Project name: AMS-02/DAMPE/HERD
Short description:
AMS-02: The largest magnetic spectrometer ever installed in space and the only one currently in operation. From its installation on the international space station (ISS) in 2011, it is the most precise cosmic-ray detector in the energy range from 0.5 GeV to few TeV (rigidity from 0.5 GV to 3 TV). It will continue its operation for the entire lifetime of ISS through 2030.
DAMPE: The largest calorimeter-based space mission. Since its launch in 2015, it is taking data in excellent working conditions. Its acceptance is three 3 that of AMS-02, and is currently providing the most precise cosmic-ray measurements up to 100 TeV. Both the excellent hardware status and the significant scientific returns ensure that its operation will continue for 5—10 more years.
HERD: The next-generation calorimeter-based space mission. Thanks to its unprecedented acceptance (ten times that of DAMPE) and precision, it will extend the energy range of the direct cosmic-ray measurements beyond the PeV. HERD will be also able to perform a gamma-ray full-sky survey from 100 MeV to 100 TeV. HERD is a China-Europe mission that is currently in the final selection phase, and if adopted, will be installed on the China Space Station in around 2028.

Involved PI(s):
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Swiss participant Institutions and investment level:
AMS (UNIGE)

- Major hardware, software, and operation contributions:
  - Construction of the AMS silicon tracker.
  - Silicon tracker charge calibration, detector monitoring and operation, Machine Learning (ML) algorithms.
- Major contributions to data analysis and publications: nuclei and isotopes spectra.

DAMPE (UNIGE, EPFL)

- Major hardware, software and operation contributions:
  - Proposer and project leader of the DAMPE silicon tracker (STK).
  - DAMPE software framework, STK simulation, reconstruction and tracking software, ML algorithms for tracking, particle ID and energy correction.
  - STK monitoring, calibration, alignment, European Monte Carlo (MC) production.
- Major contributions to data analysis and publications:
  - protons, electrons plus positrons, nuclei, and gamma rays.

HERD (UNIGE, EPFL)

- Major hardware and software contributions:
  - Proposer and project leader of the HERD scintillating-fiber tracker (FIT).
  - FIT reconstruction software.
  - ML algorithms for data reconstruction and analysis, hadronic model tuning.
  - MC studies to estimate the HERD sensitivity to a gamma-ray flux from dark-matter annihilation.

TimeLine 2018-2032 [highlight changes since roadmap**]**
AMS-02: operation and data analysis, upgrade in 2025 to increase the detector acceptance by 300%
DAMPE: operation and data analysis
HERD:

- Up to launch (~2028): detector construction and space qualification, on-ground tests of detector prototypes with particle beams, software development and data analysis preparation, detector sensitivity studies with MC simulations.
- After launch: commissioning followed by data analysis.

Objectives 2020-2032 [highlight changes since roadmap**]**
Precise measurements of cosmic ray particles, nuclei, and antiparticles spectra as function of rigidity from 0.5 GV to 3 TV (AMS); first observation of antinuclei in cosmic rays; indirect dark-matter detection through

observation of characteristic features in particle and antiparticle fluxes; first measurements of light isotope fluxes up to 12 GeV/n (AMS); first measurements of individual spectra of sub-Fe elements up to 3 TV (AMS); further extension of cosmic-ray spectra to a few hundred TeV (DAMPE) and beyond PeV (HERD); gamma-ray astronomy and search for dark-matter signatures in the diffuse gamma-ray flux (DAMPE and HERD); measurement of proton and nuclei inelastic-scattering cross sections from tens of GeV to a few PeV.

Impact:
The direct detection of cosmic rays in space up to the PeV scale is the only key to understand the origin of the most energetic processes in the Galaxy. The first observation of antinuclei in cosmic rays with AMS-02 would establish a genuine probe of matter-antimatter asymmetry in the Galaxy and provide a clean channel for dark-matter detection. A relatively small contribution of astrophysical sources in positron and antiproton fluxes (AMS-02), and electron flux beyond a TeV (DAMPE, HERD), allows to probe dark-matter annihilation or decay signals in the form of characteristic features (breaks) in cosmic ray spectra. Precise measurements of isotope fluxes of Li, Be and B, and the individual spectra of heavy secondary nuclei in the sub-Fe group will provide missing information for understanding the cosmic-ray propagation in our Galaxy, crucial to clearly assess the background for searches of signals from dark matter and primordial antimatter. The unprecedented energy resolution of DAMPE and HERD allows pinpointing smoking-gun dark matter signals in diffuse gamma rays, up to 100 TeV. The broad science program is made possible thanks to the new technology developments: the FIT subdetector of HERD, with the initial concept originating from the LHCb tracker design, will be used in space for the first time to replace conventional expensive silicon-based trackers. Moreover, recent developments in Artificial intelligence (AI) and Machine Learning with DAMPE and HERD open new scientific opportunities. They enable an order-of-magnitude enhancement in the accuracy of cosmic ray identification and facilitate measurement of hadronic cross sections, complementary to ground-beam experiments.
--Economical and Technological Impact, societal and knowledge transfer: instruments and techniques developed for space astroparticle experiments find their industrial application. As an example, a technology transfer project was established at UNIGE in cooperation with Detection Technology Plc, Finland. It is aimed at developing advanced simulations and new instrument designs for X-ray imaging detectors, based on the techniques established by UNIGE for the DAMPE experiment.

Current state and remarkable highlights: 2020-2024
AMS-02 made a major progress discovering that while all the spectra of nuclei measured so far harden around 200 GV, both primaries and secondaries exhibit two distinct classes of spectral shapes: the light He-C-O and the intermediate-mass Ne-Mg-Si-S primary classes, and the Li-Be-B and intermediate-mass F secondary classes. Fe belongs to the light He-C-O class. Secondary nuclei spectra harden about twice more than those of their primary progenitor, pointing to a propagation origin of the spectral hardening. Puzzlingly, light secondary-to-primary flux ratios, as B/O, differ from the intermediate-mass secondary-to-primary ratio F/Si. Recent DAMPE results on the helium spectrum confirm the hardening structure previously observed by AMS-02 and reveal for the first time a spectral softening at about 30 TeV. A remarkable hardening in B/C and B/O secondary-to-primary ratios at ~100 TeV/n, previously indicated by AMS-02, was detected by DAMPE in 2022 with more than 5σ significance. Finally, DAMPE puts the most stringent constraint on the isothermal dark-matter annihilation rate at ~10 GeV, with gamma rays.

Operation and sustainability in the long term, vision for the future:
AMS-02 will collect data to achieve precision measurements of individual rigidity spectra of rare heavy secondary nuclei in the sub-Fe group up to 1 TV; with the tracker upgrade it will collect sufficient data to extend measurements of rare nuclei fluxes to 3 TV, positron flux to 2 TeV, and electron flux to 3 TeV. DAMPE and HERD will directly probe cosmic-nuclei spectra towards the PeV frontier, and electrons up to 100 TeV. HERD will perform multi-messenger physics with gamma rays from a few GeV to 100 TeV.

Recommendations and findings
Do you have a proposal of update: Executive Summary Recommendation 5) 6) Overall vision: