# WP7 Timing

## DRD1 work package project preparation

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DRD1 Collaboration Meeting, Jan/Feb 2024

# WP7 Outline

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
- 17 institutes participating in RPC/MRPC activities

# WP7

Work package table represents well tasks being worked on / considered by institutes

Synergies with all DRD1 WGs

Additional information on DRD1 website: https://drd1.web.cern.ch/wp/wp7

| # | Task | Performance Goal | DRD1 WGs | ECFA DRDT | Milestones/Deliverable 12M | 24M | 36M | Institutes |
|---|---|---|---|---|---|---|---|---|
| T1 | Optimize the amplification technology towards large-area detectors | - Uniformity over $m^2$ (time resolution, rate capability, efficiency) | WG1,<br>WG2,<br>WG3,<br>WG4,<br>WG5,<br>WG6,<br>WG7 | 1.1,<br>1.3 | **M1.1**<br><br>**Prototypes review** (proof of concept, enhancing time resolution, active area of about 100 $cm^2$): status and perspectives. **[T1, T2, T5, T10]**<br><br>**M1.2**<br><br>**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**<br><br>**Prototypes suitable for large area coverage systems** review: status and perspectives. **[T1, T3, T10]**<br><br>**M2.2**<br><br>**Multichannel readout electronics**: evaluation (on small prototypes, 100 $cm^2$ active area) of different multichannel readout solutions. **[T9]** | **D**<br><br>**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]**<br><br>**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 ,<br>CERN,<br>CIEMAT,<br>CNRS-IN2P3/Omega,<br>DGIST,<br>GWNU,<br>HYU,<br>HIP,<br>INFN-BA, UniBA, PoliBA,<br>INFN-PV, UniPV, UniBG,<br>INFN-RM2, UniRomaTOV,<br>IRFU/CEA,<br>IP2I,<br>JLab,<br>LIP-Coimbra,<br>MPP,<br>RBI,<br>SIAT,<br>SJTU,<br>U Heidelberg,<br>U Kyoto,<br>U Tsinghua,<br>USTC,<br>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<br>- Stable, high-gain operation | | | | | | |
| T6 | Material studies | - Radiation-hardness<br>- Longevity | | | | | | |
| T7 | Gas studies for precise timing applications | - Eco-friendly mixtures<br>- Recuperation<br>- Ageing mitigation<br>- $CO_2$-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<br>– High input capacitance<br>– Large dynamic range<br>– Fast rise time<br>– Sensitivity to small charges<br>- Multi-channel readout solution for timing detectors | | | | | | |
| T10 | Precision mechanics and construction techniques | - Precise mechanics ($\mu$m) 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 Tasks

- T1: Optimize the amplification technology towards large-area detectors
- T2: Enhance timing performance
- T3: Enhance rate capability
- T4: Spatial resolution and readout granularity
- T5: Stability, robustness and longevity
- T6: Material studies
- T7: Gas studies for precise timing applications
- T8: Modelling and simulation of timing detectors
- T9: Readout electronics for precise timing
- T10: Precision mechanics and construction techniques
- T11: Common framework and test facilities for precise timing R&D

Tasks addressed by both MPGD and RPC/MRPC projects

# WP7 Overall milestones / deliverables

**12 months**

**M1.1**
Prototypes review (proof of concept, enhancing time resolution, active area of about 100 cm2 ): 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]

**24 months**

**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 cm2 active area) of different multichannel readout solutions.
[T9]

**36 months**

Prototypes with time resolution below 200 ps based on RPC/MRPC and MPGD technologies: demonstrate the scalability of the technologies targeting m2 size coverage. Prototypes will be characterized in terms of time resolution, rate capability, space resolution, efficiency and multi-hit re- sponse. Different examples of mul- tichannel 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]

# WP7 Resources

Overall existing and proposed funding per project, per year

| Summary - Existing resources<br>to be confirmed by funding agencies | | | | | | |
|---|---|---|---|---|---|---|
| **Institute** | **FTE** | | | **Materials (kCHF)** | | |
| | 2024 | 2025 | 2026 | 2024 | 2025 | 2026 |
| Project A: MPGD | 9.9 | 7.5 | 6.5 | 288 | 178 | 178 |
| Project B: RPC/MRPC | 14.2 | 14.2 | 14.2 | 132 | 132 | 132 |
| **Total WP7** | **24.1** | **21.7** | **20.7** | **420** | **310** | **310** |

Table 1: Existing resources per project in WP7.

| Summary - Proposed new resources<br>to be confirmed by funding agencies | | | | | | |
|---|---|---|---|---|---|---|
| **Institute** | **FTE** | | | **Materials (kCHF)** | | |
| | 2024 | 2025 | 2026 | 2024 | 2025 | 2026 |
| Project A: MPGD | 0.5 | 3 | 4.4 | 40 | 90 | 130 |
| Project B: RPC/MRPC | 2.5 | 2.5 | 2.5 | 217 | 217 | 216 |
| **Total WP7** | **3** | **5.5** | **6.9** | **257** | **307** | **346** |

Table 2: Proposed new resources per project in WP7.

# Project A

High-rate, high-granularity precise timing with MPGDs

# WP7 Project A - Participating institutes

WP7 MPGD activities focus currently on PICOSEC MM developments
Participating members mostly from PICOSEC MM collaboration

- Aristotle University of Thessaloniki (AUTh)
- IRFU, CEA, University Paris-Saclay (IRFU/CEA)
- European Organisation for Nuclear Research (CERN)
- INFN, Pavia (INFN-PV)
- Jefferson Lab (JLab)
- Ruđer Bošković Institute (RBI)
- University of Science and Technology of China (USTC)
- Laboratory of Instrumentation and Experimental Particles Physics, Lisbon (LIP)
- Helsinki Institute of Physics (HIP)

# WP7 Project A - Detailed deliverables

- 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**

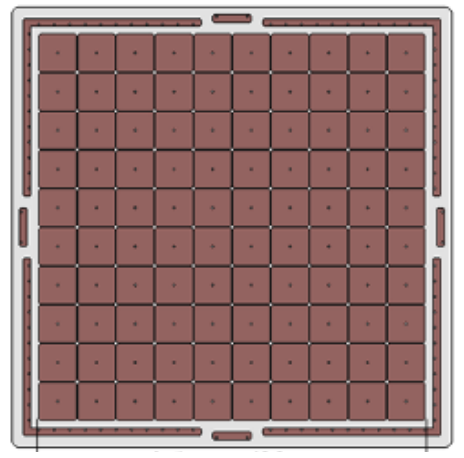
Eight deliverables, most of them currently addressed by multiple institutes

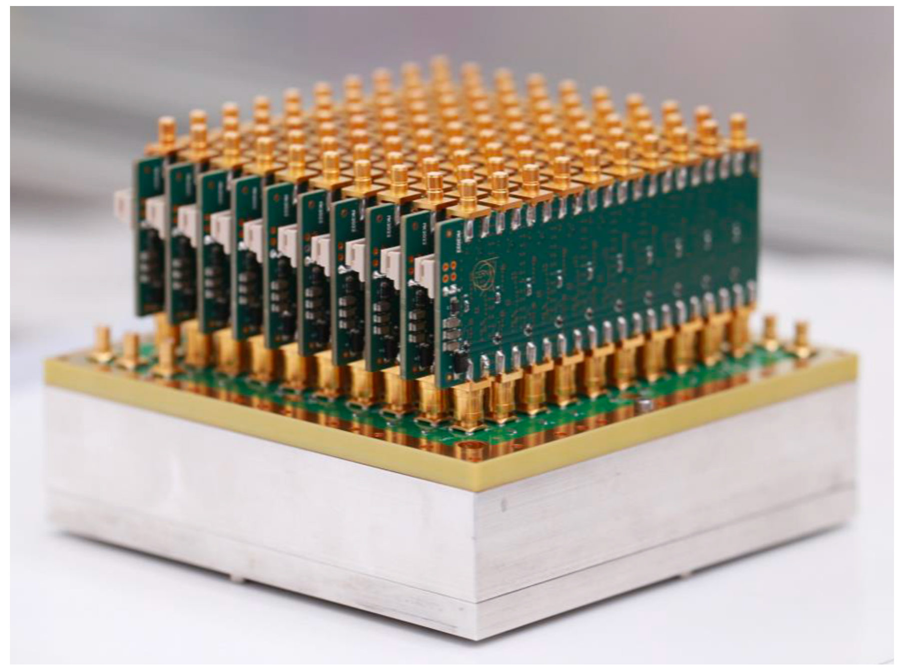
| Institute | Deliverables | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | D A.1 | D A.2 | D A.3 | D A.4 | D A.5 | D A.6 | D A.7 | D. A.8 |
| A.1: AUTh | | | | X | X | | X | |
| A.2: IRFU/CEA | | | X | X | | X | | |
| A.3: CERN | X | | X | | | | | |
| A.4: INFN-PV | X | | | | | | | X |
| A.5: JLab | X | X | X | | | | | |
| A.6: RBI | | | X | X | | | | |
| A.7: USTC | X | | | | | | | |
| A.8: LIP | | | | | | | X | |
| A.9: HIP | X | | X | | | | | |

# WP7 Project A - Detailed deliverables

- D A.1 **Large area** detector modules with scalable readout chain

**Current status:**
- 10x10 prototype module evaluated in lab and test beam measurements

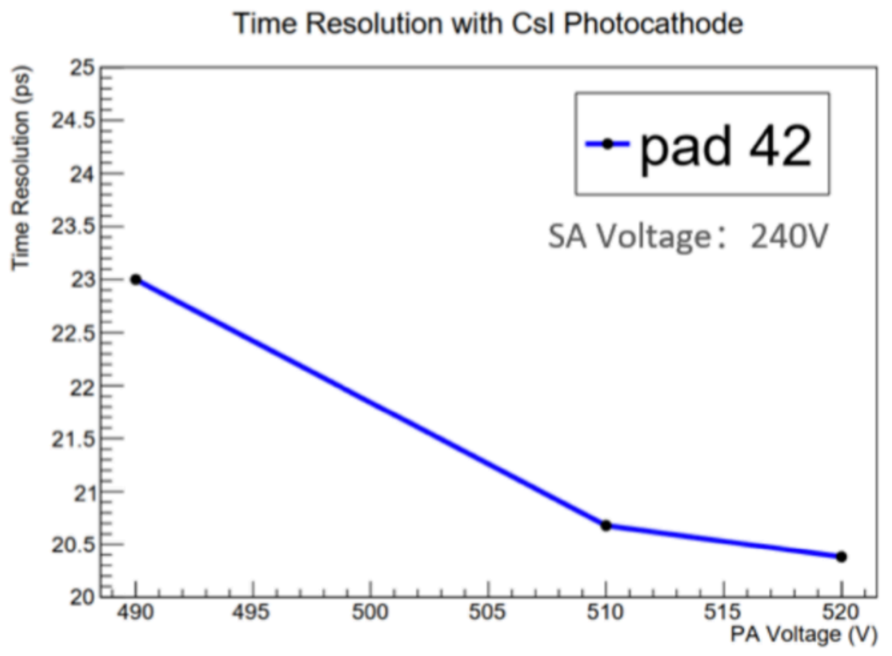


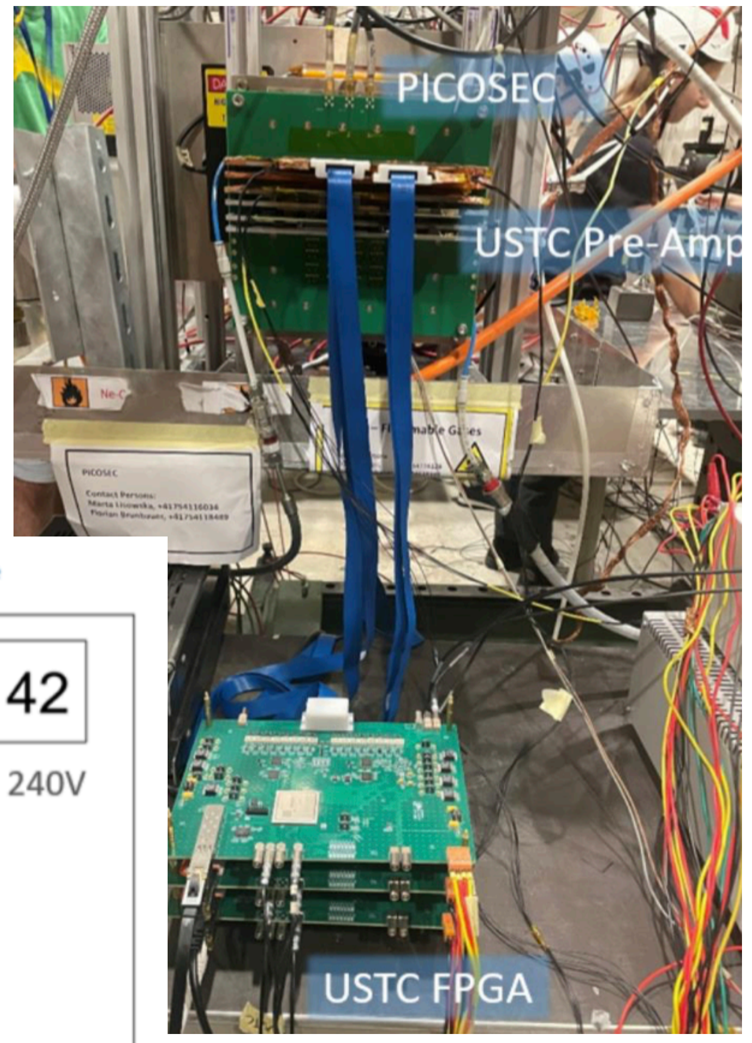


Operated and characterised with CsI and DLC photocathodes. Plan to operate with 10x10cm^2 B4C photocathode.

A. Utrobicic, M. Lisowska et al., CERN

**Current status:**
- 10x10 prototype with custom preamp electronics and FPGA based readout evaluated with CsI and DLC photocathodes

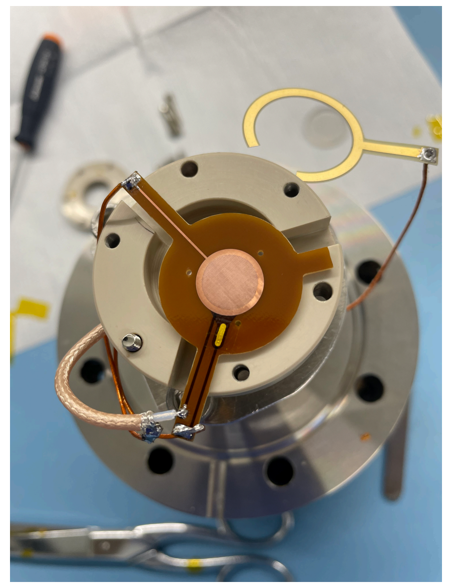



X. Wang, Y. Zhou et al., USTC

**Next steps:**
- Scaling up: 20x20cm^2 PICOSEC MM
- Alternative technology: 10x10 PICOSEC µRWELL
- Robust detector: 10x10 PICOSEC MM with different resistivities and construction schemes

- Evaluation of alternative charge evacuation schemes to increase high-rate capabilities



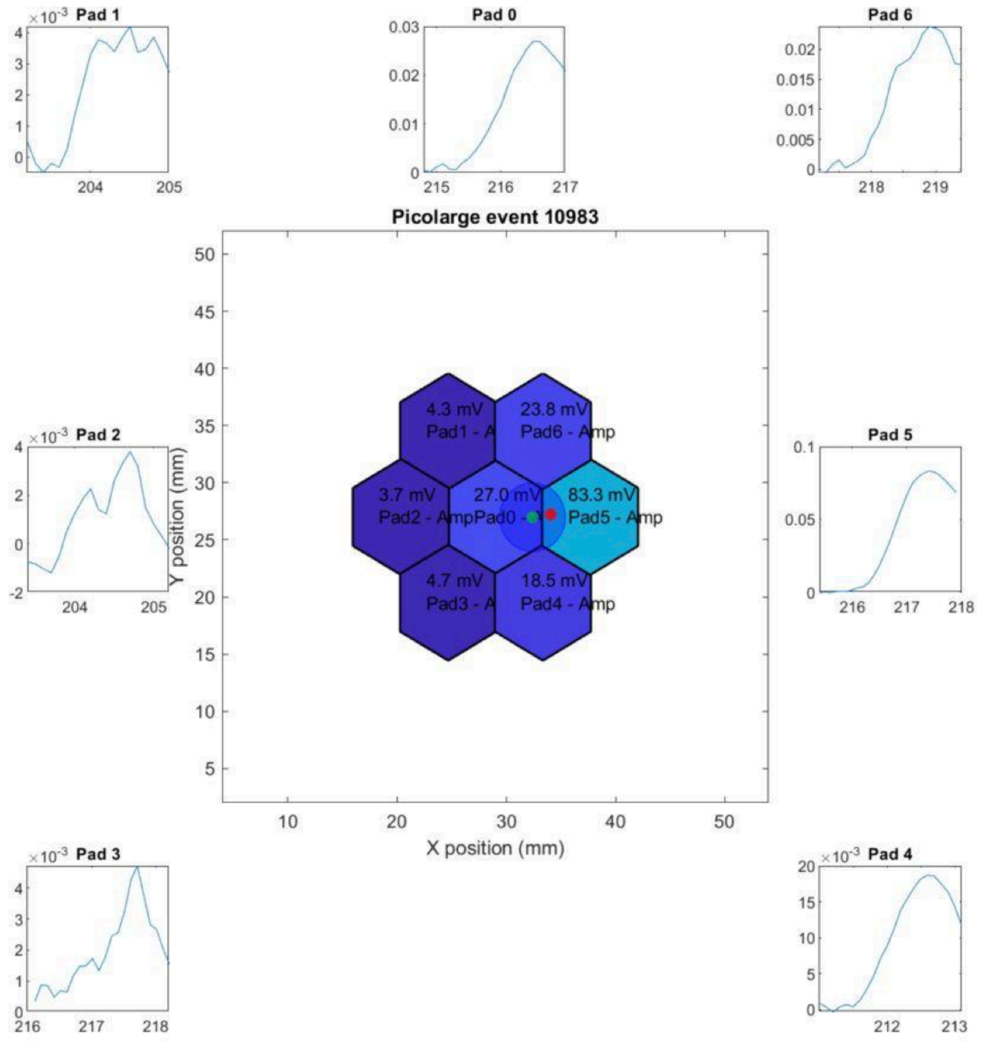
Scaling up with µRWELL PICOSEC
Comparison of single pad geometries as input for 10x10 µRWELL PICOSEC geometry

µRWELL, K. Gnanvo, JLAB

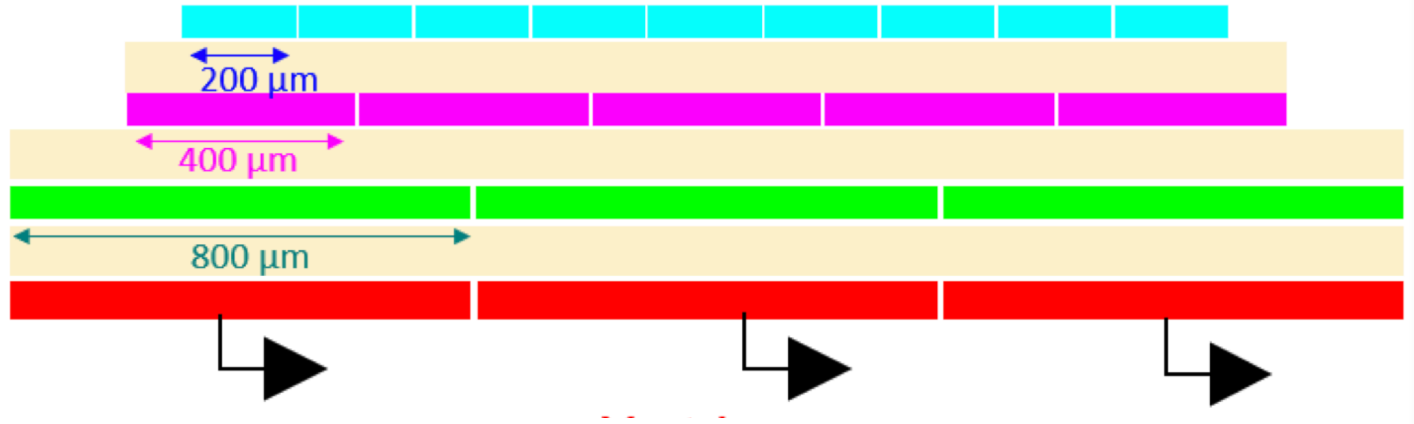
# WP7 Project A - Detailed deliverables

- D A.2 Precise timing detector prototype with **improved spatial resolution**

**Current status:**
- Different resistive detectors operated in test beam
- Preliminary measurement of spatial resolution




**Current status:**
- Preliminary test of a capacitive sharing layout on 7 pad resistive Micromegas
- Layout to be optimised for spatial resolution and signal sharing



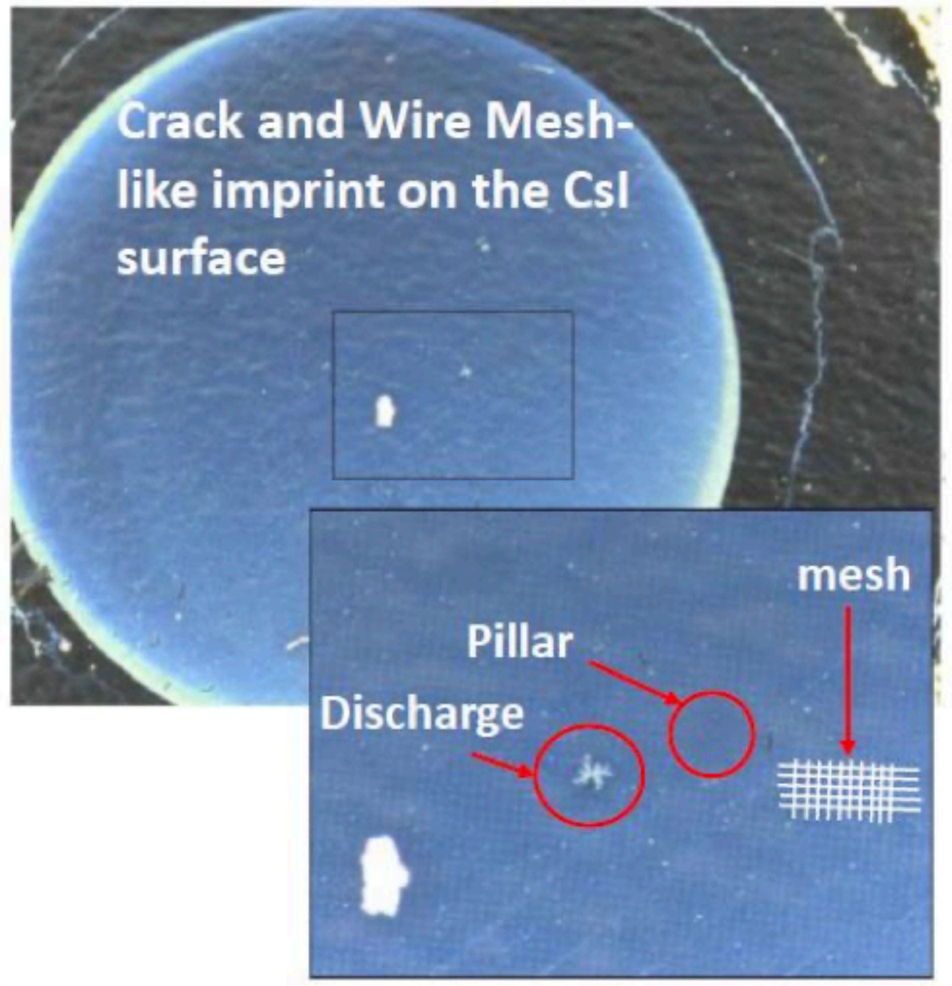

Kondo Gnanvo,

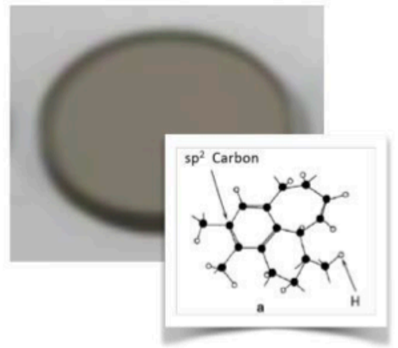
**Next steps:**
- Spatial resolution measurements of different resistive Micromegas and µRWELL prototypes
- Combination of µRWELL amplification stage with capacitive sharing readout

# WP7 Project A - Detailed deliverables

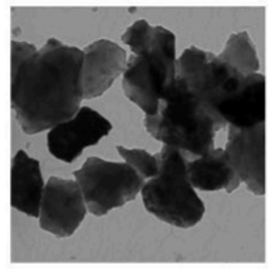
- D A.3 **Robust** detector prototype and **photocathodes** for long-term operation

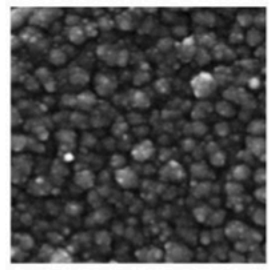
**Current status:**
- Baseline CsI photocathode provides ≈10pe/ MIP and used for single and multipad detectors
- Known degradation with accumulated charge
- Ongoing evaluation of carbon-based photocathodes



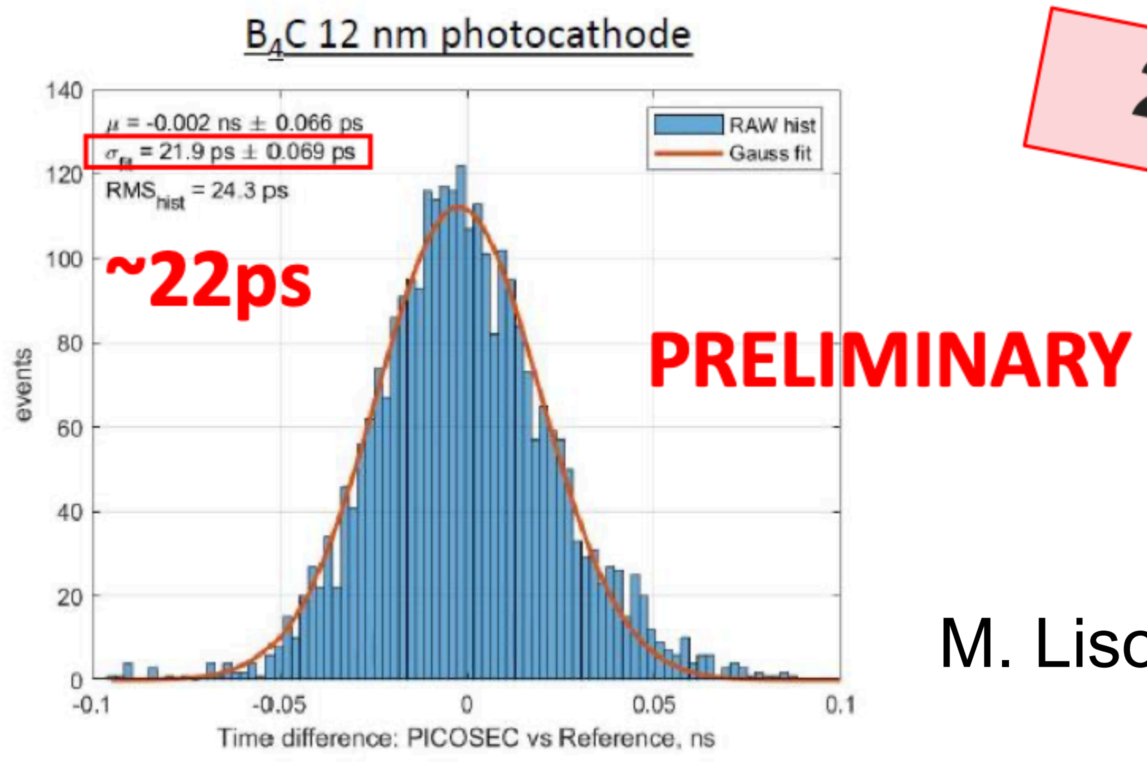



DLC, Y. Zhou et al.


ND, L. Velardi et al.


$B_4C$, 10.1016/ j.jnucmat.2015.01.015


**Next steps:**
- Comparative evaluation of DLC and B4C photocathodes
- Evaluate alternatives to Cr as conductive layers
- Nanodiamond photocathode evaluation




2022

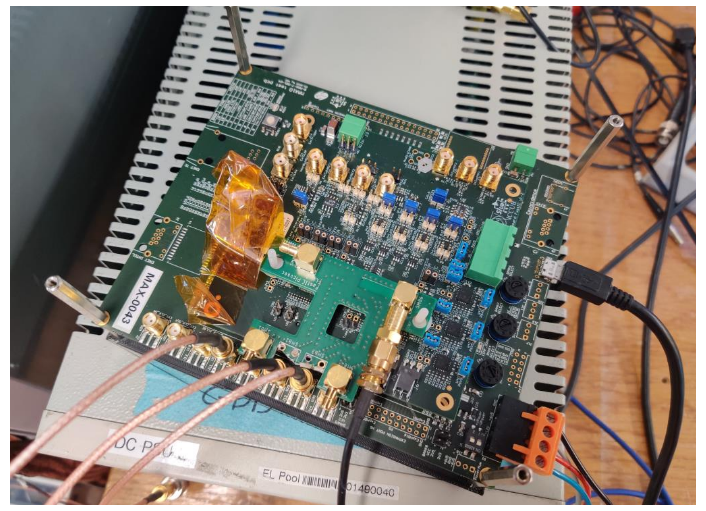
M. Lisowska

*M. Lisowska - Towards robust PICOSEC Micromegas precise timing detectors-MPGD2022*
https://indico.cern.ch/event/1219224/contributions/5130512

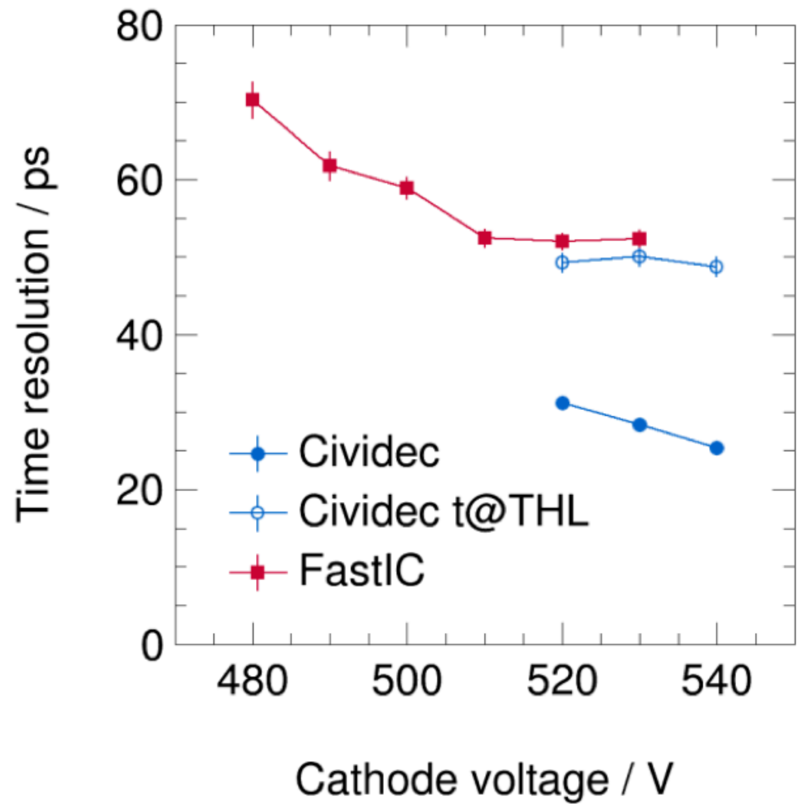
# WP7 Project A - Detailed deliverables

- D A.4 **Scalable readout** chain maintaining high time resolution

**Current status:**
- Evaluated FastIC with single and multichannel Picosec in test beam



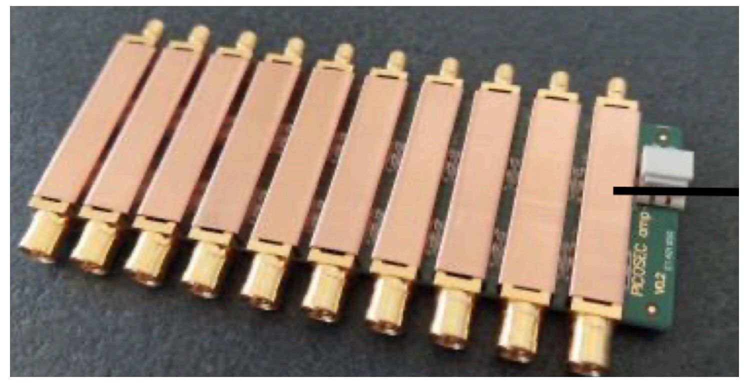
FastIC coupled to Picosec




L. Scharenberg

**Next steps:**
- Improved multichannel readout with FastIC
- Evaluate FastIC+TDC when available

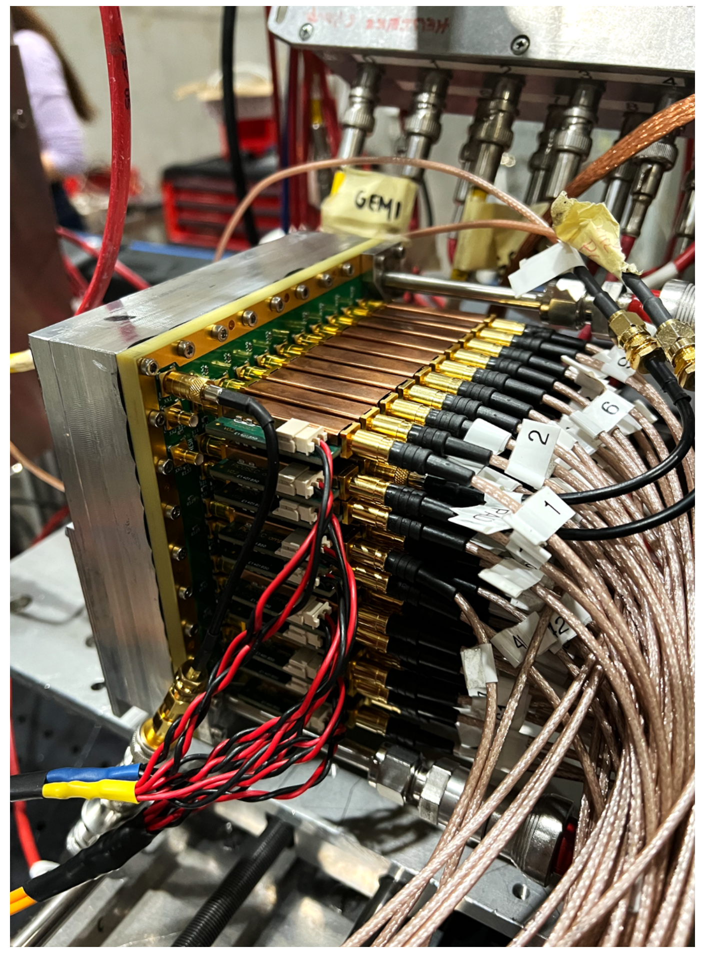
**Current status:**
- Dedicated preamplifier cards for precise timing detector



**Next steps:**
- Adapt to other detector geometries
- Integrate directly into detector outer PCB

A. Utrobicic

**Current status:**
- Achieved comparable timing resolution with SAMPIC WTDC readout as with oscilloscopes



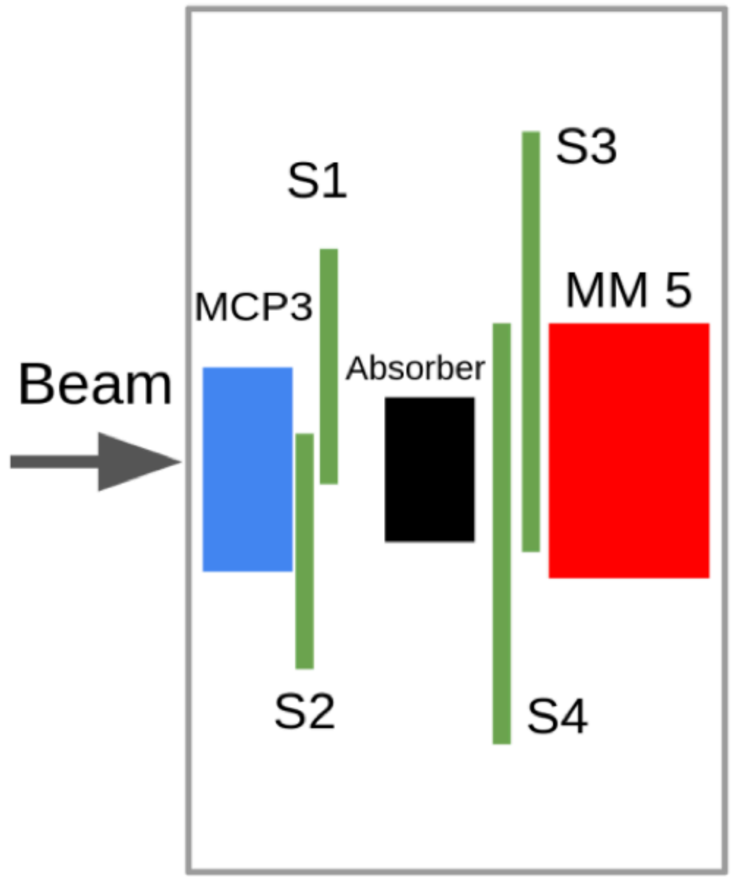
**Next steps:**
- Use as tools for multipad studies incl. spatial resolution
- Better signal routing, multi-module operation

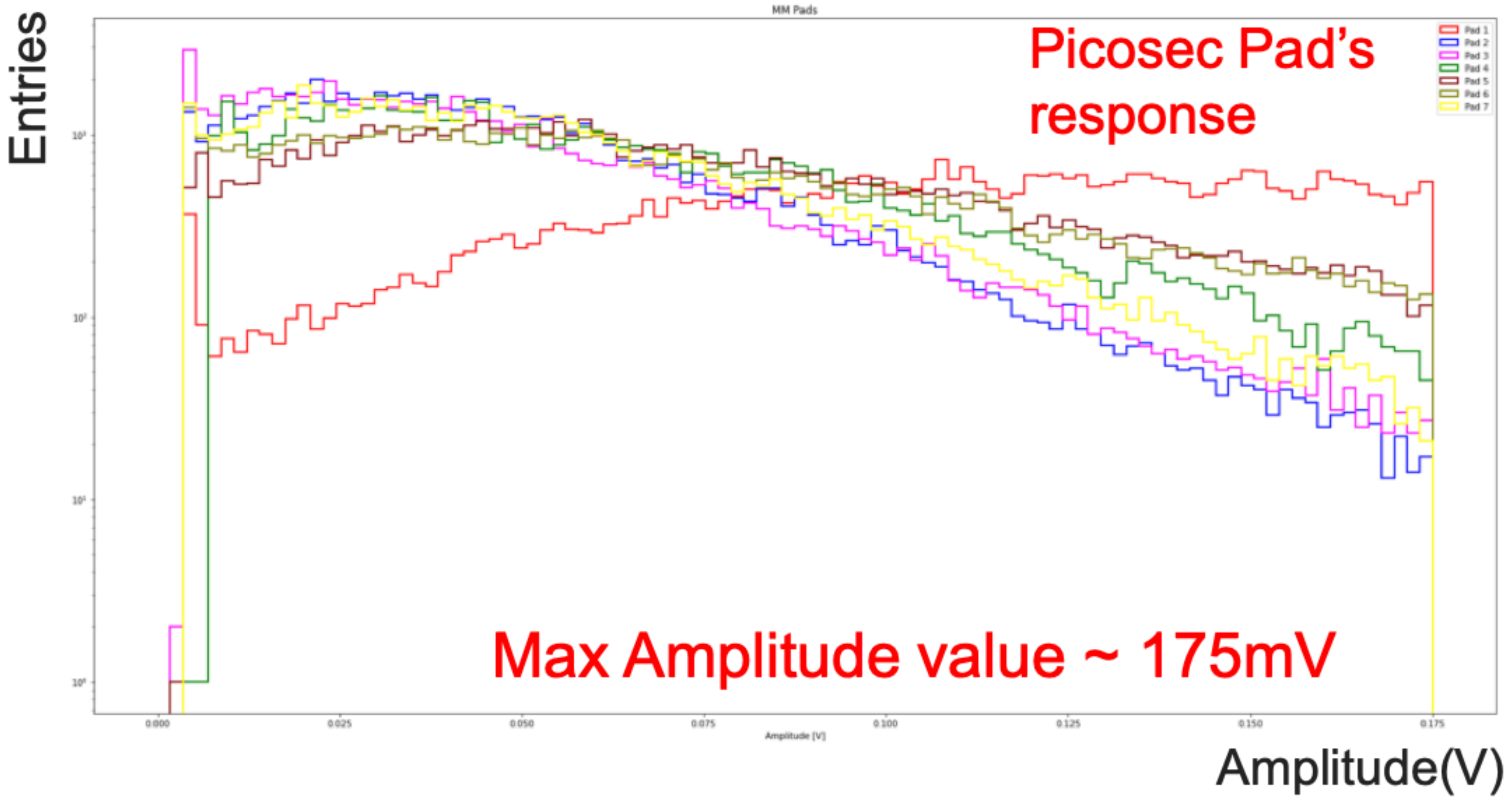
# WP7 Project A - Detailed deliverables

- D A.5 **Calorimeter embedded** precision timing-tracking

**Current status:**

- Preliminary operation in particle shower to evaluate average signal amplitude, stable operating point



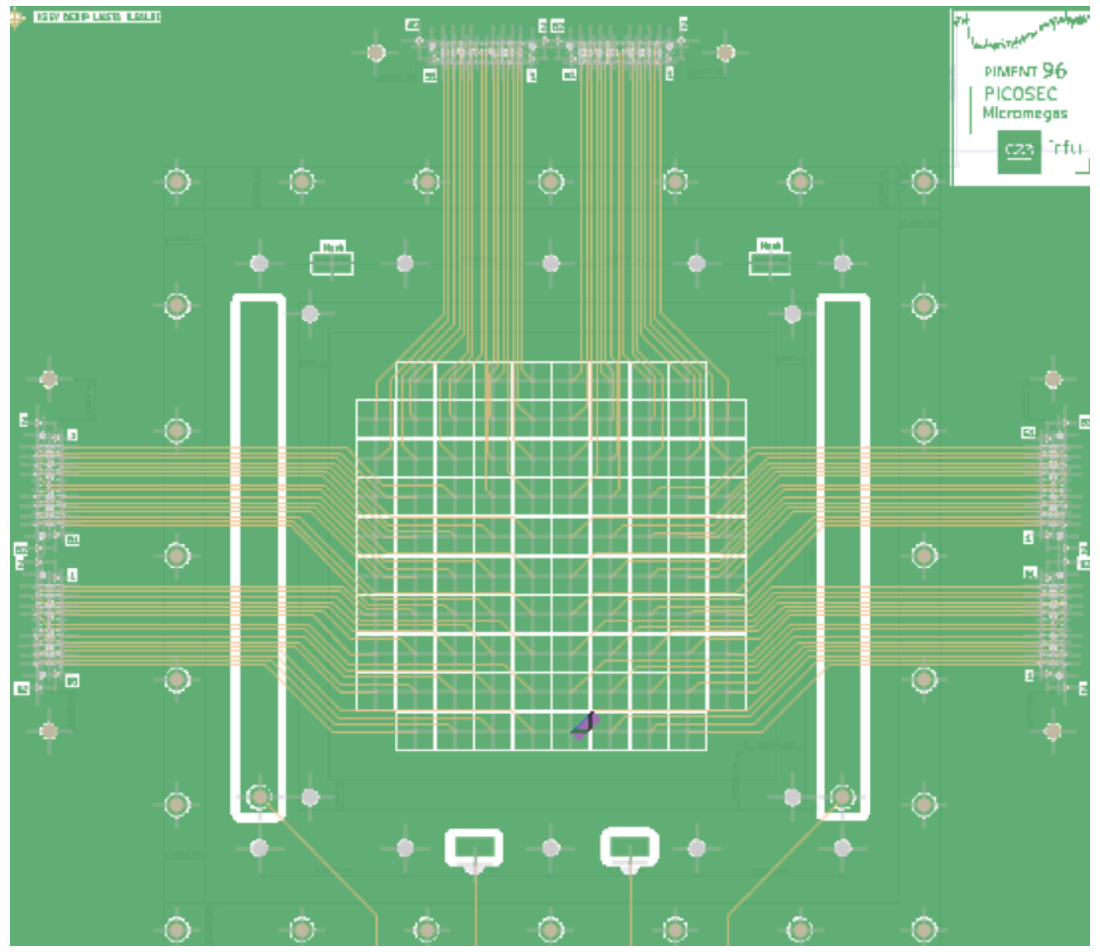




**Next steps:**

- Operation of multipad detector with particle showers
- Evaluation of resistive detector variants
- Detailed analysis of multi-pad hits

# WP7 Project A - Detailed deliverables

- D A.6 Evaluation of techniques for **minimising material budget**

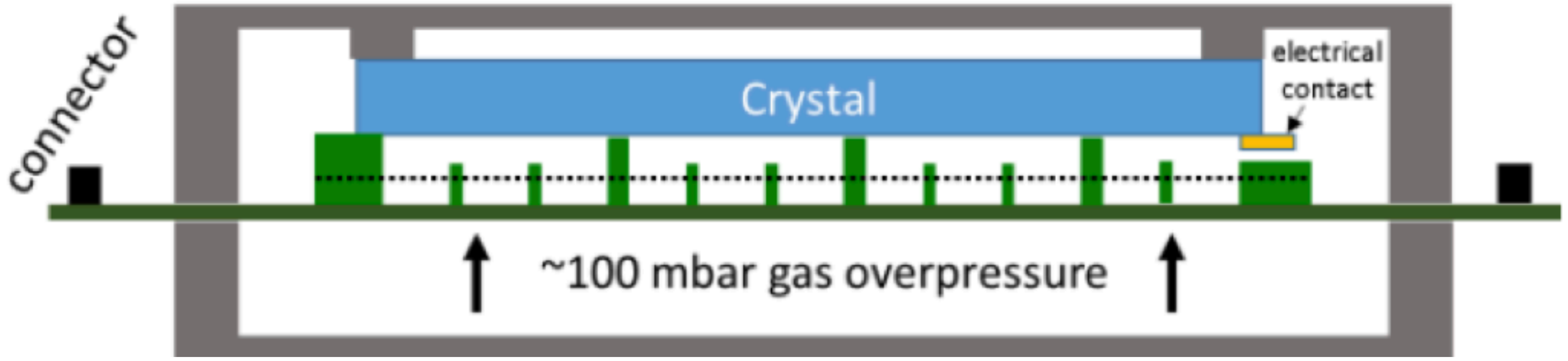


**Current status:**

- Rigid multilayer PCB to preserve planarity

**Next steps:**

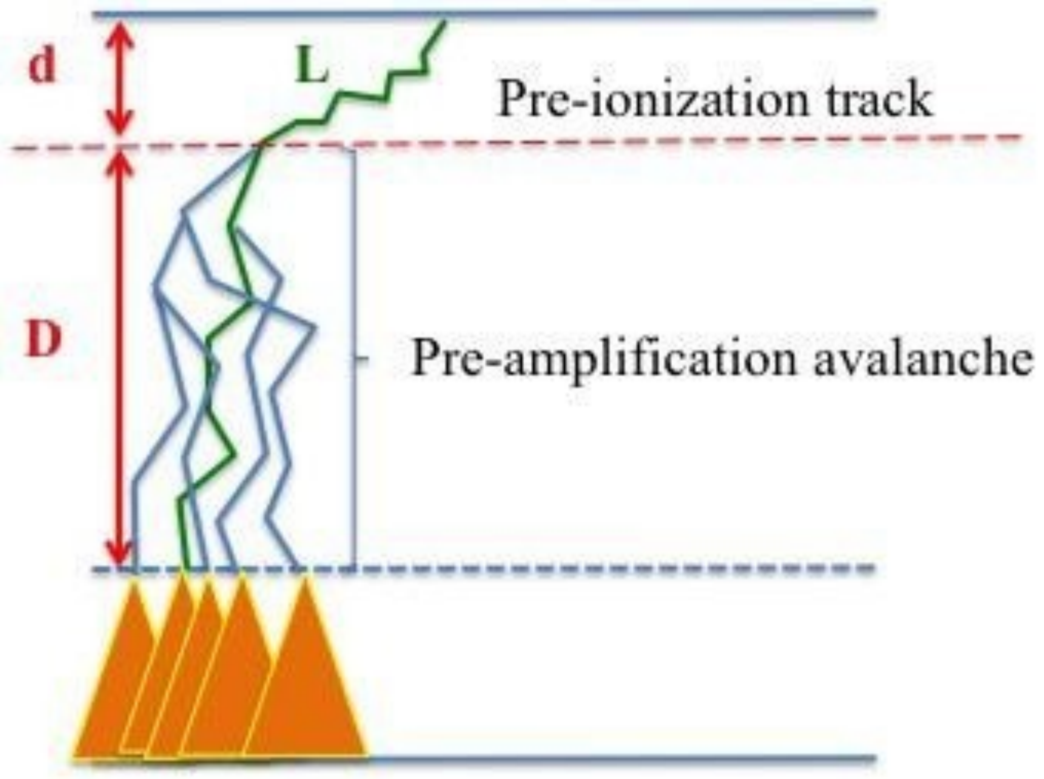
- Thinner substrate to be pressed against optically flat radiator crystal with spacers to preserve gap
- Detector in production, to be evaluated in beam tests this year




A. Kallitsopoulou, T. Papaevangelou, CEA Saclay
https://indico.cern.ch/event/1327482/contributions/5704017/attachments/2767818/4821527/RD51-Picosec-BeamsSummary.pdf

# WP7 Project A - Detailed deliverables

- D A.7 **Improved simulation model** of PICOSEC precise timing detector



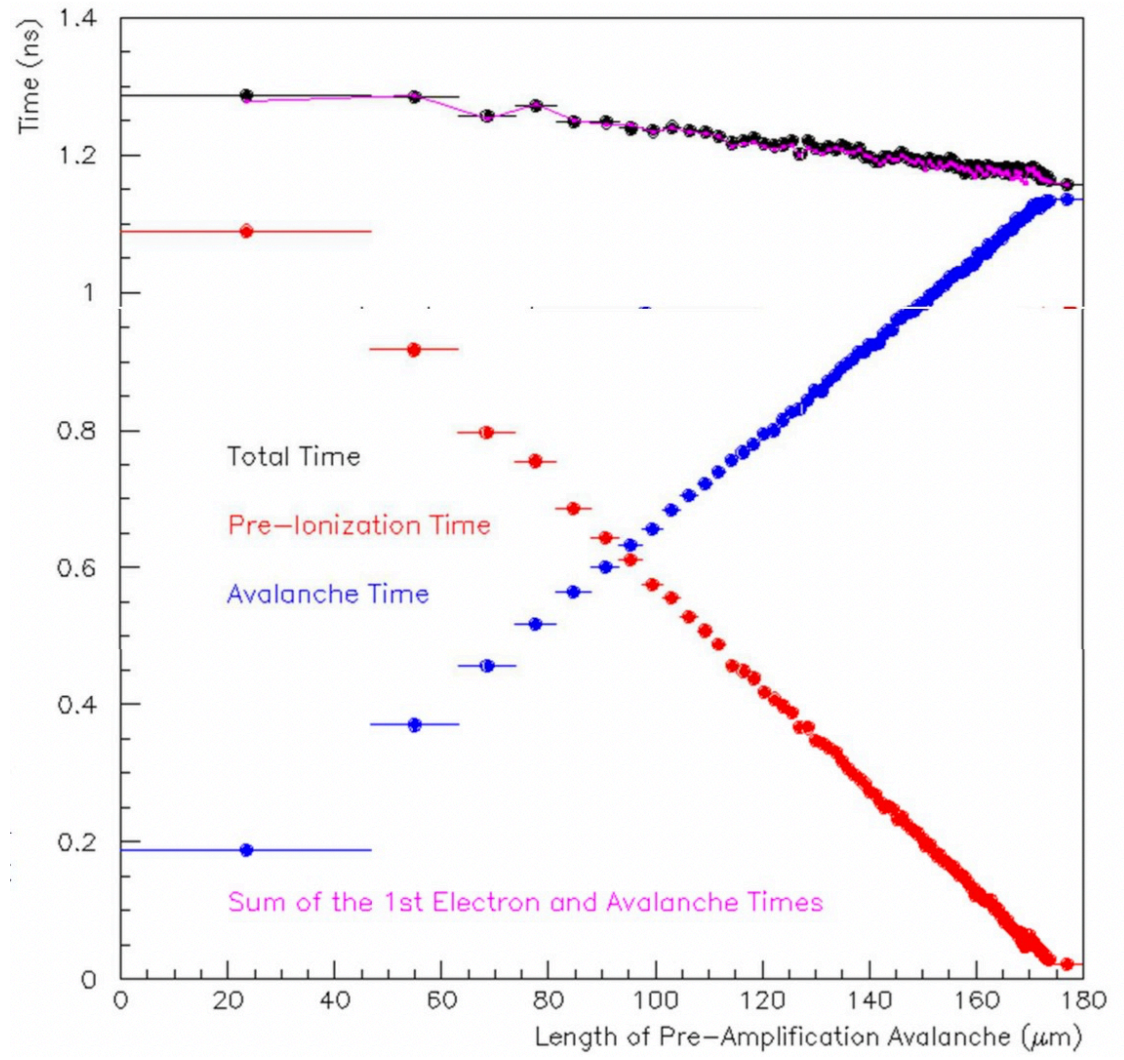

Microscopic simulation of Picosec MM

**Current status:**

- Microscopic simulation of avalanche in Picosec detectors used to understand detector performance

**Next steps:**

- Improvement of simulation framework
- Simulation of resistive Micromegas and impact on timing performance




K. Kordas, Progress on the PICOSEC-Micromegas Detector Development: towards a precise timing, radiation hard, large-scale particle detector with segmented readout, VCI2019 - The 15th Vienna Conference on Instrumentation https://indico.cern.ch/event/716539/contributions/3246636/

AUTh, LIP

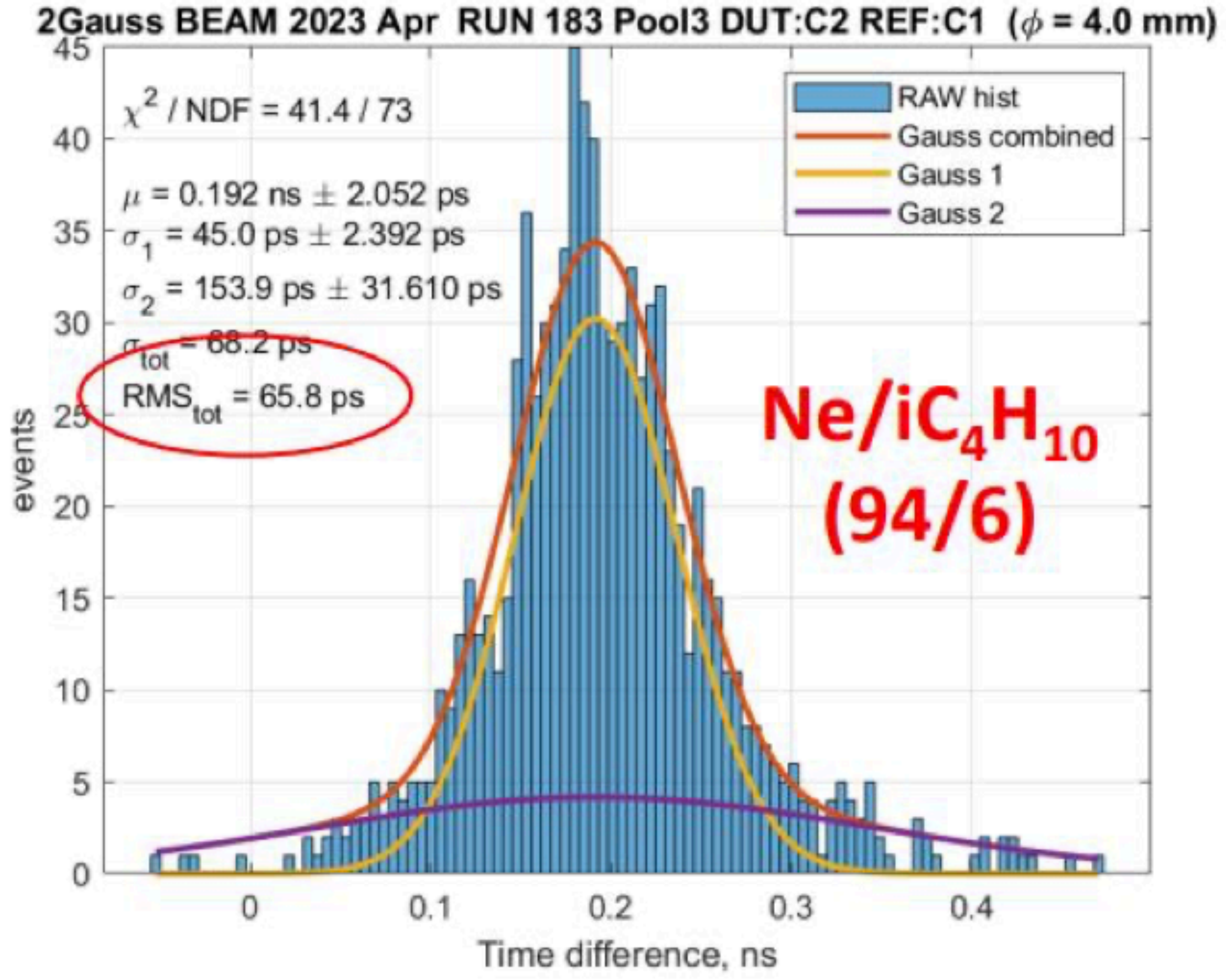
# WP7 Project A - Detailed deliverables

- D A.8 Comparison and optimisation of timing performance of **ecofriendly gas mixtures**

**Current status:**

- Baseline: COMPASS gas (Ne/CF4/Ethane 80/10/10)
- Previous tests of different mixing ratios of Ne/Ethane (L. Sohl)

- Preliminary tests of alternative gas mixtures without CF4: Ne-Isobutane




**Next steps:**

- Consolidate measurements with improved reference detectors
- Evaluate further gas mixtures and ratios

D. Fiorina, INFN-PV
https://indico.cern.ch/event/1214183/contributions/5379775/

## WP7-B

**Timing Detectors- B**

High-rate, large, precise timing RPC/MRPC

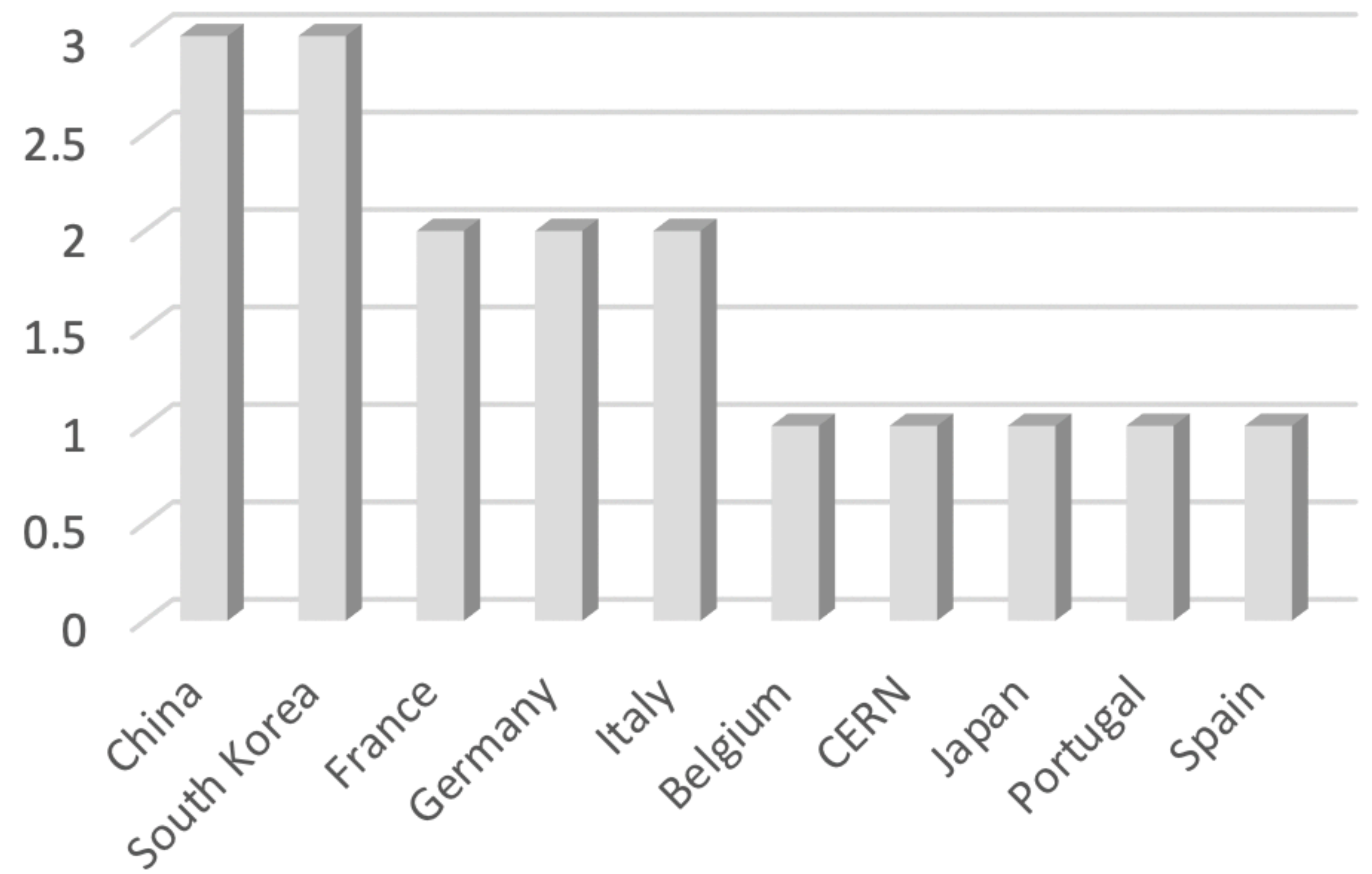
RPC/MRPC are still the reference in time resolution when large detectors are needed

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

# WP7-B

17 institutes from 9* countries with expertise in RPC/MRPC and their 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 (> 150 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.5: Preliminary results of timing and spatial resolution with standard gas Mixture (36)

# WP7-B

- ***Funding***

→ The most challenging topic is the readout electronics

Two groups (OMEGA & DGIST) will play an important role but funding is a must

**Existing**

| Institute | Materials | | | FTE | | |
|---|---|---|---|---|---|---|
| | 2024 | 2025 | 2026 | 2024 | 2025 | 2026 |
| France | 80 | 80 | 80 | 3 | 3 | 3 |
| Spain | 13 | 13 | 13 | 0.25 | 0.25 | 0.25 |
| Belgium | 25 | 25 | 25 | 0.8 | 0.8 | 0.8 |
| Italy | 40 | 40 | 40 | 2.5 | 2.5 | 2.5 |
| Germany | 20 | 20 | 20 | 1.05 | 1.05 | 1.05 |
| Portugal | 30 | 30 | 30 | 0.5 | 0.5 | 0.5 |
| Switzerland | 5 | 5 | 5 | 0.5 | 0.5 | 0.5 |
| China | 80 | 80 | 80 | 2.5 | 2.5 | 2.5 |
| South Korea | 83 | 83 | 83 | 2.4 | 2.4 | 2.4 |
| Japan | 20 | 20 | 20 | 1 | 1 | 1 |
| **Total** | 396 | 396 | 396 | 14.2 | 14.2 | 14.2 |

**Additional (not existing)**

| Institute | Materials | | | FTE | | |
|---|---|---|---|---|---|---|
| | 2024 | 2025 | 2026 | 2024 | 2025 | 2026 |
| France | 180 | 180 | 180 | 0 | 0 | 0 |
| Germany | 40 | 40 | 40 | 1 | 1 | 1 |
| Portugal | 0 | 0 | 0 | 0.5 | 0.5 | 0.5 |
| Japan | 400 | 400 | 400 | 0 | 0 | 0 |
| **Total** | 520 | 520 | 520 | 1,5 | 1,5 | 1,5 |

# WP7-B

## Next steps

We foresee to have a meeting soon (end of February /beg. of March)

- Update on the current activities and funding perspectives
- Inventory of the available facilities, tools and readout electronics within groups and for DRD1 collaborator

Here also the goal is to build on current R&D activities with available fundings and provide the needed arguments to obtain more fundings and to extend the network to new comers

# Backup

# WP7 Project A - High-rate, high-granularity precise timing with MPGDs

Tasks addressed in WP7 project A:

- T1: Optimize the amplification technology towards large-area detectors
- T2: Enhance timing performance
- T3: Enhance rate capability
- T4: Spatial resolution and readout granularity
- T5: Stability, robustness and longevity
- T6: Material studies
- T7: Gas studies for precise timing applications
- T8: Modelling and simulation of timing detectors T9: Readout electronics for precise timing
- T10: Precision mechanics and construction techniques
- T11: Common framework and test facilities for precise timing R&D

# WP7 Project A - Synergies with Working Group activities

**WG1 Technologies**: New developments and optimization of detector technologies

**WG2 Applications**: Intended applications of timing detectors for future experimental needs

**WG3 Materials**: Study of environmentally friendly gases, converter materials, photocathodes

**WG4 Modelling and Simulation**: Modelling of precise timing detector geometries, impact of resistive elements on timing performance and rate capability

**WG5 Electronics**: Dedicated electronics for precise timing detectors, input protection schemes

**WG6 Production**: Precise mechanics and control of manufacturing processes for high-quality amplification structures

**WG7 Common Facilities**: Evaluation of timing performance in common DRD1 test beam campaigns, common facilities for studies in lab (laser, photocathode characterisation, …)

**WG8 Training and Dissemination**: Sharing of relevant analysis / characterisation techniques to characterise and optimise timing response