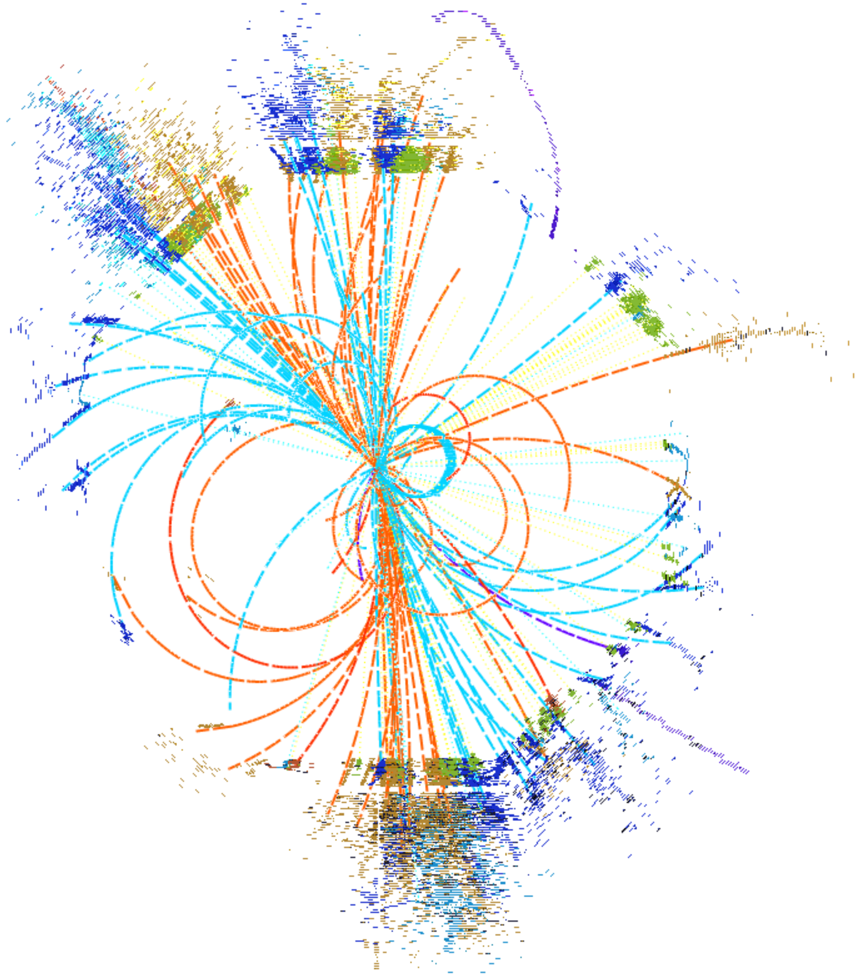
Update from the CLIC physics and detector study

Philipp Roloff (CERN PH/LCD)
on behalf of the CLIC physics and detector study



CLIC Collaboration working meeting, CERN, 11/05/2012

Outline

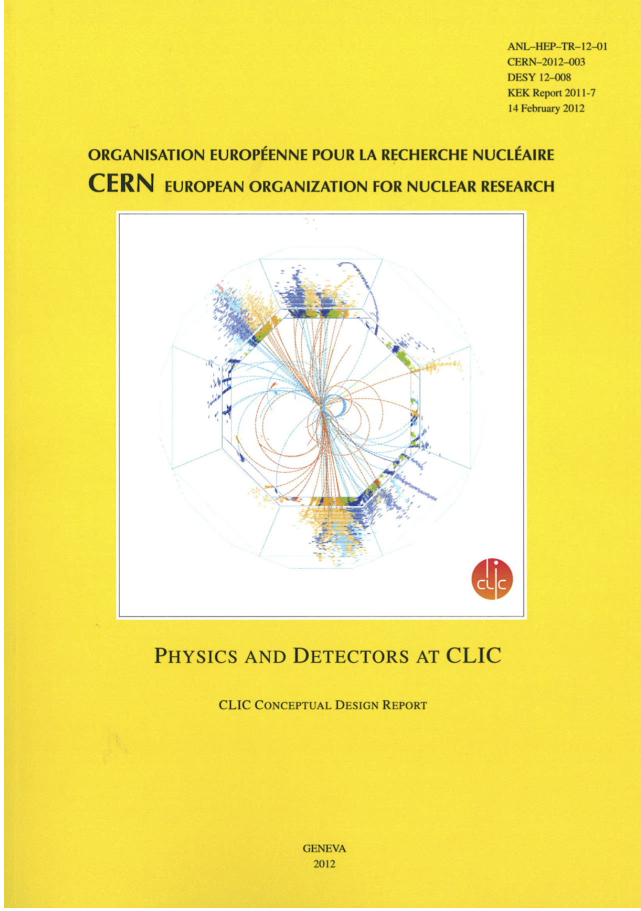
- Highlights from the CLIC physics and detector CDR
- Ongoing staged energy studies for Vol. 3 of the CLIC CDR
- Organisation of the CLIC physics and detector study

CLIC physics and detector CDR

CLIC provides the potential for e+e- collisions up to $\sqrt{s}$ = 3 TeV:
Challenging machine environment
→ detailed detector studies were needed

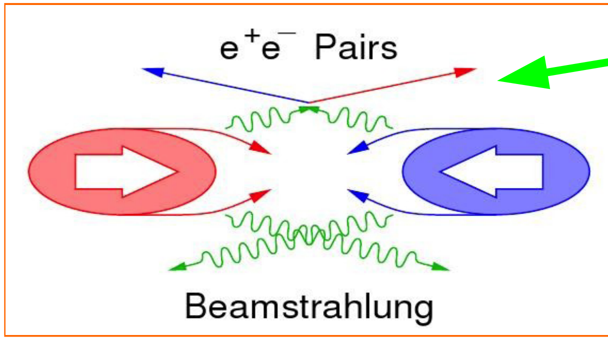
CLIC physics and detector CDR:
- Physics potential
- Demonstrate that the physics can be measured at CLIC

The CLIC physics and detector CDR is published: http://arxiv.org/abs/1202.5940

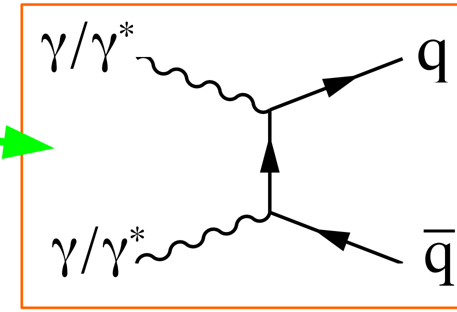


Review in October 2011:
https://indico.cern.ch/conferenceTimeTable.py?confId=146521

Impact of beam related backgrounds

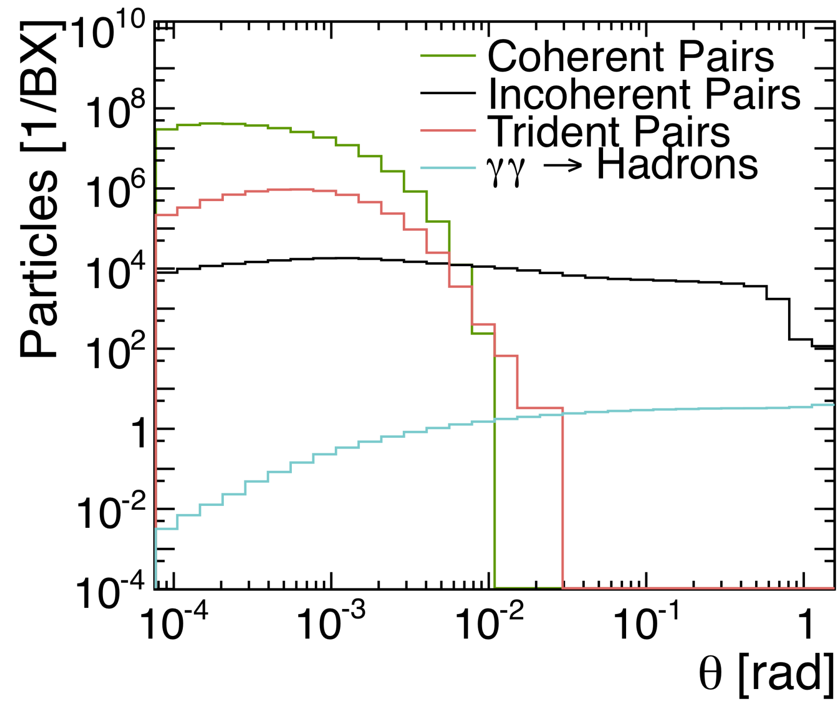


- e^+e^- pairs
- $\gamma\gamma \rightarrow$ hadrons
- Beam halo muons



Coherent e^+e^- pairs:
$7 \cdot 10^8$ per BX (at 3 TeV), very forward
Incoherent e^+e^- pairs:
$3 \cdot 10^5$ per BX (at 3 TeV), rather forward
→ Detector design issue
(high occupancies)

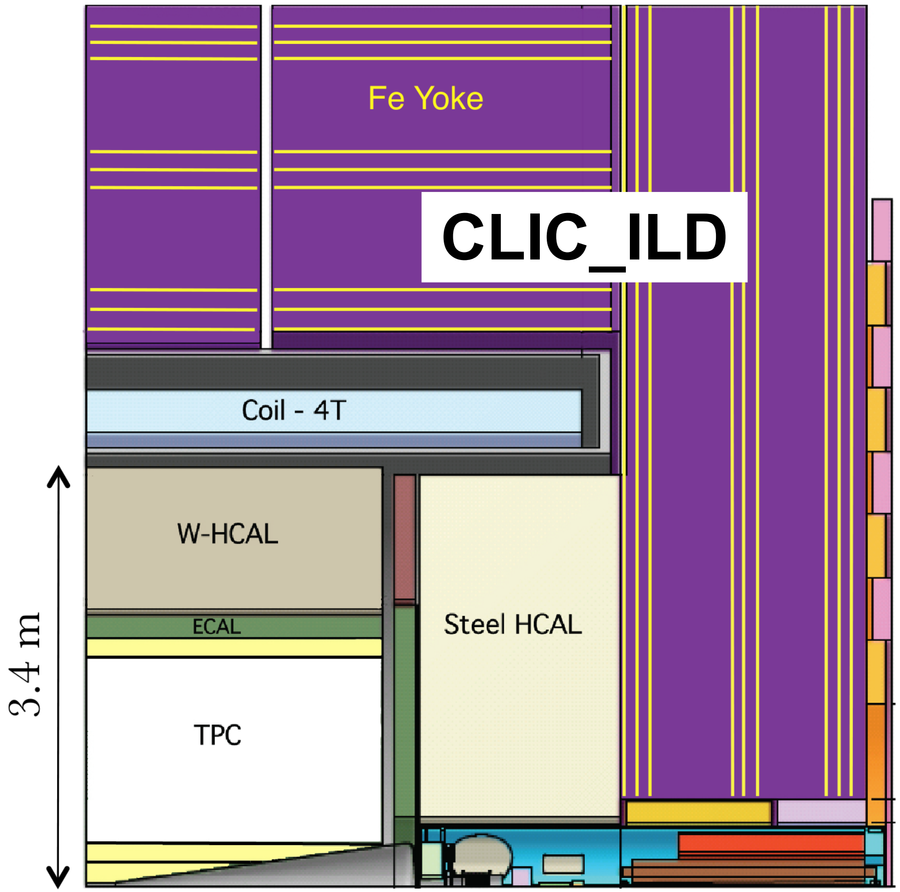
$\gamma\gamma \rightarrow$ hadrons
- Main background in calorimeters and trackers
→ Impact on physics
- 3.2 $\gamma\gamma \rightarrow$ hadrons interactions per BX (3 TeV)
- Included in simulation studies by overlaying physics events with $\gamma\gamma \rightarrow$ hadrons events

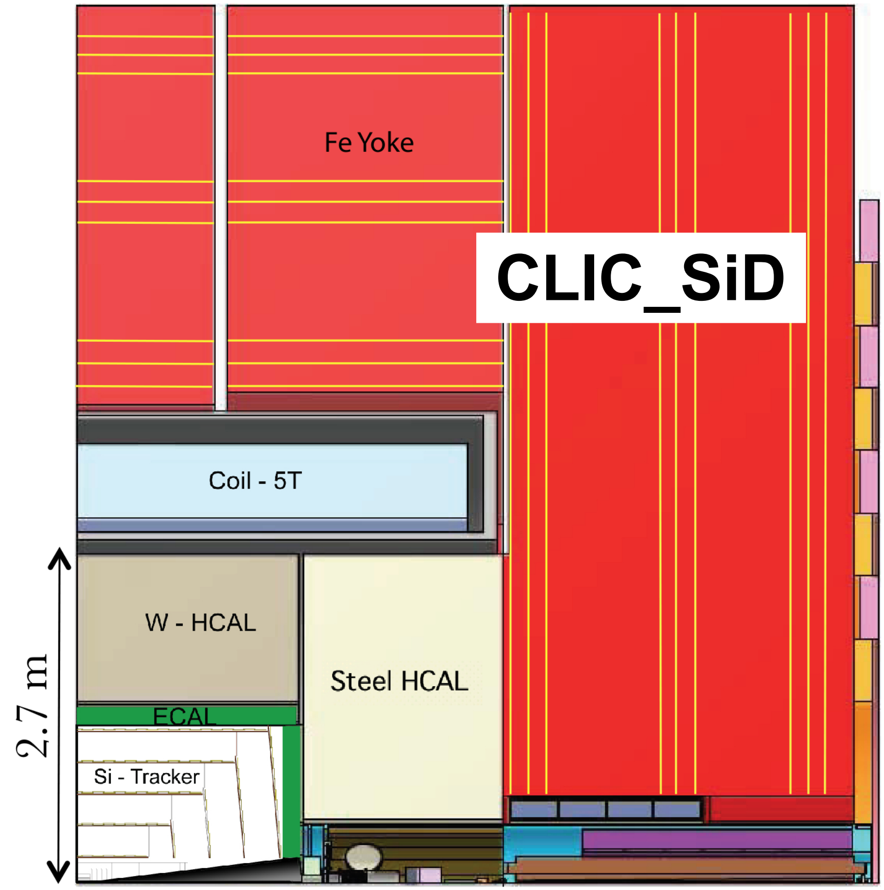


CLIC detector concepts

Based on validated ILC designs, adapted and optimised to the CLIC conditions:

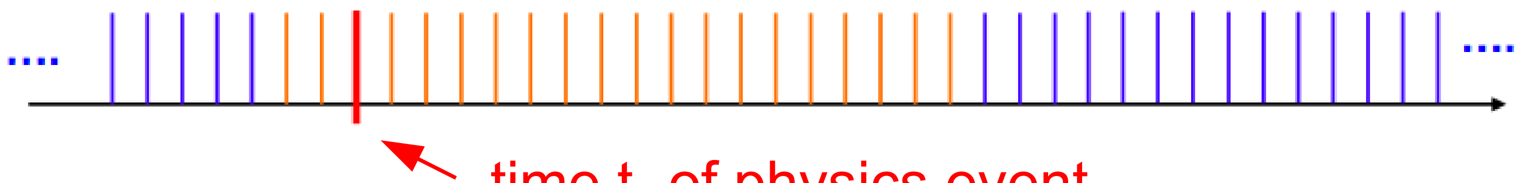
- Denser HCAL in the barrel (Tungsten, 7.5 λ)
- Redesign of the vertex and forward detectors
- Precise timing capabilities of most subdetectors



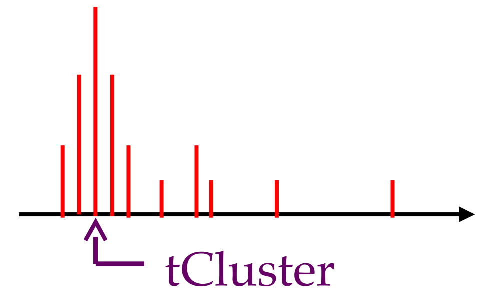


Background suppression

Triggerless readout of full bunch train:



time t_0 of physics event



Identify t_0 of physics event in offline event filter

- Define reconstruction window around t_0
- All hits and tracks in this window are passed to the reconstruction

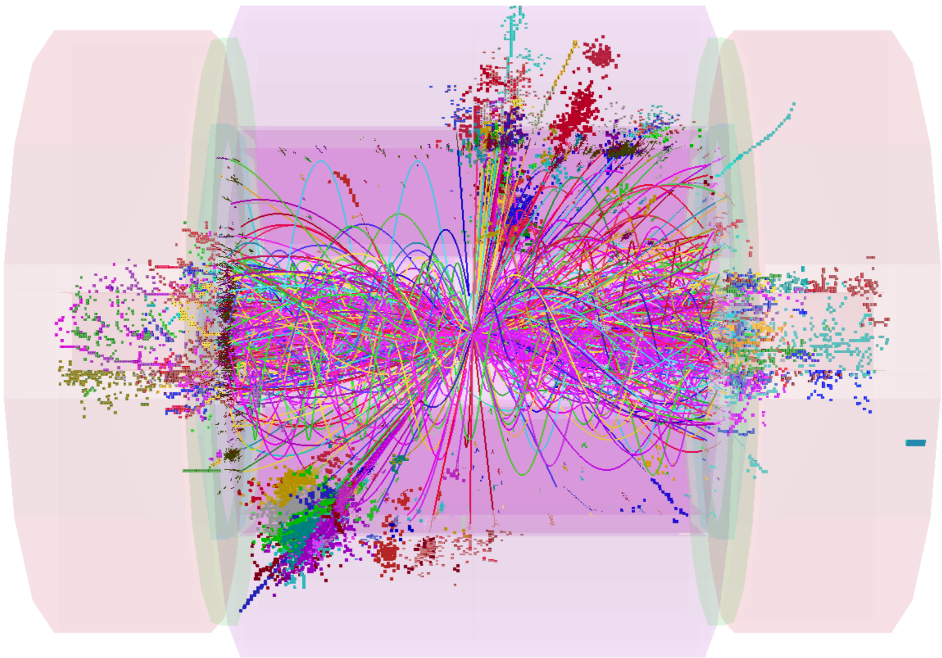
→ Physics objects with precise p_T and cluster time information

→ Background rejection using combined timing & p_T cuts

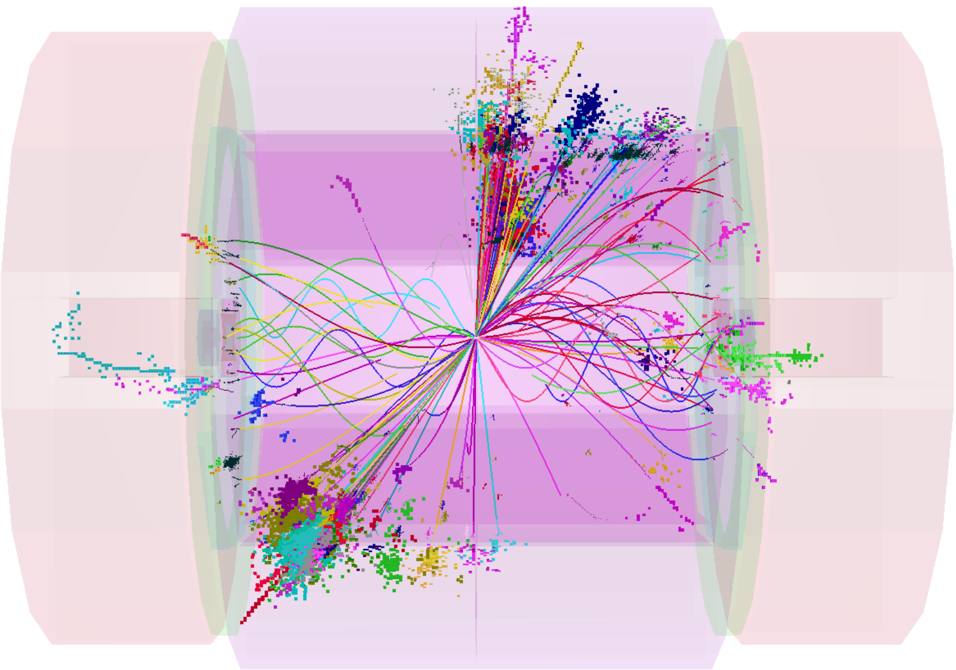
- Further reduction of the impact of the background is achieved using well-adapted jet finding strategies based on the LHC experience (FastJet)

Impact of the timing cuts

$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t}$ (8 jet final state)



1.2 TeV background
in the reconstruction window



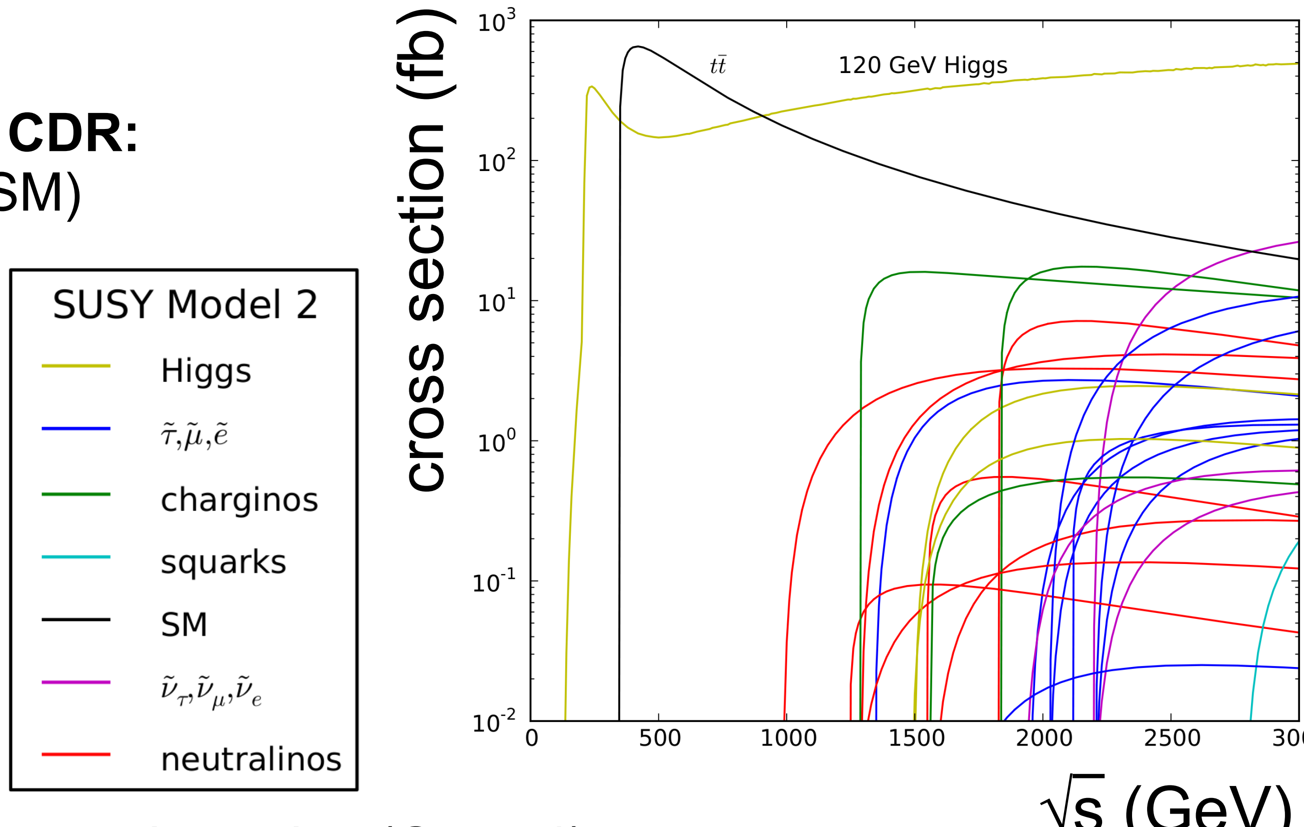
100 GeV background
after (tight) timing cuts

CLIC physics potential

Advantage of e^+e^- collisions:
- Defined initial state
- Precision measurements possible due to clean conditions
- Well suited for weakly interacting states (e.g. sleptons, gauginos)
- Polarised (electron) beam

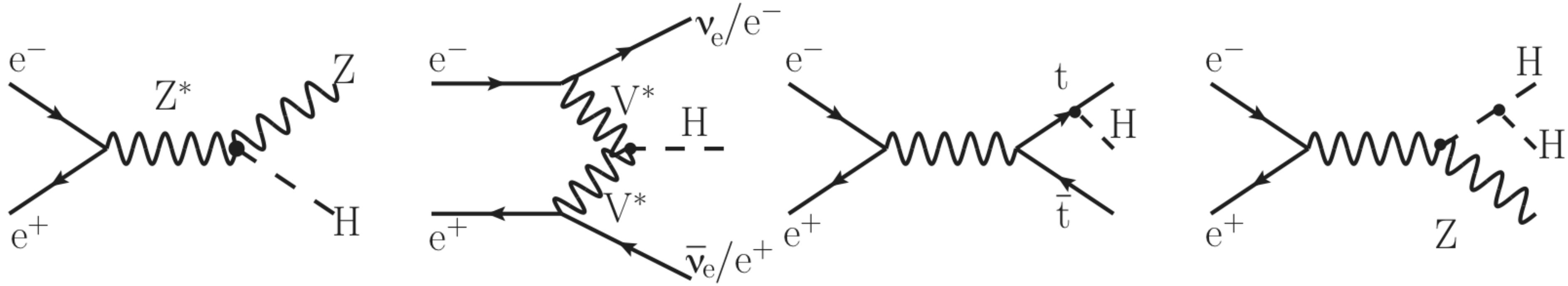
→ Complementary / enhanced discovery reach compared to the LHC

Examples highlighted in the CDR:
- Higgs physics (SM and non-SM)
- Top physics
- SUSY
- Higgs strong interactions
- Z'
- Contact interactions
- Extra dimensions
- …



All studies shown in the following are based on full detector simulation (Geant4)

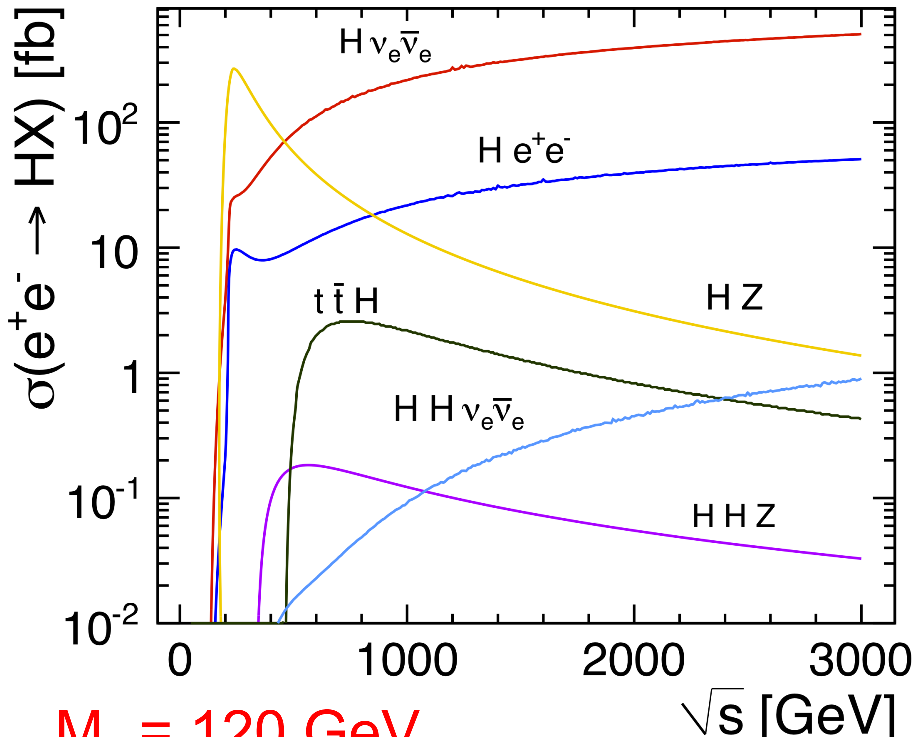
SM Higgs production



s-channel: ~ 1/s   t-channel: ~ log(s)

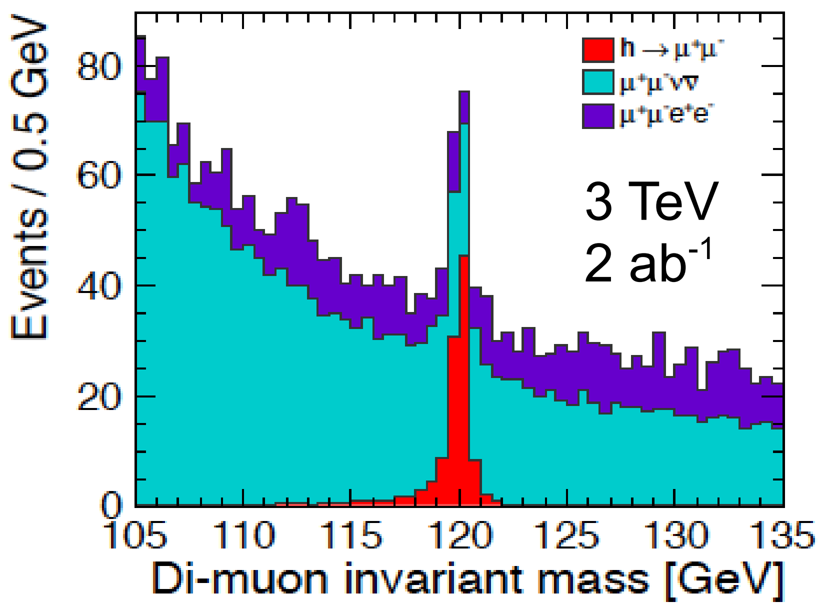
At $\sqrt{s}$ = 3 TeV:

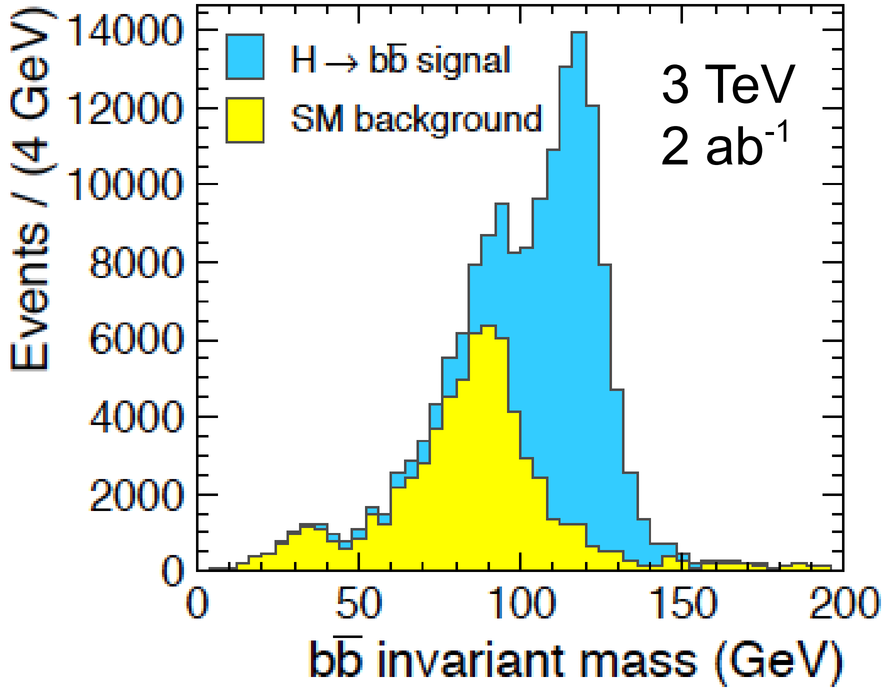
- WW fusion ($e^+e^- \rightarrow H\nu_e\bar{\nu}_e$) dominant
- Highest peak luminosity achievable



M_h = 120 GeV

Example Higgs observables





$\sigma(h \to \mu^+\mu^-) \to \pm 15\%$ (stat.)

$\sigma(h \to b\bar{b}) \to \pm 0.22\%$ (stat.)

	Coupling determination(%)	Sensitivity to SM deviation (%)
Hbb	2	4
Hcc	3	6
$H\mu\mu$	15	15

Test of the di-jet mass reconstruction

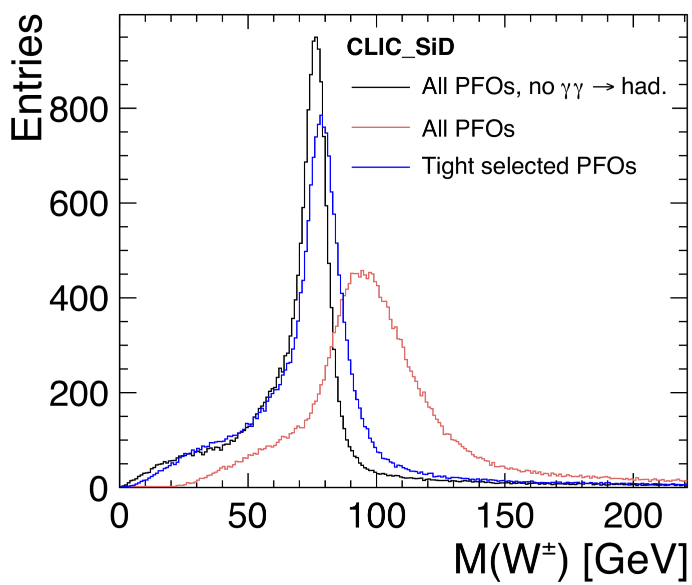
Chargino and neutralino pair production:

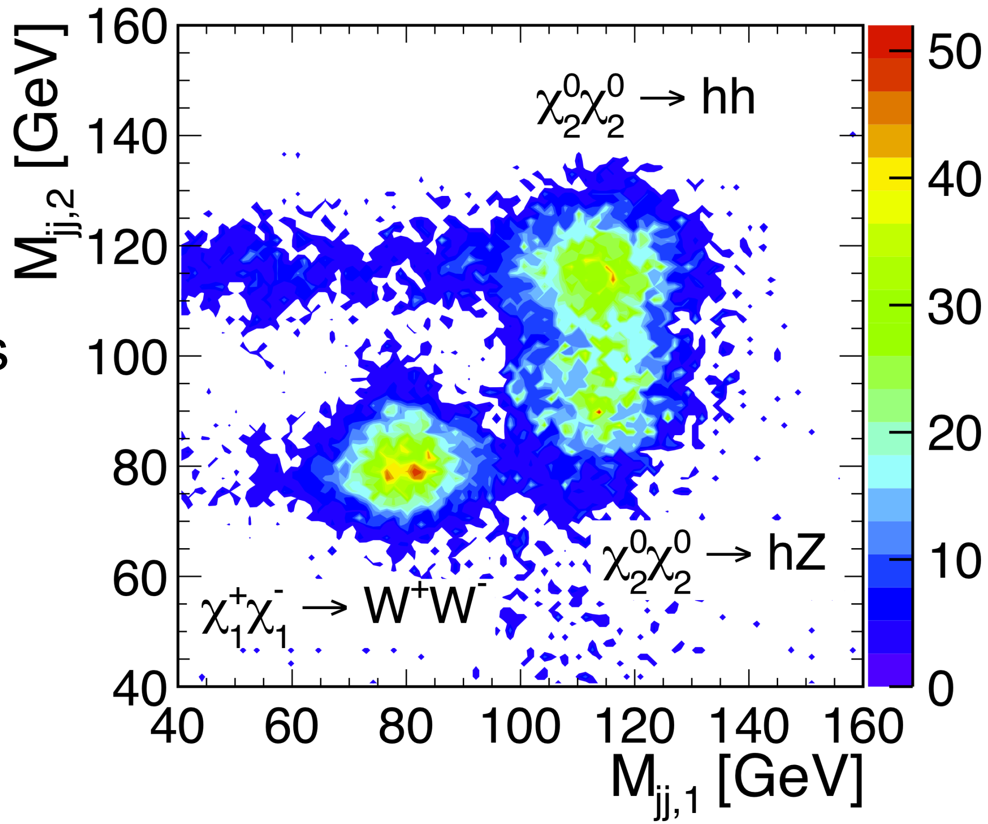
$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+ W^-$$

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

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

Reconstruct $W^{\pm}/Z/h$ in hadronic decays
→ four jets and missing energy





Precision on the measured gaugino masses (few hundred GeV): 1 - 1.5%

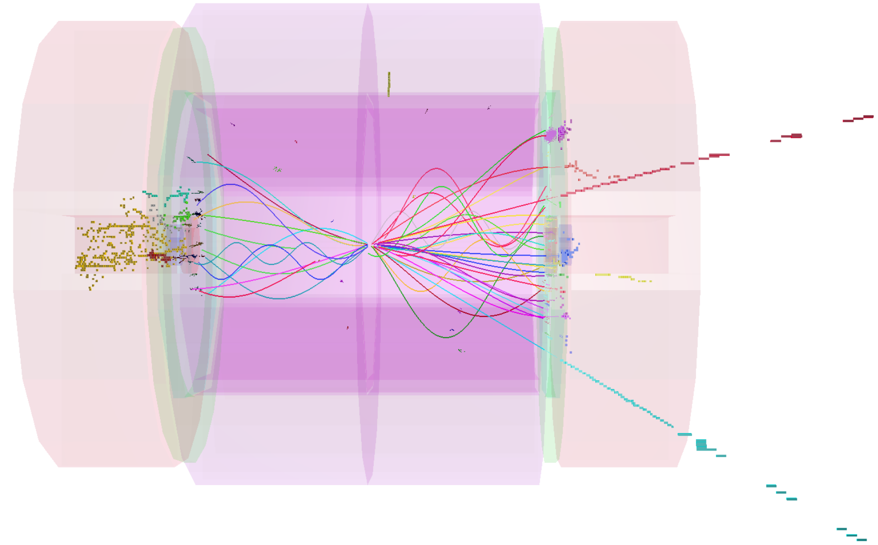
Test of the lepton reconstruction

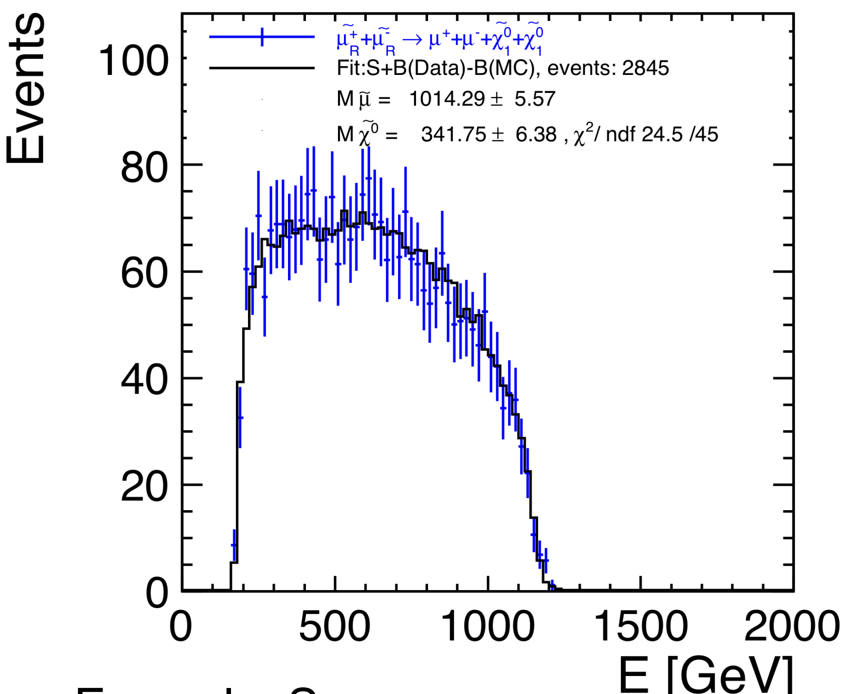
- Slepton production very clean at CLIC
- SUSY “model II”: slepton masses ≈ 1 TeV
- Investigated channels include:

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

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

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





Example: Smuons

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

$m(\tilde{\mu}_R)$	± 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

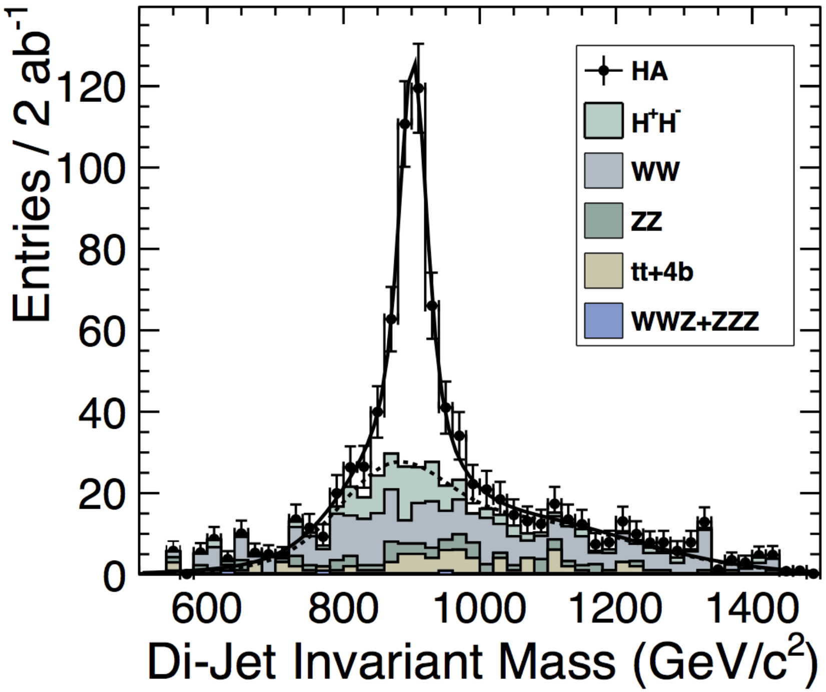
Complex final states

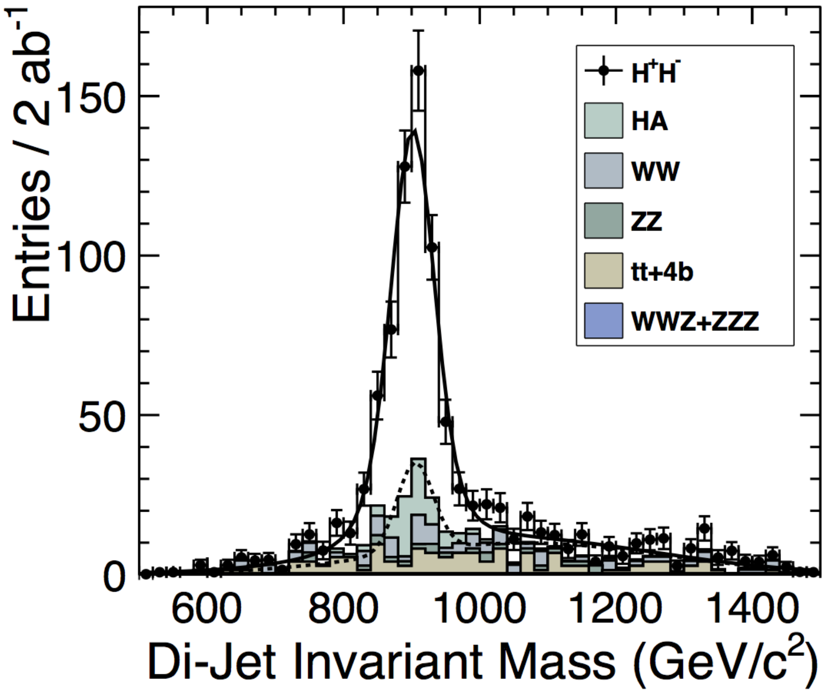
Heavy Higgs bosons:

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

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

Flavour tagging crucial!



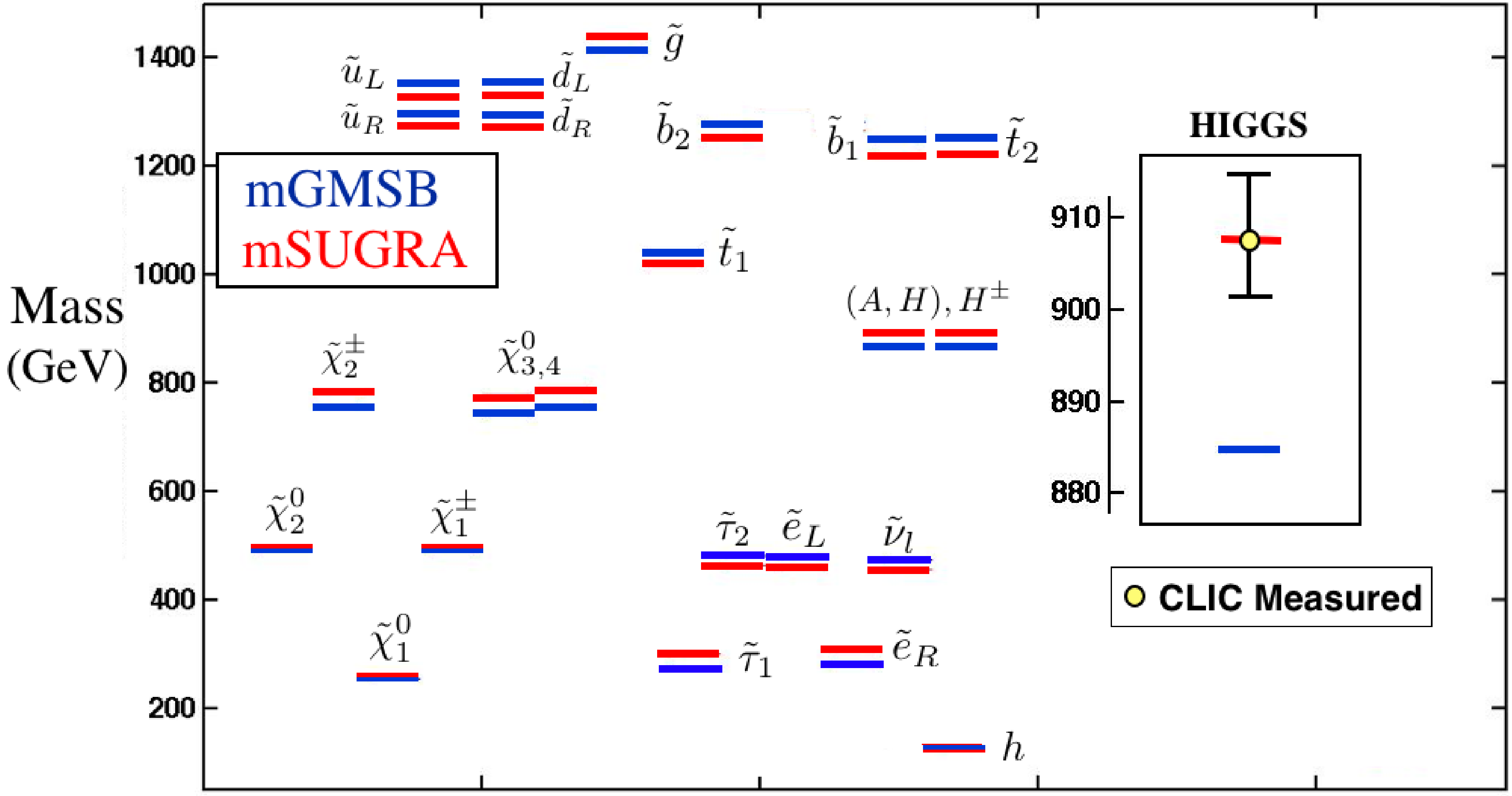


Accuracy of the heavy Higgs mass measurements: ≈ 0.3%

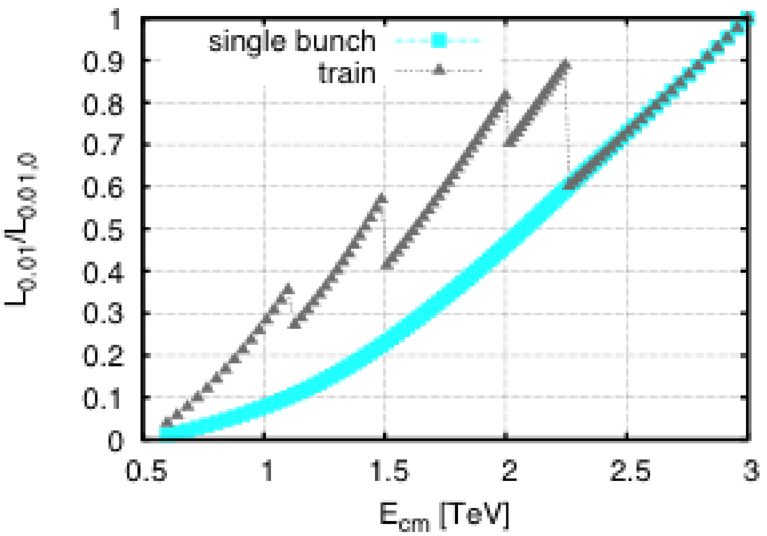
Resolving new physics models

Precision measurements at CLIC allow to discriminate between new physics models, e.g. following first observations at the LHC

Example: SUSY breaking models with nearly degenerate mass spectra



Motivation for energy staging



• Interesting physics (may) exist at various Energies:

- Few 100 GeV:
Precision SM measurements: Higgs, top,...
- Still unknown:
Beyond Standard Model physics,
Potentially various thresholds from few 100 GeV to few TeV
→ Both require high luminosities!

• Significant luminosity penalty when running far below the nominal energy

• Possibility to start physics during construction phase for higher energies

Ongoing benchmark studies for the CLIC CDR Vol. 3

Stage 1: E_{CMS} = 500 GeV, L = 500 fb^{-1}

- Top threshold scan (350 GeV)
- Higgs mass from ZH events (350 and 500 GeV)

Stage 2: E_{CMS} = 1400 GeV, L = 1.5 ab^{-1}

- Higgs self-coupling
- Several SUSY studies using a specific model

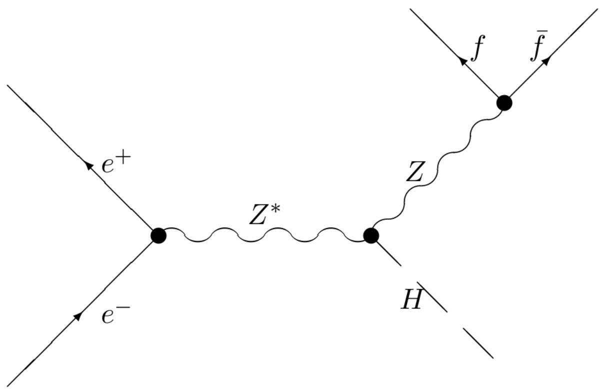
Stage 3: E_{CMS} = 3 TeV, L = 2 ab^{-1}

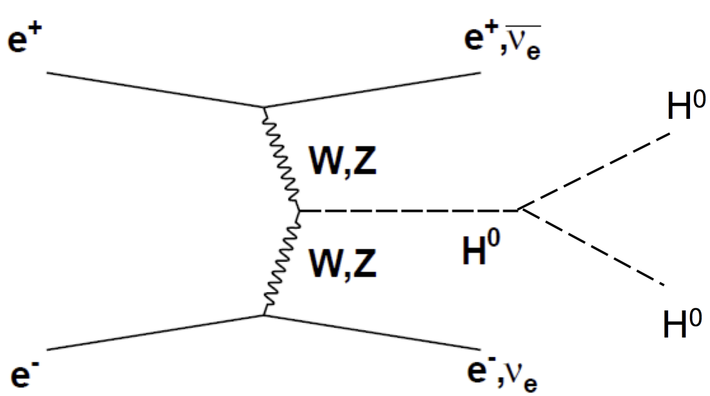
- Higgs self-coupling

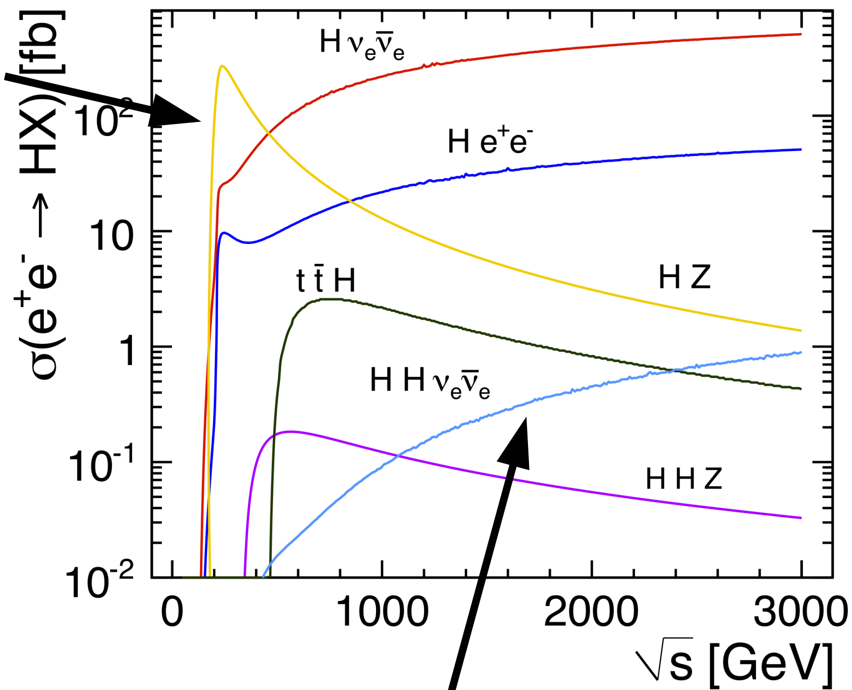
Higgs studies for Vol. 3

At 350 GeV and 500 GeV:

- Higgs mass and cross section from ZH events
- Measurement of Z recoil allows measurement without assumption on Higgs decay modes







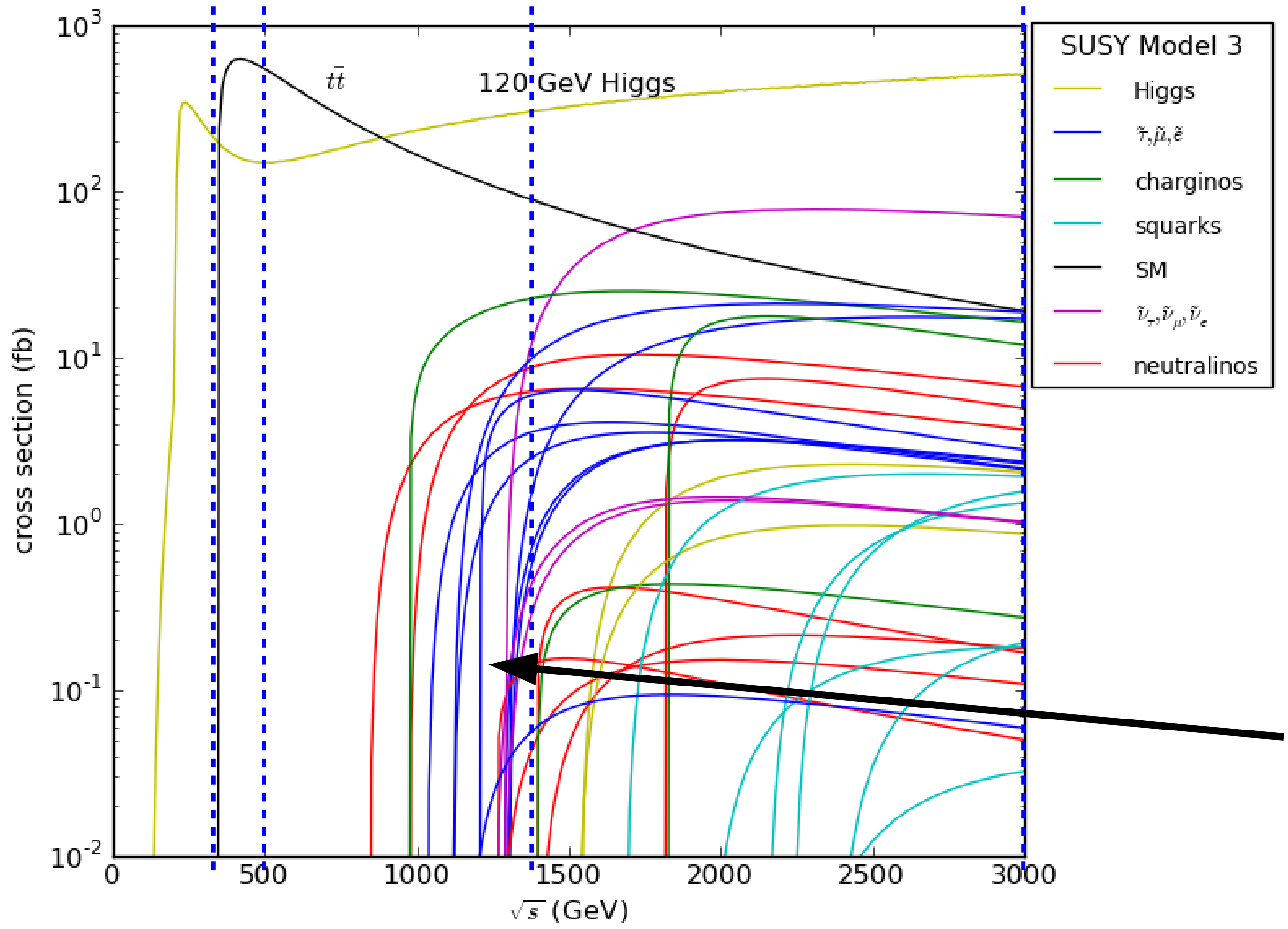
At 1.4 TeV and 3 TeV:

- Measure the HH final state

→ allows extraction of the Higgs self-coupling

- Only possible at high energy (cross section)

SUSY model for staged energy studies



Stage 2:

- light gauginos
- sleptons
- squarks and charged Higgs too heavy

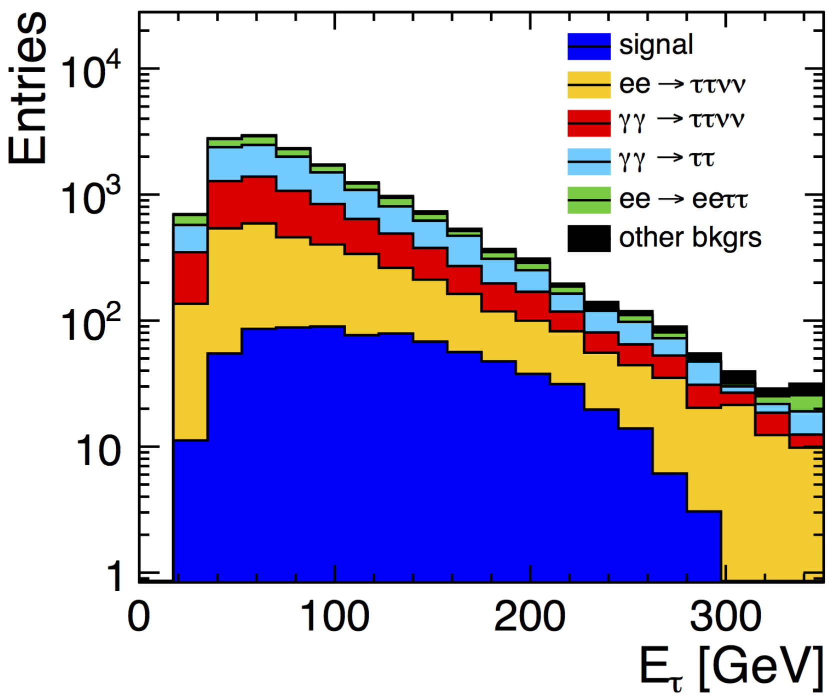
Quite different experimental challenges compared to the studies at 3 TeV, because SUSY particles produced close to threshold

Stau pair production

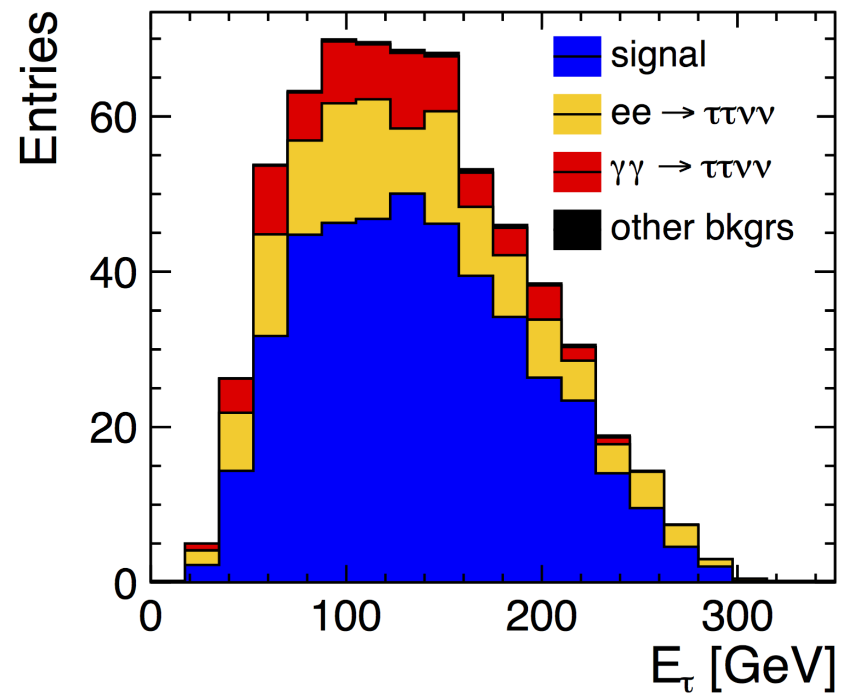
$$e^+e^- \rightarrow \tilde{\tau}_1^+\tilde{\tau}_1^- \rightarrow \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

$M(\tilde{\tau}_1^+) = 517$ GeV

Requires identification of tau leptons!



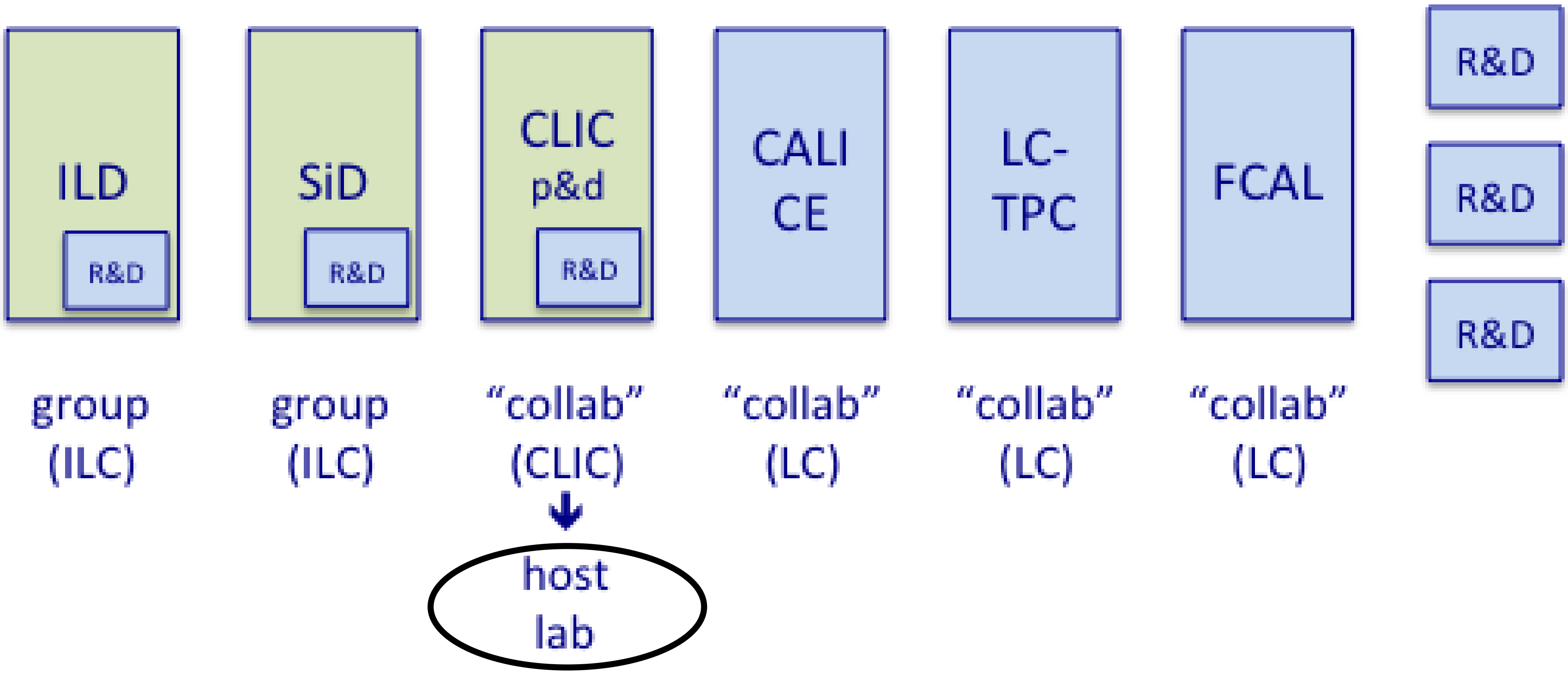
signal and backgrounds



selected candidates

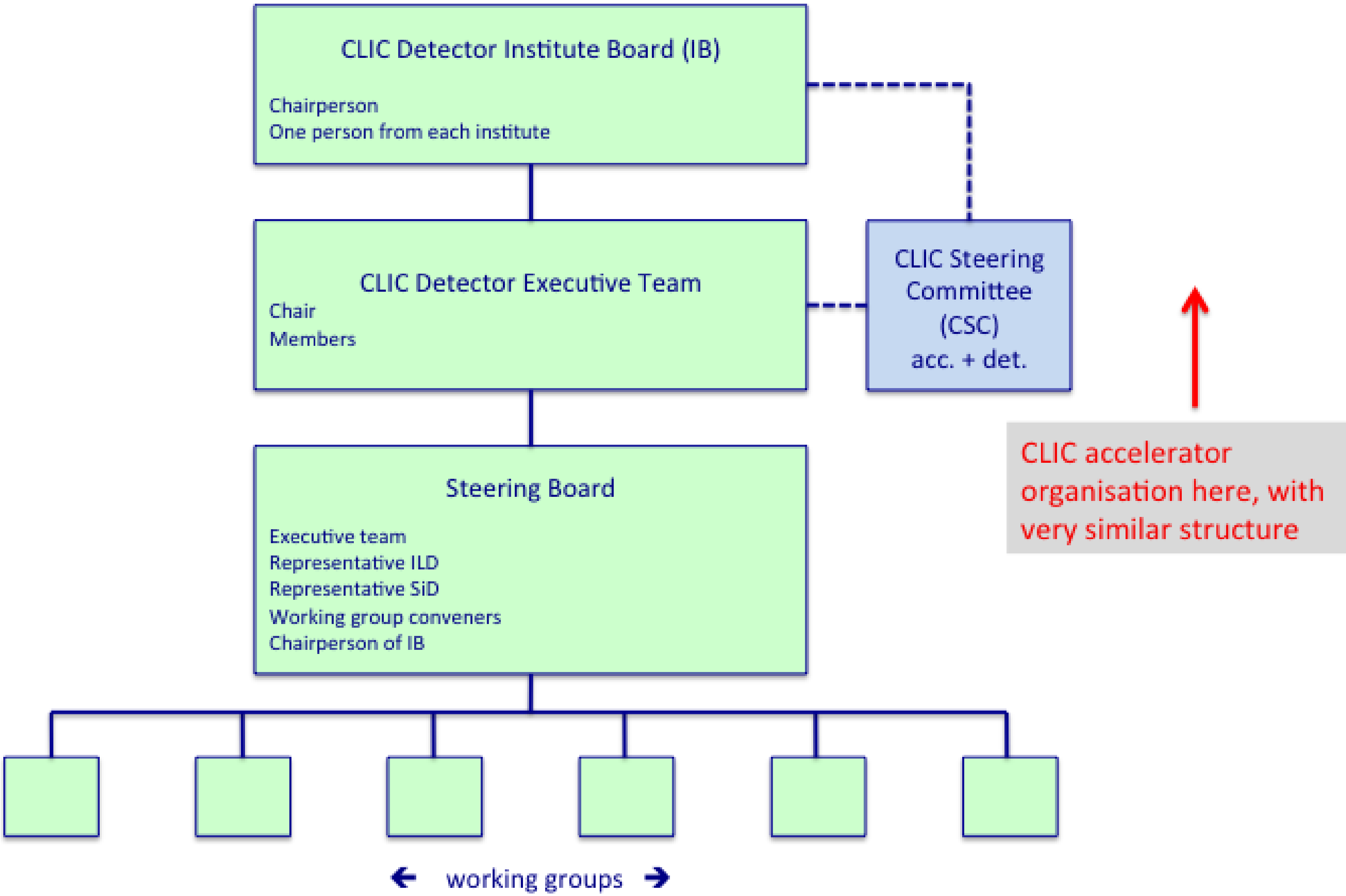
Mass precision: ≈11 GeV

Introduction: Overview of the world-wide LC detector work



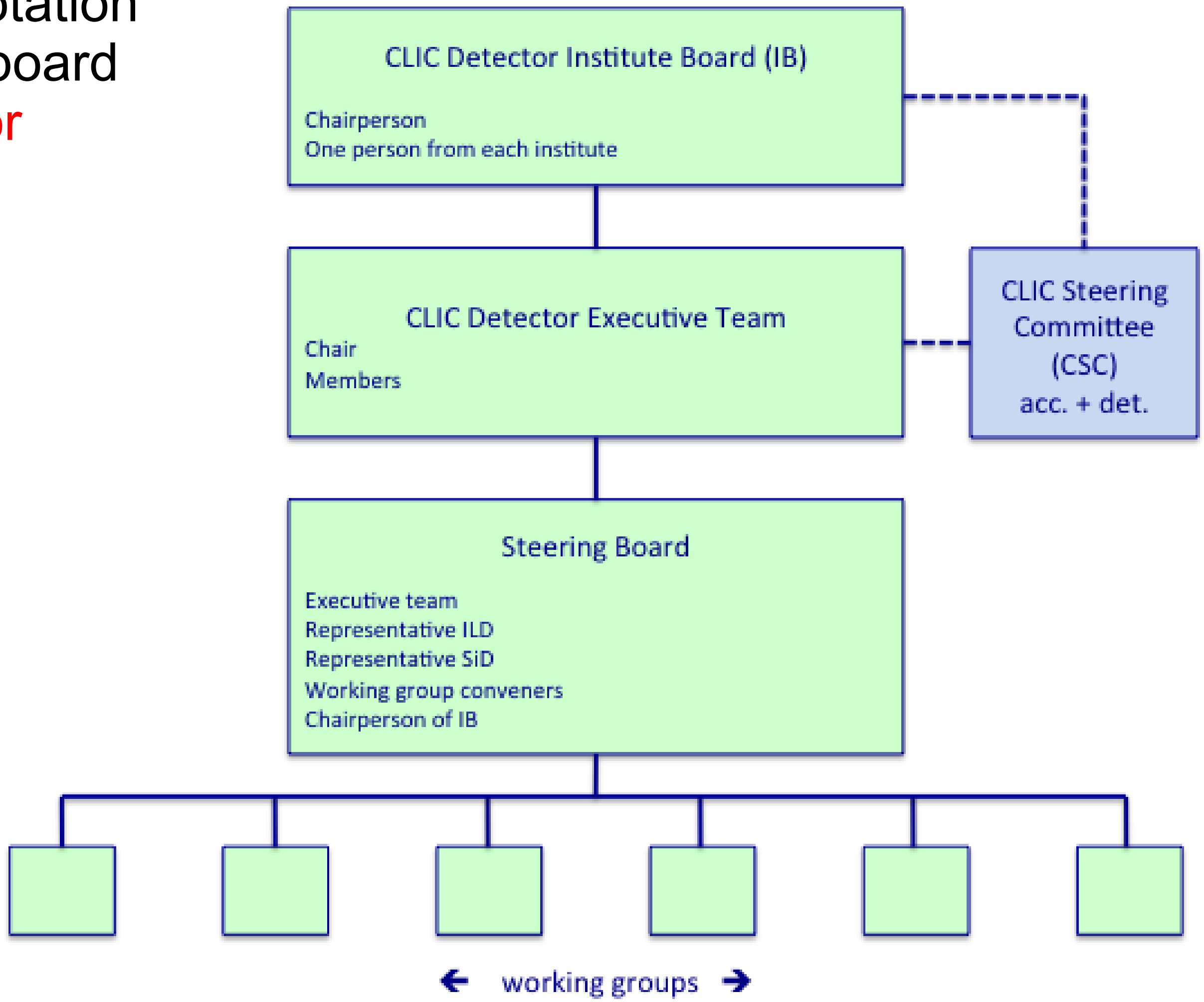
Structure for the CLIC physics and detector study

Following the model of a typical HEP experiment:

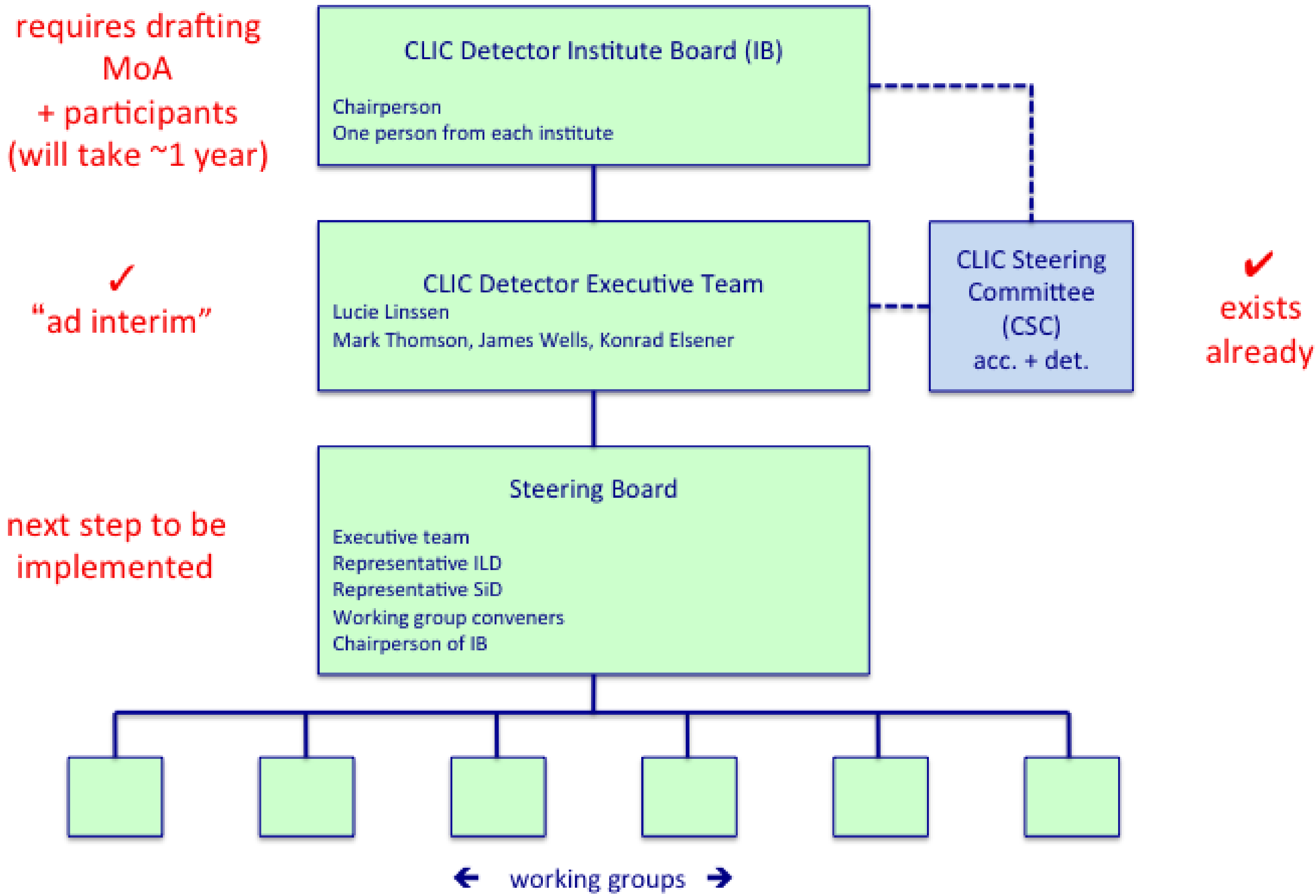


Motivations for this structure

- Allows institutes to participate (semi-) formally
- Allows participating institutes to give direction to the project
- Allows participating institutes to appoint an executive body & role rotation
- Small executive team & steering board
- Strong link to the CLIC accelerator project via the CLIC Steering Committee (CSC)



Current status



The CERN-LCD project

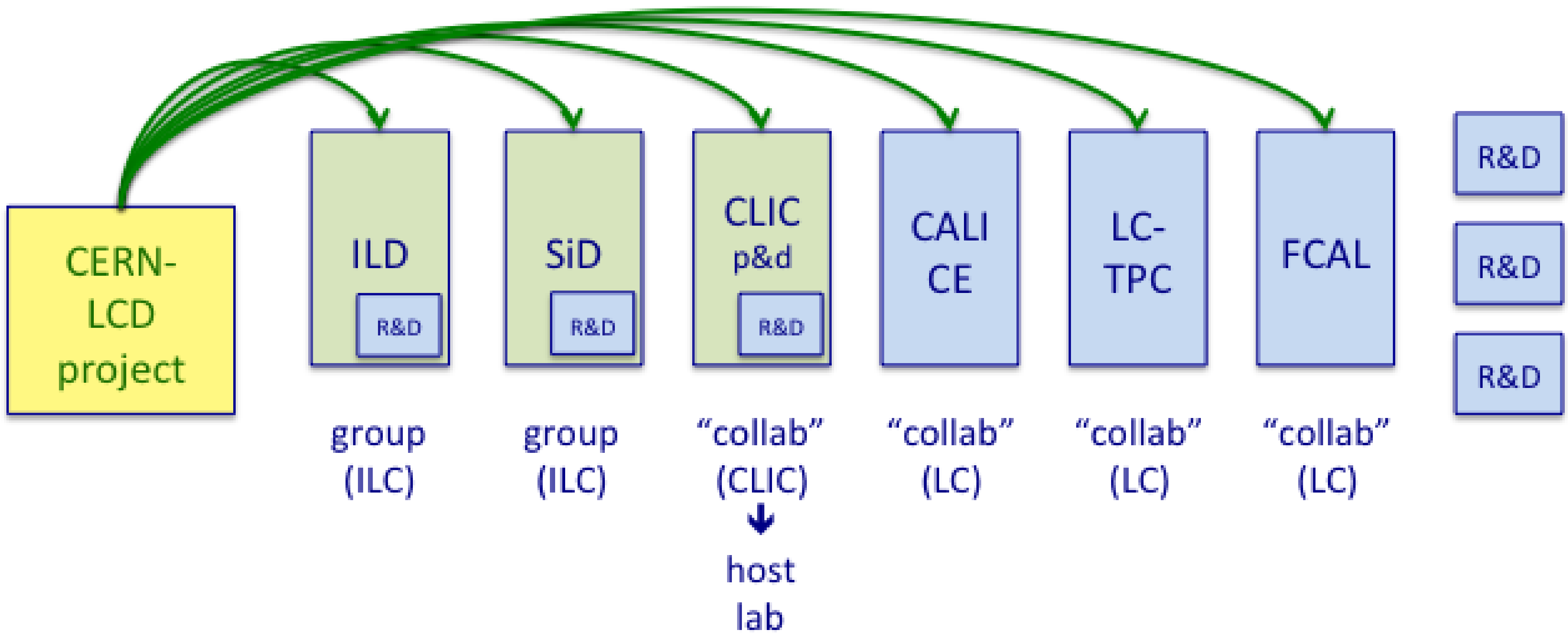
this project stands for:
"funding to work on LC detectors: ILC/CLIC concepts and R&D"

These are all CERN-funded projects ↑
(e.g. CERN contribution to LHC experiments, accelerator operation, etc, etc)

CERN-LCD project

project leader is Lucie Linssen
(nominated by CERN DG)

Activities of the CERN-LCD project



Summary & conclusions

• Main message of the CLIC physics and detector CDR:
Physics at a 3 TeV CLIC e^+e^- collider can be measured with high precision, despite challenging background conditions

• The performance of the CLIC detector concepts was demonstrated using detector benchmark reactions

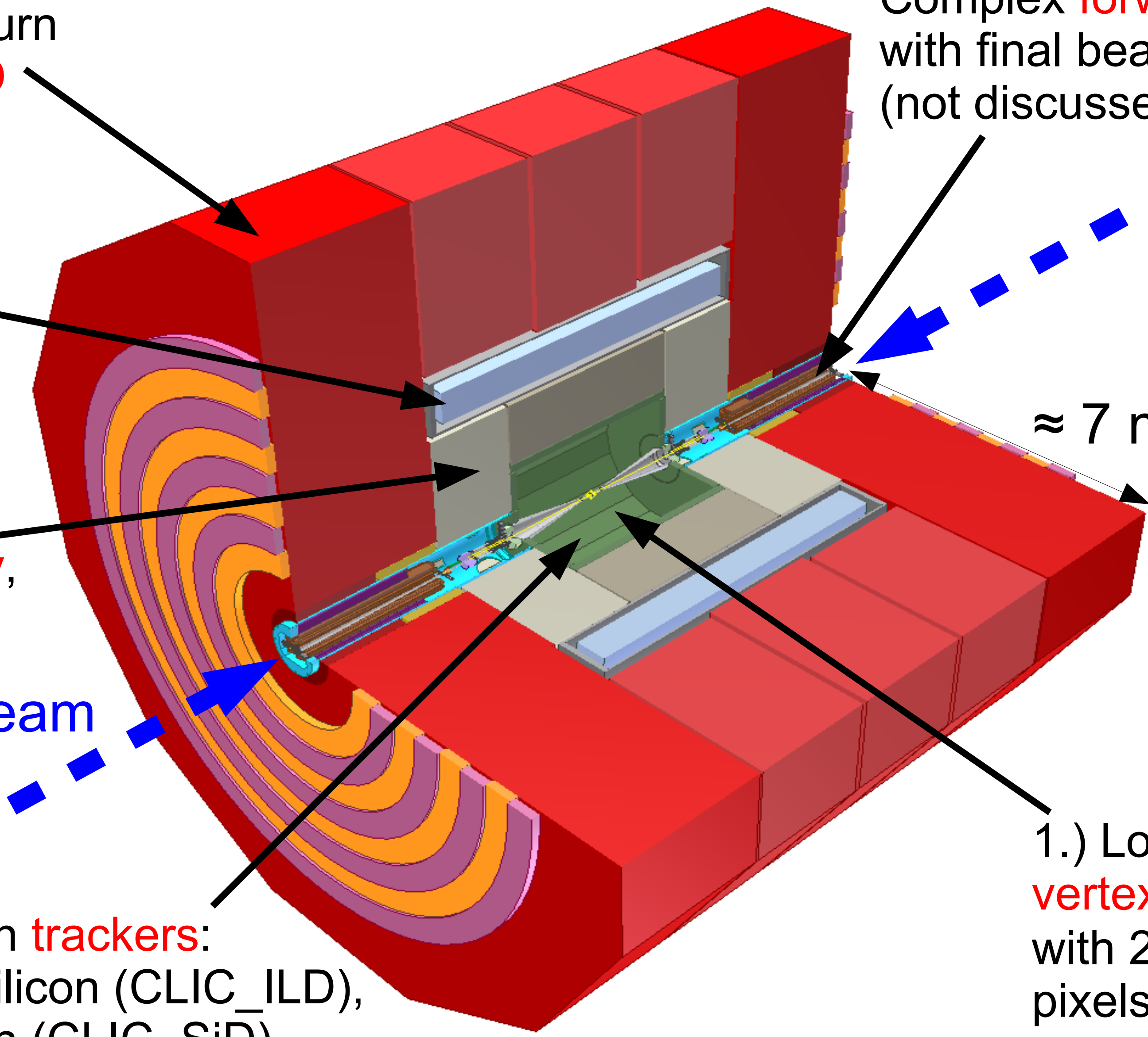
• Several ongoing benchmark studies to investigate the implications of a staged construction of the CLIC machine:

- Precision Standard Model physics
- Various processes in supersymmetry

• A structure for the CLIC physics & detector study is being implemented

Backup slides

Detector overview



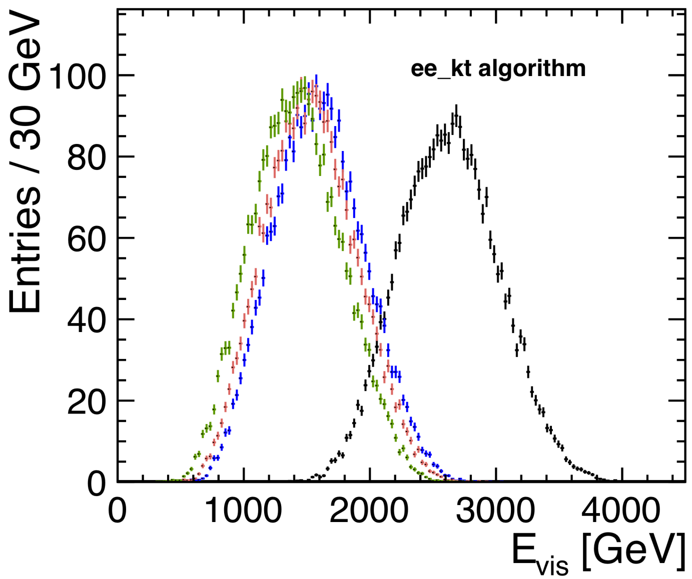
Time windows and hit resolutions

Used in the reconstruction software for CDR simulations:

Subdetector	Reconstruction window	hit resolution
ECAL	10 ns	1 ns
HCAL Endcaps	10 ns	1 ns
HCAL Barrel	100 ns	1 ns
Silicon Detectors	10 ns	$10/\sqrt{12}$ ns
TPC	entire bunch train	n/a

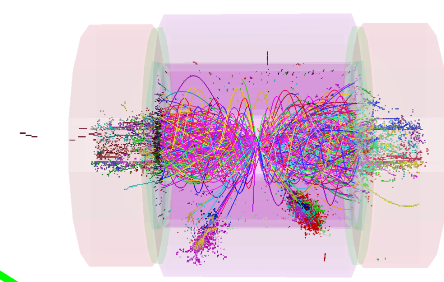
- CLIC hardware requirements
- Achievable in the calorimeters with a sampling every ≈ 25 ns

Jet reconstruction at CLIC I

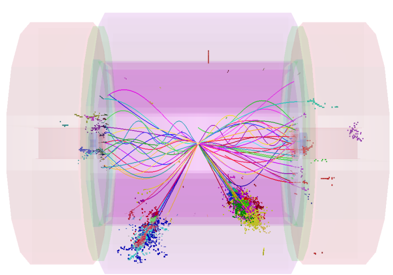


$$e^+e^- \rightarrow \tilde{q}_R \tilde{q}_R \rightarrow q\bar{q}\, \tilde{\chi}_1^0\, \tilde{\chi}_1^0$$

Two jets + missing energy



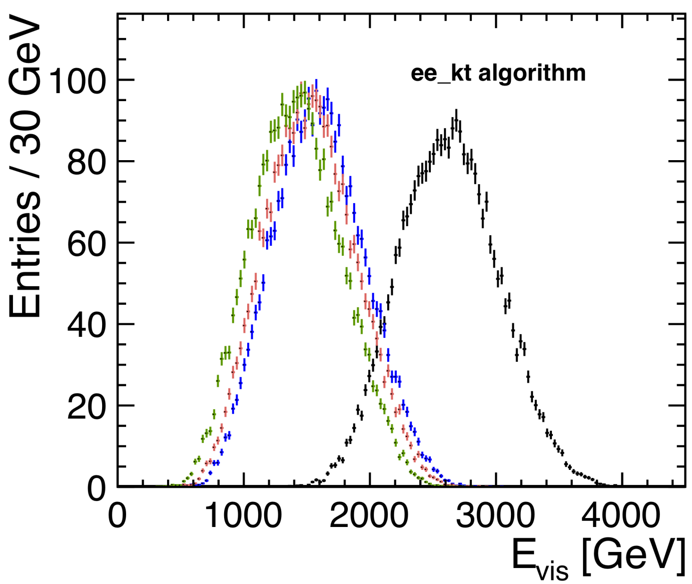
Timing cuts

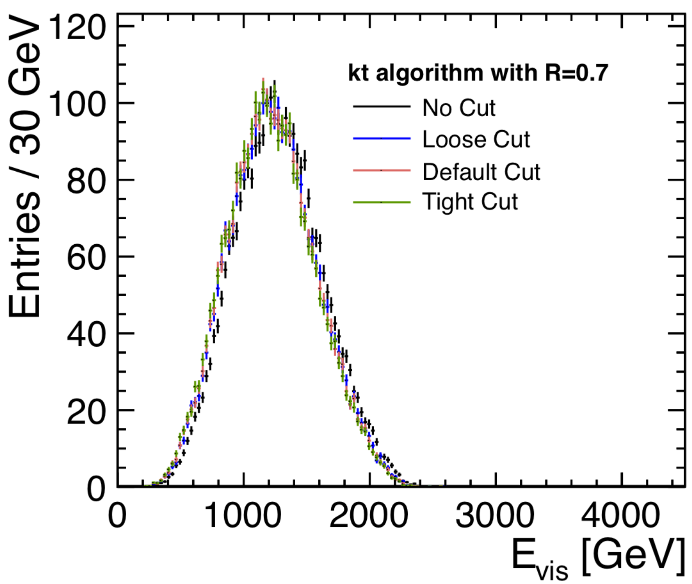


- Using Durham k_T à la LEP

→ Timing cuts are effective, but not sufficient

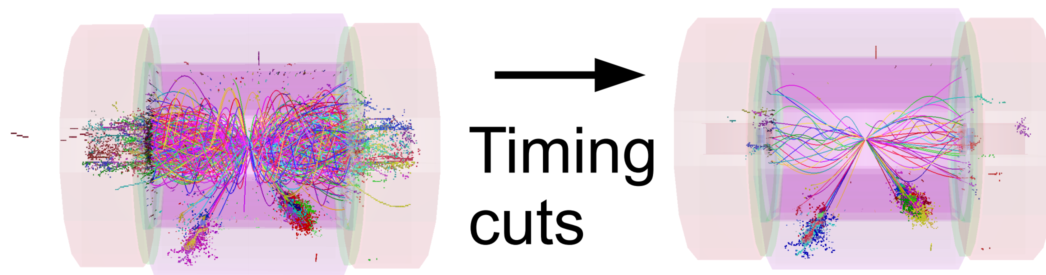
Jet reconstruction at CLIC II





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

Two jets + missing energy



- Using Durham k_T à la LEP

→ Timing cuts are effective, but not sufficient

- "hadron collider" k_T, R = 0.7

→ Background significantly reduced further

→ Need timing cut + jet finding for background reduction

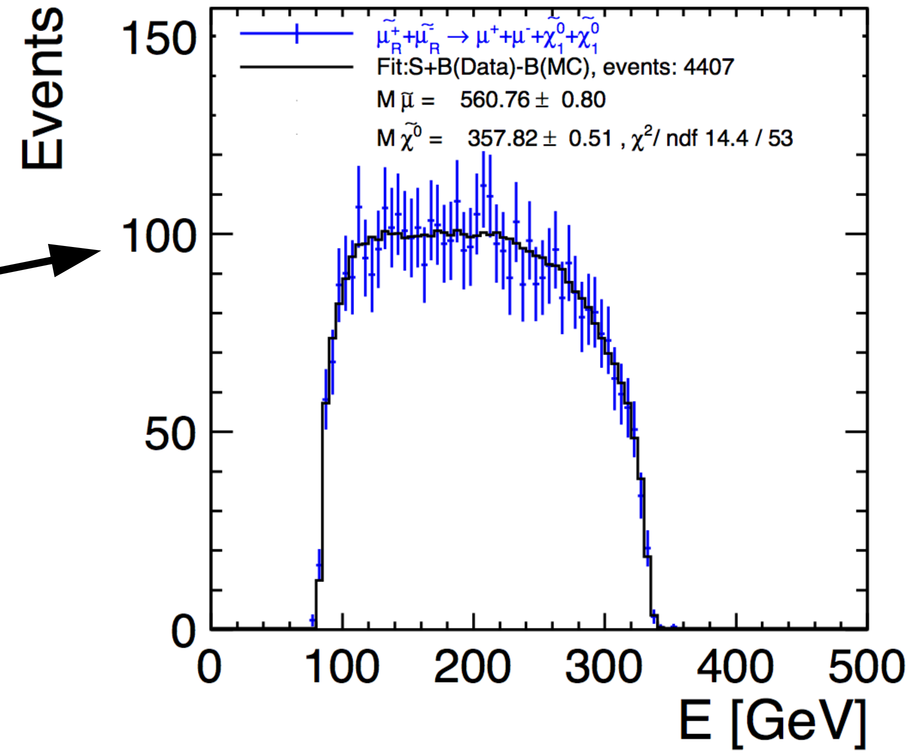
Slepton pair production at 1.4 TeV

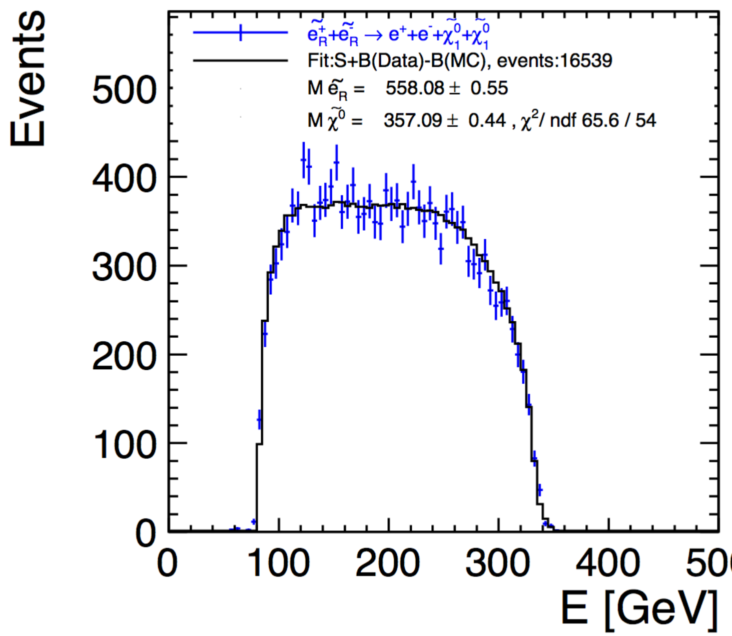
- Slepton production very clean at CLIC
- SUSY "model III":

slepton masses: a few hundred GeV

- Investigated channels include:

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





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

Precisions of the measured masses: less than 1 GeV

More detector benchmarks

- Full physics simulation and reconstruction with pileup from beam background ($\gamma\gamma \rightarrow$ hadr.)

- Seven channels chosen to cover various crucial aspects of detector performance (jet measurements, missing energy, isolated leptons, flavour tagging, ...)