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

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CLIC Workshop, February 3-7, 2014, CERN, Geneva

Overview

- Motivation for the measurement
- ILD detector for CLIC
- Electron tagging in the forward region
- Signal and background processes
- Event selection and MV analysis
- Method of the measurement
- Conclusions

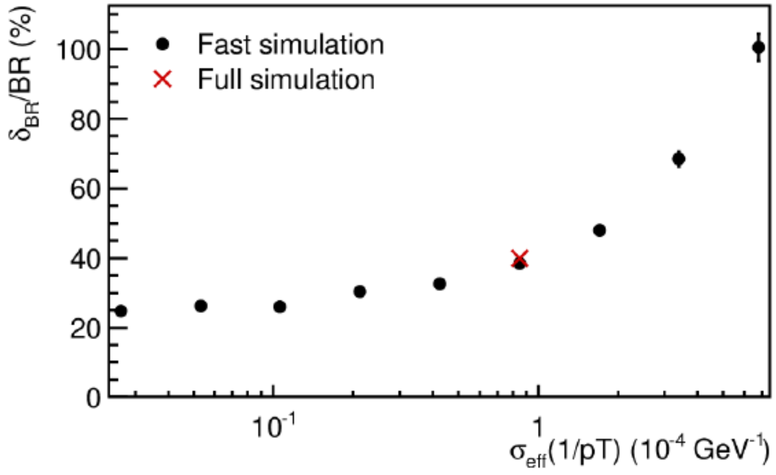
Motivation for the measurement

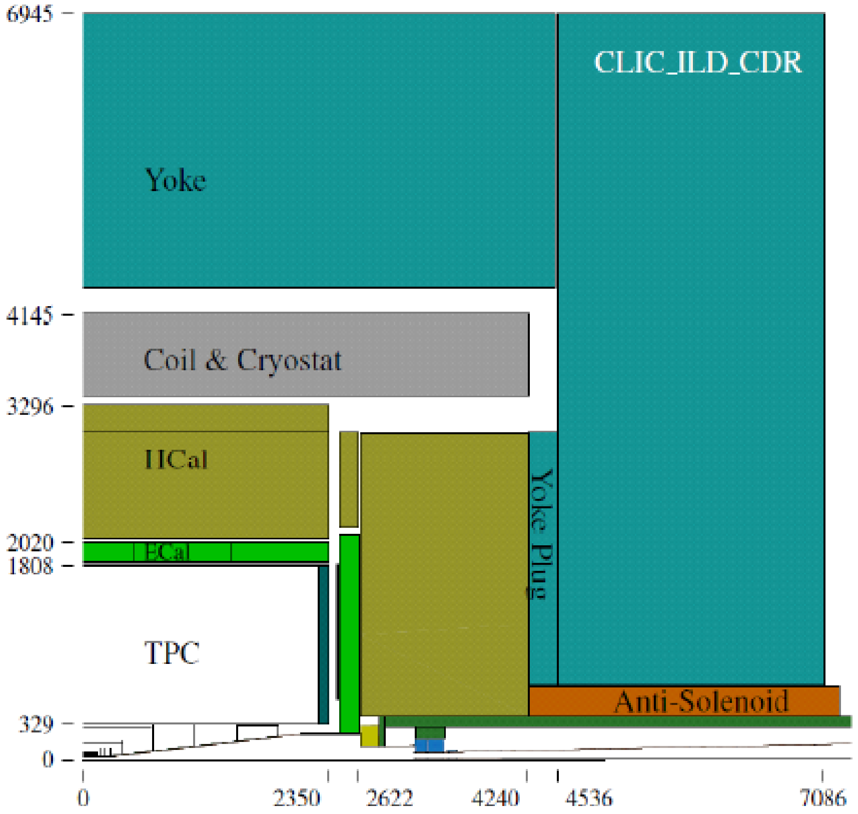
- Higgs BRs measurements are potential probe for the New Physics (i.e. models that could possibly extend SM Higgs sector impact Higgs couplings to EW bosons and/or Higgs Yukawa couplings)

- Challenging measurement due to low signal yield (predicted BR($H \to \mu^+\mu^-$) ~10^{-4}) :
  - ➡ Background has to be efficiently suppressed
  - ➡ Requires excellent momentum resolution

i.e. $\left(\frac{\Delta p_T}{p_T^2} \sim 10^{-5}\,\mathrm{GeV}^{-1}\right)$ in the barrel , as foreseen in CLIC CDR

ILD detector for CLIC





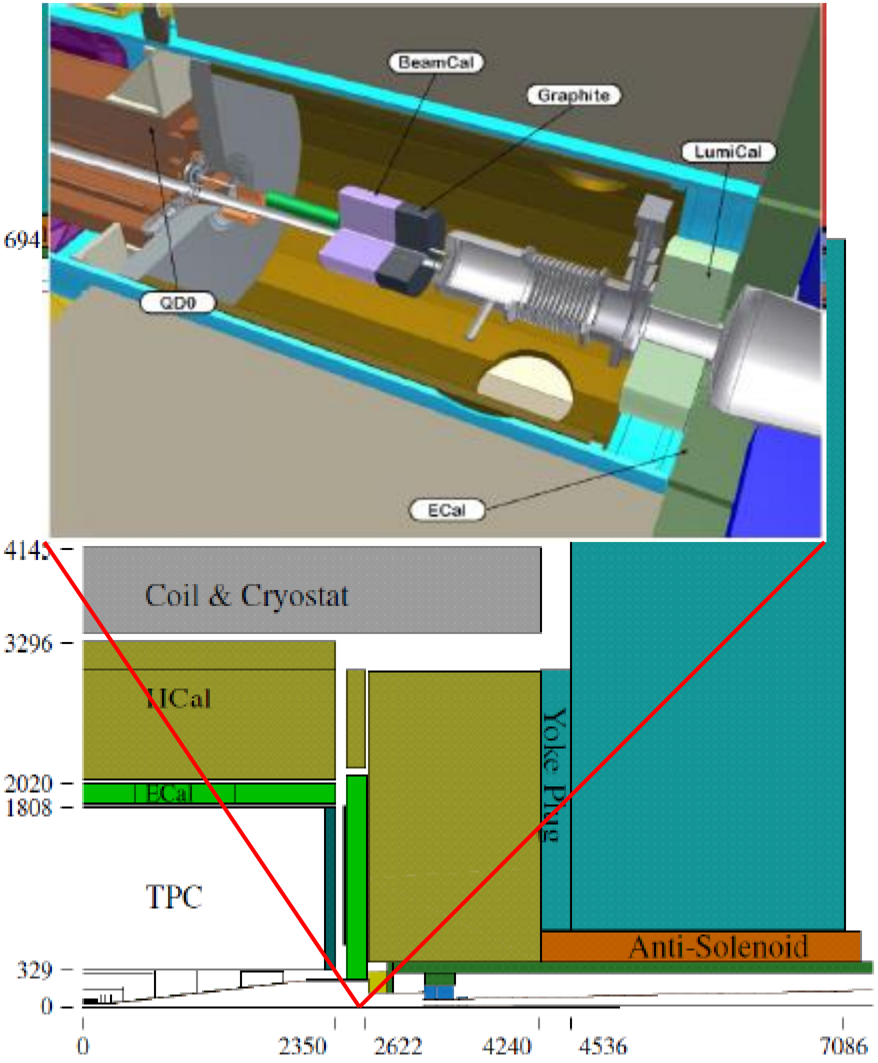
Muon p_T reconstruction translates into m(μμ) mass width ⇔ statistical uncertainty of the measurement

-Iron yoke instrumented with 9 active layers for μ identification

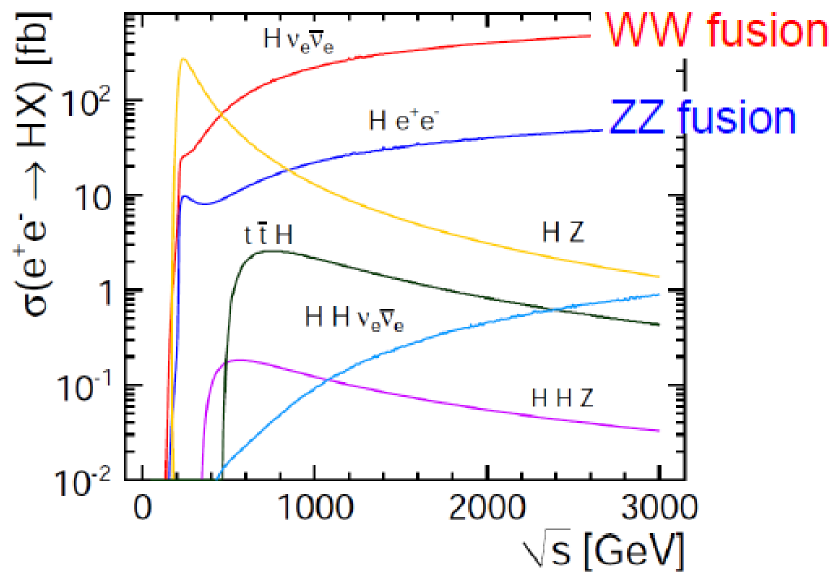
$\boxed{\Delta p_T / p_T^2 = 3.3\times10^{-5} GeV^{-1}}$ average p_T resolution in the barrel region, on the signal sample

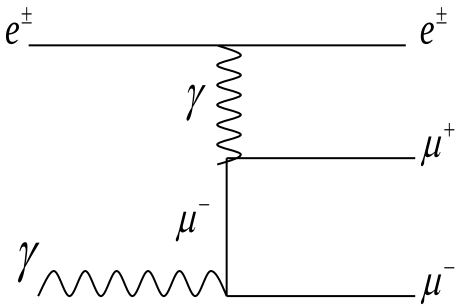
Electron tagging in the forward region

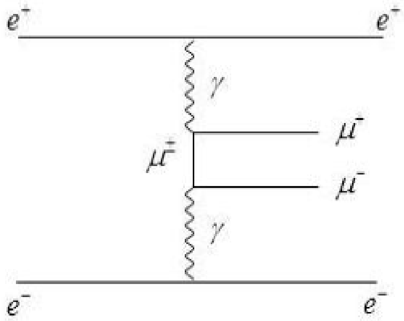
- If escapes at very small angles, undetected electron can mimic missing energy signature of the signal
- Forward region below ~ 7 deg is instrumented with calorimeters to (among others) tag (high-energy) electron
- However, detectors are overflowed with background from incoherent pairs
- Electron is tagged if reconstructed shower energy deviates for 4σ from the pair depositions in the layer with maximal deposition
- In order to reduce coincidence with Bhabha events, polar angle of the rec. shower is required > 30 mrad

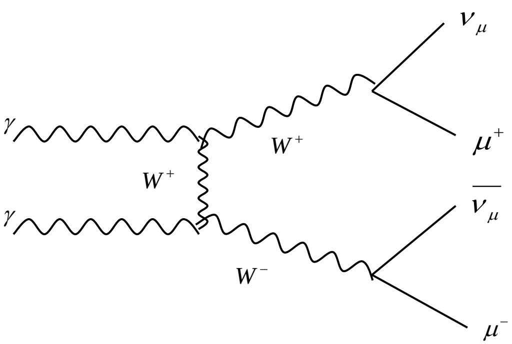


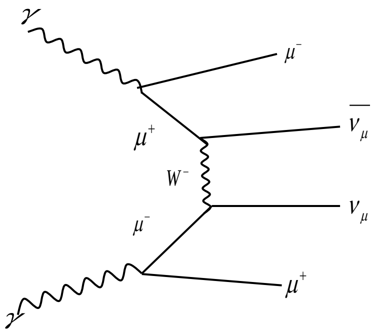
Signal and background processes

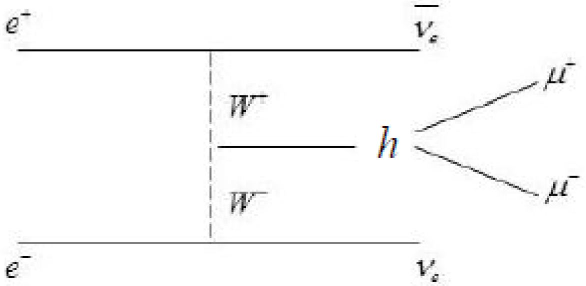


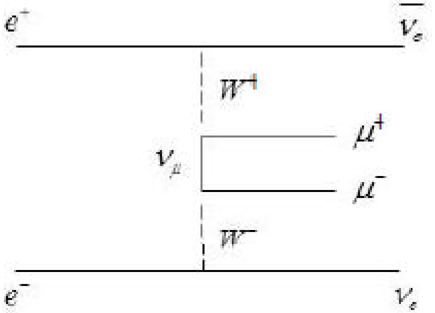












Signal

Background

Signal and background processes

-The most important kinematical property of signal is missing energy.

- Process with the same signature like $e^+e^- \rightarrow \mu^+\mu^-\nu_e\overline{\nu_e}$ and $\gamma\gamma \rightarrow \nu_\mu\overline{\nu_\mu}\mu^+\mu^-$ give irreducible background (even after MVA)

- Processes like $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ and $e^\pm\gamma \rightarrow e^\pm\mu^+\mu^-$ with low-angle electron in the final state can be dealt with in MVA + electron tagging

- We added the full simulation of $\gamma\gamma \rightarrow \nu_\mu\overline{\nu_\mu}\mu^+\mu^-$ background including now the overlay of $\gamma\gamma \rightarrow hadrons$ resulting in a change of Evis distribution (reduced MVA separation)

Signal and background processes

Process	$\sigma[fb]$	$\mathbf{N_{events}}$
$e^+e^- \to H\nu_e\bar{\nu}_e, H \to \mu^+\mu^-$	0.05	24000
$e^+e^- \to \mu^+\mu^-\nu_e\bar{\nu}_e$	129	236000
$e^+e^- \to e^+e^-\mu^+\mu^-$	431^A	1000000
$e^\pm\gamma \to e^\pm\mu^+\mu^-$	1920^A	2000000
$\gamma\gamma \to \nu_\mu\bar{\nu}_\mu\mu^+\mu^-$	110.72	350000
$e^+e^- \to \nu_\tau\bar{\nu}_\tau\tau^+\tau^-$	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

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

Event selection and MV analysis

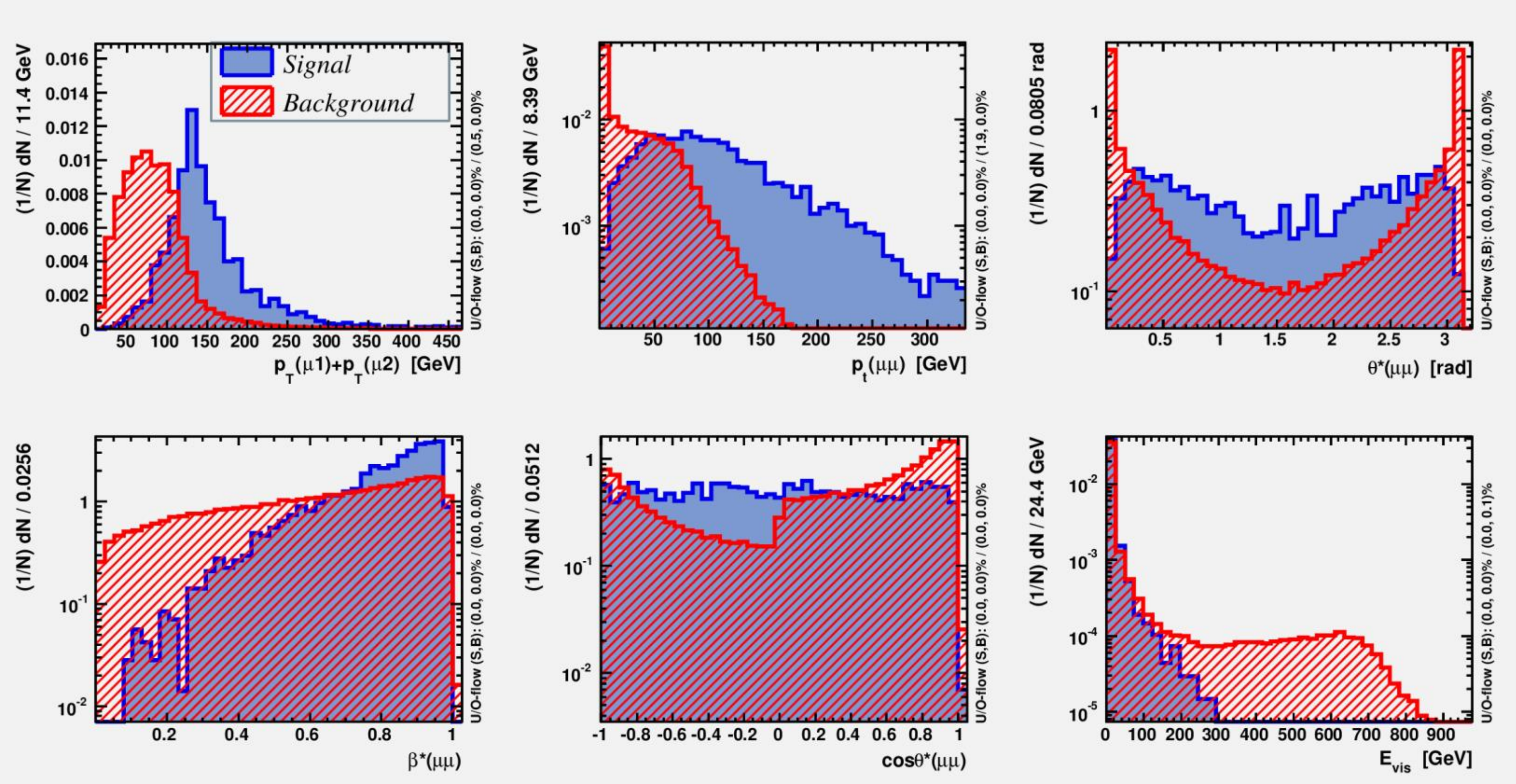
- 1.5 ab^{-1} corresponding to 4 years operation with 50% data taking efficiency.
- Pre-selection:
- two reconstructed muons, (105-135) GeV
- di-muon mass window
- absence of a E>200 GeV electron at on side of the FWD calorimeters – electron tagging

Process	***Rejection by direct tagging***	***Rejection including coincident Bhabha events***
$e^+e^- \rightarrow e^+e^-\mu^+\mu^-$	17%	24%
$e^\pm\gamma \rightarrow e^\pm\mu^+\mu^-$	11%	17%
$H \rightarrow \mu^+\mu^-$	0.2%	7%

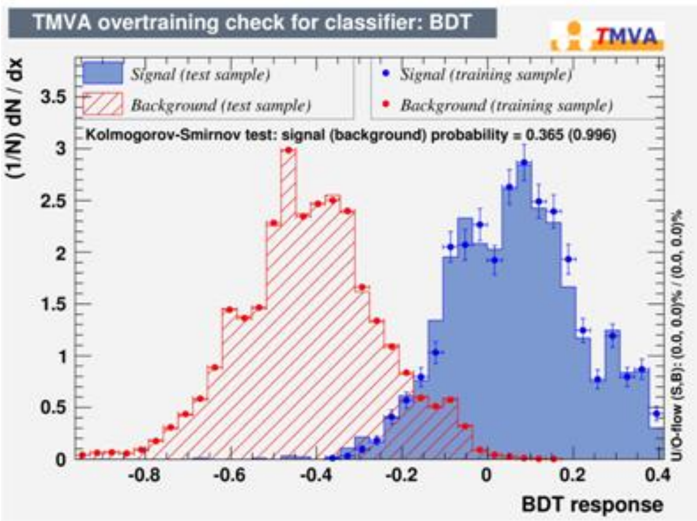
MVA

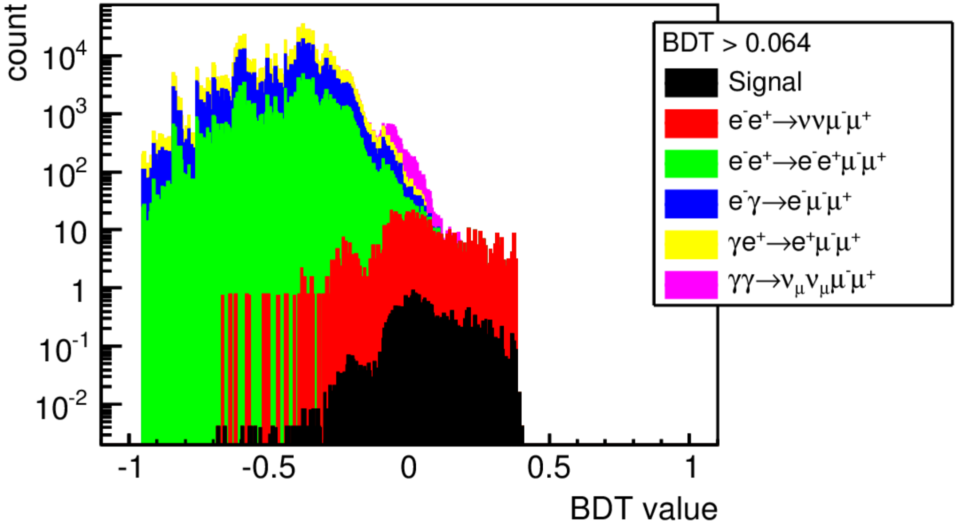
- TMVA input (E_{vis}, $p_T(\mu\mu)$, $p_T(\mu_1)+p_T(\mu_2)$, $\theta(\mu\mu)$, cos θ^*, $\beta(\mu\mu)$).
- BDT is trained on:

6000 events of signal, 250000 $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ events and 90000 $\gamma\gamma \rightarrow \nu_\mu \overline{\nu}_\mu \mu^+\mu^-$



Background suppression with MVA

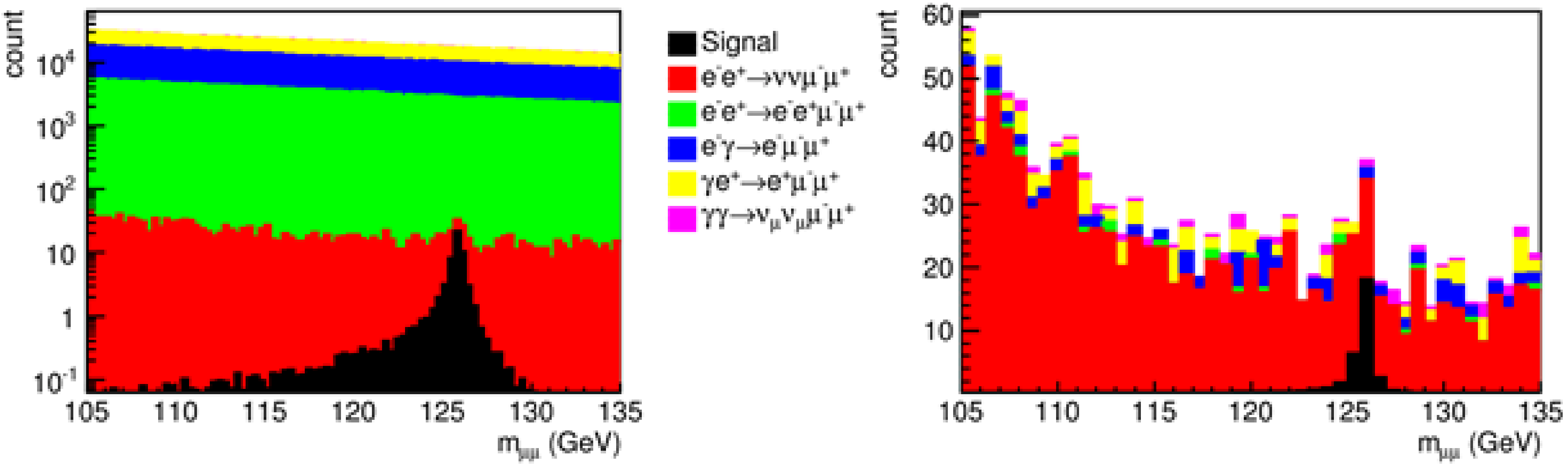




BDT>0.064

- BDT cut corresponds to the minimal relative statistical error (σ_{BR} / BR) ⇔ maximization of significance or purity·efficiency
- MVA selection efficiency is 40% for signal.
- Overall signal efficiency is 33%.

Before - after MVA



- $e^+e^- \to e^+e^-\mu^+\mu^-$ is reduced about 3 orders of magnitude
- E_{mis} signature background irreducibly present

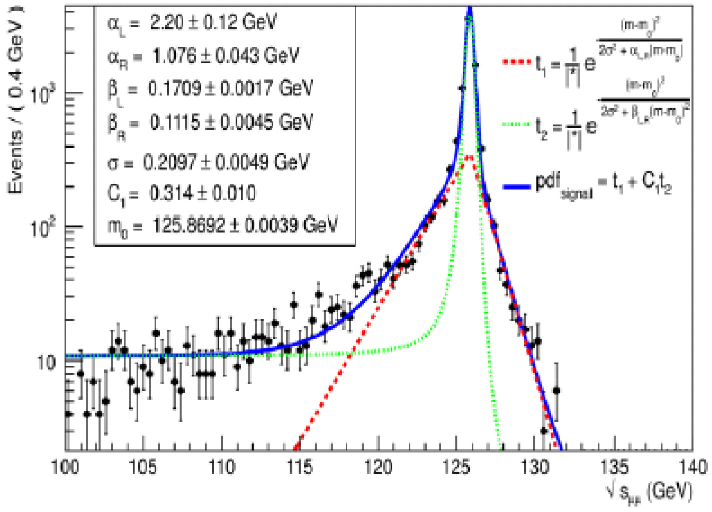
Method of the measurement

Signal and background PDFs

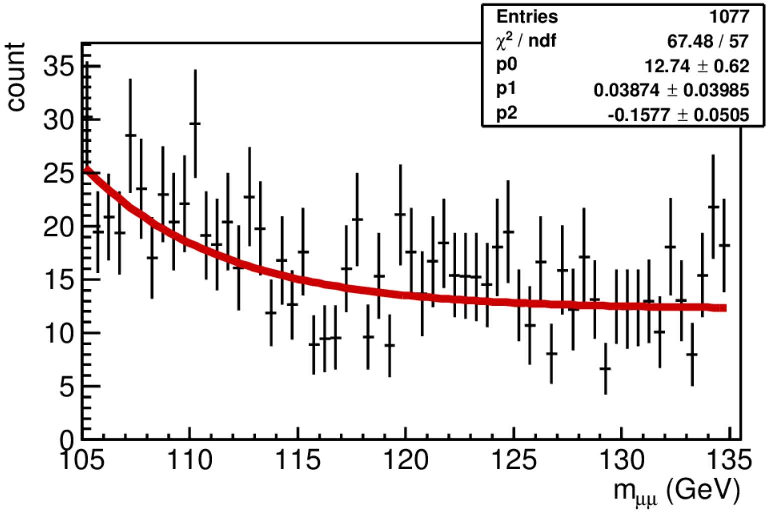
Fully simulated, as large as possible, samples of signal and background to extract PDFs

SIGNAL

ALL BACKGROUND



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



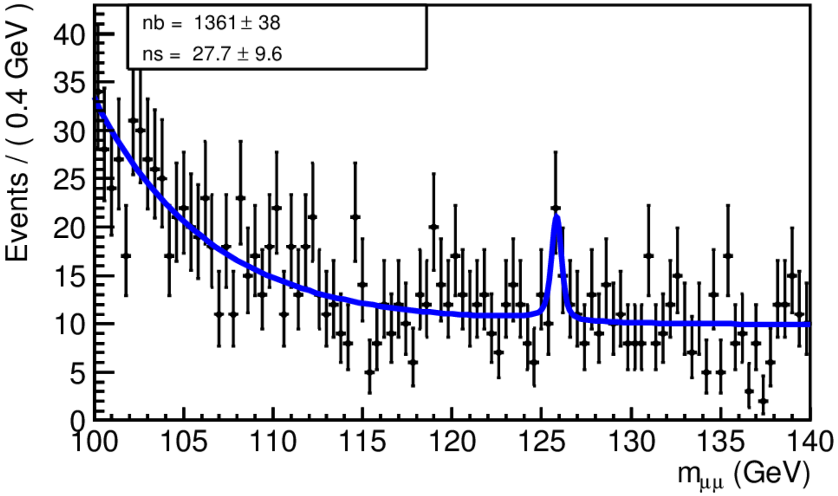
$$f_{BCK} = p_0 (p_1 e^{p_2 (x - m_H)} + (1 - p_1))$$

Method of the measurement

Toy MC experiments

- 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

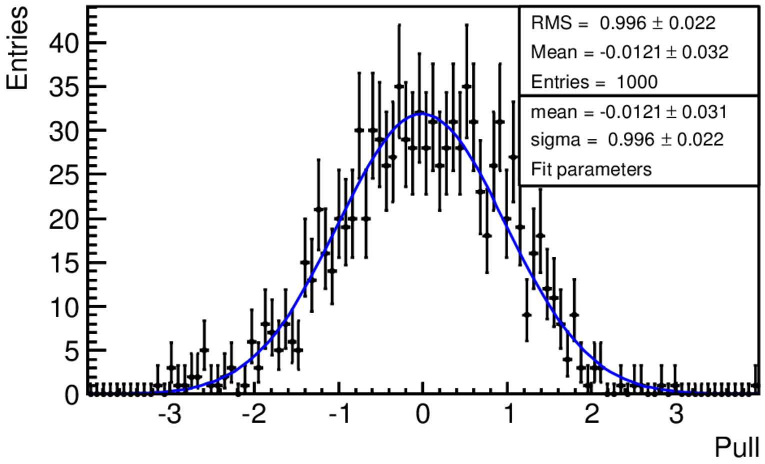
$$f = k \cdot f_S + (1-k) \cdot f_{BCK} \Rightarrow N_S = k \cdot \int f_S dm$$

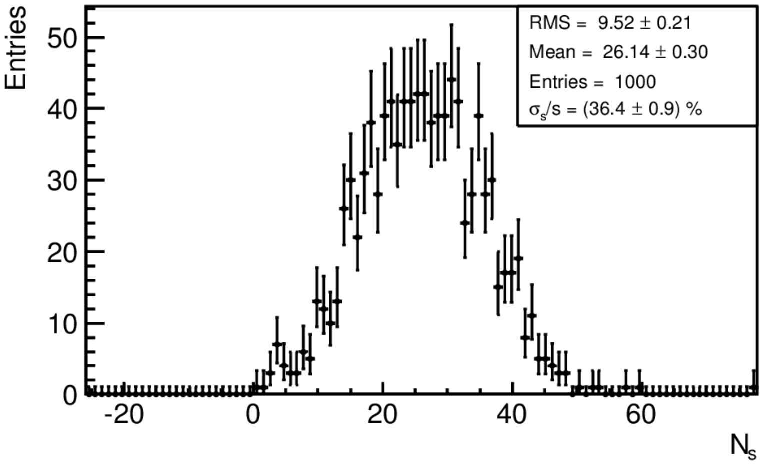


Method of the measurement

Statistical uncertainty

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

Results

N_s	**26±10**
$\boldsymbol{\varepsilon_s}$	**33%**
$\boldsymbol{\sigma_{WWH}\times BR}(H\to\mu^+\mu^-)$	**0.05 fb**
$\boldsymbol{\delta(\sigma_{WWH}\times BR}(H\to\mu^+\mu^-))$	**36%**
$\mathbf{BR}(H\to\mu^+\mu^-)$	$\mathbf{(2.0\pm0.7)\times10^{-4}}$

- Uncertainty of the measurement is dominated by the small statistics of signal and by the backgrounds with (true) missing energy.

- One should not that no polarization is included that can boost statistics by a factor 2.

- Uncertainty of the $g_{H\mu\mu}$ (12%) is estimated assuming uncertainties of g_{HWW} and Γ_H as in the Snowmass paper.

- *Processes* $e^+e^-\to e^+e^-\mu^+\mu^-$ *and* $e^\pm\gamma\to e^\pm\mu^+\mu^-$ *has to be treated in EPA for low momentum transferred by the exchanged photon. In that kinematical region electron is substituted by a quasi-real photon.*

Conclusion

- H→ $\mu^+\mu^-$ 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→ $\mu^+\mu^-$) can be measured with a statistical accuracy of order of 30+ percent (*the exact number will be provided after we introduce EPA*)
- Uncertainty of the measurement is dominated by the small statistics of signal and by the backgrounds with (true) missing energy.

BACKUP

Systematics

- Peak luminosity (estimated to be determined within ~1.4 permille at 3 TeV CLIC

- Systematic uncertainty of the signal count is relatively insensitive to the accuracy of the p_T resolution

- Uncertainties of the polar angle resolution and muon identification efficiency are expected to be at the percent level as at LEP

- Coincidence with Bhabha events with 10ns (20 BX) time stamping is found to be 7%