SESSION 15: FUTURE INSTRUMENTATION FOR DIRECT MEASUREMENTS AND MULTIMESSENGER ASTROPHYSICS

Stéphane Coutu
Penn State University

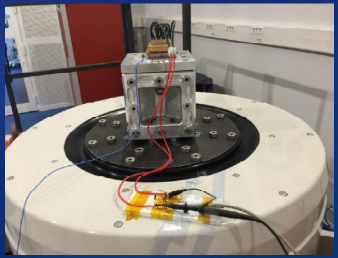
John Krizmanic
UMBC/CRESST/GSFC

ICRC 2021
Berlin
13 July 2021

CITIUS

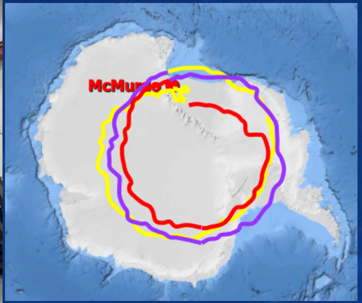
ALTIUS

FORTIUS



MAIUS

LONGIUS



OTHER RELEVANT SESSIONS

CRD rapporteur: Philipp Mertsch
MM rapporteur: Irene Tamborra

- *13 (CRI) New Instrumentation and Tools for EAS Detection (overlap with CRD)* (21 Jul, 12:00)
- *14 (CRD) CRs and ISM* (15 Jul, 12:00)
- *16 (CRD) Cosmic Ray Antiparticles and Electrons* (15 Jul, 18:00)
- *17 (CRD) Nuclear CR Spectra: Theory and Observations* (14 Jul, 18:00)
- *18 (CRD) Cosmic Ray Secondary Nuclei: Observations and Impact on Theories* (19 Jul, 18:00)
- *25 (MM) Blazars, AGN* (12 Jul, 18:00)
- *26 (MM) Galactic Sources & Winds* (21 Jul, 12:00)
- *27 (MM) GW Follow-Up Observation* (20 July, 18:00)
- *28 (MM) Searches for Transients* (16 July, 12:00)
- 33 (NU) Photodetection in Cherenkov Detectors (13 Jul, 18:00)
- 43 (GAD) New and Upcoming Instruments for Space-Based Gamma-Ray Astronomy (20 Jul, 18:00)
- 56 (GAI) New Instruments, Performance & Future Projects for Ground-Based Gamma-Ray Astronomy (20 Jul, 12:00)

THE FUTURE

For each topic:
- quick motivation by JFK/SC
- 1-2 slides and minutes per speaker
- interactive discussion

- Primary nuclei and electrons; 12:03 - 12:17
Shuang Nan Zhang / HERD
Pier Simone Marrocchesi (with Paolo Maestro) / systematics
Also invited but not confirmed: HEPD-02, GAMMA-400, NUCLEON-2

- Secondary nuclei (including isotopes); 12:17 - 12:27
Nahee Park / HELIX
Laurent Derome / future secondary nuclei measurements

- Ultraheavy nuclei; 12:27 - 12:37
Brian Rauch / TIGERISS, APT

- Antimatter, dark matter searches; 12:37 - 12:55
Philip von Doetinchem / GAPS
Stefan Schael / AMS-100
Roberto Battiston / ALADInO

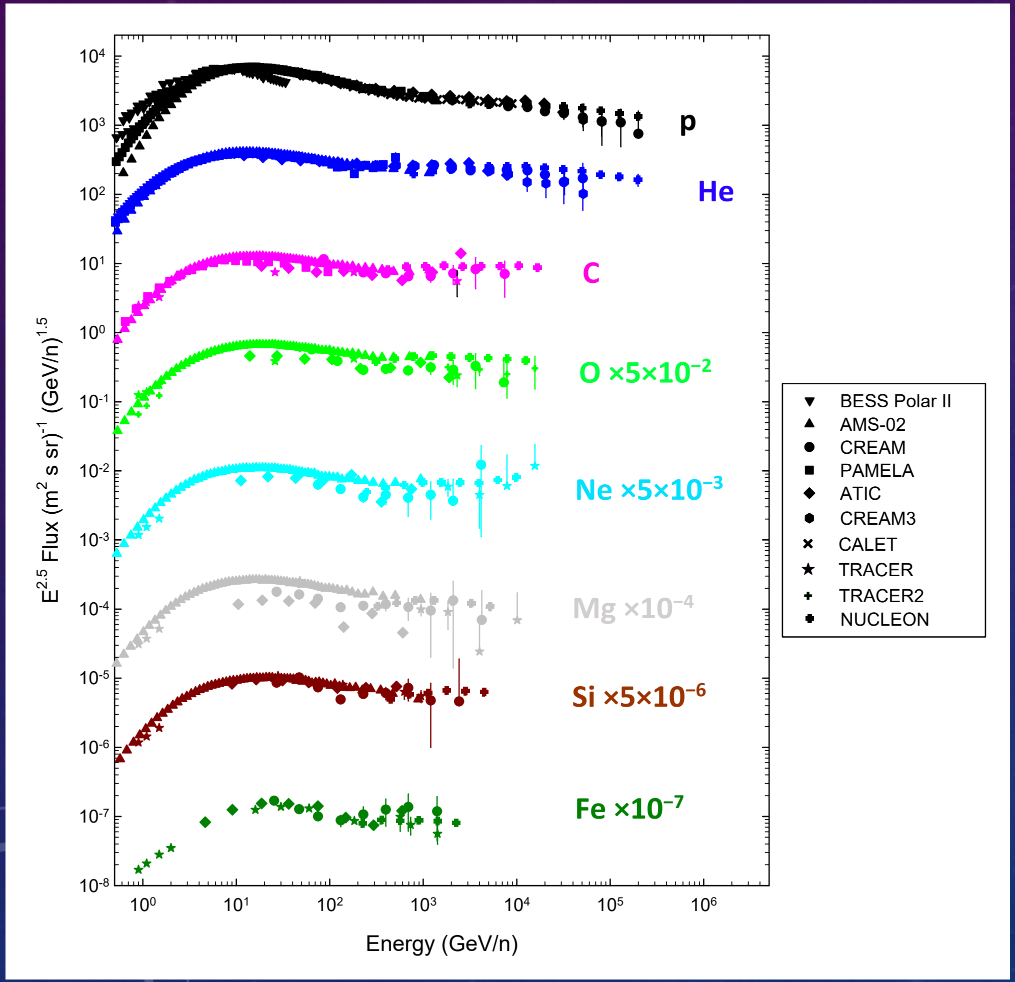
- Ultrahigh energy regime (UHECRs and neutrinos); 12:55 - 13:17
Angela Olinto / POEMMA
Abby Vieregg / PUEO
Lawrence Wiencke / JEM-EUSO, EUSO-SPB2
Joerg Hoerandel / GCOS
Stephanie Wissel/ Lunar detectors / ZAP

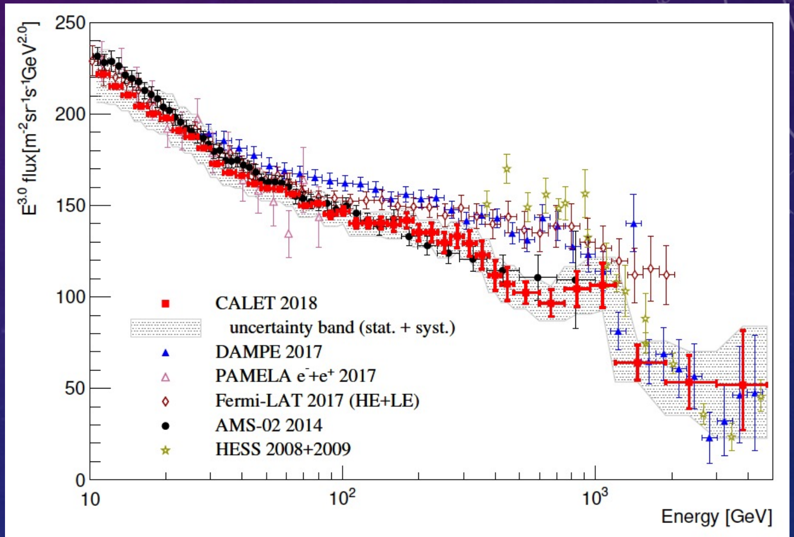
- Accelerator measurements 13:17 - 13:24
Michael Unger / NA61 / Shine

- CRI/CRD overlap 13:24 - 13:30
John Krizmanic with Toshihiro Fujii / Marco Casolino

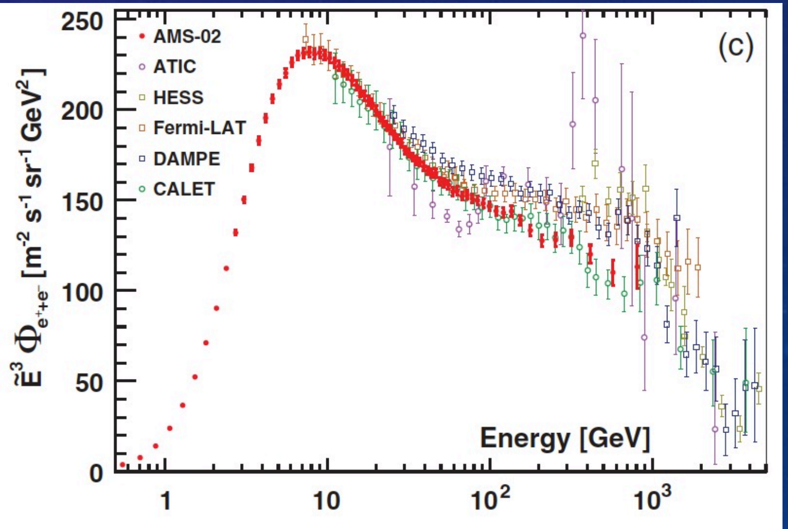
PRIMARY NUCLEI AND ELECTRONS

Need to resolve differences between experiments, confirm spectral details (slopes, hardening, diffuse vs source terms), extend to the knee…





O. Adriani et al., PRL 120, 261102 (2018)



M. Aguilar et al., PRL 122, 101101 (2019)

CRD: Cosmic Ray High-energy Nuclei Measurements

P. Maestro on behalf CALET Collab: PoS(ICRC2021)093

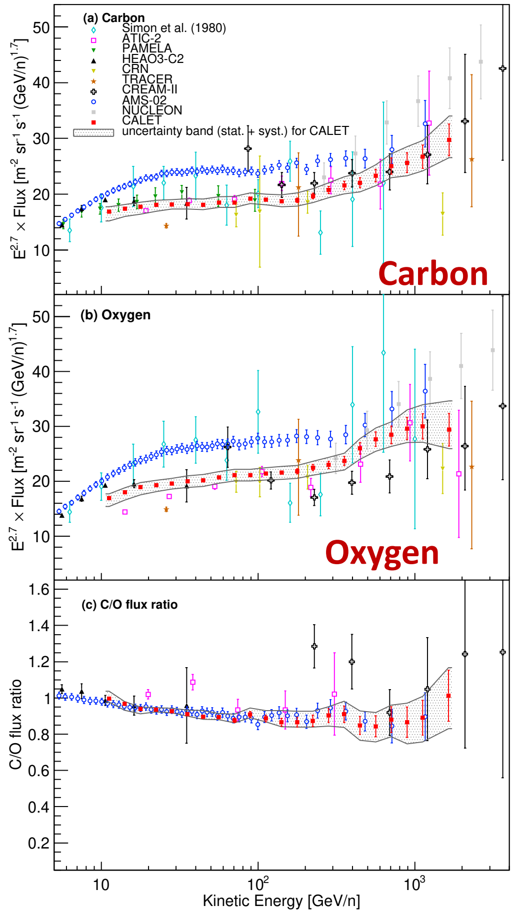
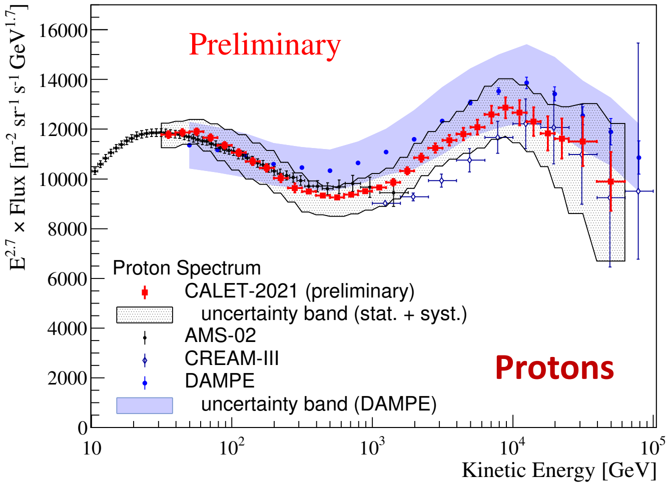
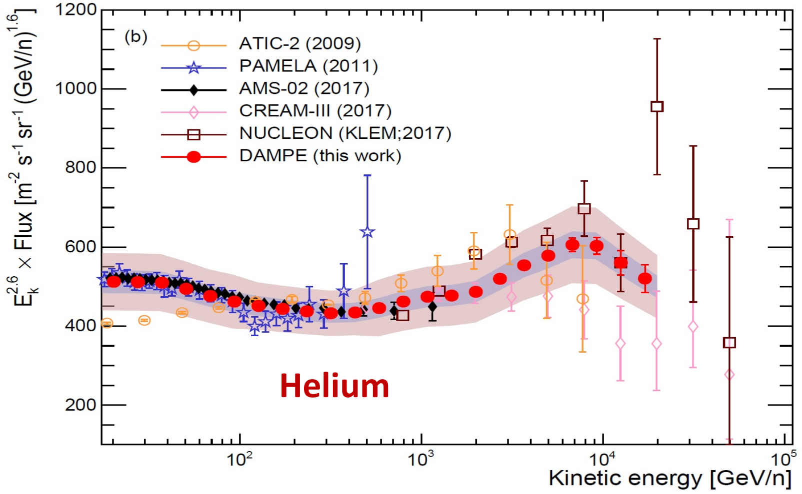


Figure 1: CALET (a) carbon and (b) oxygen flux (multiplied by $E^{2.7}$) and (c) ratio of carbon to oxygen fluxes, as a function of kinetic energy E. Error bars of CALET data (red) represent the statistical uncertainty only, while the gray band indicates the quadratic sum of statistical and systematic errors. Also plotted are other direct measurements [14–22].

K. Kobayshi & P.S. Marrocchesi on behalf CALET Collab: PoS(ICRC2021)098



M. Di Santo, P,X. Ma, A. Surdo, C. Yue, & Y.P. Zhang on behalf of DAMPE Collab: PoS(ICRC2021)114



F. Stolzi, C. Checchia, & Y. Akaike on behalf CALET Collab: PoS(ICRC2021)109

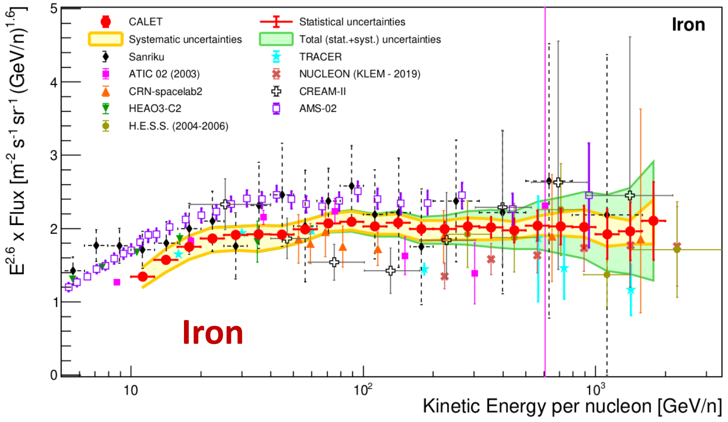
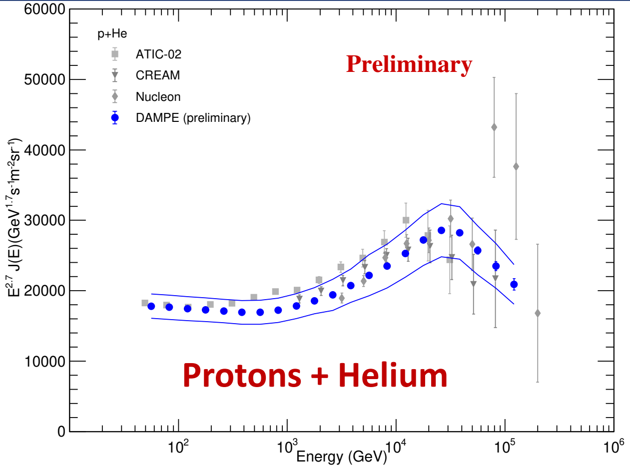


Figure 6: CALET iron flux (multiplied by $E^{2.6}$) as a function of kinetic energy per nucleon. Error bars of the CALET data (red) represent the statistical uncertainty only, the yellow band indicates the quadrature sum of systematic errors, while the green band indicates the quadrature sum of statistical and systematic errors. Also plotted are other direct measurements [36–44].

F. Alemanno, P. Bernardi, A. De Benedittis, I. De Mitri, & Z. Wang on behalf of DAMPE Collab: PoS(ICRC2021)117



The High Energy Cosmic-Radiation Detection (HERD) facility on board the Chinese Space Station

SHUANG-NAN ZHANG FOR THE HERD COLLABORATION

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

HERD Collaboration

CHINA

Institute of High Energy Physics, CAS (IHEP)
Xi'an Institute of Optical and Precision Mechanics, CAS (XIOPM)
Guangxi University (GXU)
Shandong University (SDU)
Southwest Jiaotong University (SWJTU)
Purple Mountain Observatory, CAS (PMO)
University of Science and Technology of China (USTC)
Yunnan Observatories (YNAO)
North Night Vision Technology (NVT)
University of Hong Kong (HKU)
Academia Sinica

ITALY

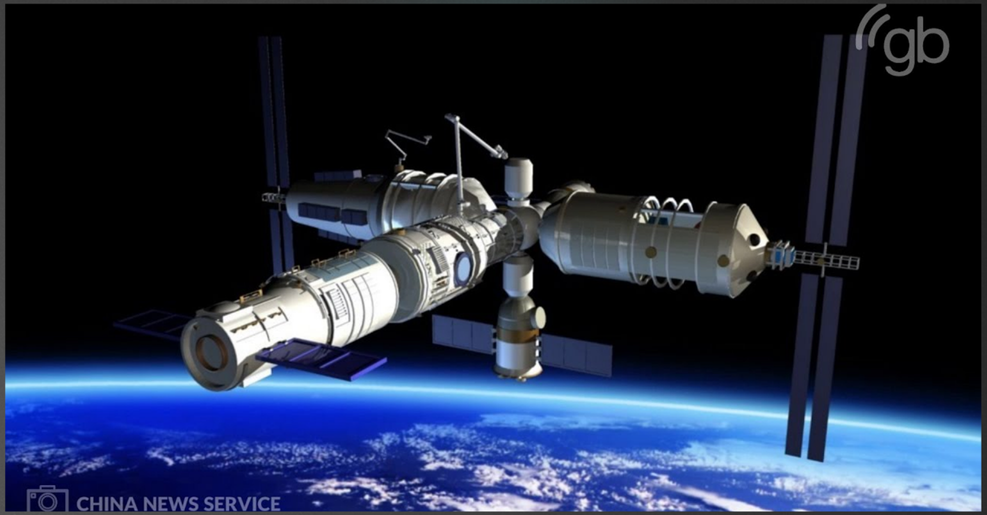
L'Aquila University
INFN Bari and Bari University
INFN Bologna
INFN Firenze and Firenze University
INFN Laboratori Nazionali del Gran Sasso and GSSI Gran Sasso Science Institute
INFN Lecce and Salento University
INFN Napoli and Napoli University
INFN Pavia and Pavia University
INFN Perugia and Perugia University
INFN Pisa and Pisa University
INFN Roma2
INFN Trieste

SPAIN

CIEMAT - Madrid
ICCUB – Barcelona
IFAE – Barcelona

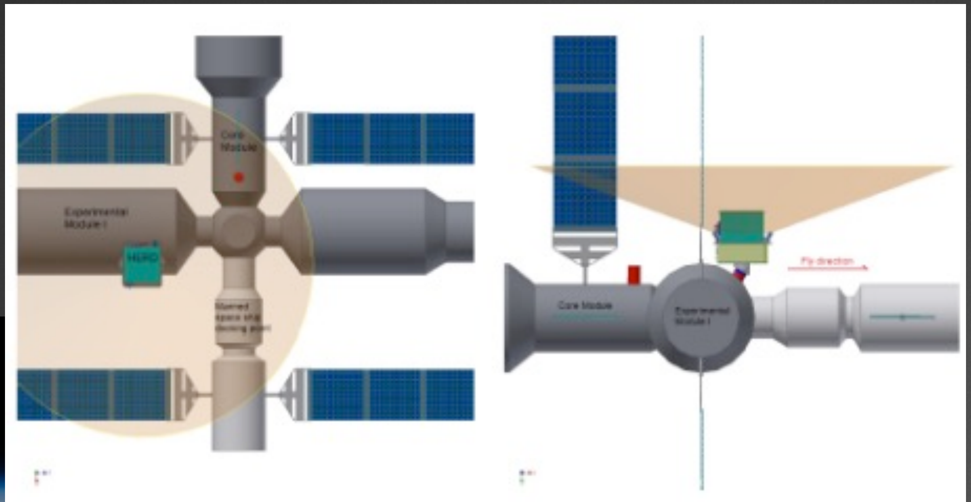
SWITZERLAND

University of Geneva
EPFL - Lausanne



The **High Energy cosmic-Radiation Detection** (HERD) facility is an international space mission that will start operation around 2027.

The experiment is based on a **3D, homogeneous, isotropic and finely-segmented calorimeter** that will measure the cosmic ray flux up to the knee region, search for indirect signal of dark matter and monitor the full gamma-ray sky



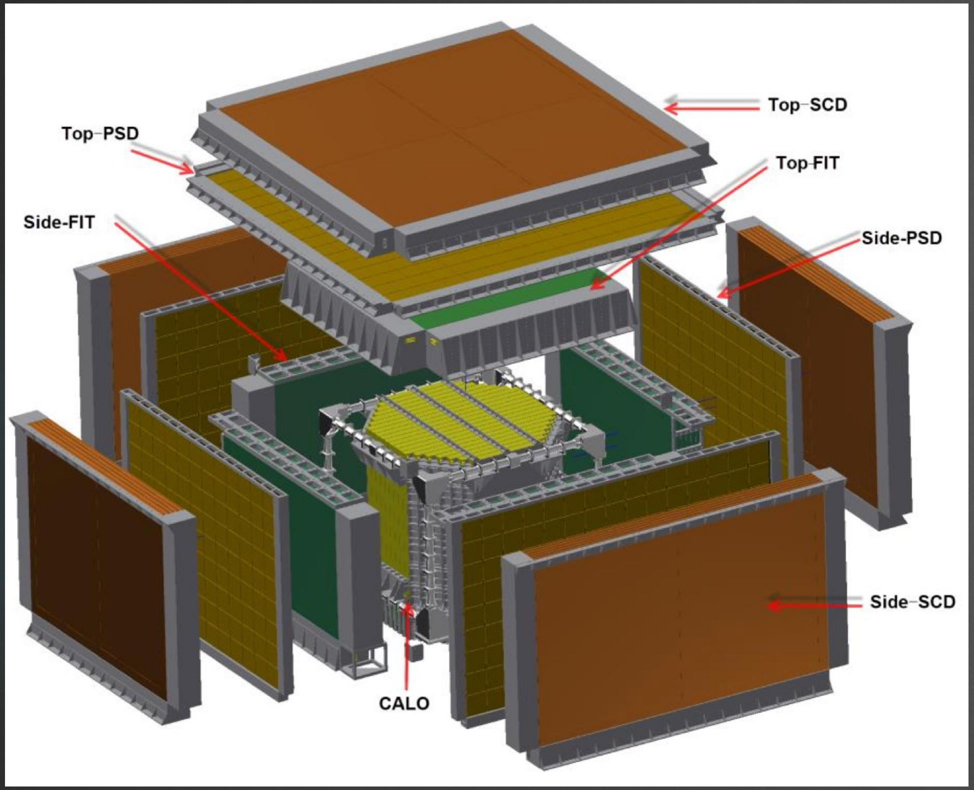
CSS expected to be completed in 2022

Life time	> 10y
Orbit	Circular LEO
Altitude	340-450 km
Inclination	42°

HERD expected to be installed around 2027

Life time	> 10y
FOV	+/- 70°
Power	< 1.5 kW
Mass	< 4 t

The detector



SCD	Charge Reconstruction
PSD	Charge Reconstruction γ Identification
FIT	Trajectory Reconstruction Charge Identification
CALO	Energy Reconstruction e/p Discrimination
TRD	Calibration of CALO response for TeV protons

Main requirements			
	γ	e	p, nuclei
Energy Range	>100MeV	10 GeV 100 TeV	30 GeV 3 PeV
Energy resolution	1% @ 200 GeV	1% @ 200 GeV	20% @ 100 GeV -1 PeV
Effective Geometric Factor	>0.2 m^2sr @ 200 GeV	>2 m^2sr @ 200 GeV	>1 m^2sr @ 100 TeV

HEPD-02 ON-BOARD CSES-02

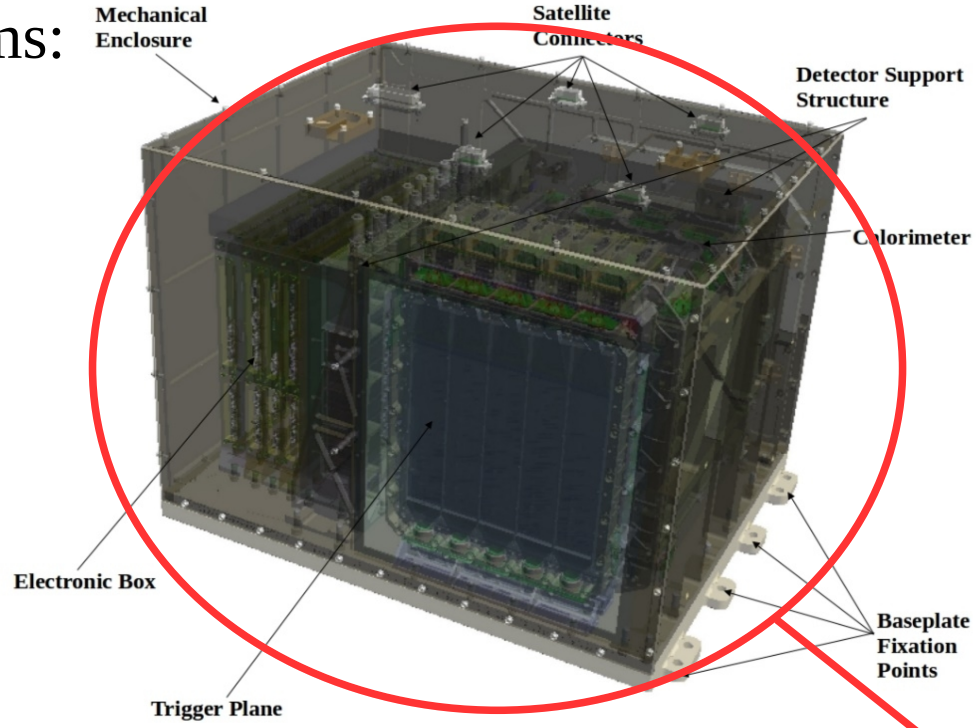
HEPD-02 MAIN REQUIREMENTS

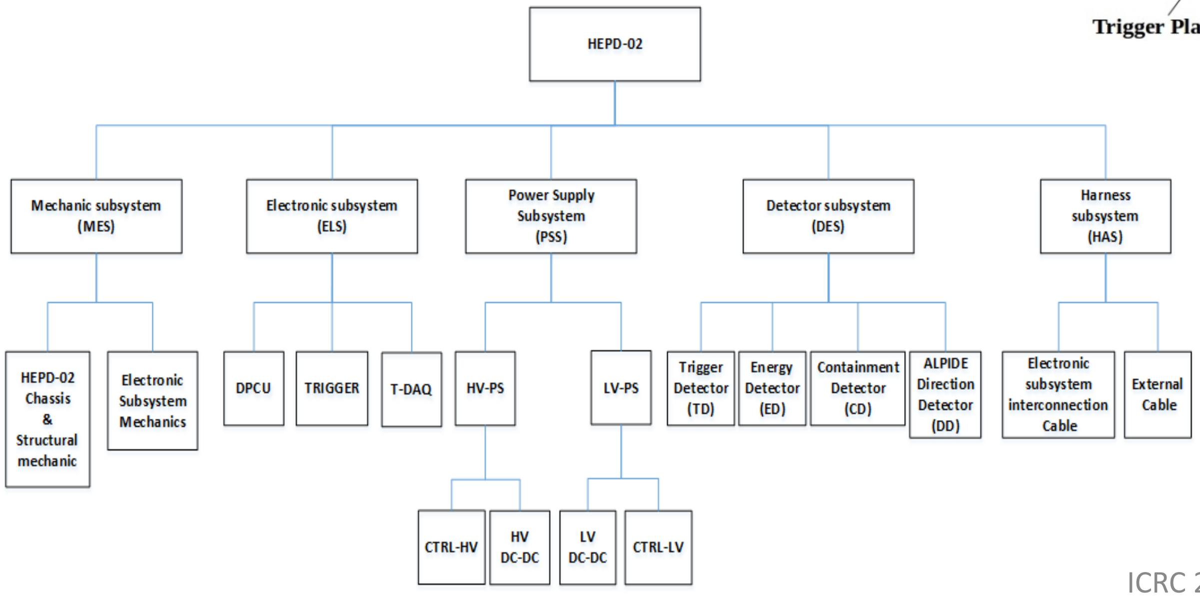
Operating temperature	-10 °C ÷ +35 °C
Operating pressure	$\leq 6.65 \cdot 10^{-3}$ Pa
Data budget	$\leq$ 100 Gb/day
Mass budget	$\leq$ 50 kg
Power budget	$\leq$ 45 W
Electron kinetic energy range	3 MeV ÷ 100 MeV
Proton kinetic energy range	30 MeV ÷ 200 MeV
Angular resolution	$\leq 10^\circ$ for e^- with E > 3 MeV
Energy resolution	$\leq 10\%$ for e^- with E > 5 MeV
Pointing	Zenith
Scientific data bus	RS-422
Data handling bus	CAN 2.0
Life cycle	> 6 years

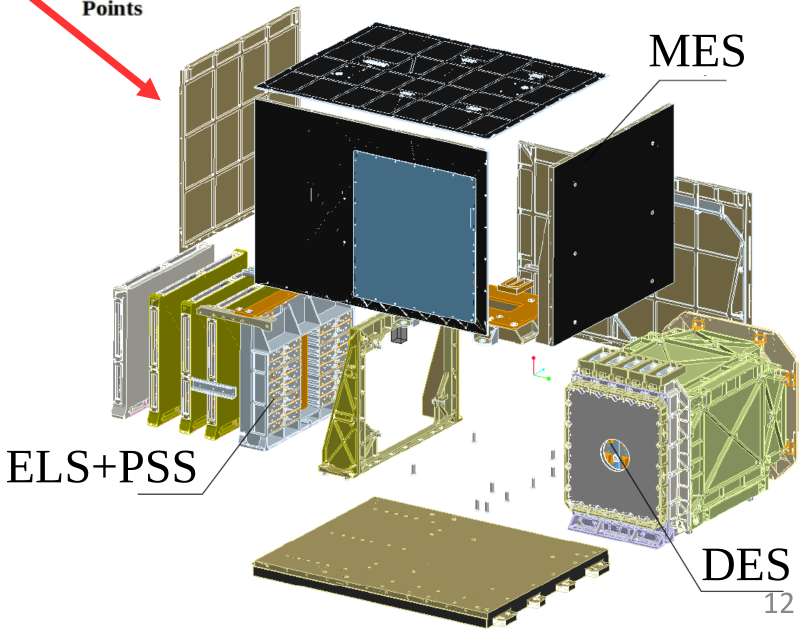
HEPD-02 SYSTEM ARCHITECTURE

HEPD-02 consists of five subsystems:

- Detector (DES)
- Mechanics (MES)
- Electronics (ELS)
- Power-Supply (PSS)
- Harness (HAS)







HEPD-02 DETECTOR LAYOUT

TRigger plane TR1 (overall dimensions 200x180 mm²) segmented in 5 plastic scintinllator bars (2 mm thick);

Direction Detector DD ("tracker") made of five standalone tracking modules ("turrets"), each composed of three sensitive planes ("staves");

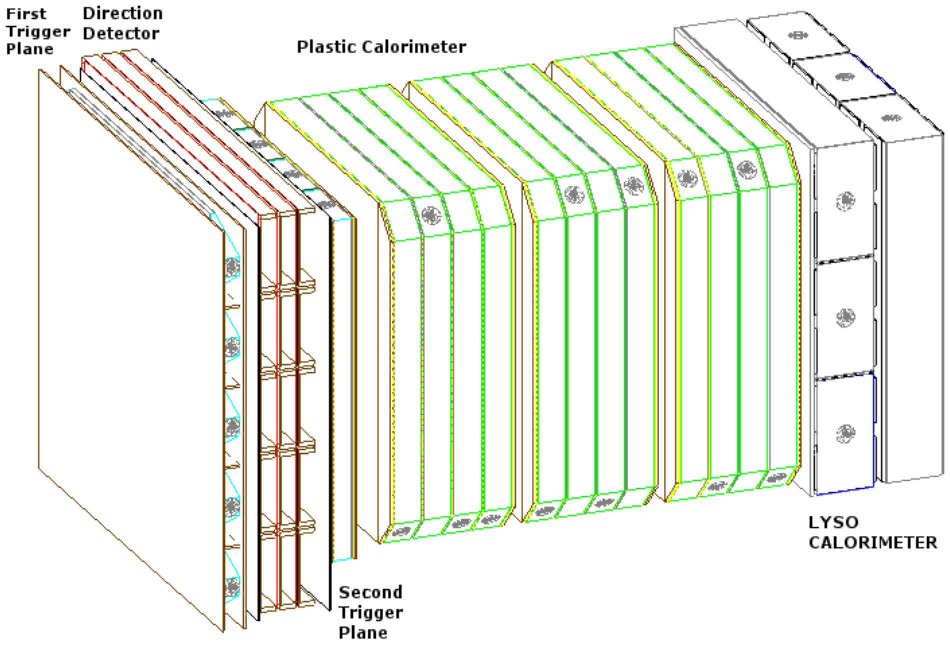
TRigger plane TR2 (overall dimensions 150 x 150 mm²)

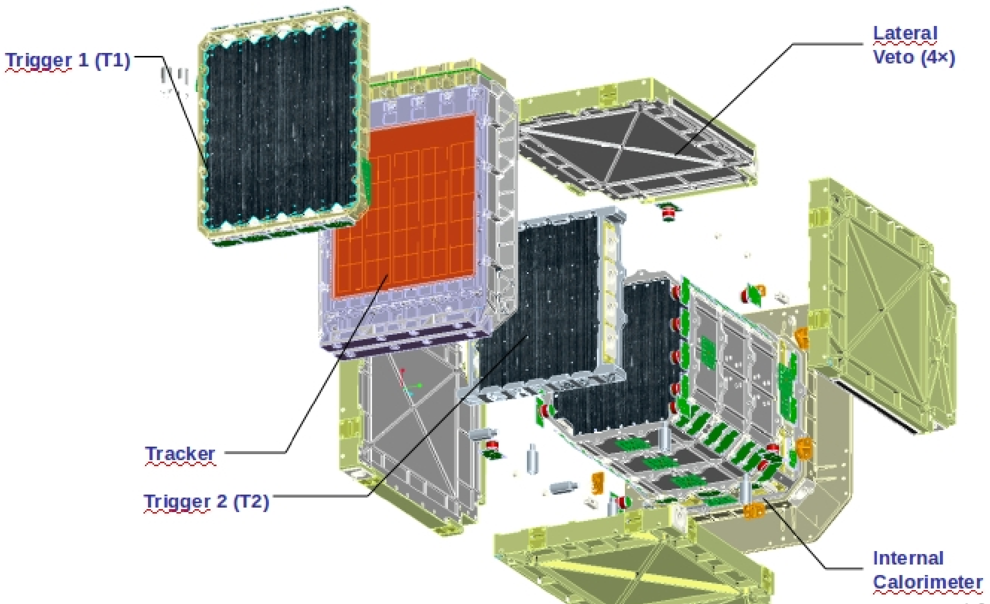
Energy Detector ED ("calorimeter") composed of:

- 12 plastic scintillator planes (150 x 150 x 10 mm³);
- 2 crystal (LYSO) scintillator planes (overall dimensions 150 x 150 mm² segmented in 3 bars (50 mm thick);

Containment Detector CD surrounding the calorimeter on 5 sides, made of plastic scintillator planes (4 lateral and 1 bottom plane), 8 mm thick.

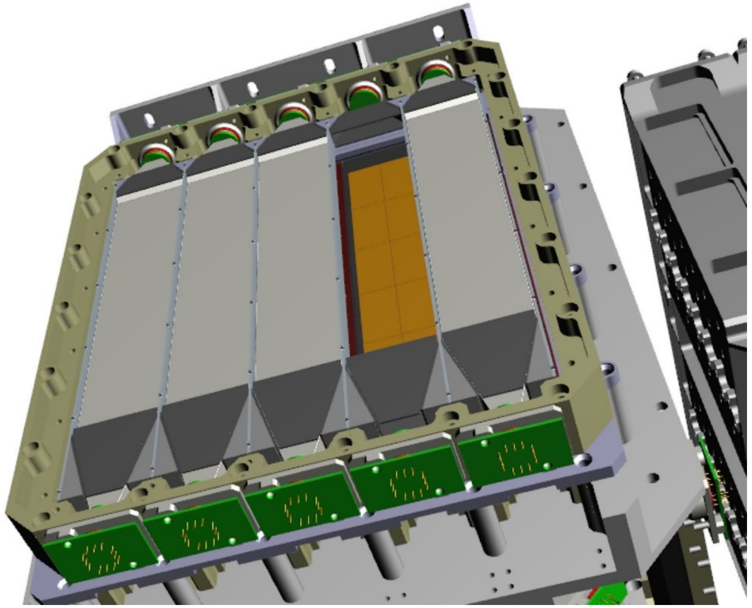
Plastic scintillators: Eljen EJ-200; PMTs: Hamamatsu R9880-210



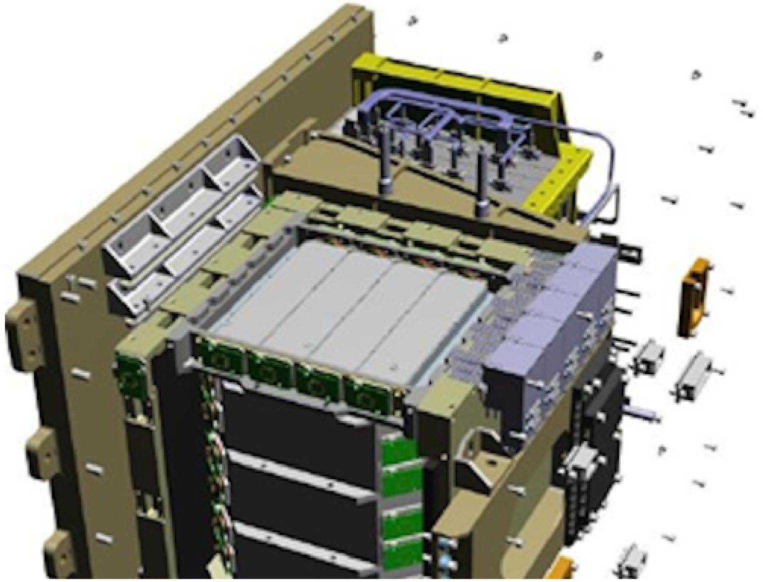


HEPD-02 DETECTOR DESIGN

- HEPD-02 designed to meet the scientific requirements (energy range, energy and angular resolution)
- Particular attention paid to the electron and proton angular and energy resolution in the explored energy range
- Given the demanding mechanical constraints, the detector has been carefully studied to obtain an optimal trade-off between active materials and support structures along the vertical axis



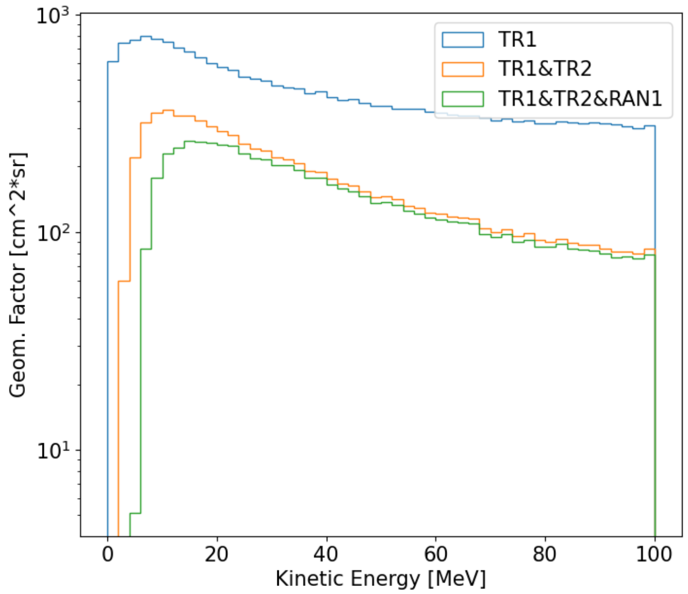
Superposition between a TR1 bar (removed from figure) and the underlying DD ALPIDE stave



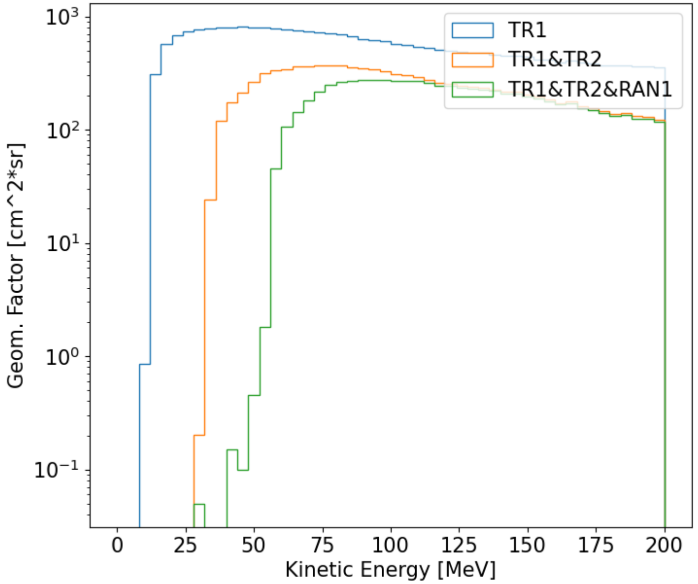
Second trigger plane TR2 on top of the ED calorimeter

HEPD-02 PERFORMANCE - ENERGY RANGE

- The scientific performance of HEPD-02 has been evaluated by means of a Geant4 simulation for an isotropic incoming flux of electrons and protons on top of the instrument
- The energy range requirement is met both for electron (3 MeV ÷ 100 MeV) and proton (30 MeV ÷ 200 MeV)
- The low energy threshold is limited by the mechanical constraints on the stiffness of the detector support layers, given by the structural requirements to sustain mechanical stresses at launch



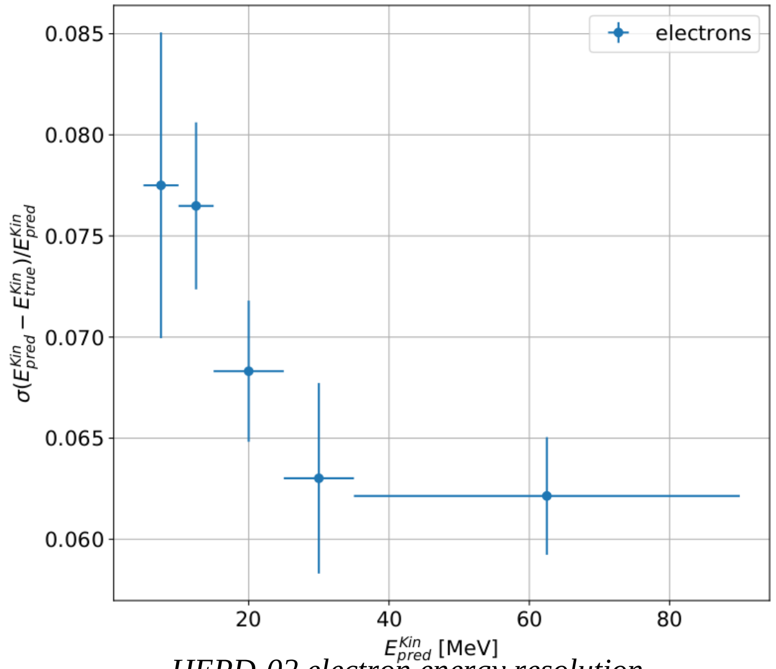
HEPD-02 electron geometric factor



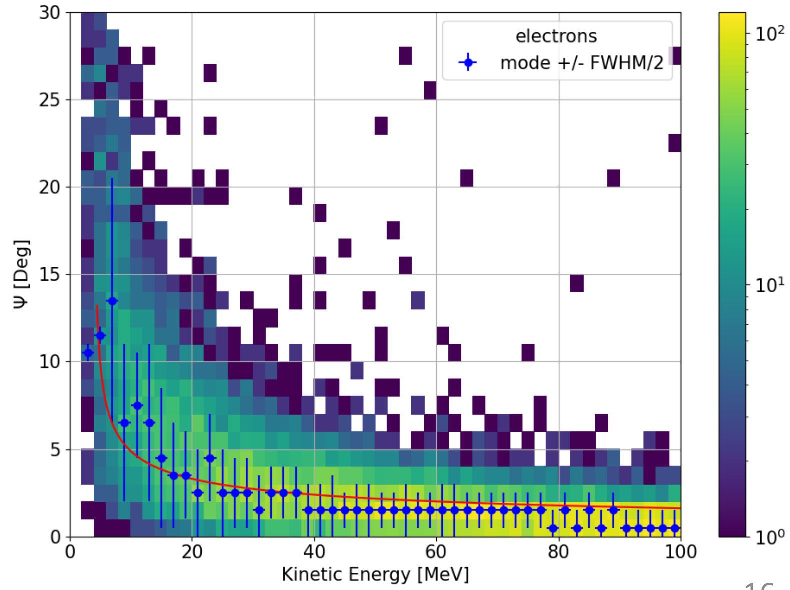
HEPD-02 proton geometric factor

HEPD-02 PERFORMANCE – ENERGY AND ANGULAR RESOLUTION

- Energy resolution: relative difference between true initial kinetic energy and reconstructed kinetic energy (selected sample)
- Electron energy uncertainty <10% for kinetic energies >5 MeV in compliance with the mission requirement
- Angular resolution: distribution of the angle between incoming electron direction reconstructed in the DD and true direction (selected sample)
- Angular resolution better than 10° for the larger part of the electron events with kinetic energies above 5 MeV in compliance with the mission requirement



HEPD-02 electron energy resolution



HEPD-02 electron angular resolution

CONCLUSIONS

- The High Energy Particle Detector (HEPD-02) is being developed to be launched on-board of the second China Seismo-Electromagnetic Satellite (CSES-02) by the end of 2022
- HEPD-02 will be capable of detecting individual incident particles and:
  - identifying type (proton, electron, nucleus)
  - measuring energy
  - determining pitch angle
- HEPD-02 main purpose: identifying particle burst from the stability bands of the Van Allen internal belt to find possible temporal correlations with terrestrial seismic events
- HEPD-02 architecture is the result of an optimized trade-off between scientific objectives of the mission and technical requirements for high-reliability operation in space environment
- Simulation demonstrate that HEPD-02 performance is expected to meet the mission requirements

CRD: Cosmic Ray High-energy all-electron Measurements

H. Motz on behalf CALET Collab:
PoS(ICRC2021)100

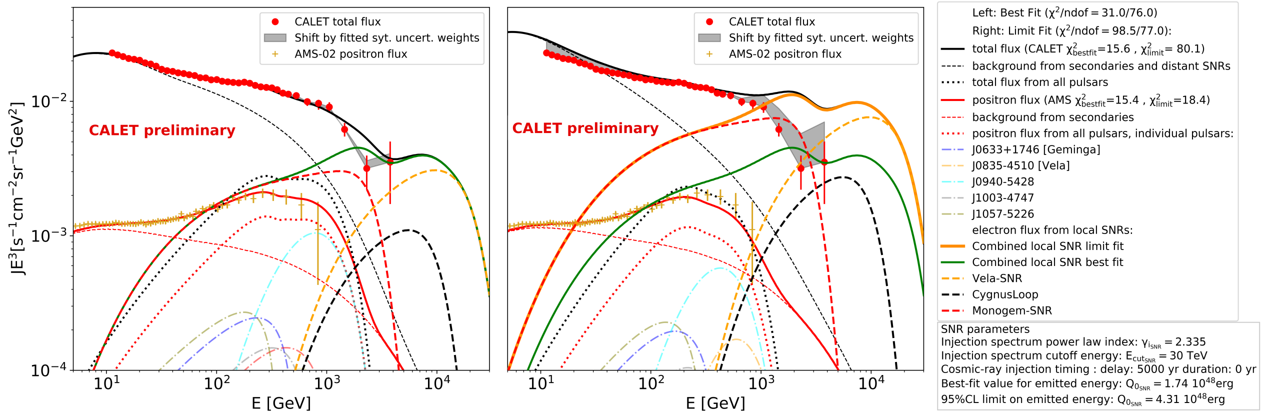
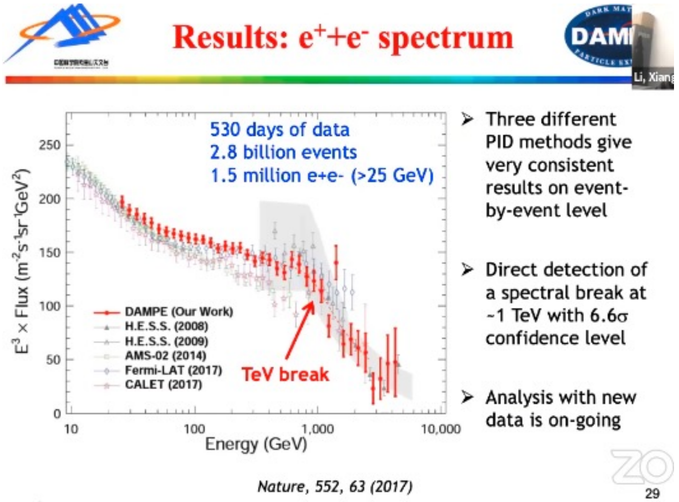


Figure 1: An example of a best fit (left) and limit fit (right) for the case of burst-like emission from the three nearby SNR after a 5 kyr delay, with a power-law injection spectrum with exponential cut-off at 30 TeV. See legend for explanation of each graph element.



S. Torii & Y. Akaike on behalf CALET Collab:
PoS(ICRC2021)105

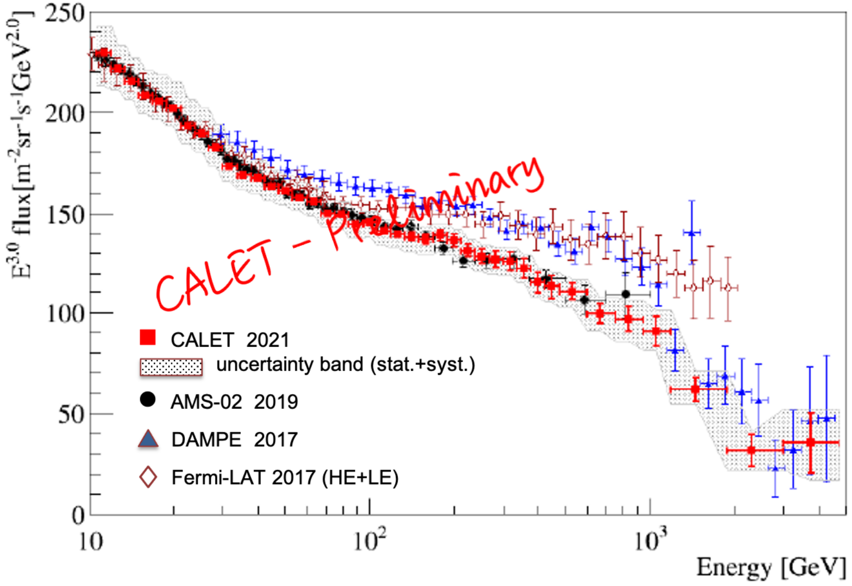


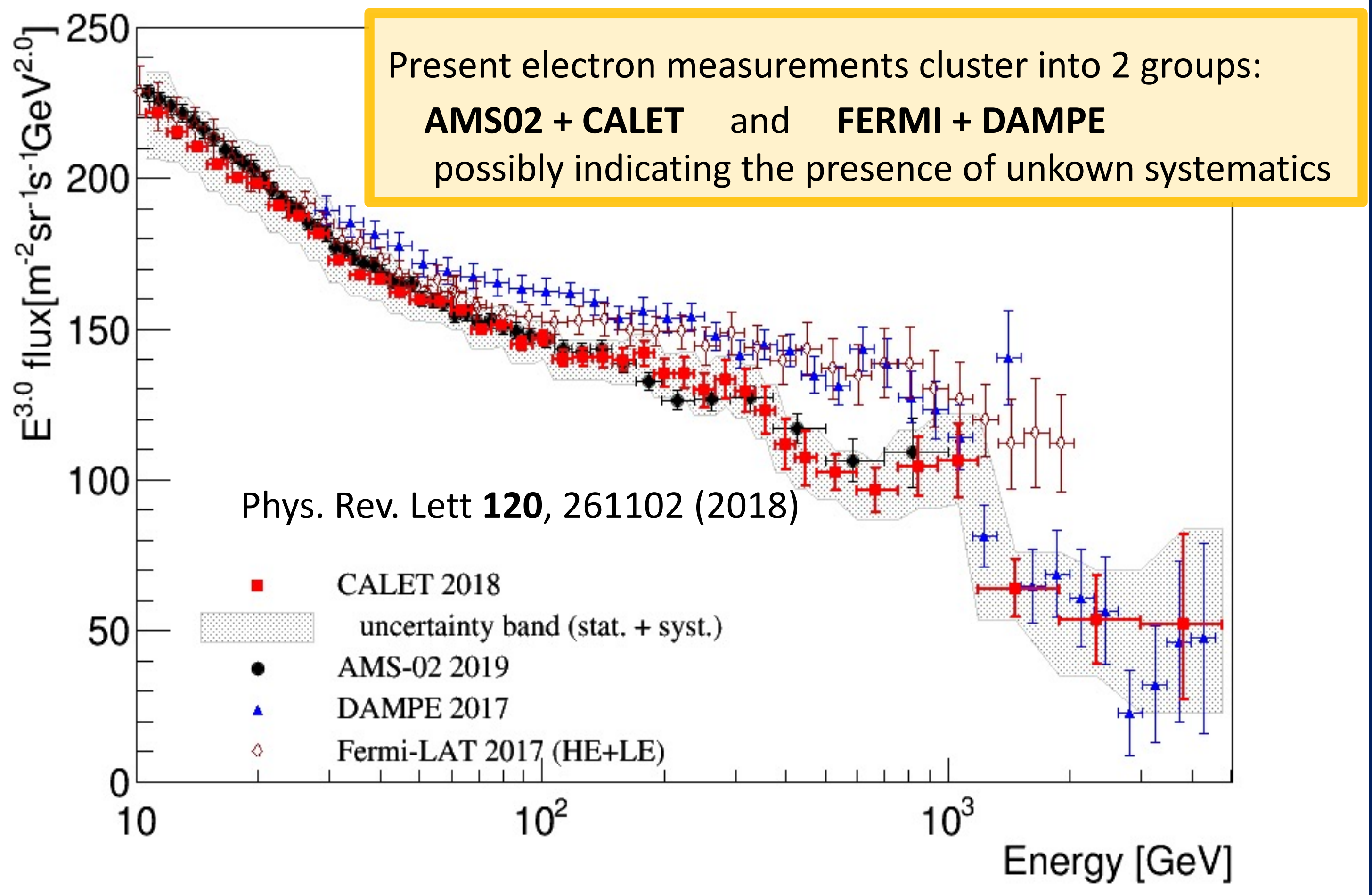
Figure 5: Cosmic-ray all-electron spectrum measured by CALET from 11 GeV to 4.8 TeV using the same energy binning as in our previous publication [7], where the gray band indicates the quadratic sum of statistical and systematic errors (not including the uncertainty on the energy scale). Also plotted are direct measurements in space [8, 17–19] for comparison.

DAMPE results reported during Plenary Session 16 July 21
Recent status and results of the Dark Matter Particle Explorer
PoS(ICRC2021)013 X. Li

Systematic errors in CRD measurements: room for improvement (1/2)

- In the present era of precision CR direct measurements, still significant tensions exist among the data from different experiments. A well known example is shown below for electrons.

- The main **"Known Sources"** of systematic errors include uncertainties on:



Present electron measurements cluster into 2 groups:
AMS02 + CALET and **FERMI + DAMPE**
possibly indicating the presence of unkown systematics

hadronic models including:

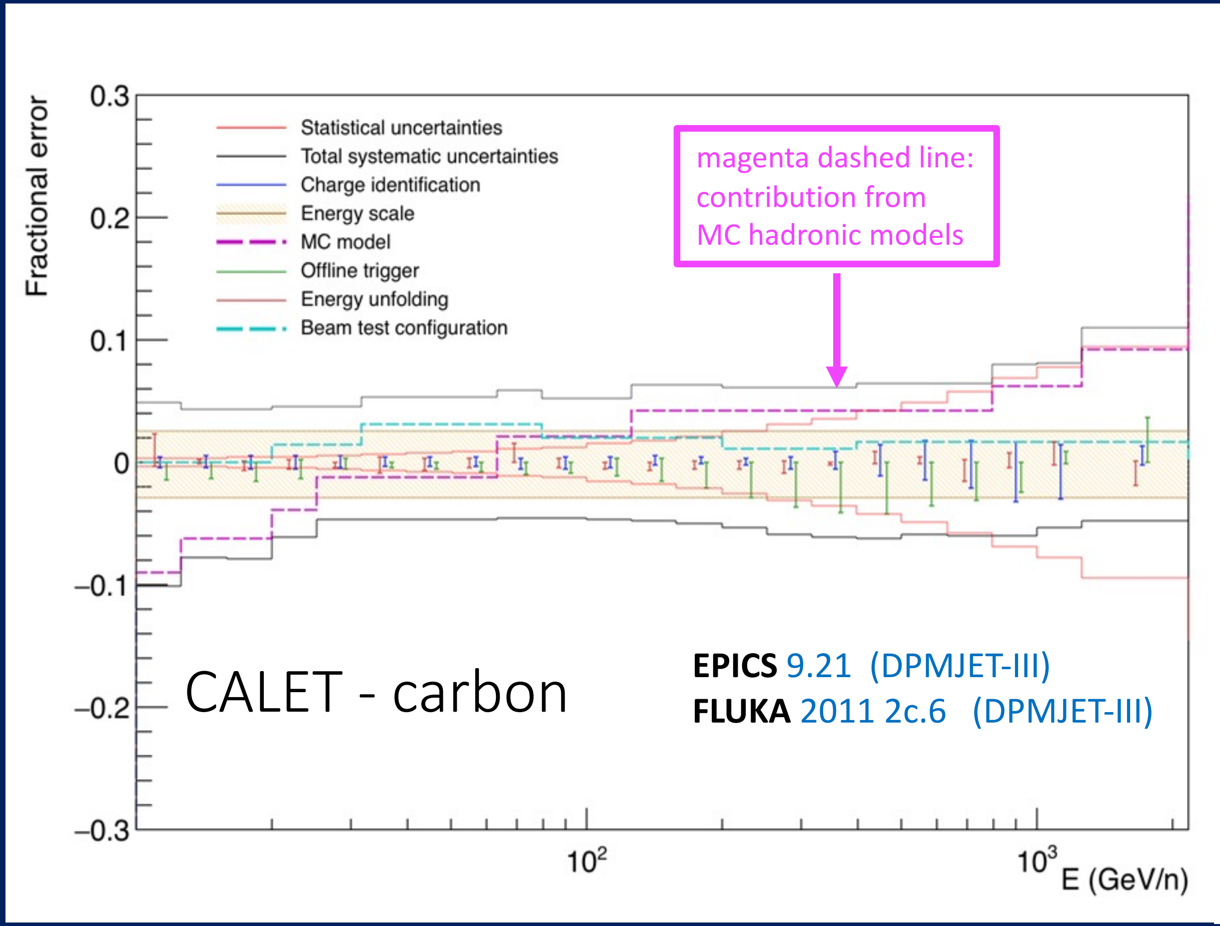
DPMJET-III in :
- EPICS 9.21
- FLUKA 2011 2c.6

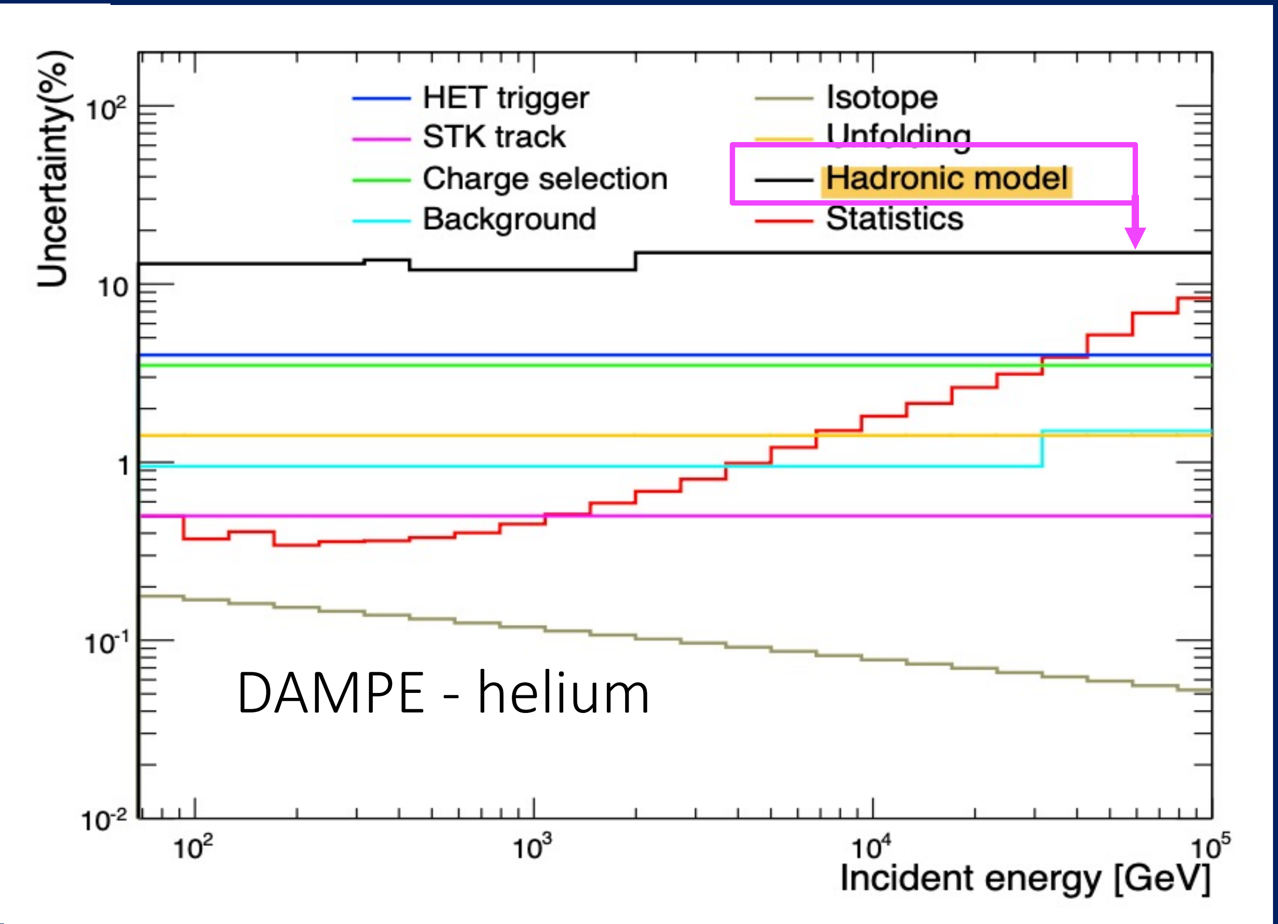
FTFP_BERT in:
- GEANT4 10.5

- Energy Scale
- MC models entangled to:
  - unfolding
  - background subtraction
  - back-scattering
- Normalization
  - live time
  - long-term stability
  - energy scale
- Event selection
  - tracking
  - charge-ID
  - trigger
  - acceptance
  - more ...

Systematic errors in CRD measurements: room for improvement (2/2)

Breakdown of systematic errors: two examples where the **uncertainty on MC hadronic models** can exceed 10%



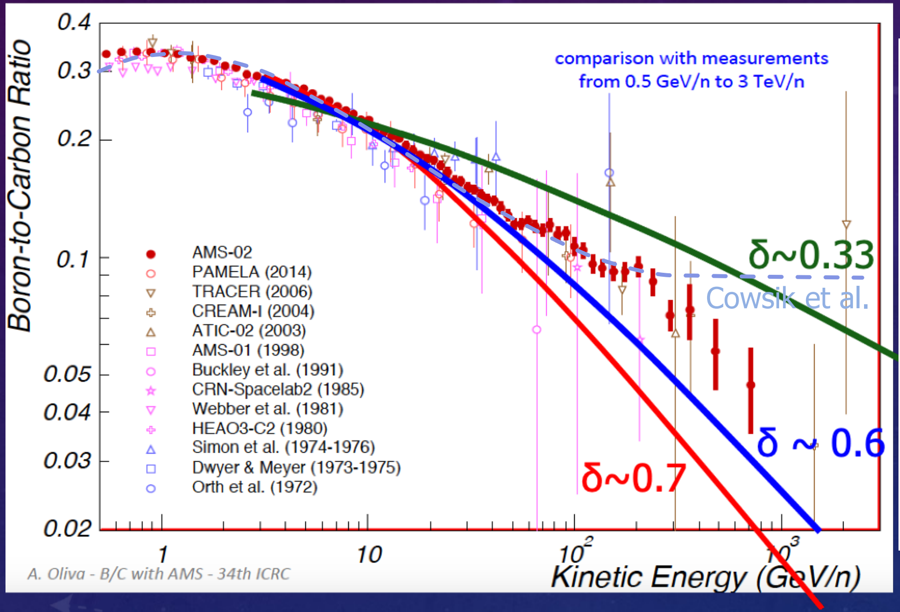


- Improvement in the understanding of **"Known Sources"** of systematics, should leave less room for the still **"Unknown Sources"** and mitigate the present discrepancies in flux normalization among AMS-02, CALET, DAMPE.

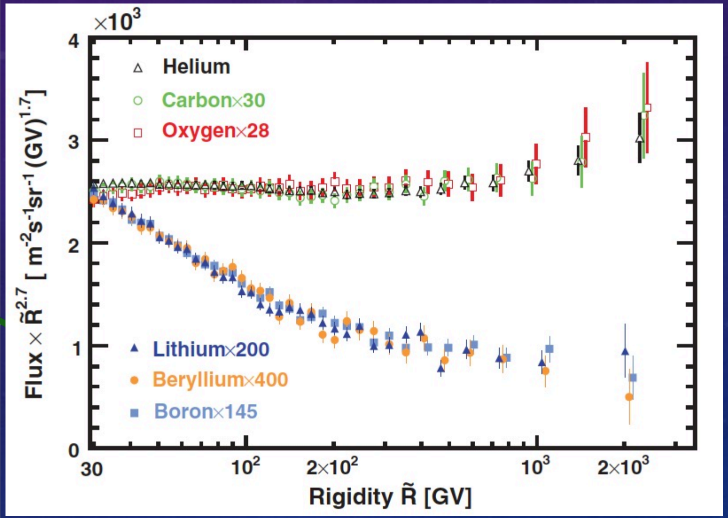
An inter-collaboration effort is needed to track down unknown systematics.

SECONDARY NUCLEI

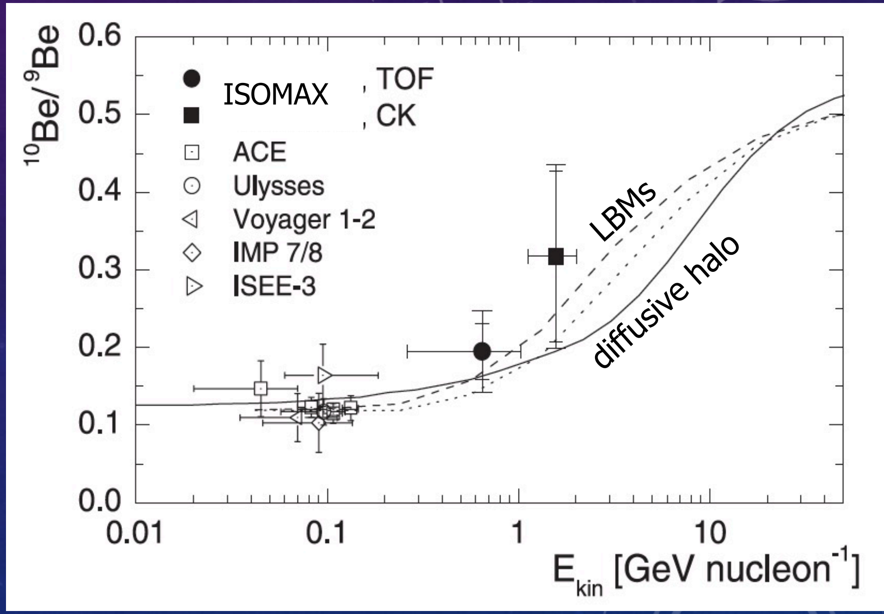
B/C shape well constrained by AMS;
interesting sec vs pri comparison;
Be and other isotopes need better measurements,
phenomenological understanding of secondary
production being refined (crucial for antimatter)



H. S. Ahn et al., Astropart. Phys. 30, 133 (2008)
A. Oliva et al., 34th ICRC (2015)
M. Aguilar et al., PRL 117, 231101 (2016)

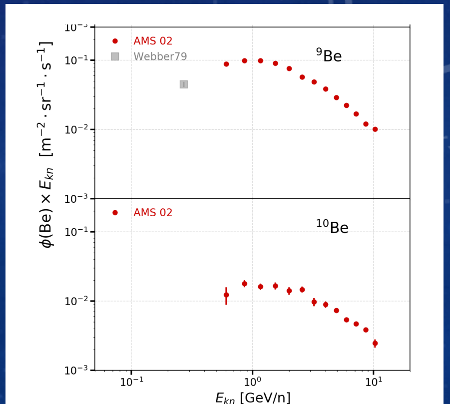


M. Aguilar et al., PRL 120, 021101 (2018)



T. Hams et al., ApJ 611, 892 (2004)

AMS-02, this ICRC



High Energy Light Isotope eXperiment

A spectrometer with 1 Tesla superconductive magnet w/ mass resolution better than 3% up to 3 GeV/n

- HELIX will provide key data to understand the propagation of cosmic rays by measurements of light isotopes ($1 \le Z \le 10$)

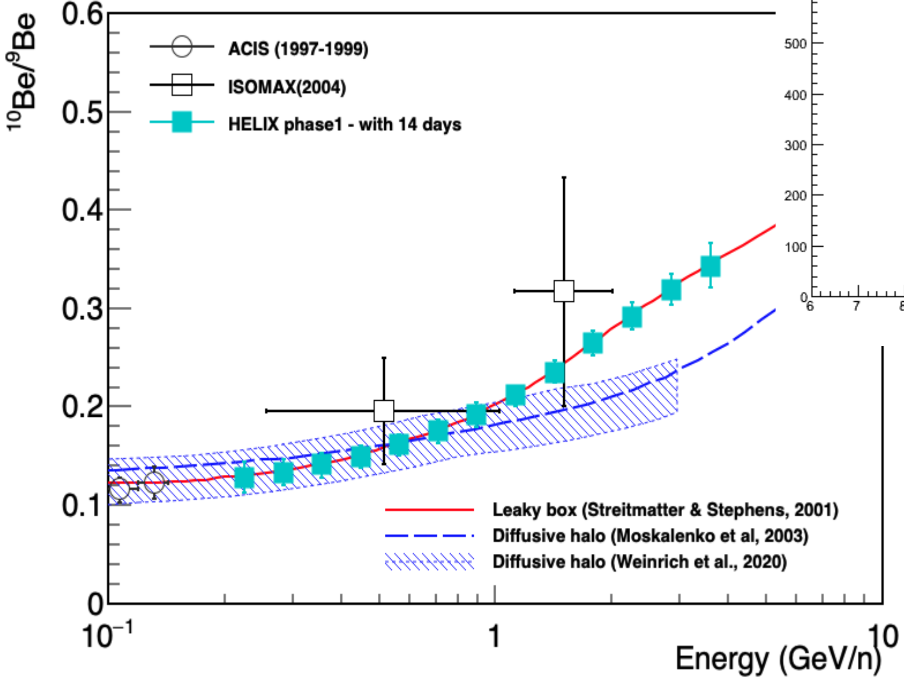
✓Mass productions of the flight hardware have finished

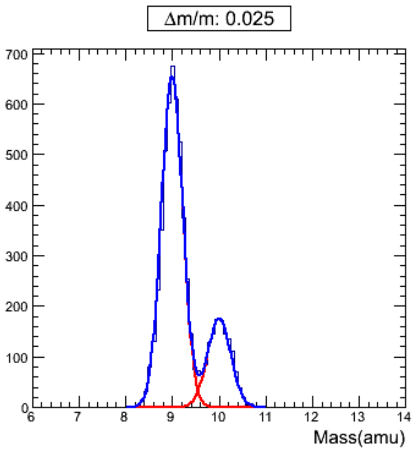
✓Performance of sub-detector components meet the design goals

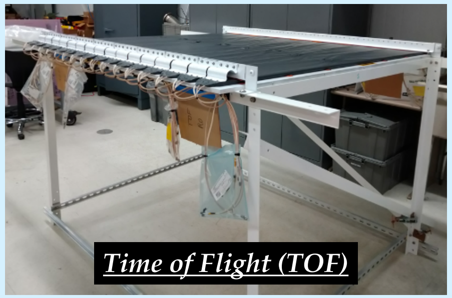
✓Integration of sub-systems underway

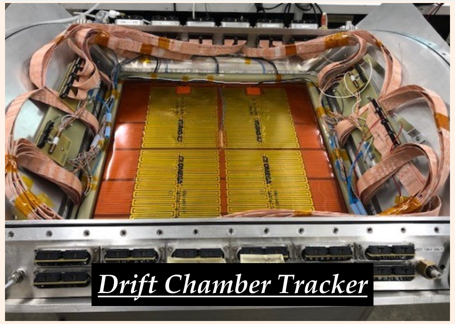
→ Full system integration test in 2021

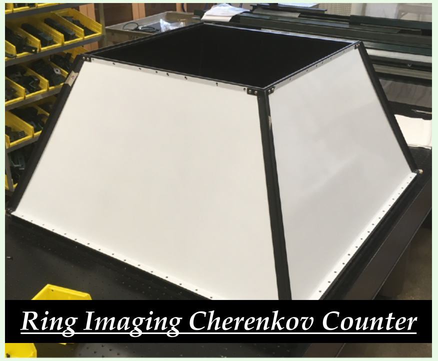
→ Flight from Sweden in 2022 summer

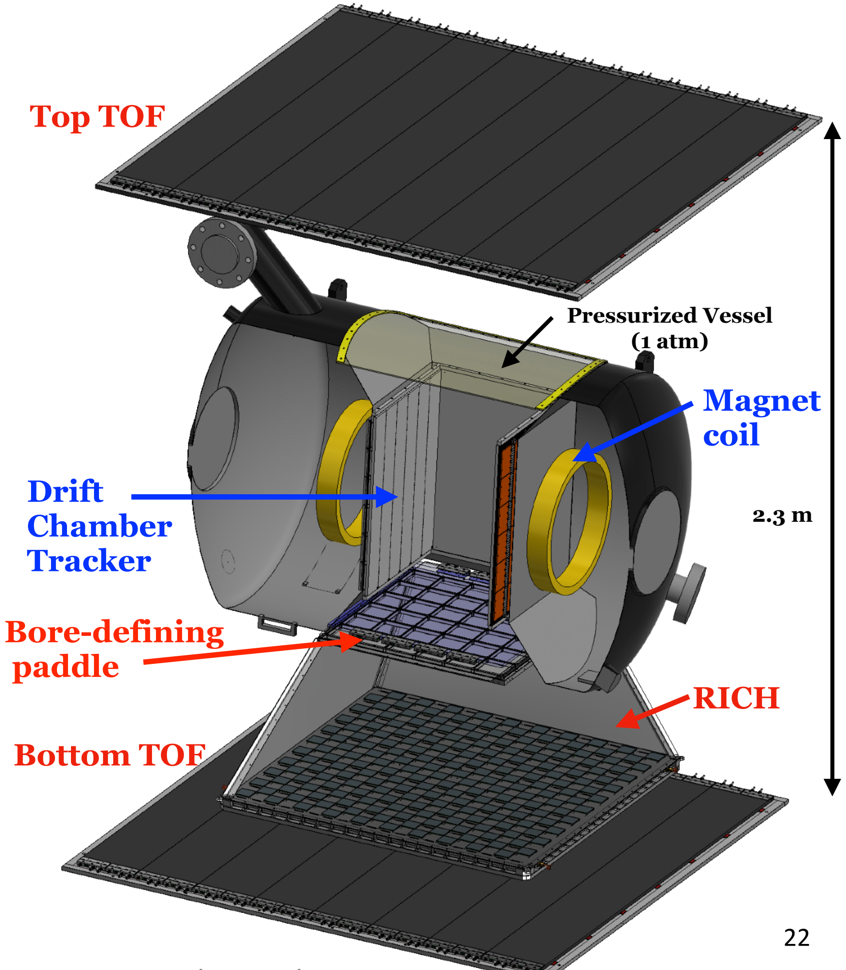












Future expansion of $\mathrm{B/C}$ ratio to higher energies

- **Current status**: Precise estimation (percent level) of B/C ratio up to TeV region with AMS, CALET, DAMPE…
- **Physical case**: $\mathrm{B/C}$ (or $\mathrm{B/O}$) is key observable to understand propagation
  - In the high energy regime, diffusion dominates and $\mathrm{B/C} \propto K_0 R^{-\delta}$:

→Large lever arm to measure the diffusion index δ and/or to investigate breaks.

→Reaching the knee region $\mathrm{B/C}$ would be of the utmost interest.

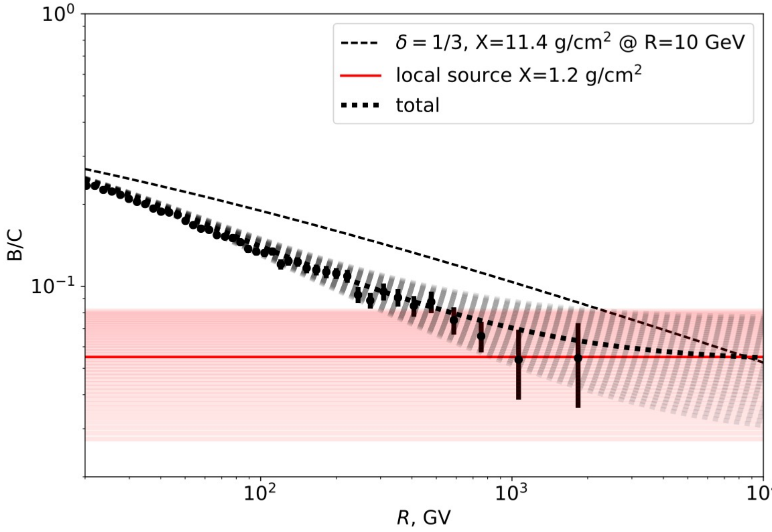
  - As diffusion increase with energy/rigidity, galactic grammage decrease and secondary production at the source can become dominant:

→$\mathrm{B/C}$ at higher energy could alternatively probe the sources/acceleration processes.

- **Experimental challenges, need for:**
  - Precise energy measurement up to the highest energy,
  - Large acceptance (as $\mathrm{B/C} \underset{R\to\infty}{\rightarrow} 0$),
  - High identification power capabilities.
  - Low grammage, thin detector.

Mertsch, P. ; Sarkar, S. PRD90 (2014)

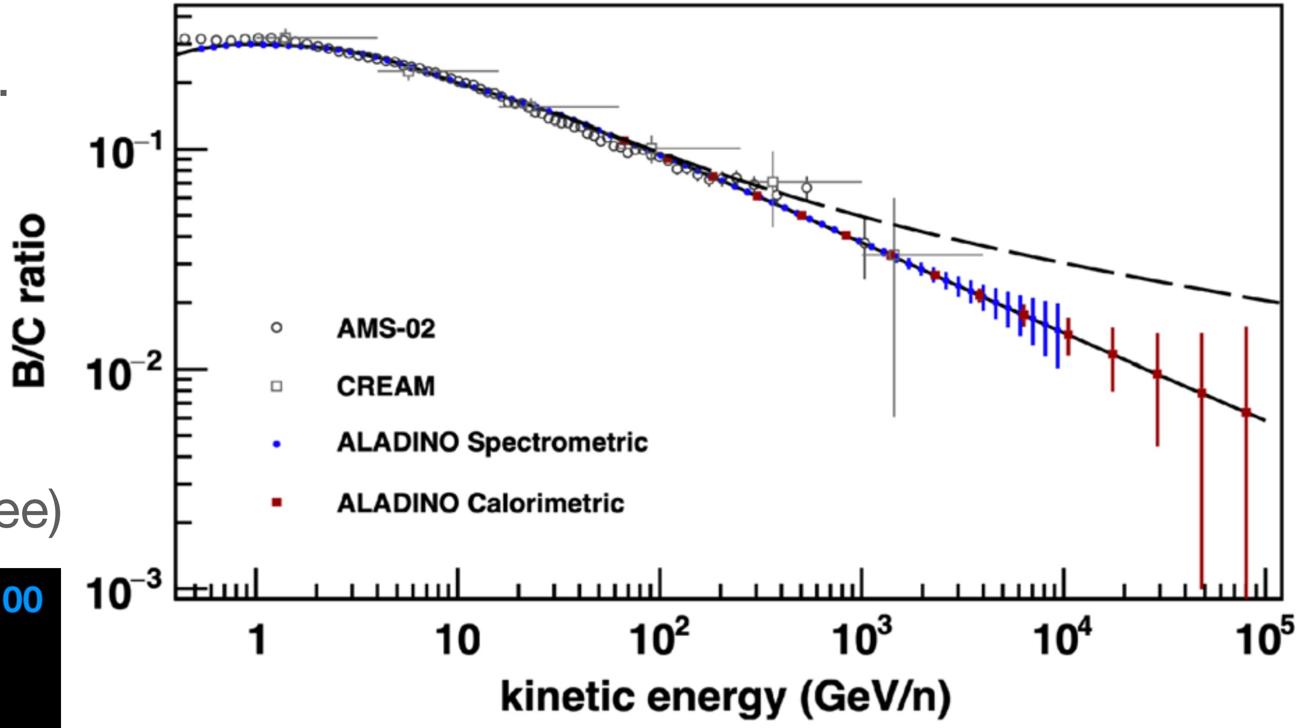
Kachelrieß, M. ; Neronov, A. ; Semikoz, D. V. PRD97 (2018)



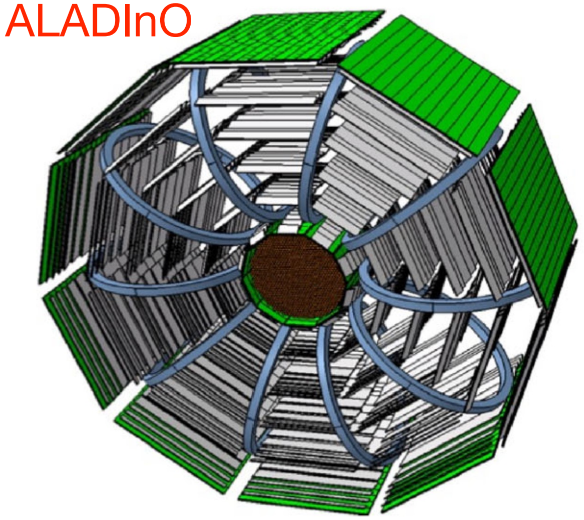
Future expansion of B/C ratio to higher energies

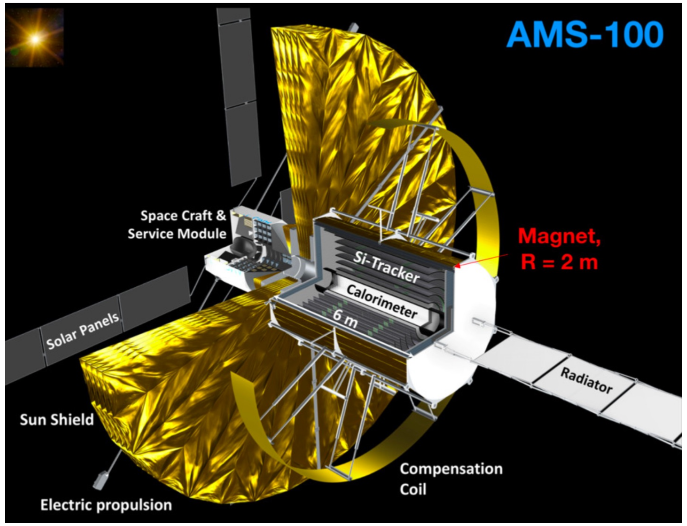
- Future projects?: 2 large acceptance magnetic spectrometer and calorimeter space experiments.
  - ALADInO:
    - Spectrometer: Acc. 10 m^{2}sr, MDR 30 TV
    - Calorimeter: Acc. 9 m^{2}sr
  - AMS-100:
    - Spectrometer: Acc. 100 m^{2}sr, MDR 100 TV
    - Calorimeter: Acc. 30 m^{2}sr (>10 up to the Knee)

ALADInO expectation for the B/C (20 m^2 sr yrs):



ALADInO





CRD: Ultra-heavy Galactic Cosmic Rays, measurements for Z > 40 critical

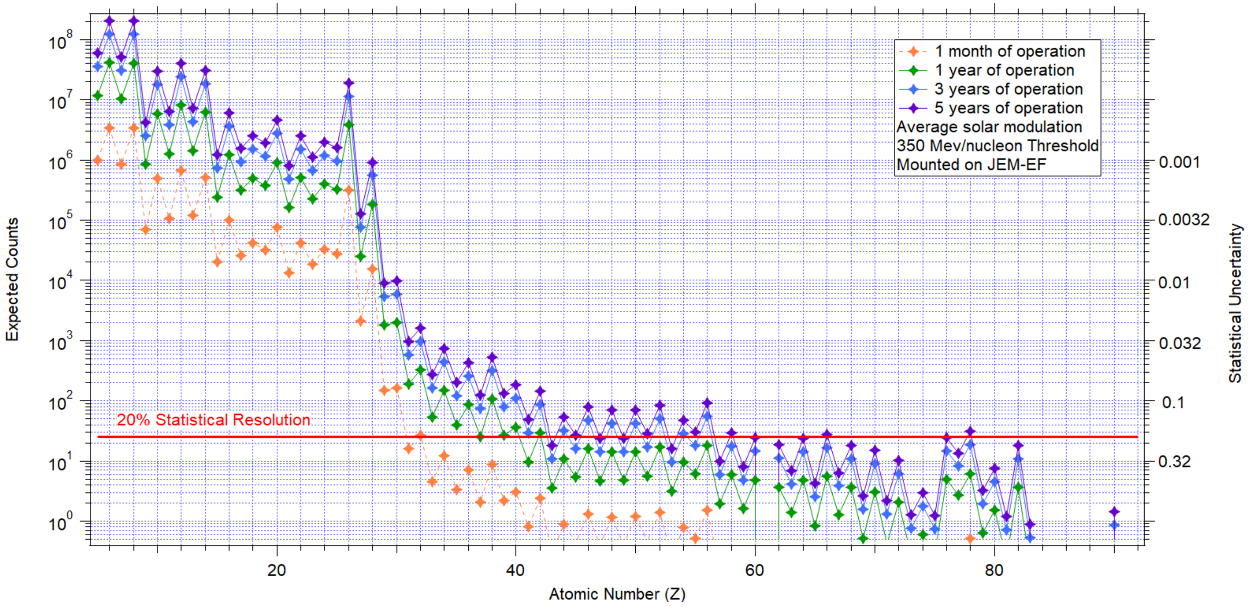


Figure 1: TIGERISS cosmic ray elemental count rates versus exposure time. The 20% resolution in not a 1 year exposure requirement but meant as a guide to the statistical resolution of TIGERISS measurements as a function of exposure time based on the current understanding of the UHGCR composition based on HEAO-3, Ariel 6, TIGER, and SuperTIGER data.

Introduction

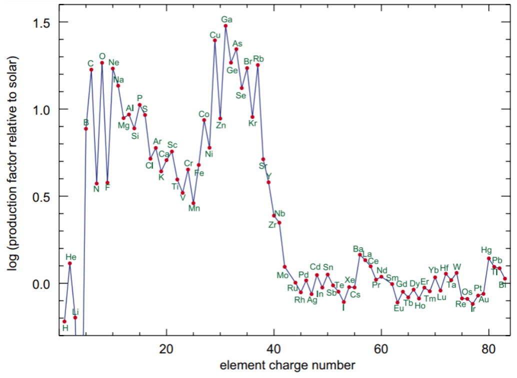


Fig. 1.4: *SN elemental production factors relative to solar (Lodders 2003[1]). Figure from Woosley & Heger 2007[4].*

Figure 3: Source Nathan Walsh's PhD dissertation, "SuperTIGER Elemental Abundances for the Charge Range 41 ≤ Z ≤56", WUSTL 2020.

Introduction

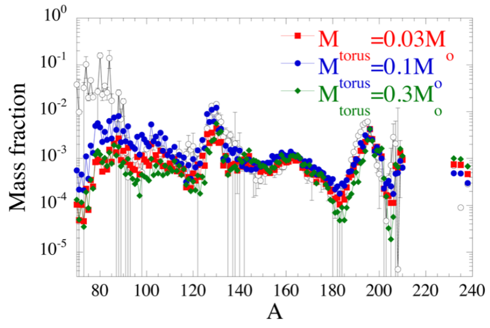


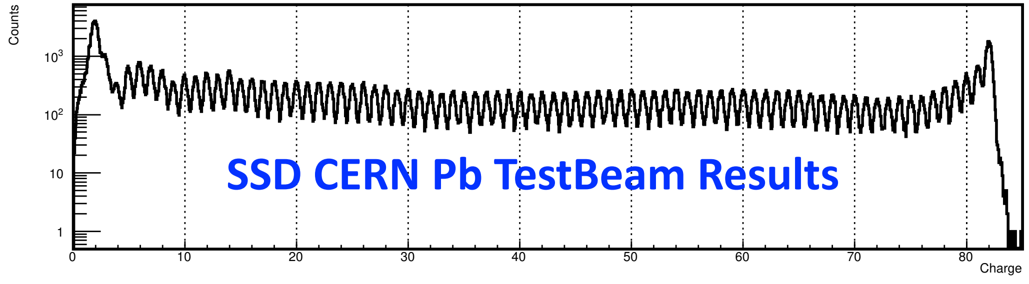
Fig. 1.5: *Mass fraction yields by atomic mass A from NS-NS and NS-BH merger simulations for different resulting BH-torus masses (all normalized to to the same solar A = 196 abundance). The white circles show solar r-process abundances from Goriely 1999[6]. Figure from Just et al. 2015[7].*

Figure 4: Source Nathan Walsh's PhD dissertation, "SuperTIGER Elemental Abundances for the Charge Range 41 ≤ Z ≤56", WUSTL 2020.

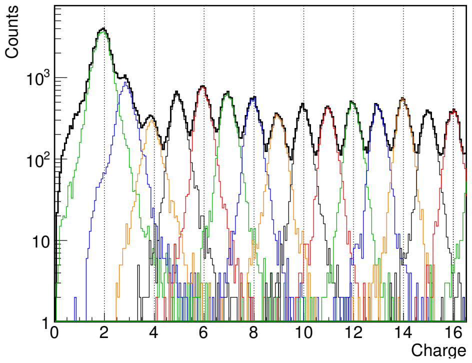
With the observation of the hypernova GW170817, the picture of UHGCR nucleosynthesis has become more interesting. It has been known that nucleosynthesis in supernovae have difficulty in producing elements with Z > 40 (see Fig 3.). However, binary-neutron-star (BNS) nucleosynthesis models appear to 'turn on' around Z > 40 (see Fig 4). ***Thus sufficiently accurate measurements of the UHGCR abundances for Z > 40, initially for a set of key elements to distinguish whether these are created by s- or r-process nucleosynthesis, provide a fundamental understanding of how the elements are created in our galaxy.***

The Trans-Iron Galactic Element Recorder for the International Space Station (TIGERISS)

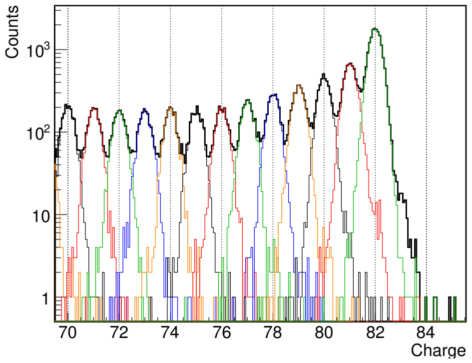
Silicon strip detector (SSD) for precision charge measurement 5 ≲ Z ≤ 82 and SiPM Cherenkov detector readout based on CERN testing.



(a) $Z = 2 - 82$



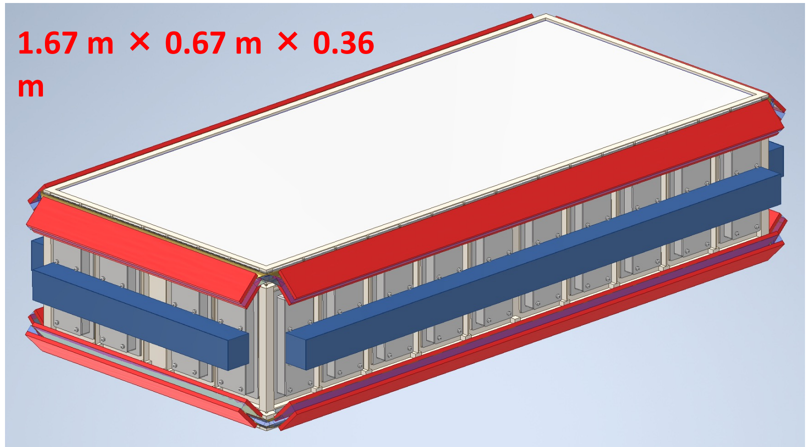
(b) $Z = 2 - 16$



(c) $Z = 70 - 82$

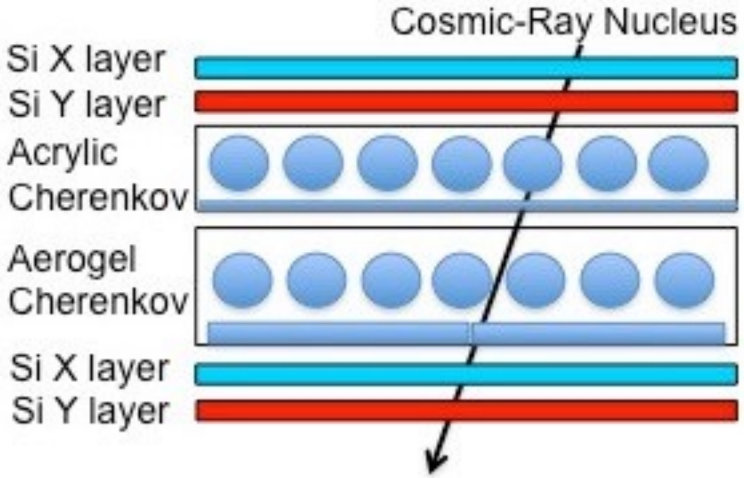
σ_Q < 0.24e for 5 ≲ Z ≤ 82

- Large electronic particle detector system – 1.1 m^2 active area, AΩ > 1.6 m^2 sr (JEM-EF version)



Charge measurement:

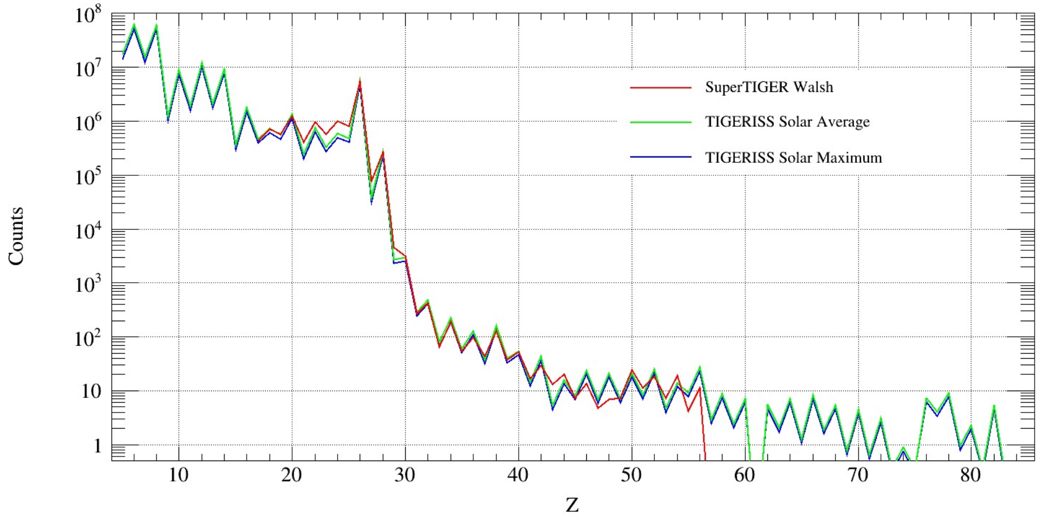
- dE/dx vs. Cherenkov
- Cherenkov vs. Cherenkov techniques:



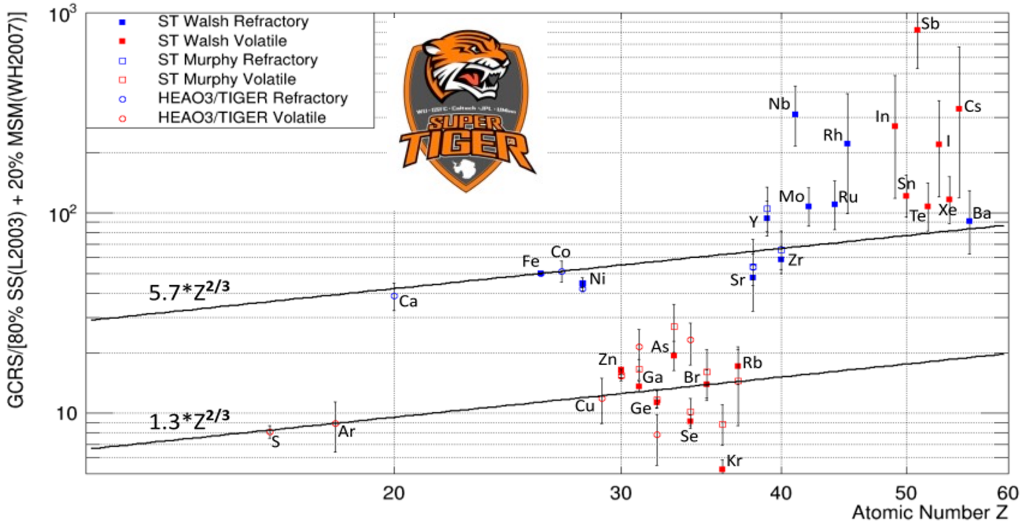
TIGERISS - Heritage

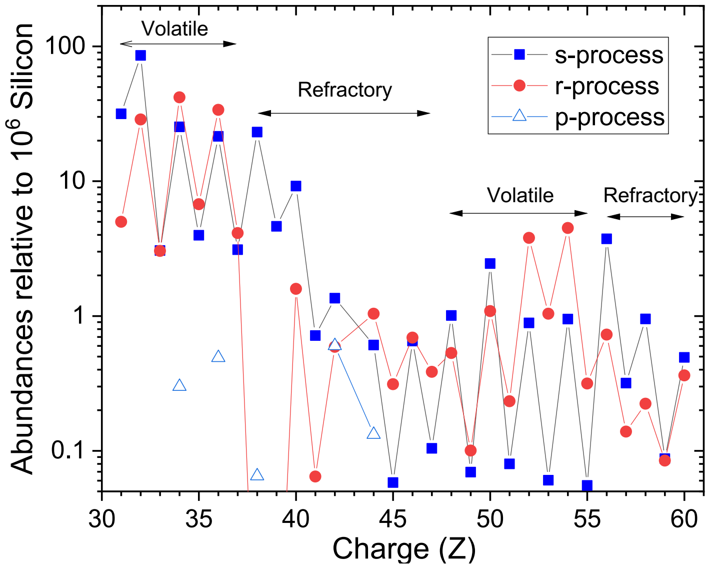
TIGERISS Measurements and Science

1341. Determination of Expected TIGERISS Observations



988. SuperTIGER Abundances of Galactic Cosmic Rays for the Atomic Number (Z) Interval 30 to 56



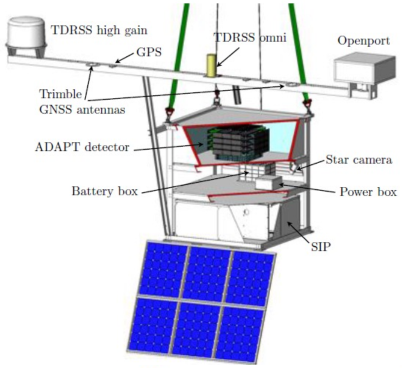


In one-year TIGERISS will have:

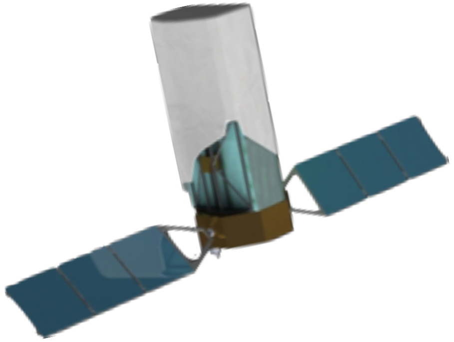
- **Comparable statistics to SuperTIGER-1**
- **~1/2 statistics for HEAO-3-HNE charge group measurements (Binns et al. 1989) with individual element resolution**
- **Probe relative amount of nucleosynthesis by s- and r-processes in GCR with significant measurements of**
  - **s-process elements $_{50}$Sn, $_{56}$Ba**
  - **r-process elements $_{52}$Te, $_{54}$Xe**

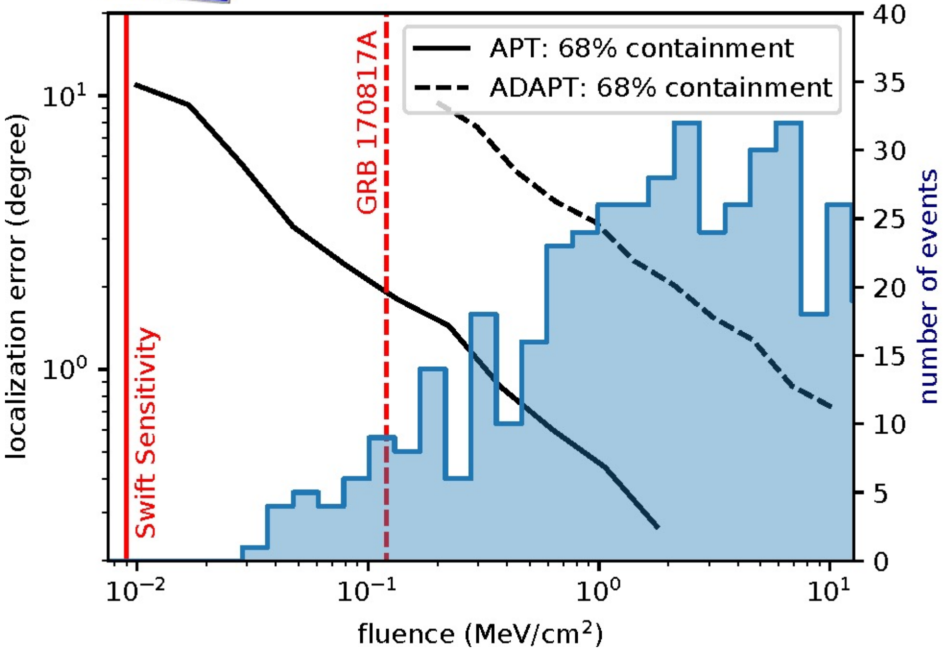
The Advanced Particle-astrophysics Telescope (APT):

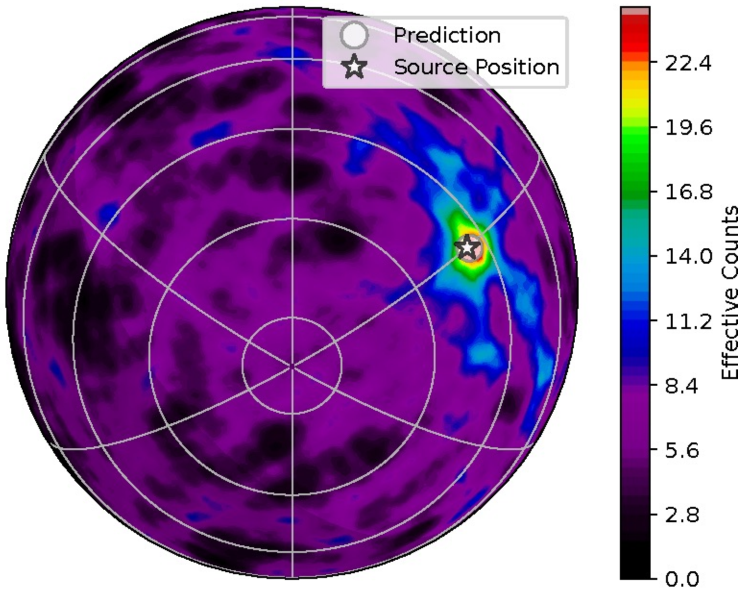
Simulation of the Instrument Performance for Gamma-Ray Detection

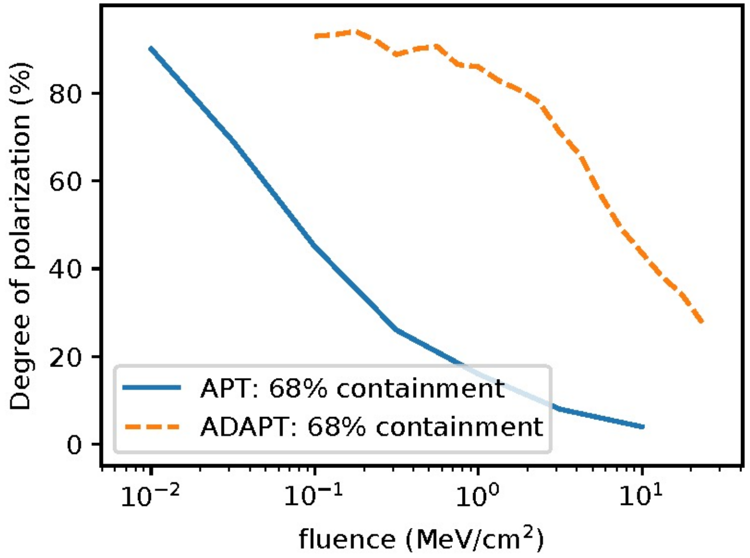


- Localize n-star mergers/GW sources over whole sky to ~1˚
- Discriminate n-star and r-process synthesis of heavy elements
- Detect or rule out WIMP dark matter over entire natural parameter space





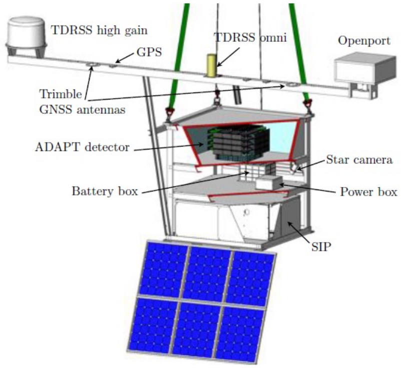


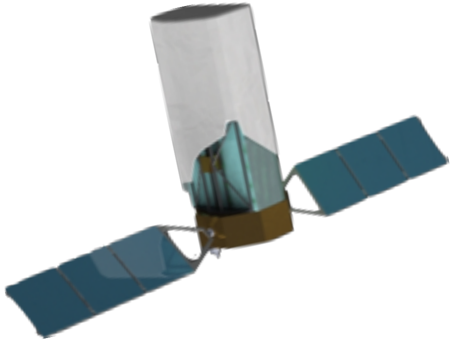


Left: Error in reconstructed direction of a Band-spectrum GRB versus fluence. Middle: An example Compton sky map of a 1 MeV/cm−2 GRB detected by the ADAPT. Right: 3-σ DOP sensitivity of the APT and ADAPT as a function of the GRB fluence.

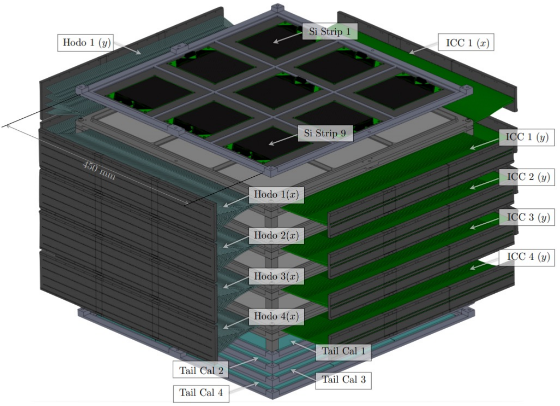
The Advanced Particle-astrophysics Telescope (APT):

Characterization of a prototype imaging calorimeter for the Advanced Particle-astrophysics Telescope from Antarctic balloon flight and CERN beam test data.

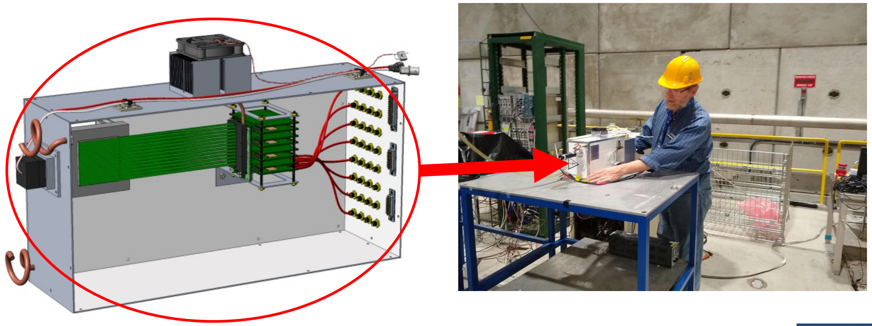


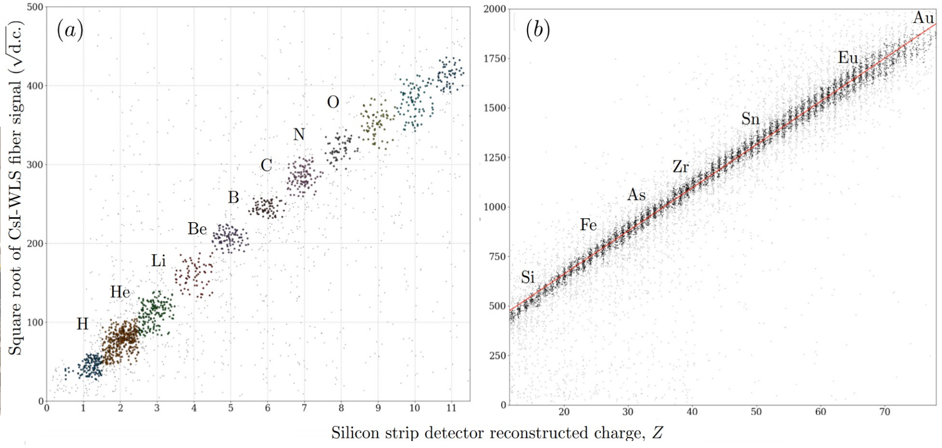


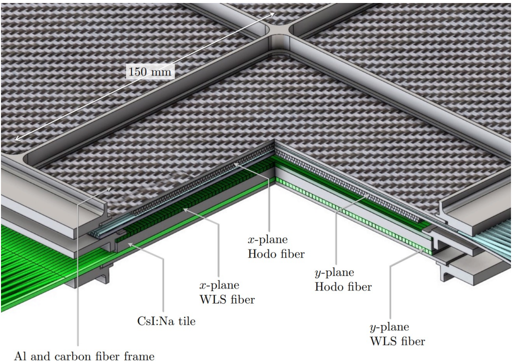
APT/ADAPT have silicon strip detectors: APT measure cosmic-rays to $_{82}$Pb+

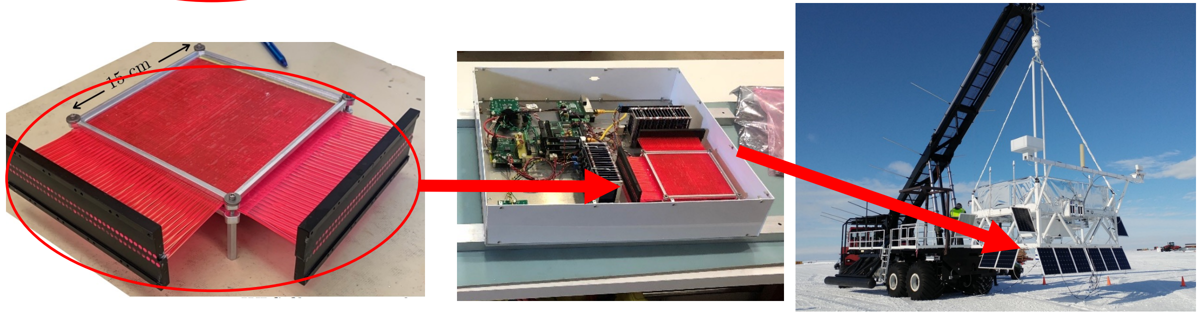


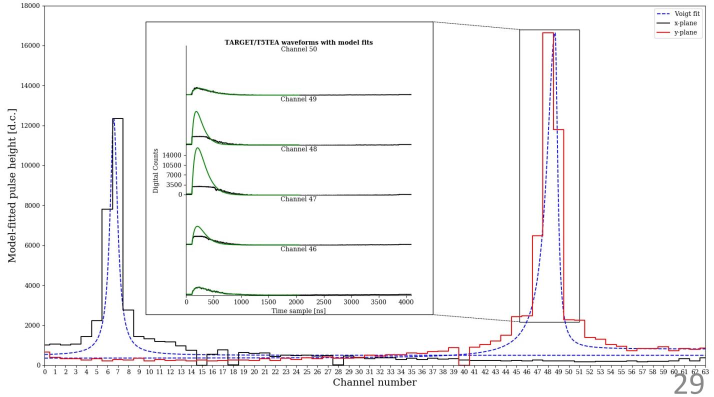
APT vs. HNX charge plot from CERN beam test.







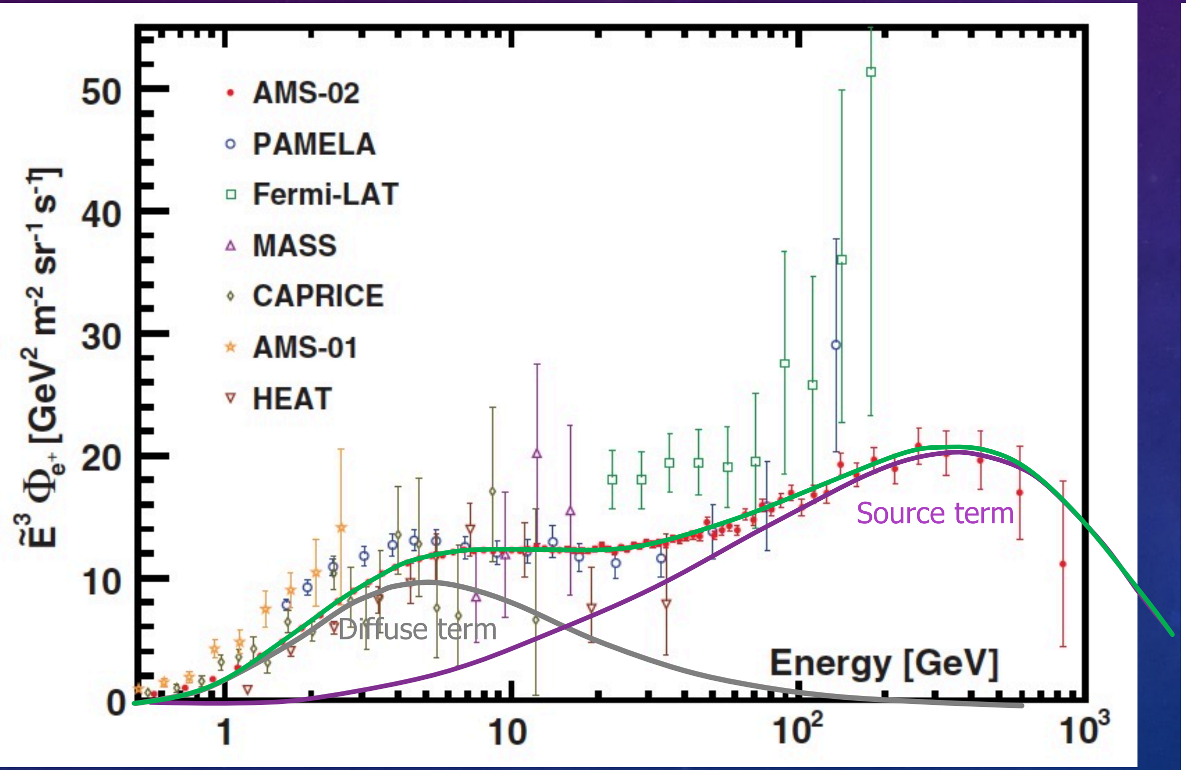




Cosmic-ray event reconstruction for 2019 APT-Lite balloon flight.

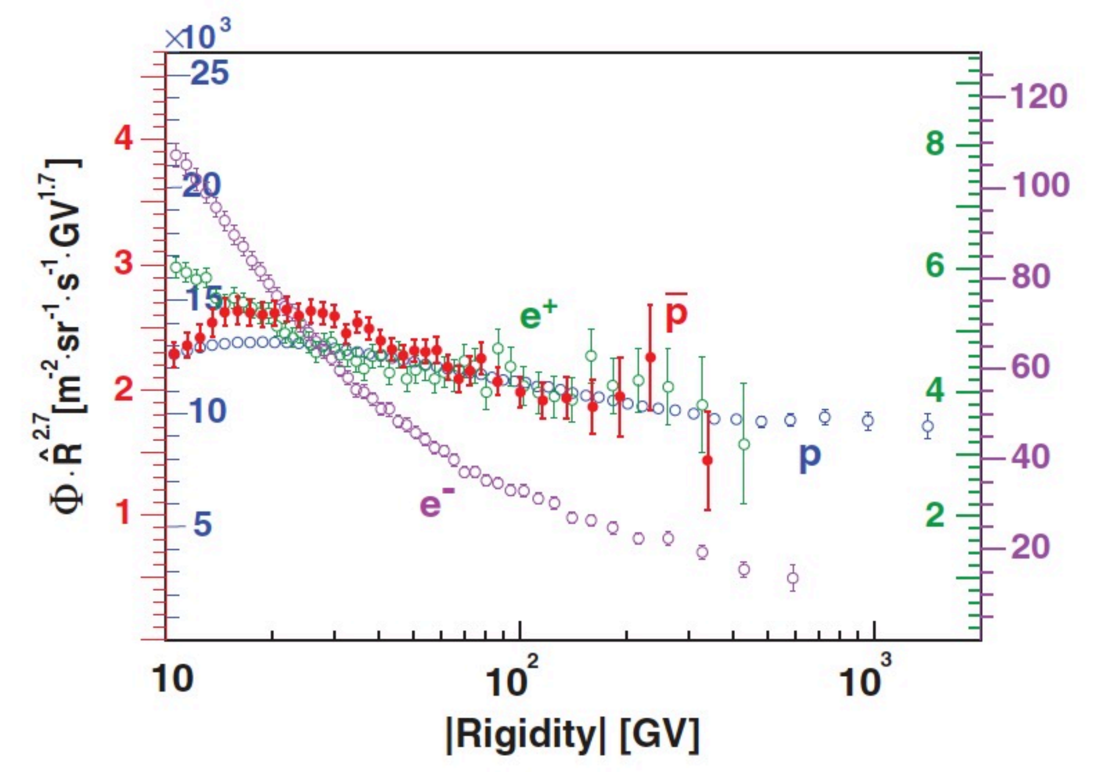
ANTIMATTER

- How well are the secondary e⁺, pbar understood? Can DM annihilations explain the excess positrons? Any meaningful pbar structure?
- New regime: antideuterons



positrons

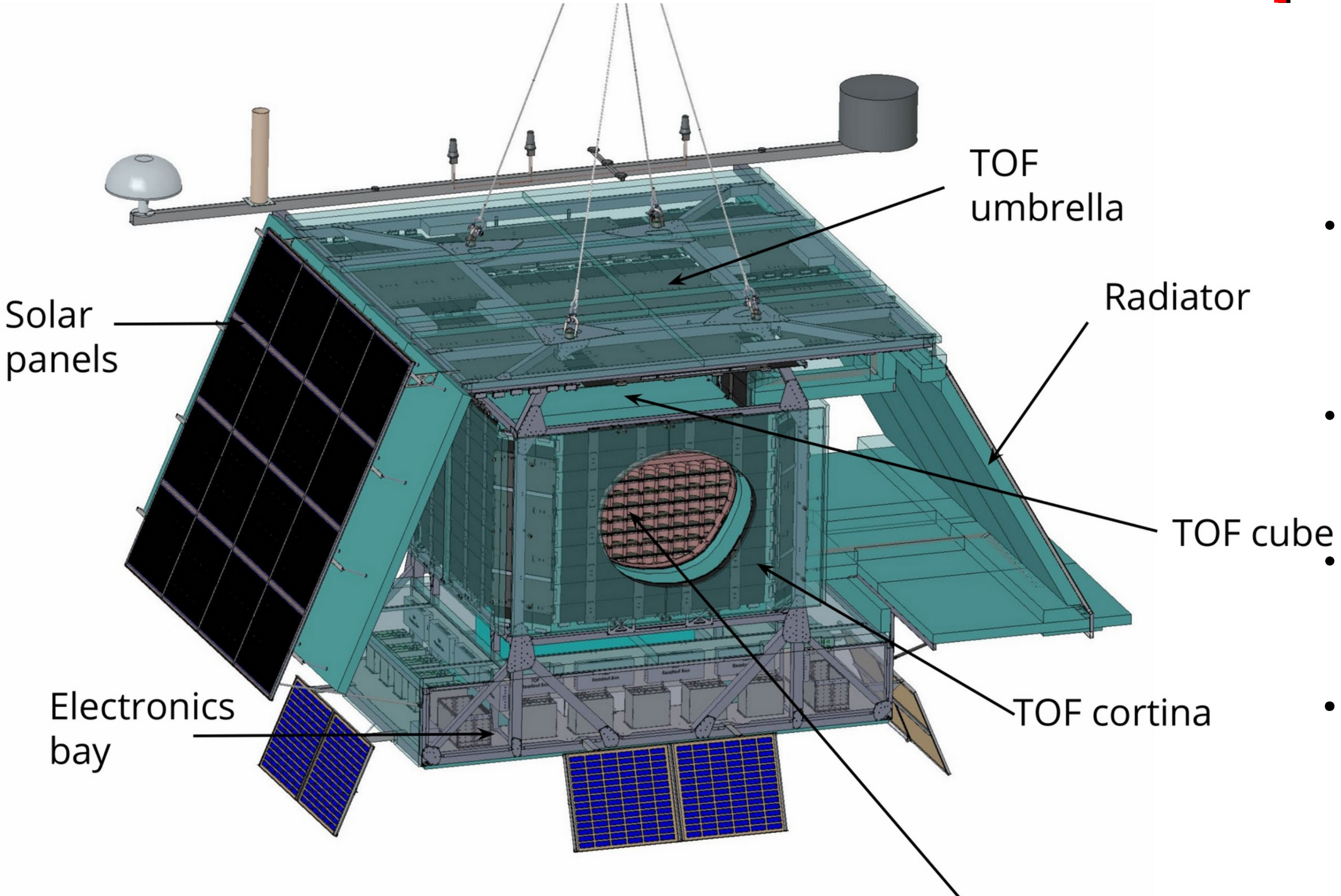
M. Aguilar et al., PRL 122, 041102 (2019)



antiprotons

M. Aguilar et al., PRL 117, 091103 (2016)

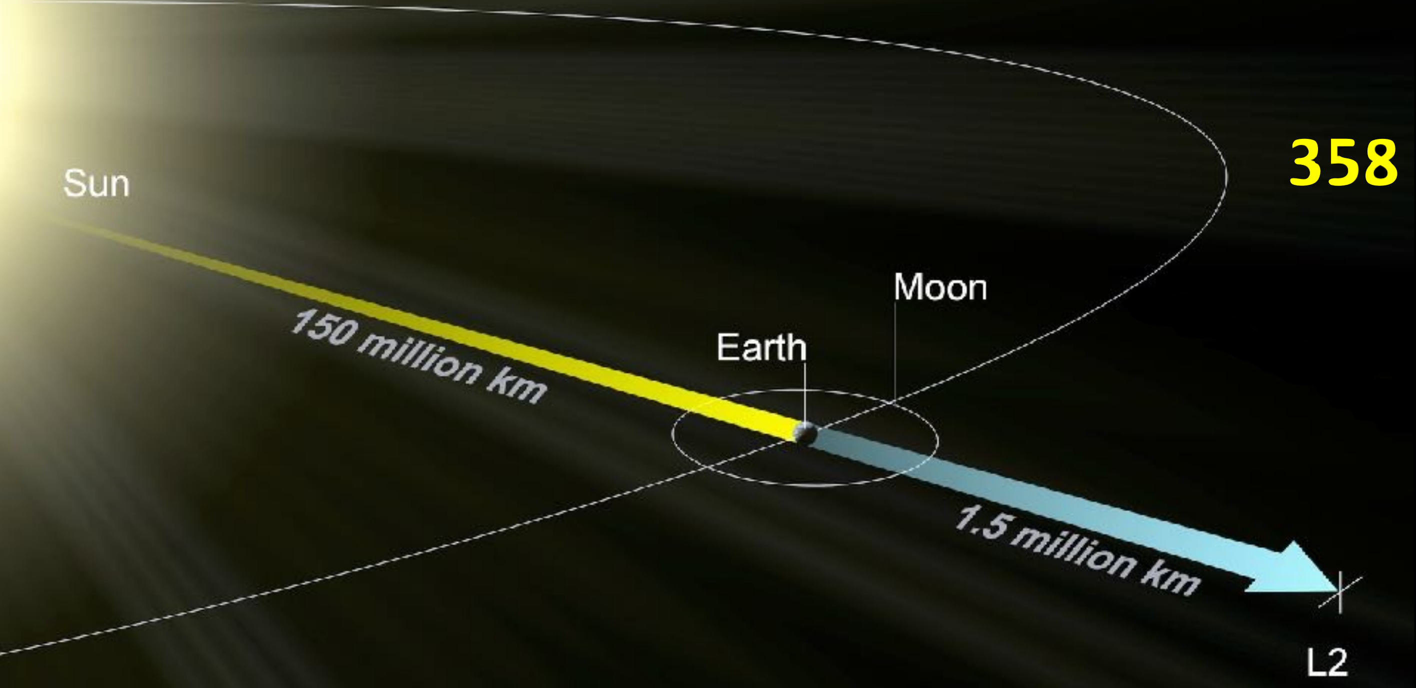
GAPS - General AntiParticle Spectrometer

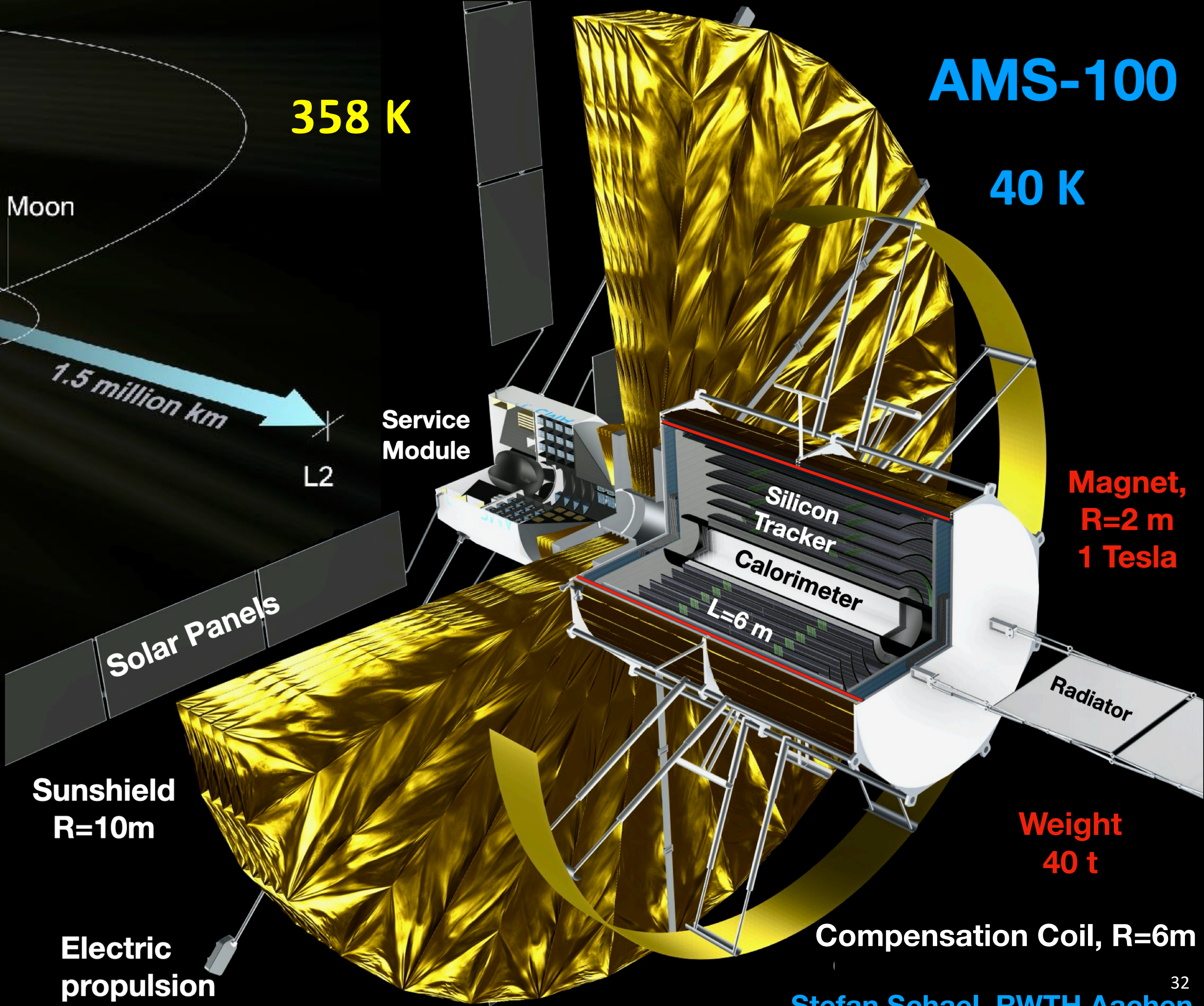


GAPS contributions to ICRC:
221: Xiao, Science overview
1028: Quinn, Instrument overview
1335: Rogers, Antiproton sensitivity
719: Stoessl, Antihelium sensitivity
1194: Tiberio, Event reconstruction
428: Marcelli, NN event reconstruction

- Low-energy cosmic-ray antideuterons are sensitive to a range of different dark matter models (review: JCAP08(2020)035, arXiv:2002.04163)
- The **G**eneral **A**nti**P**article **S**pectrometer is the first experiment dedicated and optimized for low-energy cosmic-ray antinuclei search
- Particle identification technique uses the formation and decay of an exotic atoms, followed by antinucleus-nucleus annihilation
- **GAPS will deliver:**
  - a precision antiproton measurement in an unexplored energy range <0.25 GeV/n
  - antideuteron sensitivity 1-2 orders of magnitude below the current best limits, probing a variety of DM models across a wide mass range
  - provide leading sensitivity to low-energy cosmic antihelium nuclei
- **GAPS is under construction**
  → first Long Duration Balloon flight from Antarctica in late 2022

AMS-100



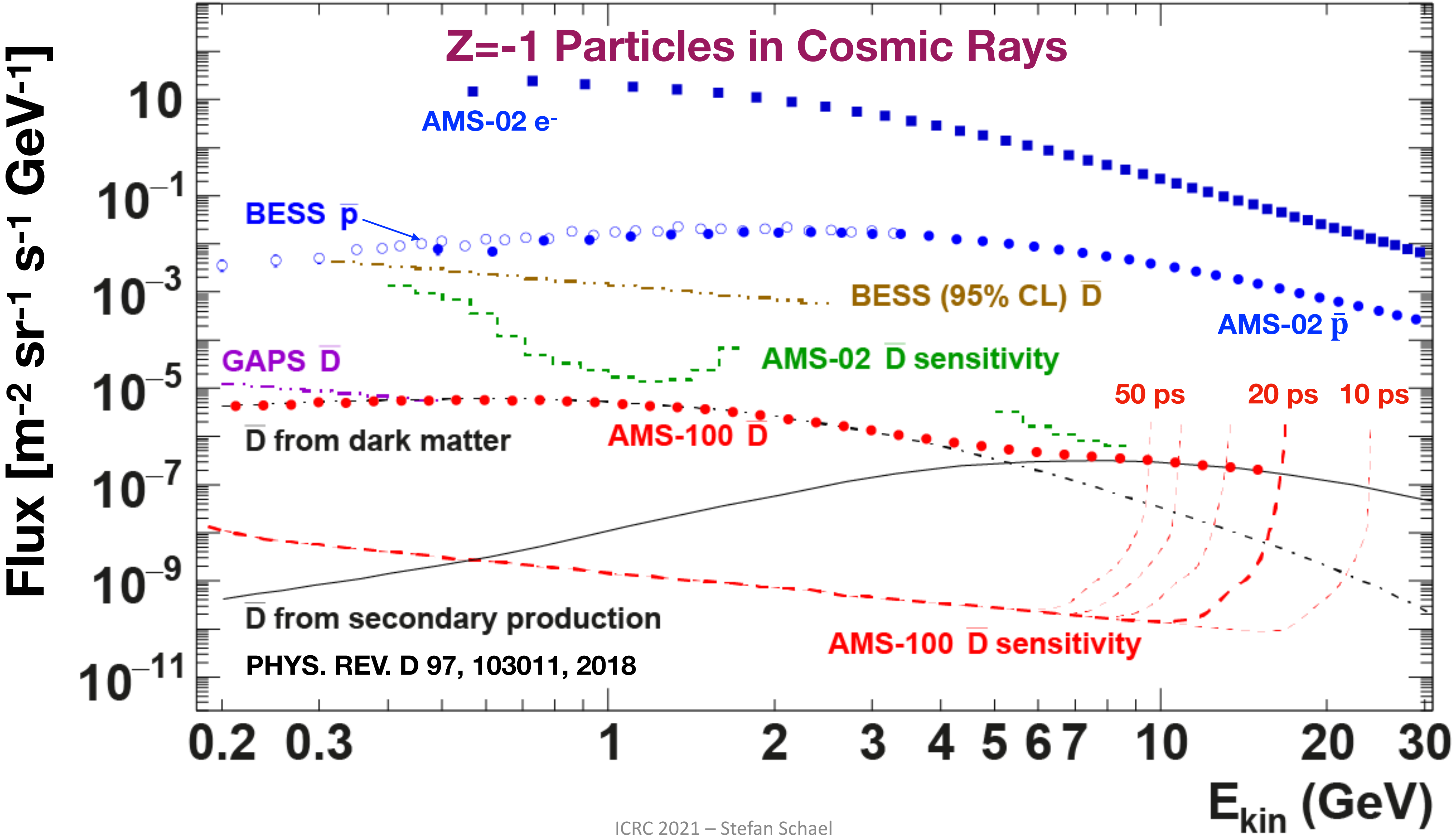


- A thin solenoid provides a magnetic field of 1 Tesla.
- The solenoid is operated at 60 K behind the sunshield in thermal equilibrium with the environment.
- An expandable compensation coil balances the magnetic dipole moment of the solenoid.
- The solenoid is instrumented on the inside with a silicon tracker and a calorimeter system.

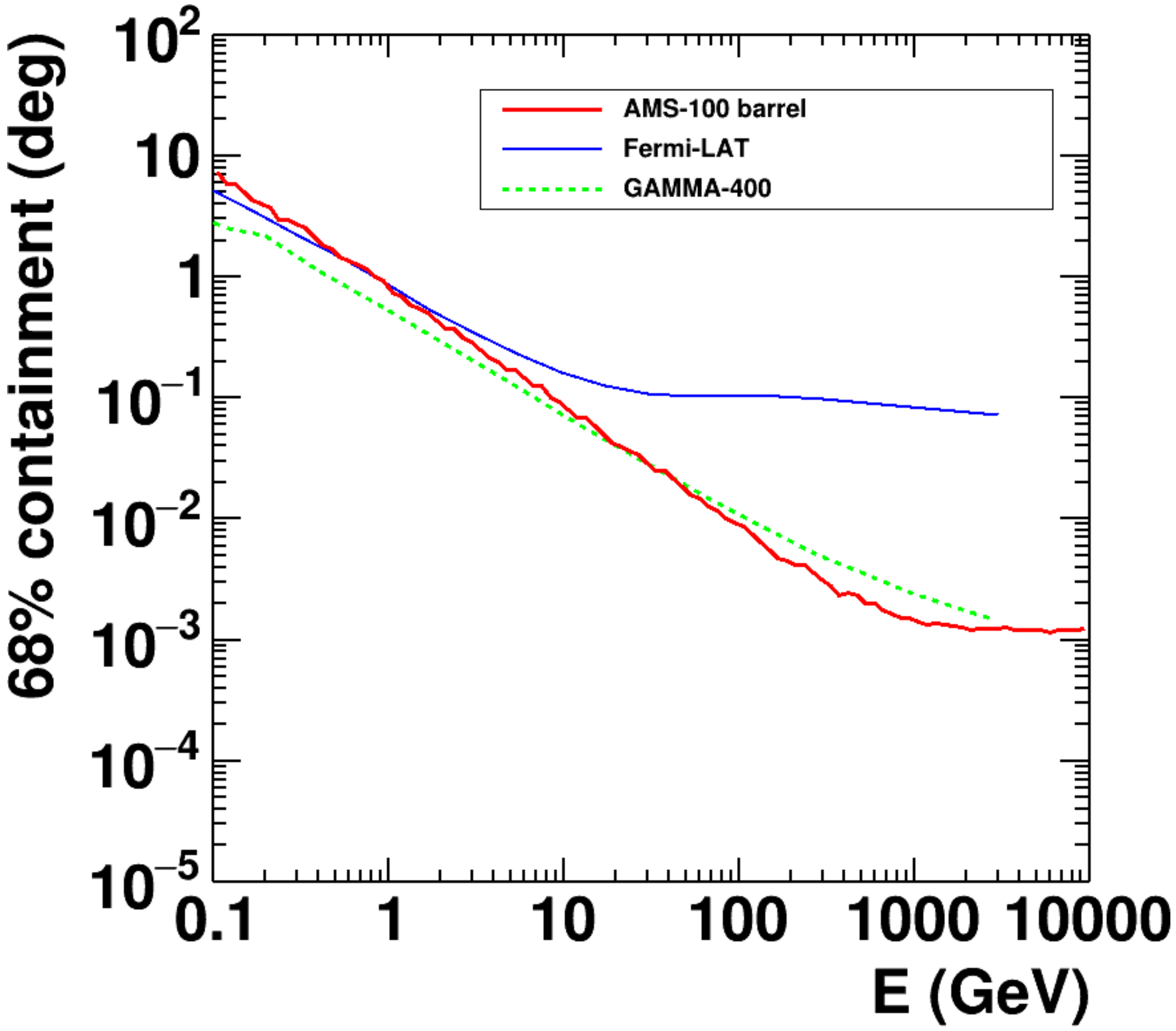
Nuclear Inst. and Methods in Physics Research, A 944 (2019) 162561

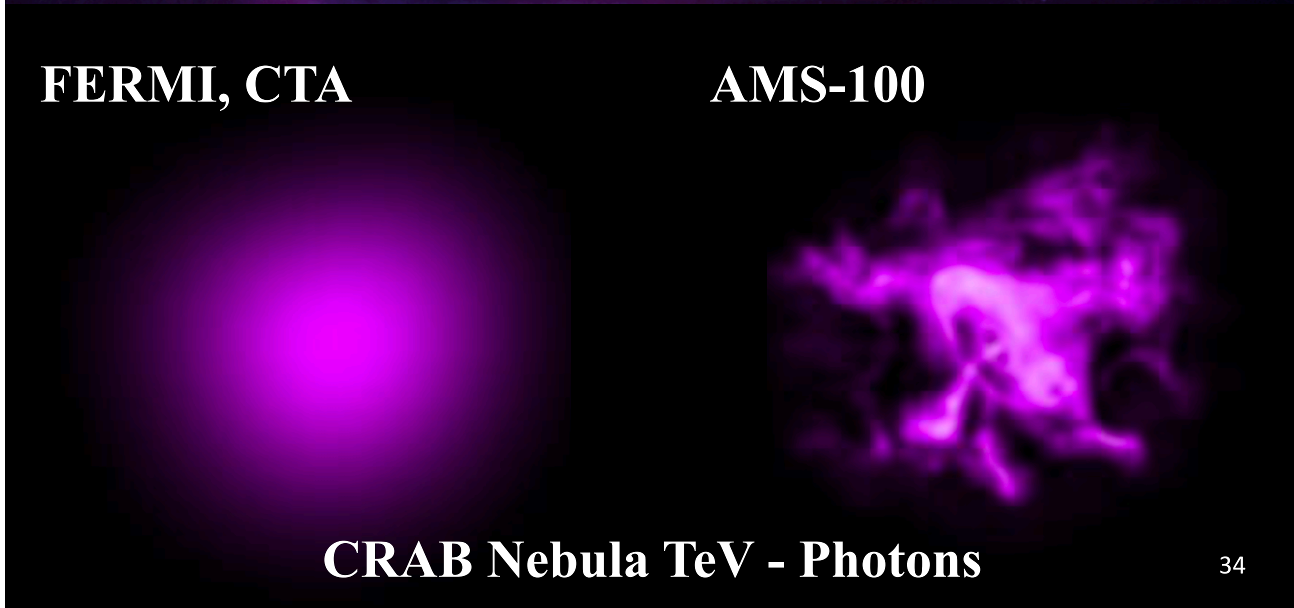
Stefan Schael, RWTH Aachen

AMS-100: Acceptance 100 m² sr, Maximum Detectable Rigidity 100 TV

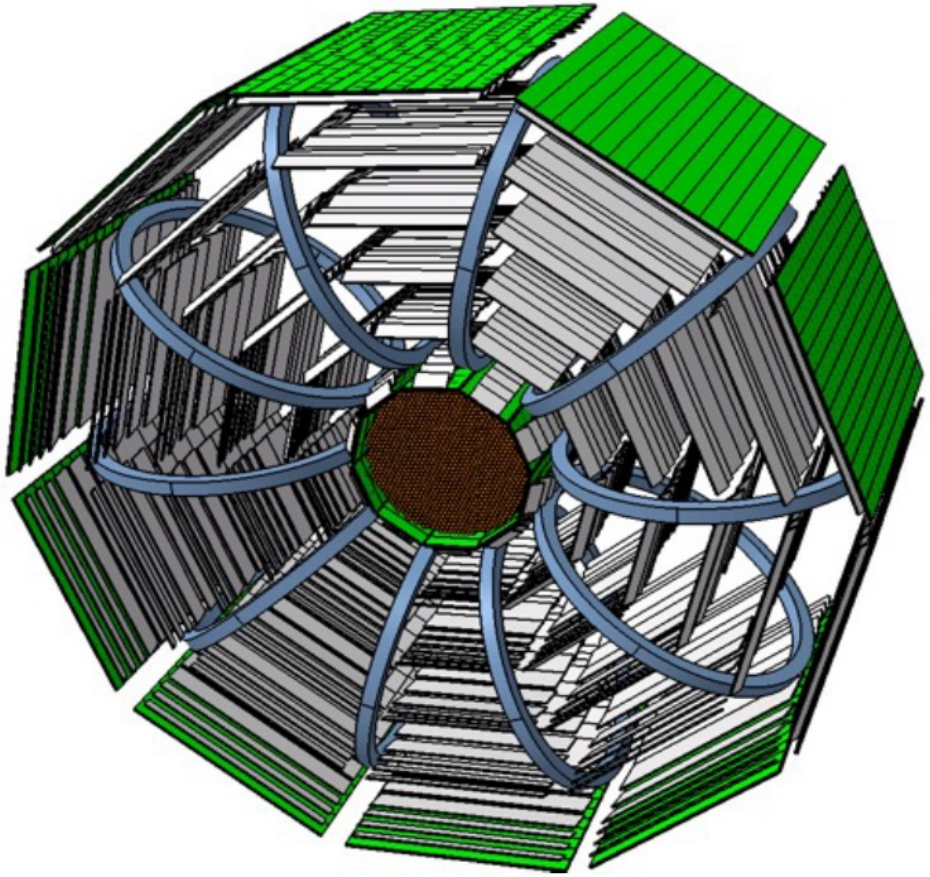


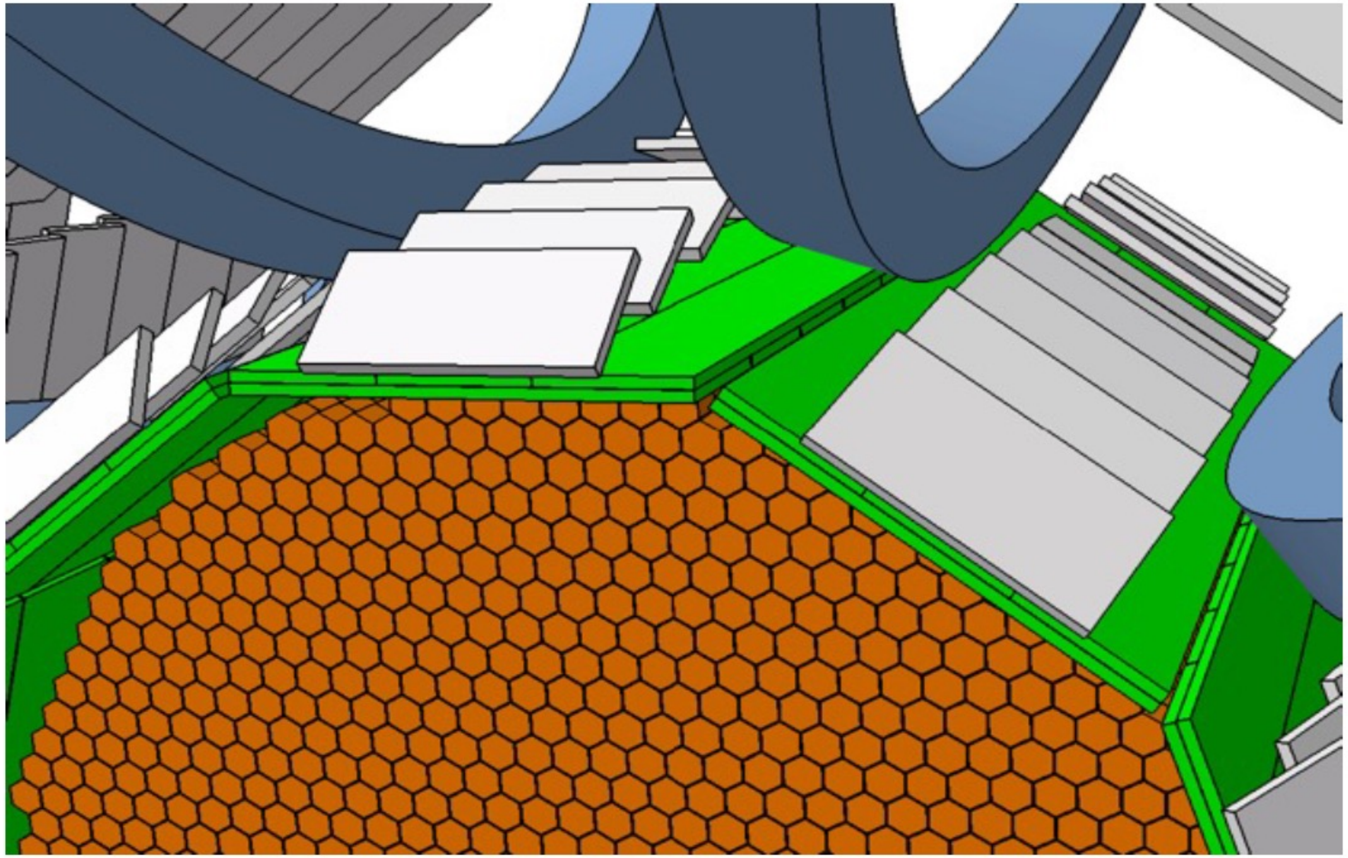
AMS-100: Angular Resolution for Converted Photons





An Antimatter Large Acceptance Detector In Orbit
ALADInO





Breakthrough physics

AMS / 10 years / ISS

170 Billions of events collected

about 1 anti-He event/year

Statistical sample too small to allow for accurate MC simulation ($1/10^{10}$) particles

ALADInO will observe 100 times more event/year than AMS

Allowing for

1- unambiguous determination of the antimatter signal

2- measurement of mass and energy spectrum

3- search of higher Z antimatter

ALADiNO
Performances (10x - 100x current/future)

Calorimeter acceptance	~ 9 m^2 sr
Spectrometer acceptance	>10 m^2 sr (~ 3 m^2 sr w/i CALO)
Spectrometer Maximum Detectable Rigidity (MDR)	> 20 TV
Calorimeter depth	61 X_0, 3.5 λ_I
Calorimeter energy resolution	25% ÷ 35% (for nuclei) 2% (for electrons and positrons)
Calorimeter e/p rejection power	> 10^5
Time of Flight measurement resolution	~100 ps
High energy γ-ray acceptance (Calorimeter)	~ 9 m^2 sr
Low energy γ-ray acceptance (Tracker)	~ 0.5 m^2 sr
γ-ray Point Spread Function	< 0.5 deg

Table 1: *Key performance parameters of the ALADINO apparatus*

ALADiNO pathfinder strategy:

- **PATHFINDER:**
  - Reduced magnetic field (10 times less) same collecting area
  - Physics goal : nuclear antimatter up to 100 GV, first class science
  - Physics goal : precision GeV energy CR physics
  - 2 Tons weight

~ 2030

- **FULL VERSION:**
  - Full magnetic field
  - 6.5 Tons weight
  - Lagrangian 2 point
  - Physics goal :
    - nuclear antimatter up to 1000 GV
    - Dark matter at the multi TeV/c^2
    - Composition of CR in the multi 10 TV, approaching the knee

~ 2040

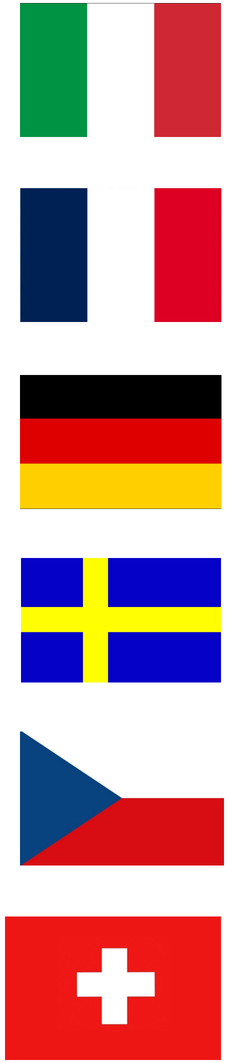
ALADiNO technology path:

- **Tracker**: *silicon strip detectors*, **already space qualified (AMS, Pamela, Fermi, Agile, Dampe…)**
- **Tracker**: *pixel strip detectors*, **advanced development for LHC upgrade ongoing (CERN-Atlas, Alice), space qualification ongoing (ASI - CSES2)**
- **Calorimeter**: *cube crystals* **R&D completed for HERD, space qualification ongoing (INFN)**
- **Superconducting Magnet**: *YBCO magnets* **under advanced development at CERN for LHC upgrade and future accelerators. Long standing collaboration between ASI, INFN and CERN.** ***Space qualification needed***.
- **Low power cryogenics**: *very efficient Pulsed Heat Pipes* **developed through the H2020 SR2S program (CEA Saclay).** ***Space qualification needed***
- **Electronics**: **extensive experience and space qualification of** *CERN experiments (micro) electronics up to O(10^6) channels* **: AMS, Pamela, Fermi, Agile, Dampe…**
- **Thermal shield**: *passive thermal shield* **to be derived from e.g. Planck, Gaia**

Core Team members

O.Adriani[1,2], G.Ambrosi[3], B. Baoudoy[4], R.Battiston[5,6], B.Bertucci[7,3], P.Blasi[8], M.Boezio[9], D.Campana[10], L. Derome[11], I. De Mitri[8], V. Di Felice[12], F. Donato[13], M.Duranti[3], V.Formato[12], D. Grasso[14], I. Gebauer[15], R. Iuppa[5,6], N. Masi[17], D. Maurin[11], N.Mazziotta[17], R. Musenich[18], F. Nozzoli[6], P.Papini[2], P. Picozza[19,12], M.Pierce[20], S.Pospíšil[21], L. Rossi[22], N.Tomassetti[6,3], V. Vagelli[23], X.Wu[24]

1) University of Florence, Italy (IT)
2) INFN-Florence, Italy (IT)
3) INFN-Perugia, Italy (IT)
4) CEA Saclay Irfu/SACM, France (FR)
5) University of Trento, Italy (IT)
6) INFN-TIFPA, Trento, Italy (IT)
7) University of Perugia, Italy (IT)
8) Gran Sasso Science Institute, Italy & INFN-Laboratori Nazionali del Gran Sasso, Italy (IT)
9) INFN-Trieste, Italy (IT)
10) INFN-Napoli, Italy (IT)
11) Universitè Grenoble Alpes and IN2P3 LSPC, France (FR)
12) INFN-Roma Tor Vergata, Italy (IT)
13) University & INFN Torino, Italy (IT)
14) INFN Pisa, Italy (IT)
15) KIT, Karlsruher Institut für Technologie, Germany (DE)
16) University and INFN Bologna, Italy (IT)
17) INFN-Bari, Italy (IT)
18) INFN-Genova, Italy (IT)
19) University of Roma Tor Vergata, Italy (IT)
20) KTH Royal Institute of Technology, Sweden (SE)
21) CTU, Czech Technical University, Czechia (CZ)
22) CERN, Switzerland (CH)
23) ASI, Italian Space Agency, Italy (IT)
24) University of Geneva, Switzerland (CH)



AMS-01

AMS-02

Pamela

FERMI

Dampe

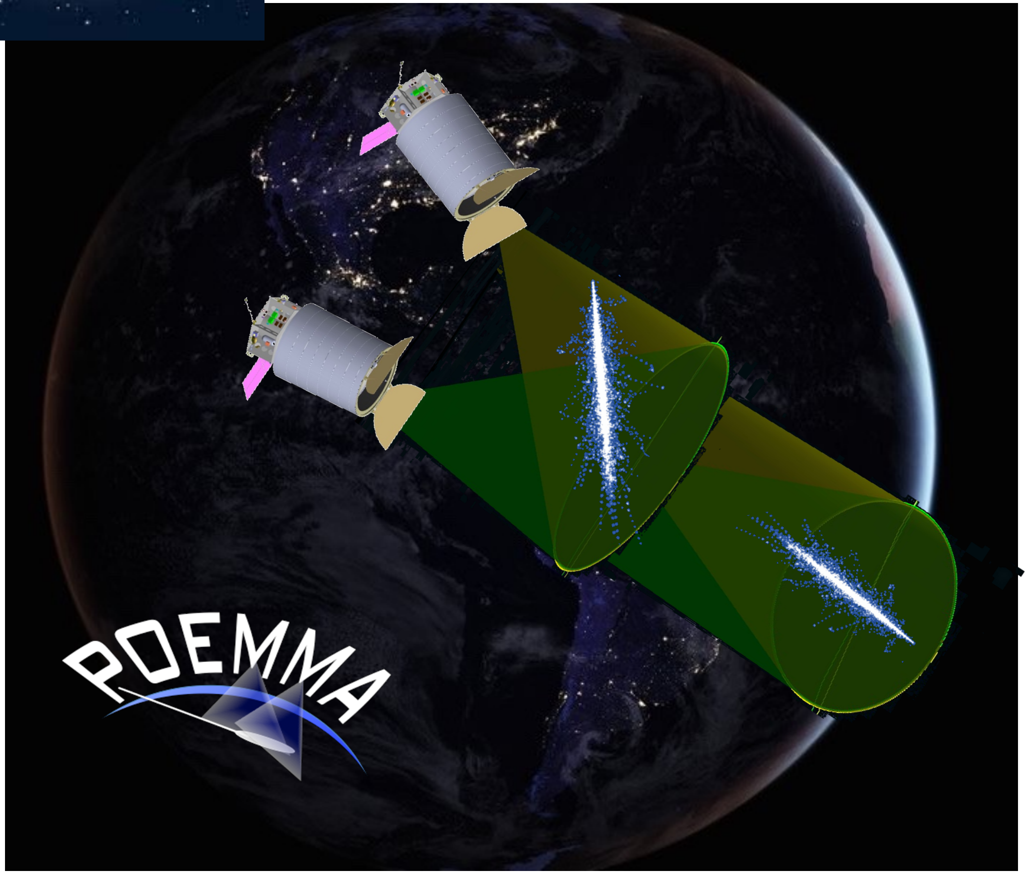
Arina

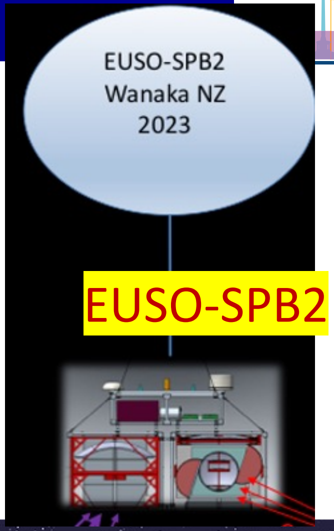
Agile

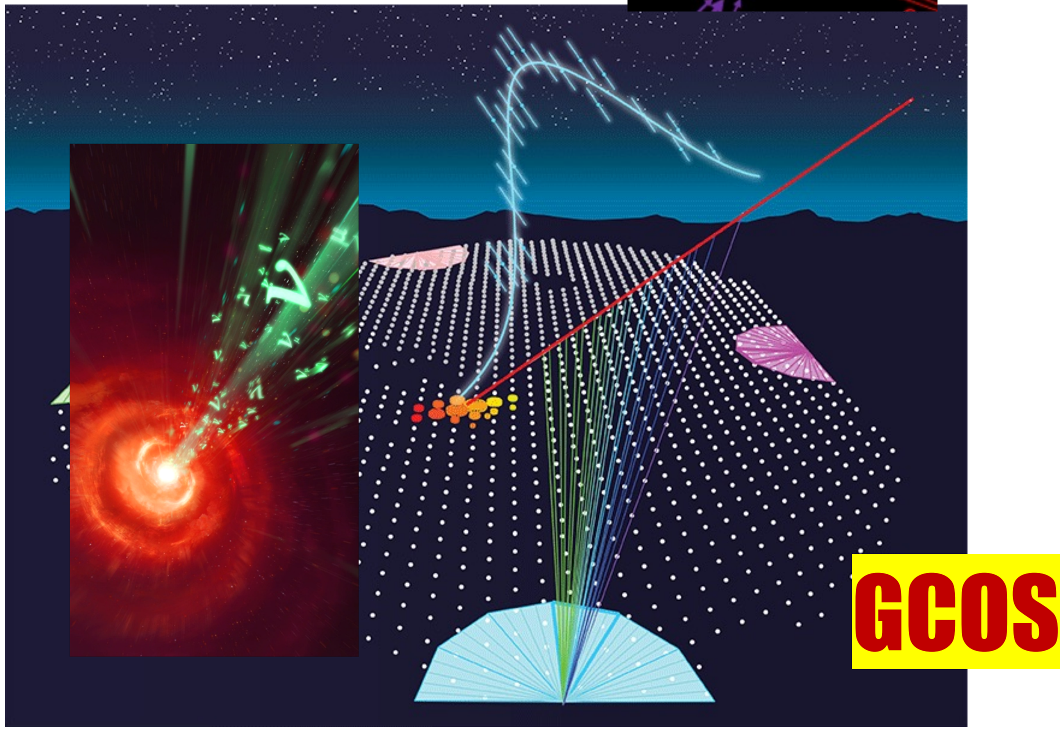
CSES-01

....

MM: Future UHECRs and VHE and UHE Neutrino Measurements





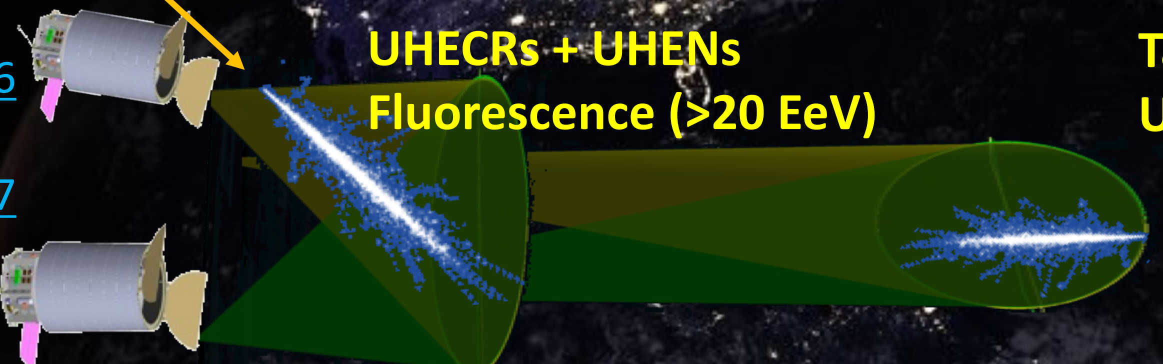


Probe Of Extreme Multi-Messenger Astrophysics

UHECRs; UHE and VHE Neutrinos

Olinto et al
https://pos.sissa.it/395/976
Venters et al
https://pos.sissa.it/395/977

/406; /419; /437; /519;
/551; /977; /1201

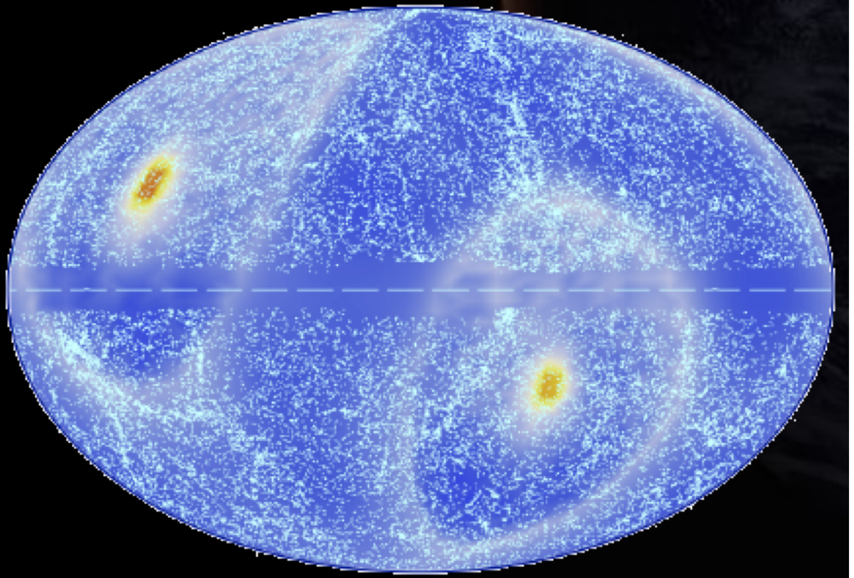


UHECRs + UHENs
Fluorescence (>20 EeV)

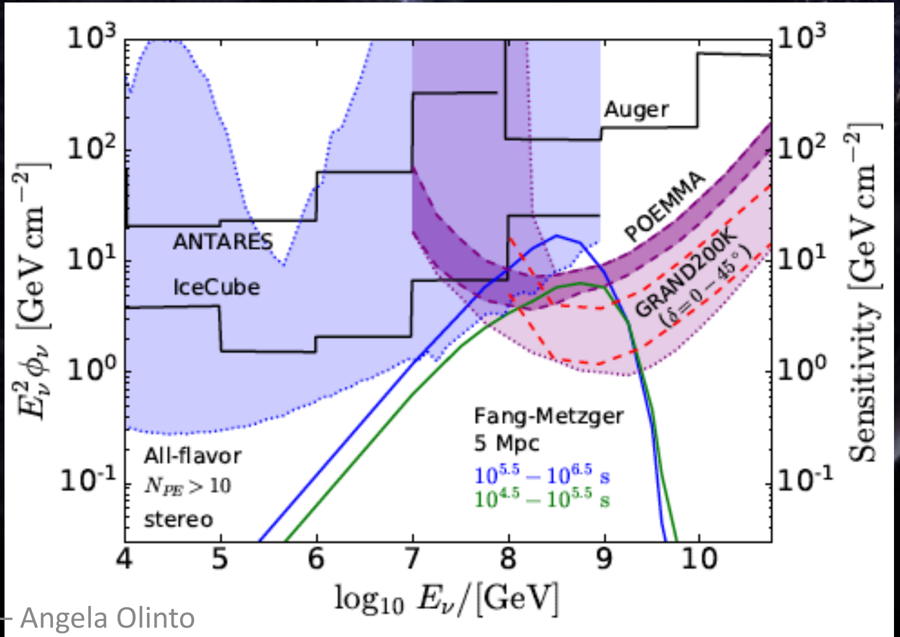
Tau Neutrinos → Tau-lepton decay
Upgoing EAS Cherenkov (>20 PeV)

TARGET OF OPPORTUNITY for Neutrinos >20PeV

Full Sky Coverage

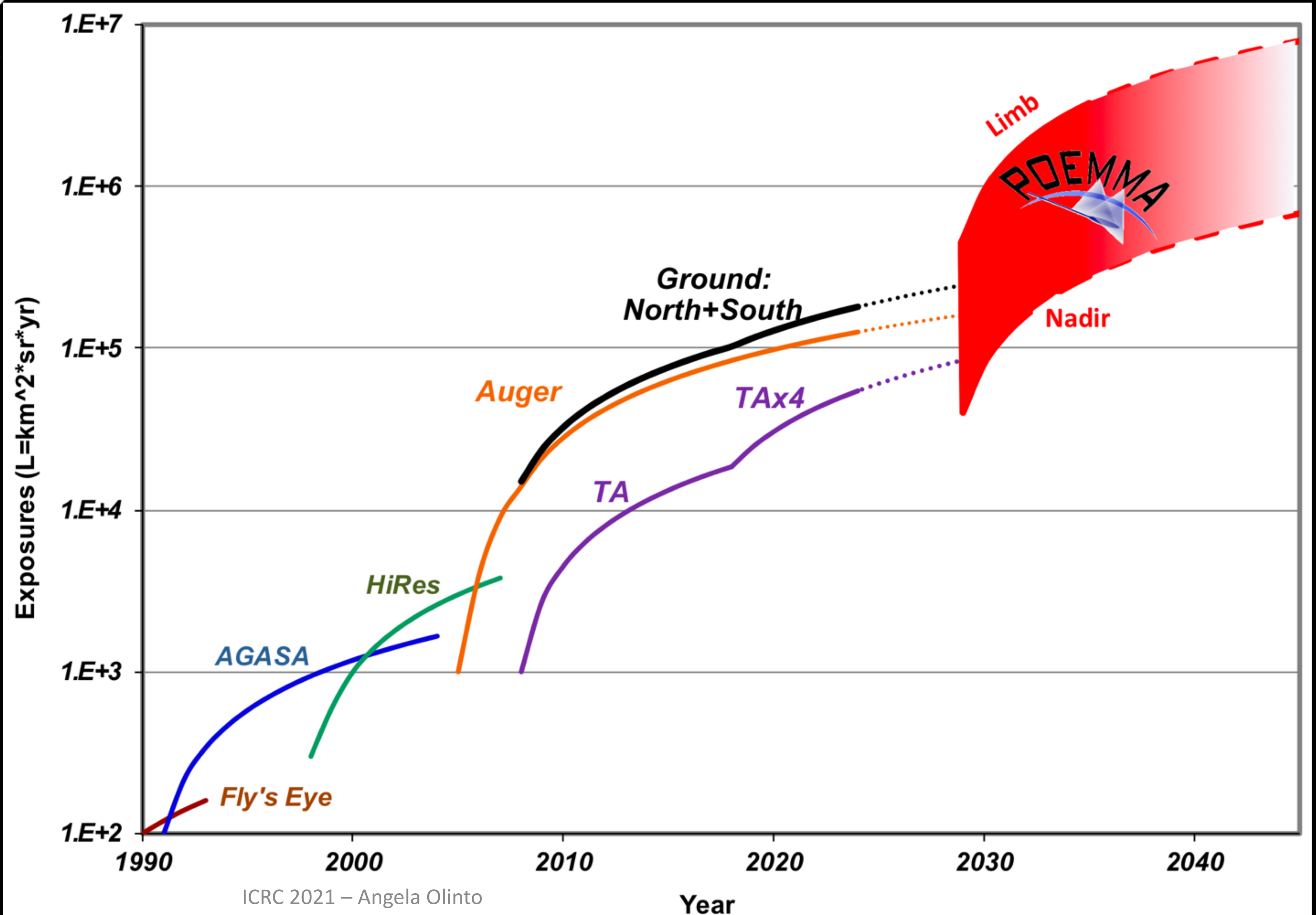


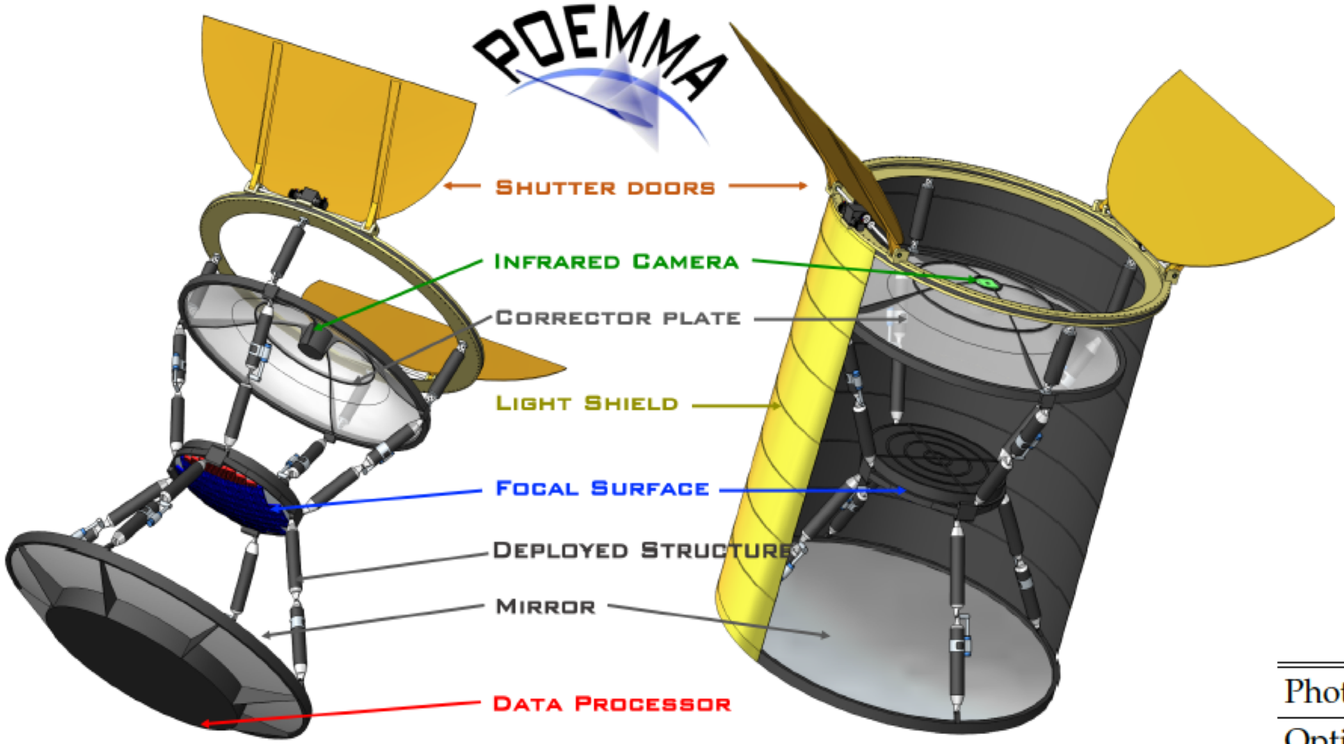
Great Sensitivity



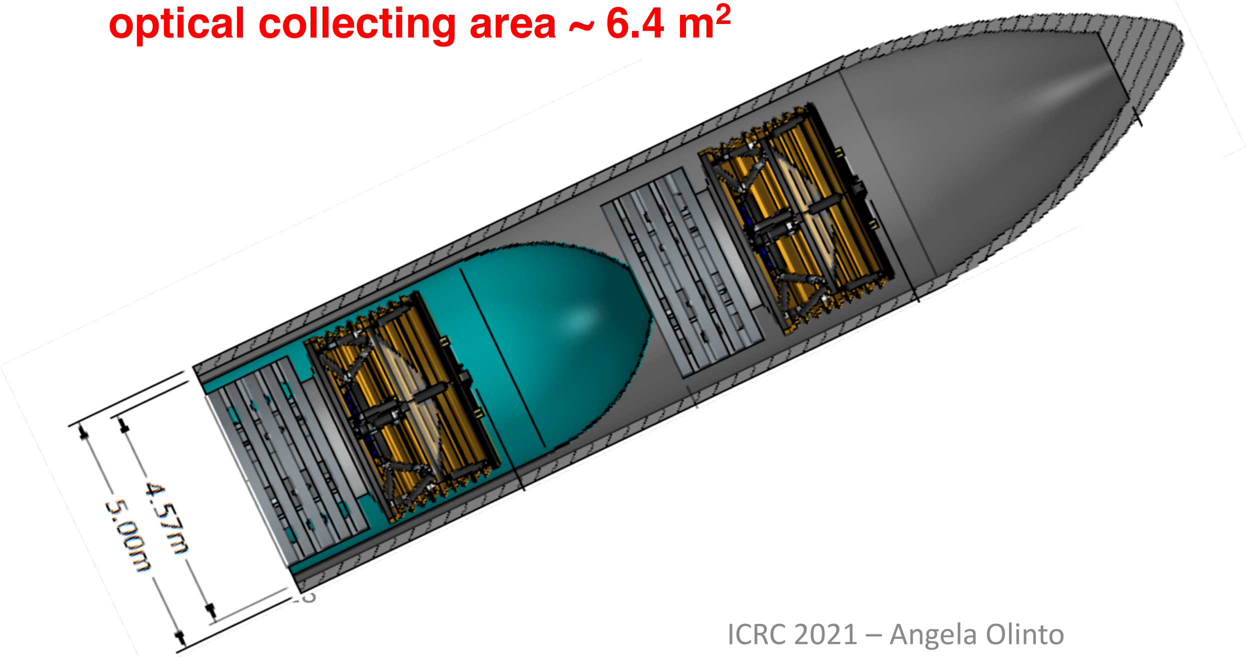
Source Class	ν Horizon Distance	Mission Time for 10% Prob.
TDE $M_{SMBH} = 5 \times 10^6 M_\odot$ Lumi Scaling	128 Mpc	1.5 yrs.
TDE Base Scenario	69 Mpc	8 yrs.
BH-BH merger Low Fluence	43 Mpc	3 yrs.
BH-BH merger High Fluence	137 Mpc	1 yr.
NS-NS merger	16 Mpc	1.5 yrs.
sGRB Moderate Extended Emission	90 Mpc	14.5 yrs.

POEMMA UHECR Exposure





optical collecting area ~ 6.4 m²



Launch: >2029 (Astro 2020)
Mission Lifetime: 3 years (5 year goal)
Orbits: 525 km, 28.5° Inc
Orbit Period: 95 min
Satellite Separation: ~25 km – 1000+ km
Satellite Position: 1 m (knowledge)
Pointing Resolution/ Knowledge: : 0.1° /0.01°
Slew Rate: 8 min for 90 °
Satellite Wet Mass: 3860 kg
Power: 2030 W; **Data:** 1 GB/day; **Data Storage:**7 days
Clock synch (timing): 10 nsec

TABLE I: POEMMA Specifications:

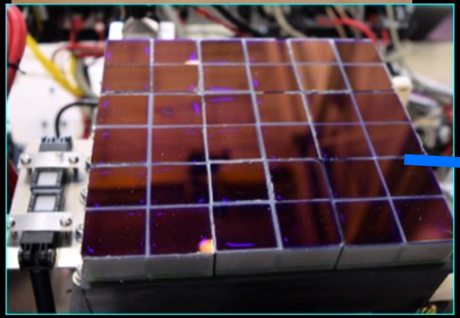
Photometer	Components		Spacecraft	
Optics	Schmidt	45° full FoV	Slew rate	90° in 8 min
	Primary Mirror	4 m diam.	Pointing Res.	0.1°
	Corrector Lens	3.3 m diam.	Pointing Know.	0.01°
	Focal Surface	1.6 m diam.	Clock synch.	10 nsec
	Pixel Size	3×3 mm^2	Data Storage	7 days
	Pixel FoV	0.084°	Communication	S-band
PFC	MAPMT (1μs)	126,720 pixels	Wet Mass	3,450 kg
PCC	SiPM (20 ns)	15,360 pixels	Total Power	880 W
Photometer	(One)		Mission	(2 Observatories)
	Mass	1,550 kg	Lifetime	3 year (5 year goal)
	Power	590 W	Orbit	525 km, 28.5° Inc
	Data	< 1 GB/day	Orbit Period	95 min
			Observatory Sep.	~25 - 1000+ km

Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories

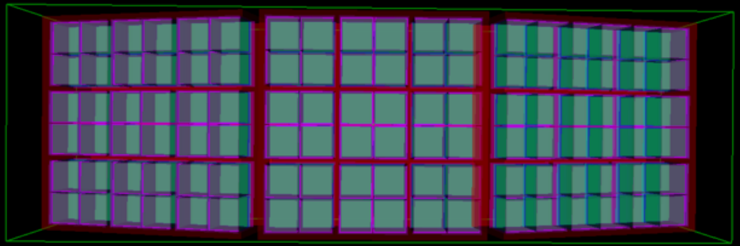
POEMMA

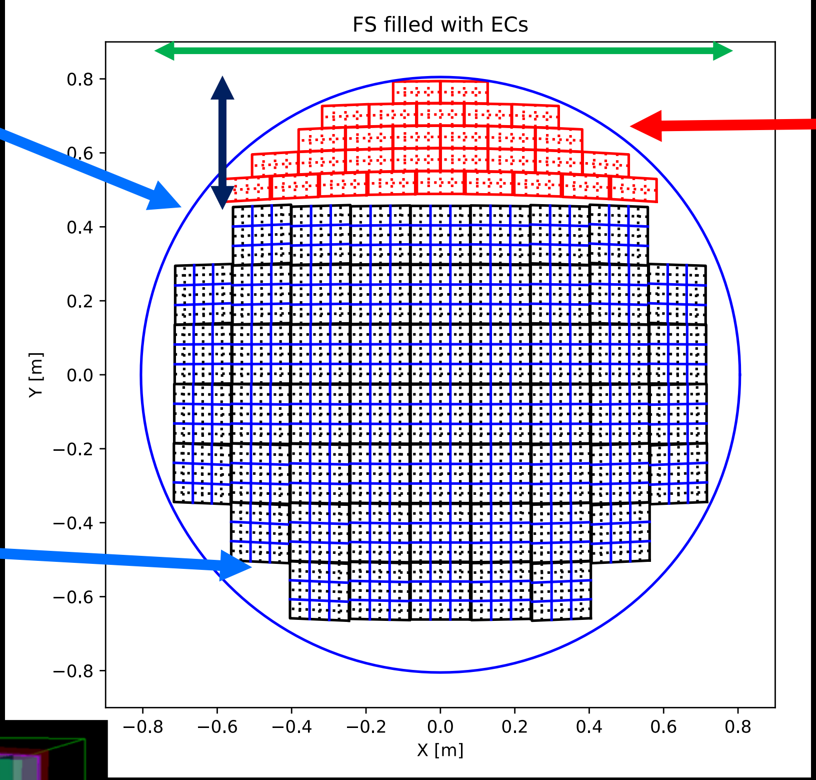
Hybrid Focal Surface

UV Fluorescence
MAPMTs with BG3 filter:
1 usec sampling



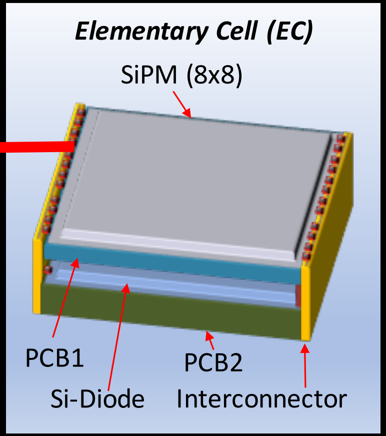
EUSO-SPB2
3 PDMs



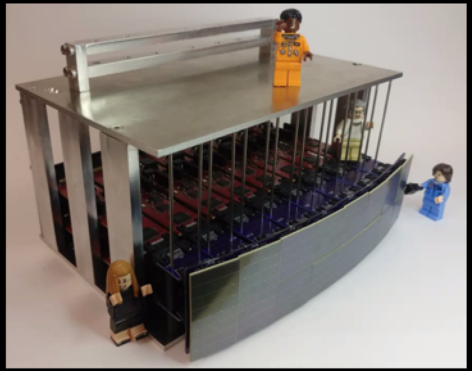


55 Photo Detector Modules (PDMs)
TOTAL 126,720 pixels
(1 PDM = 36 MAPMTs = 2,304 pixels)

Cherenkov Detection
SiPMs:
20 nsec sampling



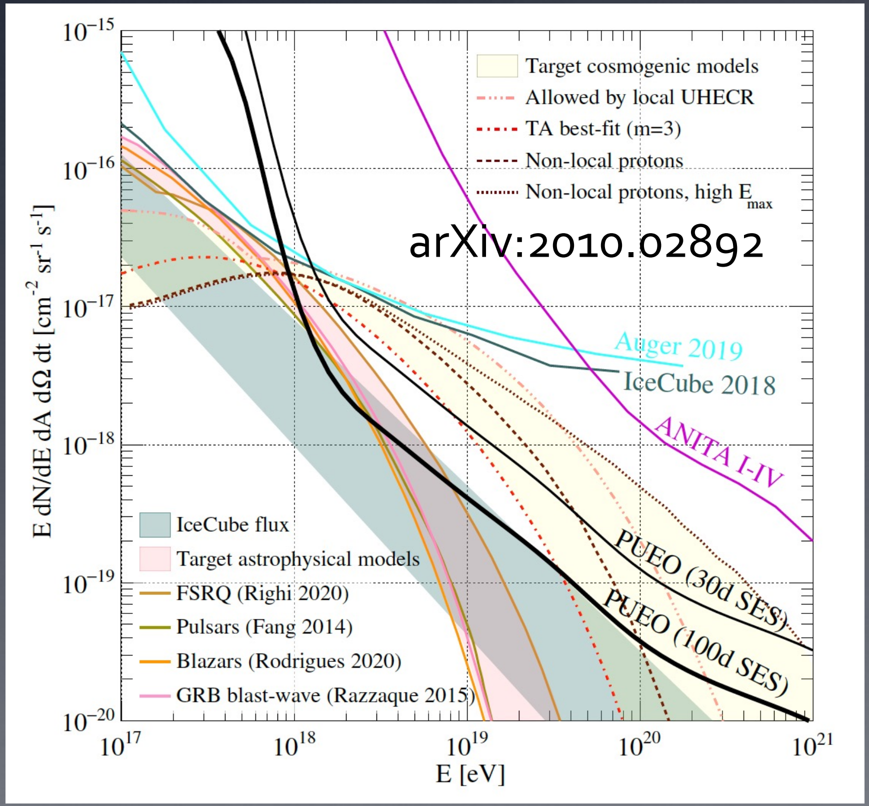
30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)



EUSO-SPB2
Cherenkov
Camera

PUEO: The Payload for Ultrahigh Energy Observations

Abby Vieregg, U. Chicago



- One of four NASA Astrophysics Pioneers Missions (the only balloon payload); Launch Planned December 2024.
- System Requirements Review in the fall
- A unique detector for the highest energy (> 10^{18} eV) cosmic particles (neutrinos, cosmic rays, ++ ?)
- Especially large instantaneous effective volume, for transient, point source, and multi-messenger searches
- Builds on heritage from ANITA, with ~order of magnitude sensitivity improvement enabled by a phased array trigger, real-time digital filtering, and antenna optimization

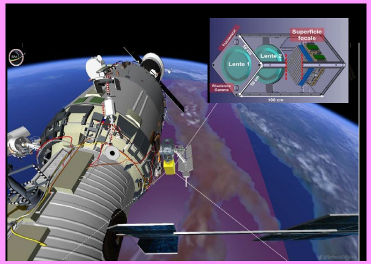
EUSO-SPB2: ULDB flight from Wanaka, New Zealand in spring 2023

JEM-EUSO Program

http://jem-euso.roma2.infn.it/

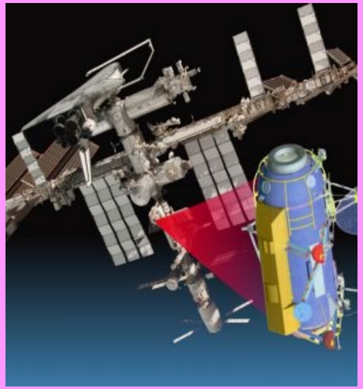
Where	Completed	Current	In Preparation	*Future*
Space	**TUS** (satellite)	**Mini-EUSO** (ISS)		**K-EUSO** **EUSO-EVA**
Suborbital (balloon)	**EUSO-Balloon** **EUSO-SPB1**		**EUSO-SPB2**	
Ground		**TA-EUSO**		

EUSO-EVA



Observe UHECRs from Space
Threshold 300 EeV
4x Pupil of Mini-EUSO

K-EUSO



Target: UHECRs
Threshold ~30 EeV
ICRC21: 754

EUSO Publications (link)

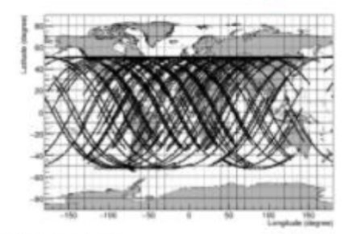
ICRC 2021
JProgram Overview 389

MiniEUSO
411, 414, 614, 757, 886, 971 1001, 1181, 1165

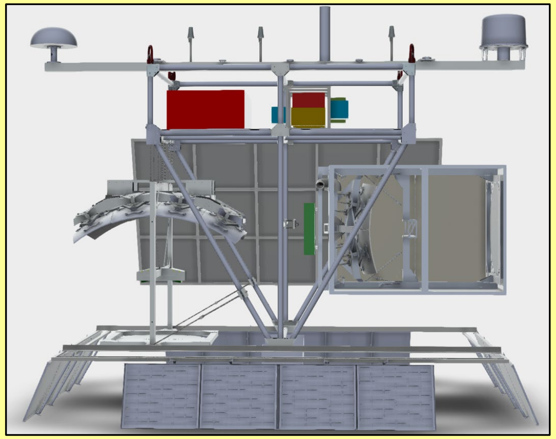
EUSO-SPB2
235, 403, 330, 403, 489, 490, 614, 867, 1091 also 1001

K-EUSO 754

MINI-EUSO (ISS)



R&D, UV Backgrounds, Flashers, TLEs

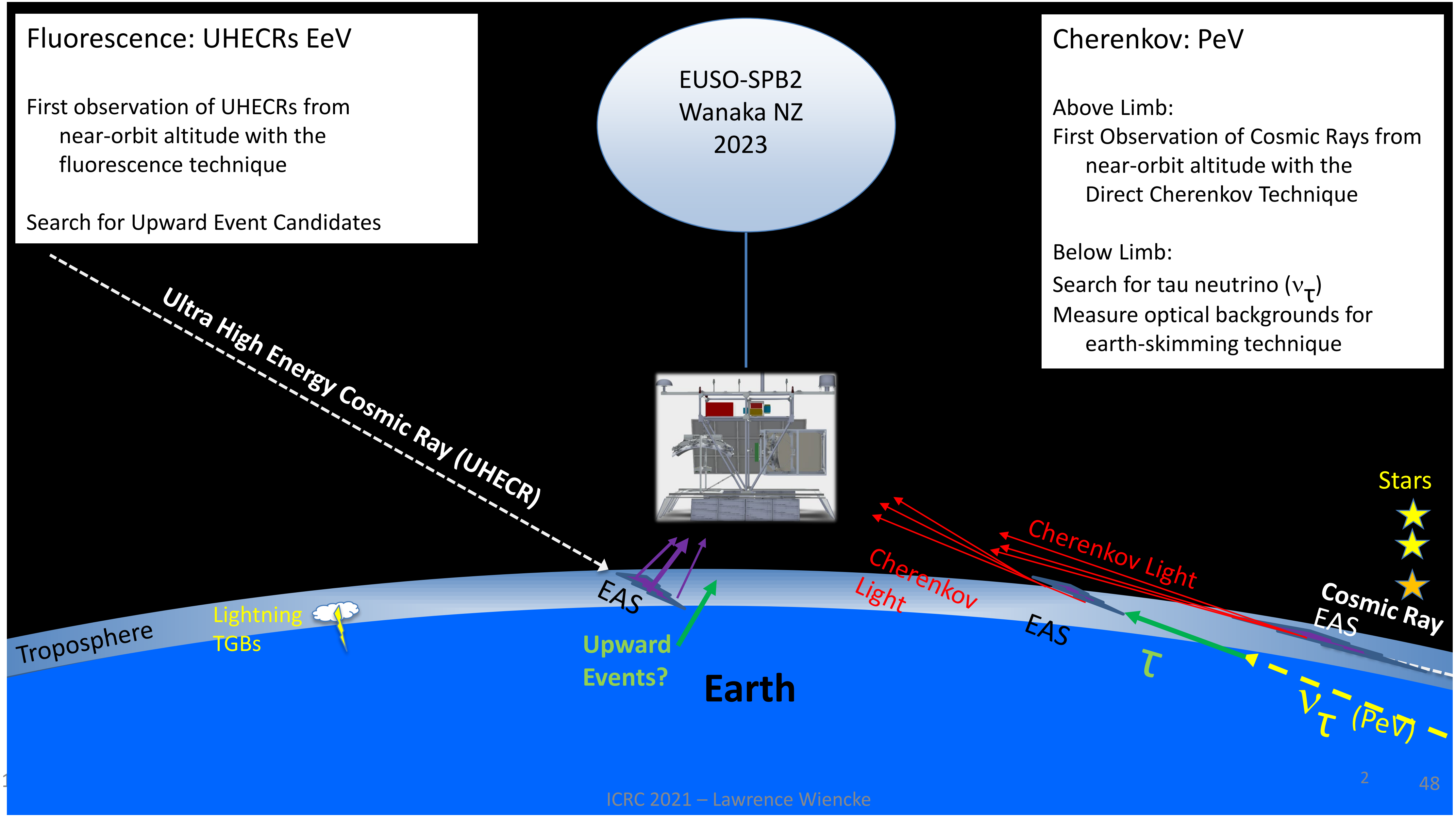


NASA SPB (Balloon) : Wanaka 2023

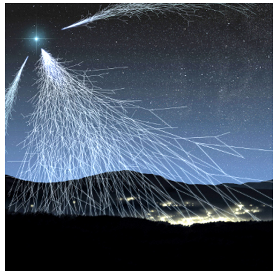
EUSO-SPB2

Goal: 3 Firsts from Near Space
UHECR via fluorescence 0.12/hr
HECR via direct Cherenkov ~1/min
Neutrino Backgrounds near limb
Also
Tau Neutrino sensitivity for transient sources: Galactic and Near Galaxies.

EUSO-SPB2: ULDB flight from Wanaka, New Zealand in spring 2023



GCOS - The Global Cosmic Ray Observatory



- World-wide initiative to conduct multi-messenger astroparticle physics beyond 2030

- MM-APP has started: GW sources, IceCube neutrinos, and follow-ups,
  key results from Telescope Array & Pierre Auger Observatory (anisotropies, mass composition)

- building on this knowledge, it is time to prepare for a Global Cosmic Ray Observatory after 2030

- aim for multi-purpose observatory:
  sources of UHE particles (charged CRs, neutrinos, gamma rays),
  dark matter searches, fundamental physics, particle physics, geophysics and atmospheric science

- considering different detection concepts, including layered/nested water Cherenkov detectors, radio antennas, and fluorescence light telescopes

- workshop with >200 participants in May 2021
  to discuss path to define physics case and develop concepts for detection technologies

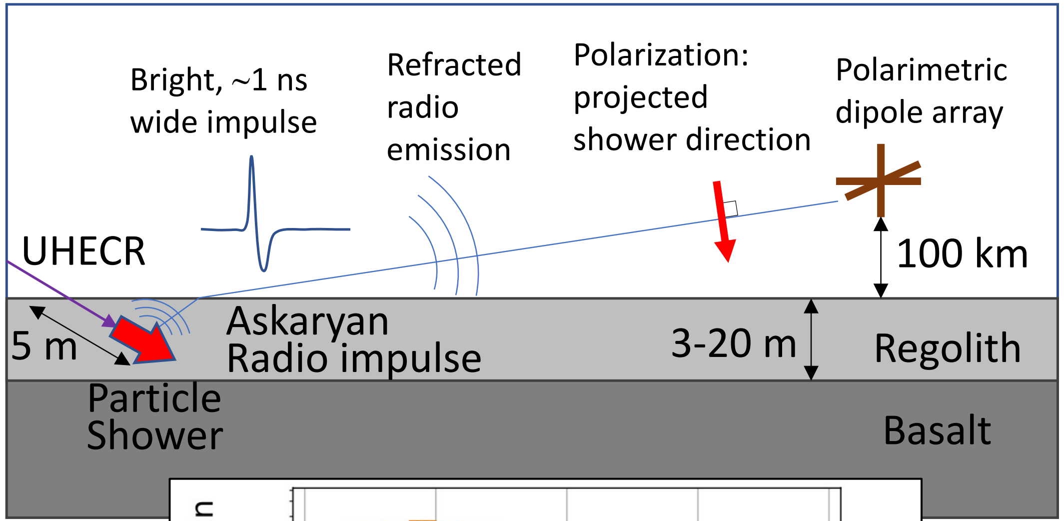
- we plan a follow-up workshop at the end of 2021/begin of 2022 with the goal
  to write a roadmap for multi-messenger astroparticle physics (CRs, GAs, NUs, GWs) beyond 2030
  and a Global Cosmic Ray Observatory

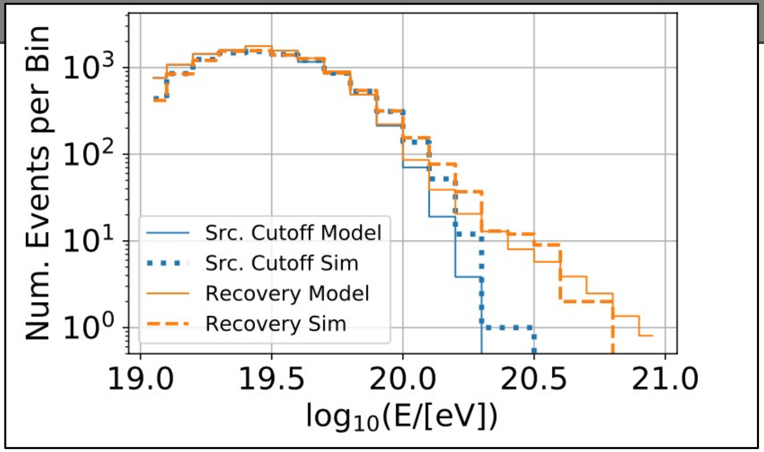
ZAP

Zettavolt Askaryan Polarimeter

Concept:

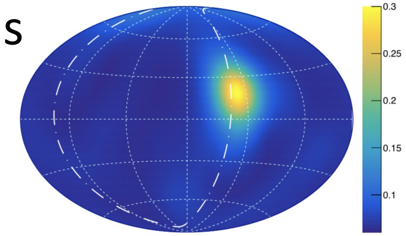
- Detection of UHECR radio pulses produced by interactions in the lunar regolith (PI: A. Romero-Wolf, JPL)
- Smallsat with VHF (30-300 MHz) polarimetric antenna array that takes advantage of broad Askaryan pulse at low frequencies



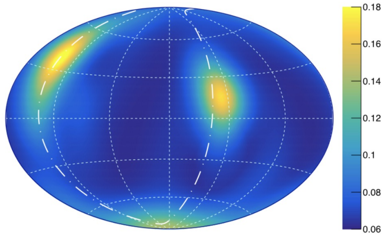


Science Targets:

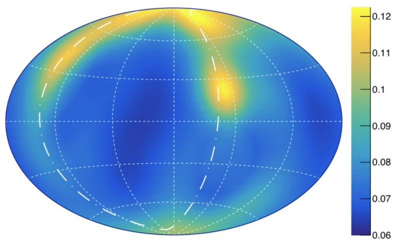
- Independent identification the sources of the highest energy cosmic rays and test the mechanism by which the spectrum cuts off
  - Full sky coverage with $\gtrsim$ 2,000 cosmic ray events with $\mathrm{E} \gtrsim 10^{19.6}$ eV
- Super-heavy dark matter searches via LPM pulse trains from $> 10^{21}$ eV ν_e correlated with galactic center
- Planetary science: subsurface ice reflectors



Swift-BAT AGNs



Starburst Galaxies



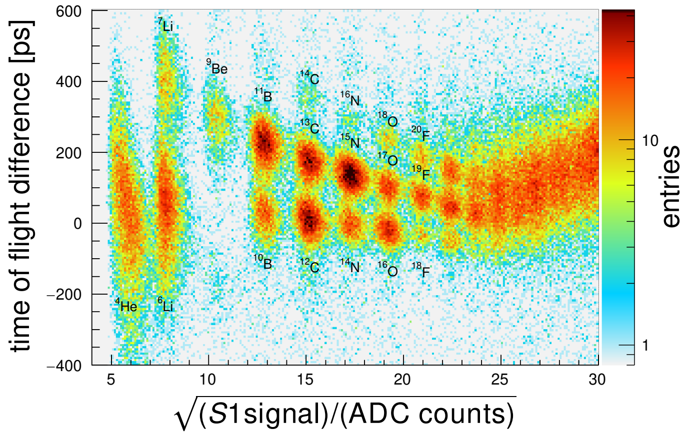
2MRS

Accelerator Measurements with NA61/SHINE at the CERN SPS

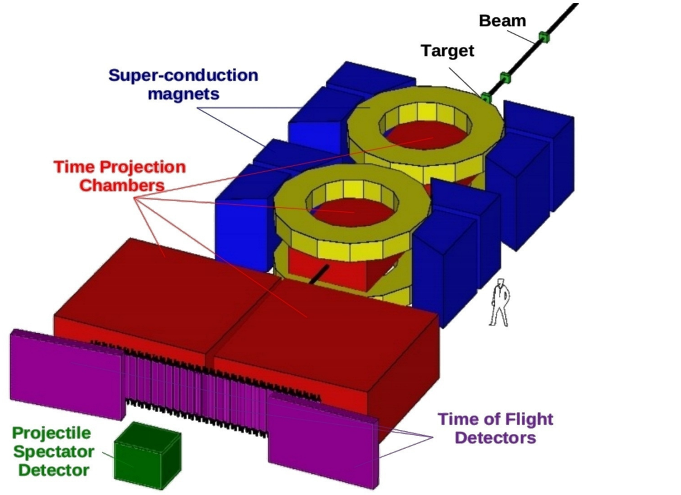
M. Unger (KIT) for NA61/SHINE

H2

SPS



secondary ion beam (Pb+Be fragments at 13.5 A GeV/c)



- large acceptance $\approx 50\%$ at $p_T \leq 2.5\,\mathrm{GeV/c}$
- momentum resolution: $\sigma(p)/p^2 \approx 10^{-4} (\mathrm{GeV/c})^{-1}$
- tracking efficiency: $> 95\%$, pid with dE/dx and ToF

p_{beam} up to $Z \times 450$ GeV/c, p, p̄, O, S, Ar, Pb...

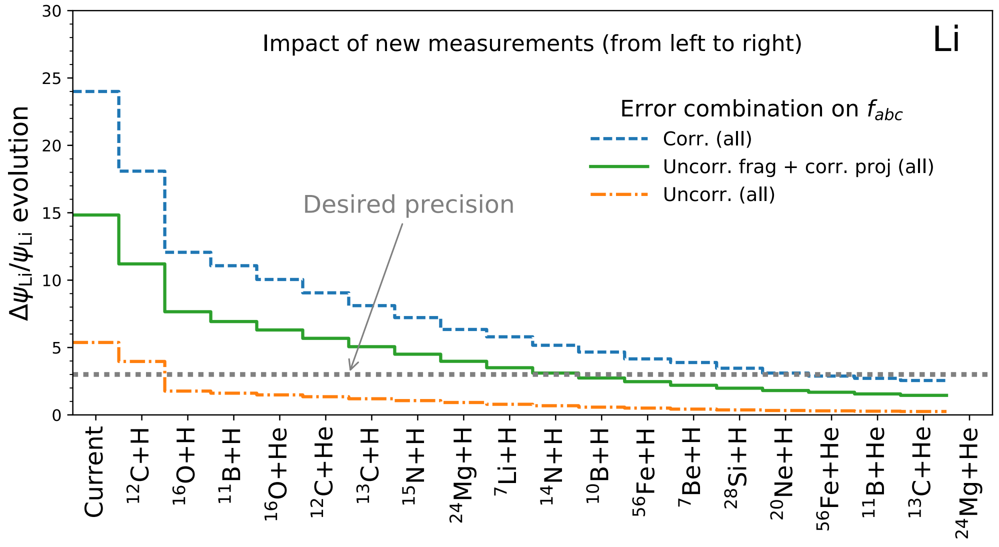
The Cosmic-Ray Program of the NA61/SHINE

Topics

- Particle Production in Air Showers
  - p+C Interactions
    (31, 60, 90 120 GeV/c)
  - π+C Interactions
    (30, 60, 158, 350 GeV/c)
- Galactic Cosmic Rays
  - d, $\bar{d}$ and $\bar{p}$ Production
    p+p at 20, 31, 40, 80, 158, 400 GeV/c
    → M. Naskret, contribution 1134/535
    → A. Shukla, contribution 1343/178
  - Nuclear Fragmentation
    light nuclei on p at 13.5 GeV/c/nucleon
    → N. Amin, contribution 609/201

Timeline

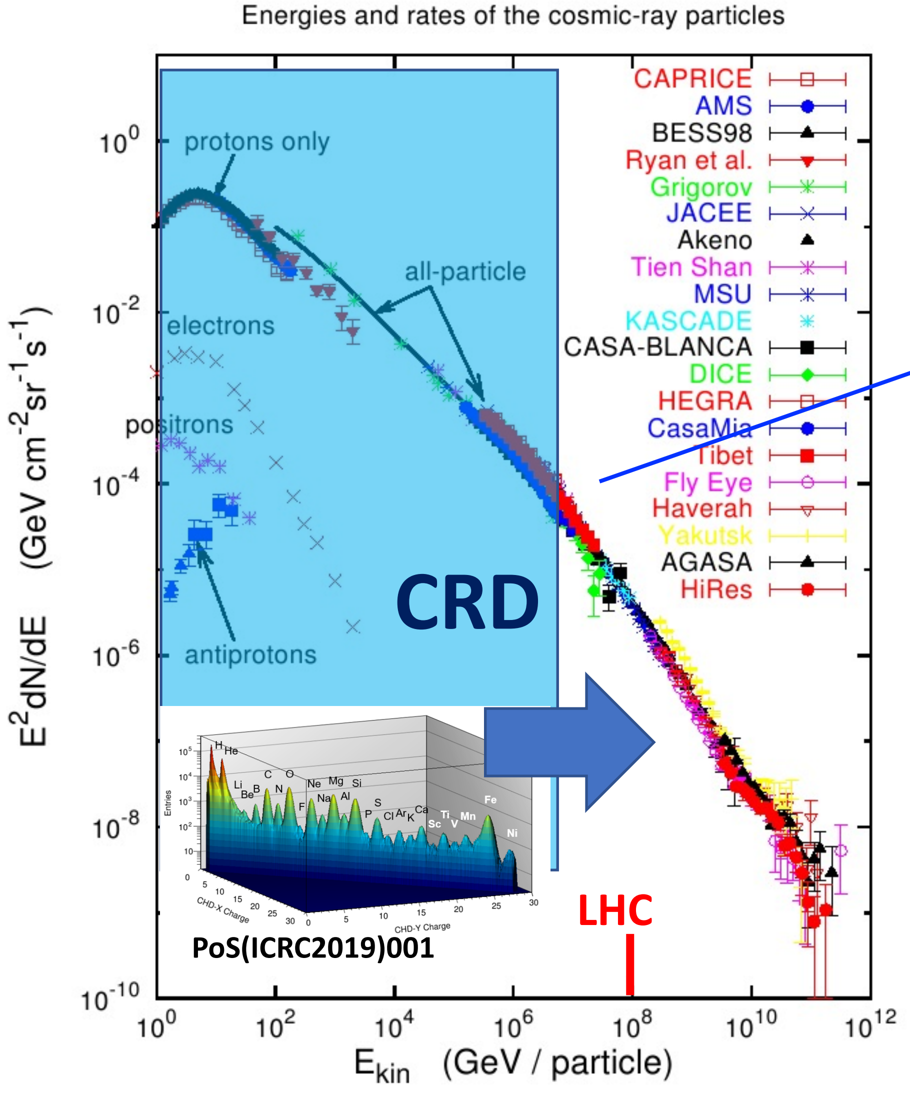
- 2018: pilot run on nuclear fragmentation
  C+C, C+CH_2 at 13.5 GeV/c/nucleon
- ongoing: NA61 detector upgrade
  increase readout rate from 80 to 1000 Hz
- 2022: physics run on nuclear fragmentation
  measure most important channels for Li, Be, B, C, N GCRs

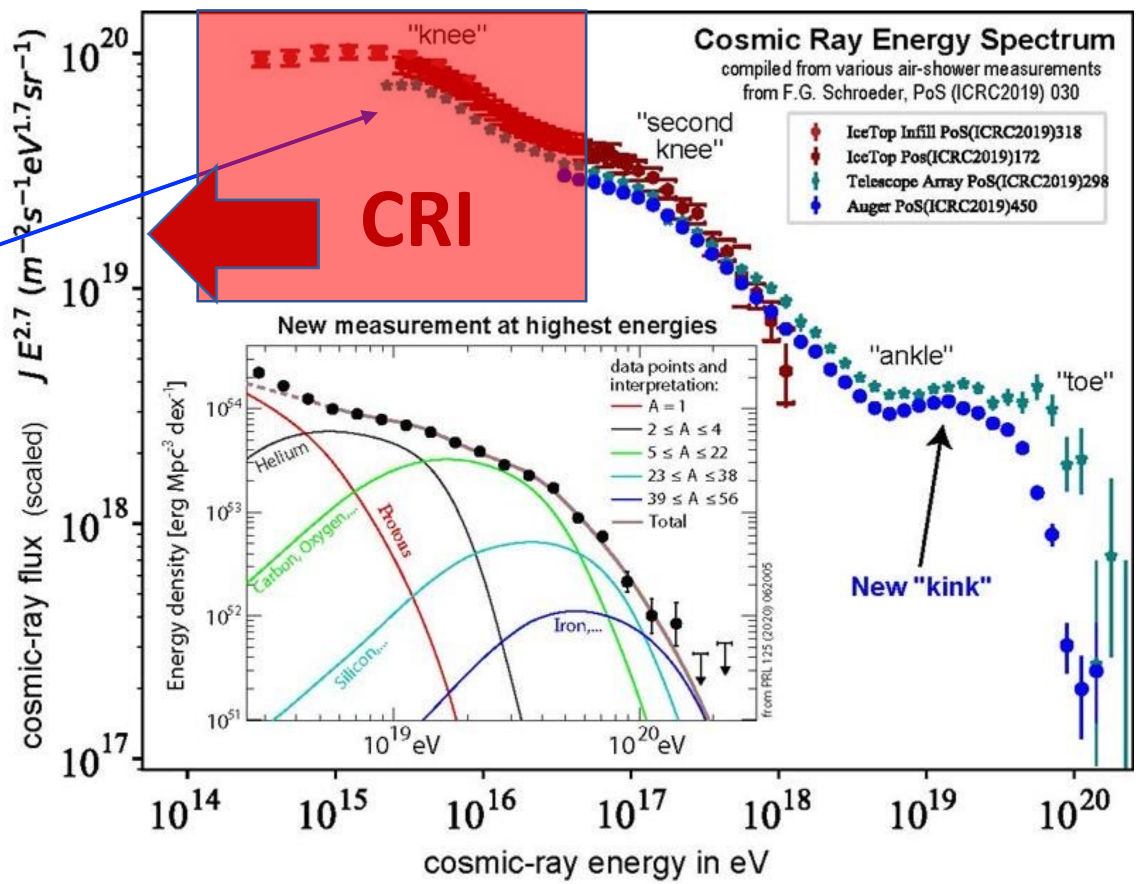


Genolini et al. Phys.Rev.C 98 (2018) 034611

- post-LS3 (2027+) program under discussion

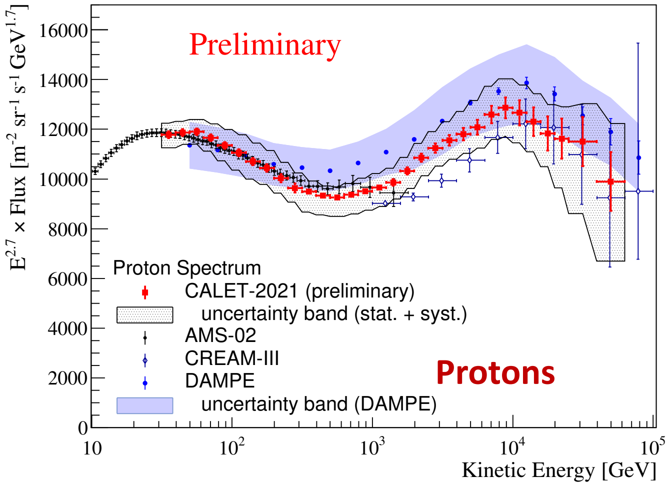
CRD + CRI : Cosmic Ray Spectrum Overlap of Measurements



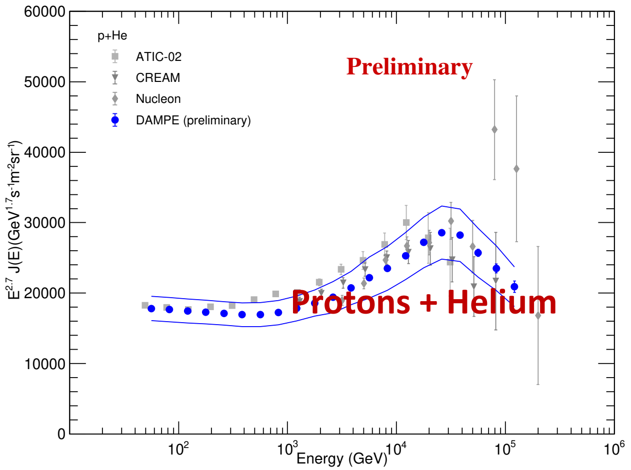


CRD + CRI : Cosmic Ray Spectrum Overlap of Measurements

K. Kobayshi & P.S. Marrocchesi on behalf CALET Collab: PoS(ICRC2021)098



F. Alemanno, P. Bernardi, A. De Benedittis, I. De Mitri, & Z. Wang on behalf of DAMPE Collab: PoS(ICRC2021)117



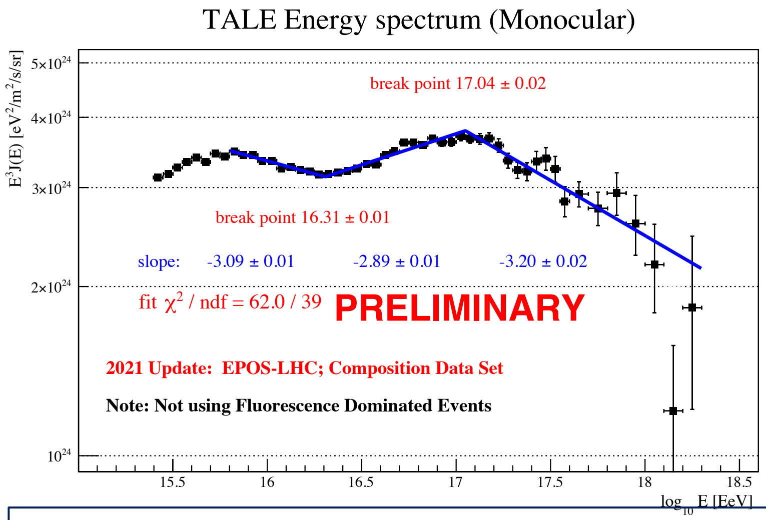
CRD Future Measurements:

- CALET: thru 2024+
- DAMPE: thru 202x?
- HERD:
  - 1+ m^2 sr GF
  - 55 X_0 Calorimeter
  - $1 \leq Z \leq 26$

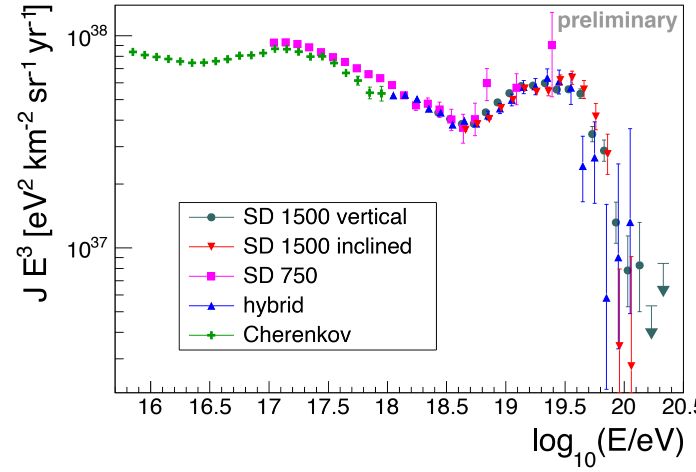
CRI Future Measurements:

- Cherenkov with FTs:
  - TALE & HEAT
- Non-Imaging Cherenkov (w/other measurement techniques_
  - TUNKA-133 **PoS(ICRC2021)361**
  - TAIGA-HiSCORE **PoS(ICRC2021)877**
  - NICHE **PoS(ICRC2021)329**

T. AbuZayyad on behalf Telescope Array Collab: PoS(ICRC2021)347



Z. Novotnyon behalf Pierre Auger Collab: PoS(ICRC2021)324



Discussion 13: New instrumentation and Tools for EAS Detection

Wednesday 21 July 2021

Discussion: 13 New Instrumentation and Tools for EAS Detection | CRI (12:00 PM-1:30 PM)

- Organize flash talks of 36 contributions, and discussions

Conveners
Toshihiro Fujii
Marco Casolino

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

Connecting multi-wavelength and multi-particle observations[2]

X-rays **MeV** **γ-rays** **γ-rays** **Neutrinos** **UHECRs**

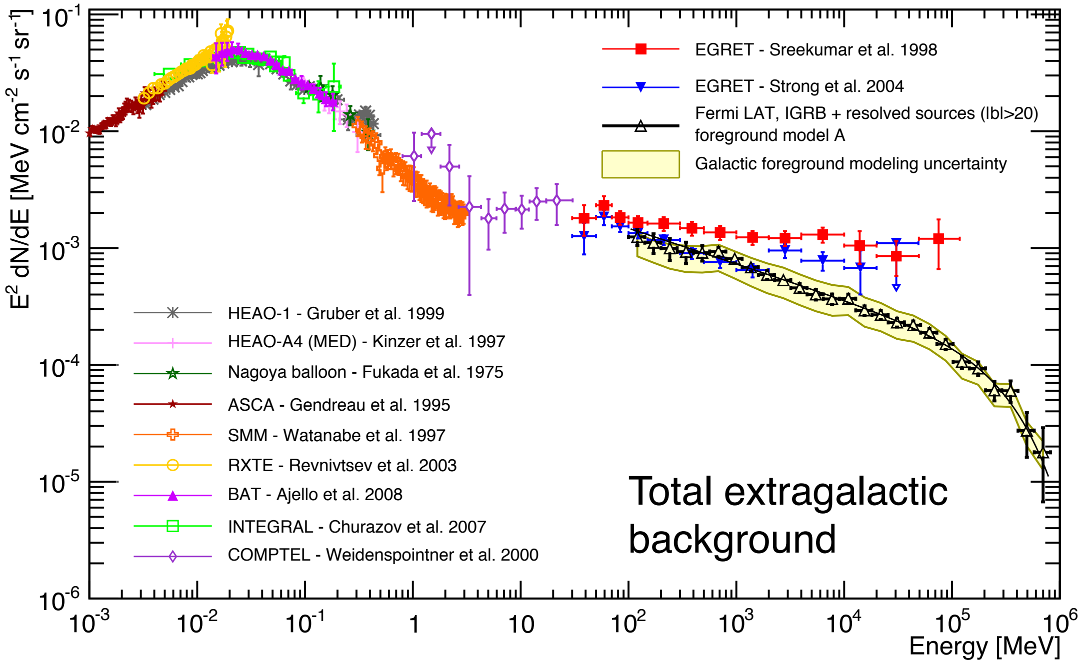
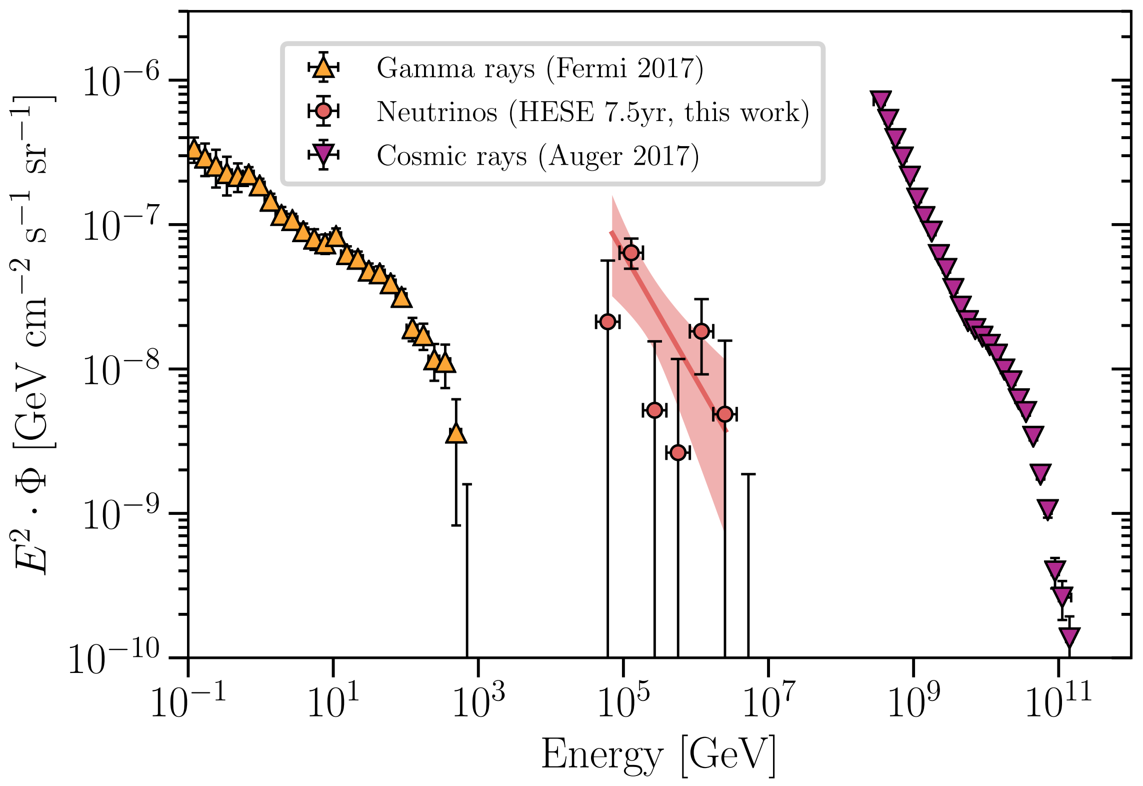


Fig. 10.— Comparison of the derived total EGB intensity (foreground model A) to other measurements of the X-ray and γ-ray background. The error bars on the LAT measurement include the statistical uncertainty and systematic uncertainties from the effective area parametrization, as well as the CR background subtraction. Statistical and systematic uncertainties have been added in quadrature. The shaded band indicates the systematic uncertainty arising from uncertainties in the Galactic foreground. (Note that the EGRET measurements shown are measurements of the IGRB. However, EGRET was more than an order of magnitude less sensitive to resolve individual sources on the sky than the *Fermi*-LAT.)

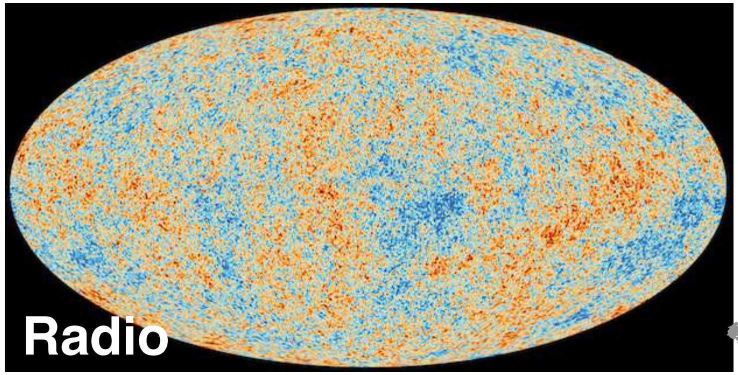
Fermi-LAT collaboration, Astrophys.J. 799 (2015) 86



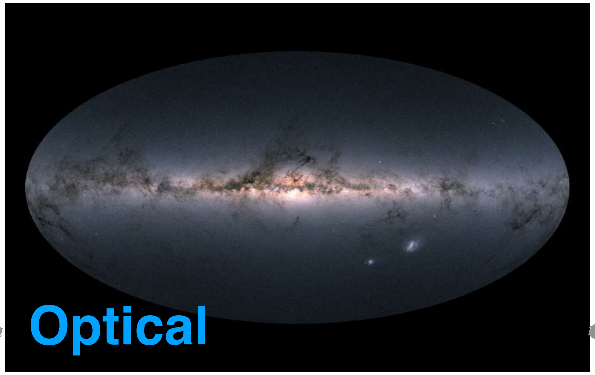
IceCube Collaboration, arXiv:2011.03545

Intriguing for both theorists and <u>experimentalists</u>

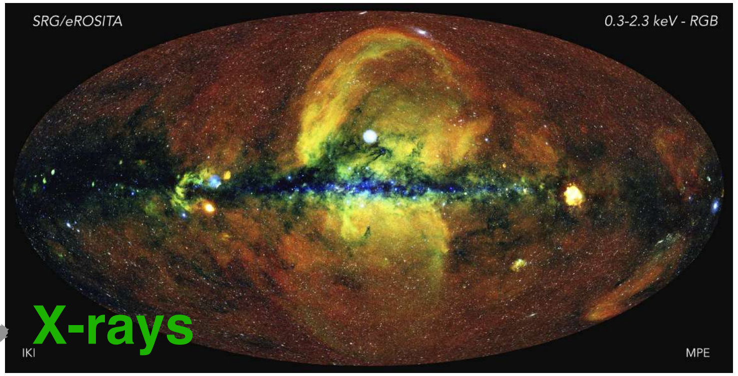
Similar sensitivity at <u>Space, South-pole and Desert</u>



Planck Collaboration

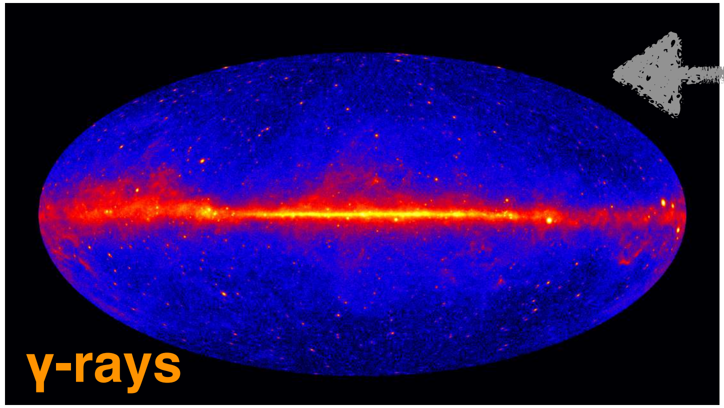


GAIA Collaboration

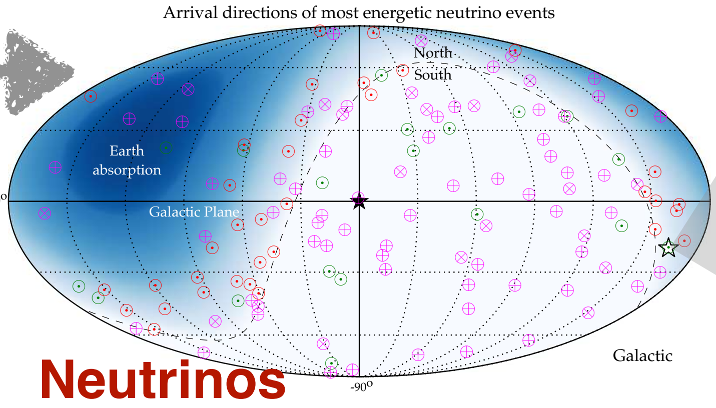


eROSITA Collaboration

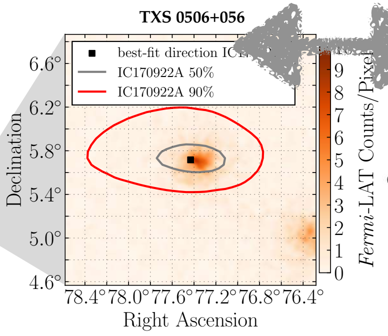
Cosmic Ray Ground Unified Theory (CR-GUT)



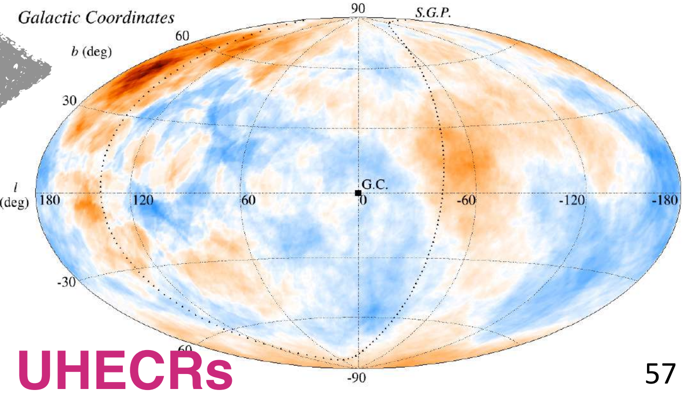
Fermi Collaboration



ICRC 2021 – Fujii - Casolino



IceCube Collaboration



Auger and TA anisotropy WG

Strategies for New instrumentations and tools

- Small instrument but "punchy"
- Low cost detectors
- Wide field-of-view for transient sources and time-domain astronomy
- Upgrade electronics
- Drone-borne calibration sources
- Detailed simulations using high-computing resources

New instrumentations and tools for EAS detection

ROBAST 3	OKUMURA, Akira	
Electrical signals induced in detectors by cosmic rays: a reciprocal look at electrodynamics	WINDISCHHOFER, Philipp	
Simulation of single, double, and triple layer GEM detectors	JUNG, Aera	
CORSIKA below the knee	WIBIG, Tadeusz	
Study of the Electron-Neutron Detector Array (ENDA) in Yangbajing, Tibet	XIAO, Dixuan	
Latest results of ultra-high-energy cosmic ray measurements with prototypes of the Fluorescence detector Array of Single-pixel Telescopes (FAST)	FUJII, Toshihiro	
FOV direction and real image size calibration of Fluorescence Detector using light source mounted on the UAV	NAKAZAWA, Arata	
New coordinate-tracking detector on drift chambers for registration of muons in near-vertical EAS	VOROBEV, Vladislav	
Status of the novel CORSIKA 8 air shower simulation framework	ALVES JUNIOR, Antonio Augusto	
Development of drone-borne aerial calibration pulser system for radio observatories of ultra-high energy air showers	KUO, Chung-Yun	
Acquisition of data from a Water Cherenkov Detector based on an on purpose acquisition card	MORENO BARBOSA, Eduardo	
Pulse Shape Discrimination for Online Data Acquisition in Water Cherenkov Detectors Based on FPGA/SoC	GARCIA ORDONEZ, Luis Guillermo	
Efficiency estimation of self-triggered antenna clusters for air-shower detection	BEZYAZEEKOV, Pavel	

New instrumentations and tools for EAS detection

The YAG Lidar System Applied in LHAASO	SUN, Qinning	
Calibration of LHAASO-WFCTA	CHEN, Long	
Application of the nitrogen laser calibration system in LAASO-WFCTA	LI, Xin	
Denoising cosmic rays radio signal using Wavelets techniques	WATANABE, Clara	
Adaptive predictor as trigger mechanism for cosmic ray radio signals corrupted by Gaussian noise	WATANABE, Clara	
Status of simulation and data comparison of wcda-1	WU, hanrong	
An Advanced Triggerless Data Acquisition System for GRAPES-3 Muon Detector	JAIN, Atul	
Integration and qualification of the Mini-EUSO telescope on board the ISS	CAMBIÈ, Giorgio	
EUSO-SPB2 Telescope Optics and Testing	KUNGEL, Viktoria	
AugerPrime Upgraded Unified Board: The New Front-End Electronics	MARSELLA, Giovanni	
Towards a full and realistic simulation framework for the Extreme Energy Events experiment	GRAZZI, Stefano	
Development of a scintillation and radio hybrid detector array at the South Pole	OEHLER, Marie	
Reconstruction of sub-threshold events of cosmic-ray radio detectors using an autoencoder	BEZYAZEEKOV, Pavel	
Electromagnetic Shower Simulation for CORSIKA 8	ALAMEDDINE, Jean-Marco	

New instrumentations and tools for EAS detection

The XY Scanner - A Versatile Method of the Absolute End-to-End Calibration of Fluorescence Detectors	SCHÄFER, Christoph	
Progress in optimizing the detection surface structure of CRAFFT	KUBOTA, Yuto	
Development of autonomous observation system for next-generation cosmic ray telescope	TOMIDA, Takayuki	
Tunka-Rex Virtual Observatory	LENOK, Vladimir	
Overview of the Mini-EUSO \$\mu s\$ trigger logic performance	BATTISTI, Matteo	
Sensitivity of the Tibet hybrid experiment (Tibet-III + MD) for primary proton spectra between 30 TeV and a few hundreds of TeV's	KURASHIGE, Daichi	
A drone-borne installation for studying the composition of cosmic rays in the range of 1-1000 PeV by registering the reflected Cherenkov light of EAS	VAIMAN, Igor	
Test of the Electron-Neutron Detector Array (ENDA) in Laboratory	YANG, Fan	
Tools and Procedures for the ASTRI Mini-Array Calibration	MINEO, Teresa	

21 July 2021, 12:00 PM - 1:30 PM

We highly welcome your attendances !