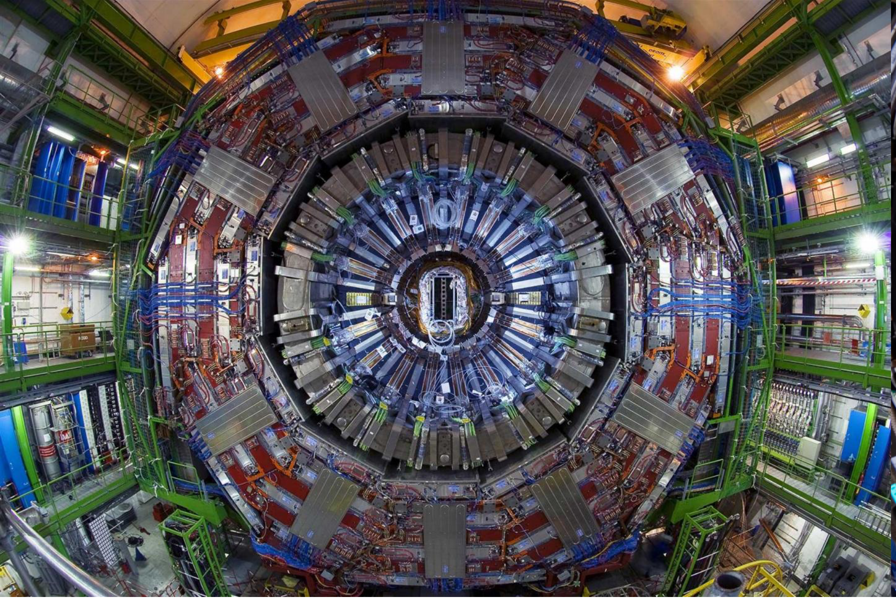
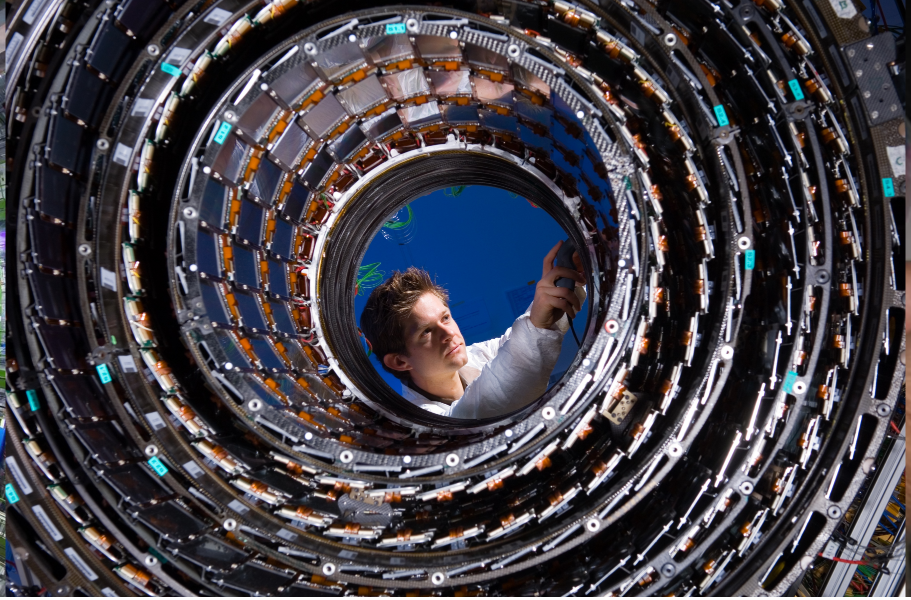
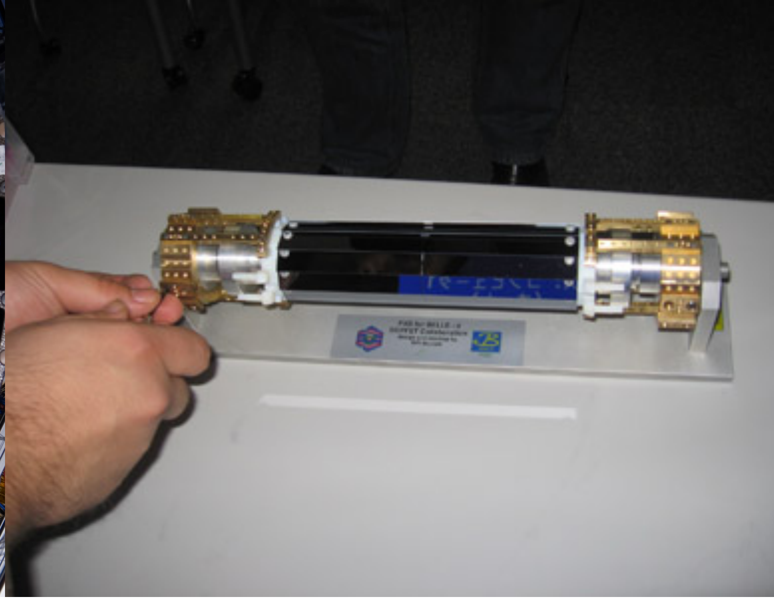




# Detector R&D for Future HEP Experiments

## Technologies, Infrastructures, Organisation

Symposium on the European Strategy for Particle Physics Update

Granada, May 14, 2019


Felix Sefkow
DESY


European Strategy Update

DESY

# Charge and Outline

## For this talk

Service to the community:

**Review the inputs** submitted to the EPPSU, and take into account these submissions in the preparation of their presentation.

Identify what are **key technologies** to develop in order to address HEP future needs

Identify **most promising R&D areas**

Discuss how the required R&D activities should/can be **supported and coordinated**

Identify **tools, platforms, common infrastructures and test facilities r**equired to carry out the required detector R&D.

**Inputs and landscape**

**Key technologies and R&D**

**Common infrastructures**

**Coordination and support**

Build on preceding presentations:

An R&D overview talk without discussion of past highlights, future requirements, emerging technologies and spin-offs… 🤔 🙇

# Input Received

## Documents Submitted for the ESPPU, and More

**36 documents with reference to detector development**

**Many emphasise the feasibility of proposed experiments, highlighting previous accomplishments**

for example ILC related submissions

**Most relevant with broad perspective:**

**16: CERN** strategic R&D programme

**68: ECFA** detector panel report on community survey

**Other submissions pointing out R&D directions:**

e+e- experiments: CLIC, CEPC and SCT

High rates and radiation: LHCb, TauFV, KLEVER

MAPS for Heavy Ions: ALICE, NA60+

Physics Beyond Colliders: SHIP, LDMX,..

Gas detectors: RD51

Cryogenic detectors: Darkside, DARWIN

Neutrino near and far: CENF, DUNE

Quantum sensors: APS, MAGIS

**I will certainly fail to do justice to all - apologies!**

**In addition I benefited enormously from discussions with my colleagues and advisors**

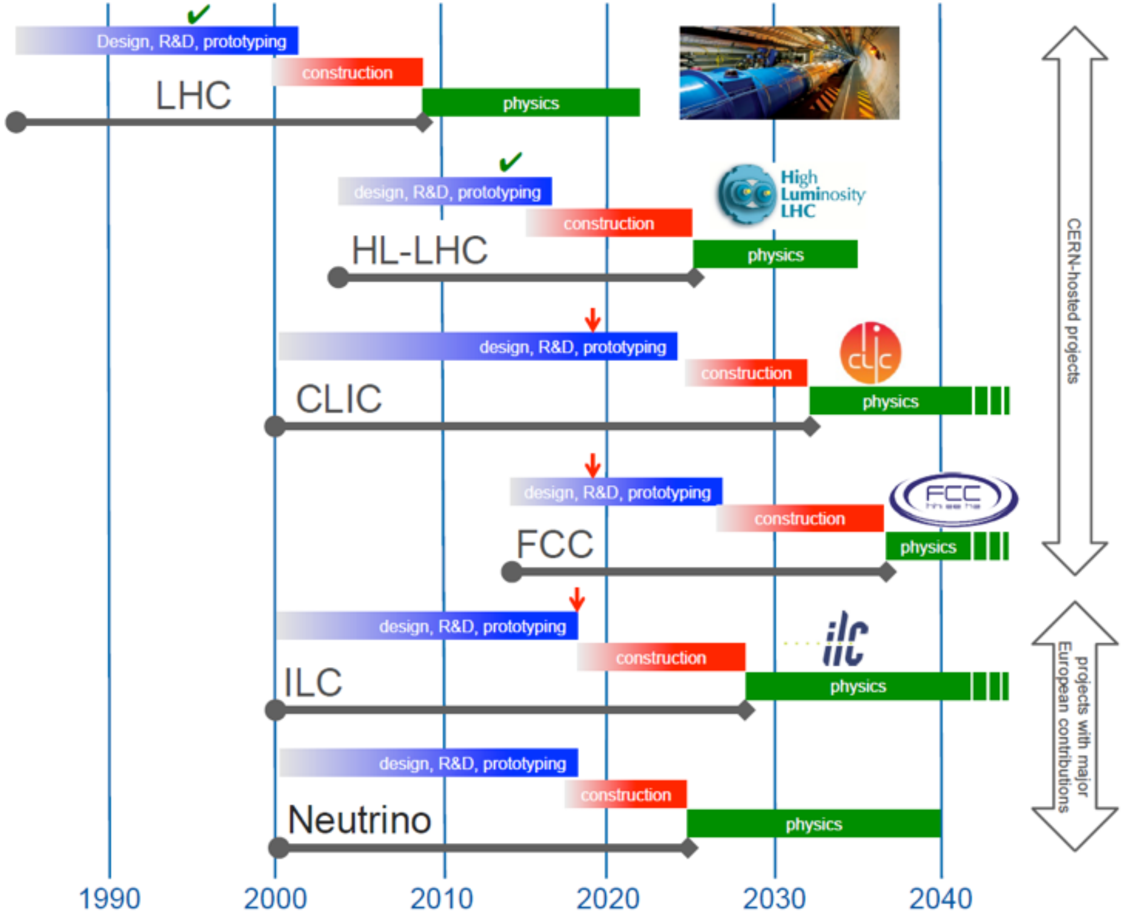
In particular at recent AIDA-2020 meetings

**A big Thank You !**

# Changed Landscape

## Painted with a Broad Brush

**Roadmap 2014: clear directions, e.g. for AIDA-2020**




**The chart in 2019: Directions - see Lucie Linsen's talk**

**e+e- Higgs factories, linear or circular**

requirements **are** different from HL-LHC: thin trackers, compact calorimeters - and not yet everywhere met

but still **synergies,** e.g calorimeter granularity, fast timing

**Hadronic colliders**

big steps for FCC required: rate, radiation, scale

but interesting **medium-term challenges** to bridge the gap,

**ALICE, LHCb LS4 upgrades, PBC experiments beyond colliders**

**Cryogenic detectors and neutrinos**

Dark Matter searches - synergies with DUNE

Near Detector R&D: infrastructures for low energies

# Key Technologies and Promising R&D

Vertical and Horizontal - see also Francesco Forti’s plenary talk

# Silicon Detectors

## For Tracking and Vertexing

**Follow both Hybrid and Monolithic CMOS approaches**

CMOS-MAPS, HV-CMOS< HR-CMPS, SOI-CMOS,…

**High resolution / low material  -  high rates / high radiation**

difficult to fulfil all at once

**Add timing: "4D trackers”**

LGAD and 3D sensors, monolithic LGADs

**Highly competitive community - but many common issues**

Basic understanding - design principles, materials

Model building, simulation and TCAD tools

Chip and wafer interconnection

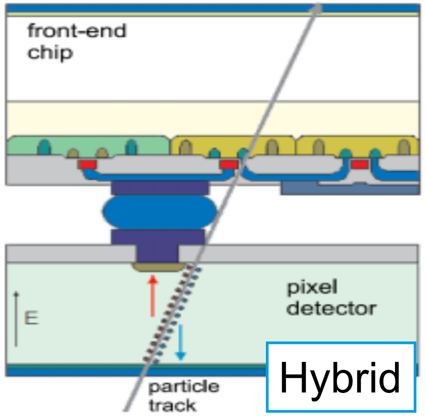
Read-out for characterisation and test

System integration challenges: cooling, power, connectivity

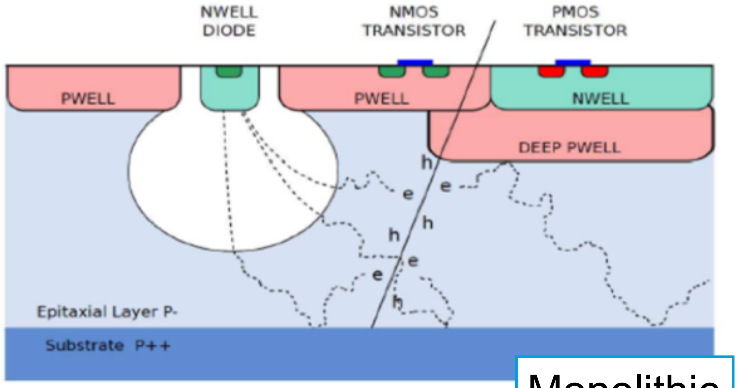
**Share expensive submissions**

Relationships with foundries (LF, TJ, ams)

**Strong synergies with other fields, e.g. photon science**

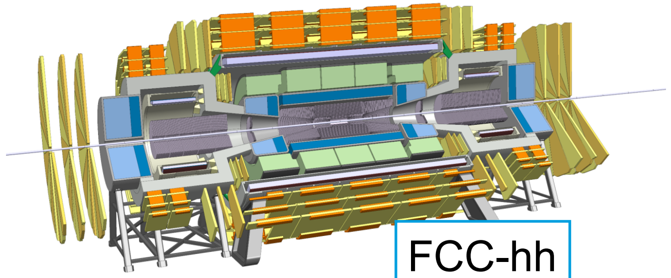


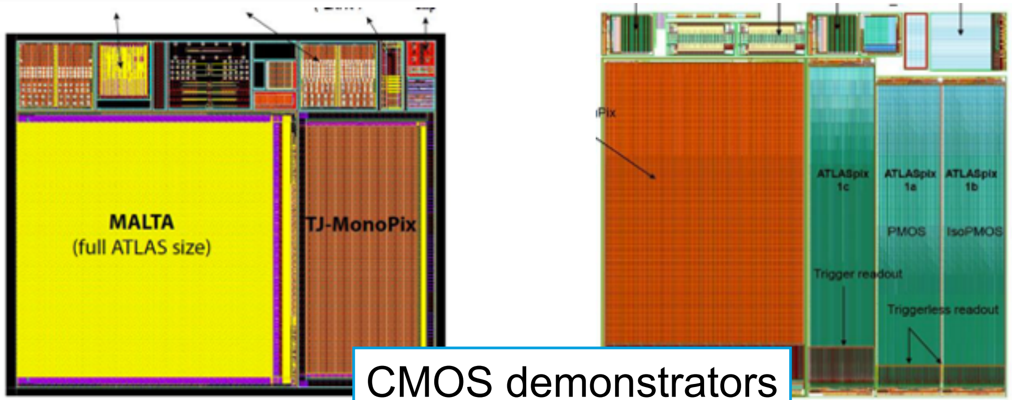
Hybrid



Monolithic

20 µm Si



FCC-hh



CMOS demonstrators

# Calorimeters

## Highly granular, of course, and 5D

**Si pad diode and SiPM-on-Tile technologies**

prime example for LC LHC synergies - and for the long timelines

particle flow driven: enabling, but not blue-sky

**Implementation in CMS HGCAL will teach important lessons**

also for Higgs factories, linear or circular

cooling, electronics integration - still to be transferred & compactified

**Gaseous alternatives in synergy with muon-oriented R&D**

**Directions:**

**More near-term applications:**

e.g. **LDMX** (PBC) **DUNE** Near Detector ECAL,..

**Optimise timing:"5D calorimetry"**

silicon, scintillator, hybrid solutions: assist particle flow and weighting

**Higher granularity for more classic technologies:**

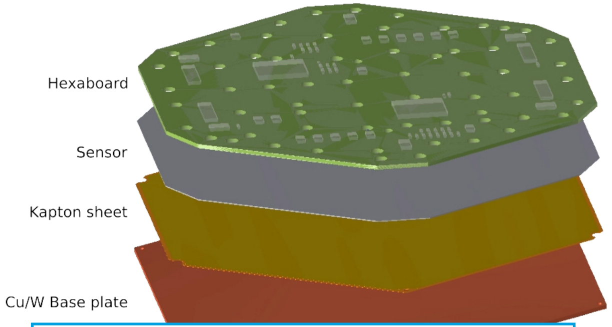
**Highly Granular Liquid Argon:** one of the few rad-hard options

finely segmented electrodes and high density feed-throughs, **timing**

ultimately: cryogenic electronics for the front end

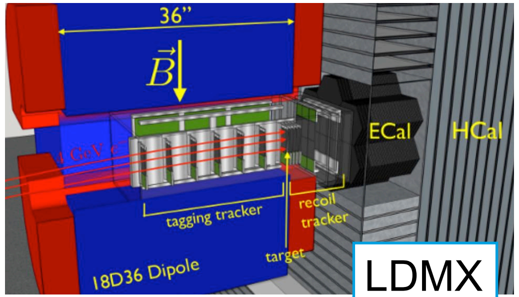
**"Particle-flow friendly" dual read-out**

with longitudinal segmentation

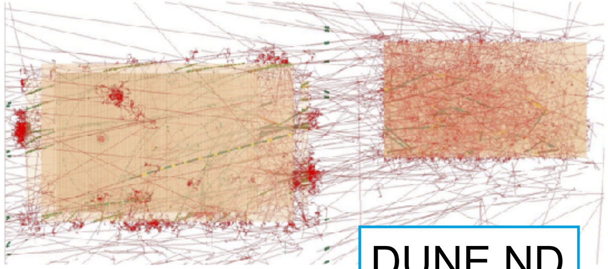


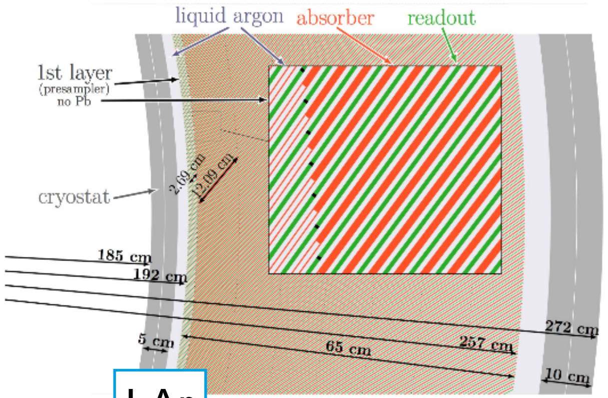
CMS Si Hexaboard module


CALICE SiPM-on-Tile

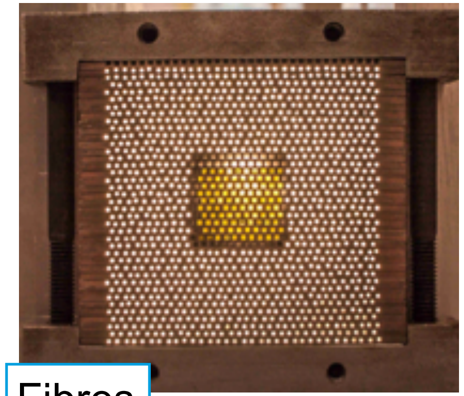


LDMX


DUNE ND



LAr


Fibres

# Optical readout

## Tracking, Calorimetry, Particle ID.

**Sci-Fi trackers**

light yield and speed of fibres, production techniques

**Multiple read-out calorimetry**

idea: separate electromagnetic hadronic and neutron components of particle showers

novel optical materials and coupling schemes

**Ring-imaging Cerenkov detector, e.g. for LHCb**

**TOF and TOP detectors**

radiators, mirrors, mechanics, cooling

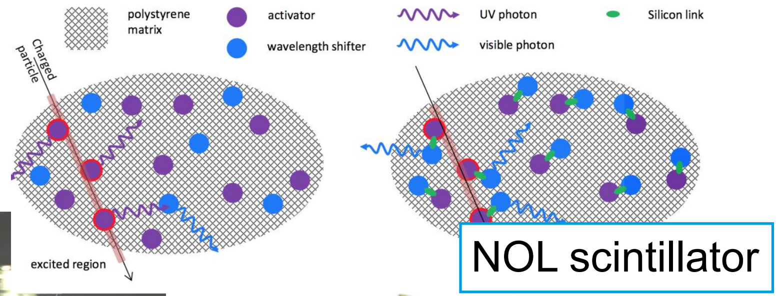
**Fast timing photo-detectors and electronics**

**SiPMs**: pushing the radiation tolerance frontier

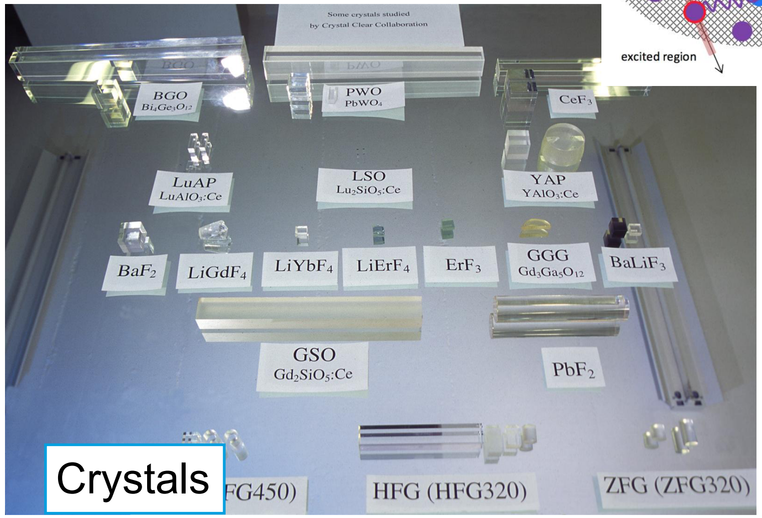
many suppliers -but only few with flexibility **and** mass production capability

**LAPPDs** (Large Area Picosecond Photodetectors (MCPs))

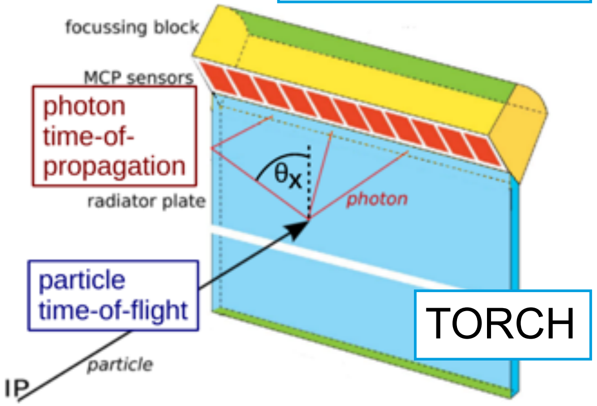
Neutrino experiments, synergies with other disciplines



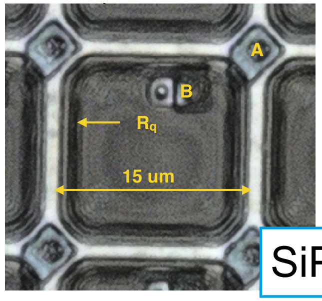
NOL scintillator

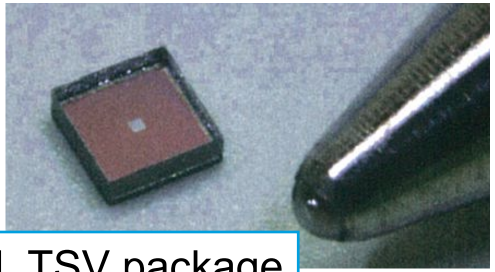


Crystals

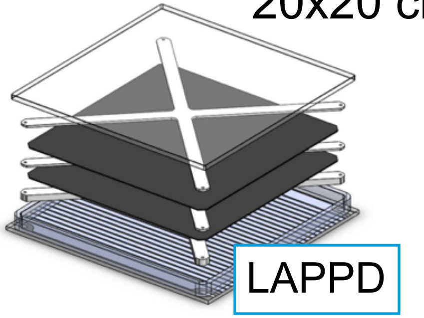


TORCH





SiPM, TSV package

20x20 cm$^2$


LAPPD

# Gas Detectors

## Still going strong

**Large volume trackers for ILC, CEPC, FCCee**

novel read-out structures for TPCs (MPGD, pixels, SiPMs)

**Main effort is in large area detectors for muons**

and - with 2D segmentation - for hadron calorimetry

MPGDs (Micromegas, GEMs, µRWELL,..) and RPCs

**Major topics - progress needed:**

resistive surfaces, charge sharing, timing

industrialisation. scaling

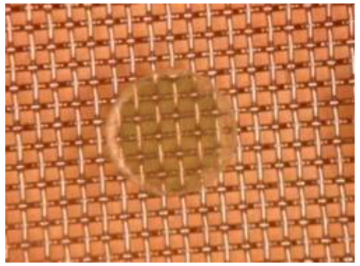
novel technologies, e.g. additive production

eco-friendly gases for RPCs and MPGD

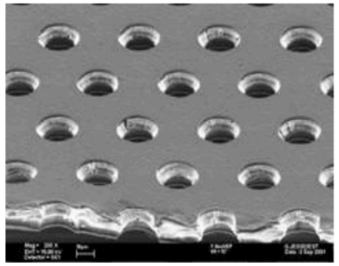
**Many common interests**

characterisation, electronics

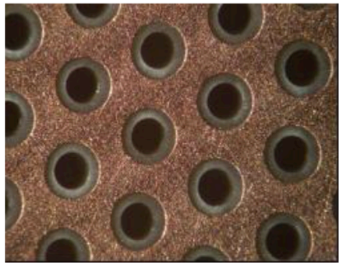
simulation and modeling



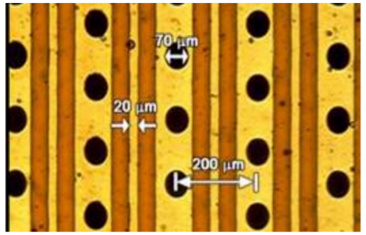
MicroMegas



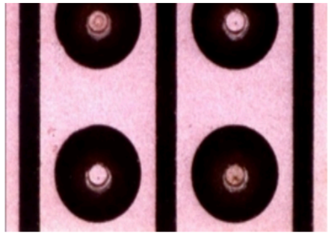
GEM



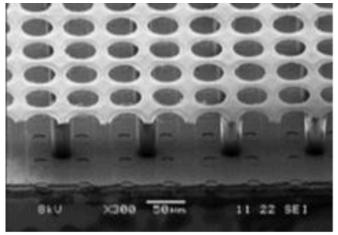
THGEM



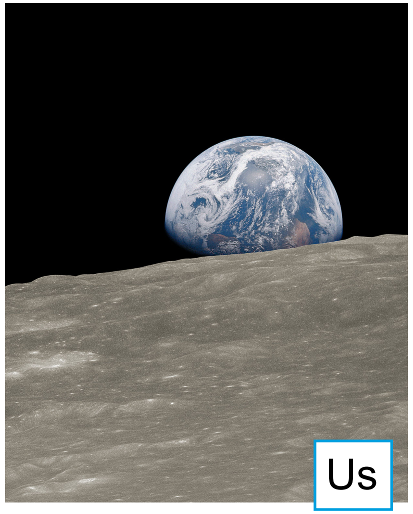

MHSP



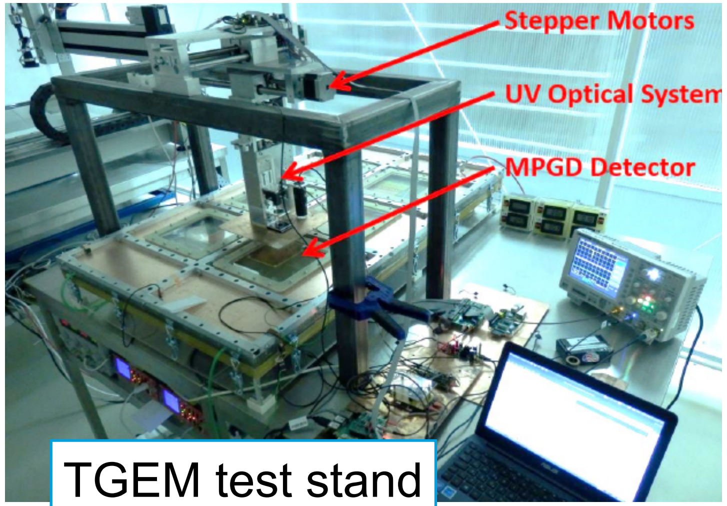
microPIC



Ingrid



Us




TGEM test stand

# Cryogenic detectors

## Neutrinos, Dark Matter - and Calorimeters

**Cryogenic detectors**

Synergies DUNE and Dark Matter Searches

also: gas detectors, calorimeters

**Only first DUNE (Single Phase) in production mode**

Dual phase and further R&D on-going

**Continue protoDUNE operation**

Very large infrastructure effort

**Topics**

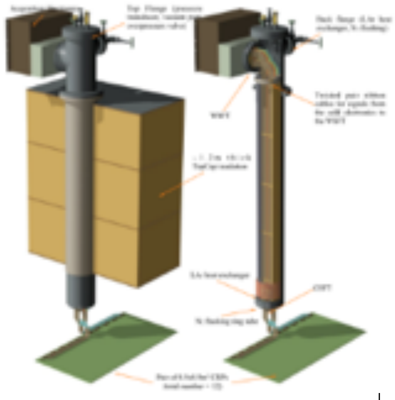
shielding

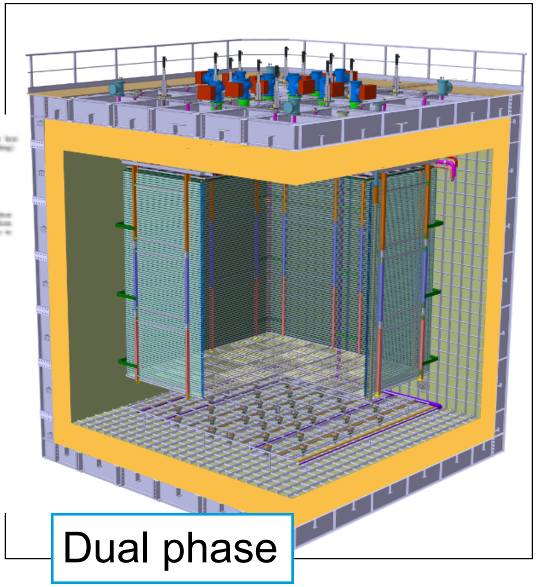
purity monitoring

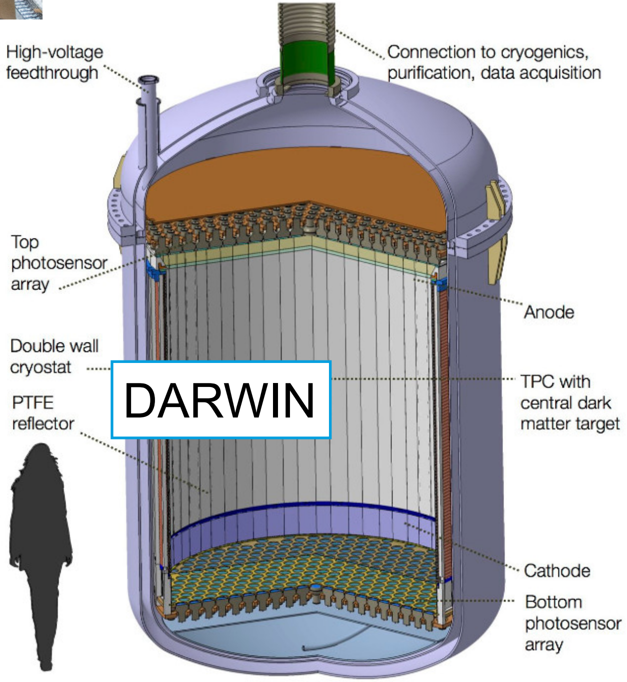
very High Voltage

cryogenic photo-detectors

cryogenic electronics

# Electronics: Integrated Circuits

No electronics, no detector.

**High load on few developer groups, strong role of CERN**

and currently driving the HL-LHC detector upgrade schedules

**Large investments - and increasing for new, smaller feature sizes**

increase speed and reduce power - inevitable anyway, driven by industry

**Next step:**

**65 -> 32 nm for tracking 130 -> 65 nm for calorimetry & timing**

collaborative tools, IP blocks, common submissions (CERN)

**Community building and support**

there are many smaller ASIC projects - provide central design support

**Next-to-next technology evaluation**

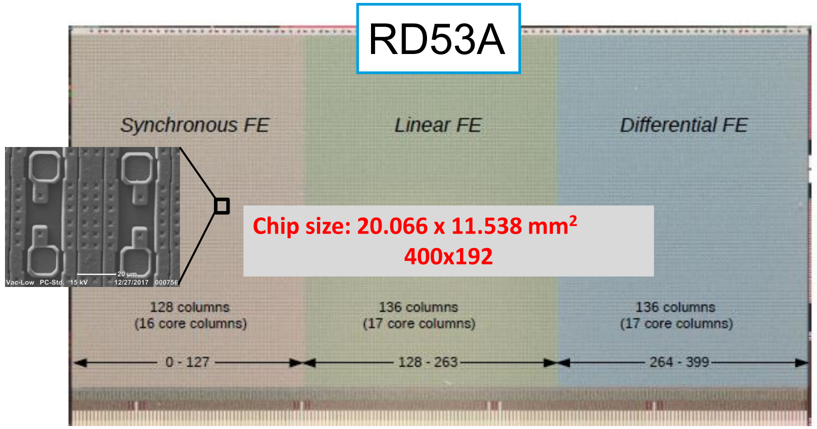
FinFET at 22 nm and below

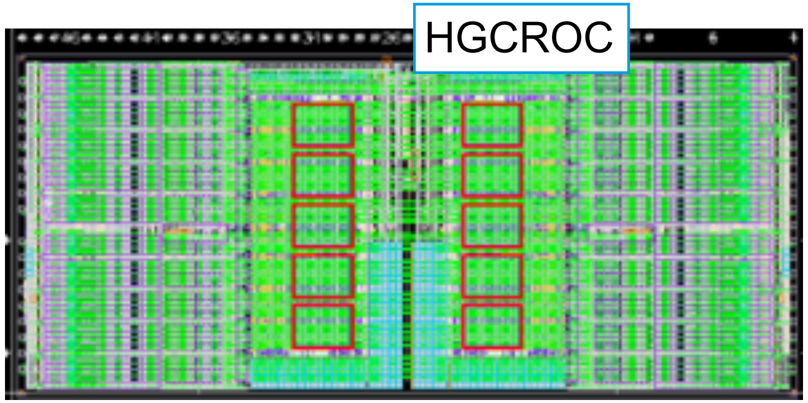
Rad-hardness

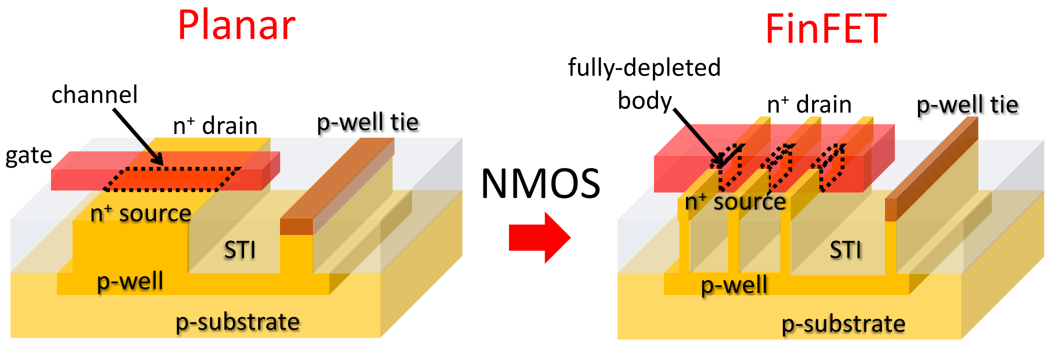
analogue challenges

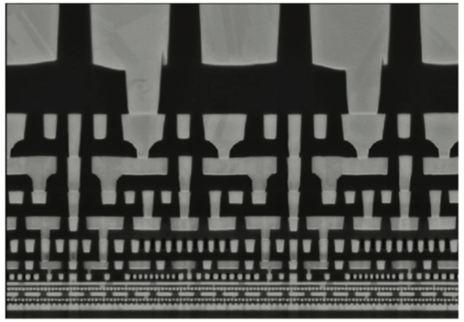
simulation and modeling

**assembly (e.g. TSVs)**



A 14 nm FINFET process metal stack

# Mechanics: Structures and Cooling

## Low tech - not at all.

**New materials - lowest mass structures**

trackers, of course, but also thin cryostats

expand large structures

**Advanced cooling**

**Airflow**

integrated design and FSI diagnostics

**Micro-channel cooling**

for micro-structures CMOS post-processing

**High performance - low temperature**

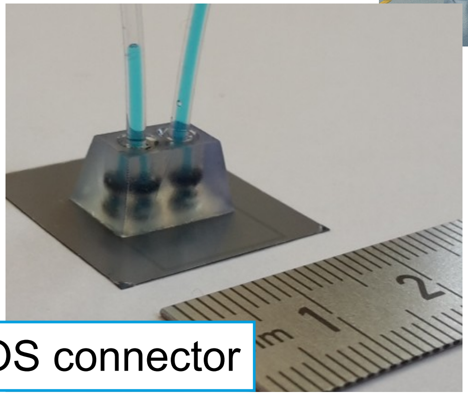
$CO_2$ for hadronic environments

**New topic: automated handling for highly irradiated environments**

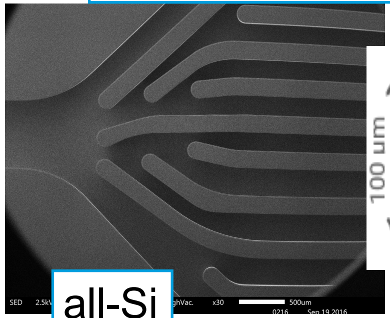
LOx cryotank


telescope backplane

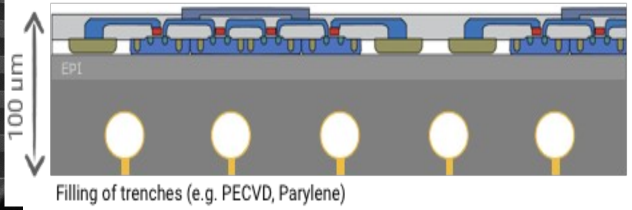
CF-honeycomb disk



CMOS connector



all-Si




CMOS structure

# Consciously not Covered

## But equally important strategic developments

**Optical links**

higher rates and radiation levels

opto-electronics, silicon photonics

very specialised expertise, (almost) exclusive role of CERN

**Detector magnets**

very specialised expertise, almost exclusive role of CERN

**NB:**

**Community needs a 4T magnet in the test beam**

**Software**

Dedicated session on software and computing **tomorrow**

# Blue-Sky R&D

## Preserve the innovative potential

**Long time scales - room for unconventional approaches**

Inspiration from neighbouring fields - and industry

**Example Quantum Sensors** https://arxiv.org/abs/1803.11306

current push in the US and UK

synergies with quantum computing

**"Crazy ideas":**

**Wireless read-out**

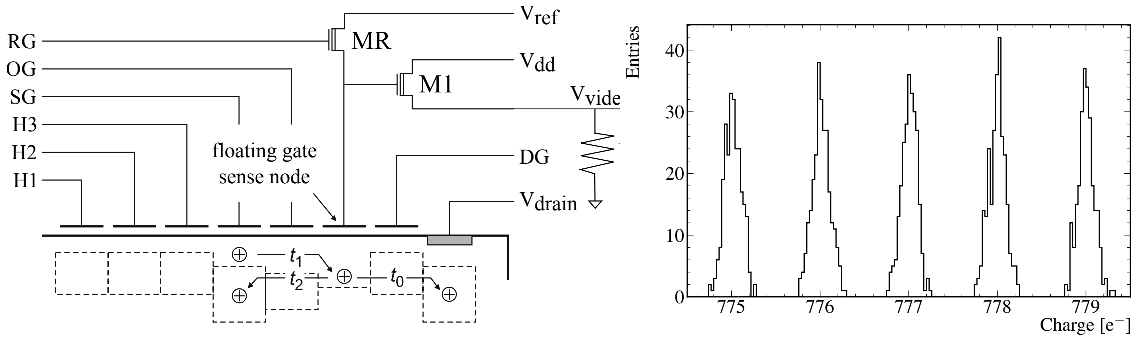
**Wireless powering**

**Instrumented SC solenoids**

**Strength of our community is to unite behind common strategies**

incremental innovation is often enough - and focussed

**Need both - strike the right balance**




Skipper CCD: arXiv: 1706.00028
single electron sensitivity for lowest signals

# Common Infrastructures: Facilities, Tools, Platforms

# Facilities

## A European Network.

**Test beams: CERN, DESY, Frascati**

indispensable, in particular for system aspects

**Irradiation facilities - across Europe**

neutrons, photons, in-situ test beams

**Characterisation facilities - new**

electromagnetic interference , ion beams

**CERN neutrino platform**

protoDUNEs, - and a **low-energy test beam line**

**EC-funded transnational access was a big success**

New solutions for the future required

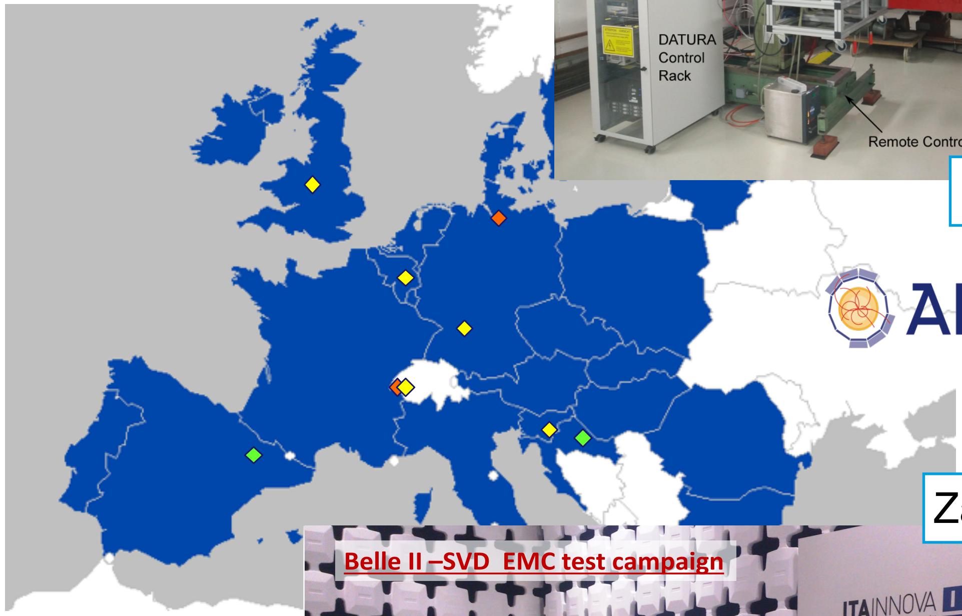
**Instrumentation and support for all of the above**

e.g. beam instrumentation needs to keep pace with increasing performance demands

Next: timing reference, clock distribution, state-of-the art position sensors

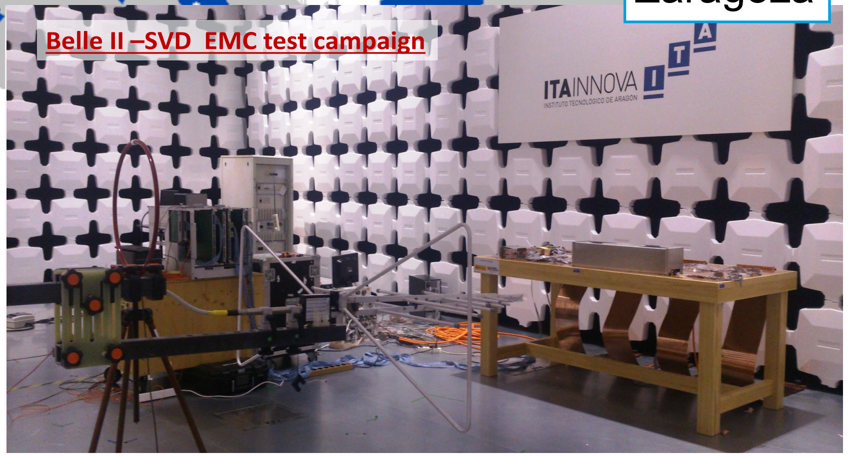
User support staff


Hamburg



AIDA2020

Zaragoza



# Tools, Platforms, Standards

## Infrastructure = common interest

**Successes from EUDET, AIDA, AIDA-2020 and R&D collaborations**

see also Didier Contardo's talk

**Some examples:**

**TCAD libraries** for CMOS and Hybrid pixel sensor design

Sensor **design guidelines**, based on efficiency and radiation tolerance

Common **ASIC development** despite different pixel matrix sizes

**TSV processes -** with industrial partners

**FPGA firmware IP blocks -** not yet

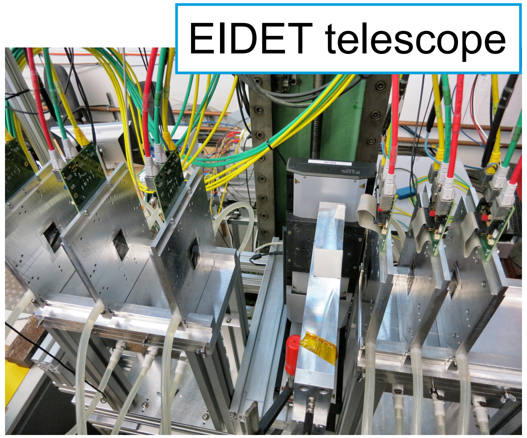
**Test installations:** optical fibres, photo-sensors, precision mechanics, gas detector qualification,…

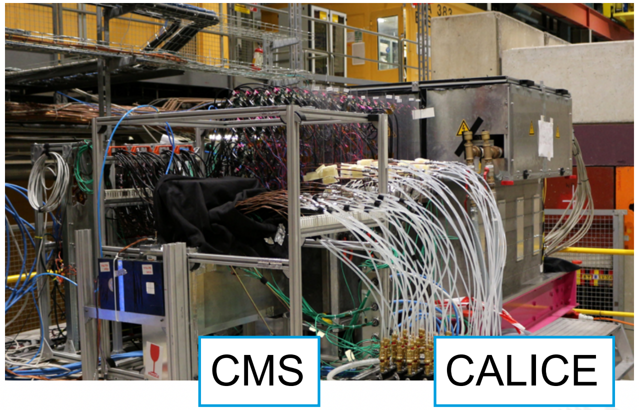
Common **test beam DAQ** - LC and LHC

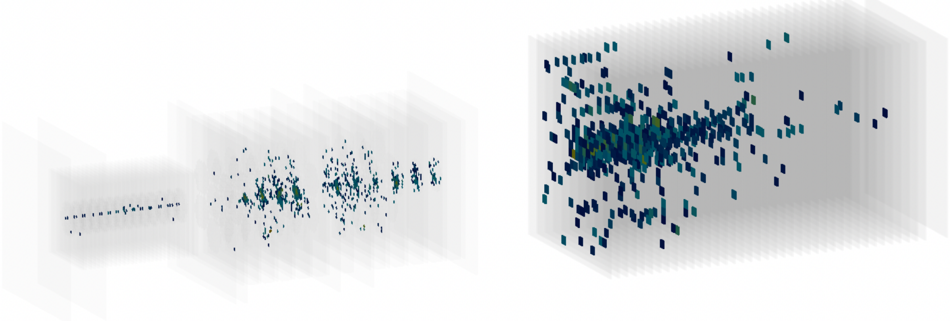
**Monitoring** frameworks, telescope **reconstruction**

**Standards:** micro-channel cooling connectors, synchronisation and trigger protocols, sensor and ASIC design kits

**and Much More**



# Coordination and Support

# ECFA Survey

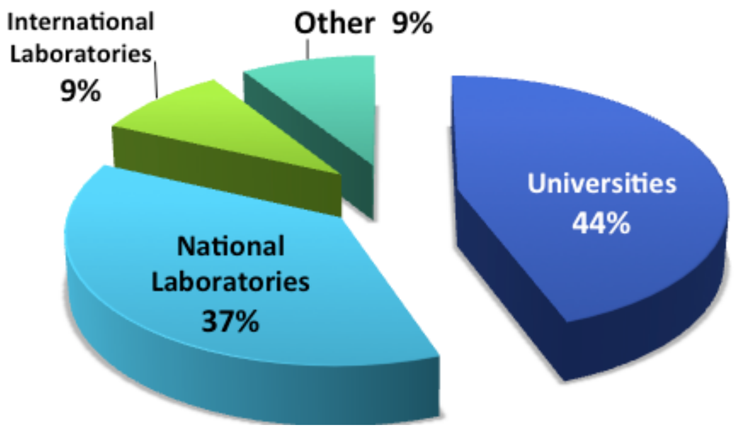
## A Look at Our Community

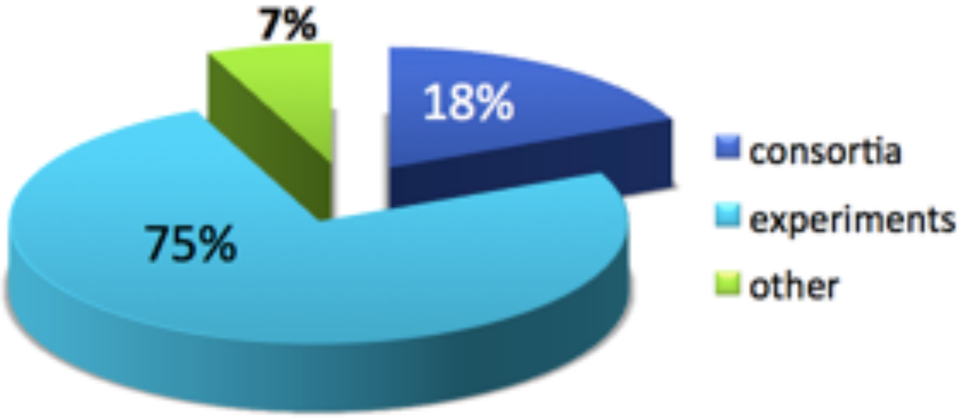
**700 replies - Today's typical HEP detector person**

- is a staff physicist or PhD student,
- affiliated with a university or national lab,
- involved with an experiment,
- funded by national agencies or home institute,
- neighbouring activities: astro- or nuclear physics,
- works on semi-conductor trackers,
- is interested in FE ASICs (65 nm),
- involved in beam or radiation tests,
- believes that precision timing is the far most promising R&D,
- and sees career perspectives for R&D experts in tertiary sector or industry - but not research.

**In general, positive feedback on R&D collaborations and EC initiatives**

**With focus moving from HL-LHC to future projects: need to strengthen R&D consortia - and establish new ones - while preserving expertise and working relationships developed in ATLAS, CMS, …**



# R&D Collaborations

## Past, and Future

**The merits of pooling resources and avoiding duplication**

see once more Didier Contardo's talk for an appraisal

Note that they are evolving in scope quite flexibly, e.g. CALICE

**Task sharing vs. competitive prototyping**

uniqueness vs redundancy, funding (dis-)continuity

**Synchronise of TRLs with proof-of-principle prototypes**

build the community and train the next generation

**Possibilities for future ones:**

**CMOS:** AIDA-2020 made a start, but there is more potential

**Mechanics:** liaise with Forum for Tracker mechanics

**Extension of RD53** towards 32 nm

**Some challenges**

Engage with world-wide (non-European) community

Integrate R&D not targeted at CERN-hosted projects

Funding ups and downs

RD50
RD51
RD53

# EC-funded Projects

## AIDA-2020 and Follow-up

**Integrating Activities since 2006**
increasing level of integration

**All have strong leverage on matching fund**

**AIDA-2020:** 2015-2020

39 beneficiaries from 19 countries

EC funds **10 M€**, total budget **29.8 M€**

**Unique in establishing coherence at European level**

**Subsidiary approach to coordination**

build on existing structures where possible

**New Call in Horizon 2020**

**Innovation Pilot for Detectors**

Expected budget 10 M€

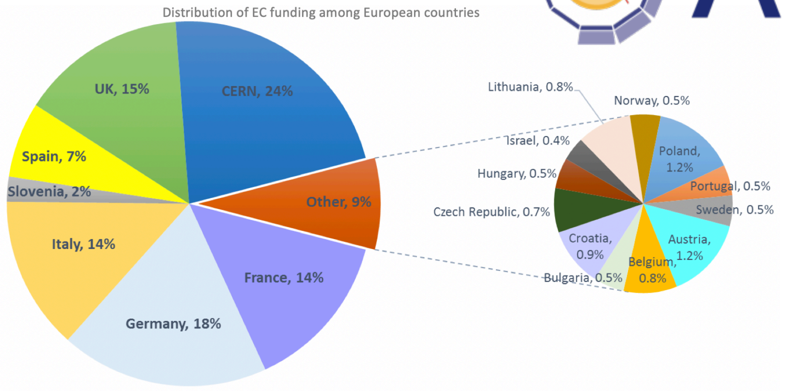
**Deadline** for submission **March 17, 2020**

**Call for Expressions of Interest this week**

Open community meeting CERN September 4

**Complementary to ATTRACT**

no double-funding



# Talent Management

## Some personal remarks

**Detector (system) prototyping is an excellent training ground for young particle physicists**
not only detectors - as evidenced by feedback

**Internally, we under-sell the intellectual challenges - and pleasures - of detector development**
University education, PhD requirements

**Externally, we under-sell the technological dimensions of particle physics**
Outreach and public relations

**Both aspects are fundamentally related to the deficit in recognition and career opportunities for instrumentation physicists**
and engineers (!)

**EDIT-2020**
**Excellence in Instrumentation Technologies**
School for advanced PhD and young postdocs
Lectures and hands-on courses, including test beam
Under the auspices of ICFA
**February 17-28, 2020 @ DESY**

# Summary

## and Conclusions

**Drawing a strategic R&D road-map at this point is challenging**

Future course of the field is just emerging

**Maybe no map yet - but a compass: directions are clear**

The goals are known - and the challenges are not small

Continued funding - and the efficient use of resources - are critical

**Near-and medium term projects play an important role**

Ensure an efficient link between experiments and R&D groups

**Community is mature and well organised**

Established successful collaborative structures

**Continue to be open-minded towards “blue sky” research**

Inspirations from neighbouring fields and industrial partners - Cinzia Da Vià’s talk

# Summary

## and Conclusions

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Continued funding - and the efficient use of resources - are critical

**Near-and medium term projects play an important role**

Ensure an efficient link between experiments and R&D groups

**The most effective means to preserve a healthy R&D community is a clear perspective on future projects.**

**Community is mature and well organised**

Established successful collaborative structures

European Strategy Update

**Continue to be open-minded towards “blue sky” research**

Inspirations from neighbouring fields and industrial partners - Cinzia Da Vià’s talk

# Acknowledgments

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Christian Joram, Frank Simon

All who contributed to this talk - consciously or not

All mistakes are mine!