

Advances in photon detection and PID: highlights from the DRD4 Collaboration

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on behalf of the DRD4 Collaboration

The 2026 International Workshop on the High-Energy CEPC

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DRD4 Collaboration

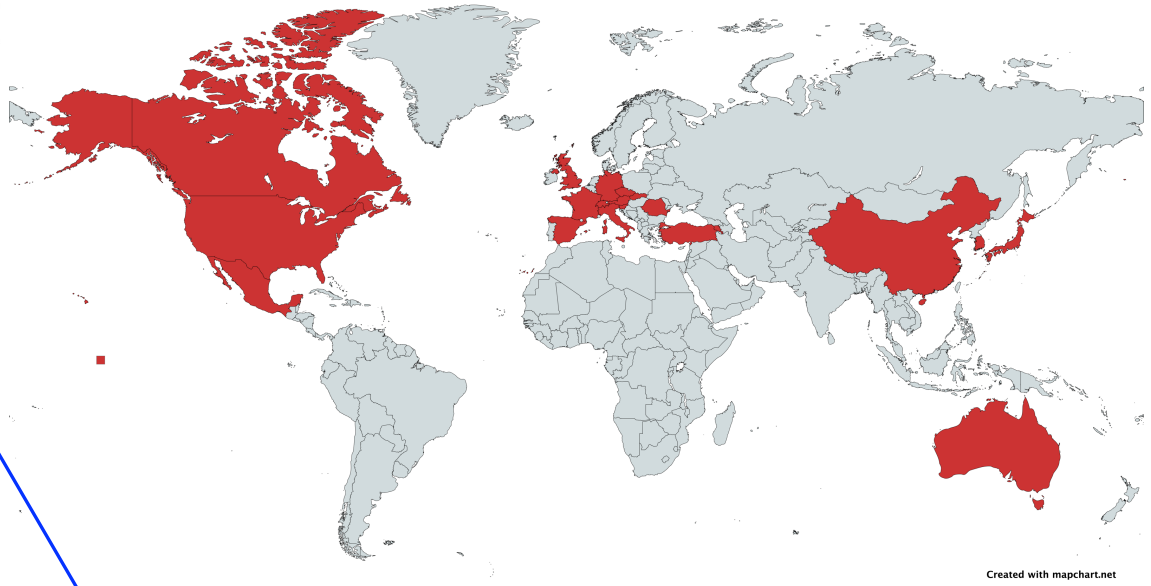
- DRD4: international Collaboration with CERN as host laboratory
  - Approved by the CERN Research Board in December 2023
- Main goal: bundle and boost R&D activities in **photodetector technology** and **Particle Identification (PID) techniques** for future HEP experiments and facilities
- To be more 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 Institutions

- In just three years, DRD4 has assembled a geographically broad community, including many small teams with limited previous experience of large R&D collaborations, and with different backgrounds
- Current status: 70 institutions from 20 countries

Table 1: Geographical distribution of DRD4 Collaborating Institutions (updated October 2026)

Nation	Number of institutions
Armenia	1
Australia	1
Austria	2
Canada	2
CERN	1
China	3
Czech Republic	2
France	6
Germany	5
Italy	17
Japan	3
Mexico	1
Romania	1
Slovakia	1
Slovenia	1
South Korea	1
Spain	1
Switzerland	3
Turkey	1
United Kingdom	9
United States	8
Total	70



Institute of High Energy Physics, Chinese Academy of Sciences (IHEP)
University of Science and Technology of China (USTC)
Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences (XIOPM)

DRD4 Governance

- In order to allow for day to day governance, we have written a Constitution
  - Intended to be lightweight: can be modified/updated as Collaboration desires
  - Constitution intended to complement MoU (it is linked from Annex 4 in the MoU)
  - v2.0 approved on April 14th 2026
- DRD4 Memorandum of Understanding sent for signature on June 16th 2026
  - Second DRD Collaboration to launch signature (after DRD1)
  - >50% of all DRD4 Funding Agencies have signed already

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Working Group activities

- Six Working Groups (WGs) defined at the Proposal stage
  - WG1: Photon Detectors (Fabrice Retiere, TRIUMF)
  - WG2: Particle ID (Sajan Easo, RAL)
  - WG3: Technological activities (Fulvio Tessarotto, Trieste)
  - WG4: Software (Maurizio Martinelli, Milano Bicocca)
  - WG5: SciFi and TR Detectors (Sune Jakobsen, CERN)
  - WG6: Novel ideas and far-future R&D (Suat Ozkorucuklu, Istanbul)
- Goals
  - Discuss scientific and technological interests
  - Share expertise on specific topics: present state-of-the-art, open issues, etc.
  - Discuss availability/need of equipment and infrastructures for specific activities (and possibility of sharing or use by other DRD4 members)
  - etc.
- Stand-alone Zoom meetings + meetings during DRD4 Weeks at CERN
- WGs have become the mechanism for building a common scientific and technical culture and represent the DRD4 Collaboration backbone

Work Package activities

- Five Work Packages (WPs) defined at the Proposal stage
  - WP1: Solid-state Photodetectors (Rok Pestotnik, Ljubljana)
  - WP2: Vacuum-based Photodetectors (Imad Laktineh, Lyon)
  - WP3: RICH and other imaging detectors (Roberta Cardinale, Genova)
  - WP4: Time-Of-Flight detectors (Jon Lapington, Leicester)
  - WP5: SciFi tracking and TR detectors (Blake Leverington, Heidelberg)
- WP meetings
  - Definition of tasks, milestones and deliverables; discussion on available and needed resources for each defined task (FTEs, materials, equipment, funds); sharing of responsibilities and synergies among the various groups; etc.
  - Presentation of results and status review at periodic meetings
- So far, few resources from Funding Agencies, hence difficult for progress on WP deliverables
  - Nonetheless, some studies have advanced - selected highlights follow
  - This, however, is unlikely to continue unless funding is forthcoming

Example of DRD4 common activities

- Test-beams
  - Test beams (CERN SPS) dedicated to DRD4 activities successfully completed in 2025 and 2026
- Writing of the "Photodetectors Compendium/Review" launched within WG1
  - Collaboration-wide effort!
  - The "Compendium" is a comprehensive review of the field of photon detectors used in fundamental and applied physics, in particular for high-energy, medical and astro-particle physics
  - Goal is to provide the reader with up-to-date information on state-of-the art photodetectors, with reference to the most relevant bibliography
  - A large effort is devoted to the standardization of procedures for characterization and comparison of different photodetector technologies
    - e.g. the definition of the most relevant parameters to be measured, how to measure them, how to report results using common terminology/plots/units to facilitate comparison, etc.
  - Writing in progress (already >300 pages): final draft expected in the next months

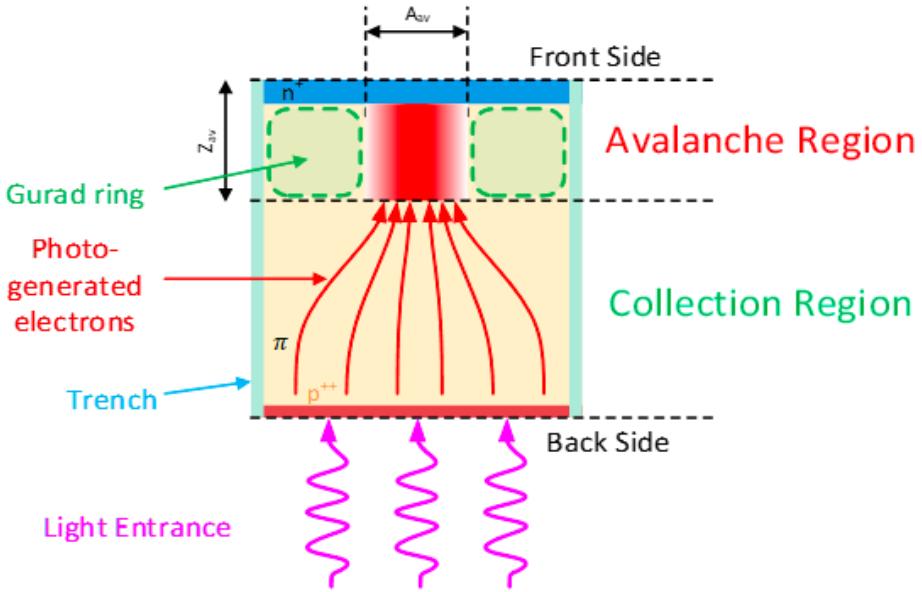
DRD4 and the ESPP update

- Update of the European Strategy for Particle Physics (ESPP)
  - FCC-ee identified as the next flagship collider
- DRD4 is already contributing to key developments for future collider experiments
  - Many DRD4 technological developments are instrumental e.g. to FCC-ee detector concepts
- A few examples:
  - Silicon Photomultipliers (SiPMs) already present in most FCC-ee scenarios
  - Ring Imaging Cherenkov detector concept for flavour physics at FCC-ee
  - Eco-friendly Cherenkov radiator gases
  - Fast electronics and vertical integration techniques
  - Lightweight optics, mechanics and cooling
  - Etc.
- For the future (2027-29 and beyond) plans of the DRD4 Collaboration, more activities targeting R&D focused on future colliders

Selected highlights from DRD4 activities

Silicon Photomultipliers

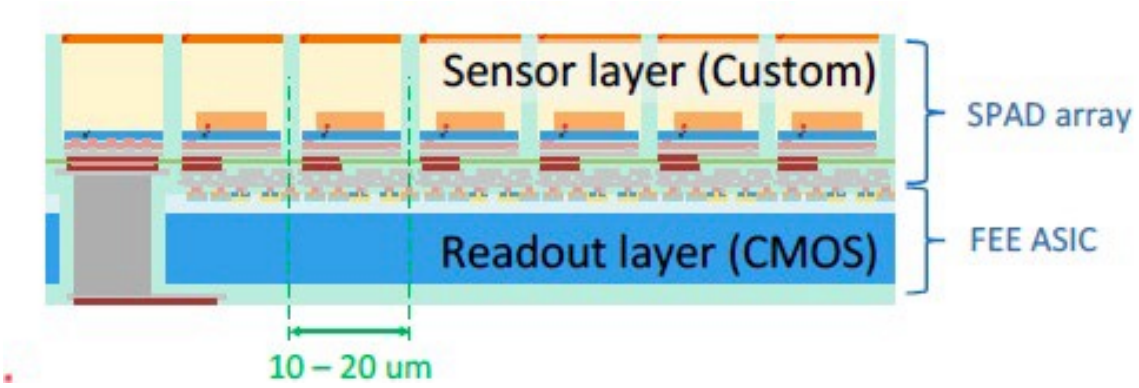
- Photon detectors with improved performance
  - SiPMs
    - Higher photodetection efficiency; Higher granularity; More compact and efficient integration with electronics and cooling; Better timing resolution
    - Various applications (RICH, ToF, SciFi, etc.)
- Back-Side Illuminated (BSI) SiPM (FBK, INFN)
  - Potential Advantages
    - ~100% fill factor, even at small pitch; Interconnection density < 15 μm; High speed, wide dynamic range; Lower gain, reduced crosstalk; Uniform backside entrance window (VUV-ready); Option for integrated, ultra-fast low-power electronics
  - Development Risks
    - Charge collection time jitter; Low Gain might impact SPTR; Effectiveness of the new window



A. Gola (FBK)

Silicon Photomultipliers

- Hybrid SiPM arrays (FBK, JSI, Barcelona)
  - Separate sensor and read-out layers,connected using 2.5D/3D techniques
  - Sensor layer
    - Custom SiPM technology, CMOS-compatible (transfer to large-volume foundries possible; lower cost per unit area compared to full CMOS process given lower number of masks)

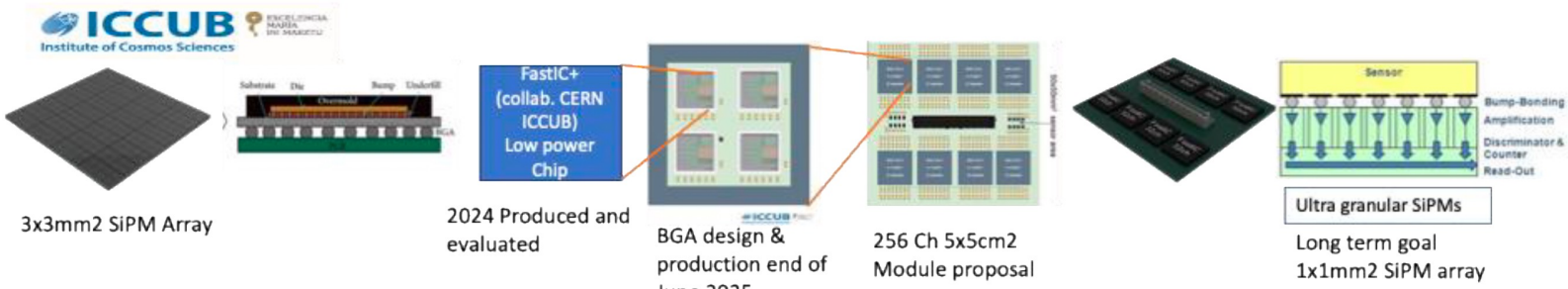


A. Gola (FBK)

    - Customized fabrication process, no constraint from transistor fabrication
    - Very high fill factor (all-active area)
  - Read-out layer
    - Free choice of CMOS node → optimal read-out performance
    - CMOS area can be smaller than sensing area (2.5D) → lower cost

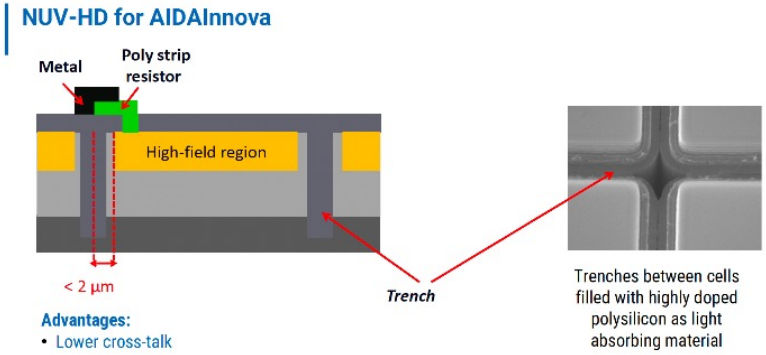
Silicon Photomultipliers

- Ultra-granular SiPMs with integrated electronics (Barcelona, FBK)
  - Timing of SSPD & Developing ultra-granular SiPM that integrates with the readout electronics



D. Gascon (Barcelona)

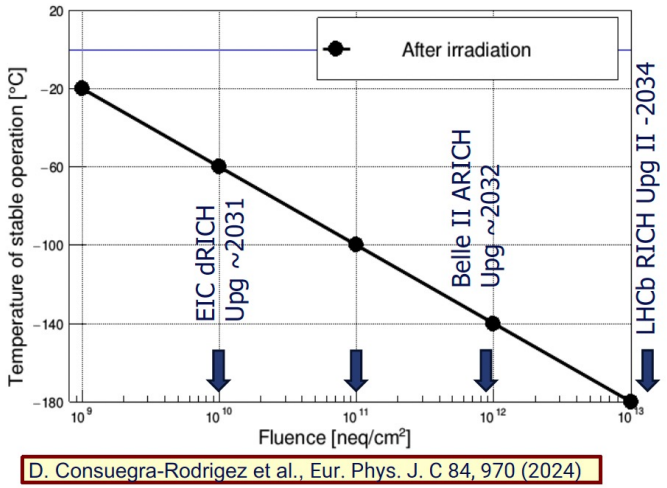
- Fast and radiation-hard SiPMs (FBK, JSI, INFN)
  - AidaInnova run (cell pitch: 15, 25, 40, 75 μm)
  - Two different technologies: Low and Ultra-Low electric field



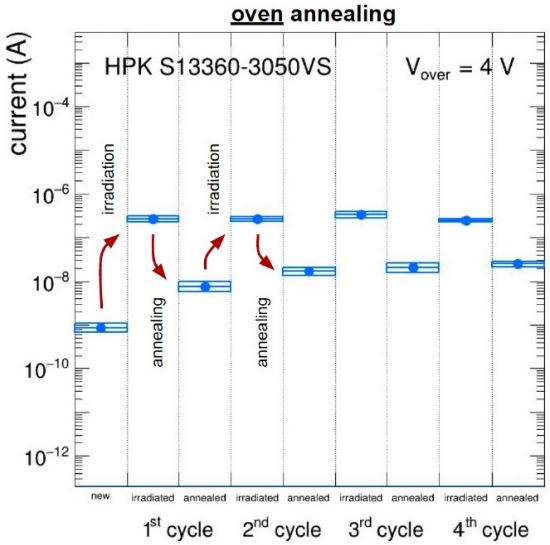
R. Pestotnik (JSI)

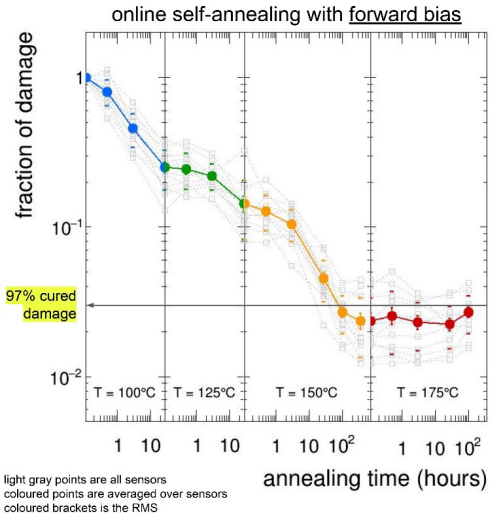
SiPM radiation hardness and annealing

- SiPM are extremely sensitive to radiation damage
- Optimize cooling and annealing procedures for long term operations
  - Cooling temperature: at which the SiPM is ”usable” for single-photon detection, i.e. where the single photo electron peak is separated from the background (and where DCR is at an “acceptable” level)
  - Annealing examples:
    - Oven (irradiation fluence/cycle : 10^9 n_{eq}/cm^2 + annealing in oven :150 hours at 150 ˚C)
    - Forward bias (how much damage is cured as a function of temperature and time)



D. Consuegra-Rodrigez et al., Eur. Phys. J. C 84, 970 (2024)

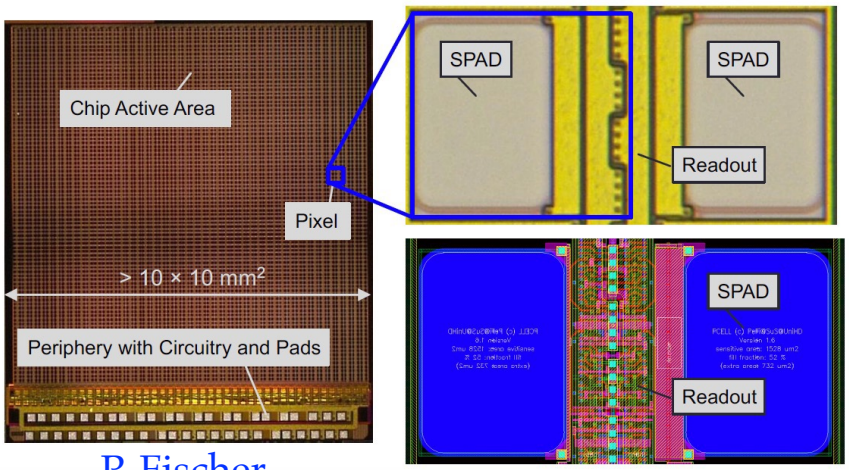




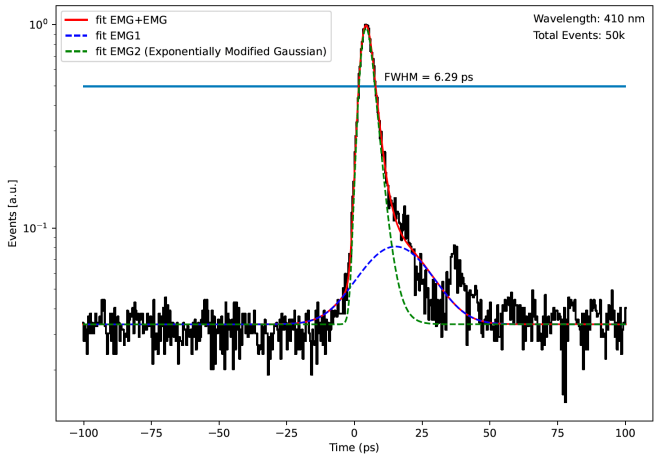
R. Preghenella (INFN)

Digital SiPMs

- Digital SiPM (dSiPM or CMOS SPAD)
  - Combines SPAD and transistors on the same chip substrate
  - Advantages
    - Can switch off individual noisy cells; Integrated read-out; Large signal from single SPAD (low power read-out); <100 μm spatial resolution easy to achieve; Excellent timing (<10 ps FWHM); CMOS mass production
  - Disadvantages
    - Still unusual approach: must design sensor (for analog SiPMs, we design ASICs); Reduced fill factor (but can improve with lenses); Limited number of vendors, fab access can be difficult (but DRD may help!)



P. Fischer



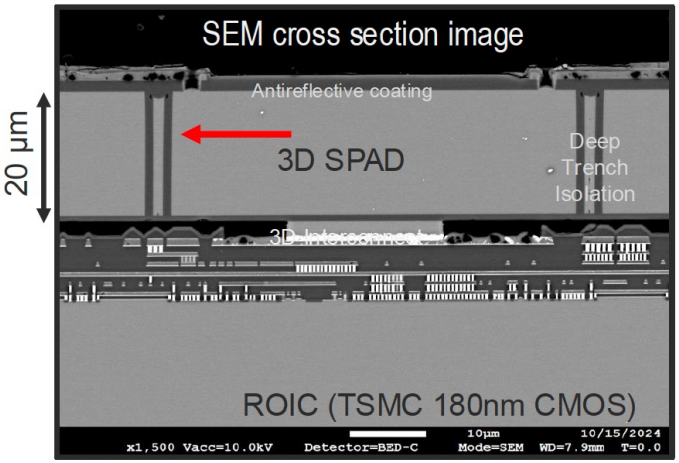
Nolet, Pratte et al. (Sherbrooke)

Digital SiPMs projects

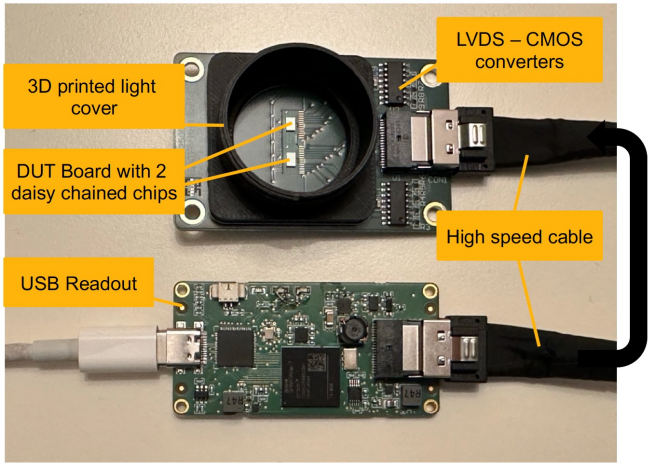
- Non-exhaustive list
- spadRICH (EPFL, JSI – R. Dolenec, R. Pestotnik, E. Charbon, C. Bruschini)
  - Granularity down to 1x1 mm^2, timing precision ~100 ps, 40 MHz trigger (25 ns), few ns gating, switching off hot pixels, 20-30% occupancy
  - Use microlenses to recover FF and reduce radiation damage
- ASPIDES (INFN, L. Ratti)
  - Fast (high time density), high dynamic range counting and high accuracy timing; application to RICH detectors, dual readout calorimetry, dark matter and neutrino experiments
- PLATON (EPFL, ETHZ – D. Sgalaberna)
  - Scintillating fibres as active neutrino target
  - Towards dedicated dSiPM: 272x192 SPAD pixels, per-cluster TDCs (200-800 ps LSB), low data rate (1-2 LVDS connections sufficient per chip)
  - Tiles of 8x8 chips, exploit event structure of neutrino beam trigger @T2K/HK

Digital SiPMs projects

- University of Sherbrooke, Canada (S.Charlebois, J.-F. Pratte)
  - dSiPMs for HEP (LAr ARGO; LXe NEXO) and related applications
  - SPAD array and CMOS readout 3D-stacked to form a single heterogeneous detector chip
  - Photon-to-Digital Converter (PDC) platform
  - 64 x 64 SPADs, active area 5 x 5 mm2, 26% fill-factor
  - PDP~50% and SPTR~160 ps @ 410 nm
- University of Heidelberg, Germany (P. Fischer, M. Keller)
  - Task: Measure the number of photons arriving during short frames (application: NEXT)
  - Size ~3 × 2 mm^2, 27 x 24 pixels, pixel pitch 105 × 60 µm2, Fill factor 38% (not optimized, standard cells)
  - Maximum Frame rate ~4 MHz



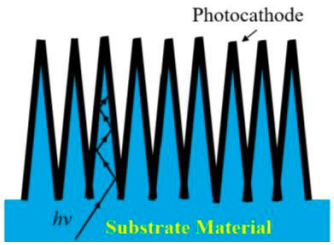
S. Charlebois (PD 2025)



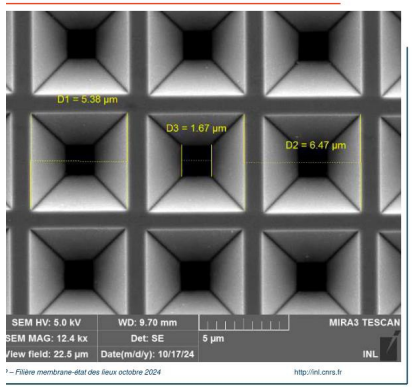
P. Fischer (PD 2025)

Vacuum Photodetectors

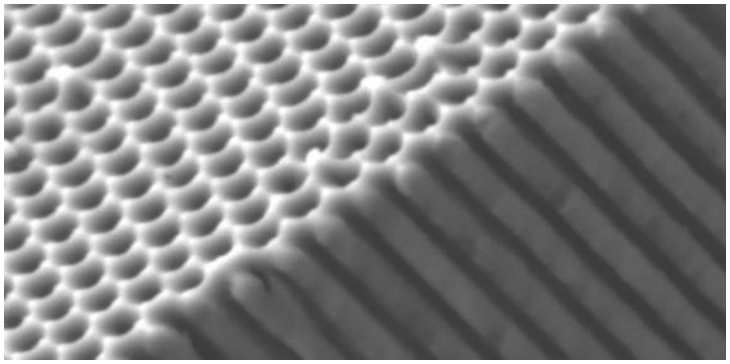
- Photon detectors with improved performance: MCP-PMTs
  - Longer lifetime and higher instantaneuos rate; Higher photodetection efficiency; Large area; Integration with electronics
- Examples:
- Improve Quantum Efficiency with new photocathode structures (XIOPM, Lyon)
- Realization of nano-channel plate (NCP) using Femtolaser technique directly on lead glass plates (Lyon)
- Diamond transmission dynode as MCP alternative (Leicester, Bristol, Warwick)
  - Use single Crystal Diamond thin plates as transmissive dynodes
  - Expected time resolution better than 10 ps with no IBF (increased lifetime and rate)



P. Chen (XIOPM, CAS)

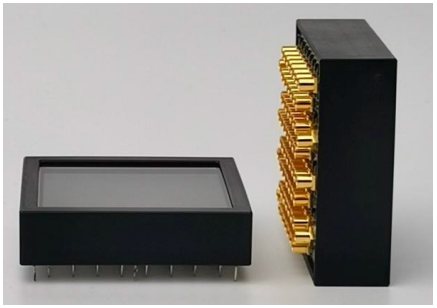


I. Laktineh (Lyon)



Vacuum Photodetectors

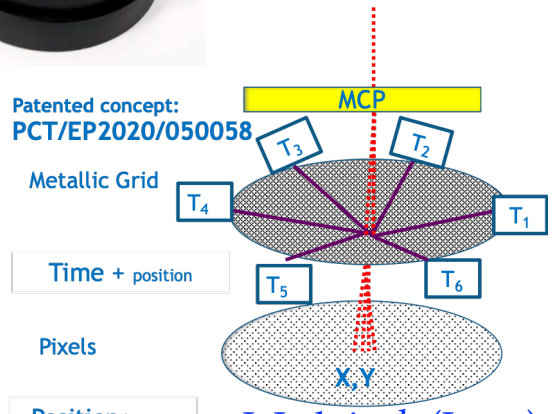
- Fast Timing MCP-PMT (FPMT) development (Photodetector Lab in IHEP)
  - Complete R&D chain from single- to multi-anodes (simulation, design, construction, characterisation, optimization)
- Development of new technologies to improve quantum efficiency, collection efficiency, lifetime and rate capabilities of MCP-PMTs (Xi'an Institute of Optics and Precision Mechanics)
  - Complete R&D chain from simulation to manufacturing and testing
- PICMIC concept to exploit MCP intrinsic spatial and temporal resolutions (Lyon)
  - Transparent grid read-out with excellent time resolution, followed by detection matrix (requires limited number of electronics ch. and achieves few μm and ~10 ps resolutions)



Yifang Wang, Qian Sen (IHEP, CAS)



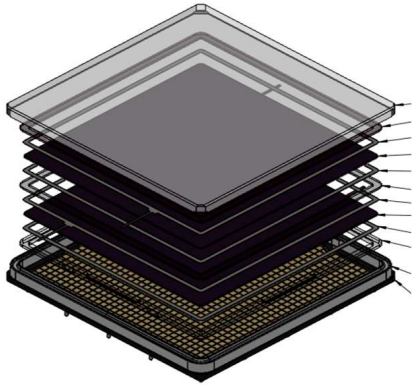
Ping Chen (XIOPM, CAS)

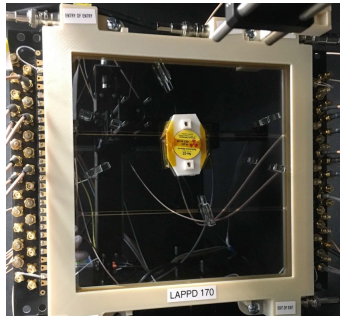


I. Laktineh (Lyon)

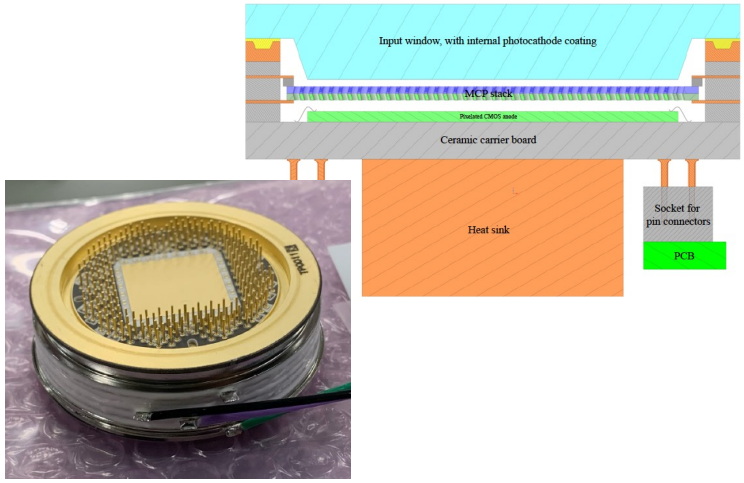
Vacuum Photodetectors

- Large Area Picosecond Photo-Detector (LAPPD, Incom)
  - 20 cm square with internal stripline; capacitively-coupled (CC) with anodes (5mm thick glass or 2mm thick ceramic)
  - HRPPD: 10 cm square with no support structures in window; directly coupled through ceramic anodes (~3mm pixels); capacitively-coupled with 2mm anode
- MCP-PMT with embedded Timepix4 ASIC as anode (INFN, CERN, UniFe)
  - Complete integration of sensor and electronics: on-detector signal processing, digitization and data transmission with large number of active channels (~230 k pixels)
  - Detection of single photons with ~70 ps and ~10 μm resolutions





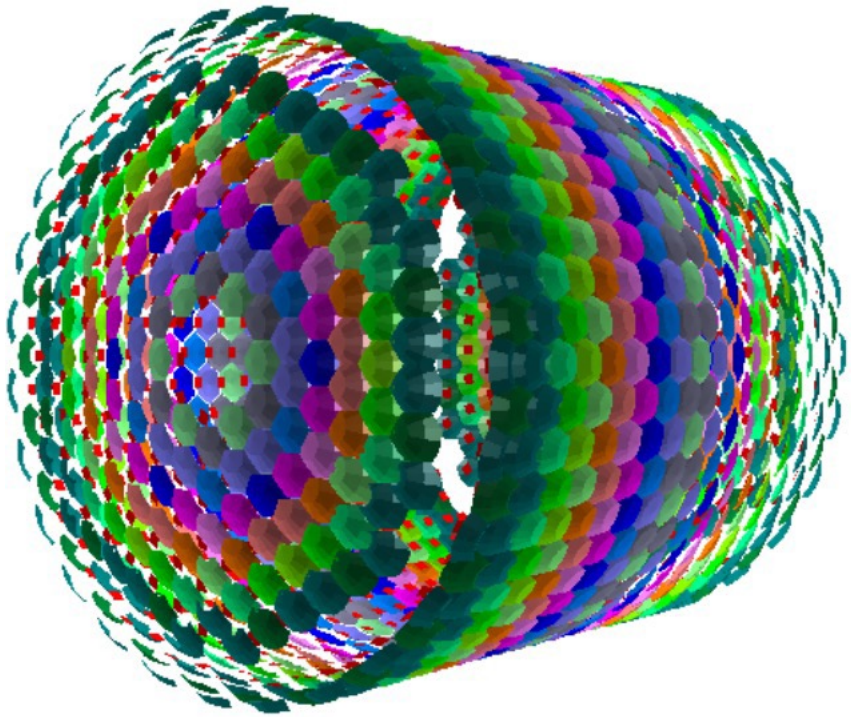
M. Popecki (Incom)



M. Fiorini NDIP 2026

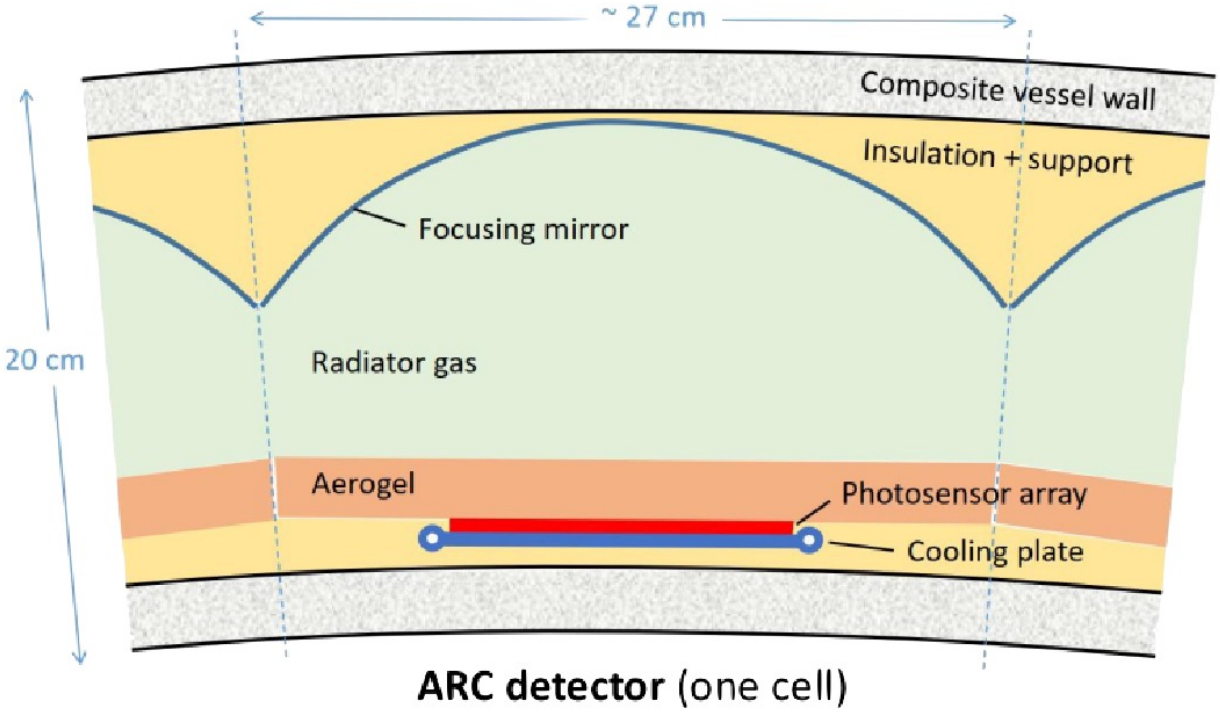
ARC detector

- FCC-ee will produce large numbers of heavy flavour hadrons
  - World class flavour physics programme is possible if one can have excellent particle identification (PID) and in particular hadron separation
  - PID crucial for B decay products (1-40 GeV), τ decays, and jet tagging in Higgs, top and W physics
- RICH detectors are a proven solution for high-momentum hadron identification
- ARC (Array of RICH Cells) is a proposed RICH detector for the FCC-ee
  - Initially adapted for the CLD and then optimized for the ALFA detector concepts
  - Dimensions: 20 cm radial depth, 2.1 m radius, 4.4 m length, target material budget <0.1 X_0
  - Cellular design (each cell acts as independent RICH detector)



ARC detector

- Two radiators: gas + aerogel (for low p tracks)
- Spherical focusing mirror
- Photosensor array: most suitable candidates are SiPM arrays with cooling plates in a 2.5D/3D integration
  - Aerogel also as thermal insulator between SiPM array and gas radiator

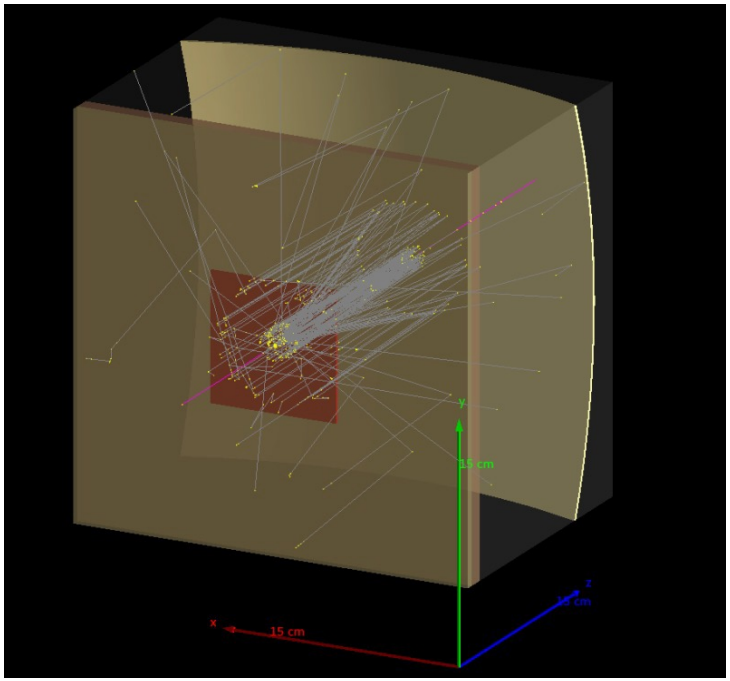


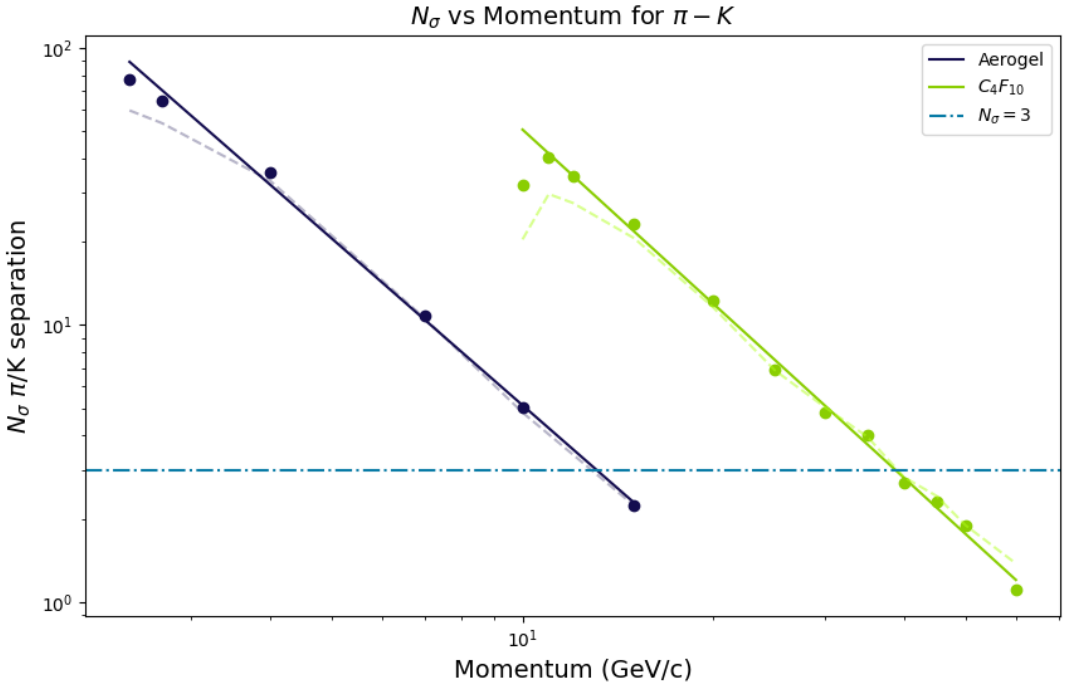
ARC detector (one cell)

- Goal: build single cell prototype within DRD4

ARC detector

- Detector simulations performed inside Key4Hep framework
- Separation above (3 sigma) threshold up to 13 GeV/c for aerogel and 40 GeV for gas





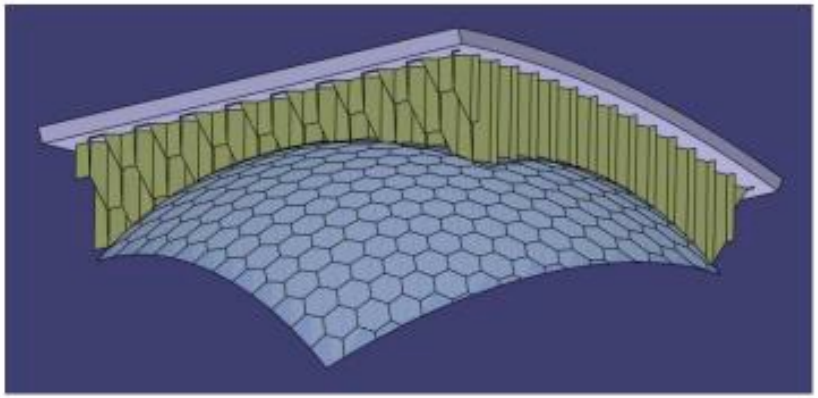
	Total error [mrad]	Photon yield
Gas	1.3	14
Aerogel [a]	1.5	7

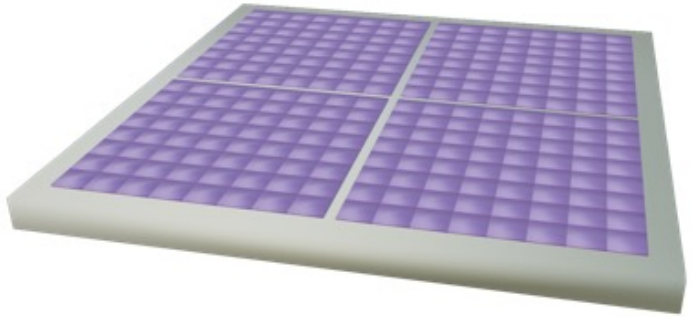
Kaon particle gun @ 45 GeV

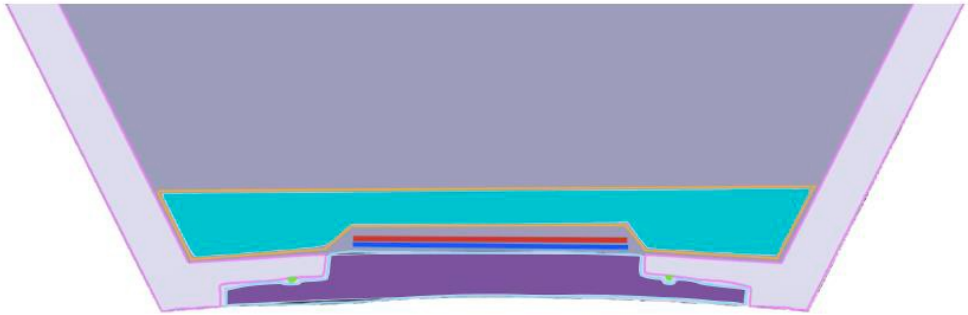
[a] 1 cm layer, n= 1.03

ARC detector

- Preliminary mechanical design
  - Investigating composite mirror surface, backed by custom CFRP honeycomb
- First efforts for 2.5/3D integration of SiPM array with ceramic interposer (coolant channels) and front-end ASICs



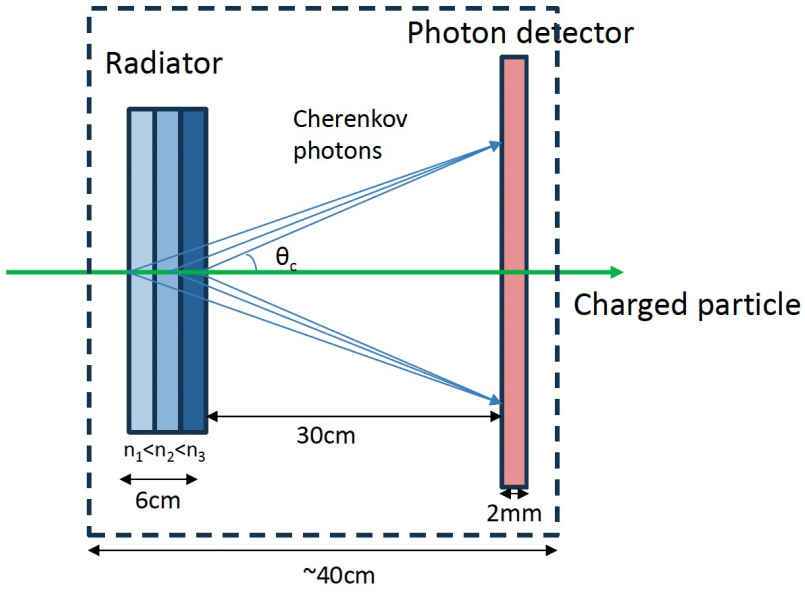




Aerogel layer, photosensor, cooling plate, detachable floor with attached electronics

Forward RICH for AGORA

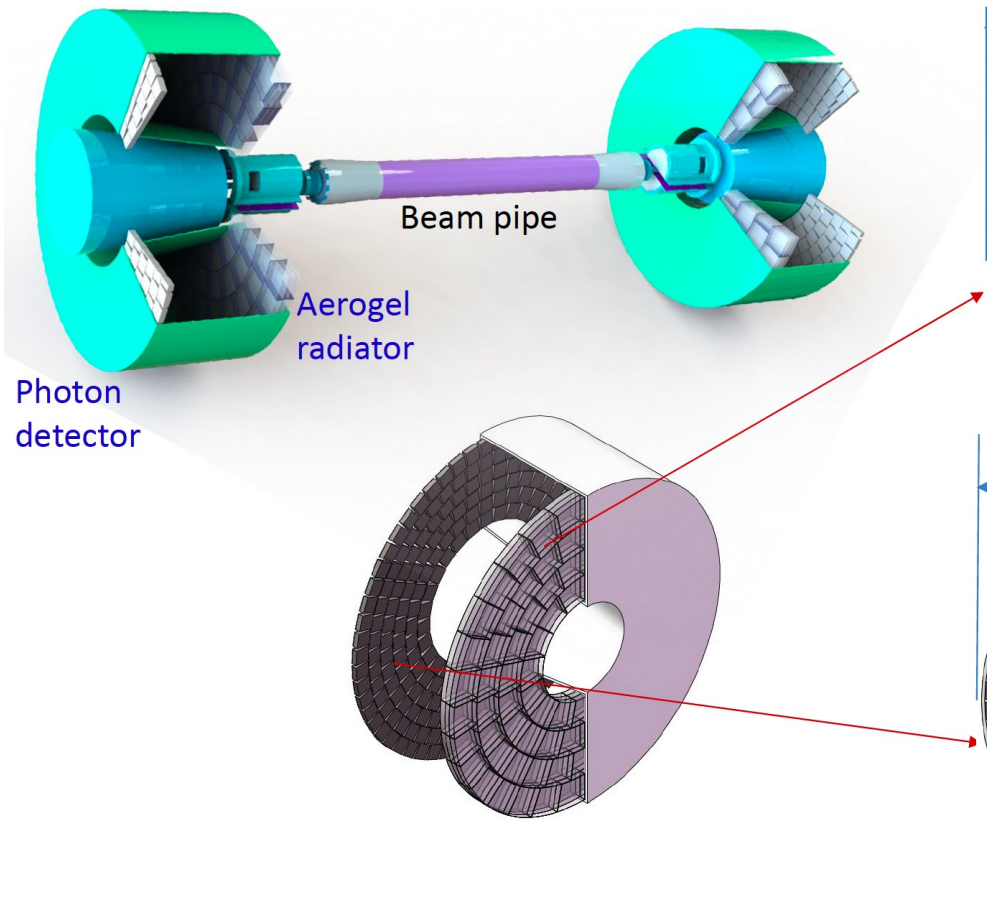
- A CEPC reference detector proposed in 2013, then changed the name in 2026 (now one of the official FCC detector concepts)
- Recently proposed the possible addition of a forward Cherenkov detector to improve PID for 3-40 GeV/c particles
- RICH based on proximity-focusing method
- Aerogel radiator tiles + SiPM with ~1 mm granularity to achieve the required Cherenkov angle resolution



Zhonghua Qin (IHEP) at DRD4 Week Oct. 2026

Forward RICH for AGORA

- Possible layout



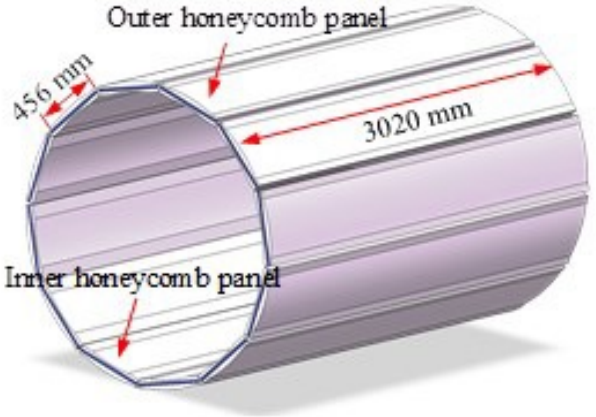
Radiator : ~0.9 m^2
-90 aerogel tiles in 4 layers
-each tile of ~10 cm x 10 cm in size

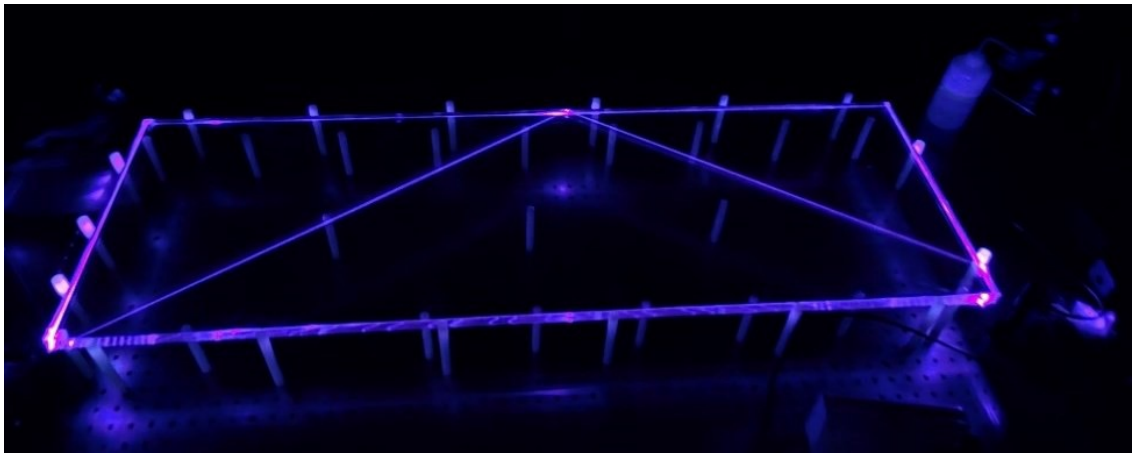
Photon detector: **~0.8 m^2**
-258 photosensor module in 6 layers
-each module of ~5 cm x 5 cm in size

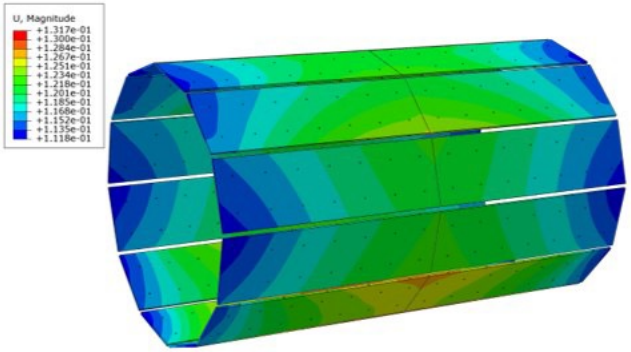
Zhonghua Qin (IHEP) at DRD4 Week Oct. 2026

DTOF for STCF

- DTOF (DIRC like TOF) for STCF (Super Tau Charm Factory) for PID (USTC)
  - Fused silica radiator read-out by MCP-PMTs with excellent timing resolution
- Light-weight mechanical structure design to reduce material budget to a minimum
  - Finite element analysis
- Optical characterization of fused silica plate
  - Roughness and flatness of lateral faces







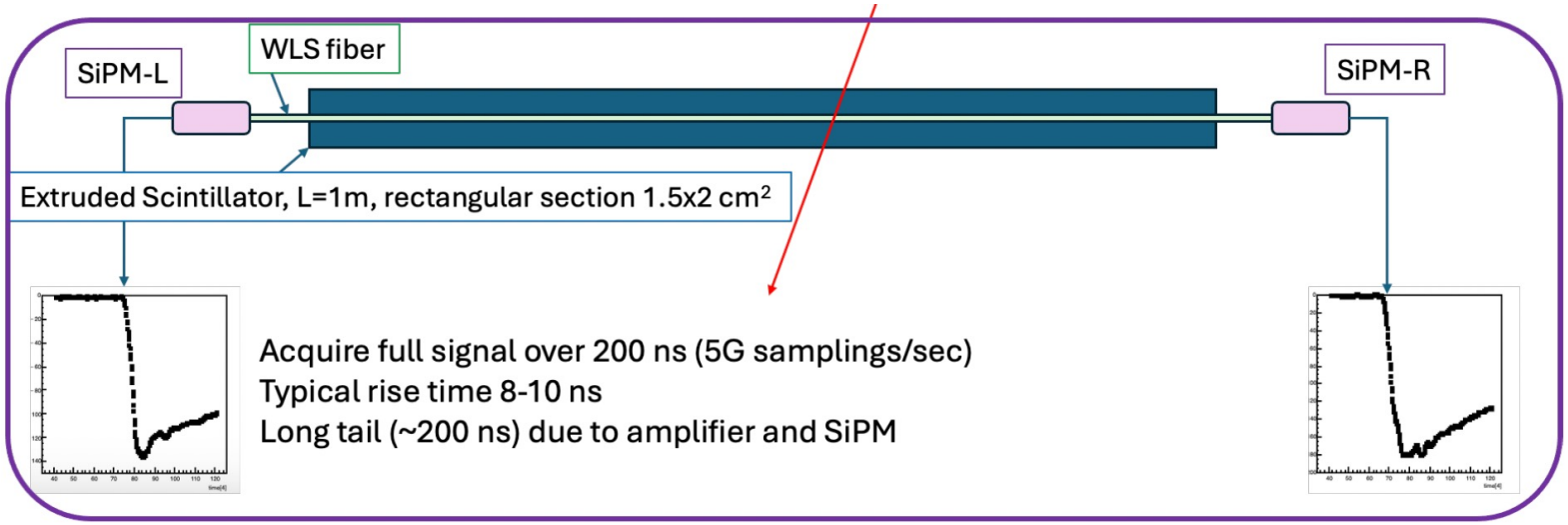
Ming Shao (USTC)

Eco-friendly gases

- The EU Regulation on fluorinated gases (Regulation 2024/573) sets strict rules to control and reduce human-made greenhouse gases
  - Large impact on most used Cherenkov radiators
- Perfluorocarbon radiators (e.g. C_4F_{10}, CF_4) are optically strong, inert and proven, but their Global Warming Potential is high (large vessels carry a major CO2-equivalent release potential)
  - Supply, regulation and cost risks make mitigation and alternatives urgent
- Future constrains (limitations, unavailability, bans, excessive cost, etc.) are not known → possible options:
  - Engineer near-zero emission systems (aim for zero/minimal emission: closed-loop filling/recovery, tight vessels, no routine venting, etc.)
  - Qualify low-GWP alternatives (fluoroketones/HFOs, xenon, etc.) → all need UV, radiation and materials qualification
  - Lower the GWP load with blends
  - Study pressurized radiators (e.g. Ar up to 3 bar tested)
- Strong synergy with DRD1 on gas characterization
  - Participation to the LDG Sustainability WG (see talk by C. Bloise)

Muon detector

- A prototype based on extruded scintillator bars with Wavelength-Shifting (WLS) fibers and SiPM read-out is being investigated for large surface, cost-effective muon detectors, competitive to gas detectors
- Systematic study of its possible use for large area muon system started
  - Availability of "low-cost" extruded scintillators; Availability of fast (~1 ns) WLS fibers; SiPM with fast timing read-out
  - Use long (~meters) scintillator bars with SiPM readout on both ends
  - Time given by the average of the time measurement at both ends (~100 ps)
  - Resolution in the direction transverse to the bar ~few mm



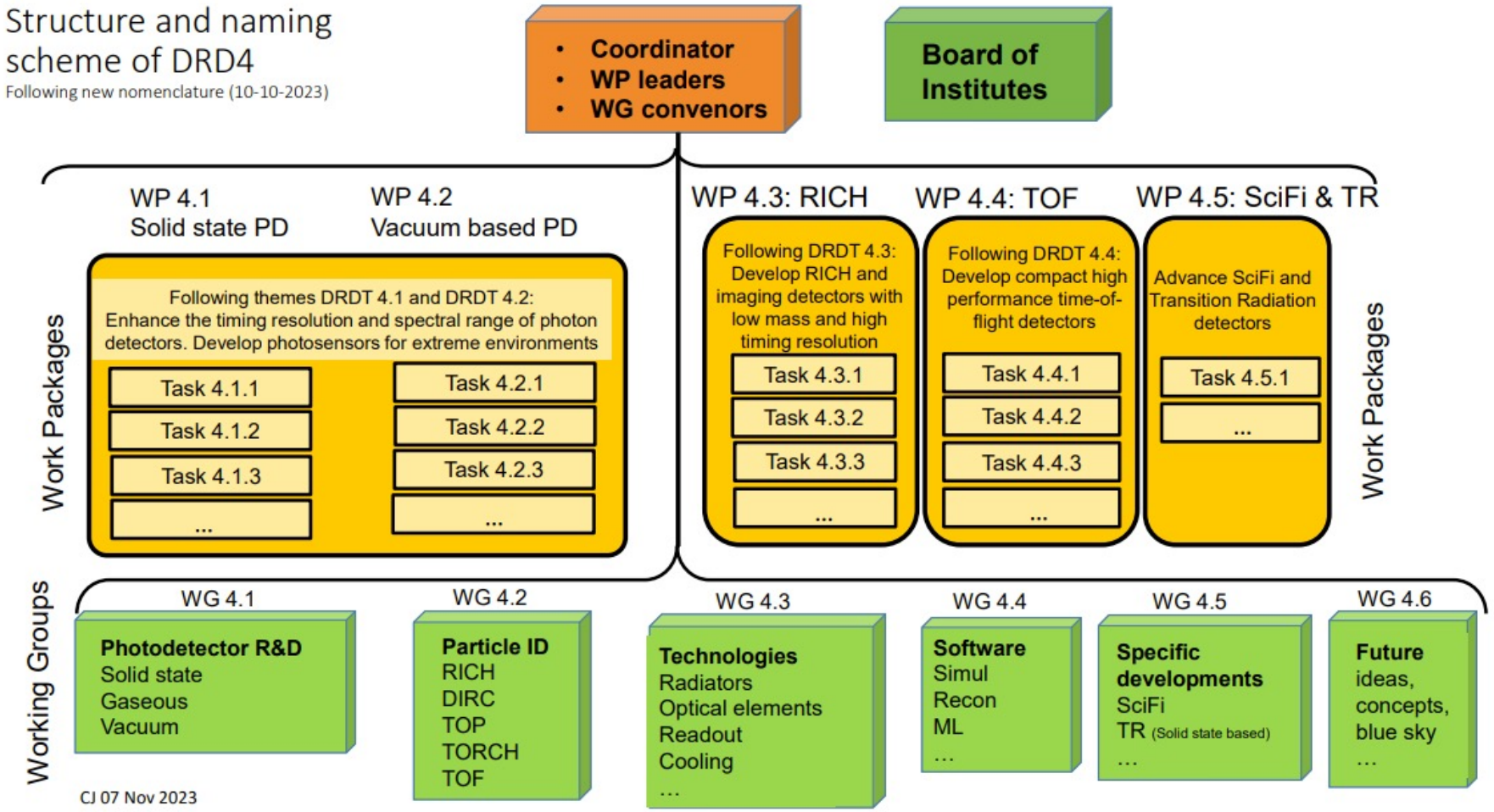
Summary

- The DRD4 Collaboration has formed to propose a broad but focused R&D program on photodetectors and PID techniques
- Thanks to the efforts of many active colleagues, the DRD4 Community has been created and has been very active in the last 3 years
- Very good progress on the various WP tasks and WG activities
  - DRD4 scientific activities have ramped up since the beginning of 2024
  - Many activities are exploiting synergies between different groups, using resources acquired mainly through other channels
- The success of DRD4 will strongly depend on the ability of the groups to grow and to find the necessary resources for future R&D activities
- DRD4 is continuously attracting new groups
  - In case of interest, please contact us (https://drd4.web.cern.ch/contacts)



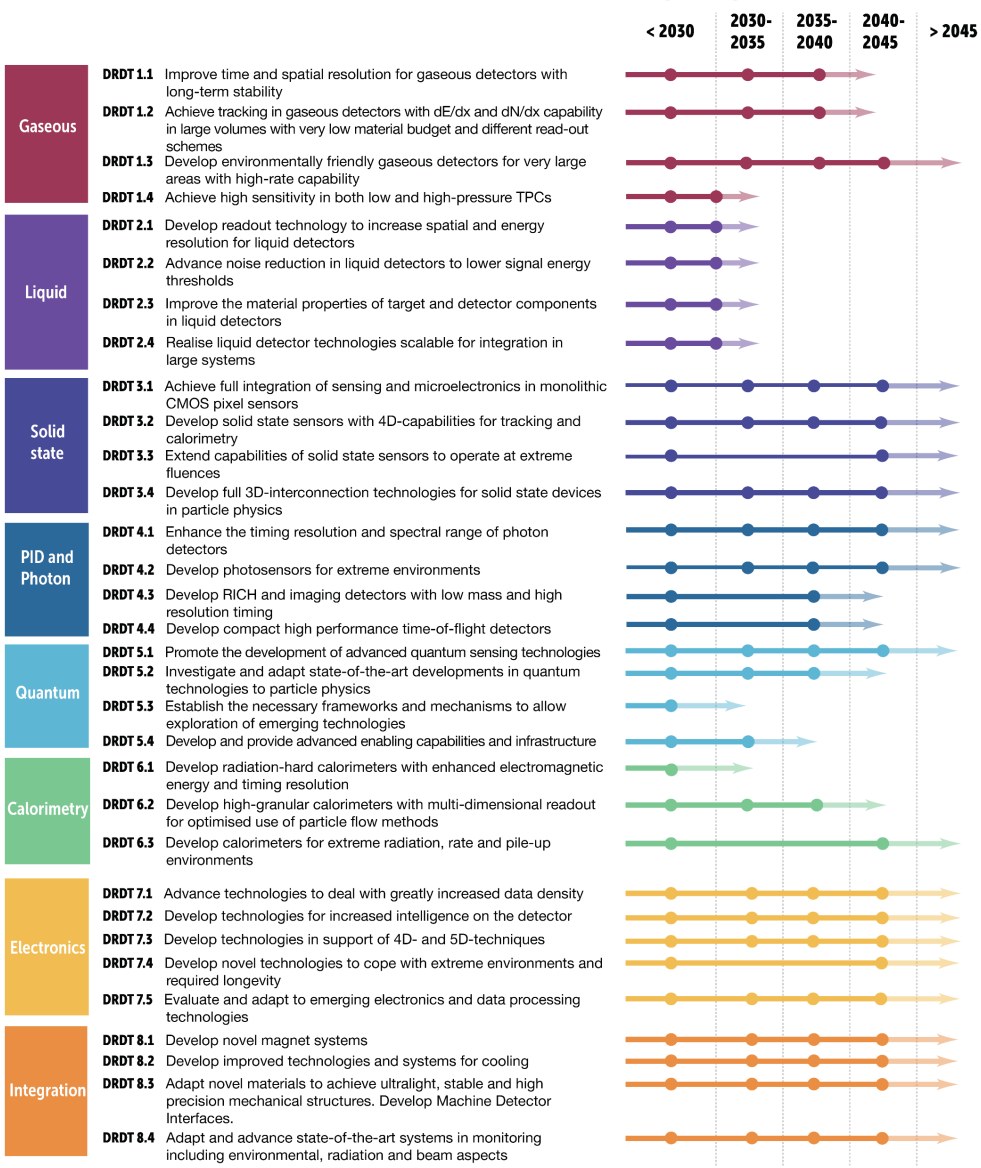
BACKUP

DRD4 structure (from the Proposal)



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



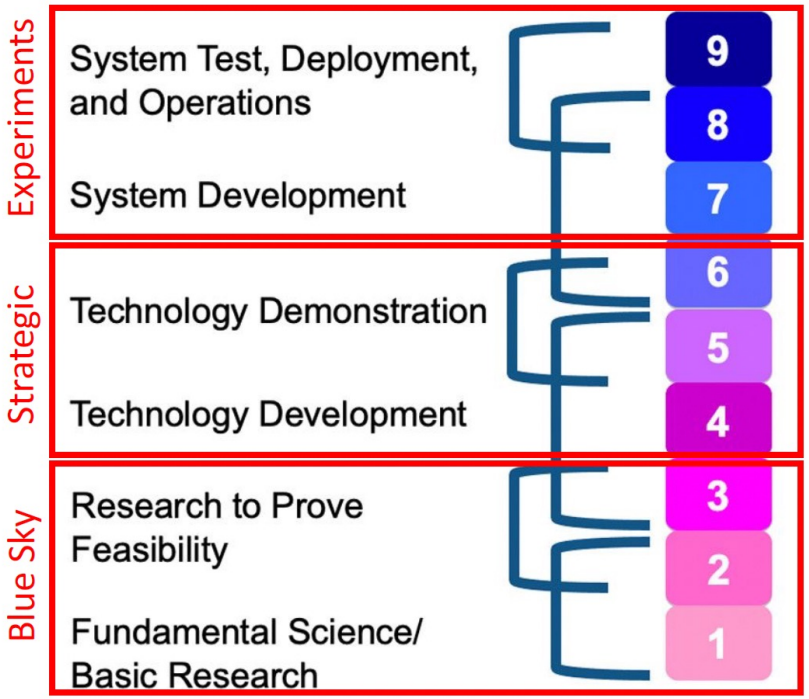
General Strategic Recommendations

- 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

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

WG1: Photon Detectors

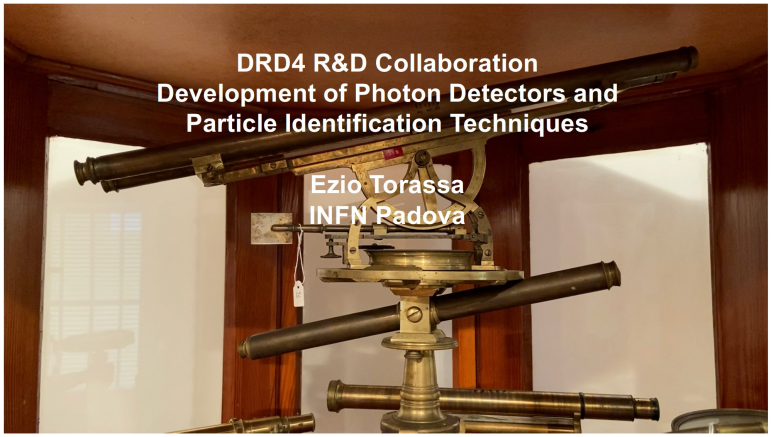
- Scientific forum for studies and development of novel photodetectors with focus on PID for future experiments
- Topics (selection):
  - Radiation hardness; timing resolution; high-rate capabilities; longevity
  - Extreme conditions: e.g., cryogenic and high magnetic field
  - Large-area (e.g. SiPMs 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

MCP-PMT performance for Belle II and future developments for upgrades

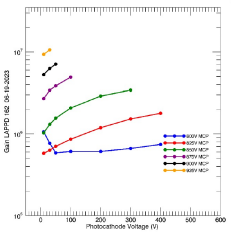


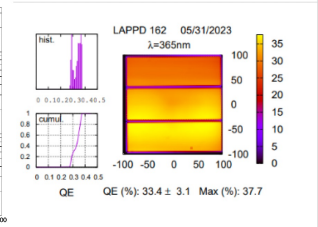
21-25 October 2024 2nd DRD4 Collaboration Meeting CERN

Gen II LAPPD #162 (#172 similar specs)

Characteristics (Incom):
- fused silica glass window (5 mm), multi-alkali photocathode (Na_2KSb)
- peak QE ≈ 33% (@365 nm)
- 2 MCPs with 10 μm pores at 13 μm pitch (>72% OAR), 13° bias angle
- ceramic back plate with interior resistive ground plane anode – 2 mm thick
- capacitively coupled readout electrode
- two parallel spacers (active fraction ≈ 97 %)
- gain ≈ $4 \cdot 10^6$ @ ROP (875 V/MCP, 50 V on photocathode)
- size 230 mm x 220 mm x 22 mm (243 mm X 274 mm X 25.2 mm with mounting case)
- LAPPD Dark Count rate @ ROP: ~ 400 Hz/cm2 at a threshold of $8x10^5$ gain







7-10 April 2025, CERN 3rd DRD4 Collaboration Meeting | 9. 4. 2025 (slide 2) | Samo Korpar Univ. of Maribor and J. Stefan Institute

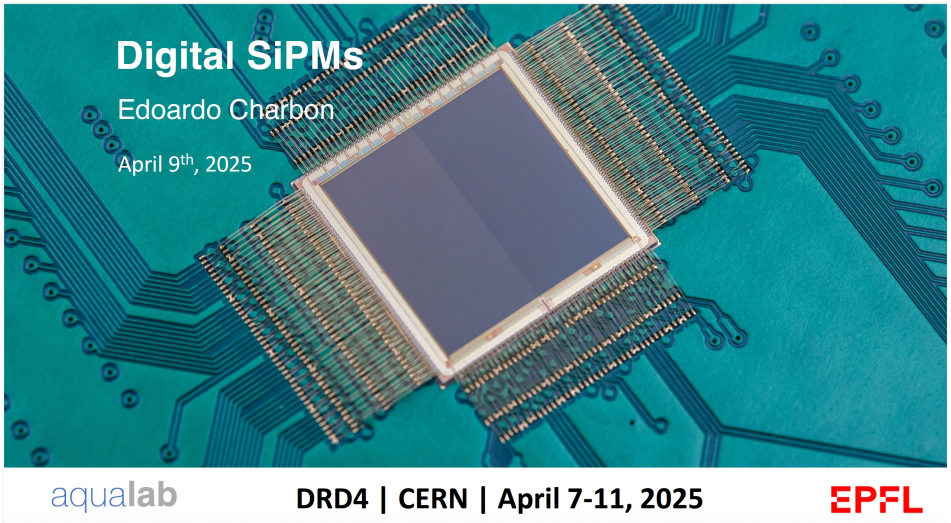
ÖAW Österreichische Akademie der Wissenschaften | HEPHY | RWTH Aachen University

SiPM Single Photon Timing Resolution

Stefan Gundacker [1, 2]

[1] Institute of High Energy Physics (HEPHY), Austrian Academy of Sciences (OEAW), Vienna, Austria
[2] Department of Physics of Molecular Imaging Systems (PMI), RWTH Aachen University, Aachen, Germany

stefan.gundacker@cern.ch



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

bRICH baseline

Proximity-focusing RICH based on aerogel + SiPMs in a projective geometry

Goal

- π/e, K/π and p/K in the p intervals [0.5, 2], [2, 10] and [4, 16] GeV/c

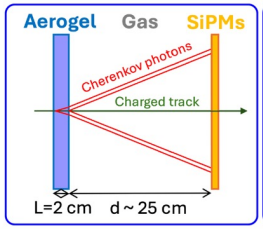
⇒ Need for n ≈1.03, $\sigma_\theta^\gamma \approx 1.5$ mrad

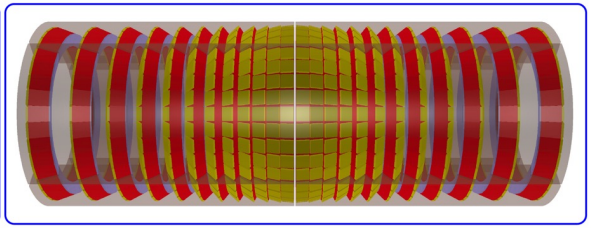
Technology

- Aerogel: L ≈ 2 cm, $n = 1.03$
- SiPMs: 2x2 mm², T = -40 °C
- DENEB FE ASIC: 1024 chan.

Geometry

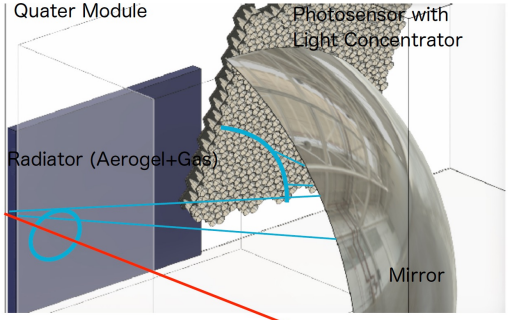
- 24 sectors x 36 modules, active area ≈ 18.6 m²
- All modules oriented toward the interaction point
- Trapezoidal tile profile for maximum acceptance





Nicola Nicassio – 4th DRD4 Collaboration Meeting 4

Cherenkov Detector Development for MARQ Spectrometer at J-PARC



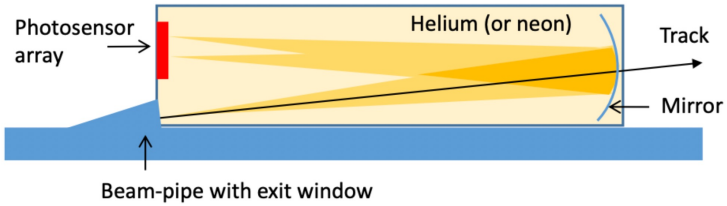
DRD4 collaboration meeting 2025 April

11.4.2025 (Fri) 9:00 (CEST)- Ken Suzuki <ken.suzuki@rcnp.osaka-u.ac.jp>



The ALADDIN RICH detector

Long vessel RICH radiator filled with **He or Ne**, originally proposed in LoI by R. Forty



Elisabetta Spadaro Norella - Università di Genova 6

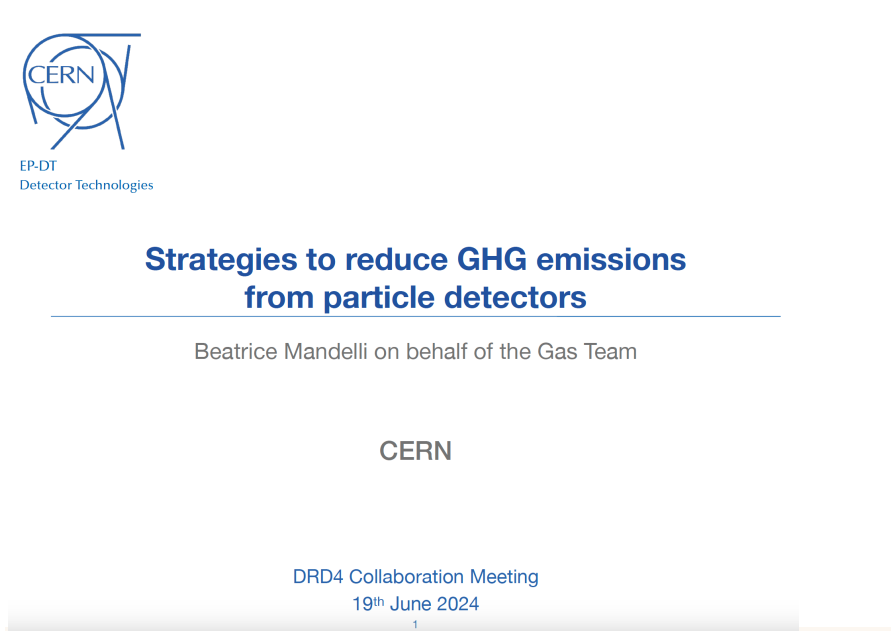
WG3: Technological activities

- 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









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)

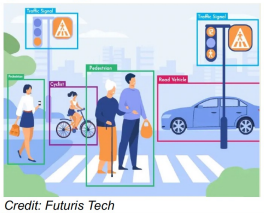
WG4: Software

Examples of presented activities

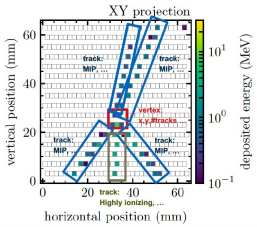
Object Identification for Particle Detectors using Deep Learning

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

cea irfu

Paris-Saclay Multimodal Biomedical Imaging Lab
BioMaps
LABORATOIRE D'IMAGERIE BIOMÉDICALE

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

CERN

Comprehensive Particle Identification (CPID) in Full-Detector Simulation

Uli Einhaus
2nd DRD4 Collaboration Meeting
23.10.2024

ILD HELMHOLTZ KIT Karlsruher Institut für Technologie DESY.

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

ETH zürich EPFL

Development of a scintillating fibre detector for neutrino experiments

DRD4 CM

Till Dieminger
for ETH Neutrino Group and AQUA Lab EPFL

October 16, 2025

CERN

Summary brainstorming meeting on future R&D on organic scintillators

E. Auffray, CERN EP-CMX

Current status of a simulation of the GaAs detector response

Ivan Zhutikov on behalf of DRD 4.5.2 working group

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

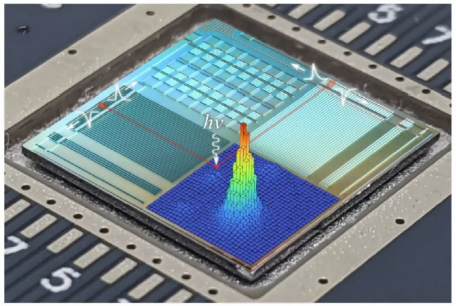
WG6: Novel ideas and far-future R&D

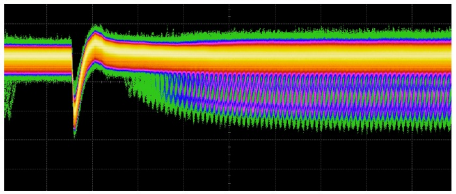
- This WG will act as the DRD4 collaboration's gate for novel ideas and revolutionary concepts
  - New ideas shall find in WG6 the right environment to prosper
  - Help the new concepts to reach the required level of maturity
  - Hope to transform some of these ideas into breakthroughs in the field,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



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

A. ALIKHANYAN National Laboratory

ARARAT

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

CERN **Prospects for Advanced Fiber Detectors** DRD4

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) → $\sigma_x \approx 50$ µm, $\sigma_t \approx 10$ ps

THE UNIVERSITY OF IOWA

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

İSTANBUL ÜNİVERSİTESİ 1453

WP1: Solid-State Photodetectors

- Task 1 - Demonstrator of BSI SiPM array
  - 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
- Task 2 - Demonstrator of CMOS-SPAD monolithic sensor
  - Implementation and characterization of CMOS-SPAD sensors for light detection in high energy physics
- Task 3 - 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; enable the use of SiPM in highly irradiated zones
- Task 4 - 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)

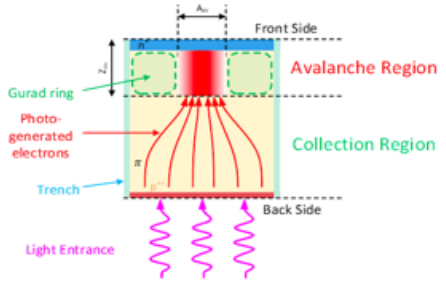
WP1 Leader: Rok Pestotnik (Ljubljana)

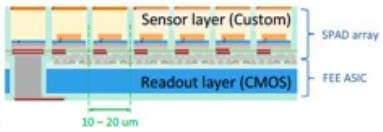
Task leaders: Alberto Gola (FBK), Lodovico Ratti (Pavia), Rok Pestotnik, Andreu Sanuy (Barcelona)

WP1: Solid-State Photodetectors

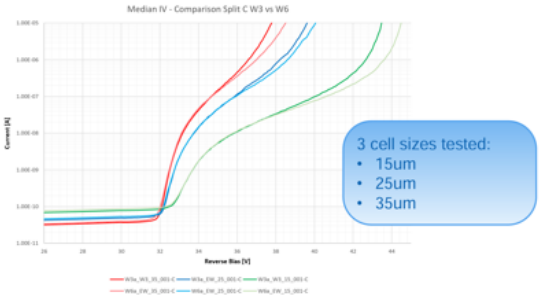
Examples of ongoing activities

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



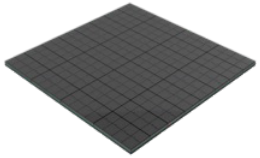


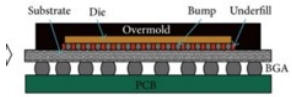
The first results of the FBK IBIS Run samples



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

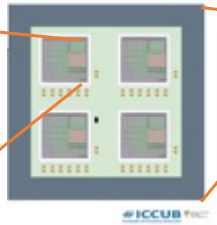
ICCUB Institute of Cosmos Sciences





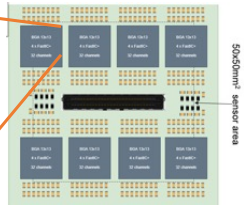
3x3mm2 SiPM Array

FastIC+ (collab. CERN ICCUB) Low power Chip

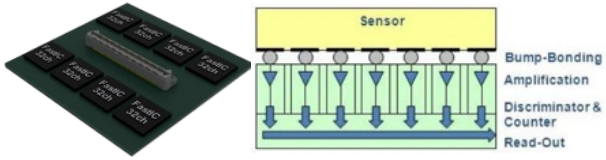


2024 Produced and evaluated

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

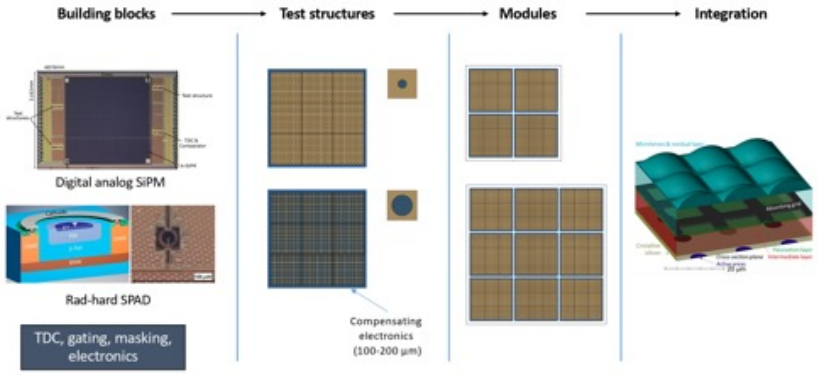
Examples of ongoing activities

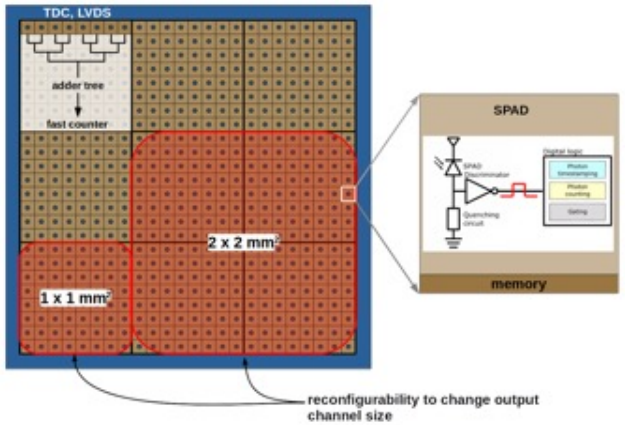
CMOS-SPAD light sensors: co-integration of SPADs and electronics, digitised output signals

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

aqualab EPFL

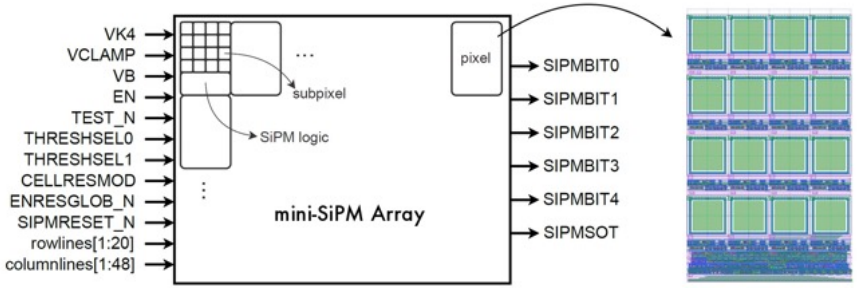
Institut "Jožef Stefan" Ljubljana, Slovenija





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

INFN Istituto Nazionale di Fisica Nucleare



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

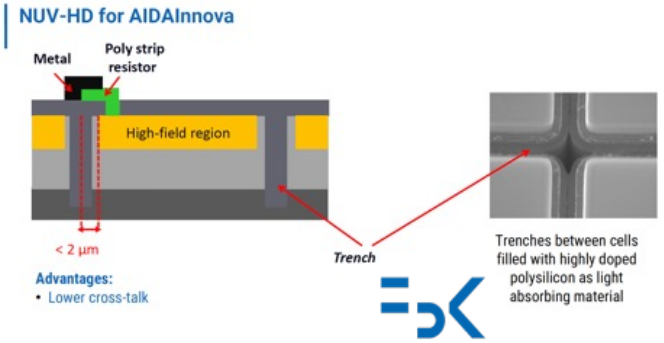
AidaInnova Run – exp. May 2025

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)

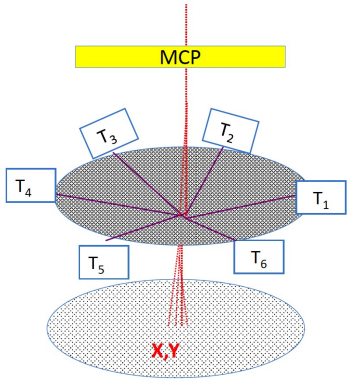
Task leaders: Silvia Gambetta (Edinburgh), Ping Chen (XIOPM-CAS), Claudio Gotti (Milano Bicocca)

WP2: Vacuum-based Photodetectors

Examples of ongoing activities

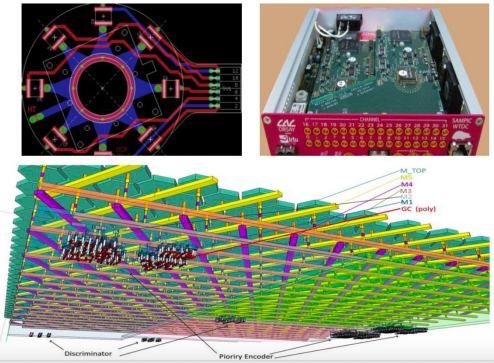
To fully exploit MCP we propose the following scheme:

- ❑ A **transparent grid** placed downstream and read out by sensors with excellent **time resolution**
- ❑ A detection **matrix with micrometric pixels** to measure with great **precision the position** of the avalanche while **requiring limited number of electronics channels.**



PCT/EP2020/050058

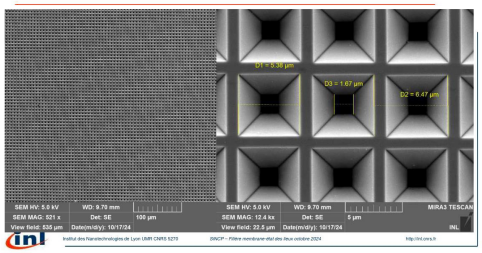
PICMIC



Reflective silicon-based photocathode development

H. Abreu(1), I. Laktineh(1,3), J.L. Leclerc(2), N. Terrier(2), C. Chevalier(2), P. Pitet(2), B. Rea(2), P. Kleimann(1,2)

(1) IP2I, Institut de Physique des 2 infinis, CNRS/IN2P3
(2) INL, Institut des Nanotechnologies de Lyon
(3) UCBL : Université Claude Bernand Lyon 1



CERN – DRD4 week, 21th October 2024

Amorphous Silicon Microchannel Plates: A new photon detector with 10 ps timing and 15 µm spatial resolution

Georgios Konstantinou, Luca Antognini, Samira Frey, Christophe Ballif and Nicolas Wyrsch

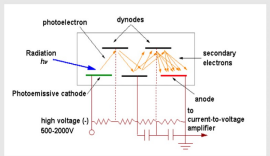
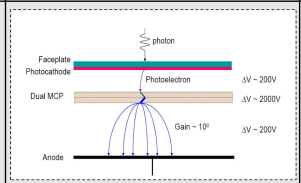
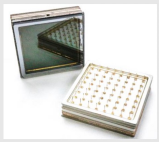
PV-lab IEM NEUCHATEL

EPFL



21/10/2024 G. Konstantinou, 2nd DRD4 Collaboration Meeting, WP2 12

2.0 The R&D of the MCP-PMT in IHEP

	Operation Principle	Small Size (proximity focusing)	Large Size (electrostatic focusing)
Dynode		2" Dynode-PMT ✓ 	20" Dynode-PMT ✓ 
MCP		2" MCP-PMT ✓ 	20" MCP-PMT ✓ 



Yifang Wang
the PMT collaboration leader

the PMT group：
LPMT：2009-2019；
FPMT：2020-2024；

4

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

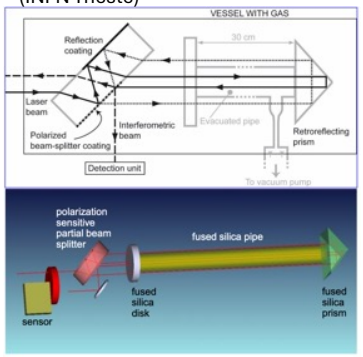
WP3 Leader: Roberta Cardinale (Genova)
Task leaders: Fulvio Tessarotto (Trieste), Sneha Malde (Oxford), Chris Jones (Cambridge)

WP3: RICH and other imaging det.

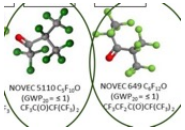
Examples of ongoing activities

- **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.

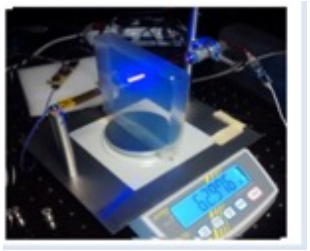
Modified folded Jamin interferometer for gas refractive index monitoring (INFN Trieste)



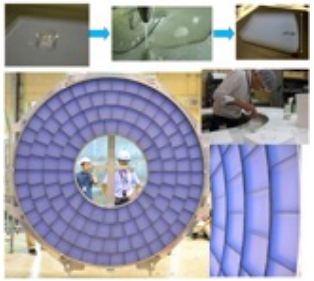
Study of gas alternatives to perfluorocarbons or eco-friendly fluorocarbon gas system



Optimized Aerogel Radiator Tiles



INFN Ferrara

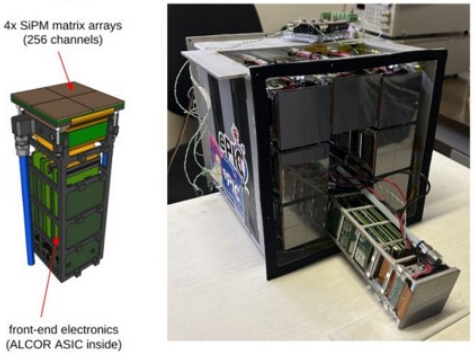


Jozef Stefan Institute

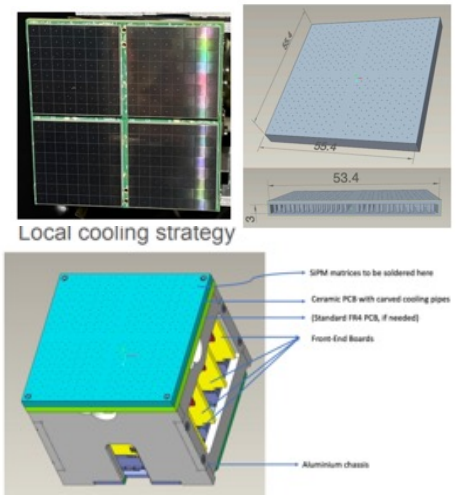
- **WP4.3.2:** Development of new RICH detector concepts for improved performance.
  - Several new concepts and detector designs under consideration including a pressurized RICH with inert gasses like Argon as a possible alternative to fluorocarbon greenhouse gases.

- **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)

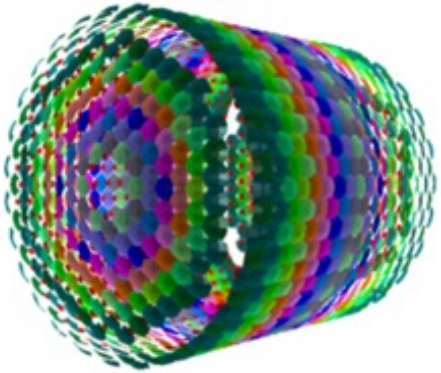


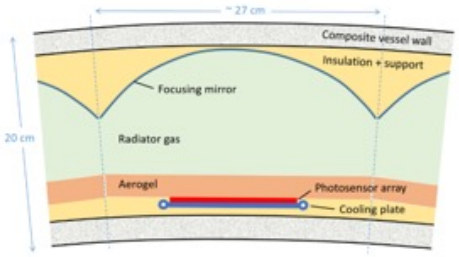
WP3: RICH and other imaging det.

Examples of ongoing activities

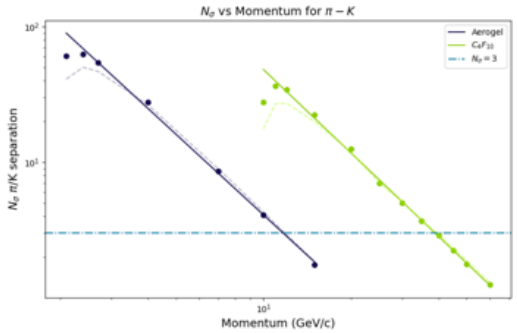
- **WP4.3.4:** Study of RICH detectors for future electron-positron colliders (CERN, University and INFN Genova, University of Oxford, University of Warwick)

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)

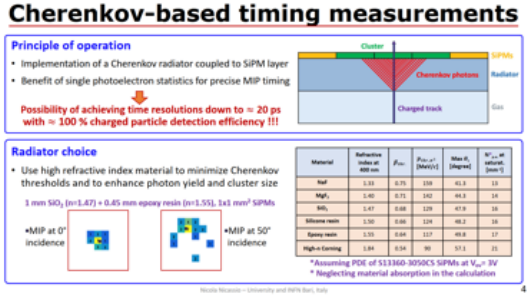
WP4: Time of Flight Detectors

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

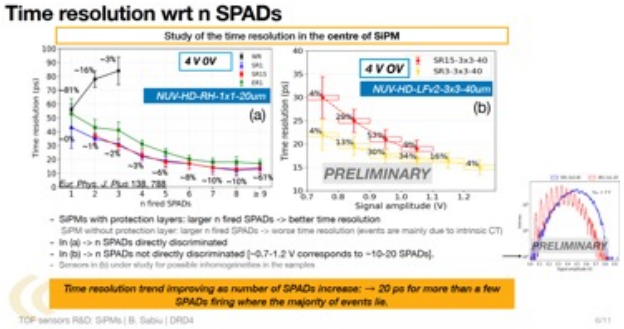
INFN Bari – SiPMs with radiators



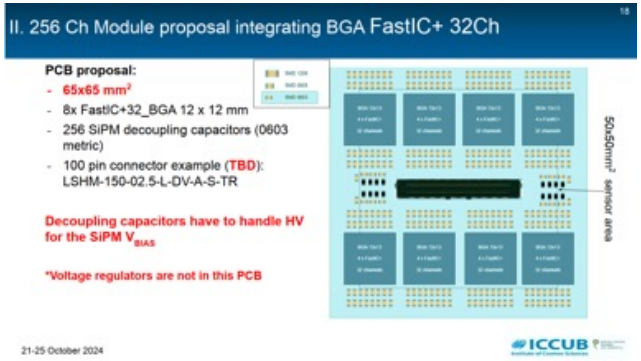
FBK – SiPM developments for ToF – synergy with WP4.1



INFN Bologna – SiPM characterization



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

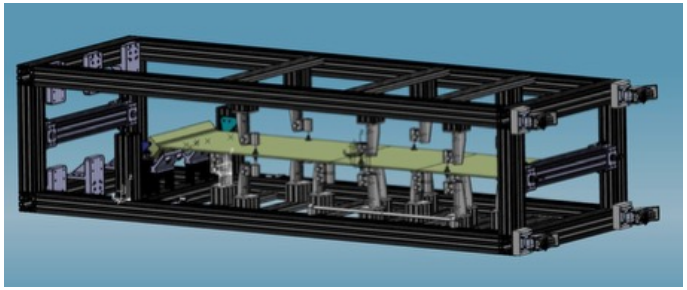


WP4: Time of Flight Detectors

Examples of ongoing activities

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

Oxford – lightweight mechanical structures for TORCH radiators



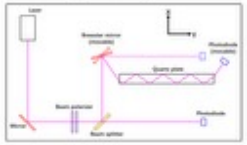
- **WP4.4.4:** Develop techniques for measuring the optical properties of optical components for TOF detectors
- **Participants:** GSI, USTC, Istanbul, Oxford, Yerevan

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

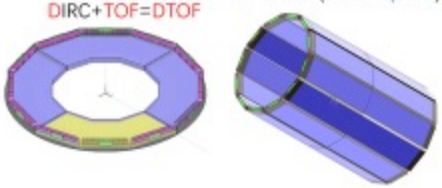
Developments at USTC – PID Mechanics

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!

