Higgs self couplings @ $\sqrt{s} = 500$GeV

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Introduction

Standard Model :

- **Higgs doublet (Φ)**
- **Higgs potential behaves as**

$$V(\Phi)=\lambda(\Phi^2-\frac{1}{2}v^2)^2 \qquad v \sim \text{ 246 GeV}$$

$$m_h^2=4\lambda v^2 \qquad \text{and} \qquad \lambda_{hhh}=\frac{6}{\sqrt{2}}\lambda v=\frac{3}{\sqrt{2}}m_h^2/v^2$$

Deviation between the direct measurement of λ_{hhh} and indirect one from m_h
$\rightarrow$ sign of NP

Goal :

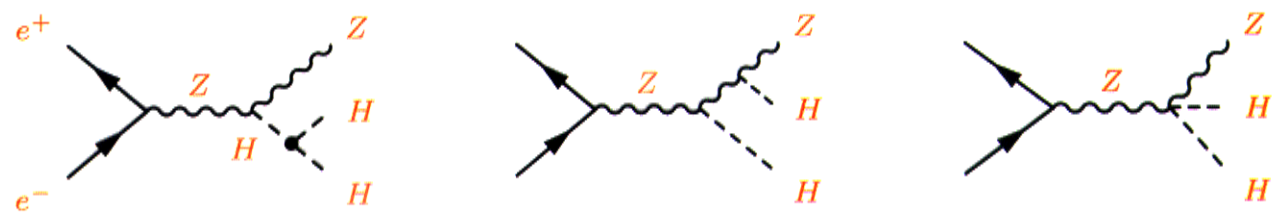
- **Reconstruction of the Higgs potential** (SM, MSSM, ...)
- **Experimental establishment of Higgs mechanism**

Refs.
A.Djouadi, W. Killian, M. Muhlleitner et P. Zerwas, Eur.Phys.J.C10,1999
P.Osland, P.N. Pandita Phys.Rev.D
D.J. Miller and S. Moretti RAL-TR-99-032, May 1999

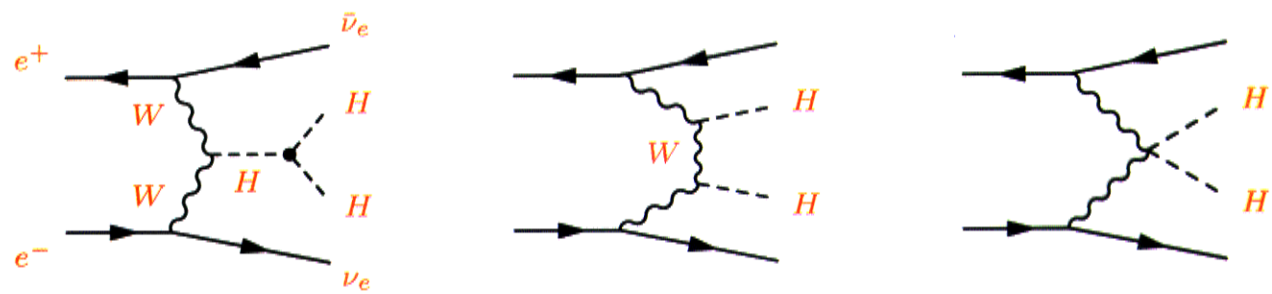
SM

$\lambda_{\rm hhh}$ **measurement through the processes**

double Higgs-strahlung: $e^+e^- \to Z{\rm hh}$



WW **double-Higgs fusion:** $e^+e^- \to \bar{\nu}_e\nu_e{\rm hh}$



@ $\sqrt{\rm s}$=500 GeV

Cross Section for $m_{\rm h}$~120 GeV $\sigma_{\rm hhZ}$=0.185 fb

→ only 93 hhZ events are expected w/ $\mathcal{L}$=500fb^{-1}

${\rm hhZ}\to {\rm b\bar{b}b\bar{b}q\bar{q}}$ ~ **60% : Major final state**

${\rm hhZ}\to {\rm b\bar{b}b\bar{b}}\ell^+\ell^-$ ~ **8%**

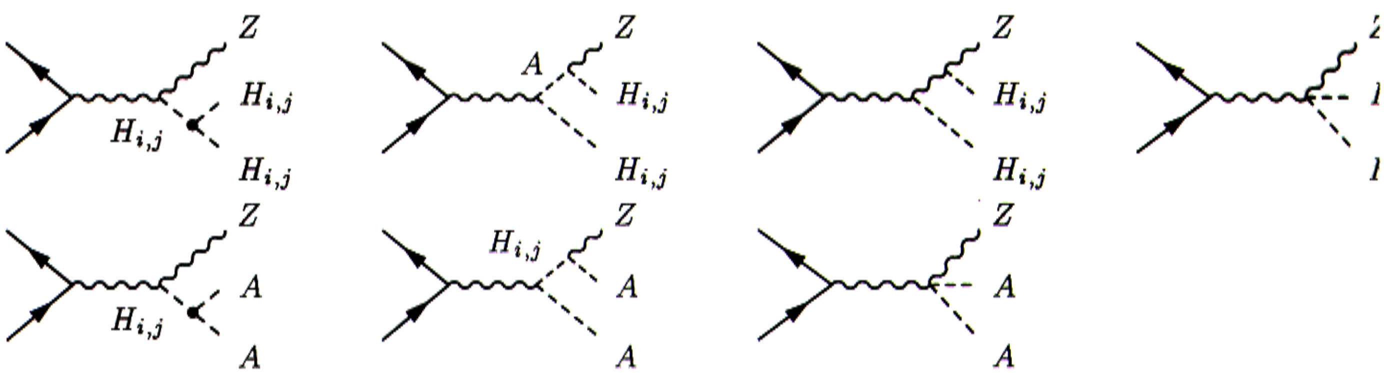
MSSM

Higgs potential is more complex

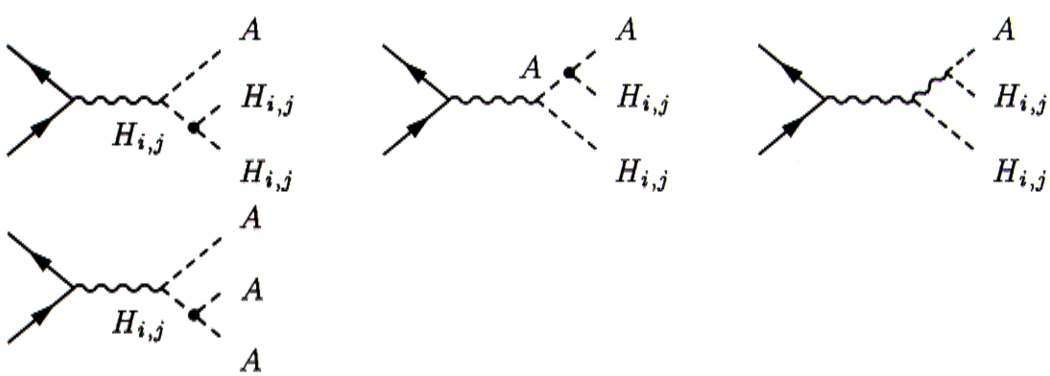
more trilinear self couplings exist :

$$\lambda_{\mathrm{hhh}}\ \lambda_{\mathrm{hhH}}\ \lambda_{\mathrm{HHH}}\ \lambda_{\mathrm{hAA}}\ \lambda_{\mathrm{hH^+H^-}}$$
$$\lambda_{\mathrm{HH^+H^-}}\ \lambda_{\mathrm{hAA}}\ \lambda_{\mathrm{HAA}}$$

double Higgs-strahlung: $e^+e^- \to ZH_iH_j,\ ZAA\ [H_{i,j} = h, H]$



triple Higgs production: $e^+e^- \to AH_iH_j,\ AAA$



No dedicated study, the SM analyses would be recycled

Feasibility studied in SM framework @ $\sqrt{s}$= 500 GeV with m_h= 120 GeV/c^2

process	N_{gen}	σ (fb)	generator	$\mathcal{L}_{sim}(\text{fb}^{-1})$
Signal				
hhZ (Z$\to q\bar{q}$)	11k	0.13	GRACE	84.10^3
hhZ (Z$\to \ell^+\ell^-$)	5k	0.02	GRACE	270.10^3
2 fermions				
$Z\gamma$	4.2M	8200.	PYTHIA	514.
Z[illegible]$\to t\bar{t}$[illegible]	150k	550.	PYTHIA	2145.
4 fermions				
WW	3.9M	7700.	PYTHIA	509.
WW$\to$Wtb	17k	16.8	PYTHIA	12.10^3
ZZ	300k	550.	PYTHIA	545.
Weν	2.6M	5300.	PYTHIA	502.
Zee	3.7M	7400.	PYTHIA	504.
hZ	35k	70.5	HZHA	1631.
$t\bar{t}h$, hZ$\to t\bar{t}h$	3k	0.4	GRACE	7500.
6 fermions				
WWZ (Z$\to q\bar{q}$)	21k	19.8	GRACE	3383.
WWZ (Z$\to \ell^+\ell^-$)	8.6k	2.8	GRACE	10225.
ZZZ (Z$\to q\bar{q}$)	6k	0.53	GRACE	30188.
ZZZ (Z$\to \ell^+\ell^-$ $\nu\bar{\nu}$)	9.5k	1.01	GRACE	28083.

Table 1: Cross-sections for signal and background processes, Monte Carlo statistics and simulated luminosity ($\mathcal{L}_{sim}$)

• $\mathcal{L}_{simulated} \gtrsim$ 500fb^{-1} At this level s/b $\sim$ 8.5 10^{-6}

DETECTOR

detector simulation with a Parametric Monte Carlo

SIMDET.3/GEANT.4

4 T magnetic field and $P_t^{min}(charged) > 0.5$GeV/c are reconstructed

VDET	$\theta \in [16°,164°]$
TPC	$\theta \in [12°,168°]$
Forward tracker	$\theta \in [5°,25°]$ and $[155°,175°]$
Forward μchambers	$\theta \in [5°,12°]$ and $[168°,175°]$

Table 2: Acceptances of the tracking system devices defined by their polar angle (θ).

Sub-detector Sub-detector	Angular acceptance	Energy Threshold	Energy resolution
ECAL	4.6°	1 GeV	$\Delta E/E=10.2\%/\sqrt{E(GeV)}$
HCAL	4.6°	1 GeV	$\Delta E/E=40.5\%/\sqrt{E(GeV)}$
LCAL	1.7-3.1°	30 GeV	$\Delta E/E=10.\%/\sqrt{E(GeV)}$

Table 3: Characteristics of the calorimeters.

Angular acceptance down to 5° (TPC+Calo.)
2° Luminometer

- **jet b-tagging**
  - **based on combination of impact parameter in rz and rϕ views.**
  - **use b-tagging parametrisation from R. Hawkings (5μm, 5 layers)**
- **Energy Flow**
  - $\Delta E_{jet}/E_{jet} \sim 40\%/\sqrt{E_{jet}}$

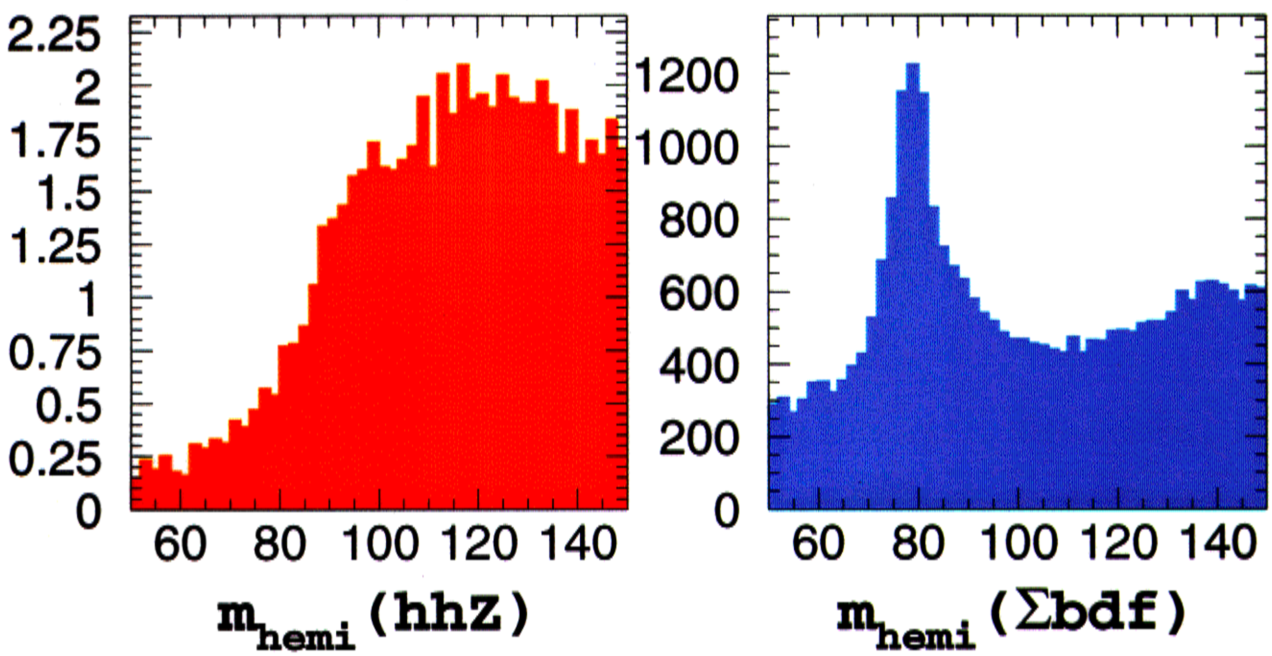
SELECTIONS

i) Preselection

multiplicity

ii) Variables based on 'Event Shape'

thr, cthr, f_{γ}, P_z^{tot}, $M_{hemispheres}$, P_{lepton}^{max}



SELECTIONS

iii) Six jets (clustered with DURHAM)

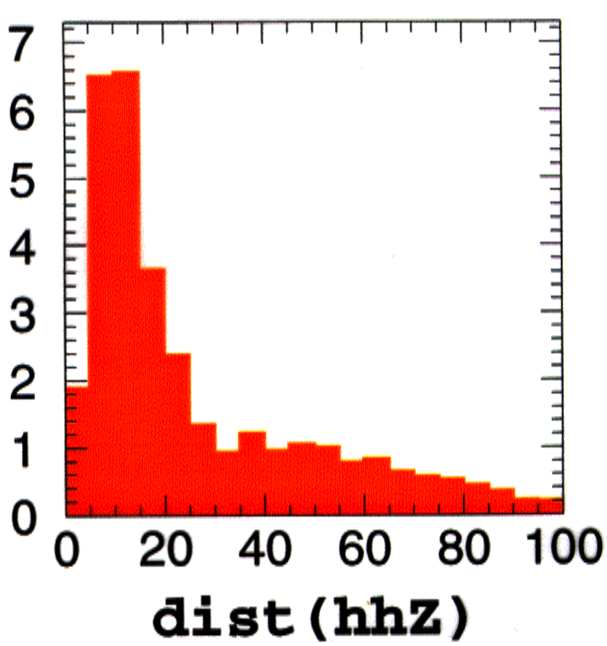
- **event forced in 6 jets topology**
- **jet b-tagging**

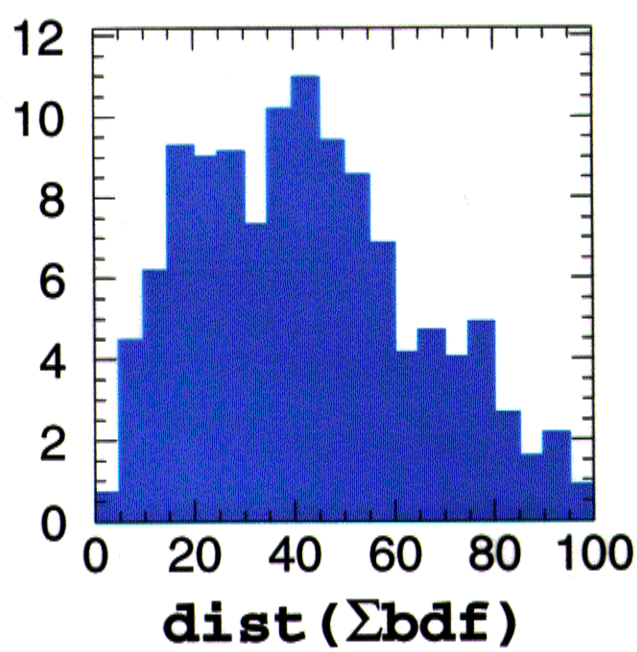
iv) Combinatory & masses

3 di-jets (hhZ) → 90 combinations

- **direct use of the reconstructed di-jets masses**
  - m_{56} **matches a** Z **mass**
  - **At least one b jet among the recoiling jets**
  - m_{12} **and** m_{34} **such that** $\|m_{12}\text{-}m_{34}\|$ **is minimum**
- **simply combined to form the *distance* Dist**

Dist$=\sqrt{((m_{12} - \underset{120}{\cancel{100}})^2 + (m_{34} - \underset{120}{\cancel{100}})^2 + (m_{56} - m_{\mathrm{Z}})^2)}$





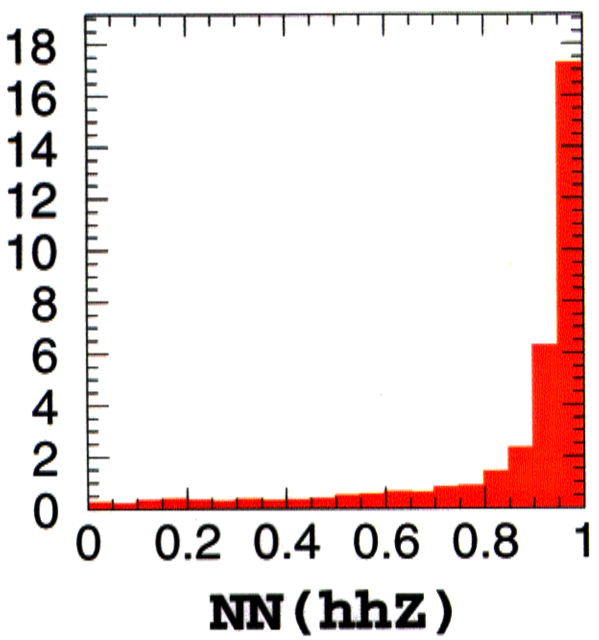
Selections

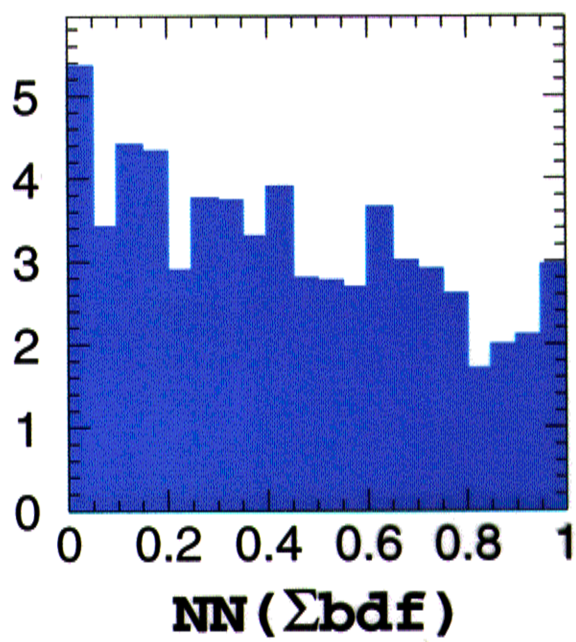
v) Multivariable

informations from

- **b-content of the system recoiling to the Z**
- **di-jet masses (m_{12}, m_{34}, m_{56})**

are combined in a multivariable analysis (NNet)





NUMBERS

Number of events with $\mathcal{L}$=500fb^{-1} (m_h=120 GeV/c^2)

process	presel event shape	b-content (1)	b-content (2)	NNet >0. (3)
$hhq\bar{q}$	41.4	34.	27.1	27.5
$hh\ell^+\ell^-$	6.7	6.2	5.1	6.4
total hhZ	49.1	40.2	32.2	33.9
ϵ_{hhZ}	52%	43%	35%	36%
WW	2114.	233.	74.3	32.
$Z\gamma$	44938.	116.	34.	24.
ZZ	484.	7.4	0.	0.
WWZ	331.	0.6	0.	0.14
ZZZ	56.6	19.	9.	8.4
hZ	174.	0.	0.	0.
$t\bar{t}h$	3.	0.	0.	0.
total bkg.	48089.	376.	117.4	64.3
s/b	0.1%	11%	27%	53%
$s/\sqrt{b}$	0.22	2.	3.	4.2
	A	B	C	D

(1): loose cuts

(2): tightened cuts

(3): w/ NN>0.5 31hhZ and 26.4 backg $\rightarrow s/\sqrt{b}$ =6.

$\Delta\sigma/\sigma$

Cross-section (σ_{hhZ})measurement takes into account a caracteristic variable (DIST, $\mathrm{NN}_{\mathrm{output}}$, ...)

	selection variable	$\Delta\sigma/\sigma$ $\mathcal{L}$= 500fb^{-1}	1000fb^{-1}	2000fb^{-1}
B	DIST	32.8 %	25.6 %	17.7 %
C	DIST	29.8 %	21.5 %	15.1 %
B	$\mathrm{N}_{\mathrm{bjets}}^{\mathrm{recoil\ syst.}}$	24.1 %	17.3 %	11.6 %
D	NN output	20.4 %	12.9 %	10.3 %

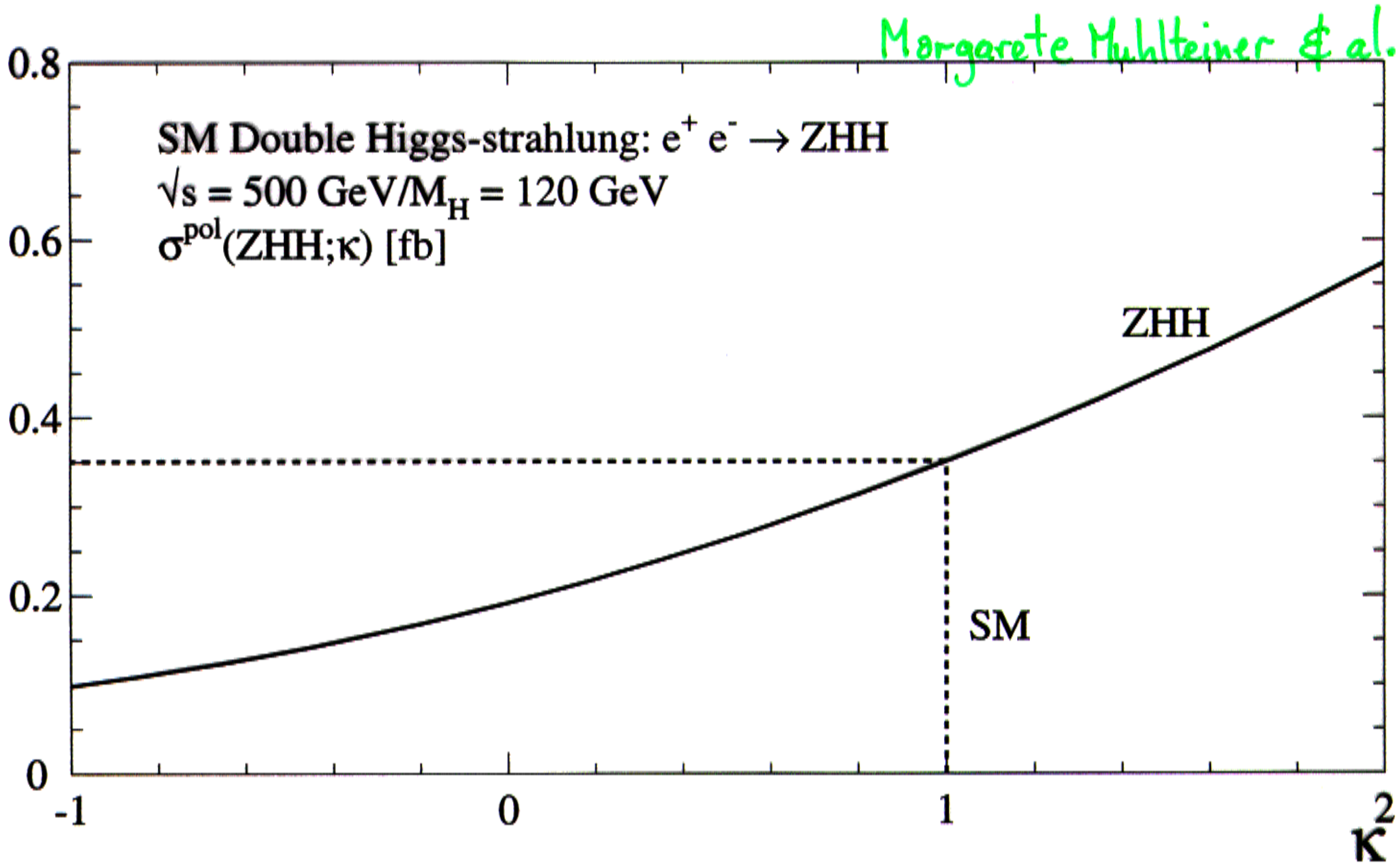
Table 4: Relative error ($\Delta\sigma/\sigma$) on σ_{hhZ} for different selections and integrated luminosities

m_{h} (GeV/c^2)	σ_{hhZ} (fb)	$\mathrm{N}_{\mathrm{hhZ}}^{500}$	ϵ_{hhZ}	$\Delta\sigma/\sigma$ $\mathcal{L}$= 500 fb^{-1}	1000 fb^{-1}	2000 fb^{-1}
120	0.186	93.	43%	24.1%	17.3%	11.6%
130	0.149	74.	43%	26.6%	19%	17.7%
140	0.115	57.	39%	32%	23 %	17%

Table 5: Relative error ($\Delta\sigma/\sigma$) on σ_{hhZ} with the selection B+$\mathrm{N}_{\mathrm{bjets}}^{\mathrm{recoil\ syst.}}$ for different Higgs boson masses and integrated luminosities; cross-sections are reported and ($\mathrm{N}_{\mathrm{hhZ}}^{500}$) the expected number of hhZ events with $\mathcal{L}$=500fb^{-1}

$\Delta\lambda/\lambda$

σ_{hhZ} as a function of λ_{hhh}



$$\Delta\lambda/\lambda \sim \mathbf{1.75} \times \Delta\sigma/\sigma$$

	selection variable	$\Delta\lambda/\lambda$ $\mathcal{L}=$ 500fb^{-1}	1000fb^{-1}	2000fb^{-1}
B	$N_{bjets}^{recoil\ syst.}$	42.2%	30.3%	20.3 %
D	NN output	35.7%	22.6%	18.0%

Table 6: Relative error ($\Delta\lambda/\lambda$) on λ_{hhh} for different selections and integrated luminosities

CONCLUSIONS

It is important to measure $\lambda_{\rm hhh}$
(reconstruction of Higgs potential)

but the Cross-section is very tiny

- MC generated up to $\mathcal{L}\sim$ 500 fb^{-1}
- Detector taken into account (SIMDET)

- very good VDET is mandatory
- Energy Flow is essential also
- Multivariable method would help
- Luminosity is welcome (*i.e.* 2000fb^{-1})

$\Delta\lambda/\lambda \sim$ 18% achievable