HEP GROUP VINCA
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SM-like Higgs decay into two muons at 1.4 TeV CLIC

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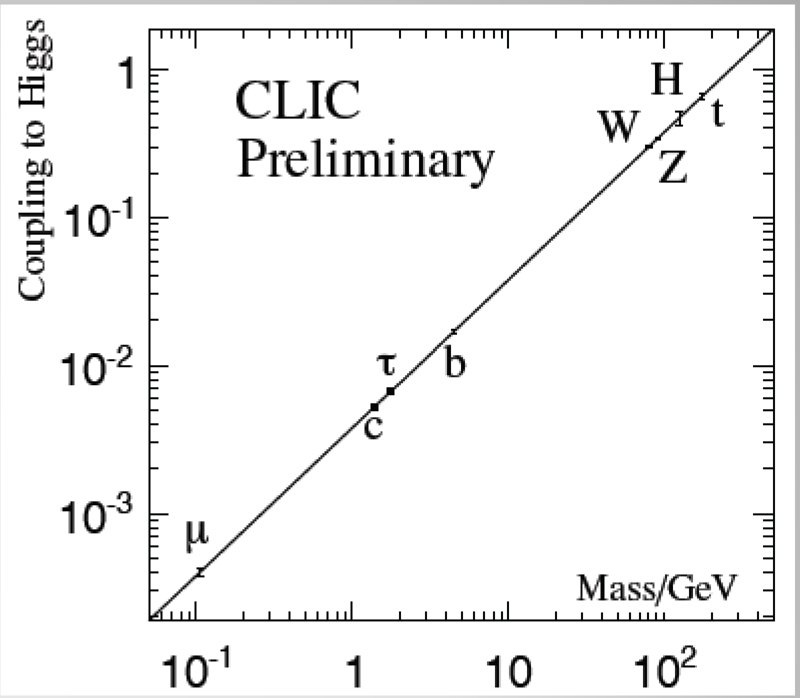
[on behalf of the CLIC detector and physics study]

- OVERVIEW

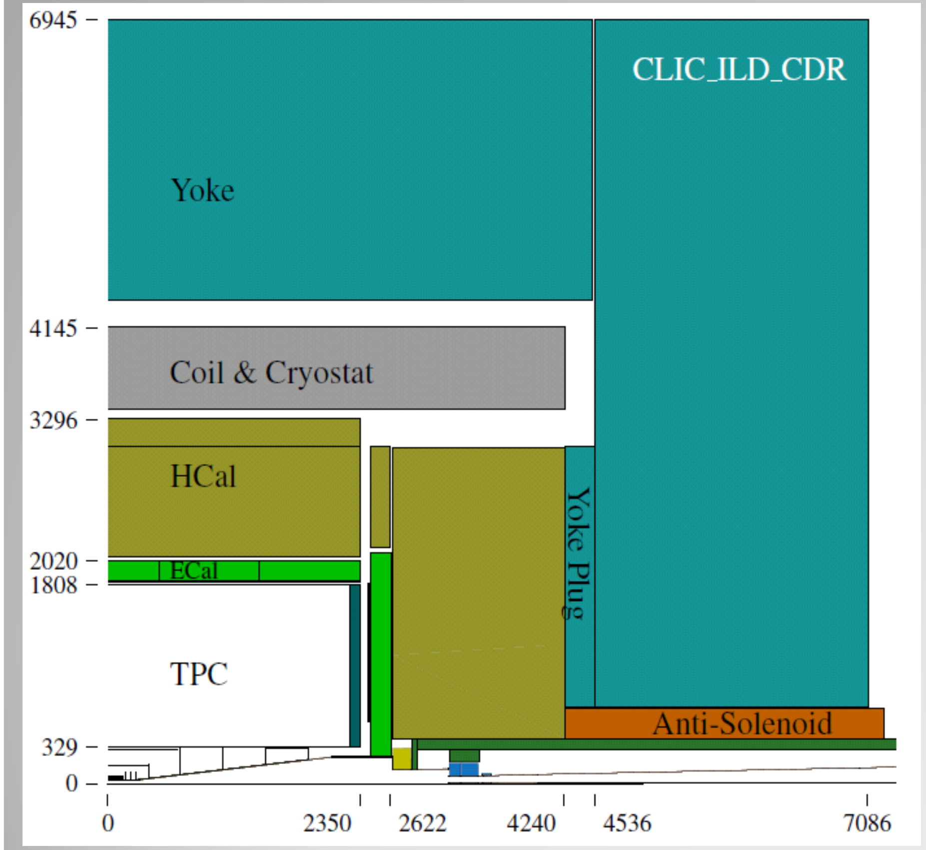
- Motivation for the measurement
- Detector for CLIC
- Signal and background
- Event simulation
- Forward electron tagging
- Multivariate approach in background suppression
- Method of the measurement: di-muon invariant mass fit and ($\sigma_{prod} \cdot BR$) extraction
- Conclusion

- MOTIVATION

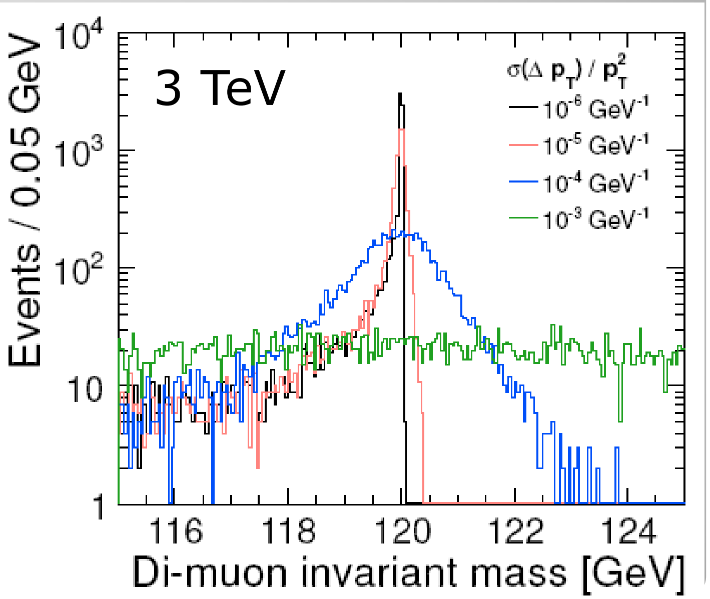
- Higgs couplings measurement ($\sigma(H\nu\nu)\times BR(H\to\mu\mu)$)
- Test SM predictions (coupling vs. mass linearity, $g_{HWW}/g_{HZZ}=cos^2\theta_w$)
- Strong BSM indication (new fermions, composite Higgs)
- Observable: $g^2_{HWW}g^2_{H\mu\mu}/\Gamma_H$ statistical precision can be enhanced by polarization up to factor 2.3



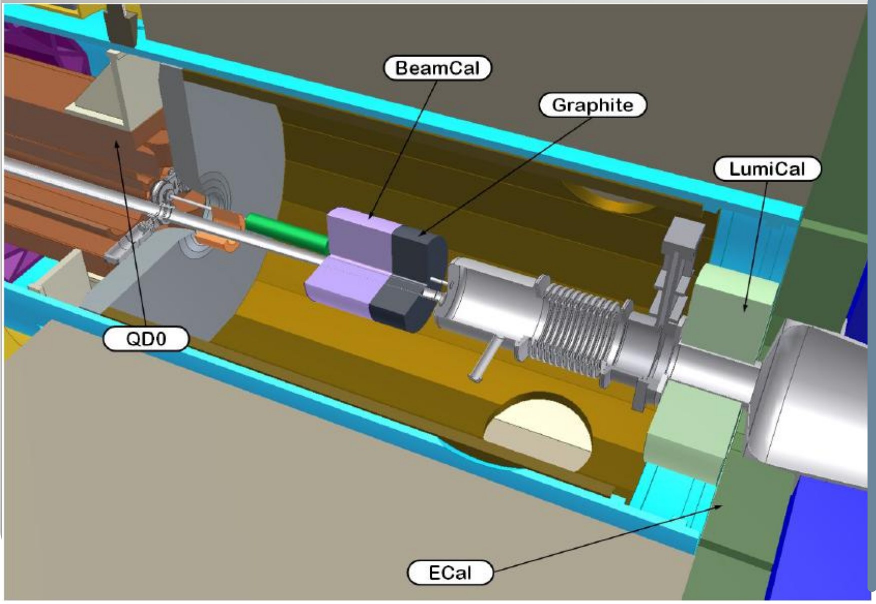
- # DETECTOR

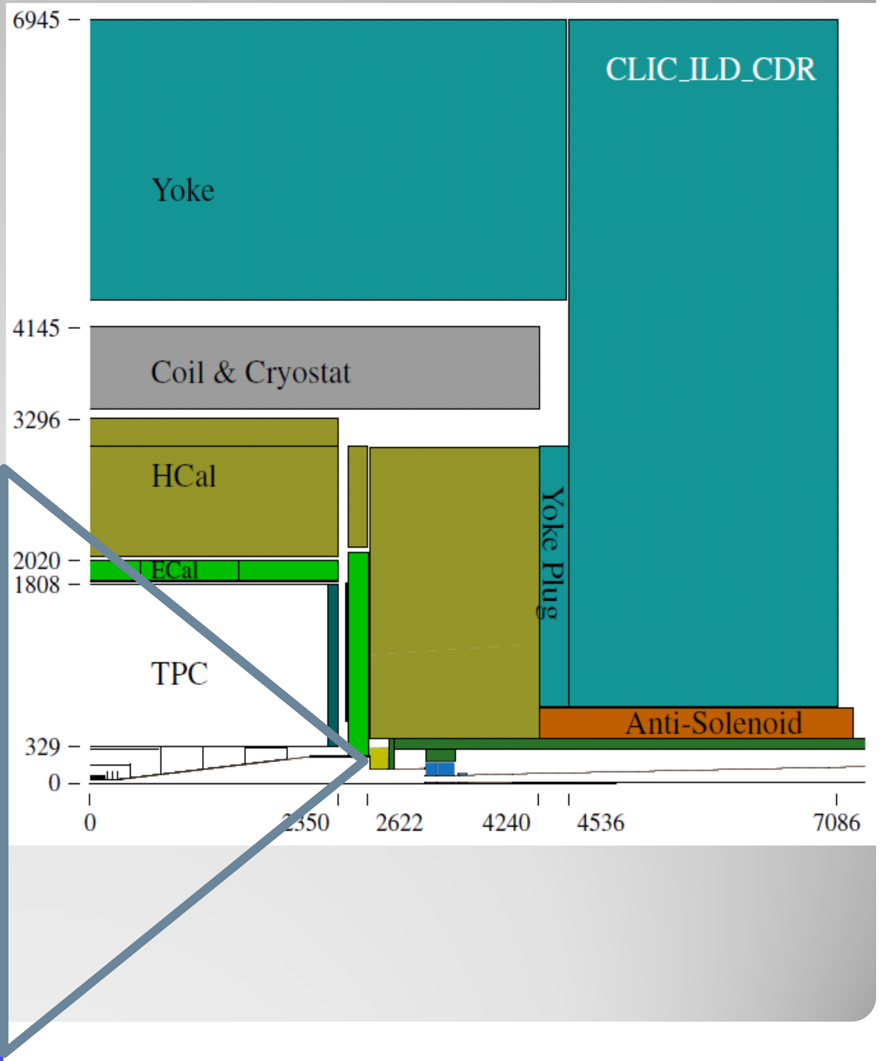


- Muon p_T resolution translates into di-muon invariant mass width
- Momentum resolution has $1/p_T$ dependence due to multiple scattering
- $\Delta p_T/p_T^2$: $1.1 \cdot 10^{-4}$ - $3.5 \cdot 10^{-5}$ GeV^{-1} depending on the θ region

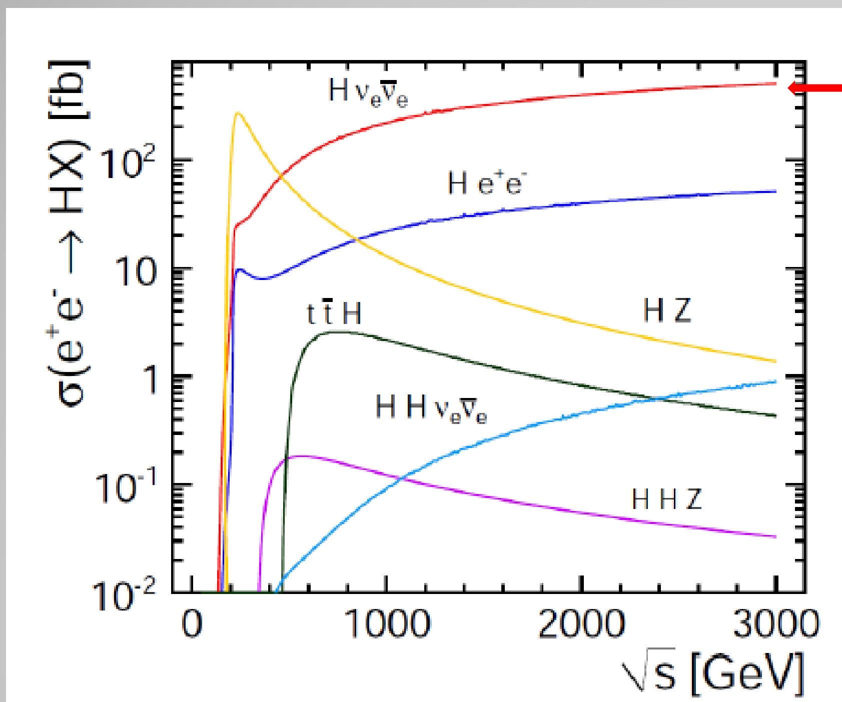


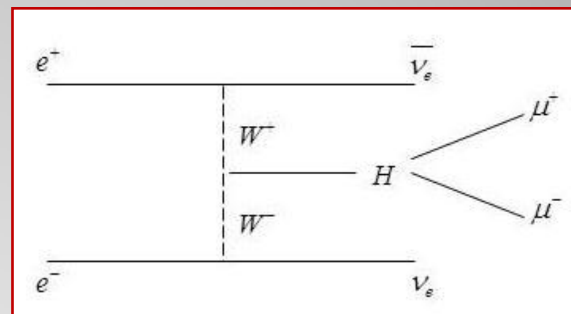
- Forward region (15-140 mrad) plays role in suppression of background with high-energy electrons emitted at low polar angles
- 98.5% (52%) LCAL (BCAL) e-tag efficiencies for background





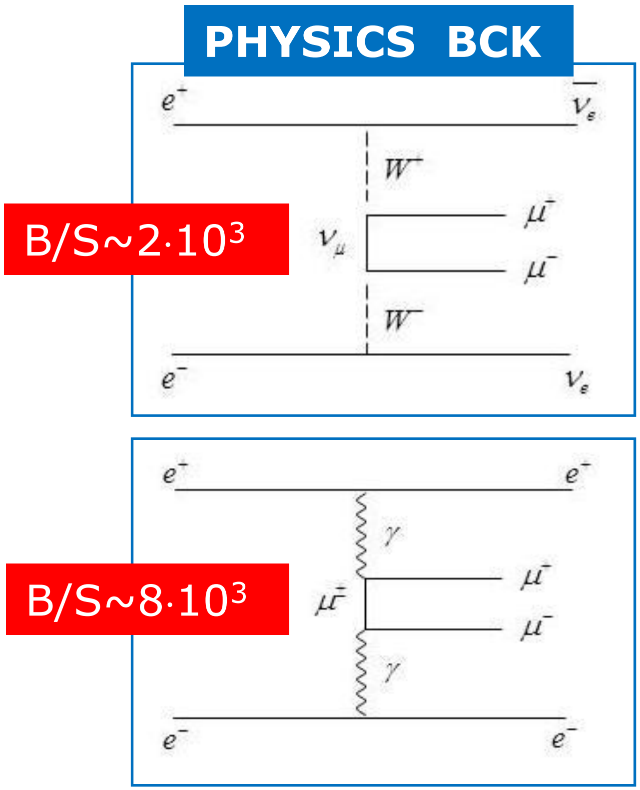
- SIGNAL AND BACKGROUND

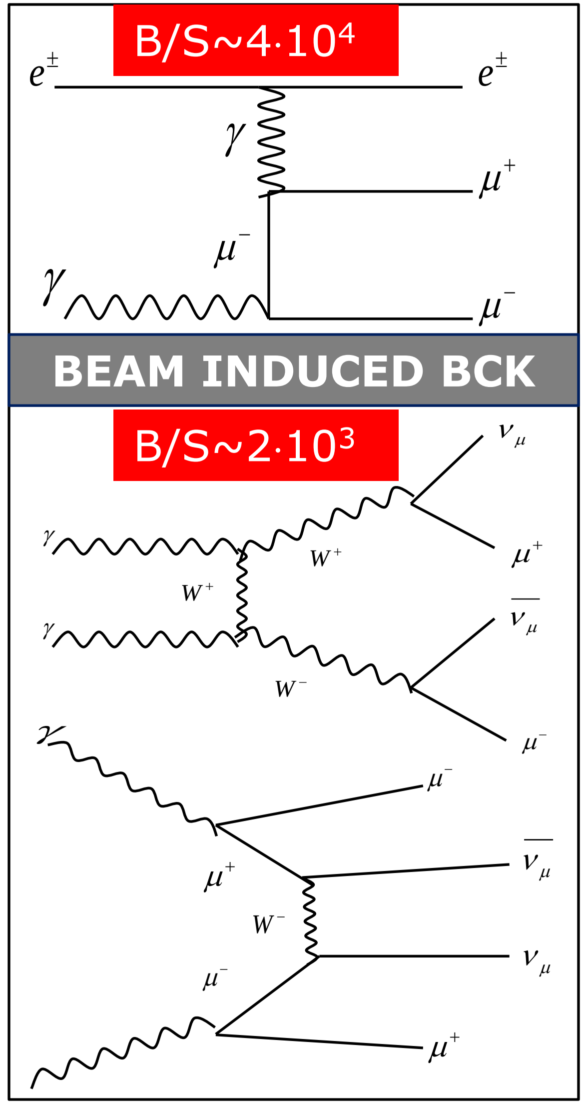




$BR\ (H \to \mu\mu) \sim 2 \cdot 10^{-4}$

• SIGNAL AND BACKGROUND





- Pre-selection:
  - two reconstr. μ
  - di-muon mass window (105-135) GeV
  - electron tagging with forward calorimeters

$\Downarrow$

- MVA to reduce background (E_{vis}, $p_T(\mu\mu)$, $p_T(\mu_1)+p_T(\mu_2)$, $\theta(\mu\mu)$, $\cos\theta^*(\mu\mu)$, $\beta(\mu\mu)$)

EVENT SIMULATION

- Common integral luminosity of 1.5 ab^{-1} is assumed, without beam polarization
- Large main background samples in order to extract PDFs

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
$e^\pm\gamma_{BS} \to e^\pm\mu^+\mu^-$	1920[A]	2000000
$\gamma_{BS}\gamma_{BS} \to \nu_\mu\overline{\nu_\mu}\mu^+\mu^-$	110.72	350000

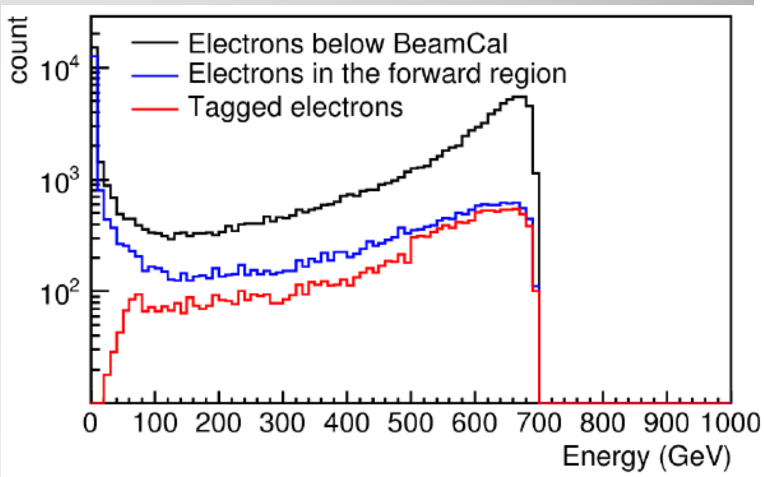
[A]Including a cut of 100 GeV <m($\mu^+\mu^-$)<140 GeV and requiring a minimal polar angle of 8° for each muon.

- ELECTRON TAGGING

- Forward region calorimetry plays an important role to veto electron spectators from 4-f and $e\gamma_{BS}$ processes.

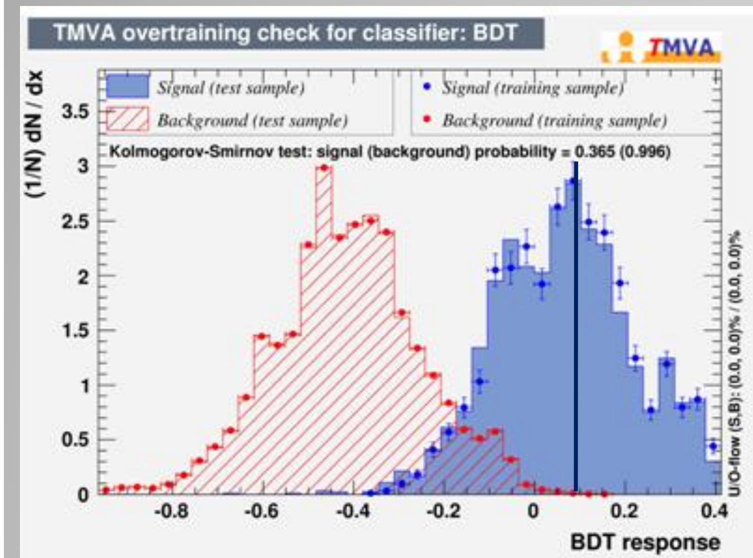
- Energy dependent tagging is introduced in LumiCal and BeamCal:
  - Take 5 mrad cone particles (e, gamma) to construct electron,
  - Require 4σ deviation from the background (converted pairs) energy in the layer with the maximal deposition. Energy resolution is taken into account, as well as fluctuations of background deposition over the θ range.

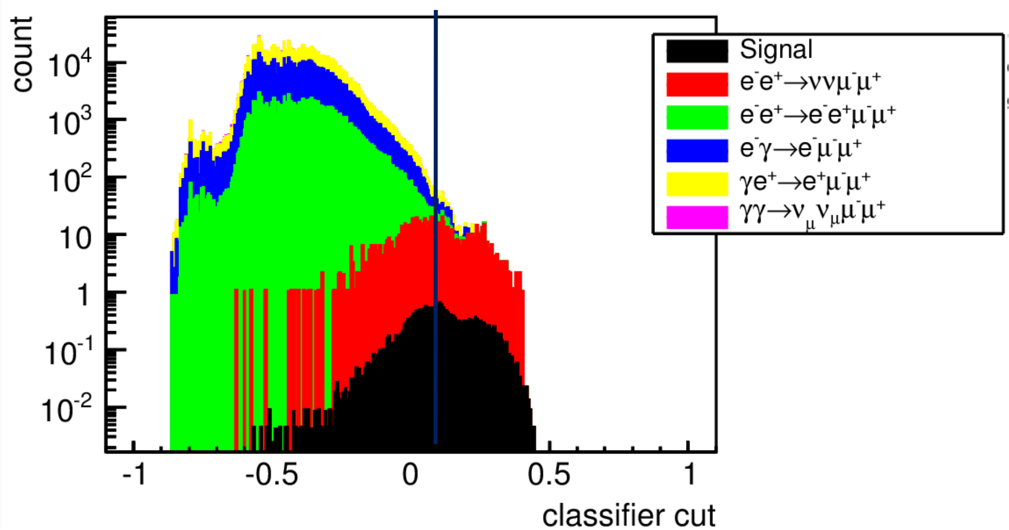
Process	Rejection
$e^+e^- \to e^+e^-\mu^+\mu^-$	25%
$e^\pm\gamma_{BS} \to e^\pm\mu^+\mu^-$	15%
$H \to \mu^+\mu^-$	0.2%



- MV approach

- TMVA is trained on $e^+e^- \to e^+e^-\mu^+\mu^-$ and $\gamma_{BS}\gamma_{BS} \to \nu_\mu\overline{\nu}_\mu\mu^+\mu^-$

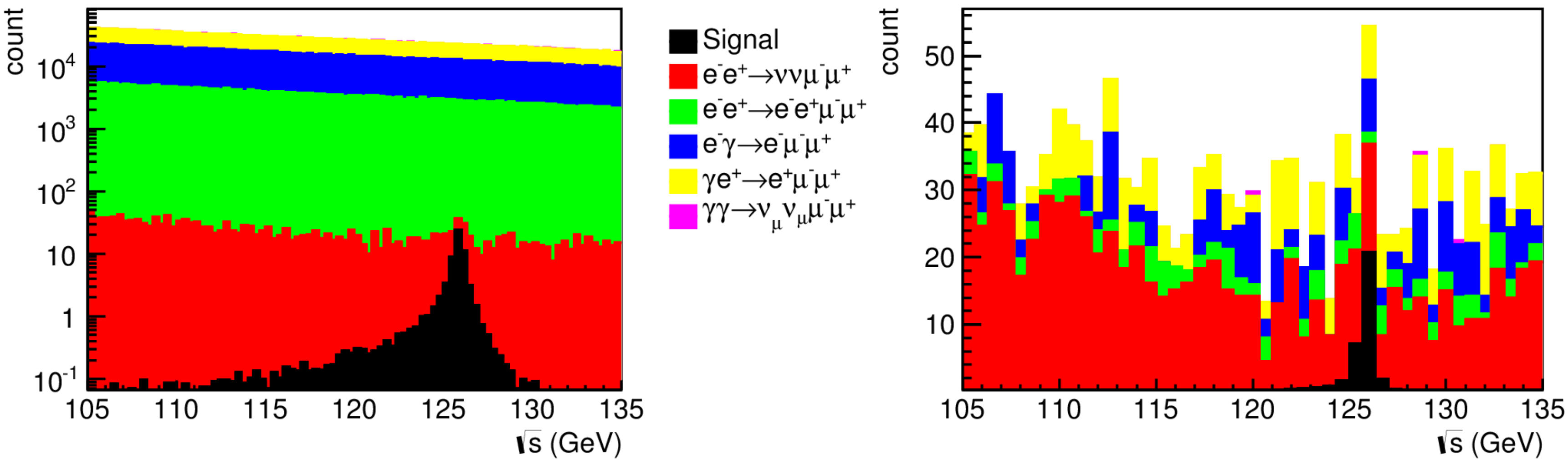




- BDT cut (0.098) corresponds to the minimal relative statistical error $\sigma_{BR}/BR \Leftrightarrow$ maximization of significance or (purity·efficiency)
- Impact of e-tagging is also in loosening BDT cut-off value resulting in enlarged signal efficiency

- Pre-selection only

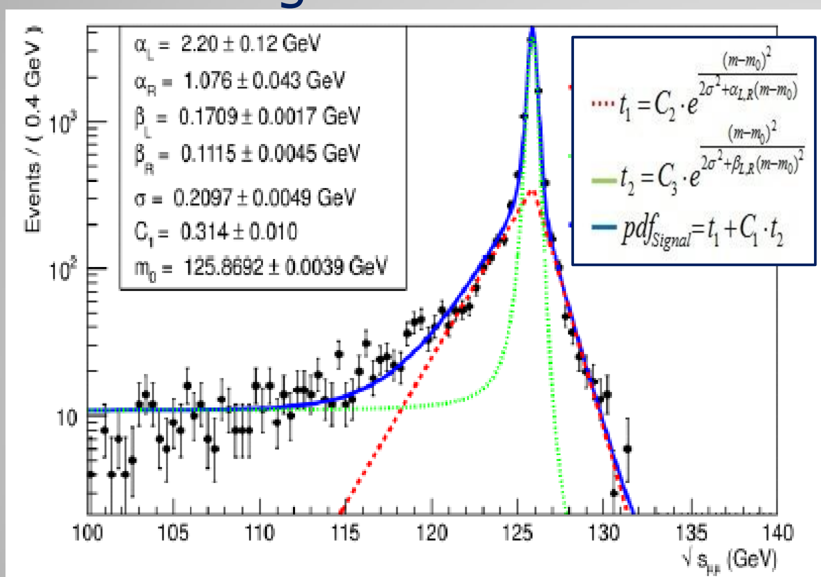
+ BDT cut



MVA helps to significantly reduce 4-f background, while signal like $e^+e^- \to \mu^+\mu^-\nu_e\overline{\nu}_e$ is irreducibly present

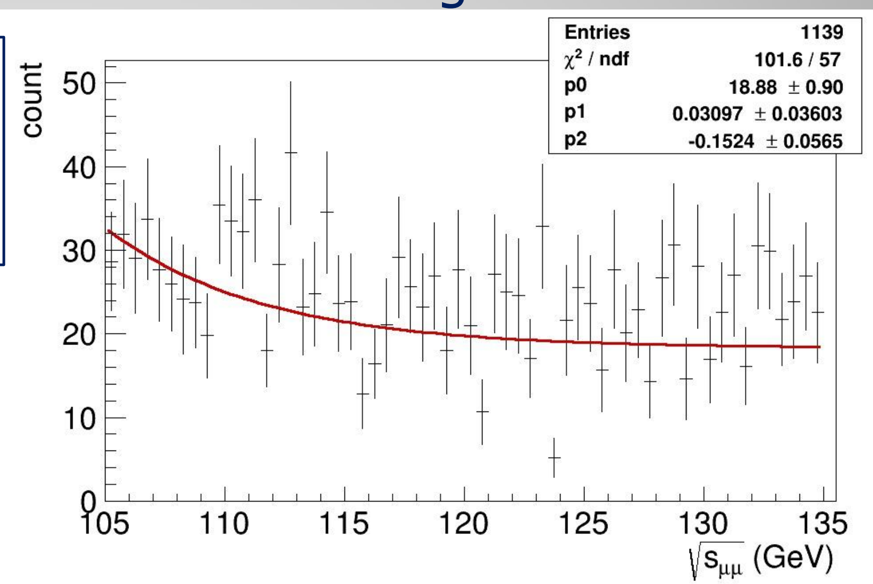
- METHOD
- SIGNAL AND BACKGROUND PDFs
- Fully simulated, as large as possible, samples of signal and background are fitted to extract PDFs

signal



$$f_S = t_1 + C_1 \cdot t_2$$

all background

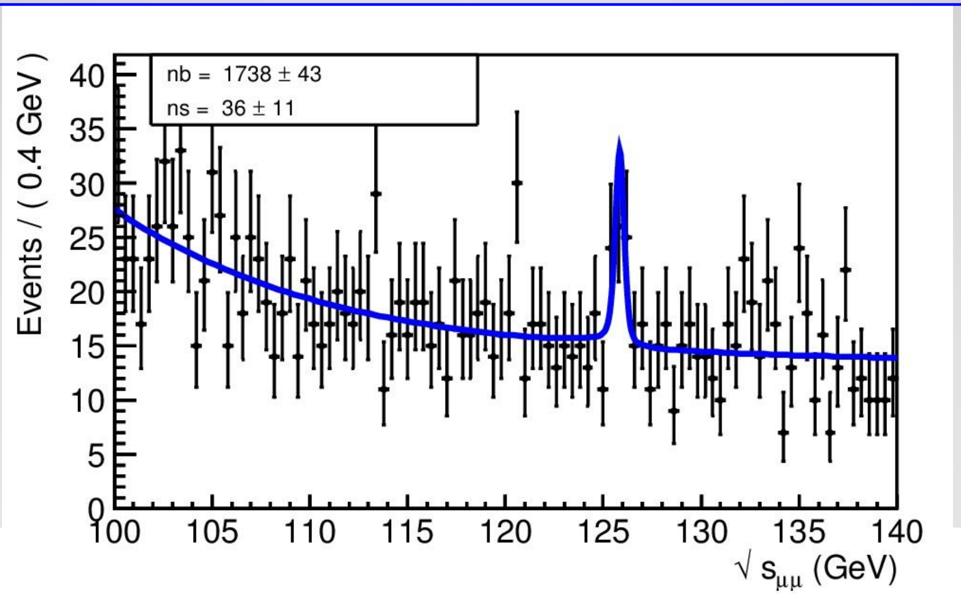


$$f_{BCK} = p_0(p_1 e^{p_2(x-m_H)} + (1-p_1))$$

DI-MUON INVARIANT MASS FIT

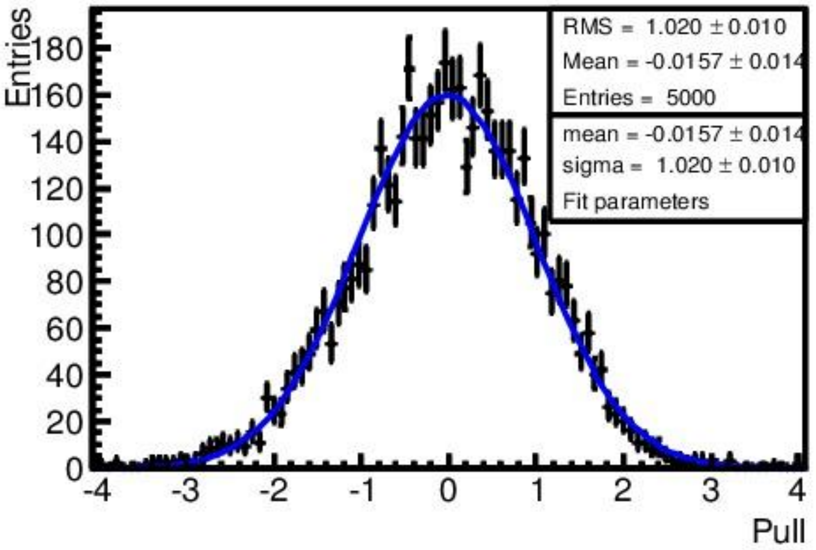
- Make pseudo experiments (Toy MC) based on randomly sampled fully simulated signal events + background generated with PDFs, $(N_i = \sigma_i \cdot \varepsilon_i \cdot L)$
- Expected shape of data (signal + background) for each Toy MC is fitted (unbinned likelihood fit) with f to extract number of signal events N_s:

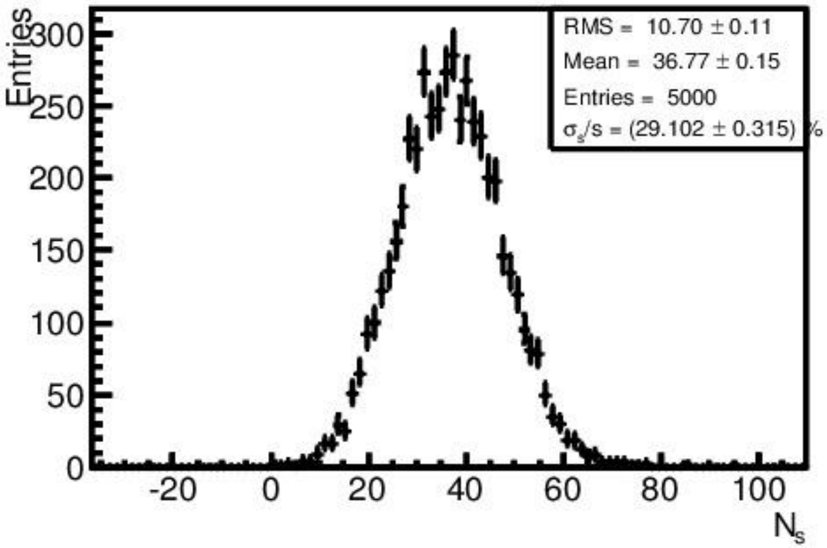
$$f = k \cdot f_S + (1-k) \cdot f_{BCK} \Rightarrow N_S = k \cdot \int f_S dm$$



TOY MC

- 5000 Toy MC experiments are performed to extract statistical uncertainty and check the pull distribution
- RMS from N_s distribution give us statistical uncertainty of the measurement
- Pull distribution confirms adequate description of signal and background with PDFs





• $\sigma(H\nu\nu)\times BR(H\rightarrow\mu\mu)$ EXTRACTION – RESULTS 1.4 TeV NO POLARIZATION

• $\sigma(H\nu\nu)\times BR(H\rightarrow\mu\mu)=N_S/L\cdot\varepsilon_S$, $\sigma(H\nu\nu)_{1.4TeV}=244.1fb$

Signal events	**36 ± 11**
Signal efficiency	**52.6%**
$\sigma_{H\nu\nu}\times BR_{H\rightarrow\mu\mu}$	**0.05 fb**
Statistical uncertainty	**29.1%**

• Uncertainty of the measurement is dominated by the small statistics of signal and by irreducible background
• Electron tagging improves signal efficiency due to the looser BDT cutoff, reducing statistical uncertainty of the measurement for ~3%.

CONCLUSION

- There is strong motivation to search for signs of BSM physics in the rare Higgs decay $H \to \mu\mu$ at CLIC.
- The measurement itself tests excellent muon identification and momentum resolution of the detector.
- It has been shown that $\sigma(H\nu\nu) \times BR(H \to \mu\mu)$ can be measured with a statistical accuracy of 29% at 1.4 TeV CLIC with unpolarized beams.
- Uncertainty of the measurement is dominated by the limited statistics of the signal.

BACKUP

- OTHER BACKGROUND

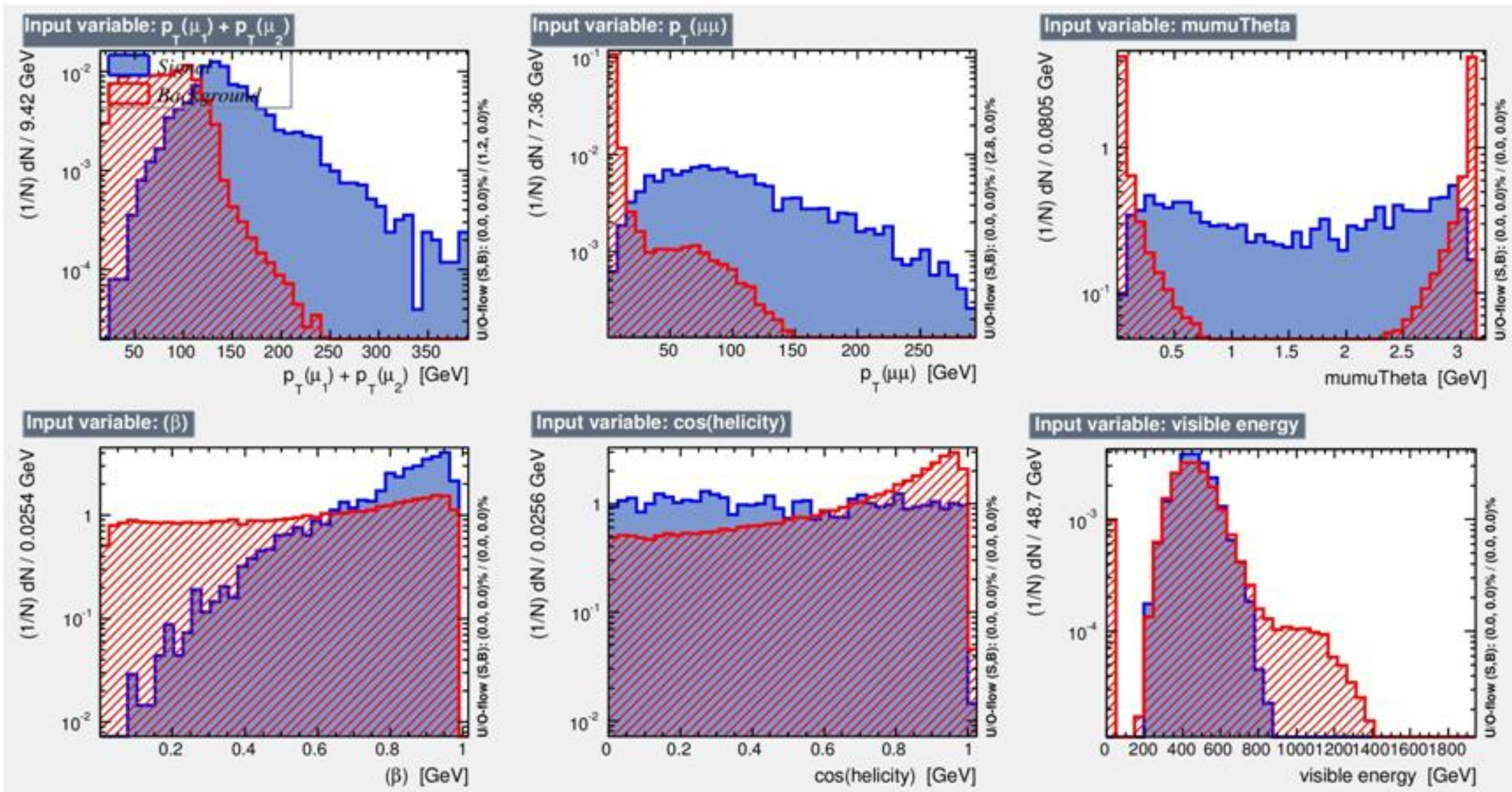
Process	$\sigma[fb]$	N events
$e^+e^- \to \nu_\tau \overline{\nu_\tau} \tau^+\tau^-$	84.5	133000
$e^+e^- \to e^+e^-\tau^+\tau^-$	1942.2	464500
$e^+e^- \to \mu^+\mu^-$	17	50000
$e^+e^- \to \tau^+\tau^-$	358	482500

& SIMULATION ASSUMPTIONS

- 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

SIGNAL

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



• OTHER ISSUES

Systematic uncertainties:

- Peak luminosity (estimated to be determined within ~1.4 permille at 3 TeV CLIC [*S Lukić et al. 2013 JINST 8 P05008*])
- Systematic error below 2% will be induced by the 5% uncertainty of the muon 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 estimated to be ≤4% at 1.4 TeV (factor x2 should be added when beam-induced effects are included in one-side tagging of Bhabha electrons above 100 GeV)