Status of a measurement of the Higgs-Bosons parity at the ILC

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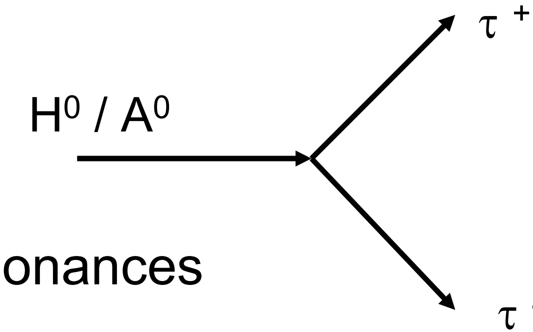
Content:

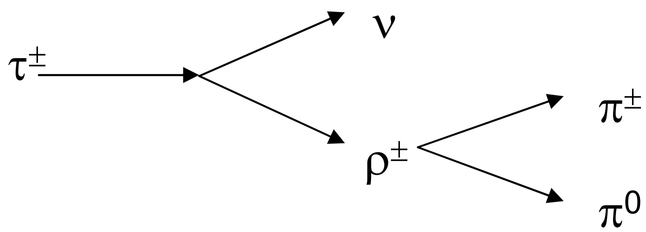
- **The CP-sensitive observable**
- **The detector simulation**
- **Selection from SM backgroun**
- **Todays status of the study**
- **Conclusion / outlook**

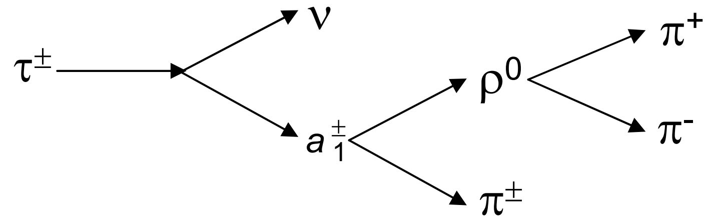
Higgs-parity $J^{PC} = 0^{??}$

- $h\tau\tau$ - 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





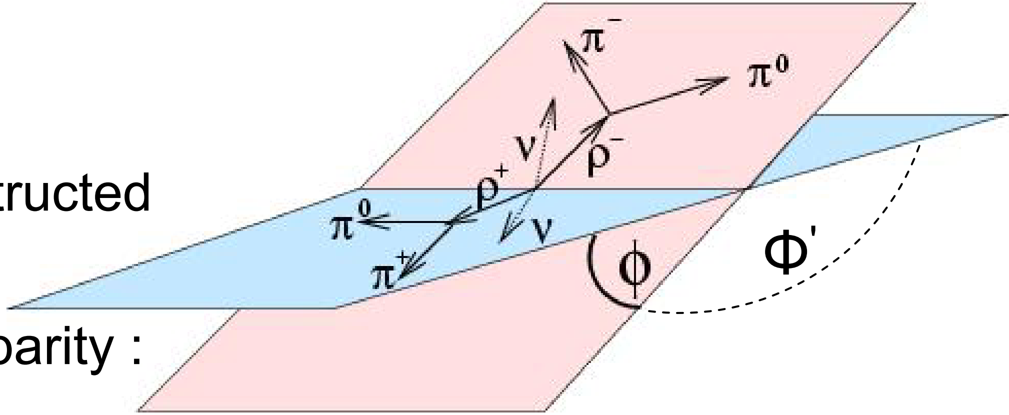
$$\frac{\Gamma\left(\tau^+ \xrightarrow{\rho} \pi^+\pi^0\nu\right)}{\Gamma_{total}} \approx 25\%$$

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

- Reconstruct τ-polarisation from the final-states
- Correlate the transverse spin-components

τ decays simulated with Tauola

The observable



- Planes spanned by the reconstructed 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 $y_1 \cdot y_2$

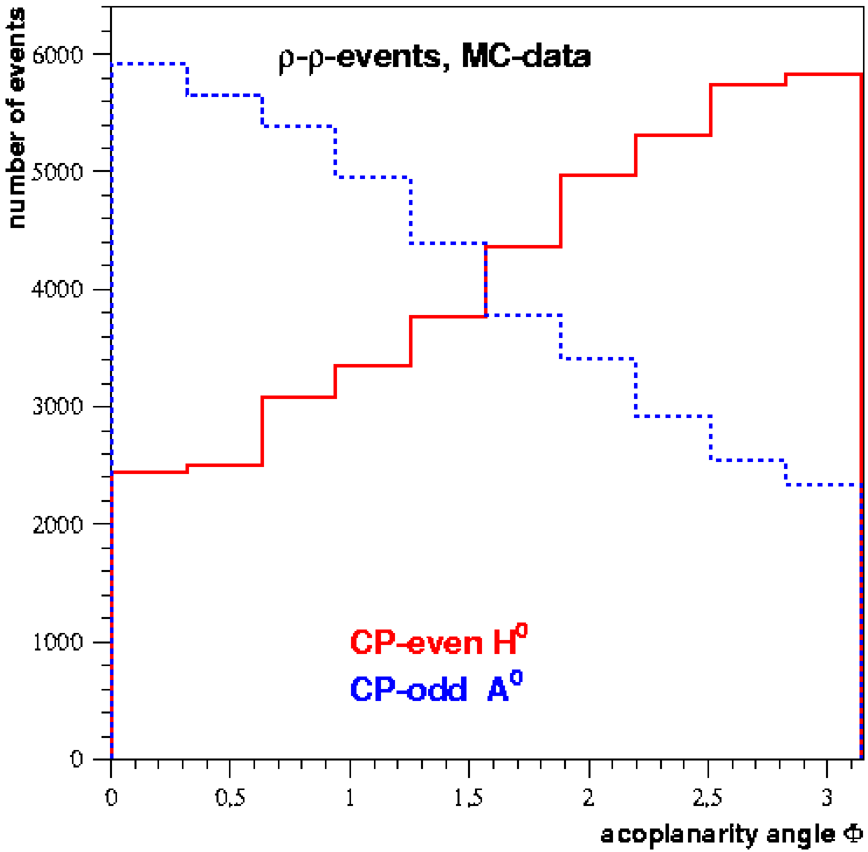
$$y_1 = \frac{E_{\pi^+} - E_{\pi^0}}{E_{\pi^+} + E_{\pi^0}} \qquad y_2 = \frac{E_{\pi^-} - E_{\pi^0}}{E_{\pi^-} + E_{\pi^0}}$$

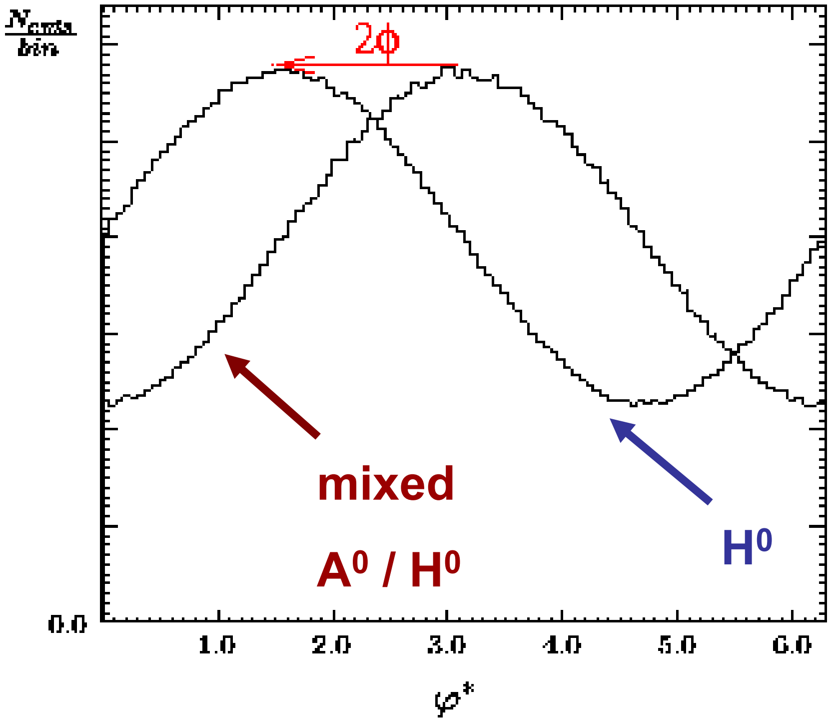
→ only direct accessible information from reconstructed momenta used

- **THUS:** precise reconstruction of the 4-momenta from (simulated) detector-output necessary. E.g. find the neutral energy (the 2 photons from the π^0) close to the $\pi^\pm$ and reconstruct the π^0-momentum.

Theoretical distributions

For mass eigenstates = CP eigenstates:





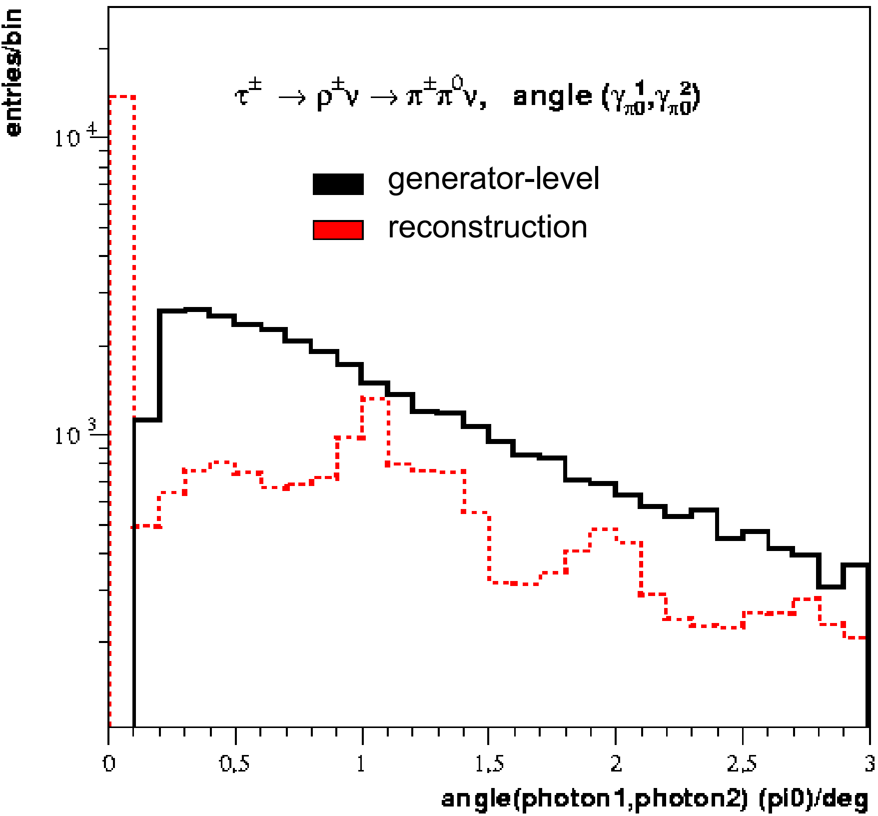
For mass-eigenstates consisting of a mixin of CP-eigenstates (mixing-angle Φ):

→ phase-shift of 2 Φ in modified acoplanarity-distribution of φ^*.

BUT…

Quality / reliability of the simulation

- Usage of the fast (parameterized) detector simulation SIMDET
- Problem: calorimeter description too much simplified for very specific tasks (mainly done for the sake of CPU-time...)



Effect for $\pi^0 \to \gamma\gamma$:

- artifacts in the position-resolution

- too high separability

(2 at exact the same position on the calorimeter surface are (without e.g. usage of shower-shapes) separately reconstructed.

→ if a realistic precision of the reconstructed 4-momenta of single (neutral) particles is needed, this simulation tool needs improvement !

Task for the simulation-tool

Main question: neutral energy in the ECAL from the photons from e.g. 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

→ New parameterization and new simulation routines necessary

- Extraction of parameters from the GEANT3 based full simulation BRAHMS

  a) isolated photons

  b) photons close to each other

  c) photons close to charged objects

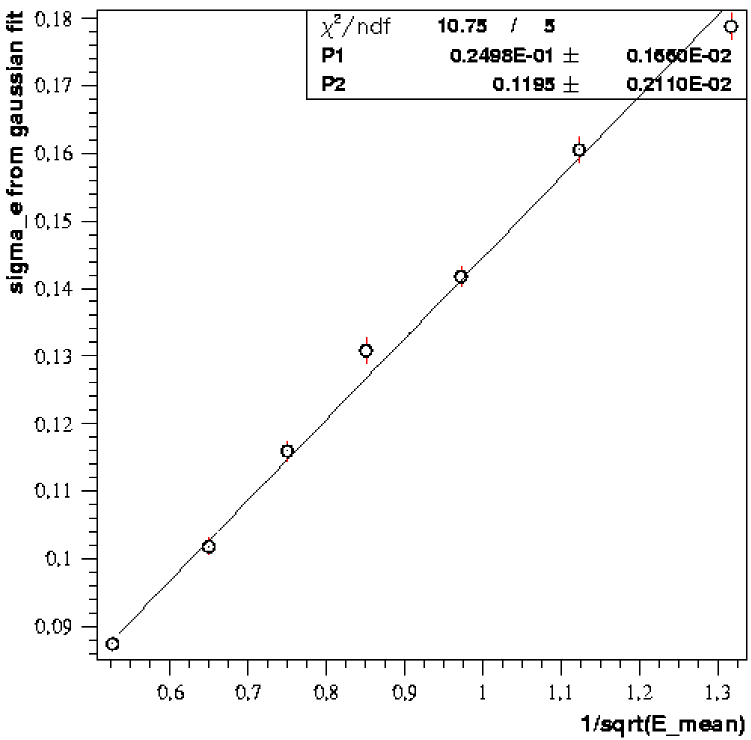
  (studied with signal events HZ $\rightarrow \tau^+\tau^- \nu\nu$ with $\tau^\pm \rightarrow \rho^\pm \nu \rightarrow \pi^\pm \pi^0 \nu$)
- Implementation of a post processing routine for the simulation

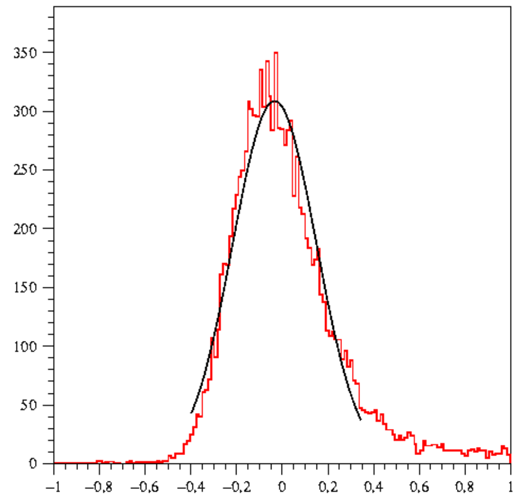
a) Isolated photons: Energy resolution

For different bins in $\frac{1}{\sqrt{E}}$:

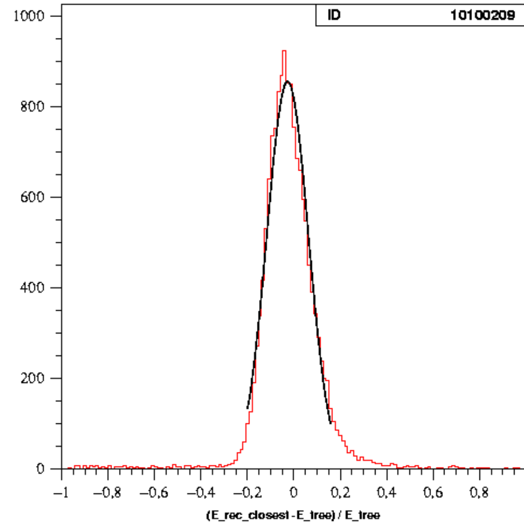
Gaussian fits to

$$\frac{E_{rec} - E_{generator}}{E_{generator}}$$





.48 GeV < E < .69 GeV



2.8 GeV < E < 5 GeV

Resulting energy resolution:

$$\sigma = \frac{12\%}{\sqrt{E}}$$

Offset of 2.5% from method/tools,

not expected in experiment. Thus skipped...

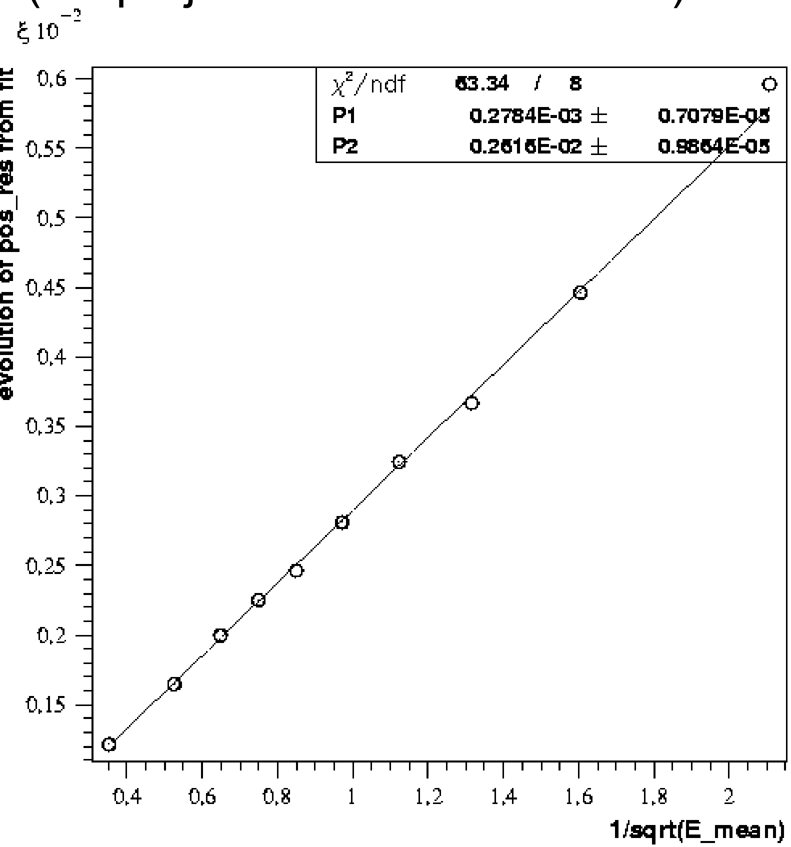
Position resolution

Fit function:

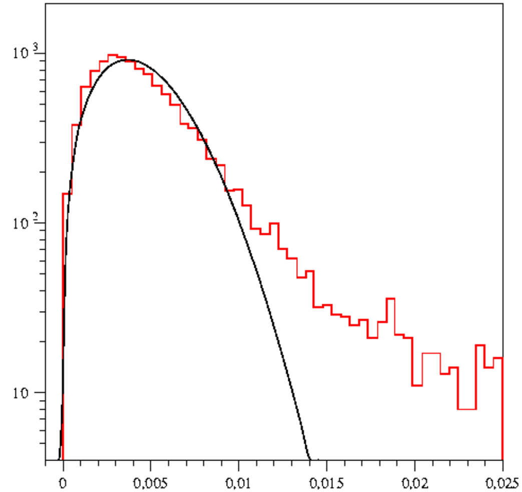
$$f(x) = a \cdot x \cdot \exp\left(-b \cdot x^2\right)$$

with $b = \dfrac{1}{2 \cdot \sigma^2}$

(1D projection of 2D-Gaussian)



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



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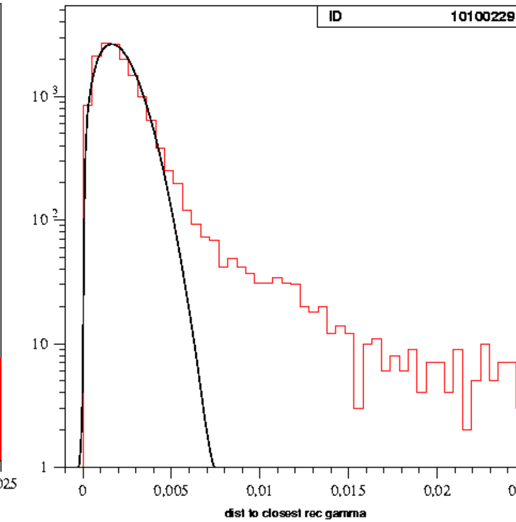


2.8 GeV < E < 5 GeV

Resulting resolutions:

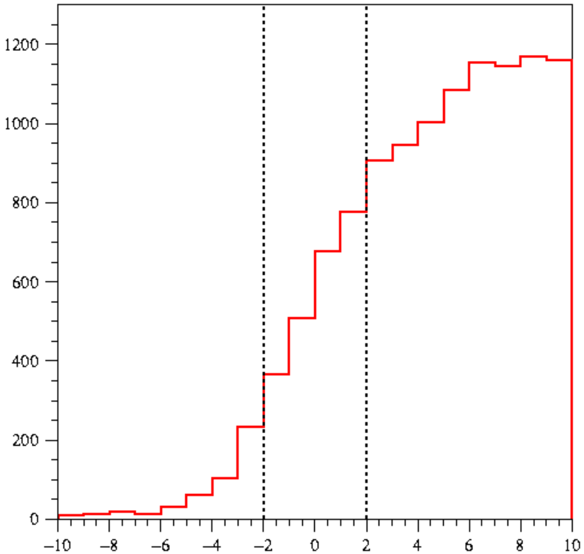
$$\sigma = 5.5\, mm \ for \ E \leq 0.25\, GeV$$

$$\sigma = .8\, mm \ for \ E \geq 25\, GeV$$

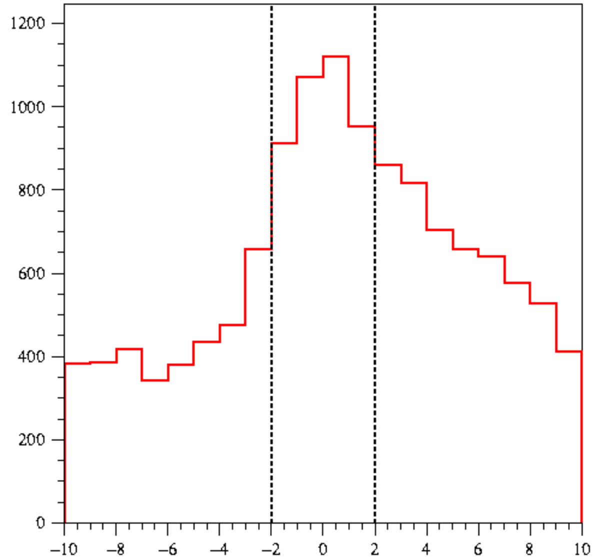
b) Photons close to each other

- Probability that 2 photons can be reconstructed separately:

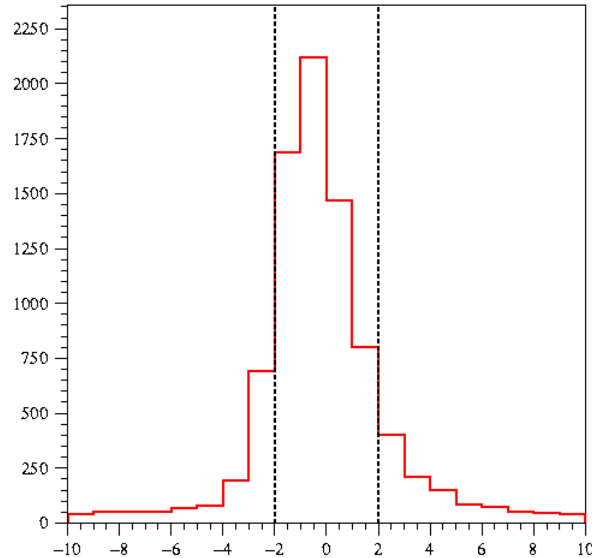
Fraction with $\left|\frac{E_{rec} - E_{generator}}{\sigma_E \cdot \sqrt{E_{generator}}}\right| \leq 2$ for different $\Delta_{(\gamma 1,\gamma 2)}$:



$2\,cm \leq \Delta < 3\,cm$



$5\,cm \leq \Delta < 6\,cm$



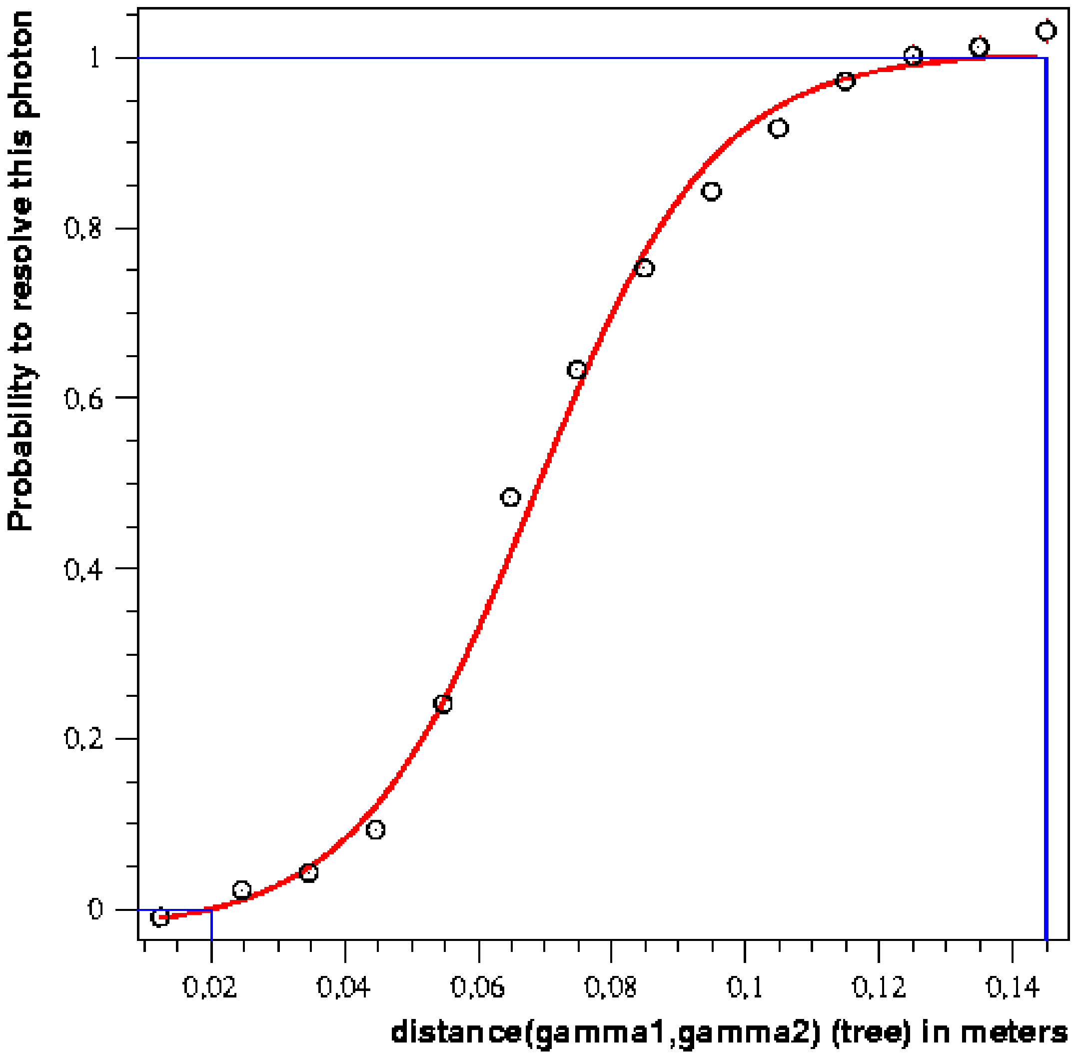
$10\,cm \leq \Delta < 11\,cm$

Resolvability of 2 photons

Fit scaled to:

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

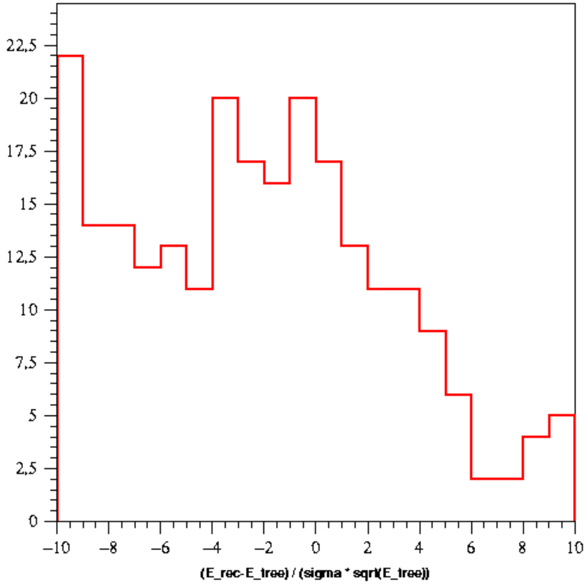
$P_{resolve}$ = 1 for Δ > 14.5 cm
(photons treated as isolated)



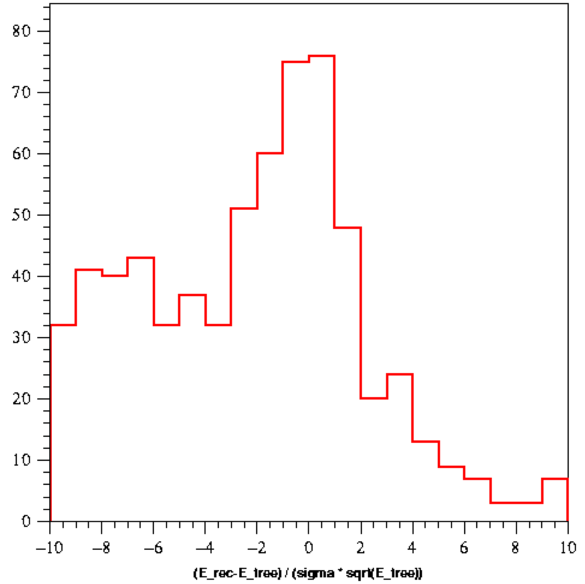
c) Photons close to charged objects

- Probability that photons can be reconstructed separately:

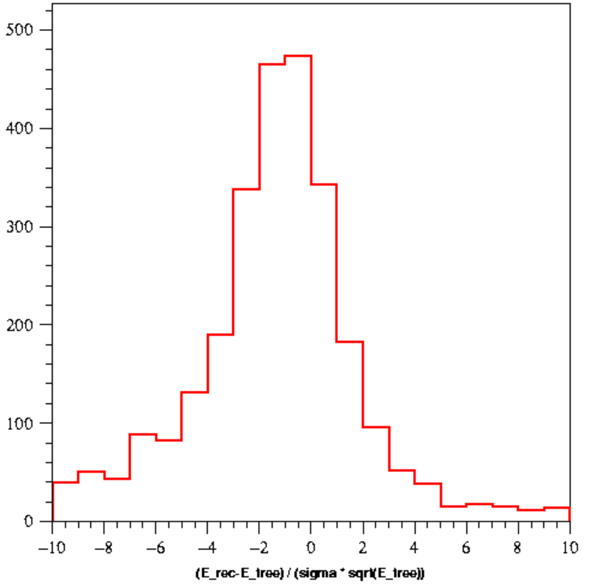
Fraction with $\left| \frac{E_{rec} - E_{generator}}{\sigma_E \cdot \sqrt{E_{generator}}} \right| \leq 2$ for different $\Delta_{(\gamma,\text{charged})}$:



$1cm \leq \Delta < 2cm$

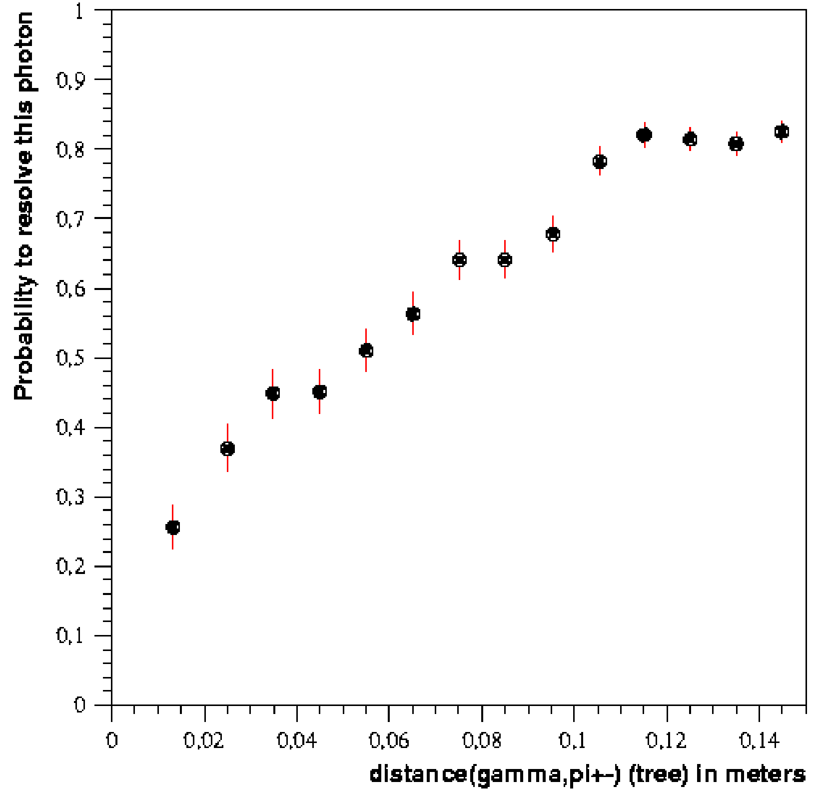


$5cm \leq \Delta < 6cm$



$10cm \leq \Delta < 11cm$

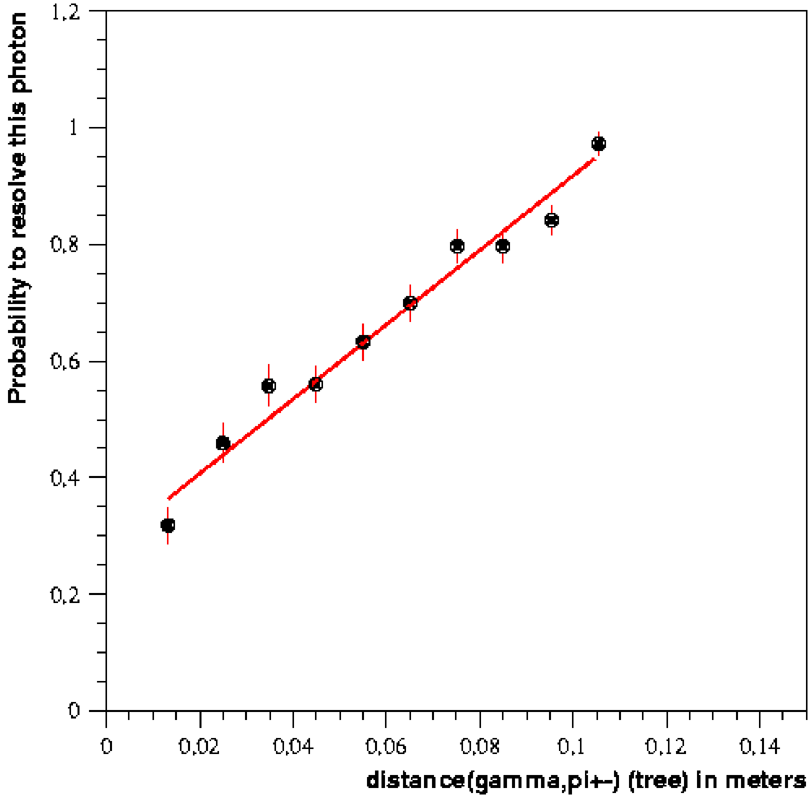
Resolvability $\gamma \leftrightarrow \pi^{\pm}$



Plateau at Δ= 11.5 cm reached

→ Fit scaled to:

$P_{resolve}$ = 1 for Δ = 11.5 cm



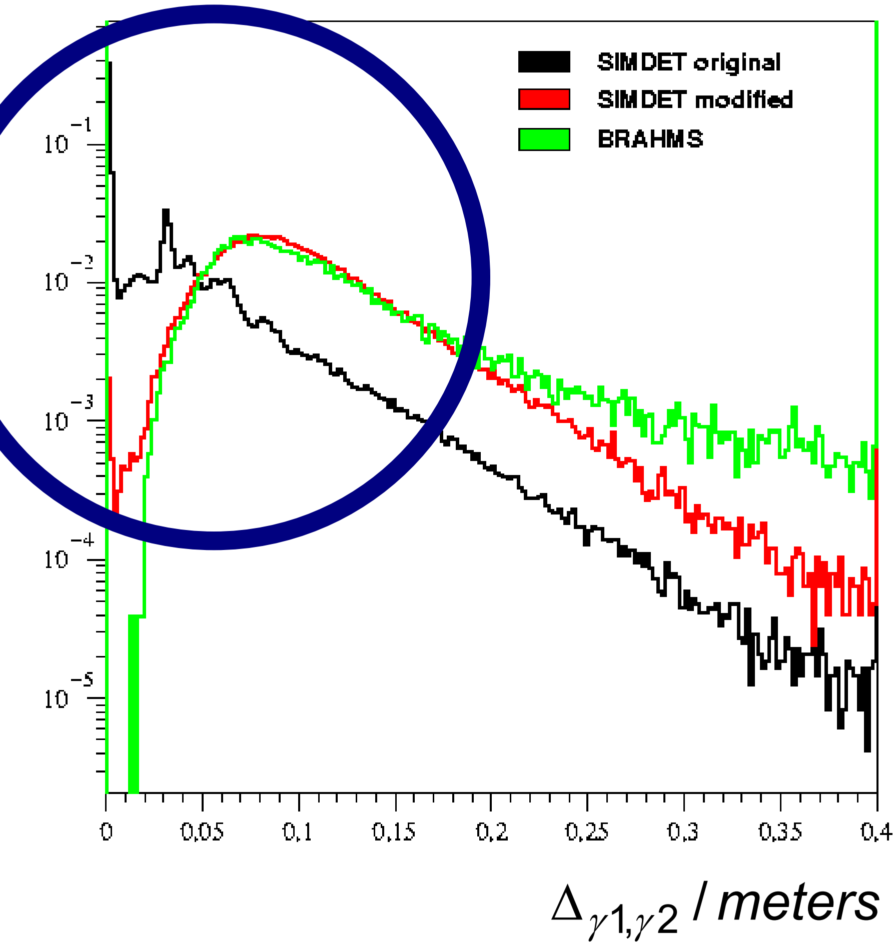
Linear fit for smaller distances.

Resulting in

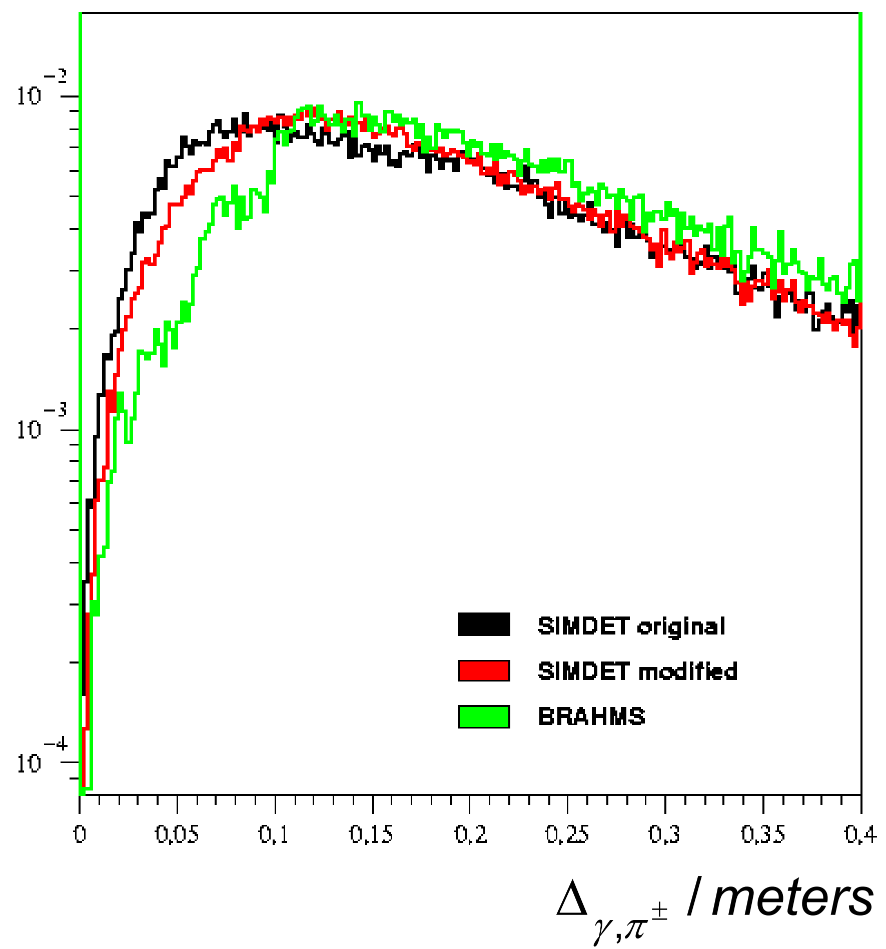
$P_{resolve}$= 28% for Δ = 0 cm.

Comparison of old and new detector-output...

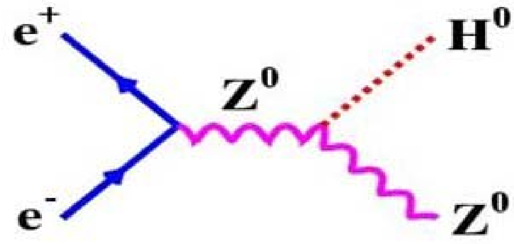
Distance at calo surface between 2 rec γ's



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 $m_H = 120\,GeV$:

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

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

Take all useful combinations of decays together with $Z \rightarrow X$, $X \neq \tau^+\tau^-$:

~ 1600 events / 1ab^{-1} available

Also the background has to be taken into account (here full SM-bckg):

Z^0Z^0, W^+W^-, $e_i\,\gamma \rightarrow e_i\,Z^0$, $e_i\,\gamma \rightarrow f_j\,W^\pm$, γ/Z^0 (together ~ 72 * 10^6 events / 1ab^{-1})

$\gamma\,\gamma \rightarrow$ ff O(10^{10}), HZ $\rightarrow$ X, X $\neq$ signal (140 k)

Statistics

Separate selection for the 3 different Z-decay mode

Dominate background classes (from now on: l= e,μ):

Signal	Backgrounds	N_{evt} / 1 ab^{-1}
$\tau\tau\ \nu\nu$ (~300 evt / 1ab^{-1})	ZZ $\rightarrow \tau\tau\ \nu\nu$	16 870
	WW $\rightarrow \tau\nu\ \tau\nu$	155 800
	$\gamma/Z^* \rightarrow \tau\tau$	2 505 000
	others like WW $\rightarrow$ l$\nu\ \tau\nu$	623 000 (after presel. 140 left, ~ 0.02%)
$\tau\tau$ ll (~100 evt / 1ab^{-1})	ZZ $\rightarrow \tau\tau$ ll	9 024
	$e_i\ \gamma \rightarrow e_i\ Z^0 \rightarrow e_i\ \tau\tau$	1 896 000
	WW $\rightarrow$ qq $\tau\nu$	1 952 000
	WW $\rightarrow$ qq lν	3 898 000
$\tau\tau$ qq (~1000 evt / 1ab^{-1})	ZZ $\rightarrow \tau\tau$ qq	65 270
	ZZ $\rightarrow$ qq qq	477 000
	WW $\rightarrow$ qq $\tau\nu$	1 952 000
	WW $\rightarrow$ qq qq	6 081 000

+ HZ $\rightarrow$ X, X $\neq$ signal in all cases

Selection from the SM background

- Cone-based search for τ-candidates

  requiring e.g. appropriate invarant mass, isolation to the next track

- (Soft) preselection:
  - minimal visible mass (112 GeV)
  - less than full energy detected (< 340 GeV at $\sqrt{s}$ = 350 GeV)
  - at least 1 pair of hadronic τ-candidates, e.g. with
    - angle between the candidates: $77° < \alpha < 176°$
    - 17 GeV < invariant di-candidate mass < 117 GeV

This reduces backgrounds with very different topology to a few percent.

Example: $e^i \gamma \rightarrow e_i Z^0 \rightarrow e_i qq$ from $13.3*10^6$ to 9100 (~0.07%)

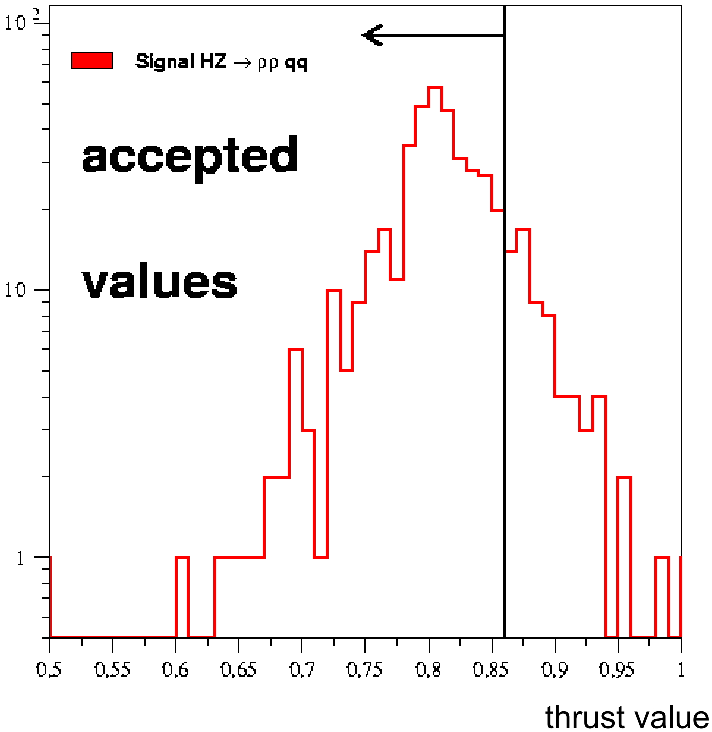
Following: a few examples of the search for $\tau\tau$ qq final-states:

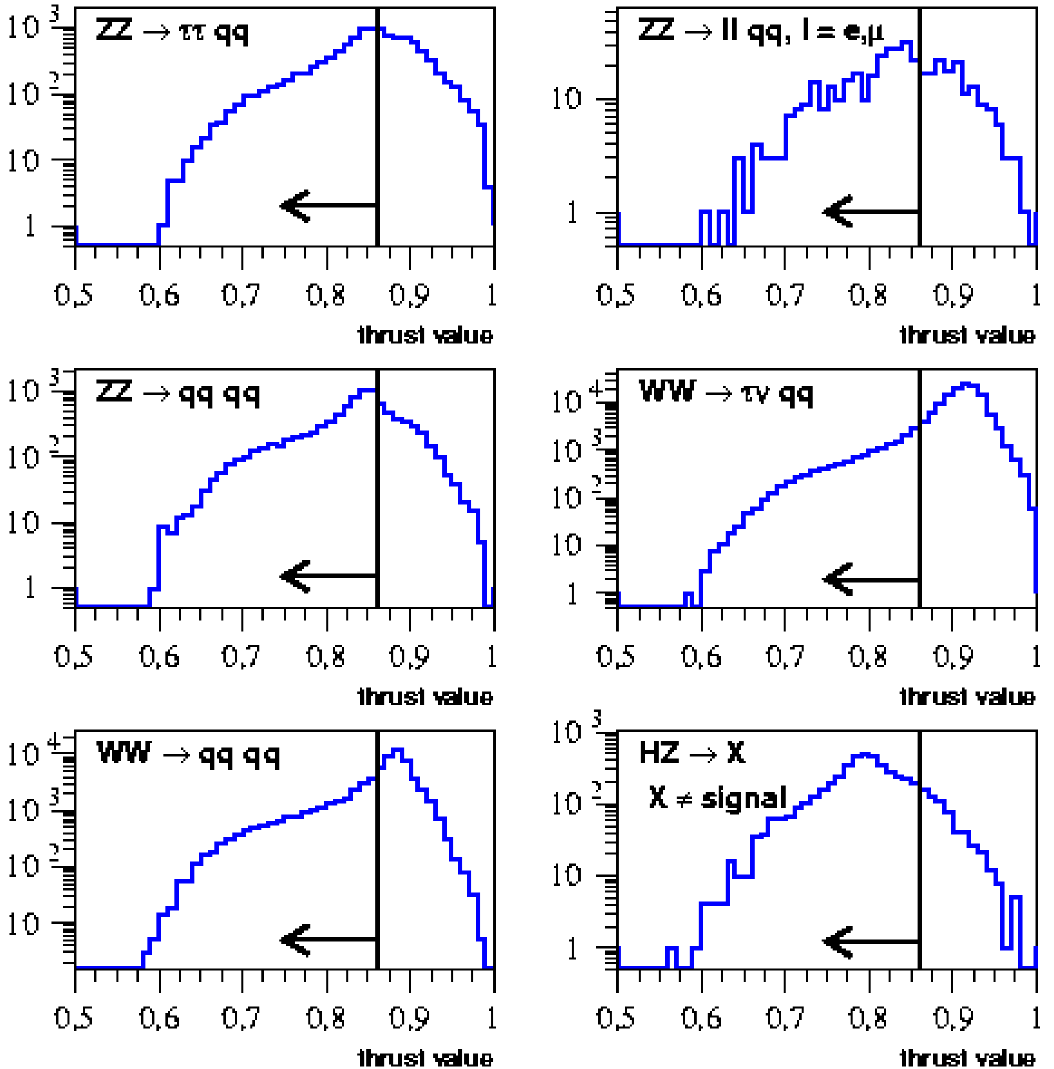
1. event shape
2. τ candidates and τ-pair candidates
3. hadronic Z-decay
4. kinematic fit to the HZ system

Selection cont.

Example for event shape:

require the thrust to be less than 0.86

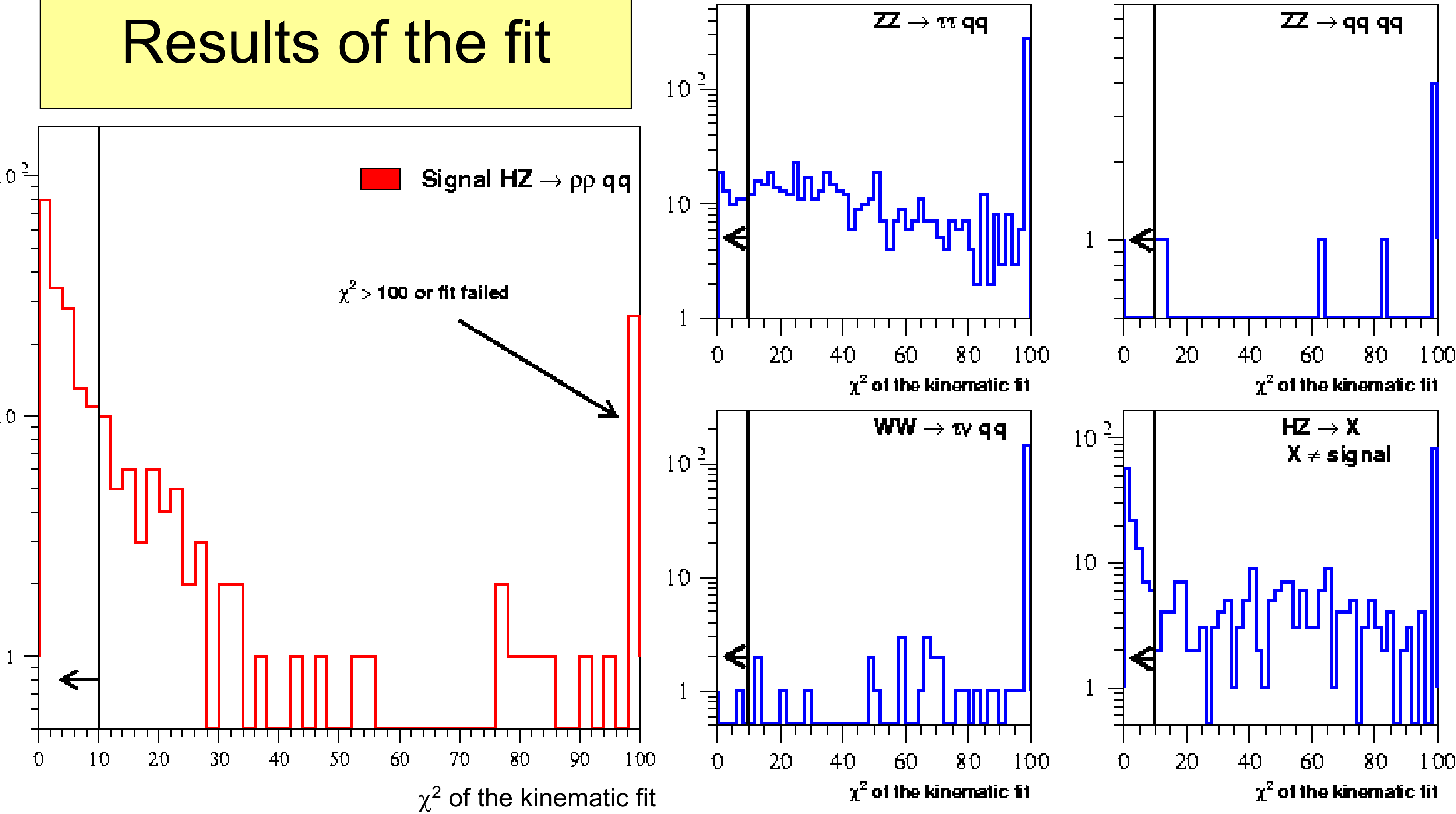




Kinematic Fit

- $Z \rightarrow qq$ system forced into 2 jets
- Input into the fit:
  - 4-momenta of the hadronic jets
  - 3-momenta of the τ-candidates, used only as directions
  - $\sqrt{s}$ = 350 GeV
- Constraints:
  - invariant mass of the Z^0 system = M_Z = 91.19 GeV
  - invariant mass of the H/A sytem = $M_{H/A}$ = 120 GeV
  - Energy and momentum conservation
- Only those events with a $\chi^2 < 10$ are accepted

Results of the fit



Hard but effective cut, rejecting all backgrounds beside ZZ →ττ qq and HZ-bckg:

N_{Signal} drops from 445 events to 296 (total efficiency drops to 28%) , N_{Bckg} from 1368 to 180

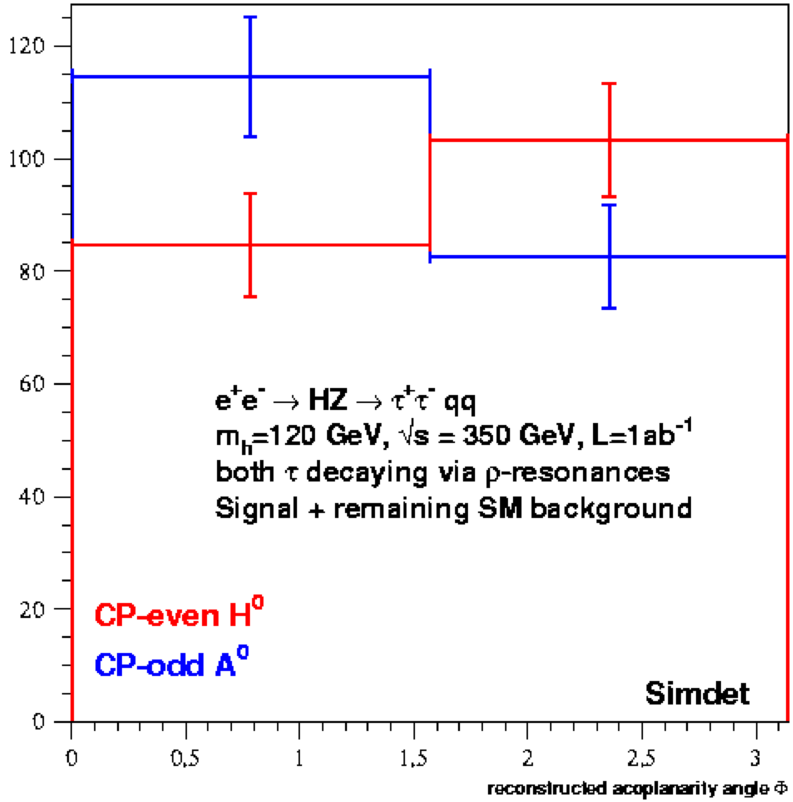
Cut-flow for $\tau\tau$ qq search (most relevant)

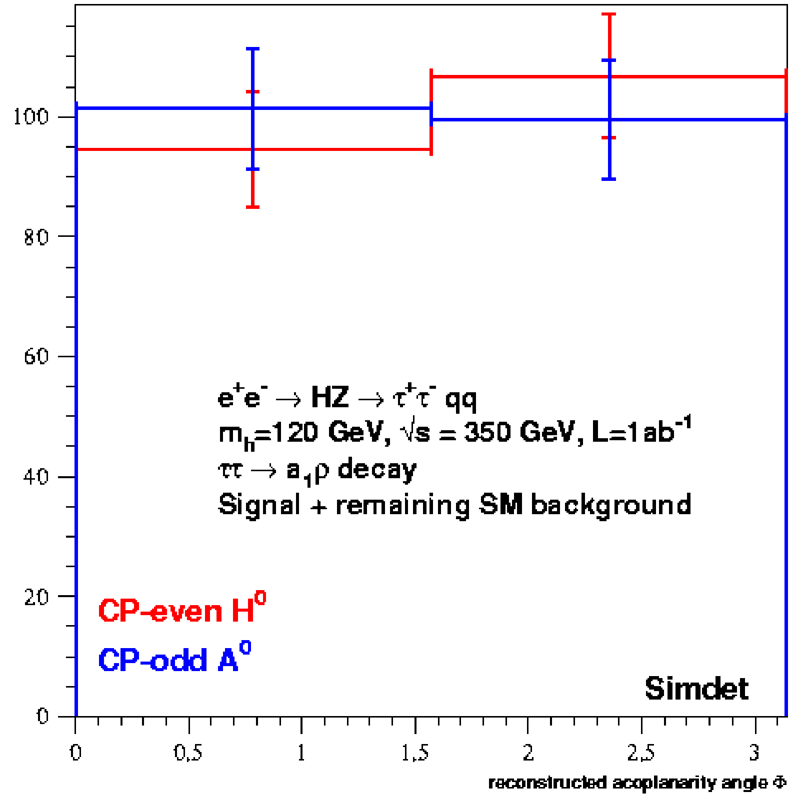
	Signal	ZZ $\to \tau\tau$ qq	ZZ $\to$ qq qq	WW$\to$qq$\tau\nu$	WW $\to$ qq qq
N_{evt} / 1 ab^{-1}	1040	65 270	477 000	1 952 000	6 081 000
preselection	838	12 350	9 373	194 127	67 124
event shape	610	6 051	3 920	8 403	12 056
τ-cand.	503	1 193	25	355	106
Z$\to$qq side	455	803	9	172	18
kin. fit	296	65	/	/	/

Resulting in S / N ~ 3.55 for $\rho\rho$

S / N ~ 1.26 for $a_1\rho$

Today's status





Aco_H = .099 ± .073
Aco_A = -.162 ± .070
→ ΔA = .261

Aco_H = .035 ± .140
Aco_A = -.084 ± .138
→ ΔA = .118

Selection status for $Z \to \nu\nu$ and ll

- In both cases no kinematic fit implemented (yet)
- Signals with $Z \to e^+e^-$ or $\mu^+ \mu^-$:
  - also primarily ZZ and HZ backgrounds left
  - $\rho\rho$ -case: S / B ~ 1.2 and $Aco_H = .035 \pm .140$ vs. $Aco_A = -.084 \pm .138$
  - $a_1\rho$-case: S / B ~ .49 and $Aco_H = .143 \pm .119$ vs. $Aco_A = -.028 \pm .118$
  - deliver each ≤ 1 sigma only
  - signal efficiency still above 50%, thus still room to play...

- Signals with $Z \to \nu\nu$:
  - hard to identify from backgrounds
  - at 30% efficiency, still other backgrounds like $WW \to \tau\nu\ \tau\nu$ left
  - $\rho\rho$ -case: S / B ~ .77
  - $a_1\rho$-case: S / B ~ .35

→ preliminary status / still some way to go....

Conclusion

- Much more realistic and reliable description for neutral energy deposition in the ECAL implemented
- The signal process is studied including
  - detector effects and
  - the full SM-background statistics
- Preliminary selection strategy shows reasonable results / performance. Especially for decay in $\rho\rho$ qq
- But there is still quite some room for improvements
- If mixed eigenstates can be determined has to be checked
- But a significance e.g. to distinguish a CP-even from a CP-odd Higgs-Boson of more than 3 σ can be expected with improvements and combination of the channels.