DRD-on-Calorimetry
Status and Scientific Programme

Roman Pöschl

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

CNRS IN2P3 Les deux infinis

université PARIS-SACLAY GRADUATE SCHOOL Physique

P2I Physique des deux Infinis

On behalf of DRD-on-Calorimetry

CALOR 2024 May 2024

DRD Calo - Proposal Team

Coordinators: Roberto Ferrari, Gabriella Gaudio (INFN-Pavia), R.P. (IJCLab)

Representative from ECFA Detector R&D Roadmap Coordination Team: Felix Sefkow (DESY)

WP 1: Sandwich calorimeters with fully embedded Electronics – Main and forward calorimeters
Conveners: Adrian Irles (IFIC, adrian.irles@ific.uv.es), Frank Simon (KIT, frank.simon@kit.edu), Jim Brau (University of Oregon, jimbrau@uoregon.edu), Wataru Ootani (University of Tokyo, wataru@icepp.s.u-tokyo.ac.jp), Imad Laktineh (I2PI, imad.laktineh@in2p3.fr), Lucia Masetti (masetti@physik.uni-mainz.de)

WP 2: Liquified Noble Gas Calorimeters
Conveners: Martin Aleksa (CERN, martin.aleksa@cern.ch), Nicolas Morange (IJCLab, nicolas.morange@ijclab.in2p3.fr), Marc-Andre Pleier (mpleier@bnl.gov)

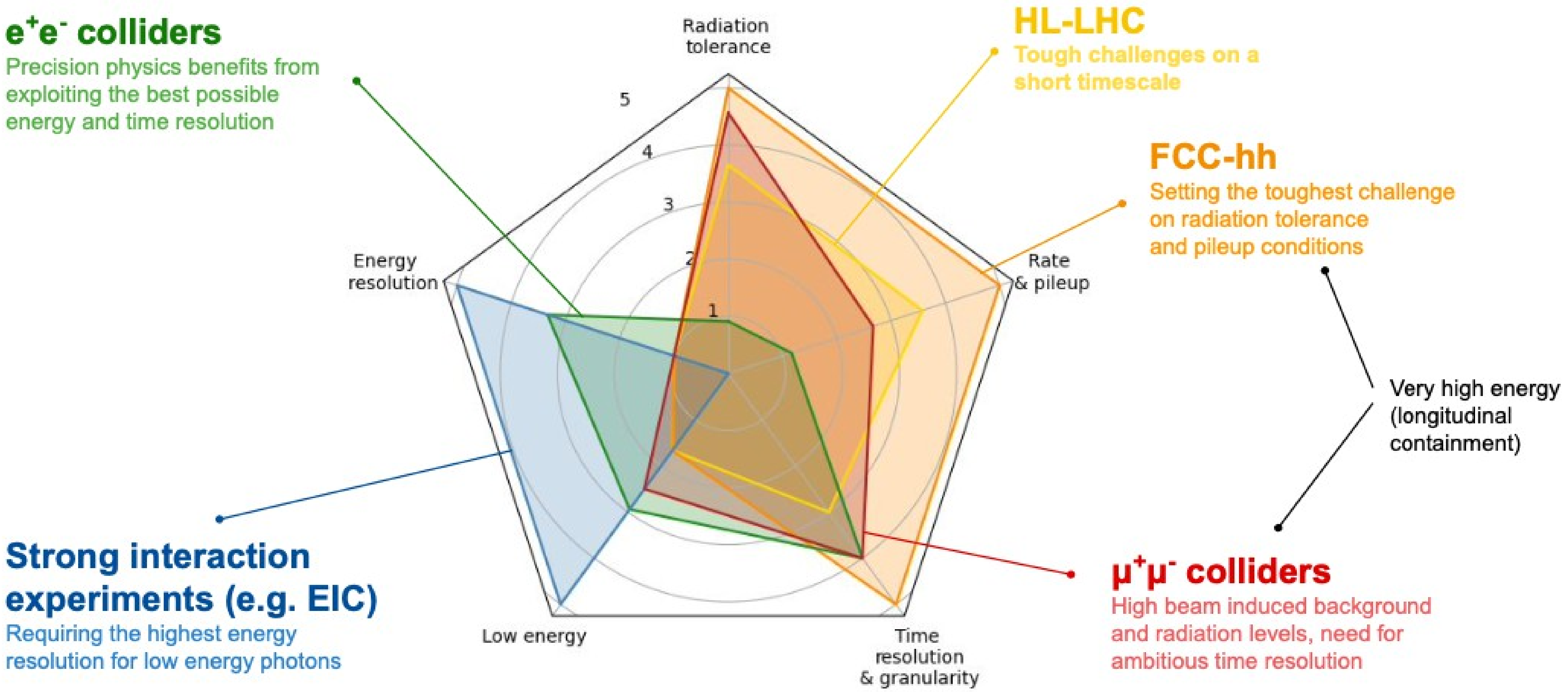
WP 3: Optical calorimeters: Scintillating based sampling and homogenous calorimeters
Conveners: Etiennette Auffray (CERN, etiennette.auffray@cern.ch),
Macro Lucchini (University and INFN Milano-Bicocca, marco.toliman.lucchini@cern.ch),
Philipp Roloff (CERN, philipp.roloff@cern.ch), Sarah Eno (University of Maryland, eno@umd.edu),
Hwidong Yoo (Yonsei University, hdyoo@cern.ch)

WP 4: Electronics and DAQ
Christophe de la Taille (OMEGA, taille@in2p3.fr)

Transversal Activitiies
Photodetectors: Alberto Gola (FBK, gola@fbk.eu)

Requirements for calorimetry at future colliders

DRD Calo



Inspired from https://indico.cern.ch/event/994685/

M. T. Lucchini, 1st Calo Community Meeting

The roadmap document(s)

- ECFA R&D Roadmap
  - CERN-ESU-017 https://cds.cern.ch/record/2784893
  - 248 pages full text and 8 page synopsis

- Endorsed by ECFA and presented to CERN Council in December 2021

The Roadmap has identified
  - General Strategic Recommendations (GSR)
  - Detector R&D Themes (DRDT)
  - Concrete R&D Tasks

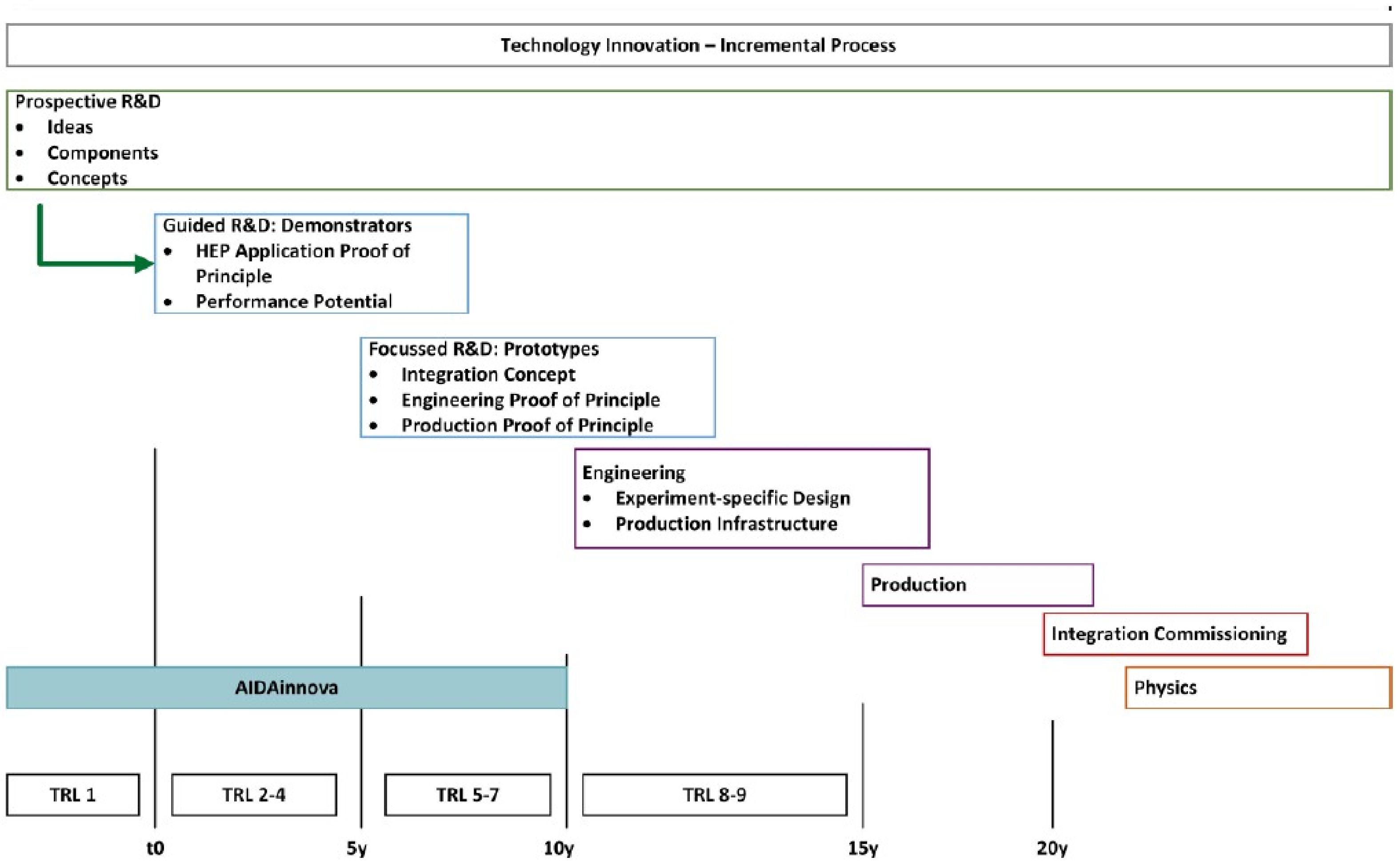
- Timescale of projects as approved by European Lab Director Group (LDG)

Guiding principle: Project realisation must not be delayed by detectors

Categories of R&D

1. Strategic R&D via DRD Collaborations **vision**
   (long-term strategic R&D lines)
   (address the high-priority items defined in the Roadmap via the DRDTs)
2. Experiment-specific R&D **focus**
   (with very well defined detector specifications)
   (funded outside of DRD programme, via experiments, usually not yet covered within the projected budgets for the final deliverables)
3. "Blue-sky" R&D **agility**
   (competitive, short-term responsive grants, nationally organised)

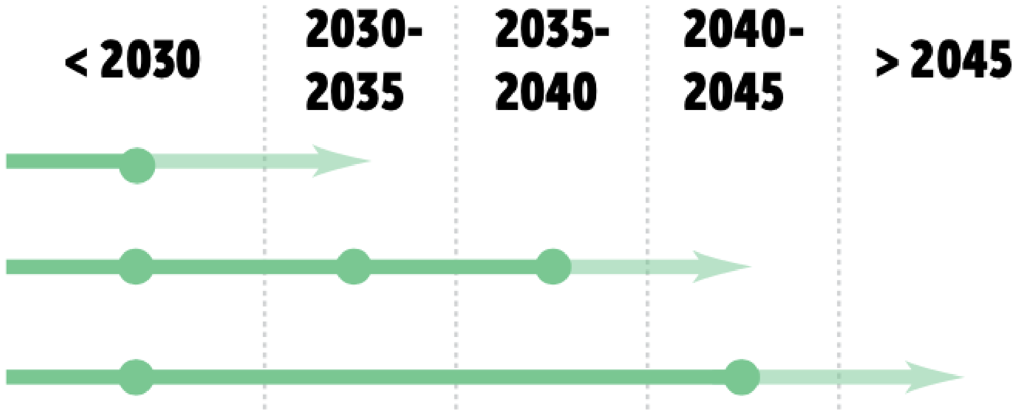
Transitions Blue-sky → Strategic → Specific expected
Cross-fertilisation desired



F. Sefkow, CALICE Meeting and ECFA Higgs/top/EW Factory Meeting

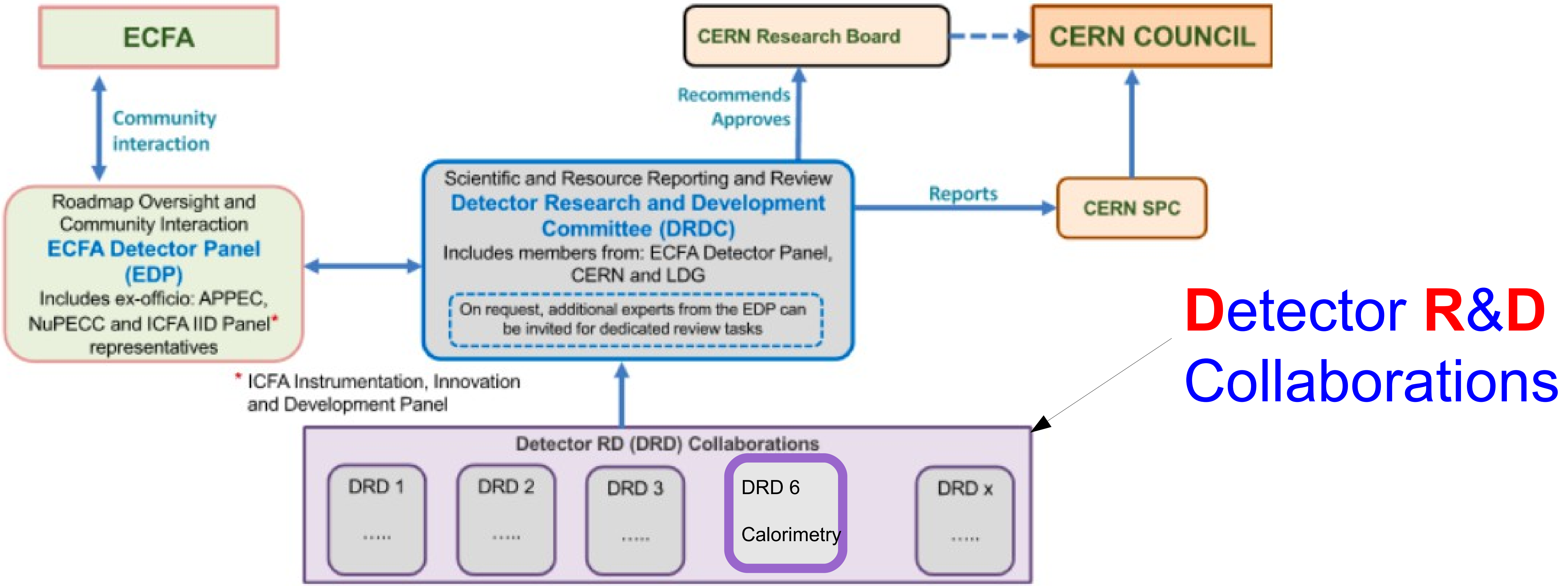
Future Facilities and DRDT for Calorimetry

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



- The **D**etector **R&D** **T**hemes and the provisional time scale of facilities set high-level boundary conditions
  - See backup slides for detailed R&D tasks

Future Organisation of Detector R&D (in Europe)



- DRD will be hosted by CERN and therefore become legally CERN collaborations
  - Significant participations by non-European groups is explicitly welcome and needed => World wide collaborations!
- The progress and the R&D will be overseen by a DRDC that is assisted by ECFA
  - Thomas Bergauer of ÖAW/Austria appointed as DRDC-Chair
- The funding will come from national resources (plus eventually supranational projects)

Towards DRD Calorimetry – Community building and proposal

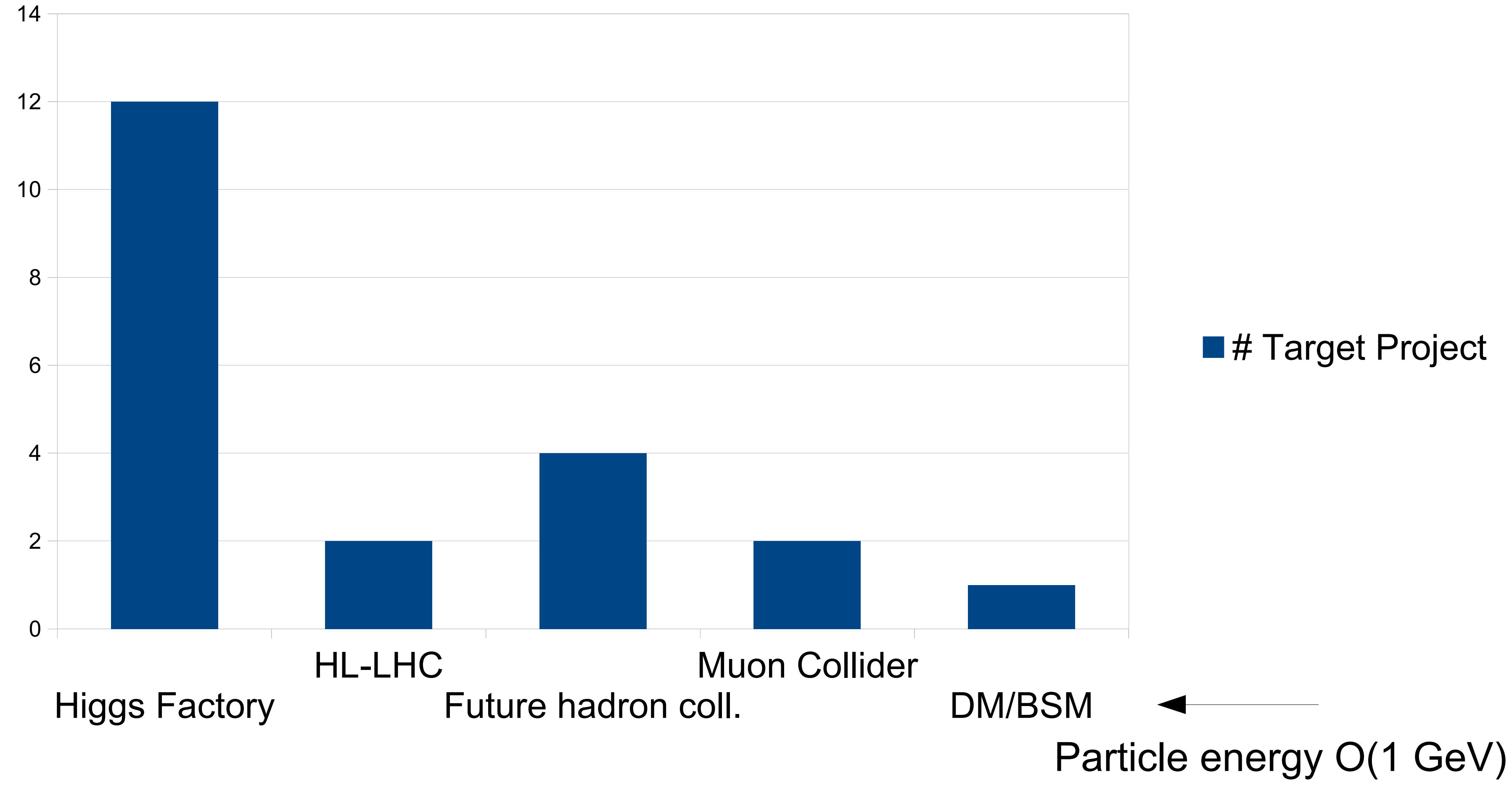
- 1st Community Meeting 12/1/23
  - https://indico.cern.ch/event/1212696/

- Proposal phase until 15th of November 2023
  - **Input proposals collected until 1st of April 2023**
  - 2nd Community Meeting 20th April 2023
    - https://indico.cern.ch/event/1246381/

  - Input proposals have been condensed into a DRD-on-Calorimetry proposal
    - First version submitted to DRDC on July 28th
    - Final version submitted to DRDC on November 15th

- **DRD-on-Calorimetry approved by CERN Research Board on December 6th to start on January 1st 2024**

DRD Calo - Input proposals and target projects



- Higgs factories dominate
  - HF includes heavy flavour (factory) that targets superb elm. energy resolutions
- (Already now) orientation towards future hadron collider and muon collider

The DRD Calo Proposal

DRD 6: Calorimetry

Proposal Team for DRD-on-Calorimetry

January 6, 2024

Martin Aleksa[1], Etiennette Auffray[1], David Barney[1], James Brau[2], Sarah Eno[3], Roberto Ferrari[4], Gabriella Gaudio[4], Alberto Gola[5], Adrian Irles[6], Imad Laktineh[7], Marco Lucchini[8], Nicolas Morange[9], Wataru Ootani[10], Marc-André Pleier[11], Roman Pöschl[9], Philipp Roloff[1], Felix Sefkow[12], Frank Simon[13] Tommaso Tabarelli de Fatis[8], Christophe de la Taille[14], Hwidong Yoo[15] (**Editors**)

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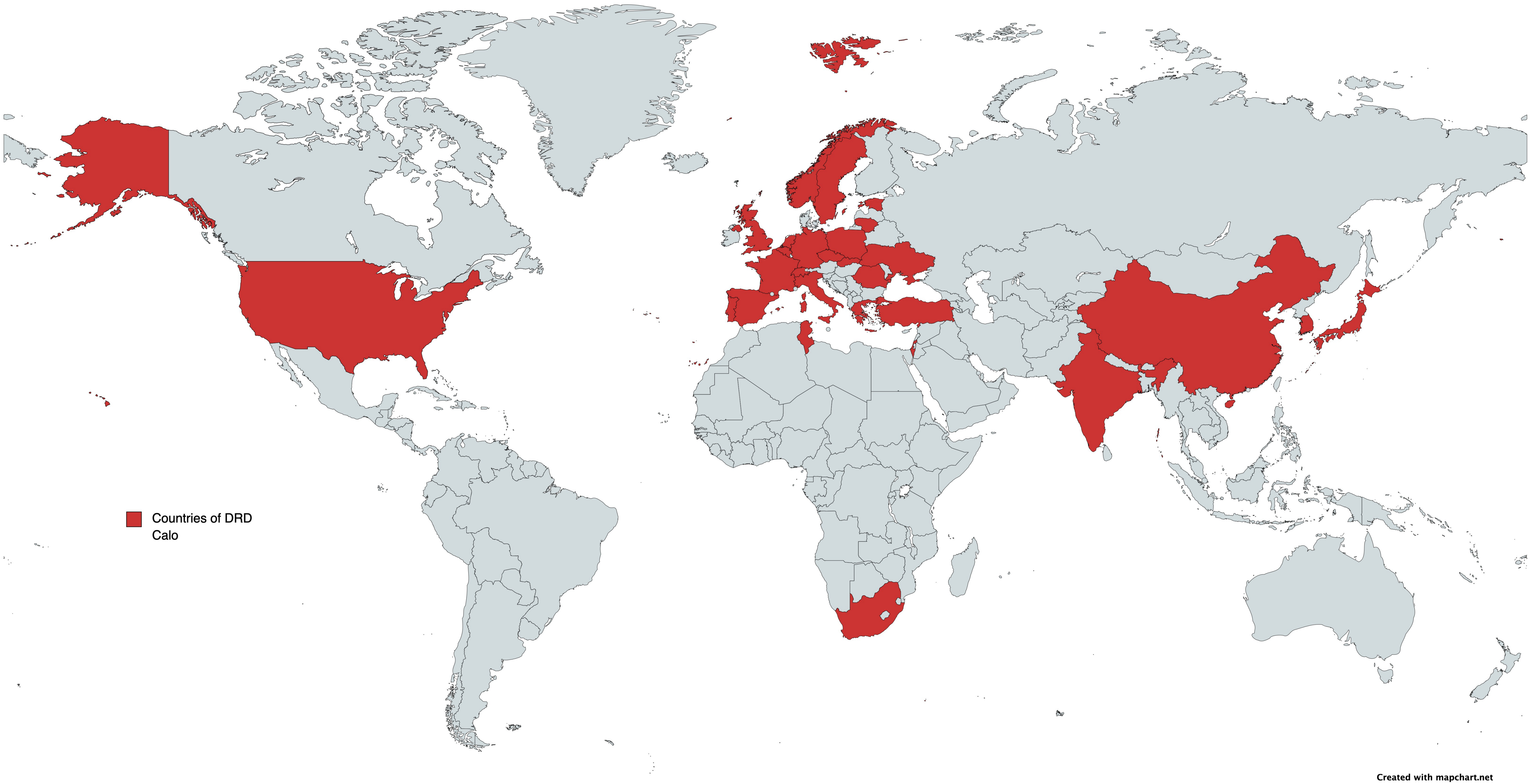
[2]University of Oregon, Eugene, OR USA
[3]University of Maryland, College Park, MD USA
[4]INFN, Pavia, ITALY
[5]FBK, Povo, ITALY
[6]IFIC, CSIC-University of Valencia, Valencia, SPAIN
[7]IP2I Lyon, Villeurbanne, FRANCE
[8]University and INFN Milano-Bicocca, Milano, ITALY
[9]IJCLab, Université Paris-Saclay, Orsay FRANCE
[10]University of Tokyo, Tokyo, JAPAN
[11]Brookhaven National Laboratory, Upton, NY USA
[12]Deutsches Elektronen-Synchrotron DESY, GERMANY
[13]Karlsruhe Institute of Technology, Karlsruhe, GERMANY
[14]OMEGA, Palaiseau, FRANCE
[15]Yonsei University, Seoul, SOUTH-KOREA

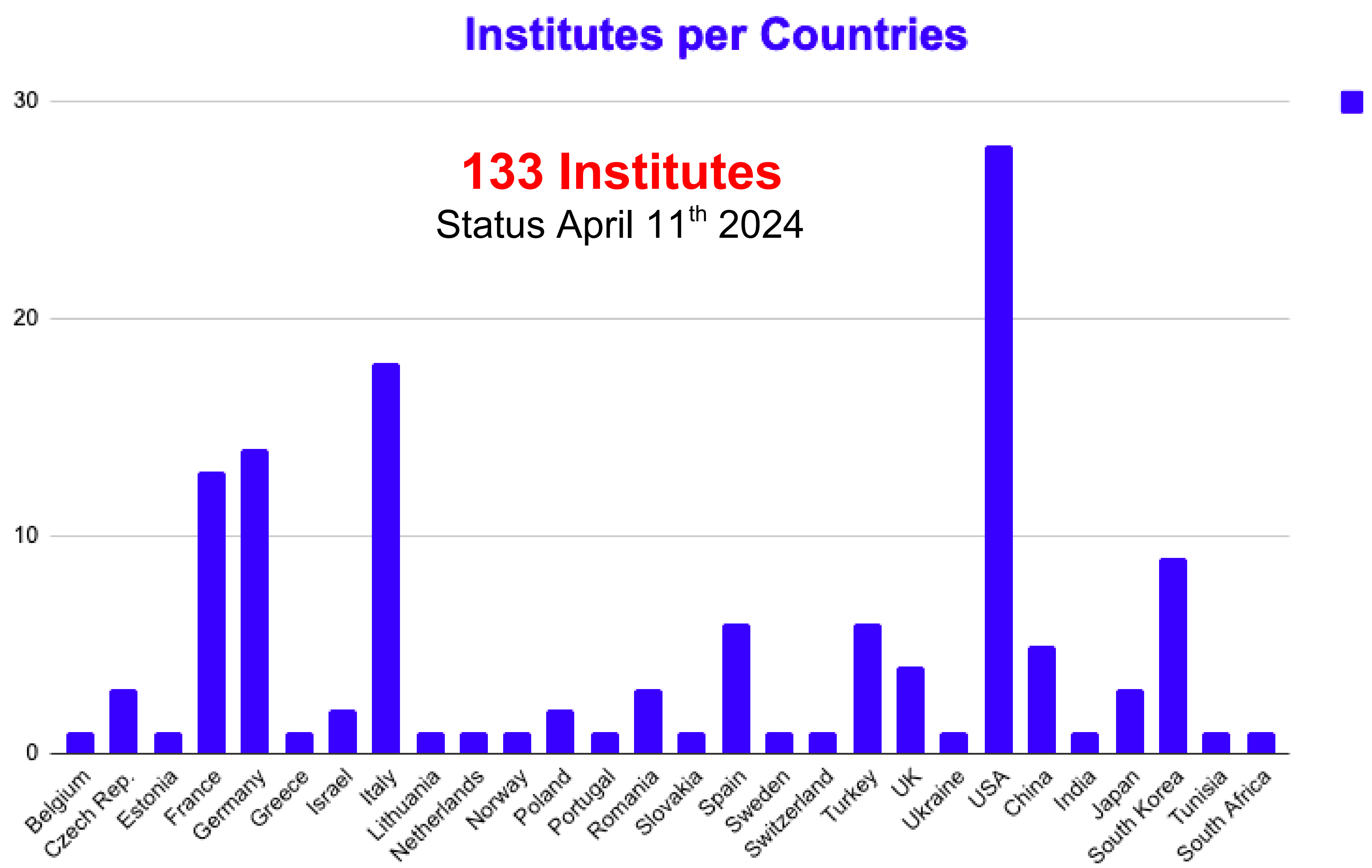
Contents

- 34 pages
  - Based on worldwide community input
- Short description of goals, projects and organisation
  - Research program (and resources) focuses on 2024 – 2026
  - ... and outlooks beyond
  - Introduction of
    - Proposal of initial Governance structure (see below)
    - Work Packages and Working Groups (see below)
- CERN-DRDC-2024-004 ; DRDC-P-DRD6: http://cds.cern.ch/record/2886494

DRD Calo – Where are we?



DRD Calo – Who are we?



- Counted are groups that have expressed an interest to join the DRD Calo via the input proposals or in communication afterwards
- Now starting to scrutinise membership

DRD Calo – Basic structure

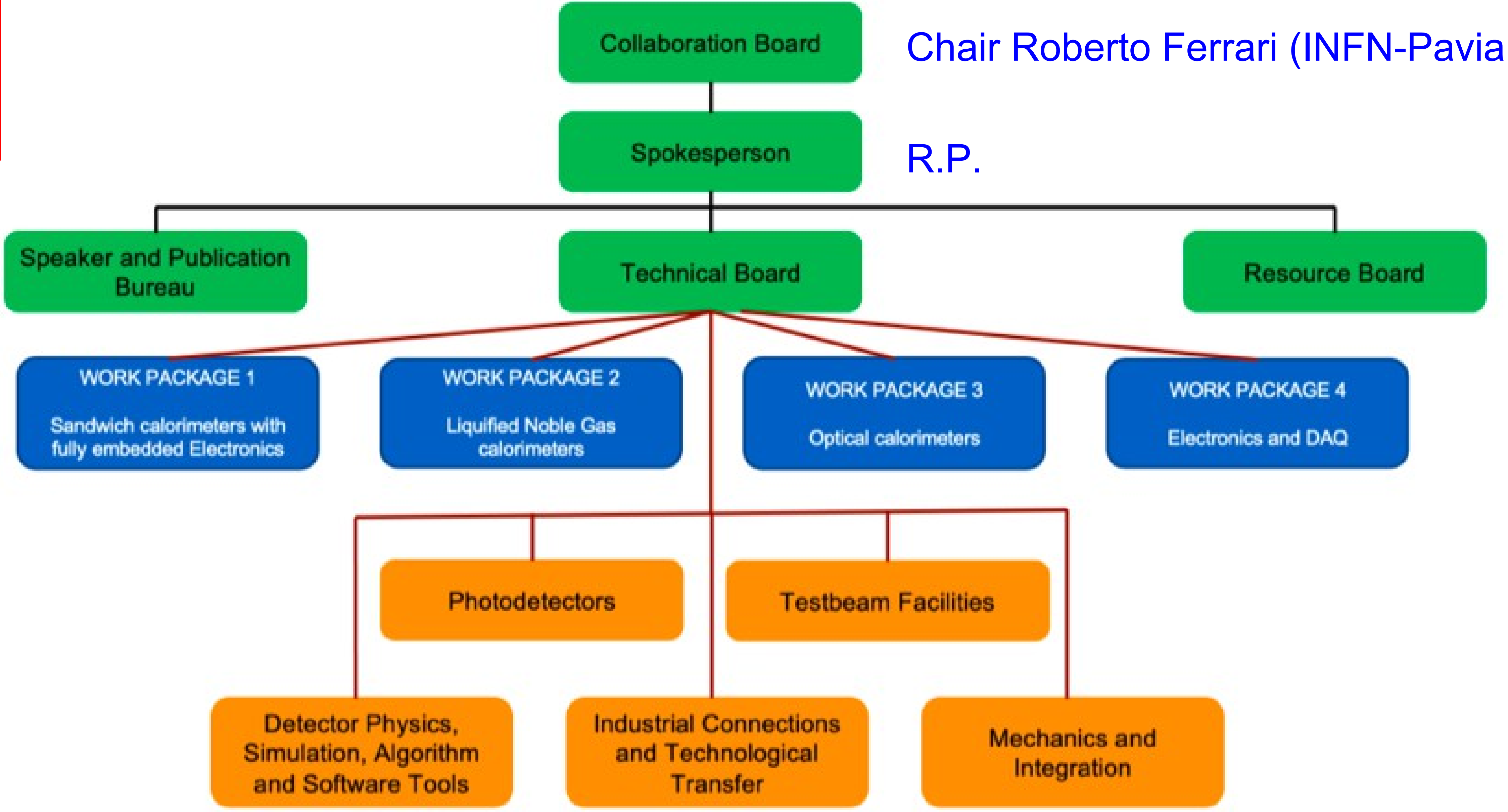
MANAGEMENT:

Chair Roberto Ferrari (INFN-Pavia)

R.P.

WORK PACKAGES:

WORKING GROUPS:



Management positions to be filled until Summer 2024

1st Collaboration Meeting - 9th - 11th of April at CERN

DRD Calo

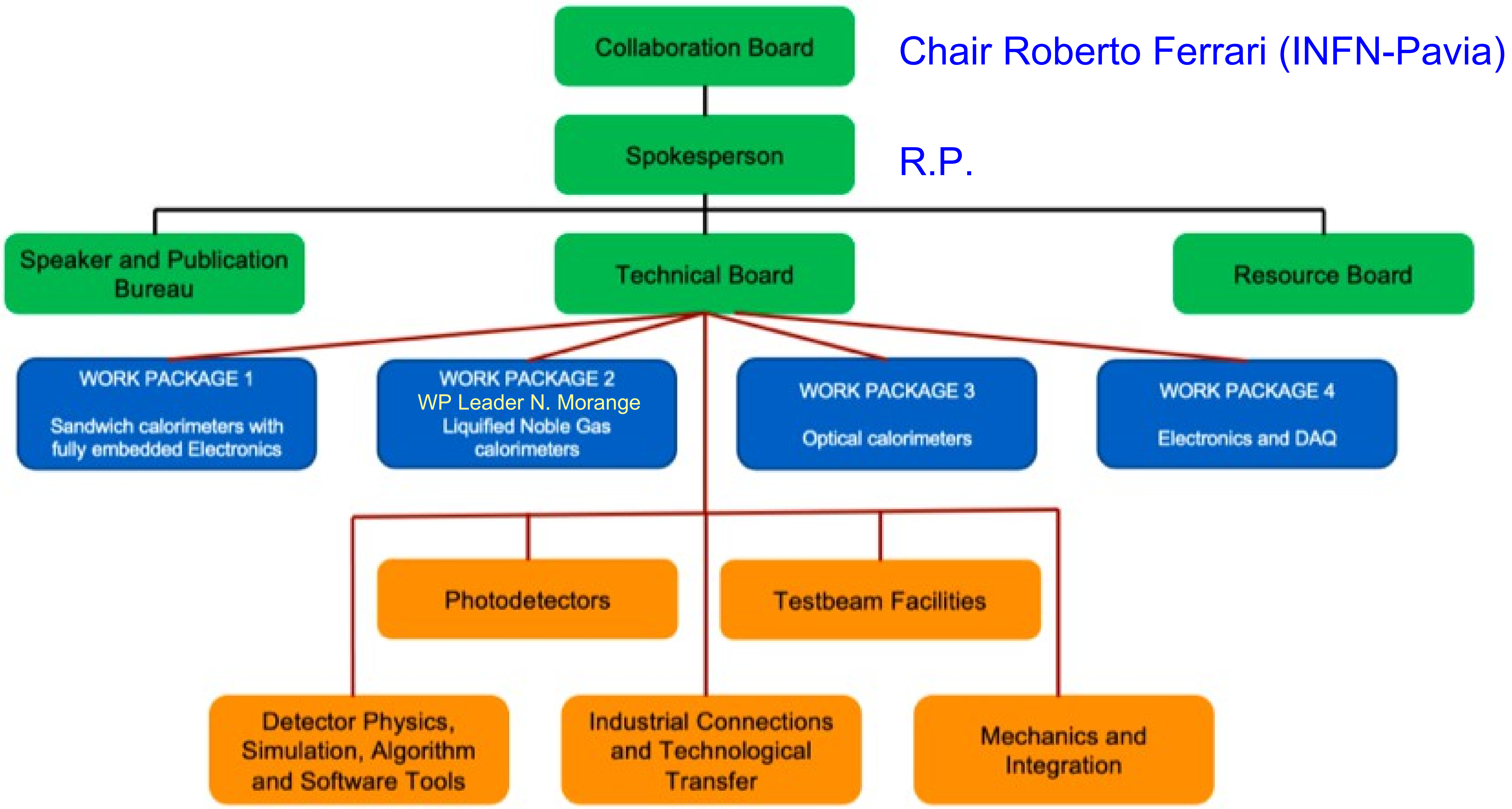
- “Real” Kick-off of the DRD-on-Calorimetry
- 133 participants, 67 on-site

DRD Calo – Basic structure

MANAGEMENT:

WORK PACKAGES:

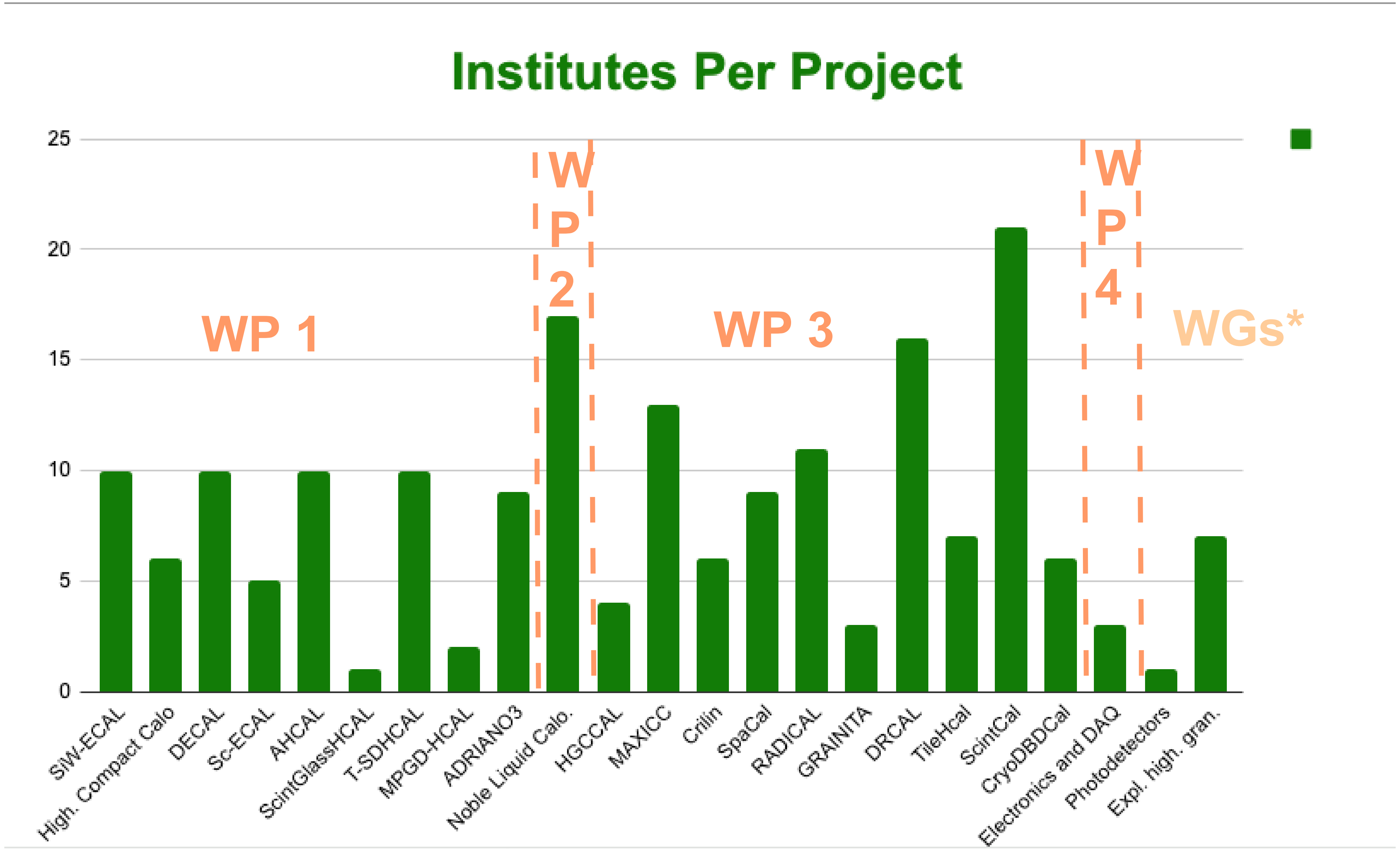
WORKING GROUPS:



DRD Calo – Some Guiding Principles

- Overall Goal: All proposals achieve a similar level of maturity to give informed input to technology decisions by future experiments
- Openness to new ideas
- Implementation of frameworks and procedures to foster mutual help within the collaboration
- The DRD-on-Calorimetry should become a home to all of its members
  - Special importance will be given to early career researchers (ECR) -> Creation of an ECR Forum and ensurinf visibility of ECR
- Gender balance and diversity as an asset for the success of the collaboration
  - Corresponding policy to be implemented in the collaboration rules
  - Propose to sign the ECFA Diversity Charter and siblings in other regions of the world

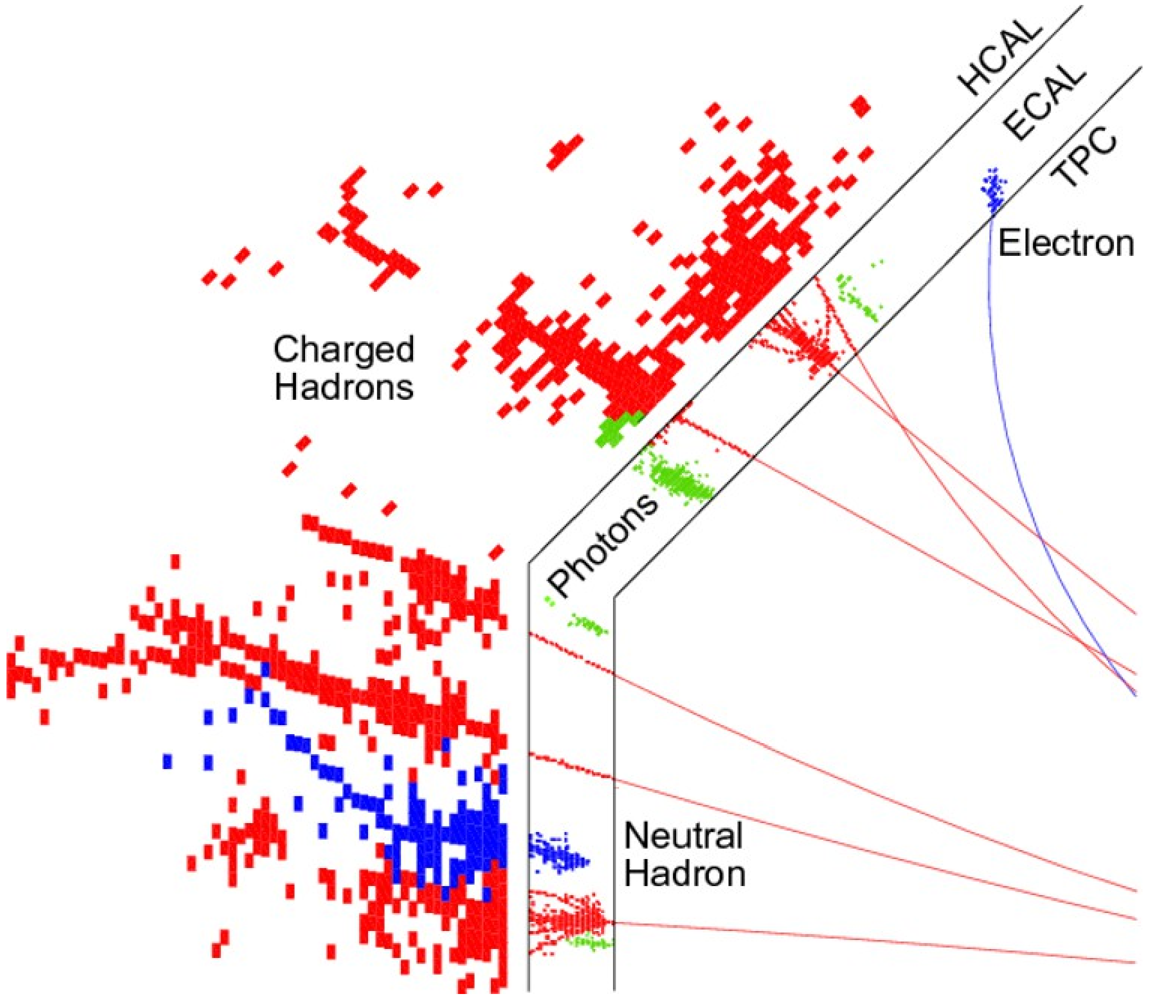
DRD Calo – Institutes and Work Packages (Working Groups)



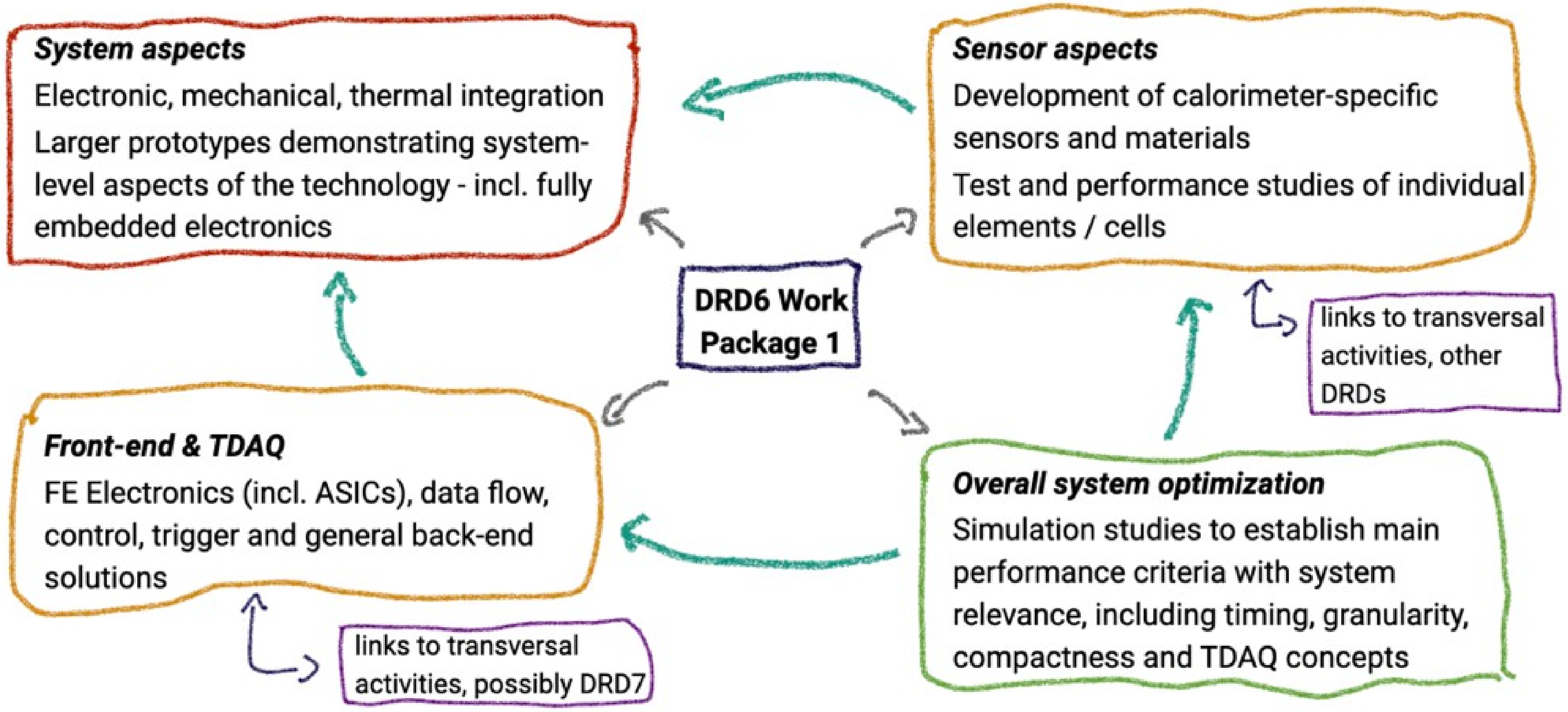
Most if not all projects united in DRD Calo will have talks at this conference

*Listing those for which a clear association could be made

Work Package 1 in a nutshell



- Imaging calorimeters live on the high separation power for Particle Flow
- One calorimeter - Subdivided into electromagnetic and hadronic sections



- Challenges:
  - High pixelisation, 4π hermetic -> little room for services
    - Detector integration plays a crucial role

- New strategic R&D issues
  - Detector module integration
  - Timing
  - High rate e+e- collider (such as FCC-ee)

Work Package 1 - Tasks

DRD Calo

Elm. sections

Hadronic sections

Task/Subtask	Sensitive Material/ Absorber	DRDT
Task 1.1: Highly pixelised electromagnetic section		
Subtask 1.1.1: SiW-ECAL	Silicon/ Tungsten	6.2
Subtask 1.1.2: Highly compact calo	Solid state (Si or GaAs)/Tungsten	6.2
Subtask 1.1.3: DECAL	CMOS MAPS/Tungsten	6.2, 6.3
Subtask 1.1.4: Sc-Ecal	Scintillating plastic strips/Tungsten	6.2
Task 1.2: Hadronic section with optical tiles		
Subtask 1.2.1: AHCAL	Scintillating plastic tiles/Steel	6.2
Subtask 1.2.2: ScintGlassHCAL	Heavy glass tiles/Steel	6.2
Task 1.3: Hadronic section with gaseous readout		
Subtask 1.3.1: T-SDHCAL	Resistive Plate Chambers/Steel	6.2
Subtask 1.3.2: MPGD-HCAL	Multipattern Gas Detectors/Steel	6.2, 6.3
Subtask 1.3.3: ADRIANO3	Resistive Plate Chambers+Scintillating plastic tiles/ Heavy Glass	6.1, 6.2, 6.3

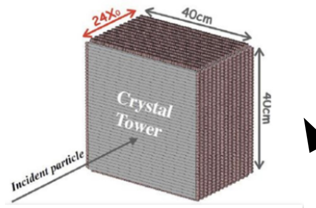
Work Package 2 – Liquified Noble Gas Calorimeters

- LAr Calorimetry is proven technology since a few decades ATLAS, H1, DO, NA31
- Challenge is to make the technology "fit" for future hadron and lepton machines
- Design is driven by particle flow
  - ATLAS Jet-Energy resolution based on PFA
  - ~24% at 20 GeV and 6% at 300 GeV
- => Increase of granularity
  - Goal: Factor ~10 w.r.t. ATLAS LAr Calorimeter
  - 220 kCells -> ~2 MCells

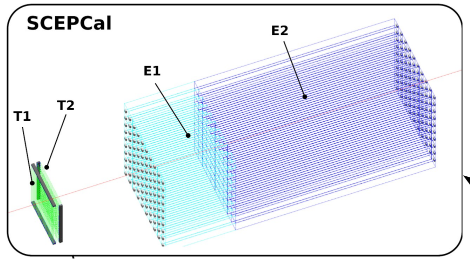
ATLAS LAr calorimeter

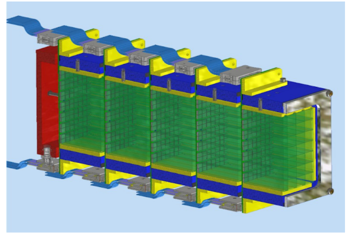
Work Package 3 – Optical Calorimeters

- More than e.g. Imaging calorimeters optical calorimeters put emphasis on the electromagnetic energy resolution
  - (Liquid Noble) interpolates a bit between these two cases
- Elm. resolutions down to 1-2%/√E are envisaged
  - Advantageous for Higgs Factory, indispensable for Heavy Flavour

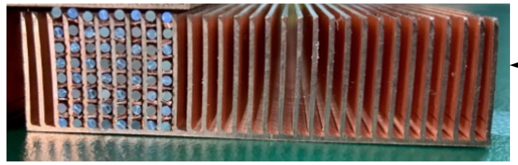


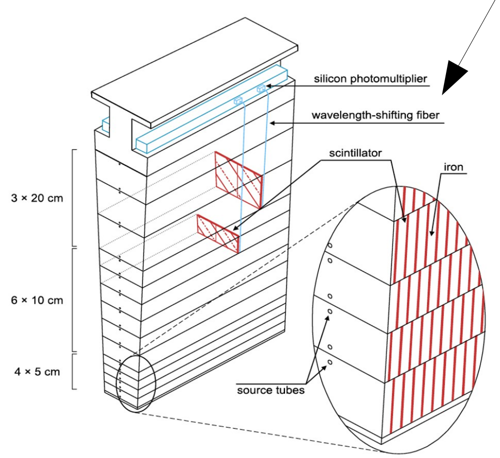
EM calorimeter module: a grid of ~1x1x40cm³ crystal bars

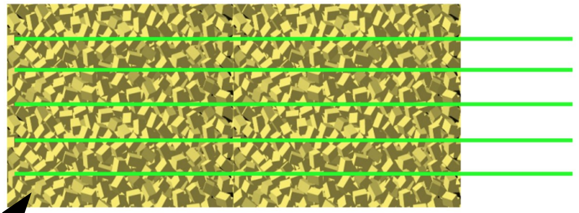


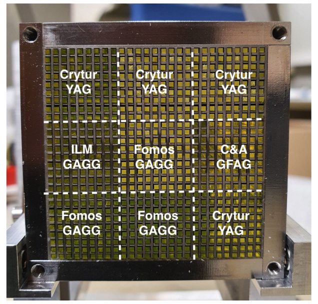


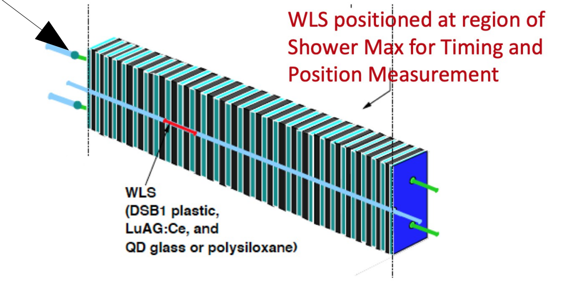
Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCP-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-$/hh
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments









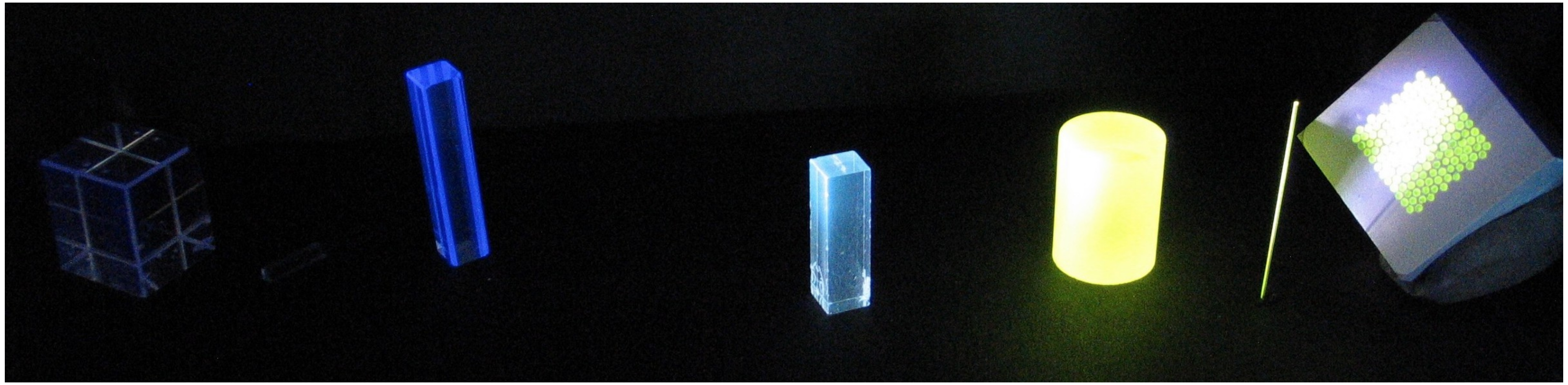


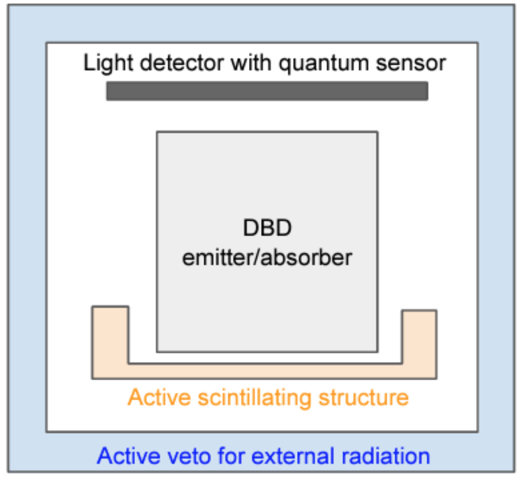
WP3 Task 3.3 - (EM+) Hadronic Sampling Calorimeters

Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-/hh$
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

- R&D on various scintillators and wavelength shifters
- Optimisation of materials (e.g. for radiation hardness, decay time, collection of Cherenkov light, mass production)
- Technology: Inorganic and organic scintillators, glasses, ceramics, quantum materials

- Future generations of double beta decay experiments based on cryogenic calorimeters benefit from a joint development of new scintillating materials
- Use as targets, active structural components or veto systems





IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

Workpackage 4 – Electronics and DAQ

DRD Calo

Name	Track	Active media	readout
LAr	2	LAr	cold/warm elx"HGCROC/CALICElike ASICs"
ScintCal	3	several	SiPM
Cryogenic DBD	3	several	TES/KID/NTL
HGCC	3	Crystal	SiPM
MaxInfo	3	Crystals	SIPM
Crilin	3	PbF2	UV-SiPM
DSC	3	PBbGlass+PbW04	SiPM
ADRIANO3	3	Heavy Glass, Plastic Scint, RPC	SIPM
FiberDR	3	Scint+Cher Fibres	PMT/SiPM,timing via CAENFERS, AARDVARC-v3,DRS
SpaCal	3	scint fibres	PMT/SiPMSPIDER ASIC for timing
Radical	3	Lyso:CE, WLS	SiPM
Grainita	3	BGO, ZnWO4	SiPM
TileHCal	3	organic scnt. tiles	SiPM
GlassScintTile	1	SciGlass	SiPM
Scint-Strip	1	Scint.Strips	SiPM
T-SDHCAL	1	GRPC	pad boards
MPGD-Calo	1	muRWELL,MMegas	pad boards(FATIC ASIC/MOSAIC)
Si-W ECAL	1	Silicon sensors	direct withdedicated ASICS (SKIROCN)
Si/GaAS-W ECAL	1	Silicon/GaAS	direct withdedicated ASICS (FLAME, FLAXE)
DECAL	1	CMOS/MAPS	Sensor=ASIC
AHCAL	1	Scint. Tiles	SiPM
MODE	4	-	-
Common RO ASIC	4	-	common R/O ASIC Si/SiPM/Lar

Different calorimeter types but similar challenges

Trends:

- On-detector embedded elx.
  - Challenges
    - #channel,
    - Low power
    - Digital noise
    - Data reduction
- Off-detector electronics:
  - Challenges for fibre/crystal readout
    - Low power
    - Data reduction
- Digital calorimetry:
  - Challenges:
    - (extreme) #channels,
    - Low power
    - Data reduction

Workpackage 4 – Electronics and DAQ

- The main goal will be to avoid parallel developments
  - Take CALICE as example
- Gather community of "calorimeter electronics developpers"
  - Share expertise and experimental results
  - Address specificities of calorimetry
  - Share fabrication (engineering) runs to equip calorimeter prototypes
- Evoke possibility to hook onto production for other large projects (EiC?)
- Close communication with DRD 3 and DRD 7

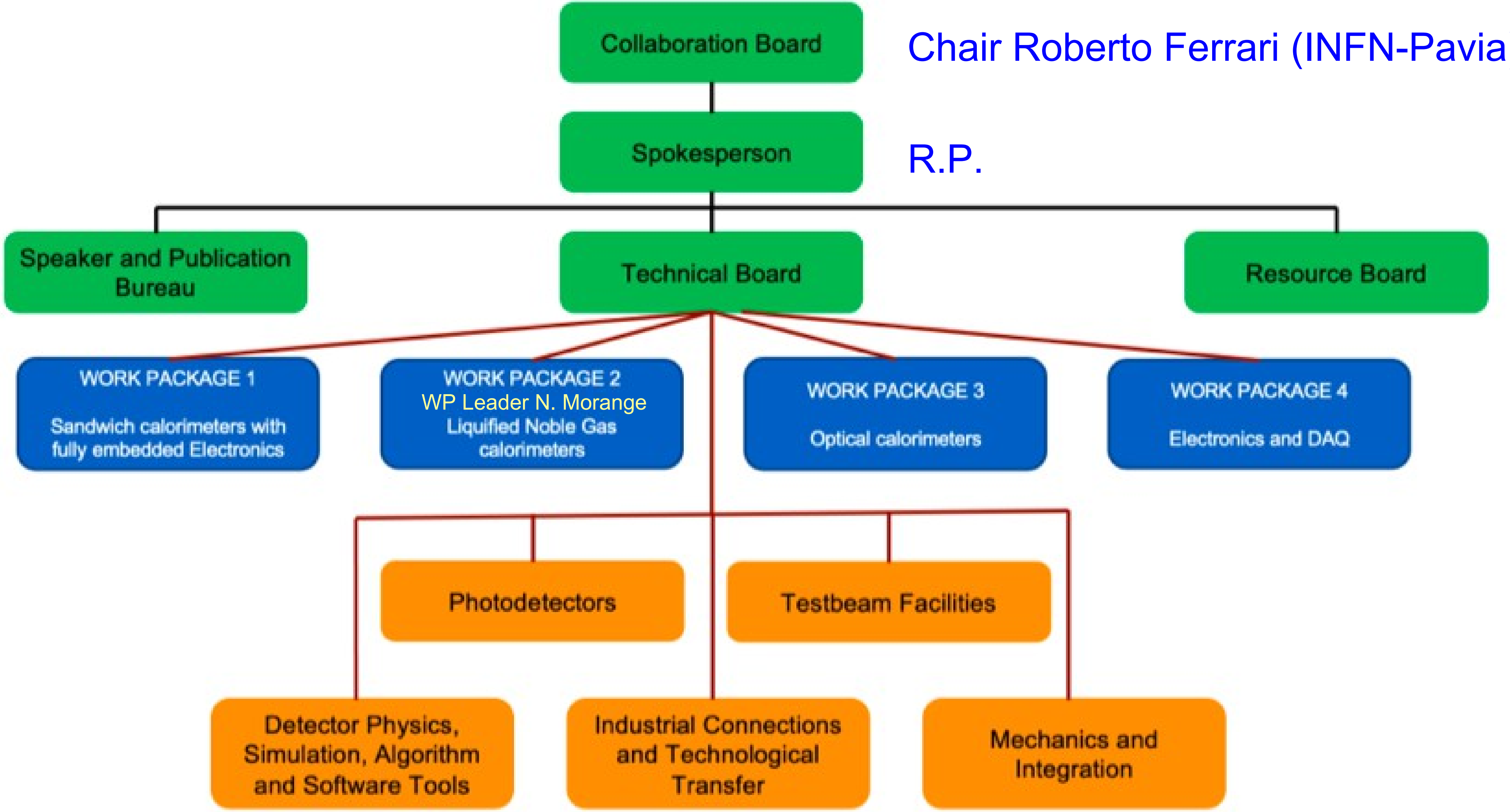
	DRDTs	Milestone	Deliverable	Description	Due date
Electronics and DAQ	6.1, 6.2, 6.3	M4.1		Specifications for common ASIC production	2024
			D4.1	Common ASIC production	2025

DRD Calo – Basic structure

MANAGEMENT:

WORK PACKAGES:

WORKING GROUPS:



Chair Roberto Ferrari (INFN-Pavia)

R.P.

Working Groups – General Scope

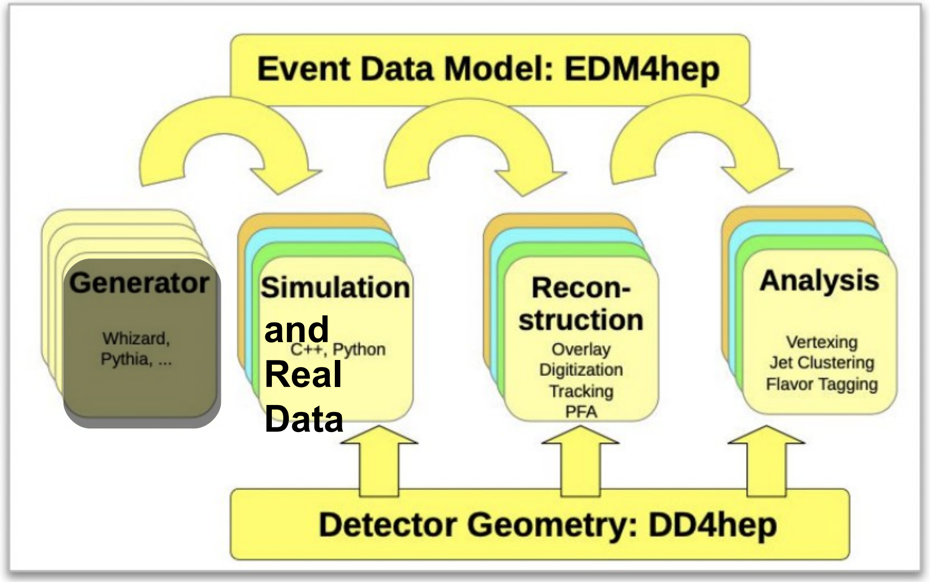
- Working Groups will address work that is common to all work packages in the DRD
- They thus ensure coherence and synergy of the scientific program of the DRD itself
- Some Working Groups cover service tasks
  - Organisation and conduction of beam tests, if possible in a dedicated beam area for calorimetry (see backup)
  - Software tools
- The detailed organisation of the work within each working group is under the responsibility of dedicated coordinator(s) or directly under the responsibility of Technical Coordination

Working Groups – Software

Data Acquisition and Monitoring

otsdaq@FNAL

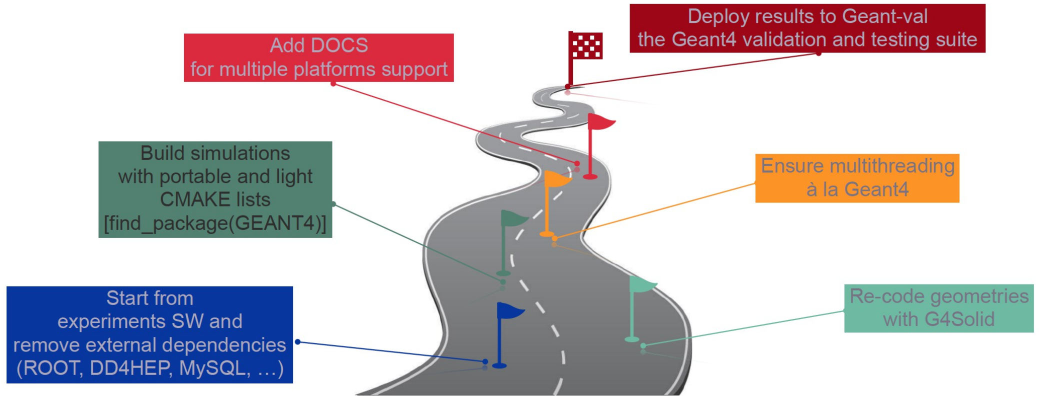
Data/Event Processing (key4hep)



Your favorite
Calo Prototype(s)

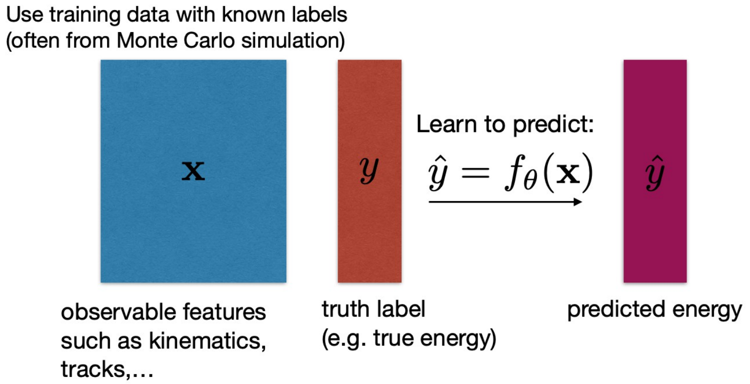
Physics output

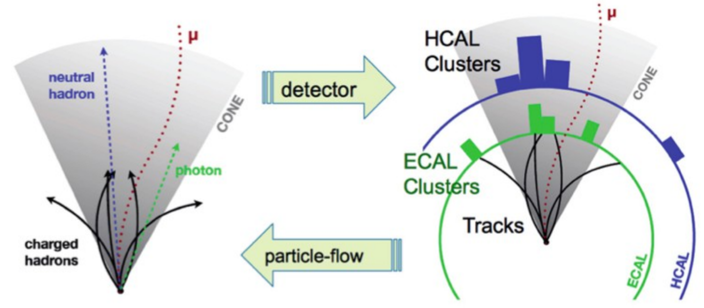
From experiments to geant-val, a winding road



Exploitation:

Pattern recognition, s/w compensation





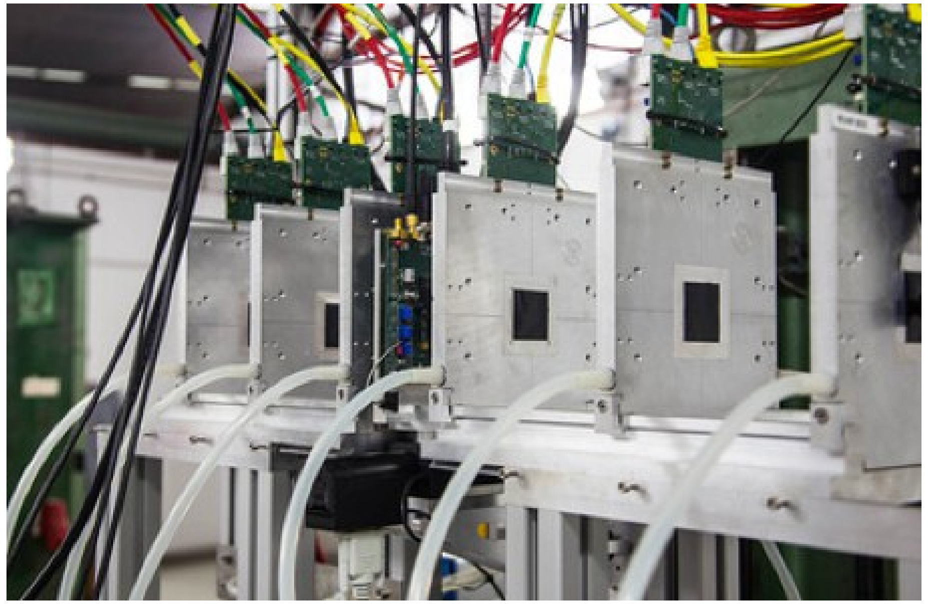
Working Groups – Testbeams ...

Generic Equipment and Tools

Overall Planning

Your favorite
Calo Prototype(s)

Beam Line Infrastructure



Communication with Operators

- Many items are common to all projects
- Common coordination will streamline beam test programme

Match Irradiation/Beamtest Facilities Detector Needs

	Energy	Irradiation
Higgs Factory CMS energy 90-1 TeV Radiation <= 10^{14} $n_{eq/}cm^2$	✓	✓
HL-LHC CMS energy 14 TeV (shared by partons) Radiation ~10^{16} n_{eq}/cm^2	(✓)	✓
Muon Collider CMS energy 3-10 TeV Radiation ~HL-LHC	X	✓
Future Hadron Collider CMS energy 100 TeV (shared by partons) Radiation up to ~10^{18} n_{eq}/cm^2	X	X

Conclusions

- DRD-on-Calorimetry will pursue strategic R&D for calorimeters for future colliders
  - Partially new efforts, partially capitalising on existing activities

- Scientific programme and first ideas of collaboration structure have been worked out by Proposal Team in collaboration with community

- Approval by CERN Research Board to start collaboration on January 1st 2024

- Now progressive move from Proposal Team to full Collaboration structure

- Rich scientific programme covering all candidates for future (HEP) calorimeter system (and beyond)
  - Trends are timing, high granularity
  - Multiple synergies within DRD and wth other DRDs
  - Though “slow ramp-up” lots of activity expected for 2024

- (Four) Resource loaded Work Packages complemented by several Working Groups

Backup

Work Package 1 – Milestones and Deliverables

DRD Calo

MS and D: Overview Table

	Milestone	Deliverable	Description	Due date
Task 1.1: Highly pixelised electromagnetic section				
Subtask 1.1.1: SiW ECAL		D1.1	Revised 15 layer stack	2024
	M1.1		Specifications for timing and cooling	2025
		D1.2	Engineering module for Higgs factory	>2026
Subtask 1.1.2: High compact calo		D1.3	Updated set of compact detection layers	2024
	M1.2		Prototype for GaAs sensors with strip readout	2026
		D1.4	Set of validated GaAs sensors	>2026
Subtask 1.1.3: DECAL	M1.3		Requirements for DECAL-specific sensor design established	2024
	M1.4		Full evaluation of (ALPIDE-based) EPICAL-2 performance	2025
	M1.5		Design for next-generation sensor with DECAL-specific optimisation (with machine-specific options)	2026
		D1.5	New sensors producted and evaluated in EPICAL-3 prototype	>2026
Subtask 1.1.4: Sc-ECAL	M1.6		Improved components (engineering for production, timing, active cooling, etc.)	2024
		D1.6	40-layer prototype and testbeam	2025
Task 1.2: Hadronic section with optical tiles				
Subtask 1.2.1: AHCAL	M1.7		Concept for continuous readout	2024
	M1.8		First layer with continuous readout	2025
		D1.7	EM prototype demonstrating system aspects	2026
		D1.8	Full-size layer and multi-layer demonstrator	>2026
		D1.9	Engineering prototype	>2026
Subtask 1.2.2: ScintGlassHCAL	M1.9		cm-scale tiles	2024
		D1.10	15-layer EM module	2025
		D1.11	40-layer prototype	>2026
Task 1.3: Hadronic section with gaseous readout				
Subtask 1.3.1: T-SDHCAL	M1.10		Study of the impact of timing on PFA performance	2024
	M1.11		Specifications for first layers	2025
	M1.12		First T-SDHCAL layers	2026
		D1.12	40-layer prototype	>2026
Subtask 1.3.2: MPGD-HCAL		D1.13	Completion of 6-layer 20×20 cm^2 prototype	2024
	M1.13		Specifications for 50×50 cm^2 prototype	2025
	M1.14		Design of 50×100 cm^2 layers	2026
		D1.14	10-layers prototype (6L: 20×20 cm^2 +4L: 50×50 cm^2)	2026
		D1.15	3 100×100 cm^2 layers	>2026
Subtask 1.3.3: ADRIANO3	M1.15		Small-scale test layers	2024
	M1.16		Small-scale prototype	2025
		D1.16	Large-scale prototype & testbeam	2026

Total: 16 Milestones and 16 deliverables

7 Milestones and 1 deliverable in 2024

- **Milestones**
  - Task 1.1
    - Requirements for DECAL-specific sensor design established
    - Sc-Ecal: Improved components (engineering for production, timing active cooling)
  - Task 1.2
    - AHCAL: Concept for continous readout
    - ScintGlass HCAL: cm scale tiles
  - Task 1.3
    - T-SDHCAL: Study of the impact of timing on the PFA performance
    - MPDG-HCAL: Completion of 6 layer 20x20 cm^2 proto
    - ADRIANO3: Small scale test layers
- **Deliverables**
  - Task 1.1
    - SiW ECAL: Revised 15 layer stack
    - Updated set of compact detector layers

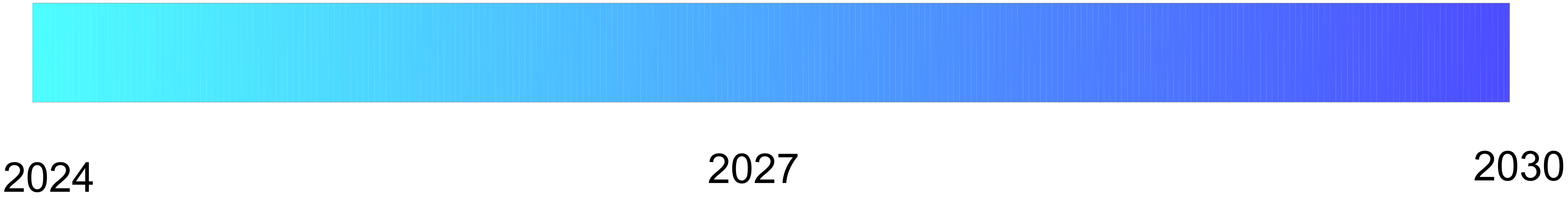
WP3 – Milestones and Deliverables

	Milestone	Deliverable	Description	Due date
HGCCAL	M3.1		Specifications of crystal, SiPM and electronics for highly granular EM crystal calorimeter prototype	2024
		D3.1	Development of 1-2 crystal EM modules to be exposed to beam tests	2024
	M3.2		Beam tests characterisation of a full containment highly granular EM crystal calorimeter prototype	2025
	M3.3		A first mechanical design for a final detector with crystal modules	2025
	M3.4		New reconstruction software for the long-bar design and updated PFA	2026
		D3.2	Large crystal module for hadronic performance, system integration studies and combined testbeam with HCAL	>2026
MAXICC	M3.5		Completion of qualification tests on components and selection of crystal, filter and SiPM candidates for prototype	2025
	M3.6		Report on the characterisation of crystal, SiPM and optical filter candidates and their combined performance for Cherenkov readout	2025
		D3.3	Full containment dual-readout crystal EM calorimeter prototype and testbeam characterisation	2026
	M3.7		Joint testbeam of EM module prototype with dual-readout fibre calorimeter prototype (DRCAL)	>2026
Crilin		D3.4	Acquisition and tests of crystals and SiPMs; design and production of electronics boards; design and production of the mechanical components	2024
		D3.5	Calorimeter fully assembled	2025
	M3.8		Beam test characterisation of a full containment EM calorimeter prototype	2025
	M3.9		Report on testbeam results	2026
GRAiNITA	M3.10		Characterisation of materials, wavelength shifters and SiPMs and identification of best technological choices	2024
		D3.6	Development of a GRAiNITA demonstrator as EM calorimeter prototype for e+e- collider (full shower containment)	2026
SpaCal		D3.7	Tungsten and lead absorbers for module-size prototypes	2024
	M3.11		Design of optimised light guides	2025
		D3.8	Set of crystal samples, SPIDER ASIC prototype	2026
	M3.12		Specification of photon detector and improved simulation framework available	2026
		D3.9	Module-size prototypes (significantly larger than EM showers) built and validated in beam tests	>2026
RADiCAL		D3.10	Single module with prototype scintillating crystals, SiPMs and front-end electronics cards built and tested.	2024
		D3.11	3x3 array of RADiCAL modules built and tested	2026
	M3.13		Paper on beam-test results for EM shower position, timing and energy	2026
	M3.14		Continue beam testing with alternative scintillation and wavelength shifting materials - for improved cost/performance.	>2026
DRCal		D3.12	Construction of full-scale dual readout module with hadronic shower containment	2025
	M3.15		Testbeam campaign to assess module performance: result paper	2026
	M3.16		Continue beam testing with alternative readout elx	>2026
TileCal	M3.17		Characterisation of PEN- and PET-based scintillating tiles including optimisation of readout with WLS fibres and SiPMs	2025
		D3.13	Construction of up to 3 prototypes of a sampling tile calorimeter module with WLS fibres and SiPM readout (for beam tests after 2026)	2026
	M3.18		Paper on beam test results	>2026
		D3.14	Full hadron-shower containment prototype built and tested	>2026
ScintCal	M3.19		Dataset of scintillation and radiation hardness properties of various scintillation materials studied	2026
		D3.15	Samples of a set of scintillators produced and characterised	2026
		D3.16	Samples of most promising glasses produced and characterised	>2026
	M3.20		Material selected for future detectors	>2029
CryoDBDCal	M3.21		Report crystals in terms of optimisation of growing/doping procedures	2024
		D3.17	Scintillating polymer for 3D-printing, with optimal mechanical and light-production properties, produced and tested	2025

3 Milestones and 4 deliverable in 2024

- **Milestones**
  - Task 3.1
    - HGCCAL: Specifications of crystal, SiPM and electronics for highly granular EM crystal calorimeter prototype
  - Task 3.2
    - GRAiNITA: Characterisation of materials, wavelength shifters and SiPMs and identification of best technological choices
  - Task 3.4
    - CryoDBDCal: Report crystals in terms of optimisation of growing/doping procedures
- **Deliverables**
  - Task 3.1
    - HCCCAL: Development of 1-2 crystal EM modules to be exposed to beam tests
    - Crilin: Acquisition and tests of crystals and SiPMs; design and production of electronics boards; design and production of the mechanical components
  - Task 3.2
    - SpaCal: Tungsten and lead absorbers for module-size prototypes
    - Radical: Single module with prototype scintillating crystals, SiPMs and front-end electronics cards built and tested

Ramp up of activities – Rough View



- Little (extra) need at the beginning (2024-2026)
  - Start with prototypes that are either existing or currently under construction
  - (Mainly) benefitting from existing funding at national or international level (i.e. AIDAinnova, EUROLABS in Europe or CalVision, RADICAL in the US [plus maybe others], US-Japan Program, R&D programs in China)
  - Specification studies, concept proof – would require fresh funding
- Relatively high density of beam tests with new (large scale) prototypes after 2026
  - Several large-scale prototypes demonstrate ambition of R&D programme
- Execution of program requires availability and support of beam test facilities

Calorimetry - "Current Ecosystem"

- Proposals comes from pre-existing collaborations or working framework
- Consolidated modus-operandi and experience
- Need to pick up all the best and put into the DRD6 collaboration

G. Gaudio, 2nd Calo Community Meeting

Working Groups – Photo Detectors

Calorimetry issues:

- Linearity
- Dynamic range
- Light yield
- UV and IR sensitivity noise and cross-talk radiation hardness time resolution scalability digital SiPMs

→ no sensor development in DRD 6, only tuning and customisation of available architectures
→ coordination with DRD 4 for sensor identification and development

- Quantum photosensors → stay in close contact w/ DRD 5

Setting up the DRD-on-Calorimetry – First actions

- 10th of January 2024
- 1st proto-Collaboration Board Meeting = First event of new DRD-on-Calorimetry Collaboration
  - Recap of way until approval of DRD
  - Outline and discussion of "way ahead"
  - First steps to implement the Collaboration and their endorsement
    - Bootstrap procedure
    - Initial Collaboration structure
    - Preparation of CB-Chair election

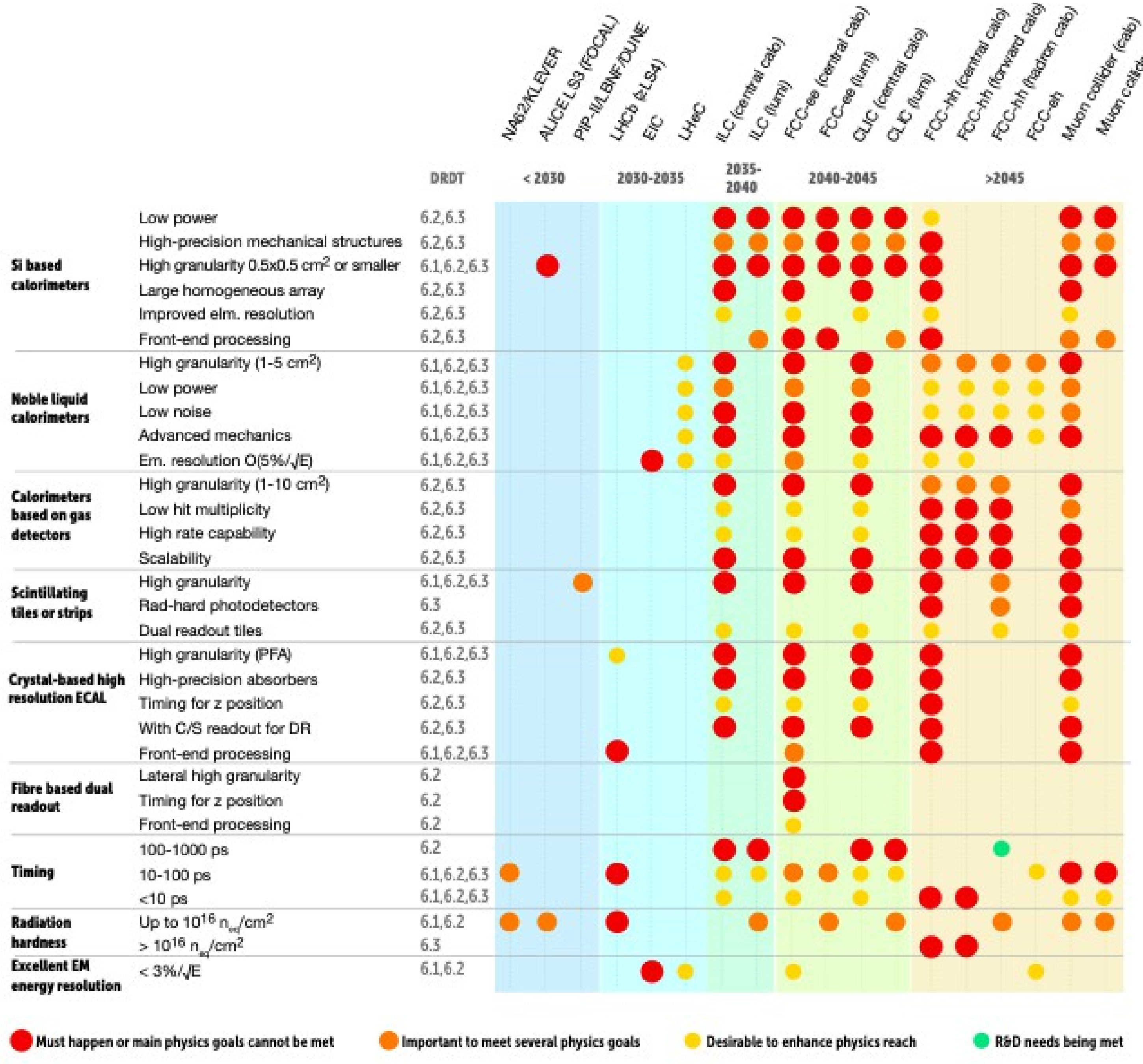
- Election of Collaboration Board Chair
  - Meeting on CB Election on February 22nd
  - Roberto Ferrari (INFN Pavia) elected on March 6th

- Preparation of Spokesperson Election
  - Call for proposals until April 4th
  - Electronic vote started on April 11th

Calorimetry- Identified Key Technologies and R&D Tasks

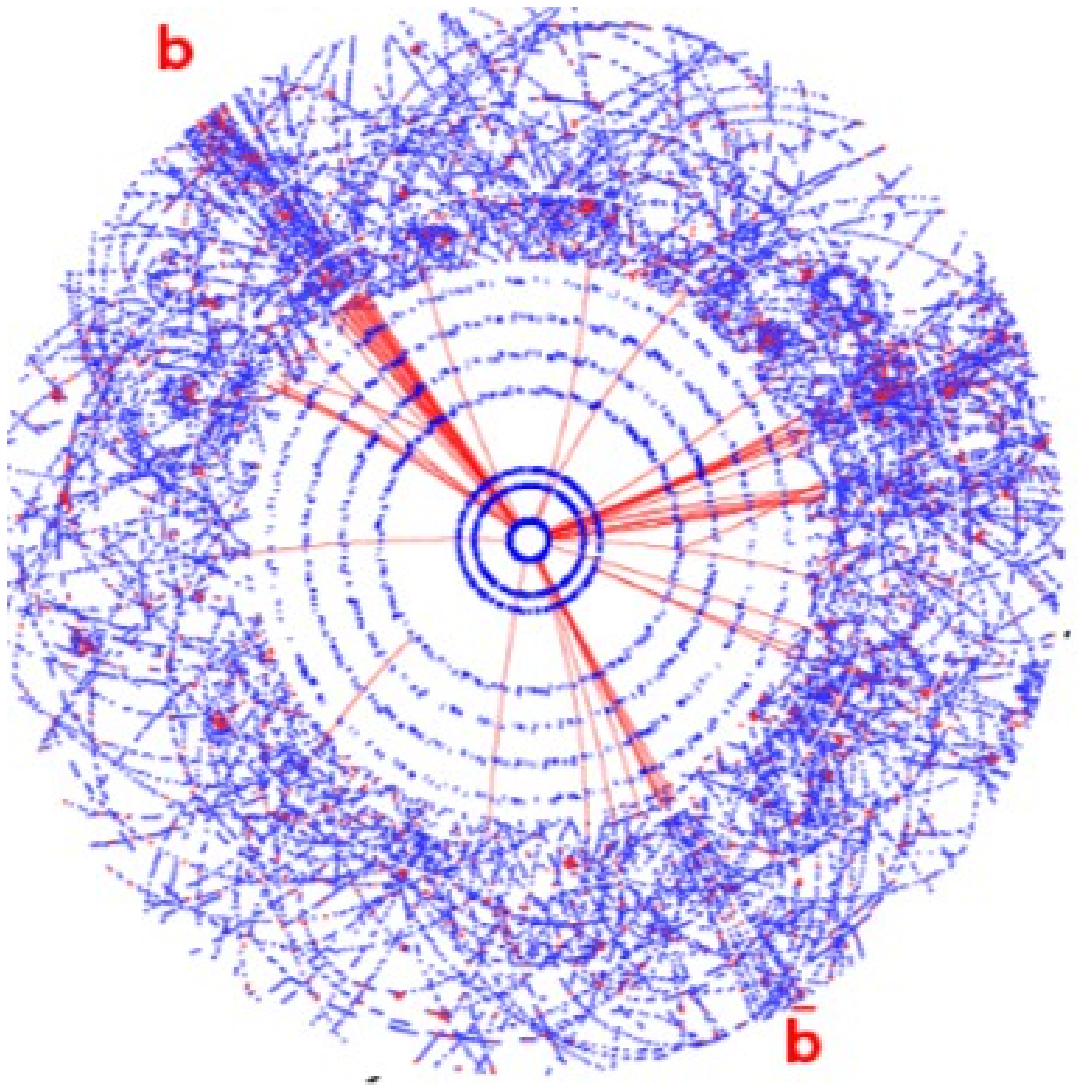
DRD Calo

- Key technologies and requirements are identified in ECFA Roadmap
  - Si based Calorimeters
  - Noble Liquid Calorimeters
  - Calorimeters based on gas detectors
  - Scintillating tiles and strips
  - Crystal based high-resolution Ecals
  - Fibre based dual readout
- R&D should in particular enable
  - Precision timing
  - Radiation hardness
- R&D Tasks are grouped into
  - Must happen
  - Important
  - Desirable
  - Already met



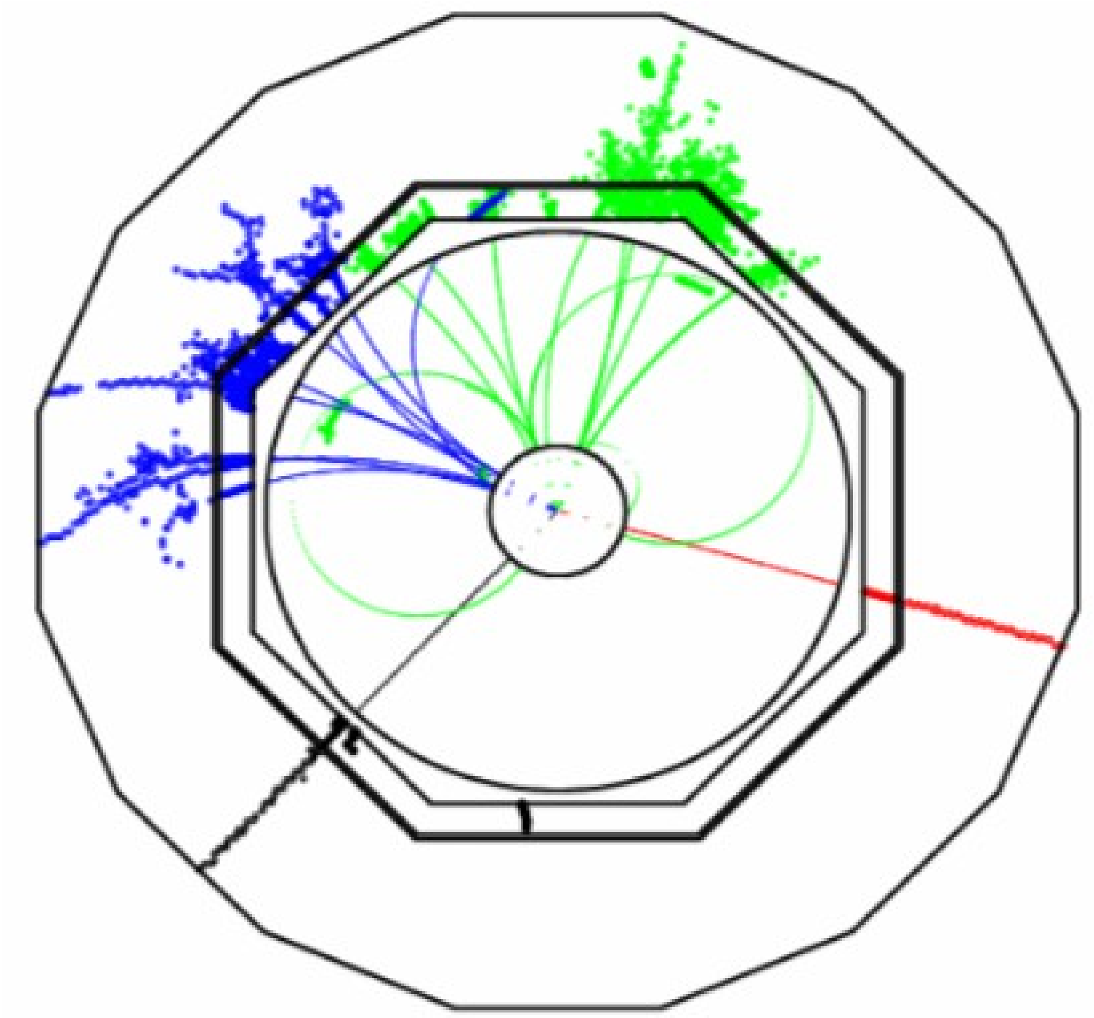
(Rough) Comparison – Hadron collisions ↔ e^+e^- collisions *DRD Calo*

Hadron-hadron collisions e.g. LHC



- Busy events
- Require hardware and software triggers
- High radiation levels

e^+e^--collisions



- Clean events
- No trigger **(??)**
- Full event reconstruction

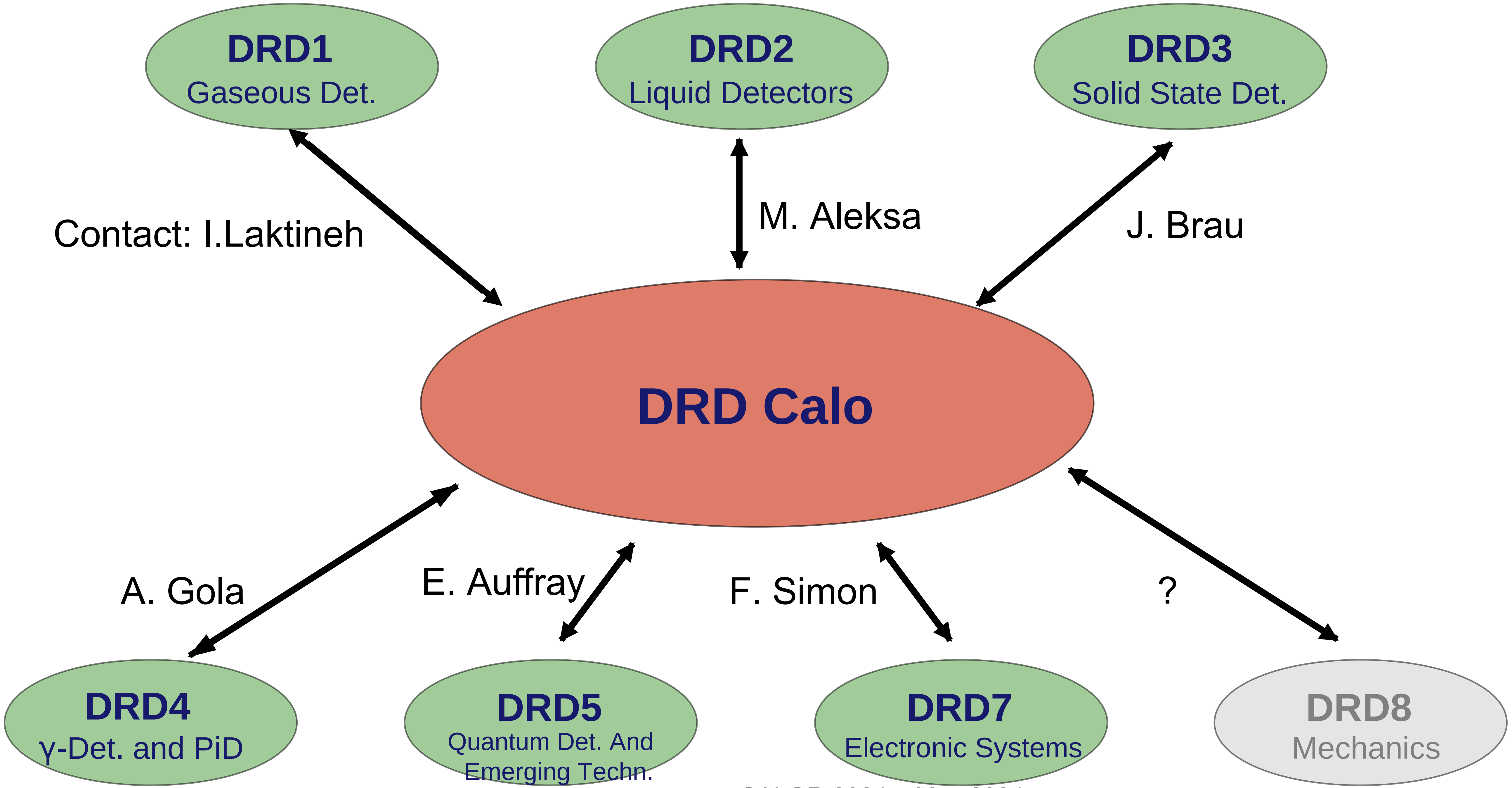
Slide from Y. Sirois

Working Groups – Software

- Calorimeter prototypes are small experiments with physics output
- Full benefit requires powerful software chain
- Establishment and coordinated application of software tools calls for s/w Working Group
  - ... lead by dedicated s/w coordinator(s)
- Operational common software tools are essential for comparing results of (friendly) competing technologies on equal footing
- Work Packages (and therefore funding agencies) have to dedicate resources (human and monetary) to software tools

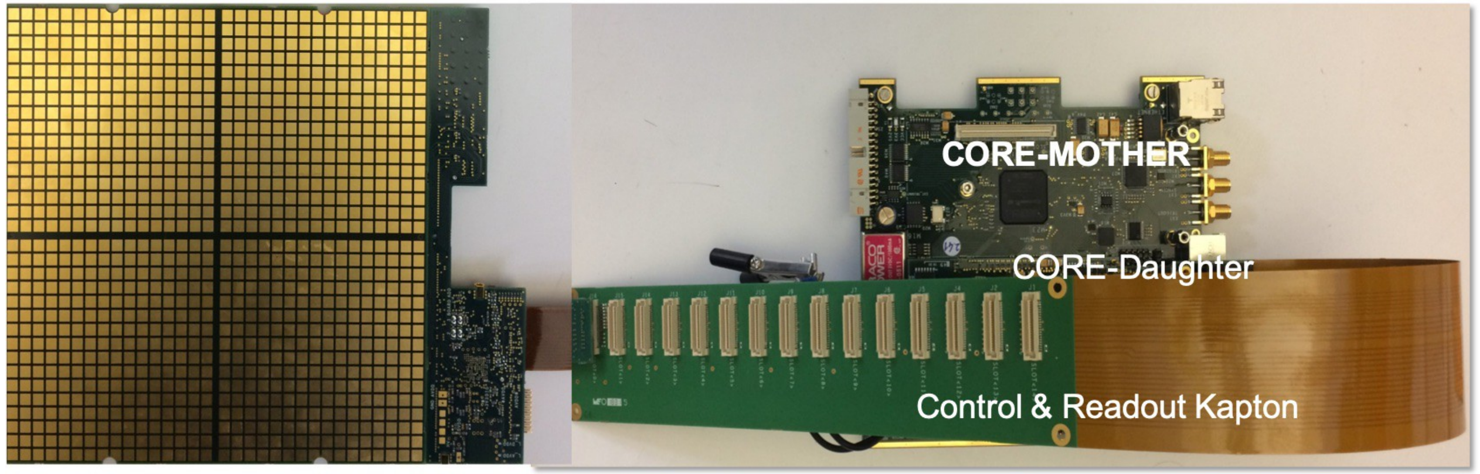
DRD Calo – Interplay wth other DRDs

No R&D on primary elements (apart from scint. materials) but adaptation, tuning and integration

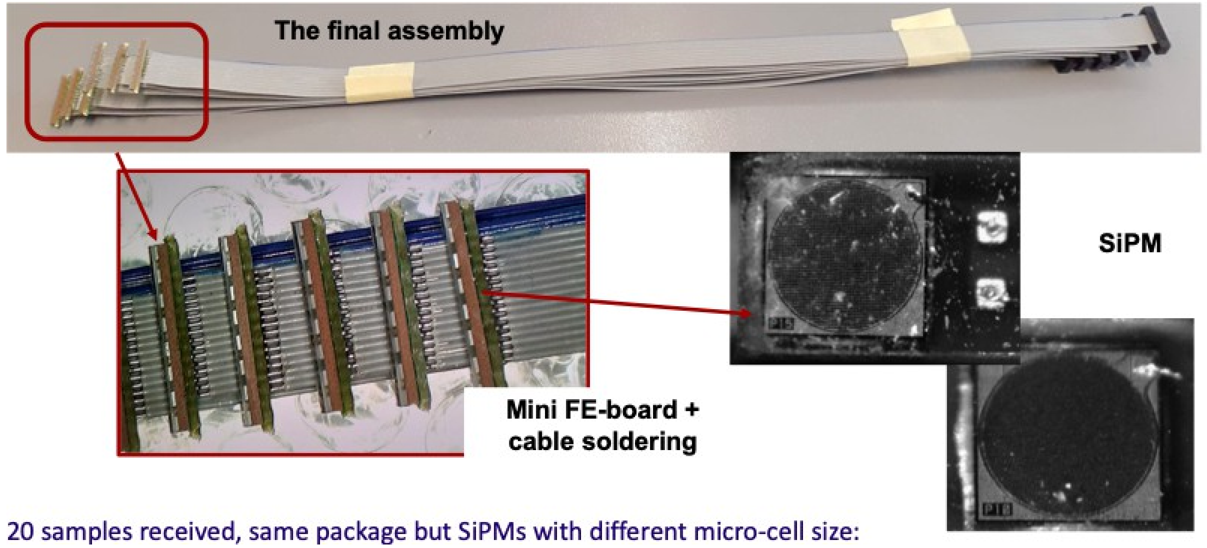


From embedded ASICs to off-detector DAQ

Early stage data concentration for e.g. SiW ECAL



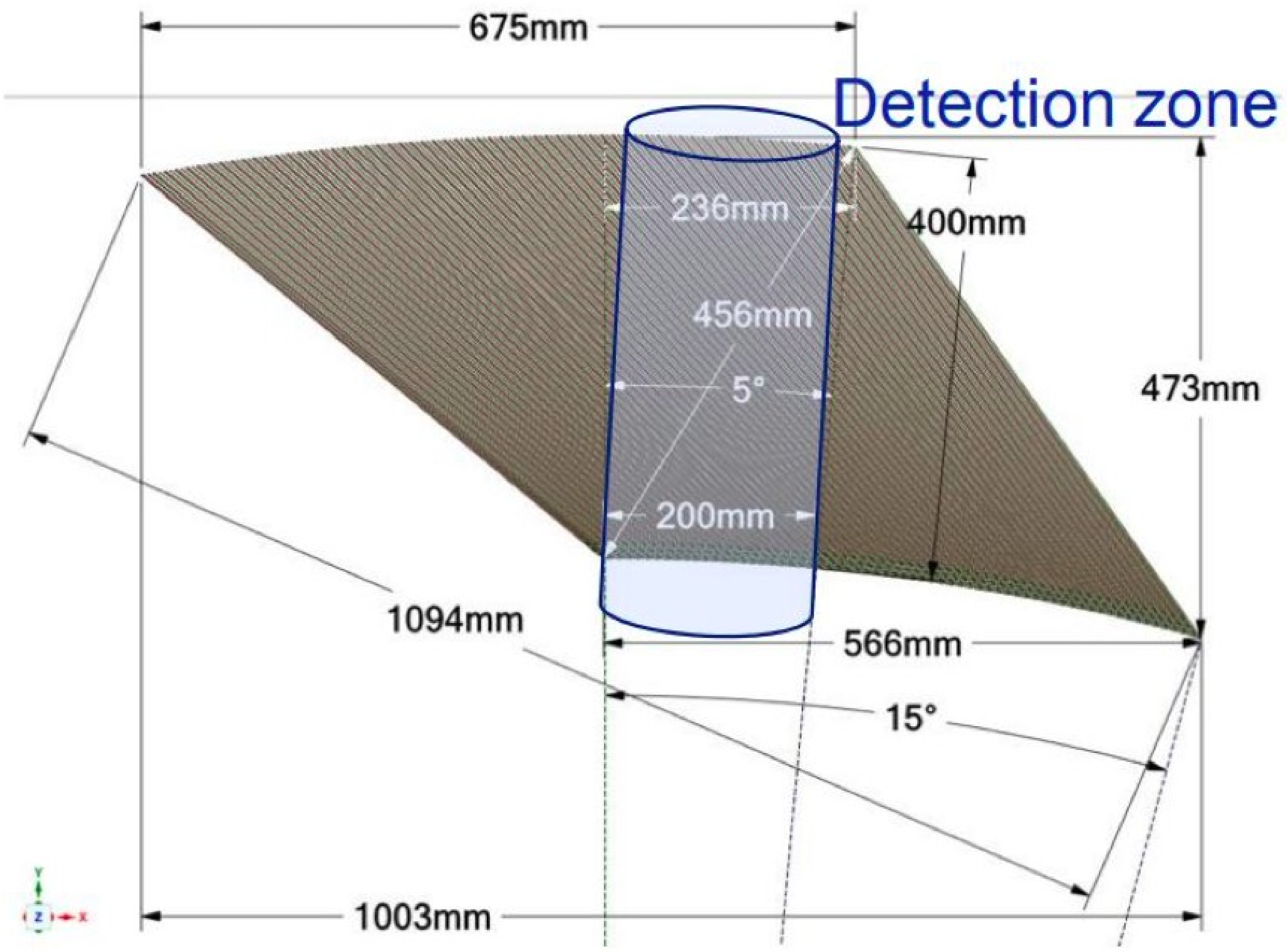
Transmitting signals to off-detector electronics e.g. SiPM readout for dual readout



20 samples received, same package but SiPMs with different micro-cell size:

- High cell density requires innovative solutions for data concentration and signal transmission
- Have to think system integration from the beginning
- Have to make sure that connectivity does not become the bottleneck
  - It is often the cheapest piece that screws up everything

Work Package 2 – Toward a prototype



N. Morange, FCC-France Meeting 2023

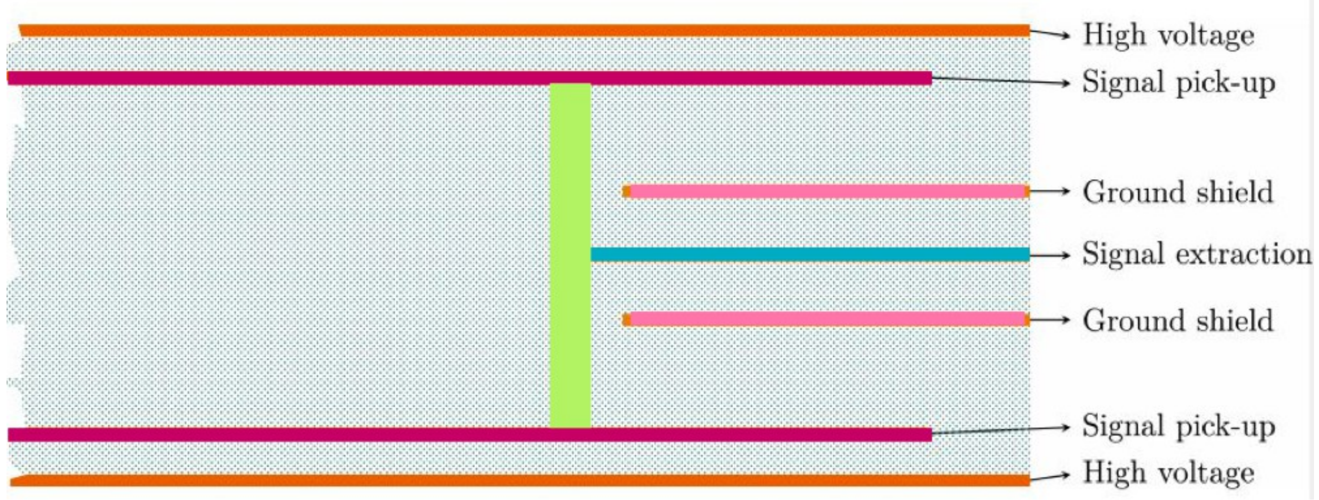
Workplan

- Absorbers
  - Find best compromise in feasibility, between thickness, rigidity, support structures
  - Prototypes in 2024 and 2025
- Small module
  - Requires to put everything together
  - Design in 2024 and 2025
  - Assemble and test at warm temperatures in 2027
  - **Cold tests and testbeam in 2028**
- Infrastructure
  - Use of common tools (EUDAQ…) would facilitate the integration in a testbeam facility
  - Strong testbeam expertise from some institutes

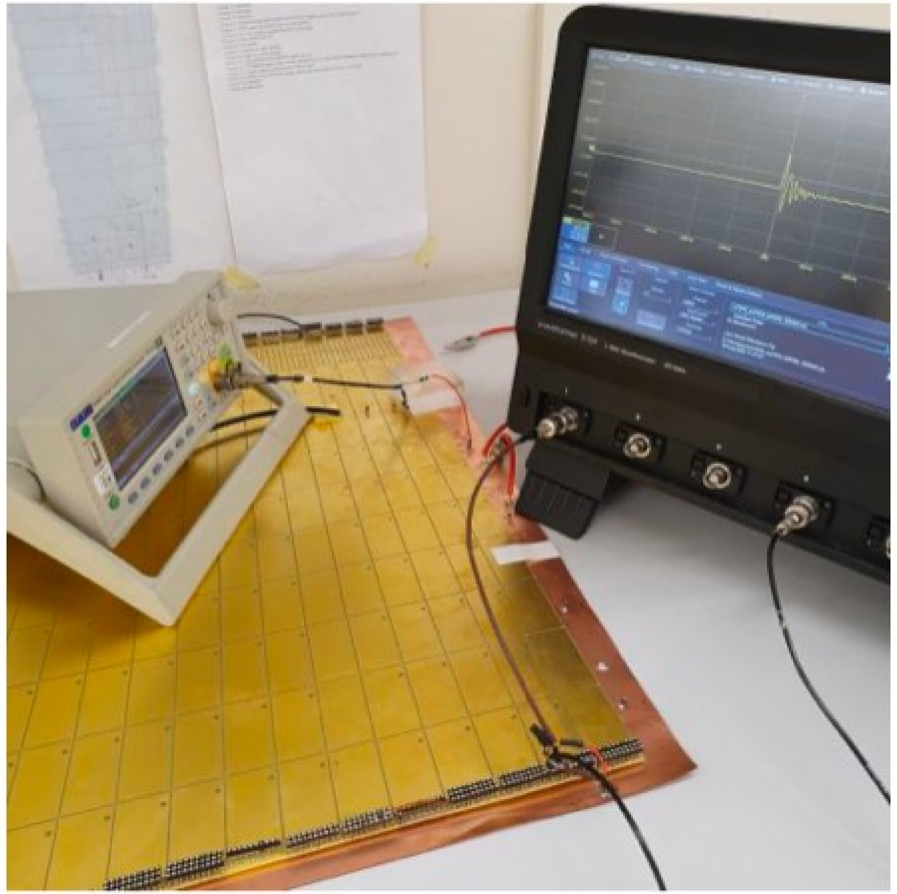
Project	DRDTs	Milestone	Deliverable	Description	Due date
Noble-Liquid Calorimeter	6.1, 6.2, 6.3	M2.1		Design review of test module - sign-off	2025
			D2.1	Test module assembled	> 2026
		M2.2		Test module ready for cool-down	> 2026

Work Package 2 – Liquified Noble Gas Calorimeters

- Development of a multilayer PCB
  - HV Layer on both sides
  - Readout layer on both sides
  - Connected to signal trace



- One signal trace is economical solution to reduce signal traces
- Pick-up of signal from both sides increases S/N



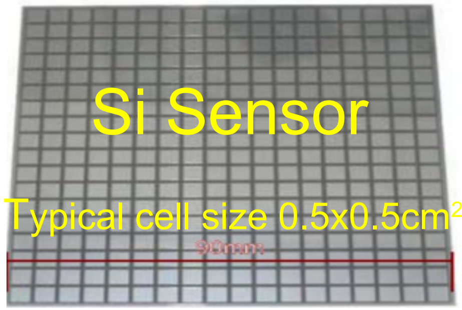
Challenges:

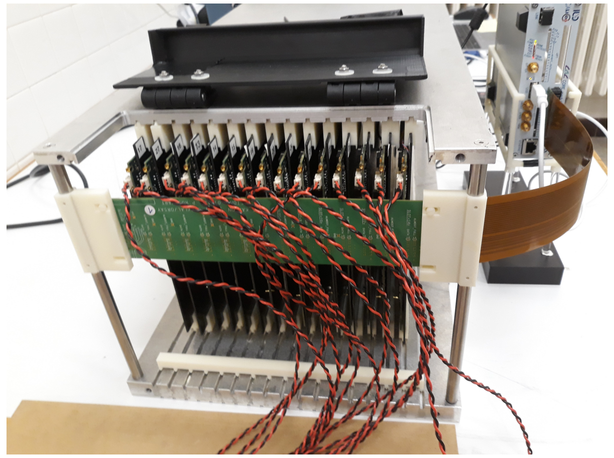
- Control number of signal traces
- Big number of capacitances => Noise
  - Goal is 300 keV Noise for 200 pF cell (S/N > 5)
  - FCC-ee allows for higher integration times
  - Cold electronics?

Task 1.1: Highly pixelised electromagnetic section

DRD Calo

Silicon **W(**olfram) ECAL

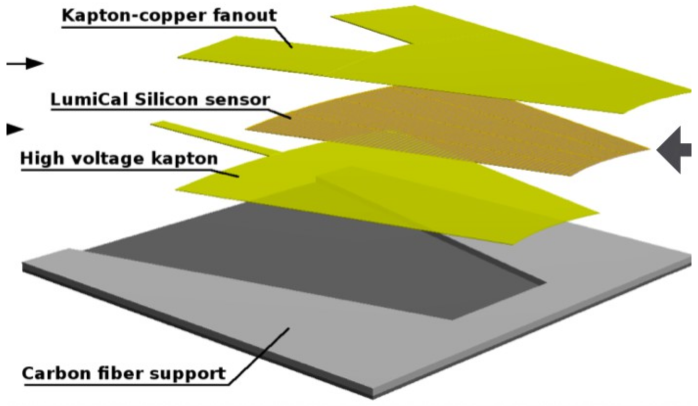




Main R&D Topics

- High level integration
- Power pulsing <-> continuous operation
- Reduction of power consumption;
- Cooling?
- Timing, if and how
- Real-size layers

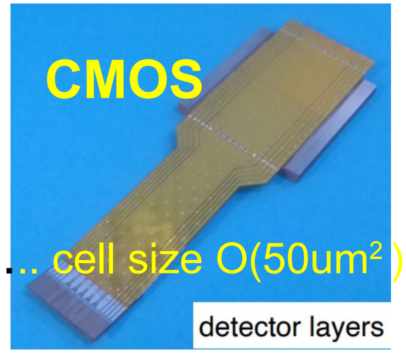
Compact Calo

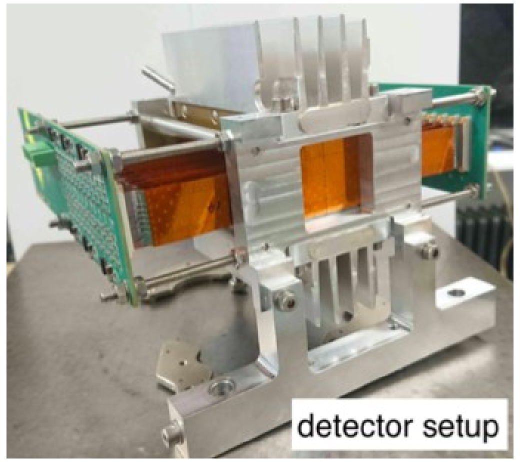


Main R&D Topics

- Testing of sensors with readout strips
- High level integration
- Study of conductive glue
- Wireless data transfer

Digital ECAL

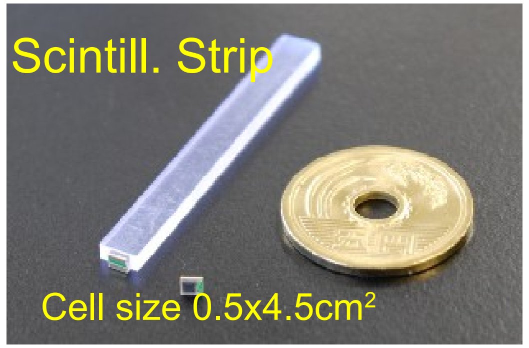




Main R&D Topics

- CMOS MAPS-based optimised for calorimetry
- Reduction of the power consumption to 1mW/cm²
- Stitching technologies for large surfaces

Scintillator ECAL

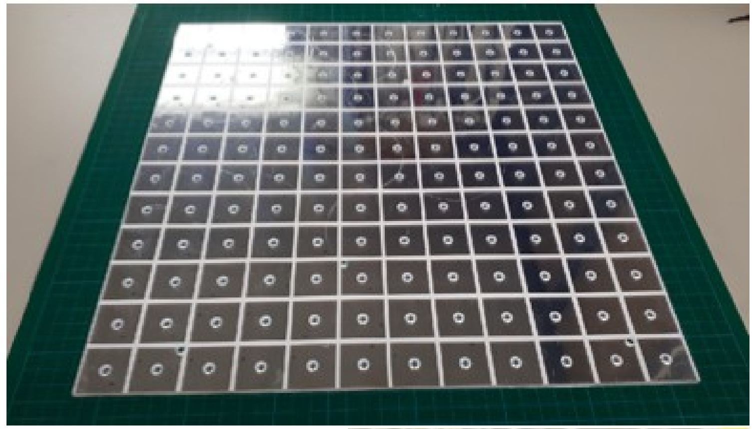


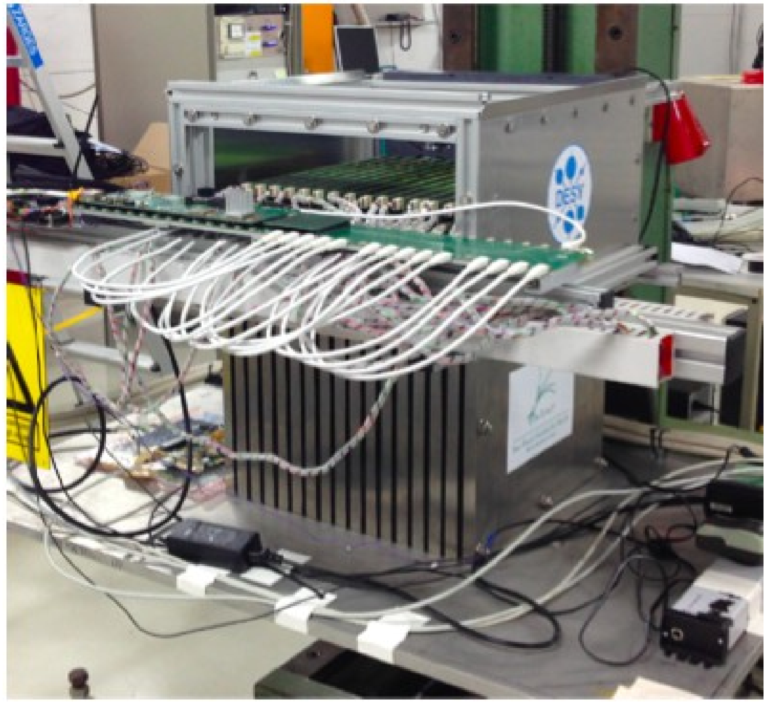
Main R&D Topics

- Power pulsing <-> continuous operations
- Reduction of power consumption
- Cooling?
- Timing, if and how
- Real-size layers

Task 1.2: Hadronic Section with Optical Tiles

Analogue HCAL

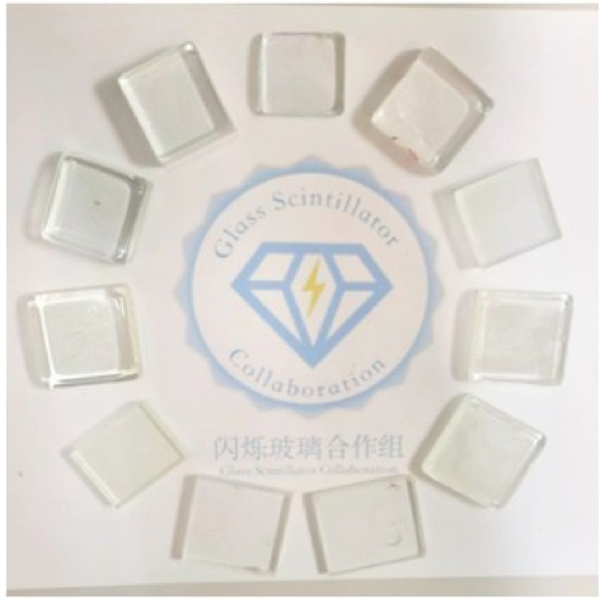


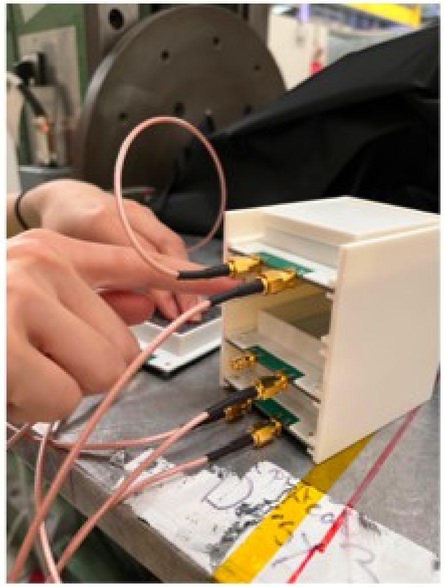
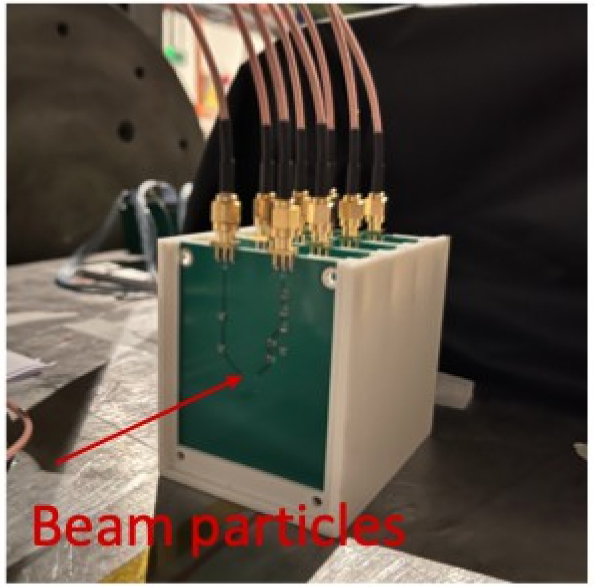



Main R&D Topics

- Continuous readout,
- Data rates and possible trigger requirements of circular Higgs Factories
- Development of appropriate electrical, thermal and mechanical integration concepts

ScintGlass HCAL



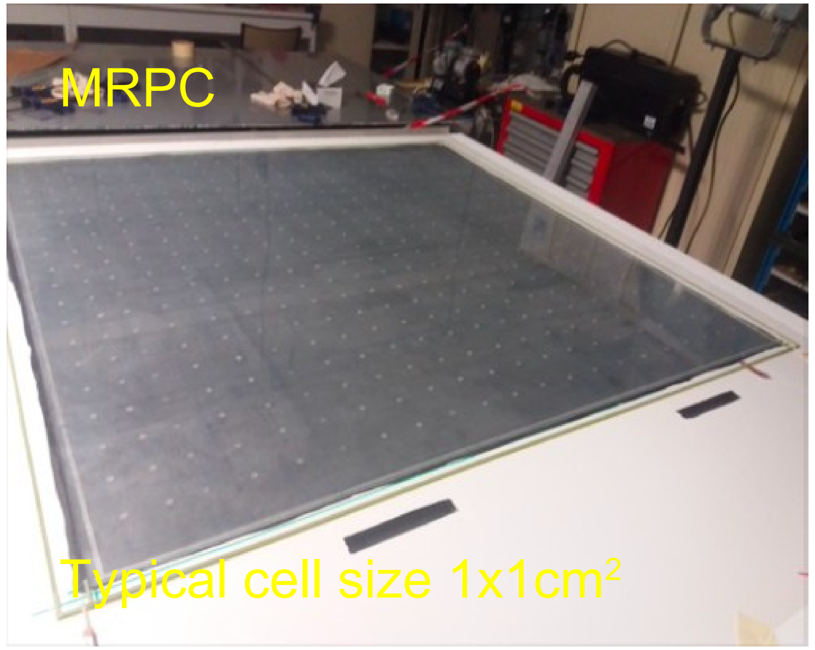
Glass scintillatiing Tile

Main R&D Topics

- Identification of optimised scintillating glass materials
- Selection of photodetectors and readout ASICs in synergy with other projects in the DRD
- Small electromagnetic prototypes -> full-scale hadronic prototype

DRD Calo

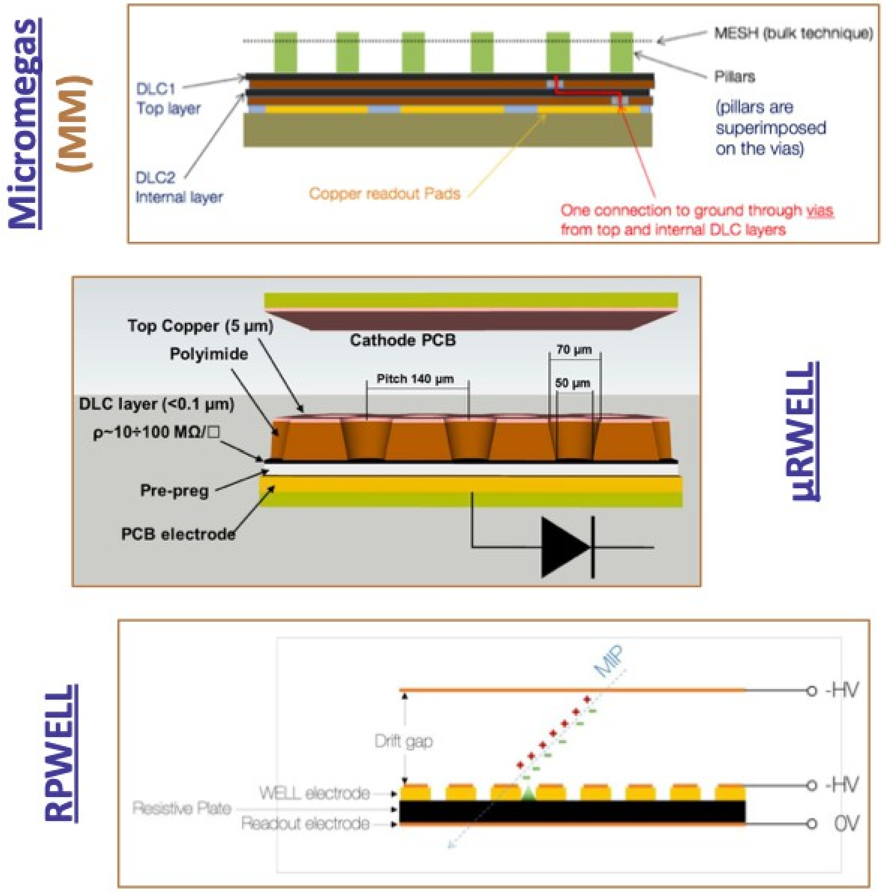
Time-Semi-Digital HCAL



Main R&D Topics

- Development of multigap RPC (MRPC) to improve timing (and rate capability)
- Readout ASIC, e.g. Liroc
- Development of a few layers of 1x1 m^2 for insertion into SDHCAL prototype

Micro-Pattern Gas Detector HCAL

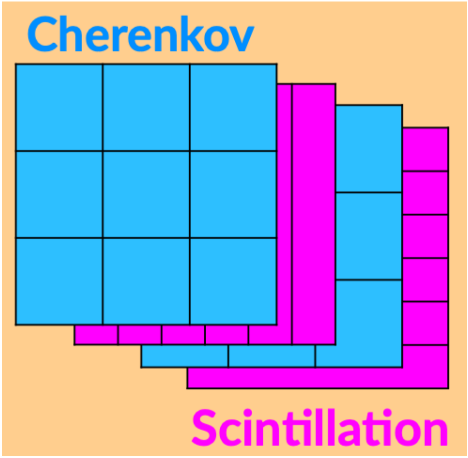


Main R&D Topics

- Simulation studies for a future muon collider
- Development of large-area MPGD chambers including adequate readout electronics

ADRIANO3

Triple r/o calorimeter



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Main R&D Topics

- Optimisation of light yield, RPC optimisation, timing resolution and cost
- Prototype layers -> medium-scale prototype

Work Package 3 – Optical Calorimeters

DRD Calo

Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCP-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-$/hh
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

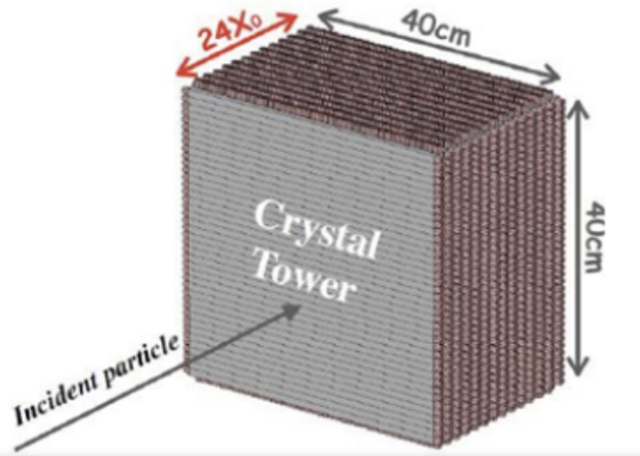
WP 3 Task 3.1 – (Quasi) Homogeneous EM Calorimeters

DRD Calo

Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$

HGCCAL

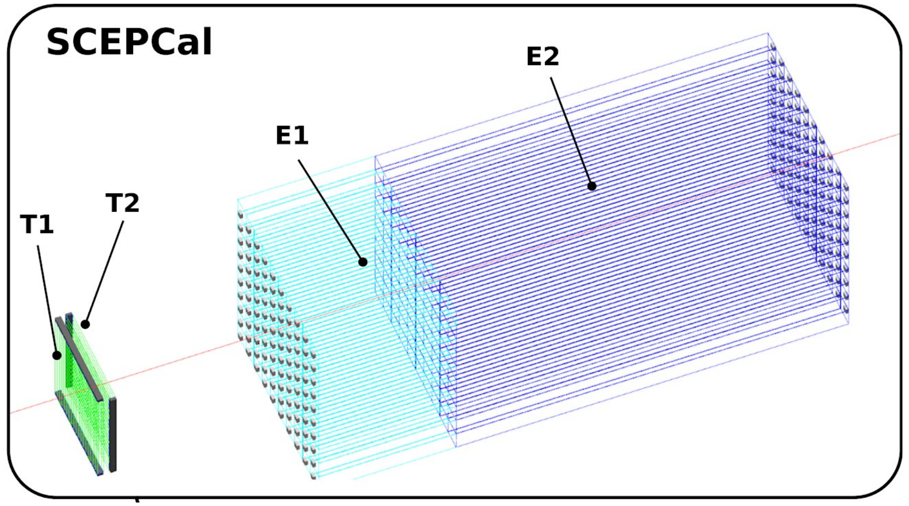
- Highly granular EM crystal based calorimeter to exploit maximum potential of PFA algorithms
- Integration, reconstruction driven by grid layout
- High density scintillating crystals with double-ended SiPM readout



EM calorimeter module: a grid of ~1x1x40cm³ crystal bars

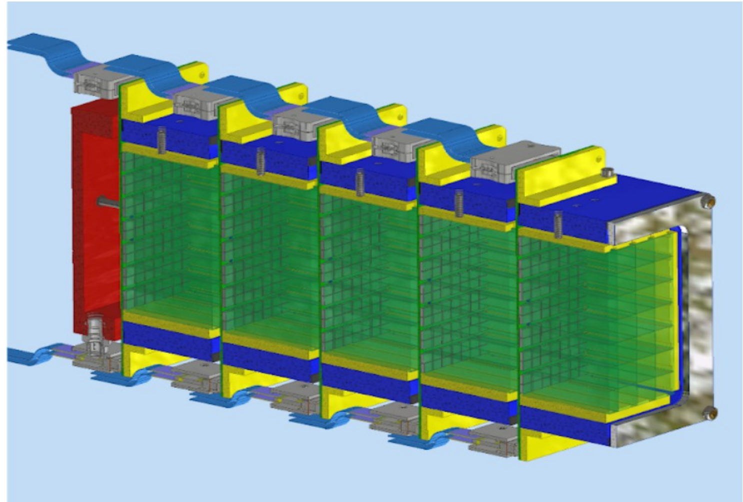
MAXICC

- Homogeneous EM calorimeter based on segmented crystals with SIPMs readout and dual-readout capability
- Simultaneous readout of scintillation and Cherenkov light signals from the same active element (heavy inorganic scintillator)
-



CRILIN

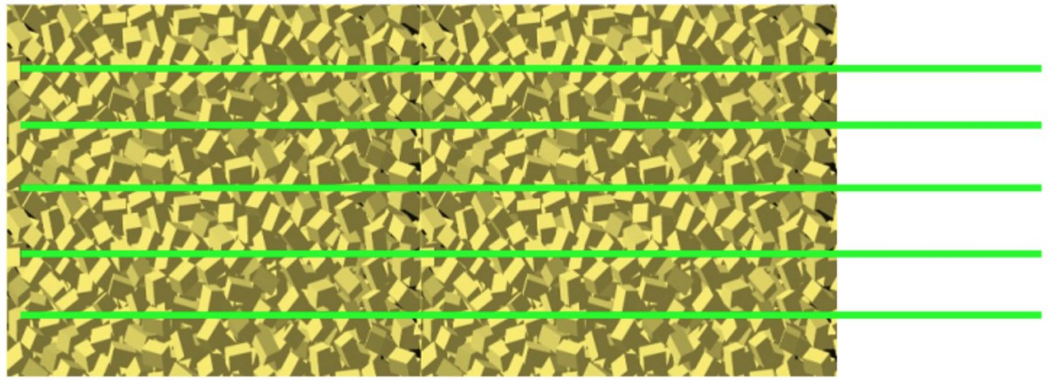
Radiation tolerant design of a longitudinally segmented crystal EM calorimeter.
Very harsh radiation environment for SiPMs, high rate of operation, large beam induced background (BIB).
Lead fluoride (PbF2) crystals, each read out with 2 channels consisting of a pair of SiPMs connected in series



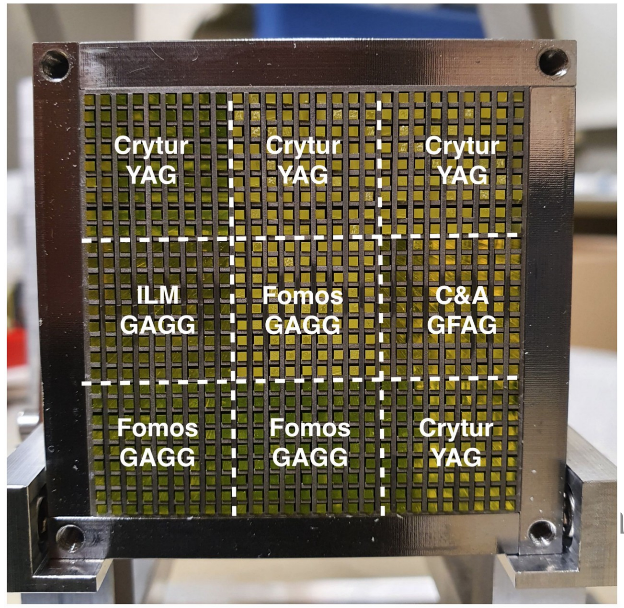
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCP-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh

GRAINITA

- Innovative technique inspired by Shashlyk-type calorimeters.
- Extremely fine granularity.
- Grain of scintillator in dense liquid

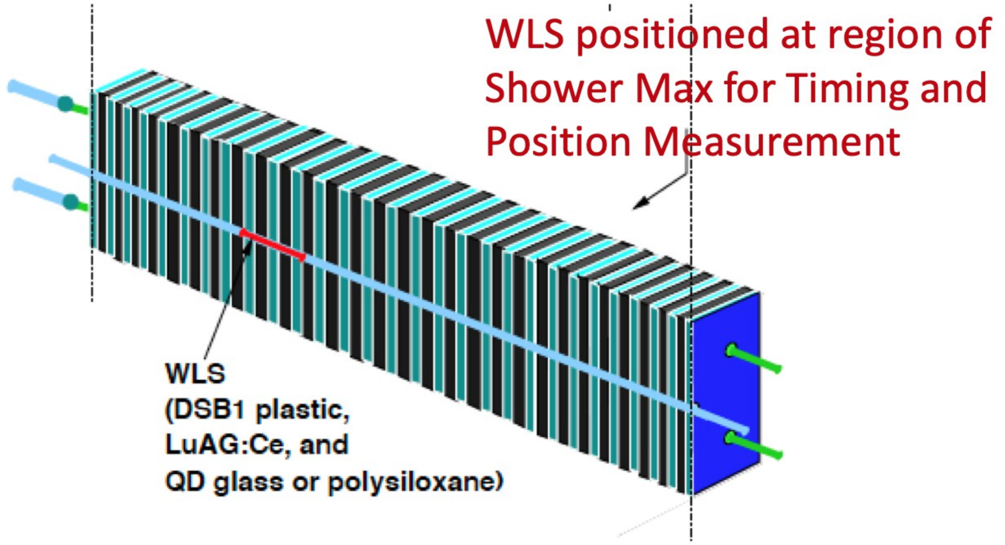


- **SpaCal** (ECAL made of scintillating fibres in dense absorbers) with O(10-20) ps time resolution
- Radiation-hard (and radiation-tolerant) scintillating fibres
- Crystal or organic fibres in lead or tungsten absorber, hollow light guides, PMT/SiPM photon detectors, SPIDER ASIC for timing



RADICAL

- Radiation-hard EM calorimeter with 10%/√E energy resolution and 25 ps timing resolution
- Radiation-hard WLS filament and SiPM Shashlik/type ECAL modules with tungsten absorber and LYSO:Ce tiles,
- WLS (full-length or in shower maximum),

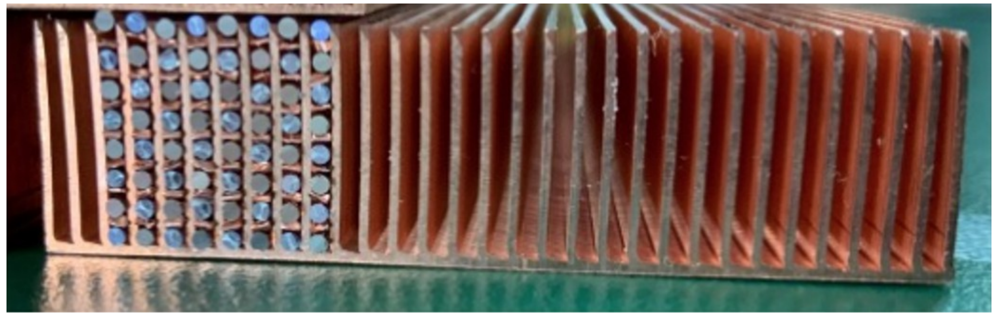


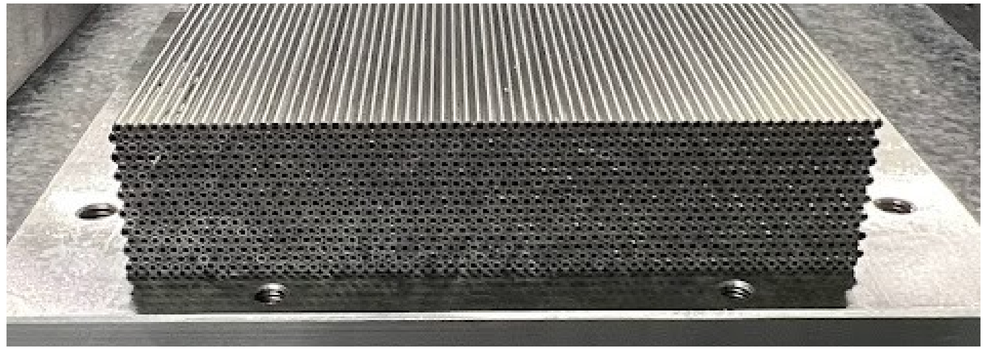
WP3 Task 3.3 - (EM+) Hadronic Sampling Calorimeters

Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh

DRCal

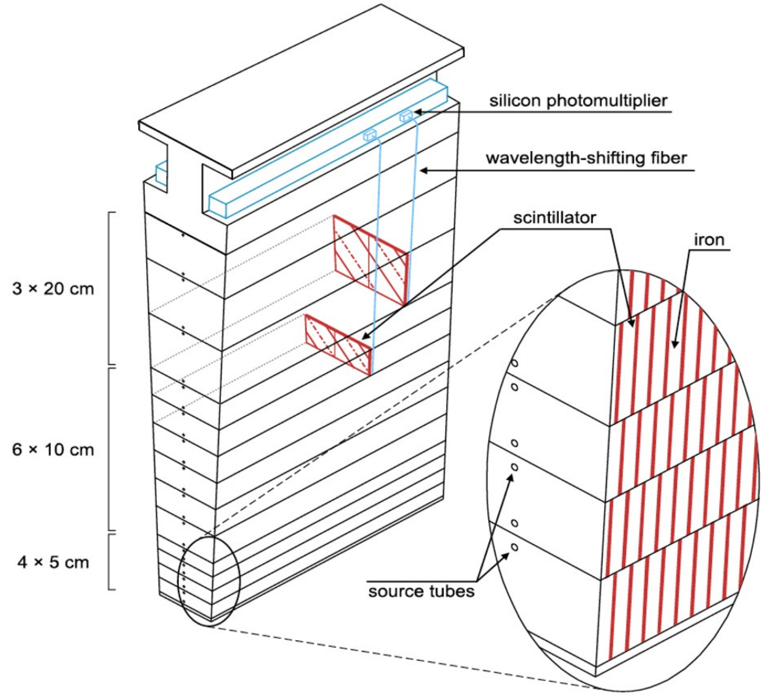
- High resolution Electromagnetic and hadronic calorimeter based on Dual-Readout Technique
- Organic scintillating fibres in brass or steel absorber (different solutions under development).
- SiPM or MCP-PMT photon detectors integration of a large number of SiPMs



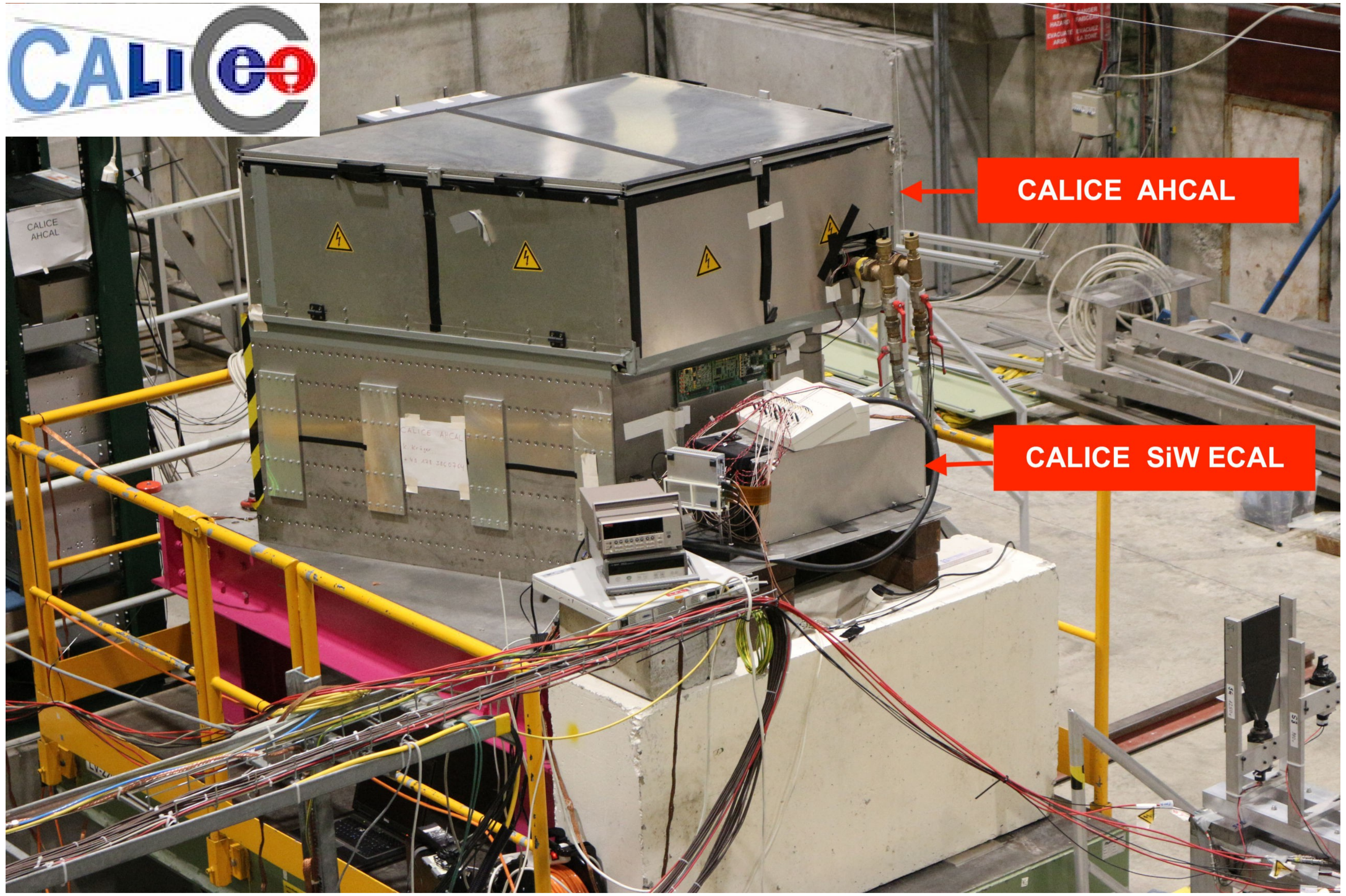


TileCal

- Hadron calorimeter with scintillating tiles and WLS fibre readout and SiPMs
- Cost-effective production of tiles, radiation hardness for FCC-hh
- Organic scintillating tiles, Steel (+Pb for FCC-hh) absorber



Dedicated Calorimeter Beam Area



Common setup at CERN June 2022

- Calorimeters are typically large objects
  - A beam test is similar to a small experiment
- Difficult for facility managers to schedule calorimeter beam tests
  - No concurring running with other devices possible
- Takes lots of expertise to carry out a successful beam test campaign
  - Implies use of infrastructure
- A dedicated beam area maybe with dedicated slots during a year may help curing these issues
  - Would need sustained expertise on the beamline
- R&D programme has to cope with facility schedules
  - e.g. CERN-SPS essentially closed 2026-2028