INTERCOS : INTEractions du Rayonnement COSmique
IN2P3 Master-Project

1. Presentation and « spirit » of the project
2. What we did
3. The LHAASO day
4. What did not fully worked
5. Next steps : INTERCOS II

A.Marcowith for INTERCOS collaboration

Why proposing such a project ?

- Reinforce the cooperation / develop collaborating effort between IN2P3 laboratory members involved in the field Cosmic Ray Astrophysics (mw, mm observations, modelling, phenomenology) and Physics (Xsection measurements, microphysics).

- **6 laboratories involved**
  - LUPM (coordinator A. Marcowith, Y. Gallant, C. Guépin, J. Lavalle)
  - APC (D. Allard, S. Gabici, E. Parizot)
  - LP2I (M. Lemoine-Goumard, M.H. Grondin)
  - IJClab (J. Biteau, V. Tatischeff)
  - LPSC (L. Derome, D. Maurin) < follows the action carried by D.Maurin for years between LPSC – LAPTH - LUPM
  - CPPM (D. Dornic)

Main project axis

1. Develop scientific animation
2. Support workshop organisation
3. Support experiments (NanoCR, Pandora, see next)
4. Support collaboration among IN2P3 teams.

Typical budget : 20 KE/year, INTERCOS is a 3 years project (ending this year)

Project realisation : scientific animation

- At CFRCOS 1 it was decided to create 3 sub-groups (CROME I-III)
- A CROME list was created by C. Guépin see Cosmic Ray site

- Low-energy Cosmic Rays (LE-CR or CROME I) : ionisation, spallation, induced chemistry – strong links with PCMI but also with PNCG? PNST and PNPS. [A. Marcowith + B. Commerçon, Y. Dubois]

- Cosmic Ray sources (CR-S, or CROME II): acceleration mechanism, multi-wavelength and multi-messengers, UHECR sources [D. Allard, C. Guépin + P. Cristofari]

- Cosmic Ray transport (CR-T, or CROME III): phenomenology and microphysics, molecular cloud studies, magnetic fields in ISM/IGM, galactic-extragalactic transition [S. Gabici + Y. Génolini, N. Globus]

CROME group activities

- CROME III (transport) proposes monthly on-line meetings see pcloud (about 11 seminars yet) organised by Y. Génolini* (LAPTH).
- CROME II (Sources) :
  - Organisation of two workshops among which the LHAASO day (see next)
- CROME I (LECR) :
  - Organisation of a parallel session during PCMI days in oct 2022 : cosmic rays and the interstellar medium
  - Organisation of a parallel session on Cosmic Rays and Cosmology during SF2A 2023.

* email C. Guépin, Y. Génolini if you want to be included in the mailing-list

Project realisation : CFRCOS 3 and 4

- CFRCOS = workshop of the French Cosmic Ray community.
- To date we had 4 workshops (2 in the course of INTERCOS)
  - CFRCOS 1 : Paris 2018
  - CFRCOS 2 : Montpellier 2019
  - CFRCOS 3 : on-line 2021
  - CFRCOS 4 : Montpellier 2023
- Usually combined themes : (eg CFRCOS 4)

  Day 1 : Sources

  Day 2 : Transport

  Day 3 : Interaction

but we can have some more coloured workshops like CFRCOS 1 : Experiments (Laser physics) and multi-messengers.

Project realisation: Support to experiments

- Ions in the interstellar medium (NanoCR) (French PI : Marin Chabot IJClab)
- UHECRS (Pandora project) (French PI: D.Allard APC)

Collaboration Marin Chabot (IJCLab), Thibault Nguyen (IJCLab), Isabelle Ribaud (IJCLab), Olivier Sublemontier (CEA), Emmanuel Dartois (INSU).

Interstellar Medium:

- Gaz (H, He)
- Dust (C, Si)

- Chemical Reactions
- UV irradiation
- ***Cosmic Rays***

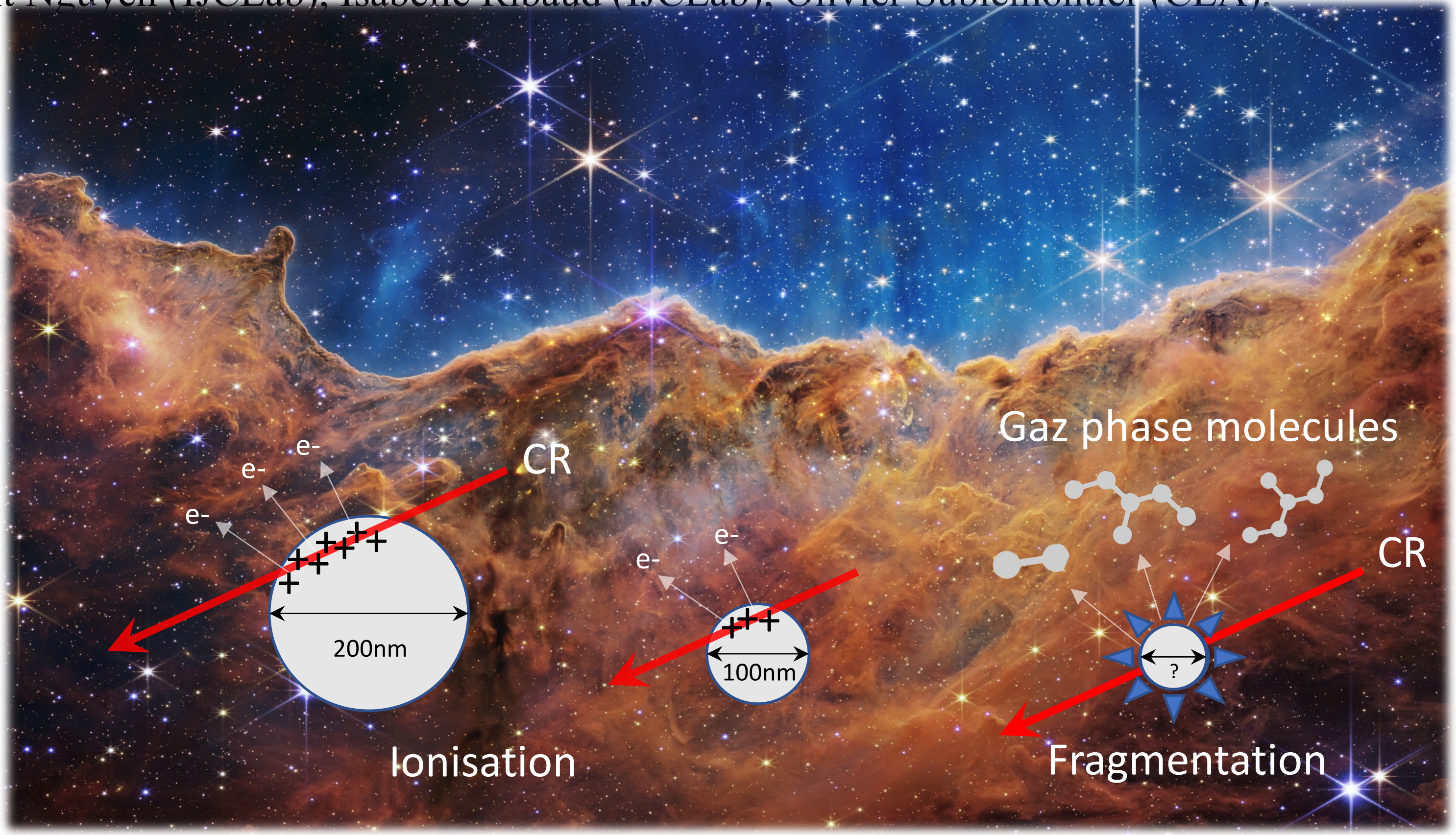
NanoCR Experiment : sur plateforme Andromède, IJCLab)

- Cosmic Rays :

  Argon ions produced by
  4 MV electrostatic accelerator

- Dust Grains:

  100nm radius Polystyrene
  Monodisperse Nanoparticles



Cosmic Ray / Interstellar dust interaction scheme
Cosmic Cliffs, NASA, ESA, CSA, and STScI

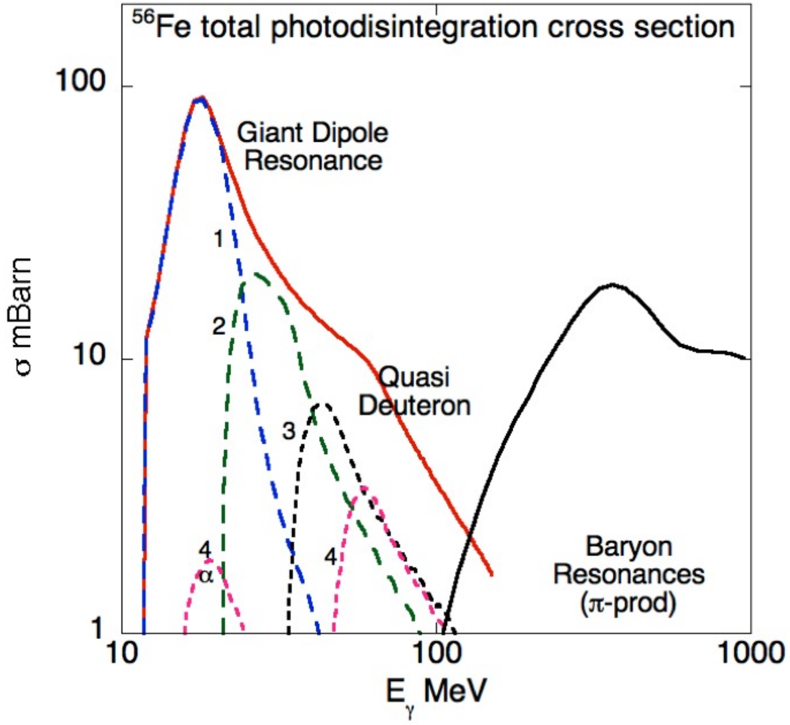
website @ IJCLab

PANDORA Project

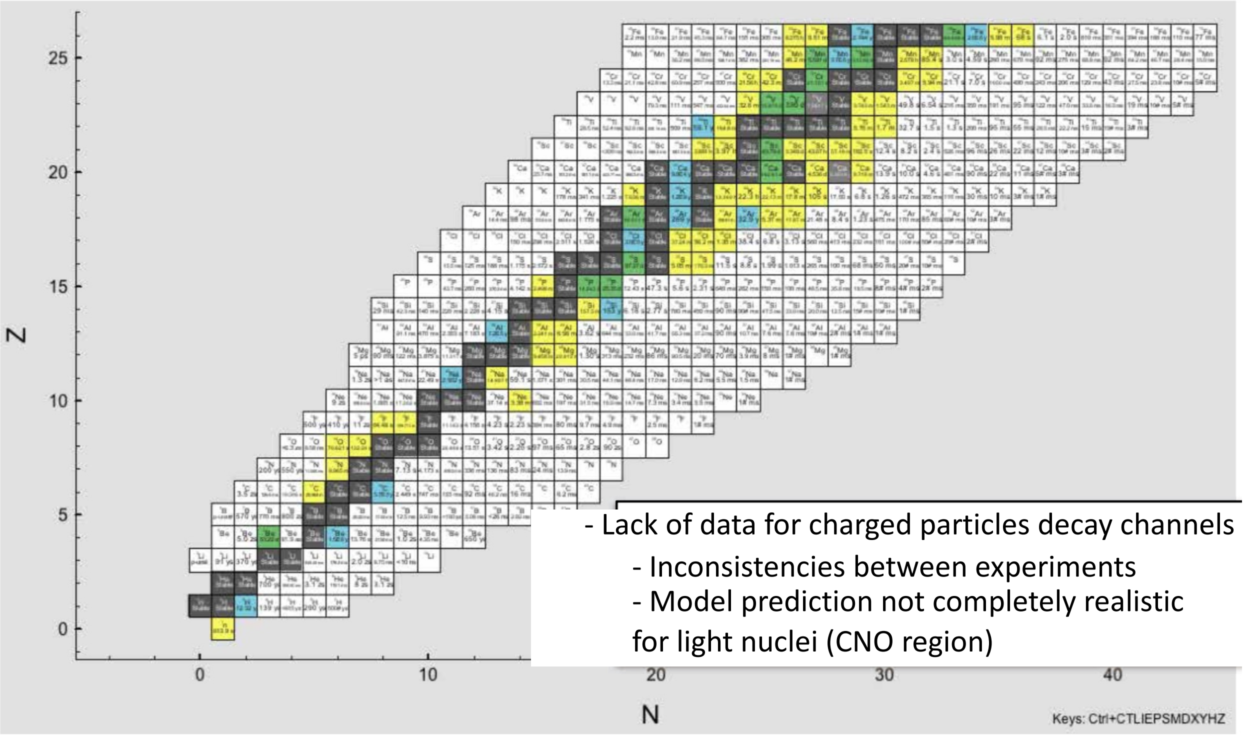
Photo-**A**bsorption of **N**uclei and **D**ecay **O**bservation for **R**eactions in **A**strophysics

French scientists involved : Denis Allard, Bruny Baret, Elias Khan, Jürgen Kiener, Etienne Parizot, Vincent Tatischeff

Photodisintegration of UHECR nuclei dominated by the Giant Dipole Resonance process



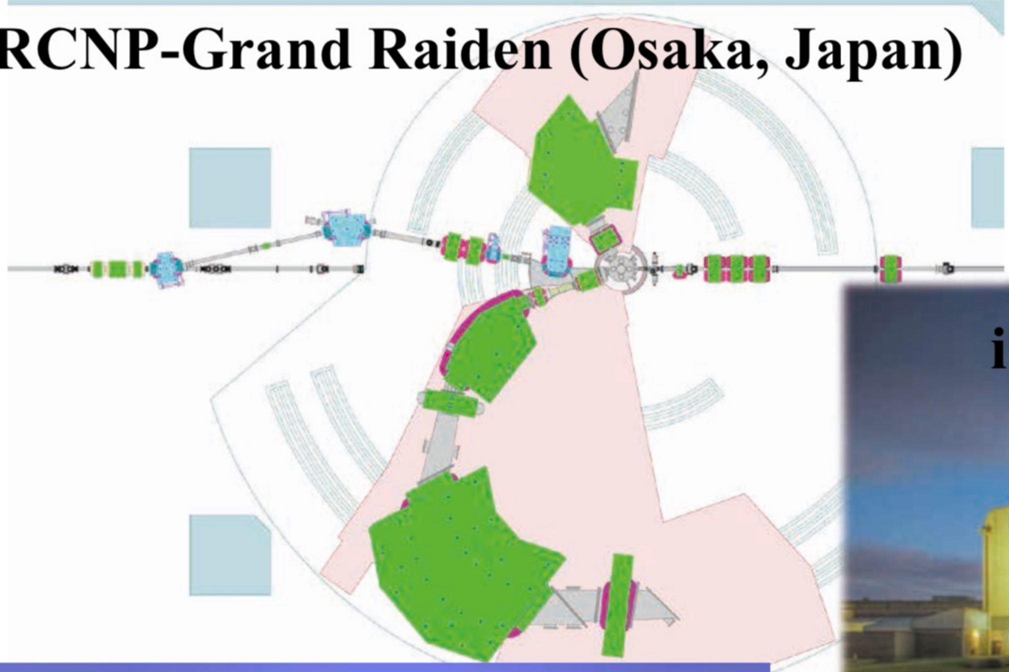
Need for good data and/or solid predictions for GDR cross sections and branching ratios (n, p, α,… decay channels) from light nuclei to A~56



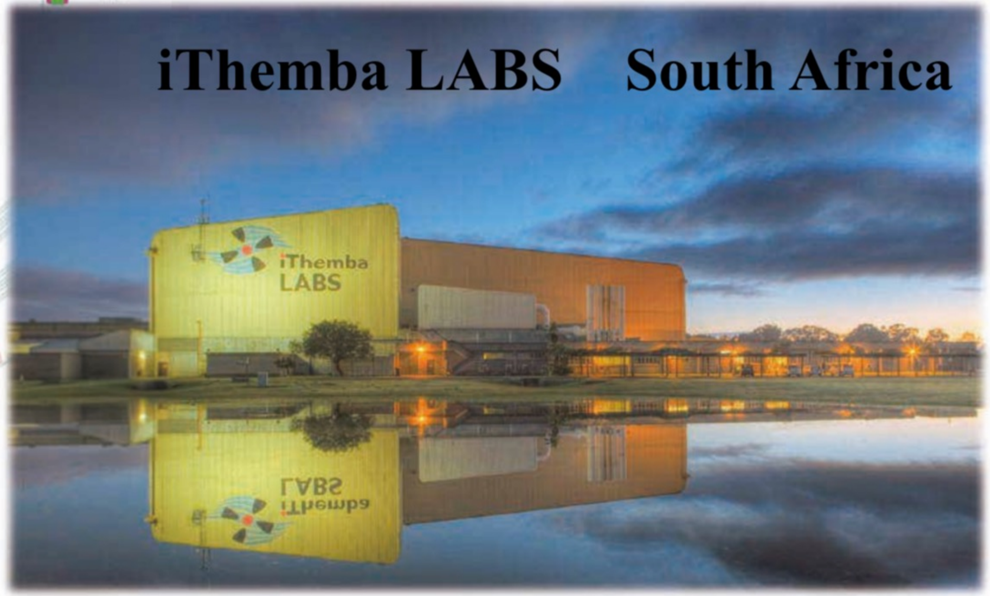
- Lack of data for charged particles decay channels
  - Inconsistencies between experiments
  - Model prediction not completely realistic for light nuclei (CNO region)

PANDORA Project

Photo-**A**bsorption of **N**uclei and **D**ecay **O**bservation for **R**eactions in **A**strophysics



experiments at three facilities
with complementary techniques



Joint project of nuclear experiment, nuclear theory and astrophysical simulation

PANDORA Project

Photo-**A**bsorption of **N**uclei and **D**ecay **O**bservation for **R**eactions in **A**strophysics

- 2015 : Elias Khan and Denis Allard presentation at ELI-NP physics workshop
  —> need for new GDR cross section measurements for light and intermediate nuclei

- 2019 : Birth of the PANDORA collaboration: Atsushi Tamii (RCPN) gathers South African (iThemba LABS) and European (ELI-NP) colleagues

- 2020-2022 : remote meetings —> science case, choice of the most interesting targets, white paper (e-Print: [2211.03986] [nucl-ex])

PANDORA project: photo-nuclear reactions below $A = 60$

A. Tamii[1,2,3,*], L. Pellegri[4,5], P.-A. Söderström[6], D. Allard[7], S. Goriely[8], T. Inakura[9], E. Khan[10], E. Kido[11], M. Kimura[12,13,11], E. Litvinova[14], S. Nagataki[11], P. von Neumann-Cosel[15], N. Pietralla[15], N. Shimizu[16], N. Tsoneva[6], Y. Utsuno[17], S. Adachi[18], P. Adsley[19,20], A. Bahini[5], D. Balabanski[6], B. Baret[10], J.A.C. Bekker[4,5], S.D. Binda[4,5], E. Boicu[6,21], A. Bracco[22,23], I. Brandherm[15], M. Brezeanu[6,21], J.W. Brummer[5], F. Camera[22,23], F.C.L. Crespi[22,23], R. Dalal[24], L.M. Donaldson[5], Y. Fujikawa[25], T. Furuno[3], H. Haoning[14], Y. Honda[3], A. Gavrilescu[6,26], A. Inoue[1], J. Isaak[15], H. Jivan[4,5], P.M. Jones[5], S. Jongile[5], O. Just[11,27], T. Kawabata[3], T. Khumalo[4,5], J. Kiener[10], J. Kleemann[15], N. Kobayashi[1], Y. Koshio[28], A. Kuşoğlu[6,29], K.C.W. Li[30], K.L. Malatji[5], R.E. Molaeng[4,5], H. Motoki[12], M. Murata[1], A.A. Netshiya[4,5,31], R. Neveling[5], R. Niina[1], S. Okamoto[25], S. Ota[1], O. Papst[15], E. Parizot[10], T. Petruse[6], M.S. Reen[32], P. Ring[33], K. Sakanashi[3], E. Sideras-Haddad[4], S. Siem[30], M. Spall[15], T. Suda[34], T. Sudo[1], Y. Taniguchi[35], V. Tatischeff[10], H. Utsunomiya[36,37], H. Wang[36,38,39], V. Werner[15], H. Wibowo[40], M. Wiedeking[4,5], O. Wieland[22,23], Y. Xu[6] and Z.H. Yang[41] (PANDORA Collaboration)

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PANDORA Project

Photo-**A**bsorption of **N**uclei and **D**ecay **O**bservation for **R**eactions in **A**strophysics

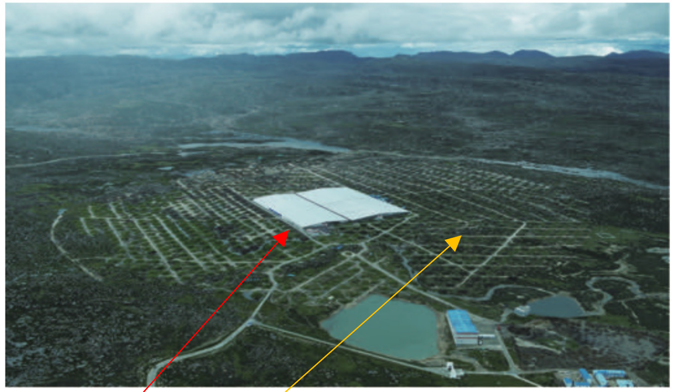
Liste des noyaux cibles privilégiés pour la campagne pluriannuelle de mesures :

- Cible de réference (intercalibration) : 27Al,
- Importance du canal α : 12C et 16O,
- Noyaux légers : 6Li, 7Li, 9Be, et 10,11B,
- Noyaux N = Z, effet de clustering α, déformation: 24Mg, 28Si, 32S and 40Ca,
- Isospin selection-rule in α-decay: paires d'isotopes 10B/11B, 12C/13C, 16O/18O and 24Mg/26Mg,
- Noyaux N > Z et émission multiple de neutrons: 13C, 18O, 26Mg, 48Ca and 56Fe,
- Noyaux impairs (A) et impairs-impairs : 7Li, 9Be, 11B, 13C, 14N.

INTERLUDE : LHAASO day May 3rd 2023

Fig. 19. (color online) Photo of LHAASO in August 2021. WCDA is the building at the center. The soil bumps are MDs. The white or green small boxes are EDs. The blue boxes beside WCDA are WFCTs.

LHAASO’s main assets for cosmic-ray measurements : the ultra-hybrid experiment



Located Sichuan China 4410 m

two types of detectors

WCDA : Water Detector Cherenkov Array
KM2A : Kilo-Meter Squared Array

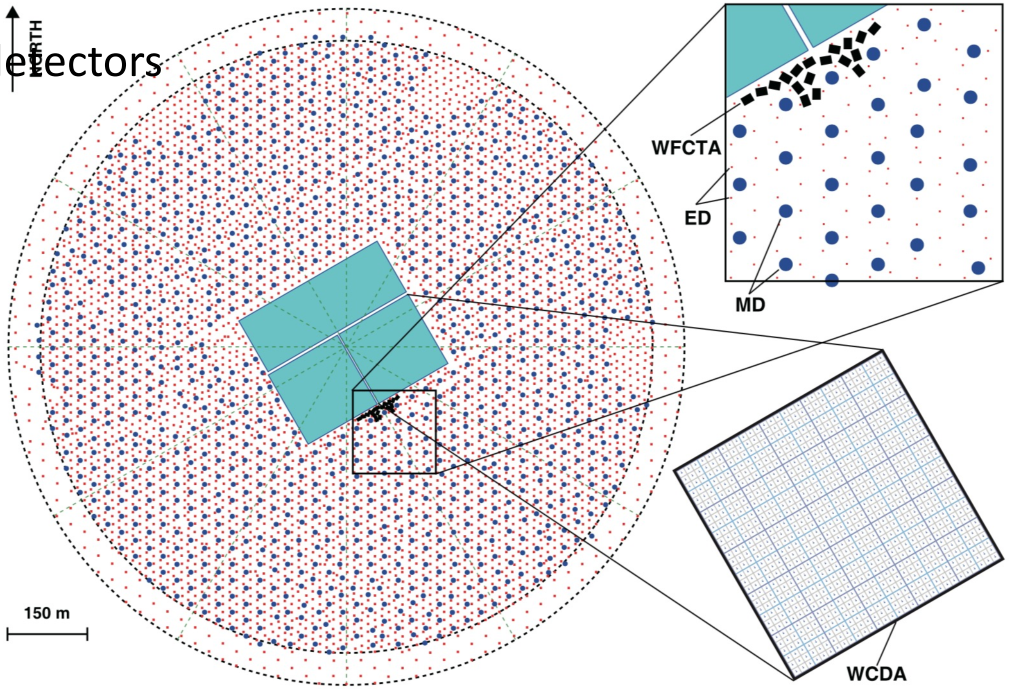
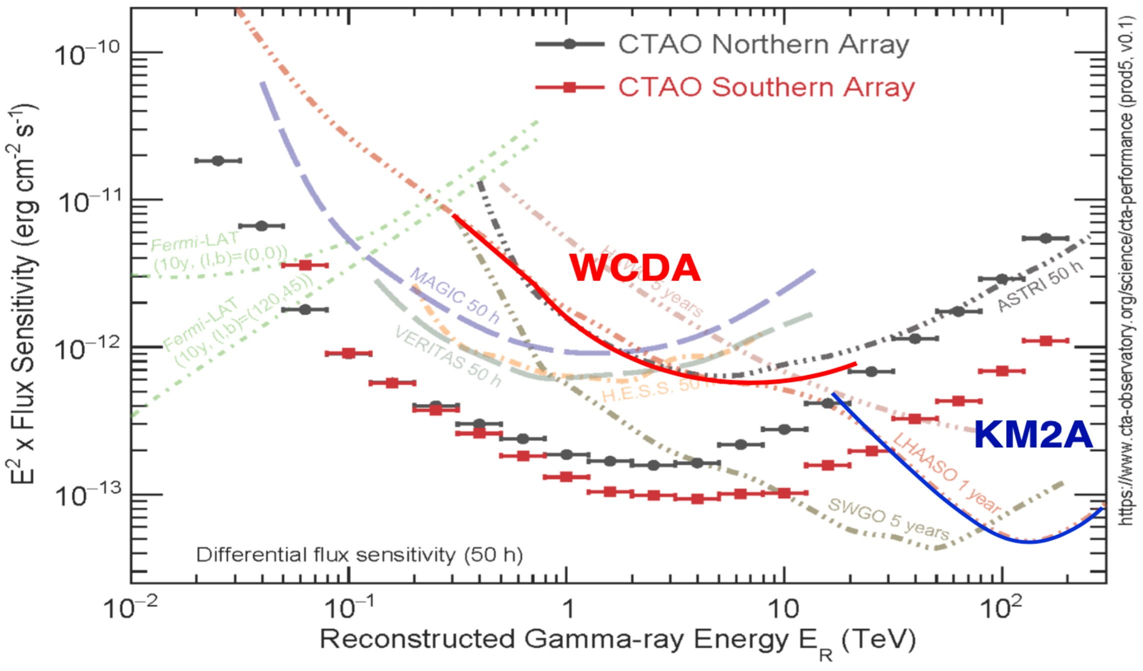


Fig. 1. (color online) Layout of LHAASO.

- LHAASO is a large, high altitude, multi-detector experiment
- high altitude —> close to the shower maximum (minimise shower to shower fluctuations)
- large —> ample statistics on a wide energy range
- Multi-detector —> good sensitivity to CR composition

LHAASO's main assets for gamma-ray and cosmic-ray measurements: the ultra-hybrid experiment



(della Volpe 2023)

KM2A better than CTA-N above 20 TeV !

Table 1. LHAASO vs other EAS arrays.

Experiment	depth/(g/cm)^2	Detector	ΔE/eV	e.m. Sensitive area/m^2	Instrumented area/m^2	Coverage
ARGO-YBJ	606	RPC/hybrid	$3\times10^{11}-10^{16}$	6700	11,000	0.93 (central carpet)
BASJE-MAS	550	scint./muon	$6\cdot10^{12}-3.5\cdot10^{16}$		10^4	
TIBET ASγ	606	scint./burst det.	$5\times10^{13}-10^{17}$	380	3.7×10^4	10^{-2}
CASA-MIA	860	scint./muon	$10^{14}-3.5\cdot10^{16}$	1.6×10^3	2.3×10^5	7×10^{-3}
KASCADE	1020	scint./mu/had	$10^{15}-10^{17}$	5×10^2	4×10^4	
KASCADE-Grande	1020	scint./mu/had	$10^{16}-10^{18}$	370	5×10^5	7×10^{-4}
Tunka	900	open Cher.det.	$3\cdot10^{15}-3\cdot10^{18}$	–	10^6	–
IceTop	680	ice Cher.det.	$10^{15}-10^{18}$	4.2×10^2	10^6	4×10^{-4}
LHAASO	600	Water C scint./mu/had Wide FoV Cher.Tel	$3\times10^{11}-10^{18}$	5.2×10^3	1.3×10^6	4×10^{-3} [KM2A]

Muon detectors

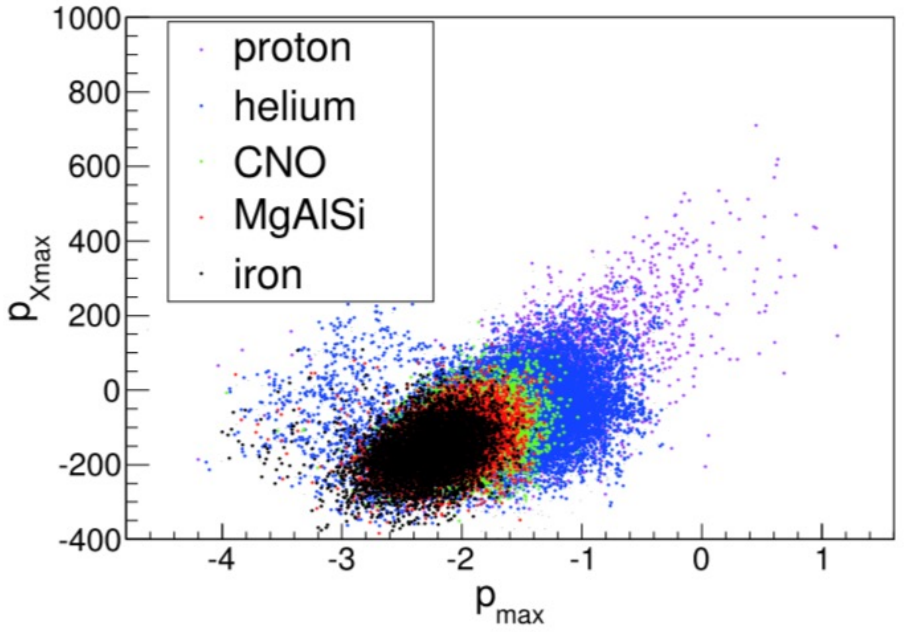
Experiment	m asl	μ Sensitive area/m^2	Instrumented area /m^2	Coverage
LHAASO	4410	4.2×10^4	10^6	4.4×10^{-2}
TIBET ASγ	4300	4.5×10^3	3.7×10^4	1.2×10^{-1}
KASCADE	110	6×10^2	4×10^4	1.5×10^{-2}
CASA-MIA	1450	2.5×10^3	2.3×10^5	1.1×10^{-2}

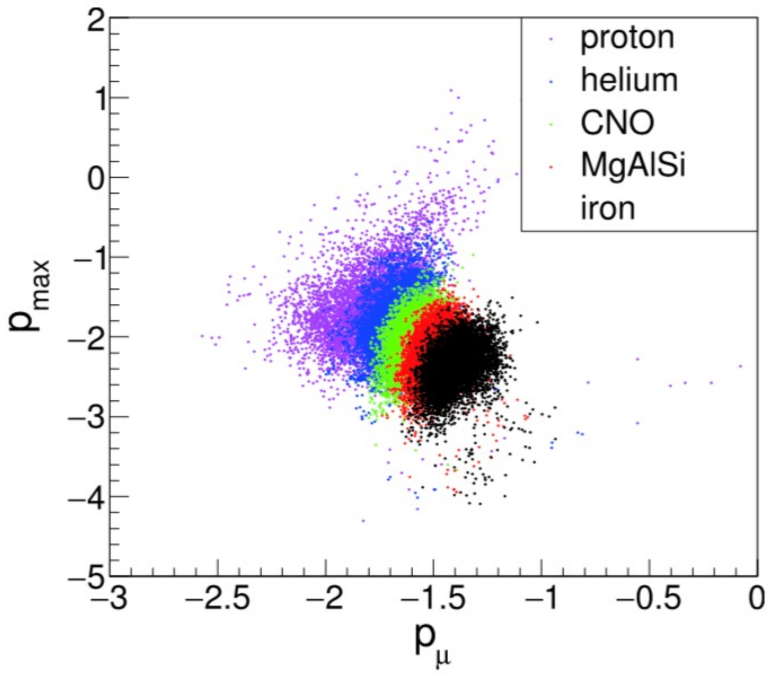
from LHAASO science book

LHAASO's main assets for cosmic-ray measurements : the ultra-hybrid experiment

- multidetector —> many shower observables related to : electromagnetic particles at ground level, muons at ground level —> multi-dimensional composition analyses

- various observational strategies to observe and constrain the CR spectrum and composition in various energy ranges (WFCTA reconverted into fluorescence telescope to measure CR composition at the highest energies)





fascinating experiment with fascinating perspectives for CR (composition) measurements on a wide energy range

LHAASO day program

A. Jardin-Blick : detection and analysis techniques

Y. Gallant : gamma-ray event reconstruction with LHAASO + Pulsar wind nebula

G. Giacinti : Pulsars + diffuse gamma-ray emission

D. Allard : cosmic-ray measurements

S. Gabici: Supernova remnants, galactic centre, massive star clusters

R. Terrier: gamma pi and LHAASO analysis

- Contributions can be retrieved here

LHAASO : an opportunity for the community ?

- Unique observatory in the world —> possibility to propose and participate to CR analyses.
- (A critical mass ready to be involved in these analyses is needed)
- Outcome of the CR analysis of interest for the whole French community interested in CR phenomenology (from low energies to the transition from GCR to EGCR).
- Complementary with the constraints brought by γ-rays on VHECR accelerators.

- What is the opinion of the PNHE community ?

[Back to INTERCOS] What did not fully worked

- Scientific animation of the LECR group
- Collaboration

Largely impacted by the covid crisis (INTERCOS started in the course of 2020 … more than half of the project occurred under covid restrictions)

Then It takes time to go back to normal business.

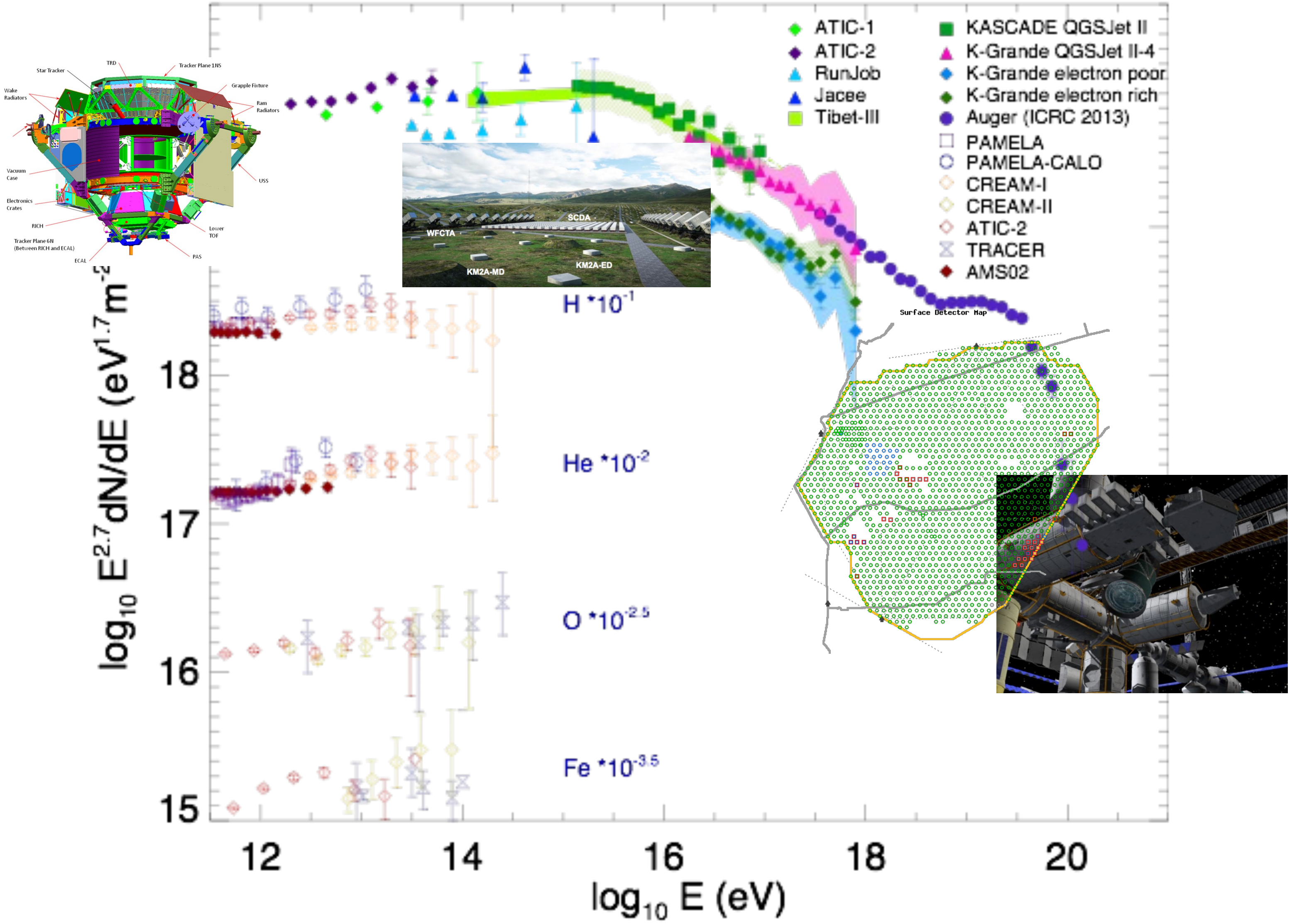
These aspects have to be improved for the next round (INTERCOS II).

Perspectives

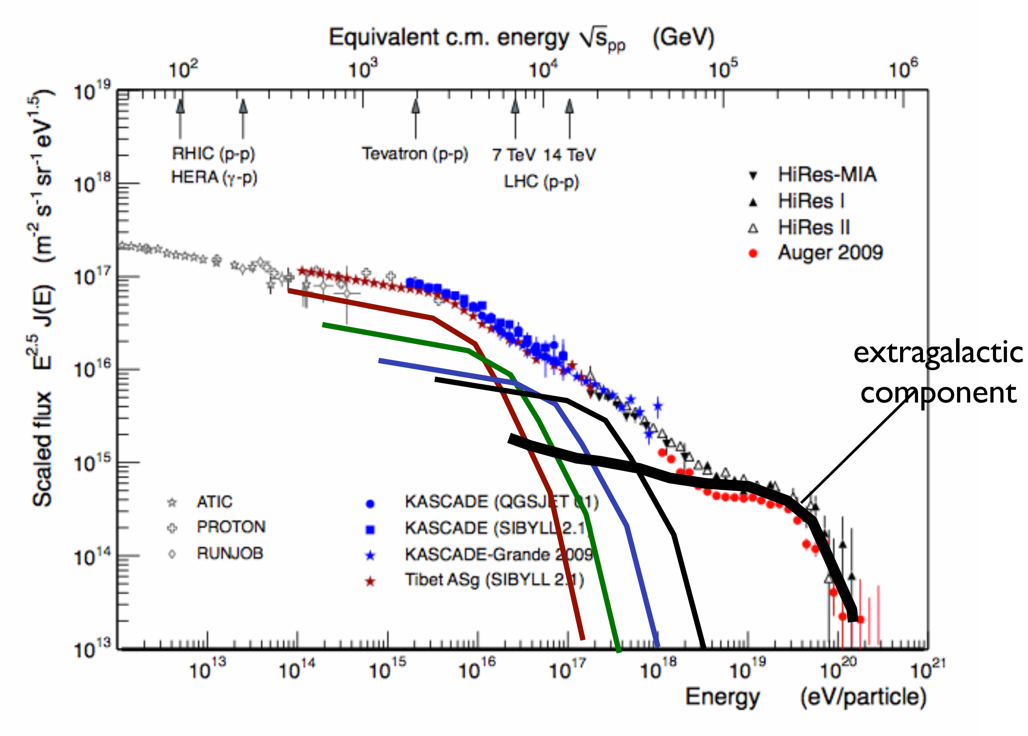
- INTERCOS 2 :
  - Continue on NanoCR and PANDORA.
  - Develop effectives collaborations (CR transport, Molecular clouds at gamma-rays, GRAND and the CR GAL-EXTRAGAL transition).
  - Continue to support workshop and meetings: CFRCOS 5 @ Bordeaux early 2025.
  - Continue of scientific animation.
  - support to some LHAASO ticket entrance ? what about SGWO ?
  - Link with any initiative on PNHE side.

Back-up

Cosmic-ray measurements in the knee region with LHAASO (from 10 TeV to 1 EeV !)

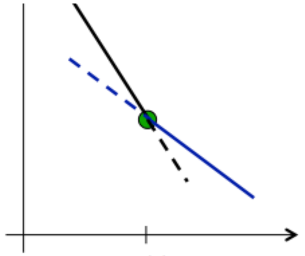


The cosmic-ray spectrum



The knee first seen in the late 50's very soon suspected to be an inflection of the light galactic component

==> one expects the composition is getting heavier in the energy decade following the knee confirmed by most experiments including KASCADE(see Blumer et al., 2009; Unger & Kampert, 2012)



ankle : transition from a softer to a harder component

==> very natural feature for the transition from galactic to extragalactic cosmic-ray

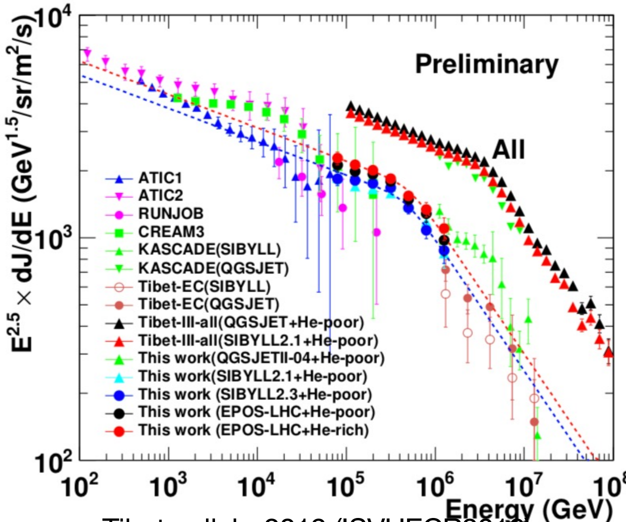
(but other interpretations have been proposed)

A complicated experimental situation in the knee region and beyond

• Kascade-Grande analyses supports the traditional interpretation of the knee and of the ankle (heavy knee and light ankle)
but :
- A lot of caution is required since there is a claimed discrepancy between the predictions of hadronic models and the observed properties of air showers with multi-component detectors
—> in particular in Auger and KASCADE data
(possibly not dramatic, but currently prevents making solid statements about relative abundances of particular elements or even group of elements)

• Sometimes very different interpretations from different experiments
—> Recent examples

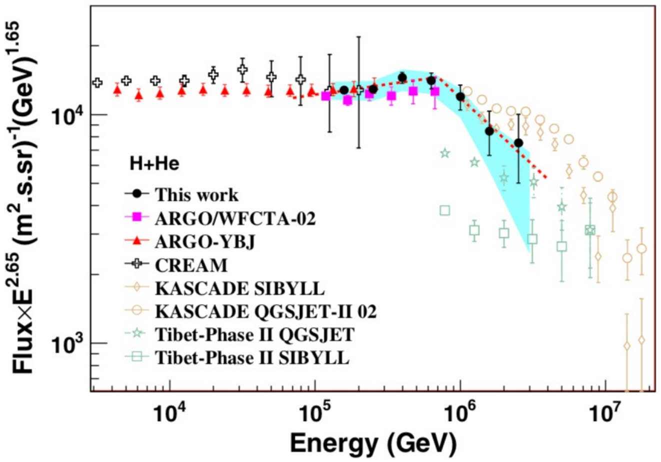
★Tibet or Argo Vs IceCube/IceTop (at the knee)



Tibet collab, 2019 (ISVHECR2018)

While IceCube/IceTop most recent study (PhysRevD2019) supports a dominant contribution of H and He at the knee, latest results from Tibet and Argo go in a radically different direction :

- P+He knee around 500 TeV and P+He abundance <30% at the knee (which is thus caused by other elements) for Tibet
- P+He knee around 700 TeV for Argo



Argo collab, 2015 (PRD)