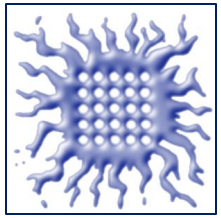
Measurement of H→WW* in HZ at 350 GeV and WW fusion at 1.4 TeV CLIC



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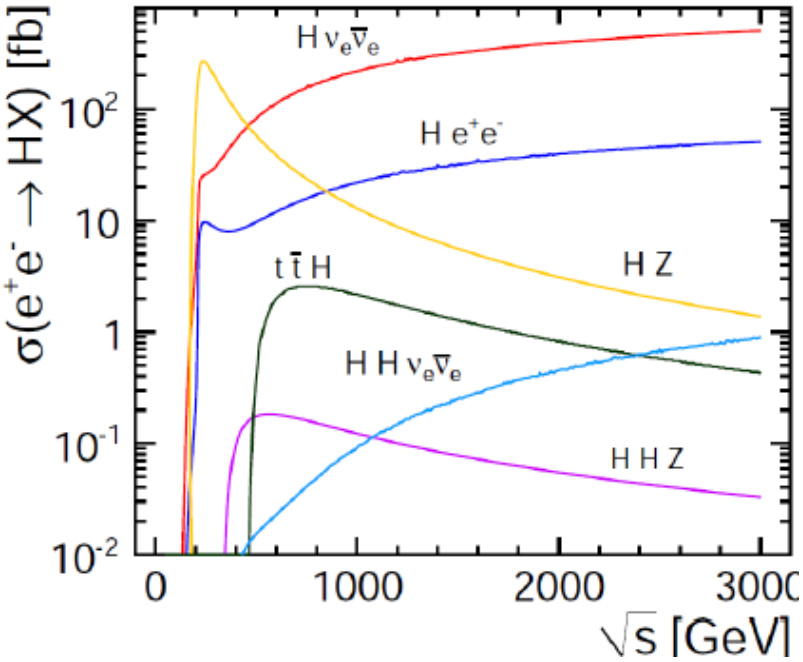
*on behalf of the **CLICdp collaboration***

Outline

- Motivation for H⟶WW* decay in CLIC physics program
- Analysis overview
- Simulation and reconstruction
- H⟶WW* at 350 GeV
- H⟶WW* at 1.4 TeV
- Conclusion

Introduction

	350 GeV	1.4 TeV	3TeV
Luminosity [ab^{-1}]	0.5	1.5	2.0
# ZH events	68,000	20,000	11,000
# Hvv events	26,000	370,000	870,000

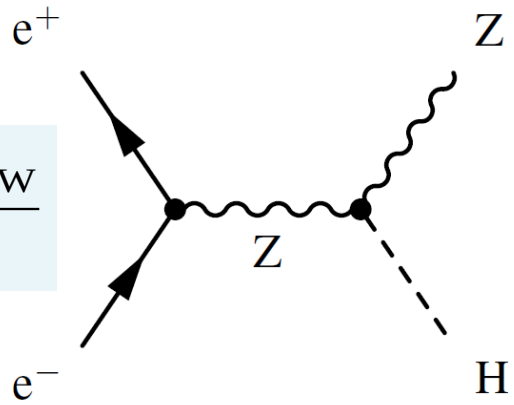


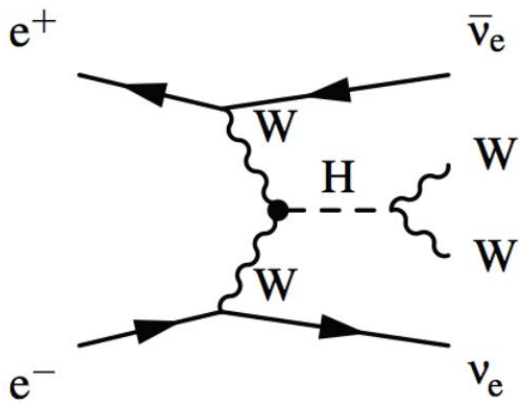
- BF (H→WW)~23%
- Considering only fully hadronic H→WW*→qqqq decays
- BF (H→WW→qqqq)~10%
- Full reconstruction of m_H possible only in these fully hadronic decays

Parallels of studies

- From ZH: model independent measurement of absolute coupling of the Higgs to Z boson $\lessapprox 0.8\ \%$

$$\frac{g^2_{HZZ} \cdot g^2_{HWW}}{\Gamma_H}$$





$$\frac{g^4_{HWW}}{\Gamma_H}$$

s-channel (central jets) t-channel (forward jets)

final states

4 jets + 2 leptons (Z→ll) **4 jets +missing energy**

6 jets (Z→qq)

Backgrounds

Process	X-sec [fb^{-1}] (350 GeV)	X-sec [fb^{-1}]; (1.4 TeV)
signal	**10.9**	**27.5**
Hνν	53.4*	**216.6****
HZ, other H decays	**92.2**	/
qq	/	4009.5
qqqq	**5847**	1328.1
qqll	**1704**	/
qqlν	**5914**	/
qqνν	324.6	**788. 0**
qqqqll	/	71.7
qqqqlν	/	115.3
qqqqνν	/	24.7
eγ→qqqqe	/	2891.0
eγ→qqqqν	/	**254.3**
γγ→qqqqe	/	30212.5

*inclusive sample ** other Higgs decays

Analysis strategy

Lepton Isolation ⇐ HZ, Z→ll at 350GeV

⇓

Fast Jet ⇐ k_T exclusive, selectedPFO's
Force events into: 4 or 6 jets

⇓

Lcfi Vertexing ⇐ 2 jet hypothesis to apply btagging

⇓

Preselection ⇐ Reduction of large cross-section background

⇓

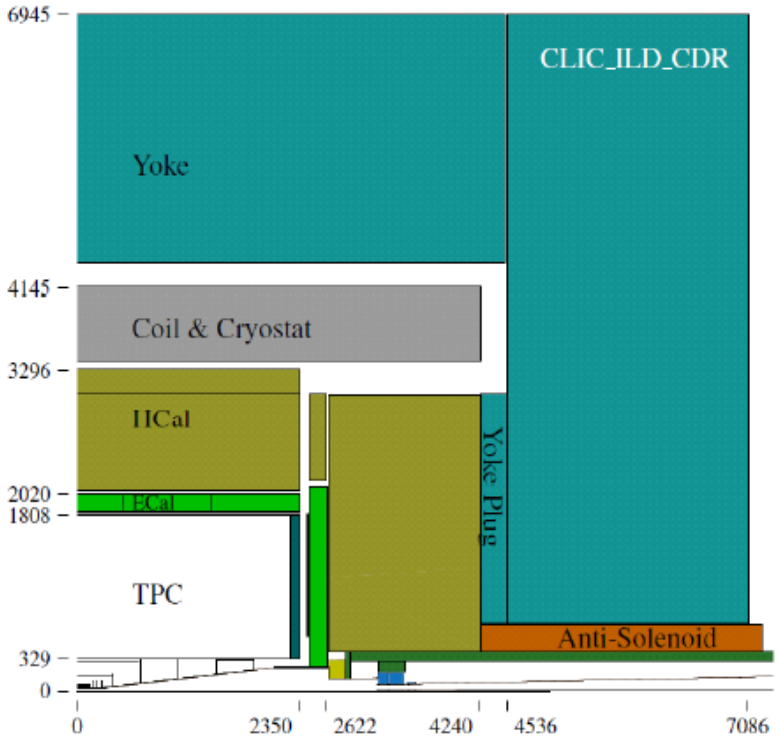
MV selection ⇐ BDT_{350} Likelihood based$_{1.4TeV}$

⇓

Results ⇐ $\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S}$ TMinuit: fit to extract x-sec

Simulation and reconstruction

- Event generation with WHIZARD v.1.95 , ISR
- Beam spectrum generated with GUINEAPIG
- Hadronization with PYTHIA
- $\gamma\gamma$- hadrons overlaid
- Assuming m_H=126 GeV
- CLIC_ILD detector
- Particle reconstruction and identification
  $\Rightarrow$ PandoraPFA



H→WW* at 350 GeV

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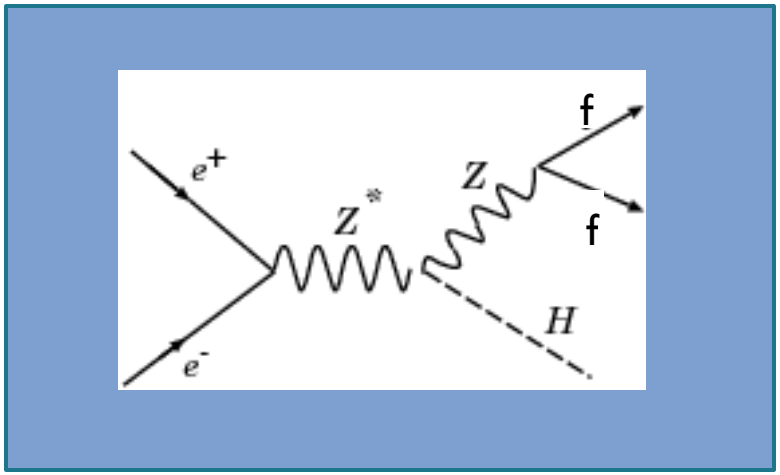
Signal signature



Signal evts:

BF(H→WW→qqqq)~10%

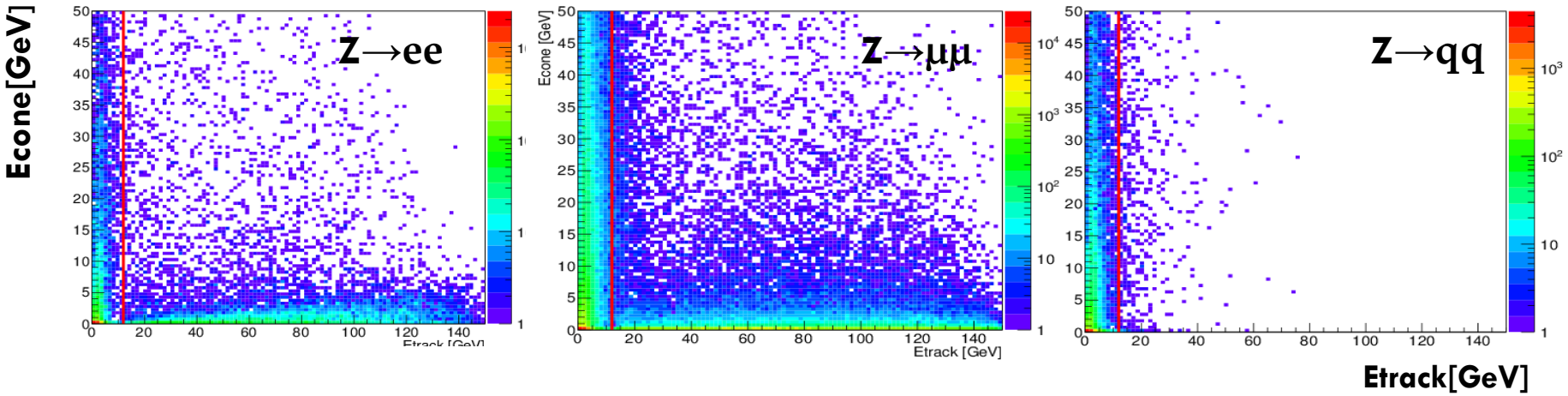
& BF(Z→ll)~10% ⇒ 1%~700 evts

& BF(Z→qq)~70% ⇒ 7%~5000 evts

- Signature:
  - Semileptonic final state: 4 jets +2 leptons
    - Main background :qqll, qqlν, other Higgs decays
  - Hadronic final state: 6 jets
    - Main background: qqqq, other Higgs decays

First step : Lepton isolation

- Lepton identification:
  - track energy >12 GeV
  - energy contained in a cone around the track (cos θ <0.995)
  - ECAL/HCAL depositions



- Signal - reconstructed lepton pairs event:

85% electron pairs 84% muon pairs 3% false lepton pairs

Jet Matching

4 jets + 2 leptons

- Grouping 4 jets to form W real

$$\min(d_{ij}) = \min|M_{ij} - M_W|$$

6 jets final state

- Grouping 6 jets to form W, Z and Higgs

$$\chi^2 = \frac{(M_{ij} - M_W)^2}{\sigma^2_W} + \frac{(M_{kl} - M_Z)^2}{\sigma^2_Z} + \frac{(M_{ijmn} - M_H)^2}{\sigma^2_H}$$

Preselection

4 jets +2 l	6 jets
$m_Z > 40$ GeV	$m_Z > 70$ GeV
$100 < E_{vis} < 300$ GeV	$E_{vis} > 250$ GeV
45 GeV $< m_W < 95$ GeV	
jetPt > 20 GeV	
	-log(y12)<2.0
-log(y23)<2.5	-log(y23)<2.6
-log(y34)<4.0	-log(y34)<3.0
	-log(y45)<3.2
	Thrust <0.9

Event selection BDT

After preselection the most difficult backgrounds are used as an input to MV:

4 jet FS

1. other H decays, HZ, Z→ll
2. qqll
3. qqlν

BDT variables	4 jets+2l
NPFO	
m_Z m_W m_H m_{W^*}	
E_{vis} Ptjet	
θ_{el}	
-log(y23), -log(y34)	
btag, ctag	

6 jet FS

1. other H decays, HZ, Z→qq
2. qqqq

BDT variables	6 jet FS
NPFO	
m_w m_H m_Z m_{w^*}	
E_{vis} P_tHiggsJets	
-log(y12), -log(y23), -log(y34),	
-log(y45), -log(y56), -log(y67)	
btag ctag	
thrust,oblatness ,sphericity, acoplanarity	

Reduction efficiencies

Process	σ [fb]	4 jets		6 jets	
		ε_{pres1}	$\varepsilon=\varepsilon_{pres1}*\varepsilon_{BDT1}$	ε_{pres2}	$\varepsilon=\varepsilon_{pres2}*\varepsilon_{BDT2}$
H→WW*→qqqq, Z→ee	0.49	83%	30%		
H→WW*→qqqq, Z→μμ	0.49	91%	35%		
H→WW*→qqqq, Z→qq	9.9			72%	50 %
Other H decays	91.8	62%	3.0%	35%	0.29%
qqqq	5847	0.2%	$<10^{-5}$ %	**18%**	**0.15%**
qqll	1704	**5.8%**	0.0006%	0.2%	<0.001%
qqlν	5914	**2.6 %**	0.001%	0.1%	$<10^{-4}$ %
qqνν	324.6	0.01%	$<10^{-5}$ %	0.0001%	$<10^{-5}$ %
Hνν	53.4	0.02%	$<10^{-5}$ %	0.0006%	$<10^{-5}$ %

Outlook

- The analysis is constructed
- Refinement of the each analysis step:
  - Lepton isolation: optimize the isolated lepton identification using MC truth matching
  - Jet matching : refine the σ's of the H,W, Z distributions
  - Include backgrounds with 6 fermions in the final state
  - Preselection: redefine
  - Optimize set of BDT variables

H→WW* at 1.4 TeV

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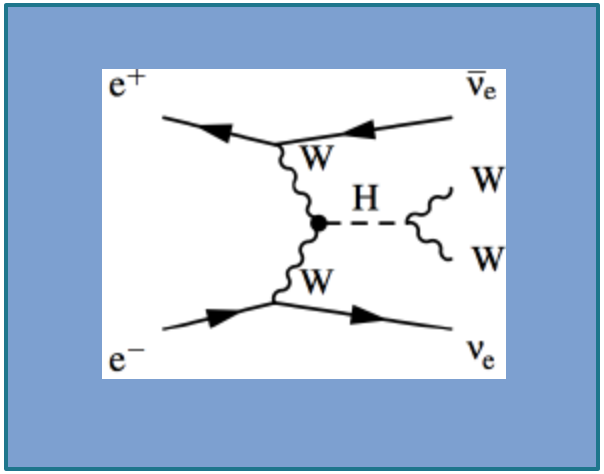
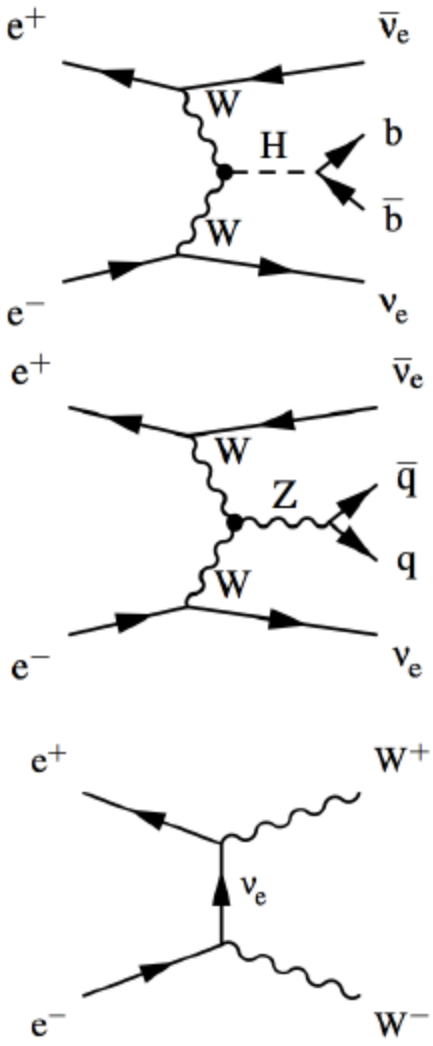
Signal signature





- Signature:
  - missing p_t
  - 4 jets
  - m_H (4 jets) , m_W (2 jets)
- Preselection targeted at main background:

  Hvv other Higgs decays, qqvv, qqqqv

Preselection

Jet Matching

grouping 4 jets to form W real

$$\Rightarrow \quad \min(d_{ij}) = \min |M_{ij} - M_W|$$

Mass variables: m_H m_W, m_{W^*}

- 70 GeV < m_H <150 GeV
- 40 GeV < m_W < 95 GeV

  m_{w^*} < 65 GeV

Jet transitions

- Force all samples into 2,3,4 jets
- Use the k_T value from which jet transitions from:
  - 2 to 3 jets $-\log_{10}(y_{23}) < 2.75$
  - 3 to 4 jets $-\log_{10}(y_{34}) < 3.5$

Evis & pt

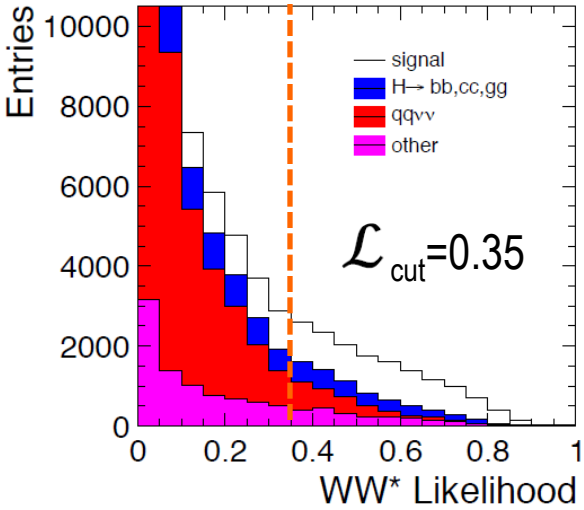
- **125 GeV < E_{vis} < 600 GeV**
- **p_T > 90 GeV**

b tag

$P(b)_1$, $P(b)_2$ < 0.95

Relative likelihood selection

- Constructing likelihood for relevant event types:
  - signal $H \rightarrow WW^*$
  - background $H \rightarrow bb, gg, qqvv, qqqqv$
- Using 2d distributions (correlations included)
  - m_W vs. m_H
  - y_{23} vs. y_{34}
  - $P(b)_1$ vs. $P(b)_2$



$$L_i = P(m_W, m_H) \times P(y_{23}, y_{34}) \times P(b_1, b_2), \quad i = (1,5)$$

- Constructing relative likelihood distributions:

$$\mathcal{L}_{WW^*} = \frac{L(WW^*)}{L(WW^*) + L(b\bar{b}) + L(gg) + L(qq\nu\nu) + L(q\bar{q}q\bar{q}\nu)}$$

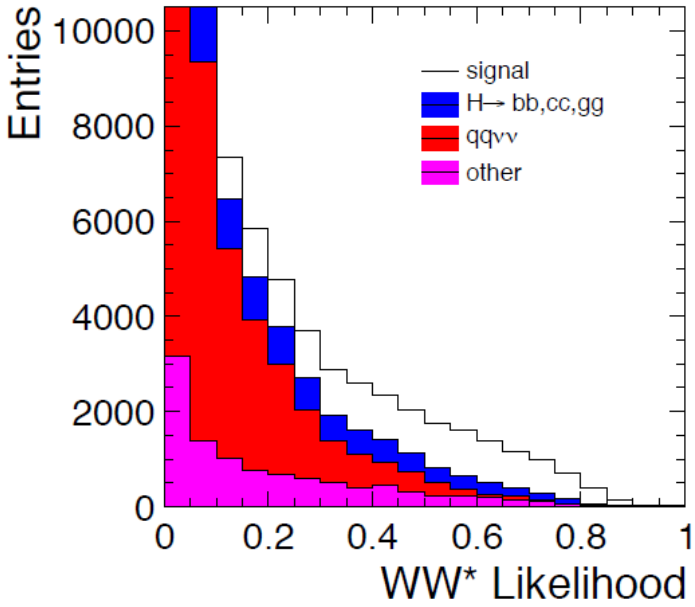
Reduction efficiencies

Process	σ [fb];	ε_{pres} .	$\varepsilon_{L>0.35}$	$N_{L>0.35}$
$H\to WW^*\to q\bar{q}q\bar{q}$	27.5	32.4 %	18.1 %	7518
$qq\nu\nu$	788.0	4.6 %	0.2 %	2225
$qqql\nu$	115.3	0.1 %	<0.1 %	43
$qqq\nu\nu$	24.7	0.8 %	0.4 %	130
$\gamma e^+(\gamma e^-)\to qqq\nu$	254.3	1.8 %	0.4 %	1389
$H\nu\nu$ other Higgs decays	216.5			3583
$H\to WW^*\to q\bar{q}l\nu$		4.4 %	0.6 %	253
$H\to b\bar{b}$		1.9 %	0.4 %	774
$H\to c\bar{c}$		8.1 %	2.1 %	209
$H\to gg$		19.1 %	7.1 %	1736
$H\to ZZ$		12.0%	5.0 %	556
$H\to$other		0.7%	0.2 %	55

S/B~1:1

Constrained fit

- Signal and background shapes not so different $\Rightarrow$ need to include constraints
- Branching fractions of Higgs to bb,cc and gg are constrained to the values obtained from the independent measurements at 1.4 TeV



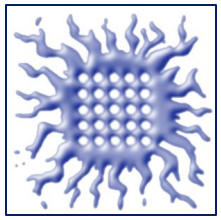
$$\chi^2 \sim \chi^2 + \frac{(1-s^2_{gg})^2}{\sigma^2_{gg}} + \frac{(1-s^2_{bb})^2}{\sigma^2_{bb}} + \frac{(1-s^2_{cc})^2}{\sigma^2_{cc}} + \frac{(1-b^2)^2}{\sigma^2_{b}}$$

$$\left.\begin{aligned} &\sigma_{bb} = 1.8\%,\ \ \sigma_{cc} = 2.9\%, \\ &\sigma_{bb} = 0.3\%,\ \ \sigma_{b} = 1.0\,\%\ (\text{assumed}) \end{aligned}\right\} \quad \text{FIT} \Rightarrow \quad \boxed{\frac{\Delta\sigma}{\sigma} = 1.4\%}$$

Conclusions

- H $\rightarrow$WW* decay plays an important role in the CLIC physics program, especially in the determination of the total Higgs decay width.
- Analysis of the H $\rightarrow$ WW* decay from the HZ at 350 GeV constructed and being refined.
- The $\sigma(h\nu_e\bar{\nu}_e)$ x BR(H $\rightarrow$WW*) at the 1.4 TeV CLIC is determined with a statistical precision of 1.4 %.

END



Acknowledgements: P. Roloff, S. Redford, S. Lukic & HEP Group Vinca