Astroparticle physics and the EPPSU

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The EPPSU question for astroparticles

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   a. What other areas of physics should be pursued, and with what relative priority?
   b. What are the most important elements in the response to 4a)? (The set of considerations in 3b should be used).
      i. Physics potential
      ii. Long-term perspective
      iii. Financial and human resources: requirements and effect on other projects
      iv. Timing
      v. Careers and training
      vi. Sustainability
   c. To what extent should CERN participate in nuclear physics, astroparticle physics or other areas of science, while keeping in mind and adhering to the CERN Convention? Please use the current level and form of activity as the baseline for comparisons.

The CERN convention (1953)

2. The Organization shall… confine its activities to the following:
    a. the construction and operation of one or more international laboratories for research in high-energy particles, including work in the field of cosmic rays; each Laboratory shall include:
        i. one or more particle accelerators;
        ii. the necessary ancillary apparatus for use in the research programmes carried out by means of the machines referred to in (i) above;
        iii. the necessary buildings to contain the equipment referred to in (i) and (ii) above and for the administration of the Organization and the fulfillment of its other functions;
    b. the organization and sponsoring of international co-operation in nuclear research, including co-operation outside the Laboratories; this co-operation may include in particular:
        i. work in the field of theoretical nuclear physics;
        ii. the promotion of contacts between, and the interchange of, scientists, the dissemination of information, and the provision of advanced training for research workers;
        iii. collaborating with and advising other research institutions;
        iv. work in the field of cosmic rays.

Interpreting the CERN convention

- Cosmic rays are clearly in-scope, as they are mentioned in both paragraphs
  - While in-scope, realistically don't expect CERN will suddenly start building new cosmic ray experiments
  - Instead, likely used to support accelerator-based programs that inform air shower models
- Other astroparticle research is a grey area, as the accelerator is not within the CERN infrastructure
  - There is an accelerator, but it may be on the other side of the galaxy or beyond
  - Could be read either way, depending on the interests of the reader

- Supporting other collaborations via training, advising, and collaborating is clearly in-scope
  - They call it "nuclear", but in other places "nuclear" and "high-energy particles" are used ~interchangeably
  - This is likely the basis for the CERN "RE" (recognised experiment) programme
  - Provides access to CERN resources for HEP-adjacent collaborations, at a small scale
  - Larger-scale is possible, but has to be cost-neutral to CERN (we'll see examples)

- The RE programme is very diverse, which also means it is not tracked in detail
  - Unlike PBC and the Neutrino Platform, astroparticle is not a programme with a CERN-level organisation
  - The level of CERN participation thus varies considerably, and can be hard to understand

CERN REs and astroparticle physics

- **Space-based:** AMS (RE1), FERMI (RE7), DAMPE (RE29), Euclid (RE31), POLAR-2 (RE40), HERD (RE44)
- **Non-terrestrial-origin neutrino:** ANTARES (RE6), IceCube (RE10), KM3NeT (RE30), Hyper-K (RE45)
- **Gravitational wave:** LISA (RE8), Virgo (RE28), LIGO (RE33), Einstein Telescope (RE43)
- **Ground-based gamma-ray:** MAGIC (RE17), CTAO (RE23)
- **Direct dark matter:** DarkSide-20k (RE37), DAMIC-M (RE38)
- (apologies if I have missed any astroparticle-relevant REs)

- Typical CERN support for REs includes testbeams, material tests, detector assembly, and computing
- In some cases, support can be more substantial
  - AMS (RE1) has their Payload Operations Control Centre (POCC) at CERN's Prevessin site
  - CTA (RE23) has received CERN support via ATTRACT funding
  - ET (RE43) has an MoU with CERN to design and produce the TDR on the vacuum pipes
    - ET pays for this level of support, as it otherwise goes beyond the cost-neutral scenario
    - CERN is also advising on site characterisation / civil engineering / site selection process

CERN Detector Research & Development

- CERN currently has seven Detector Research and Development (DRD) collaborations
  - DRD1: Gaseous detectors
  - DRD2: Liquid detectors
  - DRD3: Solid state detectors
  - DRD4: Photon detectors and particle ID
  - DRD5: Quantum sensors
  - DRD6: Calorimeters
  - DRD7: Electronics and on-detector processing
- Many (all?) of these DRD programmes have relevance to astroparticle experiments
  - For example, Swiss direct DM detection groups are part of DRD2 and DRD5
- However, focus of DRDs is mostly CERN-centred

CERN contributions beyond REs and DRDs

- **CERN TH: Th**eory group makes significant contributions to various astroparticle activities
- **ESCAPE: E**uropean **S**cience **C**luster of **A**stronomy and **P**article physics **E**SFRIs
  - Scientific computing open science consortium, mostly based on CERN computing technologies
  - ESFRIs involved: **CTAO**, EST, ELT, FAIR, HL-LHC, JIVE, **KM3NeT**, LSST, SKAO, **Virgo**
- **LHC:** LHCf and upcoming proton-oxygen runs provide info on air shower models
  - First dedicated proton-oxygen beam time in 2025 largely to support such models
  - FASER, SND, and future Forward Physics Facility (FPF) also can contribute significantly to air shower models
- **SKAO:** Square Kilometer Array Organisation
  - More astronomy than astroparticle, but a key example of a larger CERN role
  - July 2017: CERN and SKAO signed a collaboration agreement on exabyte-scale scientific computing
  - Beyond computing, CERN has aided/reviewed the SKAO construction project
- **TVLBAI:** Terrestrial Very Long Baseline Atomic Interferometry collaboration
  - Recent collaboration (formed 2024) for DM and GW searches, following 10m-scale AION in the UK
  - CERN provided support in drafting the MoU for the EoI process, thus forming the TVLBAI collaboration
  - CERN is the primary candidate to host the 100m-scale follow-up, at Point 4 of the LHC
    - Already performed site characterisation studies, funded through the PBC effort
    - Plans to install a concrete wall in the Point 4 shaft during LS3 (pending sufficient level of EoIs)
    - Collaboration then builds+runs experiment behind the wall, CERN just provides the site and support

Vision for CERN contributions

To what extent should CERN participate in nuclear physics, astroparticle physics or other areas of science, while keeping in mind and adhering to the CERN Convention? Please use the current level and form of activity as the baseline for comparisons.

- CERN currently provides support to many astroparticle experiments
  - Mostly via the recognised experiment programme, but a few are not part of this approach
  - Level of support varies considerably by experiment, likely due in part to experiment needs
  - However, likely also due to lack of knowledge of what exactly is available
- CERN supports technology development via DRDs
  - Good where collaboration is possible, but not always aligned with astroparticle priorities
- **No centralised effort to support astroparticle physics**
  - CERN neutrino platform was an outcome of the 2013 EPPSU, leading to centralised effort
    - LAr is part of this programme, but not LXe; **could re-propose to extend platform to Noble Liquids**
  - More generally, **could be a good time to propose an astroparticle programme**
    - Already lots of disparate astroparticle effort; could be more effective grouped into a platform
    - Can focus on cosmic rays (in CERN convention) as the seed to the astroparticle platform
  - Both of these would likely count as **“CERN should increase activity in astroparticle physics”**

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   - **c.** To what extent should CERN participate in nuclear physics, astroparticle physics or other areas of science, while keeping in mind and adhering to the CERN Convention? Please use the current level and form of activity as the baseline for comparisons.

Swiss input on non-collider priorities

- We have recently concluded the CHIPP roadmap process
    - This already provides clear Swiss prioritisation of astroparticle activities: question 4a)
    - We should submit our prioritised vision to the EPPSU as part of the Swiss input

Swiss astroparticle recommendations

- **Recommendation 7**: CHIPP recommends that Switzerland undergoes a **planification for the large research infrastructures** of strongest interest for the astroparticle community involving particle physicists, cosmologists and astronomers, **in synergy with CHAPS**. Plans to secure long-term data processing and storage infrastructure should also be considered.
- **Recommendation 8:** The **CTAO** exploration of the gamma-ray sky with high precision enables a new era in multi-messenger astrophysics, opening unexplored paths to study cosmic particle accelerators and the origin of cosmic rays, dark matter, cosmic magnetic fields, and star formation in synergy with new messengers. CHIPP considers it a priority for Switzerland to become a member of the almost-finalised CTAO ERIC legal entity, in order to profit from the Swiss investments in the CTAO-CH Collaboration, widely spread between relevant Institutions in Switzerland, since 2005. Sustaining a strong community of scientists and a forefront data center at CSCS will secure the exploitation of CTAO for the next 30 years
- **Recommendation 9:** The CHIPP and CHAPS communities recognise the **Einstein Telescope** (ET) as a project of significant mutual interest. In order to take a leading role in instrumentation, the communities should actively participate in the **LVK** technical activities, in preparation for similar efforts for ET. We further endorse the continued, direct, and fruitful collaboration between CHIPP and CHAPS, leveraging common interests and tuning our strategy towards strong participation in ground-based, gravitational-wave observatories, in particular, ET.
- **Recommendation 10:** CHIPP considers the support of the ongoing and future direct dark matter searches a high priority of the Swiss programme. The ongoing operation and data analysis of the current generation **XENONnT** and **LZ** experiments are at the forefront of dark matter direct detection research. CHIPP advocates for continued Swiss leadership and instrumentation contributions to the future **DARWIN/XLZD** multi-tonne dark matter search facility. To explore low-mass dark matter and foster novel instrumentation, CHIPP also supports with lower priority smaller-scale cryogenic dark matter experiments employing quantum sensors, such as **TESSERACT** and **DAMIC-M**.

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  - We should submit our prioritised vision to the EPPSU as part of the Swiss input
- Our roadmap does not directly address prioritisation criteria: question 4b)
  - Ignoring the specific research infrastructure, which criteria are more important to make support decisions?
  - Physics potential - long-term perspective - financial & human resources - timing - careers/training - sustainability
  - We include this in some extent in our internal prioritisation, but never wrote down the criteria priority
  - This also links to recommendation 7 on undergoing a planification of large RIs together with CHAPS
- Moreover, EPPSU is not the same format as our roadmap
  - Will require some conversion to provide our feedback on the requested criteria
  - Unclear how many pages we have to summarise everything, and who will lead this

- Current EPPSU physics benchmark measurement priorities for astroparticle have also been circulated
  - The scope is largely collider-based, with only a bit on astroparticle

Physics Preparatory Group (PPG) input

5. Neutrinos and cosmic messengers
   a. <four **neutrino** properties headings>
   e. Cosmic messengers:
      i. high energy cosmic **neutrinos**:rate versus energy and flavour composition
      ii. sensitivity to supernova **neutrinos**:rate, flavour, time and energy resolution
      iii. **GW** strain sensitivity versus frequency
      iv. pointing/timing capabilities of **neutrino** and **GW** experiments to identify sources
      v. **multi-messenger** signal sensitivity to cosmic-ray acceleration mechanisms
6. Dark matter and dark sector
   a. Ultralight DM: Axion, ALPs, Dark Photon (Z')
   b. Light DM: ALPs, Z' (Dark Photon), Freeze-In Dark Matter
   c. Heavy DM: Wino & Higgsino, Higgs Portal, Scalar and Pseudoscalar mediator simplified models (O1 and velocity-dependent)
   d. Exotica: Dark Showers, Dark Compact Objects (PBH + Exotic Compact Objects)

Summary

- This EPPSU is not targeted at astroparticle, but there is still scope for us to contribute
  - Both in relation to CERN's role in astroparticle, and CERN-agnostic priorities for non-collider experiments
- This may be a good time to push for a more structured CERN approach to astroparticle
  - Extending Neutrino platform to include other noble liquids (such as LXe)
  - Proposal of an astroparticle platform to enhance awareness of what can and is being done
- Beyond CERN, we have defined our physics priorities within the CHIPP 2024 roadmap update
  - We should communicate these in the EPPSU, but also need to discuss criteria for prioritisation
  - We may also want to push to extend/adjust the physics scope from the PPG for review

- As there is no central astroparticle platform at CERN, I may have missed key contributions
  - Apologies for any such oversights, and thanks to CHIPP Pillar3 PIs for helping me compile information here