

# Prospects for CLIC detector R&D studies

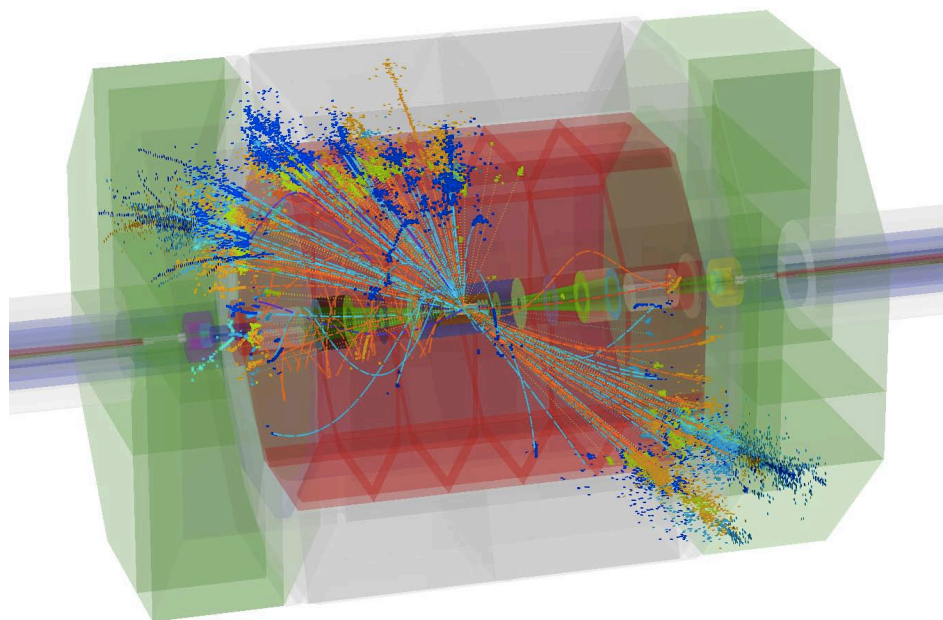
the CLIC Physics and detector CDR, and  
what comes next

Lucie Linssen  
on behalf of the CLIC detector study  
LCWS11, Granada

The CLIC physics and Detector CDR was (pre-)released recently  
<https://edms.cern.ch/document/1160419>

In-time for a review, scheduled October 18-20 in Manchester  
<http://indico.cern.ch/conferenceDisplay.py?confId=146521>

Review committee members



Name
Stefan Soldner-Rembold (chair)
Philip Bambade
Giovanni Batignani
Brigitte Bloch
Daniel Elvira
Philippe Farthouat
Paul Grannis
Marian Ivanov
Richard Nickerson
Arnulf Quadt
Rob Roser
Nobu Toge
Yifang Wang
Pipa Wells
Hitoshi Yamamoto



# the main messages from the CDR



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

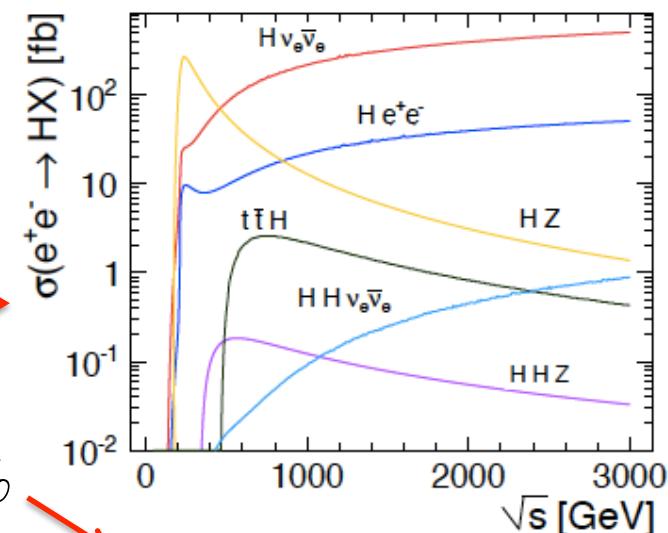


This gives CLIC a very large physics potential,  
in a broad range of centre-of-mass energies

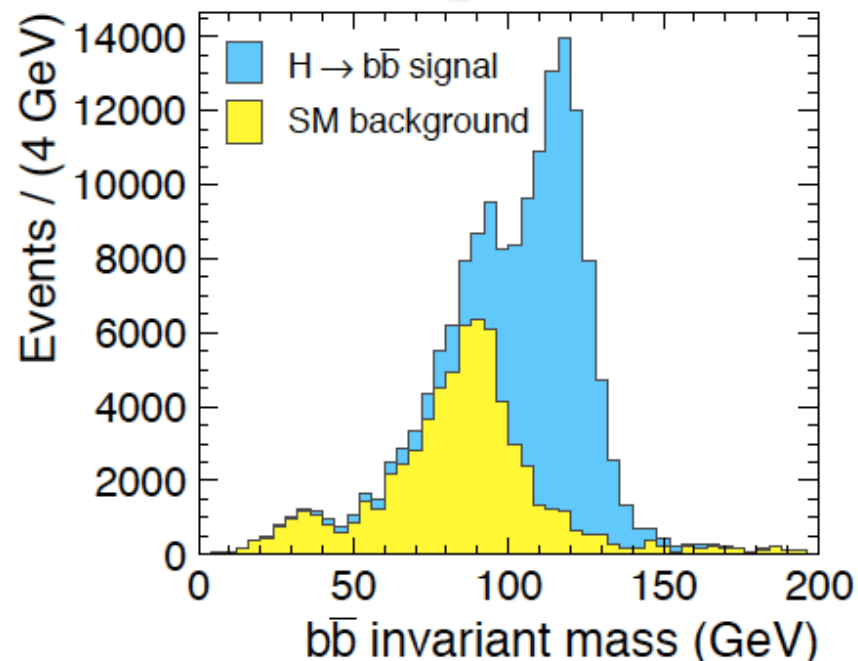
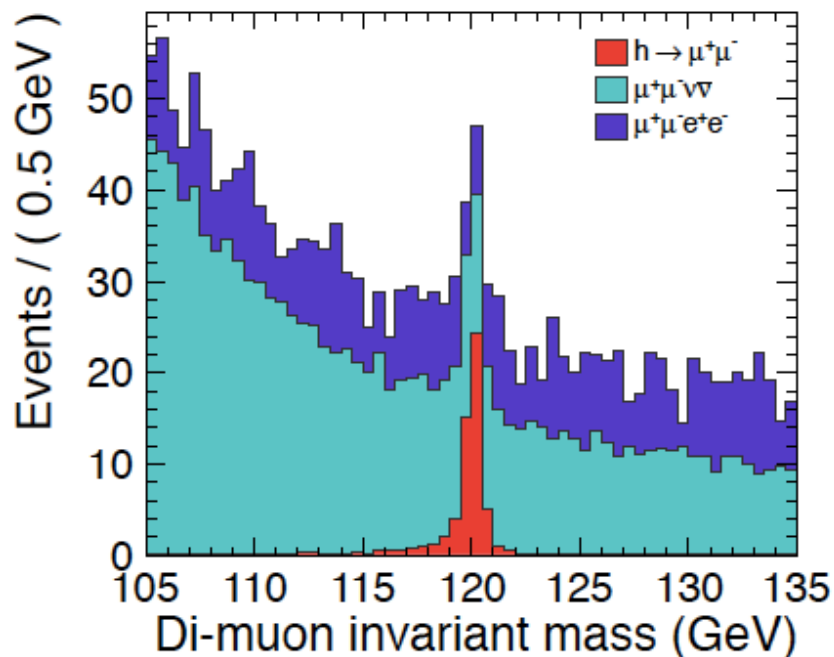
# What is the physics ? (1)

Standard model Higgs (example 120 GeV)

Access to low- $\sigma$  processes



$$\sigma(h \rightarrow \mu^+ \mu^-) < 23 \% \quad \sigma(h \rightarrow b\bar{b}) = 0.2 \%$$



Non-SM Heavy Higgs

e.g. SUSY Higgs  
or Composite Higgs

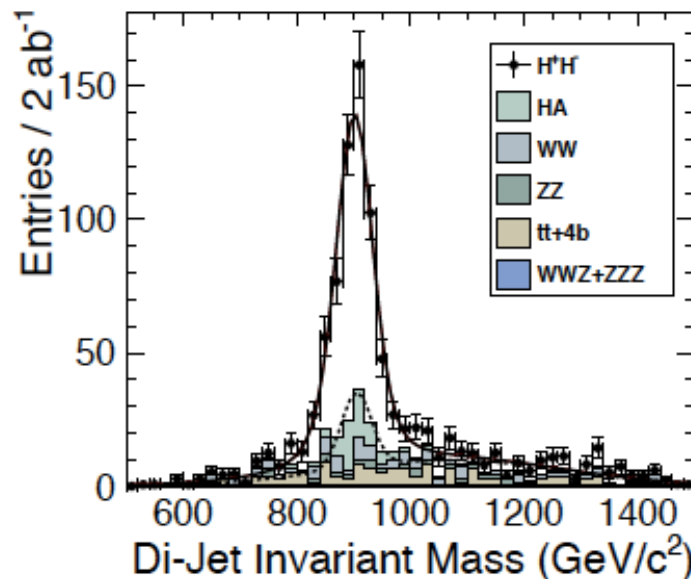
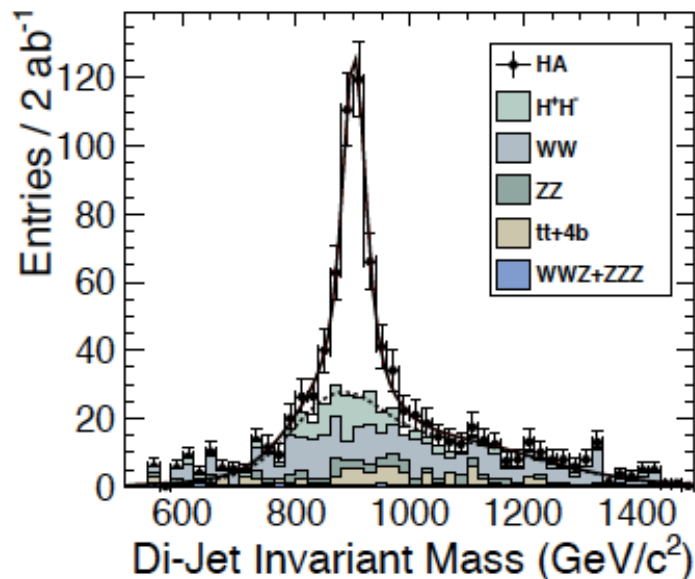
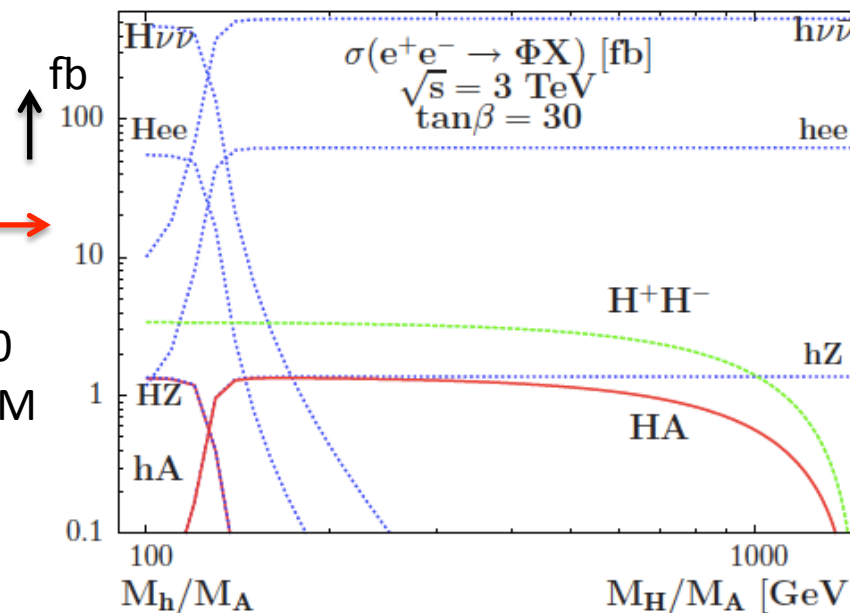
$$m_{A^0/H^0} : \pm 2.8 \text{ GeV}$$



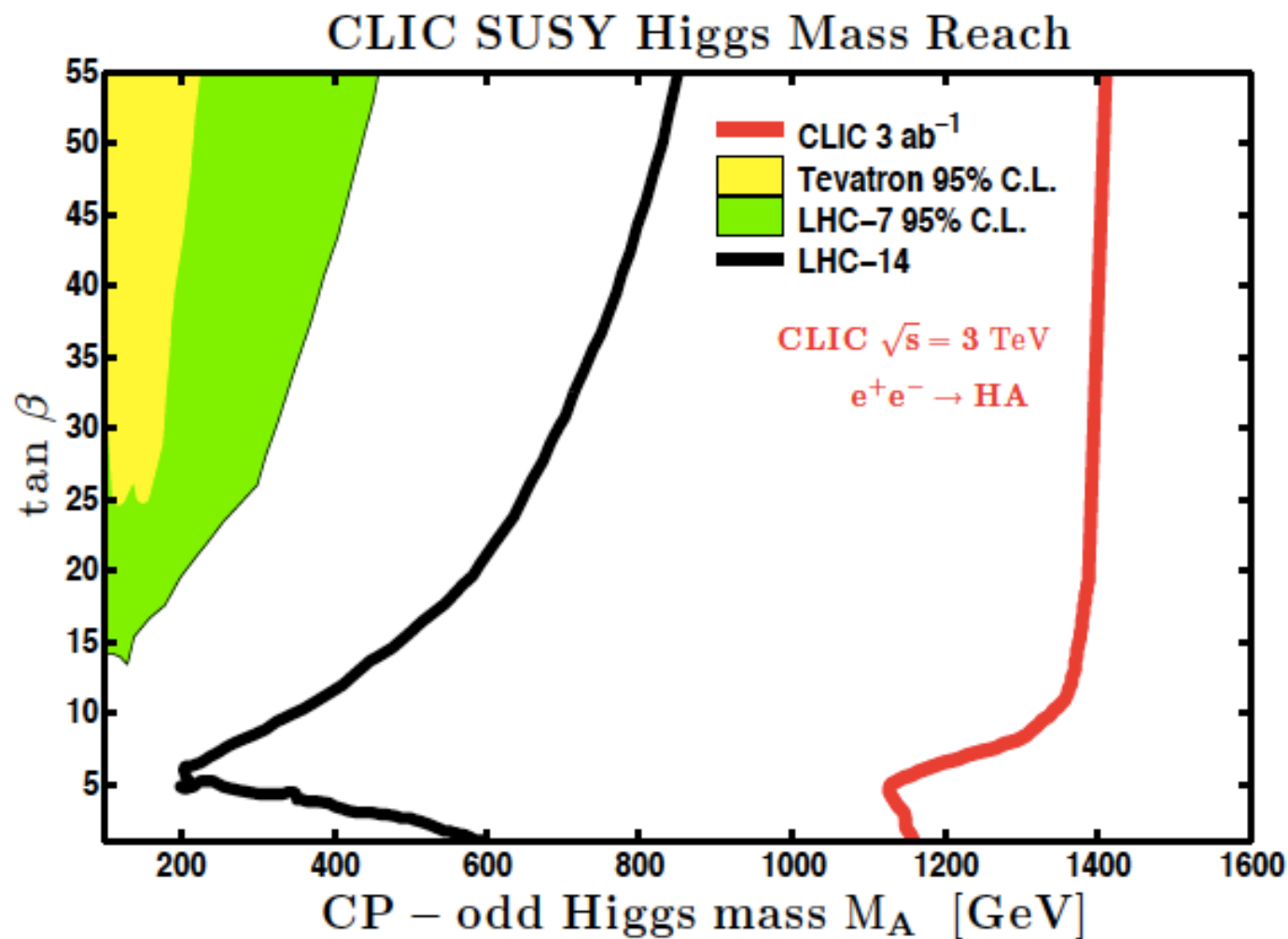
$$m_{H^\pm} : \pm 2.4 \text{ GeV}$$



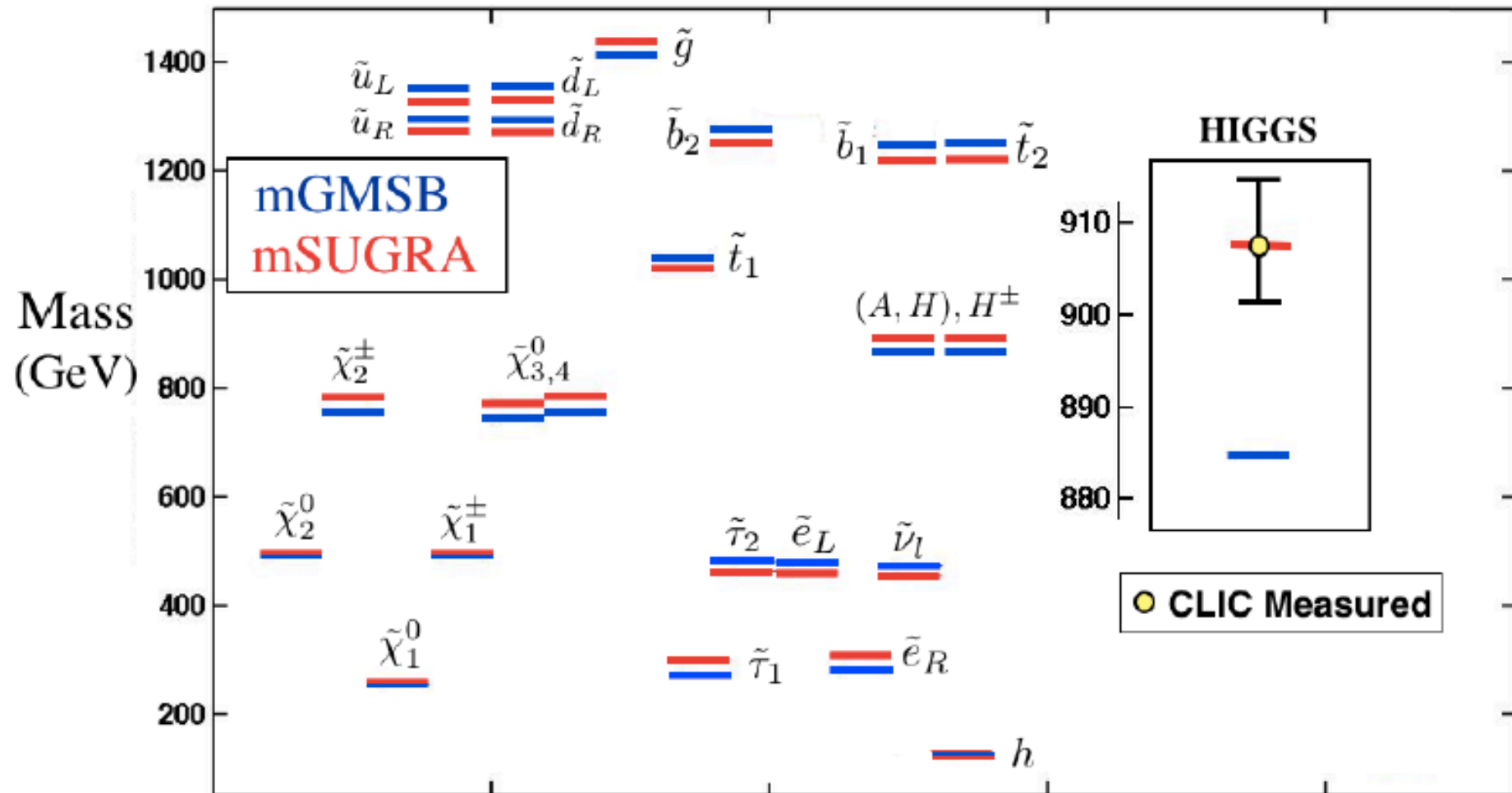
MSSM  
 $\tan\beta=30$   
3 TeV CM



## CLIC access to SUSY heavy Higgs searches



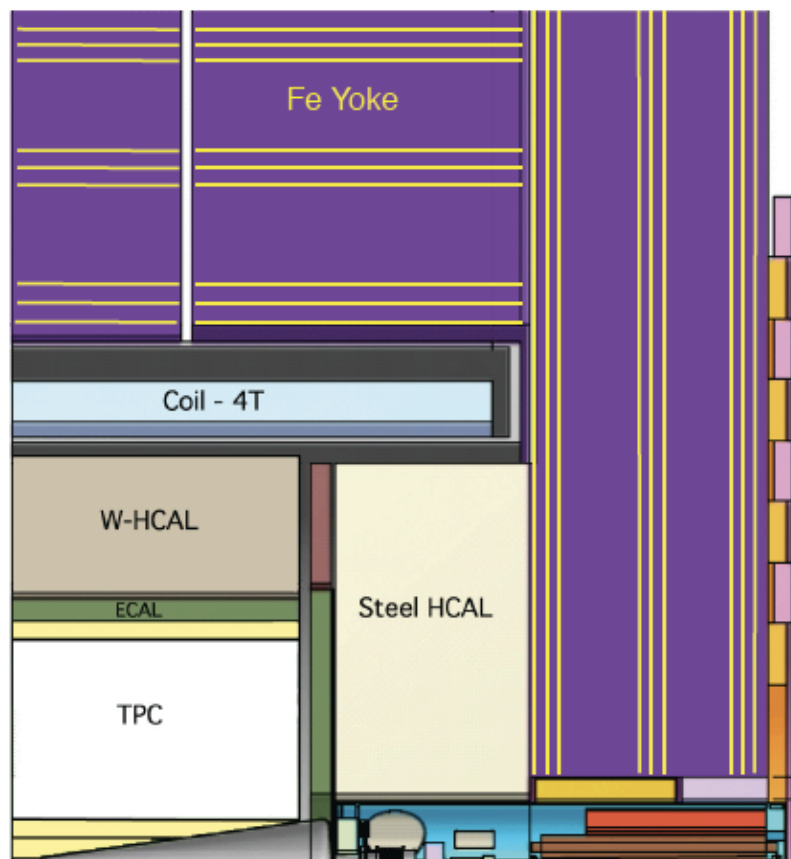
## CLIC resolving power for SUSY breaking models



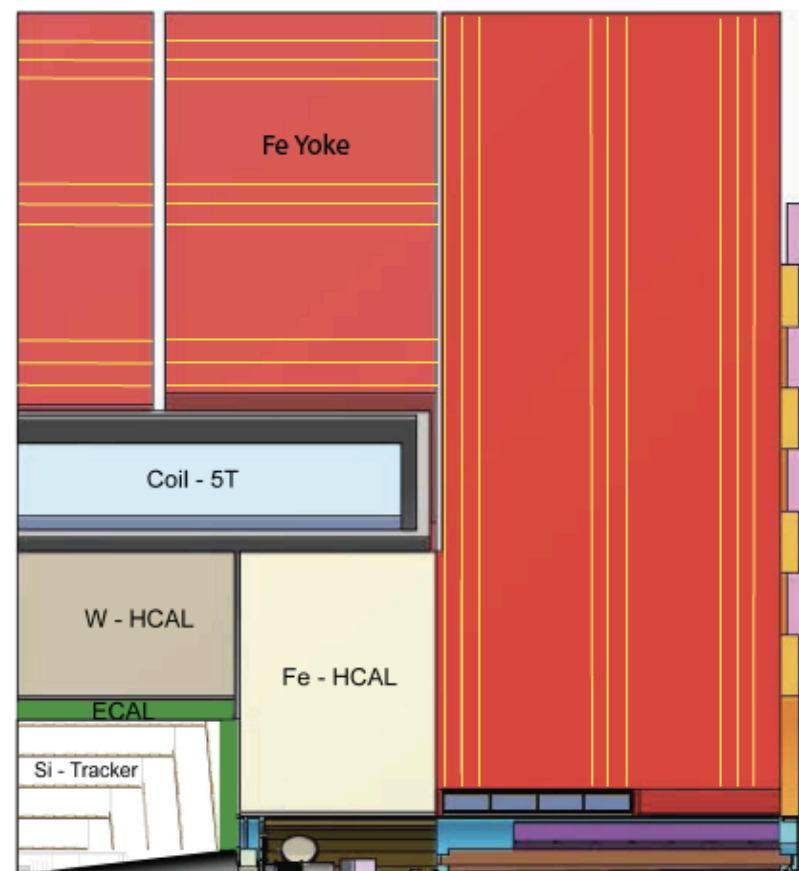
## Short overview of physics reach

New particle	LHC14	SLHC	LC800	CLIC3
squarks [TeV]	2.5	3	0.4	1.5
sleptons [TeV]	0.3	-	0.4	1.5
$Z'$ (SM couplings) [TeV]	5	7	8	20
2 extra dims $M_D$ [TeV]	9	12	5-8.5	20-30
TGC (95%) ( $\lambda_\gamma$ coupling)	0.001	0.0006	0.0004	0.0001
$\mu$ contact scale [TeV]	15	-	20	60
Higgs compos. scale [TeV]	5-7	9-12	30	30





CLIC\_ILD



CLIC\_SiD

Based on ILC detector concepts

=> thanks to many years of optimisation and hardware studies for a ~500 GeV machine

Background suppression successfully applied by:

- Precise selective timing cuts on reconstructed particles (PFO's)
- Well-adapted jet reconstruction (taken from hadron colliders)

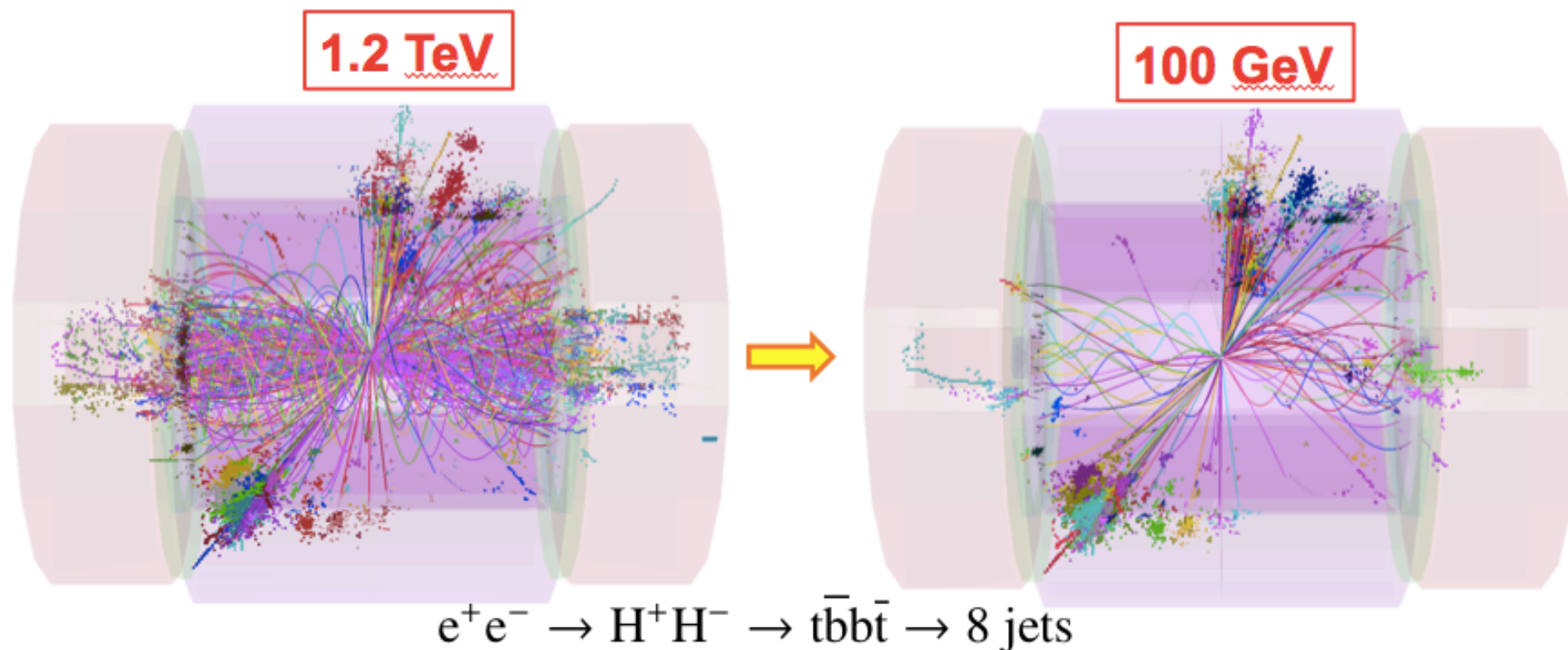


Table 12.19: Summary table of the CLIC benchmark analyses results. All studies at a centre-of-mass energy of 3 TeV are performed for an integrated luminosity of  $2 \text{ ab}^{-1}$ . The study at 500 GeV assumes an integrated luminosity of  $100 \text{ fb}^{-1}$ .

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Observable	Unit	Gene- rator value	Stat. uncert- ainty
3.0	Light Higgs production	$h \rightarrow b\bar{b}$		$\sigma$		285	0.22%
		$h \rightarrow c\bar{c}$		$\times$ Bran- ching ratio	fb	13	3.2%
		$h \rightarrow \mu^+\mu^-$				0.12	23%
3.0	Heavy Higgs production	$HA \rightarrow b\bar{b}b\bar{b}$	I	Mass Width	GeV GeV	902.4	0.3% 31%
			II	Mass Width	GeV GeV	742.0	0.2% 17%
		$H^+H^- \rightarrow t\bar{b}b\bar{t}$	I	Mass Width	GeV GeV	906.3	0.3% 27%
			II	Mass Width	GeV GeV	747.6	0.3% 23%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \rightarrow q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	Mass	GeV	1123.7	0.52%
				$\sigma$	fb	1.47	4.6%

3.0	Sleptons production	$\tilde{\mu}_R^+ \tilde{\mu}_R^- \rightarrow \mu^+ \mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$	II	$\sigma$	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\tilde{e}_R^+ \tilde{e}_R^- \rightarrow e^+ e^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$		$\sigma$	fb	6.05	0.8%
		$\tilde{\ell}$ mass		GeV	1010.8	0.3%	
		$\tilde{\chi}_1^0$ mass		GeV	340.3	1.0%	
		$\tilde{e}_L^+ \tilde{e}_L^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 e^+ e^- hh$ $\tilde{e}_L^+ \tilde{e}_L^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 e^+ e^- Z^0 Z^0$		$\sigma$	fb	3.07	7.2%
		$\tilde{\nu}_e \tilde{\nu}_e \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 e^+ e^- W^+ W^-$		$\sigma$	fb	13.74	2.4%
		$\tilde{\ell}$ mass		GeV	1097.2	0.4%	
		$\tilde{\chi}_1^\pm$ mass		GeV	643.2	0.6%	
3.0	Chargino and neutralino production	$\tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+ W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				$\sigma$	fb	10.6	2.4%
		$\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow h^0 / Z^0 h^0 / Z^0 \tilde{\chi}_1^0 \tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				$\sigma$	fb	3.3	3.2%
0.5	$t\bar{t}$ production	$t\bar{t} \rightarrow (q\bar{q}b)(q\bar{q}b)$		Mass	GeV	174	0.046%
				Width	GeV	1.37	16%
		$t\bar{t} \rightarrow (q\bar{q}b)(\ell\nu b),$ $\ell = e, \mu$		Mass	GeV	174	0.052%
				Width	GeV	1.37	18%



# CDR status and short-term plans



The CLIC CDR, frozen version for the Review in October:

<https://edms.cern.ch/document/1160419>

The CDR will be published before the end of 2011.

During the ~6-8 weeks between the Review and the final publishing the CDR will be complemented with, for example:

- \*\* Inclusion of comments by the Review committee.
- \*\* New insights of a staged energy approach for CLIC, taking LHC results into account.
- \*\* CLIC physics potential with polarised beams (additional section to chapter 1)
- \*\* Determination of the luminosity spectrum through measurement of bhabha scattering.
- \*\* .....

The CLIC physics&detector CDR will be presented to the CERN Scientific Policy Committee in December 2011



# Continuation of CDR work in 2012



There will be some continuation of CLIC CDR work in 2012

## Summary document for accelerator, physics and detectors

Will comprise:

- summary of Vol. 1&2 on accelerator and physics/detector
- staged energy approach for CLIC
- value estimate

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And also: preparation for the **update of the European Strategy for Particle Physics**  
Including a **common LC document** (see LCWS11 session 28/9 @ 18 hrs)



# After the CDR....



**The CLIC detector study team will participate in the preparations for the ILC DBD documents.**

**To this aim, several discussions took place at LCWS11**



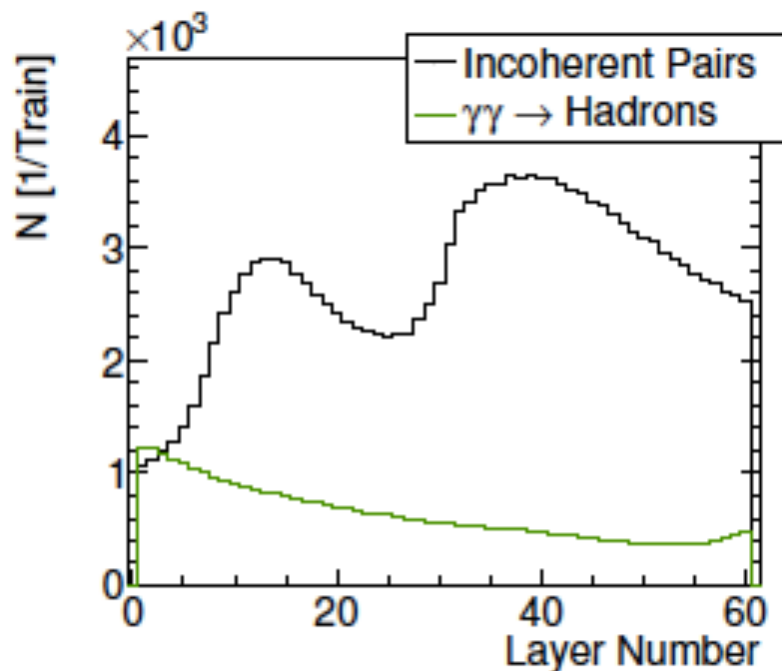
**Studies foreseen on the Medium-term => covering a ~5-year period  
(see chapter 13 of the CDR, and detailed backup slides of this talk)**

## **In a nutshell:**

- Detector simulation studies and physics studies
  - Further detector optimisation
  - Extend the CLIC physics studies to CM energies below 3 TeV
  - Gradually explore physics with a machine built in stages
- Software development (common between ILC and CLIC)
- LC detector R&D (many common activities between ILC and CLIC)
- CLIC-specific detector R&D

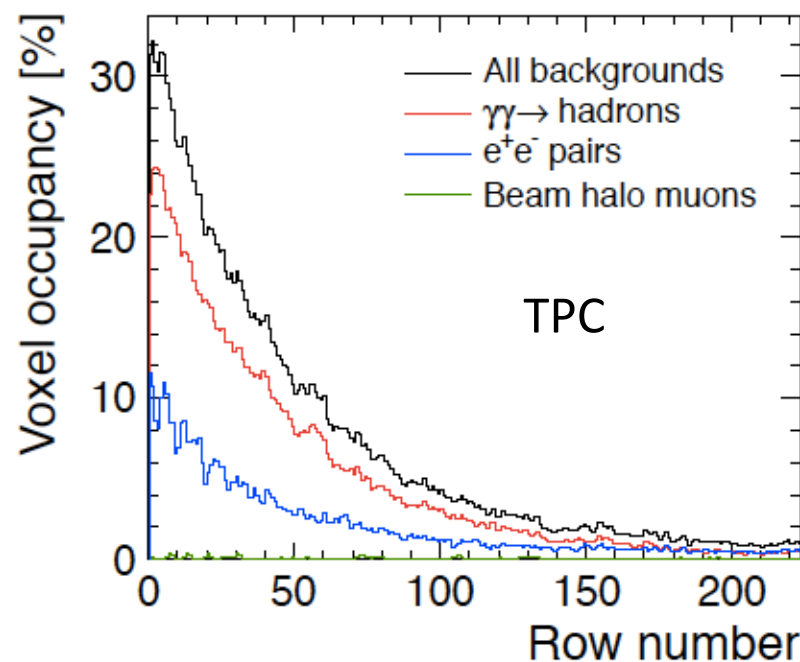
**The next slides illustrate a few of the upcoming studies**

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

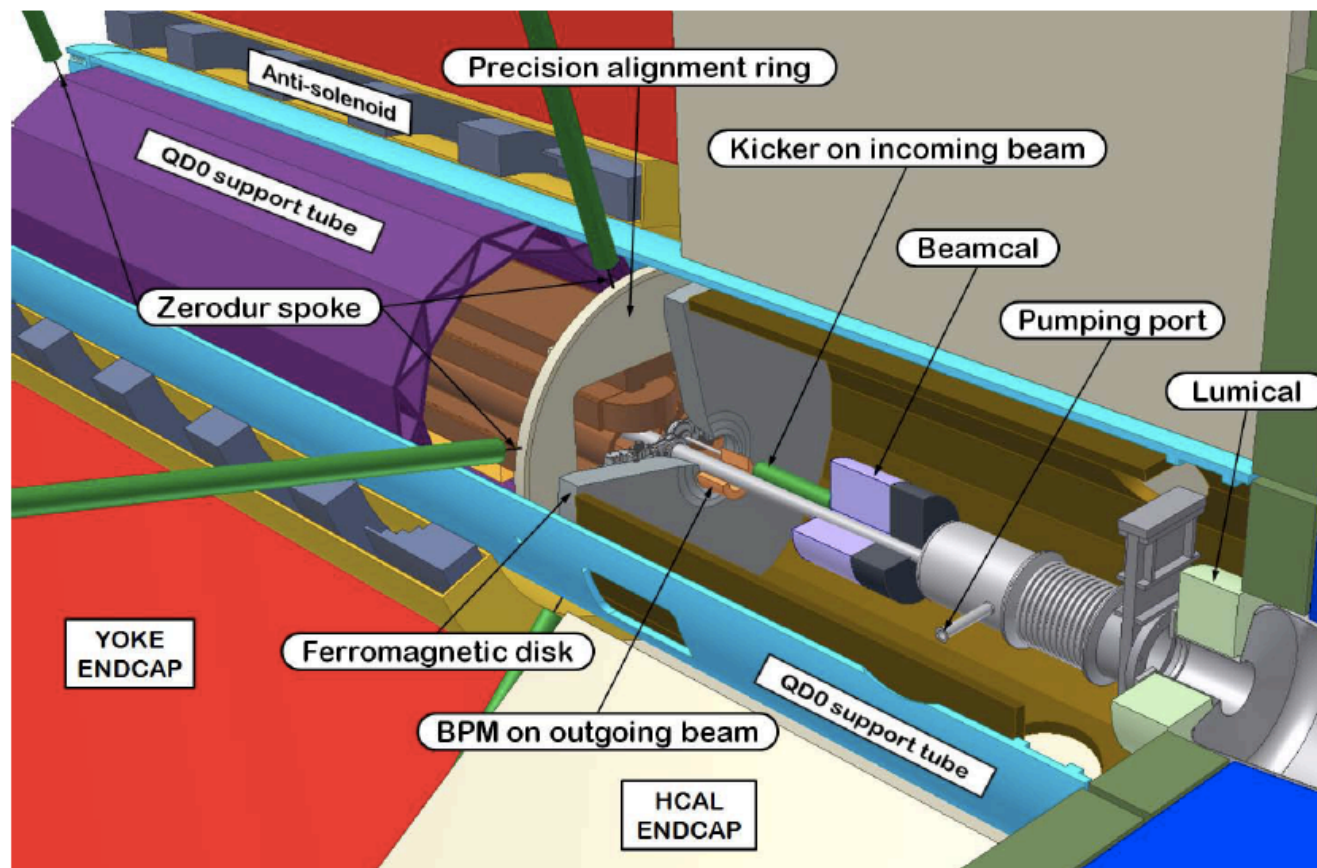
**can be solved**



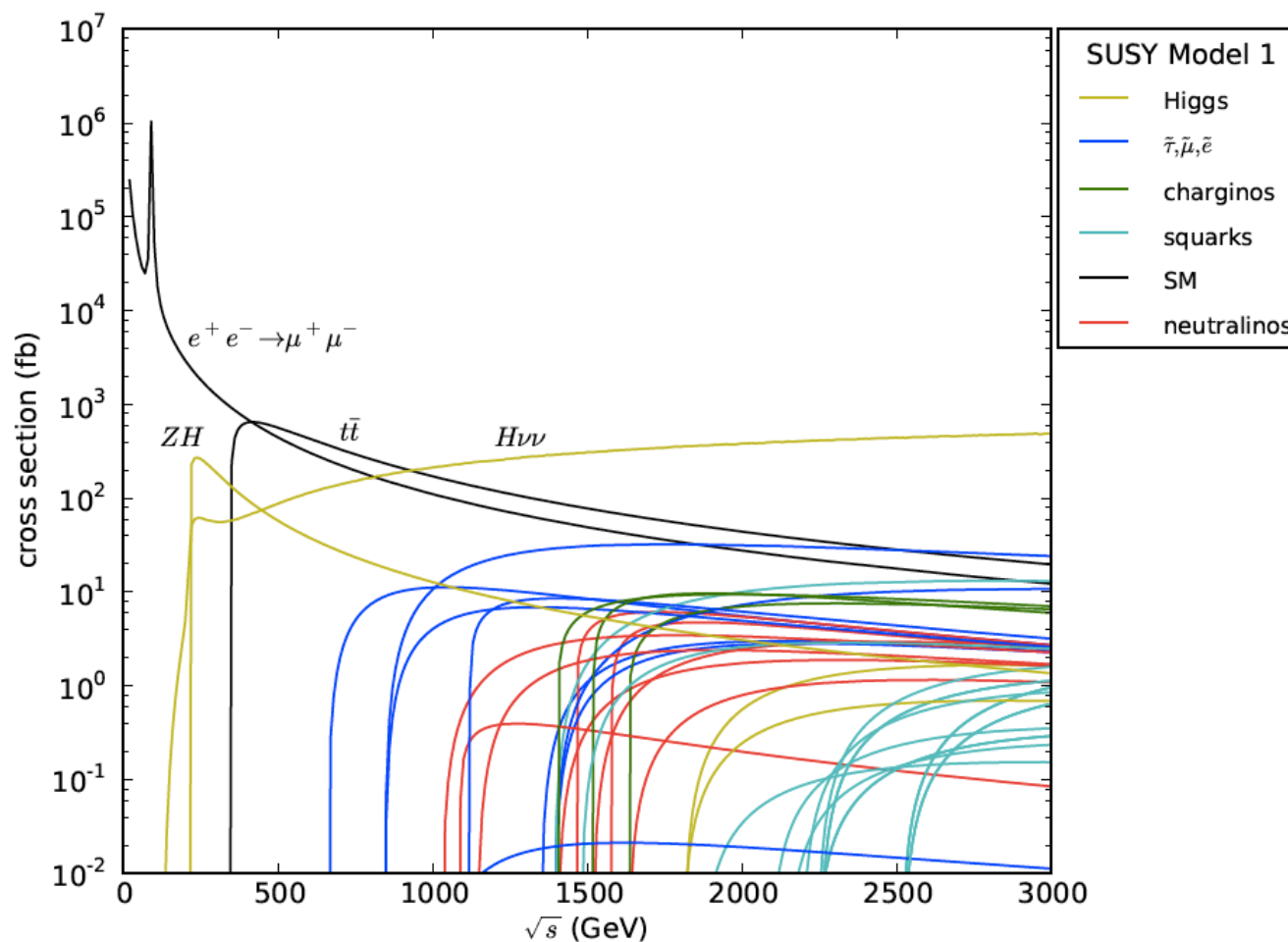
High occupancies in the TPC, mostly due to  $\gamma\gamma \rightarrow \text{hadrons}$ . One may consider pixelised readout for the TPC in this region or suppress the inner pad rows.

**requires technology/layout changes**

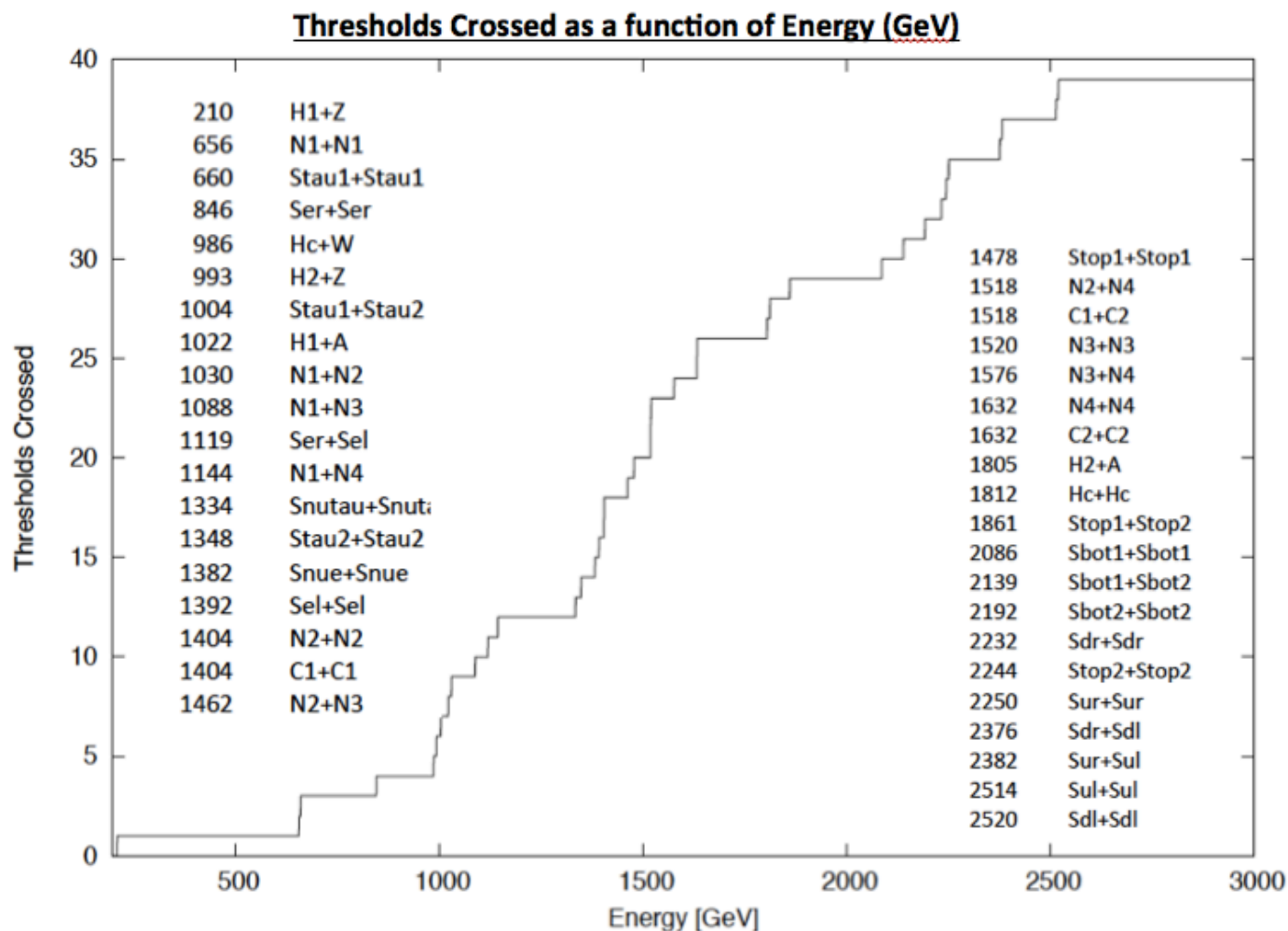




The QD0 and its stability requirements at CLIC have a significant impact on the detector layout and acceptance in the forward region. More study is needed to quantify the impact on the physics and to make a balance between pros and cons of having QD0 inside the detector.



Use a single SUSY model 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 (see James Wells presentation, LCWS11 27/9 plenary, 19 hrs)





# Software development



For the CDR used:

- Mokka/Marlin framework
- SLIC / org.lcsim framework



Quite some overhead to work with two frameworks (each having their advantages and drawbacks)

Fortunately, for the CDR, we also made use of common tools:

LCIO

Event generation (WHIZARD + PYTHIA)

ILCDIRAC grid production

PandoraPFA / SLICPandora for particle flow analysis

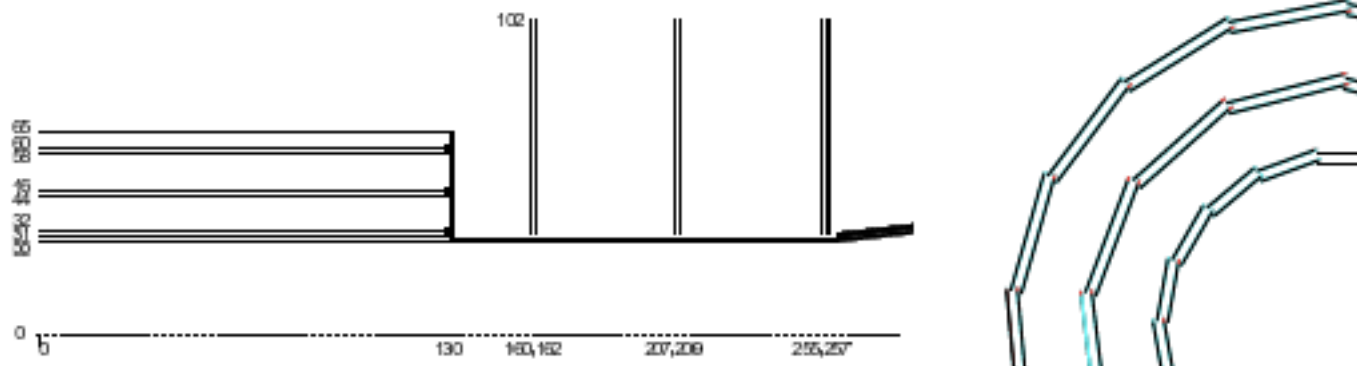
LCFI for flavour tagging

In a next phase:

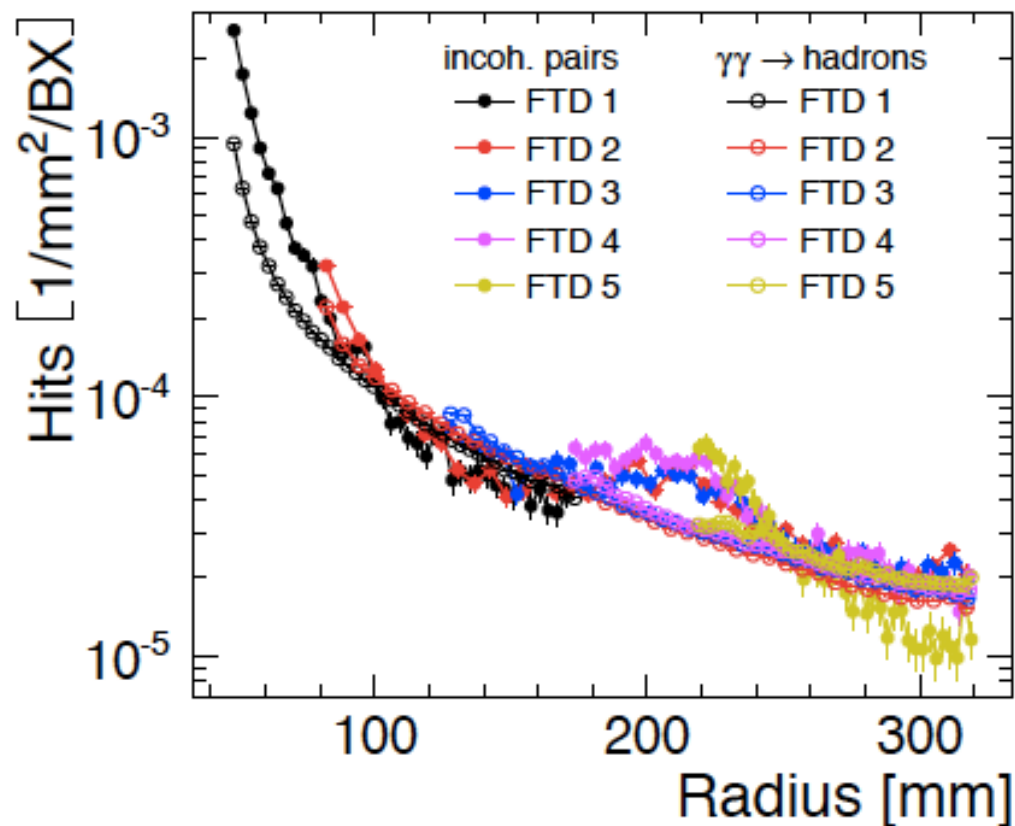
- Further improvement of simulation tools => continuation of trend to have common tools

## Vertex detector

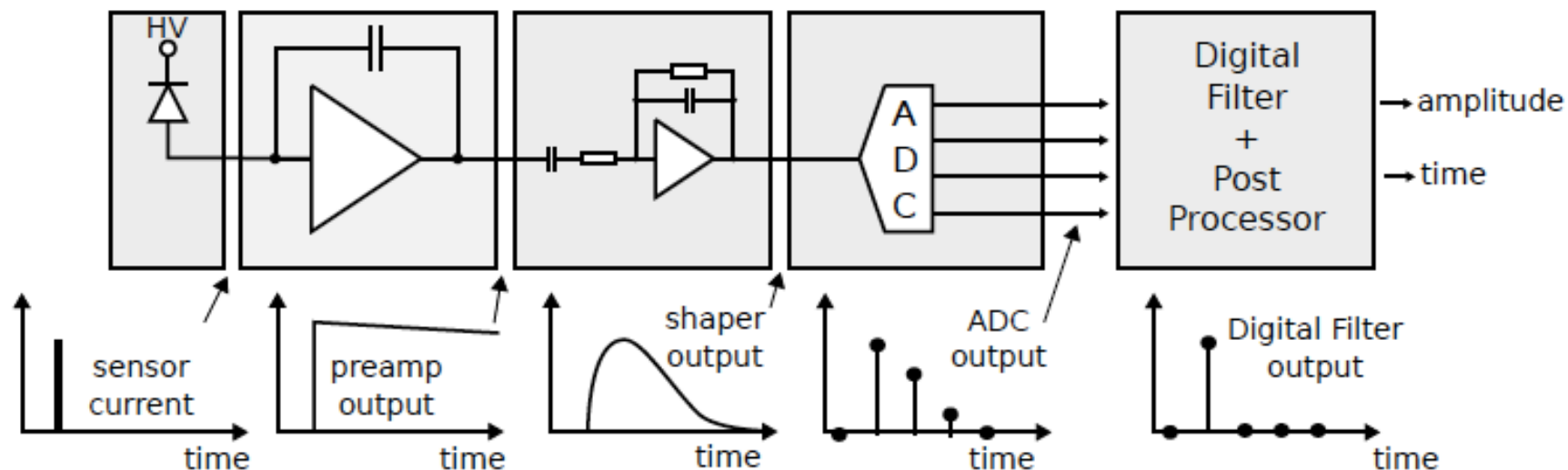
- pixel technology with small pixel sizes of  $O(20\ \mu\text{m})$
- hit time resolution of  $O(5\ \text{ns})$ ;
- $O(0.2\% X_0)$  material per layer;
  - high-density interconnect, thinning of wafers, ASICs or tiers;
  - low-mass construction and services
  - Advanced power reduction, power delivery, power pulsing and cooling developments



High occupancies per bunch train in inner strip tracking layers



~2.9 hits/strip per 156 ns bunch train in FTD2, including safety factor  
**=> Requires technology choices and hardware R&D**



Calorimeter electronics at 3 TeV requires:

- 12-14 bit pulseheight measurement
- $\sim 1$  ns time resolution for hits
- Up to 5 hits per 156 ns bunchtrain
- Very low power consumption

**Requires electronics R&D**

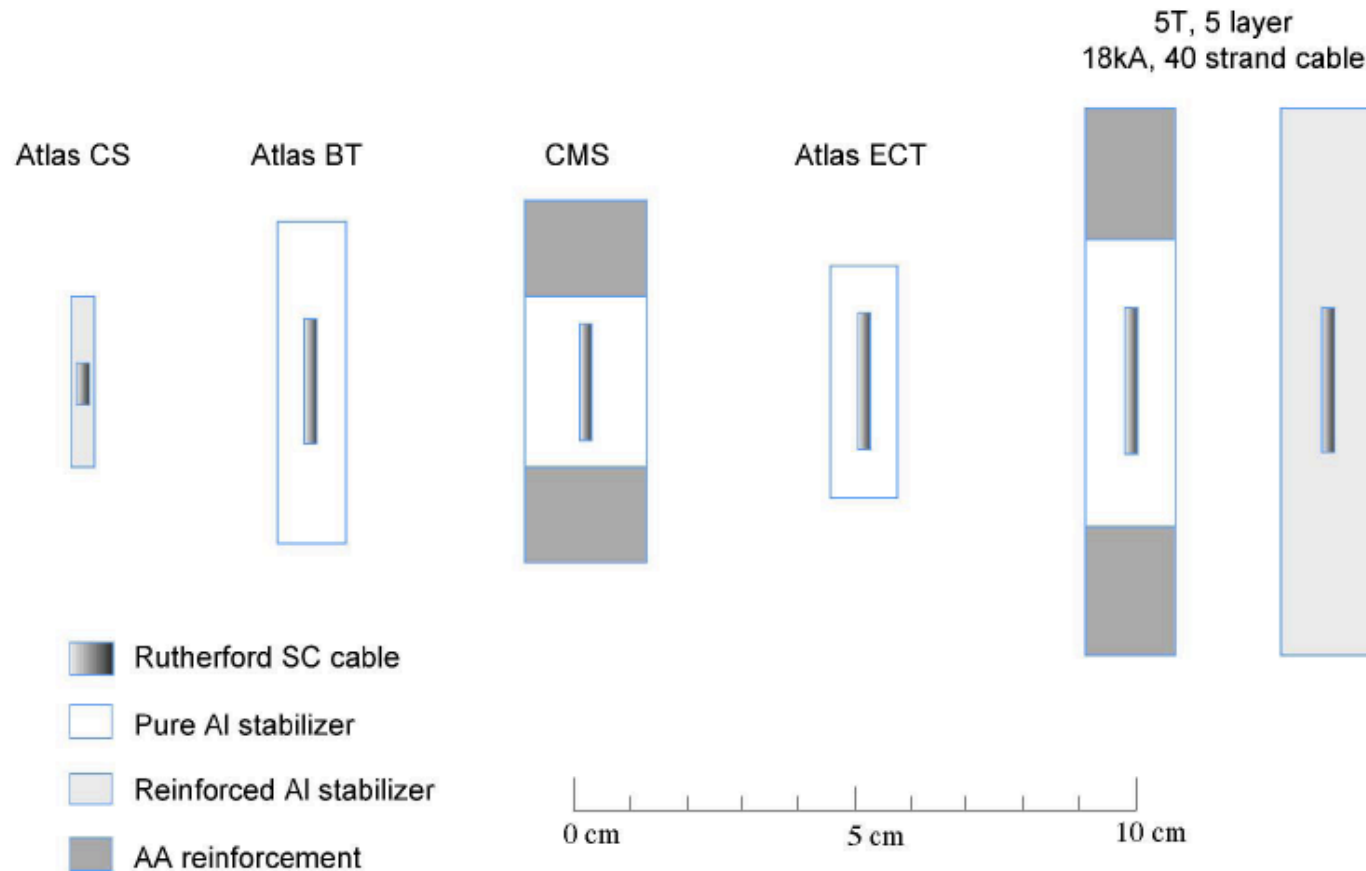
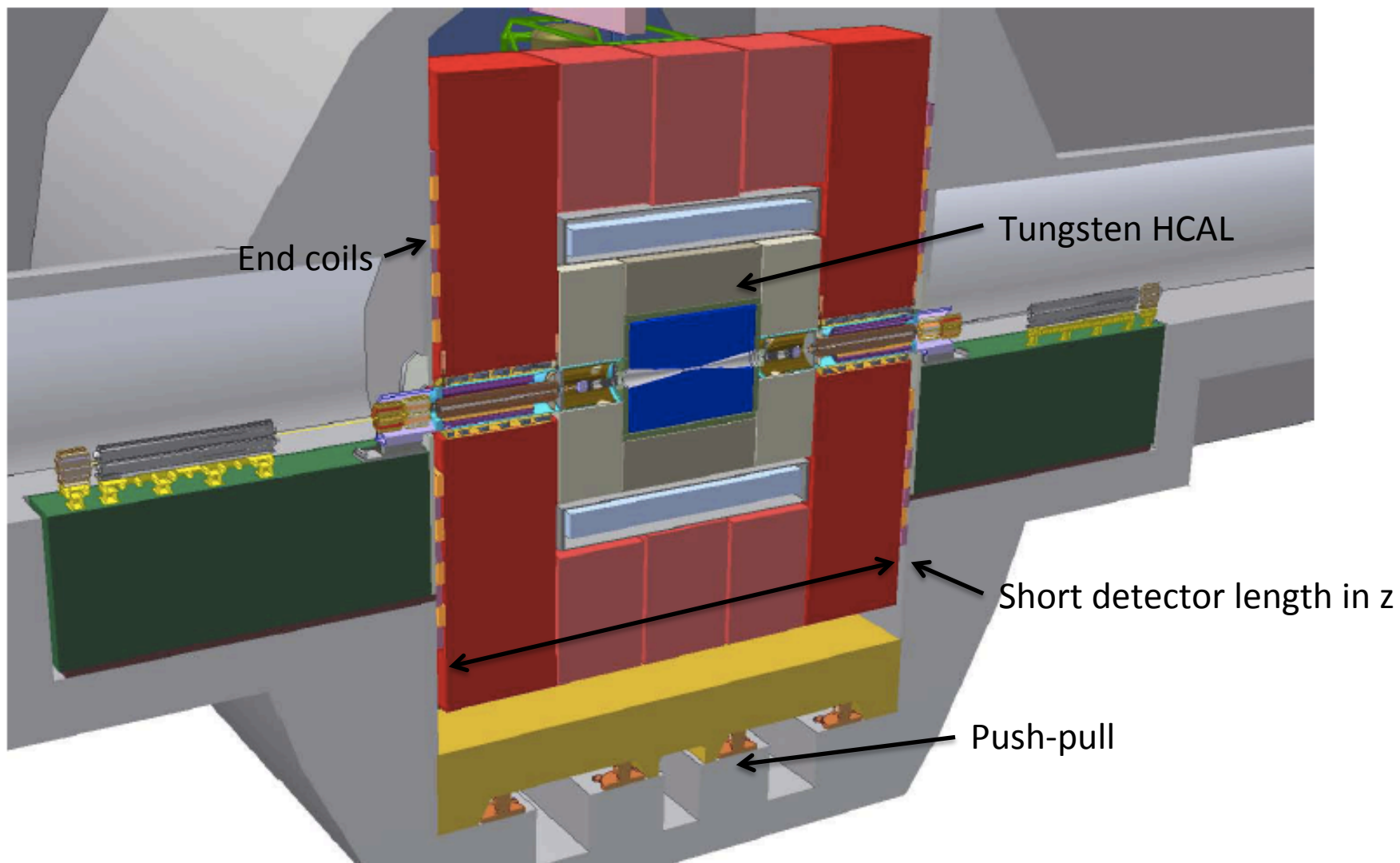


Fig. 7.3: Cross sections of Al stabilised and reinforced conductors previously used and the proposed two conductor options for the 5 T solenoid in the CLIC\_SiD design.

**Requires R&D on reinforced conductors**







# Summary/outlook



A pre-release of the CLIC physics/detector CDR is available  
<https://edms.cern.ch/document/1160419>

Confirms the strong physics case for CLIC

CLIC detector CDR work was possible following years of studies for R&D. Thank you !



Challenging R&D projects with clear spin-off the other projects and fields

Please give your support to the physics case of a future linear collider by signing up for the CDR here:

<https://indico.cern.ch/conferenceDisplay.py?confId=136364>

Does not imply any formal commitment.

# SPARE SLIDES

With detailed plans for next 5 years

## 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

- 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

- Developments towards a thin hybrid or integrated CMOS or multi-tier (SOI, 3D or other) pixel technology with small pixel sizes of  $O(20\ \mu\text{m})$  and a hit time resolution of  $O(5\ \text{ns})$ ;
- 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  $O(0.2\% X_0)$  material per layer;
- Advanced power reduction, power delivery, power pulsing and cooling developments to reach  $O(0.2\% X_0)$  material per layer.



# 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.





# TPC-based tracking



## TPC-based tracking

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



# 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.

## 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.



# 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.



## 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.