a CLIC detector
and its relations with ILD

Outline:

- Introduction
- ILC and CLIC detector studies
- CLIC timing and beam-induced background
- Jet measurement, forward region, engineering
- Current activities and R&D plan
- What CLIC detector brings to ILD
- CLIC CDR preparation
- Summary

Lucie Linssen
ILD meeting 28/1/2010

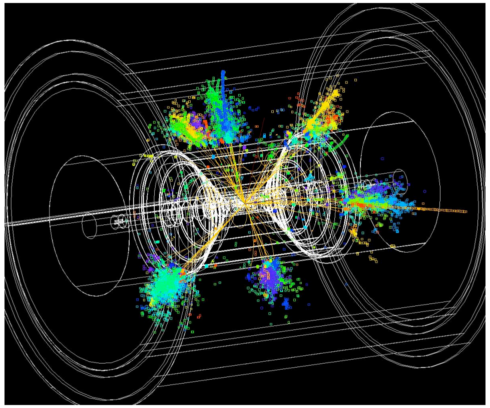
General Physics Context

- 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 or need for multi TeV?)
- Even if multi-TeV is final goal, most likely
  CLIC would run over a range of energies (e.g. 0.5 – 3.0 TeV)

ILC and CLIC detector studies (1)

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.

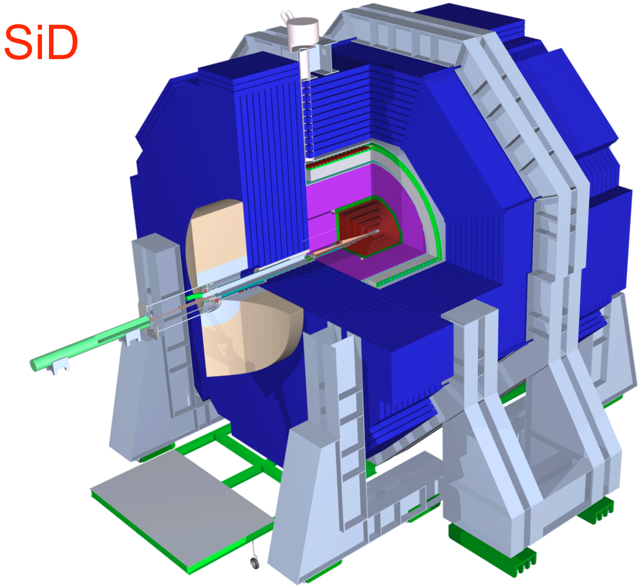
Therefore CERN has joined several Linear Collider (ILC) collaborations:

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

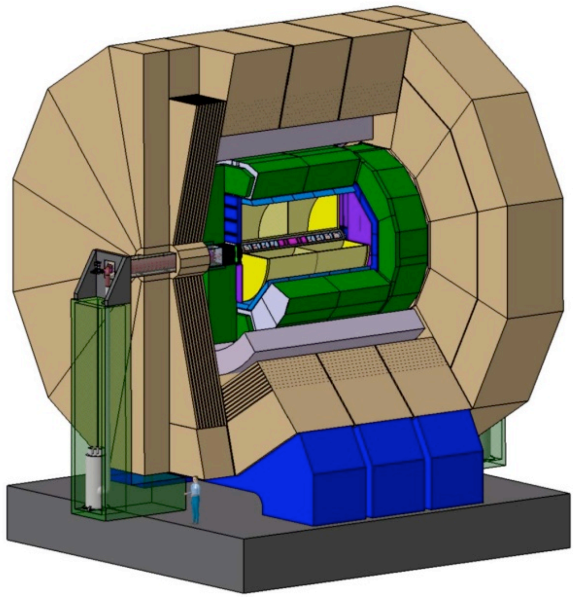
CLIC is represented in the ILC Detector R&D common task group

ILC and CLIC detector studies (2)

SiD



ILD



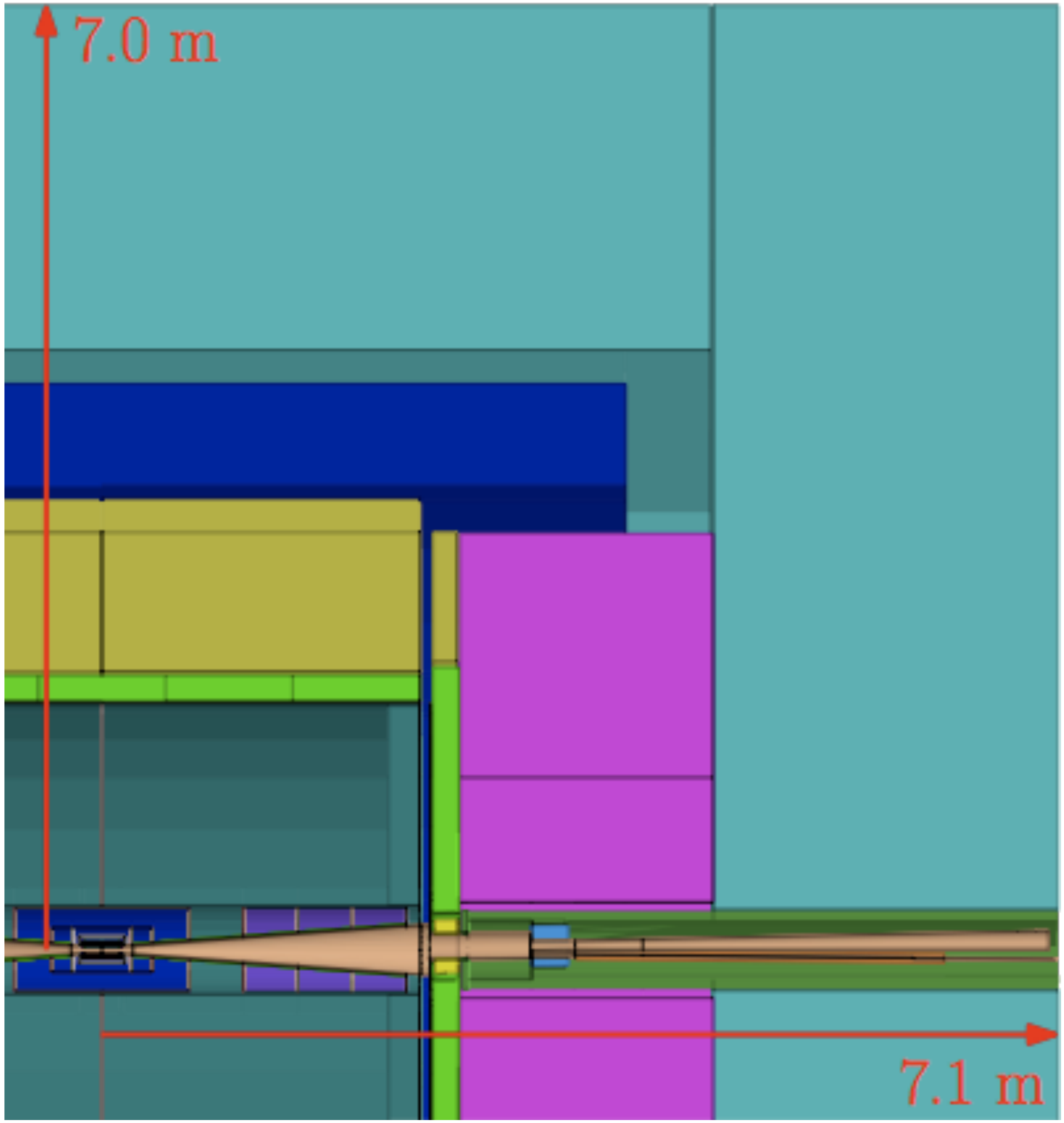
CLIC detector concepts will be based on validated SiD and ILD.

Modified to meet CLIC requirements

We are using the full ILD and SiD software suites for the study

We are currently mostly working towards the CLIC CDR, due for end-April 2011.
The physics/detector CDR will concentrate on the 3 TeV, case possibly adding a demonstration of one precision channel (e.g. Higgs strahlung) at 500 GeV

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
- HCAL barrel with 77 layers of 1 cm tungsten
- HCAL endcap with 70 layers of 2 cm steel plates
- Forward (FCAL) region adaptations

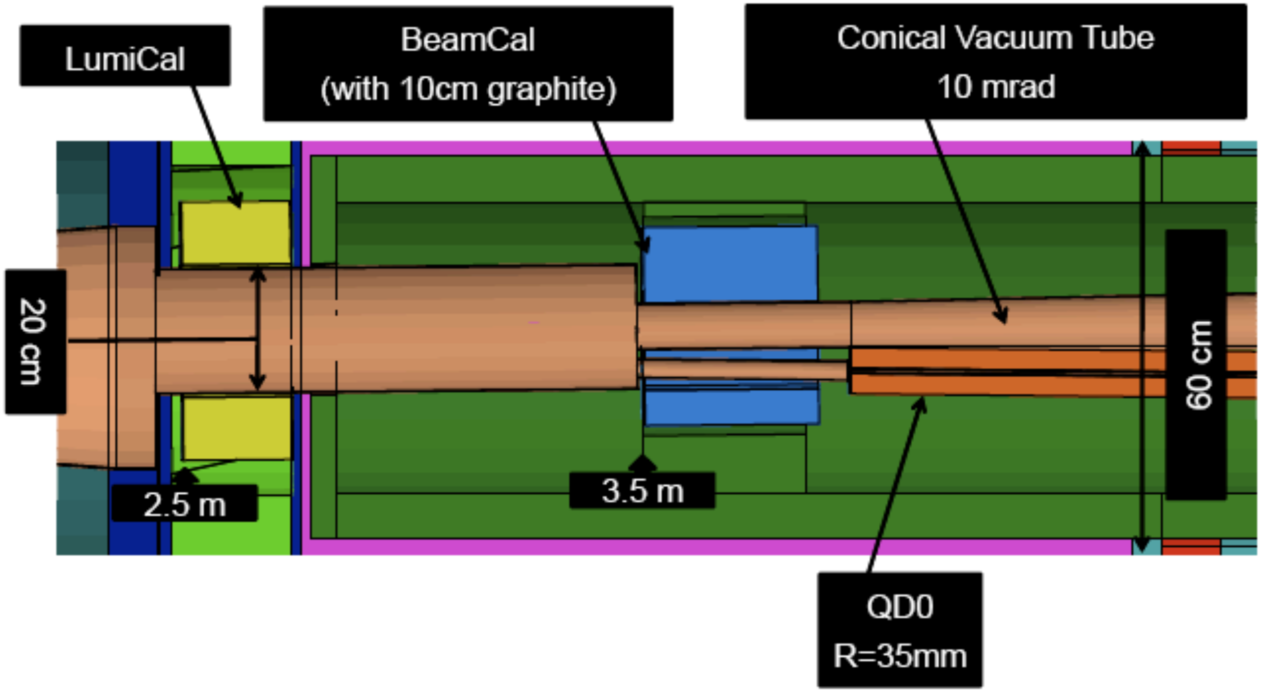
Fully implemented in Mokka/ Marlin

Andre Sailer

CLIC forward region detectors

Andre Sailer

CLIC01_ILD: LumiCal, BeamCal and QD0

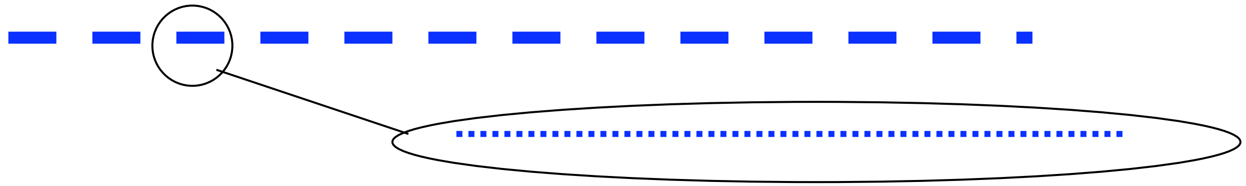


Maintain very forward calorimetry functionalities, adapt to accelerator requirements (stability!), minimise back-scattering of background

CLIC time structure

Train repetition rate 50 Hz

CLIC



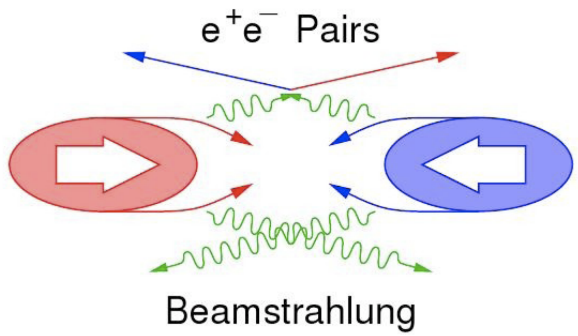
CLIC:	1 train = 312 bunches	0.5 ns apart	50 Hz
ILC:	1 train = 2625 bunches	369 ns apart	5 Hz

	LEP 2	ILC 0.5 TeV	CLIC 0.5 TeV	CLIC 3 TeV
L [$cm^{-2}s^{-1}$]	5×10^{31}	2×10^{34}	2×10^{34}	6×10^{34}
BX/train	4	2670	350	312
BX sep	~22 μs	369 ns	0.5 ns	0.5 ns
Rep. rate	50 kHz	5 Hz	50 Hz	50 Hz
L/BX [cm^{-2}]	2.5×10^{26}	1.5×10^{30}	1.1×10^{30}	3.8×10^{30}
$\gamma\gamma\rightarrow X$ / BX	neg.	0.2	0.2	3.0
σ_x/σ_y	240 / 4 mm	600 / 6 nm	200 / 2 nm	40 / 1 nm

Beam-induced background

Background sources: CLIC and ILC similar

Due to the higher beam energy and small bunch sizes they are significantly more severe at CLIC.



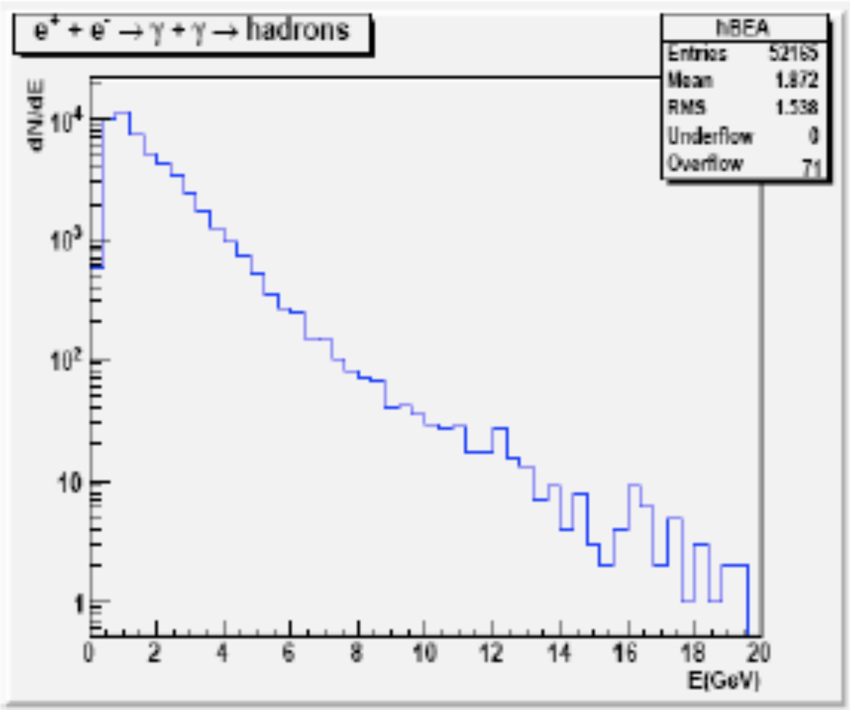
Main backgrounds:

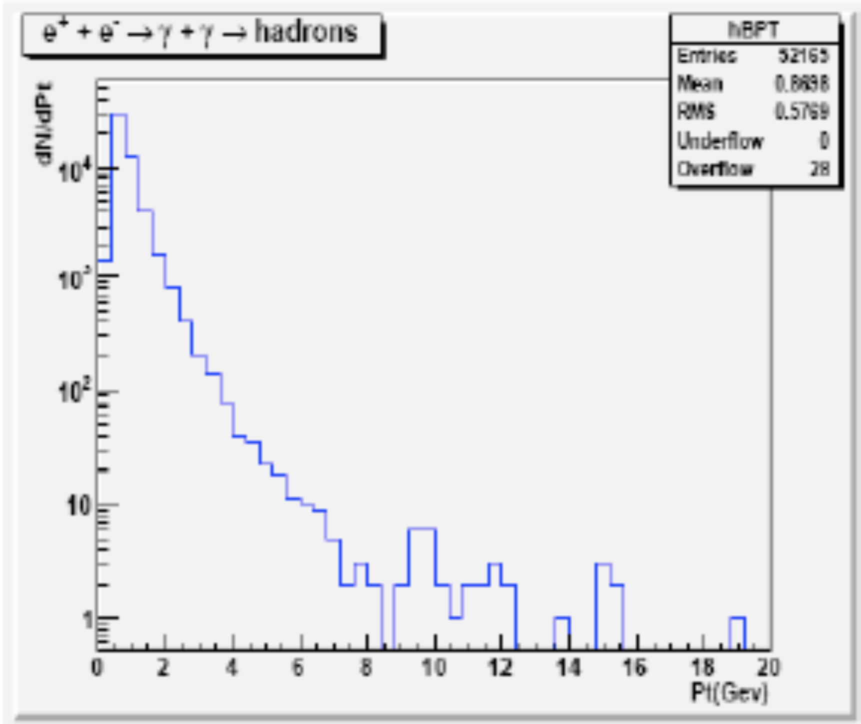
- CLIC 3TeV beamstrahlung ΔE/E = 29% (10×ILC_{value})
  - **Coherent pairs** (3.8×10^8 per bunch crossing) <= disappear in beam pipe
  - **Incoherent pairs** (3.0×10^5 per bunch crossing) <= suppressed by strong solenoid-field
  - γγ interactions => hadrons (**3.3 hadron events per bunch crossing**)
- Muon background from upstream linac
  - More difficult to stop due to higher CLIC energy (active muon shield)

http://sailer.web.cern.ch/sailer/guineapig/density.html

Beam-induced background and time–stamping

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

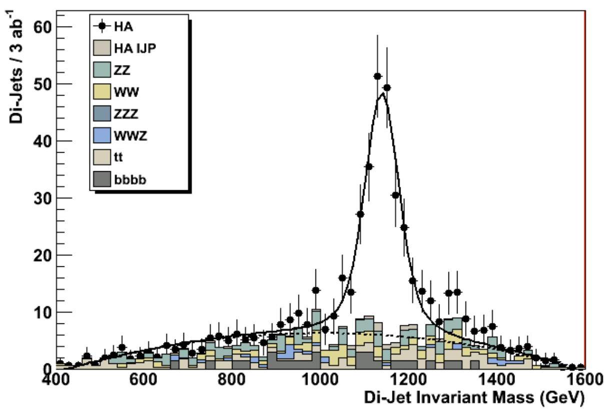
Beam-induced background and time–stamping

Simulation example of heavy Higgs doublet H^0A^0 at ~1.1 TeV mass (supersymmetry K' point)

$e^+e^- \rightarrow H^0A^0 \rightarrow bbbb$

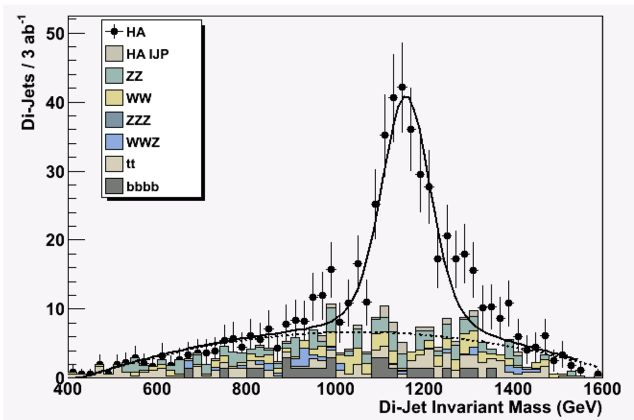
Signal + full standard model background + γγ=>hadron background

CLIC-ILD detector: Mokka+Marlin simulation, reconstruction + kinematic fit.



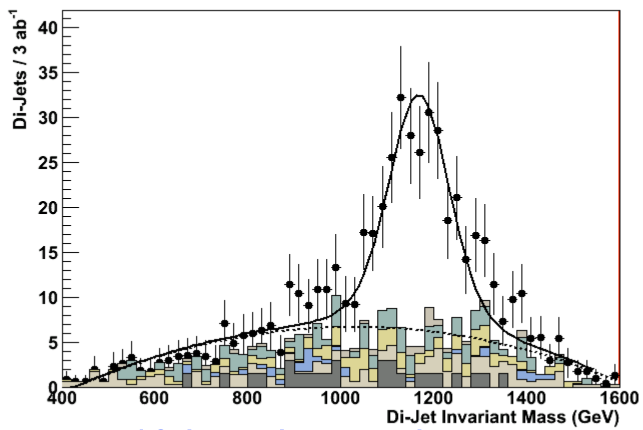
Zero bunch crossings

M_A mass resol. 3.8 GeV



20 bunch crossings

M_A mass resol. 5.6 GeV



40 bunch crossings

M_A mass resol. 8.2 GeV

Most CLIC sub-detectors will need time-stamping.

We also need to work on better separation (e.g. jet algorithms)

Marco Battaglia

Jet reconstruction

First studies have given confidence in PFA, but more detailed studies are needed.

- ★ 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 %

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

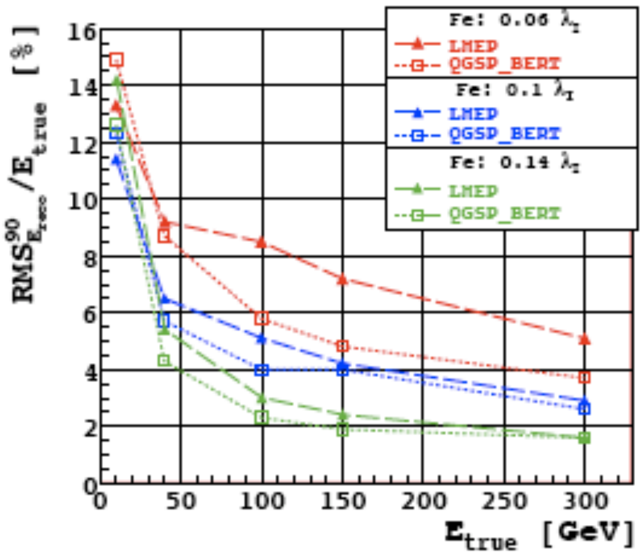
Mark Thomson
Cambridge

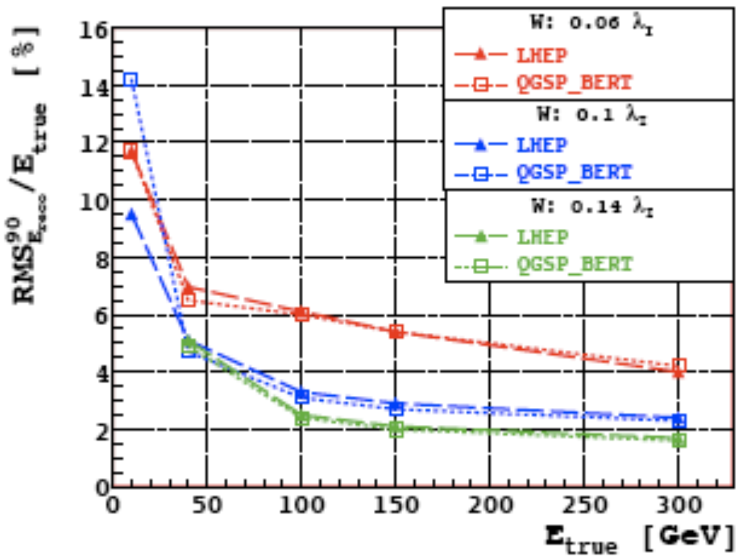
Tungsten HCAL prototype (1)

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)

Tungsten HCAL prototype (2)

Main elements (all still under discussion):

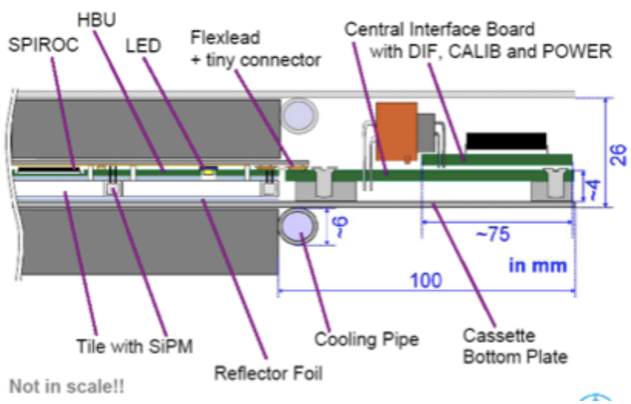
- 40 or more layers of Tungsten absorber ~10×810×810 mm^3
- Phase 1: use existing CALICE HCAL scintillator planes
- Phase 2:
  - a) New integrated AHCAL scintillator planes
  - b) New DHCAL micromegas or RPC planes

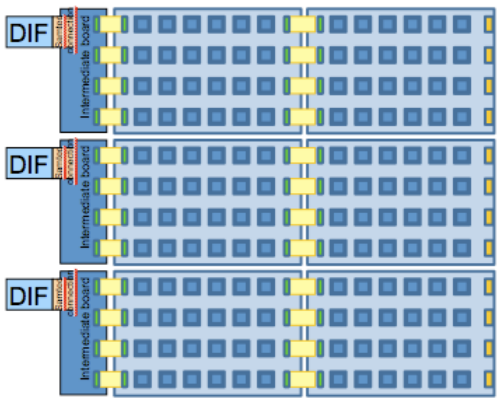
Time scale: First (limited) beam tests at CERN in 2010

This is also part of AIDA ✪

Integrated scintillator plane

DESY





Layout 1 m^2 micromegas

LAPP-Annecy

Spatial distance neutral – charged hadrons

Jean-Jacques Blaising, LAPP

Distance, Δ, at the 1. layer of HCAL

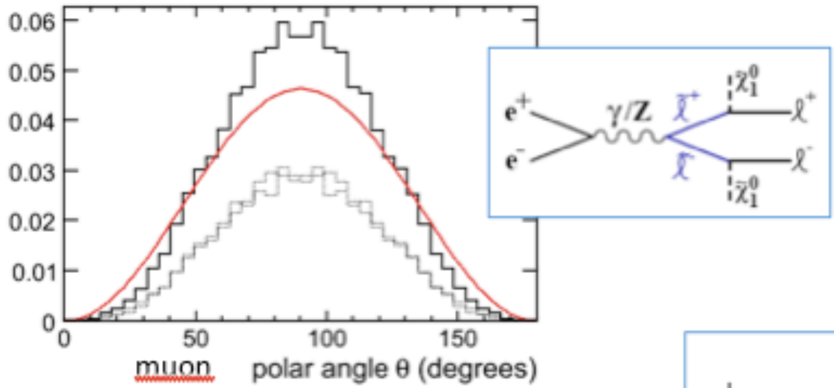
		Njet, Ecm, B	Δ (cm) MPV barrel	Δ (cm) RMS barrel	Δ (cm) MPV endcap	Δ (cm) RMS endcap
ILC	$\nu\nu H^0$	2J, 0.5 GeV,4T	8.0	3.6	9.7	4.4
ILC	$t\bar{t}$	4/6J, 0.5 GeV,4T	6.4	2.8	8.6	6.7
CLIC	$\nu\nu H^0$	2J, 3.0 TeV, 4T	3.8	2.6	2.6	2.4
CLIC	$t\bar{t}$	4/6J, 3.0 TeV, 4T	1.0	1.1	1.7	0.9
CLIC	$t\bar{t}$	4/6J, 3.0 TeV, 5T	1.4	1.2	1.9	1.0

- at 3 TeV neutral - charged particle separation only ~ 1 cm
- cluster of neutral and charged hadrons will overlap in HCAL
- neutral hadron reconstruction (with PFA) only by subtraction

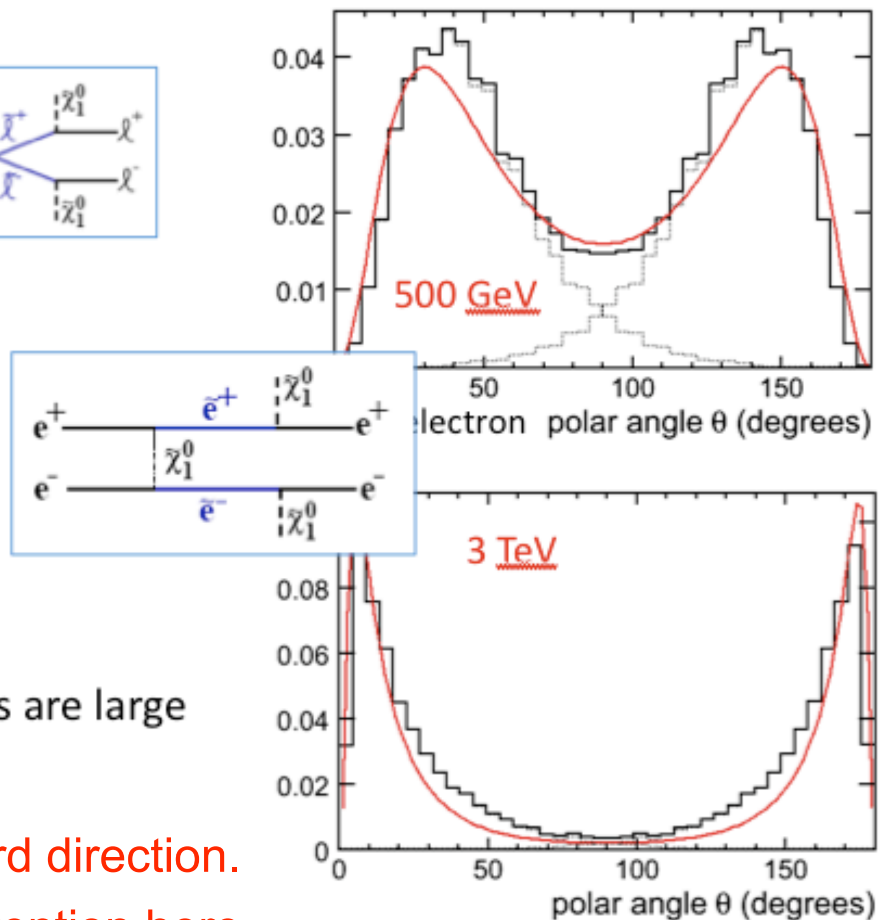
At high energy physics goes in forward direction

Example: s-lepton production

s-muon production



s-electron production



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

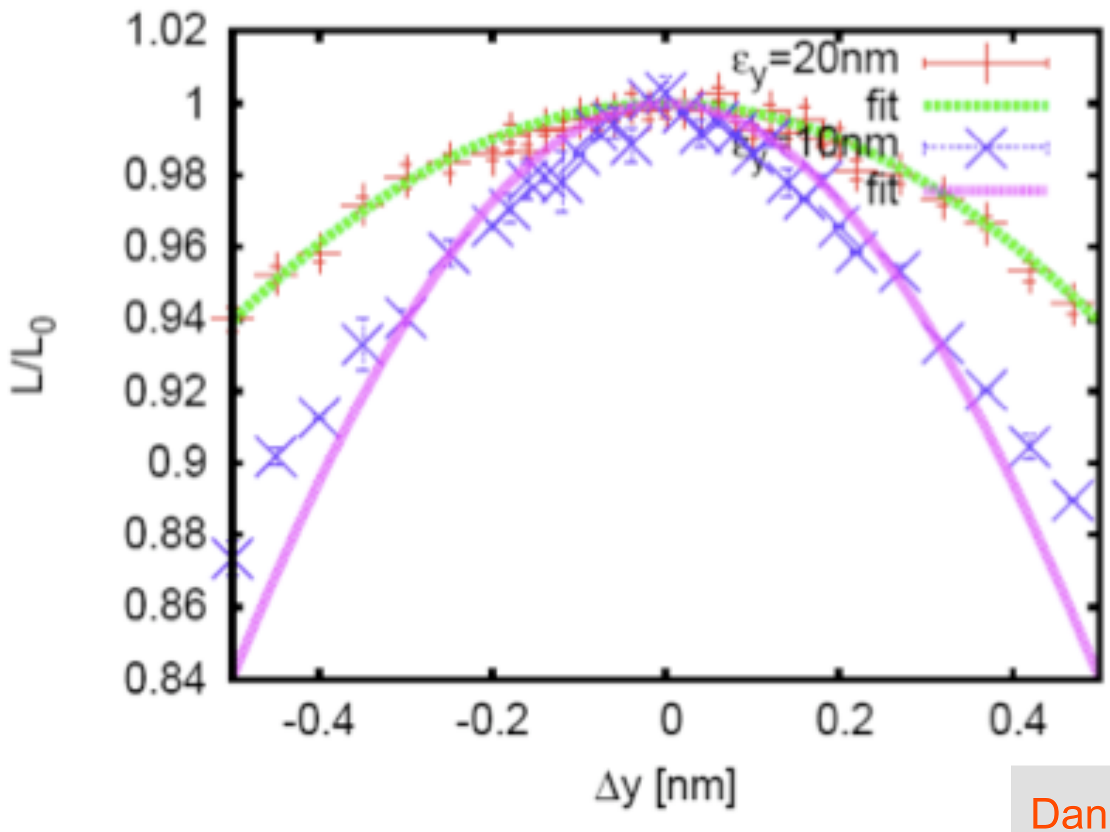
Background is also principally in forward direction.

Detector optimisation needs special attention here.

Spanish groups will be involved in this study.

Final focus stability

- Final focus quadrupoles inside experiment, L* = ~3.5 m
  - Beam focusing stability required at sub-nm level **!!**



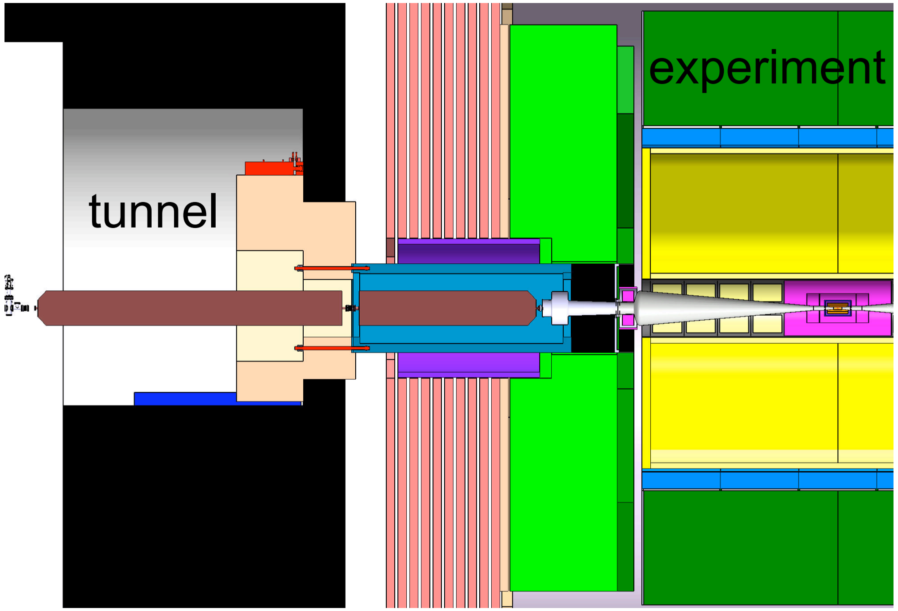
Daniel Schulte CLIC08.

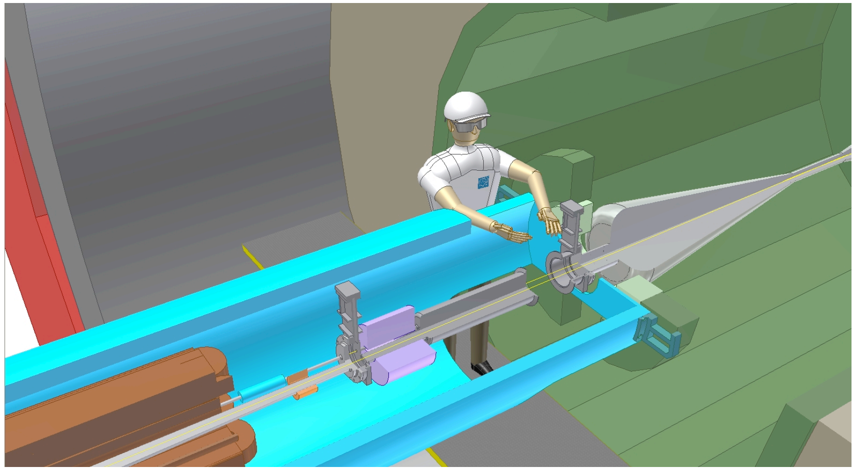
Engineering issues

Current engineering studies mostly concentrate on the critical issue of providing a stable environment for the forward focus quadrupole QD0.

Measurements in CMS and several (LHC-) underground locations have guided ideas about how to suspend QD0 within the experiment volume. These ideas are currently being worked out.

see MDI talk 27/1 Alain Herve





Forward detector region with final focus elements

Alain Herve (ETHZ), Hubert Gerwig (CERN)

Current 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 required sub-detector performances to see the physics
    - Adapted to CLIC energies (e.g deeper calorimeter)
    - In the presence of beam/background conditions
    - With particular emphasis on time-stamping needs
  - Redesign of the very forward region
  - Take engineering aspects, cost etc into account
- Preparing a targeted hardware R&D plan

Hardware/engineering R&D

Hardware/engineering R&D needed beyond present ILC developments:

- Time stamping
  - Needed for all sub-detectors; challenging in inner tracker/vertex region; trade-off between pixel size, amount of material and timing resolution
- Power pulsing and DAQ developments
  - In view of the CLIC time structure
- Hadron calorimetry
  - Dense HCAL absorbers to limit radial size (PFA calo based on tungsten)
- Solenoid coil
  - Reinforced conductor (building on CMS/ATLAS experience)
  - Large high-field solenoid concept
- Overall engineering design and integration studies
  - For heavier calorimeter, larger overall CLIC detector size etc.
  - In view of sub-nm precision required for FF quadrupoles

In addition: Core software development

Core software development

Ongoing developments with involvement of LCD@CERN team:

- Use of LHC ROOT functionalities in ILC software (focused on ILD, collab. with DESY)
- Possible transfer of ATLAS tracking code into Mokka/Marlin (in collab. ATLAS, DESY, CERN) *see talk of Steve Aplin 27/1*
- Improved geometry toolkit in Mokka/Marlin (CERN+DESY+✪) *see talk of Astrid Münning 27/1*
- Contribution to TPC reconstruction code (Martin Killenberg)
- Improvements of hadronisation process descriptions in Geant4 (collaboration between CERN/ Geant4 and CALICE)
- Re-structuring of Pandora PFA (led by M. Thomson, Cambridge). The new Pandora can also be used with SiD (SLiC) processed events. ✪ *see talk of John Marshall 27/1*
- Grid processing and file catalog: we get support from LHCb to take over their DIRAC system. Pilot project is starting now with LHCb/DESY/CERN. "ILC vo" is already activated for grid processing at CERN. *see talk of Jan Engels 27/1*

✪ also in AIDA

what LCD@CERN can bring to ILD

It is obvious that many years of ILC study bring a lot to the CLIC study and to the new LCD project at CERN.

In a nutshell, what does LCD@CERN bring to ILD?

- Use of ILD software tools at higher energy, participation in the necessary improvements => very useful for the upcoming 1 TeV ILC studies
- Participation in software framework development (including use of LHC tools) and: Grid tools, TPC pattern recognition in Marlin, contribution to Pandorra-PFA, Geant4 hadronisation process
- Studies with overlayed background and optimisation of physics observables
- Study of the ILD detector concept at higher energies and reflect on possible improvements => might be in the interest of ILD
- Dense tungsten HCAL studies/tests
- Solenoid R&D, of mutual interest
- Timepix-2 and S-Altro developments for TPC readout
- ……

CLIC physics/detector CDR

The CLIC detector CDR (due for end-April 2011) **will have 3 volumes:**

1. **Executive summary**
2. **CLIC accelerator**
3. **CLIC physics/detector** (~150 pages)

For the physics/detector CDR, some studies will be done with the SiD concept, others with the ILD concept, so the document will have a mix of both.

The CDR will mostly be based on **simulation studies for the CLIC** case and **existing ILC hardware experience**. As CLIC-specific hardware R&D will only start in 2010, its result will come too late for the CDR.

CDR working groups

We are currently putting a few working groups in place in preparation for the CDR:

1: CLIC physics potential

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

2: Physics observables related to jets (SW)

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

3: Physics observables related to tracks (SW)

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, solenoid, cost

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

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 looking for:

Three main editors

- SiD, ILD, CLIC
- from 3 regions

Chapter editors

Several volunteers already available

Work-plan to be set up with editors for each of the chapters

What else?

We would like to organise soon a short workshop on power pulsing.

We would appreciate to do it together with ILD experts

Summary

ILC gave us a jump-start (concepts, software, hardware solutions)

The LCD team at CERN is growing and working towards the CLIC CDR

Simulation tools are in place.

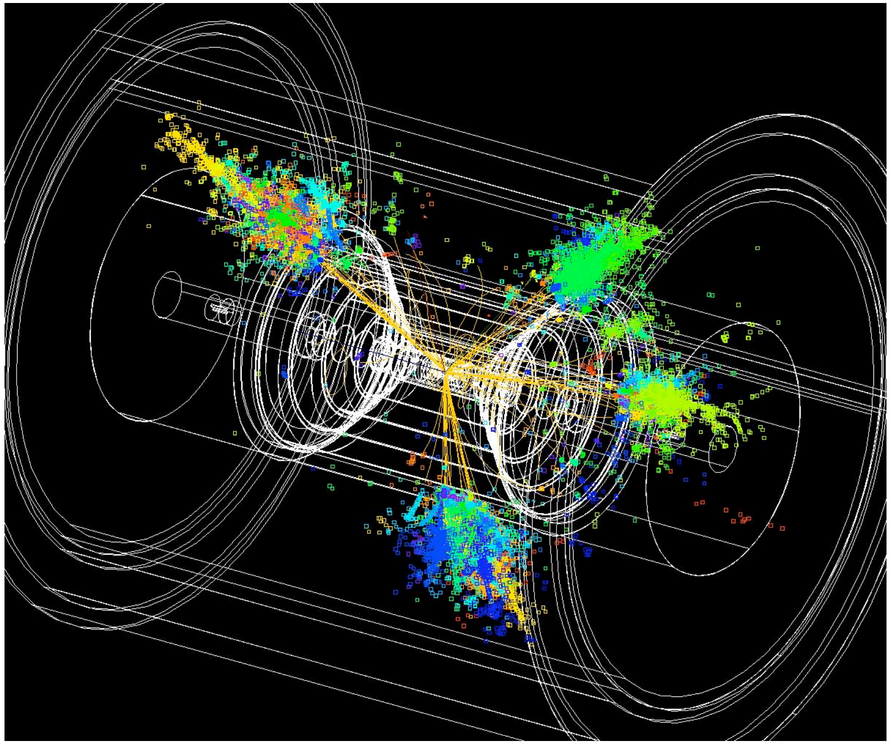
First assessments of physics performance have been made

Next ~6 months: work on tools, physics observables, performance requirements

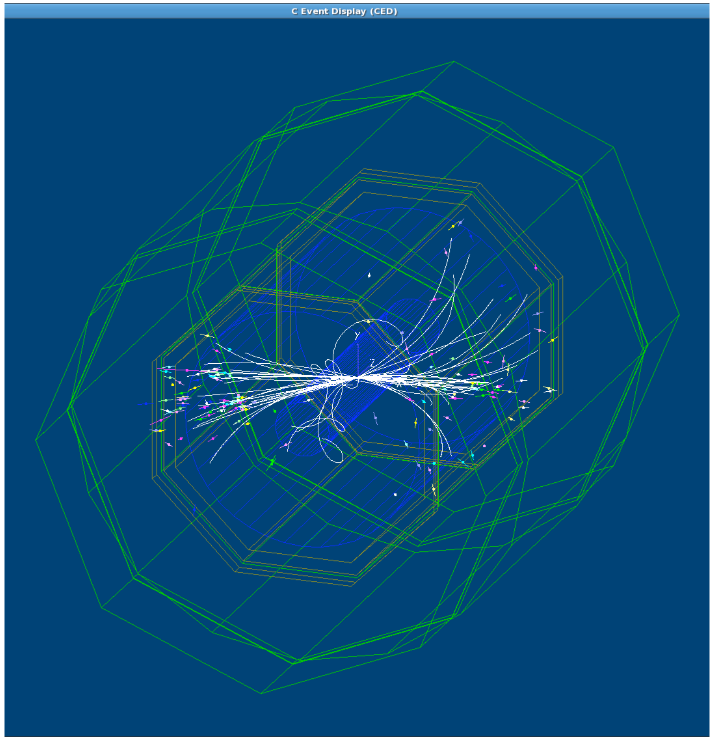
Followed by: Benchmark studies

In parallel we are starting hardware R&D

With many thanks to all our ILC physics/detector colleagues!



CLIC_SiD detector



CLIC_ILD detector

Spare Slides

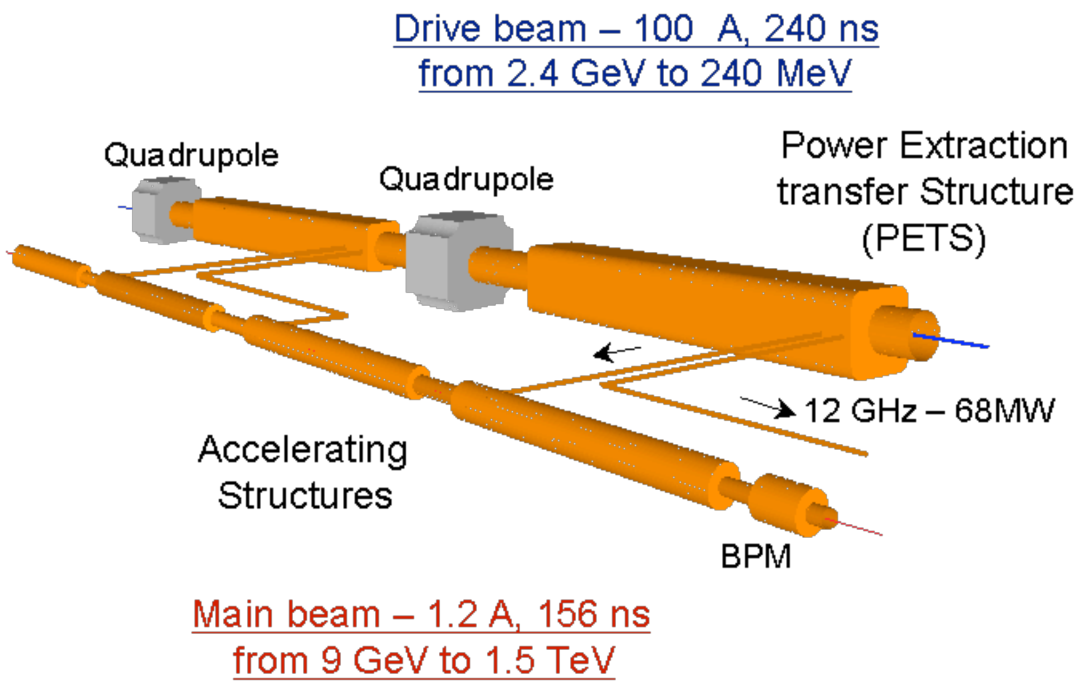
Two Beam Scheme:

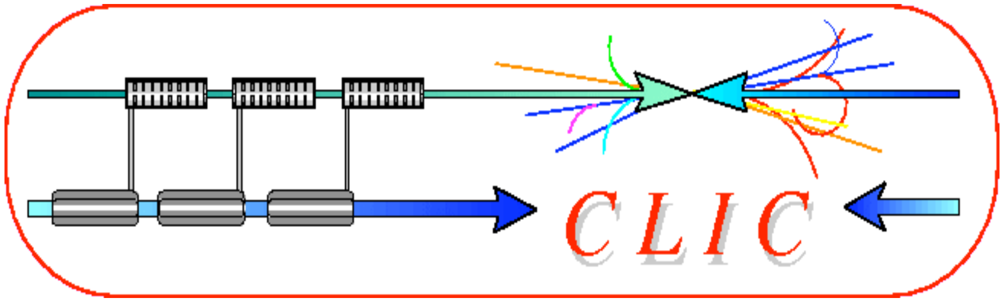
Drive Beam supplies RF power

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

Main beam for physics

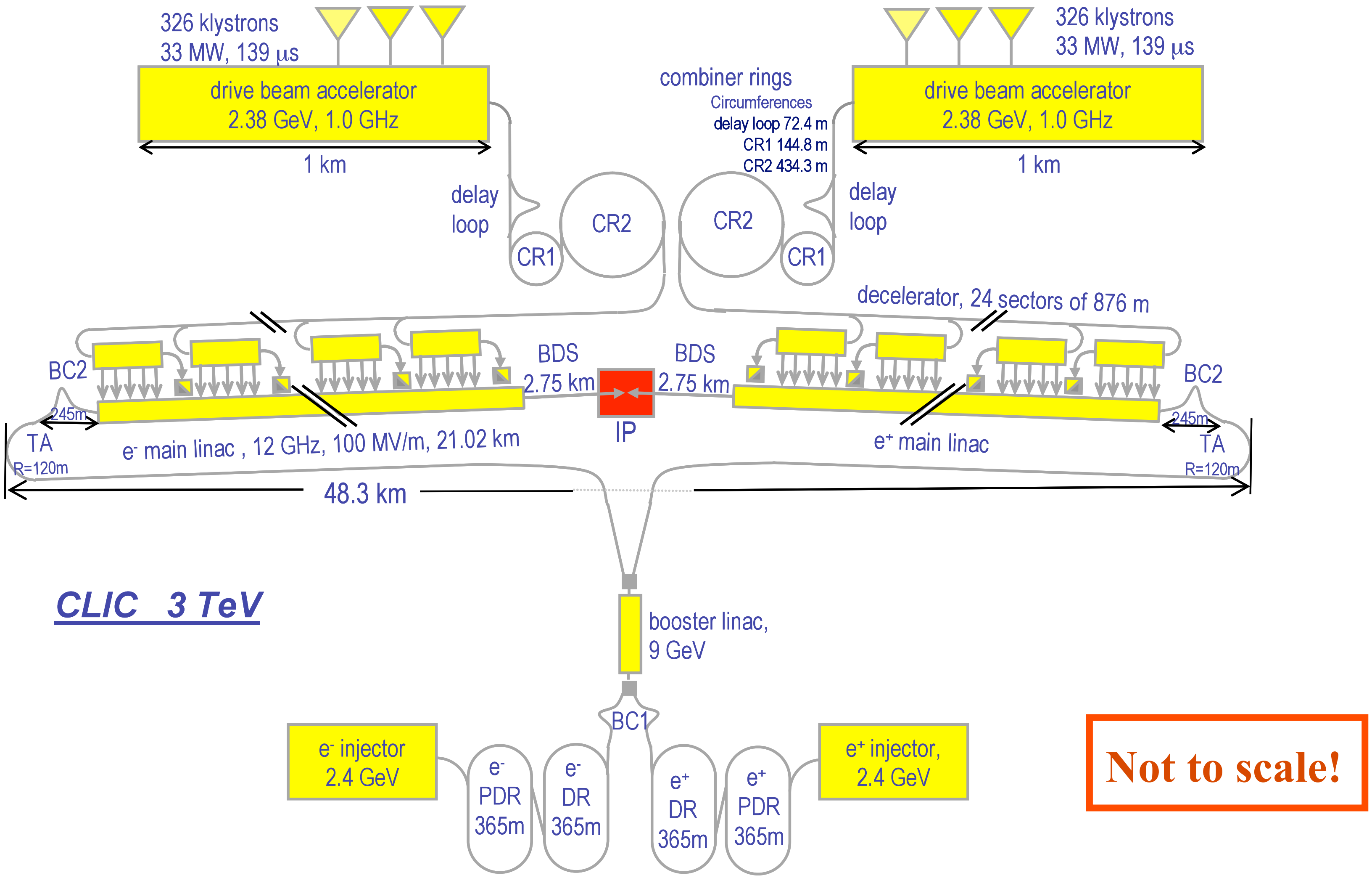
- high energy (9 GeV – 1.5 TeV)
- current 1.2 A





No individual RF power sources

The full CLIC scheme



CLIC parameters

pre-SB2009

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?

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')

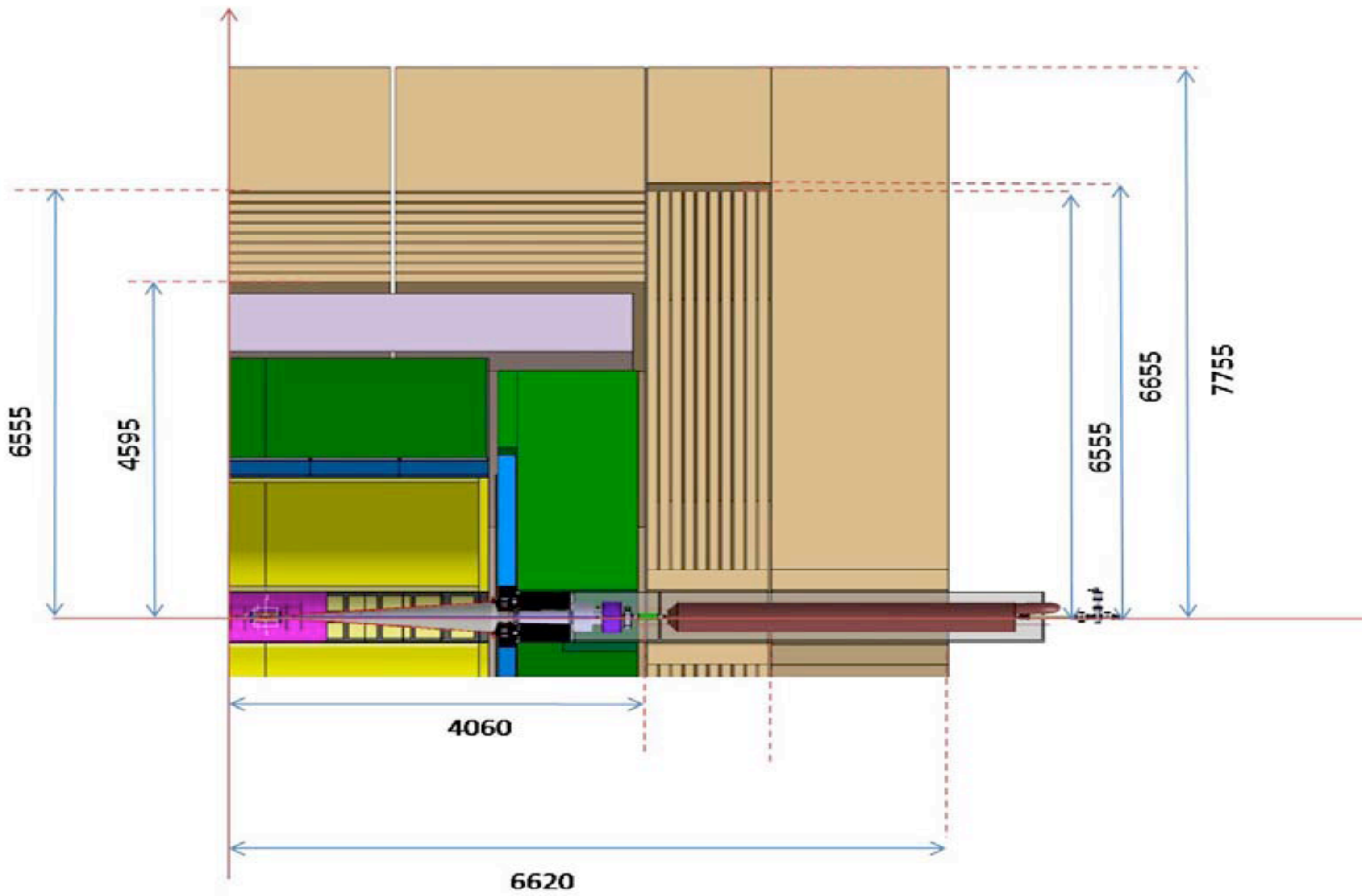
•Excited quarks or leptons

(S)LHC, ILC, CLIC reach

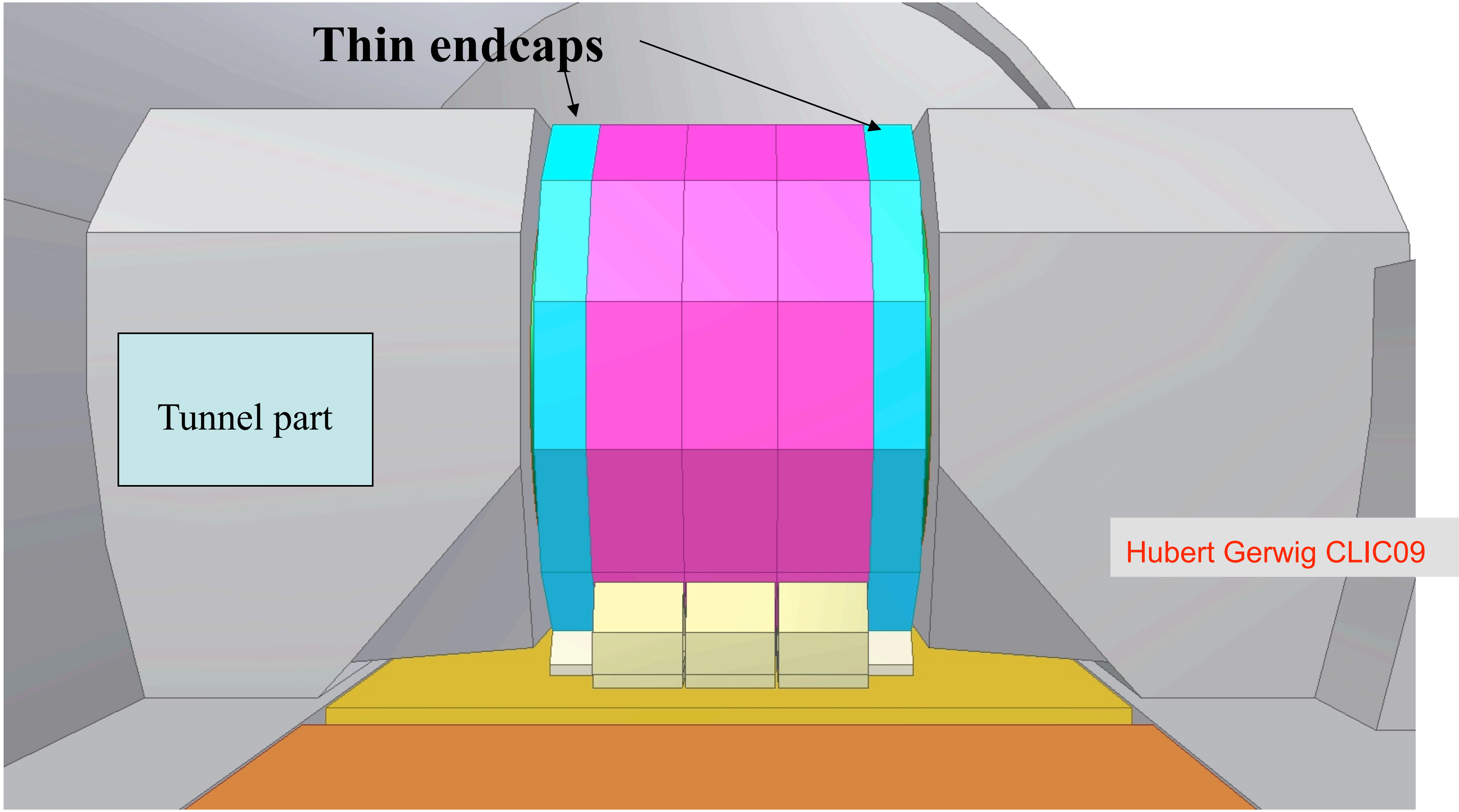
	LHC 100 fb^{-1}	ILC 800 GeV 500 fb^{-1}	SLHC 1000 fb^{-1}	CLIC 3 TeV 1000 fb^{-1}
Squarks [TeV]	2.5	0.4	3	1.5
Sleptons [TeV]	0.34	0.4		1.5
New gauge boson Z′ [TeV]	5	8	6	22
Excited quark q* [TeV]	6.5	0.8	7.5	3
Excited lepton l* [TeV]	3.4	0.8		3
Two extra space dimensions [TeV]	9	5–8.5	12	20-35
Strong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

Gian Giudice CLIC09

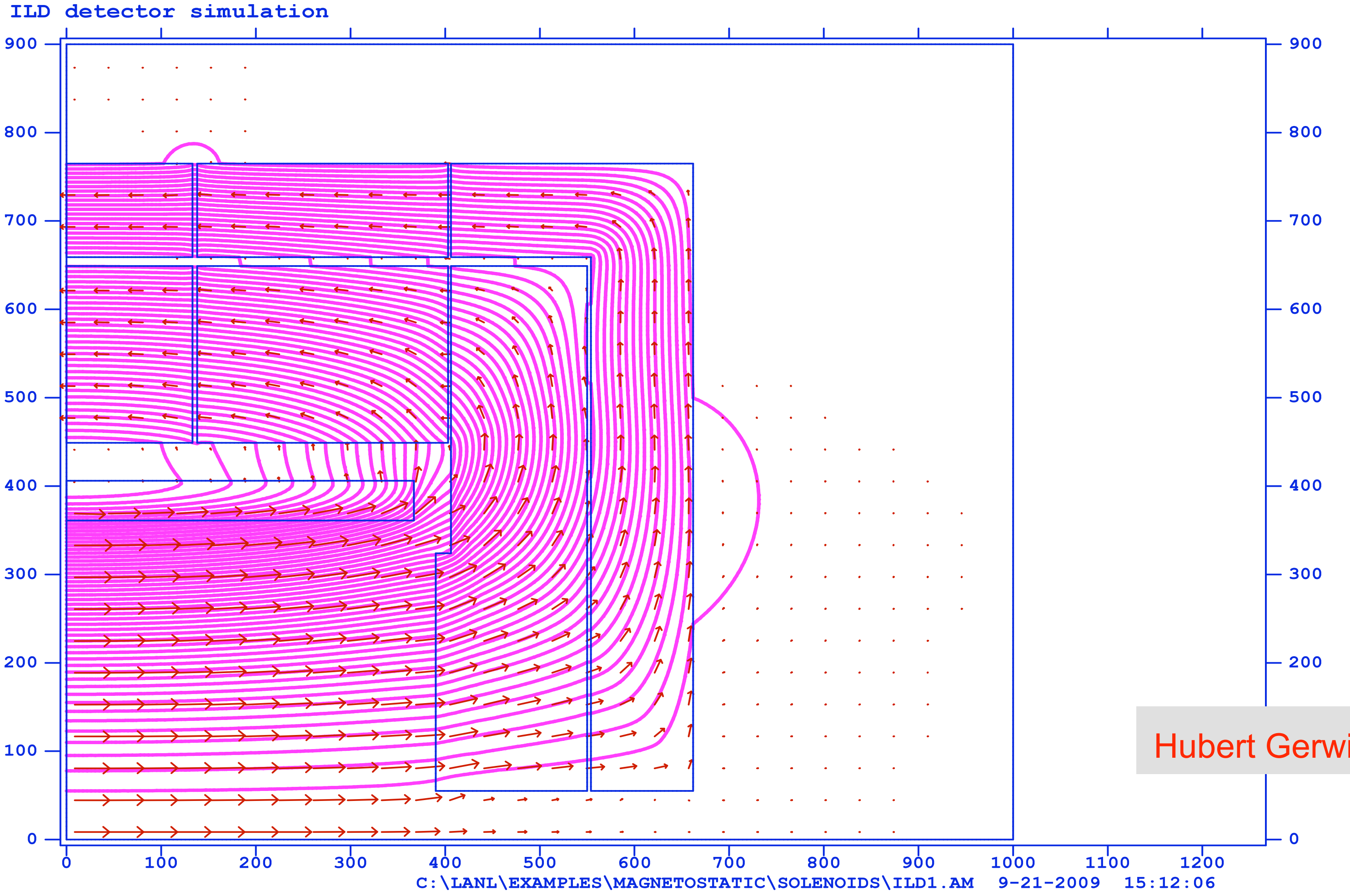
ILD Endcap thickness 2.56 meter!



Side View

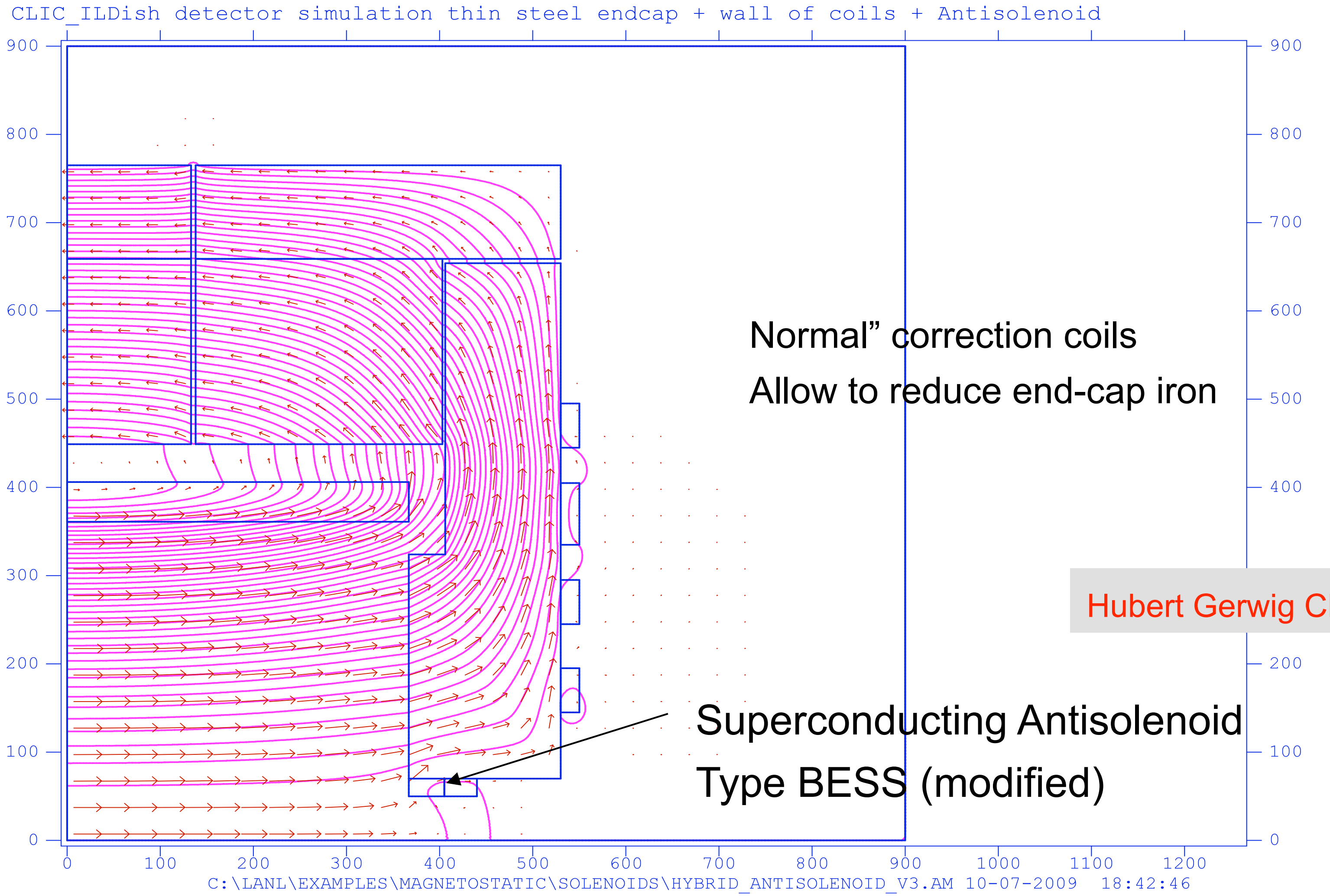


Magnetic field type "ILD"



Hubert Gerwig CLIC09

Additional complication Antisolenoid for QD0



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With reduced Endcap, part of QD0 in Tunnel!