22.9, ECFA/DESY-WS, Hamburg

Determination of the CP Quantum Numbers of the Higgs Boson

Markus Schumacher, DESY

* Introduction
* A little bit of theory
* Extraction of CP-QN
* Selection
* Fit results
* Conclusion and Outlook

Introduction

* Spin and CP-QN can be determined in several ways at a e^+e^- collider

* observation of

$$\left.\begin{array}{l} H \rightleftarrows \gamma\gamma \\ H \rightleftarrows ZZ \\ e^+e^- \to Z^* \to ZH \end{array}\right\} \begin{array}{l}\text{rule out spin 1} \\ \text{determine } C=+\end{array}$$

* but CP=++ (H) or =+− (A) or mixture?

* angular distributions of production and decay sensitive to CP-QN

* production $e^+e^- \to Z\phi \to f\bar{f}\phi$ described by Θ_Z

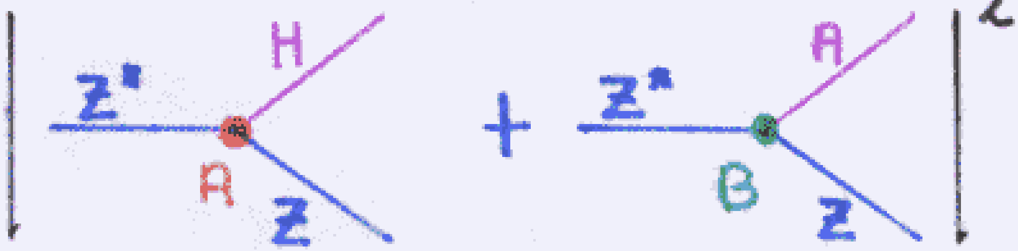
and Θ^*_f, φ^*_f in Z rest frame

* sensitive dist.: $\frac{d\sigma}{d\cos\Theta}$, $\frac{d\sigma}{d\varphi^*}$

* today: analysis of $\frac{d\sigma}{d\cos\Theta}$

A little bit of theory

* production of $Z\phi$

$m^2 = \Big|$  $\Big|^2$

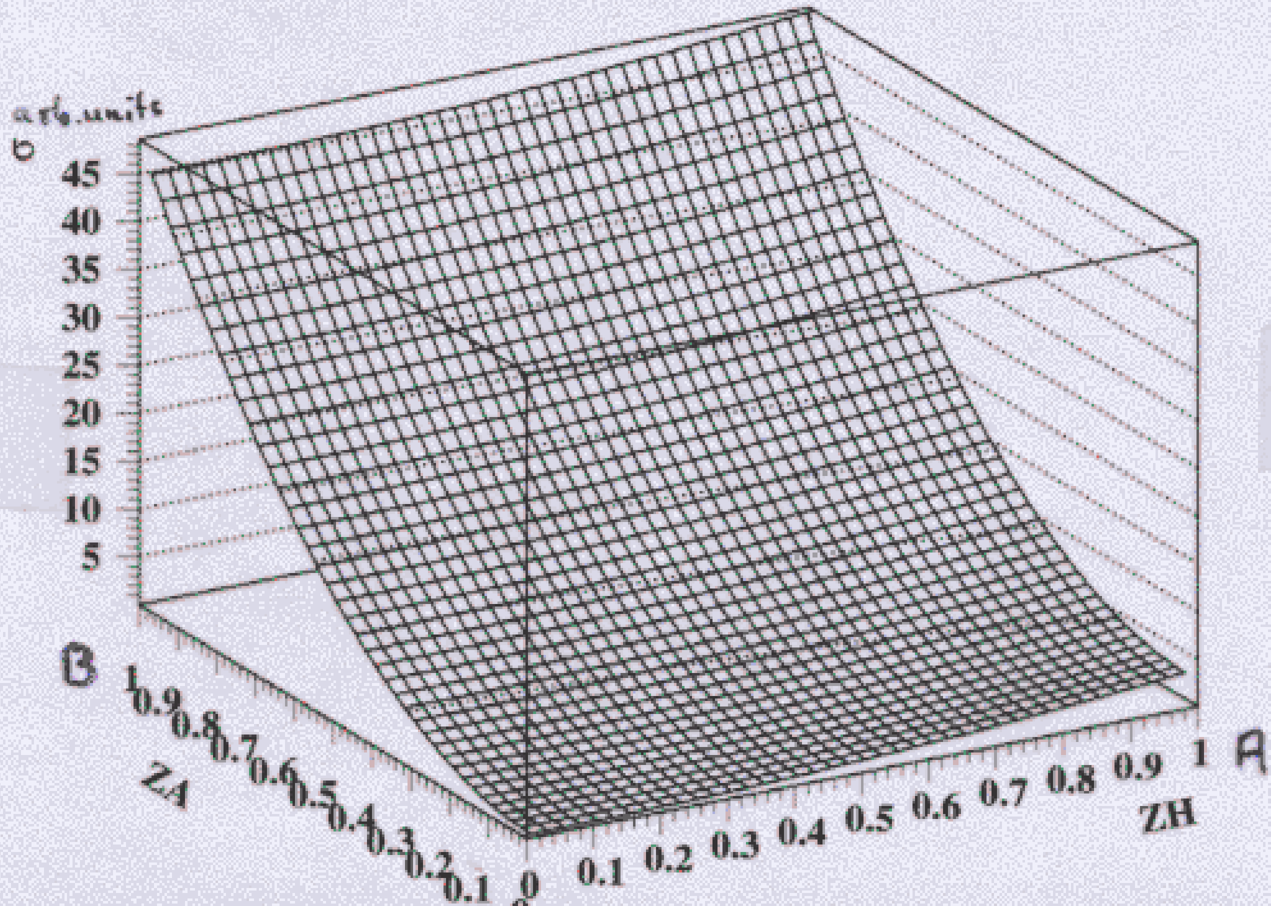
SM: $A=1 \quad B=0$

* $$\frac{d\sigma}{d\cos\theta} \sim A^2\left(1+\frac{s\beta_Z^2}{8M_Z^2}\sin^2\theta\right)$$ "HZ"

$$+2AB\,\frac{v_e a_e}{v_e^2+a_e^2}\,\frac{s\beta_Z}{M_Z^2}\cos\theta$$ intefero

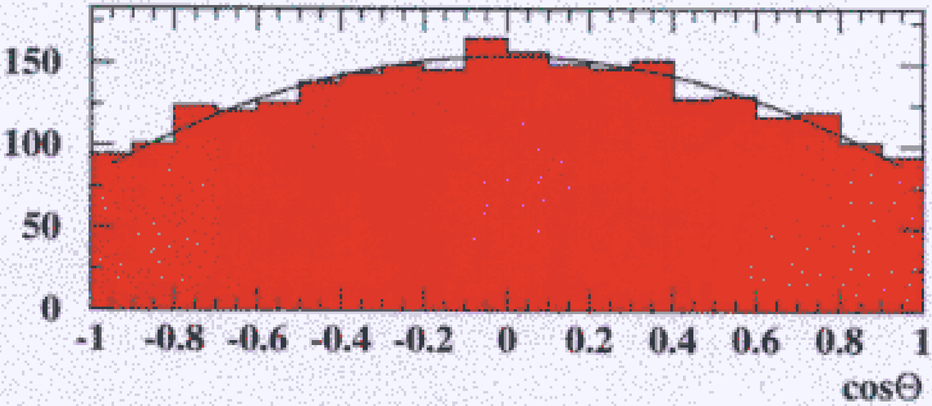
$$+B^2\,\frac{s^2\beta_Z^2}{4M_Z^4}\left(1-\frac{\sin^2\theta}{2}\right)$$ "AZ"

$$\sigma_{tot} \sim A^2\left(2+\frac{s\beta^2}{6M_Z^2}\right)+B^2\,\frac{s^2\beta^2}{3M_Z^4}$$



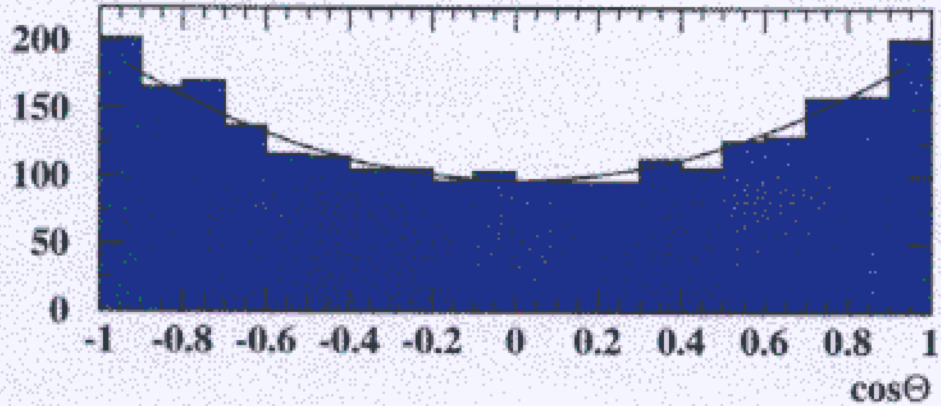
$\cos\Theta_Z$ distribution at generator level

ZH

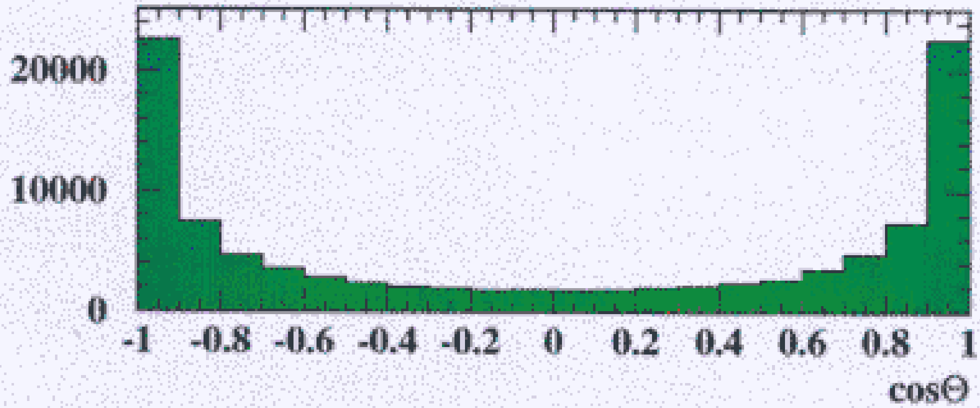


reweighting in $d\sigma/d\cos\Theta\, d\phi^*\, d\cos\Theta^*$

ZA



ZZ



Extraction of CP-QN

* $Z\phi \to \mu^+\mu^-\phi \quad \cos\Theta_Z = \cos\Theta_{\mu\mu}$
* $\sqrt{s} = 350$ GeV, $M_H = 120$ GeV, $\int\mathcal{L} = 500\,fb^{-1}$
* Simdet 3.1 including ISR + CIRCE

---

* determine couplings A and B by two kind of fits to reference histogram

I: include dependence of σ_{tot} a. interference

$$\frac{dN_{data}}{d\cos\Theta} = \frac{dN_{Z\phi}(A,B)}{d\cos\Theta} + \frac{dN_{ZZ}}{d\cos\Theta}$$

II: just use shape of $\frac{d\sigma}{d\cos\Theta}$ from

HZ and AZ production

both reference histos normalized to σ_{ZH}^{SM}

$$\frac{dN_{data}}{d\cos\Theta} = A * \frac{dN_{ZH}}{d\cos\Theta} + B * \frac{dN_{ZA}}{d\cos\Theta} + \frac{dN_{ZZ}}{d\cos\Theta}$$

Selection

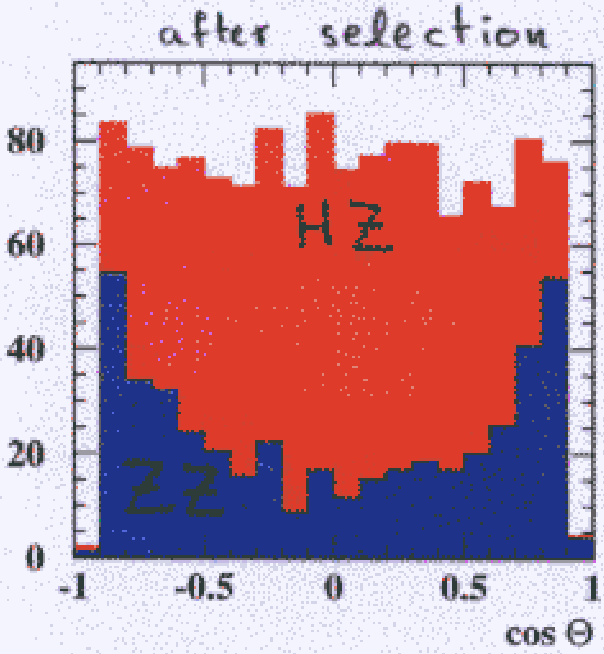
1) 2 isolated μ, $\sphericalangle iso = 10°$, $E_\mu > 15\,GeV$, perfect μ ID

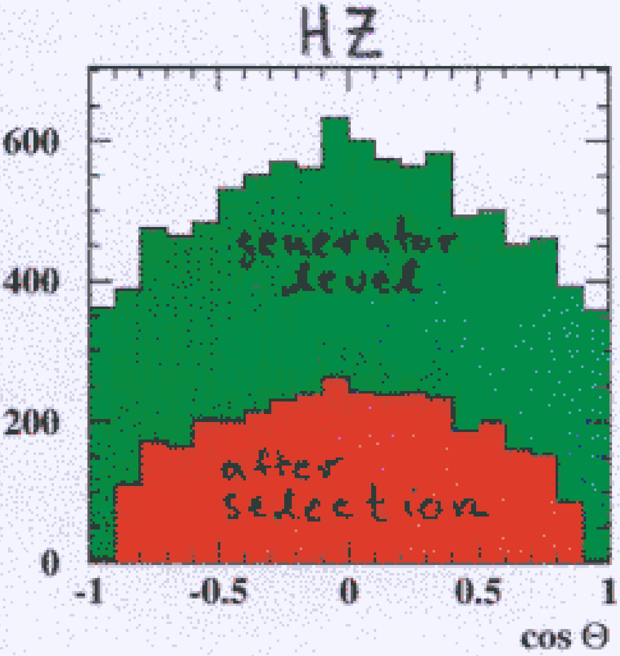
2) $|M_{\mu\mu} - M_Z| < 5\,GeV$ 3) $|M_{Rec} - M_H| < 5\,GeV$

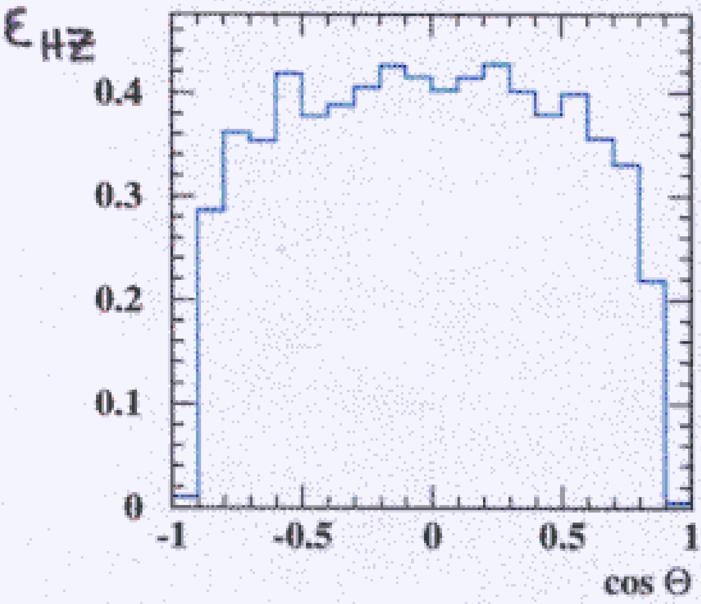
4) $|P^Z_{\mu 1} + P^Z_{\mu 2}| < 125\,GeV$ 5) $E_\gamma < 40\,GeV$

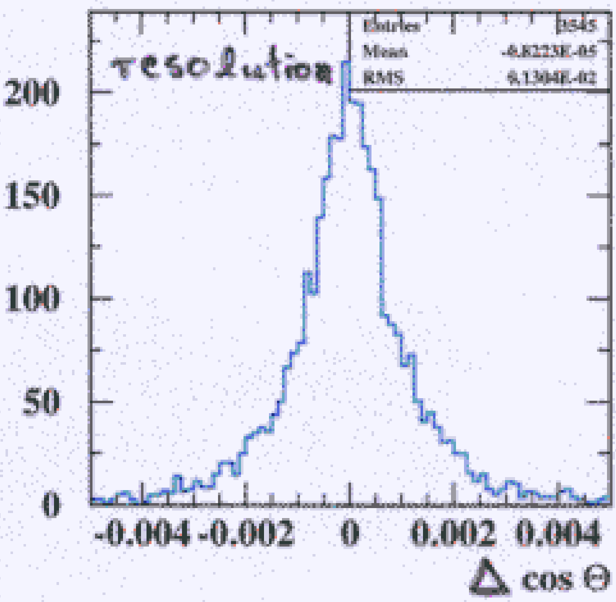
$\varepsilon = 35.5\% \hat{=} N_{HZ} = 923$ evt

BG: ZZ: 454 evt $\mu\mu$: 0 evt

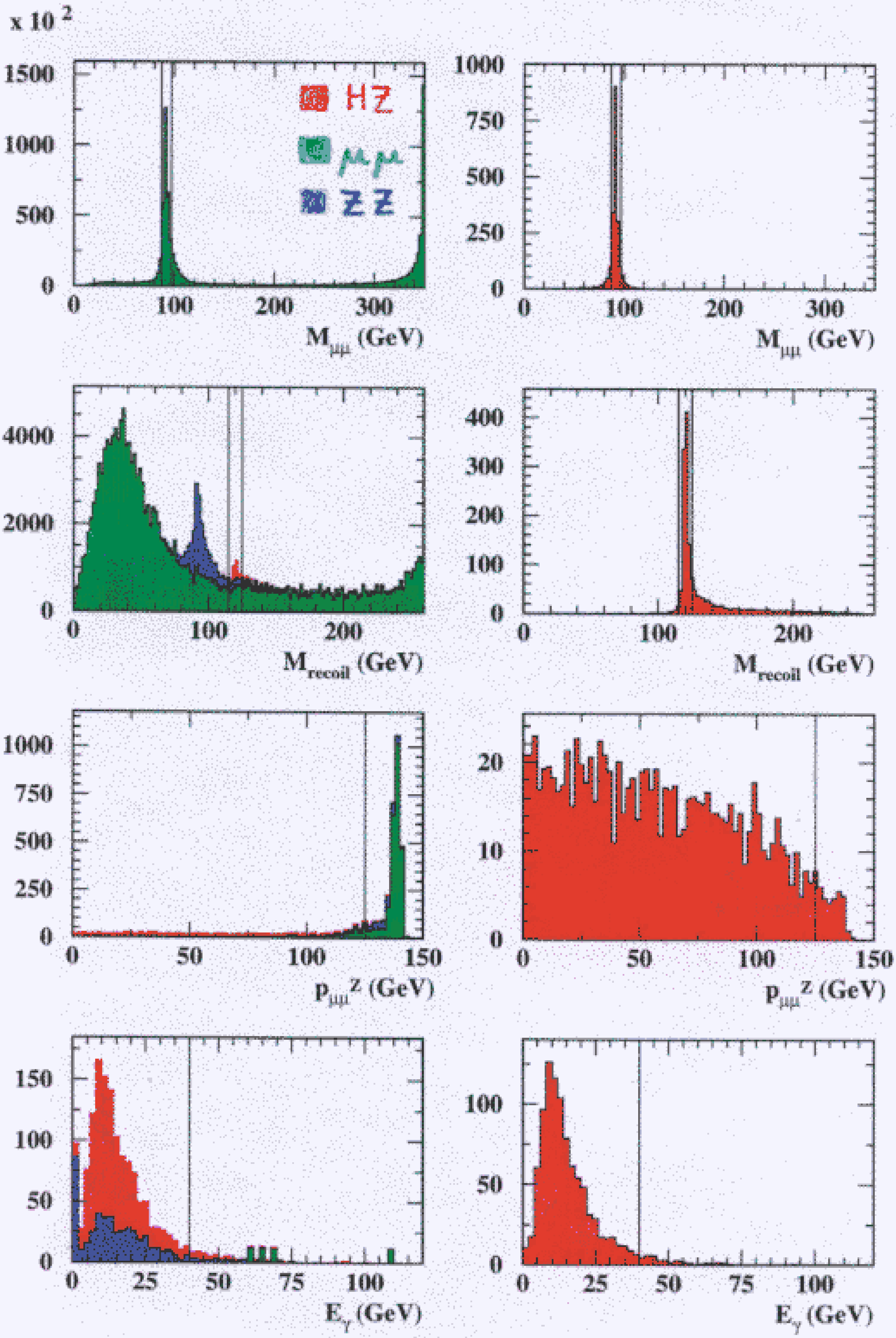




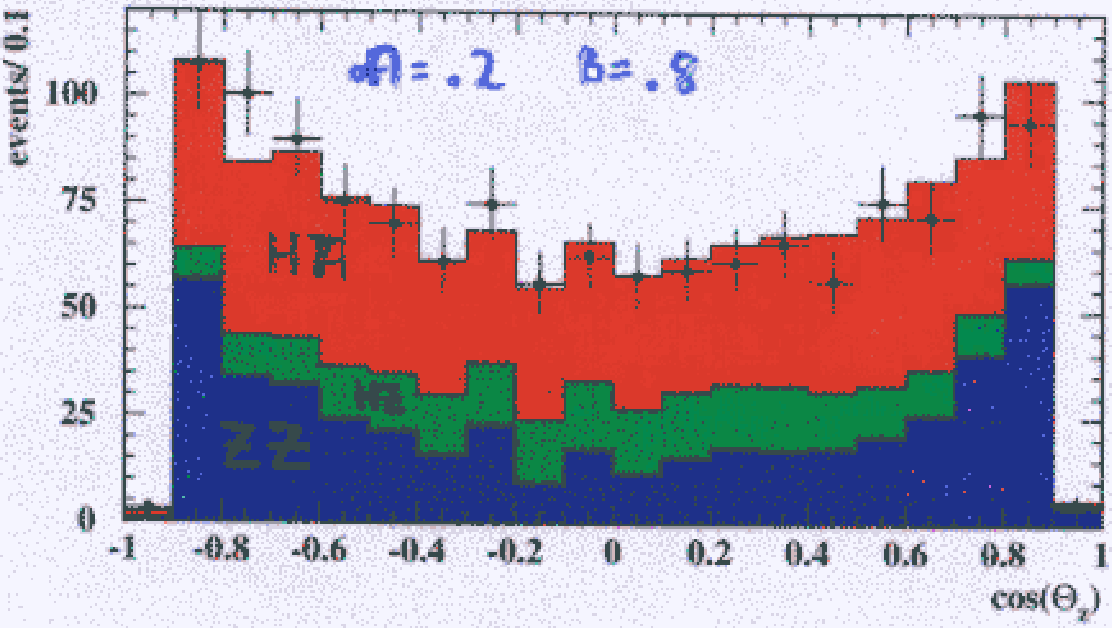




Selection Variables



Fit Results



no int.

no σ_{tot}

i) only shape, no interference, no σ_{tot}

A	B	ΔA	ΔB
1.0	.0	.12	.13
1.0	.3	.13	.14
1.0	.6	.14	.15
.5	.5	.12	.12
.2	.8	.12	.13
.0	1.0	.12	.14
.2	.2	.10	.11
.7	.3	.13	.14

ii) including interference, σ_{tot} (A, B)

A	B	ΔA	ΔB	A	B	ΔA	ΔB
1.0	0.	.02	.003	.5	.3	.51	0.07
1.0	0.3	.08	.02	.5	1.0	.22	0.005
1.0	0.6	.11	.02	.0	1.0	.02	0.006
.5	0.1	.45	.18	.0	.4	.06	0.006

Conclusion

* $CP = ++$ and $+-$ can be distinguished very clearly
* two kind of fits performed
* using only shape of $\cos\Theta$ distribution

$$\Delta A = \Delta B \approx .14$$

* including $\sigma_{tot}(A, B)$ improves sensitivity

Outlook

* do study for $M_H = 140, 160$ GeV

$\sqrt{s} = 500$ GeV

* check pull distributions of fits
* use 2nd distr.: $\frac{d\sigma}{d\phi^*_\mu}$
* investigate directly $\cancel{CP}$
  - asymmetry in $\frac{d\sigma}{d\cos\Theta}$
  - "optimal observable"