Detector Challenges at CLIC

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On behalf of the CLIC Detector and Physics collaboration

INSTR14, Novosibirsk, 24.02 – 01.03.2014

1. Introduction to CLIC Detector & Physics study and the CLIC project
2. CLIC detector requirements
3. R&D examples
4. Conclusions

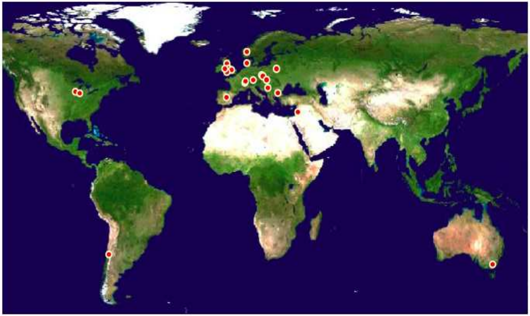
Introduction

CLIC Detector & Physics study

Who are we?

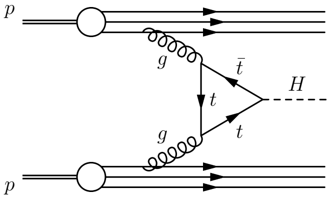
Light-weight collaboration structure
http://lcd.web.cern.ch/LCD/Home/MoC.html

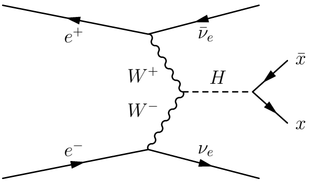
CLICdp: 22 institutes



Country	Partner	Representative in the IB
Australia	Australian Collaboration for Accelerator Science (ACAS)	M. Boland
Belarus	NC PHEP, Belarusian State University, Minsk	K. Afanaciev
Chile	The Pontificia Universidad Católica de Chile, Santiago	M.A. Diaz Gutierrez
Czech Republic	Institute of Physics of the Academy of Sciences of the Czech Republic, Prague	T. Lastovicka
Denmark	Department of Physics and Astronomy, Aarhus University	U. Uggerhoj
France	Laboratoire d'Annecy-le-Vieux de Physique des Particules (LAPP), Annecy	Y. Karyotakis
Germany	MPI Munich	F. Simon
Israel	Tel Aviv University	A. Levy
Norway	University of Bergen	G. Eigen
Poland	Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Cracow	M. Idzik
Poland	The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow	L. Zawiejski
Romania	Institute of Space Science	T. Preda
Serbia	Vinca Institute for Nuclear Sciences, Belgrade	I. Bozovic-Jelisavcic
Spain	Spanish Network for Future Linear Colliders	A. Ruiz
Switzerland	CERN	K. Elsener
United Kingdom	The School of Physics and Astronomy, University of Birmingham	N. Watson
United Kingdom	University of Cambridge	M. Thomson
United Kingdom	University of Glasgow	A. Robson
United Kingdom	The Department of Physics of the University of Liverpool	J. Vossebeld
United Kingdom	University of Oxford	Ph. Burrows
USA	Argonne National Laboratory, High Energy Physics Division	H. Weerts
USA	University of Michigan, Physics Department	J. Wells

Experimental environment at hadron vs. lepton colliders





- Proton is a compound object
  - Initial states from parton distribution functions
  - Broad distribution of CM energies, maximum at a fraction of nominal energy
- High rates of QCD background
  - Complex trigger schemes
  - Hadronic final states difficult to reconstruct
  - High radiation doses in detectors
- High cross section for hadronic states

- Leptons are elementary
  - Initial states well defined up to the luminosity spectrum
  - Most of the CM energy available for creation of new particles
- Cleaner experimental environment
  - Triggerless readout
  - Easier identification of hadronic final states
  - Radiation dose less of an issue
- Comparable reach for EW and hadronic states

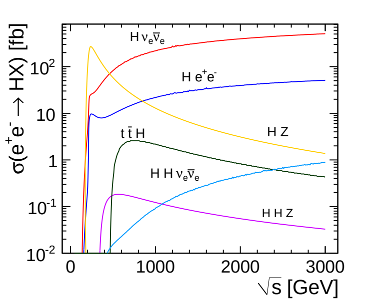
Physics goals

New Physics at multi-TeV CM energy

- Direct observation of phenomena at CM energy up to 3 TeV
- Indirect observation of phenomena at higher energy scales via loop corrections involving new particles

Precise measurement of the Higgs sector and the top physics

- Precise measurement of Higgs mass and couplings; Absolute measurement of the total Higgs width
- Precise measurement of the top mass

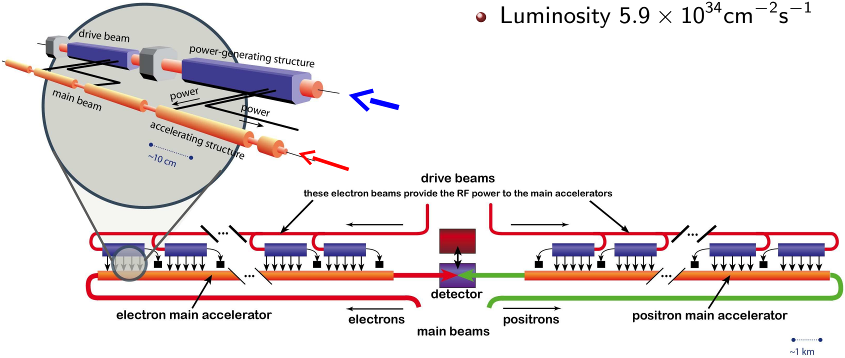


Higgs production cross section via different processes as a function of the CM energy

CLIC Accelerator

- Drive beam
  - Low energy (2.4 GeV – 240 MeV)
  - High current (100 A)
- Main beam
  - High energy (9 – 1500 GeV)
  - Current ~ 1 A

- Parameters – 3 TeV stage
  - Length 48 km
  - Pulse rate 50 Hz
  - Bunches per pulse 312
  - Bunch population 3.7×10^9
  - Bunch RMS size (x, y, z)
    $45nm \times 1nm \times 44\mu m$
  - Luminosity $5.9 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$



Staged construction

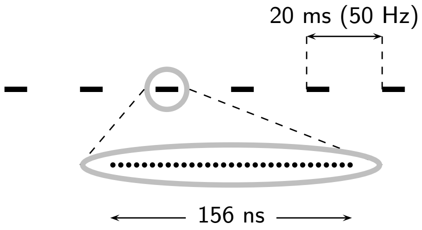
Reaching Physics goals

- in shortest time
- at lowest cost
- with maximal luminosity and physics reach at each stage

- 350 GeV stage:
  - Absolute Higgs width, mass and model-independent[a] couplings
  - Top-pair threshold scan
- $\sqrt{s} > 1\text{TeV}$:
  - High statistics Higgs samples from WW fusion for precise measurement of couplings, including rare decays, Top Yukawa coupling, Trilinear Higgs self coupling
  - New Physics via direct and/or precise indirect searches

[a] Independent of the model of the Higgs decay

Beam structure



	3 TeV CLIC	LHC 14 TeV (nominal)
Bunch crossing separation (ns)	0.5	25
Crossing angle	20 mrad	200 μrad
Instantaneous luminosity ($cm^{-2}s^{-1}$)	6×10^{34}	1×10^{34}

Low duty cycle at CLIC

- Read out in between bunch trains; No trigger
- Power pulsing of all detectors at 50 Hz, to reduce the need of cooling

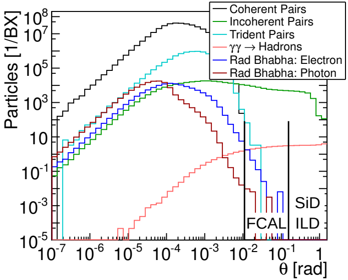
IP and background conditions

Beam related backgrounds

- Intense EM interaction between colliding bunches → Beamstrahlung
  - Production of pairs
  - Hadronization in $\gamma\gamma$ interactions
- High occupancies in trackers
- Energy deposits in calorimeters

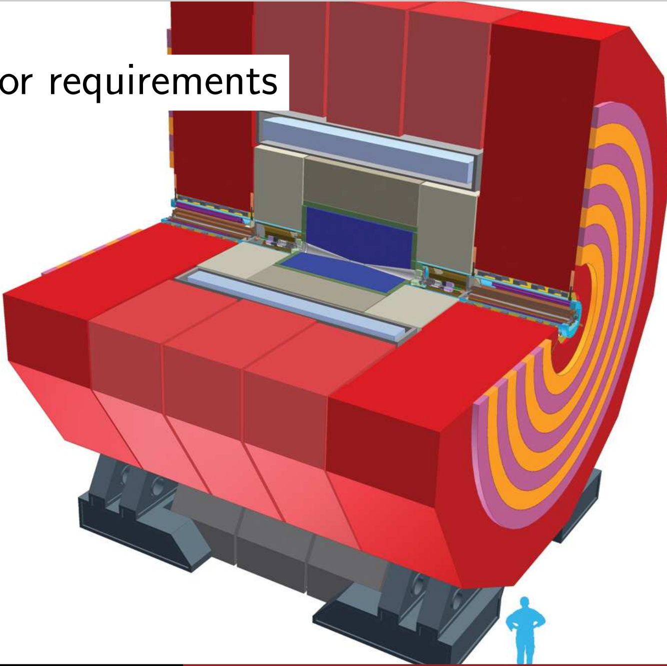
Example: 3 TeV CLIC

- Total deposited energy per bunch train:
  - ECAL endcaps: 13 TeV
  - HCAL endcaps: 22 TeV
- Maximum background occupancy in the vertex detector over 1 bunch train: 3%



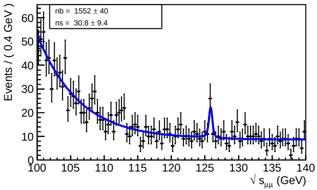
Dannheim and Sailer, LCD-Note-2011-021

CLIC detector requirements

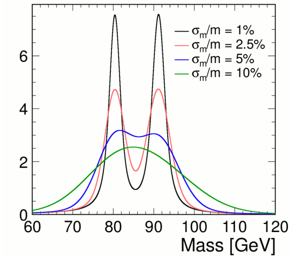


Essential requirements for precision measurements

- Excellent track momentum resolution for charged particles
  - Driven by the requirement of good invariant-mass resolution for muon pairs in $Z \to \mu^+\mu^-$ and $H \to \mu^+\mu^-$ decays
  - For high muon momenta at CLIC, $\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5} GeV^{-1}$ so that the uncertainties are not dominated by p_T resolution (vs. beam energy spread, statistics etc.)
- Good jet energy resolution
  - Good identification of hadronic events, especially with multi-jet final states
  - Discrimination between hadronic decays of W and Z boson
  - For $\sigma_E/E < 5\%$ between 50 and 1000 GeV, the uncertainties are dominated by the beam-beam effects



Dimuon invariant mass fit in the analysis of $H \to \mu\mu$ decay at 1.4 TeV CLIC



Separation of W and Z peaks for different invariant mass resolutions

Vertex and tracker requirements

Challenges

- High occupancies – need small cell sizes
- Precise hit timing to suppress background
- Ultra thin layers ($\sim 0.2\% X_0$) to minimize multiple scattering
    - Low power dissipation is a must – power pulsing

Solutions under R&D

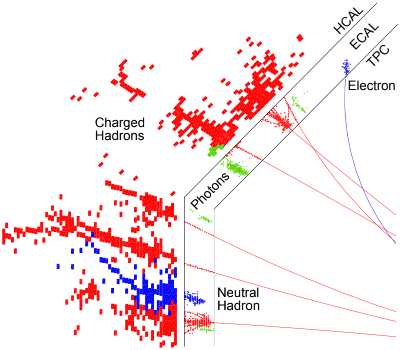
- Hybrid technology
    - Thin sensors ($\sim 50\mu m$)
    - Thinned high-density ASIC
    - High-density interconnect with micro bump-bonding and TSV

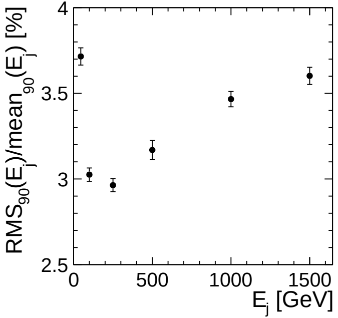
See talk by S. Redford tomorrow

Jet energy resolution with particle-flow calorimetry

- Full reconstruction of particles in a jet and their respective contributions to the jet energy
  - Energy contribution determined in the most precise way for each jet constituent – **charged particle momentum measured in the tracker**
  - Fine granularity of calorimeters to minimize confusion
  - Small tracker pixels for excellent momentum resolution

See talk by F. Sefkow on Thursday





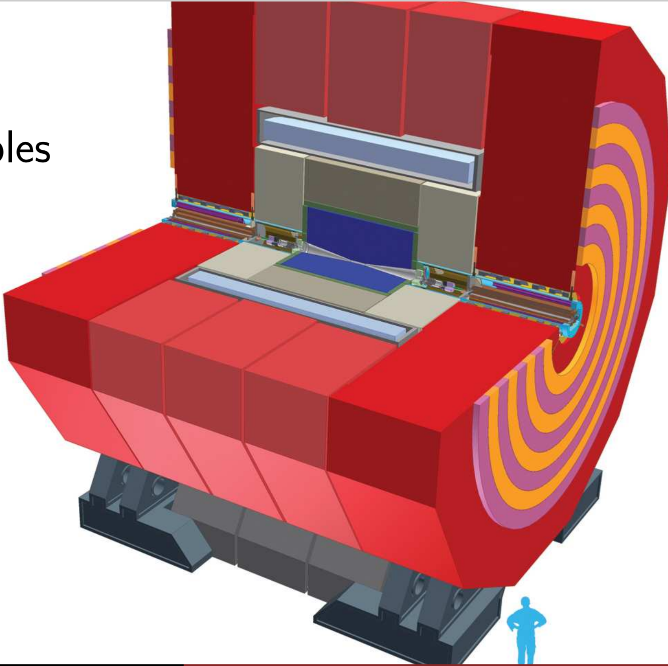
PFA performance: Jet energy resolution better than 4% in the entire region of interest (50 – 1000 GeV)

Calorimetry challenges

Challenges

- High jet energies at CLIC – dense materials required
- Finely segmented calorimeters for Particle-Flow approach
  - Accurate jet reconstruction
  - Separation of physics particles from beam-induced background
  - Mitigate high occupancies due to beam-induced background
  - Consequence – high readout channel count ($\mathcal{O}(10^7)$)
- Fast timing
- Distinction of charged from neutral hadrons

R&D examples



Calorimetry

ECAL

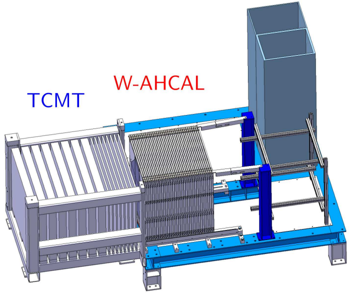
- Tungsten absorber
- Active layers
  - Silicon – response uniform, but more expensive than scintillator
  - Scintillator – fast, robust and stable, but response less uniform
  - Gaseous technologies with digital (hit / no hit) readout

HCAL

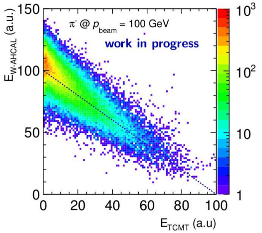
- Iron or tungsten absorber
- Active layers
  - Scintillator
  - Several different digital technologies (RPC, GEM, MicroMegas)

W-AHCAL

- Contain CLIC energetic showers while maintaining limited solenoid size – dense absorber required in the barrel
- Tungsten absorber tested with CALICE scintillator AHCAL readout layers with Si Photomultipliers (SiPM)
  - At CERN PS in 2010, 30 layers W-AHCAL, $1 \leq p_{beam} \leq 10$ GeV
  - At CERN SPS in 2011, 38 layers W-AHCAL + tail catcher, $10 \leq p_{beam} \leq 300$ GeV
- 2010 results:
  - Stochastic term for π^+: 62% (as compared to 58% with Fe)
  - Excellent agreement with simulation
- 2011 – analysis ongoing
  - Study how to combine W-AHCAL and TCMT data



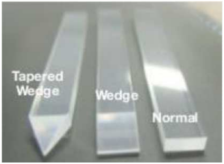
W-AHCAL and TCMT test-beam configuration



Plot of W-AHCAL vs TCMT energy data

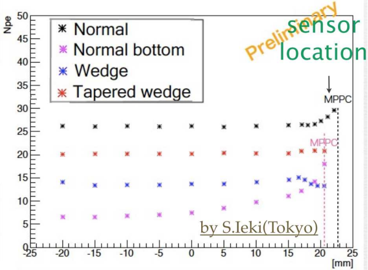
Scintillator ECAL

- Favorable cost and excellent time response (~ 1 ns)
- Issues: Uniformity, dynamic range, light yield
- Present solutions (CALICE):
  - Tapered wedge strip shape improves longitudinal uniformity
  - SiPM with many pixels to avoid saturation of yield
  - Al sputtering on Sci surface for light reflection



Test beam (CALICE)

- e^+ beam (1 – 6 GeV) at DESY
- Demonstrated feasibility, excellent shower imaging, correction of temperature dependence of response, Energy resolution $\sigma_E/\sqrt{E} = \sqrt{a^2 + b^2/E}$ ($a \approx 14\%$; $b \approx 4\%$) ...



Open issues

Uniformity of response over individual strips

T. Takeshita, CLIC workshop 2014

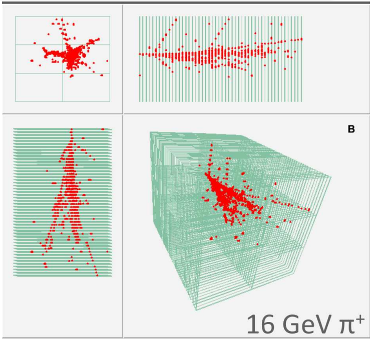
CALICE DHCAL Prototype

Digital calorimetry

- Energy reconstructed from number of “hits” (cells that fired)
- Extremely detailed image of showers
- Low-cost active layers (RPC)
- Large-scale prototype successfully tested with tungsten absorbers at CERN PS and SPS

Ongoing R&D

- Limited rate capability (charge accumulates and efficiency decreases) – lower bulk resistivity in boundary material (glass) required
- HV distribution
- Gas recycling



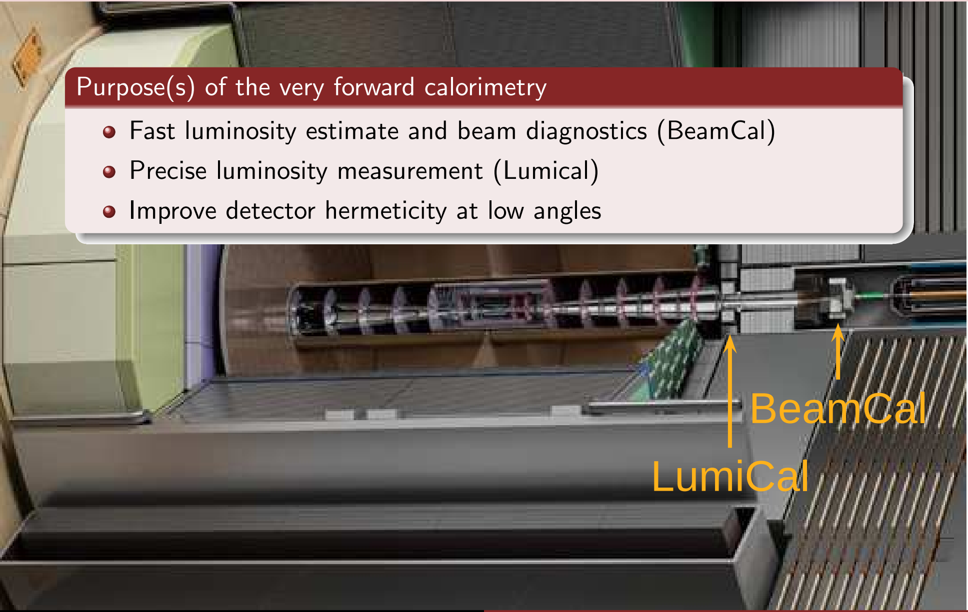
Shower image in Argonne DHCAL

FCAL Instrumentation

FCAL Instrumentation

Purpose(s) of the very forward calorimetry

- Fast luminosity estimate and beam diagnostics (BeamCal)
- Precise luminosity measurement (Lumical)
- Improve detector hermeticity at low angles



FCAL Instrumentation

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Challenges in the low-angle region around the outgoing beam

- Up to $\sim$1 MGy per year at lower angles in BeamCal
- Intensive R&D on radiation hardness (FCAL, in collaboration with LHC beam monitors)
- Very compact and precise calorimeters (Molière radius 11 mm)
- Angular coverage 10 – 40 mrad (BeamCal) and 38 – 110 mrad (LumiCal)

FCAL R&D

Challenges

- Precision – mechanics, alignment
- Radiation dose – radiation-hard sensors needed
- Occupancy – fast, low power readout

Test beam results

- One fully functional sector with readout tested
- Advanced DAQ and analysis tested (pulse-shape deconvolution)
- Good S/N ratio, uniformity and efficiency, low crosstalk
- Longitudinal shower development measured

Future

- Test beam with multiple layers in a rigid structure for precise alignment

Sensor prototype, AGH-UST Krakow

Conclusions

- CLIC provides unique potential for discovery and precision physics at the TeV scale
- Challenging requirements for the detectors – many exciting R&D projects within CLICdp – a few were named here
- A number of large-scale prototypes tested in beam with excellent results
- Many opportunities for R&D, as well as Physics-study work
- New groups/institutes are welcome to CLICdp!

References:

- CLIC Workshop 2014, 3-7 February 2014, CERN https://indico.cern.ch/event/275412/
- CLIC CDR (vol 2), *Physics and Detectors at CLIC*, CERN-2012-003, arXiv:1202.5940
- CLIC CDR (vol 3), *The CLIC Programme: towards a staged e^+e^- Linear Collider exploring the Terascale*, CERN-2012-005, arXiv:1209.2543