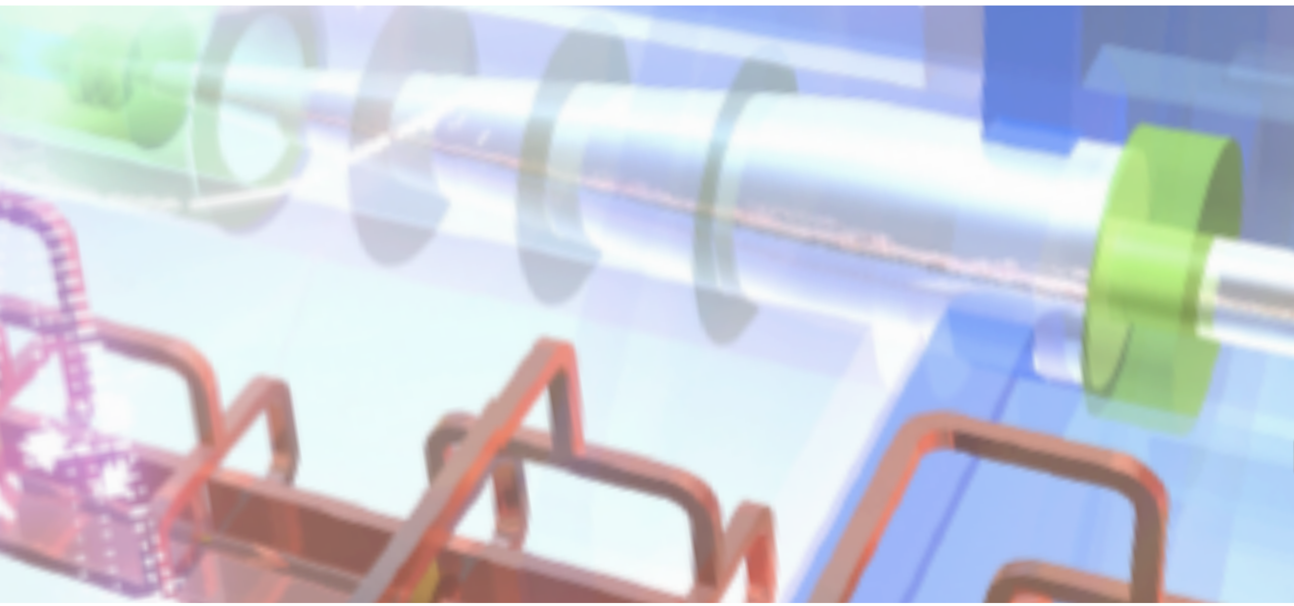
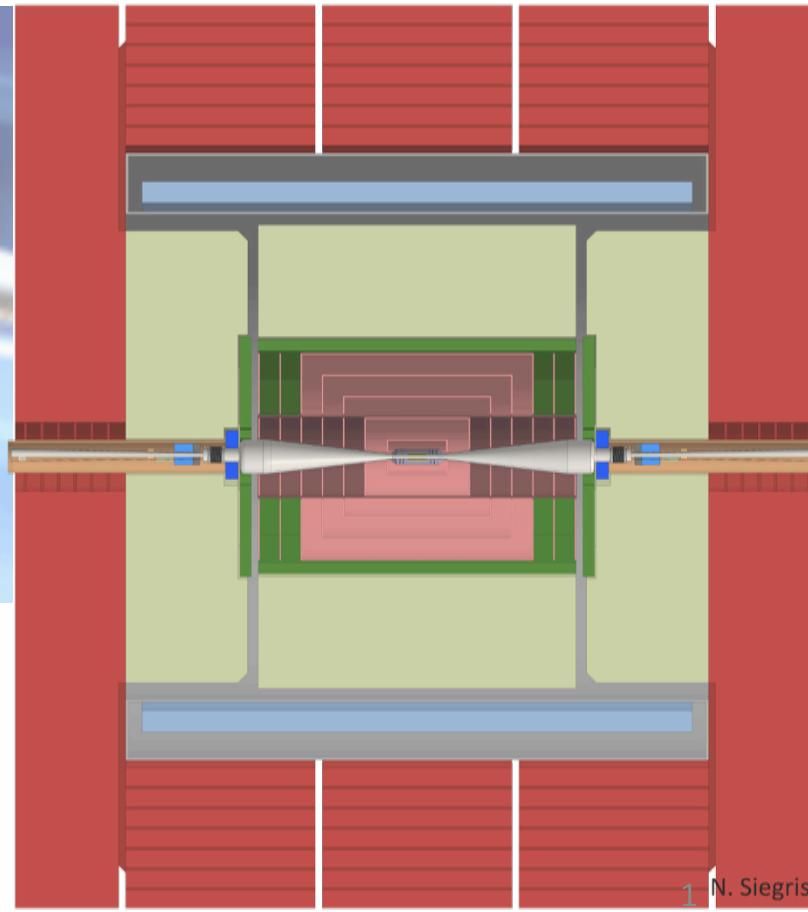
The CLIC Physics Potential





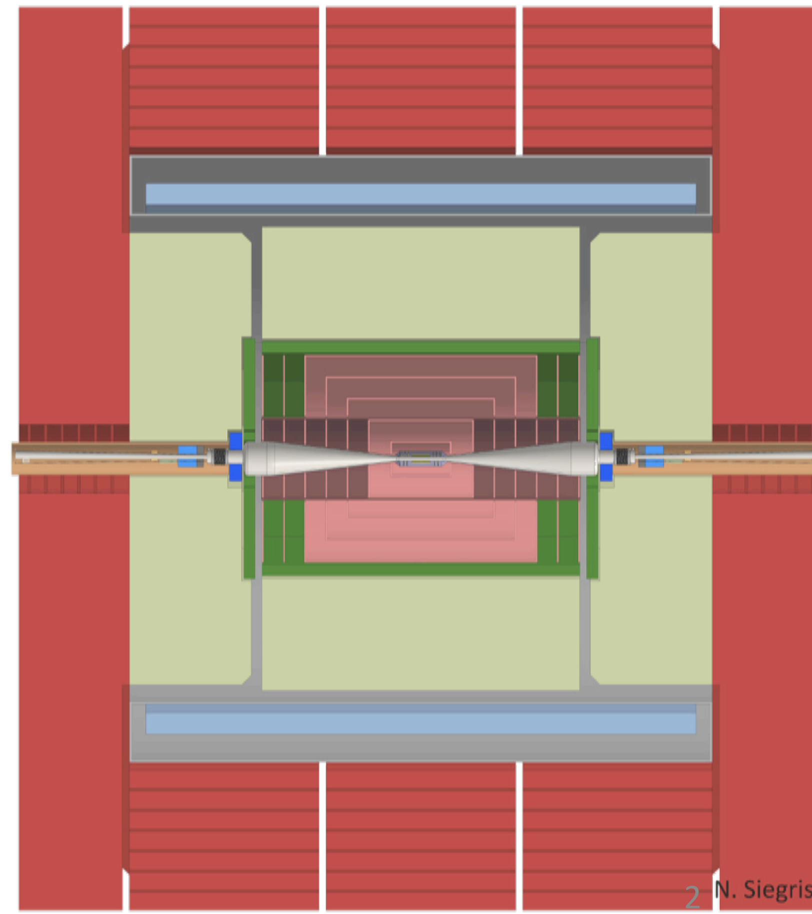
University of Glasgow

Aidan Robson

on behalf of the
CLICdp collaboration

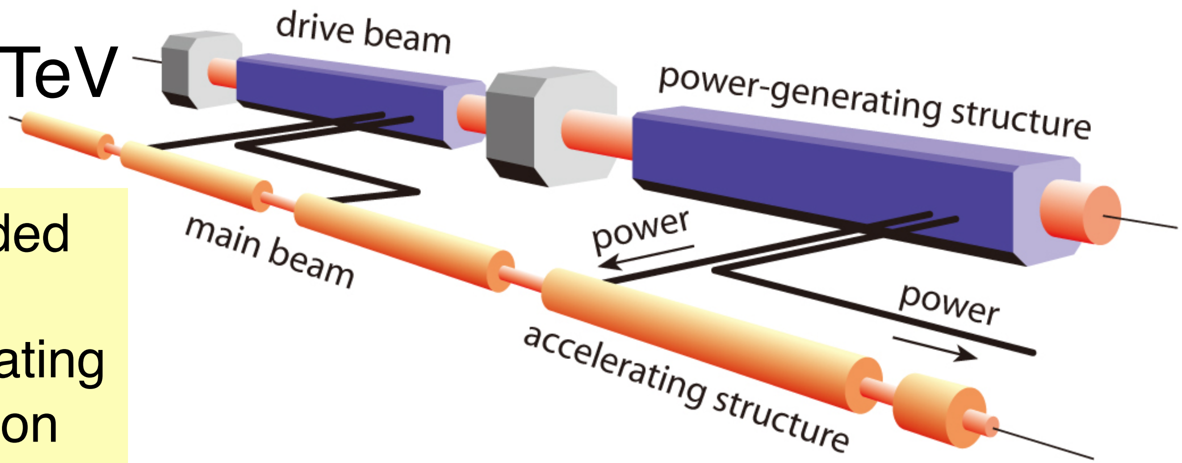
The CLIC Physics Potential

- CLIC Overview
- Physics highlights:
  - Higgs
  - top
  - BSM
- Outlook

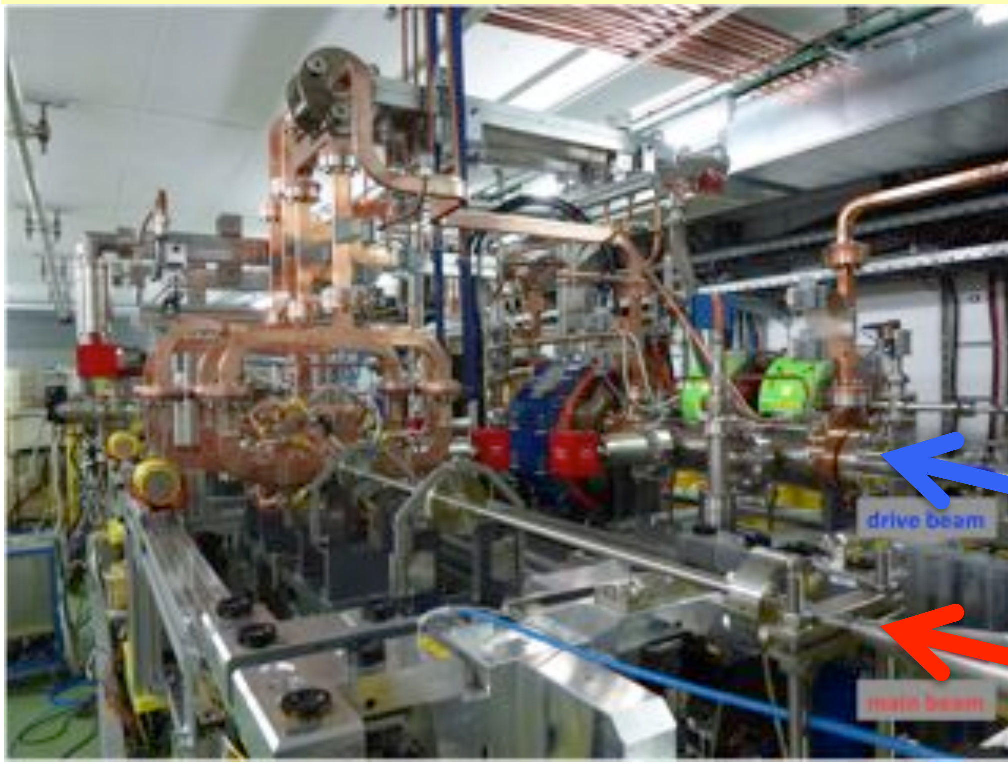


Compact Linear Collider: CLIC

e^+e^- collider with $\sqrt{s}$ up to 3 TeV



100 MV/m accelerating gradient needed for compact (~50km) machine
Based on normal-conducting accelerating structures and a two-beam acceleration scheme



CLIC foreseen as a staged machine:

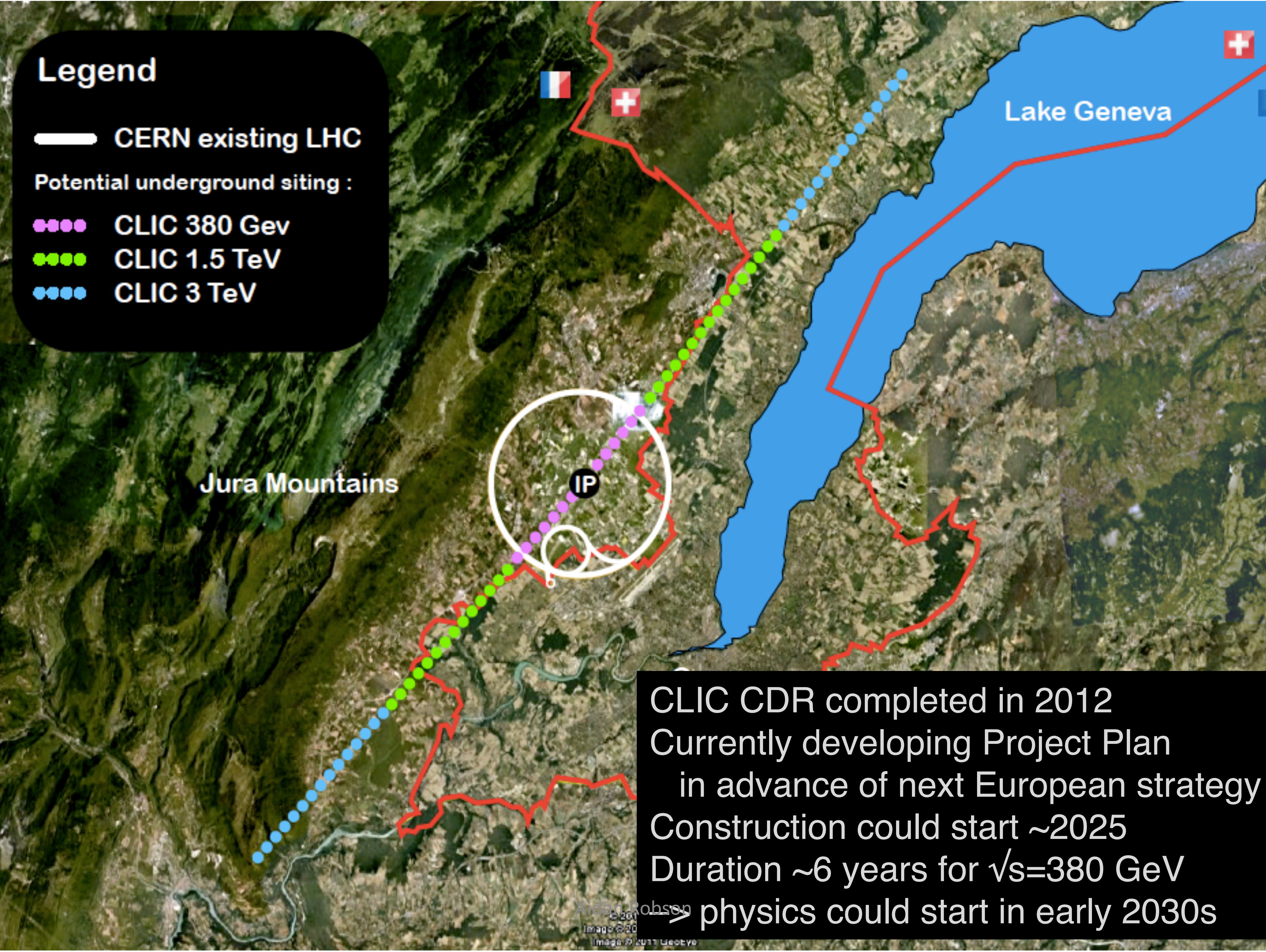
- Stage 1 baseline: $\sqrt{s}$=380GeV: precision SM physics: Higgs and top

Energies of subsequent stages motivated by physics

- Stages 2 & 3 baseline: 1.5 TeV, 3 TeV

Drive beam

Main beam



CLIC CDR completed in 2012
Currently developing Project Plan
in advance of next European strategy
Construction could start ~2025
Duration ~6 years for $\sqrt{s}$=380 GeV
--> physics could start in early 2030s

CLIC collaborations

CLIC/CTF3 accelerator collaboration
62 institutes from **28 countries**

http://clic-study.web.cern.ch/

CLIC detector and physics (CLICdp)
27 institutes from **17 countries**

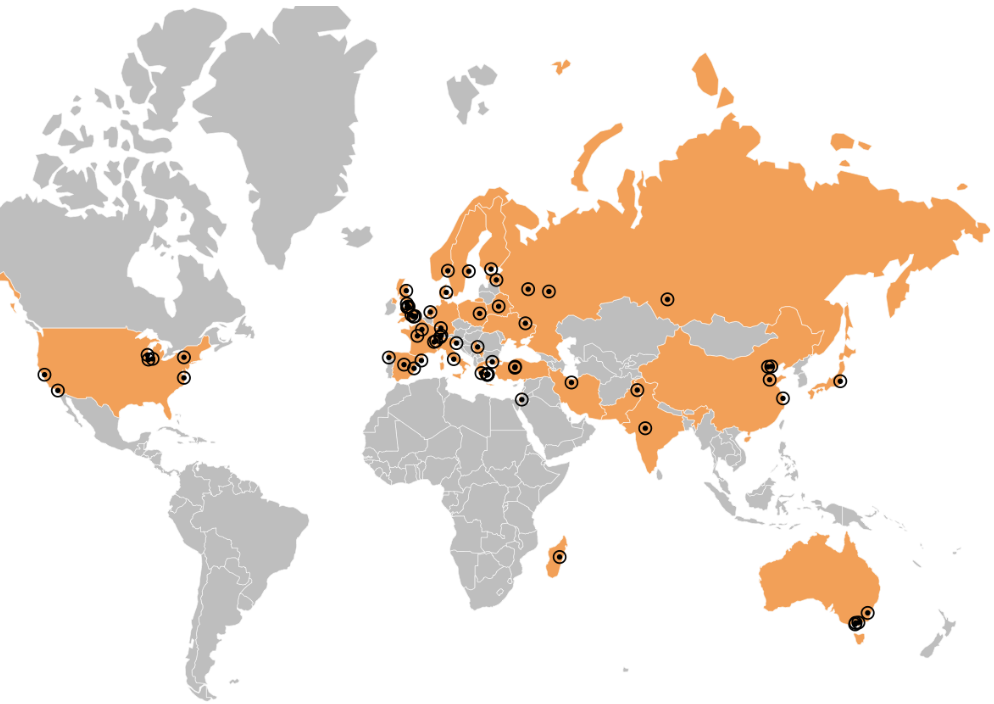
http://clicdp.web.cern.ch/

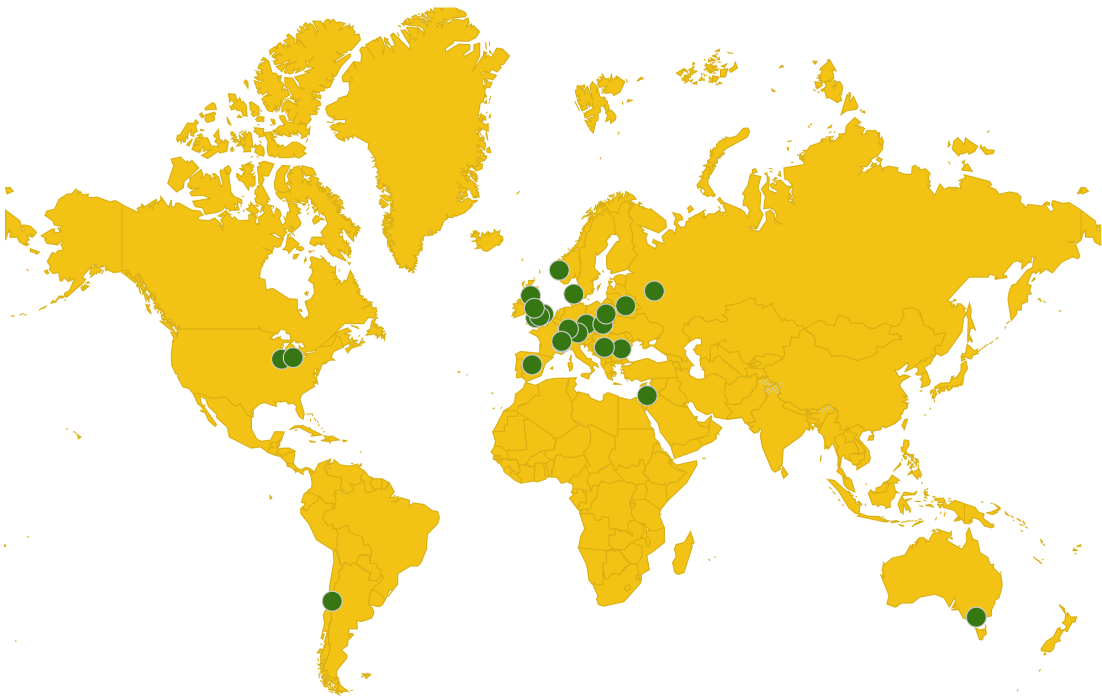
CLIC accelerator studies:

- CLIC accelerator design & development
- Construction and operation of CTF3

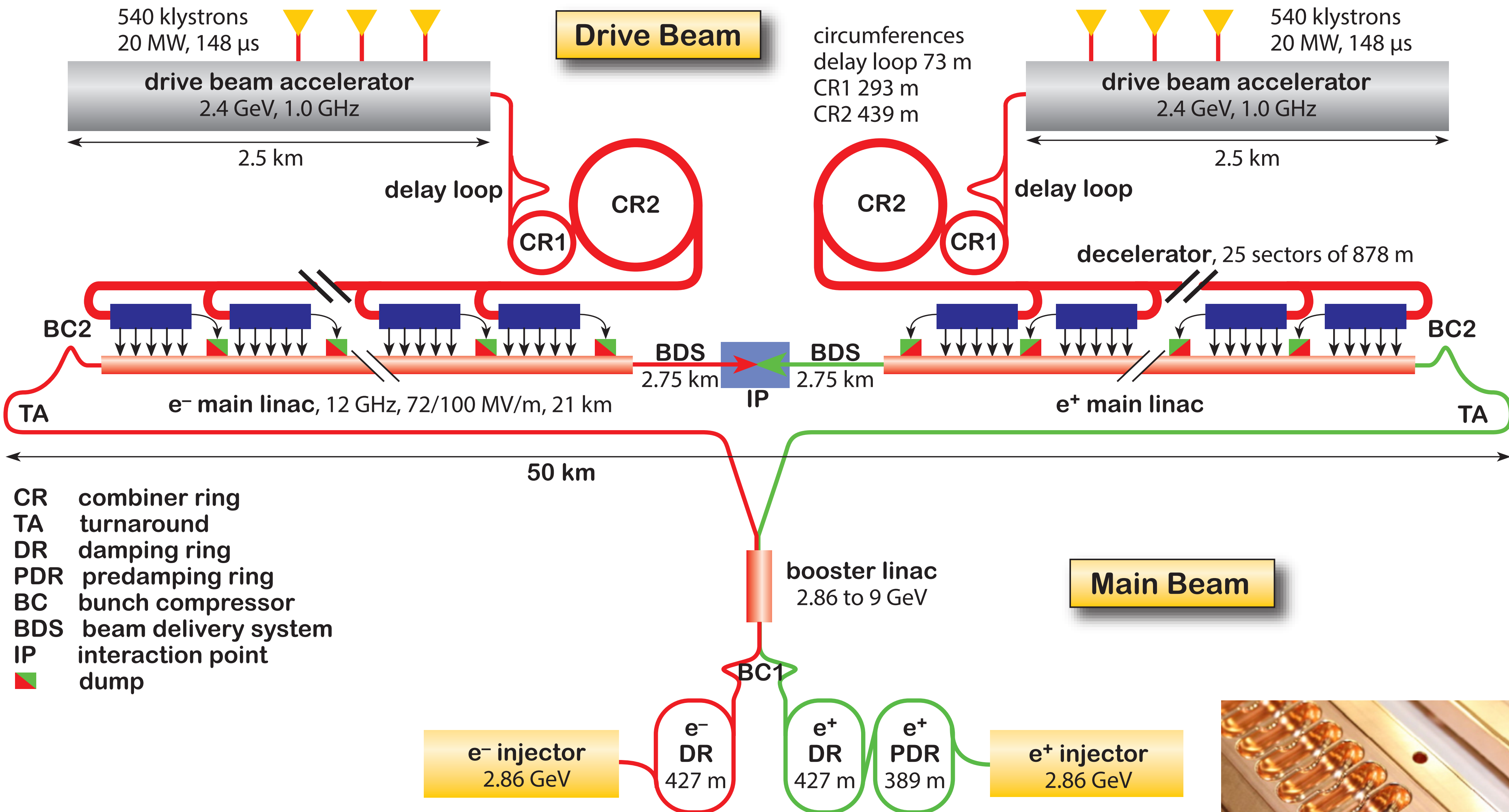
Focus of CLIC-specific studies on:

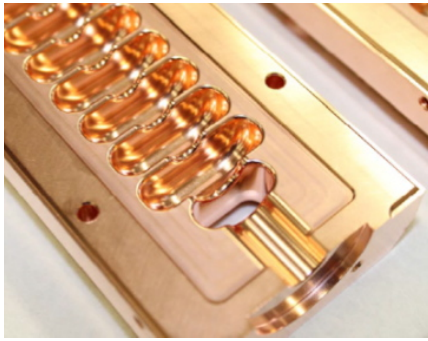
- Physics prospects & simulation studies
- Detector optimization + R&D for CLIC



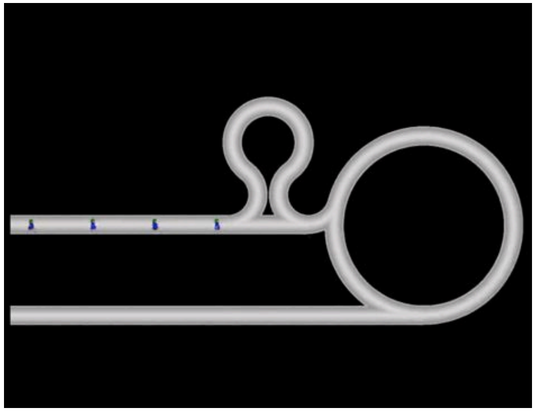


CLIC layout 3 TeV

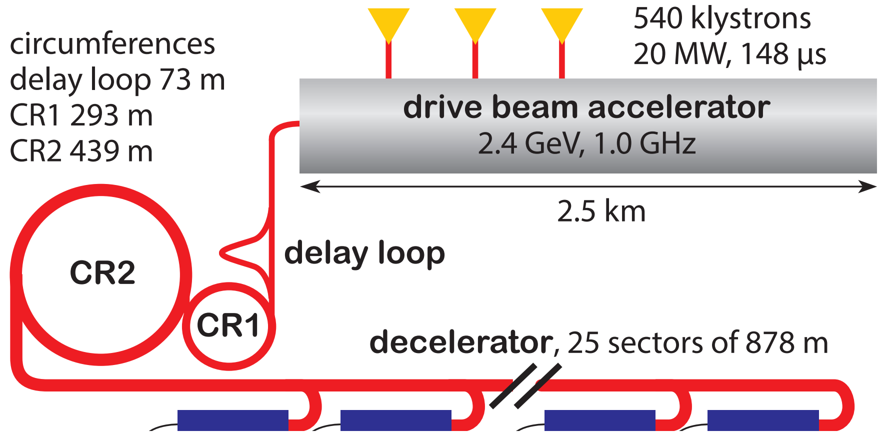


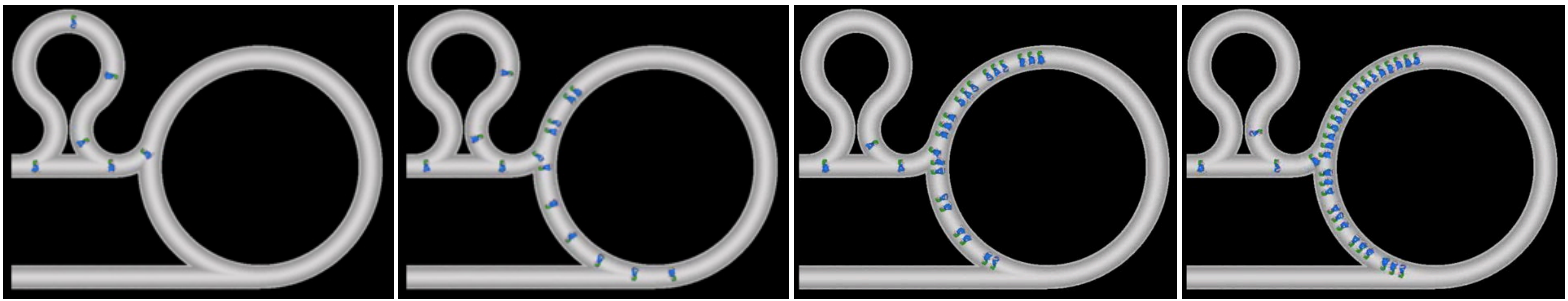


Machine context



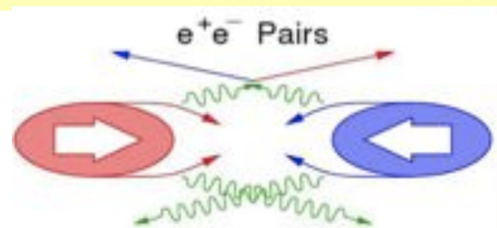
Delay loops create drive beam bunch-structure

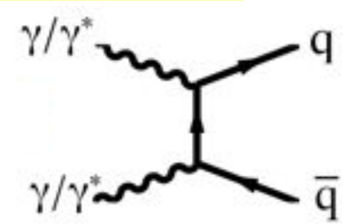




Low energy high current drive beam -> high energy low current main beam

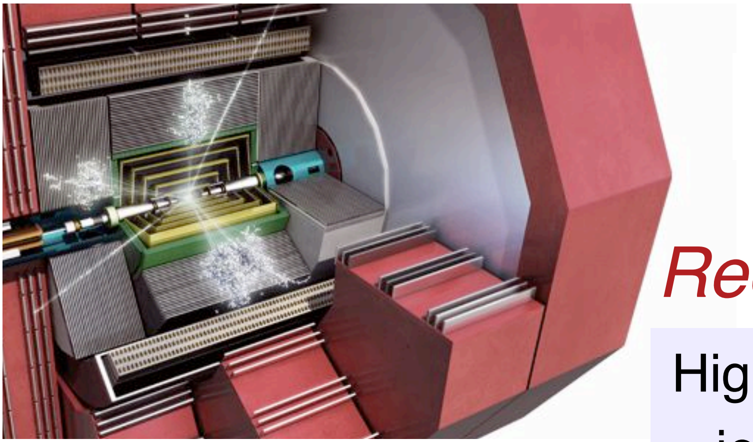
CTF3 test facility at CERN has demonstrated drive beam generation and two-beam acceleration scheme (up to 135MV/m measured)

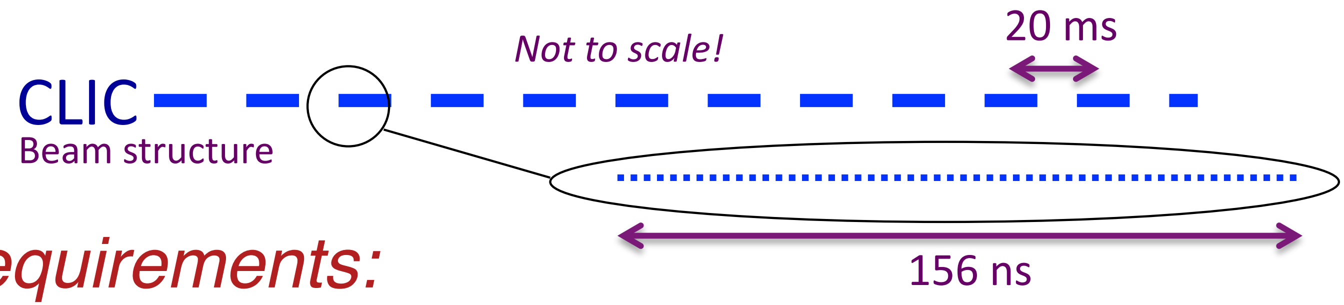




High bunch-charge density –> beamstrahlung
Incoherent e^+e^- pairs and γγ–>hadrons

CLIC detector and physics





Requirements:

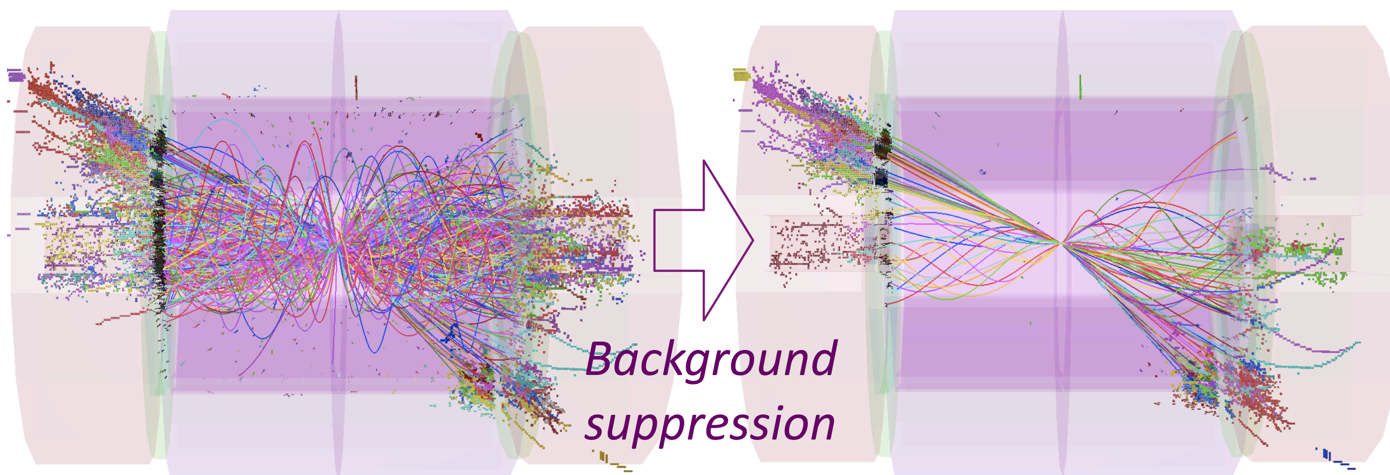
High precision:

- jet energy resolution
  –> fine-grained calorimetry — $\sigma(E)/(E) \sim 3.5\%$ for E>100GeV
- momentum resolution — $\sigma(p_T)/p_T^2 \sim 2\text{x}10^{-5}\ \text{GeV}^{-1}$
- impact parameter resolution — $\sigma_{r\phi} \sim 5 \oplus 15/(p[\text{GeV}]\sin^{3/2}\theta)\ \mu\text{m}$

CALICE / FCAL

CLICdp vertexing/ tracking programme

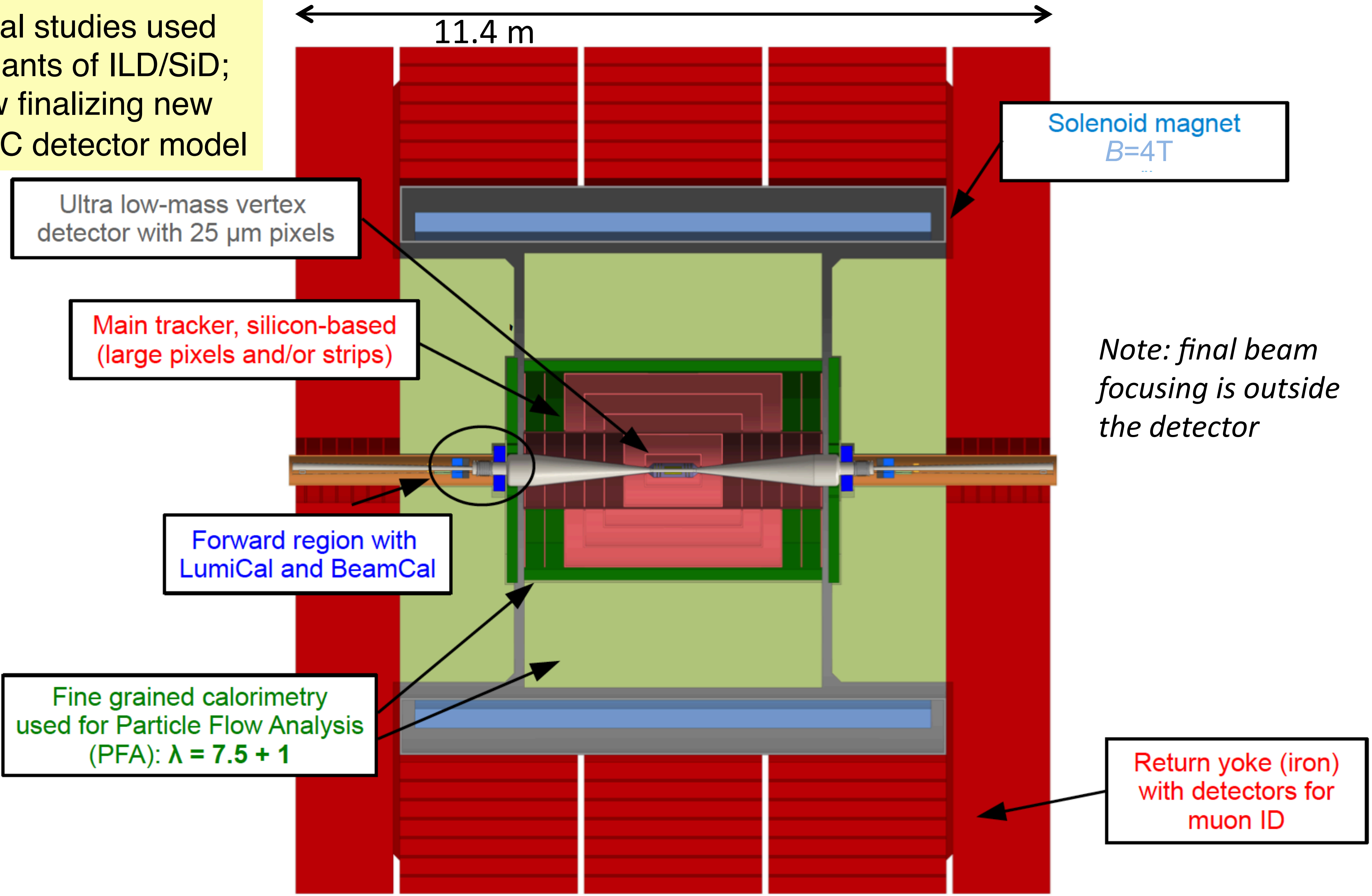
High occupancy
-> precise timing
(1ns, 10ns)



- Provide demonstrators for the main technical challenges

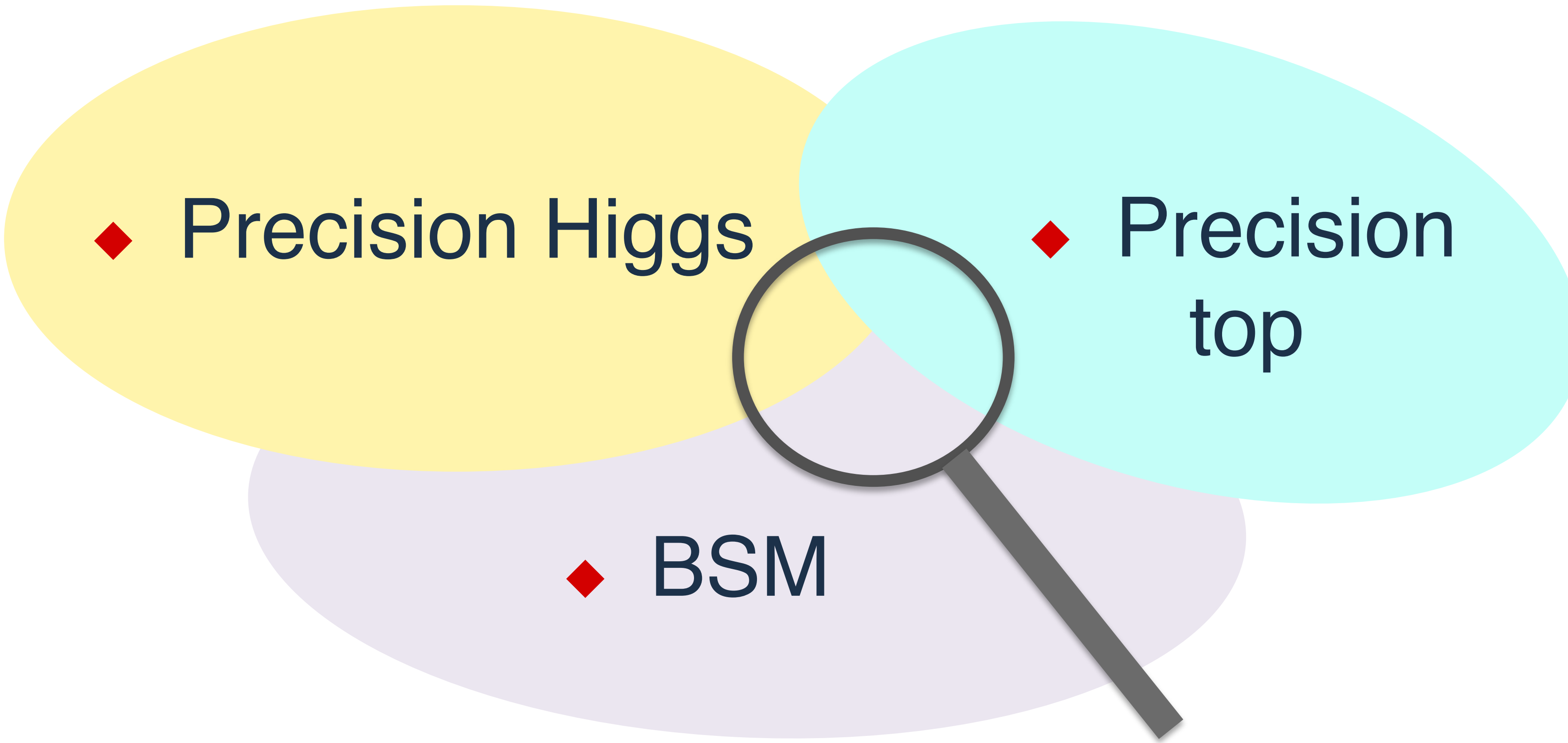
Detector optimization

Initial studies used variants of ILD/SiD; now finalizing new CLIC detector model



Note: final beam focusing is outside the detector

Physics motivations



Higgs overview

$$g^2_{HAA} \propto \Gamma(H \to AA) = \Gamma_H \cdot BR(H \to AA)$$

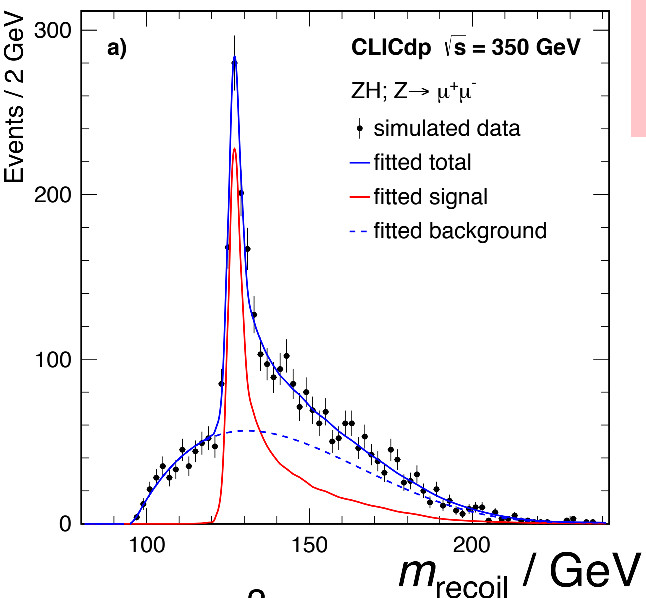
σ x Br → **Br** → **g coupling**

the key

σ from recoil mass → **Γ_H total width**

(need WW fusion for precision total width -> higher √s)

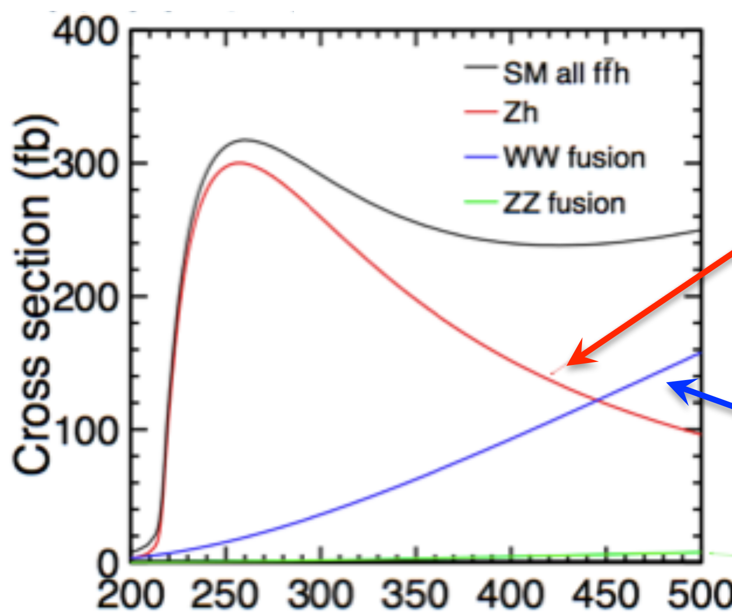
$$\frac{\sigma_{ZH}\ .Br(H\text{->}bb)}{\sigma_{\nu\nu H}\ .Br(H\text{->}bb)} \propto \frac{g^2_{HZZ}}{g^2_{HWW}}$$

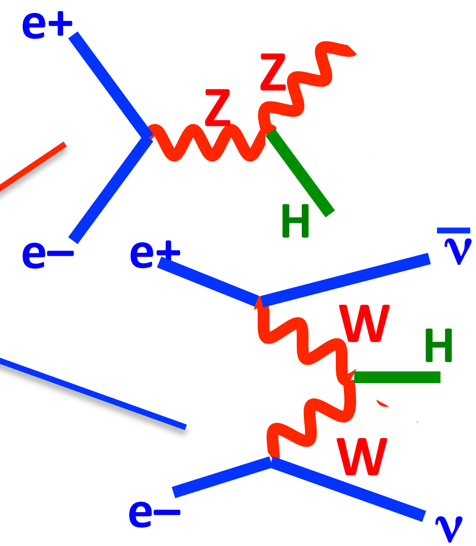


$\sigma_{ZH} \propto g^2_{HZZ}$

$\sigma_{\nu\nu H}\ .Br(H\text{->}WW) \propto g^4_{HWW}/\Gamma_H$

after Fujii/Tanabe





Higgs overview

$$g_{HAA}^2 \propto \Gamma(H \to AA) = \Gamma_H \cdot BR(H \to AA)$$

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the key

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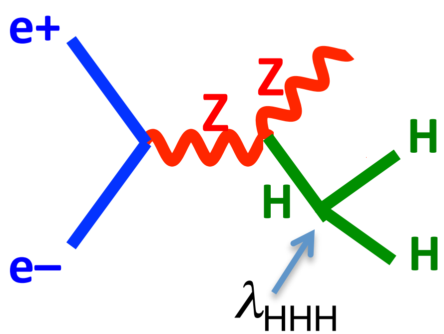
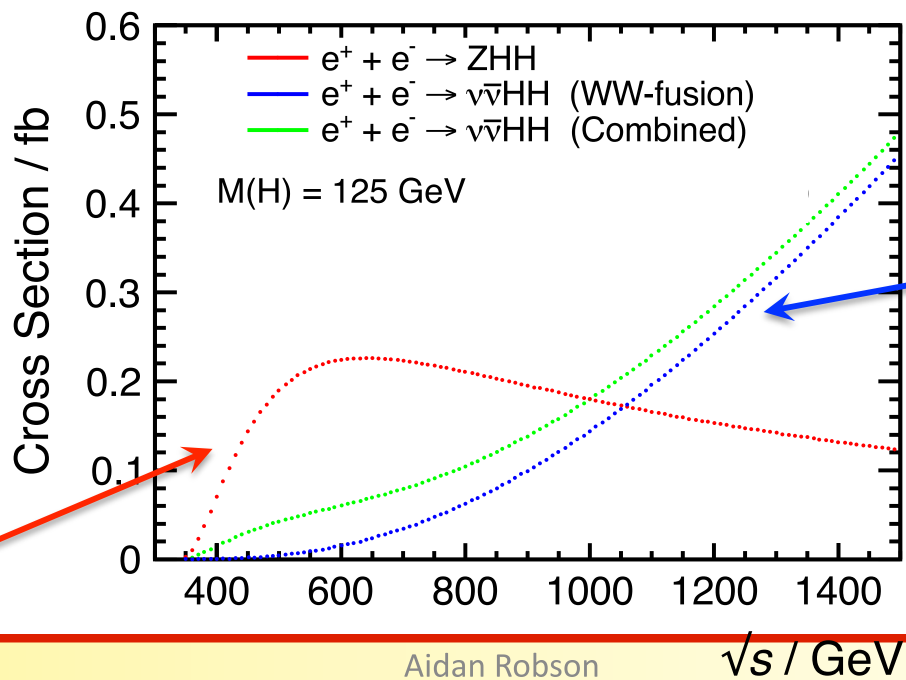
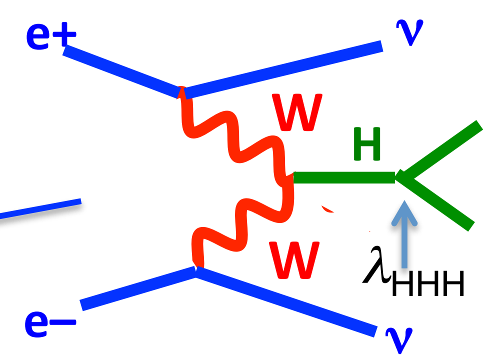
(need WW fusion for precision total width -> higher √*s*)

Higher energies:
ttH, HH



dominates around √*s*=500GeV





dominates at higher √*s*

Higgs couplings – BSM sensitivity

example scenarios in which $M \sim 1$TeV for new particles

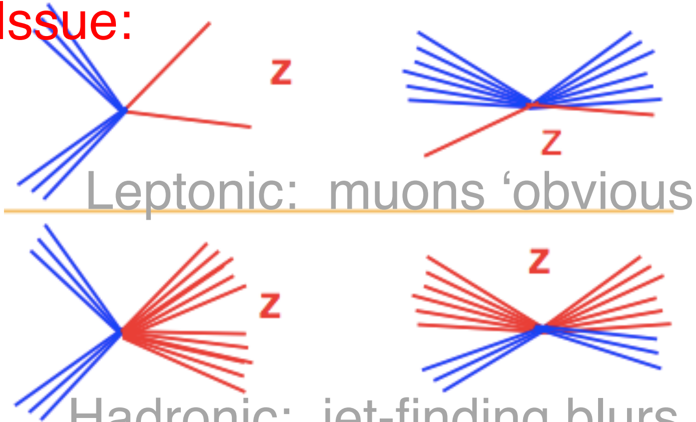
Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

arXiv: 1310.8361

Hadronic events in recoil analysis

at $\sqrt{s}$ above ZH cross-section peak: leptonic recoil does not provide required precision
–> can sensitivity be recovered using ***hadronic*** Z decay?

Issue:



Leptonic: muons 'obvious'

Hadronic: jet-finding blurs separation between H and Z

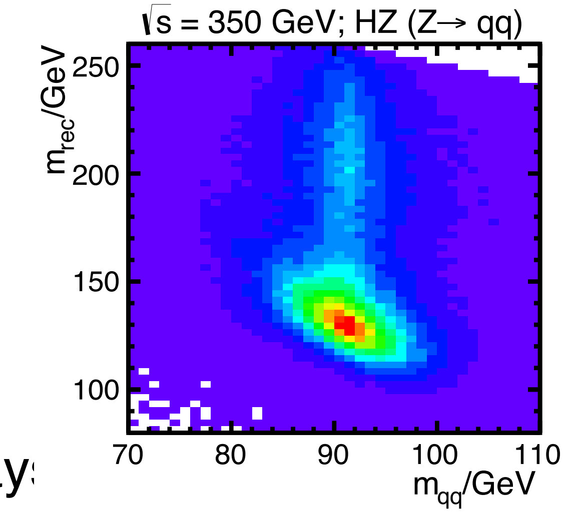
-> different efficiencies for different Higgs decays – can it be made model-independent?

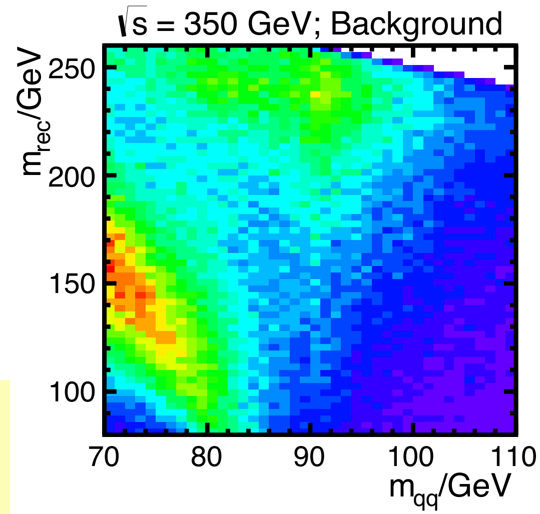
-> YES ;

consider events as candidate invisible or visible Higgs decays

reconstruct visible Higgs candidates as 4 or 5 "jets"

use m_{qq} and m_{recoil} in likelihood separator





2 jets from Z->qq, plus Higgs decay

- H→qq : 2 jets = 4 'objects' to reconstruct
- H→γγ : 2 photons = 4 'objects'
- H→ττ : 2 taus = 4 'objects'
- H→WW*→lνlν : 2 leptons = 4 'objects'
- H→WW*→qqlν : 2 jets + lepton = 5 'objects'
- H→WW*→qqqq : 4 jets = 6 'objects'
- H→ZZ*→ννqq : 2 jets = 4 'objects'
- H→ZZ*→qqll : 2 jets + 2 leptons = 6 'objects'
- H→ZZ*→qqqq : 4 jets = 6 'objects'

$\Delta\sigma_{HZ}$ ~ 4.2% for Z->ll
$\Delta\sigma_{HZ}$ ~ 1.8% for Z->qq
Δg_{HZZ} ~ 0.8% including all channels

arXiv: 1509.02853

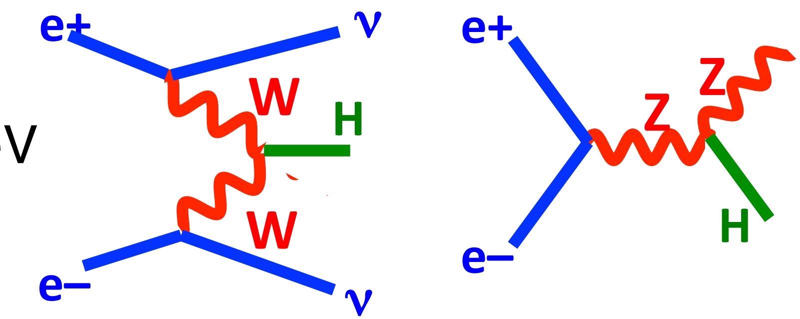
Higgs -> bb/cc/gg

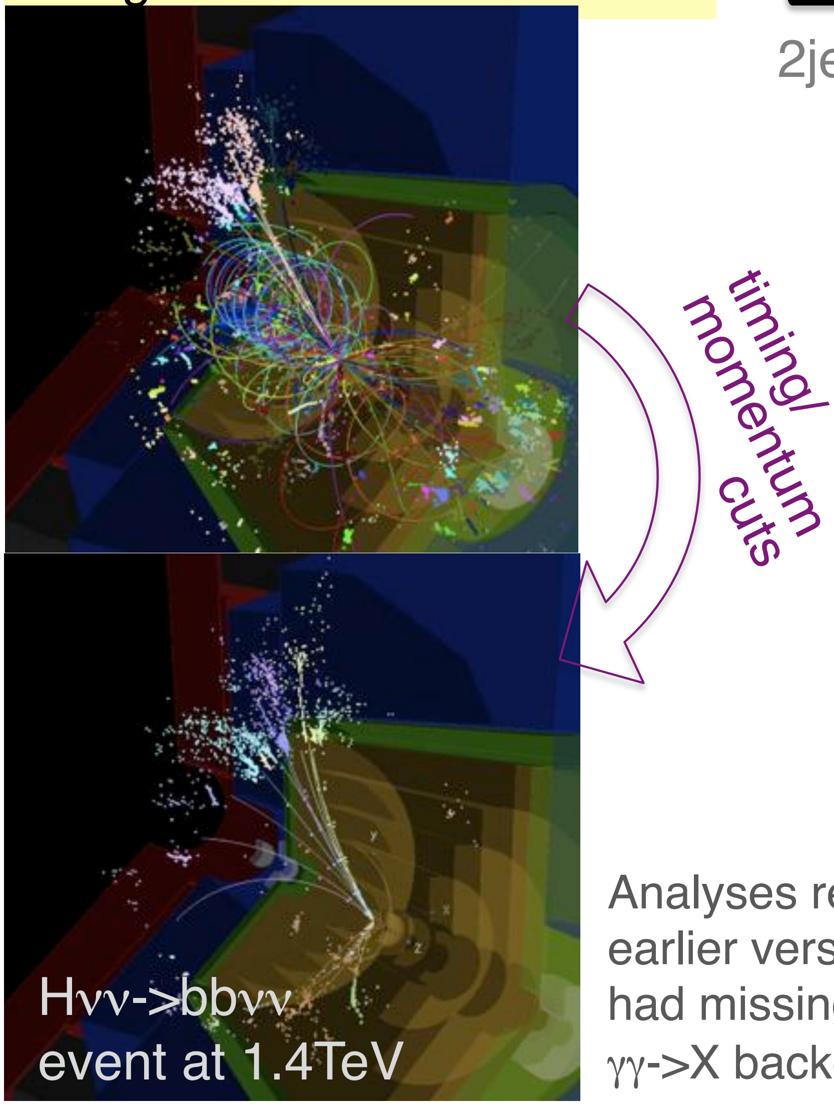
Separation of bb/cc/gg final state possible in e+e–, using excellent detector

New analyses at 3TeV, 1.4TeV, 350GeV

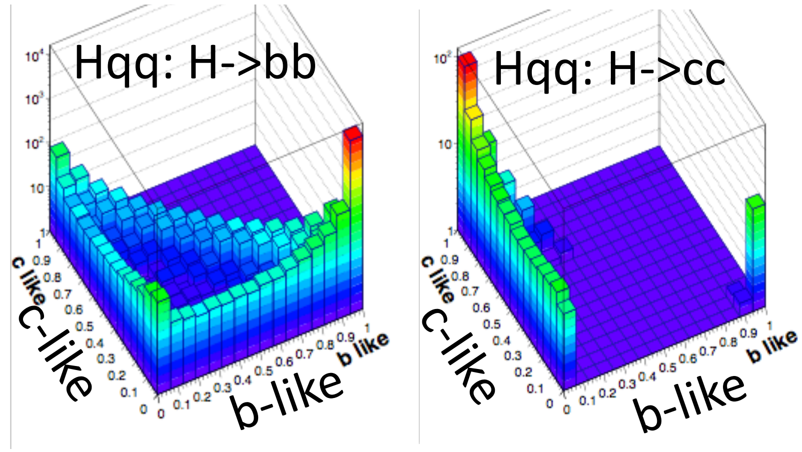
2jets+missing energy

also 2 jets + 2 leptons, and 4 jets





Train BDTs to classify events then fit templates



Analyses replace earlier versions that had missing eγ->X , γγ->X backgrounds

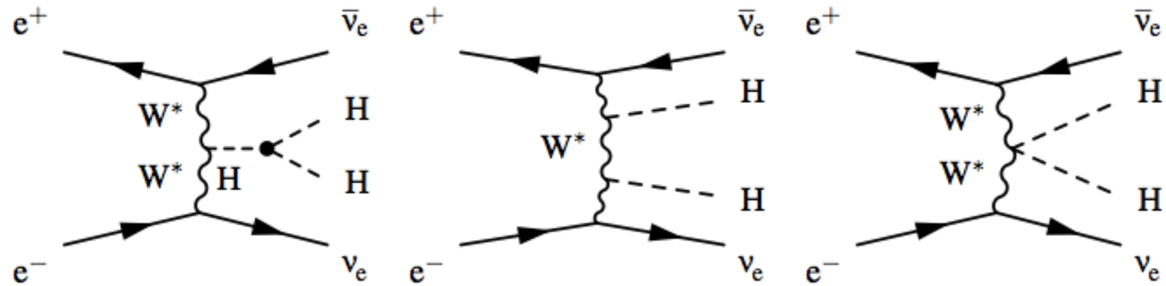
at $\sqrt{s}$=350 GeV

Δ(σxBr(H->bb)) (VBF)	1.8%
Δ(σxBr(H->bb)) (ZH)	0.85%
Δ(σxBr(H->cc))	10.7%
Δ(σxBr(H->gg))	4.1%

New!

Higgs self-coupling and mass

Self-coupling:



Looking at HHνν -> bbbbνν
4-jet final state, require 4 b-tag jets
-> systematic studies of clustering and jet algorithm to optimize for energy flow

Measure Higgs self-coupling g_{HHH} at 3 TeV; simultaneous extraction with g_{HHWW}

–> $\Delta\lambda/\lambda$ =12%
at $\sqrt{s}$=3TeV ($2ab^{-1}$)

Higgs mass:

Dataset	Δm_H unpolarised	Δm_H p(e–)
1.4 TeV	47 MeV	35 MeV
3 TeV	44 MeV	33 MeV
1.4 + 3 TeV	32 MeV	**24 MeV**

HL-LHC projection:
Δm_H = 50 MeV arXiv:1310.8361

Comprehensive Higgs studies

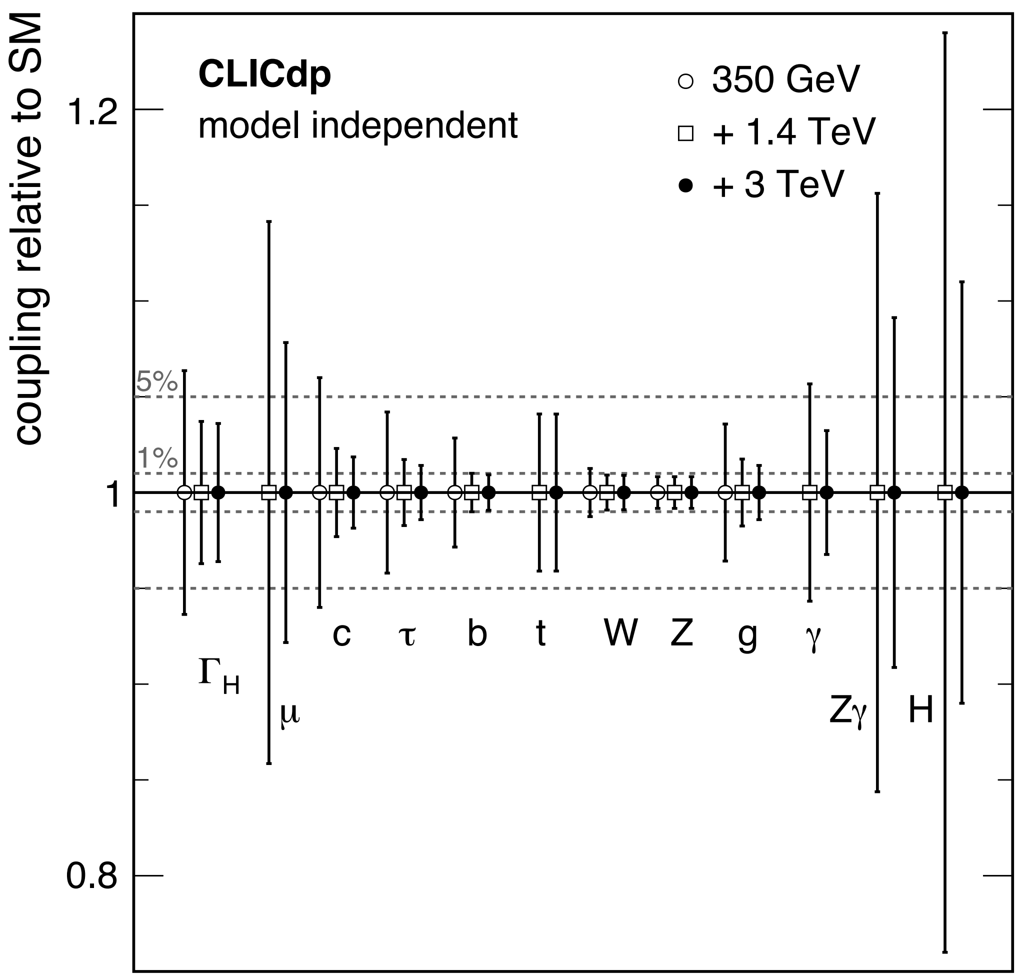
Channel	Measurement	Observable	Statistical precision 350 GeV 500 fb^{-1}
ZH	Recoil mass distribution	m_H	110 MeV
ZH	$\sigma(ZH) \times BR(H \to \text{invisible})$	Γ_{inv}	0.6 %
ZH	$\sigma(ZH) \times BR(Z \to l^+l^-)$	g^2_{HZZ}	4.2 %
ZH	$\sigma(ZH) \times BR(Z \to q\bar{q})$	g^2_{HZZ}	1.8 %
ZH	$\sigma(ZH) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	0.85 %
ZH	$\sigma(ZH) \times BR(H \to c\bar{c})$	$g^2_{HZZ} g^2_{Hcc}/\Gamma_H$	10.4 %
ZH	$\sigma(ZH) \times BR(H \to gg)$		4.5 %
ZH	$\sigma(ZH) \times BR(H \to \tau^+\tau^-)$	$g^2_{HZZ} g^2_{H\tau\tau}/\Gamma_H$	6.2 %
ZH	$\sigma(ZH) \times BR(H \to WW^*)$	$g^2_{HZZ} g^2_{HWW}/\Gamma_H$	5.1 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	1.9 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	14.5 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		5.8 %

Channel	Measurement	Observable	Statistical precision 1.4 TeV 1.5 ab^{-1}	3 TeV 2.0 ab^{-1}
$H\nu_e\bar{\nu}_e$	$H \to b\bar{b}$ mass distribution	m_H	47 MeV	44 MeV
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	0.4 %	0.3 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	6.1 %	6.9 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		5.0 %	4.3 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \tau^+\tau^-)$	$g^2_{HWW} g^2_{H\tau\tau}/\Gamma_H$	4.2 %	4.4 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \mu^+\mu^-)$	$g^2_{HWW} g^2_{H\mu\mu}/\Gamma_H$	38 %	25 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \gamma\gamma)$		15 %	10 %†
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to Z\gamma)$		42 %	30 %†
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to WW^*)$	g^4_{HWW}/Γ_H	1.0 %	0.7 %†
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to ZZ^*)$	$g^2_{HWW} g^2_{HZZ}/\Gamma_H$	5.6 %	3.9 %†
He^+e^-	$\sigma(He^+e^-) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	1.8 %	2.3 %†
$t\bar{t}H$	$\sigma(t\bar{t}H) \times BR(H \to b\bar{b})$	$g^2_{Htt} g^2_{Hbb}/\Gamma_H$	8 %	–
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	g_{HHWW}	7 %	3 %
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	λ	32 %	16 %
$HH\nu_e\bar{\nu}_e$	with −80% e$^-$ polarisation	λ	24 %	12 %

–> focus for ~3 years has been to measure many processes at all energy stages;
~20 individual analyses

- Combined fit of all the measurements –> extract fundamental parameters

Comprehensive Higgs studies

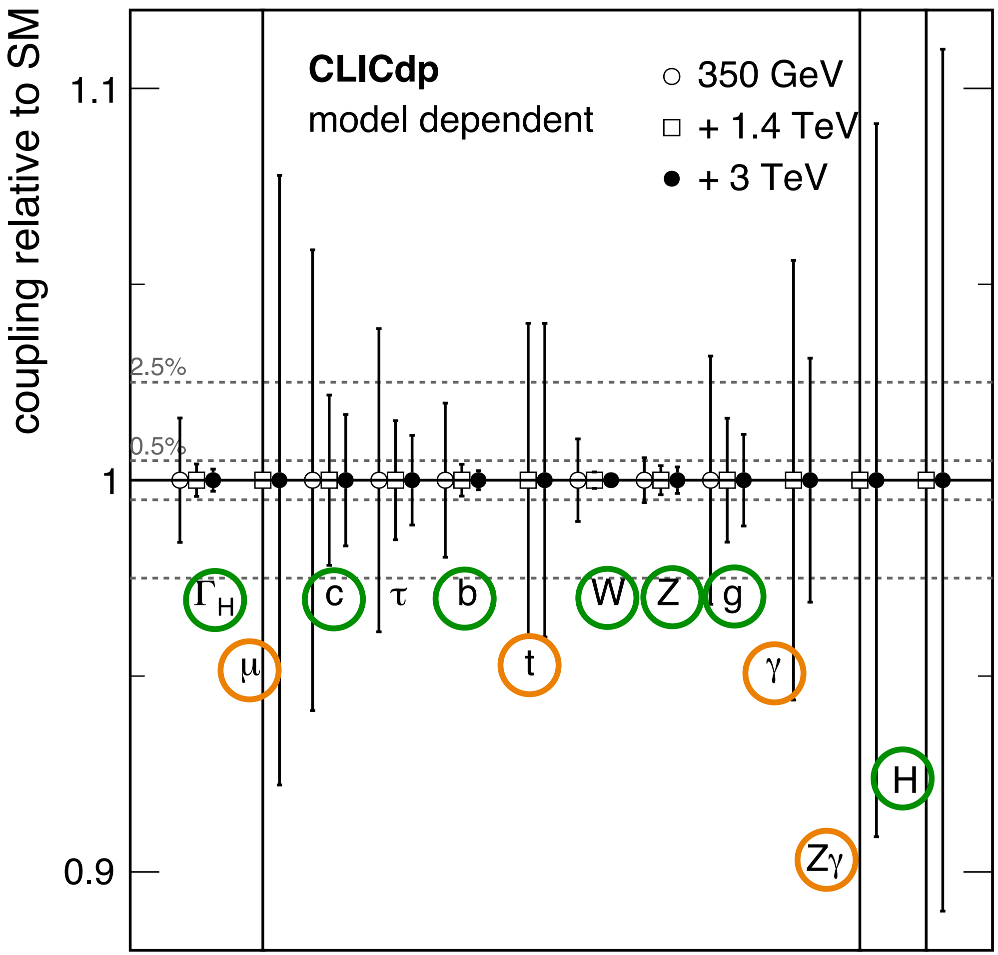


Each stage contributes significantly: first stage provides crucial model-independent Z coupling measurement, and couplings to most fermions and bosons; higher stages improve them, and add t, μ, γ couplings

- Large statistics at high energies allow unique measurements and high precision!

- Fully model-independent (possible only at a lepton collider), Γ_H free parameter
- All results limited by g_{HZZ} determination: 0.8% from σ(HZ) measurement
- Higgs width extracted with 6.3–3.6% precision

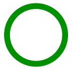
Comprehensive Higgs studies



'model-dependent' assumes fractional shift in κ is equal for u,c,t ; for d,s,b ; and for e,μ,τ ; and no Higgs decay to invisible/exotic particles

–> comparison with LHC projections

- sub-percent precisions at high energy

 Precision significantly better than HL-LHC

 Precision comparable to HL-LHC

- Comprehensive 'Higgs Physics at CLIC' paper is now in circulation -> expect to see it imminently!

- Planning to focus on BSM and top physics in the next period

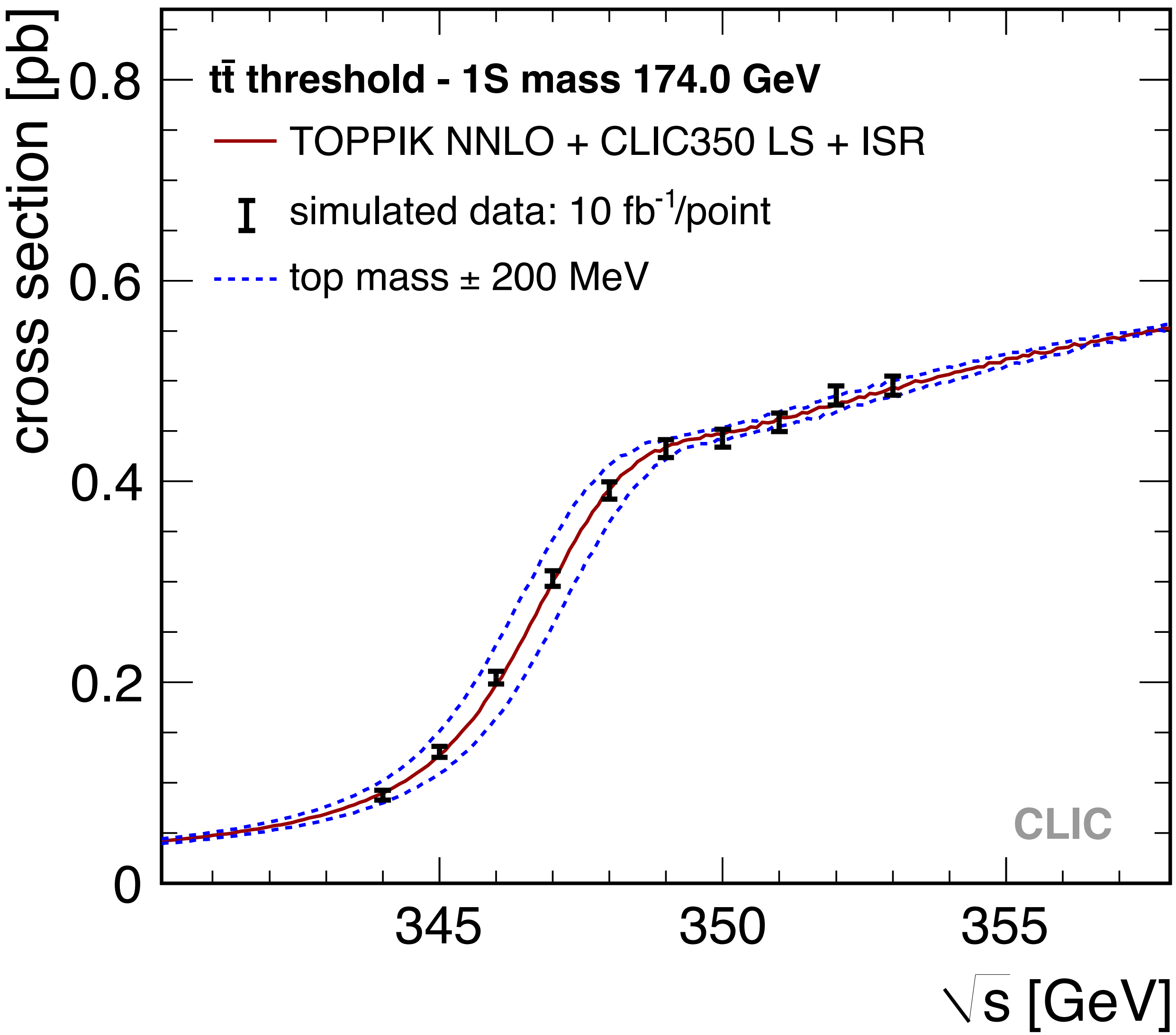
Higgs couplings – BSM sensitivity

example scenarios in which $M \sim$ 1TeV for new particles

arXiv: 1310.8361

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$
CLIC precision (model-independent)	0.8%	0.9%	3%

Precision top physics



- Intending threshold scan around 350 GeV (10 points, ~1 year) as well as main stage 1 baseline √s=380GeV

sensitive to top mass, width and couplings

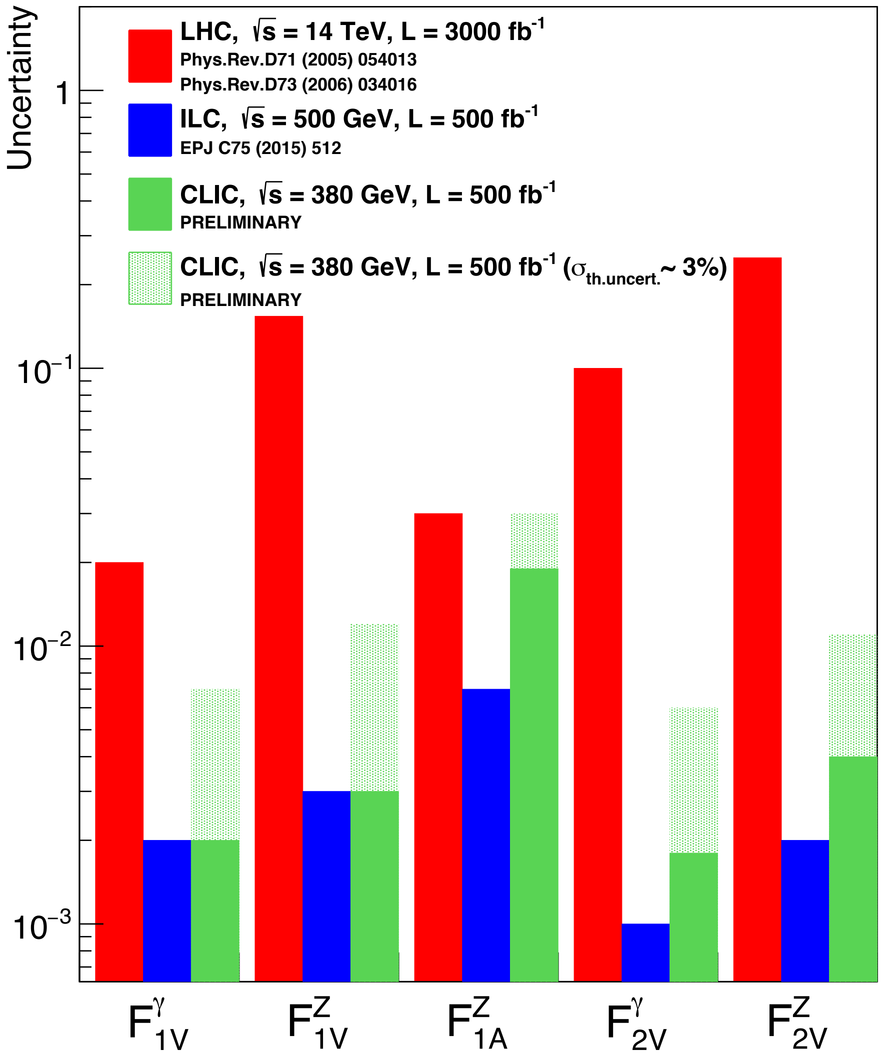
observe 1S ‘bound state’
$\Delta m_t \sim 50$ MeV

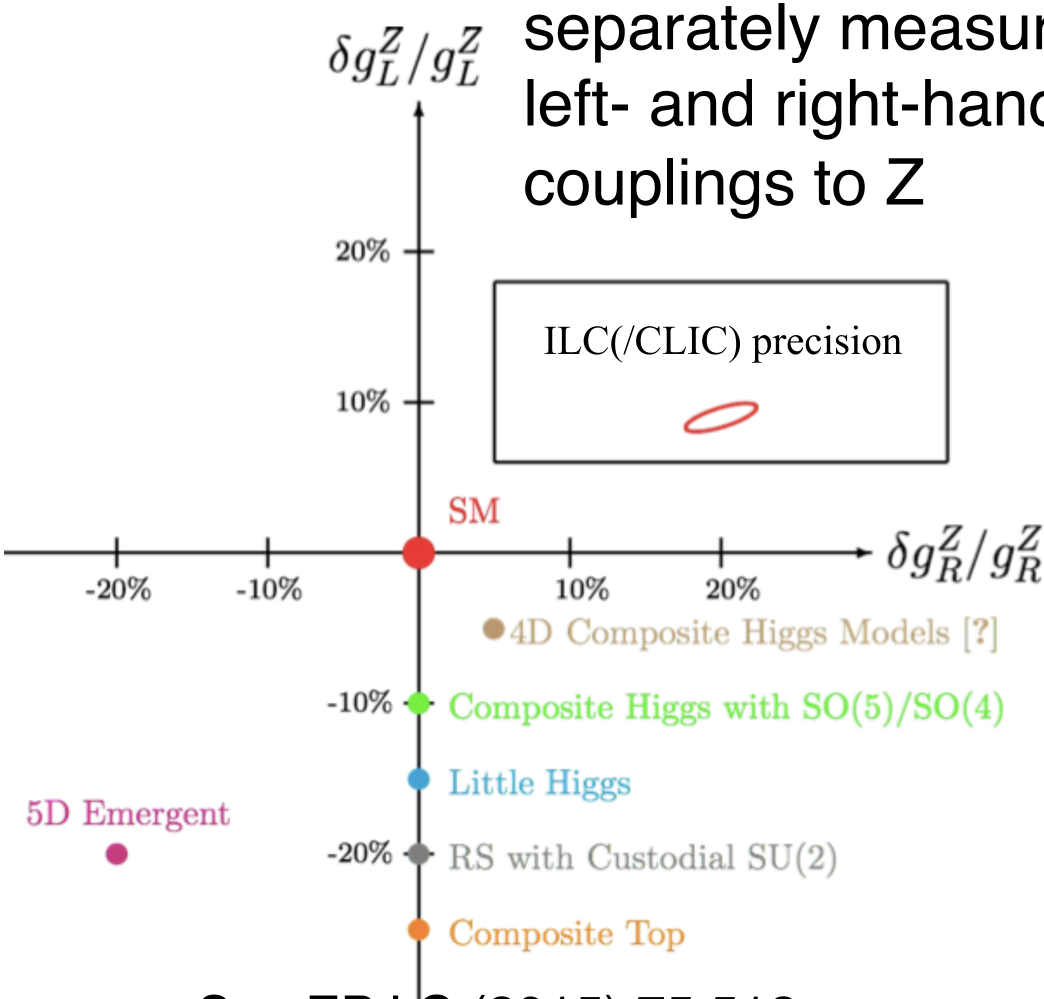
Precision top physics

parameterisation of ttX vertex

$$\Gamma^{ttX}_{\mu}(k^2,q,\bar{q}) = -ie\left\{\gamma_\mu\left(F^X_{1V}(k^2)+\gamma_5 F^X_{1A}(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\mu\left(iF^X_{2V}(k^2)+\gamma_5 F^X_{2A}(k^2)\right)\right\}$$

Vector Axial Tensorial CPV



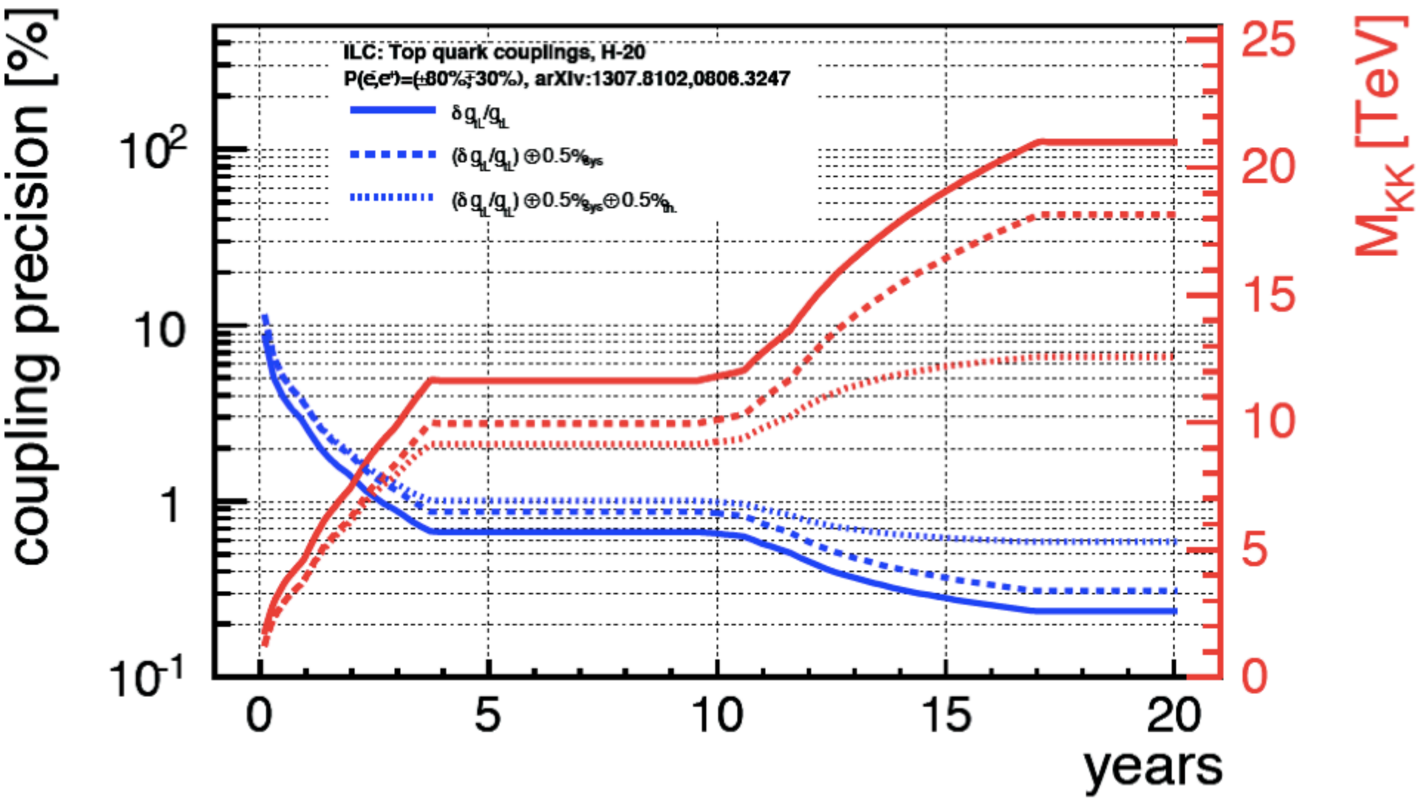


separately measure left- and right-handed couplings to Z

See EPJ C (2015) 75:512

Precision top physics

Sensitive to Higgs-sector resonance coupling to top; probes scales of ~25TeV in typical scenarios



For ILC scenarios; similar analysis in progress for CLIC

The impact of four-fermion operators increases strongly with √s

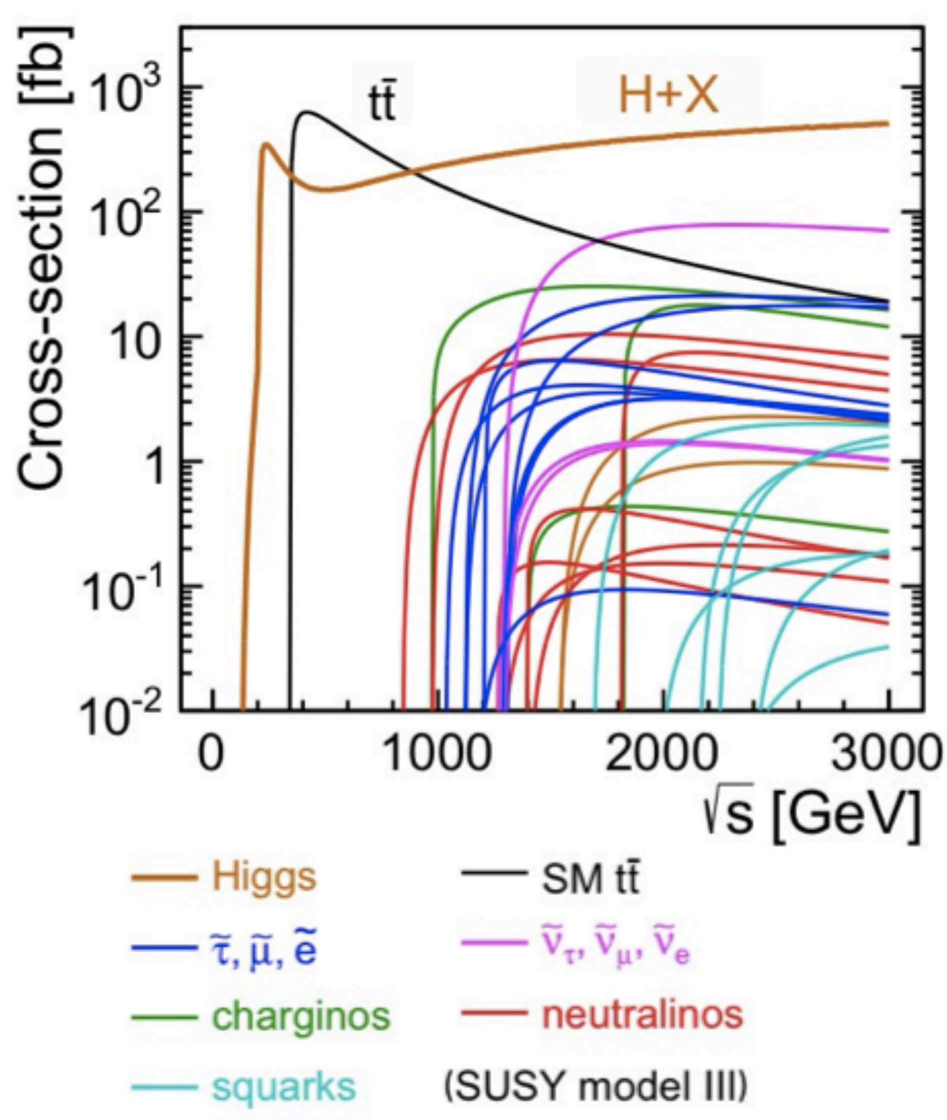
H20: 500/fb @ 500 GeV, 200/fb @ 350 GeV, 500/fb @ 250 GeV, 3500/fb @ 500 GeV, 1500/fb @ 250 GeV

Based on phenomenology described in Pomerol et al. arXiv:0806.3247

Direct BSM

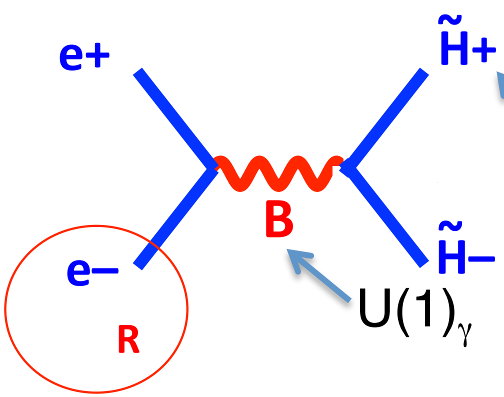
Pair production of new particles for $M < \sqrt{s}/2$:

Example: 'SUSY model III' →



Wider applicability than just SUSY: classify reconstructed particles simply as states of given mass, spin, and quantum numbers

Polarized beams -> decomposition:

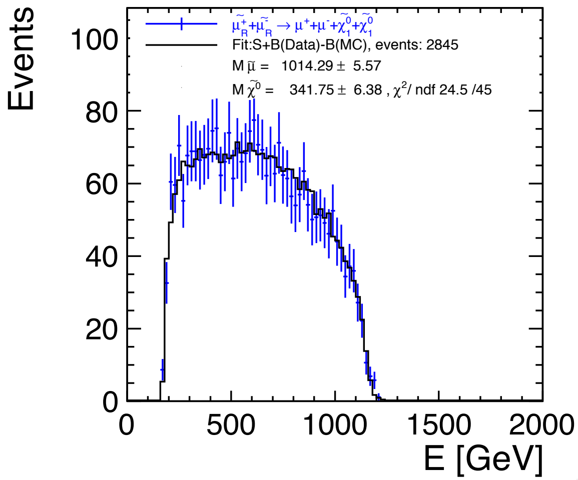


Only $\tilde{H}^\pm$ components of $\tilde{\chi}_1^\pm$ contribute

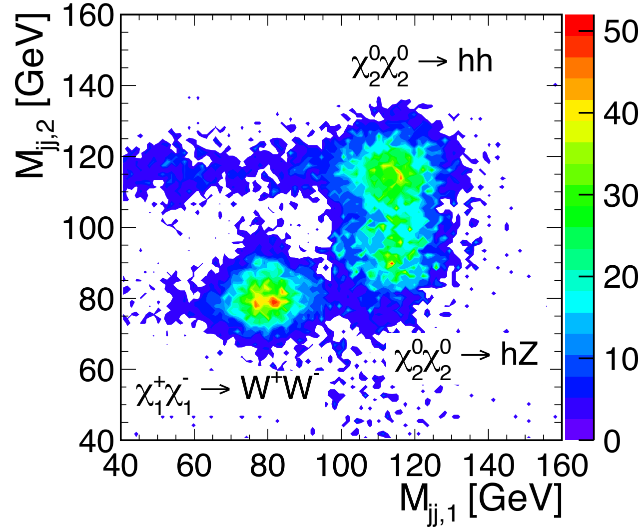
$$\tilde{\chi}_1^\pm = \alpha\tilde{W}^\pm + \beta\tilde{H}^\pm$$

Direct BSM

Endpoints:



$$e^+e^- \rightarrow \tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\mu^-\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$



Precision on gaugino masses: 1–1.5% for few hundred GeV

$$e^+e^- \rightarrow \tilde{\chi}_1^+\,\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\,\tilde{\chi}_1^0 W^+W^-$$

$$e^+e^- \rightarrow \tilde{\chi}_2^0\,\tilde{\chi}_2^0 \rightarrow hh\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

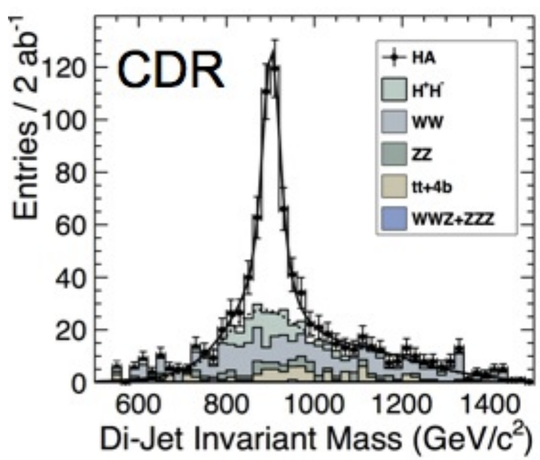
$$e^+e^- \rightarrow \tilde{\chi}_2^0\,\tilde{\chi}_2^0 \rightarrow Zh\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

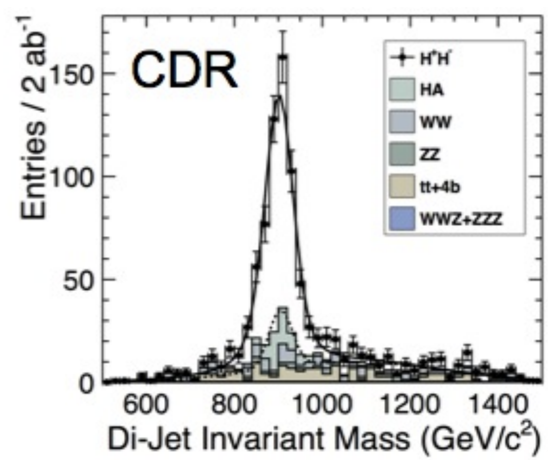
Complex final states:

e^+e^- –> HA –> $b\bar{b}b\bar{b}$

e^+e^- –> H^+H^- –> $t\bar{b}b\bar{t}$

~0.3% precision on heavy Higgs masses



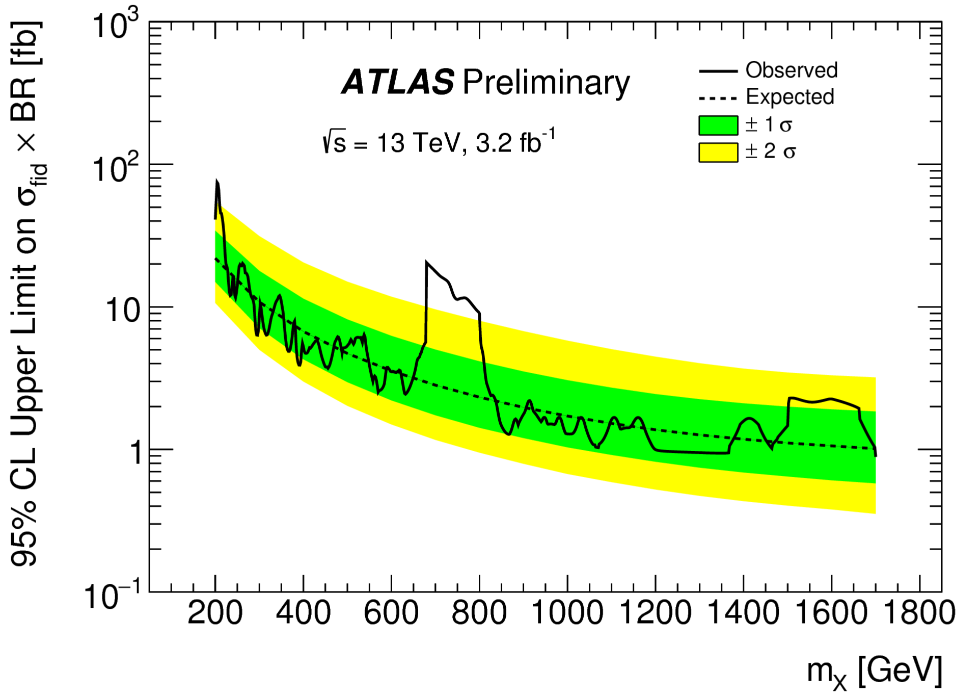


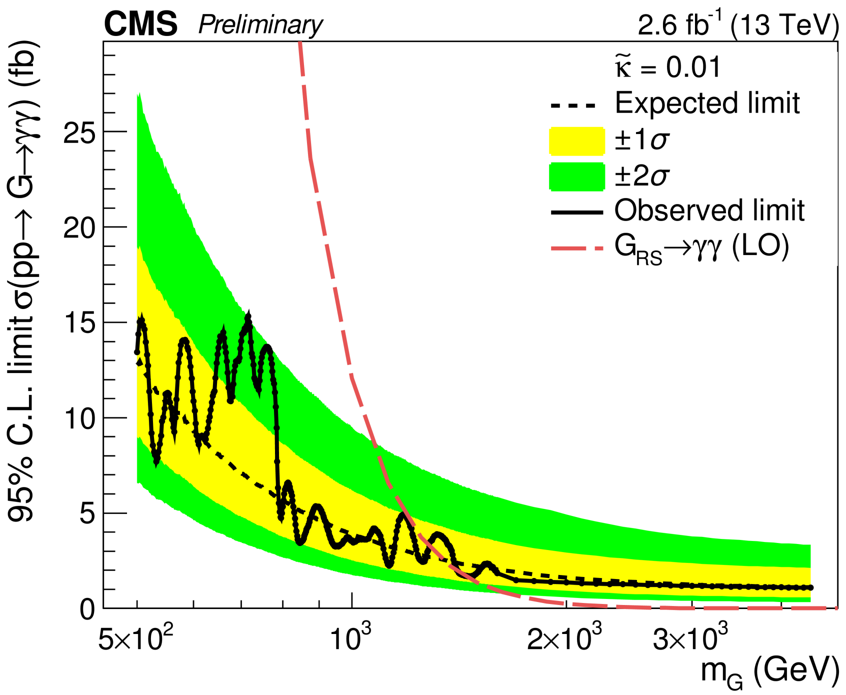
Direct BSM

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Generator value (GeV)	Stat. uncertainty
3.0	Sleptons	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	$\tilde{\ell}$ mass	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\ell}$ mass	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	340.3	1.0%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		$\tilde{\ell}$ mass	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	643.2	0.6%
3.0	Chargino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	643.2	1.1%
	Neutralino	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0\, h/Z^0\, \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	643.1	1.5%
3.0	Squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	$\tilde{q}_R$ mass	1123.7	0.52%
3.0	Heavy Higgs	$H^0A^0 \to b\bar{b}b\bar{b}$	I	H^0/A^0 mass	902.4/902.6	0.3%
		$H^+H^- \to t\bar{b}b\bar{t}$		$H^\pm$ mass	906.3	0.3%
1.4	Sleptons	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\ell}$ mass	560.8	0.1%
				$\tilde{\chi}_1^0$ mass	357.8	0.1%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\ell}$ mass	558.1	0.1%
				$\tilde{\chi}_1^0$ mass	357.1	0.1%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		$\tilde{\ell}$ mass	644.3	2.5%
				$\tilde{\chi}_1^\pm$ mass	487.6	2.7%
1.4	Stau	$\tilde{\tau}_1^+\tilde{\tau}_1^- \to \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\tau}_1$ mass	517	2.0%
1.4	Chargino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	III	$\tilde{\chi}_1^\pm$ mass	487	0.2%
	Neutralino	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0\, h/Z^0\, \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	487	0.1%

Direct BSM

React on new discoveries:





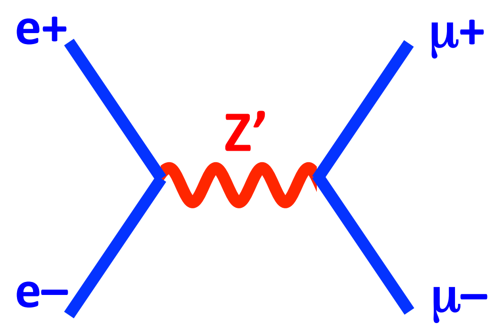
Depending on further clarification from LHC

CLIC could be an excellent facility to study the phenomenon

–> To be followed/studied closely, including machine options

Indirect BSM

Precision studies of $e^+e^- \rightarrow \mu^+\mu^-$



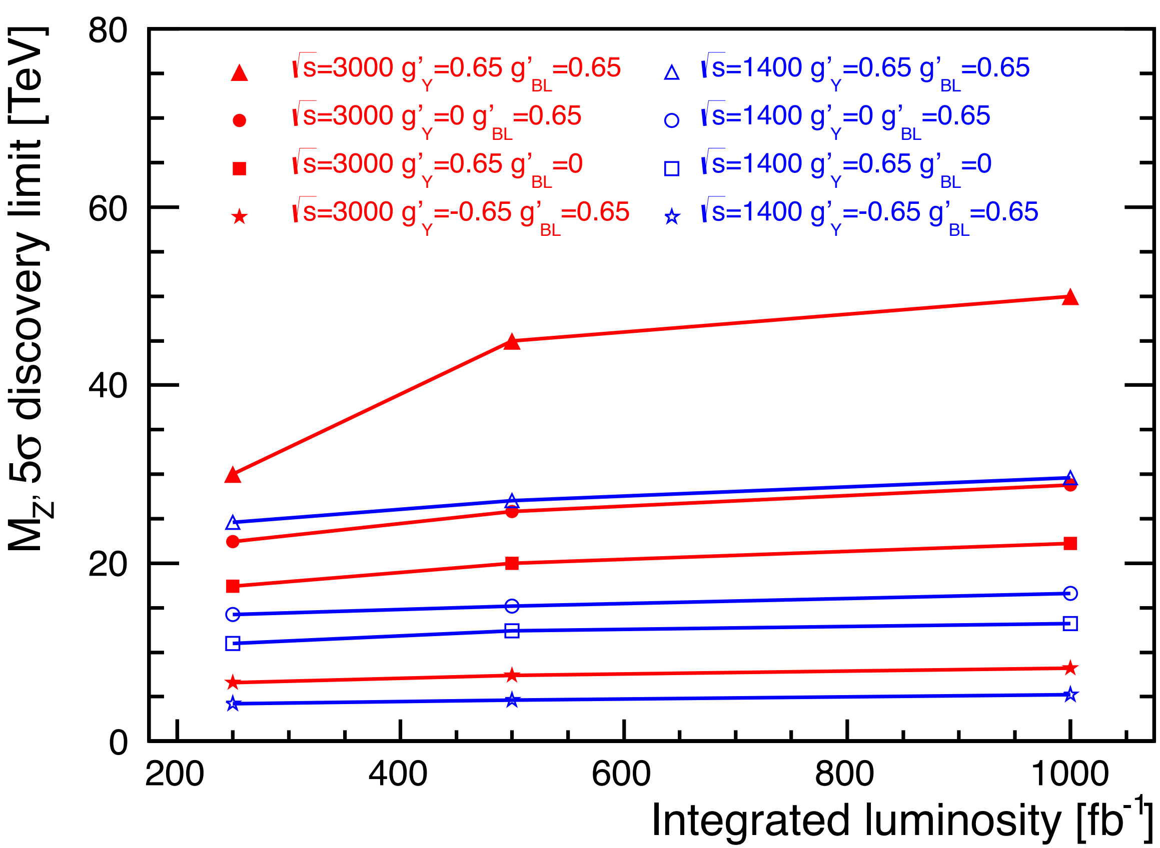
e.g. minimal anomaly-free Z' model

Observables:

- total $e^+e^- \rightarrow \mu^+\mu^-$ cross-section
- forward–backward asymmetry
- left–right asymmetry
  (±80% electron polarization)

Either: precise measurements of effective couplings following multi-TeV LHC discovery

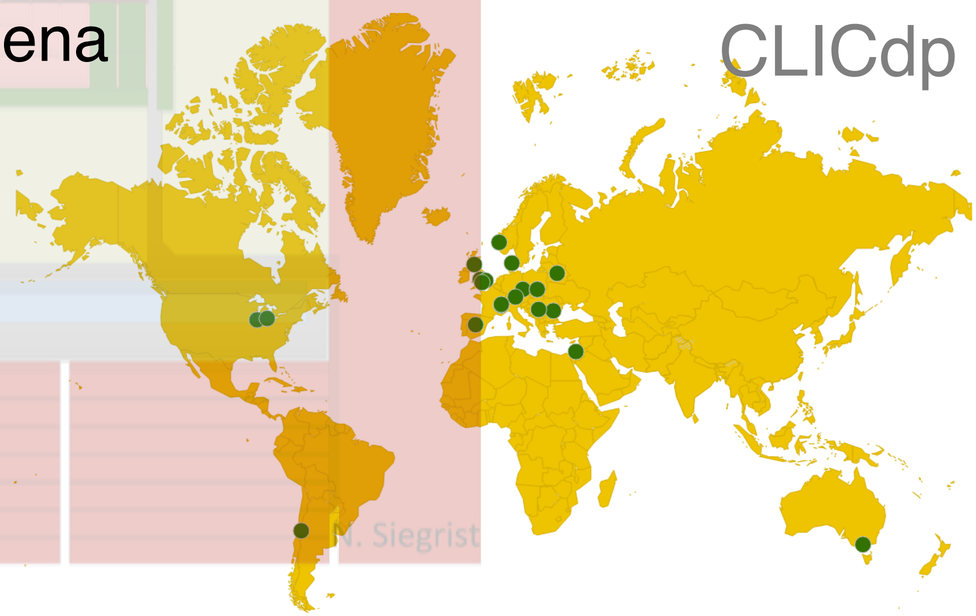
Or: discovery reach up to tens of TeV



Summary

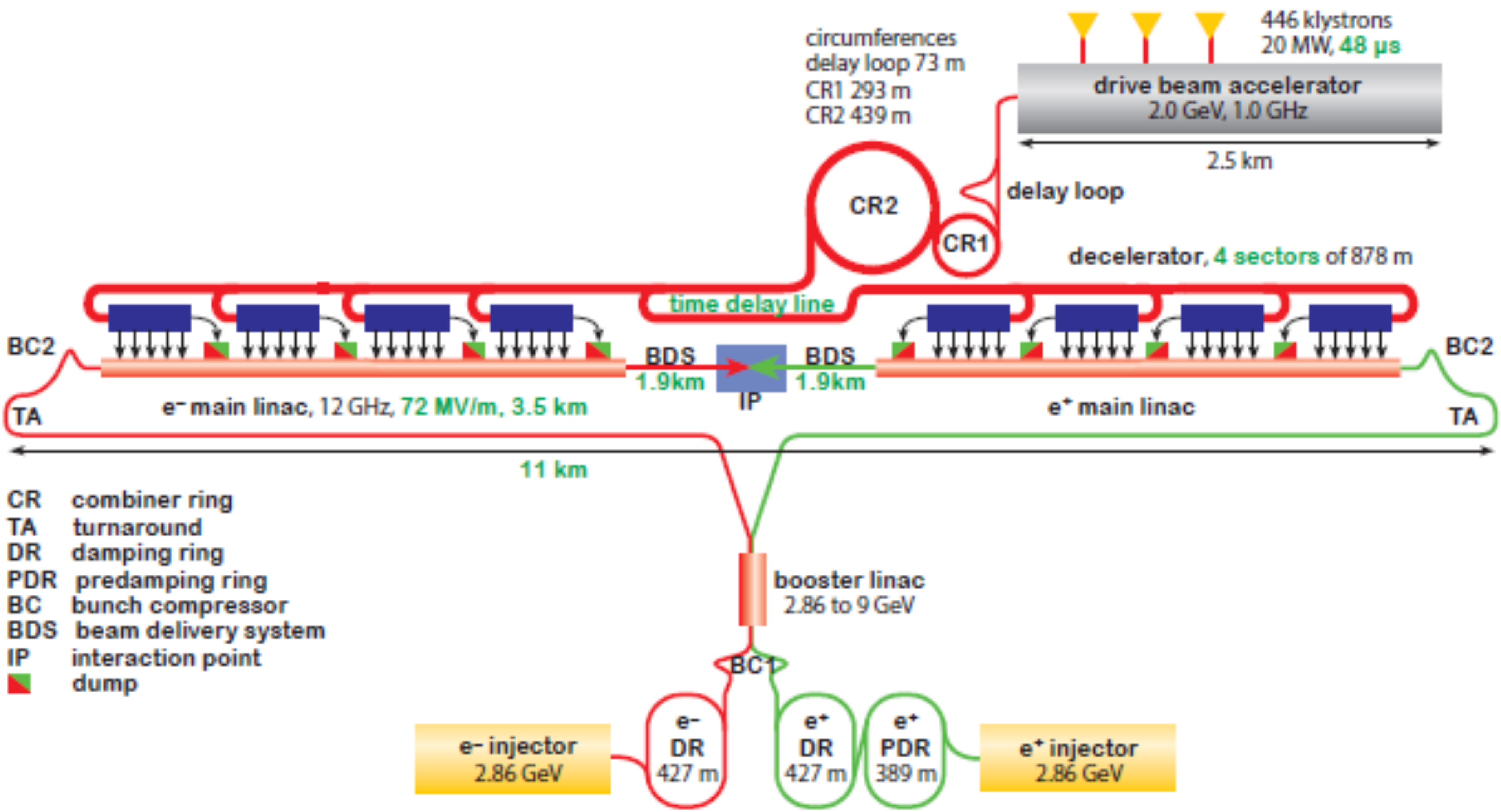
- CLIC accelerator in advanced state of development, and detector concept mature
- First energy stage provides precise measurements of many Higgs couplings, improved by subsequent high-energy running; comprehensive studies are complete
- High-energy running provides significant discovery potential for BSM phenomena
- Physics studies are ongoing
- New collaborators are welcome!

http://clic-study.web.cern.ch
http://clicdp.web.cern.ch



Backup

New CLIC layout 380 GeV



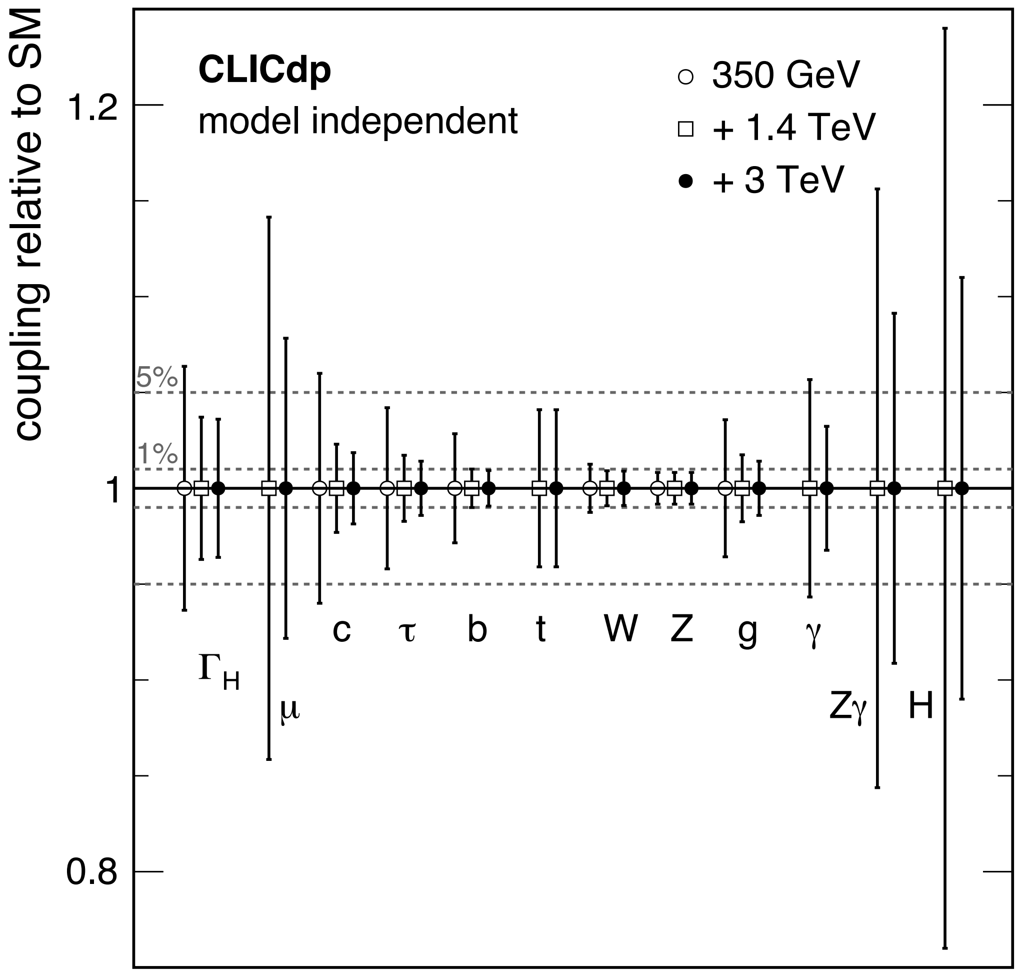
Higgs couplings

Coupling √s (TeV)→ L (fb^{-1}) →	LHC 14 3000(1 expt)	CepC 0.24 5000	FCC-ee 0.24 +0.35 13000	ILC 0.25+0.5 6000	CLIC 0.38+1.4+3 4000	FCC-hh 100 40000
K_W	2-5	1.2	0.19	0.4	0.9	
K_Z	2-4	0.26	0.15	0.3	0.8	
K_g	3-5	1.5	0.8	1.0	1.2	
K_γ	2-5	4.7	1.5	3.4	3.2	< 1
K_μ	~8	8.6	6.2	9.2	5.6	~ 2
K_c	--	1.7	0.7	1.2	1.1	
K_τ	2-5	1.4	0.5	0.9	1.5	
K_b	4-7	1.3	0.4	0.7	0.9	
$K_{Z\gamma}$	10-12	n.a.	n.a.	n.a.	n.a.	
Γ_h	n.a.	2.8	1.	1.8	3.4	
BR_{invis}	<10	<0.28	<0.19	<0.29	<1	
K_t	7-10	--	13% ind. tt scan	6.3	<4	~ 1 ?
K_{HH}	?	35% from K_Z model-dep	20% from K_Z model-dep	27	11	5-10

Units are %

summary table from Fabiola Gianotti LP15

Comprehensive Higgs studies



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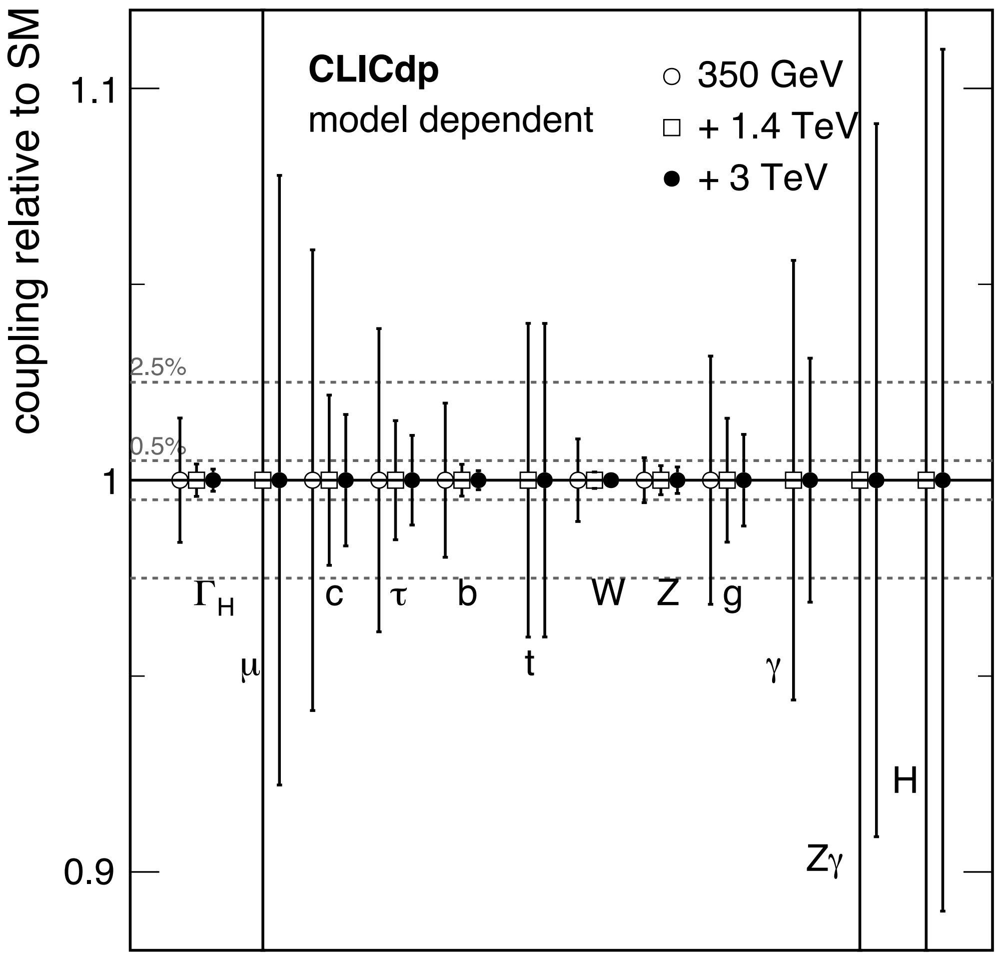
Parameter	Relative precision		
	350 GeV $500\,\mathrm{fb}^{-1}$	+ 1.4 TeV $+ 1.5\,\mathrm{ab}^{-1}$	+ 3 TeV $+ 2\,\mathrm{ab}^{-1}$
g_{HZZ}	0.8 %	0.8 %	0.8 %
g_{HWW}	1.3 %	0.9 %	0.9 %
g_{Hbb}	2.8 %	1.0 %	0.9 %
g_{Hcc}	6.0 %	2.3 %	1.9 %
$g_{H\tau\tau}$	4.2 %	1.7 %	1.4 %
$g_{H\mu\mu}$	—	14.1 %	7.8 %
g_{Htt}	—	4.1 %	4.1 %
$g^{\dagger}_{Hgg}$	3.6 %	1.7 %	1.4 %
$g^{\dagger}_{H\gamma\gamma}$	—	5.7 %	3.2 %
$g^{\dagger}_{HZ\gamma}$	—	15.6 %	9.1 %
Γ_H	6.4 %	3.7 %	3.6 %

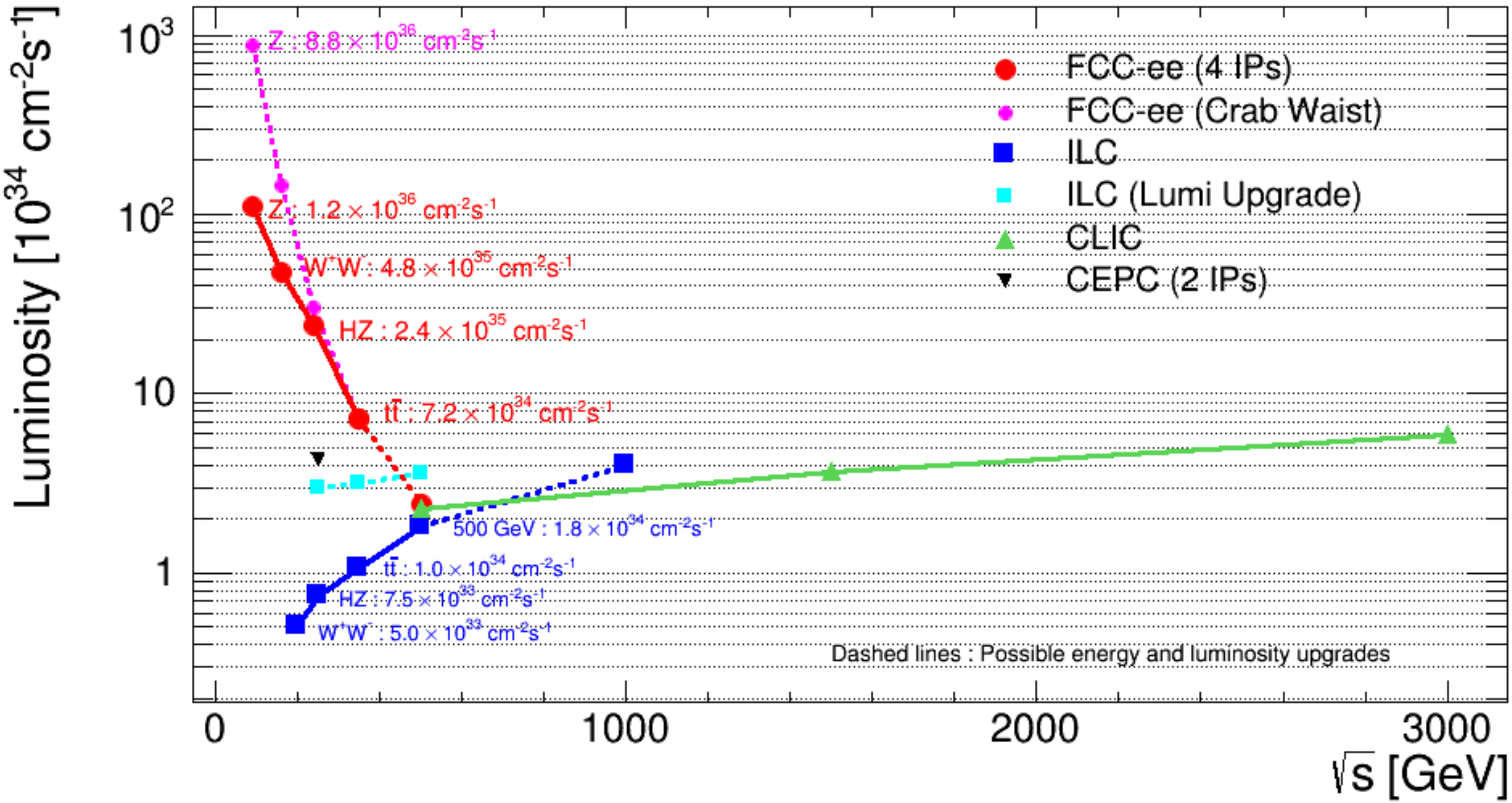
Comprehensive Higgs studies

8/4/16

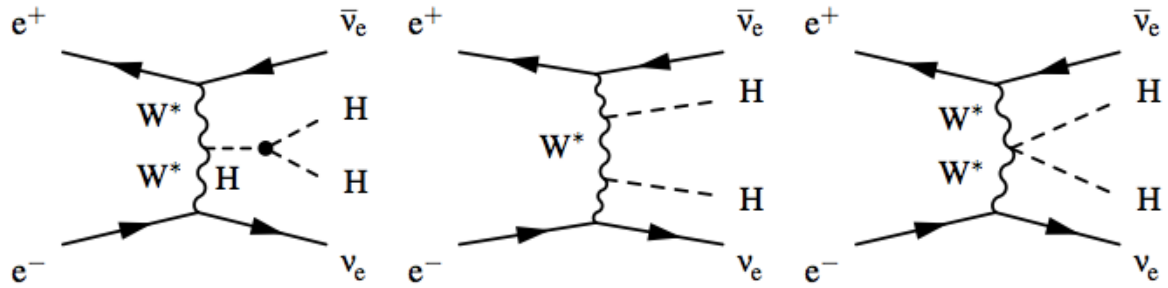


Parameter	Relative precision		
	350 GeV $500\,\mathrm{fb}^{-1}$	+ 1.4 TeV + $1.5\,\mathrm{ab}^{-1}$	+ 3 TeV + $2\,\mathrm{ab}^{-1}$
κ_{HZZ}	0.57 %	0.37 %	0.34 %
κ_{HWW}	1.1 %	0.21 %	0.14 %
κ_{Hbb}	2.0 %	0.41 %	0.24 %
κ_{Hcc}	5.9 %	2.2 %	1.68 %
$\kappa_{H\tau\tau}$	3.9 %	1.5 %	1.1 %
$\kappa_{H\mu\mu}$	–	14.1 %	7.8 %
κ_{Htt}	–	4.0 %	4.0 %
κ_{Hgg}	3.2 %	1.6 %	1.2 %
$\kappa_{H\gamma\gamma}$	–	5.6 %	3.1 %
$\kappa_{HZ\gamma}$	–	15.6 %	9.1 %
$\Gamma_{H,md,derived}$	1.6 %	0.41 %	0.28 %

Landscape: physics reach



Higgs self-coupling and mass



Measure Higgs self-coupling g_{HHH} at 3 TeV; simultaneous extraction with g_{HHWW}

–> $\Delta\lambda/\lambda$ =12% at $\sqrt{s}$=3TeV (2ab^{-1})

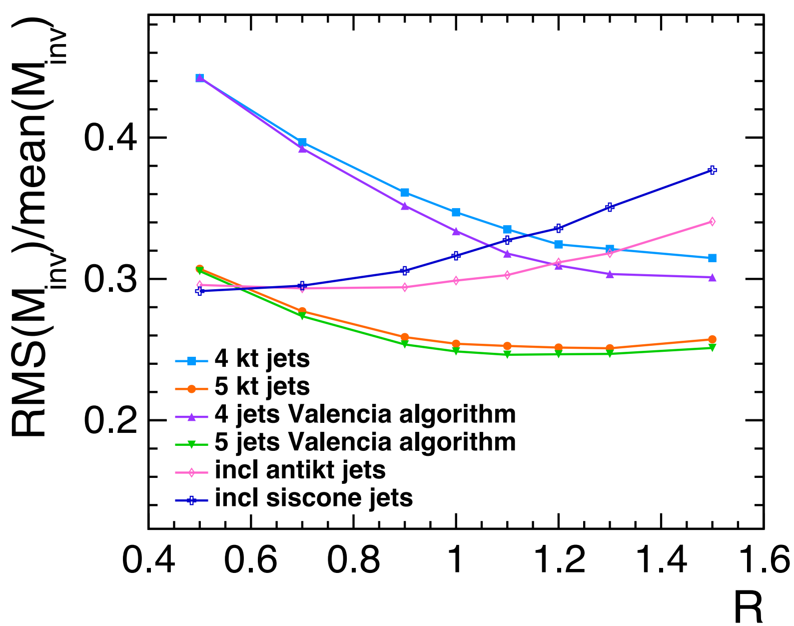
Looking at HHνν -> bbbbνν
4-jet final state, require 4 b-tag jets
-> systematic studies of clustering and jet algorithm to optimize for energy flow

optimize reconstructed m(bb)

-> use 5-jet reco with k_T or Valencia algorithm, R=1.1

MVA trained on event variables

Valencia alg.: arXiv:1404.4294



CLIC Physics

CLIC foreseen as a staged machine:

Stage 1: precision SM physics

Higgs and top

Energies of subsequent stages motivated by physics

– unique for high-precision

-> considered optimum energy for first stage

HZ production

⇨ $\sqrt{s}$ ~ 250–450 GeV

Top at threshold

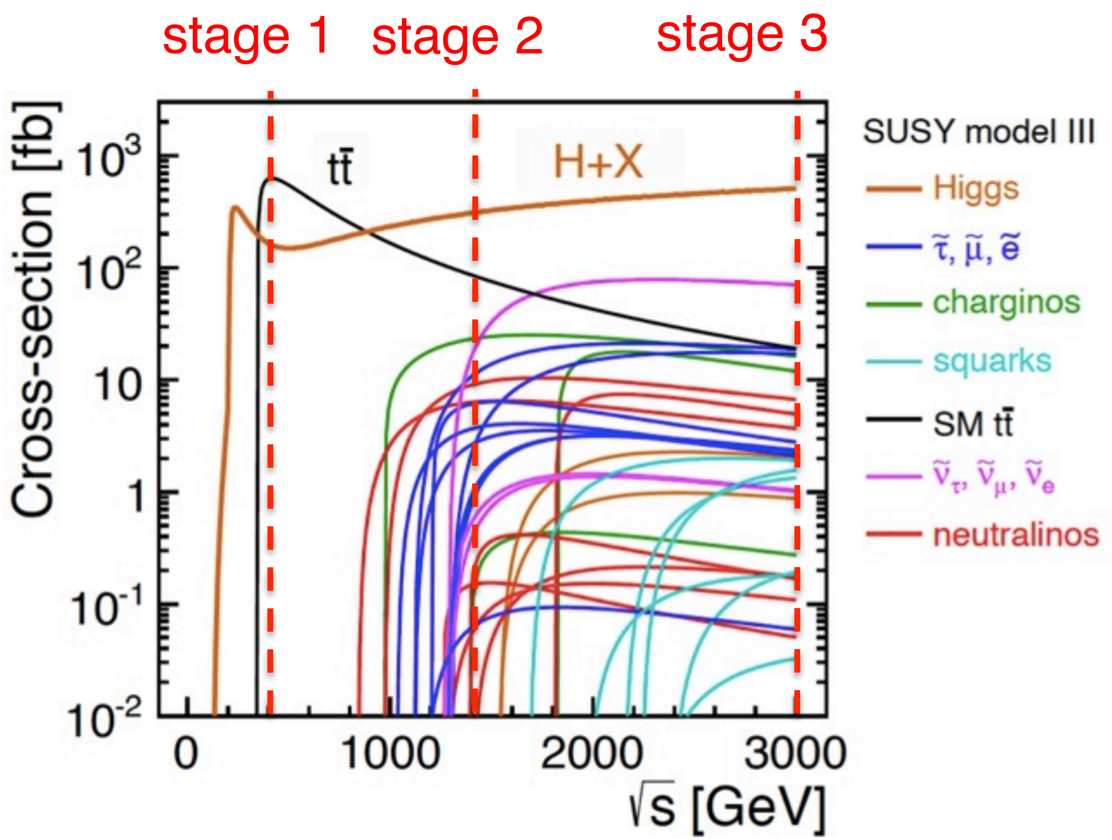
⇨ $\sqrt{s} > 350$ GeV

Top pair production

⇨ $\sqrt{s} > 360$ GeV

Recoil mass (HZ, Z->qq)

⇨ $\sqrt{s} < 400$ GeV



- $\sqrt{s}$ ~ 380 GeV

for first stage is good for both HZ and top physics programme – chosen as new baseline