DRD5

RDq collaboration for quantum sensing detector R&D

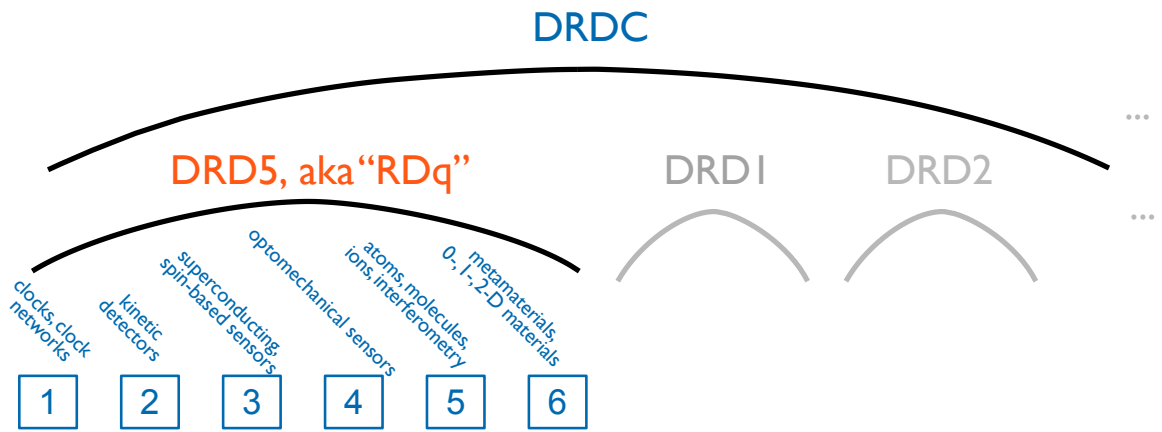
Florian Brunbauer (CERN)

DRD1 Community Meeting, June 2023

RDq / DRD5

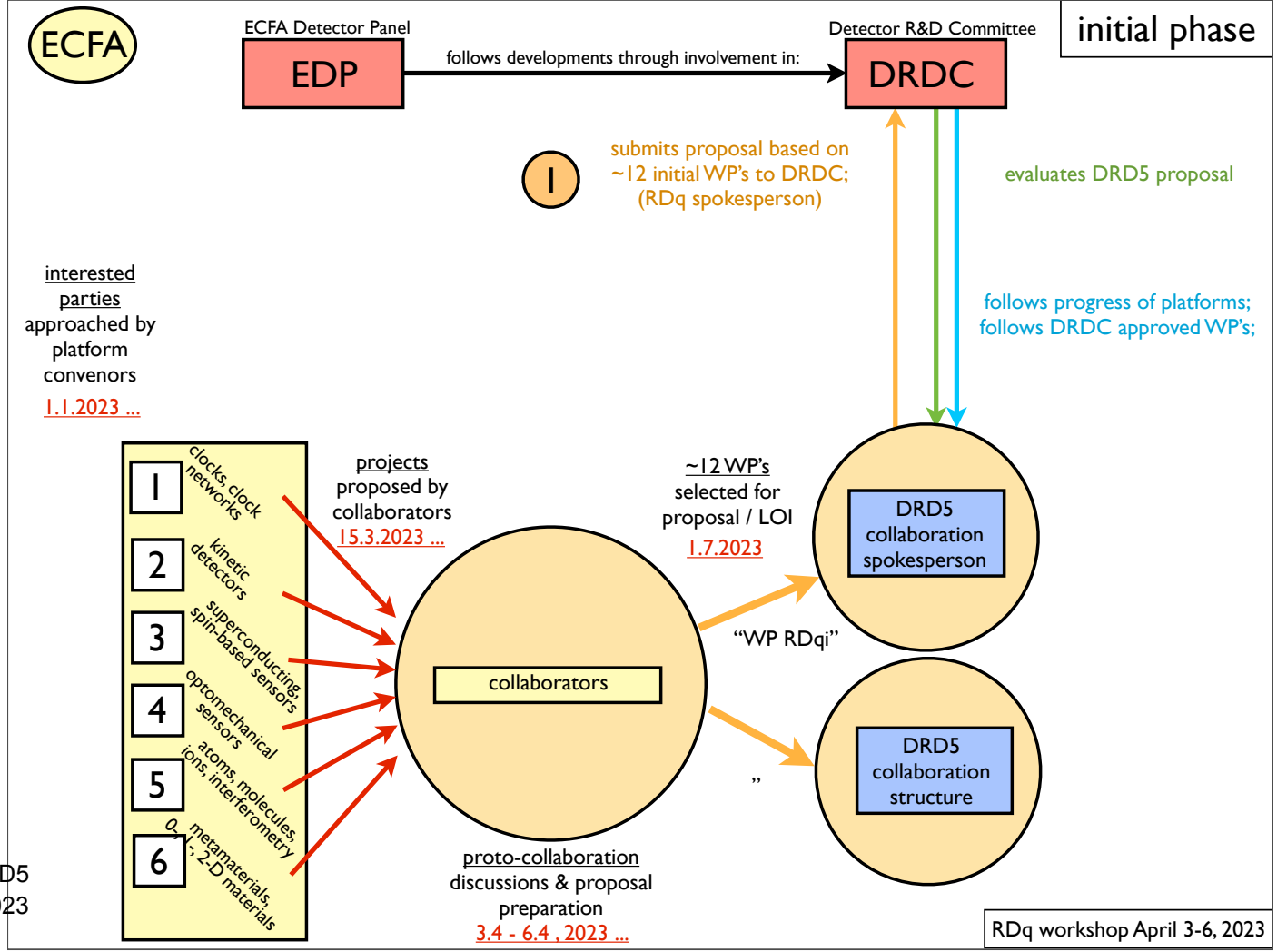
The mission of RDq is to:

i) Promote the development of advanced quantum sensing technologies;
ii) Investigate and adapt state-of-the-art developments in quantum technologies to particle physics;
iii) Establish the necessary frameworks and mechanisms to allow exploration of emerging technologies;
iv) Develop and provide advanced enabling capabilities and infrastructure.



6 families identified in ECFA roadmap

M. Doser et al. DRD5 Workshop, April 2023



M. Doser et al. DRD5 Workshop, April 2023

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Convenors of TF5 collected community input to identify technology areas of interest

Families of quantum sensors identified

- Clocks and clock networks
- Superconducting & spin-based systems
- Kinetic detectors
- Atoms/ion/molecule & atom interferometers
- Optomechanical devices
- **Nano-engineered & low-dimensional materials**

Co-convenors for different technology families reached out to community to identify interested and ask for work package ideas

Work packages proposed with varying detail / approach / scope

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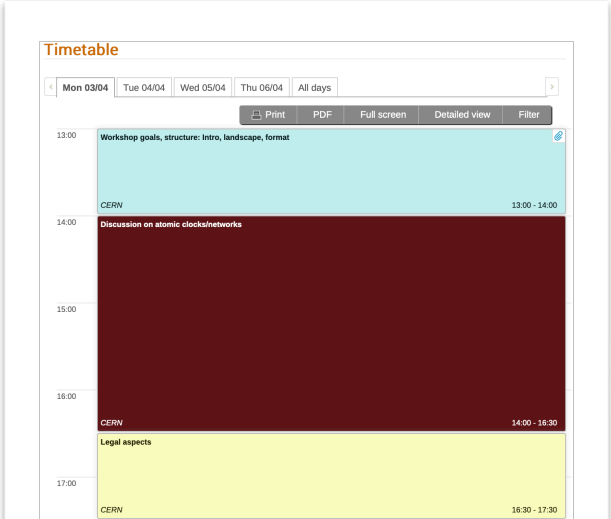
Workshop among convenors in April

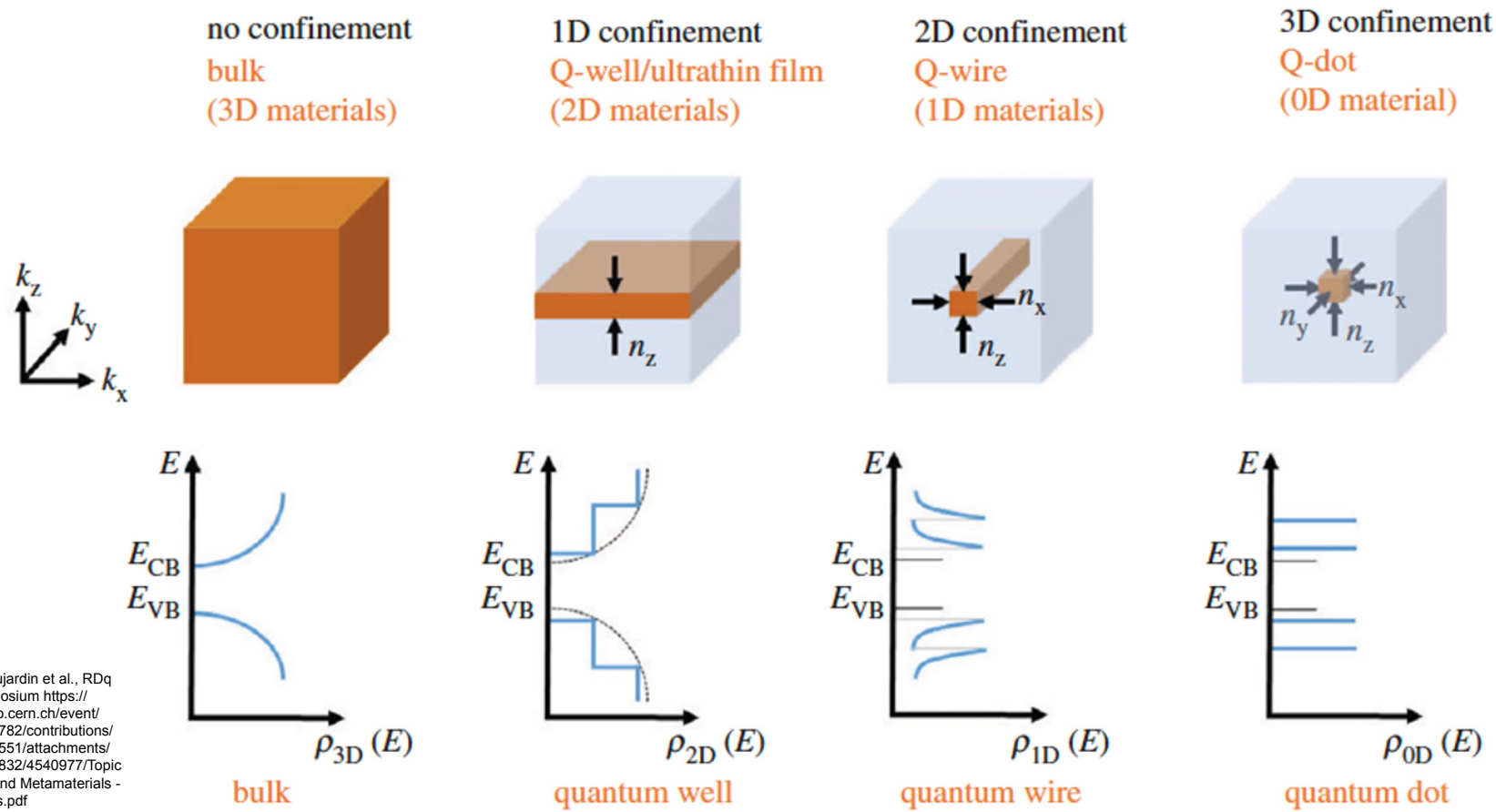
Discuss status of community in different technology families

Significant differences in communities, existing collaborative efforts, needs

Discuss submitted proto-work packages

For gaseous detectors:
Interest in interface with activities on nano materials / low-dimensional materials





C. Dujardin et al., RDq symposium https://indico.cern.ch/event/1229782/contributions/5352551/attachments/2625832/4540977/Topic QD and Metamaterials - slides.pdf

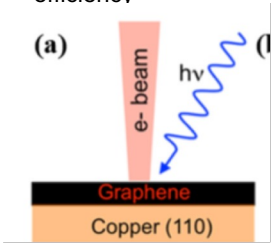
Figure 1. Schematic illustration of broken symmetry and functional form of the density of states in 1D, 2D and 3D confined materials.

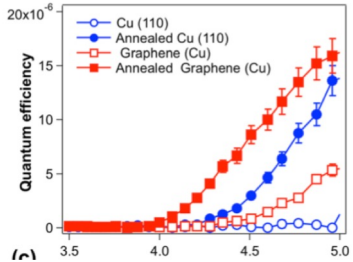
Quantum effects in 2D materials (graphene like, quantum wells..)

Change of the electronic properties: indirect to direct, enhanced quantum efficiency

Enhanced QE of Cu photocathode with Gr coating -> 25% low work function
measured Gr grown on Cu vs bare Cu

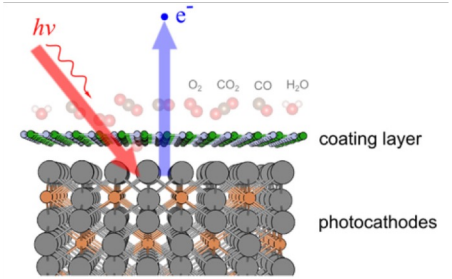
Lifetime enhancement for chemically reactive surfaces showed higher QE and lower work function after annealing, suggesting that graphene allows photoelectrons to tunnel through without any loss of efficiency



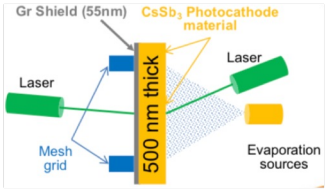


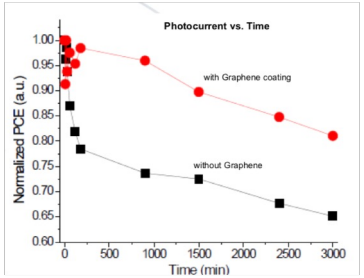
https://aip.scitation.org/doi/10.1063/1.4974738

Graphene increases work function of semiconductor photocathodes - inward pointing dipoles
few layers of BN also reduces the work function of alkali-based photocathodes
forms outward pointing dipoles
one layer preserved high QE



https://www.nature.com/articles/s41699-018-0062-6





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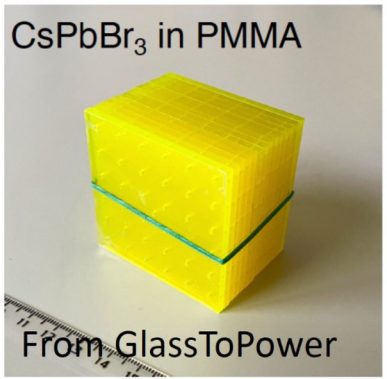
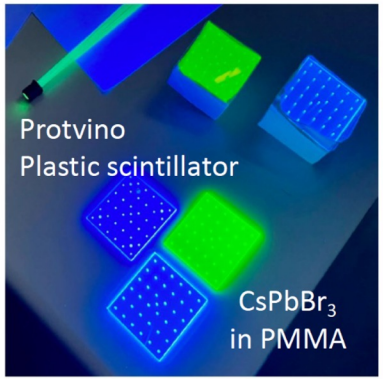
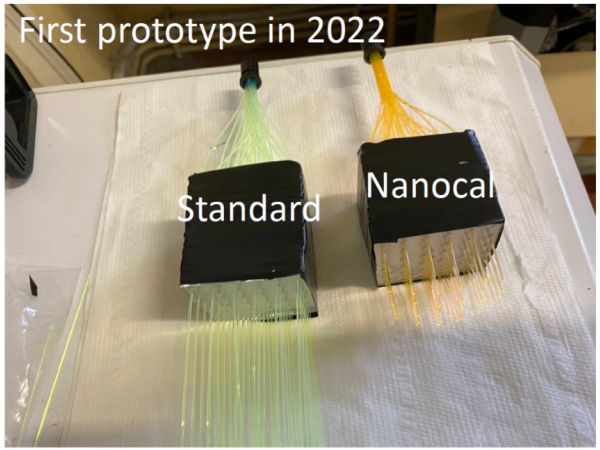
More advanced project toward HEP

First Attempt to use Nanomaterial in HEP
Nanocal Bluesky Aidainnova project

Build a Shashlik module with $CsPbBr_3$ nanomaterial embedded in PMMA







Protvino scintillator	NanoCal scintillator
Polystyrene	PMMA
1.5% PTP/0.04% POPOP	0.2% CsPbBr3
Kuraray Y-11(200) fibers	Kuraray O-2(100) fibers

From M. Moulson Aidainnova WP13 20.12.2022

First test beam performed in October 2022 in H2

See EP newsletter Nov 22
M. Moulson presentation Aidainnova WP13 20.12.2022

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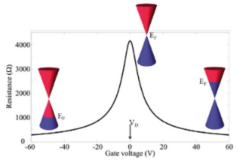
Proto-work packages submitted by interested groups to TF convenors

Focused on specific developments by involved groups

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département de physique nucléaire et corpusculaire

2D sensors with a Dirac point band structure to build an ion TPC

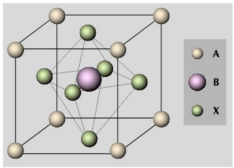
The concept of using 2D materials with a Dirac point band structure to build an ion Time Projection Chamber (TPC) originated from the use of quantum dots doped graphene for photon detection. The concept is based in the the fact that the presence of charged quantum dots, generated by the absorption of light, changes the gate voltage and the resistivity of the graphene. This concept has been demonstrated in previous studies (*Nat Commun* **7**, 11954 (2016))



Development of lead perovskite based radiation detectors

Lead halide perovskites are novel semiconductors with exceptional optoelectronic properties, versatile chemical composition and low cost synthesis. They consist of crystals with structure APbX3, such as CsPbI3.

LEAD PEROVSKITES



In the last decade, halide perovskites have emerged as alternative solar cell photosensors reaching record performances. Due to their inexpensive fabrication cost < 0.3$/cm3 [Nature Communications 10, 1066 (2019)], unique optoelectronic properties and very high atomic numbers, lead perovskites have also started to be characterised and developed for radiation detection. In this regard, the highest sensitivity of any material to x-rays has been already achieved with lead perovskites [Nature Photonics volume 16, 575–581 (2022)], and perovskite-based devices have been already demonstrated to be able to detect α [Communications Materials 1, 37 (2020)] and β [Nature Communications 11, 3395 (2020)] particles, as well as neutrons using a hybrid configuration [Scientific Reports 11, 17159 (2021)]. Moreover, lead perovskites have been used for spectroscopy at room temperature, being able to resolve gamma rays of 662 keV with 1.4% energy [Nature Photonics volume 15, pages 36–42 (2021)]. The rich

DRD5 - RDq - technology platforms

- Create collaborative structure to share information about developments and facilities

- Facilitate access to facilities - expensive infrastructures

Technology family on nano materials and low-dimensional materials

- Interface between material scientists and detector developers
- Offer opportunity to access and exploit state-of-the-art materials
- Promote evaluation of novel materials for environments relevant for HEP applications
    - Testing facilities
    - Technology forums

DRD5 - RDq - next steps

- White paper in preparation by technology co-convenors
- TF5 convenors will condense white paper into LoI in July

- LoI will be shared with interested communities who express their interest by end of July

- LoI to be submitted in summer following the request by DRDC