- reproduced probabilities of less than 10^{-5} for non-SM spin and parity fits from Lohmann et al.
- relative cross sections uncertainties are reasonable also for current collider and detector parameters
- updated the values for mH=125 GeV
- adding a high-statistics point at $\sqrt{s}$ = 250 GeV reduces non-SM probabilities considerably, can probably be improved further by optimization of running strategy
- possible further studies:
  - quantify a possible admixture of other states to SM Higgs (which number is meaningful?)

Backup

Input

source	sqrt(s)	final state	cross section (for ee → ll X)	lumi	exp. # events (for ee → ll X)	rel stat unc.	rec. # events	conservative estimate	scaled by BR and # events
Lohmann et al, 2001	215	ee → ll jet jet	7.2 fb	20 /fb	144	20.0%	32	26.0%	17.6%
	222	ee → ll jet jet	12.6 fb	20 /fb	252	12.0%	72	14.0%	13.3%
	240	ee → ll jet jet	16.8 fb	20 /fb	336	10.0%	~100	12.0%	11.5%
TESLA TDR, 2001	350	ee → ll X	5.3 fb (*2)	500 /fb	4670	2.5%			
ILD LOI, 2009 update mH=125 GeV	250	ee → ll X	~10 fb (*2)	250 /fb	~5000	2.5 – 2.7% same as LOI			2.50%

- summary of relevant cross section analyses (full detector simulation)
- blue: calculated/estimated by me
- ➔ numbers are consistent with cross sections from recoil spectrum at $\sqrt{s}$ = 250 GeV for which updates with new detector simulation and mH=125 GeV exist

- procedure: generate many sets of 3 “measurements” by gaussian smearing of SM prediction according to rel. uncertainties, test quality of fit for spins 0+, 1-, 2+