Letter of Intent

Acronym: DRESS

Project Title: ***D****igital high* ***RE****solution position-sensitive room temperature* ***S****emiconductor detectors for high precision radiation* ***S****pectroscopy in hadron physics and related areas*.

Project Leaders:

-Prof. Leonardo Abbene, Department of Physics and Chemistry (DiFC)-Emilio Segrè University of Palermo, Italy (Coordinator)

-Dott. Florin Sirghi, INFN – Laboratori Nazionali di Frascati, Italy (Co-Coordinator)

1. Research Objectives

The **DRESS** project aims to develop advanced room-temperature position-sensitive semiconductor-based radiation detectors for high-precision X-ray and gamma-ray spectroscopy. These technologies are crucial for advancing hadron physics research, particularly in studies involving exotic atoms, hadron and nuclear structures, astrophysical processes, and searches for physics beyond the Standard Model. Currently, the development of large-area room-temperature radiation detectors with ultra-high energy resolution (< 1 keV at 60 keV) and nanosecond-level timing resolution remains challenging. The proposed leading-edge detector technology will enhance the services of the transnational infrastructures involved in the project, opening the road towards new Hadron Physics research and significant societal applications, including nuclear medicine, industrial inspection and security. The overarching goal is to achieve **ultra-high energy resolution, very close to the Fano limit, (0.5 keV FWHM at 60 keV (^{241}Am source), 0.9 keV FWHM at 122 keV (^{122}Co source) and 4 keV FWHM at 662 keV (^{137}Cs source) and true nanosecond-level timing**, across a **broad energy spectrum (keV–MeV)**, with stable performance at room temperature or with minimal cooling requirements. To achieve this, **DRESS activities will cover the full detection chain**, from advanced detector materials and sensor design to custom read-out electronics and digital pulse processing:

- **Detector materials:** DRESS will focus on Cadmium Zinc Telluride (CdZnTe or CZT) and, for the first time in this context, on halide perovskites. CZT is currently the benchmark for room-temperature radiation detectors due to its high atomic number and wide band gap. Innovations will target improved charge transport properties, reduced leakage currents and enhanced timing. Detectors with co-planar, strip, and hemispherical layouts will be proposed, taking into account the enhancements of the detection area, spectroscopic and timing resolution, the reduction of the noise and the number of readout channels. Halide perovskites can offer a promising low-cost alternative and will be explored for their scalability and eco-friendly synthesis.
- **Front-end electronics:** development of ultra-low-noise and fast charge-sensitive preamplifiers (CSPs), based on a low-noise CMOS technology, will be pursued. CSPs will be designed with reset feedback circuits, allowing lower noise than the resistive one, with an ENC of few electrons (< 10 electrons; i.e. about 0.1 keV on CZT).
- **Digital pulse processing (DPP):** the signals from detector/preamplifiers will be promptly digitized and processed by using advanced DPP approaches. DPP allows the application of dedicated filtering and pulse shape analysis for timing/energy resolution improvements and high-flux measurements. AI-driven analysis techniques will also be used to improve radiation detection.
- **Demonstrators and deliverables:** The project will deliver at least **three detector prototypes** (one CZT-based detector, one perovskite-based detector, a digital detection system based on an array of

selected detectors), tested in beamlines and laboratory settings, with documented performance benchmarks (energy resolution, timing, stability) and a comprehensive evaluation report comparing CZT and perovskite solutions under identical conditions for use in hadron physics and related area experiments and applications.

The consortium brings together leading European expertise in semiconductor physics, electronics, and experimental hadron physics, with complementary know-how in detector development, signal processing, and access to major test infrastructures.

2. Connection to Transnational Access (TA) Infrastructures

DRESS will extensively leverage existing research infrastructure services through TA schemes:

- **INFN-LNF (Italy):**

  activities: detector characterization, in terms of spectroscopic and timing resolution, at the Beam Test Facility (BTF); exotic atom spectroscopy setups and studies involving advanced acceleration (e.g., plasma wakefield acceleration) with implications in astrophysics, hadron and nuclear physics and inverse Compton scattering; as an example, such wide energy range detectors will be fundamental for the Fireball experiment, presently proposed to be performed at BTF, where fundamental nuclear physics mechanisms occurring in dense plasmas under extreme conditions will be investigated;

  benefits: the developed detection system will allow accurate and precise X-ray and gamma ray measurements across broad energy ranges (keV–MeV); the high timing resolution will be key for background suppression.

- **CERN (Switzerland):**

  activities: exotic atom studies and measurements (antimatter atoms, as antiprotonic one);

  benefits: the developed detection system will allow accurate and precise X-ray and gamma ray measurements across broad energy ranges (keV–MeV); the high timing resolution is key for background suppression. Moreover, the digital electronics can be also used with other detectors for optimal pulse processing and temporal coincidences, strongly reducing the complexity of experimental set-up.

- **GSI/FAIR (Germany):**

  activities: high resolution X-ray spectroscopy at the ESR and CRYRING storage rings;

  benefits: the high energy resolution of the final detection system at room temperature will be key to enhance the current radiation instrumentation; DRESS's fast electronics and AI-enhanced digital processing will be able to perform high resolution spectroscopy even at high fluxes; the high timing resolution will be also key for background suppression; current systems (e.g., SDDs, HPGe) offer either energy or timing precision—but not both simultaneously and often require cryogenic cooling.

- **MAMI/MESA (Germany):**

  activities: through systematic studies at the MAMI and MESA accelerators, DRESS will design and optimize the detectors for enhanced sensitivity and energy resolution across a broad energy range (keV to MeV), radiation damage effects, and develop signal processing algorithms for real-time particle identification.

  benefits: the digital instrumentation, based on AI- algorithms, will be key to enhance the current radiation instrumentation, especially at high flux conditions;

- **ELSA (Germany):**

  activities: the proposed technology is of interest for beam monitoring and high flux photon counting detection;

  benefits: the system will be able to perform high resolution measurements with high throughput even at high flux conditions; the flexibility of the digital electronics in pulse processing will ensure different throughput conditions with low and well-defined dead time.

Additional access to complementary infrastructures (e.g., **PSI Villigen and J-PARC**) may be considered during project implementation.

3. Budget and Partner Institutions

The total budget is **€ 100,000**, distributed as follows:

	Partner Institutions	**Direct costs**	**Overhead (25 %)**
1	**Department of Physics and Chemistry - E. Segrè (DiFC) University of Palermo, Italy (Coordinator)**	16500 €	5500 €
2	**Laboratori Nazionali di Frascati (LNF) – INFN, Italy (Co-Coordinator)**	15000 €	5000 €
3	**IMEM, CNR, Parma, Italy**	15000 €	5000 €
4	**Politecnico di Milano, Italy**	9750 €	3250 €
5	**Charles University, Faculty of Mathematics and Physics, Institute of Physics, Prague, Czech Republic**	7500 €	2500 €
6	**University of Zagreb, Croatia**	3750 €	1250 €
7	**Jagiellonian University in Krakow, Poland**	3750 €	1250 €
8	**UKRI STFC Rutherford Appleton Laboratory, U.K**.	3750 €	1250 €