Technology Forum - Photosensors and Auxiliary Electronics
Munich 21-22 October 2010

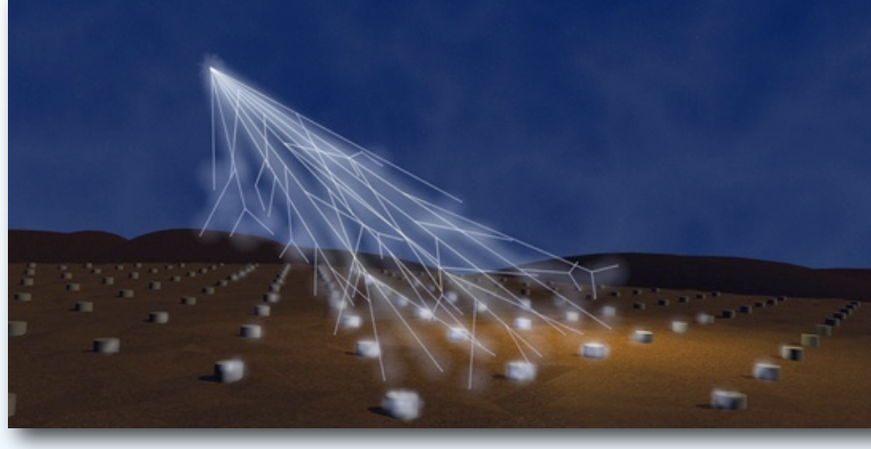
Pierre Auger Observatory

Karl-Heinz Kampert for the Pierre Auger Collaboration
(University of Wuppertal, Department of Physics)

- **Science**
  - **Experimental**
    - **Future Needs**
      - **Technological Challenges**
        - Photosensors
        - Low Power Electronics
        - Communication

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

Science



- **Particles with energies of 10^8*LHC arrive at Earth**
- **Fluxes are very low (1 particle/km2/century)**

- **Where do they come from ?**
- **What kind of particles are they ?**
- **What is the (astro)physics that provides their energy ?**

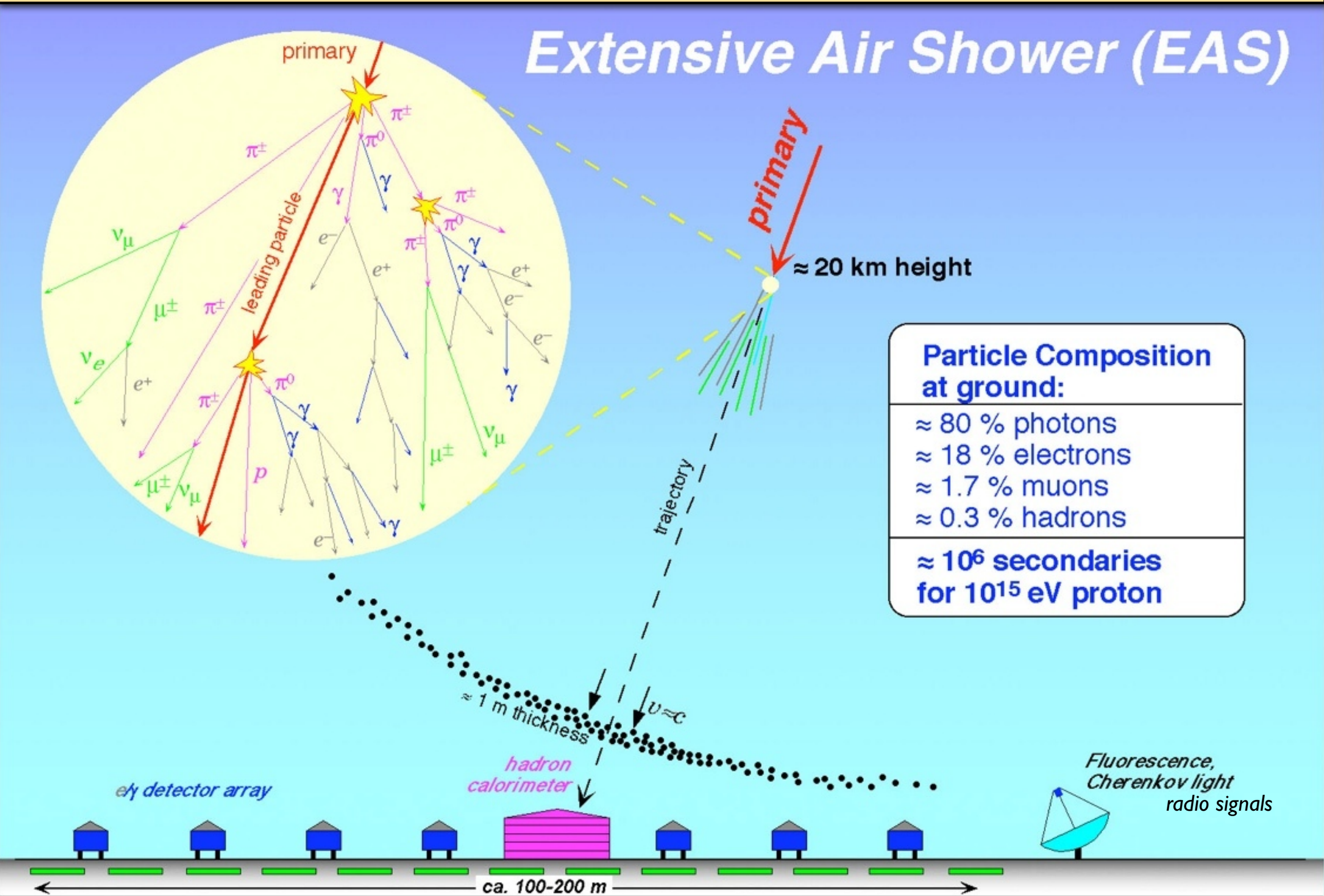
➨ **Learn about extreme processes in the Universe**

➨ **Study Particle Physics far beyond LHC energies**

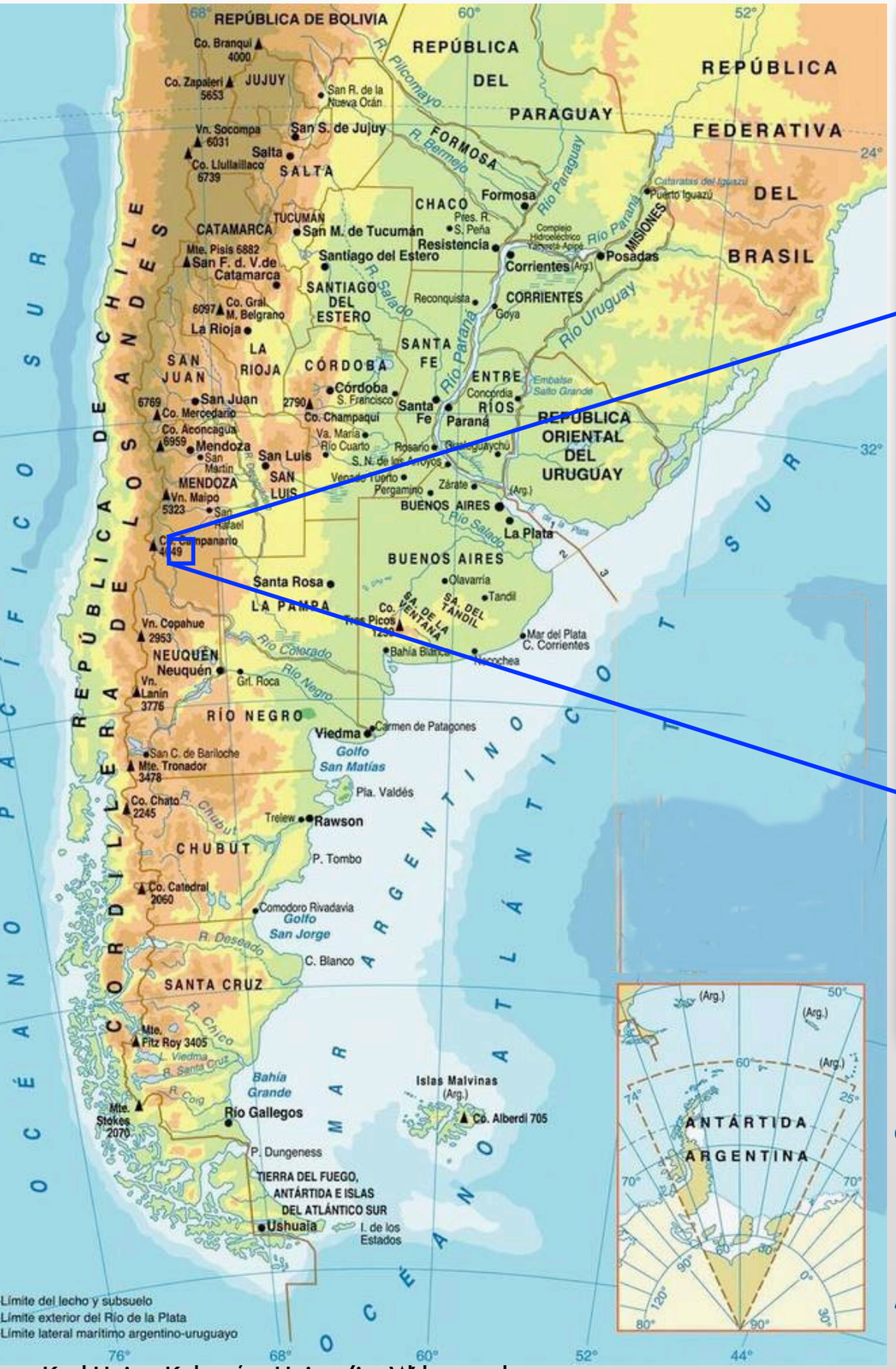
➨ **Test fundamental pillars of physics**

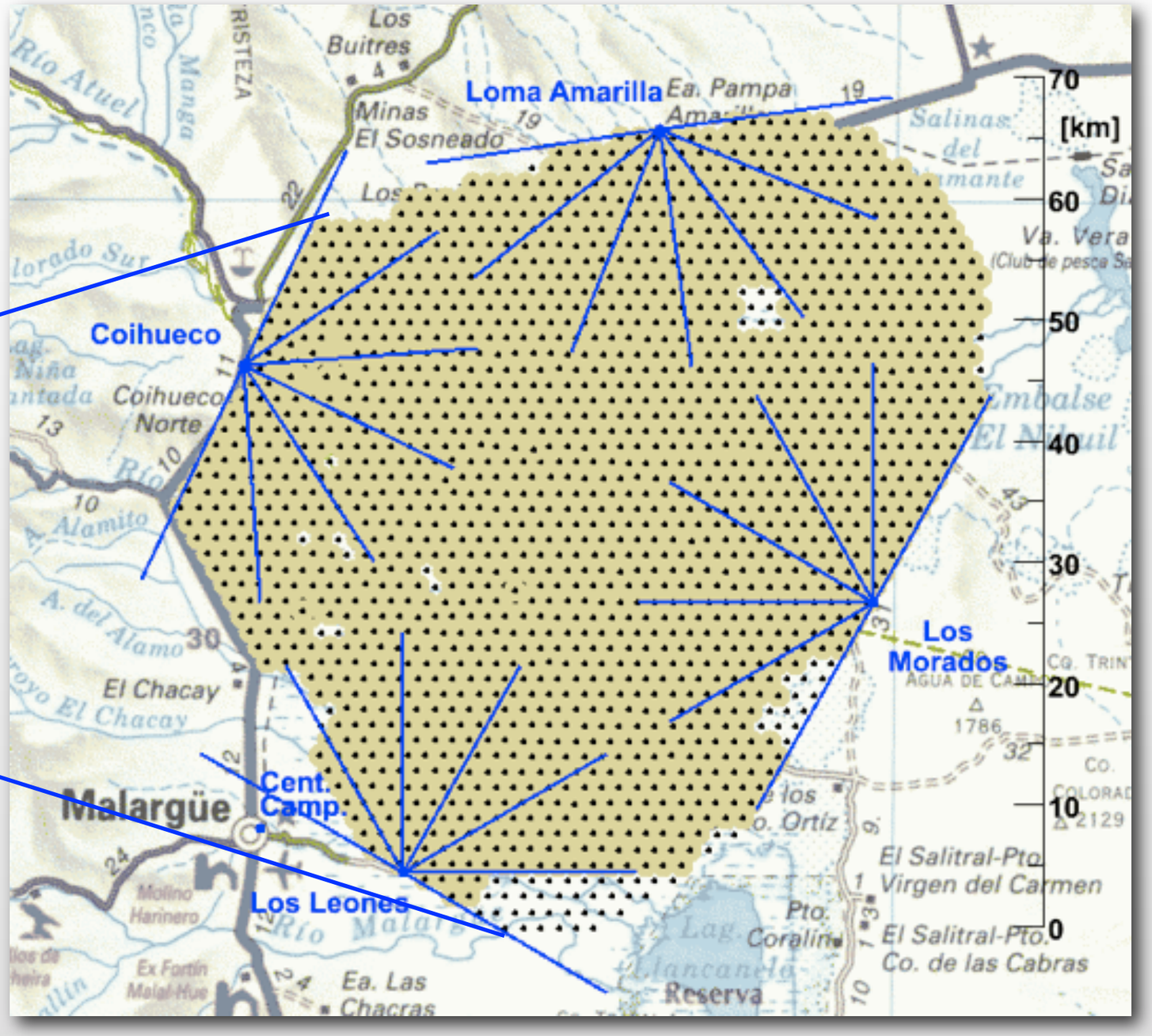
(Lorentz Invariance, Spacetime structure, etc.)

Measuring high energy CRs



Pierre Auger Observatory in Argentina





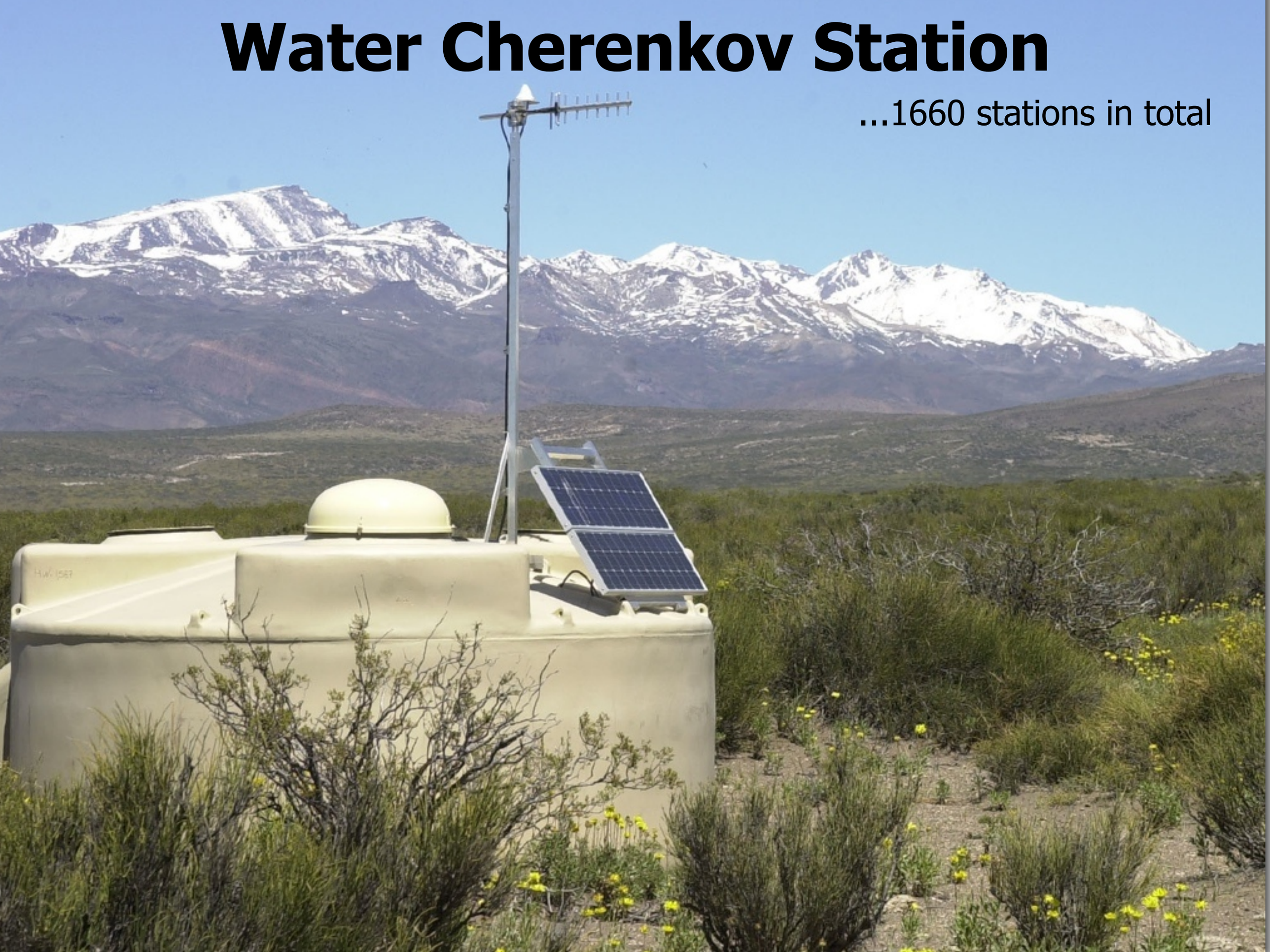
3000 km² area on a plateau 1450 m a.s.l.

1660 Detector Stations +

27 FD Telescopes at periphery

Water Cherenkov Station

...1660 stations in total



Water Cherenkov Station

...1660 stations in total

GPS

communication
ISM band (0.9 GHz)

electronics
local trigger
40 MHz digit. 10 W

battery

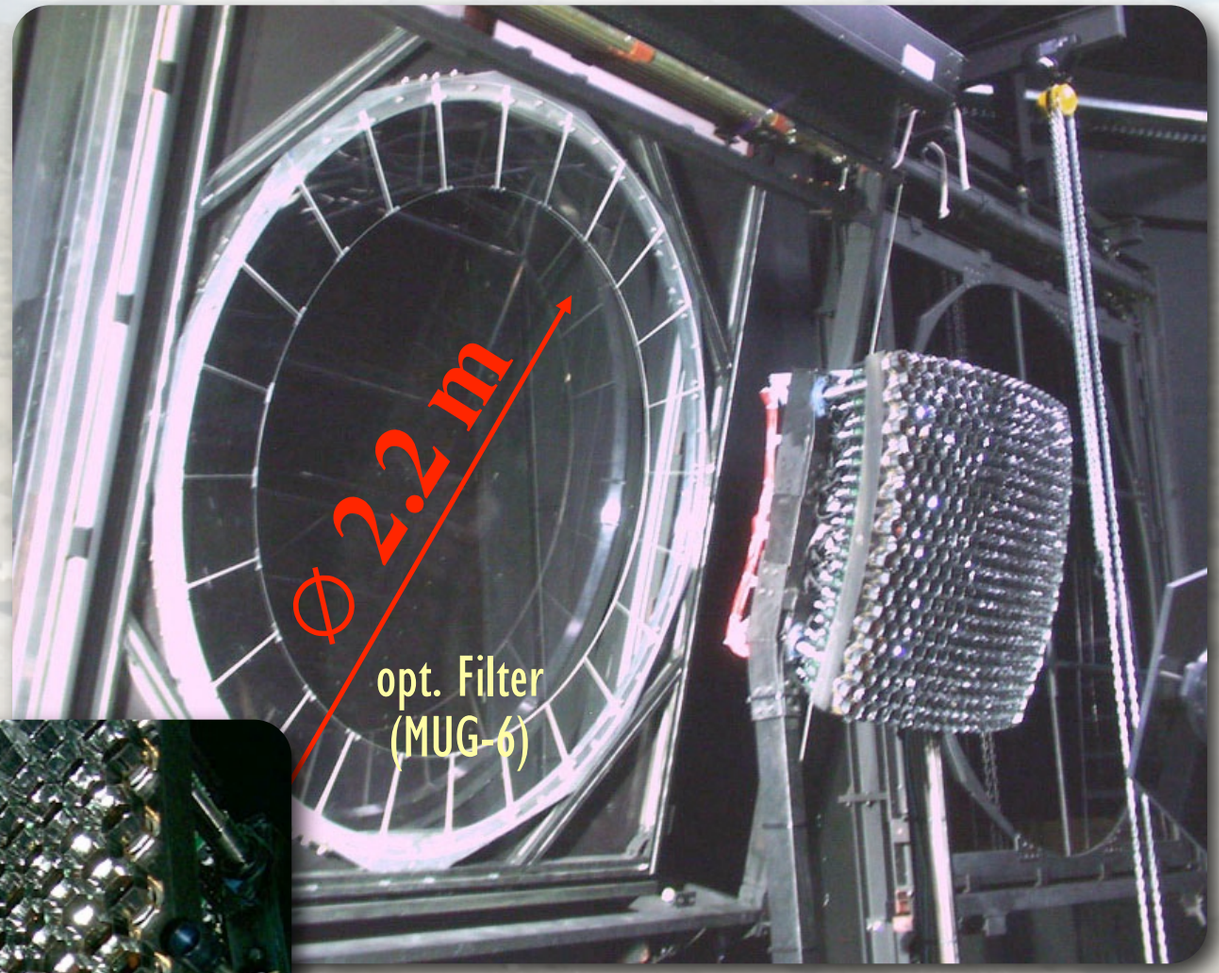
solar panel

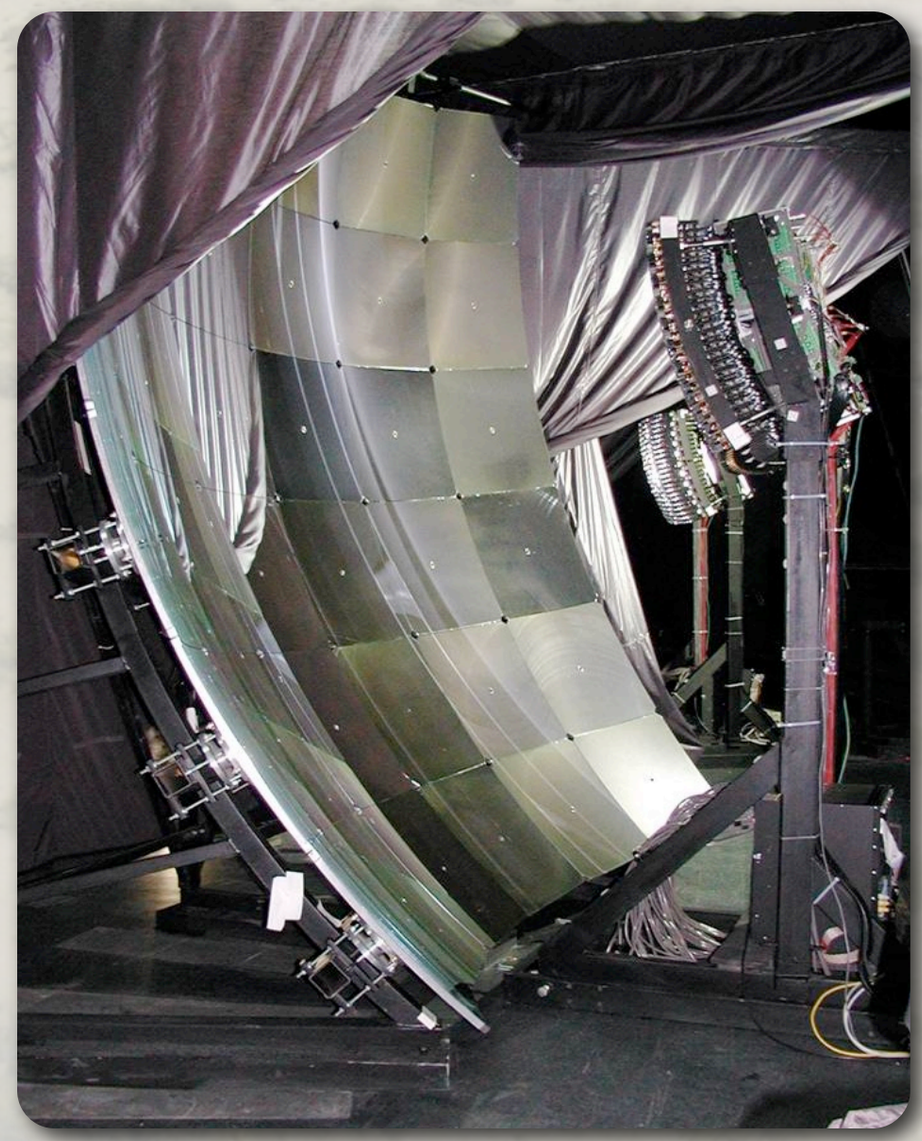
Three 9“ PMT
XP 1805

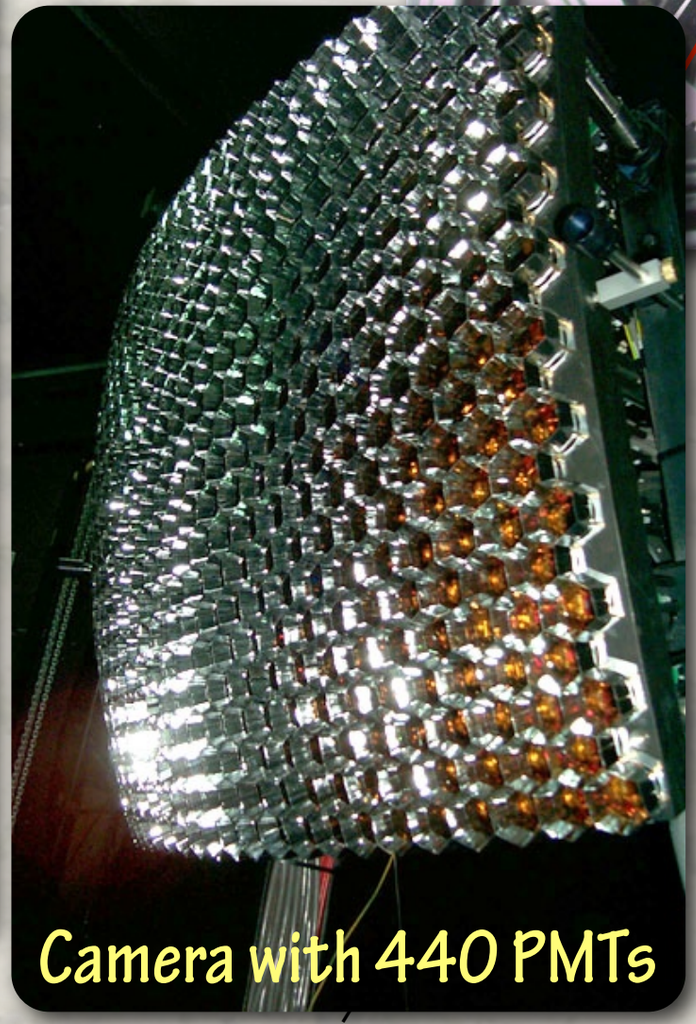
12000 ltr water

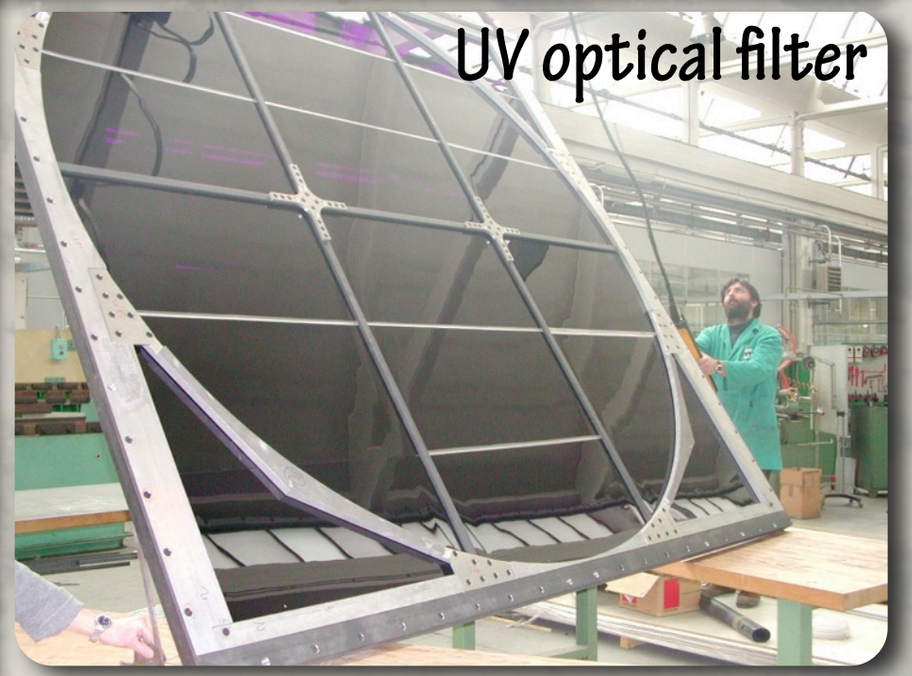
Fluorescence Telescope

24 telescopes (6 per site)
12 m^2 mirrors, Schmidt optics
30°x30° deg field of view
440 PMTs/camera (12000 PMTs)
10 MHz FADC readout

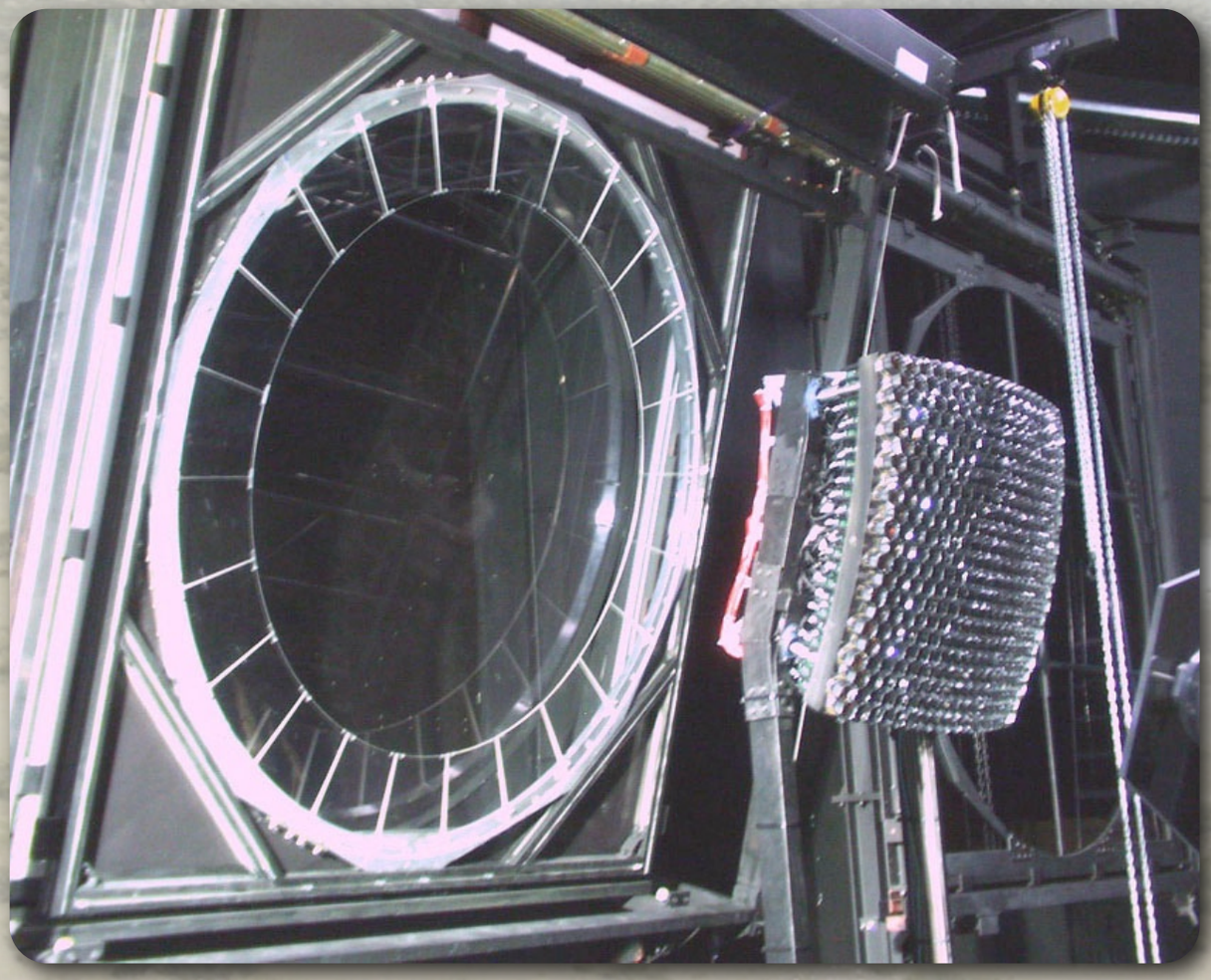






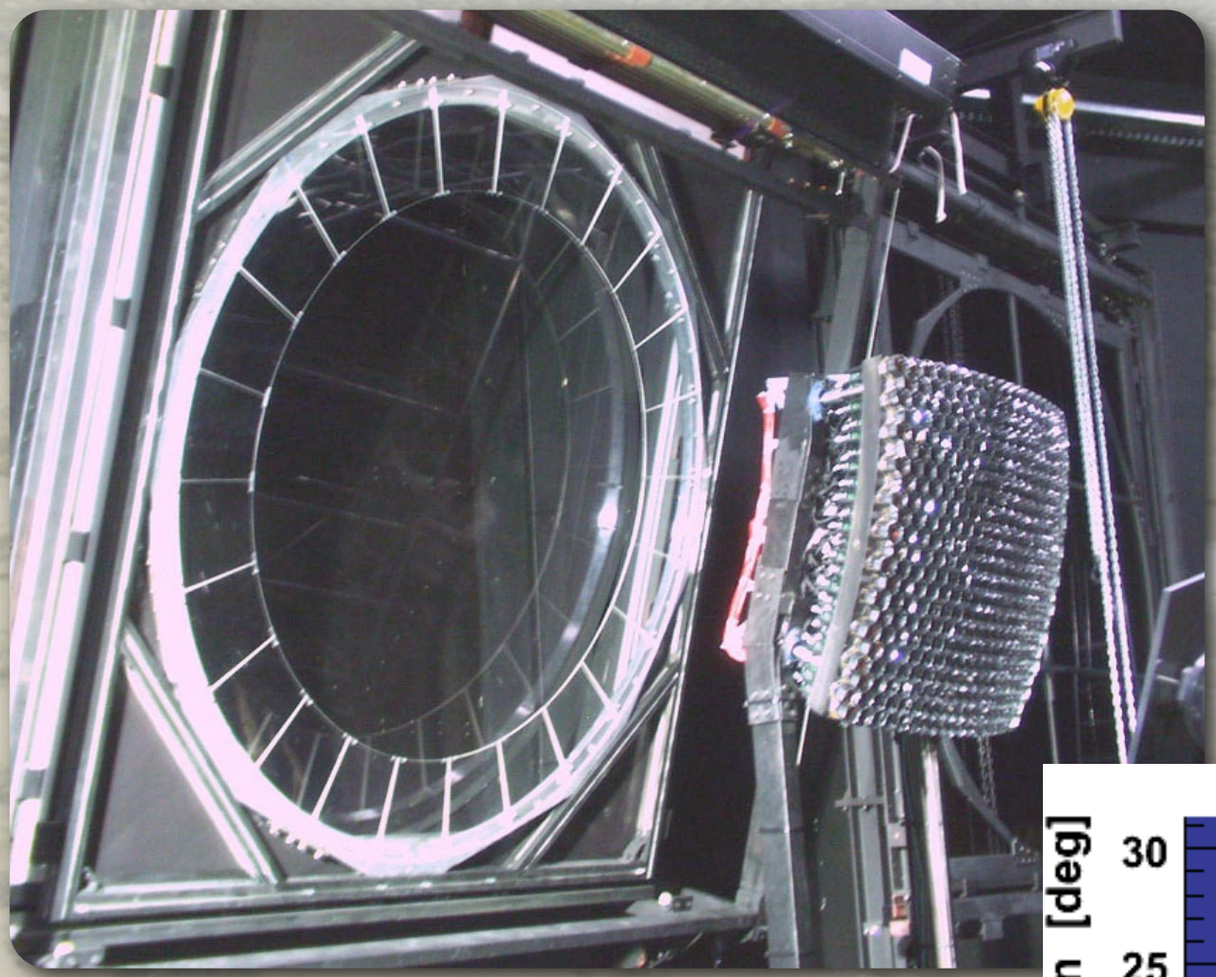


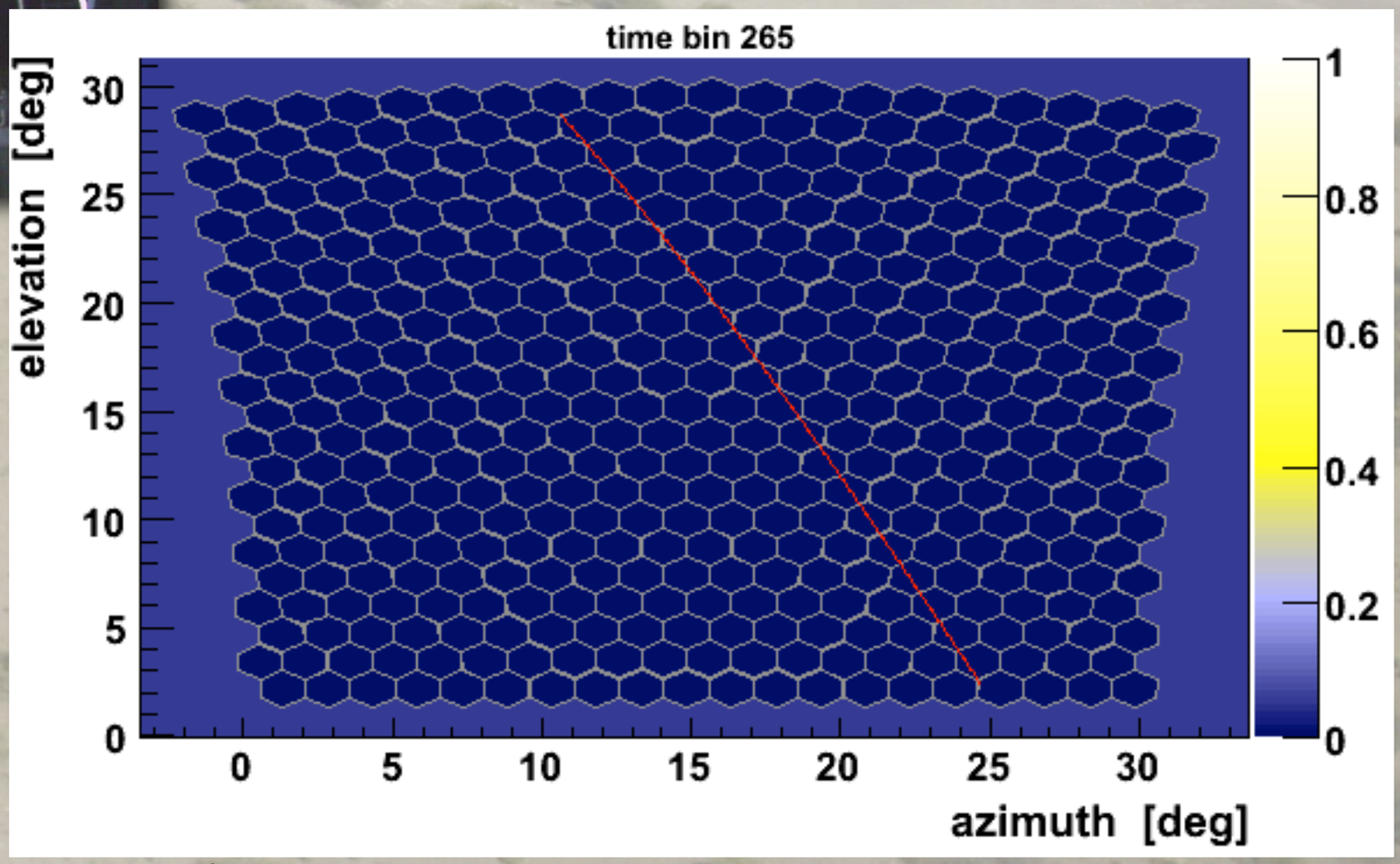
Light Spot as seen by Camera



Light spot may take several µs to propagate through camera

Light Spot as seen by Camera





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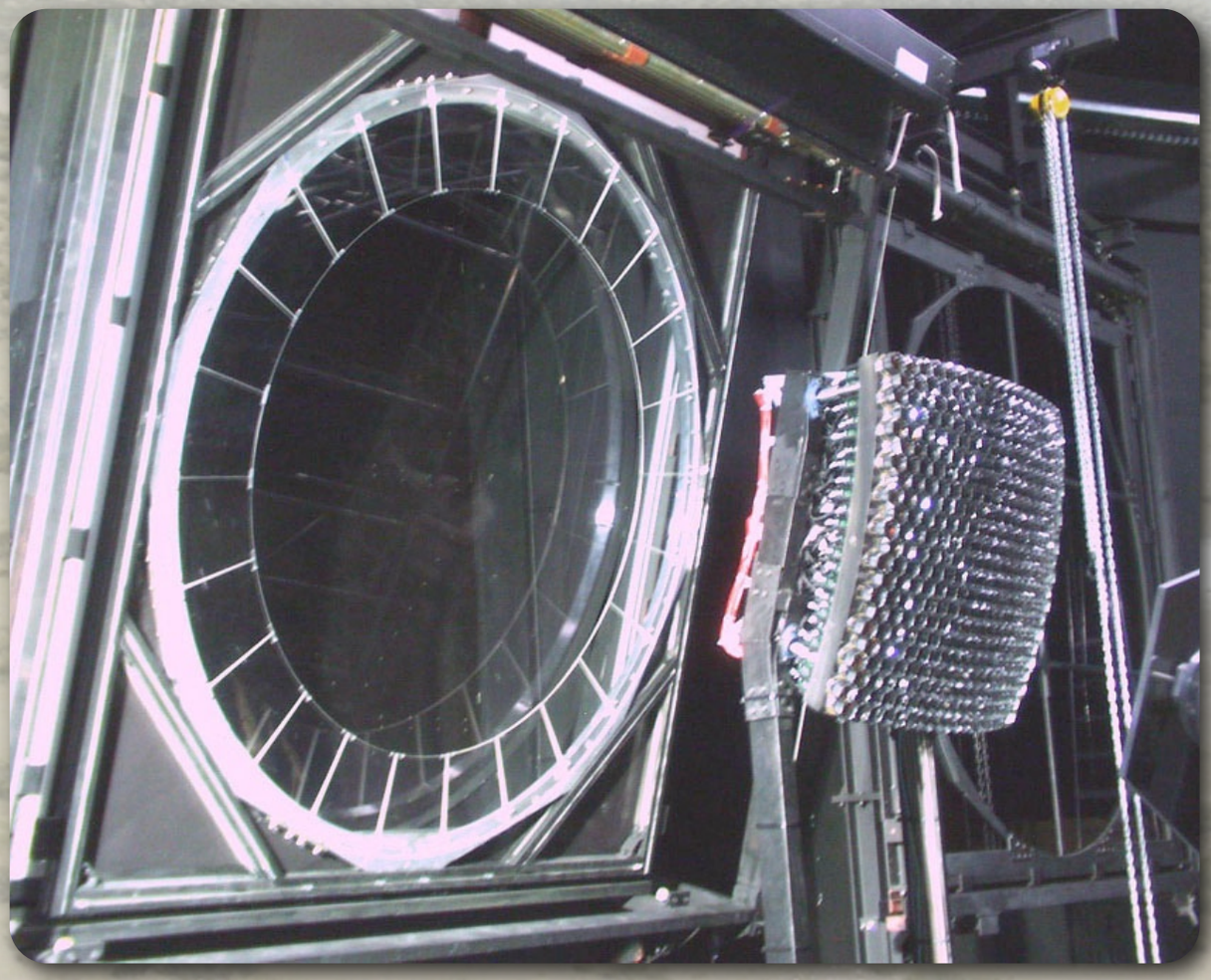


Light spot may take several µs to propagate through camera

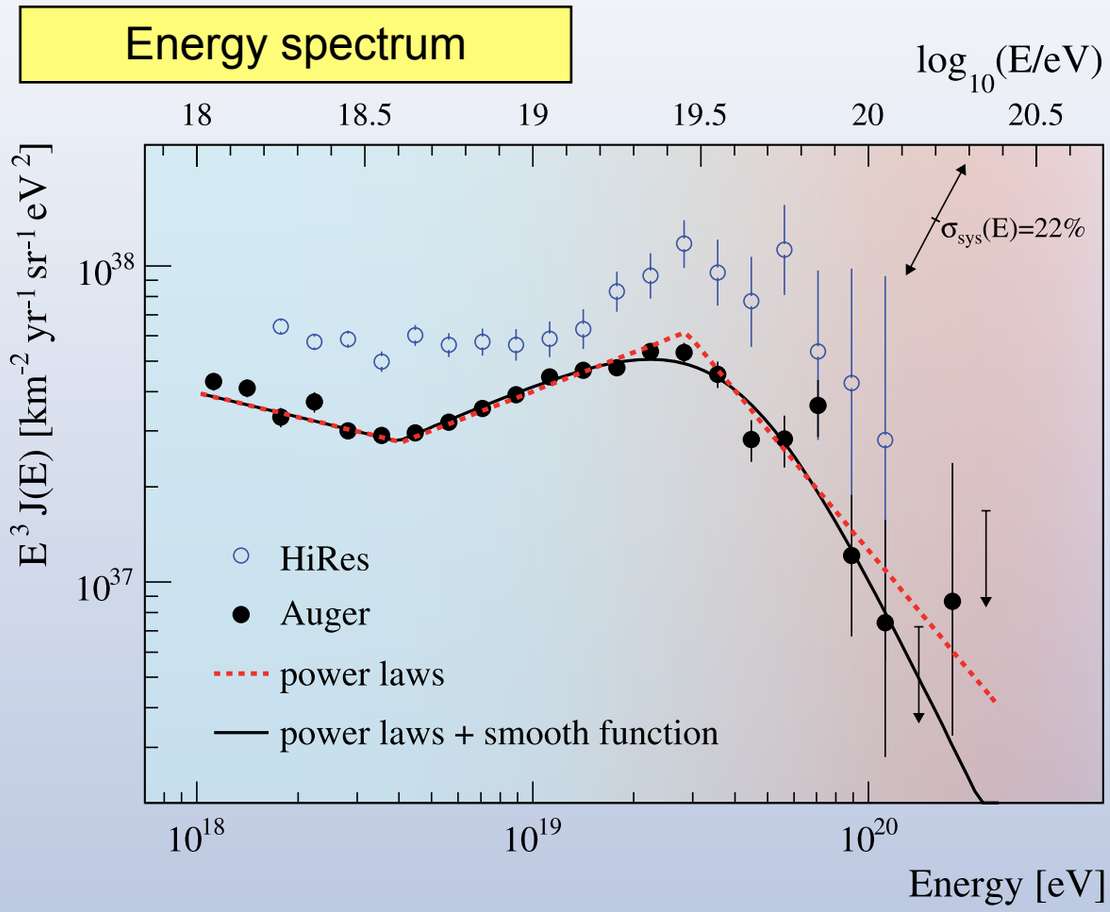
Some Highlights from Auger South at highest Energy

- Flux suppression above 40 EeV
- Anisotropy above about 55 EeV
- Change in composition (?)

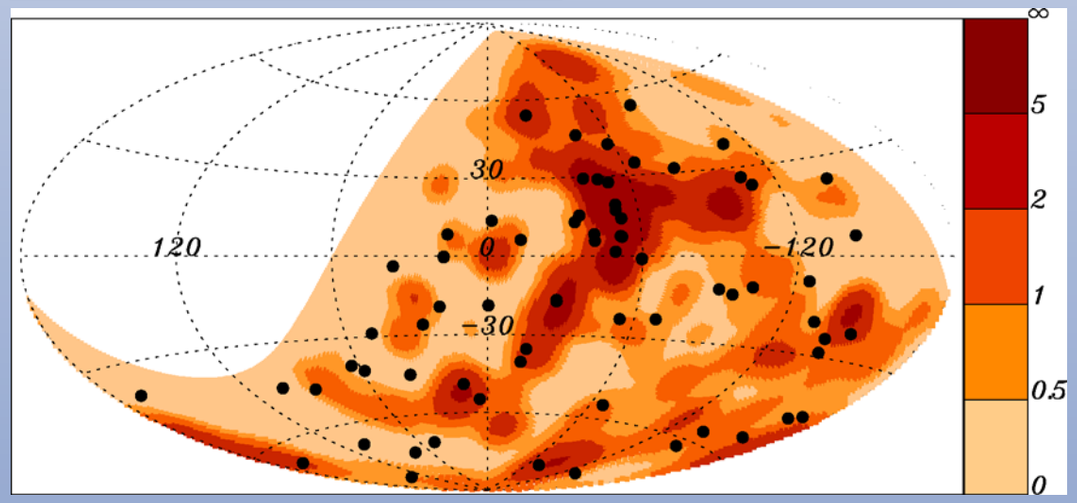
<u>Objectives for Auger North:</u>

Focus on measurements at highest energy range with very high statistics

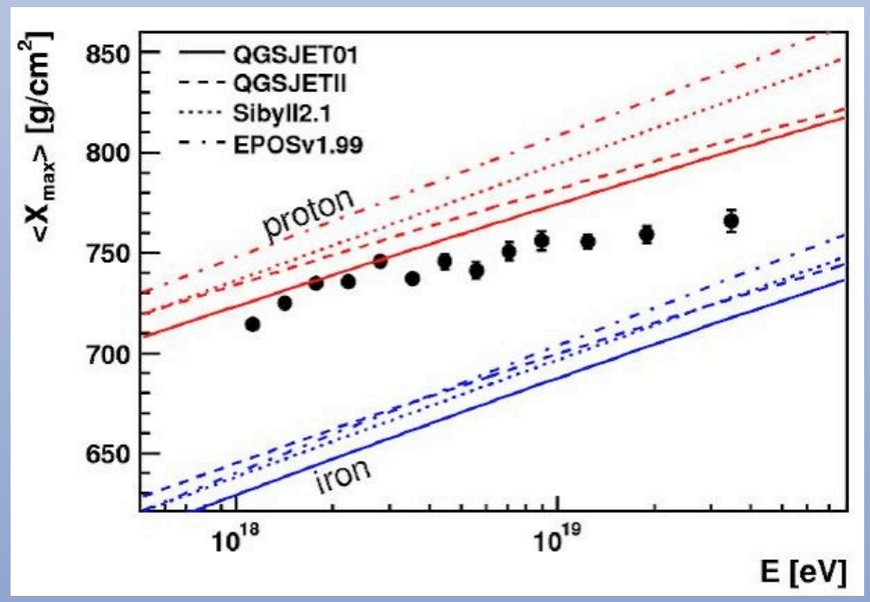
Energy spectrum



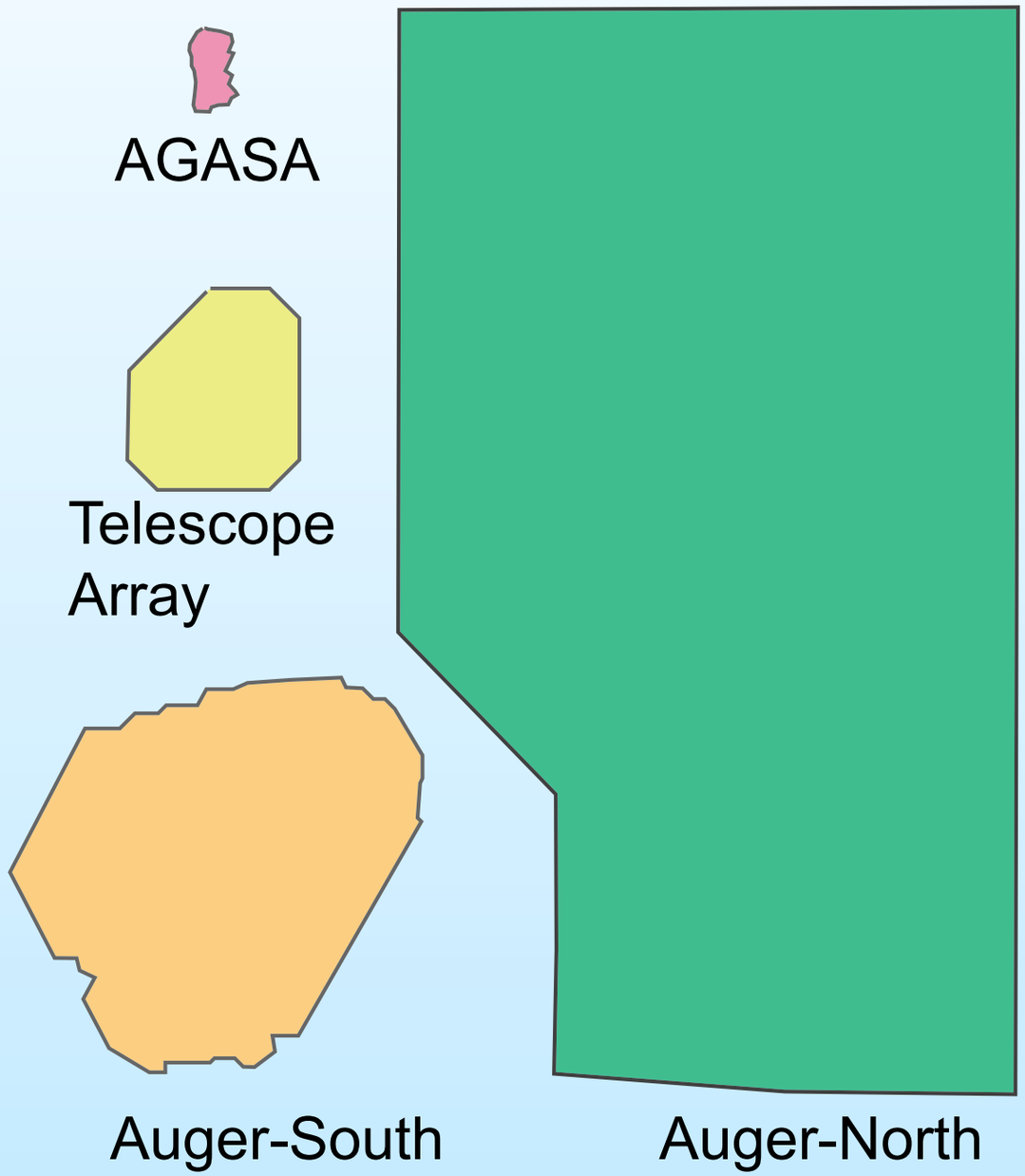
Anisotropy

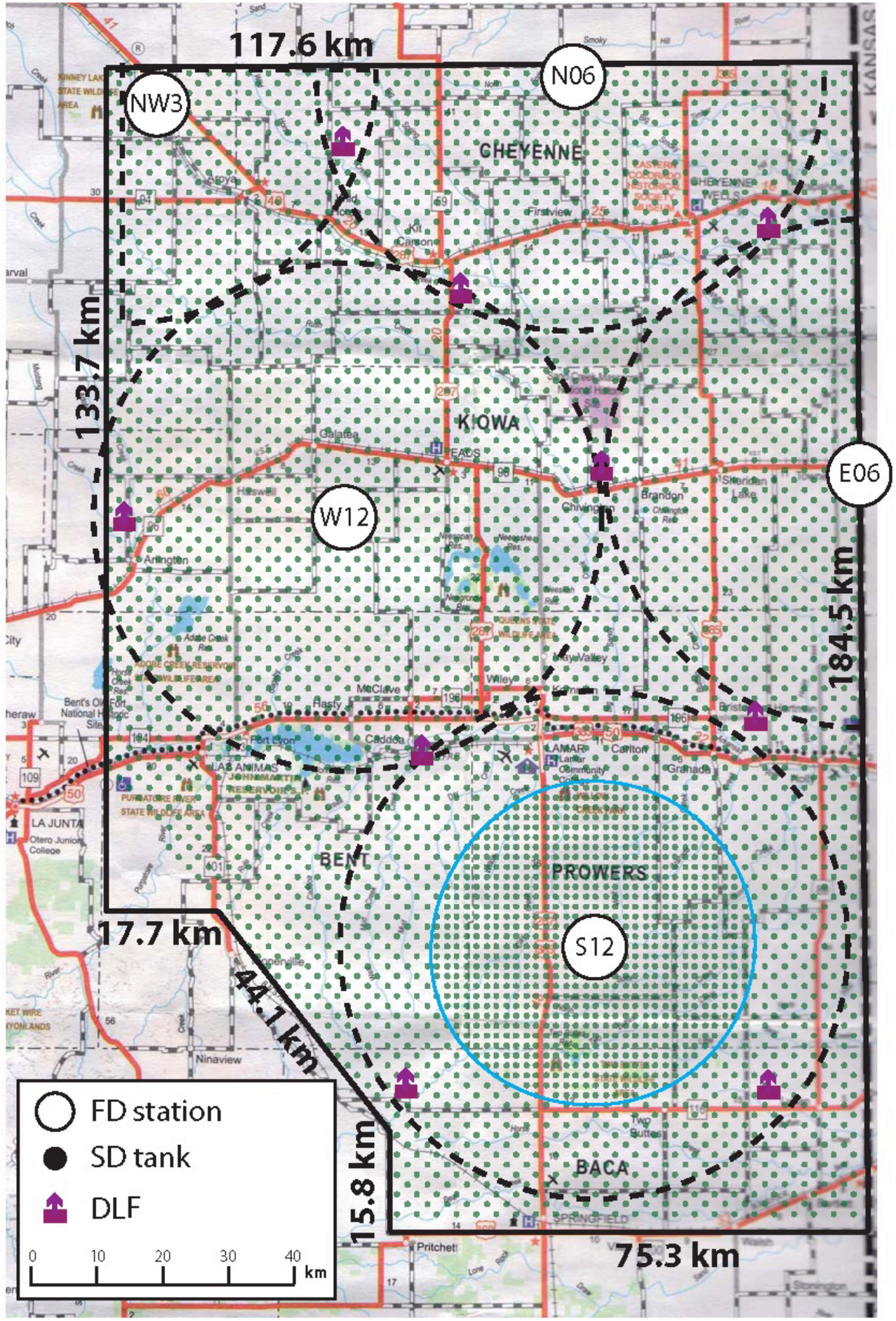


Composition



Significant increase in statistics above $5 \cdot 10^{19}$ eV requires ≳ 20000 km² Site





US Decadal Review:

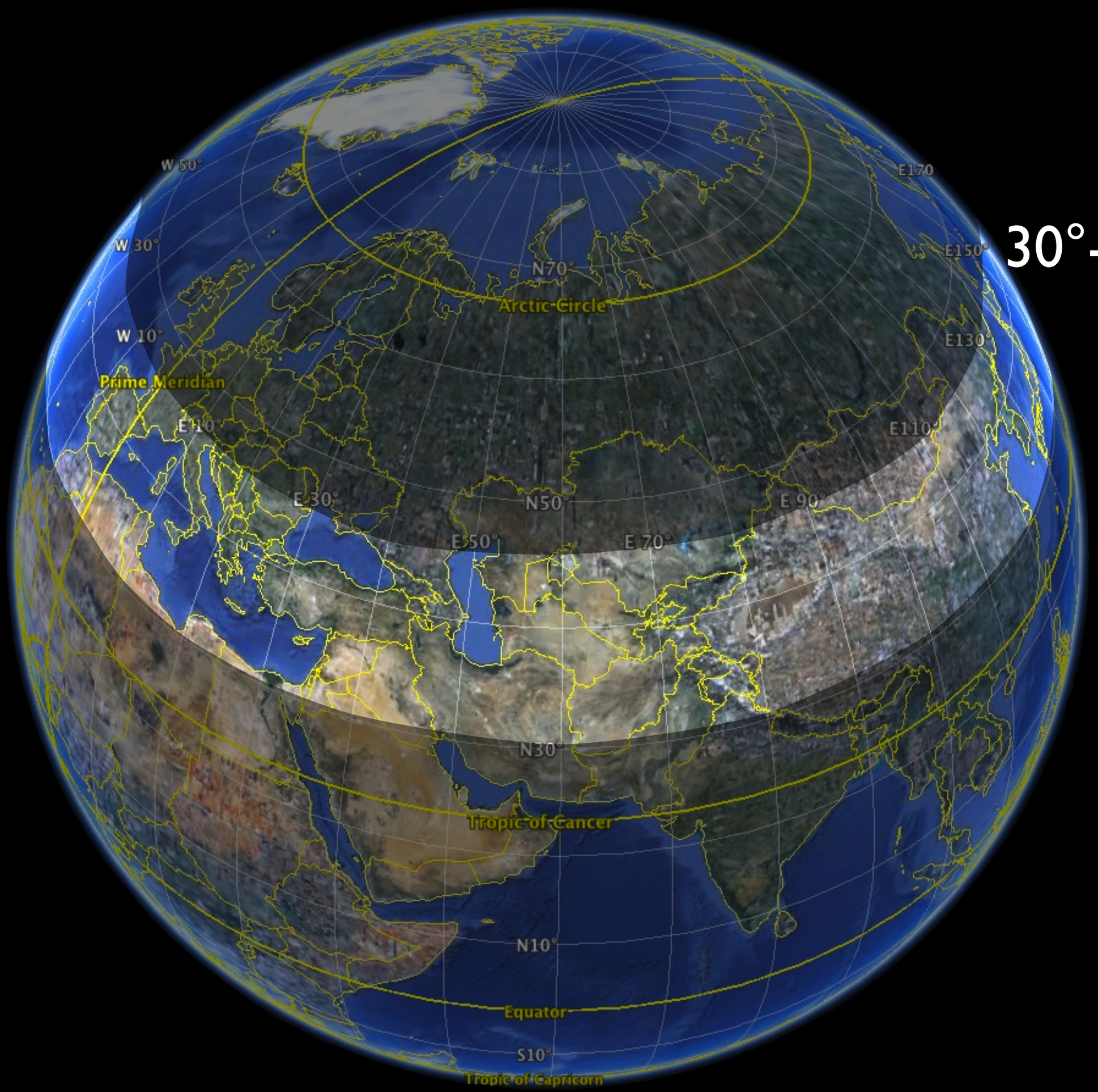
Science of AugerNorth excellent, but US funding agencies want to focus on Dark Matter and Dark Energy

- Reiterate Science Case
- Find new Site(s)
- Selection depends on available Technologies

Auger North 2010		Colorado	**other sites**
FLAT:	communications	✔	new techniques may give more flexibility
WARM:	no water freezing	✔	proper insulation & salty water may allow cold regions
CLEAR:	fluorescence	✔	radio observation techniques? difficult, but working at
NORTH:	half of the sky	✔	astronomical question
LARGE:	statistics	✔	**mandatory**

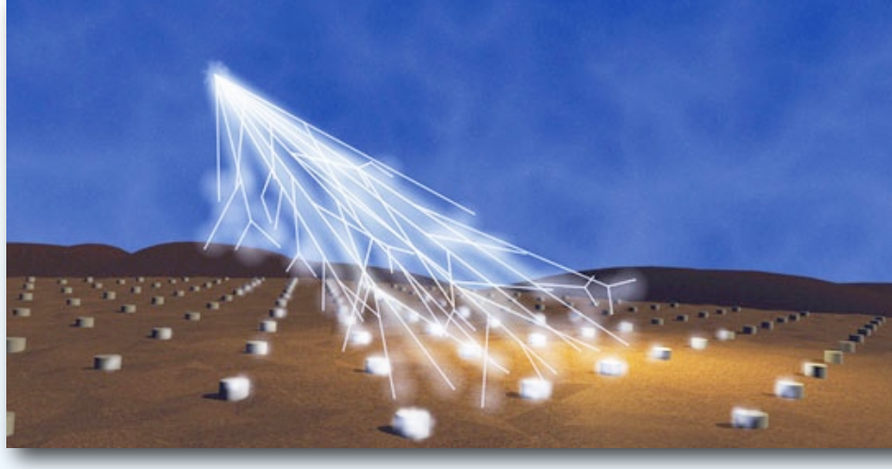
next specific proposal in 3-5 years


W 50°
W 30°
W 10°
Prime Meridian
E 10°
E 30°
E 50°
E 70°
E 90°
E110°
E130°
E150°
E170
N70°
Arctic Circle
N50°
N30°
Tropic of Cancer
N10°
Equator
S10°
Tropic of Capricorn


W 50°
E170
W 30°
E150°
N70°
Arctic Circle
W 10°
E130°
Prime Meridian
E 10°
E110°
E 30°
N50°
E 90°
E 50°
E 70°
N30°
Tropic of Cancer
N10°
Equator
S10°
Tropic of Capricorn

30°-45° N

Photosensors for Future Auger-SD



Based on values of current Design Report

- **4000 Surface Detector Stations**
- **Use only one ~9" PMT per station → 4000 9" PMTs**
- **may test alternatives, e.g. multi small PMTs/Tank**

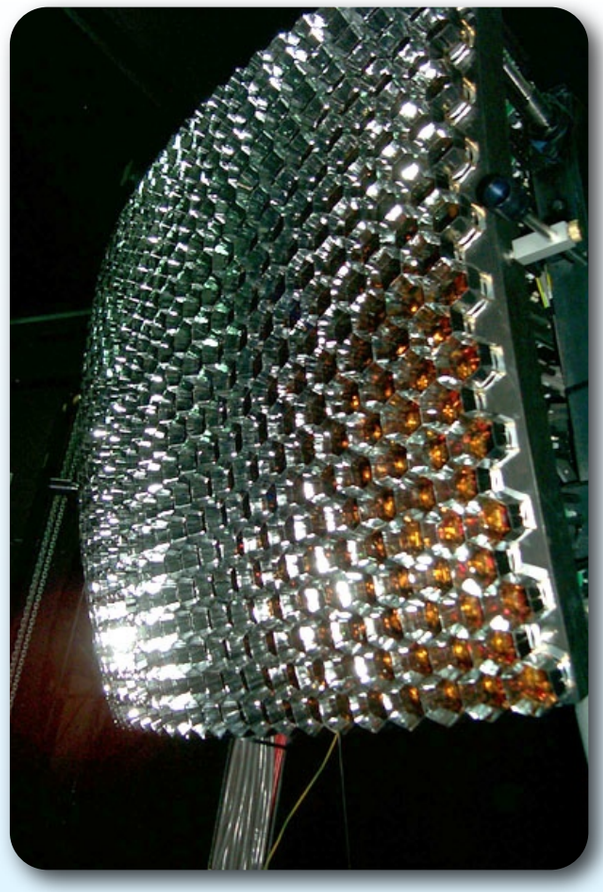
Major Requirements:

- **high dynamic range**
- **high linearity**
- **single pe detection**
- **~ ns timing**
- **low afterpulsing**

Other Quality Parameters

- **quantum efficiency**
- **homogeneity of photocathode**

Photosensors for Future Auger-FD



Based on values of current Design Report

- **39 Telescopes of 440 PMTs**

  → **17000 1.5" PMTs**

Major Requirements:

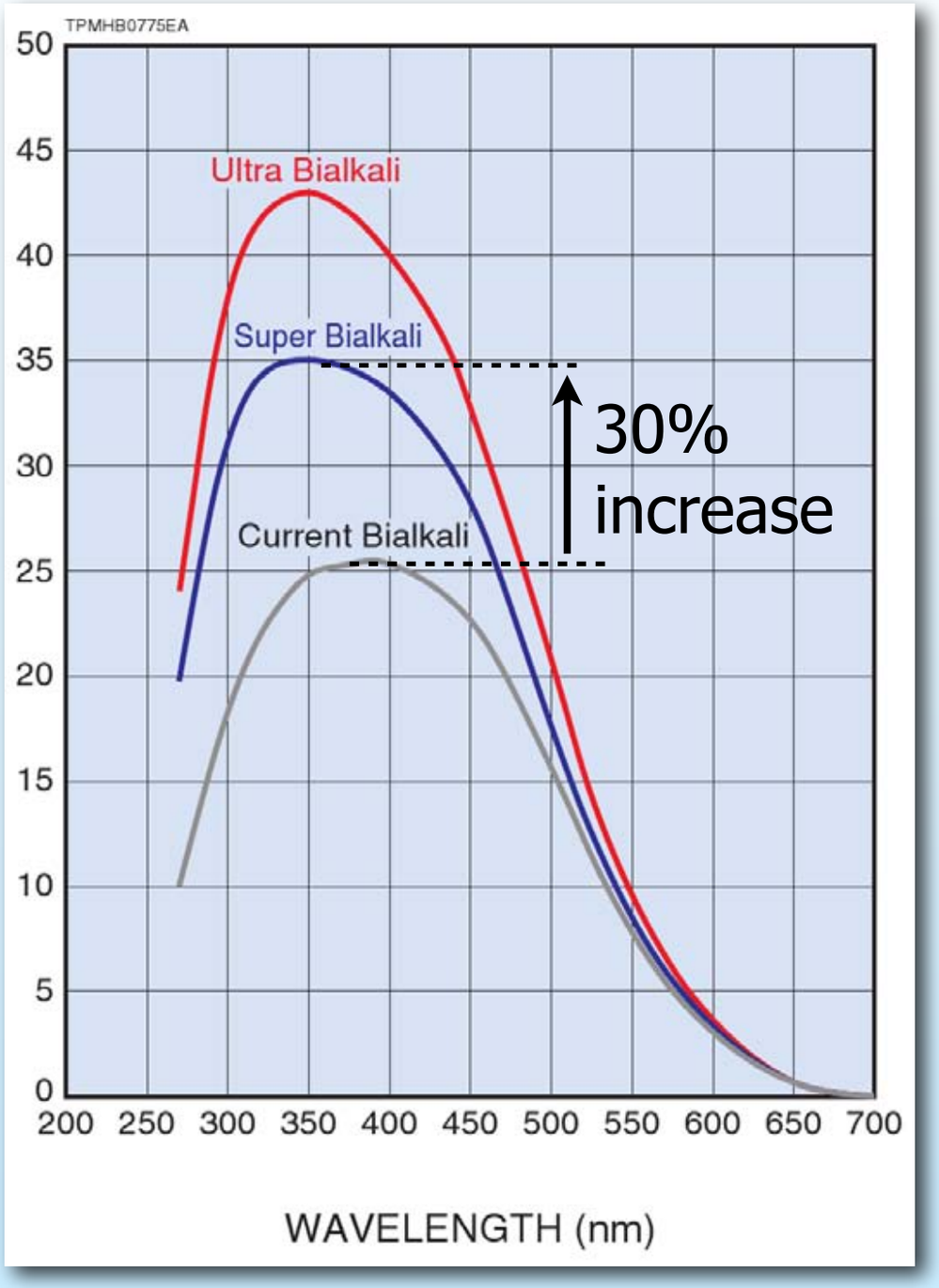
- **high dynamic range**
- **high linearity**
- **low afterpulsing**
- **long lifetime**

Other Quality Parameters

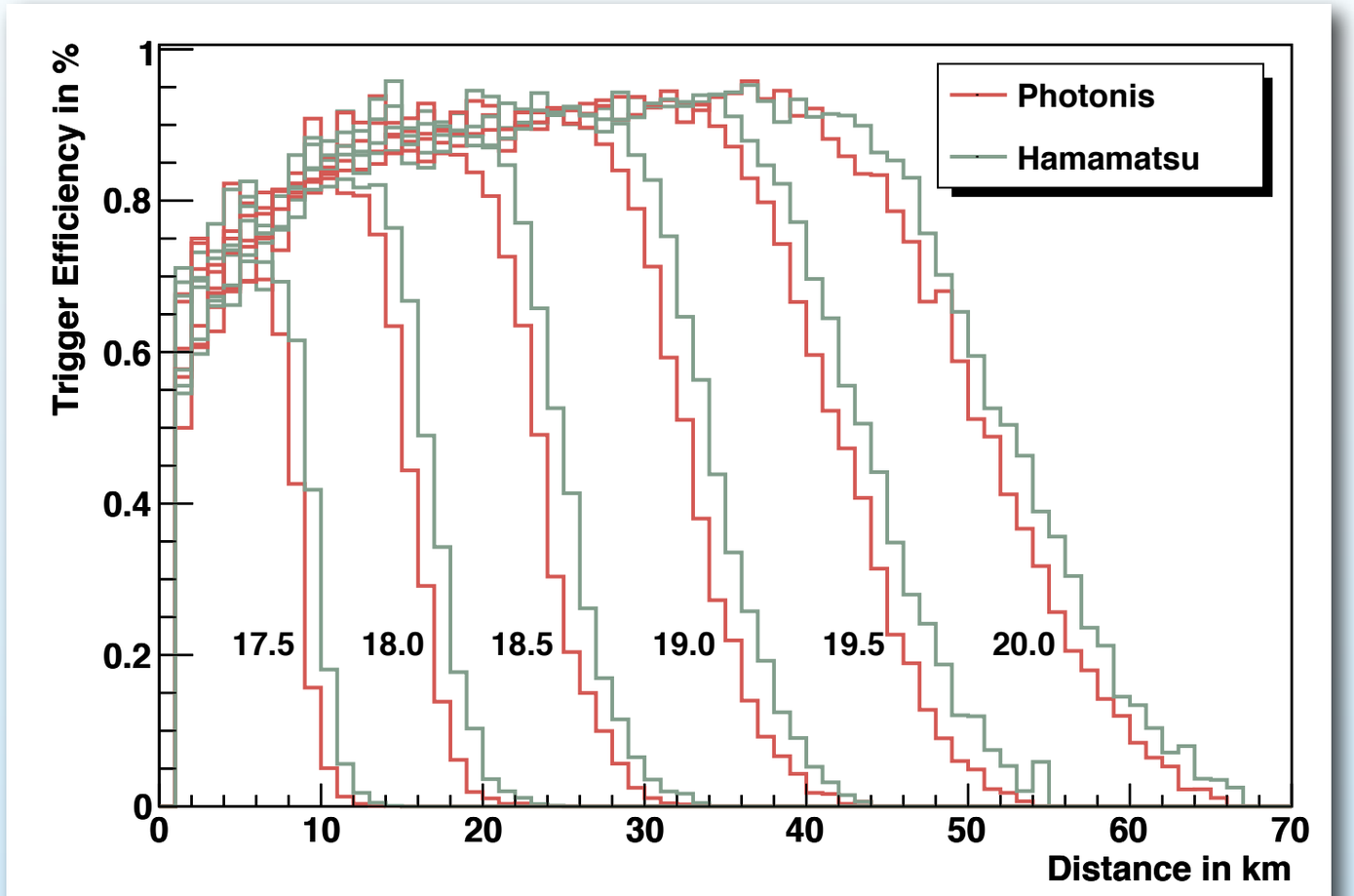
- **quantum efficiency**
- **homogeneity of photocathode**

No fast timing needed
(100 ns - µs scale)

SBA PMTs look promising



© Hamamatsu



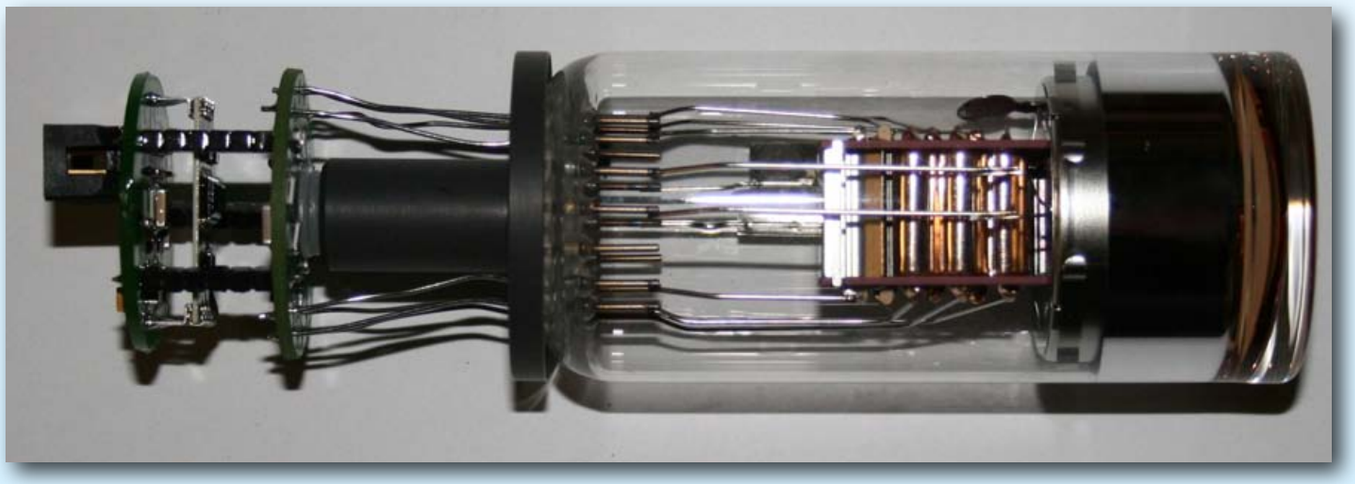
Simulations show:

- can see farther away
  → 20% increase in statistics
- improved energy resolution
- improved X_{max} resolution

Any Drawbacks?

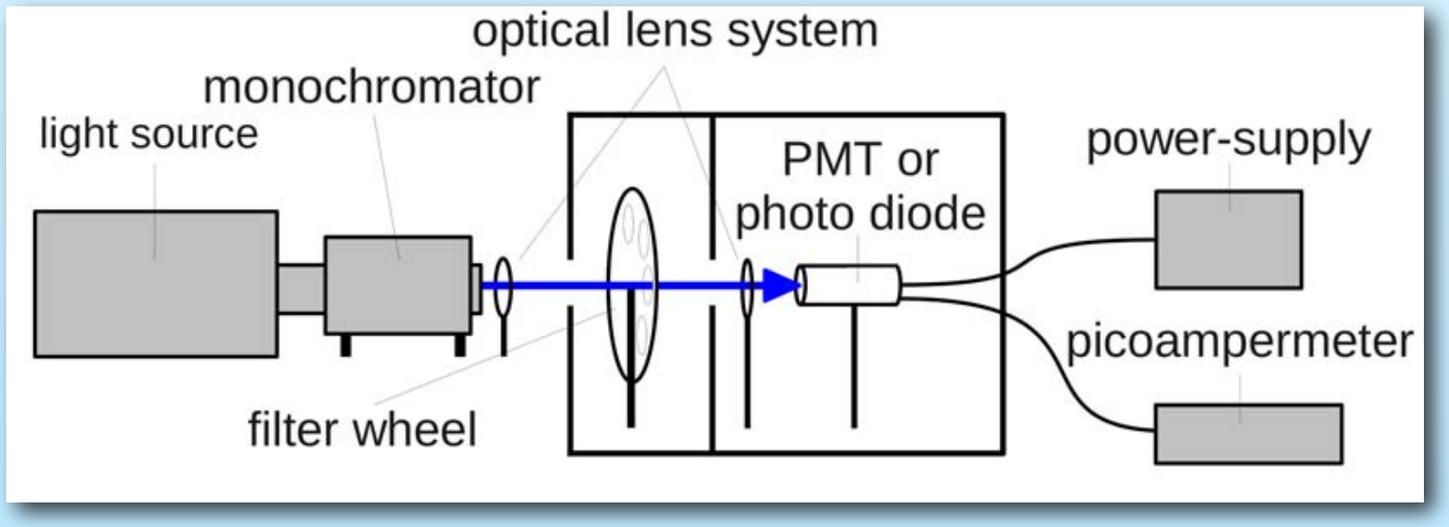
Test Samples

Photonis XP3061 (used in AS)
(hexagonal cathode)

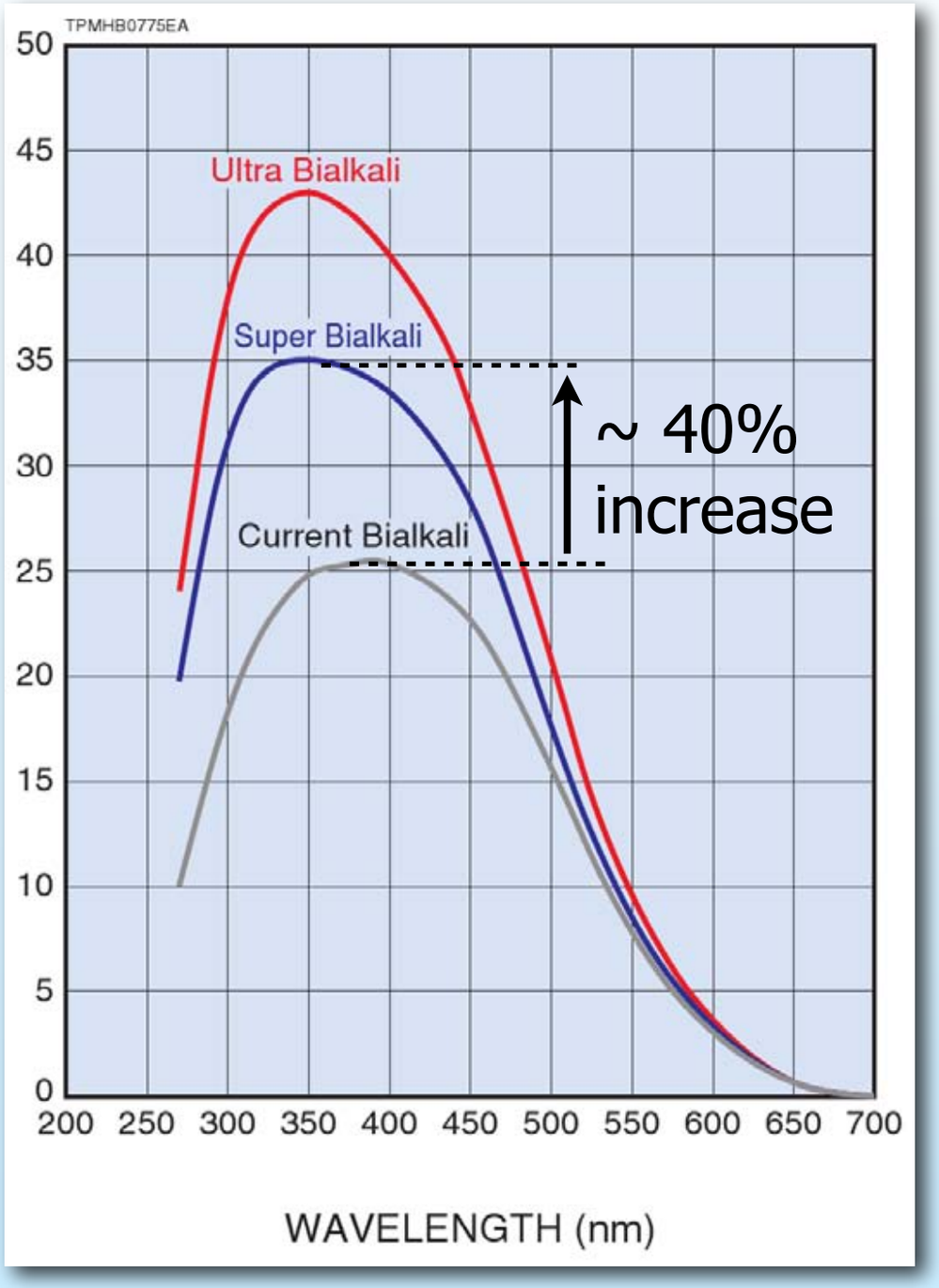


Hamamatsu R9420-100 (SBA)
(full test camera being installed)
(circular cathode)

QE measured in test setup in lab (Wuppertal)



QE confirmed in Lab-Measurements



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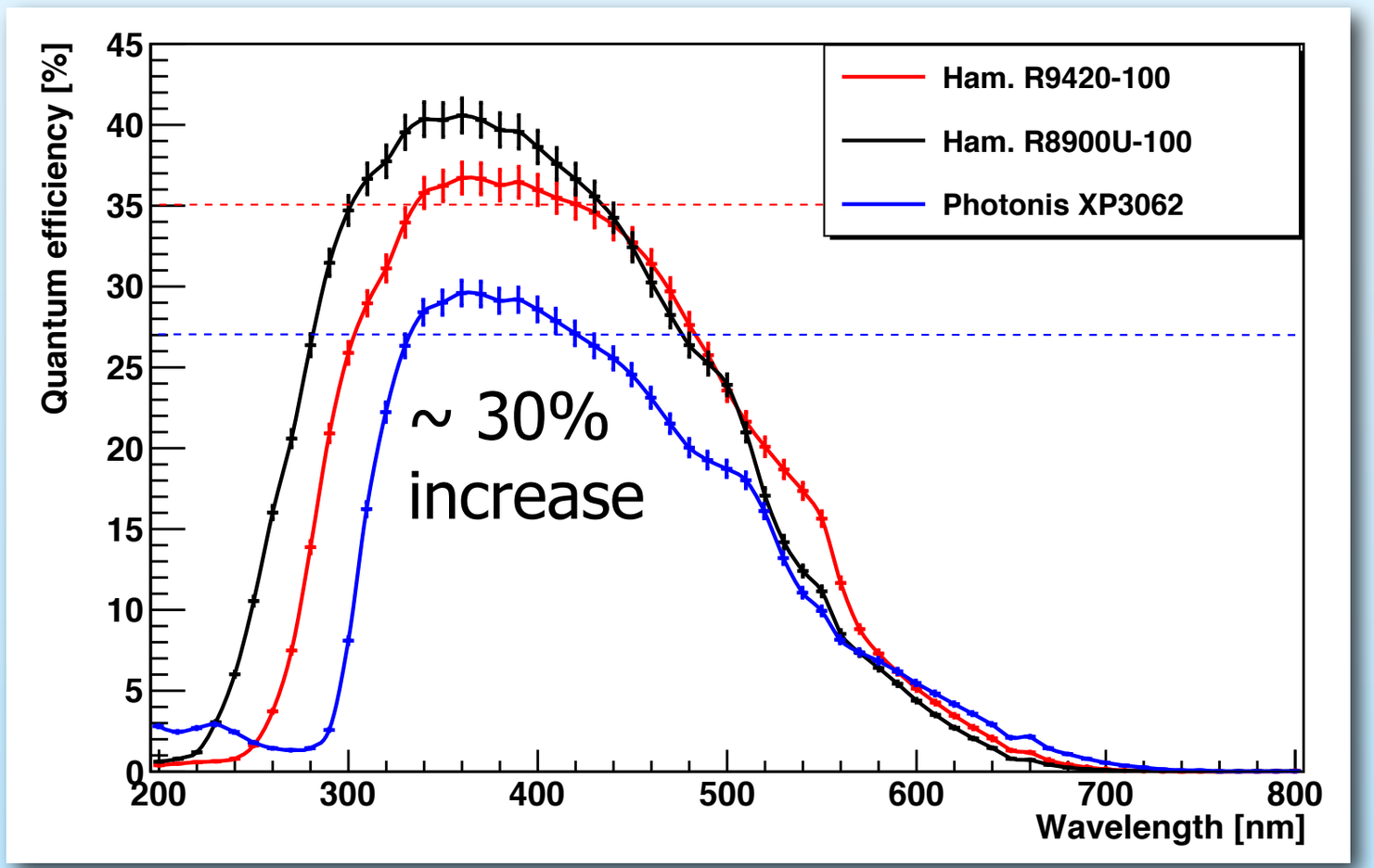
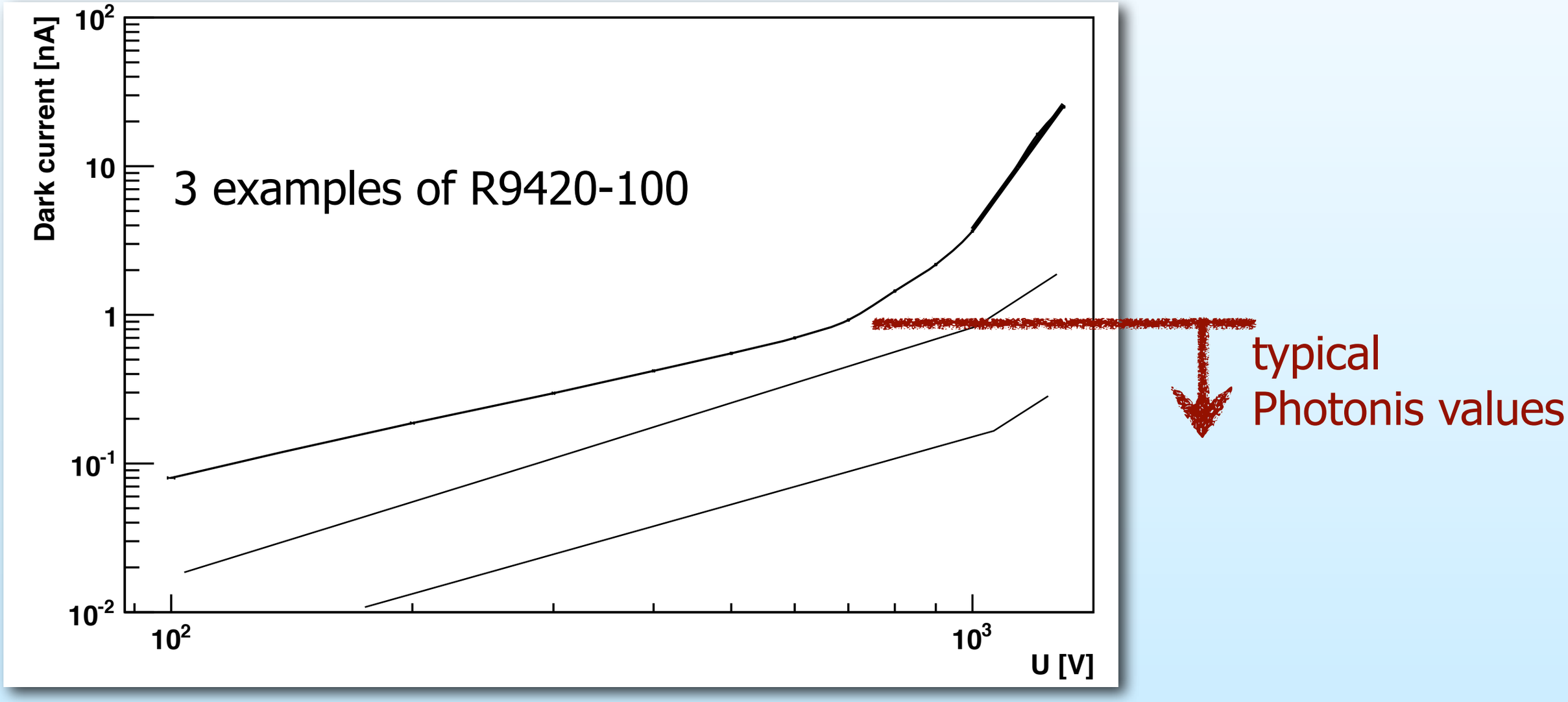
Results in lab confirm spec-sheet but do not show 40% increase relative to latest BA-photocathodes



Other Quality Criteria: Dark Current

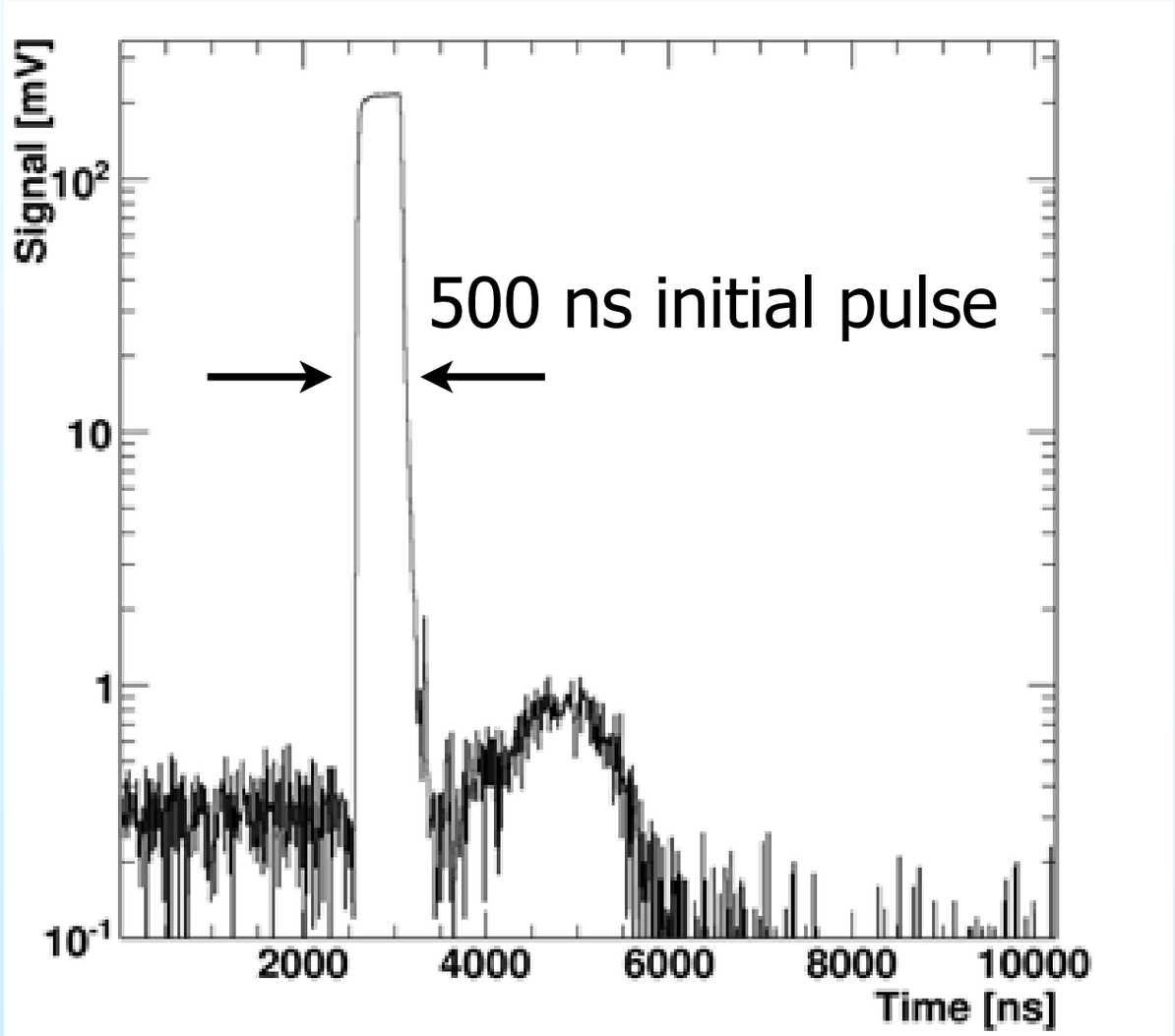
Hamamatsu specs: <100 nA
Photonis specs: <20 nA, typ. 1 nA



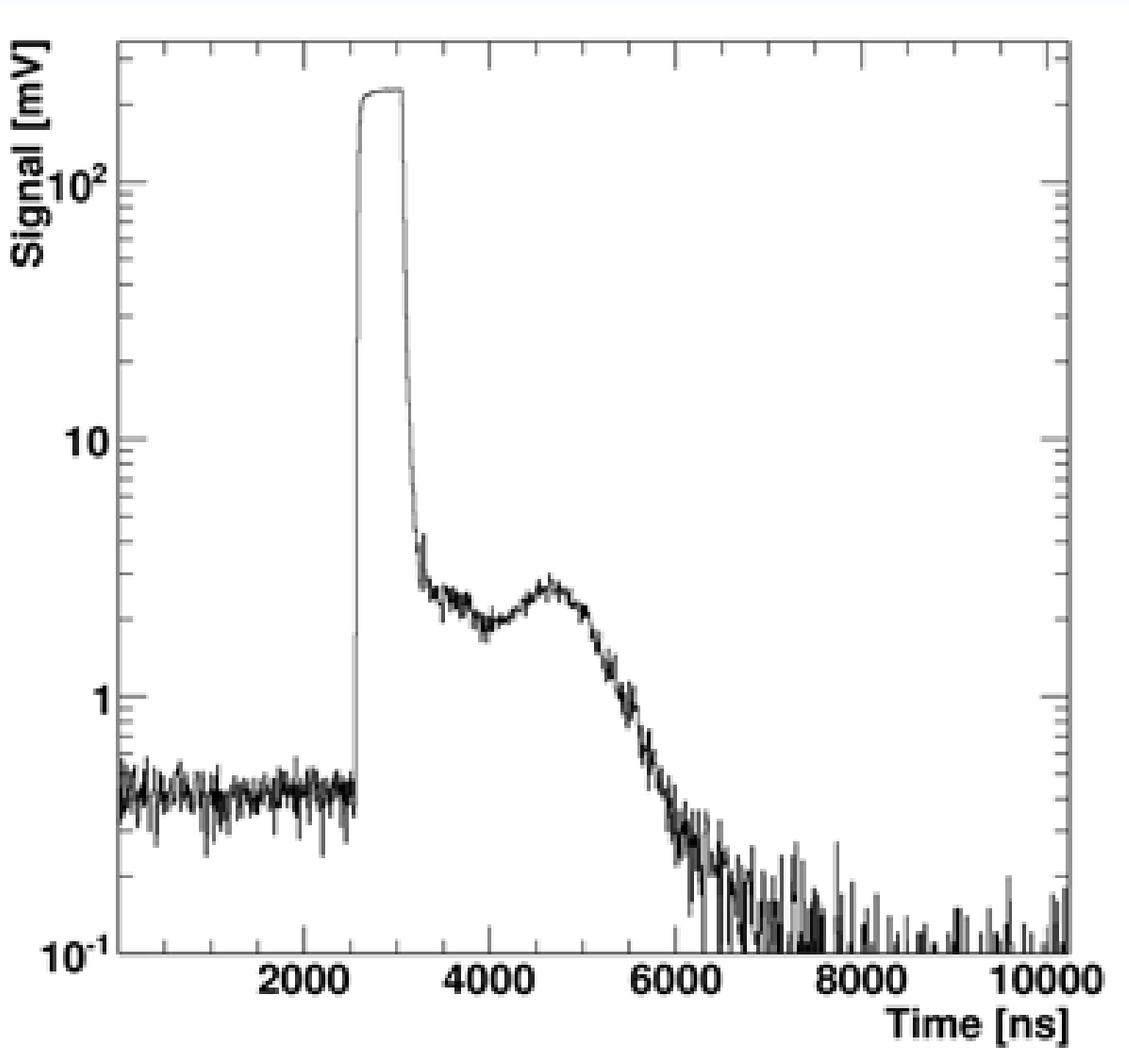
Hamamatsu SBA-PMTs were improved over production process of some 400 PMTs, some still show too high dark current

Other Quality Criteria: After Pulsing

Photonis XP3062

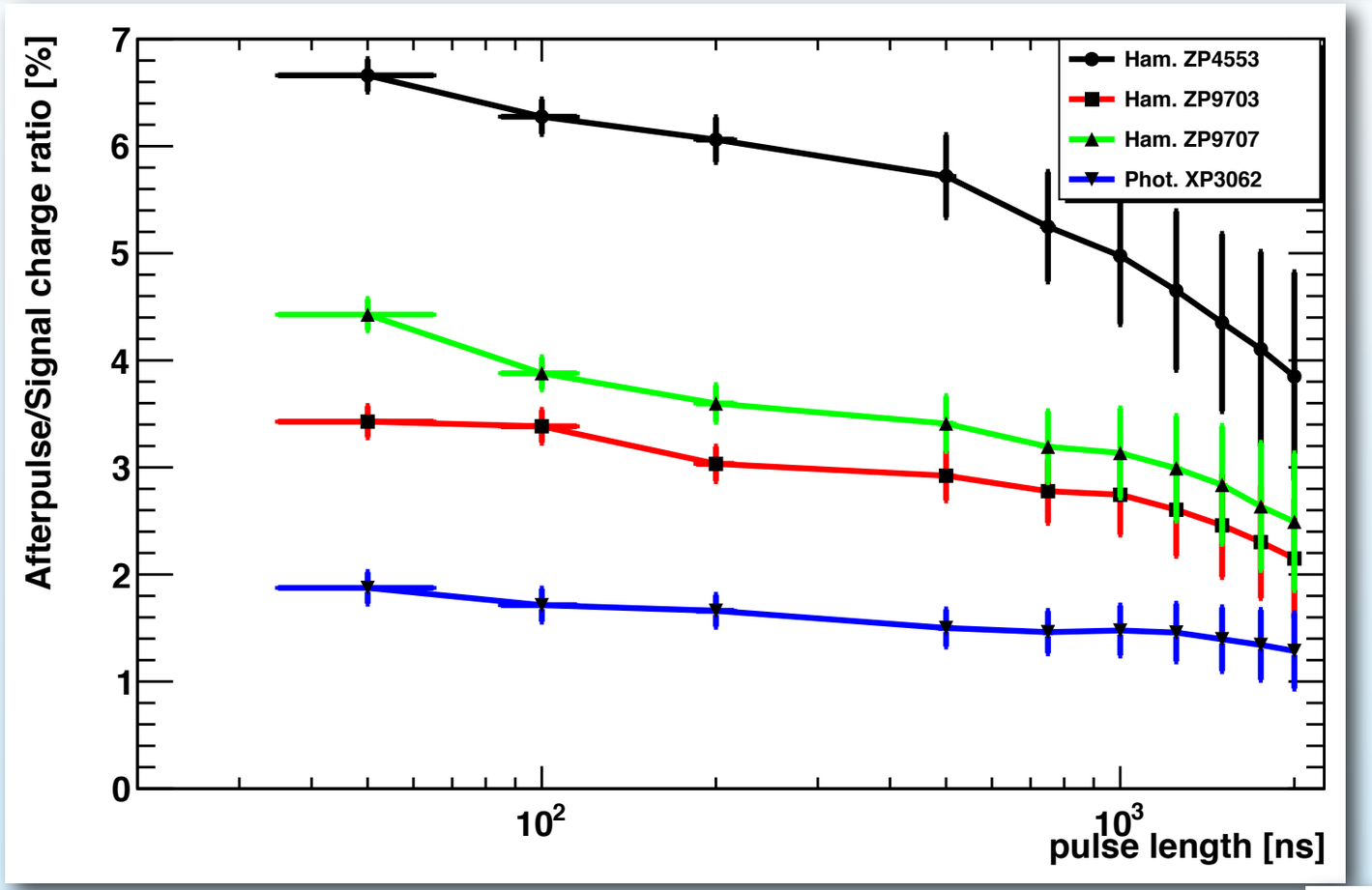


Hamamatsu R9420-100



Much higher alterpulsing in SBA PMTs !

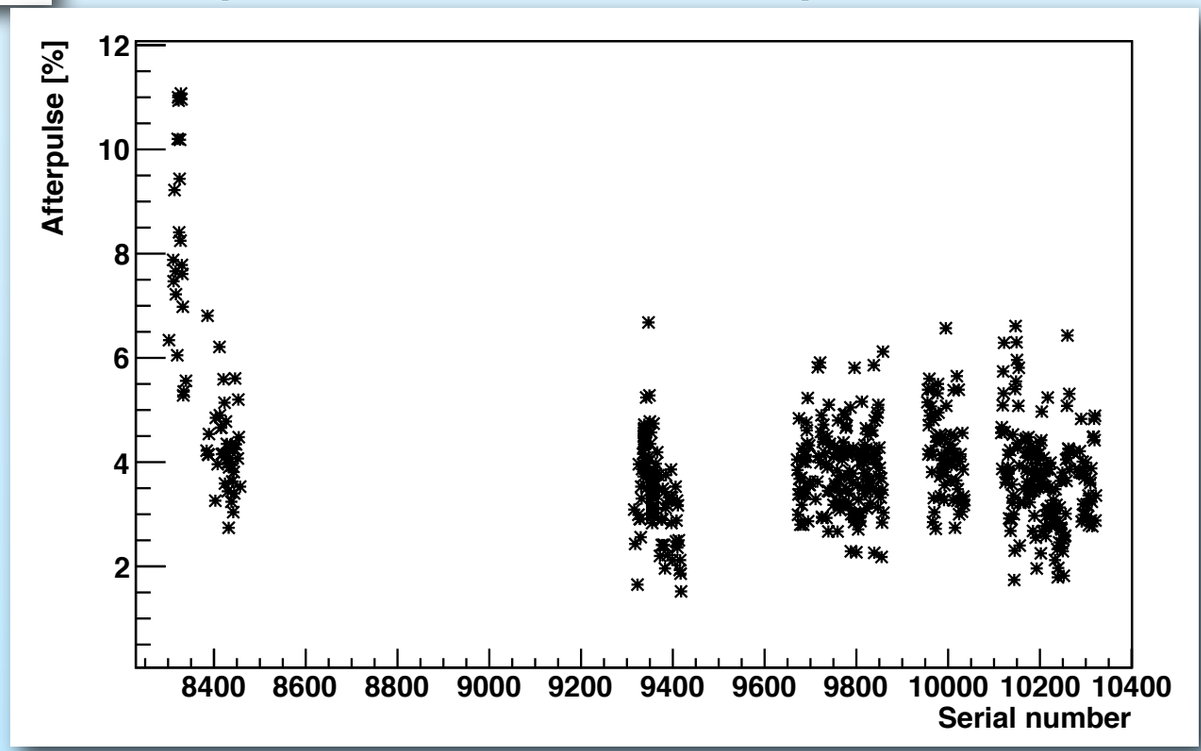
Other Quality Criteria: After Pulsing



Hamamatsu R9420-100

Photonis XP3062

Improvements already achieved



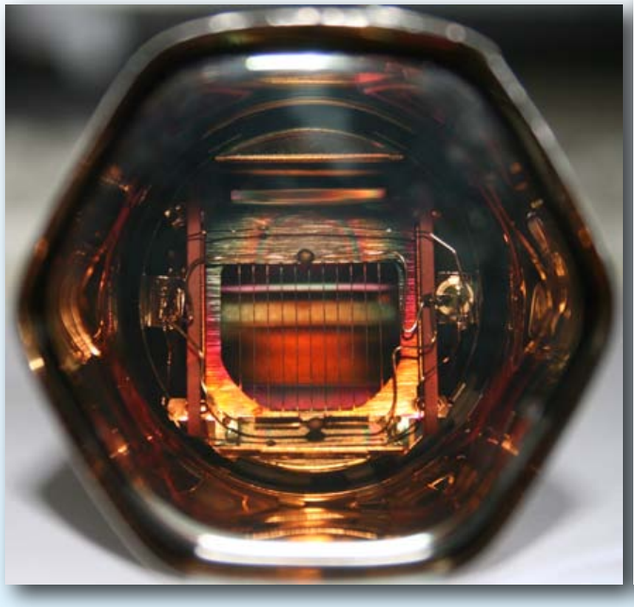
SBA: typically 4%
initially 10% !!

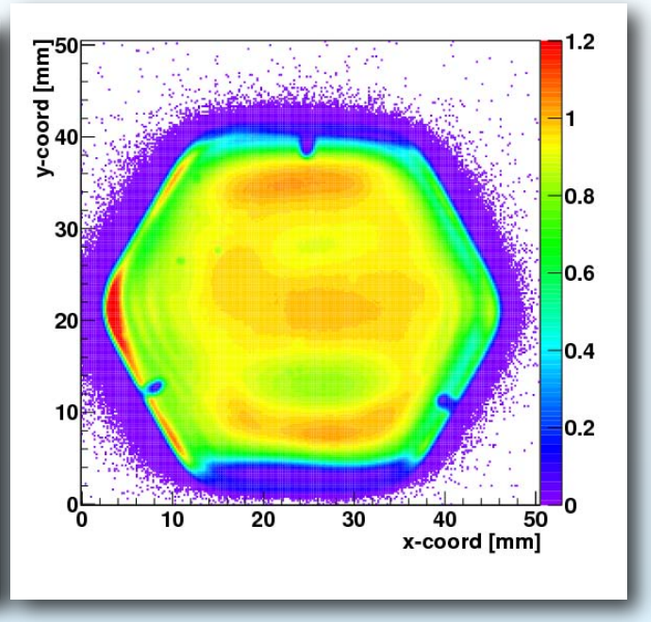
BA: typically 1-2%

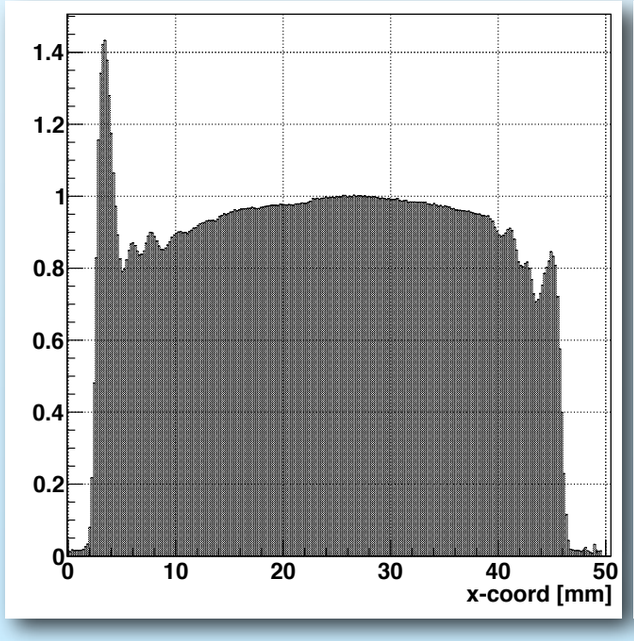
Important for fluorescence telescopes with µs signals !

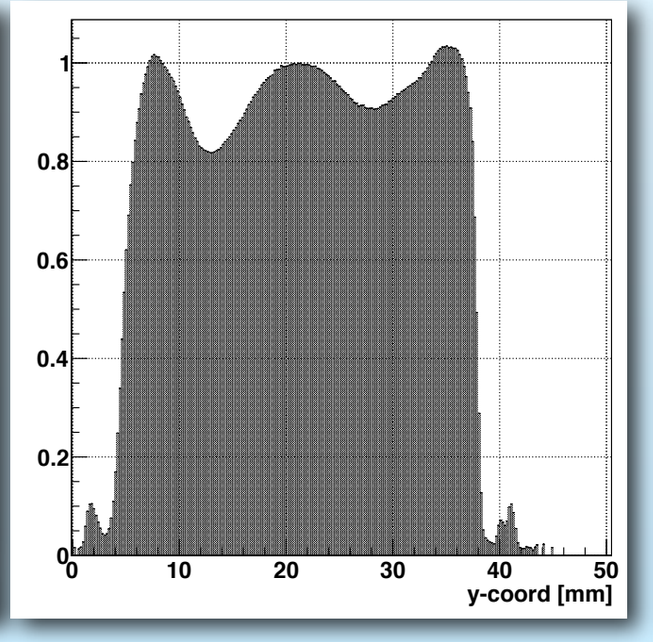
Homogeneity across Photocathode

Photonis XP3062

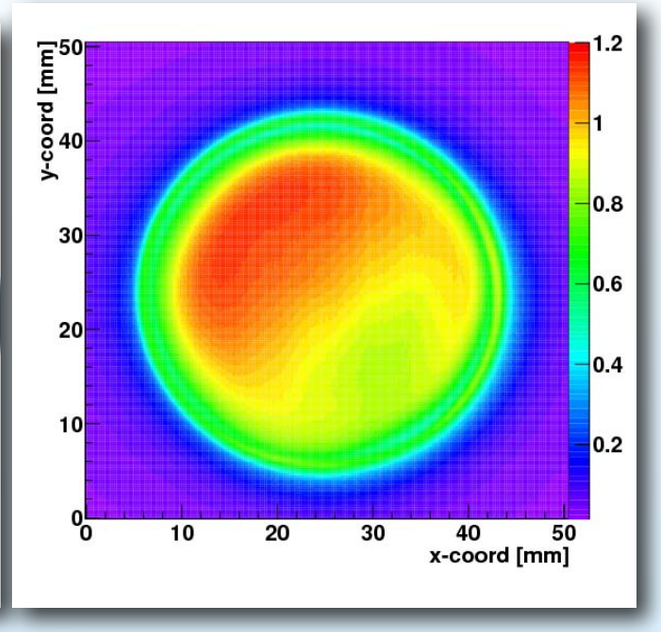


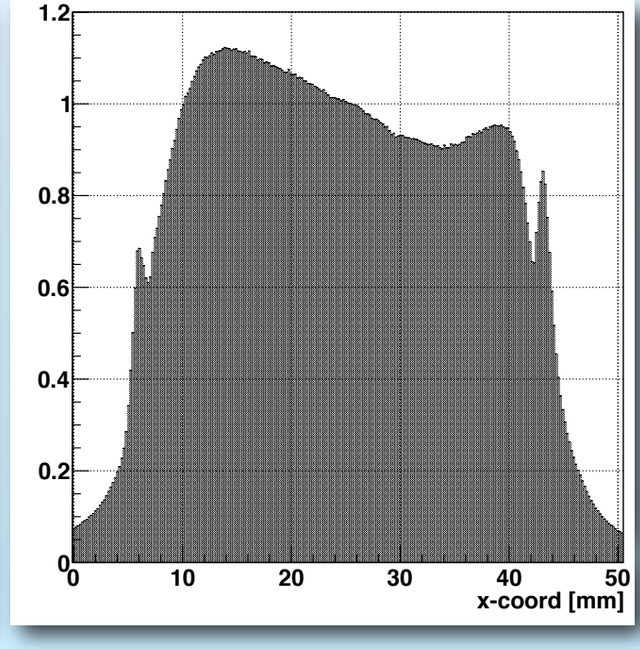


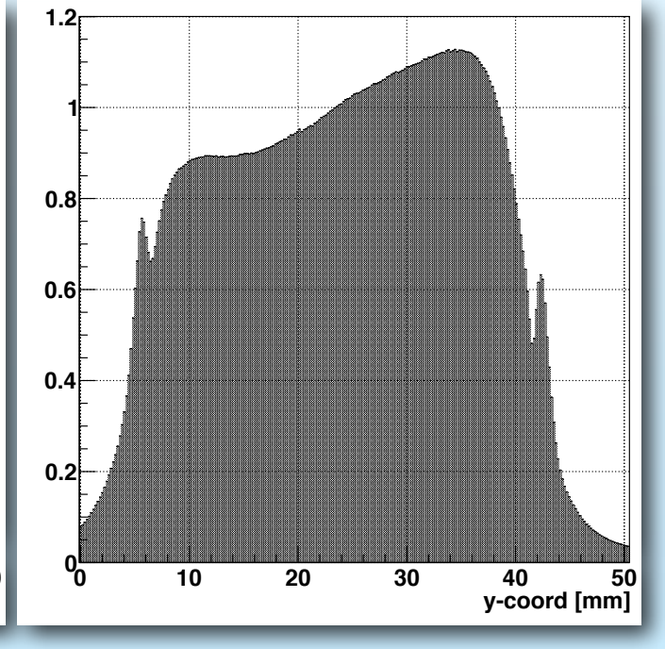




Hamamatsu R9420-100

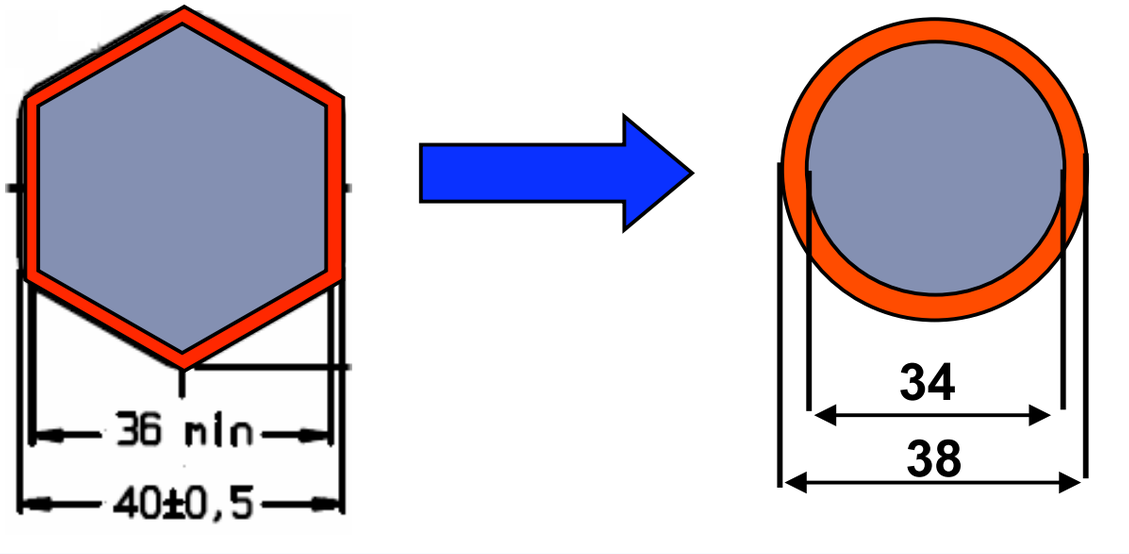






- **Inhomogeneities may be due to different collection efficiencies**
- **Inhomogeneities directly influence reconstruction qualities**

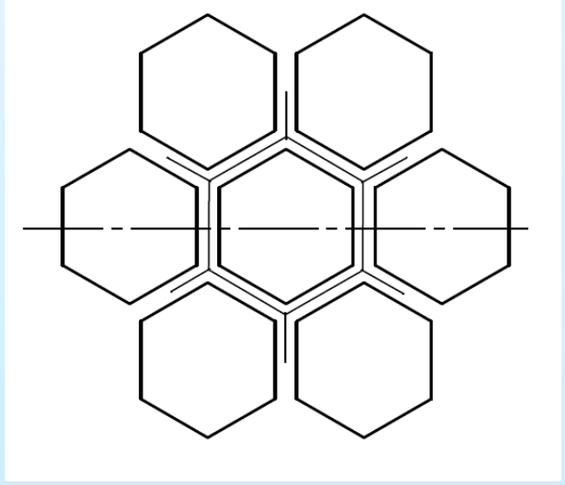
Hexagonal vs Circular Tubes

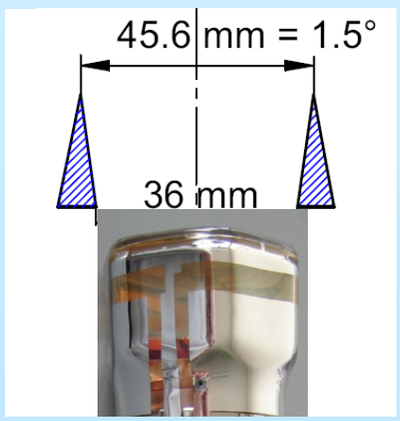


Ø of both tubes identical

1123 mm^2

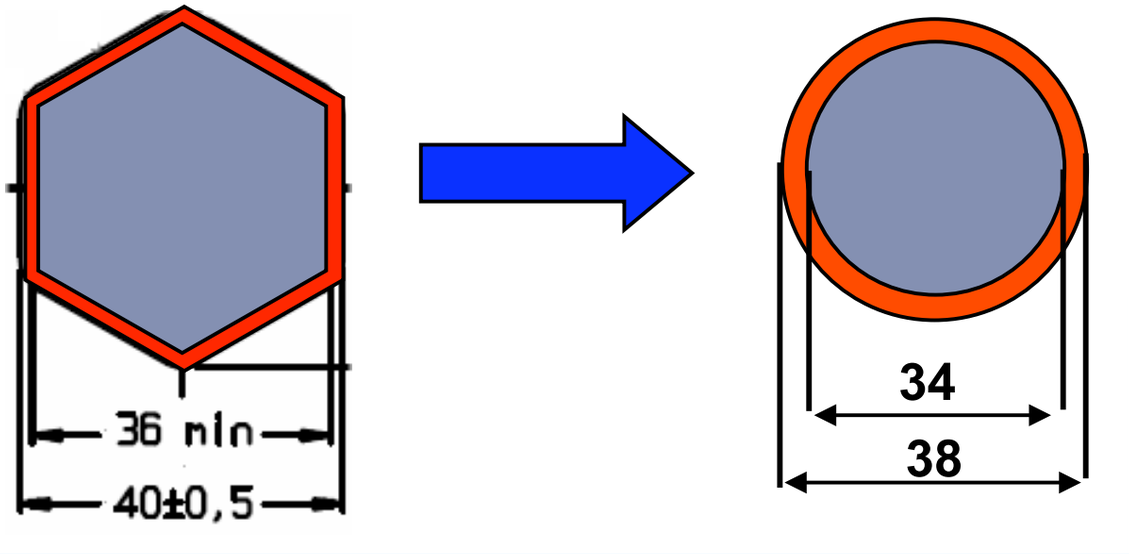
908 mm^2 sensitive area





simple triangles, 9mm base

Hexagonal vs Circular Tubes



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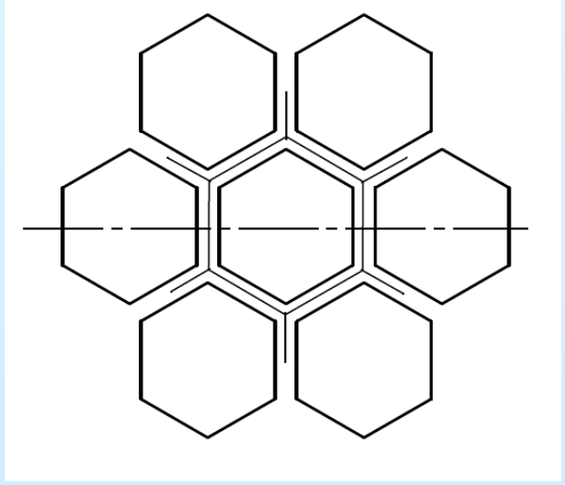
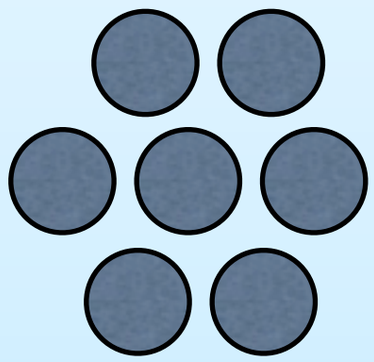
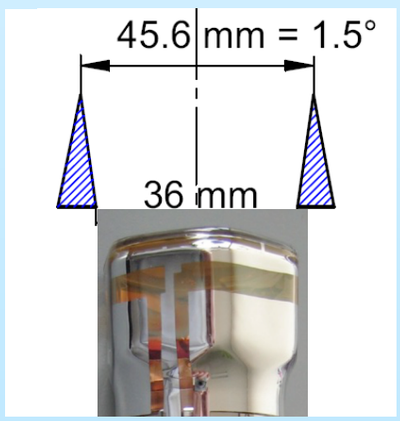




triangles with 16 mm base required



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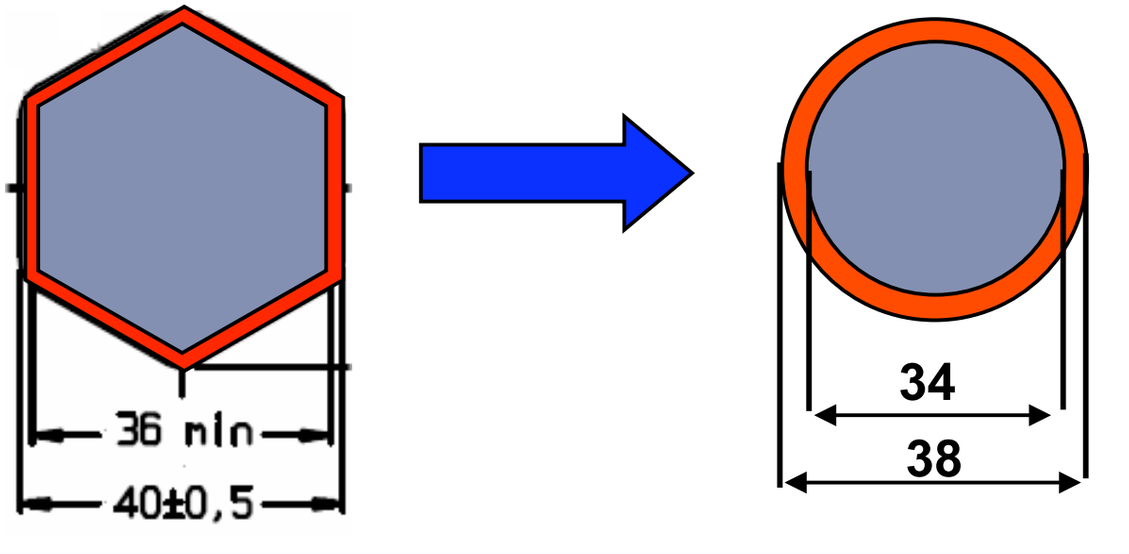

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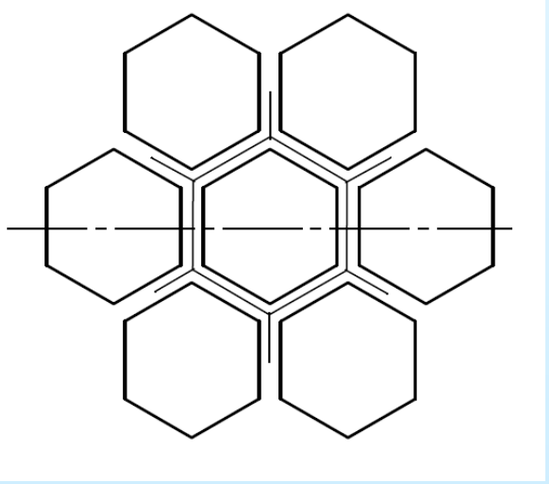
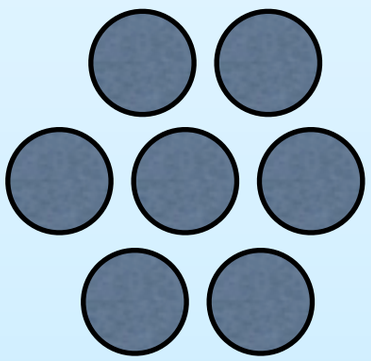
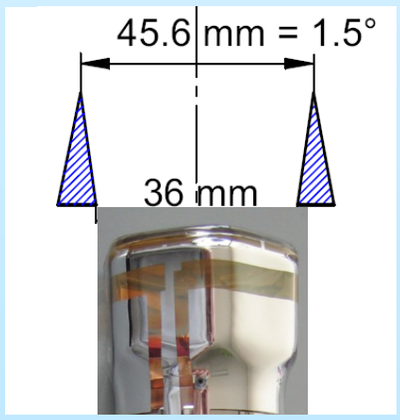
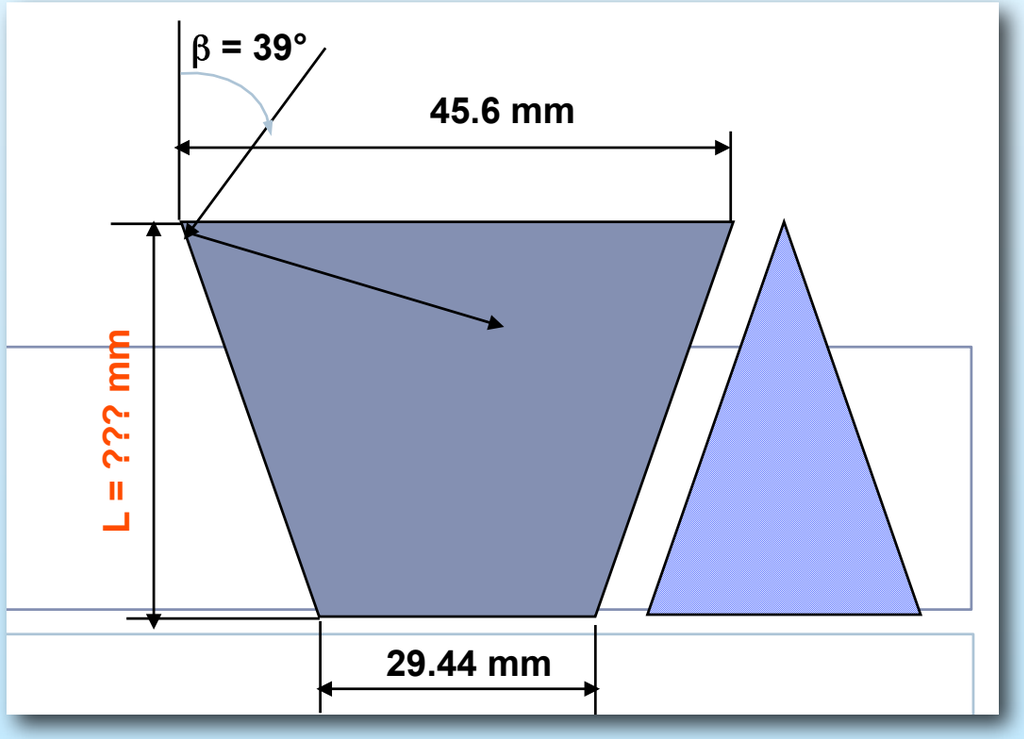




triangles with 16 mm base required

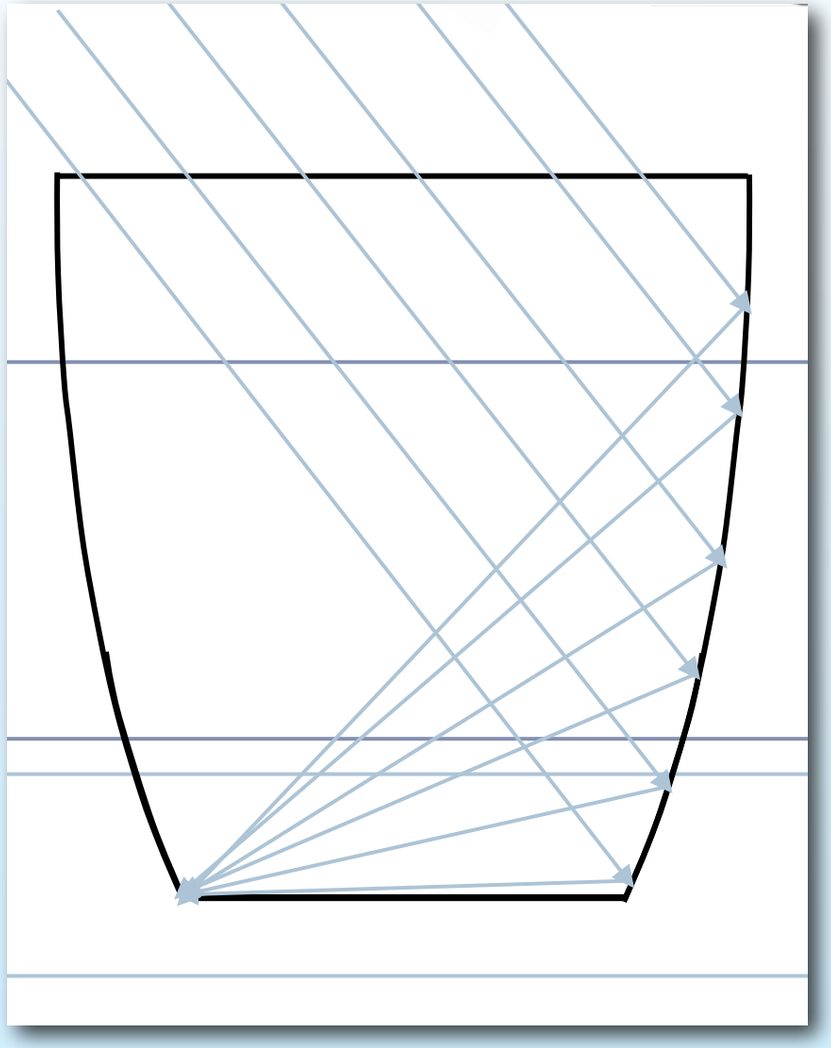


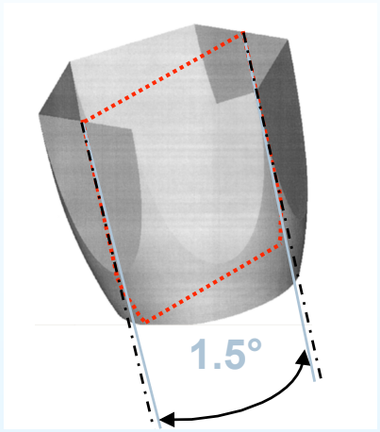
simple triangles, 9mm base

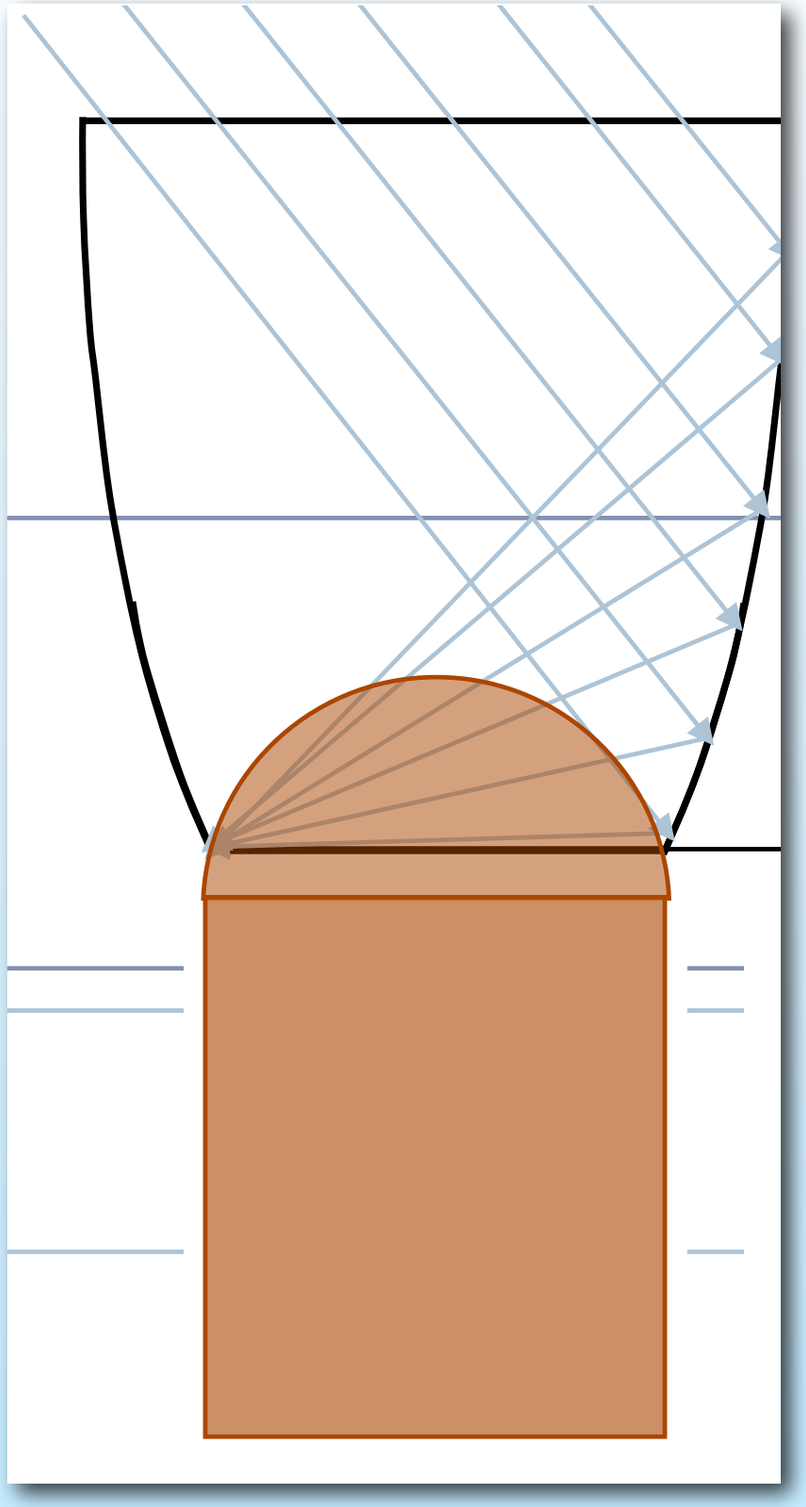


too much light is lost between PMTs
➞ need for Winston Cones

Hexagonal vs Circular Tubes





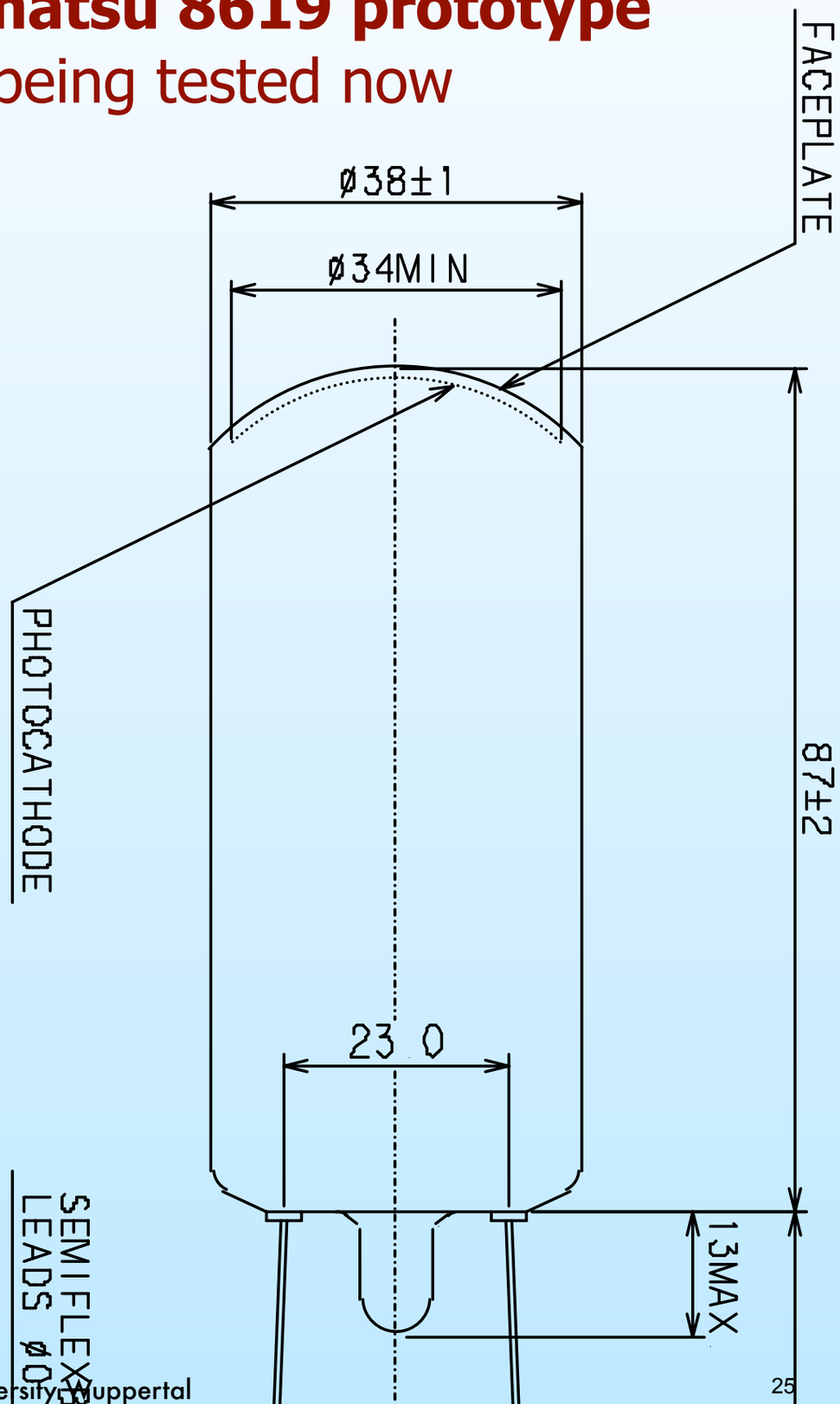


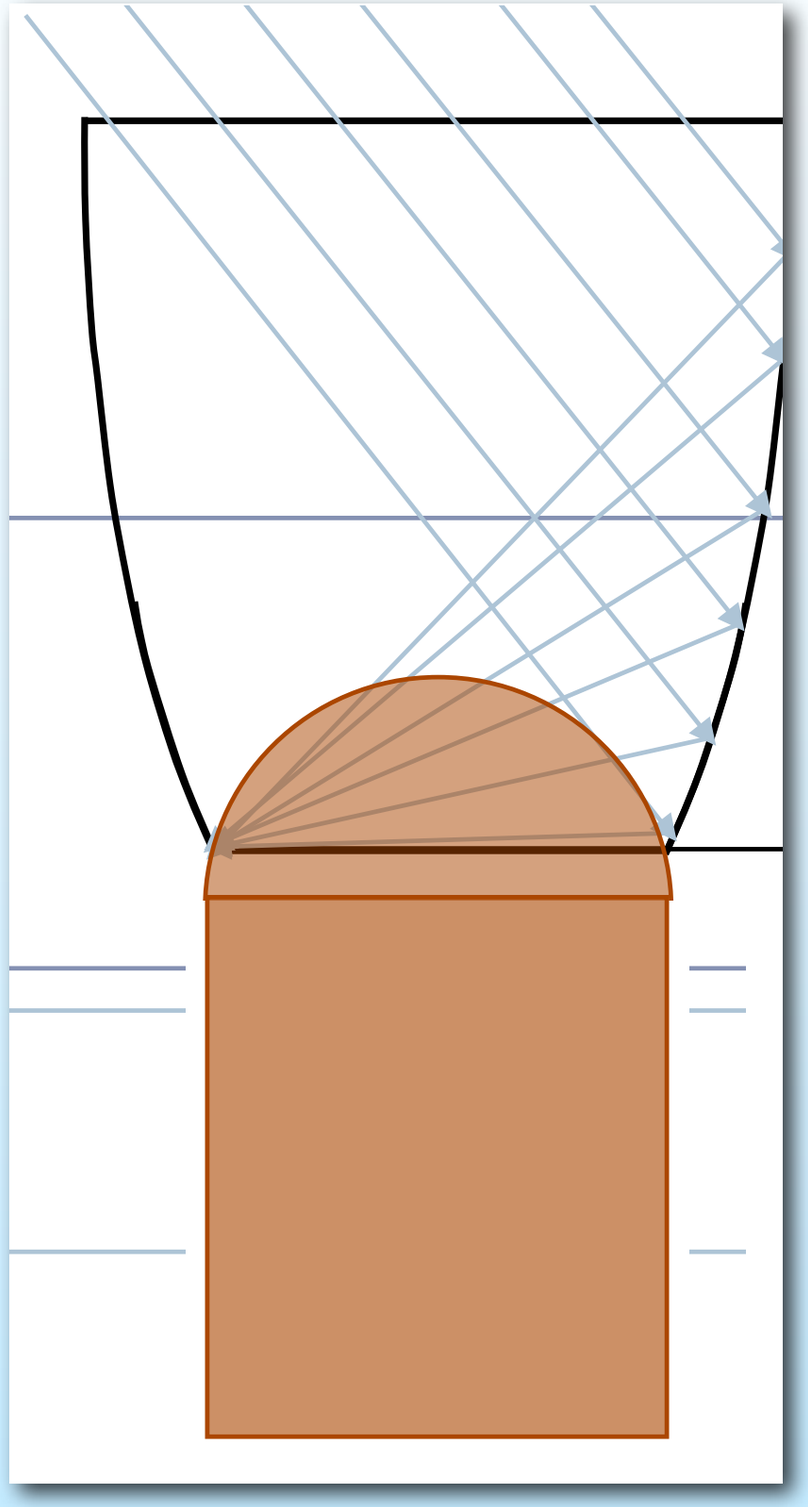
price of light concentrator:
large incident angles!

hemispherical tubes should be superior

Hexagonal vs Circular Tubes

Hamamatsu 8619 prototype
being tested now





Summary on Photosensors (I)

Fluorescence Cameras:

- light spots of ~ ø 10 mm do not call for very small pixels (at present)
- no need for fast timing response
- SBA photocathodes do have advantages
- drawbacks are being eliminated by manufacturers
- afterpulsing is still an issue
- collection efficiency seems to cause some extra electron-losses
- homogeneity of cathode response is of relevance
- high dynamic range and linear response very important
- hexagonal cathode makes life easier for the experimentalists
- no long-term experience yet with SBA cathodes (aging?)

Some Remarks:

- cooperation and interaction with industries has been beneficial
- e.g. feedback given to PHOTONIS during production of 12000 PMTs helped to improve quality
- interaction with HAMAMATSU has been very positive, too
- but monopolistic market would be very bad on the long term !

Summary on Photosensors (II)

Water Cherenkov Tanks (Surface Detector Array):

- ~ 9" PMTs most suitable
- smaller PMTs, if correspondingly cheaper could be an alternative
- do not need ultra fast response (≥ 5 ns)
- but good single pe detection
- SBA photocathodes may have advantages,
  if collection efficiency remains good enough
- afterpulsing an issue, too
- high dynamic range and linear response very important

Comparison of Demands:

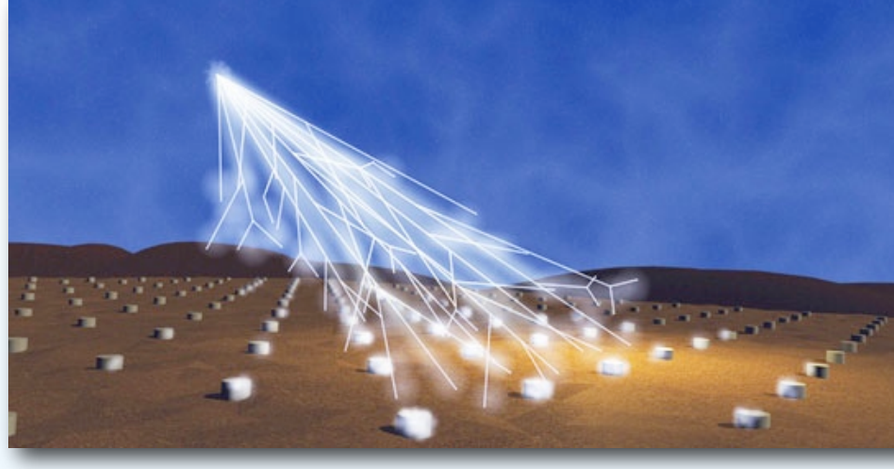
- Fluorescence and Cherenkov Telescopes (e.g. CTA) have very similar requirements, in fact Auger & CTA may use the same PMT
- Surface Water-Ch Arrays and Neutrino Telescopes share similar demands, too, e.g. concept of single large vs several small PMTs

High Voltage

- **Fluorescence Telescopes connected to power lines;**
- PMTs use classical voltage divider chain of low bleeder current
- to save costs, presently 44 PMTs connected to single HV channel
- wish to reduce this in the future by ~ factor 2 (still 800 channels)
- low cost HV power supplies allow for more individual PMT settings

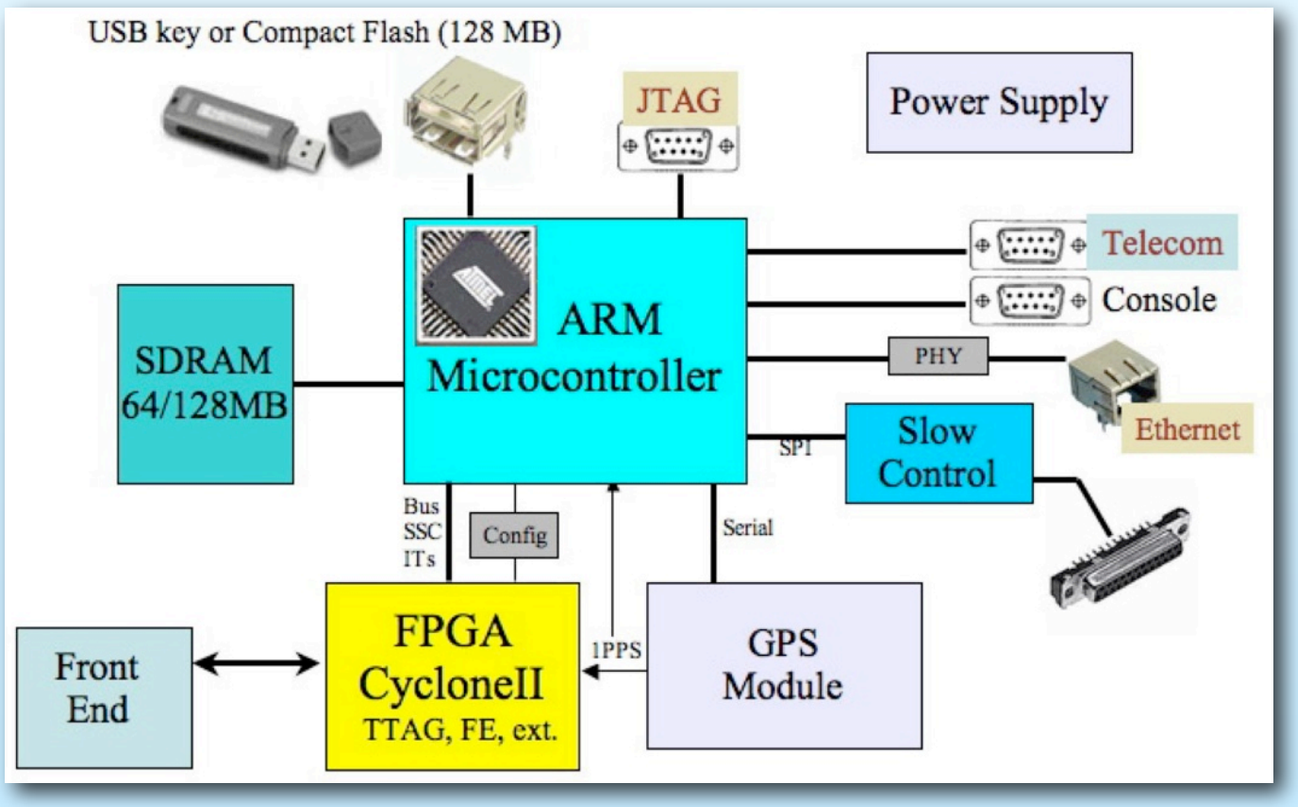
- **Surface Array powered by solar panels**
- presently, low power DC-DC HV modules are being used
  (ETL PS2010/12)
- drives the cost for the bases (more than 50% of the cost!)
- Greinacher (Cockcraft Walton) base may be an alternative and useful to look into

SD-Electronics



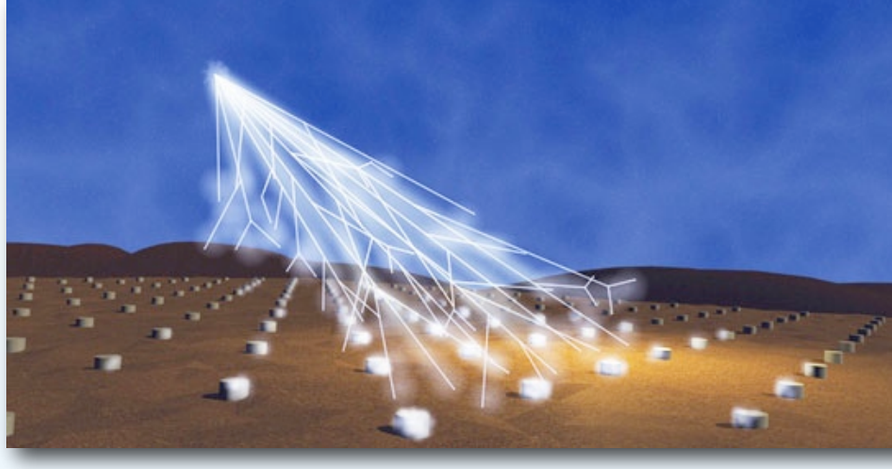
- Auger-South works very well, but not anymore state of the art
- R&D and Prototyping on Auger-North has started ~ 3 years ago

Schematics of Prototype Board



- A microcontroller, based on the ARM920 core plus an additional FPGA to perform the first level trigger and the time tagging.
- The microcontroller interfaces the GPS receiver, the trigger FPGA, communications and slow control devices.
- For time-tagging a rapid (100 MHz) counter will be latched by each local station trigger. The currently planned GPS clock is Motorola M12M.
- The time calibration across the array is better than 10 ns.

SD-Electronics



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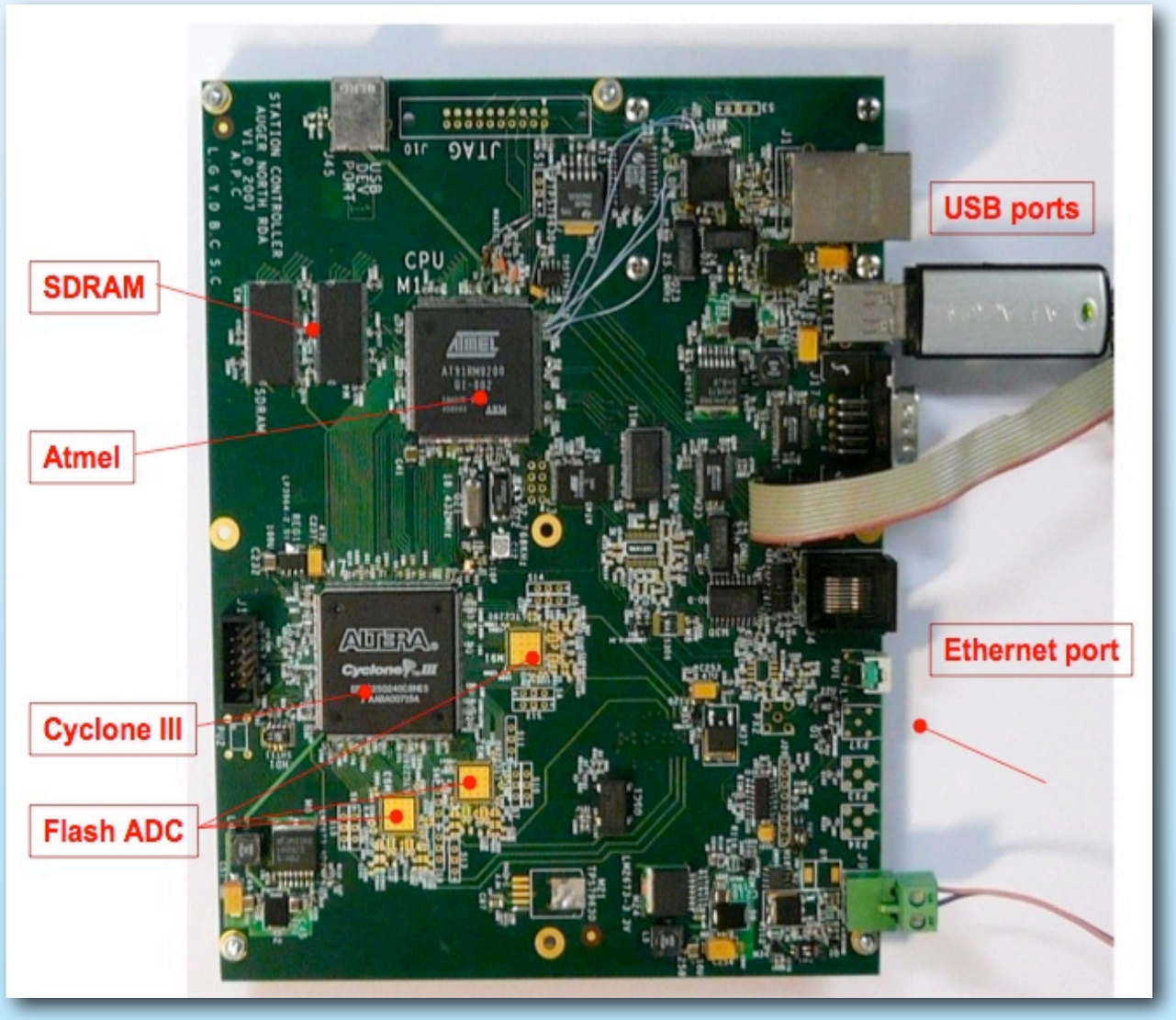

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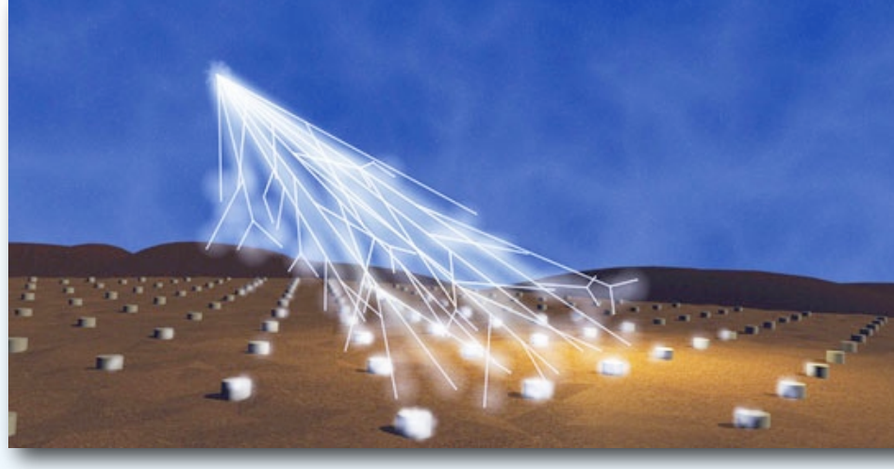
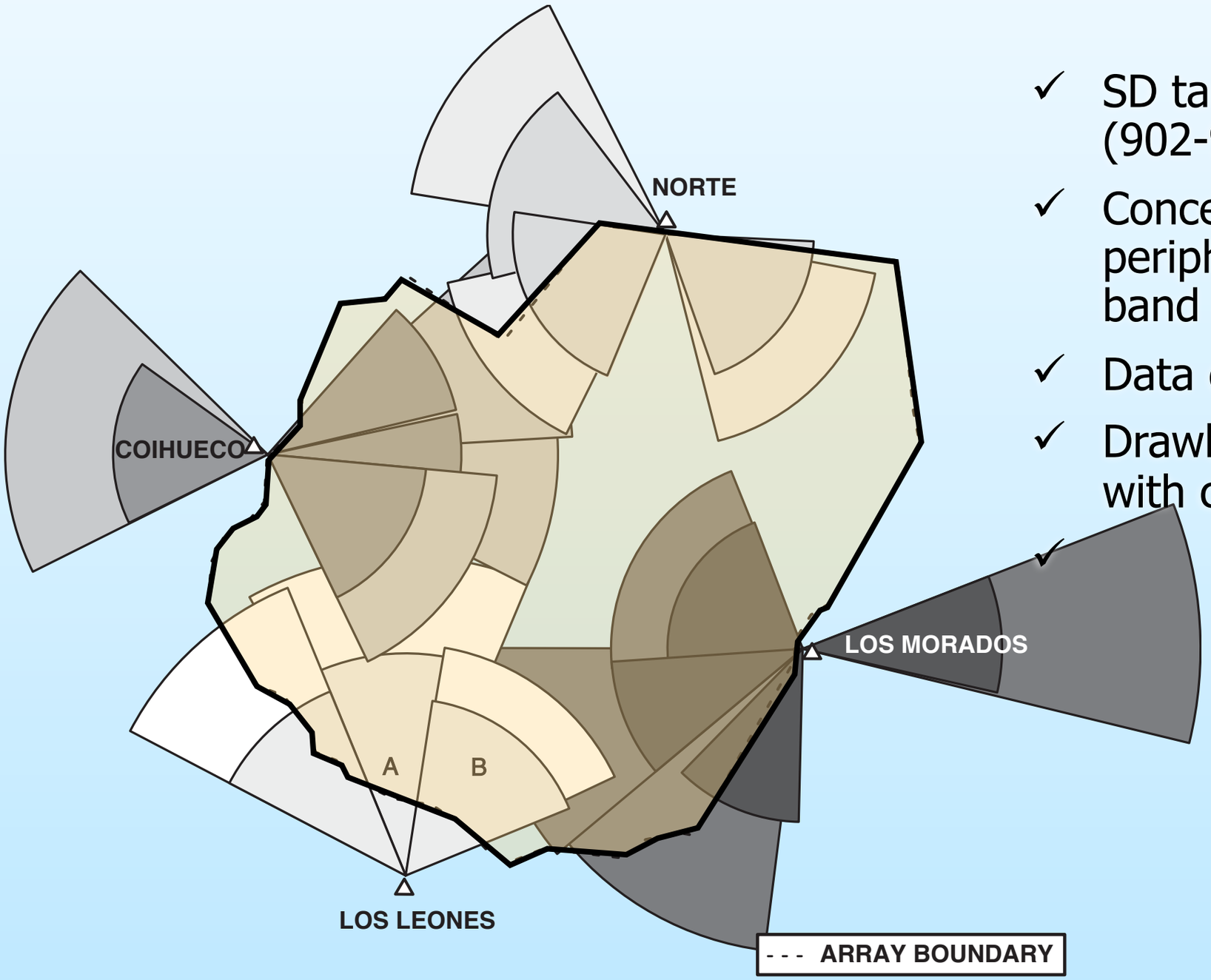
Communication

as is used in AS



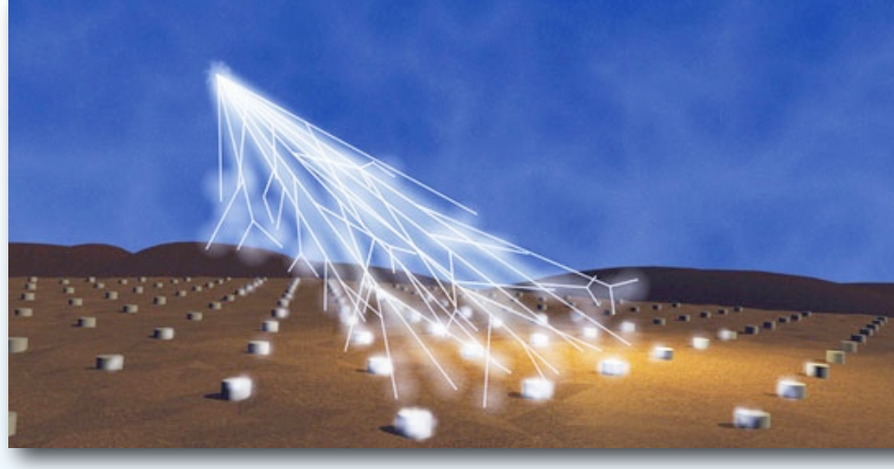
- AS used a point-to-multipoint wireless network



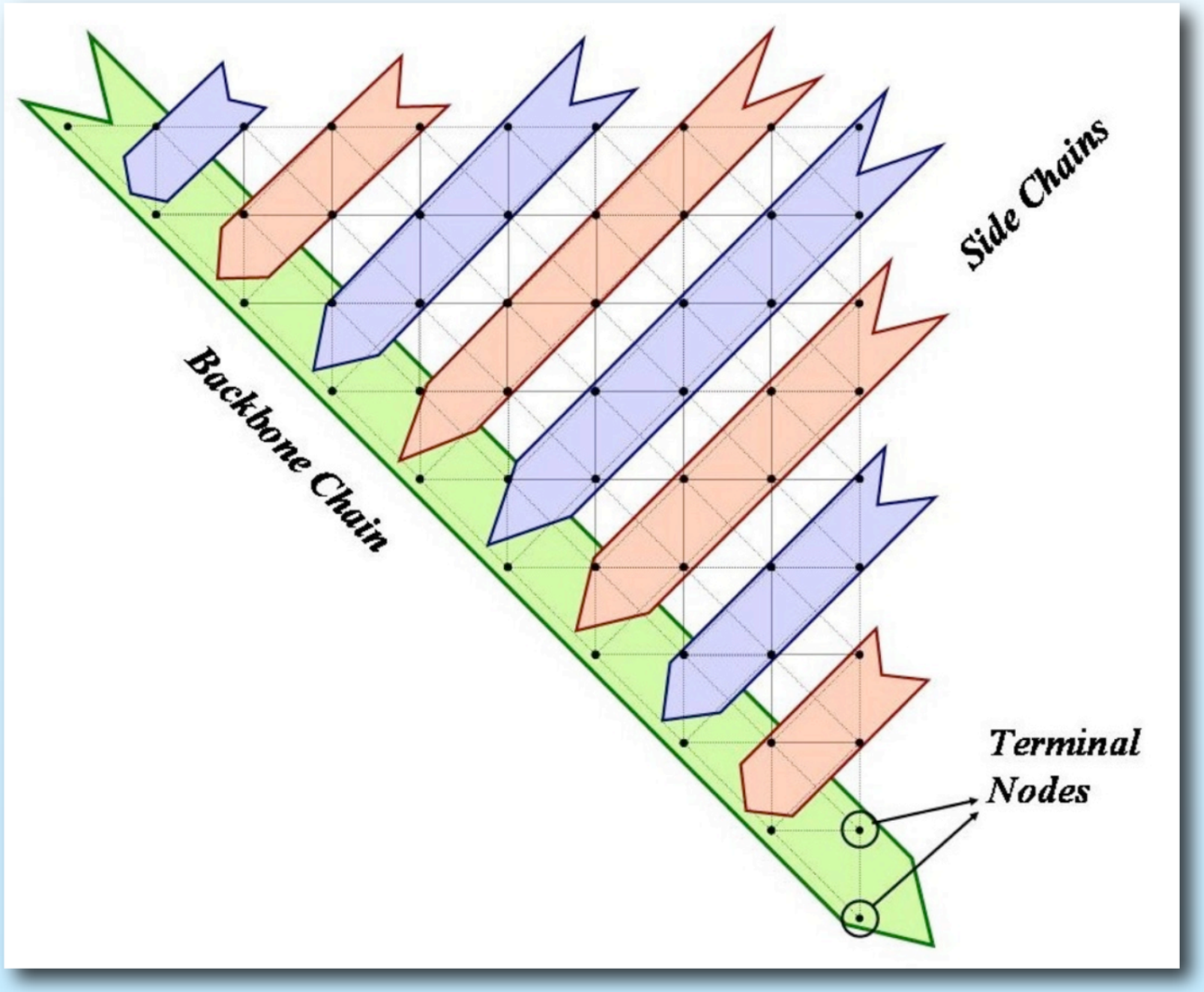
- ✓ SD tanks operate in ISM band (902-928 MHz)
- ✓ Concentrator stations on hills at periphery operate in the 7 GHz band (34 Mbps/link)
- ✓ Data collected at Campus
- ✓ Drawback: need flat landscape with concentrator stations located on hills

Communication

as presently planned for AN



- AN will use peer-to-peer wireless sensor network



A second-order power-chain intersect the backbone chain.
Each side chain is in-turn activated to relay its data to the backbone, which then forwards all messages to the two Terminal Nodes.

- ✓ tanks communicate only with their nearest neighbors
- ✓ advantage: does not need flat landscape
- ✓ challenge: reliability of network
- ✓ It will be configured as a WSN with heavy reliance on local station-to-station communication, using the Wireless Infrastructure for High Assurance Real-Time (WIHART) sensor nets paradigm.
- ✓ The SD communications system is interfaced to optical fibers for transmission of the data to the observatory central campus at Concentrator Stations (CSs) placed on each FD site.

Summary

- **Photosensors:**
  - large demands in basically any experiment
  - often with very similar requirements
  - cooperations useful between major experiments
  - and between AP physicists and companies

- **Electronics:**
  - large needs for solar power driven electronics
  - power consumption major issue
  - distributed DAQ systems

- **Communication Systems**
  - different architectures being used
  - versatility, reliability and bandwidth are key parameters
  - software (protocols) & hardware
  - AP community could profit from co-operatiom with telecom industries

In the discussions of the workshop the following questions shall be addressed:

- What are the requirements of the coming projects concerning photosensors?
- What are the technological challenges?
- What products are available and what kind of R&D activities are required?
- What is the potential of joint research activities?
- Is there an R&D strategy that can be commonly followed by research institutes and SME?
- What is the impact of developments on other scientific fields or market ready products?
- What are the bottlenecks when scientists cooperate with industries, what are the typical wishes of industrial partners and of scientists?