Experimental Summary and Future Prospects

M.Fukushima, ICRR, Univ. of Tokyo

UHECR2012 symposium
Feb.16th 2012 at CERN

UHECR 2012 LOC : M. Bertaina, J. Blümer, R. Engel, K.-H. Kampert,
A. Letessier-Selvon, F. Najeh, B. Pattison, J. Rautenberg, I. Tkachev

We appreciate hard works of Prof. Karl-Heinz Kampert and LOC members to bring us together at CERN and talk about past, present and Future of UHECR research. It was not an easy task.

Scope of the Workshop

Spectrum & its structure

- Discuss the highlights and challenges of UHECR observations.

Composition (p/Fe), N/S asymmetry,
accuracy & statistics , Isotropy

- Prepare for a next-generation ground based giant detector.

Whether can we afford one?
Purpose, Design and who bears?

- Evaluate the complementarity of ground and space based observations.

Working in line with TUS & JEM/EUSO.

- Identify technological challenges and related R&D works.

How we proceed?

UHECR 2012

Meeting at CERN: an ingenious idea.

international collaboration for
peace, unity and democracy

Working group (wg) : very successful

by young scientists facing common problems.
open discussions.

Energy Spectrum Working Group

WG members

Auger: B.R. Dawson, I.C. Mariş, M. Roth, F. Salamida,
Yakutsk: M. Pravdin, A. Sabourov
HiRes/TA: T. AbuZayyad, D. Ikeda, D. Ivanov, Y. Tsunesada

O. Deligny, A. Ivanov, J. de Mello Neto, H. Sagawa, P. Sommers, L. Timofeev, **P. Tinyakov,** I. Tkachev

J. Allen, A. Castellina, R. Engel, K. Itakura, K. Kasahara, S. Knurenko, S. Ostapchenko, T. Pierog, A. Sabourov, T. Sako, B. Stokes, R. Ulrich

HiRes/TA: Elliott Barcikowski, John W. Belz, Yuichiro Tameda, Yoshiki Tsunesada

Yakutsk: Stanislav Knurenko, Yuri Egorov

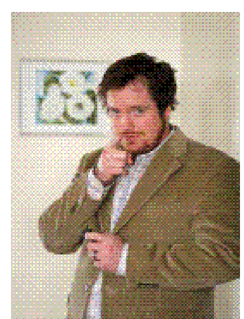
Auger: Michael Unger, Vitor de Souza, Jose Bellido

PIERRE AUGER OBSERVATORY

Jaime Alvarez-Muniz
Santiago de Comp., Spain
Auger, neutrino

Grigory I. Rubtsov
Moscow, Russia
TA (Yakutsk), photon/neutrino

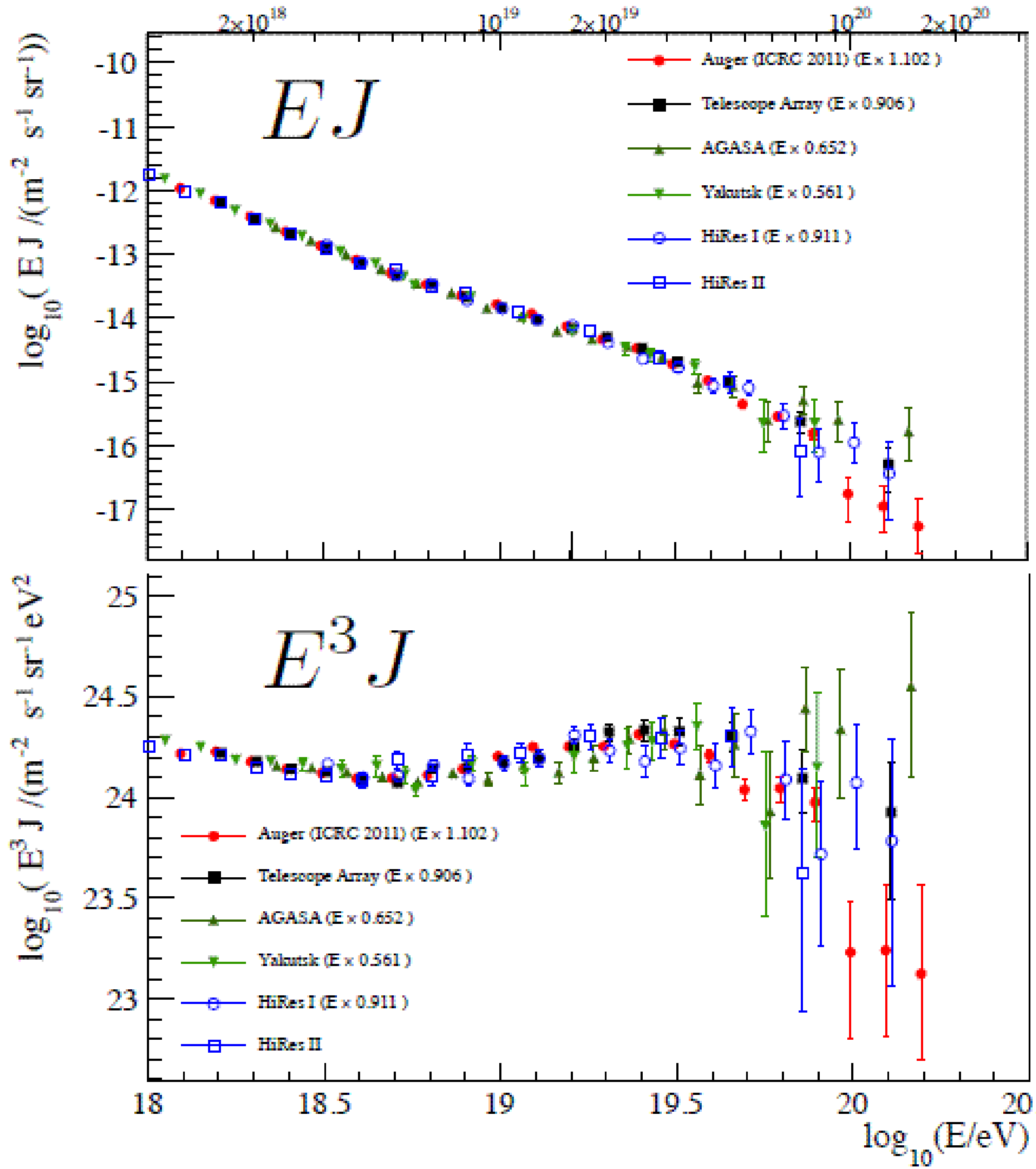
Markus Risse
Siegen, Germany
Auger, photon



Benjamin T. Stokes
Salt Lake City, USA
TA, neutrino/photon

Energy Spectra
(after the scaling)

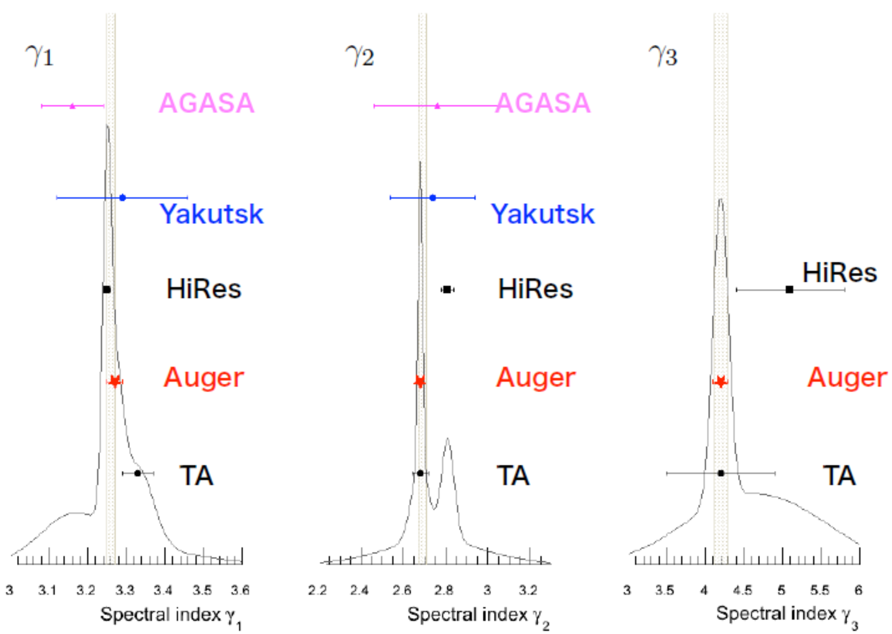
- We can find scaling factors to match the spectra: shape are similar (below log*E*=19.5)
- Auger/HiRes/TA are in agreement well within the systematic uncertainties



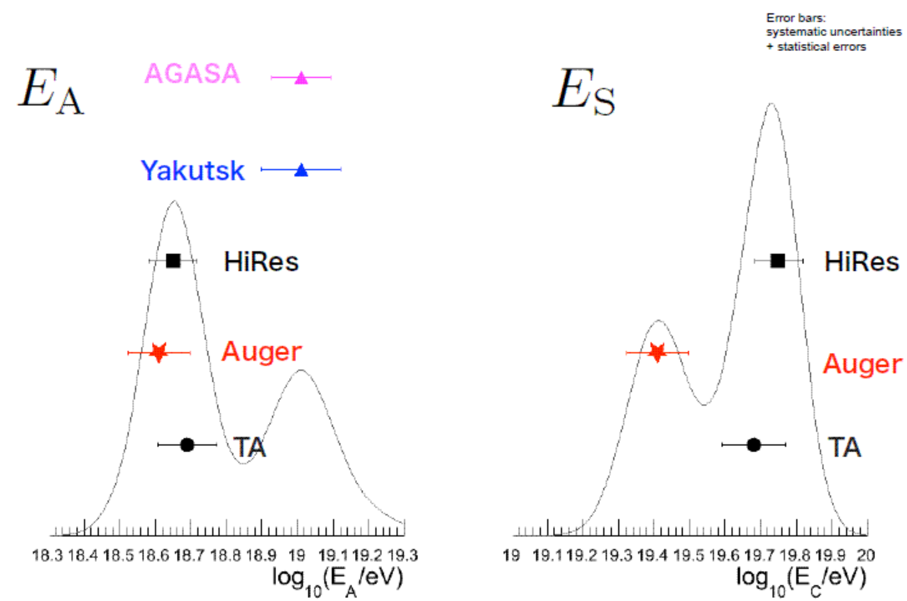
Energy Rescaling Factor

	Auger	TA	HiRes	AGASA	Yakutsk
$\log_{10}\alpha$ Relative to (Auger+TA)/2	-0.042 (0.003)	+0.042 (0.003)	+0.041 (0.005)	+0.19 ( )	+0.26 (0.004)

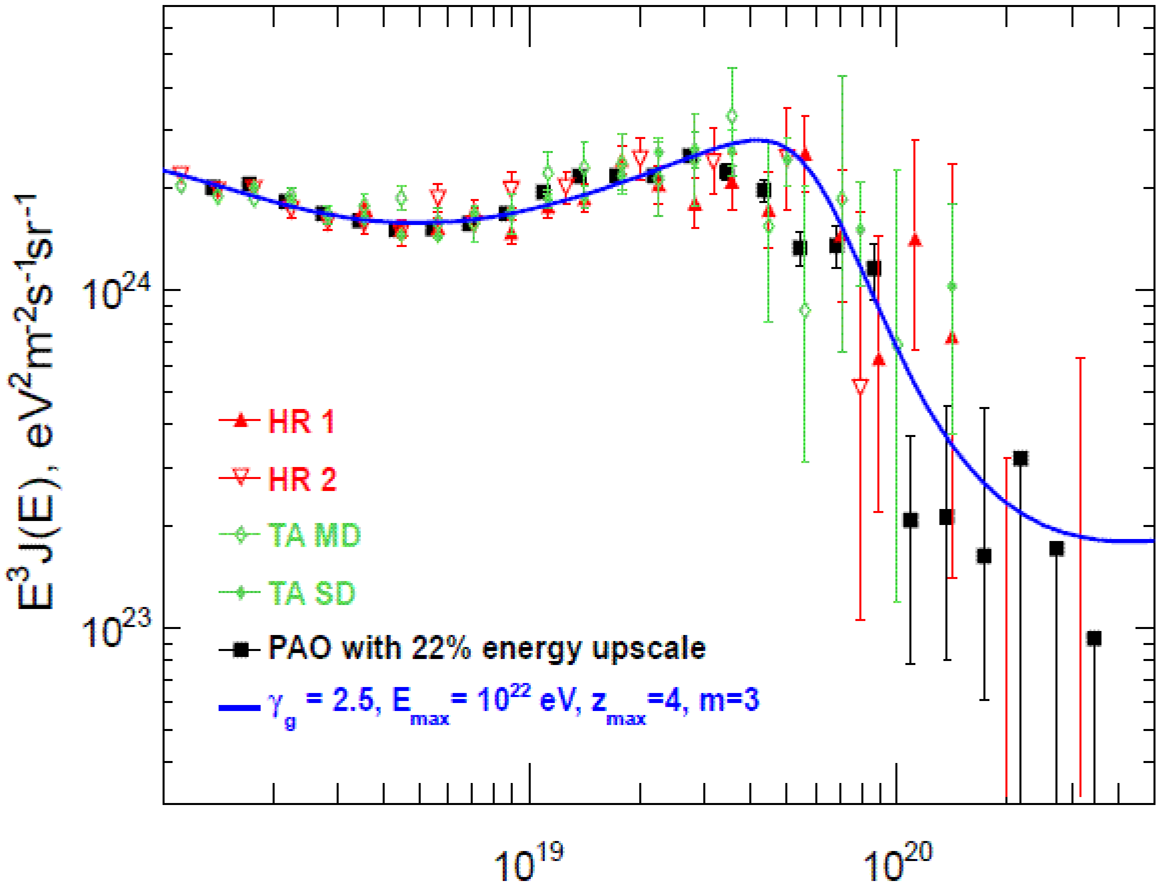
Comparison of the parameters: $E^{-\gamma}$



Ankle/Steepening Positions



GZK? and Models



- **Dip model** (transition at the second knee $E_{\rm tr} \sim (5-7) \times 10^{17}$ eV).
- **Ankle models** (transition at ankle $E_{\rm tr} \sim (0.3-1.0) \times 10^{19}$ eV).
- **Mixed composition models** (arbitrary transition).
- **Models based on Auger mass composition.**

Energy Spectrum

1. Cutoff and dip established.
2. Energy scale error ~20%.
3. Power law fits agree among exp..
4. Spectral shapes seem differ above $10^{19.5}$ eV

- Auger is based on muon (water tank)
- HiRes, TA and Yaktsuk are based on e/γ (Air Fluor., plastic scint.)
- CIC, MC zenith att. By MC, calorimetry

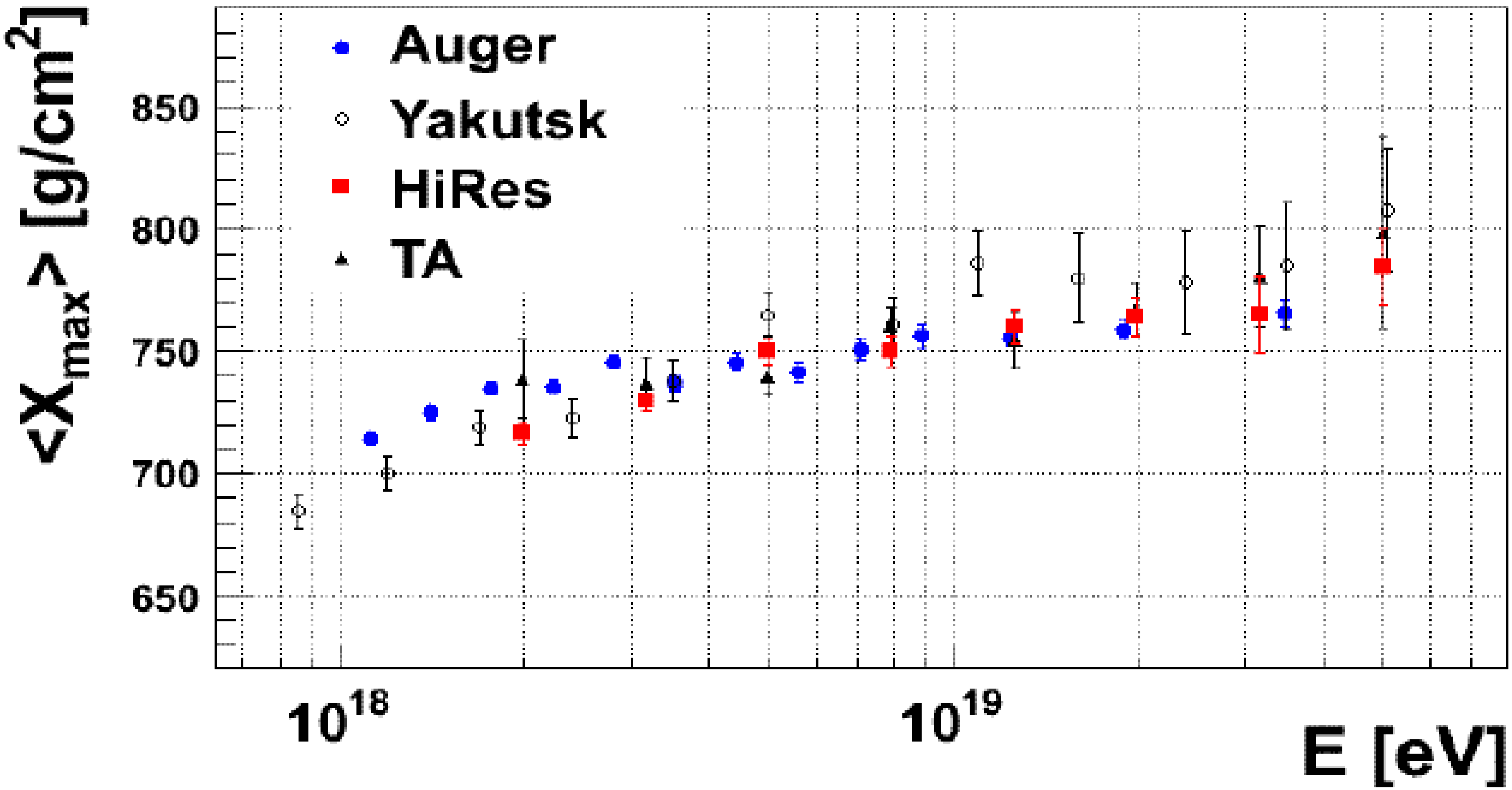
Possible Scenarios

1. Extra-galactic proton with CMB interaction.
2. Fe with EBL interaction.
3. Acceleration limit for heavy nuclei.
4. North-South asymmetry.
5. etc.

Underlying physics not identified.

Composition (p/Fe) is the key issue.

<Xmax> measurements above 10^{18} eV



due to differences in the analyses the above <Xmax> values can not be directly compared

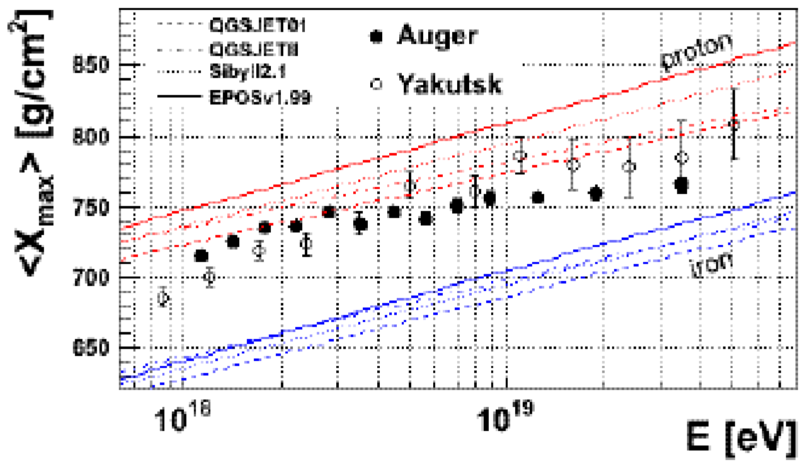
2

Are we really in-consistent? P.Privitera

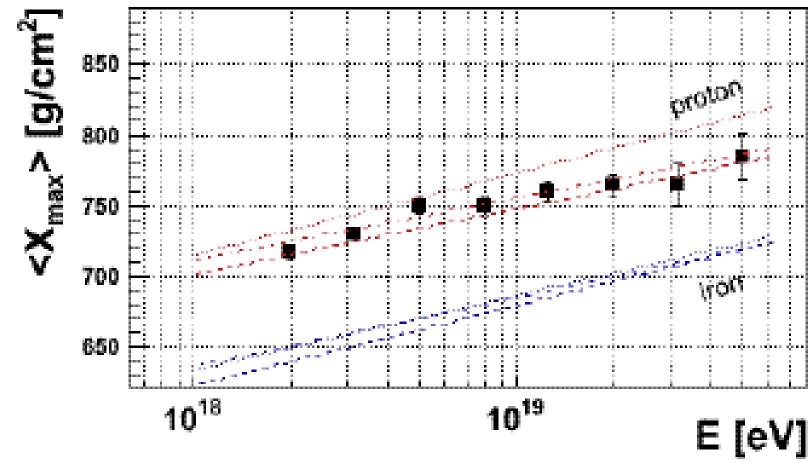
Any physics/reason behind this agreement? P.Sokolsky(?)

Composition

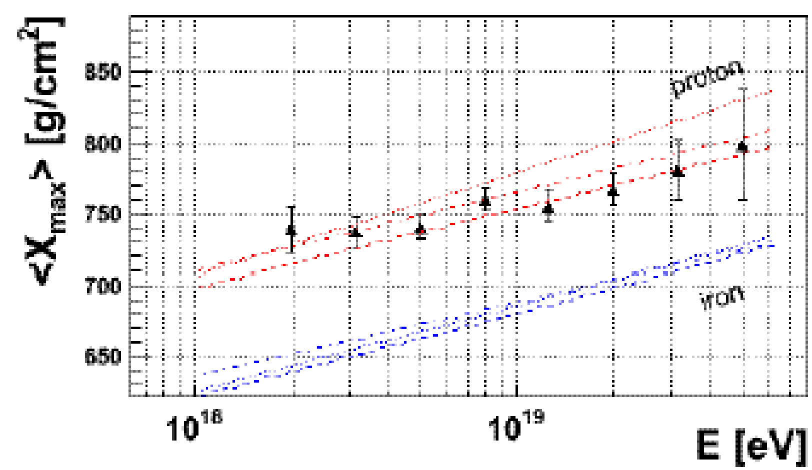
Comparing the observed <Xmax> values with the expectations for proton and iron



HiRes

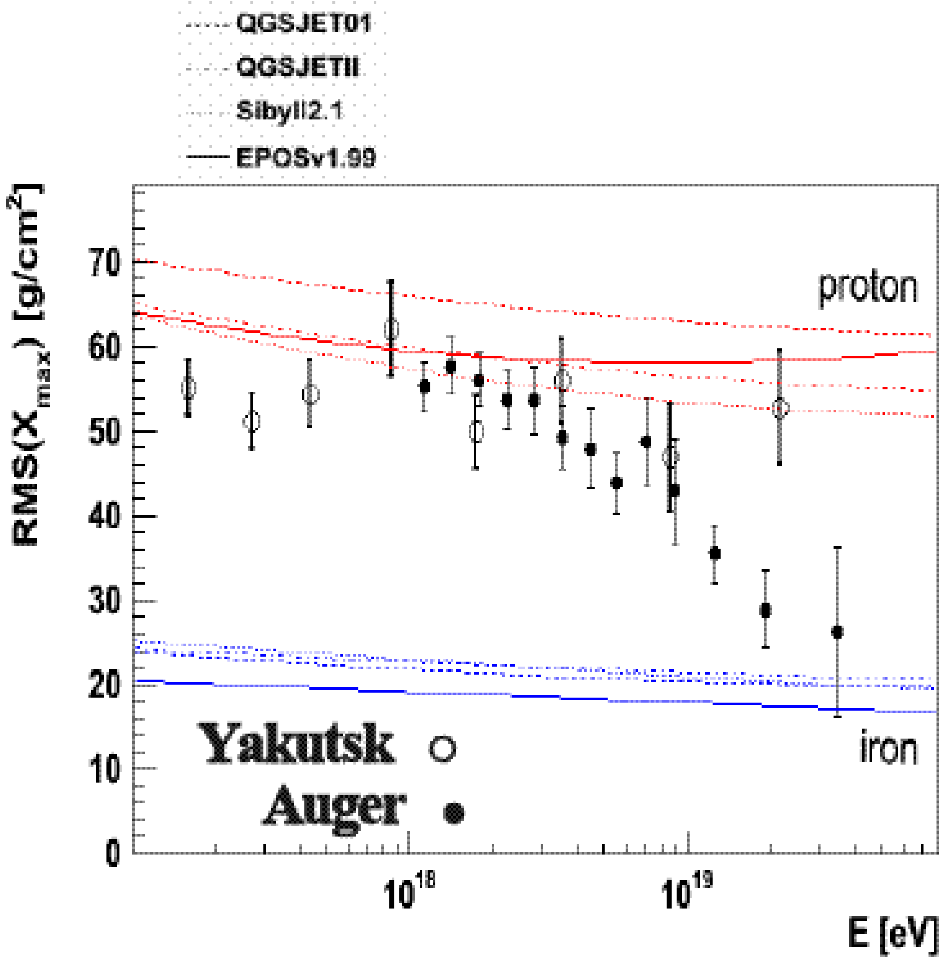


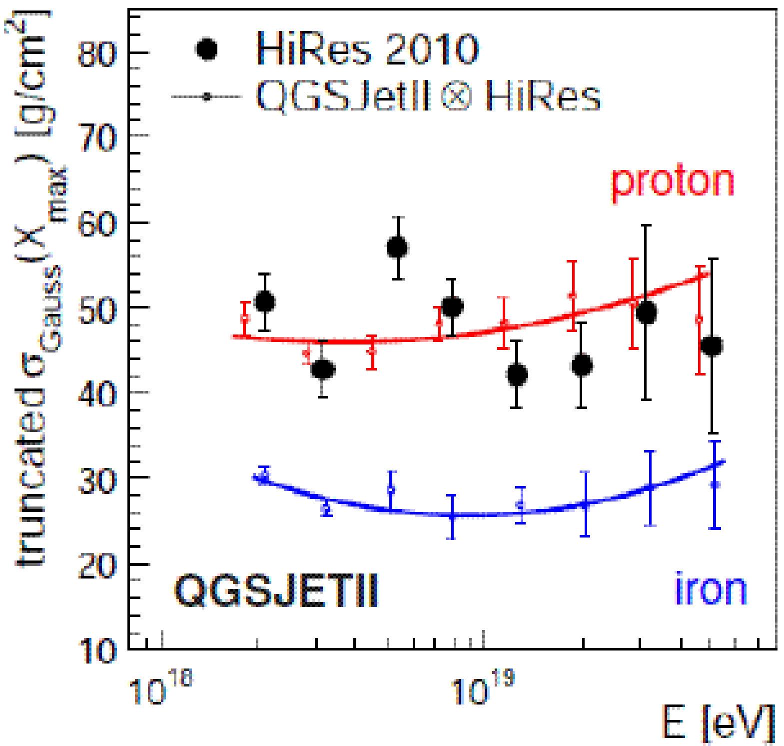
TA



- Are the differences due to issues in any of the analysis?
- Are the differences within systematic uncertainties?
- Are the Southern and Northern sky different in terms of composition?

RMS(Xmax) from: Auger, HiRes and Yakutsk





Yakutsk energy scale normalized to the Auger energy scale.

Conclusions

•Are the differences due to issues in any of the analysis?

Apparently no.

• Are the differences within systematic uncertainties?

Auger and HiRes are not consistent within the **quoted** systematic uncertainties.

• Are the Southern and Northern sky different in terms of composition?

We need more statistics in the Northern hemisphere (about 4 times the current statistics) to give a conclusive answer. The current statistics in the northern hemisphere do not allow to discriminate between a constant composition or a changing composition as suggested by Auger. More statistics is also necessary to establish whether there is a systematic difference in the RMS(Xmax) at higher energies.

• It is interesting to point out that all three experiments (Yakutsk, HiRes and TA) are consistent (within ~5g/cm^2). But, there is a large systematic difference in <lnA> equivalent to about 30 g/cm^2 between Auger and the other experiments.

Composition

Proton, Fe or mixed.

North (p) vs South (Fe) asymmetry?

e/γ based μ based

Is it Nature or Detection Systematics?

Dispute $\propto$ 1 / reliability of results

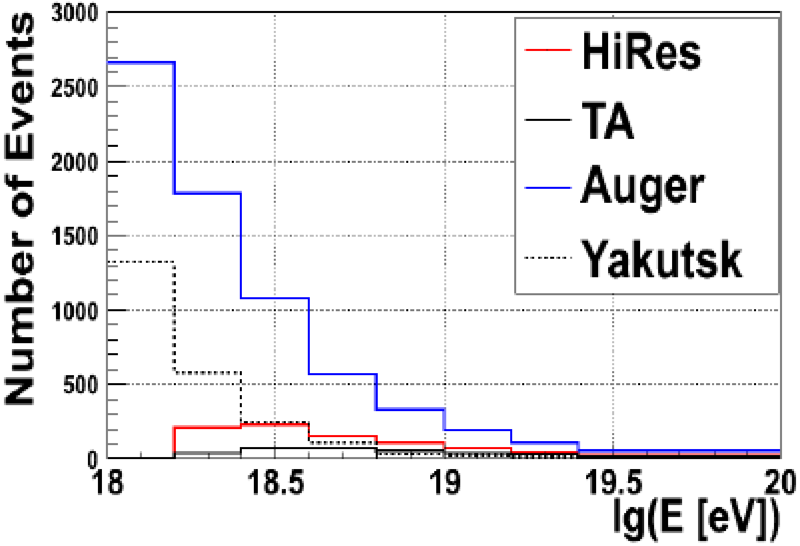
All groups are confident on the results.

No need for disputes.

We are ready proceed for solving the problem.

Statistics

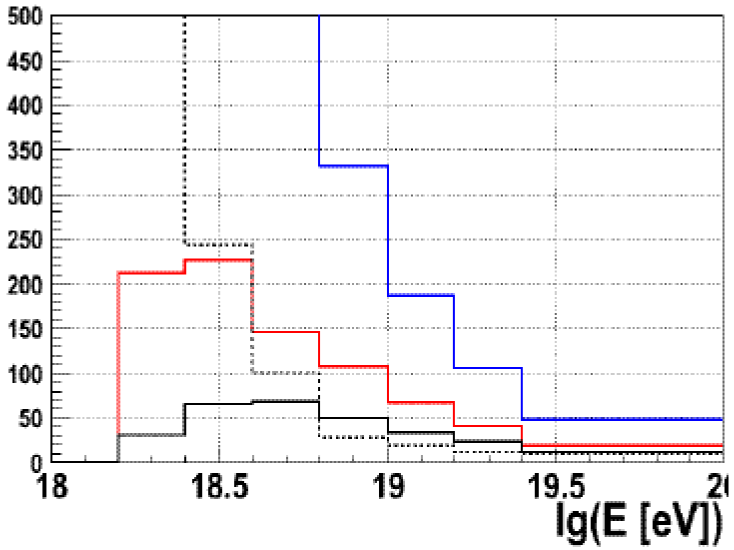
is the power!



E > 10^{18} eV

6744 Auger
2301 Yakutsk
815 HiRes
279 TA

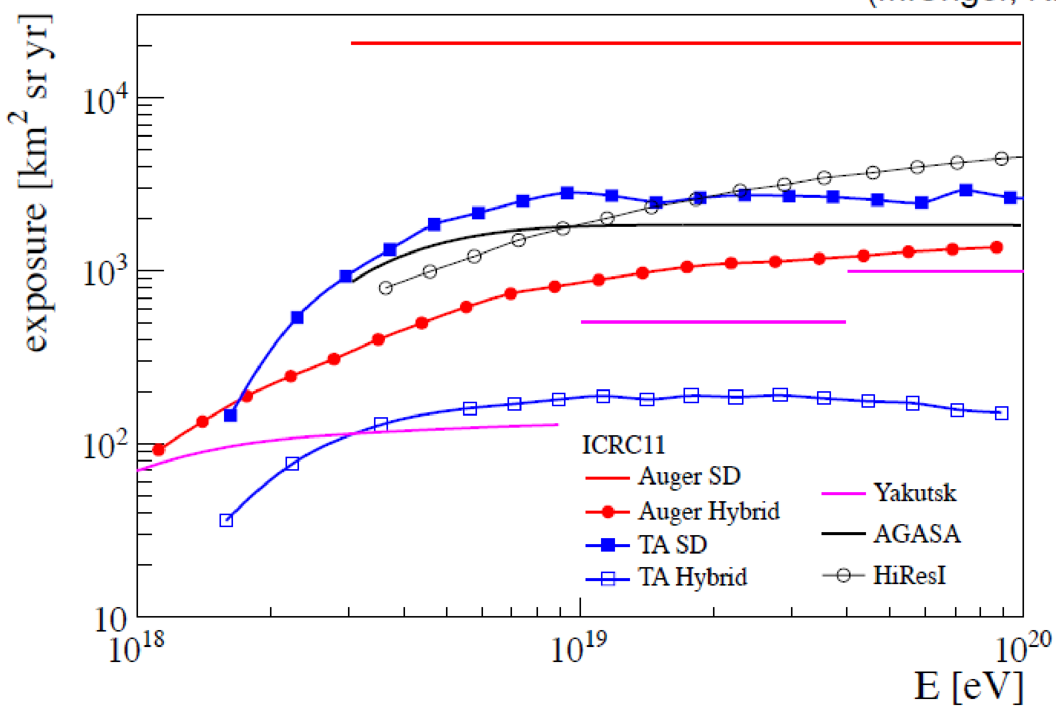
Xmax meas.



Spectrum meas.

Exposures: ~ICRC2011

(M.Unger, KIT)



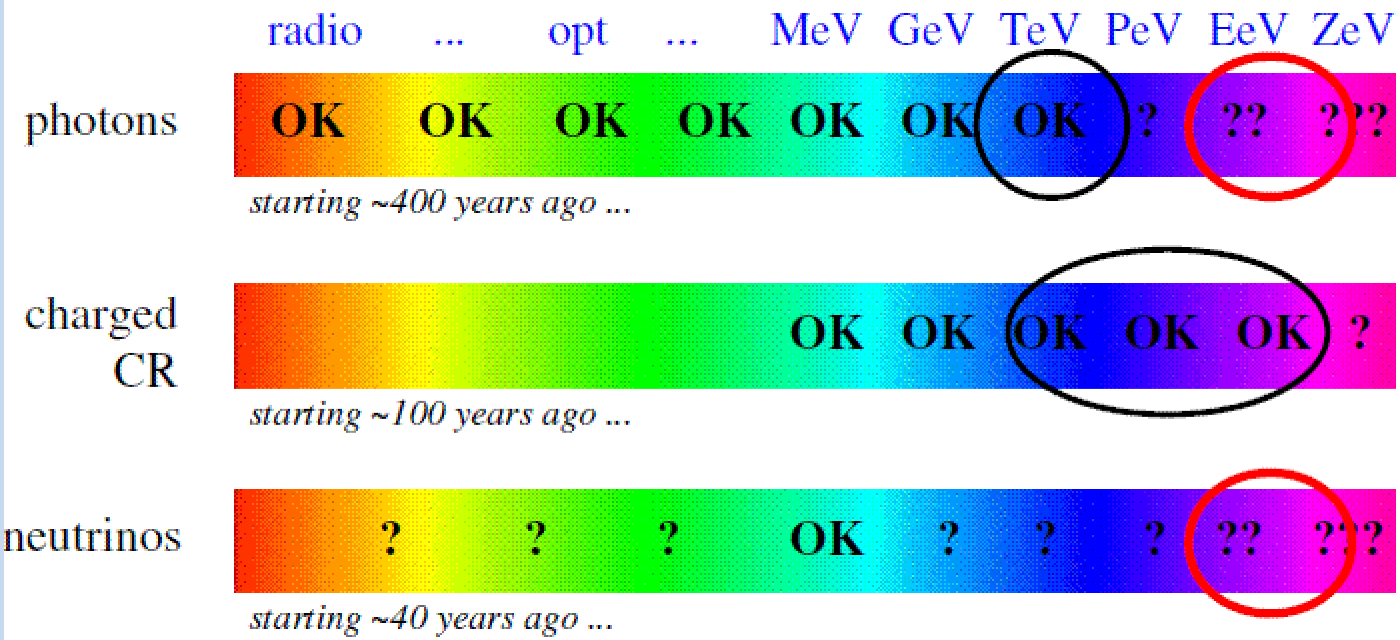
Anisotropy

- No anisotropy established with certainty; however, various hints exist
- Expectations depend crucially on the actual mass composition of UHECR
- $O(10)$ increase in statistics, together with reasonable improvements in other parameters, is needed for definitive progress

... clarifying several aspects of the puzzle. Be patient.

UHE gammas and neutrinos

Present status *vs* future directions



new windows - new discoveries
large impact, also beyond astroparticle physics

Question to EAS community:
How do we want this to look like in 10-15 years ?

UHE interactions

σ_{TOT} measurement by UHECRs.

LHC data to understand Air Shower

E_{SD} = 1.3 ~ 2.0 x E_{FD}

Excess of ground μ's.

Effect on Xmax and composition?

Air shower at UHE is poorly understood, esp. muon (had) sector is un-healthy.

UHECR research

1. What is UHECRs?
2. Where are they born and how?
3. How do they arrive at Earth?
4. How are they observed?
5. Underlying Basic Physics.
6. Discovery of unknown Nature?

We are exploring the highest energy frontier of the Universe. Origin of UHE particles? Testing basic physics at UHE.

Where are we now?

1. What is UHECRs?
2. Where are they born and how?
3. How do they arrive at Earth?
4. How are they observed?
5. Underlying Basic Physics.
6. Discovery of unknown Nature?

- Remarkable advances in last 10 years.
- We are about to answer Questions.
- No way to give up this pursuit now.
- Better and Larger detector wanted.

Future Research Directions

Next-generation Ground-based Giant Detector

“NGD” on ground : concept

Radio detection : RDs

TUS and JEM/EUSO in space : design

LHC with ions : planned

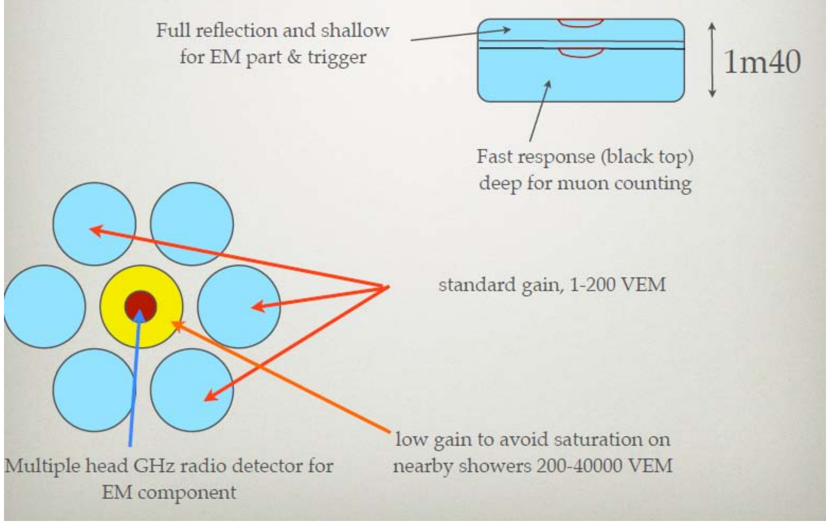
Please be warned that my summary may be biased and dogmatic.

Can we improve the situation ?

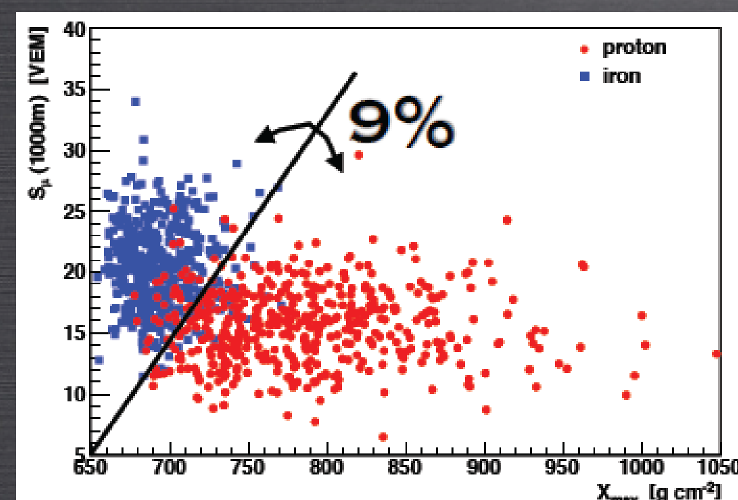
- We need very large aperture (> 30 000 km^{2}sr)
  - Any ground array will need to be sparse (spacing of a few km)
  - ** Do not trade quality for surface ** measurement precision goes as $\sigma / \sqrt{n}$
- We need to measure all EAS component
  - Sensitivity to both EM and hadronic component (muons)

Event by event p/Fe

70 m^2 Cherenkov detector --> Spacing 2-3 km



S = -130 + 0.2 X



2 TANKS

"Let a (few) thousand flowers bloom"

JWC

- The scientific case for the future of UHECR will become clearer with data collected in the next five years. A strong scientific case is necessary to justify THE next generation experiment.
- The design of this next generation experiment must proceed in parallel. The community should start very soon the process of evaluating different detector options.

- Focus on the highest energies, > $10^{19.5}$ eV, with X_{max} measurement

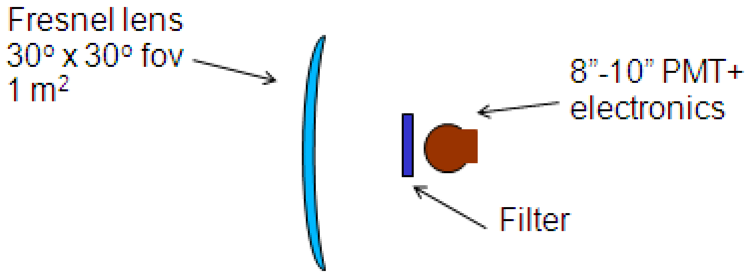
  spectrum, composition/hadronic interactions, anisotropy

- At least the same statistics of Auger above $10^{19.5}$ eV, but with high quality X_{max} measurement

  - maybe radio (MHz/GHz/radar) technique will work, but what if not?

    $A \geq 40000$ km^2 area with a Fluorescence Detection technique

A simple (low cost) design

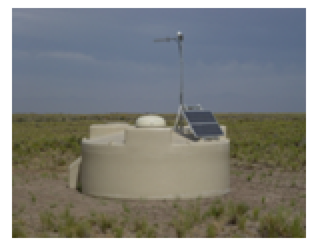


A mirror or a Winston cone would work too

A 40000 km² FD-array

Example:

- 12 PMTs/ 360° station
- 120 stations
- 1248 PMTs total



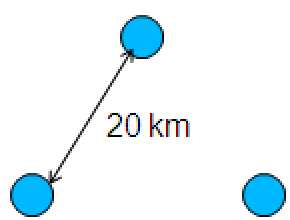
Auger SD station: 3 PMTs, electronics and comms, small solar panel enough

A "small" number of stations (1600 in Auger)

A "small" number of PMTs and electronics (4800 PMTs in Auger SD)

- Design may require a denser array, e.g. 10 km spacing, or larger elevation (24 PMTs/360° station) but n. of stations and PMTs still affordable

Potentially very low cost

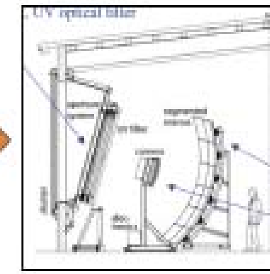


200 km

200 km

- 2 TA FD ⟷ 1 Auger FD
  (FOV ~ 20^o - 30^o)

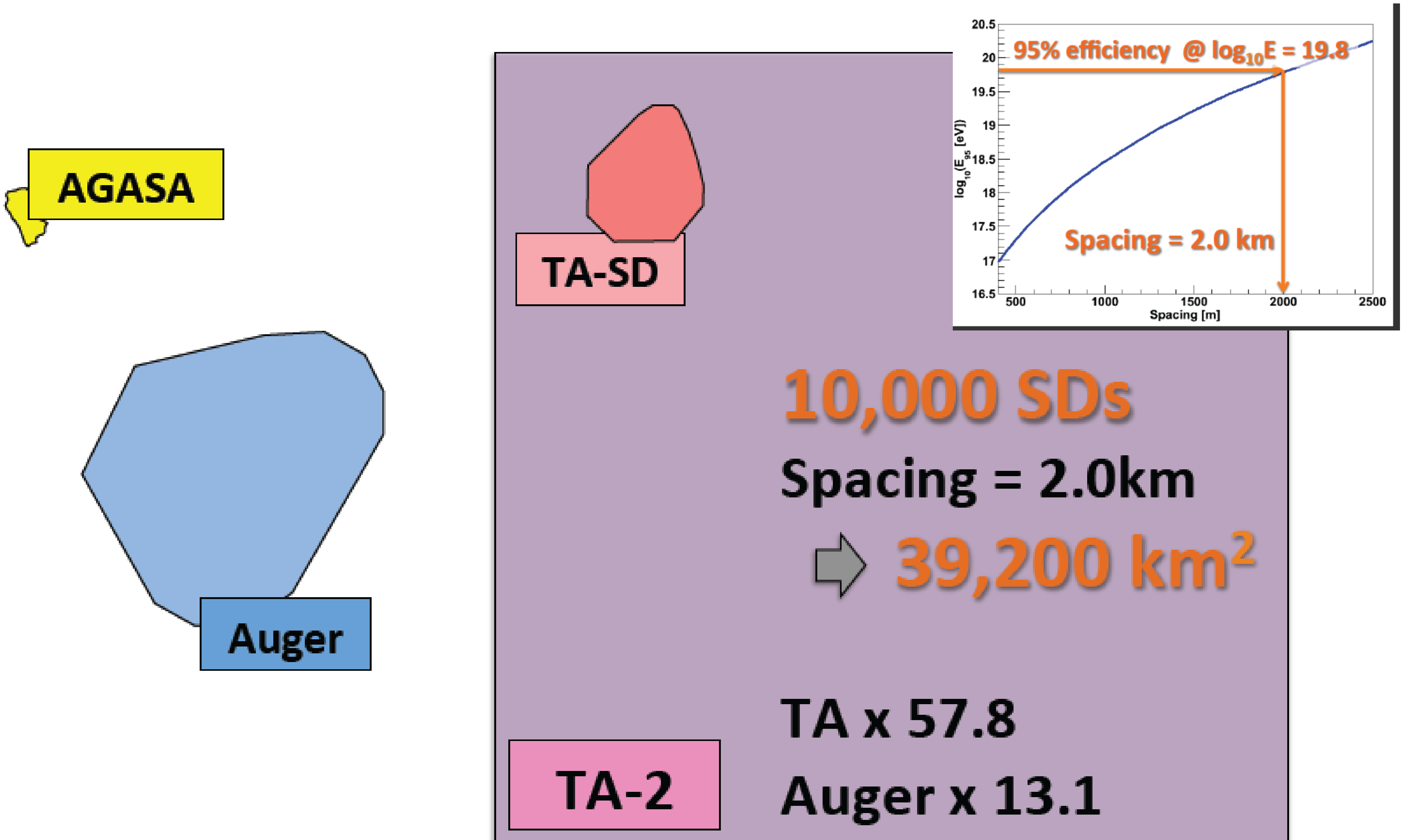
estimated cost ~ $1M



- 1 TA station + 100 TA SDs ⟷ 1 Auger station + 100 Auger SDs

estimated cost ~ $10M
(for TA < $5M)

Future Plan 3: Huge air shower array



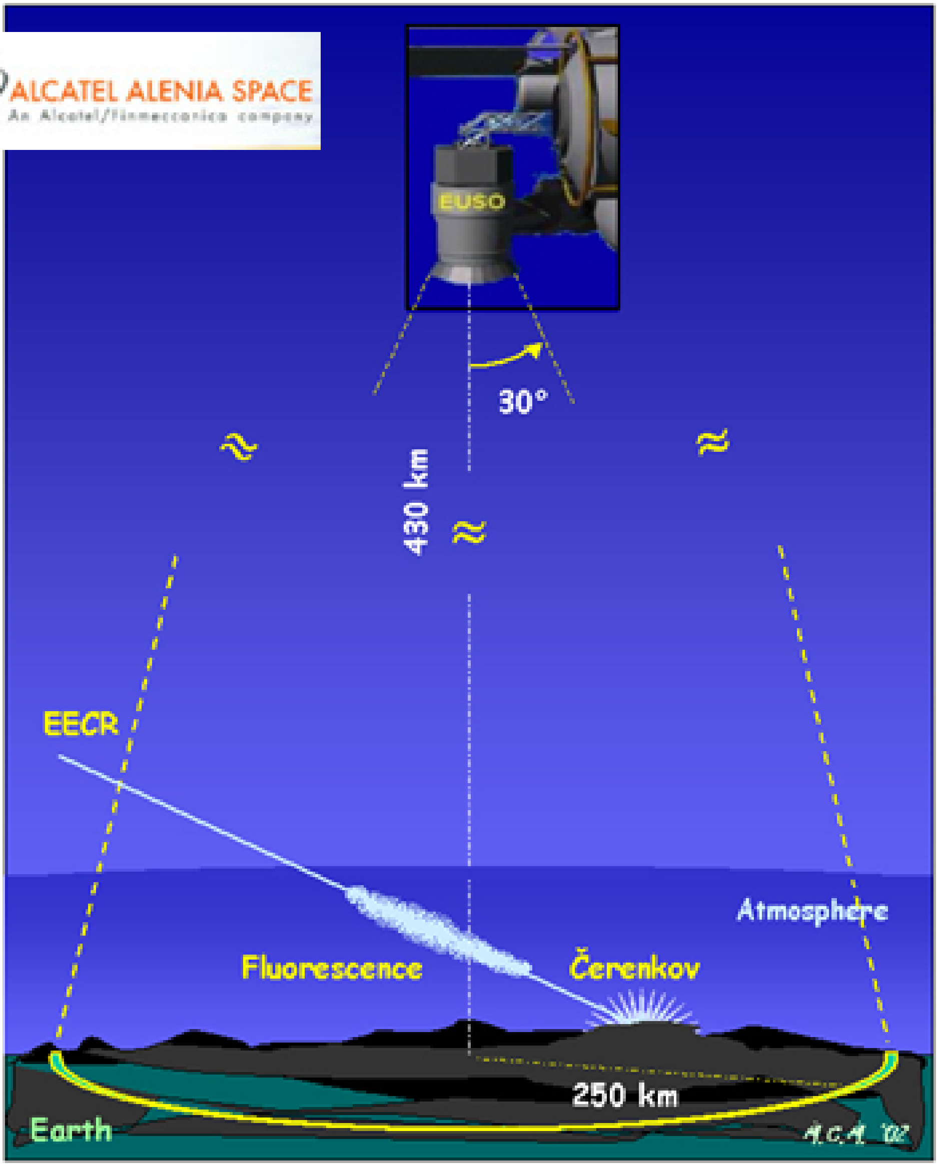
EUSO

- Large distance > 400 km
- Large FOV $\gamma \geq 30^o$
- $$A^{geo} \approx 6 \times 10^5 \ km^2 \cdot sr$$

$$\eta_{cycle} \approx 10 \div 25 \ \%$$

$$A_{Euso}^{eff} \approx (6 \div 9) \times 10^4 \ km^2 \cdot sr$$

$$\approx \ few \times 10^{12} \ tons$$



mass ($\lesssim 1.5$ ton), volume ($\lesssim 2.5 \times 2.5 \times 4.5$ m^3), power ($\lesssim 1$ kW) and telemetry ($\lesssim 180$ Mbit/orbit).

NGD on ground : concept

- Collect max. info on UHE Air Showers.
- Understand Air Shower (UHE had. Int.)
- Measure event E, θ, ϕ and “p/Fe, γ/ν”
- Confirm UHECR sources and anisotropies
- with enough statistics (for E>$10^{19.5}$ eV)

JEM/EUSO in space : design

- Realize max. acceptance on UHE primaries.
- All sky (N/S) uniform coverage
- Identify UHECR sources, and
- Measure spectrum for each source
- with large statistics

In designing NGD

e/γ based vs μ based

Composition difference, p(N) vs Fe(S) is to be understood, whether it is by nature or by detection problem.

1. Select good composition technology for NGD.
2. Aperture requirement depends on composition.
3. If proven, it becomes a prime research target.
4. Implications for UHE hadronic interactions.
5. …

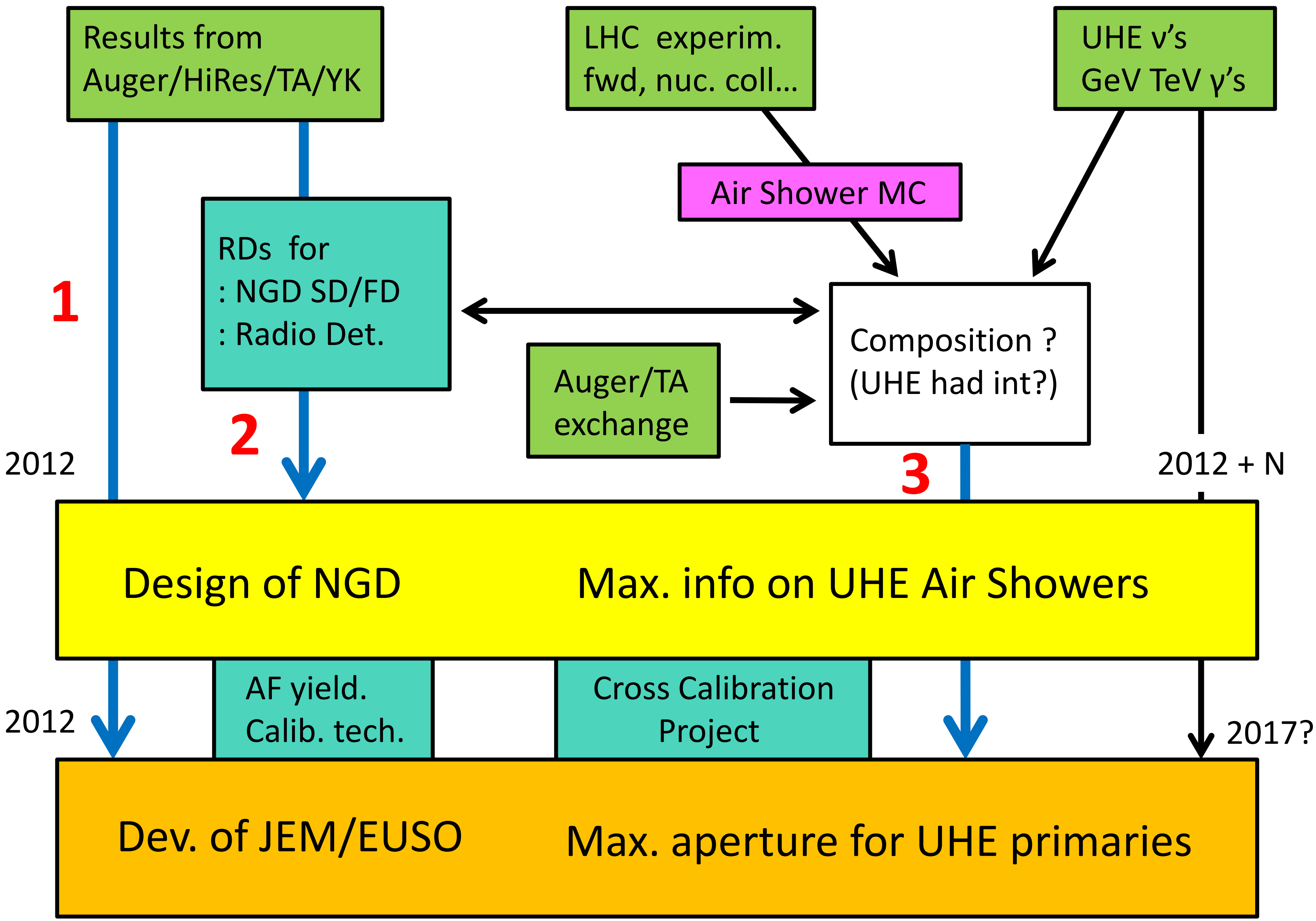
Ground and Space

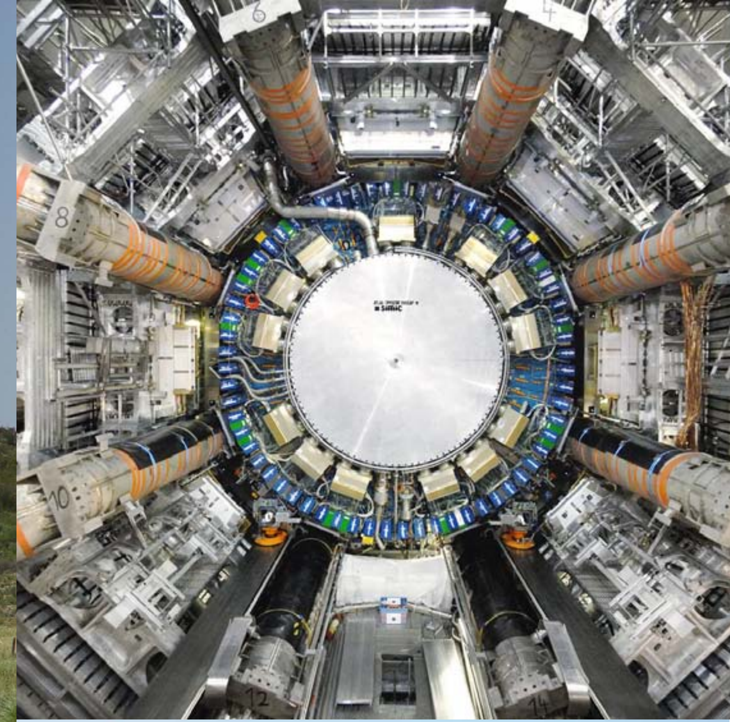
- If no NGD, we will not understand what is UHECR.
- If no JEM/EUSO, we will lose important future and hope.

Radio RDs

- ~100% duty, economic and little atmosph. effect .
- E, θ, ϕ & composition determined better by radio?
- Research, or R > D stage
- SD x Radio hybrid?

Roadmap for Ground and Space Detectors





NGD has been open, distributed and scalable..

- ✓ Concentrated RD Items.
- ✓ Possible cost reduction in mass prod.
- ✓ Space to adopt new physics and new technologies.

Auger-TA exchange program

- Data Analysis
- Calibration
- Detectors
- Scientists
- etc.

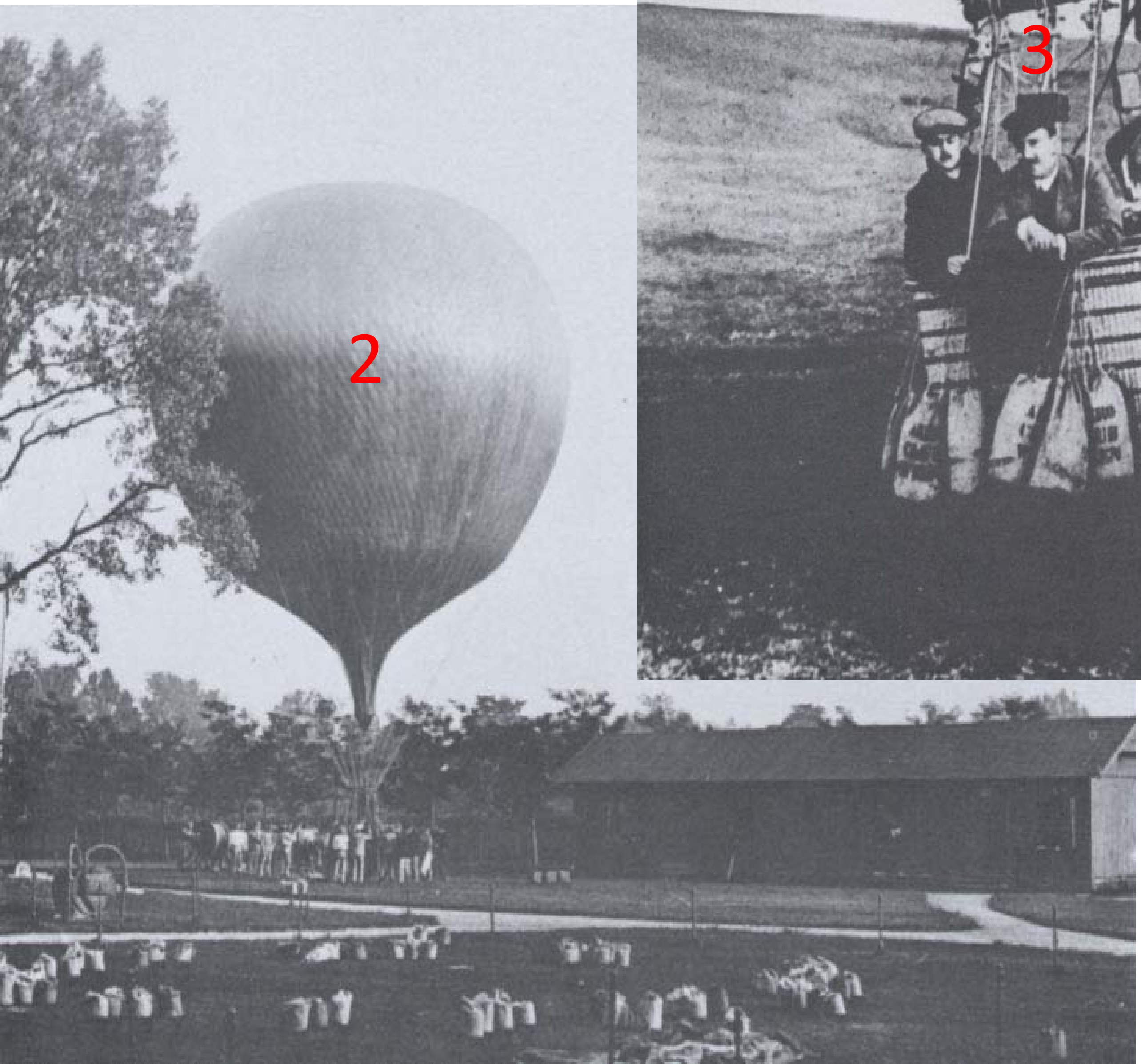
Proto-Collaboration of NGD

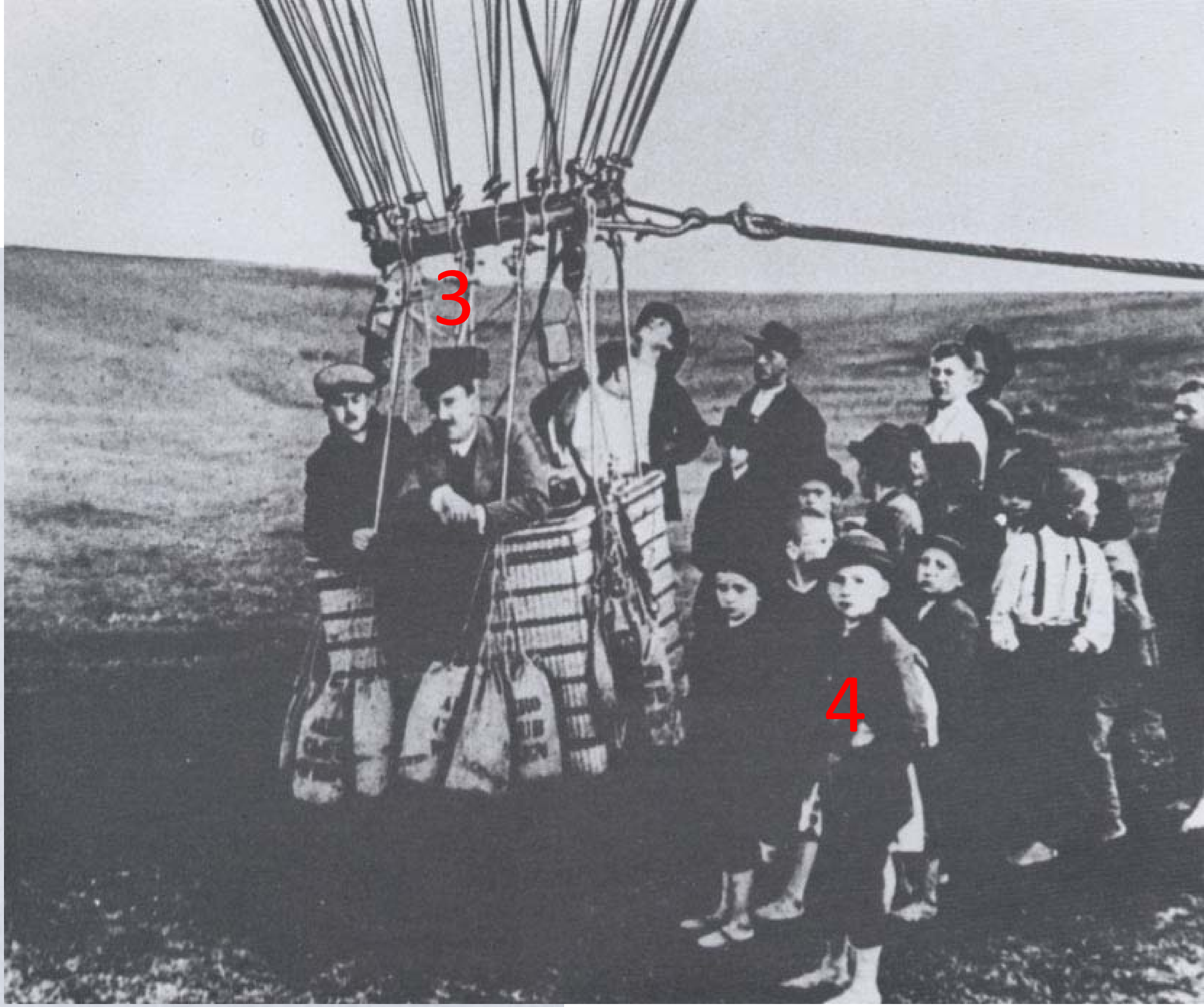
A proposal : forming NGD wg

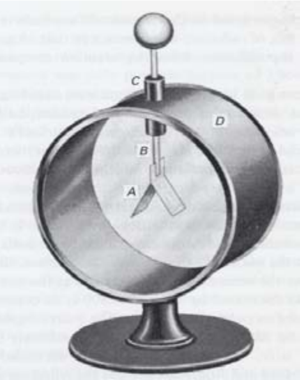
- Physics Objectives
- Conceptual Design as Hybrid Detector
- Role of Radio Detector
- Composition Technology,
  detector & data analysis.
- Aperture and calibration
- Detection of UHE γ's and ν's

~5-year (?) time scale for design and RDs.
Collaboration with space detector people.

All wg activities are expected to continue after symposium.







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Prospects

Despite different ideas on the interpretation of present observation, and different prospects for future, all 230+ physicists gathered here are convinced on the values of UHECR research, which we find interesting and rewarding. We proceed for future in collaboration.

Prospects

Disputes in science are inversely proportional to the reliability of results. In the early days, almost everything in cosmic rays was up for disputation. Today, no-one disputes that the spectrum has a cut-off. We may dispute the interpretation, but not the result. This is real progress. You may say, but it took us 50 years to get there! Yes, but the improvements in experimental technique and progress of particle physics in the period that led to this breakthrough imply that we are poised to produce many such reliable results in the coming decade. One by one, the other major issues, understanding the composition and origins of UHECR's, will be reliably clarified. We are getting close to an understanding of the remaining systematic issues and existing and future detectors will provide the necessary statistics. Experiments at the international space station will advance it further.