The DRD4 Collaboration for research and development on photon detectors and particle identification techniques

Massimiliano Fiorini
(INFN and University of Ferrara)

on behalf of the DRD4 Collaboration

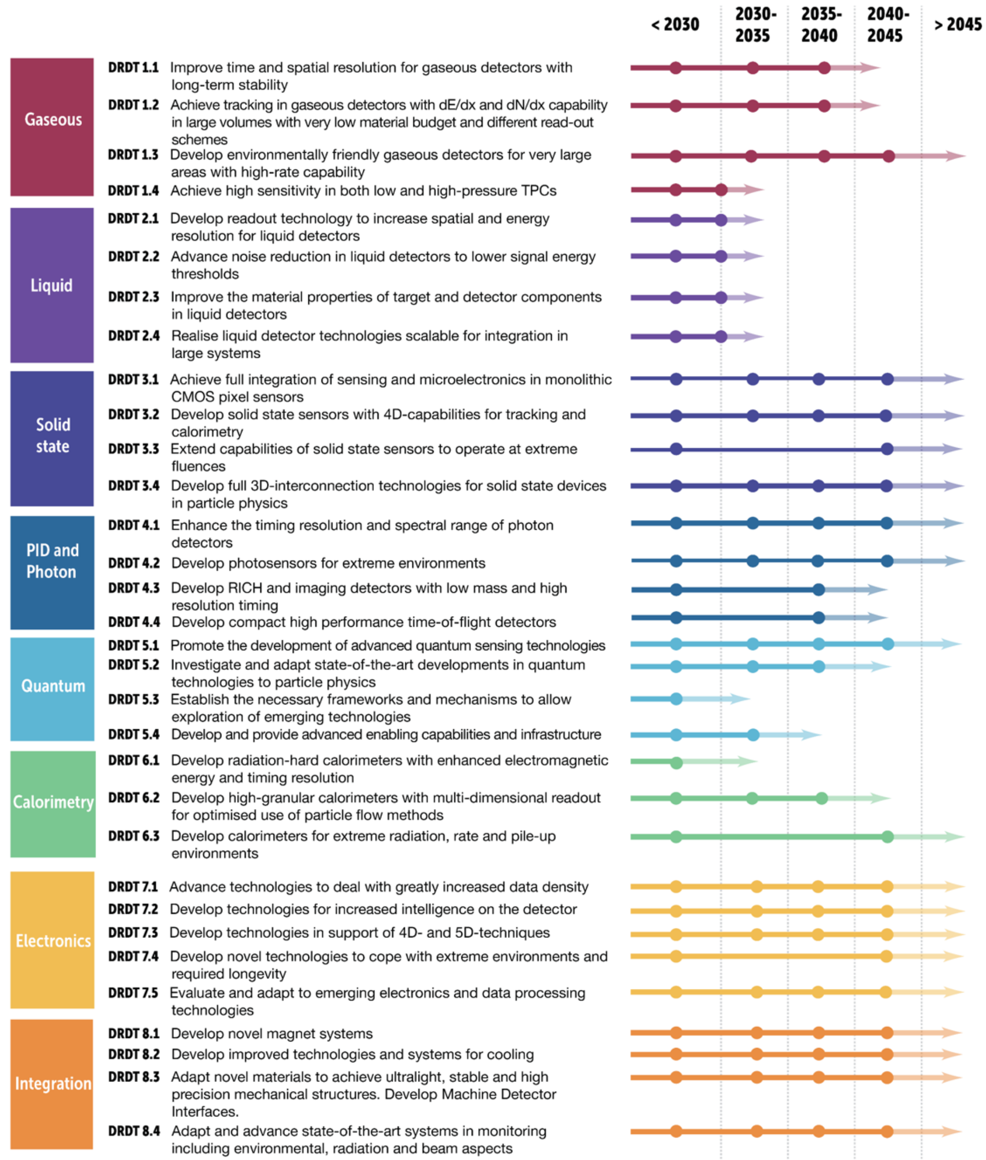
XII International Workshop on Ring Imaging Cherenkov Detectors
Mainz – 15-19 September 2025

European Strategy for Particle Physics

- The 2020 update of the European Strategy for Particle Physics (ESPP) underlined that:
  - The success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures. To prepare and realise future experimental research programmes, the community must maintain a strong focus on instrumentation
  - The community should define a global detector R&D roadmap that should be used to support proposals at the international and national levels
- A roadmap process was then started:
  - Structuring phase (May–December 2020)
  - Collection of inputs from the community by means of several open symposia (January–May 2021)
  - Drafting of the conclusive documents (June–October 2021)
- The outcome was the ECFA Detector R&D Roadmap document, published in 2021, which defines the major Detector R&D Themes (DRDTs) and ten General Strategic Recommendations (GSRs)

Detector R&D Themes

- All Themes are critical to achieving the science programme outlined in the ESPP and are derived from the technological challenges that need to be overcome for the scientific potential of the future facilities and projects listed in the ESPP to be realised
- It is important to ensure that detector readiness should not be the limiting factor in terms of when the facility in question can be realised

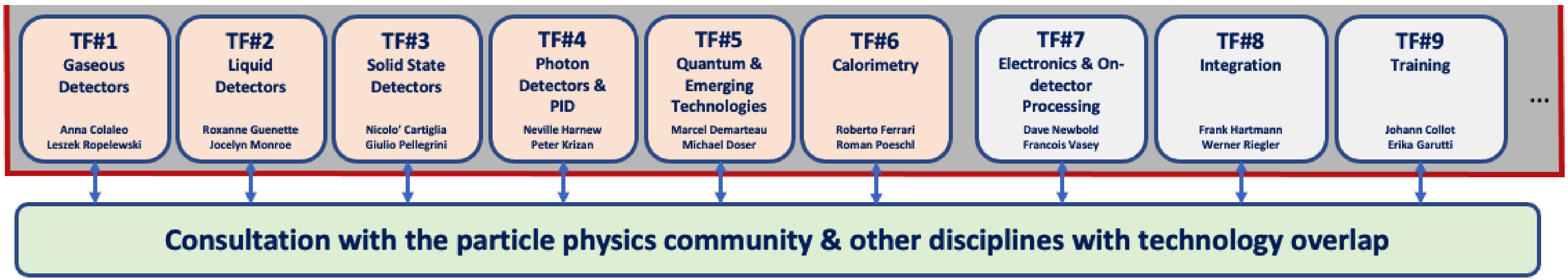


General Strategic Recommendations

- GSR 1 - Supporting R&D facilities
- GSR 2 - Engineering support for detector R&D
- GSR 3 - Specific software for instrumentation
- GSR 4 - International coordination and organisation of R&D activities
- GSR 5 - Distributed R&D activities with centralised facilities
- GSR 6 - Establish long-term strategic funding programmes
- GSR 7 - "Blue-sky" R&D
- GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts
- GSR 9 - Industrial partnerships
- GSR 10 - Open Science

DRD Collaborations

- During the roadmap process, the work was organised into nine Task Forces (TF), each focused on specific detector technology areas
  - Eight of these Task Forces submitted proposals that evolved into DRD Collaborations, while TF9 was transformed into the ECFA Training Panel



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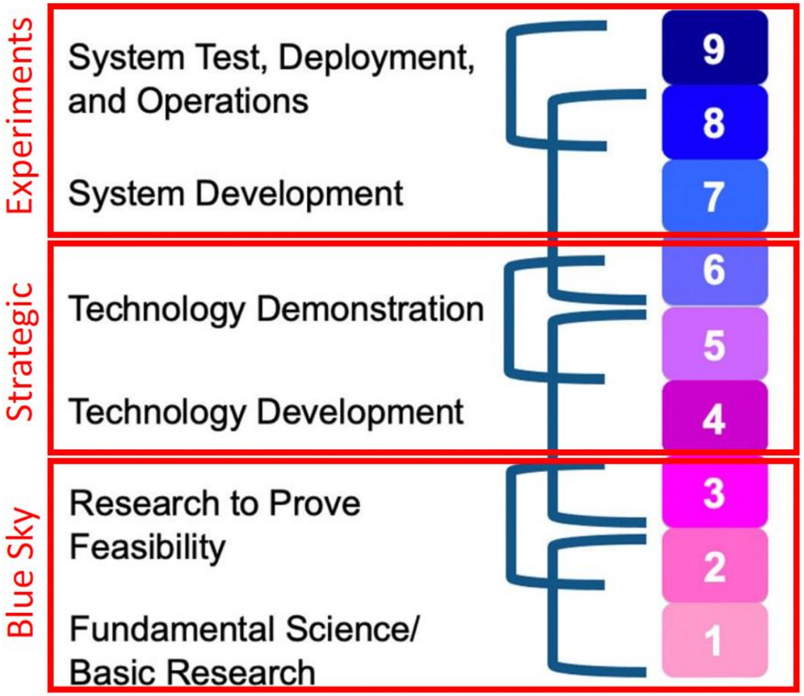
1. Gaseous	2. Liquid	3. Semiconductor	4. PID & Photon
e.g. time/spatial resolution; environment friendly gases	e.g. Light/charge readout; low background materials	e.g. CMOS pixel sensors; Time resolution (10s ps)	e.g. spectral range of photon sensors; Time resolution
5. Quantum	**6. Calorimetry**	**7. Electronics**	**8. Integration**
quantum sensors - R&D, incl. beyond QFTP in conventional detectors	e.g. Sandwich; noble liquid; optical	e.g. ASICs; FPGAs; DAQ	tracking detector mechanics

Chris Parkes, IOP APP+HEPP+NP Conference, April 2024

Strategic and Blue-Sky R&D

- Blue-Sky R&D is basic research where applications are not immediately apparent: starting point of development (very low TRL: 1-3)
- Strategic R&D bridges the gap between the idea (TRL 1-3) and the deployment and use in a HEP experiment (TRL 8-9)
- Detector R&D Collaboration should address TRL from 3 to 7, before experiment-specific engineering takes over
- Strategic R&D covers the development and maturing of technologies, for example:
  - Iterating different options
  - Improving radiation hardness
  - Scaling up detector area, number of layers, etc.
- Backed up by strategic funding, agreed with funding agencies

Technology Readiness Levels (TRLs): estimating maturity of technologies



T. Bergauer, Pisa Meeting 2024

Road to DRD4

- Short chronology of actions
  - Peter Krizan (Ljubljana) and Christian Joram (CERN) were mandated by ECFA to prepare the launch of an R&D collaboration on Photodetectors and Particle ID (including SciFi and TR) named DRD4
  - First meeting of some senior people 8 March 2023 (+ questionnaire)
  - Live community event 16-17 May 2023 at CERN. Some 50 participants were present plus about 30 on Zoom. Main goals: discuss the scientific and organisational backbones of DRD4
  - The proposal writing process was launched. A preparation team of volunteers was formed to promote the process
  - Community update event was held on 15 June (by Zoom): lots of work in the background to discuss scope, work packages, working groups
  - Submission of proposal (33 pages) on 31 July 2023
    - Then two revisions: 31 October 2023 (R1) and 14 November 2023 (R2)
  - Presentation to DRDC on 4 December 2023

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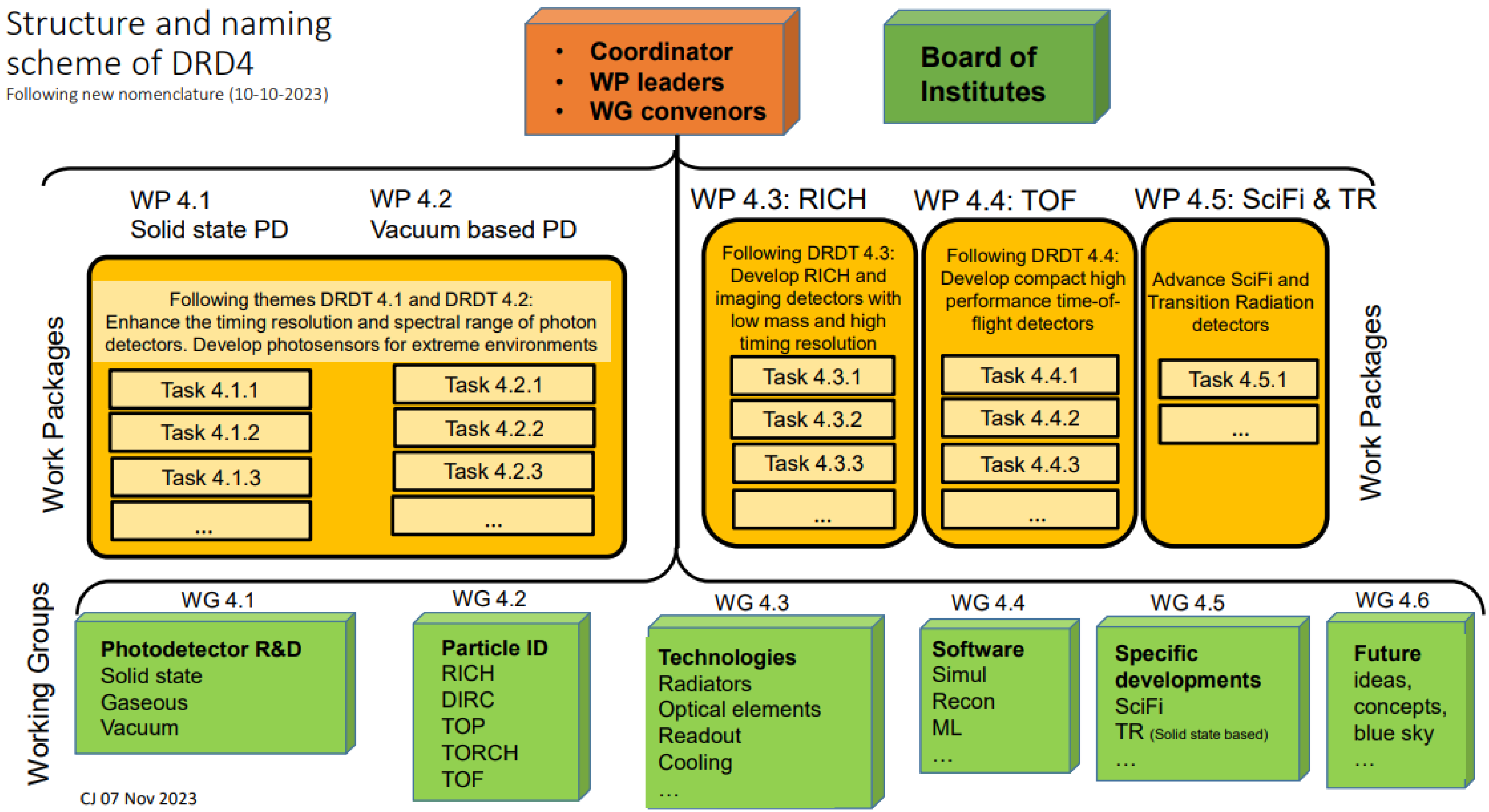
Many thanks to Christian and Peter and to the whole DRD4 preparation team
(S. Easo, M. Fiorini, S. Gambetta, C. Jones, C. Joram, P. Križan, I. Laktineh, J. Lapington, B. Leverington, F. Loparco, E. Nappi, R. Pestotnik, A. Petrolini, F. Tessarotto)

DRD4 Collaboration

- DRD4: international Collaboration with CERN as host laboratory
  - Approved by the CERN Research Board in December 2023
- Main goal: bundle and boost R&D activities in **photodetector technology** and **Particle Identification (PID) techniques** for future HEP experiments and facilities
- To be more specific, DRD4 covers the following topics:
  - Single-photon sensitive photodetectors (vacuum, solid state, hybrid)
  - PID techniques (Cherenkov based, Time of Flight)
  - Scintillating Fiber (SciFi) tracking
  - Transition Radiation (TR) using solid state X-ray detectors
- DRD4 structure initially defined in the Proposal document
  - 6 Working Groups (WGs) reflecting the main areas of R&D
    - Scientific forums for discussion: no agreed tasks, no committed resources
    - Facilitate exchange of information, know-how, samples, infrastructure, etc.
  - 5 Work Packages (WPs) reflecting the main ECFA roadmap themes and goals
    - Run like projects: divided in tasks, with agreed goals, milestones, deliverables, and are jointly funded by the resources of the participants

DRD4 structure (from the Proposal)



DRD4 structure implementation

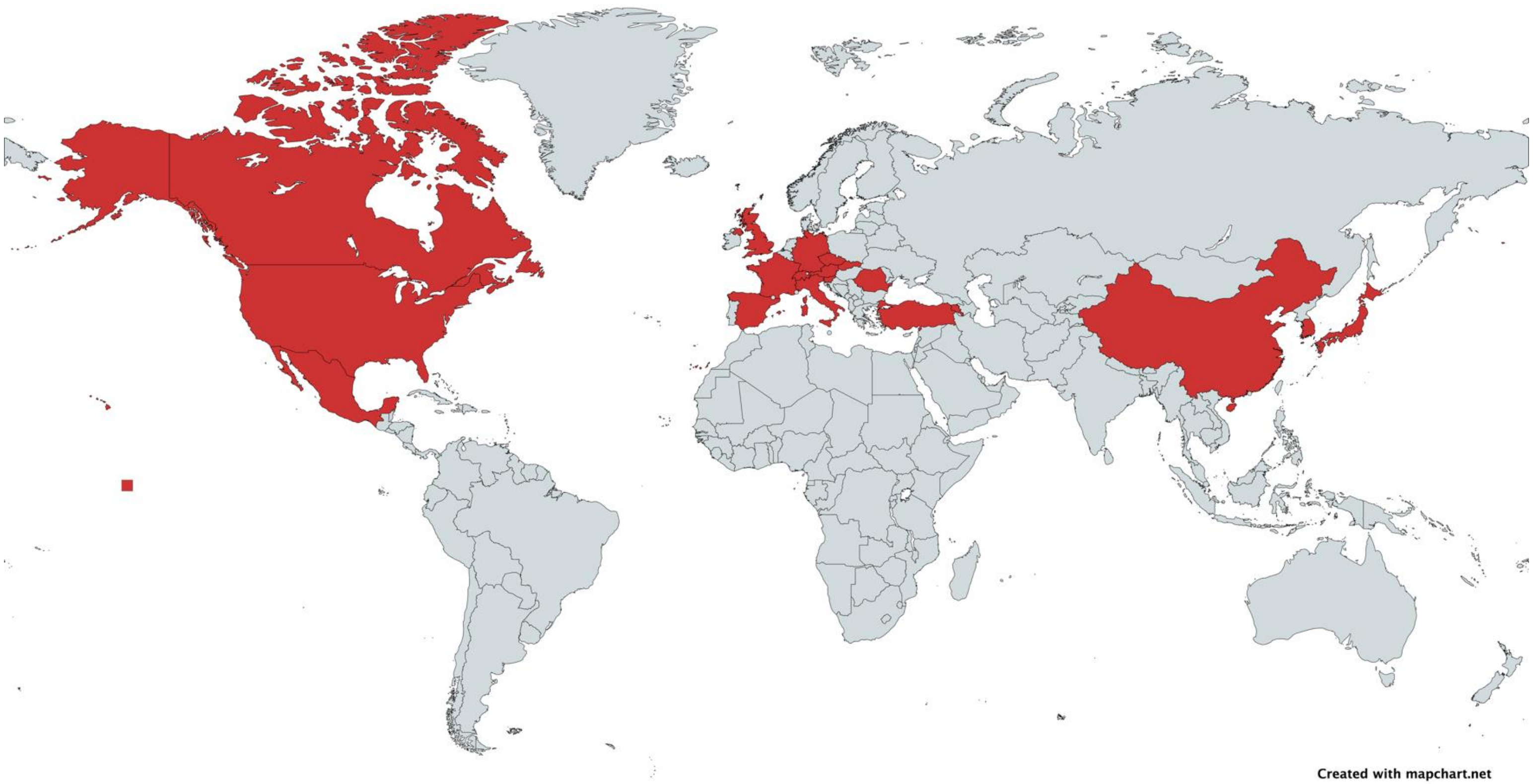
- DRD4 Constitutional meeting at CERN in January 2024
  - First DRD4 Collaboration Board (CB) Meeting: elections of main roles + admission of new groups
  - Initial terms for all elected roles: 1 year
- Later in 2024
  - Definition of provisional governance arrangements
  - First DRD4 Week (June 2024)
  - Nomination of Constitution and Membership Committee (CMC)
  - Second DRD4 Week (October 2024)
  - Constitution v1.0 approved by the CB
  - Preparation of draft Memorandum of Understanding (MoU)
- In 2025
  - Elections: all roles confirmed/renewed (February 2025)
  - Third (April 2025) and fourth DRD4 Week (October 2025)
  - Finalization of MoU document: in progress

DRD4 main roles

- Elected roles:
  - DRD4 Collaboration Board Chair: Guy Wilkinson (Oxford)
  - DRD4 Spokesperson: Massimiliano Fiorini (Ferrara)
  - WP1 Leader: Rok Pestotnik (Ljubljana)
  - WP2 Leader: Imad Laktineh (Lyon)
  - WP3 Leader: Roberta Cardinale (Genova)
  - WP4 Leader: Jon Lapington (Leicester)
  - WP5 Leader: Blake Leverington (Heidelberg)
  - WG1 Convener: Fabrice Retiere (TRIUMF)
  - WG2 Convener: Sajan Easo (RAL)
  - WG3 Convener: Fulvio Tessarotto (Trieste)
  - WG4 Convener: Maurizio Martinelli (Milano Bicocca)
  - WG5 Convener: Sune Jakobsen (CERN)
  - WG6 Convener: Suat Ozkorucuklu (Istanbul)
- Nominated roles:
  - Technical Coordinator: Sune Jakobsen (CERN)
  - Resources Coordinator: Roberto Preghenella (Bologna)

DRD4 groups

- Current status: 67 groups from 20 countries
  - Many small groups, many with no prior experience in large R&D collaborations
  - Large effort to constitute a collaborative effort amongst a research community that has not traditionally worked together in the recent past



DRD4 activities

- Different levels of activities
  - WG meetings organized by the corresponding Conveners
  - WP meetings organized by the corresponding Leaders
  - Management meeting
    - Periodic meetings between the WG Conveners, WP Leaders, SP and CB chair to monitor progress and proper inclusion of new teams and members
  - Collaboration meetings
- DRD4 scientific activities ramped up since the beginning of 2024: many scientific and technological discussions
- DRD4 Collaboration web-page:
  - https://drd4.web.cern.ch/
- DRD4 Indico meetings page:
  - https://indico.cern.ch/category/17388/

DRD4 Collaboration Meetings

- Constitutional meeting (CERN, 23-24 January 2024)
- 1st DRD4 Collaboration meeting (CERN, 17-20 June 2024)
- 2nd DRD4 Collaboration meeting (CERN, 21-25 October 2024)
- 3rd DRD4 Collaboration meeting (CERN, 7-11 April 2025)
  - On average 130 participants (in presence + via Zoom)
  - Next one: 13-17 October 2025 → if interested get in touch with us → registration is free of charge: https://indico.cern.ch/event/1473150/

DRD4 Working Group activities

- Crucial to build our (new!) community, enabling discussion of activities and the spread of information
- Goals
  - Discuss and present scientific and technological activities
  - Share expertise in the specific topics
  - Discuss availability/need of equipment and infrastructures for specific activities (and possibility of sharing or use by other DRD4 members)
  - Present new technologies
  - Etc.

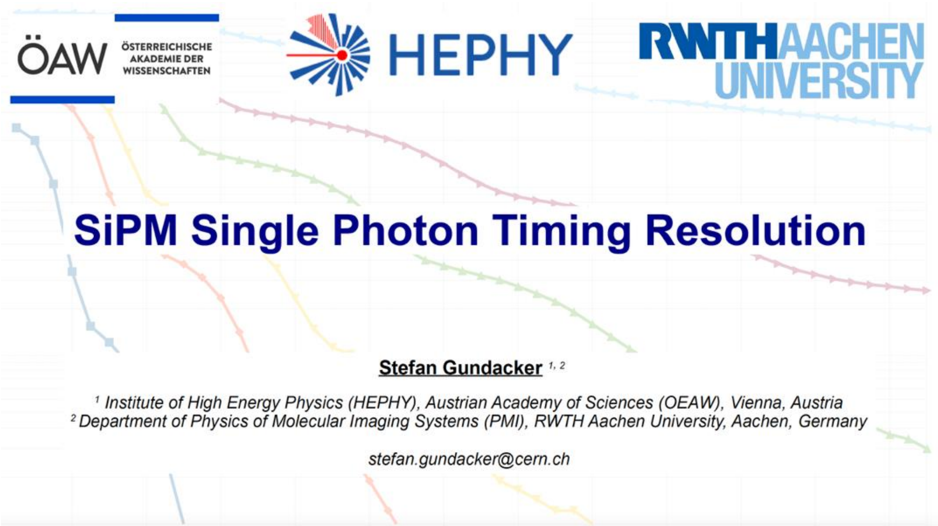
WG1: Photon Detectors

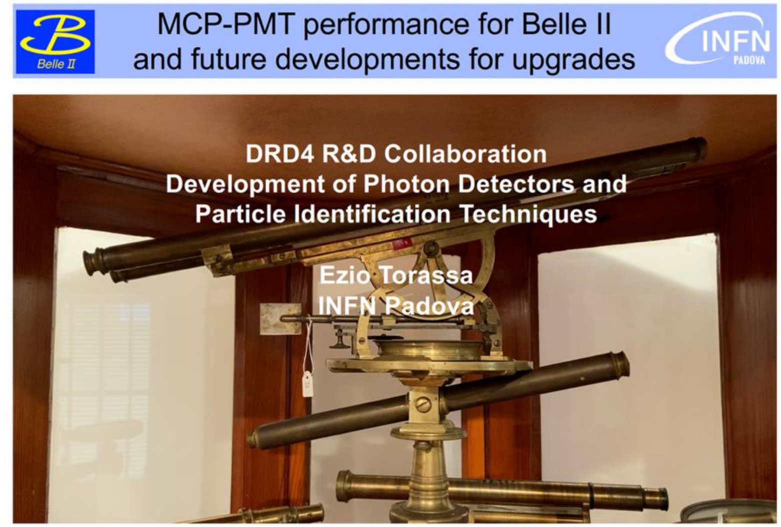
- Scientific forum for studies and development of novel photodetectors with focus on PID for future experiments
- Topics (selection):
  - Radiation hardness; timing resolution; high-rate capabilities; longevity
  - Extreme conditions: e.g., cryogenic and high magnetic field
  - Large-area (e.g. SiPMs arrays, LAPPDs, etc.); hybrid detectors
  - Fine granularity detectors for future high-rate experiments
  - New technologies: CMOS-SPADs, new SiPM structures, BSI SiPMs
  - New photocathode structures and materials
  - Novel materials for photon detection: e.g., Ge-on-Si APDs;
  - Read-out electronics for extreme environments, fast timing and high channel density; optimal sensors and R/O electronics integration
  - Simulations of photo-detector response
- Standardization of procedures for photodetectors characterization

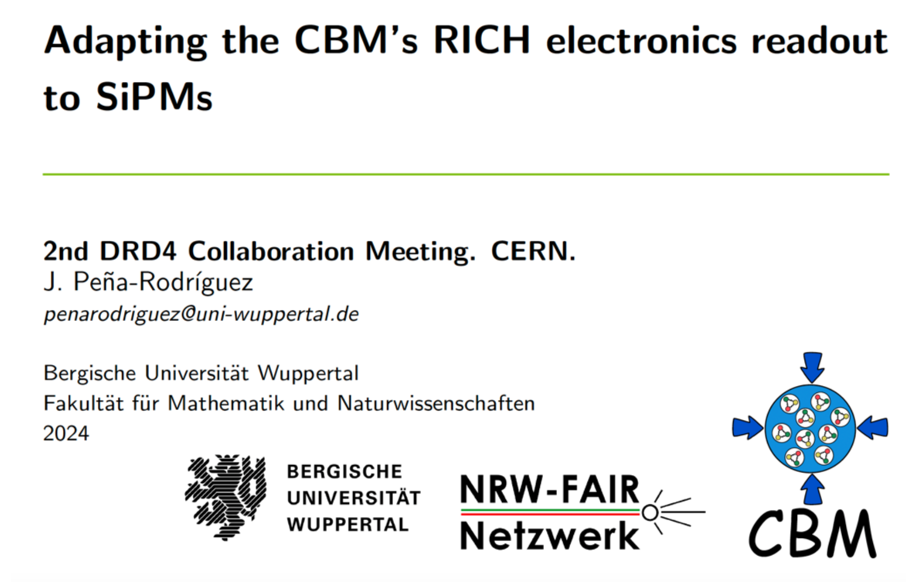
WG1 Convener: Fabrice Retiere (TRIUMF)
Deputies: Angela Romano (Birmingham), Qian Sen (IHEP-CAS)

WG1: Photon Detectors

Examples of presented activities







WG2: Particle ID

- Study of new and improved detector concepts, achievable performance, and intrinsic limitations of Cherenkov-based and TOF detectors employed for PID (such as RICH, DIRC, TOF, TOP, TORCH) plus any new concept
- Topics of interest
  - Study of advanced PID techniques
  - Development of new compact RICH concepts
  - Optimal operation of new detectors
  - Future DIRC detector applications
  - Development of innovative RICH configurations, like e.g. pressurized argon RICH, Aerogel-based RICH, lightweight RICH
  - Study the impact of time-resolved readout for future RICH detectors

WG2 Convener: Sajan Easo (RAL)

WG2: Particle ID

Examples of presented activities

A RICH detector for TeV Particles in the ALADDIN Experiment

Jascha Grabowski

University of Bonn

24-06-19

on behalf the proto-collaboration for the ALADDIN LoI

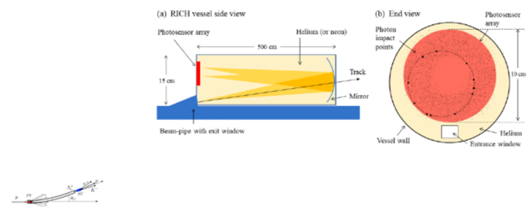
UNIVERSITÄT BONN

Layout

- use spherical mirror on one side, focal length 5m $\rightarrow R = 10m$
- Cherenkov angle = 8.4 mrad for helium $\rightarrow$ rings are quite small: $d = R\theta_C = 8.4$cm
- channeled Λ_c^+ have angle of 7 mrad $\rightarrow$ photons have 7 cm offset at detector plane [a]
- Λ_c^+ daughters highly boosted: most lie within $\theta_{track} \in [5, 11]$ mrad

$\rightarrow$ Cherenkov photons hit detector plane in a region of $\approx$ **10×10 cm²**

[a] plus contribution from tilt of mirror



RICH vessel could look like a telescope: **5 m** cylindrical pipe with **15 cm** diameter and a mirror on one side

Jascha Grabowski | A RICH for ALADDIN | 24-06-19 | 6

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

"***Green radiators***": Controlling refractive index & reducing Cherenkov gas radiator GWP: a challenge in an era of diminishing fluorocarbon availability

Related paper: https://link.springer.com/article/10.1140/epjp/s13360-023-04703-w

See also:
https://indico.cern.ch/event/1263731/contributions/5398511/attachments/2648319/4584649/G_Hallewell_DRD4%20Rad%20Gas%20GWP%20with%20annexes%20May%2016%202023.pdf
https://indico.cern.ch/event/1371158/contributions/5773321/attachments/2788215/4861759/G_Hallewell_ATLAS_sustainability_forum_Jan_26_2024_v2.pptx

ICHEP2024 (July 2024): https://indico.cern.ch/event/1291157/contributions/5900402/

G. Hallewell
Aix Marseille Université,
CNRS/IN2P3, CPPM, Marseille, France

CNRS IN2P3 Les deux infinis

DRD4 Collaboration Meeting,
WG-2: CERN Oct 21-25 2024

Aix Marseille université

1

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

Approaches to low-GWP fluorocarbon RICH radiator gases

See also:

(1) https://link.springer.com/article/10.1140/epjp/s13360-023-04703-w
(paper: EuroPhysics J. Plus, Dec 2023)

(2) https://indico.cern.ch/event/1263731/contributions/5398511/attachments/2648319/4584649/G_Hallewell_DRD4%20Rad%20Gas%20GWP%20with%20annexes%20May%2016%202023.pdf

(3) https://indico.cern.ch/event/1410802/ (DRD4 WG2 meeting 17 May 2024)

(4) https://indico.cern.ch/event/1420840/ (DRD4 WP_3.1 meeting 28 May 2024)

G. D. Hallewell
Aix Marseille Université, CNRS/IN2P3, CPPM, Marseille, France

With thanks to many people for information, as detailed in link (1) above

CNRS IN2P3 Les deux infinis

DRD4 Collaboration meeting: WG 2
Low GWP FC radiator gases: June 19 2024

Aix Marseille université

1

WG3: Technological activities

- Focus on the key technologies for RICH and other imaging detectors systems, including the full read-out chain
- WG3.A - Key technologies for RICH and other imaging detectors
  - Radiators (gas, aerogel, etc.) characterization, purity, fluid circulation, monitoring
  - Optical technologies: mirrors, lenses, coatings, aspherical elements, etc.
  - Thermo-mechanical engineering design: light materials, active local cooling, annealing in situ techniques, etc.
  - Ancillary instrumentation: for control of systematic uncertainties (calibration, alignment, monitoring) of PDE, (n-1), etc.
- WG3.B – Read-out electronics
  - Solutions to develop full read-out system chain for fast low-noise pixelated single-photon counters (for PMT/MCP/SiPM/etc.) with $O(10^3)$ channels, to be used as a general tool in DRD4 for laboratory tests, test-beam setups, etc.

WG3 Convener: Fulvio Tessarotto (Trieste)

WG3: Technological activities

Examples of presented activities

EP-DT
Detector Technologies

Strategies to reduce GHG emissions from particle detectors

Beatrice Mandelli on behalf of the Gas Team

CERN

DRD4 Collaboration Meeting
19th June 2024

DRD4 – WP3 – CERN OCT 2024

LATEST DEVELOPMENTS ON & AROUND THE SAMPIC WAVEFORM TDC

D. Breton[2], C.Cheikali[2], **E. Delagnes**[1], H. Grabas[3], O. Lemaire[4], **J. Maalmi**[2], P. Rusquart[2], P. Vallerand[2]

[1] CEA/IRFU Saclay (France)
[2] CNRS/IN2P3/IJCLab Orsay (France)
[3] Anciennement CEA/IRFU Saclay (France)
[4] Anciennement CNRS/IN2P3/LAL Orsay (France)

The Picopix Project

Xavier Llopart
On behalf of the LA-PicoPix design team

Aerogel characterization studies

Rocco Liotino, Eugenio Nappi, Nicola Nicassio, Giacomo Volpe

University & INFN, Bari

WG4: Software

- Address software issues related to the next generation of detectors developed in DRD4
  - Develop software packages of common interest to the DRD4 community and share experiences from software developments in different projects
  - Some of the recent advances in software technologies can provide significant improvements in the simulation and analysis of the data produced in Cherenkov detectors
- Topics (selection)
  - ML techniques to improve PID algorithms
  - Develop software that runs on GPUs to speed up simulation/reconstruction
  - Simulate the next generation of photon detectors and their read-out
  - Create framework to evaluate the new algorithms that will be developed on different software platforms

WG4 Convener: Maurizio Martinelli (Milano Bicocca)

WG4: Software

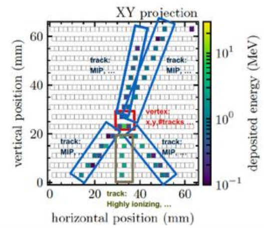
Examples of presented activities

Object Identification for Particle Detectors using Deep Learning

Thomas Pöschl[a,b], Sara Aumiller[a,b], Sergei Gerassimov[b], Nicole Hartman[b], Lukas Heinrich[b], Florian Kaspar[b], Karina-Sanziana Stelea[b], Stefan Wallner[c], Dominik Ecker[b], Luise Meyer-Hetling[b], Andrii Maltsev[b]

[a] European Organization for Nuclear Research (CERN)
[b] Technical University of Munich (TUM)
[c] Max-Planck-Institute for Physics, Munich (MPP)
thomas.poeschl@cern.ch

Credit: Futuris Tech



1

Simulation for the ClearMind Project

Viatcheslav Sharyy
For the ClearMind Collaboration

DRD4 meeting
May 31, 2024

Software Ecosystem for DRDs: Key4Hep

Alvaro Tolosa-Delgado (CERN)

Second DRD4 collaboration meeting (CERN)
Oct. 23th, 2024

Comprehensive Particle Identification (CPID) in Full-Detector Simulation

Uli Einhaus
2nd DRD4 Collaboration Meeting
23.10.2024

WG5: SciFi and TR Detectors

- R&D of segmented detectors based either on scintillating fibers or on pixelated semiconductor detectors for high precision tracking, eventually exploiting the transition radiation for PID
- WG5.A - Scintillating Fibers
  - Novel fast & radiation-hard scintillating fibers
  - Tracking with photon timing information in high occupancy environments
  - Micro-lenses on SiPMs
  - Fiber ribbon and detector plane production techniques (flexible ribbons)
  - Cryogenic cooling of SiPMs
- WG5.B - Transition Radiation Detectors
  - Development of a novel TRD based on highly segmented pixel semiconductor detectors (Si, GaAs, CdTe) for measuring both the energies and the emission angles of TR X-rays, for hadron ID in the TeV range

WG5 Convener: Sune Jakobsen (CERN)
Deputy: Francesco Loparco (Bari)

WG5: SciFi and TR Detectors

Examples of presented activities

R&D on Scintillating Fibres and SPAD array sensor readout for future Neutrino experiments

Till Dieminger*, K. Kaneyasu[2], M. Franks[1,3],
C. Bruschini[2], E. Charbon[2], D. Sgalaberna[1]

*tilld@ethz.ch

[1] Neutrino Group, ETH Zurich
[2] AQUA Lab, Neuchatel, EPFL
[3] Now: CMS Group, ETH Zurich

ETH zürich EPFL Swiss National Science Foundation Funded by SNSF

ETH Zürich, Institute of Particle Physics and Astrophysics (IPA), Otto-Stern-Weg 5, 8093, Zürich, Switzerland

Characterization of pixelated high-Z sensor for X and gamma-ray detection

Petr Smolyanski & Benedikt Bergmann
Institute of Experimental and Applied Physics, Czech Technical University in Prague
Petr.smolyanskiy@utef.cvut.cz
Benedikt.bergmann@utef.cvut.cz

medipix collaboration

Development of a scintillating fiber tracker with SiPM readout for a space-borne cosmic-ray detector

Roberta Pillera
on behalf of
G. De Robertis, L. Di Venere, F. Gargano, M. Giliberti, A. Liguori, F. Licciulli, F. Loparco, L. Lorusso, M.N. Mazziotta, G. Panzarini, D. Serini
With the support of the technical staff of INFN Bari

3rd DRD4 Collaboration Meeting
11/04/2025
roberta.pillera@ba.infn.it

INFN Istituto Nazionale di Fisica Nucleare

High purity electron and hadron beams for PID studies at SPS.

On behalf of the DRD _4.5.2 working group.

Anatoli Romaniouk. DRD 4.5 meeting, 25.10.2024.

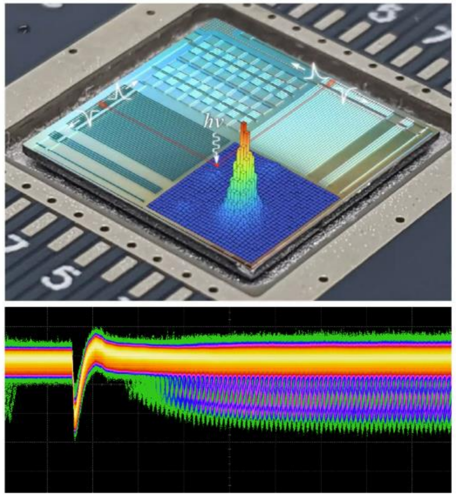
WG6: Novel ideas and far-future R&D

- This WG acts as the DRD4 collaboration's gate for novel ideas and revolutionary concepts
  - New ideas shall find in WG6 the right environment to prosper
  - Help the new concepts to reach the required level of maturity
  - Hope to transform some of these ideas into breakthroughs in the field, impact the future of photon detection

WG6 Convener: Suat Ozkorucuklu (Istanbul)

WG6: Novel ideas and far-future R&D

Examples of presented activities



9th April 2025

Large-scale superconducting nanowire readout

Boris Korzh
University of Geneva, Switzerland

UNIVERSITÉ DE GENÈVE

A. ALIKHANYAN National Laboratory

DRD4

Radio Frequency Photo-Multiplier Tube, RFPMT

Amur Margaryan on behalf of the Advanced Radiofrequency Timing AppaRATus (ARARAT) collaboration

Ani Aprahamian[a,h,1,8], Vanik Kakoyan[a,1,2,5,10], Simon Zhamkochyan[a,1,2,8], Sergey Abrahamyan[a,4,5,8], Hayk Elbakyan[a,2,3], Arsen Ghalumyan[a,2,3,5], Gagik Sughyan[a,2,3,5], Hasmik Rostomyan[a,2,5,7], Anna Safaryan[a,2,5,10], Samvel Maiylyan[a,2,3,5], Artashes Papyan[a,2,3,5], John Annand[b,2,3,5], Kenneth Livingston[b,2,3,5], Rachel Montgomery[b,2,3,5], Patrick Achenbach[c,1,2,5,8], Josef Pochodzalla[d,5,8], Dimiter L. Balabanski[e,5,8], Satoshi N. Nakamura[f,2,5,8], Viatcheslav Sharyy[g,2,5,9], Dominique Yvon[g,2,5,9], Khachatur Manukyan[h,2]

a) A.I. Alikhanyan National Science Laboratory, b) School of Physics & Astronomy, University of Glasgow, c) Thomas Jefferson National Accelerator Facility, d) Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, e) Extreme Light Infrastructure- Nuclear Physics (ELI-NP), f) Department of Physics, Graduate School of Science, the University of Tokyo, g) Département de Physique des Particules Centre de Saclay, h) Department of Physics and Astronomy, University of Notre Dame

Activities: 1 management, 2 R&D, 3 hardware, 4 software, 5 test studies, 6 fundamental studies, 7 quantum technologies, 8 nuclear physics, 9 imaging, 10 material science

Outline
- Advanced RF timing technique
- Radio Frequency Photo-Multiplier Tube (RFPMT)
- RFPMT and Optical Frequency Comb/RF Synchronized Photon Source
- Time-Resolved Photoelectron Emission Lifetime Spectrometer
- Heavy Ion Detector
- Time Microscope of Nuclear Reactions

7/4/2025-11/4/2025 DRD4 1

Recent developments of amorphous selenium-based X-ray detectors

Shiva Abbaszadeh
Radiological Instrumentation Laboratory
Electrical and Computer Engineering
ril.soe.ucsc.edu

UC SANTA CRUZ | Baskin Engineering

Prospects for Advanced Fiber Detectors

3rd DRD4 Collaboration Meeting
(WG6 : Blue Sky R&D)

A mature and successful technology

Optical fibers:
- widely used in **fiber-optic networks** for ***long-distance*** and ***high-bandwidth*** data transmission, essential in telecommunications;
- for **particle detection**: ***scintillating*** or ***Cherenkov***-light-emitting fibers, coupled to **multichannel photodetectors**

Extra bonus using ***quartz fibers*** :
- ***Radiation resistance***
- ***Time resolution***

A 4D QCTD (= Quartz Cherenkov Timing Detector) → $\sigma_x \approx 50\ \mu m$, $\sigma_t \approx 10\ ps$

A. Penzo, 10/04/2025
(For Iowa – Istanbul QCTD)

The University of Iowa

Work Package activities

- WP meetings
  - Discussion on available and needed resources for each defined task (persons, materials, equipment, funds); milestones and deliverables; sharing of responsibilities and synergies among the various groups; etc.
  - Presentation of results and status review at periodic meetings

WP1: Solid-State Photodetectors

- Task 1 - SSPD with new configurations and modes
  - Development of back-side illuminated SiPM (potential for better PDE and radiation tolerance); development of ultra-granular SiPM that integrates with the electronics by using 2.5D or 3D interconnection techniques; development of CMOS-SPAD light monolithic sensors for HEP; study of new materials for light detection
- Task 2 - Fast radiation hard SiPMs
  - Standardize procedures for quantification of radiation effects; irradiated SiPMs characterization in wide temperatures range (down to -200 ˚C); study of annealing; study and quantify other measures enabling the use of SiPM in highly irradiated areas (e.g. smaller SiPMs, macro- and micro-light collectors)
- Task 3 - Timing of SSPD, including readout electronics
  - Study and improve the timing of SiPMs; co-design of a multi-ch. readout ASIC exploiting the timing potential; integration and packaging with integrated cooling; vertical integration of SiPM arrays to FEE (better timing via reduction of interconnections' parasitic inductances and capacitances)

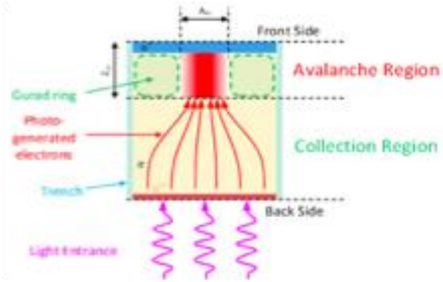
WP1 Leader: Rok Pestotnik (Ljubljana)

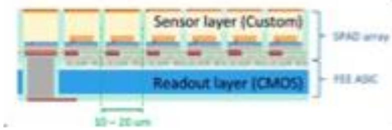
Task leaders: Alberto Gola (FBK), Lodovico Ratti (Pavia), David Gascon (Barcelona)

WP1: Solid-State Photodetectors

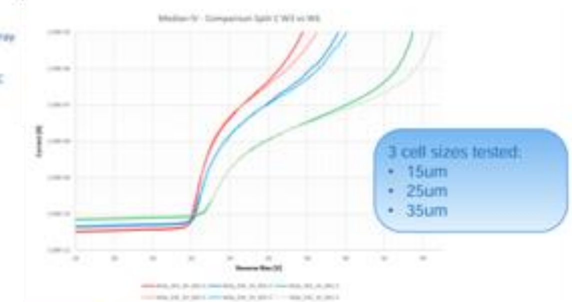
Examples of ongoing activities

Backside illuminated (BSI) SiPMs: potential for an enhanced PDE and a better radiation tolerance.

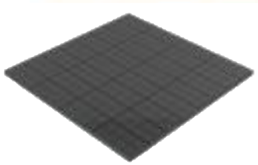




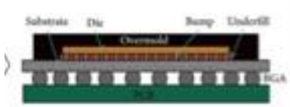
The first results of the FBK IBIS Run samples



Timing of SSPD & Developing ultra-granular SiPM that integrates with the readout electronics

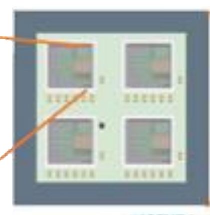


3x3mm2 SiPM Array

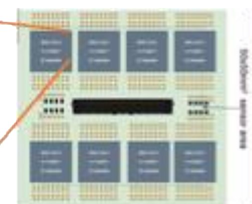


FastIC+ (collab. CERN ICCUB) Low power Chip

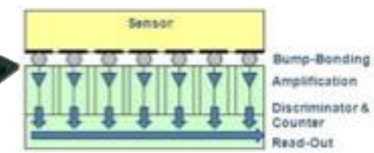
2024 Produced and evaluated



BGA design & production end of June 2025



256 Ch 5x5cm2 Module proposal



Ultra granular SiPMs

Long term goal 1x1mm2 SiPM array

- Study and **improve the timing of SiPMs**.
- **Optimised, reliable, cost-effective integration** and packaging with integrated cooling.
- **Vertical integration of SiPM arrays to FEE:** optimise timing by reducing the interconnections' parasitic inductances and capacitances.

WP1: Solid-State Photodetectors

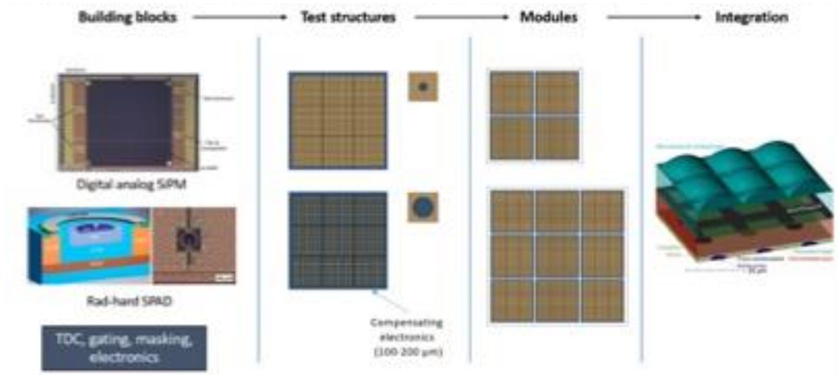
Examples of ongoing activities

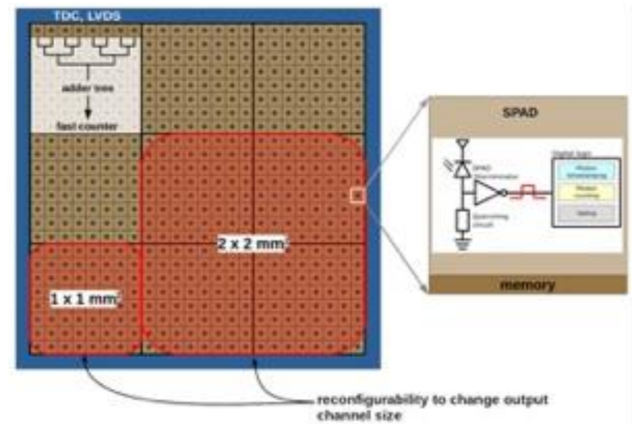
CMOS-SPAD light sensors: co-integration of SPADs and electronics, digitised output signals

spadRICH - Radiation-hard digital analog silicon photomultipliers for future upgrades of Ring Imaging Cherenkov detectors

aqualab EPFL

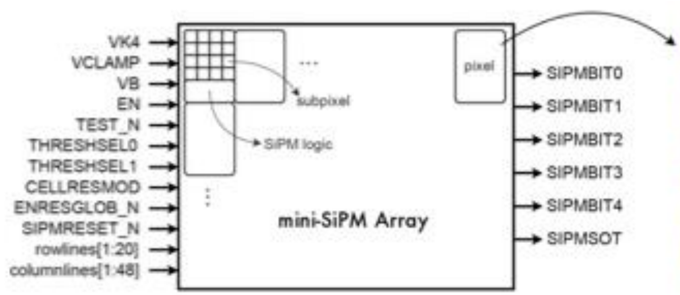
Institut "Jožef Stefan" Ljubljana, Slovenija

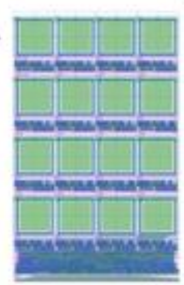




ASPIDES -Development of a technology platform for the design, production and commissioning of dSiPMs

INFN





WP1: Solid-State Photodetectors

Examples of ongoing activities

Fast & radiation hard SiPMs - enabling the use of SiPM in highly irradiated areas

- **Characterise SiPMs** to -200 deg. C
- **Study of annealing.**
- **Study and quantify other measures :**

Test samples of different producers (Hamamatsu, Broadcom, FBK, ...)
Quantify different parameters

Experimental structures

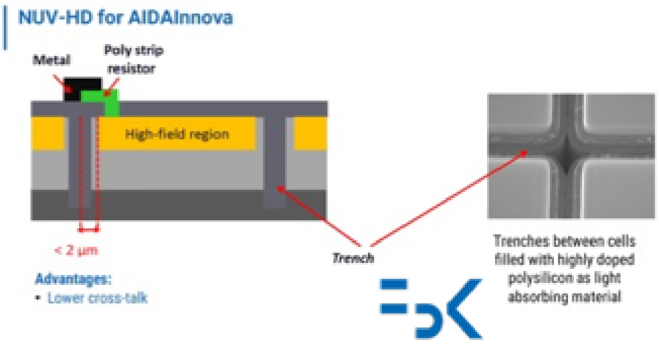
AidaInnova Run – exp. May 2025

Two different technologies:

- Low electric field
- Ultra Low electric field

Cell pitch: 15, 25, 40, 75um

SiPM sizes: (0.25, 0.5,1,2,3)^2 mm^2



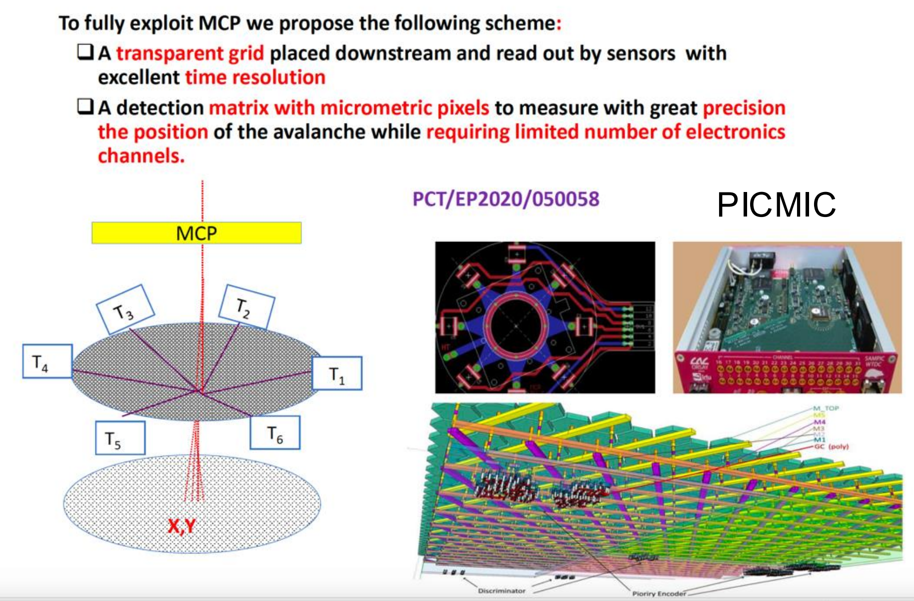
WP2: Vacuum-based Photodetectors

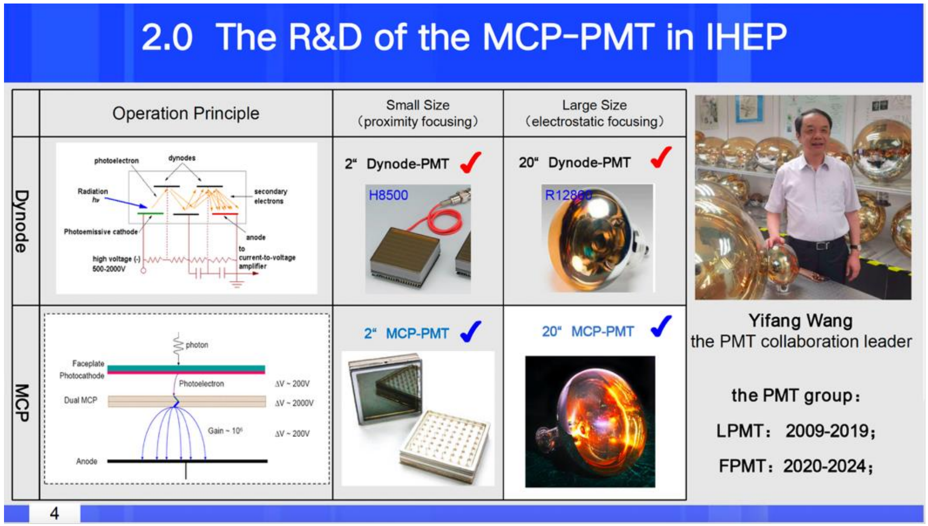
- Task 1 - New materials, coatings, longevity and rate capability studies
  - Develop new materials and techniques to increase MCP-PMT tube lifetime and improve rate capabilities; use new techniques with new materials to achieve high aspect ratio with small diameter for better gain, time, and spatial resolution
- Task 2 - New photocathode materials, structure and high QE VPD
  - Search for new materials with the required characteristics to be used as photocathodes; develop photocathodes with new structures
- Task 3 - VPD time and spatial resolution performance
  - Development of large area MCP-based photodetector with combined excellent timing and position resolution, including electronics integration

WP2 Leader: Imad Laktineh (Lyon)
Task leaders: Silvia Gambetta (Edinburgh), Thierry Gys (CERN), Ping Chen (XIOPM-CAS), Claudio Gotti (Milano Bicocca)

WP2: Vacuum-based Photodetectors

Examples of ongoing activities





WP3: RICH and other imaging det.

- Task 1 - New Materials Radiators and Components
  - Gas alternatives; optimized aerogel modules; precise interferometric measurement of refractive index
- Task 2 - Development of new RICH detector concepts for improved performance
  - High-pressure gas radiator; fast timing, combined RICH/TOF; cryo-RICH; modular RICH; technological demonstrators & proof of concepts
- Task 3 - Prototype Single-Photon Sensitive Module for Imaging Arrays from sensor to DAQ and self-calibration systems
  - Fully functional autonomous modules; scalable R/O electronics; integration to arrays with cooling; on-detector calibration/alignment/monitoring
- Task 4 - Study of RICH detectors for future e^+e^- colliders
  - Prototype a cell for the ARC concept
- Task 5 - Software and Performance
  - Fast simulation; reconstruction for high occupancy, high background

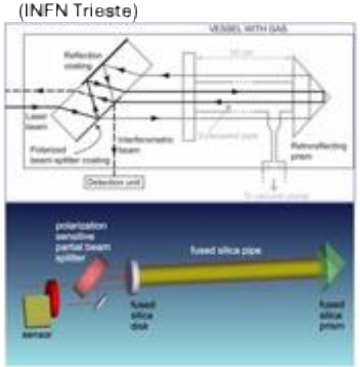
WP3 Leader: Roberta Cardinale (Genova)
Task leaders: Fulvio Tessarotto (Trieste), Sneha Malde (Oxford), Chris Jones (Cambridge)

WP3: RICH and other imaging det.

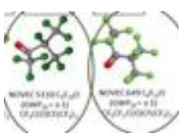
Examples of ongoing activities

- **WP4.3.1:** New Materials Radiators and Components
  Study of novel and optimized radiators, including gas alternatives to perfluorocarbons and enhanced aerogel tiles, along with the development of advanced instrumentation and techniques for the characterization, quality assessment, and monitoring of Cherenkov radiators.

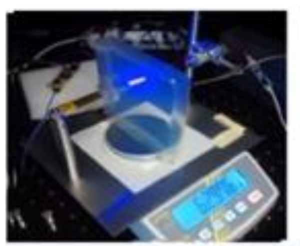
Modified folded Jamin interferometer for gas refractive index monitoring (INFN Trieste)



Study of gas alternatives to perfluorocarbons or eco-friendly fluorocarbon gas system



Optimized Aerogel Radiator Tiles



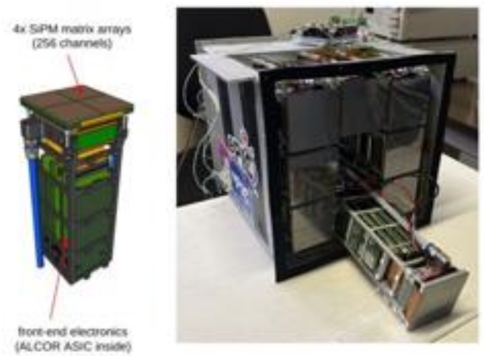
INFN Ferrara

Jozef Stefan Institute

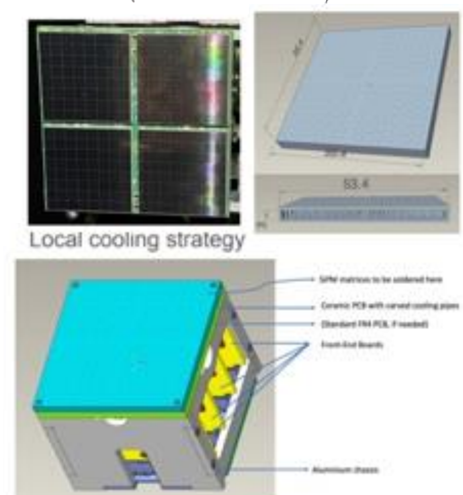
- **WP4.3.2:** Development of new RICH detector concepts for improved performance.
  - Several new concepts and detector designs under consideration including a pressurized RICH with inert gasses like Argon as a possible alternative to fluorocarbon greenhouse gases.

- **WP4.3.3:** Prototype Single-Photon Sensitive Module for Imaging Arrays from sensor to DAQ and self-calibration systems.

EPIC dRICH prototype SiPM module (INFN Bologna)



Prototype SiPM Housing with local cooling (Uni and INFN Genova)

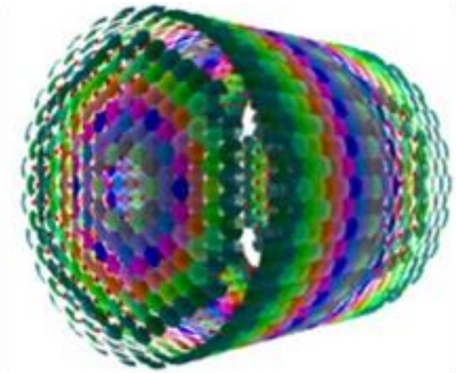


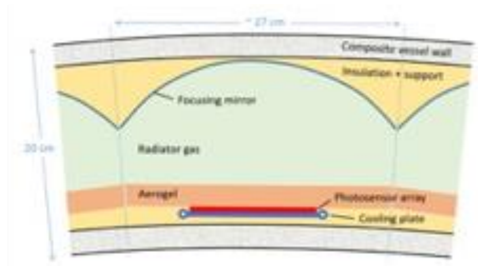
WP3: RICH and other imaging det.

Examples of ongoing activities

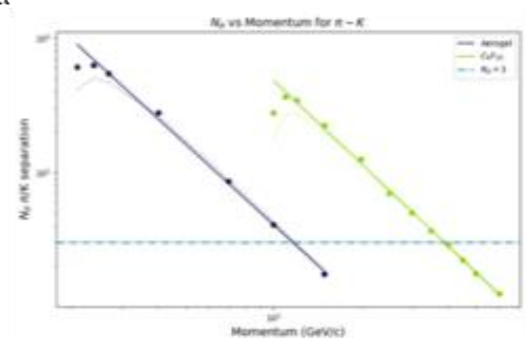
- **WP4.3.4:** Study of RICH detectors for future electron-positron colliders (CERN, University and INFN Genova, University of Oxford, University of Warwick)

ARC detector concept for FCC-ee





- Performance evaluation with simulation and development and testing of a prototype compact RICH cell



- **WP4.3.5:** Software and Performance
  - Review of available frameworks for fast Cherenkov optical photon tracing within the context of Geant4 simulations
  - Review of approaches for PID algorithms, including those based on Machine Learning (ML) and Artificial Intelligence (AI)
  - Review of external software tools used by the community

WP4: Time of Flight Detectors

- Task 1 - Study the coupling of a thin Cherenkov radiator to a single-photon detector array, for TOF of charged particles
  - High precision timing (~10 ps) using high refractive index solid Cherenkov radiators coupled to SiPMs arrays or MCPs
- Task 2 - Develop a SiPM array for single-photon detection, with mm-scale pixelation, suitable for use in TOF prototypes
  - Integration of SiPM arrays with multichannel R/O electronics to provide mm-scale position sensitivity and fast timing of Cherenkov light at the very high rates expected with HL-LHC and future colliders
- Task 3 - Develop lightweight mechanical supports for DIRC-type TOF
  - Development of prototype support using lightweight materials with minimal distortion of quartz, detectors, electronics
- Task 4 - Develop techniques for measuring the optical properties of optical components for TOF detectors
  - Develop precision measurement characterization of quartz Cherenkov radiators; share existing facilities

WP4 Leader: Jon Lapington (Leicester); Deputy: Eugenio Nappi (Bari)
Task leaders: Christian Morel (Marseille), Neville Harnew (Oxford), Suat Ozkorucuklu (Istanbul)

WP4: Time of Flight Detectors

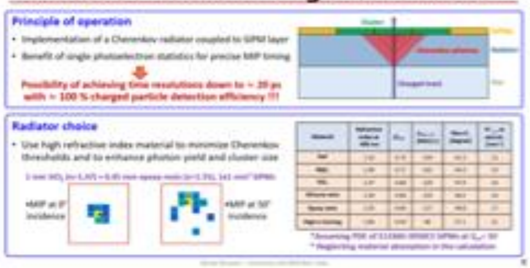
Examples of ongoing activities

- **WP4.4.1:** Study the coupling of a thin Cherenkov radiator to a single-photon detector array, for TOF of charged particles
- **Participants:** INFN Bari, INFN Bologna, FBK, Istanbul, Marseille

- **WP4.4.2:** Develop a SiPM array for single-photon detection, with mm-scale pixelation, suitable for use in TOF prototype
- **Participants:** Aachen, Barcelona, INFN Bari, FBK, Leicester, Marseille

INFN Bari – SiPMs with radiators

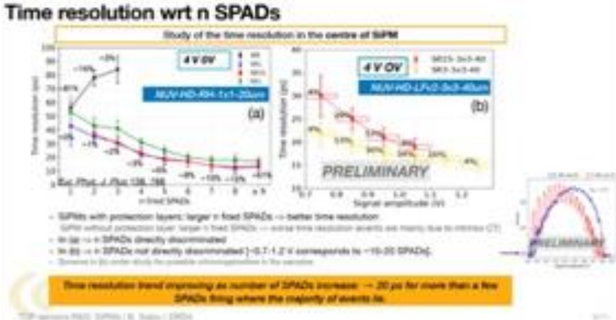
Cherenkov-based timing measurements



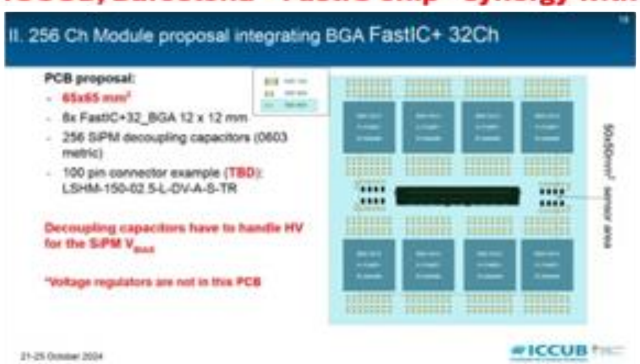
FBK – SiPM developments for ToF – synergy with WP4.1

INFN Bologna – SiPM characterization

Time resolution wrt n SPADs



ICCUB, Barcelona – FastIC chip - synergy with WP4.1



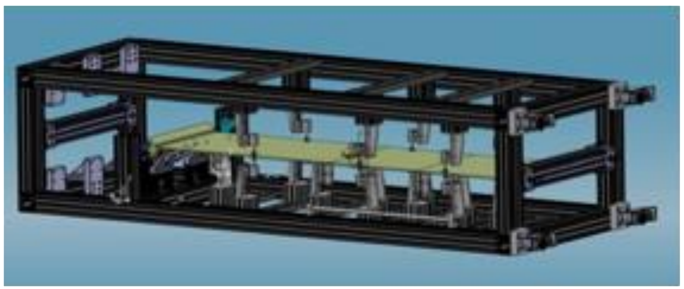
WP4: Time of Flight Detectors

Examples of ongoing activities

- **WP4.4.3:** Develop lightweight mechanical supports for DIRC-type TOF detectors
- **Participants:** GSI, USTC, Oxford

- **WP4.4.4:** Develop techniques for measuring the optical properties of optical components for TOF detectors
- **Participants:** GSI, USTC, Istanbul, Oxford, Yerevan

Oxford – lightweight mechanical structures for TORCH radiators

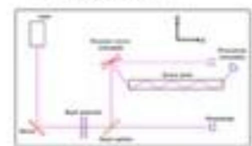


Developments at USTC – Optical characterizations

DTOF R&D related to WP4.4.4

Optical characterization of fused silica

- Requirements
  - Roughness <1nm (reflectivity error <0.1%)
  - Absorption length >100m, ±10% (λ>300nm)



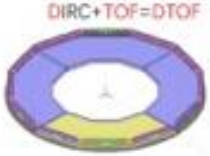
- Method
  - Measuring laser intensity change after crossing fused silica
- Plan
  - Setup optical test stand in dark room, 2024~2025
  - Test fused silica plates for endcap and barrel DTOF prototype, 2025-2026

Developments at USTC – PID Mechanics

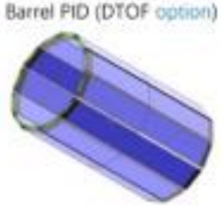
DTOF R&D related to WP4.4.3

Light-weight mechanical structure

Endcap PID
DIRC+TOF=DTOF



Barrel PID (DTOF option)



- Requirements:
  - Overall material budget <0.3 X_0, as low as possible
  - Fit in the limited space between tracker and ECAL
- Plan:
  - 1st-version design (C fiber, Al honeycomb), 2024
  - Prototyping & optimization, 2025
  - Final design, 2026

Plan to join LHCb-TORCH group (associate membership)
→ Contribute to detector/electronics/mechanical etc.

WP5: SciFi and TR Detectors

- Task 1 - Develop an improved radiation hard scintillating fiber with a fluorescence decay time near 4 ns
  - Standard fast fiber is over 25 years old (SCSF-78M and -78MJ from Kuraray); develop improved radiation hard fiber (should have same or better light yield, attenuation, decay time, and stable in time)

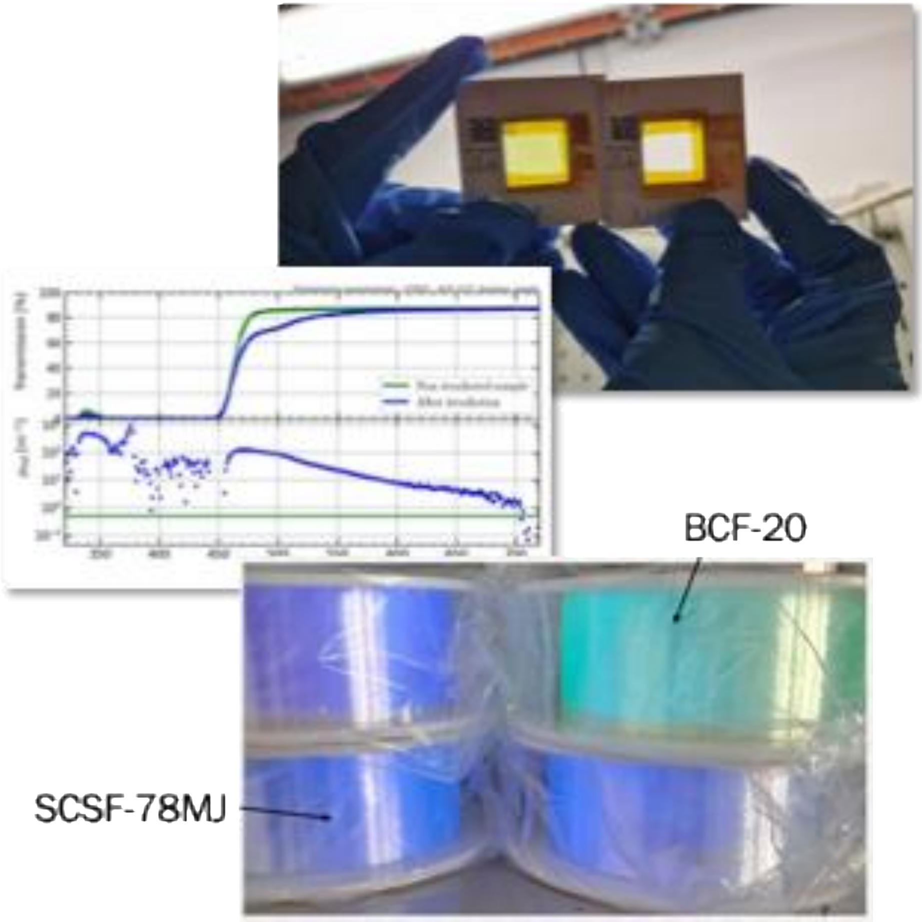
WP5 Leader: Blake Leverington (Heidelberg); Deputy: Guido Haefeli (EPFL)

WP5: SciFi and TR Detectors

Examples of ongoing activities

Recent Developments:

1. Irradiation of new green commercial sample with good timing (in partnership with ECAL DRD6 WP3) shows poor hardness (transmission loss) even at 10 kGy
2. Samples of 3 improved attenuation length Luxium (formerly Saint Gobain) fibres delivered to EPFL.
   - Will be wound as fibre mats and irradiated at IRRAD to LHCb Upgrade 2 doses in April (10 kGy peak)
3. Discussions with Organic Scintillator developers at Scintillator Brainstorming Meeting organized by E. Auffray https://indico.cern.ch/event/1507749/
   - Very useful, made new contacts!



DRD4 common activities (1)

- Test-beams
  - Beam time (CERN SPS) allocated for DRD4 activities in 2025
  - Goal for the medium-long term: have a DRD4-dedicated setup at CERN for test-beams
- Available facilities in the various institutes
  - Sharing instrumentation/knowledge (training of young colleagues)
- Common electronics tools
  - Availability of high-performance electronics is crucial for most DRD4 R&D activities
  - Empower the DRD4 community with "common electronics tools" for better comparison of detectors characterization and "standardization" of test procedures

DRD4 common activities (2)

- Common software tools
  - Survey of software available to the collaboration
  - Many software (simulation) tools developed by different groups (device-level simulation, electronics, system level, optics, etc.) → join efforts for common development (possibly open source)
- Compendium on specific photodetector technologies (SiPMs, PMTs, MCP-PMTs, etc.) under preparation
  - Collaboration-wide effort: technical document
  - Goal: summarize state-of-the-art and create "standard procedures" for the characterization and comparison of detectors
    - How to measure main detector parameters (for different photodetector types - SiPMs, PMTs, MCP-PMTs, etc. - including also rad. hardness)
    - How to report results using common terminology and measurements to allow easy comparison between different groups/labs
  - Very useful for the whole photodetector community
  - If interested in joining the work team, contact us!

Summary

- The DRD4 Collaboration has formed to propose a broad but focused R&D program on photodetectors and PID techniques
- The scope of DRD4 is very strong
  - PID is a key component in modern HEP experiments, and is often achieved with Cherenkov and TOF detectors, that often rely on photodetection
  - Photodetection is undergoing a strong transformation (e.g. SiPMs invade in fields that were occupied since decades by vacuum and gas-based devices)
  - DRD4 includes also SciFi tracking and TRD: they fit well into DRD4
- Thanks to the efforts of many colleagues, the DRD4 Community has been created and is very active
  - DRD4 is continuously attracting new groups
  - In case of interest, please contact us (https://drd4.web.cern.ch/contacts)

DRD4