CALICE and CLIC detector study

Outline:

- Introduction to CLIC accelerator, and CLIC physics
- Detector requirements, comparison between ILC and CLIC
- Current activities and R&D plan
- Timeline and links with CALICE
- Summary

Lucie Linssen and Wolfgang Klempt

CALICE collaboration meeting, March 11th 2010

General LCD Context

- The LHC will determine the future of high-energy physics. The linear collider is one of the best options to complement and extend the LHC programme

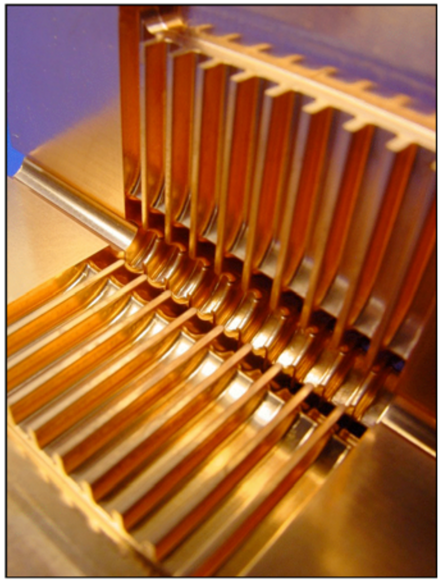
- New physics expected in TeV energy range
  - E.g. motivated by particle astrophysics (dark matter)
  - Higgs, Supersymmetry, extra dimensions, …?

- LHC will indicate what physics, and at which energy scale:
  - Is 500 GeV enough (ILC)
  - Is there a need for multi TeV? (CLIC)

- The CERN “Linear Collider Detector” project addresses both ILC and CLIC, though current focus is on the preparation of the CLIC physics/detector CDR, due for April 2011

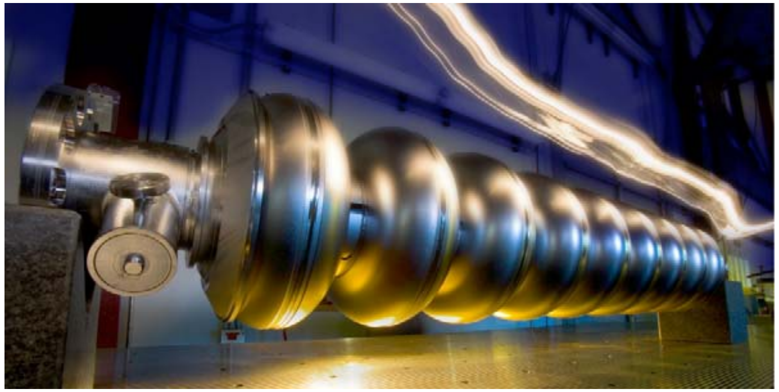
ILC and CLIC in a few words…

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} $cm^{-2}s^{-1}$

The CLIC Two Beam Scheme

Two Beam Scheme:

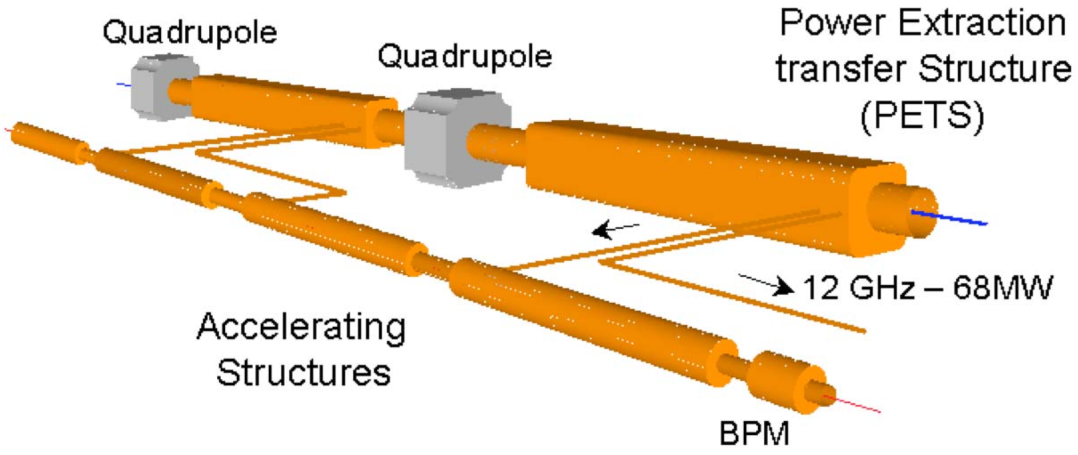
Drive Beam supplies RF power

- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

Main beam for physics

- high energy (9 GeV – 1.5 TeV)
- current 1.2 A

Drive beam – 100 A, 240 ns
from 2.4 GeV to 240 MeV



Main beam – 1.2 A, 156 ns
from 9 GeV to 1.5 TeV

No individual RF power sources

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 physics up to 3 TeV

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

In a nutshell…

Higgs physics:

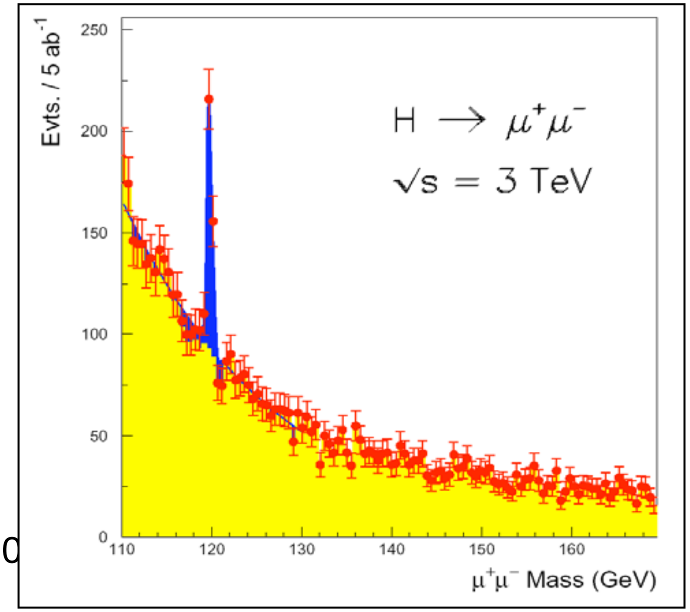
- Complete study of the light standard-model Higgs boson, including rare decay modes (rates factor ~5 higher at 3 TeV than at 500 GeV)
  - Higgs coupling to leptons
  - Study of triple Higgs coupling using double Higgs production
- Study of heavy Higgs bosons (supersymmetry models)

Supersymmetry:

- Extensive reach to measure SUSY particles

And in addition:

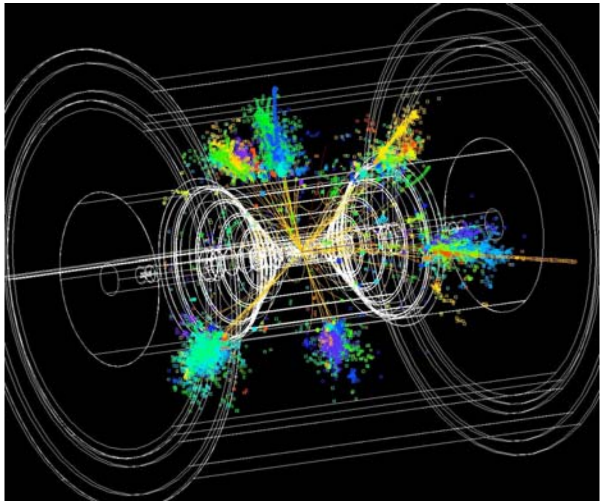
- Probe for theories of extra dimensions
- New heavy gauge bosons (e.g. Z')
- Excited quarks or leptons



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 we have joined several Linear Collider (ILC) collaborations:

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

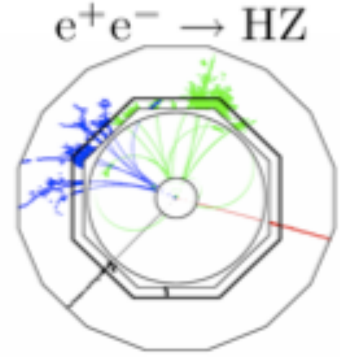
ILC detector requirements, also valid for CLIC case

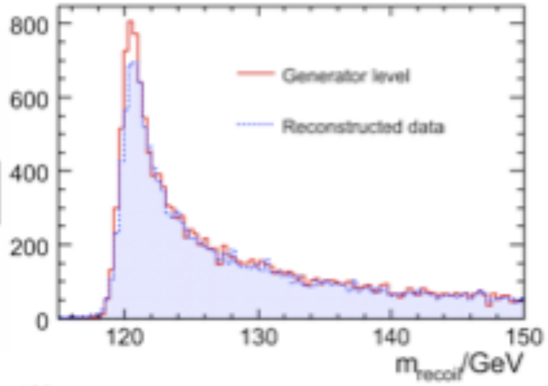
★ **momentum:** (1/10 x LEP)

e.g. Muon momentum

Higgs recoil mass

$$\boxed{\sigma_{1/p} < 5\times10^{-5}\,\mathrm{GeV}^{-1}}$$



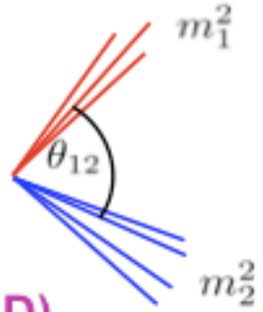


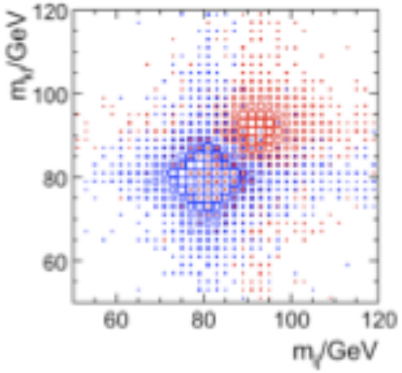
★ **jet energy:** (1/3 x LEP/ZEUS)

e.g. W/Z di-jet mass separation

EWSB signals

$$\boxed{\frac{\sigma_E}{E} \approx 3-4\,\%}$$



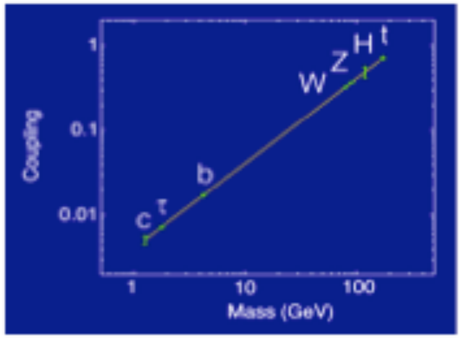


★ **impact parameter:** (1/3 x SLD)

e.g. c/b-tagging

Higgs BR

$$\boxed{\sigma_{r\phi} = 5 \oplus 10/(p\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}}$$



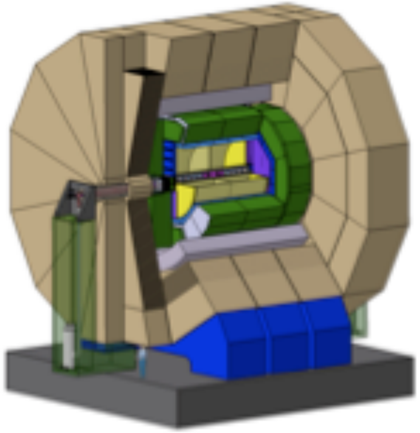
★ **hermetic:** down to θ = 5 mrad

e.g. missing energy signatures in SUSY

Validated ILC concepts

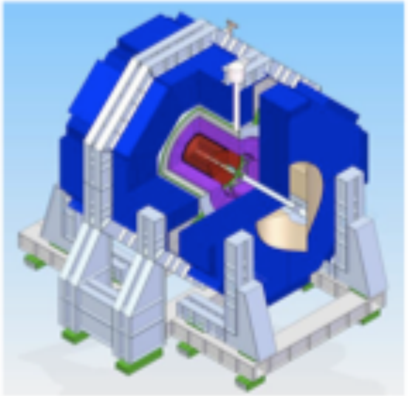
ILD: International Large Detector

"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

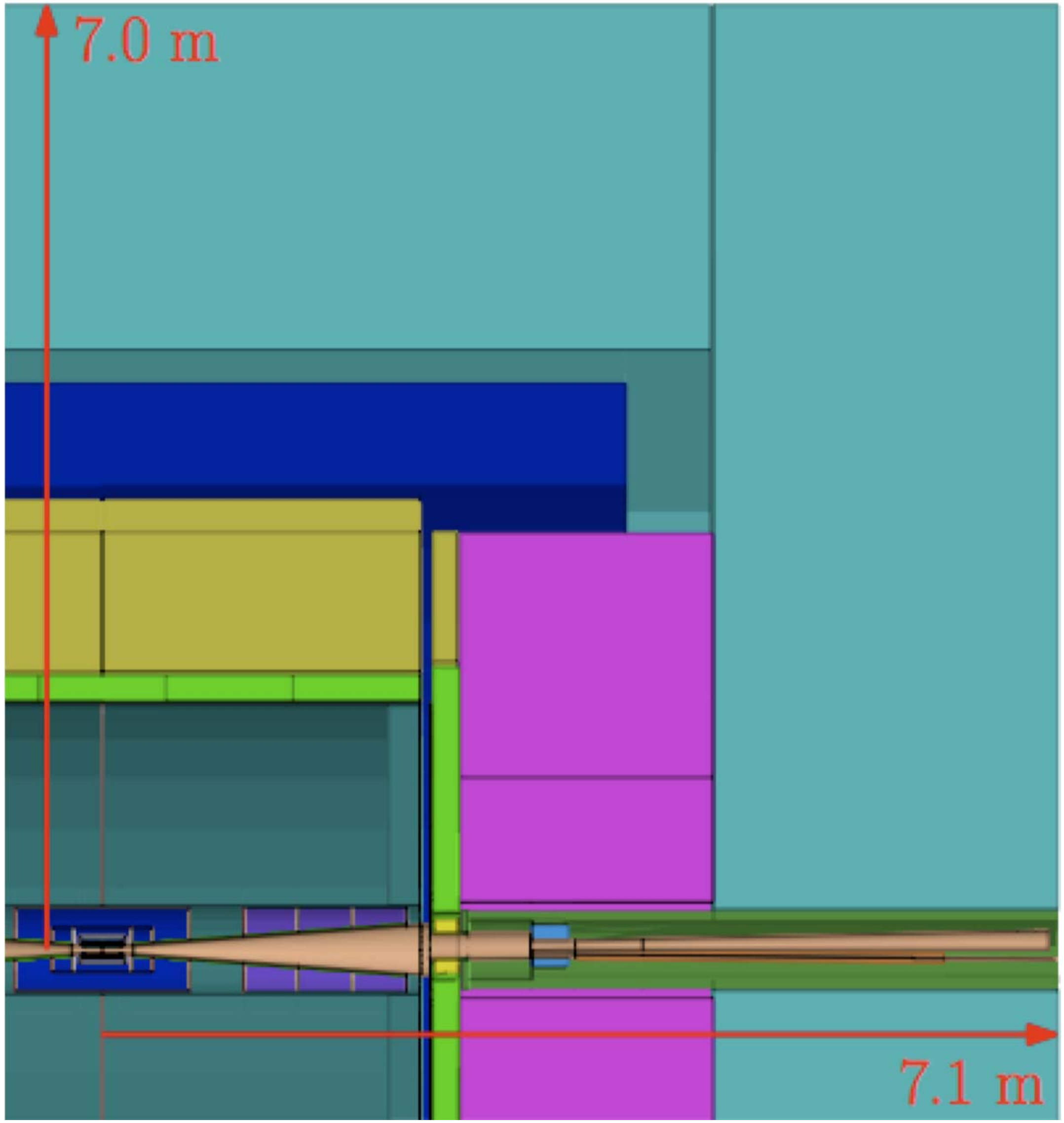


CLIC detector concepts will be based on SiD and ILD.

Modified to meet CLIC requirements

The LCD team at CERN uses SiD and ILD software tools

ILD concept adapted to CLIC



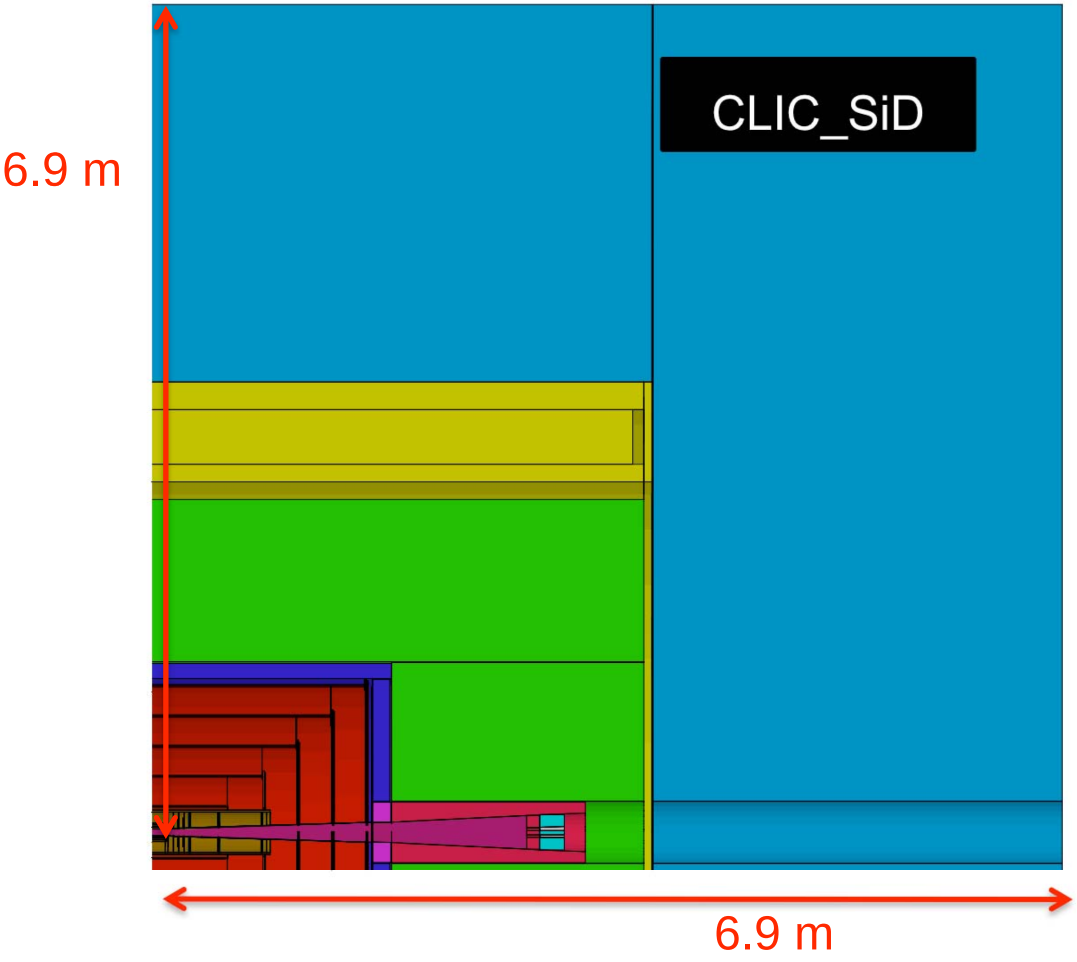
Changes to the ILD detector:

- 20 mrad crossing angle
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- Magnetic field 4 Tesla
- HCAL barrel with 77 layers of 1 cm tungsten
- HCAL endcap with 70 layers of 2 cm steel plates
- Forward (FCAL) region adaptations

Fully implemented in Mokka/ Marlin

Andre Sailer

SiD concept adapted to CLIC



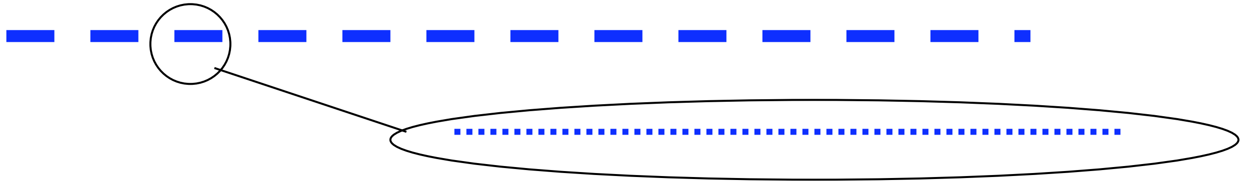
Changes to the SiD detector:

- 20 mrad crossing angle
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- HCAL barrel with 77 layers of 1 cm tungsten
- HCAL endcap with 70 layers of 2 cm steel plates
- Inner bore of cryostat moved to 2.9 m radius
- Forward (FCAL) region adaptations

Fully implemented in SiD SLIC software framework

http://www.cern.ch/lcd L. Linssen and W. Klempt 11/3/2010

CLIC and ILC time structure

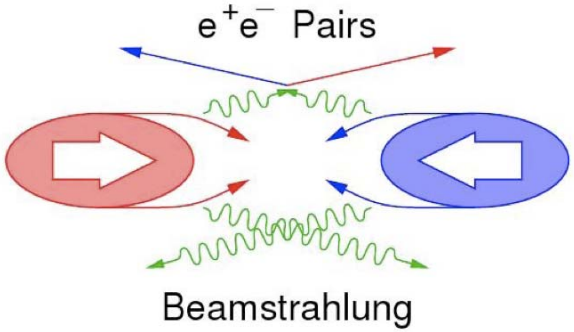


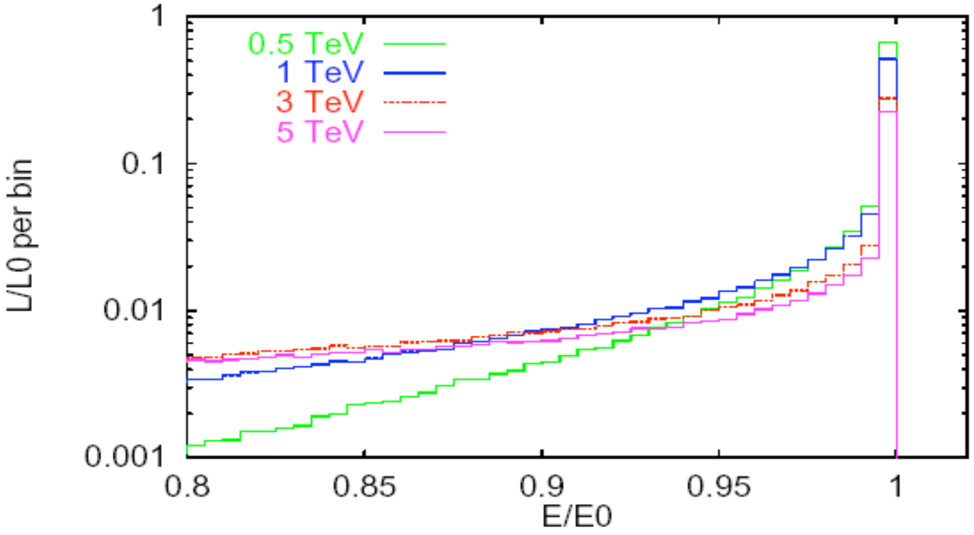
Train repetition rate 50 Hz

CLIC

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

Beam-induced background





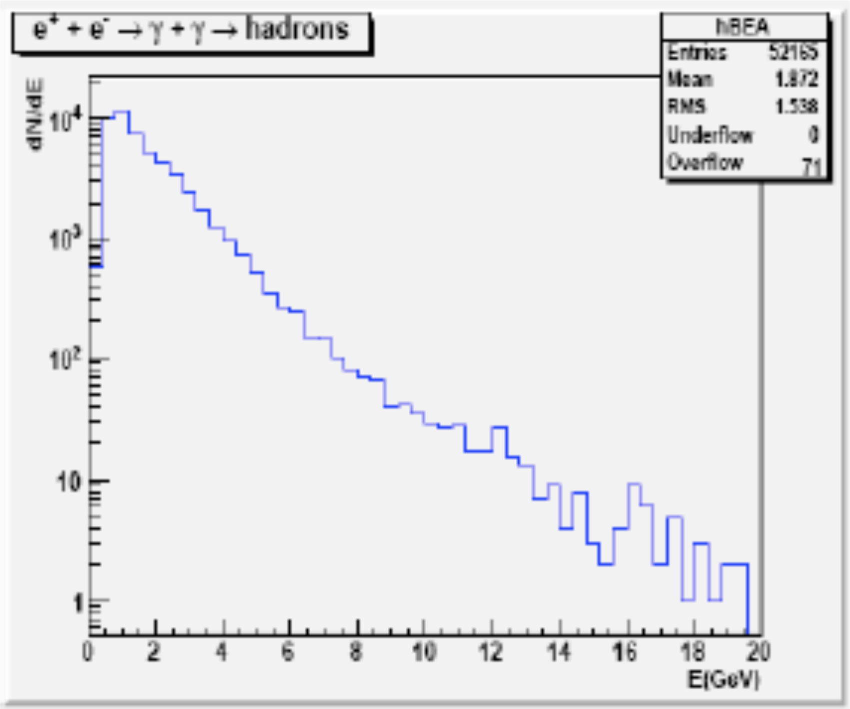
Main backgrounds:

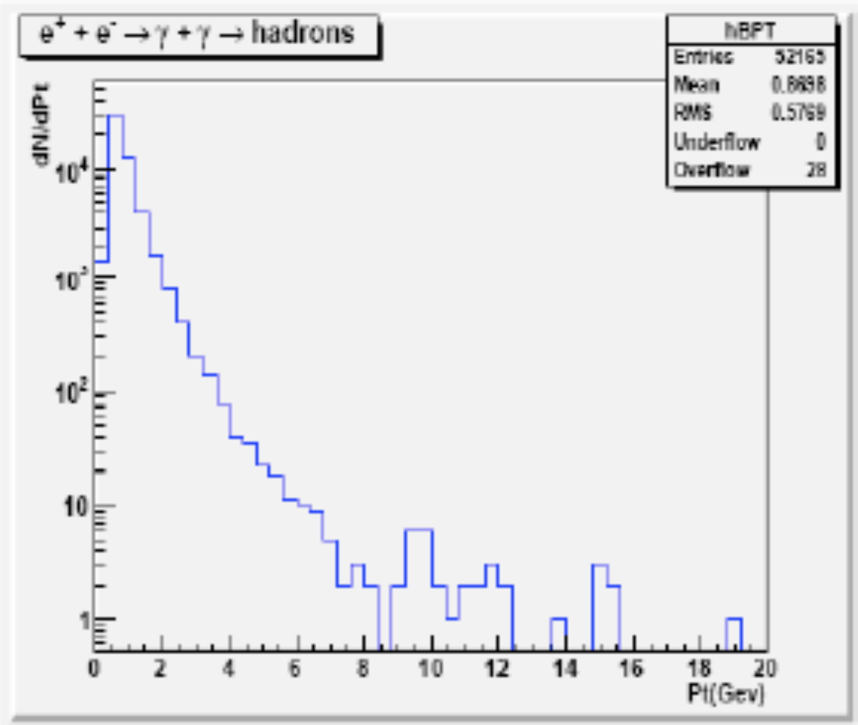
- CLIC 3TeV beamstrahlung ΔE/E = 29% (10×ILC$_{value}$)
  - **Coherent pairs** (3.8×10^8 per bunch crossing) <= disappear in beam pipe
  - **Incoherent pairs** (3.0×10^5 per bunch crossing) <= suppressed by strong solenoid-field
  - γγ interactions => hadrons (**3.3 hadron events per bunch crossing**)

- In addition: Muon background from upstream linac (tbc, up to 10^5 muons/train)

Beam-induced background and time–stamping

At 3 TeV ~ 3.3 $e^+ + e^- \rightarrow \gamma\gamma \rightarrow$ hadrons events / Bx → ~ 13 particles/Bx





<Eh> ~ 1.9 GeV

<Pt> ~ 0.9 GeV.

γγ=> hadron events dump 7.5 TeV in the detector for each bunch train

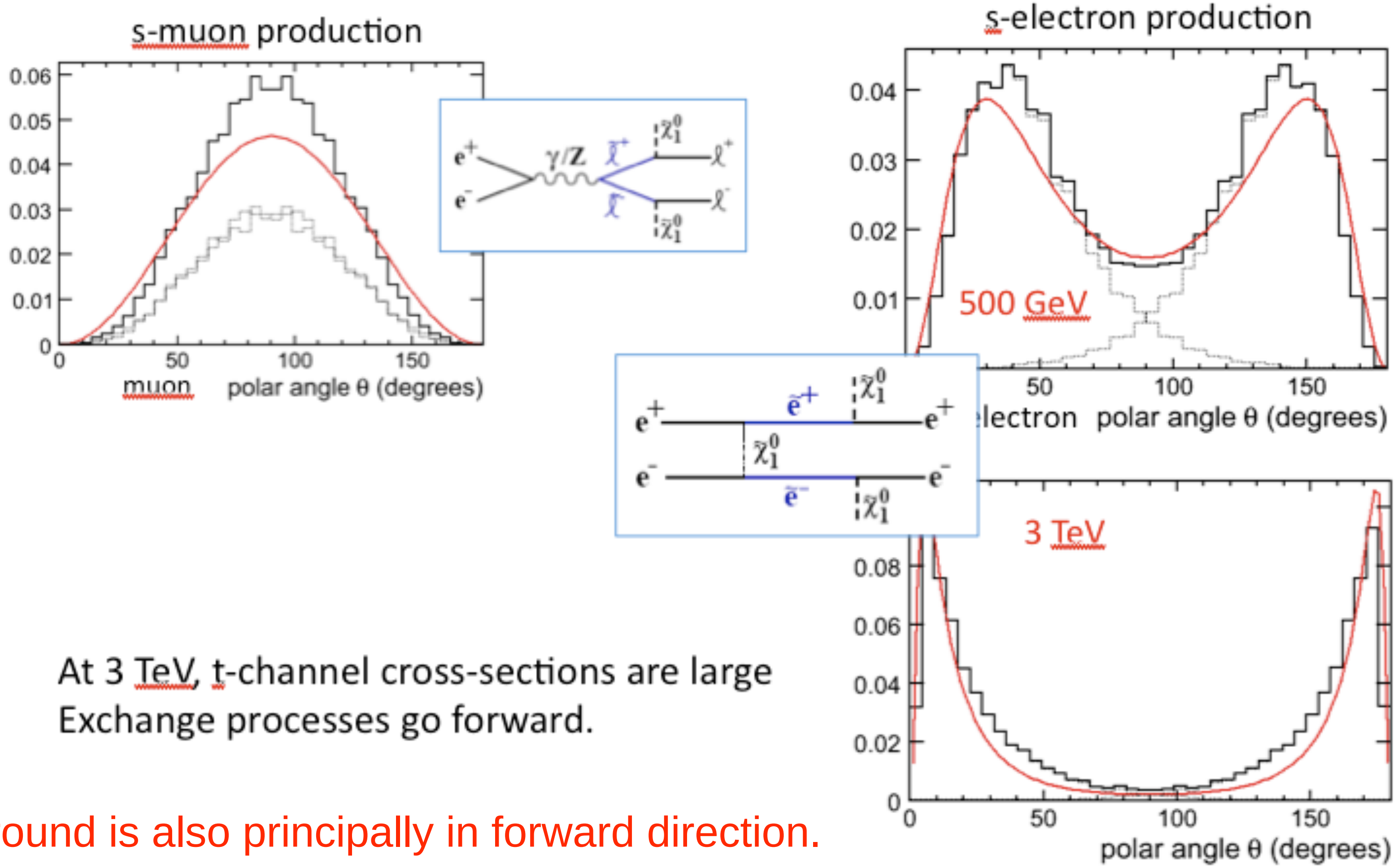
For example: ±10 degrees jet cone and 10 nsec time stamping:

=> 2 GeV in the cone (barrel) and 20 GeV in the cone (end cap)

http://www.cern.ch/lcd L. Linssen and W. Klempt 11/3/2010

At high energy physics goes in forward direction

Example: s-lepton production



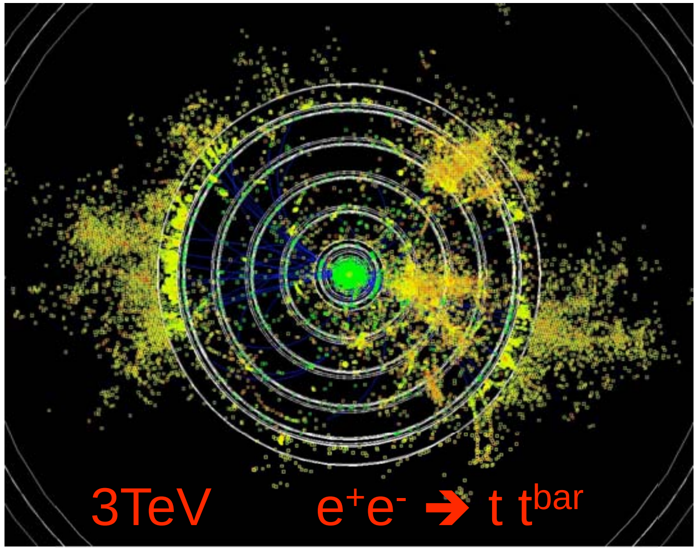
At 3 TeV, t-channel cross-sections are large
Exchange processes go forward.

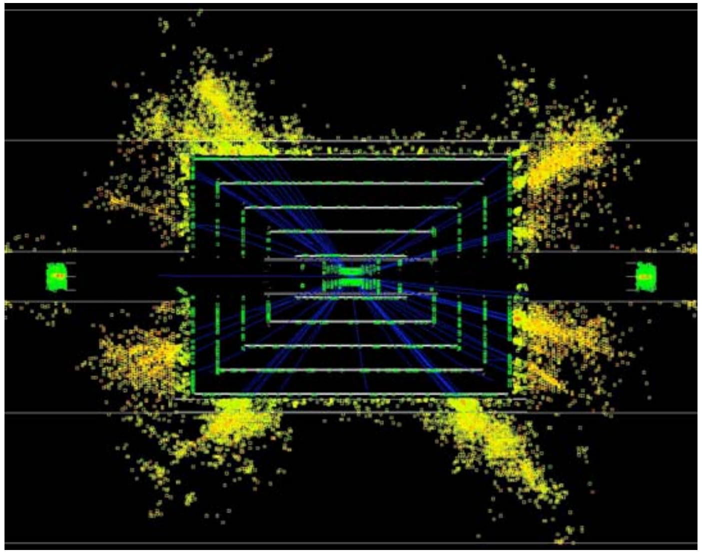
Background is also principally in forward direction.

Detector optimization needs special attention here.

CLIC calorimetry issues

- Due to beam-induced background and short time between bunches:
  - Time-stamping will be needed for (almost) all detectors, typically at the 5 ns level
  - Forward (= end-cap) region needs special attention
- Due to high energy
  - Narrow jets: Will Particle Flow Analysis still work?
  - Calorimeter has to be sufficiently deep (leakage)


3TeV $e^+e^- \rightarrow t\,t^{bar}$



Jet Energy Resolution and PFA

- ★ Is an ILD-sized detector based on PFA suitable for CLIC ?
- ★ Defined modified ILD$^+$ model:
  - B = 4.0 T (ILD = 3.5 T)
  - HCAL = 8 Λ_I (ILD = 6 Λ_I)
- ★ Jet energy resolution

PFA

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ |cosθ|<0.7	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	28.7 %	2.9 %
180 GeV	37.5 %	2.8 %
250 GeV	44.7 %	2.8 %
375 GeV	71.7 %	3.2 %
500 GeV	78.0 %	3.5 %

Mark Thomson
Cambridge

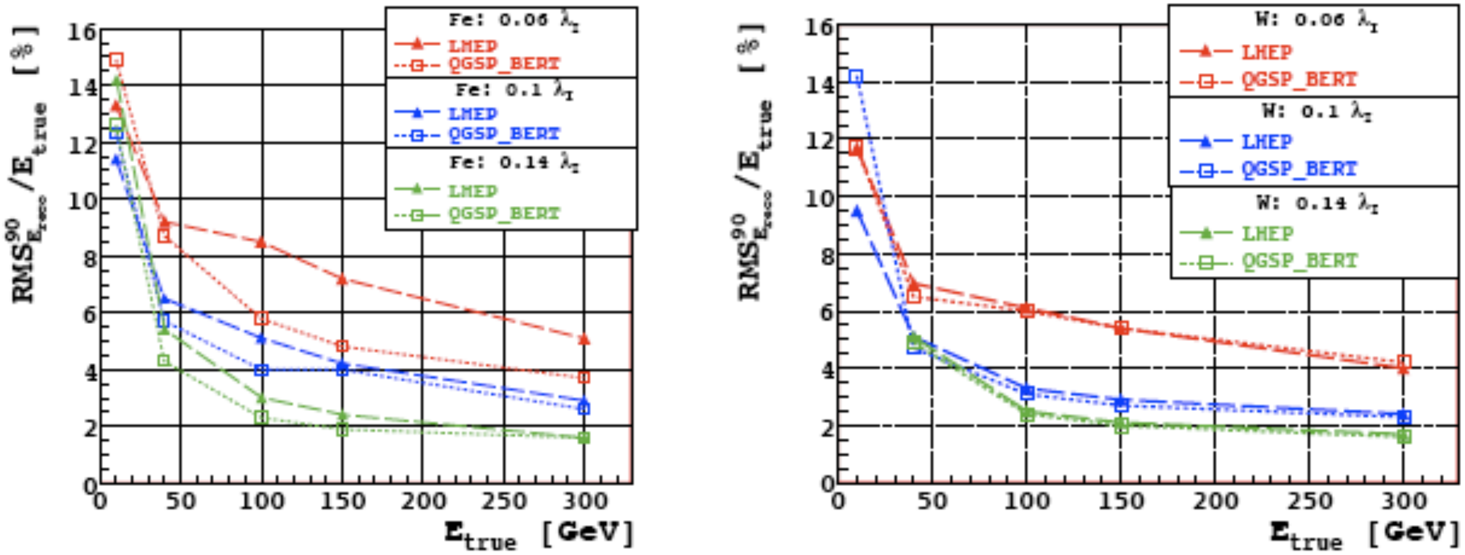
- ★ Meet “LC jet energy resolution goal [~3.5%]” for 500 GeV ! jets

Tungsten HCAL prototype

Motivation:

- To limit longitudinal leakage CLIC HCAL needs ~7Λ_i
- A deeper HCAL pushes the coil/yoke to larger radius (would give a significant cost and risk increase and for the coil/yoke)
- A tungsten HCAL is more compact than Fe-based HCAL, while resolutions are similar (increased cost of tungsten barrel HCAL compensates gain in coil cost)

➔Prototype tungsten HCAL: check simulation in test beam



Fe and W based HCAL resolutions

Angela Lucaci-Timoce DESY)

Current LCD activities

Current activities concentrate on preparation for CDR

- Mostly simulation studies:
  - Demonstrate that CLIC physics potential can be extracted from detector
  - Propose ILD-type and SiD-type detectors that can do the job
- Concentrate on critical issues
  - Determine sub-detector performances required for the physics
  - Work on ways to reduce impact of the background
  - Take engineering aspects, cost etc into account
- Preparing a targeted hardware R&D plan, of which in a CALICE context:
  - Beam-tests of tungsten-based HCAL (see talks high-E session of 12/3)
- Core software developments, of which in a CALICE context:
  - Optimisation of Geant4 hadronisation processes (see talks opening session10/3)
  - Participation in Pandora-PFA development

CLIC and CALICE

- The CLIC physics/detector study team wishes to carry out its activities in the domain of fine-grained (PFA) calorimetry within the CALICE framework.

- **Beam tests of tungsten-based HCAL prototype with CALICE active layers** (scintillator or gas detectors)
  - Starting Autumn 2010 at CERN PS
  - 2011 continue at PS, then SPS
  - 2012 further tests at SPS

- Using **optimised simulation tools**, adapted to high-energy case (e.g. PandoraPFA, description of detector geometries):
  - Deadline to fix tools/geometries for CLIC CDR benchmarking: August 2010

- Participation in CALICE also through **Geant4 hadronisation process**.

- CLIC CDR: deadline April 2011 <= CALICE contribution to ECAL/HCAL sections?
- CLIC TDR: approx. 2015-2016

Summary

CLIC physics/detector studies are carried out in close collaboration with ILC
Growing community both inside and outside CERN.

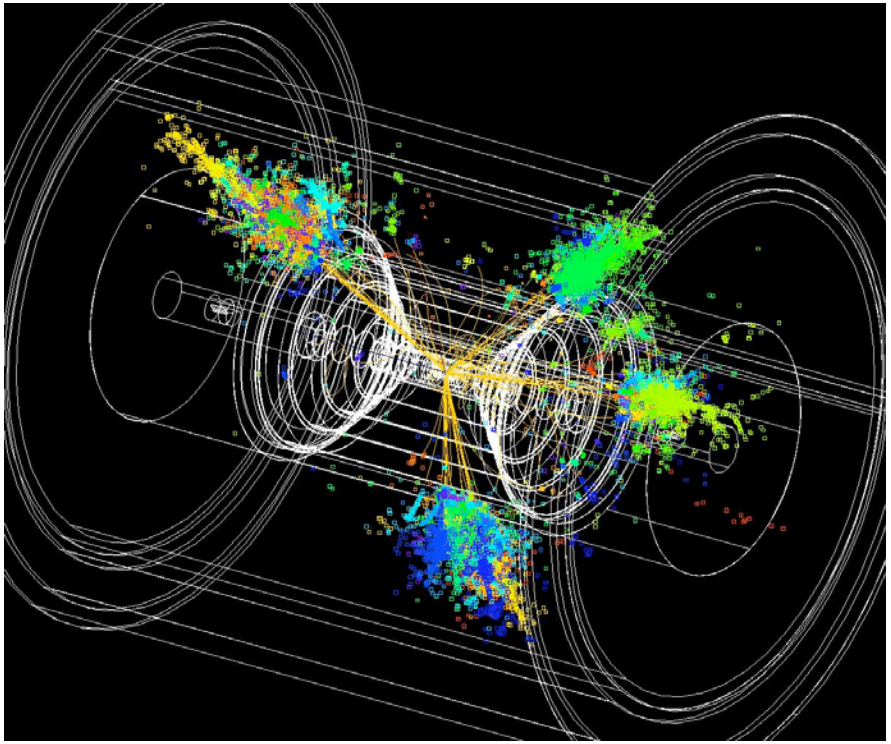
Detector models in place for adapted ILD and SiD concepts.
First assessment of PFA at CLIC energies => encouraging

Work currently focuses on CLIC physics/detector CDR (April 2011)
Plan to freeze CDR detector geometry and CDR software tools by end-August 2010, in time for CDR benchmarking studies.

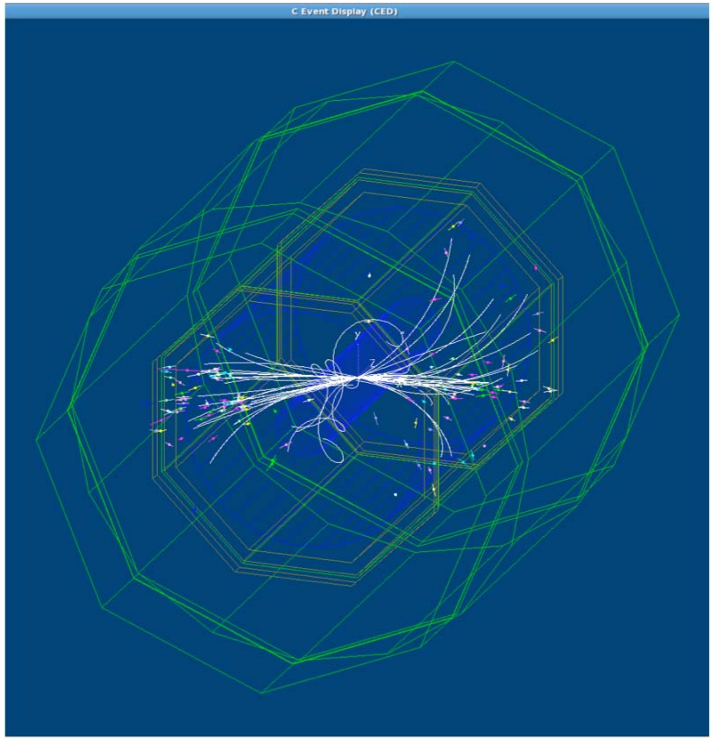
LCD@CERN participation in CALICE: W-HCAL, Geant4, Pandora-PFA

Beam tests of Tungsten-based HCAL, within CALICE framework, will start in autumn 2009.

Thank you!



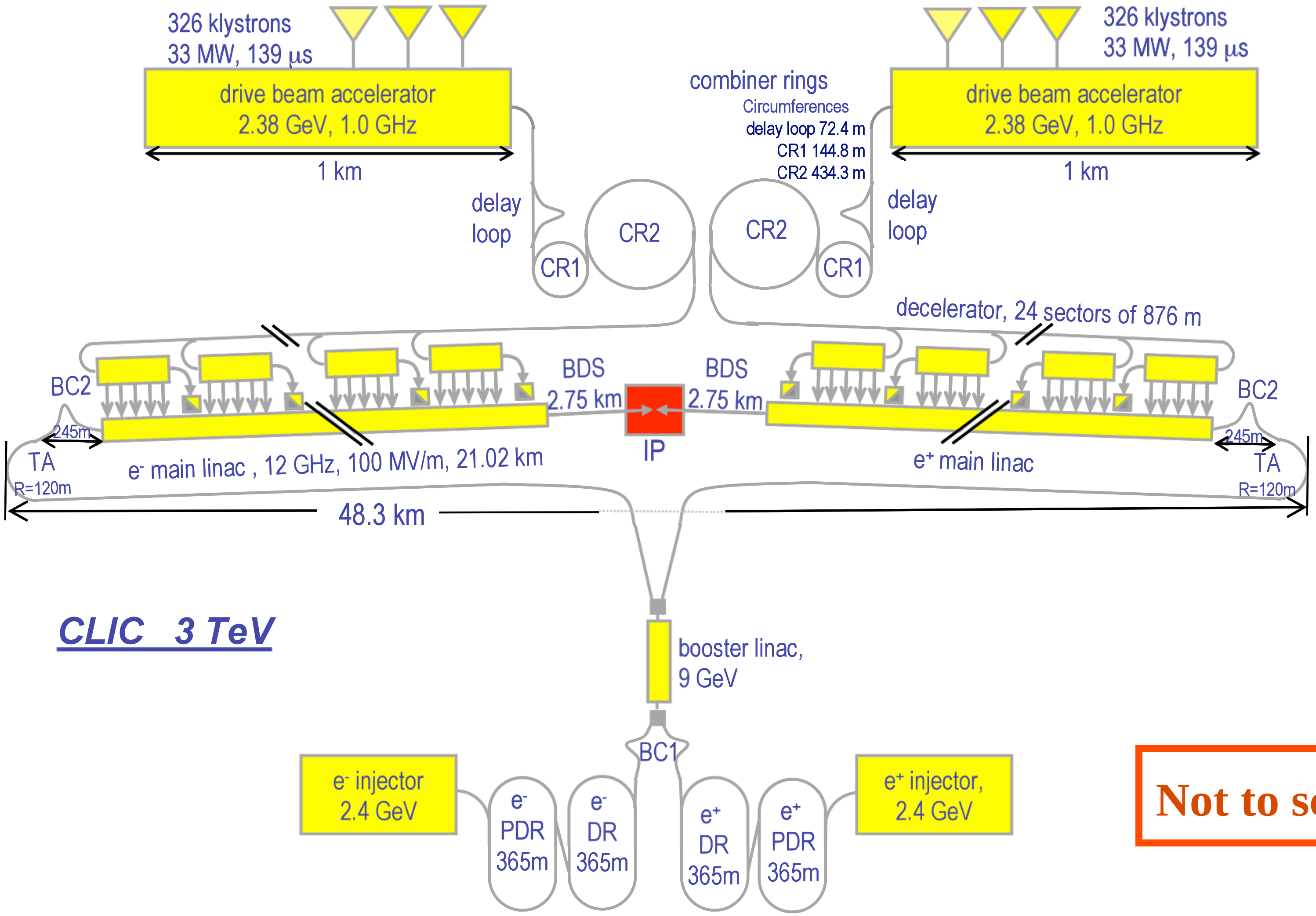
CLIC_SiD detector



CLIC_ILD detector

Spare Slides

The full CLIC scheme



CLIC 3 TeV

Not to scale!

(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

det. CDR layout and organisation

1. Introduction
2. CLIC physics potential
3. CLIC experimental conditions and detector concept design choices
4. Detector performance requirements
5. Tracking system
6. Calorimeter system
7. Superconducting Solenoid
8. Muon system
9. Very forward calorimeters
10. Readout electronics and data acquisition
11. Detector integration
12. Physics performance
13. R&D prospects
14. Costs
15. Conclusions

Currently setting up structure with:

Four main editors

- SiD, ILD, 2*CLIC
- from 3 regions

Chapter editors

Timeline:

Until end-August: pre-studies+tools

From September: benchmarking + writing

CDR ready: April 2011

CDR working groups

CLIC CDR preparation working groups:

1: “CLIC physics potential”

Scenarios, e.g. also taking possible early LHC results into account

2: “Physics observables related to jets (SW)”, convener Mark Thomson

PFA optimisation for high-E jets, jet resolution, jet algorithms, missing E

3: “Physics observables related to tracks (SW)”, convener Marco Battaglia

Track/vertex optimisation, flavour tagging, lepton id (tau id), muon background

4: “Vertex detector (mostly HW)”

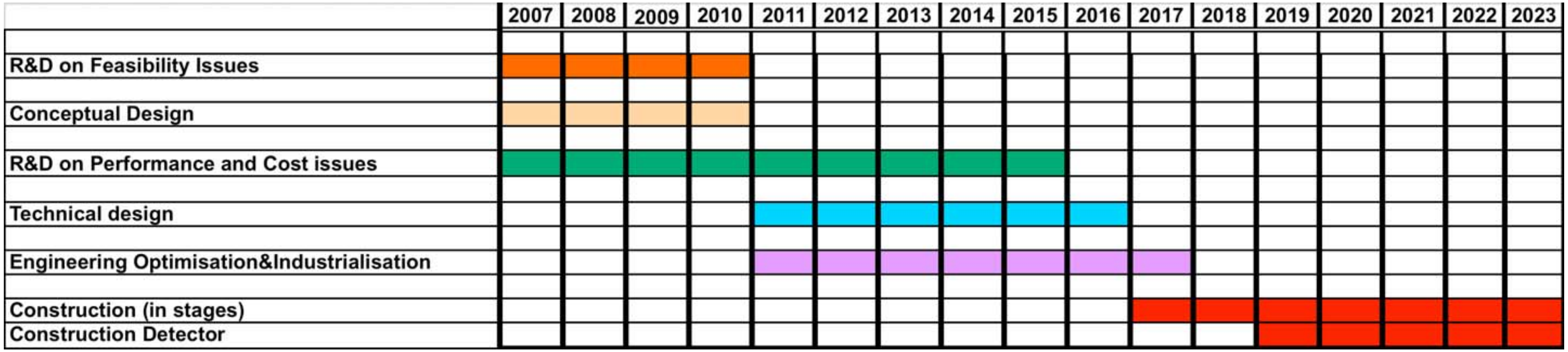
Review possible solutions for a CLIC vertex detector with time-stamping, set R&D goals

5: “Engineering, layout and cost”, convener Konrad Elsener

May add “benchmarking” later (possibly merge of 2+3)

Tentative long-term CLIC scenario

Technology evaluation and Physics assessment based on LHC results
for a possible decision on Linear Collider with staged construction starting
with the lowest energy required by Physics



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
R&D on Feasibility Issues	🟧	🟧	🟧	🟧													
Conceptual Design	🟧	🟧	🟧	🟧													
R&D on Performance and Cost issues	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
Technical design					🟦	🟦	🟦	🟦	🟦	🟦							
Engineering Optimisation&Industrialisation					🟪	🟪	🟪	🟪	🟪	🟪	🟪						
Construction (in stages)											🟥	🟥	🟥	🟥	🟥	🟥	🟥
Construction Detector													🟥	🟥	🟥	🟥	🟥

Conceptual Design Report (CDR)

Technical Design Report (TDR)

Project approval ?

First Beam?