The ECFA 2021 Roadmap for Detector Development

DESY Particle and Astroparticle Physics Colloquium

February 22, 2022

Felix Sefkow
DESY

Outline

Menue

- **Introduction: how and why it started**
- **The process: engaging with the community**
- **The Roadmap: how to read it**
- **Implementation: next steps**

Selection of examples
with maximal personal bias

Stolen slides from many people -
all mistakes are mine

Horizon 2020 - Proposal for AIDA-2020 Follow-up

An Opportunity

From the EC Call:

- Scope: **Funding** will be provided to research infrastructure networks to kick-start the **implementation of a common strategy/roadmap for technological developments** required for improving their services through partnership with industry.
- Proposals should address:
  - **if not already done,** the identification of key techniques and trends which are crucial for future construction and upgrade of the involved Research Infrastructures and **the definition of roadmaps and/or strategic agendas for their development,**

Started discussions with ECFA…

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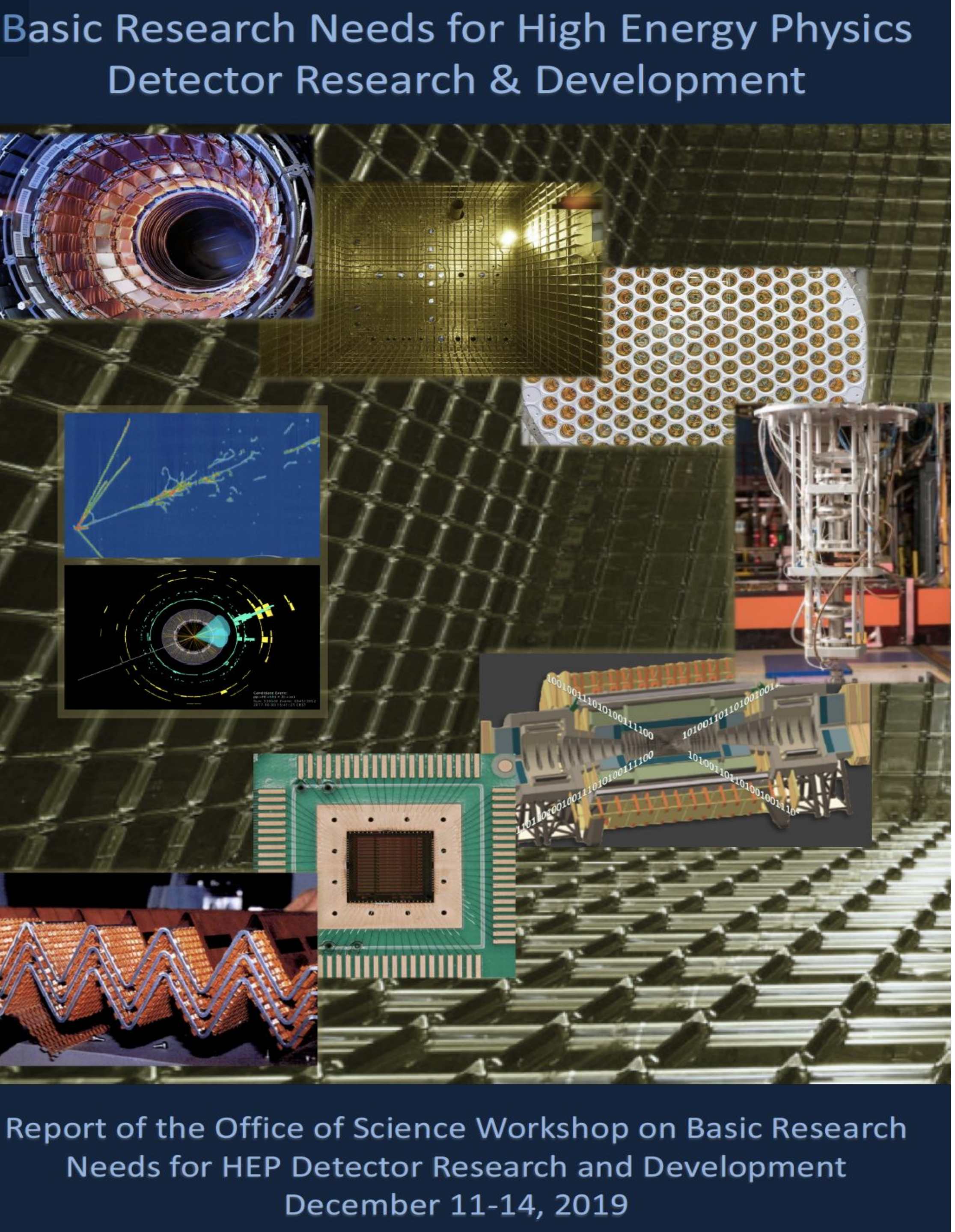
From the proposal:

- **A roadmap for European Detector R&D is part of the overall long-range planning** of European high-energy physics facilities and its associated technologies and infrastructures.
- The **Update of the European Strategy for Particle Physics (ESPP),** to be published in summer 2020, **will be followed by a process** towards establishing the corresponding European roadmap for detector R&D.
- This process, initiated **under the responsibility of the European Committee for Future Accelerators (ECFA),** will cover a broad consultation (…)
- It has been **agreed that ECFA and AIDAinnova will work closely together** in setting up this process, in organising inclusive community meetings and in establishing the roadmap.



DOE Basic Research Needs Study on Instrumentation

(Report to HEPAP - final draft)

Final Meeting: December 2019

Bonnie Fleming
Ian Shipsey
(on behalf of the BRN Panel)

2 European Contributors: P.Krizan, FS

European Strategy

Detectors for What?

European Strategy for Particle Physics Update 2020

- clear directions (often underestimated)

Consensus:

- an e+e- Higgs factory is the preferred next collider

No consensus:

- linear or circular collider: ILC, CLIC, FCCee,…

In addition: long timelines

- different for different projects
- important tasks to be accomplished before

Not trivial to motivate a strategic detector development

- ESPPU requested a Detector Roadmap (organised by ECFA)
- Accelerator Roadmap in parallel, by Lab Directors Group

European Strategy Update

European Particle Physics Strategy Update

"**Main report**: *"Recent initiatives with a view towards strategic R&D on detectors are being taken by CERN's EP department and by the ECFA detector R&D panel, supported by EU-funded programmes such as AIDA and ATTRACT. Coordination of R&D activities is critical to maximise the scientific outcomes of these activities and to make the most efficient use of resources; as such, there is a clear need to strengthen existing R&D collaborative structures, and to create new ones, to address future experimental challenges of the field beyond the HL-LHC. Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields."*

Deliberation document: *"Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels."*

Extracted from the documents of 2020 EPPSU, https://europeanstrategyupdate.web.cern.ch/

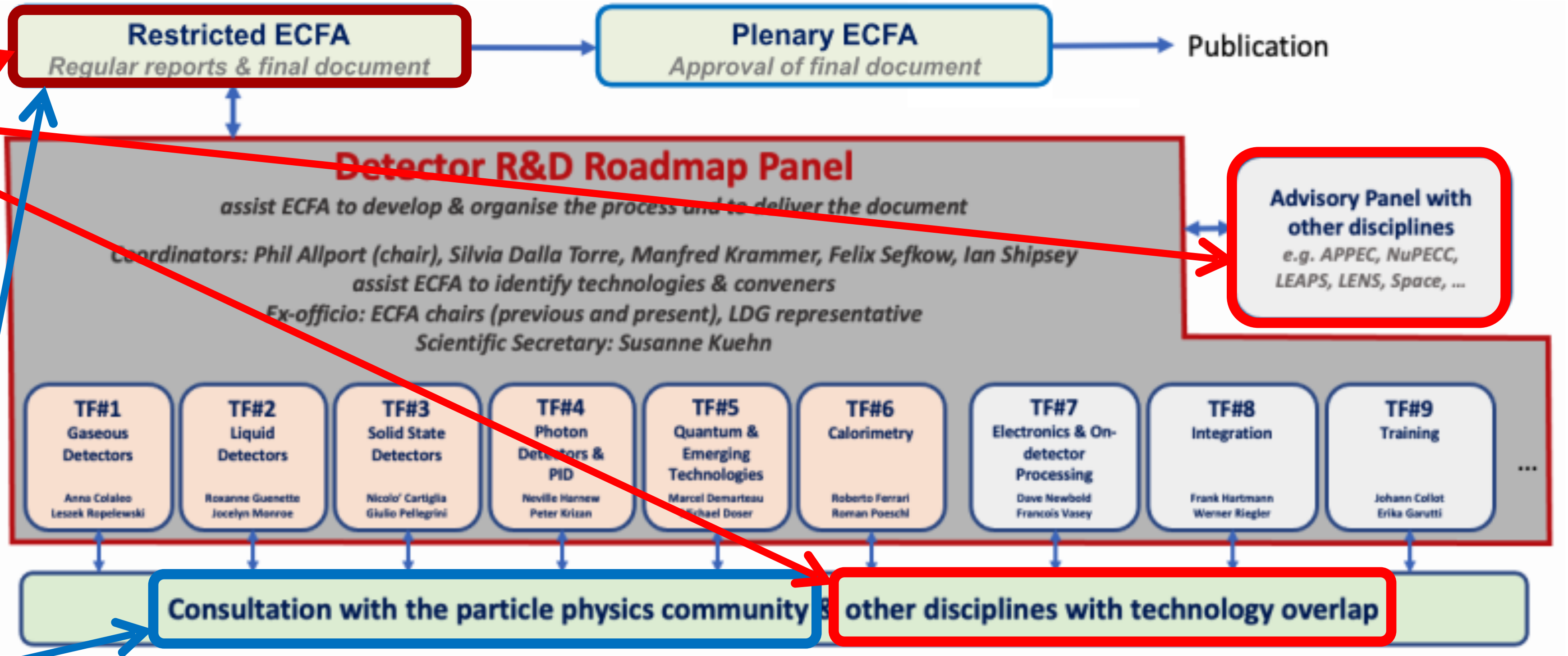
More roadmap process details at: https://indico.cern.ch/e/ECFADetectorRDRoadmap

Phil Alport

Roadmap Process

Roadmap Organisation

"Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields" *



"The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels" *

ECFA Detector R&D Roadmap Panel web pages at:
https://indico.cern.ch/e/ECFADetectorRDRoadmap

*** 2020 European Particle Physics Strategy Update**
https://europeanstrategyupdate.web.cern.ch/

Detector R&D Roadmap Process Group

Task Force convenors, Task Force expert members and Panel members of the ECFA Detector R&D Roadmap Process Group

Task Force 1 Gaseous Detectors: Anna Colaleo[1], Leszek Ropelewski[2] *(Conveners)*
Klaus Dehmelt[3], Barbara Liberti[4], Maxim Titov[5], Joao Veloso[6] *(Expert Members)*

Task Force 2 Liquid Detectors: Roxanne Guenette[7], Jocelyn Monroe[8] *(Conveners)*
Auke-Pieter Colijn[9,10], Antonio Ereditato[11,12,28], Inés Gil Botella[13],
Manfred Lindner[14] *(Expert Members)*

Task Force 3 Solid State Detectors: Nicolo Cartiglia[15], Giulio Pellegrini[16] *(Conveners)*
Daniela Bortoletto[17], Didier Contardo[18], Ingrid-Maria Gregor[19,20] Gregor Kramberger[21],
Heinz Pernegger[2] *(Expert Members)*

Task Force 4 Particle Identification and Photon Detectors: Neville Harnew[17],
Peter Krizan[21] *(Conveners)*
Ichiro Adachi[22], Eugenio Nappi[1] Christian Joram[2],
Hans-Christian Schultz-Coulon[23] *(Expert Members)*

Task Force 5 Quantum and Emerging Technologies: Marcel Demarteau[24],
Michael Doser[2] *(Conveners)*
Caterina Braggio[25], Andy Geraci[26], Peter Graham[27], Anna Grasselino[28],
John March Russell[17], Stafford Withington[29] *(Expert Members)*

Task Force 6 Calorimetry: Roberto Ferrari[30], Roman Pöschl[31] *(Conveners)*
Martin Aleksa[2], Dave Barney[2], Frank Simon[32],
Tommaso Tabarelli de Fatis[33] *(Expert Members)*

Task Force 7 Electronics: Dave Newbold[34], Francois Vasey[2] *(Conveners)*
Niko Neufeld[2], Valerio Re[30] Christophe de la Taille[35], Marc Weber[36] *(Expert Members)*

Task Force 8 Integration: Frank Hartmann[36], Werner Riegler[2] *(Conveners)*
Corrado Gargiulo[2], Filippo Resnati[2], Herman Ten Kate[37], Bart Verlaat[2],
Marcel Vos[38] *(Expert Members)*

Task Force 9 Training: Johann Collot[39], Erika Garutti[40] *(Conveners)*
Richard Brenner[41], Niels van Bakel[9] Claire Gwenlan[17], Jeff Wiener[2], Robert Appleby[42]
(Expert Members)

The Task Force Convenors join those listed below to compose the Detector R&D Roadmap Panel.

Panel coordinators: Phil Allport[42] *(Chair)*, Silvia Dalla Torre[43], Manfred Krammer[2],
Felix Sefkow[19], Ian Shipsey[16]

Ex-officio Panel members: Karl Jakobs[44] *(Current ECFA Chair)*,
Jorgen D'Hondt[45] *(Previous ECFA Chair)*, Lenny Rivkin[46] *(LDG Representative)*

Scientific Secretary: Susanne Kuehn[2]

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[19] DESY, Hamburg, Germany
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[22] KEK, Tsukuba, Japan
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...f Cambridge, Cambridge, UK
...a, Pavia, Italy
...say, FranceMPP
...cca and INFN Milano-Bicocca, Milano, Italy
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[46] IIHE, Vrije Universiteit Brussel, Brussels, Belgium
[47] ETH Lausanne and PSI, Villigen, Switzerland

Good German Representation

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[3] Stony Brook University, New York, US

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National Contacts ECFA

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Germany	Lutz Feld
Greece	Dimitris Loukas
Hungary	Dezso Varga
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Norway	Gerald Eigen
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Romania	Mihai Petrovici
Serbia	Lidija Zivkovic
Slovakia	Pavol Strizenec
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Swtizerland	Ben Kilminster
Turkey	Kerem Cankocak
United-Kingdom	Iacopo Vivarelli
Ukraine	Nikolai Shulga
CERN	Christian Joram

Good German Representation

ECFA

European Committee for Future Accelerators

Advisory Panel with Other Disciplines

Organisation name	Contact name
APPEC	Andreas Haungs (Chair)
NuPECC	Marek Lewitowicz (Chair)
LEAPS	Caterina Biscari (Chair)
LENS	Helmut Schober (Chair)
ESA	Guenther Hasinger (Director of Science) Franco Ongaro (Director of Technology, Engineering and Quality)

APPEC: Astro-Particle Physics European Consortium
ESA: European Space Agency
LEAPS: League of European Accelerator-based Photon Sources
LENS: League of advanced European Neutron Sources
NuPECC: Nuclear Physics European Collaboration Committee

Named expert contacts		
APPEC	TF1	~~Jennifer L Raaf (Fermilab)~~
	TF2	Manfred Lindner (MPI Heidelberg)
	TF3	~~Fabrice Retiere (TRIUMF)~~
	TF4	~~Tina Pollmann (Nikhef)~~
	TF5	Harald Lück (Hannover)
	TF6	~~Federica Petricca (MPI Munich)~~
	TF7	Marc Weber (KIT)
	TF8	~~Aldo Ianni (LNGS)~~
	TF9	Katrin Link (APPEC)
NuPECC	TF1	Laura Fabbietti (TUM Munich)
		Bernhard Ketzer
	TF2	
	TF3	Luciano Musa (CERN)
		Michael Deveaux
	TF4	Eugenio Nappi (INFN Bari)
		~~Jochen Schwiening~~
	TF5	: Christian Enss (Heidelberg),
	TF6	~~Thomas Peitzmann (Utrecht)~~
		Ulrike Thoma (Bonn)
	TF7	~~David Silvermyr (Lund)~~
		Christian J. Schmidt
	TF8	~~Werner Riegler (CERN)~~
		Lars Schmitt
	TF9	Michael Deveaux,
LEAPS	Bernd Schmitt (PSI)	
	Fabienne Orsini	
	Steve Aplin (European	
	Heinz Graafsma (DESY)	

Named contacts for each TF where appropriate

LENS	TF1	Bruno Guerard (ILL)
	TF2	Manfred Lindner (MPI Heidelberg)
	TF3	
	TF4	
	TF5	Helmut Schober (ILL)
	TF6	
	TF7	Bruno Guerard (ILL)
	TF8	
	TF9	
ESA	TF1	Nick Nelms
	TF2	
	TF3	Brian Shortt
		Nick Nelms
		Giovanni Santin
		Alessandra Constantino Mucio
	TF4	Brian Shortt
		Peter Verhoeve
		Sarah Wittig
		Nick Nelms
		Giovanni Santin
	TF5	Peter Verhoeve
		Sarah Wittig
		Nick Nelms
	TF6	Nick Nelms
	TF7	Joerg Ter Haar
		Christophe Honvault
		Nick Nelms
		Alessandra Constantino Mucio
	TF8	Massimo Braghin
	TF9	Christophe Honvault

Process and Timeline

Organisation

May 2020
EPPSU mandate to ECFA to develop a roadmap for detector R&D efforts in Europe

Sep 2020
Structure in place with **Detector R&D Roadmap Panel**

Dec 2020
Task Forces active

Website: https://indico.cern.ch/e/ECFADetectorRDRoadmap

Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
Questionnaires of Task Forces to national contacts

Task Forces liaise with experts in
- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia

Drafting Roadmap & Feedback

May 2021
Task Forces collate input from symposia

25-28 May 2021 **Drafting sessions**
- opening session with all experts involved
- plenary & parallel sessions with Task Force members
- final session of Roadmap Panel

July 2021
Near final draft shared with RECFA*

30 July 2021
Presentation at Joint ECFA-EPS session

August 2021
Collect final community feedback*

October-December 2021
Detector R&D Roadmap Document circulated for approval to ECFA in Nov 2021 and presentation to Council in Dec 2021

- **European Strategy Update gives guidance and priorities for future particle physics projects - what we want to do**

- **Coordination of Detector R&D is necessary to maximise the scientific outcome of these activities - how we get there**

- **The roadmap process involves wide community consultation in order to capitalise on best available expertise - but since it is based on the EPPSU, it cannot be fully bottom-up**

- **The roadmap is not resource-loaded, but the common aspirations should establish coherence of funding requests and so unfold its momentum**

Collecting Requirements

Two Days of Input Sessions

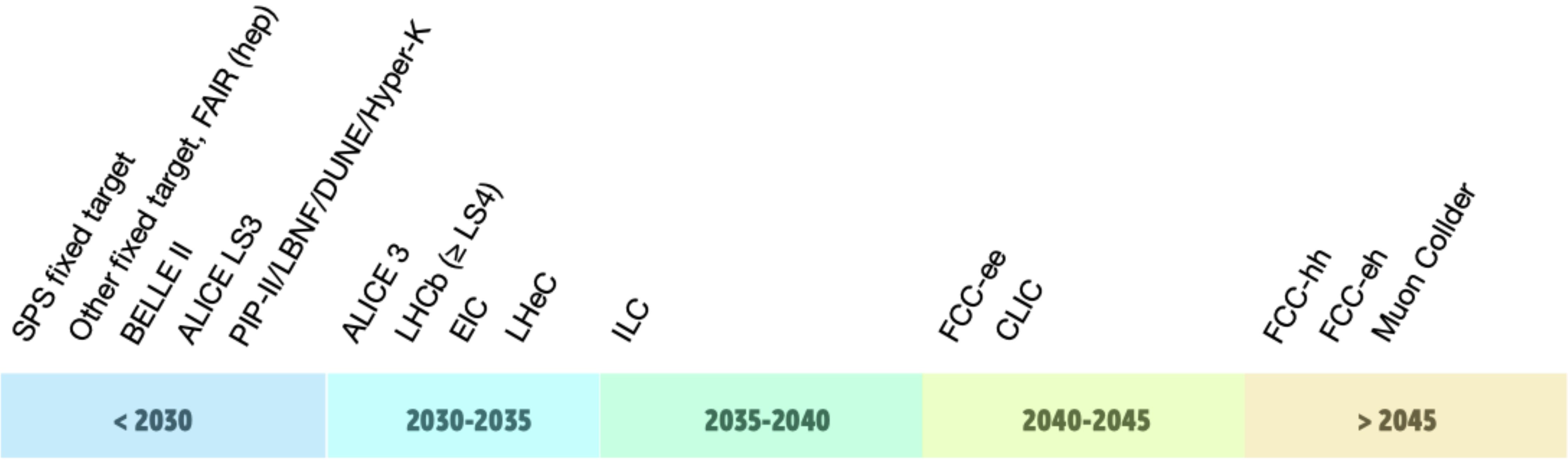
Input Session speakers provided detailed specifications and continued giving support for the process

… particularly for checking if there were any unmet detector R&D needs for the ESPP identified programme which may have been overlooked in the symposia programmes.

	Speaker	Presentation Topic
1	Chris Parkes	Detector R&D requirements for HL-LHC
2	Luciano Musa	Detector R&D requirements for strong interaction experiments at future colliders
3	Johannes Bernhard	Detector R&D requirements for strong interaction experiments at future colliders
4	Frank Simon	Detector R&D requirements for future linear high energy e+e- machines
5	Mogens Dam	Detector R&D requirements for future circular high energy e+e- machines
6	Martin Aleksa	Detector R&D requirements for future high-energy hadron colliders
7	Nadia Pastrone	Detector R&D requirements for muon colliders
8	Marzio Nessi	Detector R&D requirements for future short and long baseline neutrino experiments
9	Maarten De Jong	Detector R&D requirements for future astro-particle neutrino experiments
10	Laura Baudis	Detector R&D requirements for future dark matter experiments
11	Cristina Lazzeroni	Detector R&D requirements for future rare decay processes experiments
12	Alexandre Obertelli	Detector R&D requirements for future low energy experiments

Future Projects Timeline (Accelerator Roadmap)

Accelerator Roadmap - as seen by the Lab Directors Group



The dates shown in the diagram have low precision, and are intended to represent the earliest “feasible start date” (where a schedule is not already defined), taking into account the necessary steps of approval, development and construction for machine and civil engineering.

How Much Time Do We Need?

“Random” Examples - and NOT from the start of the R&D

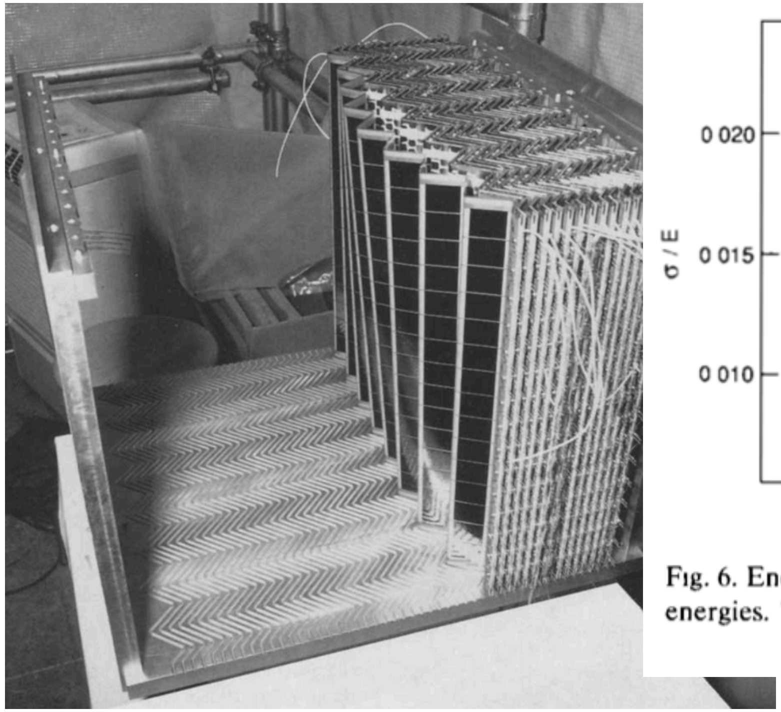
Nuclear Instruments and Methods in Physics Research A309 (1991) 438–449
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

t0 -17y

Performance of a liquid argon electromagnetic calorimeter with an “accordion” geometry

RD3 Collaboration



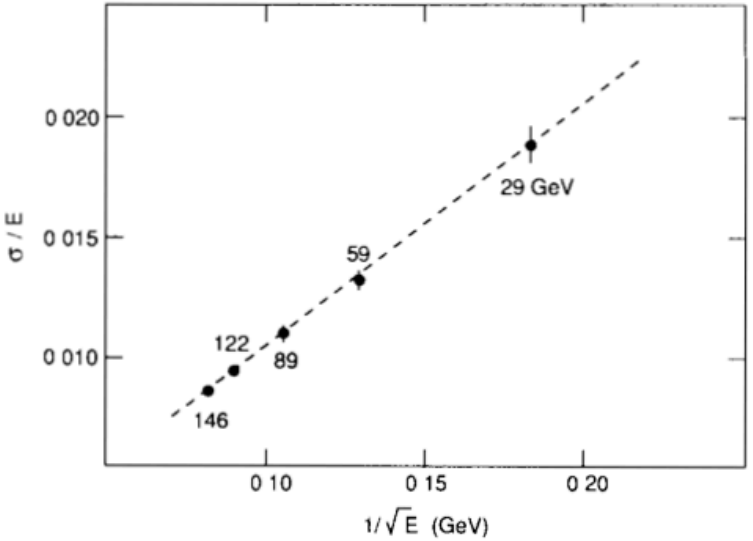
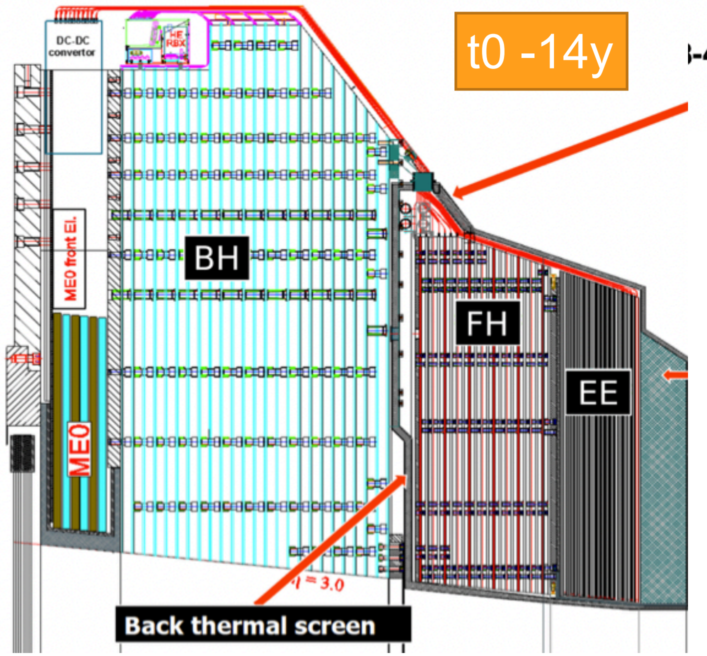


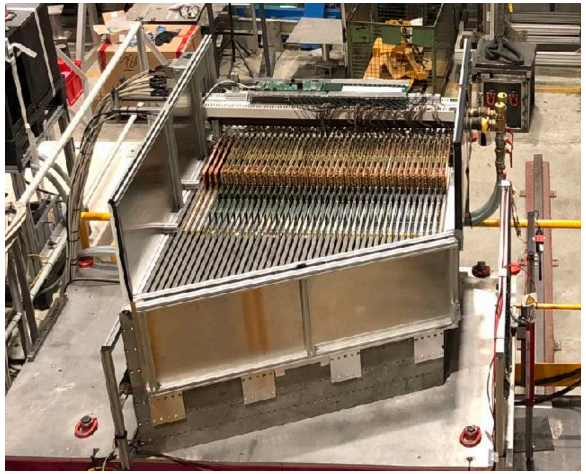
Fig. 6. Energy resolution of the prototype at different electron energies. The dashed line is a linear fit to the experimental points.

CMS

CERN-LHCC-2015-10
LHCC-P-008

t0 -14y





CALICE 2018

Hi-Lumi LHC Detectors Post LS3

Yes…

Our ability to exploit the HL-LHC is limited by our detector technology: spatial & time resolution, radiation hardness, cost

ATLAS

- partial replacement of inter tracker pixels (Ink-Pix)
- and High Granularity Timing Detector (HGTD)
- maybe trigger

CMS:

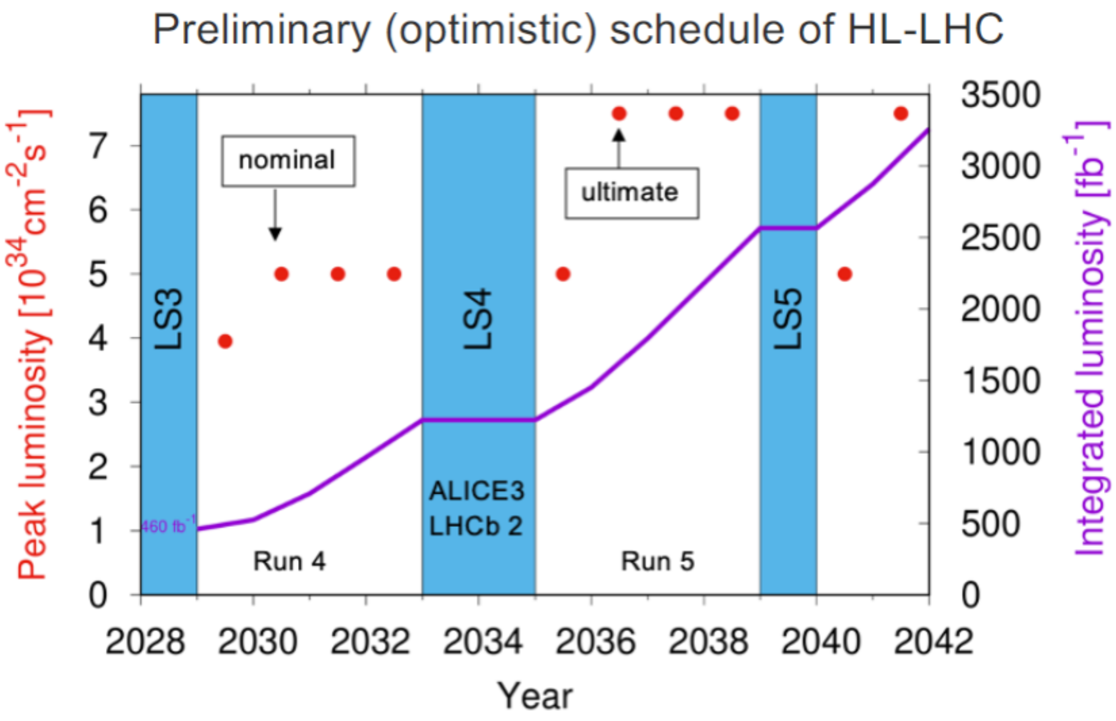
- one exchange of the inner part of the pixel detector
- maybe inner rings of Endcap Timing Layer (ETL)
- some ideas to benefit from technology advances (manly forward)

LHCb: major upgrade in LS4

- Velo, Mighty Tracker, TORCH (PiD), Calorimeter, Muons, 28 nm, ML for Real Time Analysis

LHC experiments happy to collaborate on R&D across projects

- physics only in one experiment
- technical and engineering staff in multiple experiments
- Technical Associate Memberships

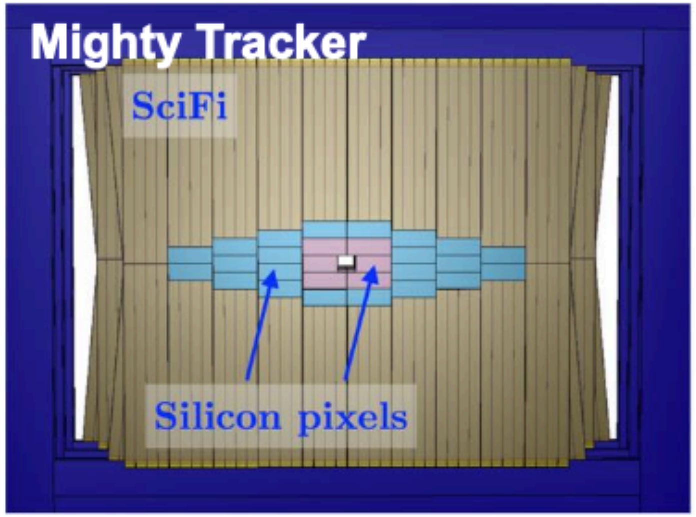


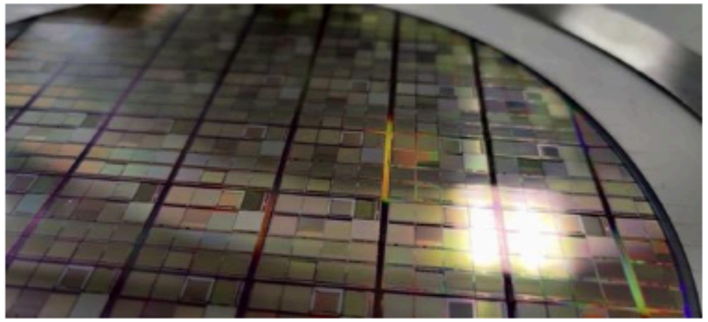
Fair reasons not to discuss heavy ions here

TF3: Solid State Detectors

LHCb Upgrade II : Tracking System

- System before magnet (UT), inside SciFi (MT)
- Requirements:
  - Si Area for LS4 (with aim small scale in LS3)
    - UT Si – 6m^2 . MT Si - 20m^2
  - Pixel size e.g. 50x150,100x300µm^2
  - Radiation e.g. 5x10^{13}-5x10^{14} 1MeV n_{eq}/cm^2
  - Precision timing ?





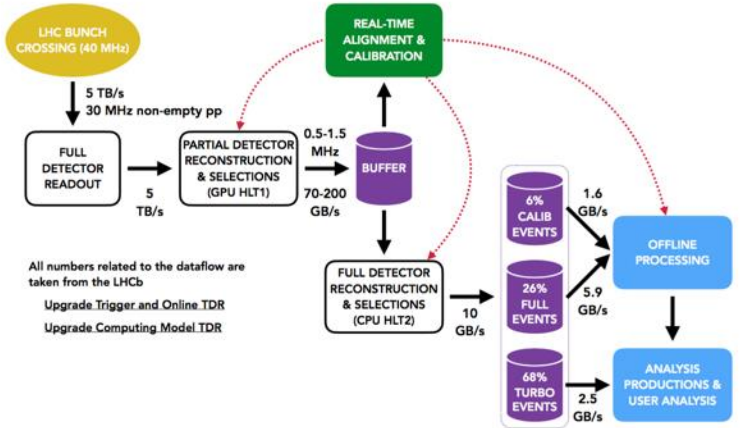
- R&D: MAPS. **First large-scale rad-hard CMOS detector at LHC**
  - MightyPix based on MuPix/ATLASPix HV-CMOS
  - Other solutions ? Synergy EP R&D , future accelerators ?

TF7: Electronics & On-detector Processing

ATLAS/ CMS / LHCb

- ASIC feature size CMOS e.g. 28 nm
- CERN support for chips important
- Next-generation rad hard data optical links
  - Low power,low-mass, towards 100 Gbps?
  - with silicon photonics ?
- DC-DC converters – higher input V?
- Processing Both **ON** and **OFF** detector
- Innovative algorithms for real-time trigger applications in **heterogeneous** architectures
  - GPUs, IPUs, TPUs, FPGAs
- data-centre / commodity / cloud technologies for Online processing?

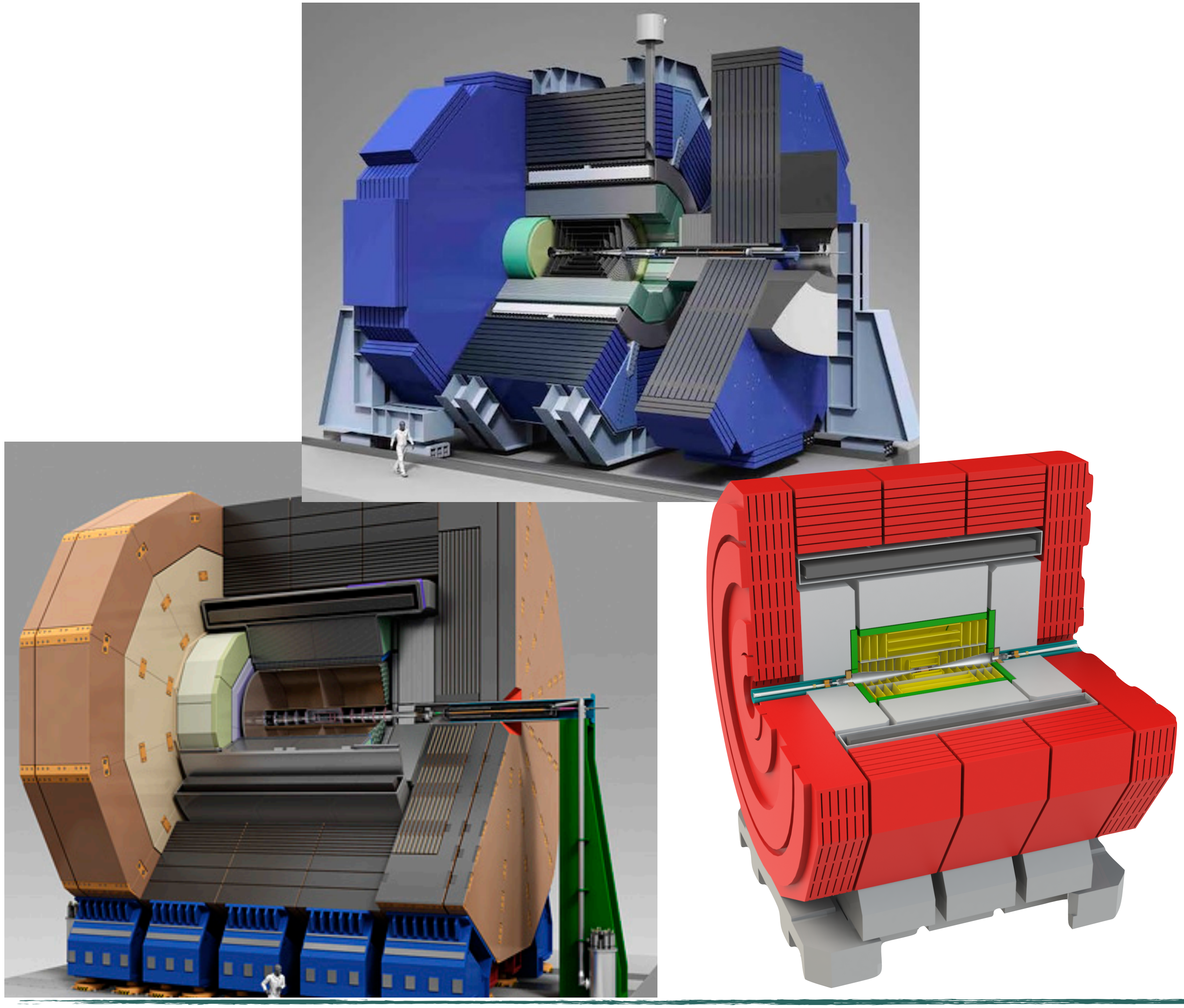
LHCb Upgrade II: Trigger & DAQ system



- GPU based real-time HLT1 reconstruction and triggering In LHCb Upgrade I
- U2 foresees 5x data throughput

The Linear Collider Detector Design - Main Features

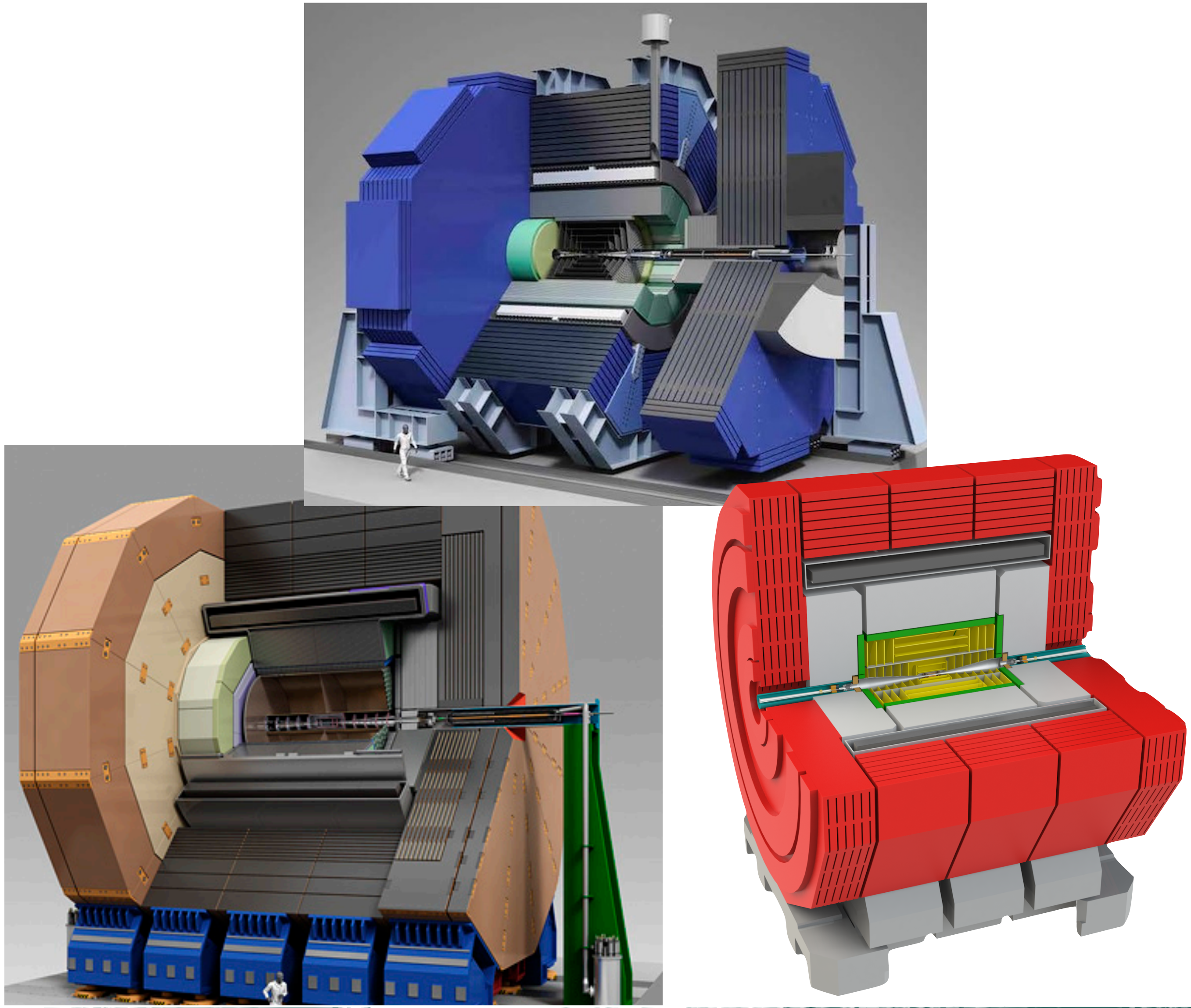
Focusing on general aspects



- A **large-volume solenoid** 3.5 - 5 T, enclosing calorimeters and tracking
- **Highly granular calorimeter systems**, optimised for particle flow reconstruction, best jet energy resolution *[Si, Scint + SiPMs, RPCs]*
- **Low-mass main tracker**, for excellent momentum resolution at high energies *[Si, TPC + Si]*
- **Forward calorimeters,** for low-angle electron measurements, luminosity *[Si, GaAs]*
- **Vertex detector**, lowest possible mass, smallest possible radius *[MAPS, thinned hybrid detectors]*
- **Triggerless readout** of main detector systems

Beyond the Baseline

Possible Ideas going beyond current technology & ideas



particle ID systems - improved flavour tagging with better π/K separation via TOF or other means

added readout dimensions in calorimetry: highly granular dual readout, new optical materials

exploiting ps timing capabilities in calorimeters and trackers

highly pixelated sensors throughout all silicon systems of the detectors

New radiation hard sensor materials for forward instrumentation

Ultra-low mass mechanics, ultra-low mass & ultra-low power interfaces and services

Requirements

1st Order

Second Order Corrections:

Experimental conditions

- bunch structure
- background
- constraints on experimental magnetic field

Energy and luminosity

- higher or lower c.m. energies emphasise different detector properties
- extremely high luminosity on Z pole: challenge for systematics

e^+e^- physics performance requirements

Note: differences between requirements ILC, CLIC, FCC-ee, CEPC rather small

★ **momentum resolution:**
e.g, HZ recoil, $g_{H\mu\mu}$, Smuon endpoint

$$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$$

★ **jet energy resolution:**
e.g. W/Z/H di-jet mass separation, Z and W width, HZ with Z→qq, background reduction

$$\frac{\sigma_E}{E} \sim 3.5 - 5\ \%$$

(for high-E jets, light quarks)

★ **impact parameter resolution:**
e.g. c/b-tagging, Higgs branching ratios

$$\sigma_{r\phi} = 5 \oplus 15/(p[\mathrm{GeV}] \sin^{\frac{3}{2}} \theta)\ \mu\mathrm{m}$$

★ **angular coverage, very forward electron tagging**

+ requirements from experimental conditions

Linssen, Granada symposium 2019

12

From Linear to Circular e+e- Colliders

Conceptual Adaptations

Lower energy jets and particles, less collimated jets:

- reduced calorimeter depth
- shift imaging vs. energy resolution balance towards the latter
- jet assignment ambiguities: added value of $\pi^0 \rightarrow \gamma\gamma$ mass reconstruction
- tracking even more multiple-scattering dominated: **increased pressure on material budget of vertex detector and main tracker**
    - fresh air to gaseous tracking

Limitations on solenoidal field B < 2T, to preserve luminosity:

- recover momentum resolution with tracker radius
- on the other hand larger magnetic volume also more easily affordable (coil and yoke)

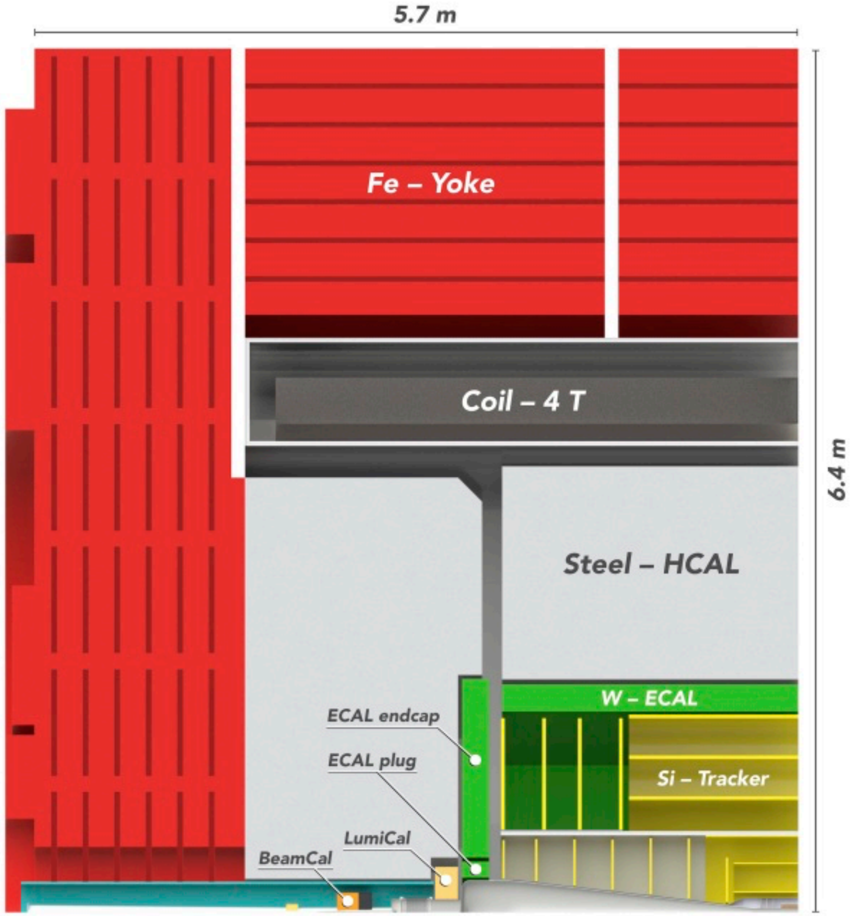
Main difference: no bunch trains; collisions every 20 ns (~ at LHC)

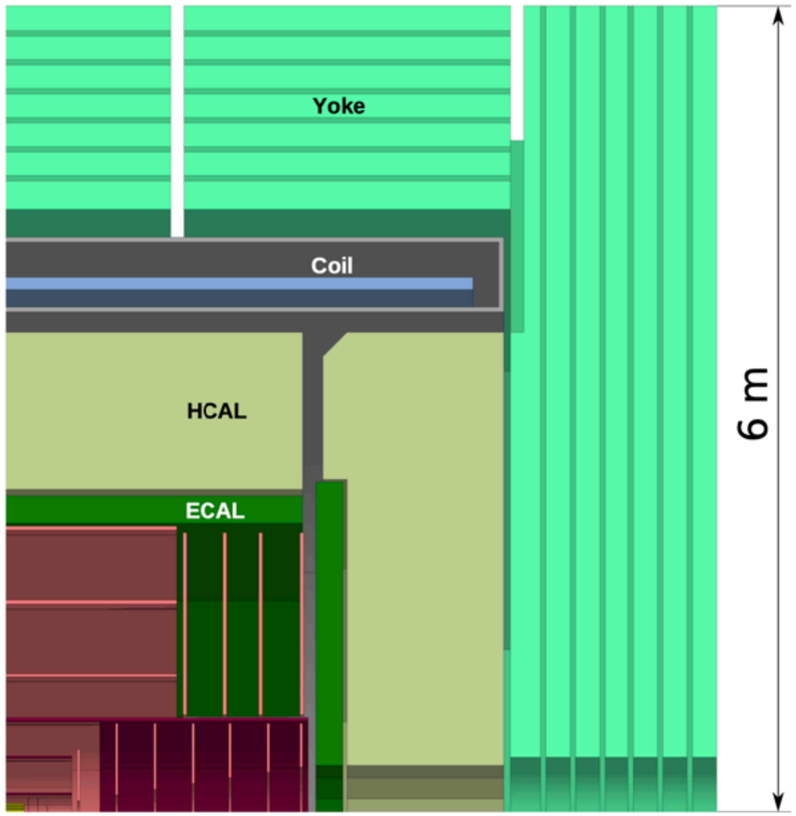
- **no power pulsing, more data bandwidth: both imply larger powering and cooling needs**
- **adds material to the trackers and compromises calorimeter compactness - or reduce granularity, timing, speed**
- **implications strongly technology-dependent, interesting optimisation challenges**
- **Trigger and DAQ re-enter the stage**

From LCs to FCCee

From CLICdet to CLD

- A LC-inspired FCCee detector concept - retaining key performance parameters
  Evolving from CLIC to CLD





From LCs to FCCee

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MAX-PLANCK-INSTITUT FÜR PHYSIK

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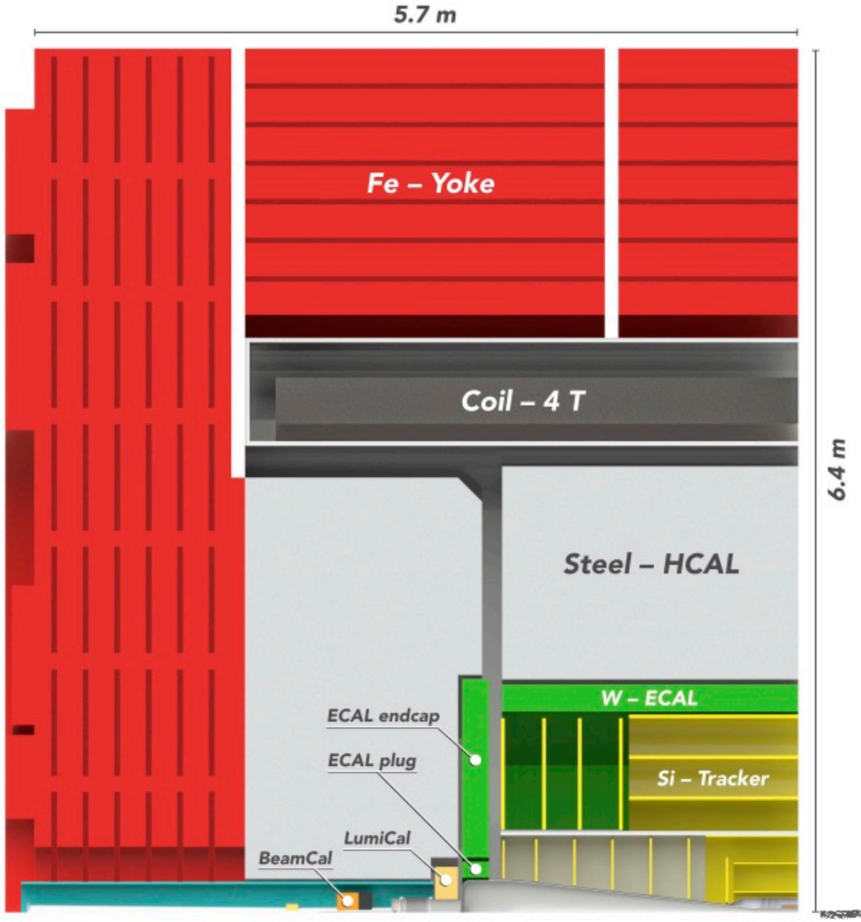
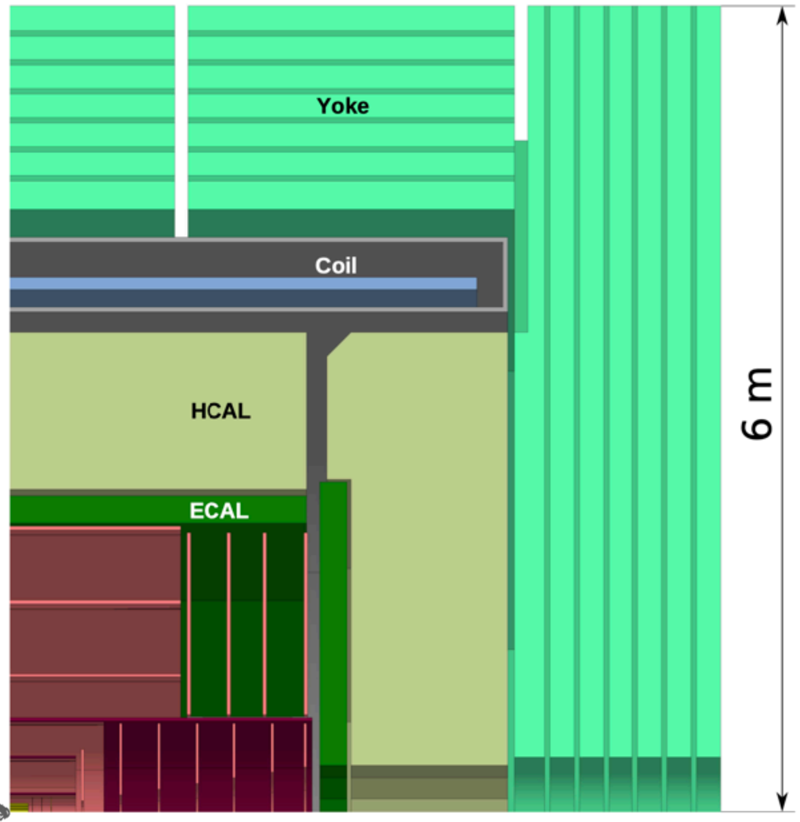


smaller VTX radius: profit from lower backgrounds, compensate material



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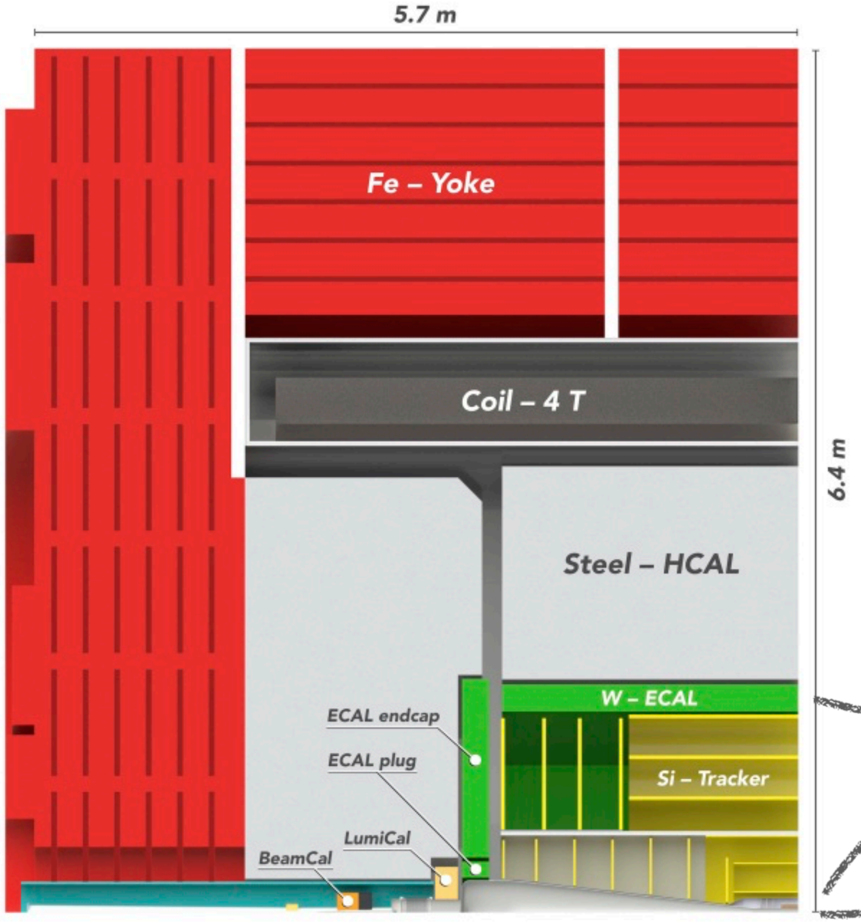
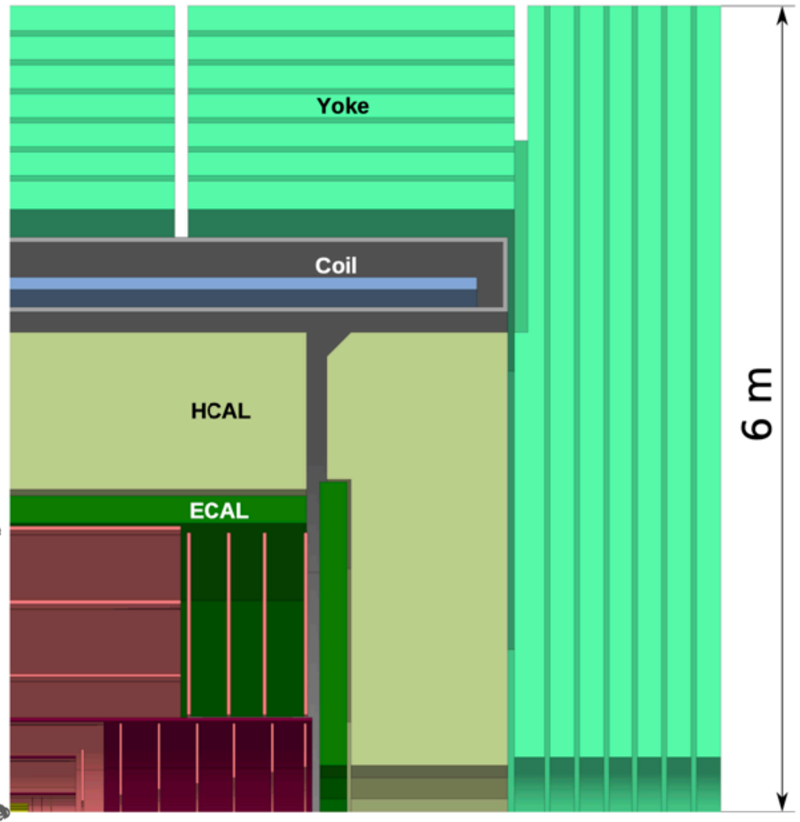


increase in tracker radius: retain p resolution

smaller VTX radius: profit from lower backgrounds, compensate material



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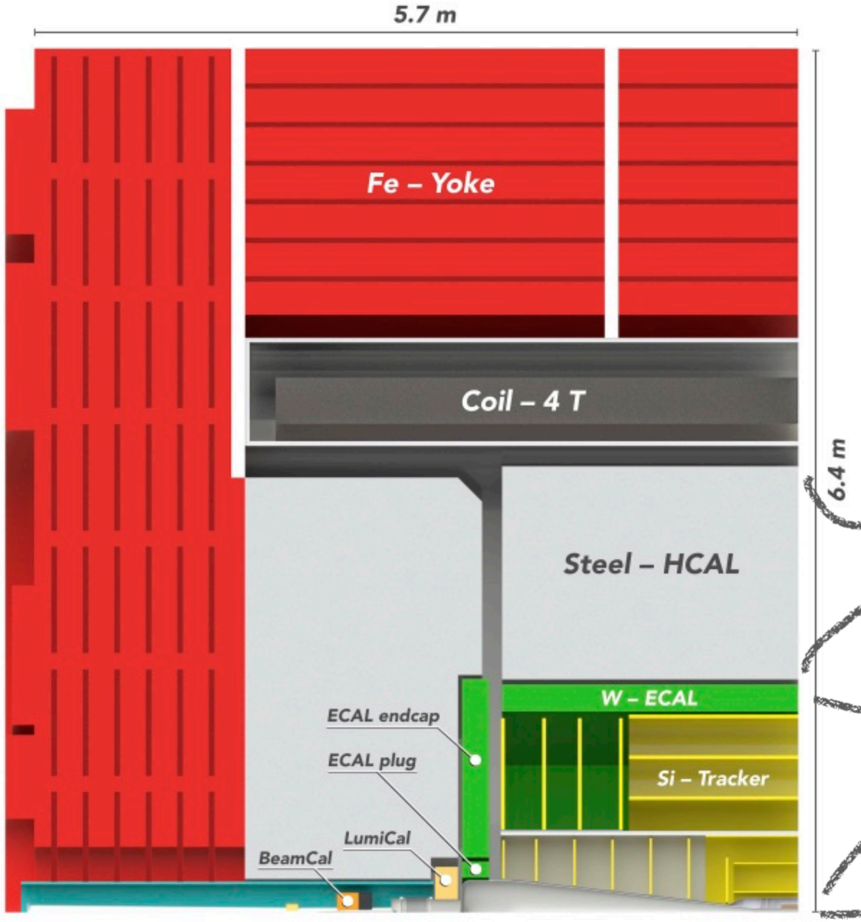
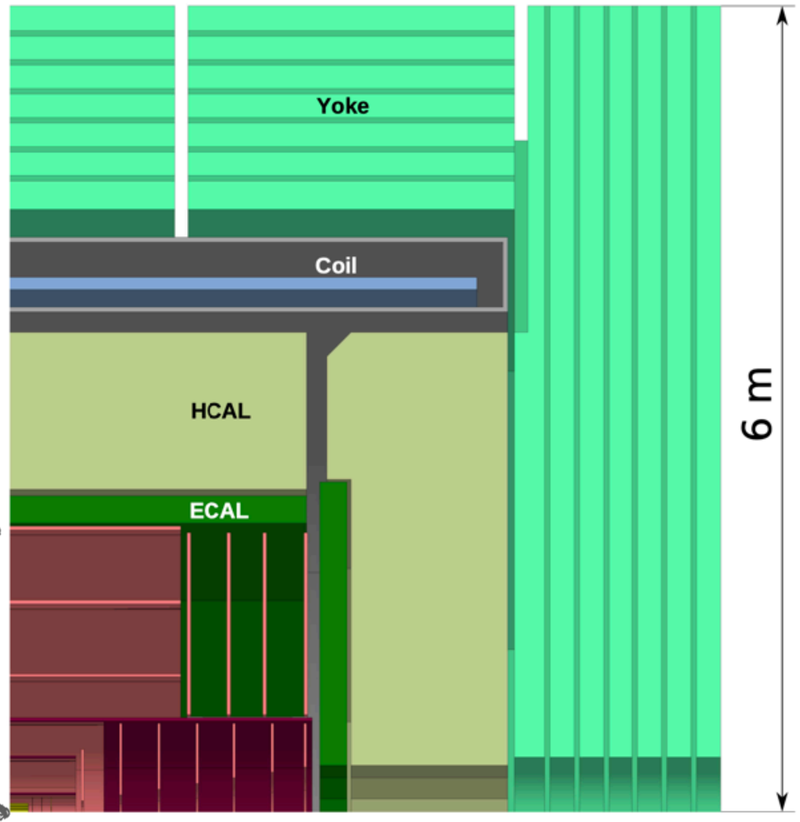


reduced HCAL thickness: enabled by lower energy

increase in tracker radius: retain p resolution

smaller VTX radius: profit from lower backgrounds, compensate material



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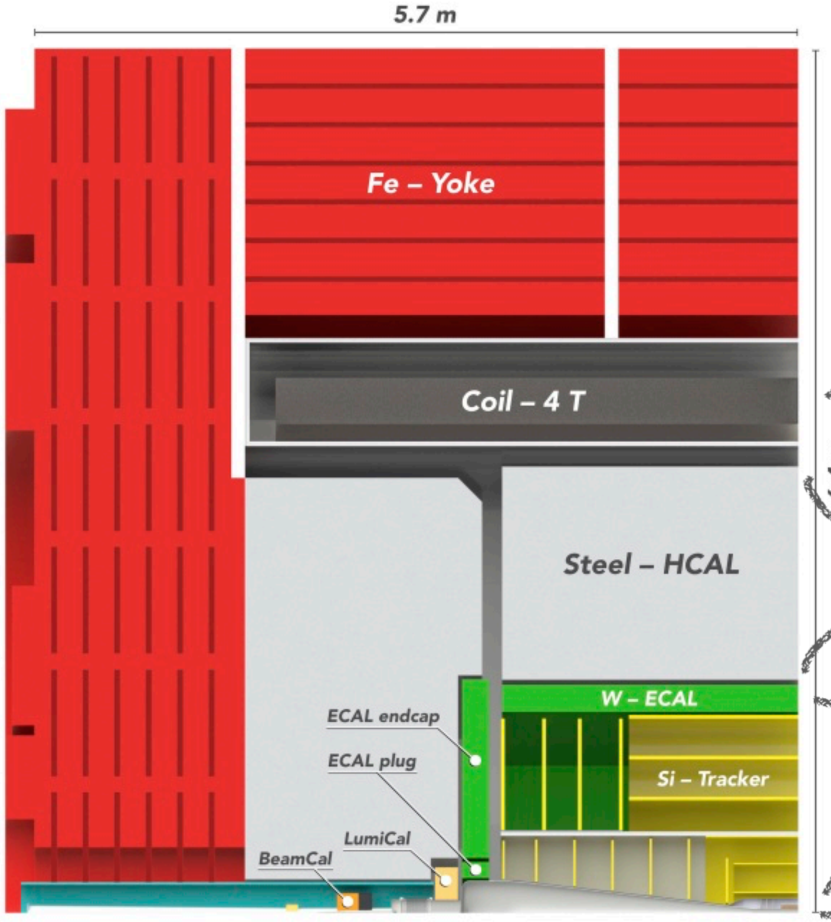
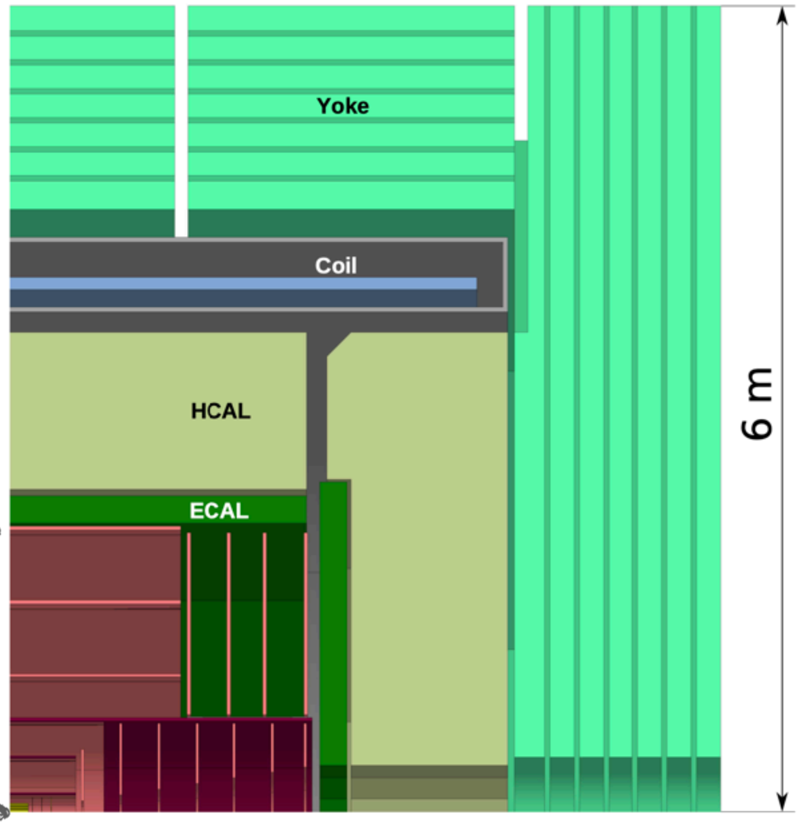


lower field: enable high luminosity in circular collider

reduced HCAL thickness: enabled by lower energy

increase in tracker radius: retain p resolution

smaller VTX radius: profit from lower backgrounds, compensate material



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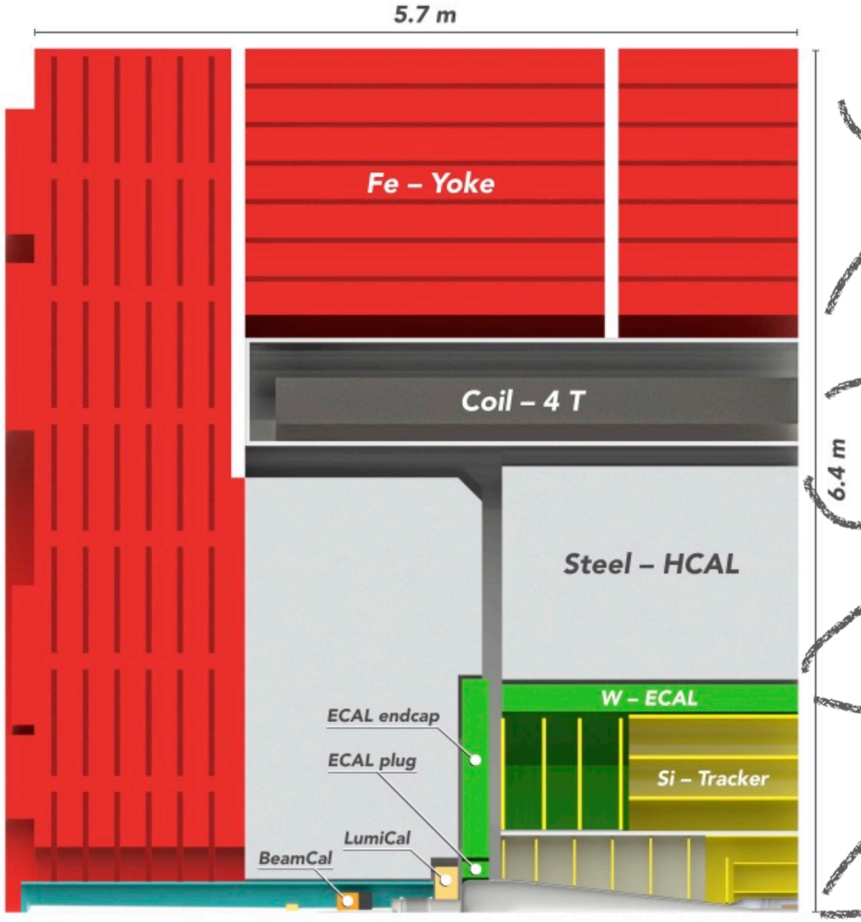

less steel: lower field allows reduced yoke thickness

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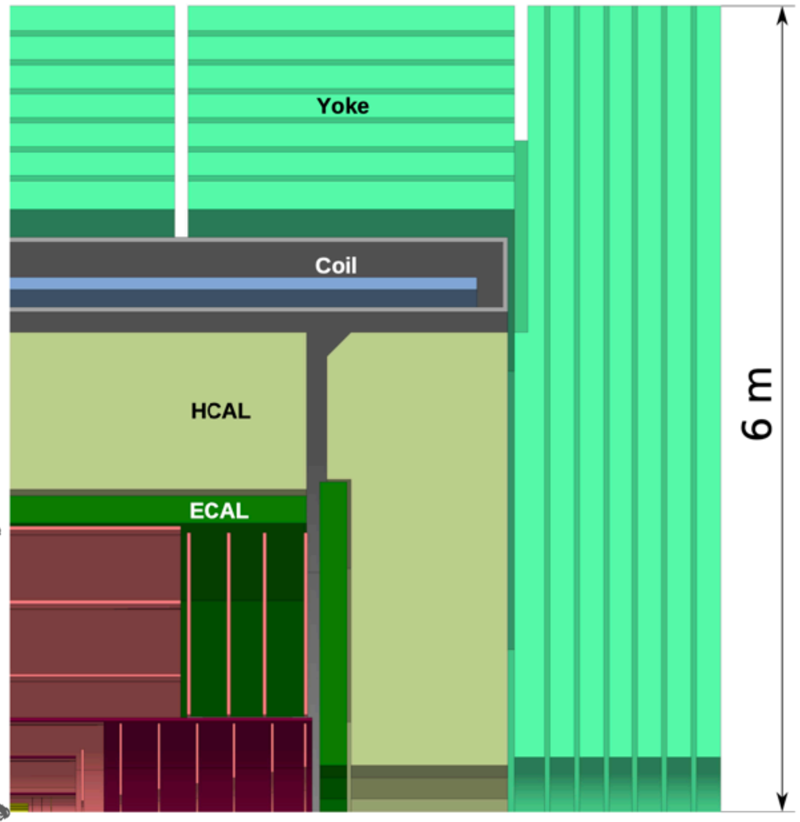
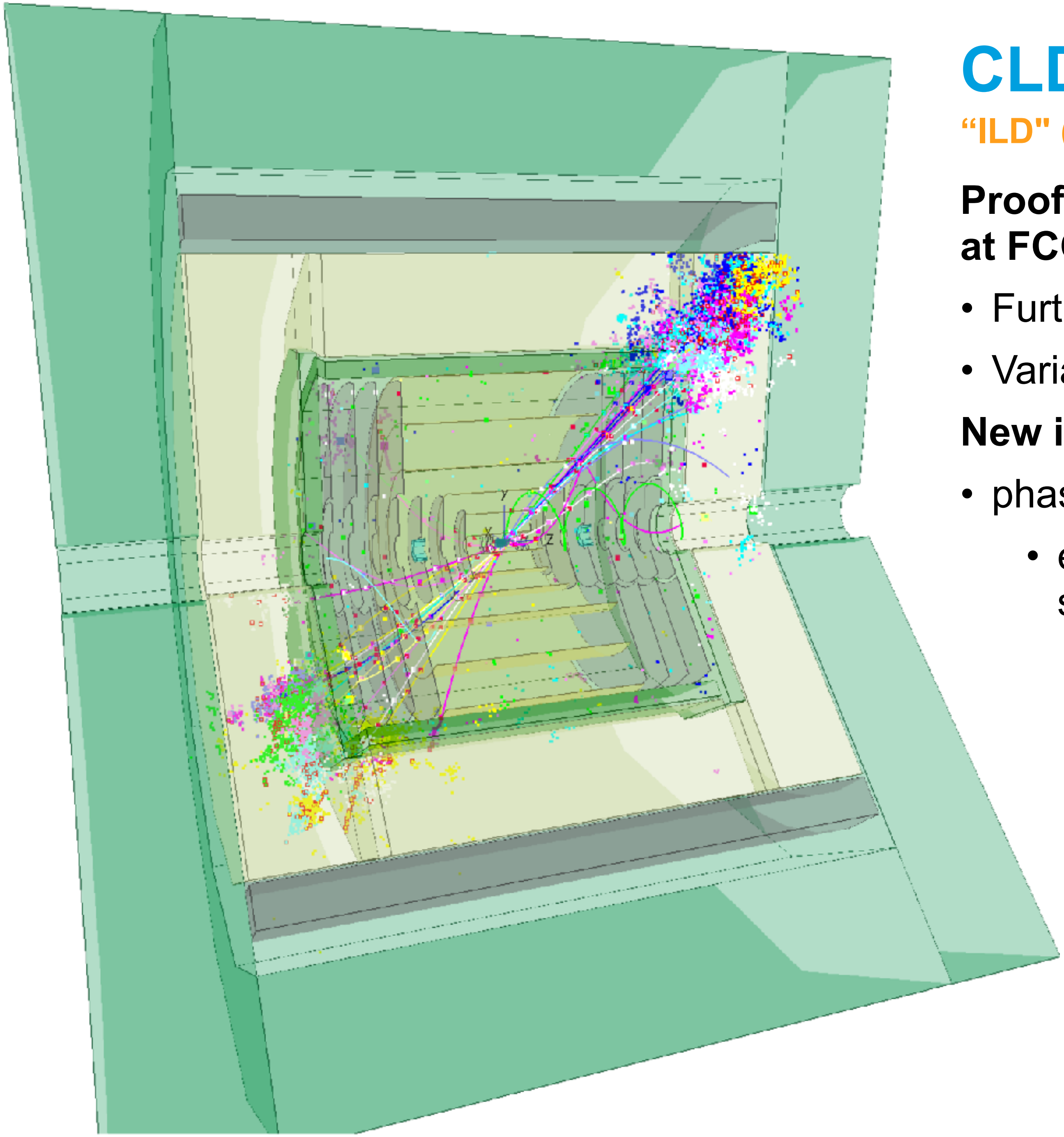




CLD: CLIC-like Detector for FCCee

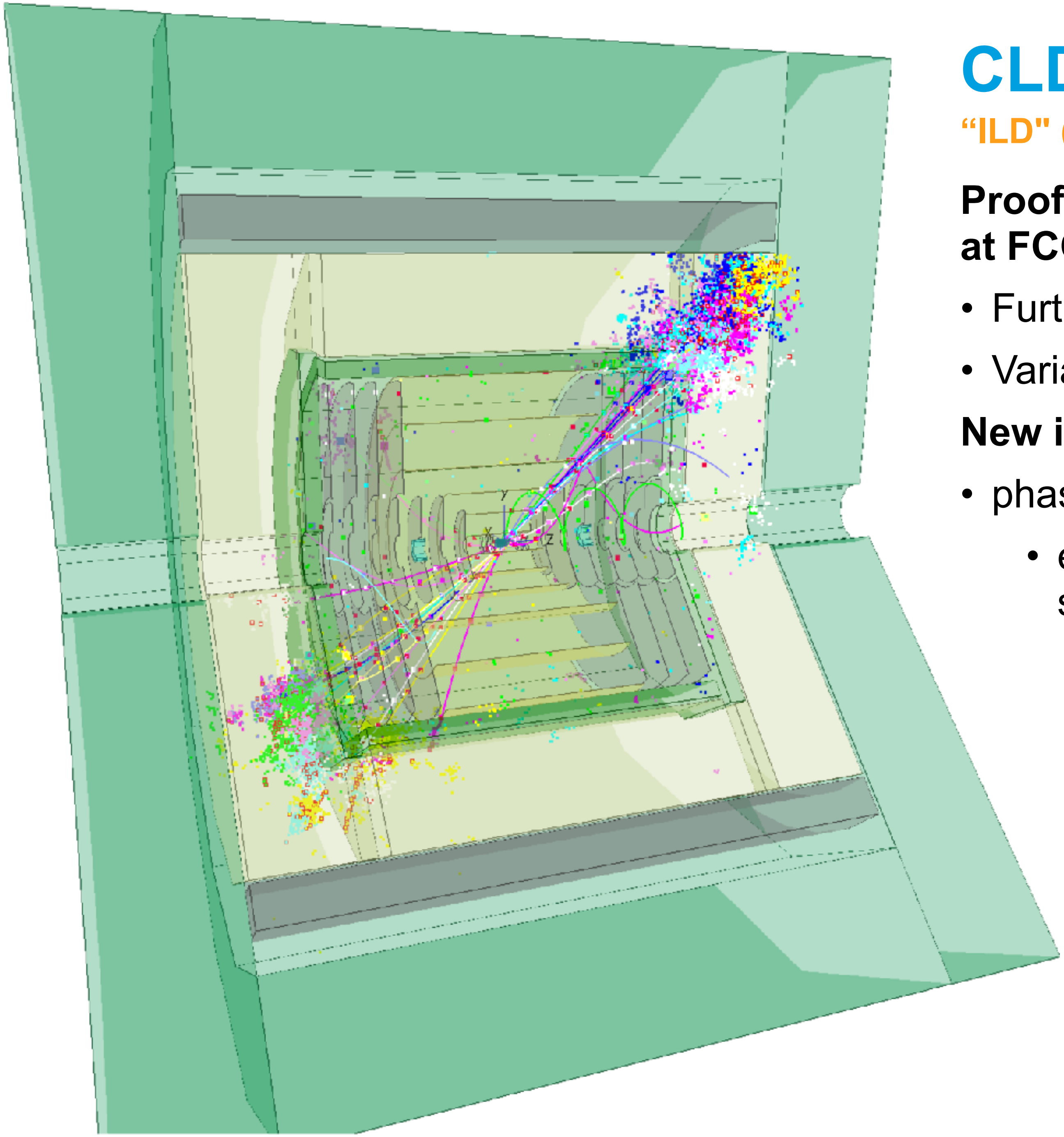
“ILD" (with Gaseous Tracking) also Possible

Proof-of-principe for a particle-flow detector concept at FCCee

- Further optimisation possible - and likely
- Variants also (e.g. gaseous tracker, gaseous HCAL,…)

New ideas and technologies

- phase space largely overlaps with that for LCs
    - e.g. fast timing for particle ID, new tracker read-out schemes, more compact electronics,…



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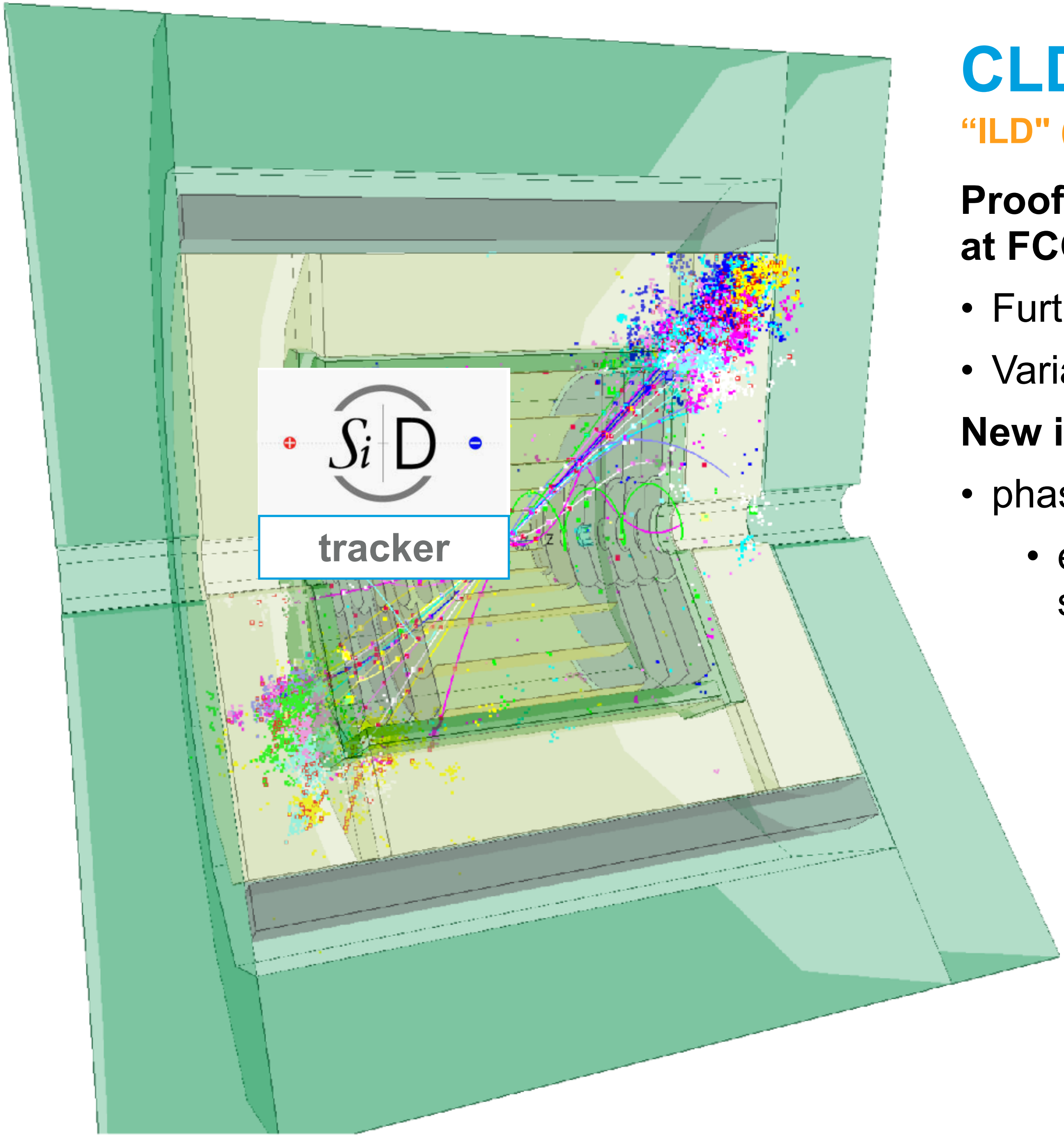
Inherits ILC and CLIC assets

- software framework **key4HEP (DESY)**
- performance validation with prototypes

However, in most if not all cases feasibility of continuous readout, including power and cooling is still to be demonstrated - clear R&D path

- benefit from HL-LHC upgrades, e.g. CMS HGCAL
- **need engineers already in R&D phase**



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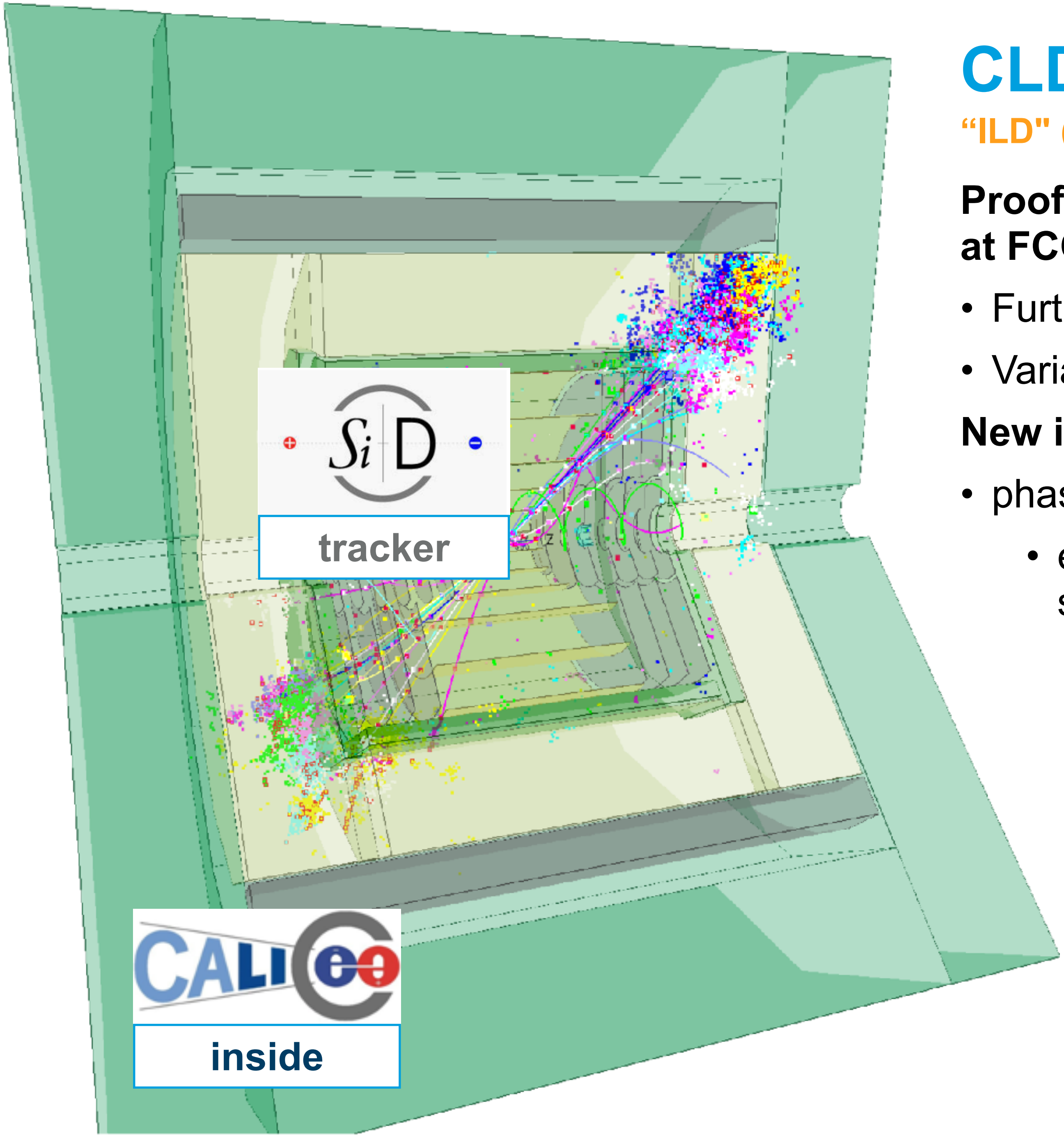

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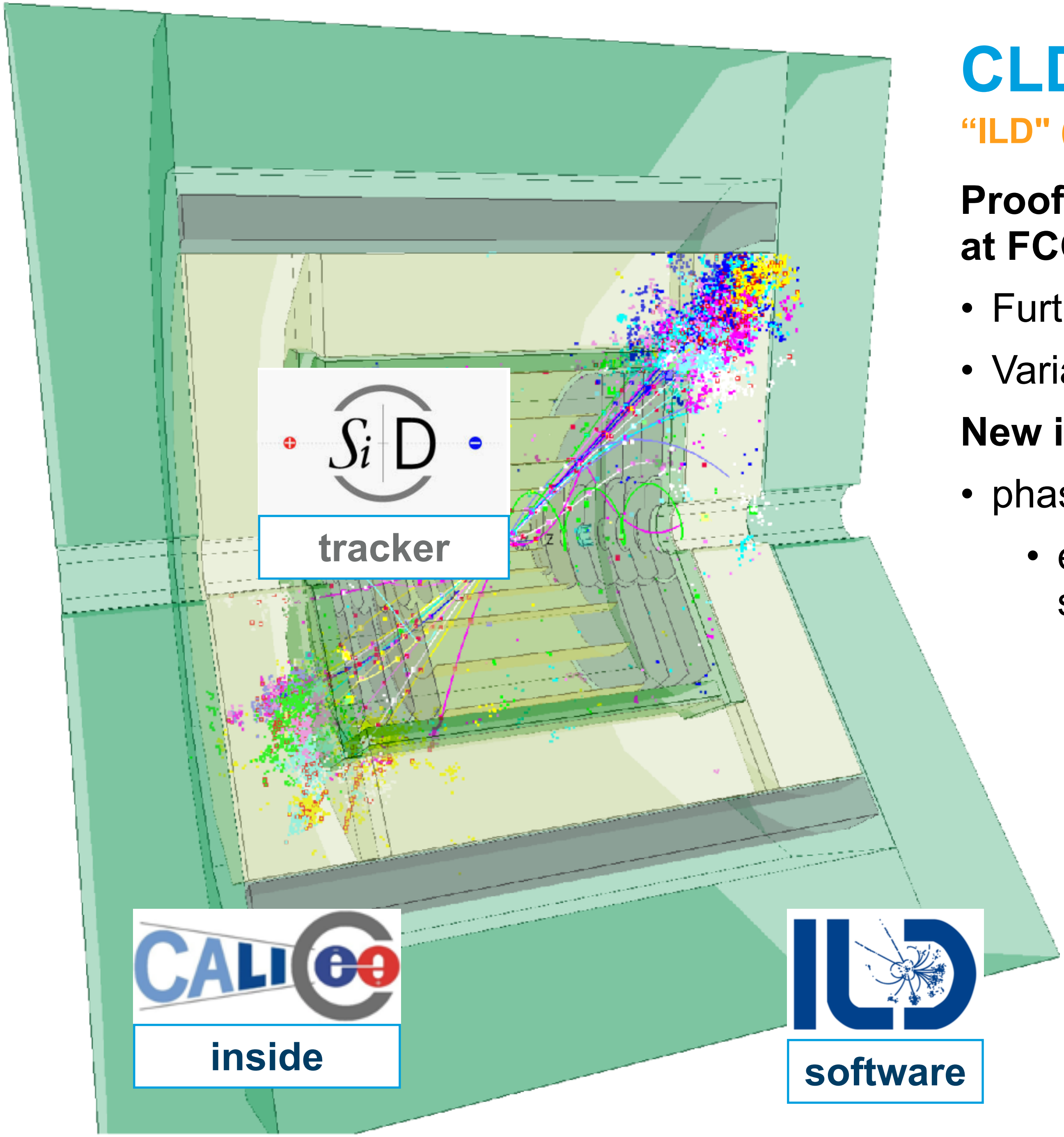

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R&D Overview

Synergies Dominate

Detector Technology	Linear & Circular Colliders common R&D	Differences
All	test infrastructure prototype electronics software for reconstruction and optimisation	readout rates power and cooling requirements
Silicon Vertex and Track Detectors	highest granularity and resolution, timing ultra-thin sensors and interconnects simulation and design tools low-mass support structures cooling micro-structures	emphasis on timing (background) and position resolution
Gaseous Trackers and Muon Chambers	ultra-light structures for large volumes industrialisation for large area instrumentation eco-friendly gases	DC and TPC presently considered only at some colliders
Calorimeters and Particle ID	highly compact structures and interfaces advanced photo-sensors and optical materials ps timing sensors and electronics	emphasis on granularity and stability DR and LAr pesresently only considered for circular

- **Requirements for future experiments envisaged by the European Strategy form the starting point**

- **A - coarsely binned - timeline of future projects was provided by the parallel accelerator roadmap process driven by the lab directors group**

- **Detector development for colliders has a lead time of 10 - 20 years - less for pixels, more for calorimeters**

- **Detectors for linear or circular Higgs factories have much in common - so FCCee does not start from zero, but it poses a well defined set of open challenges**

Open Symposia

Open Symposia

Symposia

Nine one-day symposia took place as listed below. The attendance was as follows.

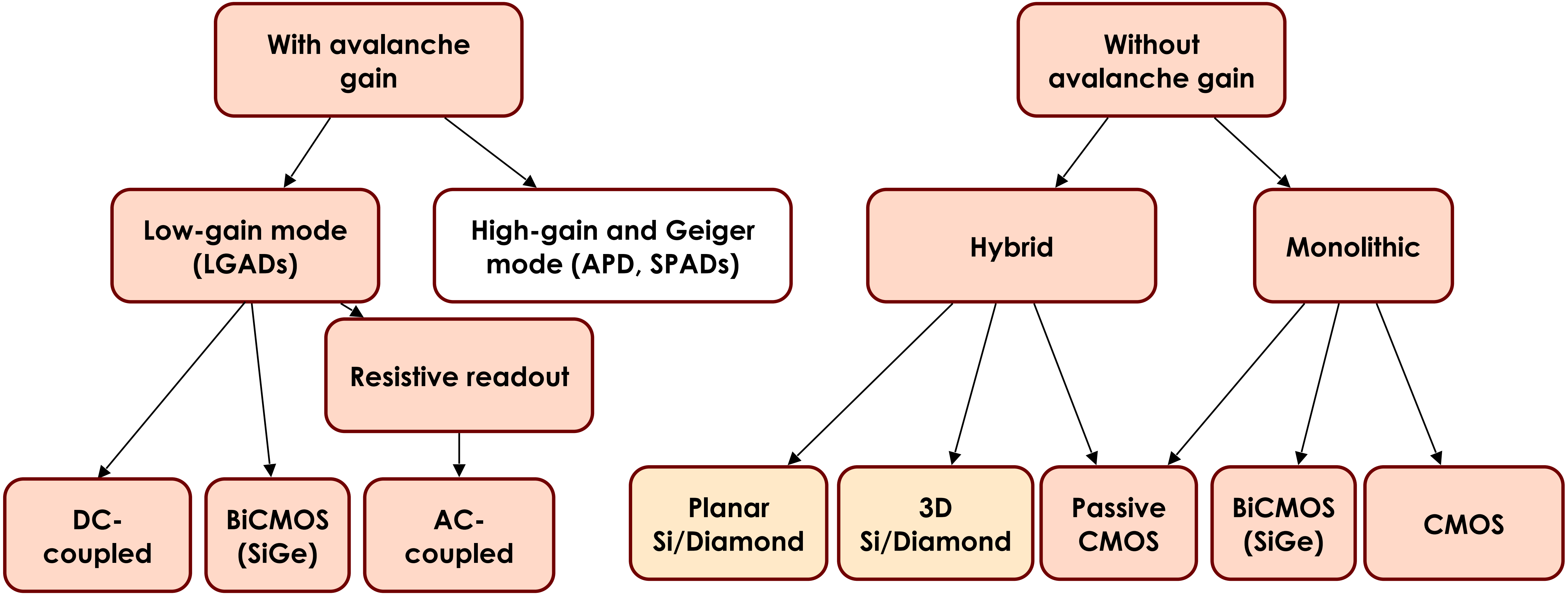
	TF7	TF8	TF2	TF5	TF3	TF1	TF9	TF4	TF6
Unique users	369 + 123 webcast*	154 + 17 webcast*	197 + 5 webcast*	220	504	339	105	207	201
Max. number of concurrent views	230 + 123 webcast*	76 + 17 webcast*	130 + 5 webcast*	100	275	191	59	110	115

* Might have overlapping users.

Thanks a lot for attending and contributing to the discussions!

Schematics of TF3
Solid State

Sensors for future trackers



Welcome: Introduction
Conveners: Philip Patrick Allport (University of Birmingham (UK)), Nicolo Cartiglia (INFN Torino (I
TF3_Introduction.pdf

Vision on electronics for future trackers in 20 years, 3D integration
Speaker: Valerio Re (Universita and INFN (IT))
Re_ECFA_TF3.pdf | Re_ECFA_TF3.pptx

electronics trends

Questions

Summary of accelerator input section, day 1
Speaker: Didier Claude Contardo (Centre National de la Recherche Scientifique (FR))
ECFA_TF3_Sympos... | ECFA_TF3_Sympos...

requirements

Questions

4D tracking - sensors without internal gain - 3D and more, intrinsic limitation
Speaker: Gregor Kramberger (Jozef Stefan Institute (SI))
TF3-3D-Timing-GK....

4D sensors - w/ and w/o gain

Well organised sessions
Best experts from the field
Lively discussions
https://indico.cern.ch/event/999816/

4D tracking - sensors with internal gain
Speaker: Nicolo Cartiglia (INFN Torino (IT))
4DGain_NC2.pdf | 4DGain_NC2.pptx

Silicon at extreme fluences
Speaker: Prof. Marko Mikuz (Jozef Stefan Ins
Extreme-TF3-Apr21... | Extreme-T

extreme

Passive CMOS in twenty years
Speakers: David-Leon Pohl (University of Bon
ECFA2021_Passive... | ECFA2021

Future CMOS technologies for charge particles tracking and high time resolution in CMOS , beyond 65 nm
Speaker: Walter Snoeys (CERN)
ECFA_monolithic_...

CMOS

Questions

Evolution of the CMOS technology for monolithic detectors, 3D - modules, 20 years visionary talk from a physicist point of view
Speaker: Petra Riedler (CERN)
ECFA_riedler_future...

interconnections

Questions

Future Requirements on Interconnection Technologies for Hybrid Detector Modules
Speaker: Thomas Fritzsch (Fraunhofer IZM)
TF3-Hybrids and Int...

Use of diamond detectors in 20 years: what R&D needs to be done to use it in the first layer of FCC?
Speaker: Alexander Oh (University of Manchester (GB))
AOH_ECFA2021.pptx | AOH_ECFA2021-v5....

diamonds

Questions

Simulation tools for radiation detectors before and after irradiation
Speaker: Dr Joern Schwandt (Hamburg University (DE))
ECFA_TF3_js_2021...

simulations

Introduction to panels discussion

Beam test/irradiation/femto laser: key facilities needed to pursue the R&D phase (EU project, funding tools)
Speakers: Dr Ivan Vila Alvarez (Instituto de Física de Cantabria (CSIC-UC)), Marcel Stanitzki (Deutsches Elektronen-Synchrotron (DE)), Marko Mikuz (J Institute (SI))
Facilities.pdf

facilities

Industrialization/supply chain for small - medium - large project (EU project, funding tools)
Round table
Speakers: Iain Sedgwick (STFC), Jerome Baudot (IPHC - Strasbourg), Michael Campbell (CERN)
Industrialization.pdf

industry

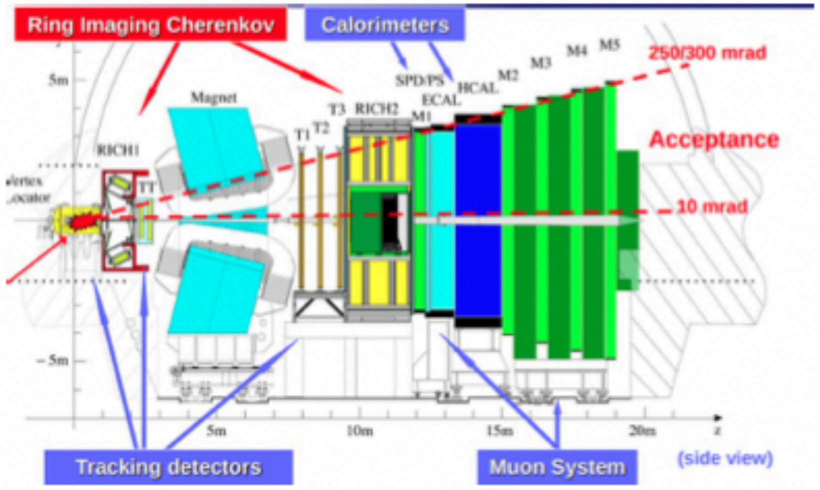
ECFA

Calorimeters

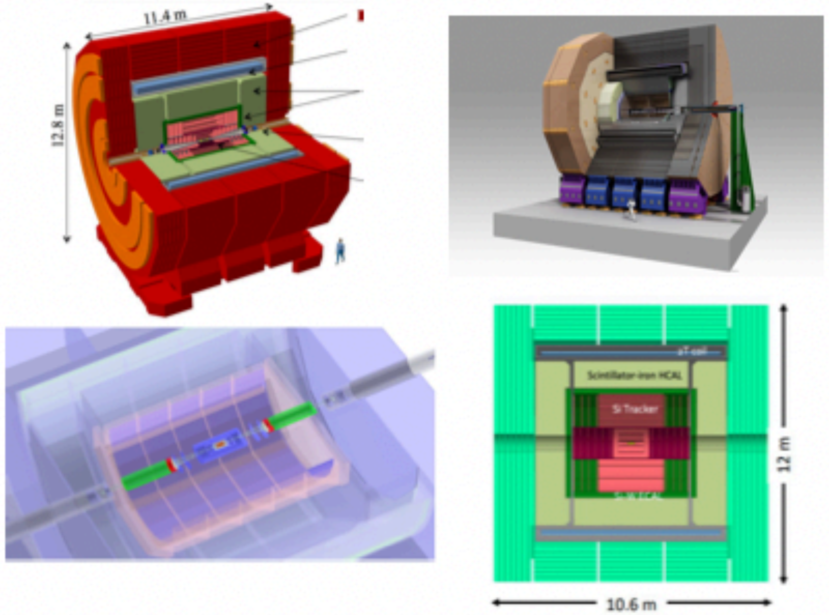
TF6 (Main) Target Projects

European Strategy Update

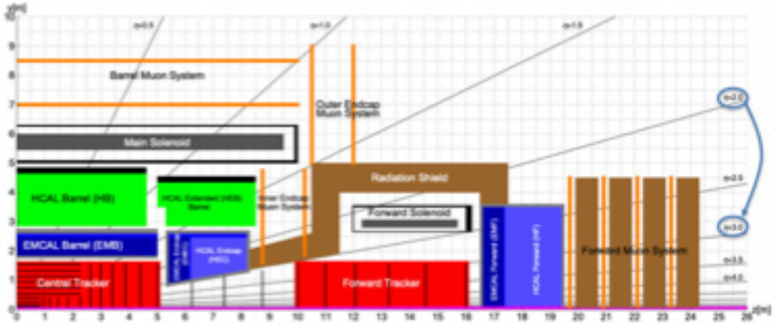
HL-LHC after LS4



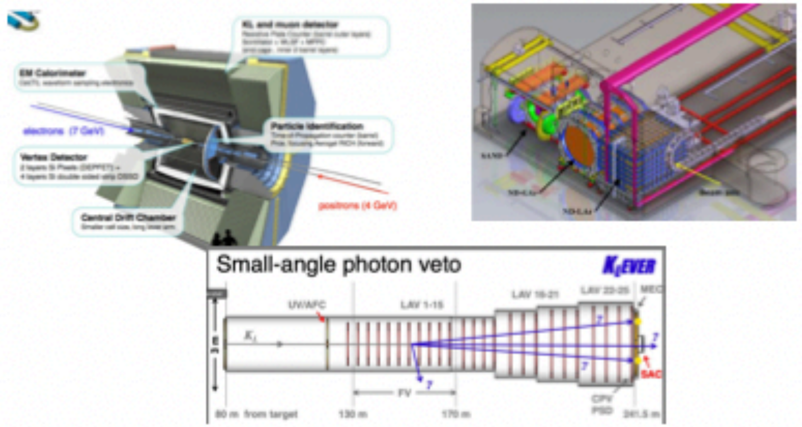
Higgs Factories



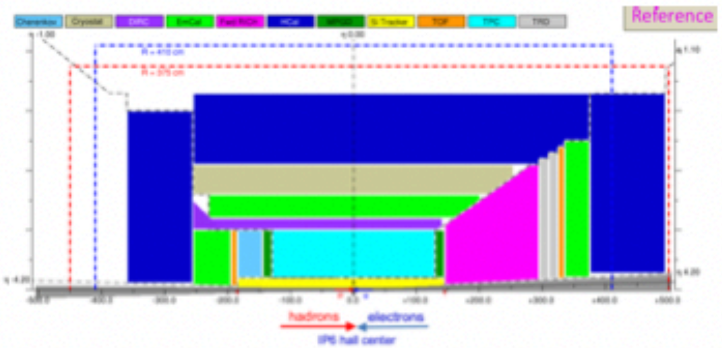
Future hadron colliders (including eh colliders)



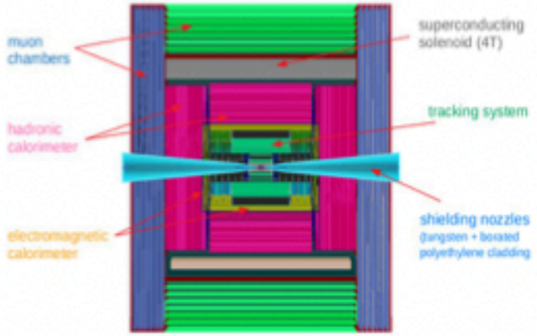
SuperKEKB, DUNE ND and Fixed Target



EiC



Muon Collider



Calorimeter Symposium

Orthogonal Views

Lessons learned: calorimeter upgrade R&D for HL-LHC & by Calice

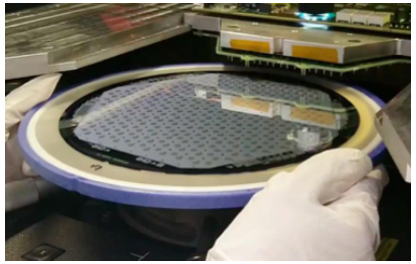
Speaker: David Barney (CERN)

ECFA_TF6_LessonsL... | ECFA_TF6_LessonsL...

Precision timing and their applications in calorimetry

Speaker: Nural Akchurin (Texas Tech University (US))

ECFA_PrecisionTimi... | ECFA_PrecisionTimi...



Si based highly and ultra-highly granular calorimeters

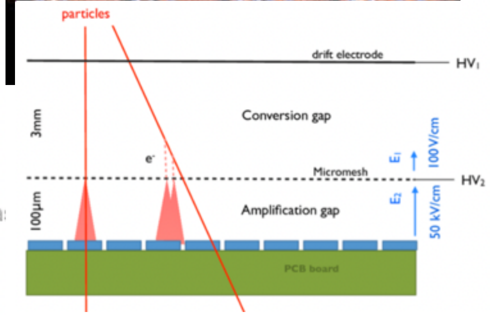
Speaker: Vincent Boudry (LLR – CNRS, École polytechnique, Institut P

ECFA_TF6_SiHGCalo... | ECFA_TF6_SiHGCalo... | EC

Future Noble Liquid Systems

Speaker: Brieuc Francois (CERN)

ECFA_TF6_NobleLiq...



Gaseous calorimeters

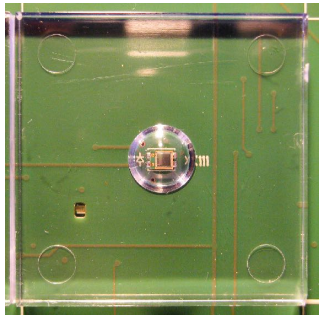
Speaker: Maria Fouz Iglesias (Centro de Investigaciones Energéti ca

ECFATF6_GaseousD...

Tile and strip calorimeters ¶

Speaker: Katja Kruger (Deutsches Elektronen-Synchrotron (DE))

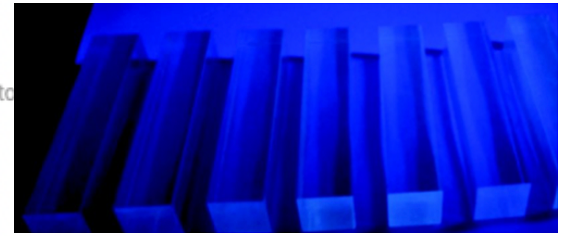
TF6_Tiles_strips_v2....



Crystal calorimetry

Speaker: Marco Toliman Lucchini (Princeto

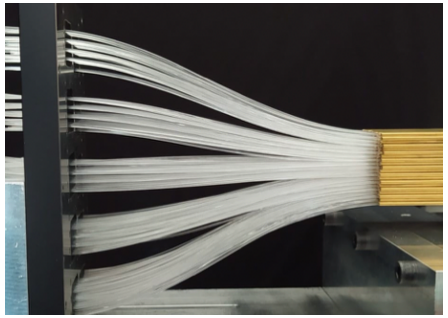
2021_05_07_ECFA_T...



R&D for Dual-Readout fibre-sampling calorimetry

Speakers: Gabriella Gaudio (INFN-Pavia), Gabriella Gaudio (

20210407_DualRead...



Compact and high performant readout systems

Speaker: André David (CERN)

20210507 ECFA TF6 ...

Symposia shed light along the technological direction
https://indico.cern.ch/event/999820/

Detector Technologies Roadmap


THE 2021 ECFA DETECTOR
RESEARCH AND DEVELOPMENT ROADMAP
The European Committee for Future Accelerators
Detector R&D Roadmap Process Group
European Strategy
Update
ECFA
European Committee
for Future Accelerators

Contents


We ought, in every instance, to submit our reasoning to the test of experiment, and never to search for truth but by the natural road of experiment and observation.
Antoine Lavoisier
Traité élémentaire de chimie, 1789
More information:
https://europeanstrategy.cern
https://indico.cern.ch/e/ECFADetectorRDRoadmap
https://ecfa.web.cern.ch/
ISBN 978-92-9083-614-8 (online)
ISBN 978-92-9083-615-5 (paperback)
European Strategy
Update
ECFA
European Committee
for Future Accelerators
2021

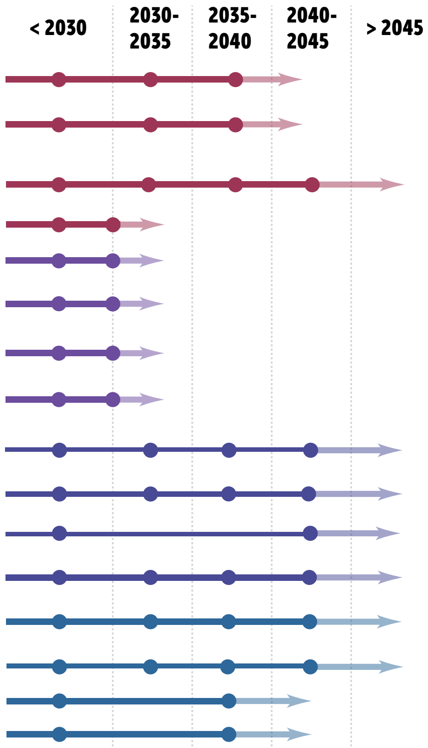
8 page synopsis brochure also prepared for less specialist audience

ECFA Detector Roadmap Summary

Relating Technology R&D to Major Drivers from Facilities

stepping stones | ILC | FCC, CLIC

DETECTOR RESEARCH AND DEVELOPMENT THEMES (DRDTs) & DETECTOR COMMUNITY THEMES (DCTs)



Gaseous
- **DRDT 1.1** Improve time and spatial resolution for gaseous detectors with long-term stability
- **DRDT 1.2** Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes
- **DRDT 1.3** Develop environmentally friendly gaseous detectors for very large areas with high-rate capability
- **DRDT 1.4** Achieve high sensitivity in both low and high-pressure TPCs

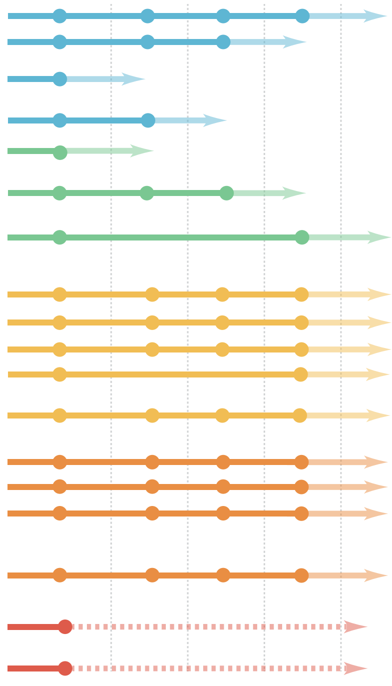
Liquid
- **DRDT 2.1** Develop readout technology to increase spatial and energy resolution for liquid detectors
- **DRDT 2.2** Advance noise reduction in liquid detectors to lower signal energy thresholds
- **DRDT 2.3** Improve the material properties of target and detector components in liquid detectors
- **DRDT 2.4** Realise liquid detector technologies scalable for integration in large systems

Solid state
- **DRDT 3.1** Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
- **DRDT 3.2** Develop solid state sensors with 4D-capabilities for tracking and calorimetry
- **DRDT 3.3** Extend capabilities of solid state sensors to operate at extreme fluences
- **DRDT 3.4** Develop full 3D-interconnection technologies for solid state devices in particle physics

PID and Photon
- **DRDT 4.1** Enhance the timing resolution and spectral range of photon detectors
- **DRDT 4.2** Develop photosensors for extreme environments
- **DRDT 4.3** Develop RICH and imaging detectors with low mass and high resolution timing
- **DRDT 4.4** Develop compact high performance time-of-flight detectors

Dates when R&D finished and real engineering & construction can start

stepping stones | ILC | FCC, CLIC



Quantum
- **DRDT 5.1** Promote the development of advanced quantum sensing technologies
- **DRDT 5.2** Investigate and adapt state-of-the-art developments in quantum technologies to particle physics
- **DRDT 5.3** Establish the necessary frameworks and mechanisms to allow exploration of emerging technologies
- **DRDT 5.4** Develop and provide advanced enabling capabilities and infrastructure

Calorimetry
- **DRDT 6.1** Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution
- **DRDT 6.2** Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods
- **DRDT 6.3** Develop calorimeters for extreme radiation, rate and pile-up environments

Electronics
- **DRDT 7.1** Advance technologies to deal with greatly increased data density
- **DRDT 7.2** Develop technologies for increased intelligence on the detector
- **DRDT 7.3** Develop technologies in support of 4D- and 5D-techniques
- **DRDT 7.4** Develop novel technologies to cope with extreme environments and required longevity
- **DRDT 7.5** Evaluate and adapt to emerging electronics and data processing technologies

Integration
- **DRDT 8.1** Develop novel magnet systems
- **DRDT 8.2** Develop improved technologies and systems for cooling
- **DRDT 8.3** Adapt novel materials to achieve ultralight, stable and high precision mechanical structures. Develop Machine Detector Interfaces.
- **DRDT 8.4** Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects

Training
- **DCT 1** Establish and maintain a European coordinated programme for training in instrumentation
- **DCT 2** Develop a master's degree programme in instrumentation

Detector R&D Themes (DRDTs) and Detector Community Themes (DCTs). Here, except in the DCT case, the final dot position represents the target date for completion of the R&D required by the latest known future facility/experiment for which an R&D programme would still be needed in that area. The time from that dot to the end of the arrow represents the further time to be anticipated for experiment-specific prototyping, procurement, construction, installation and commissioning. Earlier dots represent the time-frame of intermediate "stepping stone" projects where dates for the corresponding facilities/experiments are known. (Note that R&D for Liquid Detectors will be needed far into the future, however the DRDT lines for these end in the period 2030-35 because developments in that field are rapid and it is not possible today to reasonably estimate the dates for projects requiring longer-term R&D. Similarly, dotted lines for the DCT case indicate that beyond the initial programmes, the activities will need to be sustained going forward in support of the instrumentation R&D activities).

ECFA Detector Roadmap Summary: TF3

Relating Technology R&D to Major Drivers from Facilities

Example:
Solid State Detectors

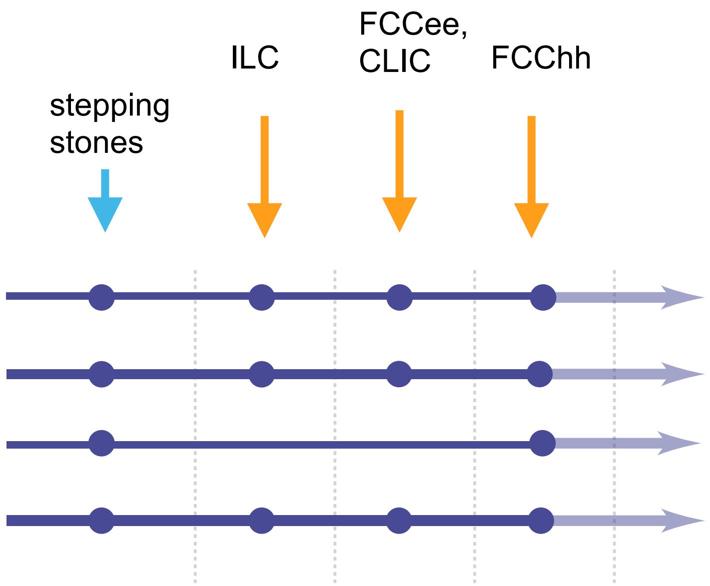
Solid state

DRDT 3.1 Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors

DRDT 3.2 Develop solid state sensors with 4D-capabilities for tracking and calorimetry

DRDT 3.3 Extend capabilities of solid state sensors to operate at extreme fluences

DRDT 3.4 Develop full 3D-interconnection technologies for solid state devices in particle physics

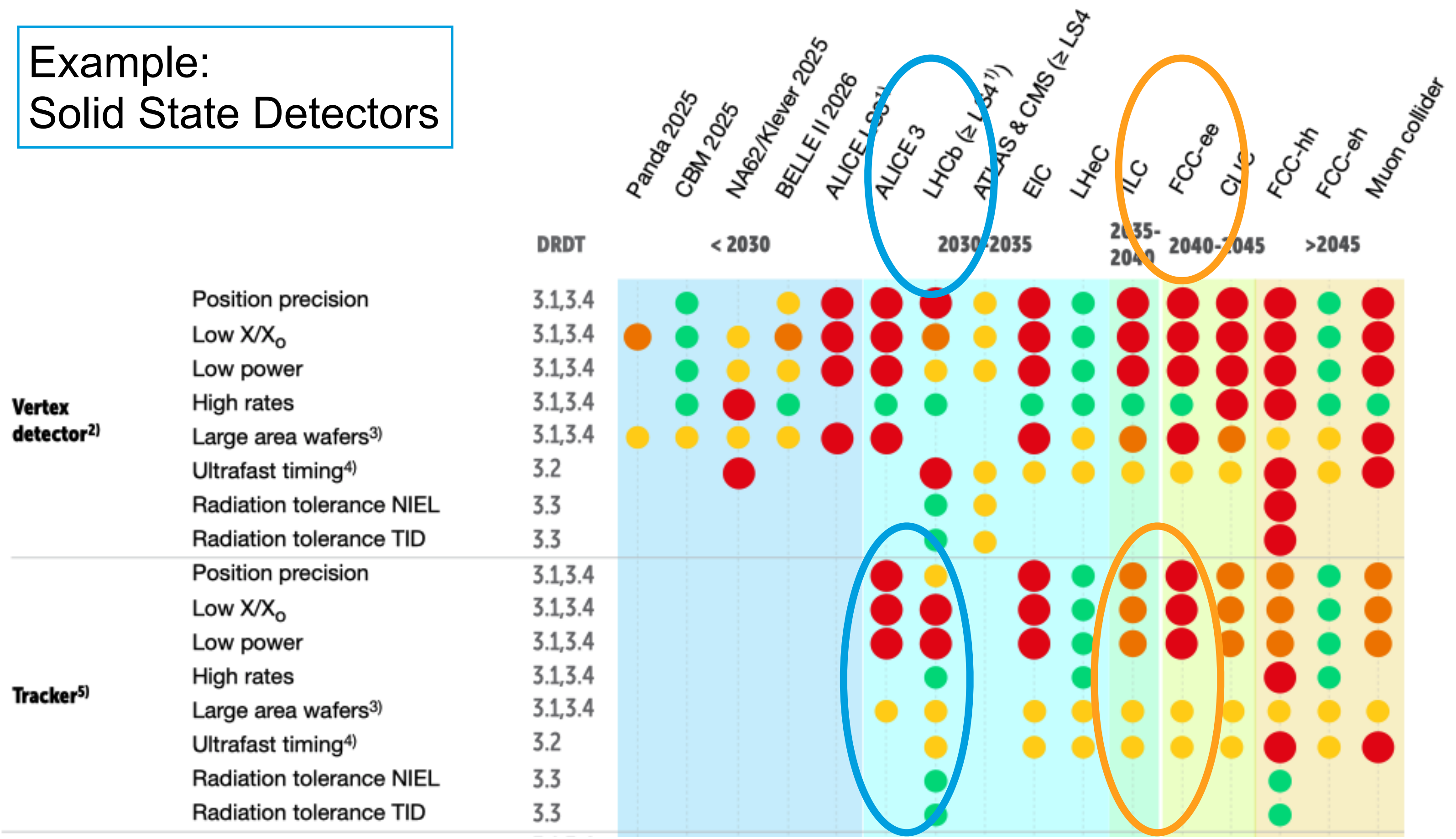


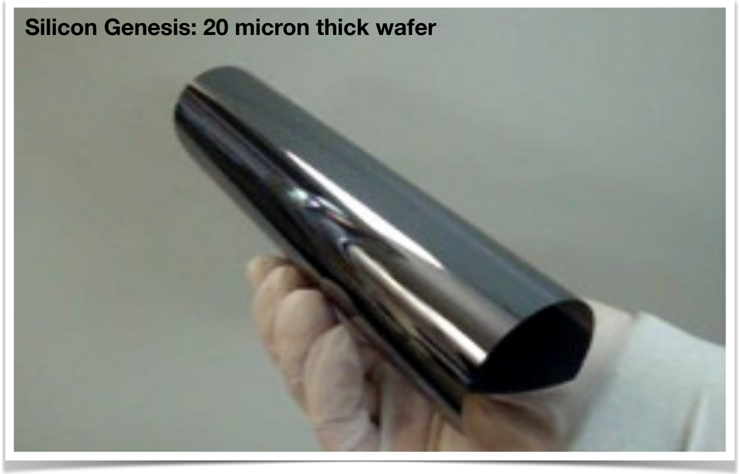
"Technical" Start Date of Facility (This means, where the dates are not known, the earliest technically feasible start date is indicated - such that detector R&D readiness is not the delaying factor)				< 2030					2030-2035					2035 - 2040	2040-2045		> 2045		
				Panda 2025	CBM 2025	NA62/Klever 2025	Belle II 2026	ALICE LS3 [1]	ALICE 3	LHCb (≳LS4) [1]	ATLAS/CMS (≳ LS4) [1]	EIC	LHeC	ILC [2]	FCC-ee	CLIC [2]	FCC-hh	FCC-eh	Muon Collider
Vertex Detector [3]	MAPS Planar/3D/Passive CMOS LGADs	DRDT 3.1 DRDT 3.4	Position precision σ_{hit} (µm)		≃ 5		≲ 5	≃ 3	≲ 3	≃ 10	≲ 15	≲ 3	≃ 5	≲ 3	≲ 3	≲ 3	≃ 7	≃ 5	≲ 5
			X/X_0 (%/layer)	≲ 0.1	≃ 0.5	≃ 0.5	≲ 0.1	≃ 0.05	≃ 0.05	≃ 1		≃ 0.05	≲ 0.1	≃ 0.05	≃ 0.05	≲ 0.2	≃ 1	≲ 0.1	≲ 0.2
			Power (mW/cm^2)		≃ 60			≃ 20	≃ 20			≃ 20		≃ 20	≃ 20	≃ 50			
			Rates (GHz/cm^2)		≃ 0.1	≃ 1	≲ 0.1		≲ 0.1	≃ 6		≲ 0.1	≃ 0.1	≃ 0.05	≃ 0.05	≃ 5	≃ 30	≃ 0.1	
			Wafers area (") [4]					12	12			12			12		12		12
		DRDT 3.2	Timing precision σ_t (ns) [5]	10		≲ 0.05	100		25	≲ 0.05	≲ 0.05	25	25	500	25	≃ 5	≲ 0.02	25	≲ 0.02
		DRDT3.3	Radiation tolerance NIEL (x10^{16} neq/cm^2)							≃ 6	≃ 2						≃ 10^{2}		
			Radiation tolerance TID (Grad)							≃ 1	≃ 0.5						≃ 30		
Tracker [6]	MAPS Planar/3D/Passive CMOS LGADs	DRDT 3.1 DRDT 3.4	Position precision σ_{hit} (µm)						≃ 6	≃ 5		≃ 6	≃ 6	≃ 6	≃ 6	≃ 7	≃ 10	≃ 6	
			X/X_0 (%/layer)						≃ 1	≃ 1		≃ 1	≃ 1	≃ 1	≃ 1	≃ 1	≲ 2	≃ 1	
			Power (mW/cm^2)						≲ 100	≃ 100		≲ 100		≲ 100	≲ 100	≲ 150			
			Rates (GHz/cm^2)							≃ 0.16									
			Wafers area (") [4]						12			12		12	12	12	12		12
		DRDT 3.2	Timing precision σ_t (ns) [5]						25	≲ 25		25	25	≲ 0.1	≲ 0.1	≲ 0.1	≲ 0.02	25	≲ 0.02
		DRDT3.3	Radiation tolerance NIEL (x10^{16} neq/cm^2)							≃ 0.3							≲ 1		
			Radiation tolerance TID (Grad)							≃ 0.25							≲ 1		

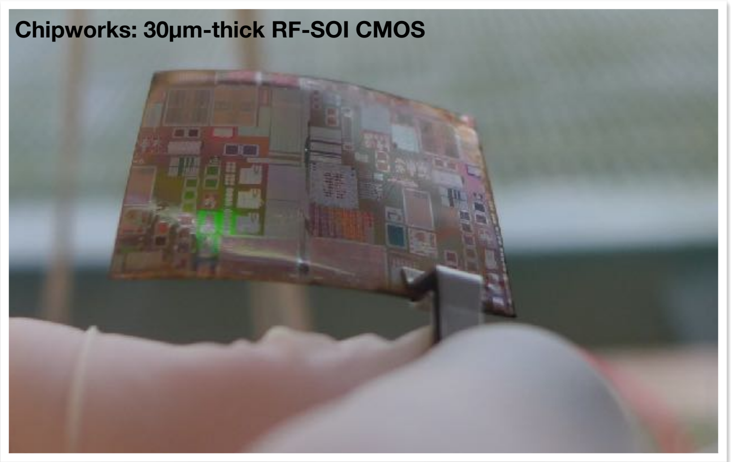
Synergies, Stepping Stones, R&D collaborations

Looking Across the Fence, and Beyond Tomorrow

Example:
Solid State Detectors







Magnus Mager (CERN) | ALICE ITS3 | CERN detector seminar | 24.09.2021 | 9

Must happen or main physics goals cannot be met · Important to meet several physics goals · Desirable to enhance physics reach · R&D needs being met

ECFA Detector Roadmap Summary: TF6

Relating Technology R&D to Major Drivers from Facilities

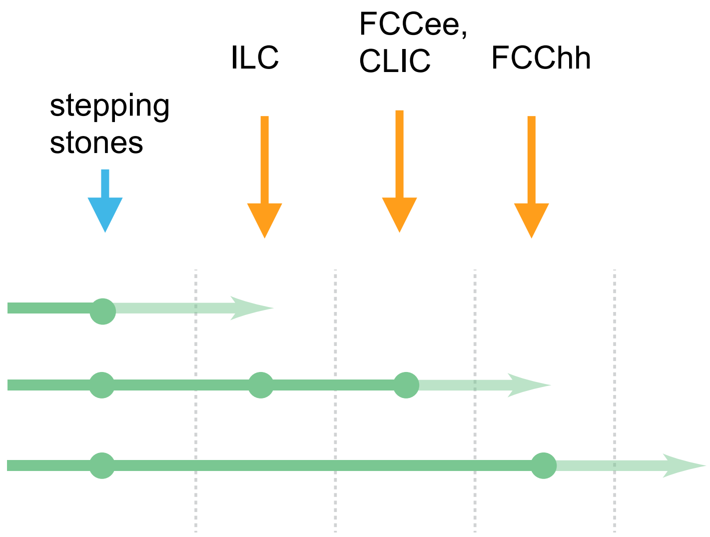
Example:
Calorimeters

Calorimetry

DRDT 6.1 Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution

DRDT 6.2 Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods

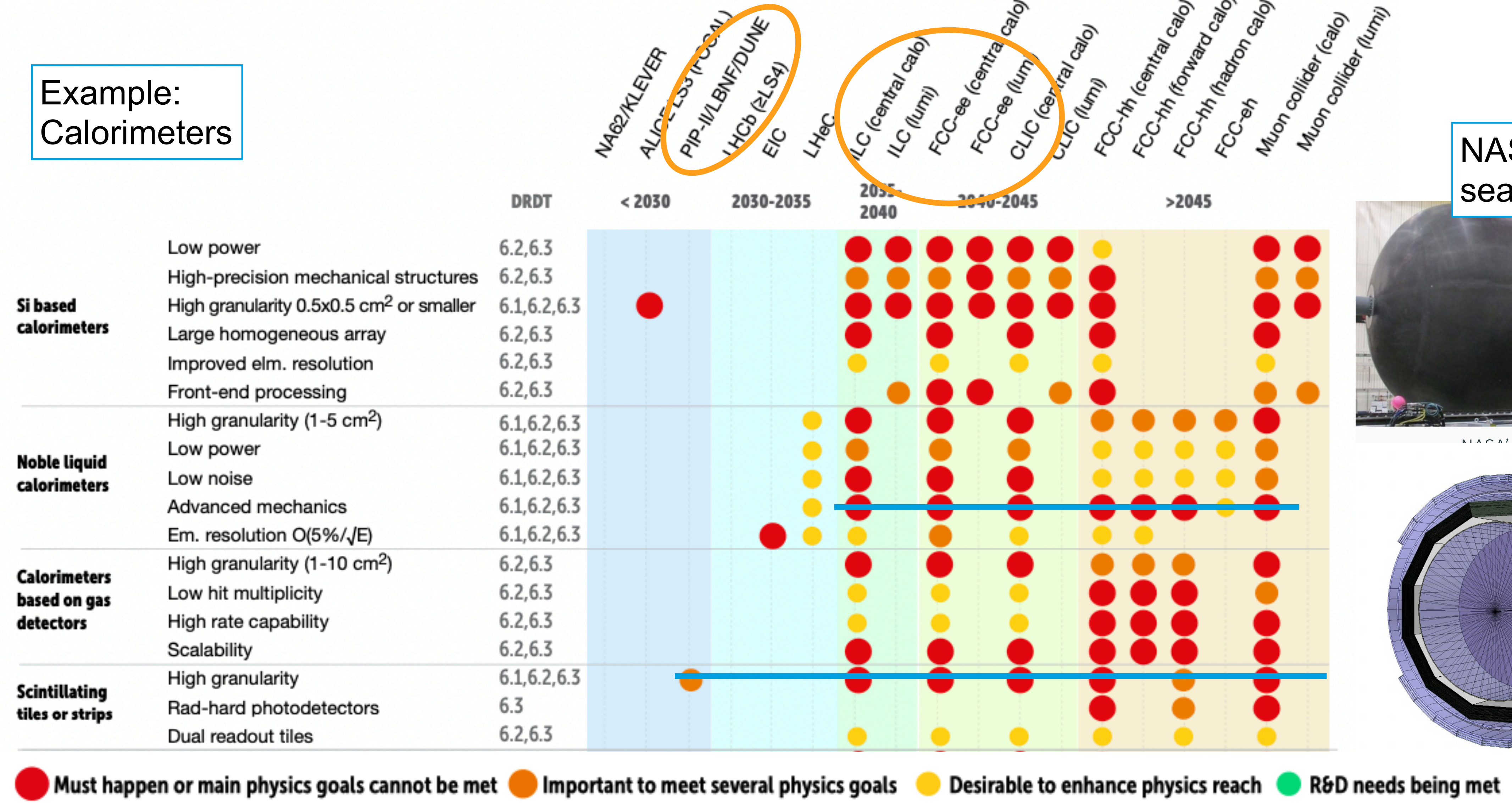
DRDT 6.3 Develop calorimeters for extreme radiation, rate and pile-up environments



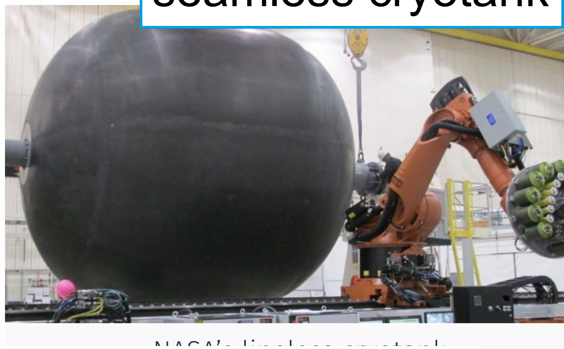
Synergies, Stepping Stones, R&D collaborations

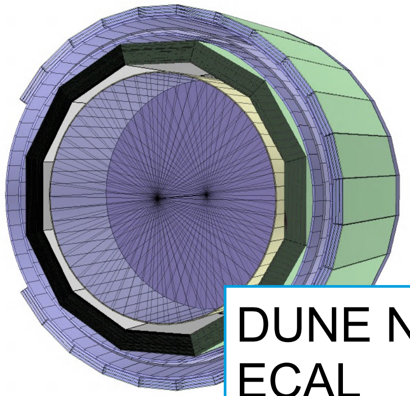
Looking Across the Fence, and Beyond Tomorrow

Example:
Calorimeters



NASA
seamless cryotank



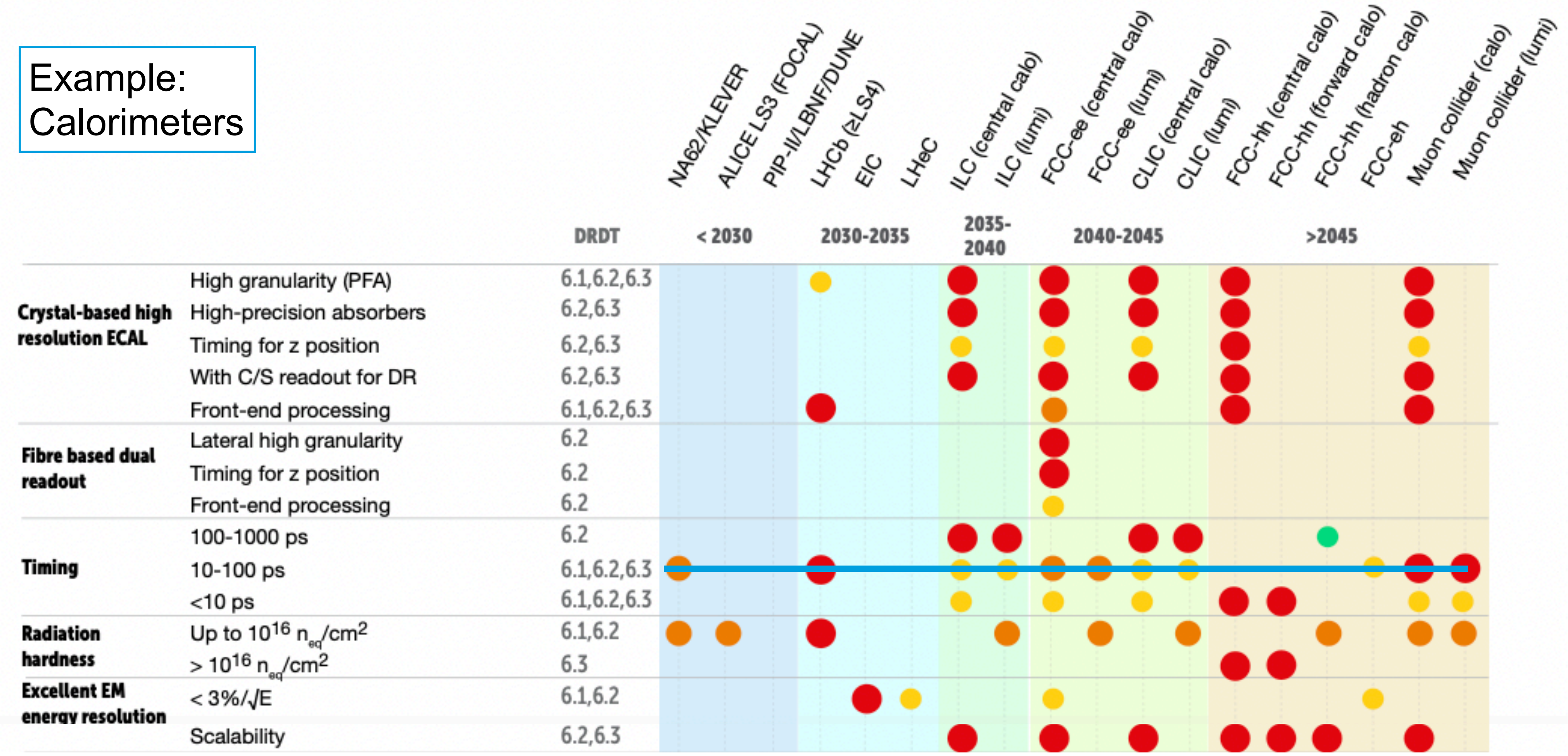


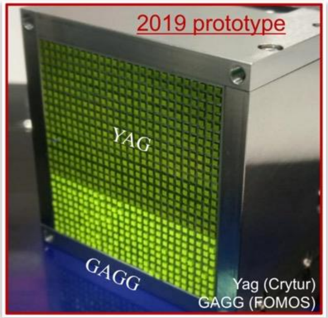
DUNE ND
ECAL

Synergies, Stepping Stones, R&D collaborations

Looking Across the Fence, and Beyond Tomorrow

Example:
Calorimeters





Fast timing
SPACAL

Must happen or main physics goals cannot be met | Important to meet several physics goals | Desirable to enhance physics reach | R&D needs being met

General Strategic Recommendations

GSR 1 - Supporting R&D facilities

It is recommended that the structures to provide Europe-wide coordinated infrastructure in the areas of: test beams, large scale generic prototyping and irradiation be consolidated and enhanced to meet the needs of next generation experiments with adequate centralised investment to avoid less cost-effective, more widely distributed, solutions, and to maintain a network structure for existing distributed facilities, e.g. for irradiation

GSR 2 - Engineering support for detector R&D

In response to ever more integrated detector concepts, requiring holistic design approaches and large component counts, the R&D should be supported with adequate mechanical and electronics engineering resources, to bring in expertise in state-of-the-art microelectronics as well as advanced materials and manufacturing techniques, to tackle generic integration challenges, and to maintain scalability of production and quality control from the earliest stages.

GSR 3 - Specific software for instrumentation

Across DRDTs and through adequate capital investments, the availability to the community of state-of-the-art R&D-specific software packages must be maintained and continuously updated. The expert development of these packages - for core software frameworks, but also for commonly used simulation and reconstruction tools - should continue to be highly recognised and valued and the community effort to support these needs to be organised at a European level.

GSR 4 - International coordination and organisation of R&D activities

With a view to creating a vibrant ecosystem for R&D, connecting and involving all partners, there is a need to refresh the CERN RD programme structure and encourage new programmes for next generation detectors, where CERN and the other national laboratories can assist as major catalysers for these. It is also recommended to revisit and streamline the process of creating and reviewing these programmes, with an extended framework to help share the associated load and increase involvement, while enhancing the visibility of the detector R&D community and easing communication with neighbouring disciplines, for example in cooperation with the ICFA Instrumentation Panel.

Detector R&D Roadmap

General Strategic Recommendations

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GSR 5 - Distributed R&D activities with centralised facilities

Establish in the relevant R&D areas a distributed yet connected and supportive tier-ed system for R&D efforts across Europe. Keeping in mind the growing complexity, the specialisation required, the learning curve and the increased cost, consider more focused investment for those themes where leverage can be reached through centralisation at large institutions, while addressing the challenge that distributed resources remain accessible to researchers across Europe and through them also be available to help provide enhanced training opportunities.

GSR 6 - Establish long-term strategic funding programmes

Establish, additional to short-term funding programmes for the early proof of principle phase of R&D, also long-term strategic funding programmes to sustain both research and development of the multi-decade DRDTs in order for the technology to mature and to be able to deliver the experimental requirements. Beyond capital investments of single funding agencies, international collaboration and support at the EU level should be established. In general, the cost for R&D has increased, which further strengthens the vital need to make concerted investments.

GSR 7 – "Blue-sky" R&D

It is essential that adequate resources be provided to support more speculative R&D which can be riskier in terms of immediate benefits but can bring significant and potentially transformational returns if successful both to particle physics: unlocking new physics may only be possible by unlocking novel technologies in instrumentation, and to society. Innovative instrumentation research is one of the defining characteristics of the field of particle physics. "Blue-sky" developments in particle physics have often been of broader application and had immense societal benefit. Examples include: the development of the World Wide Web, Magnetic Resonance Imaging, Positron Emission Tomography and X-ray imaging for photon science.

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GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts

Innovation in instrumentation is essential to make progress in particle physics, and R&D experts are essential for innovation. It is recommended that ECFA, with the involvement and support of its Detector R&D Panel, continues the study of recognition with a view to consolidate the route to an adequate number of positions with a sustained career in instrumentation R&D to realise the strategic aspirations expressed in the EPPSU. It is suggested that ECFA should explore mechanisms to develop concrete proposals in this area and to find mechanisms to follow up on these in terms of their implementation. Consideration needs to be given to creating sufficiently attractive remuneration packages to retain those with key skills which typically command much higher salaries outside academic research. It should be emphasised that, in parallel, society benefits from the training particle physics provides because the knowledge and skills acquired are in high demand by industries in high-technology economies.

GSR 9 - Industrial partnerships

It is recommended to identify promising areas for close collaboration between academic and industrial partners, to create international frameworks for exchange on academic and industrial trends, drivers and needs, and to establish strategic and resources-loaded cooperation schemes on a European scale to intensify the collaboration with industry, in particular for developments in solid state sensors and micro-electronics.

GSR 10 – Open Science

It is recommended that the concept of Open Science be explicitly supported in the context of instrumentation, taking account of the constraints of commercial confidentiality where these apply due to partnerships with industry. Specifically, for publicly-funded research the default, wherever possible, should be open access publication of results and it is proposed that the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP^3) should explore ensuring similar access is available to instrumentation journals (including for conference proceedings) as to other particle physics publications.

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- **The detector roadmap depicts a rich landscape of connected R&D activities**
- **It exhibits synergies between parallel activities targeted at different future projects at different facilities**
- **Opportunities appear where near-term projects with less demanding conditions may serve as stepping stones for a strategic R&D targeting more aggressive requirements**
- **General strategic recommendations capture the needs of an evolving field with central importance for our future ambitions**

Implementation

Next Steps: Implementation Plan

In its December meeting, CERN Council has mandated ECFA to work out a plan

"The Council further took note of the report by the Scientific Policy Committee Chair, Professor Rivkin, on the SPC's positive response to the roadmaps [Accelerator and Detector R&D] at its September and December meetings, and of the statements by delegations voicing support for the content of the documents and expressing appreciation to ECFA, the LDG and all the members of the respective communities who had contributed to the preparation of the roadmaps.

The Council agreed ***to invite ECFA and the LDG to elaborate, in close collaboration with the SPC, the funding agencies and the relevant research organisations in Europe and beyond, detailed implementation plans*** *setting out milestones, priorities and funding sources, for consideration by the Council at its Session in March 2022."*

Consensus that momentum must be kept and a plan be put in place as early as possible

Next Steps: Implementation Plan

- ECFA Roadmap Coordination group has been entrusted to work out the implementation plan

  Coordination Group: Phil Allport, Silvia Dalla Torre, Jorgen D'Hondt, Karl Jakobs,
  Manfred Krammer, Susanne Kühn, Felix Sefkow and Ian Shipsey

- To be iterated with Restricted ECFA

- Discussions with Funding Agencies are planned (together with LDG) before March Council week

- First presentation and discussion in March Council

It may be possible that important detector R&D activities can be embedded in the defined Detector R&D Themes (DRDTs) of the ECFA Detector R&D Roadmap and in the emerging structures set up during the implementation process

Conclusions

Requested by the EPPSU, ECFA set up a Roadmap process with broad community consultation

- Ensure that detector development with its long time scales does not become the limiting factor for the future projects envisaged by the European Strategy

A matrix structure is laid out, displaying synergies between concurrent and subsequent projects

- complemented by general strategic recommendations to strengthen the field

Discussions towards the implementation are on-going

- R&D collaborations and review processes will be important ingredients for success

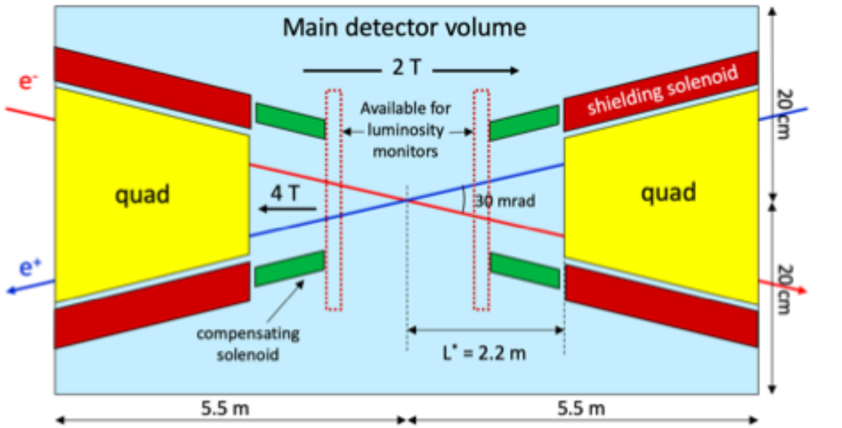
The roadmap should be updated together with the European Strategy

Back-up

FCCee Experimental challenges

- 30 mrad beam crossing angle
  - Detector B-field limited to 2 Tesla at Z-peak operation
  - Very complex and tightly packed MDI (Machine Detector Interface)
- "Continuous" beams (no bunch trains); bunch spacing down to 20 ns
  - Power management and cooling (no power pulsing)
- Extremely high luminosities
  - High statistical precision – control of systematics down to 10^{-5} level
  - Online and offline handling of $\mathcal{O}(10^{13})$ events for precision physics: "Big Data"
- Physics events at up to 100 kHz
  - Fast detector response ($\lesssim$ 1 µs) to minimise dead-time and event overlaps (pile-up)
  - Strong requirements on sub-detector front-end electronics and DAQ systems
    - At the same time, keep low material budget: minimise mass of electronics, cables, cooling, …

Central part of detector volume – top view

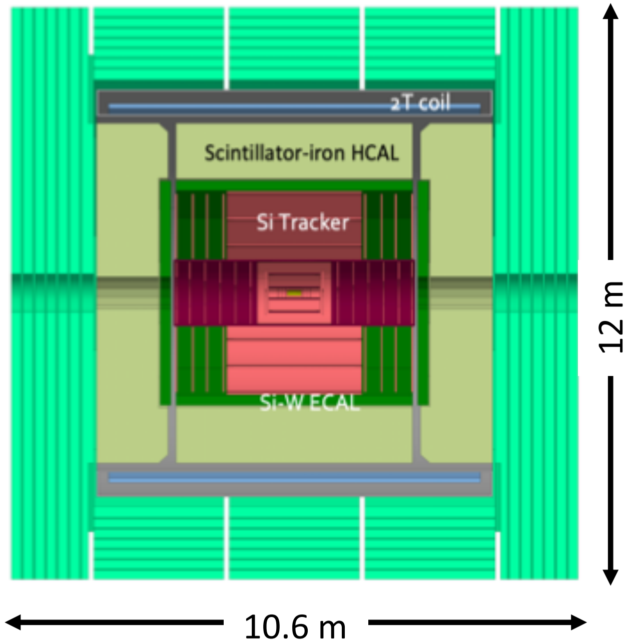


- More physics challenges
  - Luminosity measurement to 10^{-4} – luminometer acceptance to 1 µm level
  - Detector acceptance to ~10^{-5} – acceptance definition to few 10s of µm, hermeticity (no cracks!)
  - Stability of momentum measurement – stability of magnetic field wrt E_{cm} (10^{-6})
  - Impact parameters, detached vertices – Higgs physics (b/c/g jets); flavour and τ physics, life-time measurements
  - Particle identification (π/K/p) without ruining detector hermeticity – flavour and τ physics (and rare processes)

CDR: Two Complementary Detector Concepts

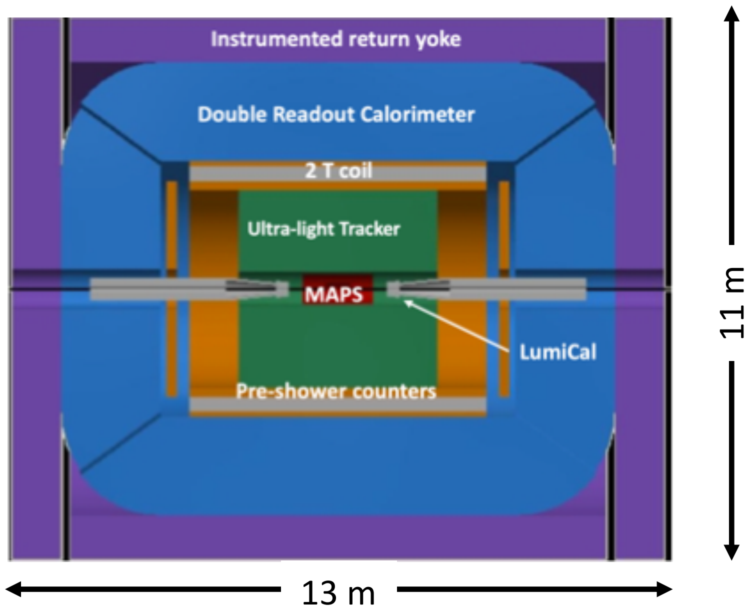
"Proof of principle concepts"
- Not necessarily matching (all) detector requirements, which are still being spelled out

CLD



- Based on CLIC detector design; profits from technology developments carried out for LCs (c.f. F.Simon's talk)
  - All silicon vertex detector and tracker
  - 3D-imaging highly-granular calorimeter system
  - Coil *outside* calorimeter system

IDEA



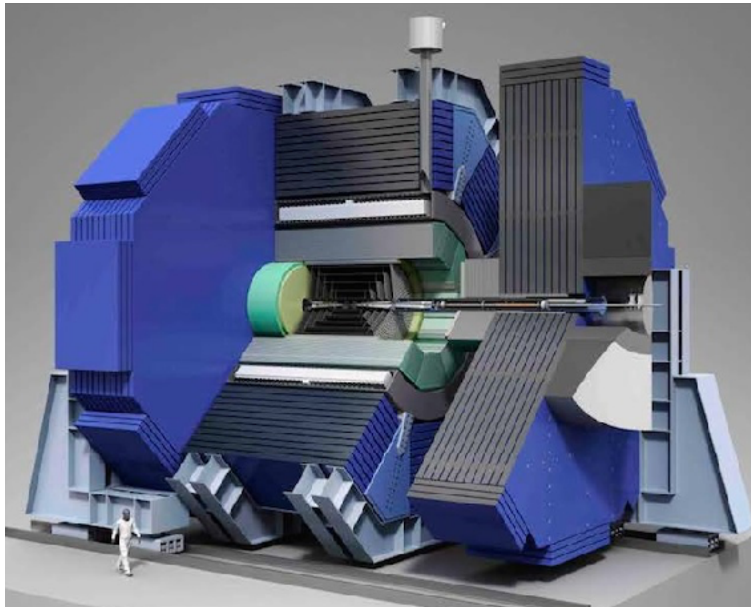
- New, innovative, possibly more cost-effective concept
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil *inside* calorimeter system

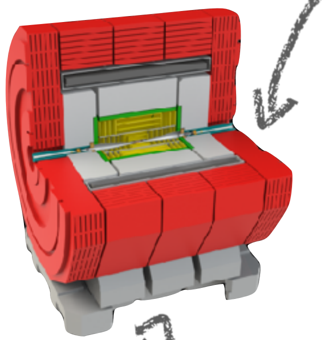
https://arxiv.org/abs/1911.12230, https://arxiv.org/abs/1905.02520 https://pos.sissa.it/390/

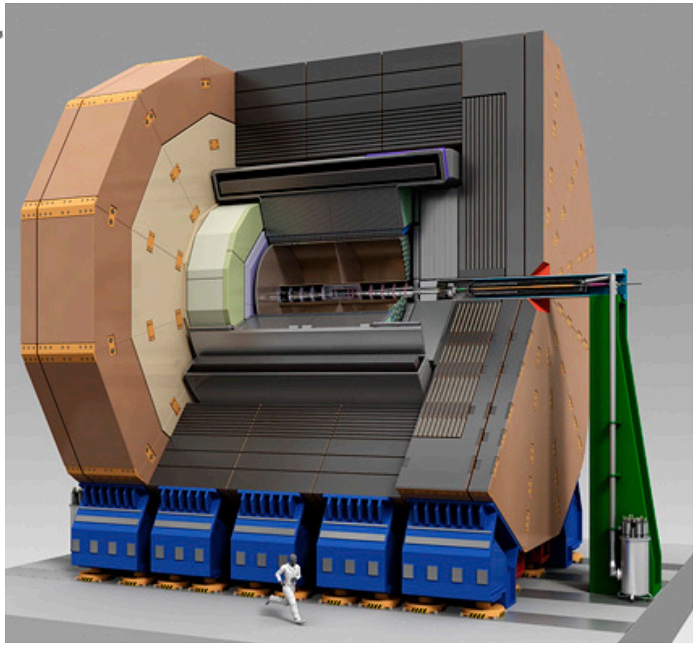
CLICdet: The Best of ILD and SID Worlds

Particle-flow Driven Detector Concepts

- Two detector concepts for ILC: SiD, ILD - with somewhat different optimisation







For ILD: 2 versions (large / small) under study

5T field

all-Si tracker with outer radius of 1.2 m

VTX inner radius 14 mm

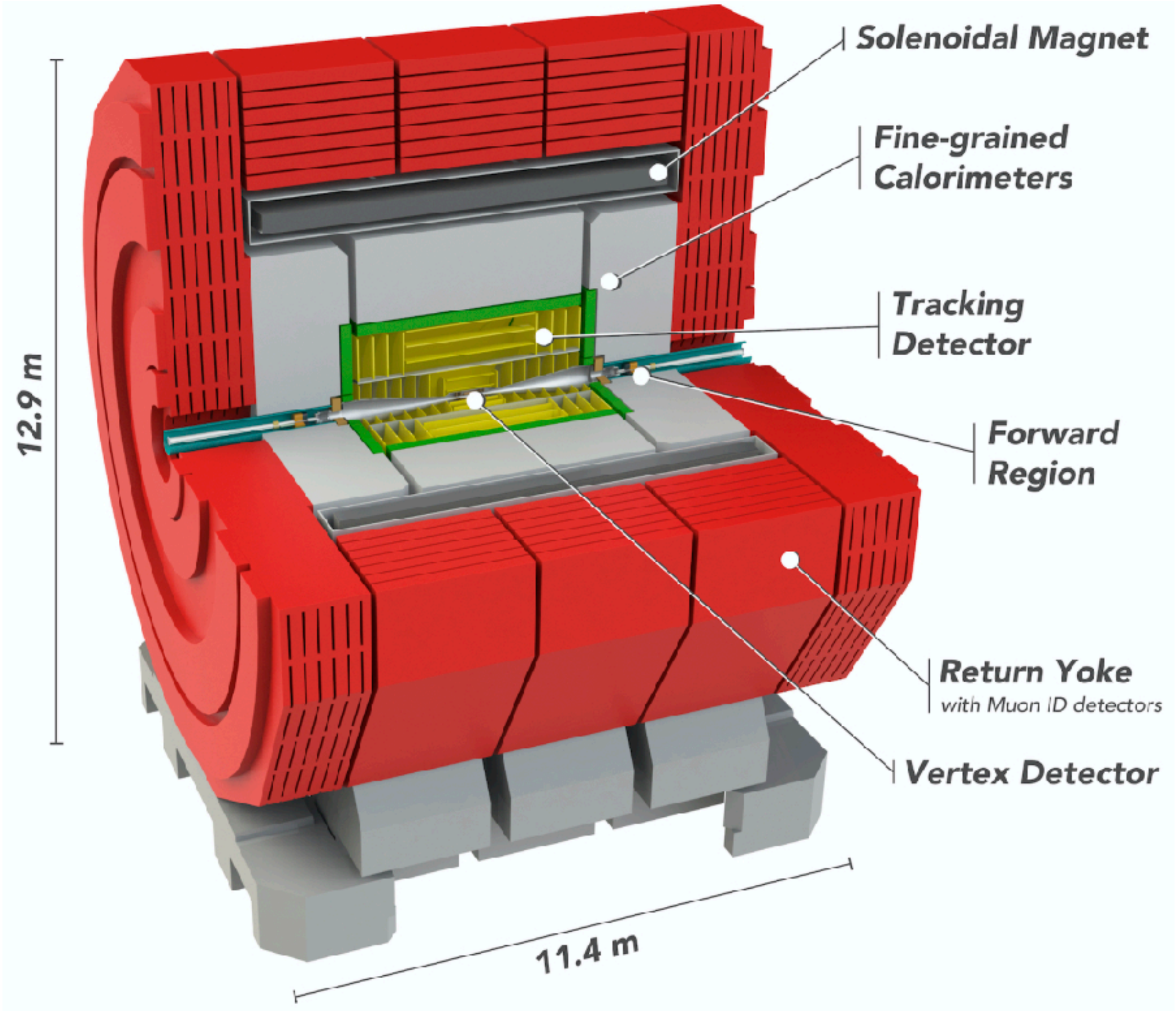
4.5 λ_I HCAL

- 3.5T / 4T field
- TPC as main tracker, supplemented by outer Si envelope radius 1.77 m / 1.43 m
- VTX inner radius 16 mm
- 6 λ_I HCAL

Frank Simon

CLICdet: The Best of ILD and SID Worlds

Particle-flow Driven Detector Concepts



- A **4T solenoid**, enclosing calorimeters and tracking
- **All-silicon tracker**, with 1 - 2% X_0 / layer, 1.5 m radius, 7 μm single point resolution
- **Vertex detector**, with 3 double layers in barrel, 31 mm inner radius
  0.2% X_0 per layer, 25 μm pixels, 3 μm single point resolution, forced air cooling
- **Highly granular calorimeters**: 40 layers SiW ECAL (22 X_0), 60 layers Scint/Steel HCAL (7.5 λ_I + 1 λ_I in ECAL)

Frank Simon

Highly Granular Liquid Argon Calorimeters

For Example

Originally started with FCChh in mind

Following recent advances on advanced materials for thin cryostats also studied for FCCee

- both cryostat and high granularity are critical R&D directions

Both warm and cold electronics considered

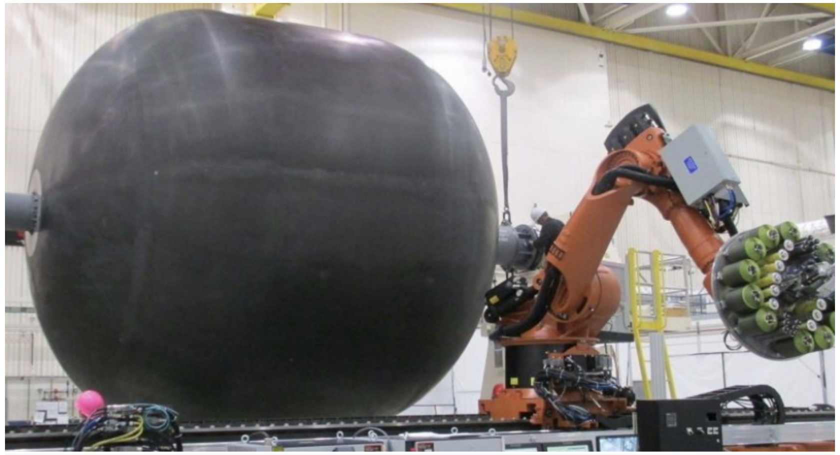
- high-density feedthroughs
- heat management of embedded FE chips
- MIP sensitivity in reach

High-tech development

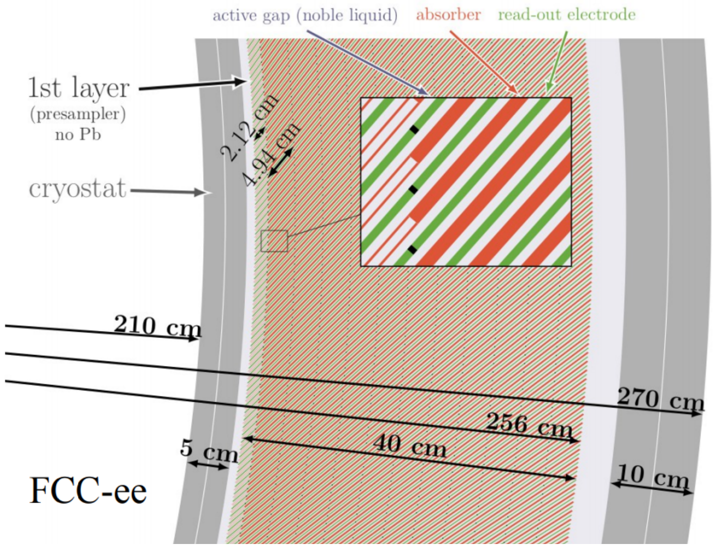
- and room for ideas, e.g. optical readout with UV-sensitive SiPMs
- synergies with other noble liquid detectors

See talk by N. Morange tomorrow

- still need to build a Detector Concept around LAr Calo



NASA's lineless cryotank



Scope

AIDAinnova focusses on Strategic R&D in the pre-TDR phase

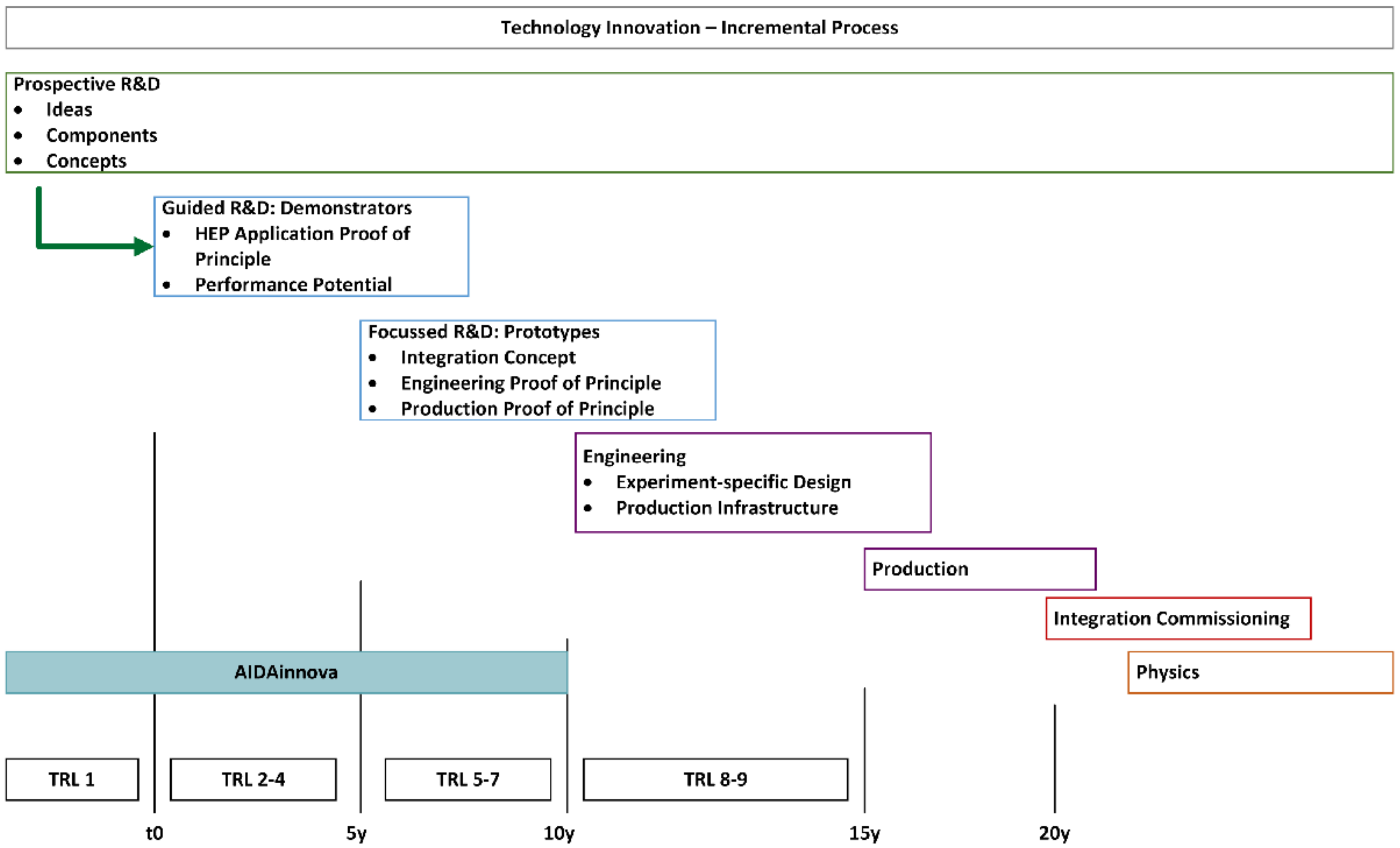
- Technology Readiness Levels 2-7
- Not yet experiment-specific: potential to unfold synergies

Include some prospective R&D

- competitive call at start of project
- “Blue Sky”, quantum sensors,…

Targeted applications

- Higgs Factories
- ALICE, LHCb LS3 pre-TDR, ATLAS & CMS LS4
- Accelerator-based neutrino experiments
- and others



Budget

49% is "generic", beneficial for all future projects:

- Testbeam and facility upgrades
- Mechanics and cooling, Software
- "Blue Sky" R&D plus some tasks in other WP

51% can be associated with 1 to 3 projects

- "Matrix" to be taken with a grain of salt…
- Sharing will influence generic part, too
- Higgs factory detectors have largest share