The Southern Wide-field Gamma-ray Observatory

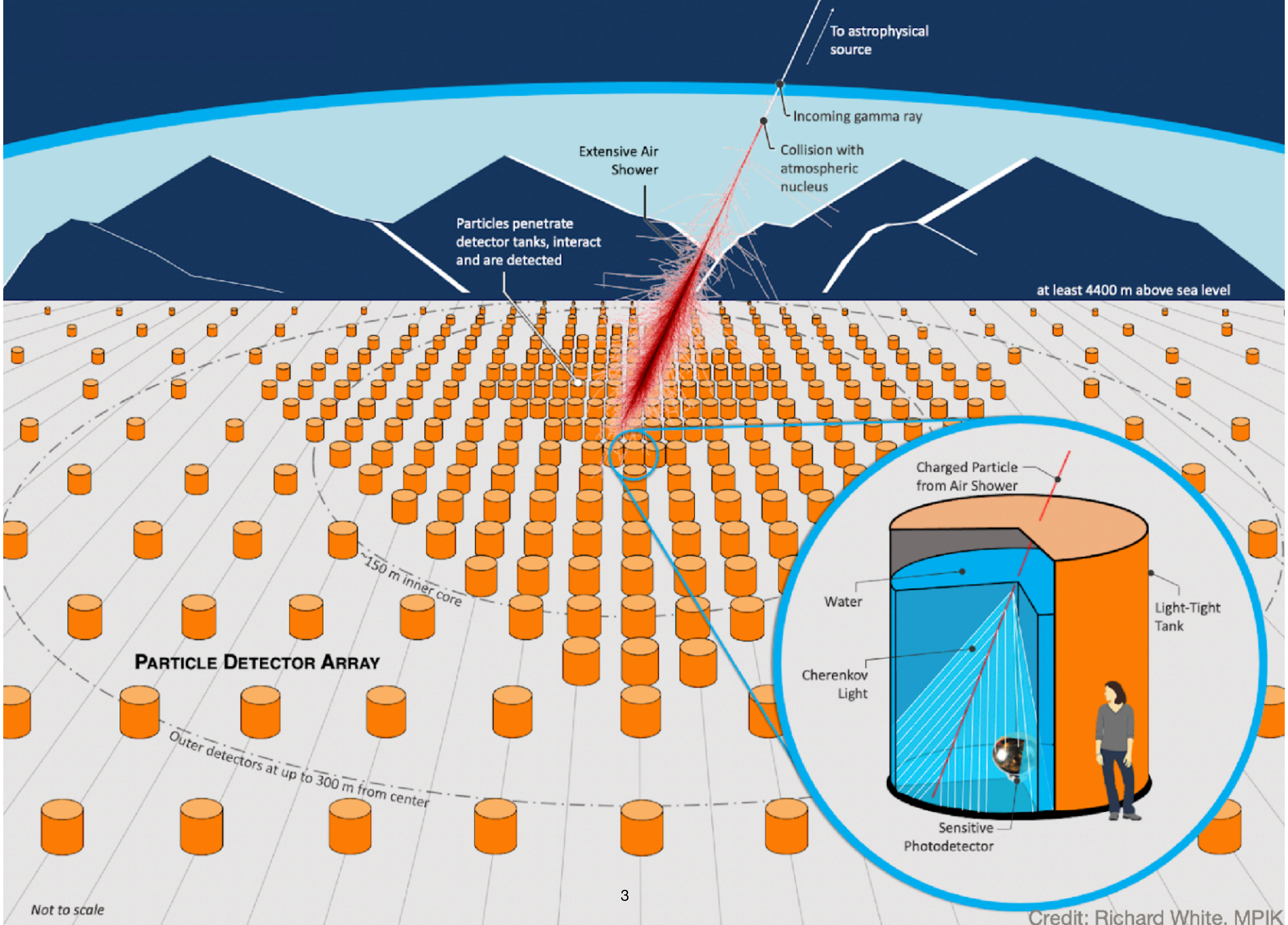
A next generation particle detector array to survey the Southern Sky

Harm Schoorlemmer

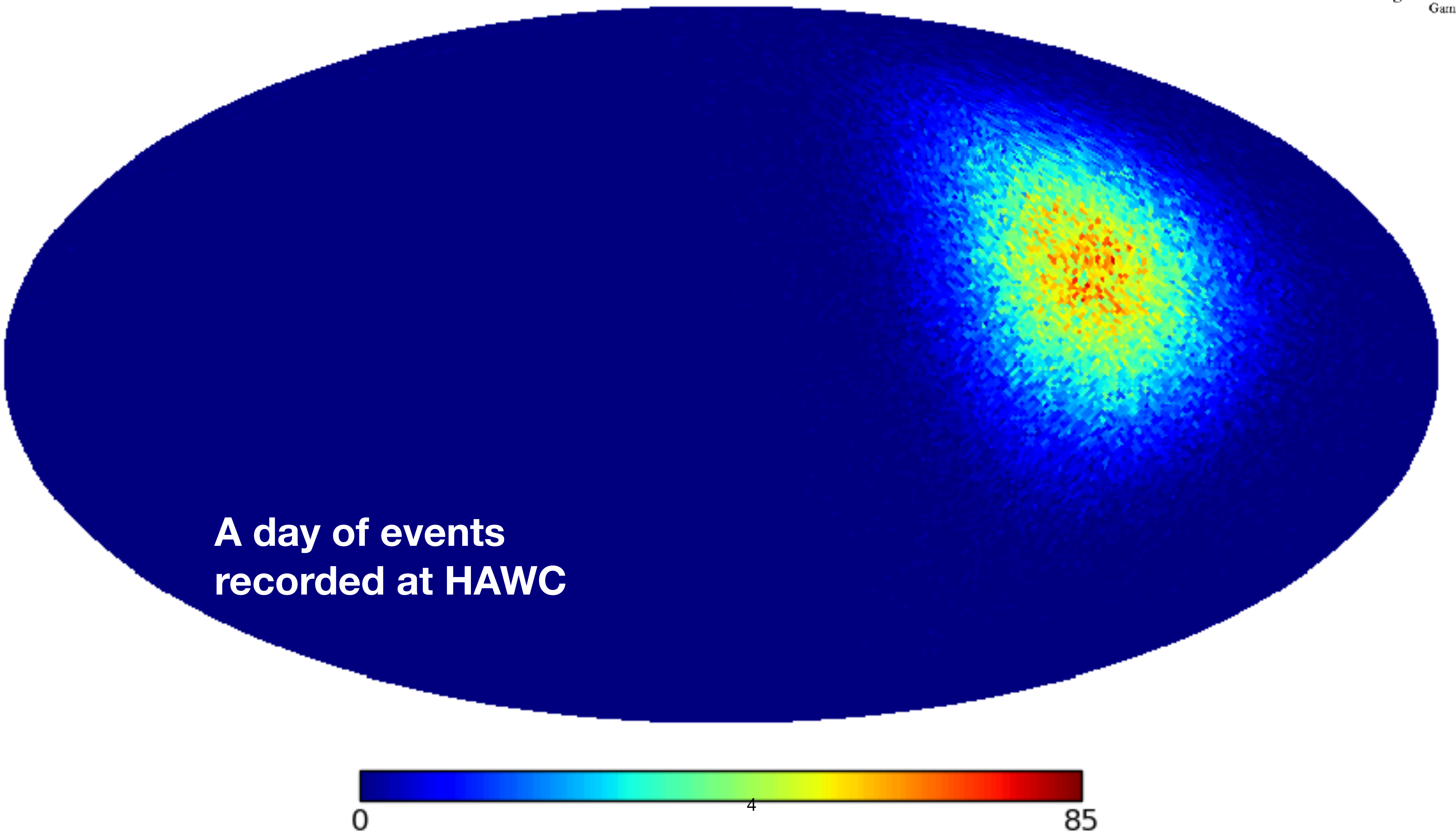
Radboud University

Max-Planck-Institut für Kernphysik Heidelberg


Salta, Argentina
4.8 km above sea level


To astrophysical source
Incoming gamma ray
Collision with atmospheric nucleus
Extensive Air Shower
Particles penetrate detector tanks, interact and are detected
at least 4400 m above sea level
~150 m inner core
Particle Detector Array
Outer detectors at up to 300 m from center
Charged Particle from Air Shower
Water
Light-Tight Tank
Cherenkov Light
Sensitive Photodetector
Not to scale
Credit: Richard White, MPIK

Wide-view gamma-ray observatories

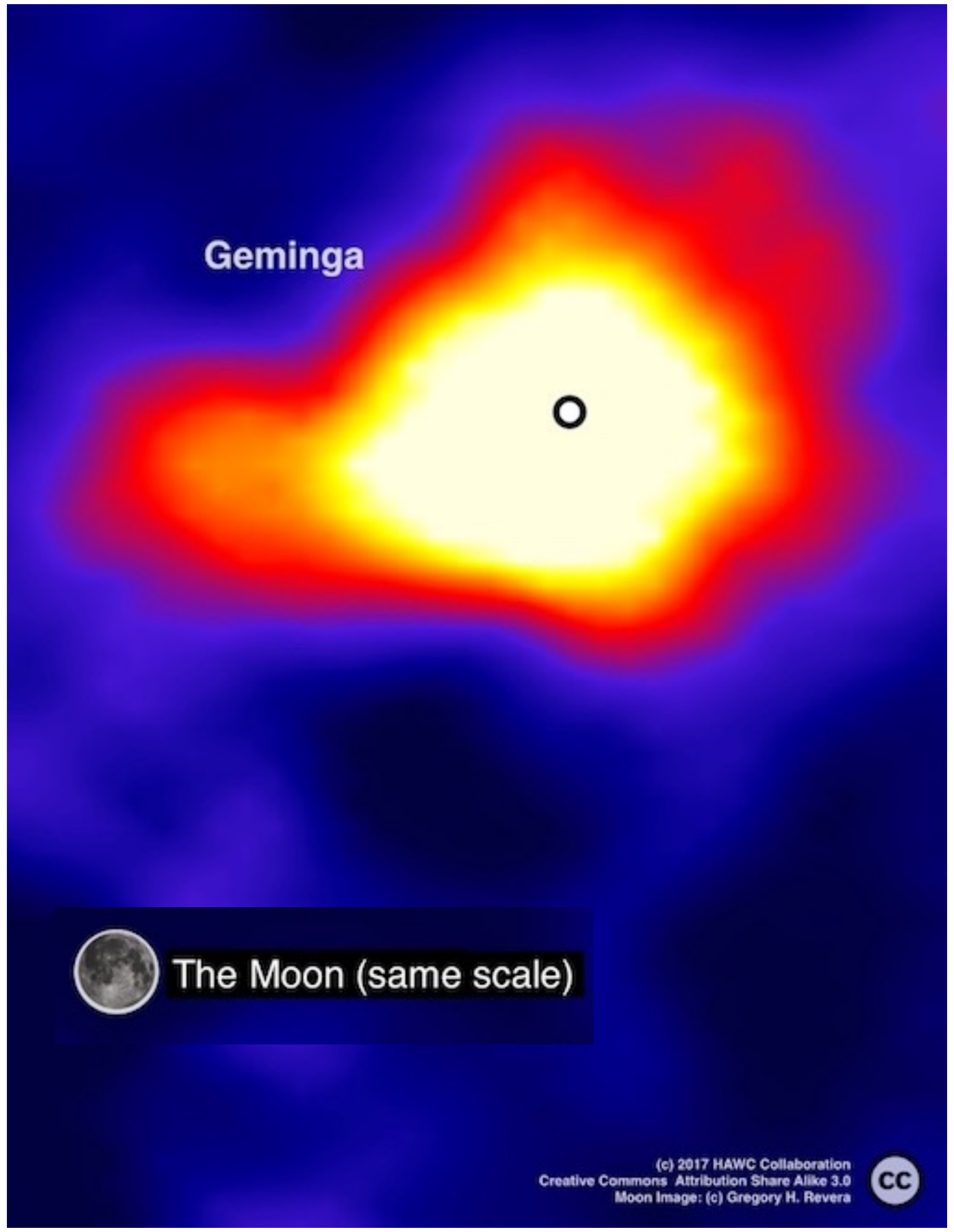


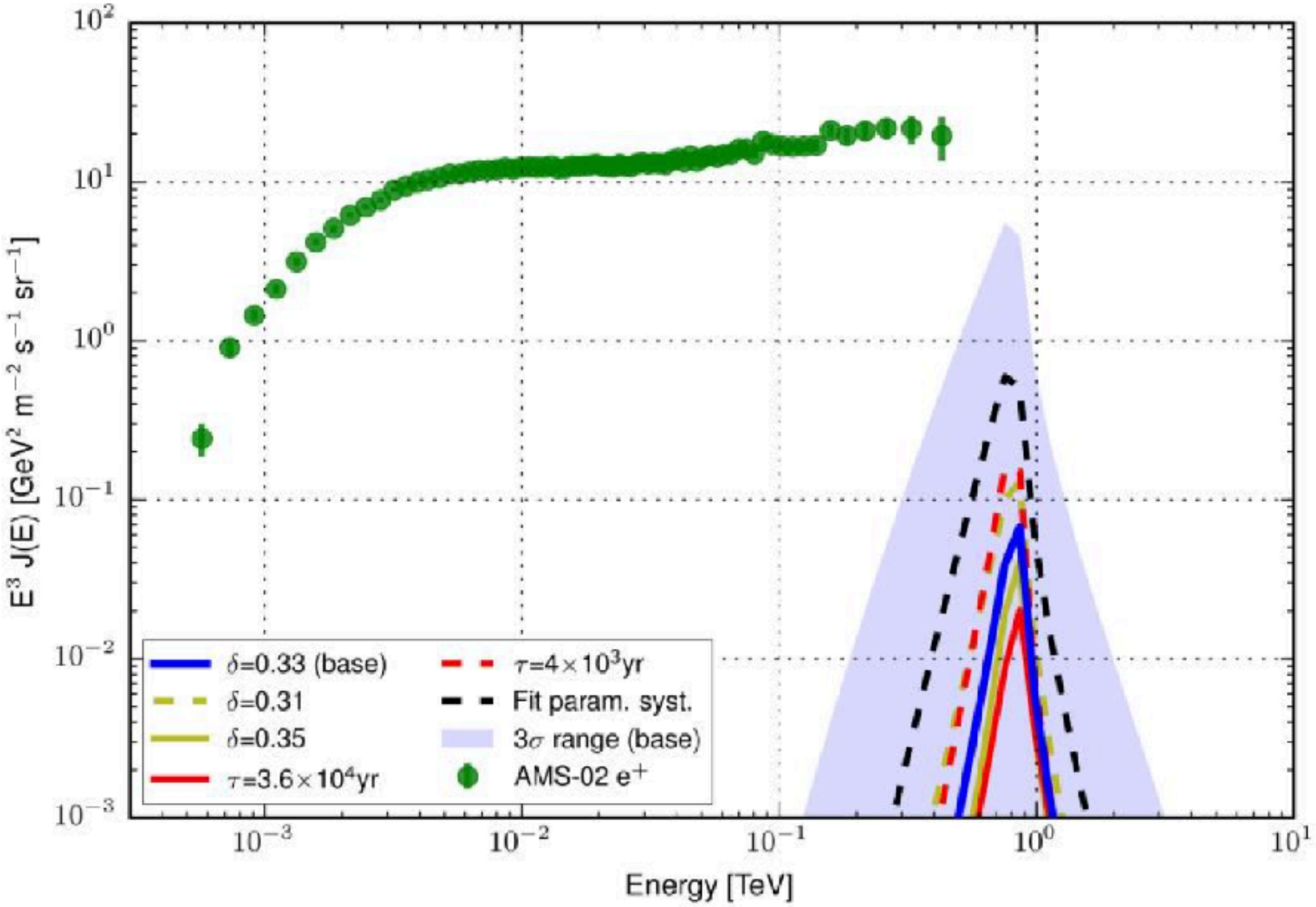
The northern gamma-ray sky as seen by HAWC

1523 days of data

Some highlights: TeV Halo around middle-aged pulsars

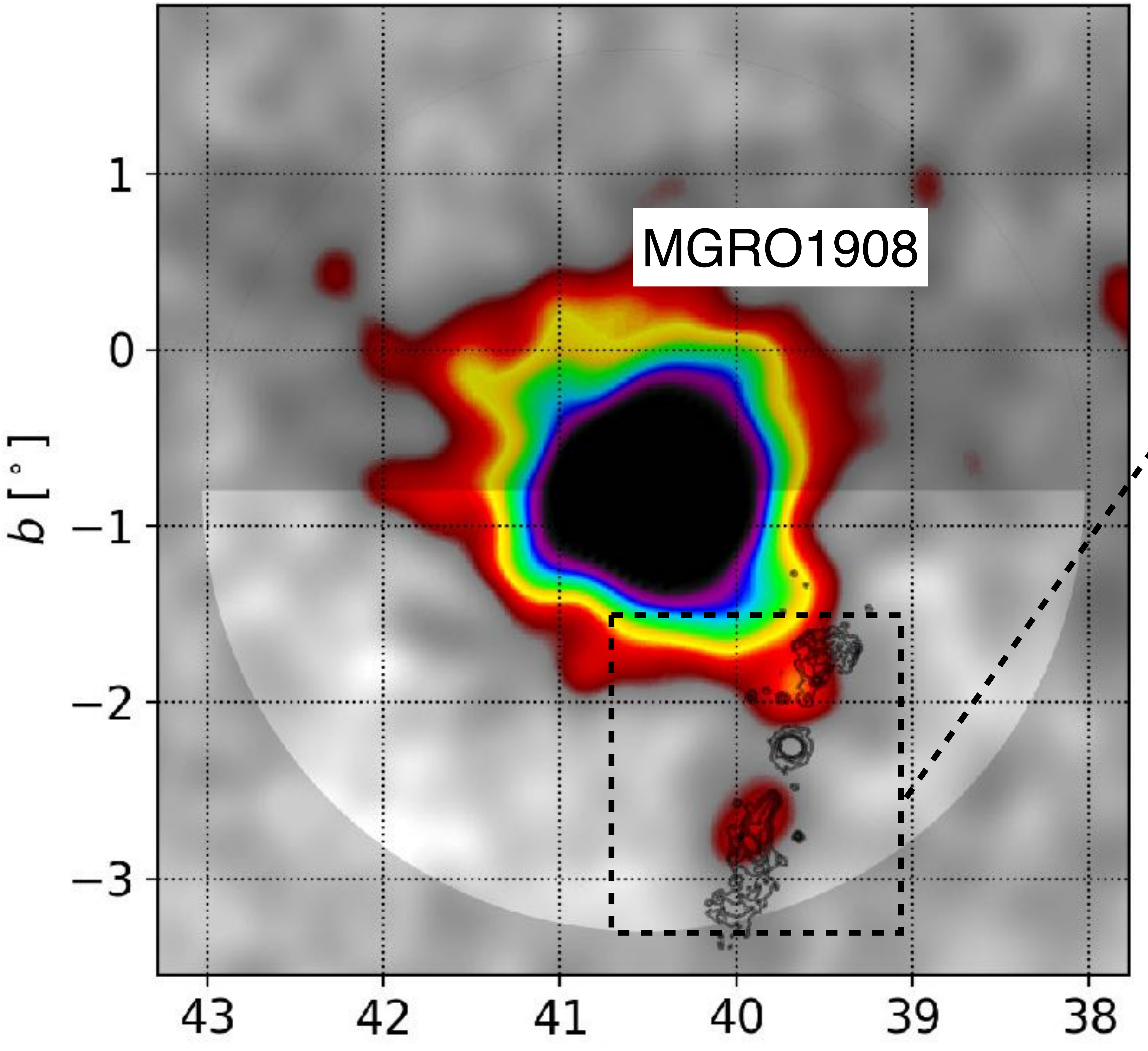
- Profile fits well with diffusion profile
- Fitted diffusion constant predicts too little positrons at Earth to explain positron excess (under the assumption of homogenous isotropic diffusion)

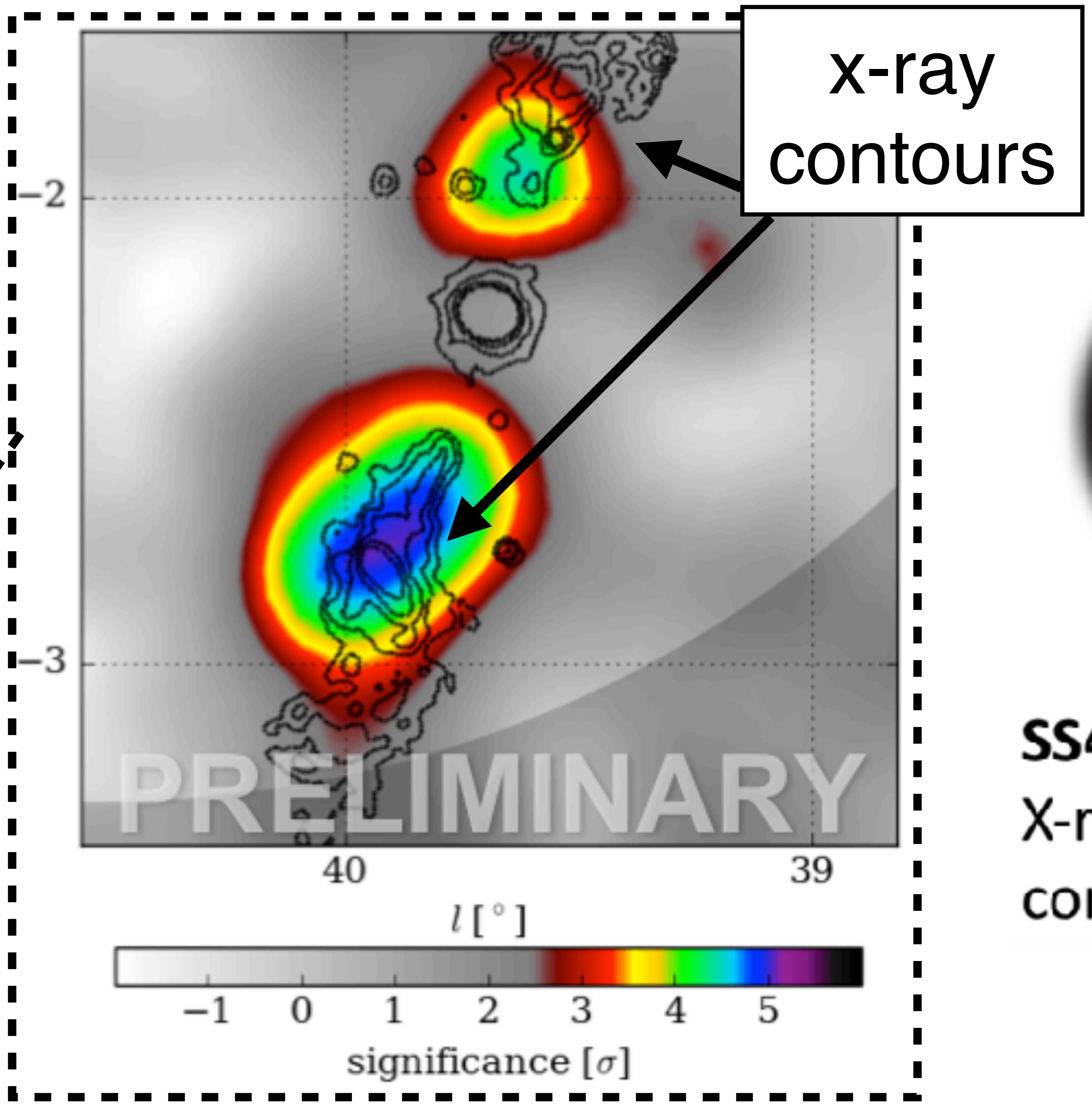


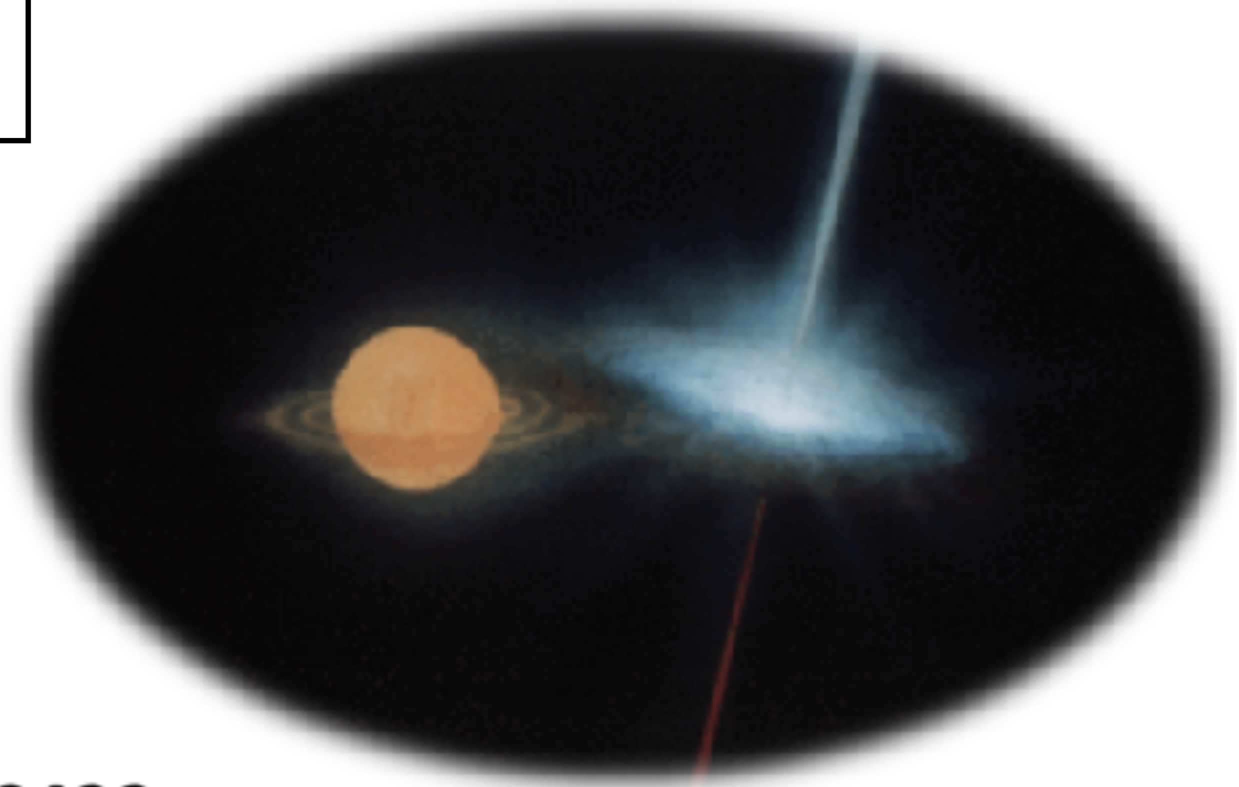


*A. U. Abeysekara et al, Science **358** (2017)*

Some highlights: Micro Quasar SS 433







SS433:
X-ray Binary, star with ~30 $M_\odot$ and compact object with many $M_\odot$

- First time jets are resolved at such high energies
- TeV emission from jet, not the central binary
- Leptonic scenario favoured over pure-hadronic scenario

*A. U. Abeysekara et al, Nature **562** (2018)*

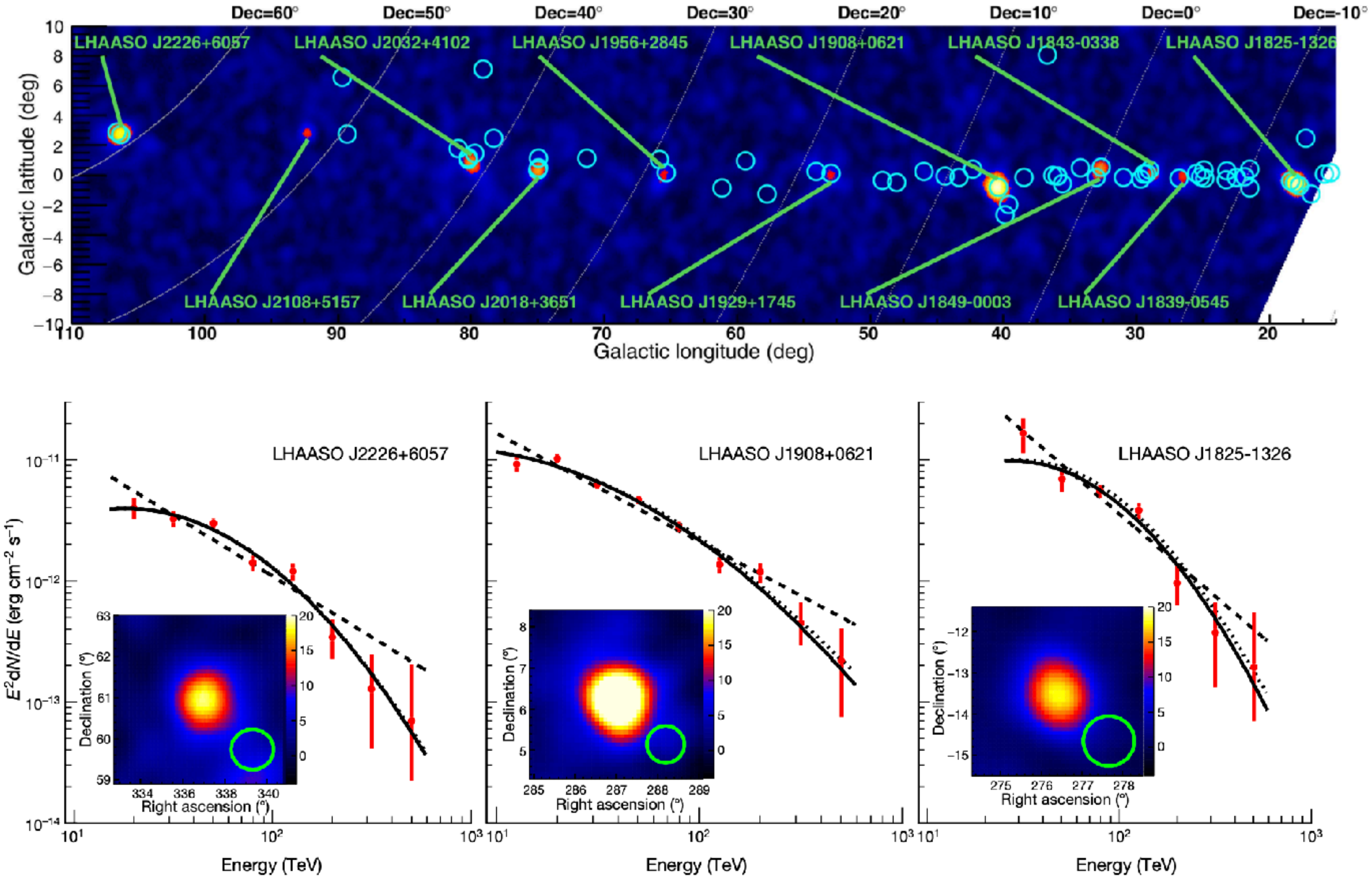
Some highlights: The dawn of ultra-high-energy gamma-ray astronomy

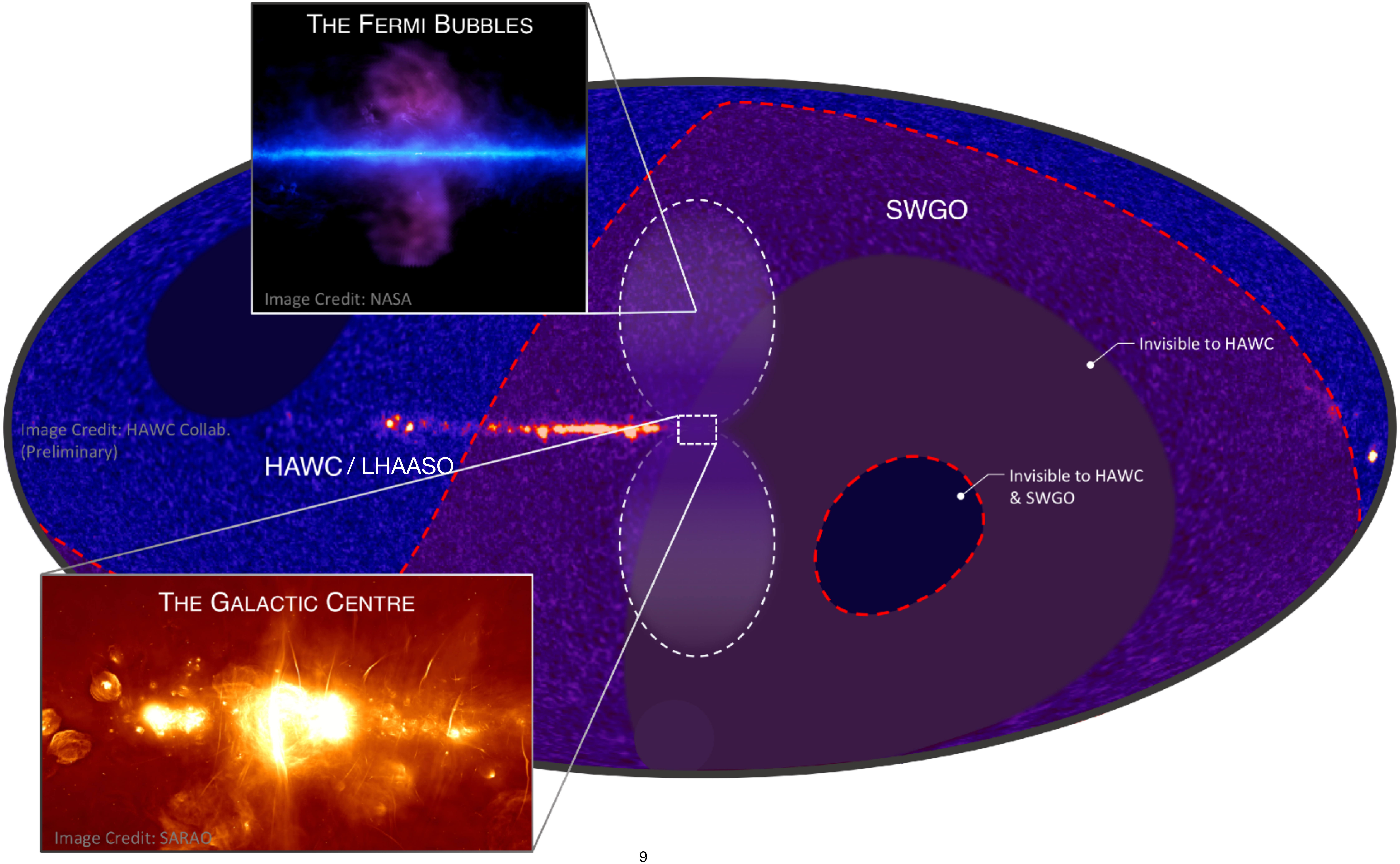
LHAASO

- 12 sources above 100 TeV
- Photons up to PeV energy

Cao, Z., et al,

Nature **594,** 33–36 (2021)



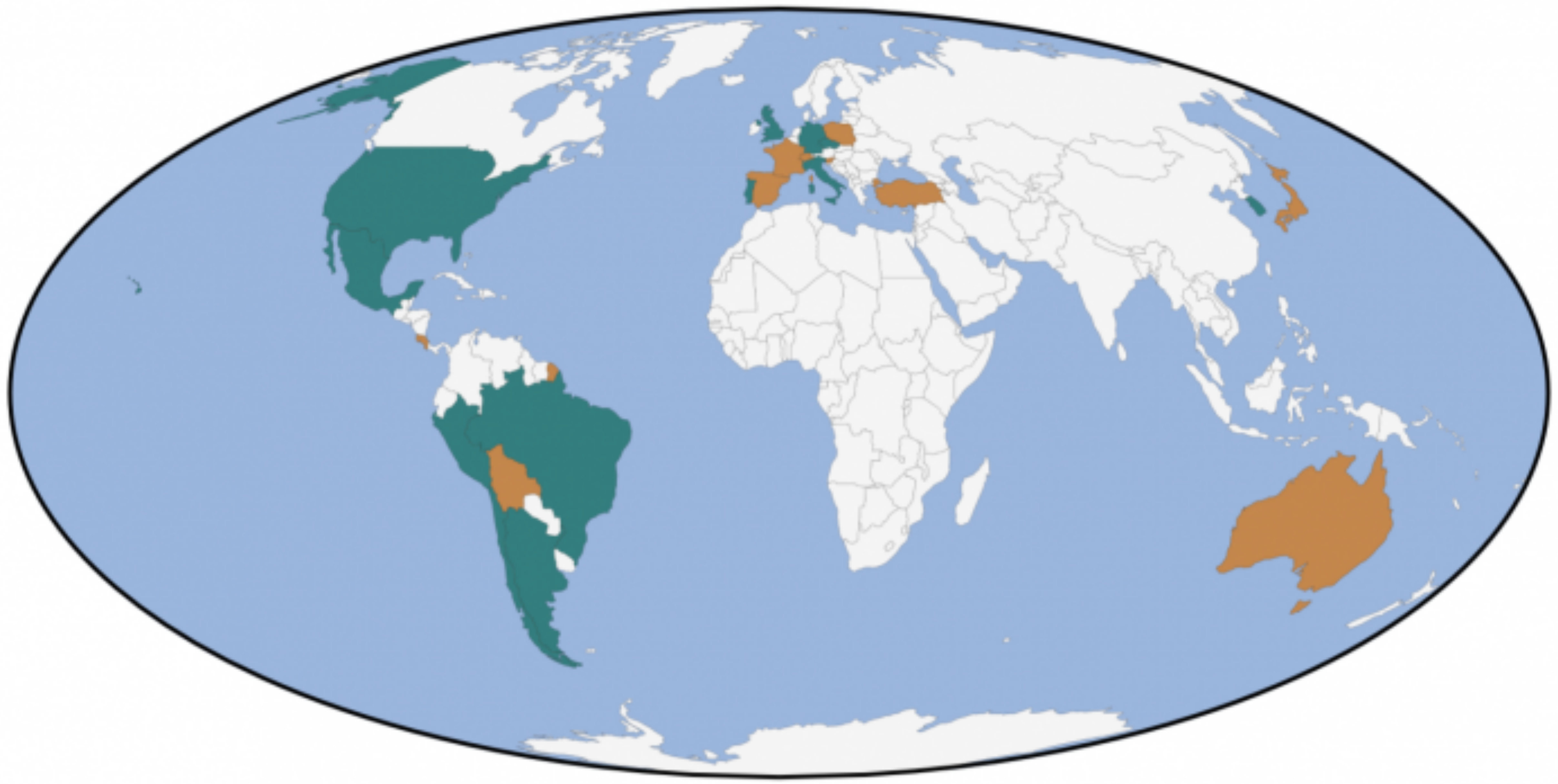

THE FERMI BUBBLES
Image Credit: NASA
SWGO
Invisible to HAWC
Image Credit: HAWC Collab.
(Preliminary)
HAWC / LHAASO
Invisible to HAWC
& SWGO
THE GALACTIC CENTRE
Image Credit: SARAO

Who & What is SWGO

International collaboration of scientists that aims to build a wide-view gamma-ray observatory in the Southern Hemisphere

The SWGO collaboration was formed to facilitate common R&D activities to design and propose such facility

47 Institutes in 12 countries + supporting scientist



Countries in SWGO

Institutes

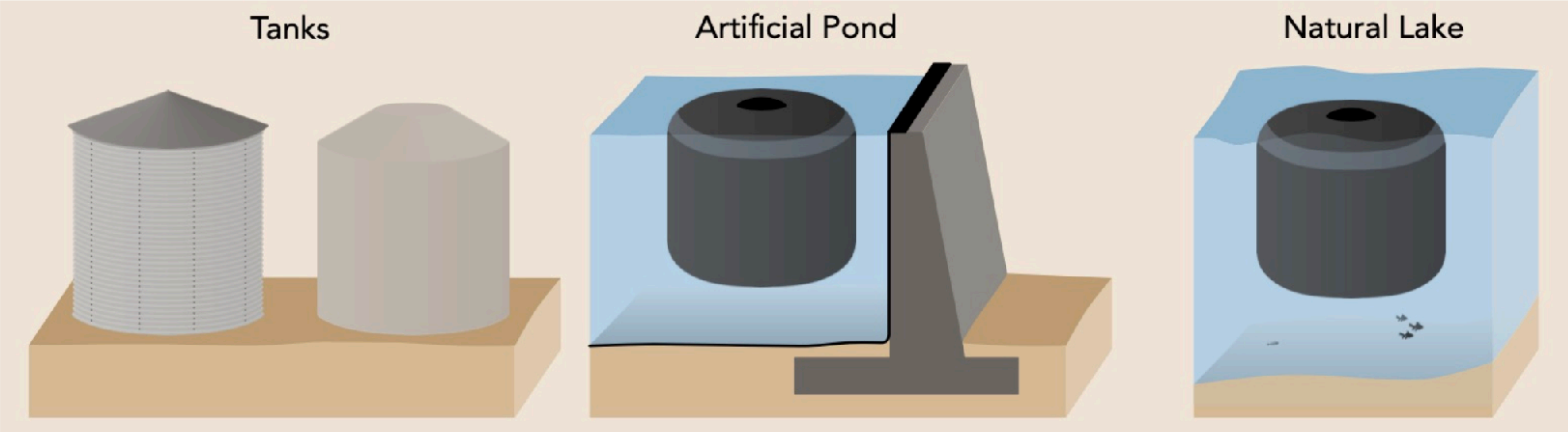
Argentina*, Brazil, Chile, Czech Republic, Germany*, Italy, Mexico, Peru, Portugal, South Korea, United Kingdom, United States*

Supporting scientists

Australia, Bolivia, Costa Rica, France, Japan, Poland, Slovenia, Spain, Switzerland, Turkey

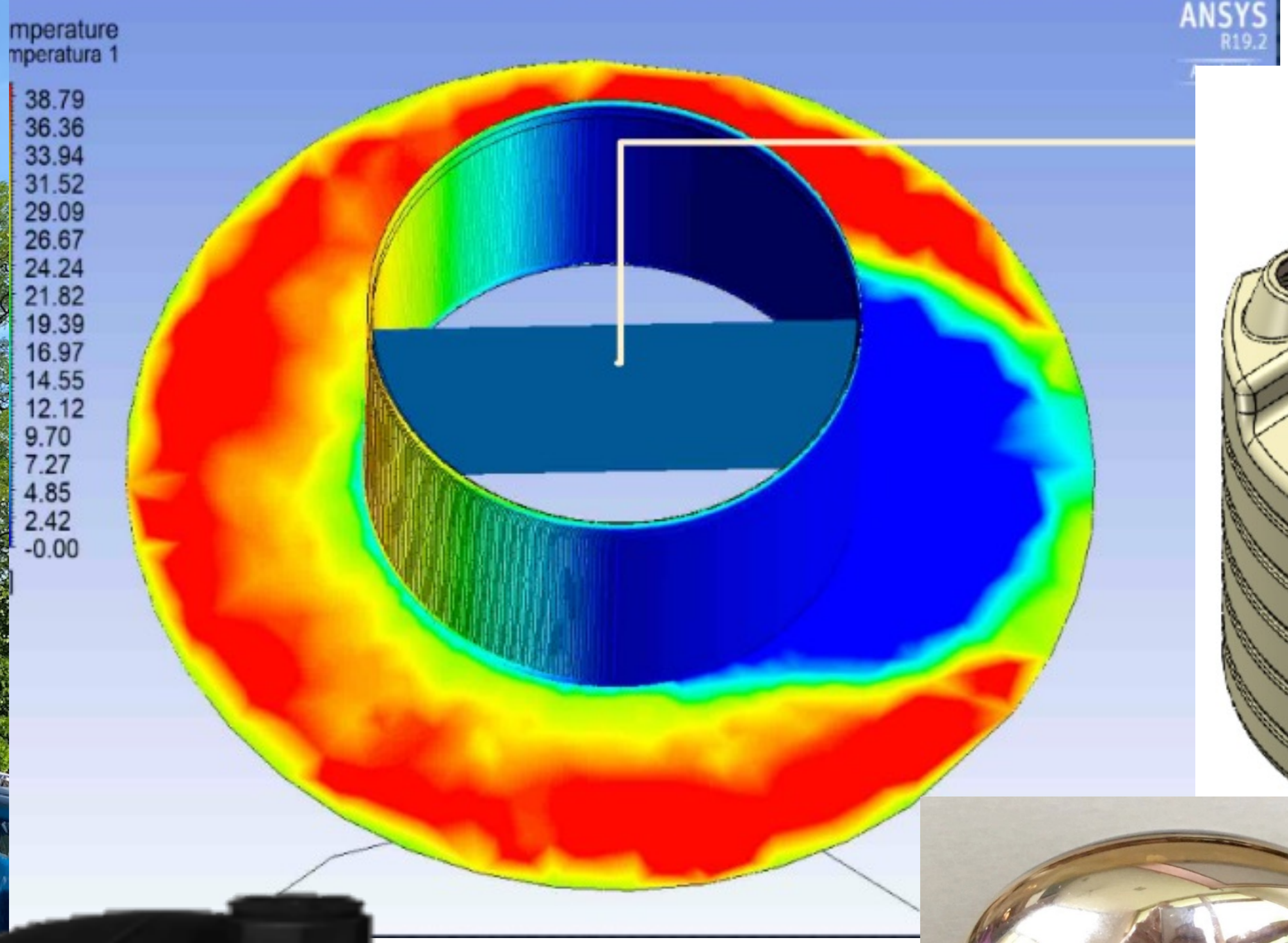
**also supporting scientists*

Design Options



- Exploring three concepts for the detector units
  - → Tanks (like HAWC), Artificial Pond (like LHAASO) and Natural Lake
- …as well unit dimensions, photosensors, +++
  - → Performance/cost optimisation


Bolivia 4.7k
Chile 4.8 k
Argentina 4.8 k
Peru 4.9 k
Peru
Bolivia
Chile
Mina Chungar (Peru)
Huascacocha Lagoa (Peru)
Lake Sibinacocha (Peru)
Imata (Peru)
Chacaltaya (Bolivia)
ALMA site (Chile)
Alto Tocomar (Argentina)
Cerro Armazones (CTA-S...



mperature
mperatura 1
38.79
36.36
33.94
31.52
29.09
26.67
24.24
21.82
19.39
16.97
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12.12
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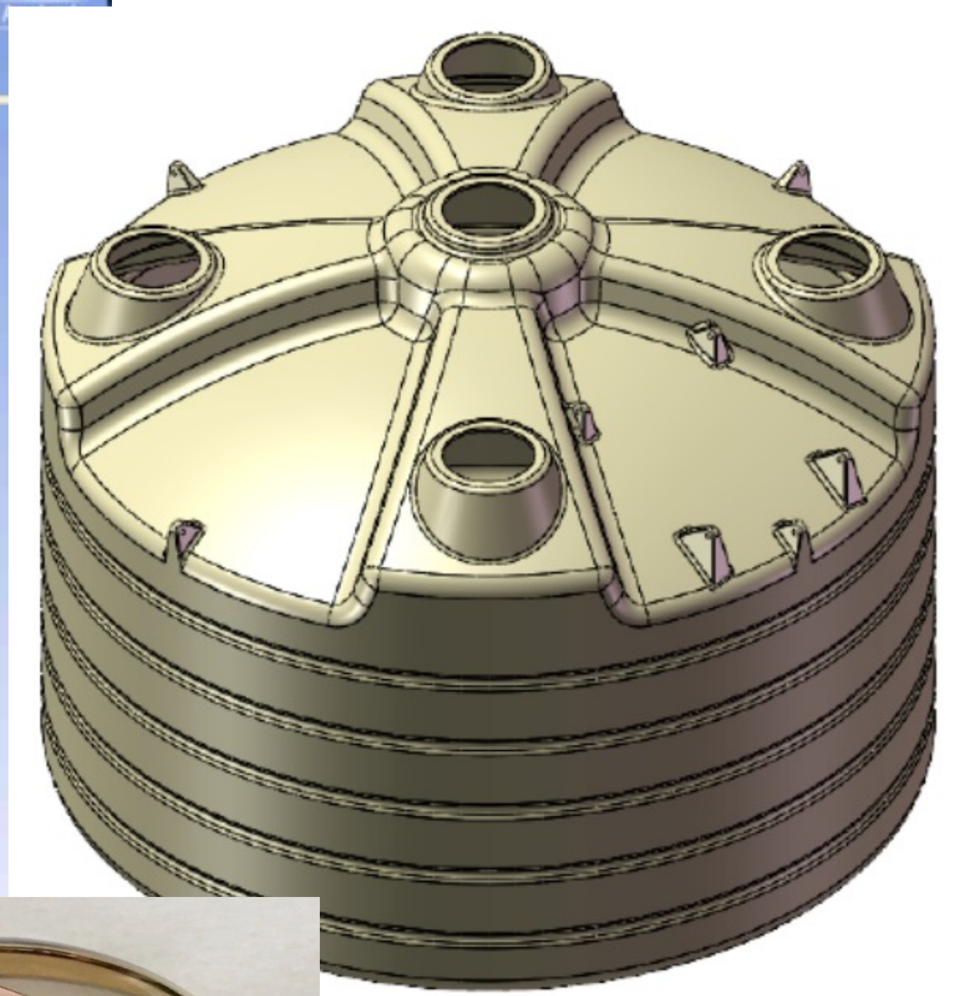
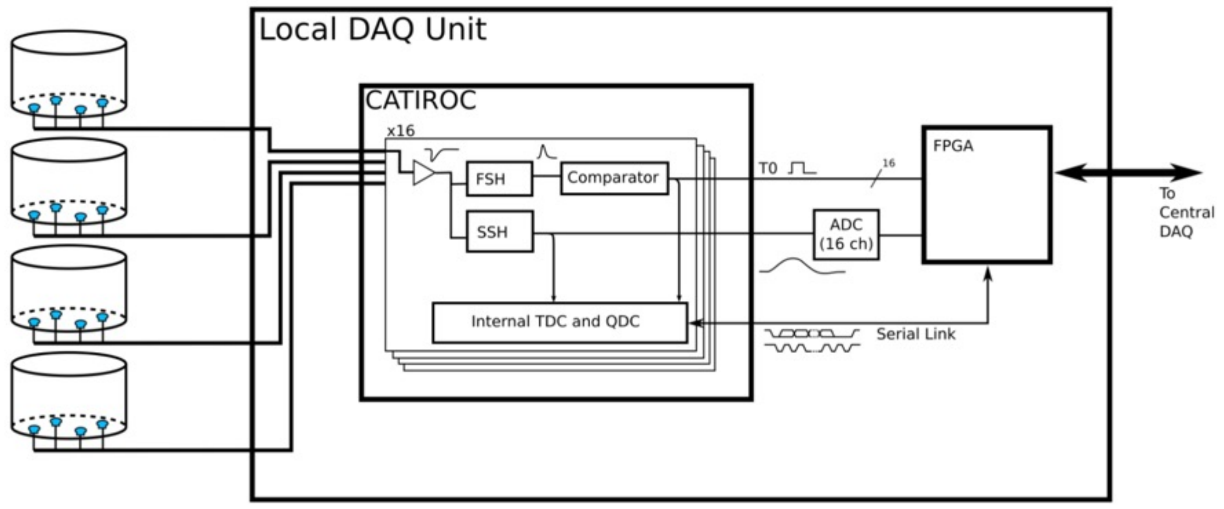
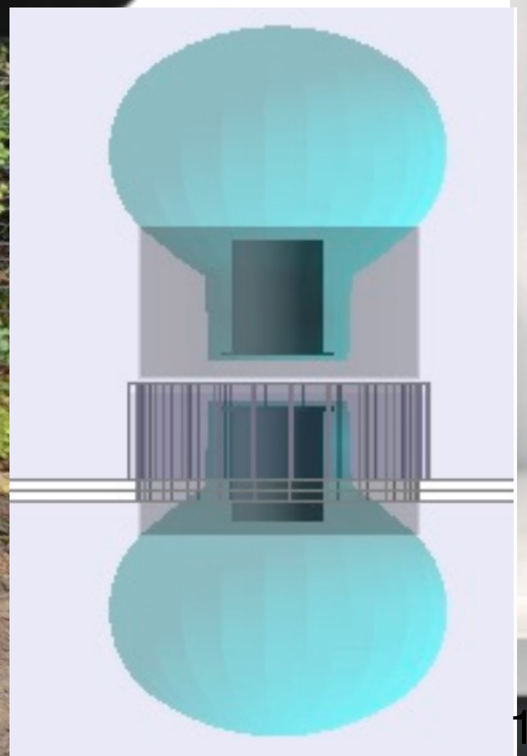
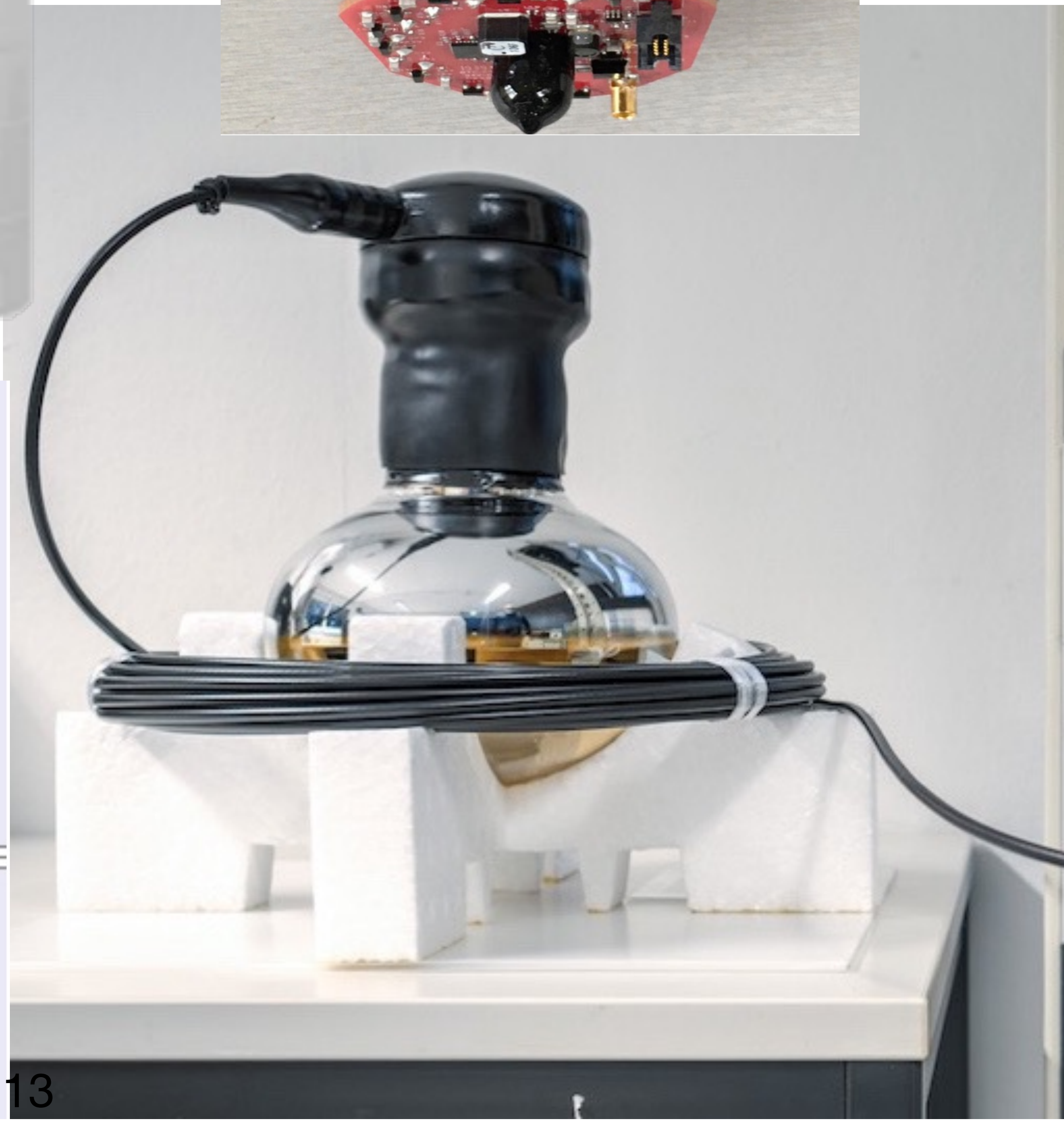
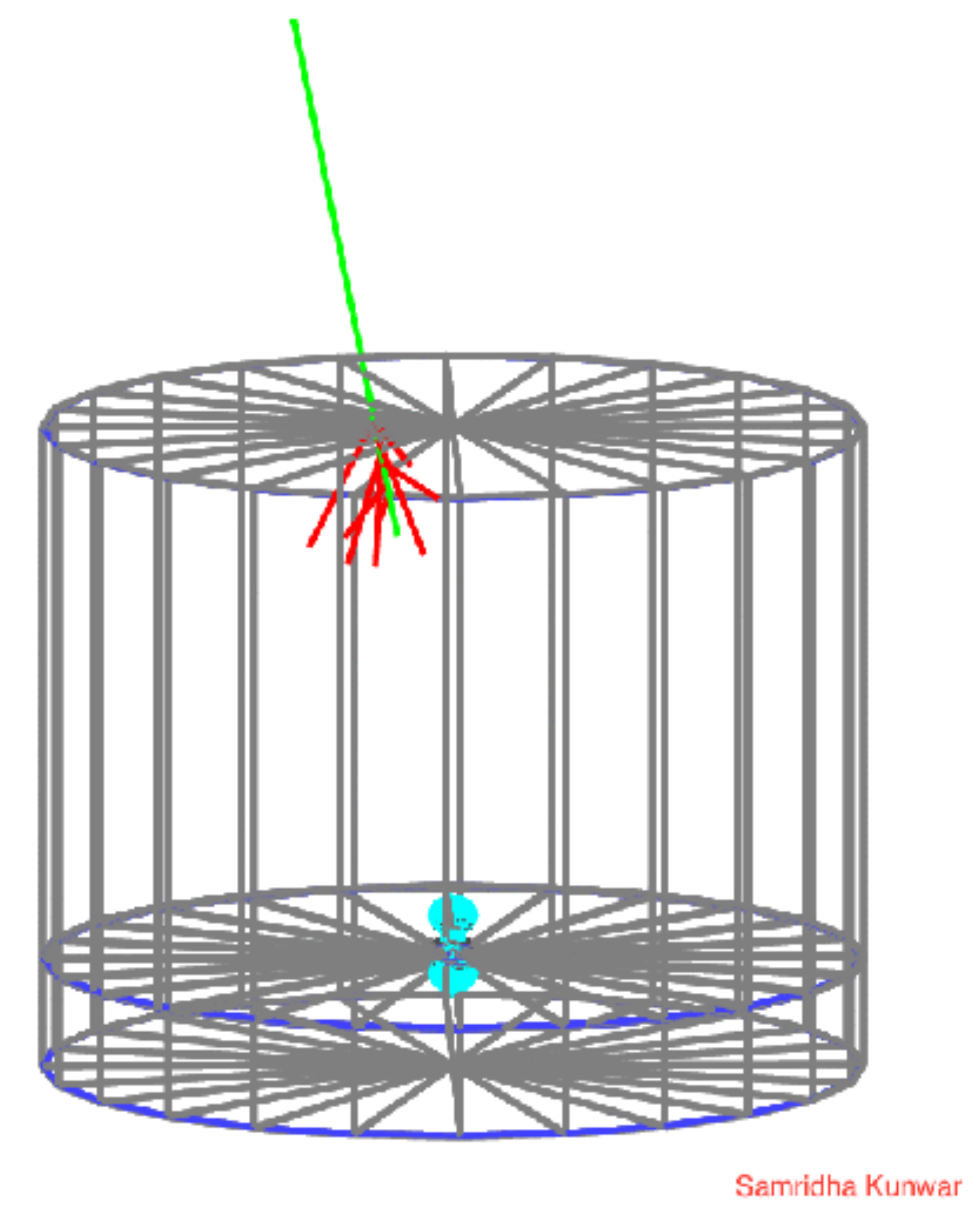
-0.00
ANSYS
R19.2



TYPE: R15458-20
NO. BA0818
MADE IN JAPAN

Local DAQ Unit
CATIROC
x16
FSH
Comparator
SSH
Internal TDC and QDC
T0
16
ADC (16 ch)
FPGA
Serial Link
To Central DAQ

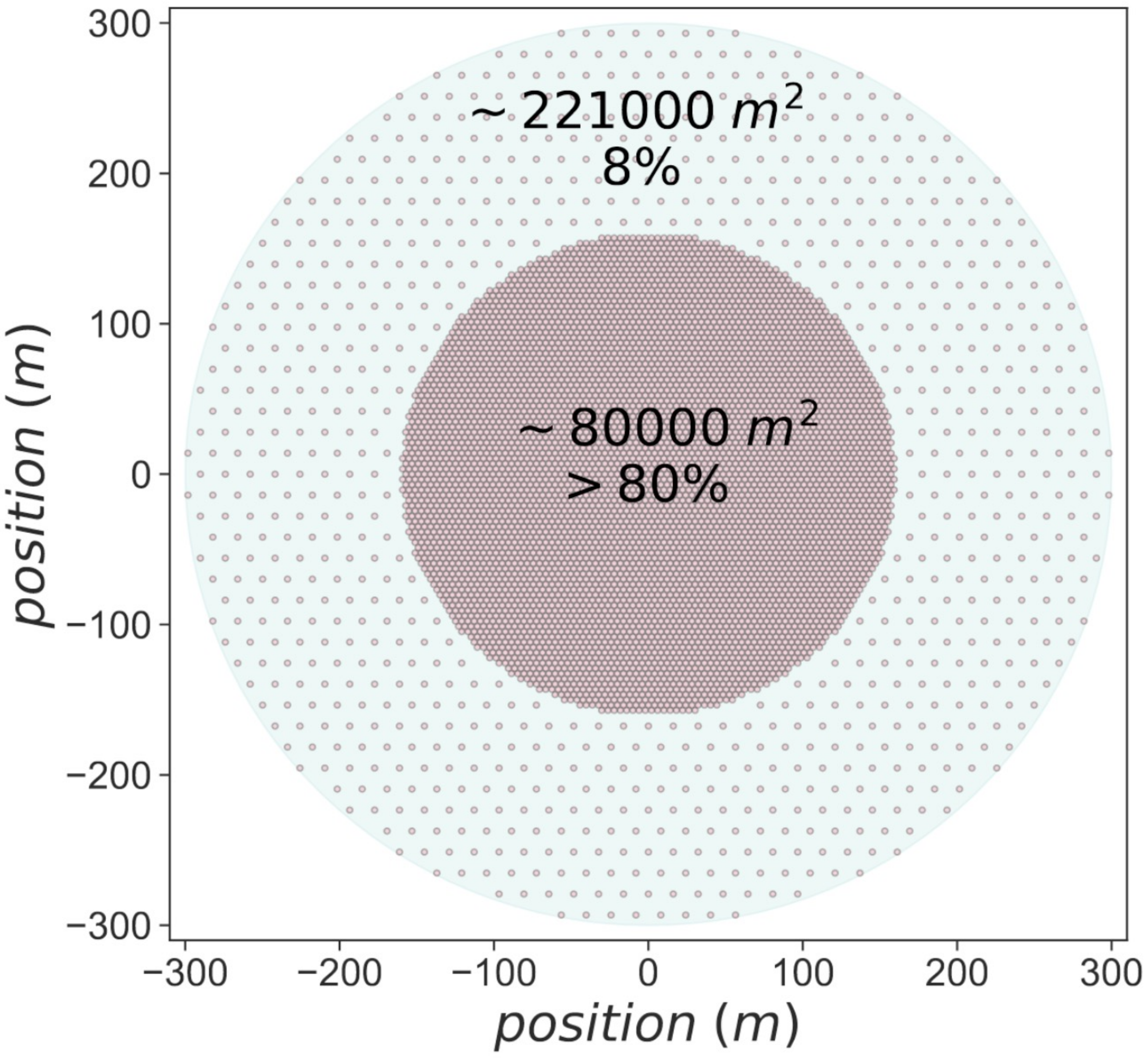
Rotoplas
Rotoplas
Rotoplas
Rotoplas

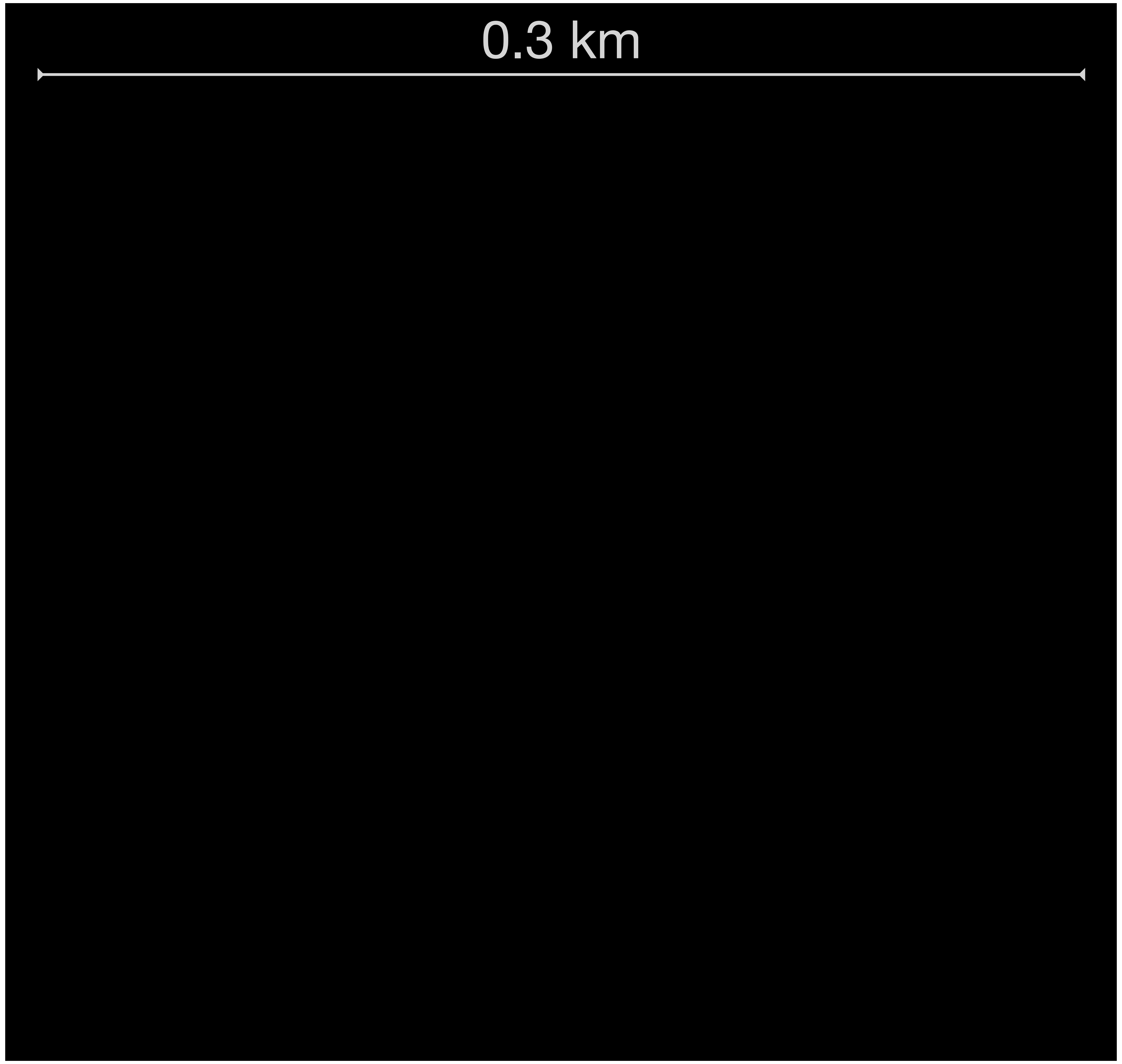

Reference Configuration



muon identification key in background rejection

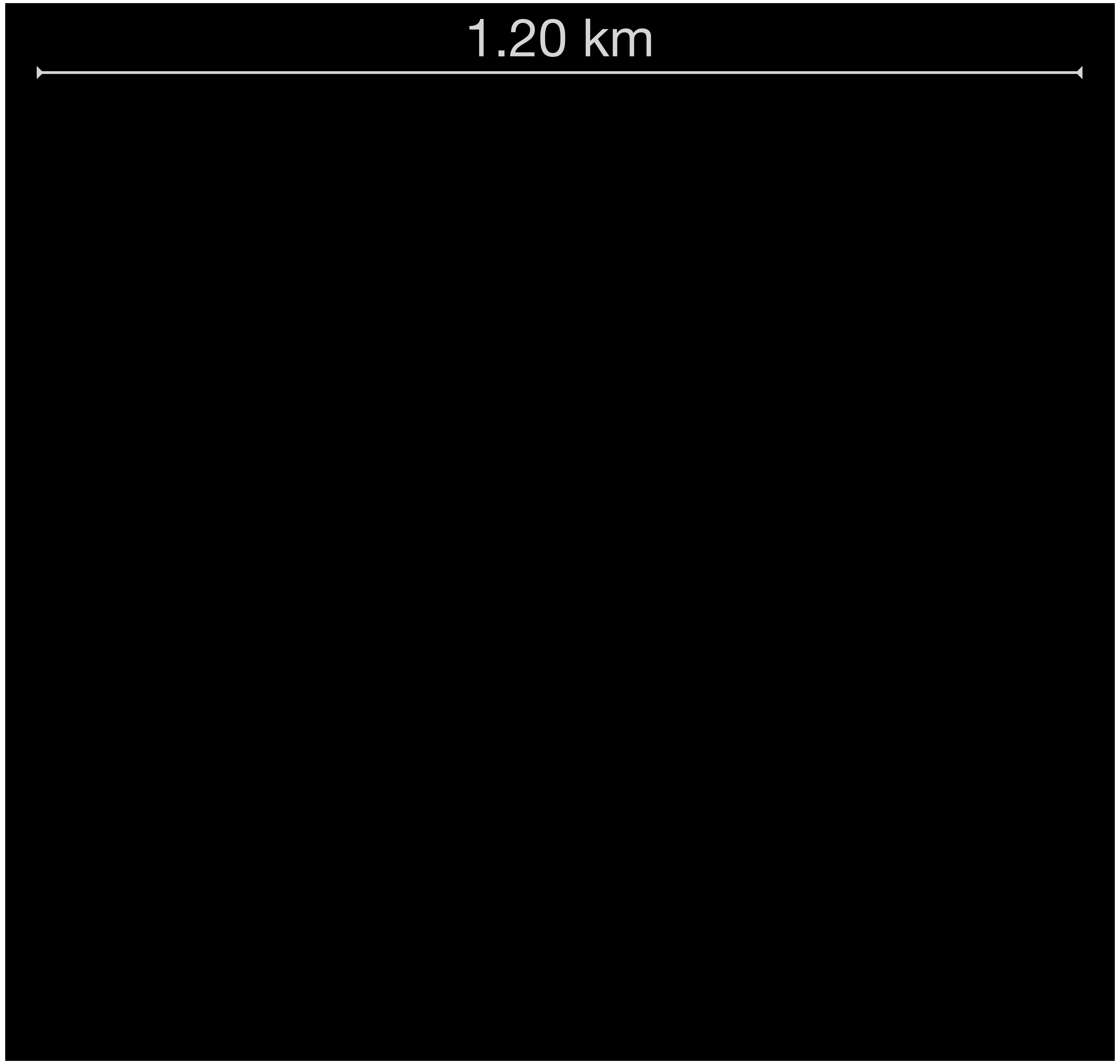


1 TeV gamma ray, vertical, inner array

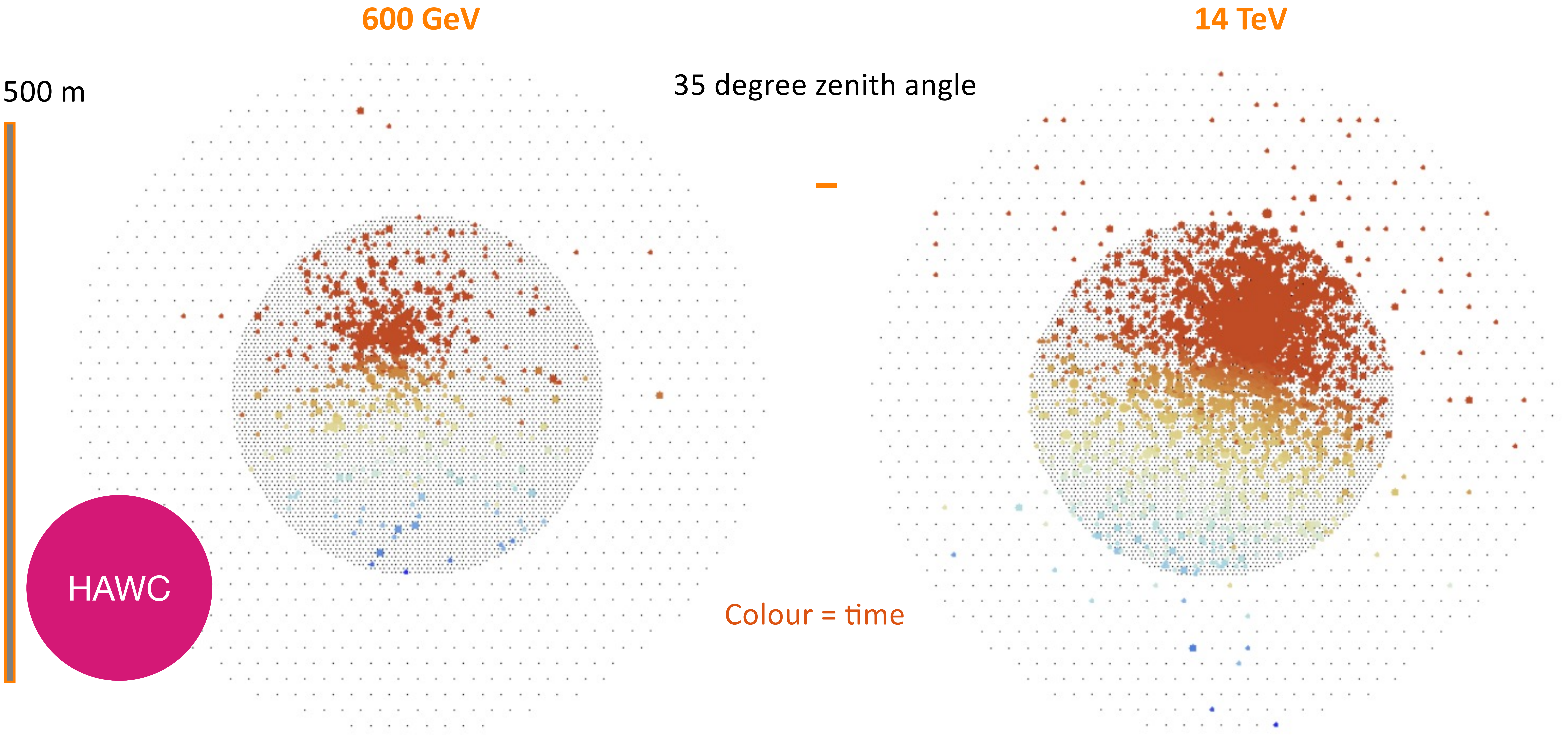


Frame 0.5 ns, duration 50 ns

50 TeV gamma ray, 45 degrees, full array



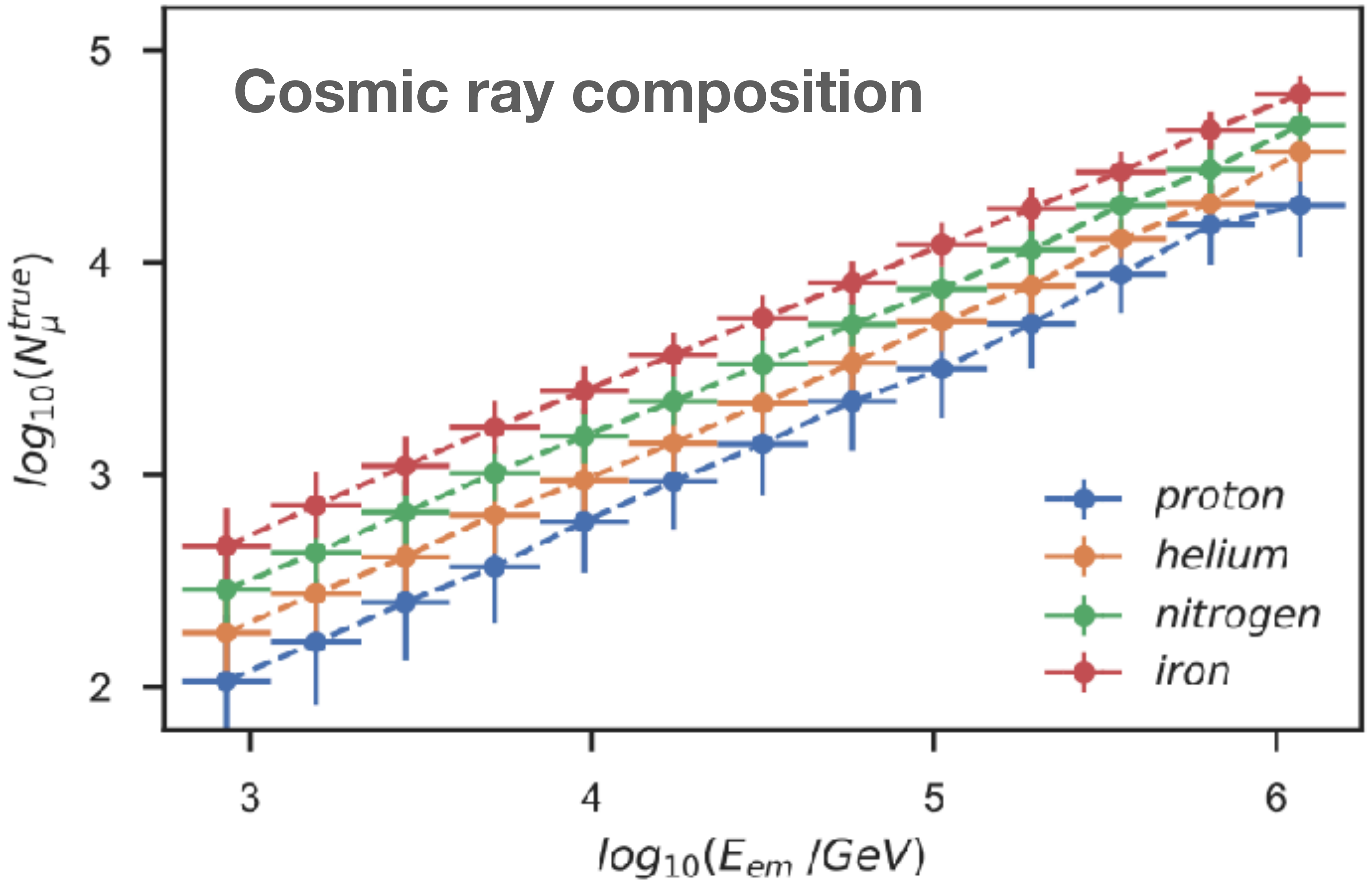
Frame 28 ns, duration 2800 ns

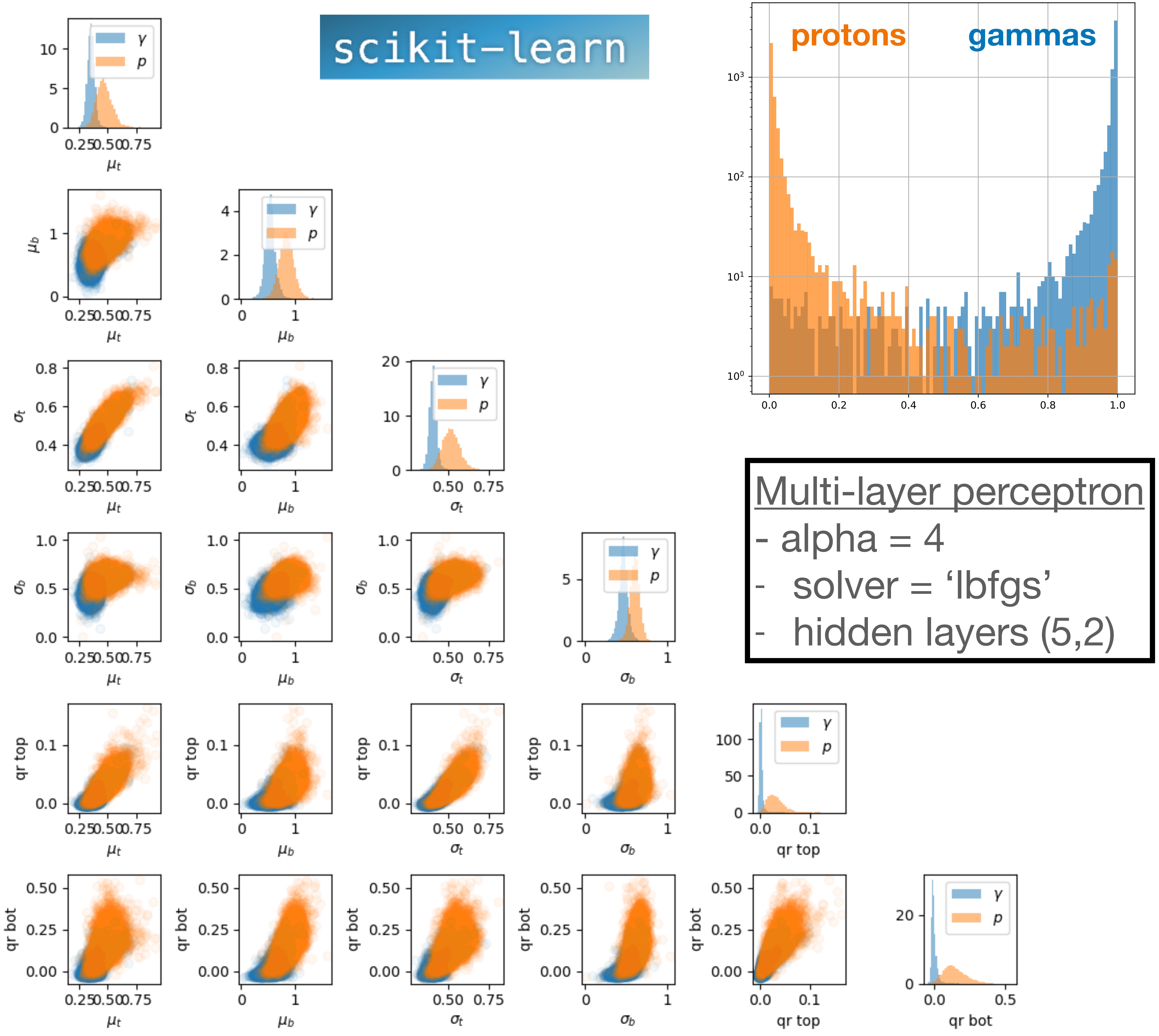


- Larger detector array and increased altitude w.r.t. HAWC
  - → Very precise measurements possible even below 1 TeV

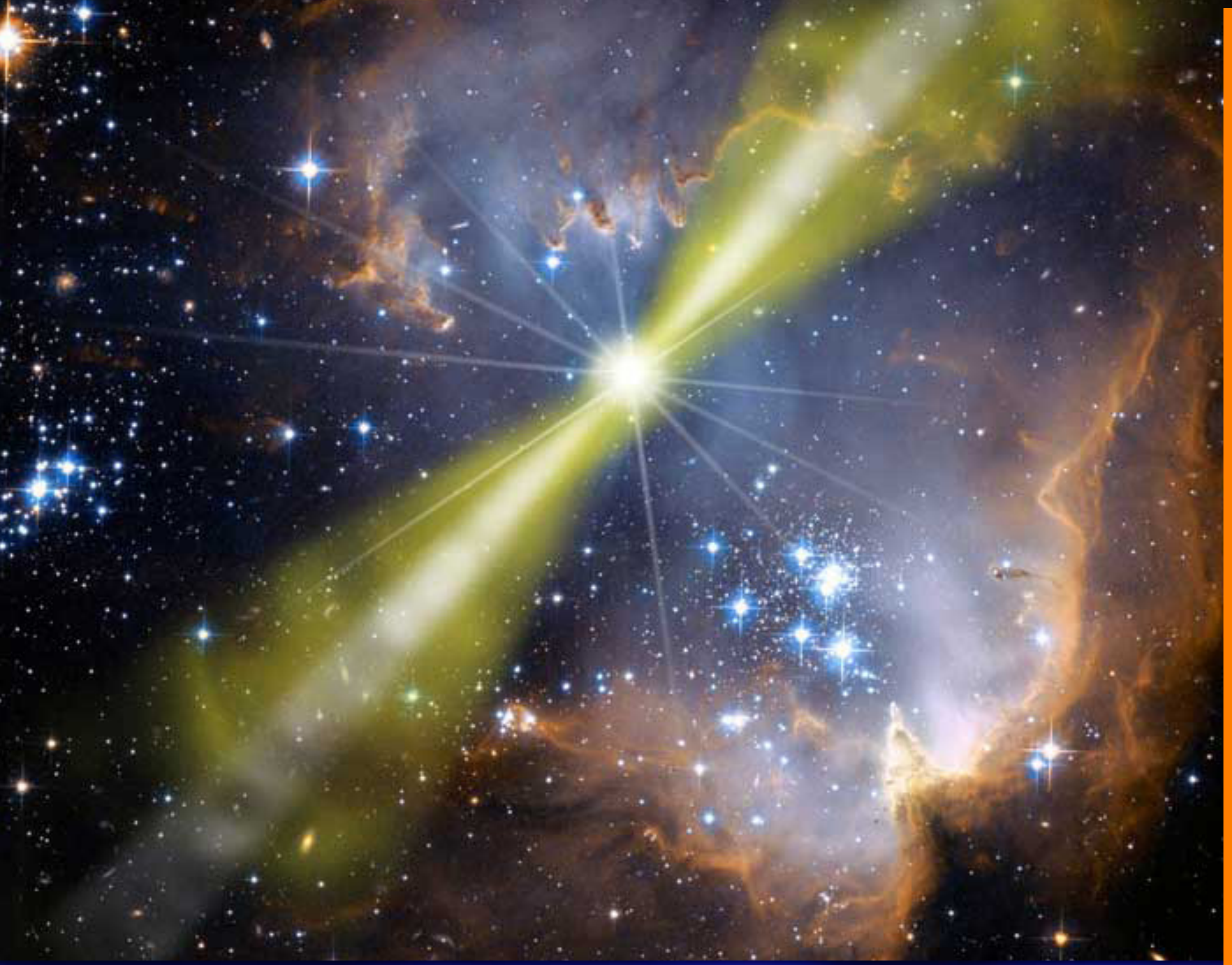
Event classification

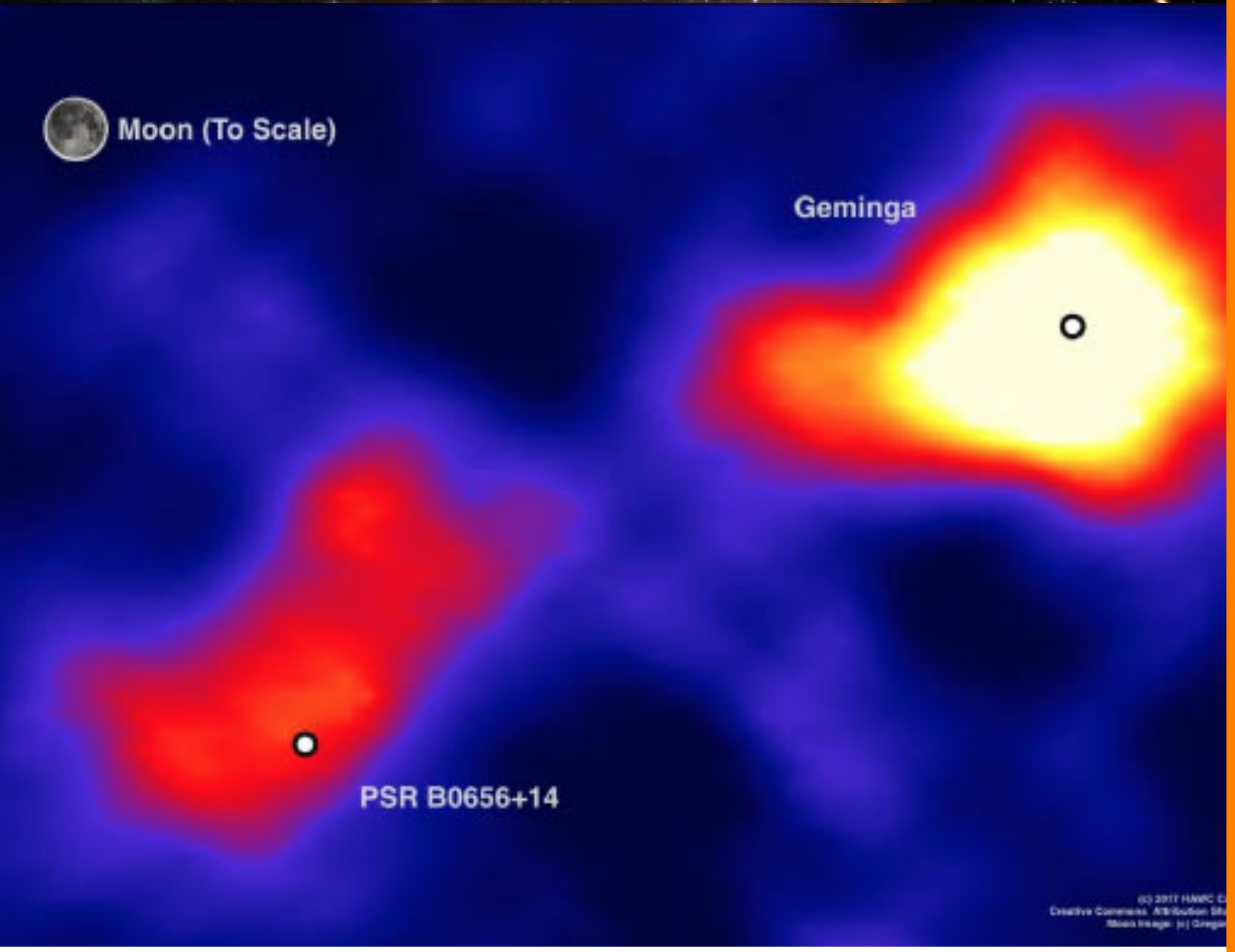
- Extract features that are sensitive to particle type (muon number, shape footprint)
- Can we push-further with “image recognition”?

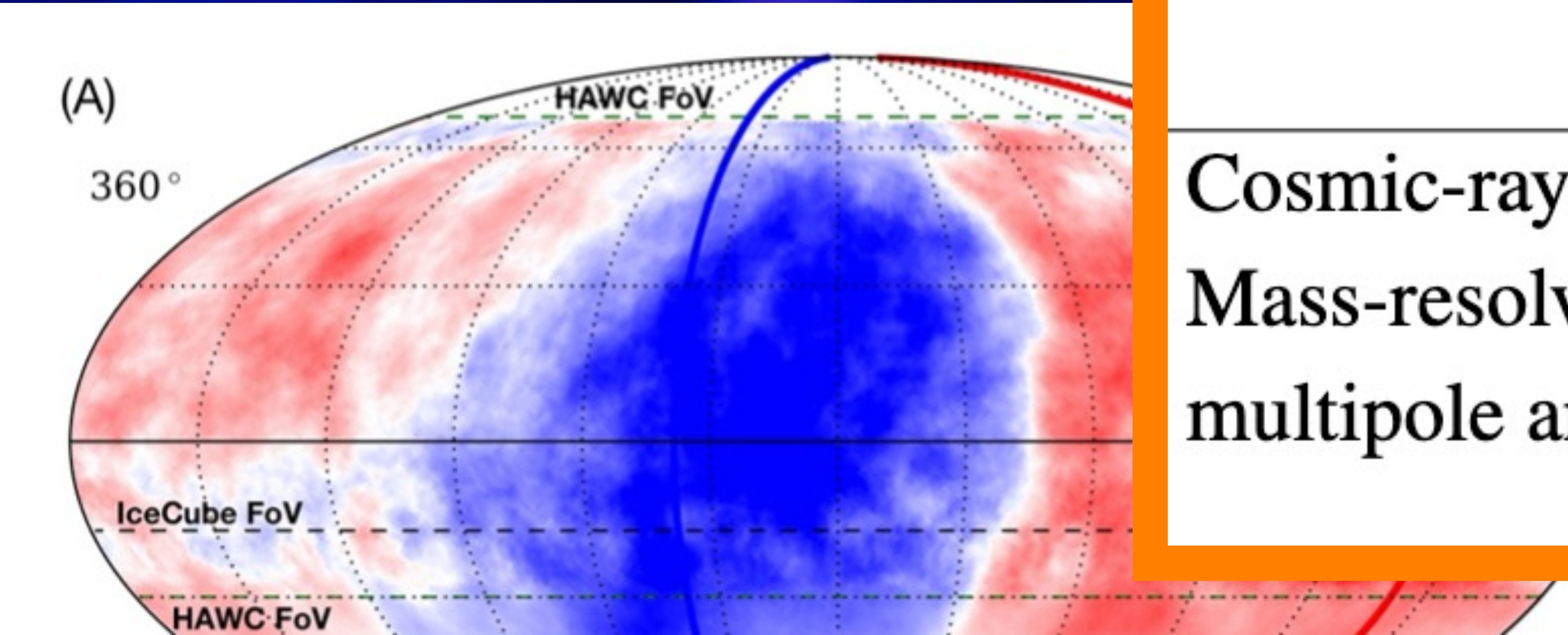




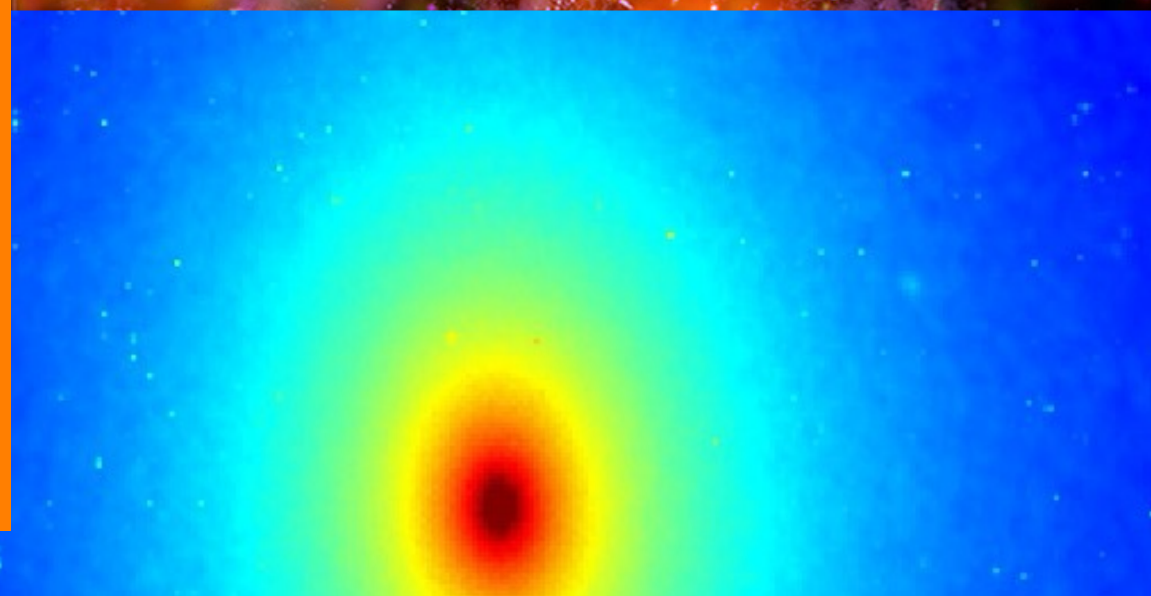
<u>Multi-layer perceptron</u>
- alpha = 4
- solver = ‘lbfgs’
- hidden layers (5,2)





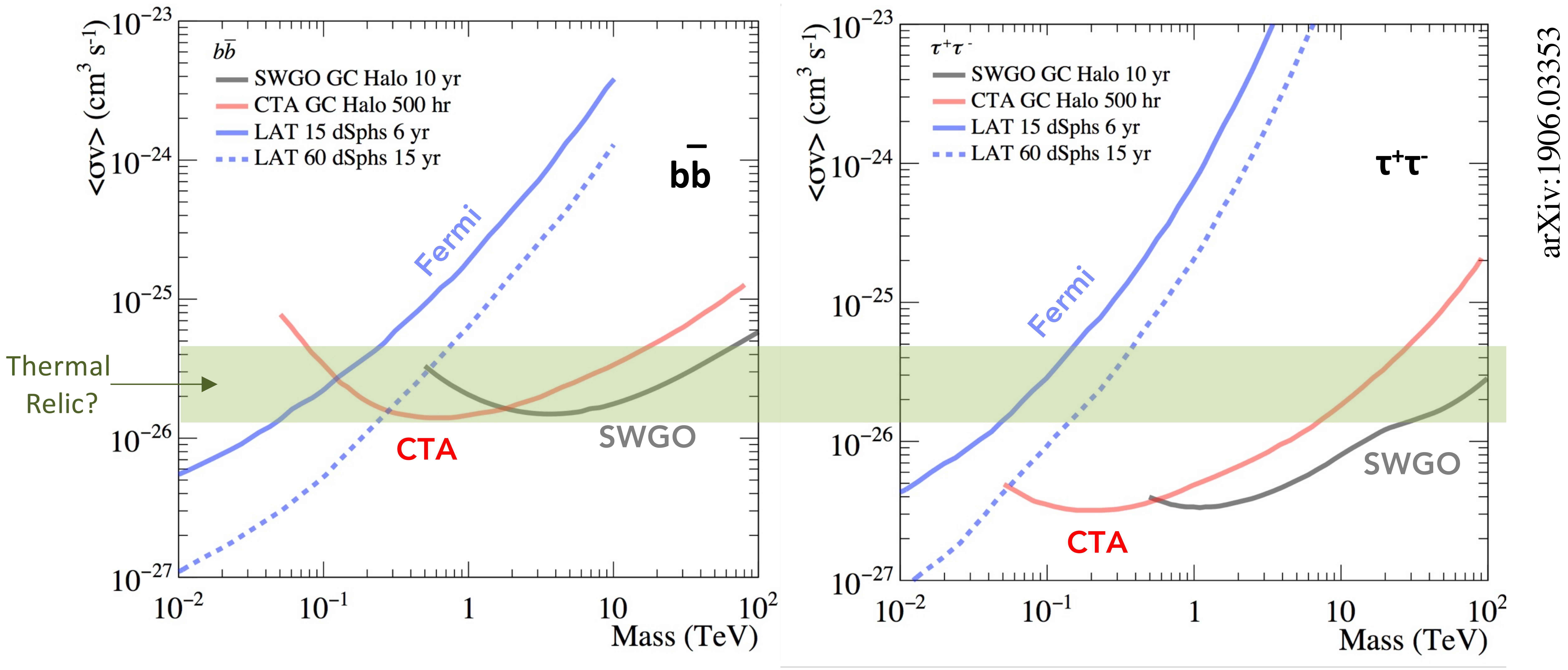


Science Case	Design Drivers
Transient Sources: Gamma-ray Bursts	Low-energy sensitivity & Site altitude[a]
Galactic Accelerators: PeVatron Sources	High-energy sensitivity & Energy resolution[b]
Galactic Accelerators: PWNe and TeV Halos	Extended source sensitivity & Angular resolution[c]
Diffuse Emission: Fermi Bubbles	Background rejection
Fundamental Physics: Dark Matter from GC Halo	Mid-range energy sensitivity Site latitude[d]
Cosmic-rays: Mass-resolved dipole / multipole anisotropy	Muon counting capability[e]



Dark Matter

- Thermal relic WIMP annihilation signature accessible over a very wide mass range (Galactic Centre/Halo observations @ VHE)



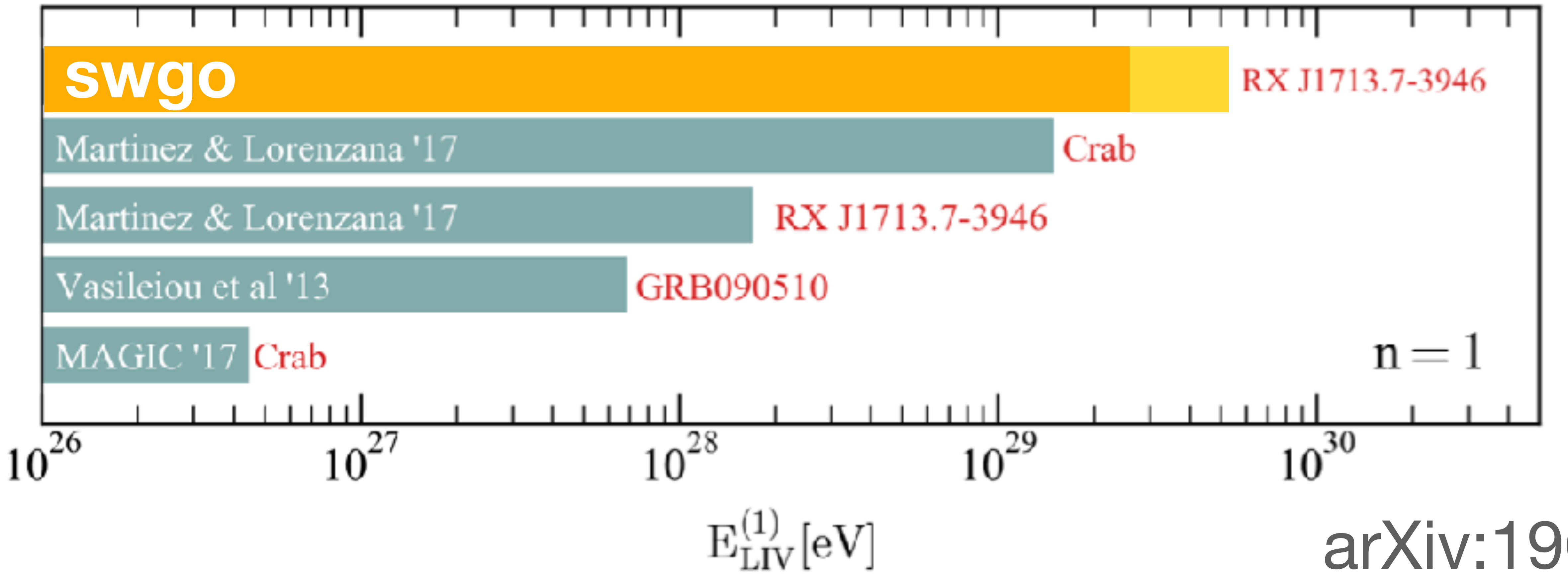
NB Sensitivity improving for both CTA + SWGO – analysis improvements

Test of Lorentz Invariance Violation

- Test if above a certain energy: $\gamma \rightarrow e^- + e^+$
- This would constrain the propagation of photons over **<u>any</u>** astrophysical distance.
- Each highest energy photon will improve upon this limit

$$E_\gamma^2 - p_\gamma^2 = \pm \frac{E_\gamma^{n+2}}{\left(E_{LIV}^{(n)}\right)^n}$$

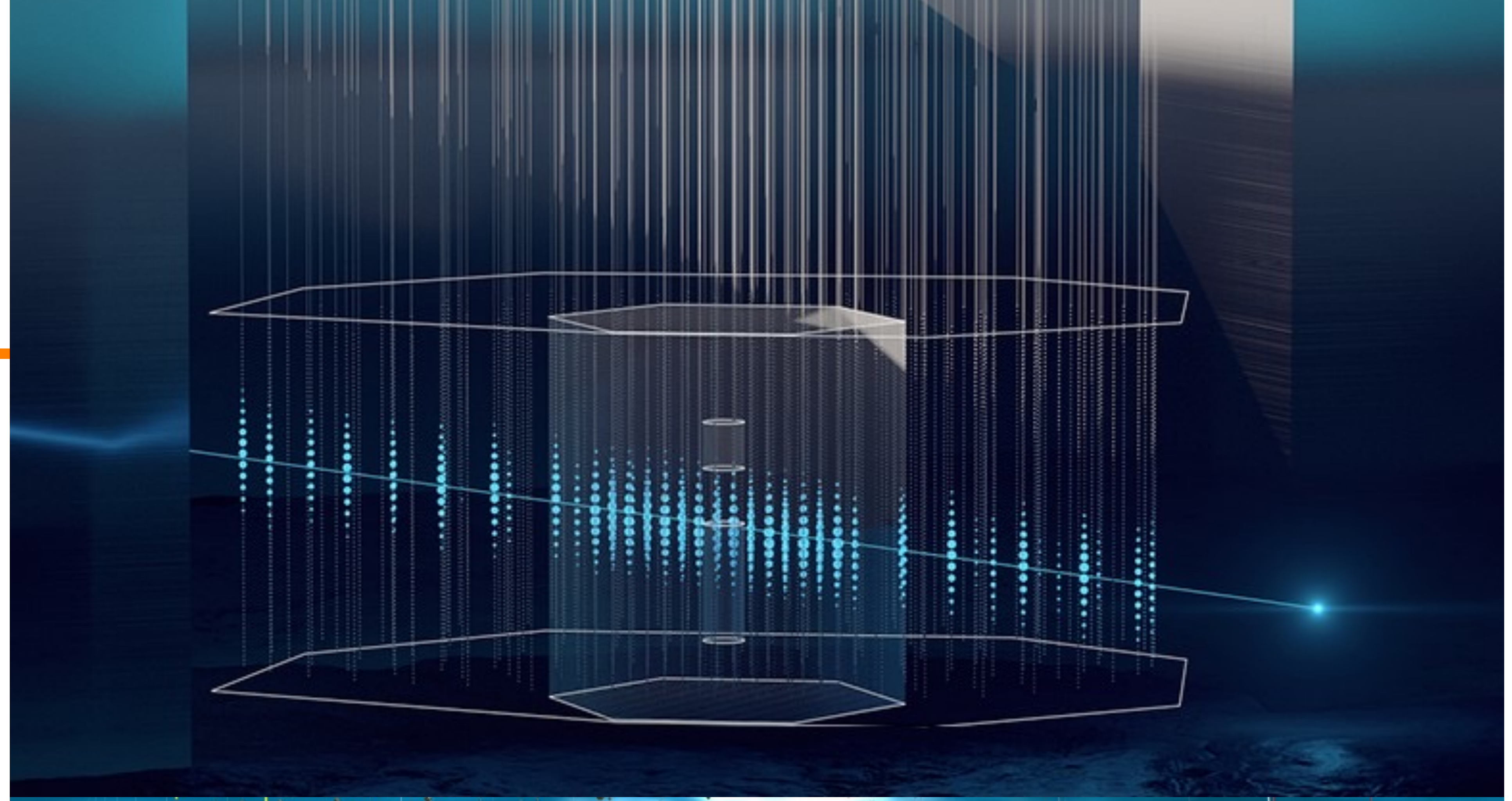
$$E_{LIV}^{(n)} > E_{obs} \left[\frac{E_{obs}^2 - 4m_{e^-}^2}{4m_{e^-}^2} \right]^{1/n}$$

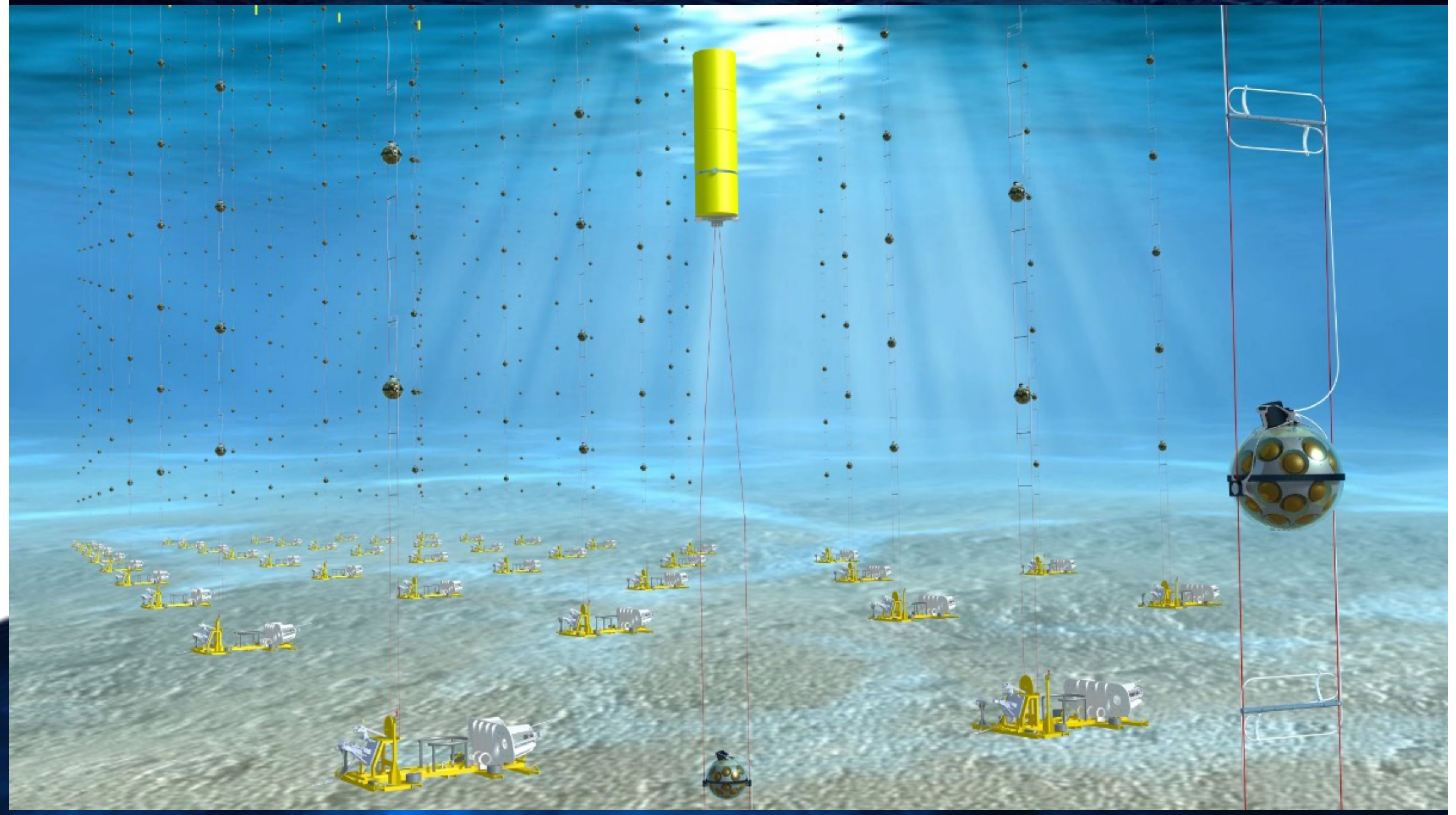


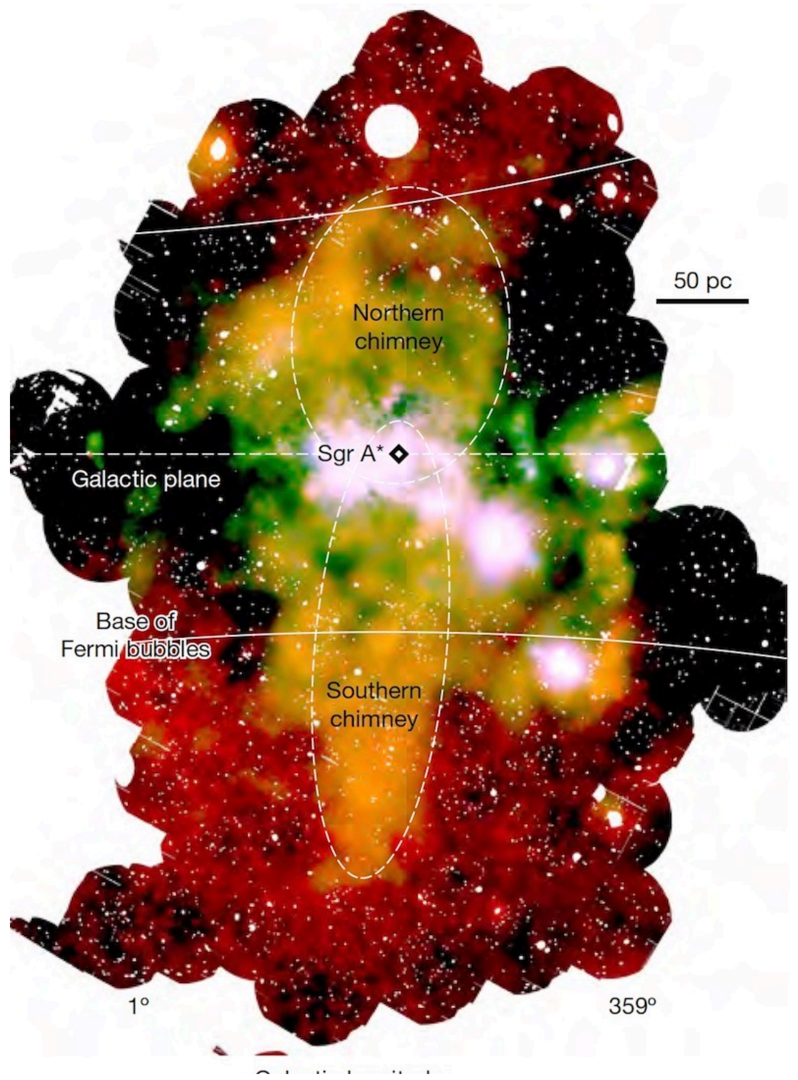
arXiv:1902.08429

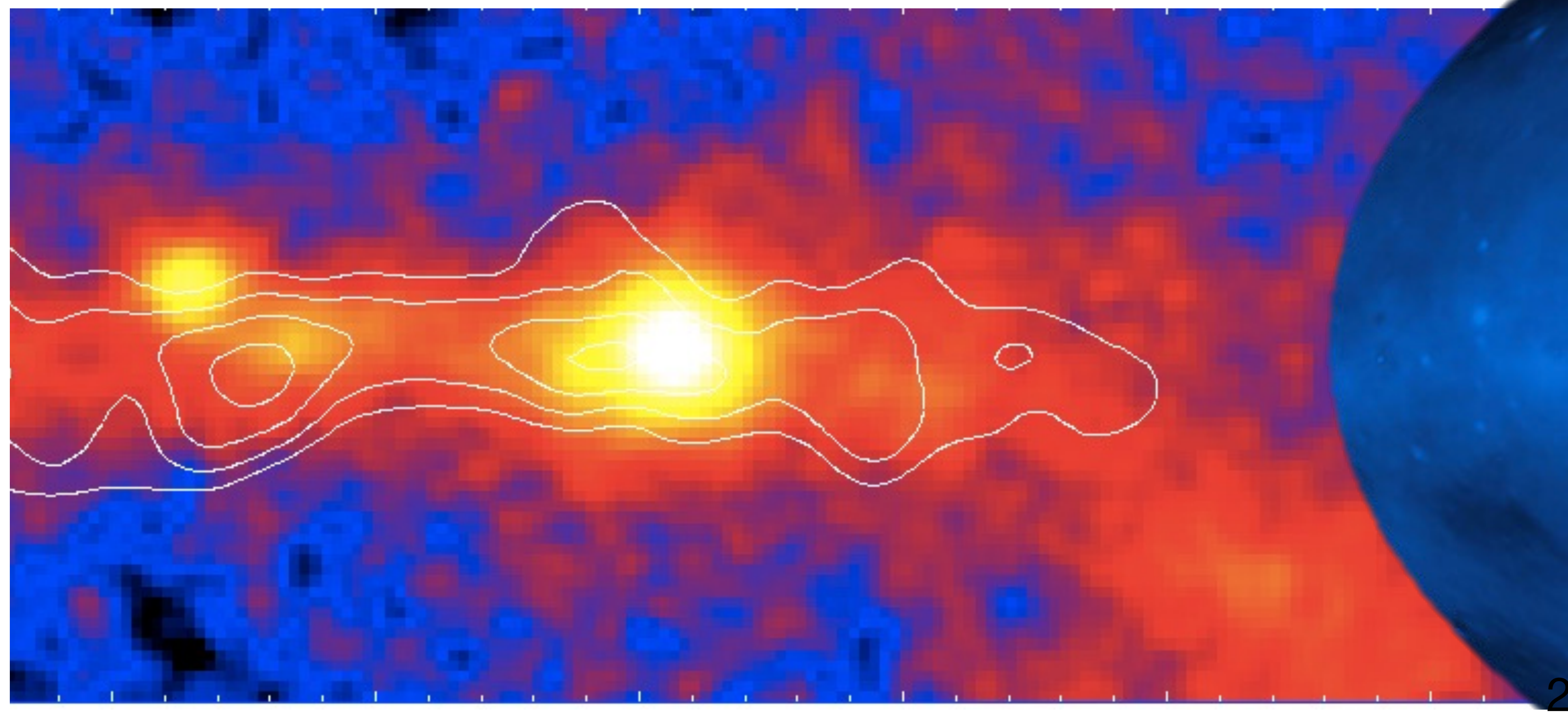
Neutrino Synergies

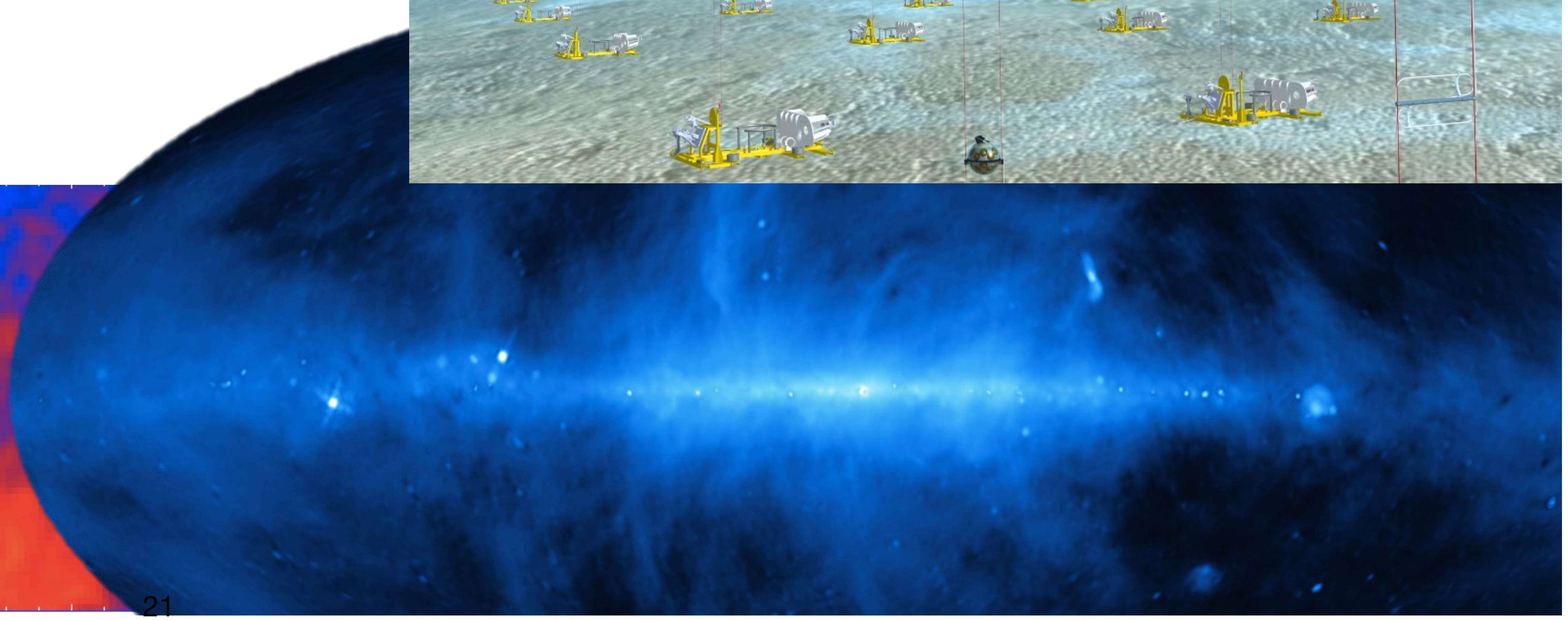
- SWGO+LHAASO
  - → Full sky map of TeV-PeV emission
- Strongly complements new generation of **neutrino instruments**
  - → Mapping out diffuse emission / separating IC + pion decay emission +++







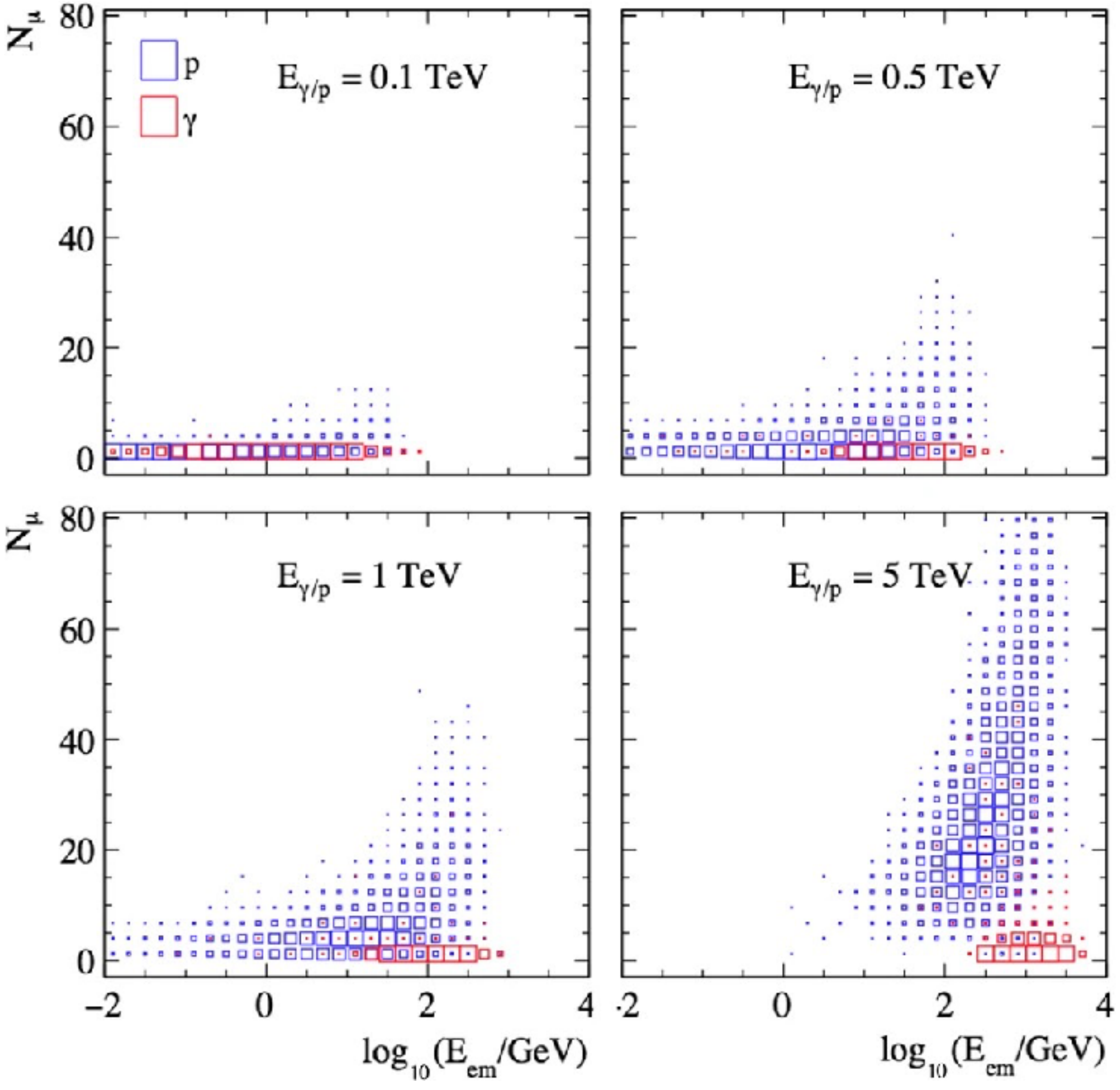


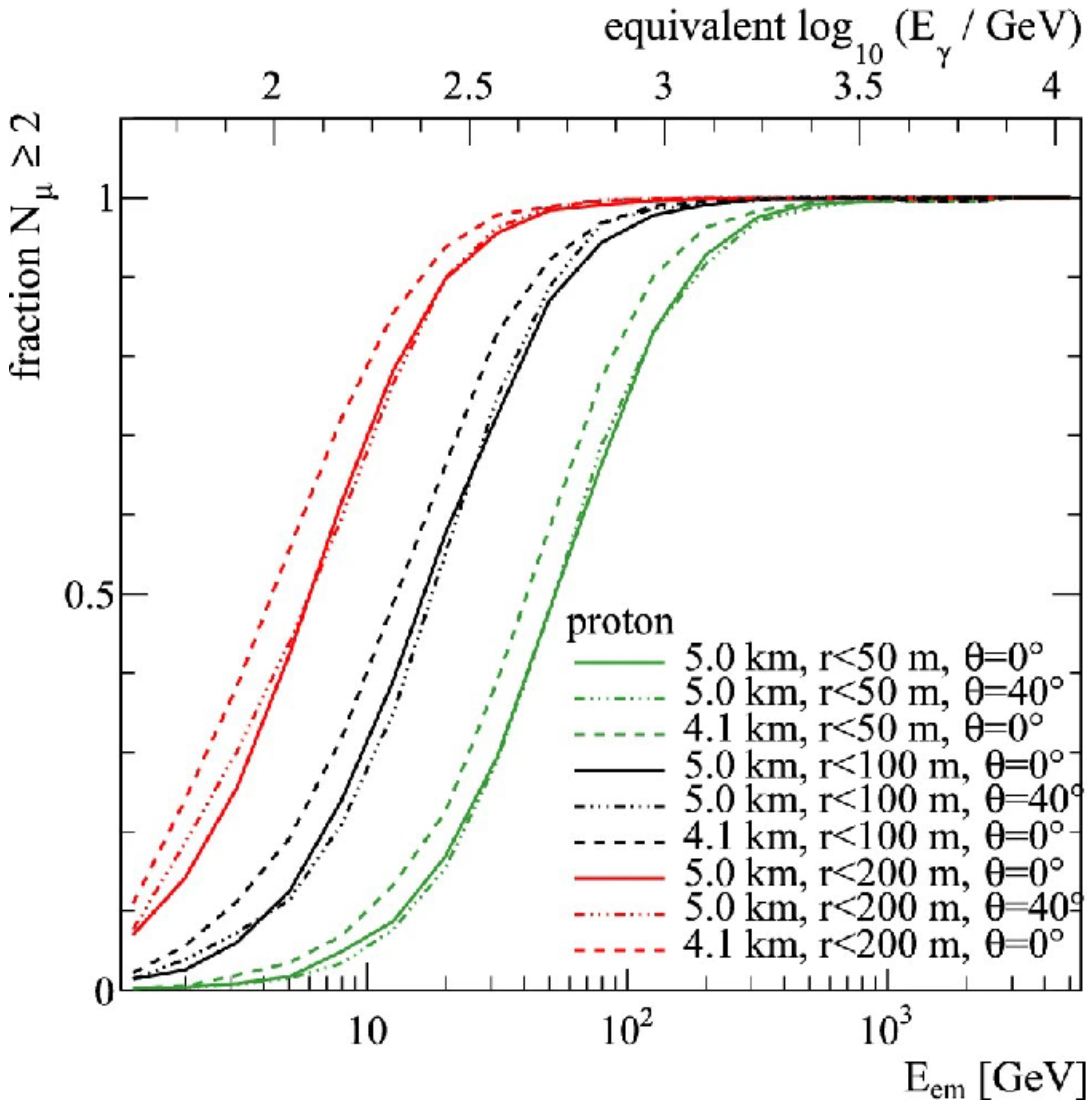


Conclusions

- The Southern Sky needs a wide field VHE-UHE gamma-ray instrument!
  - → Complementing LHAASO – a complete view of the TeV-PeV sky
  - → Strong synergies with CTA and the new generation neutrino telescopes
  - → Transient phenomena, diffuse emission, UHE sources +++
- SWGO advancing towards design and site choices
  - → Despite pandemic!
- Very open for new partners and new ideas
- Looking forward to strong partnerships with LHAASO & CTA

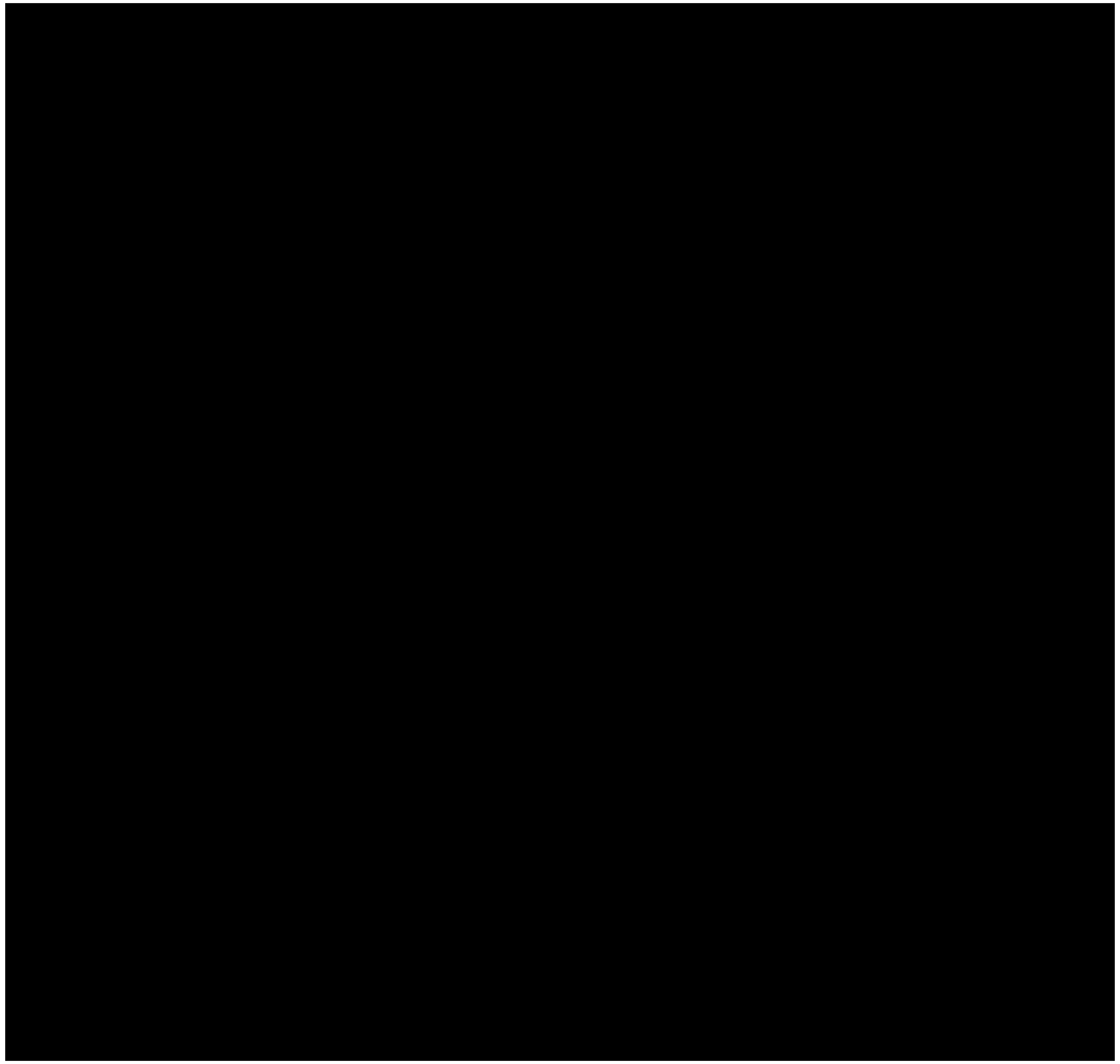
Identifying gamma rays using muons





HS., Hinton, J. & López-Coto, R.
Eur. Phys. J. C 79, 427 (2019).

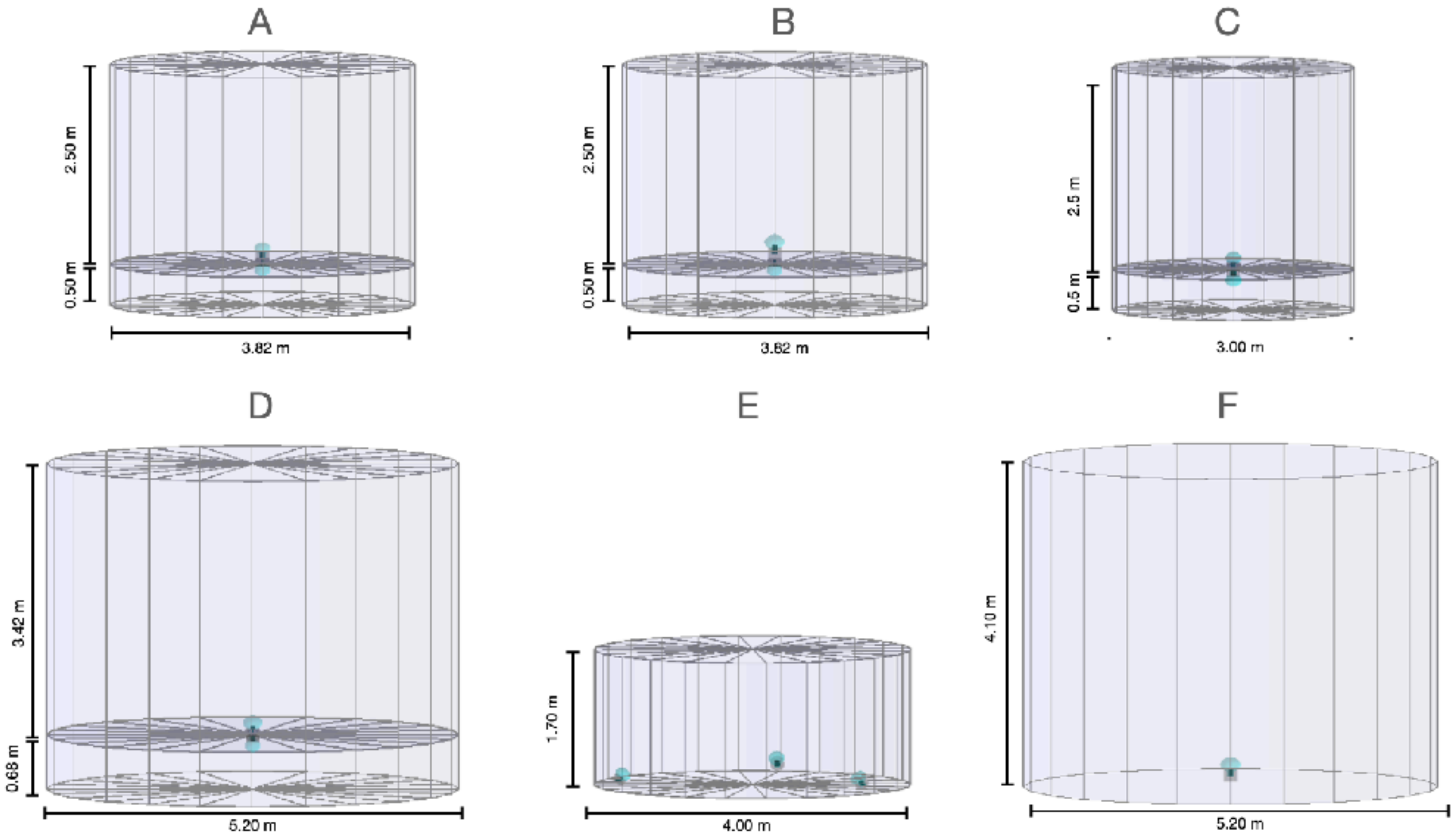
- Also look to pattern of detector hits!
- How low in energy can we go?



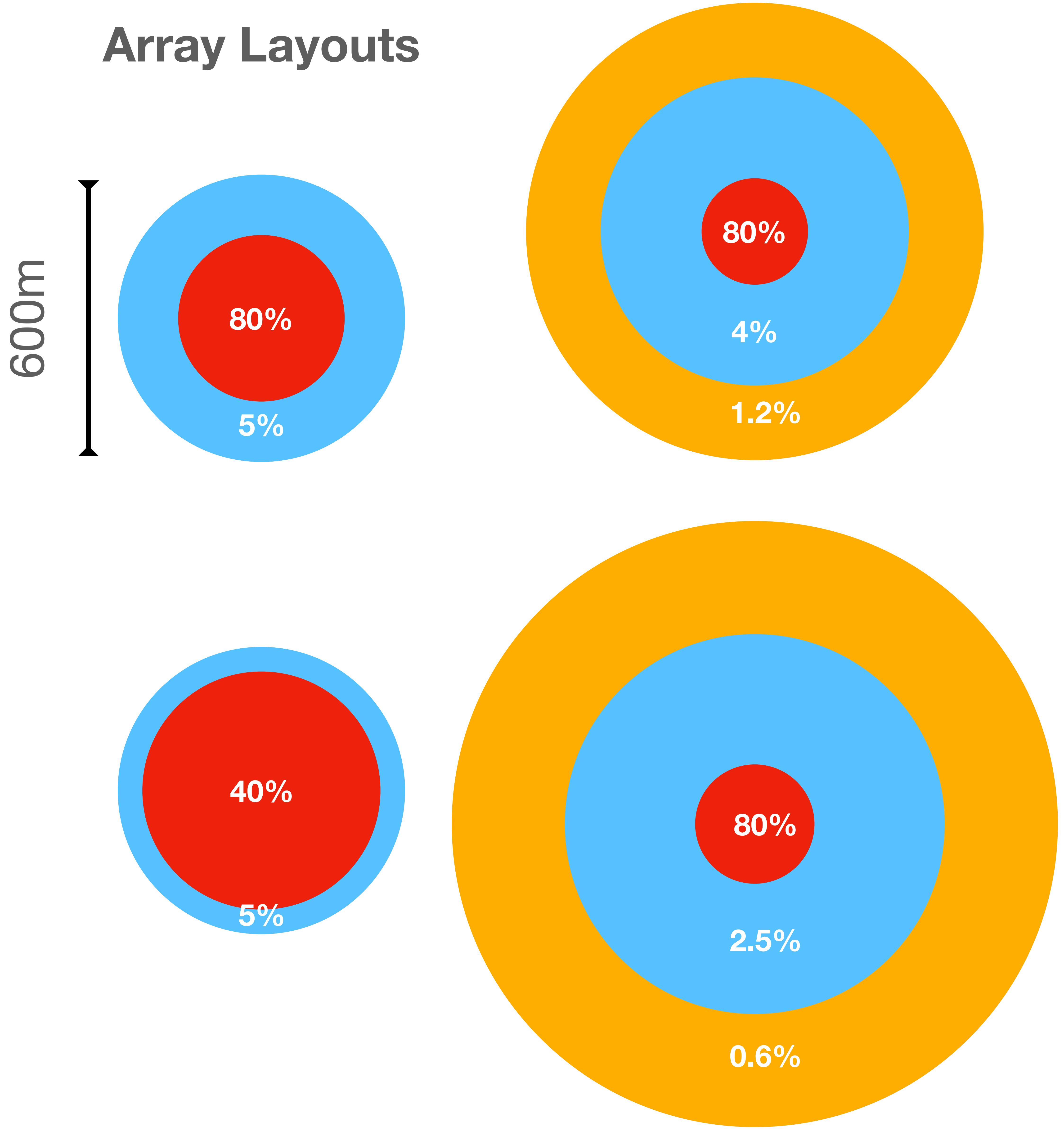
Frame 28 ns, duration 2800 ns

Currently testing different configurations

Unit Configurations

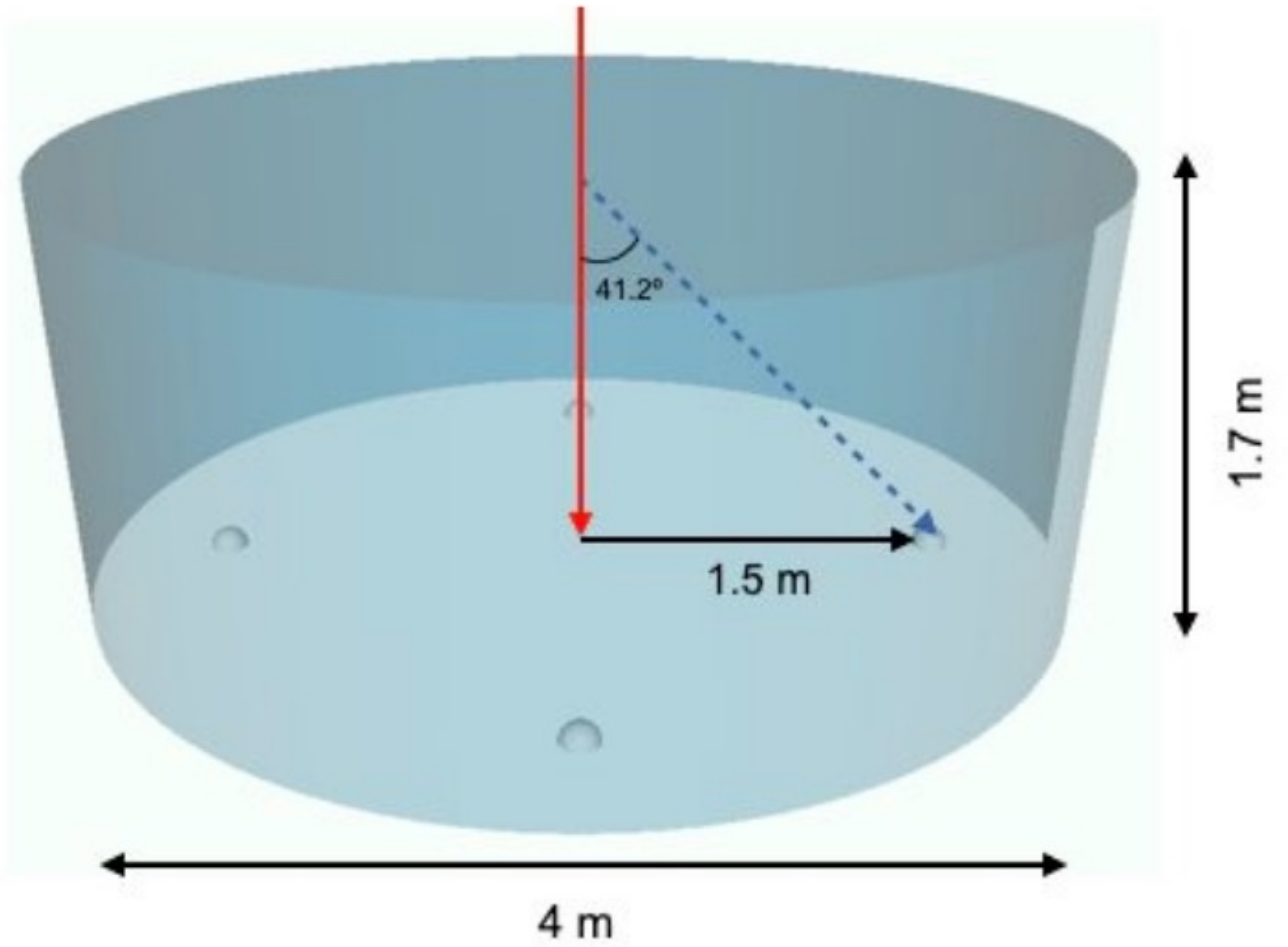


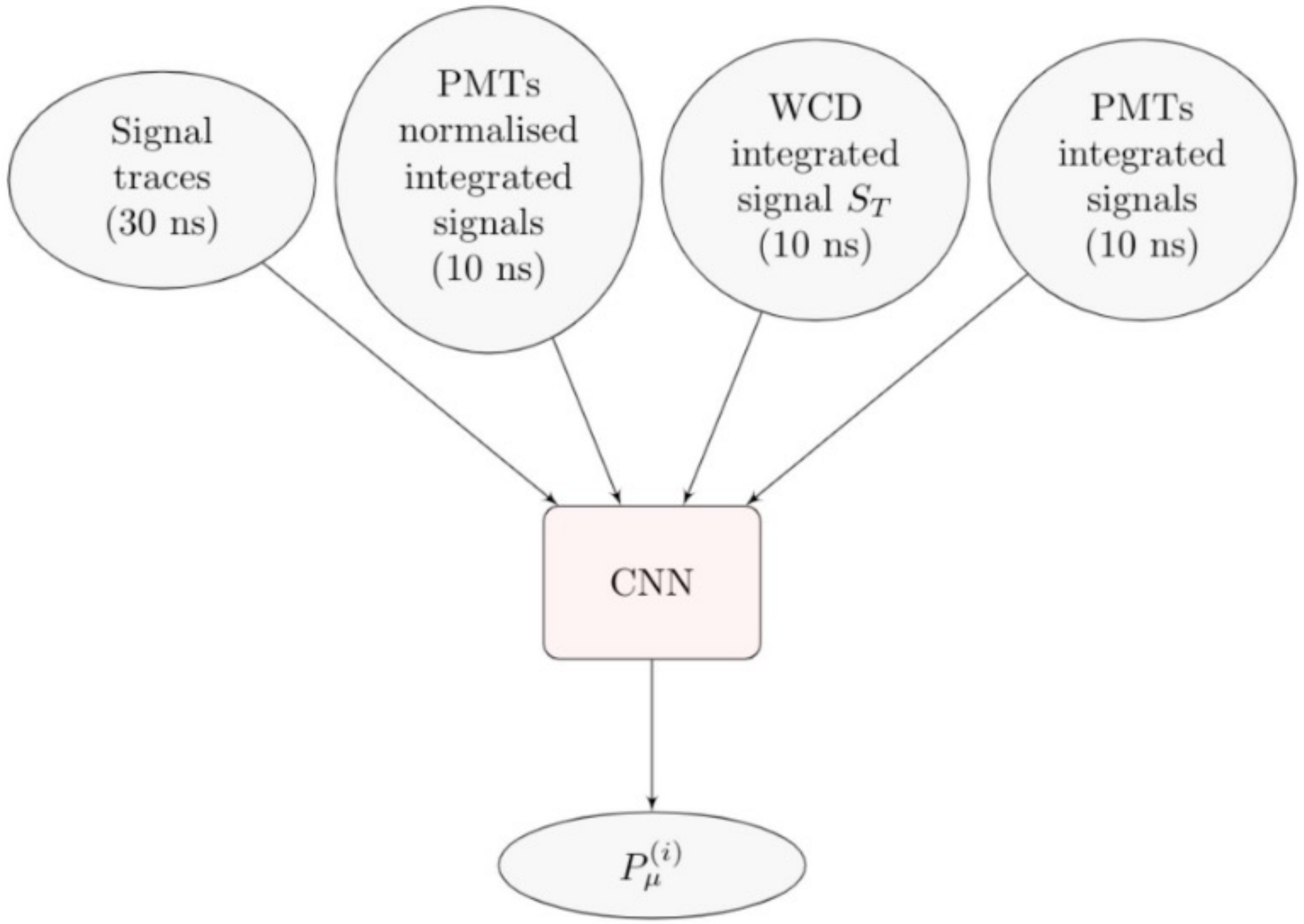
Array Layouts



Alternative to double-layer

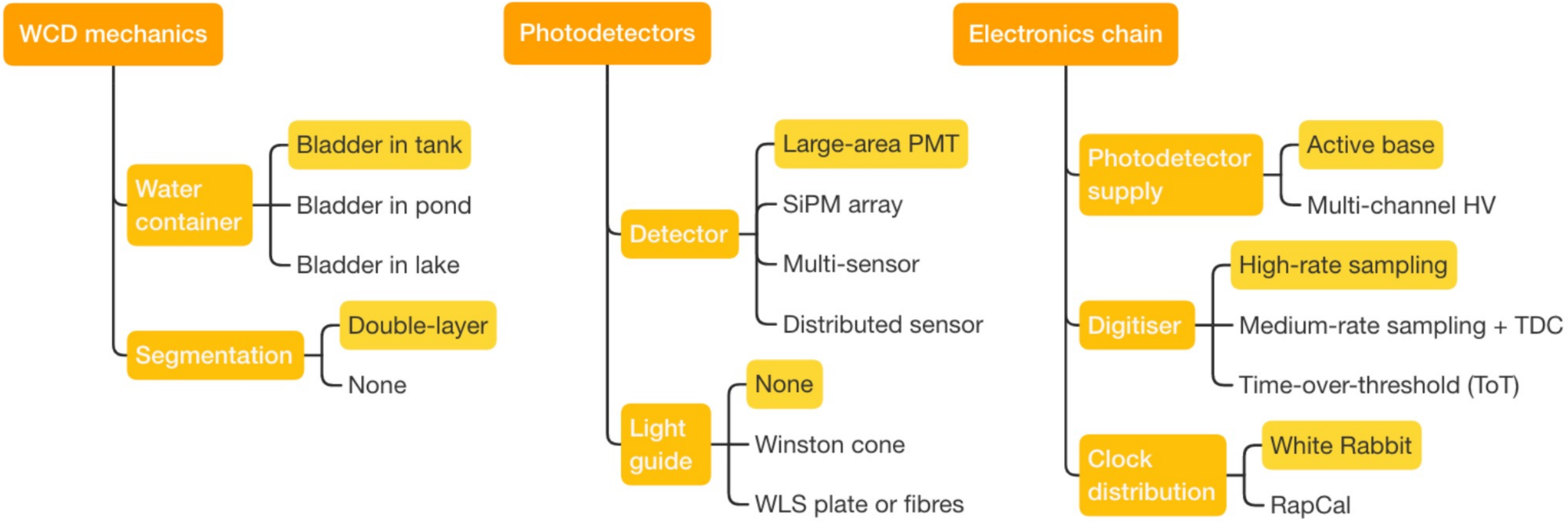
- Use multiple photosensors per detection unit to distinguish single through-going particle (=muon)
- Promising! Performance/Cost trade-off to decide





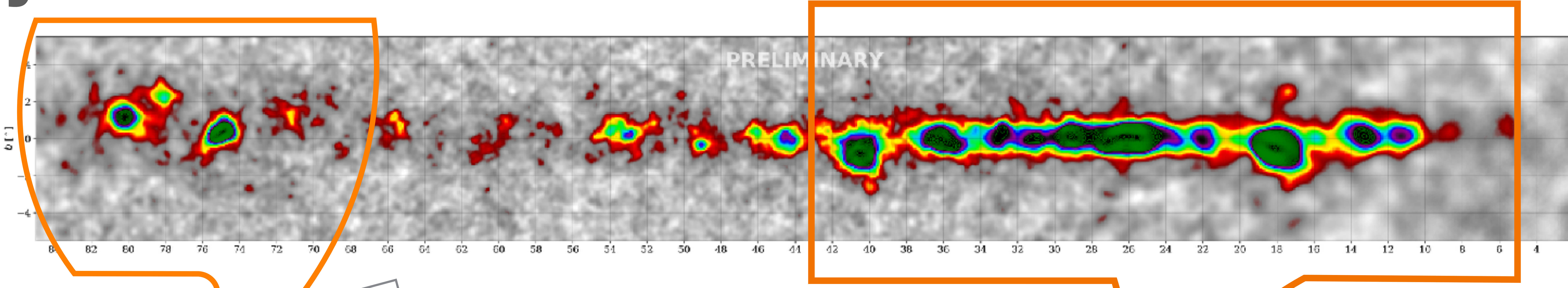
Reference Configuration

- Establish a plausible, costable and realisable (with existing tech) design to serve as reference to alternative approaches

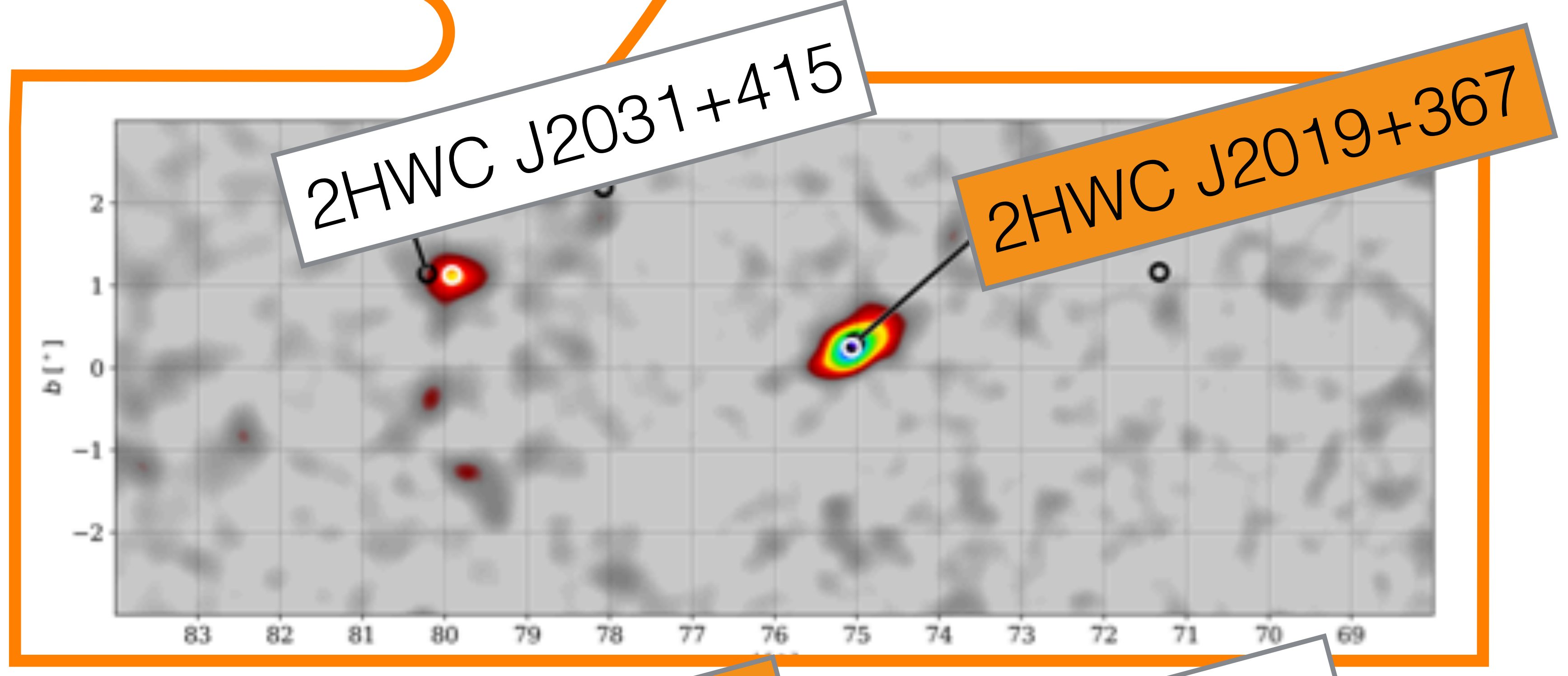


Some highlights: The dawn of ultra-high-energy gamma-ray astronomy

> 1 TeV

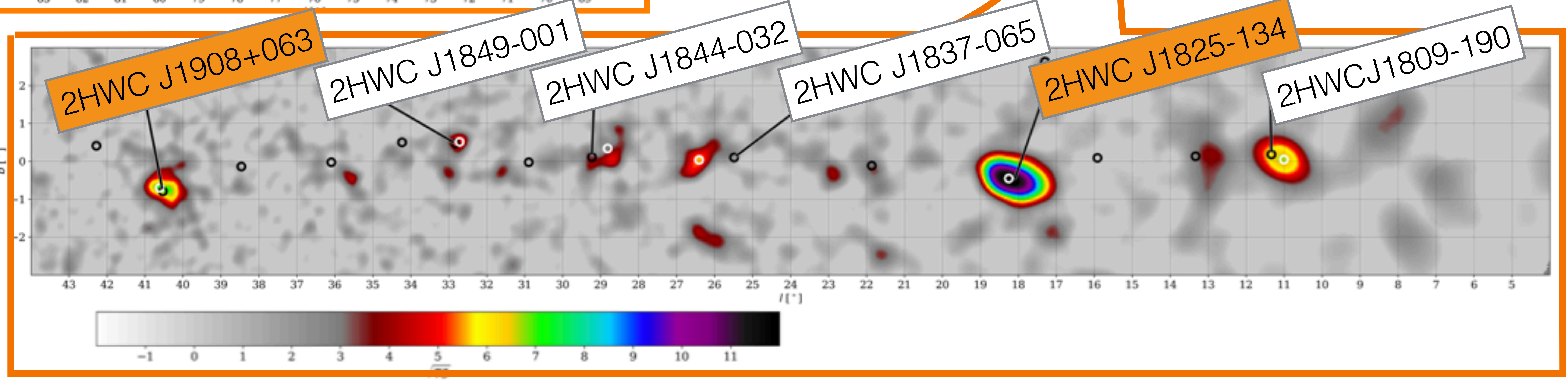


> 56 TeV



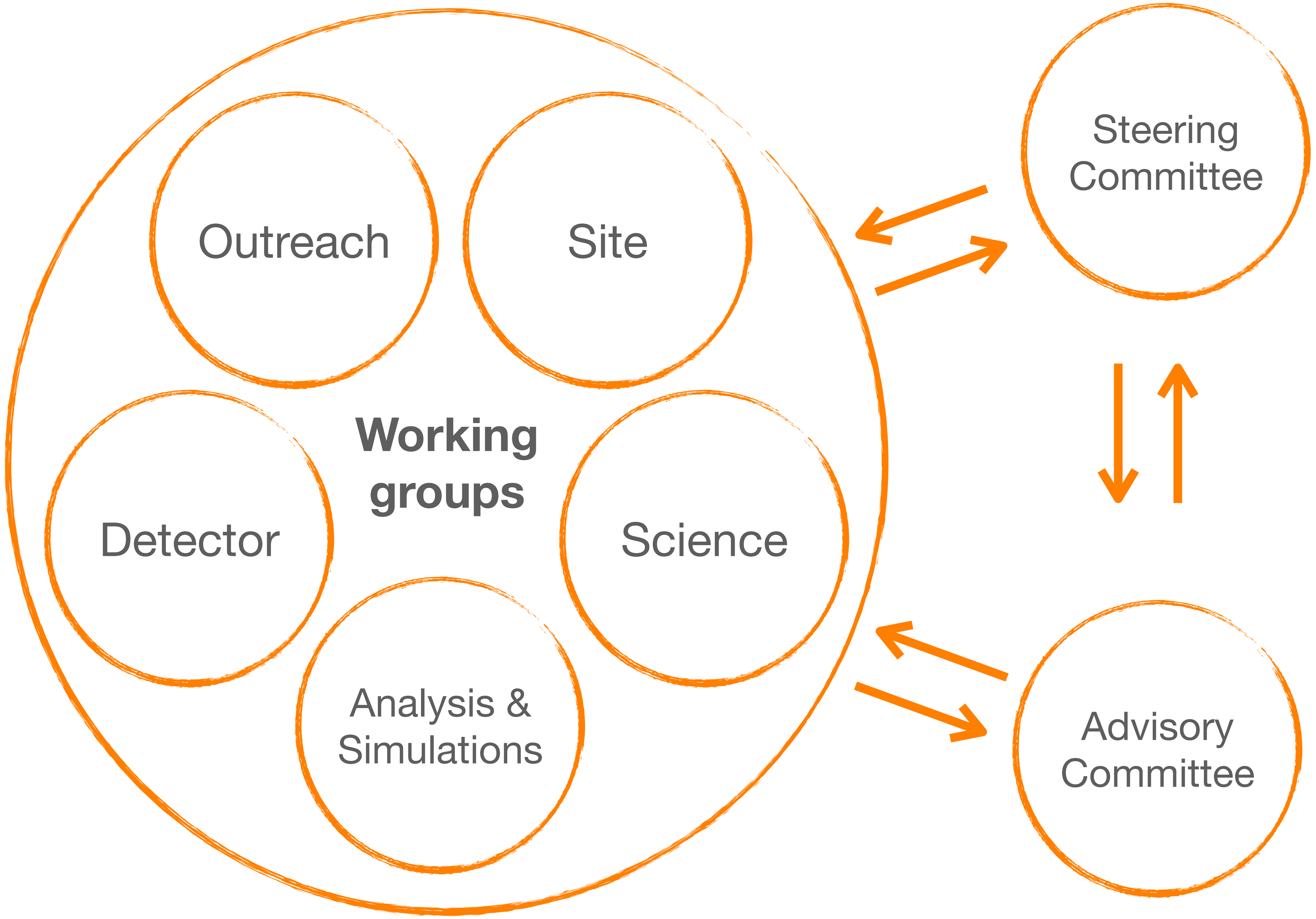
> 100 TeV

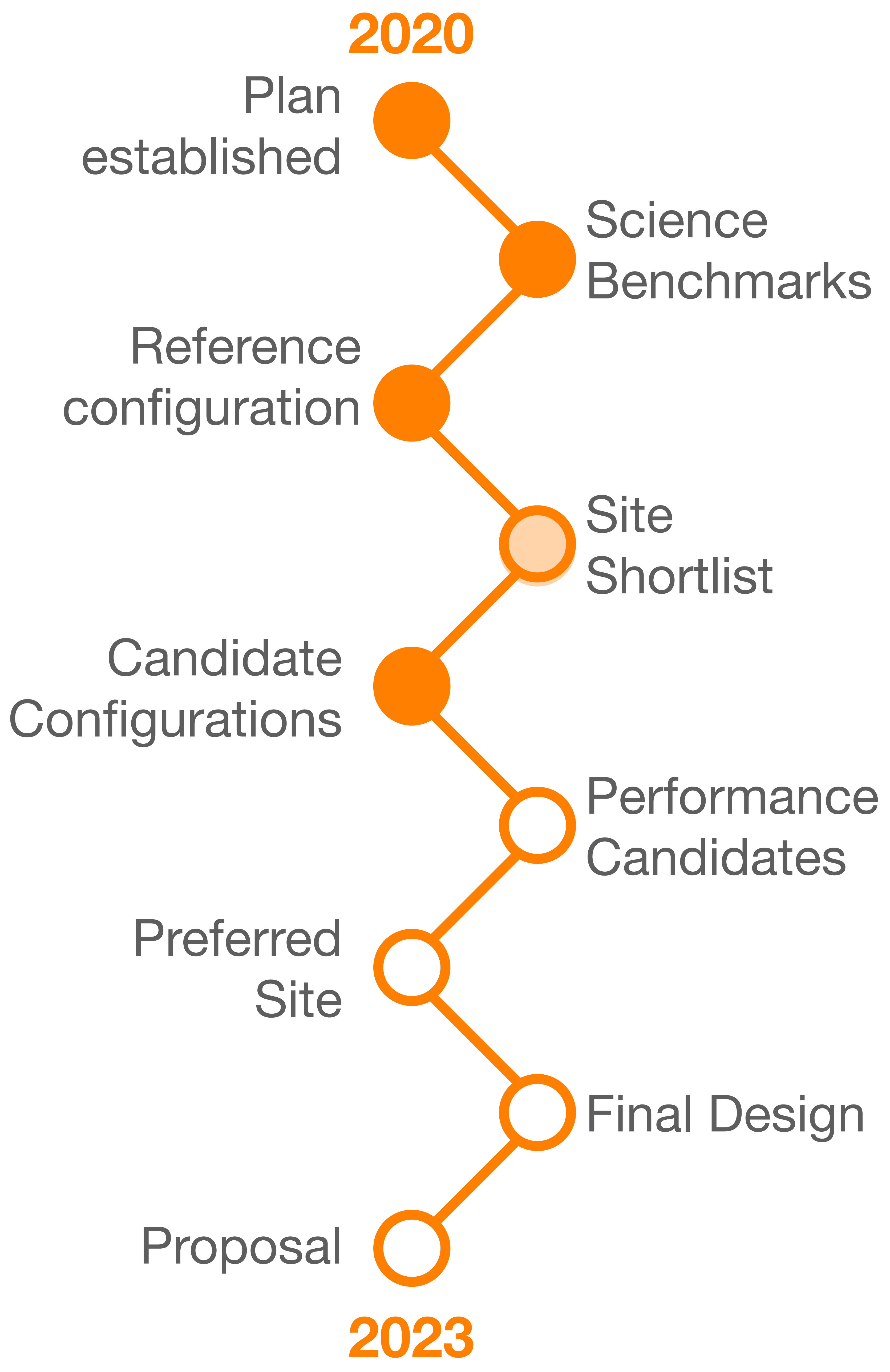
A. U. Abeysekara *et al.* (HAWC Collaboration) Phys. Rev. Lett. **124**, 021102

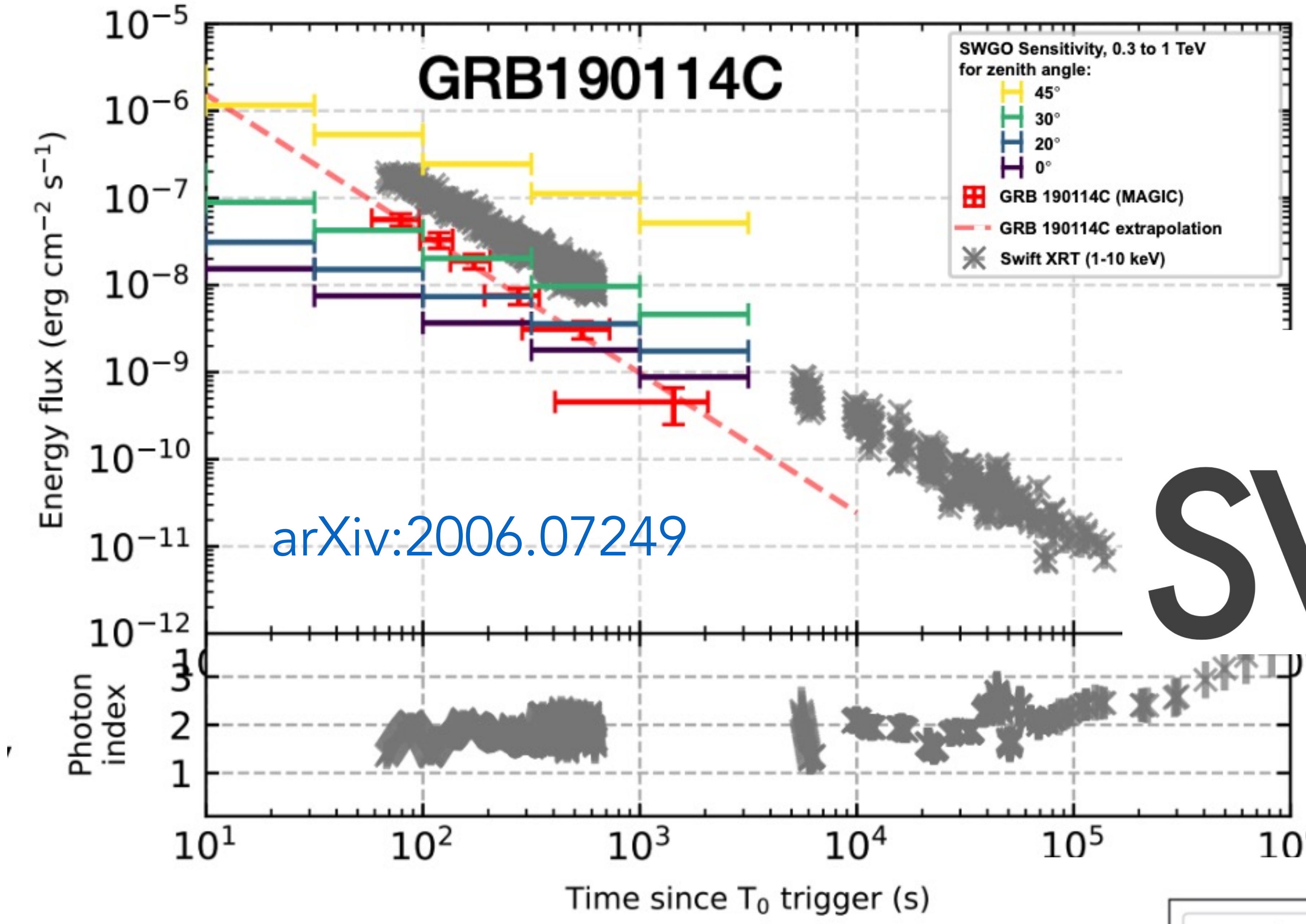


Long exposure opens up a new energy regime in gamma-ray astronomy

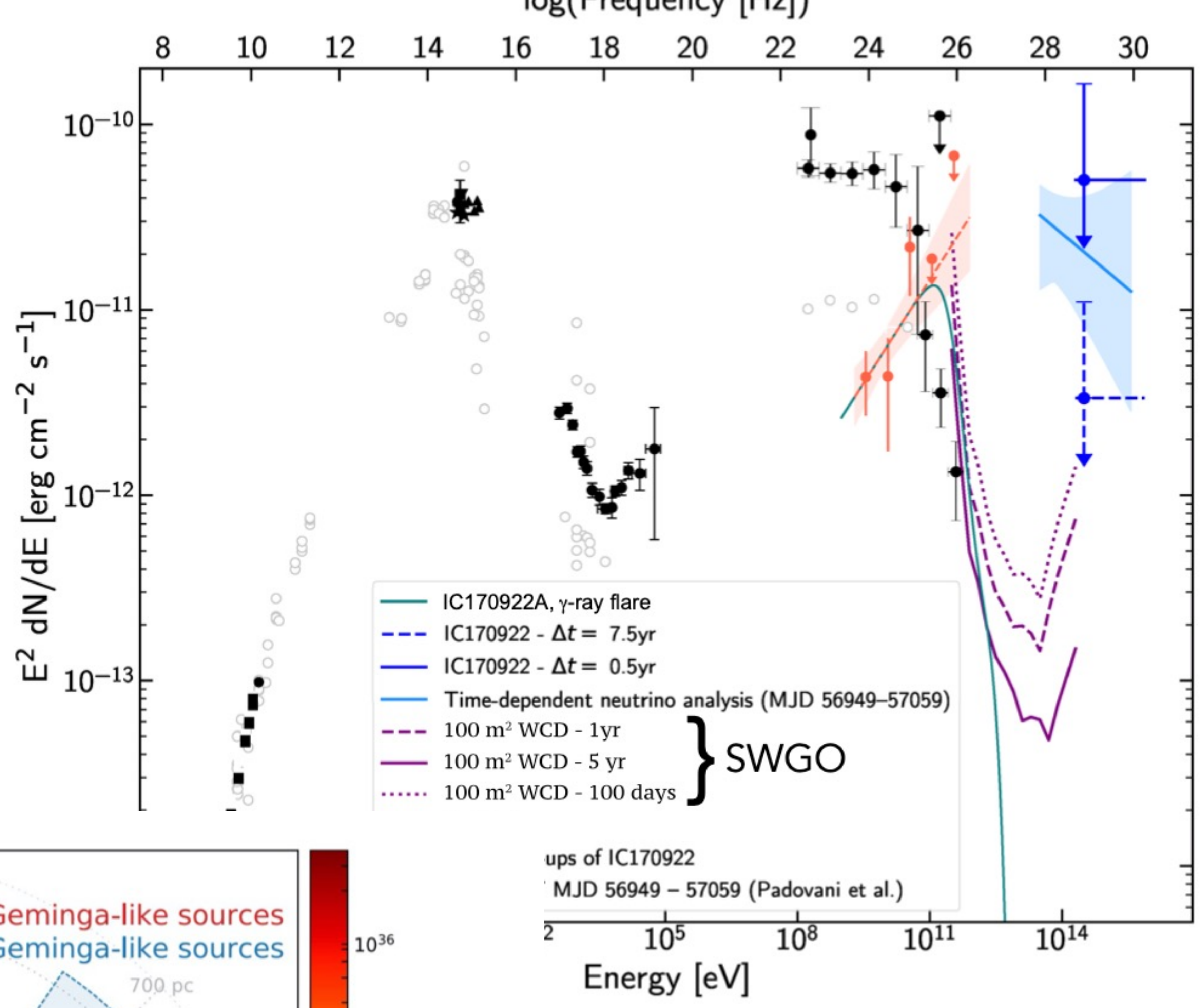
SWGO organisation





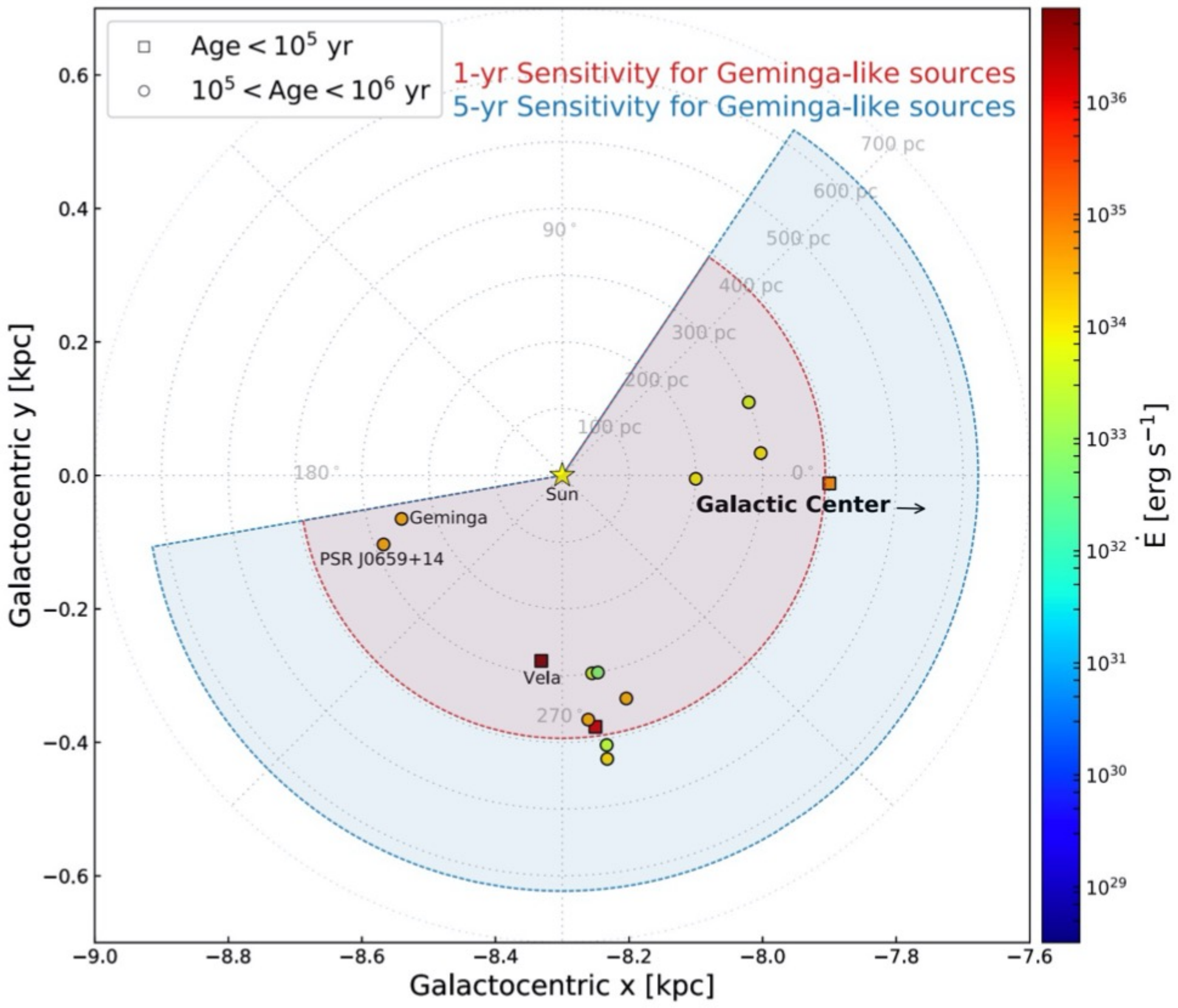


- Early phase **Gamma Ray Bust** sensitivity



Modified from arXiv: 1812.01036

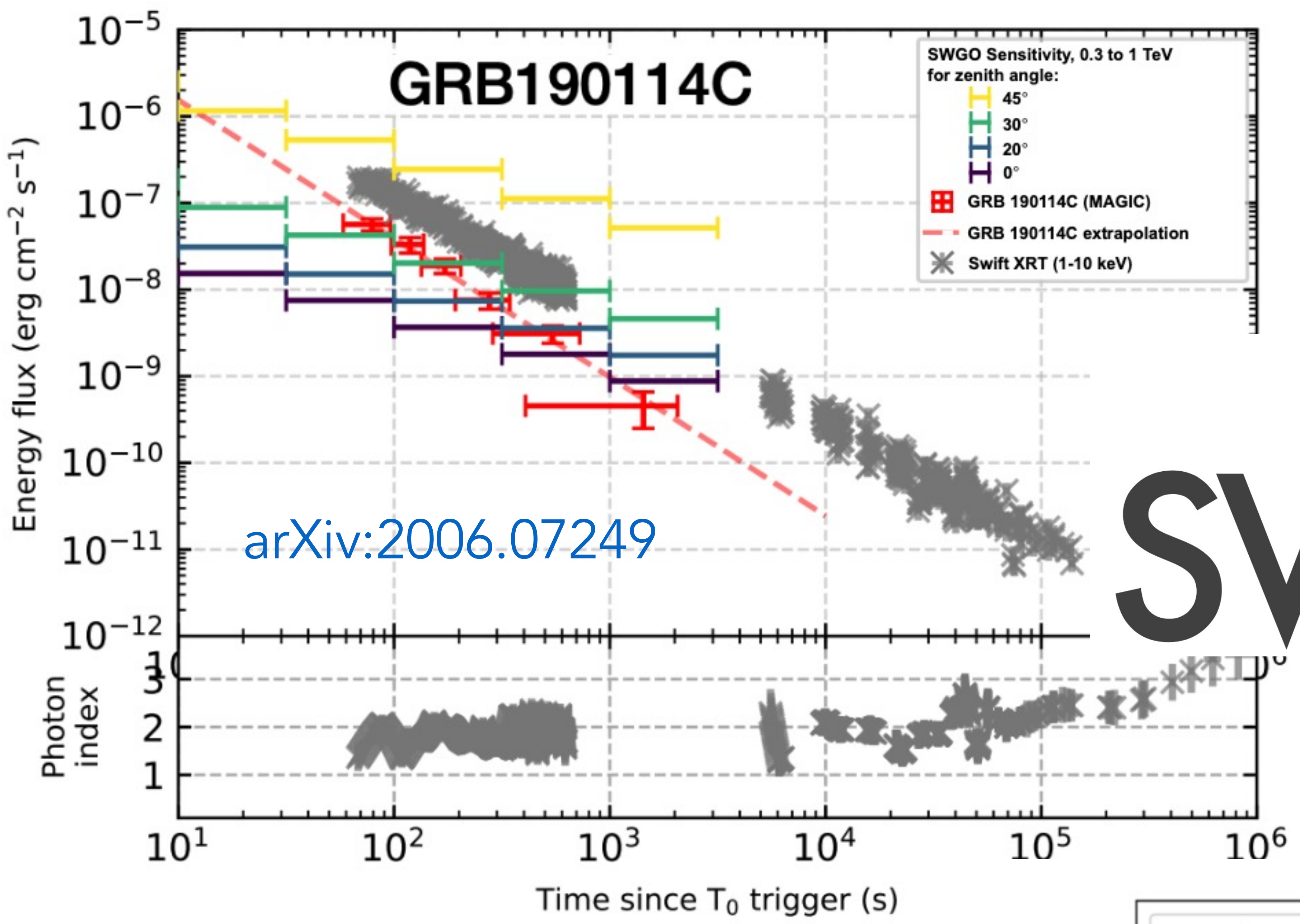
- SWGO monitoring CF **TXS 0506+056**

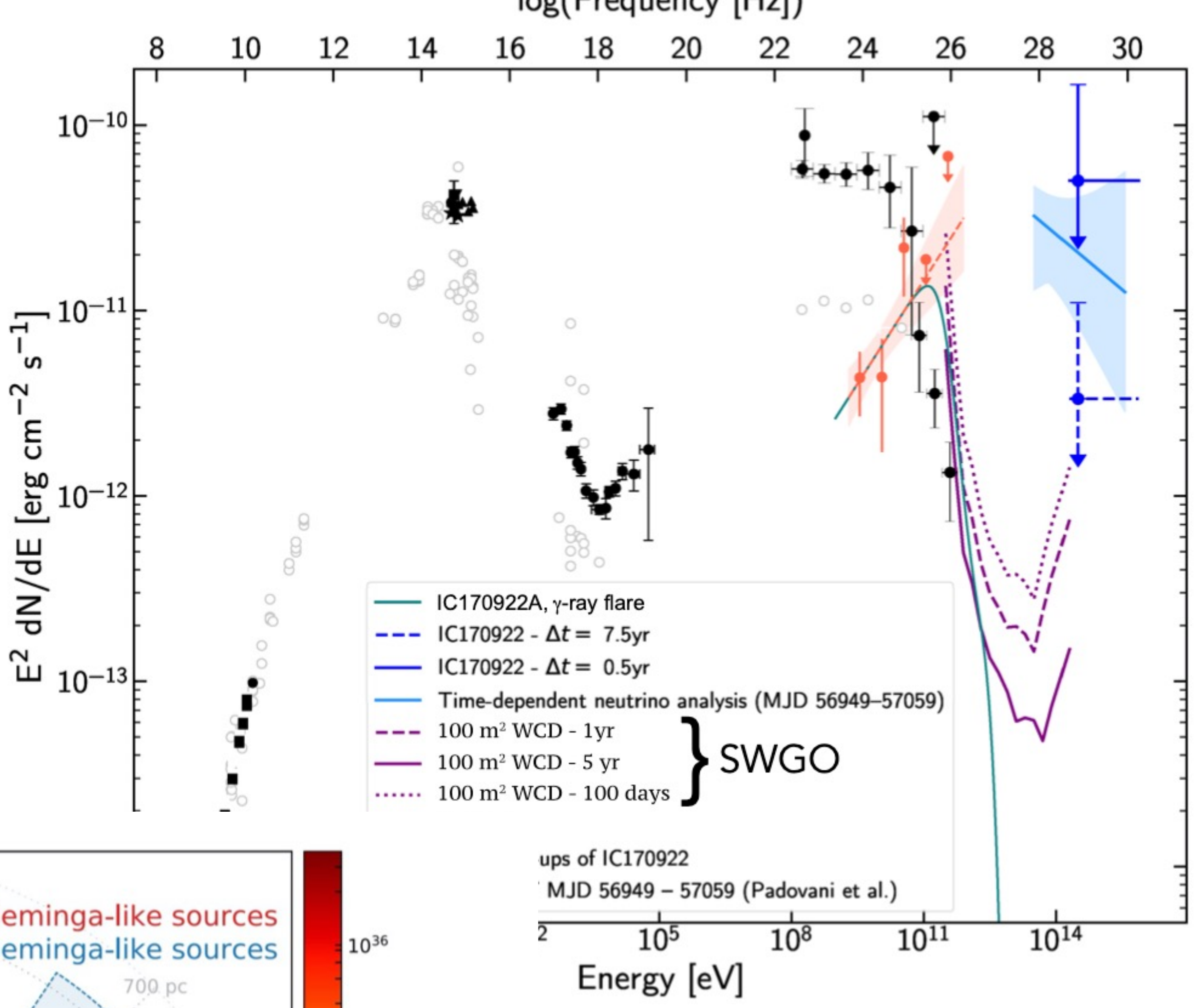


arXiv:1902.08429

- Geminga-like **PWN Halo** Sensitivity

All with pessimistic sensitivity estimates





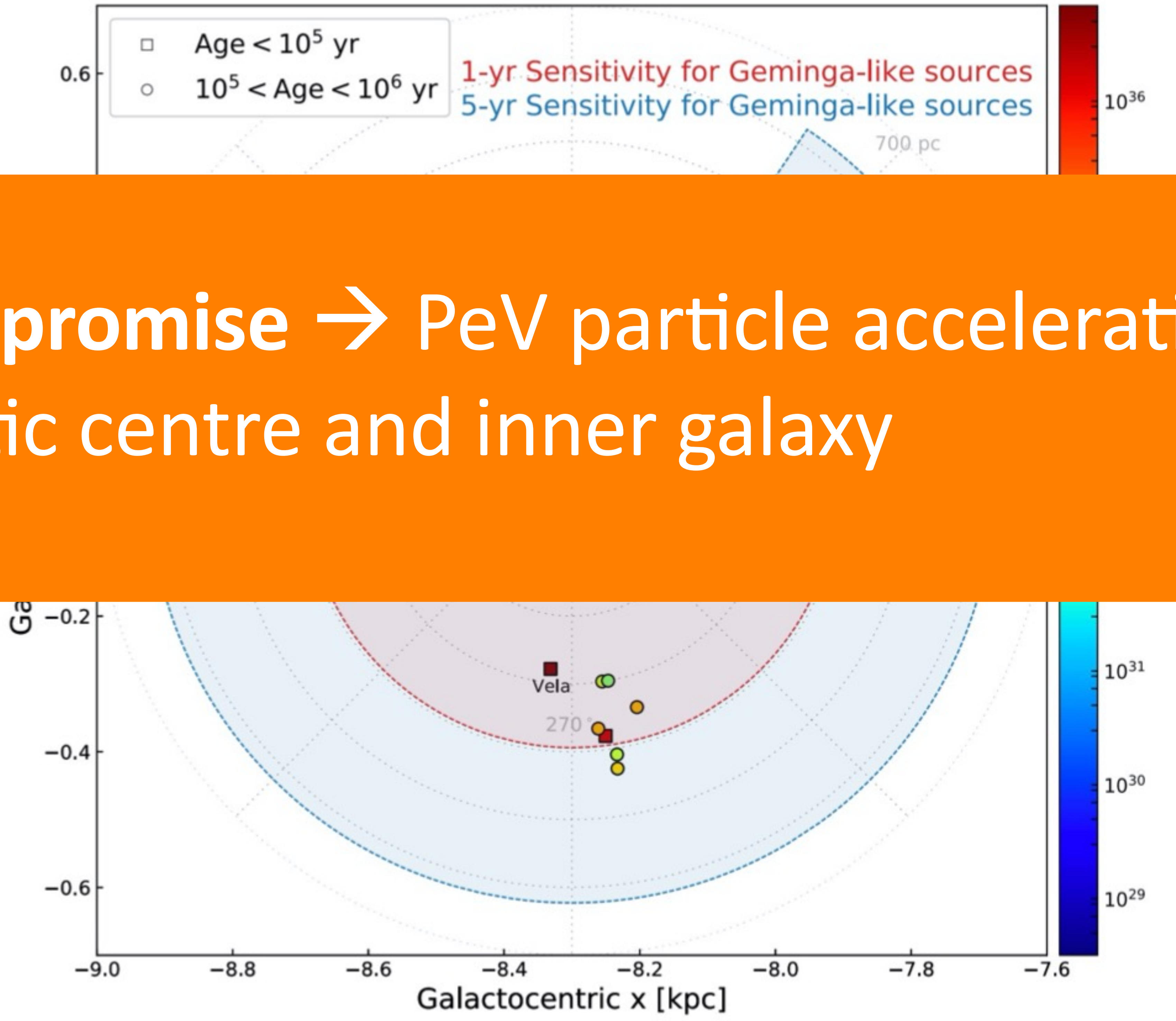
Modified from arXiv: 1812.01036

◎ Early phase
Gamma
Bust ser

Plus – huge promise → PeV particle acceleration in the galactic centre and inner galaxy

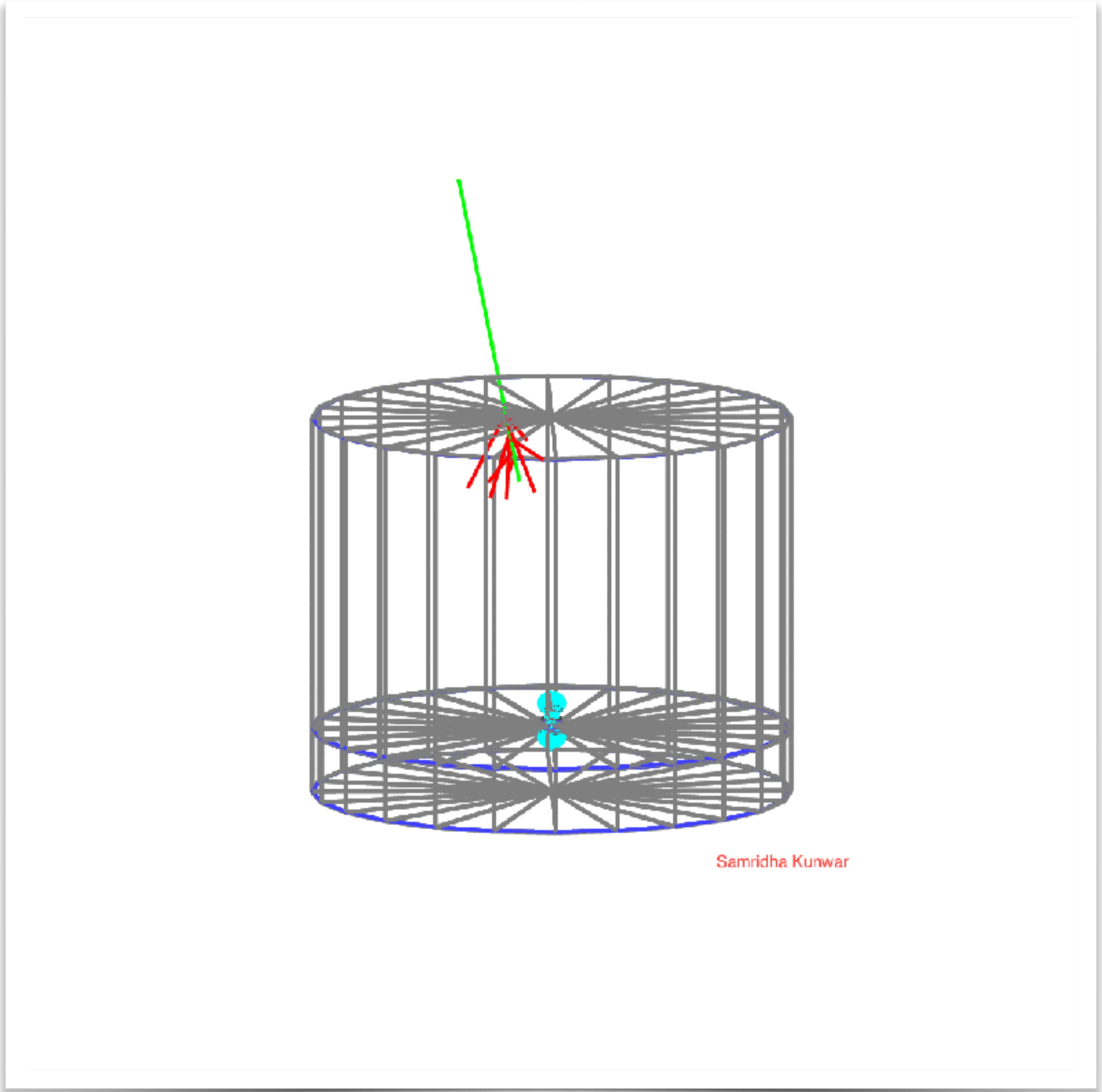
SWGO
monitoring CF
TXS 0506+056

◎ Geminga-like
PWN Halo
Sensitivity



arXi

All with pessimistic sensitivity estimates

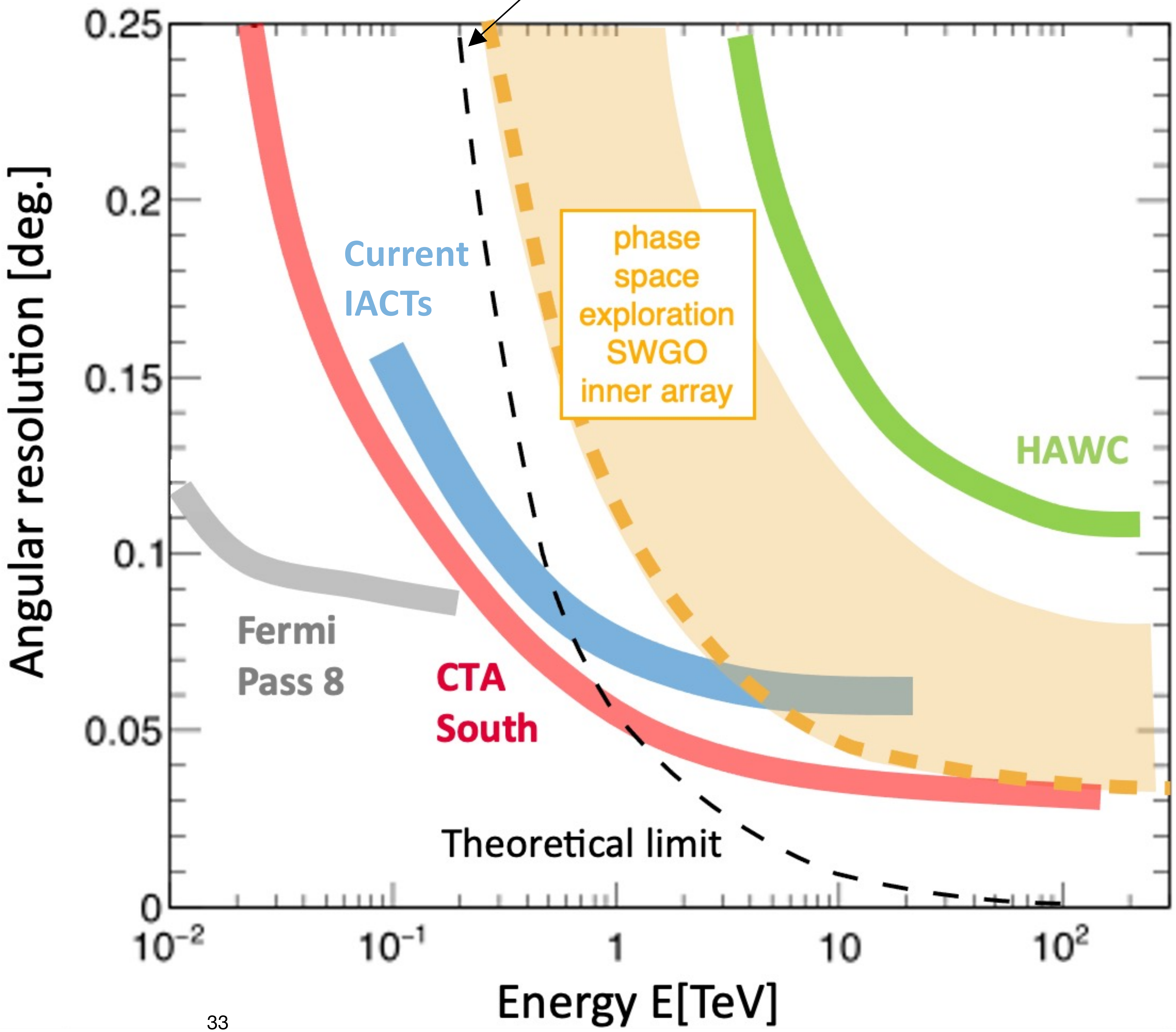


Frame 28 ns, duration 2800 ns

Resolution?

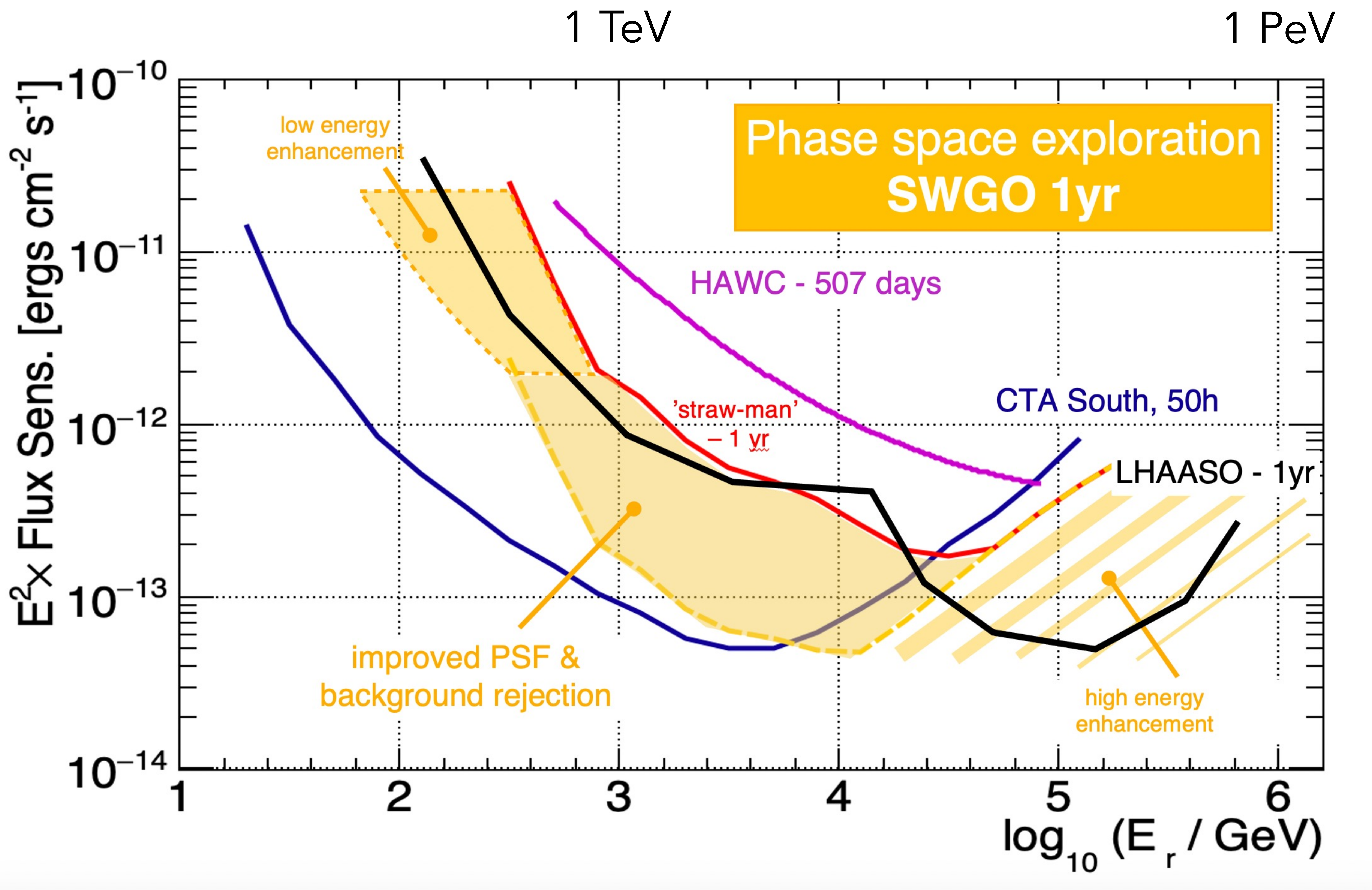
Goal → unprecedented resolution for a **wide field** VHE-UHE instrument

Hofmann (2020) Astroparticle Physics 123, 102479

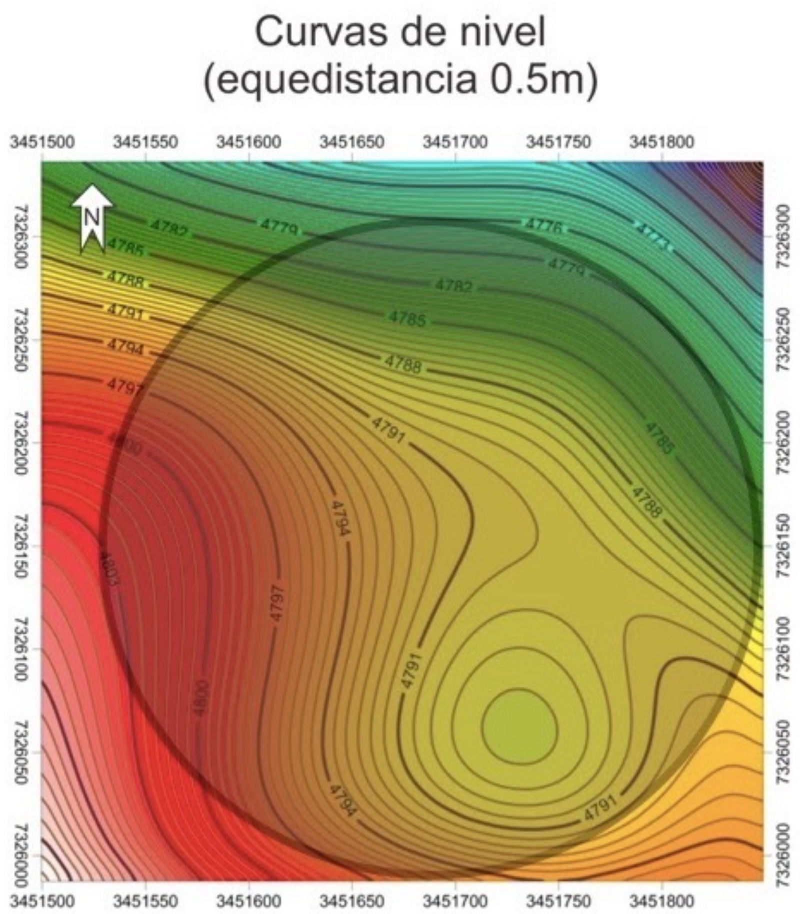


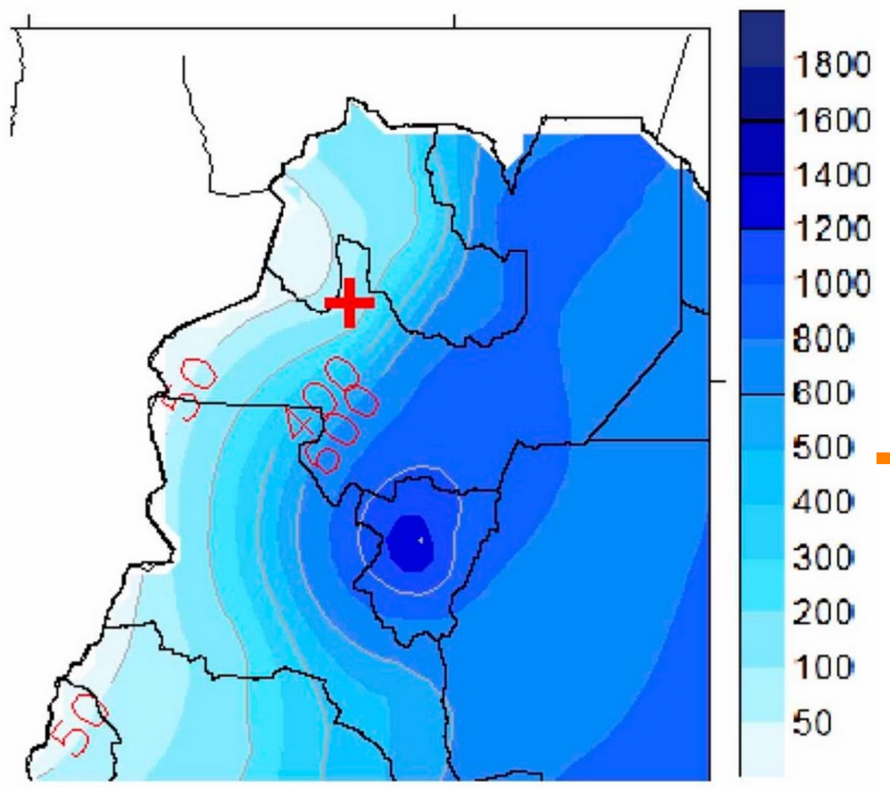
Goal Sensitivity

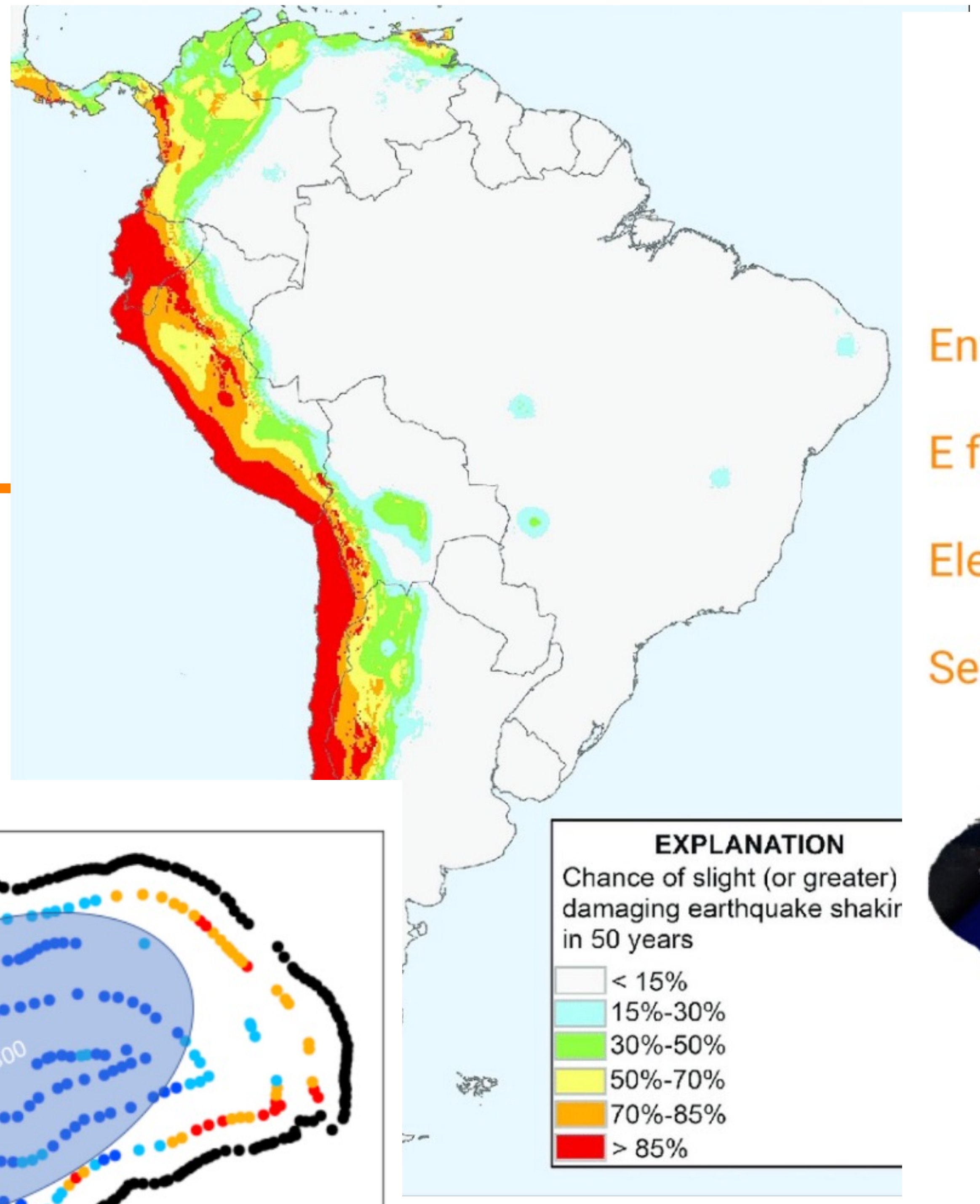
- Improve significantly over HAWC
- Complementary to CTA and LHAASO
- Comparable performance than LHAASO (or better?)

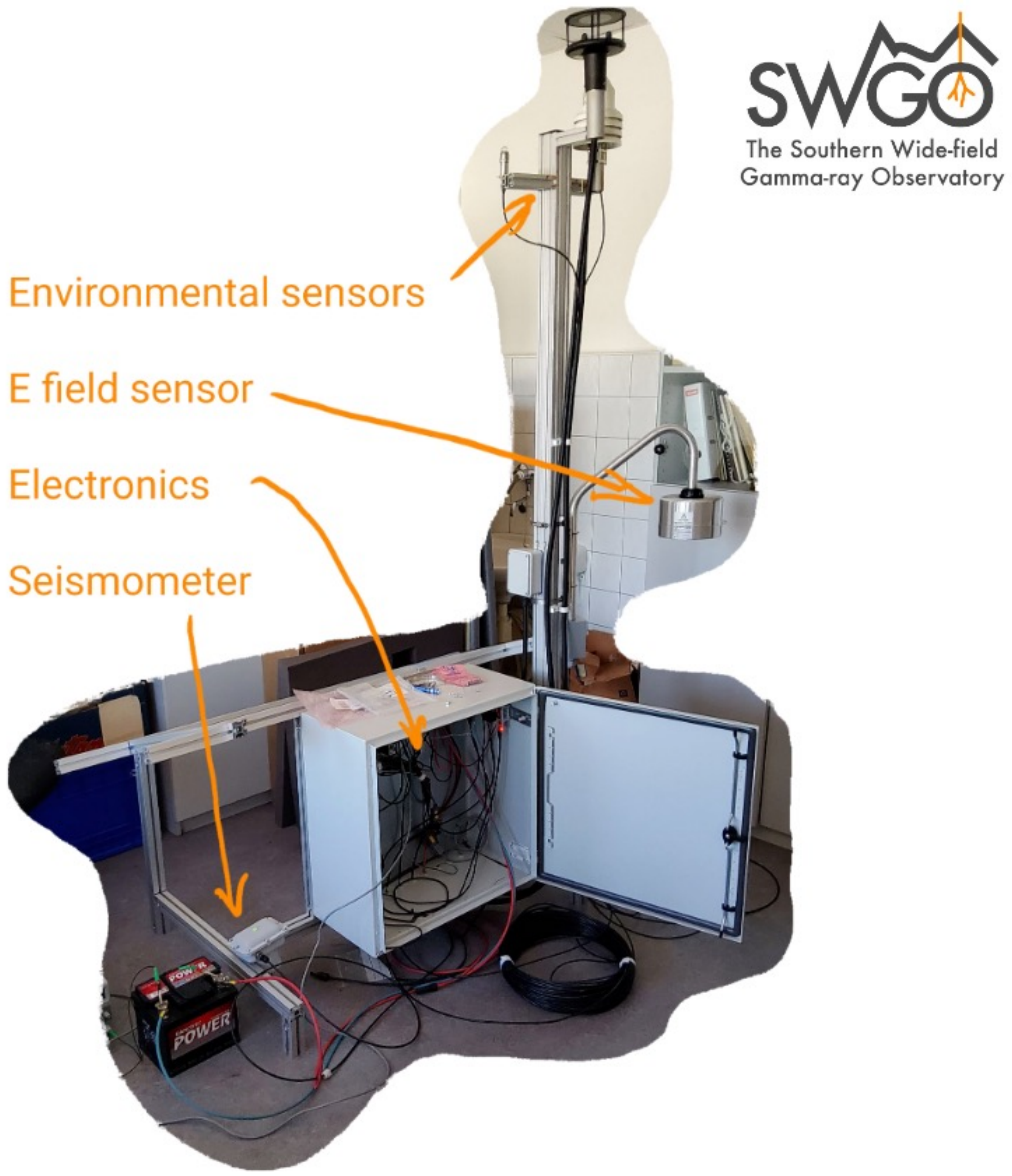


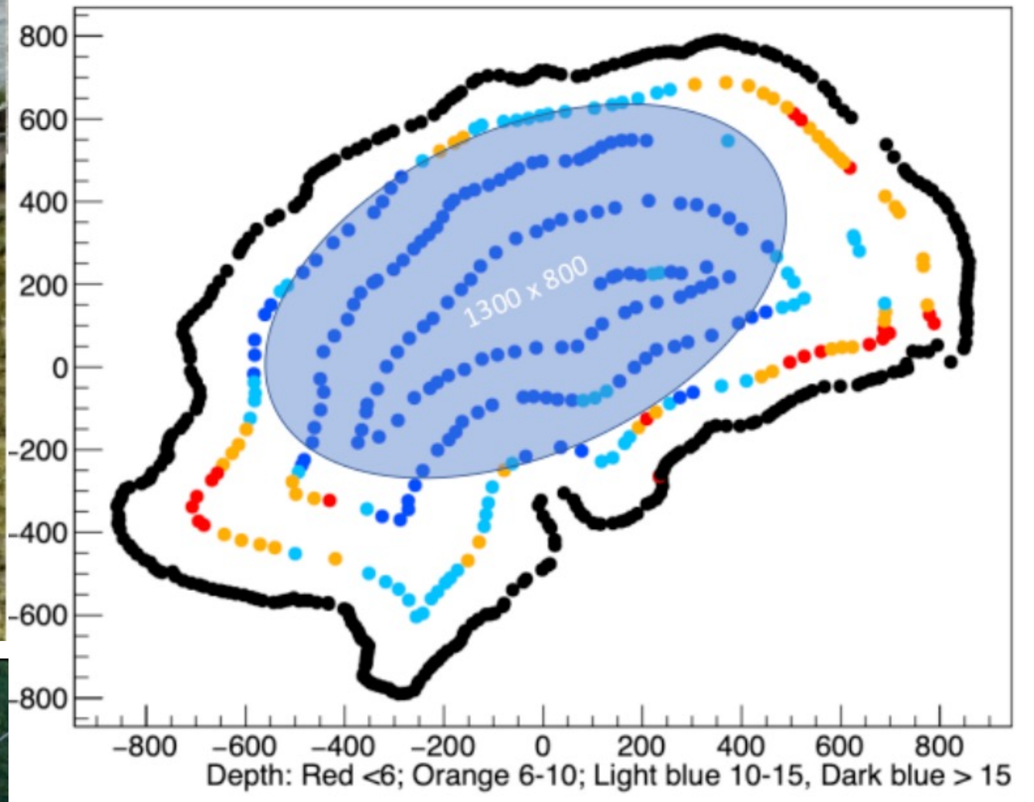
PoS(ICRC2021)903

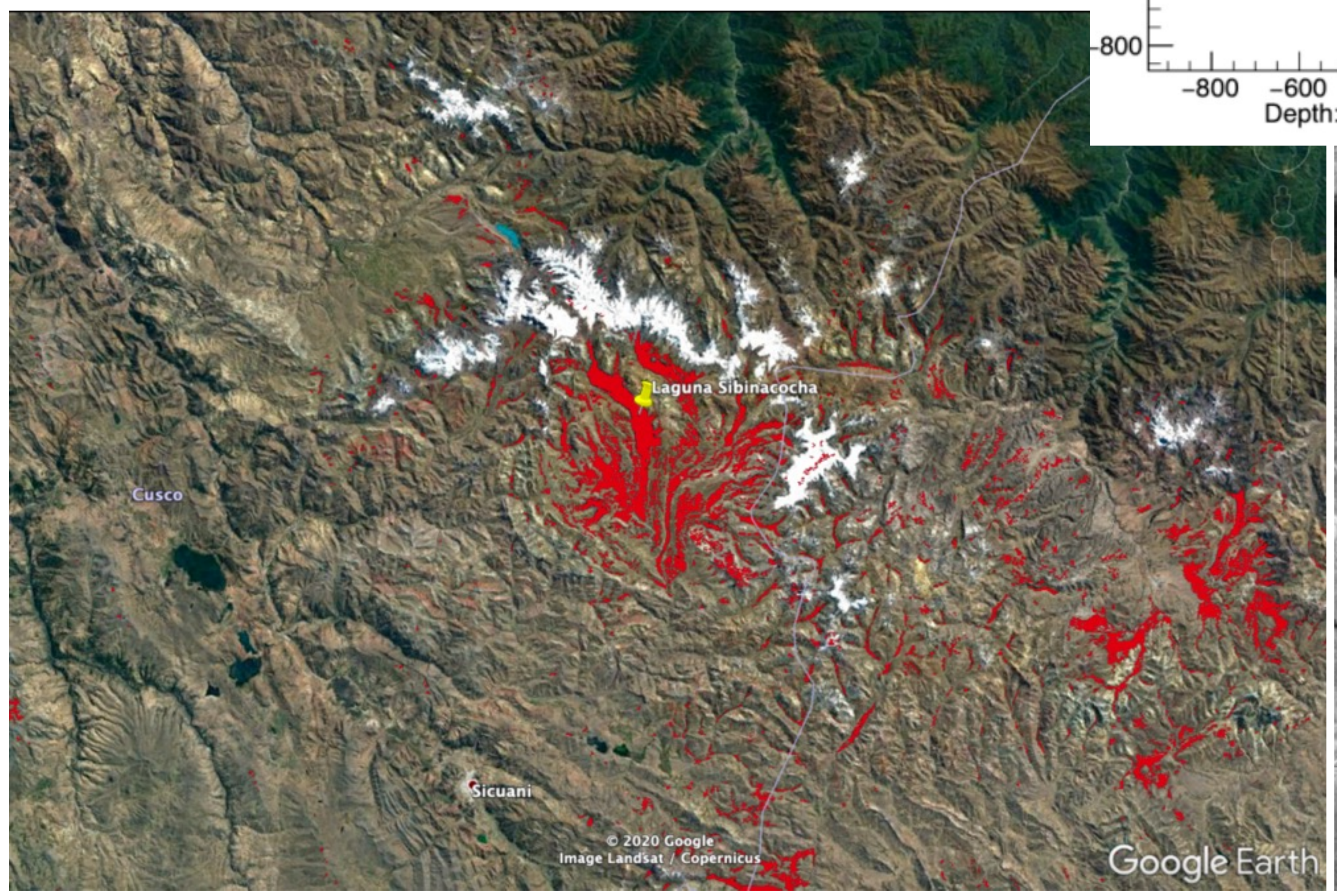

Curvas de nivel
(equedistancia 0.5m)

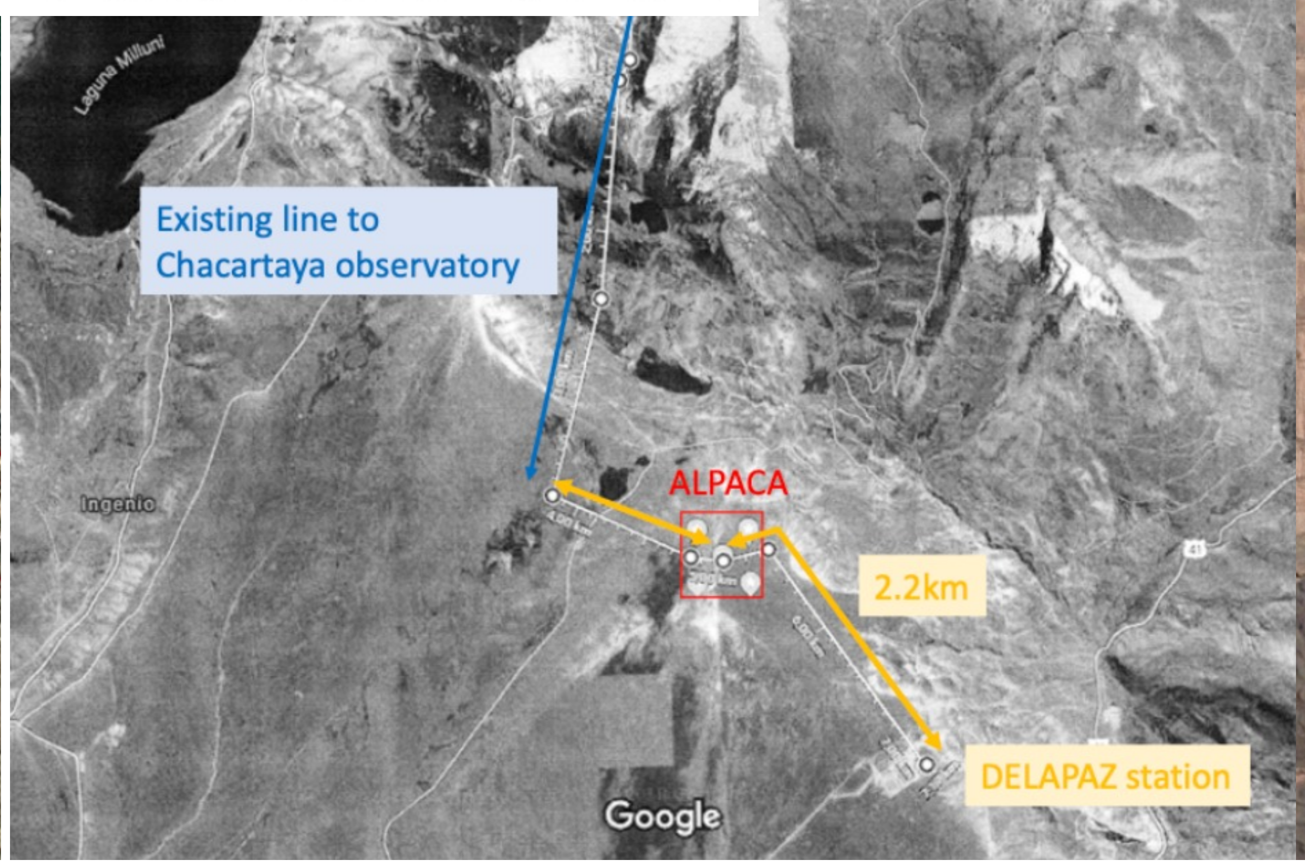

1800
1600
1400
1200
1000
800
600
500
400
300
200
100
50

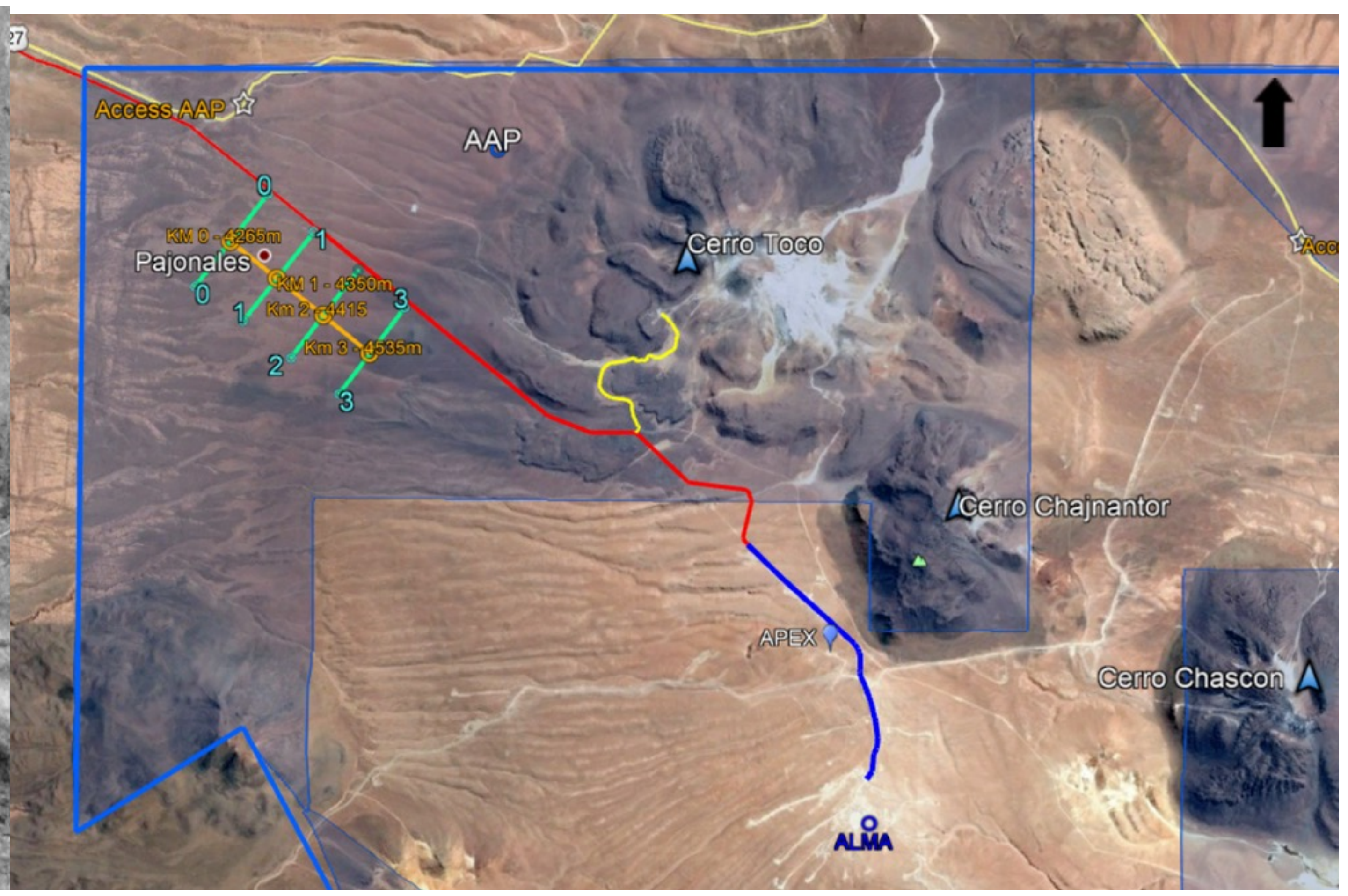

EXPLANATION
Chance of slight (or greater)
damaging earthquake shakir
in 50 years
< 15%
15%-30%
30%-50%
50%-70%
70%-85%
> 85%


SWGO
The Southern Wide-field
Gamma-ray Observatory
Environmental sensors
E field sensor
Electronics
Seismometer


1300 x 800
Depth: Red <6; Orange 6-10; Light blue 10-15, Dark blue > 15


Laguna Sibinacocha
Cusco
Sicuani
Google Earth


Existing line to
Chacartaya observatory
ALPACA
2.2km
DELAPAZ station
Google


Access AAP
AAP
Pajonales
Cerro Toco
Cerro Chajnantor
APEX
Cerro Chascon
ALMA

The northern gamma-ray sky as seen by HAWC

1523 days of data