CLIC CDR

What are the next steps ?

Lucie Linssen

on behalf of the CLIC physics and detector study

The main message from the CDR

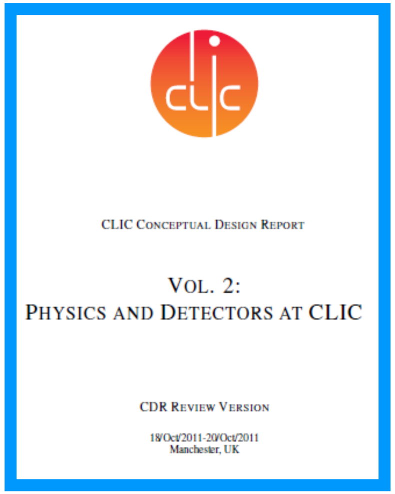
Physics at a 3 TeV CLIC machine can be measured with high precision, despite challenging background conditions

★ ★ ★

This gives CLIC a very large physics potential, in a broad range of centre-of-mass energies

The CLIC CDR studies allowed to extract the principal message.
Lots of work ahead, in simulation studies and hardware R&D, to bring this to a fully mature level for a future implementation.

CDR status and short-term plans


CLIC Conceptual Design Report

Vol. 2:
Physics and Detectors at CLIC

CDR Review Version

18/Oct/2011-20/Oct/2011
Manchester, UK

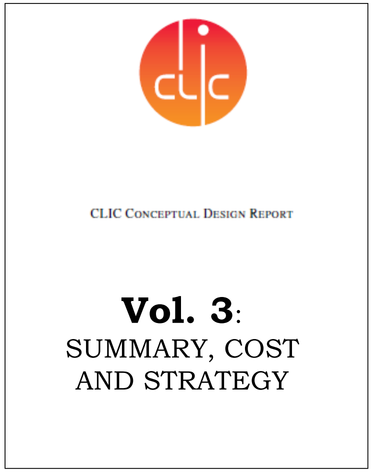
The CDR contents will be **finalised before the end of 2011**.
During the ~8 weeks between the Review and the final publishing, the CDR will be complemented with:

** Inclusion of Review comments and correction of errors.
 Small modifications, otherwise adaptations of future plans
** CLIC physics potential with polarised beams
 A few examples, work in progress => additional section in chapter 1
** Measurement of the luminosity spectrum using bhabha scattering.
 Work in progress

The CLIC physics&detector CDR will be presented to the **CERN Scientific Policy Committee**, December 12+13th, 2011

Publication of the CDR in the form of a **CERN yellow report**

Continuation of CDR work in 2012


CLIC Conceptual Design Report

Vol. 3:
SUMMARY, COST AND STRATEGY

There will be some continuation of CLIC CDR work in 2012

Summary document for accelerator, physics and detectors (Volume 3)

Volume 3 will comprise:

- summary of Vol. 1&2 on accelerator and physics/detector
- staged energy approach for CLIC
- cost estimate
- future plans: 2012-2016 and beyond

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And also: preparation for the update of the European Strategy for Particle Physics
Including a common LC physics document

After the CDR….

Studies foreseen on the Medium-term => covering a ~5-year period
(see chapter 13 of the CDR, and detailed backup slides of this talk)

In a nutshell:

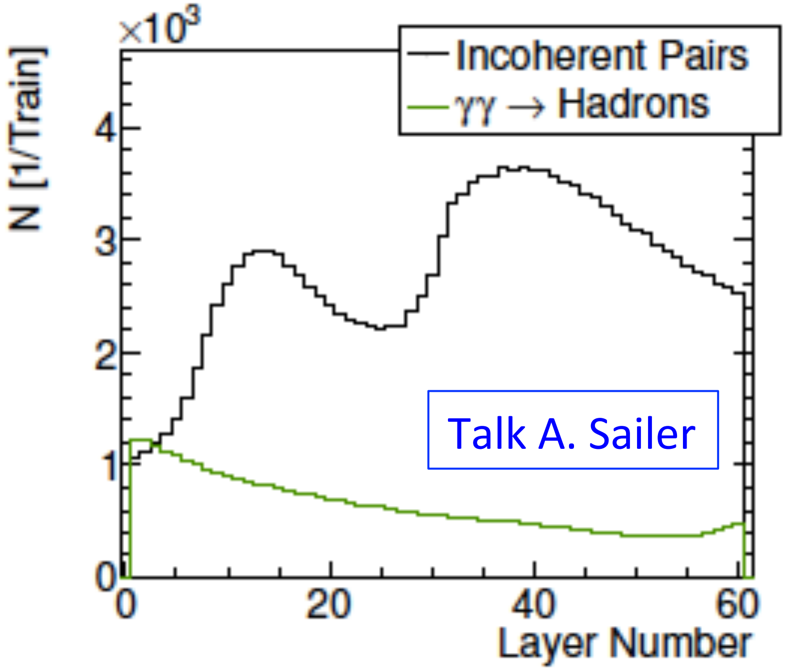
- Detector simulation studies and physics studies
  - Further detector optimisation
  - Explore physics potential with a machine built in stages
  - **Adaptation to LHC results**
- LC detector R&D (many common activities between ILC and CLIC)
- CLIC-specific detector R&D

The next slides illustrate a few of the upcoming studies

The slides focus mostly on CLIC-specific items
There is also a lot of work in common with ILC

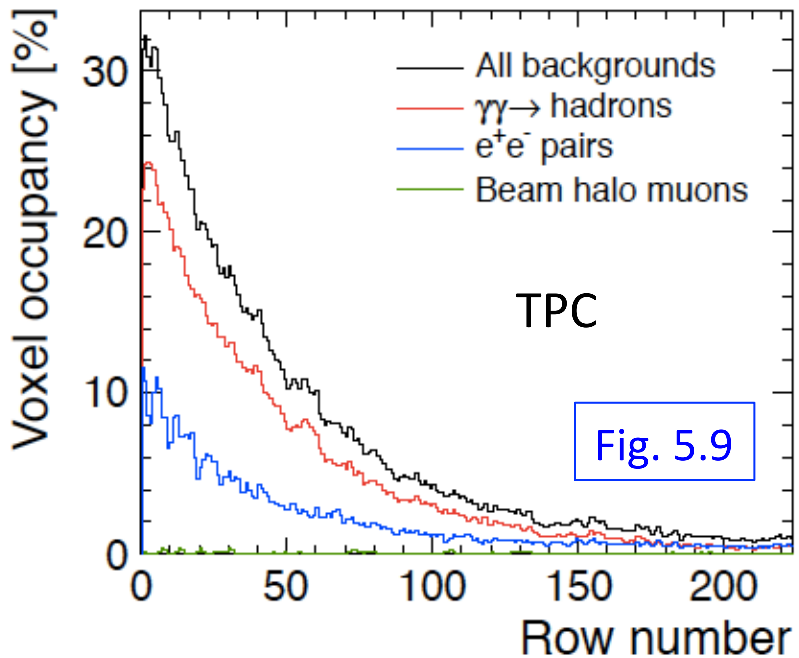
Detector simulation studies

Examples of high occupancy regions requiring further study at 3 TeV



High occupancy due to incoherent pairs in the high-z regions of the HCAL end cap. This points to inadequate shielding from the very forward calorimetry region

can be solved



High occupancies in the TPC, mostly due to γγ=>hadrons. One may consider pixelised readout for the TPC in this region or suppress the inner pad rows.

requires technology/layout changes

Simulation+engineering studies

1.3 m diam.

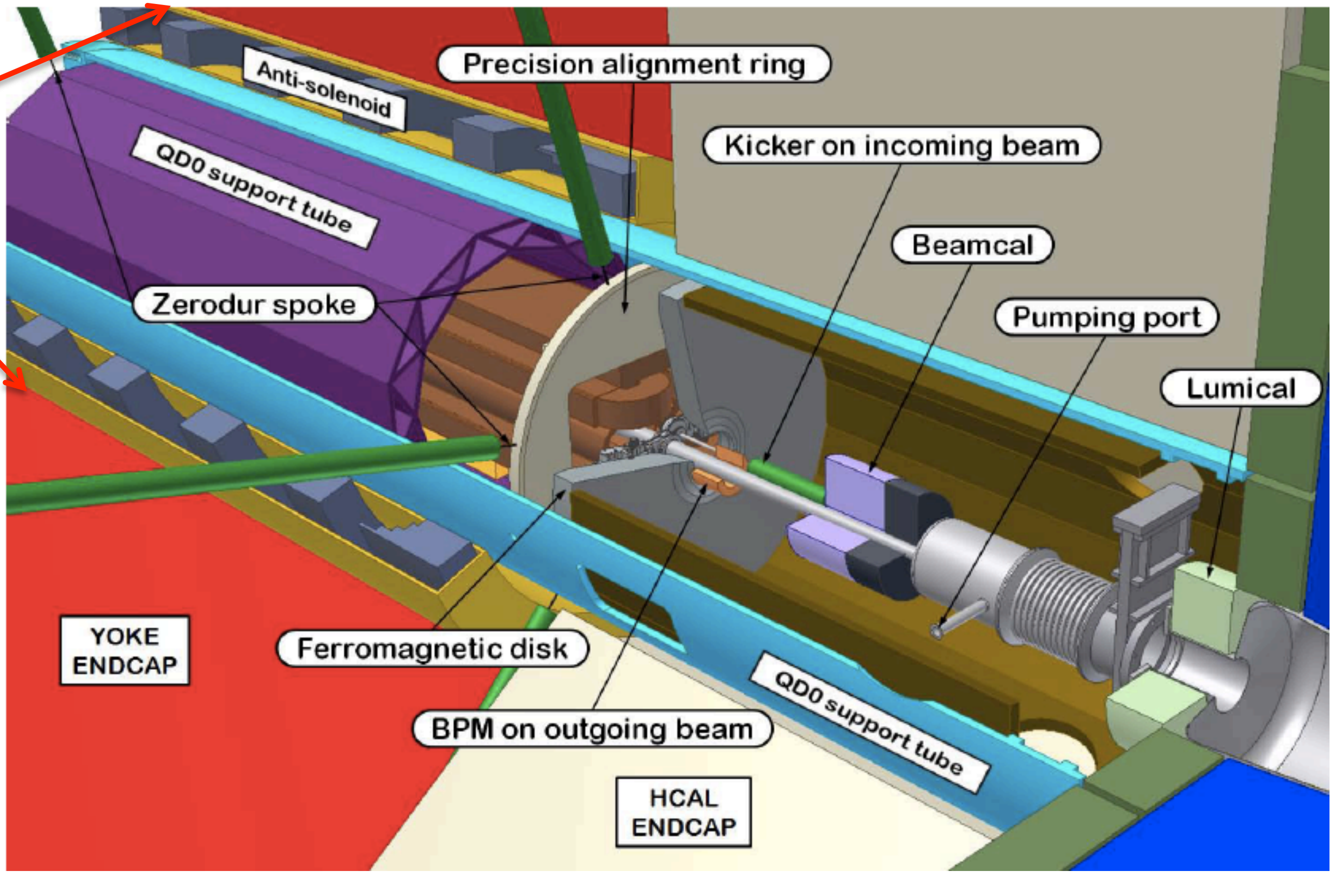
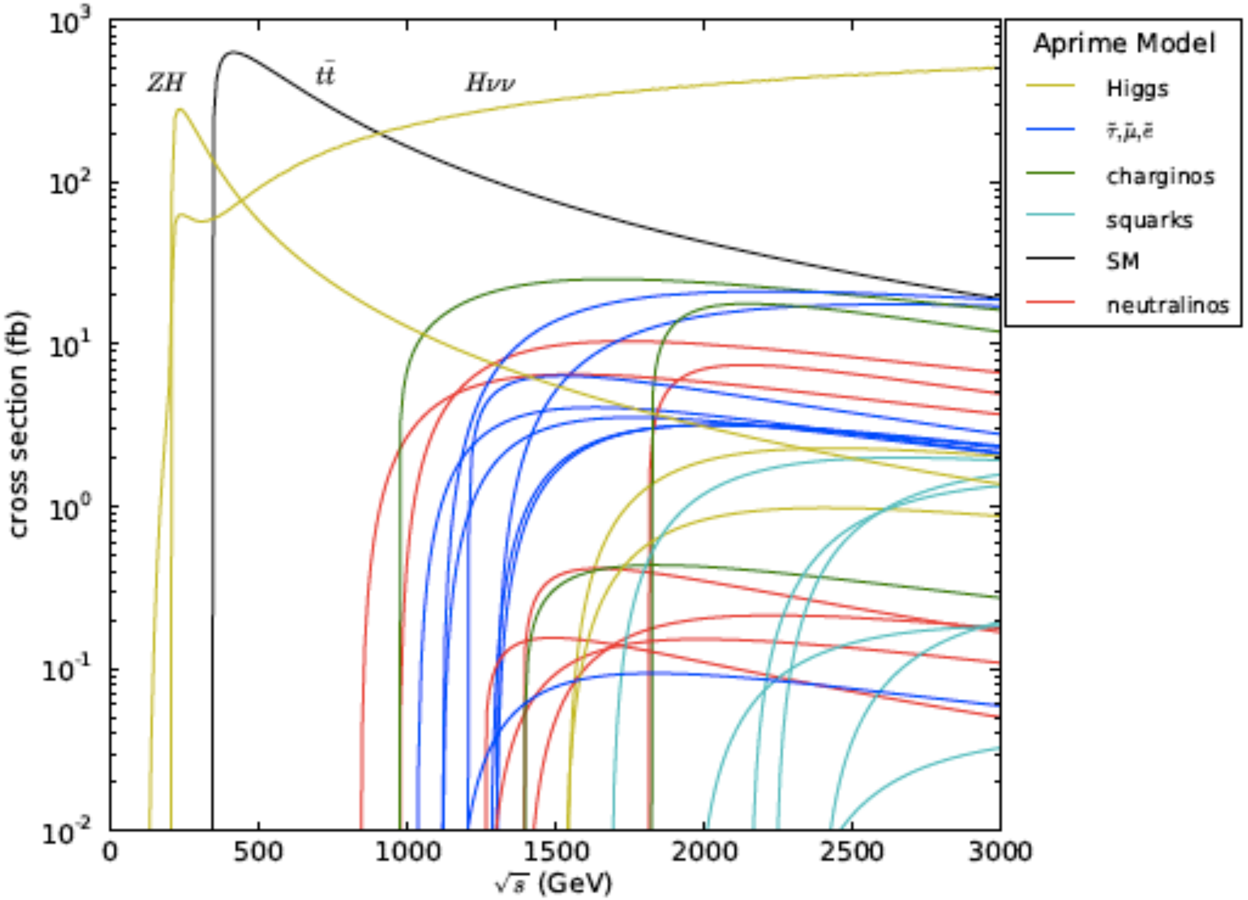


Fig. 11.13

The QD0 and its stability requirements at CLIC have a significant impact on the detector layout and acceptance in the forward region. More study is needed to quantify the impact on the physics and to make a balance between pros and cons of having QD0 inside the detector. **QD0 in or out of the detector?**

Physics at CLIC, staged √s energy



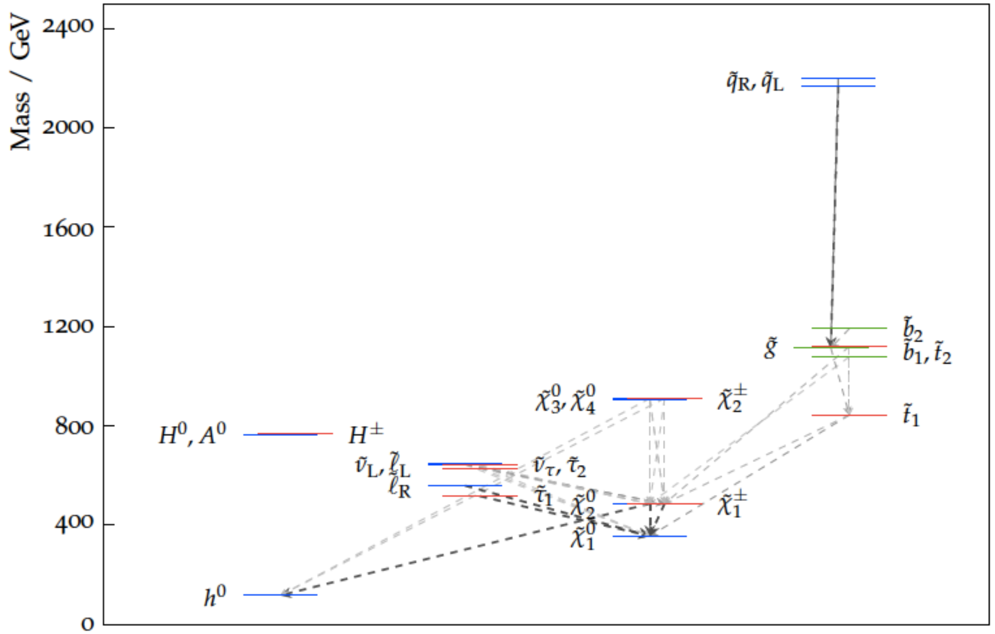
Like Fig 1.9, but different model

Use a single SUSY model + SM physics as an example to study how a LC built and operated in energy stages could explore new physics, including the gradual accumulation of knowledge on e.g. EW symmetry breaking, DM relic abundance, GUT scale unification

Study in close collaboration with CLIC accelerator

Physics at CLIC, staged √s energy

Study physics reach at a few staged √s energy points, including SM physics, and its implications on our understanding of the physics picture

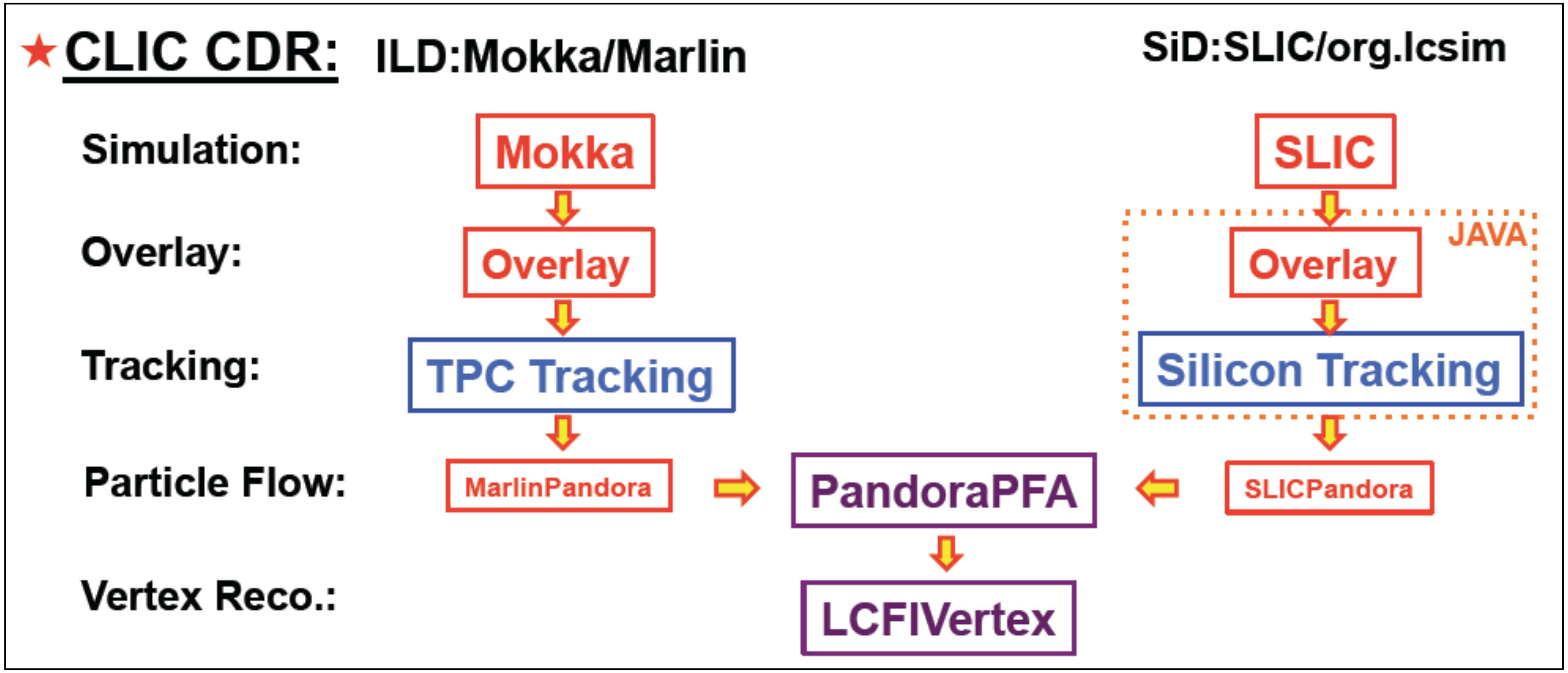


Physical masses in GeV

Neutralinos $(\tilde{N}_{1,2,3,4})$:	357, 487, 904, 911
Charginos $(\tilde{C}_{1,2})$:	487, 911
Sleptons $(\tilde{e}_R, \tilde{e}_L, \tilde{\nu}_e)$:	559, 650, 644
$(\tilde{\tau}_1, \tilde{\tau}_2, \tilde{\nu}_\tau)$:	517, 642, 630
Squarks $(\tilde{t}_1, \tilde{t}_2, \tilde{b}_1, \tilde{b}_2)$:	844, 1120, 1078, 1191
$(\tilde{d}_R, \tilde{u}_R, \tilde{d}_L, \tilde{u}_L)$:	2167, 2181, 2197, 2196
Higgs bosons $(h^0, A^0, H^0, H^\pm)$:	117.8, 765, 765, 769

Software development

See talk Mark Thomson



In a next phase:

- **Further improvement of simulation tools**
  - **In particular track reconstruction**

=> <u>continuation of trend to have common tools</u>

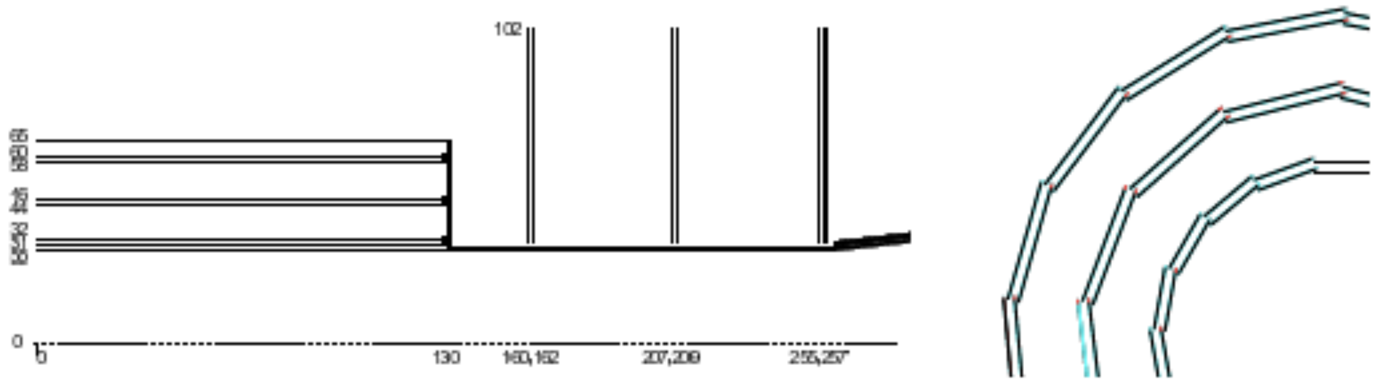
Vertex detector

See talk Dominik Dannheim

- 20x20 µm^2 pixel sizes → need small feature sizes
- Time-stamping ~5-10 ns → need high-resistivity sensor
- ~0.2% material/layer → corresponds to ~200 µm silicon (incl. support + cables)
- 156 ns bunch train every 20 ms → trigger-less readout, power pulsing
- Radiation exposure <10^{11} n_{eq}/cm^2/yr → radiation hardness not a major concern

The CLIC timing requirements have a large impact on the vertex detector R&D => very challenging R&D

Fig. 4.1



Silicon strip tracking

High occupancies per bunch train in inner strip tracking layers

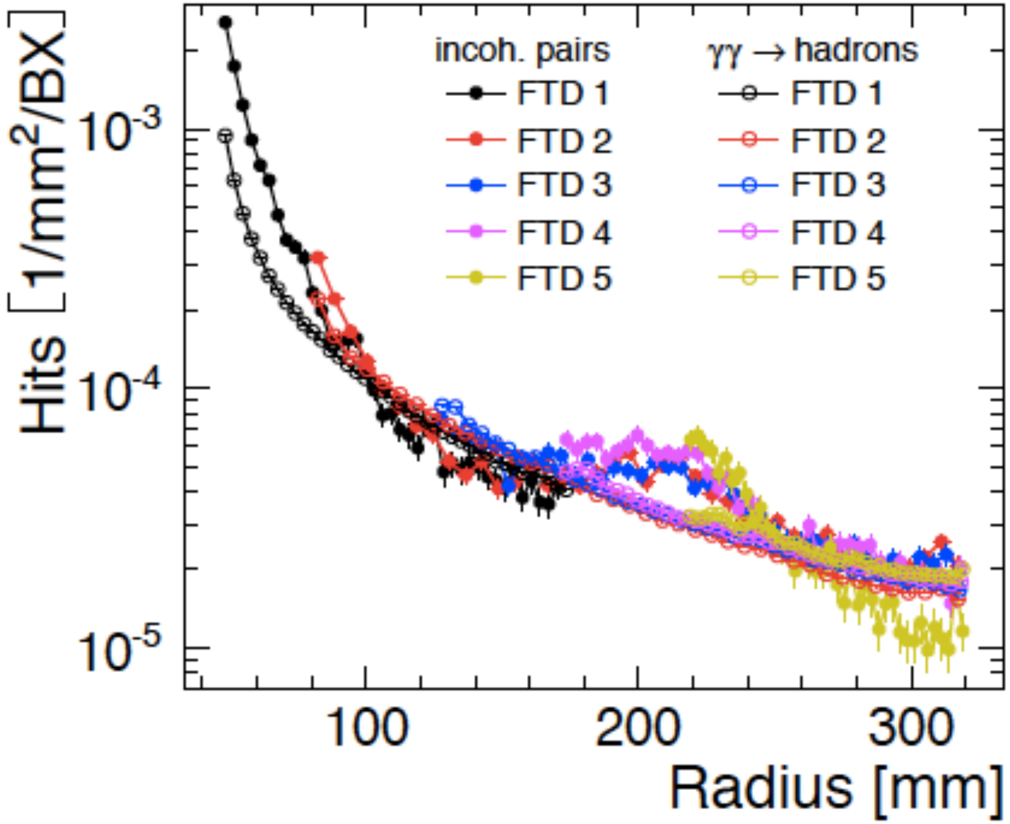


Fig. 5.8

~2.9 hits/strip per 156 ns bunch train in FTD2, including safety factor

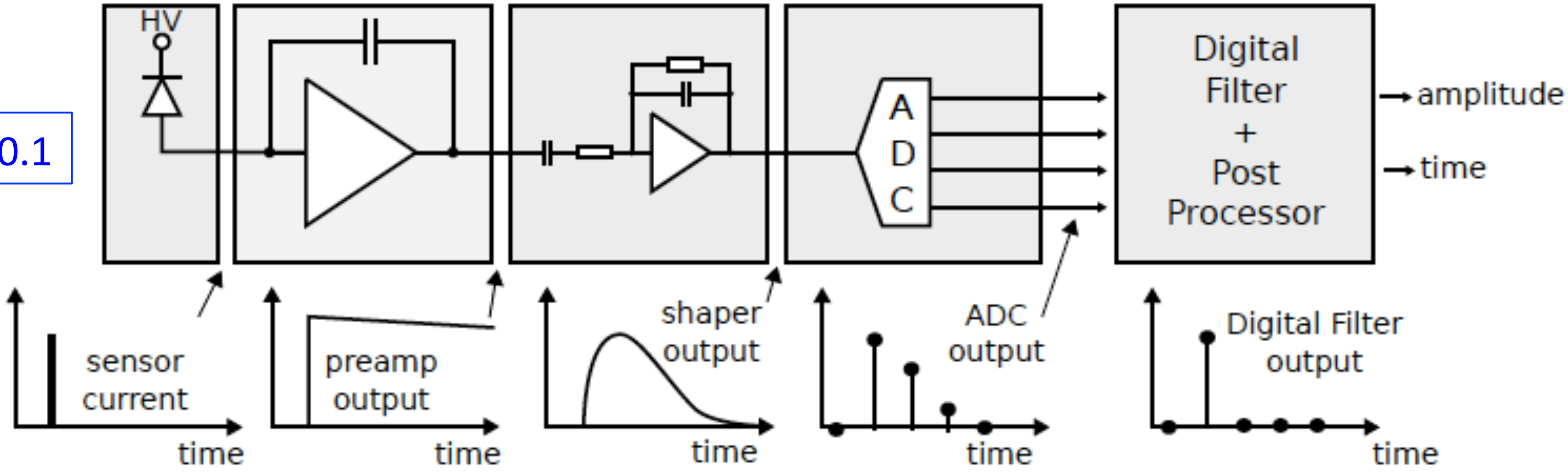
Similar situation in most inner barrel strip layers

=> Requires technology choices and hardware R&D

Electronics and power delivery

Many challenges in electronics. This is just an example.

Fig. 10.1



Calorimeter electronics at 3 TeV requires:

- 12-14 bit pulseheight measurement
- ~1 ns time resolution for hits
- Up to 5 hits per 156 ns bunchtrain
- Very low power consumption, and power pulsing in addition

Requires electronics R&D, going beyond ILC requirements in a few domains (e.g. timing, multi-hit)

Magnet and ancillary systems

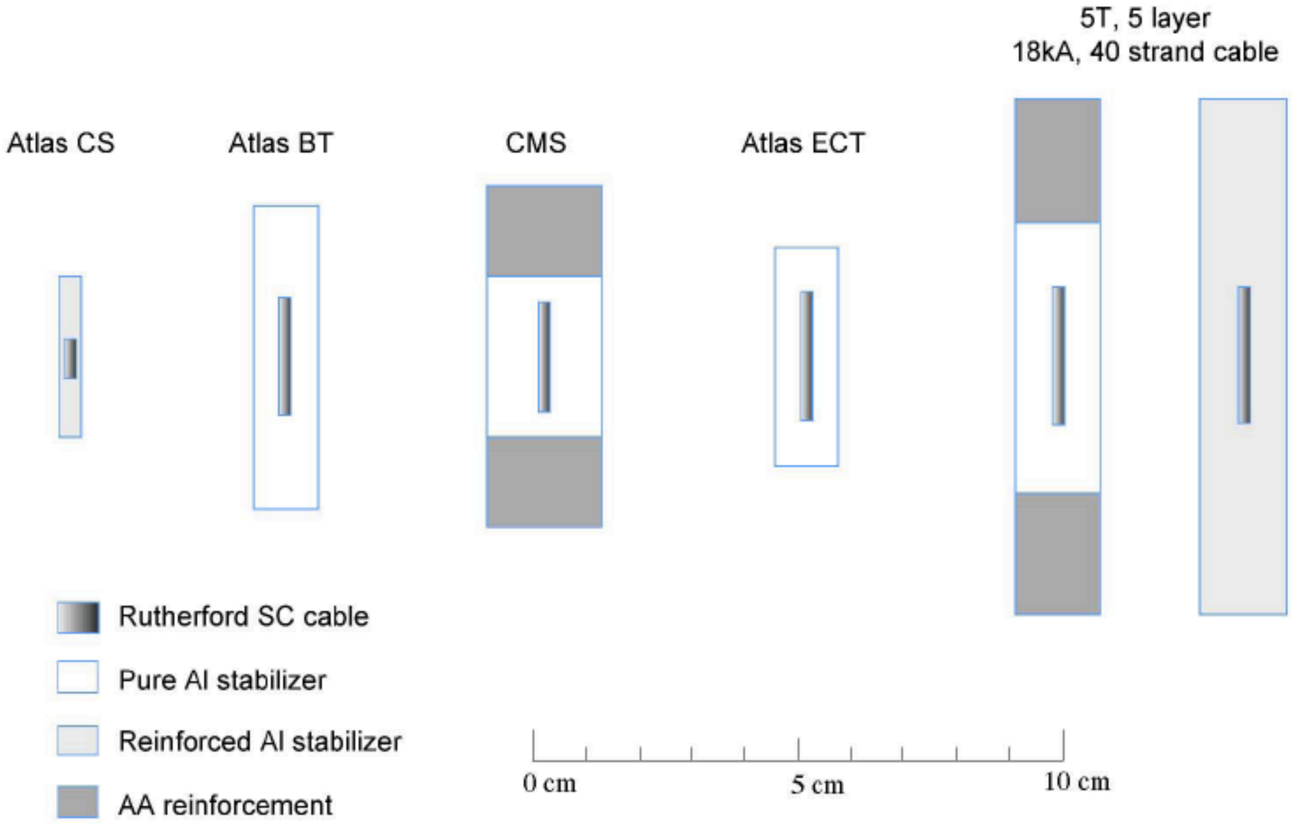


Fig. 7.3

Fig. 7.3: Cross sections of Al stabilised and reinforced conductors previously used and the proposed two conductor options for the 5 T solenoid in the CLIC_SiD design.

Requires hardware R&D on reinforced conductors, and movable services for push-pull

Engineering and Integration

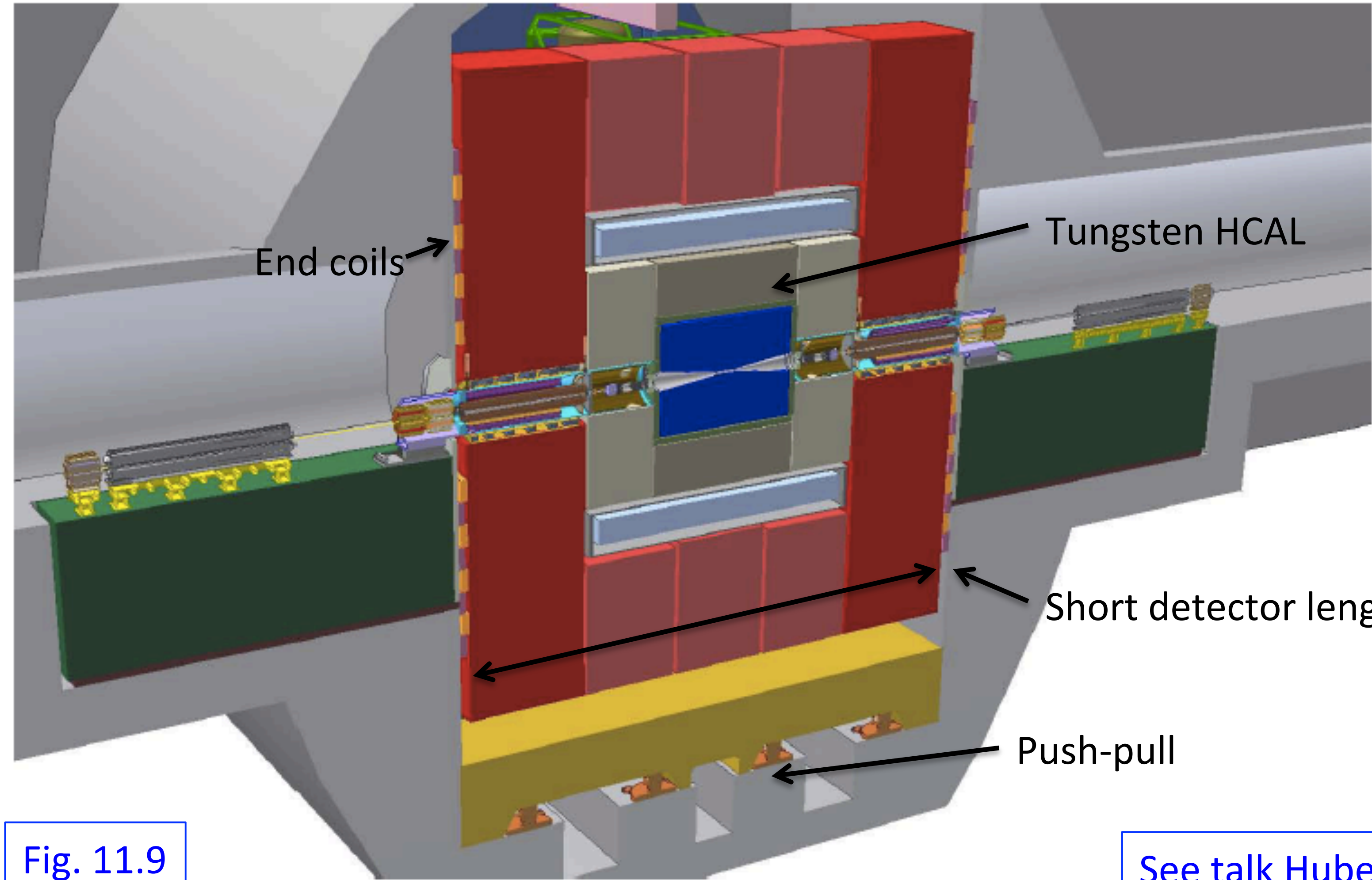


Fig. 11.9

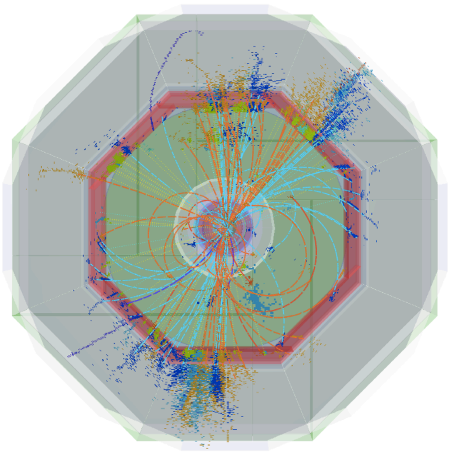
See talk Hubert Gerwig

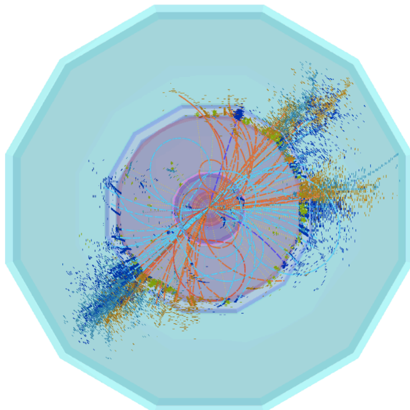
e.g. development of short detector length (z), detector movements, alignment, construction methods for tungsten HCAL, etc…

Summary/outlook

CLIC detector CDR was only possible thanks to years of ILC detector optimisation studies and hardware R&D.

Synergy with ILC will continue during the next project phase.





Huge thank you
to the reviewers
for their careful investigation of our work.

In case you would like to give your support to the physics case and R&D towards a future linear collider based in CLIC technology, you are invited to sign up here:
https://indico.cern.ch/conferenceDisplay.py?confId=136364
Does not imply any formal commitment.

SPARE SLIDES

With detailed plans for next 5 years

Detector simulation studies

Simulation Studies and Detector Optimisation

- Origin and mitigation of high occupancies in low-angle region of endcap calorimetry;
- Location of QD0 inside or outside the detector and impact on the physics;
- Origin and mitigation of high TPC occupancies;
- Occupancies in inner tracking regions and related technology choices;
- Detector optimisation and background suppression at intermediate centre-of-mass energies;
- Simulation studies in support of detector development and beam tests;
- Implementation of the response of various detector readout technologies in the full-detector simulations.

general ILC + CLIC

CLIC-specific

Physics at CLIC

Physics at CLIC

- Monitor the developments at the LHC and report on their implications for the physics potential of CLIC; <= preferable in broad LC context
- Investigate the physics opportunities and challenges of a staged approach to reaching the highest energy of the CLIC machine;
- Investigate the relative merits of electron polarisation versus electron and positron combined polarisation;
- → Study a supersymmetric benchmark model point in full detail to determine all the masses and mixings that can be measured, and investigate how well these measurements can lead us to answers to fundamental questions such as the verification of supersymmetry, the origin and mediation of supersymmetry breaking, the relic abundance of the lightest neutralino, and the compatibility of the model to various approaches to explaining the baryon asymmetry of the universe. <= could be done in collaboration with a similar study for ILC

Software development

Software development

- Roadmap towards common software tools for both experiments;
- Improved and well-maintained tracking codes;
- Improved software tools for geometry descriptions;
- More advanced reconstruction methods, making use of the granularity in space and time.

Vertex detector

Vertex detector

- Developments towards a thin hybrid or integrated CMOS or multi-tier (SOI, 3D or other) pixel technology with small pixel sizes of O(20 µm) and a hit time resolution of O(5 ns);
- Development of high-density interconnect technologies towards maximum detector integration and seamless tiling;
- Thinning of wafers, ASICs or tiers and development of low-mass construction and services materials to reach O(0.2% X0) material per layer;
- Advanced power reduction, power delivery, power pulsing and cooling developments to reach O(0.2% X0) material per layer.

→ **The CLIC timing requirements have a large impact on the vertex detector R&D => very challenging R&D**

Silicon tracking

Silicon tracking

- Study of technology choices to mitigate high occupancies in the inner tracking regions;
- Development and beam tests of low-mass silicon strip detectors with time stamping functionalities, low-power electronics, power pulsing, air cooling and low-mass supports.

The main challenge for ILC and CLIC is to make very thin silicon strip trackers.

TPC-based tracking

TPC-based tracking

- Continued TPC prototype tests (GEM, Micromegas, pad, pixel, ion backflow);
- TPC endplate integration and cooling.

no clear sign yet of TPC hardware R&D needed for CLIC, which goes beyond what is currently developed for ILC

Calorimetry

Calorimetry

- Beam tests of fine-grained ECAL, HCAL and forward calorimeter modules based on different active and passive layers (including tungsten for HCAL) and accompanying validation of GEANT4 modelling;
- Engineering designs and technological prototypes of ECAL, HCAL and forward calorimetry;
- Electronics developments for calorimetry at CLIC, including power delivery and power pulsing tests at the system level.

→ **In addition to R&D for ILC, a tungsten barrel HCAL and very precise timing are required for CLIC**

Electronics and power delivery

Electronics and power delivery

- Qualification of deep sub-micron technologies for the integration of advanced functionalities in compact detector ASICs;
- Studies and prototyping of core front-end functionalities with low power consumption, in particular: pulse height and time measurements, in some cases (silicon tracking and calorimetry) combined with multi-hit functionality within the 156 ns bunch train, as well as on-chip power pulsing features;
- Power delivery and power pulsing at the system level, including system tests in a 4 to 5 T magnetic field;
- Interconnect technologies for front-end electronics and low-mass services.

Many challenges in electronics, often beyond ILC and LHC requirements

Magnet and Ancillary Systems

Magnet and Ancillary Systems

- Extrusion tests and characterisation of a large re-inforced superconductor;
- Material studies and tests of new conductor re-inforcement materials;
- Winding technique for a large conductor;
- Flexible high-temperature power line;
- Prototyping of safety elements, e.g. a water-cooled dump resistor.

R&D required, can build on LHC experience

Engineering and Integration

Engineering and Detector Integration

- Design and integration of the detector concepts in gradually increasing detail;
- Construction and joining techniques with tungsten;
- Engineering and layout studies for a short detector length including end-coils;
- Detector movements and push-pull operation;
- Alignment techniques and deformation measurements;
- Engineering and production techniques of a beryllium with steel beam pipe.

Significant engineering challenges in many different domains, drawing on LHC experience and going well beyond.