Preparation for CHIPP Roadmap for Pillar 3 (Astroparticle) update meeting 18-19 Jan 2024 Balsthal

- Define relevant experiments/line of research for the PIs for the 2029-2032
- Template collection launched per experiment, line of research

- Project name:
- Short description :
- Involved PI(s):
- Swiss participant Institutions:
- Swiss % to Investment level:
- TimeLine 2018-2032 [highlight changes since roadmap]
- Objectives 2020-2032 [highlight changes since roadmap]
- Impact:
    - Scientific:
    - Economical and Technological:
    - Societal and knowledge transfer
- Current state and remarkable highlights: 2020-2024
- Operation and sustainability in the long term:
- Recommendations and findings
- Do you have a proposal of update?

- CTAO: CHIPP Board A. Biland, E. Charbon, D. Della Volpe, TM, P. Saha, N. Serra, R. Walter) Staff: M. Heller + CHAPS: JP Kneib, S. Paltani, Staff: N. ProduitM. Falanga. Others : A. Neronov (EPFL), T. Schulthess, P. Fernandez, V. Holanda (CSCS). Participating Inst. UNIGE (DPNC,ASTRO), EPFL (LASTRO, AQUALab), ETHZ/CSCS, UZH, BernU

- Dark Matter Direct Detection: L. Baudis (Xenon/Darwin), B. Kiliminster (DAMIC) B. Penning (Tesseract/LZ). Part. Inst. UZH

- ET, Gravitational waves cosmology: S. Schramm, M. Maggiore, T. Riotto, M. Soares Dos Santos (CHIPP Board member), senior scientists: Paul Laycock, Stefano Foffa; CHAPS: A. Fragkos, C. Charbonnel; other: C. Bonvin. Part. Inst: UNIGE, maybe ETHZ

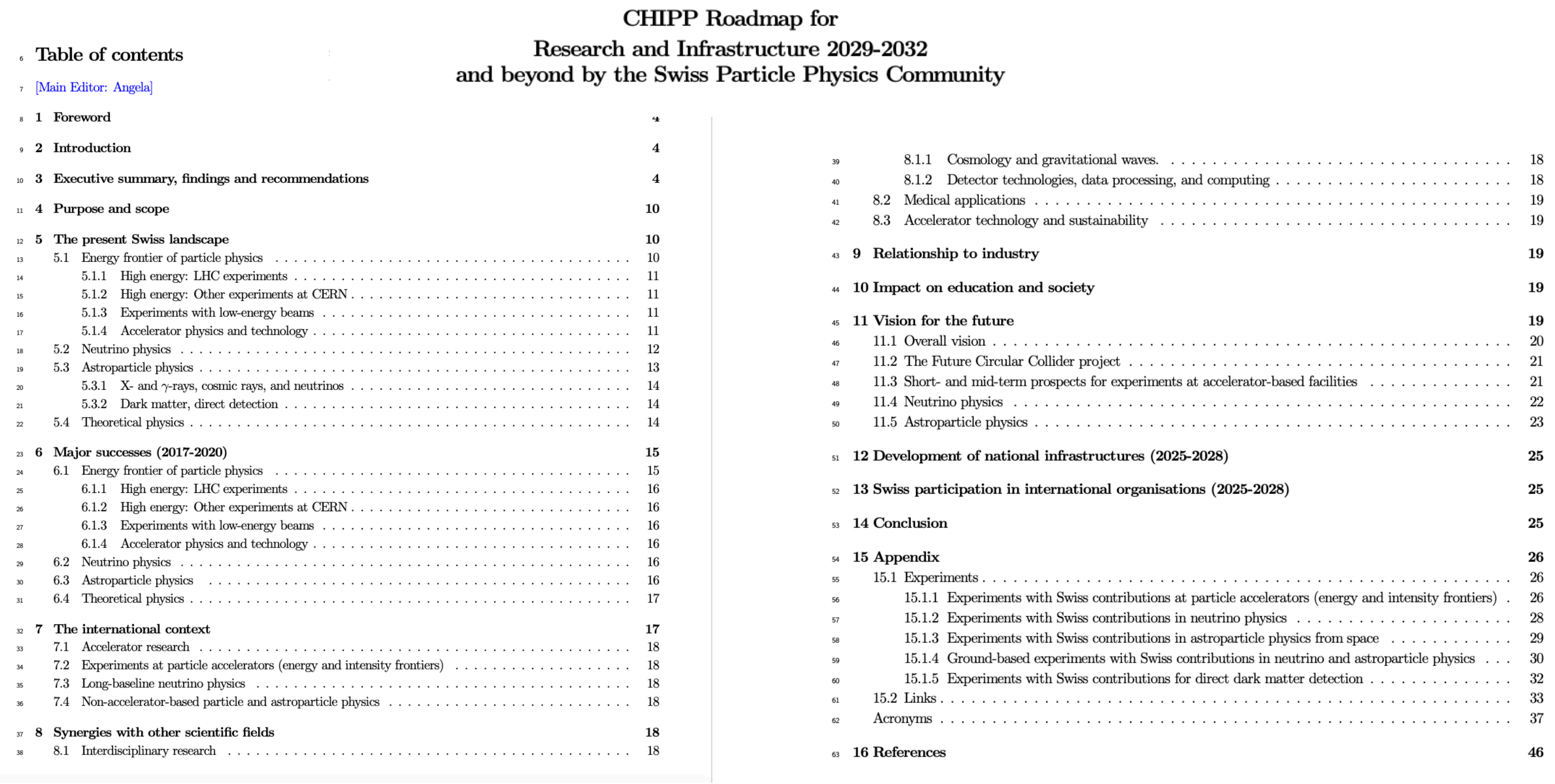
- DM indirect detection + Multi-Messenger from space: A. Tykhonov, X. Wu, Senior Scientist: M. Paniccia, Philippe Azzarello (AMS, DAMPE, HERD)+NUSES/EUSO (Cherenkov from space), Chiara Perrina

Teresa.montaruli@unige.ch

Why an update?

- Why an update?
  - explicitly refer to 2029-2032
  - Revisit high-level recommendations, underline change of priorities
  - Refine schedules, deliverables
  - Impact : scientific, knowledge and technological transfers, on society

New Roadmap Update document



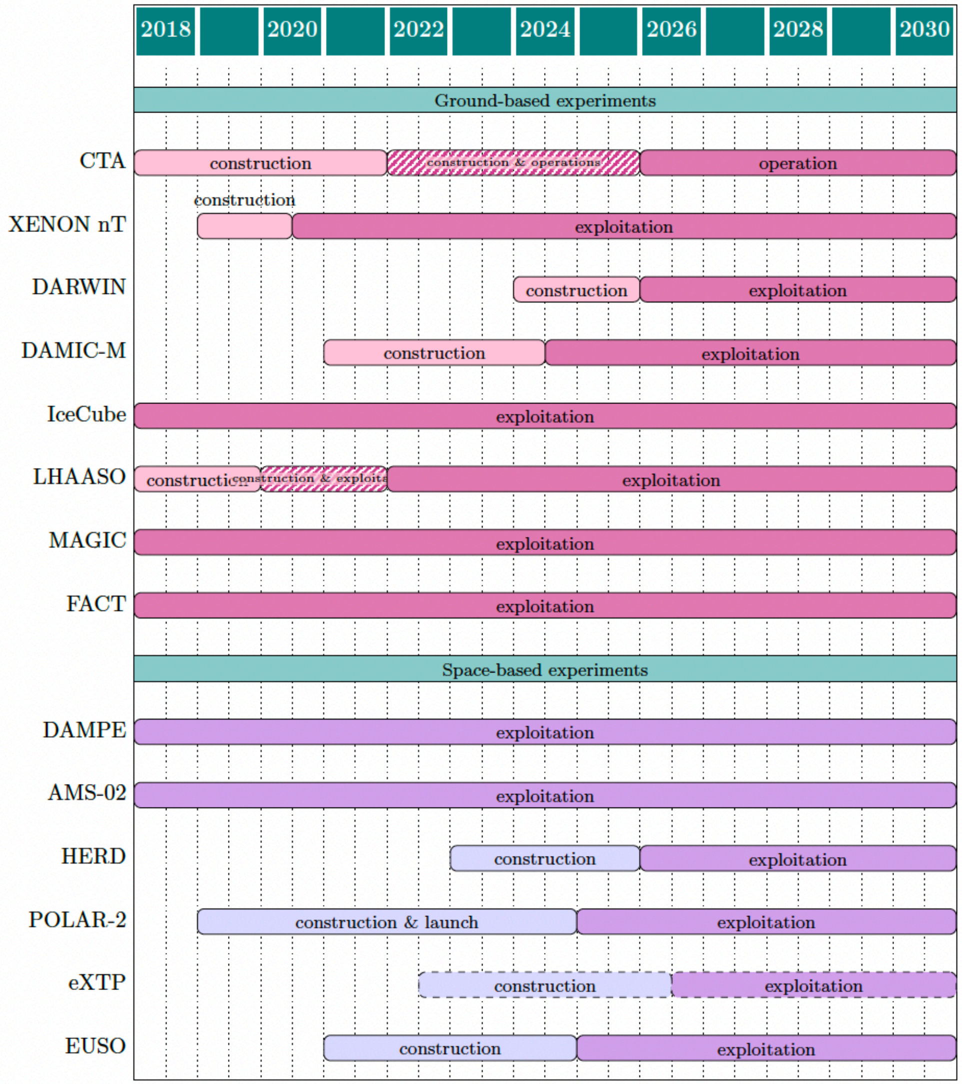
CHIPP Roadmap for
Research and Infrastructure 2029-2032
and beyond by the Swiss Particle Physics Community

Table of contents

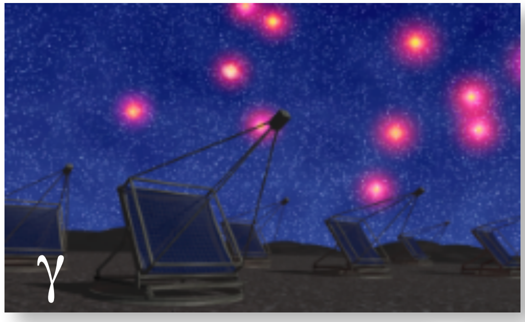
[Main Editor: Angela]

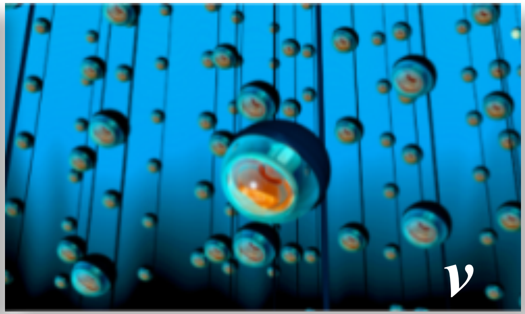
Pillar schedule

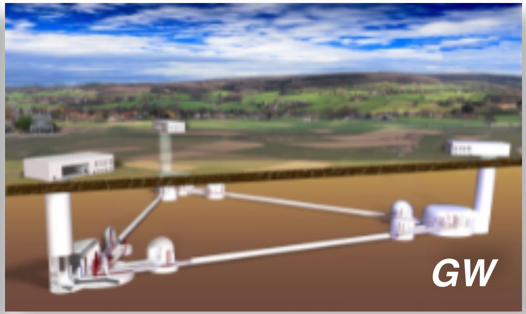
- why separate schedules per pillar?
- Large RI require a cumulative planning
- CTAO ERIC 2025 end of construction 2029
- ET operation in 2035
- IceCube construction restarted in 2023 towards x 10

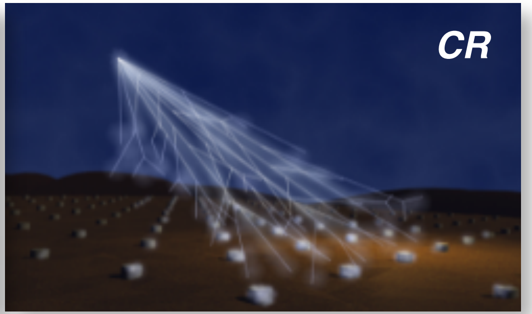


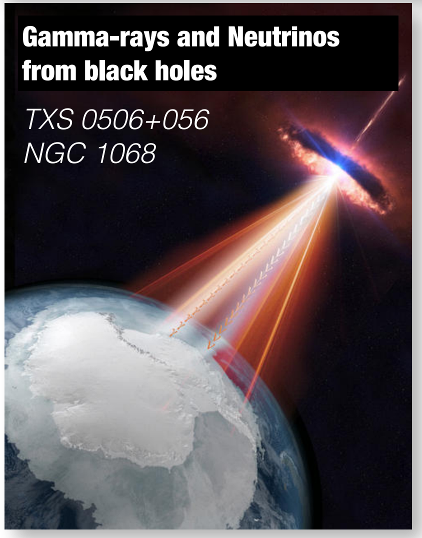
Input on Multi-Messenger











Gamma-rays and Neutrinos from black holes

TXS 0506+056
NGC 1068

Chasing the ammonia economy *p. 120*

Time invested matters for mice, rats, and humans *pp. 124 & 178*

Two spindles are better than one *pp. 128 & 189*

Science

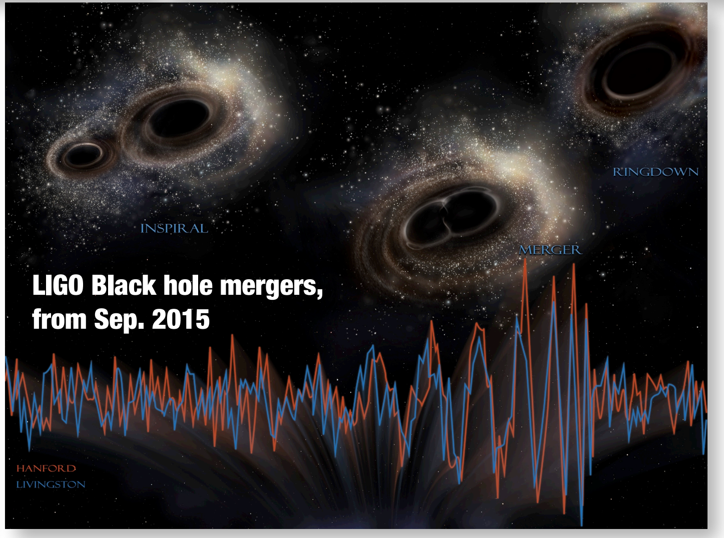
$15
13 JULY 2018
sciencemag.org

AAAS

NEUTRINOS FROM A BLAZAR

Multimessenger observations of an astrophysical neutrino source *pp. 115, 146, & 147*

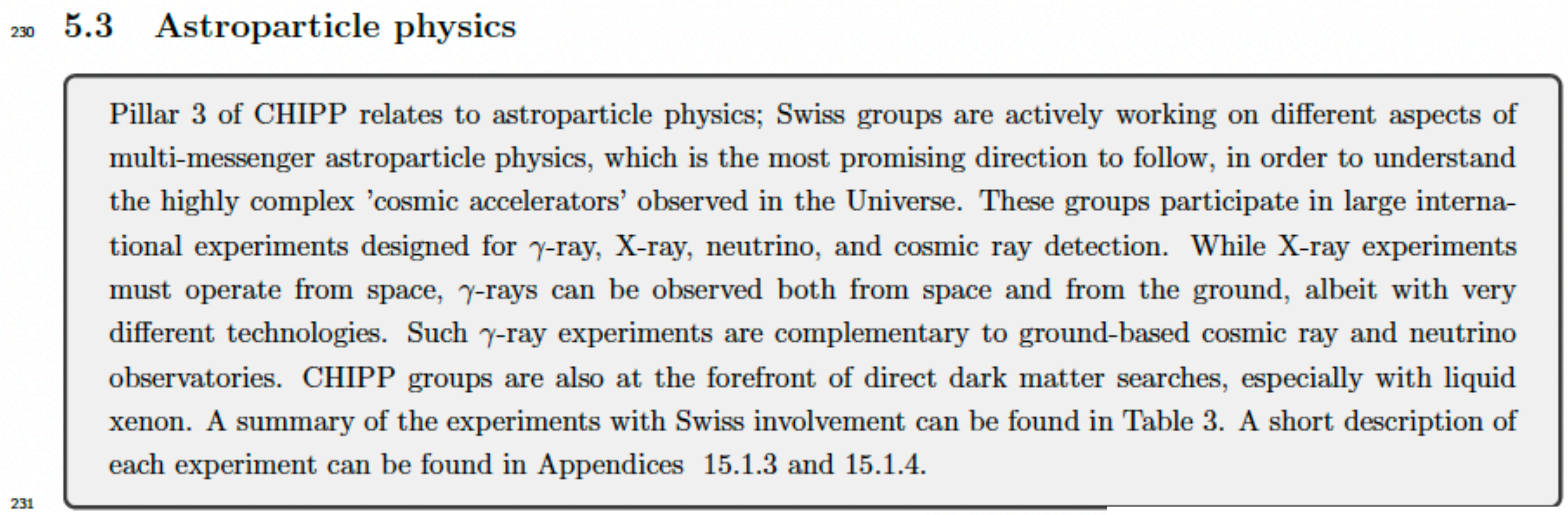
Science 361 (2018)



LIGO Black hole mergers, from Sep. 2015

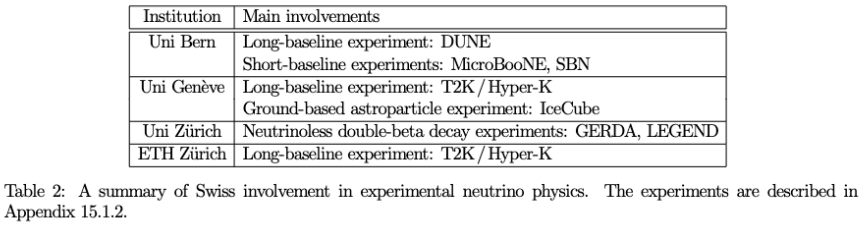
GW170817 Neutron star mergers in GW (VIRGO, LIGO) & Photons (Fermi-LAT,...)

Update the present Swiss landscape?



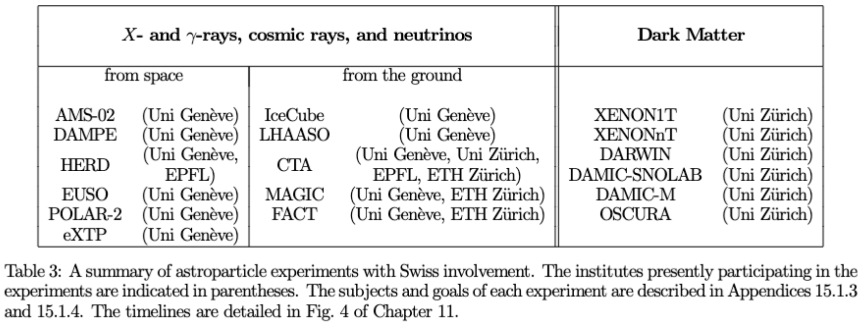
5.3 Astroparticle physics

Pillar 3 of CHIPP relates to astroparticle physics; Swiss groups are actively working on different aspects of multi-messenger astroparticle physics, which is the most promising direction to follow, in order to understand the highly complex 'cosmic accelerators' observed in the Universe. These groups participate in large international experiments designed for γ-ray, X-ray, neutrino, and cosmic ray detection. While X-ray experiments must operate from space, γ-rays can be observed both from space and from the ground, albeit with very different technologies. Such γ-ray experiments are complementary to ground-based cosmic ray and neutrino observatories. CHIPP groups are also at the forefront of direct dark matter searches, especially with liquid xenon. A summary of the experiments with Swiss involvement can be found in Table 3. A short description of each experiment can be found in Appendices 15.1.3 and 15.1.4.



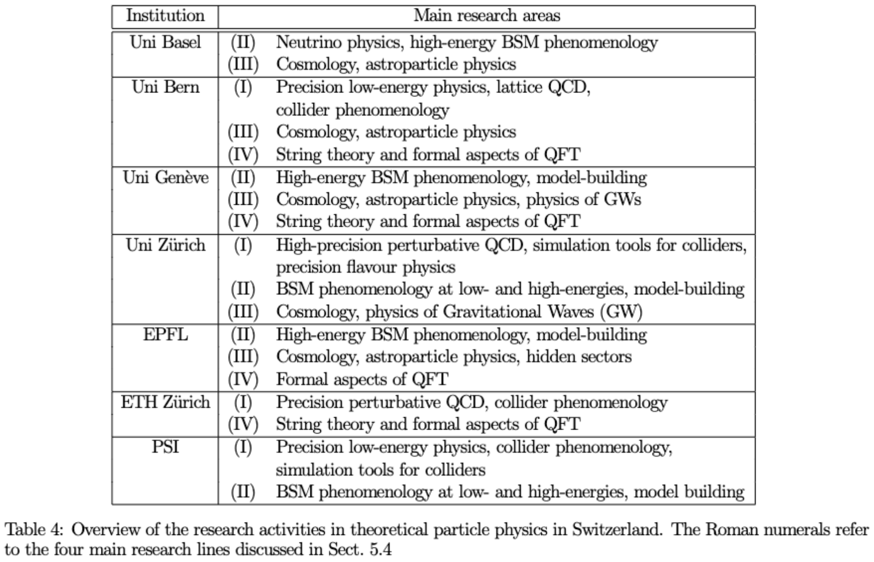
Institution	Main involvements
Uni Bern	Long-baseline experiment: DUNE Short-baseline experiments: MicroBooNE, SBN
Uni Genève	Long-baseline experiment: T2K / Hyper-K Ground-based astroparticle experiment: IceCube
Uni Zürich	Neutrinoless double-beta decay experiments: GERDA, LEGEND
ETH Zürich	Long-baseline experiment: T2K / Hyper-K

Table 2: A summary of Swiss involvement in experimental neutrino physics. The experiments are described in Appendix 15.1.2.



X- and γ-rays, cosmic rays, and neutrinos				**Dark Matter**	
from space		from the ground			
AMS-02	(Uni Genève)	IceCube	(Uni Genève)	XENON1T	(Uni Zürich)
DAMPE	(Uni Genève)	LHAASO	(Uni Genève)	XENONnT	(Uni Zürich)
HERD	(Uni Genève, EPFL)	CTA	(Uni Genève, Uni Zürich, EPFL, ETH Zürich)	DARWIN	(Uni Zürich)
				DAMIC-SNOLAB	(Uni Zürich)
EUSO	(Uni Genève)	MAGIC	(Uni Genève, ETH Zürich)	DAMIC-M	(Uni Zürich)
POLAR-2	(Uni Genève)	FACT	(Uni Genève, ETH Zürich)	OSCURA	(Uni Zürich)
eXTP	(Uni Genève)				

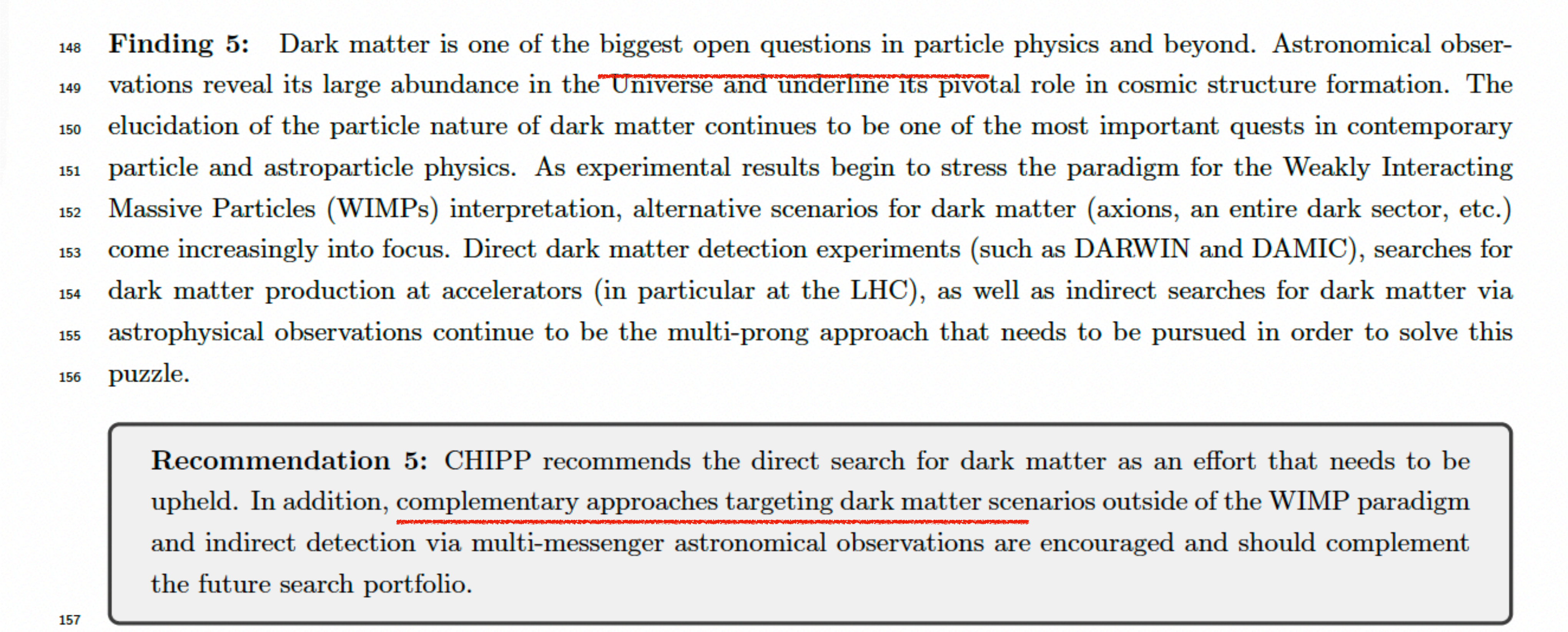
Table 3: A summary of astroparticle experiments with Swiss involvement. The institutes presently participating in the experiments are indicated in parentheses. The subjects and goals of each experiment are described in Appendices 15.1.3 and 15.1.4. The timelines are detailed in Fig. 4 of Chapter 11.



Institution	Main research areas	
Uni Basel	(II)	Neutrino physics, high-energy BSM phenomenology
	(III)	Cosmology, astroparticle physics
Uni Bern	(I)	Precision low-energy physics, lattice QCD, collider phenomenology
	(III)	Cosmology, astroparticle physics
	(IV)	String theory and formal aspects of QFT
Uni Genève	(II)	High-energy BSM phenomenology, model-building
	(III)	Cosmology, astroparticle physics, physics of GWs
	(IV)	String theory and formal aspects of QFT
Uni Zürich	(I)	High-precision perturbative QCD, simulation tools for colliders, precision flavour physics
	(II)	BSM phenomenology at low- and high-energies, model-building
	(III)	Cosmology, physics of Gravitational Waves (GW)
EPFL	(II)	High-energy BSM phenomenology, model-building
	(III)	Cosmology, astroparticle physics, hidden sectors
	(IV)	Formal aspects of QFT
ETH Zürich	(I)	Precision perturbative QCD, collider phenomenology
	(IV)	String theory and formal aspects of QFT
PSI	(I)	Precision low-energy physics, collider phenomenology, simulation tools for colliders
	(II)	BSM phenomenology at low- and high-energies, model building

Table 4: Overview of the research activities in theoretical particle physics in Switzerland. The Roman numerals refer to the four main research lines discussed in Sect. 5.4

Executive summary recommendations



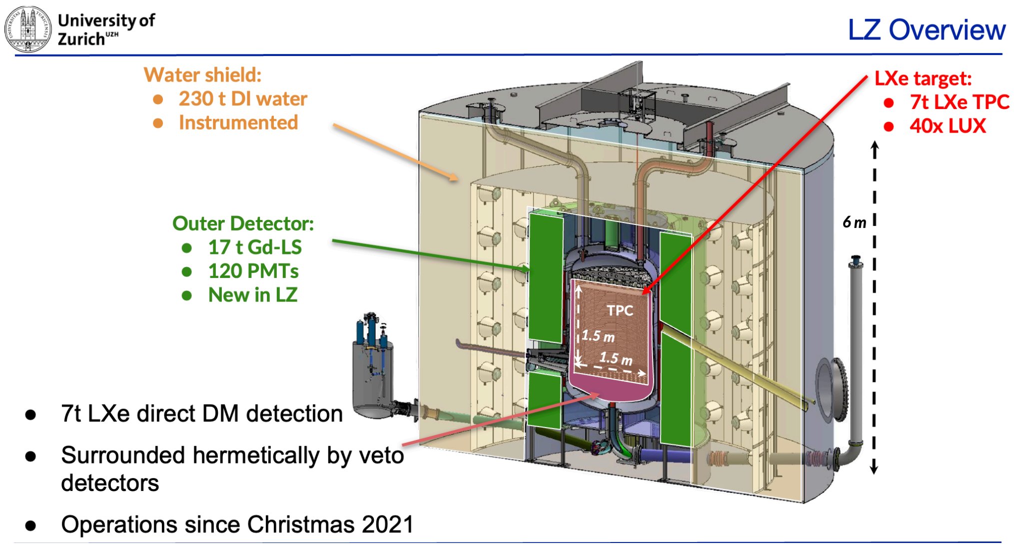
Finding 5: Dark matter is one of the biggest open questions in particle physics and beyond. Astronomical observations reveal its large abundance in the Universe and underline its pivotal role in cosmic structure formation. The elucidation of the particle nature of dark matter continues to be one of the most important quests in contemporary particle and astroparticle physics. As experimental results begin to stress the paradigm for the Weakly Interacting Massive Particles (WIMPs) interpretation, alternative scenarios for dark matter (axions, an entire dark sector, etc.) come increasingly into focus. Direct dark matter detection experiments (such as DARWIN and DAMIC), searches for dark matter production at accelerators (in particular at the LHC), as well as indirect searches for dark matter via astrophysical observations continue to be the multi-prong approach that needs to be pursued in order to solve this puzzle.

Recommendation 5: CHIPP recommends the direct search for dark matter as an effort that needs to be upheld. In addition, complementary approaches targeting dark matter scenarios outside of the WIMP paradigm and indirect detection via multi-messenger astronomical observations are encouraged and should complement the future search portfolio.

Multi-messenger, multi-technology, across all fields

LZ, Tesseract

LXe Time Projection Chambers - convergence towards DARWIN



University of Zurich

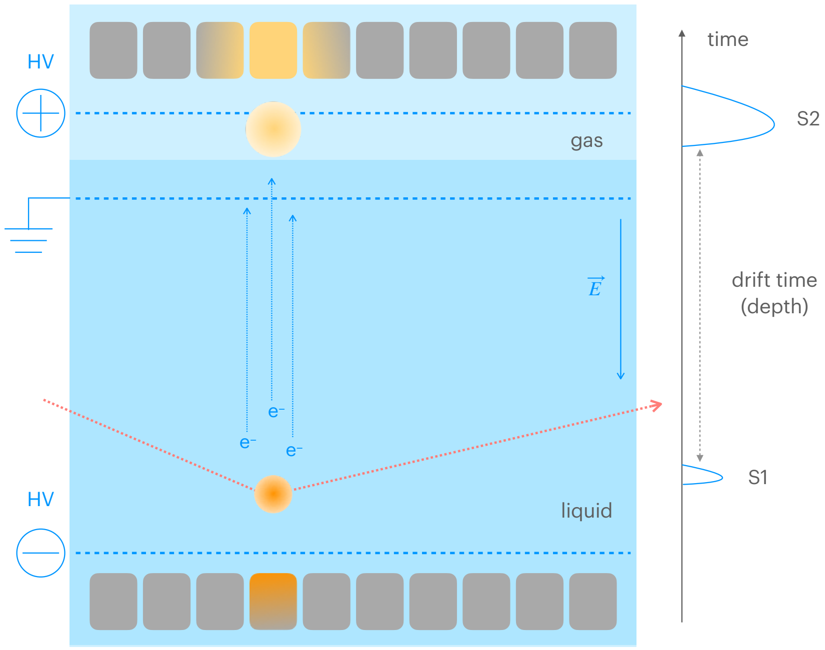
LZ Overview

Water shield:
- 230 t DI water
- Instrumented

Outer Detector:
- 17 t Gd-LS
- 120 PMTs
- New in LZ

LXe target:
- 7t LXe TPC
- 40x LUX

- 7t LXe direct DM detection
- Surrounded hermetically by veto detectors
- Operations since Christmas 2021

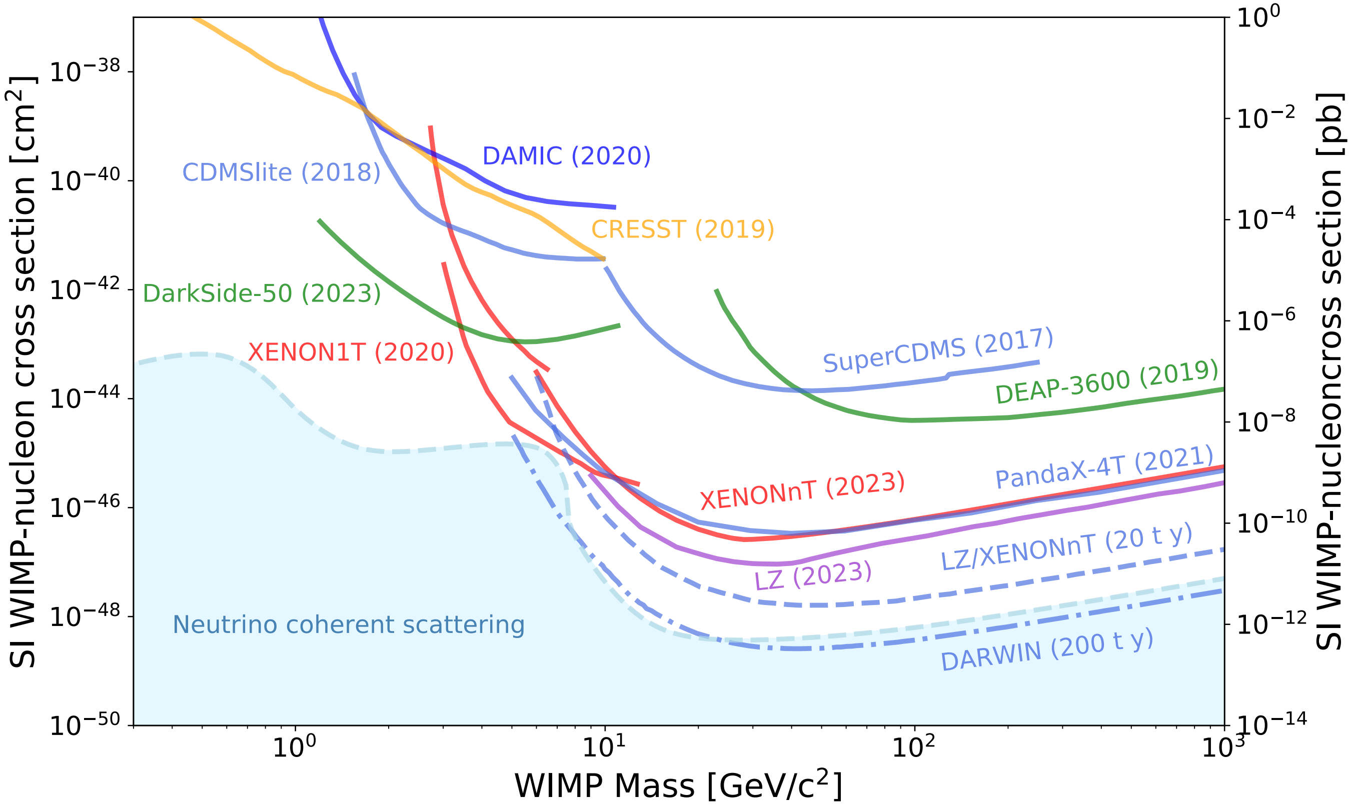


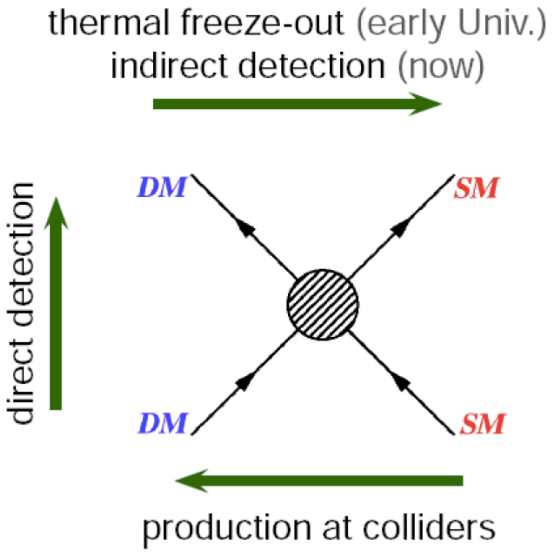
$$\lambda_{LXe} = 175 \text{ nm}$$

- Observe the small light and charge signals when a particle interacts in the dense liquid target
- 3D position reconstruction
- Good energy resolution
- Particle discrimination: ratio of charge/light

LZ, Xenon nT , Tesseract

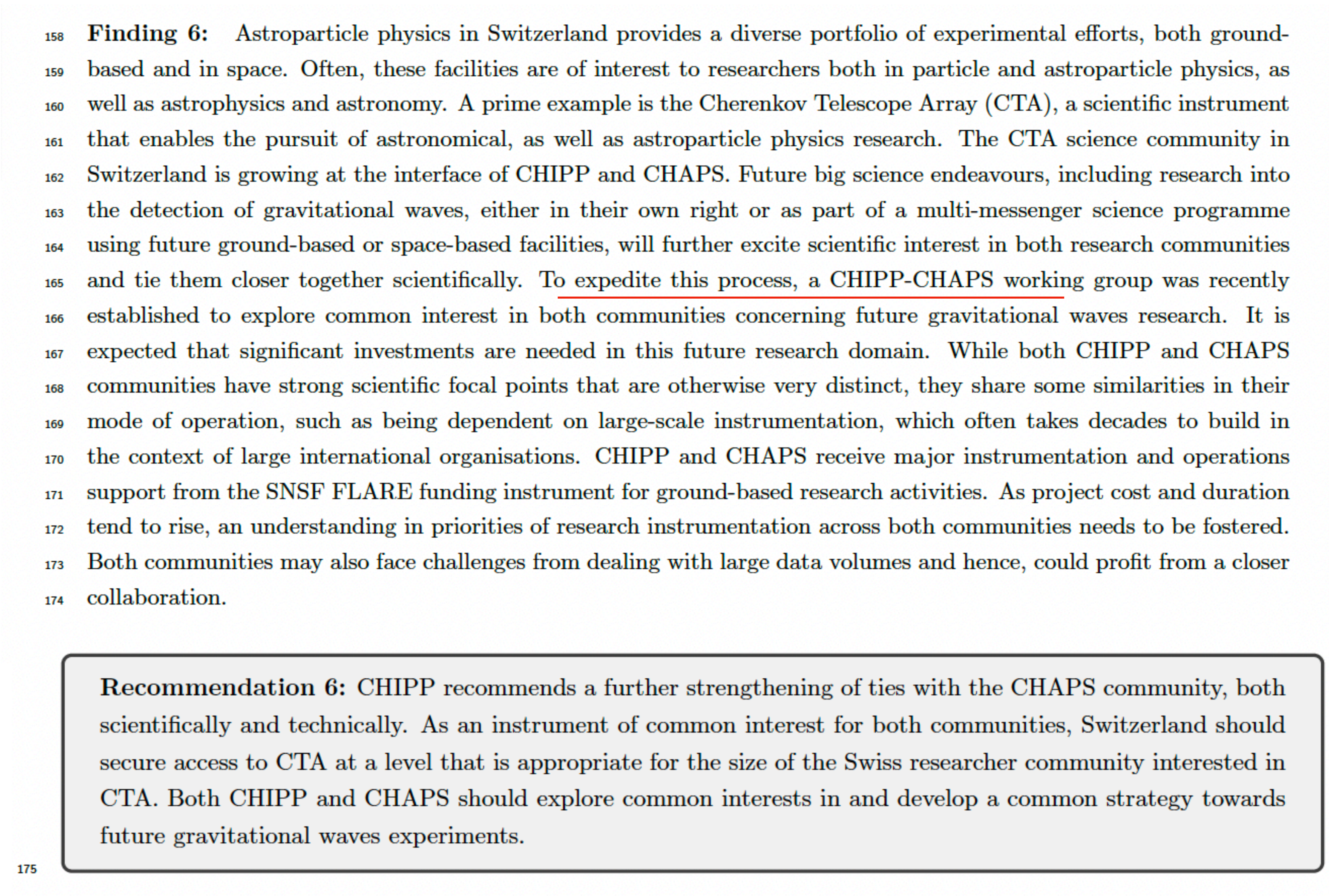
Beyond the neutrino floor (overlap with Pillar 2?)





What if DM is the only resource if only gravitationally interacting (role of primordial BHs, Large scale surveys, GWs roadmap (ground and space?), Profit of new instruments (Gaia, EUCLID, SKAO, CTAO,…)

Executive summary recommendations



Finding 6: Astroparticle physics in Switzerland provides a diverse portfolio of experimental efforts, both ground-based and in space. Often, these facilities are of interest to researchers both in particle and astroparticle physics, as well as astrophysics and astronomy. A prime example is the Cherenkov Telescope Array (CTA), a scientific instrument that enables the pursuit of astronomical, as well as astroparticle physics research. The CTA science community in Switzerland is growing at the interface of CHIPP and CHAPS. Future big science endeavours, including research into the detection of gravitational waves, either in their own right or as part of a multi-messenger science programme using future ground-based or space-based facilities, will further excite scientific interest in both research communities and tie them closer together scientifically. To expedite this process, a CHIPP-CHAPS working group was recently established to explore common interest in both communities concerning future gravitational waves research. It is expected that significant investments are needed in this future research domain. While both CHIPP and CHAPS communities have strong scientific focal points that are otherwise very distinct, they share some similarities in their mode of operation, such as being dependent on large-scale instrumentation, which often takes decades to build in the context of large international organisations. CHIPP and CHAPS receive major instrumentation and operations support from the SNSF FLARE funding instrument for ground-based research activities. As project cost and duration tend to rise, an understanding in priorities of research instrumentation across both communities needs to be fostered. Both communities may also face challenges from dealing with large data volumes and hence, could profit from a closer collaboration.

Recommendation 6: CHIPP recommends a further strengthening of ties with the CHAPS community, both scientifically and technically. As an instrument of common interest for both communities, Switzerland should secure access to CTA at a level that is appropriate for the size of the Swiss researcher community interested in CTA. Both CHIPP and CHAPS should explore common interests in and develop a common strategy towards future gravitational waves experiments.

Multi-disciplinarity is a plus. CHIPP / CHAPS overlap concerns GWs and CTAO. They are big RIs in synergy with Astro projects like SKAO,…

Big science, Big Data and technology challenges in Swiss industry

Long-term operation is a challenge as construction. Means sustaining legal entities and data centres in Switzerland

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

The Cherenkov Telescope Array Observatory (CTAO)

www.cta-observatory.org/

cta cherenkov telescope array

University of Zurich UZH

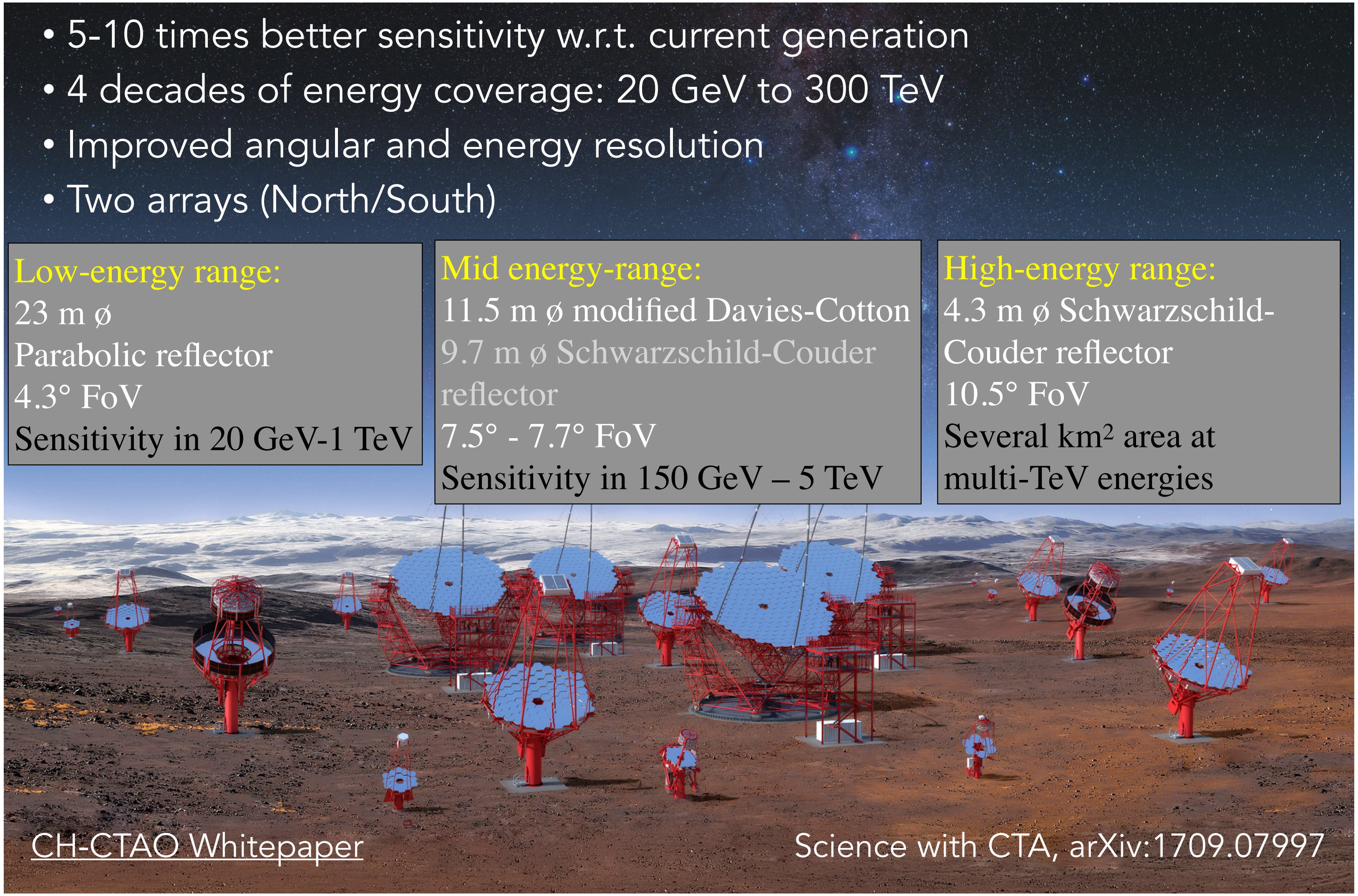
ETH zürich

CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

EPFL

UNIVERSITÄT BERN

CTAO-CH Collaboration is regulated by a collaboration agreement



- 5-10 times better sensitivity w.r.t. current generation
- 4 decades of energy coverage: 20 GeV to 300 TeV
- Improved angular and energy resolution
- Two arrays (North/South)

Low-energy range:
23 m ø
Parabolic reflector
4.3° FoV
Sensitivity in 20 GeV-1 TeV

Mid energy-range:
11.5 m ø modified Davies-Cotton
9.7 m ø Schwarzschild-Couder reflector
7.5° - 7.7° FoV
Sensitivity in 150 GeV – 5 TeV

High-energy range:
4.3 m ø Schwarzschild-Couder reflector
10.5° FoV
Several km^2 area at multi-TeV energies

CH-CTAO Whitepaper

Science with CTA, arXiv:1709.07997

Update in recommendations (CTAO)

Accession to Switzerland to the CTAO/ET… final legal entity should be secured.

- Should it become a recommendation for distributed RI recognised in the Roadmap for IGO, ERIC,… (ERIC is difficult…)?

The operation of CTAO is foreseen to last order of 20-30 yr from its completion.

- Should it be a recommendation? Operation requires a comparable investment to Construction, long-term interest of the community requires solid consortia;

- Data Centre in Astrophysics/Astroparticle at CSCS: one of the 4 off-site data centres of CTAO (and Regional Data Centre of SKAO,…), this will require securing annual operation funds in synergy with SKAO and other big data projects in astronomy. What instrument in the long term? FLARE as LHC, other?

CTAO Science

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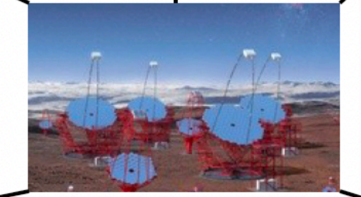
FACULTÉ DES SCIENCES



Galactic Science: SNRs, PWNe, Gal. Cent., Pulsars, novae ...

Extragalactic Science: AGNs and beyond

Transients and Multi-Messanger: Follow up of GRBs, GW, ν, ...

Fundamental Physics and Cosmology: Probing Dark Matter, LIV, EBL, IGMF, ...

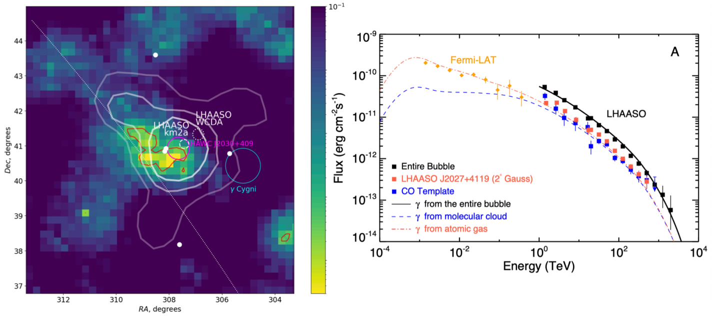
More than gamma rays: Cosmic Rays, Intensity interferometry, optical measurements, ...

Current generation : MAGIC measures Crab-like spectra in 1.5 min with 30% accuracy

1000 hours per year good weather dark time

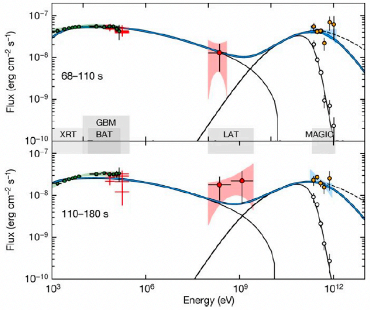
Every hour of CTAO will be precious!

Cygnus cocoon stay tuned



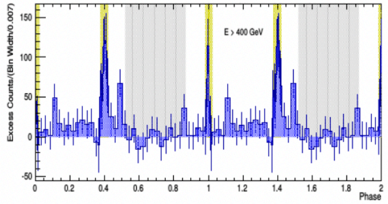
GRB 190114C detection by MAGIC

- The first GRB reported to be detected in VHE gamma rays
- Highly significant signal of over 50σ
- Emission detected up to ~40 min from the onset of the burst
- Energy fluxes of TeV, GeV and X-ray ranges are comparable
- Spectrum reaching TeV energies – new emission component
- The most impressive GRB until the time of “BOAT” GRB 221009A detected by LHAASO

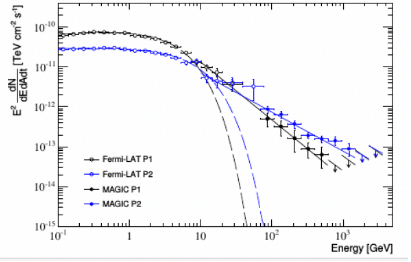


Acciari et al. 2019

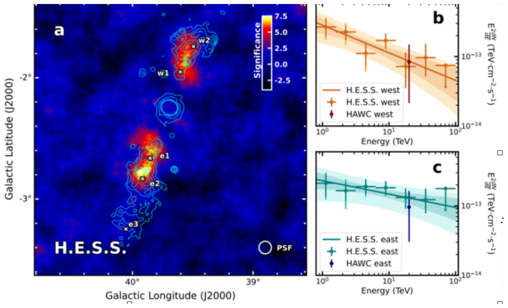
Pulsars: from 10 GeV to TeV



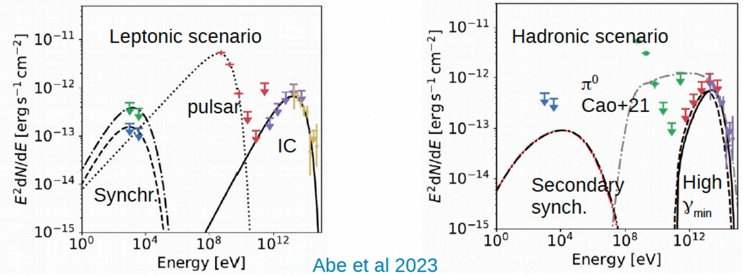
Ansoldi et al. 2016



Microquasars: SS433



LHAASO J2108+5157 : hadronic or leptonic

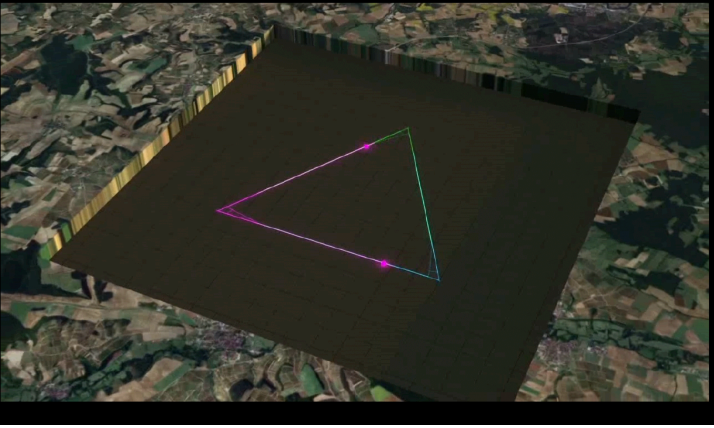


Abe et al 2023

PWN or TeV halo

ET: the European 3G GW observatory concept

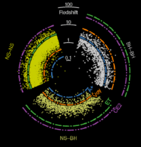
ET EINSTEIN TELESCOPE

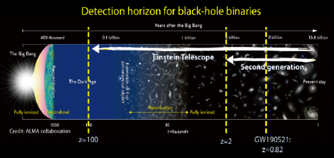


Triangular shape
Arms: 10 km
Underground
Cryogenic
Increase laser power
Xylophone
...

The ET sensitivity will make it possible:

- EARLY UNIVERSE
- POPULATION

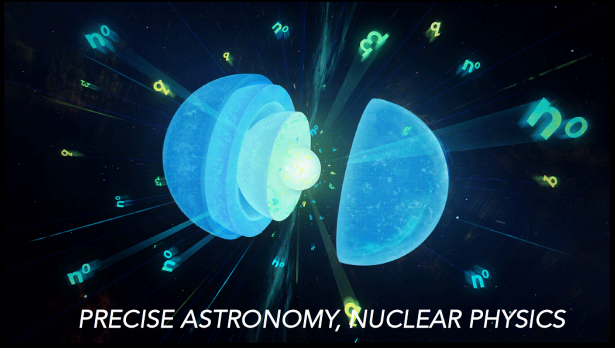




- PRECISION GW ASTRONOMY: exceptional parameter estimation accuracy for very high SNR events

Remote Universe

Nearby Universe



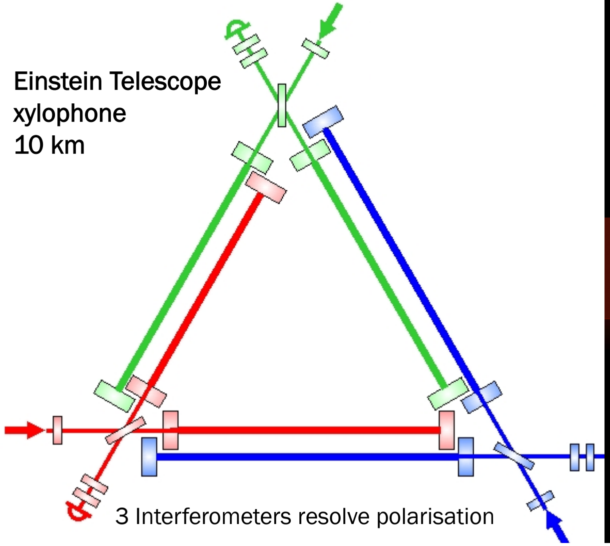
PRECISE ASTRONOMY, NUCLEAR PHYSICS

RELATIVISTIC JET PHYSICS,
GRB EMISSION MECHANISMS,
COSMOLOGY and MODIFIED GRAVITY

Credit: Ronchini

KILONOVA PHYSICS,
NUCLEOSYNTHESIS, NUCLEAR
PHYISCS and H0 ESTIMATE

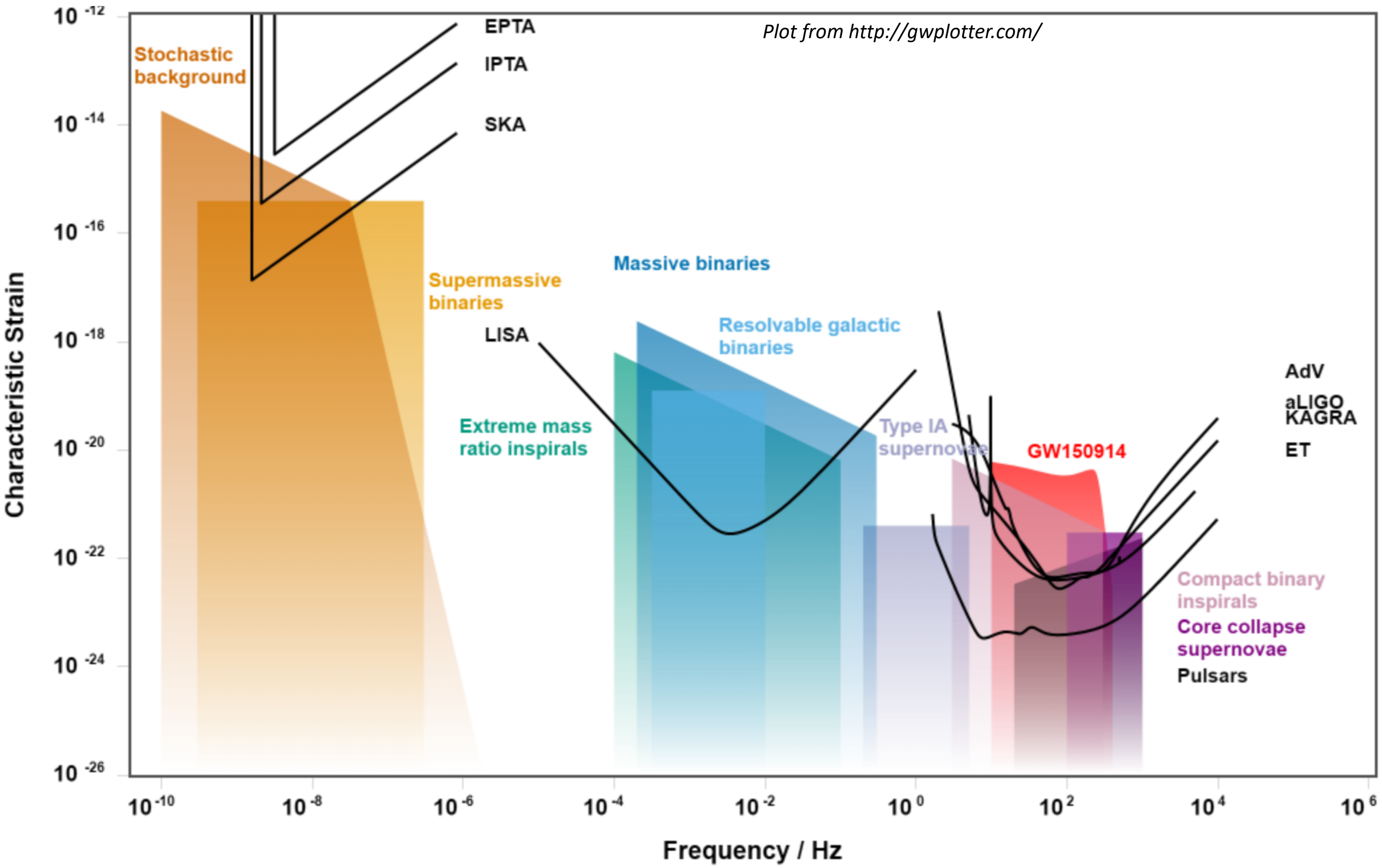
Image credit: NASA Goddard Space Flight Center



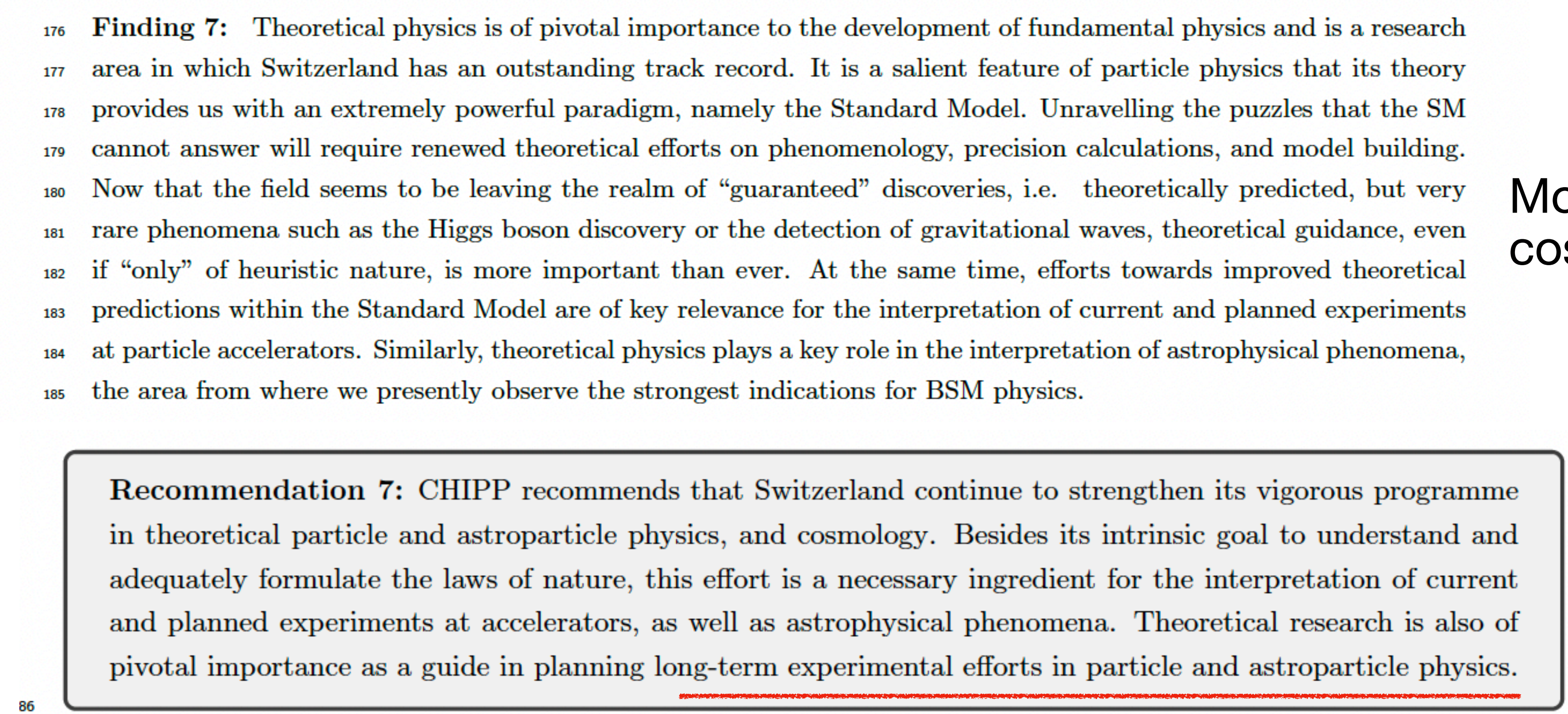
Einstein Telescope
xylophone
10 km

3 Interferometers resolve polarisation

Gravitational wave searches



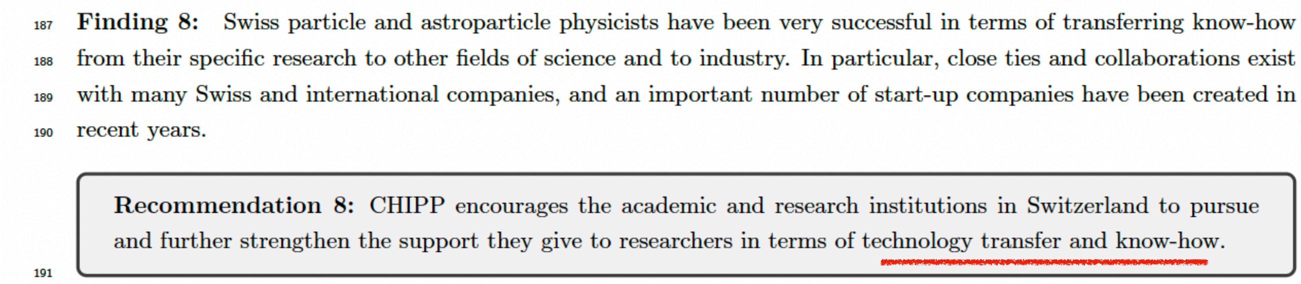
Executive summary recommendations



Finding 7: Theoretical physics is of pivotal importance to the development of fundamental physics and is a research area in which Switzerland has an outstanding track record. It is a salient feature of particle physics that its theory provides us with an extremely powerful paradigm, namely the Standard Model. Unravelling the puzzles that the SM cannot answer will require renewed theoretical efforts on phenomenology, precision calculations, and model building. Now that the field seems to be leaving the realm of "guaranteed" discoveries, i.e. theoretically predicted, but very rare phenomena such as the Higgs boson discovery or the detection of gravitational waves, theoretical guidance, even if "only" of heuristic nature, is more important than ever. At the same time, efforts towards improved theoretical predictions within the Standard Model are of key relevance for the interpretation of current and planned experiments at particle accelerators. Similarly, theoretical physics plays a key role in the interpretation of astrophysical phenomena, the area from where we presently observe the strongest indications for BSM physics.

Recommendation 7: CHIPP recommends that Switzerland continue to strengthen its vigorous programme in theoretical particle and astroparticle physics, and cosmology. Besides its intrinsic goal to understand and adequately formulate the laws of nature, this effort is a necessary ingredient for the interpretation of current and planned experiments at accelerators, as well as astrophysical phenomena. Theoretical research is also of pivotal importance as a guide in planning long-term experimental efforts in particle and astroparticle physics.

More on cosmology?

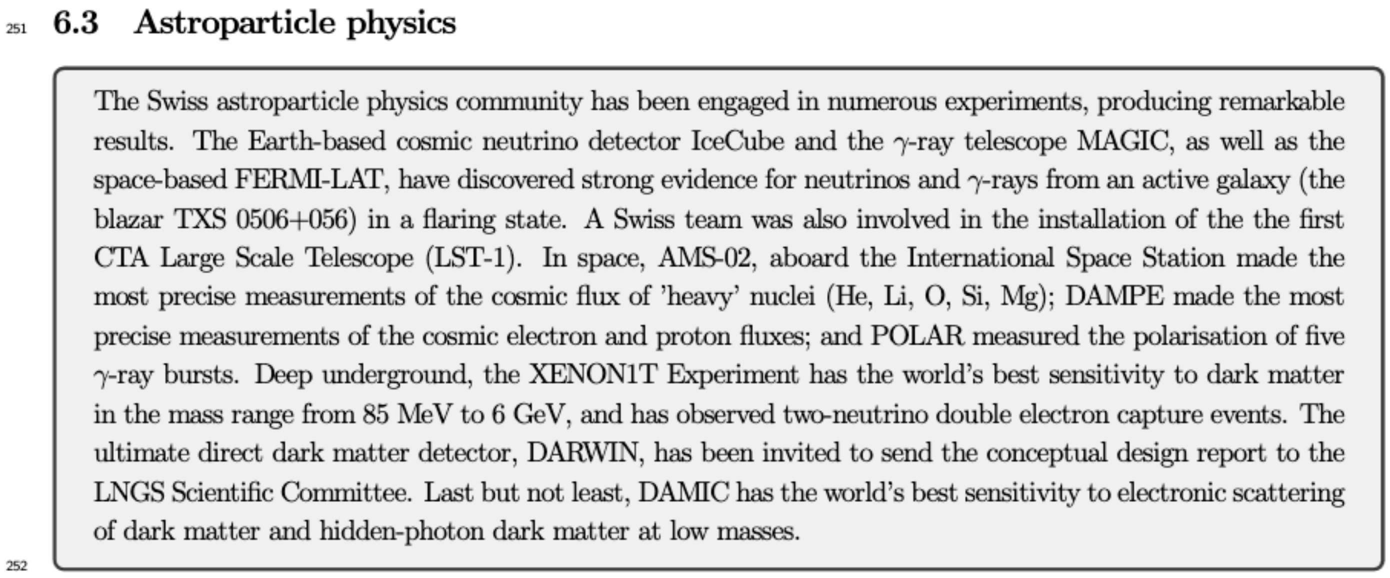


Finding 8: Swiss particle and astroparticle physicists have been very successful in terms of transferring know-how from their specific research to other fields of science and to industry. In particular, close ties and collaborations exist with many Swiss and international companies, and an important number of start-up companies have been created in recent years.

Recommendation 8: CHIPP encourages the academic and research institutions in Switzerland to pursue and further strengthen the support they give to researchers in terms of technology transfer and know-how.

Innovation hubs more useful to researchers also in cantonal universities

Major successes (2017-2020) update?



6.3 Astroparticle physics

The Swiss astroparticle physics community has been engaged in numerous experiments, producing remarkable results. The Earth-based cosmic neutrino detector IceCube and the γ-ray telescope MAGIC, as well as the space-based FERMI-LAT, have discovered strong evidence for neutrinos and γ-rays from an active galaxy (the blazar TXS 0506+056) in a flaring state. A Swiss team was also involved in the installation of the the first CTA Large Scale Telescope (LST-1). In space, AMS-02, aboard the International Space Station made the most precise measurements of the cosmic flux of 'heavy' nuclei (He, Li, O, Si, Mg); DAMPE made the most precise measurements of the cosmic electron and proton fluxes; and POLAR measured the polarisation of five γ-ray bursts. Deep underground, the XENON1T Experiment has the world's best sensitivity to dark matter in the mass range from 85 MeV to 6 GeV, and has observed two-neutrino double electron capture events. The ultimate direct dark matter detector, DARWIN, has been invited to send the conceptual design report to the LNGS Scientific Committee. Last but not least, DAMIC has the world's best sensitivity to electronic scattering of dark matter and hidden-photon dark matter at low masses.

New multi messenger evidence

GW170817 (GW-gamma-rays)

TXS 0508+05 (nu+gamma-rays)

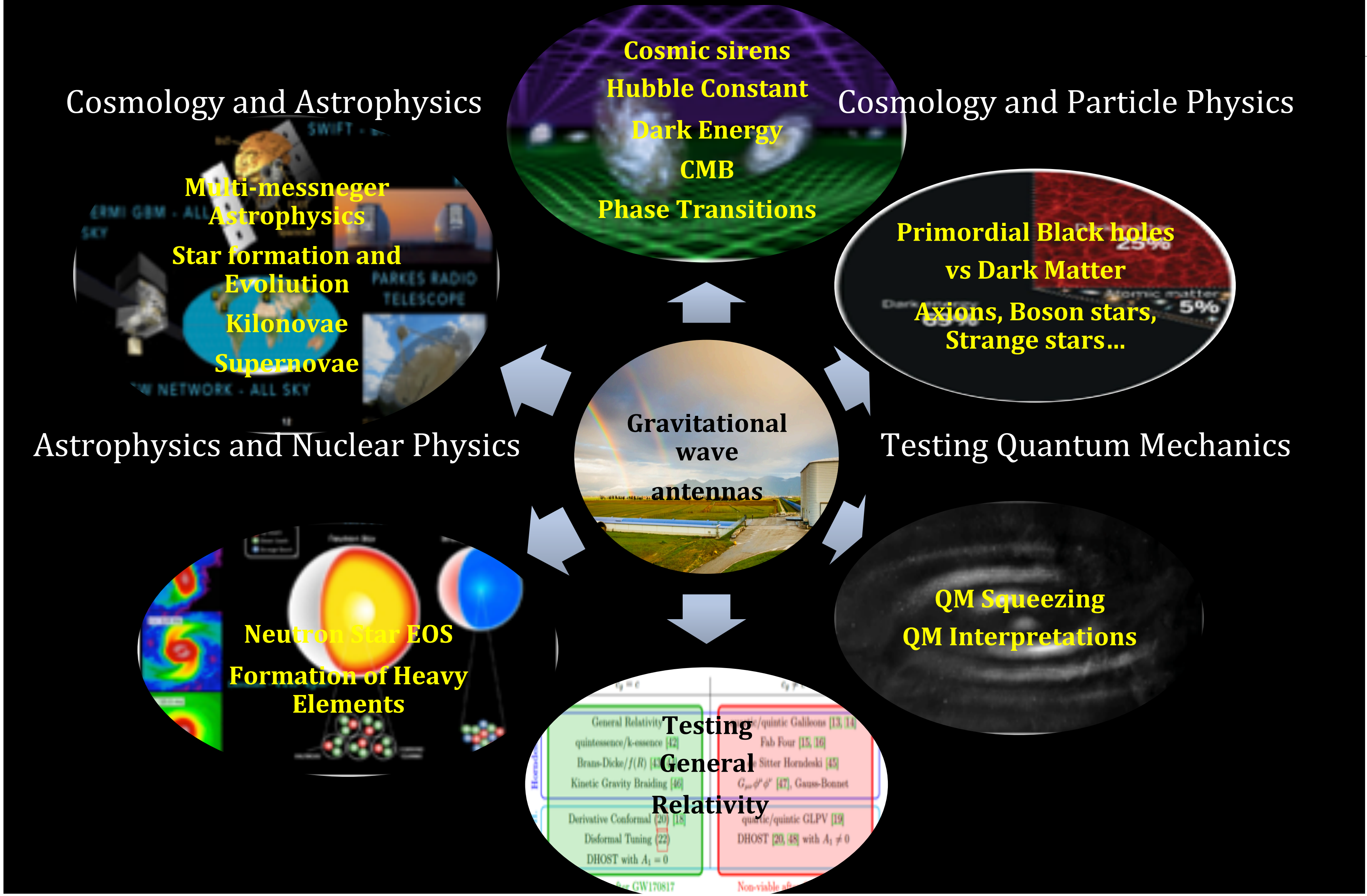
About 8 GRBs from ground to 20 TeV in LHAASO

First neutrino only source: NGC 1068 challenges standard hadronic models

Neutrinos from the galactic plane

Limits 2023 LZ almost at the neutrino floor,…

Gravitational waves and Fundamental Science



Gravitational wave antennas

Cosmology and Astrophysics

Multi-messneger Astrophysics

Star formation and Evolution

Kilonovae

Supernovae

Cosmic sirens

Hubble Constant

Dark Energy

CMB

Phase Transitions

Cosmology and Particle Physics

Primordial Black holes vs Dark Matter

Axions, Boson stars, Strange stars…

Astrophysics and Nuclear Physics

Neutron Star EOS

Formation of Heavy Elements

Testing Quantum Mechanics

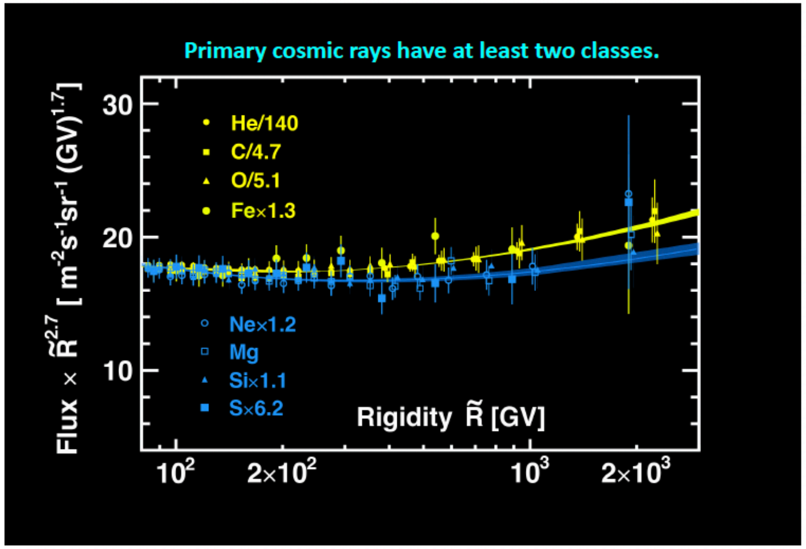
QM Squeezing

QM Interpretations

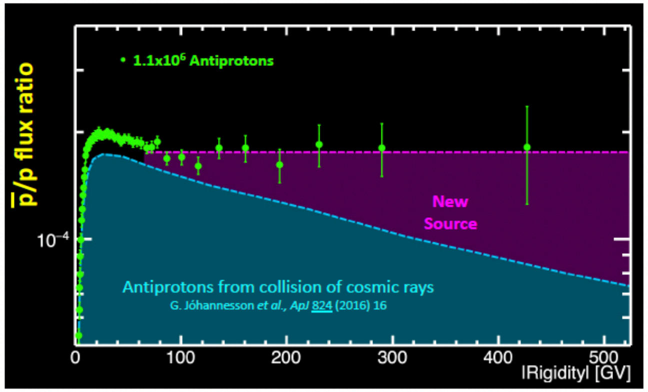
Testing General Relativity

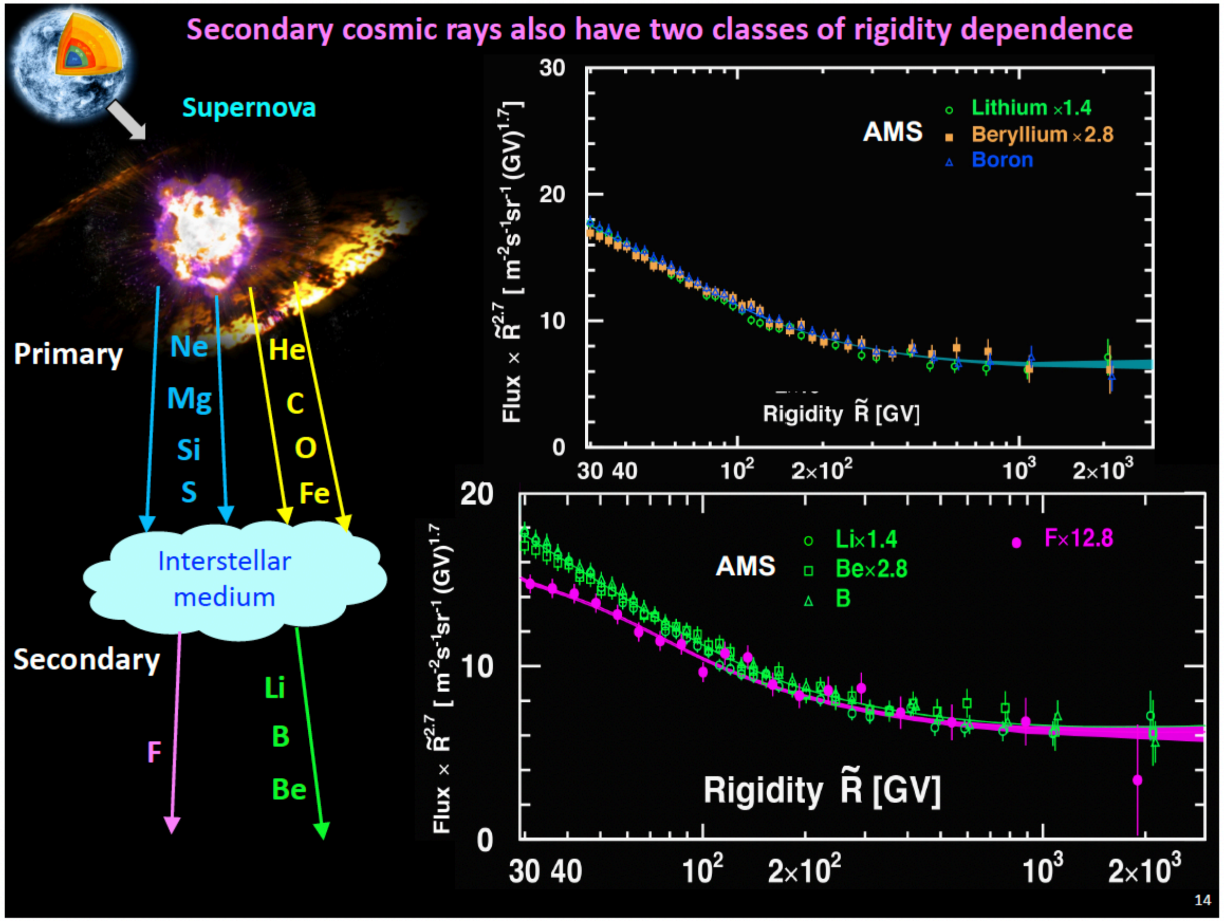
GW address exciting science: tests of gravity in regions of greates6t space-time curvature, graviton mass constraints, Hubble constant, black holes existence, their horizon and their connection to dark matter, matter in extreme environment, origin of heavy elements, equation of state of ultra-dense matter elements, exotic objects

Cosmic ray from space



Primary cosmic rays have at least two classes.

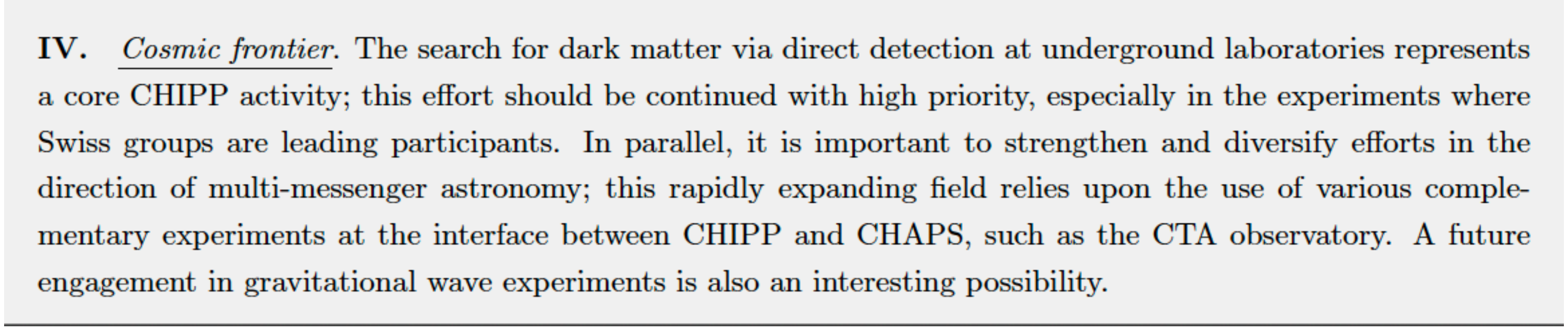




Secondary cosmic rays also have two classes of rigidity dependence

Slides credit: ICRC2023 highlight talk

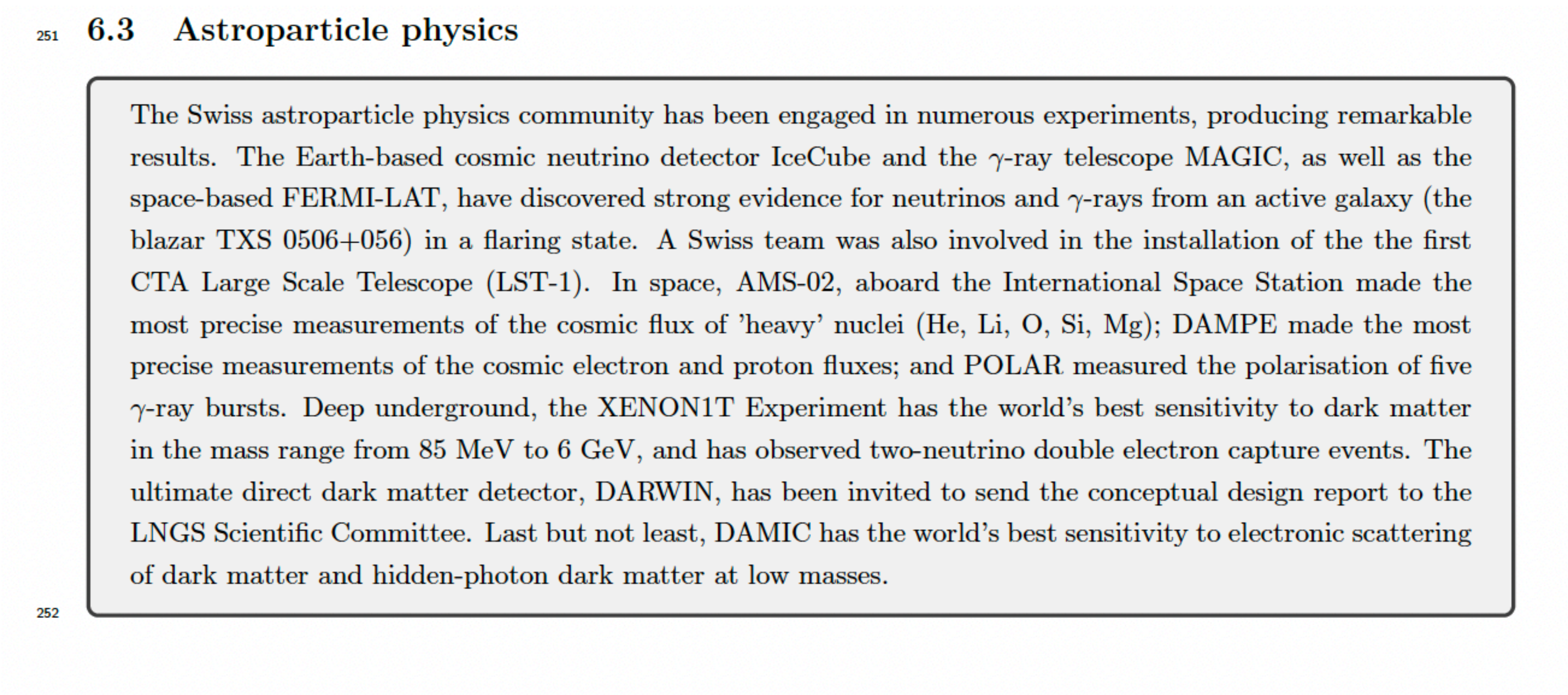
Overall Vision



IV. *Cosmic frontier*. The search for dark matter via direct detection at underground laboratories represents a core CHIPP activity; this effort should be continued with high priority, especially in the experiments where Swiss groups are leading participants. In parallel, it is important to strengthen and diversify efforts in the direction of multi-messenger astronomy; this rapidly expanding field relies upon the use of various complementary experiments at the interface between CHIPP and CHAPS, such as the CTA observatory. A future engagement in gravitational wave experiments is also an interesting possibility.

- Secure long-term engagement in RI operation
- More specific plans for Darwin, CTAO and ET require a spending profile

Major successes (2017-2020)



6.3 Astroparticle physics

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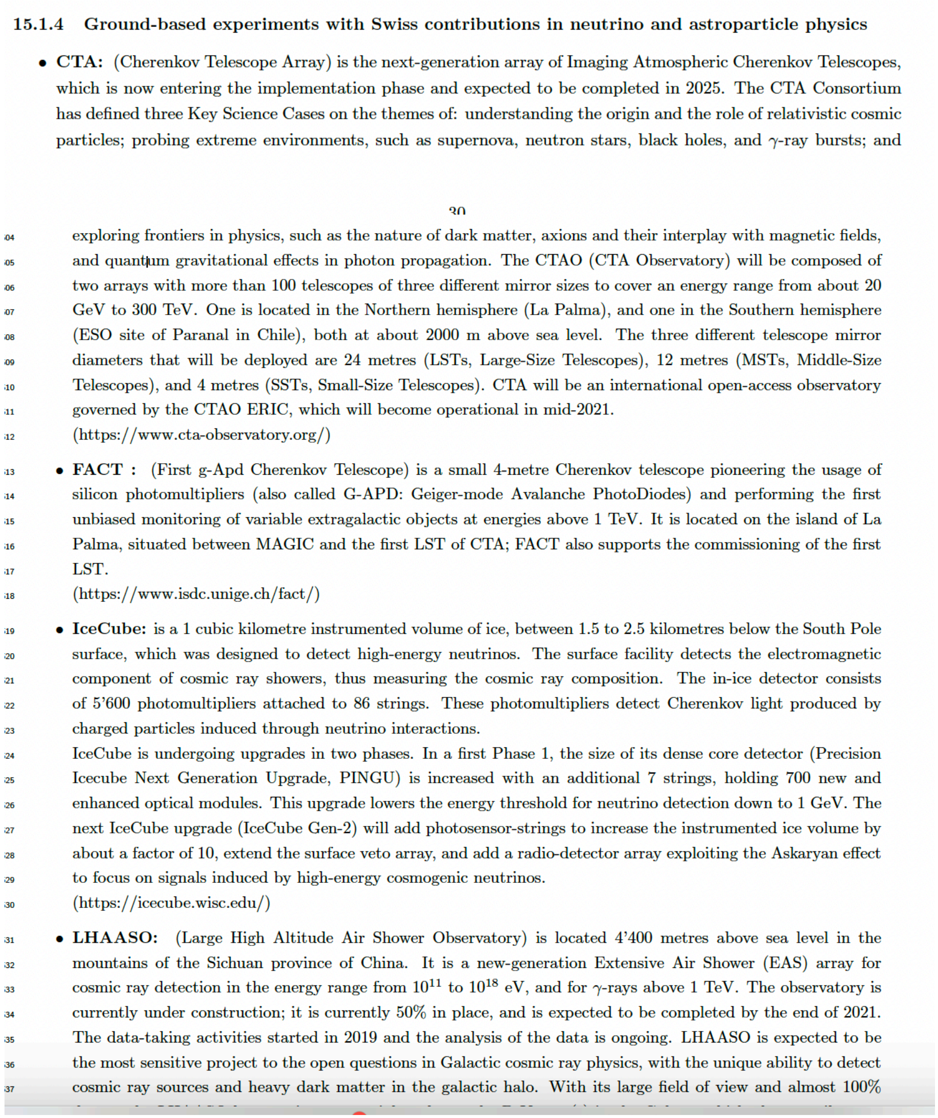
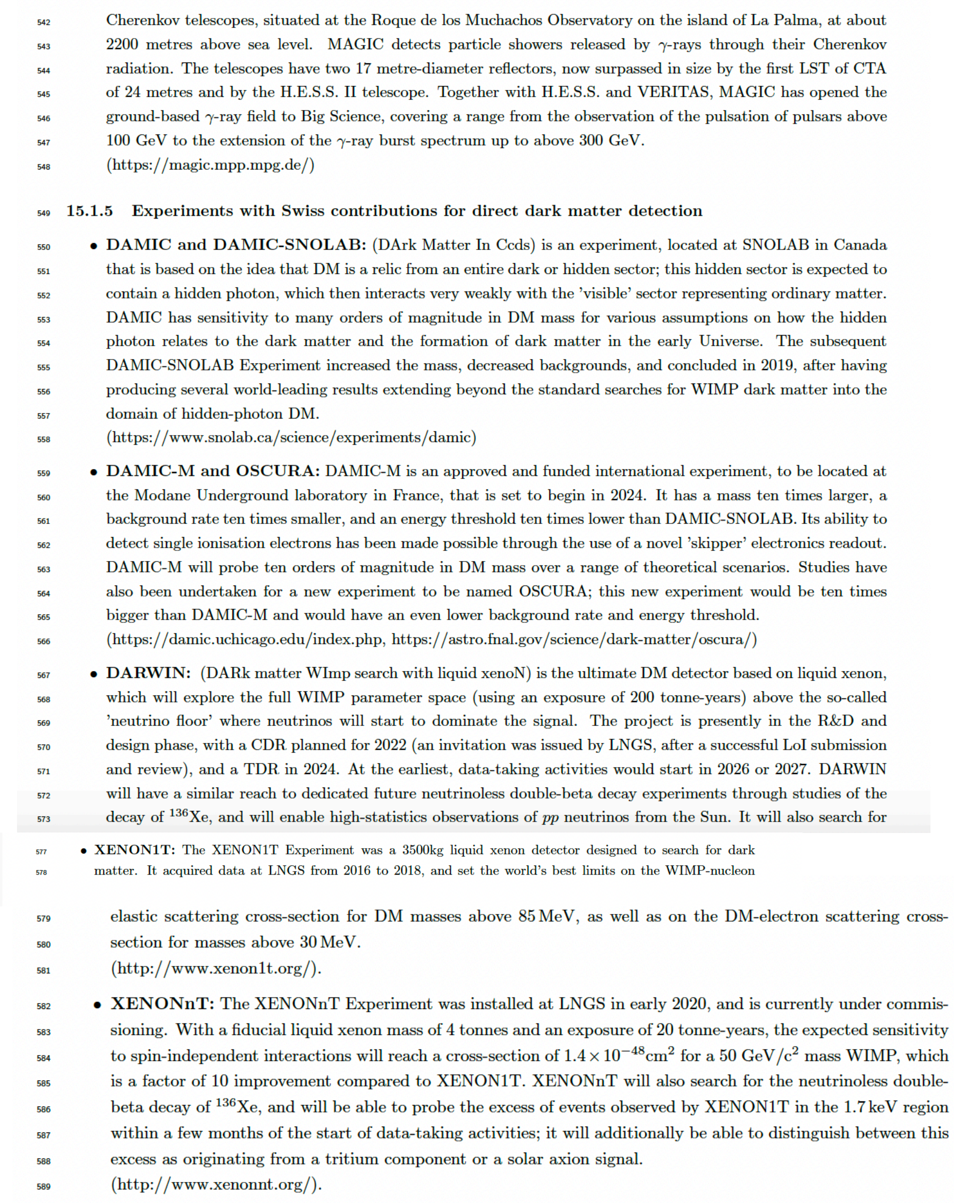
List of experiments



15.1.4 Ground-based experiments with Swiss contributions in neutrino and astroparticle physics

- **CTA:** (Cherenkov Telescope Array) is the next-generation array of Imaging Atmospheric Cherenkov Telescopes, which is now entering the implementation phase and expected to be completed in 2025. The CTA Consortium has defined three Key Science Cases on the themes of: understanding the origin and the role of relativistic cosmic particles; probing extreme environments, such as supernova, neutron stars, black holes, and γ-ray bursts; and

  exploring frontiers in physics, such as the nature of dark matter, axions and their interplay with magnetic fields, and quantum gravitational effects in photon propagation. The CTAO (CTA Observatory) will be composed of two arrays with more than 100 telescopes of three different mirror sizes to cover an energy range from about 20 GeV to 300 TeV. One is located in the Northern hemisphere (La Palma), and one in the Southern hemisphere (ESO site of Paranal in Chile), both at about 2000 m above sea level. The three different telescope mirror diameters that will be deployed are 24 metres (LSTs, Large-Size Telescopes), 12 metres (MSTs, Middle-Size Telescopes), and 4 metres (SSTs, Small-Size Telescopes). CTA will be an international open-access observatory governed by the CTAO ERIC, which will become operational in mid-2021.
  (https://www.cta-observatory.org/)
- **FACT :** (First g-Apd Cherenkov Telescope) is a small 4-metre Cherenkov telescope pioneering the usage of silicon photomultipliers (also called G-APD: Geiger-mode Avalanche PhotoDiodes) and performing the first unbiased monitoring of variable extragalactic objects at energies above 1 TeV. It is located on the island of La Palma, situated between MAGIC and the first LST of CTA; FACT also supports the commissioning of the first LST.
  (https://www.isdc.unige.ch/fact/)
- **IceCube:** is a 1 cubic kilometre instrumented volume of ice, between 1.5 to 2.5 kilometres below the South Pole surface, which was designed to detect high-energy neutrinos. The surface facility detects the electromagnetic component of cosmic ray showers, thus measuring the cosmic ray composition. The in-ice detector consists of 5'600 photomultipliers attached to 86 strings. These photomultipliers detect Cherenkov light produced by charged particles induced through neutrino interactions.
  IceCube is undergoing upgrades in two phases. In a first Phase 1, the size of its dense core detector (Precision Icecube Next Generation Upgrade, PINGU) is increased with an additional 7 strings, holding 700 new and enhanced optical modules. This upgrade lowers the energy threshold for neutrino detection down to 1 GeV. The next IceCube upgrade (IceCube Gen-2) will add photosensor-strings to increase the instrumented ice volume by about a factor of 10, extend the surface veto array, and add a radio-detector array exploiting the Askaryan effect to focus on signals induced by high-energy cosmogenic neutrinos.
  (https://icecube.wisc.edu/)
- **LHAASO:** (Large High Altitude Air Shower Observatory) is located 4'400 metres above sea level in the mountains of the Sichuan province of China. It is a new-generation Extensive Air Shower (EAS) array for cosmic ray detection in the energy range from 10^{11} to 10^{18} eV, and for γ-rays above 1 TeV. The observatory is currently under construction; it is currently 50% in place, and is expected to be completed by the end of 2021. The data-taking activities started in 2019 and the analysis of the data is ongoing. LHAASO is expected to be the most sensitive project to the open questions in Galactic cosmic ray physics, with the unique ability to detect cosmic ray sources and heavy dark matter in the galactic halo. With its large field of view and almost 100%



Cherenkov telescopes, situated at the Roque de los Muchachos Observatory on the island of La Palma, at about 2200 metres above sea level. MAGIC detects particle showers released by γ-rays through their Cherenkov radiation. The telescopes have two 17 metre-diameter reflectors, now surpassed in size by the first LST of CTA of 24 metres and by the H.E.S.S. II telescope. Together with H.E.S.S. and VERITAS, MAGIC has opened the ground-based γ-ray field to Big Science, covering a range from the observation of the pulsation of pulsars above 100 GeV to the extension of the γ-ray burst spectrum up to above 300 GeV.
(https://magic.mpp.mpg.de/)

15.1.5 Experiments with Swiss contributions for direct dark matter detection

- **DAMIC and DAMIC-SNOLAB:** (DArk Matter In Ccds) is an experiment, located at SNOLAB in Canada that is based on the idea that DM is a relic from an entire dark or hidden sector; this hidden sector is expected to contain a hidden photon, which then interacts very weakly with the 'visible' sector representing ordinary matter. DAMIC has sensitivity to many orders of magnitude in DM mass for various assumptions on how the hidden photon relates to the dark matter and the formation of dark matter in the early Universe. The subsequent DAMIC-SNOLAB Experiment increased the mass, decreased backgrounds, and concluded in 2019, after having producing several world-leading results extending beyond the standard searches for WIMP dark matter into the domain of hidden-photon DM.
  (https://www.snolab.ca/science/experiments/damic)
- **DAMIC-M and OSCURA:** DAMIC-M is an approved and funded international experiment, to be located at the Modane Underground laboratory in France, that is set to begin in 2024. It has a mass ten times larger, a background rate ten times smaller, and an energy threshold ten times lower than DAMIC-SNOLAB. Its ability to detect single ionisation electrons has been made possible through the use of a novel 'skipper' electronics readout. DAMIC-M will probe ten orders of magnitude in DM mass over a range of theoretical scenarios. Studies have also been undertaken for a new experiment to be named OSCURA; this new experiment would be ten times bigger than DAMIC-M and would have an even lower background rate and energy threshold.
  (https://damic.uchicago.edu/index.php, https://astro.fnal.gov/science/dark-matter/oscura/)
- **DARWIN:** (DARk matter WImp search with liquid xenoN) is the ultimate DM detector based on liquid xenon, which will explore the full WIMP parameter space (using an exposure of 200 tonne-years) above the so-called 'neutrino floor' where neutrinos will start to dominate the signal. The project is presently in the R&D and design phase, with a CDR planned for 2022 (an invitation was issued by LNGS, after a successful LoI submission and review), and a TDR in 2024. At the earliest, data-taking activities would start in 2026 or 2027. DARWIN will have a similar reach to dedicated future neutrinoless double-beta decay experiments through studies of the decay of ^{136}Xe, and will enable high-statistics observations of *pp* neutrinos from the Sun. It will also search for
- **XENON1T:** The XENON1T Experiment was a 3500kg liquid xenon detector designed to search for dark matter. It acquired data at LNGS from 2016 to 2018, and set the world's best limits on the WIMP-nucleon elastic scattering cross-section for DM masses above 85 MeV, as well as on the DM-electron scattering cross-section for masses above 30 MeV.
  (http://www.xenon1t.org/).
- **XENONnT:** The XENONnT Experiment was installed at LNGS in early 2020, and is currently under commissioning. With a fiducial liquid xenon mass of 4 tonnes and an exposure of 20 tonne-years, the expected sensitivity to spin-independent interactions will reach a cross-section of $1.4 \times 10^{-48}\mathrm{cm}^2$ for a 50 GeV/c^2 mass WIMP, which is a factor of 10 improvement compared to XENON1T. XENONnT will also search for the neutrinoless double-beta decay of ^{136}Xe, and will be able to probe the excess of events observed by XENON1T in the 1.7 keV region within a few months of the start of data-taking activities; it will additionally be able to distinguish between this excess as originating from a tritium component or a solar axion signal.
  (http://www.xenonnt.org/).