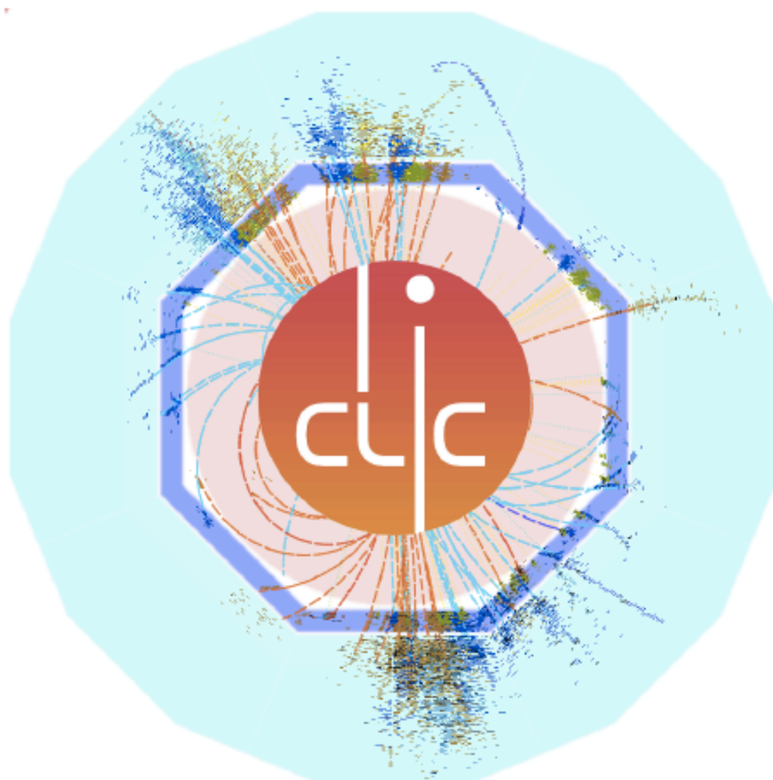
prospects for Beyond Standard Model physics at CLIC

Lucie Linssen, CERN

on behalf of the CLIC detector and physics collaboration (CLICdp)



this talk

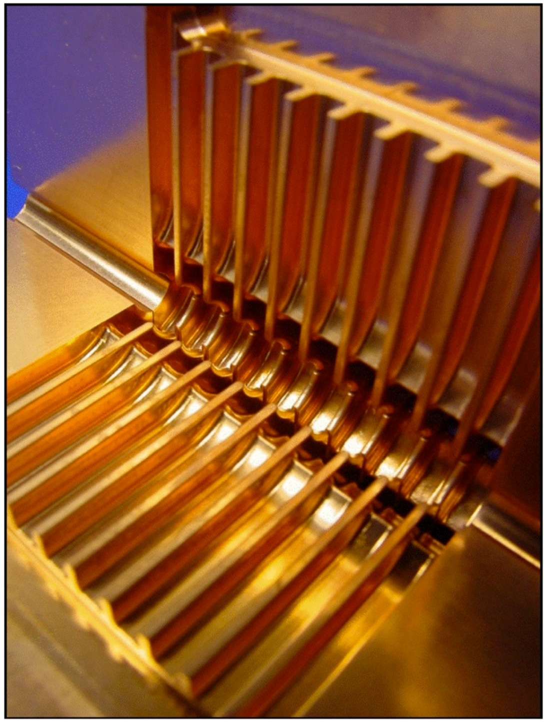
- Introduction to CLIC
- Direct BSM searches
  - Use SUSY models as example
- Precision measurements
  - Examples: Higgs compositeness, Z'
- Summary

Other CLIC physics talks at this conference:

- Higgs physics: https://indico.desy.de/contributionDisplay.py?sessionId=32&contribId=125&confId=8648
- Top physics: https://indico.desy.de/contributionDisplay.py?contribId=123&sessionId=32&confId=8648

the CLIC accelerator

CLIC is the most mature option for a future multi-TeV scale e^+e^- collider



- 2-beam acceleration scheme at room temperature
- Gradient 100 MV/m => √s up to 3 TeV
- Staging scenario ~350 GeV up to 3 TeV
- High luminosity (a few 10^{34} $cm^{-2}s^{-1}$)

CLIC focus is on energy frontier reach !

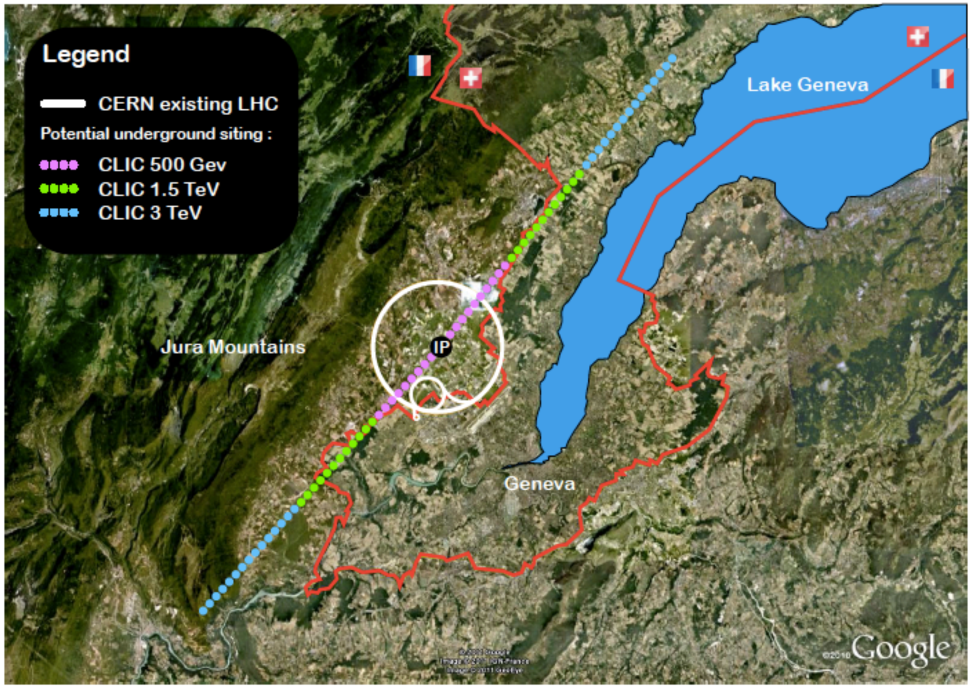


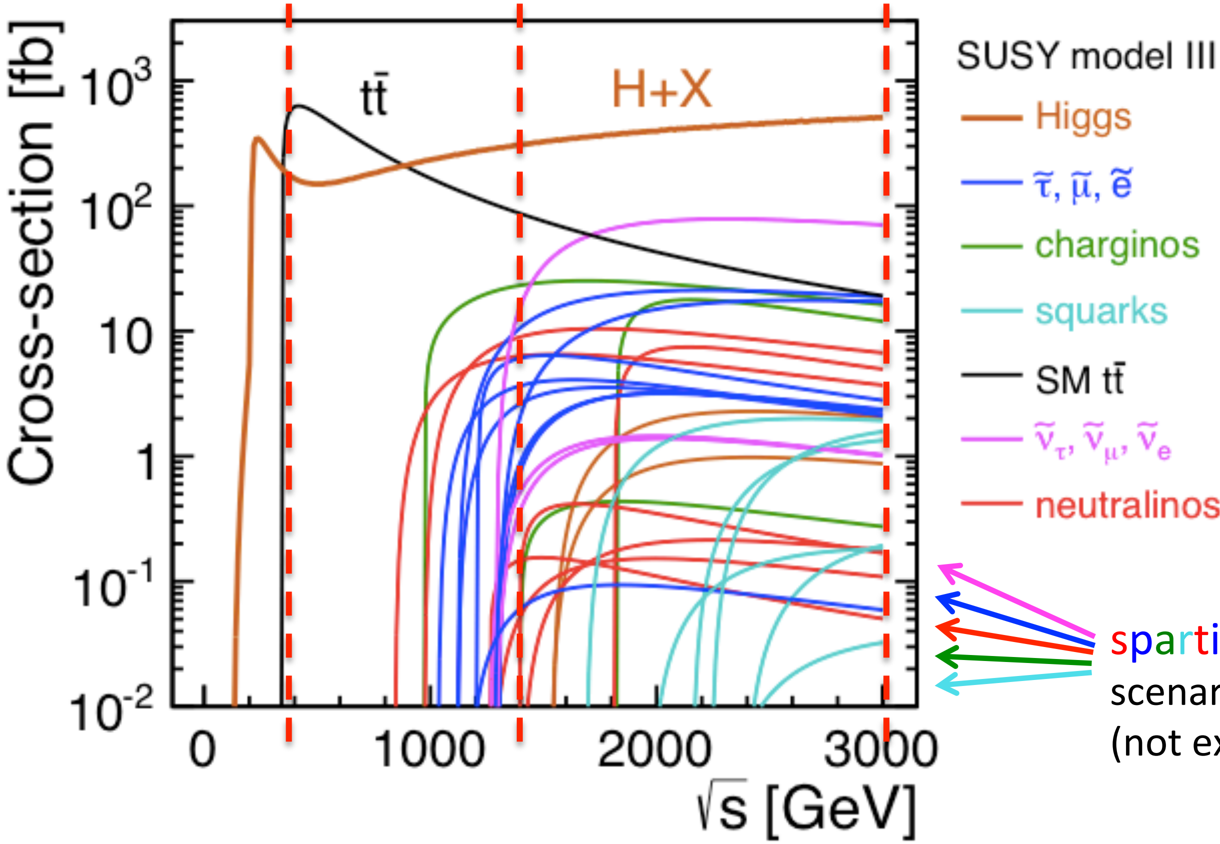
Fig. 7.2: CLIC footprints near CERN, showing various implementation stages [5].

energy stages at CLIC

CLIC: e^+e^- collider, staged approach

- **350 – 375 GeV**, 500 fb^{-1} : precision Higgs and top physics
- **~1.4 TeV**, 1.5 ab^{-1} : **targeted at BSM physics,** precision Higgs
- **~ 3 TeV,** 2 ab^{-1} : **targeted at BSM physics,** precision Higgs

Exact energies of TeV stages would depend on LHC results



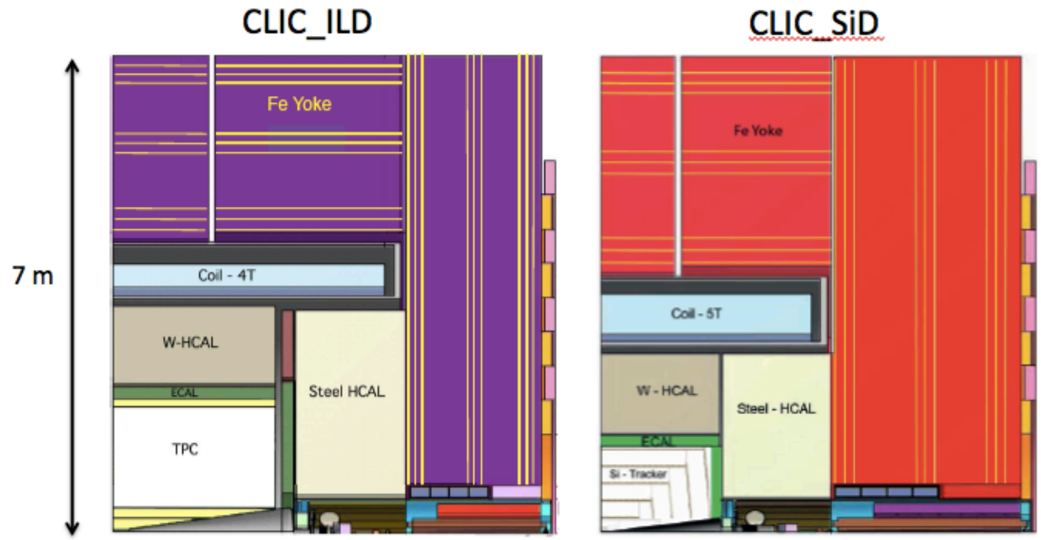
Example of energy staging

(with an example SUSY model)

sparticles in **SUSY** example scenario (not excluded by LHC results)

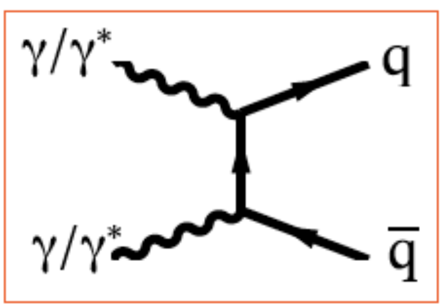
detector benchmark studies

Benchmark studies based on full detector simulations (Geant4)

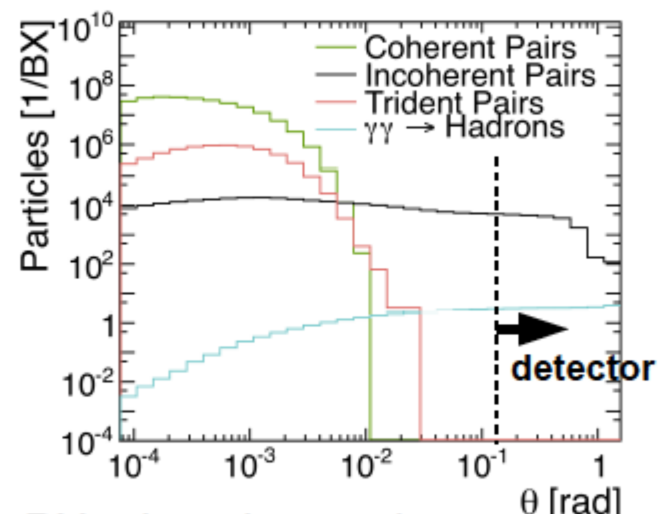


CLIC detector concepts based on ILC detector concepts adapted for CLIC

Pile-up from γγ→hadrons interactions overlaid on the physics event

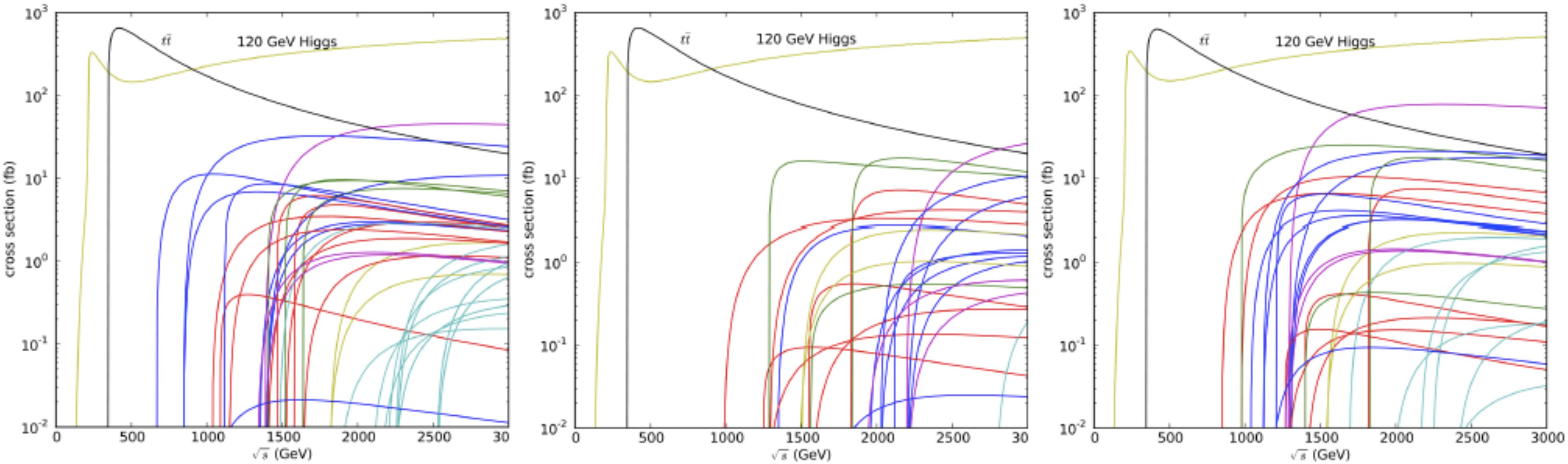


- 3.2 event per BX at 3 TeV
- Suppressed using timing information of the detectors and hadron-collider type jet algorithms



BX = bunch crossing

investigated SUSY models



CDR model I, 3 TeV:
- Squarks
- Heavy Higgs

CDR model II, 3 TeV:
- Smuons, selectrons
- Gauginos

CDR model III, 1.4 TeV:
- Smuons, selectrons
- Staus
- Gauginos

— Higgs
— $\tilde{\tau}, \tilde{\mu}, \tilde{e}$
— charginos
— squarks
— SM $t\bar{t}$
— $\tilde{\nu}_\tau, \tilde{\nu}_\mu, \tilde{\nu}_e$
— neutralinos

Wider capability than only SUSY: reconstructed particles can be interpreted as "states of given mass, spin and quantum numbers"

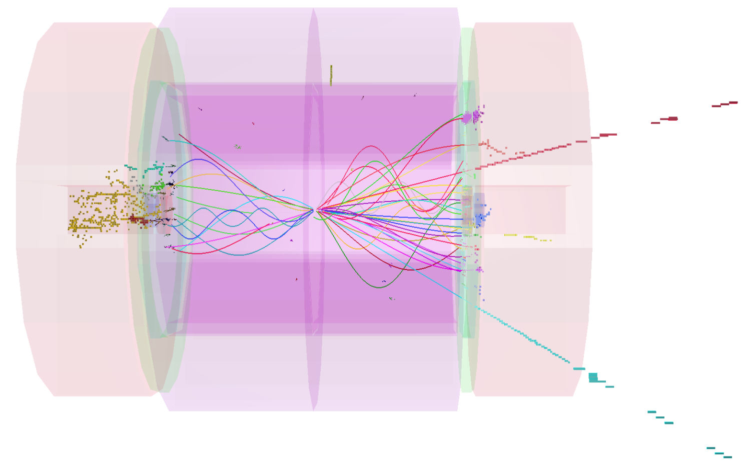
the simplest case: slepton at 3 TeV

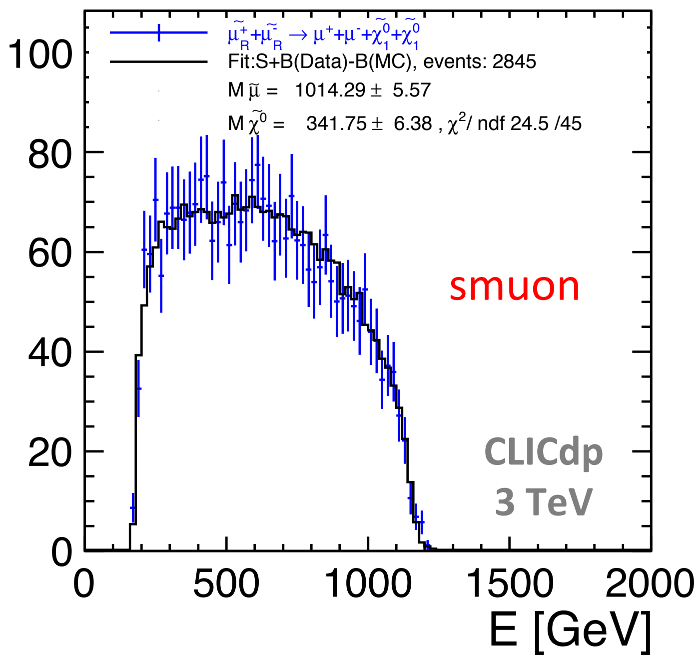
Slepton production at CLIC very clean

slepton masses ~ 1 TeV

Investigated channels include

- $e^+e^- \rightarrow \tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$
- $e^+e^- \rightarrow \tilde{e}_R^+\tilde{e}_R^- \rightarrow e^+e^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$
- $e^+e^- \rightarrow \tilde{\nu}_e\tilde{\nu}_e \rightarrow e^+e^- W^+W^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$





- Leptons and missing energy
- Masses from analysis of endpoints of energy spectra

stat. error, all channels combined

$m(\tilde{\mu}_R)$: ± 5.6 GeV
$m(\tilde{e}_R)$: ± 2.8 GeV
$m(\tilde{\nu}_e)$: ± 3.9 GeV
$m(\tilde{\chi}_1^0)$: ± 3.0 GeV
$m(\tilde{\chi}_1^\pm)$: ± 3.7 GeV

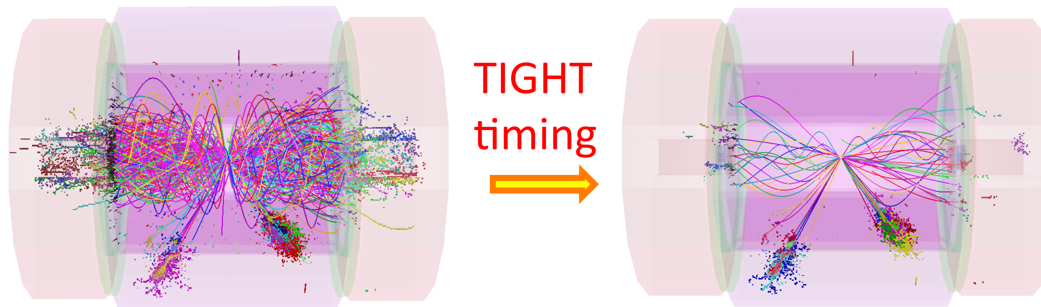
result: $\Delta m/m \leq 1\%$

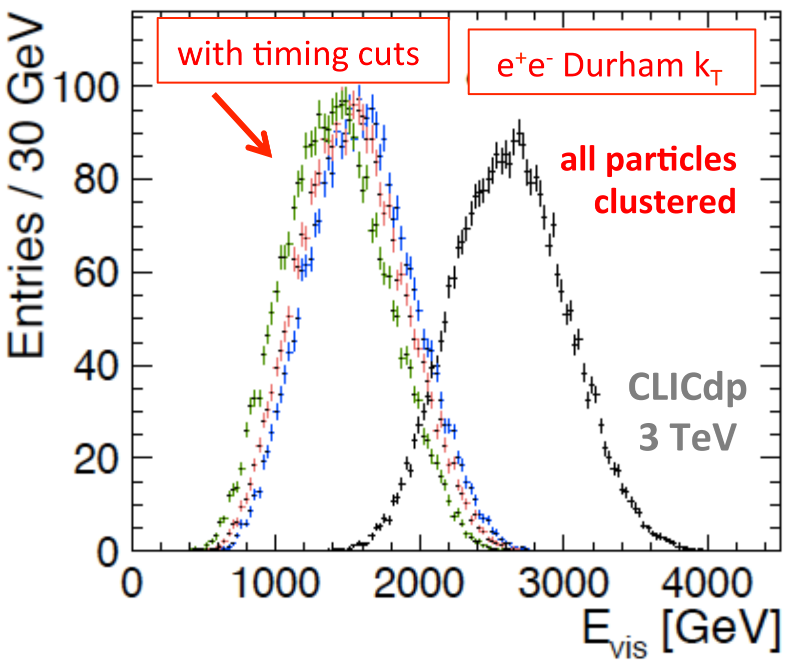
jet clustering, e.g. squark study at 3 TeV

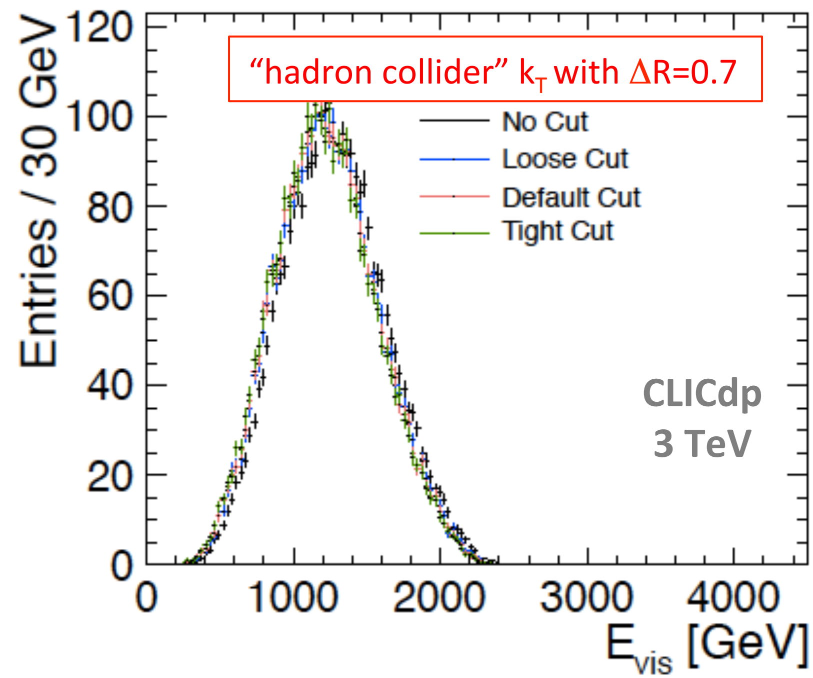
$$e^+e^- \rightarrow \tilde{q}_R\tilde{q}_R \rightarrow q\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

$m_{\tilde{q}_R}$ = 1.12 TeV

- Suppression of beam-induced background by timing cuts and “hadron collider” jet clustering







result: $\Delta m/m$ = 0.6%

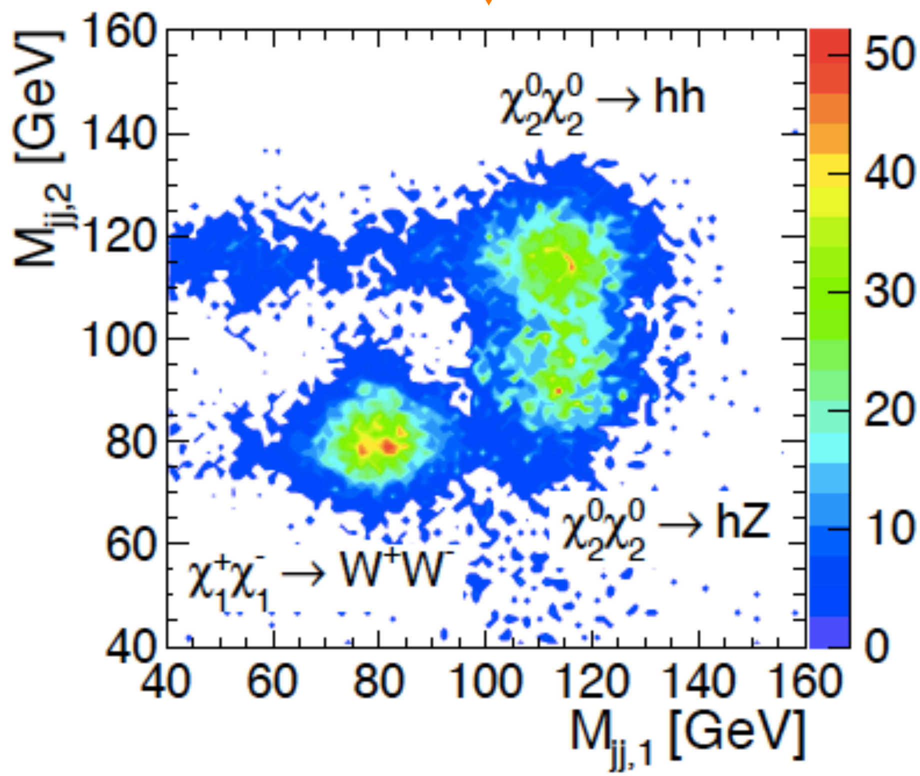
di-jet masses: gauginos at 3 TeV

$$m(\tilde{\chi}_1^0) = 340\,\text{GeV}$$
$$m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^+) \approx 643\,\text{GeV}$$

Chargino and neutralino pair production

$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+W^-$$
$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow hh\, \tilde{\chi}_1^0 \tilde{\chi}_1^0 \quad 82\,\%$$
$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow Zh\, \tilde{\chi}_1^0 \tilde{\chi}_1^0 \quad 17\,\%$$

- separation using di-jet invariant masses (test of PFA)



$$m(\tilde{\chi}_1^\pm) : \pm 7\,\text{GeV}$$
$$m(\tilde{\chi}_2^0) : \pm 10\,\text{GeV}$$

use slepton study result
$$m(\tilde{\chi}_1^0) : \pm 3\,\text{GeV}$$

result: $\Delta m/m \leq 1\%$

sensitivity to Higgs partners

Higgs partners BSM ➔ accessible up to √s/2

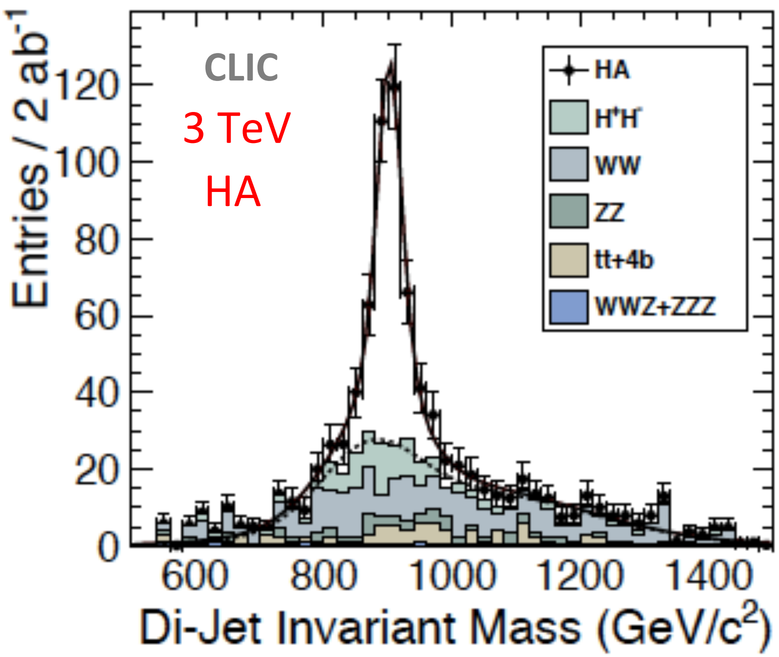
Example MSSM benchmark study at 3 TeV, 2 ab^{-1}

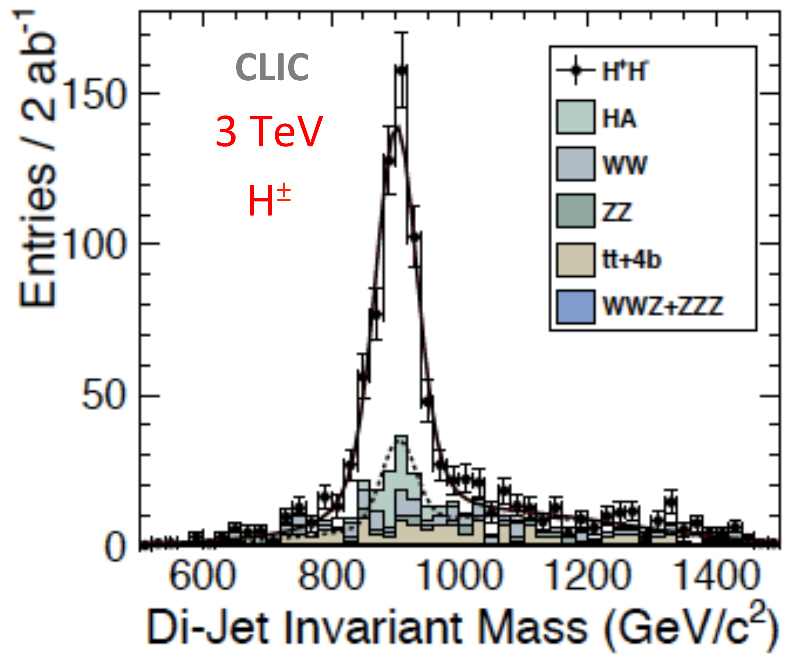
- $e^+e^- \rightarrow HA \rightarrow b\bar{b}b\bar{b}$
- $e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t}$

(H, A and H$^+$ almost degenerate in mass)

- Complex final states

$M_1 = 780$ GeV, $M_2 = 940$ GeV, $M_3 = 540$ GeV
$A_0 = -750$ GeV, $m_0 = 303$ GeV, $\tan\beta = 24$, $\mu > 0$
$m_t = 173.3$ GeV, $M_b(M_b) = 4.25$ GeV, $\alpha_S(M_Z) = 0.118$





result: $\Delta m/m$ = 0.3%

summary of SUSY studies

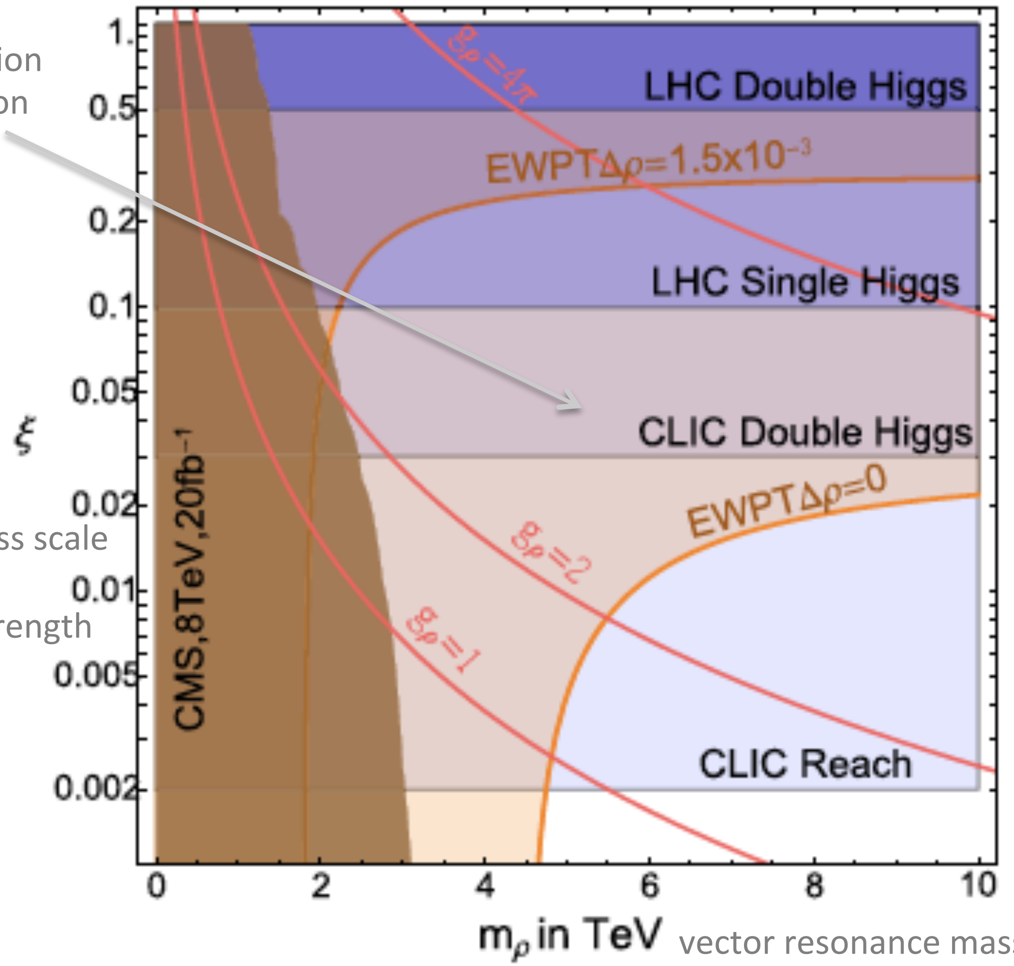
$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Generator value (GeV)	Stat. uncertainty
3.0	Sleptons	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	$\tilde{\ell}$ mass	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\ell}$ 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 Neutralino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	643.2	1.1%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0\, h/Z^0\, \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ 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 Neutralino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	III	$\tilde{\chi}_1^\pm$ mass	487	0.2%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0\, h/Z^0\, \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	487	0.1%

Large part of the SUSY spectrum measured at <1% level

composite Higgs bosons

allowed region
EW precision
tests

dimensionless scale parameter, measures strength of Higgs interactions

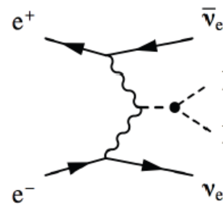


vector resonance mass of the composite theory

LHC: WW scattering and strong double Higgs production

LHC: single Higgs processes

CLIC: double Higgs production via vector boson fusion

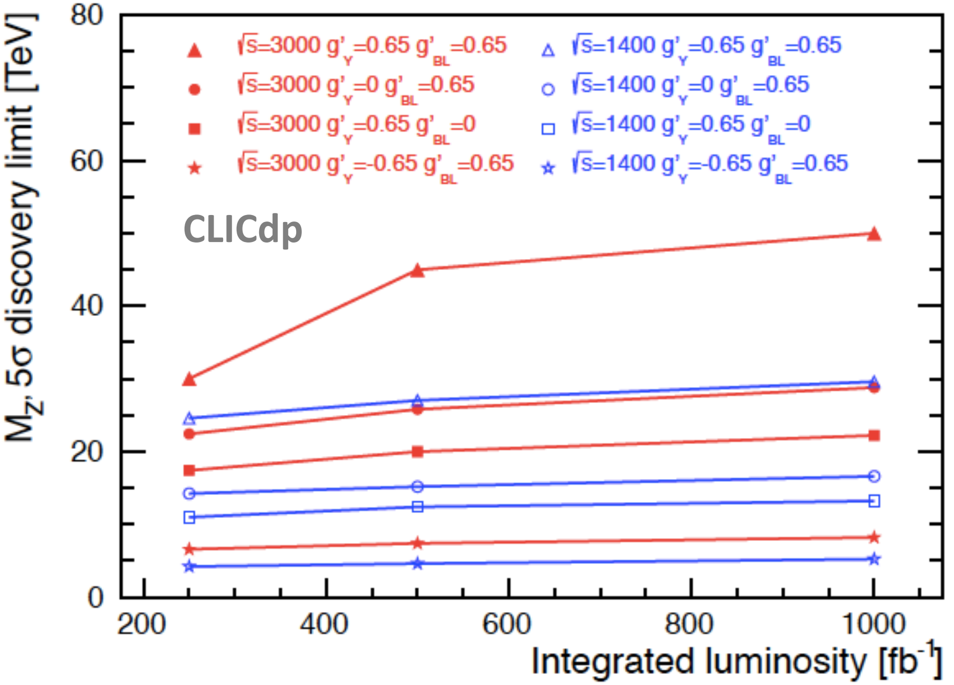


LHC: direct search WZ =>3 leptons

Allows to probe Higgs compositeness at the 30 TeV scale for 1 ab^{-1} at 3 TeV
(70 TeV scale if combined with single Higgs production)

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

Minimal anomaly-free Z' model
charge of SM fermions under U(1)' symmetry:
$Q_f = g_Y'(Y_f) + g'_{BL}(B\text{-}L)_f$



Observables:

- Total $e^+e^- \Rightarrow \mu^+\mu^-$ cross section
- Forward-backward asymmetry
- Left-right asymmetry (±80% e^- polarisation)

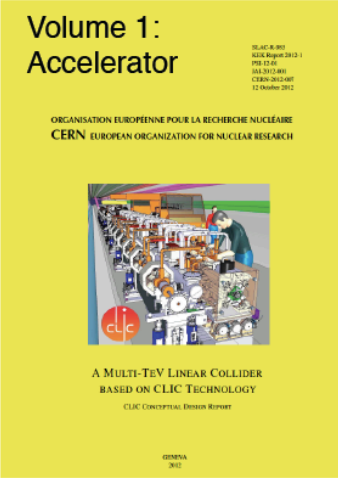
If LHC discovers Z'
(e.g. for $M_{Z'}$=5 TeV)
Precision measurement of effective couplings

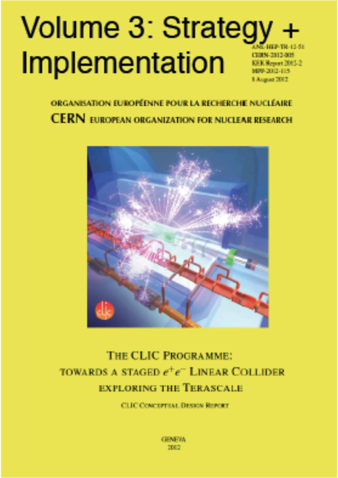
Otherwise:
Discovery reach up to tens of TeV (depending on the couplings)

if you want to know more

CLIC Conceptual Design report (2012)

- **CLIC CDR** (#1), A Multi-TeV Linear Collider based on CLIC Technology, CERN-2012-007, https://edms.cern.ch/document/1234244/
- **CLIC CDR** (#2), Physics and Detectors at CLIC,
  CERN-2012-003, arXiv:1202.5940
- **CLIC CDR** (#3), The CLIC Programme: towards a staged e^+e^- Linear Collider exploring the Terascale, CERN-2012-005, http://arxiv.org/abs/1209.2543





CLIC physics input to the Snowmass process (2013)

- Physics at the CLIC e+e- Linear Collider, Input to the USA Snowmass process 2013, http://arxiv.org/abs/1307.5288

welcome to join us !

Australia	Australian Collaboration for Accelerator Science (ACAS), University of Melbourne
Belarus	National Scientific and Educational Centre of Particle and High Energy Physics (NC-PHEP), Belarusian State University, Minsk
Chile	Pontificia Universidad Católica de Chile, Santiago
Czech Republic	Institute of Physics of the Academy of Sciences of the Czech Republic, Prague
Denmark	Department of Physics and Astronomy, Aarhus University
France	Laboratoire d'Annecy-le-Vieux de Physique des Particules (LAPP), Annecy
Germany	Max-Plack-Institut für Physik, Munich
Israel	Department of Physics, Faculty of Exact Sciences, Tel Aviv University
Norway	Department of Physics and Technology, University of Bergen
Poland	The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow
Poland	Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Cracow
Romania	Institute of Space Science, Bucharest-Magurele
Serbia	Vinca Institute for Nuclear Sciences, Belgrade
Spain	Spanish Network for Future Linear Colliders
Switzerland	CERN
United Kingdom	The School of Physics and Astronomy, University of Birmingham
United Kingdom	University of Bristol
United Kingdom	University of Cambridge
United Kingdom	University of Glasgow
United Kingdom	The Department of Physics of the University of Liverpool
United Kingdom	Oxford University
USA	Argonne National Laboratory, High Energy Physics Division
USA	University of Michigan, Physics Department

CLICdp: 23 institutes

Light-weight cooperation structure, on best-effort basis, with strong collaborative links to ILC

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

Focus of CLIC-specific studies on:

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

Summary

CLIC at high energy (~1.4 TeV and 3 TeV) provides significant discovery potential for BSM phenomena

- Measurement of the slepton, squark, gaugino and heavy Higgs masses with O(1%) precision up to kinematic limit √s/2
- In addition to direct particle searches: sensitivity to New Physics at large scales (tens of TeV) through precision measurements (examples composite models and Z')

New particle	LHC (14 TeV)	HL-LHC	CLIC3	
squarks [TeV]	2.5	3	$\lesssim 1.5$	Direct observation
sleptons [TeV]	0.3	-	$\lesssim 1.5$	Direct observation
Z' (SM couplings) [TeV]	5	7	20	Loop / effective operator
2 extra dims M_D [TeV]	9	12	20–30	Loop / effective operator
TGC (95%) (λ_γ coupling)	0.001	0.0006	0.0001	Loop / effective operator
μ contact scale [TeV]	15	-	60	Loop / effective operator
Higgs composite scale [TeV]	5–7	9–12	70	Loop / effective operator

SPARE SLIDES

CLIC strategy and objectives

2013-18 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.

4-5 year Preparation Phase

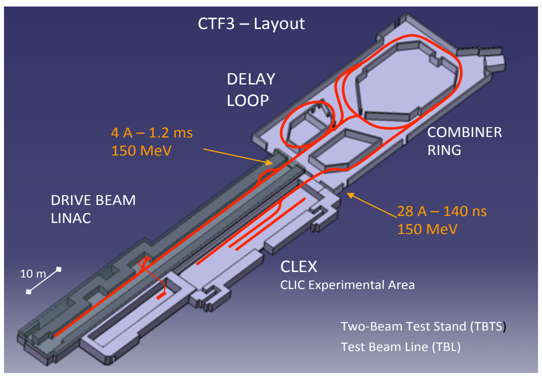
Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

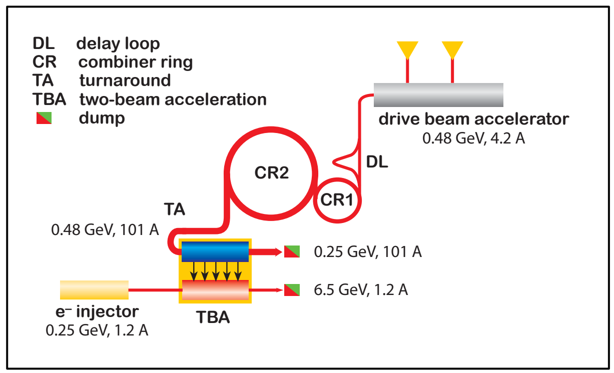
Prepare detailed Technical Proposals for the detector-systems.

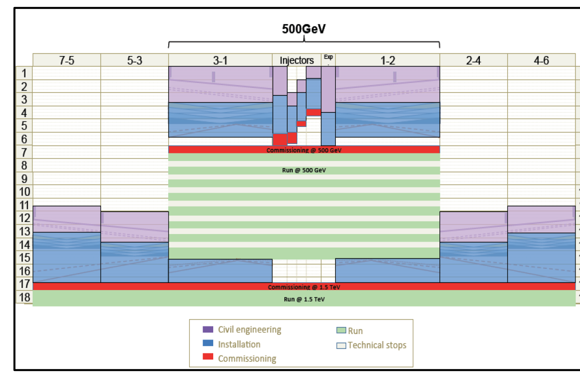
Construction Phase

Stage 1 construction of CLIC, in parallel with detector construction.

Preparation for implementation of further stages.







2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2024-25 Construction Start

Ready for full construction and main tunnel excavation.

Commissioning

Becoming ready for data-taking as the LHC programme reaches completion.

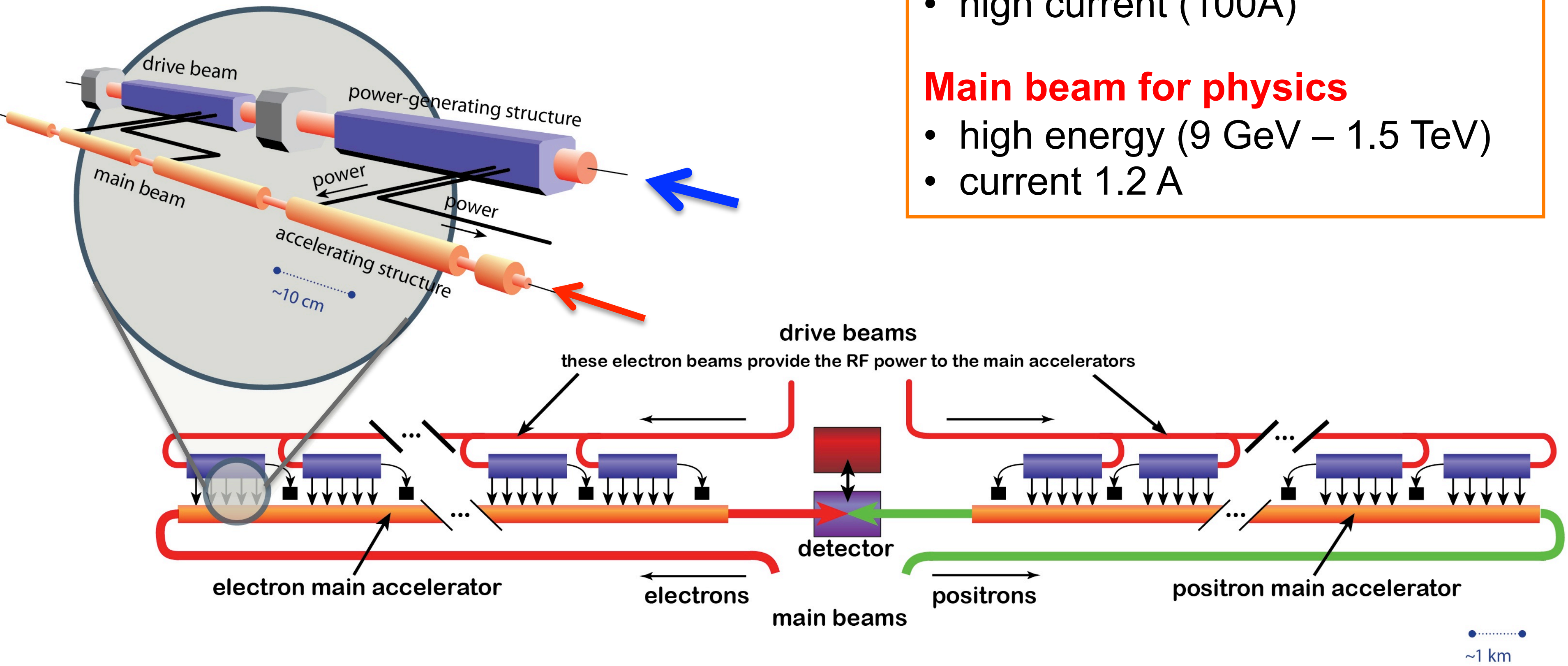
CLIC two-beam acceleration scheme

Two Beam Scheme:

Drive Beam supplies RF power
- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

Main beam for physics
- high energy (9 GeV – 1.5 TeV)
- current 1.2 A

Accelerating gradient: 100 MV/m



CLIC layout at 3 TeV

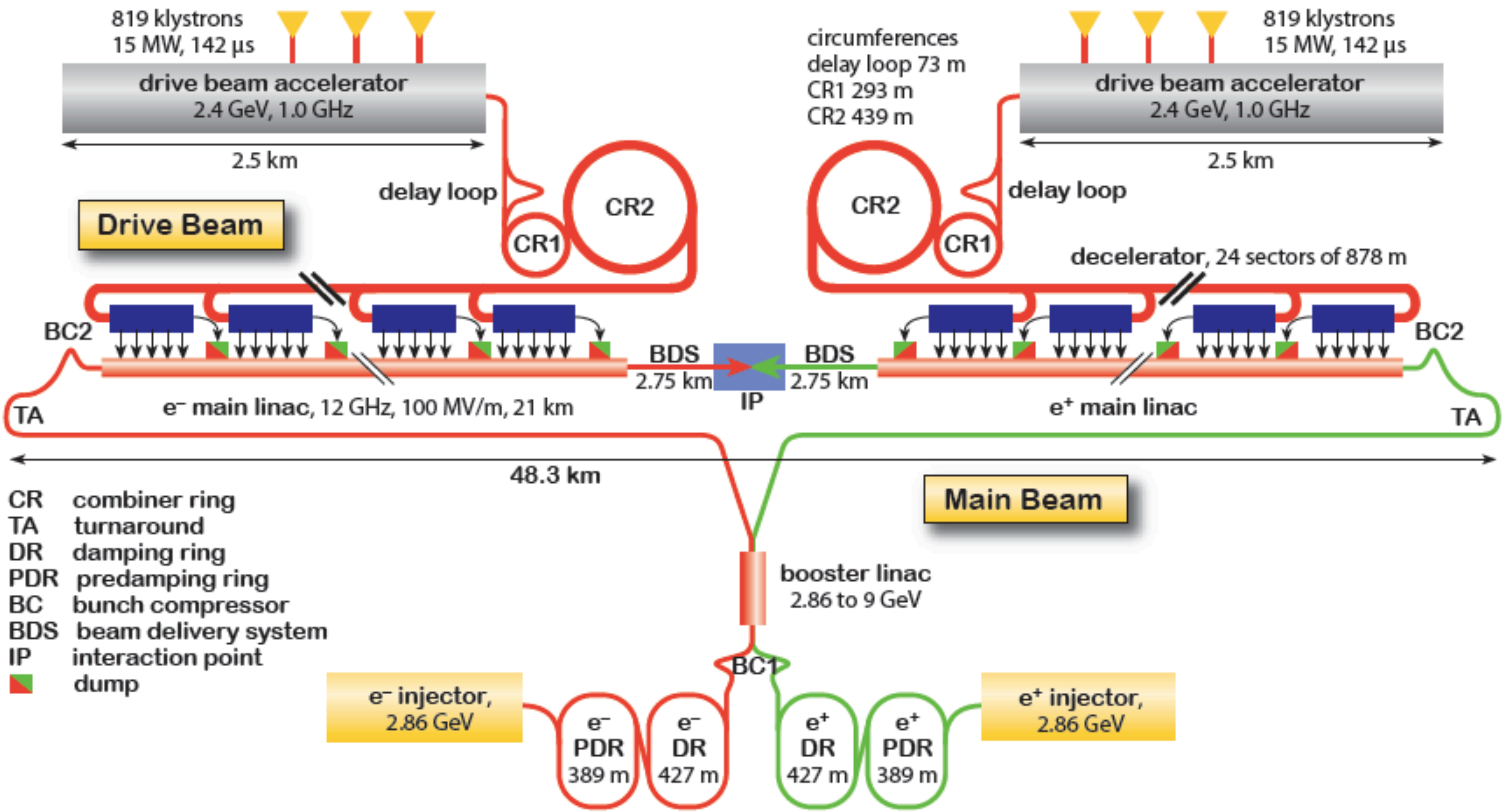


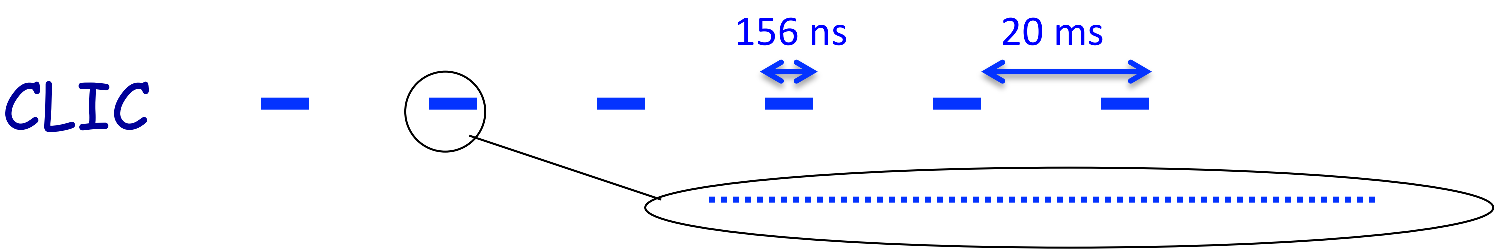
Fig. 3.1: Overview of the CLIC layout at $\sqrt{s} = 3$ TeV.

CLIC machine environment

	CLIC at 3 TeV
L ($cm^{-2}s^{-1}$)	5.9×10^{34}
BX separation	0.5 ns
#BX / train	312
Train duration (ns)	156
Rep. rate	50 Hz
Duty cycle	0.00078%
σ_x / σ_y (nm)	≈ 45 / 1
σ_z (μm)	44

Drives timing requirements for CLIC detector

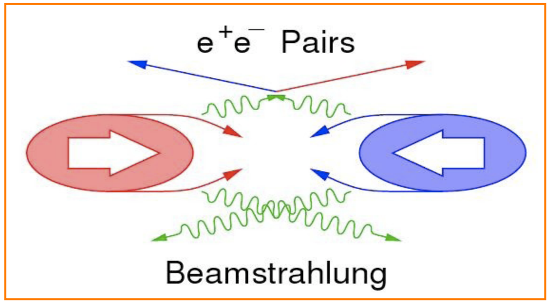
very small beam size



1 train = 312 bunches, 0.5 ns apart

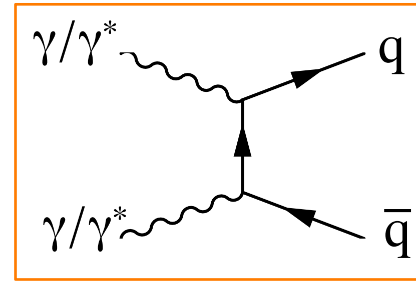
- not to scale -

CLIC machine environment



Beam related background:

- Small beam profile at IP leads very high E-field
  - **Beamstrahlung**
    - Pair-background
      - High occupancies
    - γγ to hadrons
      - Energy deposits



Beamstrahlung ➔ important energy losses right at the interaction point

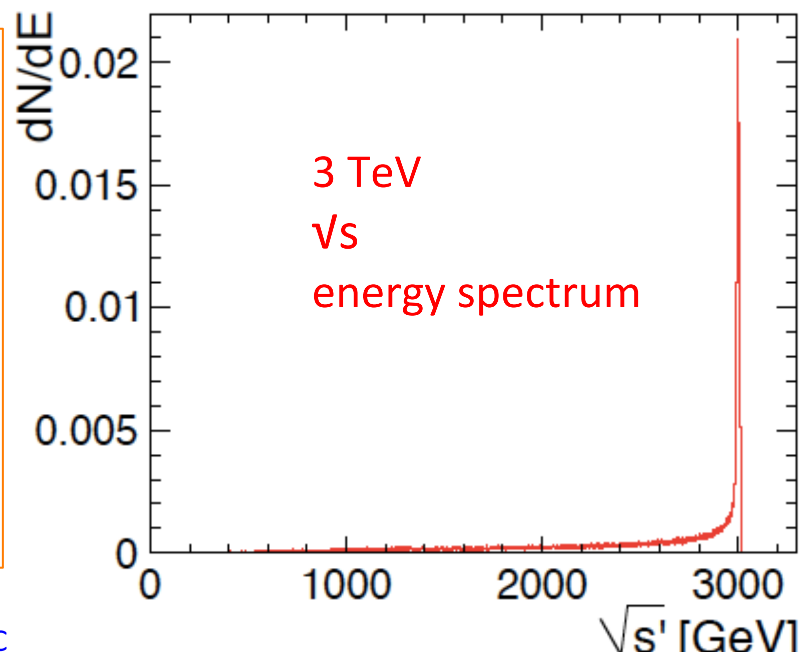
E.g. full luminosity at 3 TeV:

$5.9 \times 10^{34}\ cm^{-2}s^{-1}$

Of which in the 1% most energetic part:

$2.0 \times 10^{34}\ cm^{-2}s^{-1}$

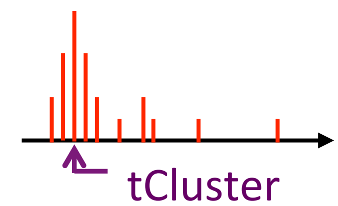
Most physics processes are studied well above production threshold => profit from full luminosity



background suppression at CLIC

Triggerless readout of full train

- **Full event reconstruction + PFA analysis with background overlaid**
  - => physics objects with precise p_T and cluster time information
  - Time corrected for shower development and TOF
- **Then apply cluster-based timing cuts**
  - Cuts depend on particle-type, p_T and detector region
  - Allows to protect high-p_T physics objects

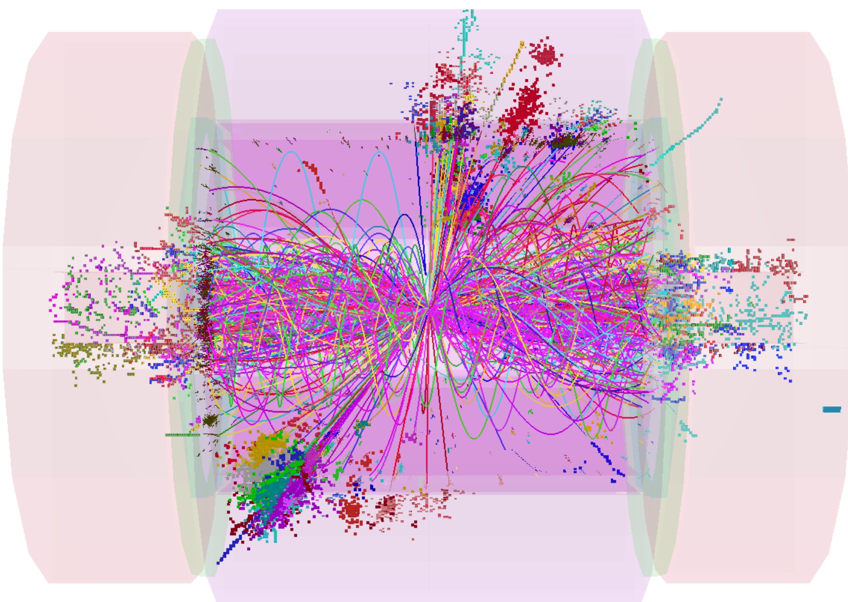


+

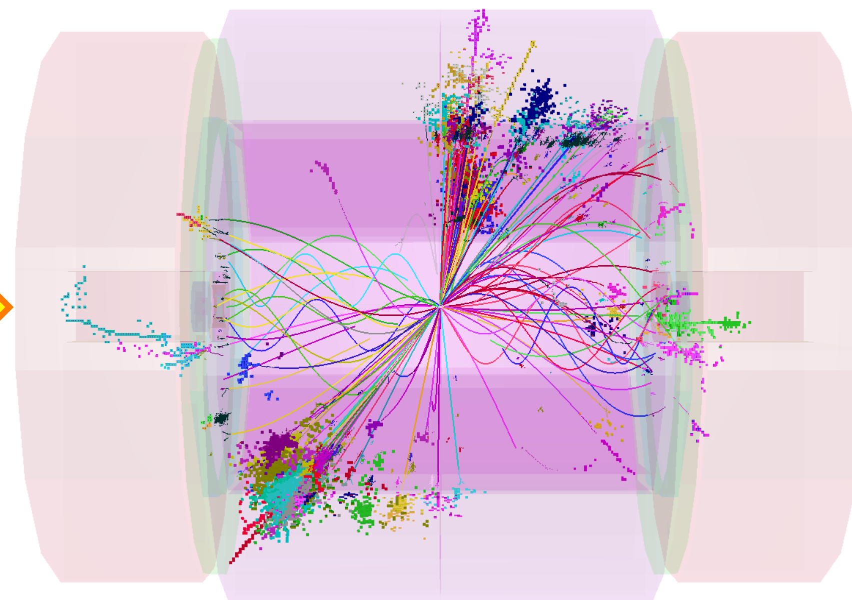
- **Use well-adapted jet clustering algorithms**
  - Making use of LHC experience (FastJet)

combined p_T and timing cuts

1.2 TeV



100 GeV



$$e^+e^- \to H^+H^- \to t\bar{b}b\bar{t} \to 8 \text{ jets}$$

1.2 TeV background in reconstruction time window

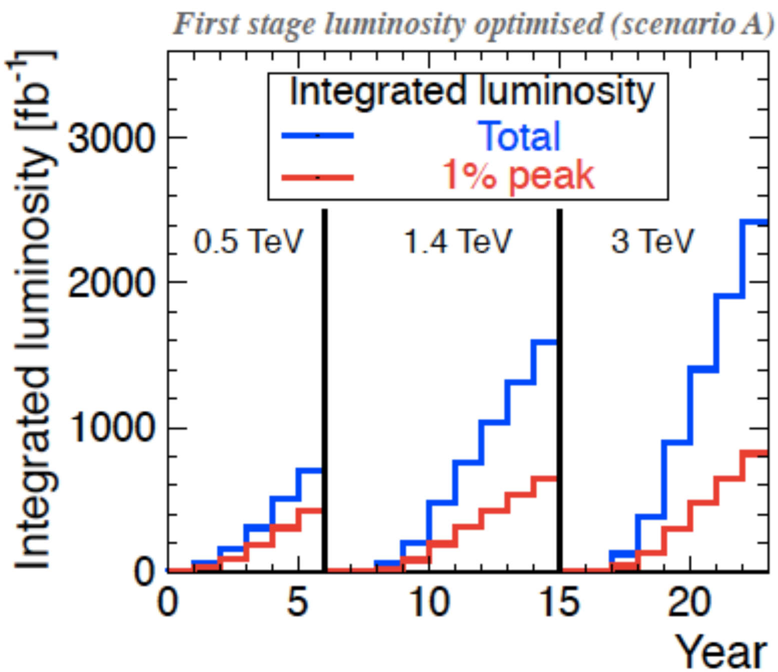
100 GeV background after tight cuts

PFO-based timing cuts

Region	p_t *range*	Time cut
Photons		
central ($\cos\theta \leq 0.975$)	$0.75\ \text{GeV} \leq p_t < 4.0\ \text{GeV}$	$t < 2.0$ nsec
	$0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 1.0$ nsec
forward ($\cos\theta > 0.975$)	$0.75\ \text{GeV} \leq p_t < 4.0\ \text{GeV}$	$t < 2.0$ nsec
	$0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 1.0$ nsec
Neutral hadrons		
central ($\cos\theta \leq 0.975$)	$0.75\ \text{GeV} \leq p_t < 8.0\ \text{GeV}$	$t < 2.5$ nsec
	$0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 1.5$ nsec
forward ($\cos\theta > 0.975$)	$0.75\ \text{GeV} \leq p_t < 8.0\ \text{GeV}$	$t < 2.0$ nsec
	$0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 1.0$ nsec
Charged PFOs		
all	$0.75\ \text{GeV} \leq p_t < 4.0\ \text{GeV}$	$t < 3.0$ nsec
	$0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 1.5$ nsec

Integrated luminosity

Possible scenarios "A" and "B", these are **"just examples"**



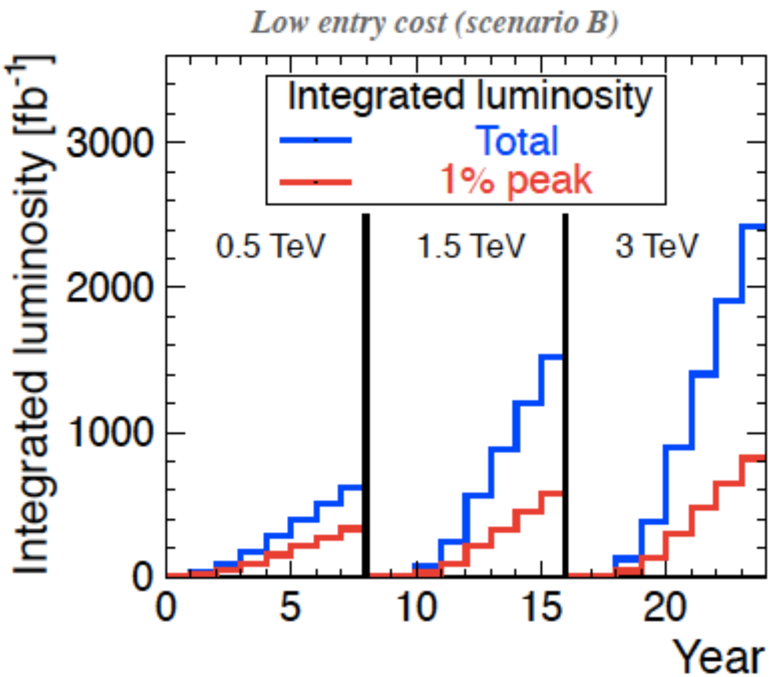


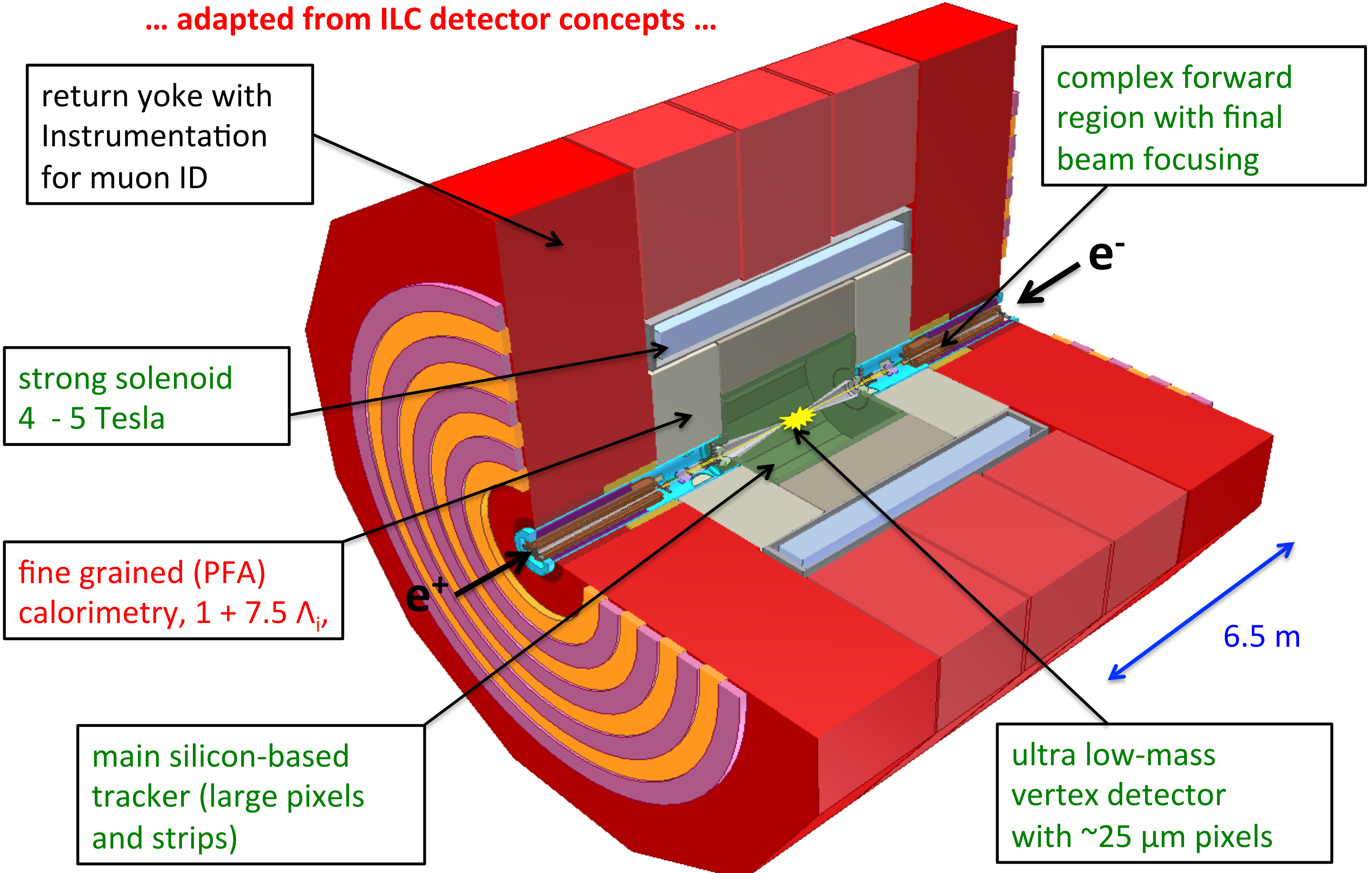
Fig. 5.2: Integrated luminosity in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right). Years are counted from the start of beam commissioning. These figures include luminosity ramp-up of four years (5%, 25%, 50%, 75%) in the first stage and two years (25%, 50%) in subsequent stages.

Based on 200 days/year at 50% efficiency (accelerator + data taking combined)

=> CLIC can provide an evolving and rich physics program over several decades

CLIC detector concept

… adapted from ILC detector concepts …



Summary of Higgs measurements

Channel	Measurement	Observable	Statistical precision		
			350 GeV 500 fb^{-1}	1.4 TeV 1.5 ab^{-1}	3.0 TeV 2.0 ab^{-1}
ZH	Recoil mass distribution	m_H	120 MeV	–	–
ZH	$\sigma(HZ) \times BR(H \to \text{invisible})$	Γ_{inv}	0.6%	–	–
ZH	$H \to b\bar{b}$ mass distribution	m_H	tbd	–	–
$H\nu_e\bar{\nu}_e$	$H \to b\bar{b}$ mass distribution	m_H	–	40 MeV*	33 MeV*
ZH	$\sigma(HZ) \times BR(Z \to \ell^+\ell^-)$	g^2_{HZZ}	4.2%	–	–
ZH	$\sigma(HZ) \times BR(Z \to q\bar{q})$	g^2_{HZZ}	1.8%	–	–
ZH	$\sigma(HZ) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	1%†	–	–
ZH	$\sigma(HZ) \times BR(H \to c\bar{c})$	$g^2_{HZZ} g^2_{Hcc}/\Gamma_H$	5%†	–	–
ZH	$\sigma(HZ) \times BR(H \to gg)$		6%†	–	–
ZH	$\sigma(HZ) \times BR(H \to \tau^+\tau^-)$	$g^2_{HZZ} g^2_{H\tau\tau}/\Gamma_H$	5.7%	–	–
ZH	$\sigma(HZ) \times BR(H \to WW^*)$	$g^2_{HZZ} g^2_{HWW}/\Gamma_H$	2%†	–	–
ZH	$\sigma(HZ) \times BR(H \to ZZ^*)$	$g^2_{HZZ} g^2_{HZZ}/\Gamma_H$	tbd	–	–
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	3%†	0.3%	0.2%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	–	2.9%	2.7%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		–	1.8%	1.8%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \tau^+\tau^-)$	$g^2_{HWW} g^2_{H\tau\tau}/\Gamma_H$	–	3.7%*	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \mu^+\mu^-)$	$g^2_{HWW} g^2_{H\mu\mu}/\Gamma_H$	–	38%	16%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \gamma\gamma)$		–	15%	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to Z\gamma)$		–	42%	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to WW^*)$	g^4_{HWW}/Γ_H	tbd	1.1%*	0.8%*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to ZZ^*)$	$g^2_{HWW} g^2_{HZZ}/\Gamma_H$	–	3%†	2%†
He^+e^-	$\sigma(He^+e^-) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	–	1%†	0.7%†
$t\bar{t}H$	$\sigma(t\bar{t}H) \times BR(H \to b\bar{b})$	$g^2_{Htt} g^2_{Hbb}/\Gamma_H$	–	8%	tbd
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	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^- polarization	λ	–	24%	12%

Summary of CLIC Higgs benchmark simulations

http://arxiv.org/abs/1307.5288

Work in progress !

* Preliminary
† Estimate

CLIC Higgs global fits

Work in progress !

★ Model-independent global fits

80% electron polarisation assumed above 1 TeV

Parameter	Measurement precision		
	350 GeV 500 fb^{-1}	+ 1.4 TeV +1.5 ab^{-1}	+3.0 TeV +2.0 ab^{-1}
m_H	120 MeV	30 MeV	20 MeV
λ	–	24%	11%
Γ_H [%]	5.0	3.6	3.4
g_{HZZ} [%]	0.8	0.8	0.8
g_{HWW} [%]	1.8	0.9	0.9
g_{Hbb} [%]	2.0	1.0	0.9
g_{Hcc} [%]	3.2	1.4	1.1
g_{Htt} [%]	–	4.1	4.1
$g_{H\tau\tau}$ [%]	3.5	1.6	< 1.5
$g_{H\mu\mu}$ [%]	–	14	5.6
g_{Hgg} [%]	3.6	1.1	1.0
$g_{H\gamma\gamma}$ [%]	–	5.7	< 5.7

★ ~1 % precision on many couplings

- limited by g_{HZZ} precision

★ Constrained "LHC-style" fits

- Assuming no invisible Higgs decays (model-dependent):

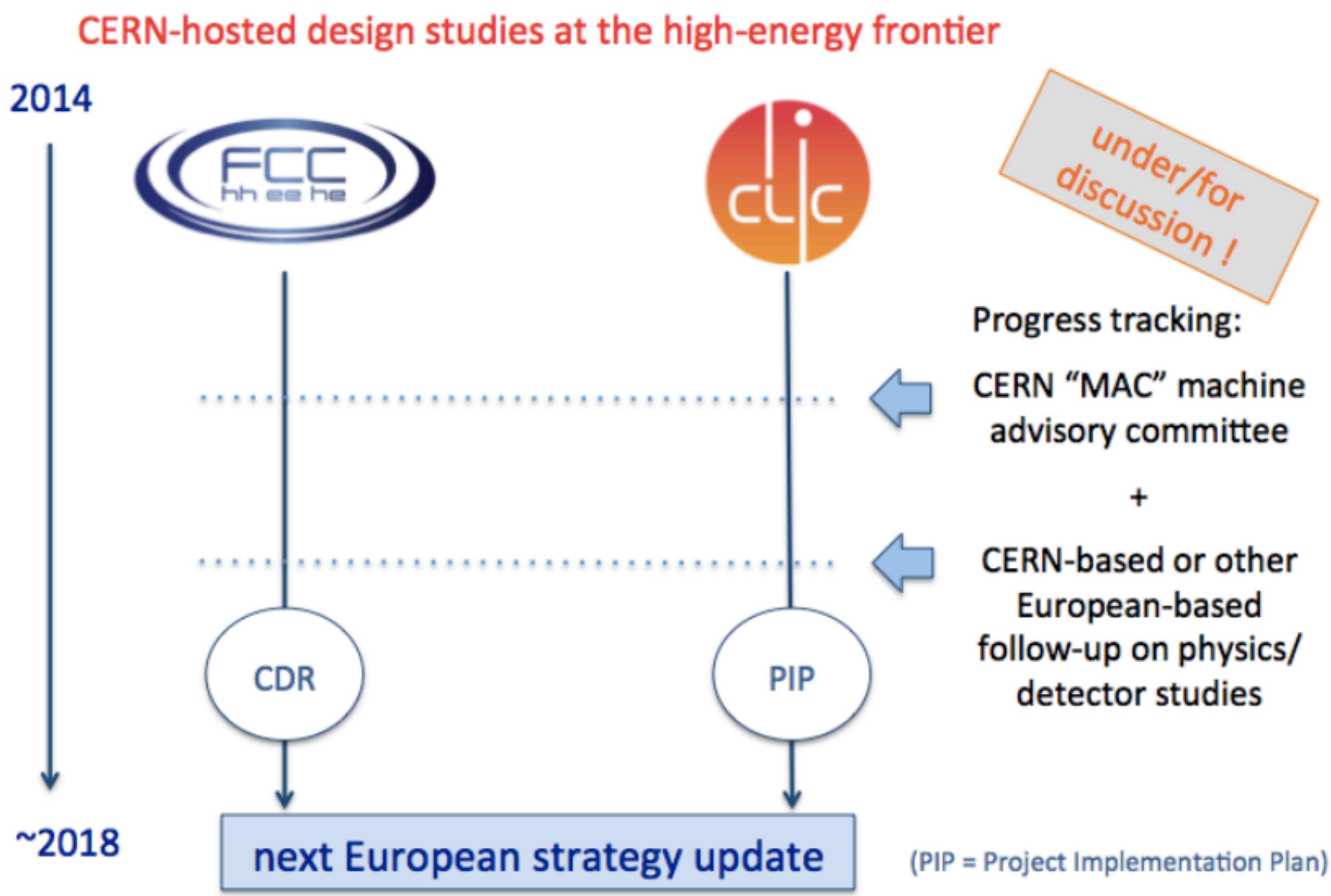
$$\kappa_i^2 = \frac{\Gamma_i}{\Gamma_i|_{SM}}$$

$$\Gamma_{H,md} = \sum_i \kappa_i^2 BR_i$$

Parameter	Measurement precision		
	350 GeV 500 fb^{-1}	+ 1.4 TeV +1.5 ab^{-1}	+3.0 TeV +2.0 ab^{-1}
$\Gamma_{H,model}$ [%]	1.6	0.29	0.22
κ_{HZZ} [%]	0.43	0.31	0.23
κ_{HWW} [%]	1.5	0.15	0.11
κ_{Hbb} [%]	1.7	0.33	0.21
κ_{Htt} [%]	3.1	1.0	0.74
$\kappa_{H\tau\tau}$ [%]	3.4	1.3	< 1.3
κ_{Hgg} [%]	3.6	0.76	0.56
$\kappa_{H\gamma\gamma}$ [%]	–	5.6	< 5.6

★ sub-% precision for most couplings

CLIC and FCC


CERN-hosted design studies at the high-energy frontier
2014
FCC
hh ee he
under/for discussion !
Progress tracking:
CERN "MAC" machine advisory committee
+
CERN-based or other European-based follow-up on physics/ detector studies
CDR
PIP
~2018
next European strategy update
(PIP = Project Implementation Plan)