Federal Ministry
of Education
and Research

ASPERA

Global cosmic-ray detection:

A technology review
(brainstorming)

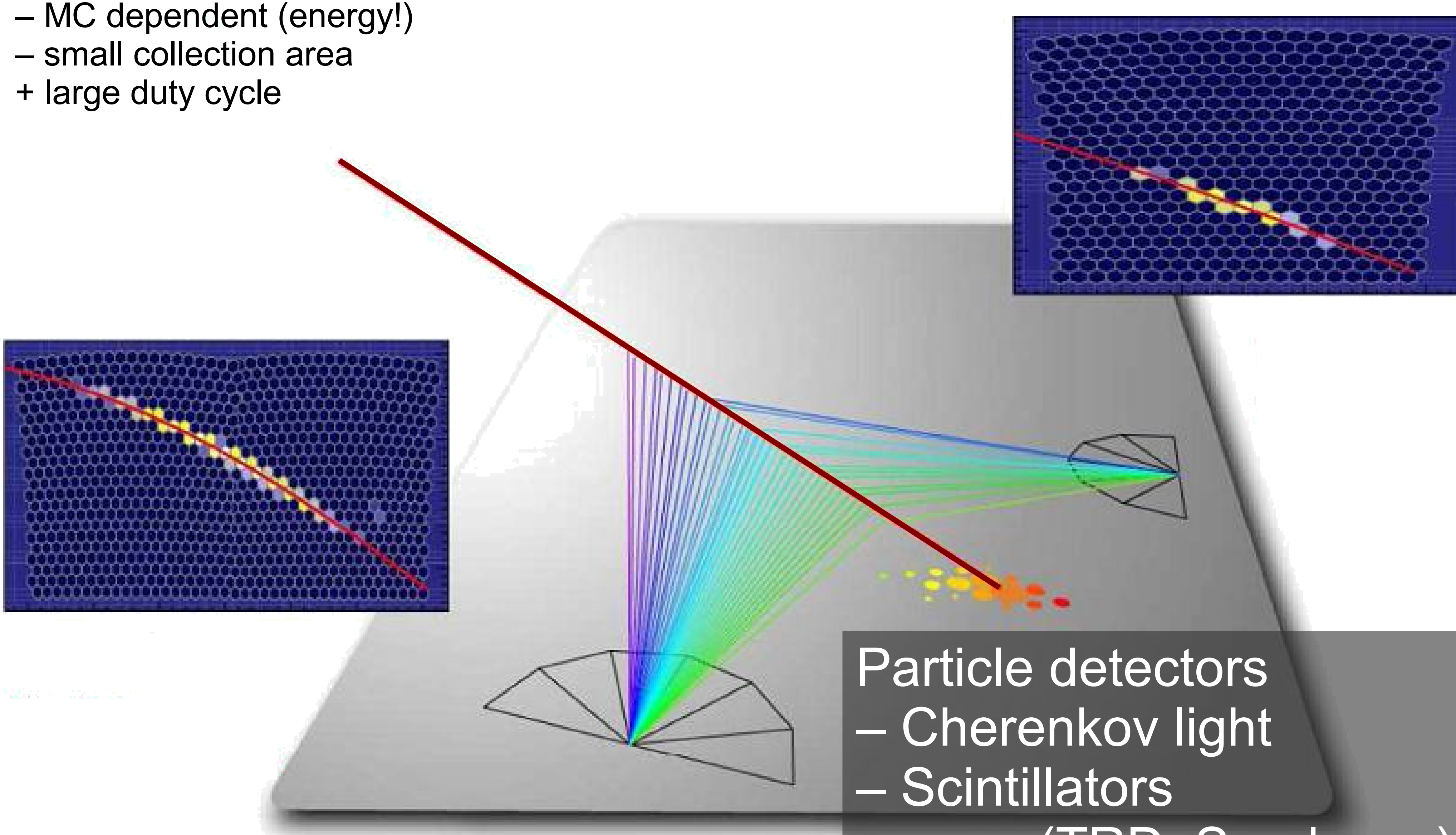
from my perspective
and incomplete!

Thomas Bretz

RWTH AACHEN UNIVERSITY

Particle shower detection

– MC dependent (energy!)
– small collection area
+ large duty cycle

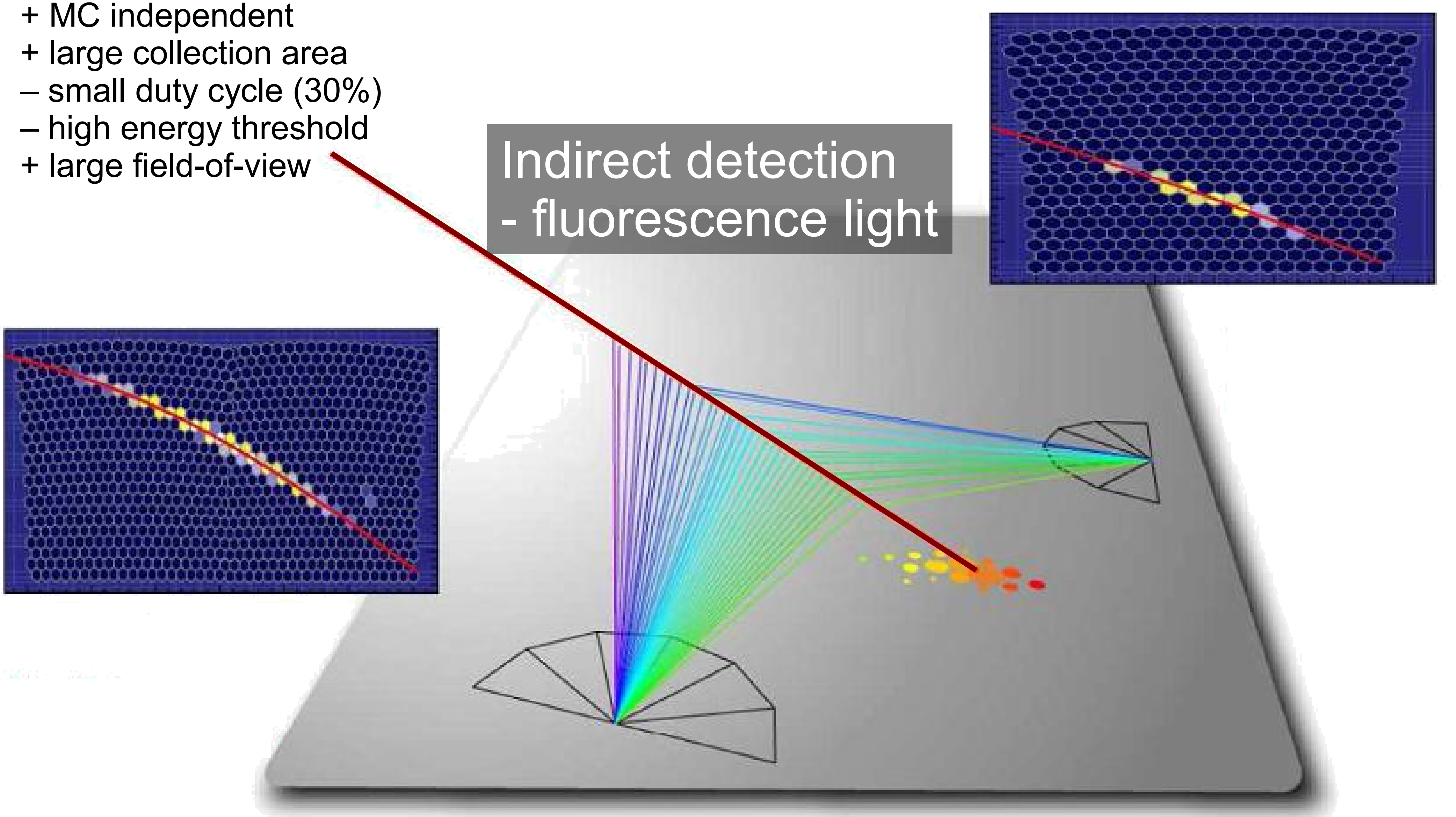


Particle detectors
– Cherenkov light
– Scintillators
– more (TRD, Sparks, ...)

Telescope Array, Pierre Auger, HAWC, IceTop

Particle shower detection

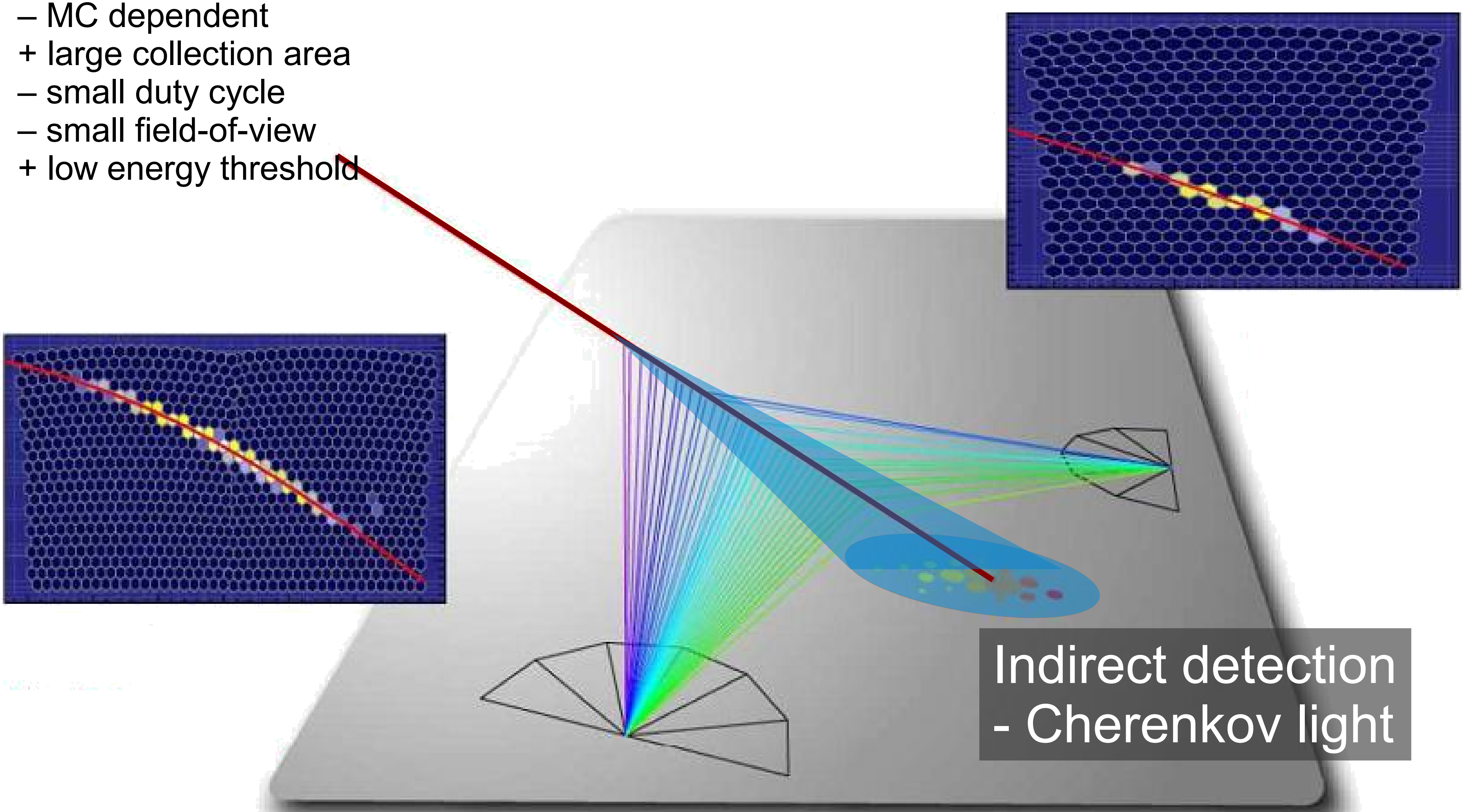
+ MC independent
+ large collection area
– small duty cycle (30%)
– high energy threshold
+ large field-of-view



Pierre Auger, Telescope Array

Particle shower detection

– MC dependent
+ large collection area
– small duty cycle
– small field-of-view
+ low energy threshold

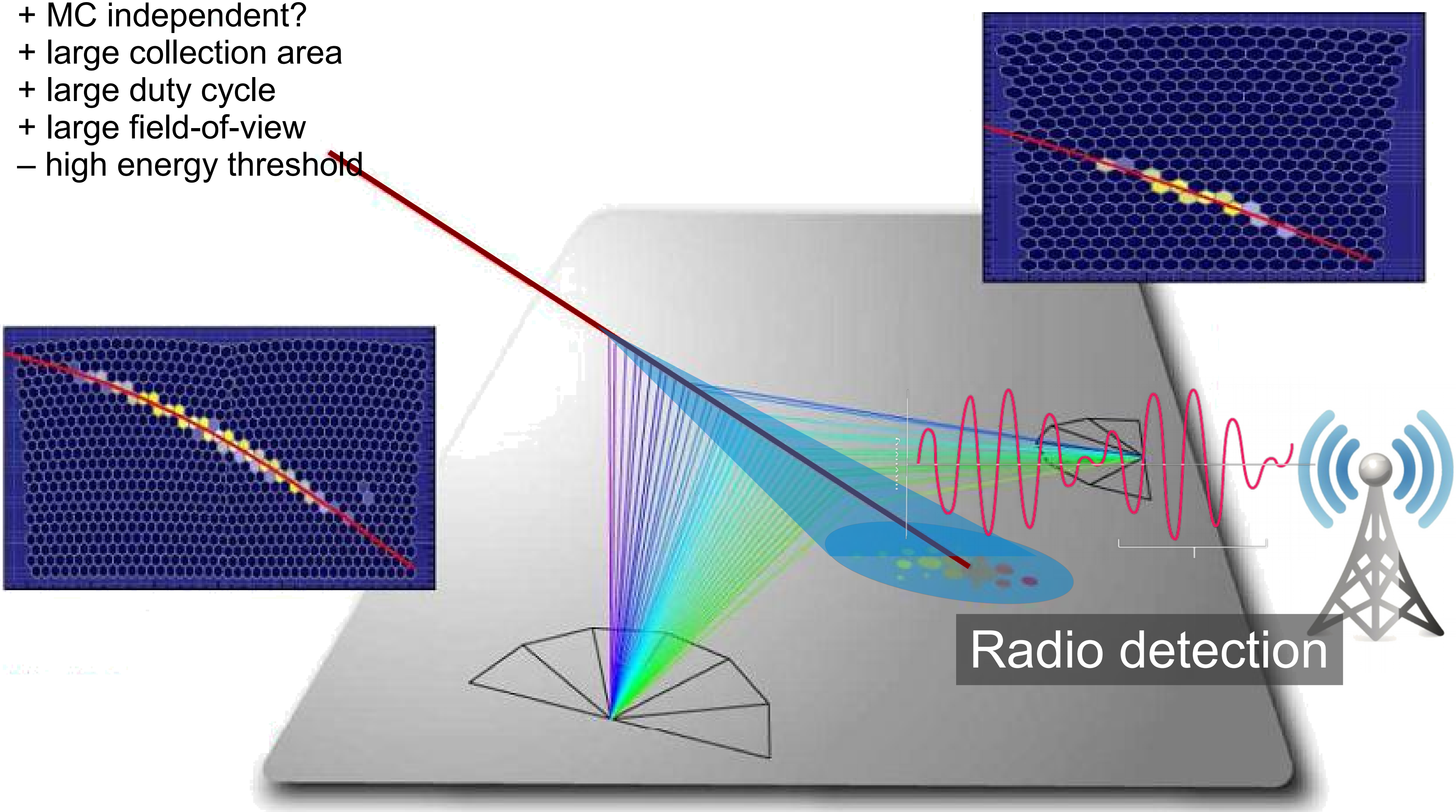


Pointed or ground array

FACT, M@TE, H.E.S.S., MAGIC, VERITAS, CTA, HiSCORE

Particle shower detection

+ MC independent?
+ large collection area
+ large duty cycle
+ large field-of-view
– high energy threshold



AERA, Tunka, ...


Pampa Amarilla, Argentina
?


Pampa Amarilla, Argentina

Weather monitoring?

- ***Global***
  → politics? masses?
  → price
  → maintenance

- ***cosmic-ray***
  → duty cycle
  → large detector surface

- ***detection***
  → direct vs indirect

  → detector technology
  (e.g. PMT vs SiPM)

Global

- **Distributed network**
  → networking, time resolution (nanoseconds?), hybrid
- **Mass product**
  → Distribution, public relation
- **Location**
  → Weather conditions, detector position, data analysis
- **Robustness**
  → Weather, maintenance (e.g. car electronics)
- **Deployment**
  → Mobile phones? Manual deployment?
- **Politics**
  → Many countries involved

→ ***All this needs to be considered in the design***

Cosmic-rays

- **Energy range**
  → Particle density on ground
- **Expected flux**
  → Background
- **Dynamic range**
  → Data acquisition, detector technology
- **Angular acceptance**
  → Imaging vs. non-imaging, etc.

→ ***All this needs to be considered in the design***

Detector technology

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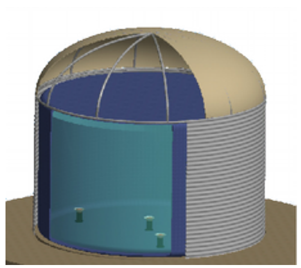
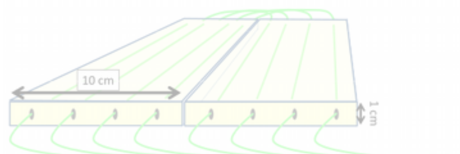


- ***Water***
  → Auger
  → HAWC

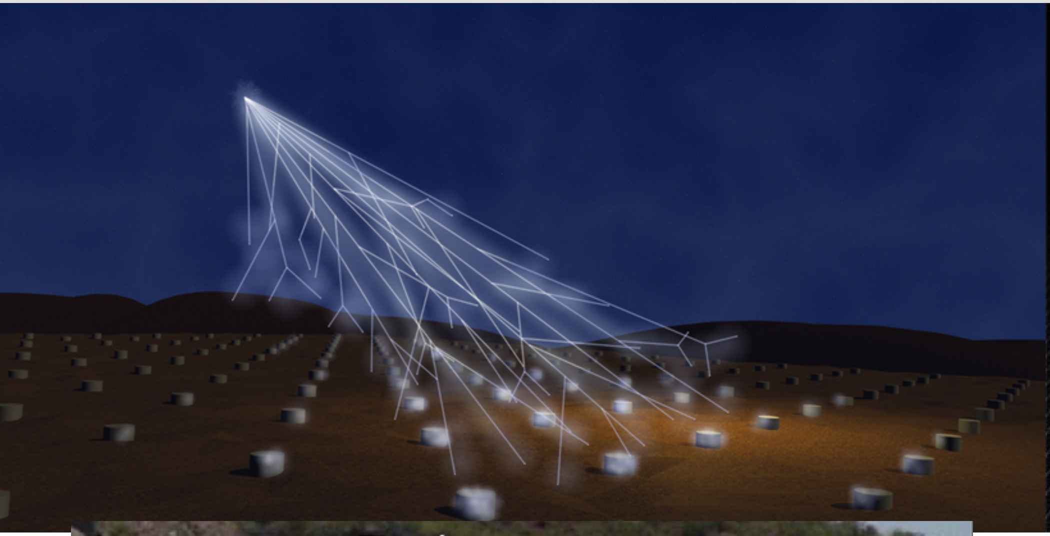


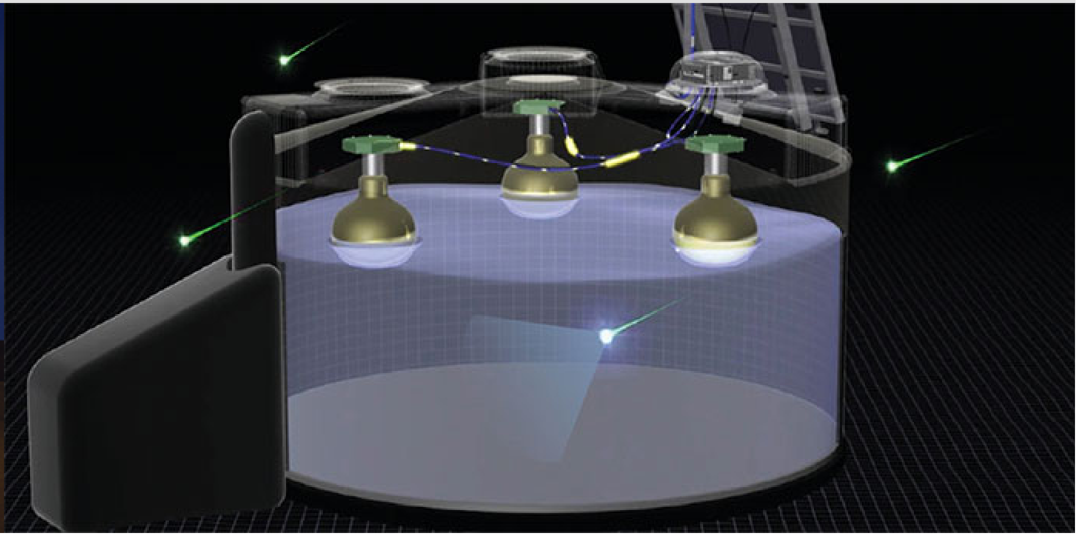
- ***Plastic scintillator***
  → Telescope Array
  → Auger Prime (SSD)

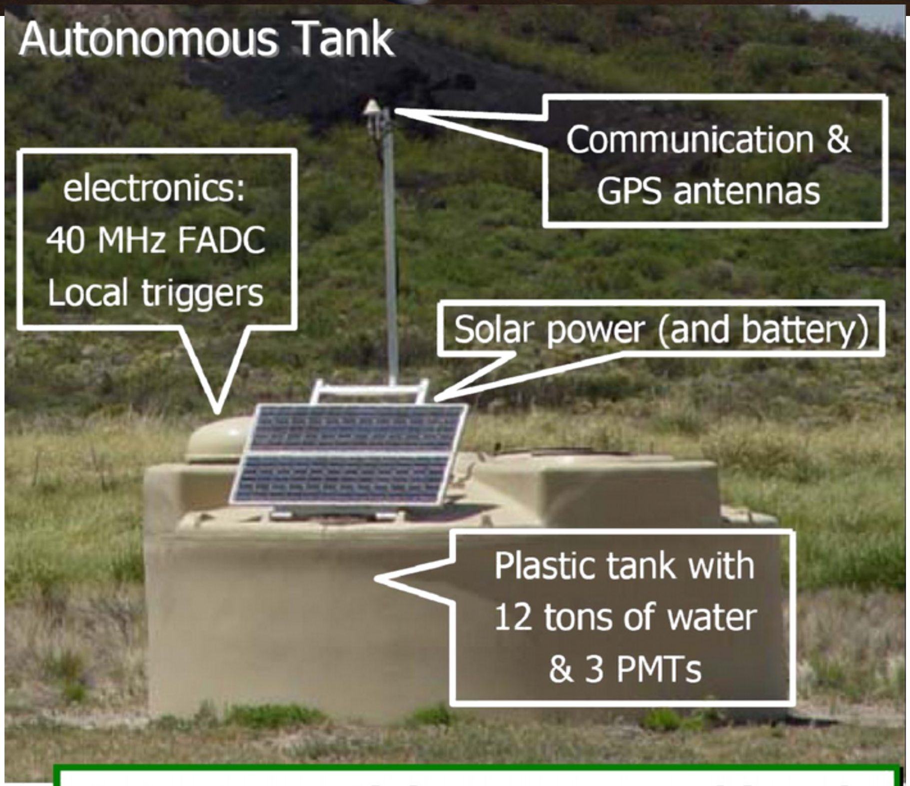
- ***Air***
  → Cherenkov telescopes
  → Fluorescence telescopes

- ***Radio***
  → Tunka
  → Auger
  → Lofar

Auger surface detectors







Detects particles on ground level

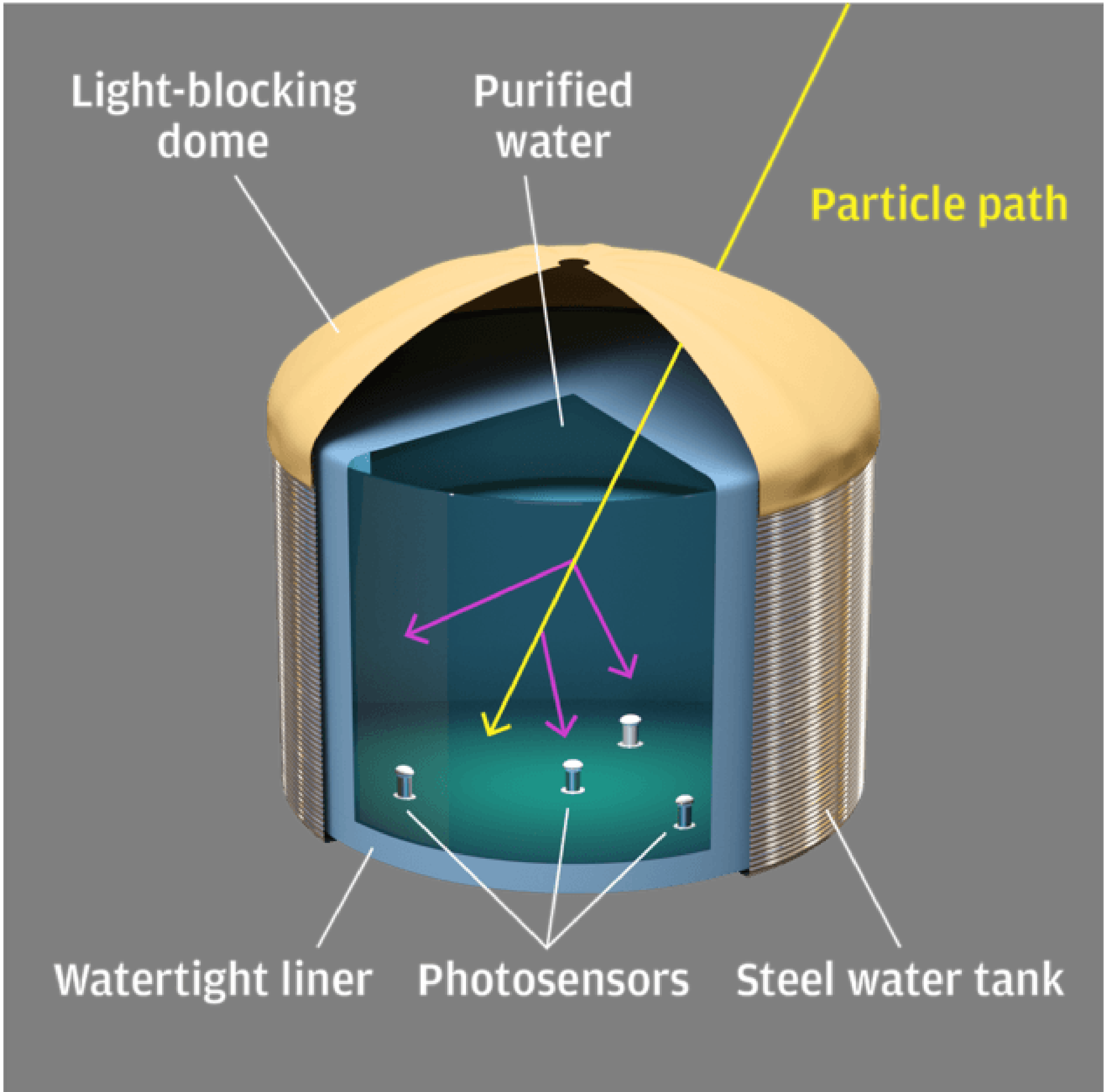
Larger Volume → more light
Needed surface depends on particle density (= energy)

Use of existing water reservoirs?
Lakes?
Swimming pools?
What's the energy threshold?

HAWC Observatory

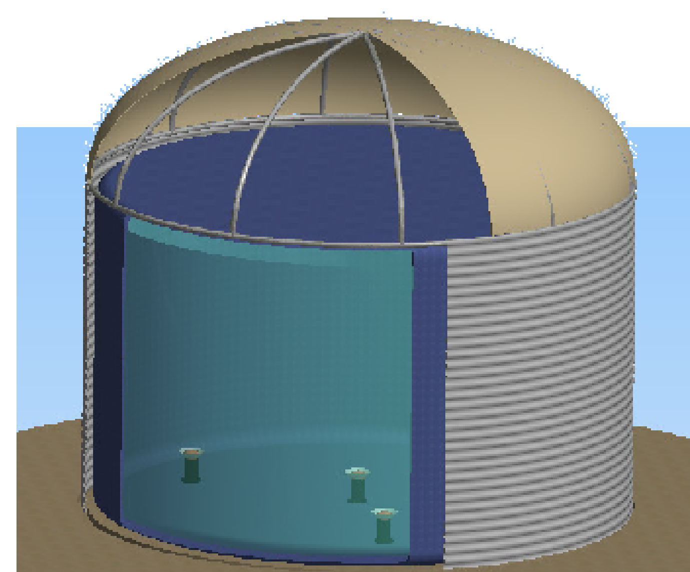

HAWC – High altitude water Cherenkov observatory
TeV astronomy
(Pico de Orizaba, Mexico)
300 5m water tanks with 4 PMT to detect Cherenkov light

Water tanks (HAWC)

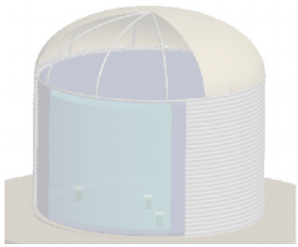


Water quality is an issue
Tank can be low-cost
Needs large photon detectors

No SiPM solution yet (maybe for small tanks? New development?)



Detector technology



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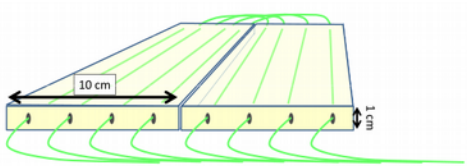

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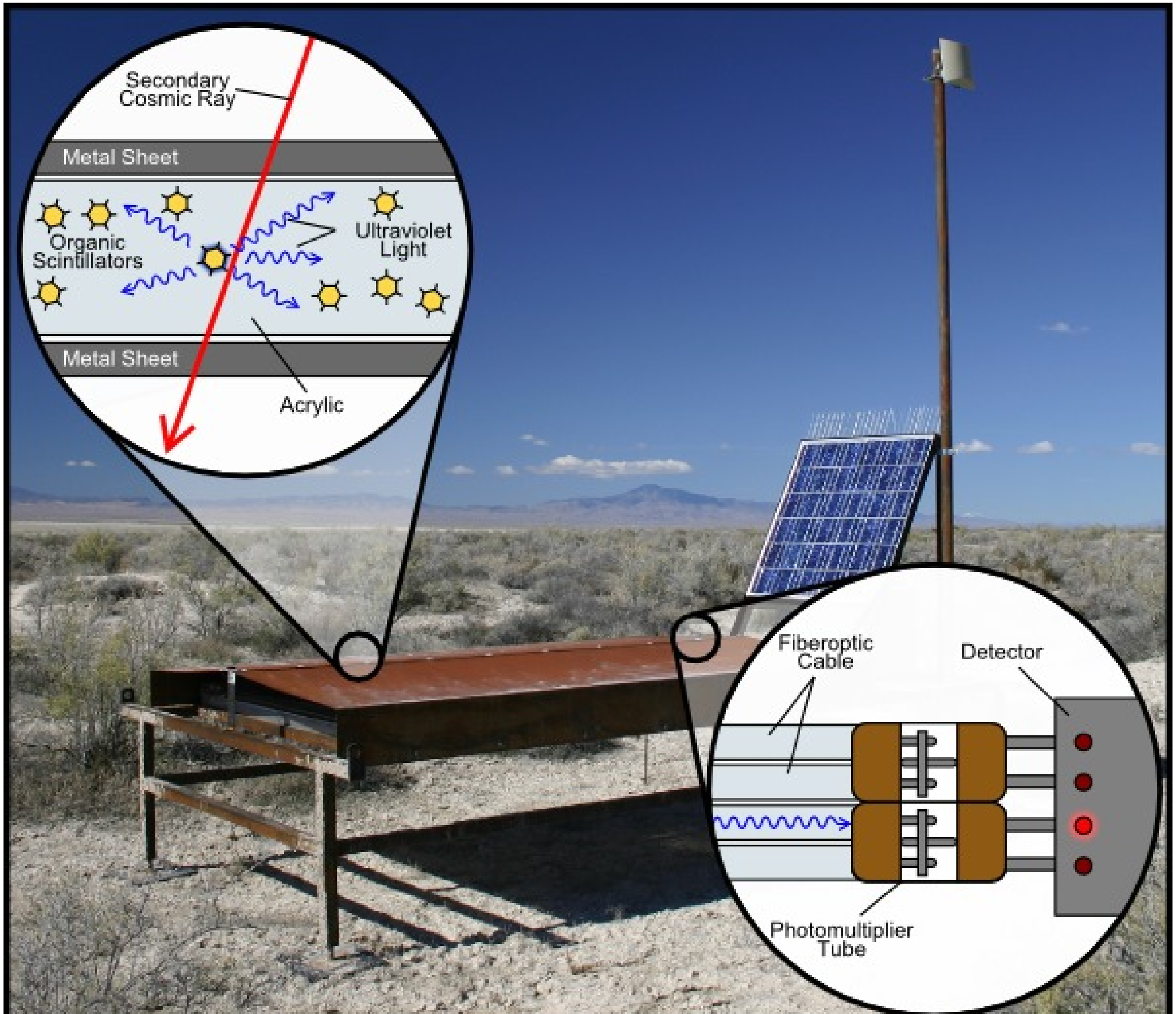


Easier to handle than water

no fluid components

higher light yield
→ smaller volume

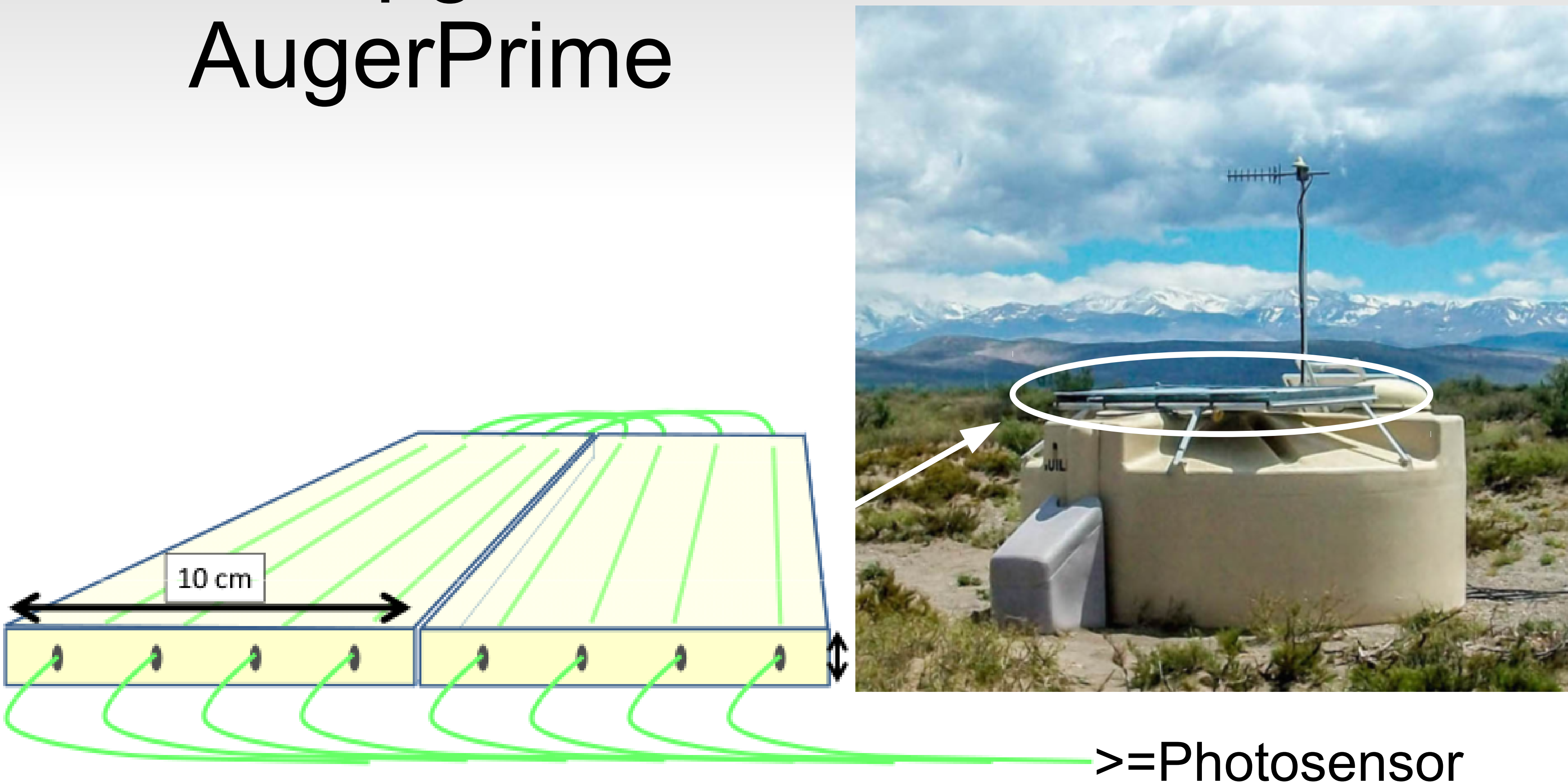
Needed surface depends on particle density (= energy)

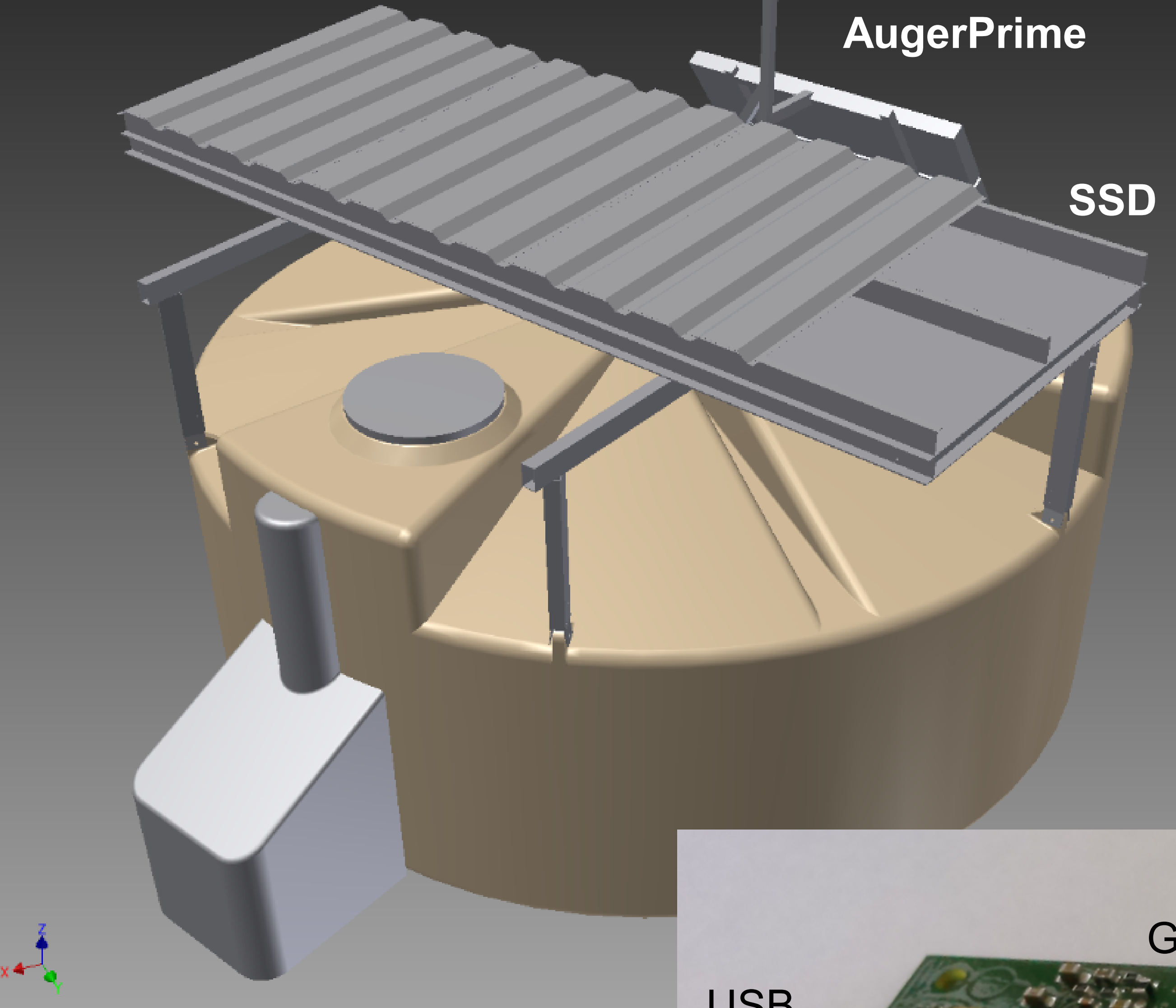
Well established

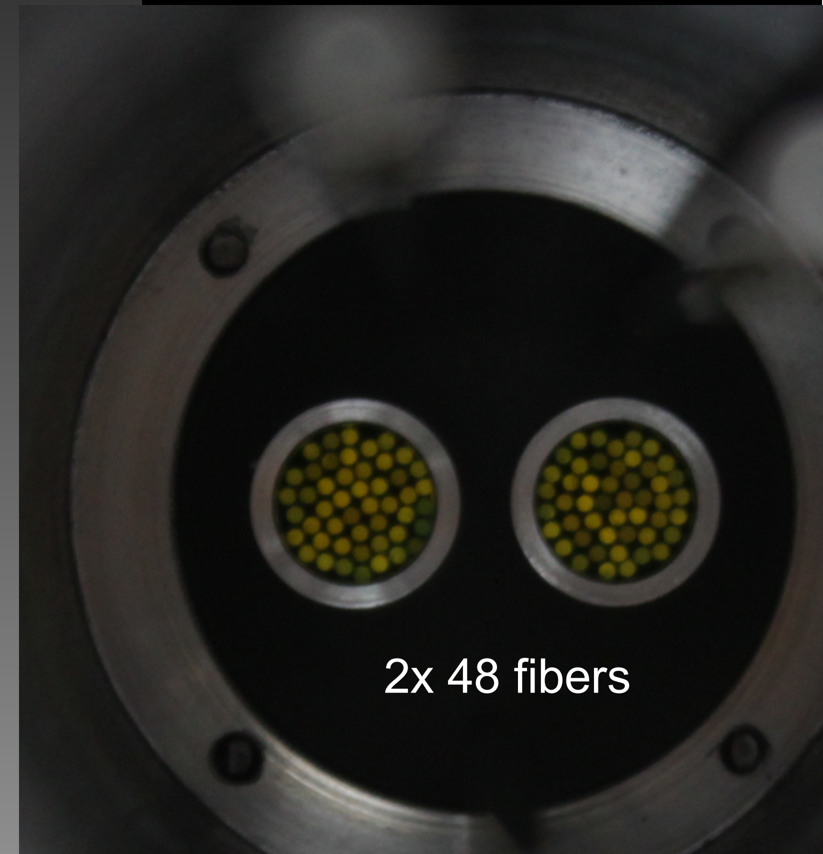
scalable

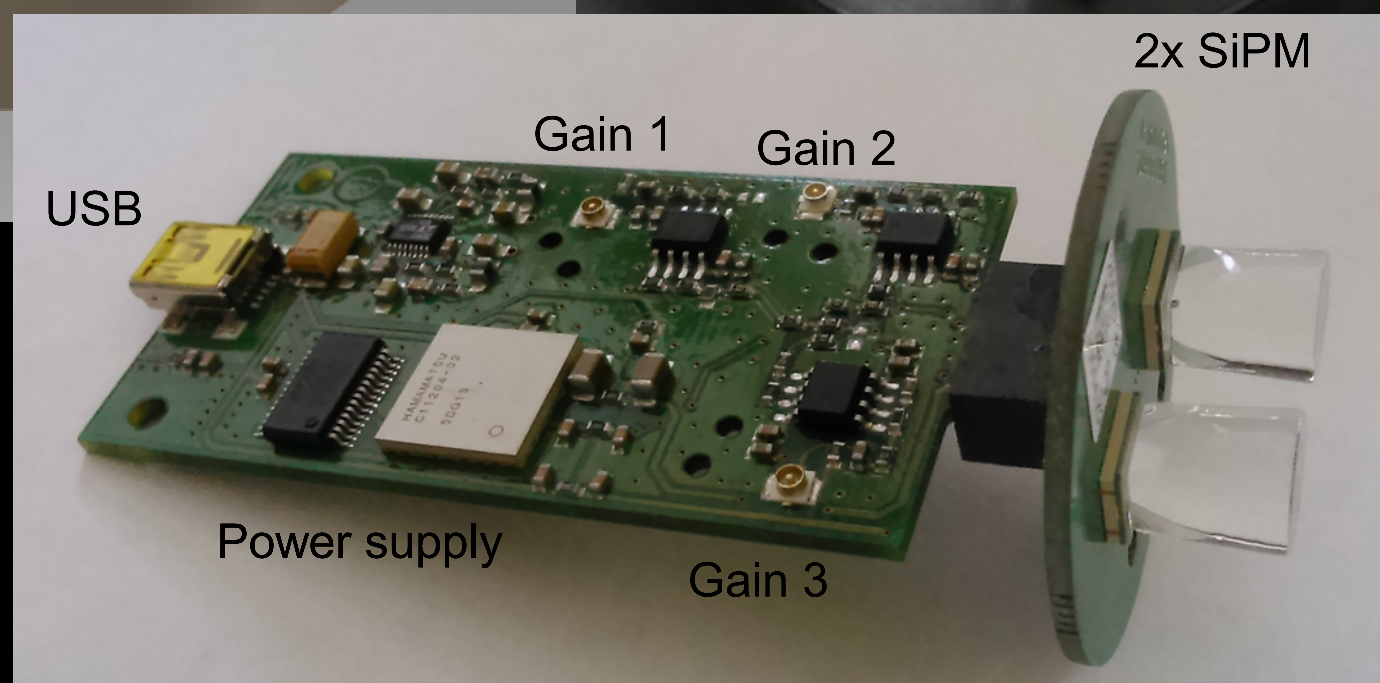
Pierre Auger – AugerPrime SSD

The Upgrade – AugerPrime



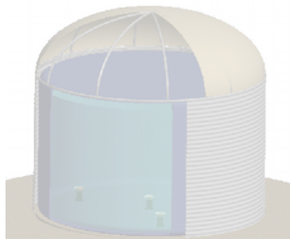






Installation
→ this week

Detector technology



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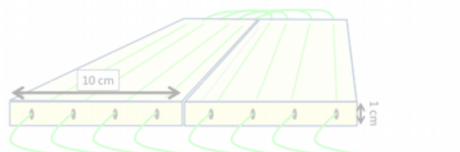

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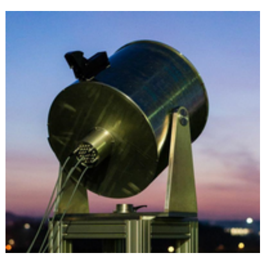
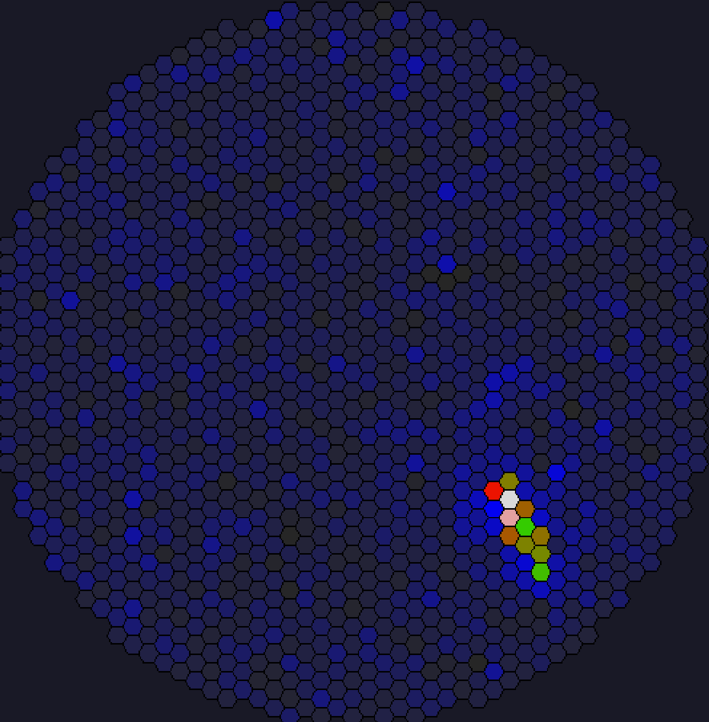
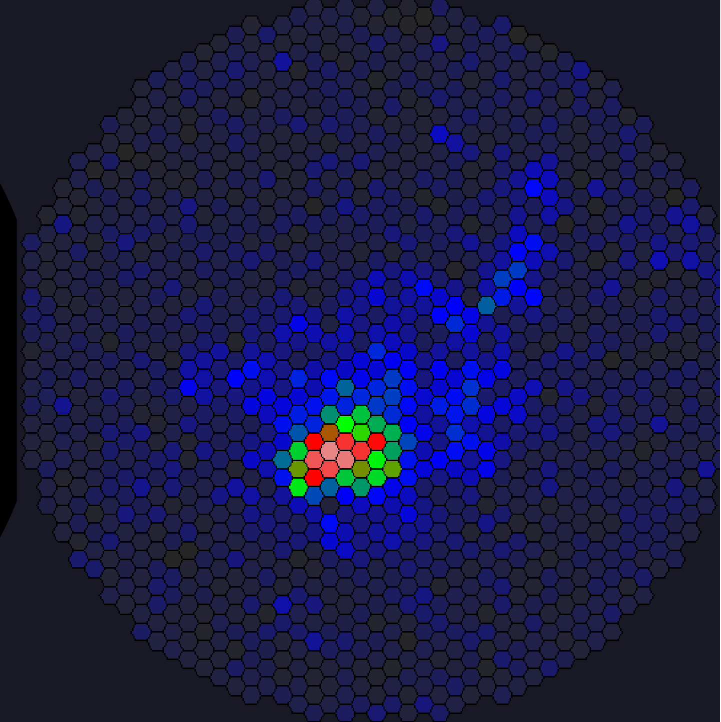


- ***Air***
  → Cherenkov telescopes
  → Fluorescence telescopes

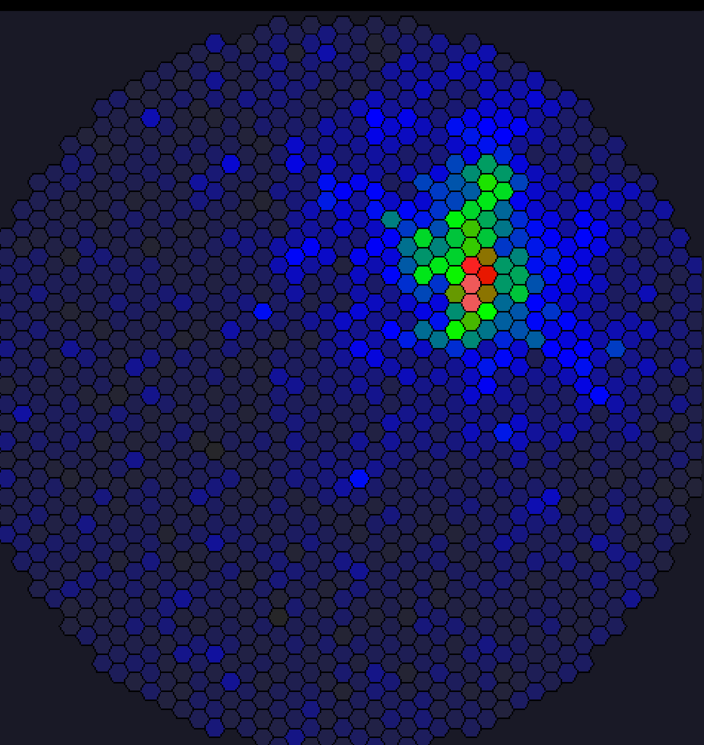
- ***Radio***
  → Tunka
  → Auger
  → Lofar

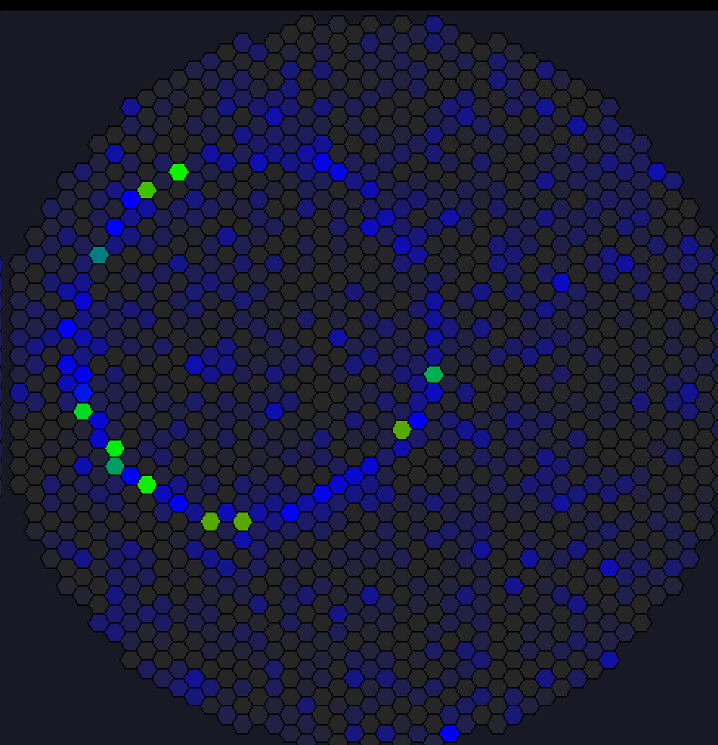


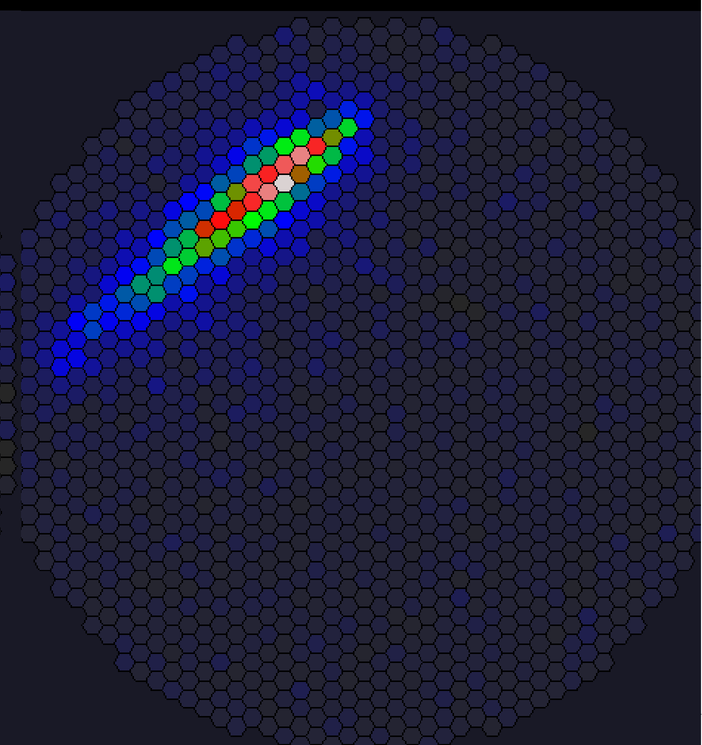
Imaging?
- expensive
- smaller FoV

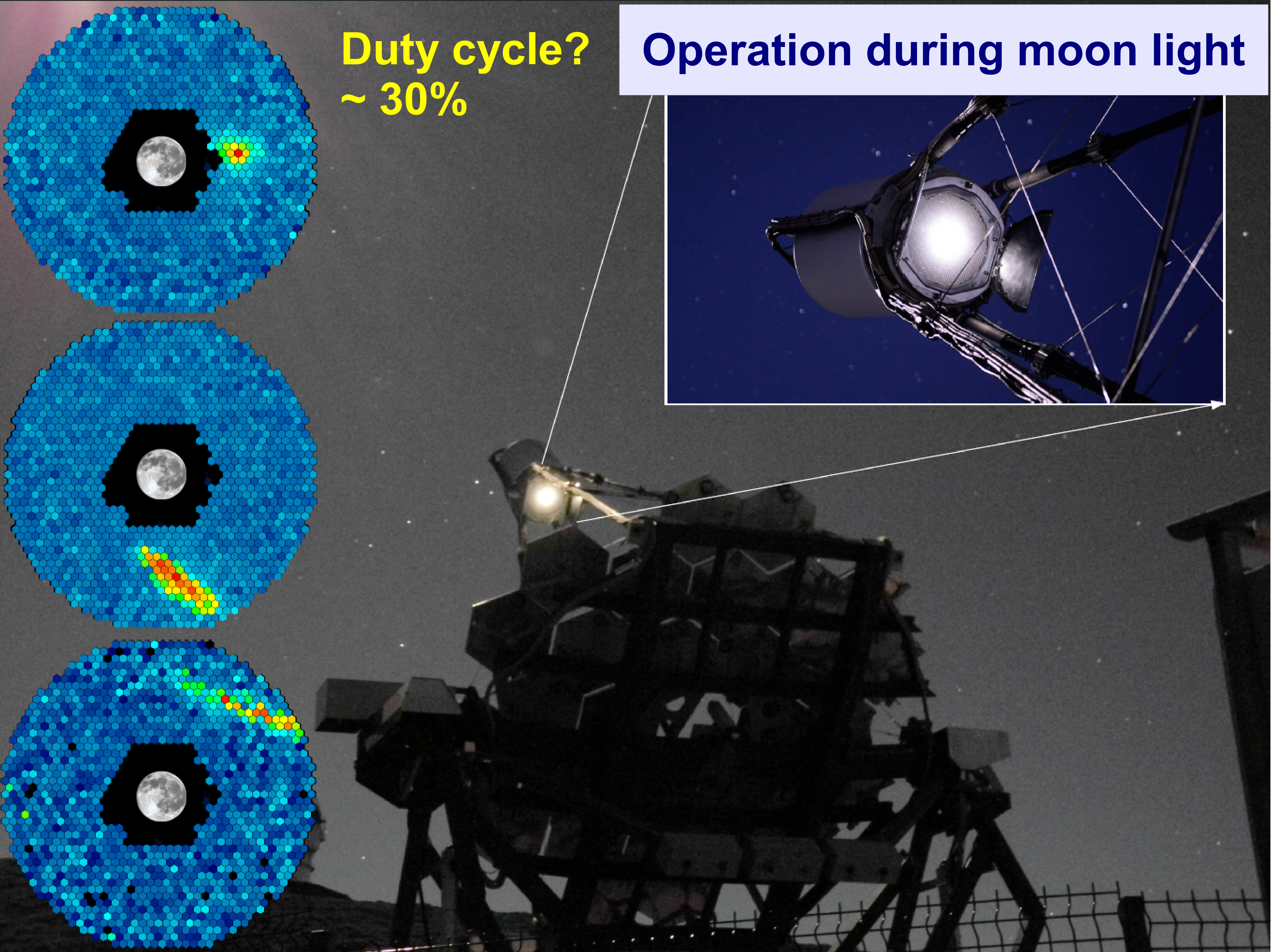


FACT – Selected events of the first nights of data-taking (11 Oct. 2011)

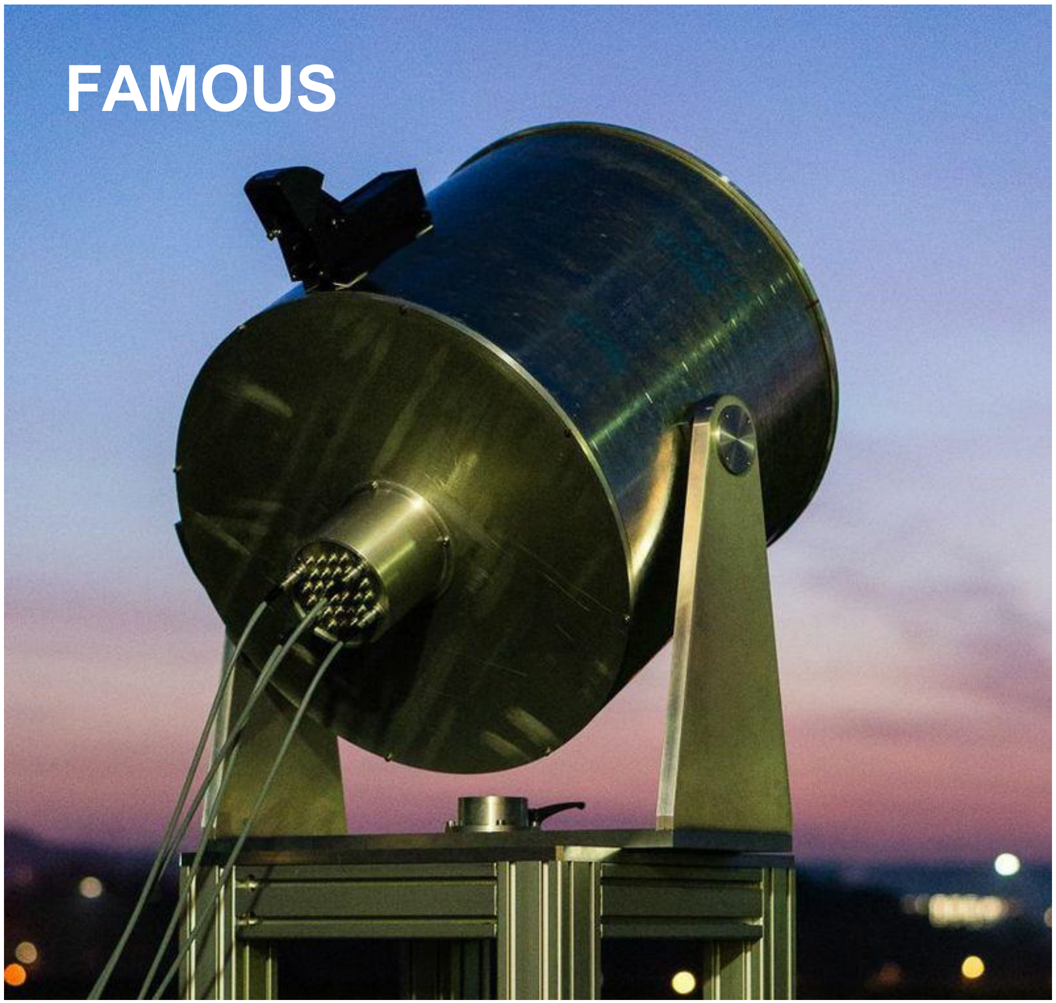







Duty cycle?
~ 30%
Operation during moon light

Small (fluorescence?) telescopes



Small duty cycle (max 40%, typ. <30%)

Field-of-view

Reflector surface depends on photon density (= energy)

Needs imaging?

Isotropic (low light yield) vs. beamed (high light yield)

prototype → goal: installation at Auger site

HAWC's eye (Cherenkov telescope)

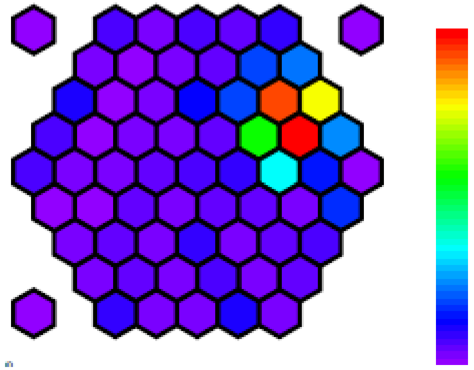
12° FOV

64 pixel (1.5°)

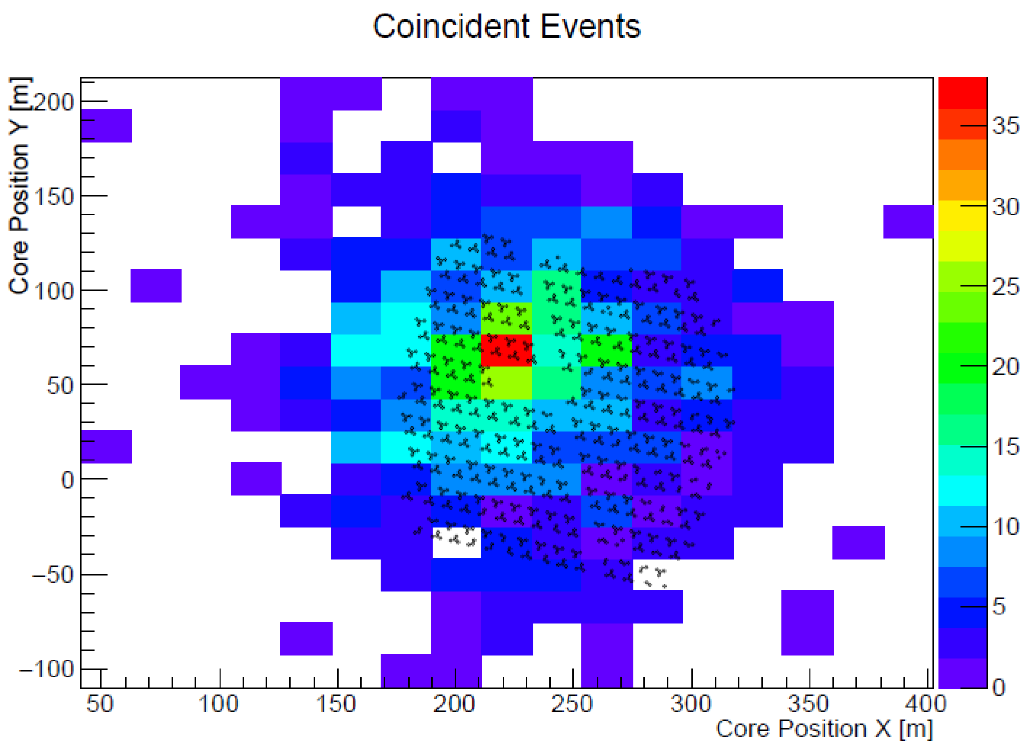
Threshold ~ 30 TeV
→ smaller version possible
→ Larger FOV possible

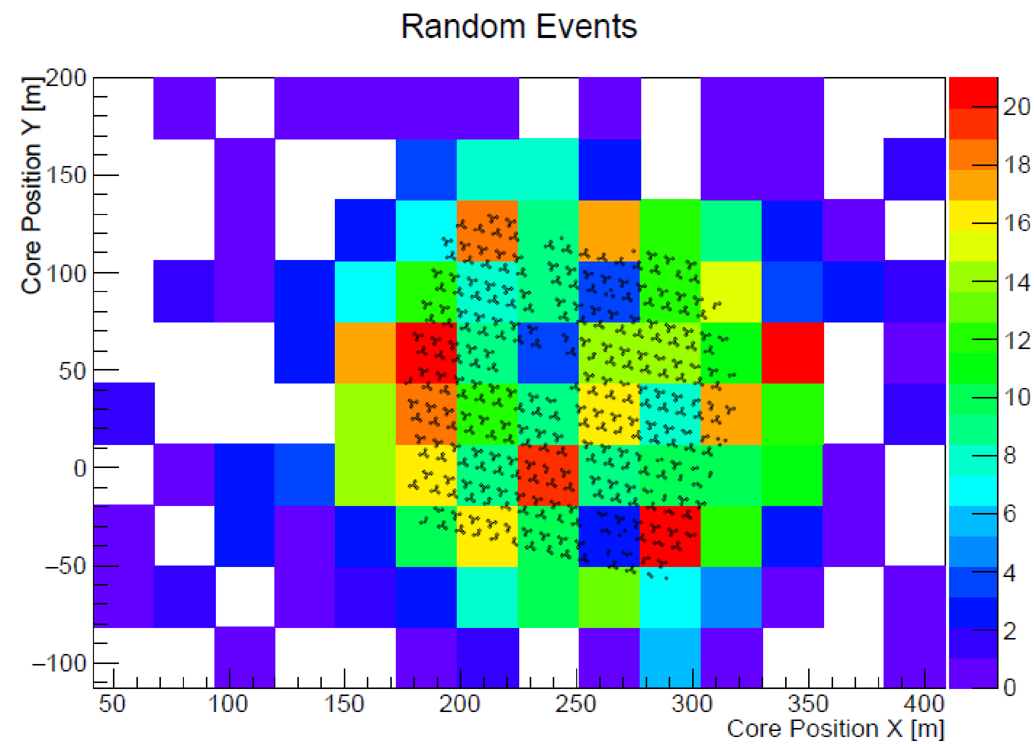
Price < 8000 €

Increases Collection Area



HAWC measured core position

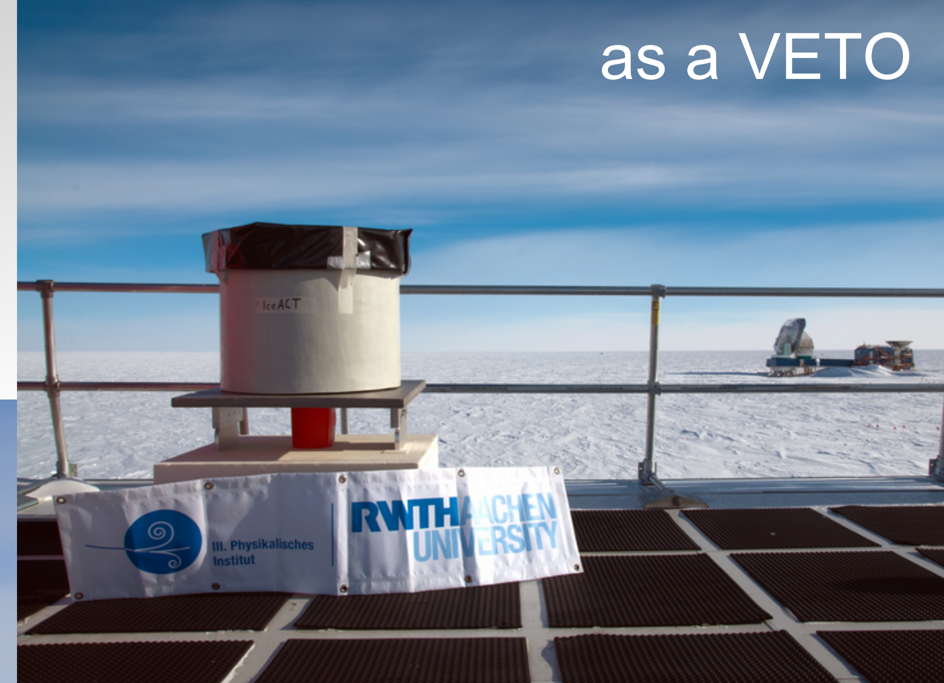




But what do we do without HAWC?

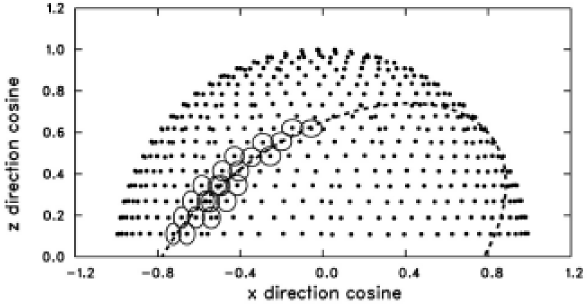
FAMOUS / IceAct

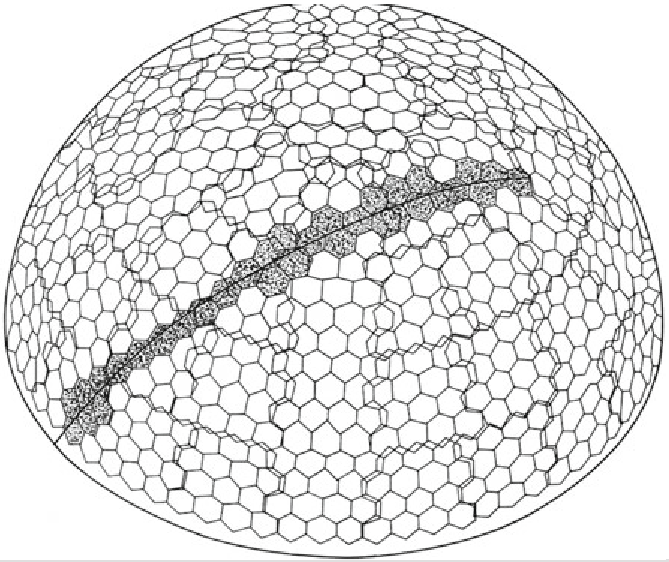
First SiPMs at South Pole!



Fly's eye concept?

University of Utah
1989 – 1992 (Five Miles Hill)
First tests at Volcano Ranch





Hybrid technology?

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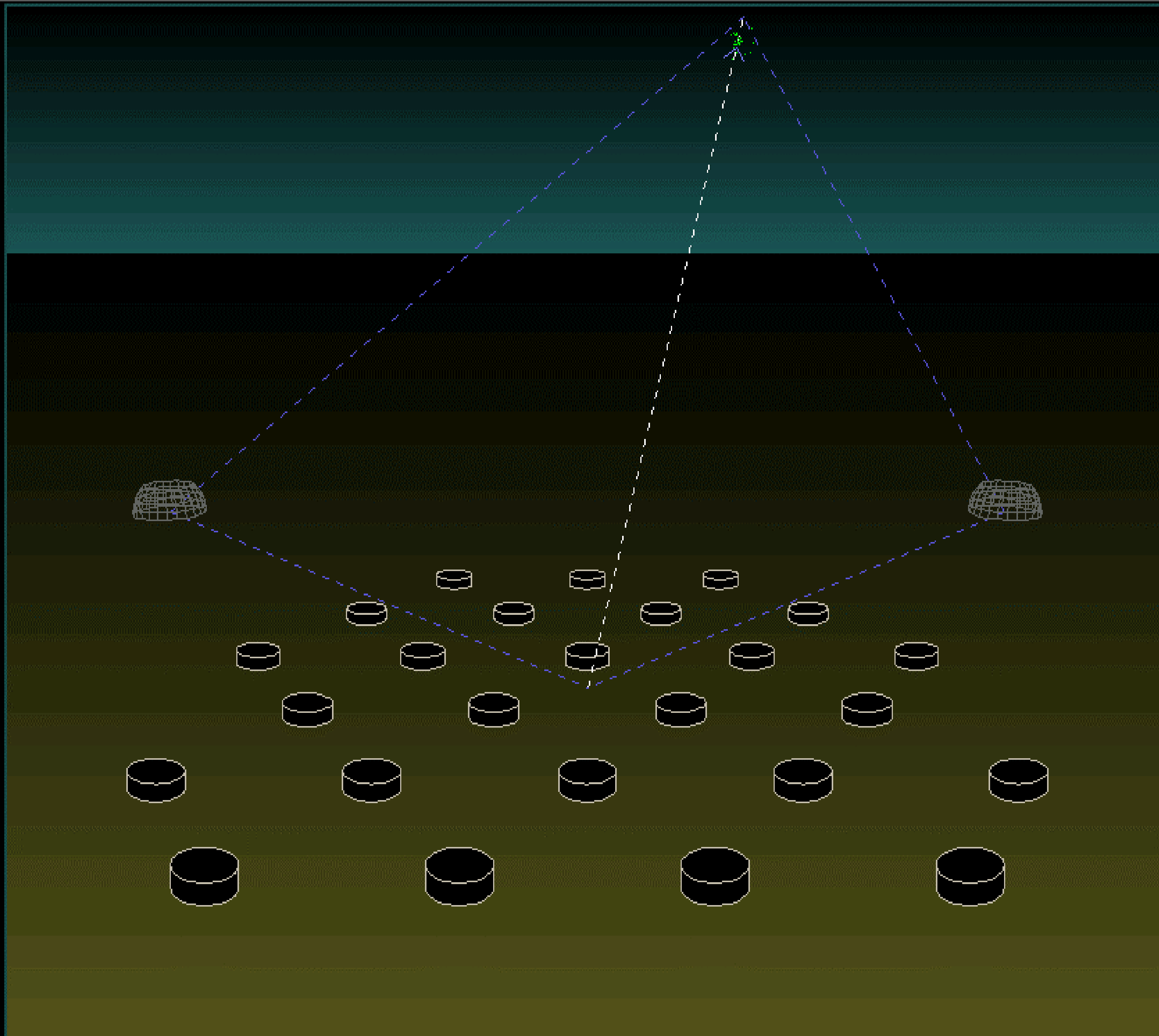
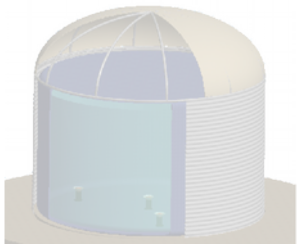


Detector technology



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  → Auger
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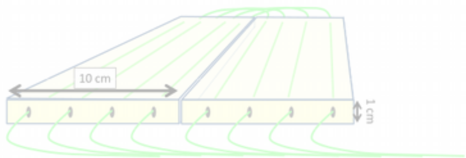

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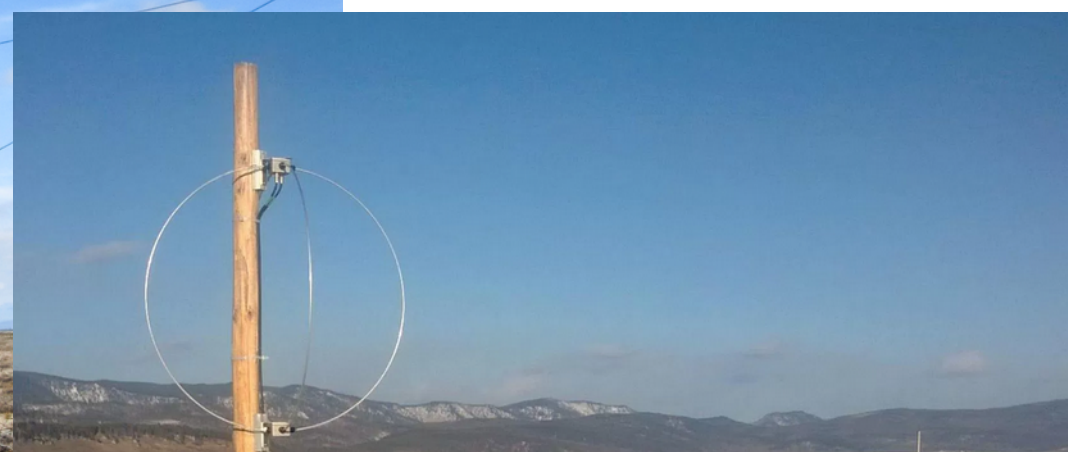
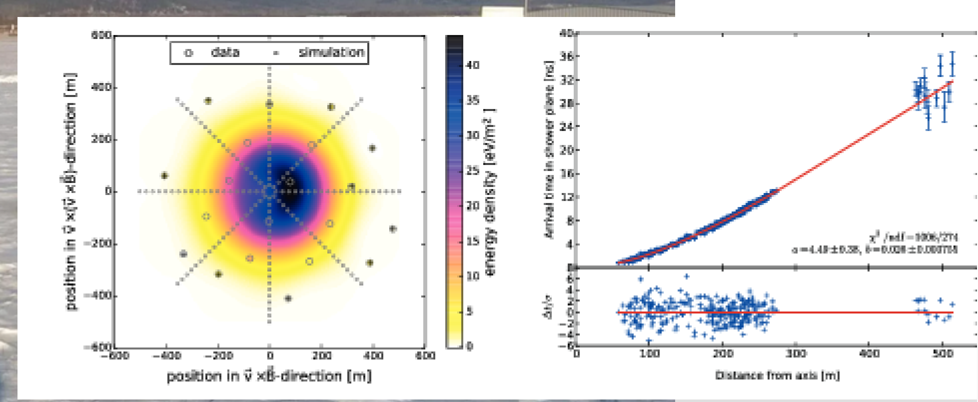
Radio detection



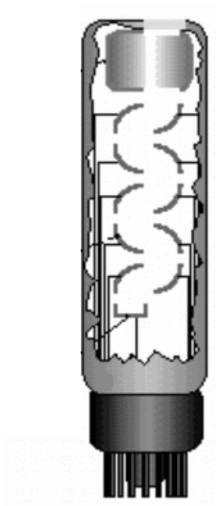


Inexpensive?

Joint infrastructure?

Needs low noise environment
→ Trigger!

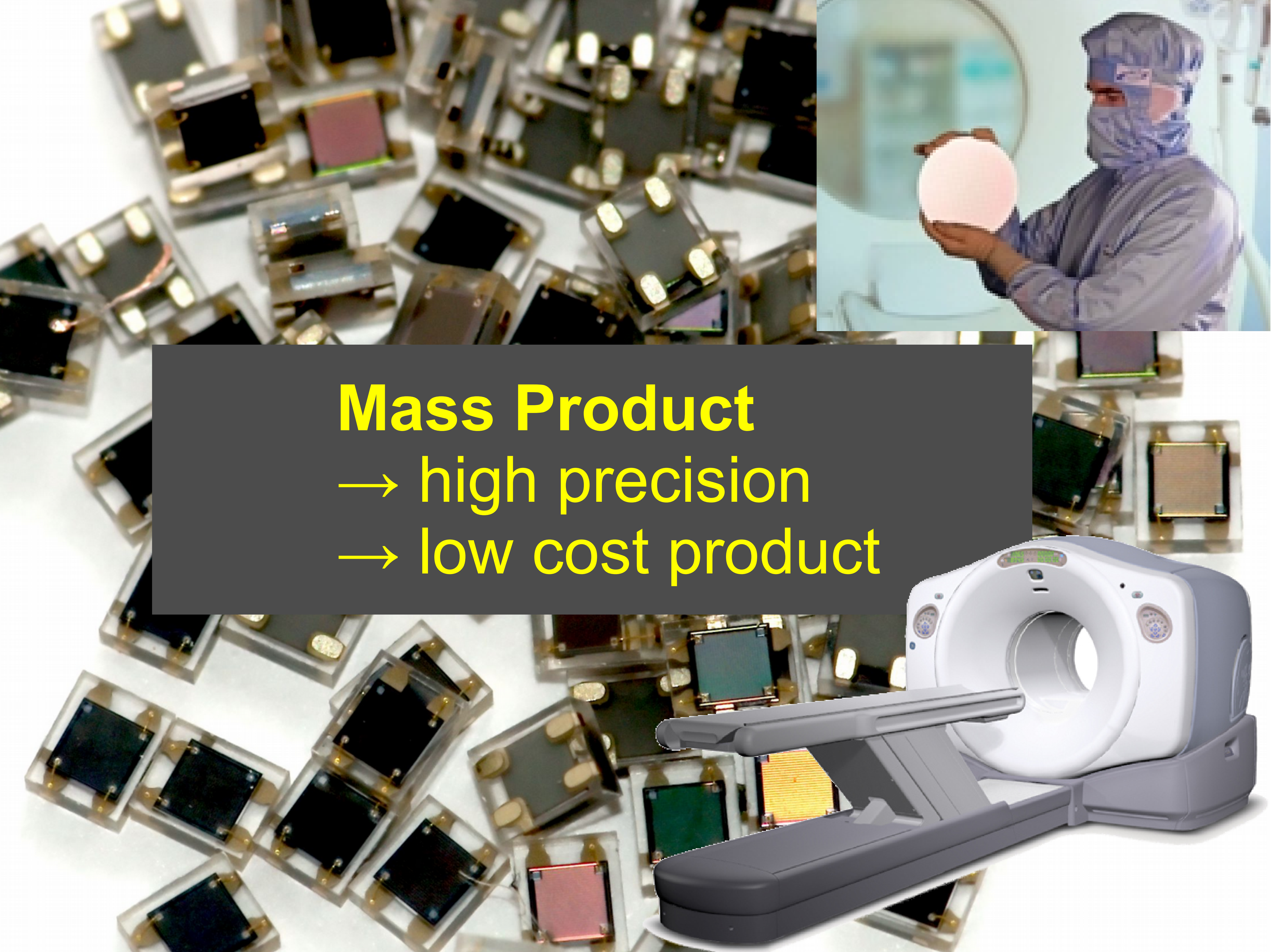
~1934



21st century

- ***Photo multiplier***
  - – mechanically sensitive
  - – High voltages needed
  - – easy to damage (by light)
  - – expensive
  - o well established
  - + low dark count rate
  - + large surfaces

- ***SiPM***
  - – high dark cont rate (10x)
  - – small surface
  - – voltage correction circuit req.
  - o recent technology
  - + mechanically robust
  - + survive bright light
  - + inexpensive / higher PDE



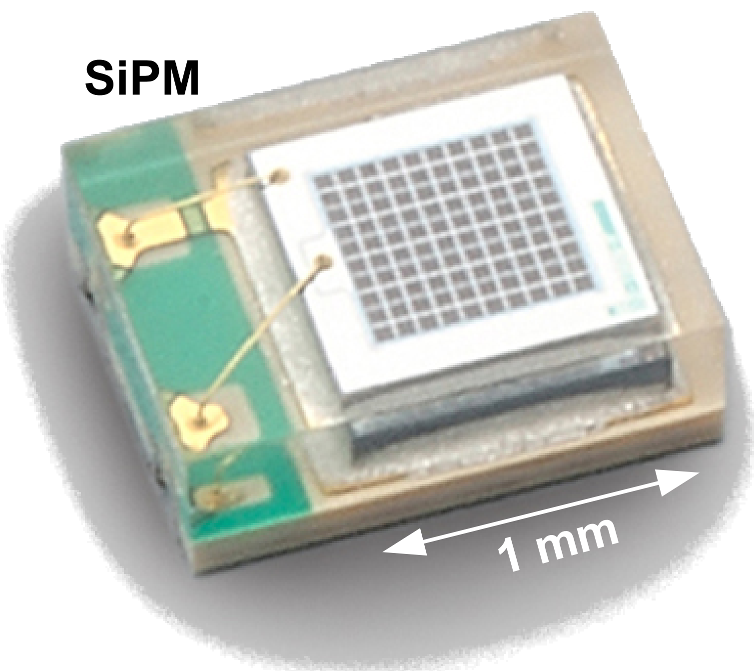
Mass Product

→ high precision

→ low cost product

Silicon based photo sensors

SiPM



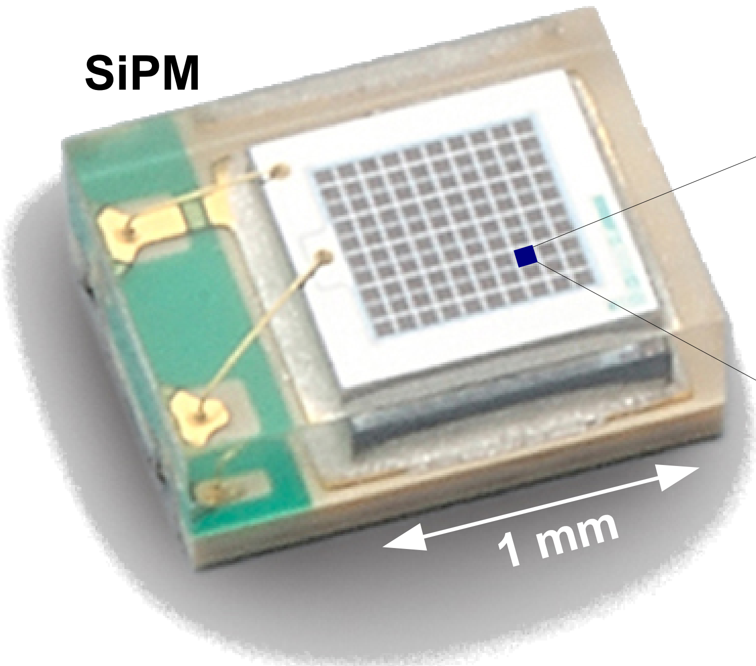
Example: Hamamatsu 1mm²

Credits: Hamamatsu

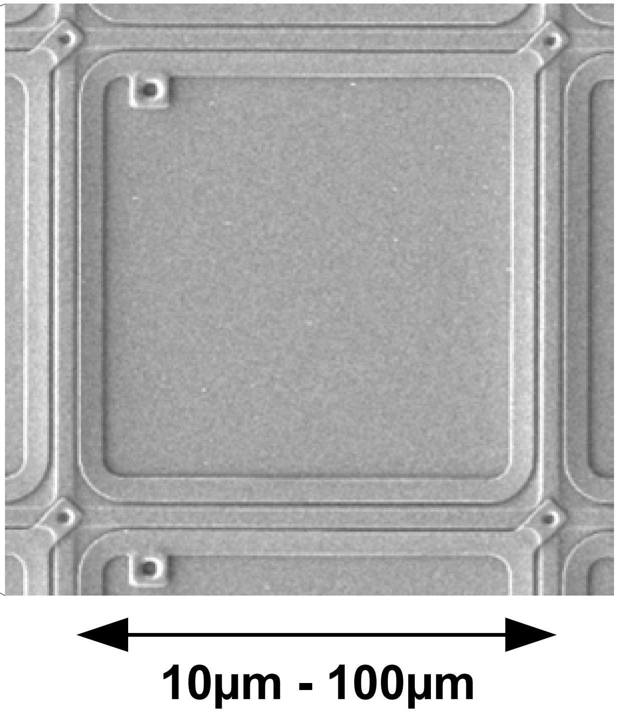
What is a G-APD?

Silicon based photo sensors

Geiger-mode
avalanche photo diode



Example: Hamamatsu 1mm²



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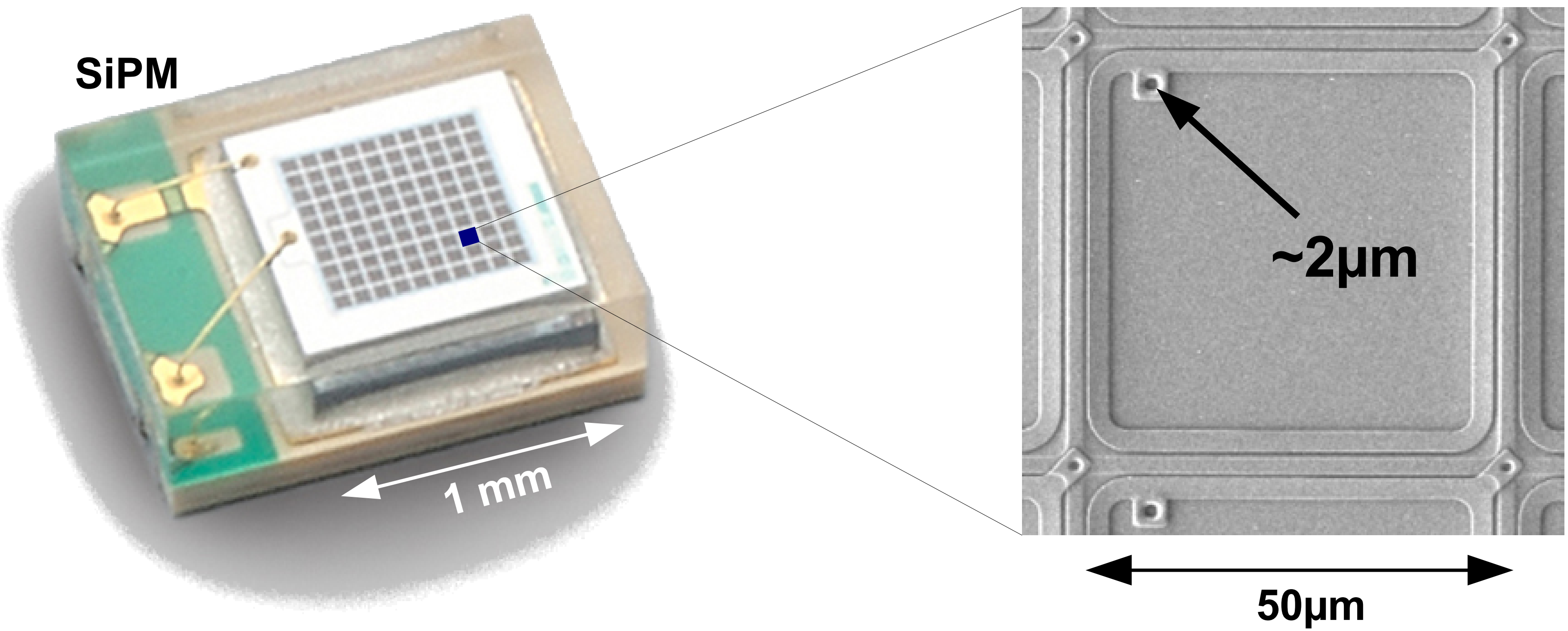


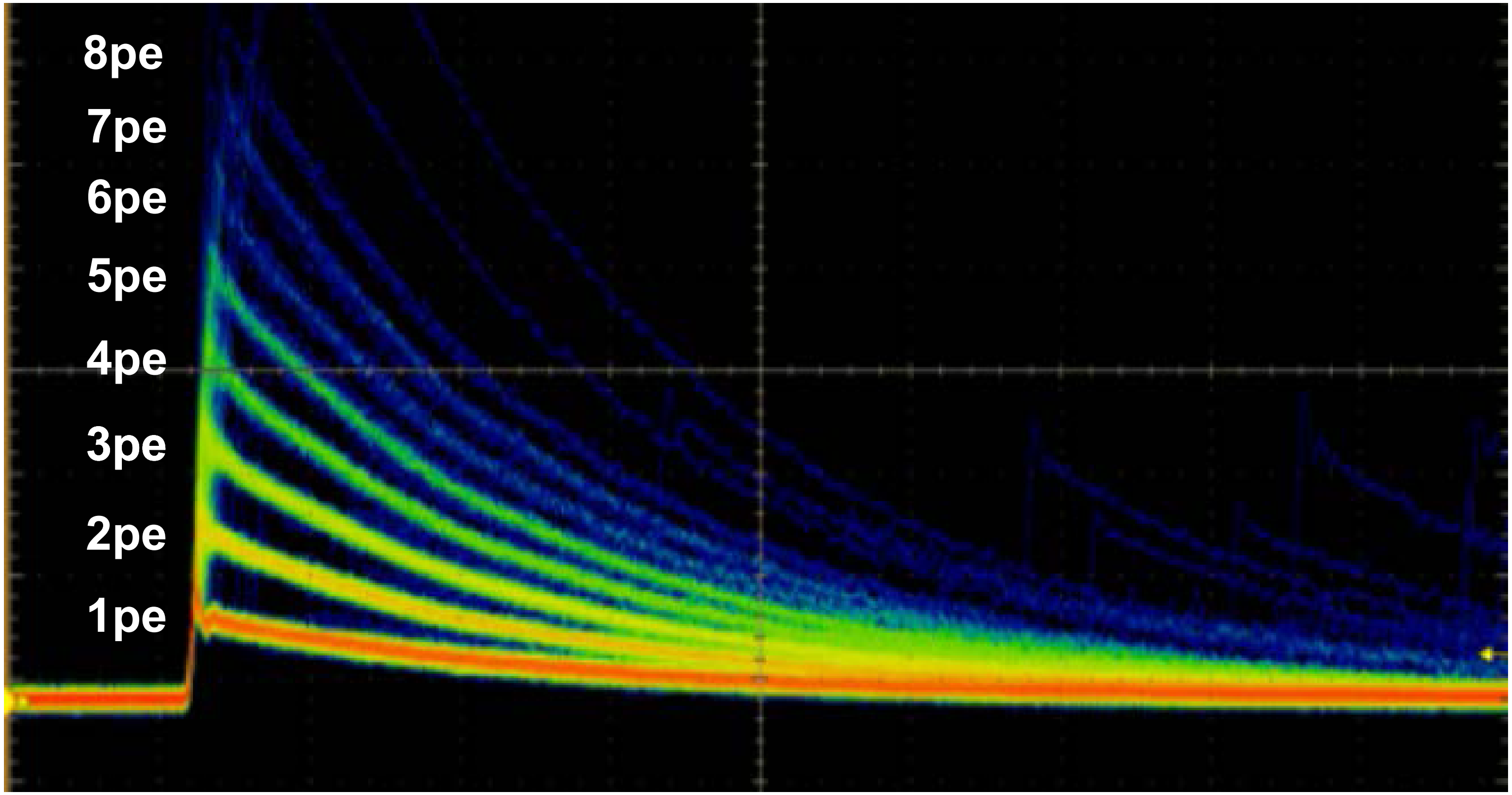
Example: Hamamatsu 1mm²

Transistor in 2015: ~20nm(!)

Credits: Hamamatsu

Single photon counting

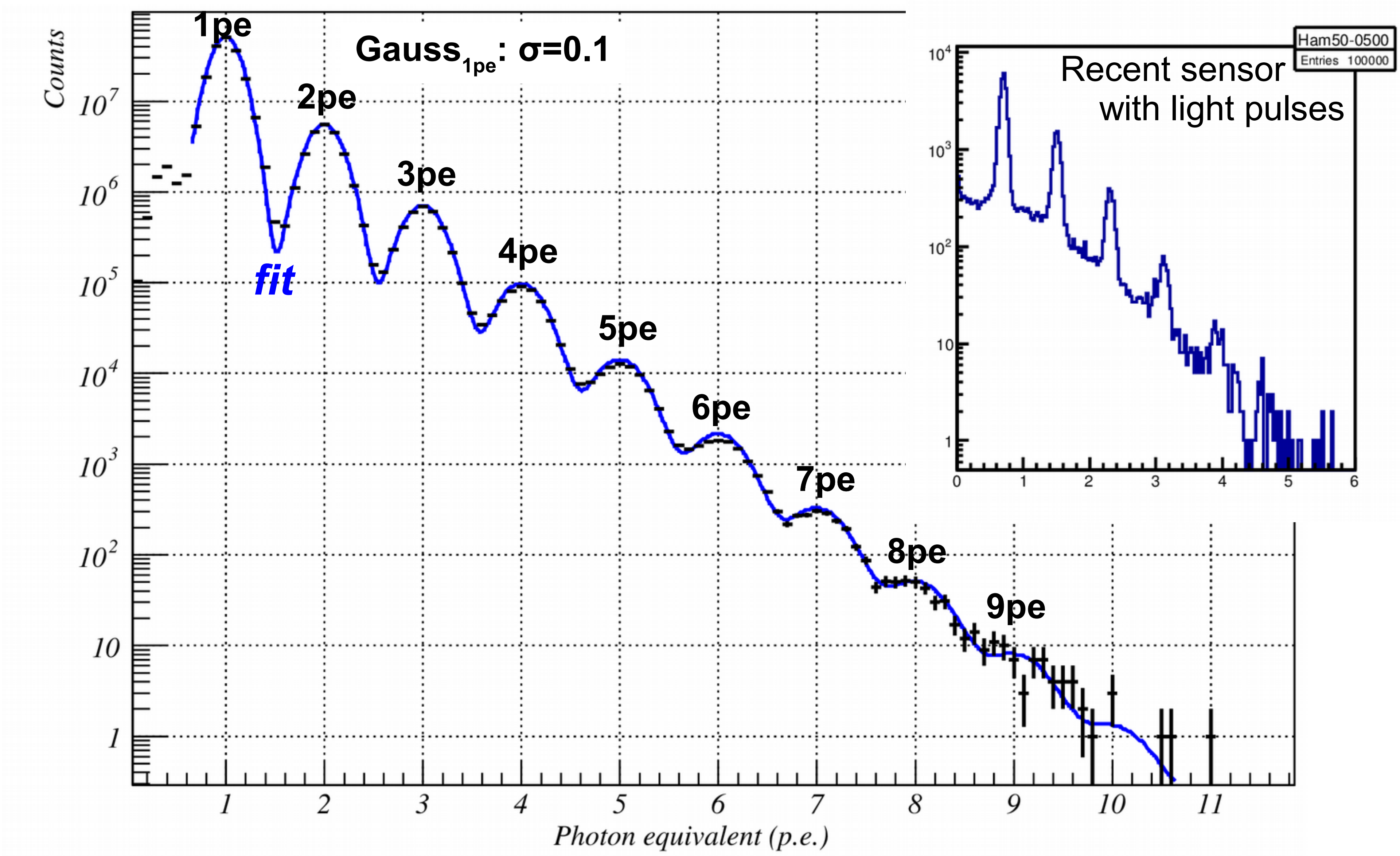
High precision → every avalanche (cell) releases similar charge



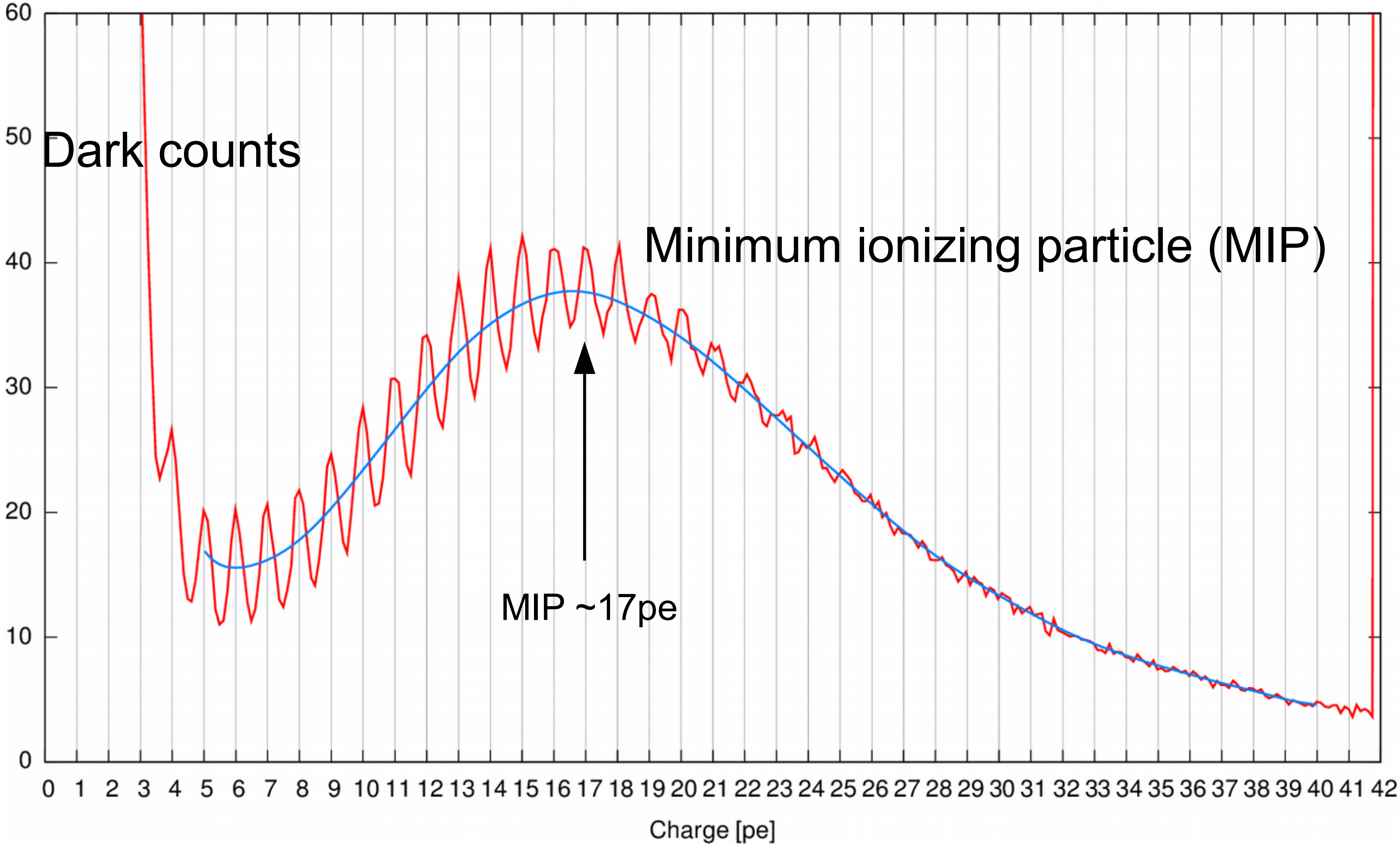
Credits: Hamamatsu

Self calibrating / Stability

all pixels; **one year**; temp: ~0°C – 25°C

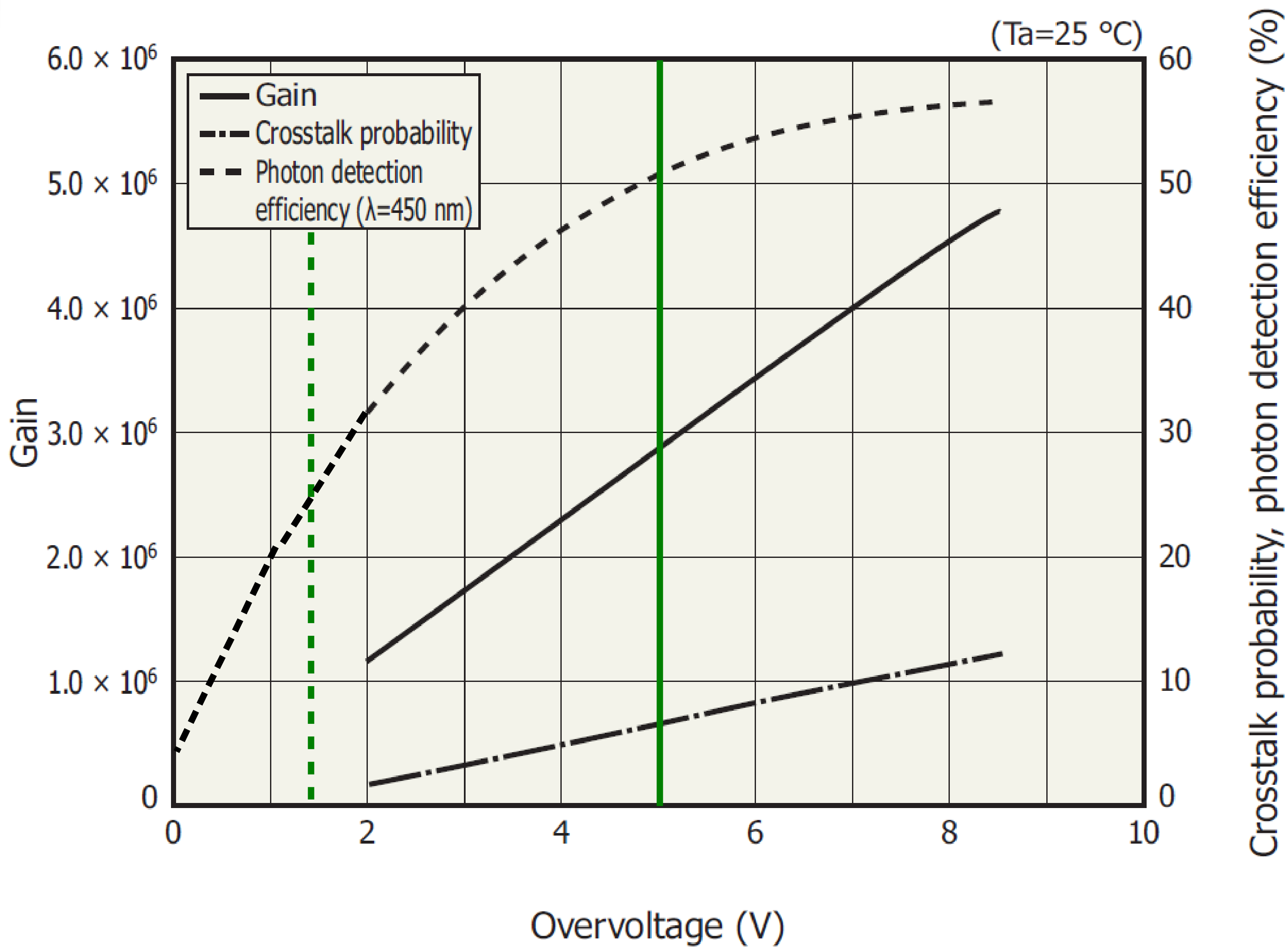


MIP spectrum of a scintillator



Temperature dependence

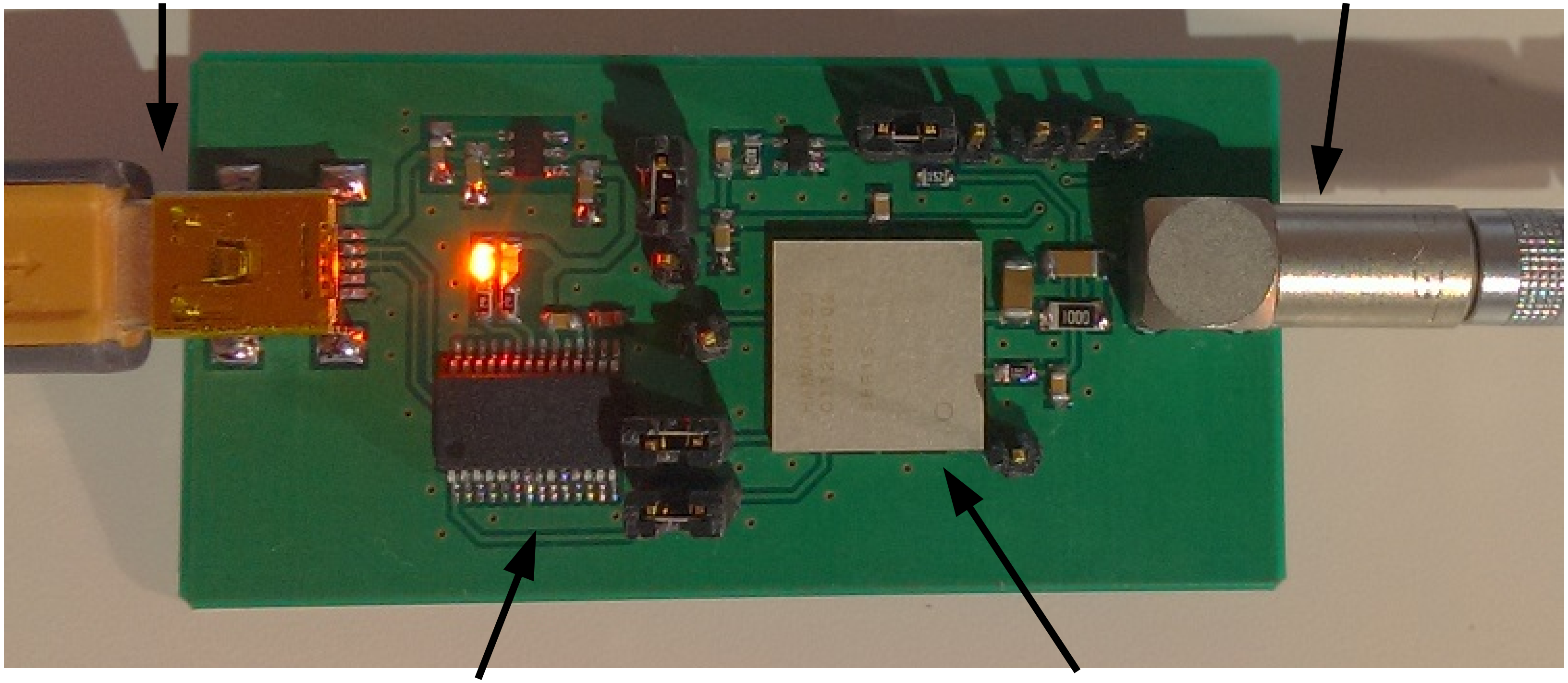
- O(few % / K)



Integrated circuits

IN:
USB for Communication and power

OUT:
Temp. compensated SiPM voltage



FTDI (USB driver)

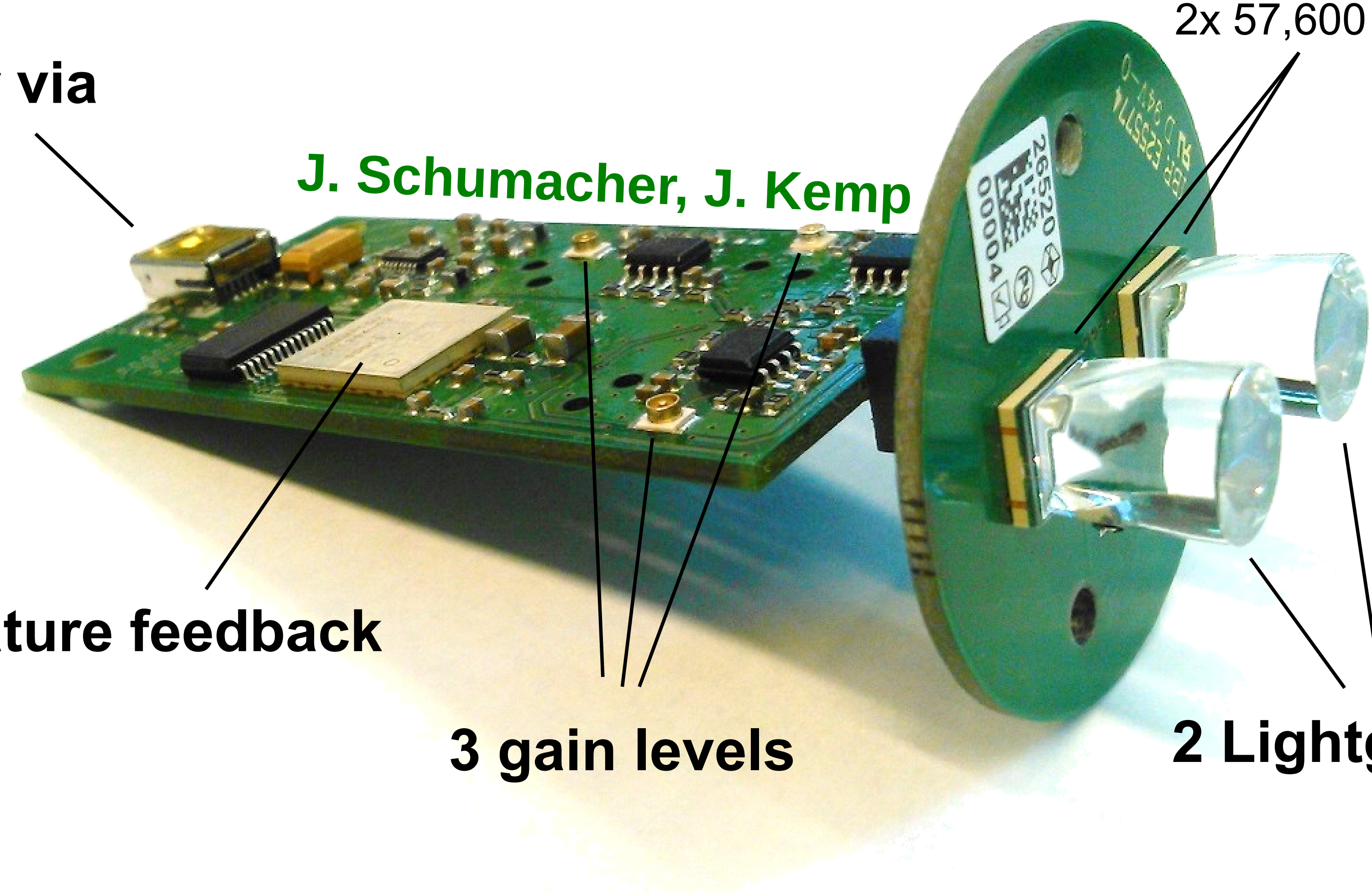
Hamamatsu C11204-02

The SiPM optical module

2 SiPMs (sum)
2x 57,600 G-APDs

Power via USB

J. Schumacher, J. Kemp



Temperature feedback

3 gain levels

2 Lightguides

Further size reduction possible!

RadIIS The Project:

The Idea:

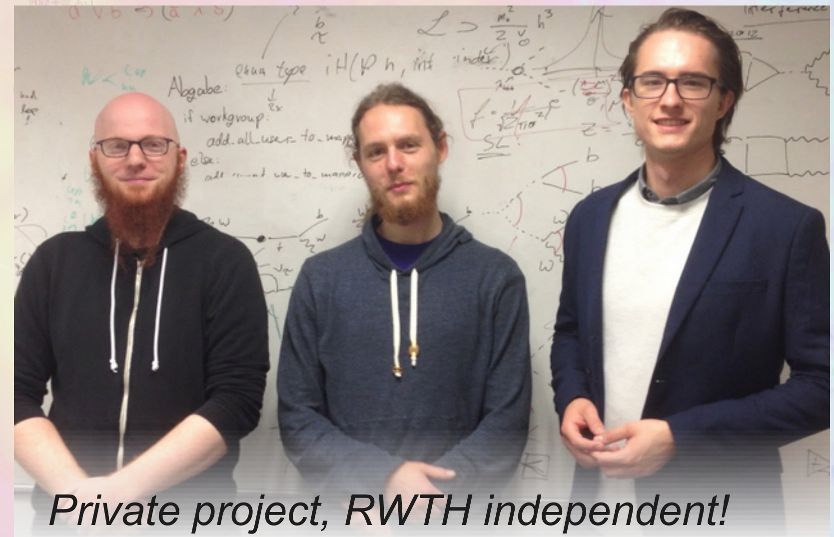
“Open assessment of radioactivity”

- Existing instruments are expensive:
  → RadIIS is cheap (< 200 Euro)
- Usage possible only by experts:
  →RadIIS delivers an intuitive and automated analysis
- Instruments are inaccurate:
  →RadIIS uses sensitive and precise gamma spectroscopic methods with multiple self-calibration systems

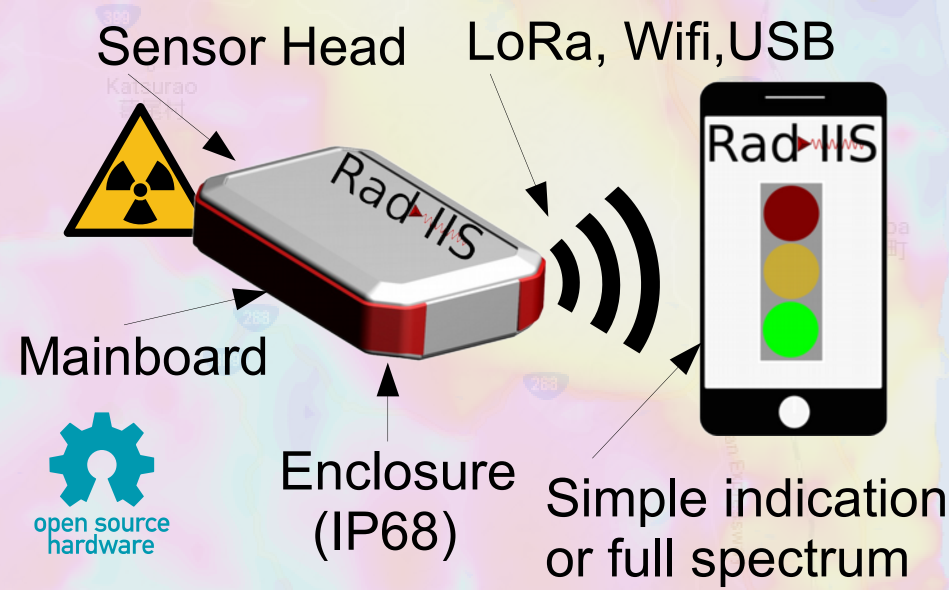
Features:

- ✓ Neuronal net based analysis recognizes isotopes with high reliability
- ✓ LoRa RF crosslinks devices to a monitoring network (e.g. *tdrm.fiff.de*)
- ✓ Extension connector enables external detectors (parallel with internal!)

The Team: *contact@radiis.de*

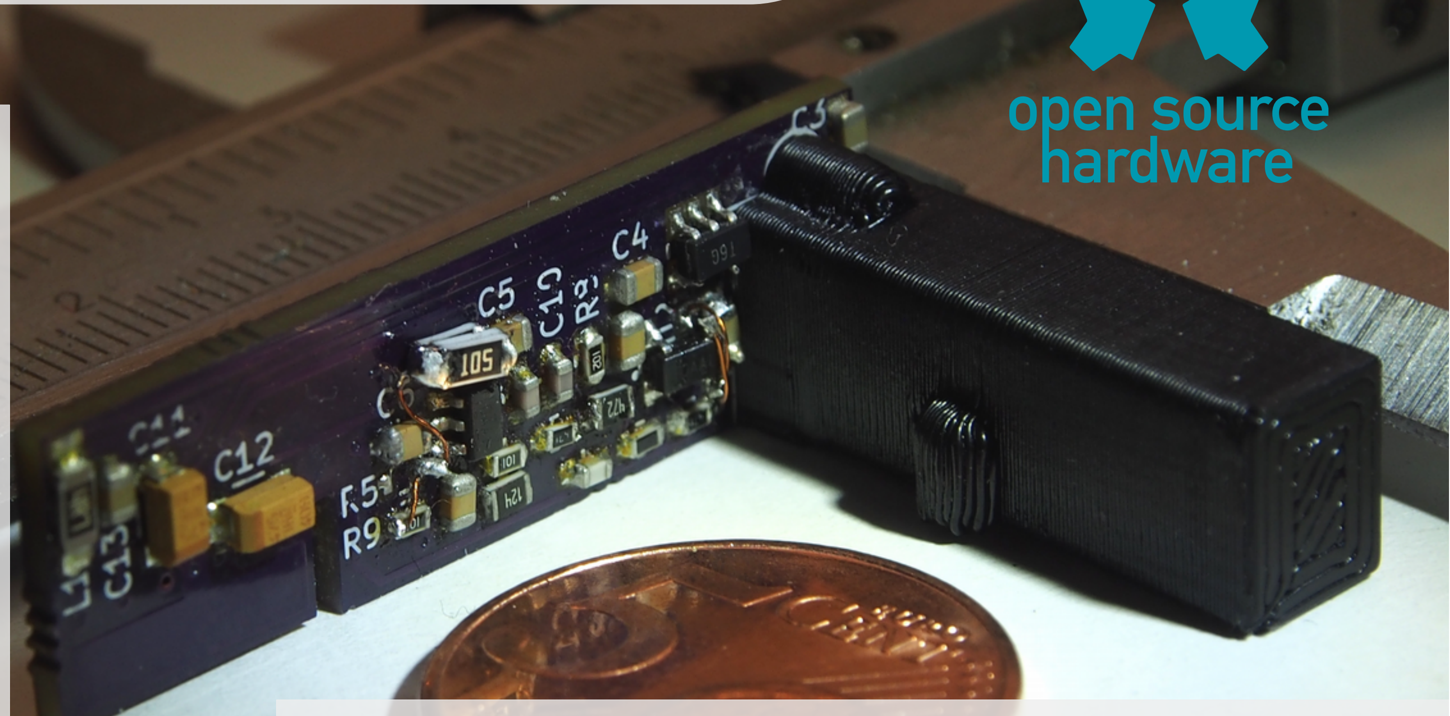


Private project, RWTH independent!



RadIIS The Sensor Head:

open source hardware



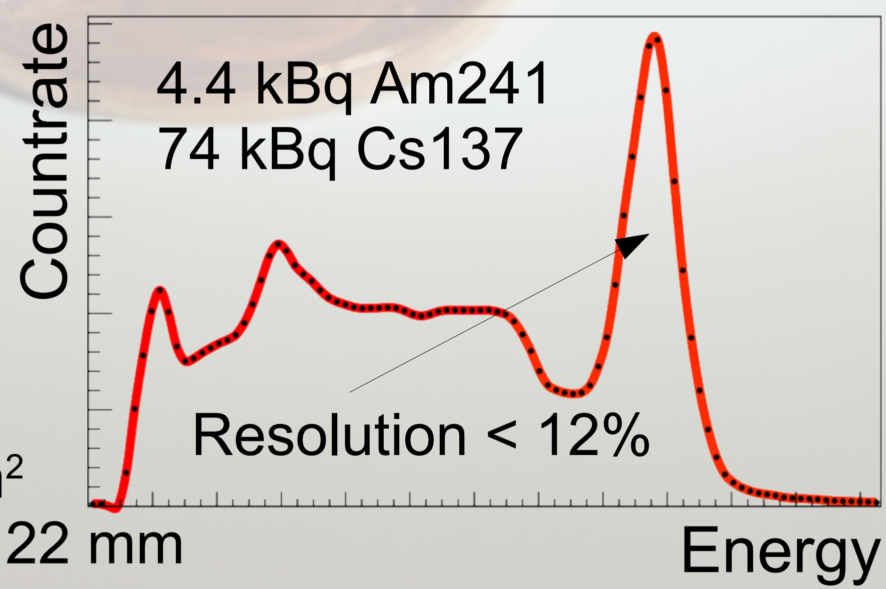
Detector Head:

- SiPM (SensL)
- 3x3 mm^2 sensor
- Amp. and shaper
- T compensation
- Price < 50 Euro

LYSO Crystal :

- Economic
- Not hygroscopic
- High density
- High light yield
- Intrinsic spectrum
- But: Also testing CsI, BGO, LaBr,..

LYSO:



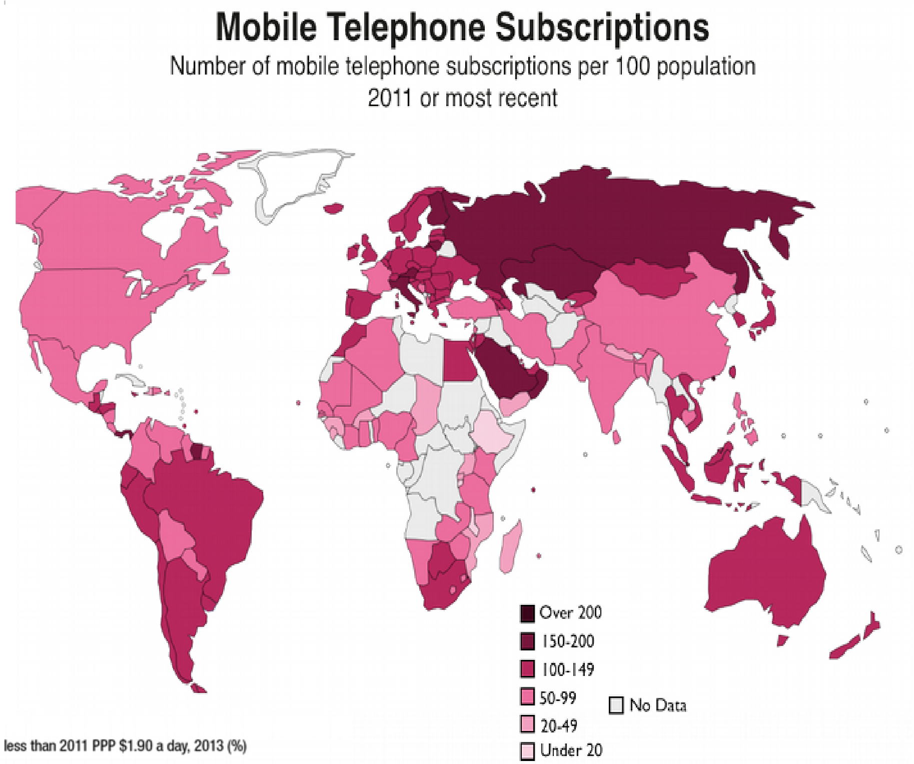
Size:
4x4 mm^2
length: 22 mm

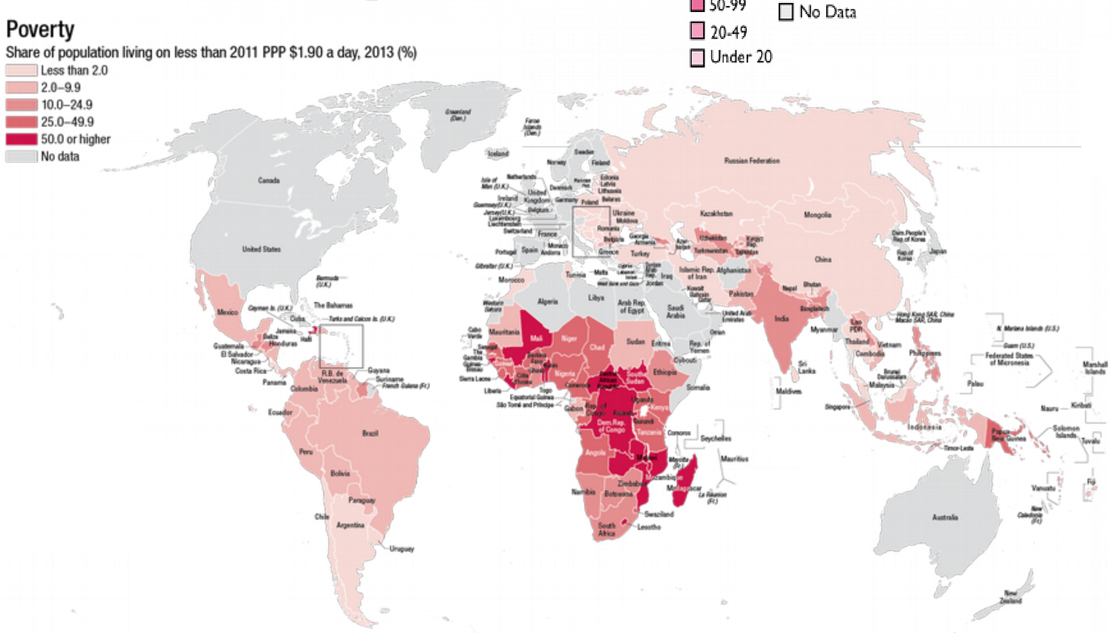
No conclusions...

No conclusions...

… but a remark!

Fund raising: Example...





- Mobile phone subscriptions

- Poverty