Status and plans of the CLIC detector study

Outline:

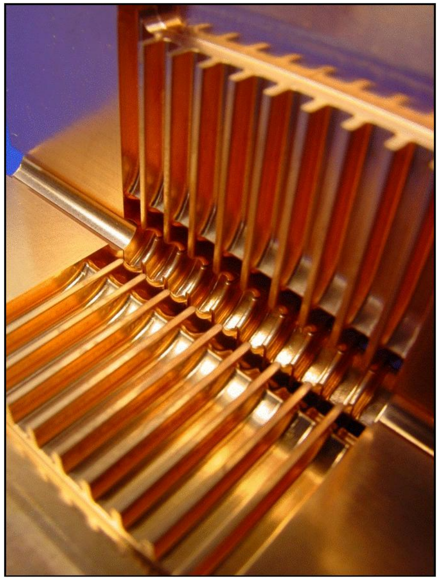
- Introduction to the CLIC physics/detector study
- CLIC CDR preparations
- Status of detector simulations and software tools
- Hardware R&D
- Summary

Lucie Linssen

Luminosity + polarization workshop, Tel Aviv, Oct^{4th} 2010

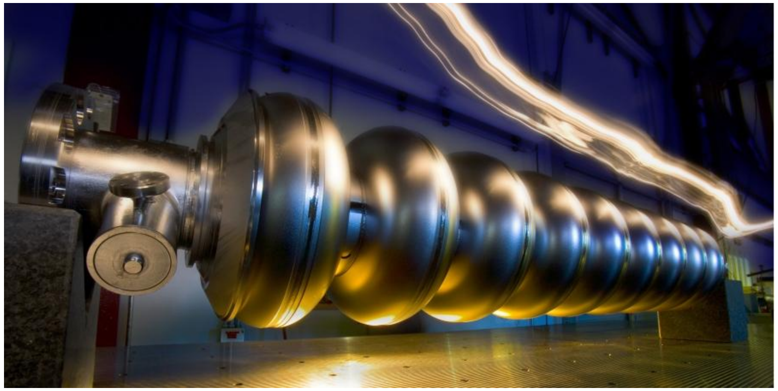
ILC and CLIC in a few words…

linear collider, producing e^+e^- collisions



CLIC

ILC



- Based on superconducting RF cavities
- Gradient 32 MV/m
- Energy: 500 GeV, upgradeable to 1 TeV (lower energies also considered)
- Detector studies focus mostly on 500 GeV

- Based on 2-beam acceleration scheme
- Gradient 100 MV/m
- Energy: 3 TeV, though will probably start at lower energy (~0.5 TeV)
- Detector study focuses on 3 TeV

Luminosities: few 10^{34} $cm^{-2}s^{-1}$

CLIC physics up to 3 TeV

What can CLIC provide in the 0.5-3 TeV range?

In a nutshell…

Higgs physics:

•Complete study of the light standard-model Higgs boson, including rare decay modes (rates factor ~5 higher at 3 TeV than at 500 GeV)

- •Higgs coupling to leptons
- •Study of triple Higgs coupling using double Higgs production

•Study of heavy Higgs bosons (supersymmetry models)

Supersymmetry:

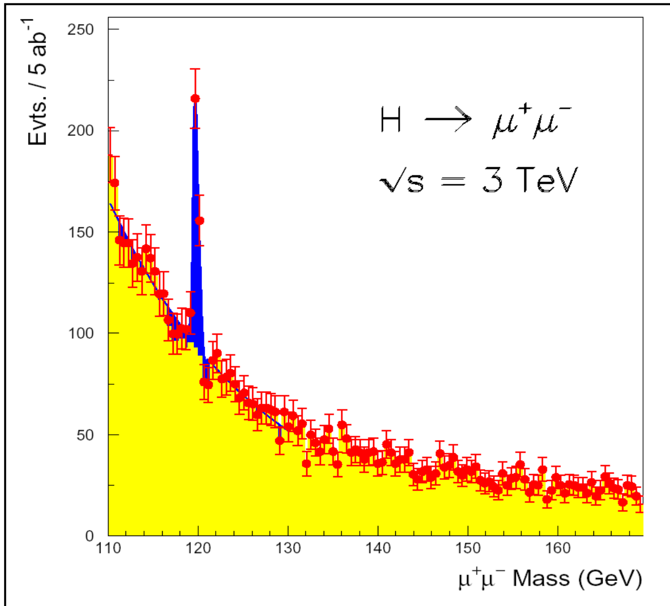
•Extensive reach to measure SUSY particles

And in addition:

•Probe for theories of extra dimensions

•New heavy gauge bosons (e.g. Z')

•Excited quarks or leptons



(S)LHC, ILC, CLIC reach

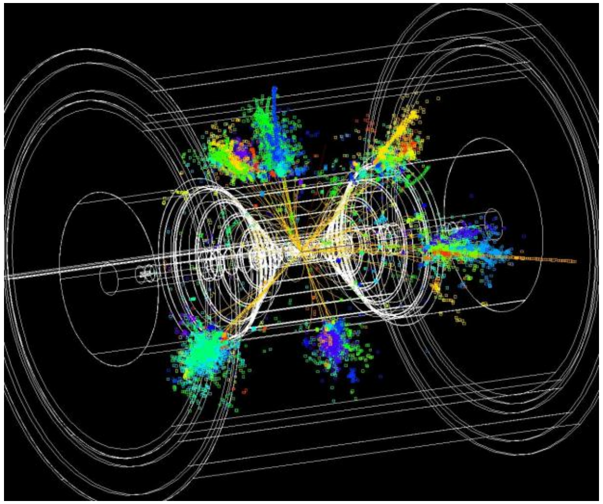
	LHC 100 fb^{-1}	ILC 800 GeV 500 fb^{-1}	SLHC 1000 fb^{-1}	CLIC 3 TeV 1000 fb^{-1}
Squarks (TeV)	2.5	0.4	3	1.5
Sleptons (TeV)	0.34	0.4		1.5
New gauge boson Z' (TeV)	5	8	6	22
Excited quark q* (TeV)	6.5	0.8	7.5	3
Excited lepton l* (TeV)	3.4	0.8		3
Two extra space dimensions (TeV)	9	5-8.5	12	20-35
Strong $W_L W_L$ scattering	2σ	-	4σ	70σ
Triple-gauge Coupling (95%)	.0014	0.0004	0.0006	0.00013

Gian Giudice CLIC09

ILC and CLIC detector studies

In several aspects the CLIC detector will be more challenging than ILC case, due to:

- Energy 500 GeV => 3 TeV
- More severe background conditions
  - Due to higher energy
  - Due to smaller beam sizes
- Time structure of the accelerator



Detector studies and R&D for the ILC are most relevant for CLIC.

Many years of investment in ILC e^+e^- physics/detector simulations, hardware R&D and detector concepts. No need to duplicate work.

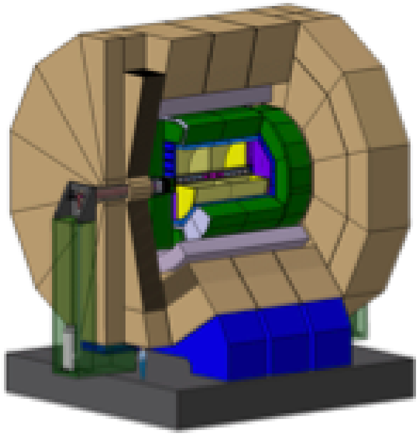
Therefore the CLIC detector study links to several ILC collaborations:

ILD concept, SiD concept, CALICE, FCAL, LC-TPC + EU projects (EUDET/AIDA).

Validated ILC concepts

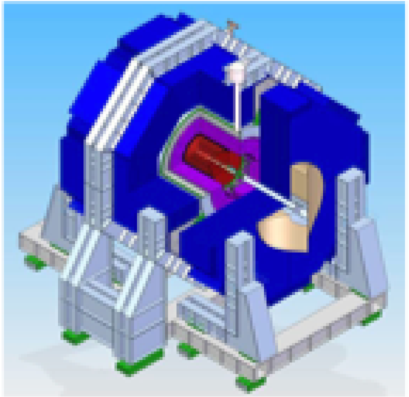
ILD: International Large Detector

"Large" : tracker radius 1.8m
B-field : 3.5 T
Tracker : TPC + Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



SiD: Silicon Detector

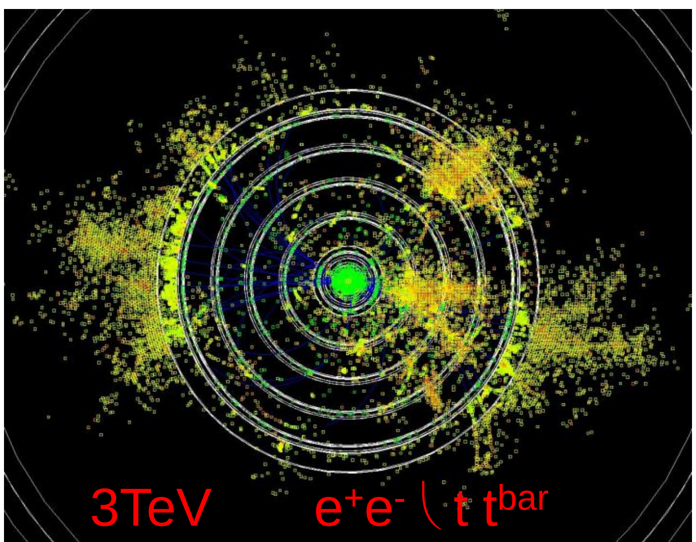
"Small" : tracker radius 1.2m
B-field : 5 T
Tracker : Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid

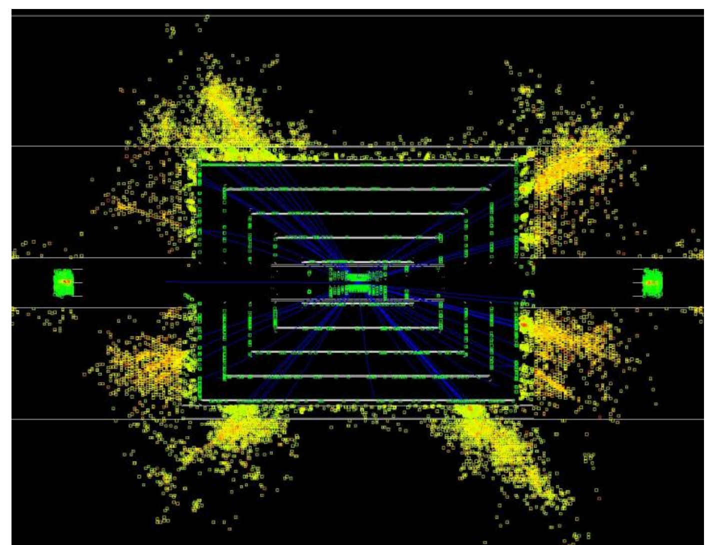


CLIC detector concepts will be based on SiD and ILD.
Modified to meet CLIC requirements

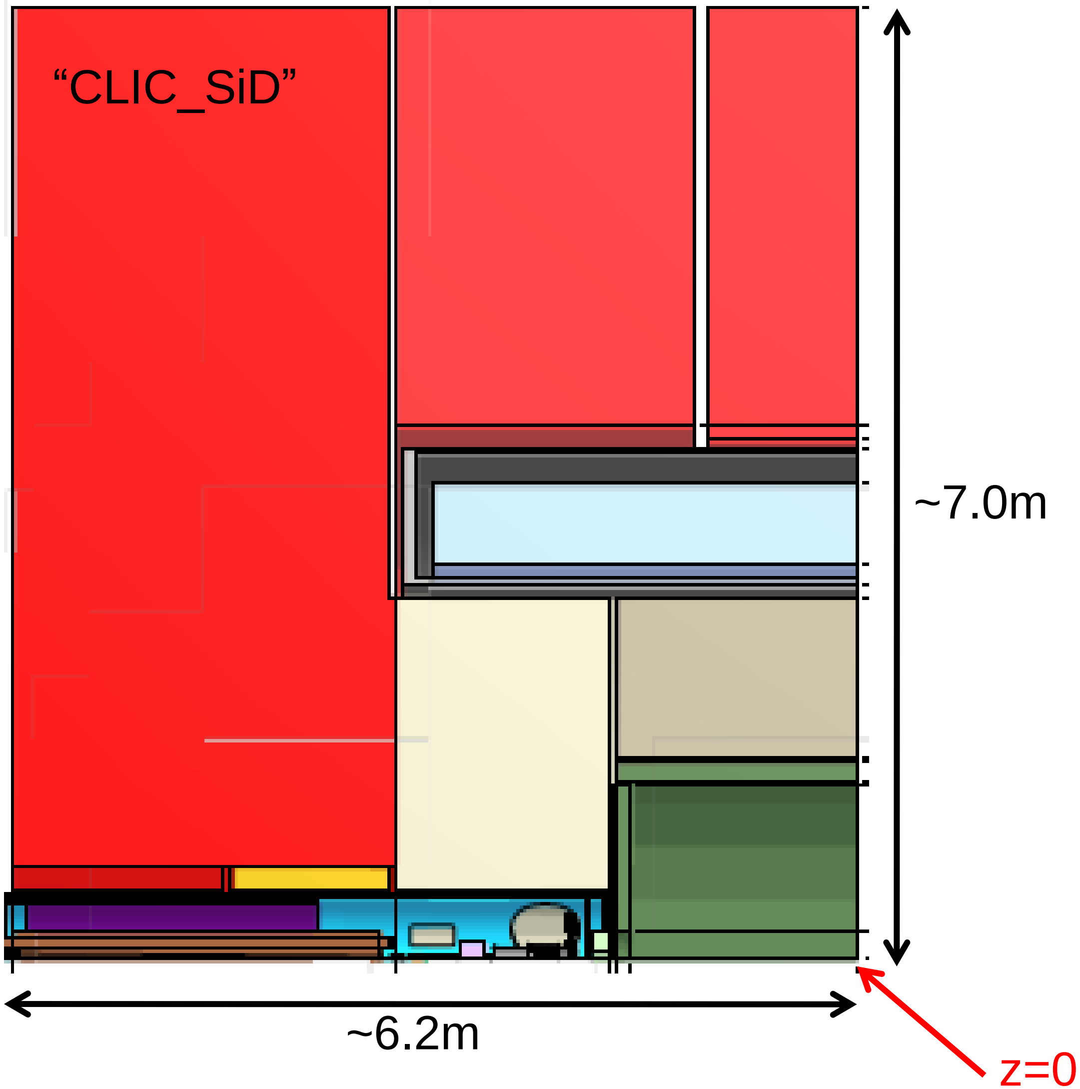
CLIC tracking/calorimetry issues

- Due to beam-induced background and short time between bunches:
  - High occupancy in the inner regions (incoherent, tridents)
  - Jets scale and resolution are affected (γγ=>hadrons)
  - Time-stamping is a must for almost all detectors
- Narrow jets at high energy
  - Calorimeter has to measure high-energy particles (leakage)
  - Separation of tracks in dense jets





the ILC concepts adapted to CLIC



Changes to the ILC detectors:

- 20 mrad crossing angle
- Vertex Detector to 25-30 mm inner radius, due to Beam-Beam Background
- HCAL barrel with 7.5 Λ_i with 1 cm tungsten plates
- HCAL endcap with 7.5 Λ_i with 2 cm steel plates
- Forward (FCAL) region adaptations (see next talks)

CLIC CDR

The CDR will have 3 volumes:

1 Executive summary (~50 pages)

2 The CLIC accelerator and site facilities (~800 pages)

3 Physics and detectors at CLIC (~150 pages)

Main aim of the CDR:

Accelerator:

- demonstrate the feasibility of the CLIC technology
- design of a linear collider based on CLIC technology

Feasibility issues ⬄ to be addressed in the CDR

Performance issues and cost optimisation ⬄ to be addressed in the TDR phase

Physics and Detectors:

- Describe the CLIC physics potential
- Demonstrate that CLIC physics can be measured with adequate precision

CLIC physics/detector CDR

The CLIC CDR will present the CLIC_ILD and CLIC_SiD concepts and their detector technologies.

Performances will be demonstrated with either CLIC_ILD **or** CLIC_SiD (presenting some results for each).

Dedicated working groups are addressing specific aspects:

WG1: CLIC physics potential

WG2: Physics observables related to jets

WG3: Physics observables related to tracks

WG4: Vertex detector technology

WG5: Engineering, layout, solenoid, cost

WG6: CLIC benchmark studies

Current focus of the work: gear up for detector benchmark simulations

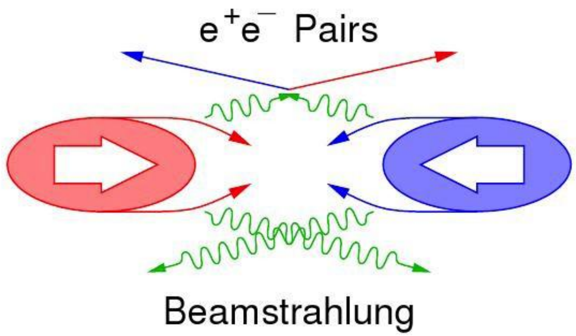
Deadline for final document ~Aug. 2011 (present to CERN Council in Dec. 2011)

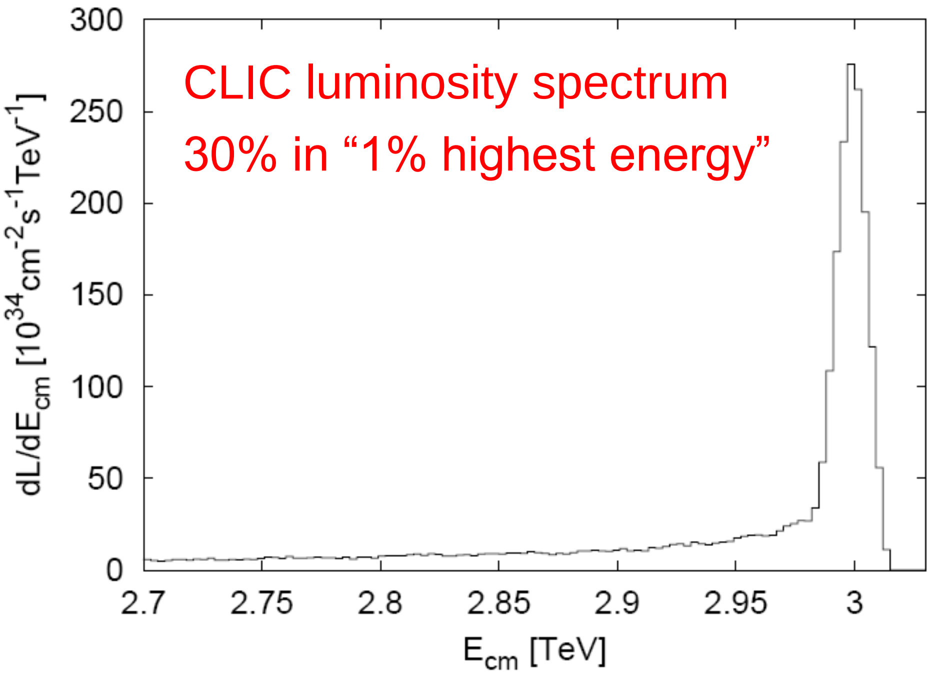
CLIC "editing" status

Status of CDR preparation following dedicated meetings for each of the chapters

Chapter	Subject	Bullet CDR status	Comment
1	Introduction	OK	Draft chapter text exists
2	Physics potential	Promised for after IWLC	
3	Expt. conditions, benchmarks, detector requirements	Draft version	
4&5	ILD+SiD detectors	Draft version	
5			Chapter suppressed
6	Vertex	Draft version	
7	Tracking	Draft version	
8	Calorimetry	Draft version	
9	Magnet systems	OK	
10	Muon system	~OK	
11	Very forward calorimetry	Promised for ~7/10/2010	
12	Readout and DAQ		Pending, No editors
13	Mechanical concepts and integration	OK	Draft chapter text exists
14	Physics performance	No	Too early still?
15	Future plans and R&D prospects	No	Too early still
16	Detector cost	Draft promised for 21/10/2010	
17	Conclusions	No	Too early still

Beam-induced background





Main backgrounds:

- CLIC 3TeV beamstrahlung $\Delta E/E$ = 29% ($10\times ILC_{value}$)
  - **Coherent pairs** (3.8×10^8 per bunch crossing) <= disappear in beam pipe
  - **Incoherent pairs** (3.0×10^5 per bunch crossing) <= suppressed by strong solenoid-field
  - **"Tridents"** <= give an impact "similar" to incoherent pairs
  - γγ interactions => hadrons (**3.3 hadron events per bunch crossing**)

- In addition: Muon background from upstream linac

Beam-induced backgrounds and forward-region studies

Subject are covered in the talks of Andre Sailer and Konrad Elsener

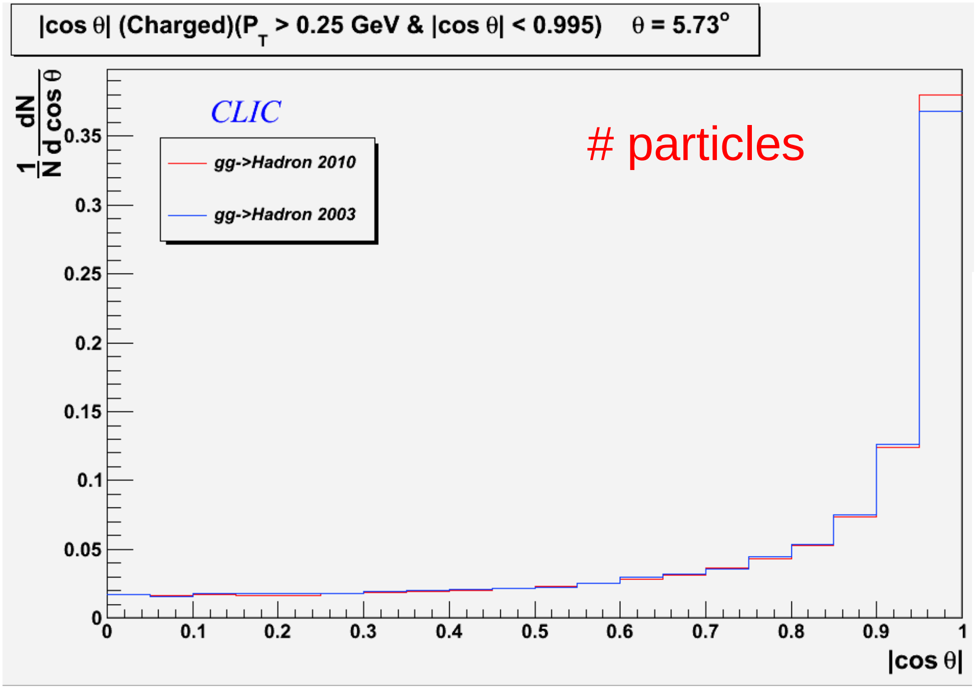
- Forward region layout and optimisation
- Suspension and stability of QD0
- Background events, including trident events
- Radiation doses in Beamcal

In the next slides: Update on γγ => hadron background

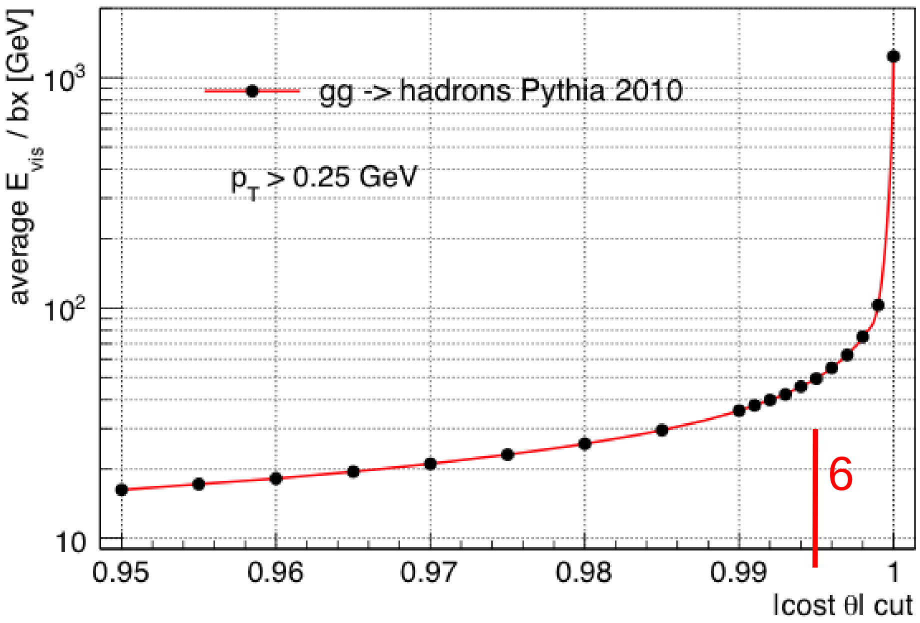
Until now, slightly different models were used by ILC and CLIC communities (some differences in: production cross section, inv. mass cut-off, software tools/version).

- A systematic study was done => agree on a common method
- Results on characteristics of the γγ=>hadron background

γγ=>hadron background (1)

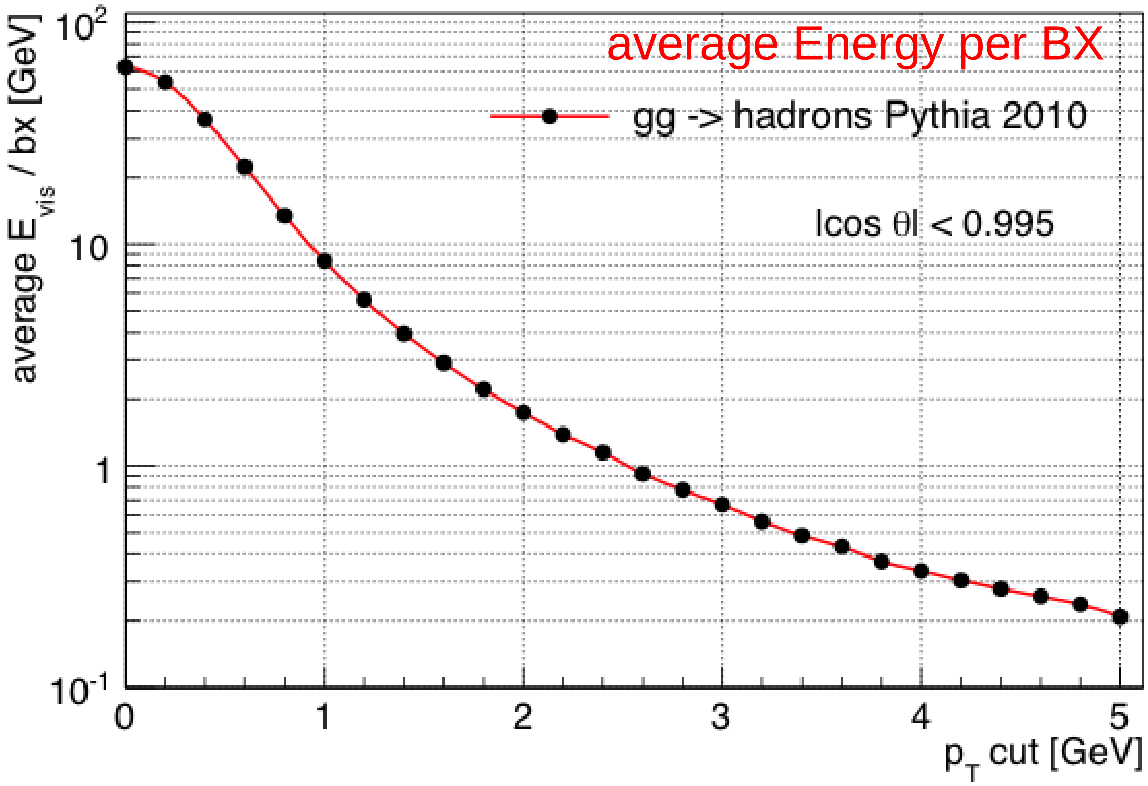


average Energy per BX



The γγ=>hadron background is forward-peaked

γγ=>hadron background (2)



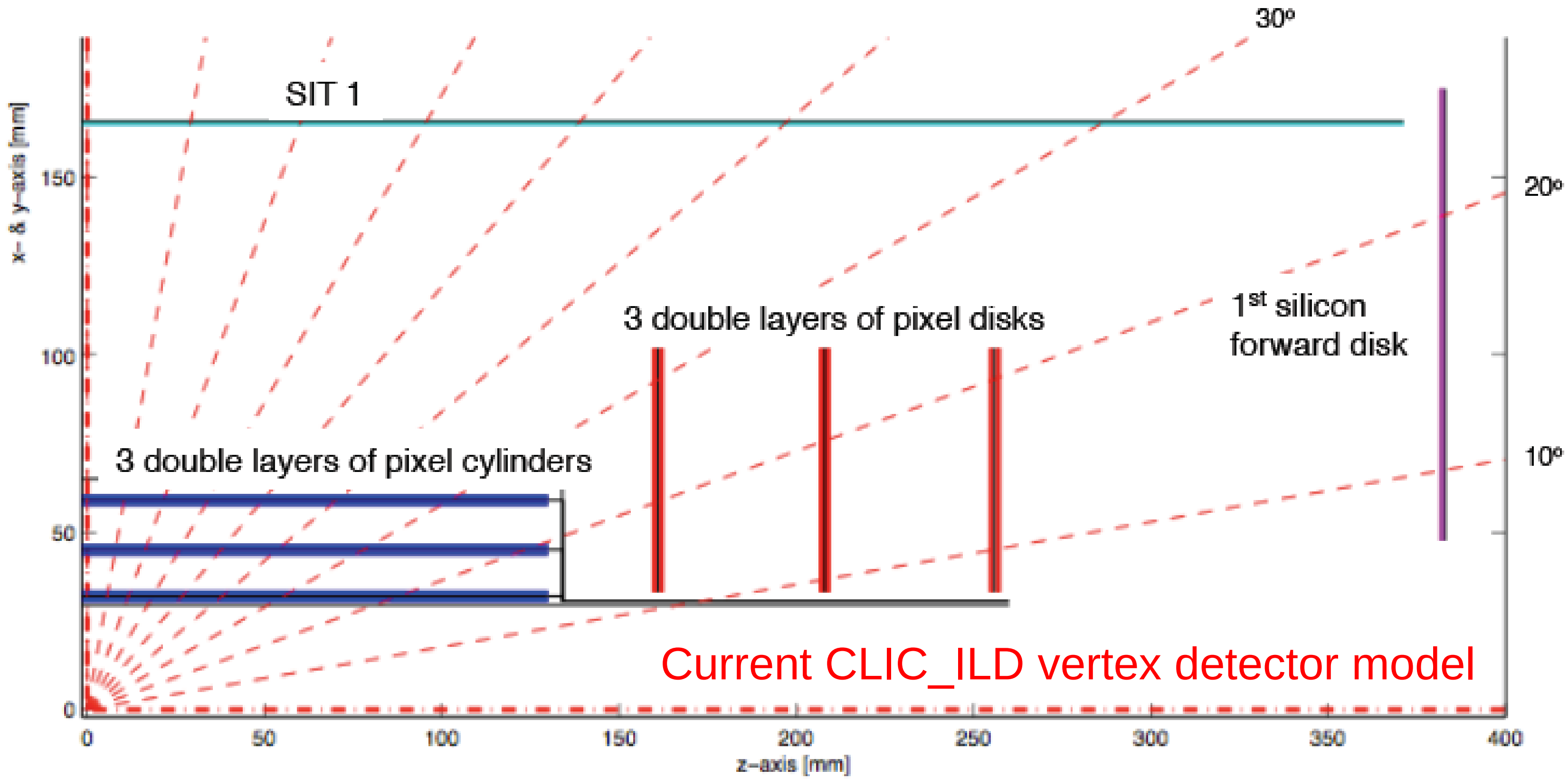
Per bunch crossing:

- 3.3 such events
- ~28 particles into the detector
- 50 GeV
- Forward-peaked

15 TeV dumped in the detector per 156 ns bunch train !

we need time-stamping and optimal selection methods

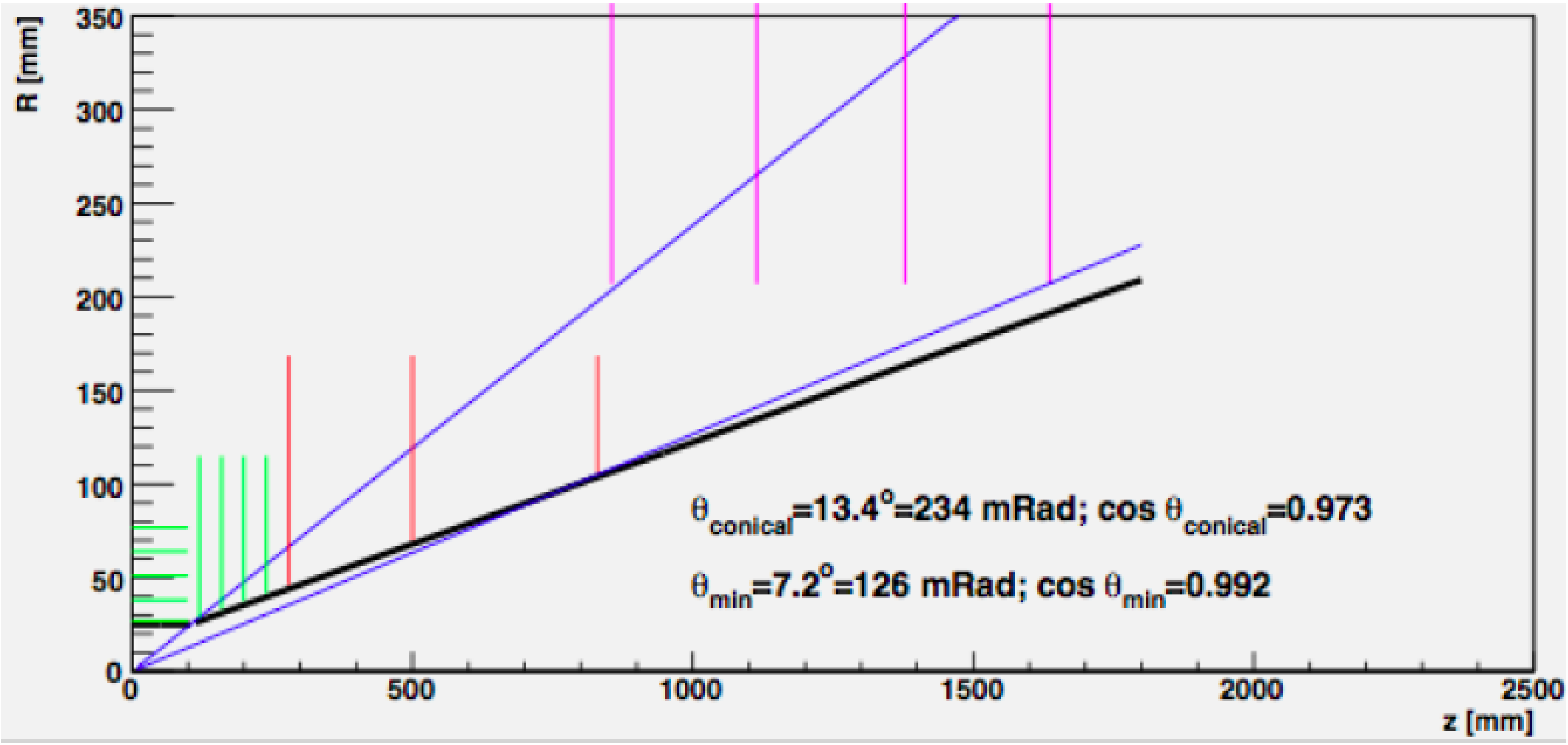
CLIC vertex detector (1)



Stand-alone Monte Marlo models and some full simulation studies have been carried out.

A detector layout is proposed: compatible with required precision, background conditions, flavour tagging capabilities, tracking coverage

CLIC vertex detector (2)



Current CLIC_SiD vertex detector model

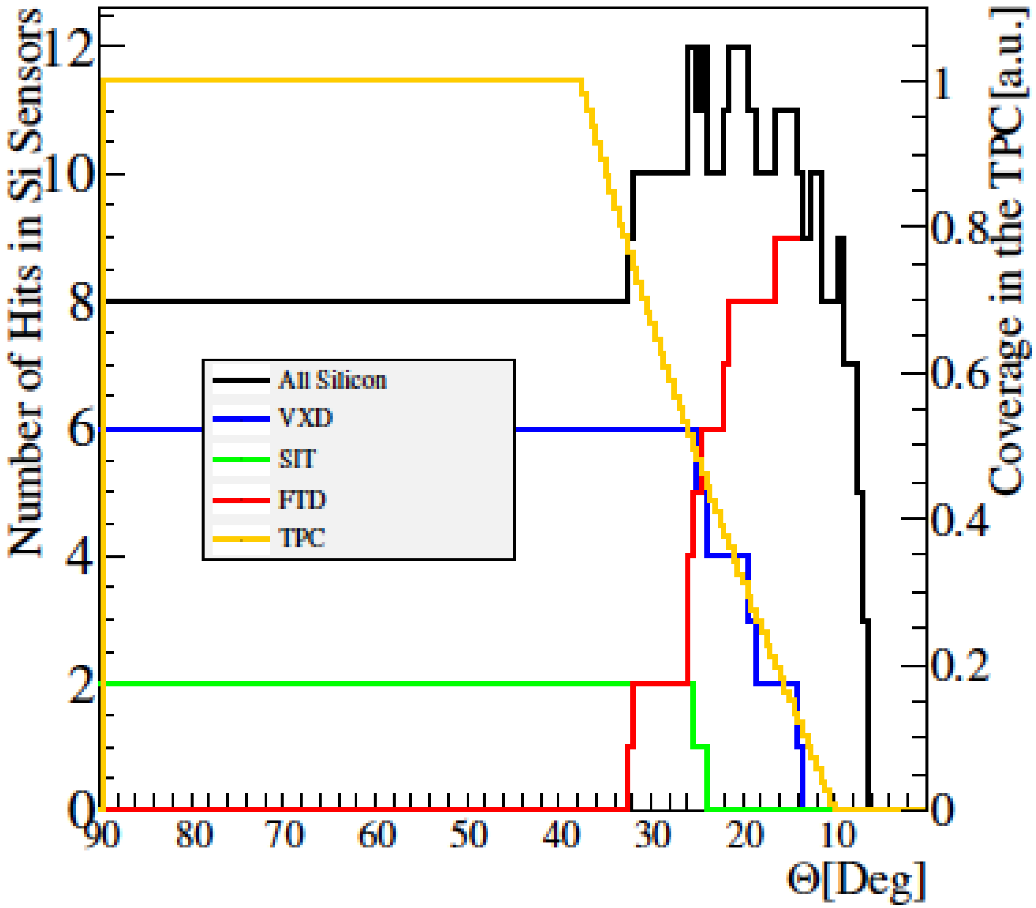
CLIC vertex detector (3)

Requirements for the vertex detector need to be determined more precisely. Global needs:

- Single-layer position resolution ~3μm – 5 μm
  - Typically achieved with 20*20 micron pixels
- Single-layer material thickness 0.1%X_0 – 0.2%X_0
- Time-stamping ~5-10 ns (?)
  - Still needs more study with full simulation
- Occupancy
  - Will be at the ~10% level for the innermost layer
  - Therefore we need multi-hit capability
- Triggerless readout over the 156 ns bunch-train
  - With full data readout in less than 200-400 μsec to allow power-pulsing

Very challenging hardware project

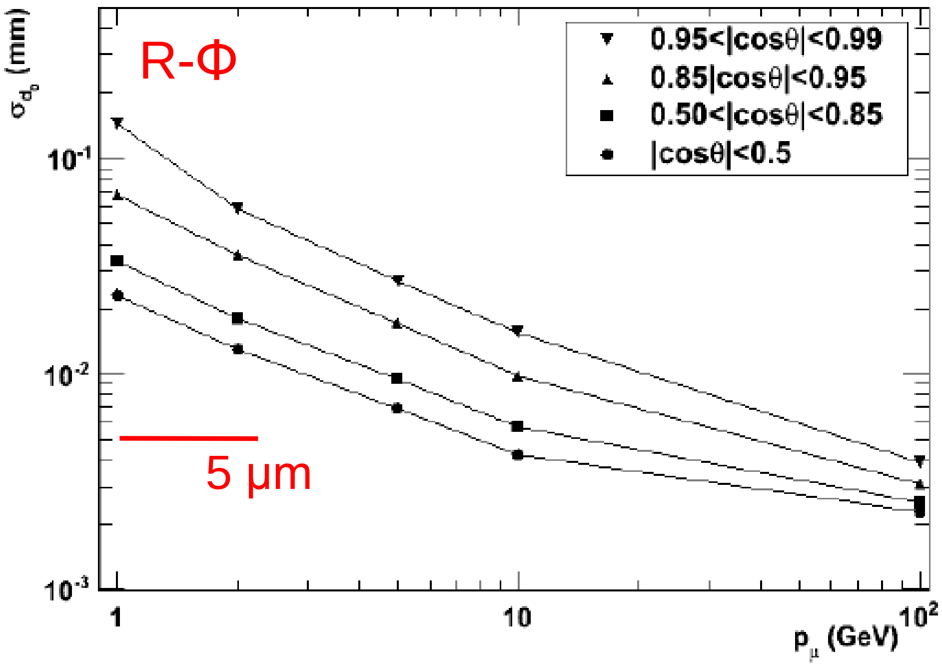
CLIC_ILD tracking coverage

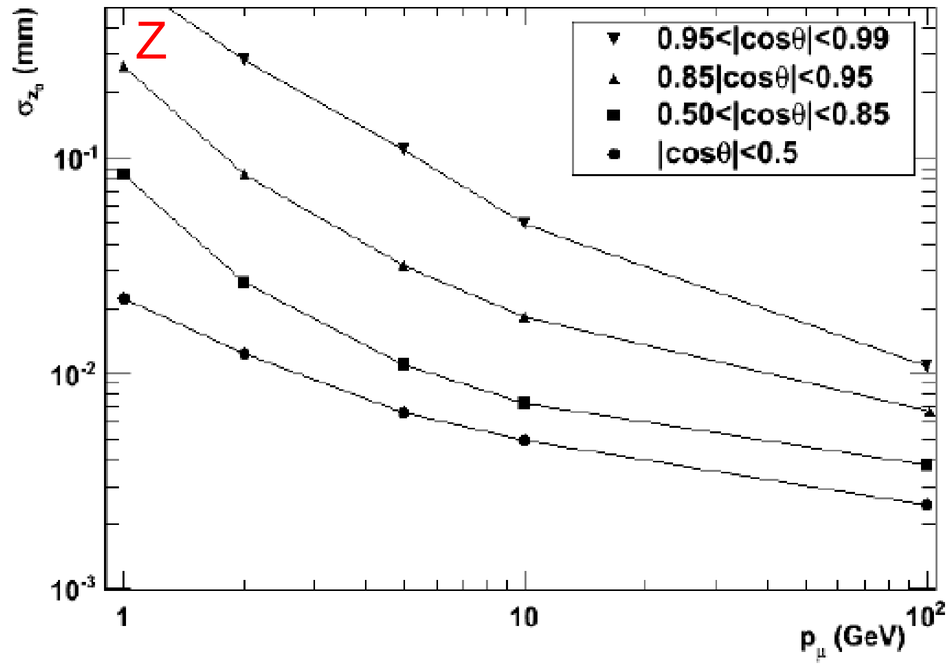


A. Sailer, CERN+Berlin

CLIC_ILD impact parameter

Impact parameter resolution for single muons





M. Battaglia, UCSC+CERN

Calorimetry and particle flow

Tungsten-based HCAL motivation:

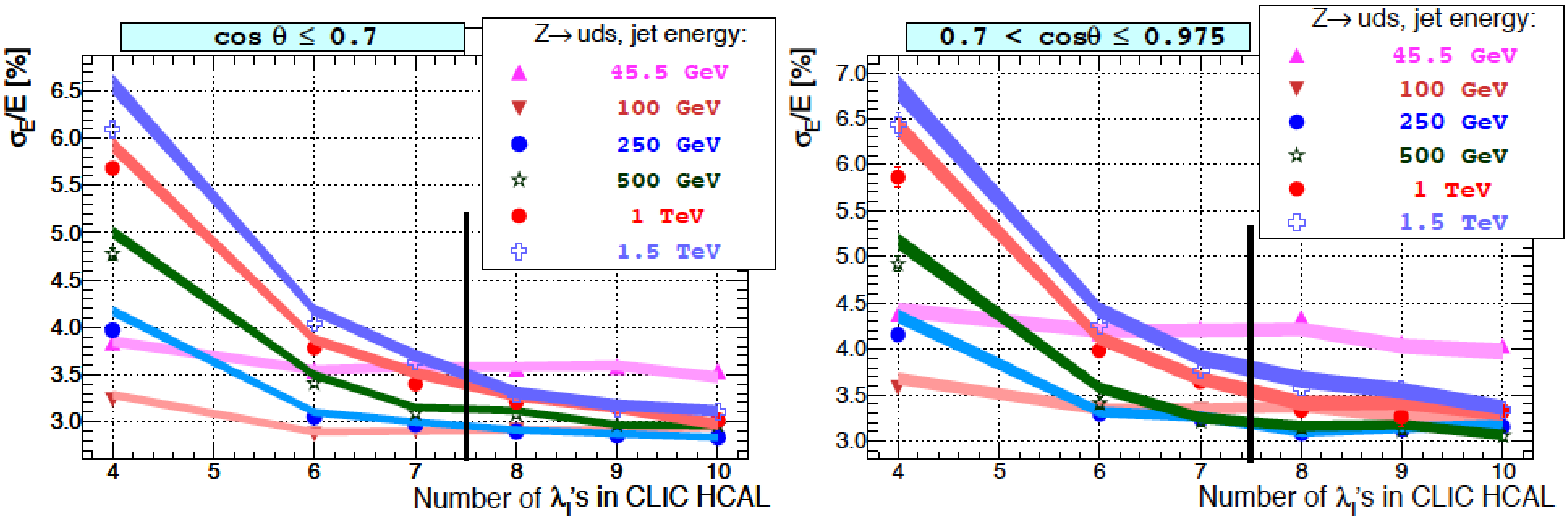
- To limit longitudinal leakage CLIC HCAL needs to be rather deep
- A deep HCAL pushes the coil/yoke to larger radius (would give a significant increase in cost and risk for the coil/yoke)
- A tungsten HCAL (CLIC option) is more compact than Fe-based HCAL, (ILC option) while Geant4 performance (resolution) is similar
- Increased cost of tungsten barrel HCAL compensates gain in coil cost

Particle-flow calorimetry for CLIC:

- ILC calorimeters are based on particle flow
- At high energies, jets become more dense => a-priori not clear whether PFA provides adequate resolution at CLIC
- New, more flexible, version of Pandora PFA code was written (Cambridge Univ.)
- Can be used for CLIC_ILD and CLIC_SiD detector simulations

HCAL depth studies, Pandora PFA

- Studies done with $Z \rightarrow uds$ events, based on a modified CLIC01_ILD model
- Jobs submitted to the GRID, via DIRAC
- Markers: with Tail Catcher
- Bands: WITHOUT Tail Catcher



- Small influence of the Tail Catcher
- Final decision on HCAL depth: 7.5 λ_I

A. Lucaci-Timoce, CERN

Tungsten-based HCAL and R&D

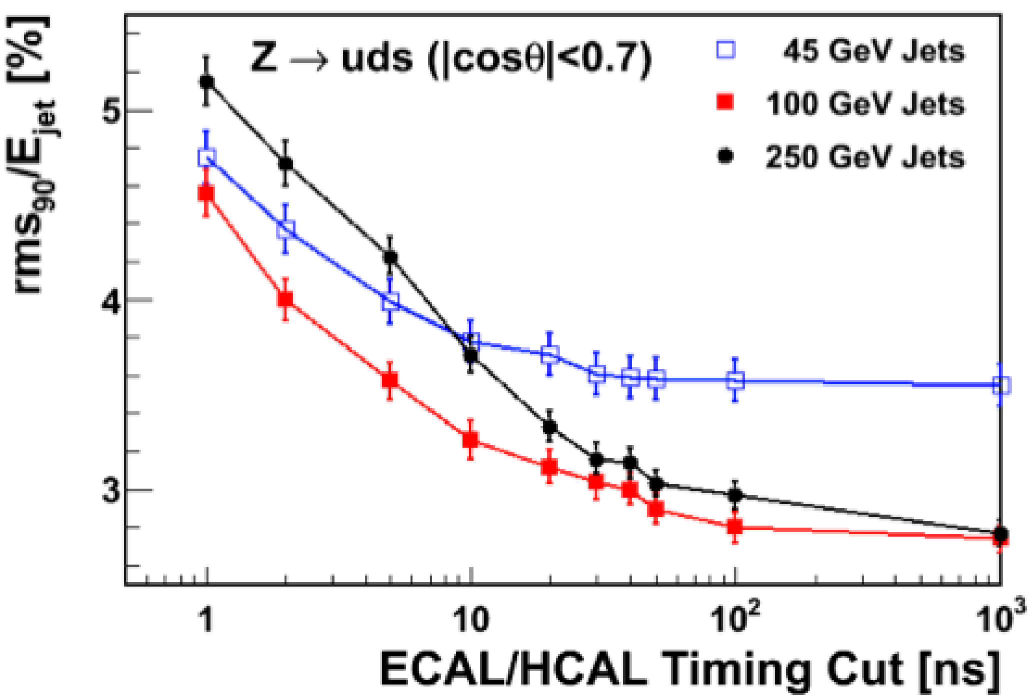
CLIC CDR HCAL depth is 7.5Λ_i. Absorber choices:

- 10 mm tungsten platen in the barrel (70 layers)
- 20 mm steel plates in the end-cap (60 layers)

The hadronic shower development in tungsten is slower than in steel, because the shower in tungsten has an important slow-neutron component.

This needs to be understood well, because we also need precise time-stamping to distinguish physics from background

=> Test beam prototype !



M. Thomson, Cambridge

Tungsten HCAL prototype

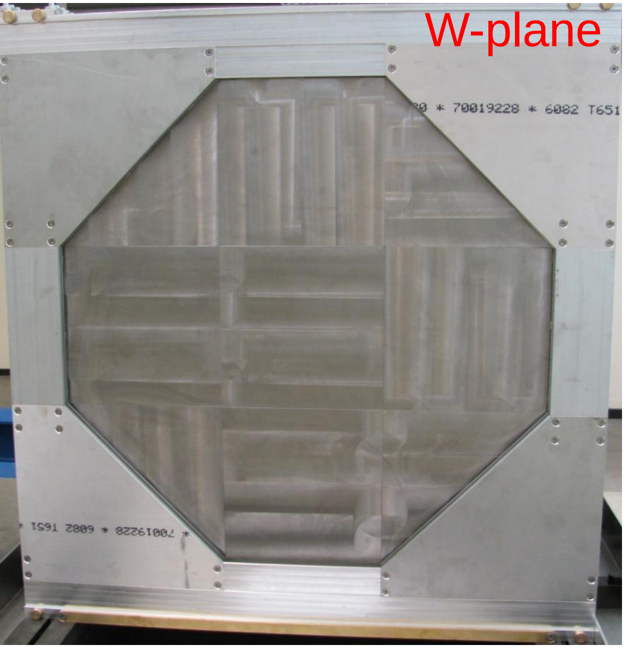
Check Geant4 simulation in test beam

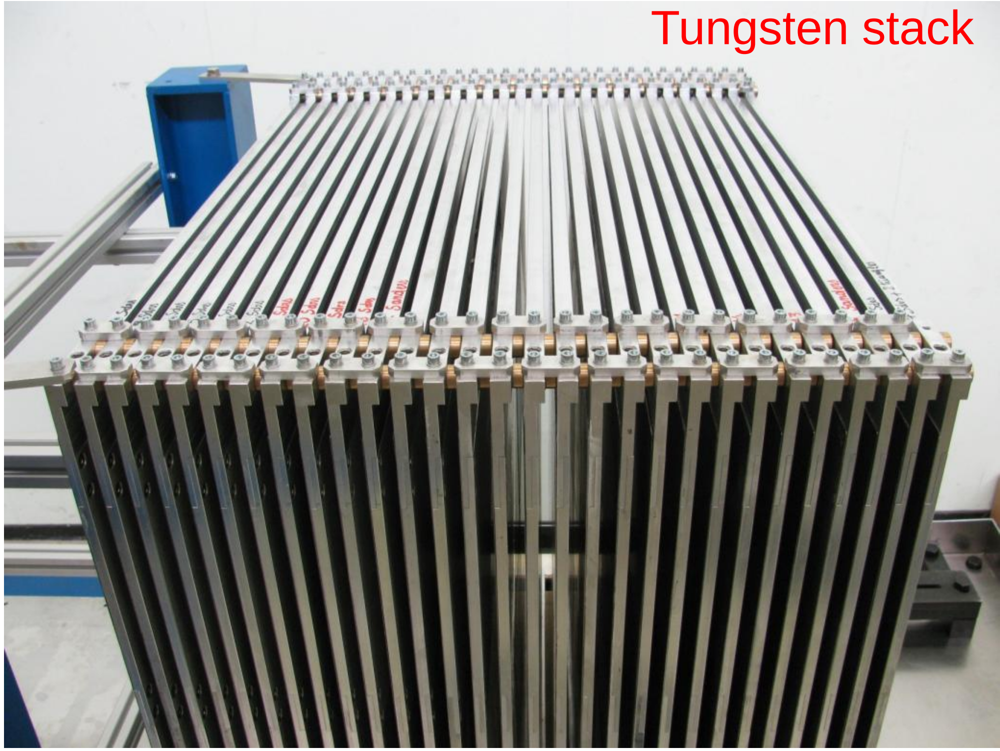
Prototype tests performed within CALICE collab.

Use 30-40 layers of Tungsten, 1 cm thick, 80 cm Ø

Use different active materials

Start in Nov 2010, with 30 W plates, and scintillator planes





Pandora PFA and particle ID

Smuon (di-muon) events at 3 TeV

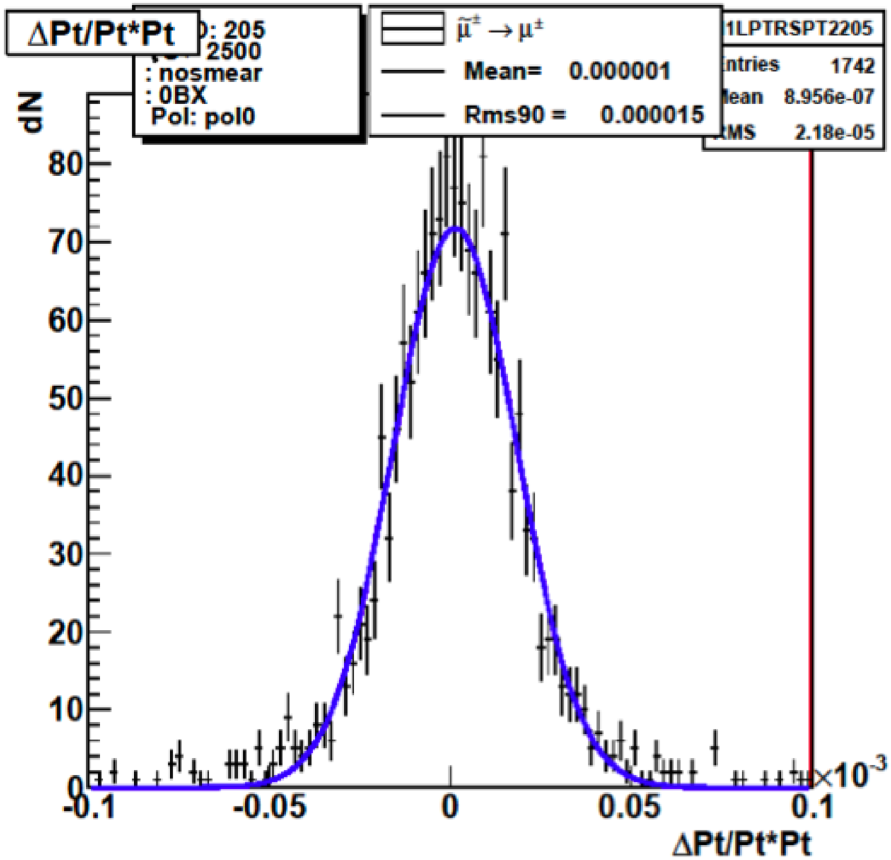
1000 events analyzed:

2 muons: 90%

1muon and 1 (e/pion):8%

no muon (2%)

$\sigma Pt/Pt*Pt \sim 1.5\ 10^{-5}$



JJ.Blaising, Annecy

Muon measurements

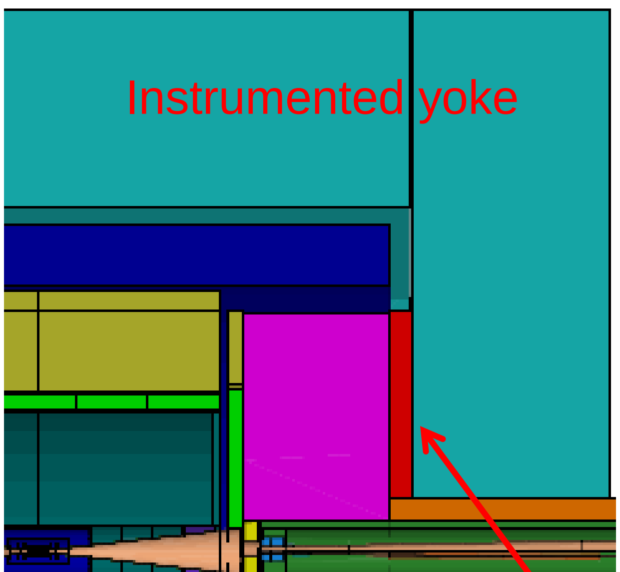
Working towards an optimised yoke system and muon ID

•Taking engineering and magnetic field contraints into account

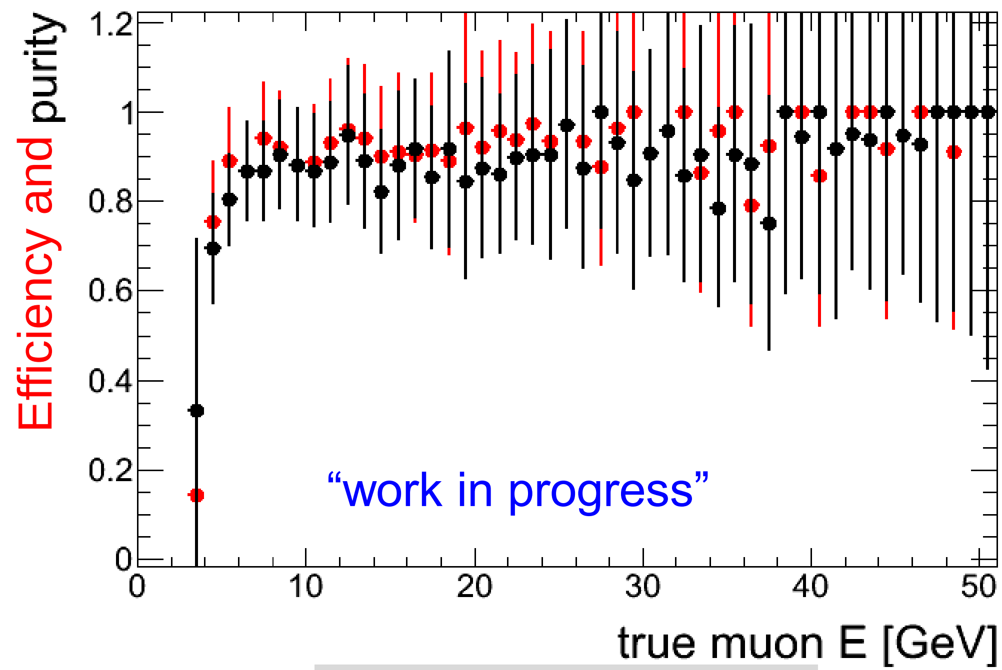
•Tail catcher function

•Muon ID, integrated with calorimeter and tracker => linked to PFA

Currently considering: 3 layers (tail catcher) + 2*3 layers (muon id)



Instrumented yoke plug



E. van der Kraaij, CERN

and also…

In addition: many other activities on…

- CLIC physics potential (kick-off @ IWLC)
- Polarisation working group
- Detector requirement studies, using benchmark processes
- Detector benchmark studies
- Grid development and event generation
- Magnet system
- Cost
- …

.. All activities in direct contact with ILC groups

CLIC detector R&D, overview

CLIC hardware/engineering R&D (needed beyond ILC developments):

- Vertex detector
  - trade-off between pixel size, amount of material and timing resolution
- Hadron calorimetry
  - Tungsten-based HCAL (trade-off between Energy and time resolution)
- Solenoid coil
  - Large high-field solenoid concept, reinforced conductor (CMS/ATLAS experience)
- R&D to support mechanical stability modeling
  - In view of sub-nm precision required for FF quadrupoles (QD0)
- Time stamping
  - Needed for (almost) all subdetectors (typically 5-10 nsec resolution required)
- Power pulsing
  - In view of the 50 Hz CLIC time structure => allows for low-mass detectors

Summary

CLIC detector studies are well under way

Community is growing, in close contact with ILC groups

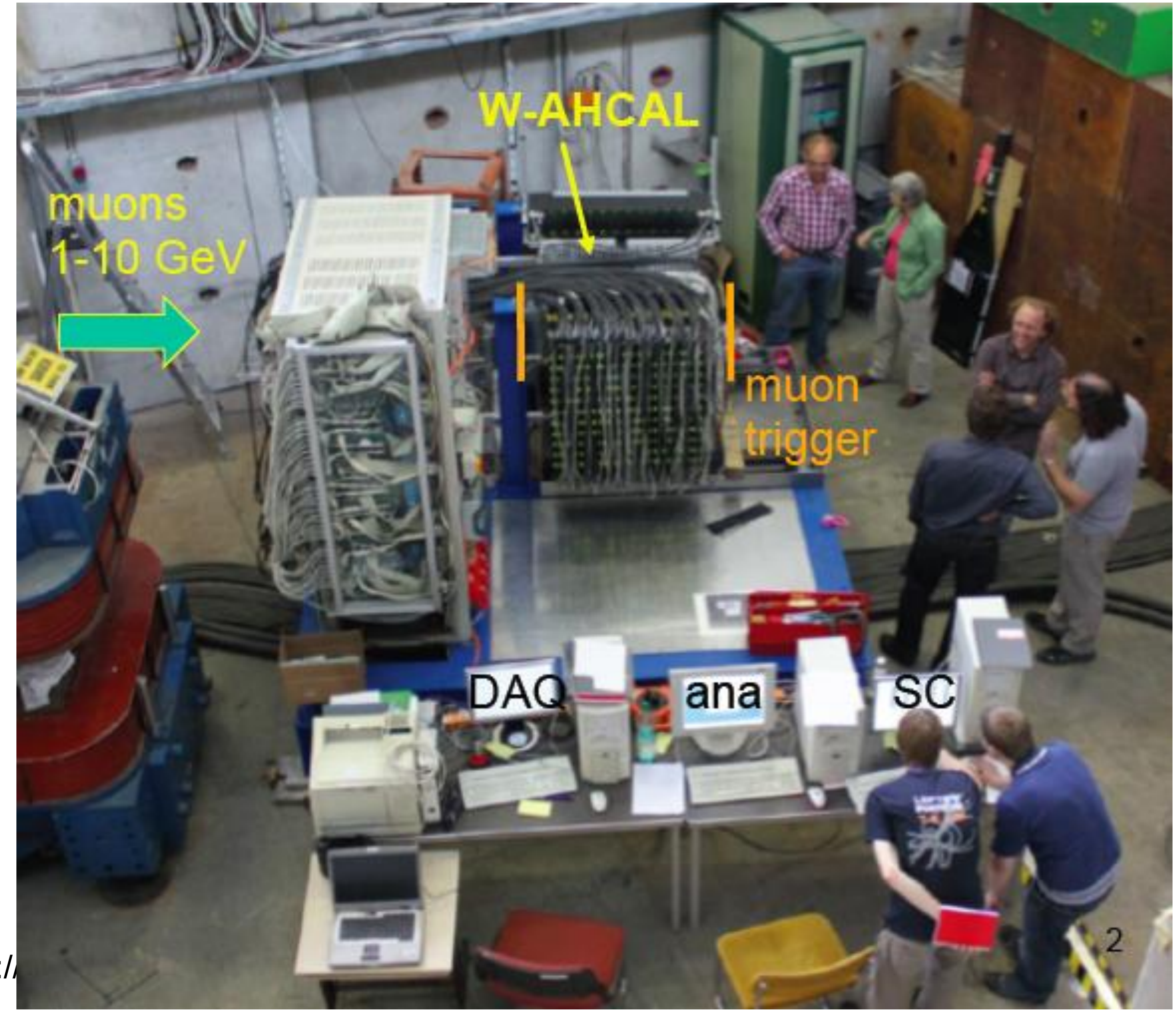
Work currently focuses on CLIC physics/detector CDR (Mid-2011)

- •Detector requirements globally "understood"
- •Detector geometries for CDR simulations are being finalised
- •Software tools for CDR benchmark studies are being finalised (~1 month)
- •Physics benchmark studies for the CDR are starting
- •Hardware R&D has really started

Time schedule for the CDR is tight, but feasible

Welcome to join !

Thank you !



http://

Spare Slides

CLIC parameters

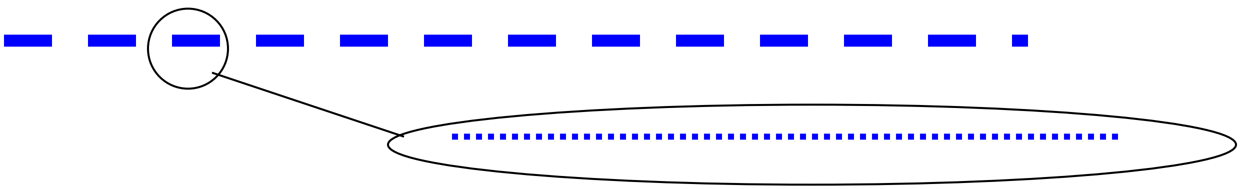
Center-of-mass energy	ILC 500 GeV	CLIC 500 GeV	CLIC 3 TeV
Total (Peak 1%) luminosity [$\cdot 10^{34}$]	2(1.5)	2.3 (1.4)	5.9 (2.0)
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	32	80	100
Main linac RF frequency GHz	1.3	12	
Bunch charge [$\cdot 10^9$]	20	6.8	3.7
Bunch separation (ns)	370	0.5	
Beam pulse duration (ns)	950μs	177	156
Beam power/beam (MWatts)		4.9	14
Hor./vert. IP beam size (nm)	600 / 6	200 / 2.3	40 / 1.0
Hadronic events/crossing at IP	0.12	0.2	2.7
Incoherent pairs at IP	$1 \cdot 10^5$	$1.7 \cdot 10^5$	$3 \cdot 10^5$
BDS length (km)		1.87	2.75
Total site length km	31	13	48
Total power consumption MW	230	130	415

Crossing Angle 20 mrad (ILC 14 mrad)

CLIC and ILC time structure

Train repetition rate 50 Hz

CLIC



CLIC:	1 train = 312 bunches	0.5 ns apart	50 Hz
ILC:	1 train = 2820 bunches	308 ns apart	5 Hz

Vol. 3 CDR editors (1)

	Name	Detector	Region	Country	Institution
CLIC CDR main editors	**Harry Weerts**	SiD	America	USA	Argonne
	Akiya Miyamoto	ILD	Asia	Japan	KEK
	Marcel Stanitzki	CLIC	Europe	UK	RAL
	Lucie Linssen	CLIC	Europe	Switzerland	CERN
CLIC CDR chapter editors					
Chapter 1 Introduction	Main Editors				
Chapter 2 CLIC physics potential	**Gian Giudice**	CLIC	Europe	Switzerland	CERN
	James Wells	CLIC	Europe	Switzerland	CERN
Chapter 3 CLIC experimental conditions and physics performance requirements	**Mark Thomson**	ILD	Europe	UK	Cambridge
	Marco Battaglia	CLIC	America	USA	UCSC
Chapter 4 The CLIC_ILD detector concept	**Graham Wilson**	ILD	America	USA	Kansas
	Frank Simon	CLIC	Europe	Germany	MPI
Chapter 5 The CLIC_SiD detector concept	**Jim Brau**	SiD	America	USA	Oregon U.
	Dieter Schlatter	CLIC	Europe	Switzerland	CERN
Chapter 6 CLIC vertex detectors	**Steve Worm**		Europe	UK	RAL
Chapter 7 Tracking systems	**Jan Timmermans**	ILD	Europe	Netherlands	NIKHEF
	Takeshi Matsuda	ILD	Asia	Japan	KEK
	Marcel Demarteau	SiD	America	USA	Fermilab
	Tim Nelson	SiD	America	USA	SLAC
	Carlos Lacasta		Europe	Spain	IFIC
Chapter 8 Calorimetry	**Felix Sefkow**		Europe	Germany	DESY
	Andy White	SiD	America	USA	UTA
	Tohru Takeshita	ILD	Asia	Japan	Shinsu U.

Vol. 3 CDR editors (2)

Chapter 9 Solenoids and magnet systems	**Andrea Gaddi** **Yasuhiro Makida**	CLIC	Europe Asia	Switzerland Japan	CERN KEK
Chapter 10 Muon systems at CLIC	**Burkhard Schmidt**	CLIC	Europe	Switzerland	CERN
Chapter 11 Very forward calorimeters	**Wolfgang Lohmann** **Halina Abramowicz**		Europe	Germany Israel	DESY Tel Aviv
Chapter 12 Readout electronics and data acquisition					
Chapter 13 Detector integration	**Hubert Gerwig** **Marco Oriunno**	CLIC SiD	Europe America	Switzerland USA	CERN SLAC
Chapter 14 Physics Performance	**Jan Strube** **Jean-Jacques Blaising** **Frederic Teubert**	SiD CLIC CLIC	Europe Europe Europe	UK France Switzerland	RAL LAPP CERN
Chapter 15 Future plans and R&D prospects	Main Editors				
Chapter 16 Detector costs	**Markus Nordberg** **Marty Breidenbach** **Catherine Clerc**	CLIC SiD ILD	Europe America Europe	Switzerland USA France	CERN SLAC LLR
Chapter 17 Conclusion	Main Editors				

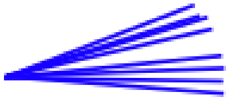
SiD	8
ILD	7
CLIC	13

Europe	20
Asia	4
America	9

❷ The Particle Flow Paradigm

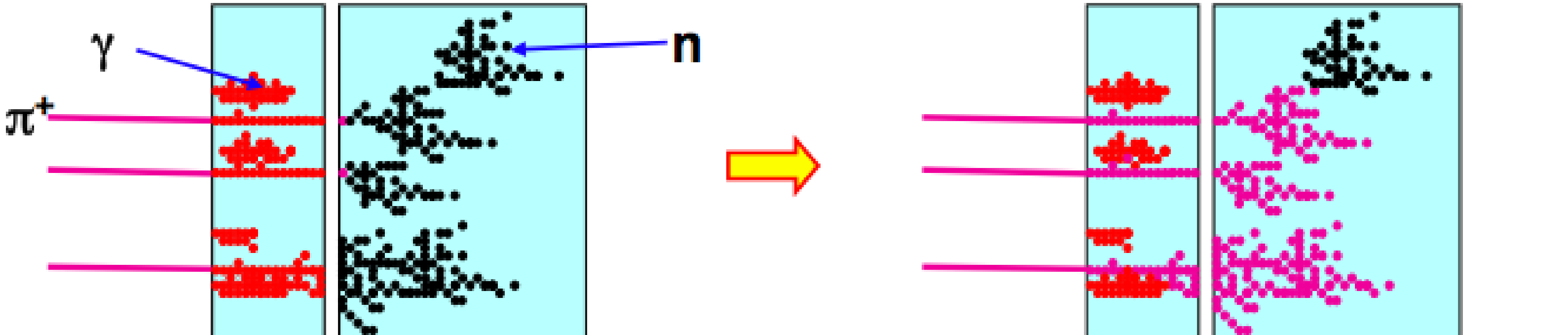
★ **In a typical jet :**

- **60 % of jet energy in charged hadrons**
- **30 % in photons (mainly from $\pi^0 \rightarrow \gamma\gamma$)**
- **10 % in neutral hadrons (mainly n and K_L)**



★ **Traditional calorimetric approach:**

- **Measure all components of jet energy in ECAL/HCAL !**
- **~70 % of energy measured in HCAL: $\sigma_E/E \approx 60\,\%/\sqrt{E(GeV)}$**
- **Intrinsically "poor" HCAL resolution limits jet energy resolution**



$E_{JET} = E_{ECAL} + E_{HCAL}$

$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

★ **Particle Flow Calorimetry paradigm:**

- **charged particles measured in tracker (essentially perfectly)**
- **Photons in ECAL: $\sigma_E/E < 20\,\%/\sqrt{E(GeV)}$**
- **Neutral hadrons (ONLY) in HCAL**
- **Only 10 % of jet energy from HCAL ⇨ much improved resolution**

Mark Thomson

LINKS

and

MAILING LISTS

Links

LCD project web page:

http://lcd.web.cern.ch/LCD/

LCD internal notes:

http://lcd.web.cern.ch/LCD/Documents/Documents.html

Wiki page with various documentation:

https://twiki.cern.ch/twiki//bin/view/CLIC/Detector

For example, in the wiki page you can find the SiD' and ILD' modified detector geometries for CLIC, and the software documentation

LCD indico pages:

http://indico.cern.ch/categoryDisplay.py?categId=1954

How to join our mailing lists

For a list/description of our working groups, see our indico page:
http://indico.cern.ch/categoryDisplay.py?categId=1954

If you want to join one or several of our working groups you can subscribe to the respective mailing lists, by following the e-groups link:
https://groups.cern.ch/Pages/GroupSearch.aspx?k=lcd-wg

In case you encounter any problems, please contact:
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