Vinca Institute of Nuclear Sciences Belgrade

Branching ratio measurement of the SM-like Higgs decay into $\mu^+\mu^-$ at 1.4 TeV CLIC

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Overview

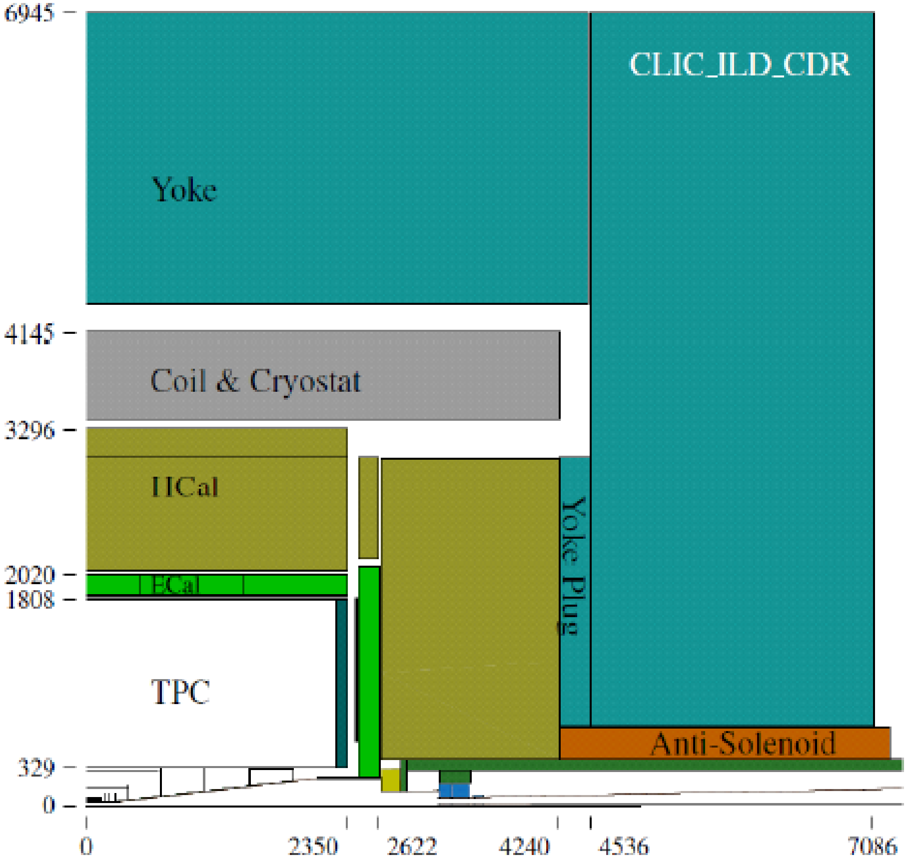
- Motivation for the measurement
- ILD detector for CLIC
- Signal and background processes
- Event selection
- Method of the measurement
- Impact of forward electron tagging
- Conclusions

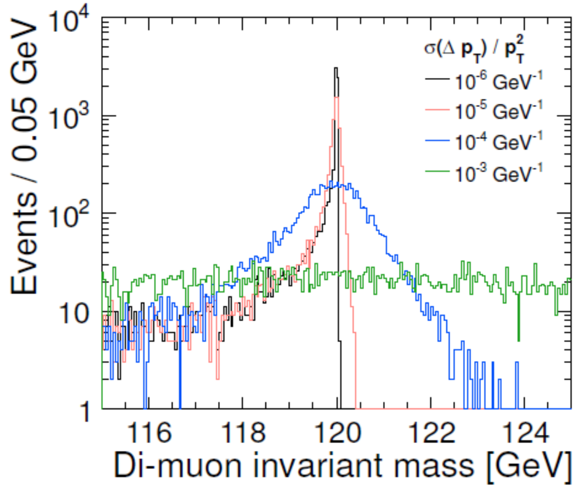
Motivation for the measurement

- Higgs BRs measurements are potential probe for the New Physics (i.e. couplings to the second generation fermions)

- Challenging measurement due to low signal yield (predicted BR($h \to \mu^+ \mu^-$) = $2.14 \cdot 10^{-4}$) :
  - ➡ Background has to be efficiently suppressed
  - ➡ Requires excellent momentum resolution in the barrel $\left(\frac{\Delta p_T}{p_T^2} \leq 2 \cdot 10^{-5} GeV^{-1} \right)$, also in the forward region $\left(\frac{\Delta p_T}{p_T^2} \sim 10^{-4} GeV^{-1} \right)$

ILD detector for CLIC





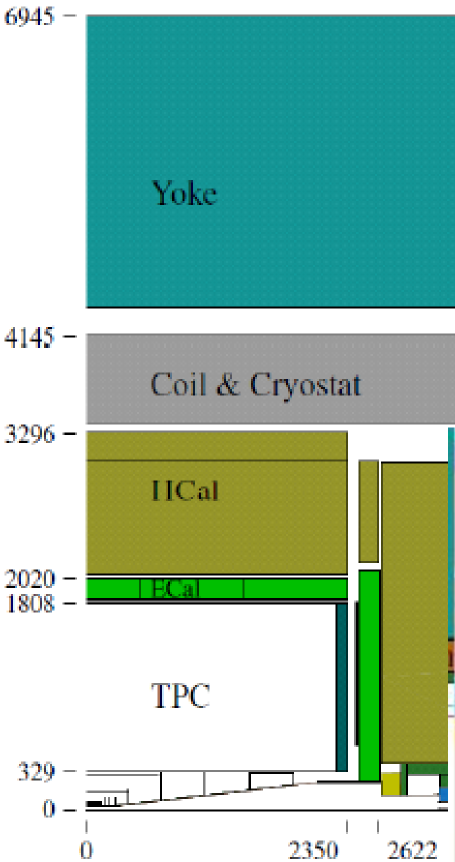
C.Grefe, LCD-Note-2011-035

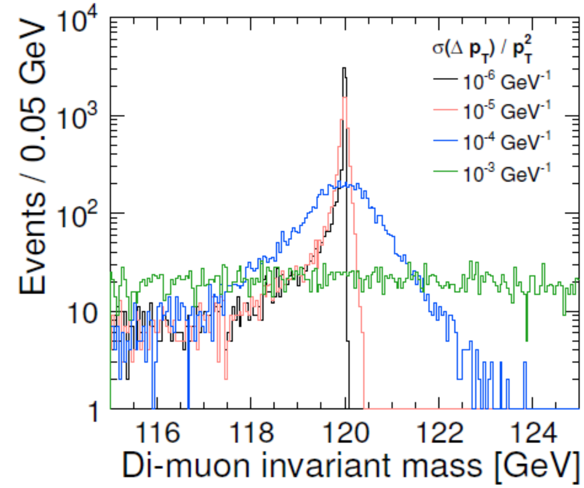
-Challenging p_T muon reconstruction down to the lowest angles ⇒ translates into m(μμ) mass width

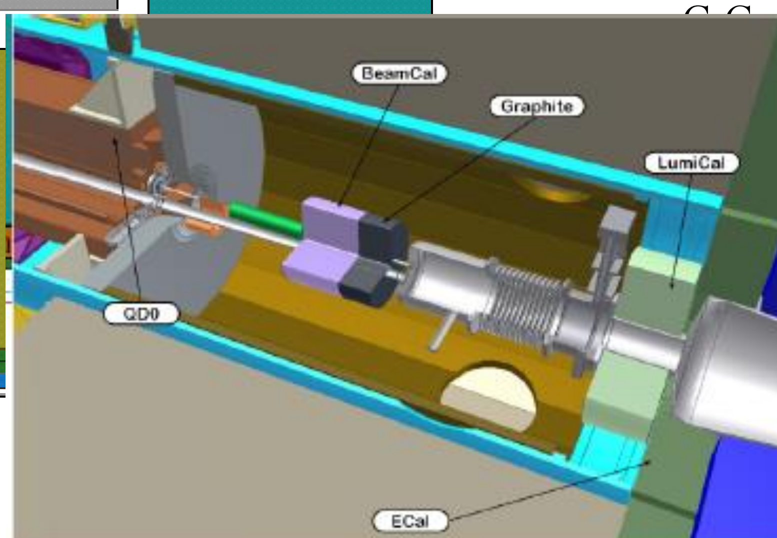
-Iron yoke instrumented with 9 active layers for μ identification

-Momentum resolution has $\frac{1}{p_T}$ dependence due to multiple scattering

ILD detector for CLIC







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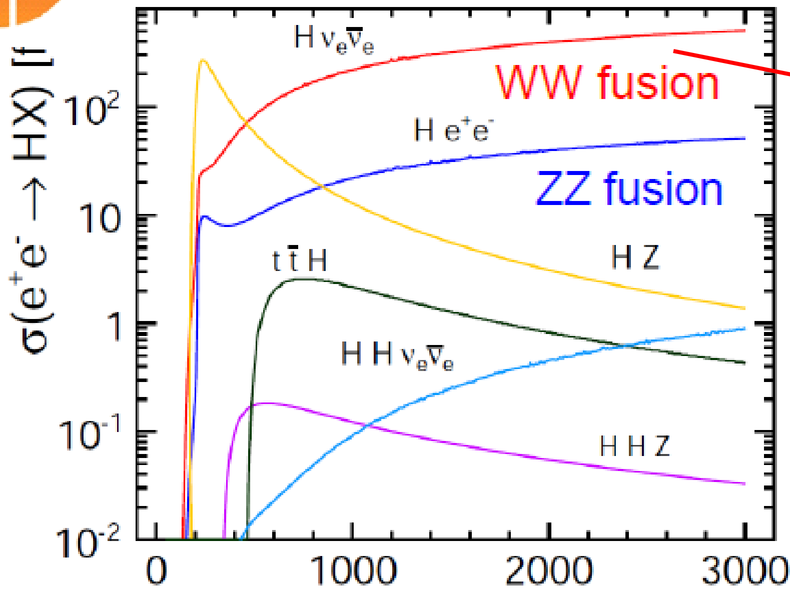
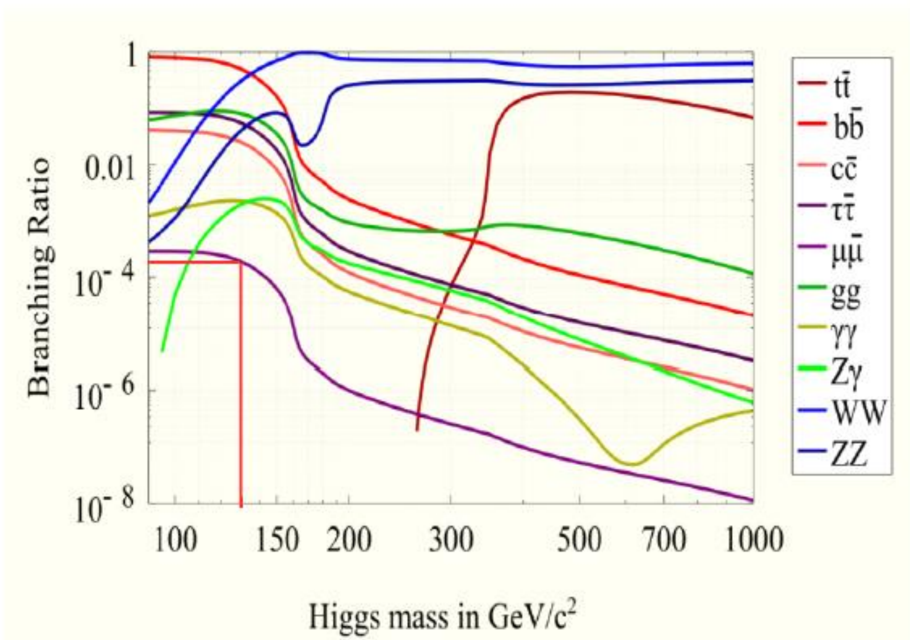
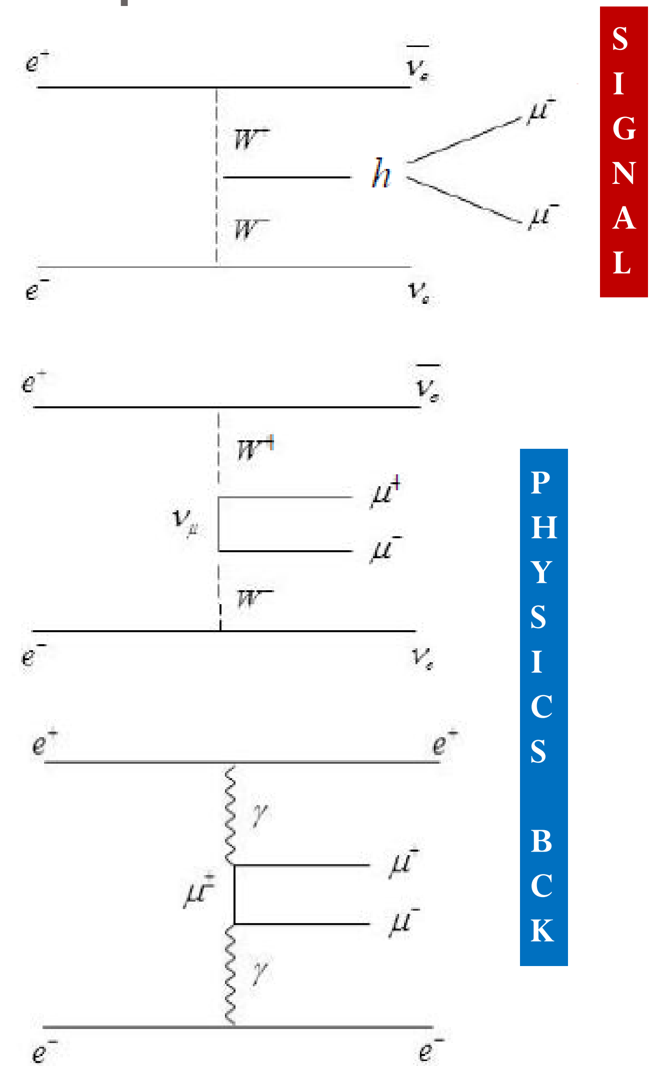
Signal and background processes







$$e\gamma_{BS} \rightarrow e\mu^- \mu^+$$

$$\gamma_{BS}\gamma_{BS} \rightarrow \nu_\mu \overline{\nu_\mu} \mu^- \mu^+$$

$$\gamma_{BS}\gamma_{BS} \rightarrow hadrons$$

Signal and background processes

Process	$\sigma[fb]$	N_{events}
$e^+e^- \to h\nu_e\overline{\nu_e}, h \to \mu^+\mu^-$	0.0522	24000
$e^+e^- \to \mu^+\mu^-\nu_e\overline{\nu_e}$	129	236000
$e^+e^- \to e^+e^-\mu^+\mu^-$	431^A	1000000
$e^\pm\gamma_{BS} \to e^\pm\mu^+\mu^-$	960(x2)^A	2000000
$\gamma_{BS}\gamma_{BS} \to \nu_\mu\overline{\nu_\mu}\mu^+\mu^-$	110.72	350000

^{A}*Including a cut of 100GeV <M($\mu^+\mu^-$)<140GeV and requiring a minimal polar angle for both muons of 8°.*

Event selection

- All samples are normalized to 1.5 ab^{-1} corresponding to 4 years operation with 50% data taking efficiency
- Event generation: WHIZARD 1.95 (+ISR), x-angle 20 mrad (Lorentz boost of the final state particles), Higgs decay: PYTHIA 6.4 (+FSR), Lumi spectrum: GuineaPig 1.4.4
- Pre-selection:

  - two reconstructed muons

  - (105-135) GeV di-muon mass window

  - electron tagging with the forward calorimeters
- Using TMVA to reduce backgrounds

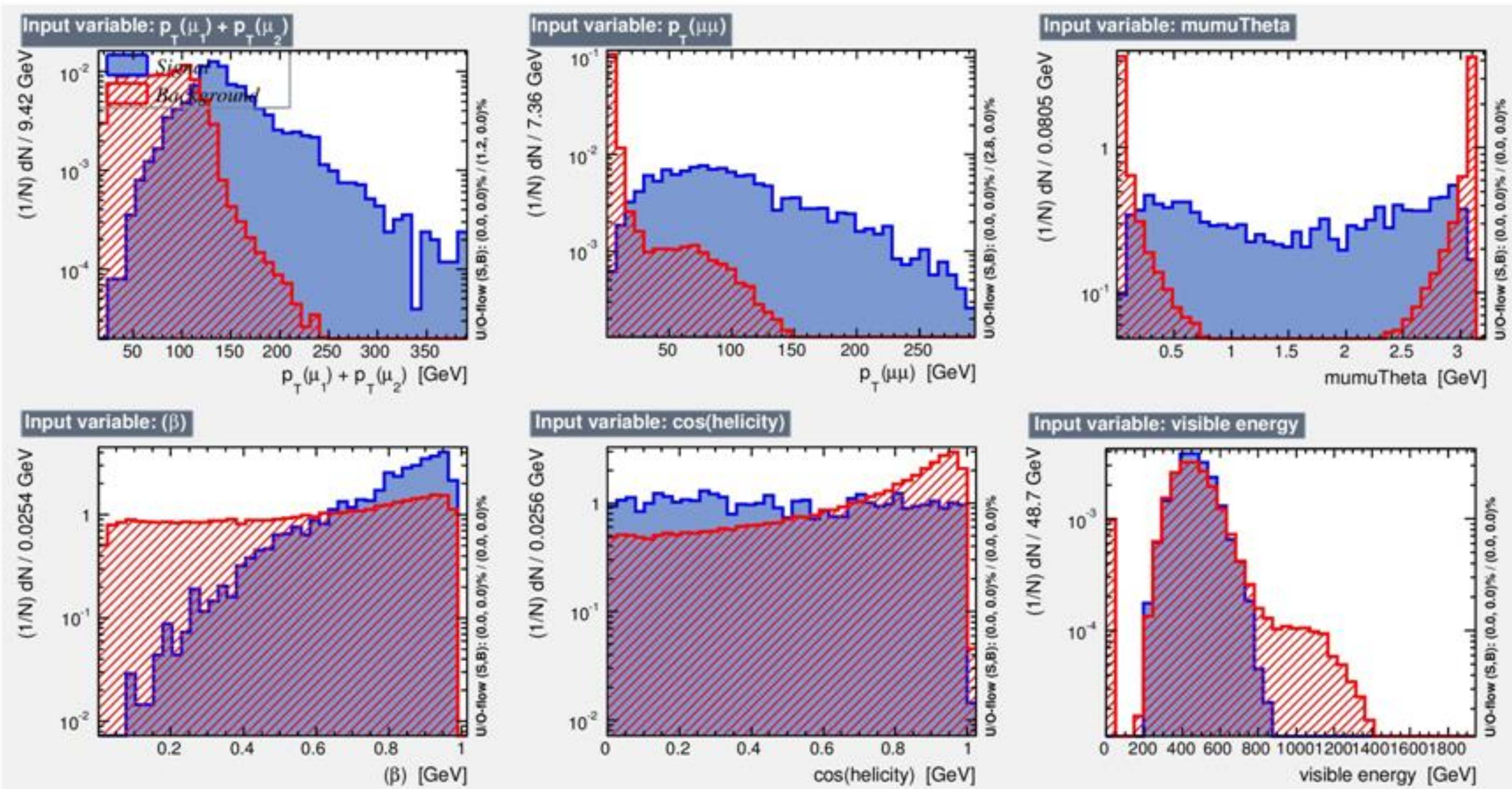
Background suppression with MVA

Signal

Background

$$e^+e^- \to e^+e^-\mu^+\mu^-$$

$$\gamma_{BS}\gamma_{BS} \to \nu_\mu \overline{\nu_\mu} \mu^+\mu^-$$

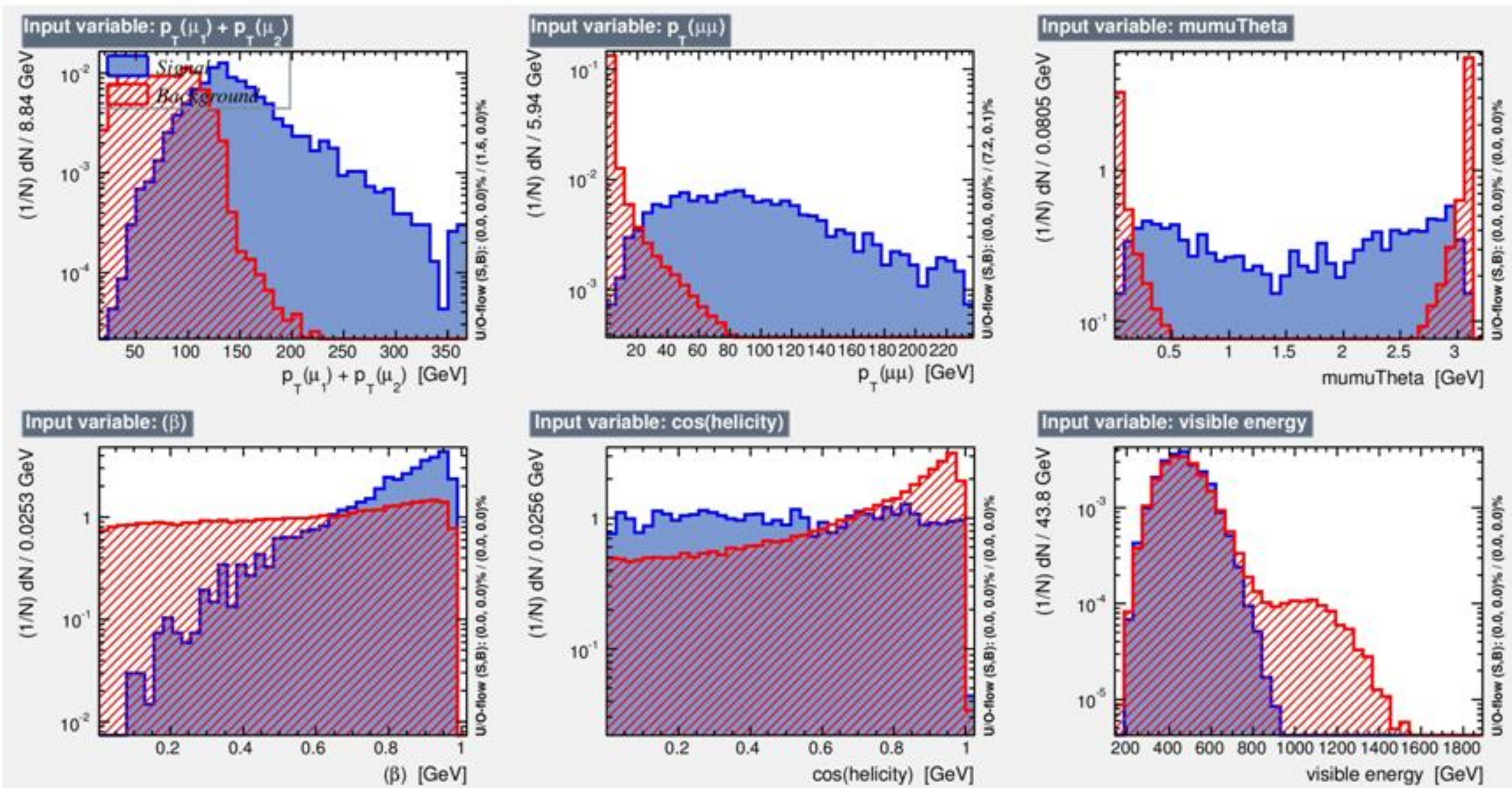


Background suppression with MVA

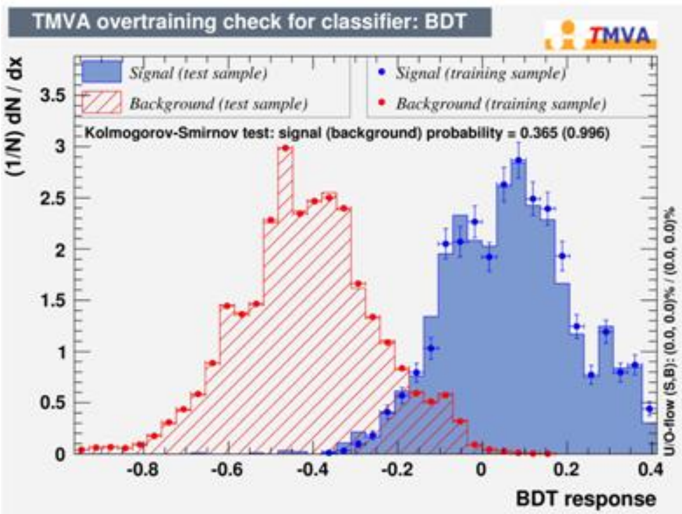
Signal

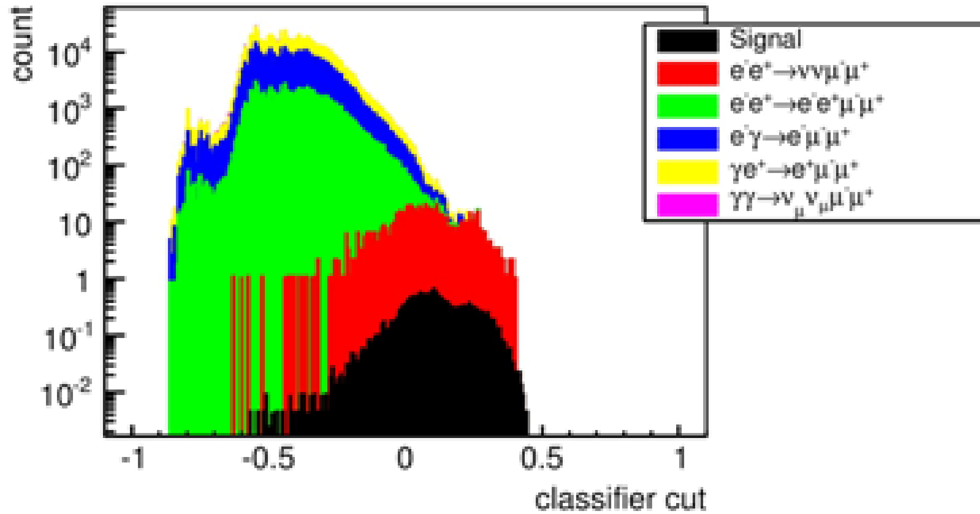
Background

$$e^{\pm}\gamma_{BS} \rightarrow e^{\pm}\mu^{+}\mu^{-}$$



Background suppression with MVA



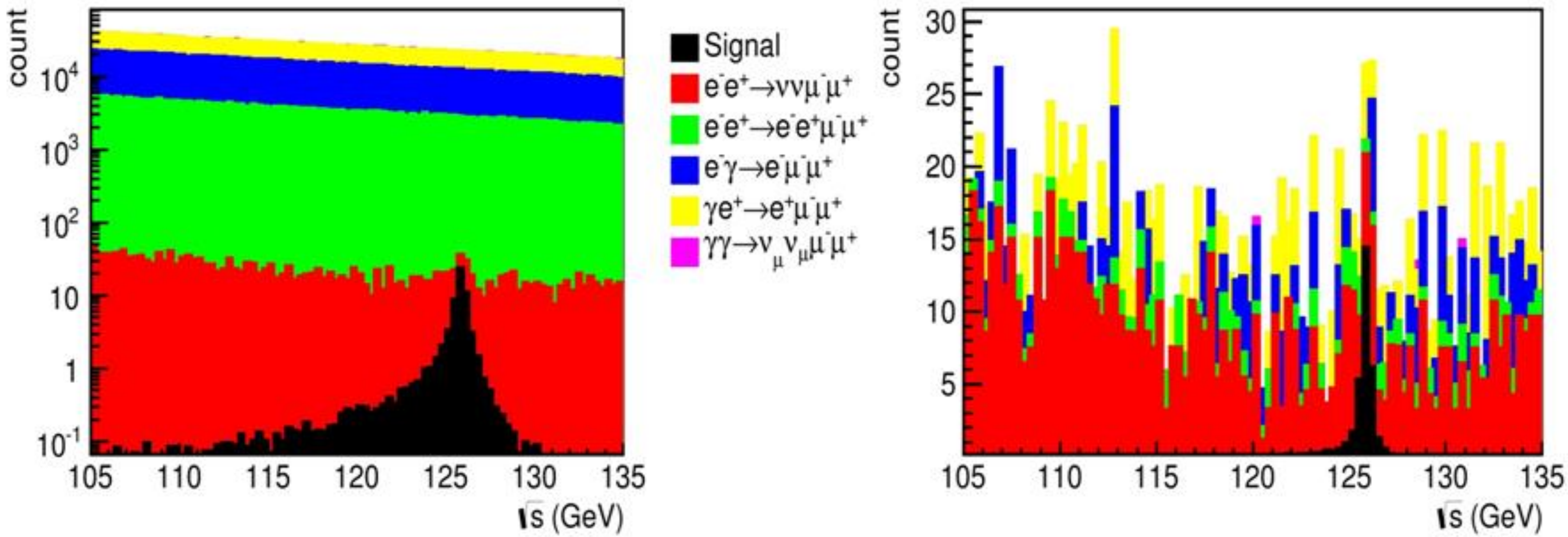


BDT cut > 0.098

BDT cut corresponds to the minimal relative statistical error $(\sigma_{BR} / BR) \Leftrightarrow$ maximization of significance or purity·efficiency

Impact of e-tagging is also in loosening BDT cut-off value (w.r.t. 0.12) that will result in enlarged signal efficiency

Background suppression with MVA

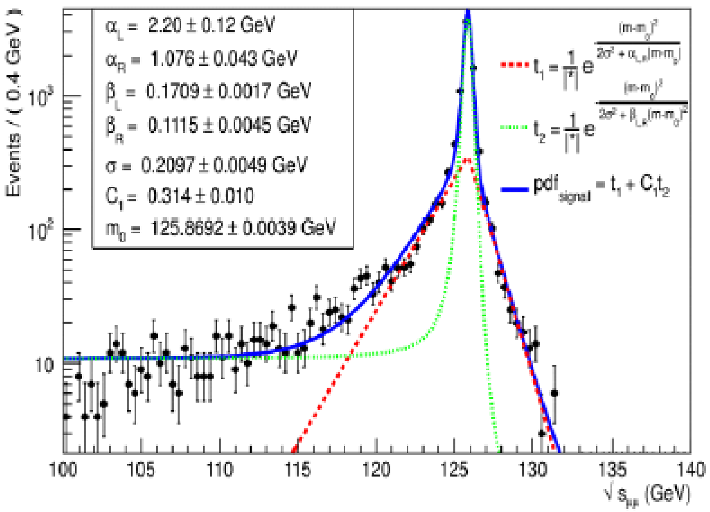


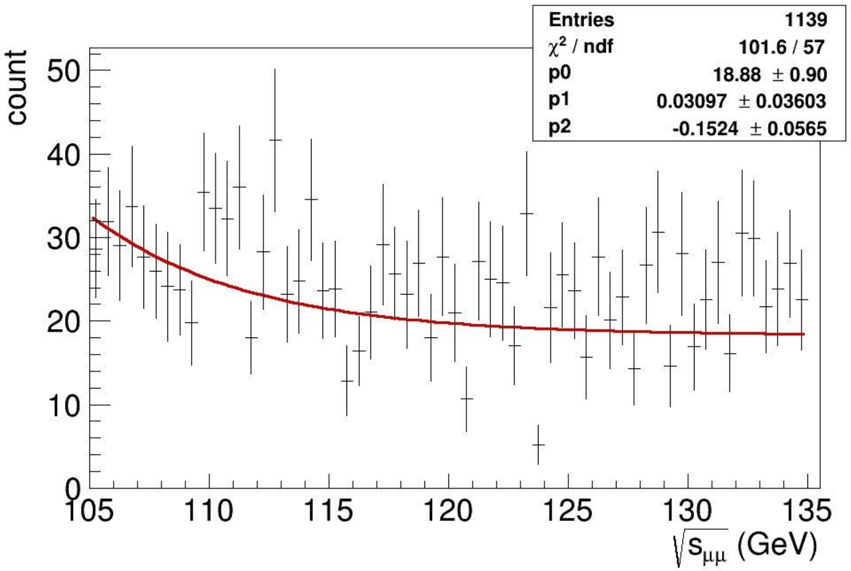
Reduction of the dominant $e^+e^- \to e^+e^-\mu^+\mu^-$ background by factor 1000.

Method of the measurement

Signal and background PDFs

Fully simulated, as large as possible, samples of signal and background to extract PDF s





$$f_S = t_1 + C \cdot t_2$$

$$f_{BCK} = p_0 (p_1 e^{p_2 (x - m_H)} + (1 - p_1))$$

-Composite Gaussian (flat tail+exp.tail)

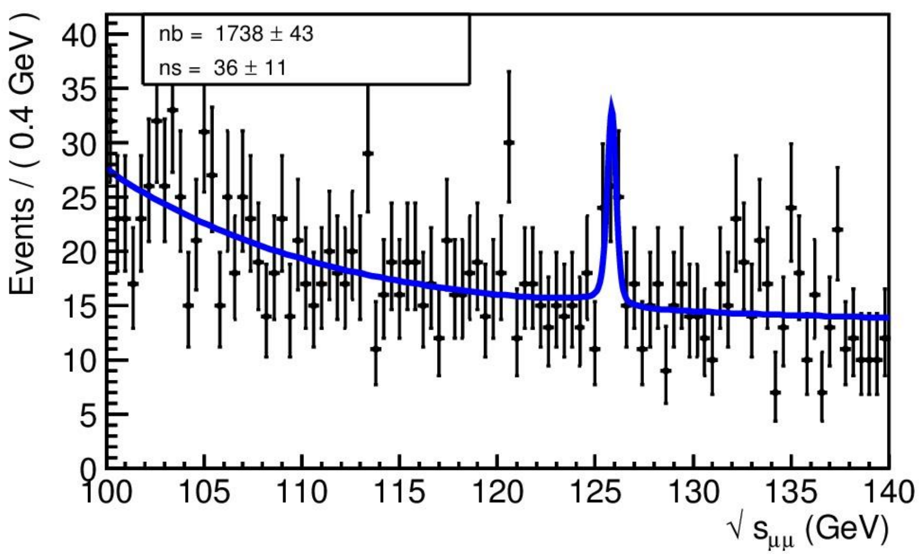
- All backrounds included

Method of the measurement

Toy MC experiments

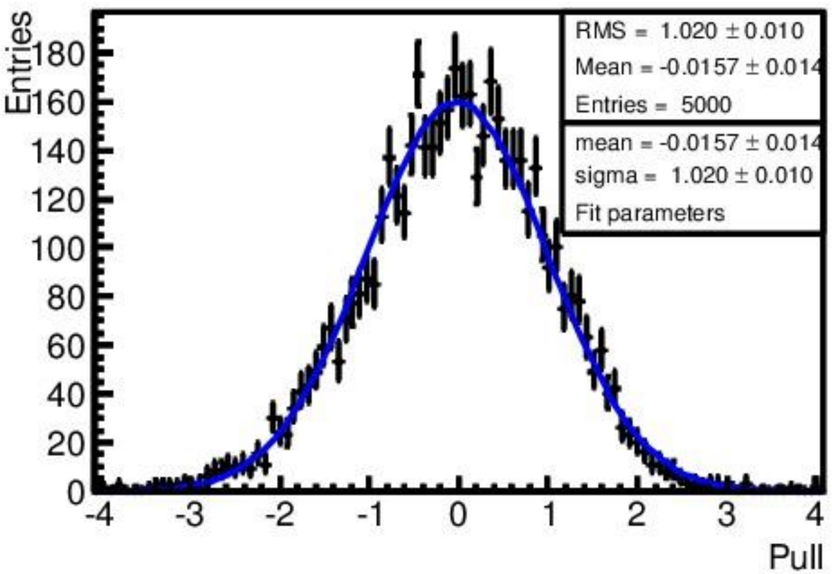
- Make pseudo experiments based on randomly sampled fully simulated signal events + backgrounds generated with PDFs
- Expected shape of data (signal + background) for each Toy MC is fitted with f to extract number of signal N_s

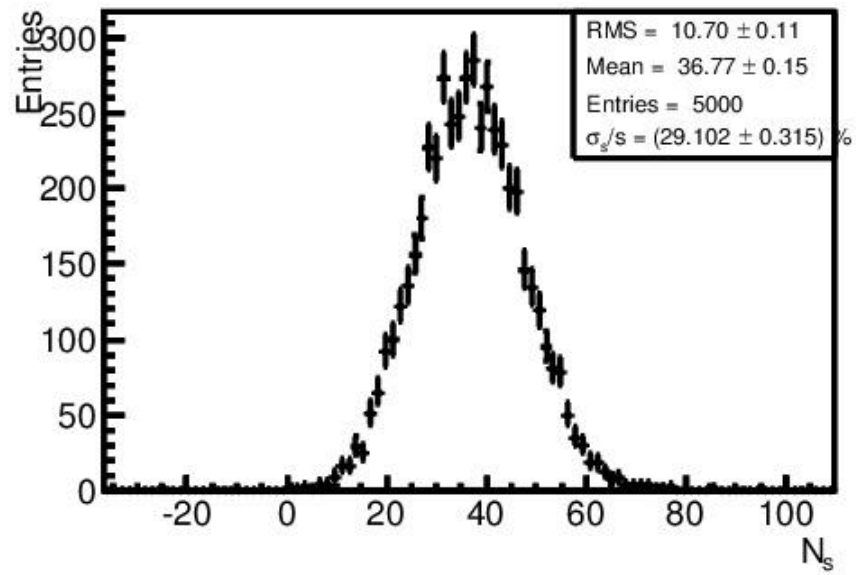
$$f = k \cdot f_S + (1-k) \cdot f_{BCK} \Rightarrow N_S = k \cdot \int f_S dm$$



Method of the measurement

- 5000 Toy MC experiments is performed to extract statistical uncertainty and check the pull distribution





- RMS from Ns distribution give us statistical uncertainty of the measurement
- Pull distribution confirms adequate description of signal and background with PDFs

Impact of forward electron tagging

- Forward region calorimetry plays important role to veto electron spectators from 4-f and γ_{BS} processes.
- At 3 TeV a random approach is employed assigning 99% (70%) predefined efficiency in LumiCal (BeamCal) to the two most energetic electrons.
- We introduce E dependent tagging (*see S.Lukic talk)* in LumiCal and BeamCal

- Take 5 mrad cone particles (e, gamma) to construct electron,

- Require 4σ deviation from the background (converted pairs) energy in the layer with the maximal deposition.

$$E_{dep} > \langle E_{bck} \rangle + 4\sigma_{bck}$$

Impact of forward electron tagging

- Event is rejected at the preselection level if electron is tagged in forward calorimeters.
- Background rejection rates by e-tagging:

Process	***Rejection rate***
$e^+e^- \to e^+e^-\mu^+\mu^-$	25%
$e^\pm\gamma_{BS} \to e^\pm\mu^+\mu^-$	15%
Signal	0.2%

Results

Signal events	**36±11** ***(25±10)****
Signal efficiency	**52.6%** *(36.5%) **
$\sigma_{h\nu\nu} \times BR_{h\to\mu\mu}$	**0.052 fb**
Statistical uncertainty	**29.1%** *(31.9%)**

**without e-tagging*

- Statistical uncertainty of the measurement at 1.4 TeV is **29.1%**. Improved efficiency due to the looser BDT cut with e-tagging (also signal μ are less forward w.r.t 3 TeV case)
- Impact of electron tagging reduce stat. uncertainty of the measurement for ≤ 3%.
- e-tagging impact is less than at 3 TeV (less 4-f bck in the very forward region w.r.t. 3 TeV case).

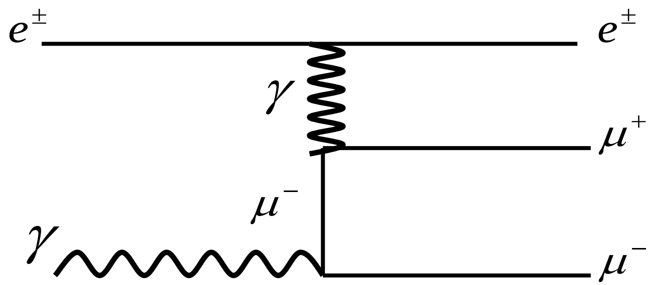
Conclusion

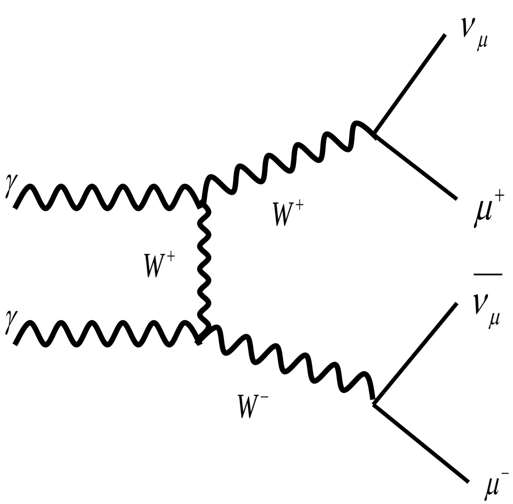
- $h \rightarrow \mu^+\mu^-$ analysis at 1.4 TeV completes Higgs BRs studies at CLIC energy stages.
- All relevant backgrounds are considered as well as a realistic electron tagging performance in the forward region.
- It has been shown that BR($h \rightarrow \mu^+\mu^-$) can be measured with a statistical accuracy of ~29% assuming 4 years of operation.
- Systematic uncertainties are estimated (at 3 TeV) to be negligible compared to the statistical uncertainty. However uncertainty of: luminosity, momentum resolution and muon reconstruction efficiency will be quantified at 1.4 TeV.

BACKUP

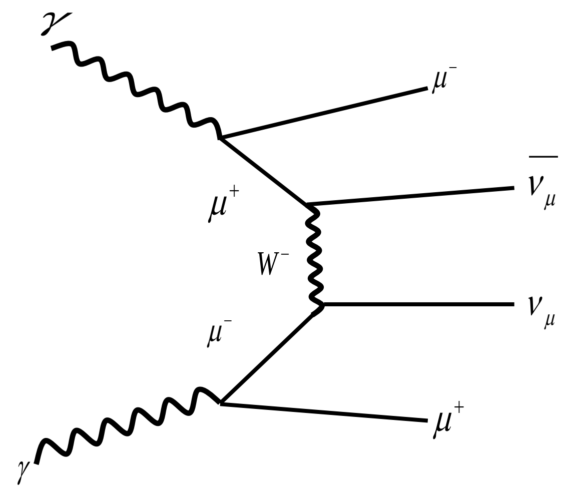
Feynman diagrams for $e^{\pm}\gamma \rightarrow e^{\pm}\mu^{+}\mu^{-}$ and $\gamma\gamma \rightarrow \nu_{\mu}\overline{\nu_{\mu}}\mu^{+}\mu^{-}$

$e^{\pm}\gamma \rightarrow e^{\pm}\mu^{+}\mu^{-}$





$\gamma\gamma \rightarrow \nu_{\mu}\overline{\nu_{\mu}}\mu^{+}\mu^{-}$



Less relevant background samples

$Process$	$\sigma[fb]$	N_{events}
$e^+e^- \to \nu_\tau \overline{\nu_\tau} \tau^+\tau^-$	84.5	133000
$e^+e^- \to e^+e^-\tau^+\tau^-$	1942.2	464500
$e^+e^- \to \mu^+\mu^-$	17	50000
$e^+e^- \to \tau^+\tau^-$	358	482500

Background suppression with MVA

Signal

Background

$$e^+e^- \rightarrow \nu_\mu \overline{\nu}_\mu \mu^+ \mu^-$$