Calorimetry - Toward DRD Calo

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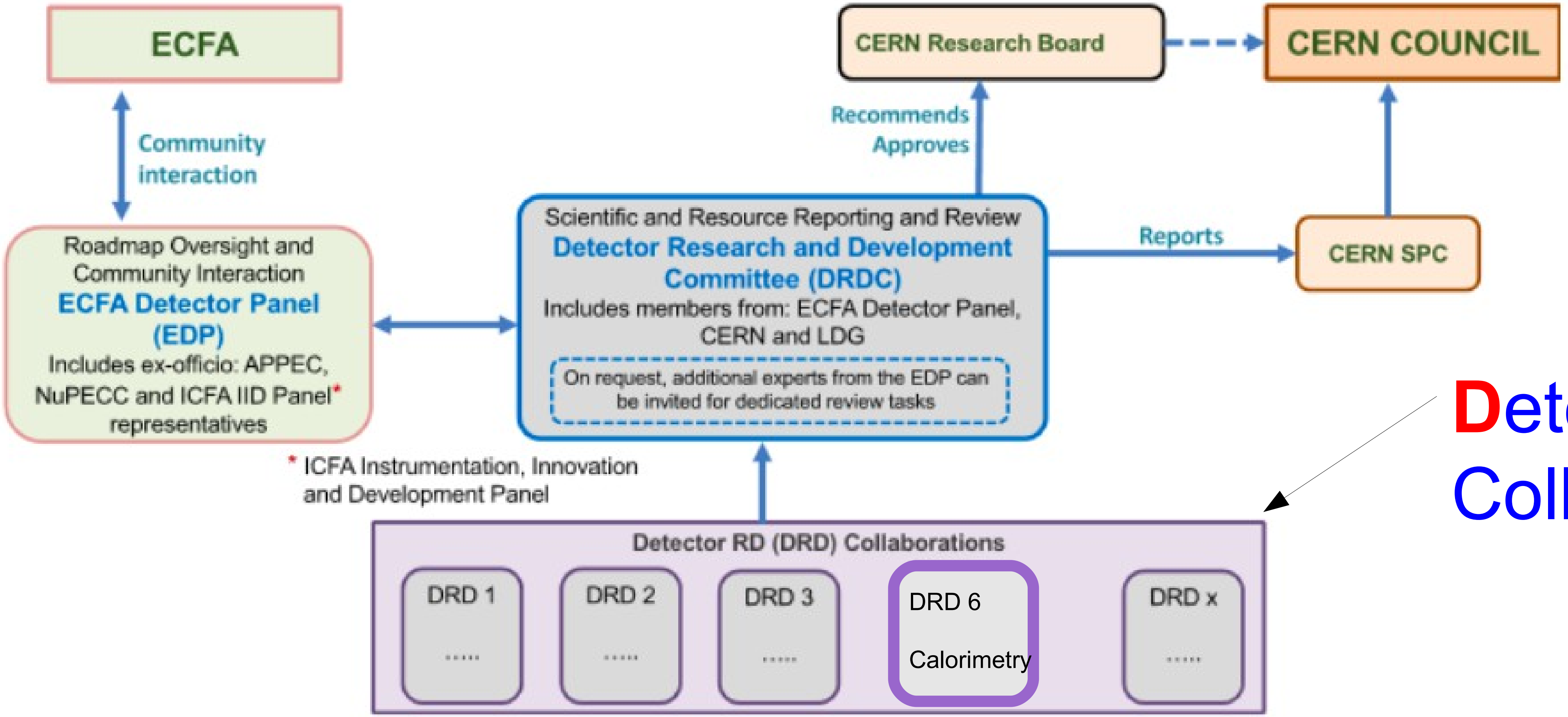
université PARIS-SACLAY GRADUATE SCHOOL Physique | P2I Physique des deux Infinis

On behalf of DRD Calo Proposal Team

ECFA HET Workshop, October 2023, Paestum (I)

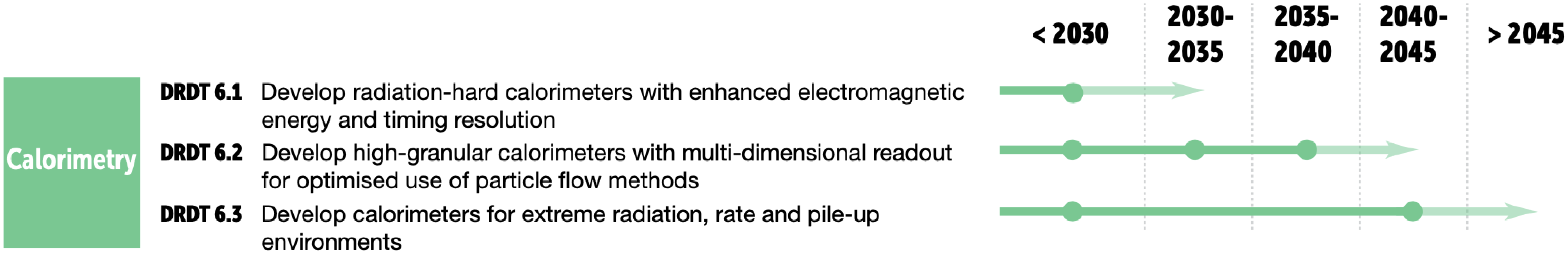
Future Organisation of Detector R&D (in Europe)



Detector R&D Collaborations

- Current model: 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
  - https://committees.web.cern.ch/drdc
  - Thomas Bergauer of ÖAW/Austria appointed as DRDC-Chair
- The funding will come from national resources (plus eventually supranational projects)

Future Facilities and DRDT for Calorimetry

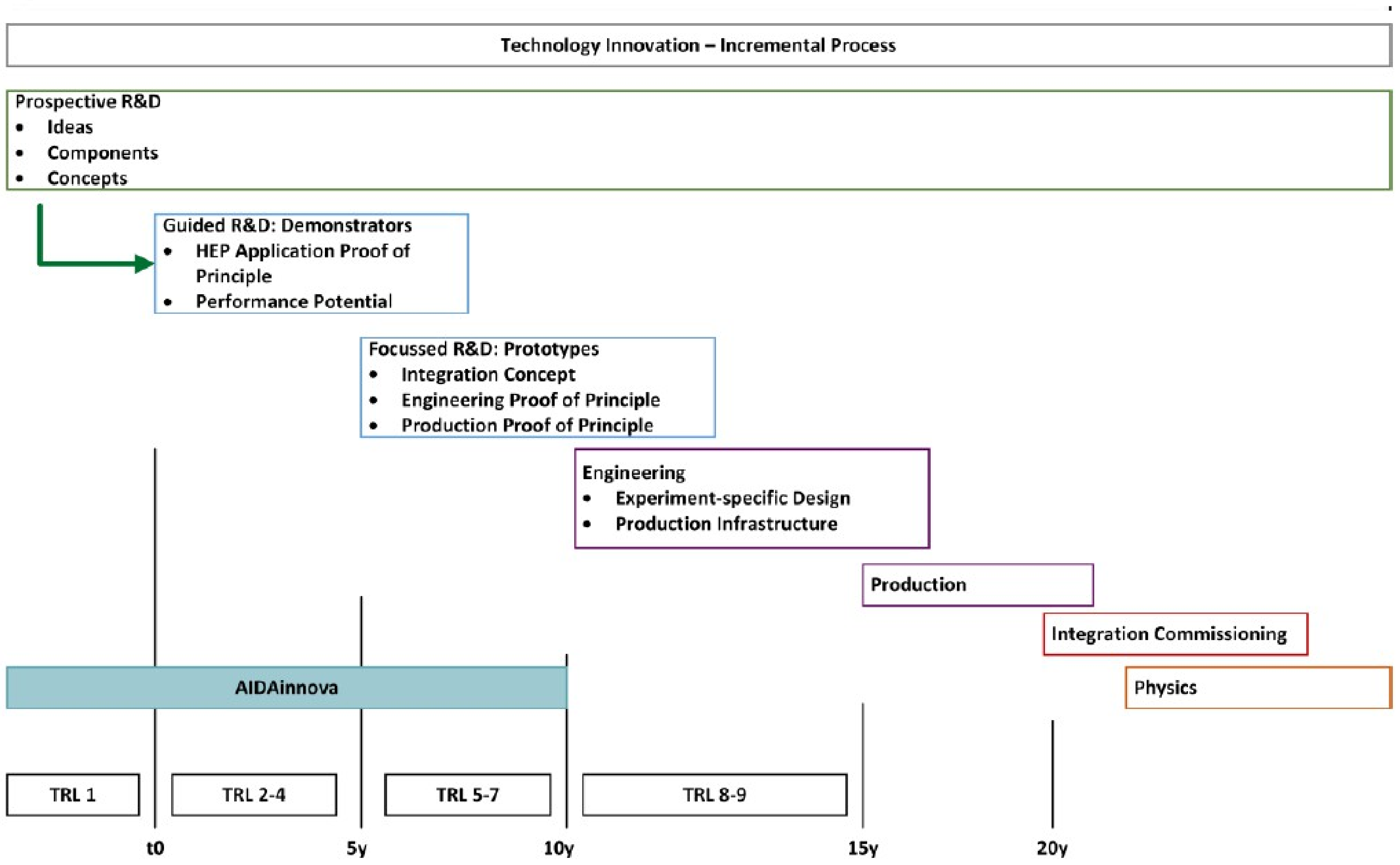


- The **D**etector **R&D** **T**hemes and the provisional time scale of facilities set high-level boundary conditions
  - See backup slides for detailed R&D tasks

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) **agility**
3. "Blue-sky" R&D
   (competitive, short-term responsive grants, nationally organised)

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



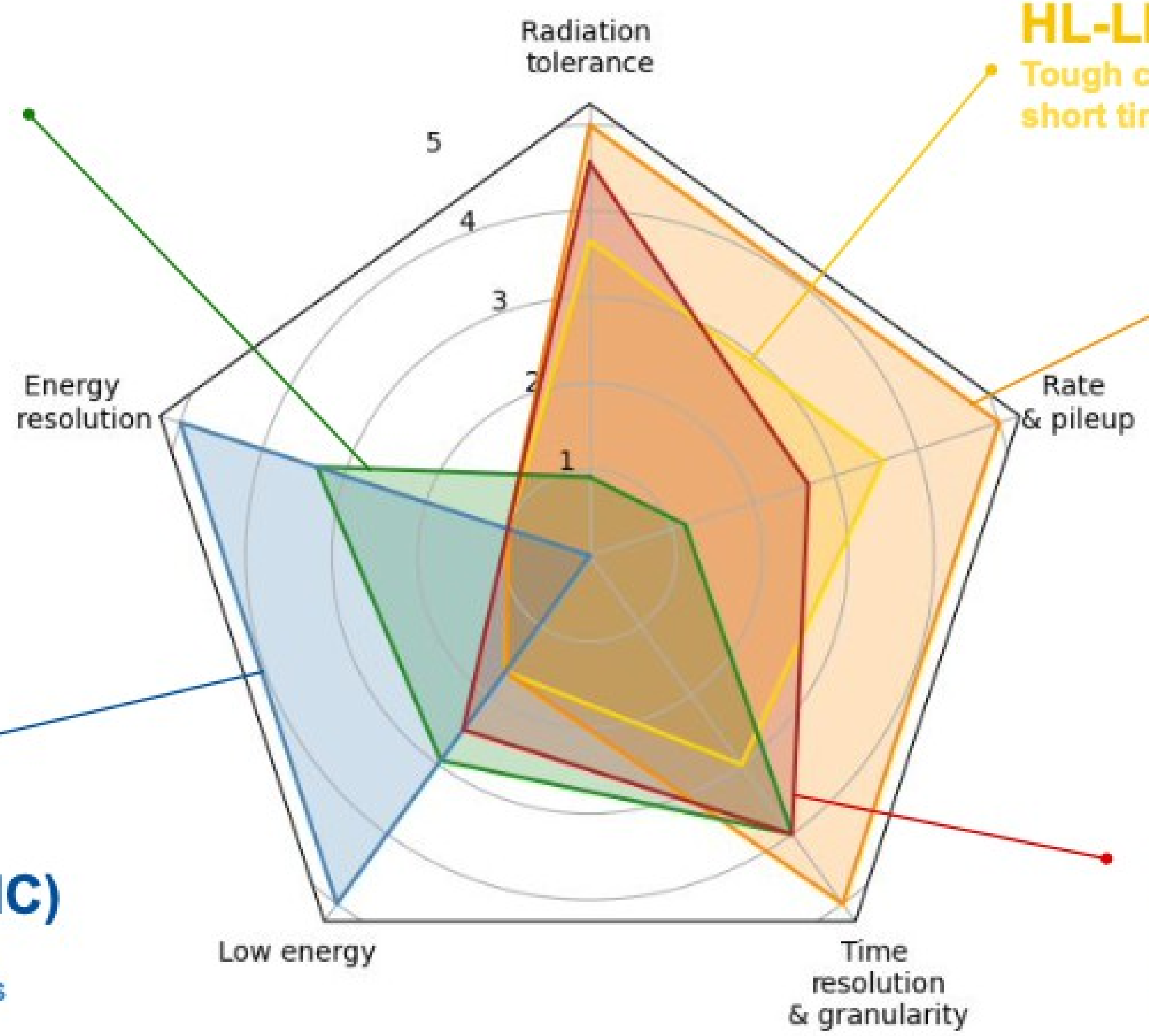
F. Sefkow, CALICE Meeting and ECFA Higgs/top/EW Factory Meeting

Requirements for calorimetry at future colliders

e^+e^- colliders
Precision physics benefits from exploiting the best possible energy and time resolution

HL-LHC
Tough challenges on a short timescale

FCC-hh
Setting the toughest challenge on radiation tolerance and pileup conditions



Very high energy (longitudinal containment)

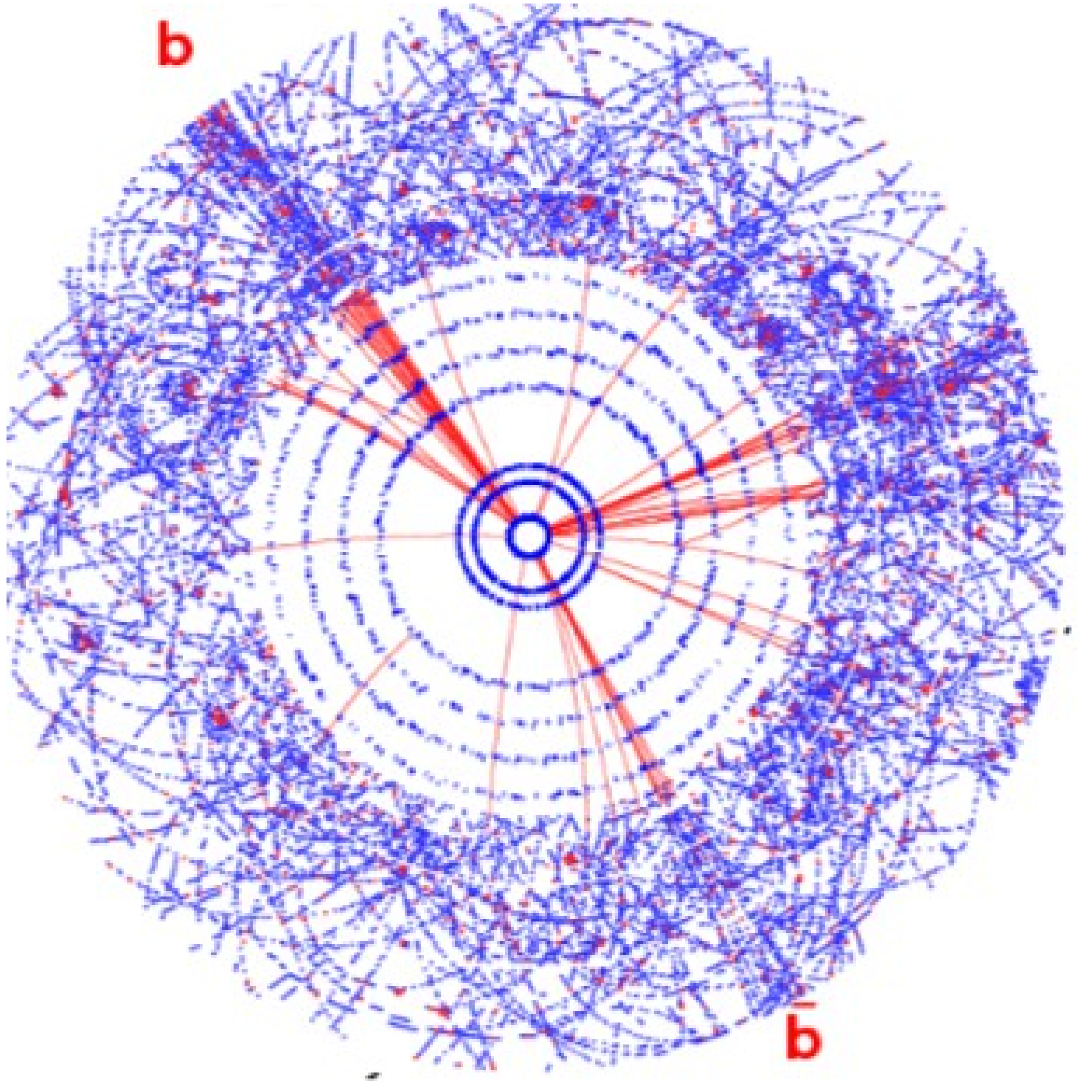
Strong interaction experiments (e.g. EIC)
Requiring the highest energy resolution for low energy photons

$\mu^+\mu^-$ colliders
High beam induced background and radiation levels, need for ambitious time resolution

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

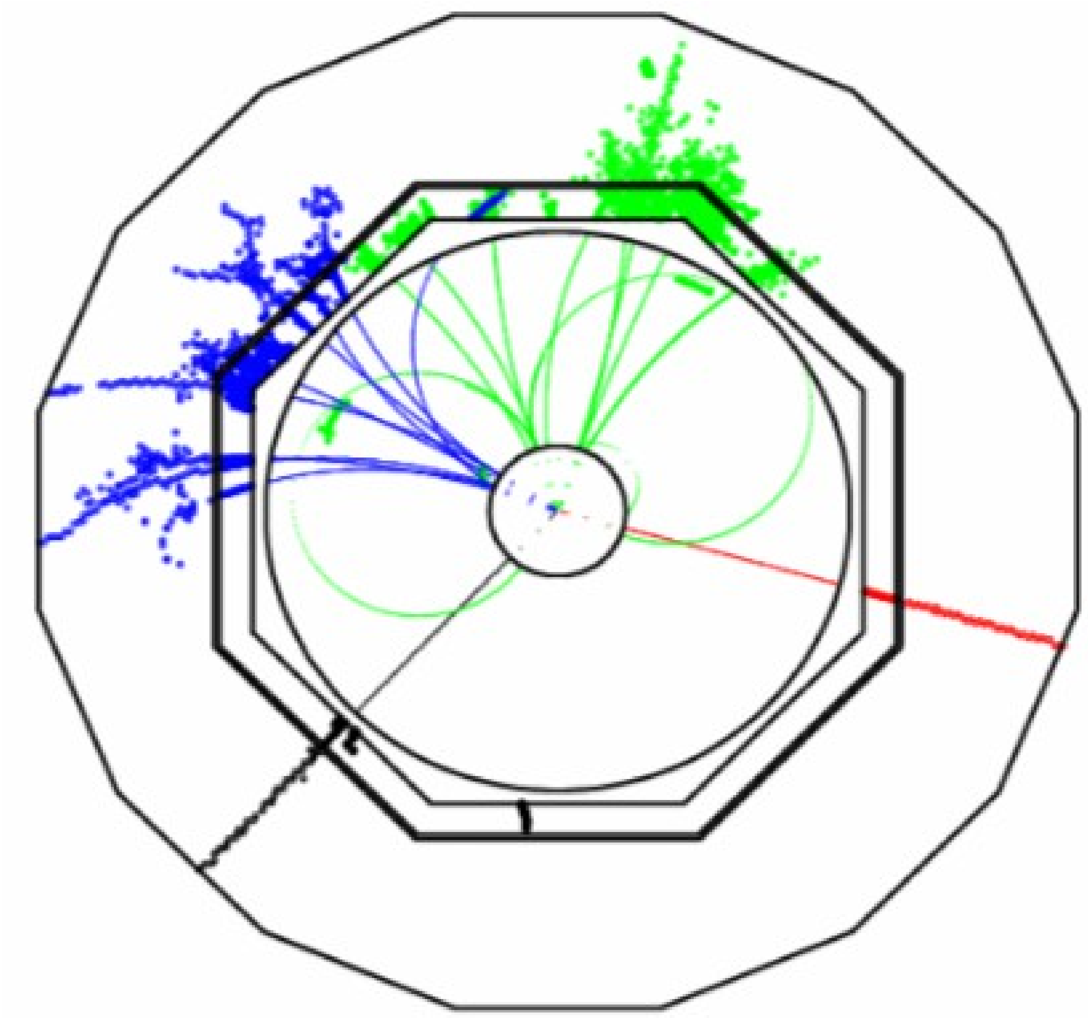
(Rough) Comparison – Hadron collisions ↔ e^+e^- collisions

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

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

Towards Implementation of DRD Calorimetry

- **Entry point, "DRD Calo indico page": https://indico.cern.ch/category/12772/**
  - Information on important events and access to relevant documents
  - 234 people from four regions registered so far

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

- Proposal phase until 31st of July 2023
  - **Input-proposals collected until 1st of April 2023**
  - 2nd Community Meeting 20th April
    - https://indico.cern.ch/event/1246381/
    - Presentation of summaries of input-proposals (w/o disclosing confidential information)
    - Presentation of a WP Structure of DRD Calorimetry

  - Input-proposals have been condensed into a DRD on Calorimetry proposal
    - Submitted to DRD-C on July 28th and shared with submitters of input-proposal
    - Proposal has been accompanied by a set of resource table
      - (compiled to the best of our knowledge with the help of magic bowls ;-))

DRD Calo – From input proposals to working structure

The Proposal Team

WA1 Sandwich calorimeters with fully embedded Electronics – Main and forward calorimeters
Track conveners:
Adrian Irles (IFIC), **Frank Simon** (KIT), **Jim Brau** (U. of Oregon), **Wataru Ootani** (U. of Tokyo) Imad Laktineh

WA2 Liquified Noble Gas Calorimeters
Track Conveners:
Martin Aleksa (CERN), **Nicolas Morange** (IJCLab), **Marc-André Pleier** (BNL)

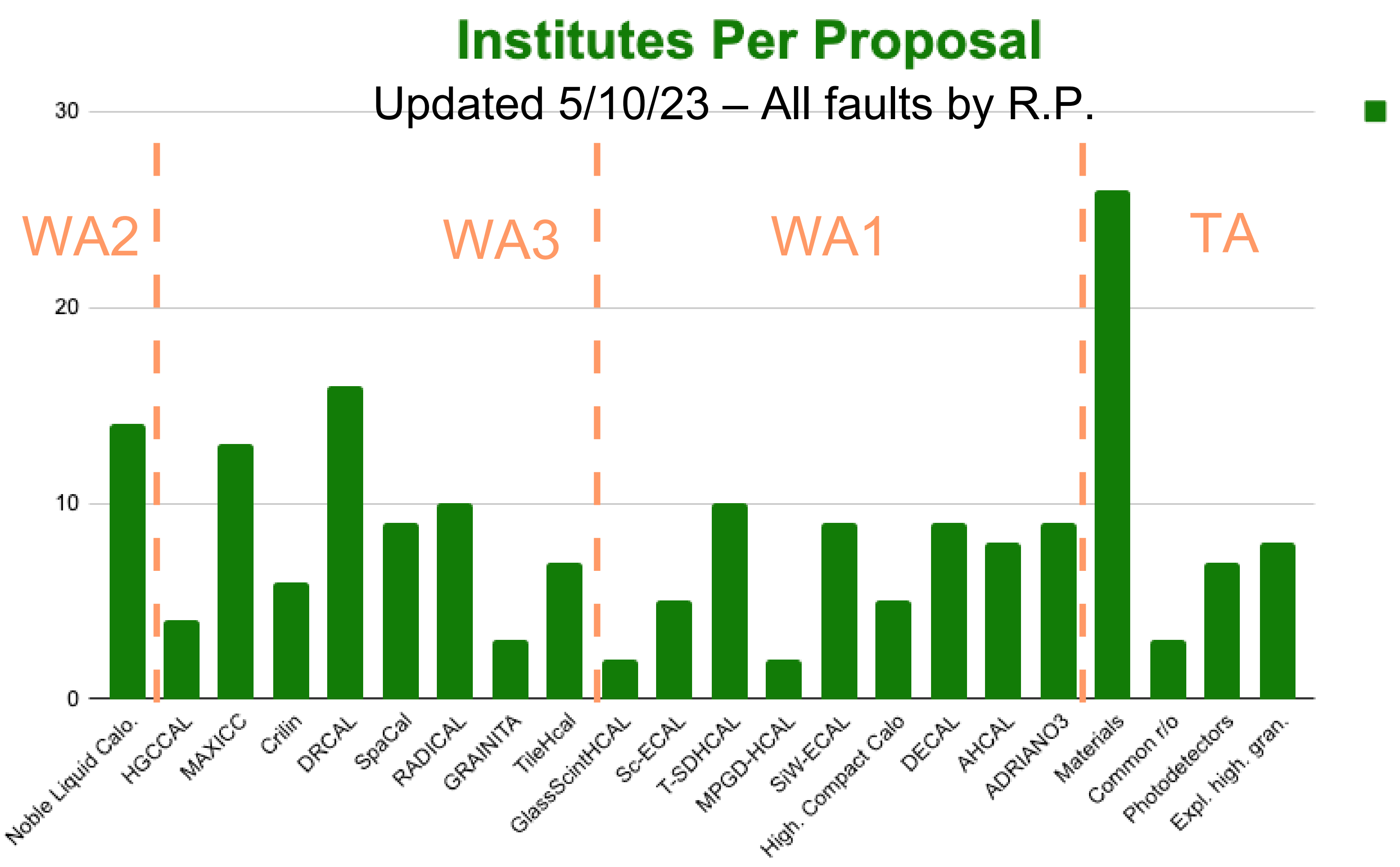
WA3 Optical calorimeters: Scintillating based sampling and homogenous calorimeters
Track Conveners:
Etiennette Auffray (CERN), **Gabriella Gaudio** (INFN-Pavia), **Macro Lucchini** (U. and INFN Milano-Bicocca), **Philipp Roloff** (CERN), **Sarah Eno** (U. of Maryland), **Hwidong Yoo** (Yonsei Univ.)

: Transversal Activities
Christophe de La Taille (Lab. Omega) Alberto Gola

Conveners: Gabriella Gaudio (INFN-PV), Roberto Ferrari (INFN-PV), R.P. (IJCLab)

Input proposals

23 comprising 123 (and counting) institutes/labs received
From all over the world!!!

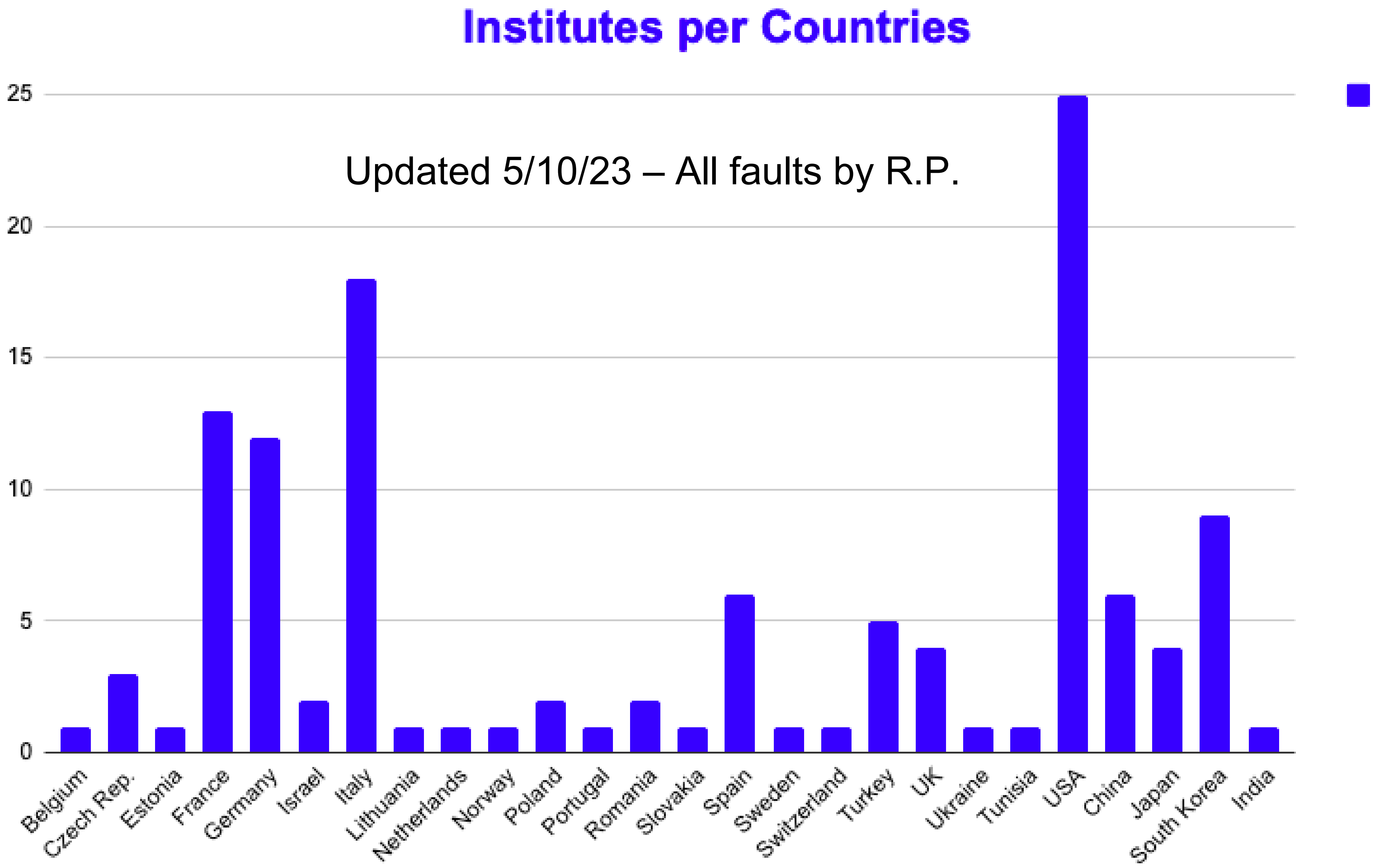


For further details of input-proposals and formation of DRD Calo see:

https://indico.cern.ch/event/1246381/

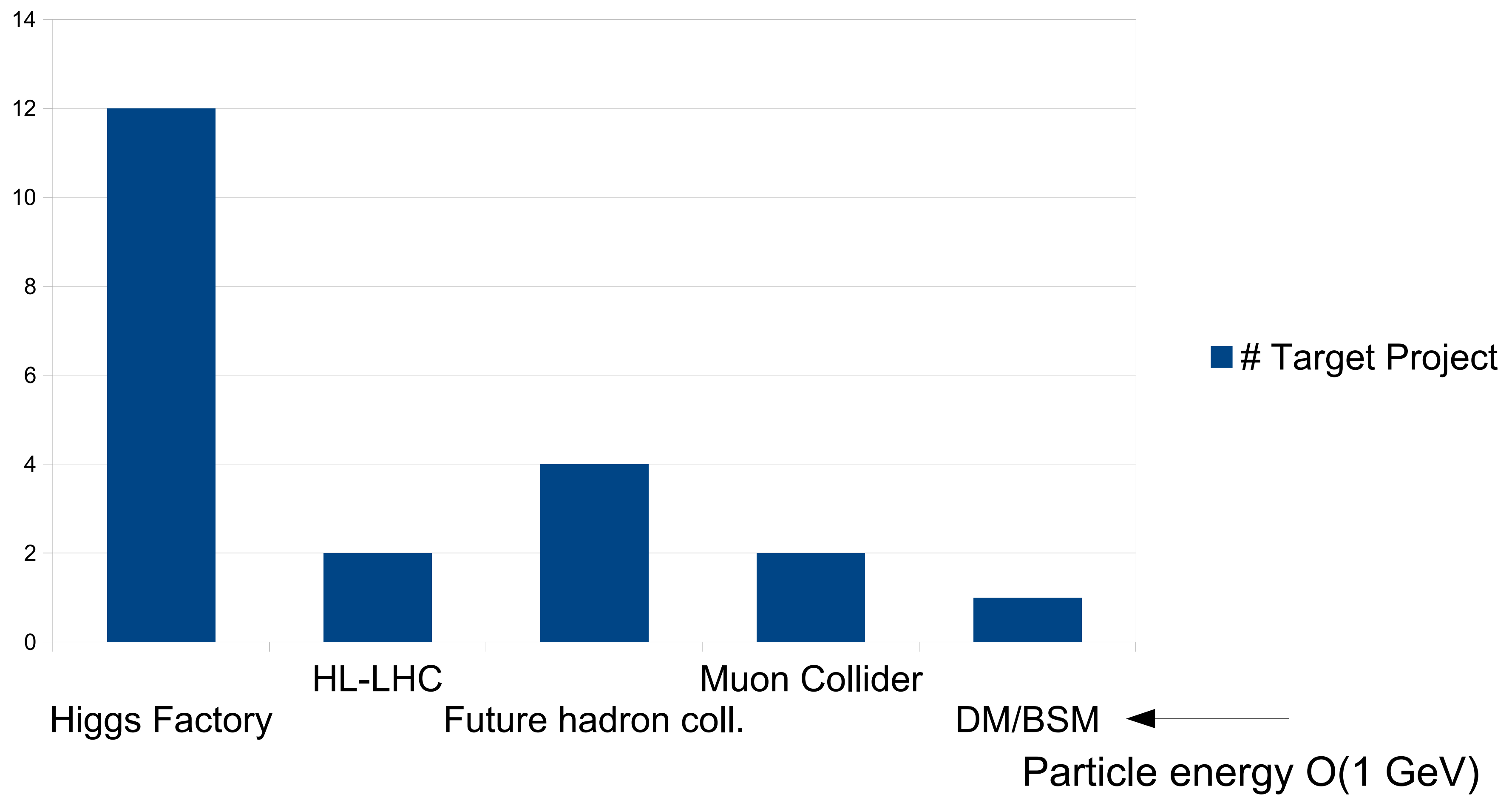
WA = Work Area

DRD Calo – Overall Interest



- Mainly European Groups but interest from all over the world (37%)
  - US biggest single participation -> close contact to emerging effort in US
  - Very visible Asian participation

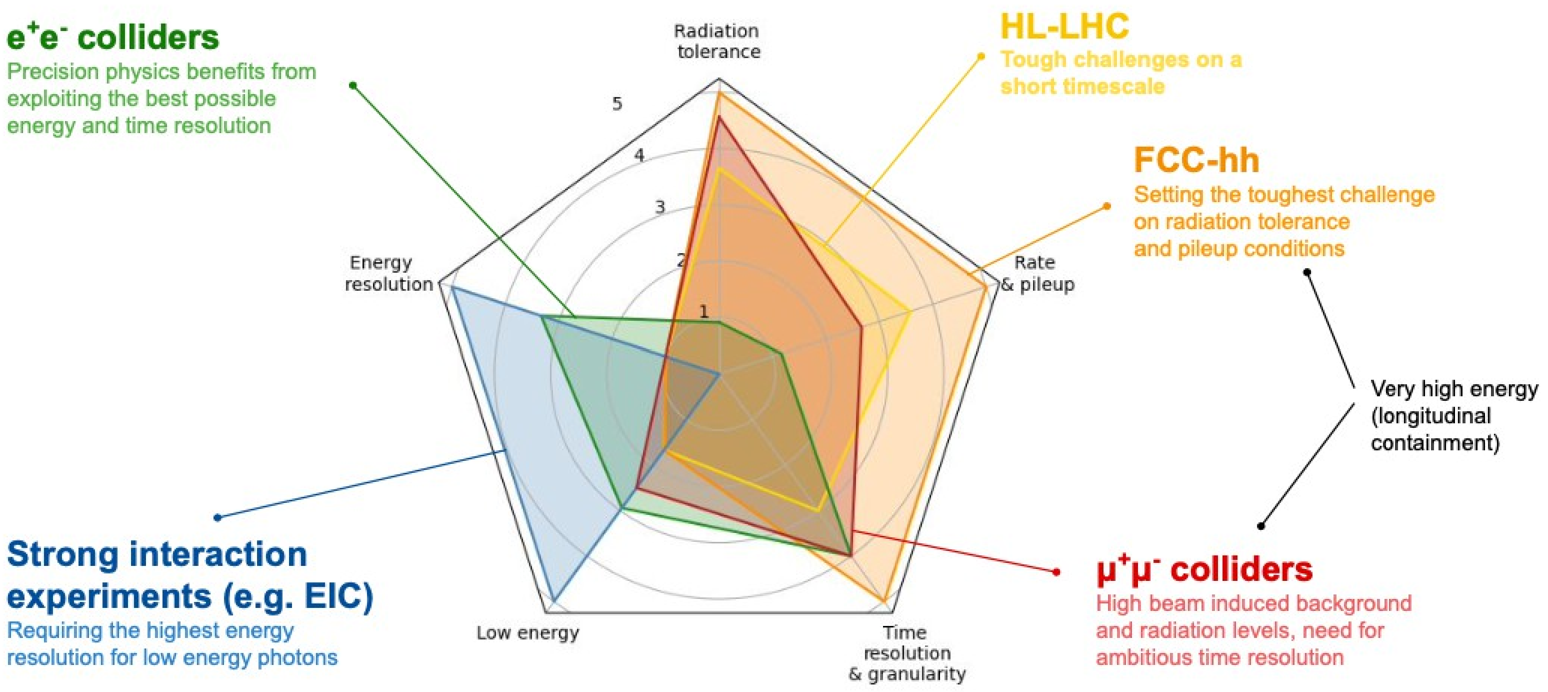
DRD Calo - Input proposals and target projects



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

Requirements for calorimetry at future colliders

e+e- Colliders
Precision physics benefits
From the best precision
in energy and time



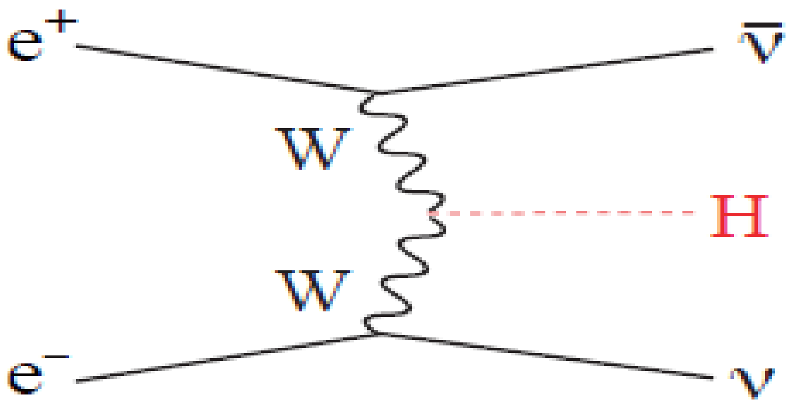
Inspired from https://indico.cern.ch/event/994685/

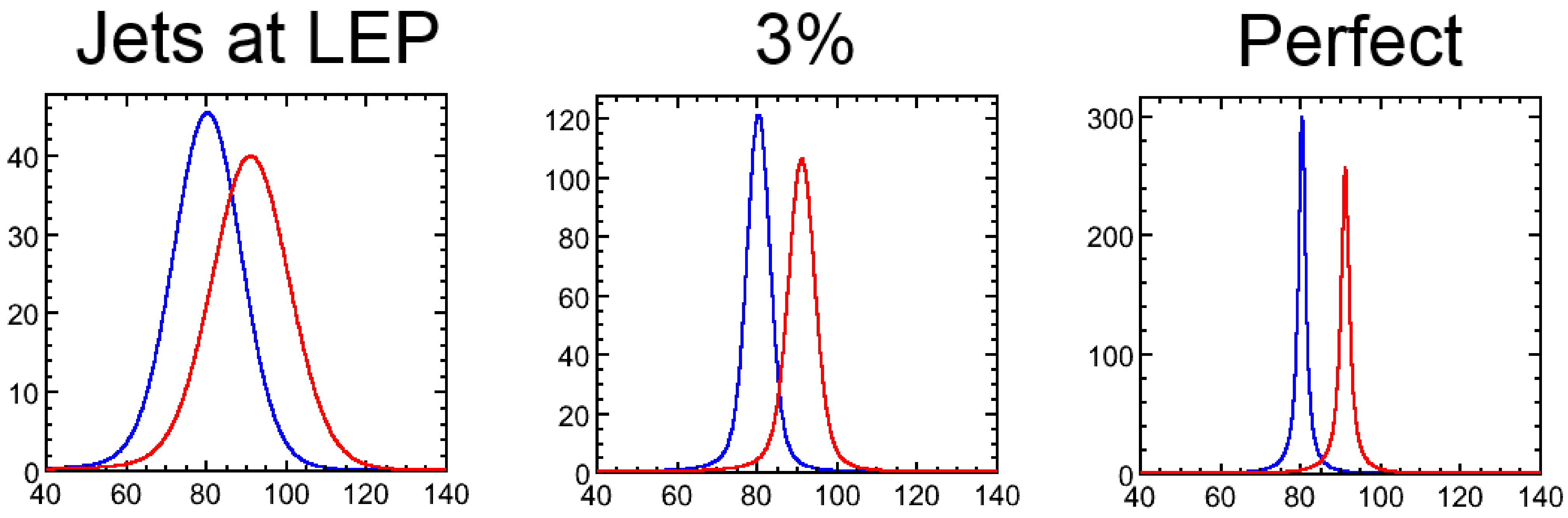
Motivation for excellent jet energy resolution

Examples:

- W Fusion with final state neutrinos requires reconstruction of H decays into jets

- Jet energy resolution of ~3% for a clean W/Z separation





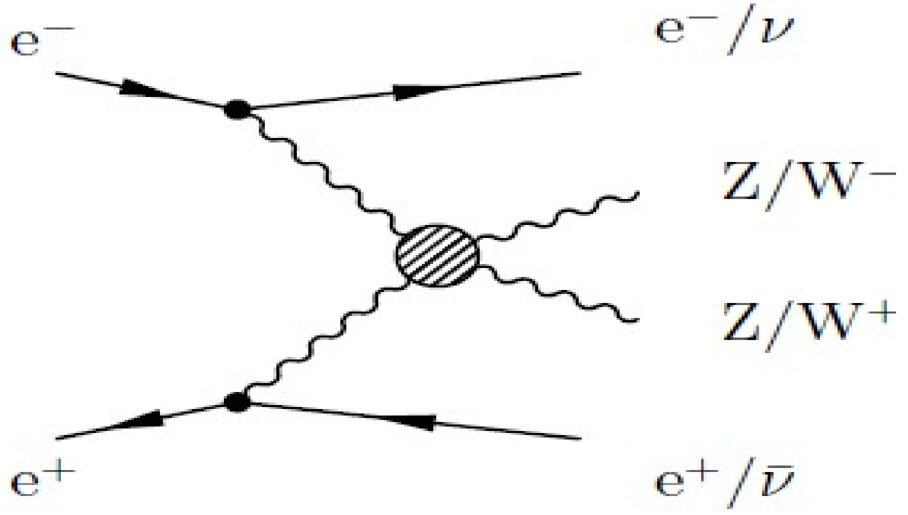


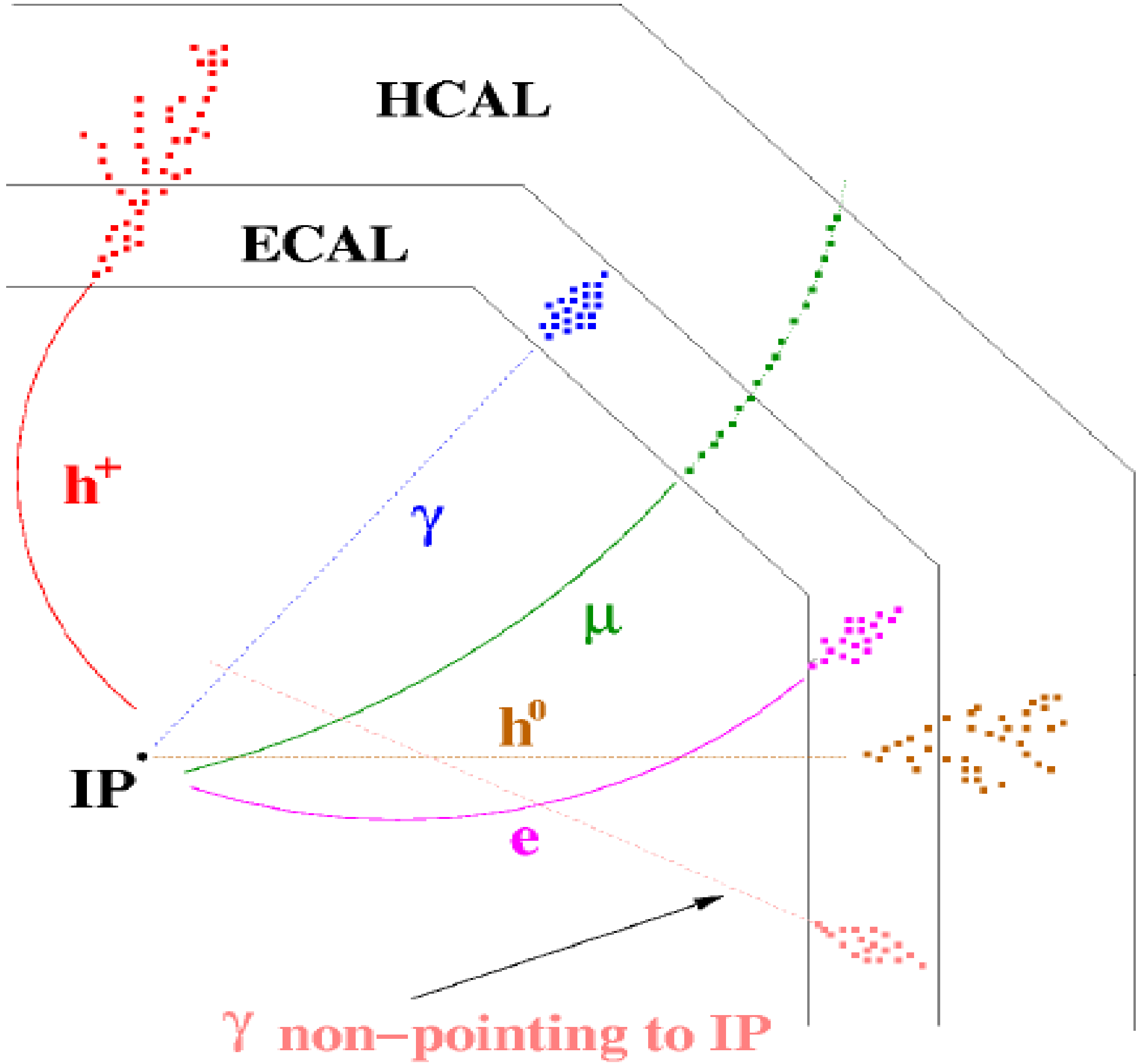
Figure by M. Thomson

Slide: F. Richard at International Linear Collider – A worldwide event

Particle Flow Detector Layout

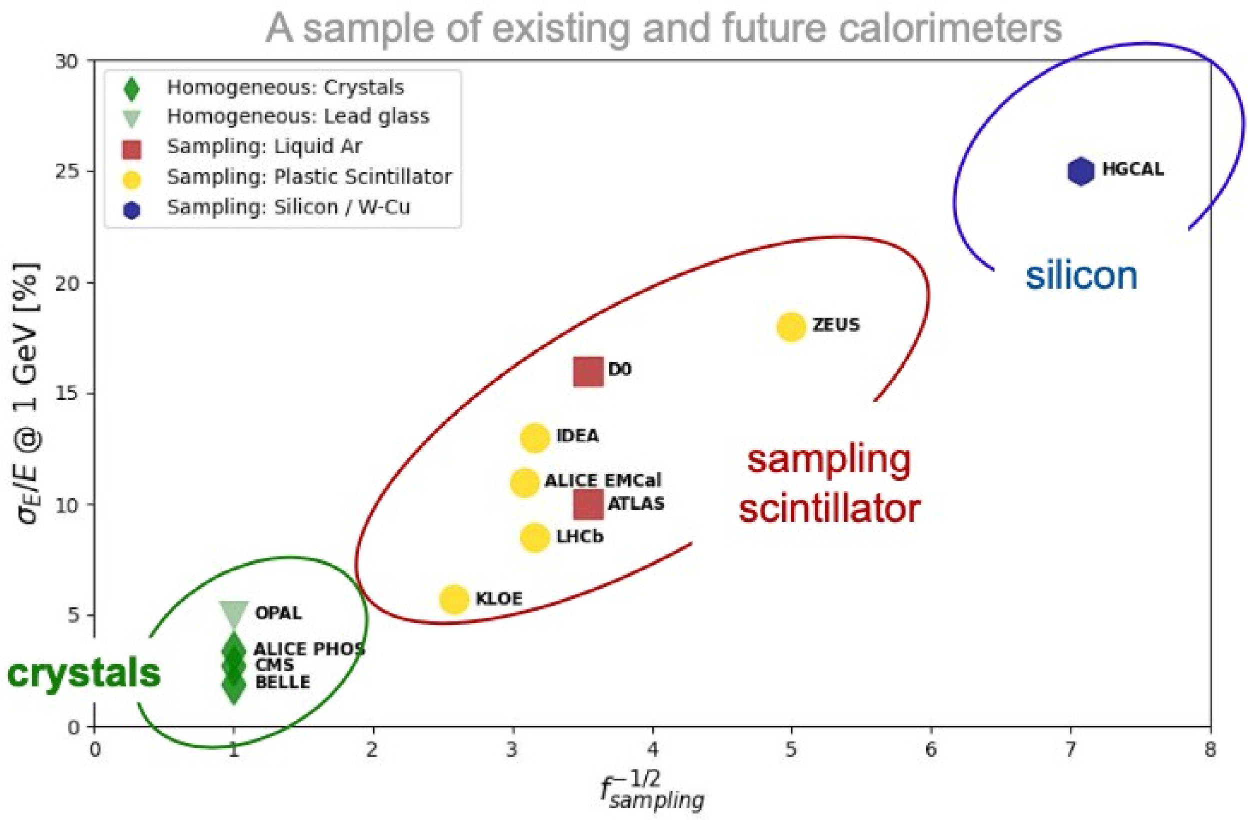
- Jet energy measurement by measurement of **individual particles**
- Maximal exploitation of precise tracking measurement

- Large radius and length
  - → to separate the particles
- Large magnetic field
  - → to sweep out charged tracks
- "no" material in front of calorimeters
  - → stay inside coil (the puristic viewpoint)
  - → see later discussion
- Minimize shower overlap
  - → Small Molière radius of calorimeters
- **high granularity of calorimeters**
  - → to separate overlapping showers

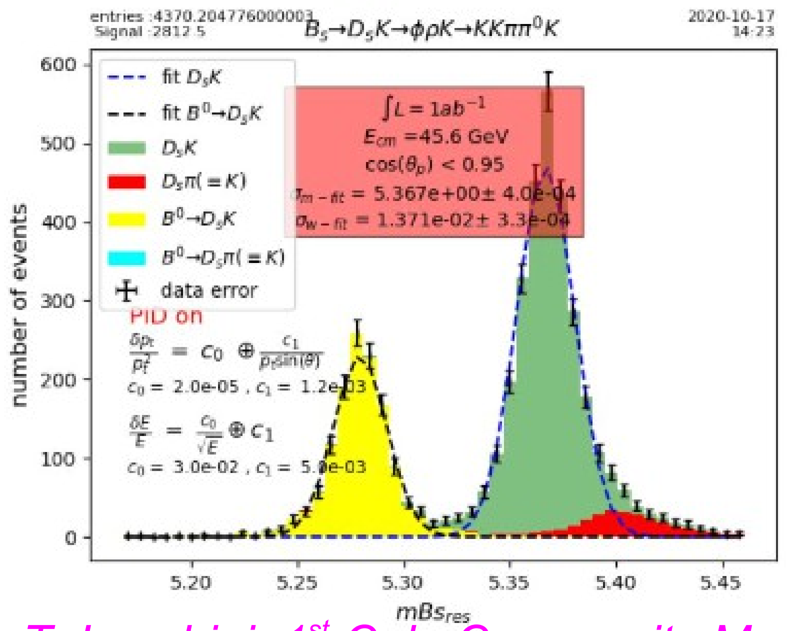


Sampling and Homogeneous Calorumeters

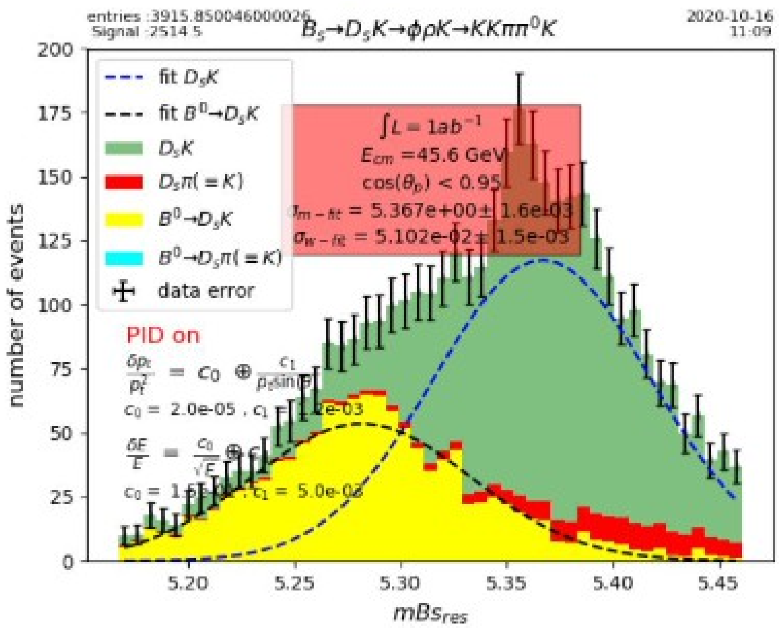
- Many proposals are based on sampling calorimeters
  - i.e. Separation of sensitive and absorber medium
- Sampling leads to limitations in elm. energy resolution 10-15%/√E
- (Most likely) homogeneous calorimeters remain the only way to get to energy resolutions of 1-5%/√E



3%/√E



15%/√E



CP violation studies with B_s decay to final states with low energy photons

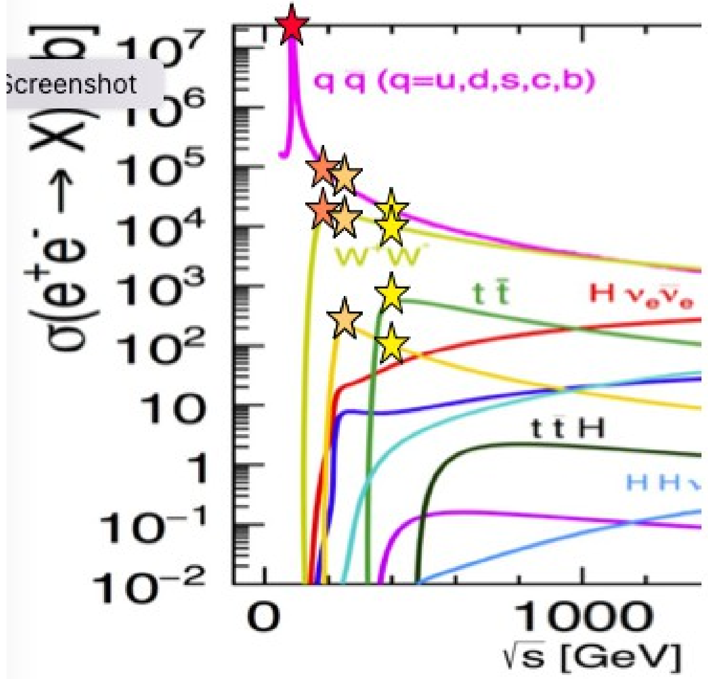
[R.Aleksan et al., *Study of CP violation in B± decays to D0(D0)K± at FCCee,* arXiv:2107.05311]

M. T. Lucchini, 1st Calo Community Meeting

Future direction of R&D - Impact of event rates

Processes & Configurations

- Order of magnitude → Statistics ?
- Mininum bias
- Leading processes (at all angles)
- Worse case (scans)



Processes: min. bias

- All
  - ee → qq
  - ee → $\mu\mu$, $\tau\tau$
  - ee → ee (⊃ Bhabha)
  - $\gamma\gamma$→ VV
  - Machine background (ee pairs)
- $E_{CM} \geq 160$ GeV
  - ee → WW
- ($E_{CM} \geq 240$ GeV)
  - ee → HZ
- ($E_{CM} \geq 360$ GeV)
  - ee → $t\bar{t}$

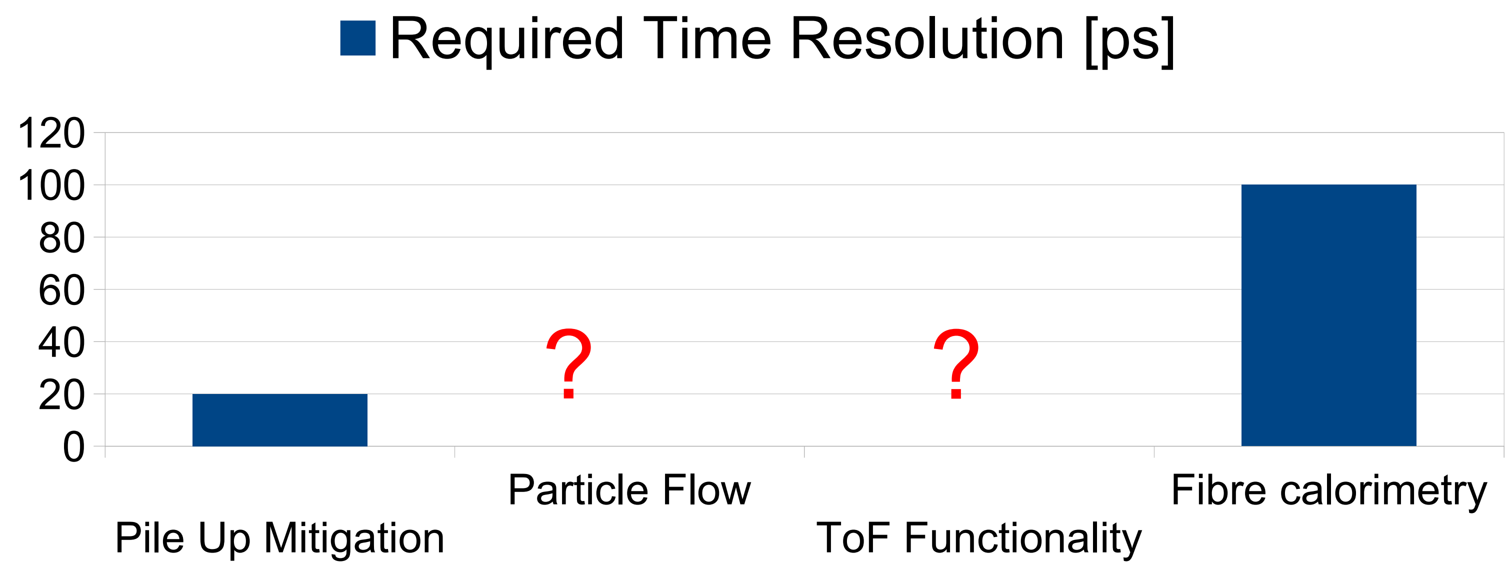
Config	#IP	E_{Beam}	#BX	$\mathcal{L}$ [10^{34}/cm²/s]	ΔT [μs]	Freq[Hz]	√s [GeV]
FCC-Z2	2	45,6	12000	180,0	0,025		91,2
FCC-Z4	4	45,6	15880	140,0	0,019		91,2
FCC-W	4	81,3	688	21,4	0,442		162,5
FCC-ZH	4	120,0	260	6,9	1,169		240,0
FCC-tt	4	182,5	40	1,2	7,600		365,0
ILC250 [1]	1	125,0	1312	1,4	0,554	5,0	250,0
ILC500	1	250,0	1312	1,8	0,554	5,0	500,0
ILC1000	1	500,0	2450	4,9	0,366	5,0	1000,0
CLIC380	1	160,0				10,0	380,0
ILC-GZ	1	45,6				5,0	91,2
ILC250-HL	1	125,0	2625	2,7	0,366	5,0	250,0
CEPC							
C^3							
⋮							

ILC from: P. Bambade et al., The International Linear Collider: A Global Project, arXiv:1903.01629 [Hep-Ex, Physics:Hep-Ph, Physics:Physics]. (2019).
FCC from: Tor Raubenheimer, FCC Week June 2023

Setup of a rate study by Vincent Boudry

Requirements on Timing

- Timing is a wide field
- A look to 2030 make resolutions between 20ps and 100ps at system level realistic assumptions
- At which level: 1 MIP or Multi-MIP?
- For which purpose ?
  - Mitigation of pile-up (basically all high rate experiments)
  - Support of PFA – unchartered territory
  - Calorimeters with ToF functionality in first layers?
    - Might be needed if no other PiD detectors are available (rate, technology or space requirements)
    - In this case 20ps (at MIP level) would be maybe not enough
  - Longitudinally unsegmented fibre calorimeters



- A topic on which calorimetry has to make up it's mind
  - Remember also that time resolution comes at a price -> High(er) power consumption and (maybe) higher noise levels

On the DRD Calo proposal ...

DRD 6: Calorimetry

Proposal Team for DRD on Calorimetry

July 28, 2023

Martin Aleksa[1], Etiennette Auffray-Hillemanns[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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[3]University of Maryland, College Park, MD USA
[4]INFN, Pavia, ITALY
[5]FBK, Povo, ITALY
[6]IFIC, CSIC-Unversity of Valencia, Valencia, SPAIN
[7]IP2I Lyon, Villeurbanne, FRANCE
[8]University and INFN Milano-Bicocca, Milano, ITALY
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[14]OMEGA, Palaiseau, FRANCE
[15]Yonsei University, Seoul, SOUTH-KOREA

Contents

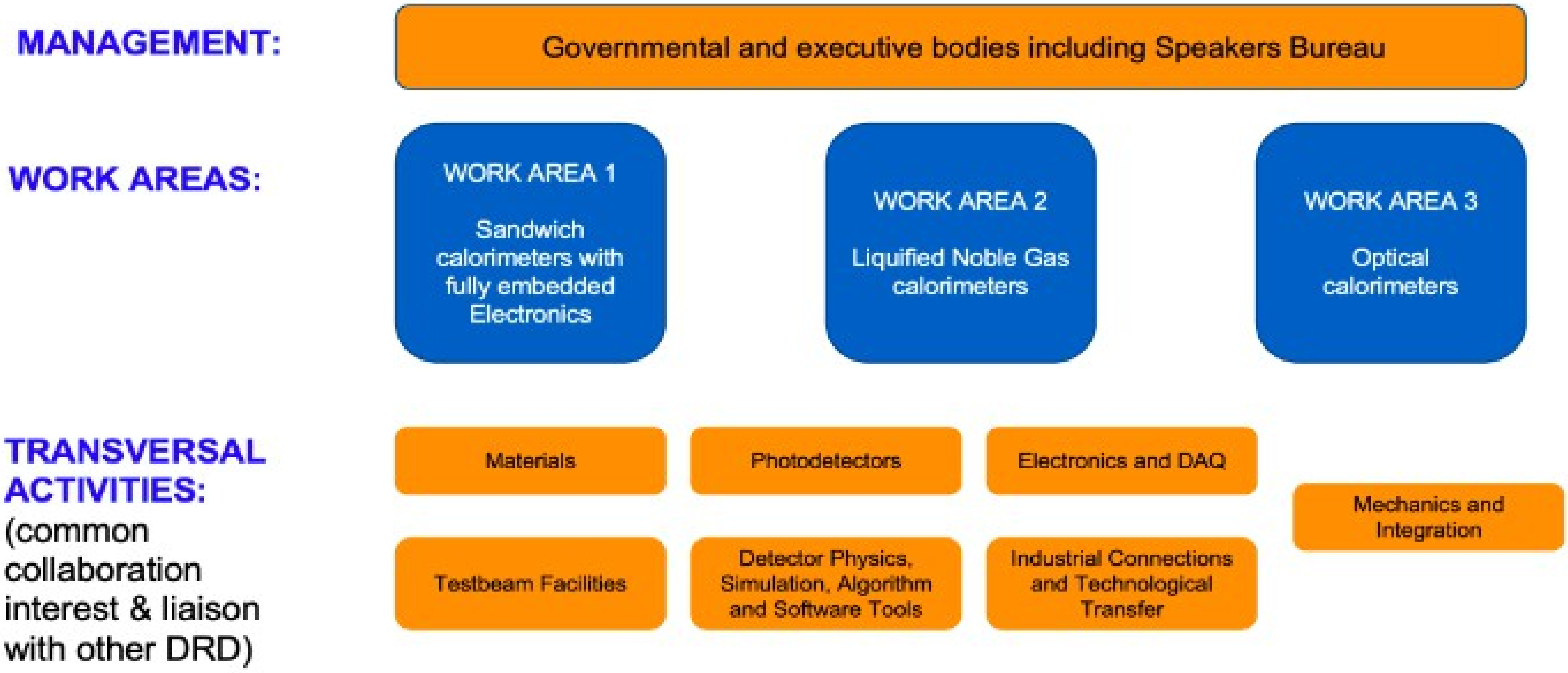
- https://drive.google.com/drive/folders/1_xvY32h2hrcSN9TRYYZZcn9fW_8PnrWd
  - 24 pages
  - Based on world wide community input as sketched above
- Short description of goals, projects and organisation
  - Organisational chart, see below
  - Example for table from Work Area 3 with short description

Table 2: Overview of R&D activities on optical calorimeter concepts.

Name	Calorimeter type	Application	Scintillator/WLS	Photodetector
HGCCAL	EM / Homogeneous	e^+e^- collider	BGO, LYSO	SiPMs
MAXICC	EM / Homogeneous	e^+e^- collider	PWO, BGO, BSO	SiPMs
CRILIN	EM / Quasi-Homog.	$\mu^+\mu^-$ collider	PbF_2, PWO-UF	SiPMs
GRAINITA	EM / Quasi-Homog.	e^+e^- collider	$ZnWO_4$, BGO	SiPMs
SPACAL	EM / Sampling	e^+e^-/hh collider	GAGG, organic	MCD-PMTs, SiPMs
RADICAL	EM / Sampling	hh collider	LYSO, LuAG	SiPMs
DRCAL	EM+HAD / Sampling	e^+e^- collider	PMMA, plastic	SiPMs, MCP
TILECAL	HAD / Sampling	e^+e^-/hh collider	PEN, PET	SiPMs

- Feedback by DRDC on last Thursday
  - Revision until end of October 2023
- Approval of DRD Calo by CERN Research Board on Dec. 6th

DRD Calo – Basic structure



Remark: "Tracks" during proposal phase have been turned into "Work Areas" for DRD Calo Proposal (therefore for this talk "Tracks" = "Work Areas")

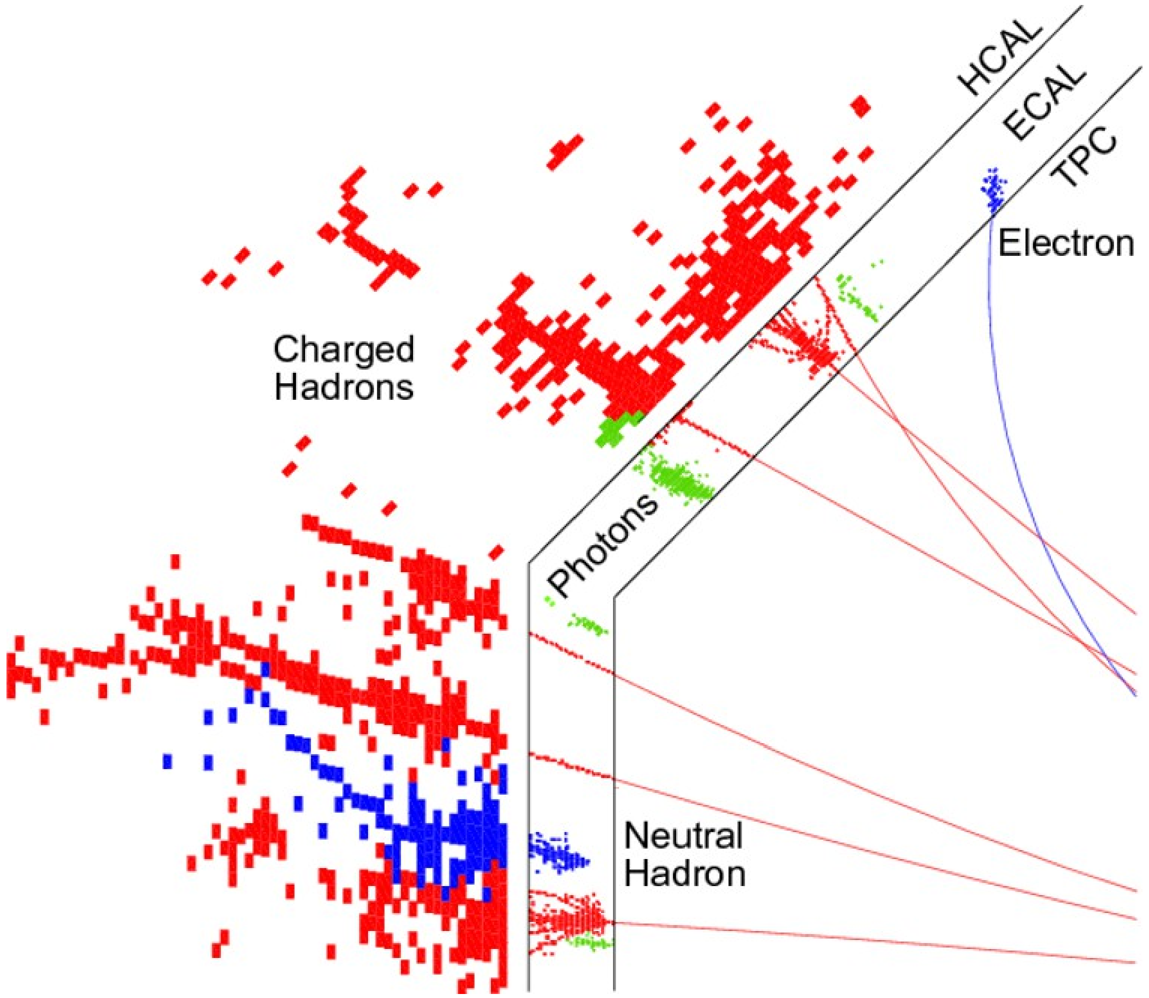
Drawing: G. Gaudi

Ramp up of activities – Rough View

2024 2027 2030

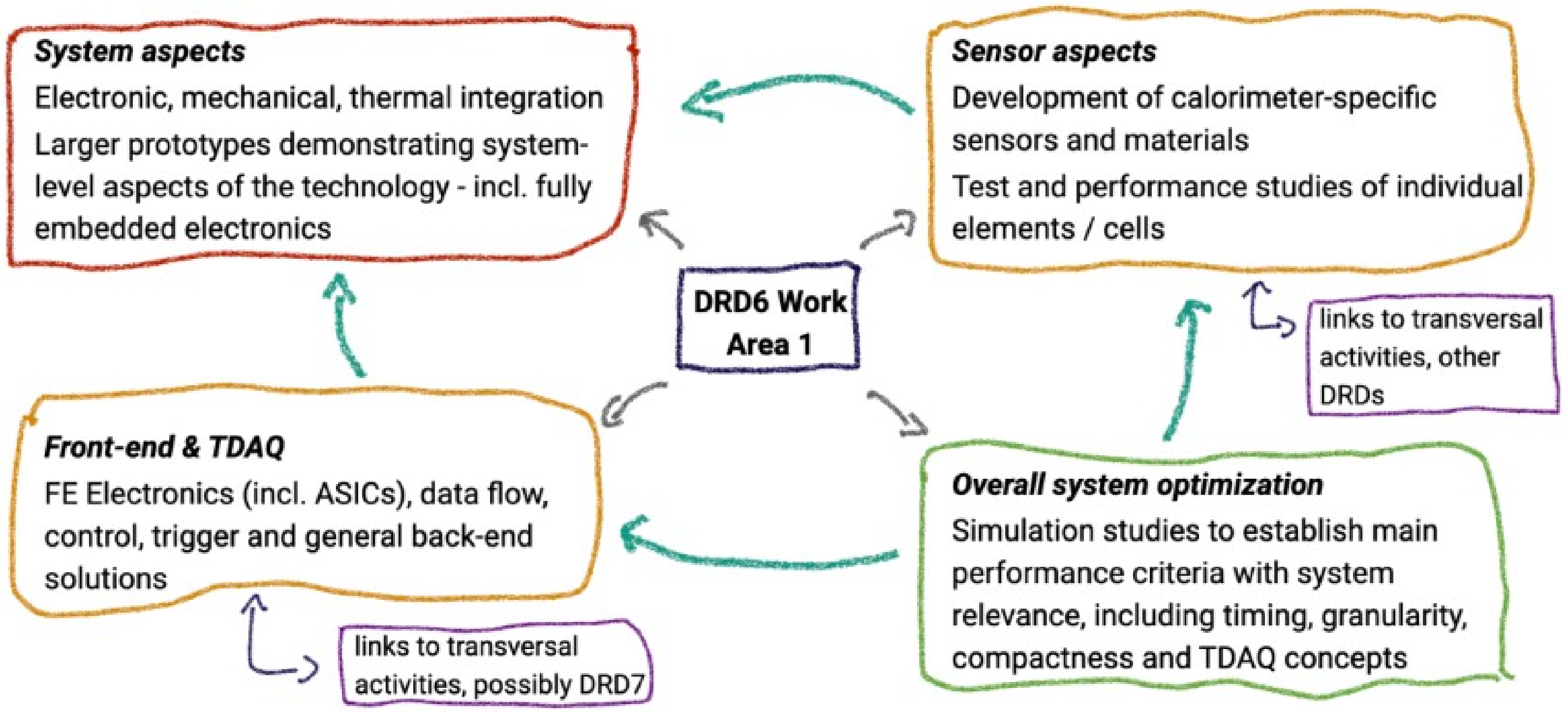
- Input-proposals reveal little (extra) need at the beginning (2024-2026)
  - Start with prototypes that are either existing or currently under construction
  - (Mainly) benefitting from existing funding at national level of international level (i.e. AIDAinnova, EUROLABS in Europe or CalVision, RADICAL in the US [plus maybe others])
  - 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 <u>availability and support</u> of beam test facilities
  - See also later

Work Area 1 – Imaging calorimeters



Imaging calorimeters live on the high separation power for Particle Flow

1st version of DRD Calo Proposal



- Challenges:
  - High pixelisation, 4pi 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 FCCee)

Work Area 2 – Liquid Noble Gas Calorimeters

- Develop the calo design
  - Study design solutions for endcaps
  - Study general performance in simulation, in combination with some HCAL concept
  - Optimize granularity
- Build a first prototype and measure performance in testbeam
  - Need to design and optimize electrodes, absorbers
  - Readout electronics
  - Can then be refined to test further developments / new ideas

4 Work Areas

1. General design and expected performance
2. Readout electrodes
3. Readout electronics
4. Mechanical studies and prototype

WA 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

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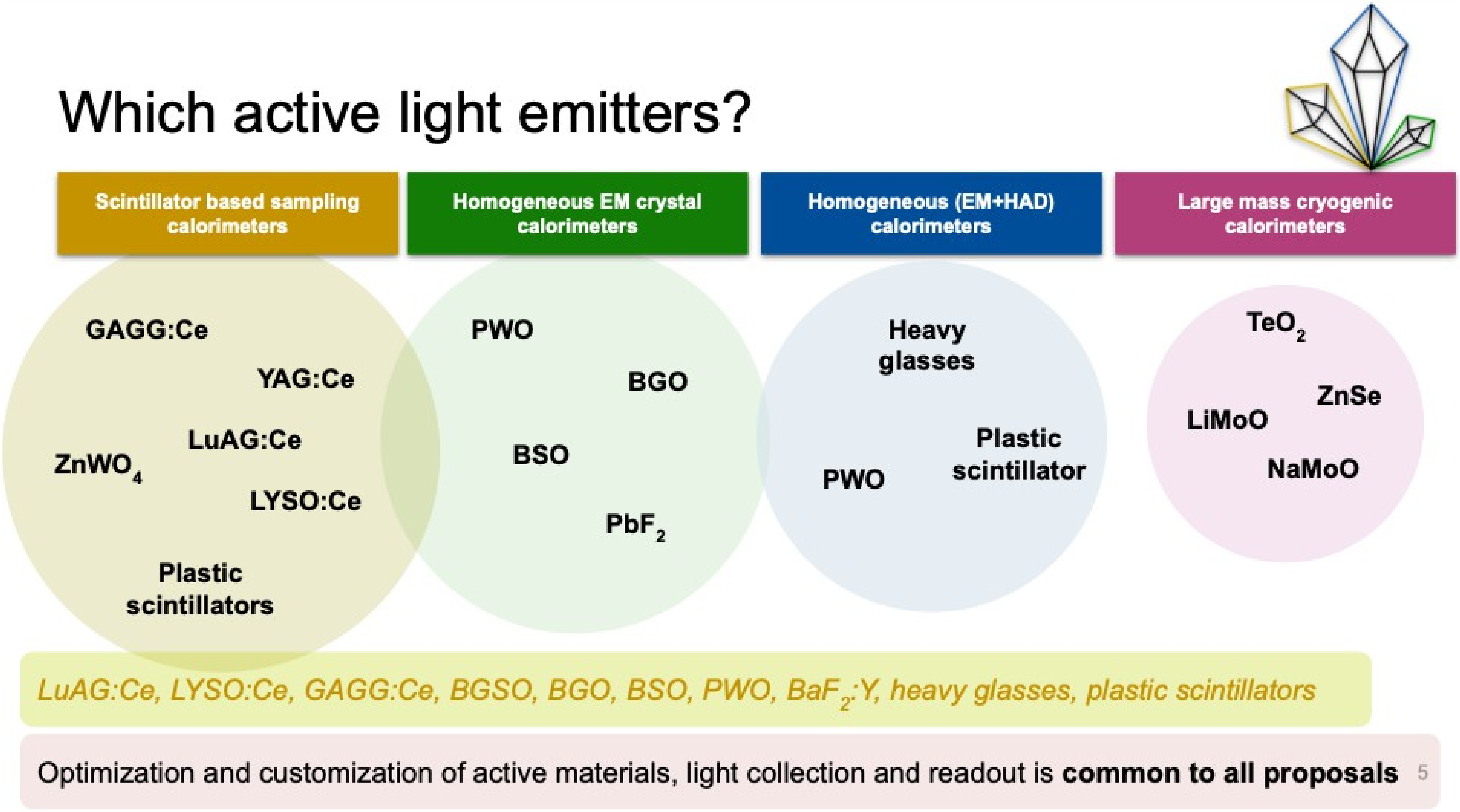
TILECAL	HAD / Sampling	e^+e^-/hh collider	PEN, PET	SiPMs

- Main challenges
  - Find the good optical material
  - Find the adequate photosensor
  - Move from table top to system
    - First project to fully make this step is SpaCal (LHCb)

Materials for optical calorimeters

P. Roloff, M. Lucchini
2nd Calo Community Meeting



- R&D will have to break down the plethora of materials to few on which the R&D will focus on
- Definition of criteria needed!

DRD Calo - The “readout landscape”

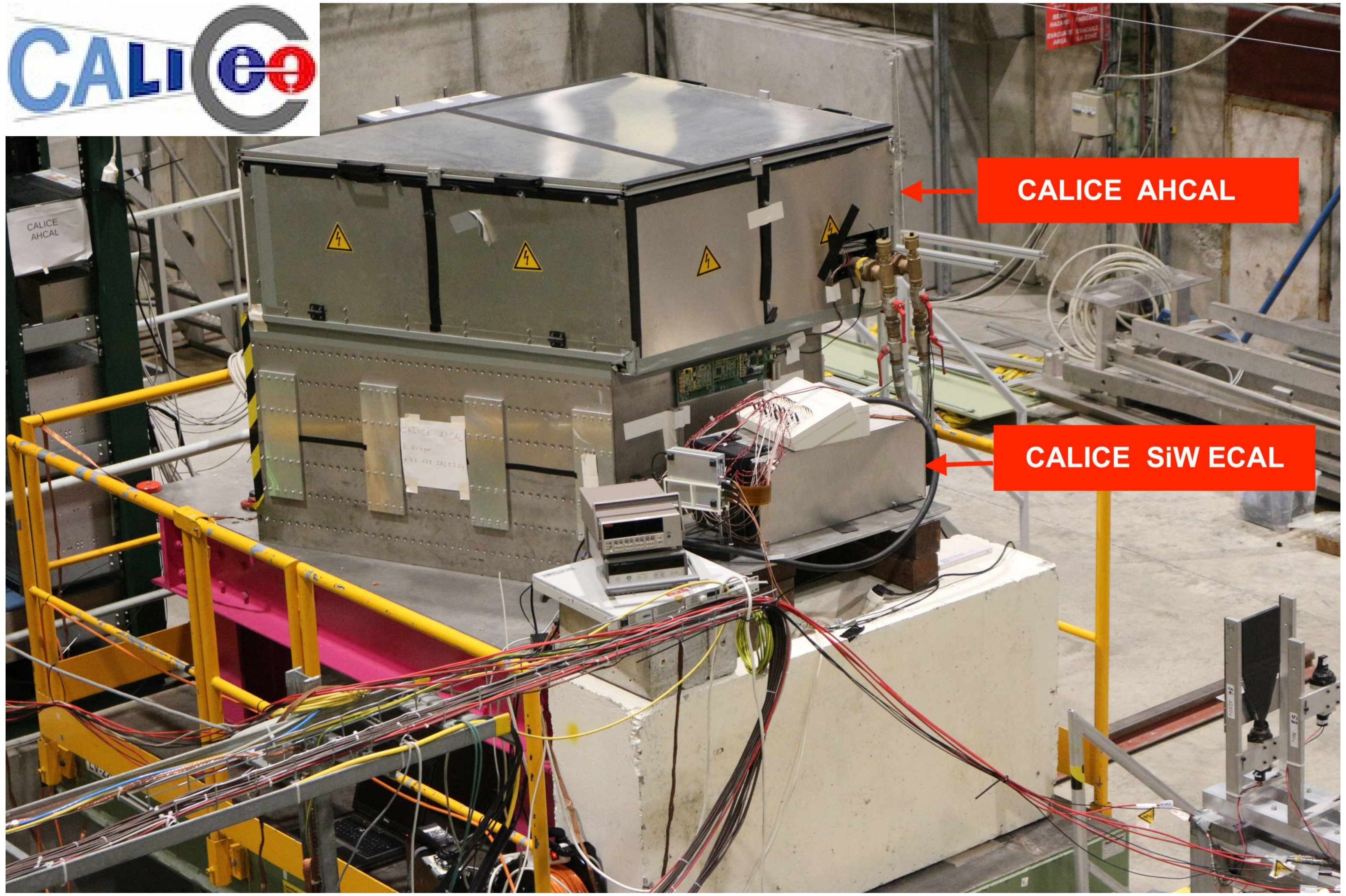
Name	Track	Active media	readout
LAr	2	LAr	cold/warm elx"HGCROC/CALICElike ASICs"
ScintCal	3	several	SiPM
Cryogenic DBD	3	several	TES/KID/NTL
HGCC	3	Crystal	SiPM
MaxInfo	3	Crystals	SIPM
Crilin	3	PbF2	UV-SiPM
DSC	3	PBbGlass+PbW04	SiPM
ADRIANO3	3	Heavy Glass, Plastic Scint, RPC	SIPM
FiberDR	3	Scint+Cher 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

Trends:

- On-detector embedded elx.
  - Challenges: #channels, Low power digital noise, data reduction
- Off-detector electronics: Fibre/crystal readout
  - Challenges:
  - Low power, data reduction
- Digital calorimetry:
  - Challenges:
  - (extreme) #channels, low power, data reduction

Different calorimeter types but similar challenges

Dedicated Calorimeter Beamline?



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 line 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

Further transversal activities and resources

- Photodetectors
  - Many optical systems need in particular novel SiPM --> Overlap with DRD 4
- Unified backend/data acquisition systems
  - Common ASICs should yield common backends
  - EUDAQ as backbone
- Data analysis
  - Calorimeter data have a high scientific value beyond the actual hardware tests
    - GEANT4 comparison including the inclusion into the geant4-val suite
    - Playground for algorithms (there was a dedicated input proposal on that)
  - The full exploitation of data requires the development of data models and the availability of CPU and storage resources
- Human and financial resources are needed to ensure the service tasks
  - => Add 10-15% of HR and financial resources for service tasks
  - Service tasks should be covered from Day 1 on (i.e. 1/1/2024)

DRD Calo – Next Steps

- 28th July 2023 – Submission of DRD Calo proposal

- Now - Autumn 2023
  - Implementation of feedback from proposal review
  - Detailed structure of work areas and transversal activities
  - Consolidation of organisation
    - Formation of a proto-collaboration board
    - Management structure
    - Including roadmap on assigning names to the different boxes
  - Understanding of which kind of documents we will need (MoU/MoA) and by when

- Organisation will benefit from experience by existing R&D Collaborations (see above)

- 1st January 2024 – DRD on Calorimetry in place
  - Kick-off Meeting Spring 2024?

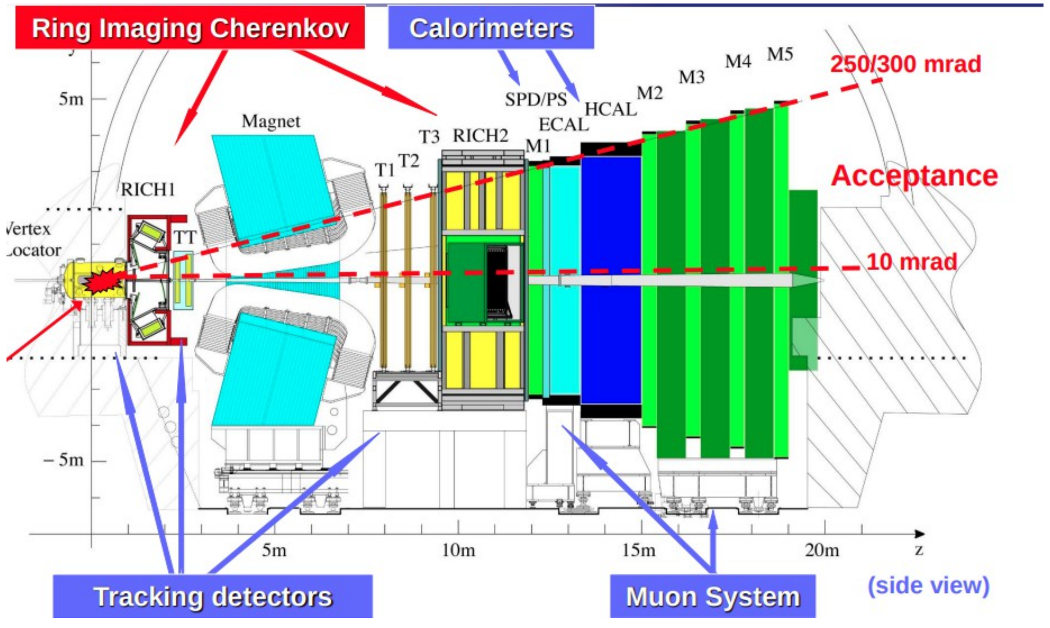
Conclusions

- DRD on Calorimetry will pursue strategic R&D for calorimeters for future colliders
  - Partially new efforts, partially capitilising on existing activities
- Programme will cover wide area of calorimeters that are suited to meet the DRDT
  - Programme compiled based on Community consultation
  - A worldwide effort with pure European, European/non-European, pure non-European projects
- Separation in three work areas and several transversal activities
  - Transversal activities ensure synergies within DRD Calo and with other DRDs
  - Strong links to other DRDs
- Discussion to (concretely) set up the DRD are making progress in proposal team
- **Goal is to have the DRD Calo in place on January 1st 2024**
- It is important to organise the R&D on a worldwide level and to avoid duplication
  - This is true for actual R&D items and for the overall organisation
  - Meeting like tho one today are instrumental to achieve these goals

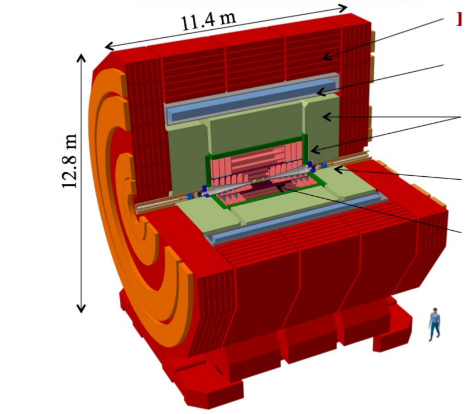
Backup

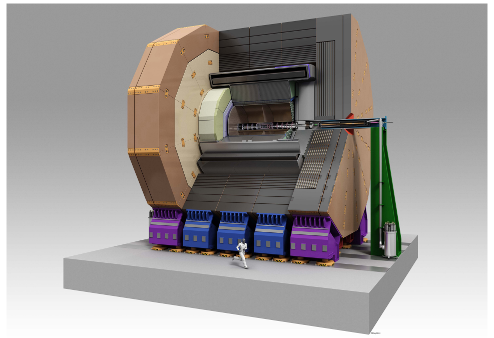
(Main) Target Projects of Detector R&D

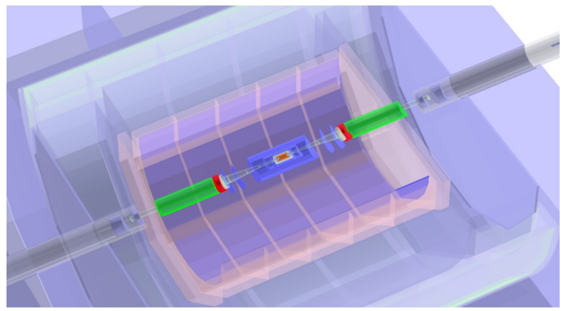
HL-LHC after LS4

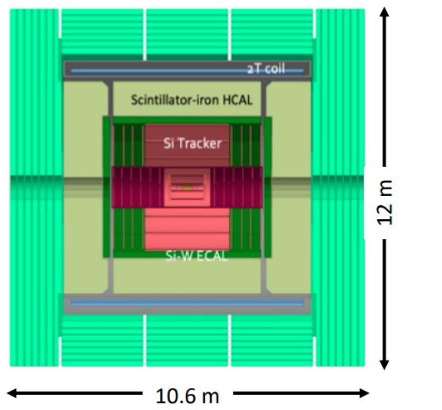


Higgs Factories

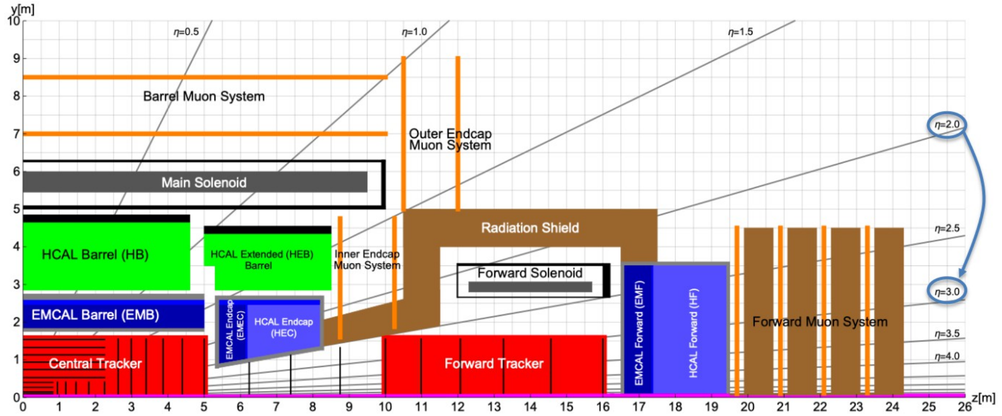




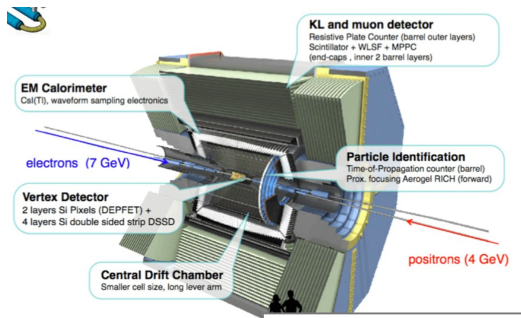


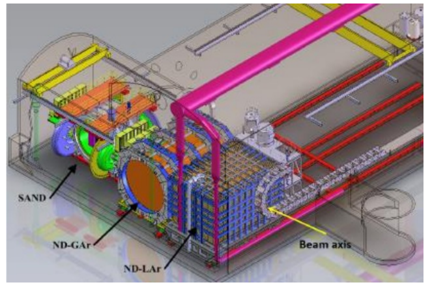


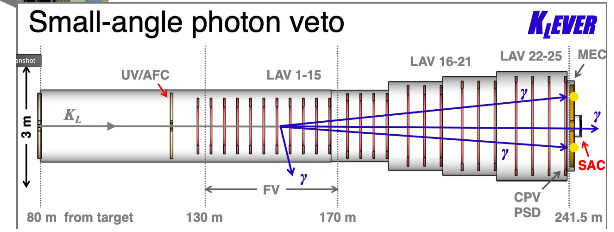
Future hadron colliders (including eh colliders)



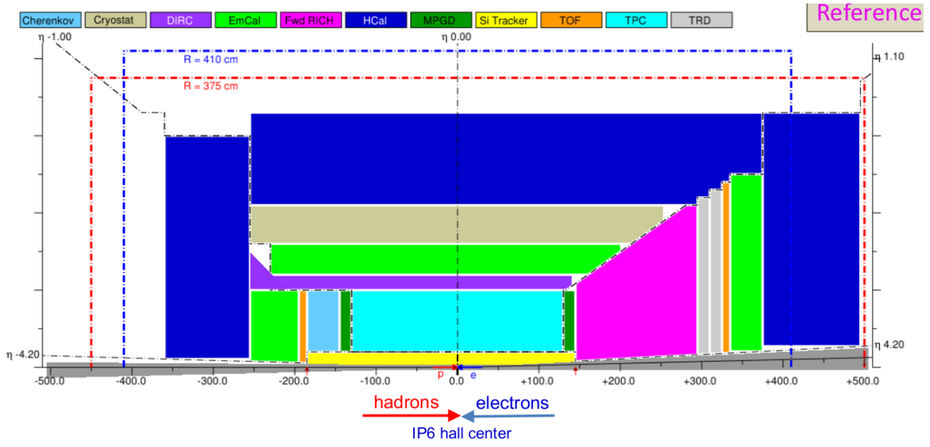
SuperKEKB, DUNE ND and Fixed Target



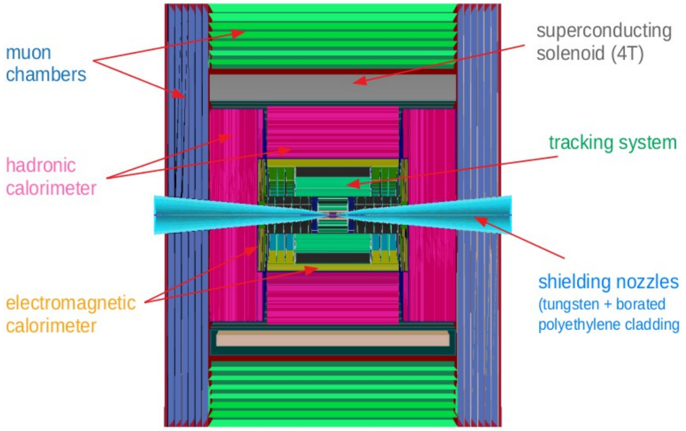




EiC



Muon Collider



Common ASICs development within DRD Calo

- The main goal will be to avoid parallel developments
  - Take CALICE as example
- ASICs needed for prototypes > 2025/26 should be produced in a common MPW run that serve many projects within DRD Calo
  - ASICs for prototype that should take data in ~2027 have to be available latest around one year earlier
- => Common ASICs production will be one overarching goal of the DRD Calo
- Evoke possibility to hook onto production for other large projects (EiC?)
  - Agree on sharing among DRD Calo institutes and maybe with MPW runs in other DRD
- Requires close communication with DRD 3 and DRD 7

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) for each of the taskforce topics
  - 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

Developments in 2022

*In December 2021, ECFA was invited by CERN Council to elaborate, in close contact with the SPC, funding agencies and relevant research organisations in Europe and beyond, a **detailed implementation plan***

*Likewise, the European Lab Director Group (LDG) was mandated to work out an implementation plan for the **Accelerator R&D Roadmap***

K. Jakobs, ECFA Meeting, November 2022

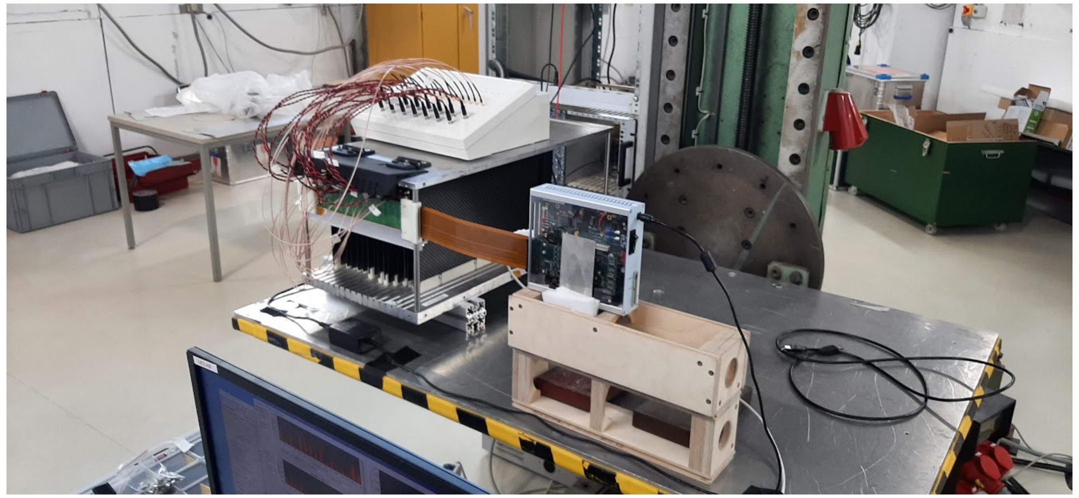
- ECFA Roadmap Coordination group has worked out a proposal that was broadly discussed and finally endorsed by CERN Council in September 2022 (CERN/SPC/1190)
  - P. Allport, S. Dalla Torre, J. D'Hondt, K. Jakobs, M. Krammer, S. Kühn, F. Sefkow and I. Shipsey
    - D. Contardo joined end of 2022
- Main outcomes are the organisation of the Detector R&D in form of DRD (Detector R&D) Collaborations, the overall organisation of the detector R&D and an outline of the way towards the formation of the DRD Collaborations
- Main ideas to form DRD:
  - Bigger entities allow for assembling the critical mass for strategic R&D
  - Bigger entities are easier to review

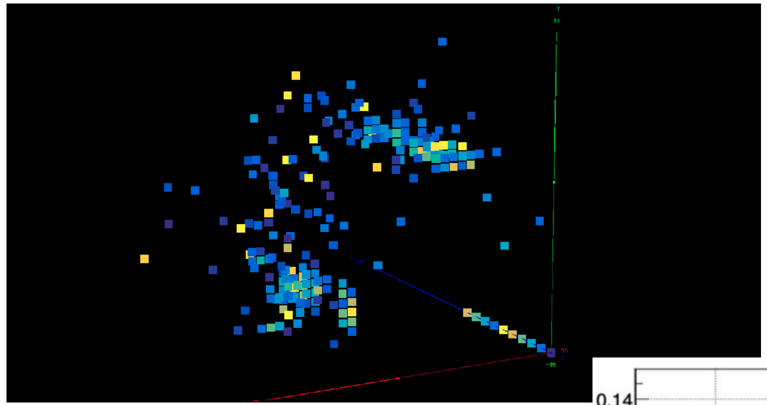
Proposal Cryogenic Calo for Double Beta Decay

- Proposal for Double Beta Decay with IN2P3 Participation
  - Submitted to DRD Calo but might be better hosted elsewhere
  - In contact with DRD 5 conveners (Meeting on Friday 16/6/23)
  - Partners:
    - IN2P3: IJCLAB (Pole APC)
    - Others: U Milano-Boccia/INFN Milano, La Sapienzia Rome/INFN Rome, INFN Gran Sasso, INFN LNL, CEA-Irfu

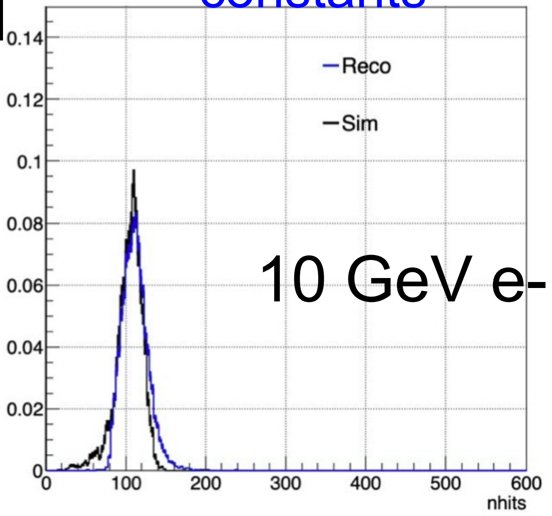
Imaging calorimeters – Testbeams 2022/23

Silicon tungsten (SiW) Ecal





- 15 layers
- 15000 cells 5x 5mm^2
- **Analogue** r/o
- 450000 calib constants

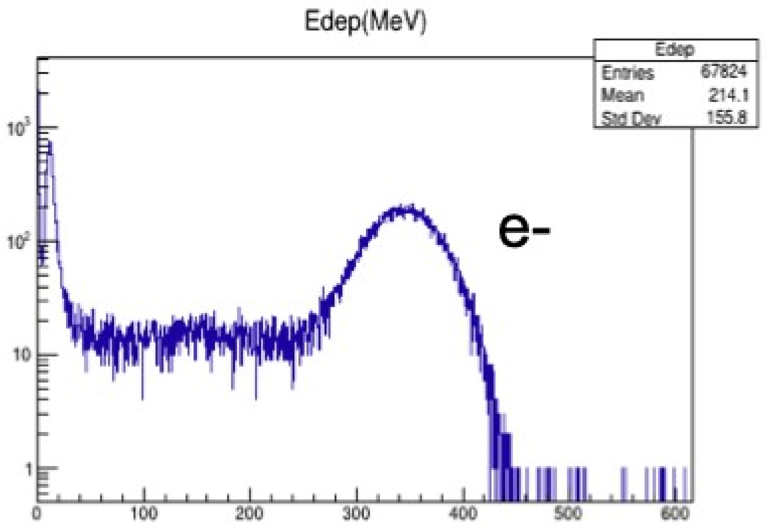


Getting control

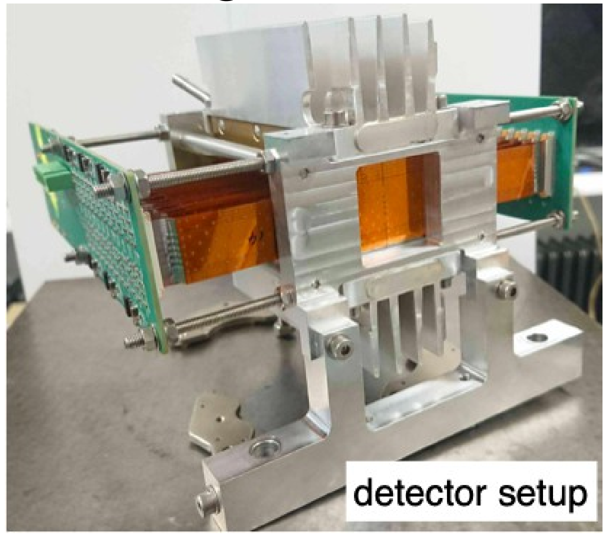
Scintillator Tungsten ScEcal

- 16 layers
- 7000 strips 5x45 mm^2
- Analogue r/o

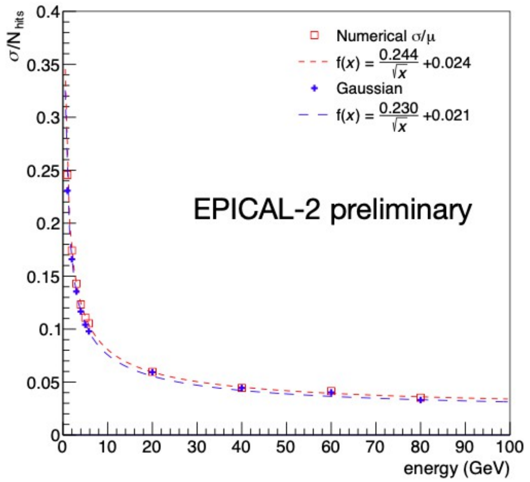
10 GeV/c



Digital ECAL



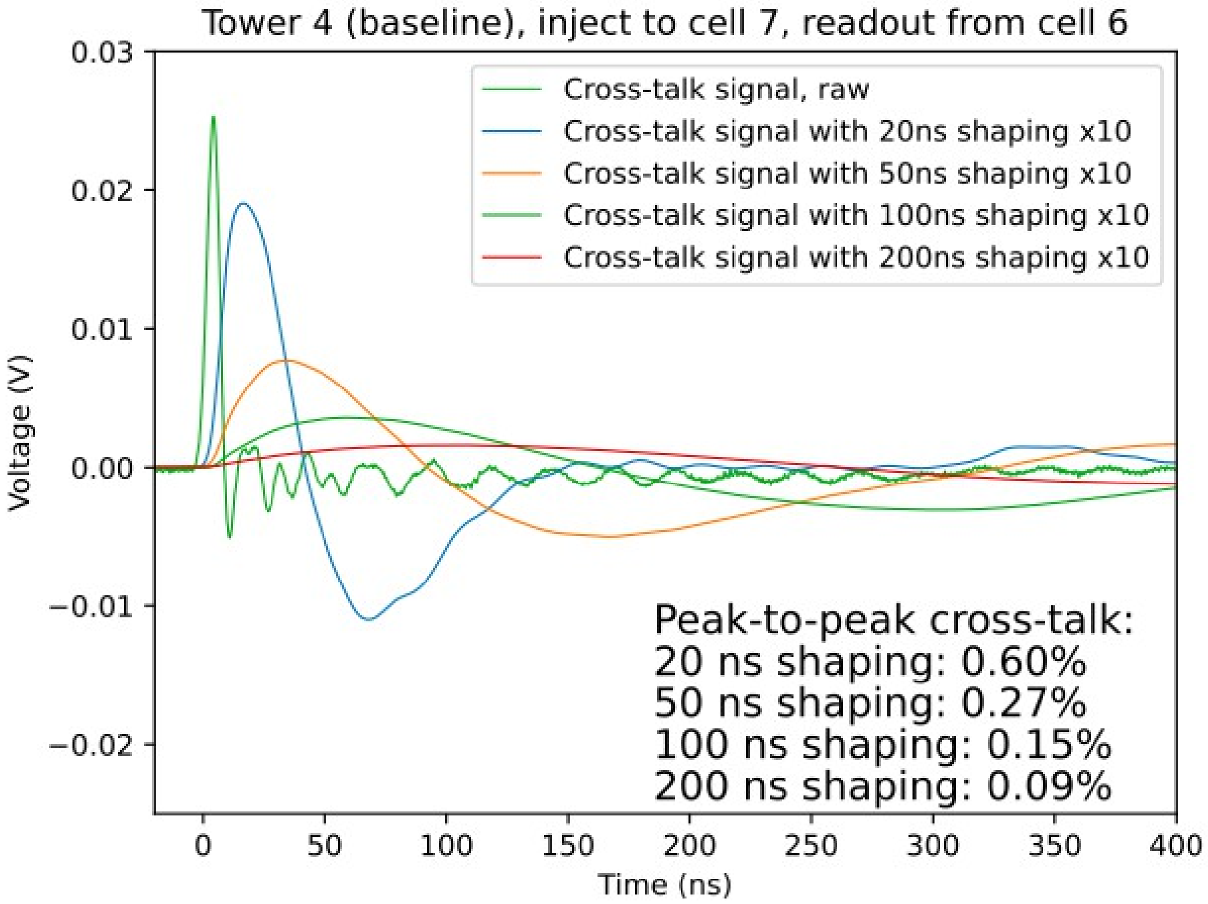
- 24 layers with each
  - 3mm tungsten absorber
  - 2 Alpide CMOS Sensors (NIM A 845:583-587, 2017)
  - Ultra thin flex cables
- 29.24x26.88 µm2 pixel size
  - Active surface 3x3 cm2



R&D for Liquid Noble Gas Calorimeters

Highly segmented -> highly dense PCB

"Greatest enemy": Cross talk



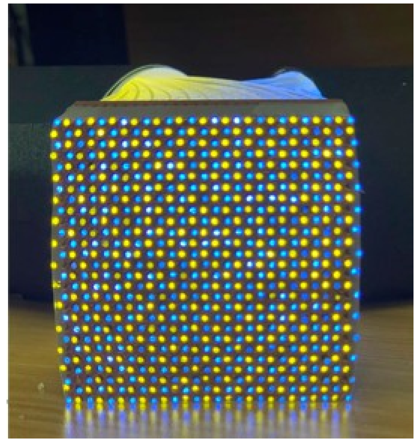
Long shaping time helps

N. Morange, 2nd Calo Community Meeting

Dual readout calorimetry – Building Blocks

Fast signals

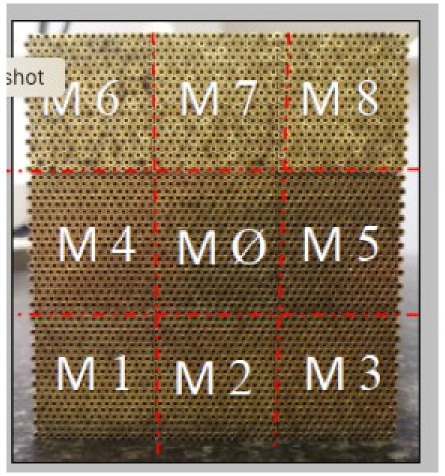
Slow signals



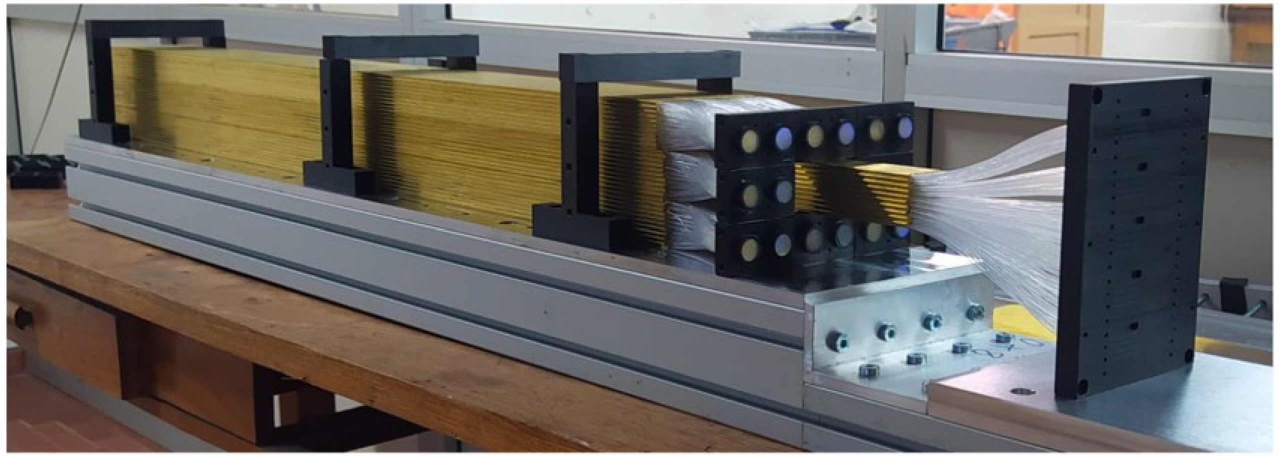
Dual readout to capture Electromagnetic and hadronic components of shower

Prototype development

- First step "electromagnetic prototype" 10x10x100cm^3
  - Qualification of
    - Assembly procedure
    - Readout systems



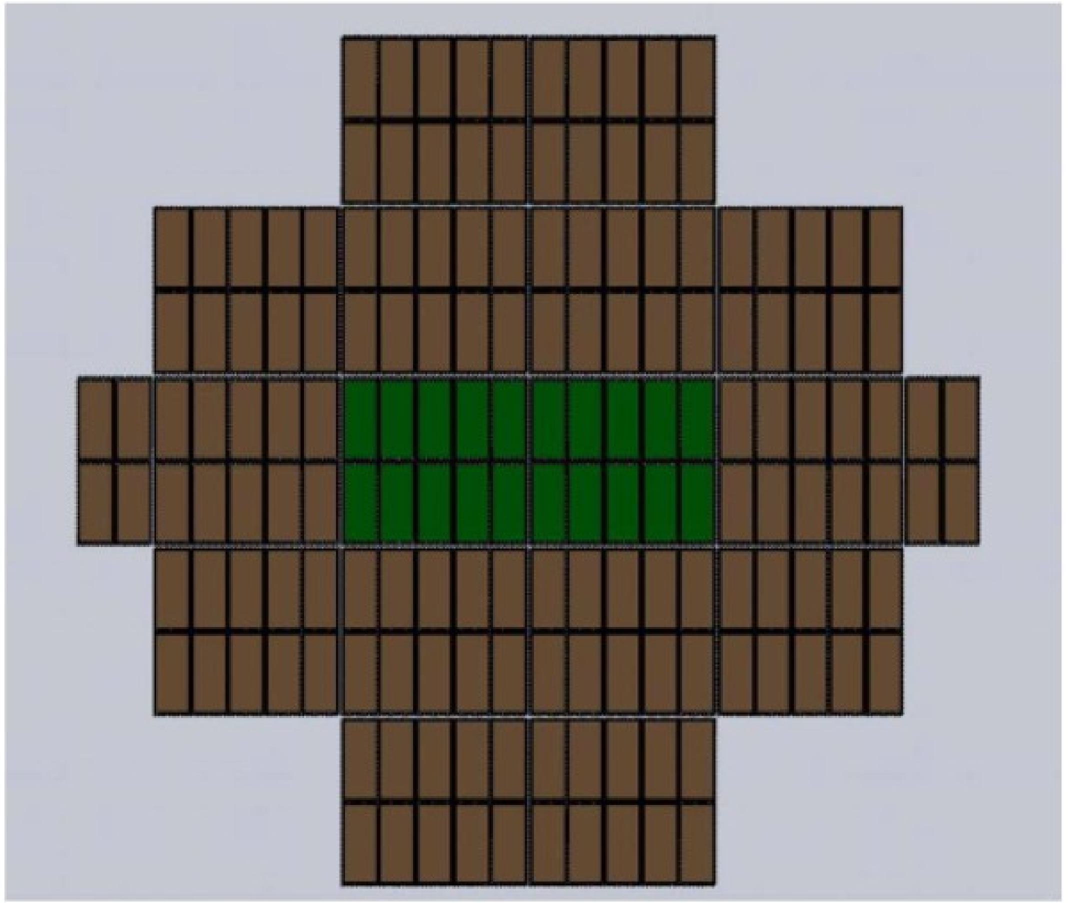
Stack of capillaries



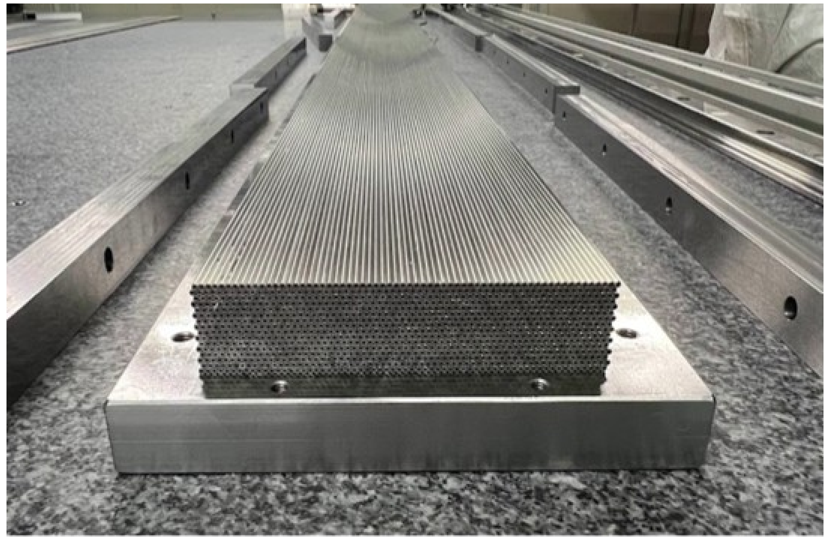
Outgoing fibres guided to readout plane

Dual readout calorimetry – Towards large prototype

Prototype with hadronic containment

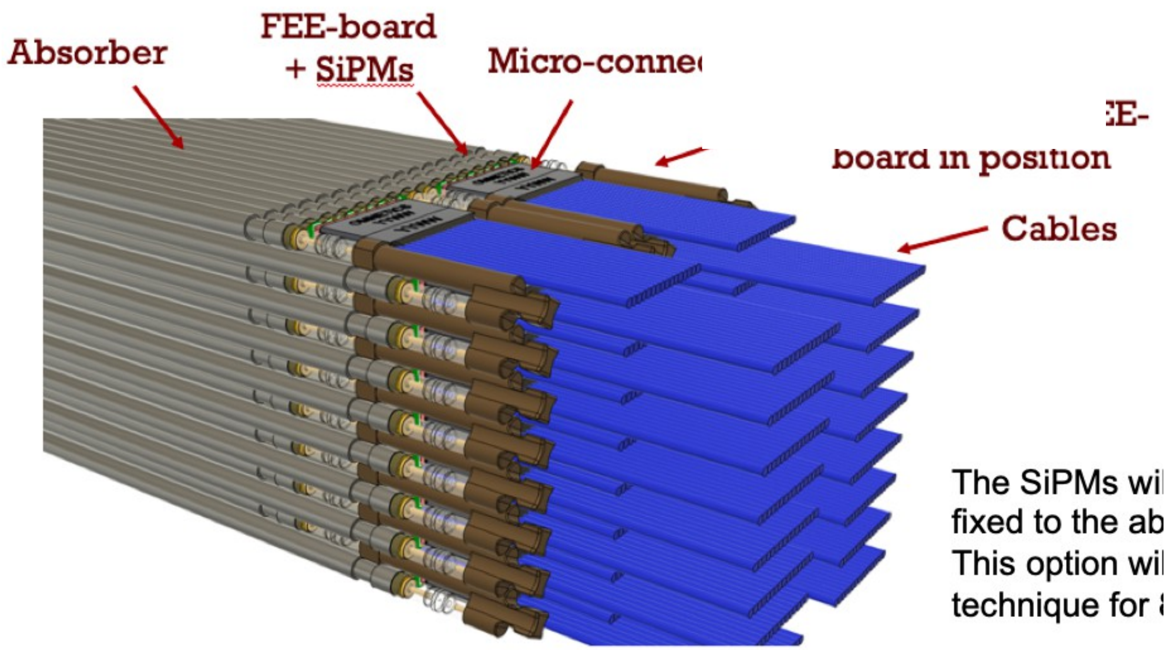


- 65x65x200 cm^3
- 17 modules in total
- 2 central modules equipped with SiPMs
- 15 modules equipped with PMTs



Under construction as we speak

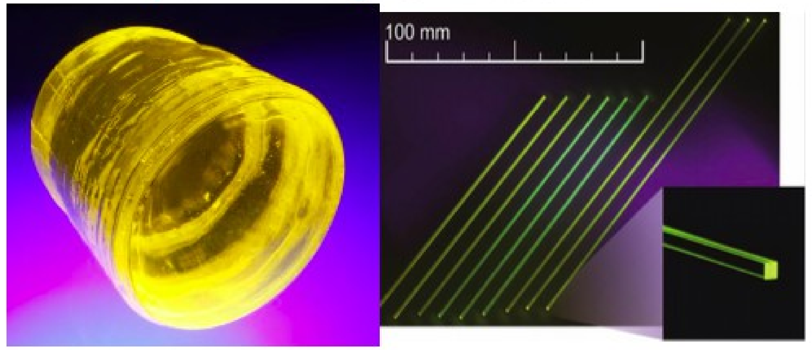
Major challenge SiPM integration



Novel optical materials

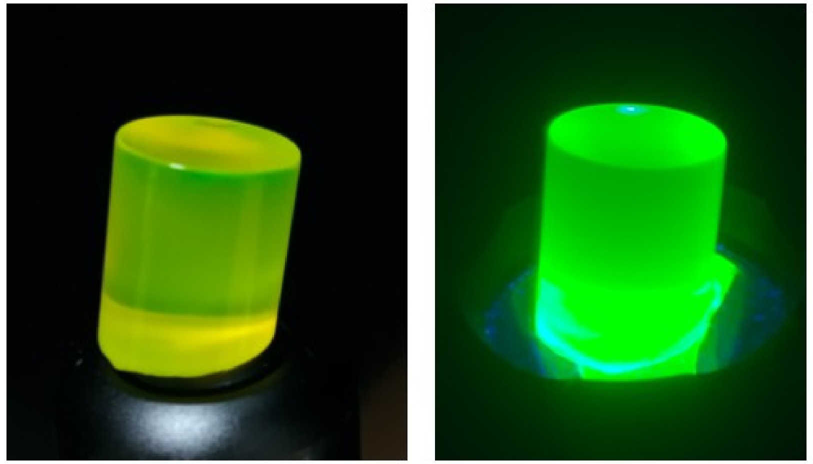
- Radiation hard optical materials with ultrafast timing response are required for new detectors in HEP, nuclear medicine and industry
- A time resolution below 30 ps or even in the sub ps domain requires a better understanding of the fast signal production mechanisms in detection materials
- Innovative test suites required for the combination of fast timing and radiation tolerance will be developed for the characterisation and classification of materials
- Scalable and cost effective production techniques for the novel materials have to be explored together with the industrial partners

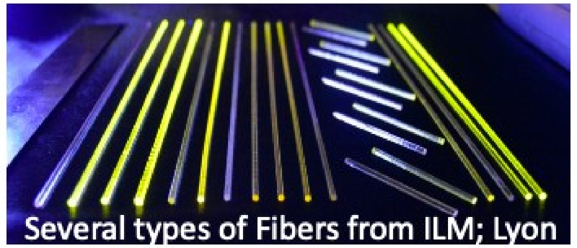
Crytur YAG ingots => fibers



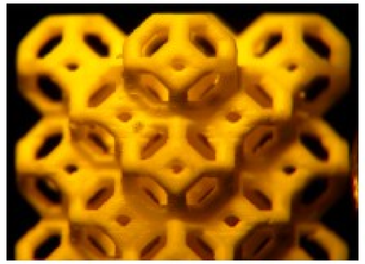
Crytur PWO crystals

GlasstoPower development on quantum materials





3 D printed garnet Crystals



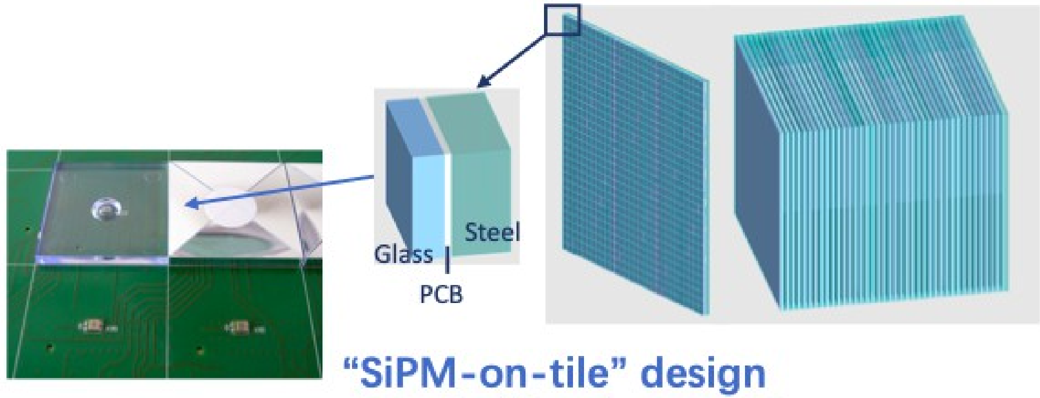
Courtesy G. Dosovitskyi, Kurchatov Institute

Glass Scintillators – The bright future?

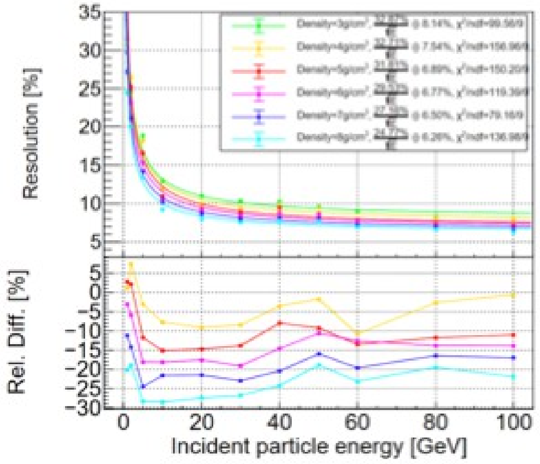
Glass scintillator HCAL

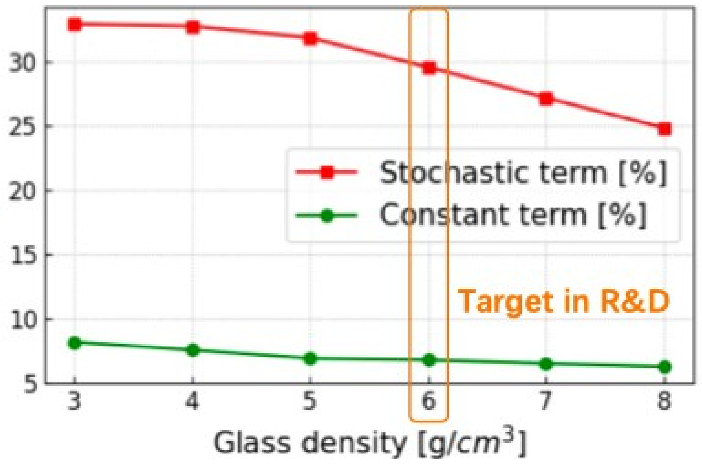
- **Motivation: better energy resolution**
  - Higher density ➡ higher sampling fraction.
- **Validate with standalone simulation:**
  - $\lambda_I = 23.83$ cm, MIP response ~7 MeV/cm.
  - Standalone simulation of glass-steel:
    - 40 layers, total depth 5λ.

Sen & Dejing, TIPP 2023



"SiPM-on-tile" design
AHCAL-like glass HCAL





- HCAL resolution can be improved with higher density.
- Consider $6\ g/cm^3$ as glass scintillator R&D target (a balance with the light yield).

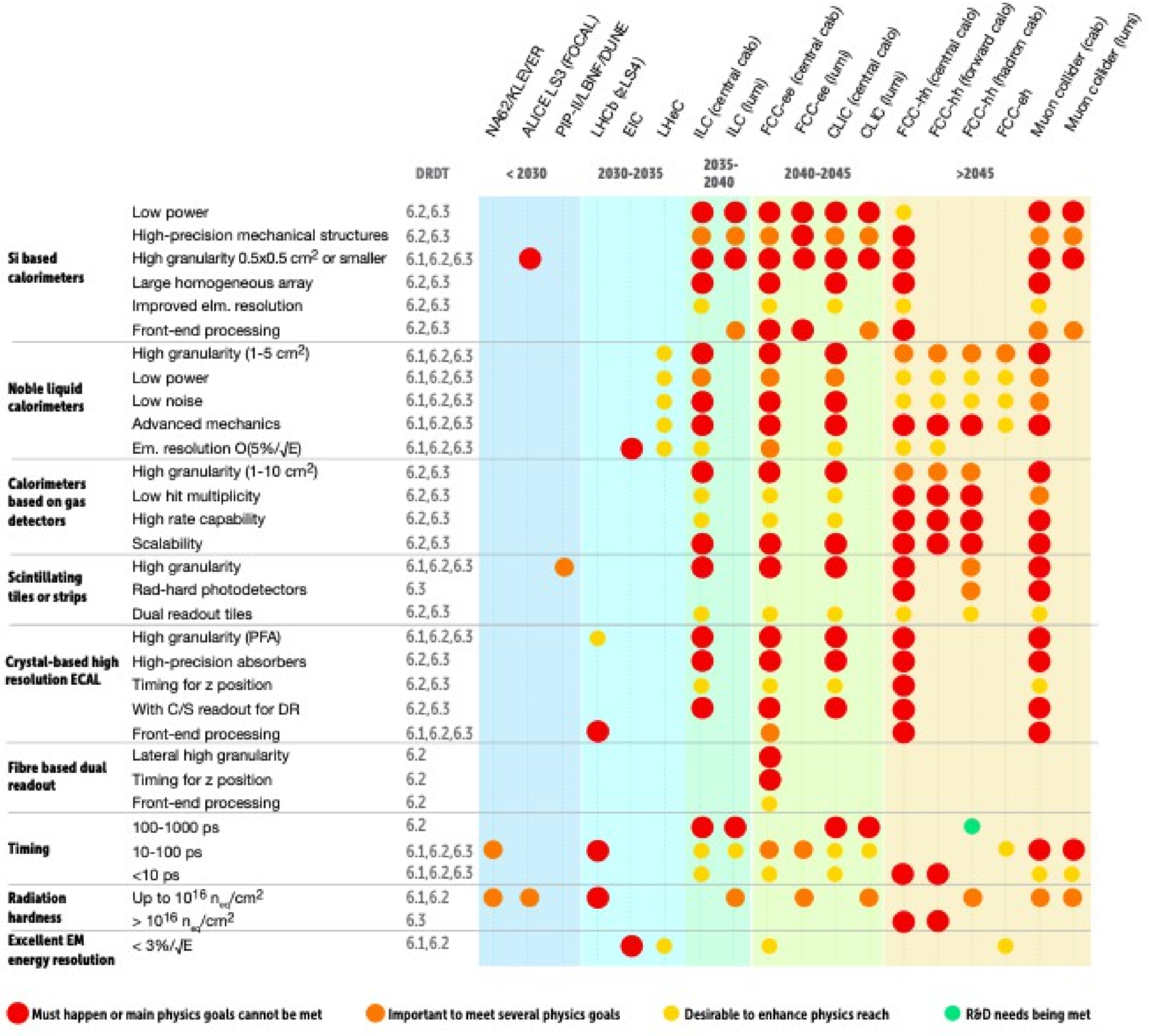
2023/10/11 Fangyi Guo | Second ECFA Workshop, 2023 16

Two points to take home (my understanding):

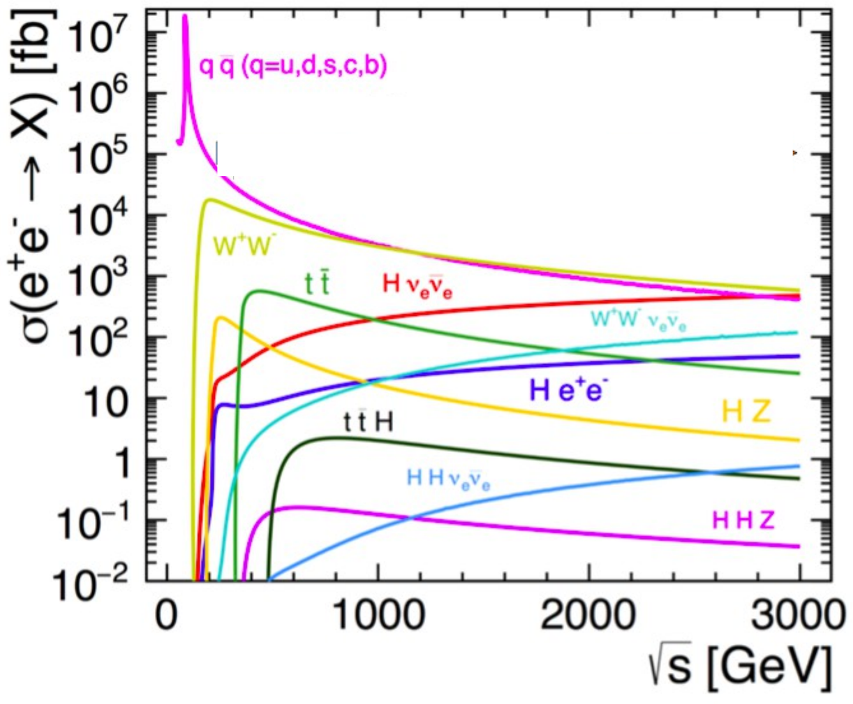
- Would be relatively cheap
- Problem is optial diping to achieve transparency

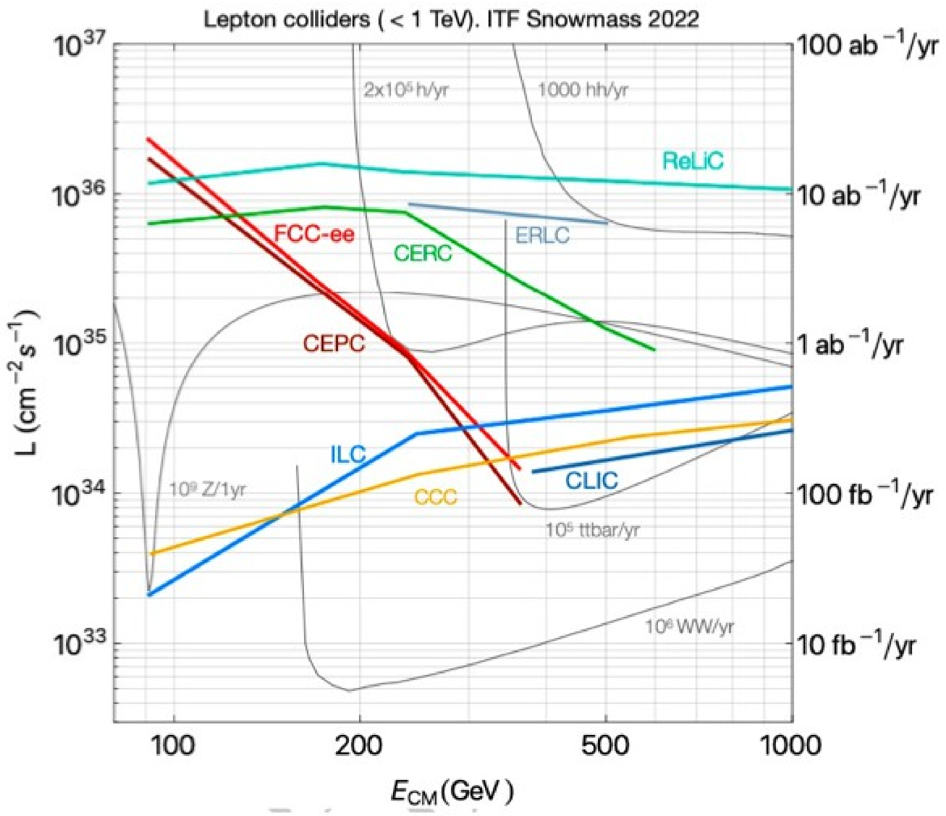
Calorimetry- Identified Key Technologies and R&D Tasks

- 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



Future direction of R&D - Impact of event rates





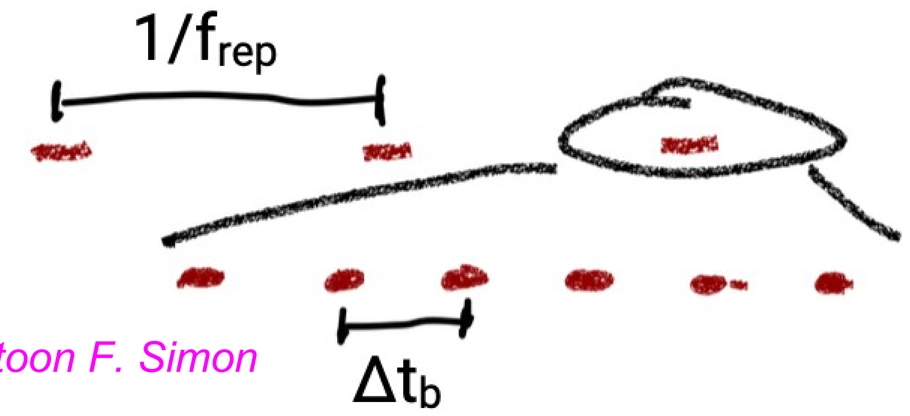
High energy e+e- colliders:

- Physics rate is governed by strong variation of cross section and instantaneous luminosity
- Ranges from 100 kHz at Z-Pole (FCC-ee) to few Hz above Z-Pole
- (Extreme) rates at pole may require other solutions than rates above pole

- Event and data rates have to looked at differentially
  - In terms of running scenarios and differential cross sections
  - Optimisation is more challenging for collider with strongly varying event rates
    - Z-pole running must not compromise precision Higgs physics

Operation mode- pulsed or continous

- Linear Colliders operate in bunch trains



Cartoon F. Simon

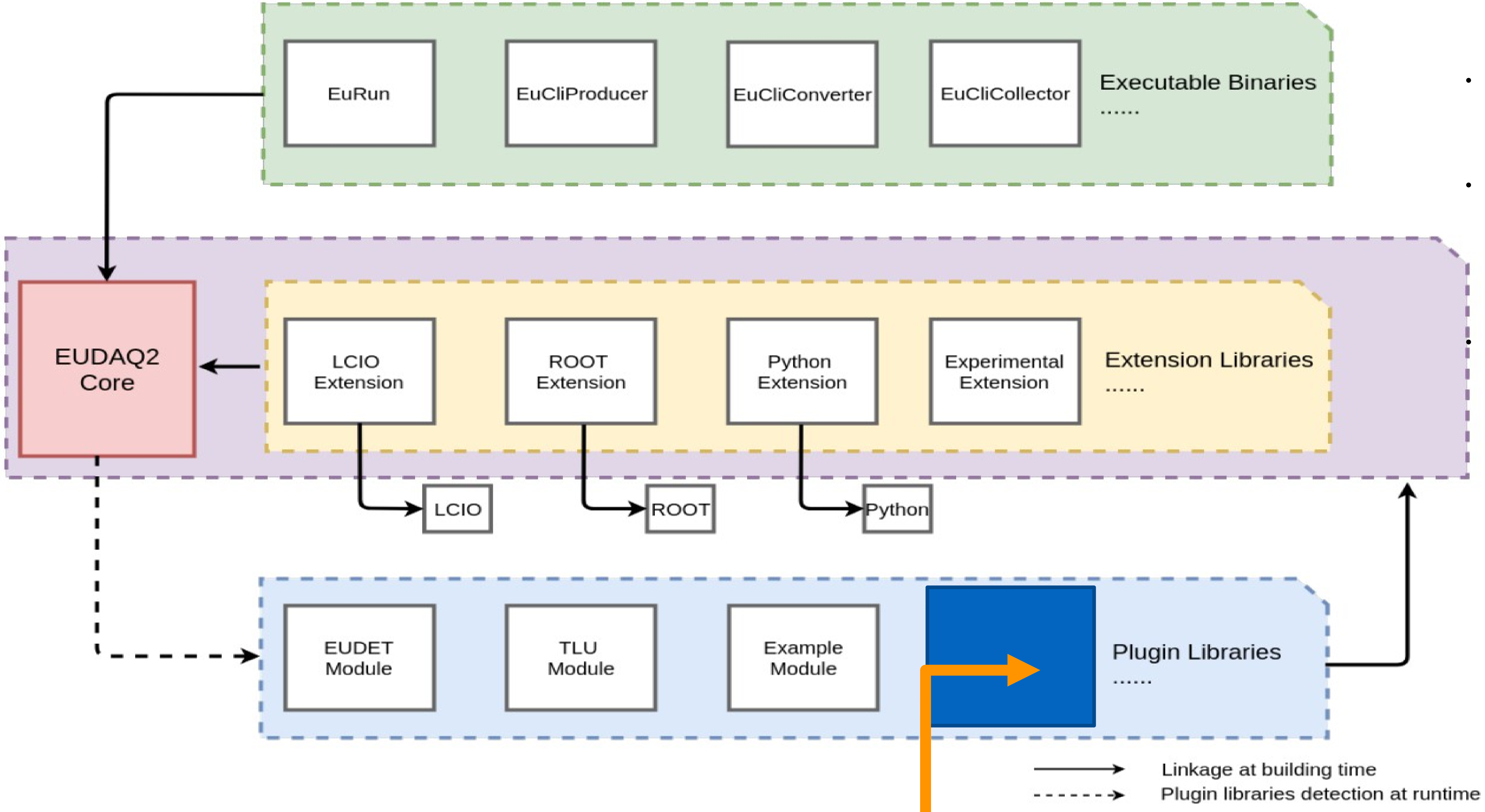
CLIC: Δt_b ~ 0.5ns, frep = 50Hz
ILC: Δt_b ~550ns, frep = 5 Hz (base line)

- Power Pulsing reduces dramatically the power consumption of detectors
  - e.g. ILD SiECAL: Total average power consumption 20 kW for a calorimeter system with 10^8 cells
- Power Pulsing has considerable consequences for detector design
  - Little to no active cooling
  - => Supports compact and hermetic detector design

- Upshot: Pulsed detectors face other R&D challenges than those that will be operated in “continuous” mode
  - R&D Goal: Avoid/minimise active cooling also in continuous mode
  - Challenge differs depending on where the electronics will actually be located

Future Homogeneous Calorimeters

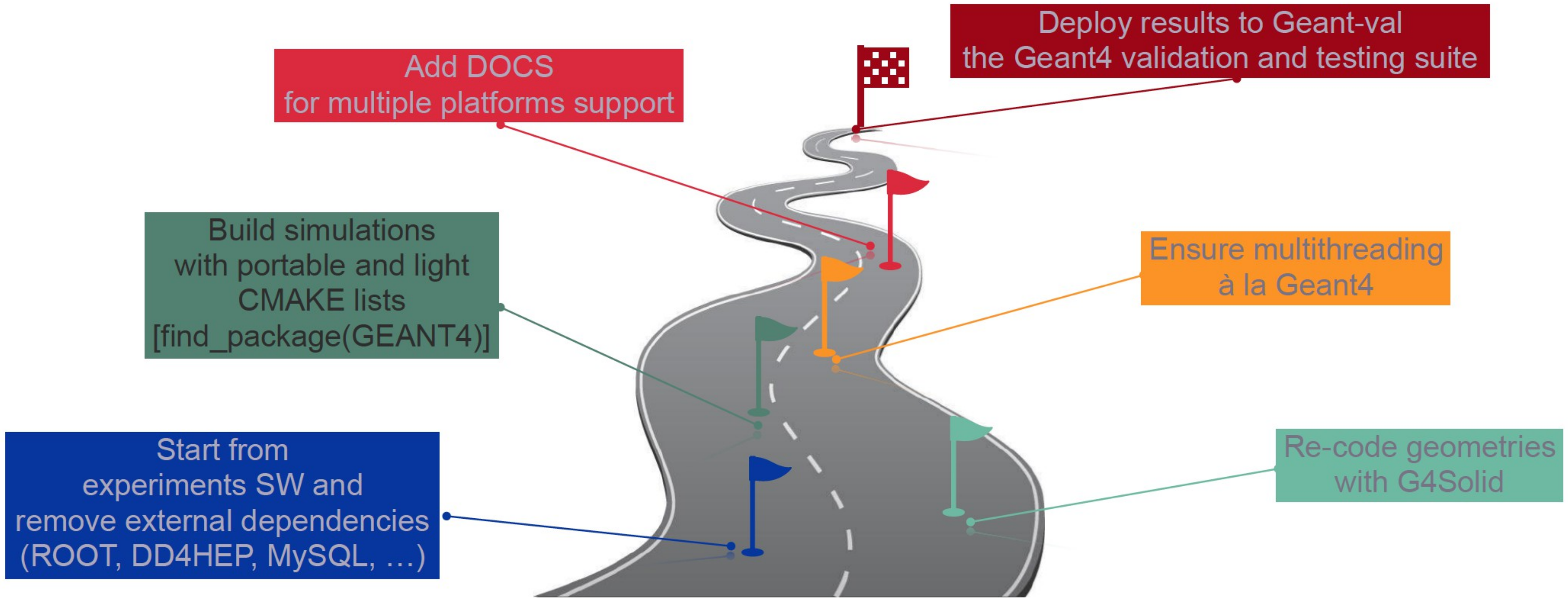
EUDAQ Data Acquisition Systems



PUT your calorimeter library here!

- Implementation of custom producers is rather simple
- easier integration with other eudaq producers (TLU, Telescopes)
- Already a long list of custom producers integrated:
  - CALICE SiWECAL,
  - CALICE AHCAL,
  - CALICE SiWECAL + AHCAL,
  - CMS HGCAL silicon prototype + CALICE AHCAL, ...

From experiments to geant-val, a winding road



geant-val.cern.ch

Geant-val is the Geant4 validation and testing suite.

For the Community, it allows to deploy results on a common data-base and fetch the information via a web-interface.

For the developers, it allows to Create multiple jobs over beam energies, particle types, physics lists

Better to involve G4 collaboration at the beginning of the testbeam. G4 collaboration available to help with the geant4-val inclusion

Complex Calorimeters – A playground for modern algorithms

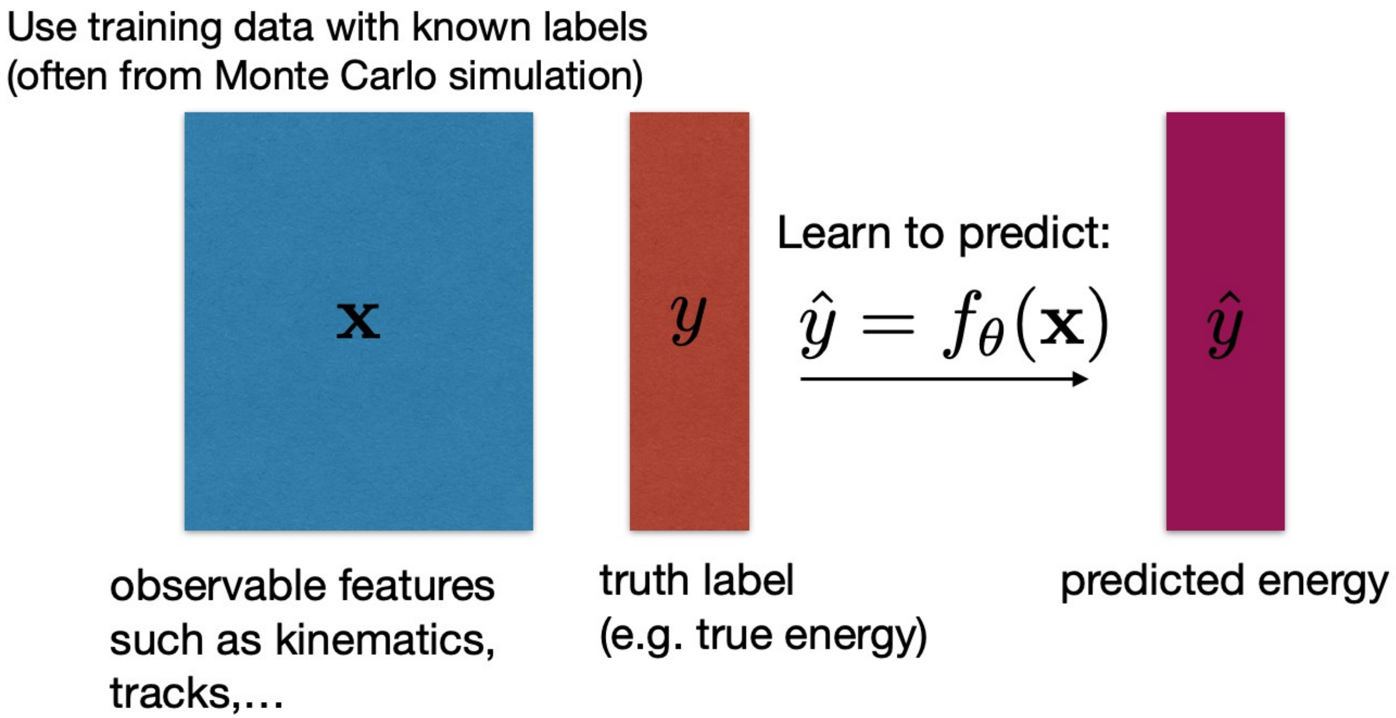
Tommaso Dorigo and MODE Collaboration

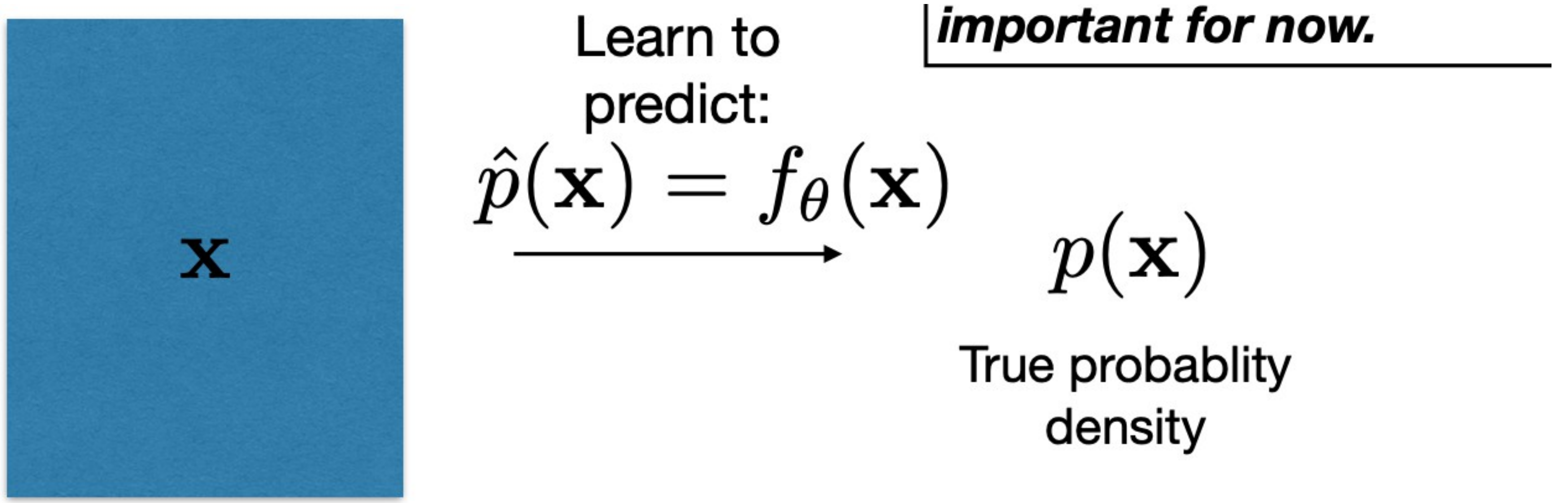
Machine Learning approach is gaining more and more importance in HEP and in calorimetry in particular

highly complex data with large number of detailed information

Simulation provides tagged data for supervised learning

Tracking, clustering, particle ID ...





ECFA

CERN Schedule according to recent MTP

European Strategy Update