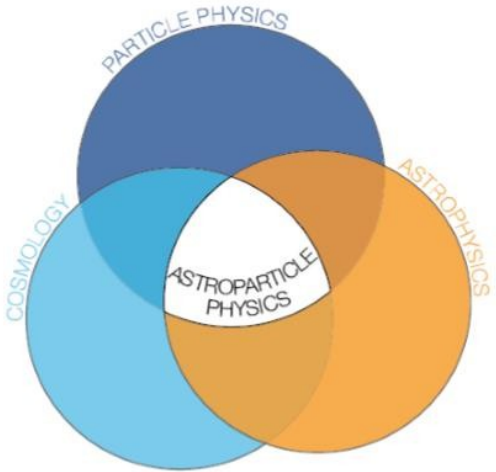
Astroparticle Experiments



Vladimír Novotný

novotnyv@ipnp.mff.cuni.cz

FZU
Institute of Physics of the Czech Academy of Sciences

Institutes and activities

- **Astronomical Institute CAS (ASU)**: Cherenkov Telescope Array (CTA), SST-1M, theories of cosmic-ray accelerations, magnetic fields, black holes, LISA
- **Charles University (CUNI)**: Pierre Auger Observatory (Auger), CTA, neutrino experiments (Daya Bay, NovA, JUNO, ...)
- **Czech Technical University (CTU)**: Baikal-GVD, PICO, CZELTA (outreach)
- **Institute of Atmospheric Physics (IAP), Institute of Thermomechanics (IT) CAS:** LISA
- **Institute of Physics CAS (FZU)**: Auger, CTA, SST-1M, FAST, Vera C. Rubin Observatory, CEICO, SWGO, Laboratory astrophysics (ELI Beamlines), LISA
- **Nuclear Physics Institute CAS**: Trojan Horse Method - nuclear astrophysics
- **Palacky University in Olomouc (UP)**: Auger, CTA, SST-1M, FAST
- **Silesian University in Opava (SLU)**: theories of black holes, cosmic-ray acceleration, cosmology

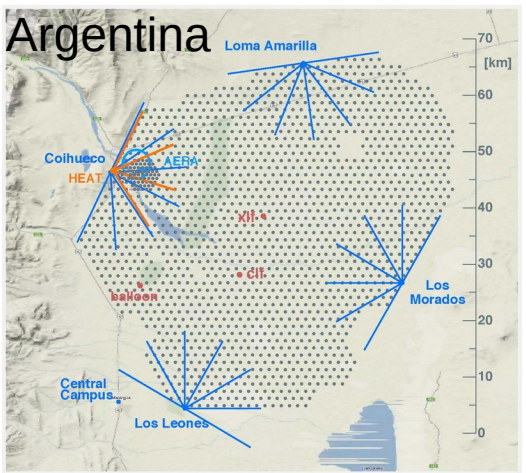
Pierre Auger Observatory (FZU, CUNI, UP)

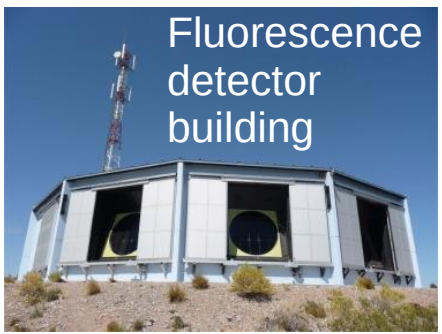
Air-showers initiated by the most energetic (~10^8 TeV) particles in the Universe!

www.auger.org

- Data analysis (FZU-Prague, CUNI): mass composition, testing models of hadronic interactions, energy spectrum, anisotropy searches
- Atmospheric monitoring (FZU-Prague, FZU-Olomouc, UP)
- Absolute calibration of Fluorescence detector (UP)
- GRID computing (FZU-Prague)
- Production and management of official Auger simulation library (FZU-Prague)
- Remote shifts from Prague since 2020

Team of ~30 people



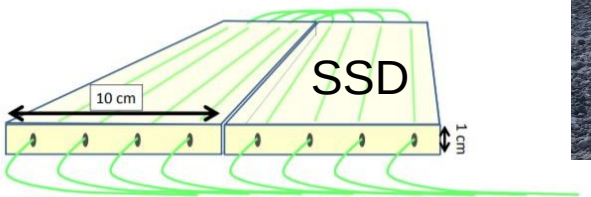


AugerPrime (2020-2030)

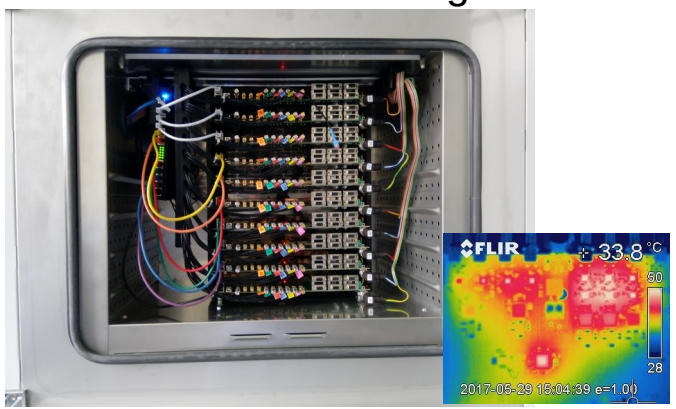
Science Reviews

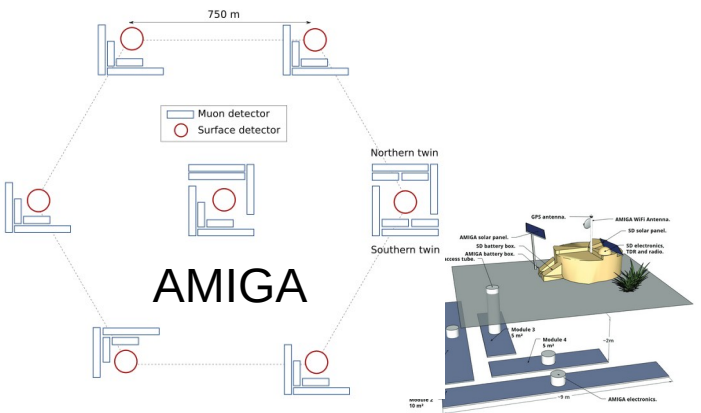
- Ongoing Auger upgrade

  (SSDs on site, ~1000 UUBs tested, ~800 UUBs in Argentina)
  - full upgrade ~1500 stations
- Scintillators (SSDs) - measurement of EM component to be subtracted from muon+EM in WCD
- Radio - EM for inclined showers
- AMIGA - muon detectors
- UUBs - tested in Prague



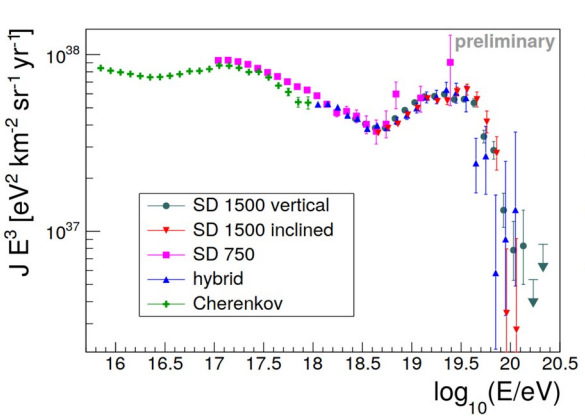
Climate chamber in Prague lab

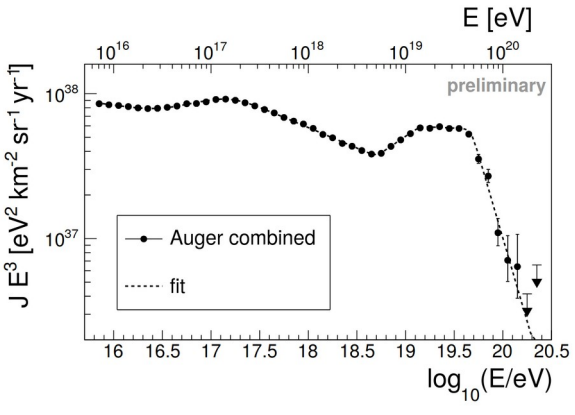




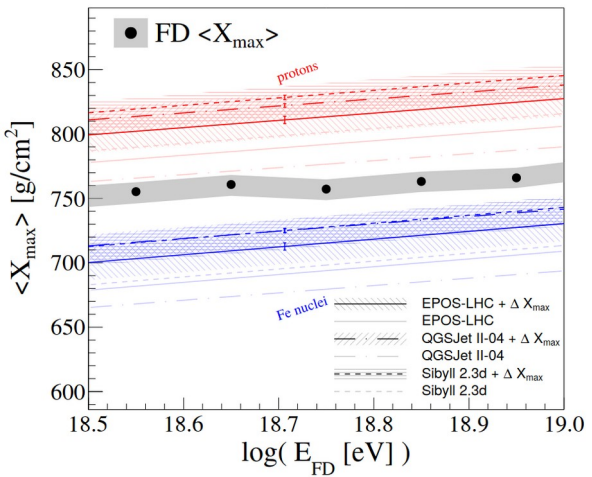
Recent Auger results + ICRC 2021

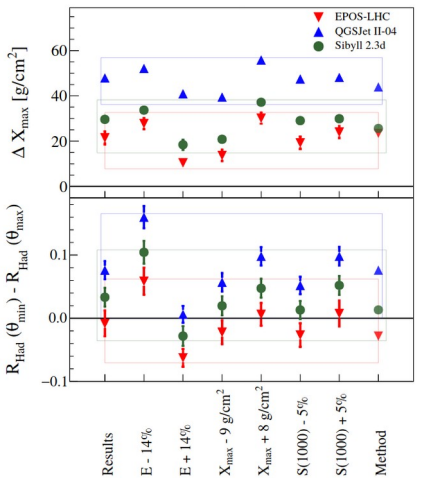
- Energy spectrum
  - presented by V. Novotný @ ICRC
  - > 4 orders of magnitude in energy
  - low energy spectrum starts just above the Knee





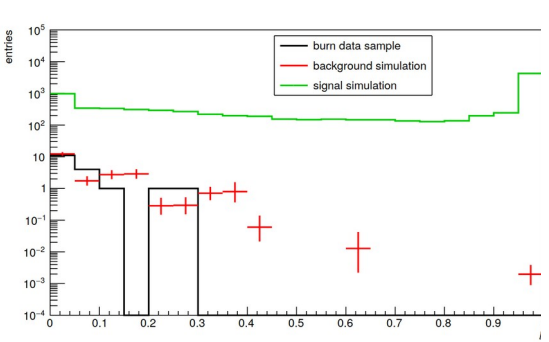
- Adjustments to Model Predictions
  - presented by J. Vícha @ ICRC (FZU)
  - model predictions must be changed a lot to describe Auger FD+SD data

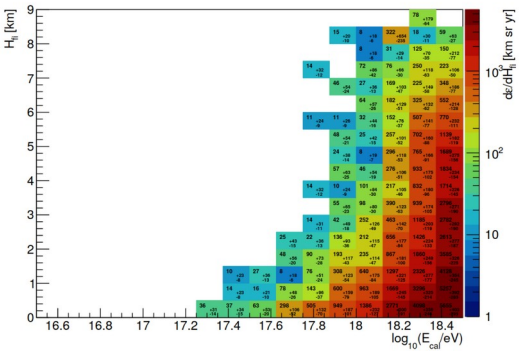




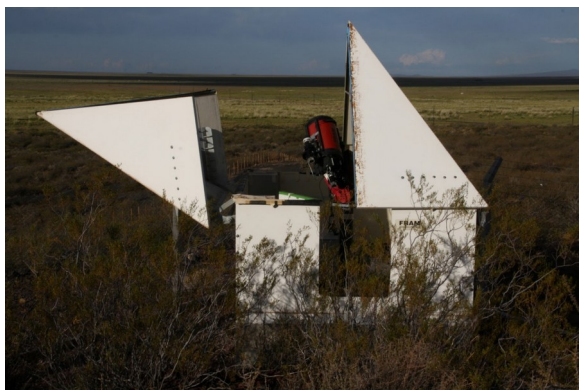
Recent Auger results + ICRC 2021

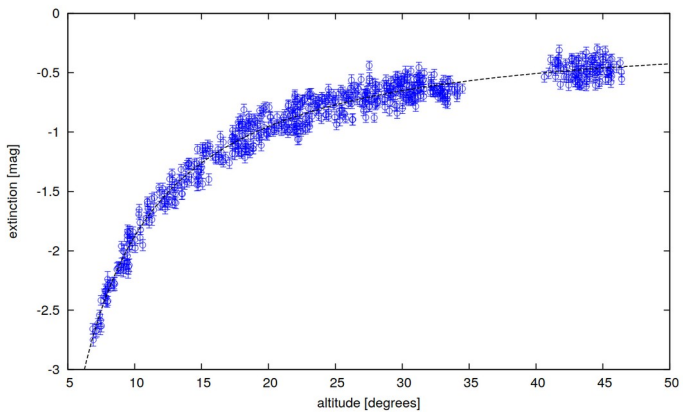
- Search for upward going showers
  - presented by M. Mastrodicasa @ ICRC
  - no signal seen ~ contradicts ANITA





- FRAM telescope description
  - JINST 16 P06027 (2021)
  - written by J. Ebr (FZU)
  - 2nd FRAM @ Auger!
    - shoot-the-shower for low energy showers





- ... other Auger articles and Auger+Czech ICRC contributions

CTA: Cherenkov Telescope Array (FZU, CUNI, UP, ASU)

Air-showers initiated by the most energetic (~100 TeV) photons in the Universe!

completed > 2024

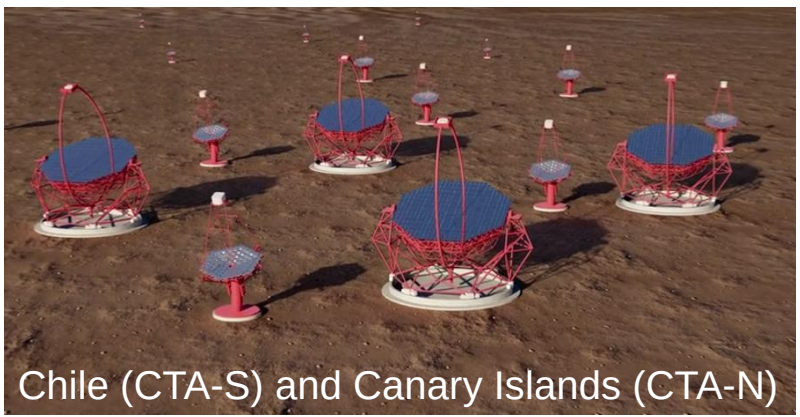
www.cta-observatory.org

Team of ~30 people

- FZU, CUNI, UP, ASU joined LST in Dec 2020
- Past activities
  - Site selection process, development of SST-1M, atm. calibration
- Current activities → independent array @ Ondřejov
  - Optics for LST & MST, mirror construction & testing, atm. calibration, GRID computing

MST

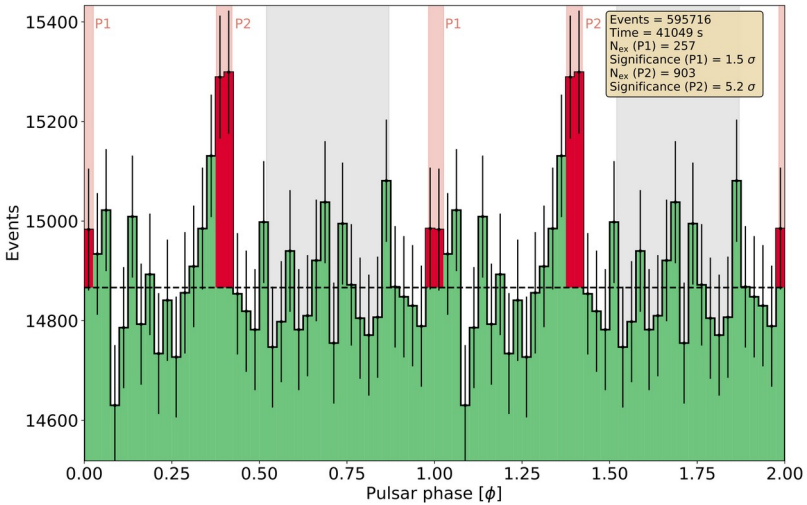
SST



CTA news 2021

link

- LST-1 in operation and first data (Crab)
- Czech LST shifts and actuator maintenance @ La Palma
- La Palma volcano erruption
  - 85 days from September to December
  - CTA equipment undamaged
  - LST and FRAM observation suspended due to the volcanic dust in the atmosphere
- LST-1 will work again in early 2022



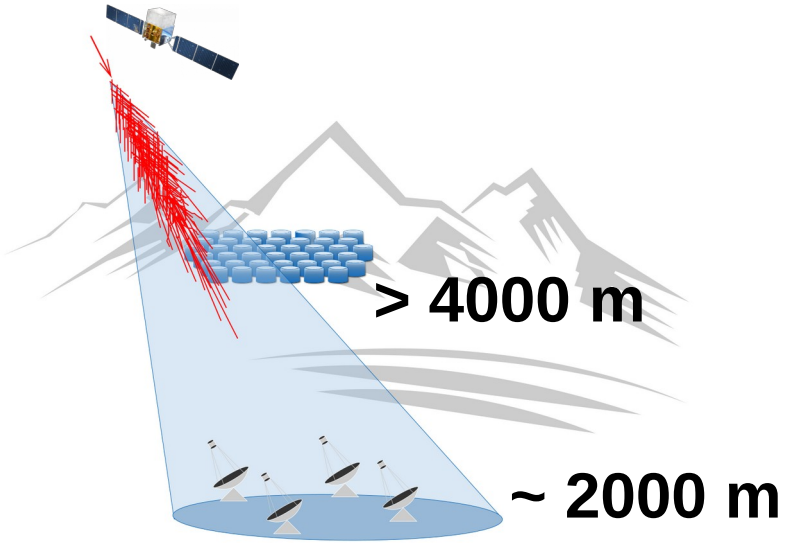
SST-1M @ Ondřejov

- Independent of CTA
- 1st telescope operational by the end of January 2022
- 2nd telescope construction done
  - mirrors to be added
- Stereo observations ~ mid 2022

1st installed

2nd installed

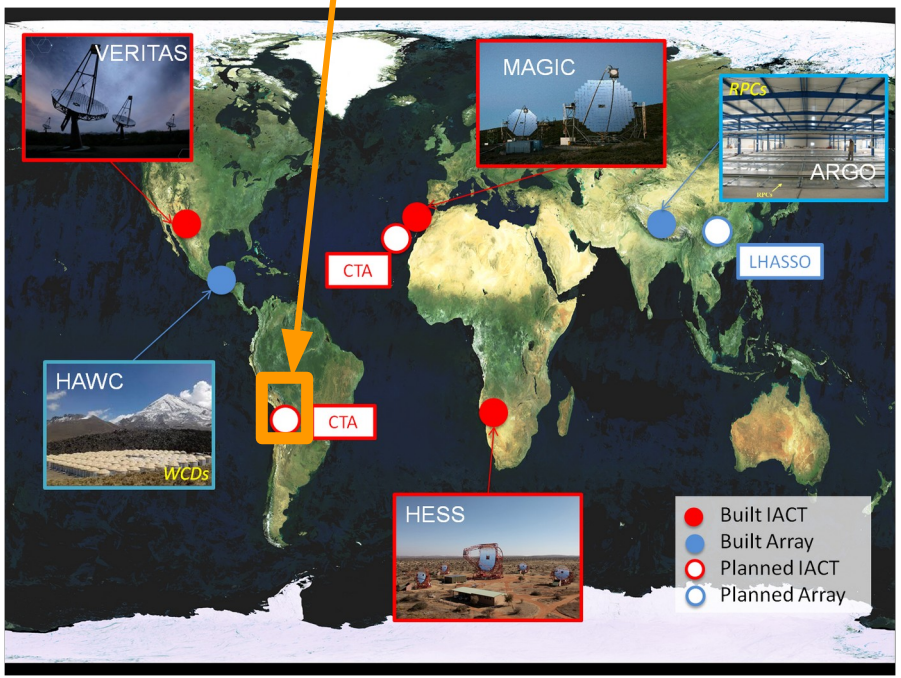
SWGO: Southern Wide-field Gamma-ray Observatory (FZU)



Team of
~10 people

SWGO
The Southern Wide-field Gamma-ray Observatory

www.swgo.org



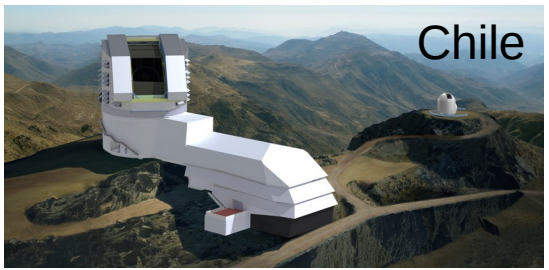
- Currently no wide-field observatory in the South at ~4.7 km
- Complementary to wide-field LHAASO in the North and to narrow-field CTA-S
- Collaboration established in July 2019 (LATTES+SGSO)
- Now 3-year R&D phase (detector concept, site, science, ...)
- Studies of the WCD concept, site characterisations - AEROSITE instruments and study of potential hybrid concept)

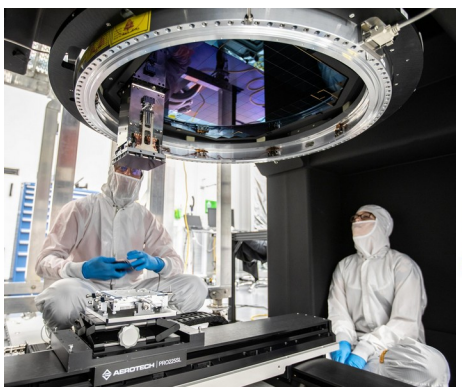
VRO: Vera C. Rubin Observatory (FZU)

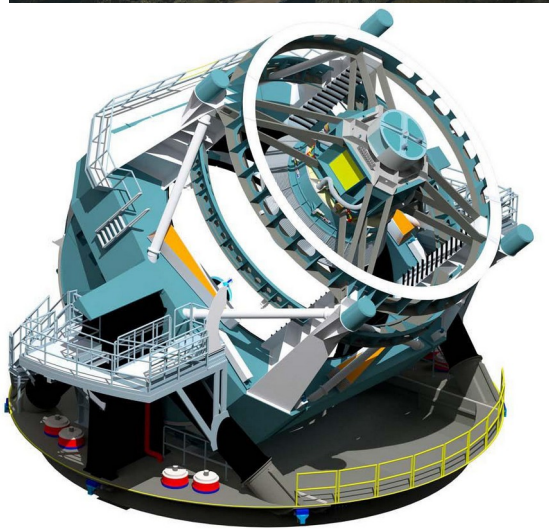
- Previous name: LSST
- FZU is one of the three European VRO members
- Building finished, telescope being built (2022)
- Laboratory in Prague fully functional since 2020
- Evaluation of test data of finished CCD camera
- Activities in Dark Energy Science Collaboration (simulations of modified gravity, sensor anomalies and their impact on cosmological observations)
- Transients, Multimessenger astronomy

Team of ~5 people

www.lsst.org



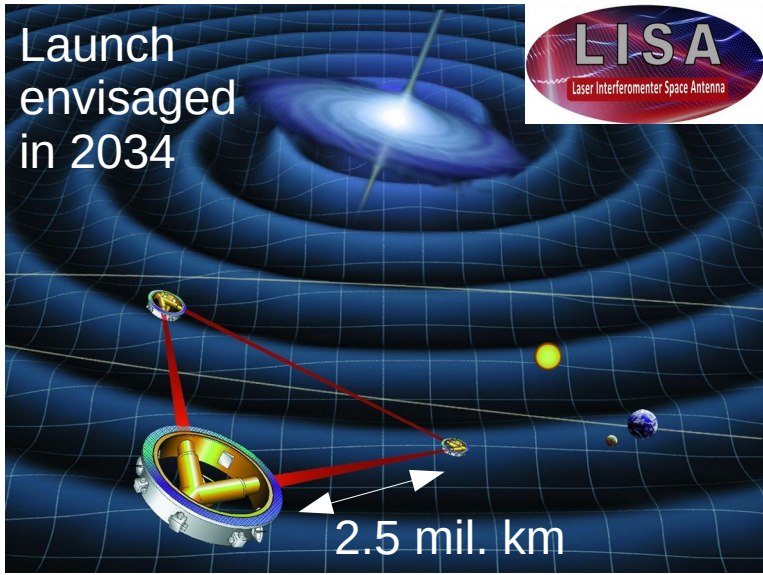


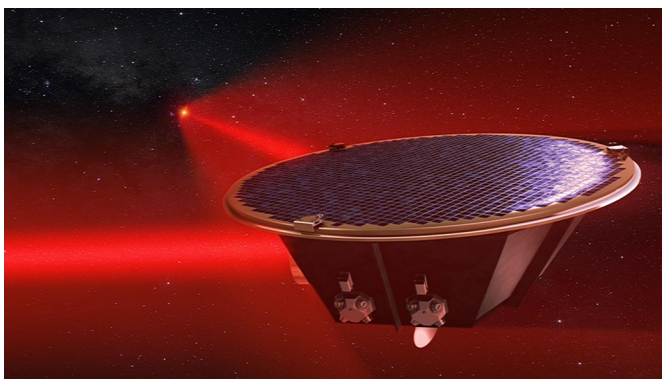


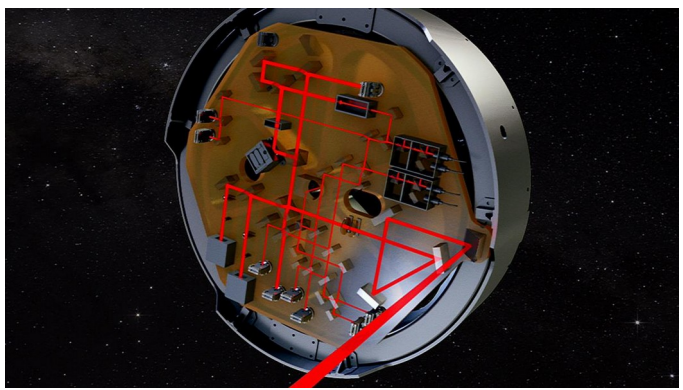
LISA: Laser Interferometer Space Antenna (FZU, ASU, IAP, IT)

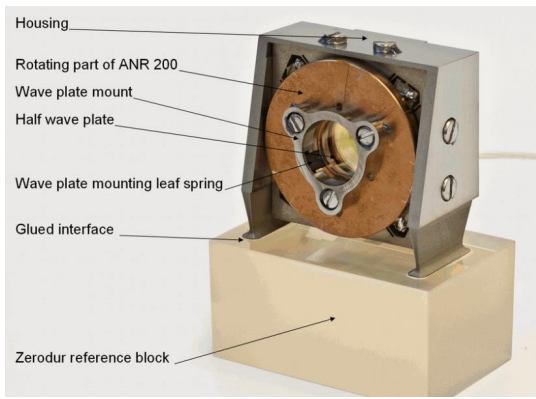
https://lisa.nasa.gov/

- CR joined in 2020
- ESA+NASA+JAXA+international consortium lead by Germany
- Development of the LISA Fiber Switch Unit Actuator
  - used to switch between the main and redundant laser on the Optical Bench

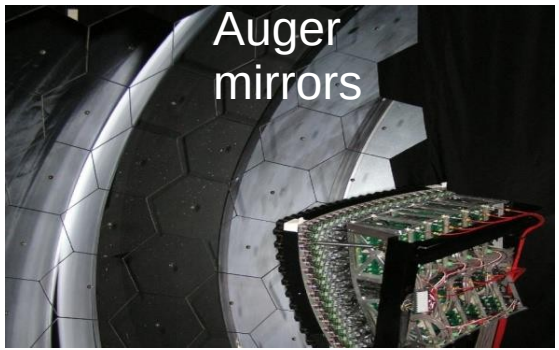


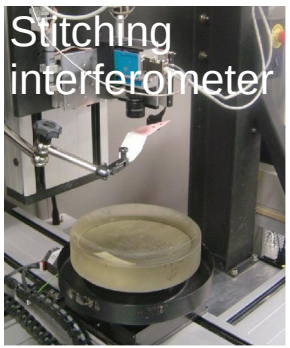


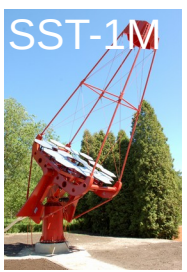




Optics for Astroparticle Physics (Olomouc, FZU and UP)







https://jointlab.upol.cz

Team of ~10 people

- Mirror production up to 1m size
- Devices to study optical properties of components used in astroparticle physics (CASI, nanoindentor, spectrometers, absolute reflectivity setup, ...)
- Alignment of fluorescence and gamma-ray telescopes
- Calibration of telescopes
- New technologies for simple fluorescence detectors - FAST

Institute of Experimental and Applied Physics, CTU

www.utef.cvut.cz

Medipix

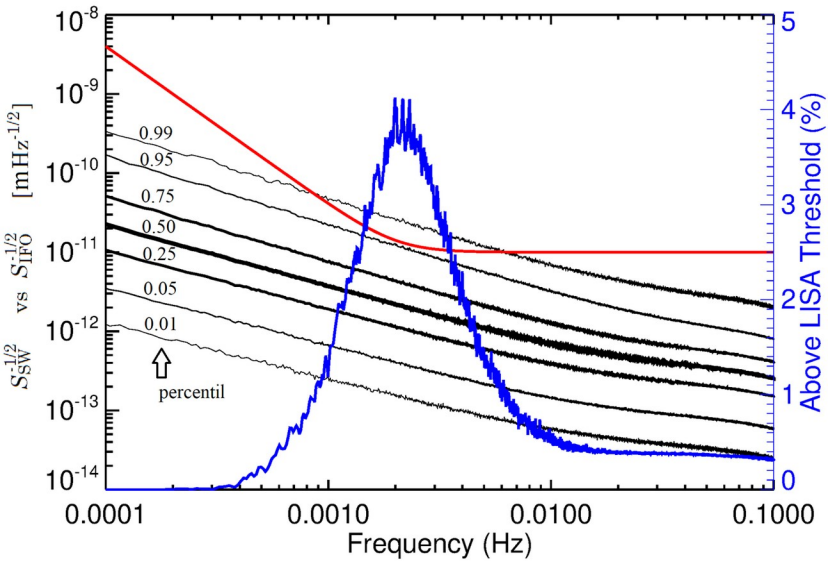
- Detection of cosmic radiation
  - pixel detectors providing composition and spectral characteristics of mixed fields of radiation in energy range from keV to TeV
  - PROBA-V (ESA), radiation monitors for ISS (NASA, in collaboration with the University of Houston) or RISESAT (JAXA)
- Member of International Astronautical Federation (2020)
- **PICO** - DM neutralino search, SNOLAB, Canada
  - www.picoexperiment.com
- **Baikal-GVD** - astrophysics neutrino experiment, Russia
  - https://baikalgvd.jinr.ru/ - 2021 GVD-I completed (~0.5 km^3)
- CZELTA: detection of high energy cosmic rays with scintillating detectors, cooperation with secondary schools

Background for gravitational wave signal at LISA from refractive index of solar wind plasma

Mon Not R Astron Soc Lett (2020) slaa155 1745-39254

František Němec[b)], Zdeněk Němeček[b)], Adam Smetana[a)], Jana Šafránková[b)]

a)Institute of Experimental and Applied Physics, Czech Technical University in Prague, Czech Republic
b)Department of Surface and Plasma Science, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic



About the plot:

- WIND data
- 2004 – 2019
- 24h window
- shifted by 1h → 76210 spectra
- interpolated data resampled to 10 Hz
- single-arm-interferometer model

Conclusion for LISA:

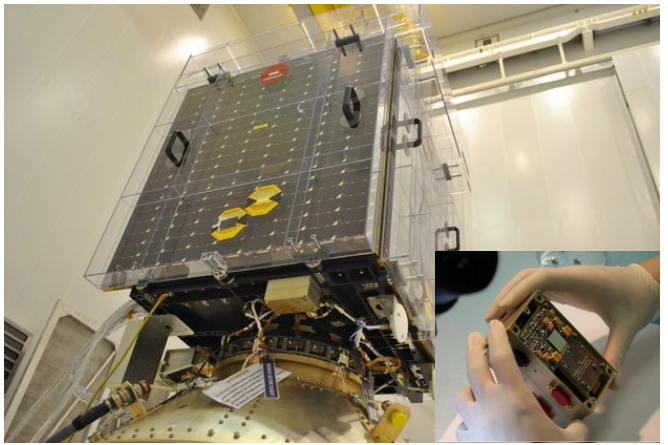
LISA might see the effect of solar wind

- in the range from ~1 mHz to ~10 mHz
- in up to 4% of exposure time.
- It has not been considered before.
- Highly relevant for future space-based GW antennas

Timepix in space

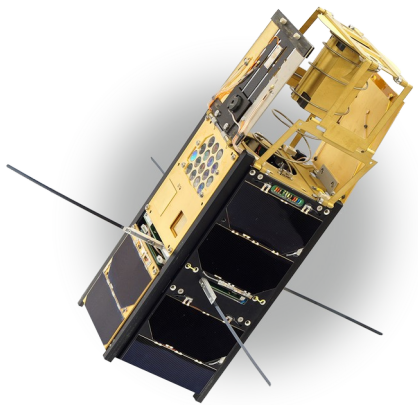
5 Timepix detectors placed on ISS since 2012 in collaboration with NASA and the University of Houston.

USB-Lite interface developed at IEAP.

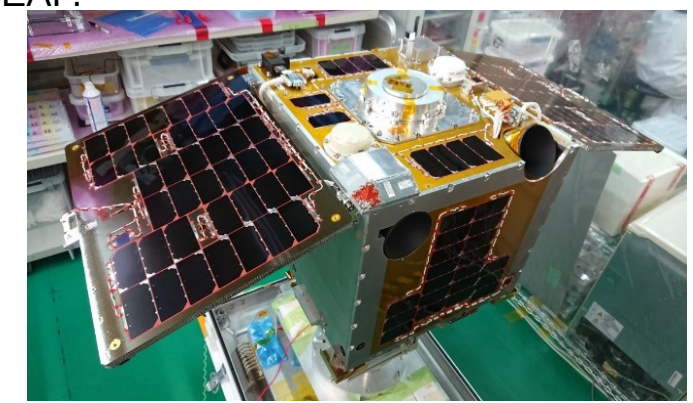


SATRAM module with Timepix detector onboard ESA satellite Proba-V. Characterization of space radiation at LEO since 2013.

Developed by IEAP and BD Sensors.

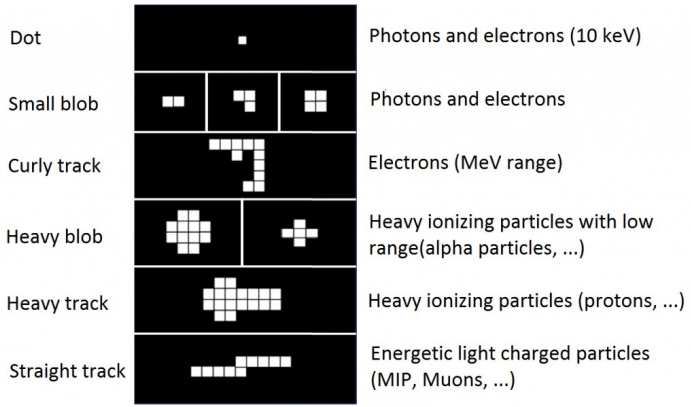


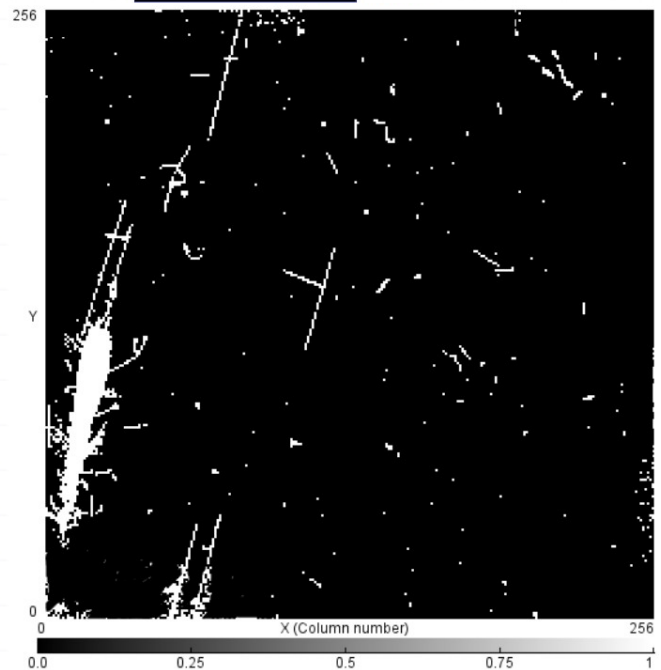
Timepix detector as part of miniature X-ray telescope onboard VZLUSAT-1 cubesat since 2017 . The first Czech satellite since 1996.



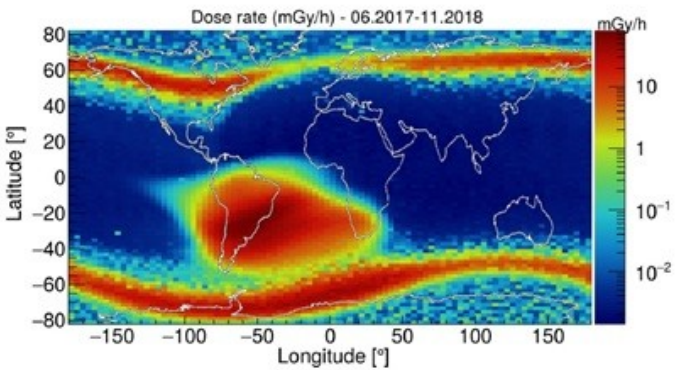
Telescope with 2 Timepix detectors onboard Japanese microsatellite RISESAT since 2019.

Data from orbit



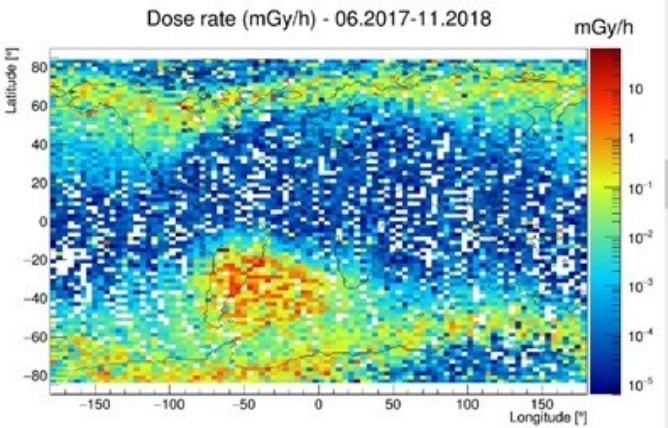


Astroparticle tracks imaging allows particle identification. Flux and energy spectra are measured for each particle species.



SATRAM

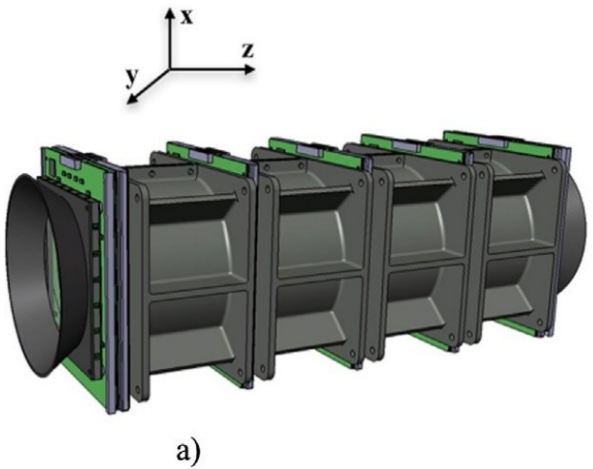
Total eposure time ≈ 340 days

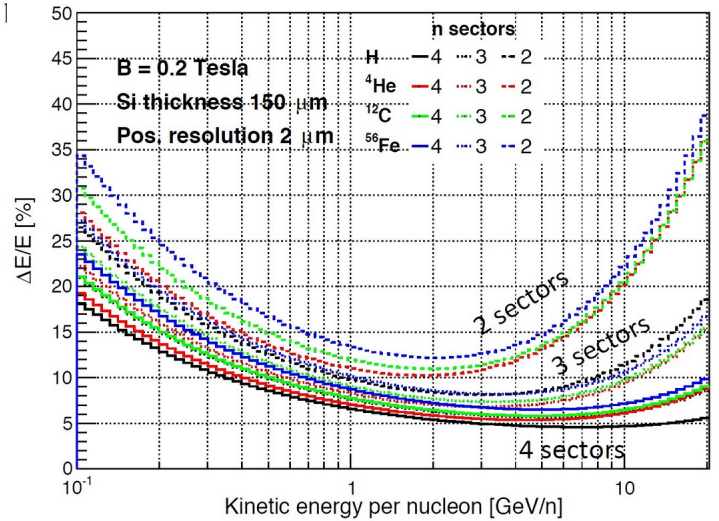


VZLUSAT-1

Total exposure time ≈ 11 hours

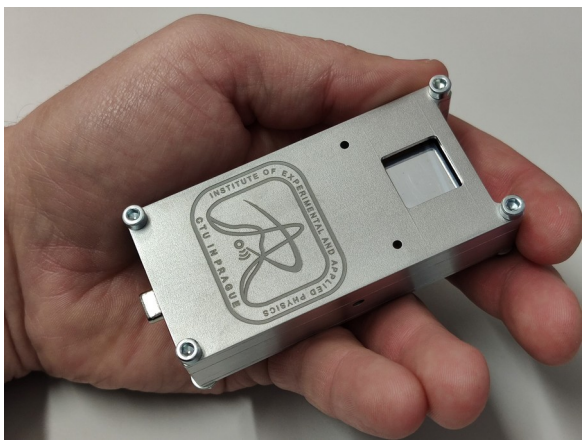
Current astroparticle projects



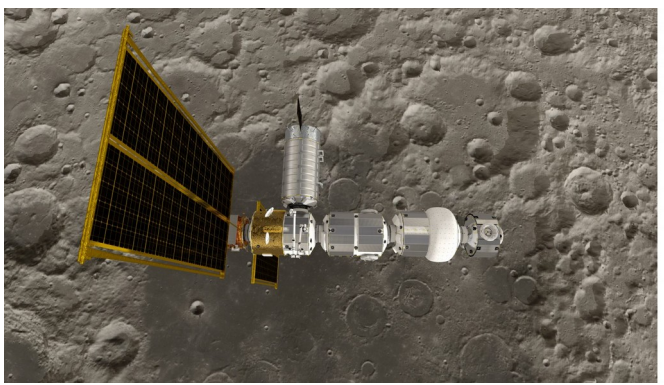


Magnetic spectrometer
PAN (strip, pixel + magnet)

Energies up to 20 GeV in compact (~40 cm) spectrometer



HardPix radiation monitor



1 or 2 Timepix3 layers

On-board processing

8x4x2 cm, 140 g, 1.5 – 2.5 W

2x HardPix outside Lunar Gateway as part of ESA ERSA

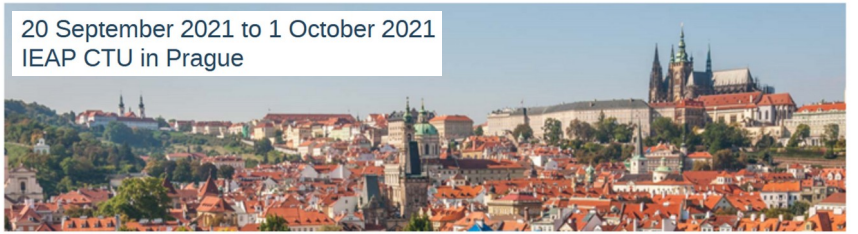
Institute of Experimental and Applied Physics, CTU

www.utef.cvut.cz

EuCAPT

Astroneutrino Theory Workshop 2021

Prague, Czech Republic



Scope: We brought together representatives of the selected areas, from whom the participants (experts and students) could learn, and we built up a creative environment for new ideas and collaborations.

Numbers: **42** registrants (**26** in person, **16** online), **12** invited speakers (**7** in person, **5** online), **2** weeks, **50** contributions (**27** invited, **20** participants, **3** guest talks), **6** discussion sessions, **2** social dinners

Agenda:

Field	Subtopic	Speaker
Aspects of Cosmic Neutrino Background (CNB)	Evolution of neutrino relics	S. Pastor (Valencia U., IFIC) & S. Gariazzo (Valencia U., IFIC)
	CNB detection	
	Neutrinos as a component of dark matter	
	Gravitational clustering of cosmic relic neutrinos	
	Theory of non-relativistic Majorana fermion systems	S. Flörchinger (U. Heidelberg, ITP) & L. Heyen (U. Heidelberg, ITP)
	CNB self-interactions and condensation	A. Trautner (Heidelberg, MPI)
Electromagnetic properties of neutrinos	Current limits on neutrino elmag properties	A.I. Studenikin (Moscow State U.)
	Neutrino oscillations in intergalactic magnetic fields	
	Neutrino properties in hot and dense medium	S.S. Masood (UHCL Houston)
Neutrinos in dynamics of celestial bodies	Cooling of celestial bodies	K.A. Maslov (JINR Dubna)
	Neutrinos in supernovae, neutron stars and black holes	D.E. Alvarez Castillo (INP Cracow, JINR Dubna)
	Electric charge in stars	M.I. Krivoruchenko (Moscow, ITEP)
Neutrinos in cosmic rays	Ultra-high energetic cosmic neutrinos	W. Winter (DESY, Zeuthen)
	Interactions of cosmic rays with CNB	R. Wigmans (Texas Tech.)

Cosmic-ray theory (FZU, ASU, SLU)

- Kološ M., Tursunov A., Stuchlík Z. (SLU): Radiative Penrose process: Energy gain by a single radiating charged particle in the ergosphere of rotating black hole, PRD 103 (2021) 024021
- Dovčiak M., Caballero-Garcia M.D., Karas V. (ASU) et al.: UV/Optical Disk Thermal Reverberation in Active Galactic Nuclei: An In-depth Study with an Analytic Prescription for Time-lag Spectra, ApJ 907 (2021) 20
- Suková P., Karas V. (ASU) et al.: Stellar Transits across a Magnetized Accretion Torus as a Mechanism for Plasmoid Ejection, ApJ 917 (2021) 43
- Araudo A. (FZU, ASU) et al.: Particle acceleration and magnetic field amplification in massive young stellar object jets, MNRAS 504 (2021) 2405-2419
- ...

- Central European Institute for Cosmology and Fundamental Physics (FZU) CEICO

Team of
~30 people

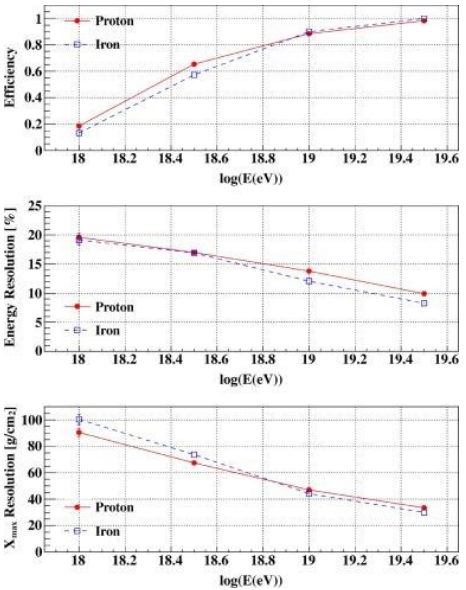
FAST (FZU, UP)

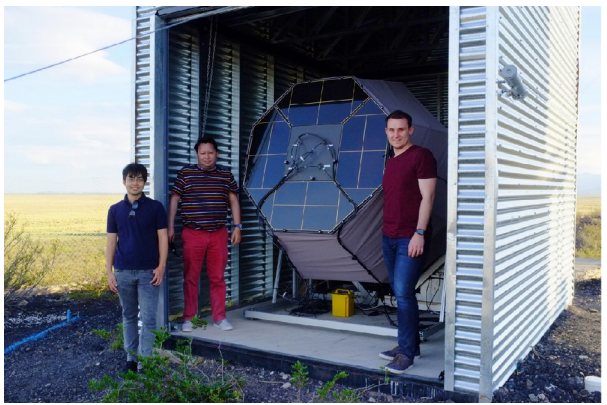
www.fast-project.org

- Fluorescence Detector Array of Single-pixel Telescopes
- R&D of simplified FD - future of UHECR?
  - New initiative: The Global Cosmic Ray Observatory (>2030)
- 3 prototypes at Telescope Array

  1st at Auger (2019), 2nd and 3rd in near future
  - cross-calibrations of experiments

Team of
~10 people

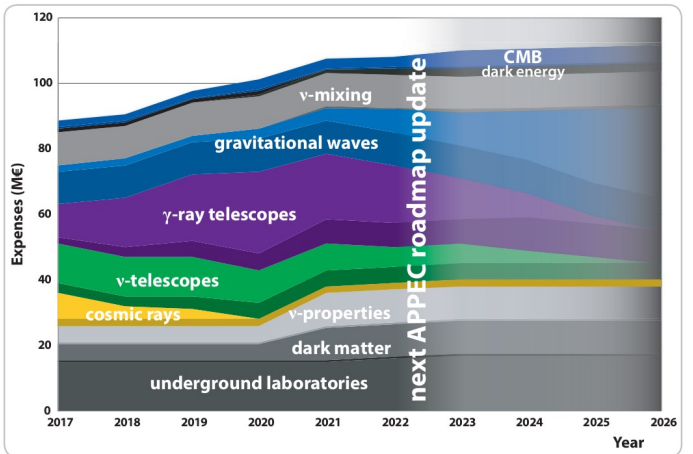


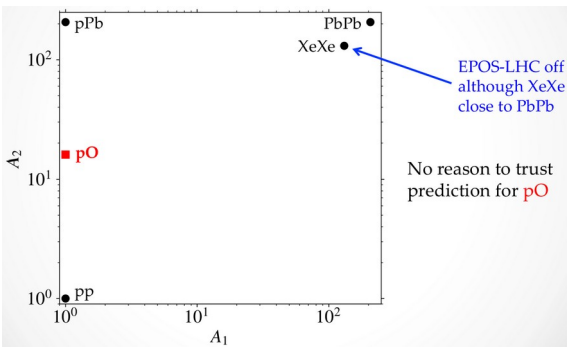


Astroparticle Physics European Consortium (APPEC)

www.appec.org

- CR is the member through CTU
- European Astroparticle Physics Strategy 2017-2026
  1) Connecting the Infinitely Large and Infinitely Small (**LISA**) Mentioned in ECFA Strategy update
  2) The Extreme Universe: a Multi-Messenger Approach (**Auger, CTA, Baikal-GVD**) **"+ SWGO"**
  3) Mysterious Neutrinos
  4) The Early Universe
  5) The Dark Universe (**VRO**) **"+ PICO"**





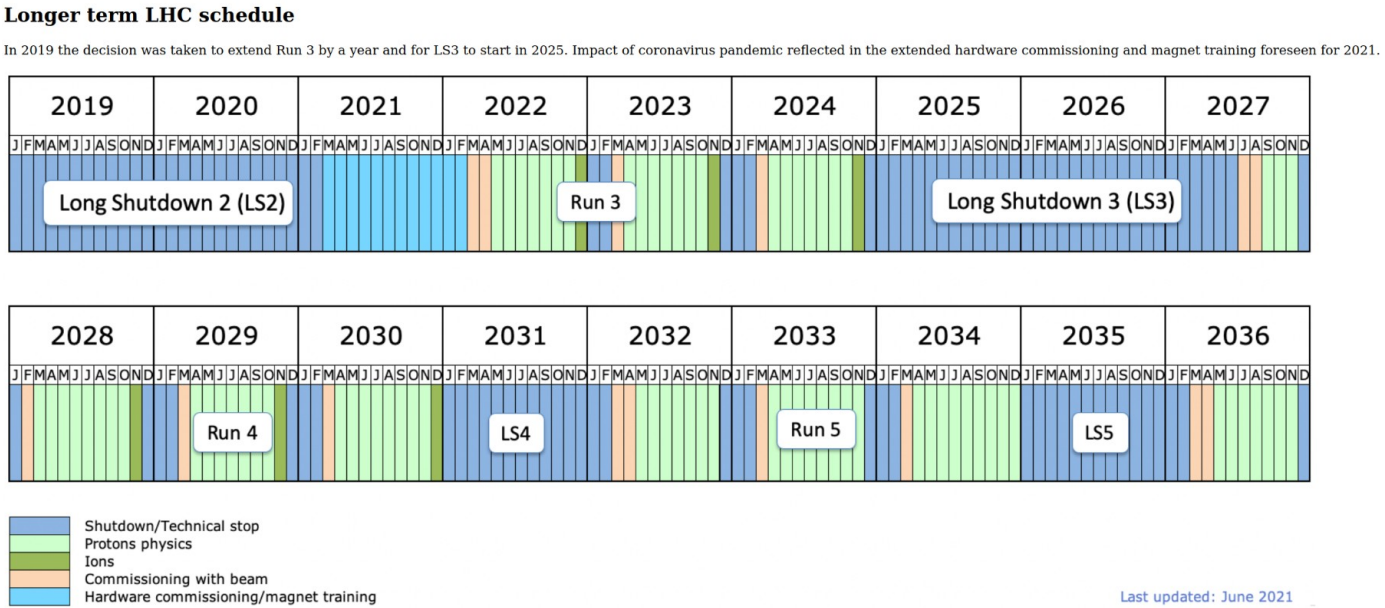
- Joint ECFA-NuPECC-ApPEC Activities (JENAS-2019)
  - find synergies in technology, physics, organization and/or applications
  - Workshop Opportunities of OO and pO collisions at the LHC 4-10 February 2021

From ECFA Strategy update:

"Synergies between particle and astroparticle physics should be strengthened through scientific exchanges and technological cooperation in areas of common interest and mutual benefit."

p-O and O-O @ LHC run 3

- also LHCf in operation – forward region important



Preliminary **luminosity targets:** (from B. Petersen at LMC)

- O-O: ~0.5/nb for soft physics program, ~2/nb equivalent to 2010 PbPb run for hard-probes
- p-O: LHCb would like >2/nb, LHCf would like ~1.5/nb
- LHCf requests low pileup of 0.02 in p-O (update: previously 0.01)
- ALICE wants low pileup of 0.1-0.2