WP2 Gas Detectors

Christoph Rembser, Eraldo Oliveri

EP R&D

CERN

WP2 Program's **activities**

Large Area

- Exploring new structures (e.g. resistive/DLC) and solution suitable for large area detectors (e.g. Picosec mm)
- Prototyping modules for large area coverage (e.g. GEM, mm, μRWELL)

R&D framework and tools

- Gas (e.g. novel mixtures)
- Modelling and Simulation (e.g. signal induction)
- Electronics (e.g. multichannel FE ASICs & DAQ)

Novel technologies

- New materials (e.g. converters)
- Novel manufacturing techniques`(e.g. 3D printing)
- Exploring novel readout technologies (e.g. photons, pixels ASICs)

People and Teams

Antonija Utrobicic, (FELL) GDD
Antonio Teixeira , (STAFF) MPT
Beatrice Mandelli , (STAFF) Gas Group
Bertrand Mehl , (STAFF) MPT
Christoph Rembser (STAFF)
Djunes Janssens, (DOCT) GDD
Eraldo Oliveri, (STAFF) GDD
Fabio Sauli (HM) GDD
Florian Brunbauer, (FELL, STAFF) GDD
Gianluca Rigoletti , (DOCT) Gas group
Giorgio Orlandini, (DOCT/QTI) GDD
Hans Muller , (EXT User)
Heinrich Schindler , (STAFF)
Karl Jonathan Floethner, (DOCT/Gentner), GDD
Leszek Ropelewski , (STAFF) GDD
Lucian Scharenberg , (DOCT) GDD
Marta Lisowska, (DOCT) GDD
Mattia Verzoli, (TEE, TECH) Gas Group
Miranda Van Stenis, (STAFF) GDD/TFG lab
Olivier Pizzirusso , (STAFF) MPT
Rob Veenhof , (EXT User)
Roberto Guida , (STAFF) Gas Group
Rui De Oliveira , (STAFF) MPT
Thomas Schneider , (STAFF) TFG lab
Maria Cristina Arena , (DOCT, soon) Gas Group
Demetrio Magatti (TECH, 2021) Gas Group
Federico Cambie (TEE, 2021) Gas Group

RED = covered partially or completely by EP RD budget

Laboratories & workshops

- Gaseous Detector Development (GDD) laboratory (**EP-DT**-DD)
- Gas Group laboratory (**EP-DT**-FS)
- Micro Pattern Technology (MPT) Workshop (**EP-DT**-EF)
- Thin Film and Glass (TFG) Laboratory (**EP-DT**-EF)

Additional Resources and Synergies

Wolfgang Gentner Scholarships

- Lucian Scharenberg, **Next Generation Electronics for the Read-Out of Micro-Pattern Gaseous Detectors, EP-RD/R&D Framework and Tools/Electronics.** Six months DOCT extension on EP-RD. FELL from Sept.
- Karl Jonathan Flöthner**, R&D on GEM-based tracking system for future experiments, EP-RD/Large Area**

Wolfgang Gentner Scholarships

AIDAinnova-WP3-Test beam and DAQ infrastructure

Task 3.5.2 **VMM3 common readout to support gas detector R&D**

AIDAinnova-WP7-Gaseous detectors

Task 7.2 **Eco-friendly gas mixtures for RPCs**

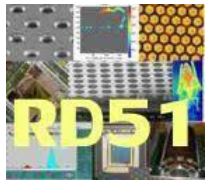
R&D on Gas Recirculating and Recovery (CF4, C4F10 e R134a) Systems

CERN Environmental Protection Steering board (CEPS)

CERN Quantum Initiative - Quantum Sensing

Giorgio Orlandini (DOCT), **Graphene-based functional structures and nanostructures for novel gaseous detectors, EP-RD/Novel Technologies**

Large synergy in several topics: PICOSEC, μRWELL high rate 2D readout, photon readout, modelling and simulation, electronics, test beam



Pillar Projects (cross-cutting the three activities)

EP-RD Day 2021-1

PICOSEC micromegas for precise (tens of psec) timing

- Synergy with RD51 PICOSEC collaboration. CERN EP-RD taking care of scaling up. 100cm2 module built, custom made electronics developed, ready to be fully readout (digitizer**) → Antonija's contribution (EP-RD Day 2022-1).** 100cm2 tracking (50um/GEM) and timing (20ps/mm) telescope soon @ SPS test beam. Large area next: robustness. Alternatives to CsI (DLC,B4C) photocathodes and resistive (DLC) micromegas (successfully tested in cm2 prototype) scaled up to 100cm2. (M. Lisowska)

Micro Pattern Elements for large area MPGD

- Towards large area MPGD. Several solution under test: small pitch GEMs, high LPI mm, three-coordinates readout planes (improving dynamic range, space resolution, rate capabilities and multiplicities,..) . In pipeline: 2D readout uRWELL prototype for high rate to be designed (linked to modelling part/synergy with RD51), new structures with resistive elements (DLC) connected to DLC machine @ MPT workshop (K. J. Floethner)

Gas Mixtures studies (environmentally friendly)

- Lab. and GIF++ studies of eco-gas for RPC → **Gianluca's contribution (EP-RD Day 2022-1)**, "potential" joint project on "Environmental Friendly Gas Mixtures for Gas Based Tracking and Timing Detectors" with ETH Zurich HV laboratory (modelling and measurements). Synergies with AIDAinnova & CEPS

Modelling (signal induction with resistive elements)…beyond gaseous detector

- COMSOL/Garfield++ implementation done, several technologies modelled (MPGD, RPC, Silicon, Diamond), test bench phase → **Djunes' contribution (EP-RD Day 2022-1)**

Front End electronics and DAQ for MPGDs

- Synergy with RD51 and AIDAinnova. Prototype based on SRS and VMM3a done. Applied to different detectors, laboratory and test beam use. (L. Scharenberg)

New materials

- 2D materials (graphene) free standing mesh (aiming to asymmetric transparency between electrons and ions) and as protection layer for photocathode (CsI) – new materials / new converters (absorption/conversion into electrons in gas). In synergy with QTI, linked to material science lab (NEST, IIT) → Giorgio's inputs to **(EP-RD Day 2022-1/QTI)**

3D Printing

- New manufacturing techniques, 3D inkjet printers (Nano Dimension and Super Inkjet Printer) prototypes of basic elements. (F. Brunbauer)

Optical Readout

- Optical TPC. SiPM Readout (F. Brunbauer)

More details on annual report: http://cds.cern.ch/record/2808204/files/EP%20R&D%20AR%202021%20complete.pdf

EP R&D Internal Seminars

Signal formation in detectors with resistive elements, Djunes Janssens, https://indico.cern.ch/event/1167590/

Precise timing with large area Picosec Micromegas detector, Antonija Utrobicic, https://indico.cern.ch/event/1110585/

Precise timing with gaseous detectors: towards robust and tileable Picosec Micromegas detectors, Florian Brunbauer, https://indico.cern.ch/event/1016656/

DT Training Seminars

Studies to reduce greenhouse gas emissions from detectors at the LHC, Gianluca Rigoletti, https://indico.cern.ch/event/1155238/

Developing a general purpose readout system for gaseous detectors, Lucian Scharenberg, https://indico.cern.ch/event/1102899/

RD51 Collaboration Meeting

Jun 13, 2022, 9:00 AM → Jun 17, 2022, 5:00 PM Europe/Zurich

160/1-009 (CERN)

Leszek Ropelewski (CERN) , Silvia Dalla Torre (Universita e INFN Trieste (IT))

Last week

Advancements in a large area 100 channel PICOSEC Micromegas detector module, A. Utrobicic , RD51 CM June 2022 (CERN)
https://indico.cern.ch/event/1138814/contributions/4915978/attachments/2462081/4221391/Picosec_Advacments_f_AU.pdf

Elaboration of the XYU readout and first measurements, J. Floethner , RD51 CM June 2022 (CERN)
https://indico.cern.ch/event/1138814/contributions/4917313/attachments/2462126/4221473/2022_06_14_XYU_Floethner.pdf

Update on numerical signal modelling in detectors with resistive elements, D. Janssens, RD51 CM June 2022 (CERN)
https://indico.cern.ch/event/1138814/contributions/4913670/attachments/2462796/4222726/RD51June2022DjunesJanssens.pdf

Latest experiences and test beam results using VMM3a/SRS, L. Scharenberg, RD51 CM June 2022 (CERN)
https://indico.cern.ch/event/1138814/contributions/4921252/attachments/2463182/4223357/lucian_2022-06-15_vmm-srs-first-test-beam-results.pdf

Transfer of CVD grown graphene onto GEM foils, G. Orlandini, RD51 CM June 2022 (CERN)
https://indico.cern.ch/event/1138814/contributions/4922756/attachments/2463381/4224343/220615_RD51.pdf

PICOSEC micromegas, M. Lisowska, RD51 CM June 2022 (CERN)
https://indico.cern.ch/event/1138814/contributions/4917138/attachments/2464462/4225861/PICOSEC_Micromegas_Test_Beam_May22_CM.pdf

Large area gaseous detector systems
New structures, concepts and approaches for large area systems will be investigated with this activity, prototypes built and tested, specifications and procedures developed and documented. The ongoing Phase-1 upgrade of the LHC experiments has shown that the industrial production brings the schedules of the projects to a very high risk and that a reliable and efficient technological transfer is crucial. The most reliable and efficient strategy, during the prototyping phase, thus need to be identified taking into account the final production process.

Deliverables (max. 5)

date (count month from start of R&D)	item	
24	[D2.1-1] --- Prototype O(m^2) of a single stage detector for high rate condition (larger than 1Mhz/cm2), based on resistive electrodes;	[1]
36	[D2.1-2] --- Prototype O(100cm^2) of a detector with embedded/integrated readout electronics, for thin detector and high granularity readout applications;	[2]
48	[D2.1-3] --- Prototype O(m^2) of a multi-stages detector for high rate condition (larger than 1Mhz/cm2);	[3]
60	[D2.1-4] --- Prototype O(100cm2) of a detector with discrete and distributed RPC-like readout electronics;	[4]
60	[D2.1-5] --- Report on Activity 2.1.	

Milestones (max. 5)

6	[M2.1-1] --- Review and documentation of the status and guidelines on large area gaseous detectors from LHC and upgrades experience;
12	[M2.1-2] --- Design of deliverable D2.1-1;
24	[M2.1-3] --- Design of deliverable D2.1-2;
36	[M2.1-4] --- Design of deliverable D2.1-3;
48	[M2.1-4] --- Design of deliverable D2.1-3;

Ongoing…

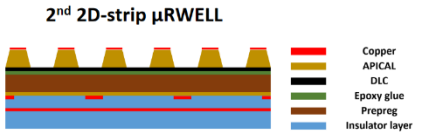
Done…

EP R&D

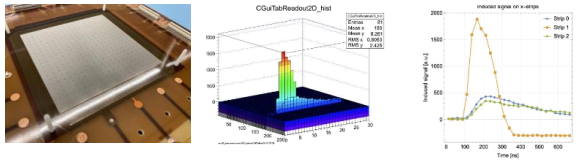
CERN

[1] Delayed..2D readout uRWELL prototype for high rate to be designed (linked to modelling part/synergy with RD51 – test bench ongoing /mm and uRWELL), new structures with resistive elements (DLC) connected to DLC machine @ MPT (coming soon).

uRWELL prototype from USTC

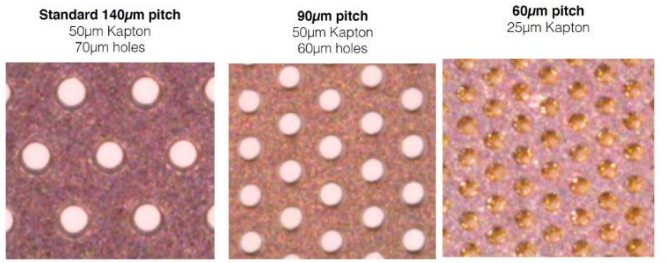


Resistive micromegas (DLC plane)

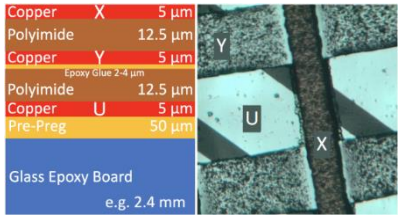


[2] Budget cut / Not considered for the time being

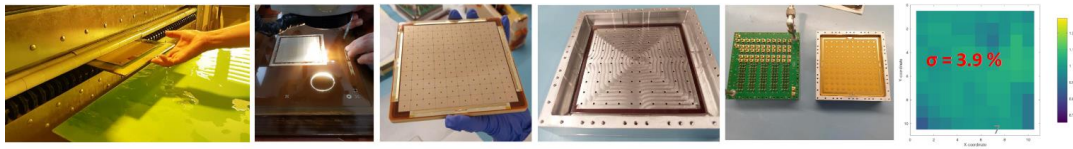
[3] Ongoing... Connected to COMPASS++/AMBER (Gentner), 50cmx50cm. Potential implementations under test: small pitch GEMs three-coordinates readout planes (improving dynamic range, space resolution, rate capabilities and multiplicities,..)..



XYU readout plane



[4] multipad PICOSEC micromegas module for precise timing. 100cm2 with 100 readout pads of 1cm2 area. Custom electronics (see delivery of activity 2). Readout via digitizer (SAMPIC, 128channels).

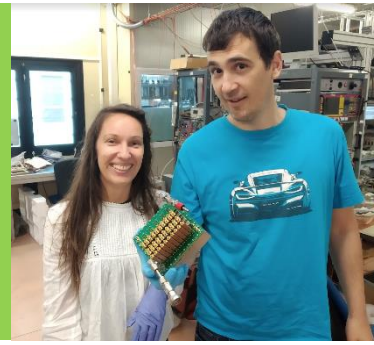


R&D framework and tools
The aim of this activity is to foster compulsory tools for future detector developments and for prototypes design and evaluation. It will focus on strengthening the R&D environment at CERN. Gas studies and analysis, simulation and modelling, electronics and instrumentation will be subjects of this activity. Large interaction with the community (as RD51) will be pursued and priority will be given to what is already under development and supported at CERN. A few examples are activities in EP-DT-FS for environmental protection and gas analysis, activities in EP-DT-DD for gaseous detector simulation as Garfield, and activities in EP-DT-DD/DI for gaseous detector front end electronics and instrumentation.

	date	(count month from start of R&D) item	
Deliverables (max. 5)	18	[D2.2-1] --- Framework and support for modelling and simulation;	[1]
	30	[D2.2-2] --- Prototype of a single channel readout for fast and precise timing;	[2]
	36	[D2.2-3] --- Laboratory, equipments and database for outgassing studies and measurements on new material and components;	[3]
	42	[D2.2-4] --- DAQ system for laboratory, test beams and small experiments;	[4]
	60	[D2.2-5] --- Final report on Activity 2.2	
Milestones (max. 5)	12	[M2.2-1] --- Definition of requirements for a gas analysis laboratory (for delivearble D2.2-3);	
	12	[M2.2-2] --- Definition of strategies and guidelines for modelling and simulation, existing tools and availale interfaces (for deliverable D2.2-1);	
	12	[M2.2-4] --- Definition of requirements for the gaseous detector electronics laboratory (for deliverables D2.1-2, D2.1-4, D2.2-2);	
	12	[M2.2-3] --- Definition of future strategies on generic DAQ (for deliverable D2.2-4);	

[1] Modelling of signal induction w/wo resistive elements (Garfield++, COMSOL). Several use cases in MPGD and beyond (RPC for gaseous… silicon (LGAD) and diamond (TimeSpot) for solid state). In synergy with RD51.

[2] High Bandwidth fast amp, based on C. Hoarau (LPSC) RF amplifier, optimized for Picosec by M. Kovacic (CERN SY-EPC-HPM)). CSA (H. Muller, under development/test). See Antonija's contribution…



[3] In pipeline - Synergy with RD51/Experiments (potential starting point – setup ATLAS TRT, K. Vorobev, Outgassing studies of materials, RD51 CM June 21, https://indico.cern.ch/event/1040996/contributions/4408965/attachments/2266035/3848571/TRT%20ageing%20setup%202021.pdf)

[4] In synergy with RD51 and AIDAinnova. DAQ (SRS/RD51) and FE (VMM3a, BNL/ATLAS). Prototype system ready for lab & test beam. Several new developments ongoing (rate, integration with other DAQ,..)

Novel technologies
This activity aims to explore new solutions for future detector developments. Novel materials, new fabrication techniques and new technological solutions will be implemented in view of improving our detection capabilities. Solid converters for fast and precise timing and 3D printing of amplifying structures are two examples. This activity will enlarge CERN expertise in fields as nanotechnologies and material science, fields that are not exhaustively covered today and with high potential in pioneering research.

Deliverables

(max. 5)

date (count month from start of R&D)	item
12	[D2.3-1] --- Photocathode test stand: measurement of quantum efficiency in vacuum and gas, aging characterization;
36	[D2.3-2] --- Prototype of a gaseous detector made with novel techniques as 3-D printing;
36(*)	*[D2.3-3] --- prototype of optical reaodut with fast imaging camera and on-board fast image processing;*
48	[D2.3-4] --- Test stand for secondary emitter studies and characterisation;
60	[D2.3-5] --- Final report on activity 2.3

(*) In case of additional resources (1 Fellow for three years and 250kCHF in total)

Milestones

(max. 5)

6	[M2.3-1] ---Review on photocathodes in gaseous detector and strategy definition (for deliverable D2.3-1);
6	[M2.3-2] --- Availability Survey of new manufacturing techniques as 3D printer, Inkjet Printer, DRIE plasma, laser in external facilities as EPFL (for deliverable D2.3-2);
18	[M2.3-3] --- Design of key prototypes for porcess evaluation (for deliverrable D2.3-2);
24 (*)	*[M2.3-4] --- Design of delievrable D2.3-3 (in case of additional resources);*
36	[M2.3-5] --- Design of delievrable D2.3-4;

(*) In case of additional resources (1 Fellow for three years and 250kCHF in total)

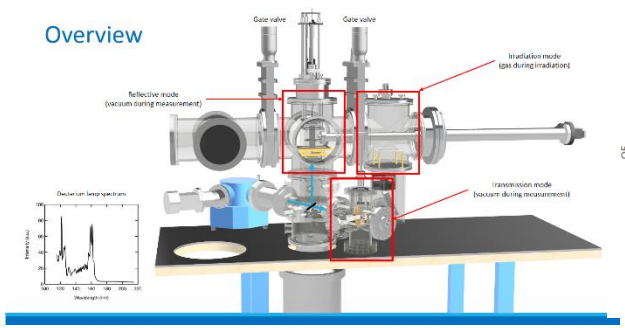
[1]

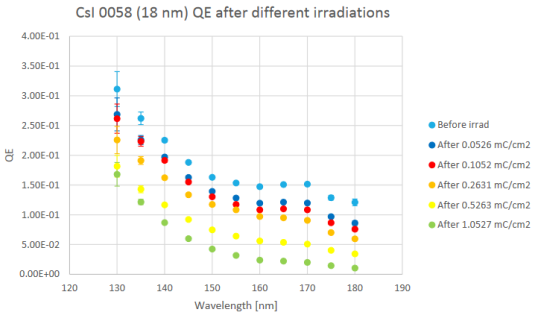
[2]

[3]

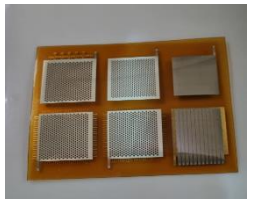
[4]

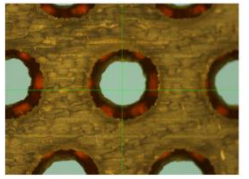
[1] ASSET setup. Ready for Reflective and Transmission mode. Ion bombardment for PC ageing studies in reflective mode. Ref. to Marta's contribution @ RD51 mini week https://indico.cern.ch/event/872501

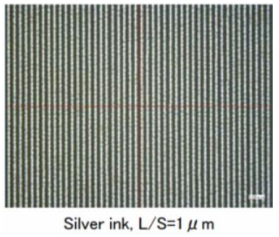




[2] Test ongoing with 3D inkjet printing (Nano Dimension/Israel and Super Inkjet Printer/ Japan).

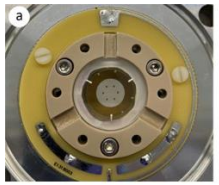


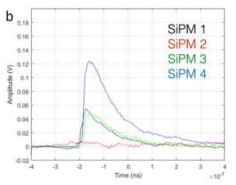




[3] Ongoing activities in optical TPC with various amplification structures, operation at different pressures and with different mixtures, negative ions. In parallel … SiPM Readout.

[4] Budget cut / Closely linked to activities on new materials (synergy with QTI).

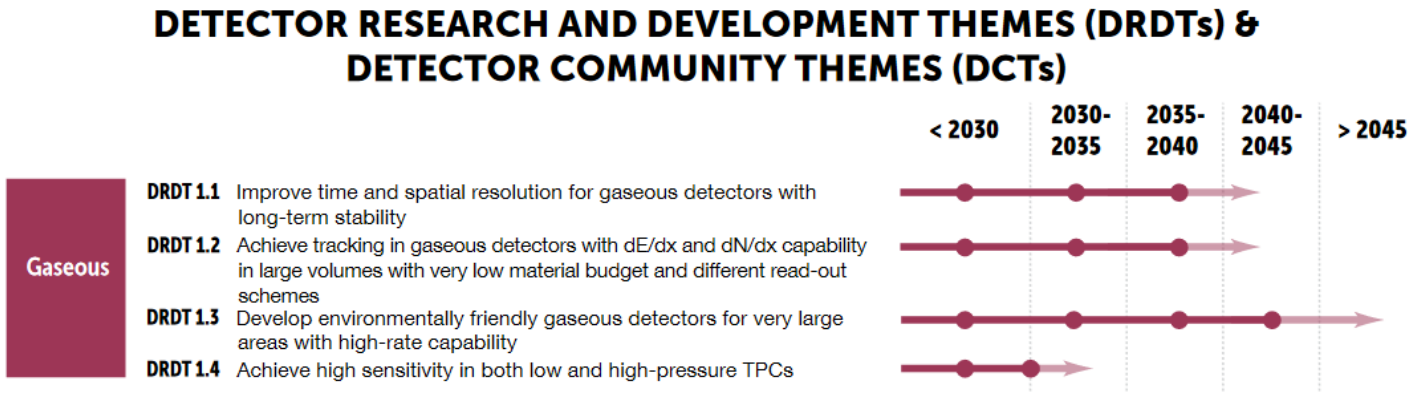




EP R&D

CERN

ECFA ROADMAP



https://cds.cern.ch/record/2784893

Highlighting overlaps…

ECFA
European Committee for Future Accelerators

Roadmap Organisation

ECFA Detector R&D Roadmap Organisational Structure

Restricted ECFA
Regular reports & final document

→ **Plenary ECFA**
Approval of final document

→ Publication

Detector R&D Roadmap Panel

assist ECFA to develop & organise the process and to deliver the document

Coordinators: Phil Allport (chair), Silvia Dalla Torre, Manfred Krammer, Felix Sefkow, Ian Shipsey
assist ECFA to identify technologies & conveners
Ex-officio: ECFA chairs (previous and present), LDG representative
Scientific Secretary: Susanne Kuehn

↔ **Advisory Panel with other disciplines**
e.g. APPEC, NuPECC, LEAPS, LENS, Space, …

TF#1	TF#2	TF#3	TF#4	TF#5	TF#6	TF#7	TF#8	TF#9	…
Gaseous Detectors	Liquid Detectors	Solid State Detectors	Photon Detectors & PID	Quantum & Emerging Technologies	Calorimetry	Electronics & On-detector Processing	Integration	Training	
Anna Colaleo, Leszek Ropelewski	Roxanne Guenette, Jocelyn Monroe	Nicolo' Cartiglia, Giulio Pellegrini	Neville Harnew, Peter Krizan	Marcel Demarteau, Michael Doser	Roberto Ferrari, Roman Poeschl	Dave Newbold, Francois Vasey	Frank Hartmann, Werner Riegler	Johann Collot, Erika Garutti	

Consultation with the particle physics community & other disciplines with technology overlap

https://indico.cern.ch/e/ECFADetectorRDRoadmap

A “small” detail that we should take into account… ☺

Recommendations / Key technologies

… For **MPGDs**, the main challenges remain **large area, high rate, precise timing capabilities** (PICOSEC [Ch1-28], FTM [Ch1-26], [Ch1-27]), and **stable discharge-free operation**. They are addressed by developing **resistive electrodes** and exploring **novel materials, amplifying structures, and detector architectures**. **Precise assembly** at an **industrial** scale and **integration of large area** detector systems are additional items to be faced.

The focus for **RPCs, MRPCs** stays with the improvement of high-rate and precise timing capabilities, uniform detector response, and mechanical compactness. Exploration of novel materials [Ch1-88], [Ch1-89], [Ch1-90], [Ch1-91] and readout patterns, development of low noise electronics [Ch1-92], [Ch1-93], **optimisation of gas mixtures**, including **eco-friendly** ones, and mechanical designs [Ch1-94] are the main future R&D lines.

Requirements for straw tubes include extended length and smaller diameter, low material budget, and operation in a highly challenging radiation environment. Primary efforts will focus on ultra-thin wall development, long and thin wire handling, precise mechanics, innovative designs, and over-pressure for vacuum operation. **Additionally classical ageing issues should not be neglected.**

Large volume drift chamber operation with a reduced material budget in a high-rate environment requires searches for new wire materials and wiring procedures to increase the detector granularity and optimisation of gas mixtures to mitigate classical ageing effects. **The application of cluster counting techniques, one of the motivation behind the future adoption of this approach, requires the development of dedicated electronics.**

IBF remains the main challenge for TPC applications in future facilities. The goal is to minimise IBF while reserving good energy and spatial resolution, uniformity of response, stable operation, and low material budget. Exploration of **novel readout sensor architectures** and amplifying elements, including hybrid solutions with pixel **ASICs** (e.g. GridPix), are the main directions in this domain.

IBF minimisation is also one of the recipes to extend the **photocathode** lifetime in gaseous photodetectors in RICH and **PICOSEC**, with a similar approach to the described above and an additional challenge of **high gain stable operation**. An alternative solution is the development of **robust photocathodes** by exploration of novel materials and **photo converter protection**. The development of **dedicated low noise electronics** coping with high input capacitance and large dynamic range requirements are also essential in the future.

TPCs for rare event searches represent a specific class of applications probing fundamental physics with the properties of the gas molecules used for ionisation, charge transfer and amplification, or light emission. Those applications have additional requirements like radio-purity and ultra low noise electronics. In addition, they explore core topics in detector physics, i.e**. different amplifying structure designs for high/low-pressure stable operation**, **ions as charge carriers** to mitigate charge diffusion or gas electroluminescence for **optical readout**, with potential for many novel applications…

Recommendations / Common Challenges

- **Gas Mixture Optimization**
- **Large system**
- **Ageing**
- **FE electronics**
- **Alternative readout (optical, pixels)**

Orange = Not (or not yet) directly covered

Recommendations / R&D environment and development tools

- **Knowledge Sharing and dissemination**
- **Infrastructures**
- **Electronics**
- **Modelling and Simulation**

"Cooperation"

- **Production**
- **Technology Transfer**
- **Applications of scientific, social and industrial interest**

Roadmap Implementation…

Impact on RD51 (as for RD50) … RD51 5-years term ending next year…
Discussion planned this week (RD50 & RD51) with panel…

A few (not all) aspects to address (RD51)...

- Considered as a successful collaboration… should not be unintentionally spoiled but preserved and improved
- Transition time …to implement a proper bottom-up approach
- Size (gaseous detector community very large/diversified):
  - preserving focus and a deep-in-technology confrontation…
  - preserving flexibility and dynamism required by R&D…
- Wide spectrum of applications…beyond HEP…
- International… several non EU members (reviewing and resources)…
- Review process.. as light as reasonably possible to avoid overload on core teams

From our (CERN team) perspective: understanding the role of CERN team (core, nucleus) and evaluate resources … experience of RD51/White Paper with direct and crucial support to backing the collaboration (common tools/facilities/infrastructures)..EP-RD more “cooperation” …

Full alignment with ECFA Detector R&D Roadmap and its recommendation…
Need of granting a continuity on R&D funding for all collaborators well recognized and shared
Positive attitude if bottom-up process

Beyond 2024

Large Area MPGD (key technologies/ECFA)

- Precise timing and PICOSEC micromegas: Toward a different phase / project driven tough some basic/generic R&D still to be done (PC, resistive, electronics)…
- DLC machine @ MPT: Good opportunity in the context of MPGD with resistive elements (and potentially on alternative photocathodes…)

R&D framework and tools (common challenges and R&D environment/ECFA)

- Gas (mixtures, ageing and outgassing…), Modelling and simulation (amplification, induction and rate, discharges..), electronics (new FE ASICs, discrete,…) …

New Technologies…(key technologies, common challenges and development tools/ECFA)

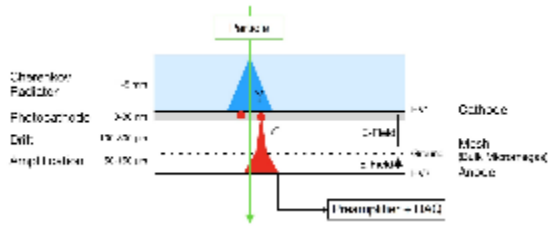
- Conversion layers/new materials.. research line with high potential in different applications…
- Novel manufacturing techniques… still not there but to be constantly explored/monitored…
- Highly pixelated readout (both charge and photon)…

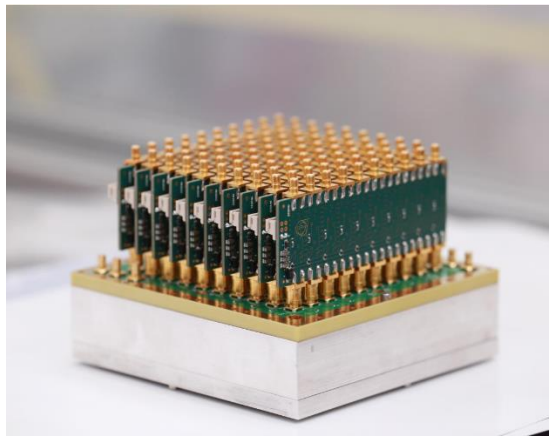
…

Continuity and research path opportunities for young team experts… (beneficial for CERN at first…)

Today

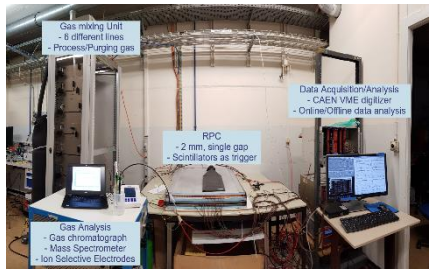
PICOSEC multipad micromegas (**Antonija**)

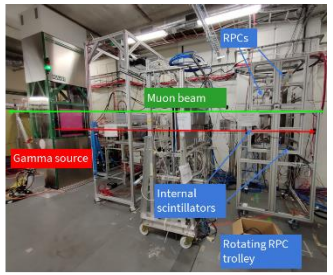


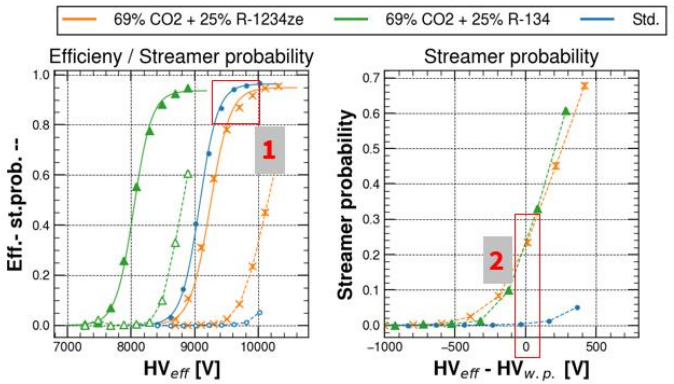


100 channels, 100cm2, fully equipped and readable...

Studies on the performance of RPCs operated with R-1234ze gas mixtures (**Gianluca**)



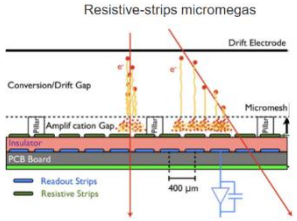


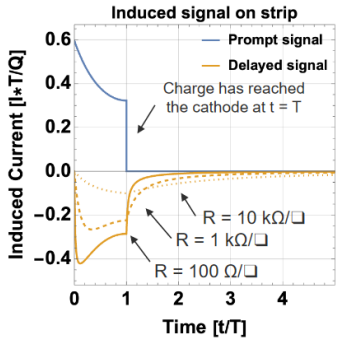


Laboratory and GIF++ studies.. for existing detectors

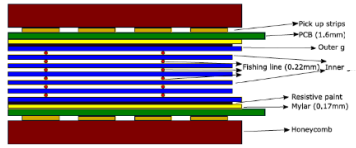
Signal formation in detectors with resistive elements (**Djunes**)

MPGD (micromegas)



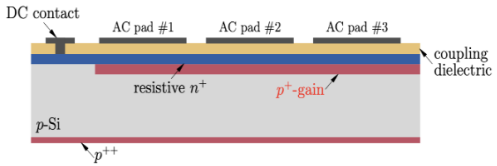


RPC



Garfield++/COMSOL

LGAD



Diamond