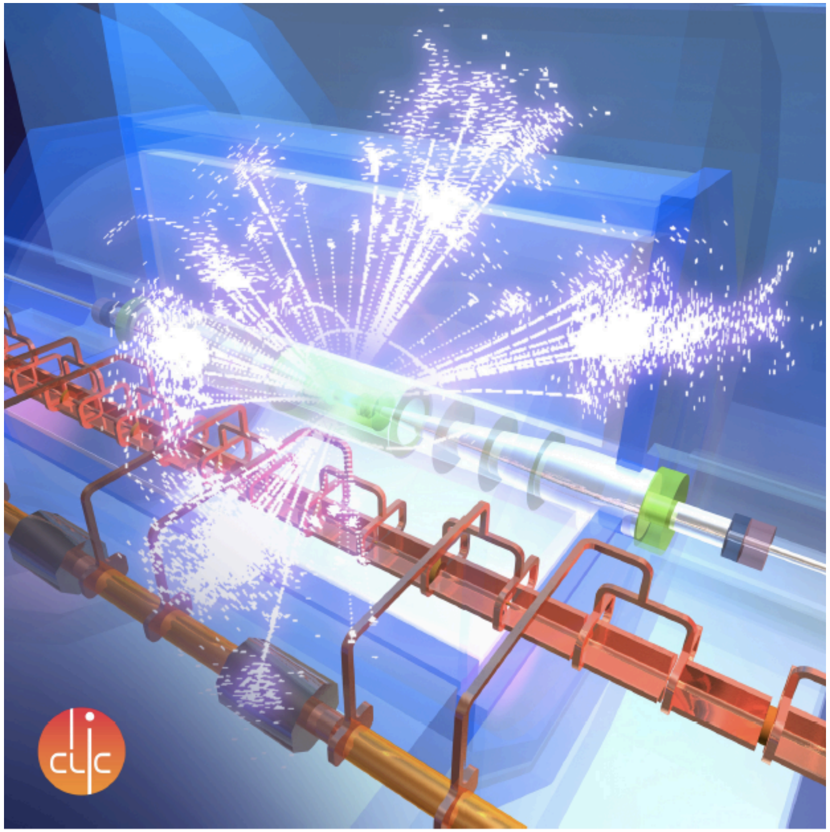
European Strategy

and

CLIC



Lucie Linssen, CERN

on behalf of the CLIC detector and physics study

Outline

- European strategy
- CLIC timeline and plan
- CLIC vertex detector R&D
- HCAL beam tests
- ECAL optimisation study
- CLIC => benchmark studies
- CLIC detector and physics study => MoC

European strategy

From Rolf Heuer's New Year speech, January 9th 2013

from Choices ? *to* Choice !

- Update of the European Strategy for Particle Physics in 2013
  - open meeting September 2012 very well attended
  - drafting the European Strategy: **21-25 January**
  - discussion of the draft Strategy in **March Council**
  - approval **30th May** in Brussels (special Council session)

- Planning for CERN projects will need to be adjusted accordingly, available resources are at the limit (!) and this will require setting priorities …..

European strategy => SPC (1)

SPC report to Council

Open Session
December 14, 2012

CERN Scientific Policy Committee
≠
European strategy group

Fabio Zwirner

1

European strategy => SPC (2)

SPC consensus on the following conclusions (I):

- The SPC believes that the strategy discussion is progressing well towards its timely completion, involving wide community participation with the global landscape of the field in mind.
- The full exploitation of the LHC potential, including the high-luminosity upgrade of the machine and of the detectors in view of collecting 3 ab^{-1} until 2030 or so, should be the highest scientific priority. A strong scientific case is already in place: longitudinal vector boson scattering, Higgs self-coupling, rare Higgs decay modes, more precise measurements of the Higgs properties. This will also provide additional opportunities for the searches for new physics.

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European strategy => SPC (3)

SPC consensus on the following conclusions (II):

- CERN should have a vision of its long-term future and pursue vigorous accelerator R&D, in particular towards projects at the new high-energy frontier after the LHC. To decide on the next large project at CERN, the physics output of the 2015-2017 full-energy run of the LHC is essential.
- The participation of CERN and its member states in global projects outside Europe, and of CERN non-member states in global projects at CERN, can foster new opportunities for world-class science. Such initiatives can be to the mutual benefit of all regions and will require appropriate organizational frameworks; they can help make effective use of financial and human resources and bring long-term benefits to CERN and its member states.

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European strategy => SPC (4)

SPC consensus on the following conclusions (III):

- There is a strong scientific case for a lepton collider that could initially study the Higgs properties with high precision, in a way complementary to the LHC, and be later upgraded to higher energy. There is also a strong case for a long-baseline neutrino programme capable of determining the mass hierarchy, exploring a good fraction of the parameter space for CP violation in the neutrino sector and measuring more precisely the oscillation parameters. The role of European particle physics in the realization of these programs belongs to the strategy discussion.
- The SPC thinks that it would be important to reconstitute an activity in neutrino physics at CERN to provide technical expertise, support and focus to a European contribution to the next generation of accelerator neutrino experiments, wherever they are based.
- The SPC would assign lower priority to the projects that are proposed to run concurrently with the LHC (LEP3 and LHeC).

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- European strategy
- CLIC timeline and plan
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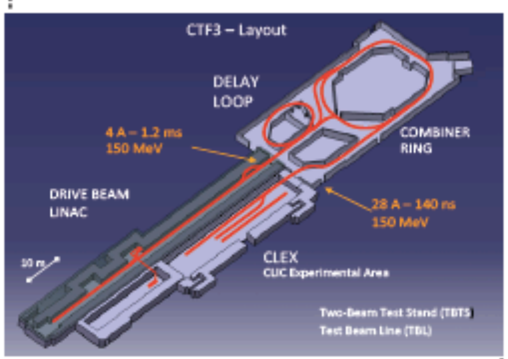
CLIC strategy and objectives

2012-16 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.



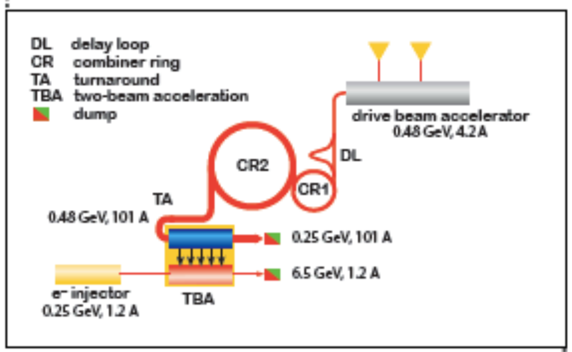
2016-17 Decisions

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.

2017-22 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.



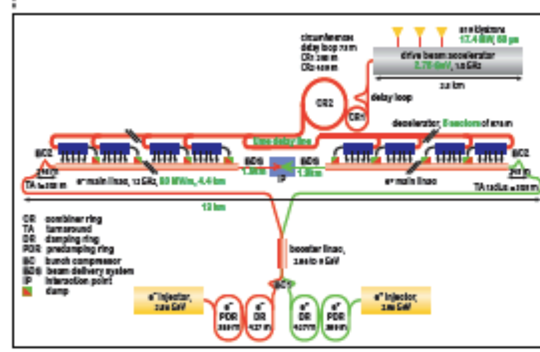
2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.



2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

Faster implementation possible: **klystron-based initial stage at ~375 GeV**

physics/detector objectives: 2012-2016

Lots of work in common with ILC

Implementation study and technical demonstration phase

✔ **Physics studies**, following up on 8 TeV and 14 TeV LHC results

Exploration of SM physics (incl. Higgs, top) and reach for new physics

Adaptation of strategy for CLIC energy staging and luminosity levels

✔ **Detector optimisation**

General detector optimisation + in close relation with detector R&D => move to 1 concept

R&D: Implementation examples ***demonstrating the required functionality***

✔ ***Vertex detector***

Demonstration module, meeting requirements of high precision, 10 ns time stamp and ultra-low mass

Main tracker

Demonstration modules, including manageable occupancies in the event reconstruction

✔ **Calorimeters**

Demonstration modules, technological prototypes + addressing control of cost

✔ **Electronics**

Demonstrators, in particular in view of power pulsing

✔ **Magnet systems**

Demonstrators of conductor technology, safety systems and moveable service lines

✔ **Engineering and detector integration**

Engineering design and detector integration harmonized with hardware R&D demonstrators

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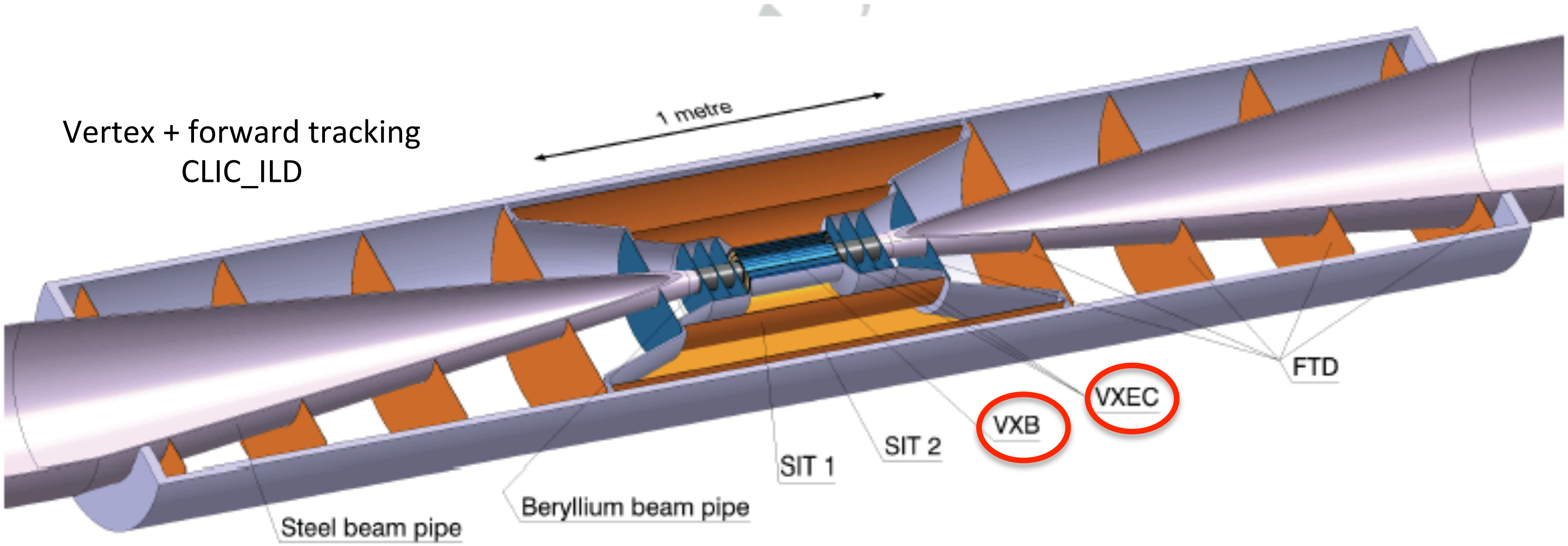
CLIC vertex detector



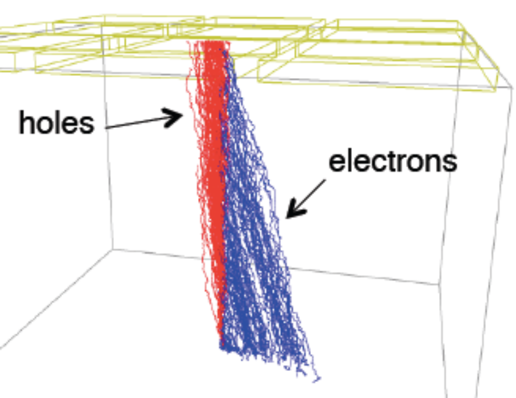
- ~20×20 µm pixel size
- 0.2% X_0 material par layer <= very thin !
  - Very thin materials/sensors
  - Low-power design, power pulsing, air cooling
- Time stamping 10 ns
- Radiation level $<10^{11}\ n_{eq}cm^{-2}year^{-1}$ <= 10^4 lower than LHC

Challenging ongoing R&D project

Vertex detectors: CLIC R&D

Hybrid approach:

- Thin (~50 µm) sensors (e.g. Micron, CNM, VTT)
- Thinned High density ASIC in very-deep-sub-micron:
  - TimePix3, Smallpix <= R&D steps
  - CLICpix
- Low-mass interconnect
  - Micro-bump-bonding (Cu-pillar option, Advacam)
  - Through-Silicon-Vias (R&D with CEA-Leti)
  - Chip-stitching
- Power pulsing and air cooling



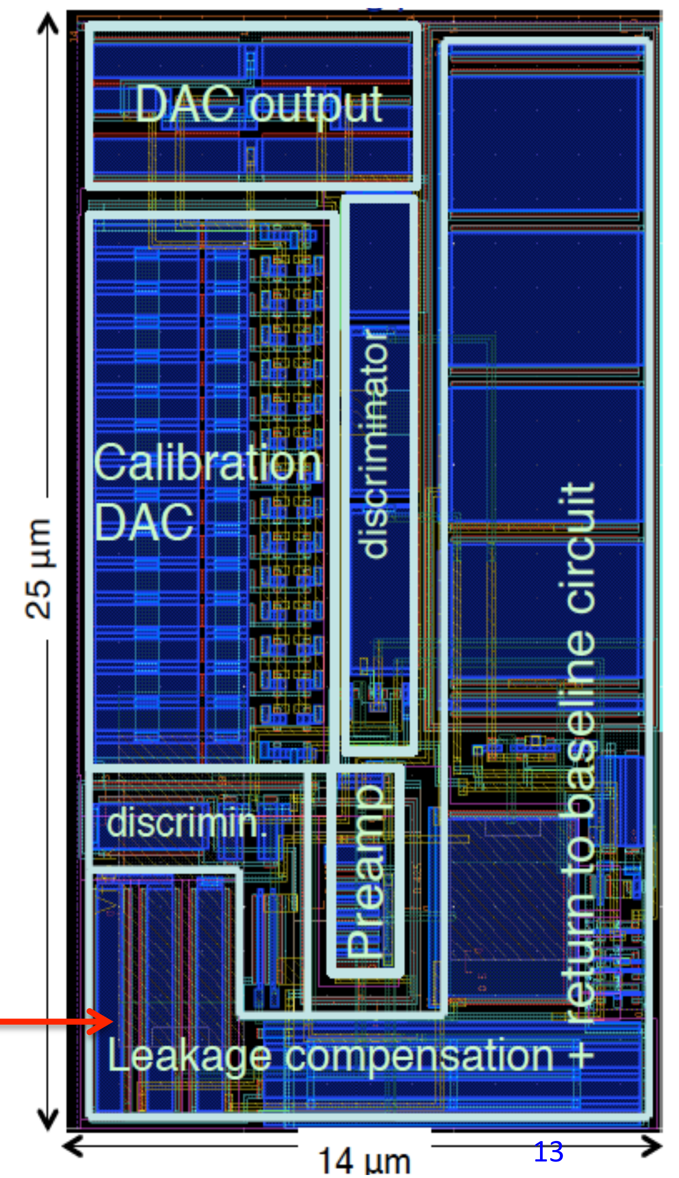
Detailed TCAD signal formation simulation

CLICpix

- 65 nm technology
- 25×25 µm² pixels
- 4-bit TOA and TOT information
  - 10 nsec time-slicing
- Power 2 W/cm² (continuous)
- With sequential power pulsing
  - 50 mW/cm²

64×64 pixel demonstrator
Submitted end 2012

Analog part of a CLICpix pixel



CLIC vertex R&D: Power pulsing

Vertex power pulsing design + first lab tests:

- With vertex analog powering in mind: ~2 A at 1.2 V for ~15 µs
- **Low-mass !**

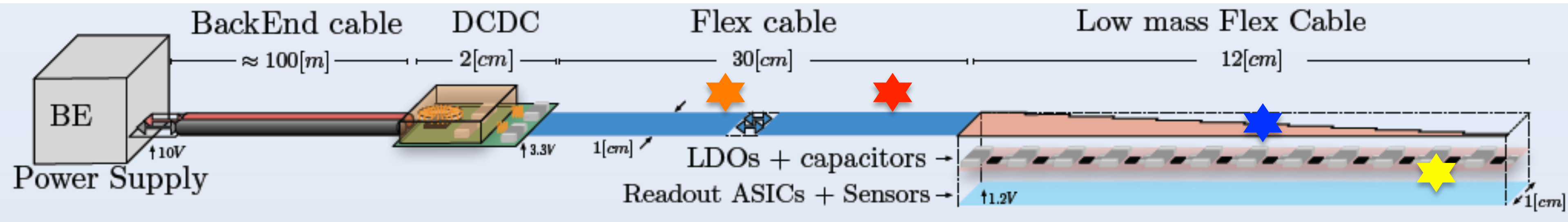
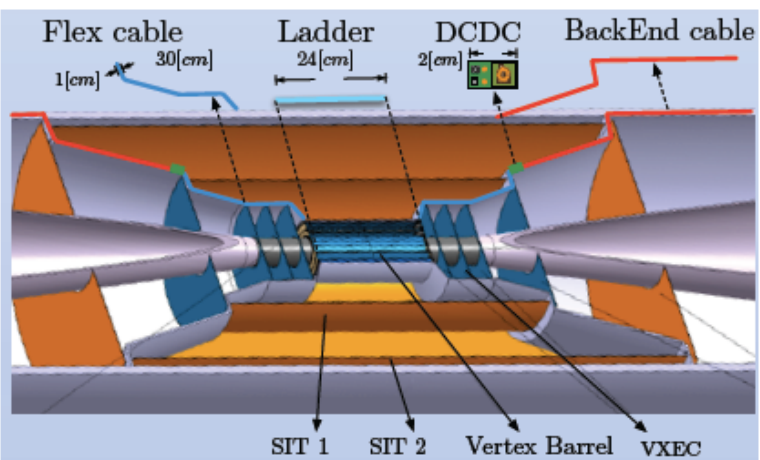


Figure: Half ladder proposed powering scheme

Emulation of: DC-DC converter + flex cable + (LDO/capacitors) + Pixel module

Equivalent 0.145% X0/layer in vertex region

20 mV Voltage ripple achieved



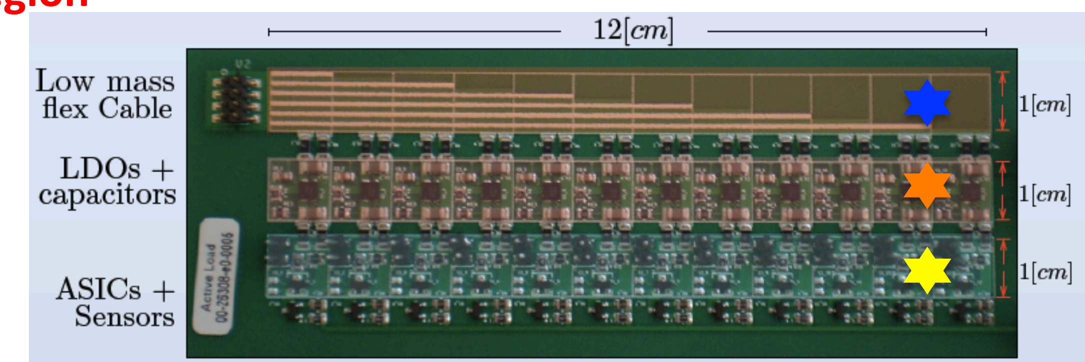


Figure: PCB that emulates the readout ASICs power consumption. It integrates the low mass flex cable, the array of LDOs and capacitors, and their interconnections.

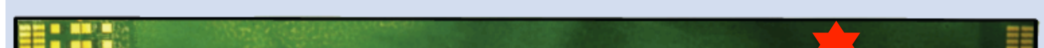
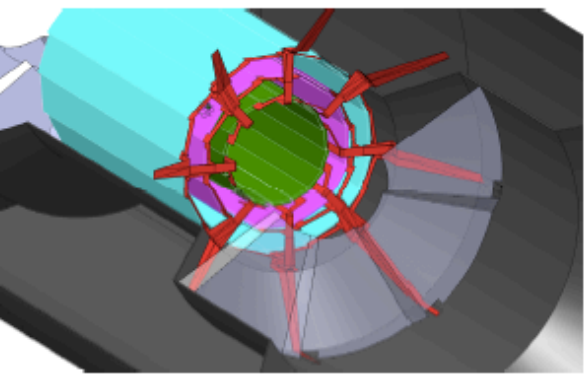
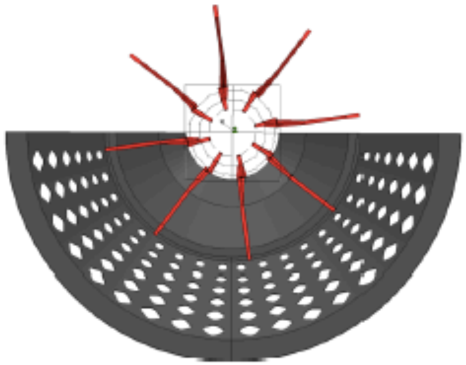


Figure: 30 cm long Flex cable

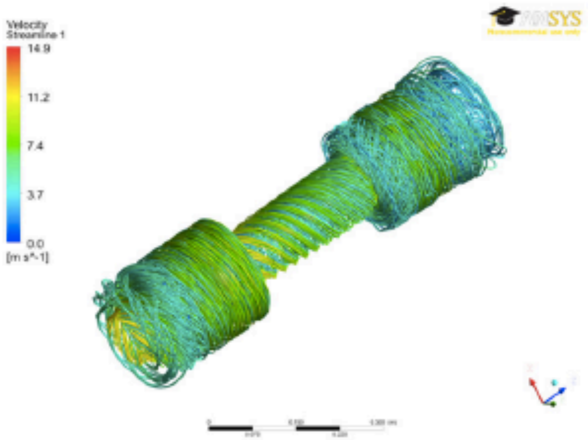
Vertex detector engineering

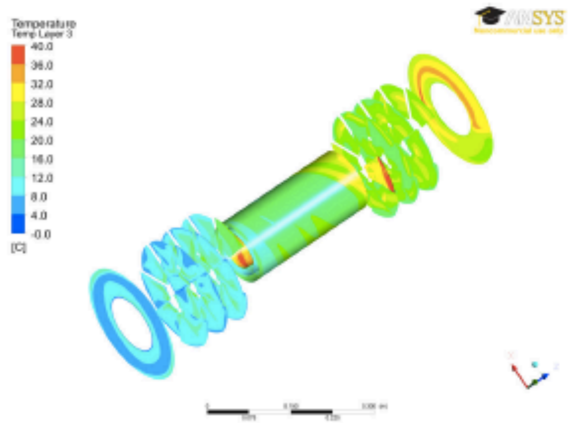
Cabling layout



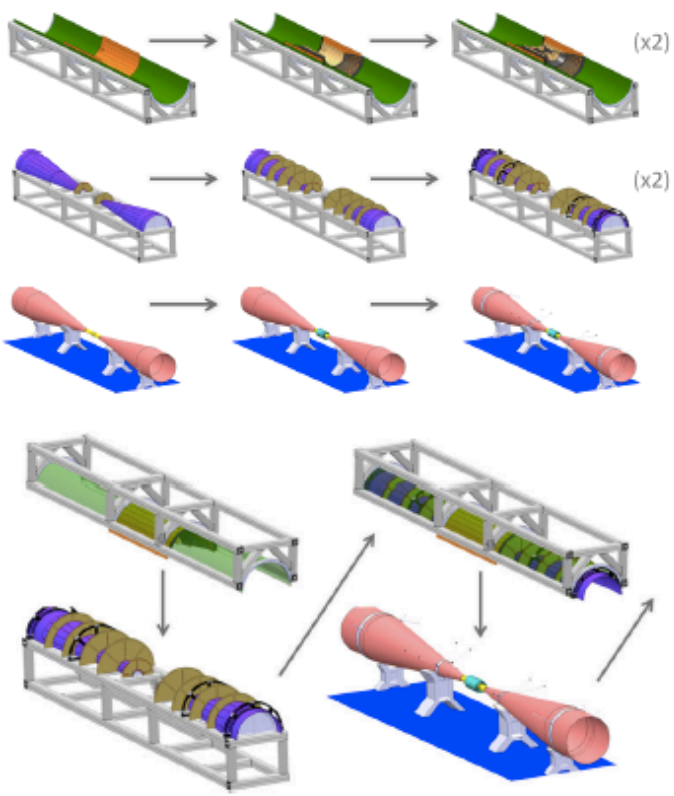


Cooling strategy





Assembly sequence



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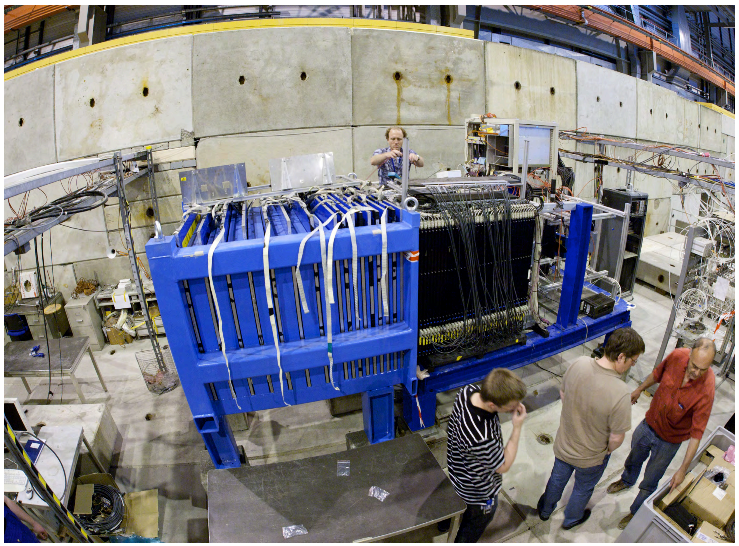
Analog HCAL: scintillator/tungsten

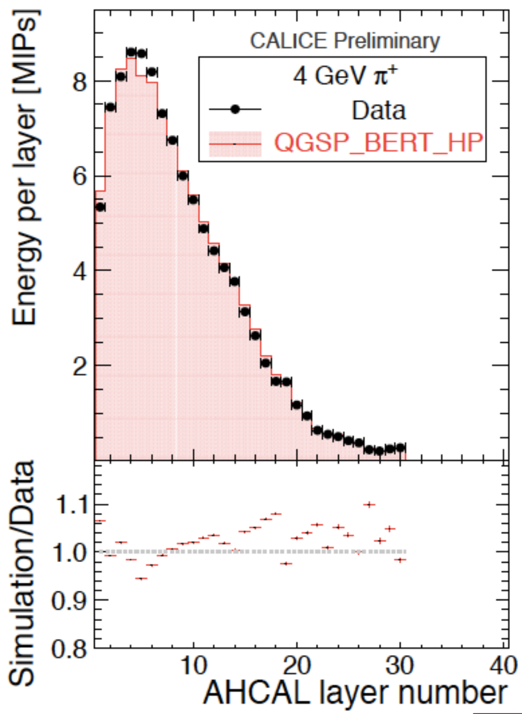
HCAL tests with 10 mm thick **Tungsten absorber** plates,
Tests in 2010+2011 with scintillator active layers, 3×3 cm^2 cells => analog readout

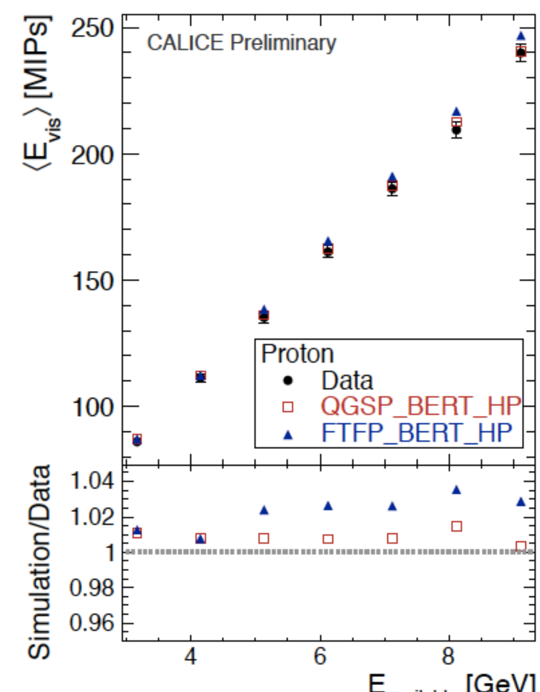


CERN SPS 2011

longitudinal shower profile, pions

visible Energy protons

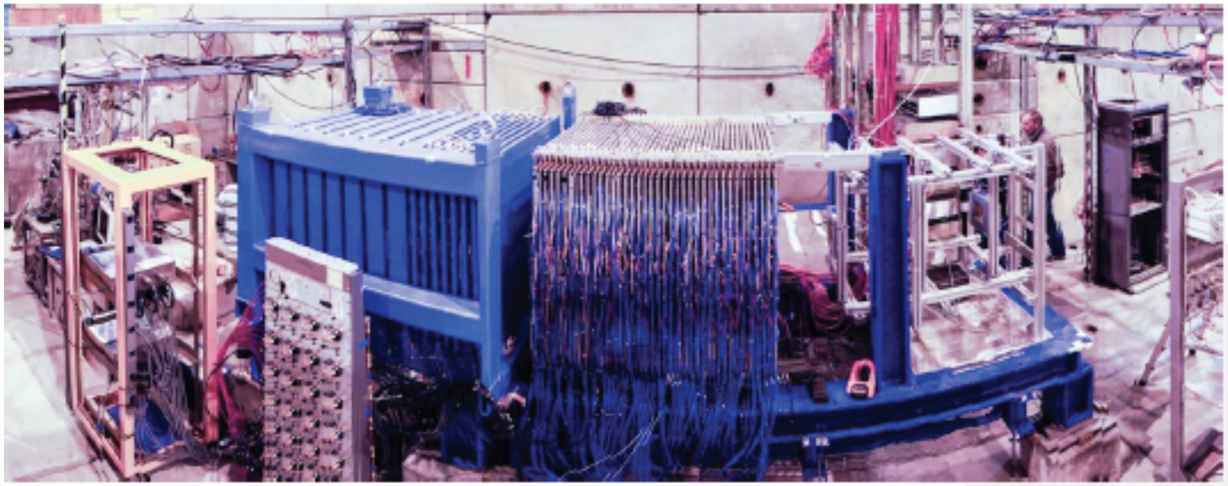




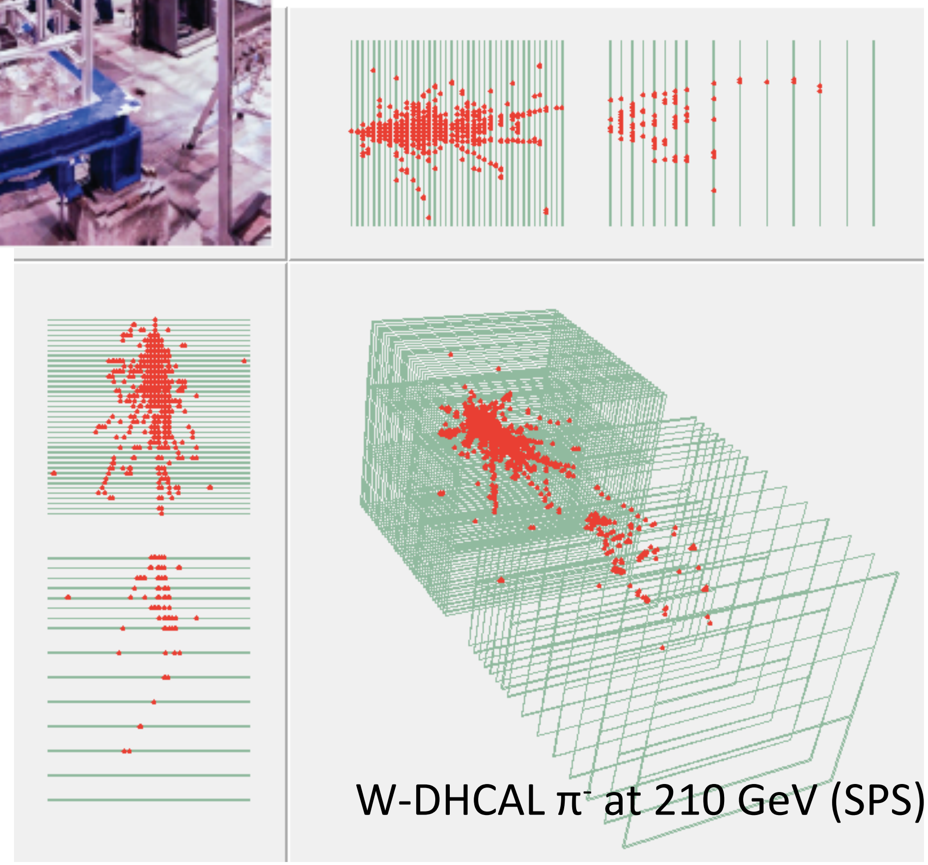
Good progress with the analysis
Hope to have main results paper in spring 2013

CALICE preliminary

Digital HCAL: scintillator/RPC



Steel DHCAL
Tungsten DHCAL
500'000 readout channels



54 glass RPC chambers, 1m^2 each
PAD size 1×1 cm^2
Digital readout (1 threshold)
Main DHCAL stack (39) + tail catcher (15)
Tungsten absorber

Successfully beam tests
2012 **CERN** PS + SPS

Data analysis
Was delayed due to DBD work
=> Will pick it up soon at CERN

CERN test setup includes **fast readout RPC** after (**T3B**)

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Cost-effective ECAL

New initiative, for ILC and CLIC

It is just starting => better understand ECAL requirements

Simulation study
Convener: John Marshall

Varying ECAL geometries
- # layers
- Granularity

- Stand-alone calorimeter stacks
- Full-detector + PFA (CLIC_ILD)

+

Hardware (lab) study
Convener: Christian Joram

Very thin scintillator tiles
SiPM readout

Hybrid solution:
scintillator +silicon ?

https://indico.cern.ch/categoryDisplay.py?categId=4379

Several labs joining/interested: Cambridge, CERN, DESY, Heidelberg
MPI Munich, Rome-I, Shinshu

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CLIC benchmark analysis plans

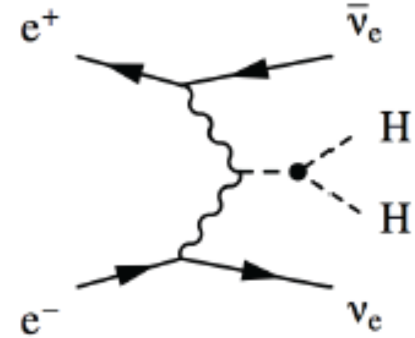
Studies towards paper on **Higgs studies** at CLIC at 350 GeV, 1.4 TeV and 3 TeV.
To be ready by (hopefully) LC2013 @ DESY

- Simultaneous extraction of H -> bb, H -> cc and H -> gg at 350 GeV and 1.4 TeV
- H -> τ τ at 350 GeV and 1.4 TeV
- H -> WW* at 350 GeV and 1.4 TeV (and 3 TeV?)
  - At 1.4 TeV potential for absolute Higgs to W coupling
- ZZ fusion at 1.4 TeV (and 3 TeV?)
  - Ratio of the ZZH to WWH couplings
  - Potential for other coupling measurements
- Higgs -> γγ and Zγ at 1.4 TeV
- Higgs -> μμ at 1.4 TeV
- ttHiggs at 1.4 TeV
- Higgs self-coupling at 1.4 TeV and 3 TeV (ongoing)
- Longitudinal WW scattering at 1.4 TeV (and 3 TeV?) (also for the Higgs paper)

Other ongoing analysis on **BSM physics**:

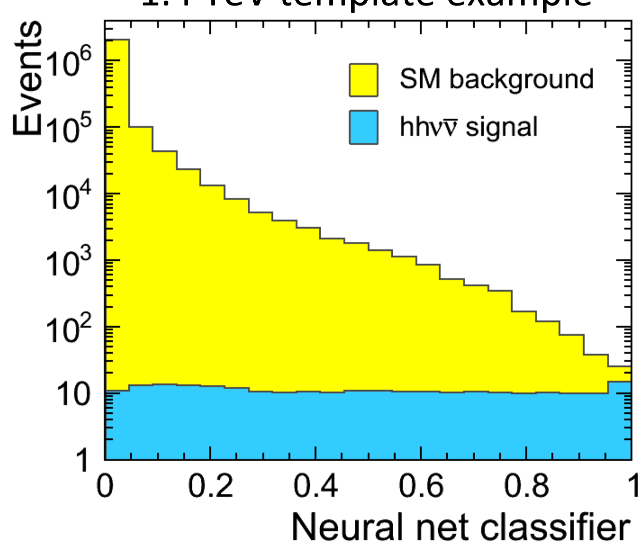
- Generic search for dark matter at 1.4 and 3 TeV
- Composite Higgs at 3 TeV?

HHH studies at 1.4 TeV and 3 TeV



- CLIC_SiD
- LCWS2012 results updated
  - More template fitting; qqqqlv background added @3 TeV
- Unpolarised beams
  - Further approx. 20% (30%) improvement expected for 80-0 (80-30) polarisation.
- 120 GeV Higgs
  - Currently being replaced by 126 GeV Higgs
- Experimentally challenging due to
  - Multi-jet final state with missing energy
  - Pile-up from γγ→hadrons beam background
- Target integrated luminosity
  - 1.5 ab^{-1} (1.4 TeV) and 2.0 ab^{-1} (3 TeV)

1.4 TeV template example



Preliminary $\sigma_{HH\nu\nu}$ λ_{HHH} results

1.4 TeV		$\sigma_{HH\nu\nu}$ uncertainty	λ_{HHH} uncertainty
	Cut-and-count	30.2%	(x1.20 = 36%)
	Template CS fit	24 - 26%	(x1.20 = 29 - 31%)
	Template λ_{HHH} fit		
	from RMS	-	30 - 31 %
	per experiment	-	31.5 - 33 %
3.0 TeV			
	Cut-and-count	13.8%	(x1.54 = 21.2%)
	Template CS fit	9.7 - 10.8%	(x1.54 = 15 - 16.6%)
	Template λ_{HHH} fit		
	from RMS	-	16.2 - 18.5%
	per experiment	-	15.4 - 17.2%

Preliminary λ_{HHH} results

1.4 TeV		$\sigma_{HH\nu\nu}$ uncertainty	λ_{HHH} uncertainty
	Cut-and-count	30.2%	(x1.20 = 36%)
	Template CS fit	24 - 26%	(x1.20 = 29 - 31%)
	Template λ_{HHH} fit		
	Cut-and-count	[illegible]	[illegible]
	Template CS fit	9.7 - 10.8%	(x1.54 = 15 - 16.6%)
	Template λ_{HHH} fit		
	from RMS	-	16.2 - 18.5%
	per experiment	-	15.4 - 17.2%

1.4 TeV (1.5 ab^{-1}): **31%** no polarisation, **22%** with (80,30) beam polarisation

3.0 TeV (2.0 ab^{-1}): **16%** no polarisation, **11%** with (80,30) beam polarisation

Tomas Lastovicka
Jan Strube

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Organisation (CLIC)

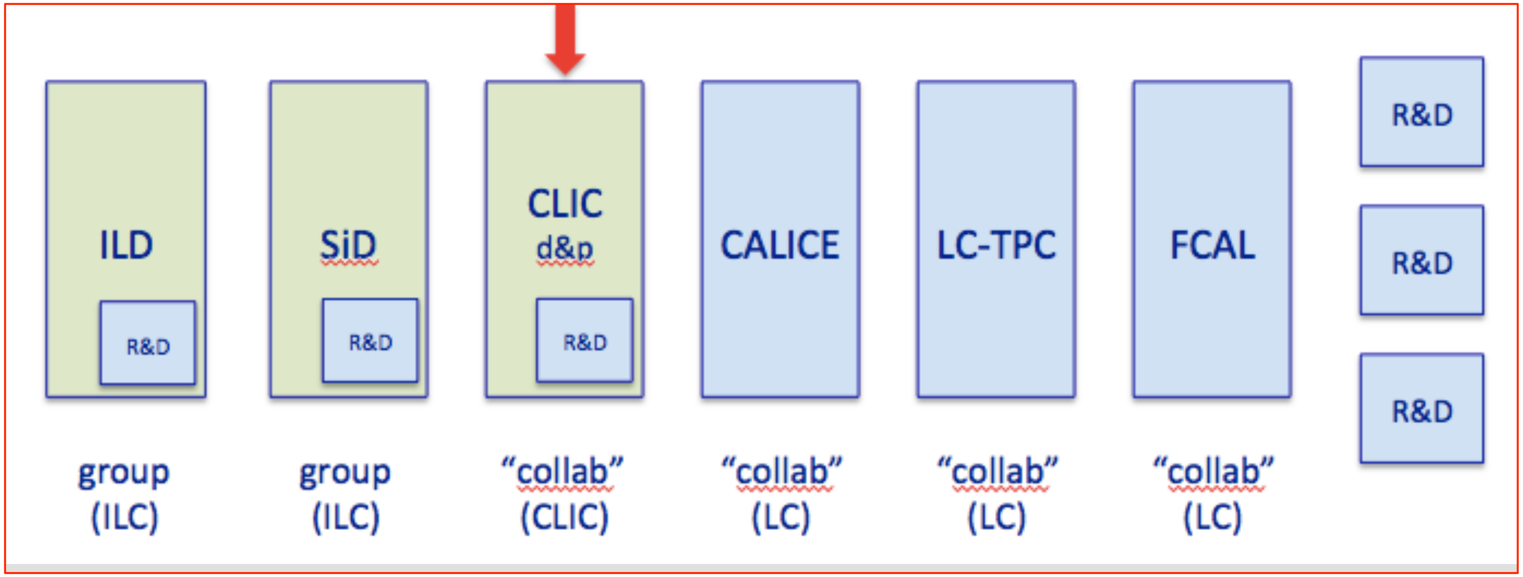
Since November 2012 "semi-formal" organisation
Like a normal particle physics experiment => light weight !

Memorandum on Cooperation for the CLIC detector and physics study
http://lcd.web.cern.ch/LCD/Home/MoC.html

Currently 10 groups have joined (some signatures still in the mail)

Aarhus Univ., ANL, Bergen Univ., Cambridge Univ., CERN, MPI Munich, NC PHEP Minsk, Spanish Network for Future LC, Tel Aviv, Vinca Belgrade

Discussions ongoing with other groups



Memorandum on Cooperation

Basic notions of the organisation are described in the Memorandum of Cooperation

- Link with the LC organisation under ICFA
- Link and synergy with the LC concept groups and the LC detector R&D collaboration

- Institutes can join (semi)-formally
- Formation of an **Institute board (IB)** with representation from all institutes
- IB gives direction to the project
- IB appoints persons with roles of responsibility
- Rotation of roles of responsibility
- Small and enlarged executive bodies (ET and SB)
- Link to the CLIC accelerator project via the CLIC Steering Committee
- CERN as the host laboratory

The MoC document.....

The MoC is set up in a very flexible way, allowing for future adaptations

"the MoC"

Base text (generic and flexible)

Annex 1
List of institutes

Annex 2
Objectives of the study

Annex 3
Organisation

Annex 4
Publications / talks

Annex 5
CERN host

Annex 6
Signature template

Defined and updated by the IB (Annexes 2–4)

Objectives of the study

The Study

2.1 The Study, in coordination with the worldwide Linear Collider organisation under the *International Committee for Future Accelerators* ("ICFA"), aims at:

- Studies of the physics discovery potential and prospects for precision measurements at the CLIC e^+e^- collider, including aspects related to beam polarisation;
- Detector simulation and optimisation studies;
- Software development for event generation, detector simulation, event reconstruction and analysis;
- Hardware development for detector sub-systems and their readout electronics, in part carried out within the Linear Collider R&D collaborations;
- Engineering and integration studies for a future CLIC experiment, including supporting infrastructures and underground facilities related to it.

2.2 The detailed scientific and technical objectives of the Study shall be as described in Annex 2 to this MoC, that shall be updated on a regular basis, subject to the approval of the Institute Board (IB).

CLIC d&p

R&D

Responsibility of the partners

Article 5

Responsibilities of the Partners

5.1 The Partners shall, on a best effort basis, contribute to the Study.

5.2 Any specific agreement on a contribution to the Study by a Partner may be set out in an Annex to this MoC.

Admission of partners

All partners are welcome, initially, on a "best effort" basis.

First "informal" Institute Board meeting at the CLIC workshop on January 29th 2013

Later => the IB decides on the admission of new Partners

THANK YOU !

Welcome to join the MoC

http://lcd.web.cern.ch/LCD/Home/MoC.html

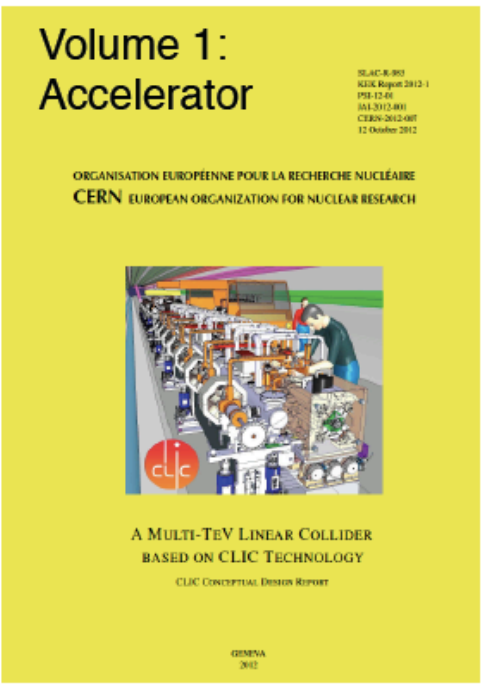
and the CLIC workshop

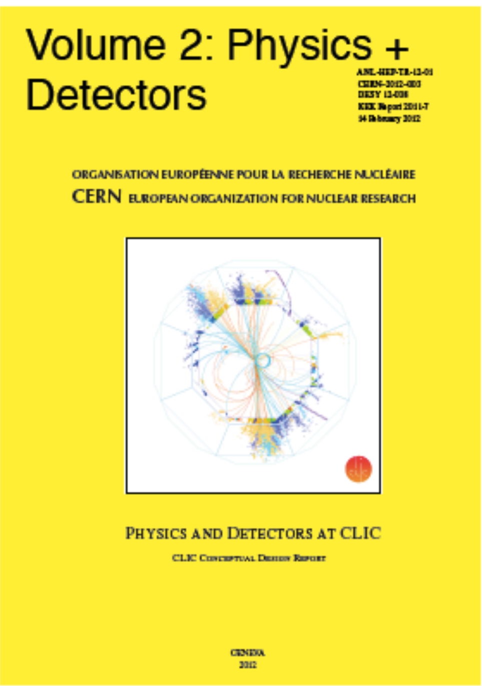
http://indico.cern.ch/conferenceDisplay.py?confId=204269

SPARE SLIDES

CLIC CDR => all finished

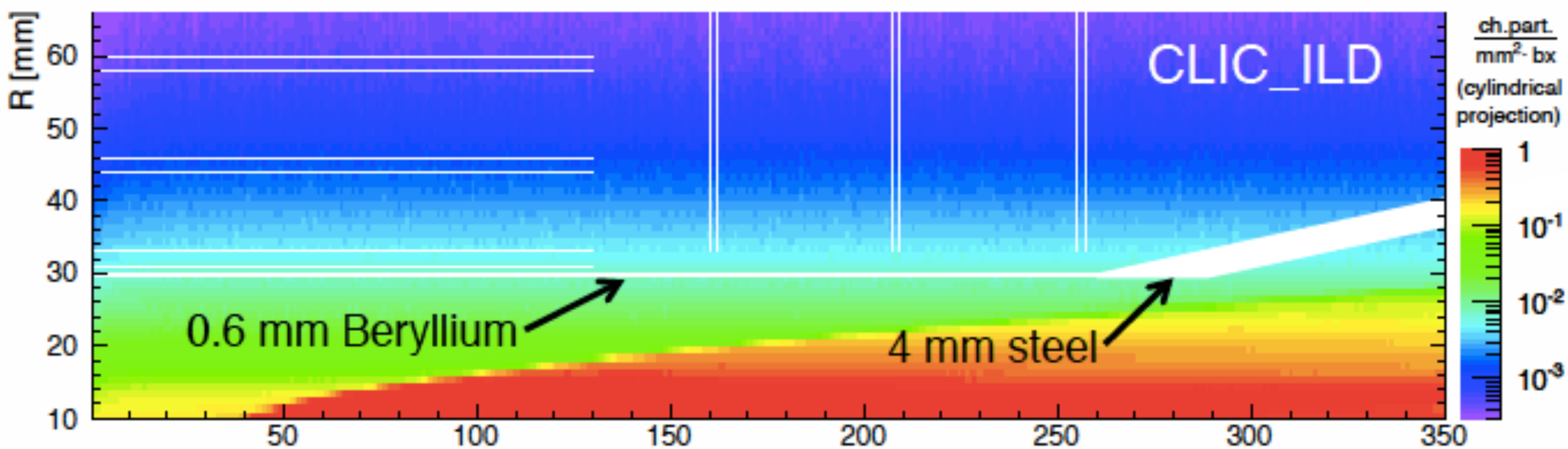
- **CLIC CDR** (#1), A Multi-TeV Linear Collider based on CLIC Technology, CERN-2012-007, http://cds.cern.ch/record/1500095?ln=en
- **CLIC CDR** (#2), Physics and Detectors at CLIC, CERN-2012-003, arXiv:1202.5940
- **CLIC CDR** (#3), The CLIC Programme: towards a staged e^+e^- Linear Collider exploring the Terascale, CERN-2012-005, http://arxiv.org/abs/1209.2543





CLIC vertex detector

Background considerations influence layout choices of vertex detector



R_{min} = 27 mm CLIC_SiD
R_{min} = 31 mm CLIC_ILD

Maximum occupancy 1.9% per pixel (including safety factor of 5)

	CLIC_ILD_CDR	CLIC_SiD_CDR	CMS
Material X/X0 (90°)	~0.9% (3x2 layer)	~1.1% (5 layer)	~10% (3 layer)
Pixel size	20 x 20 μm²	20 x 20 μm²	100 x 150 μm²
# pixels	2.03 G	2.76 G	66 M
Time slicing resolution	~10 ns	~10 ns	<~25 ns
Avg. power/pixel	<~0.2 μW	<~0.2 μW	28 μW

Results of Higgs benchmark studies

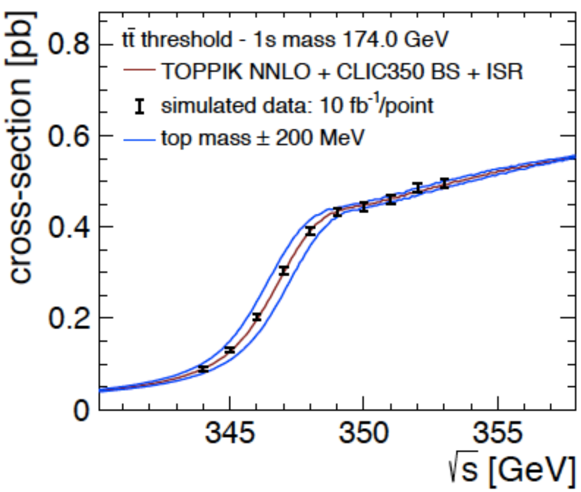
Table 6.1: Summary of results obtained in the Higgs studies for m_H =120 GeV. All analyses at centre-of-mass energies of 350 GeV and 500 GeV assume an integrated luminosity of 500 fb^{-1}, while the analyses at 1.4 TeV (3 TeV) assume 1.5 ab^{-1}(2 ab^{-1}).

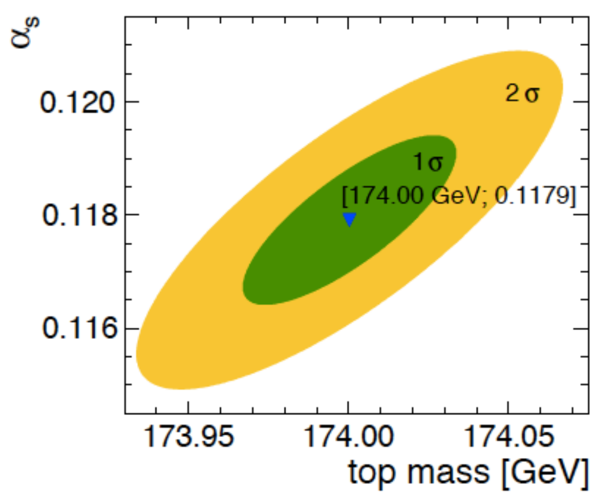
Higgs studies for m_H =120 GeV							
$\sqrt{s}$ (GeV)	Process	Decay mode	Measured quantity	Unit	Generator value	Stat. error	Comment
350	SM Higgs production	$ZH \to \mu^+\mu^- X$	σ	fb	4.9	4.9%	Model independent, using Z-recoil
			Mass	GeV	120	0.131	
500	SM Higgs production	$ZH \to q\bar{q}q\bar{q}$	$\sigma \times$ BR	fb	34.4	1.6%	$ZH \to q\bar{q}q\bar{q}$ mass reconstruction
			Mass	GeV	120	0.100	
500	SM Higgs production	$ZH, H\nu\bar{\nu} \to \nu\bar{\nu}q\bar{q}$	$\sigma \times$ BR	fb	80.7	1.0%	Inclusive sample
			Mass	GeV	120	0.100	
1400	WW fusion	$H \to \tau^+\tau^-$	$\sigma \times$ BR	fb	19.8	$<3.7\%$	
3000	WW fusion	$H \to b\bar{b}$	$\sigma \times$ BR	fb	285	0.22%	
		$H \to c\bar{c}$			13	3.2%	
		$H \to \mu^+\mu^-$			0.12	15.7%	
1400	WW fusion		Higgs tri-linear coupling g_{HHH}			$\sim$20%	<= study still ongoing
3000						$\sim$20%	

Results of top benchmark studies

Table 6.2: Summary of full detector-simulation results obtained under realistic CLIC beam conditions in the top quark studies. The first (second) threshold scan contains 6 points (10 points) separated by 1 GeV and with 10 fb^{-1} of luminosity at each point.

Top studies							
$\sqrt{s}$ (GeV)	Technique	Measured quantity	Integrated luminosity (fb^{-1})	Unit	Generator value	Stat. error	
350	Threshold scan	Mass	6×10	GeV	174	0.021	left
		Mass α_S	10×10	GeV	174 0.118	0.033 0.0009	right plot
500	Invariant mass	Mass	100	GeV	174	0.060	





Results of SUSY benchmarks, 1.4 TeV

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
1.4	Sleptons production	$\widetilde{\mu}_R^+\widetilde{\mu}_R^- \to \mu^+\mu^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$	III	σ	fb	1.11	2.7%
				$\tilde{\ell}$ mass	GeV	560.8	0.1%
				$\widetilde{\chi}_1^0$ mass	GeV	357.8	0.1%
		$\widetilde{e}_R^+\widetilde{e}_R^- \to e^+e^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$		σ	fb	5.7	1.1%
				$\tilde{\ell}$ mass	GeV	558.1	0.1%
				$\widetilde{\chi}_1^0$ mass	GeV	357.1	0.1%
		$\widetilde{\nu}_e\widetilde{\nu}_e \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 e^+e^-W^+W^-$		σ	fb	5.6	3.6%
				$\tilde{\ell}$ mass	GeV	644.3	2.5%
				$\widetilde{\chi}_1^\pm$ mass	GeV	487.6	2.7%
1.4	Stau production	$\widetilde{\tau}_1^+\widetilde{\tau}_1^- \to \tau^+\tau^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$	III	$\widetilde{\tau}_1$ mass	GeV	517	2.0%
				σ	fb	2.4	7.5%
1.4	Chargino production	$\widetilde{\chi}_1^+\widetilde{\chi}_1^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 W^+W^-$	III	$\widetilde{\chi}_1^\pm$ mass	GeV	487	0.2%
				σ	fb	15.3	1.3%
	Neutralino production	$\widetilde{\chi}_2^0\widetilde{\chi}_2^0 \to h/Z^0 h/Z^0 \widetilde{\chi}_1^0\widetilde{\chi}_1^0$		$\widetilde{\chi}_2^0$ mass	GeV	487	0.1%
				σ	fb	5.4	1.2%

all results with L => 1.5 ab^{-1}

CLIC CDR Vol. 3

Results of SUSY benchmarks, 3 TeV

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
3.0	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	σ	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-hh$ $\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-Z^0Z^0$		σ	fb	3.07	7.2%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		σ	fb	13.74	2.4%
				$\tilde{\ell}$ mass	GeV	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	GeV	643.2	0.6%
3.0	Chargino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
	Neutralino production	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0 h/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	Mass	GeV	1123.7	0.52%
				σ	fb	1.47	4.6%
3.0	Heavy Higgs production	$H^0A^0 \to b\bar{b}b\bar{b}$	I	Mass	GeV	902.4	0.3%
				Width	GeV		31%
		$H^+H^- \to t\bar{b}b\bar{t}$		Mass	GeV	906.3	0.3%
				Width	GeV		27%

all results with L => 2 ab^{-1}

CLIC CDR Vol. 2

Spare slides

Recycled material, presented in spring 2012

2 explanatory slides, serving just to give background info…

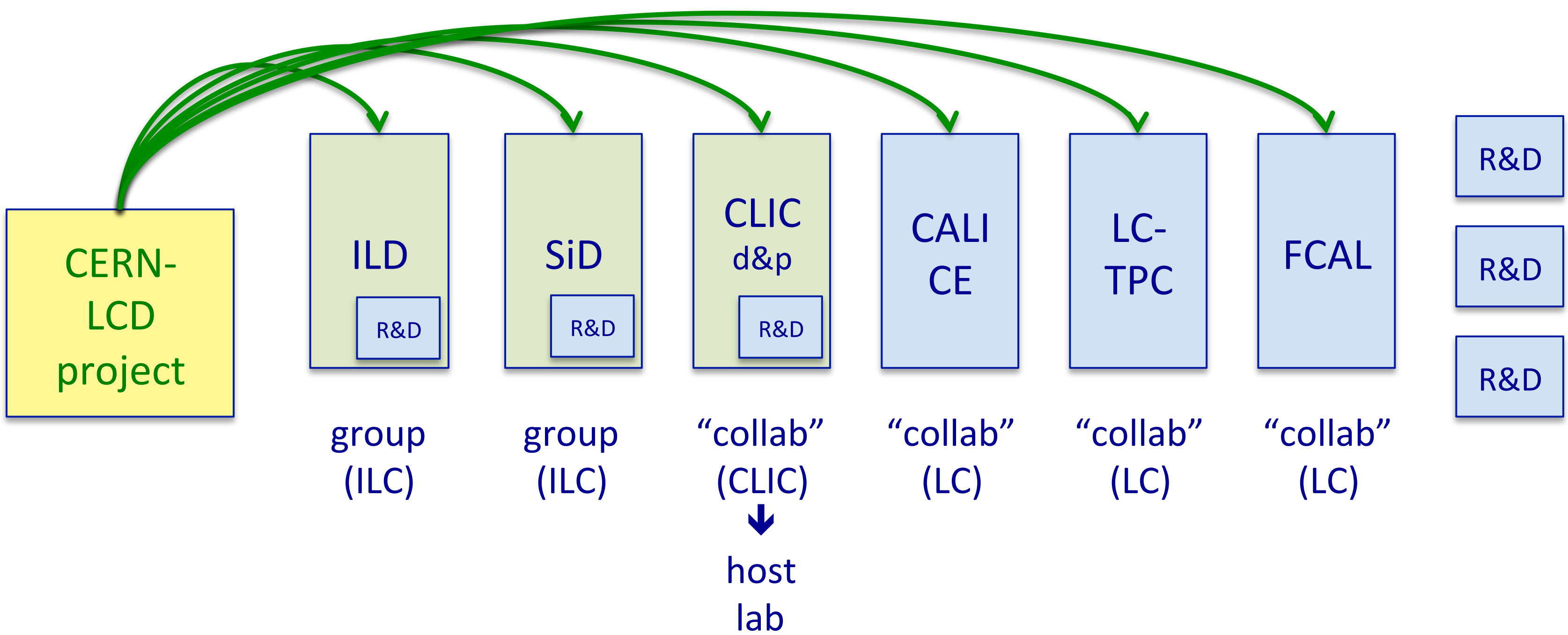
this project stands for: "funding to work on LC detectors: ILC/CLIC concepts and R&D"

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

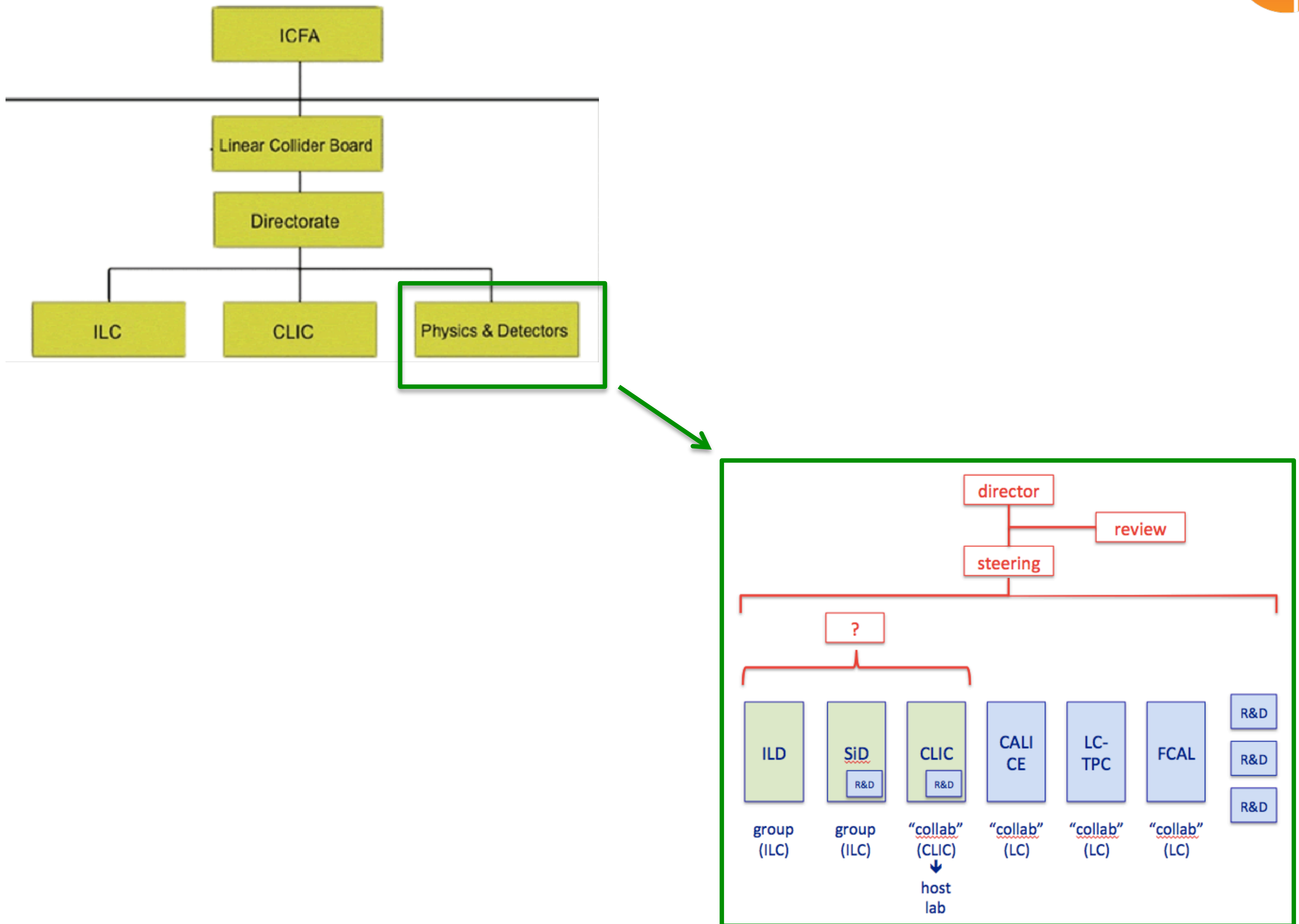
CERN-LCD project

project leader is Lucie
(nominated by CERN DG)

CERN LCD project participation



Possible future LC organisation



Possible future LC organisation