Highlights from ECFA TF-4 Community Meeting on Photon Detections and PID

Liang Guan University of Michigan

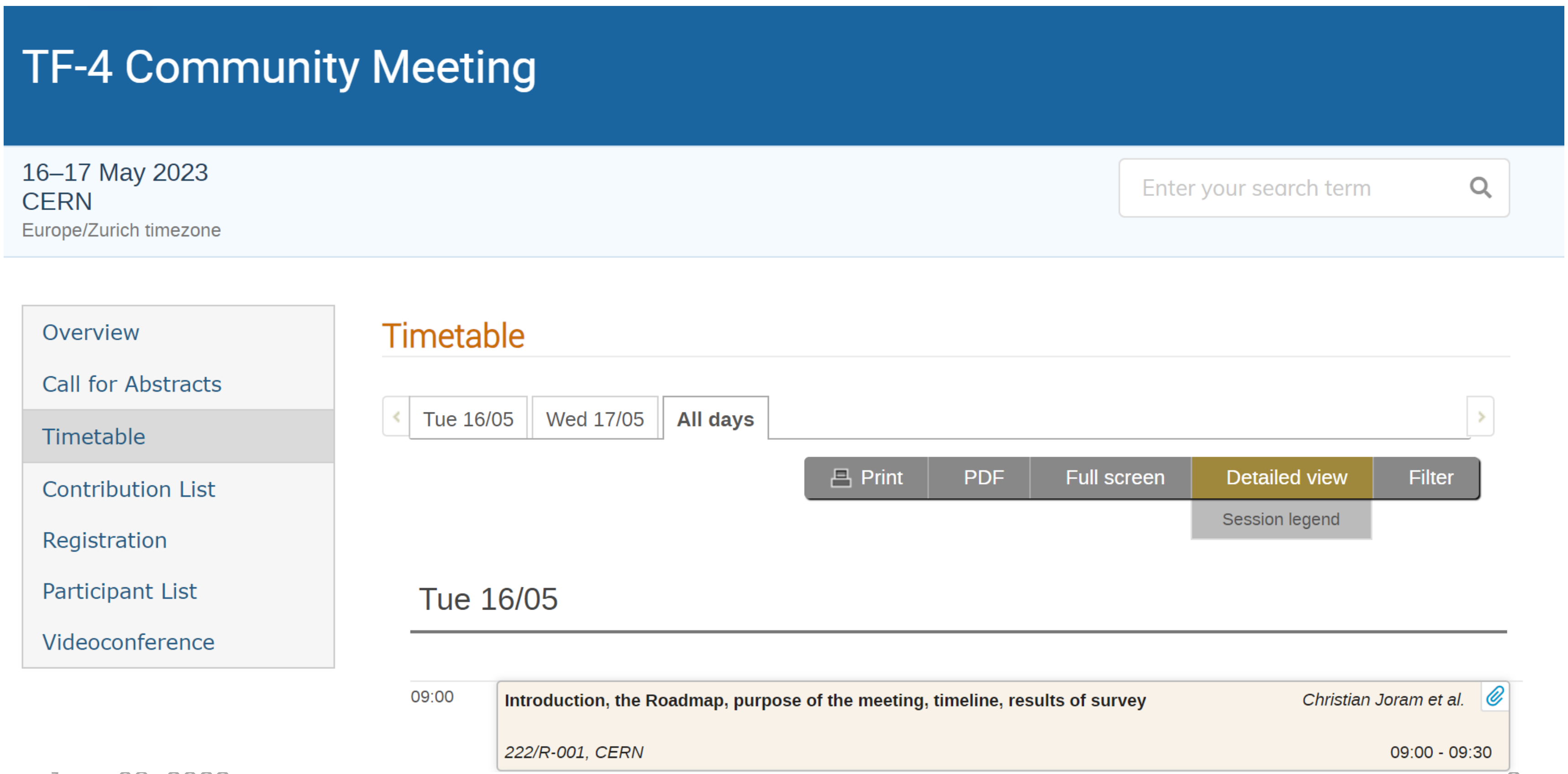
CalVision General Meeting

June 08, 2023

TF-4 Community Meeting towards DRD4

- TF-4 Community meeting held at CERN on 16-17 May 2023
- The goal is to initiate discussions and launch efforts in the photon detector and particle ID community towards the formation of a Detector R&D Collaboration (DRD4) not limited to HEP.

https://indico.cern.ch/event/1263731



TF-4 Community Meeting towards DRD4

91 participants

Tue, 16/05, morning, 0.5h

- Introduction, the Roadmap, purpose of the meeting, timeline, results of survey

Session Photodetection,
- SiPM, SPAD, PMT, MCP 12 talks

Session Technologies 3 talks
- **Materials**
- **Software**

Session Particle ID 6 talks
- RICH/DIRC
- TOF/TORCH

Social dinner

Wed, 17/05

Session 'blue sky', special, etc. 3 talks

Session Organisation 1
- Introduction to Organisation
- Presentation of groups and their interests

Session Organisation 2
- Structure of DRD4
- Which WPs? Scopes ?
- Financial
- Common projects

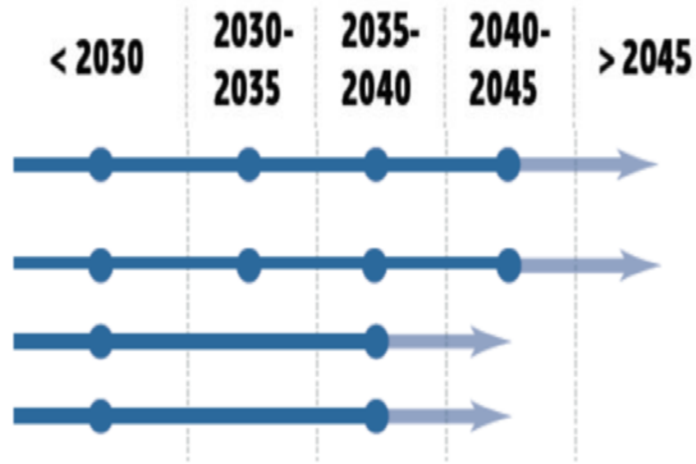
Session Organisation 3
- Proposal, content, timeline, signatories
- Contributors

DRD4 Community Meeting 16 & 17 May 2023 C. Joram, P. Krizan 5

I mainly followed up on the development on SiPM, SPAD which of interest to the Calorimeter community. Apologies about the selection of highlights which is highly biased ...

DRD4: Detector research and development themes

DRDT 4.1	Enhance the timing resolution and spectral range of photon detectors
DRDT 4.2	Develop photosensors for extreme environments
DRDT 4.3	Develop RICH and imaging detectors with low mass and high resolution timing
DRDT 4.4	Develop compact high performance time-of-flight detectors



- Required for fast timing in Cerenkov and time of flight detectors, for operation with high particle fluxes and pile-up, and in extending the wavelength coverage of scintillation photons from noble gases and Cerenkov photons.
- Essential for operation in the high-radiation environments at the HL-LHC, Belle II Upgrade, EIC and FCC-hh; and similarly for cryogenic operation.
- Required for particle identication at HL-LHC, Belle II upgrade, EIC, and FCC-ee.
- As a complementary approach for particle identification at HL-LHC, EIC and FCC-ee.

SiPM Technology: key areas of development

- SiPMs are photosensors of choice for many applications – HL-LHC & FCC-hh mainly drive the HEP technology limits
- Important features are their compactness, low operation voltage, robustness to magnetic fields and reasonable price
- Timing, radiation tolerance, low backgrounds are key :
  - Wide applications for scintillating fibres, calorimeters, neutrinos and DM experiments (pulse shape discrimination), noble liquid detectors (eg MEG-II with LXe), gamma ray astronomy
  - SiPMs now becoming the detector of choice for RICH and DIRC-type detectors (LHCb, ALICE, EIC, FCC-ee etc). And also calorimetry.
    - High QE around 50-60% in the visible (350-600 nm)
    - However high dark count rates 10-100 kHz mm^{-2} at room temperature need to improve towards 1 Hz mm^{-2}
    - Rad hardness : lose sensitivity to single photons at around 1×10^{11} n cm^{-2} eq, need to improve (1×10^{14} n cm^{-2} eq @ CMS ; 10^{17}-10^{18}@ FCC-hh !)
    - Fast timing response – significantly below 100 ps (aspire to 10 ps or below for time resolution)
    - Small cell sizes which are tuneable – integration of large systems (cooling etc) important
    - Note requirements for single photon detection and calorimeters (with many photons) could be conflicting

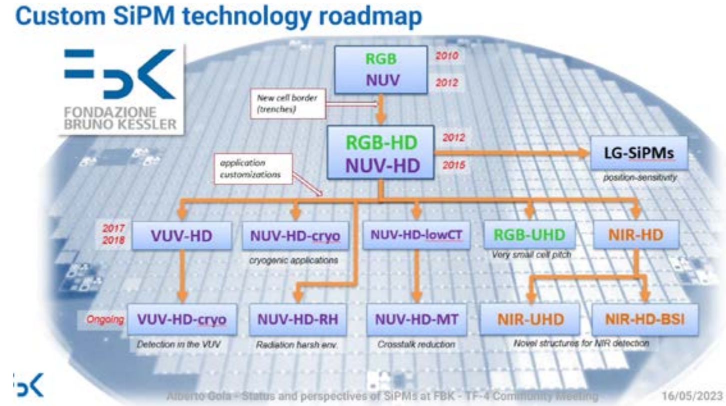
DRD4 Community Meeting 16 & 17 May 2023 C. Joram, P. Krizan 15

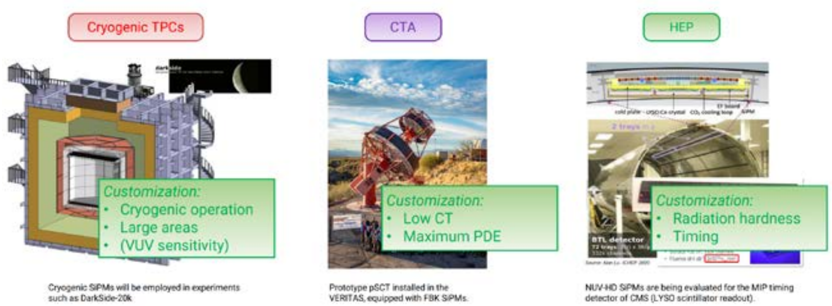
Please see the ECFA report for more details on the key areas of activity for other photon sensors (PMT, MCP etc.) and for TOF,TOP detector developments.

Status and Perspective of SiPM from FBK

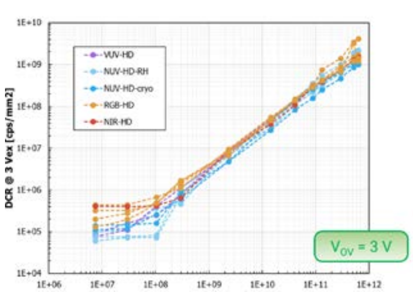
Alberto Gola

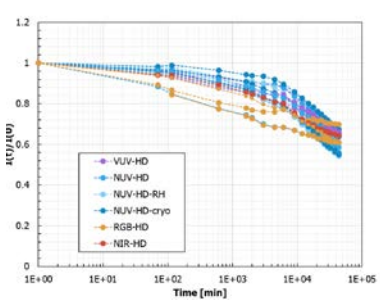
- FBK: private research foundation in Trento, Italy with a major effort in the development and fabrication of custom and CMOS SiPM.
- Long-term strategy: combine custom analog SiPM with CMOS digital SiPMs through 3D integration techniques.

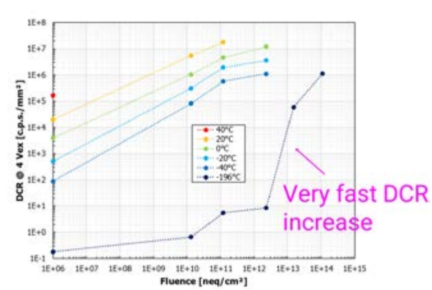


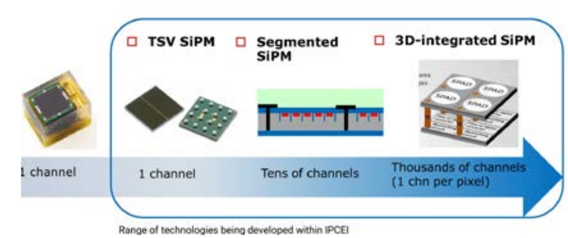


- FBK SiPMs development for Cryogenic TPC, CTA, HEP (MIP timing for CMS LYSO scintillaor readout)
- Extensive studies on dark count rate vs. fluence, annealing, temperature.
- Ongoing development towards next generation 2.5D, 3D integration of Hybrid SiPM, Back-illuminated SiPM







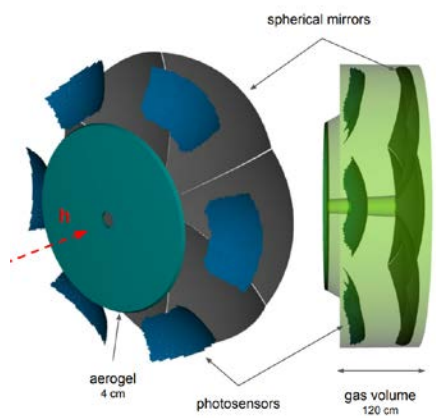


More details in [this talk].

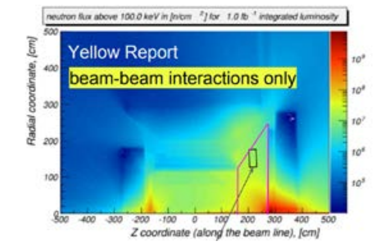
Mitigation of radiation damage in EIC RICH SiPM

Roberto Preghenella (INFN, Sezione di Bologna)

- EIC dual-radiator RICH for forward PID.
- Main R&D on mitigate SiPM sensor dark count rate and radiation damage. Need to survive 10^{11} 1-MeV n_{eq}/cm^2 flux.
- Radiation tests of commercial SiPM sensors and FBK porotypes.
- Exploration of in-situ annealing to reduce dark count rate and extend detector life-time.

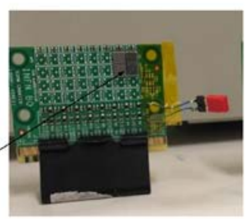


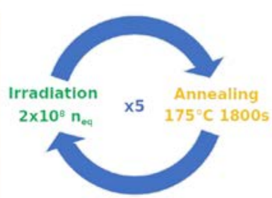
Neutron fluxes at the EIC



location of dRICH photosensors
neutron fluence ~ 1-5 10^7 n / cm^2 / fb^{-1}
(> 100 keV ~ 1 MeV n_{eq})

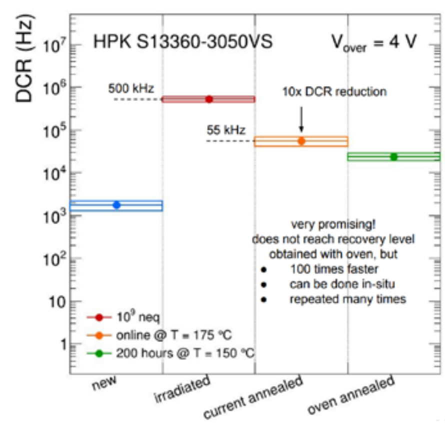
- radiation level is moderate
- magnetic field is high(ish)

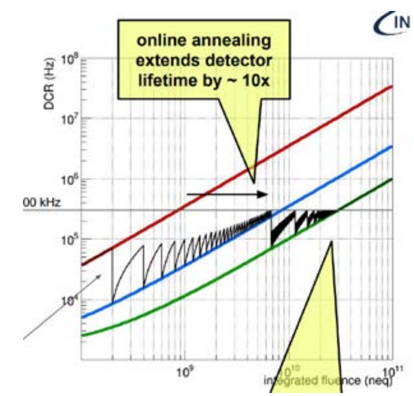




explore solutions for in-situ annealing

- total fluence of 10^9 n_{eq}
  - delivered in 5 chunks
  - each of 2 10^8 n_{eq}
- interleave by annealing
  - forward bias, ~ 1 W / sensor
  - T = 175 °C, thermal camera
  - 30 minutes
- preliminary tests
  - Hamamatsu S13360-3050

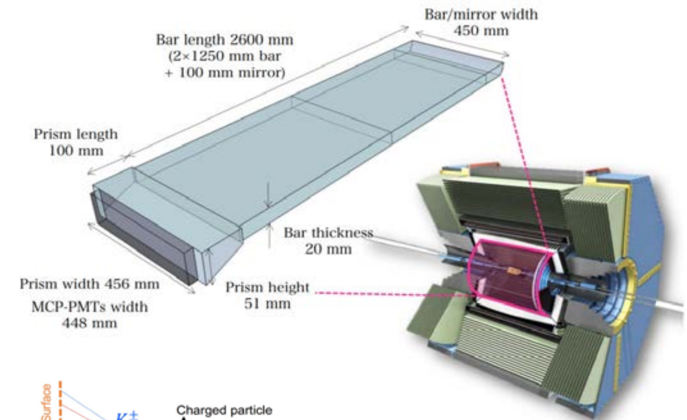




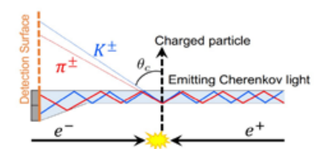
SiPM development for Belle-II TOP

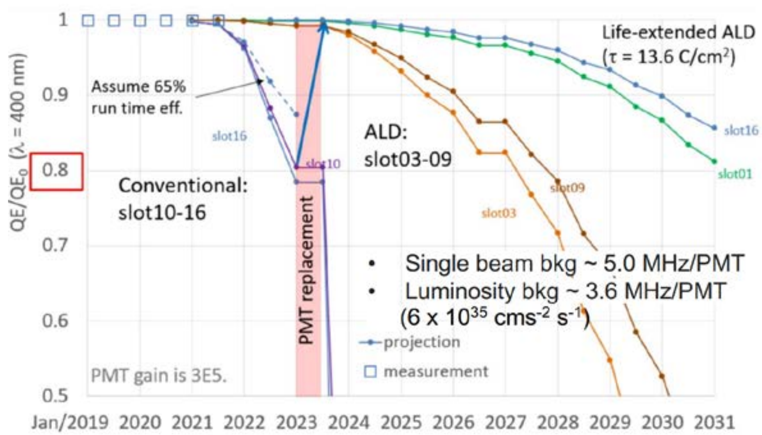
Ezio Torassa (INFN, Padova)

- 16 Time of Propagation (TOP) modules surrounding the tracking detector for particle ID: MCP-PMT based photo-detectors.

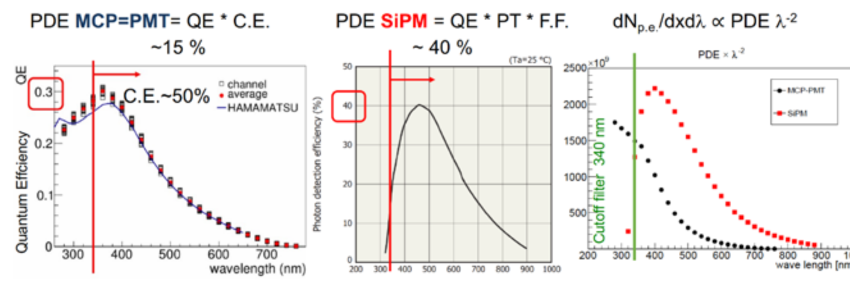


- The main challenge is the degradation of quantum efficiency for MCP as a function of accumulated charge. Life-time is a major concern if the accelerator goes to high luminosity.

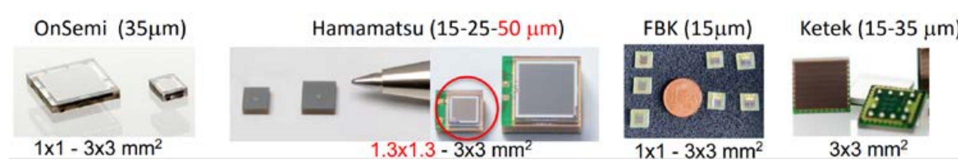




- Imperative to develop radiation-tolerant SiPM with high PDE.



- Extensive tests and characterization of commercial SiPMs: gain, breakdown voltage, dark count rate. w. or w/o radiation, cooling.

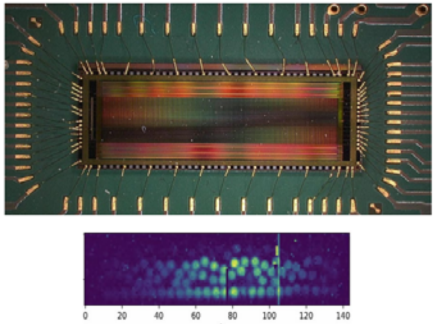


CMOS SPAD for the readout of scintillating fibers

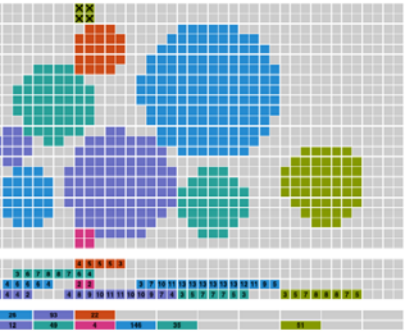
M. Nicola Mazziotta (INFN, Bari)

- Detection of light from optical fibers for particle fiber trackers
- SPAD pitches of 42/56 µm to accommodate large or small fibers
  - 350 nm CMOS technology with 4 metal layers (IMS in Duisburg, Germany)
- Each SPAD can be associated to a group by enabling a programmable switches
  - The total current is $N \times I_0$ when N (enabled) SPADs have fired and I_0 the unit current

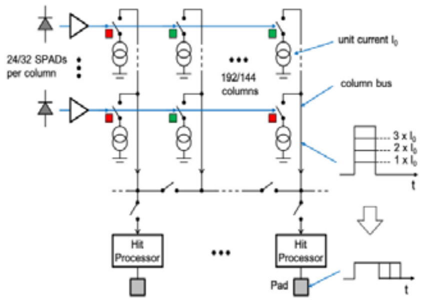
Sensitive area: 8064 × 1792 µm2
Pixel size: 56 x 56 µm2



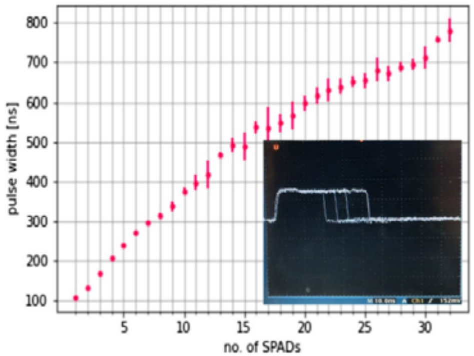
https://www.sciencedirect.com/science/article/pii/S0168900222004582

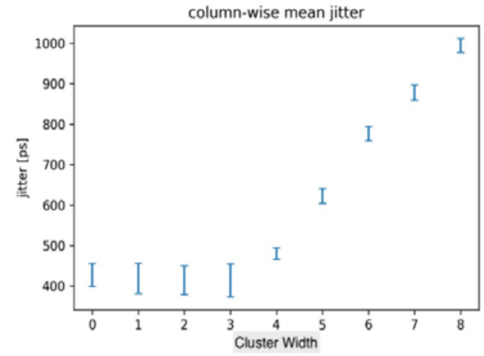


Example of SPAD groupings and limitation of the architecture



Principle of SPAD counting in a column group.



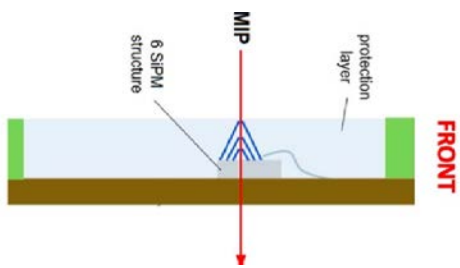


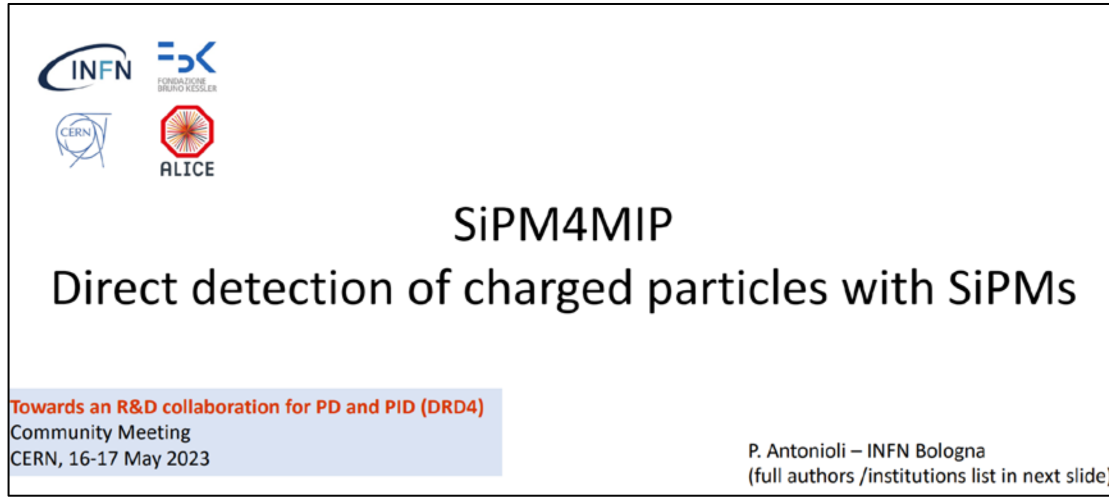
Nicola M - CMOS SPAD - CERN May 16-17, 2023 5

- Exploration of CMOS SPAD with highly integrated sensor-readout electronics. Digital output with low power consumption. Back-side illumination possible.

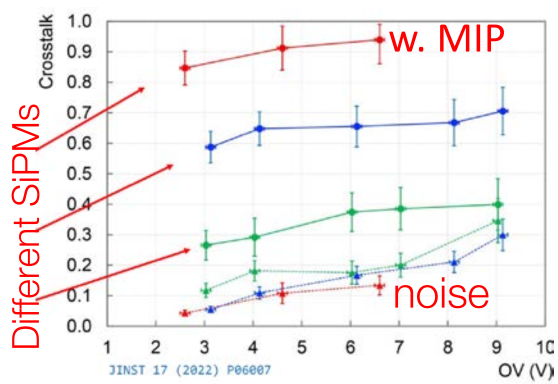
SiPM for direct charge particle detection

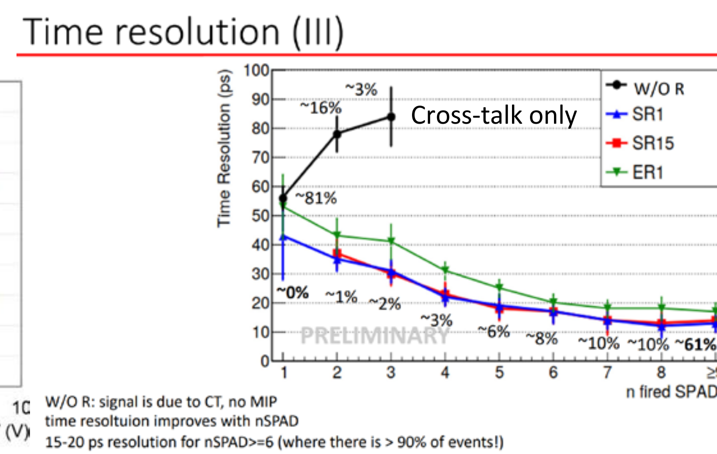
- Innovation to detect charged particles based on Cerenkov light generated in the protection layer of the SiPM.





- Attempt to understand high cross-talk from MIPs w.r.t intrinsic noise.
- Study of energy dependent Cerenkov effect.
- Good timing resolution (10-20 ps) for 90% events





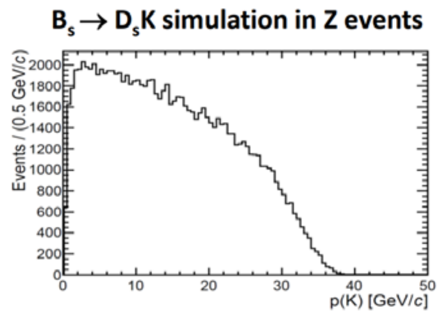
- Potential for precision timing, TOF+RICH detector, SiPM based tracker ...

R&D also driven by application in ALICE 3 (after Run 5)

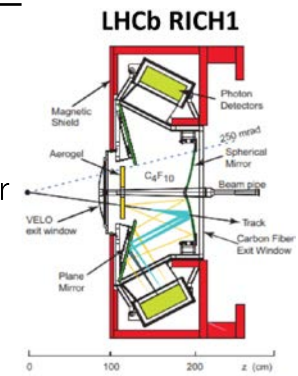
A Compact RICH for Higgs Factory

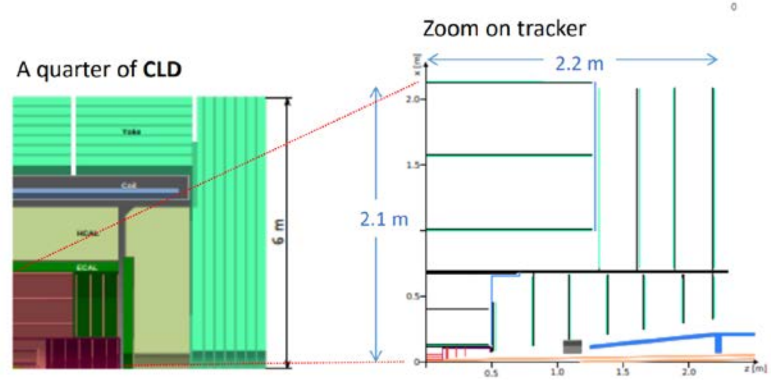
Roger Forty (CERN)

- Conceptual design of a compact RICH for charged hadron PID. Identify H and W decays and exploit flavor physics enabled by huge Z statistics. Momentum range: 1-40GeV/c.
- Target a radial depth of 20cm and a material budge of a few % X_0.
- Challenge is to arrange optical elements to focus Cerenkov light on a single sensor plane.
- Fly-eye inspired cell design to have sperate spherical focusing mirror and sensors.
- Optimization on radiator, sensor and geometric design. Simulations on performances ongoing.

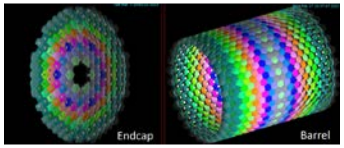


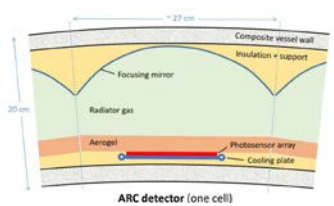
How to adapter LHCb style RICH for 4pi experiment ?

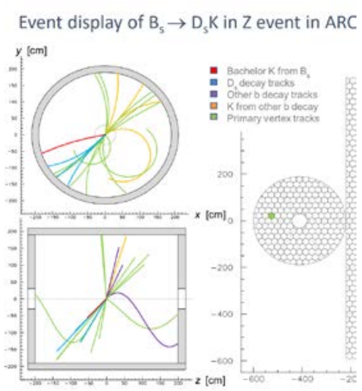


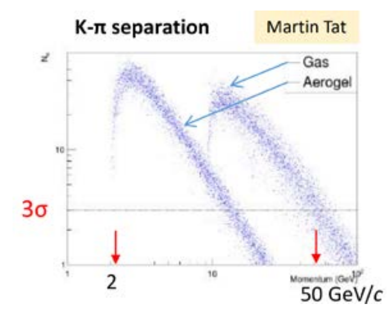


Reduce tracker radial space occupation



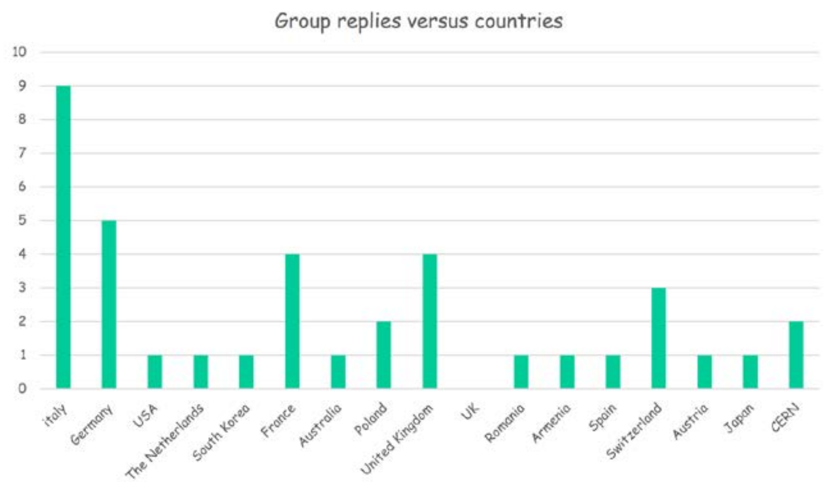






Groups interested in DRD4 efforts

- About 40 groups expressed interests to join the DRD4 efforts.
- Larges number of groups from Italy with a substantial presence of PID detector development for the LHCb experiment
- Only 1 US institution engaged so far.



INFN Rome 1 and CREF
Bergische Universität Wuppertal
INFN Padova
GSI Helmholtzzentrum fuer Schwerionenforschung GmbH, Darmstadt, Germany
Georgia State University
infn
School of Physics and Astronomy, Monash University
Seoul National University
University of Warwick
IRFU, CEA
INFN Bari
INFN Bari
European Space Agency (ESA/ESTEC)
STFC - RAL
Institute of Plasma Physics and Laser Microfusion
CERN
IFIN-HH
IJCLab
INFN Milano Bicocca
Particle Therapy Research Center, University Medical Center Groningen
LHCb TORCH R&D project
A. I. Alikhanyan National Science Laboratory (Yerevan Physics Institute)
AANL
ICCUB // University of Barcelona
DESY, Hamburg
University Giessen, Germany
CERN
Institut des 2 infinis de Lyon
INFN
KM3NeT Collaboration
AstroCeNT / Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences
ISTITUTO NAZIONALE DI FISICA NUCLEARE, Division of Ferrara
DESY
Fondazione Bruno Kessler
University of Oxford
The Catholic University of America
Queen Mary University of London
Aix-Marseille Univ, CNRS/IN2P3, CPPM, imXgam research team
Innsbruck University, NRNU MEPhI Moscow
Belle II, ARICH at KEK
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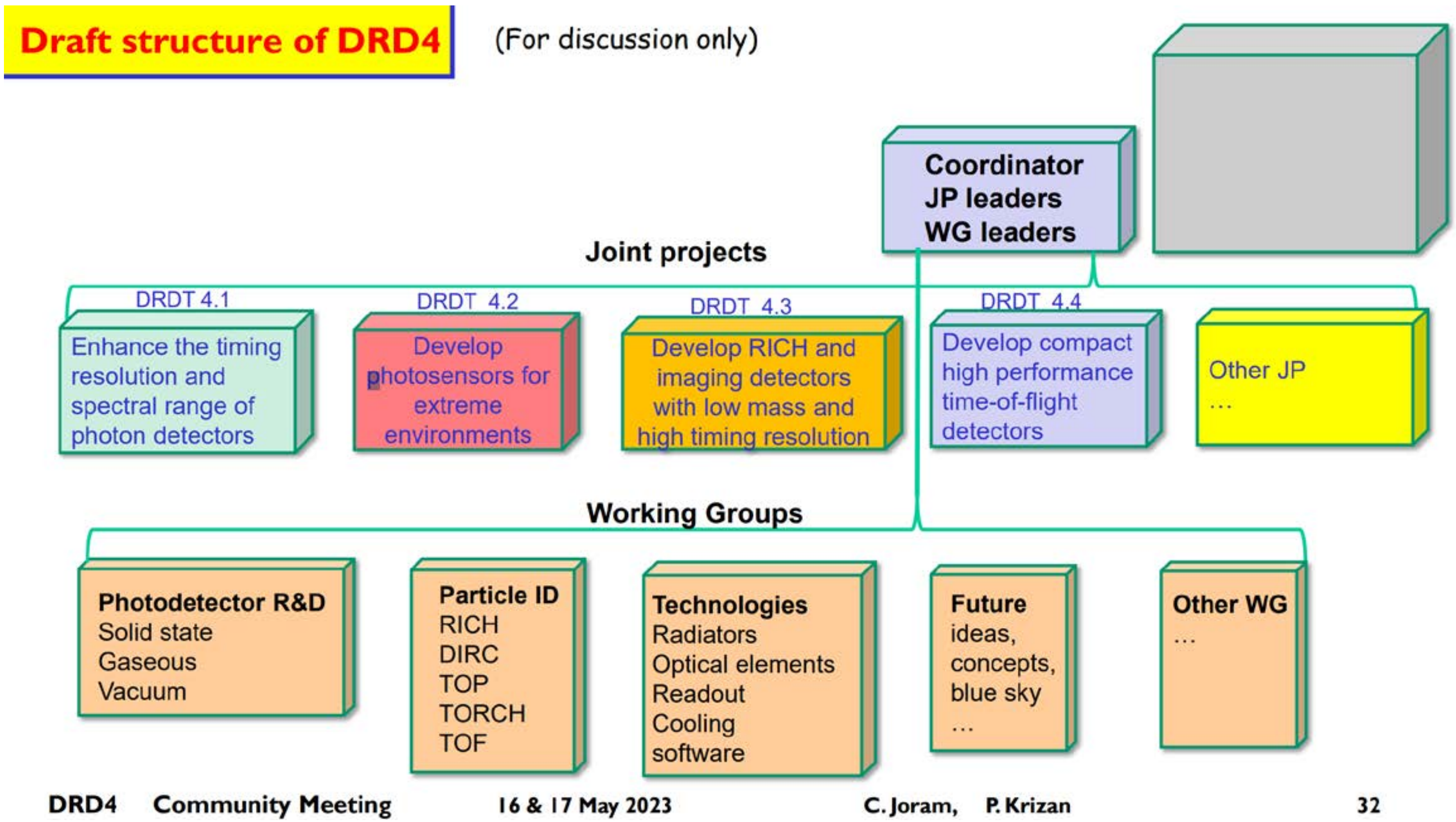
Draft structure of DRD4



There are 26 group presentations summarizing their activities and areas of interests within the DRD4 community. Please look at their presentations to find possible collaboration on common efforts of testing photon detectors.

Next DRD4 community update meeting @ 15 June 2023
https://indico.cern.ch/event/1294239/

Towards formation of DRD4 collaboration with working groups and joint projects (after the survey from 50 groups...)