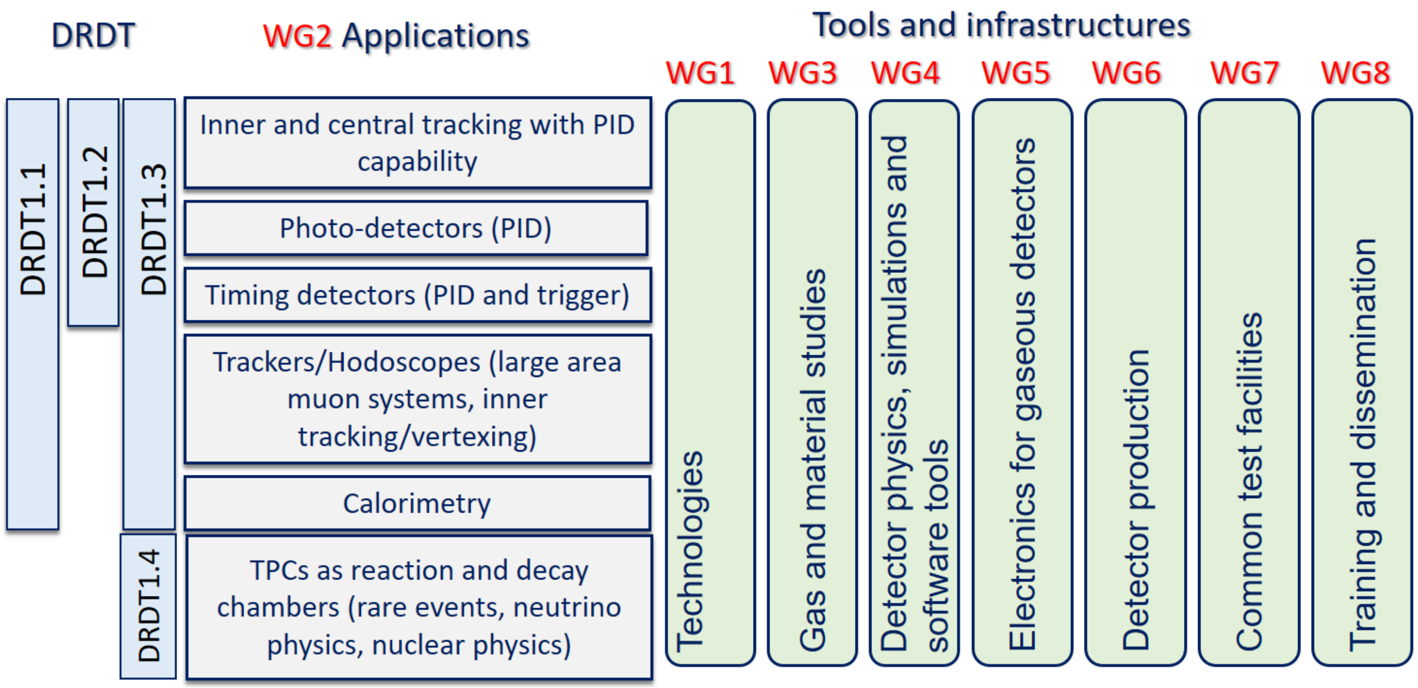
Calorimetry and Timing with Gaseous detectors in DRD1

I. Laktineh

DRD1 Scientific organization: Working groups

- **Structure in Working Groups, forum for scientific discussions, coordinated by conveners:**
  - aligned with the scientific program of the ECFA roadmap through the applications related to future facilities challenges, outlined by R&D Themes (DRDTs*), but also to the GSRs

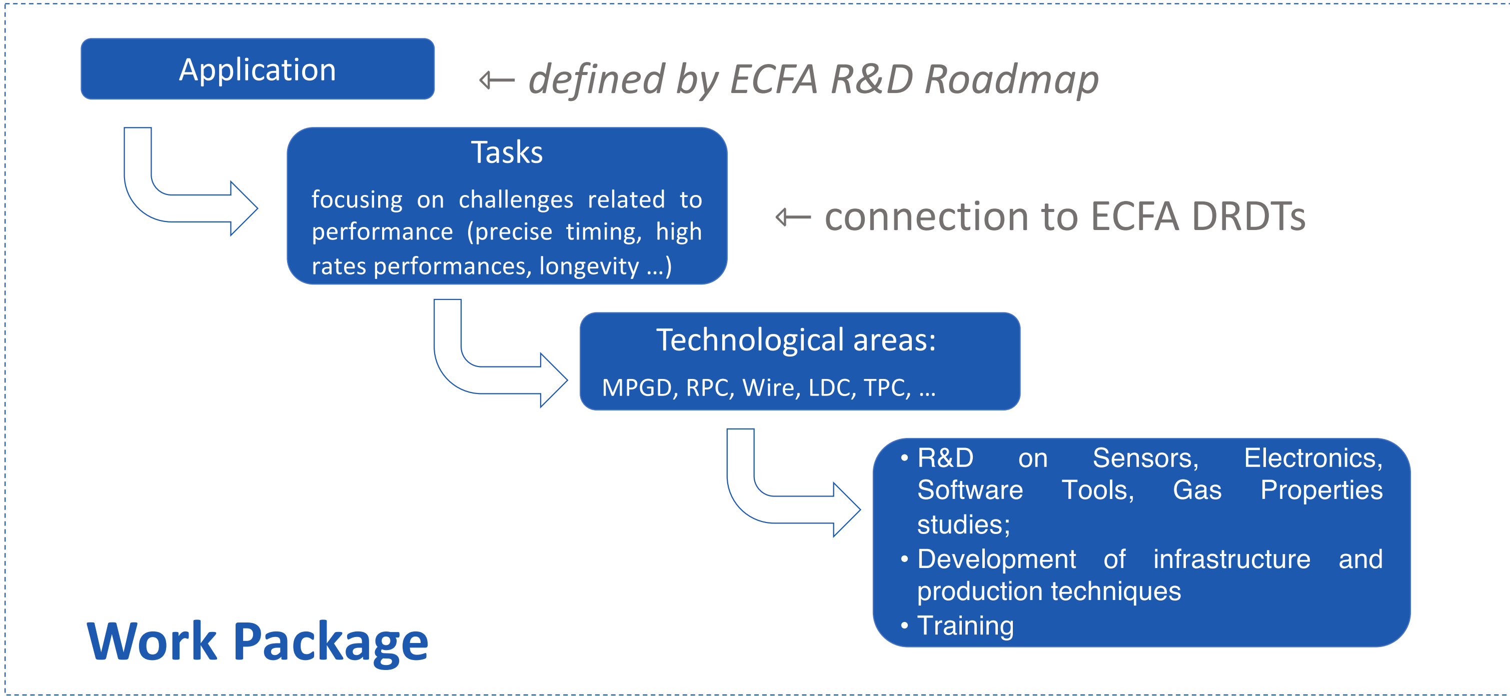


DRD1, DRD4 and DRD6 were the first to be approved by DRDC ion 6th of December 2023

Strategic R&D = Work Package

Strategic R&Ds (according to ECFA Detector R&D Roadmap) **organized in Work Packages**

- group activities of the Institutes with **shared research interests** around **Applications** with a focus on a **specific task(s)** devoted to a specific DRDT challenge, typically related to specific **Detector Technologies** and to the development of **specific tool or infrastructure**



WP

WP1
(Trackers)
- Atsuhiko Ochi
- Gabriella Pugliese
- Giulio Aielli
- Mauro Iodice
- Riccardo Farinelli

WP2
(Drift chambers)
- Francesco Grancagnolo

WP3
(Straw tubes)
- Peter Wintz

WP4
(Tracking TPCs)
- Diego Gonzalez Diaz
- Esther Ferrer Ribas
- Francisco Ignacio Garcia Fuentes
- Jochen Kaminski
- Piotr Gasik

WP5
(**Calorimeters**)
- Imad Laktineh

WP6
(Photodetectors)
- Fulvio Tessarotto
- Florian Brunbauer
- Piotr Gasik

WP7
(**Timing**)
- Diego Gonzalez Diaz
- Florian Brunbauer
- Imad Laktineh
- Ingo Deppner

WP8
(Reaction/Decay TPCs)
- Diego Gonzalez Diaz
- Esther Ferrer Ribas
- Francisco Ignacio Garcia Fuentes
- Jochen Kaminski
- Piotr Gasik

WP9
(Beyond HEP)
- Jona Bortfeldt
- Gabriele Croci
- Dezso Varga

WP5

Innovative gaseous detectors for calorimetry

- To develop precise gaseous detectors as active media for future calorimeters
- Several technologies are of interest : (M)RPC, MPGD
- The boundaries with DRD6 are well defined

WP5

#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Milestones/Deliverable			Institutes
					12M	24M	36M	
T1	Conception, construction and characterization of large sampling elements for calorimeters	- High efficiency with thin large detectors - Compactness of the active unit including cassettes and possible cooling system - Uniformity in terms of thickness, resistivity and gas circulation	WG1, WG2, WG4, WG7	1.1, 1.3	**M1.1** Construction of medium-sized gaseous detector fulfilling the requirements on efficiency and small dead zones [T1].	**M2.1** Uniformity study including efficiency and cluster size distribution with medium-size detectors. Expected timing performance better than 3 ns in the case of MPGD, 0.7 ns for RPC and 0.15 ns for MRPC with 4 gaps [T2]. **M2.2** Construction of large and thin (few mm) detectors of different technologies (MRPC, RPC, MM, µRWELL, RPWELL) with small dead zones ($<$ 2% dead zone). We propose to build detectors larger than 50 cm $\times$ 50 cm in the case of MPGD and larger than 100 cm $\times$ 100 cm for (M)RPC, featuring dead zones $<$ 2%. The detectors should feature an efficient gas circulation to be used as active layers in granular calorimeters [T1].	**D1.1** **Performance and uniformity** studies of the large and thin detectors of different technologies. Performance goals in terms of: - detector uniformity: $<$ 10% in terms of efficiency an in terms of cluster size [T1], - time resolution below few ns [T2], - high detection rate capabilities up to a few kHz/cm^2 [T4], to be obtained with different kinds of gas mixtures. **D1.2** **The readout electronics** [T3] associated with pickup pads of the order of 1 cm^2: - threshold down to a few fC for MPGD and tens of fC for (M)RPC - time resolution better than 100 ps	IP2I, CIEMAT, VUB and UGent, GWNU, SJTU, MPP, WIS, INFN-BA, UniBA, PoliBA, INFN-RM3, INFN-NA
T2	Timing performance of gaseous detectors for calorimeters	- Timing performance of different technologies - Uniformity of the detector response in terms of timing						
T3	Readout electronics for calorimeter gaseous detectors	- Low-jitters readout electronics - Low power consumption per channel - Active Sensitive Unit (ASU) of large size with good flatness						
T4	High-rate capability gaseous detectors for circular collider calorimeters	- High-rate capability exceeding a few KHz in case of (M)RPC and tens of KHz in case of MPGD - Impact of high particle rate on the detector performance (efficiency, spatial resolution, timing..etc)						

Uniformity, efficiency, high-rate and timing

WP5

- **How the WP covers the topics in the ECFA roadmap**

DRDTs

- ❖ DRDT 1.1 - Precise timing detectors with rate capability, spatial resolution.
- ❖ DRDT 1.3 – Study eco-friendly solutions for gaseous timing detector

Challenges

-Realization of thin and large surface detectors with high efficiency, excellent uniformity and high-rate capabilities operated with eco-friendly gases

- Very good time resolution

-Embedded readout electronics

Goals

To provide high granular hadronic calorimeters with active media made of gaseous detectors to efficiently apply the PFA techniques and at the same time provide good energy resolution

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WP5

Strategy: One project associating different technologies

Two Deliverables

D1.1- Performance and uniformity study of **large detectors built** with different technologies ((M)RPC, MPGD) : **Uniformity** (efficiency&cluster size), **high rate, time** resolution.

D1.2 – Production of panels equipped **with low-noise, low time-jitter readout electronics** to read out large detectors of different technologies in collaboration with **DRD6**

Two milestones

M1.1 : Performance and uniformity study with prototypes of medium size

M1.2: Conception and construction of large surface detectors

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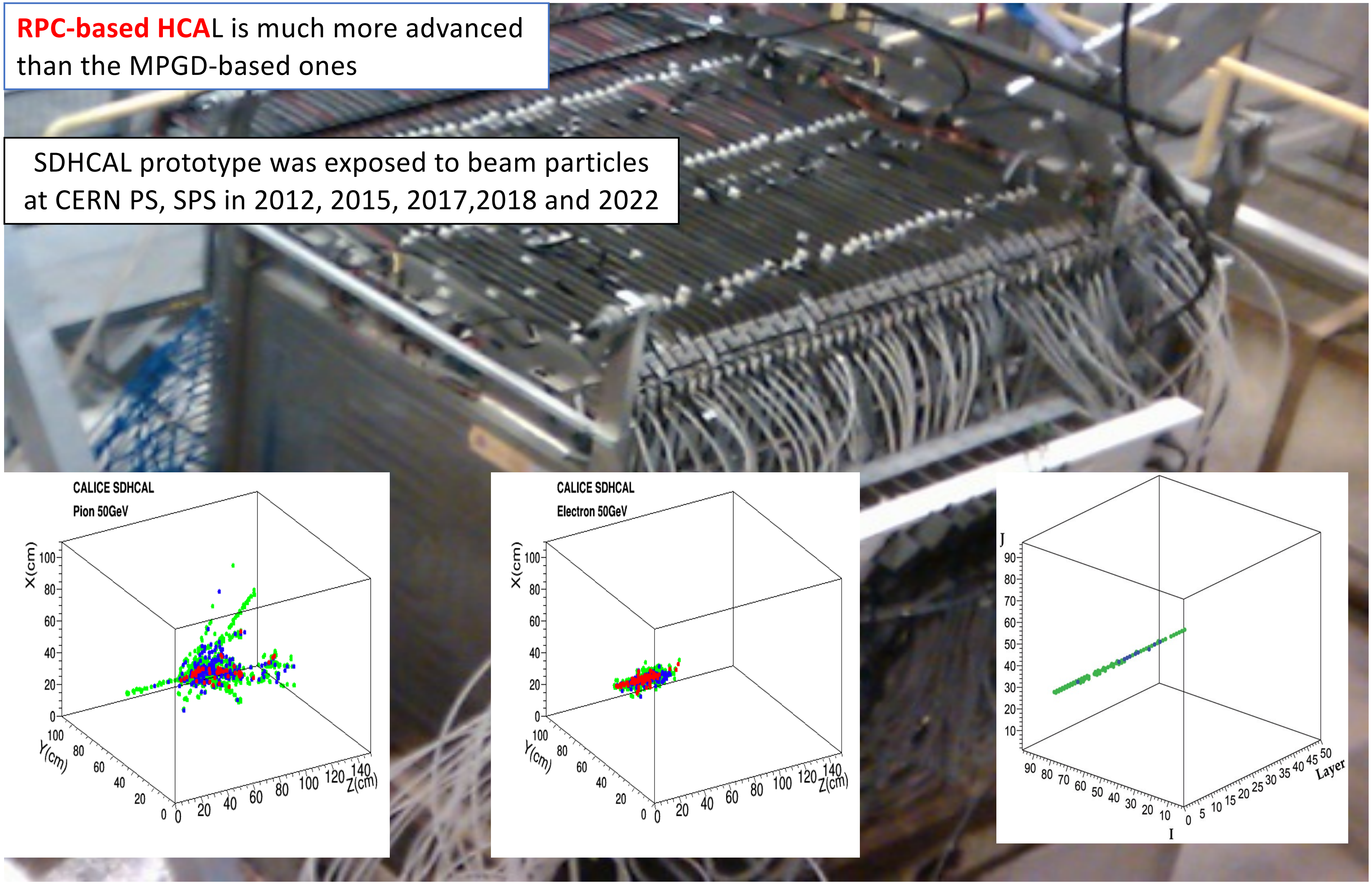
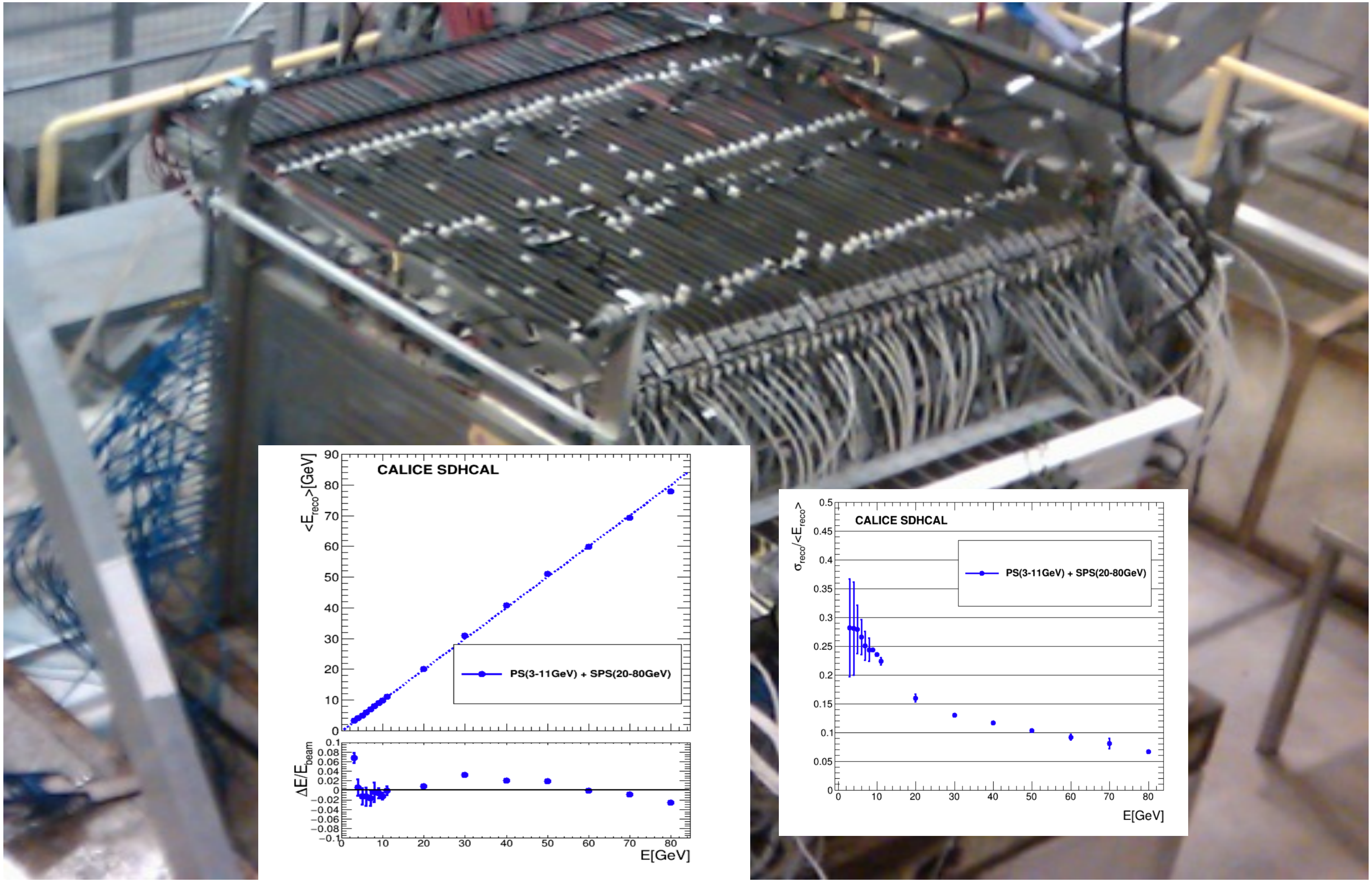
WP5

- ***Institutes***
  - → 10 institutes from 8 countries
  - → Most of all are also involved in DRD6 (calorimetry)
  - → Most of them have already worked together on a given technology but in this proposal common studies will be an essential feature

- ➢ Institut de la physique des 2 infinis (IP2I)
- ➢ Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)
- ➢ Vrije Universiteit Brussel (VUB)
- ➢ Gangneung-Wonju National University (GWNU)
- ➢ Shanghai Jiao Tong University (SJTU)
- ➢ Max-Planck Institute for Physics (MPP)
- ➢ Weizmann Institute of Science (WIS)
- ➢ Bari INFN & University (INFN-ba)
- ➢ ROME3 University (ROME3)
- ➢ Naples INFN (INFN-Na)


RPC-based HCAL is much more advanced than the MPGD-based ones
SDHCAL prototype was exposed to beam particles at CERN PS, SPS in 2012, 2015, 2017,2018 and 2022
CALICE SDHCAL
Pion 50GeV
X(cm)
Y(cm)
Z(cm)
CALICE SDHCAL
Electron 50GeV
X(cm)
Y(cm)
Z(cm)
J
I
Layer

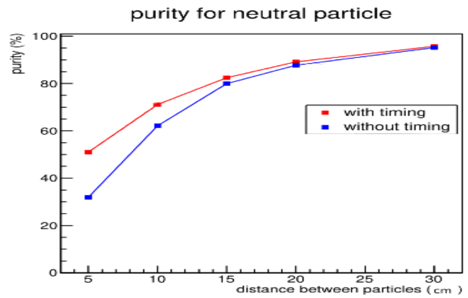


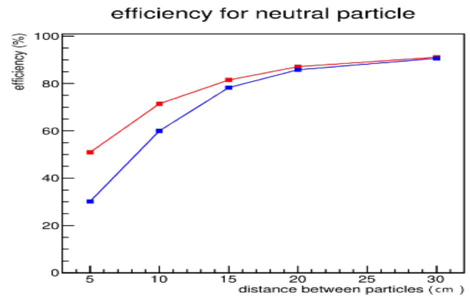
CALICE SDHCAL
<E_reco>[GeV]
PS(3-11GeV) + SPS(20-80GeV)
ΔE/E_beam
E[GeV]
CALICE SDHCAL
σ_reco/<E_reco>
PS(3-11GeV) + SPS(20-80GeV)
E[GeV]

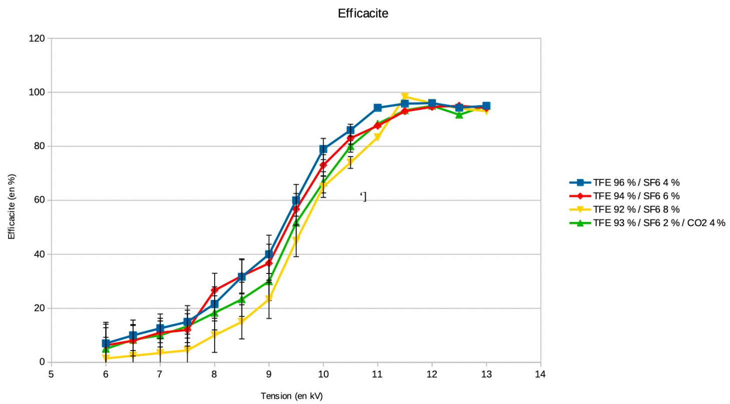
RPC-based SDHCAL→ (M)RPC-based HCAL

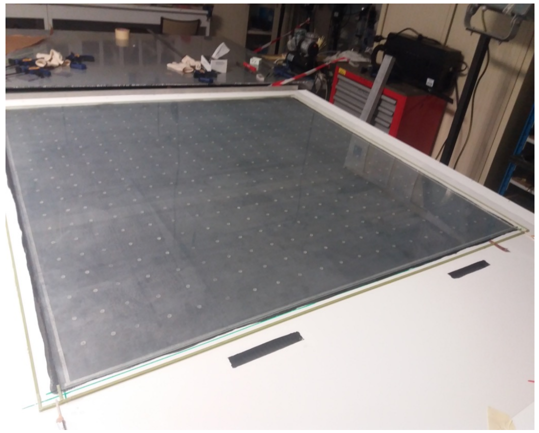
- Better time resolution leading to better PFA performance with better energy and PID

- Higher rate capabilities (less charge) and possibility to have low resistivity glass plates





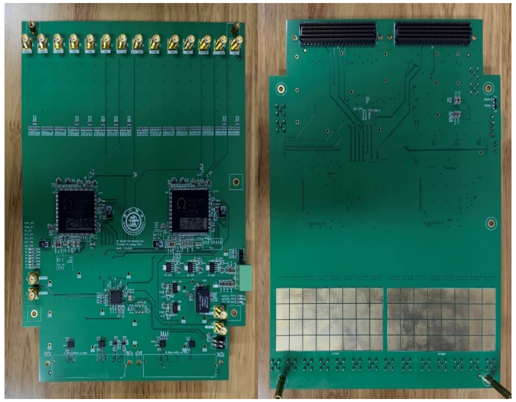


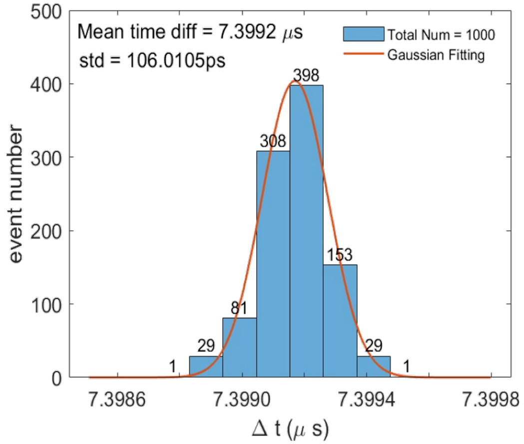


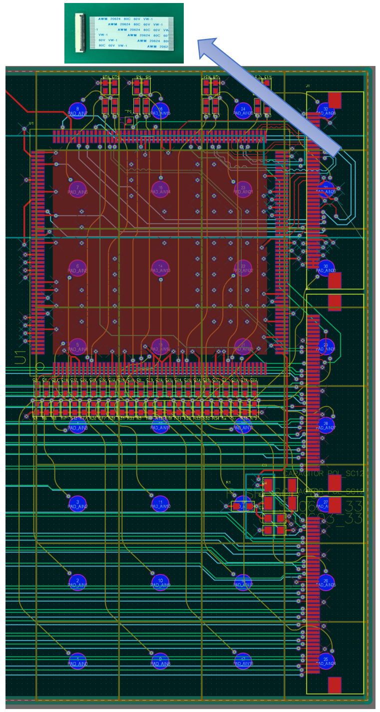
Electronics:

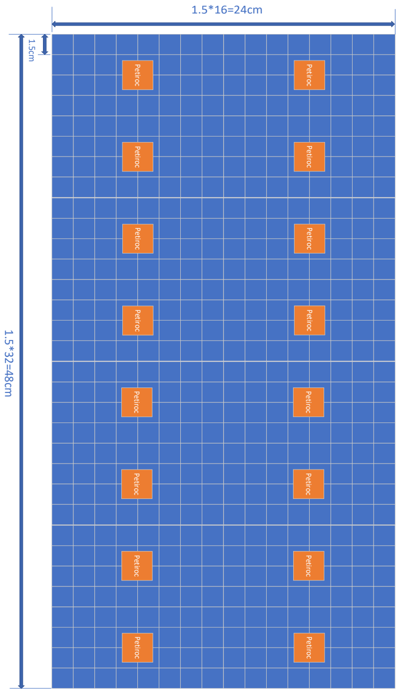
We need new electronics to read out (M)RPC and exploit the timing performance.

PETIROC was proposed for iRPC@CMS. Excellent performances are obtained with doublet RPC using pickup strips
→ A good candidate to start with







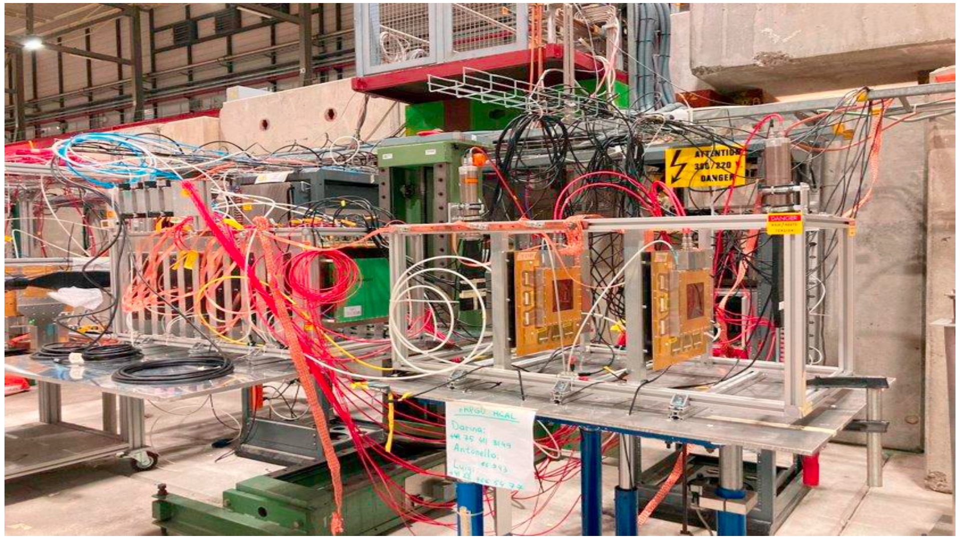


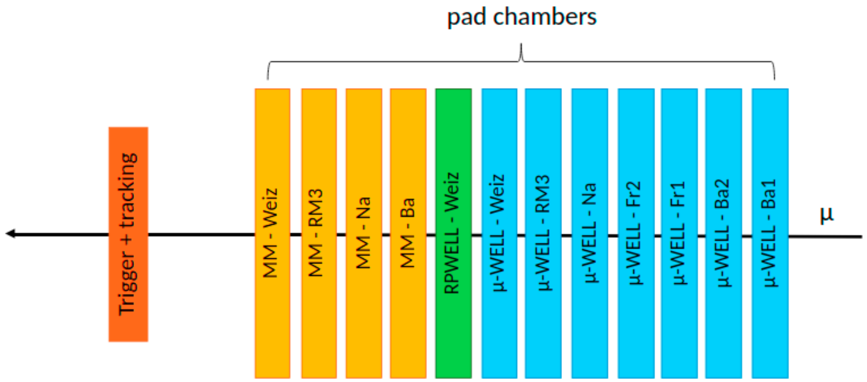
The problem with PETIROC TDC is the deadtime (12.5 µs)
Within DRD6 a new ASIC (CALOROC) will be developed and a variant adapted to MRPC readout

MPGD-based SDHCAL

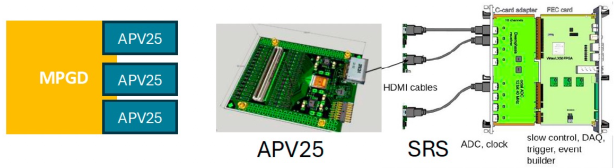
The activities started in 2012 with the DHCAL-ANR where in addition to the 48 RPC chambers, 4 large MICROMEGAS conceived by LAPP and equipped with similar electronics were inserted in the SDHCAL prototype.

Groups from Italy and Israel have started similar activities including other MPGD technologies such that MICROMEGAS, µWELL and RPwell

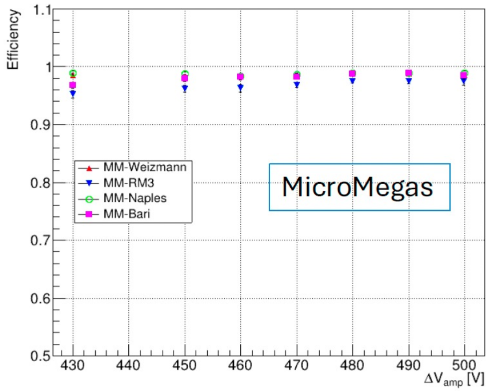


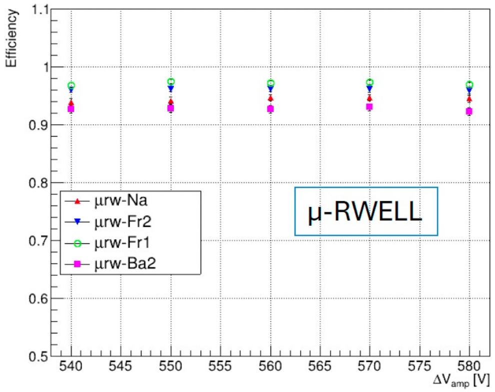


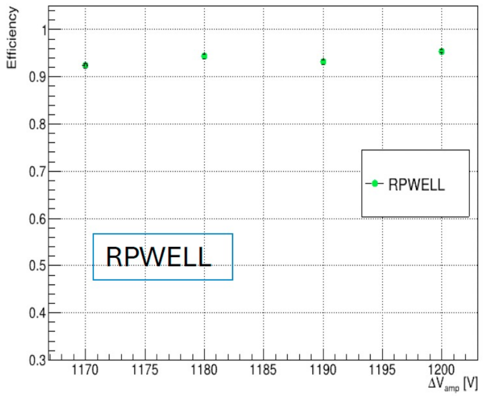
- detector size: 20x20 cm2
- ~6 mm drift gap
- Common readout board: 1x1cm2 pad→ 384 pads



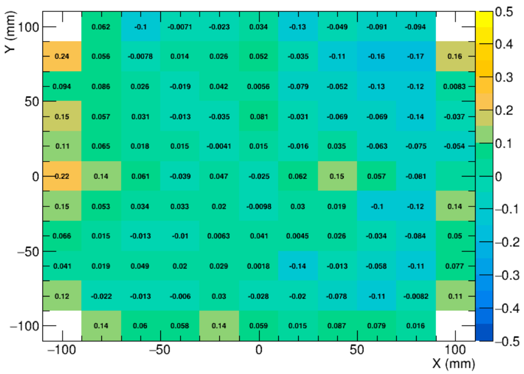
Good efficiency for all technologies

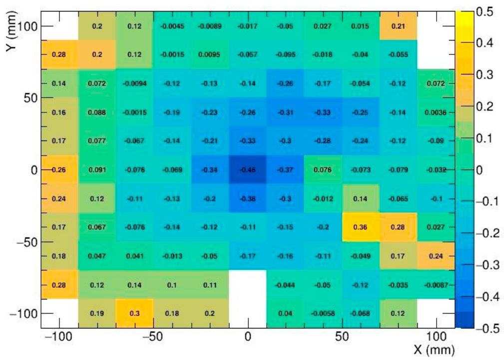




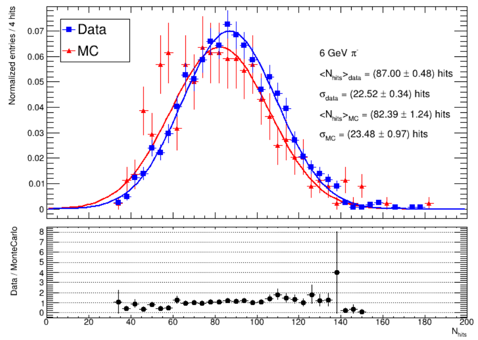


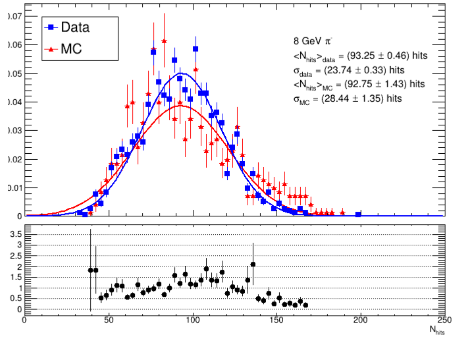
Uniformity is better for µMegas than for the µwell and Rpwell. Some X-talk issues….





First results at PS





WP7

The role of detectors featuring timing capability will become crucial in the future experiments in High Energy Physics (HEP) field as well as in nuclear and hadronic physics. In many of these future experiments the **time information will play a major role** in studying the interaction of particles in more precise way by providing 4D information. Their role has recently been **emphasized in the LHC upgrade** towards high luminosity where high interaction rate created by the pileup at the interaction point configurations can only be mitigated by a precise time information.

The long-term plans of this projects aims to match the requirements highlighted in the 2021 ECFA detector research and development roadmap. The relevant parts in terms of facilities requirements and recommendation are reported here. The proposed activities are covering the Detector Research and Development Themes **DRDT 1.1 (Improve time and spatial resolution for gaseous detectors with long-term stability)** and **DRDT 1.3 (Develop environmentally friendly gaseous detectors for very large areas with high-rate capability)**.

Two technology specific projects •
WP7 Project A - High-rate, high-granularity precise timing with MPGDs •
WP7 Project B - High-rate, large, precise timing RPC/MRPC
• 9 institutes participating in MPGD activities
• 21 institutes participating in RPC/MRPC activities

WP7

#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Milestones/Deliverable			Institutes
					12M	24M	36M	
T1	Optimize the amplification technology towards large-area detectors	- Uniformity over m^2 (time resolution, rate capability, efficiency)	WG1, WG2, WG3, WG4, WG5, WG6, WG7	1.1, 1.3	**M1.1** **Prototypes review** (proof of concept, enhancing time resolution, active area of about 100 cm^2): status and perspectives. **[T1, T2, T5, T10]** **M1.2** **Common activities and material studies**: Support and development of modelling and simulation (time resolution, rate capabilities) tools and testing facilities (time resolution, rate capability, space resolution, gas and material studies). **[T3, T4, T6, T7, T8, T11]**	**M2.1** **Prototypes suitable for large area coverage systems** review: status and perspectives. **[T1, T3, T10]** **M2.2** **Multichannel readout electronics**: evaluation (on small prototypes, 100 cm^2 active area) of different multichannel readout solutions. **[T9]**	**D** **Prototypes with time resolution below 200 ps based on RPC/MRPC and MPGD technologies**: demonstrate the scalability of the technologies targeting m^2 size coverage. Prototypes will be characterized in terms of time resolution, rate capability, space resolution, efficiency and multi-hit response. Different examples of multichannel readout electronics will be provided. **[T1, T3, T4, T5, T9, T10]** **Guidelines for future developments**: At the end of the three years, development directions will be summarized based on future facilities' requirements and the achievable performances of the studied solutions. Status and strategies towards the use of sustainable gas mixtures will be given. **[T7]**	AUTH , CERN, CIEMAT, CNRS-IN2P3/Omega, DGIST, GWNU, HYU, HIP, INFN-BA, UniBA, PoliBA, INFN-PV, UniPV, UniBG, INFN-RM2, UniRomaTOV, IRFU/CEA, IP2I, JLab, LIP-Coimbra, MPP, RBI, SIAT, SJTU, U Heidelberg, U Kyoto, U Tsinghua, USTC, VUB and UGent
T2	Enhance timing performance	- Time resolution $<$ 50 ps up to 30 kHz/cm^2						
T3	Enhance rate capability	- Time resolution $<$ 200 ps up to 100-150 kHz/cm^2						
T4	Spatial resolution and readout granularity	- Spatial resolution of mm with low number of readout channels						
T5	Stability, robustness and longevity	- IBF $<1\%$ with <100 ps time resolution for single photoelectrons - Stable, high-gain operation						
T6	Material studies	- Radiation-hardness - Longevity						
T7	Gas studies for precise timing applications	- Eco-friendly mixtures - Recuperation - Ageing mitigation - CO_2-based mixture with geometrical quenching						
T8	Modelling and simulation of timing detectors	- Accurate modelling of charge transport and signal induction processes in precise timing detector geometries						
T9	Readout electronics for precise timing	- Low-noise FEE – High input capacitance – Large dynamic range – Fast rise time – Sensitivity to small charges - Multi-channel readout solution for timing detectors						
T10	Precision mechanics and construction techniques	- Precise mechanics (μm) over relatively large active areas (hundreds of cm^2)						
T11	Common framework and test facilities for precise timing R&D	- Test bench for precise timing studies						

Timing , readout electronics, high-rate with eco-friendly gases

WP7

- **How the WP covers the topics in the ECFA roadmap**
  - DRDTs:
    - DRDT 1.1 - Precise timing detectors with rate capability, spatial resolution.
    - DRDT 1.3 – Study eco-friendly solutions for gaseous timing detector
  - Challenges
    - Eco-friendly gases: decreasing availability, increasing cost of GH gases
    - Detector ageing: operational instabilities/ageing in harsh environments,
    - Front end electronics: timing performance, low power, robustness
  - Goals
    - Development of scalable precise timing detector with operational stability and long term robustness
    - High-rate capability and spatial resolution with suitable FE electronics for the required readout granularity

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T9	Readout electronics for precise timing	- Low-noise FEE – High input capacitance – Large dynamic range – Fast rise time – Sensitivity to small charges - Multi-channel readout solution for timing detectors						
T10	Precision mechanics and construction techniques	- Precise mechanics (μm) over relatively large active areas (hundreds of cm^2)						
T11	Common framework and test facilities for precise timing R&D	- Test bench for precise timing studies						

WP7

- **Two projects based on different technologies:**
  - Project A - High-rate, high-granularity precise timing with MPGDs
  - Project B - High-rate, large, precise timing (M)RPC
- **Deliverables in WP7**

Project A:

- D A.1 Large area detector modules with scalable readout chain
- D A.2 Precise timing detector prototype with improved spatial resolution
- D A.3 Robust detector prototype and photocathodes for long-term operation
- D A.4 Scalable readout chain maintaining high time resolution
- D A.5 Calorimeter embedded precision timing-tracking
- D. A.6 Evaluation of techniques for minimising material budget
- D A.7 Improved simulation model of PICOSEC precise timing detector
- D A.8 Comparison and optimisation of timing performance of ecofriendly gas mixtures

Project B:

- D B.1: Production and comparison of full large (> 1 m2) MRPC built with different techniques
- D B.2: Production of large PCB equipped with precise timing electronics
- D B.3: Production of a stable single cell MRPC with very high-rate and timing capability
- D B.4: Construction of large-area double-gap RPC with a time resolution better than 200ps
- D B.5: Timing and spatial resolution studies versus different gas mixtures

#	Task	Performance Goal	DRD1 WGs	ECFA DRDT
T1	Optimize the amplification technology towards large-area detectors	- Uniformity over m^2 (time resolution, rate capability, efficiency)	WG1, WG2, WG3, WG4, WG5, WG6, WG7	1.1, 1.3
T2	Enhance timing performance	- Time resolution < 50 ps up to 30 kHz/cm^2		
T3	Enhance rate capability	- Time resolution < 200 ps up to 100-150 kHz/cm^2		
T4	Spatial resolution and readout granularity	- Spatial resolution of mm with low number of readout channels		
T5	Stability, robustness and longevity	- IBF <1% with <100 ps time resolution for single photoelectrons - Stable, high-gain operation		
T6	Material studies	- Radiation-hardness - Longevity		
T7	Gas studies for precise timing applications	- Eco-friendly mixtures - Recuperation - Ageing mitigation - CO_2-based mixture with geometrical quenching		
T8	Modelling and simulation of timing detectors	- Accurate modelling of charge transport and signal induction processes in precise timing detector geometries		
T9	Readout electronics for precise timing	- Low-noise FEE – High input capacitance – Large dynamic range – Fast rise time – Sensitivity to small charges - Multi-channel readout solution for timing detectors		
T10	Precision mechanics and construction techniques	- Precise mechanics (μm) over relatively large active areas (hundreds of cm^2)		
T11	Common framework and test facilities for precise timing R&D	- Test bench for precise timing studies		

Milestones/Deliverable 12M	Milestones/Deliverable 24M	Milestones/Deliverable 36M	Institutes
M1 **Prototypes review** (proof of concept, enhancing time resolution, active area of about 100 cm^2): status and perspectives. [T1, T2, T5, T10] **Common activities and material studies**: Support and development of modelling and simulation (time resolution, rate capabilities) tools and testing facilities (time resolution, rate capability, space resolution, gas and material studies). [T3, T4, T6, T7, T8, T11]	**M2** **Prototypes suitable for large area coverage systems** review: status and perspectives. [T1, T3, T10] **Multichannel readout electronics**: Evaluation (on small prototypes, 100 cm^2 active area) of different multichannel readout solutions. [T9]	**D** **Prototypes with time resolution below 100ps based on RPC/MRPC and MPGD technologies**: demonstrate the scalability of the technologies targeting m^2 size coverage. Prototypes will be characterized in terms of time resolution, rate capability, space resolution, efficiency and multi-hit response. Different examples of multichannel readout electronics will be provided. [T1, T3, T4, T5, T9, T10] At the end of the three years, guidelines for future developments will be summarized based on future facilities' requirements and the achievable performances of the studied solutions. Status and strategies towards the use of sustainable gas mixtures will be given. [T7]	AUTH , CERN, CIEMAT, CNRS-IN2P3/Omega, DGIST, GWNU, HYU, HIP, INFN-BA, UniBA, PoliBA, INFN-PV, UniPV, UniBG, INFN-RM2, UniRomaTOV, IRFU/CEA, IP2I, JLab, LIP-Coimbra, MPP, RBI, SIAT, SJTU, U Heidelberg, U Kyoto, U Tsinghua, USTC, VUB and UGent

WP7-B

Timing Detectors- B

High-rate, large, precise timing (M)RPC

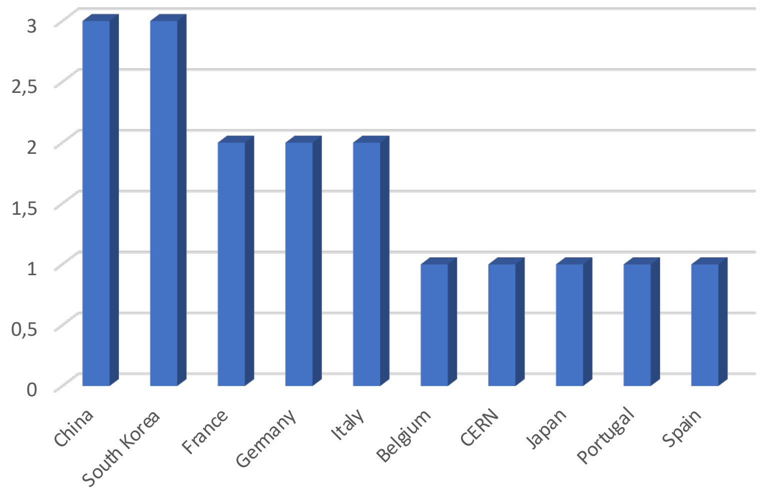
(M)RPC are still the reference in time resolution when large detectors are needed

- Trigg, ToF, PFA-based Calorimetry
- Some applications need few hundreds of ps resolution other a few tens of ps

WP7-B

17 institutes from 3 continents with expertise in RPCs/MRPCs and its readout electronics

- Institut de la physique des 2 infinis de Lyon (IP2I)
- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)
- Vrije Universiteit Brussel (VUB)
- Gangneung-Wonju National University (GWNU)
- Shanghai Jiao Tong University (SJTU)
- Organisation de Micro-Électronique Générale Avancée (OMEGA)
- Physikalisches Institut, Heidelberg University (HDU)
- Kyoto University (KU)
- Laboratório de Instrumentação e Física Experimental de Partículas (LIP)
- Tsinghua University (TSU)
- Shenzhen Institute of Advanced Technology (SIAT)
- Daegu Gyeongbuk Institute of Science and Technology (DGIST)
- Max-Planck Institute for Physics (MPP)
- INFN-BARI
- Roma Ter Vergata
- Hanyang University
- CERN EP-DT gas team



WP7

D B.1: Production and comparison of full large (> 1 m2) MRPC detectors with different techniques (24M).
M B.1: production of small detector O(10 cm) of 4-8 gaps prototypes using different technologies.

D B.2: Production of large PCB of strip and PAD-based pickup configuration equipped with electronics able to reach better than 100 ps time resolution (36 M)

M B.2: Review of the needed electronics components to achieve 100 ps for strips and pad-like and performance comparison between direct and differential readout techniques.

WP7-B

D B.3: Production of a stable single cell MRPC with very high-rate capability (> 50 kHz/cm2) and time resolution better than 100 ps (36M).

M B.3: High-rate tests with small detector prototypes (24M)

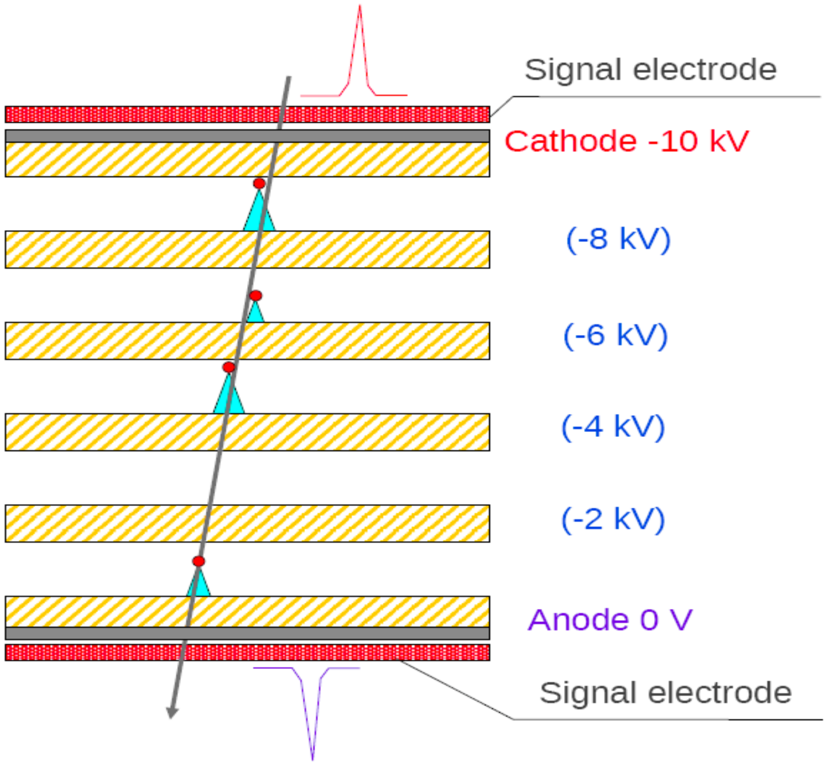
D B.4: Construction of large-area double-gap RPC with a time resolution better than 200 ps (36M).

M B.4: Construction of small prototype (50x50 cm2) reaching 200 ps (24M).

D B.5: Timing and spatial resolution studies versus different gas mixtures (48M).
M B.4: Construction of small prototype (50x50 cm2) reaching 200 ps (24M).

M B.5: preliminary results of timing and spatial resolution with standard gas Mixture (36)

Multigap Resistive Plate Chamber

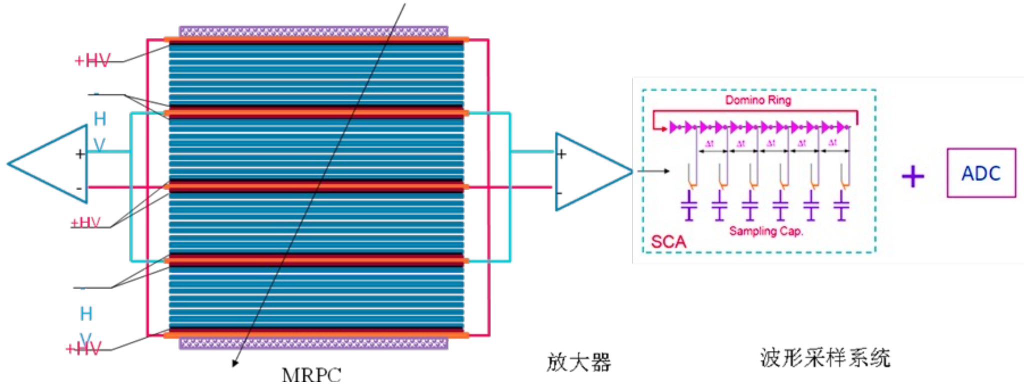


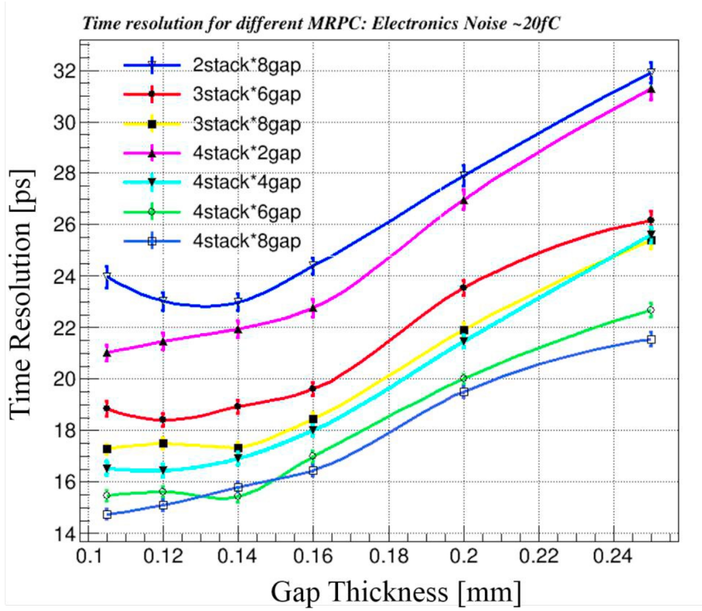
stack of equally-spaced resistive plates with voltage applied to external surfaces (all internal plates electrically floating)

pickup electrodes on external surfaces (resistive plates transparent to fast signal)

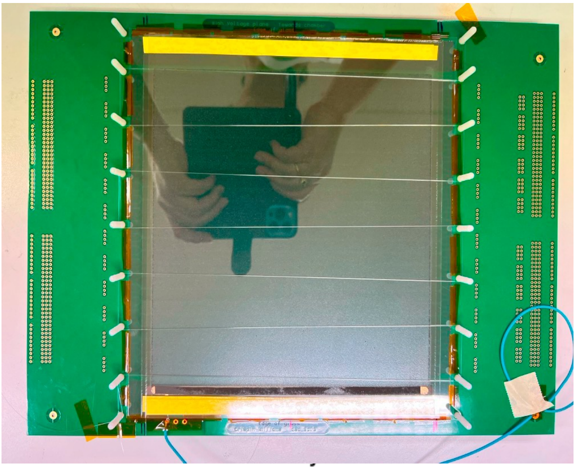
internal plates take correct potential – initially due to electrostatics but kept at correct potential by flow of electrons and positive ions - feedback principle that ensures equal gain in all gas gaps

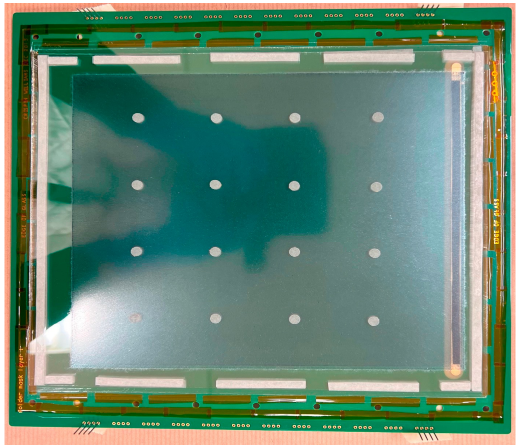
Excellent time resolution could be obtained with many gas gaps

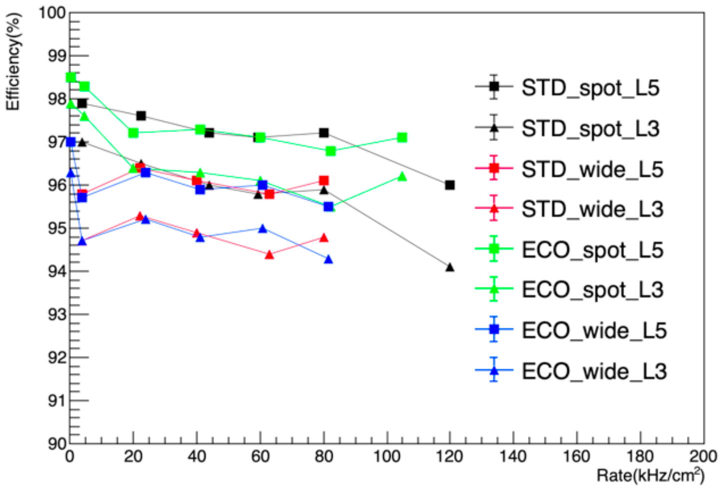


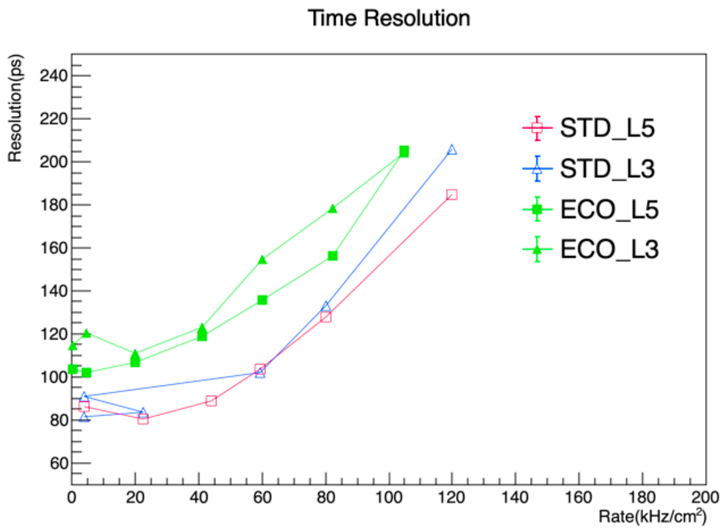


Two technologies and different gas mixtures are being tested









Conclusion

- DRD1 is very robust collaboration that succeeds to gather different technologies ensuring a very smooth passage from RD51
- 8 Working Groups (forums) and 9 WP that include important tasks to prepare the future collider experiments
- WP5 (gaseous detectors for calorimetry) and WP9 (timing gaseous detectors) have started with very promising results
- The WG as WP7 are open to new groups that want to join the adventure