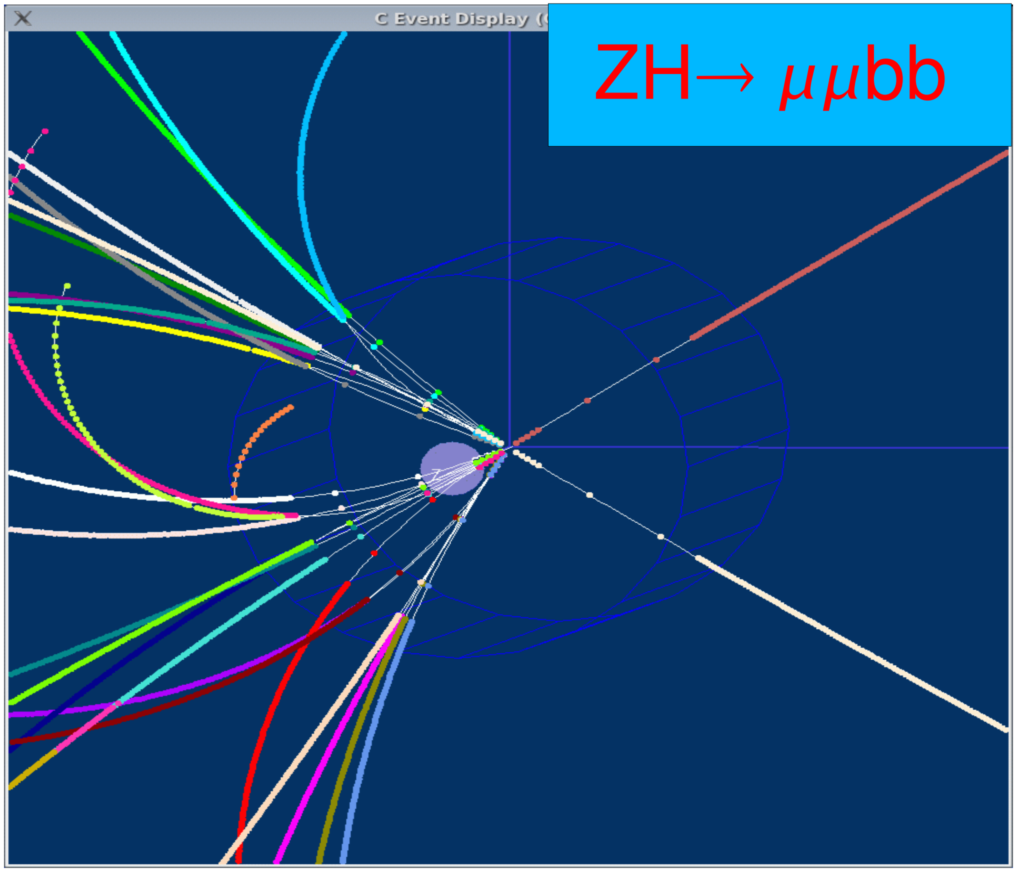
Higgs Physics @ ILC (Experimental Aspects)



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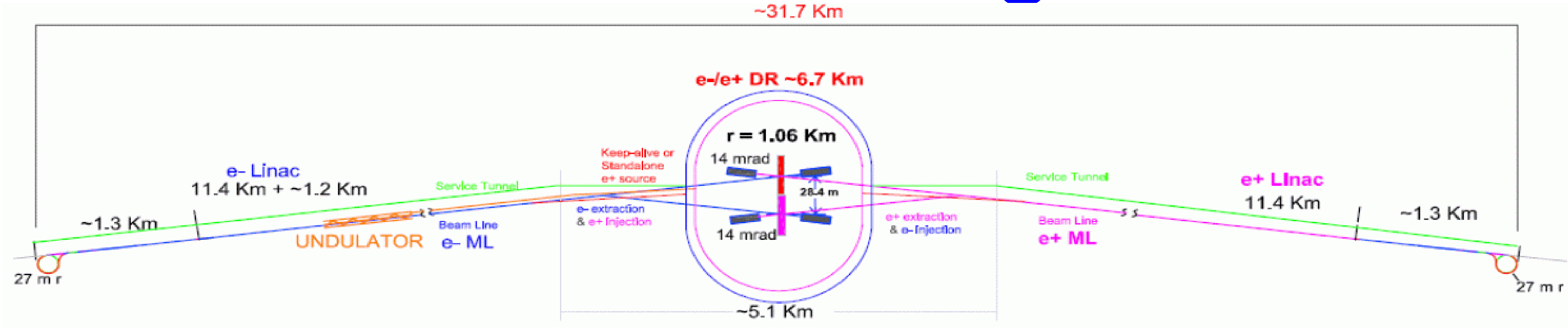
Workshop „LHC Early Phase for ILC“

Fermilab 12/04/2007

Content

- Recent news from ILC
  - ILC baseline configuration Document
  - Detector concepts and R&D
- Higgs Physics (focus on SM-like state)
  - Measurements, Analyses, Channels
  - Fast simulation vs. full simulation results
  - Presicion vs. Machine and Detector Performance
- ILC running strategy (input from LHC)

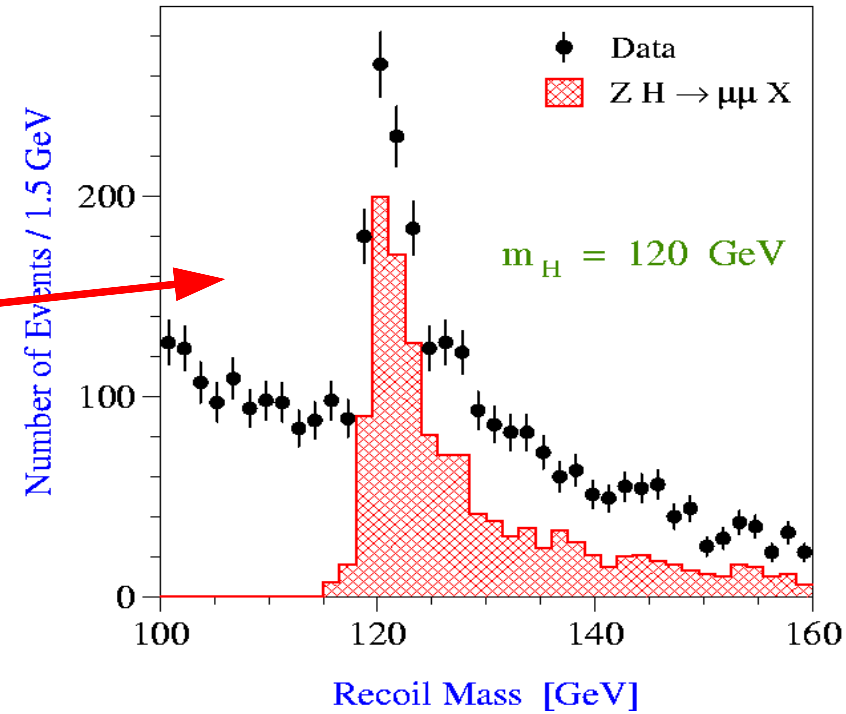
ILC Baseline Configuration



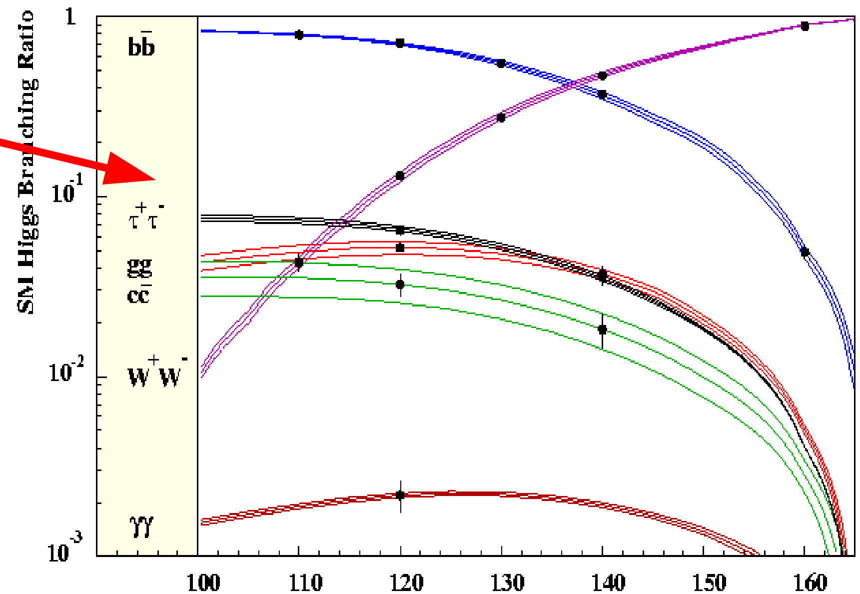
- Baseline parameters (Baseline Configuration Document, Nov 2006):
  - Accelerating gradient: 31.5 MV/m for 500GeV, 36 MV/m for upgrade
  - # particles / bunch: $2 \cdot 10^{10}$; # bunches / pulse: 2820
  - Linac inter-bunch interval: 300 ns; pulse frequency: 5Hz
  - Bunch dimensions @ IP ($\sigma_x/\sigma_y/\sigma_z$) : 0.4$\mu$m / 3nm / 300 μm
- Luminosity=$2 \cdot 10^{34}$ cm^{-2}s^{-1} ; Energy reach in the first stage : 500 GeV
- Two IR's with 14mrad crossing angle (baseline option) but for cost reasons an option with only one IR (2 detectors) is also under considerations ⇨ <u>push-pull scenario for ILC detectors</u>

Requirements on Detector Driven by Higgs Program

- Excellent momentum resolution ($\delta p/p^2 = 5\cdot10^{-5}$[GeV^{-1}c])
  - ➔ ZH➔$\mu\mu$(ee)X (model independent analysis)



- Excellent performance of VXD (σ_{d0}= 5μm$\oplus$10μm/p[GeV/c]$\cdot\sin^{3/2}\theta$), high track finding efficiency down to low track momentum (p ~ 500 MeV)
  - ➔ H➔bb,cc,gg,$\tau\tau$ decays (branchings, parity)
  - ➔ Vtx charge ➔ reduction of combinatorics (e.g. HHZ 6jet)

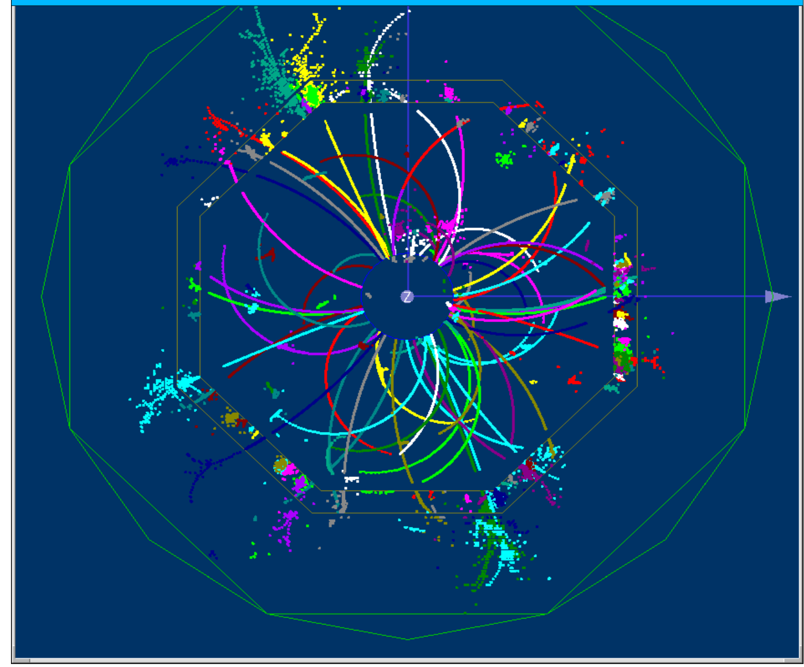


- Precise jet reconstruction in multi-jet final states ($\delta E/E$ = 30%/$\sqrt{E}$)
  - ➔ Higgs self-couplings (HHZ process)
  - ➔ Other signals: HA,HZ➔4jets(6jets)

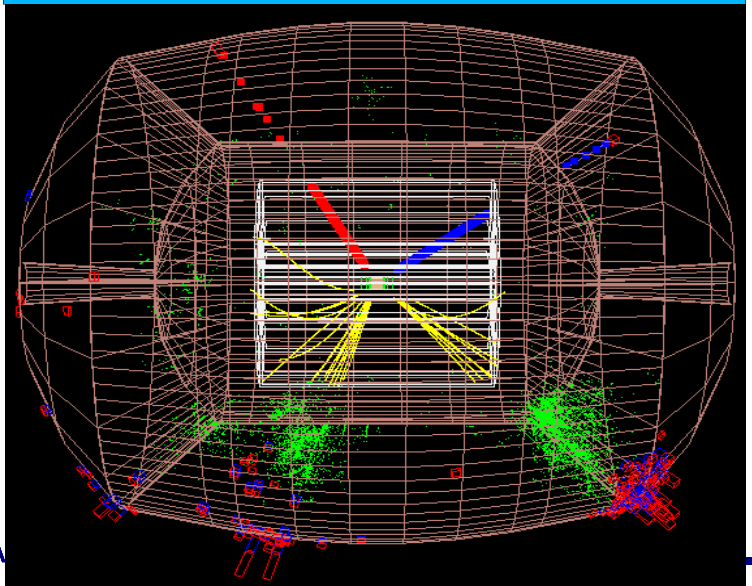
Detector Concepts

- SiD, LD & GLD driven by pflow, differ by size and B field
  - SiD/LDC/GLD : $R_{solenoid}$=3.3/3.8/4.4 m , B=5/4/3 T
- high granularity sandwich calorimeters (few cm^2 cell size) efficient shower separation & individual particle reconstruction in multi-jet events
- Pixelized VXD (5 layers, innermost layer at 1.5cm from IP)
- Central tracking : gaseous detector (TPC) : LDC & GLD; double-sided silicon strip layers : SiD
- Instrumented return yoke as muon detector

tt→6jets @ 500 GeV in LD



ZH→$\mu\mu$qq in 4th detector



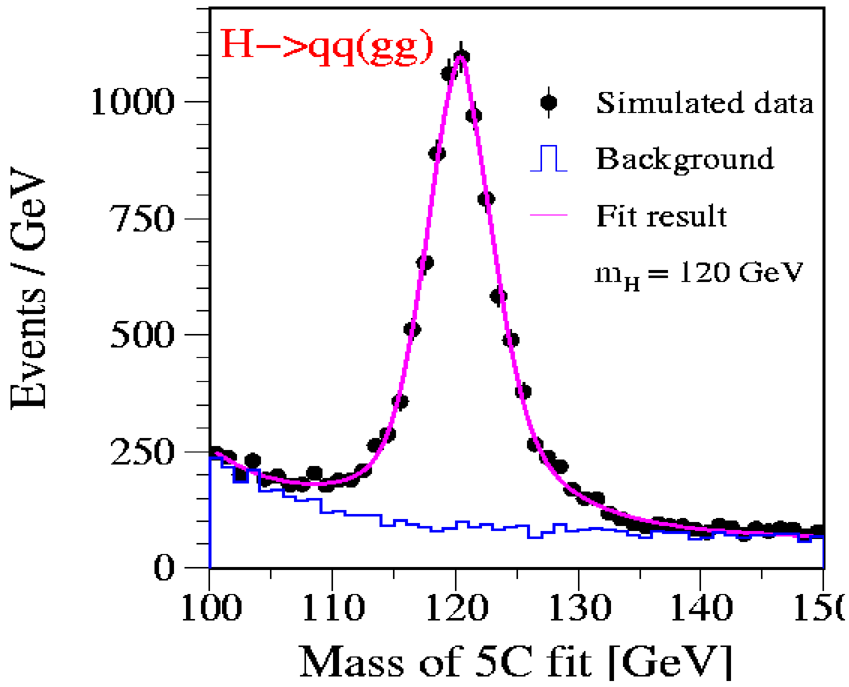
- 4th Concept : emphasis on calorimetry
- reconstruction of jet as a whole object with dual readout calorimeters; projective copper towers with embedded quartz and scintillating fibers enable to measure separately EM energy fraction within showers and thus improve energy resolution
- The same concept of tracking system as in LDC & GLD

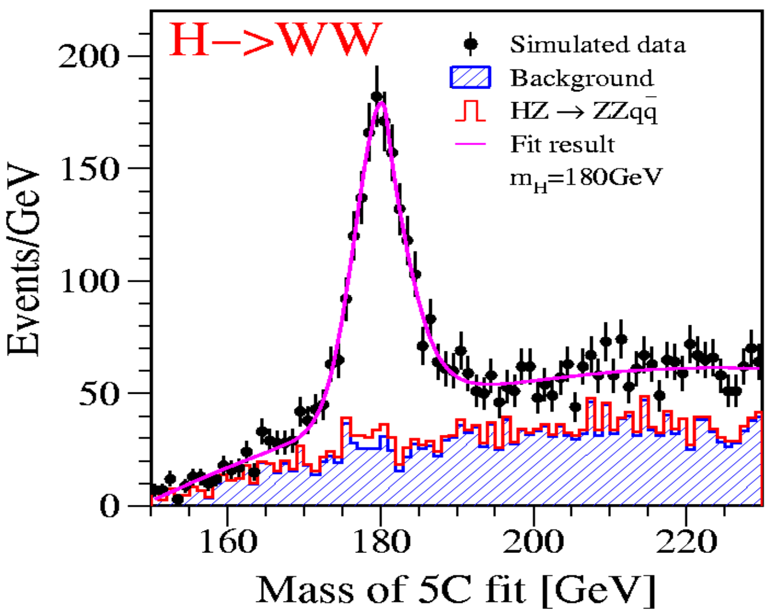
Higgs Physics at ILC

- Early analyses, evaluating ILC potential for determination of (SM-like) Higgs profile, include simulation of following measurements
  - Higgs mass, width;
  - Couplings to fermions, gauge bosons, self-couplings;
  - Quantum numbers (spin, parity)
- Most of these analyses are done with fast simulation program SIMDET (must be revised with full & detailed simulation and realistic reconstruction)
- Though beamstrahlung (reducing $\sqrt{s}$) is taken into account , other beam-induced effects (e.g. impact e+e- pair background on pattern recognition in VTX detector) are not studied in detail
- Assumed centre-of-mass energies: 350, 500, 800(1000) GeV depending on channel (an issue optimal ILC running strategy still to be addressed)
- Analyses were ment to give an approximate estimate on achievable precision of Higgs measurements and maybe provide a bit too optimistic forecast
- In the following selected analyses are reviewed

Higgs Mass

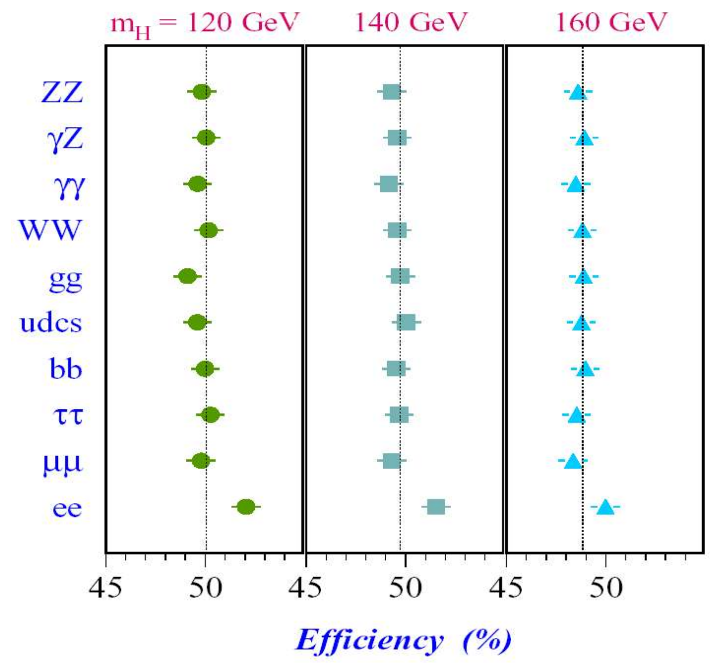
- Mass measurement @ ILC
  - $\sqrt{s}$ = 350 GeV, L=500 fb^{-1}
  - Exploits all visible decay channels of Z (e^+e^-, $\mu^+\mu^-$, 2jets)
  - Higgs mass range 120-180GeV
  - Employed Higgs decays modes: h→2jets, h→WW/ZZ→4jets
  - Relies on kinematic fit -> bias in mass due to ISR+BS. Eliminated by mapping reconstructed mass value to generated mass value
- Estimated statistical precision varies from 40 to 70 MeV for m_H = 120/180 GeV
- Beam energy must be measured at 10^{-4} level to keep systematic uncertainty below statistical uncertainty

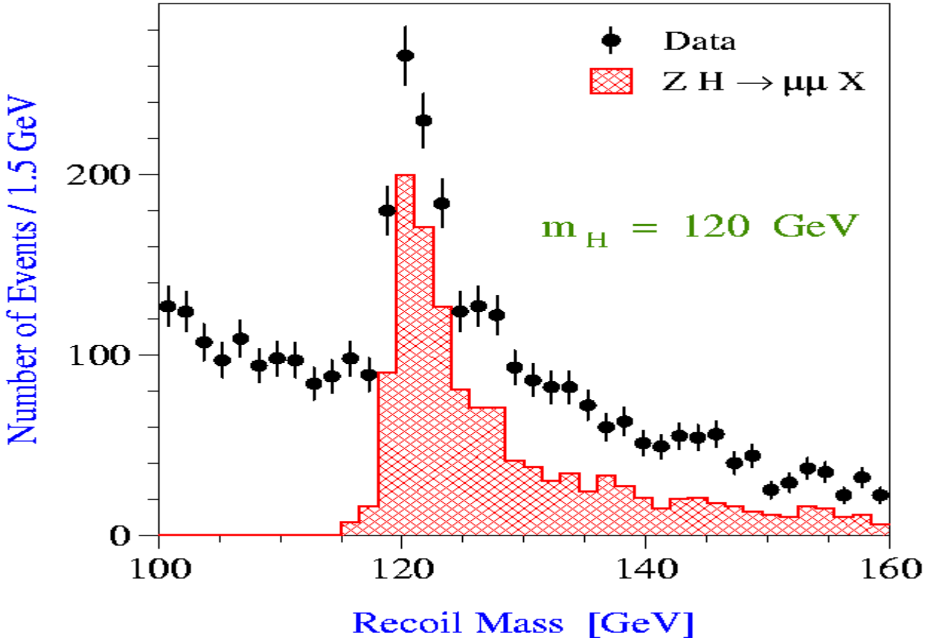




Model Independent Observation

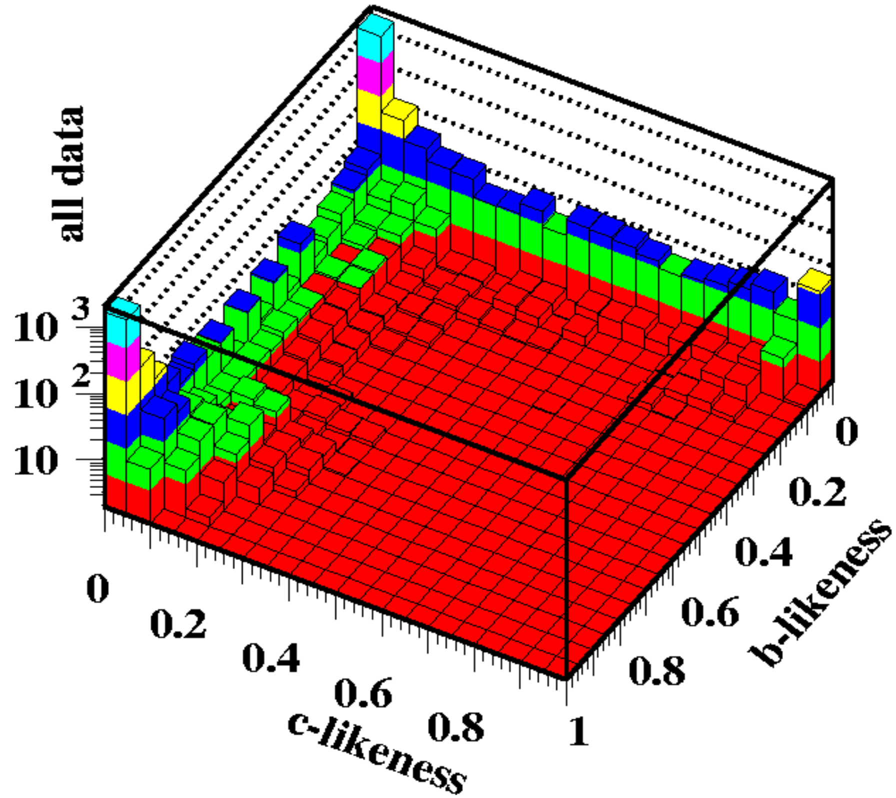
- σ_{ZH} from $ZH \rightarrow ee(\mu\mu)X$
- Selection independent of Higgs decay
- Analysis of recoil mass spectrum
  - $m = \sqrt{(\sqrt{s} - E_- - E_+)^2 - (p_- + p_+)^2}$
- $\sigma = (N_{data} - Bkgd) / (L \cdot Br(Z \rightarrow ee, \mu\mu) \cdot \varepsilon)$
- $\sigma \propto g^2_{HZZ}$
- $\sqrt{s} = 350$ GeV, $L = 500\ fb^{-1}$
- $\delta\sigma/\sigma = 2.6(3.1)\%$ $m_H = 120(160)$ GeV combining $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$





Hadronic Branchings of Higgs

- *$\sqrt{s}$= 350GeV, L=500/1000 fb^{-1} for m_H=120/140 GeV*
- *Likelihood selection of inclusive samples (H→bb,cc,gg)*
- *All decay modes of Z are exploited*
- *NNet b and c-tagging instead of coarse jet tag parameterization, but still fast parametric smearing of final-state particle 4-momenta*
- *Fit of two dimensional distribution (b-tag vs. c-tag) with three normalisation factors for the H→bb,cc,gg signals*



Statistical accuracy on $\sigma \cdot Br(H \to X)$

m_H [GeV]	bb	cc	gg
120	1.0%	12.3%	8.3%
140	1.8%	27.0%	16.0%

Higgs Branchings

- **Indirect method:**
  - Measure first topological x-section $\sigma(X,Y)=\sigma(ZH)\cdot Br(Z\rightarrow Y)\cdot Br(H\rightarrow X)$ by selecting sample of events compatible with the topology under study
  - $\sigma(ZH)$ is determined from the analysis of inclusive sample $ZH\rightarrow(ee,\mu\mu)X$
  - $Br(H\rightarrow X) = \sigma(X,Y)/[\sigma(ZH)\cdot Br(Z\rightarrow Y)]$
- **Direct method:**
  - Decay independent selection of sample $ZH\rightarrow\mu\mu(ee)X$
  - Extract the fraction of events compatible with a given topology of Higgs decay
  - error is reduced by factor $\sqrt{1-Br(H\rightarrow X)}$ due to binomial statistics ⇒ optimal method for large $Br(H\rightarrow X)$

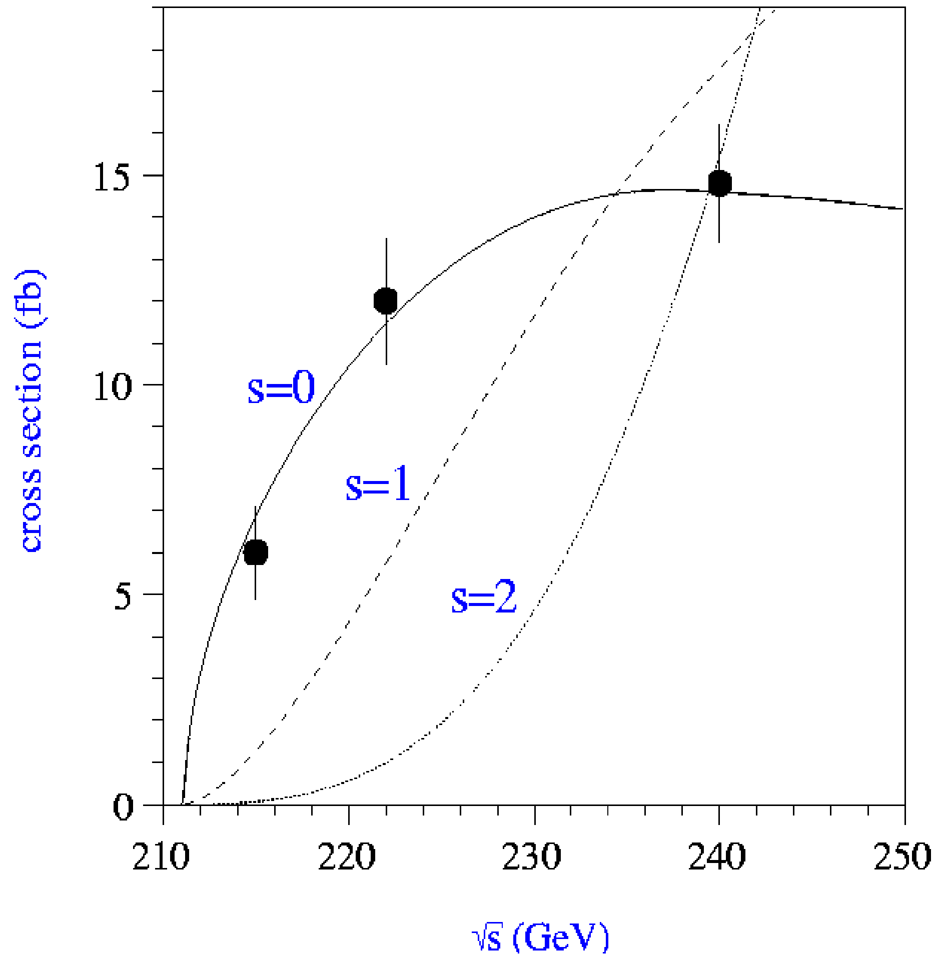
Higgs branchings

$m_h=120$, $\sqrt{s} = 350$GeV $L=500$ fb^{-1}

	Indirect	Direct
bb	2.4%	1.9%
WW	4.2%	3.6%
$\tau\tau$	5.0%	7.1%
$\gamma\gamma$	26%	35%

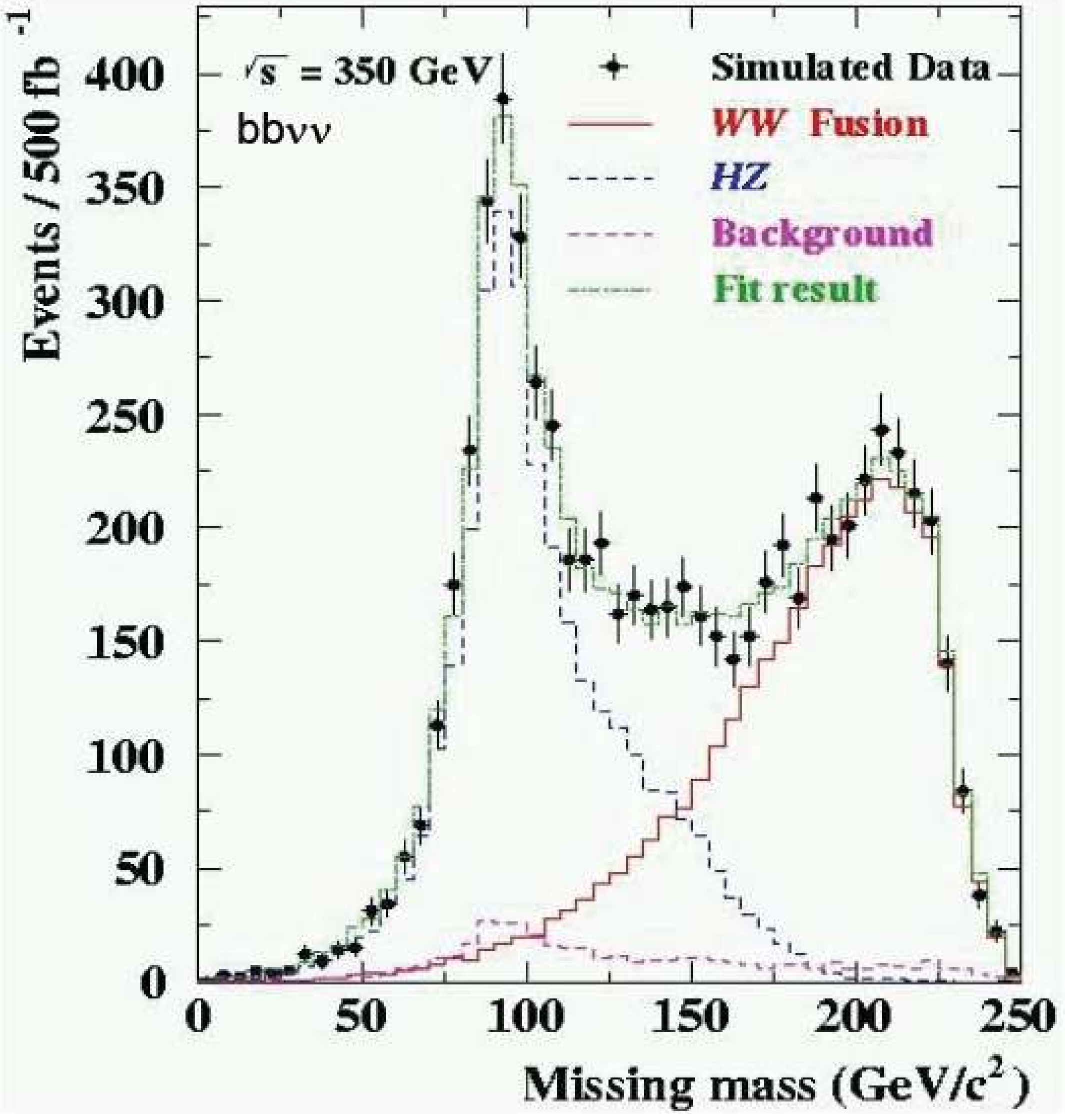
Spin

- Threshold scan :
  - for J=0 : $\sigma \propto \beta$
  - for J>0 : $\sigma \propto \beta^k$, k>1
  - Some cases for J=2 are also $\propto\beta$ but can be distinguished from J=0 via angular distributions
- $ZH \rightarrow \mu^+\mu^- X$
- Three energy points with 20 fb^{-1} will be sufficient to discriminate between different spin scenarios



Width Measurements

Indirect measurement (for $m_H < 2\, m_W$):



Large WW fusion cross-section at large $\sqrt{s} \Rightarrow g_{HWW} \Rightarrow \Gamma_{WW}$

Combine with BR(H→WW) measurement from Higgs-strahlung

$$\Gamma_{tot} = \frac{\Gamma_{WW}}{BR(H \to WW)}$$

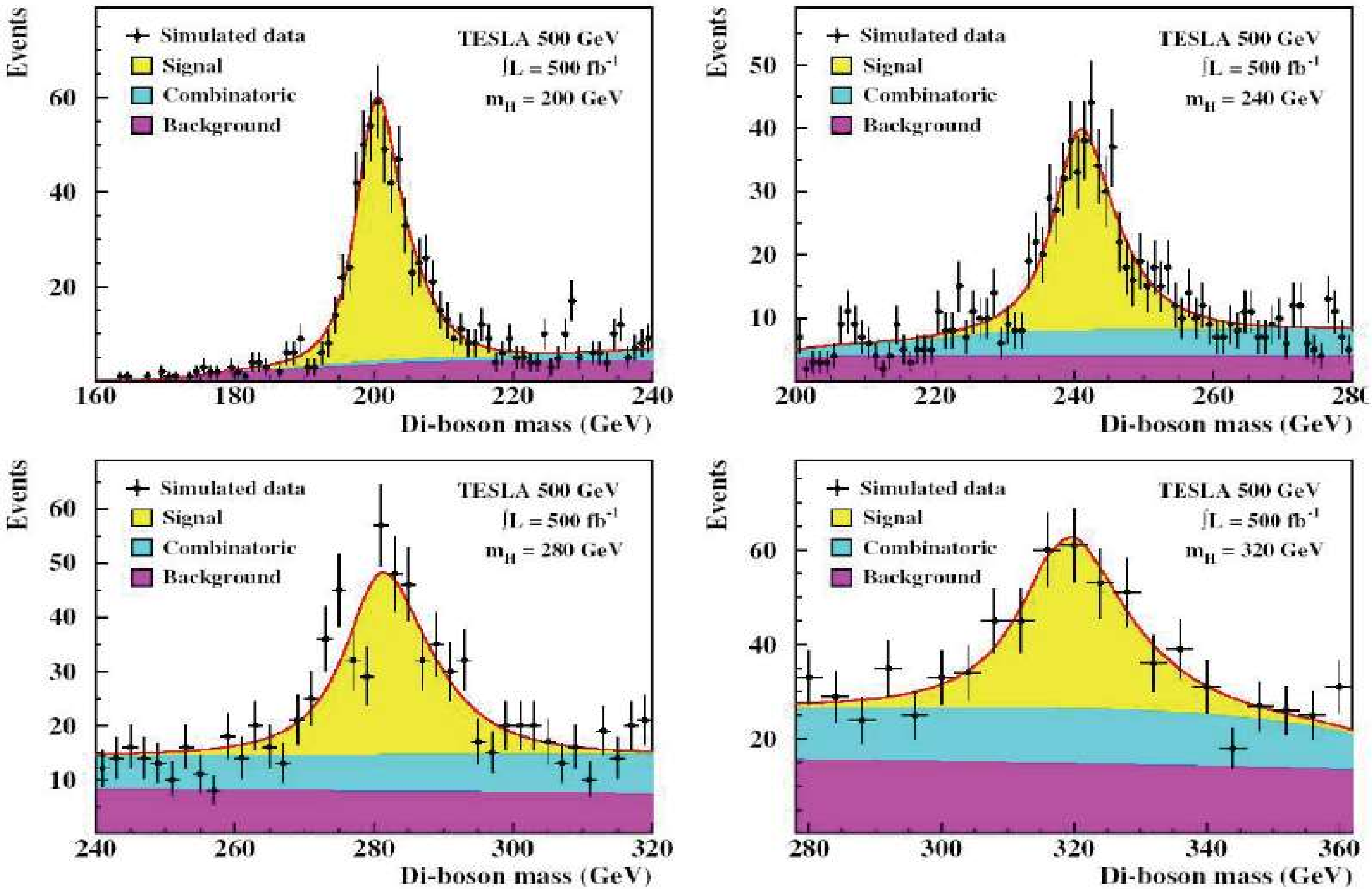
Model-independent meas.

Alternative:

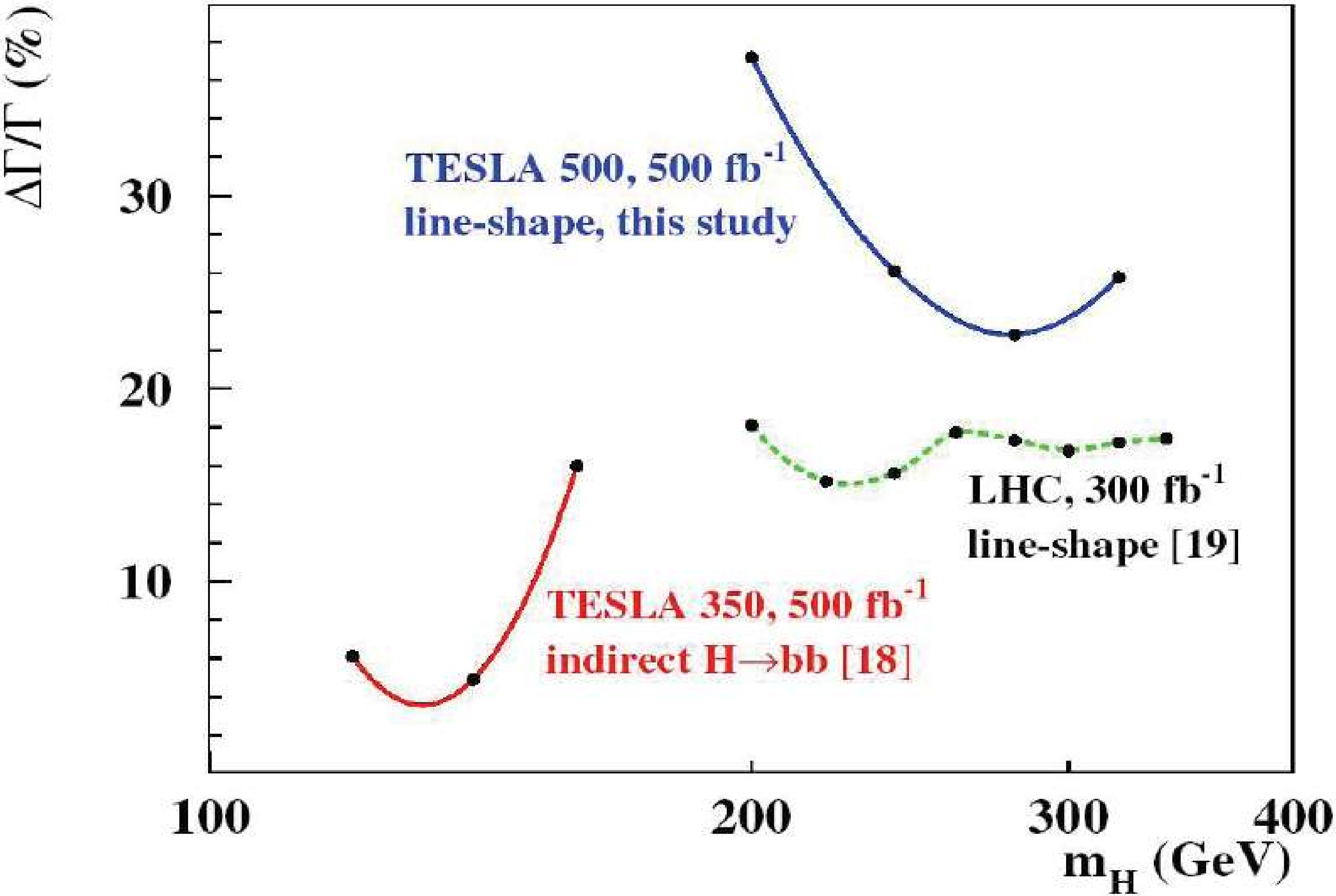
$$\Gamma_{tot} = \frac{\Gamma_{\gamma\gamma}}{BR(H \to \gamma\gamma)}$$

Width Measurements

Direct measurement from lineshape (for $m_H > 2\ m_W$):



Precision overview:



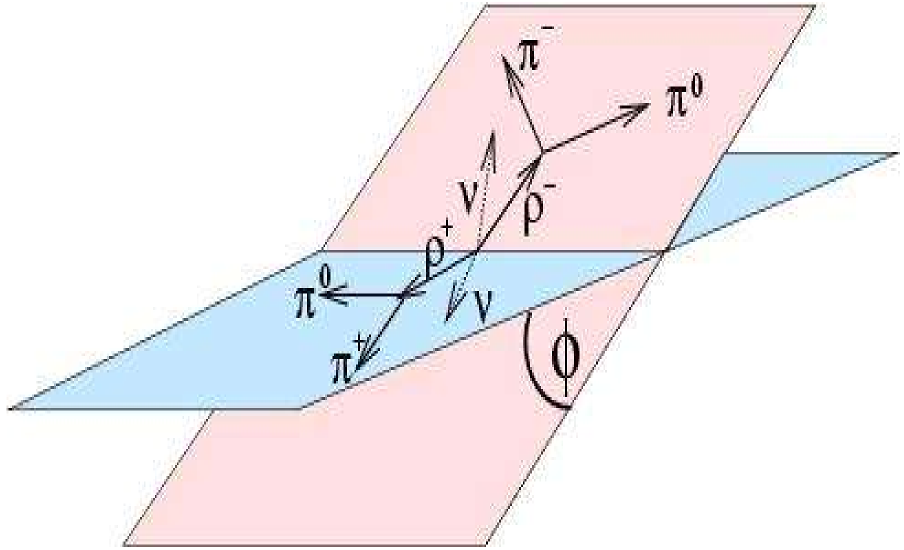
Higgs Parity via Tau Decays

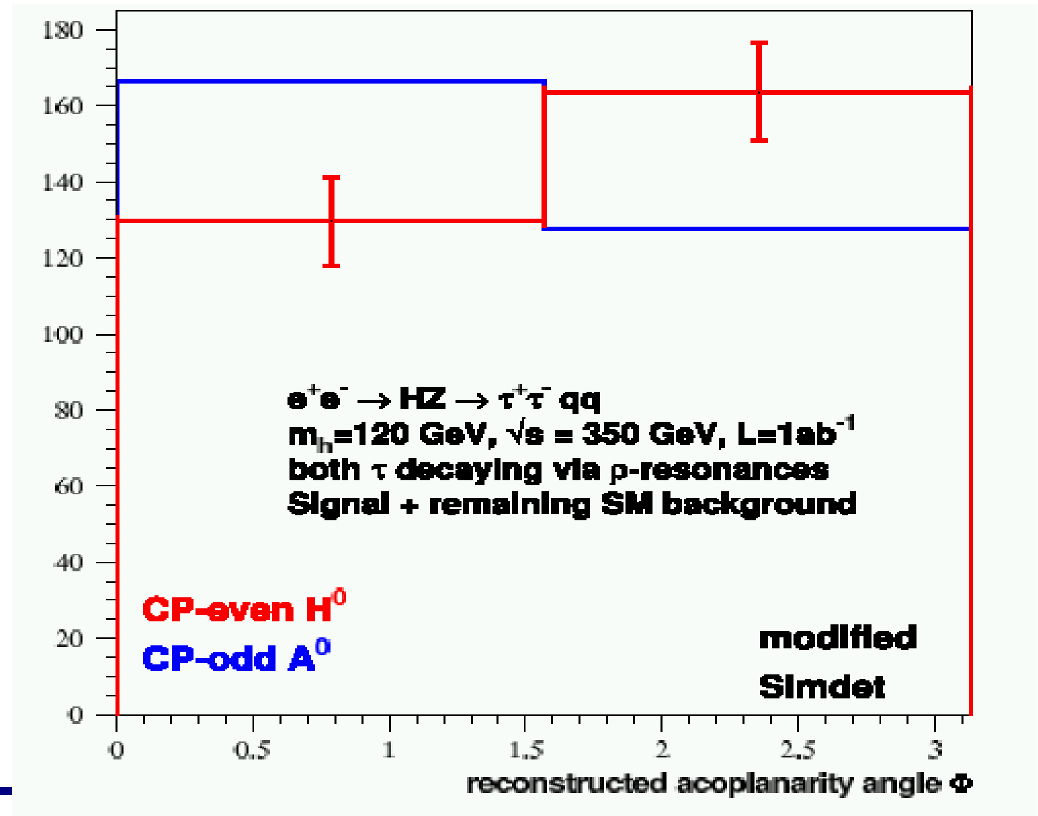
$$\Gamma(H, A \rightarrow ff) = 1 - s_z s_z \pm s_\perp s_\perp$$

- Depolarisation effects in jet fragmentation dilute spin information in H→qq channel

→ Use $H\rightarrow\tau\tau$ (light Higgs)

- $H\rightarrow\tau\tau,\ \tau^{\pm}\rightarrow\rho^{\pm}\nu\rightarrow\pi^{\pm}\pi^{0}\nu$
- Acoplanarity angle ϕ discriminates between scalar and pseudoscalar states (4.0σ separation)
- Mixed state: mixing angle can be measured with an accuracy of 6°
- Benchmark channel for ECAL design
  - High transverse granularity ~ cm²
  - Ecal energy resolution $\Delta E/E\sim10\%/\sqrt{E}$





Parity in ϕZ Production

- Mixed state: production matrix element:

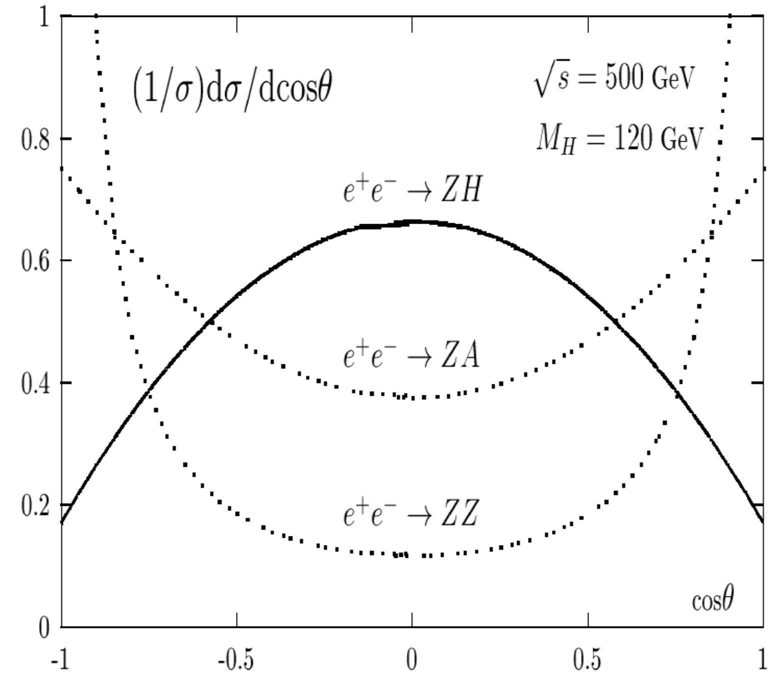
$$M = M_{ZH} + i\eta M_{ZA}$$

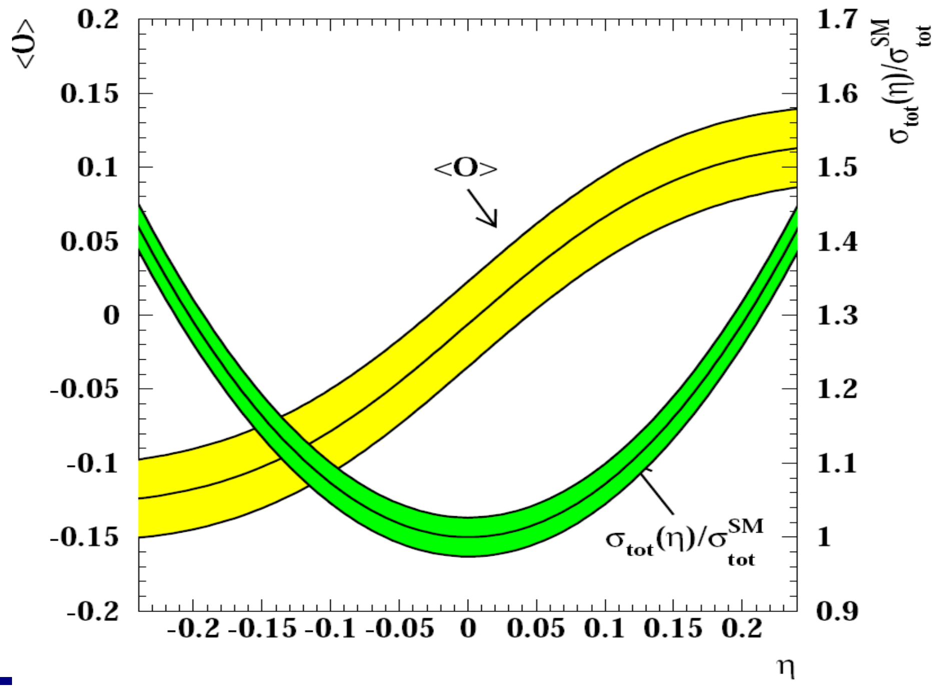
- Scalar and pseudoscalar components are discriminated by
  - Angular distributions
  - Different cross-sections
- Optimal observable:

$$O = 2Re(M^{*}_{ZA} M_{ZH}) / |M_{ZH}|^2$$

- ***350GeV (500 fb^{-1})***

$$\delta\eta \simeq 0.03$$



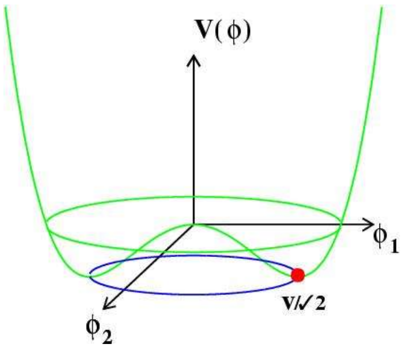


Higgs Self-Coupling

Higgs self-coupling ('the holy grail'):

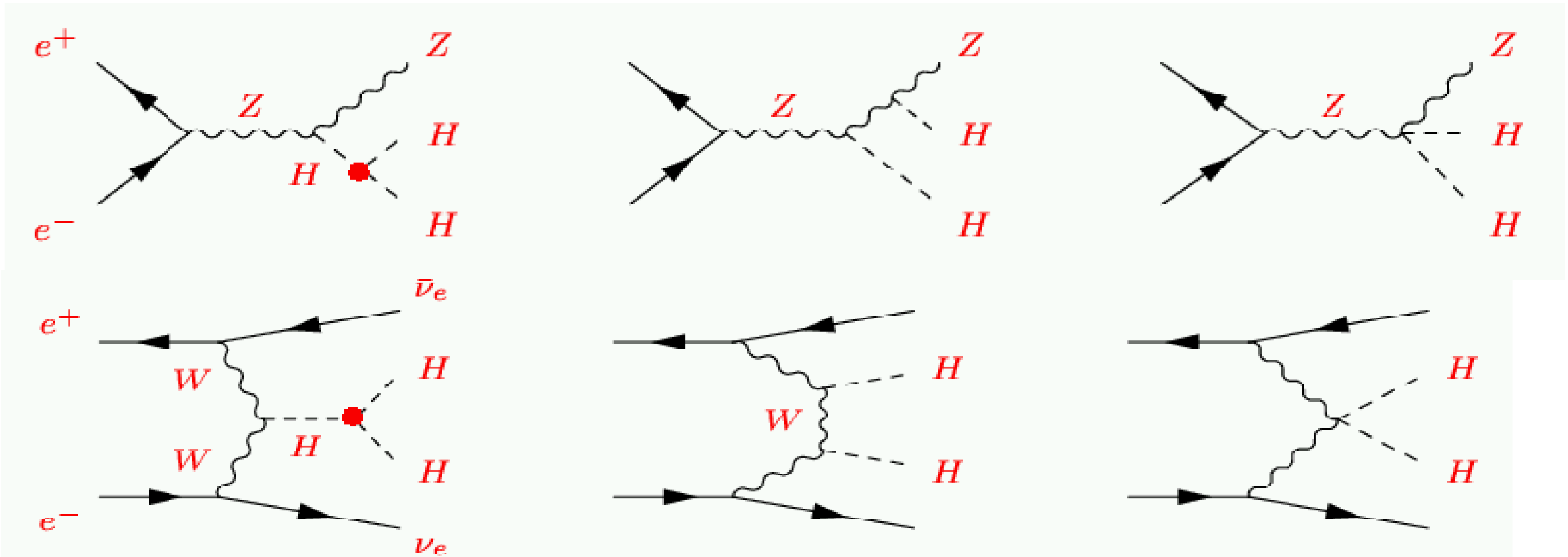
$$\mathcal{V} = \quad v^2 \mathcal{H}^2 + \quad v \mathcal{H}^3 + 1/4 \quad \mathcal{H}^4$$

$$\text{SM: } g_{\mathcal{HHH}} = 6 \quad v, \text{ fixed by } \mathcal{M}_{\mathcal{H}}$$



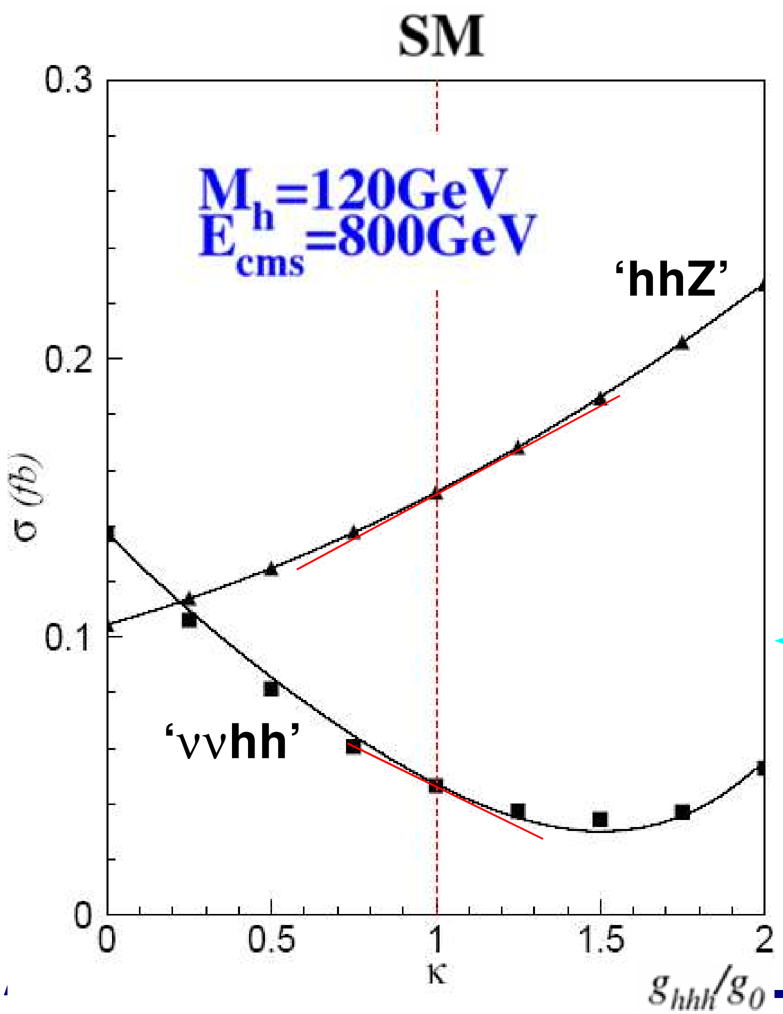
essential test of the mechanism of spontaneous symmetry breaking

Dominant topologies
m_H<130GeV : 6-jet
m_H>130GeV : 10-jet (!)
⇒ Real challenge for detector!

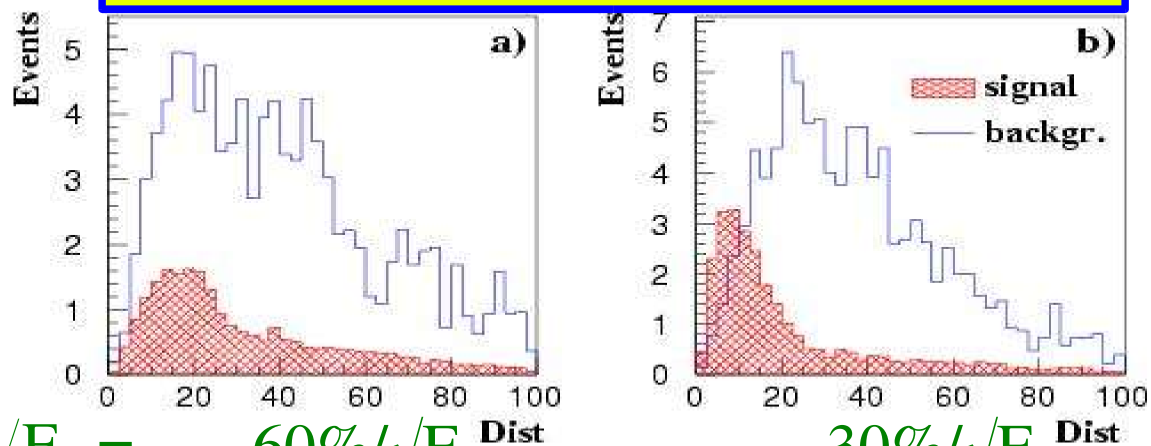


Higgs Self-Coupling

TESLA TDR analysis
500GeV (1 ab^{-1})
ZHH, $H \rightarrow bb$
$\delta\lambda/\lambda \simeq 23\%$



Benchmarking Detector Performance



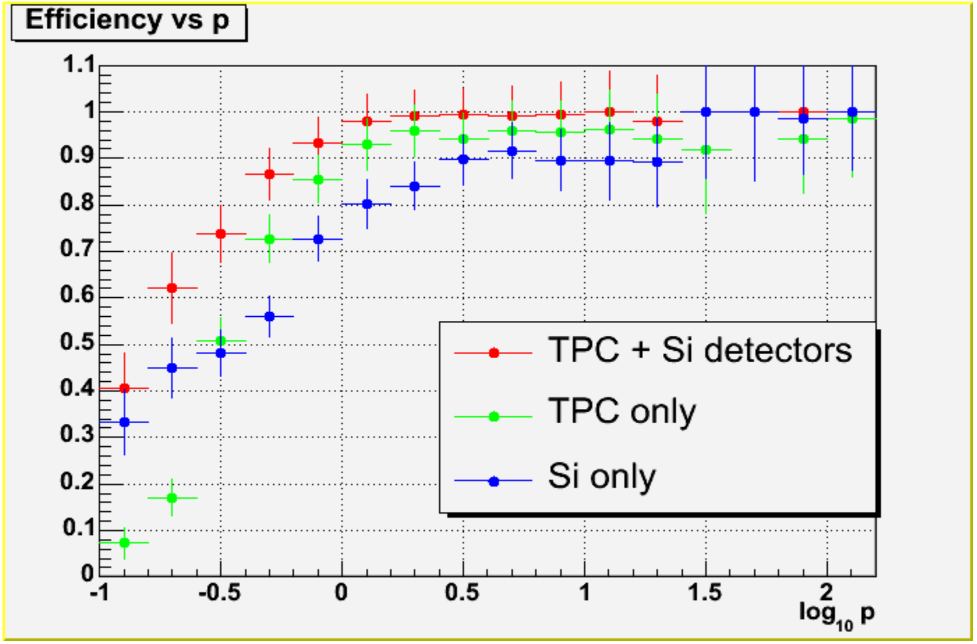
$\Delta E_{jet}/E_{jet} =$ $60\%/\sqrt{E_{jet}}$ $30\%/\sqrt{E_{jet}}$

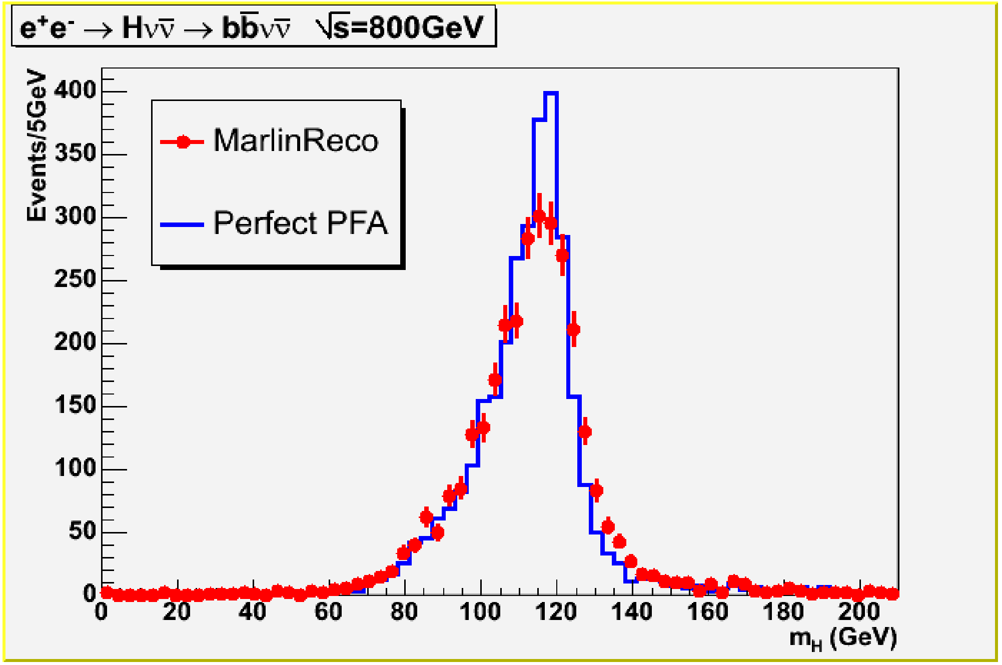
40%->30% move from 4.5 to 2 years data taking!

Recent Update
800GeV (2ab^{-1})
ZHH & ννHH combination
$\delta\lambda/\lambda \simeq 14\%$

Flaws of Fast Parametric Simulation

- 4P of all final state particles smeared according to the particle type (photon, neutral hadron, charged particle)
- Idealistic pattern recognition is assumed
  - High track finding efficiency (close to 100%) over the entire momentum range
  - Perfect track-cluster matching and separation of close-by showers
- Recent studies with full simulation & realistic reconstruction revealed
  - Track finding efficiency drops at low momenta (multiple scattering effect) and close to 100% only for p>1GeV
  - Slightly worse jet resolutions compared to fast simulators → worse boson mass resolutions

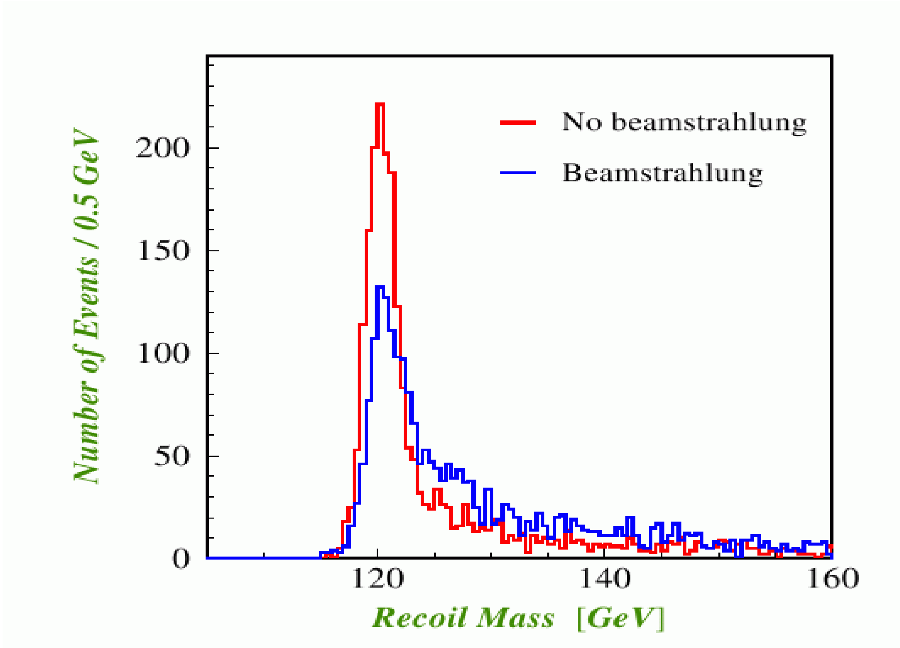


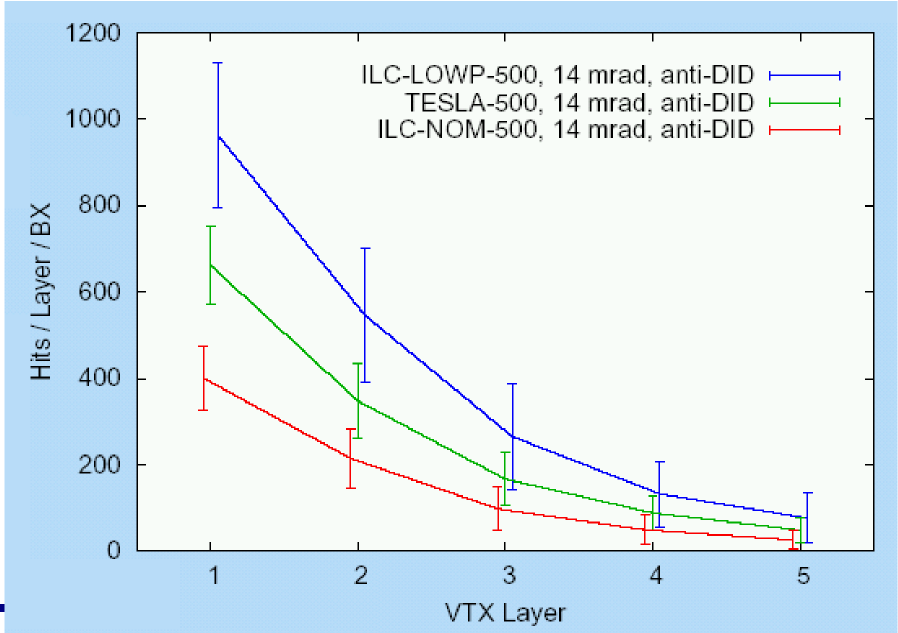


➔ **<u>Early Higgs analysis must be revisited!</u>**

Beam Related Effects & Beam Induced Backgrounds

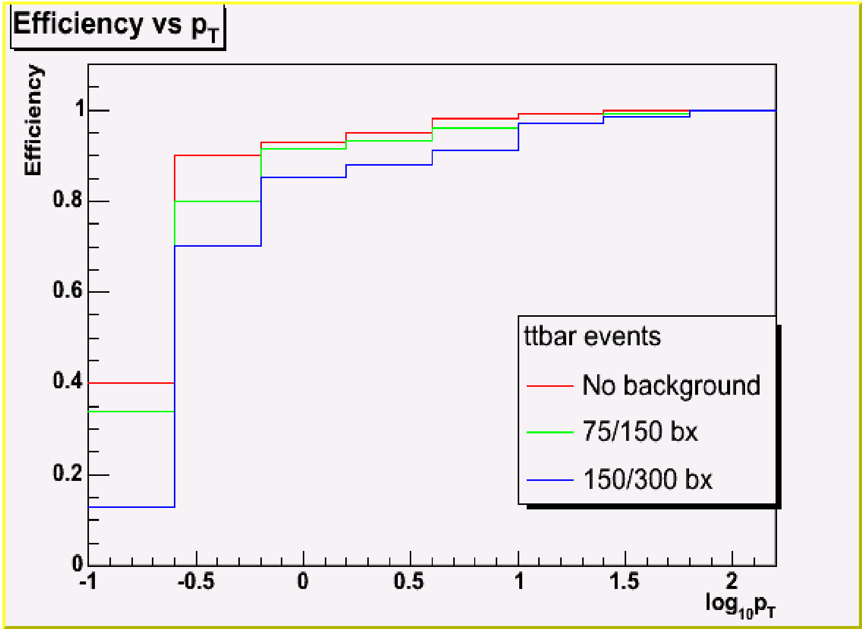
- High charge densities of colliding beams @ ILC ⇒ beamstrahlung
- Reduction of effective c-o-m energy (accounted for in early analyses)
- Production of e+e- pairs
  - Deteriorates patrec in VTX detector, affect heavy-flavour tagging and consequently hadronic Higgs measurements
- $\gamma\gamma\rightarrow hadrons$ events overlaid with physics signal ⇒deteriorate jet/τ reconstruction
- These issues should be addressed in the next generation of analyses

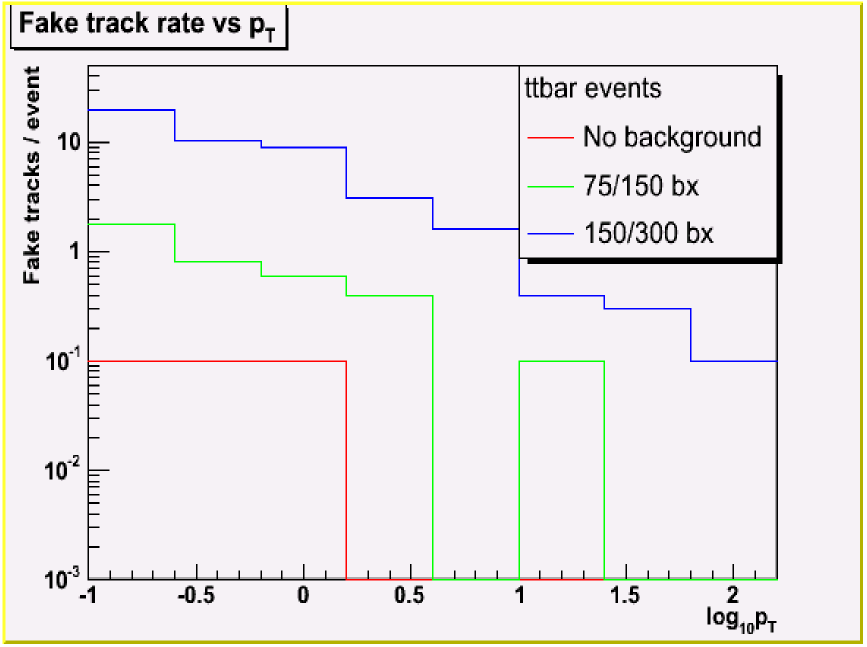




Beam Induced Backgrounds in VTX

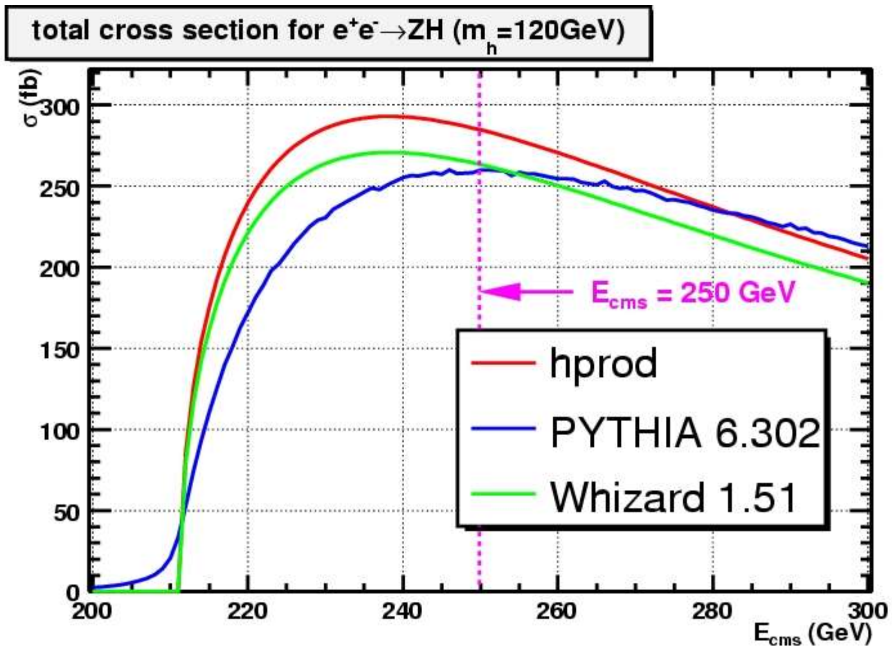
- Efficient patrec in VTX crucial for Higgs analyses relying upon b/c-tagging
- Anticipated VTX readout speed ~ 50-100 μs (integration over 150-300 bx)
- Impact on pattern recognition is sizable
  - Rise of fake rate from 0.4 (no bkg) up to 40 fakes per physics event (worst scenario)
  - Drop in track efficiency from 95% (no bkg) down to 86% (worst scenario)
- Strict requirements are posed on VTX readout speed
- Impact should be quantified in terms of precision on hadronic branchings and self-coupling measurements -> guideline for VTX R&D

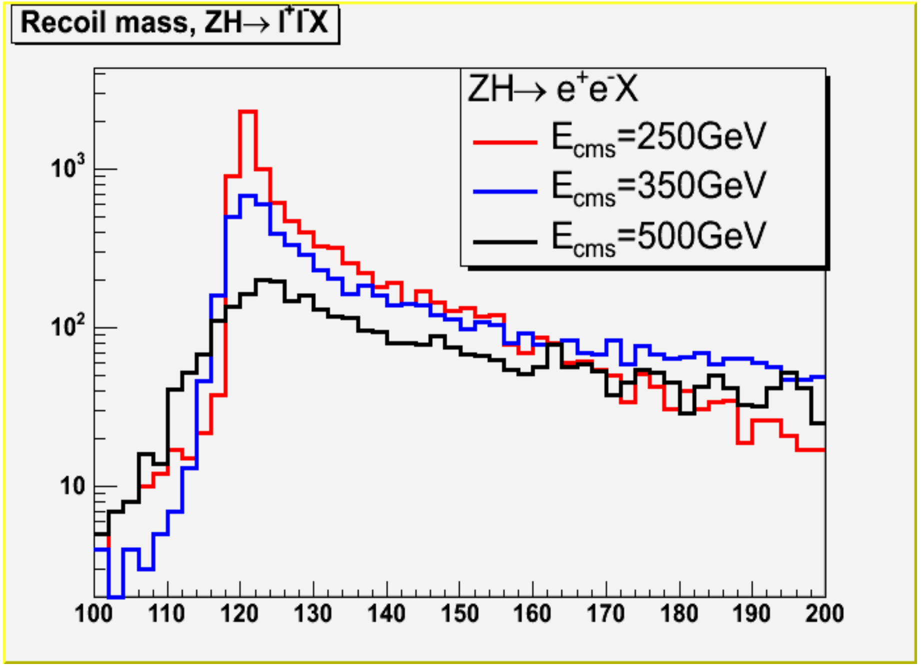




ILC Running Strategy

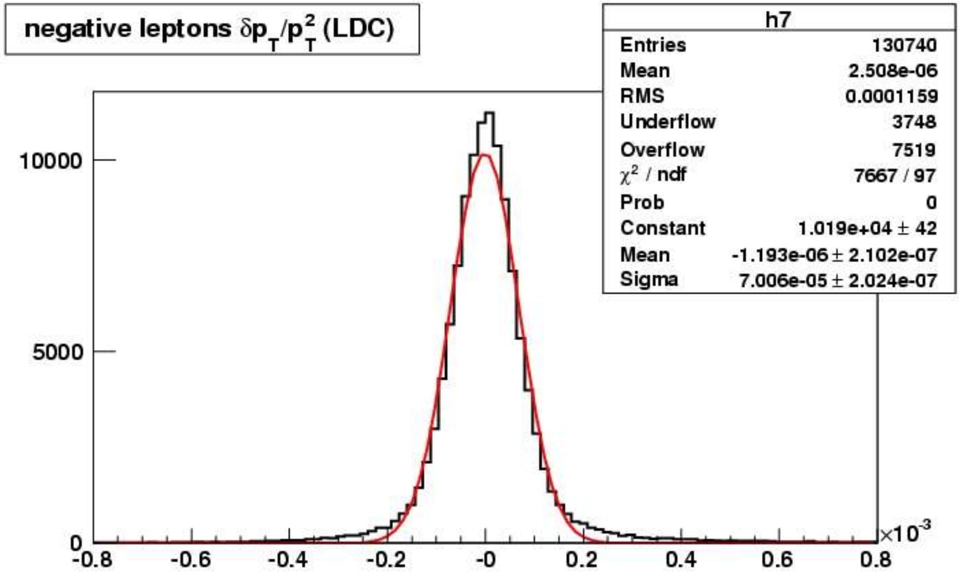
- Usual ILC scenario for ZH(m_H=120GeV): 500 fb-1 at √s=350 GeV (the top threshold)
- But running at √s closer to threshold is more attractive for light Higgs scenario
  - Larger cross-section
  - Better recoil mass and jet resolution
  - threshold scan (Higgs spin)
- Keep in mind other possible channels, requiring higher energies (gaugino, slepton pair production)
- Careful evaluation needed (luminosity per energy point, energy grid, *etc*)
- **Input from LHC (Higgs mass, SUSY particles spectrum) is valuable!**

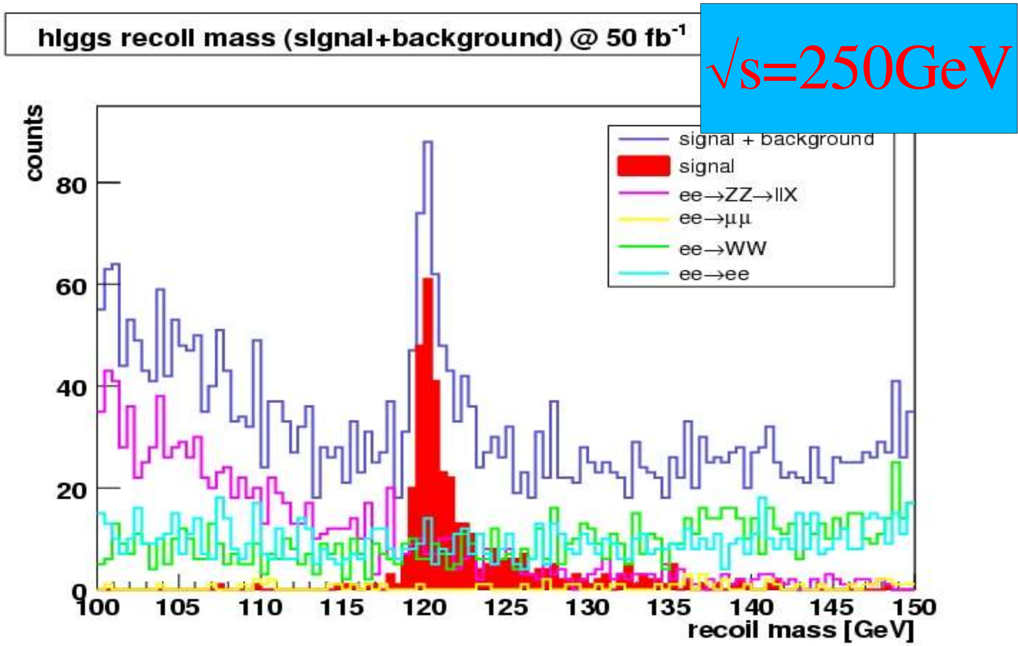




Higgs Analyses With Full Simulation/Reconstruction

- New generation of analyses
  - full simulation/reconstruction
  - revision of early analyses based on fast simulation
  - input for detector optimization
- Example : model independent measurement of σ(ZH)
  - Simulation with G4 based program Mokka
  - Realistic patrec in tracking system and Kalman track fitting
  - Particle identification based on analysis of hit pattern in calorimeters





Summary

- *ILC offers rich and interesting Higgs Program*
  - *Many measurements in Higgs sector @ LHC can be refined*
  - *Higgs properties inaccessible @ LHC can be probed*
- *New generation of Higgs analyses based on*
  - *Revision of early analyses based on fast simulation*
  - *Input for detector optimization*
- *ILC running strategy : new and hot topic*
  - *Good reasons [dictated by Higgs physics] to run machine for some [not too short] period at energy just above ZH threshold...*
  - *but keeping in mind other channels [sparticle, heavy Higgs production, etc] which may require higher energies*
  - *Elaboration of optimal ILC running strategy needs input from LHC!*