CLIC Detector and Physics Study

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on Behalf of the CLIC Detector and Physics Study

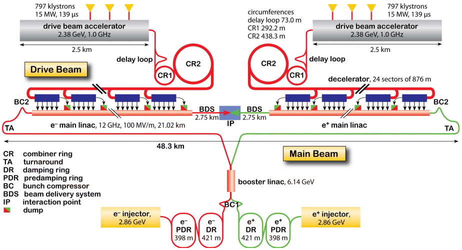
Linear Collider Workshop
November 11–15, 2013
Tokyo, Japan

Overview

Compact Linear Collider

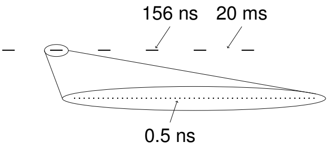
Compact Linear Collider

- CLIC is based on room temperature copper cavities powered by a two-beam acceleration scheme (See Steinar's Talk this morning)
- Currently, the only concept for a multi-TeV electron–positron collider
- The acceleration scheme imposes extremely short bunch spacing with long gaps between short bunch train



Detector and Physics Study:

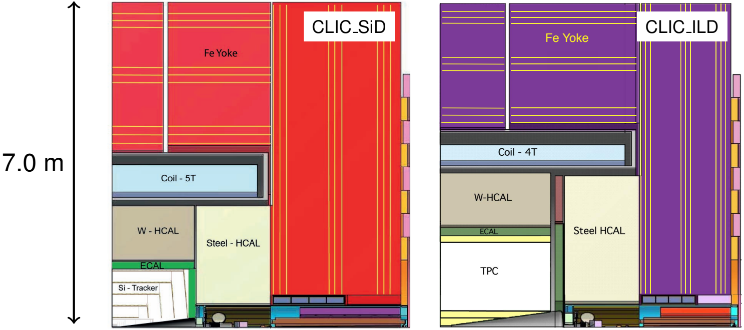
- In the last years, studied the requirements on the hardware for successful physics programme at CLIC
- Now: Detector optimisation, physics studies, and hardware R&D



CLIC: trains at 50 Hz, 1 train = 312 bunches

Detector Models and Requirements

- Detector models for CLIC based on ILC LoI detector models
  - Including simulation and reconstruction frameworks, have since helped in their development
- Adapted geometry for higher energy and CLIC beam-induced backgrounds



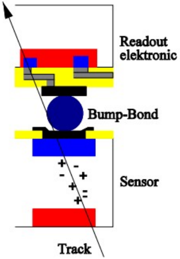
- Successfully used for conceptual design reports and beyond
- Identified areas where detector technology has to be studied and developed
  - Tungsten as the absorber in hadronic calorimeter barrels
  - Vertex detector

Section 2: Hardware R&D for CLIC

Hardware: You design everything including every detail; then you build it.
— Robert Lupton, CHEP13

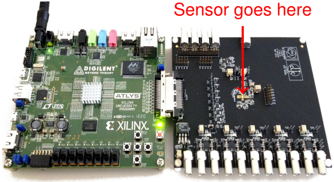
Vertex Detector

- Hybrid technology with ultra-thin (50 μm) sensors and ASICs
  - Goal: 25 μm pitch, 10 ns time-stamping, 50 mW/cm^2
- M. Benoit: Vertex-detector R&D for CLIC
- S. Arfaoui: Calibration, simulation and test-beam characterisation for Timepix hybrid-pixel readout assemblies with ultra-thin sensors

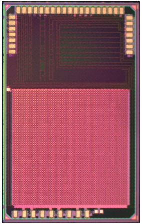


DAQ board

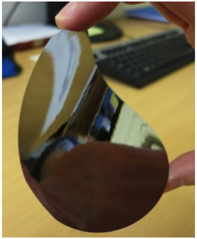
Sensor goes here



CLICPix: Readout with 25 μm pitch

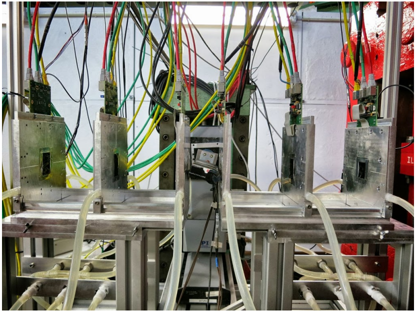


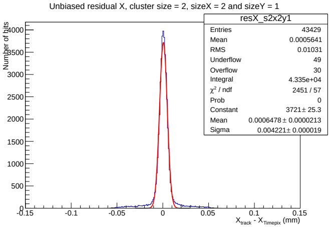
50 μm thick wafer



Thin Sensors in the Test-beam

- 50 µm sensors with 55 µm pitch (Timepix) in the test-beam at DESY
- For two pixel wide clusters (charge sharing), achieve a resolution of ≈ 4 µm (see lower right)
- Next assemblies with 25 µm pitch (CLICPix)





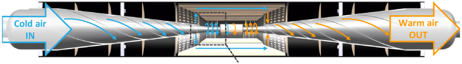
Cooling: From Simulation to Reality

To reach low material budget:

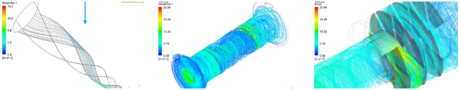
- Cooling the vertex detector with air flowing through the double walled beam pipe
- Computational Fluid Dynamics (CFD) simulation show promising results
- Test-stand in construction to test the stability, vibrations, and cooling; and cross-check the simulation
    - Study different ladder structures

Also in M. Benoit: Vertex-detector R&D for CLIC

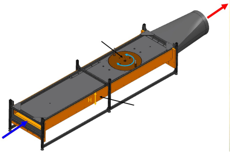
Sketch of the air cooling for the VXD



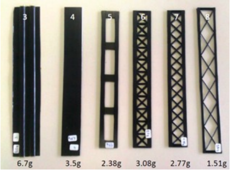
CFD Simulations of the air cooling



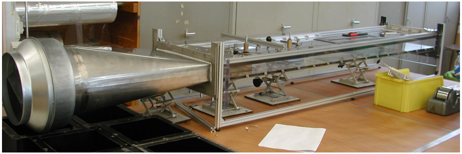
Sketch of the test stand



Different ladder structures



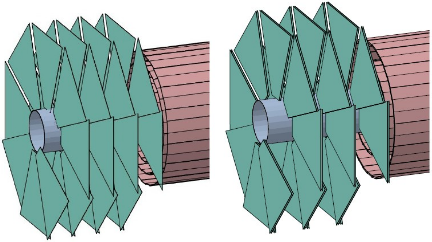
Photograph of the test stand



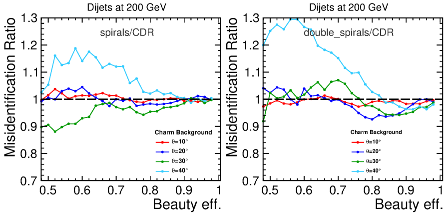
Vertex Layout and Material

- Air cooling requires spiral layout to let air flow through all of the vertex detector
- Flavour tagging performance with different layouts and material budgets
  - Compare different layouts and understand (in)efficiencies
  - Different spiral structures implemented in the simulation
  - Flavour-tagging efficiencies studied in full simulation with different jet energies and angles
- N. Alipour Tehrani: Physics performance studies for different CLIC vertex detector geometries

Single spirals Double spirals



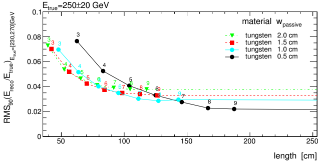
Misidentification ratio of spiral geometries compared to disks



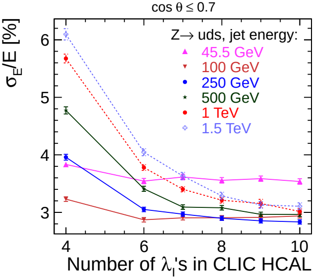
Tungsten in Hadronic Calorimeters

- Particle Flow + Desired Magnetic Field + High jet energy + Cost considerations = Tungsten HCal (in the barrel)
- Test beams at the CERN PS and SPS with the Calice Analog Scintillator HCal (2010–2011) and Calice Digital RPC HCal (2012)
- Also in the test beam: Planes equipped with fast readout to study time-structure of showers in tungsten: T3B (scintillator), FastRPC
- Studying the performance of tungsten with hadronic showers and compare data with different GEANT4 physics lists

Energy resolution as a function of calorimeter size for different tungsten absorber thicknesses and total nuclear interaction lengths



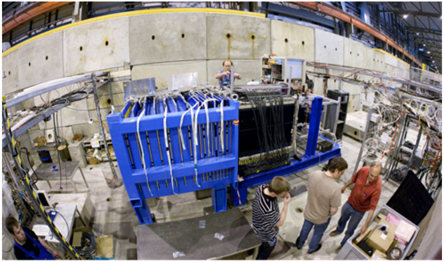
Jet energy resolution as a function of calorimeter size

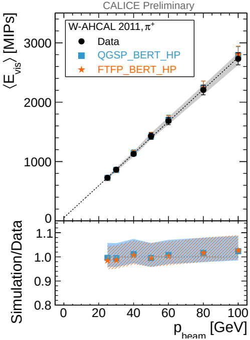


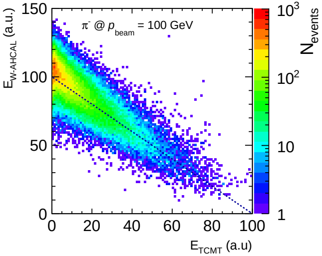
Analog HCal with Tungsten Absorbers

Calice Analog Scintillator HCal with tungsten absorber

- First analyses of data are under review for publication
- High-energy-data analyses on going
  - Including tail catcher (Steel absorber with scintillator) used for energy correction
- E. Sicking: Analysis of CALICE W-AHCAL data at 10 – 100 GeV





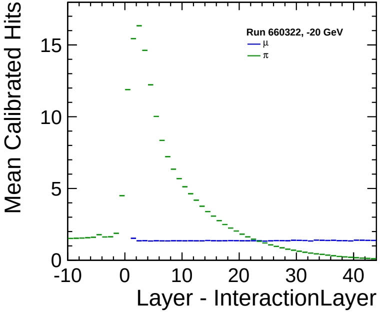


Digital HCal with Tungsten Absorbers

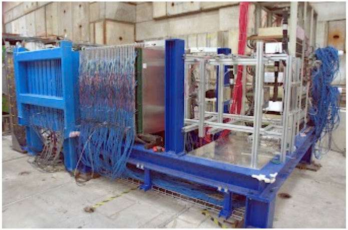
Calice Digital RPC HCal with tungsten absorbers

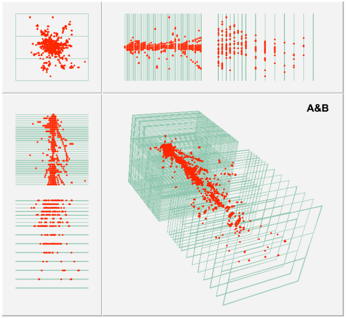
- Analysis of data going on
- Calibration going well, e.g., constant number of hits per layer from Muons

Hit-multiplicity after calibration



C. Grefe: Calibration of the W-DHCAL test beam data

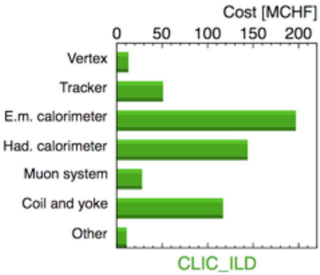




180 GeV Pion

ECal Optimisation

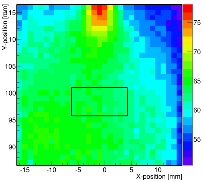
- Large area of silicon sensors drive the ECal cost
- Study: Reduced radius, fewer layers, alternative readout (scintillator pads/strips) with larger segmentation: trade-off between jet-energy resolution and cost



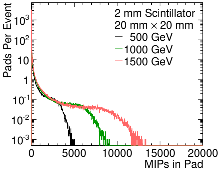
Scintillator Readout

- Evaluating use of scintillator pads in the ECal
- Setup to study scintillator tiles and SiliconPMs
- Need large dynamic range for TeV e.m. showers ($\geq$ 10k MIPs/Pad)

Tile Scan

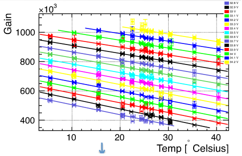


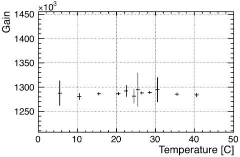
MIPs per Pad



Also under development:

- Temperature stabilisation of SiPM gain



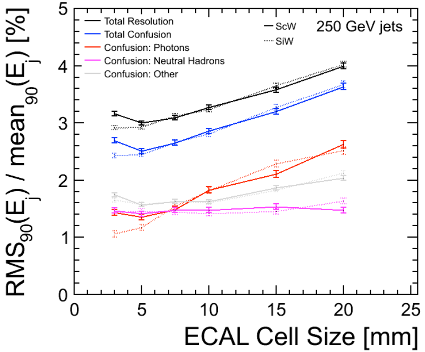


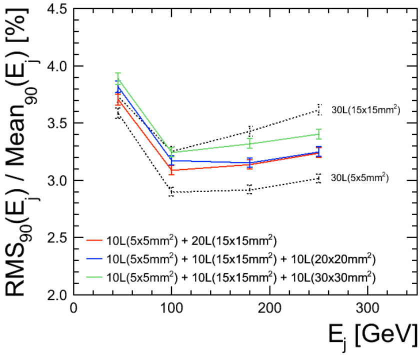
G. Eigen: Gain Stabilisation of SiPMs

- LED and fibre based calibration system for SiPMs J. Kvasnicka: Optical fibre calibration system and adaptive power supply

ECal Optimisation and Software

- ECal optimisation requires in depth understanding of Particle Flow Algorithms and their tuning
  - Calibration is necessary for any ECal layout
- Improvements in the ECal simulation (Thanks to: D. Jeans, A. Lucaci, J. Marshall, K. Coterra)

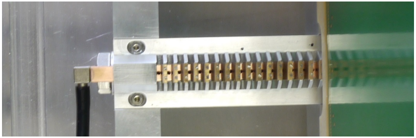


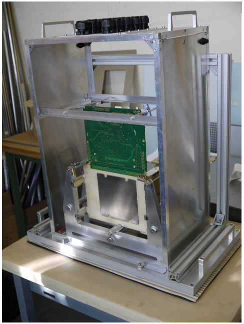


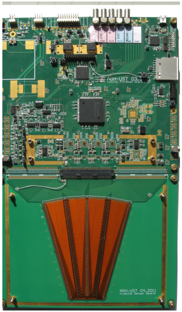
J. Marshall: PandoraPFA with SiW and ScW ECAL Models

Forward Calorimetry

- Test beam structure for precise position of absorber and sensor planes
- Reproducible 50 μm positioning: Using precision tooled combs and permaglass frames to fix locations







- Ready for test beams
- W. Lohmann: FCAL – results from beamtests and future plans

- Electronics for fast readout of the Forward Calorimeters

Section 3: Software

Software: You design everything including every detail; then you're done.
— Robert Lupton, CHEP13

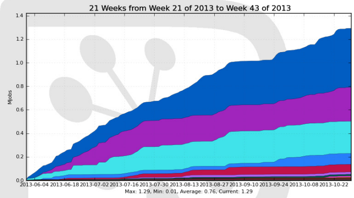
ILCDIRAC

ILCDIRAC offers a easy access to GRID computing resources

- All LC software supported via simplified interface: Mokka, Marlin (inc. PandoraPFA, LCFIPlus), Slic, org.lcsim, Whizard
- Production system for SiD DBD and CLICdp; Used by Calice and users
  - 1.4 Million jobs in the last 6 months
  - Now also being adopted by ILD
- For CLICdp physics studies
  - About 40 million events produced
- Managing more than 1 PB
- C. Grefe: ILCDirac status and future

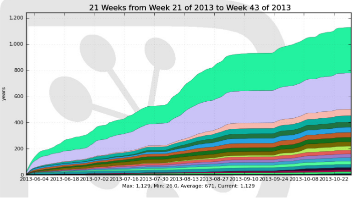
Many Thanks to the GRID site admins, and DIRAC developers for fast responses

Jobs by Users
(Max.: 1.4 Million Jobs)



Users: C.Grefe, N. Alipour, C. Calancha, A. Lucaci…

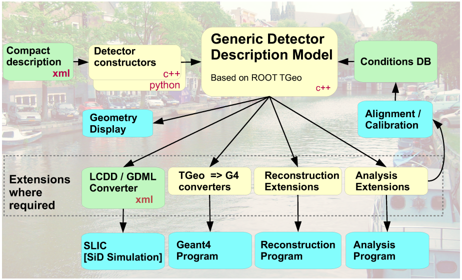
CPU Time by Site(Max.: 1.2k years)



Sites: Desy, CERN, Freiburg, Brunel…

DD4hep: Detector Description for HEP

- AIDA supported general purpose detector geometry package, for the full experiment life-cycle
  - Single source of information for simulation, reconstruction, visualisation
- Common geometry framework
  - Enables common implementations for reconstruction
- Currently under development: developers from all LC concepts
- Plan to have new CLIC detector model implemented by end of next year

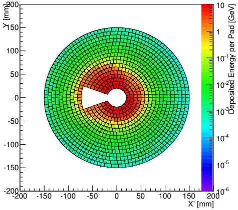


(M. Frank, CHEP13)

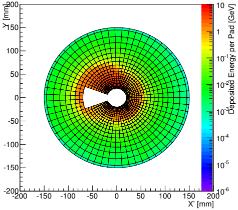
Forward Clustering and Tagging

- Working on clustering package for forward calorimeters: consolidation of existing implementations
  - Many possible geometries

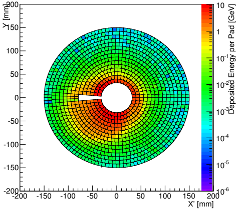
ILC: Uniform segmentation



ILC: Proportional segmentation



CLIC: Uniform Segmentation



- AS: Clustering Algorithms for the Forward Calorimeters
- For full simulation need to overlay background files
  - Library under development: Use estimated efficiencies for electron tagging

Section 4:

Physics Studies at CLIC

Physics Studies at CLIC

Higgs Physics can be done at any stage of the CLIC programme

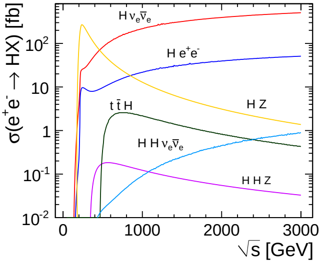
- Higher energies benefit from increased WW-fusion Higgs production cross-section

Number of Higgs events including ISR and Beamstrahlung

	350 GeV	1.4 TeV	3 TeV
$\mathscr{L}_{\mathrm{int}}$ [fb^{-1}]	500	1500	2000
# ZH events	68,000	20,000	11,000
# $H\nu_e\bar{\nu}_e$ events	26,000	370,000	830,000
# He^+e^- events	3,700	37,000	84,000

- Larger centre-of-mass energies allow more precise study of rare Higgs decays

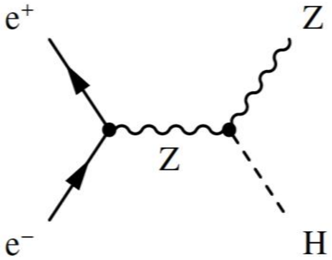
Reach for New Physics via production of heavy particles, or indirect evidence



Higgs Physics

Broad range of Higgs studies at different centre-of-mass energies

- **M. Thomson: H$\rightarrow$WW* at 1.4 TeV and HZ$\rightarrow$Hqq at 350 GeV**
- E. Sicking: Higgs boson decays to $\gamma\gamma$ and to $Z\gamma$ at 1.4 TeV
- I. Bozovic-Jelisavcic: $H \rightarrow \mu\mu$ at 1.4 TeV CLIC
- A. Robson: Fusion Higgs production in ZZ fusion at 1.4 TeV
- M. Vogel: Measurement of the top Yukawa coupling at a 1.4 TeV CLIC
- T. Lastovicka: Higgs self-coupling at 1.4 and 3 TeV
- P. Roloff: Higgs Physics at CLIC



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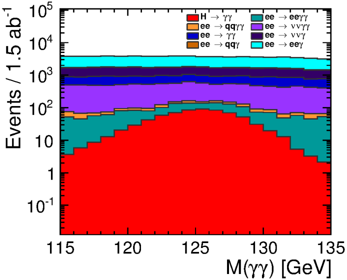

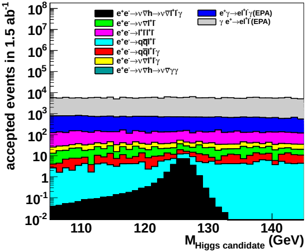

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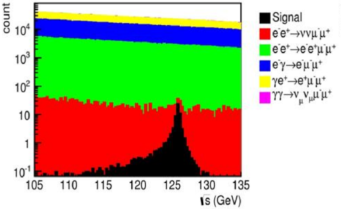
Pre-selected event-distribution for $H \to \mu\mu$



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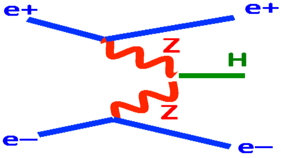

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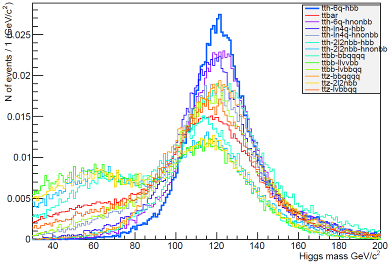
Higgs Mass in signal and background events



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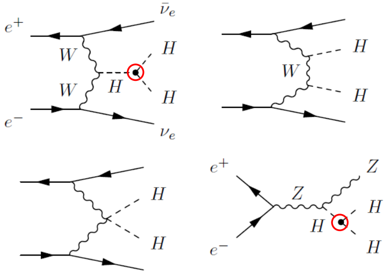
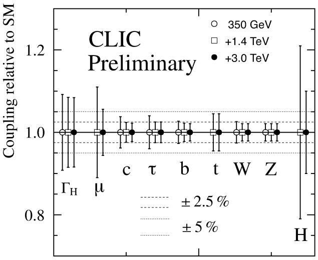
- A. Robson: Fusion Higgs production in ZZ fusion at 1.4 TeV
- M. Vogel: Measurement of the top Yukawa coupling at a 1.4 TeV CLIC
- **T. Lastovicka: Higgs self-coupling at 1.4 and 3 TeV**
- P. Roloff: Higgs Physics at CLIC



Higgs Physics

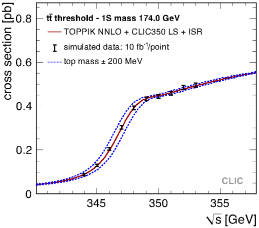
Broad range of Higgs studies at different centre-of-mass energies

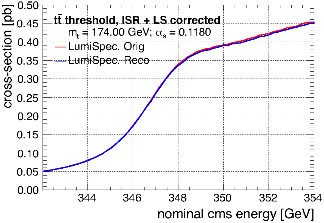
- M. Thomson: H→WW* at 1.4 TeV and HZ→Hqq at 350 GeV
- E. Sicking: Higgs boson decays to γγ and to Zγ at 1.4 TeV
- I. Bozovic-Jelisavcic: H → μμ at 1.4 TeV CLIC
- A. Robson: Fusion Higgs production in ZZ fusion at 1.4 TeV
- M. Vogel: Measurement of the top Yukawa coupling at a 1.4 TeV CLIC
- T. Lastovicka: Higgs self-coupling at 1.4 and 3 TeV
- **P. Roloff: Higgs Physics at CLIC**



Non-Higgs Studies

- Top physics at CLIC, threshold scan, including reconstructed luminosity spectrum, invariant mass reconstruction, and possible studies at higher energies F. Simon: Top mass and future top studies at CLIC





- Model Independent Dark Matter Searches via excess in the single photon spectrum
  - Reach is limited by systematics: Theoretical uncertainty in background cross-sections, uncertainty of electron tagging efficiency, photon reconstruction efficiency,. . .

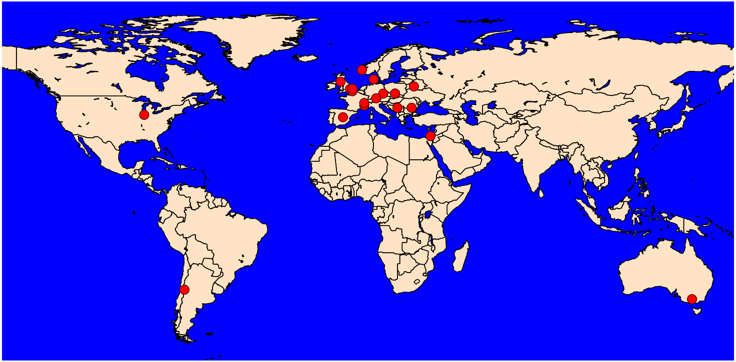
Section 5:
The CLIC Detector and Physics Study Group

The CLIC Detector and Physics Study

- Collaboration-like structure based in Memorandum of Cooperation `http://lcd.web.cern.ch/lcd/Home/MoC.html`
- Total of 20 members at the moment
  - Further members welcome (given approval by institute board)
- CERN is the host laboratory
- Chair of institute board: Frank Simon
- Spokesperson: Lucie Linssen
- Publication committee: Aharon Levy (Chair), Philip Burrows, Dieter Schlatter, Ulrik Uggerhøij
- Speakers committee: Erik van der Kraaij (Chair), Ivanka Božović-Jelisavčić, Maximilien Chefdeville

CLICdp session on Thursday afternoon

CLIC MoC Members



Australia:	Australian Collaboration for Accelerator Science (ACAS)	Poland:	The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow
Belarus:	NC PHEP, Belarusian State University, Minsk	Romania:	Institute of Space Science
Chile:	The Pontificia Universidad Catolica de Chile, Santiago	Serbia:	Vinca Institute for Nuclear Sciences, Belgrade
Czech Republic:	Institute of Physics of the Academy of Sciences of the Czech Republic, Prague	Spain:	Spanish Network for Future Linear Colliders
Denmark:	Department of Physics and Astronomy, Aarhus University	Switzerland:	CERN
France:	Laboratoire dAnnecy-le-Vieux de Physique des Particules (LAPP), Annecy	UK:	The School of Physics and Astronomy, University of Birmingham
Germany:	MPI Munich	UK:	University of Cambridge
Israel:	Tel Aviv University	UK:	University of Glasgow
Norway:	University of Bergen	UK:	University of Oxford
Poland:	Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Cracow	USA:	Argonne National Laboratory, High Energy Physics Division

Summary

- CLIC detector and physics study is in post-conceptual-design phase
- Focus on hardware required for detector at CLIC
  - Vertex Detector
  - Hadronic Tungsten-Calorimeter
- Including optimisation, engineering, and integration studies
- Software:
  - ILCDirac, DD4hep, Forward Clustering, and ECal optimisation/PF: benefits all LC detectors
- Physics: CLIC Multi-TeV electron–positron collider can make high precision measurements
- CLICdp moved to more formal structure with election of Institute Board Chair, Spokesperson, and committees

Thanks to everyone for providing Material!

Thank you for your Attention!