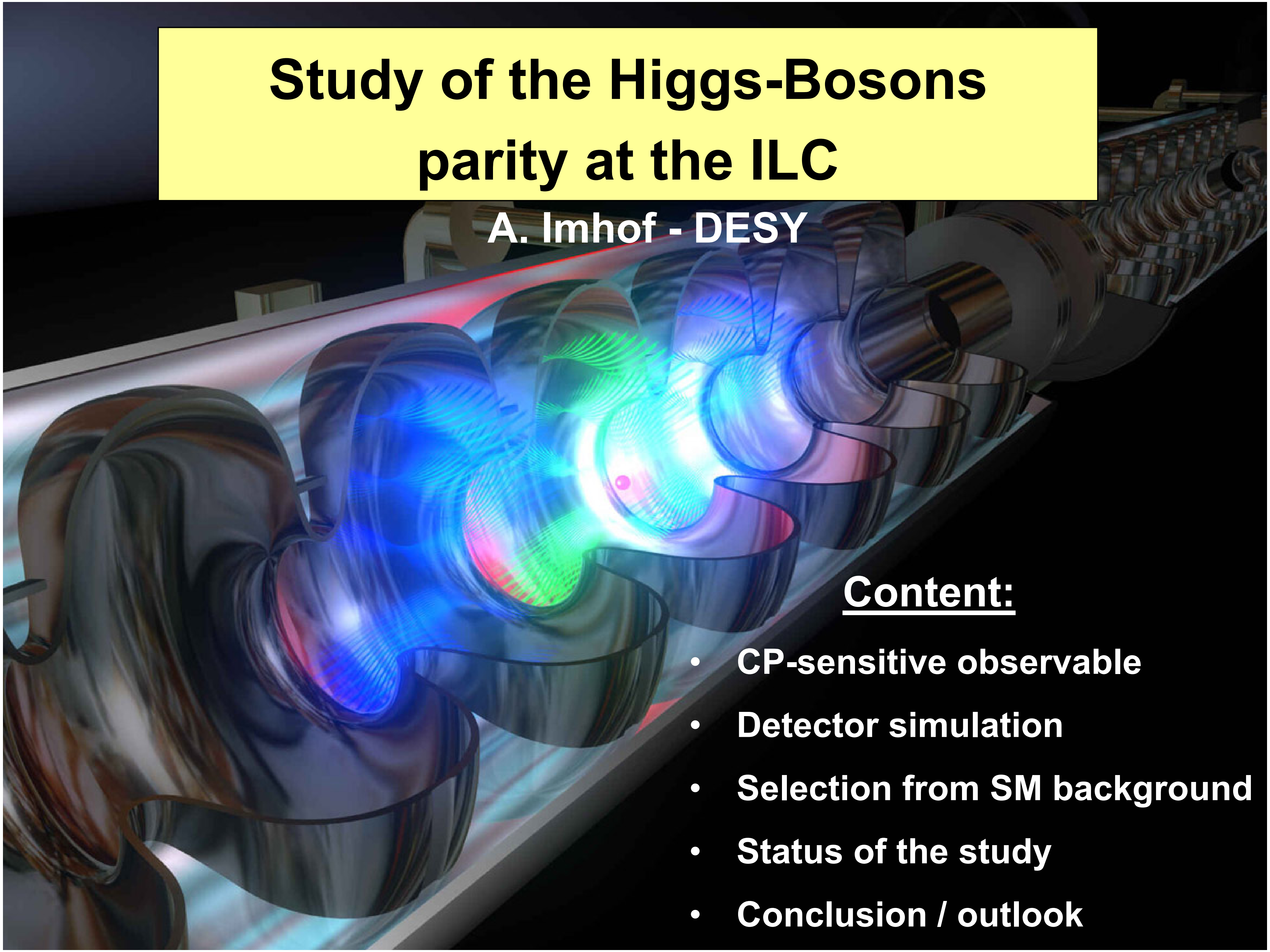


Study of the Higgs-Bosons parity at the ILC

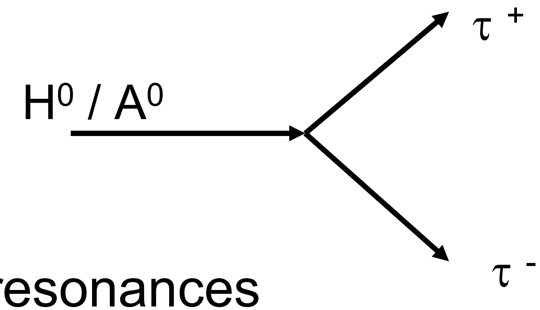
A. Imhof - DESY

Content:

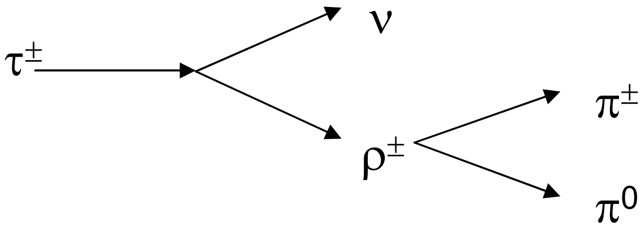
- CP-sensitive observable
- Detector simulation
- Selection from SM background
- Status of the study
- Conclusion / outlook

Higgs-parity $J^{PC} = 0^{??}$

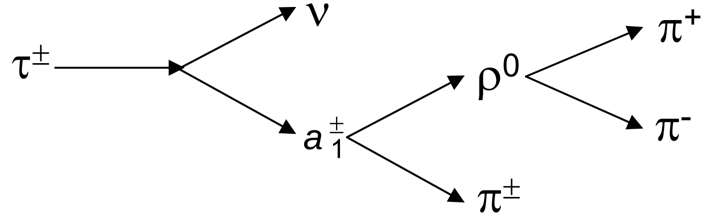
- CP-even SM-like Higgs or CP-odd like e.g. A^0 in 2HDM?
- $h\tau\tau$ - coupling transmits Higgs-parity into spin-polarisation of the τ's



- For τ-decays into 2 or 3 pions via ρ- or a_1- resonances



$$\frac{\Gamma\left(\tau^+ \xrightarrow{\rho} \pi^+\pi^0\nu\right)}{\Gamma_{total}} \approx 25\%$$



$$\frac{\Gamma\left(\tau^+ \xrightarrow{a} \pi^+\pi^+\pi^-\nu\right)}{\Gamma_{total}} \approx 10\%$$

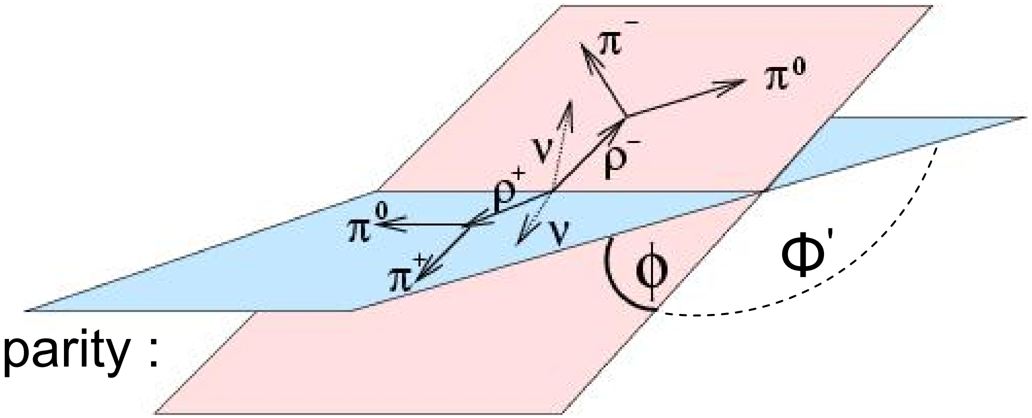
- Reconstruction of the τ-polarisation from the final-states
- Reconstruction of the correlation of the transverse spin-components

τ decays simulated with Tauola/Photos

The observable

- Planes spanned by the 4-momenta of the pions
- Correlation sensitive to Higgs-parity :

the acoplanarity Φ.



- Use energies to distinguish between Φ and Φ' by the sign of $y_1 \cdot y_2$

$$y_1 = \frac{E_{\pi^+} - E_{\pi^0}}{E_{\pi^+} + E_{\pi^0}} \qquad y_2 = \frac{E_{\pi^-} - E_{\pi^0}}{E_{\pi^-} + E_{\pi^0}}$$

$\rightarrow$ only direct accessible information from reconstructed momenta used.

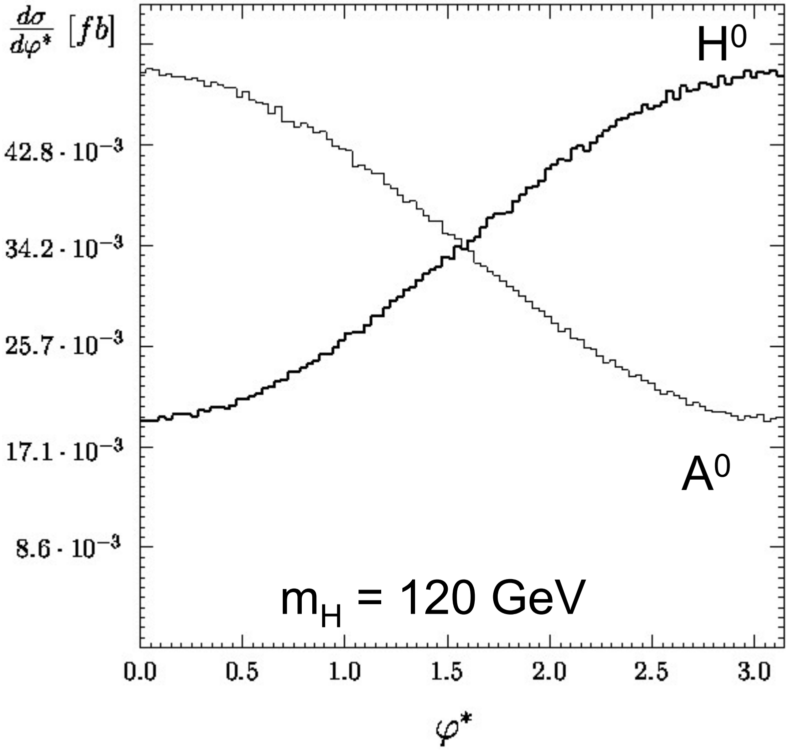
THUS: precise reconstruction of the 4-momenta both for neutral (e.g. the photons from the π^0) and charged objects is essential.

$\rightarrow$ Challenge to the performance of a high precision detector, especially to the calorimeter.

Theoretical distributions

Observable proposed by

T. Pierzchała, Z. Wąs, M. Worek



Thus:

- N_{signal} according to expected σ_i and Γ_i
- SM-background: O(10^8) evt / 1 ab^{-1}
- include detector-effects like expected precisions on 4-momenta reconstruction

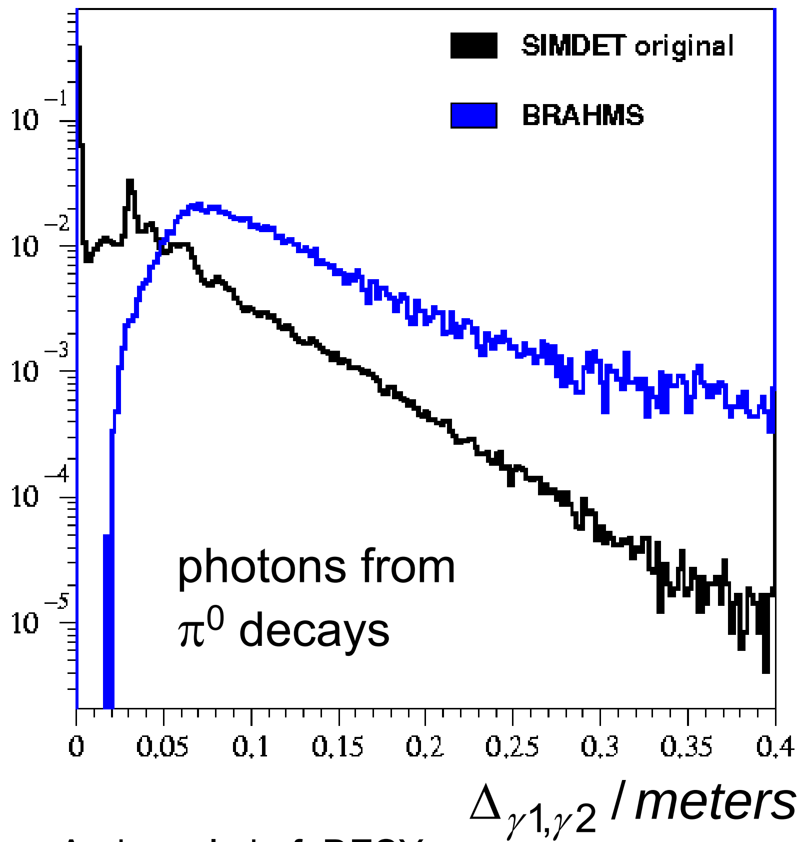
→ **usage of the fast/ parameterized detector simulation SIMDET (based on the TESLA-design)**

But:

- generator-level / no detector effects
- pure signal / no backgrounds
- scaled from very high statistics

Quality of the fast simulation (especially calorimeter)

- Precision of the position- and energy-reconstruction for photons
- Resolvability of objects close to each other
- Problem: calorimeter description too much simplified for very specific tasks



Comparison with the GEANT3-based full simulation BRAHMS shows large differences:

- artefacts in the position-resolution

- too high separability for close-by photons

→ for such exclusive reconstructions: modifications for the fast simulation are necessary.

GEANT 3 studies

Main question: detector response for $E_{neutral}$ in the ECAL (e.g. γ from π^0):

- precision of the reconstruction of
  - the particle energy
  - the position and thus the direction of the momentum
- separability of energy-depositions close to each other
  - neutral close to an other neutral
  - neutral close to a charged energy-deposition

→ Study of this parameters with GEANT 3 for a signal channel to build a post processing routine: HZ $\rightarrow \tau^+\tau^- \nu\nu$ with $\tau^\pm \rightarrow \rho^\pm \nu \rightarrow \pi^\pm \pi^0 \nu$

Resulting parameterizations:

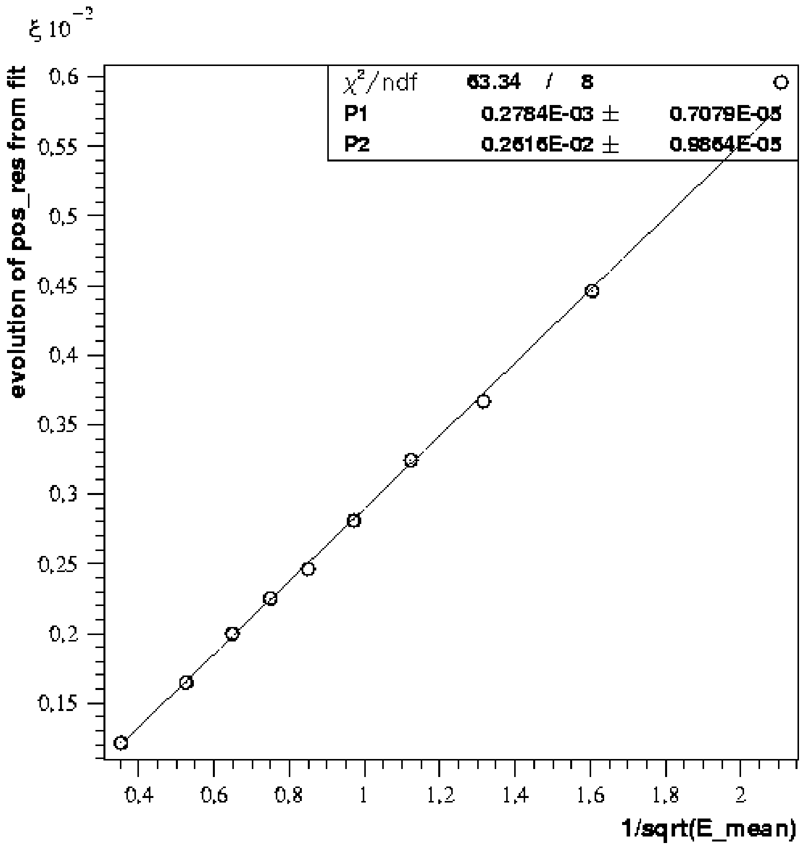
a) energy resolution for the ECAL: $$\sigma = \frac{12\%}{\sqrt{E}}$$

b) Position resolution

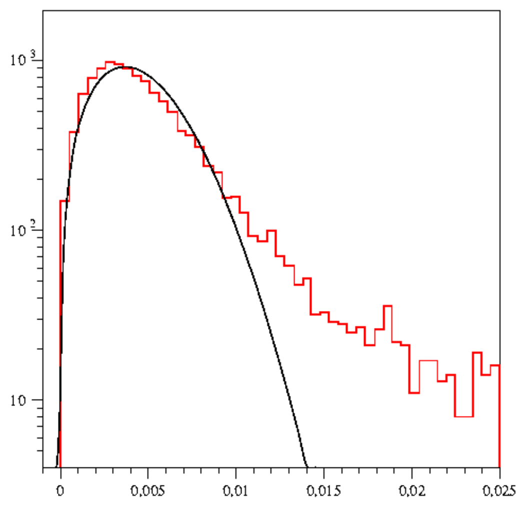
Fit function:

$$f(x) = a \cdot x \cdot \exp\left(-b \cdot x^2\right),\; b = \frac{1}{2 \cdot \sigma^2}$$

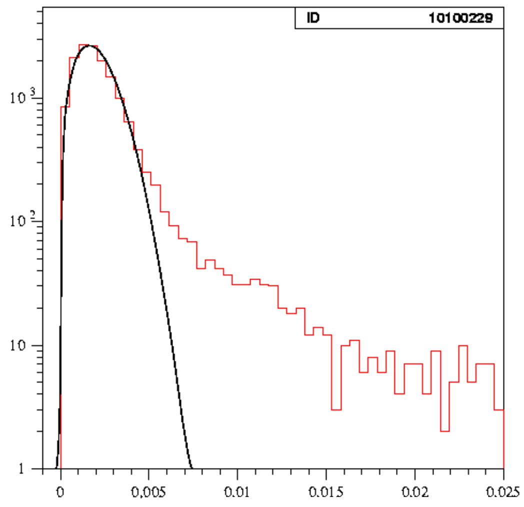
(1D projection of 2D-Gaussian)



Distance at the calorimeter surface (generator-level to closest reconstructed)



0.48 GeV < E < 0.69 GeV



2.8 GeV < E < 5 GeV

Resulting resolutions:

$$\sigma = 5.5\,mm\ for\ E \leq 0.25\,GeV$$

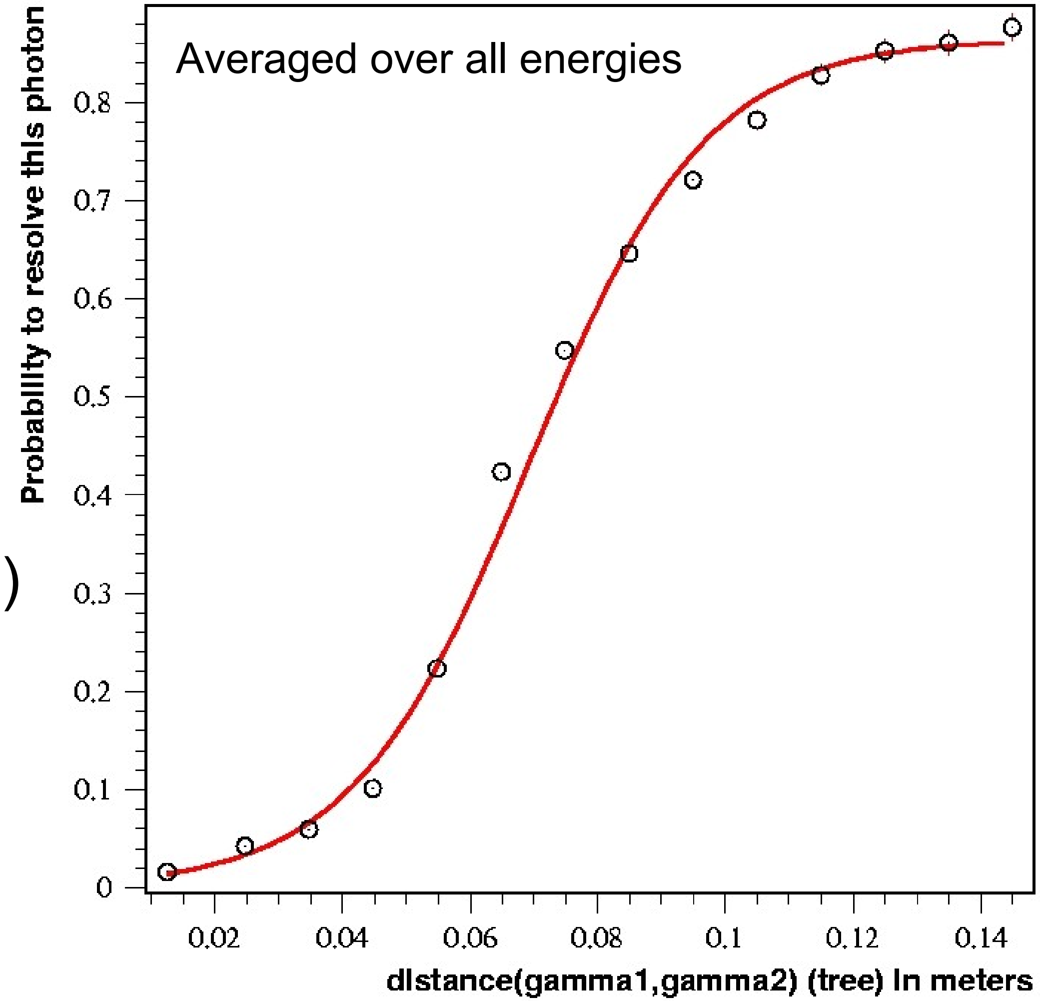
$$\sigma = 0.8\,mm\ for\ E \geq 25\,GeV$$

c) Resolvability of 2 photons

Distribution fitted and then scaled to:

$P_{resolve} = 0$ for $\Delta < 2$ cm
(~ 2 · Moliere radius)

$P_{resolve} = 1$ for $\Delta > 14.5$ cm
(photons treated as isolated)

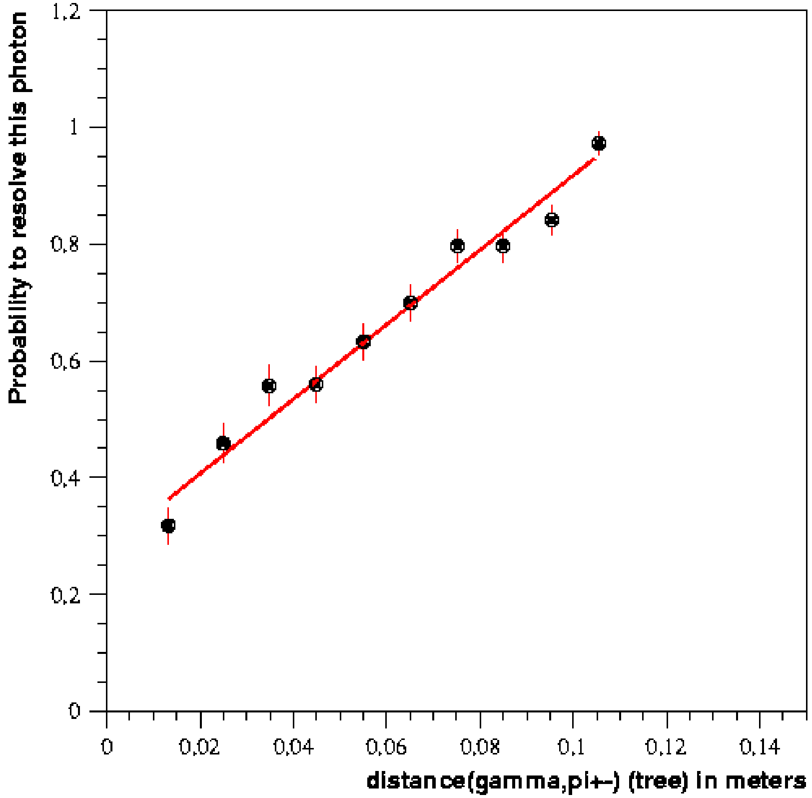


d) Resolvability $\gamma \leftrightarrow \pi^{\pm}$

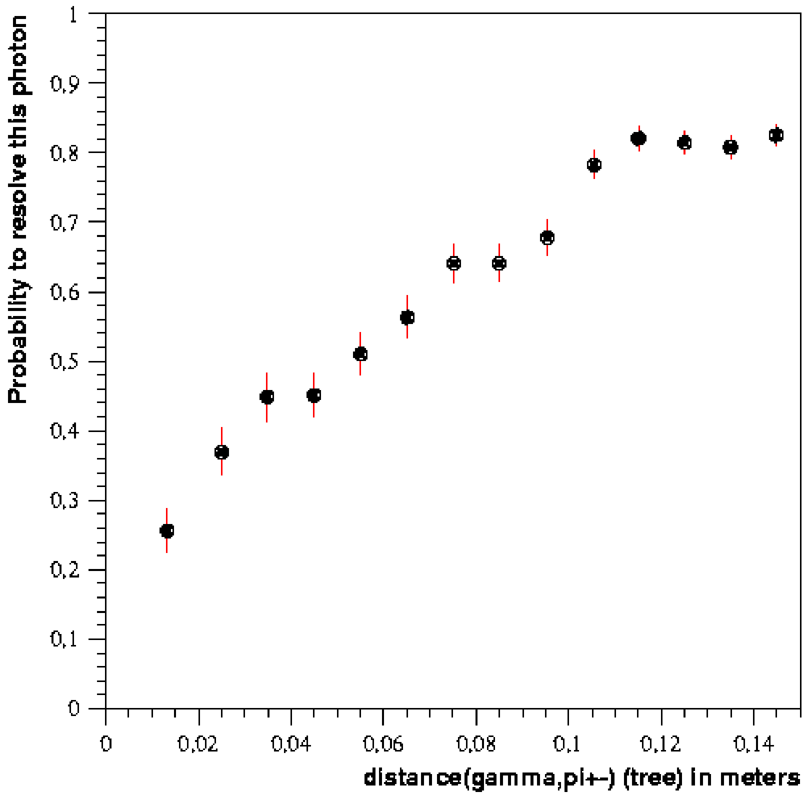
Plateau at Δ= 11.5 cm reached

$\rightarrow$ Fit scaled to:

$P_{resolve}$ = 1 for Δ = 11.5 cm



Averaged over all energies



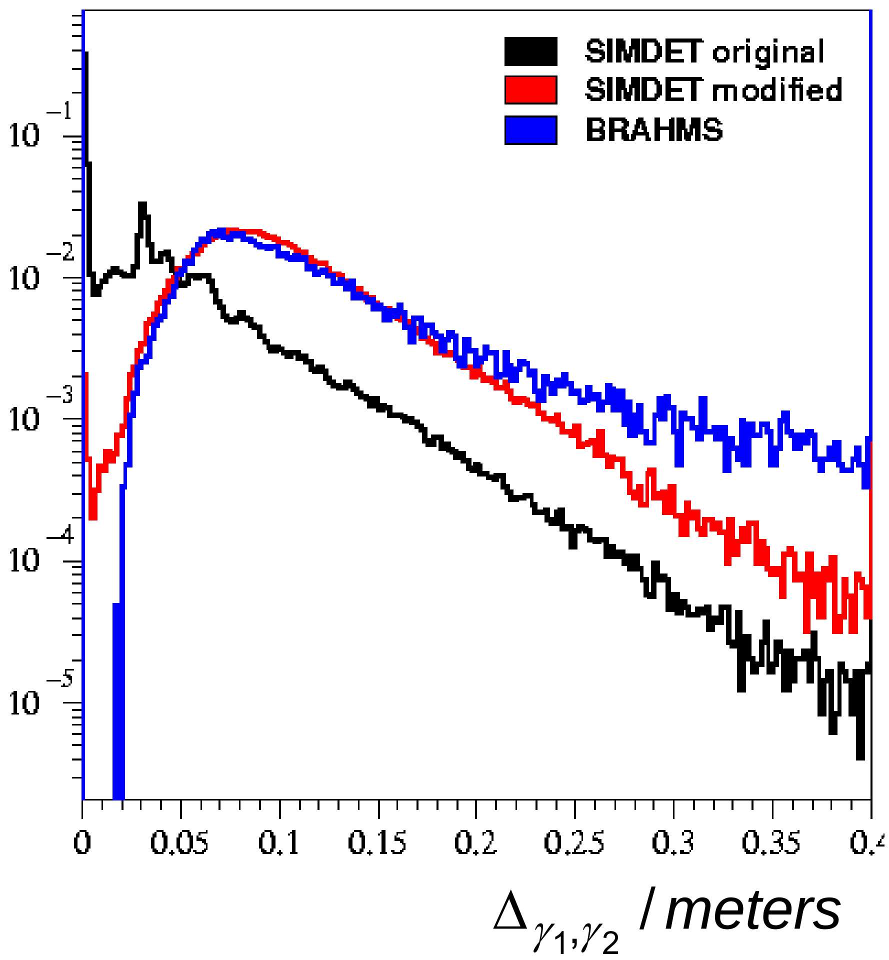
Linear fit for smaller distances.

Resulting in

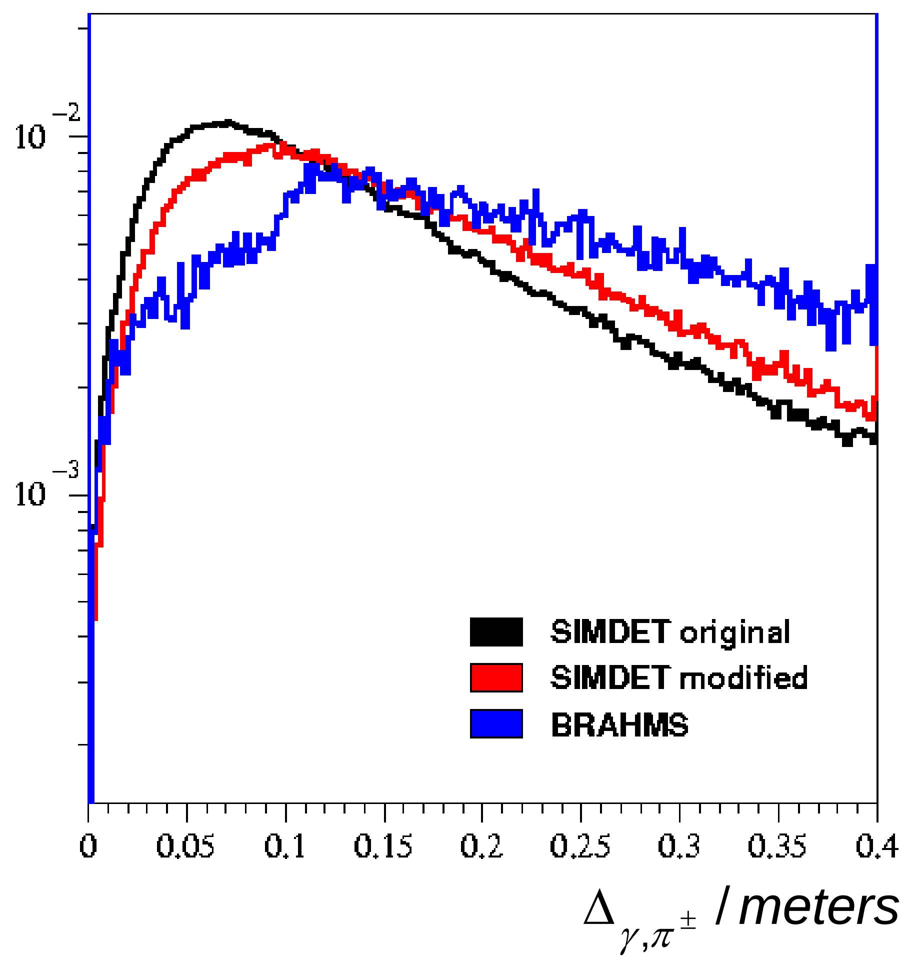
$P_{resolve}$= 28% for Δ = 0 cm.

Comparison of old and new detector-output

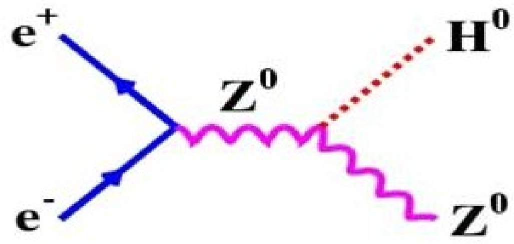
Distance at calo surface between 2 rec γ's



γ close to charged object ($\pi^{\pm}$)



Back to the main task



Find and reconstruct the useful H $\rightarrow$ $\tau\tau$ events.

Example: Higgsstrahlung-process at $\sqrt{s} = 350\,GeV$ and $m_H = 120\,GeV$

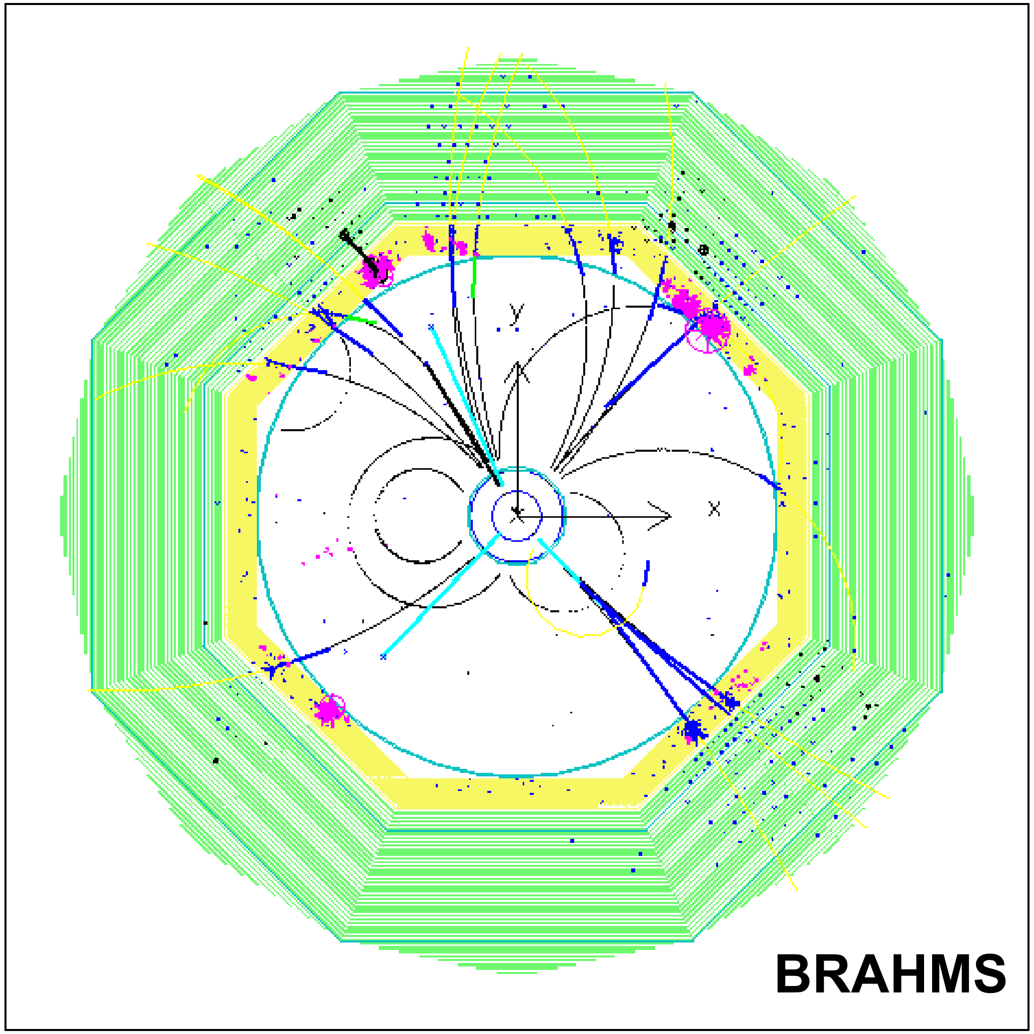
$$\sigma\left(e^+e^- \rightarrow Z^0H^0\right) = 0.148\,pb \qquad \frac{\Gamma\left(H^0 \rightarrow \tau^+\tau^-\right)}{\Gamma_{total}} = 9.2\%$$

$$\frac{\Gamma\left(\tau^+ \xrightarrow{\rho} \pi^+\pi^0\nu\right)}{\Gamma_{total}} \approx 25\% \qquad \frac{\Gamma\left(\tau^+ \xrightarrow{a} \pi^+\pi^+\pi^-\nu\right)}{\Gamma_{total}} \approx 10\%$$

<u>Expected number of events per 1 ab^{-1}:</u> **1616**

	Z $\rightarrow$ X	$\rightarrow\nu\nu$	$\rightarrow$ **$e^+e^-/\mu^+\mu^-$**	**$\rightarrow$qq**
$\rho\rho$	832	166	**56**	**582**
$a_1\rho$	655	131	**44**	**458**
a_1a_1	129	26	9	90
SUM	**1616**	**323**	**109**	**1130**

Simulated signal-topology



Topology:

$e^+e^- \rightarrow Z^0H^0 \rightarrow qq\tau^+\tau^-$,

$\tau_1{}^{\pm} \rightarrow \rho^{\pm}\nu \rightarrow \pi^{\pm}\pi^0\nu$,

$\pi^0 \rightarrow \gamma\gamma$

$\tau_2{}^{\pm} \rightarrow a_1{}^{\pm}\nu \rightarrow \pi^{\pm}\rho^0\nu$

$\rightarrow \pi^{\pm}\pi^+\pi^-\nu$

SM-background considered

$e^+e^- \rightarrow$	final-state	σ (ab)
Z^0Z^0 ($\gamma^*/Z^0\ \gamma^*/Z^0$)	4 l	0.7 *10^5
	4 q	4.8 *10^5
	ll qq	4.4 *10^5
W^+W^-	lν lν	1.4 *10^6
	qq lν	5.9 *10^6
	4 q	6.1 *10^6
γ/Z^0	all visible	35.0 *10^6
$e_i\ \gamma \rightarrow e_i\ \gamma^*/Z^0$	qq	13.3 *10^6
	ll (visible)	5.7 *10^6
$e_i\ \gamma \rightarrow f_j\ W^\pm$	qq	2.5 *10^6
	l ν	1.2 *10^6
HZ → X	non-signal	1.4 *10^5

All together:

~ 7.4 * 10^7 events

+ 2 photon background

Spin correlation for SM-background not taken into account. Assumption: well understood (specially for ZZ)

Event generation with PYTHIA (no full 4-f generator used)

Full interference γ^*/Z^0 taken into account

All τ decayed via Tauola/Photos

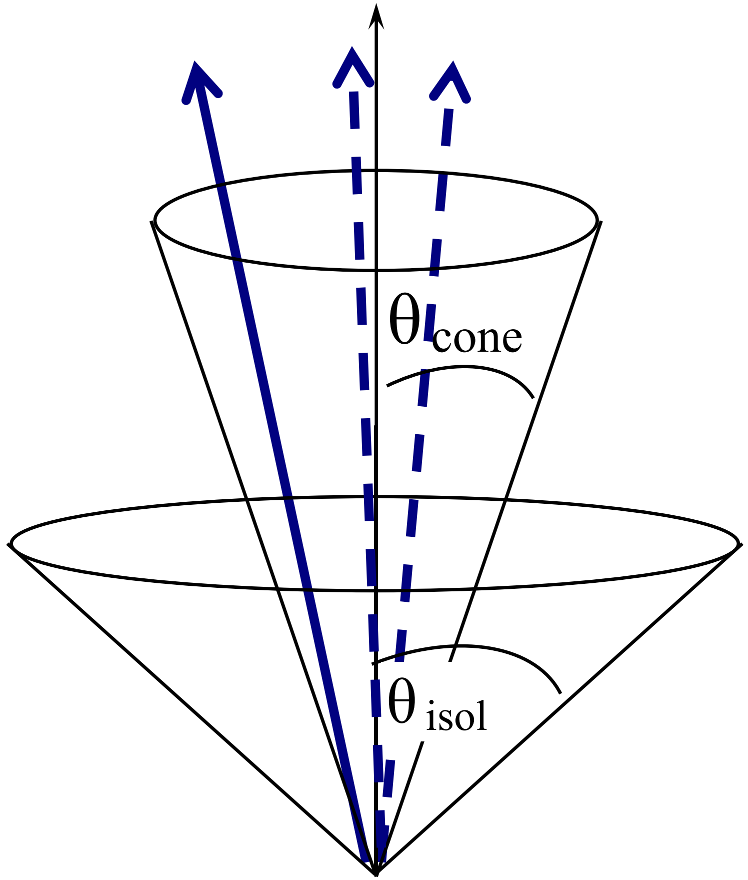
τ-identification

Typically low multiplicity, isolated jets

Thus: Cone-based lepton identification

(based on algorithm by B. Sobloher)

- 1 or 3 tracks
- cone half-angle: 9.5°
- $E_{seed,min}$ > 0.7 GeV
- $E_{sum,cone,min}$ > 5 GeV
- cos $\theta_{beam\ axis}$> 9.5°
- isolation to other tracks with half-angle: 12.5°



Preselection

- 21GeV < $m_{visible}$ < 355 GeV
- event multiplicity: ≤ 80 reconstructed eflow-objects
- $\left|\cos\theta_{event\ momentum}\right| \leq 0.995$
- ≥ 1 pair of hadronic τ-candidates from the lepton ID, with
  - angle between the candidates: 75° < α < 175°
  - 21 GeV < $m_{\tau\tau}$ < 120 GeV (m_H = 120 GeV)

→ Effective reduction of backgrounds with very different topology:

$e^i \gamma \rightarrow e_i\ \gamma^*/Z^0 \rightarrow e_i\ qq$ from $13.3 \cdot 10^6$ to 5218 (~0.04%)

$\rightarrow e_i\ ll$ from $5.7 \cdot 10^6$ to 21659 (~0.38%)

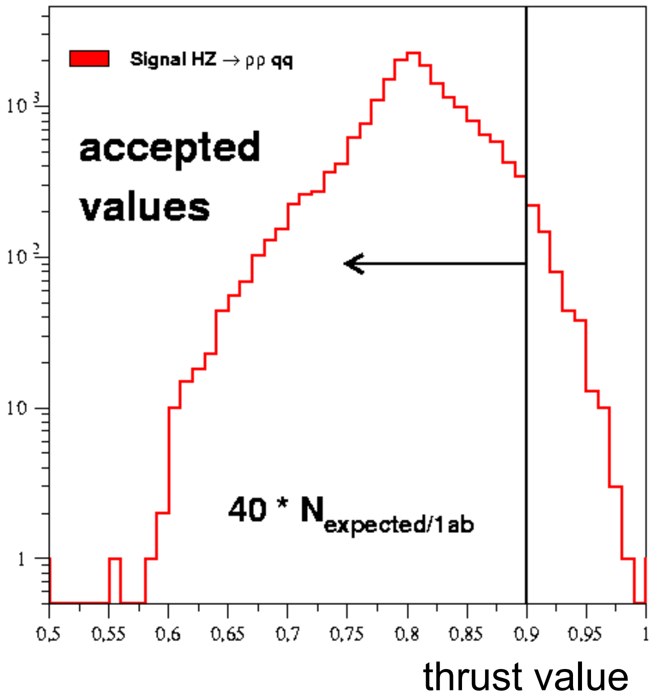
$e^+e^- \rightarrow Z^0 Z^0 \rightarrow \tau\tau\ qq$ to 15006 (~25%)

Keeping the signal-efficiency above 84.5 % in all signal-channels.

Selection for ττ qq final states

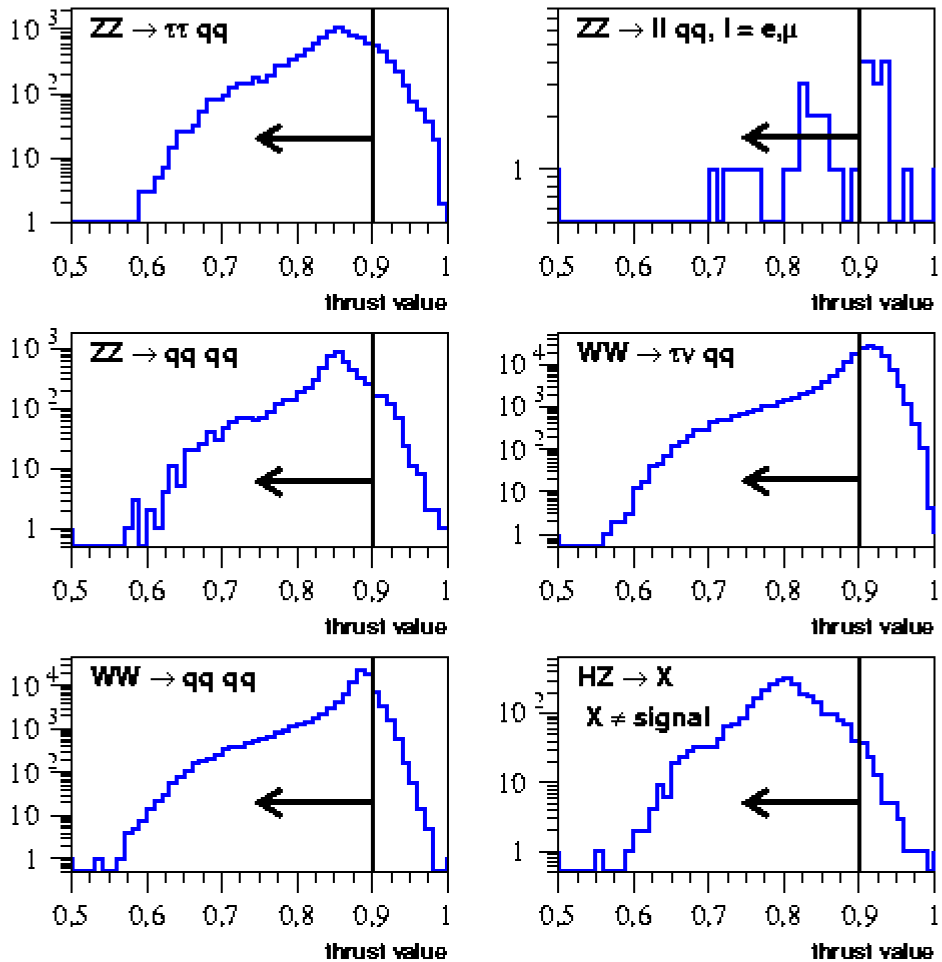
Consists of 4 main steps:

1. event shape
2. τ candidates
3. hadronic Z-decay
4. kinematical fit to the HZ system

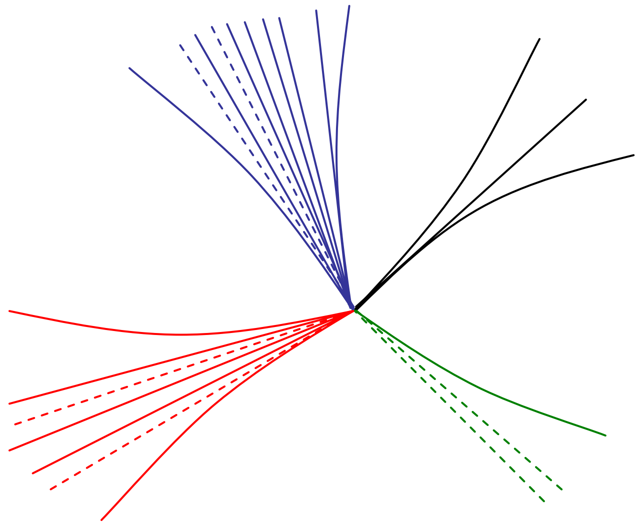


Example for global event shape:

thrust value

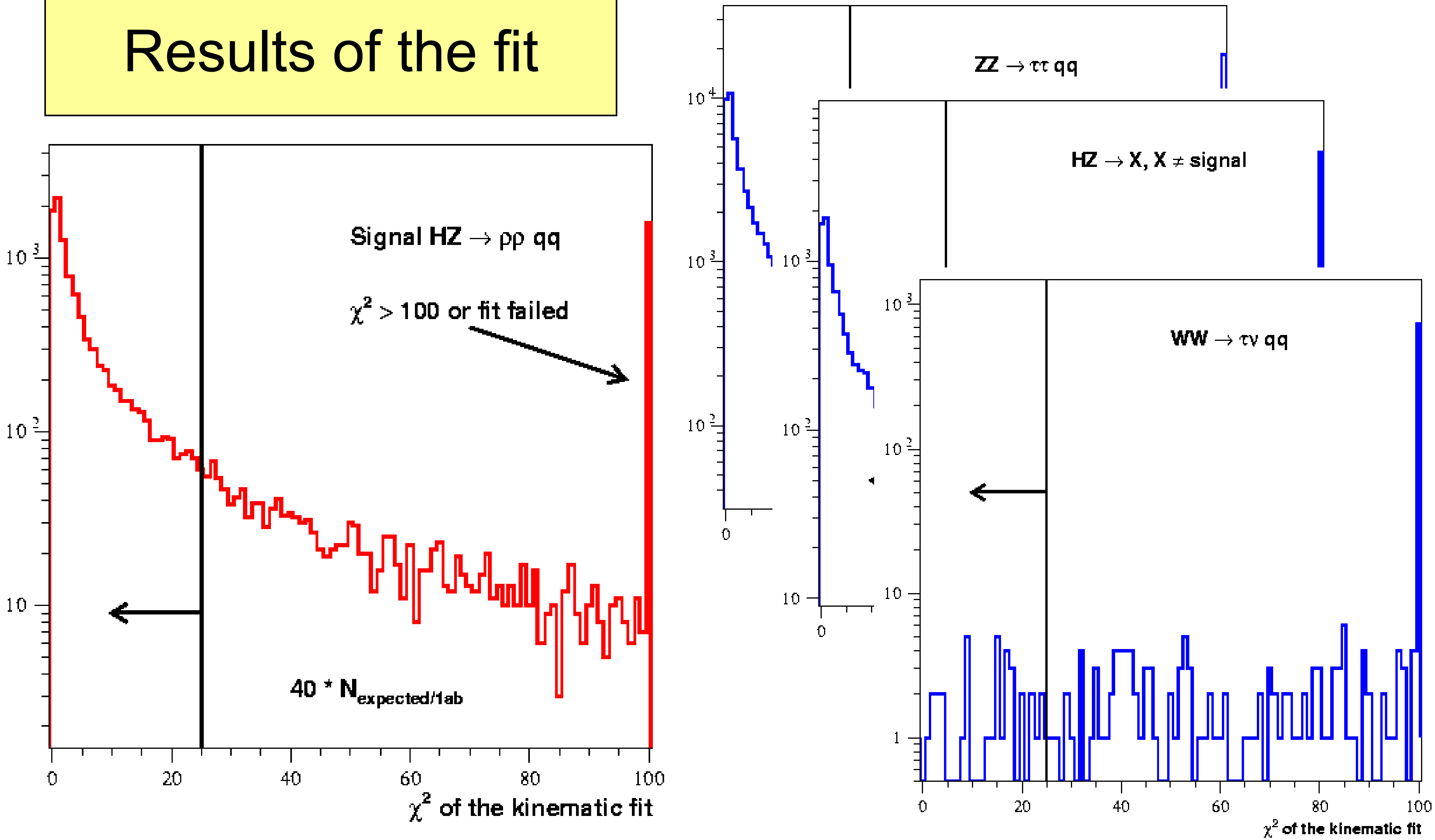


Kinematic Fit



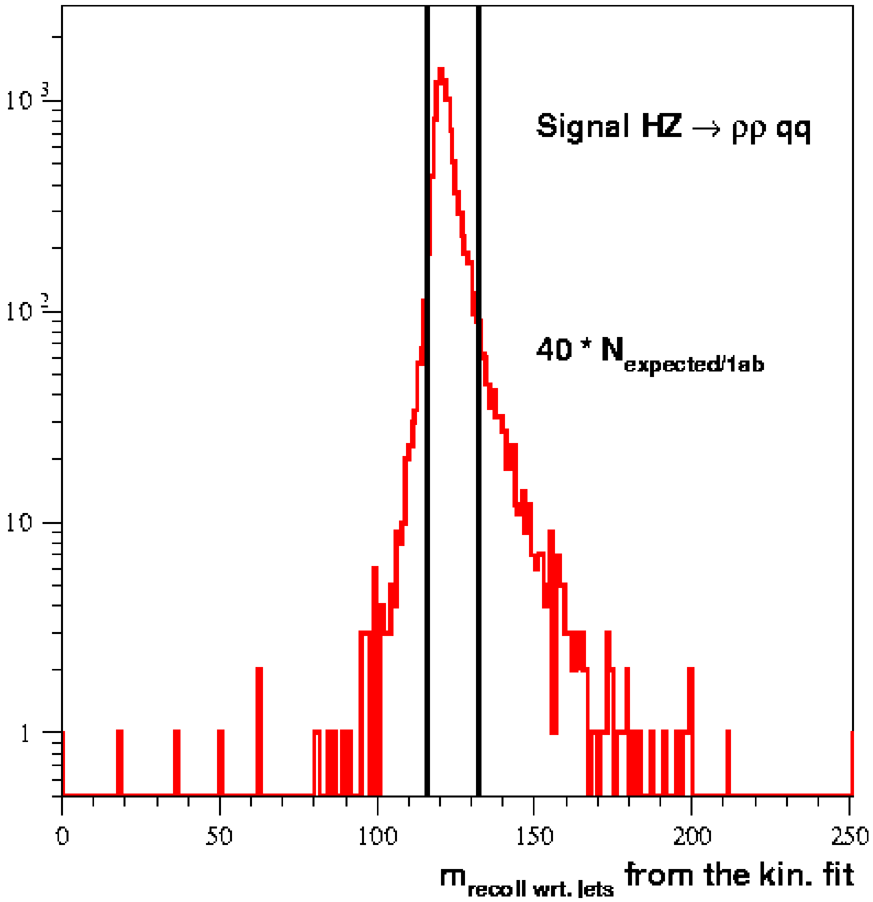
- $Z \rightarrow qq$ system forced into 2 jets
  - soft cut on y_{12}
- Input into the fit:
  - 4-momenta of the hadronic jets
  - 3-momenta of the τ-candidates, used only as directions
- Constraints:
  - invariant mass of the Z^0 system = M_Z = 91.19 GeV
  - momentum conservation $\Sigma p_x = \Sigma p_y = \Sigma p_z = 0$
  - energy conservation ΣE = 350 GeV
- Only fits with $\chi^2 < 25$ (with 7 d.o.f) are accepted

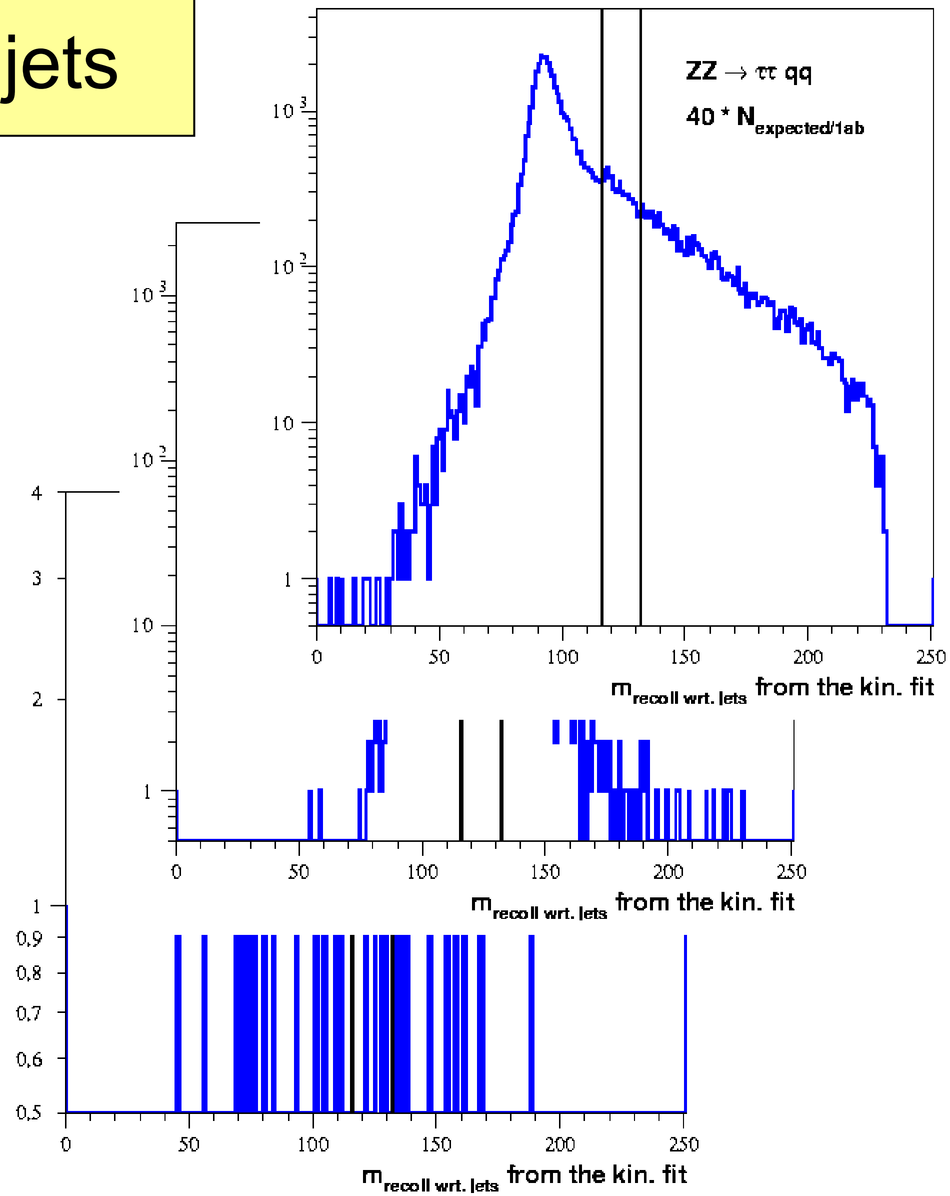
Results of the fit



Rejecting (almost) all backgrounds beside ZZ $\rightarrow\tau\tau$ qq and HZ-backgrounds

Recoil-mass w.r.t. the 2 jets





Cut-flow for $\tau\tau$ qq search (most relevant)

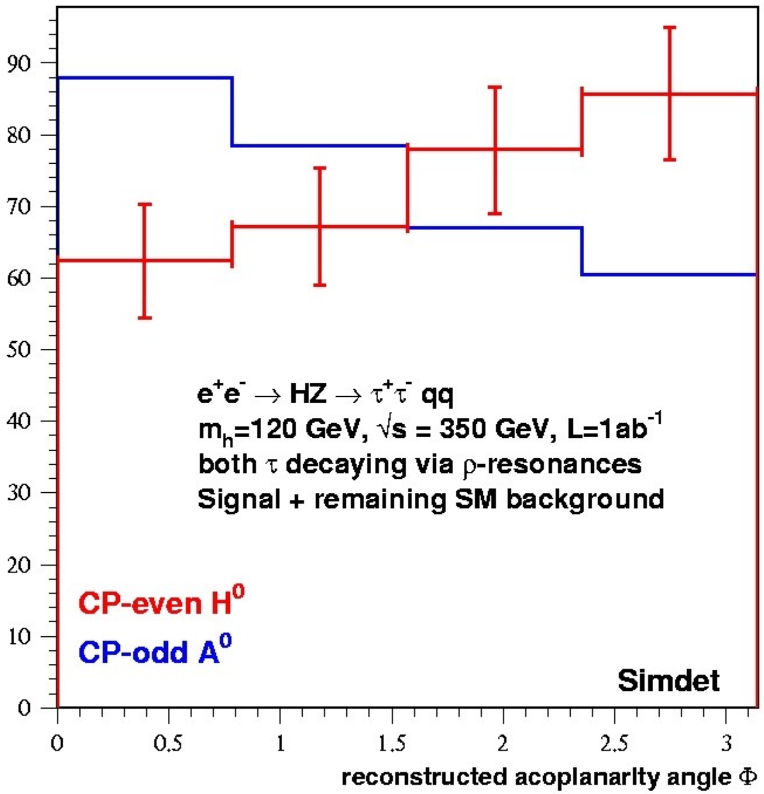
	Signal	other HZ	ZZ $\rightarrow \tau\tau$ qq	ZZ $\rightarrow$ 4q	WW$\rightarrow$qq$\tau\nu$	WW $\rightarrow$ 4q
N_{evt} / 1 ab^{-1}	1040	~140 000	65 270	477 000	1 952 000	6 081 000
preselection	881	4 940	14 293	8 554	198 021	142 905
evt shape	810	2 928	7 961	4 374	52 493	57 456
τ-cand.	604	481	2 190	7	1 980	130
Z$\rightarrow$qq side	594	467	1 942	1	901	30
kin. fit	410	187	97	/	6	/
$\rho\rho$ and $a_1\rho$	401	126	97	/	4	/

Resulting in $\rho\rho$-case: ε ~ 38% at S / B ~ 3.05

$a_1\rho$-case: ε ~ 39% at S / B ~ 1.15

Reconstructed acoplanarities

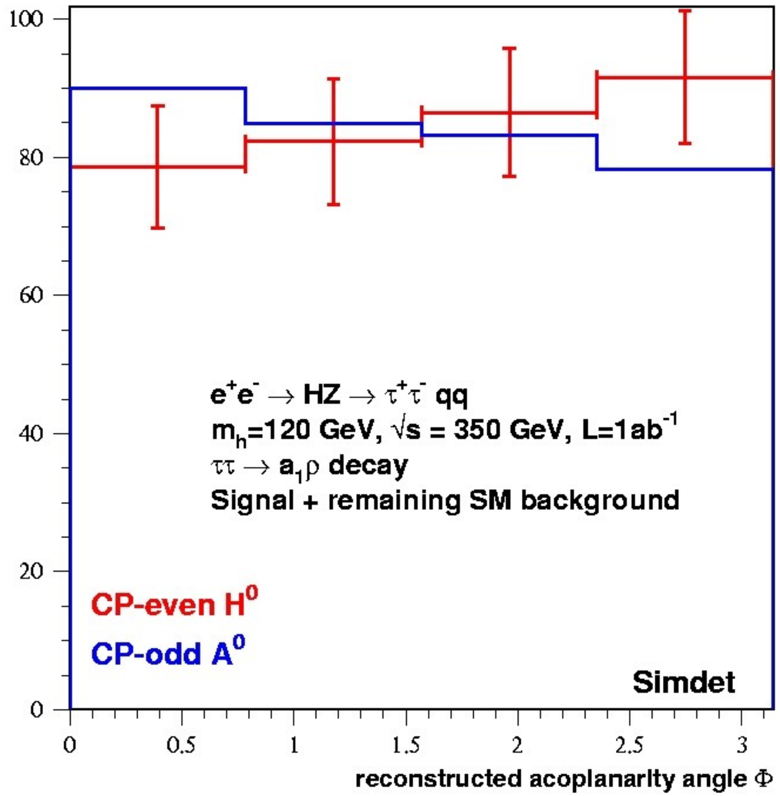
from high statistics and scaled to N_{exp}/ $1ab^{-1}$



A_H = 0.116 ± 0.058

A_A = -0.132 ± 0.058

$\rightarrow \Delta A = A_H - A_A = 0.248$



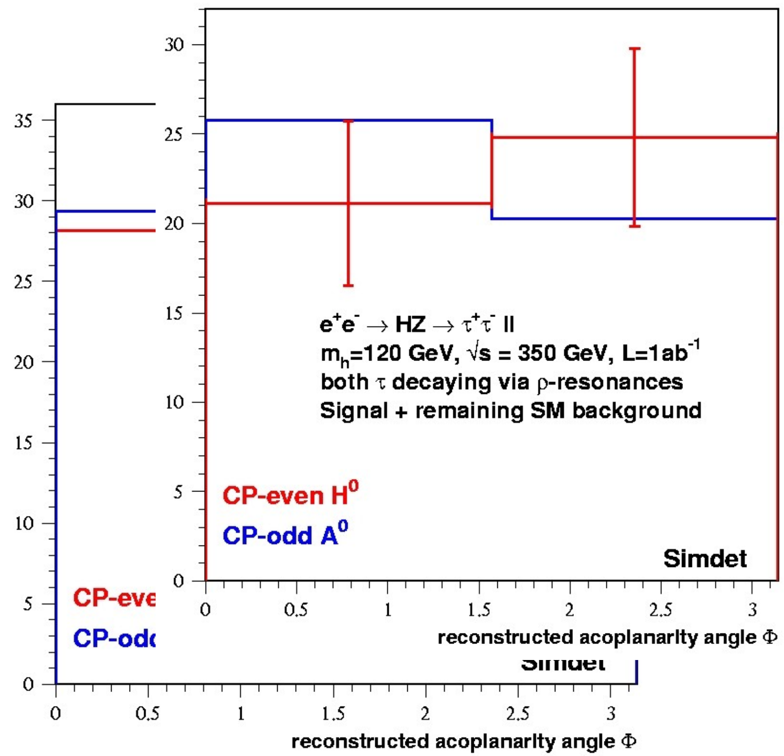
A_H = 0.051 ± 0.054

A_A = -0.040 ± 0.054

$\rightarrow \Delta A = 0.091$

Selection for Z $\rightarrow$ ll, l = e, μ

- event-shape like $\cos\theta_{event\text{-}momenta}$
- 1 pair of hadronic τ-candidates
    - invariant mass
    - angle between the candidates
- 1 e^+e^- or $\mu^+\mu^-$ pair
    - invariant mass
    - recoil mass



$\rightarrow$ With only HZ- and ZZ-backgrounds left:

$\rho\rho$-case: signal efficiency ε ~ 47.5%, S / B ~ 1.55

A_H = 0.041 $\pm$ 0.133

A_A = -0.077 $\pm$ 0.124

$\rightarrow \Delta A$ = 0.118

$a_1\rho$-case: signal efficiency ε ~ 46.5%, S / B ~ 0.6

A_H = 0.034 $\pm$ 0.112

A_A = -0.027 $\pm$ 0.116

$\rightarrow \Delta A$ = 0.061

Summary / Conclusion

- τ identification and reconstruction possible at high efficiency with anticipated detector
- Realistic measurement for CP in $H \rightarrow \tau\tau$ performed
- Including
  - detector effects
  - full SM-background statistics
  - 2-photon backgrounds
  - full effects of ISR and FSR
- Significance to distinguish a CP-even from a CP-odd Higgs-Boson of $4.7\ \sigma$ for 1 ab^{-1} can be expected
- Techniques like likelihoods, NN could enhance significances