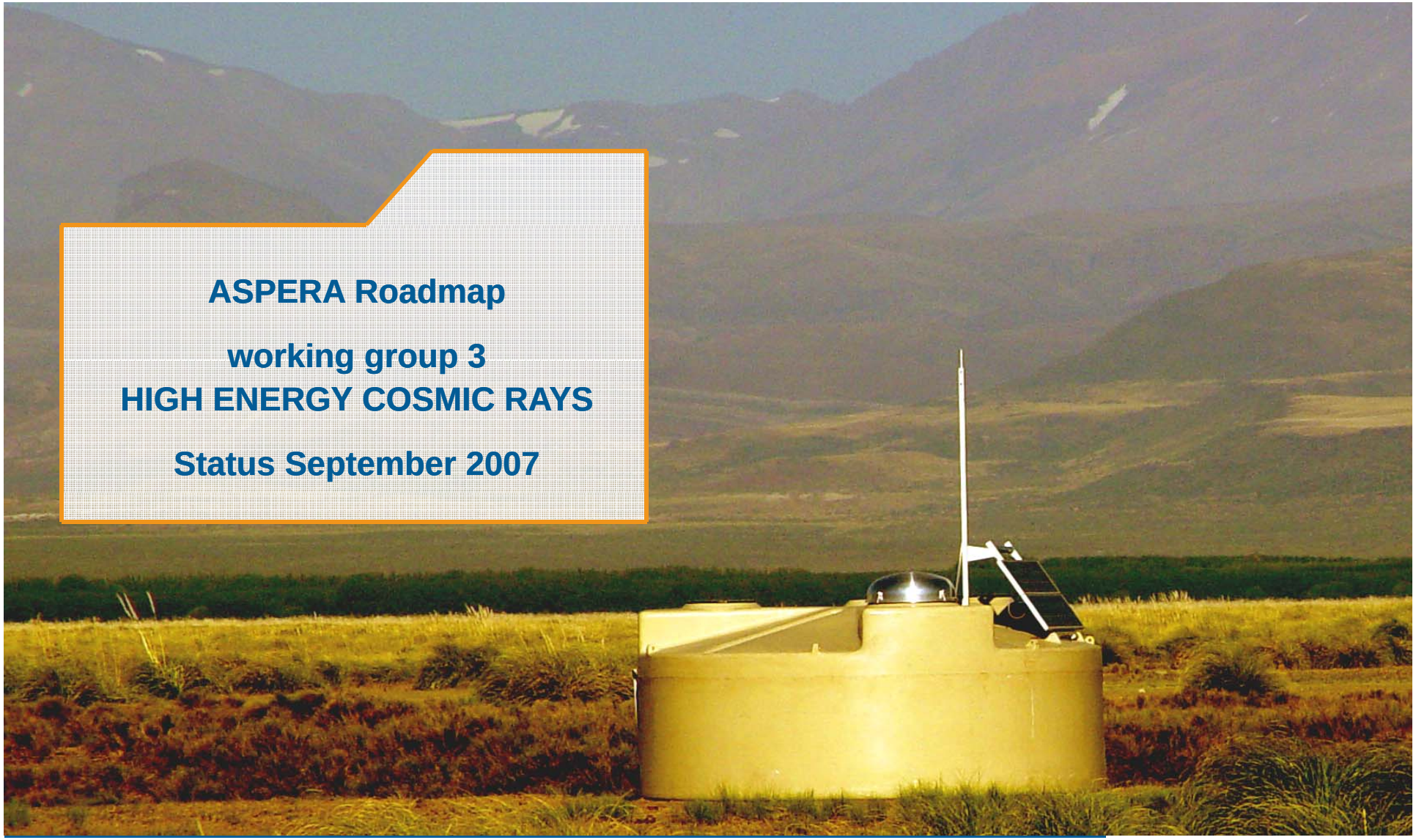
European strategy for astroparticle physics

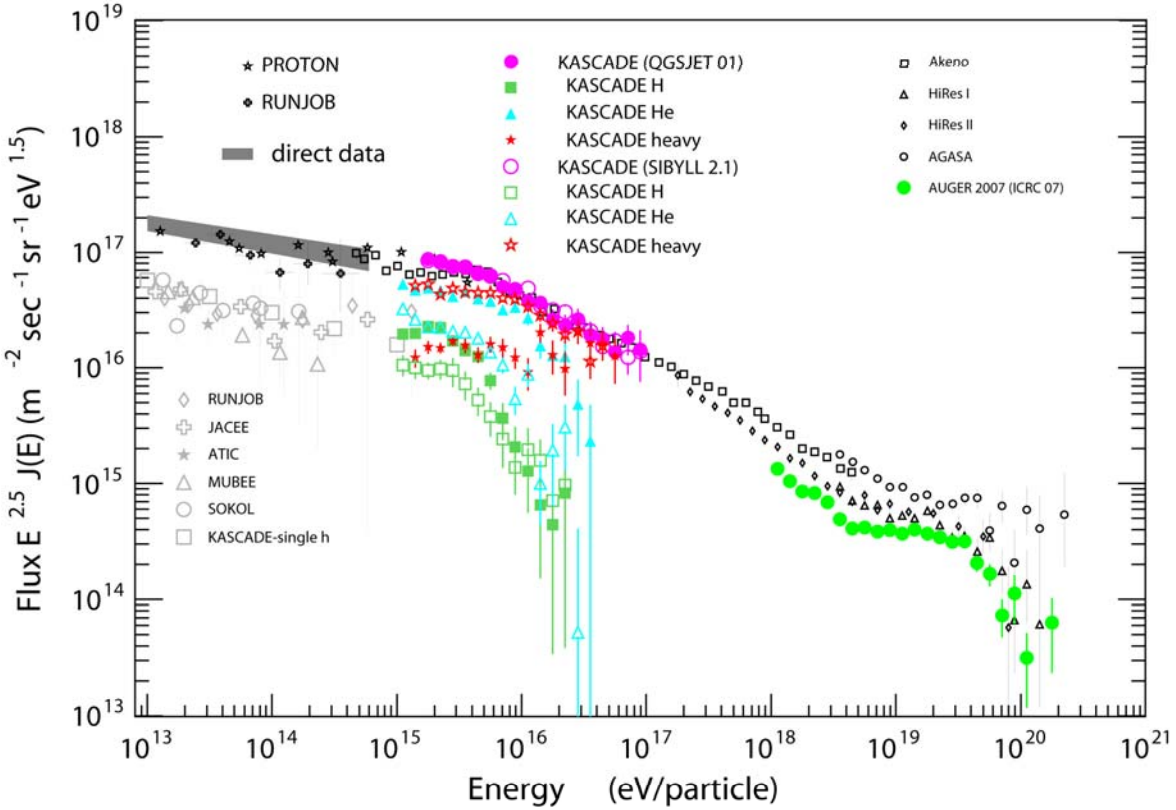


ASPERA Roadmap

working group 3
HIGH ENERGY COSMIC RAYS

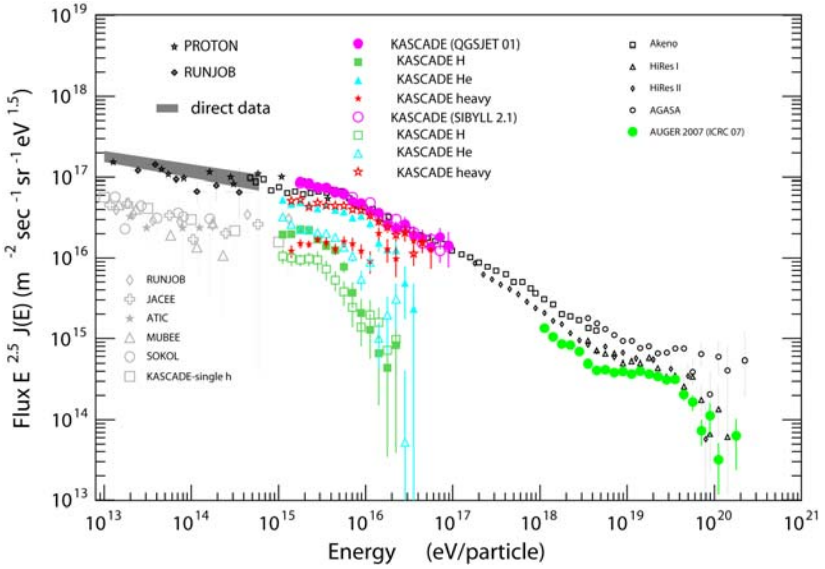
Status September 2007

High Energy Cosmic Rays



Do we understand the spectrum of cosmic particles ?
I.e. Sources ? Acceleration ? Propagation ?

High Energy Cosmic Rays



Last decade ~(1993-2005):

Big step forward by sophisticated experiments:
(AMS01, ATIC, TRACER, PAMELA, KASCADE, AUGER,…)

By multi-detector and hybrid measurements of cosmic rays and air showers with high accuracy.

next decade ~(2008-2018):

- **Covering with same quality the whole spectrum.**
- **Energy spectra of individual particles over whole energy range.**
- **At highest energies: sources? and source spectra?**
- **Start with particle astronomy (with full sky coverage).**

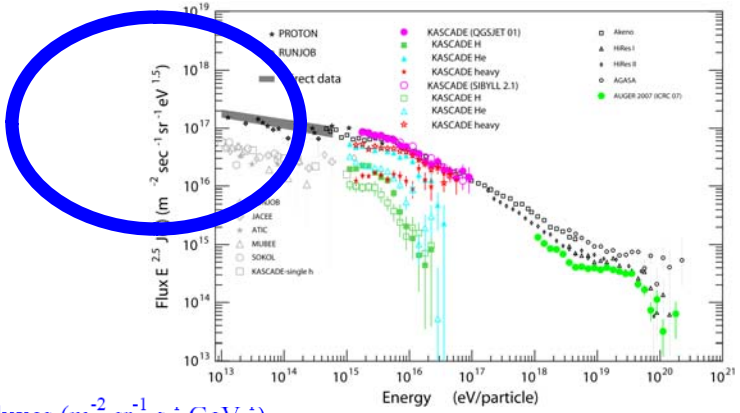
Working group 3

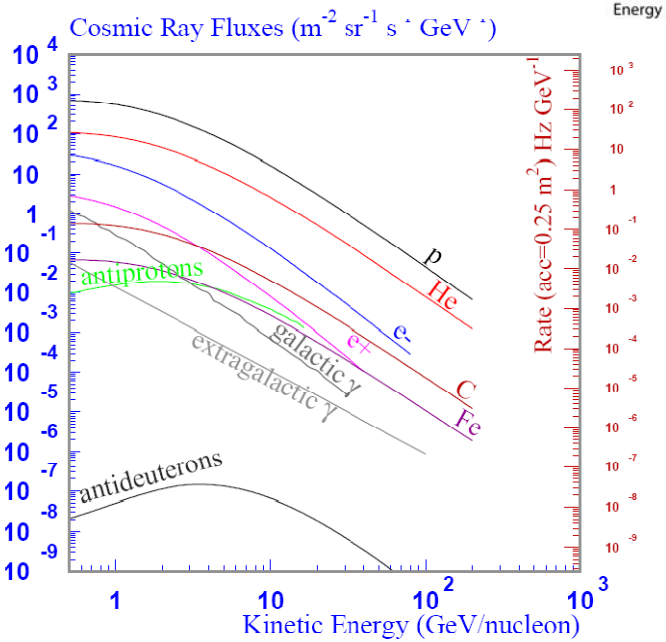
Experiments asked for questionnaires:

Auger (south):	ground based	GZK	ok
Auger (north):	ground based	GZK+beyond	ok
JEM-EUSO:	space based	GZK+beyond	ok
SUPER-EUSO:	space based	GZK+beyond	ok
LOFAR:	ground based	ankle,GZK+beyond (CR+ν)	ok
SKA:	ground based	GZK + beyond (moon, only)	no response
Emma:	ground based	knee	no response
NUCLEON:	space based	direct knee	ok
AMS-02:	space based	direct GeV-TeV	ok

Also important for understanding cosmic rays:
H.E.S.S. / MAGIC / CTA ➔ working group gamma rays
ICECUBE / KM3Net ➔ working group neutrinos
Theory / …..

Direct measurements in the GeV-TeV range:

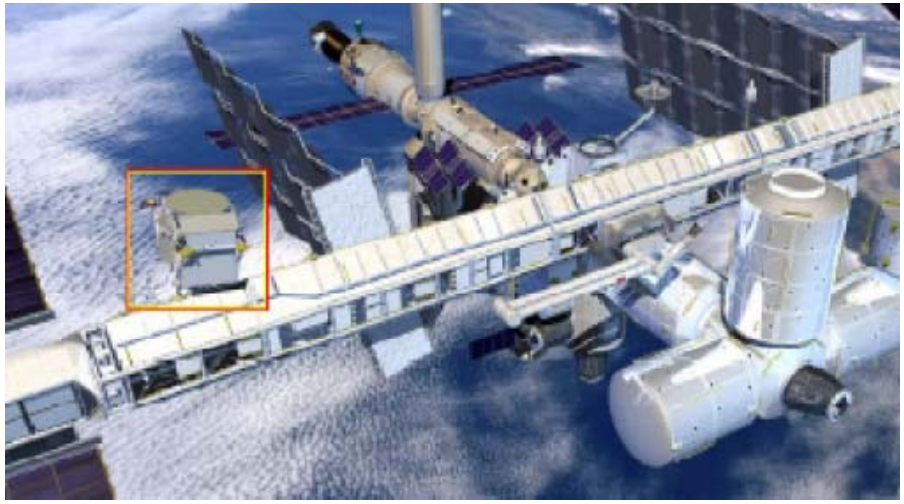


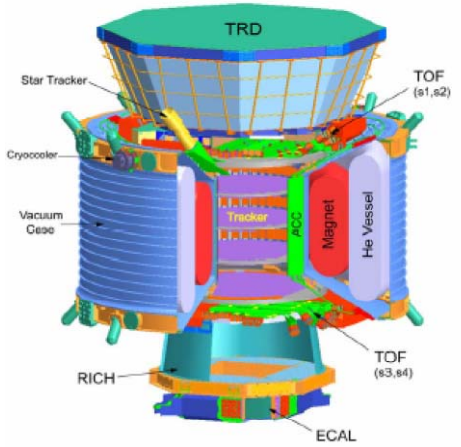


Open questions:

- **Details on production, acceleration and propagation of cosmic rays**
- **Details of solar modulation**
- **Antimatter in cosmic rays**
- **Dark matter signals**

AMS-02: Alpha Magnetic Spectrometer





AMS on ISS for 3 years

- An experiment to search in space for dark matter, missing matter and antimatter on the international space station.

- High precision direct measurement of CR composition and spectrum.

- **Hadronic cosmic rays:**
  - **Secondary/primary ratios (propagation models)**
  - **Confinement times (galactic halo)**
  - **Solar cycle effects**
- **Antimatter (direct detection of anti-nuclei)**
- **Dark matter signals (antiprotons, electrons/positrons)**

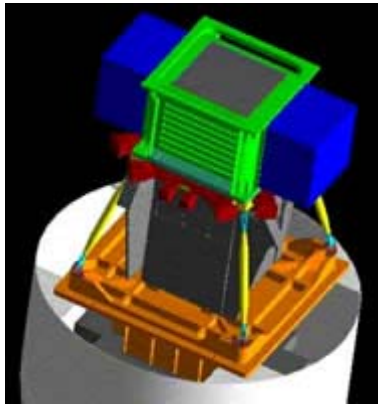
AMS-02 – Status and plans 2008-2018:

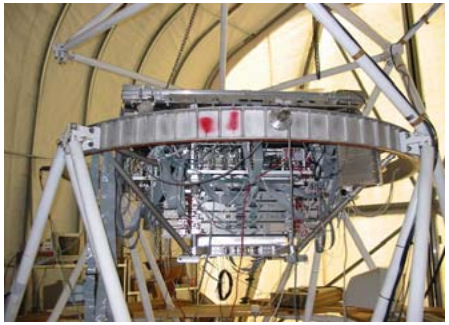
- **Status**
  - Final constructed – launch with space shuttle not yet approved
- **Timetable:**
  - Commissioning 2008 Operation 2009-2015
- **Collaboration:**
  - Exists 600 scientists ~70% EU ~60% ASPERA
  - 9 European countries: CH,DE,ES,FI,FR,IT,NL,P,RO
- **Resources:**
  - 20.000 k€ 600 FTE 70% Europe 30% Others
  - Commissioning and launch by space agencies
  - Operation costs ~800 k€ per year ← ASPERA
- **ASPERA:**
  - 8.500 k€ 335 FTE per year (2010-18): 800 k€
    per year (2010-18): 35 FTE
- **Compiled by**
  - Roberto Battiston r.battiston@tiscali.it

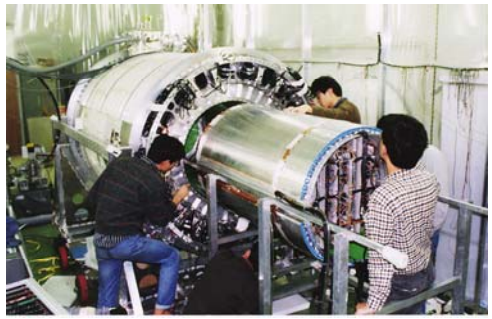
Direct measurements in the GeV-TeV range:

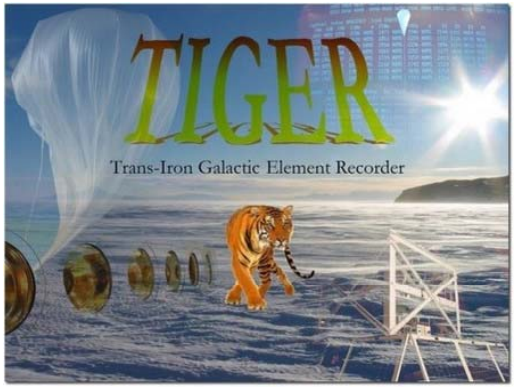
Further experiments
(non ASPERA or too small) :

- **PAMELA**
  - Antiprotons, Protons, Electrons, Positrons 0,25 - 100 GeV
- **CREAM**
  - 10^{12} to > 5 x 10^{14} eV cosmic rays
- **BESS**
  - Antiprotons and Antihelium 0,25 - 100 GeV
- **ATIC**
  - Proton- and Heliumspectra 10 - 10000 GeV
- **TRACER**
  - spectra 8 < Z < 26 <10 TeV/n
- **TIGER**
  - spectra 30 < Z < 40 >0,5 GeV/n
- …

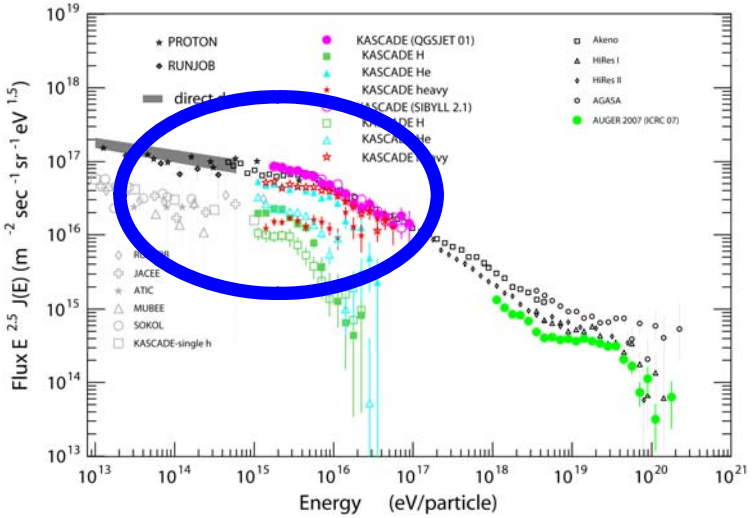








Reaching the Knee:

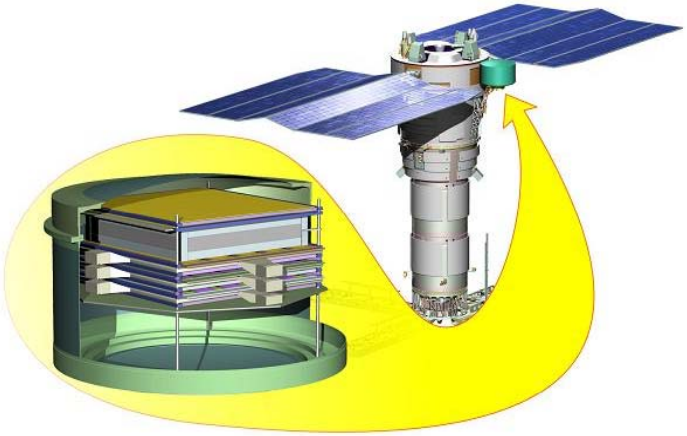


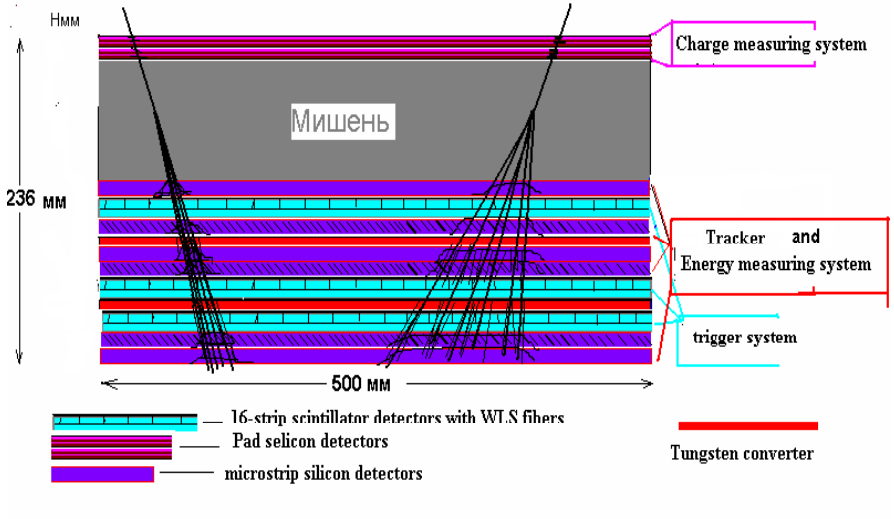
2007:
Origin of the knee still unknown!

Tasks, experimentally to be solved:

- **differences in slopes of different nuclear components (below the knee);**
- **CR anisotropy in time and space (propagation in Galaxy, nearby source?);**
- **electrons and gammas;**
- **isotopes after iron;**
- **Knee position(s);**
- **composition at the knee;**
- **anisotropy around the knee;**
- **structure of spectrum (below, around, and above the knee);**
- **overlap direct with air-shower measurements (hadronic interaction models);**

NUCLEON

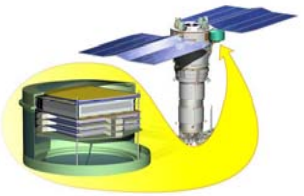




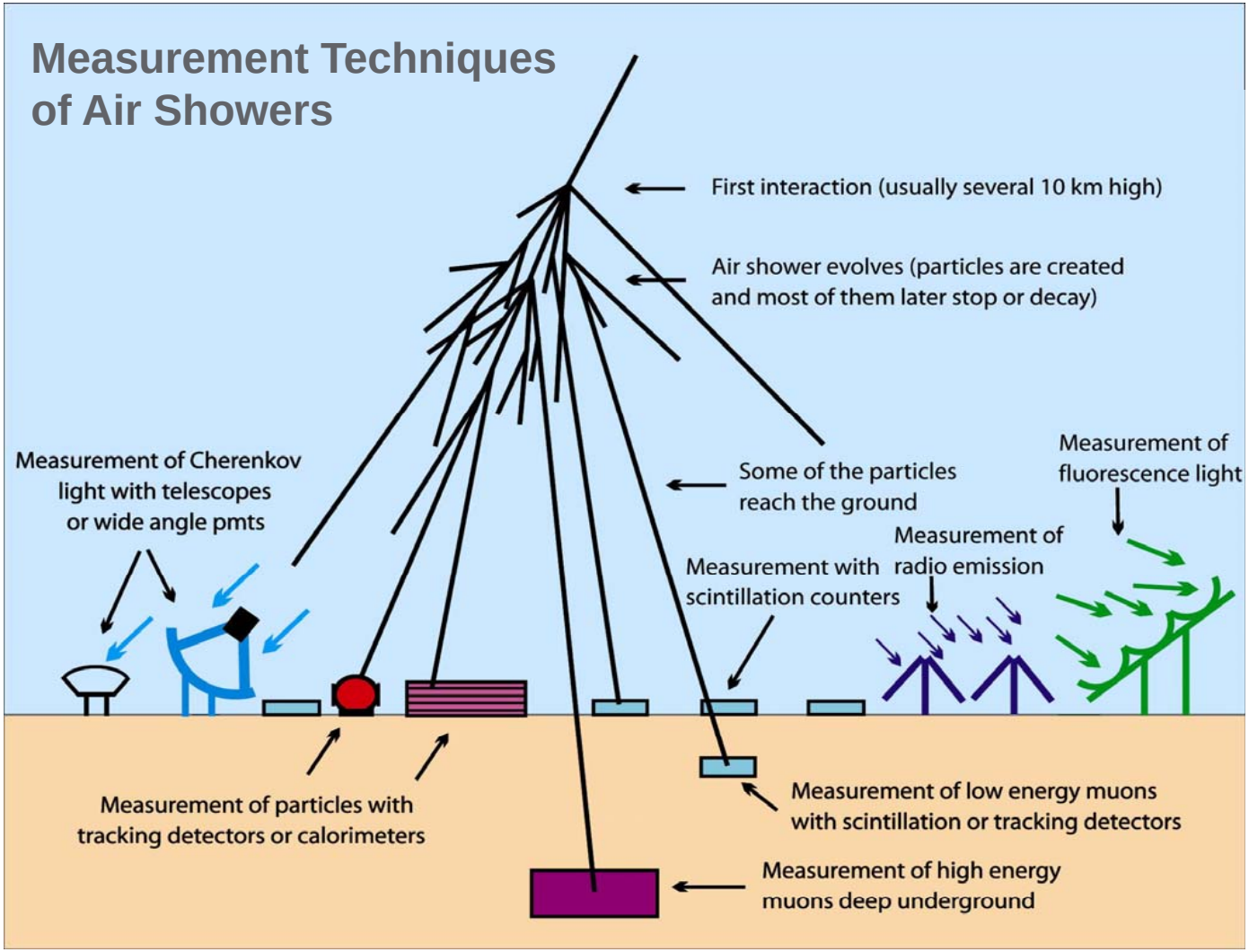
- Satellite experiment (included in Russian Space Program 2005-2010)
- Measurements of charged particles of 10^{12}-10^{16} eV to clarify:
  - the Cosmic Rays origin
    - differences in slopes of different nuclear components (changing a type of sources in this energy region?)
  - propagation of CR in Galaxy
    - secondary to primary ratio (diffusion coefficient?)
  - CR anisotropy (nearby source ?)

NUCLEON – Status and plans 2008-2018:

- **Status**
  - prototype flight approved -- R&D phase B (L-NUCLEON) design study
- **Timetable:**
  - R&D 2008-10 — Construction 2011-14
  - Commissioning 2014-15 — Operation 2015-16
  - Conceptional Design Study 2008/09 — Technical DS 2008-2015
  - Decision for Construction 2011 — Launch 2015?
- **Collaboration:**
  - Exists: 40 scientists ~100% EU ~40% ASPERA
  - 2 European countries: Italy + Russia
- **Resources:**
  - 40.150 k€ 600FTE 40% Europe 60% Others
  - + 30.000 k€ for launching (Russia)
- **ASPERA:**
  - 3.212 k€ 151 FTE construction (2011-15) 3.000 k€
    per year (2009-18): ~15 FTE
- **Compiled by** Andrea Vacchi vacchi@ts.infn.it



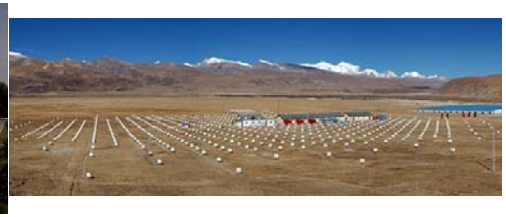
Indirect measurements:

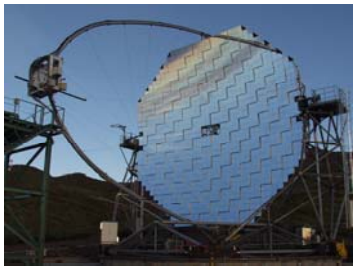


Around the knee:

Present experiments (non ASPERA or too small or no further investments or main topic not cosmic rays):

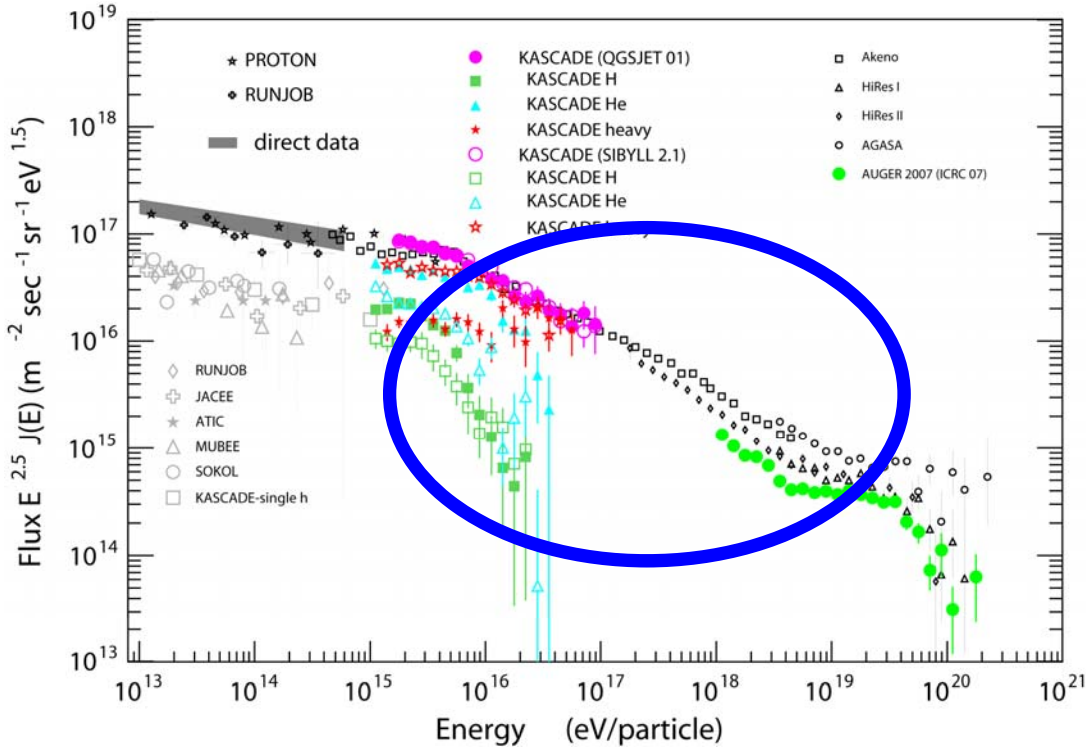
- EMMA
  - construction phase
- KASCADE
  - data analysis
- GRAPES
  - Indian/Japanese project (knee)
- TUNKA
  - Cherenkov-array, data analysis
- TIBET AS-γ / ARGO-YBJ
  - 4300m asl, CR + gammas ~100GeV
- MILAGRO➔HAWC
  - Water Cherenkov pool, Gammas (TeV)
- HESS / MAGIC / CTA
  - Cherenkov telescopes
- …


•No dedicated air-shower experiment planed for the overlap region of direct and air shower measurements (high-altitude KASCADE-like detector)

Between Second Knee and Ankle:



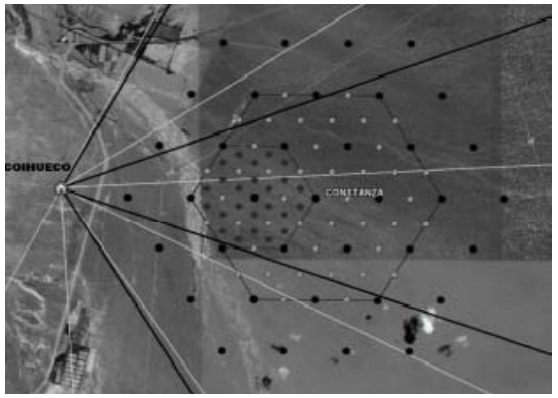
2007:
Least explored energy range !

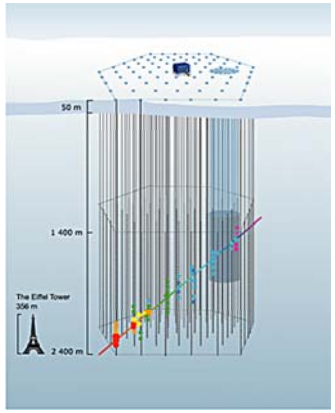
- **The iron knee?**
- **Transition to extragalactic CR?**
- **Composition**
- **Anisotropies, Point Sources?**

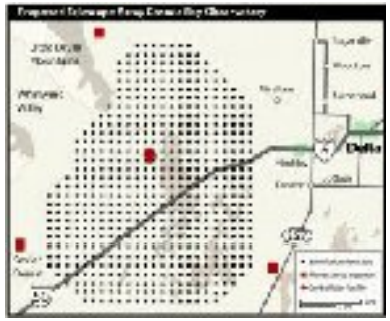
Between Second Knee and Ankle:

Experiments (non ASPERA or in other working groups or different main task of the project):

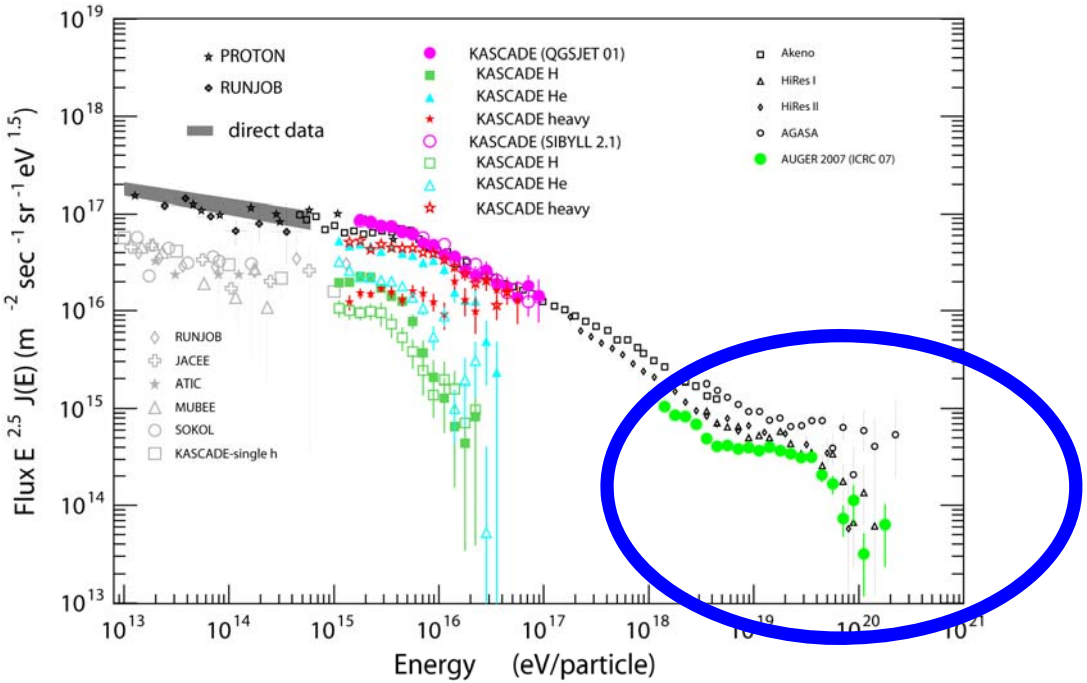
- **KASCADE-Grande**
  - **10^{16}-10^{18}eV (finish in 2009)**
- **AUGER South Enhancements**
  - **HEAT, AMIGA**
- **ICETOP / ICECUBE**
  - **See neutrino wg**
- **TALE (Telescope Array Low Energy Extension)**
  - **American-Japanese proposal**
- **LOFAR**
  - **Radio astronomy (see later)**
- **…**







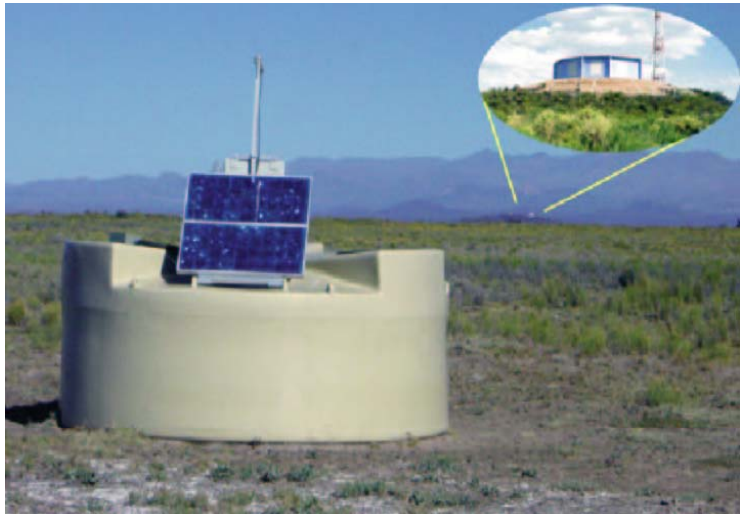
Ankle and GZK range:

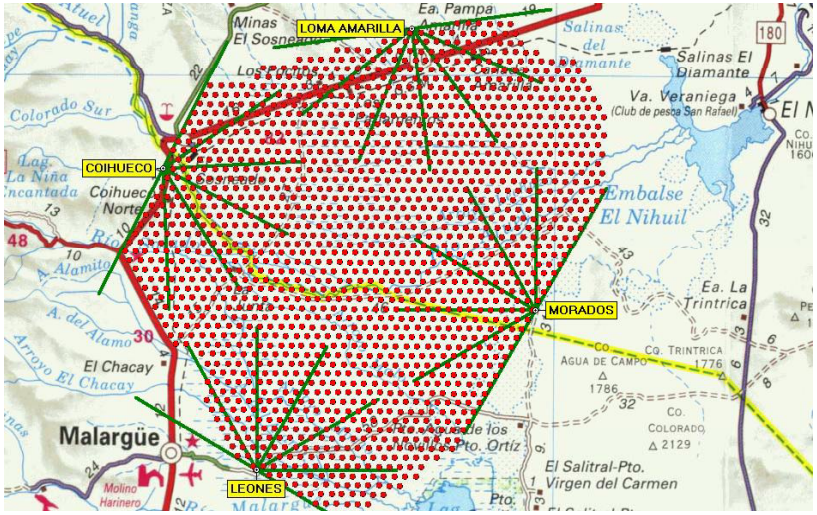


2007:
There is break in the spectrum !
(GZK cutoff?)

- **How can cosmic accelerators boost particles to these energies?**
- **What is the maximum energy achievable?**
- **What is the nature of the particles?**
- **How do they propagate through the Universe?**
- **What is the view of the sky at extreme energies?**
- **New techniques for shower detection?**

Pierre Auger Observatory - South



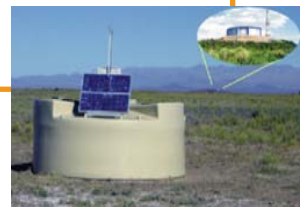


Giant air shower array in the Argentinean Pampas!

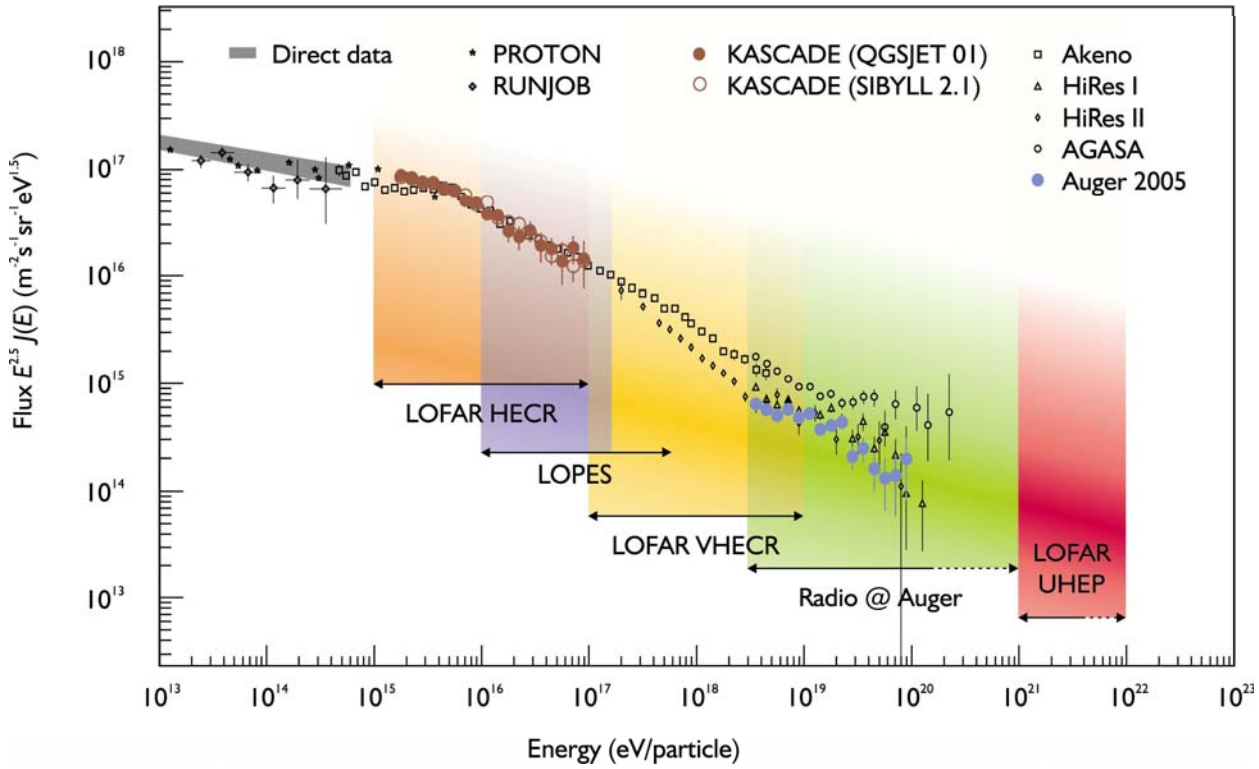
- **Where does the spectrum end ?**
  - **Is there a GZK cutoff ?**
- **Primary nature (composition) ?**
  - **Nuclei ? Protons ? Gamma rays ? Neutrinos ? Or……?**
- **What is the source of UHECR ?**
  - **Bottom-Up or Top-Down scenario ?**
- **Arrival direction distribution**
  - **Search for departure from isotropy – point sources**

Pierre Auger Observatory – South -- Status and plans 2008-2018:

- **Status**
  - Operational - commissioning phase of enhancements
- **Timetable:**
  - Construction (+enhancements) until 2010 Operation 2018+
- **Collaboration:**
  - Exists 400 scientists ~50% EU ~45% ASPERA
  - 10 European countries: CZ,DE,ES,FR,IT, NL,PL,PT,SI,UK
- **Resources:**
  - 30.000 k€ 0 add. FTE 50% Europe 50% Others
  - Operation costs ~1.600 k€/year
- **ASPERA:**
  - 15.000 k€ existing FTE only enhancements (2008-10): 2.000 k€/year (2008-18): 800 k€/year operation costs
- **Compiled by** Johannes Knapp j.knapp@leeds.ac.uk



Radio Detection of Cosmic Rays:



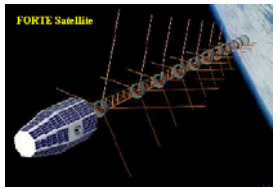
2005-2007:
Proof-of-principle of the technique!

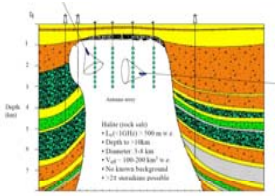
•Promising technique for high-energy cosmic rays and neutrinos !!

Radio Detection of Cosmic Rays:

Present activities:

- **Pierre Auger Observatory**
  - Radio test/engineering array (South)
  - Based on LOPES / CODALEMA
- **LOFAR**
  - Cosmic ray key science program
  - Based on LOPES
- **NuMoon / LOFAR / SKA**
  - ν und CR detection by moon observations
- **ICECUBE / ICETOP**
  - radio in ice
  - radio on ice
- **SALSA**
  - radio in salt (ν detection)
- **JEM-/SUPER-EUSO**
  - thoughts on radio from space
- **ANITA**
  - radio in ice from balloons (ν)
- **....**





- **radio R&D embedded in large projects ← ASPERA !!**
- **(also acoustic detection)**

LOFAR

Large radio telescope (10 – 240 MHz) 100s of antennas at an area of > 100 000 km²

Key science programs:

- **Cosmology:** epoch of re-ionization
- **All-Sky Surveys:** star forming galaxies, AGN, clusters, etc.
- **Transient detection:** everything that bursts and varies
- **Solar physics:** solar radio bursts
- **Astroparticle Physics:** direct detection of cosmic rays
  cosmic rays & neutrinos impacting the moon

LOFAR – Status and plans 2008-2018:

- **Status**
  - Approved (astronomy community)
  - Commissioning (first core station in operation)
- **Timetable:**
  - R&D until 2010 Construction until 2011
  - Commissioning and operation until 2018+
- **Collaboration:**
  - Exists / expand ~50 scientists ~100% EU ~100% ASPERA
- **Resources:**
  - 104.000 k€ ← ASTRONOMY 77 FTE (CR),100% Europe, 0% Others
  - Ca. 1.000 k€ for CR program ← ASPERA
- **ASPERA:**
  - 1.000 k€ 77 FTE for CR key science program
    ~70k€/year 2011-2018 operation
    ~150k€/year 2008-10 construction
- **Compiled by** Olaf Scholten scholten@kvi.nl

SKA – Square Kilometer Array

TIMELINE

Concept

1994
International Working Group

1995
Start of Prototyping

2000
Signing of first Memorandum of Agreement

2005
Signing of extended Memorundum of Agreement

2006
Site Ranking Decision

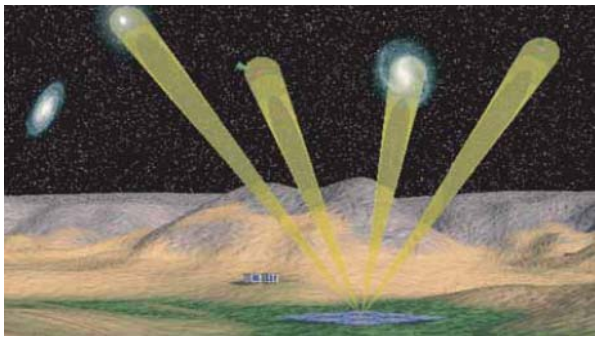
2009
Final Technology Decision

2010
Construction of pathfinder on site

2013
Early Science

2014
Construction of full array

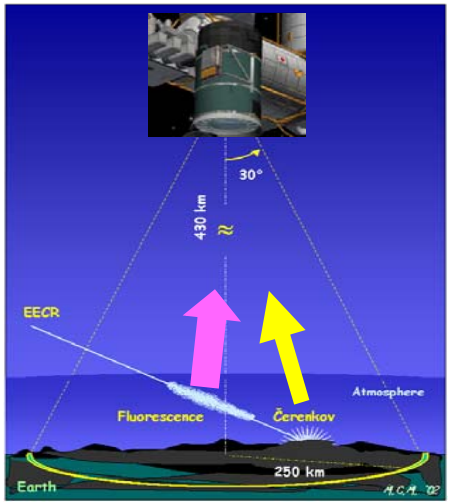
2020
Full SKA operational!

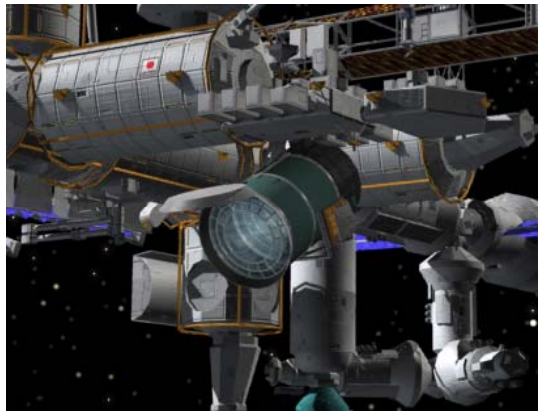


- **Square Kilometer Array (SKA) = Follow-up of LOFAR**
- **to be built between 2014 and 2020 at the Southern hemisphere (South-Africa or Australia)**
- **included in the ESFRI list**
- **Cosmic rays (Moon observations) as science program**

- **LOFAR and SKA will give important information to theoretical modelling of magnetic field distributions!!**

JEM-EUSO





An ISS based air-fluorescence experiment aiming for extreme energy astronomy by particle channel.

- **Cosmic ray measurements for energies > $1 \cdot 10^{19}$eV**
- **Detection of compact sources of UHECRs**
- **Detection of extreme energy neutrinos**
- **Exploration of fundamental physics questions like neutrino cross sections, etc.**
- **Global observations of night-glows, plasma discharges and lightings**

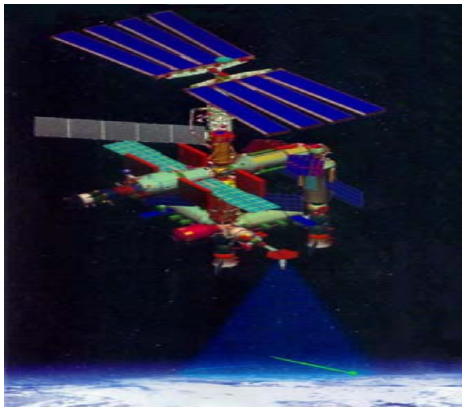
JEM-EUSO – Status and plans 2008-2018:

- **Status**
  - approved phase A+B 2007-2009 in Japan -- decision of construction in 2009!
  - launch possible (30%) 2013
- **Timetable:**
  - CDR 2008 TDR 2009 R&D 2008-09
  - Construction 2010-12 Commissioning 2013 Operation 2013-17
- **Collaboration:**
  - Exists 139 scientists ~35% EU ~35% ASPERA
- **Resources:**
  - 90.000 k€ - 26.000 k€ Europe - add.150 FTE 33% Europe - 66% Others
  - Operation costs ~1.000 k€/year ← 10% ASPERA
- **ASPERA:**
  - 2.600 k€ 50 FTE (operation only) -- per year:
    50k€/08-09 R&D 600k€/10-12 construction 100k€/13-17 operation
- **Compiled by**
  Andrea Santangelo andrea.santangelo@uni-tuebingen.de

Ankle and GZK range:

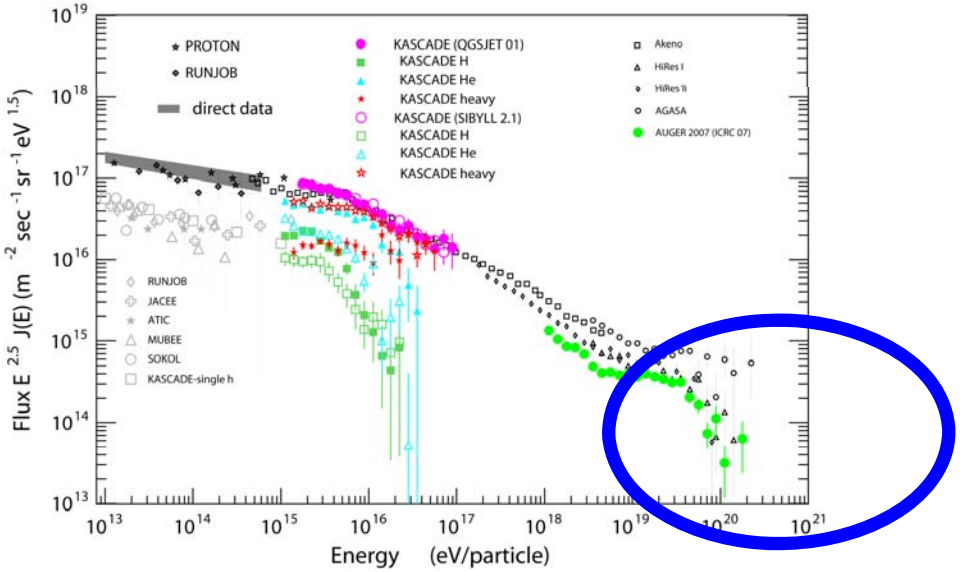
Further experiments (non ASPERA) :

- **TUS-KLYPVE**
  - Russian fluorescence experiment at ISS or as free flyer
- **Telescope Array TA**
  - American-Japanese hybrid experiment
- **LORD**
  - Lunar orbiter radio detector (Russia, Sweden)
- **…?**



All these experiments are also looking for high-energy cosmic neutrinos!!

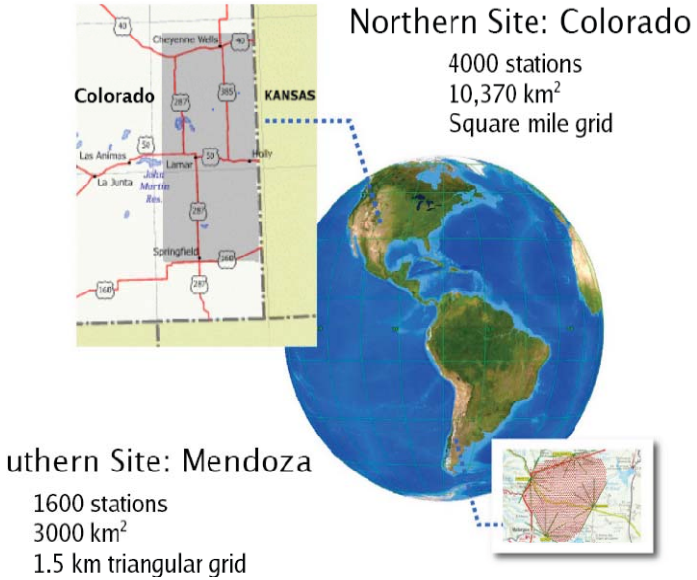
Beyond GZK: Particle Astronomy

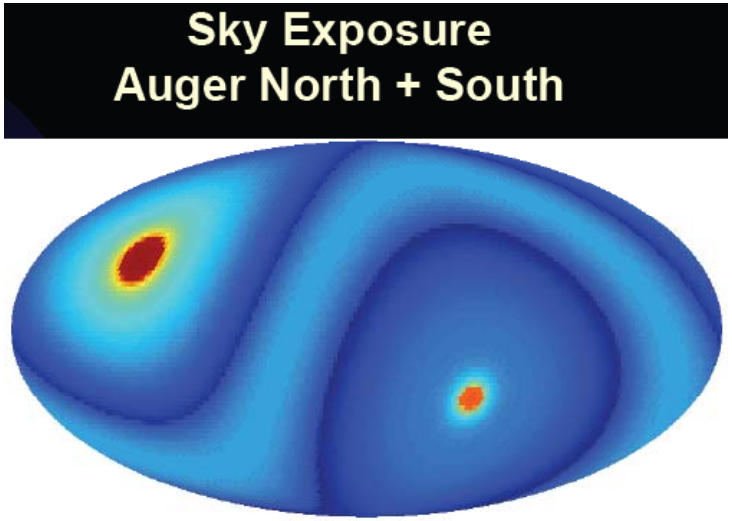


Task next decade:
Towards
Particle Astronomy !!

- **Window of Opportunity: 10^{19} - 10^{21} eV**
- **Maximize Statistics in this energy range**
- **Identify Sources**
- **Towards Source Spectra**
- **Multi-Messenger Source Observations**
- **Photon Observations**
- **High Energy Neutrino Detection via air-showers**

Pierre Auger Observatory – North





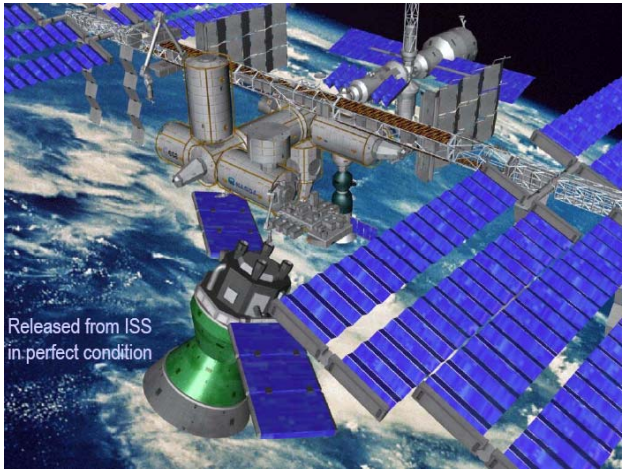
Giant air shower arrays in Southern and Northern Hemisphere for Full Sky Coverage

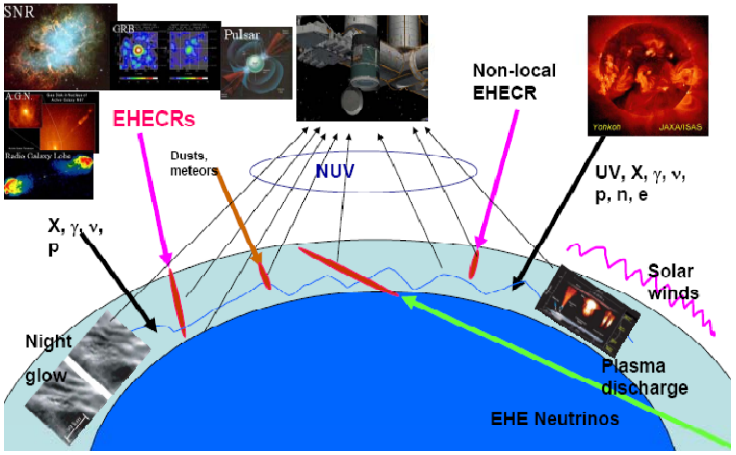
- **Sources in the sky ?**
  - **Near sources: source spectra - Far sources: spectral cutoff**
- **Primary nature (composition) ?**
  - **Nuclei ? Protons ? Gamma rays ? Neutrinos ? Or……?**
- **Source spectra ?**
- **Multimessenger astronomy**

Pierre Auger Observatory – North -- Status and plans 2008-2018:

- **Status**
  - conceptual – R&D
- **Timetable:**
  - R&D 2008-10 Construction 2009-13 Operation 2011-2018+
- **Collaboration:**
  - exists (Auger south + more?) 400+ scientists ~50% EU ~45% ASPERA
- **Resources:**
  - 70.000 k€ 1400 FTE ~50% Europe ~50% Others
  - Construction costs ~80.000 k€ ~50% Europe
- **ASPERA:**
  - 45.700 k€ 655 FTE:
    peak 2010-13: 10.000 k€/year + ~60 FTE/year
- **Compiled by** Johannes Knapp j.knapp@leeds.ac.uk

SUPER-EUSO

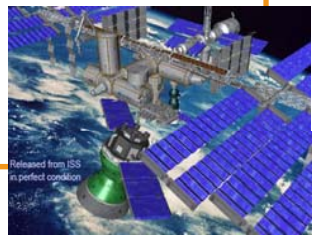




- conception and design of a space-based experiment for observation of UHE cosmic particles from space (in the post Pierre Auger Observatory era)
- Studies within the ESA Cosmic Vision (2015-2025) program
  - Cosmic ray measurements for energies > 10^{20} – 10^{22} eV
  - Where does the spectrum end ?
    - Is there a GZK cutoff ? Are the sources local (<100 Mpc) ?
  - Primary nature (composition) ?
    - Nuclei ? Protons ? Gamma rays ? Neutrinos ? Or……?
  - Global sky observations
    - night-glows, plasma discharges and lightings

SUPER-EUSO – Status and plans 2008-2018:

- **Status**
  - Conceptual, technology is in R&D - proposal for ESA cosmic vision
- **Timetable:**
  - CDR 2008-09 TDR 2010-11 TUS and JEM_EUSO as “pathfinder”
  - Critical Reviews and Decision for construction 2012-?
  - R&D 2008-11 - Construction 2012-15 - Commissioning 2015-18 launch >2018
- **Collaboration:**
  - just formed ~130 scientists 80% Eu 75%ASPERA
- **Resources:**
  - 155.000 k€ -- 93.000 k€ Europe 335 FTE – 200 FTE Europe
  - 60% Europe 40% Others
  - ASPERA 20% of Invests 25% of FTE
- **ASPERA:**
  - 18.600 k€ 50 FTE
    peak 2013-16: ~4.000 k€ / 8 FTE per year
- **Compiled by** Alessandro Petrolini Alessandro.Petrolini@ge.infn.it



Conclusions

Plans for next decade (2008-2018):
(Recommendations from Roadmap Phase 1):

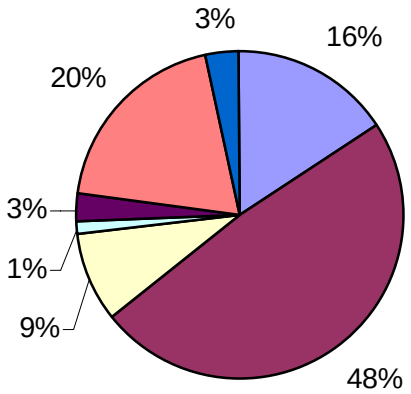
- **Present efforts (focused in Auger South with 50% European contribution)**
  - ➔ **pursued with vigour**
- **Establish scientific case and make significant contribution to Auger North**
  - ➔ **Towards particle astronomy**
- **Support of R&D of new detection techniques**
- **Inclusion of high-energy cosmic rays in the ESA Cosmic Vision 2015-2025**
- **Close cooperation with accelerator physics (LHC)**
  - ➔ **hadronic interaction models**
- **Bridge gap of direct to shower measurements**

Summary: total costs

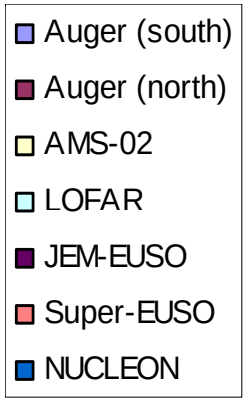
Experiment	k€	FTE (additional 2008-18)
main source		milestones
•Auger (south):	30.000	-
Astrop.Phys.		operation 2018++; construction<2011
•Auger (north):	91.400	1400
Astrop.Phys.		R&D<2012; construction<2015; operation 2018++
•JEM-EUSO:	90.000	150
space agencies		2009 A+B report JAXA, launch 2013
•SUPER-EUSO:	155.000	335
space agencies		R&D<2012, constr.<2016 commis.<2019
•LOFAR:	104.000	77(only CR)
astronomy		R&D+construction CR-KSP <2012 (1M€)
•NUCLEON:	40.150	600
space agencies		operation >2014 construction<2011
•AMS-02:	20.000	600
space agencies		operation >2008 end 2015

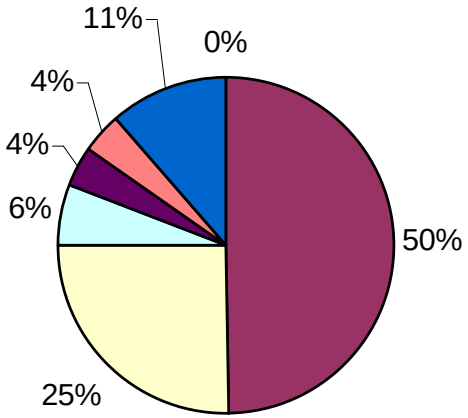
Summary: ASPERA sum 2008-2018

Experiment	k€	FTE (additional 2008-2018)	main funding source
•Auger (south):	15.000	-	astrop. physics
•Auger (north):	45.700	655	astrop. physics
•AMS-02:	8.500	335	space agencies
•JEM-EUSO:	2.600	50	space agencies
•SUPER-EUSO:	18.600	50	space agencies
•LOFAR(CR):	1.000	77	astronomy
•NUCLEON:	3.212	151	space agencies



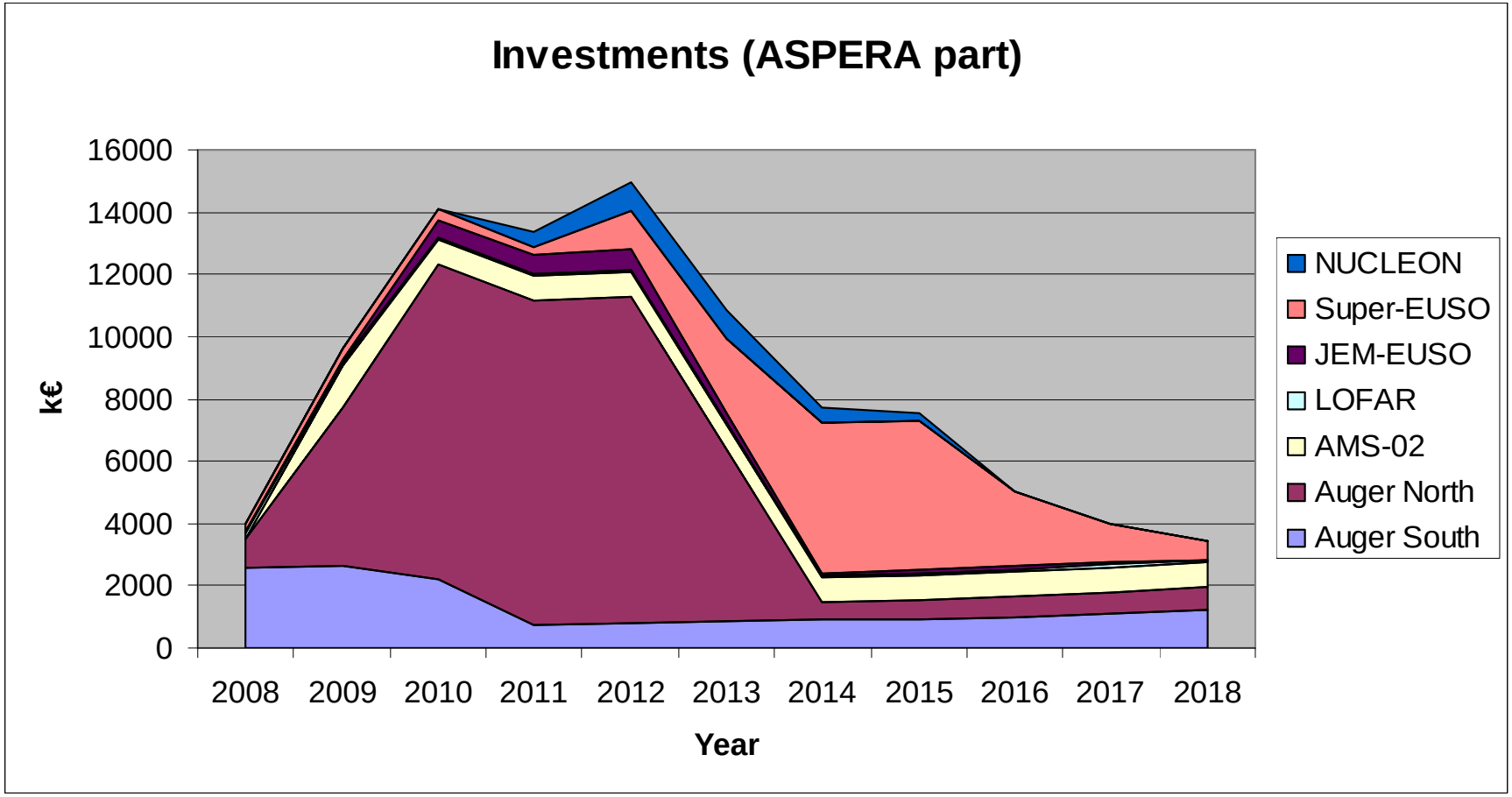
Investments k€



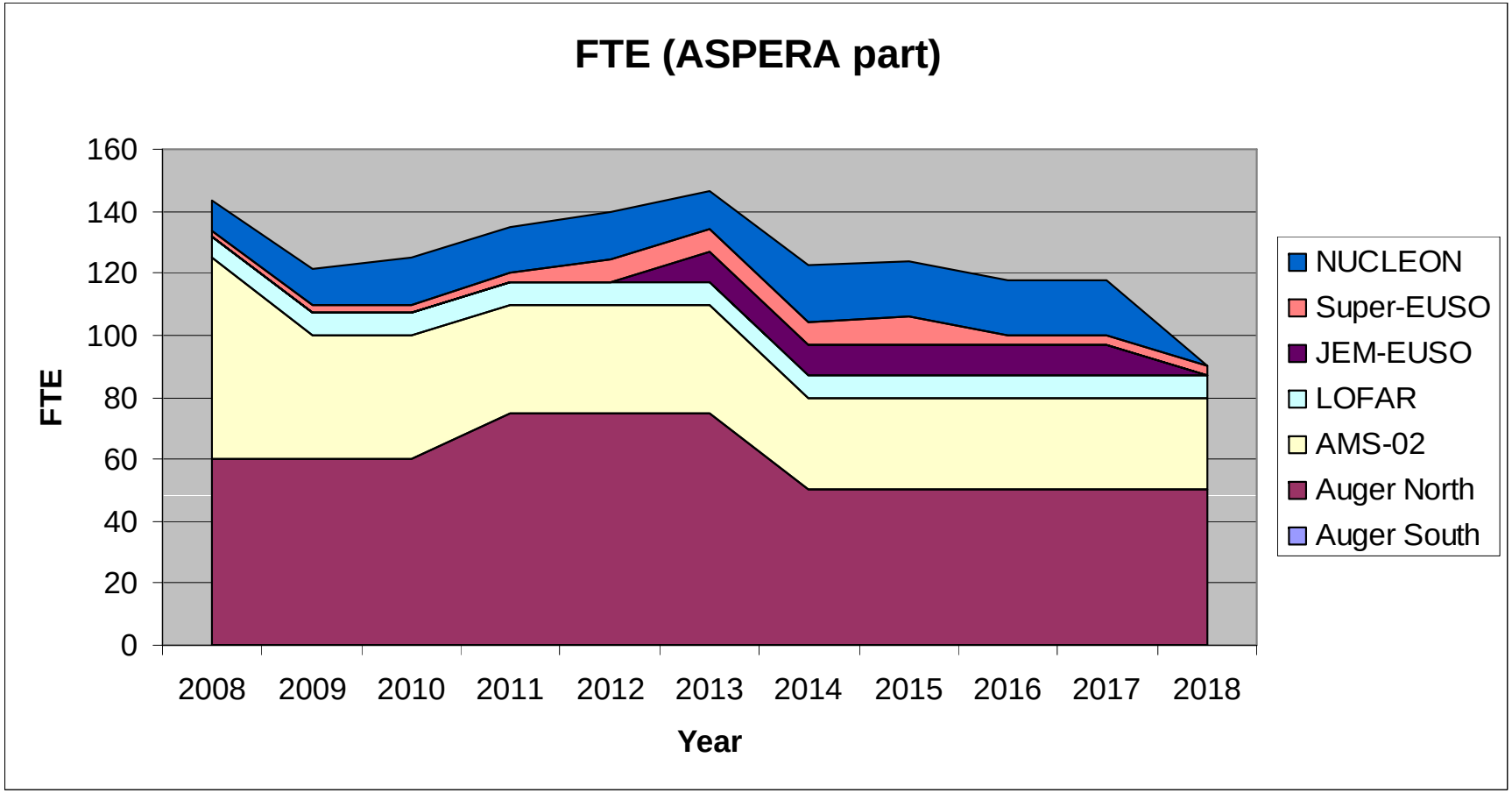


FTE

Summary: ASPERA investments time profile:



Summary: ASPERA FTE time profile:



Conclusions

Scope for next decade (2008-2018):

- **Significant recent experimental progress needs follow up with further detailed investigations and theoretical activities**
- **New generation of experiments is on the way**
- **most important (largest investments) concerns the investigation of the highest energy particles**

➔Towards particle astronomy

- **first with Auger (south and north)…**
  ….and then with a next generation of space based devices

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