Angular distributions of Higgs boson decay products at CMS $h \to ZZ \to 4\ell$ (first look)

Michał Bluj

Outline

- Introduction
- Simulation
- Selection
- Azimuthal angle ϕ
- Polar angle θ
- Summary (to be done...)

These foils were prepared with LaTeX on April 16, 2004.

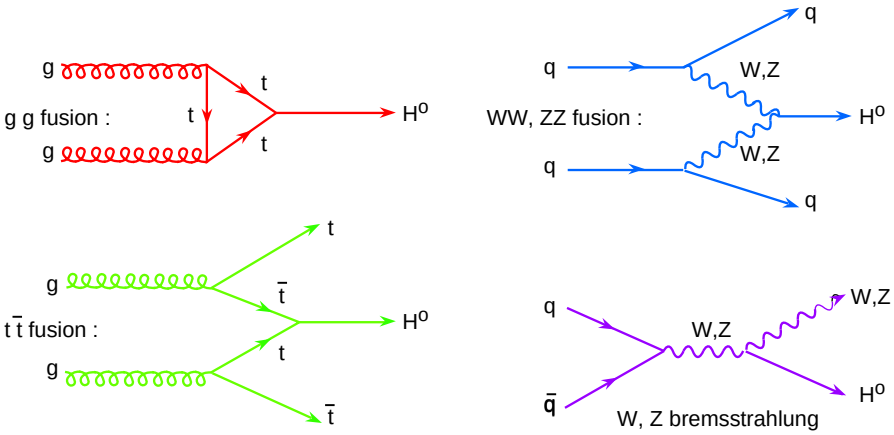
Motivations

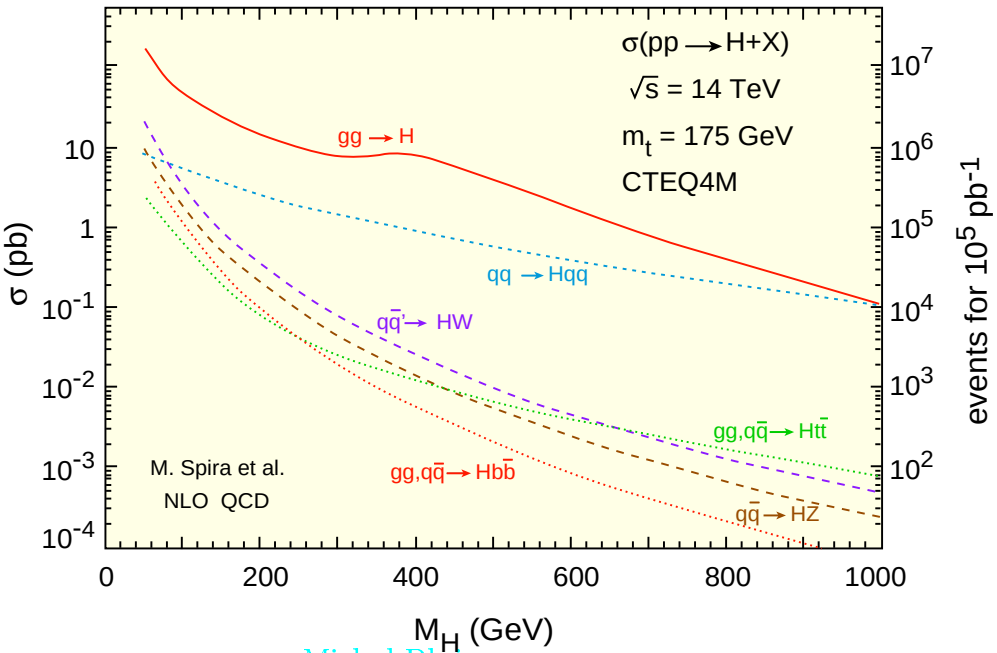
Different models assign different quantum numbers to Higgs bosons:

- SM $\rightarrow$ 1 scalar Higgs boson ($S^{CP} = 0^{++}$)
- MSSM, 2HDM (with CP conserving)$\rightarrow$ 5 Higgs bosons:
  - 2 neutral scalars ($S^{CP} = 0^{++}$)
  - 1 neutral pseudoscalar ($S^{CP} = 0^{+-}$)
  - 2 charged ($S^{CP} = 0^{+}, 0^{-}$)
- strongly interacting models predict vector ($S^{CP} = 1^{+}$)
- CP violation could be present in Higgs sector

Higgs at LHC

H^0 production at hadron colliders:





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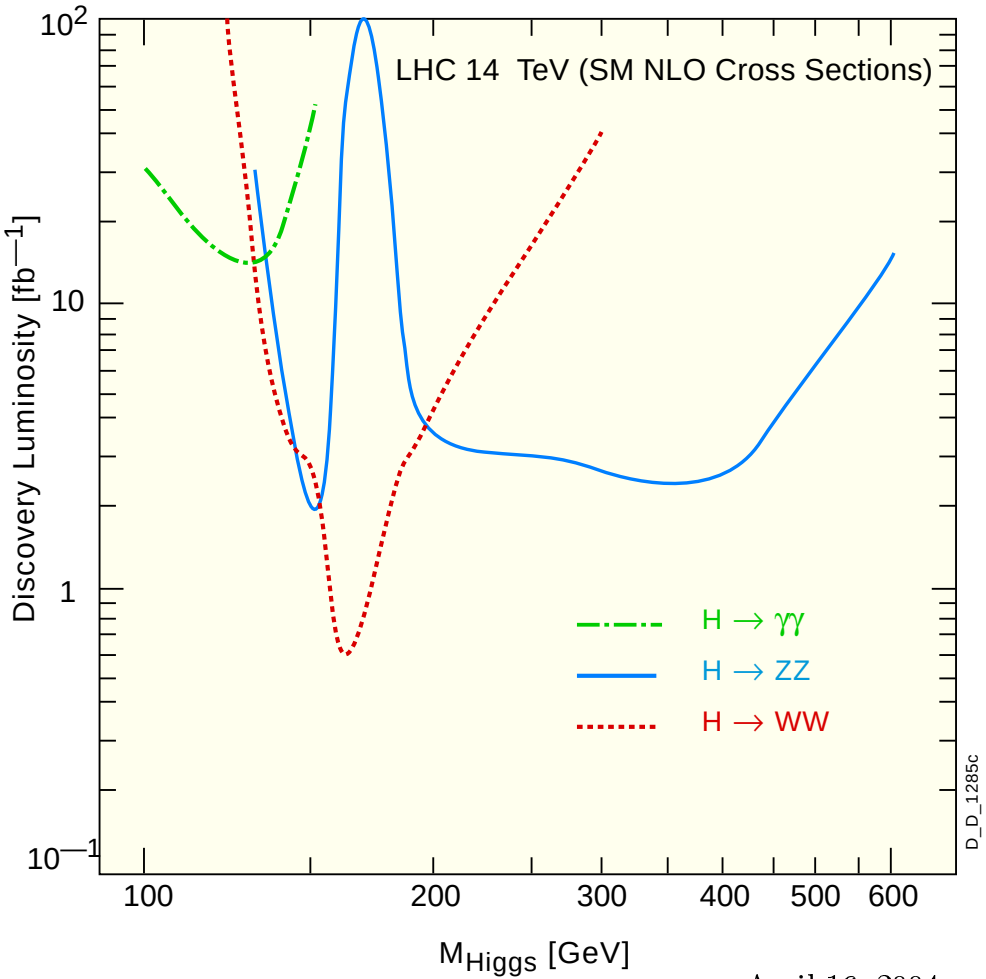
Two main higgs production processes:

- gluon fusion $gg \to H$
- vector boson fusion $qq \to qqH$

SM Higgs boson will be discovered in first year of LHC

5σ Higgs Signals (statistical errors only)



Observables - decay angles

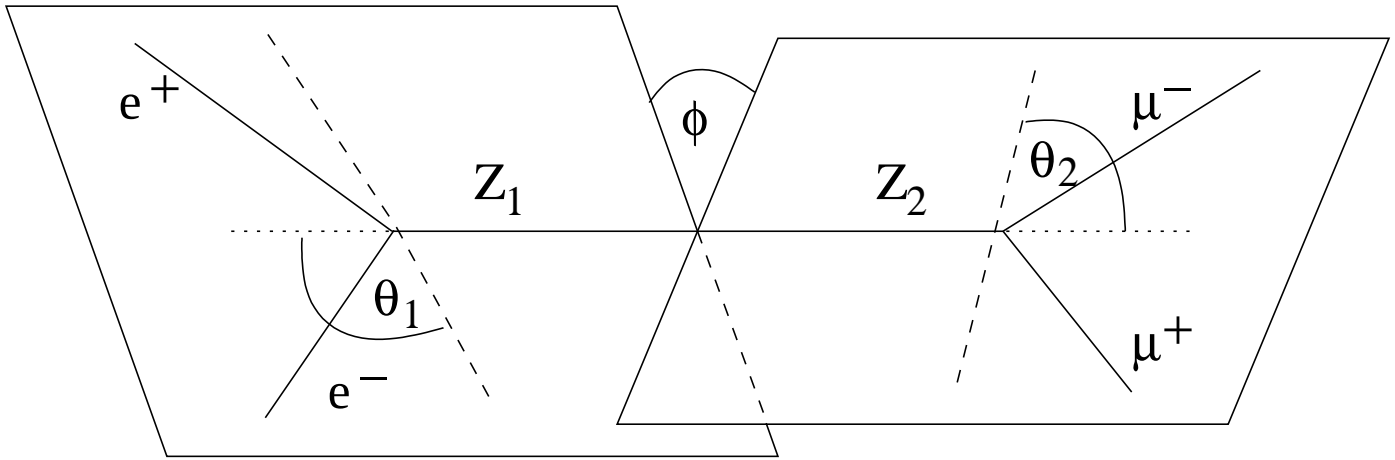
- Angular correlations of decay products carry on information about C/CP and spin decaying particle
- Yang theorem (Phys. Rev. 77 (1950))
  - scalar decays into $\gamma\gamma$ with parallel polarization planes
  - pseudoscalar decays into $\gamma\gamma$ with perpendicular polarization planes
  - vector cannot decay into $\gamma\gamma$
  - example: process $\pi^0 \to \gamma\gamma \to 2e^+e^-$

    $N \sim 1 \pm \beta cos(2\phi)$, + scalar, - pseudoscalar

Observables - decay angles (cont.)

- Process $H \to ZZ \to 4\ell$:
  - analogical to $\pi^0 \to \gamma\gamma \to 2e^+e^-$ in limit $m_H \to \infty$
  - correlations between Z polarization planes correspond with correlations between decay planes ($\Rightarrow \phi, \theta$)
  - covers wide higgs mass range

Definition of the polar and azimuthal angles of the $H \to ZZ \to 4\ell$ decay (C.P. Buszello, I. Fleck, P. Marquard, J.J. van der Bij, hep-ph/0212396)

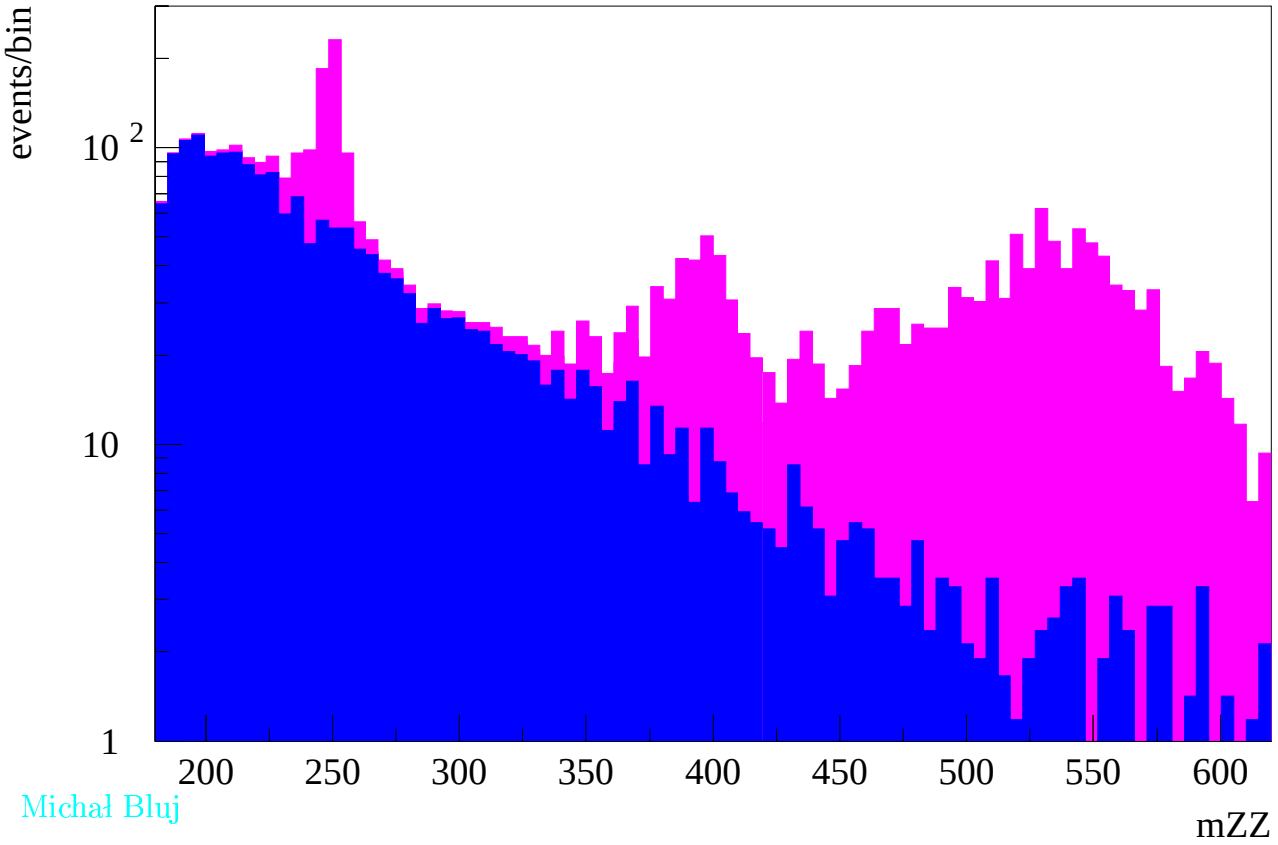


Simulation

- Signal: PYTHIA 6.215 + CMSJET 4.801 (fast simulation)
  higgs masses: 250, 400, 550 GeV
  - $gg \to H(CP \pm 1) \to ZZ \to 4\mu, 4e, 2\mu 2e$ (6×2k ev.)
  - $qq \to H(CP \pm 1) \to ZZ \to 4\mu, 4e, 2\mu 2e$ (6×2k ev.)
- Background: PYTHIA 6.215 + CMSJET 4.801 (fast simulation)
  - $qq \to ZZ \to 4\mu, 4e, 2\mu 2e$ (3×10k ev.)
  - $gg \to ZZ$ (lack in PYTHIA, but added as a fraction (30%) of $qq \to ZZ$)
  - other background types ($tt \to 4\ell, Zbb \to 4\ell$, pile-up) are supposed to be effectively suppressed by isolation cuts
- Parton density function: CTEQ4L
- Simplifications:
  - Fast simulation
  - Efficiency of lepton identification 100%
  - Pile-up events not considered
- All figures normalized to the luminosity 100/fb (1 LHC year)

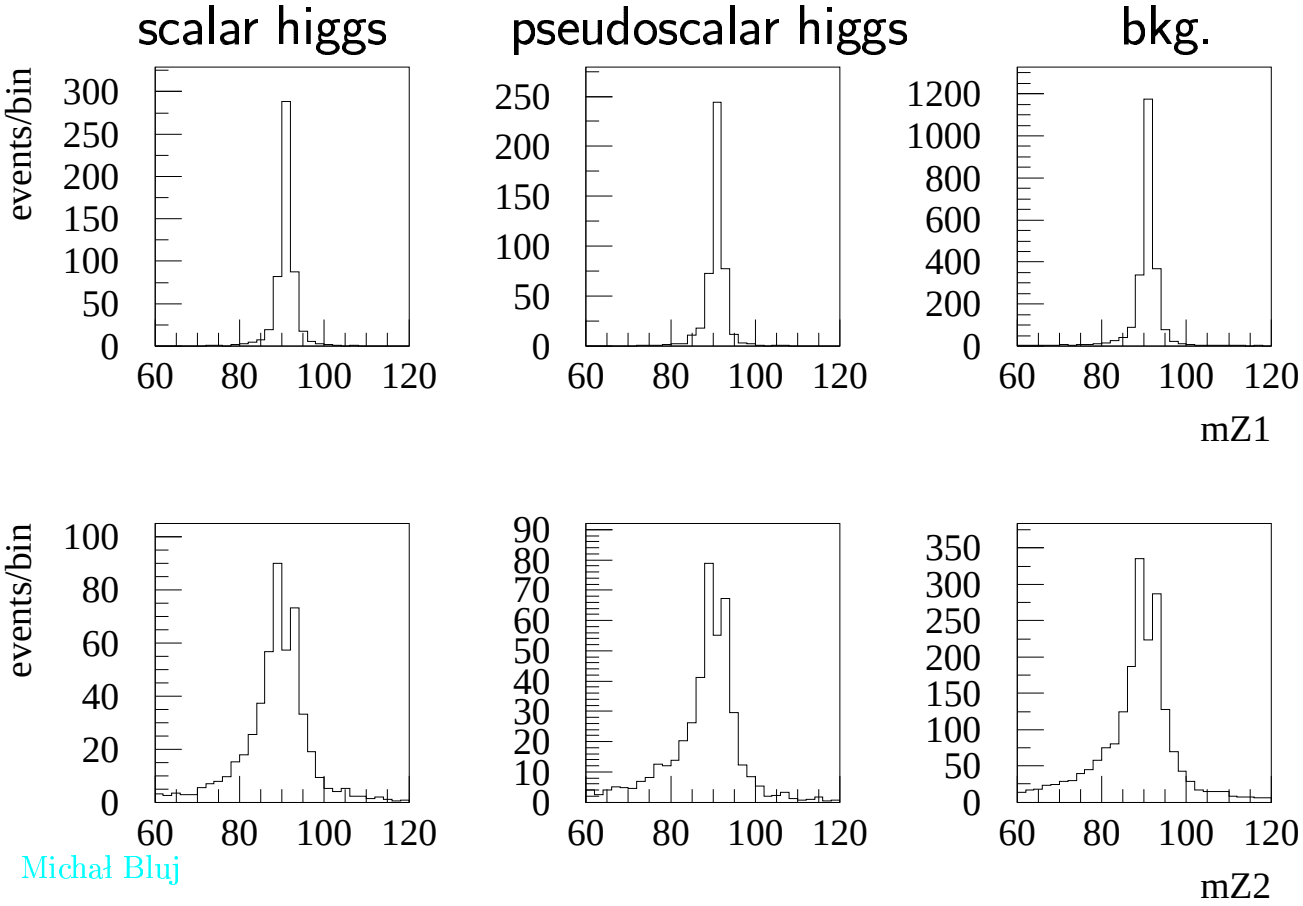
Preselection

- muon $p_t > 10GeV$, electron $p_t > 20GeV$
- $|\eta| < 2.4$
- isolation: $\Delta R := \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$
  - at tracker: no charged particles with $p_t > 2GeV$ inside cone $\Delta R < 0.3$
  - at calo : $\Sigma E_t / E_t^{lep} < 0.1$ inside cone $\Delta R < 0.3$
- 4 the most energetic leptons should form 2 e^+e^- or $\mu^+\mu^-$ pairs



Selection

- Mass of better reconstructed Z within 10 GeV window.
- Mass of worse reconstructed Z within 20 GeV window.
- Mass of higgs candidate within 20, 90, 160 GeV window.

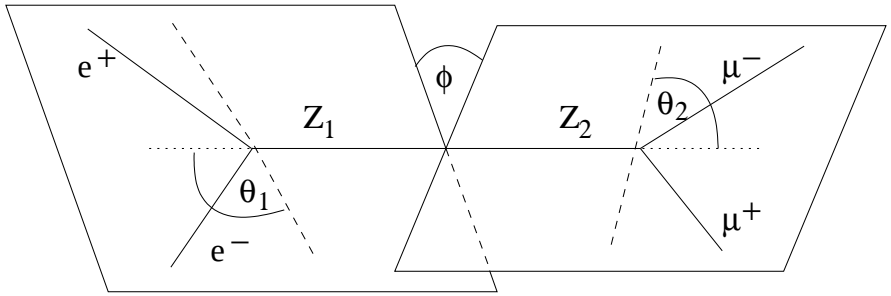


Efficiency

	signal eff.			# bkg.		
	$2ee$	$2\mu\mu$	$2e\mu$	$2ee$	$2\mu\mu$	$2e\mu$
	$m_h = 250$					
$N_\ell \geq 4$	.45	.62	.54	464.7	715.4	1111.7
$pairs$	.45	.62	.54	464.5	715.4	1110.3
$2m_Z$	.42	.95	.51	422.3	636.1	1032.7
m_H	.31	.47	.38	37.6	67.5	113.6
	$m_h = 400$					
$N_\ell \geq 4$	.60	.70	.67	464.7	715.4	1111.7
$pairs$	.60	.69	.66	464.5	715.4	1110.3
$2m_Z$	.56	.66	.63	422.3	636.1	1032.7
m_H	.46	.56	.51	31.7	51.4	84.8
	$m_h = 550$					
$N_\ell \geq 4$	.66	.76	.71	464.7	715.4	1111.7
$pairs$	.66	.76	.71	464.5	715.4	1110.3
$2m_Z$	.61	.72	.67	422.3	636.1	1032.7
m_H	.43	.55	.49	14.9	24.2	46.9

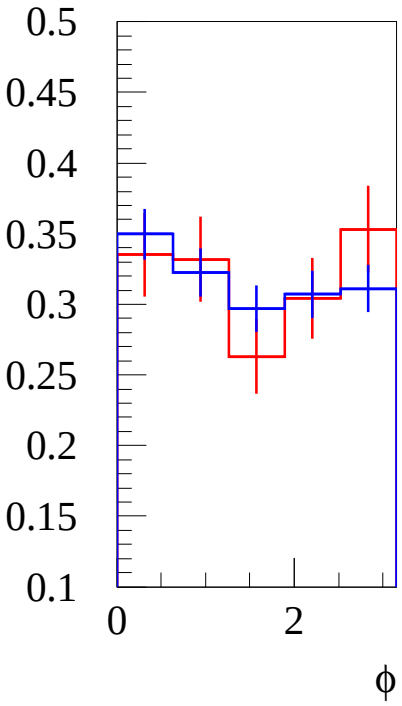
$$\mathcal{L} = 100\ fb^{-1}$$
$$\sigma \cdot BR(m_H = 250) = 0.605 + 1.78\ fb$$
$$\sigma \cdot BR(m_H = 400) = 0.270 + 1.25\ fb$$
$$\sigma \cdot BR(m_H = 550) = 0.133 + 4.09\ fb$$

Azimuthal angle ϕ

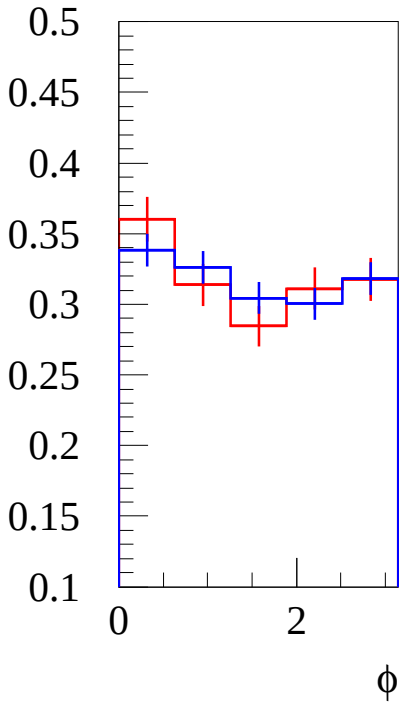


Acceptance of detector suppresses $\phi \approx \frac{\pi}{2}$
and gains $\phi \approx 0, \pi$
$\Rightarrow$ signal more "scalar-like"

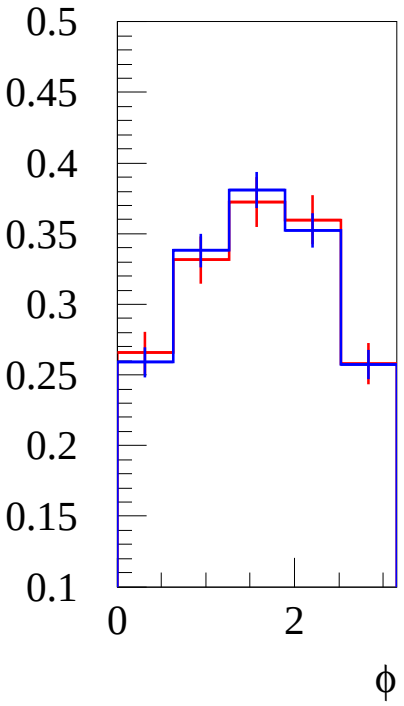
scalar higgs



pseudoscalar higgs

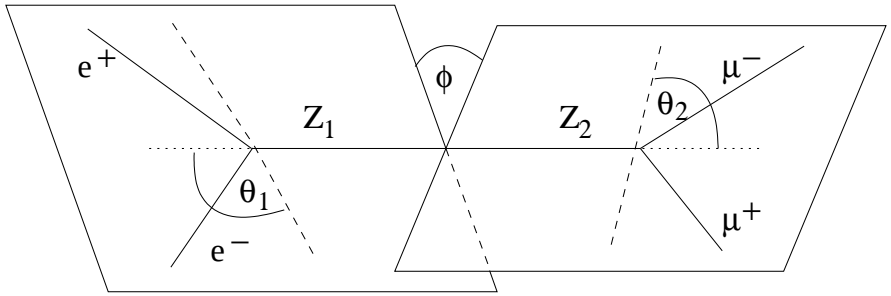


bkg.



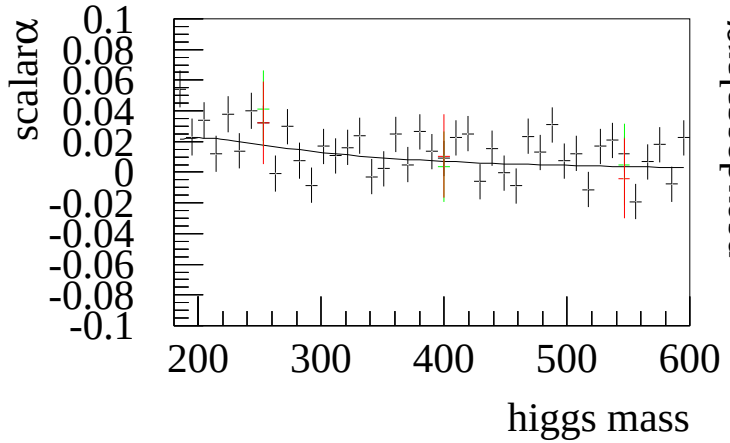
$m_H = 250$ GeV
+ after detector simulation
+ before detector simulation (MC)

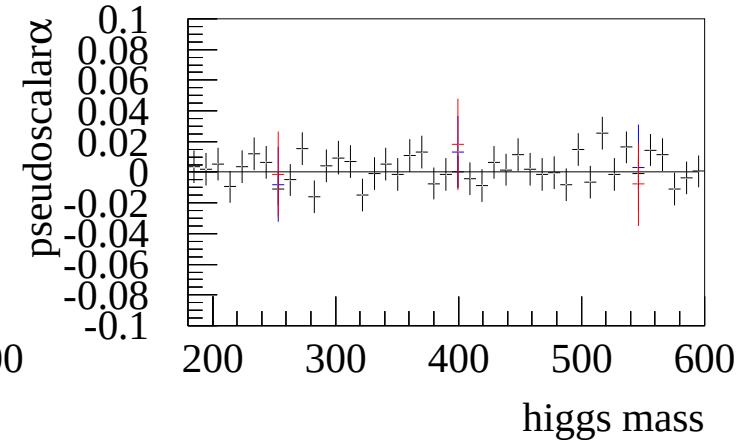
Azimuthal angle ϕ

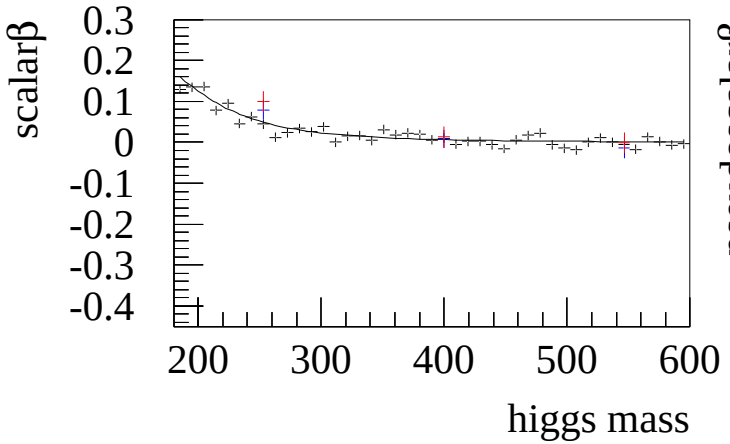


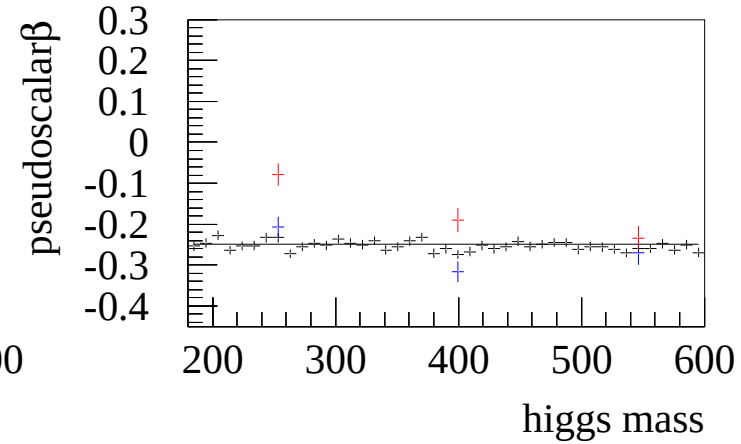
Parametrization:

$$\frac{d\sigma}{d\phi} \sim 1 + \alpha \cos\phi + \beta \cos 2\phi$$









– theory

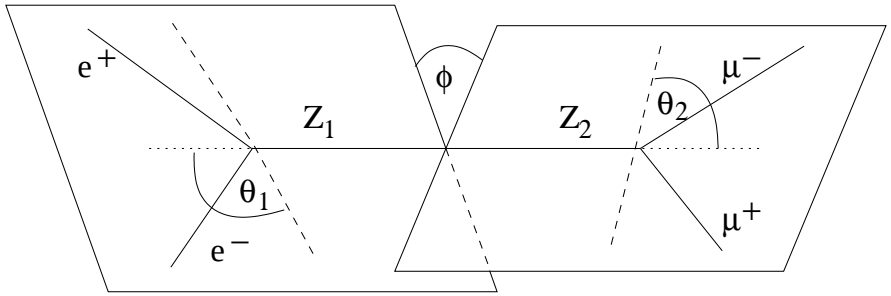
fit to

+ MC (Pythia 6.215)

+ signal

+ "data" (signal+bkg.)

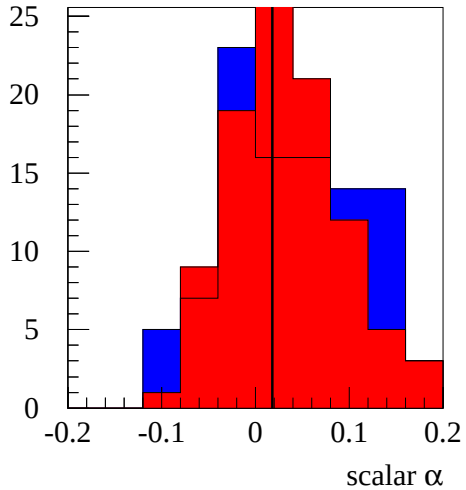
Azimuthal angle ϕ

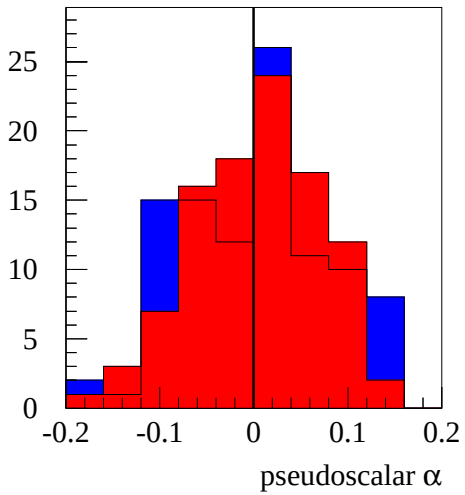


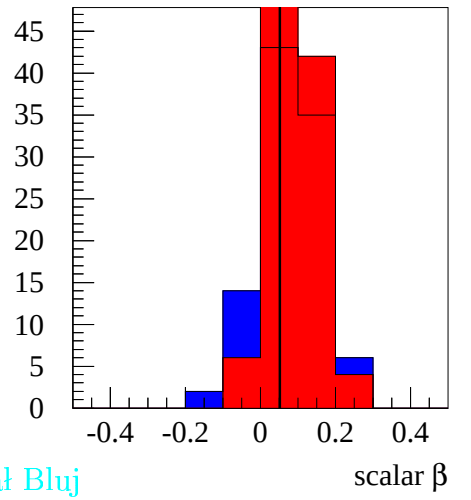
Parametrization:

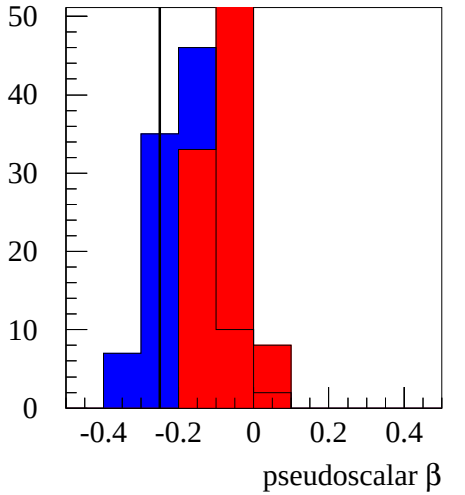
$$\frac{d\sigma}{d\phi} \sim 1 + \alpha \cos\phi + \beta \cos 2\phi$$

Distributions of fitted parameters α and β (100 mock samples)









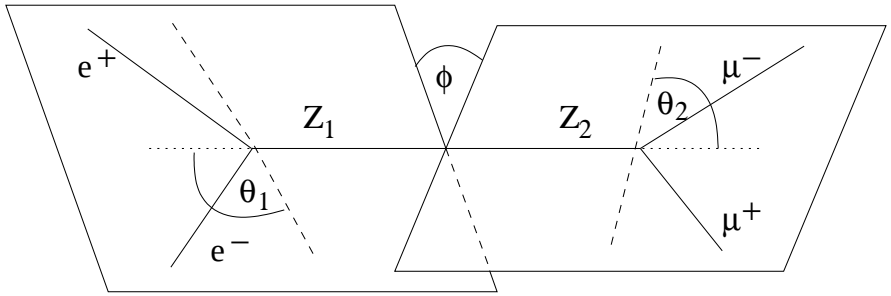
$m_H = 250$ GeV

| theory

+ signal

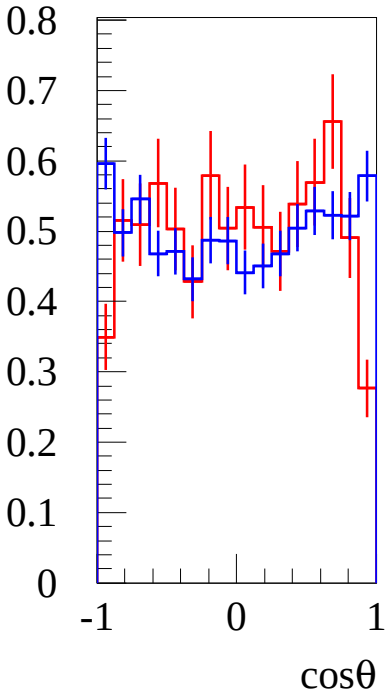
+ "data" (signal+bkg.)

Polar angle θ

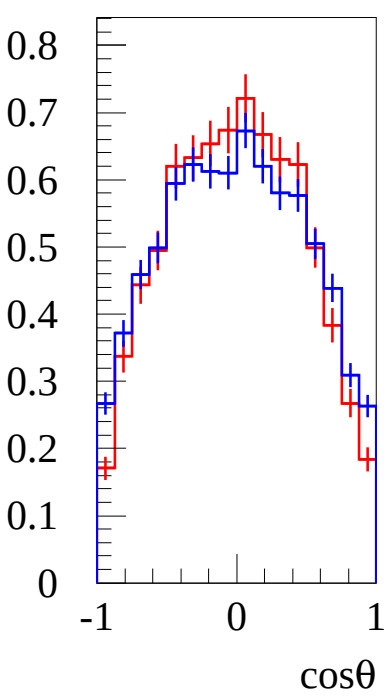


Acceptance of detector
suppresses $\cos\theta \approx \pm 1$ $(\theta \approx 0, \pi)$
and gains $\cos\theta \approx 0$ $(\theta \approx \frac{\pi}{2})$

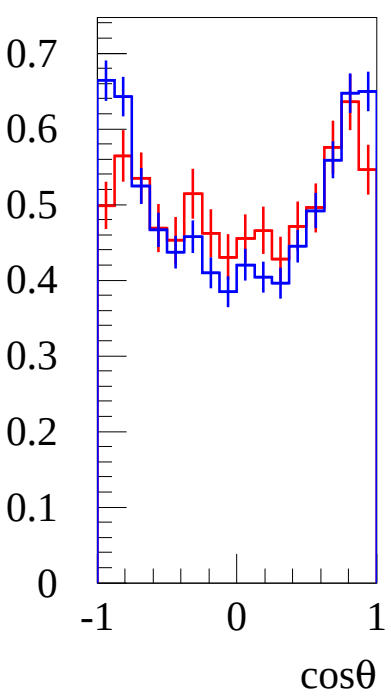
scalar higgs



pseudoscalar higgs

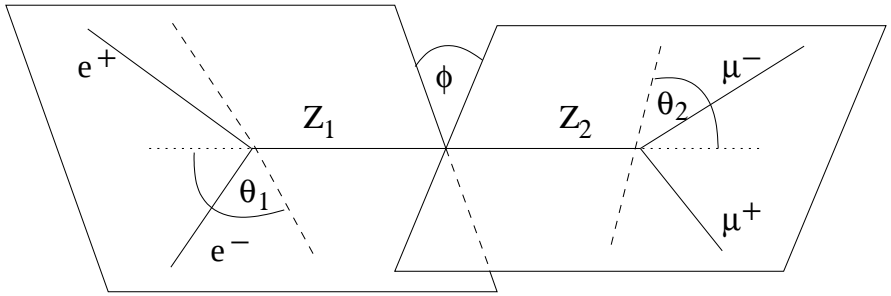


bkg.



$m_H = 250$ GeV
+ after detector simulation
+ before detector simulation (MC)

Polar angle θ

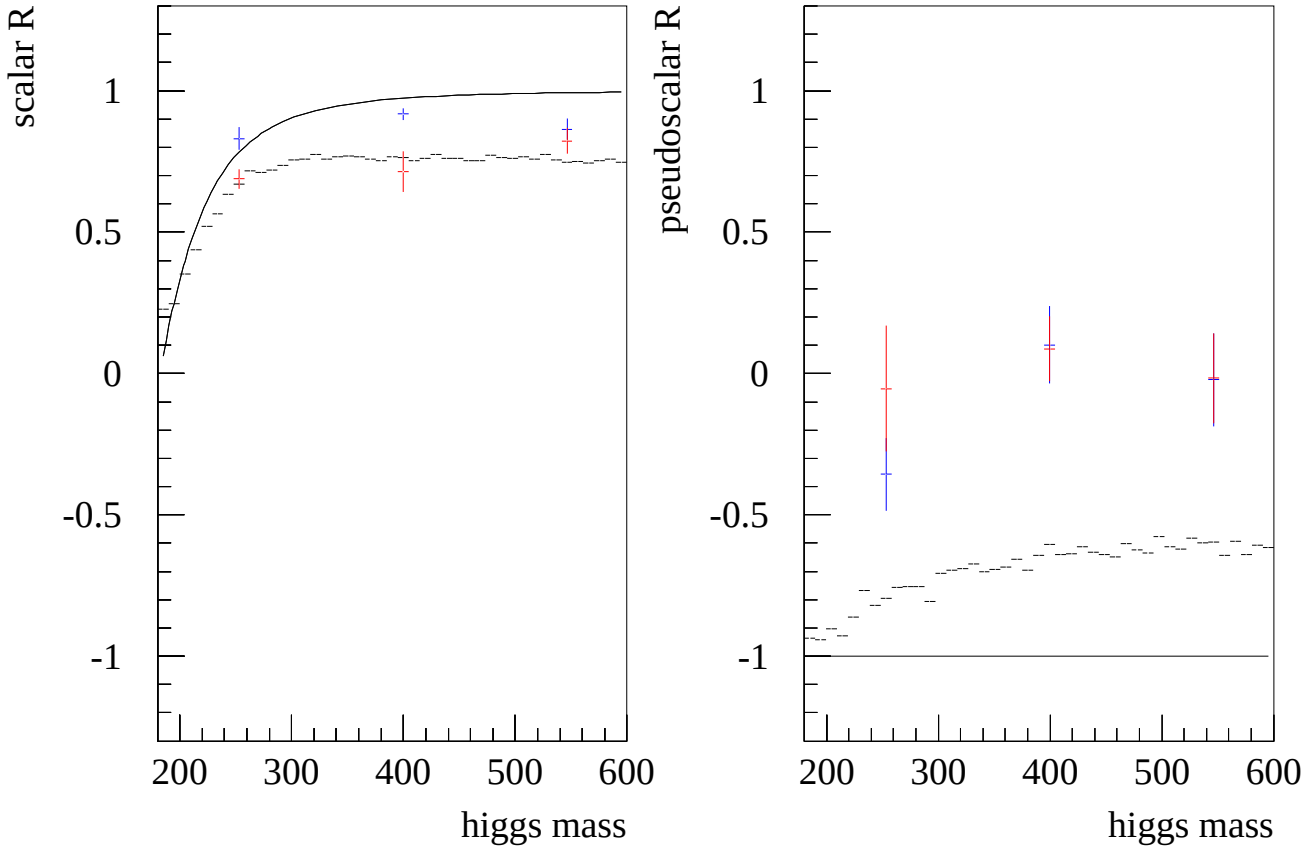


Parametrization:

$$\frac{d\sigma}{d\cos\theta} \sim T(1+cos^2\theta) + Lsin^2\theta,$$

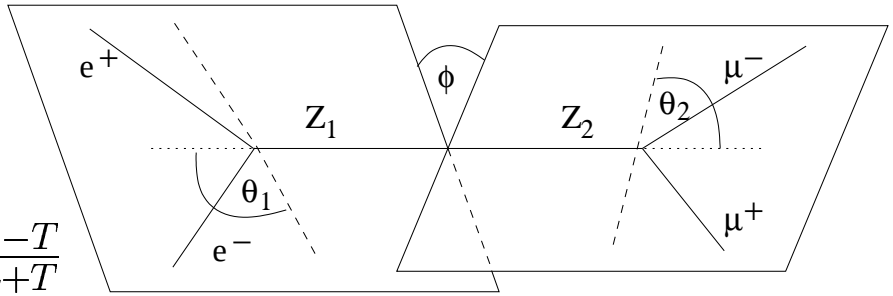
For better distinguishing between different S^{CP} cases asymmetry R is defined:

$$R \equiv \frac{L-T}{L+T}$$



– theory
fit to
+ MC (Pythia 6.215)
+ signal
+ "data" (signal+bkg.)

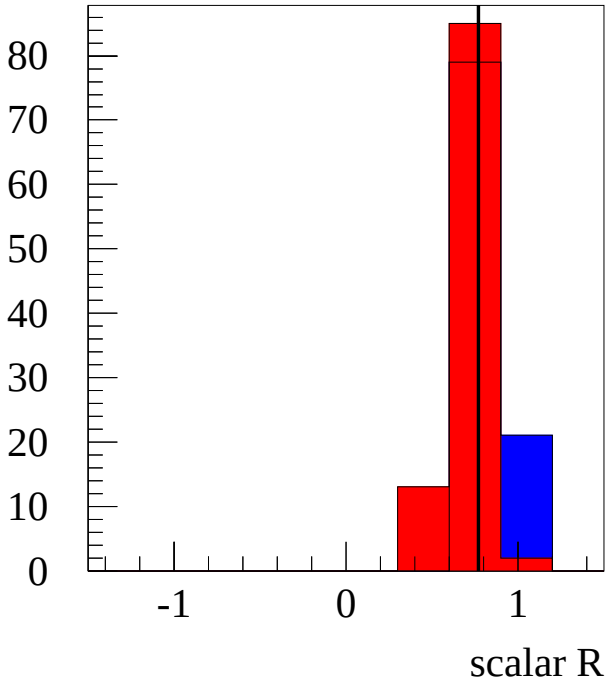
Polar angle θ

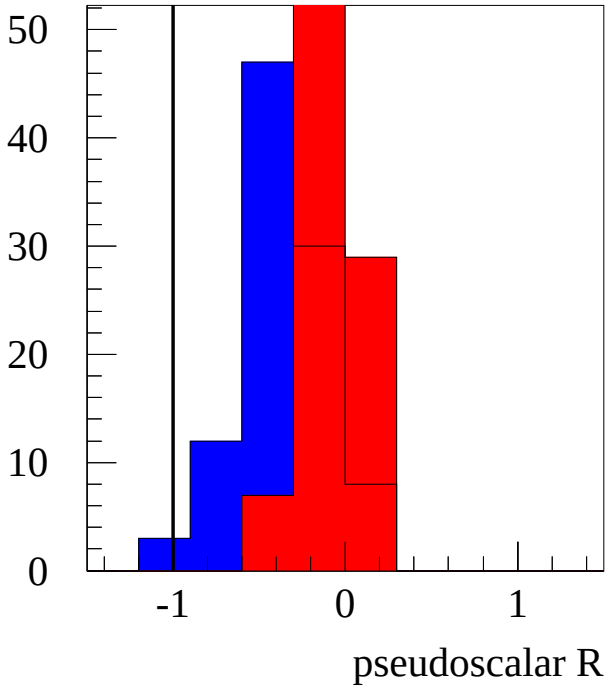


Parametrization:

$$\frac{d\sigma}{d\cos\theta} \sim T(1+cos^2\theta) + Lsin^2\theta, \qquad R := \frac{L-T}{L+T}$$

Distribution of fitted parameter R (100 mock samples)





$m_H = 250$ GeV
| theory
+ signal
+ "data" (signal+bkg.)

Significance

- Definition:
  $S = \frac{|mean_{scalar} - mean_{no-scalar}|}{error_{scalar}}$
- Azimuthal angle ϕ significance $S_\phi = \sqrt{S_\alpha^2 + S_\beta^2}$
- Combined significance $S = \sqrt{S_\phi^2 + S_R^2}$

Obtained significances
(VERY PRELIMINARY! - problem with stability of $\cos\theta$ fit)

m_H (GeV)	S_ϕ^s	S_ϕ^{s+b}	S_R^s	S_R^{s+b}	S^s	S^{s+b}
250	3.14	2.58	9.64	7.19	10.15	7.64
400	3.52	3.03	5.83	6.09	6.81	6.80
550	4.10	4.12	6.71	13.93	7.86	14.53

Summary (to be done...)

LHC has a potential to distingiush between different S^{CP} states of Higgs bosnon using azimuthal and polar correlations in $H \to ZZ \to 4\ell$ proces, for wide range of m_H,
but list things to be done is long:

- Check of fitting procedure for polar angle θ.
- Generation of $gg \to ZZ$ bkg. and check of their influence.
- Check of significance.
- Check of other bkg. sources (e.g. pile-up).
- K-factors (NLO).
- Full detector simulation.
- Higgs with $m_H < 2m_Z$
- ...
- Study a possibility to measure CP violation in the Higgs sector