On study of angle correlations in $\Phi \rightarrow ZZ \rightarrow 2e2\mu$ at the CMS

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Outline

- Model
- Methodology
- MC Samples
- Selection
- Results

The results presented here are preliminary and can't be distributed before they get approved by the CMS collaboration.

These foils were prepared with LaTeX on December 13, 2005.

Model

- An effective model of ΦZZ coupling with scalar ($g^{\mu\nu}$) and pseudoscalar ($\epsilon^{\mu\nu\rho\sigma}k_{1\rho}k_{2\sigma}$) terms (A.Skjold, P.Osland Phys. Lett. B**329**, 305 (1994), implemented in `Pythia`):

$$C_{\Phi ZZ} \sim m_Z^2 g^{\mu\nu} + \tan\xi \cdot \epsilon^{\mu\nu\rho\sigma}k_{1\rho}k_{2\sigma}$$

  where $k_1 = (q_1 + q_2)$, $k_2 = (q_3 + q_4)$, $q_{i=1\ldots4}$ momenta of Z^0s and leptons;

  $\tan\xi$ describes deviation from SM (scalar $\xi = 0$, pseudoscalar $\xi = \pm\pi/2$, CP-violation $\xi \neq 0, \pm\pi/2$).

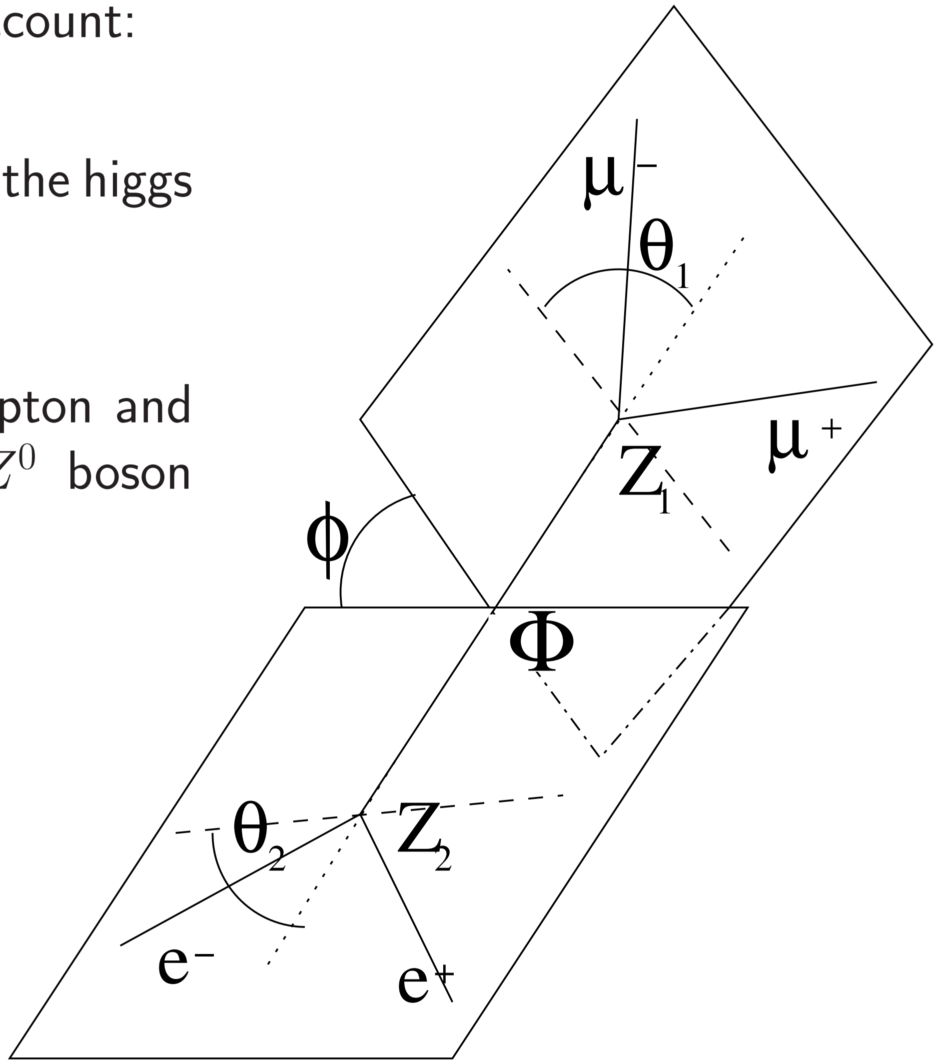
- Differential cross-section:

$$d\sigma(\xi) \sim \mathcal{H} + \tan\xi \cdot \mathcal{V} + \tan^2\xi \cdot \mathcal{A}$$

  where:
  – scalar: $\mathcal{H}$
  – mixing term: $\mathcal{V}$
  – pseudoscalar: $\mathcal{A}$

Methodology: definition of observables

- Angular distributions distinguish between states with different ξ's
- Two distributions taken in to account:
  - Plane angle φ between decay planes of Z^0s in the higgs rest frame
  - Polar angle $\theta_{1,2}$ between negatively charged lepton and the direction of Z^0 in the Z^0 boson rest frame



Methodology: maximization of likelihood function

- Definition of likelihood function

$$\mathcal{L}(\xi,R) \equiv 2 \sum_{x_i \in data} \log \mathcal{Q}(\xi,R;\ x_i)$$

where

$$\mathcal{Q}(\xi,R;\ x_i) \equiv R \cdot \mathcal{P}_S(\xi;\ x_i) + (1-R) \cdot \mathcal{P}_B(x_i)$$

$\{x_i\}$ – data event,
R – fraction of signal in data sample (1$^{\mathrm{st}}$ parameter of fit),
$\mathcal{P}_B$ and $\mathcal{P}_S(\xi)$ – probability density functions for background and signal:

$$\mathcal{P}_B \equiv \mathcal{P}_B^M \cdot \mathcal{P}_B^\varphi \cdot \mathcal{P}_B^{\cos\theta_1} \cdot \mathcal{P}_B^{\cos\theta_2}$$

$$\mathcal{P}_S(\xi) \equiv \mathcal{P}_S^M \cdot (\mathcal{P}_S^\varphi \cdot \mathcal{P}_S^{\cos\theta_1} \cdot \mathcal{P}_S^{\cos\theta_2})(\xi)$$

where
$\mathcal{P}^M$, $\mathcal{P}^\varphi$, $\mathcal{P}^{\cos\theta_{1,2}}$ – probability density functions for $m_{4\ell}$, φ and $\cos\theta_{1,2}$ respectively obtained by MC simulation.

Methodology: determination of ξ

- Definition of signal part of $\mathcal{Q}$-function according to expression for $d\sigma(\xi)$:

$$\mathcal{P}_S^{\varphi} \cdot \mathcal{P}_S^{\cos\theta_{1,2}}(\xi) \equiv (\mathcal{H} + \tan\xi \cdot \mathcal{V} + \tan^2\xi \cdot \mathcal{A})/(1 + \tan\xi + \tan^2\xi)$$

$-$ $\mathcal{H} \equiv \mathcal{P}_H^{\varphi} \cdot \mathcal{P}_H^{\cos\theta_{1,2}}$ and $\mathcal{A} \equiv \mathcal{P}_A^{\varphi} \cdot \mathcal{P}_A^{\cos\theta_{1,2}}$ – probabilities for scalar (H) and pseudoscalar (A)

$-$ $\mathcal{V}$ is normalized angle distribution for mixing term (V), not probability! (isn't positive) thus it can't be simulated separately

- Determination of $\mathcal{V}$ from probability for $\xi = \pi/4$

$$\mathcal{J} \equiv \mathcal{P}_S^{\varphi} \cdot \mathcal{P}_S^{\cos\theta_{1,2}}(\xi = \pi/4) = (\mathcal{H} + \mathcal{V} + \mathcal{A})/3$$

$$\Longrightarrow \mathcal{V} = 3\,\mathcal{J} - \mathcal{H} - \mathcal{A}$$

and finally:

$$\mathcal{P}_S^{\varphi} \cdot \mathcal{P}_S^{\cos\theta_{1,2}}(\xi) \equiv [(1 - \tan\xi) \cdot \mathcal{H} + \tan\xi \cdot 3\,\mathcal{J} + (\tan^2\xi - \tan\xi) \cdot \mathcal{A}]/(1 + \tan\xi + \tan^2\xi)$$

MC samples for "golden" channel $\Phi \to ZZ \to 2e2\mu$

- Samples generated with detector acceptance preselection:
  $-2e$ with $p_t>$5 GeV & $\eta<$2.7
  -2μ with $p_t>$3 GeV & $\eta<$2.5

- Signal $\Phi \to ZZ \to 2e2\mu$:
  - Samples generated for three masses above ZZ threshold m_Φ=200, 300, 400 GeV
  - Samples used for construction of $\mathcal{P}$ (scalar, pseudoscalar and $\xi=\pi/4$) – 10k. evts.
  - For CP-violating case samples
    $\tan\xi$=0.1, 0.4, 4 – 5k. evts.
    $\tan\xi$=-0.1, -0.4, -4 – 1k. evts. (limited statistic)

- Background:
  - $ZZ \to 2e2\mu$ – 20k. evts.
  - $t\bar{t} \to 2e2\mu$ – 48k. evts.
  - $Zb\bar{b} \to 2e2\mu$ – 4k. evts.

- All samples generated with low-lumi pile-up ($\sim$3.5 "soft" evts./"hard" evt.).
- Full simulation & reconstruction of the CMS detector were used.

Selection

- CMS selection for Higgs boson in $\Phi \rightarrow ZZ \rightarrow 2e2\mu$ channel (by D.Futyan, D.Giordano)
  - Di-electron or di-muon trigger ("$Z \rightarrow 2\ell$-trigger")
  - Reconstructed two lepton pairs e^+e^- and $\mu^+\mu^-$
  - All 4 leptons originate at one vertex
  - Isolation at tracker
  - Kinematic cuts

    a) Cuts on p_ts of leptons ($p_{t1}, p_{t2}, p_{t3}, p_{t4}$)

    b) Cuts on mass of Z candidates:
      - ∗ Symmetric window around better Z candidate (Δm_{Z1})
      - ∗ Asymmetric mass window in mass of worse Z candidate ($m_{Z2}^{min} \div m_{Z2}^{max}$)

    c) Mass window in four lepton mass (mass of higgs candidate) ($m_H^{min} \div m_H^{max}$)

- Cuts optimiziation (for each higgs mass) performed automatically to maximize significance:

$S = \sqrt{2lnQ}$, where $Q = \left(1 + \frac{N_S}{N_B}\right)^{N_S+N_B} e^{-N_S}$

Selected cross-sections

	$m_\Phi = 200$ GeV				$m_\Phi = 300$ GeV				$m_\Phi = 400$ GeV			
	sig.	ZZ	$t\bar{t}$	$Zb\bar{b}$	sig.	ZZ	$t\bar{t}$	$Zb\bar{b}$	sig.	ZZ	$t\bar{t}$	$Zb\bar{b}$
σ_{tot} (pb)	17.86	21.2	886	525	9.41	21.2	886	525	8.71	21.2	886	525
$\sigma_{tot} \cdot \epsilon \cdot BR$	7.65	11.81	817.52	116.38	5.08	11.81	817.52	116.38	4.45	11.81	817.52	116.38
rec. $2\mu 2e$	5.46	6.71	173.02	32.77	3.74	6.71	173.02	32.77	3.35	6.71	173.02	32.77
Z mass	3.89	3.74	0.09	<0.02	2.69	2.17	0.14	0.05	2.46	1.59	0.10	<0.02
Φ mass	3.34	0.58	<0.03	<0.02	2.10	0.23	<0.03	<0.02	2.02	0.16	<0.03	<0.02
S/B	$\sim$ 5.3				$\sim$ 7.5				$\sim$ 9.6			

- All cross-section, but σ_{tot} in fb.
- ϵ stands for detector acceptance efficiency
- Signal cross-section & BR assumed to be independent from value of ξ; SM cross-section & BR are assumed.
- Only $q\bar{q} \to ZZ$ contribution for ZZ cross-section taken in account; Contribution of $gg \to ZZ$ ($\sim$20% of $\sigma_{q\bar{q}\to ZZ}$) not included.
- All background types, but ZZ negligible after selection for $m_\Phi > 2m_Z$ $\Longrightarrow$ not taken in account in further analysis.

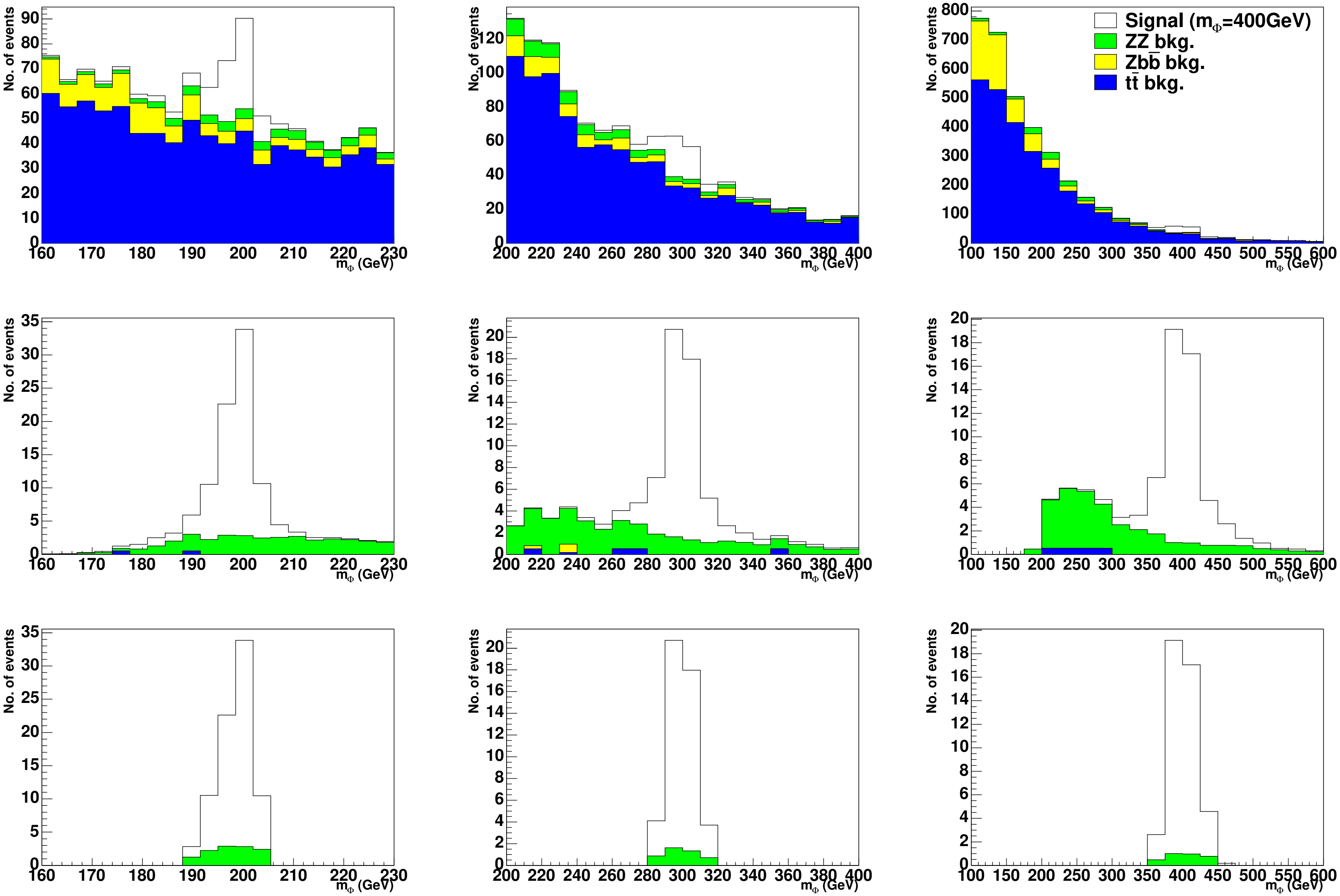
Selection: mass of 4 leptons

$m_\Phi = 200$ GeV | $m_\Phi = 300$ GeV | $m_\Phi = 400$ GeV

rec. $2\mu 2e$

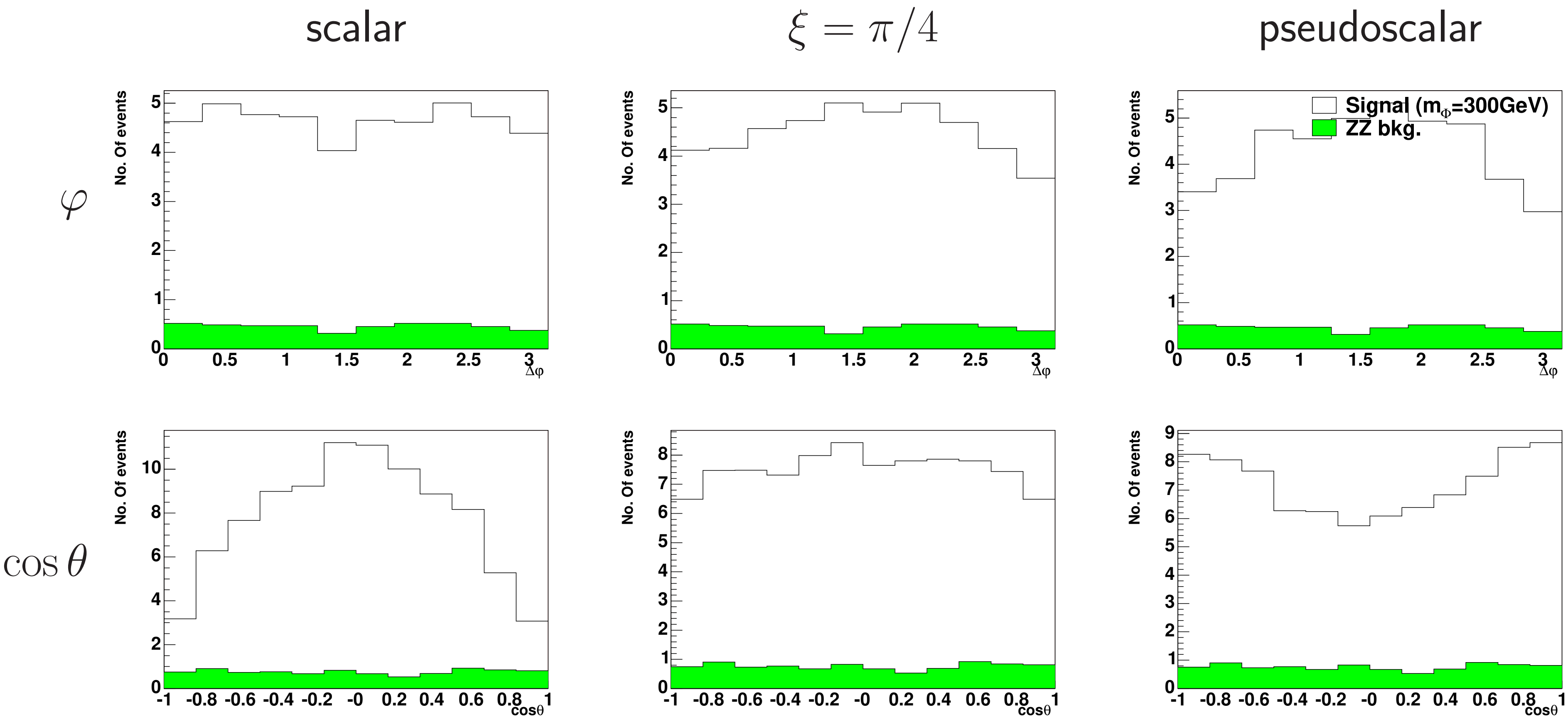
Z mass cut

Φ mass cut



- Plots normalized to 20/fb (1 year of LHC at low lumi)

Reconstructed angle distributions

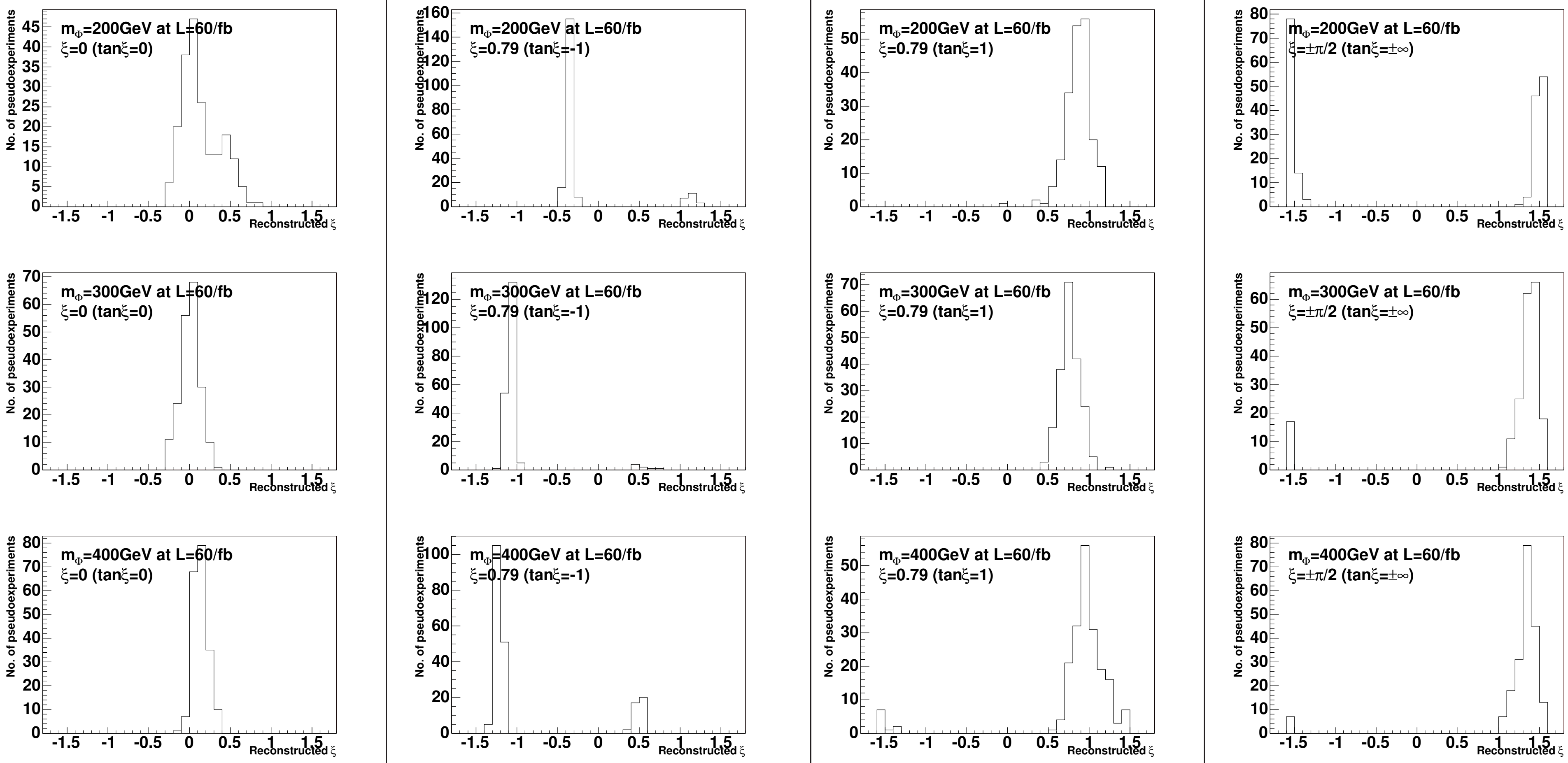


- Reconstructed angle distributions for m_Φ=300 GeV
- Plots normalized to 20/fb (1 year of LHC at low lumi)
- Histograms for $\cos\theta$ contain sum of distributions for both θ_1 and θ_2
- Angle distributions not very smooth $\Longrightarrow$ bigger MC samples needed

Results: reconstructed ξ

Distribution of reconstructed parameter ξ for 200 pseudoexperiments
(Results for $\mathcal{L}$=60/fb – 3 years of LHC at low lumi.)

$\xi=0$ (scalar)	$\xi=-\pi/4\ (tan\xi=-1)$	$\xi=\pi/4\ (tan\xi=1)$	$\xi=\pi/2$ (pseudoscalar)



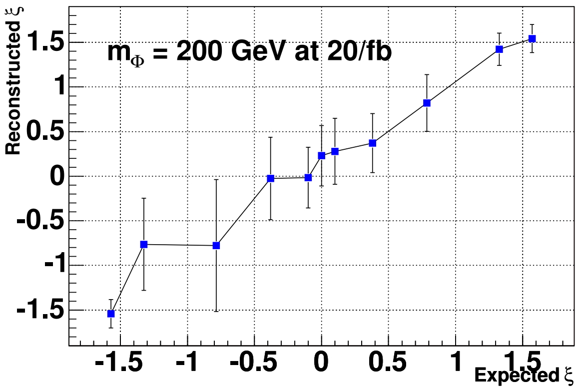
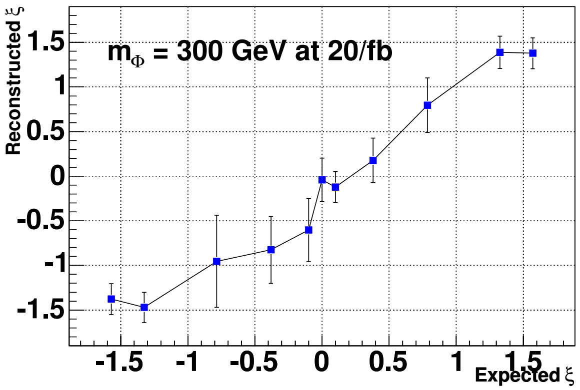
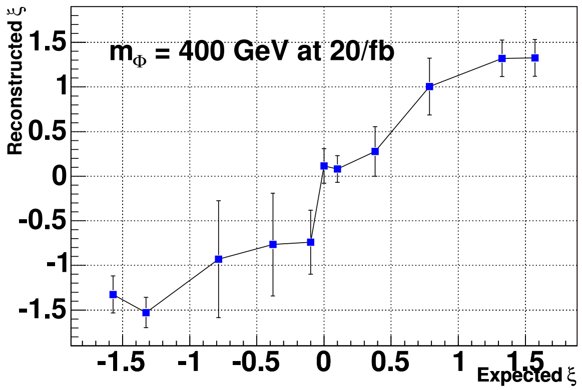
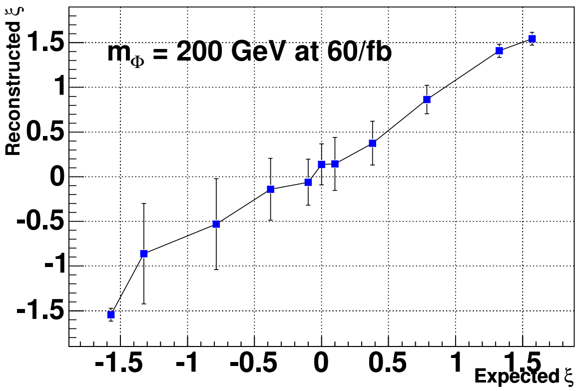
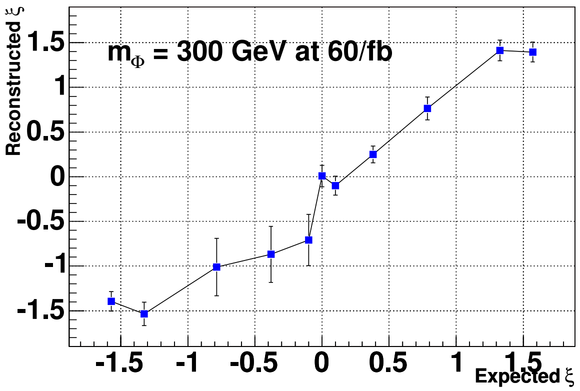
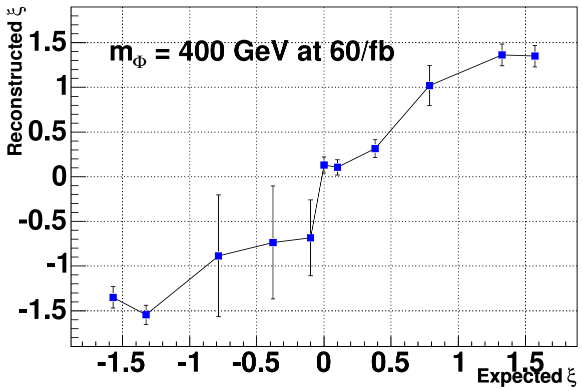
m_Φ=200 GeV

m_Φ=300 GeV

m_Φ=400 GeV

Results: $\xi_{\rm rec}$ in function $\xi_{\rm true}$

- Mean and standard deviation of distribution of parameter ξ are taken as an estimator of ξ and $\Delta\xi$ respectively.
- Results for negative values of ξ with limited statistic.
- Results for integrated luminosities $\mathcal{L}$=20, 60/fb.

	m_Φ=200 GeV	m_Φ=300 GeV	m_Φ=400 GeV
20/fb			
60/fb			

Summary

- Measurement of CP-violation in $\Phi \rightarrow ZZ \rightarrow 2e2\mu$ with the CMS is feasible
  - Sensitivity for distinguishing between CP-conserving and CP-violating cases is ~ 0.25 for 20/fb and ~ 0.15 for 60/fb.
- Quite good accuracy and precision of determination of ξ parameter:
  - Distinguishing between scalar and pseudoscalar with $S \equiv \frac{|\xi_A^{rec} - \xi_H^{rec}|}{\sqrt{(\Delta\xi_A)^2 + (\Delta\xi_H)^2}}$ bigger than ~ 3.5 for 20/fb and ~ 5.8 for 60/fb.
  - Precision of measurement of ξ in order of 0.3 for 20/fb and 0.2 for 60/fb.
- To improve results smoother angle distributions for reference probabilities $\mathcal{P}$ are needed
  $\Longrightarrow$ bigger MC samples for scalar, pseudoscalar and $\xi = \pi/4$.
- All $\Phi \rightarrow ZZ \rightarrow 4\ell$ channels should be used.

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