Linear Collider Detector project @ CERN

towards a CLIC (ILC) detector

R&D

Lucie Linssen
CERN

Outline and useful links

Outline:

- Short introduction to the CLIC accelerator
- Linear Collider Detector project @ CERN
- CLIC detector issues
  - difference wit ILC case
- CLIC detector R&D
- Outlook

Useful links:

- **Linear Collider Detector project at CERN**
- http://lcd.web.cern.ch/LCD/NewWelcome.html

- **CLIC08 workshop, October 14-17 2008**
- http://project-clic08-workshop.web.cern.ch/project-clic08-workshop/

The CLIC Two Beam Scheme

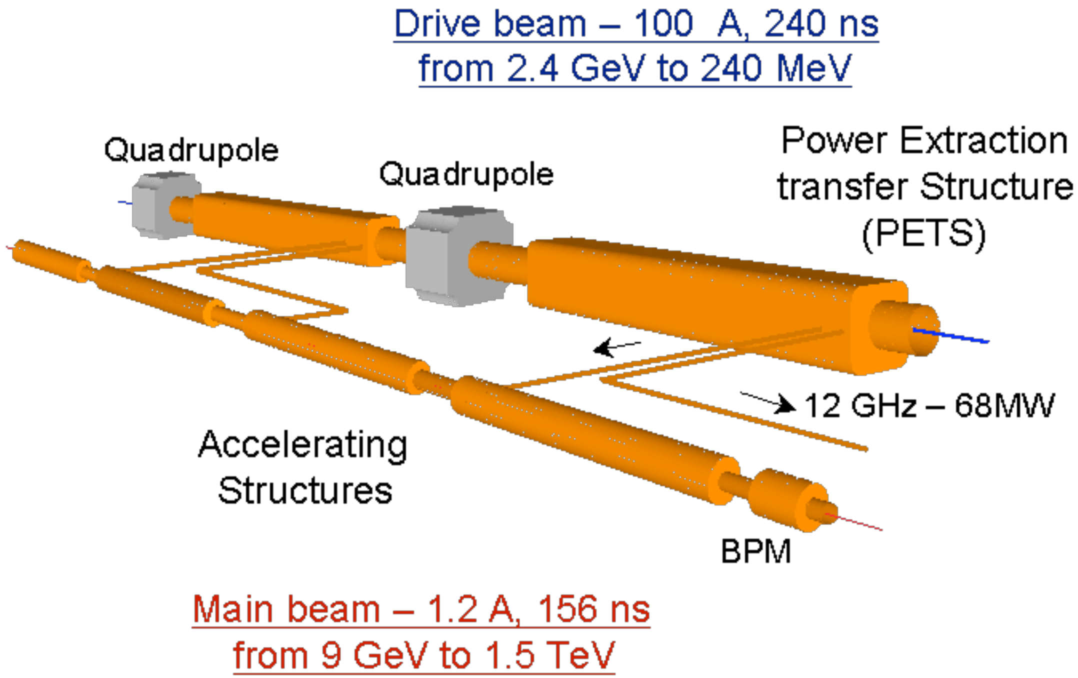
Two Beam Scheme:

Drive Beam supplies RF power

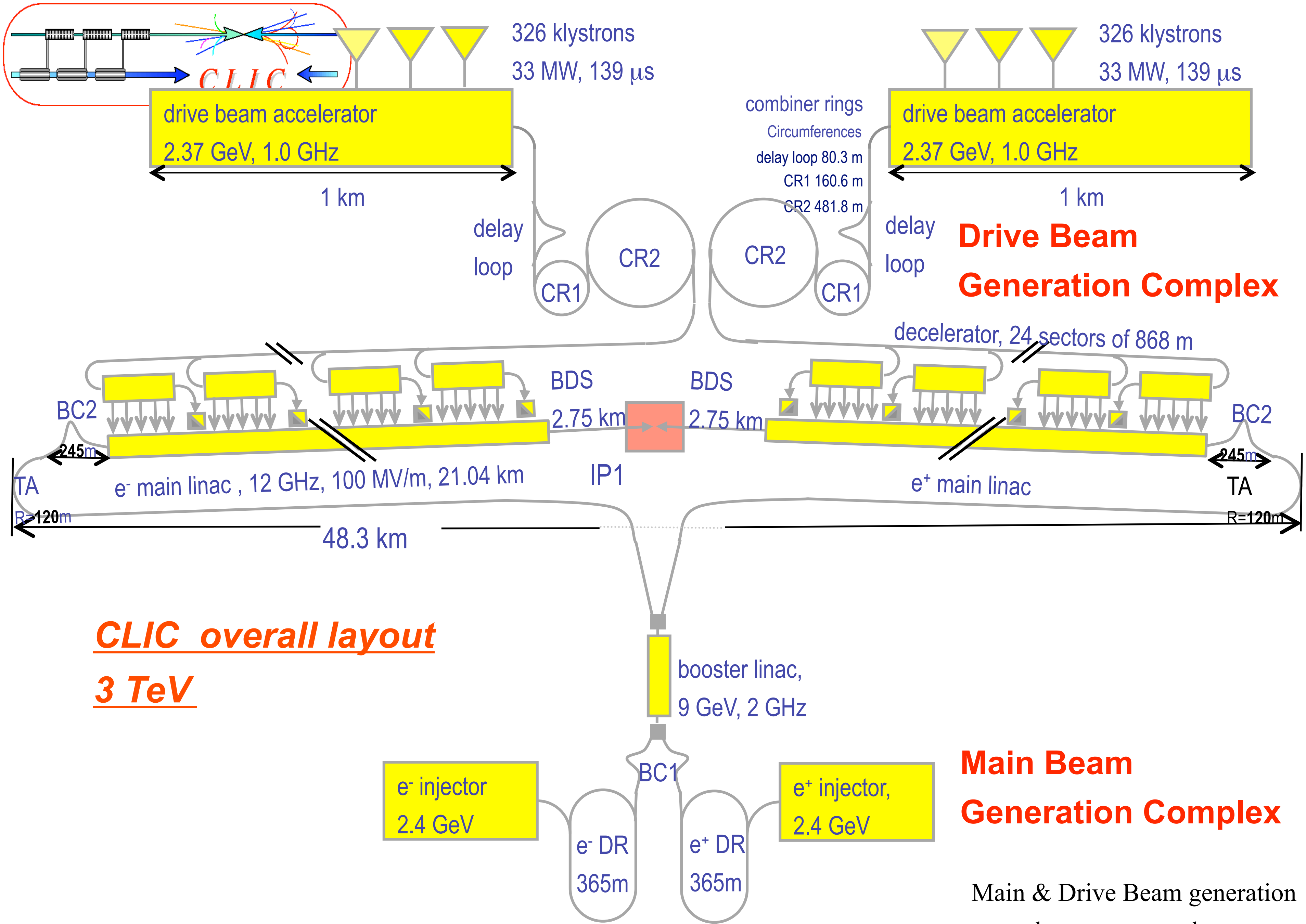
- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

Main beam for physics

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

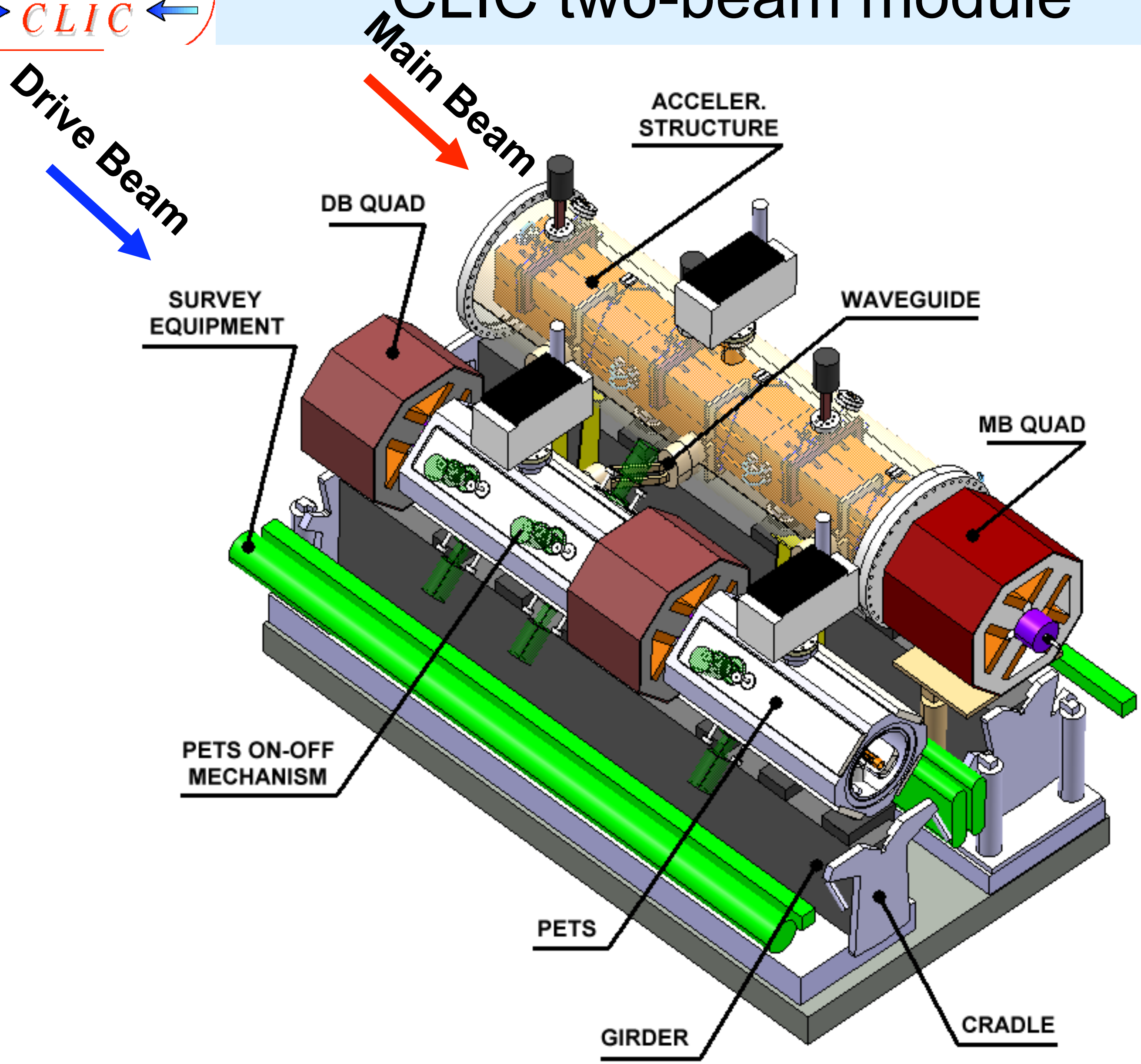


No individual RF power sources

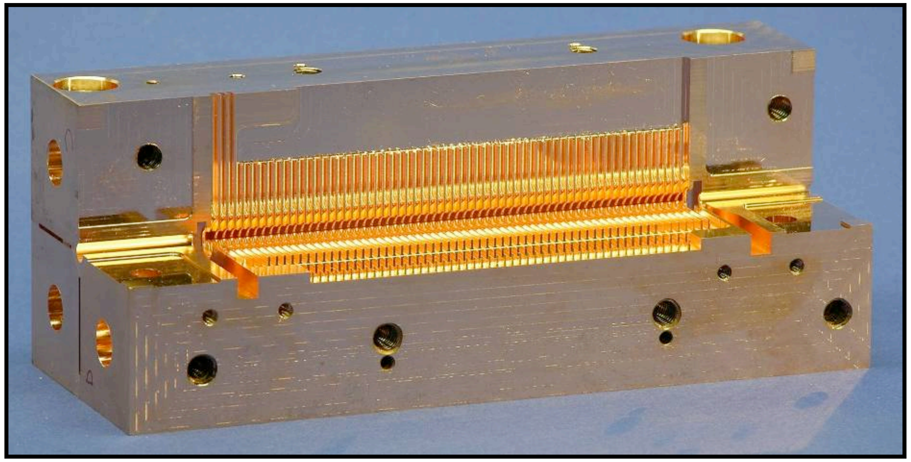


Main & Drive Beam generation complexes not to scale

CLIC two-beam module



Main beam accelerating structures

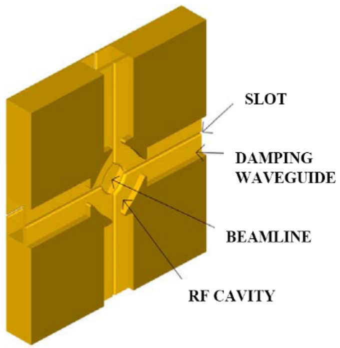


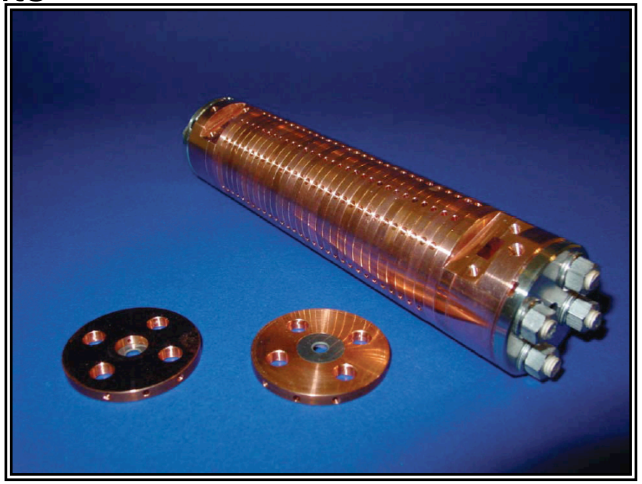
Objective:

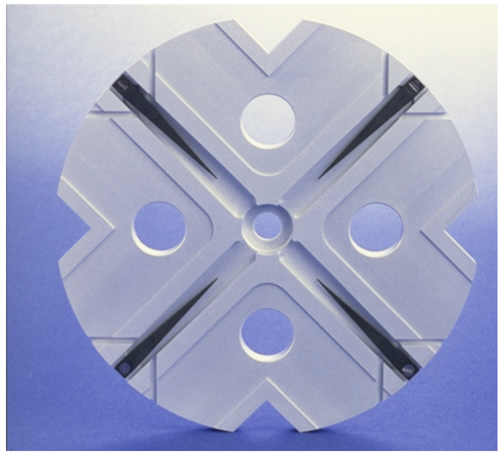
- Withstand of 100 MV/m without damage
- Breakdown rate < 10^{-7}
- Strong damping of HOMs

Technologies:

Brazed disks - milled quadrants

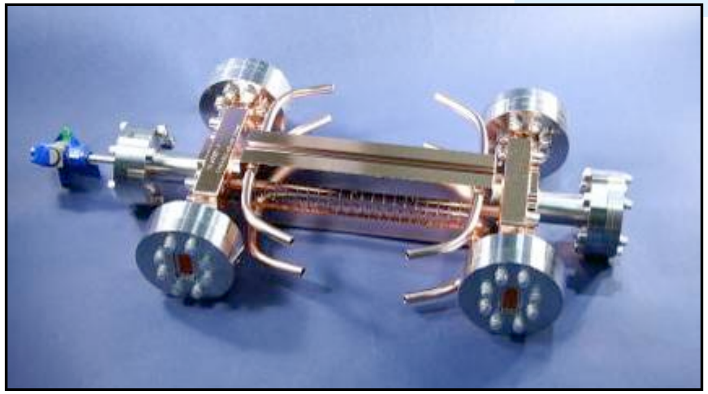






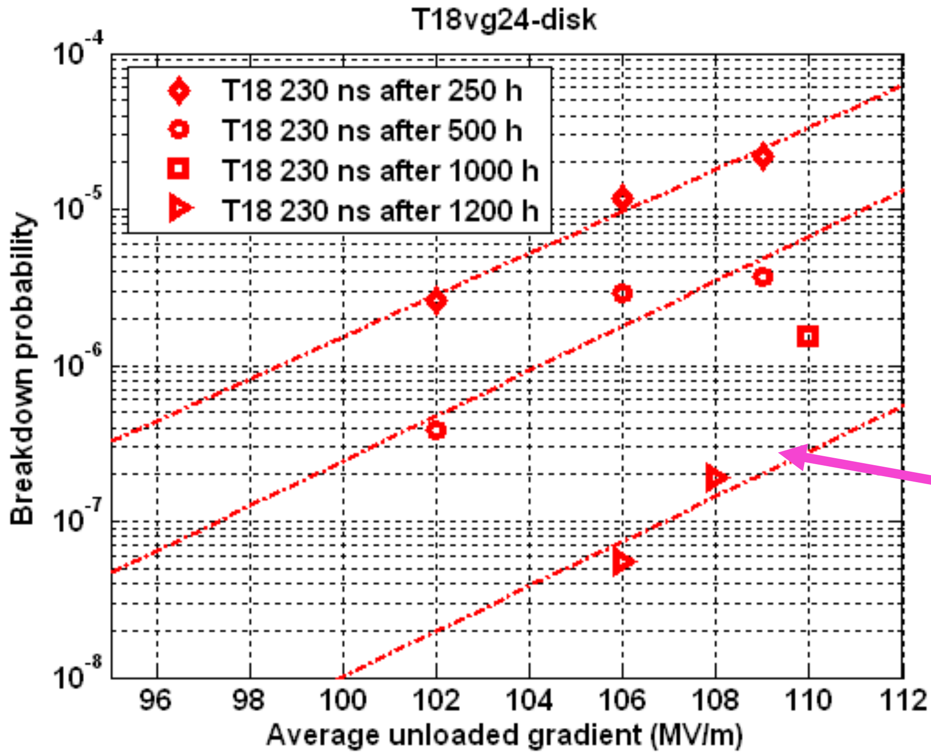
Collaboration: CERN, KEK, SLAC

Best result so far



High Power test of T18_VG2.4_disk (without damping)

- Designed at CERN,
- Machined by KEK,
- Brazed and tested at SLAC

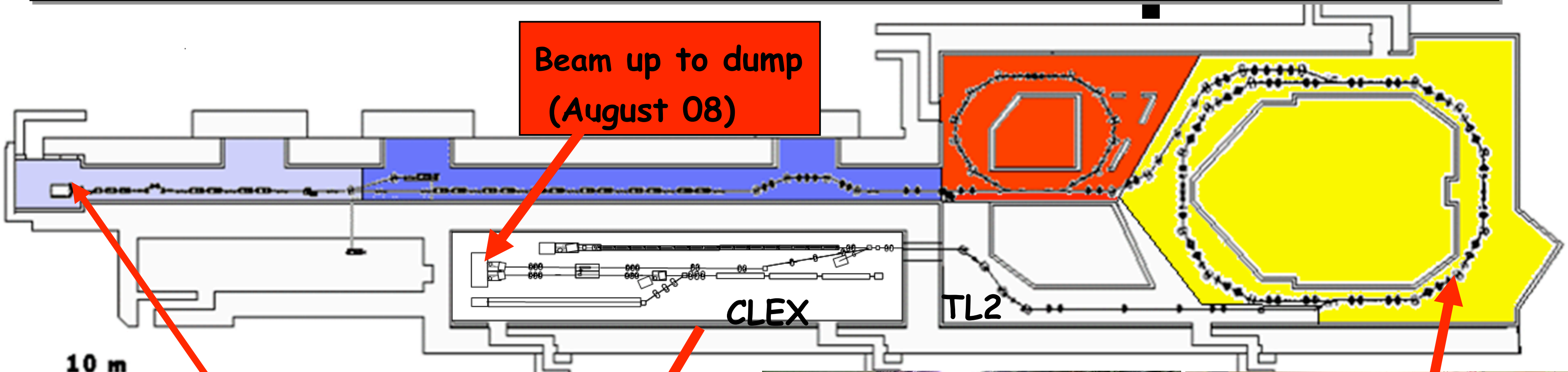


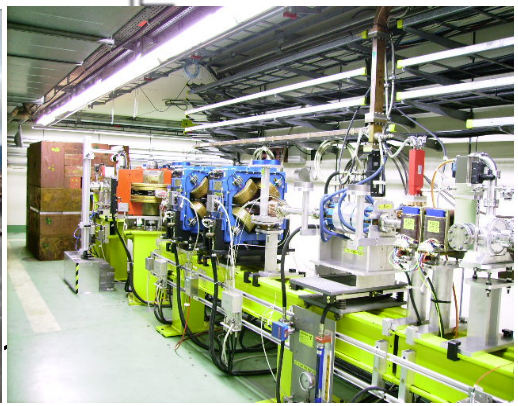
Improvement by RF conditionning

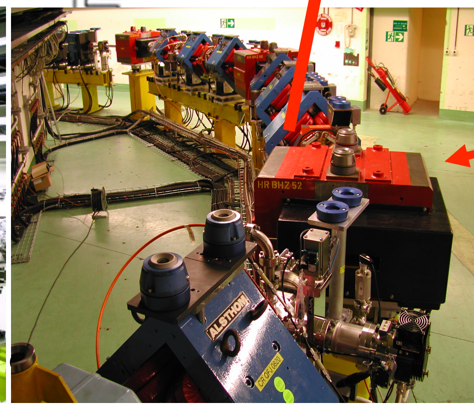
CLIC target

CLIC test facility CTF3

- **Demonstrate Drive Beam generation**
  (fully loaded acceleration, beam intensity and bunch frequency multiplication x8)
- **Demonstrate RF Power Production and test Power Structures**
- **Demonstrate Two Beam Acceleration and test Accelerating Structures**
- **Operational Experience (reliability) by continuous operation (10m/year)**







World-wide CLIC / CTF3 accelerator collab.

http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm

24 members representing 27 institutes involving 17 funding agencies of 15 countries

Ankara University (Turkey)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)
IRFU/Saclay (France)

Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
Instituto de Fisica Corpuscular (Spain)
INFN / LNF (Italy)
J.Adams Institute, (UK)

JINR (Russia)
JLAB (USA)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)

University of Oslo (Norway)
PSI (Switzerland),
Polytech. University of Catalonia (Spain)
RRCAT-Indore (India)
Royal Holloway, Univ. London, (UK)
SLAC (USA)
Uppsala University (Sweden)

CLIC parameters

Center-of-mass energy	CLIC 500 GeV	CLIC 3 TeV
Total (Peak 1%) luminosity	$2.3\ (1.4) \cdot 10^{34}$	$5.9\ (2.0) \cdot 10^{34}$
Repetition rate (Hz)	50	
Loaded accel. gradient MV/m	80	100
Main linac RF frequency GHz	12	
Bunch charge [10^9]	6.8	3.72
Bunch separation (ns)	0.5	
Beam pulse duration (ns)	177	156
Beam power/beam (MWatts)	4.9	14
Hor./vert. IP beam size (nm)	202 / 2.3	40 / 1.0
Hadronic events/crossing at IP	0.19	2.7
Coherent pairs at IP	100	$3.8\ 10^8$
BDS length (km)	1.87	2.75
Total site length km	13.0	48.3
Total power consumption MW	129.4	415

Collaboration between ILC and CLIC

Since February 2008: official collaboration between ILC and CLIC

http://clic-study.web.cern.ch/CLIC-Study/CLIC_ILC_Collab_Mtg/Index.htm

	CLIC	ILC
Physics & Detectors	L.Linssen, D.Schlatter	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)	D.Schulte, R.Tomas Garcia E.Tsesmelis	B.Parker, A.Seriy
Civil Engineering & Conventional Facilities	C.Hauviller, J.Osborne.	J.Osborne, V.Kuchler
Positron Generation (new)	L.Rinolfi	J.Clarke
Damping Rings (new)	Y.Papaphilipou	M.Palmer
Beam Dynamics	D.Schulte	A.Latina, K.Kubo, N.Walker
Cost & Schedule	H.Braun (P.Lebrun), K.Foraz, G.Riddone	J.Carwardine, P.Garbincius, T.Shidara

Linear Collider Detector project at CERN

What is our goal ?

We are working towards a linear collider detector which will operate in an energy range (CM) from 500 GeV to 3 TeV

Working together with the ILC concepts (SiD, ILD, 4^{th}) and with the detector collaborations (LC-TPC, EUDET, FCAL, CALICE).

In a concerted effort with the individual concepts, we work towards describing the possible changes or upgrades to the ILC concepts to make them compatible with multi-TeV energies and CLIC beam conditions.

Current schedule: CLIC CDR end 2010, CLIC TDR 2015

LCD@CERN, who are we?

Who are we ?

- LL (project leader)
- Dieter Schlatter
- Konrad Elsener
- Peter Speckmayer (Fellow)
- Christian Grefe (Doct)
- Andre Sailer (Doct)
- Marco Battaglia (PDSA)

+ part time help from CERN staff

+ CERN contribution to EUDET

LAPP Annecy	ETH Zurich	STFC-RAL
Jean-Jacques Blaising	Alain Hervé	Marcel Stanitzki
Jan Blaha (Doct)		Jan Strube

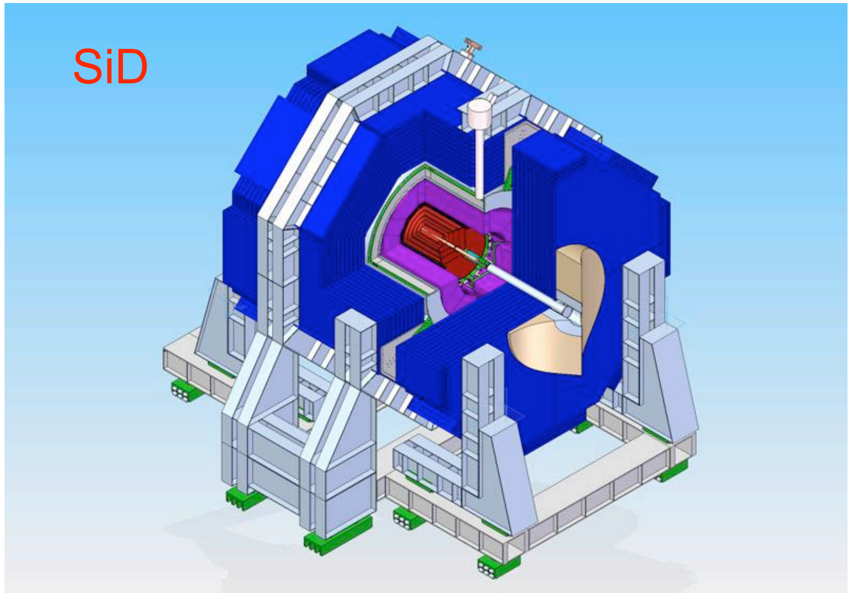
+ further contacts with ILC collaborations

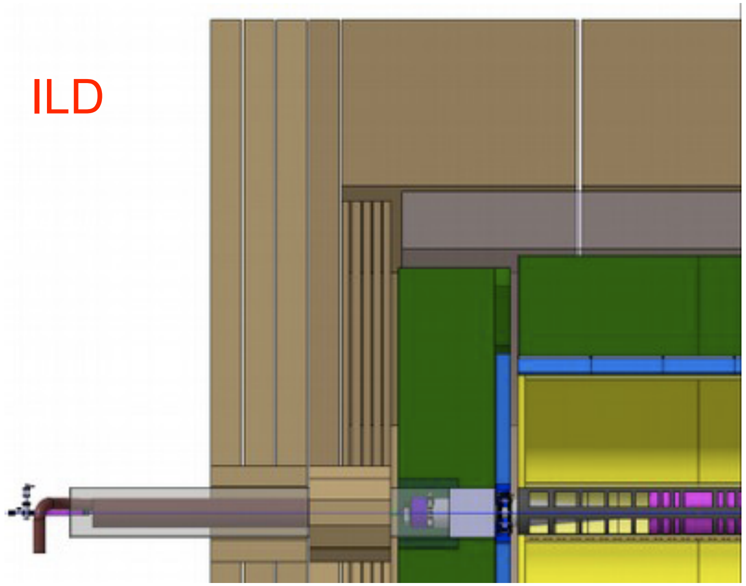
General Context

- New physics expected in TeV energy range
  - 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 detector concepts are excellent starting point for high energy detector
  http://documents.cern.ch/cgi-bin/setlink?base=cernrep&categ=Yellow_Report&id=2004-005
- Like for ILC, assume 2 CLIC detectors in pull push mode

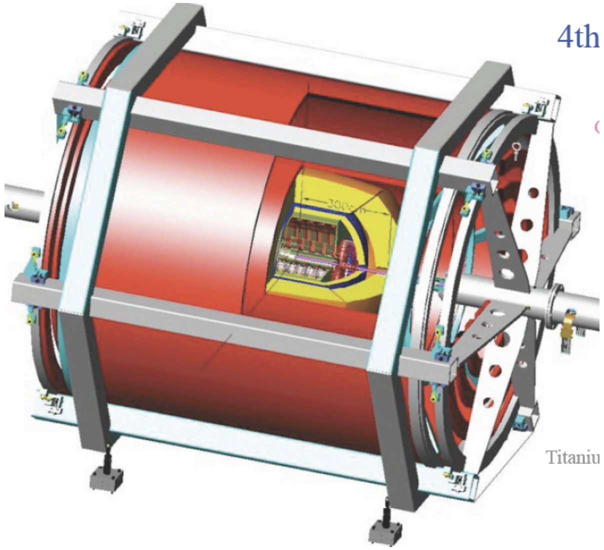
CLIC detector issues, and comparison with ILC

ILC experiment concepts





4th



Some Detector Design Criteria

Harry Weerts

Requirement for ILC

- Impact parameter resolution

$$\sigma_{r\phi} \approx \sigma_{rz} \approx 5 \oplus 10/(p\sin^{3/2}\vartheta)$$

- Momentum resolution

$$\sigma\left(\frac{1}{p_T}\right) = 5\times10^{-5}\ (GeV^{-1})$$

- Jet energy resolution goal

$$\frac{\sigma_E}{E} = \frac{30\%}{\sqrt{E}} \qquad \frac{\sigma_E}{E} = 3-4\%$$

- Detector implications:
  - Calorimeter granularity
  - Pixel size
  - Material budget, central
  - Material budget, forward

Compared to best performance to date

- Need factor 3 better than SLD

$$\sigma_{r\phi} = 7.7 \oplus 33/(p\sin^{3/2}\vartheta)$$

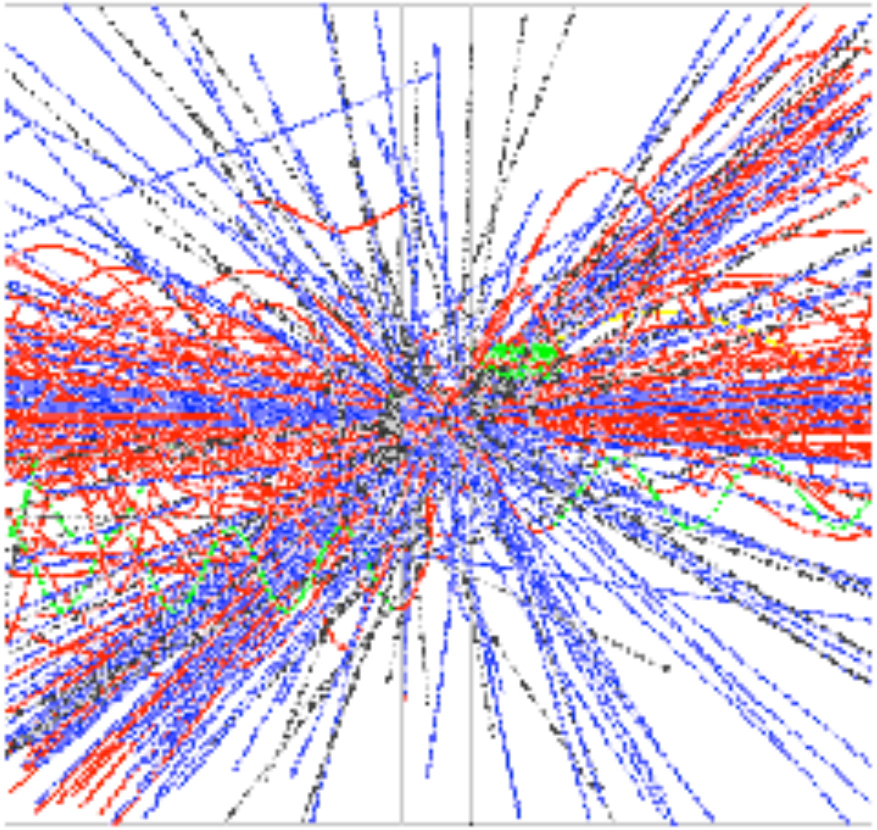
- Need factor 10 (3) better than LEP (CMS)
- Need factor 2 better than ZEUS

$$\frac{\sigma_E}{E} = \frac{60\%}{\sqrt{E}}$$

- Detector implications:
  - Need factor ~200 better than LHC
  - Need factor ~20 smaller than LHC
  - Need factor ~10 less than LHC
  - Need factor ~ >100 less than LHC

LHC: staggering increase in scale, but modest extrapolation of performance
ILC: modest increase in scale, but significant push in performance

CLIC detector issues



3 main differences with ILC:

•Energy 500 GeV => 3 TeV

•More severe background conditions

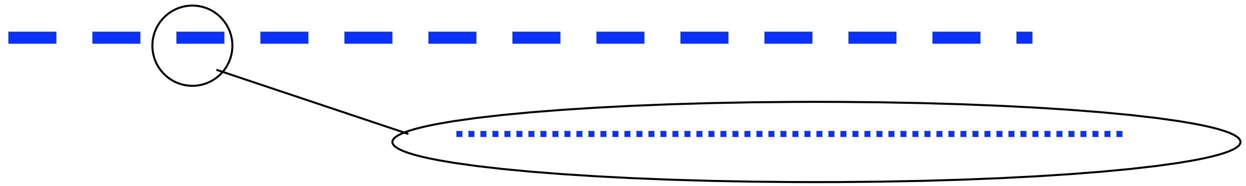
- •Due to higher energy
- •Due to smaller beam sizes

•Time structure of the accelerator

CLIC time structure

Train repetition rate 50 Hz

CLIC



CLIC:	1 train = 312 bunches	0.5 ns apart	50 Hz
ILC:	1 train = 2820 bunches	337 ns apart	5 Hz

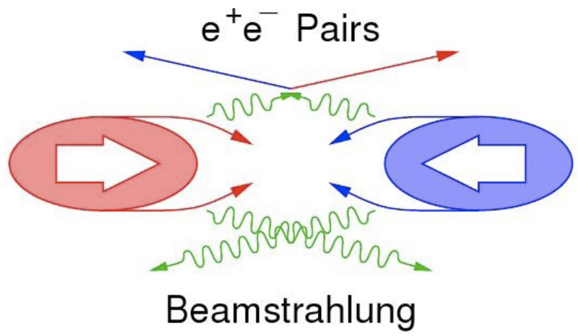
Consequences for CLIC detector:

- Assess need for detection layers with time-stamping
  - Innermost tracker layer with sub-ns resolution
  - Additional time-stamping layers for photons and for neutrons (needed?)
- Readout/DAQ electronics will be different from ILC
- Consequences for power pulsing?

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.

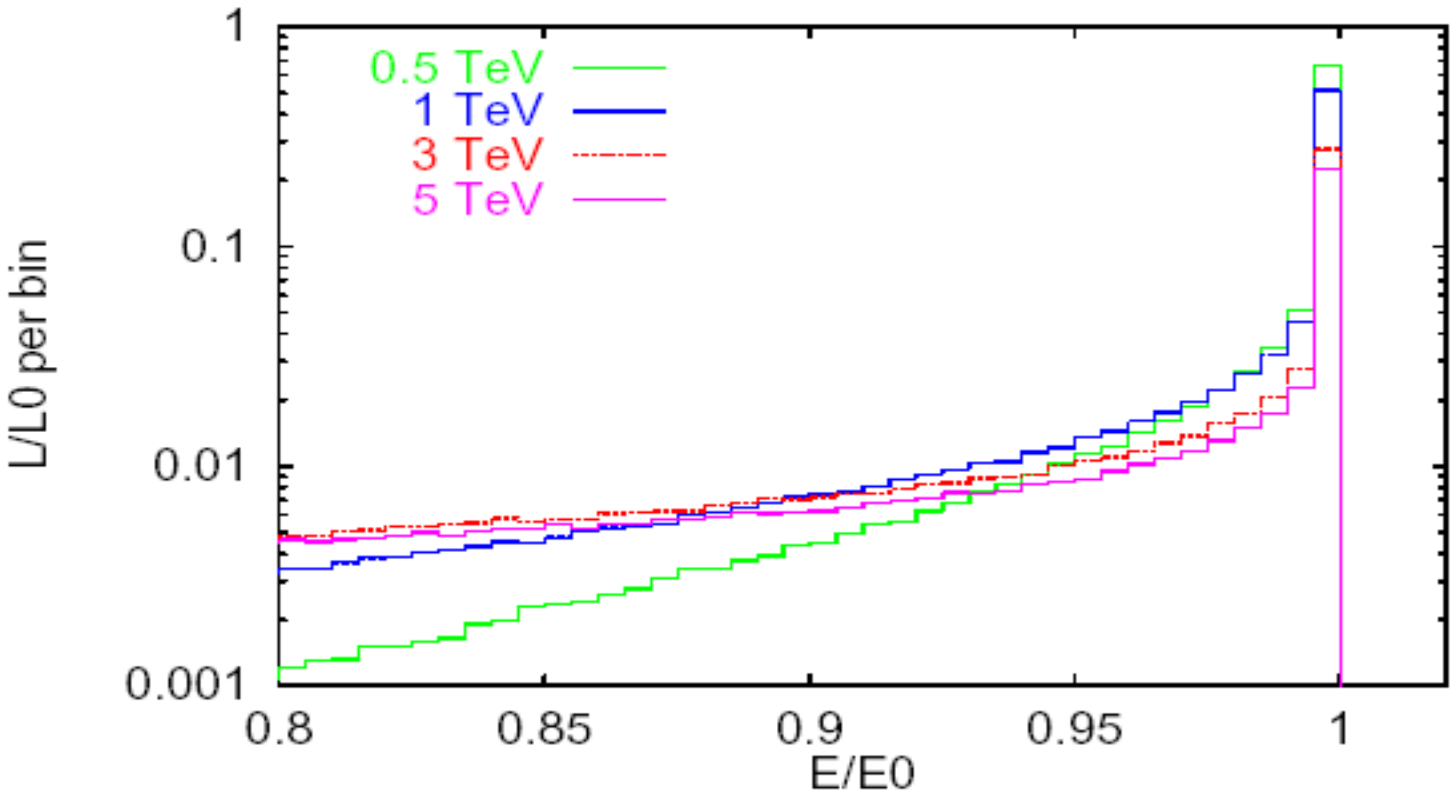


- CLIC 3TeV beamstrahlung $\Delta E/E$ = 29% ($10\times ILC_{value}$)
  - **Coherent pairs** (3.8×10^8 per bunch crossing) <= disappear in beam pipe
  - **Incoherent pairs** (3.0×10^5 per bunch crossing) <= suppressed by strong solenoid-field
  - **γγ interactions => hadrons** (2.7 hadron events per bunch crossing)

- **Muon background from upstream linac**
  - More difficult to stop due to higher CLIC energy (active muon shield)

- \+ a few more standard background sources

CLIC CM energy spectrum

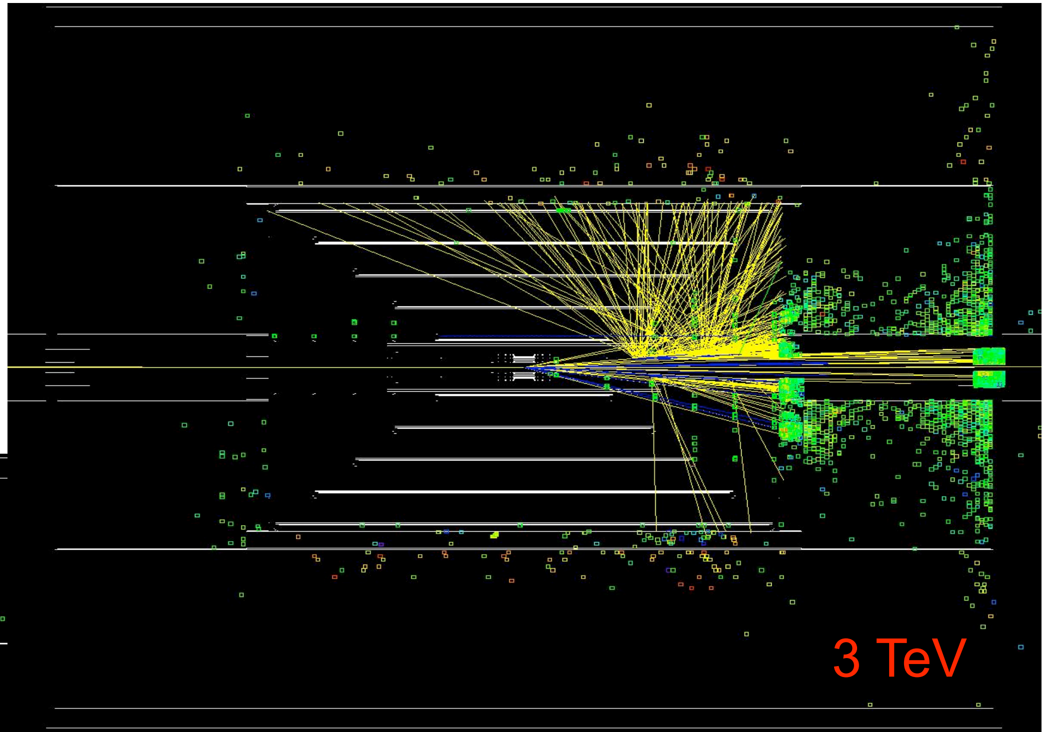


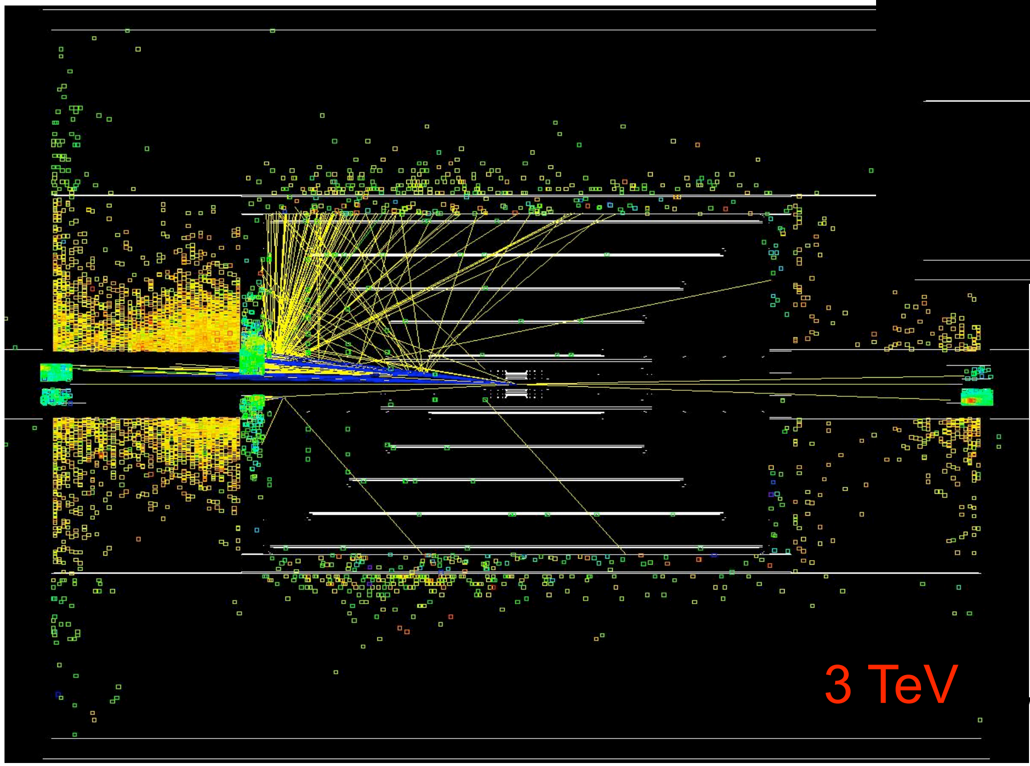
Due to beamstrahlung:

- At 3 TeV only 1/3 of the luminosity is in the top 1% Centre-of-mass energy bin
- Many events with large forward or backward boost

Beamstrahlung, continued…..

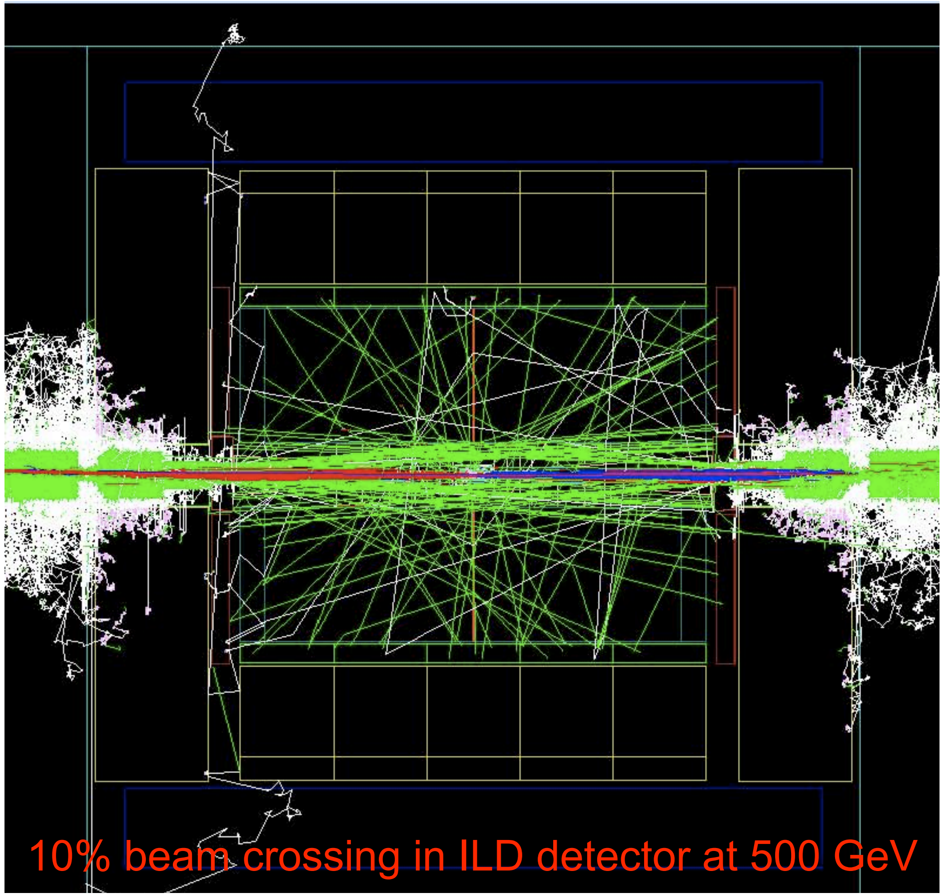
At 3 TeV many events have a large forward or backward boost, plus many back-scattered photons/neutrons





Lessons learnt from ILC case

Adrian Vogel, DESY



- Pair production is the dominant background
- Most backgrounds can be controlled by a careful design
- Use full detector simulation to avoid overlooking effects

- Innermost Vertex layer (r=1.5 cm) has 0.04 hits/mm^2/BX
- Critical level of neutrons (radiation damage) at small radii of HCAL end-cap

Extrapolation ILC = > CLIC

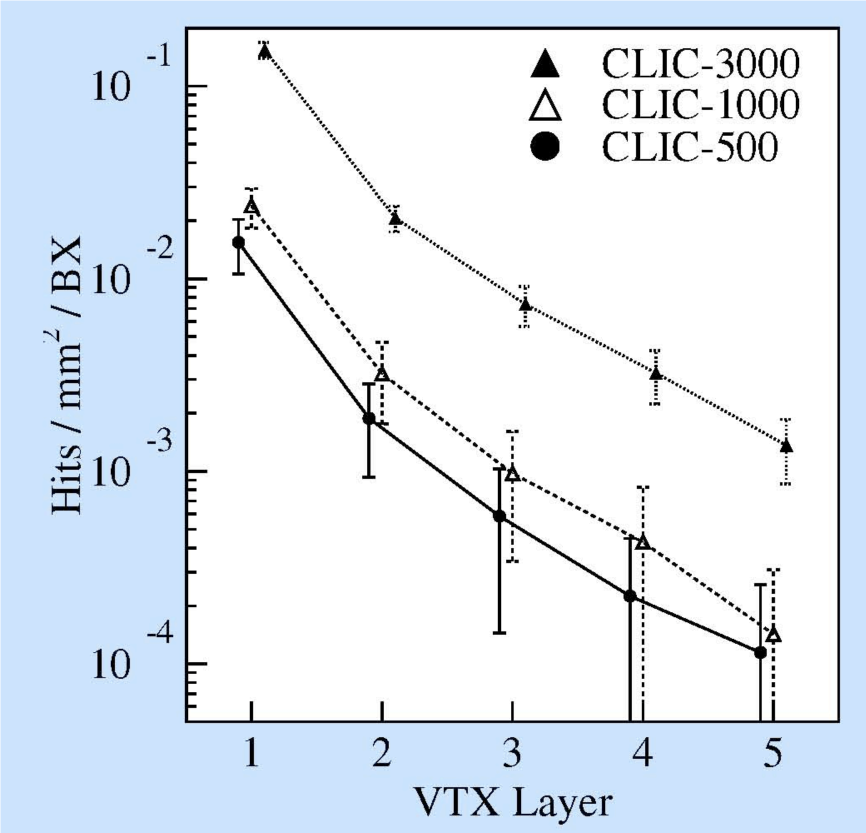
Full LDC detector simulation at 3 TeV

Simulation of e^+e^- pairs from beamstrahlung origin

Adrian Vogel, DESY

- **Conclusion of the comparison:**
- ILC, use 100 BX (1/20 bunch train)
- CLIC, use full bunch train (312 BX)

- **CLIC VTX: O(10) times more background**
- **CLIC TPC: O(30) times more background**



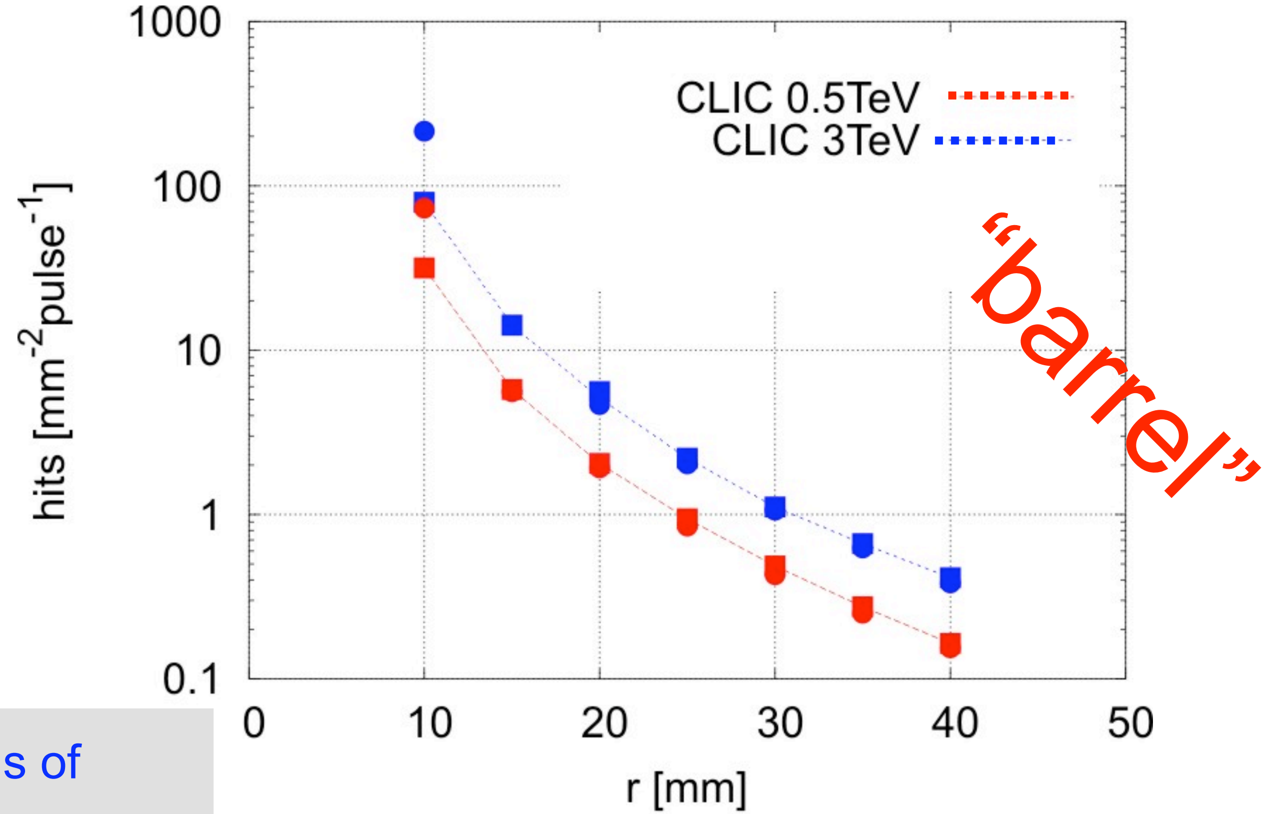
LDC 3 TeV, with forward mask

Vertex Detector

Daniel Schulte

Vertex detector hits from incoherent pairs, B=5T,
two angular coverages

for
312 BX



z=3r z=5r ←vertex opening angle

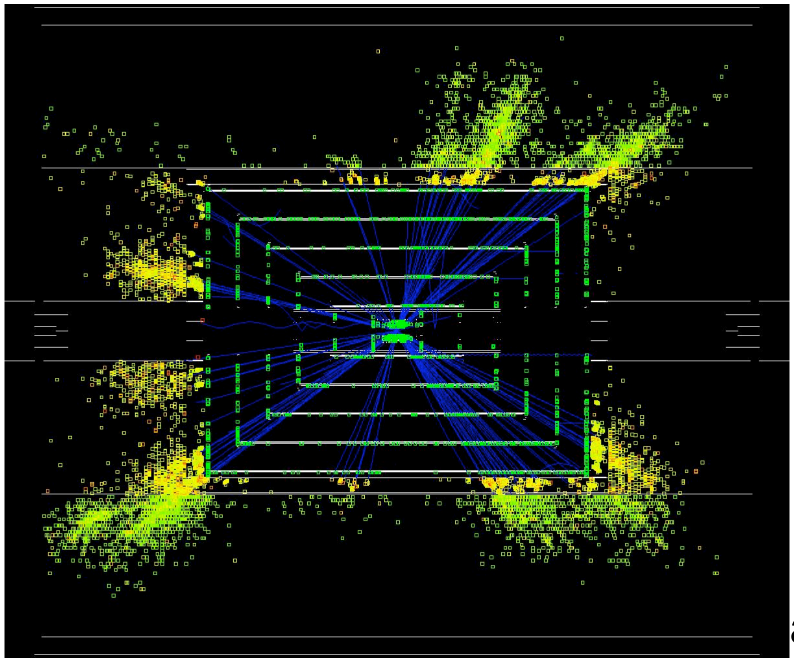
PRELIMINARY

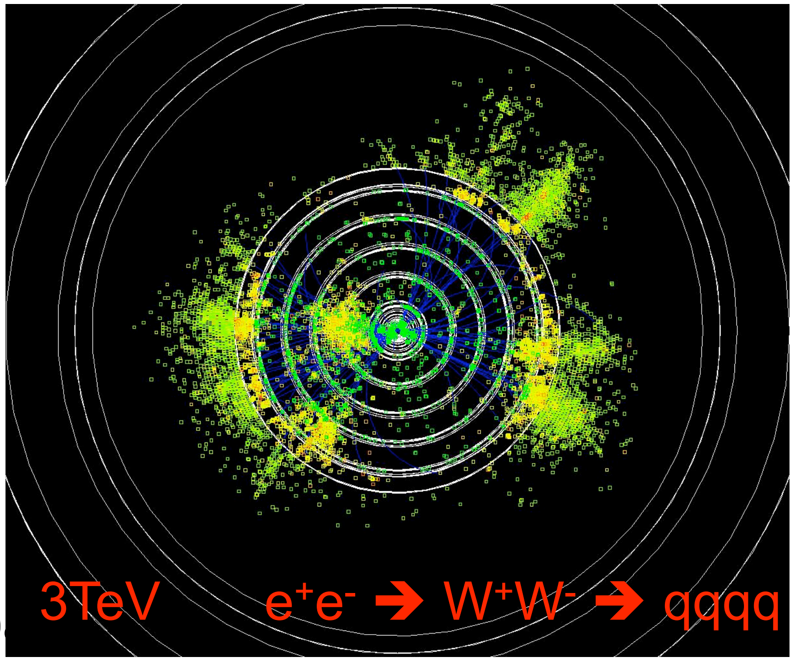
=> CLIC inner radius of vertex det. at R=~30 mm (15 mm for ILC)

CLIC Tracking

Tracking issues:

- Due to beam-induced background and short time between bunches:
  - Inner radius of Vertex Detector has to move out (30 mm)
  - High occupancy in the inner regions
- Narrow jets at high energy
  - 2-track separation is an issue for the tracker/vertex detector
  - Track length may have to increase (fan-out of jet constituents)?





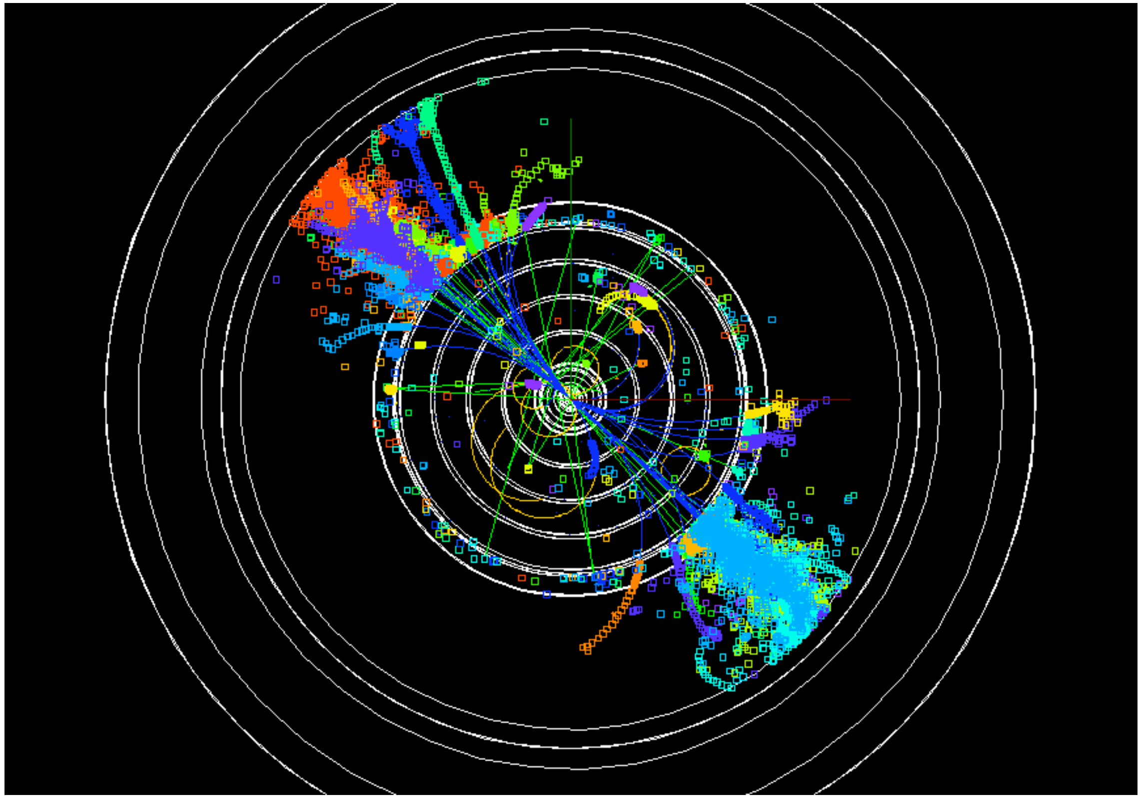
CLIC Calorimetry

Need deep HCAL ($\geq 8\lambda_i$)

Cannot increase coil radius too much => need heavy absorber

- Choice of suitable HCAL material

Choice of technology (PFA or dual readout)



3 TeV e^+e^- event on SiD detector layout, illustrating the need for deeper calorimetry

Which calorimetry at CLIC energies?

To overcome known shortfalls from LEP/LHC experience, new concepts/technologies are chosen for ILC:

- **Based on Particle Flow Algorithm**
  - Highly segmented (13-25 mm^2) ECAL (analog)
  - Very highly segmented ECAL (digital)
  - Highly segmented (1 cm^2) HCAL (digital)
  - Segmented HCAL (analog)
- **Based on Dual (Triple) readout**
  - Sampling calorimeter
    - Plastic fibres
    - Crystal fibres (<= materials studies)
  - Fully active calorimeter (EM part)
    - Crystal-based

Method and Engineering difficult, but conventional

Limited in energy-range to a few hundred GeV

Method and Engineering difficult and non-proven

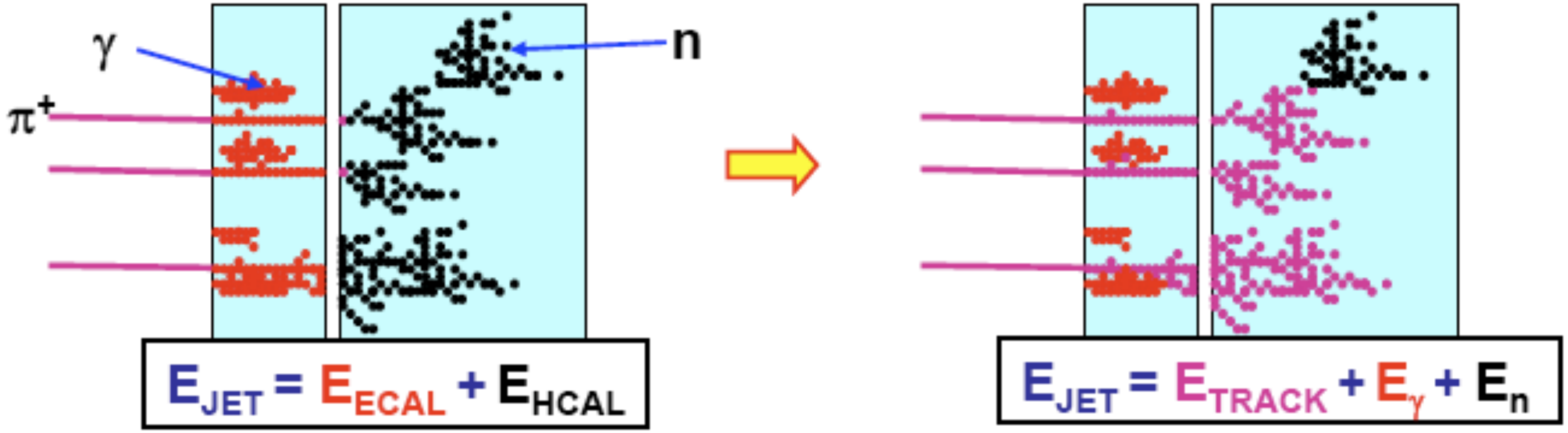
Not limited in energy range

❷ The Particle Flow Paradigm

Mark Thomson CLIC08

★ In a typical jet :
- 60 % of jet energy in charged hadrons
- 30 % in photons (mainly from $\pi^0 \to \gamma\gamma$)
- 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

Alternative to PFA calorimetry

R&D on dual/triple readout calorimetry

Basic principle:

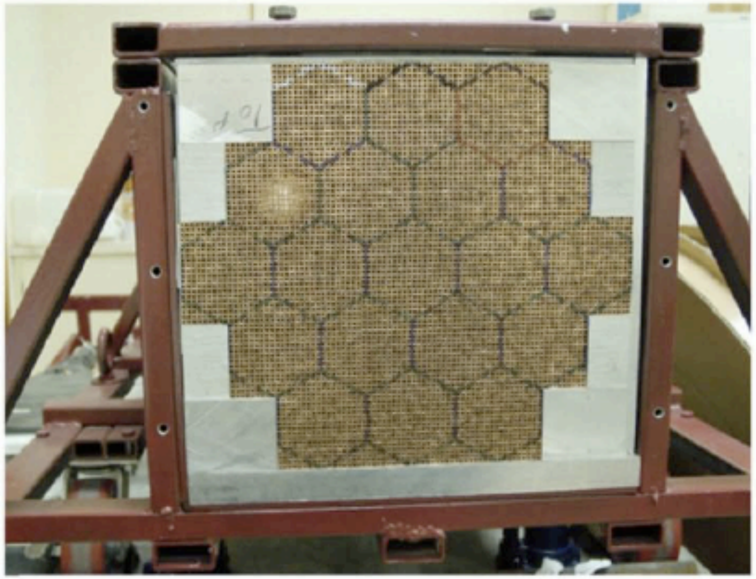
- Measure EM shower component separately
- Measure HAD shower component separately
- Measure Slow Neutron component separately

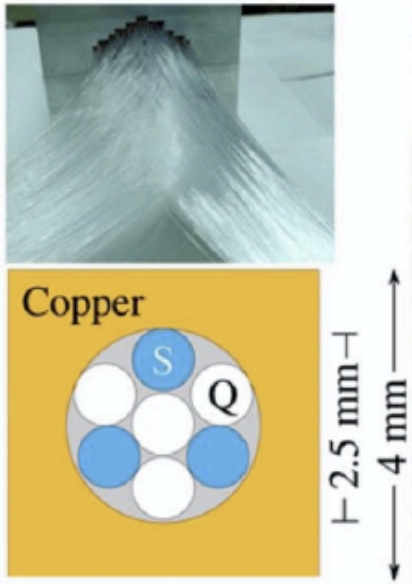
} **Dual** } **Triple**

EM-part=> electrons => highly relativistic => Cerenkov light emission

HAD-part=> “less” relativistic => Scintillation signal

Slow neutrons => late fraction of the Scintillation signal



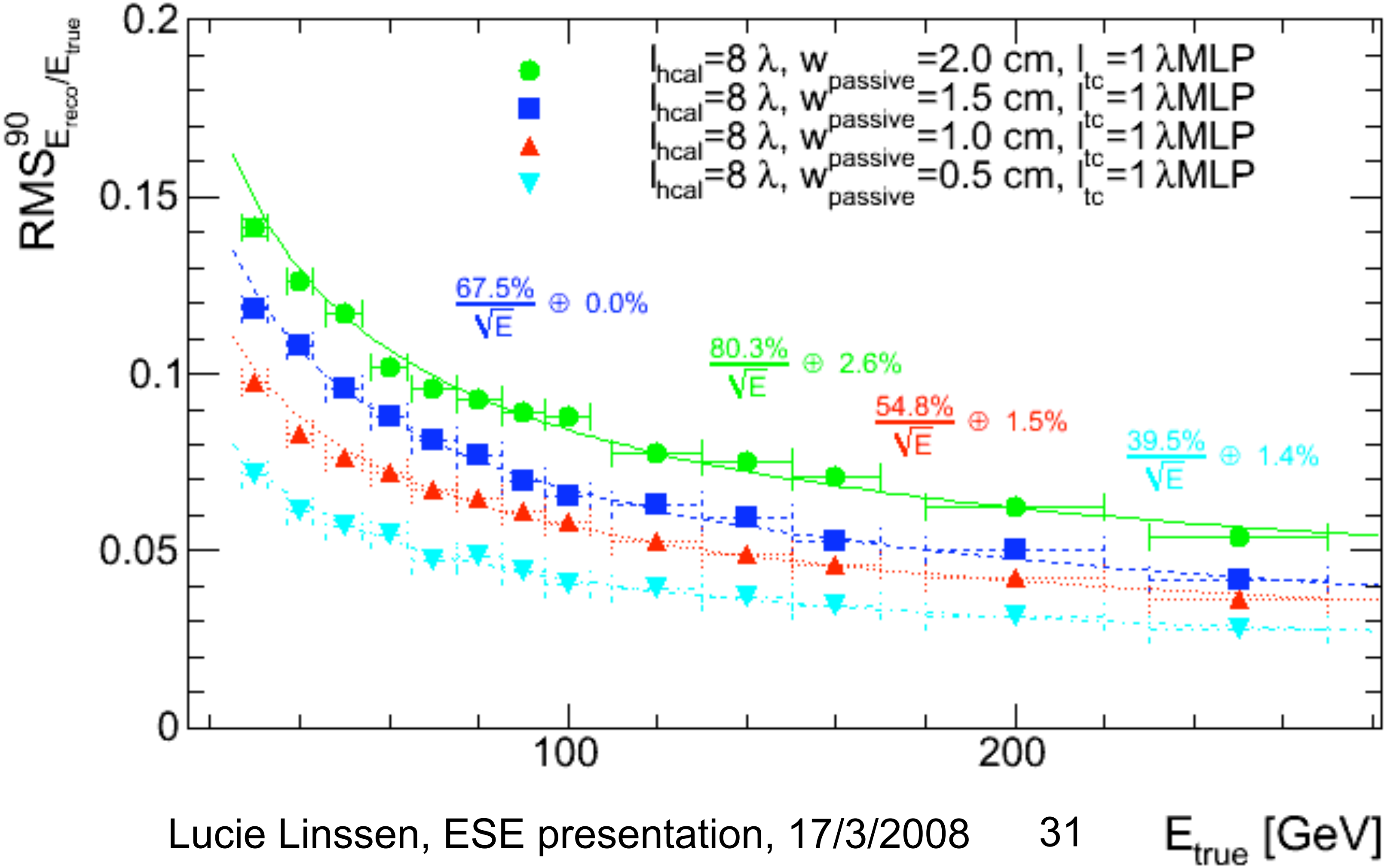


Requires broader collaboration on materials + concept

Peter Speckmayer / Christian Grefe

Tungsten – Scintillator calorimeter

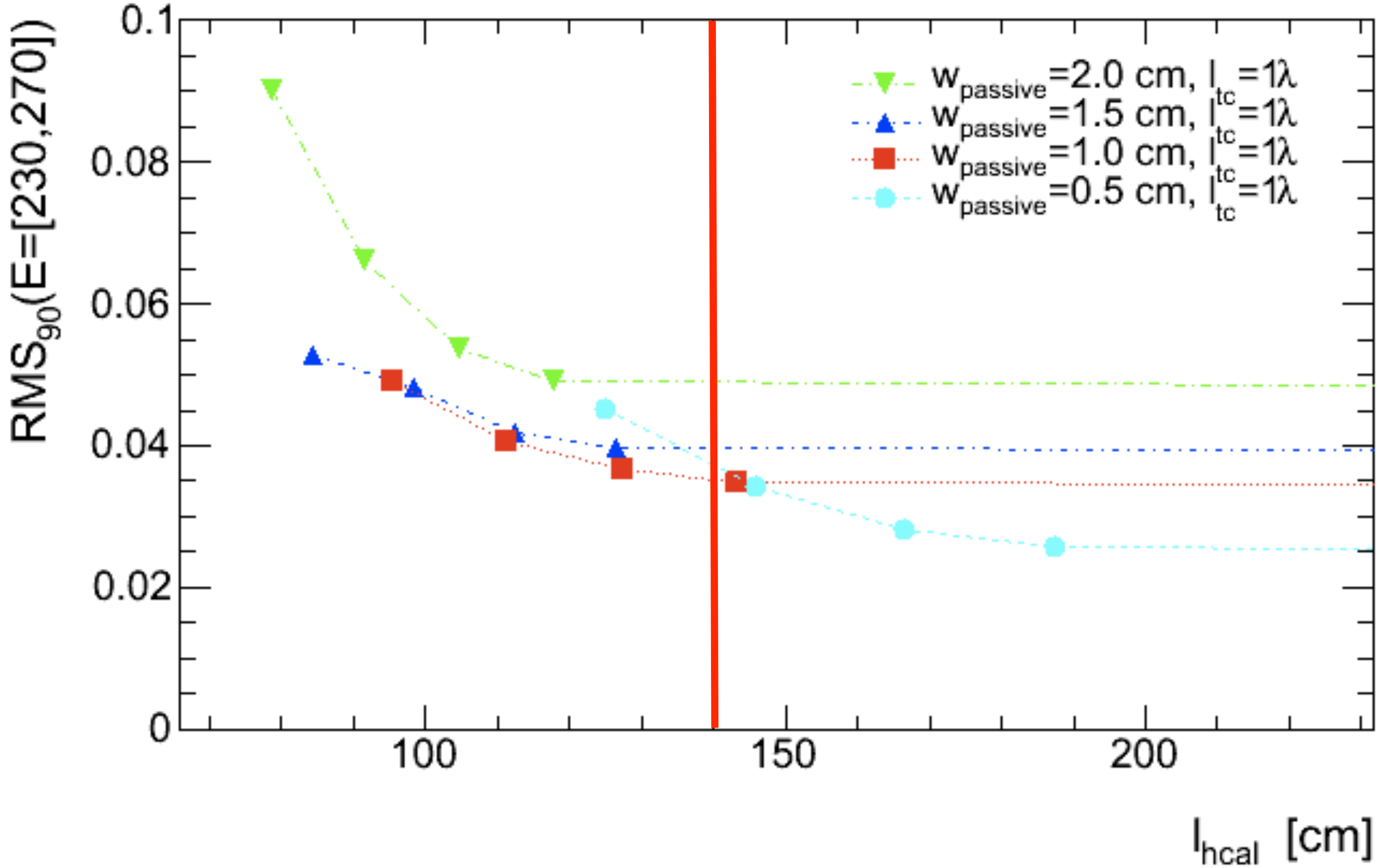
Conventional Calorimetry, resolution for **8λ**



Hadron Calorimetry

Peter Speckmayer / Christian Grefe

230-270 GeV **6,7,8,9 -> 40 λ**



Opportunities for Detector R&D and engineering studies

Opportunities for detector R&D

First assessment of R&D required for CLIC beyond present ILC developments

- Time stamping
- Power pulsing and adaptation of electronics readout to CLIC
- Alternative to PFA calorimetry (dual readout calorimetry)
- Mechanical engineering studies
  - Heavy calorimeter concept
  - Large high-field solenoid concept
  - Integration studies
- Precise stability/alignment studies

Other R&D activities to ensure continued good collaboration with ILC physics community

- TPC electronics developments (S-ALTRO and Timepix2)
- Participation in CALICE
- Core software development

R&D for Time stamping

0.5 nsec bunch spacing, 312 bunches/train, 50 Hz

overlapping background for 312 BX will be an issue

exact needs will come out of detector concept simulations

- **(sub)-ns time stamping in most inner tracking double-layer**
- Time stamping needed for photons? => preshower
- Time stamping needed for neutron? => layer within HCAL

Technical challenges for time-stamping in the inner tracking layer:

- Critical analog design involving sensor+electronics+interconnect for good time resolution
- High granularity (short strips?)
- Power consumption is an issue for high-precision TDC

Power pulsing and other electronics developments

ILC => 5 Hz

=> “on”-time 0.5%

CLIC => 50 Hz

=> “on”-time 10^{-5}

- Systematic study of power-pulsing feasibility
  - Needed for ILC and CLIC
  - Leading to recommendations for optimised design
  - Real case implementation
  - (What about influence on wire-bonds?)

- Overall electronics implementation compatible with CLIC time-structure
  - Study of the adaptations required (analog, digital, readout sequence)
    - Readout full bunch trains or fraction of it?
    - Where to buffer the data? When to reduce the data?
    - Implementation of some of the ILC vertex/tracker/calo hardware developments for CLIC

TPC electronics developments

- S-ALTRO pad readout
  - Ultimate aim: compact on-chip readout system for MPGD signals
  - Measure tracks in 3D and DE/Dx => need for high precision
  - High data reduction capability
  - Pad readout sizes typically 1*4 mm^2
  - Basic microelectronics aspects addressed in EUDET (financed up to end 2009)
  - Need for system studies and iteration on microelectronics part

- Timepix2 development
  - Pixel readout of MPGD signals
  - Preamp – shaper – discriminator
  - Time measurement (TDC), pulse height measurement (TOT)
  - Clock distribution to all pixels, efficient readout, triggerable (?)
  - Follow-up of Timepix1, successfully developed under EUDET
  - In collab. with Medipix3, Nikhef, Bonn, Saclay…

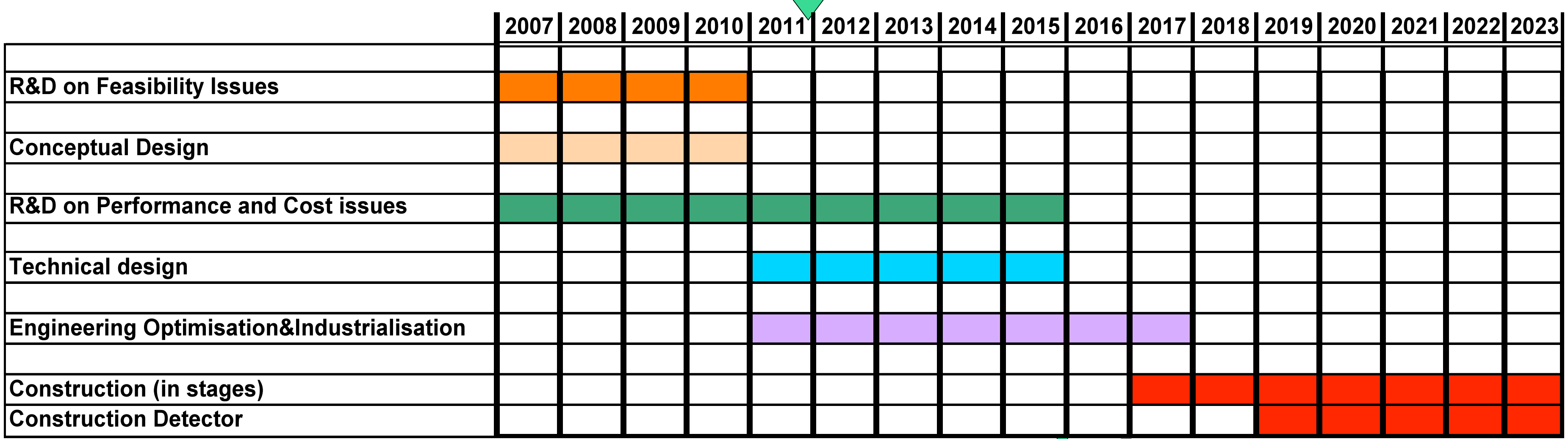
Signing of ILC LoI’s

- For the ILC, there will be 3 letters of intent for the 3 detector concepts (SiD, ILD, 4th), submission date 31/3/2009.
- PH-ESE staff have contributed (mainly to ILD).
- We hope to work towards “addenda” to these LoI’s for CLIC (towards end of 2010?).
- In this context it is logic/desirable that some PH staff sign the current LoI’s……….

Spare slides

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



Conceptual Design Report (CDR)

Technical Design Report (TDR)

Project approval ?

First Beam?

SiD Forward Region

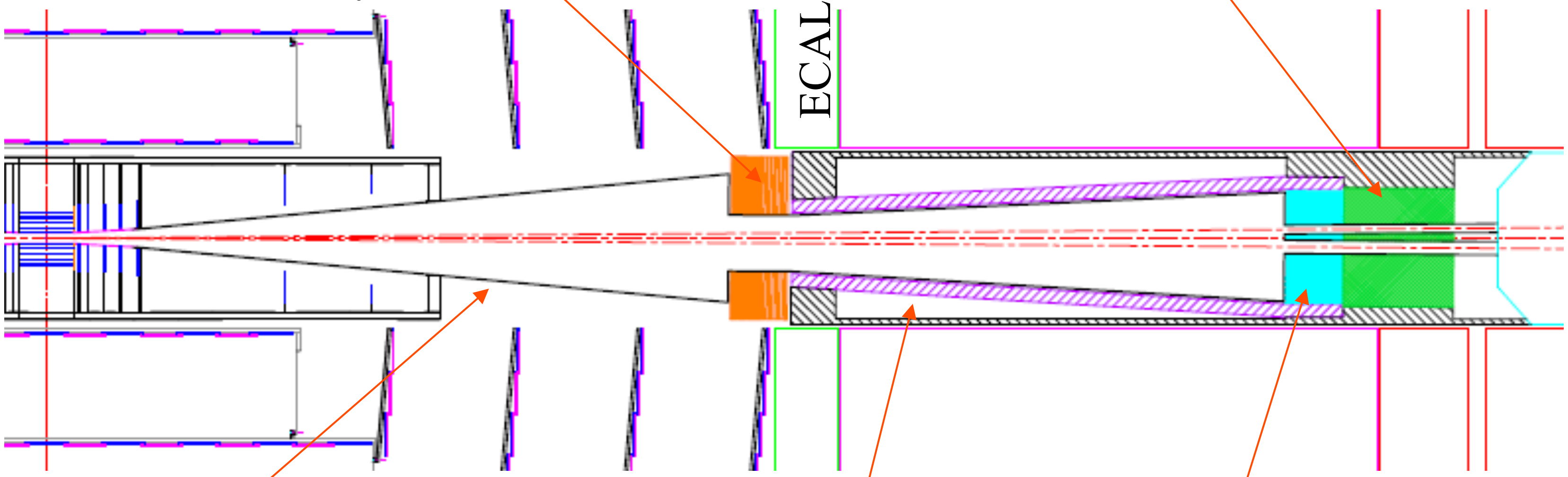
LumiCal

20 layers of 2.5 mm W +

10 layers of 5.0 mm W

BeamCal

50 layers of 2.5 mm W



Beampipe

+/- 94 mrad (detector)

+101 mrad, -87mrad (ext. line)

3cm-thick Tungsten Mask

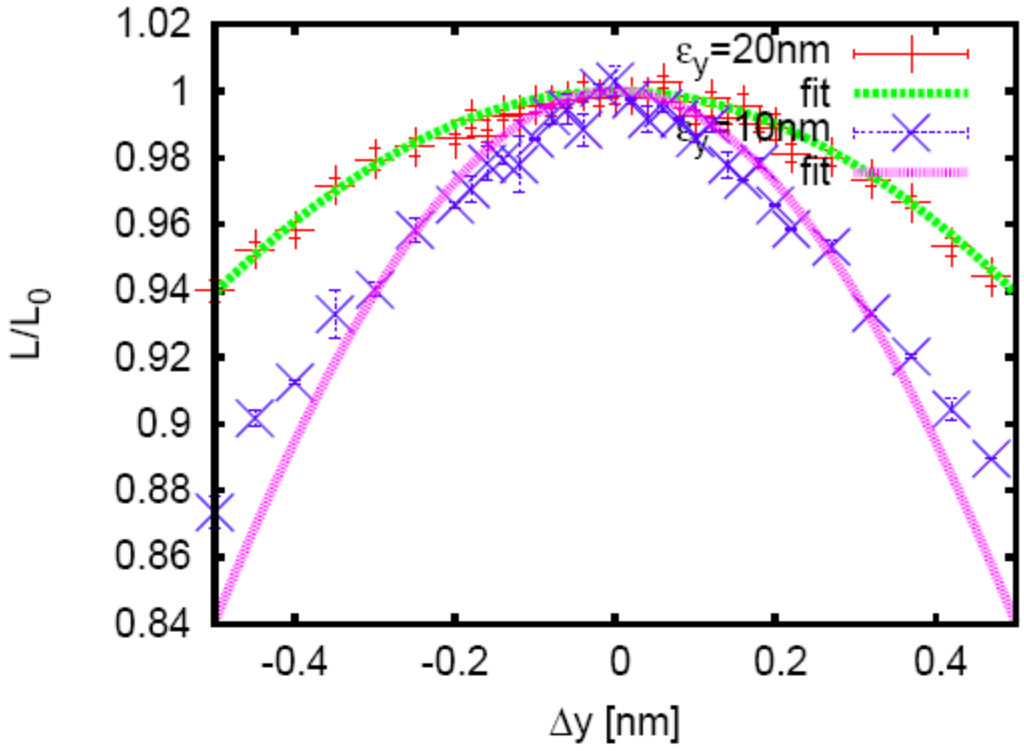
13cm-thick BoratedPoly

Centered on the outgoing beam line

Beam-Beam Jitter Tolerance

Daniel Schulte CLIC08

- At 3 TeV one finds vertical beam-beam jitter tolerance of 0.3 nm
- At 500 GeV ≈ 0.7 nm
  - for conservative parameters ≈ 1.7 nm
- Quadrupole jitter tolerances range from 0.5 to 4 times beam-beam jitter tolerance, depending on configuration
- Can on imagine a support through the detector?
- Beam-beam feedback can give up to about a factor 2



These extremely high stability requirements of the accelerator also impose high stability requirements on the experiment (vibrations, turbulences…)

PFA for high-energy jets

Mark Thomson CLIC08
ILD detector description

- Traditional calorimetry $\sigma_E/E \approx 60\%/\sqrt{E/\text{GeV}}$
- Does not degrade significantly with energy (but leakage will be important at CLIC)
- Particle flow gives much better performance at "low" energies
  - very promising for ILC

rms90 PandoraPFA v03-β

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	23.8 %	3.5 %
100 GeV	29.1 %	2.9 %
180 GeV	37.7 %	2.8 %
250 GeV	45.6 %	2.9 %
500 GeV	84.1 %	3.7 %
500 GeV	64.3 %	3.0 %

63 layer HCAL (8 λ_I)
B = 5.0 Tesla

What about at CLiC ?

- PFA perf. degrades with energy
- For 500 GeV jets, current alg. and ILD concept:

$$\sigma_E/E \approx 85\%/\sqrt{E/\text{GeV}}$$

- Crank up field, HCAL depth…

$$\sigma_E/E \approx 65\%/\sqrt{E/\text{GeV}}$$

- Algorithm not tuned for very high energy jets, so can probably do significantly better

Conclude: for 500 GeV jets, PFA reconstruction not ruled out