Higgs self coupling at e^+e^- Linear Collider

P. Gay
LPC Univ. B. Pascal -IN2P3

Introduction

Standard Model

- Higgs doublet (ϕ)
- Higgs potential behaves as $V(\phi) = \lambda(\phi^2 - \frac{1}{2}\upsilon^2)^2$

$$\upsilon \approx 246\, GeV$$

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

Deviation between **the direct measurement of λ_{hhh}**

and

indirect measurement from m_h **➔ sign of NP**

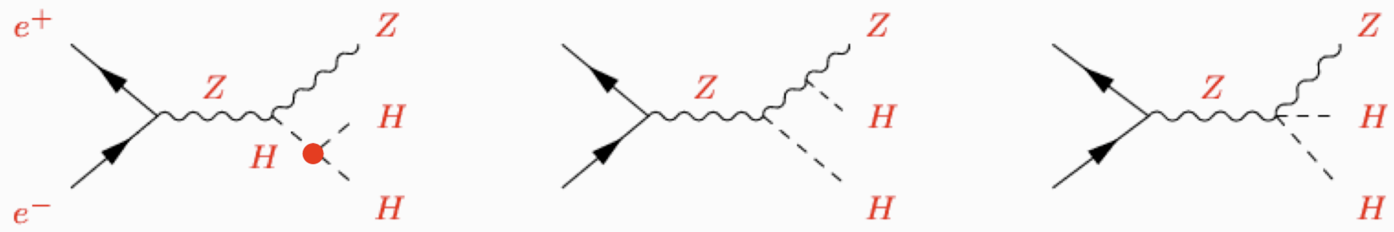
Goal

- **Reconstruction of the Higgs potential**
- **Experimental establishment of the Higgs mechanism**
- **Benchmark for detector optimisation (?)**

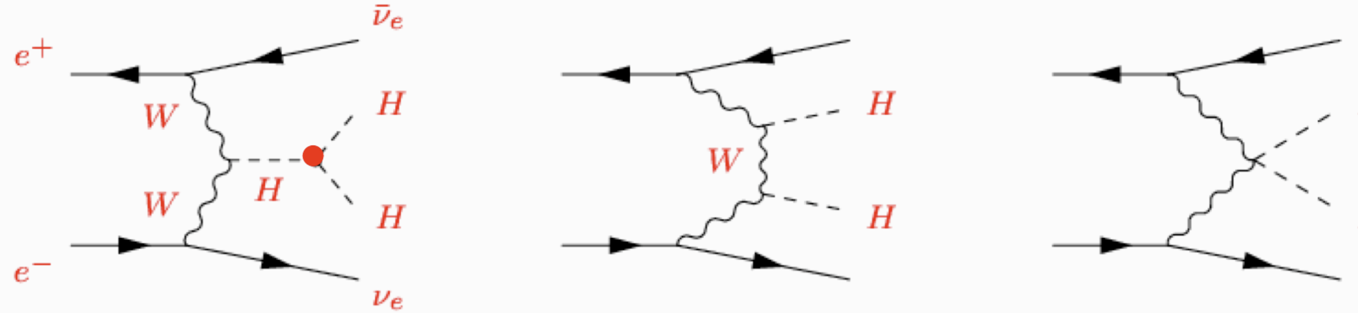
Standard Model

λ_{hhh} **measurement through the processes**

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



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



Processes @ 800 GeV

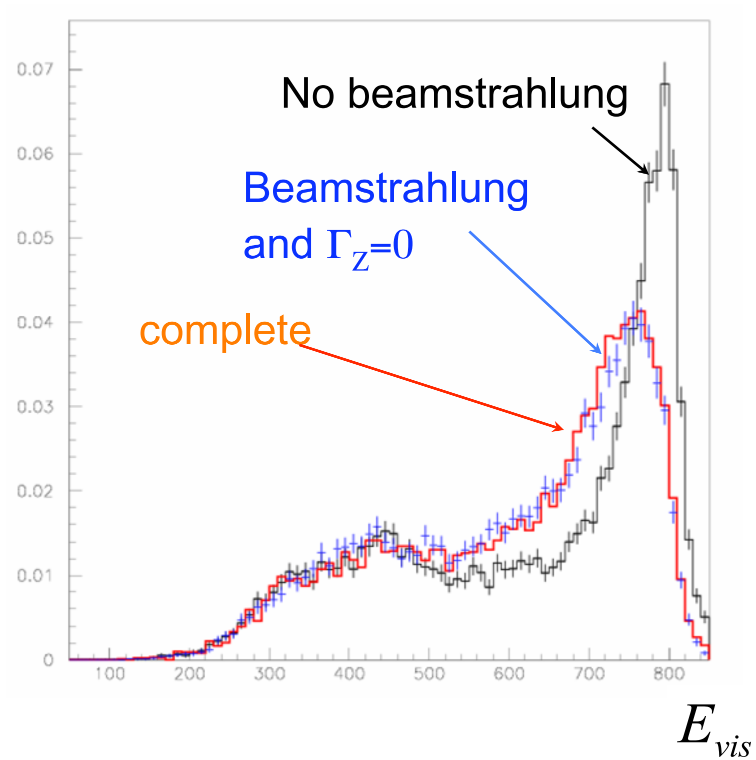
Process	N_{Gen}	σ (fb)	$\mathcal{L}_{sim}(fb^{-1})$
Signal	10k	0.1844	54227
hhZ *tri*	10k	0.0571	
ννhh *tri*	9k	0.0536	
tth	20k	2.498	8006
ttZ	25k	4.528	5521
tt	1M	260.4	3840
hZ	160k	22.65	7064
ννWW	60k	12.43	4827
eeZZ	3k	0.287	10400
ννZZ	25k	3.477	7190
WW	9.2M	668.8	13890
ZZ	1.5M	222.4	6744
ννtt	20k	0.787	25400
eνZW	12k	10.09	1176
ZZZ	25k	0.729	34280
WWZ	100k	56.96	1755

Generated w/ WHIZARD

M_h=120 GeV/c^2

Impact of the beamstrahlung

CIRCE/ TESLA



Expected signal for 500fb-1 is ~92 events

Detector simulation

detector simulation with a Parametric Monte Carlo

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**

$$\Delta E_{jet}/E_{jet} \sim 30\%/\sqrt{E_{jet}}$$

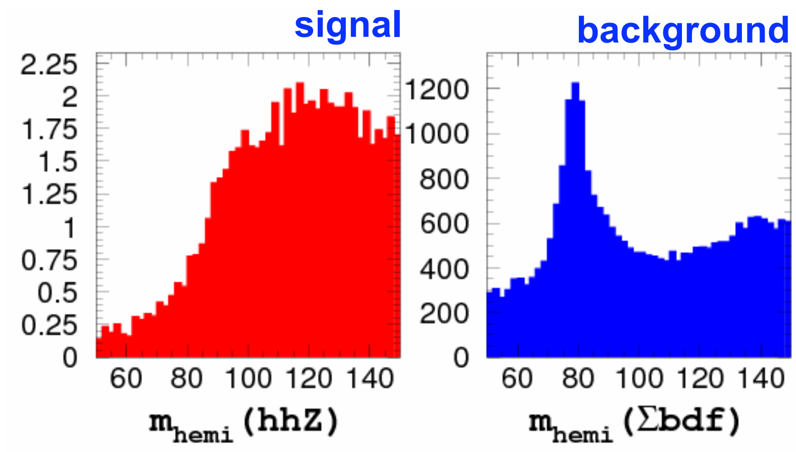
Selections

Preselection

i) multiplicity

ii) Variables based on 'Event Shape'

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



Selection in two branches

Evis < 500 GeV → 4 jets

Evis > 500 GeV → 6 jets

“hhZ”-Selection

iii) Six jets (clustered with DURHAM)

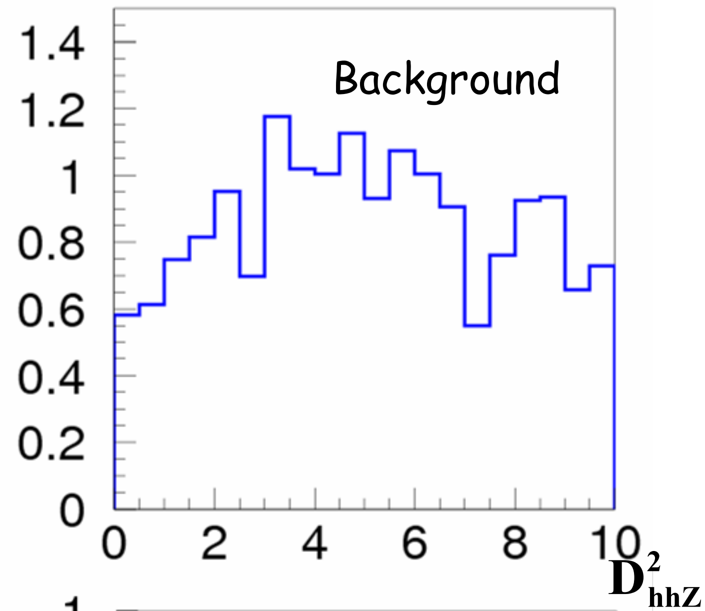
- event forced in 6 jets topology
- jet b-tagging

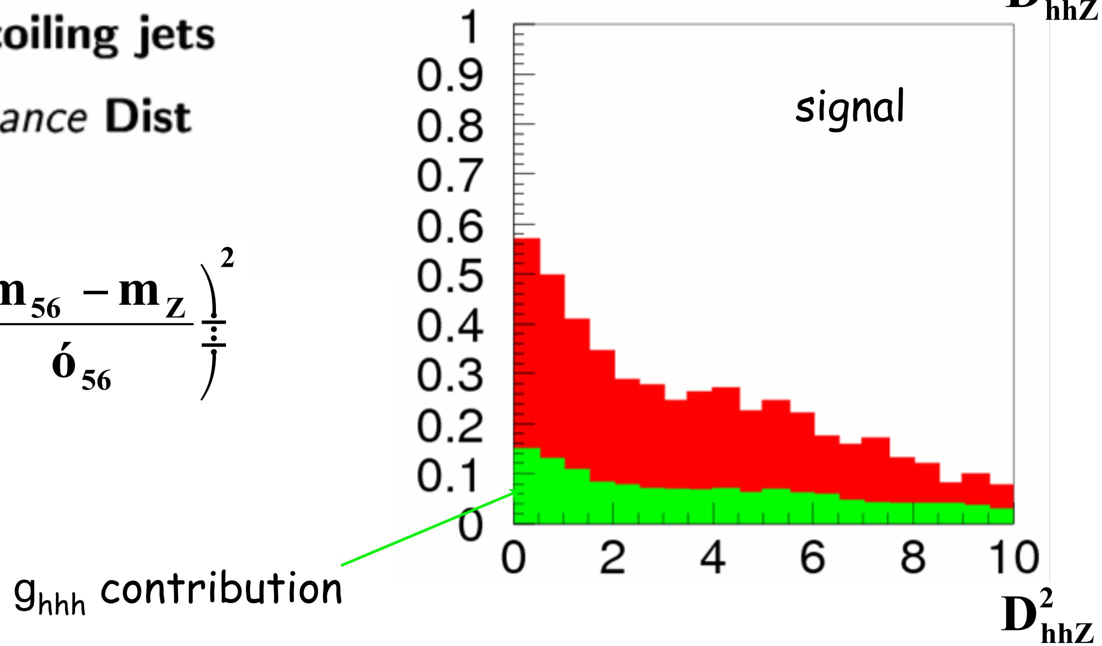
iv) Combinatory & masses

3 di-jets (hhZ) $\rightarrow$ 90 combinations

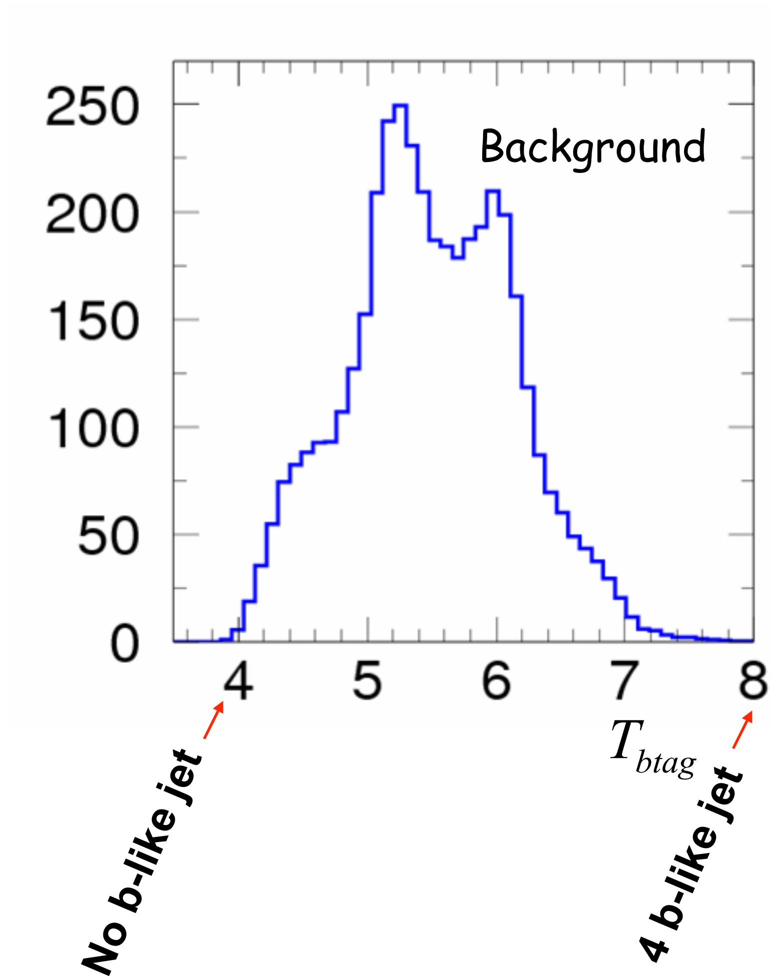
- direct use of the reconstructed di-jets masses
  - m_{56} matches a Z mass
  - At least one b jet among the recoiling jets
- simply combined to form the *distance* Dist

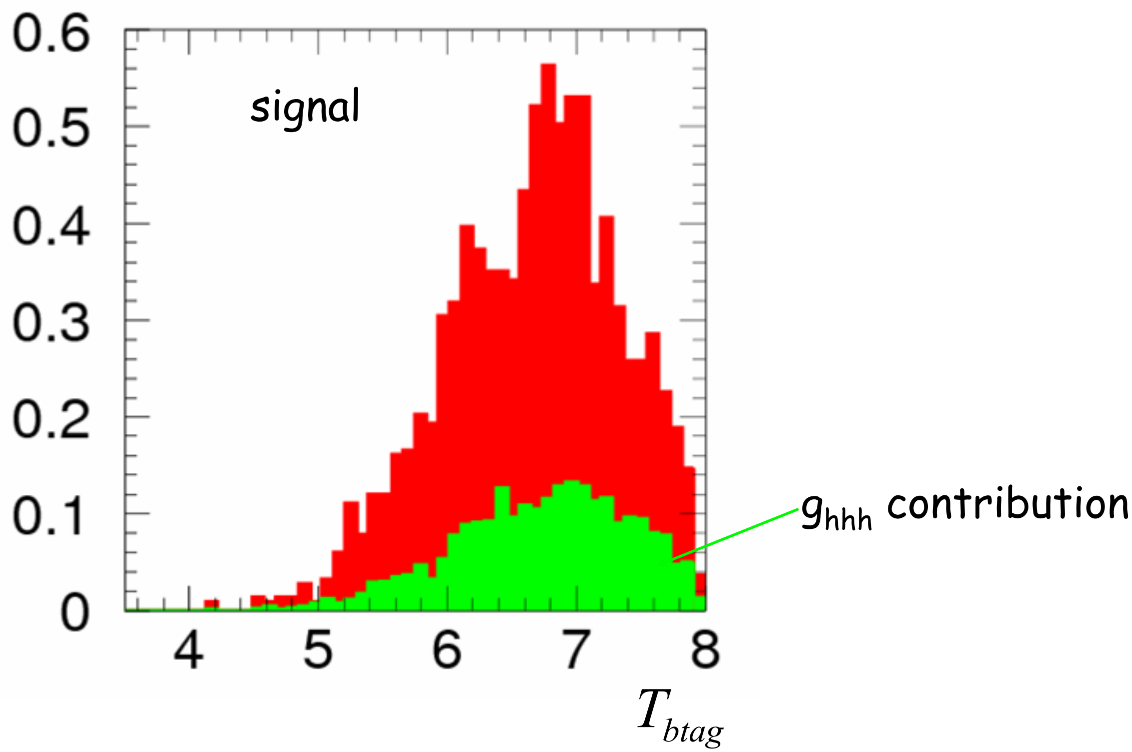
$$D^2_{hhZ} = \left(\frac{m_{12} - m_h}{\sigma_{12}}\right)^2 + \left(\frac{m_{34} - m_h}{\sigma_{34}}\right)^2 + \left(\frac{m_{56} - m_Z}{\sigma_{56}}\right)^2$$





“hhZ”-Selection





$$T_{btag} = \sum_{i=1}^{4} (1 + NN_{jet_i}) \qquad NN_{jet_i} \in [-1,+1]$$

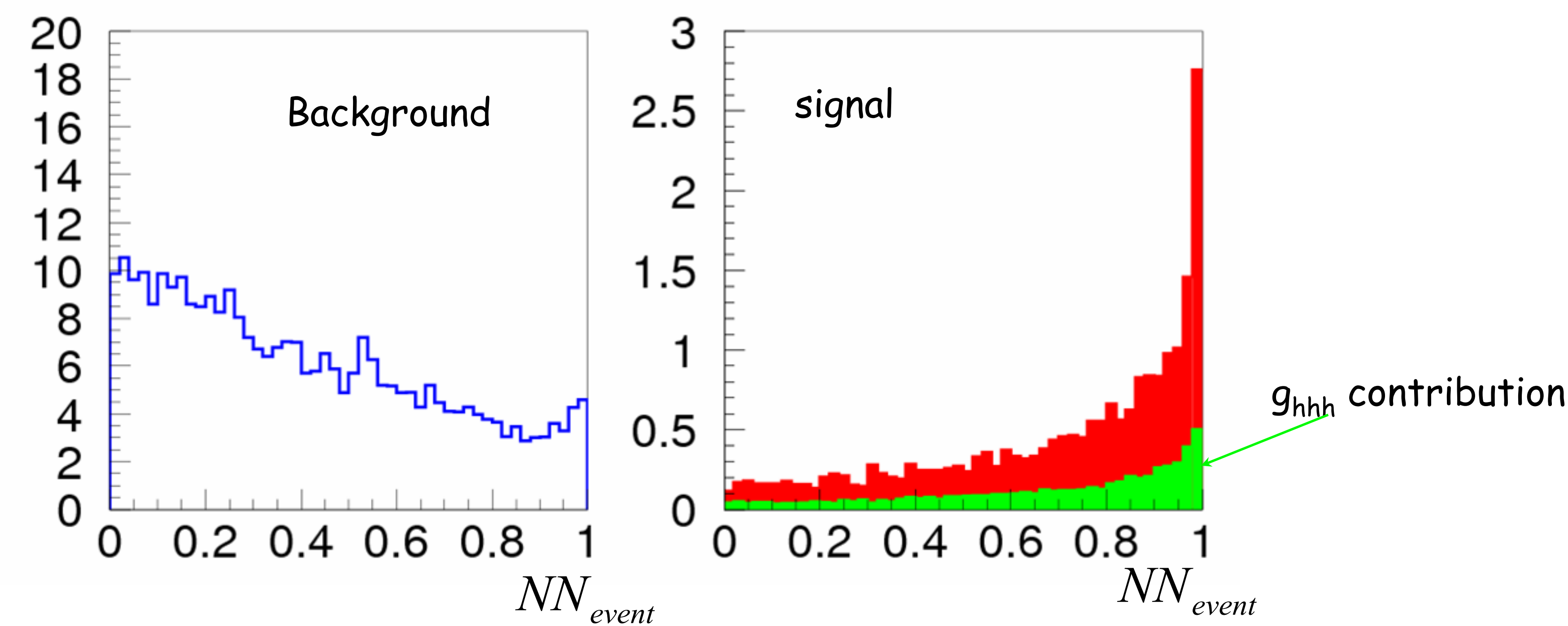
"hhZ"-Selection

v) **Multivariable**

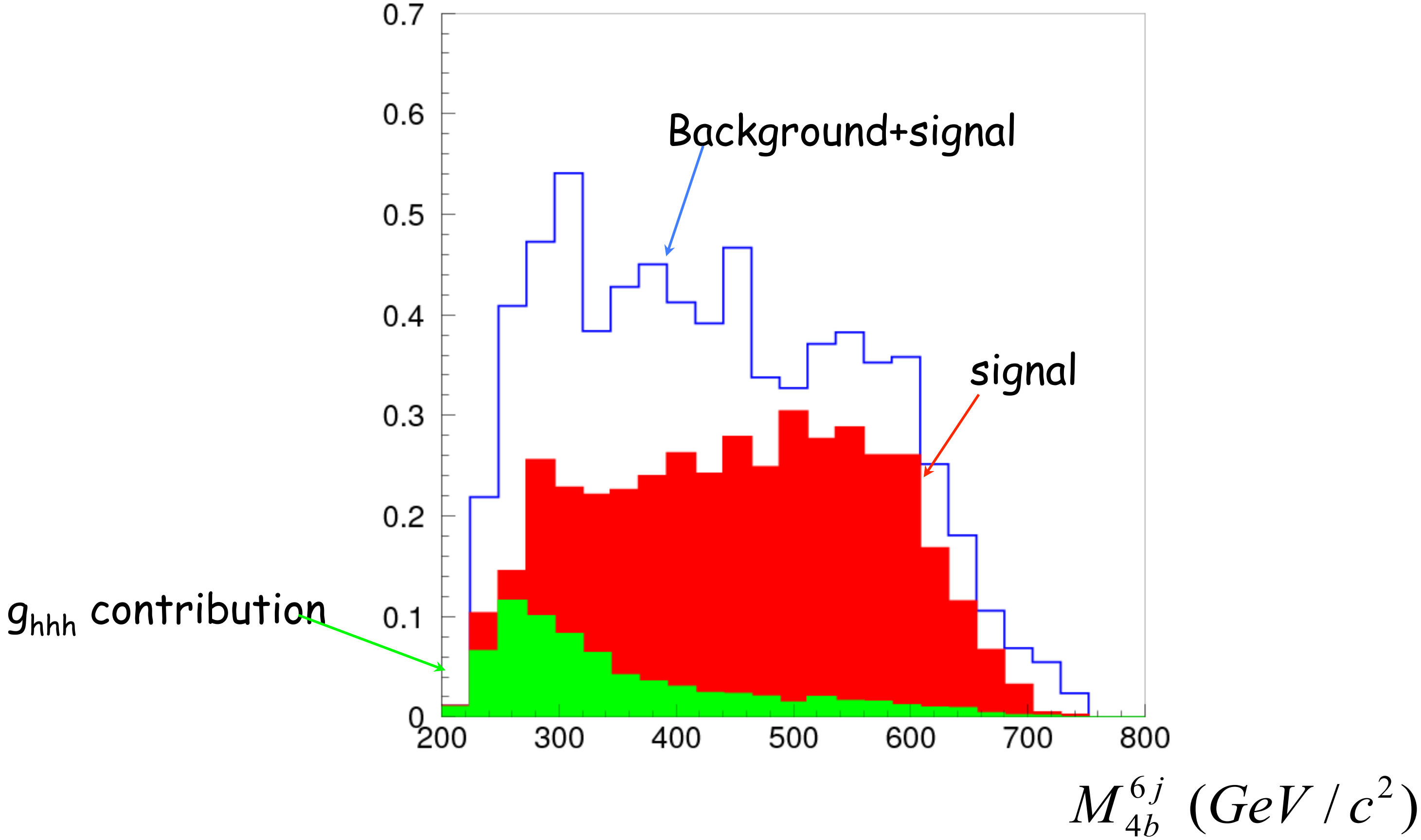
informations from

- **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)



“hhZ”-Selection



“ννhh”-Selection

iii) 4 jets

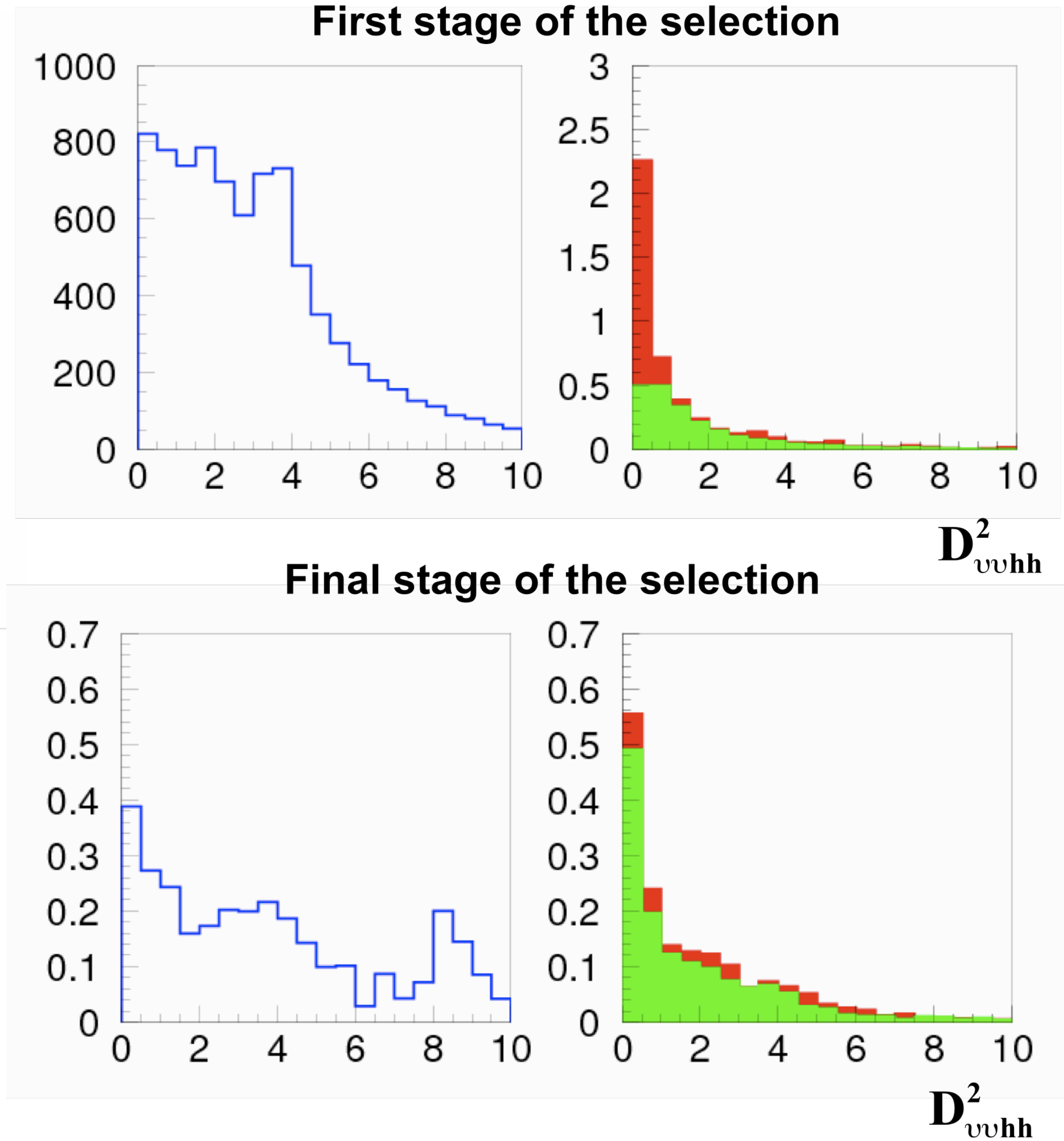
(clustered with DURHAM)

- event forced in 4 jets topology
- jet b-tagging

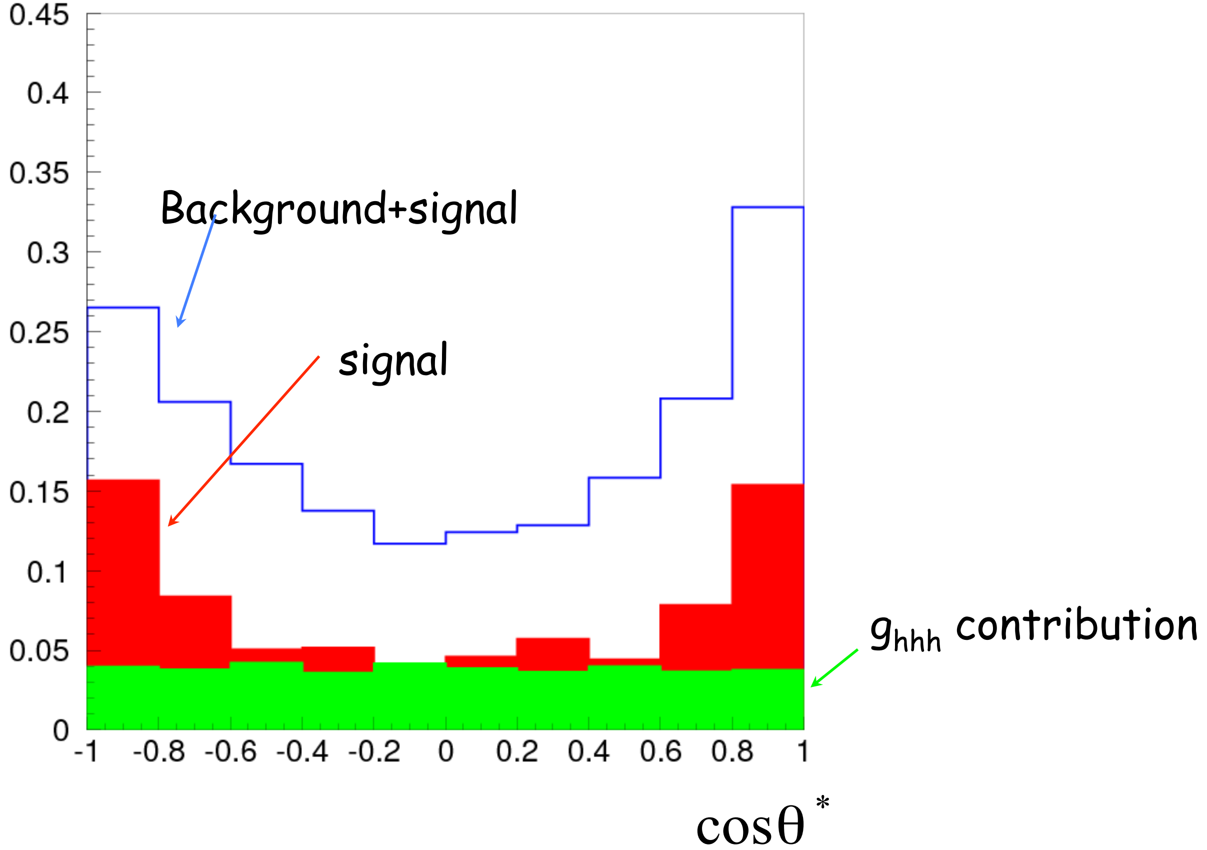
iv) Combinatory & masses

- direct use of the reconstructed di-jets masses combined to form the *distance* Dist

$$D^2_{\upsilon\upsilon hh} = \left(\frac{m_{12} - m_h}{\sigma_{12}}\right)^2 + \left(\frac{m_{34} - m_h}{\sigma_{34}}\right)^2$$

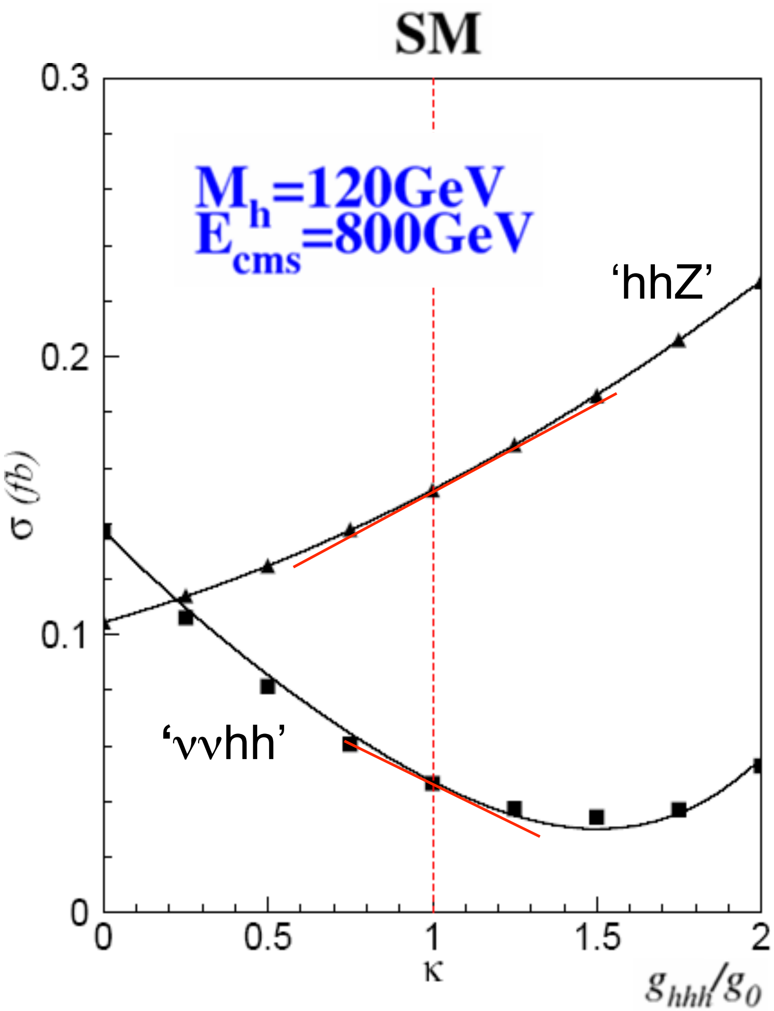


"ννhh"-Selection



$\cos\theta^*$ angle measured in the cme of the pair between the higgs direction and the boost axis

Interpretation



for 2 ab^{-1}

Process	hhZ sel.	*vvhh-sel.*
Backg	21.8	9.1
signal	88.0	34.
Eff. (%)	30.2%	37.3%
$s/\sqrt{b+s}$	8.2	5.2

Counting event only

hhZ channel (6jets) $\Delta\lambda/\lambda = 22\%$

ννhh **channel (4jets)** $\Delta\lambda/\lambda = 18\%$

likelihood + combination

$\Delta\lambda/\lambda = 16\%$

$\lambda = g_{hhh}/g_0$

hhZ @ 500 GeV

- Additional backgrounds w.r.t published analysis
- m_H = 120 GeV, Br(H→bb) = 68%
- Signal cross section 0.18 pb
- $\Delta\lambda_{hhh}/\lambda_{hhh} \sim 1.75\ \Delta\sigma_{hhZ}/\sigma_{hhZ}$

3 selections

Main steps (similar to 800 GeV)

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 $\|m_{12}$-$m_{34}\|$ is minimum
- simply combined to form the *distance* Dist

$$\text{Dist}=\sqrt{((m_{12}-120)^2+(m_{34}-120)^2+(m_{56}-m_Z)^2)}$$

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)

Analysis & results

Processes	σ(pb)	N Generated	Generated luminosity (pb^{-1})	N expected (L = 500 pb^{-1})
hhZ	0,18441	15k	81340,49	92,2
Backgrounds	699	1820k		332167
tt	526,4	740k	1880,7	263200
ZZZ	1,051	40k	38059,0	525
tbtb	0,7	20k	28571,4	350
ZZ	45,12	50k	1108,2	22560
nntt	0,141327	20k	141515,8	70
wwz	35,3	130k	3682,7	17650
wtb	16,8	200k	2976,2	8400
eezz	0,287	10k	34843,2	143
nnww	3,627	30k	8271,3	1813
evzw	10,094	60k	5944,1	5047
nnzz	1,08257	20k	18474,6	541
ttZ	0,6975	20k	28673,8	541

Signal 3 channels

- **hhqq**
  - 6 jets
  - m_h & m_Z
- **hhνν**
  - 4 jets
  - missing energy
  - M_h
- **hhll**
  - 4 jets
  - 2 energetic leptons
  - m_Z & m_h

- **ε_b=90%**

L = 2 ab^{-1}

- **hhqq**
  - Signal : 67.3
  - Background : 93
    - tt 9.2
    - tbtb 37.
    - ZZZ 16.4
    - ttZ 18.8
- **hhνν**
  - Signal : 20
  - Background : 14.6
    - ZZ 2.4
    - tbtb 6.8
- **hhll**
  - Signal 10.3
  - Background : 26.8

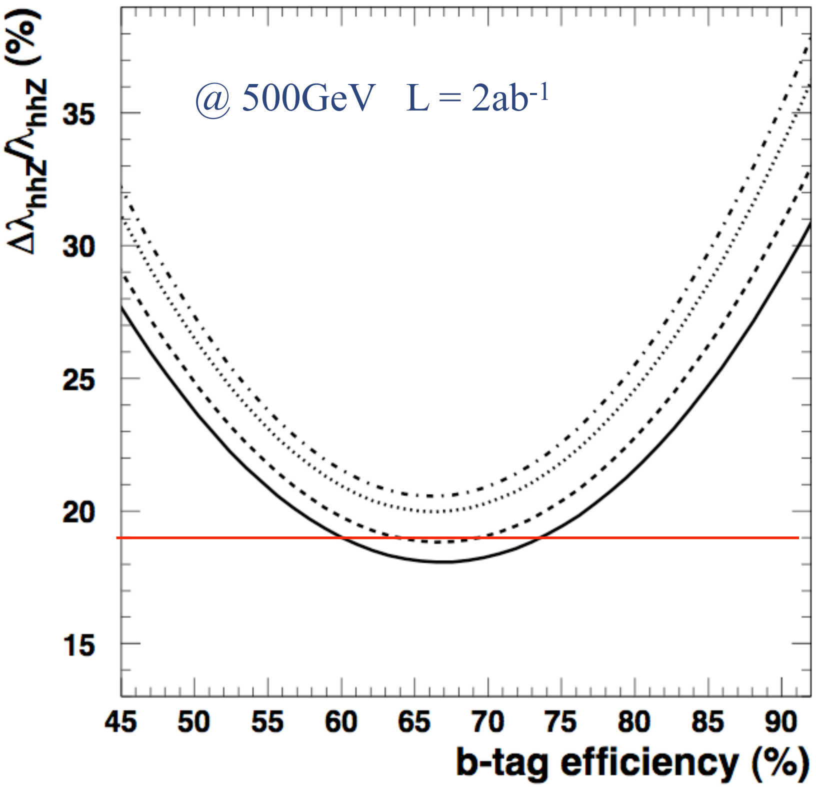
6.6 σ

Measurement of the cross section and of the **hhh** coupling

- σ_{hhZ} **is measured using a maximum likelihood method and assuming a Poisson law distribution for the NN output x btag**
- **The two dimensional distribution is fitted : NN Output X b-tag**

$\Delta\lambda_{hhh}/\lambda_{hhh}$ versus b-tag & pflow

D. Boumedienne et al. arXiv:0801.0866v1 [hep-ex]



$\Delta\lambda_{hhh}/\lambda_{hhh}$ **= 19%**

$$\Delta E_{jet}/E_{jet} \sim 0, 30, 60, 130\%/\sqrt{E_{jet}}$$

Jet charge can help …

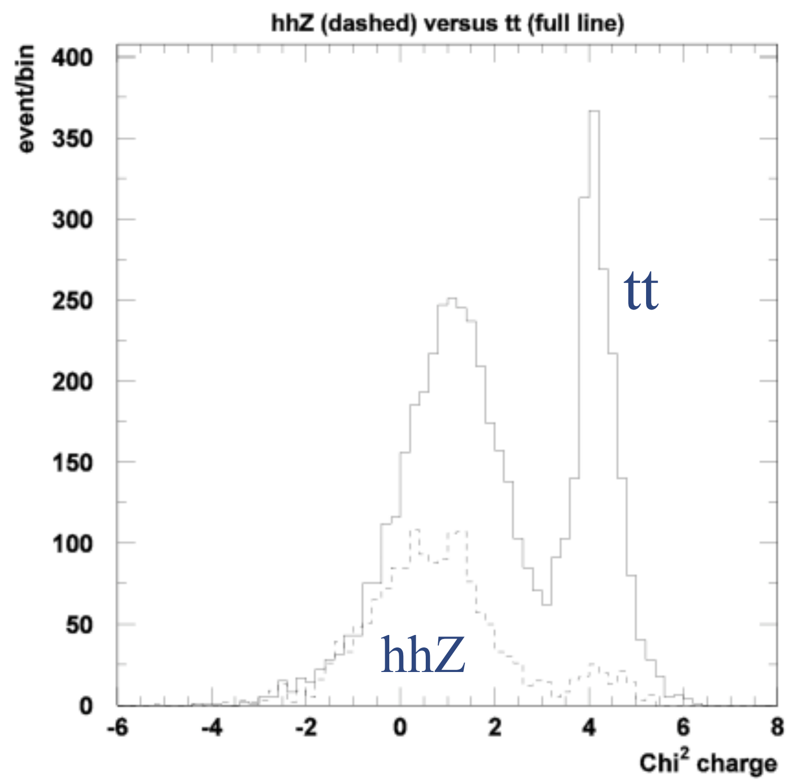
- **Definition of the jet charge (Ch_j):**
  - For a jet j : $Ch_j = \Sigma\, q_i\, w_i \,/\, \Sigma\, w_i$
    where q_i is the charge of the particle i
  - ↳ $w_i = \sqrt{(p_i . e_j)}$
    p_i is the particle's momentum, e_j the jet direction

- **Boson charge = sum of the charges of the two jets**

- **For a given event, definition of a χ^2**

$$\chi^2 = (Ch_{h1})^2/\sigma'' + (Ch_{h2})^2/\sigma'' + (Ch_Z)^2/\sigma''$$

- **It should improve the hhZ selection**



Summary

- @ 500 GeV, selection of the events 6 jets have been performed to hhZ final state.
- @ 800 GeV, selections of the events with 4 and 6 jets have been performed to respectively cover ννhh and hhZ final states
- Beamstralhung & ISR has been taken in account
  Realistic Fast simulation of the detector has been used

With 2 ab^{-1}

- At center of mass energy of 500 GeV, hhZ process leads to $\Delta\lambda/\lambda = 19\%$

- combination of hhZ and ννhh channel, at center of mass energy of 800 GeV, leads to $\Delta\lambda/\lambda = 16\%$

Higher energies

- **Self Higgs coupling is really a difficult measurement. The previous results should be taken with care.**

  The evaluation of the background is painful : dealing with long tail of important cross-section processes (as tt) and difficulties to simulate all the "small" cross-section processes.

- **Higher energy :**
- advantage: signal cross-section

√s	σ (fb) mH= 120 GeV
1 TeV	0.22
2 TeV	0.52
3 TeV	0.94
10 TeV	3.66

- Analysis and extraction of the self-higgs coupling is possible mainly thanks to hhvv process

M. Battaglia et al. arXiv:hep-ph/0111276v2

M_H (GeV)	$\sigma_{HH\nu\bar{\nu}}$ Only	$\lvert\cos\theta^*\rvert$ Fit
120	$\pm$ 0.094 (stat)	$\pm$ 0.070 (stat)
180	$\pm$ 0.140 (stat)	$\pm$ 0.080 (stat)

$\int L = 5\ \mathrm{ab}^{-1}$

Tim Barklow SLAC 2007 and LCWS07 Higgs Self Coupling measurement

A precision of 10% can eventually be achieved when data at Ecm=500 GeV and 1000 GeV are combined.
$L = 2000\ fb^{-1}$

Higher energies

- Most of the signal event is on the forward region (WW diffusion) → need a careful attention to design the end-caps part of the detector. And also in the detector simulation
- Contamination of the off-particles from the beam? how to include them in the simulation in the forward region?
- Beam-strahlung is of importance. is there a description/model at centre-of-energy greater than 1.6TeV?

Even @ 500 GeV, Higgs self coupling may be done with accuracy (19%) but with long term data taking.

Reach higher energies like 800 GeV and multi-TeV is a suitable solution but a very good description of the background processes and detailed detector simulation are mandatory.

Anyway long data taking should be needed.