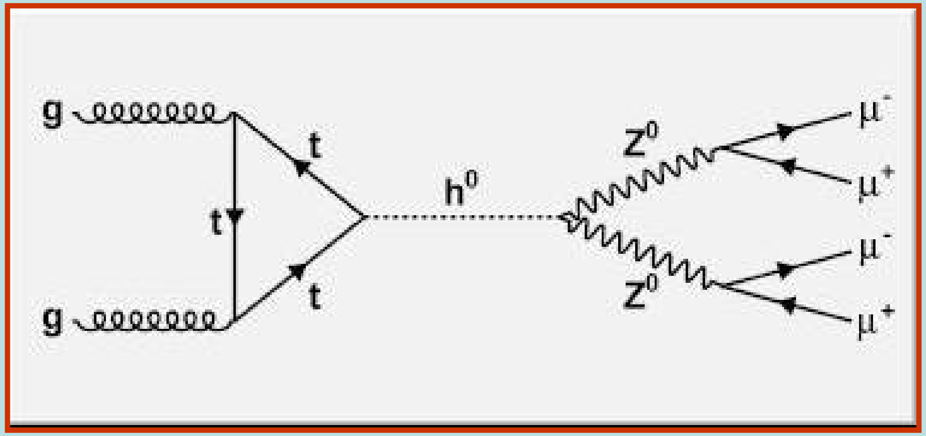
Study of angular variables for rejection of irreducible ZZ EW Background

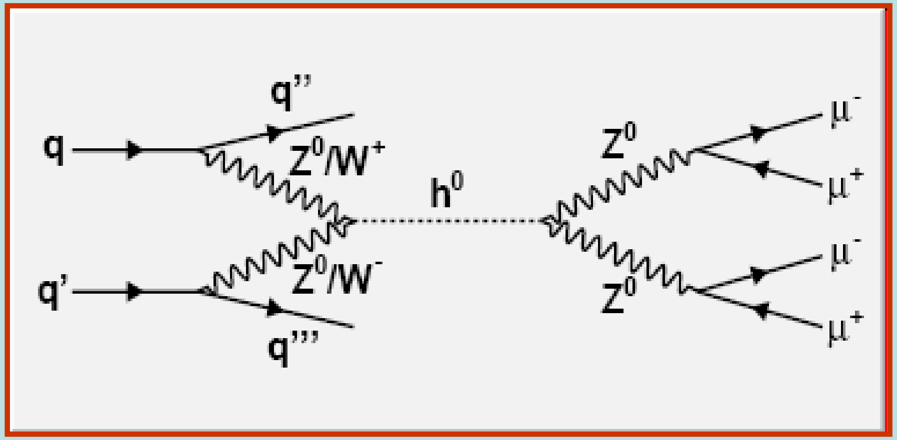
Marco Musich

Signal H $\rightarrow$ ZZ$\rightarrow$4 μ

$gg \rightarrow h \rightarrow ZZ \rightarrow 4mu$



$VV \rightarrow h \rightarrow ZZ \rightarrow 4mu$



σ = 0.43 fb (m_H = 175 GeV)

σ = 0.75 fb (m_H = 180 GeV)

σ = 1.82 fb (m_H = 185 GeV)

σ = 2.64 fb (m_H = 190 GeV)

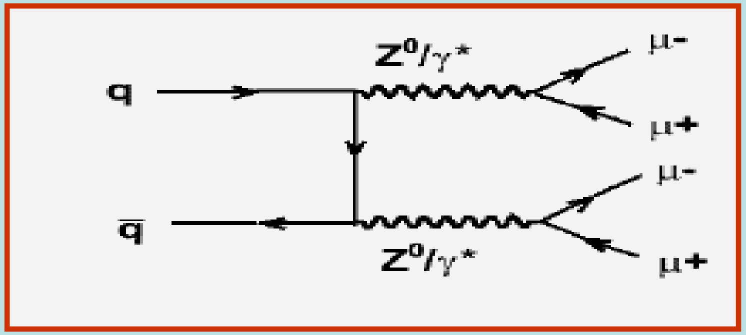
The considered cross-sections come from *Pythia* output and take in account the CKIN cuts in the range of allowed mass values of primary resonances

Main Backgrounds

- ZZ($\gamma\gamma^*$) $\rightarrow$ 4mu

  $\sigma = 17.8 \, fb$

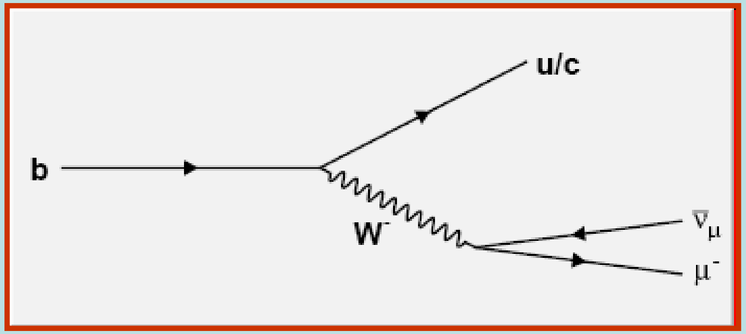
This will be our irreducible background



- Zbb $\rightarrow$ 4mu

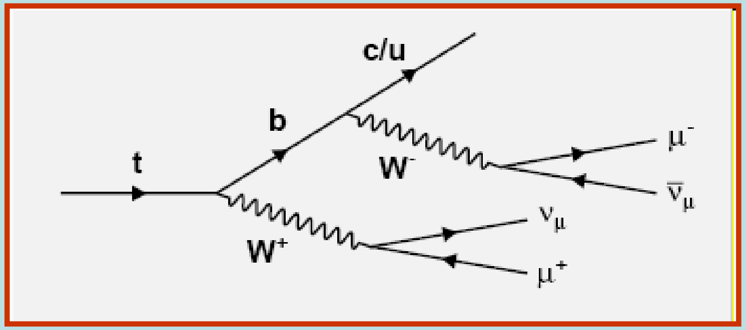
  $\sigma = 2.6 \cdot 10^4 \, fb$

Leading Order Feynman Diagrams



- tt $\rightarrow$ 4mu

  $\sigma = 5.69 \cdot 10^3 \, fb$



Event Generation with Pythia

Event data from MC are skimmed through a Filter Module.
To be accepted the event must have in the final state:
at least 4 mu, 2 positive and 2 negative, with Pt > 3 GeV, $|\eta| < 2.5$.
After the filter the number $N = N_{gen} \cdot \varepsilon_{filt}$ of events for each sample is:

Signal processes

- $gg \rightarrow h \rightarrow ZZ \rightarrow 4mu$
- $VV \rightarrow h \rightarrow ZZ \rightarrow 4mu$

$N_{gen} = 1.0 \cdot 10^5$ $N = 0.61 \cdot 10^5$

Background processes

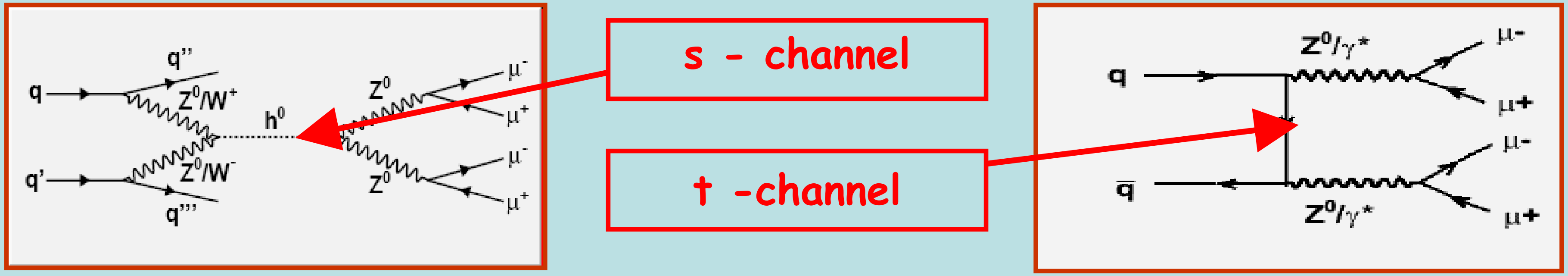
- $ZZ \rightarrow 4mu$ — $N_{gen} = 1.0 \cdot 10^5$ $N = 0.41 \cdot 10^5$
- $Zbb \rightarrow 4mu$ — $N_{gen} = 2.0 \cdot 10^5$ $N = 650$
- $tt \rightarrow 4mu$ — $N_{gen} = 5.0 \cdot 10^5$ $N = 10^4$

The number of event has been re-weighted in order to get the same integrated luminosity for all considered samples

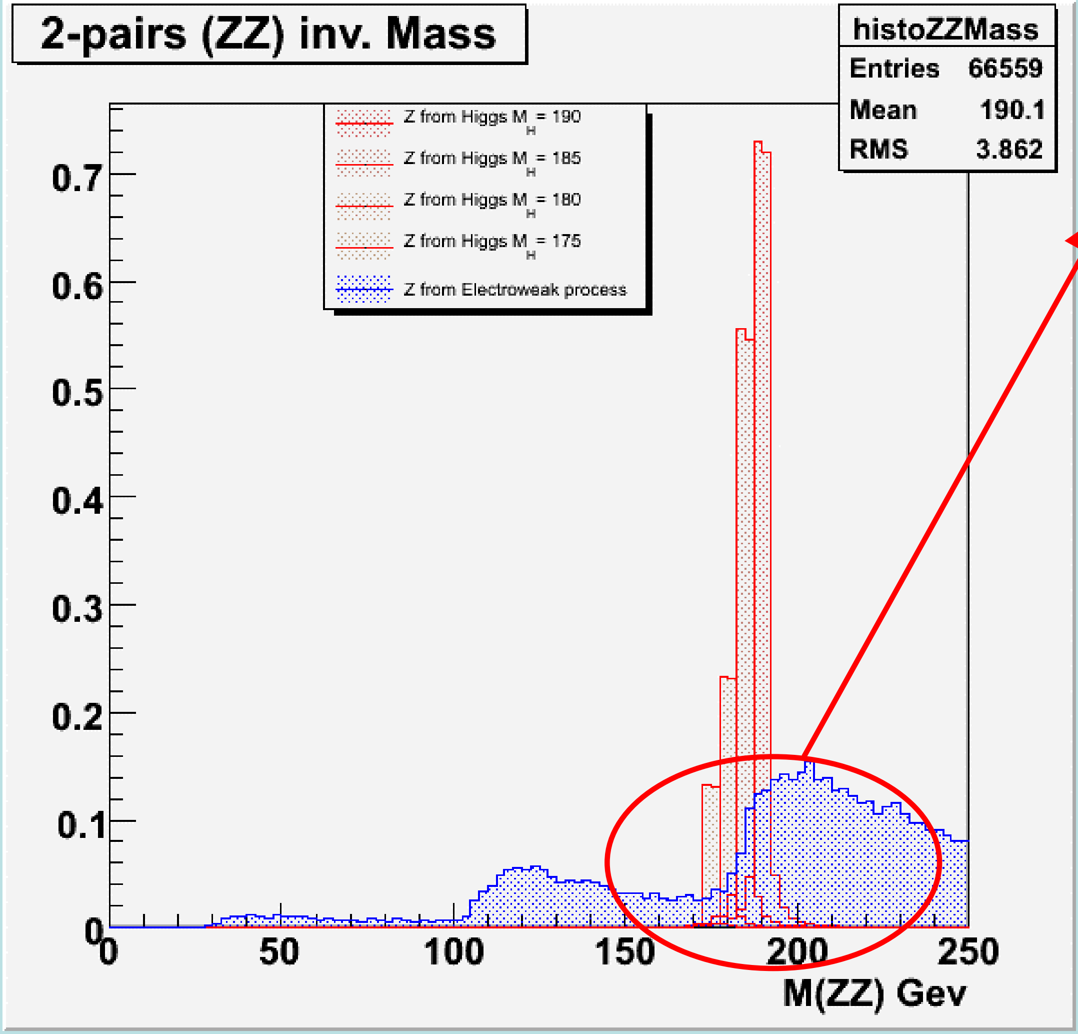
Irreducible Background

Since Zbb and tt channels could be rejected trough adequate invariant mass cuts, from here onwards we'll focus on the irreducible background (i.e. ZZ EW).

ZZ Electroweak process evolves in a t-channel, while Higgs decay is in an s-channel, therefore we expect that an angular variable would help rejecting this background.



Invariant mass distributions



Electroweak ZZ Background peaks in the region around 200 GeV

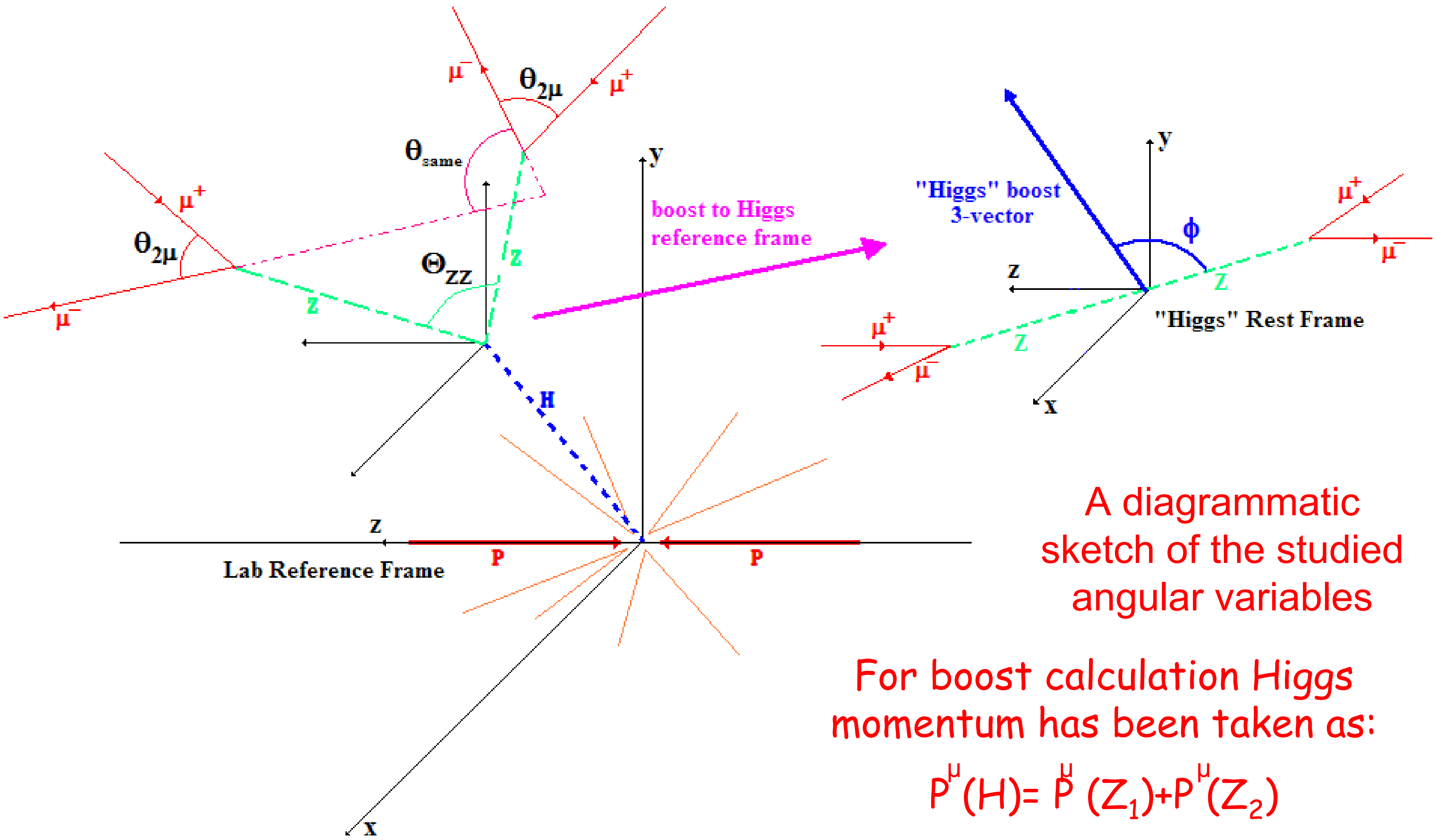
If $M_{higgs} > 190$ GeV signal is large enough to let M(ZZ) discriminate signal from background

It could be convenient to study an angular variable alternative to M(ZZ) for $M_{higgs} < 190$ GeV

Plots in the following for M(H)=190 GeV

It could be interesting a study for M(H)=180 GeV

Angular Variables I



A diagrammatic sketch of the studied angular variables

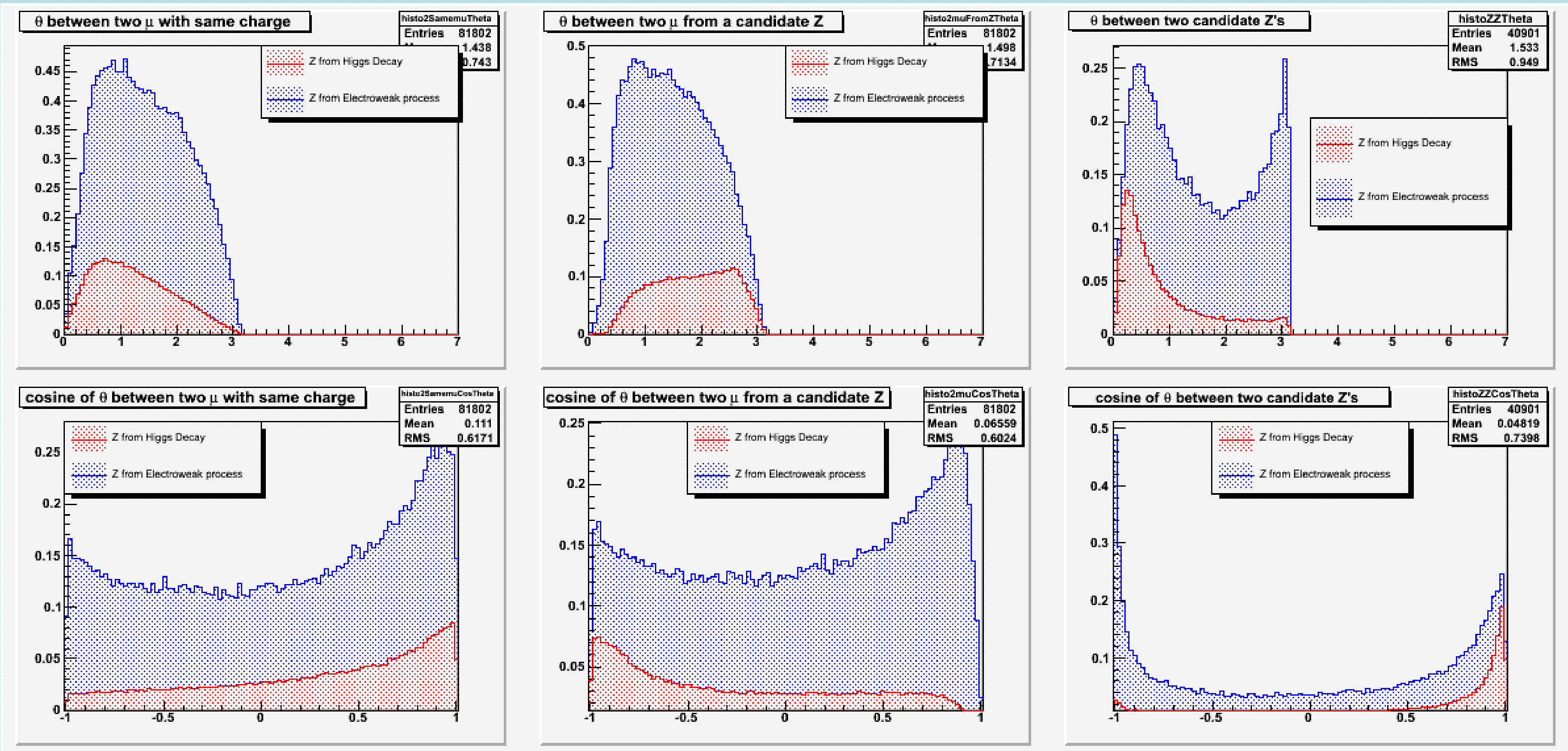
For boost calculation Higgs momentum has been taken as:

$$P^{\mu}(H) = P^{\mu}(Z_1) + P^{\mu}(Z_2)$$

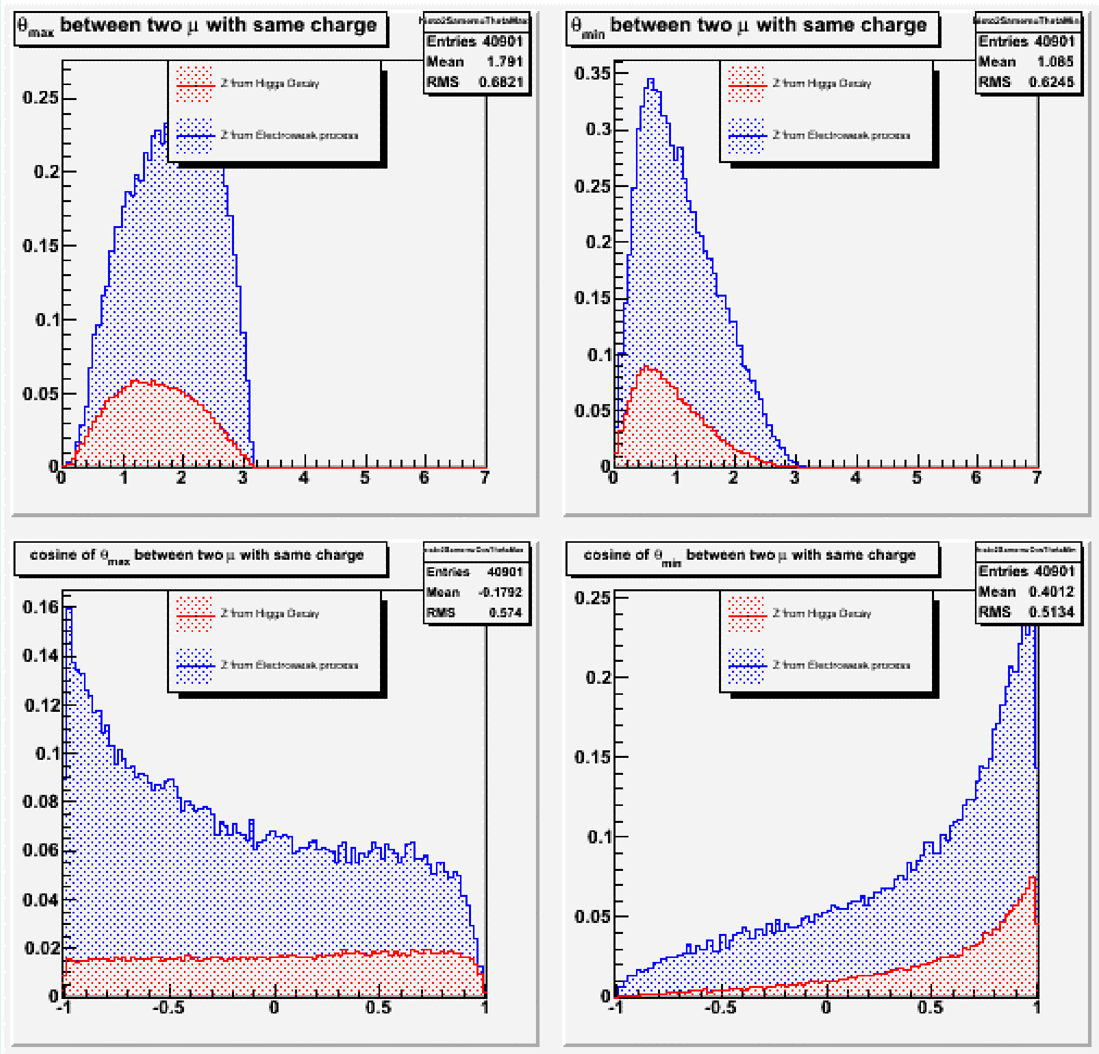
Angular Variables (Lab Frame)

Angular distributions for Higgs decay and ZZ Electroweak Background.

Z are reconstructed from μ, NO CUTS in invariant mass are required.



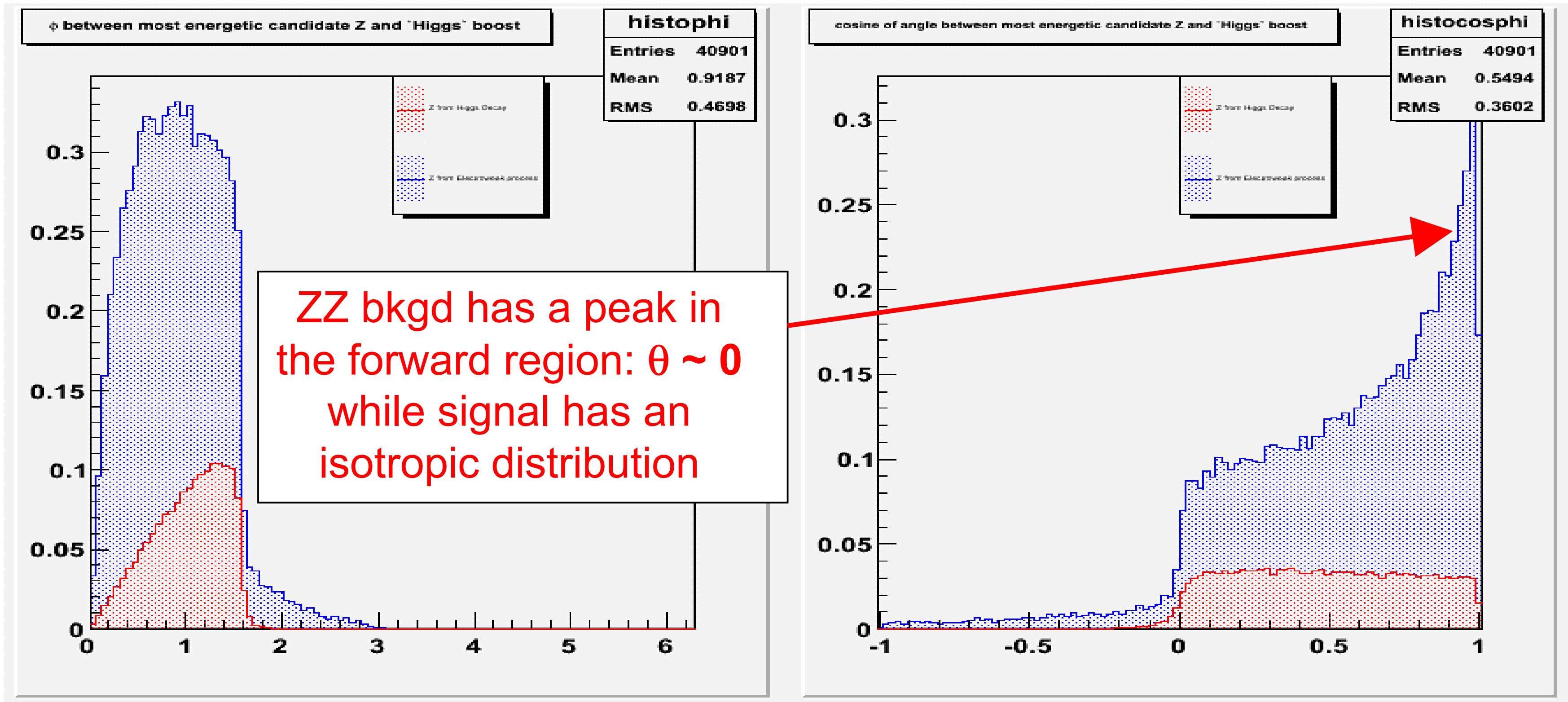
Angular Variables (Lab Frame)



Plot of angle between two muons with same charge. To have the same number of events of the previous plots we have alternatively selected the smaller and the bigger angle between muons' momenta.

After this splitting the distribution of the larger angle seems to discriminate better than that for the smaller angle

Angular Variable (Higgs Frame)



The plot refers to the angle between momentum of most energetic Z taken in the "Higgs" rest frame and the direction of the "Higgs" boost.

Higgs or "pseudo-Higgs" 4-momentum is calculated by summing Zs' 4-momenta.

Variables Definition

In order to make the analysis more quantitative we plot, for the four considered angular variables, some statistical observables. The variable on which we are cutting is the cosine of considered angles.

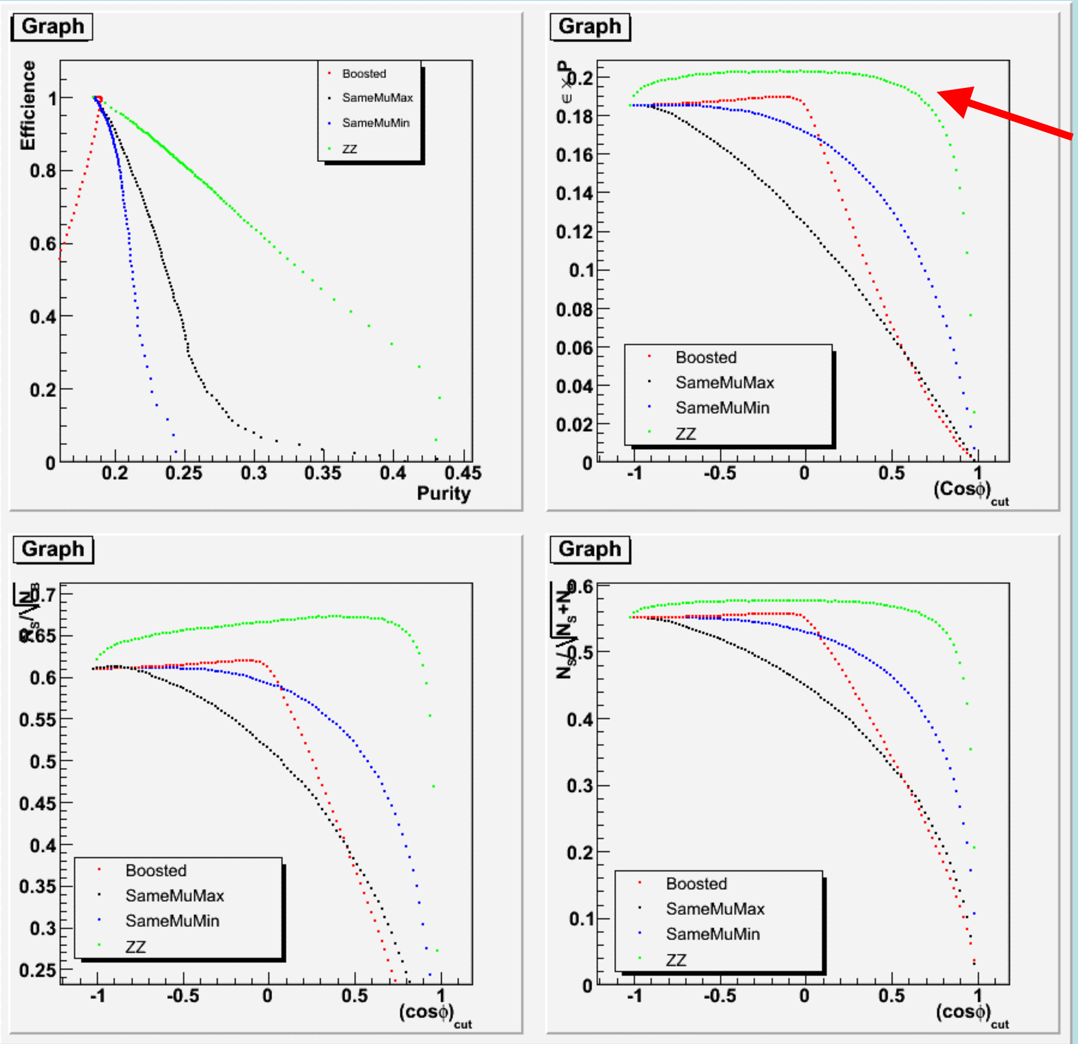
$$\varepsilon(\cos\phi_{cut}) = \frac{\int_{\cos\phi_{cut}}^{1} \frac{dS}{dx} dx}{\int_{-1}^{1} \frac{dS}{dx} dx}$$

$$p(\cos\phi_{cut}) = \frac{\int_{\cos\phi_{cut}}^{1} \frac{dS}{dx} dx}{\int_{\cos\phi_{cut}}^{1} \frac{dS}{dx} dx + \sum_k \int_{\cos\phi_{cut}}^{1} \frac{dB_k}{dx} dx}$$

$$\frac{N_S}{\sqrt{N_B}} = \frac{\int_{\cos\varphi_{cut}}^{1} \frac{dS}{dx} dx}{\sqrt{\sum_k \int_{\cos\varphi_{cut}}^{1} \frac{dB_k}{dx} dx}}$$

$$\frac{N_s}{\sqrt{N_s + N_b}} = \frac{\int_{\cos\varphi_{cut}}^{1} \frac{dS}{dx} dx}{\sqrt{\int_{\cos\varphi_{cut}}^{1} (\sum_k \frac{dB_k}{dx} + \frac{dS}{dx}) dx}}$$

Statistical Variables



- The variable which discriminates better is the one having the highest distribution curve for Efficiency times Purity vs the cut.
- Best cut position is determined by taking the one corresponding to global maximum of the curve.
- So, angle between 2 Z in the lab reference frame maximizes the product Efficiency times Purity in function of the cut.
- *The variable in the "Higgs" reference frame is the second best choice.*

First conclusions

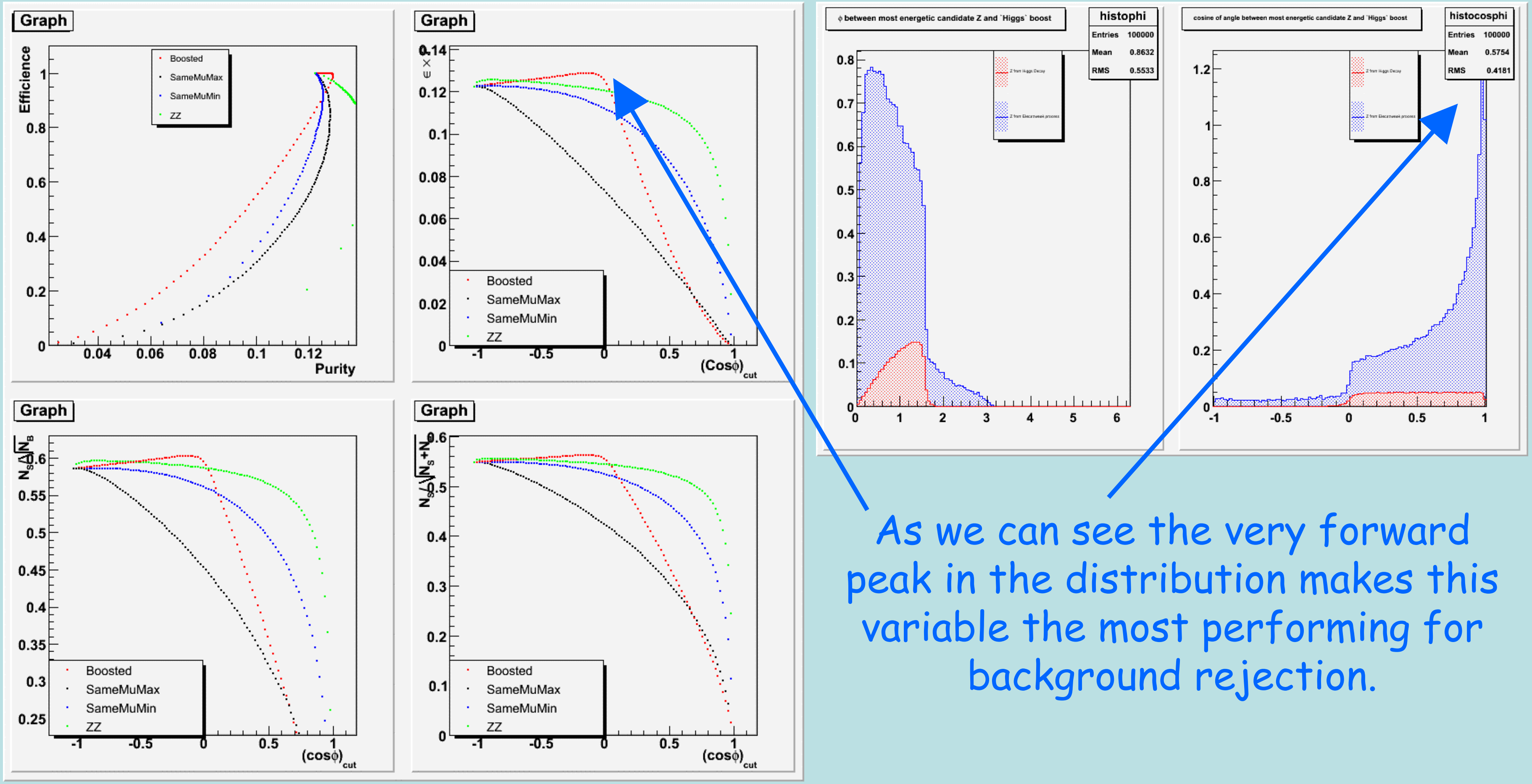
- We have studied variables alternative to invariant mass to reject irreducible ZZ electroweak background in the range of Higgs mass 170 GeV <M(H)<190 GeV.
- We considered four angular variables since we expected differences in angular distributions of the two processes' products.
- In principle one would have said the "boosted" variable should better discriminate between a t and an s-channel process, because of very forward events in ZZ EW distribution.
- Theta between two Z is the best choice and not the boosted variable.

WHY?

Filter in η skips events with very forward and backward muons.

Unfiltered Events

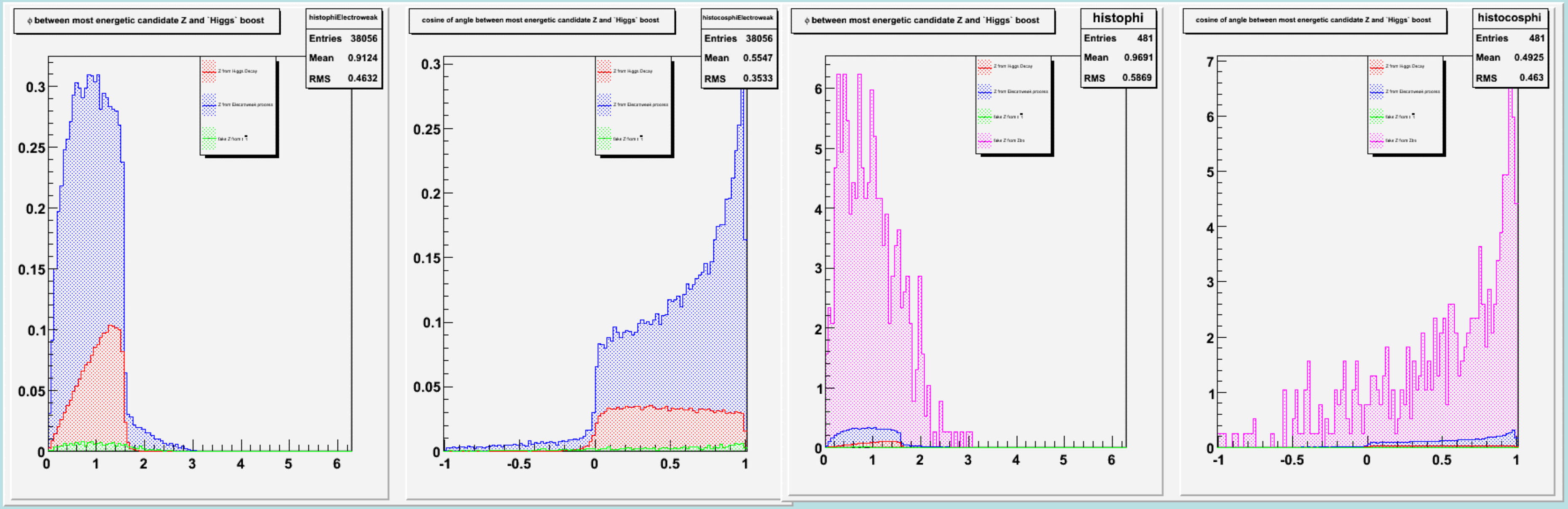
For comparison we show the distribution of the boosted "variable" and the plot of statistical variables for unfiltered events



As we can see the very forward peak in the distribution makes this variable the most performing for background rejection.

Reducible Backgrounds?

Requiring a cut on invariant mass of the best candidate Z from muons (min(|$M(\mu^+\mu^-)$|-M(Z))) one can control tt background which has a cross-section 10^3 times greater than signal, but not Zbb, which has a cross-section 10^4 times the Higgs' one :



With tt background **With Zbb background**

So, before taking in account an angular variable to reject Zbb background one should study a more refined kinematic cut to reject the bulk of those events