Detector studies for e+e- collisions at CLIC

Outline:

- CLIC physics potential
- CLIC experimental conditions (comparison to ILC)
- CLIC experiment
- Current activities and R&D plan
- Summary

Lucie Linssen

CHIPP meeting, Zurich, Sept 2nd 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 is expected in TeV energy range
  - E.g. motivated by particle astrophysics (dark matter)
  - Higgs, Supersymmetry, extra dimensions, …?

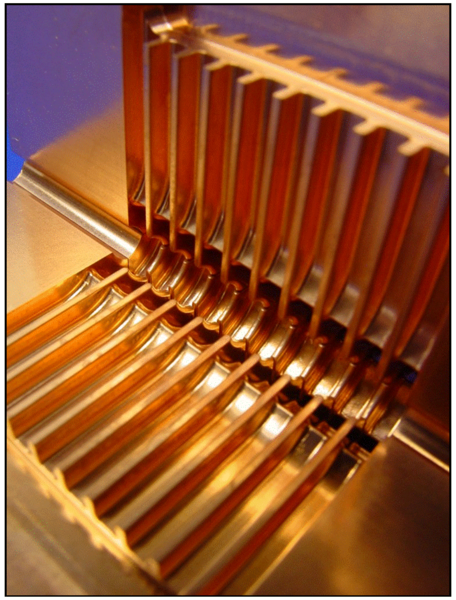
- LHC will indicate what physics, and at which energy scale:
  - Is 500 GeV enough (ILC)
  - Is there a need for multi TeV? (CLIC)

- 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 Mid-2011

ILC and CLIC in a few words…

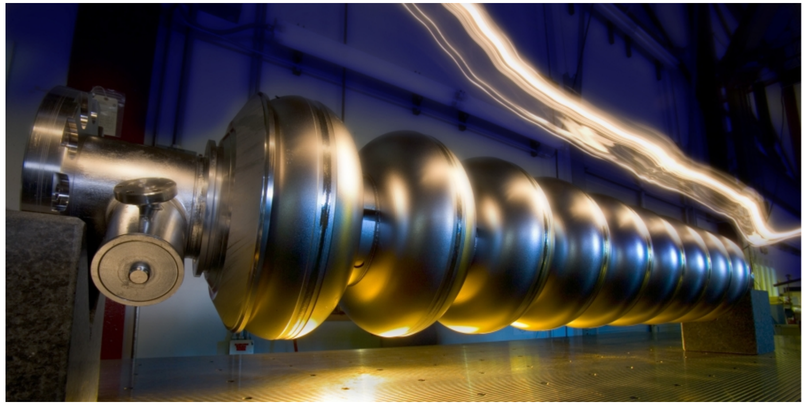
linear collider, producing e^+e^- collisions

CLIC



- 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

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

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:

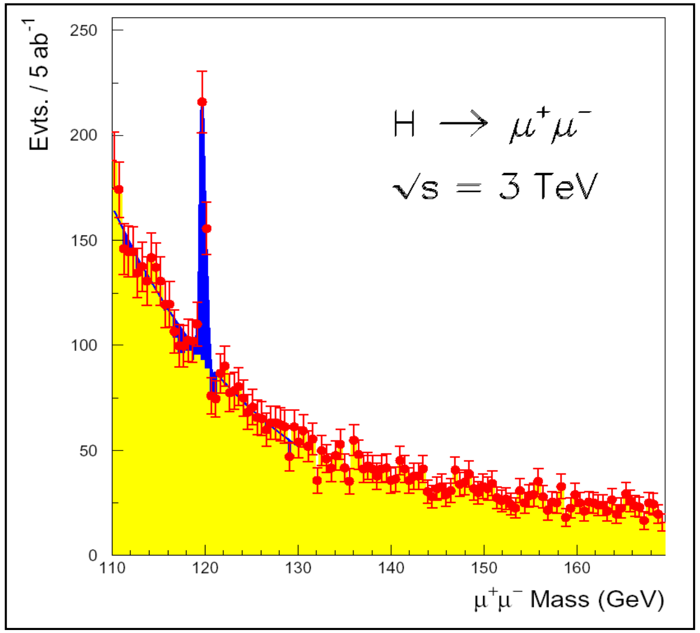
- Complete study of the light standard-model Higgs boson, including rare decay modes (rates factor ~5 higher at 3 TeV than at 500 GeV)
  - Higgs coupling to leptons
  - Study of triple Higgs coupling using double Higgs production
- Study of heavy Higgs bosons (supersymmetry models)

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

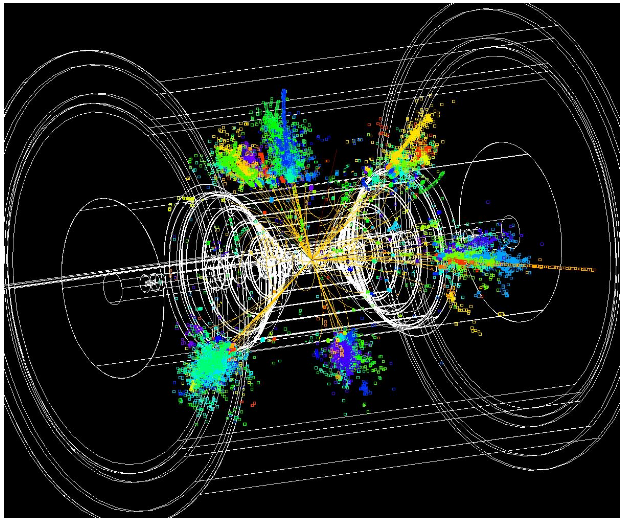
	LHC 100 fb^{-1}	ILC 800 GeV 500 fb^{-1}	SLHC 1000 fb^{-1}	CLIC 3 TeV 1000 fb^{-1}
Squarks [TeV]	2.5	0.4	3	1.5
Sleptons [TeV]	0.34	0.4		1.5
New gauge boson Z′ [TeV]	5	8	6	22
Excited quark q* [TeV]	6.5	0.8	7.5	3
Excited lepton l* [TeV]	3.4	0.8		3
Two extra space dimensions [TeV]	9	5–8.5	12	20-35
Strong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

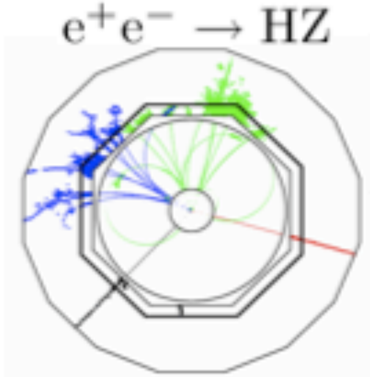
ILC=>CLIC detector requirements

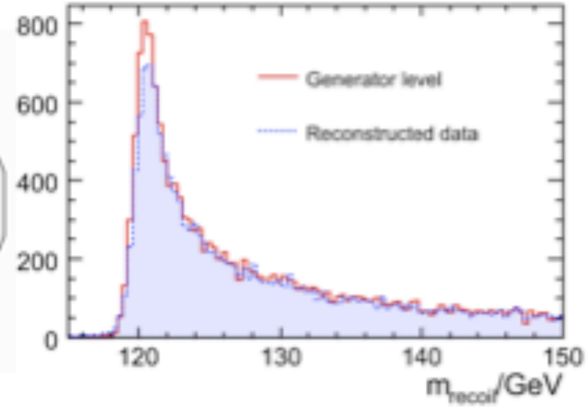
★ **momentum:** **(1/10 x LEP)**

e.g. Muon momentum

Higgs recoil mass

$$\sigma_{1/p} < 5 \times 10^{-5}\,\mathrm{GeV}^{-1}$$



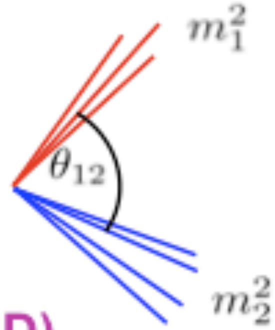


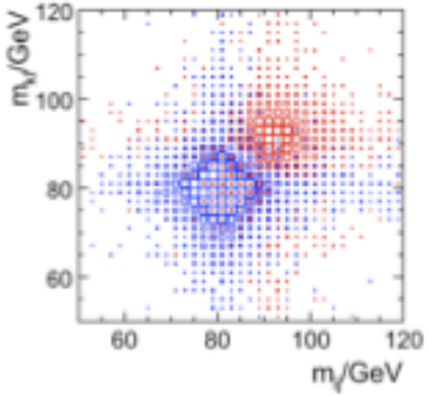
★ **jet energy:** **(1/3 x LEP/ZEUS)**

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

EWSB signals

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





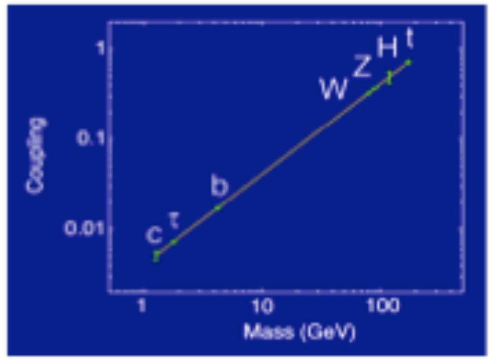
★ **impact parameter:** **(1/3 x SLD)**

e.g. c/b-tagging

Higgs BR

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

will use softer require-ment for CLIC



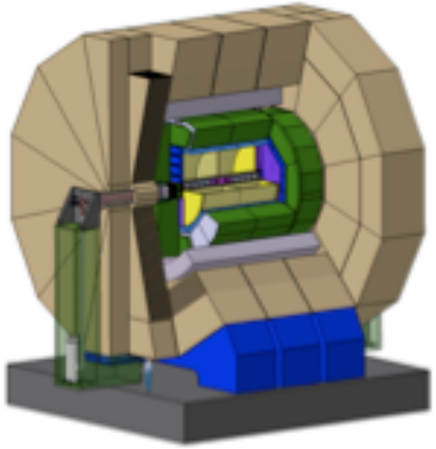
★ **hermetic:** **down to θ = 5 mrad**

e.g. missing energy signatures in SUSY

Validated ILC concepts

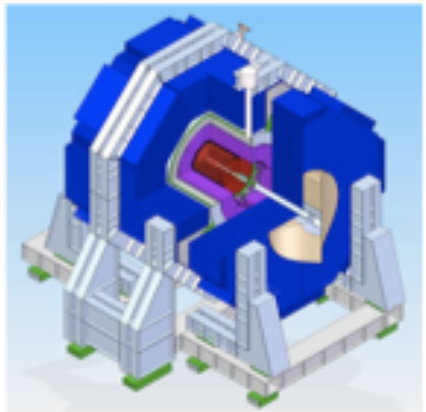
ILD: International Large Detector

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



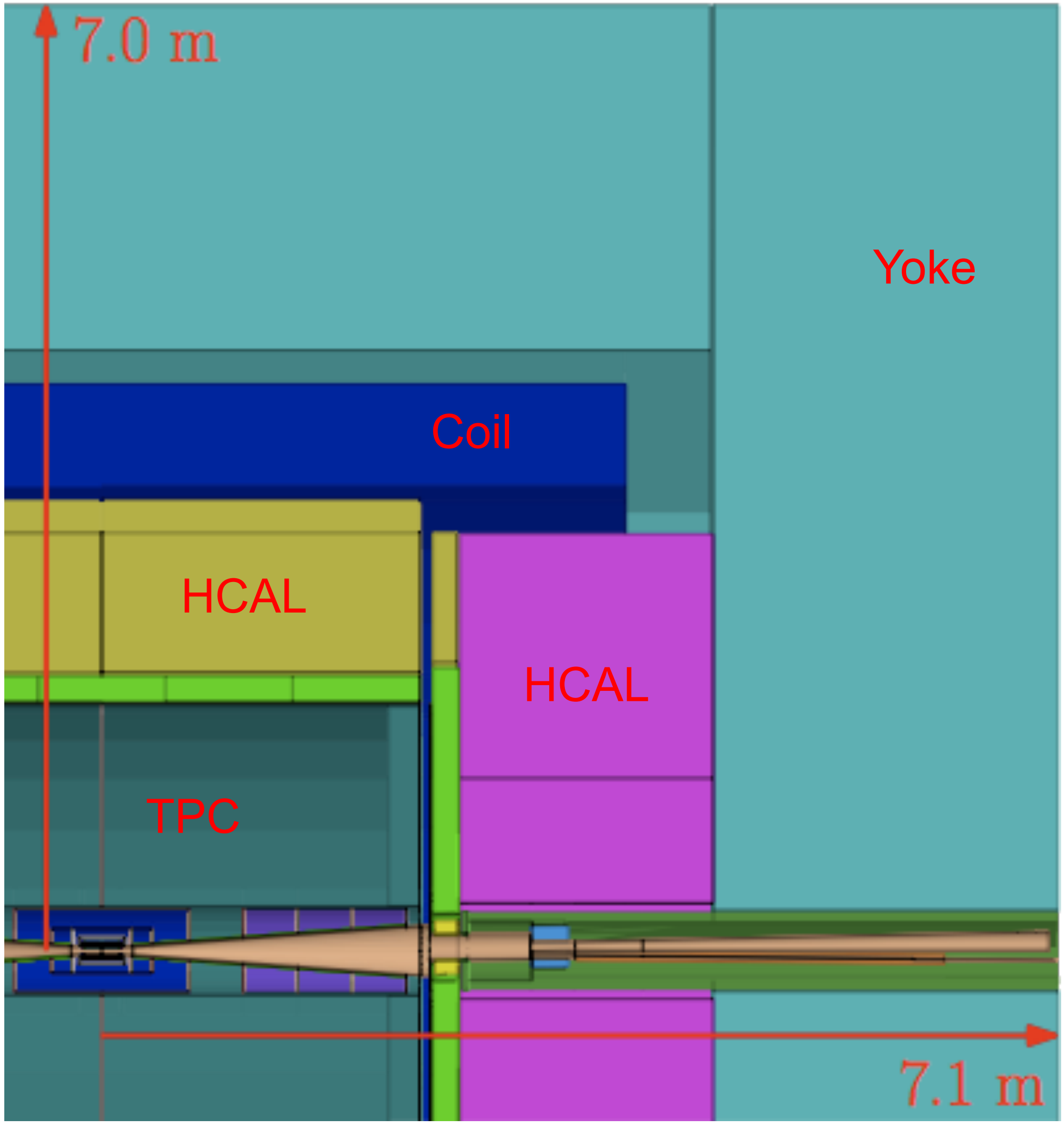
SiD: Silicon Detector

"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

e.g. ILD concept adapted to CLIC



Changes to the ILD detector:

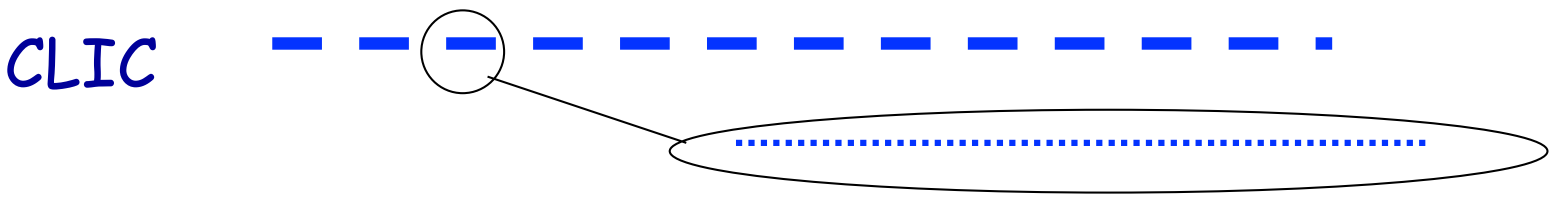
- 20 mrad crossing angle
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- HCAL barrel with ~7 Λ_i with 1 cm tungsten plates
- HCAL endcap with ~7 Λ_i with 2 cm steel plates
- Forward (FCAL) region adaptations

… and similarly for SiD

Andre Sailer

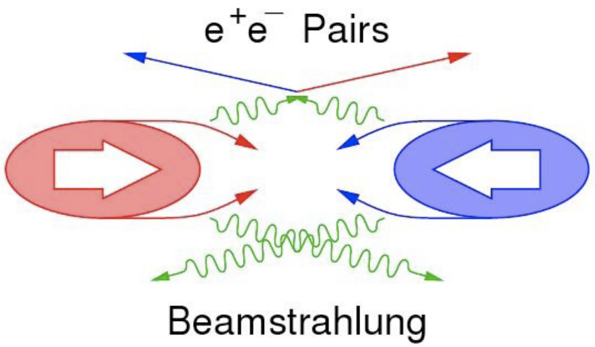
CLIC and ILC time structure

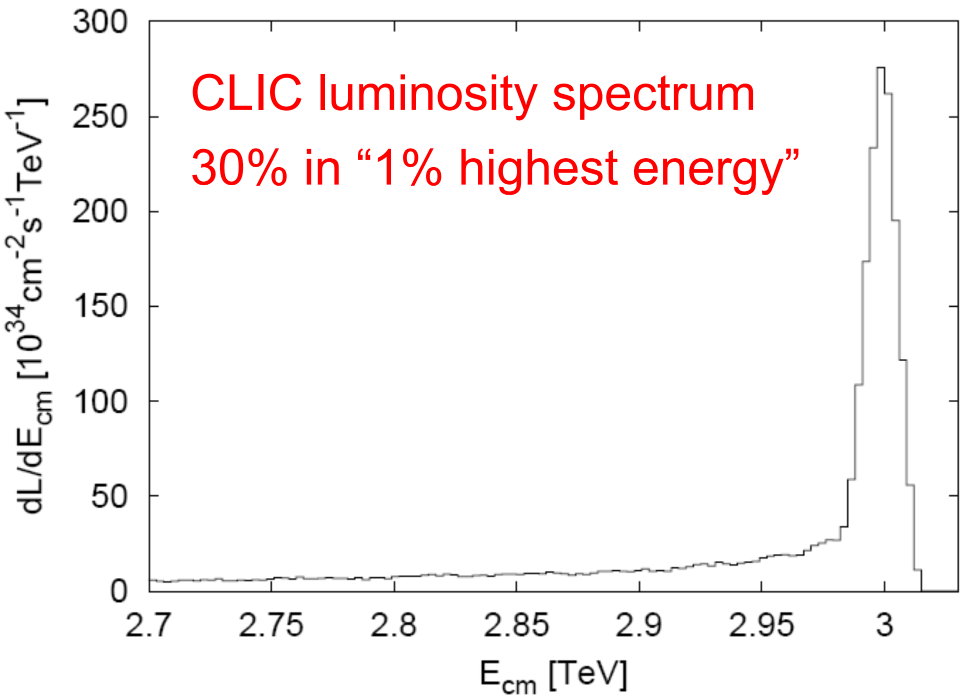
Train repetition rate 50 Hz



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

Beam-induced background (1)



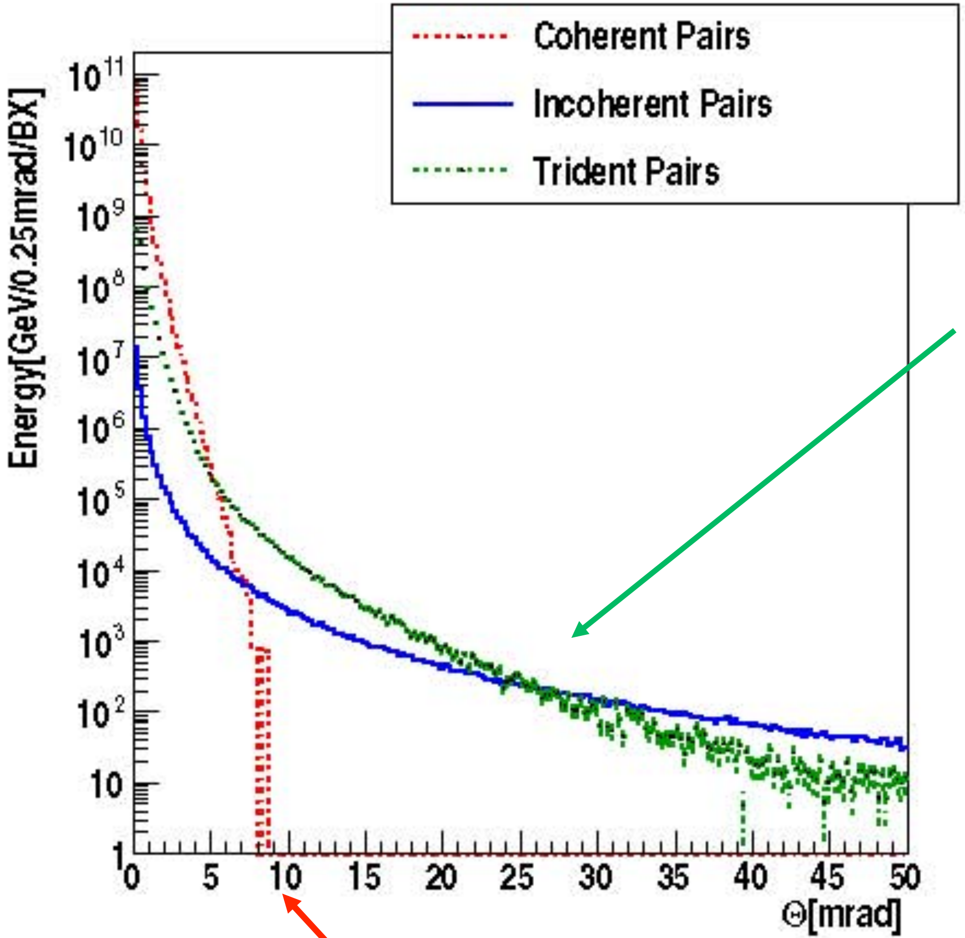


Main backgrounds:

- 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
  - **“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 background (2)

CLIC beamstrahlung: coherent, incoherent + trident pairs



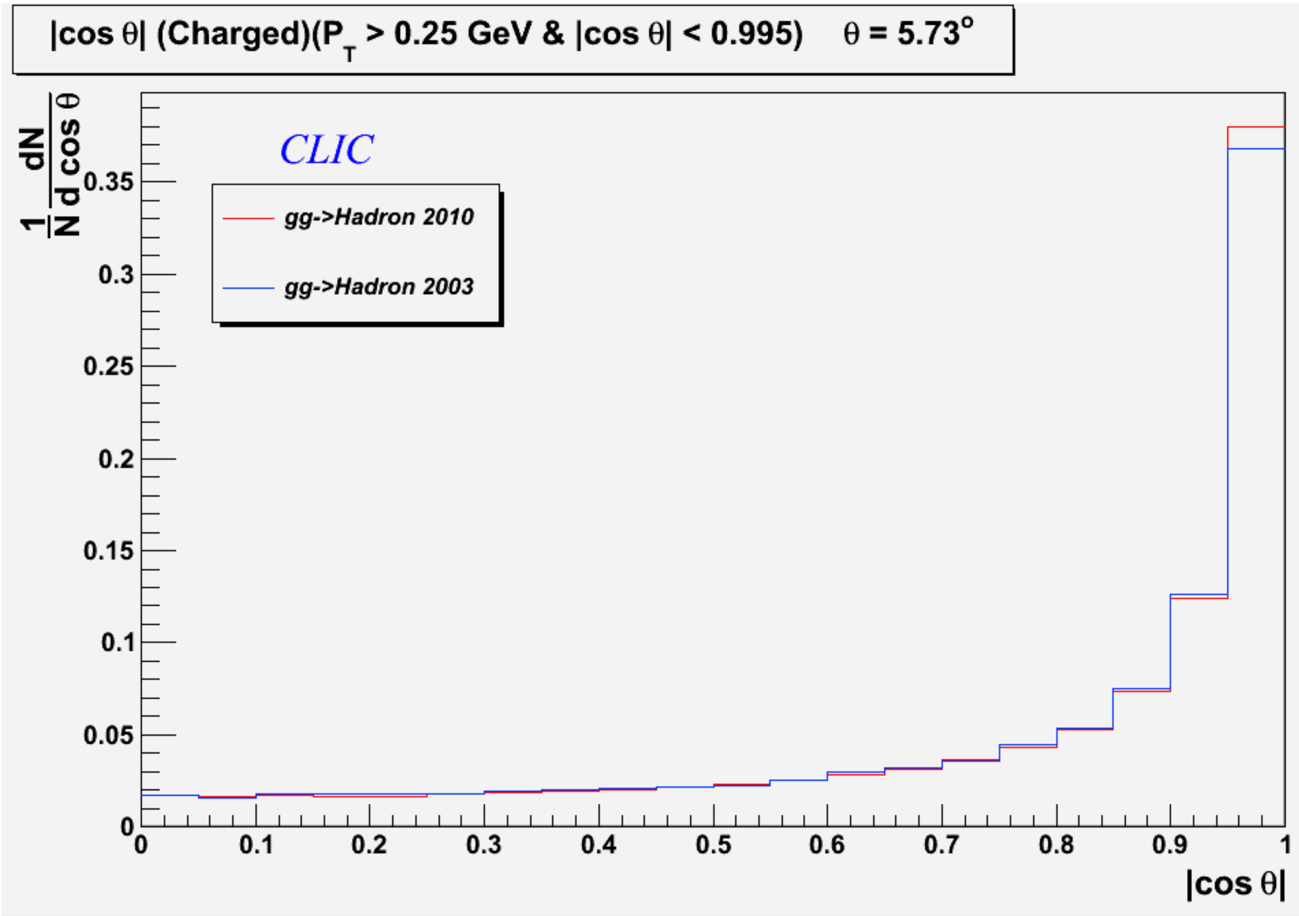
Impact on vertex detector radius (vs. solenoid field),
+ very forward calorimeter radii,
+ choice of materials to reduce backscattering,
etc.

governs opening angle of forward geometry

A. Sailer, CERN+Berlin

Beam-induced background (3)

CLIC beamstrahlung: γγ ➔ hadrons



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

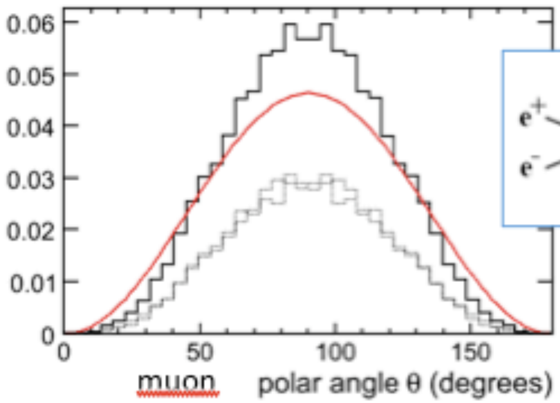
TIME STAMPING !

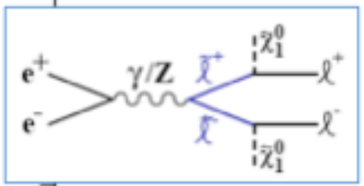
O. Sahin, CERN

At high energy physics goes in forward direction

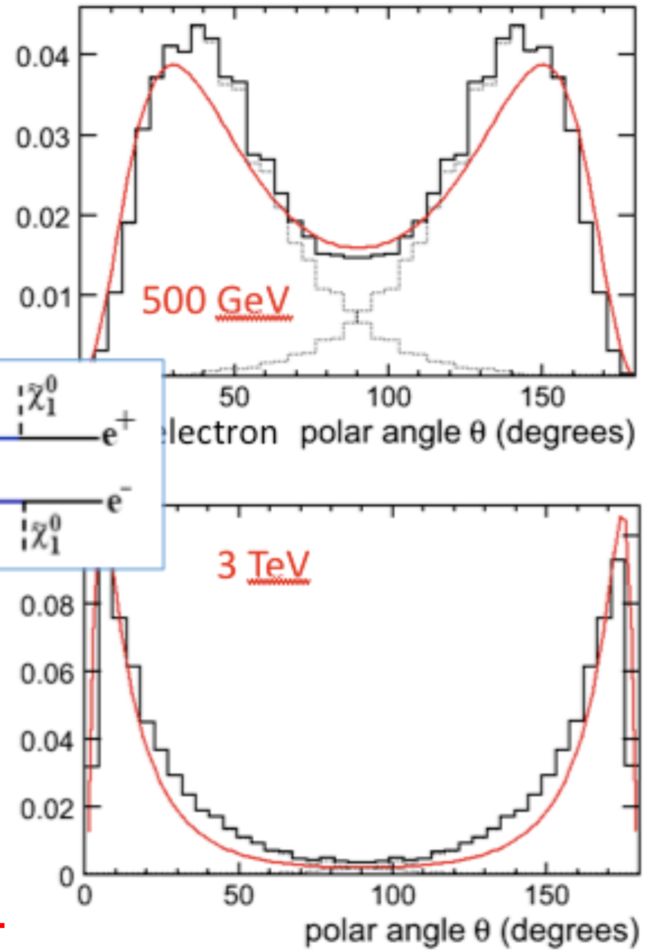
Example: s-lepton production

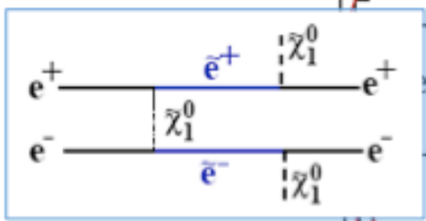
s-muon production





s-electron production



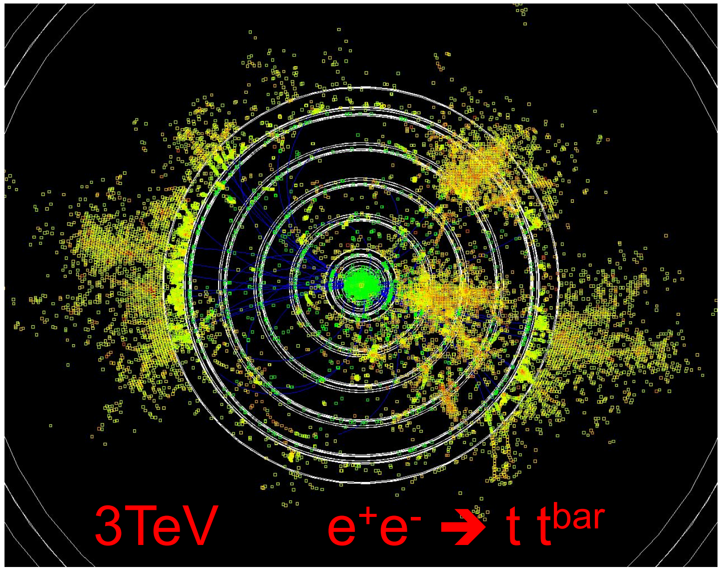


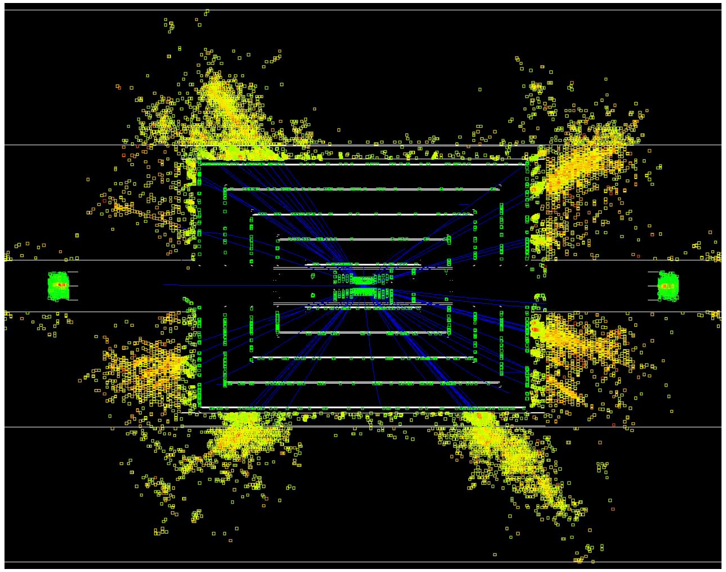
At 3 TeV, t-channel cross-sections are large
Exchange processes go forward.

Background is also principally in forward direction.
Detector optimisation needs special attention here.

CLIC tracking/calorimetry issues

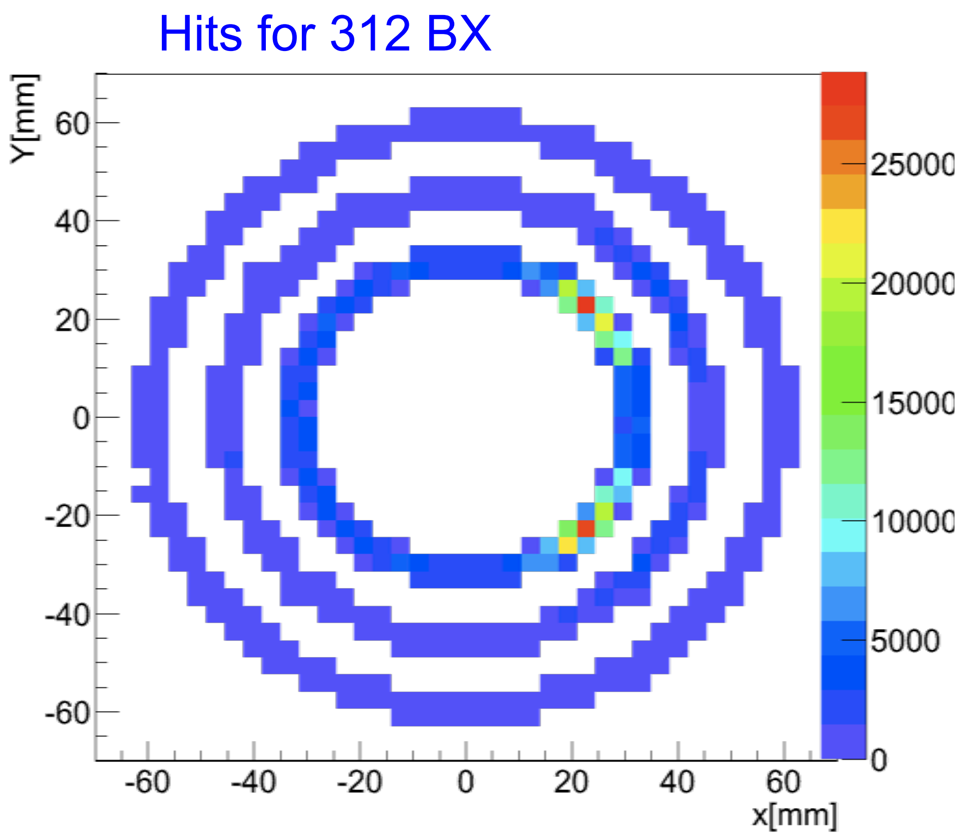
- Due to beam-induced background and short time between bunches:
  - High occupancy in the inner regions (incoherent, tridents)
  - Jets scale and resolution are affected (γγ=>hadrons)
  - Time-stamping is a must for almost all detectors
- Narrow jets at high energy
  - Calorimeter has to measure high-energy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





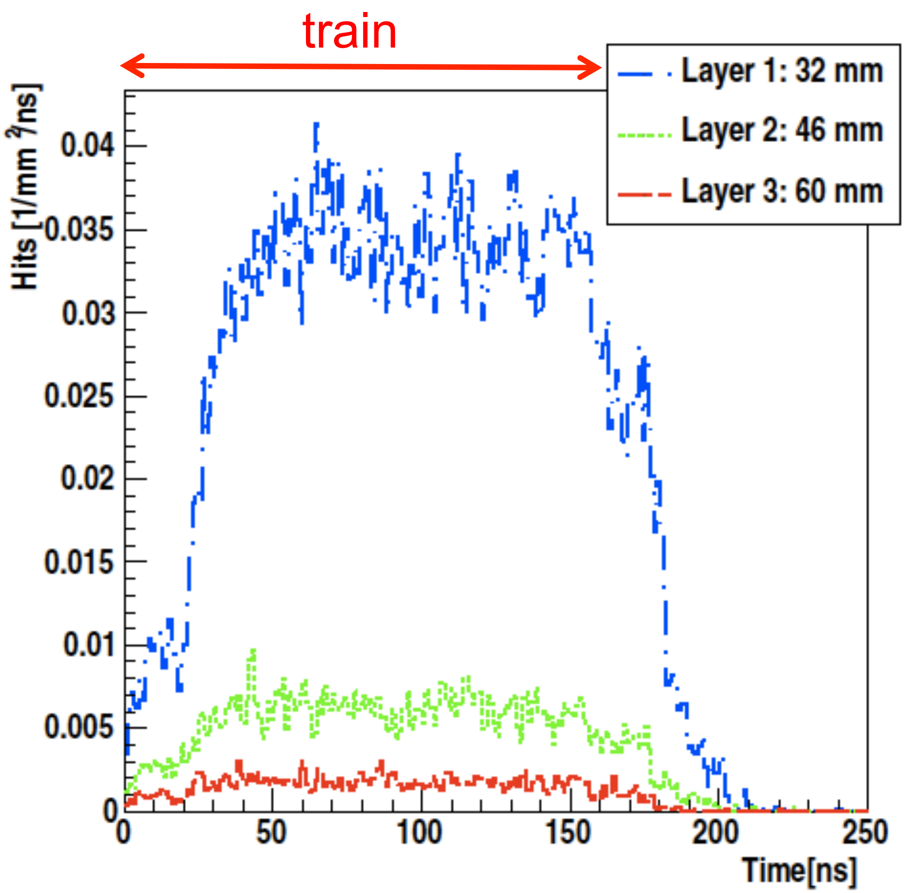
Vertexing - Background

incoherent pairs (and backscattering) hitting the CLIC vertex detector:



X-Y distribution of BG hits

in barrel vertex



time distribution of BG hits

=> ~0.036 hits/mm^{2}ns average

A. Sailer, CERN+Berlin

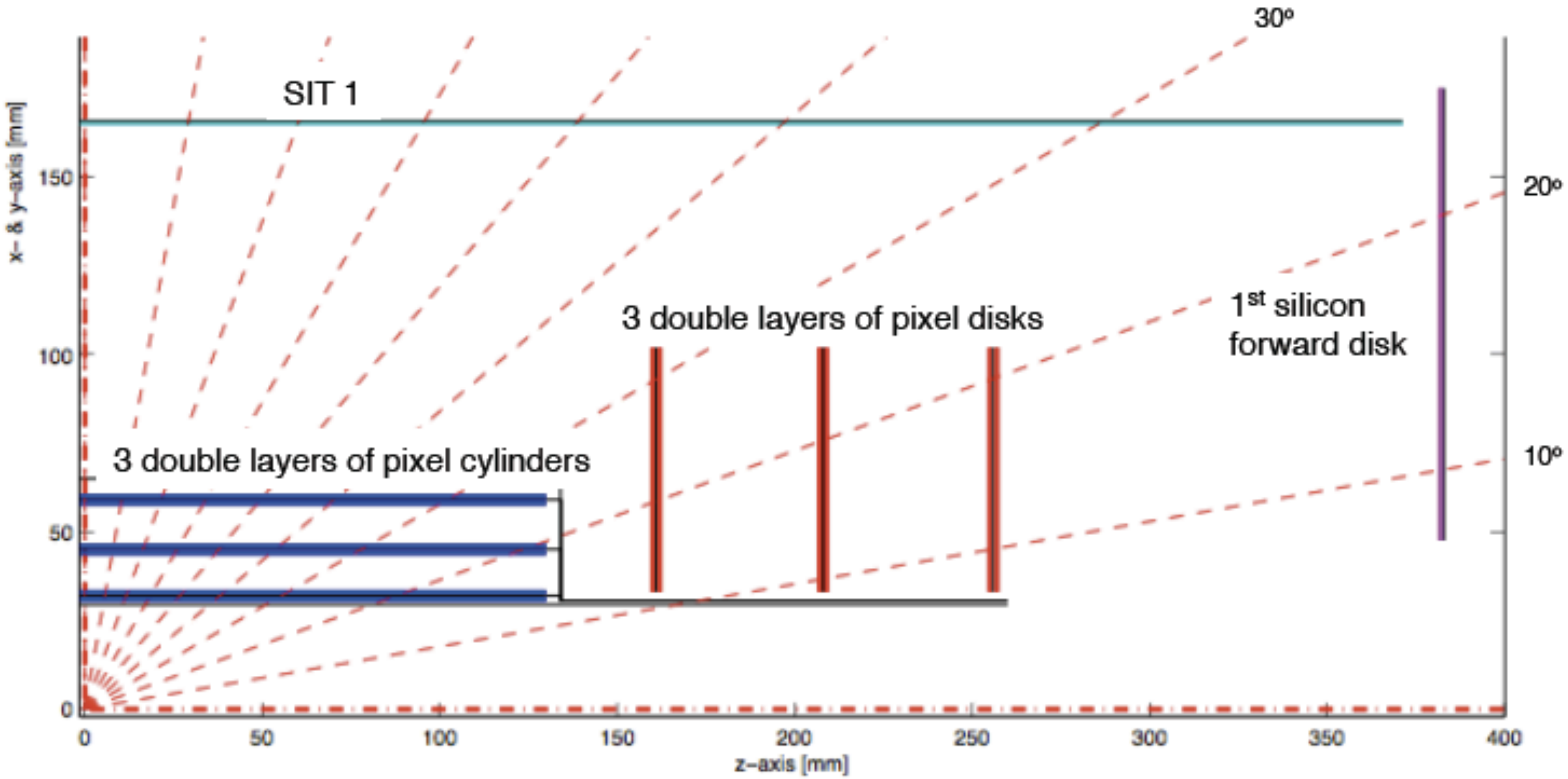
CLIC vertex detector requirements

Requirements for the vertex detector need to be determined more precisely. However, we have already a global view on the 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 vertex detector



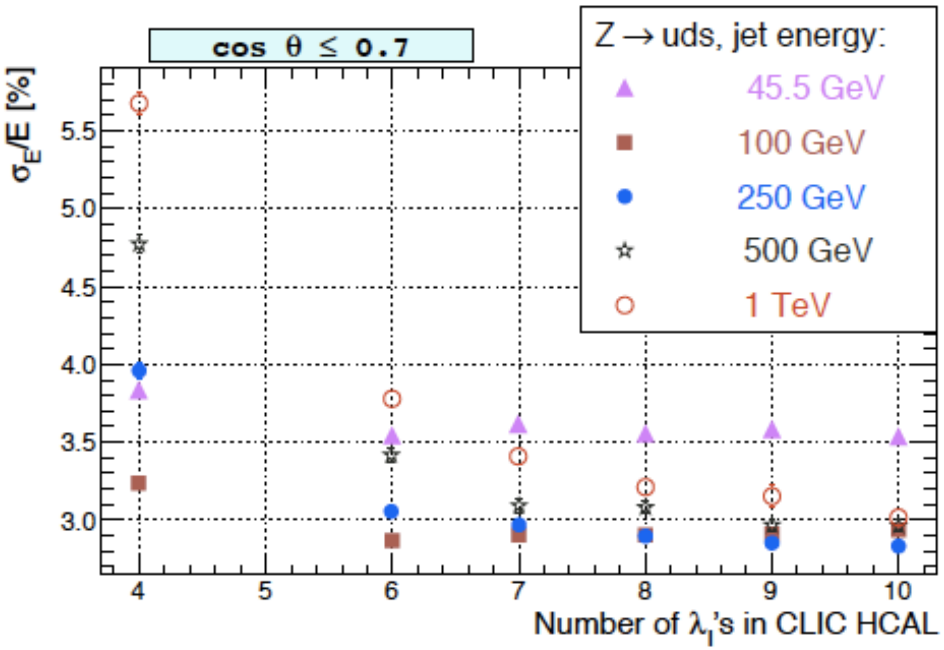
….first layouts are now being implemented in full simulation

Jet Energy Resolution and PFA

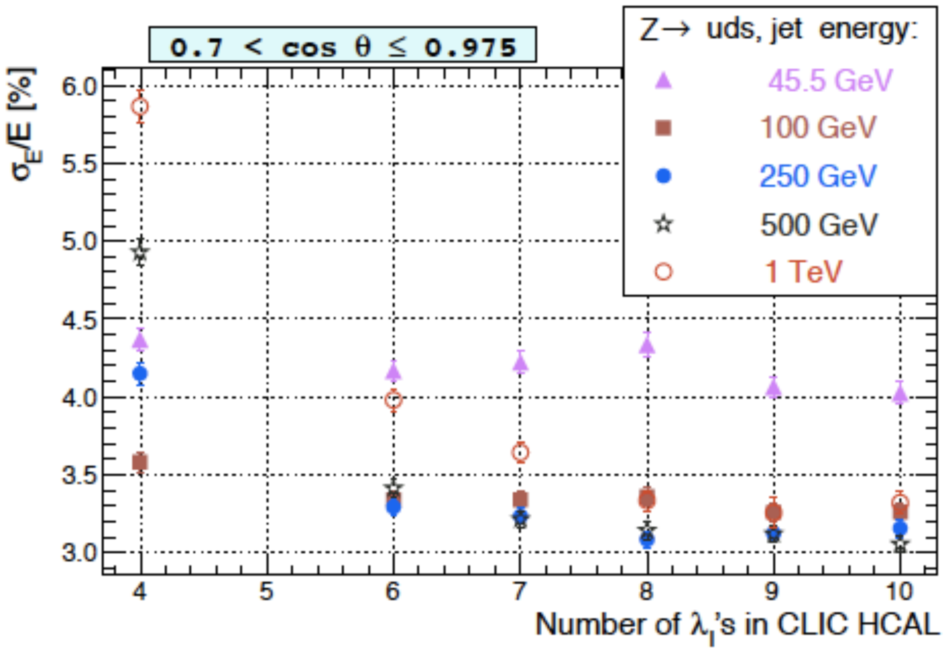
★ Is a detector based on PFA suitable for CLIC ?

★ Study jet energy resolution of a detector with Tungsten HCAL of different depth

Barrel



End-cap



Angela Lucaci-Timoce.CERN

★ The jet energy resolution goal of ~3% can be met for 1 TeV jets

Tungsten HCAL => prototype

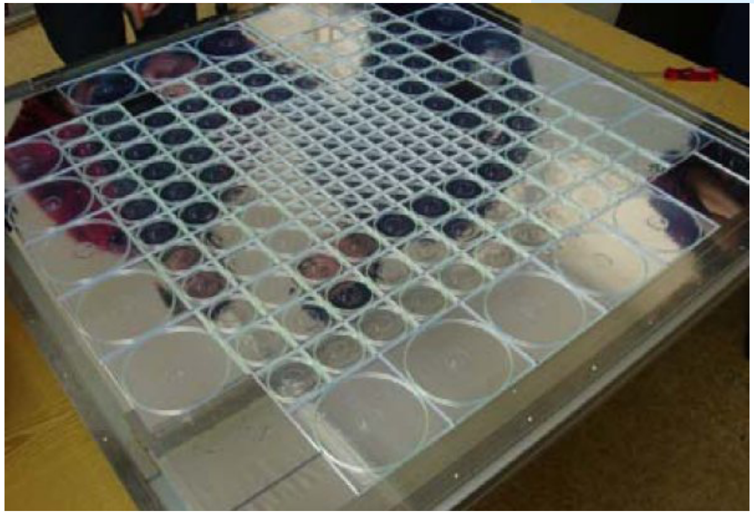
Motivation:

- To limit longitudinal leakage CLIC HCAL needs ~7Λ_i
- 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 is similar
- Increased cost of tungsten barrel HCAL compensates gain in coil cost

Prototype tungsten HCAL: check simulation in test beam

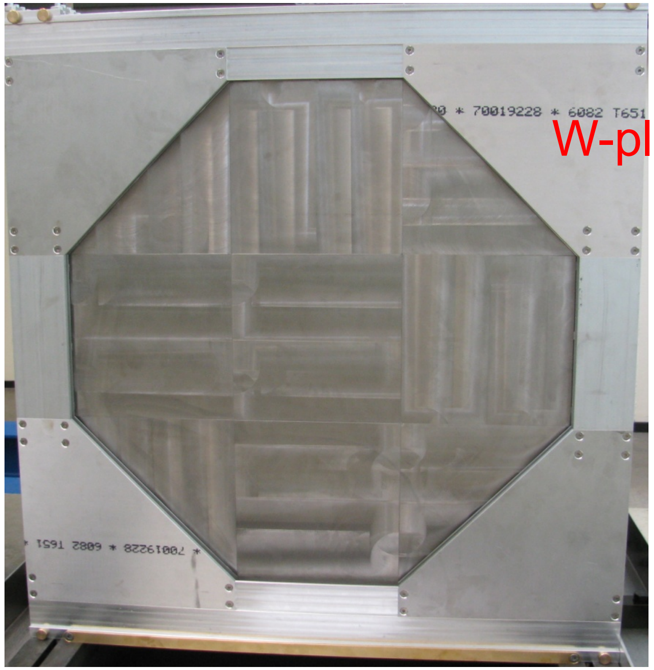
- Prototype tests performed within CALICE collab.
- Use 30-40 layers of Tungsten, 1 cm thick, 80 cm Ø
- Use different active materials
- Start in Nov 2010, with 30 W plates, and scintillator planes

Tungsten HCAL prototype

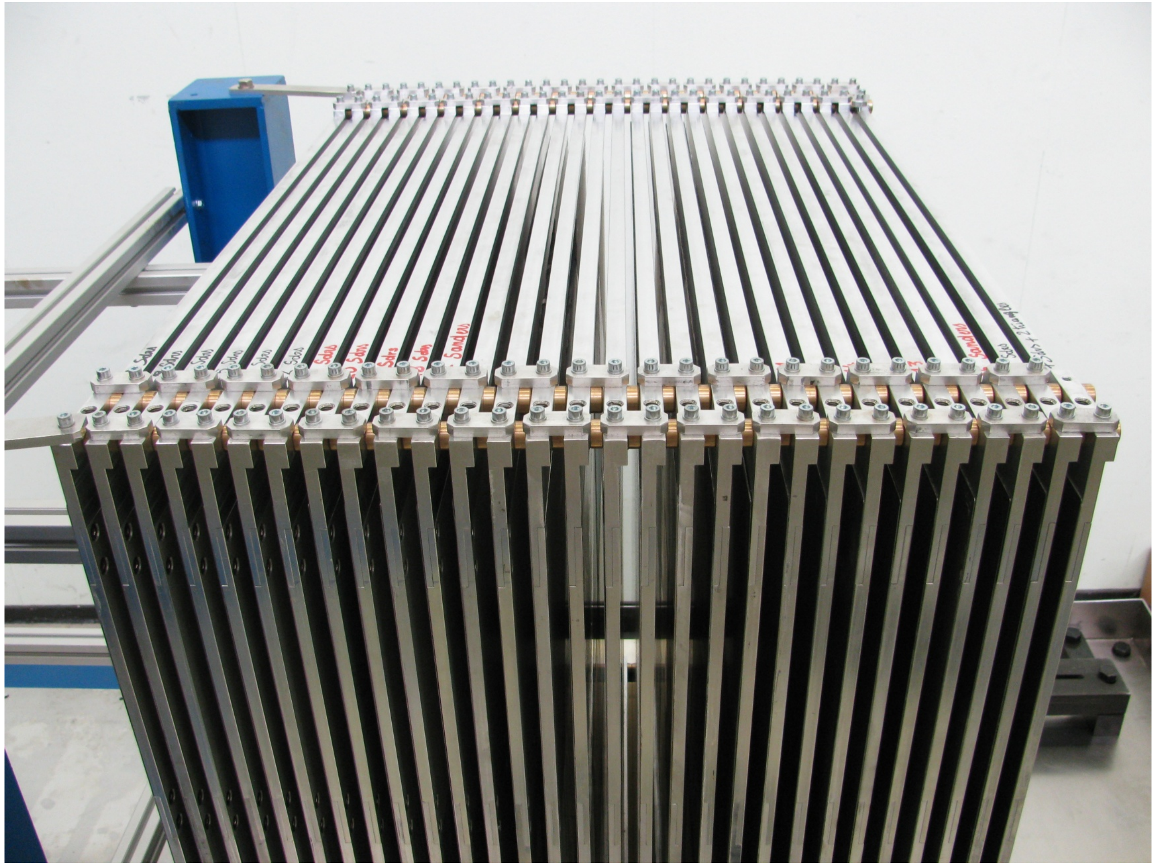


Scintillator plane

Tungsten stack



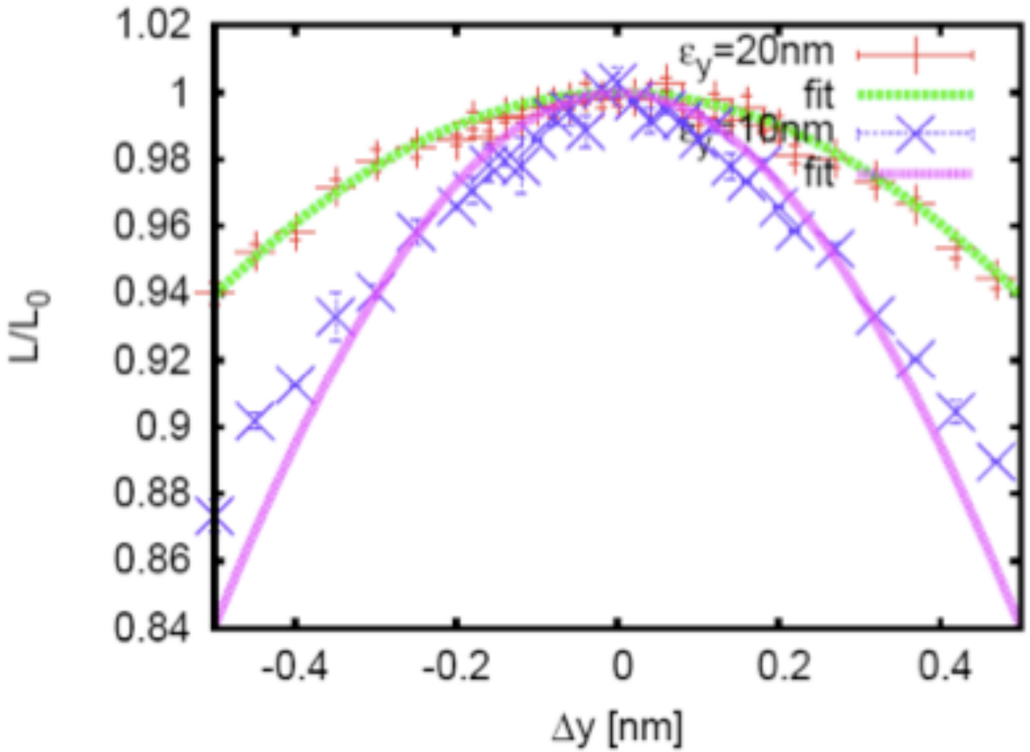
W-plane



Final focus stability

- Final focus quadrupole QD0 inside experiment, L* = ~3.6 m

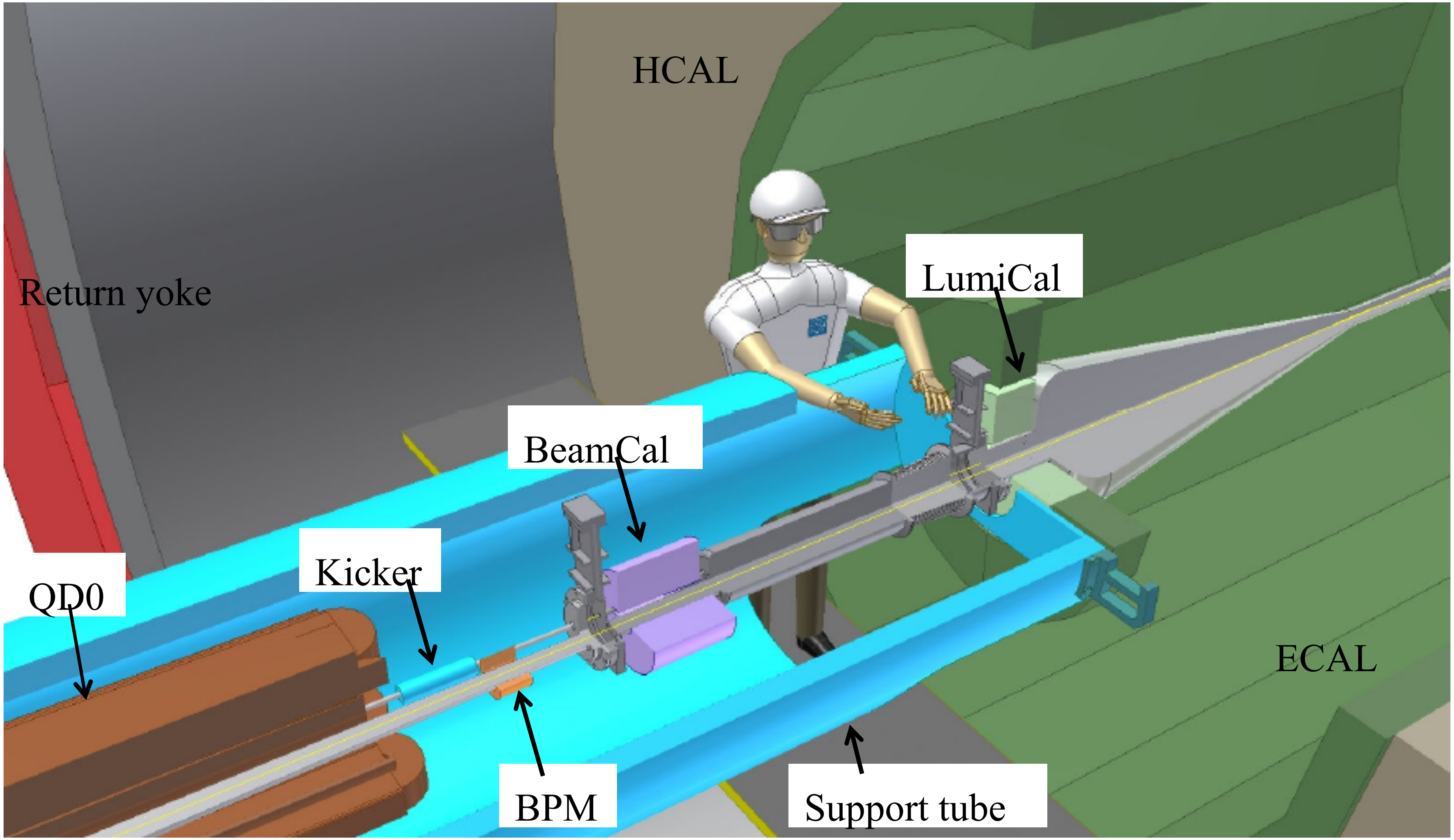
  -- Beam focusing stability required at sub-nm level **!!**



Daniel Schulte CLIC08.

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

Final focus (QD0) stability



Alain Herve (ETHZ), Hubert Gerwig (CERN)

Current LCD@CERN 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
  - Perform physics benchmark studies
- Concentrate on critical issues
  - Determine required sub-detector performances to see the physics
  - Redesign of the very forward region
  - Take engineering aspects, cost etc into account
- Preparing and starting targeted hardware R&D

Hardware/engineering R&D

LCD 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 (PFA calo, within CALICE)
- Time stamping
  - Needed for (almost) all subdetectors
- Power pulsing
  - In view of the 50 Hz CLIC time structure => allows for low-mass detectors
- Solenoid coil
  - Large high-field solenoid concept, reinforced conductor (CMS/ATLAS experience)
- Overall engineering design and integration studies
  - In view of sub-nm precision required for FF quadrupoles
  - For heavier calorimeter, larger overall CLIC detector size etc.

- In addition: TPC electronics development (Timepix-2, S-ALTRO)

Summary

CLIC has a large physics potential, complementary to LHC

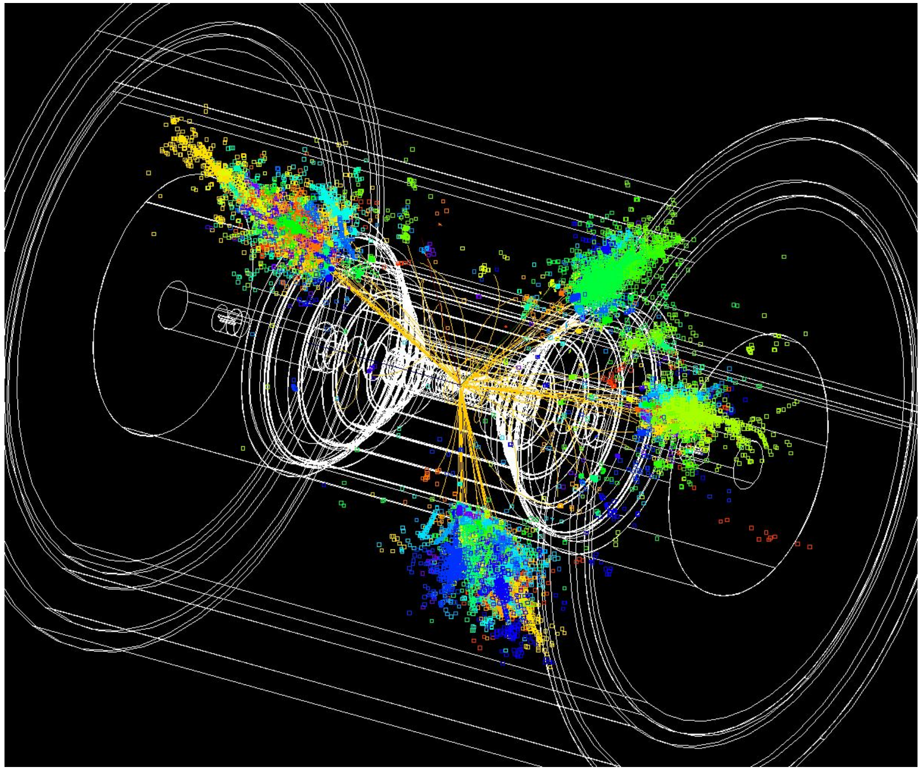
CLIC physics/detector studies in close collaboration with ILC
Growing community both inside and outside CERN

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

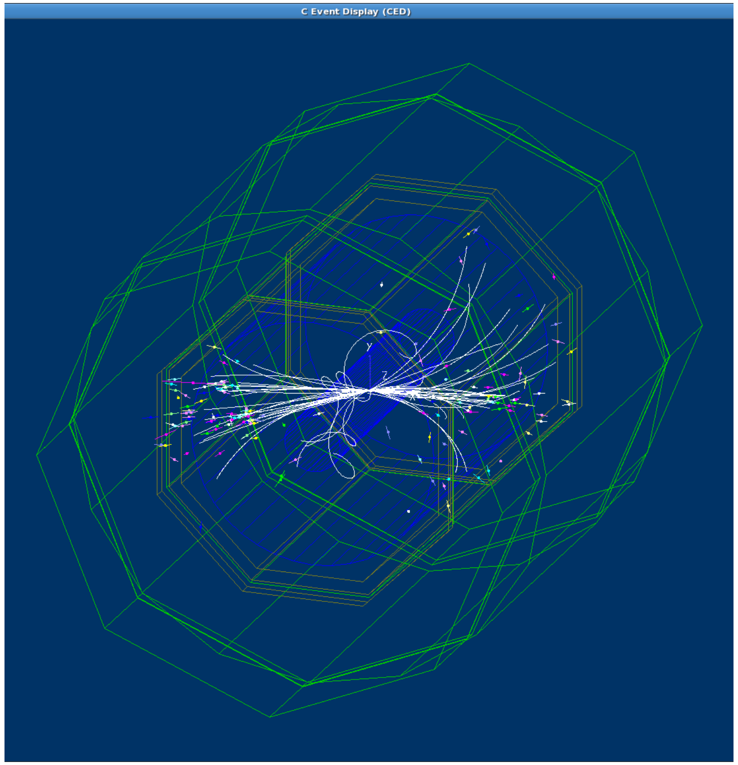
- Software tools in place for adapted ILD and SiD detector models
- Detector requirements globally "understood"
- Detector geometries for CDR simulations being finalised
- Physics benchmark studies for the CDR are starting
- Hardware R&D has started

Welcome to join

Thank you!



CLIC_SiD detector



CLIC_ILD detector

Spare Slides

CLIC parameters

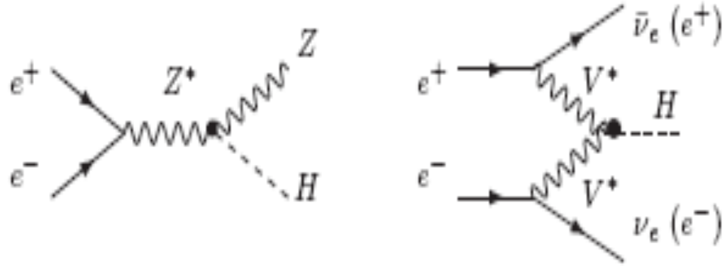
Center-of-mass energy	ILC 500 GeV	CLIC 500 GeV	CLIC 3 TeV
Total (Peak 1%) luminosity [$\cdot 10^{34}$]	2(1.5)	2.3 (1.4)	5.9 (2.0)
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	32	80	100
Main linac RF frequency GHz	1.3	12	
Bunch charge [$\cdot 10^9$]	20	6.8	3.7
Bunch separation (ns)	370	0.5	
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)

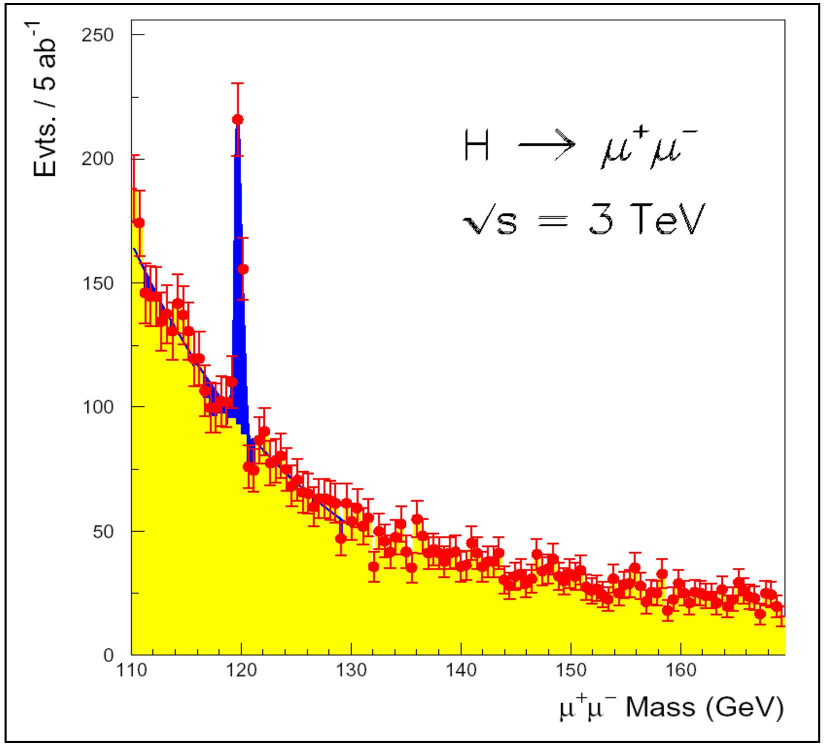
Example:…. light SM-like Higgs

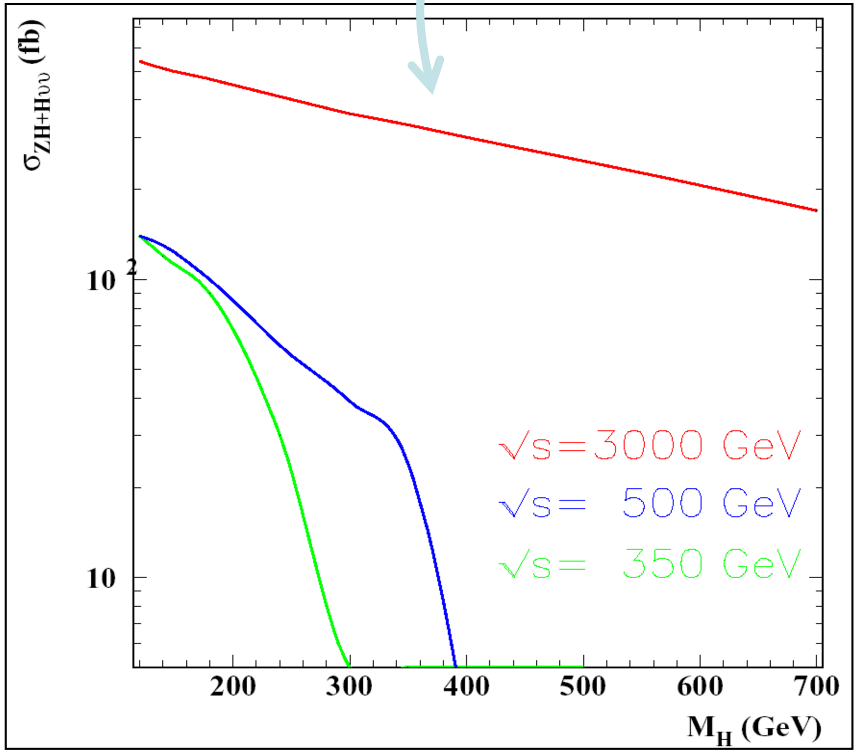
The cross-section at ~3TeV is very large
→ access to very rare decays (BR~10^{-4}).

Measure Higgs couplings to leptons, for instance with 0.5 ab^{-1}, we expect ~70 $H \rightarrow \mu^+\mu^-$ decays for M_h=120 GeV/c^2, and measure the couplings with ~4% precision.



$\sigma \propto 1/s$ $\sigma \propto \log(s)$



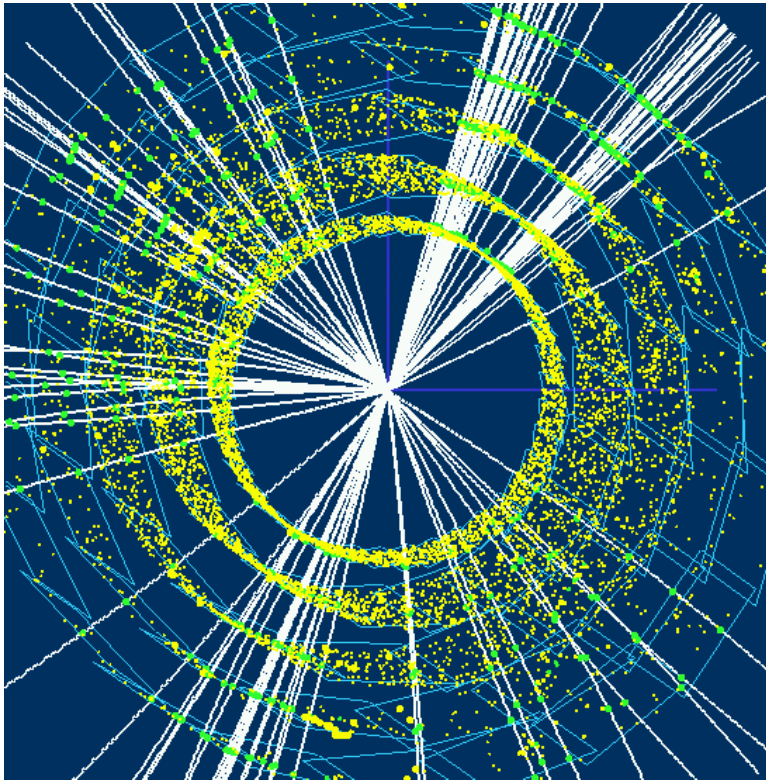


http://www.cern.ch/lcd Lucie Linssen, 2/9/2010

Example: heavy mass SUSY particles

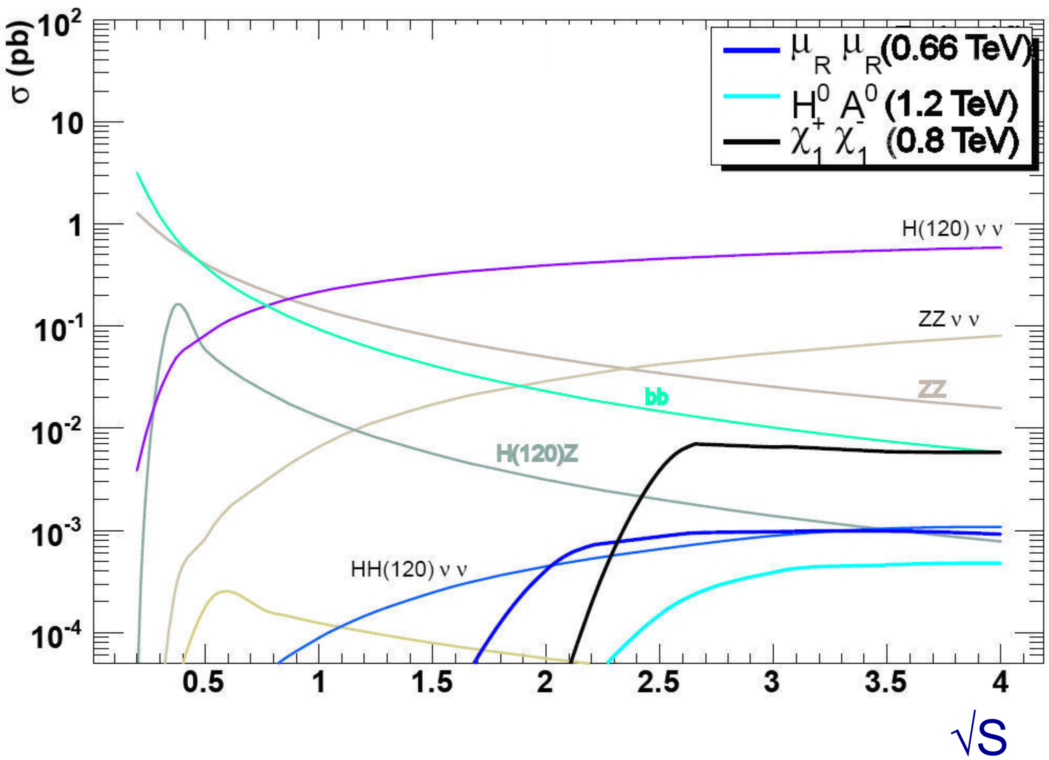
e.g. $e^+e^- \rightarrow H^0A^0$ production

$e^+e^- \rightarrow H^0A^0 \rightarrow b\bar{b}b\bar{b}$



$m_{H,A} \approx 1$ TeV
Yellow dots mostly from $\gamma\gamma$

s-channel vs t-channel cross sections



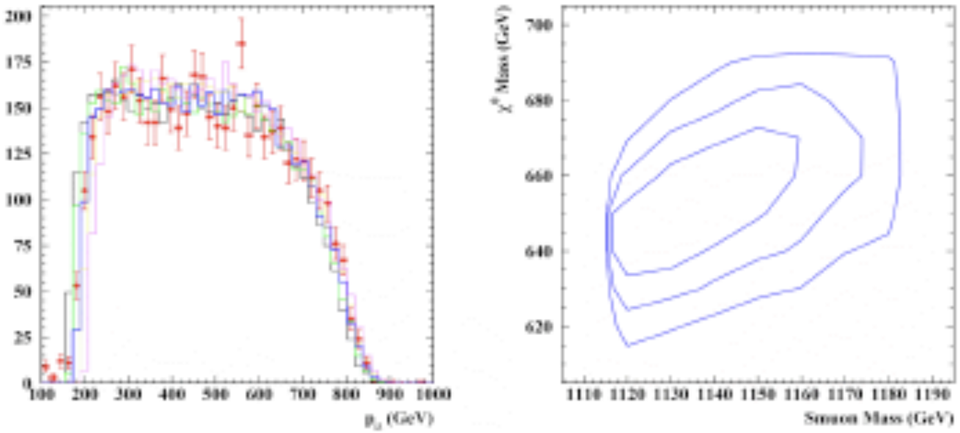
Marco Battaglia

Example: SUSY mass measurement

Mass determinations: $e^+e^- \to \tilde{\mu}_L^+ \tilde{\mu}_L^- \to \mu^+ \chi_1^0 \mu^- \chi_1^0$

- If $\sqrt{s} >> 2\tilde{m}_\mu$, μ spectrum end points

$$E_{\min,\max} = \frac{\sqrt{s}}{4}\left(1 - \tilde{m}_\chi^2 / \tilde{m}_\mu^2\right)\left(1 \pm \sqrt{1 - 4\tilde{m}_\mu^2 / s}\right)$$



Two-parameter fit

$\tilde{m}_\mu = (1145 \pm 25)$ GeV 2%

$\tilde{m}_\chi = (652 \pm 22)$ GeV 3%

- Energy scan of cross section close to threshold

$$\delta\tilde{m}_\mu = 15 \text{ GeV}$$

LHC mass determinations improve if info from CLIC is included in decay chains

Gian Giudice CLIC09

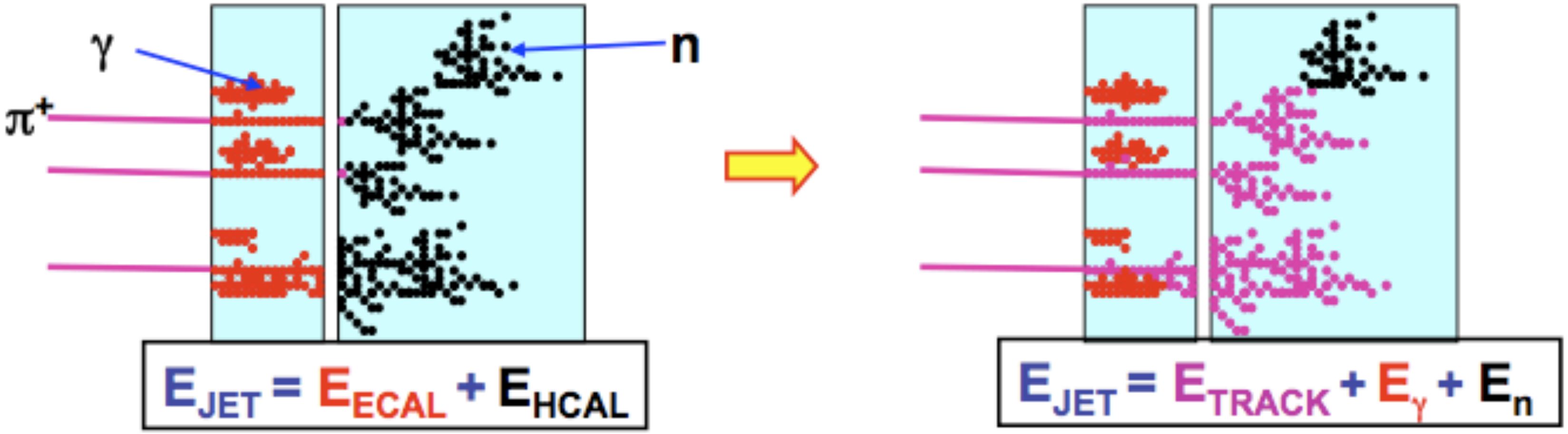
❷ The Particle Flow Paradigm

★ **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: $\sigma_{\mathrm{E}}/\mathrm{E} \approx 60\,\%/\sqrt{\mathrm{E(GeV)}}$
- Intrinsically "poor" HCAL resolution limits jet energy resolution



★ **Particle Flow Calorimetry paradigm:**

- charged particles measured in tracker (essentially perfectly)
- Photons in ECAL: $\sigma_{\mathrm{E}}/\mathrm{E} < 20\,\%/\sqrt{\mathrm{E(GeV)}}$
- 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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