Karlsruhe Institute of Technology

HELMHOLTZ GEMEINSCHAFT

Allianz für Astroteilchenphysik

The non-thermal Universe

“Novel Detection Technologies and Future Challenges”

(Technological Challenges next 5 years….)

Andreas Haungs

Topics

Slide: 2011

- Radio Detection of Air Showers;
- **Microwave Detection of High-Energy Cosmic Rays;**
- Detection of High-Energy Neutrinos by radio or acoustic emissions;
- **Cherenkov Array for Air Showers and High-energy Gamma Rays;**
- Advancements of PMT Development;
- **Multi-channel Read-out System;**
- Air Shower Observations from Space;
- **Low-energy extension of IceCube.**

- required high flexibility
- rapid change of interests
- interesting findings

Participants: Aachen, Bonn, DESY, Erlangen, Hamburg, KIT, München MPP+TU, Mainz, Tübingen, Würzburg, Wuppertal

Slide: 2011

Radio Detection of Air Showers

Goal:

Scalability of present radio-detector-stations to large arrays!

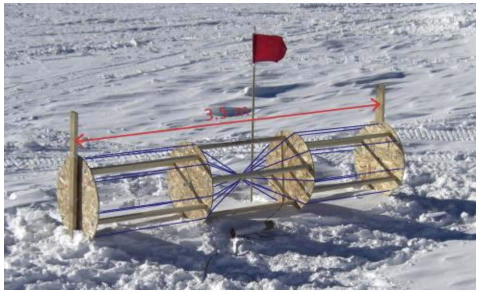
= cost reduction / self-healing of present layouts of

AERA and RASTA

2016:

- AERA
- Tunka-Rex
- ….

Milestone: **2015 White paper on large-scale radio antenna arrays**



Microwave Detection of High-Energy Cosmic Rays

Slide: 2011

Goal:

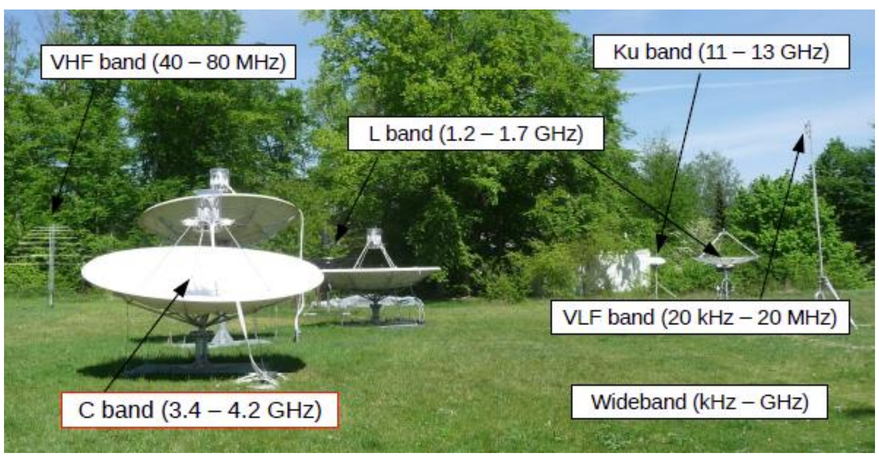
Proof-of-Principle of the Detection Technique

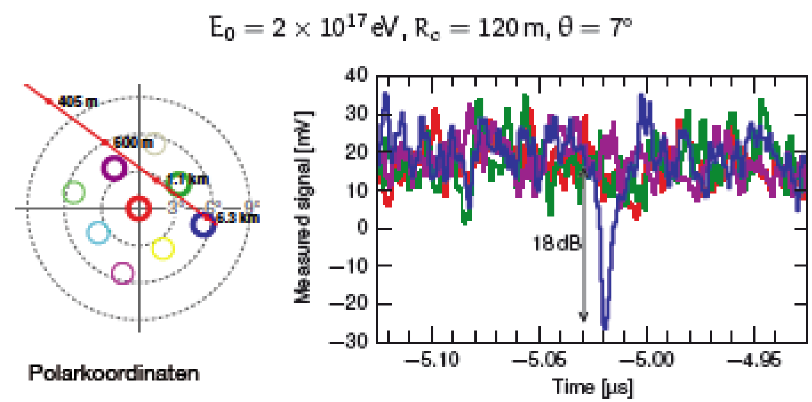
2016:

- Fulfilled !

Milestone: 2014 Paper on detection capabilities and detection limits

CROME





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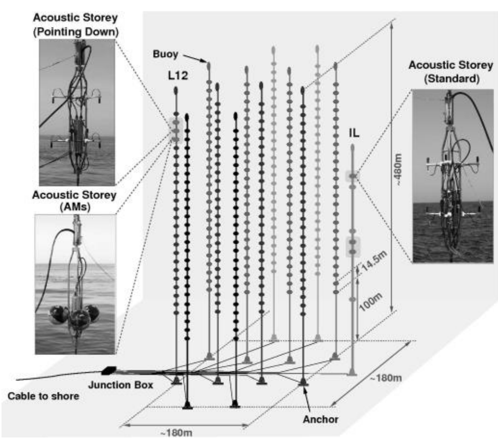
Detection of High-Energy Neutrinos by radio or acoustic emissions

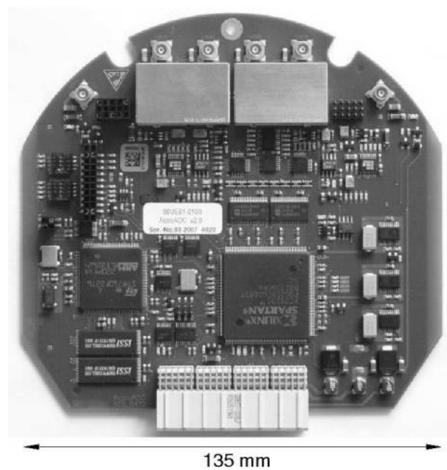
Slide: 2011

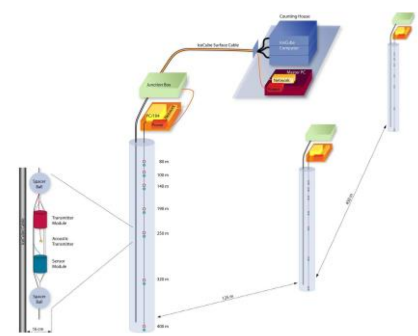
Goal:

Proof-of-Principle of acoustic (in-ice, in-water) and radio (in-ice, in-salt) detection of neutrinos by developing mid-size detectors from the present prototypes (RICE, SPATS, AMADEUS)

Milestone: 2013 analysis results of acoustic prototype detectors







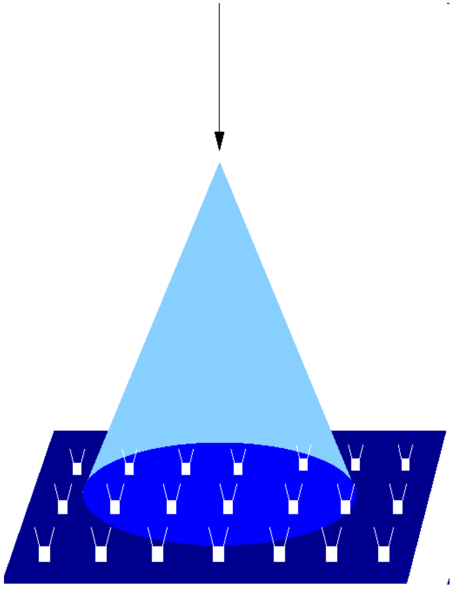
Cherenkov Array for Air Showers and High-energy Gamma Rays

Slide: 2011

Goal:

Development of a non-imaging Cherenkov Gamma-ray detector

Milestone: **2014 Prototype of SCORE at Auger Observatory**



21-23.09.2016, Erlangen
HAP workshop, Non-thermal Universe
Andreas Haungs
IKP

Advancements of PMT Development

Slide: 2011

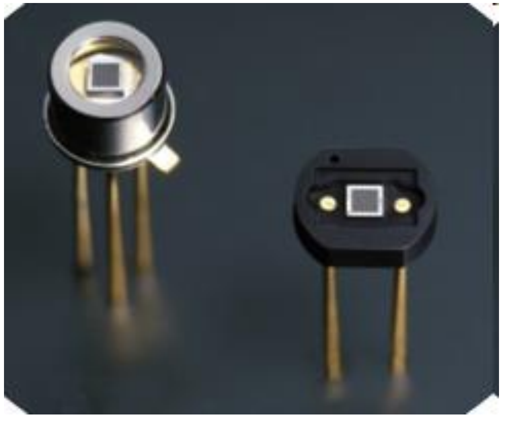
Goal:

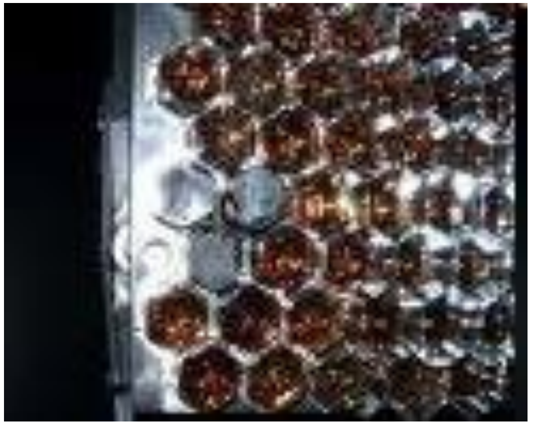
Investigating application capability of next generation PMT's for large experiments (KM3NeT, Auger, LENA, IceCube, CTA)

Milestone: 2015 Feasibility study for new PMT's (SiPM, HQ-PMT)

- AMD
- IceAct
- HEAT
- FAMOUS
- SiECA

2016:





Slide: 2011

Multi-channel Read-out System

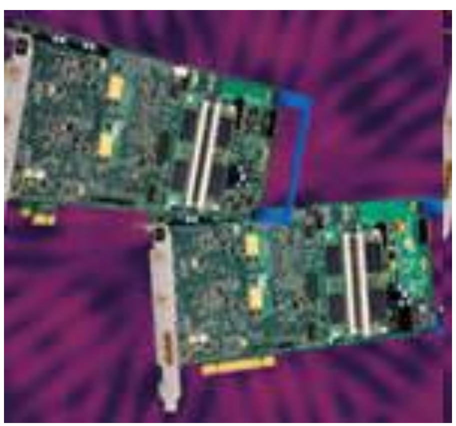
Goal:

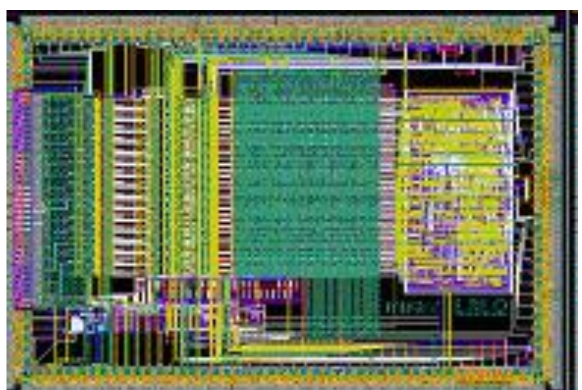
Optimization of multitude photosensor readout

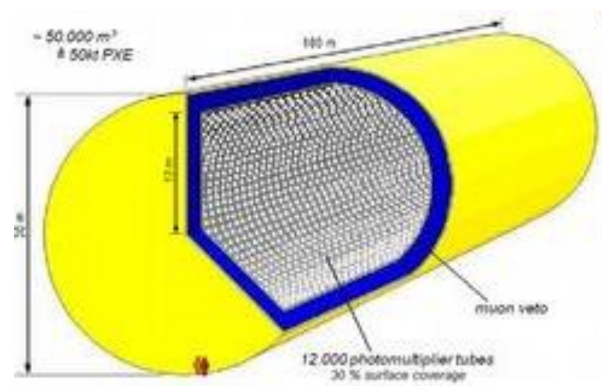
Milestone: **2015 Technical report on LENA read-out chain**

2016:

- LENA activity was stopped….







Air Shower Observations from Space

Slide: 2011

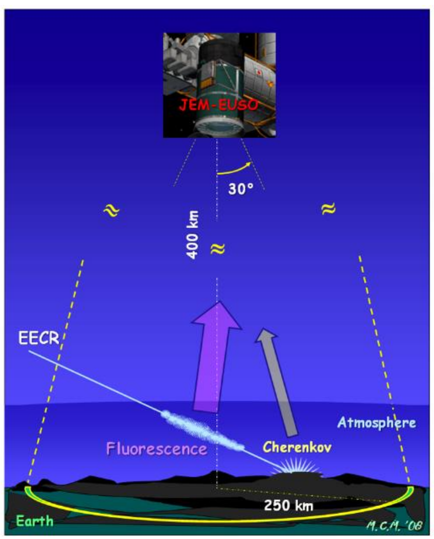
Goal:

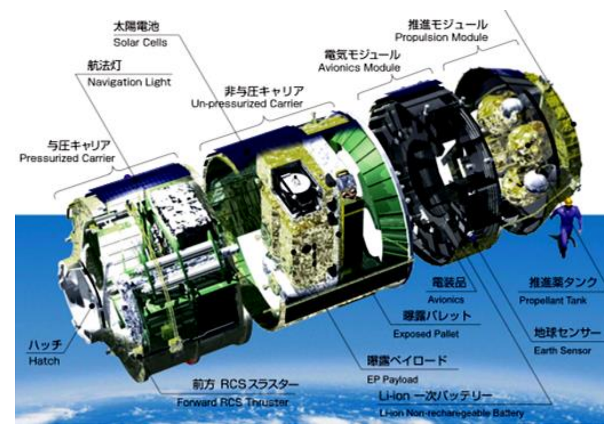
JEM-EUSO: Pathfinder project to observe air-shower from space; HAP brings in expertise in fluorescence detection.

Milestone: **2015 Calibration and monitoring system for JEM-EUSO**

2016:

- SPOCK





Slide: 2011

Low-energy extension of IceCube

Goal:

Lowering IceCube energy threshold with DeepCore for a better Dark Matter sensitivity or even Supernova sensitivity.
Development of adapted Optical Module within HAP

Milestone: 2015 Feasibility study on IceCube DeepCore extension

2016:

- IceCube-Gen2
- PINGU
- KM3NeT
- ORCA

What would we consider now as topics for

The non-thermal Universe

“Novel Detection Technologies and Future Challenges” ?

Mission:

The goal of this work package is to support and structure innovative R&D strategies to improve detection techniques in order to extend the acceptance, energy range, and sensitivity of existing or future facilities for astroparticle physics.

The non-thermal Universe 2017-202x

“Novel Detection Technologies and Future Challenges” ?

Experiments:

Cherenkov Telescope Array

IceCube-Gen2 (KM3NeT, GVD)

Pierre Auger Observatory – GCOS

EUSO-like mission program

HAWC-South like experiment – HiScore - LHAASO

FACT (++)

Einstein Telescope

X-ray missions

Overlaps with DM, LE-ν, …

Overlaps with particle physics detector development

What would we consider now as topics for

The non-thermal Universe

"Novel Detection Technologies and Future Challenges" ?

A few examples:

- Application of the radio detection technique
- Particle detectors for large sensitive area (scintillators)
- Development of Optical Modules
- SiPM vs. PMT
- Readout electronics ASICs
- Computing; Data Preservation
- Data Release
- ??

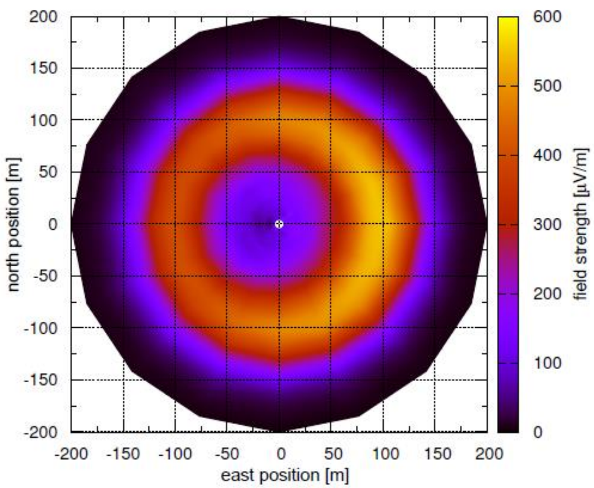
Application of the Radio Detection Technique in future Experiments

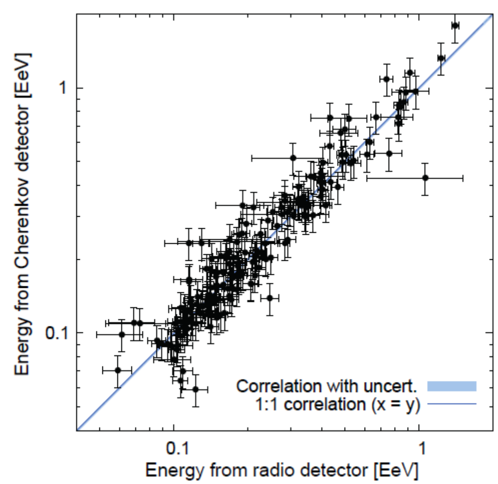
Energy, Xmax, and direction reconstructable with sufficient accuracy

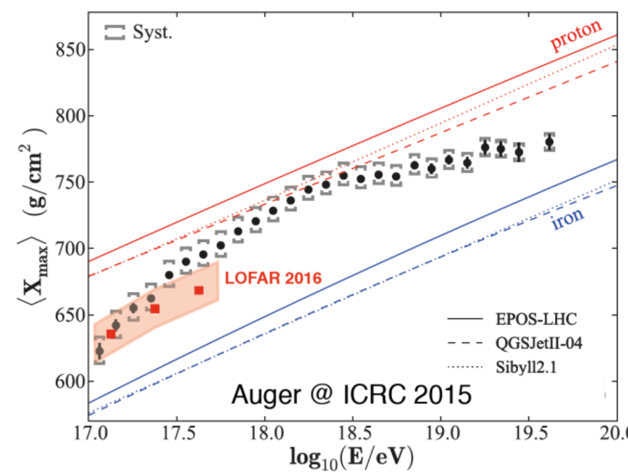
- **Emission understood**
- **Energy (AERA/Tunka-Rex): σ<15%**
- **Xmax (LOFAR et al): σ~20g/cm^2**
- **Direction : no problem σ<1°**
- **Horizontal air shower detection possible and promising**

← ready for application **needs to be optimized for science cases**

Tim Huege Phys.Rept. 620 (2016) 1-52





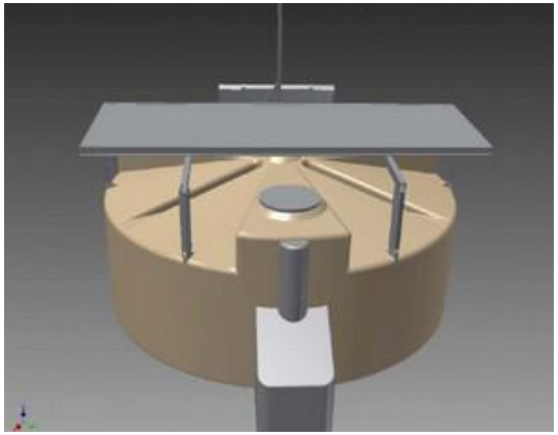


Advanced radio stations (AERA, LOPES, LOFAR, Tunka-Rex, SKA, …) are able to considerably enhance CR reconstruction capabilities!

e.g. enhancing AugerPrime?

for composition measurements of inclined showers

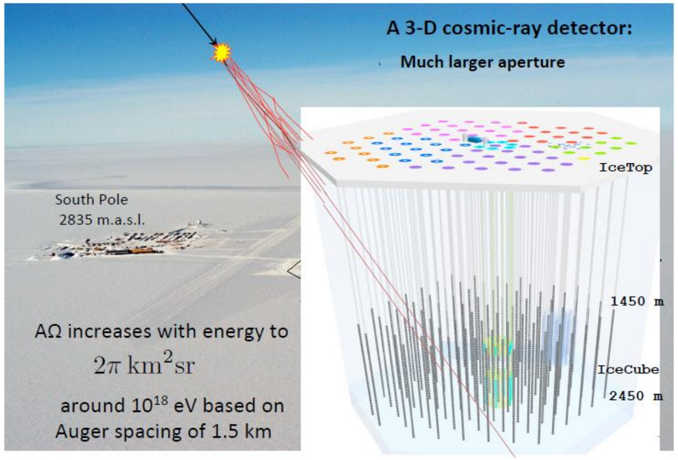
- **Design / realization of a hybrid detector**
- **Integration**



e.g. IceTop Enhancement by Radio Stations?

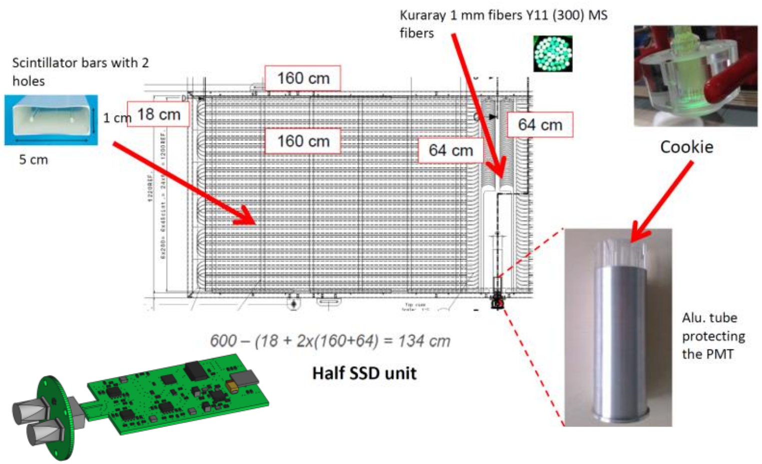
to upgrade / enhance IceTop
to open new physics
(PeVatrons from galactic centre)

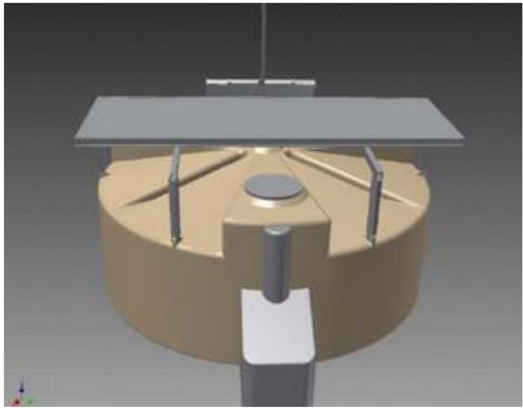
- **Sensitivity and physics study**
- **Design of antenna/electronics/mechanics**
- **Design / realization of a hybrid detector**
- **Integration**



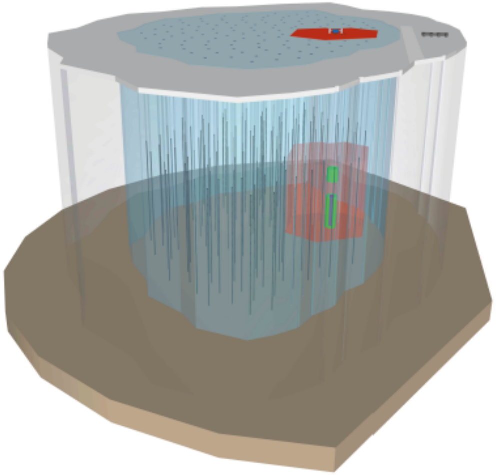
Particle detectors for large sensitive area (scintillators)

AugerPrime: 1660 x 4m^2 sensitive area



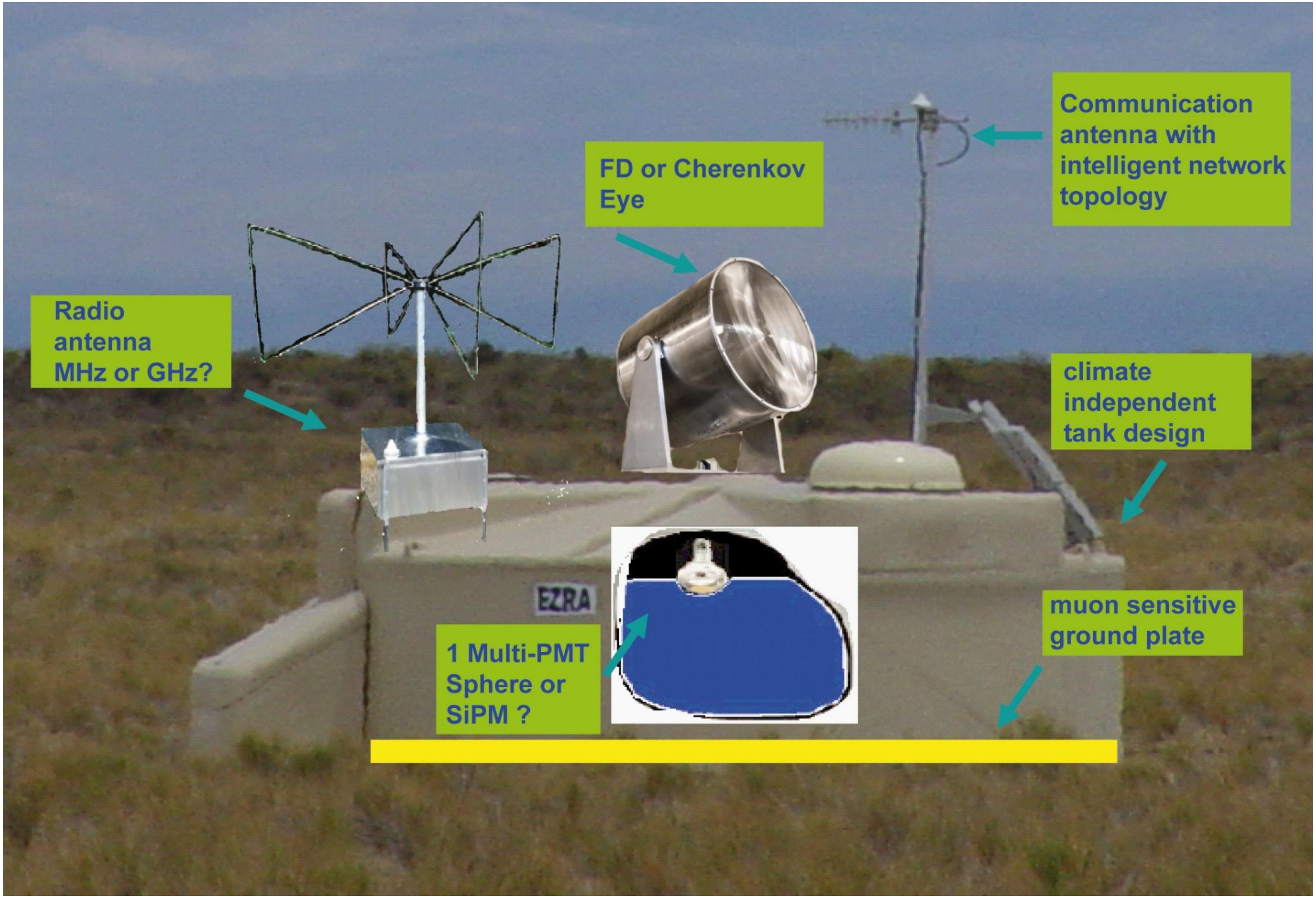


IceCube-Gen2 surface veto array:
75 km^2 with 75000 m^2 sensitive area

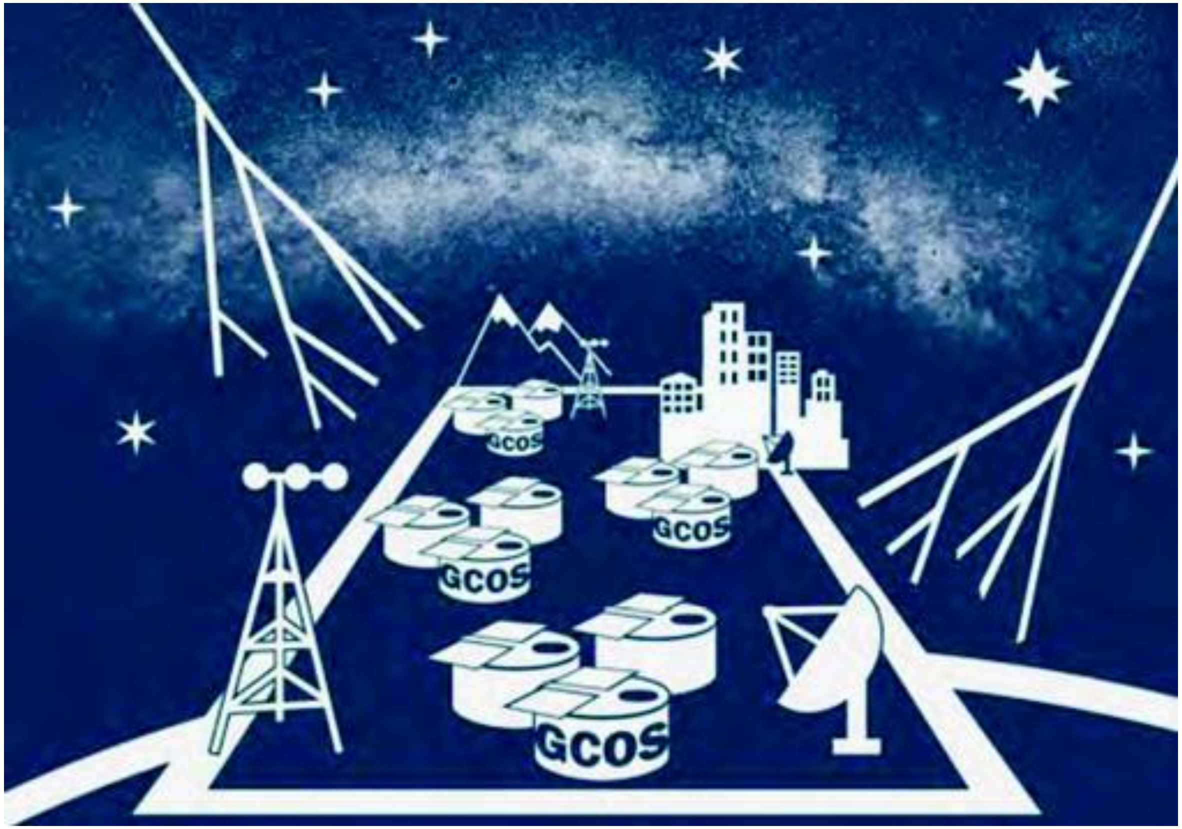


- Cost efficient instrumentation
- Robust mechanics adapted to environment
- Flexible electronics
- Easy deployment

Future (next generation) surface detector:



GCOS = Global COSmic ray observatory



Helmholtz (D) large infrastructure Roadmap

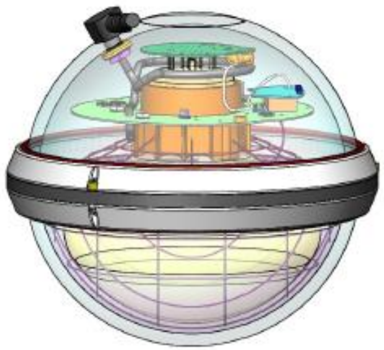
p-astronomy with sources

- Global, few sites, N+S
- ca. 90,000 km^2 (x30 Auger)
- Optimal detector for composition-sensitivity

- Design in 2020-25
- Operation 2025-2050
- Cost 390 M€ (120 M€ European contr.)
- Operation cost 6 M€/y

Optical Modules
IceCube-Gen2 – KM3NeT – ORCA – PINGU - GVD

Gen2 DOM
(baseline)



Modernized Gen1
Digital Optical Module

D-Egg

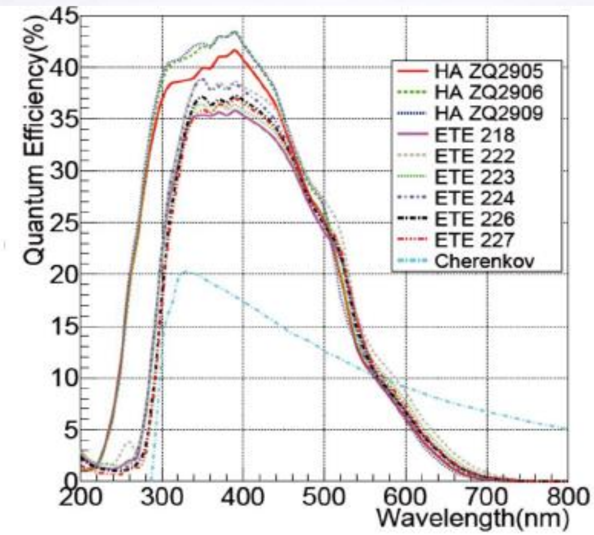
mDOM

WOM

- **Cost efficient instrumentation**
- **Robust mechanics adapted to environment**
- **Flexible electronics**
- **Easy deployment**

Standard PMT

Very small, mid & very large size PMTs



- **broad application**
- **good QE**

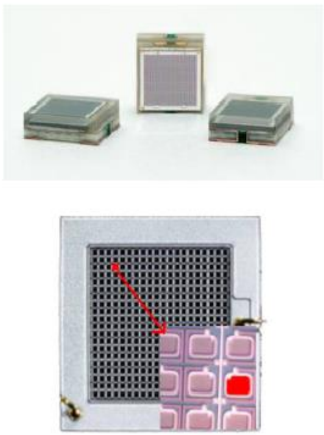
Still improvements possible

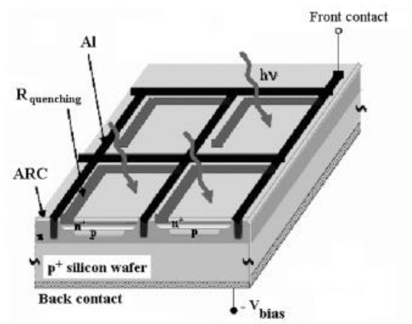
- **QE**
- **afterpulsing**
- **pulse width**
- **dynode coating**
- **various dynodes**
  (intrinsic dynamic range)
- **noise factor**
- **HV adjustment**
- **ageing**
- **more competition**

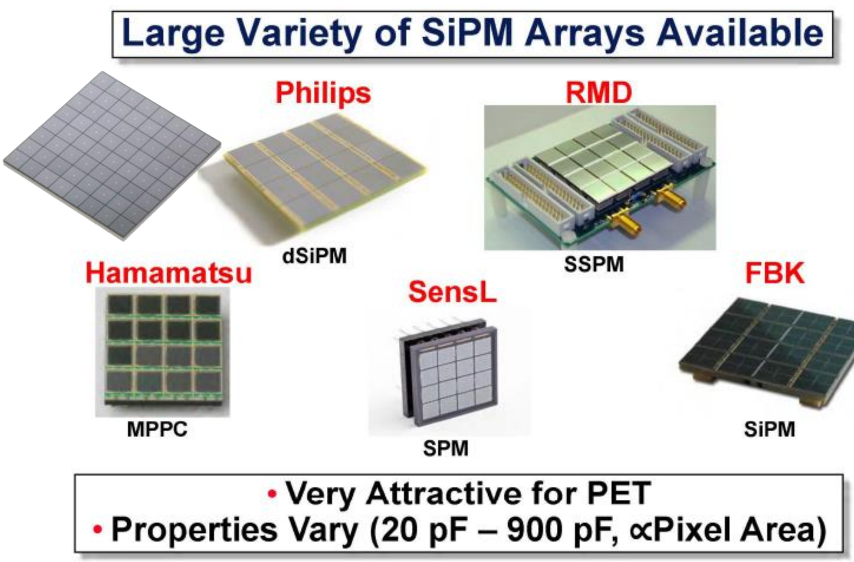
Though, okay for most applications

Conclusion:
Often no need to run behind newest SiPM developments

SiPM







- **fast development**
- **good PDE**

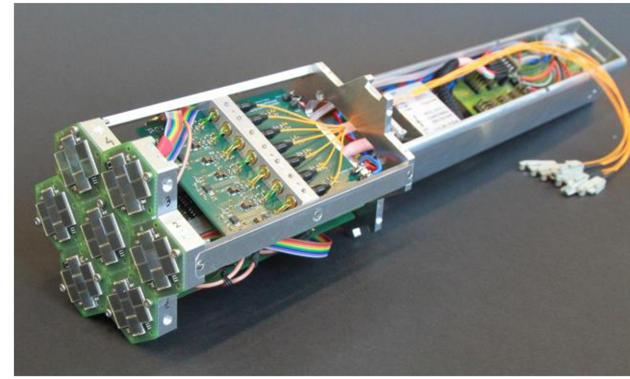
Still improvements needed

- PDE (=QE?)
- crosstalk
- dark current
- fast readout
- large areas
- operation temperature
- wavelength range
- cost reduction
- .....

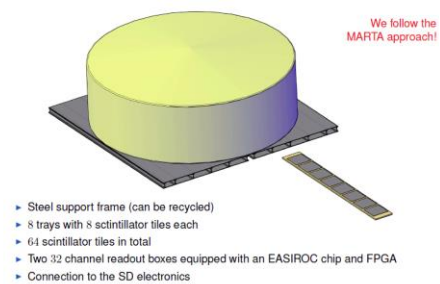
Conclusion:
Will be the future!
Need close cooperation between companies and experiments

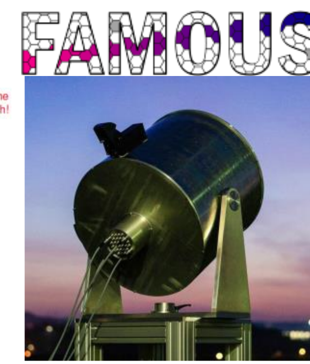
Examples of SiPM presently used in Astroparticle Physics

- **CTA**
  - **SST prototype with SiPM = ASTRI**
  - **Already existing: FACT**
  - **MAGIC started to replace**



- **Pierre Auger Observatory**
  - **FAMOUS - IceAct**
  - **AMD**
  - **SSD (AugerPrime)?**





- **Dark Matter**
  - **Low radioactivity**
  - **Low dark current**

- **JEM-EUSO**
  - **SiECA**
  - **Future EUSO missions**


Bottom view of the DarkSide TPC


Setup to test 250 PMTs for XENON1T


Bottom array of the PandaX detector

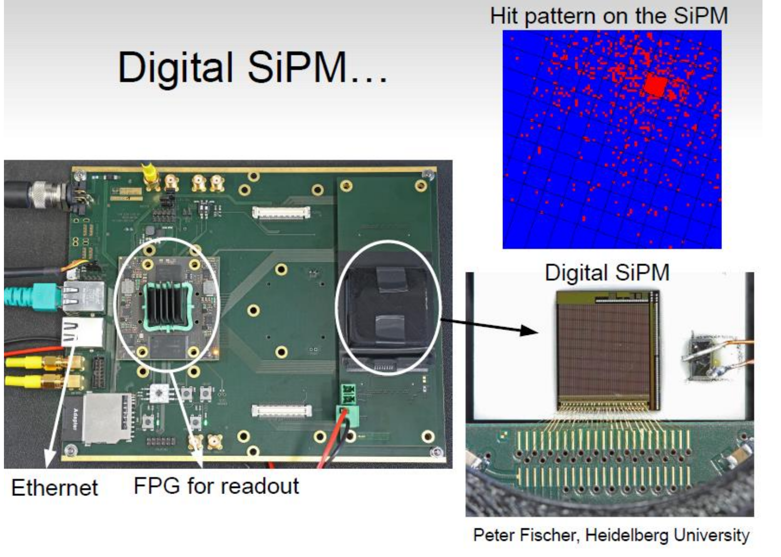
Requirements for (SiPM) Electronics

Further Development:

Monolithic SiPM+ASIC arrays

Companies only interested if it is a "Million dollar business"

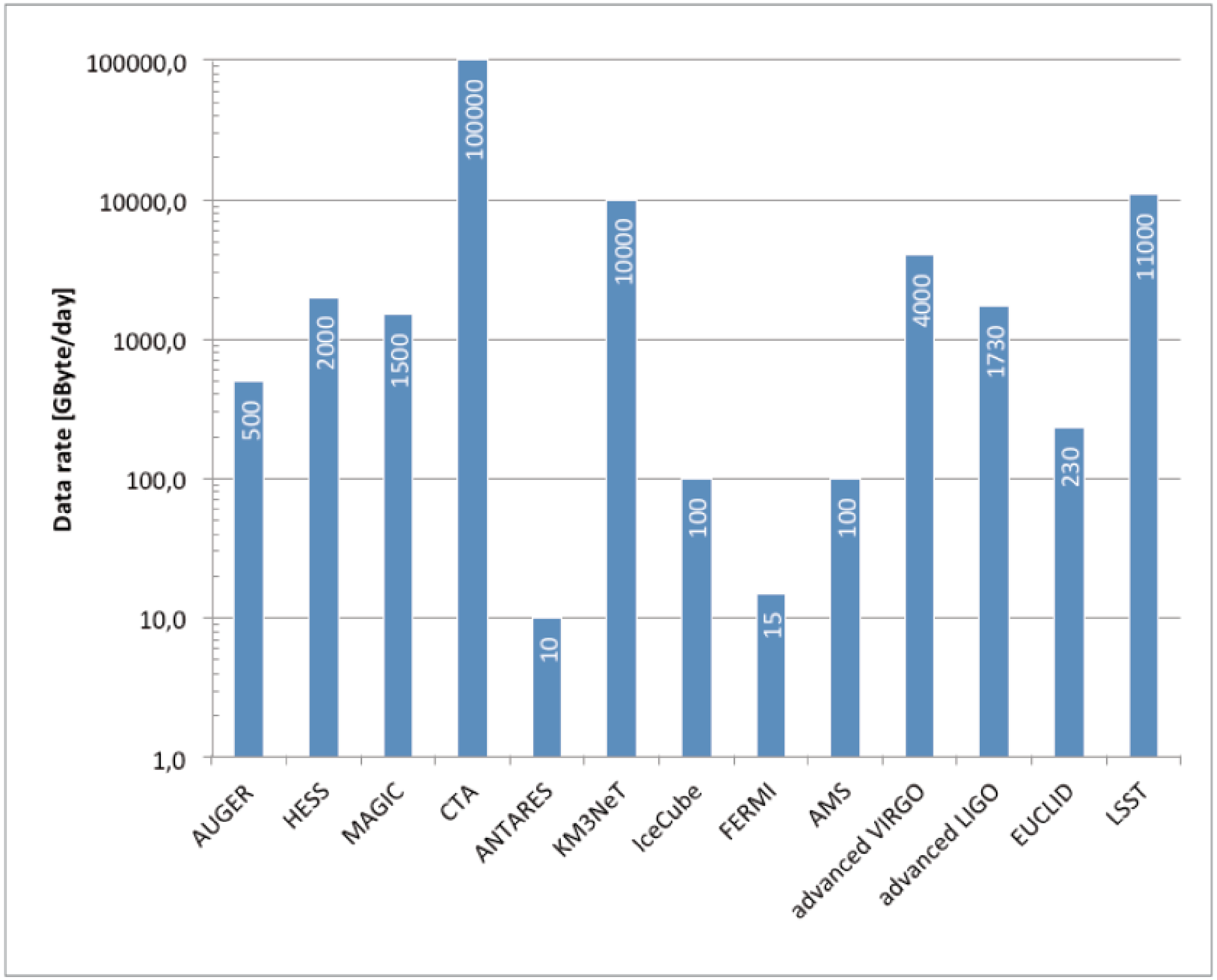
filter+SiPM+ASIC
(temperature control) + power
in a modular design
connected to a CPU



Requirements for ASIC Development for EUSO-like devices, e.g.:
(compared to presently available Citiroc)

- **Larger number of channel input: 64, 128, 256?**
- **5 ns timing resolution and pulse shaping**
- **Low power consumption (2mW/ch or less)**
- **Internal biasing for flat fielding/temperature control**
- **Bin length selectable from 250ns-5µs**
- **Internal biasing for flat fielding/temperature control**
- **….**

Computing in Astroparticle Physics (Astro-GRID?)



➔Do we need an own (astroparticle) infrastructure?

Source: APPEC brochure on Computing, 2016

Big Data – Digital Agenda - Data Preservation – Deep Learning

Big Data Science: Astroparticle Physics

Digitale Agenda

Bundesministerium für Bildung und Forschung

1. Digitalen Wandel in der Wissenschaft forcieren
2. Zugang zu Wissen als Grundlage für Innovation sichern
3. Bildungsoffensive für die digitale Wissensgesellschaft
4. Innovationspotenziale der Digitalisierung nutzen
5. Durch Forschung den digitalen Wandel verstehen
6. Kultur und Medien

Big Data Science Astroparticle Physics

- **Open data storage & Software to access data**
- **Deep Learning**

HAP workshop on **Big Data Science in Astroparticle Physics** voraussichtlich 2/2017

M. Erdmann, A. Haungs

Martin Erdmann 24

→ We need to give more attention to this group of topics

Open access:
https://kcdc.ikp.kit.edu

….as example, there are also other activities…
(Vista, AMON, ….)

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"Novel Detection Technologies and Future Challenges"

(Technological Challenges next 5 years….)

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➔ (again) a lot of challenges …..