SnowMass2021

APS | DIVISION OF PARTICLES & FIELDS

DPF Core Principles and Community Guidelines (CP&CG)

- By participating in this meeting, you agree to adhere to the CP&CG
  - **Respect and support community members**
  - **Commit to constructive dialogue and take initiative**
  - Details of what this means, expectations for behavior, and accountability procedures are provided in the CP&CG document linked at: https://snowmass21.org/cpcg/start
- Everyone is invited to invoke the CP&CG as needed to encourage constructive and supportive collaboration
- The conveners of this meeting are your recommended first point of contact for reports of CP&CG violations occurring here
  - The conveners have received training in the CP&CG and how to handle reports
  - The CP&CG accountability procedure is designed to encourage early intervention and is flexible enough to appropriately address issues ranging from the discourteous to the egregious
  - Please do not hesitate to contact us!
- Snowmass is most successful when everyone's voice can be heard!

Recording

Fermilab would like to record this session.

In order to do so they need verbal consent from presenters/panelists that they agree to be recorded.

For the recordings to be put on a public website in the future will also need a written consent form signed.

Do the panelists and organizers agree to be recorded?

Snowmass Community Planning Meeting

Breakout Session #140
Future Medium to Ultra-high-energy Gamma-ray Detectors

Joint Session between

Cosmic Frontier 7: Cosmic Probes of Fundamental Physics (CF7)

and Instrumentation Frontier 2: Photon Detectors (IF2)

Session Co-organizers: **Jim Beatty, Ke Fang, Kirsten Tollefson**

October 6, 13:30-14:30 CT, Zoom Room #14

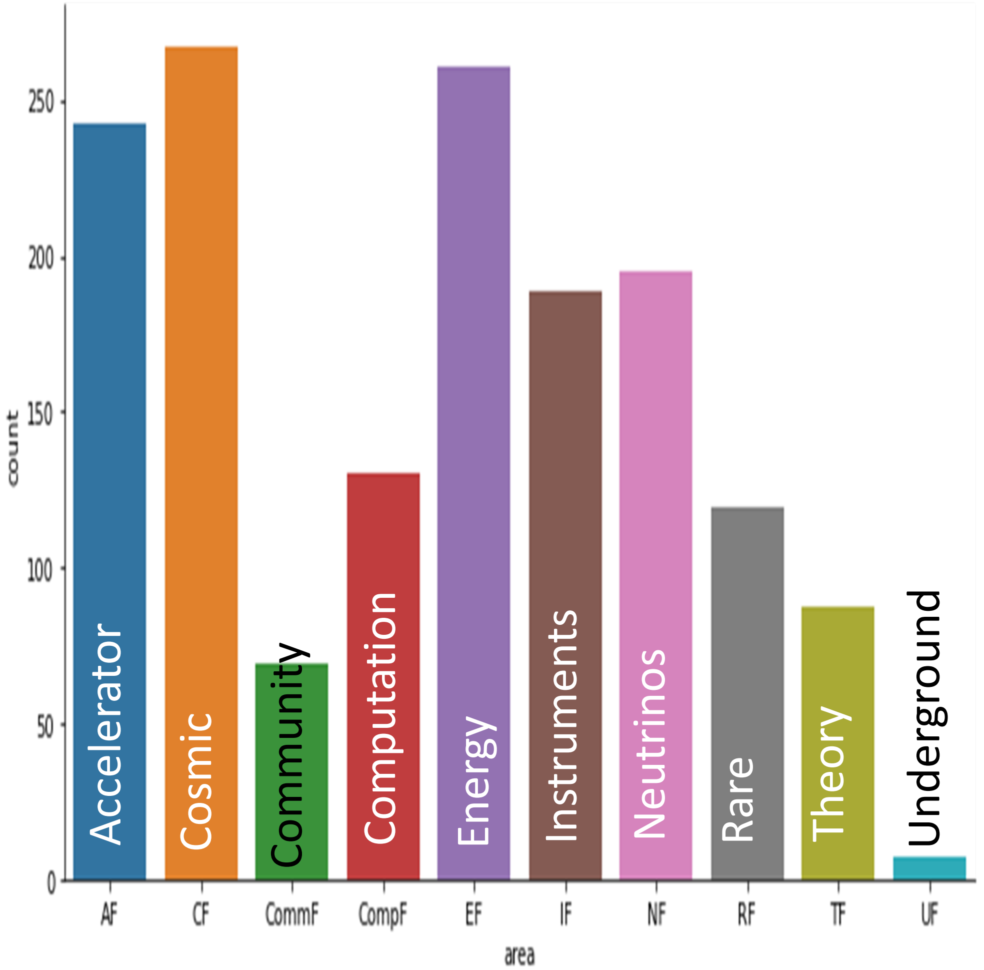
Agenda

- Introduction – 5 min
  - Session Organizers: Jim Beatty, Ke Fang, Kirsten Tollefson
- Panel on MeV to EeV gamma-ray detectors – 25 min
- Discussion – 25 min
- Summarize Plan – 5 min

Letters of Interest (LOIs)

- Total of 1,574 LOIs by August 31, 2020 with Cosmic Frontier >250 and Instrumentation Frontier ~200
- 140 LOIs reference CF7 with 71 listing CF7 as primary

  (32 theory based, rest on experiments/detectors)
- By messenger type:
  - 30 gravitational waves
  - 22 cosmic rays
  - 35 neutrinos
  - **45 photons/gamma rays**



Primary Frontiers

Other Joint Sessions that Overlap with CF7 LOIs (Sponsored by CF7 conveners)

CF7 covers cosmic probes of fundamental physics topics beyond Dark Matter and Dark Energy using gravitational waves, cosmic rays, gamma rays, and neutrinos, as well as their combined studies to facilitate the multi-messenger science. It also covers various tests of ΛCDM using high and low redshift observations and the potential of standard siren cosmology to address existing tensions in the data.

- #003, Tue 11:00-11:30, zoom 03, Cosmic Frontier Introduction
- #072, Tue 11:30-12:30, zoom 14, Dark energy origins, light relics (+ primordial GWs),
- #074, Tue 13:00-14:30, zoom 13, Atomic to Cosmic: Wave Dark Matter and Beyond
- #077, Tue 11:30-12:30, zoom 03, Quantum sensors for wave and particle detectors
- #097, Tue 15:00-16:00, zoom 02, Neutrinos as Probes of SM & BSM Particle Physics
- #127, Tue 14:00-16:00, zoom 01, Searches for dark sectors
- #136, Tue 11:30-12:30, zoom 13, Heavier particle dark matter >10 GeV
- **#139, Tue 12:30-13:00, zoom 14, Testing LCDM cosmology at low- and high-redshifts**
- **#140, Tue 13:30-14:30, zoom 14, Future Medium to UHE Gamma-ray Detectors**
- **#141, Tue 15:30-16:00, zoom 06, Gravitational-wave source modeling**
- **#145, Tue 11:30-12:00, zoom 17, Ultra-dense nuclear matter & QCD phase transitions**
- #075, Wed 13:00-14:30, zoom 03, Cosmic probes of dark matter physics,
- **#137, Wed 13:00-14:00, zoom 14, High and Ultrahigh Energy Neutrino Experiments**
- **#138, Wed 14:00-15:00, zoom 14, Synergy of Astroparticle Physics and Collider Physics**
- **#148, Wed 13:00-14:00, zoom 13, Future gravitational-wave facilities**
- #203, Wed 15:00-16:00, zoom 03, Cosmic Frontier Planning

Report Structure from Snowmass 2013

Frontier Reports

Frontier Summary (20-50 pages)

Topical Group Reports (20-50 pages per TG)

Contributed Papers as References

Executive Summary

(~50 pages) Intro + few pages from each Frontier

Snowmass 2013 Cosmic Frontier Report

https://www.slac.stanford.edu/econf/C1307292/docs/CosmicFrontier.html

Cosmic Frontier

Chapter 4: Cosmic Frontier
Conveners: J. L. Feng and S. Ritz

Working Group Summary (arXiv:1401.6085)

Subgroup Reports:

24.	WIMP Dark Matter Direct Detection	1310.8327
25.	WIMP Dark Matter Indirect Detection	1310.7040
26.	Non-WIMP Dark Matter	1310.8642
27.	Dark Matter Complementarity	1310.8621
28.	Dark Energy and CMB	1309.5386
29.	Cosmic Probes of Fundamental Physics	1310.5662

Contributed Papers:

General:

023	M.W. Cahill-Rowley, *et al.*	pMSSM Benchmark Models for Snowmass 2013	1305.2419 (PDF)
040	Pierre Auger Collaboration	The Next Frontier in UHECR Research with an Upgraded Pierre Auger Observatory	1307.0226 (PDF)
093	L.A. Anchordoqui, *et al.*	Roadmap for Ultra-High Energy Cosmic Ray Physics and Astronomy	1307.5312 (PDF)

Cosmic Probes of Physics:

004	S. R. Klein, *et al.*	Neutrino Absorption in the Earth, Neutrino Cross-Sections, and New Physics	1304.4891 (PDF)
007	VERITAS Collaboration	VERITAS contributions to CF6-A: Cosmic Rays, Gamma Rays and Neutrinos	1304.6764 (PDF)
009	F. Krennrich, *et al.*	The Extragalactic Background Light (EBL): A Probe of Fundamental Physics and a Record of Structure Formation in the Universe	1304.8057 (PDF)
010	A. Weinstein, *et al.*	The impact of astrophysical particle acceleration on searches for beyond-the-Standard-Model physics	1305.0082 (PDF)
011	J. Dumm, *et al.*	Gamma-ray Signatures of Ultra High Energy Cosmic Ray Line-of-sight	1305.0253 (PDF)
015	N. Otte, *et al.*	Tests of Lorentz Invariance Violation with Gamma Rays to probe Quantum Gravity	1305.0264 (PDF)
116	E. G. Adelberger	Torsion-balance probes of fundamental physics	1308.3213 (PDF)
117	F. Halzen, *et al.*	IceCube: Neutrino Physics from GeV - PeV	1308.3171 (PDF)

Preliminary Snowmass Timeline / Process

Starting point for discussion with the community during CPM

Meetings & Workshops (10 Frontiers & 80 Topical Groups) + Contributed Papers

Nov. 2020	Dec. 2020	Jan. 2021	Feb. 2021	Mar. 2021	Apr. 2021	May 2021	Jun. 2021	Jul. 2021	Aug. 2021	Sep. 2021	Oct. 2021

Community Meeting (APS April Meeting)

Community Summer Study (CSS) July 11-20, 2021 + DPF 2021 (UW Seattle)

Snowmass Report

TGs: effort on consolidation, coordination & solicitation, leading to studies & Contributed Papers

TGs develop their key questions and opportunities

TGs produce outlines of their reports

(TGs: communication with authors of Contributed Papers)

Frontiers/TGs produce Preliminary Frontier Reports
Community feedback on Preliminary Frontier Reports

CSS

Build consensus on key questions / opportunities of particle physics, enabling technologies, and community engagement;
Formulate the content of the Snowmass Executive Summary

Frontiers/TGs produce Final Frontier Reports
Steering Group produces Preliminary Executive Summary
Community feedback on Prelim. Exec. Summary
Snowmass Draft Report and Review
Snowmass Final Report

Goal for Today:
Start discussion on how to bring LOIs together into contributed "white" papers

Slide from YKK's talk on Oct. 5

Questions for Discussion

- Are there gamma-ray detectors that we missed?
- Focus on science capabilities and synergies, complementarities between experiments
  - What science advances can be driven by future observation of MeV, TeV and EeV photons?
  - Timeline for the different experiments, possibilities for multi-messenger and multi-wavelength observations
    - Want to make a matrix of experiments and science opportunities as a function of frequency band/messenger type
- How best to organize ourselves over the next 2-3 months so the community can start working on their contributed ”white” papers?

The Panel

Each panelist will have 5 minutes:

- Medium-energy gamma-ray detectors
  - AMEGO – Carolyn Kierans
  - Liquid Argon Time Projection Chamber – Tom Shutt
- High-energy to Very-high-energy gamma-ray detectors
  - CTA – Jamie Holder
  - SWGO – Andrea Albert
- Ultra-high-energy photon detectors
  - Auger – Marcus Niechciol

AMEGO

All-sky Medium Energy Gamma-ray Observatory

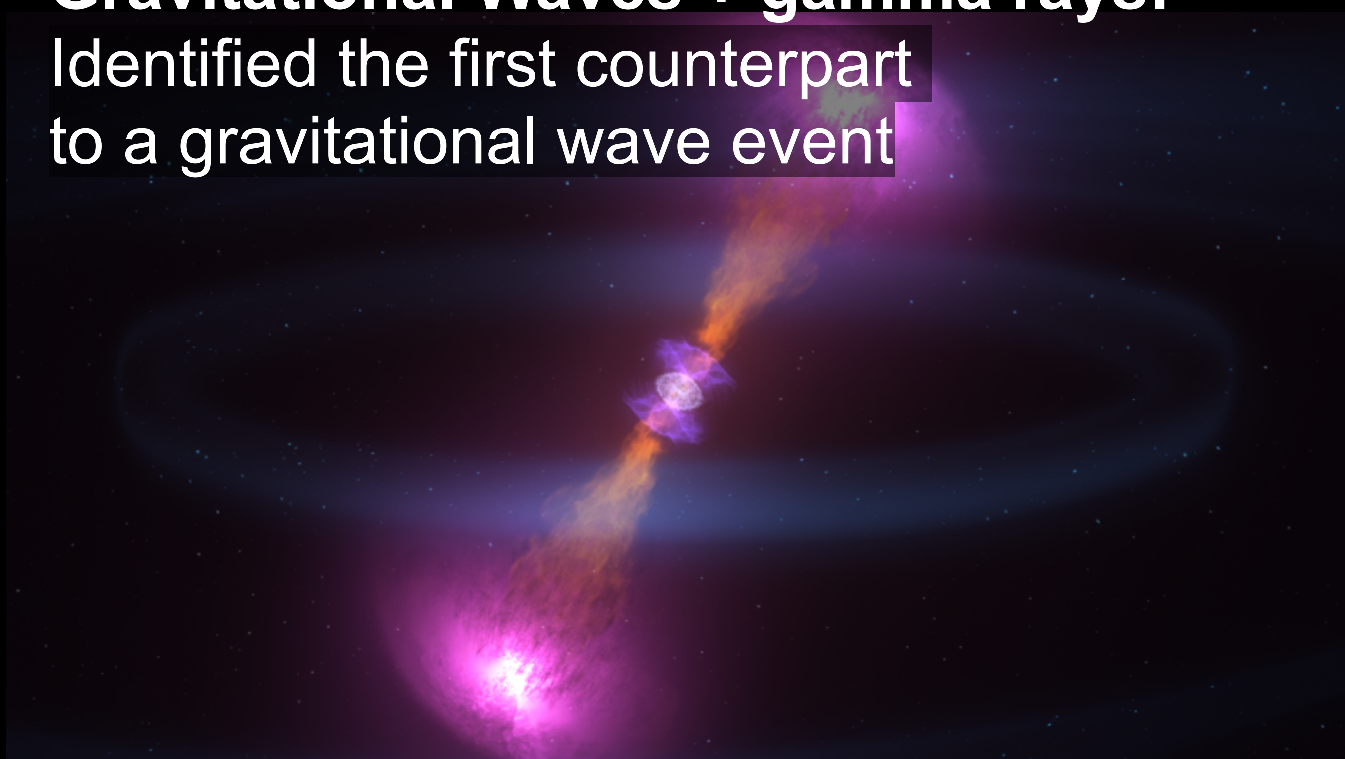
Carolyn Kierans[a] on behalf of the AMEGO Team[b]
[a]NASA/GSFC, [b]https://asd.gsfc.nasa.gov/amego/

Snowmass 2021 Community Planning Meeting, Session #140
October 6th, 2020

AMEGO is a Multimessenger Observatory

Gamma-ray observations played the critical discovery role in *all* major multimessenger discoveries in the past half decade

Gravitational Waves + gamma rays:
Identified the first counterpart to a gravitational wave event



Measuring fundamental parameters of spacetime

High energy neutrinos + gamma rays:
Identified the first source of high energy neutrinos outside the galaxy

Discovering one of the most extreme accelerators in the universe

From stellar mass to supermassive black holes: multimessenger sources are gamma-ray sources

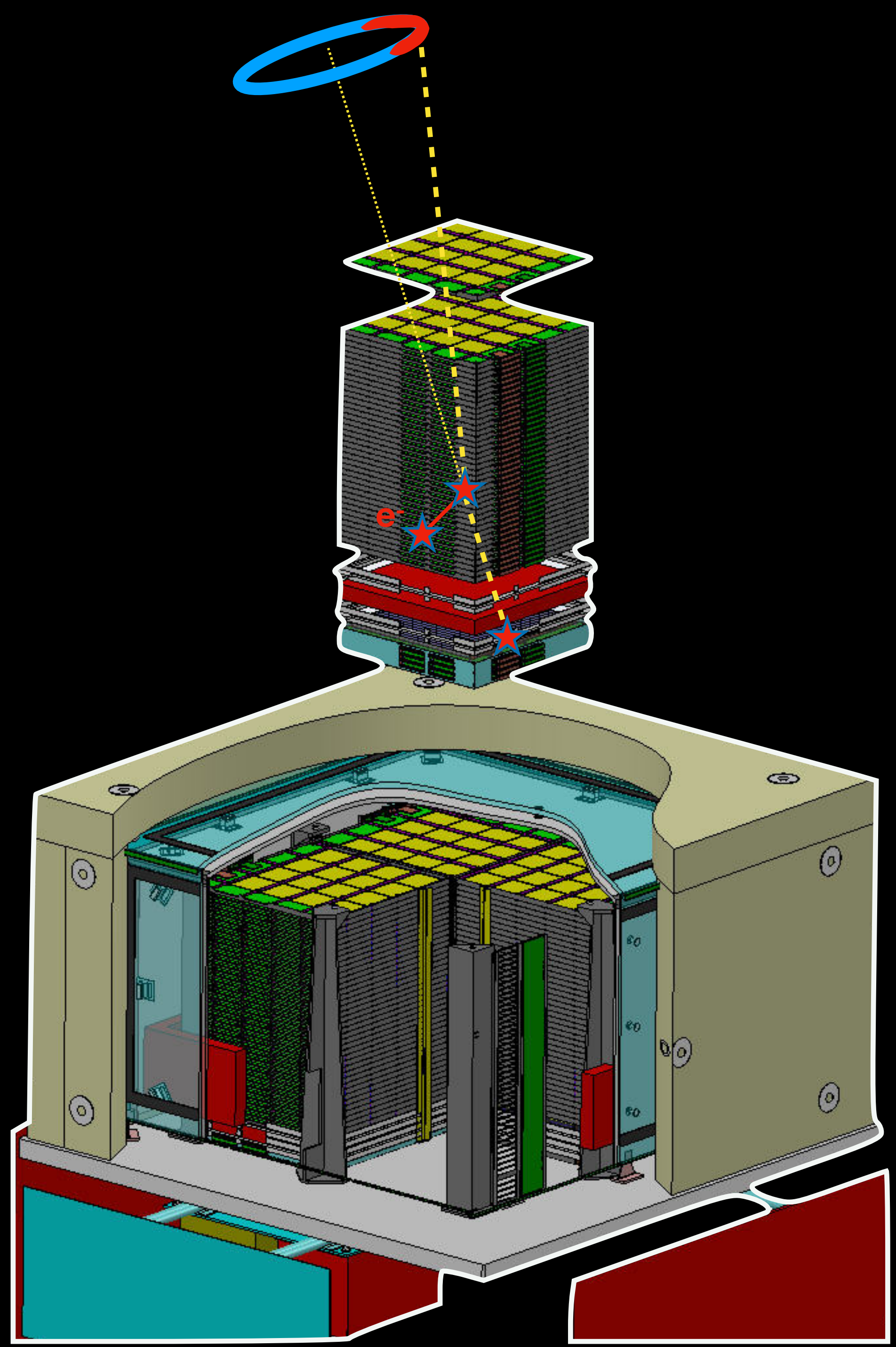
CF LOIs: 046, 121, 122, 143, 151, 176, 182, 214

J. McEnery et al. Astro2020

AMEGO – Instrument Design

IF LOIs: 100, 115, 127, 154, 170

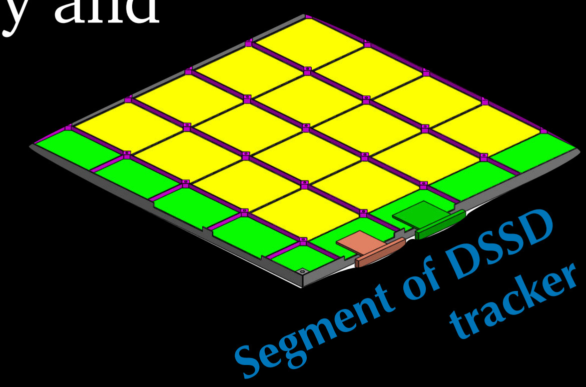
Compton telescope ≲10 MeV



Tracker

Incoming photon undergoes pair production or Compton scattering. Measure energy and track of electrons and positrons

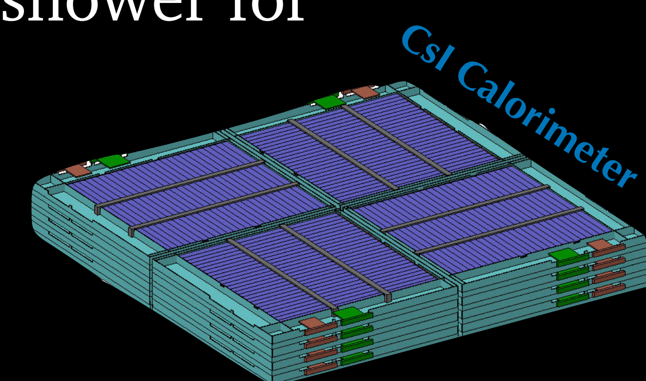
- 60 layer DSSD, spaced 1 cm
- Strip pitch 0.5mm



CZT Calorimeter

Measures location and energy of Compton scattered photons, and head of the shower for pair events

- Array of 0.6 x 0.6 x 3 cm position sensitive CdZnTe bars



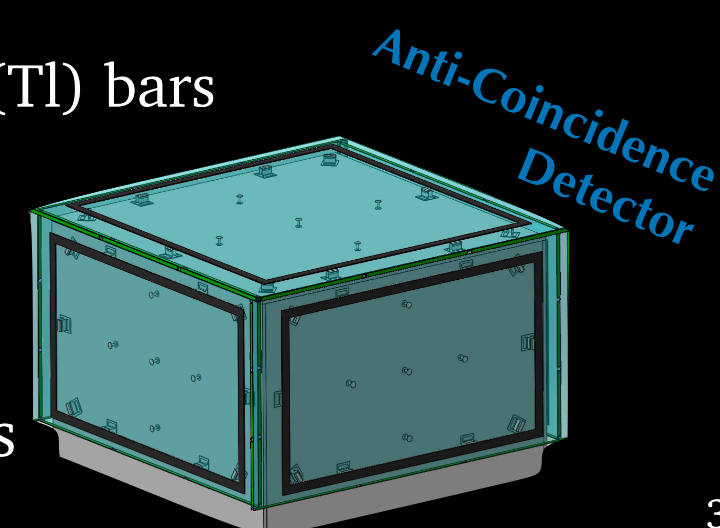
CsI Calorimeter

Extends upper energy range

- 6 planes of 1.5cm x 1.5 cm CsI(Tl) bars

Anti-Coincidence Detector

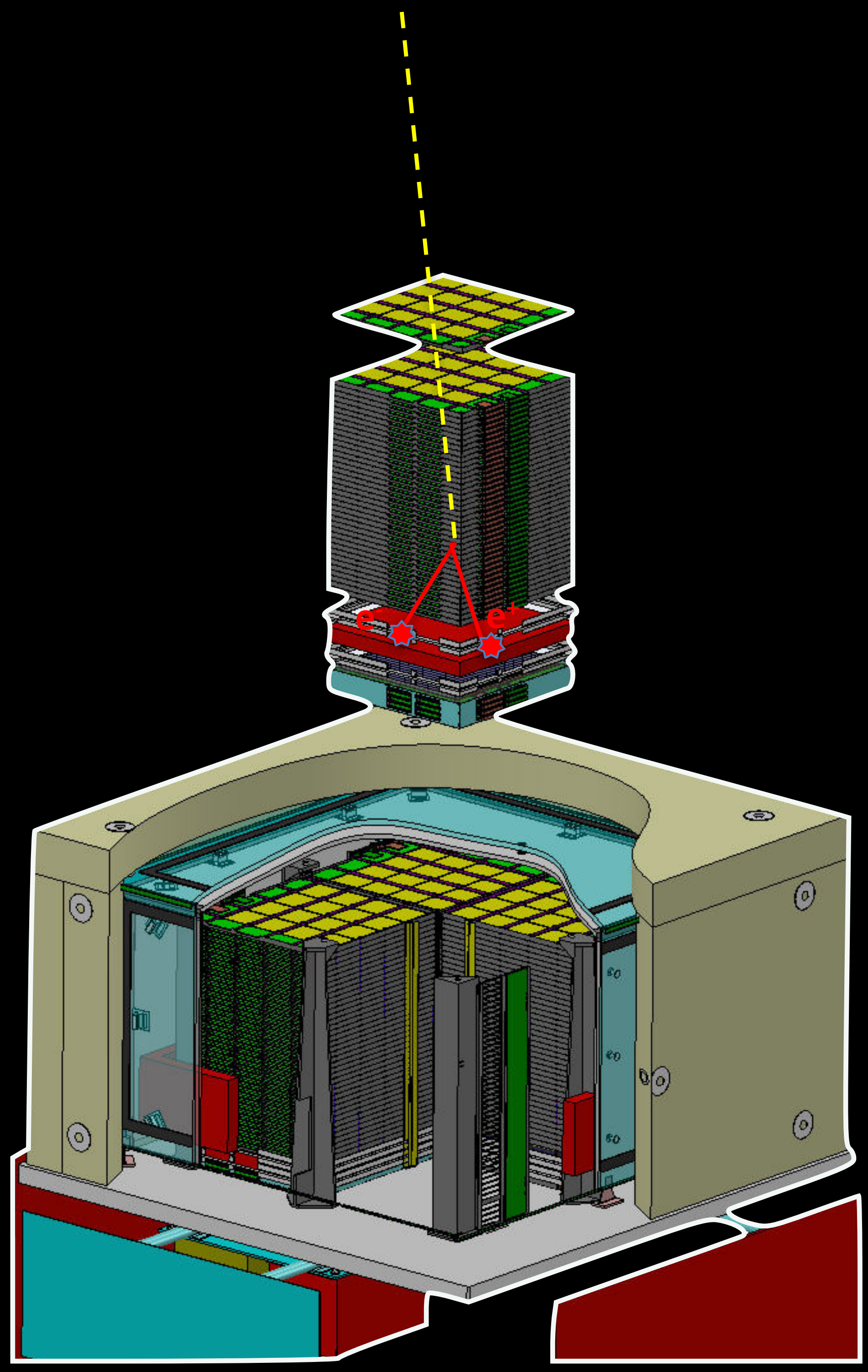
Plastic scintillator with SiPM readout vetos cosmic ray events



AMEGO – Instrument Design

IF LOIs: 100, 115, 127, 154, 170

Pair telescope ≳10 MeV



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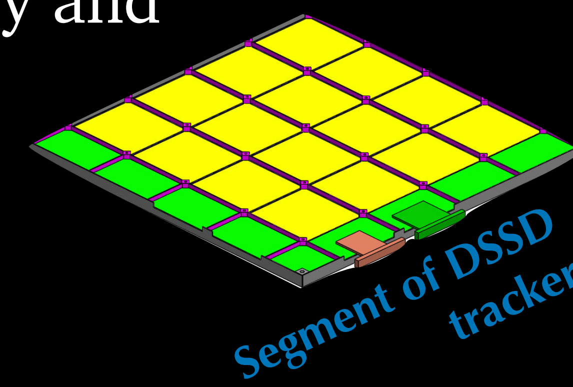

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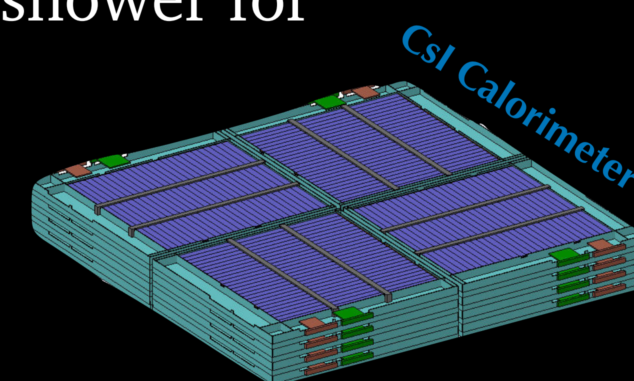

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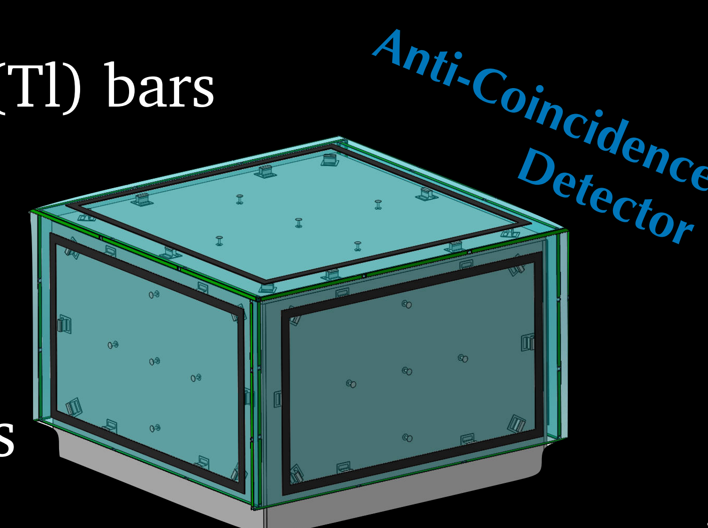


GammaTPC: a new liquid argon time projection chamber based MeV gamma ray instrument

T. Shutt, SLAC

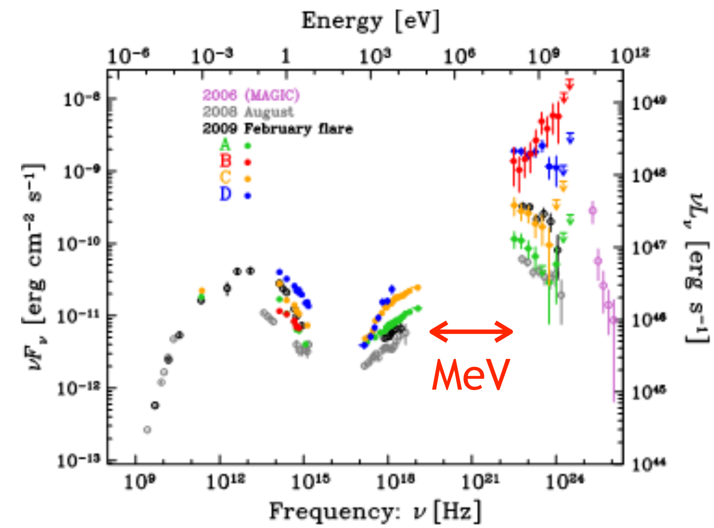
Snowmass CPM, CF7 breakout

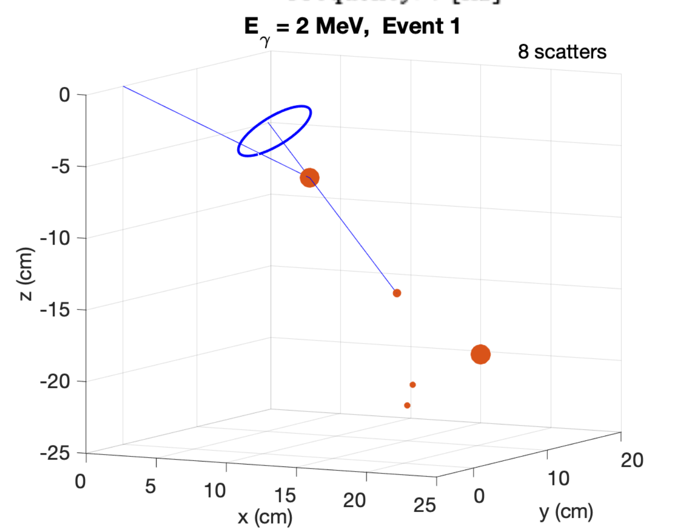
10/6/2020

D.S. Akerib, S. Breur, M. Buuck, A. Dragone, S.W. Digel, G. Haller, O.A. Hitchcock, R. Linehan, S. Luitz, G.M. Madejski, M.E. Monzani, G. Petrillo, M.J. Pivovaroff, T. Shutt, H.A. Tanaka, L. Tompkins, B. Trbalic, and Y.-T. Tsai

Why a liquid Ar TPC Compton Camera?

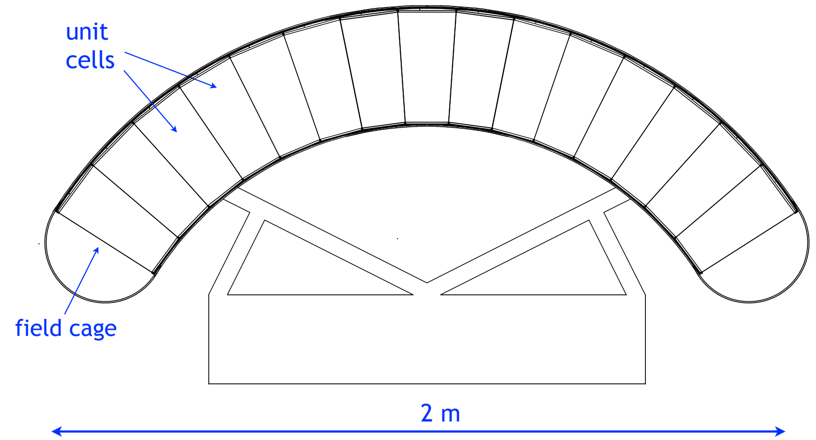
- Exciting, largely unexplored energy window with significant discovery potential.
- Large area instrument excellent for multi-messenger
- Challenge: fine grained read out of large mass
- Time Projection Chamber (TPC)
  - Uniform active volume: *High fidelity event reconstruction, background rejection*
  - 3D readout with 2D instrumentation: large mass with modest power and channel count
- Liquid Ar - optimal target

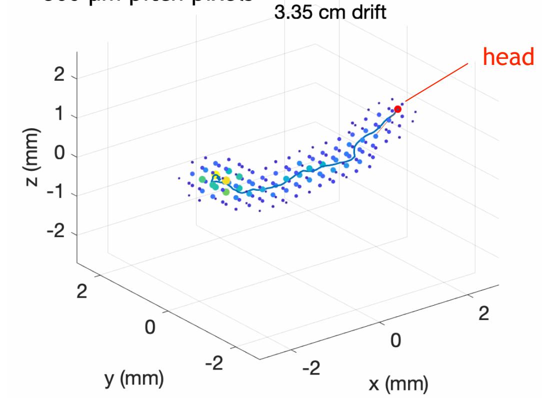


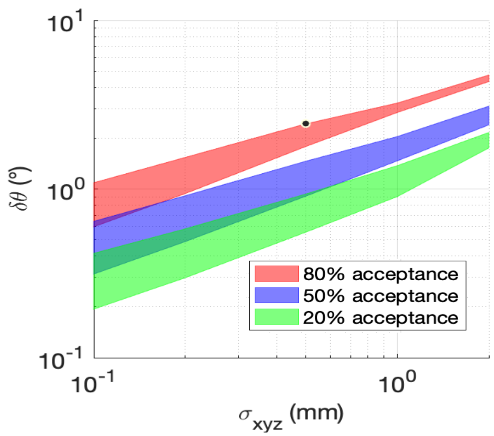


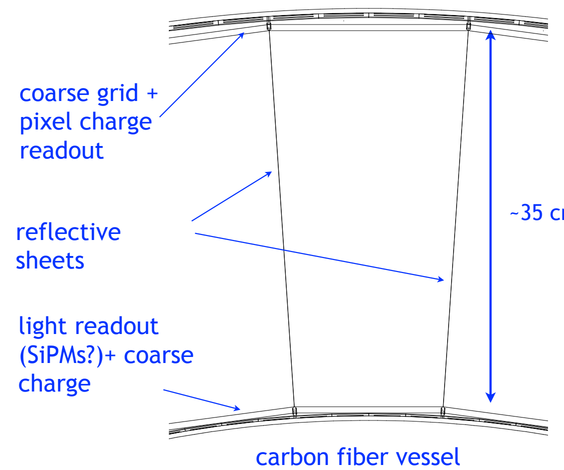
GammaTPC

- Design very much in progress
- Multi-level trigger
  - Handle high rate with ~200 μs drift
  - Reduce power: grids turn on after light signal
- Pixel readout
  - Coarse grid trigger allows true pixel readout
  - Requires development of new true power-off state









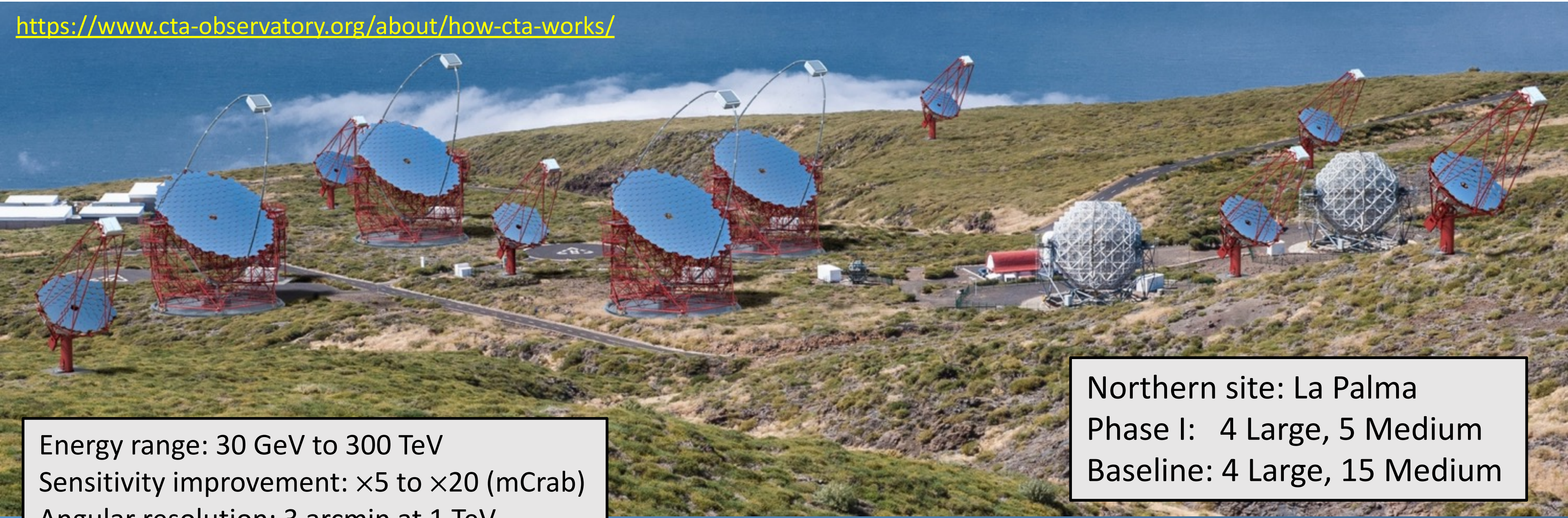
Prospects

- Initial studies look promising
  - Pointing on degree scale or better, depending on E
  - Energy resolution ~2% fwhm $\Delta E/E$ at 1 MeV
  - Effective area / actual area appears high
- Significant issues to be address, including:
  - Pixel readout, extreme low power electronics
  - Liquid noble handling in space
- Leverages 20+ years liquid noble development for DM and ν
- Appears worth pursuing as successor to mature Si technology

CTA Slides for Snowmass session 140

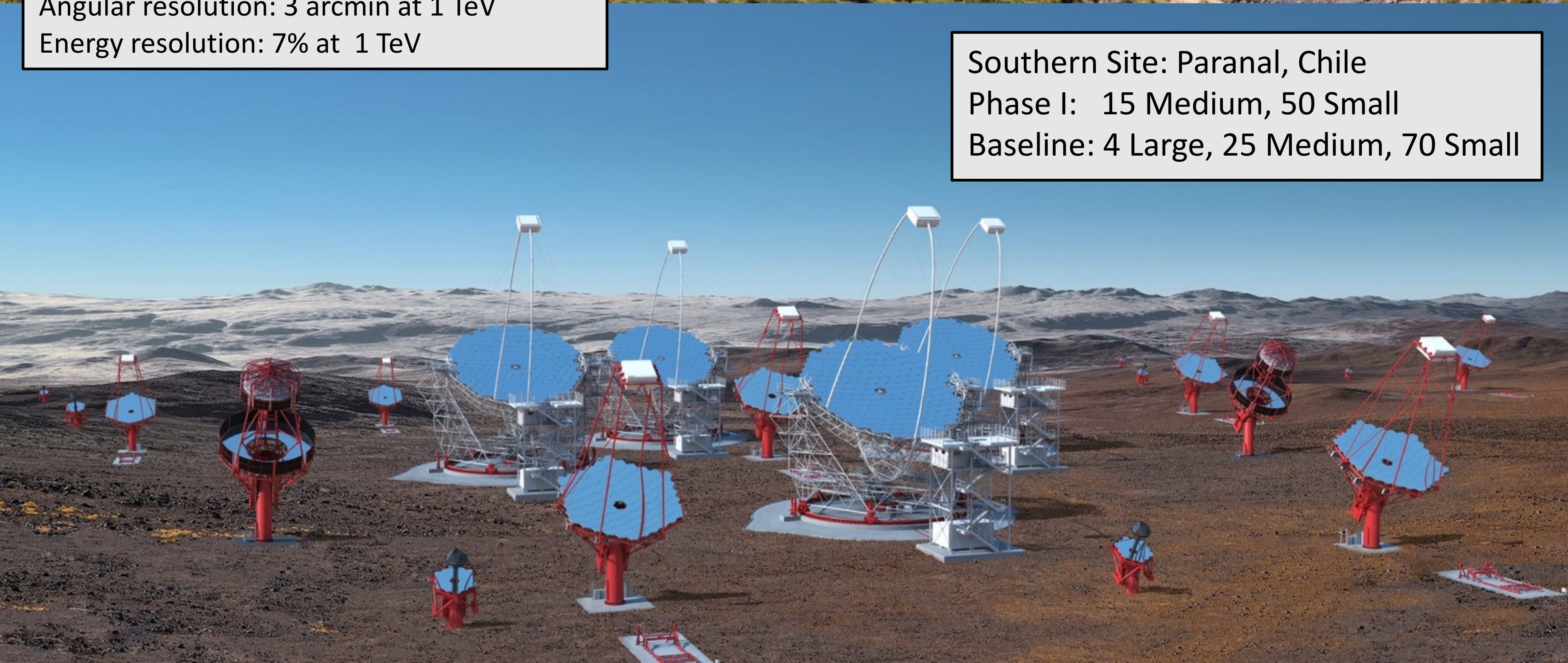
Jamie Holder, for the CTA Consortium

https://www.cta-observatory.org/about/how-cta-works/



Northern site: La Palma
Phase I: 4 Large, 5 Medium
Baseline: 4 Large, 15 Medium

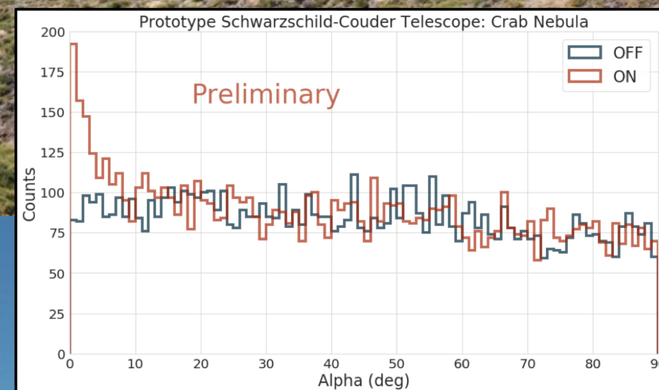
Energy range: 30 GeV to 300 TeV
Sensitivity improvement: ×5 to ×20 (mCrab)
Angular resolution: 3 arcmin at 1 TeV
Energy resolution: 7% at 1 TeV

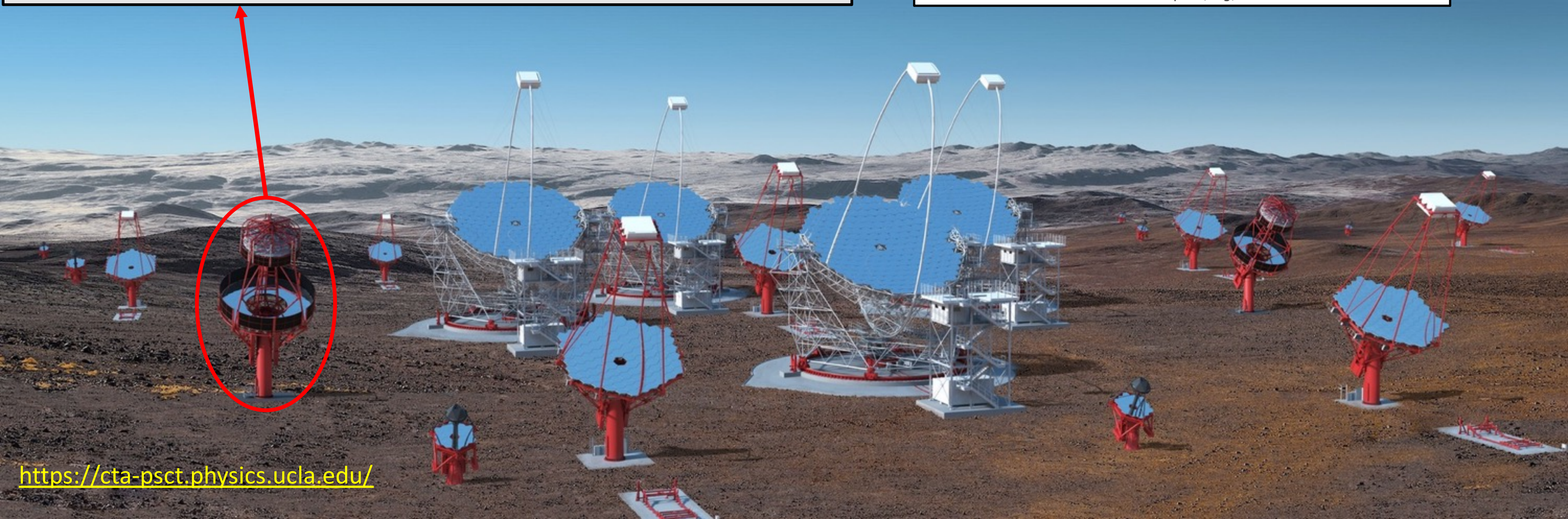


Southern Site: Paranal, Chile
Phase I: 15 Medium, 50 Small
Baseline: 4 Large, 25 Medium, 70 Small

U.S. group’s planned contribution:

- ≥10 Medium-sized Schwarzschild-Couder telescopes.
- Ground-breaking new design.
- Prototype in operation at VERITAS site.
- First source detection recently announced.





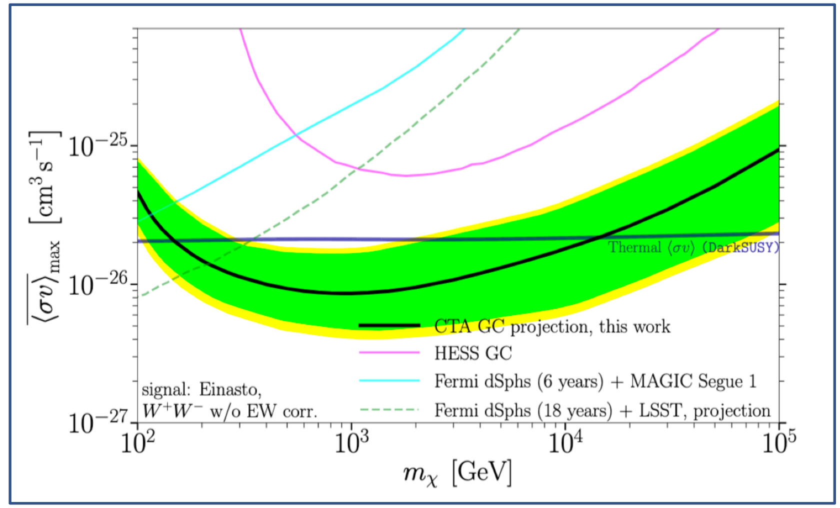
https://cta-psct.physics.ucla.edu/

CTA Key Science

- Galactic Centre Survey
- LMC Survey
- Galaxy Clusters

→

- Dark Matter studies



- Extragalactic Survey
- Active Galactic Nuclei

→

- Axion-Like Particles
- Lorentz Invariance Violation
- Extragalactic background light
- Intergalactic B-fields

- Galactic Plane Survey
- Transients
- PeVatrons
- Star Forming Systems
- Capabilities beyond gamma-rays

- Electron/positron spectrum
- Multimessenger science
- Synergy with aLIGO, IceCube Gen2, Rubin Observatory, Fermi Space Telescope, AMEGO, SWGO, Auger, etc…

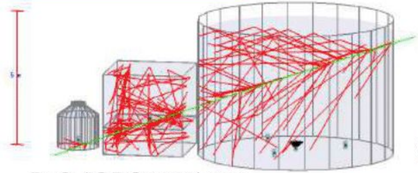
https://arxiv.org/abs/1709.07997

SWGO
The Southern Wide-field Gamma-ray Observatory

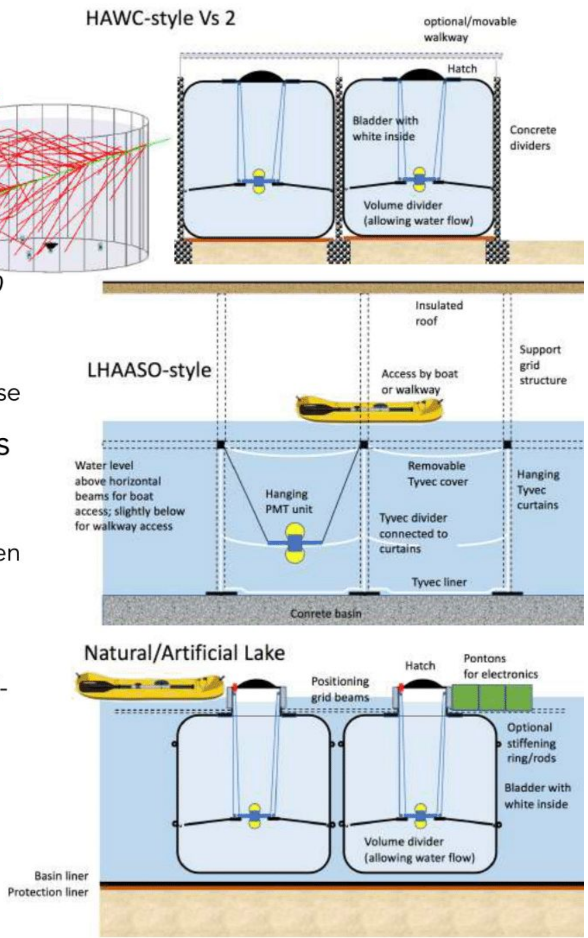
The SWGO Concept

Detector units

Multiple detector options to be investigated


PoS (ICRC2019) 720

- Core unit is a water-Cherenkov Detector
  - Options being investigated based on tanks (HAWC-like), ponds (Milagro-like) and lake-base
- Simulations currently ongoing to constrain all aspects of the detectors
- Design strongly dependent on site choice
  - Water access, construction costs, infrastructure feasibility, compatibility with scientific driven main design goals…
- Strong muon detection capability
  - Large potential for gamma/hadron separation above 1 TeV and consequently background-free conditions driving high sensitivity at the highest 100+ TeV range,
- Muon-tagging in all units?
  - Double layer WCD unities
  - Time-intensity tagging of single through-going particles



Slide from U. Barres Centro Brasileiro de Pesquisas Físicas | CBPF (2020)

The SWGO Concept

Detector units

	IACT Arrays	Ground-particle Arrays
Field of view	3°–10°	90°
Duty cycle	10%–30%	>95%
Energy range	30 GeV – >100 TeV	~500 GeV – >100 TeV
Angular resolution	0.05°–0.02°	0.4°–0.1°
Energy resolution	~7%	60%–20%
Background rejection	>95%	90%–99.8%

Science Case White Paper arXiv:1902.08429

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- S ... equently background-free conditions driving high sensitivity at the highest 100+ TeV range,
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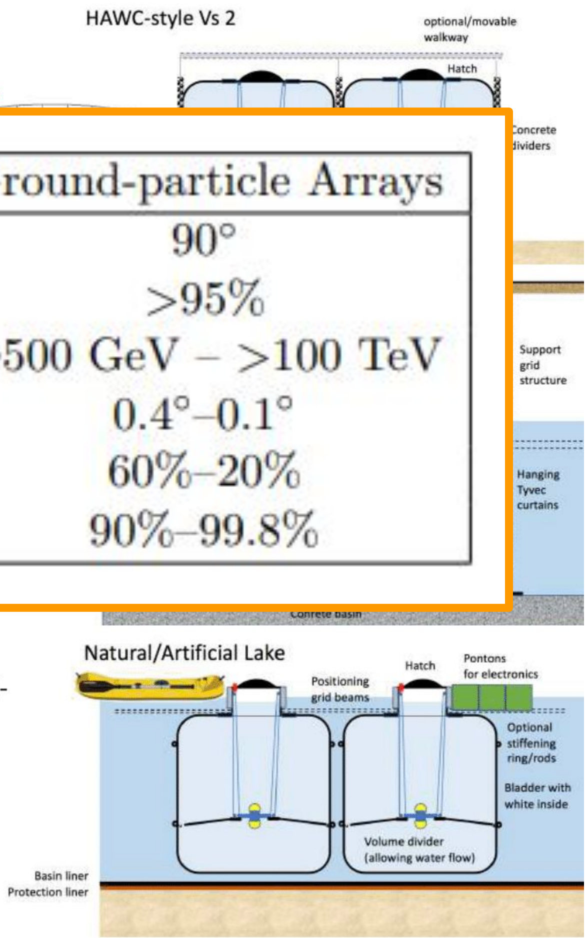


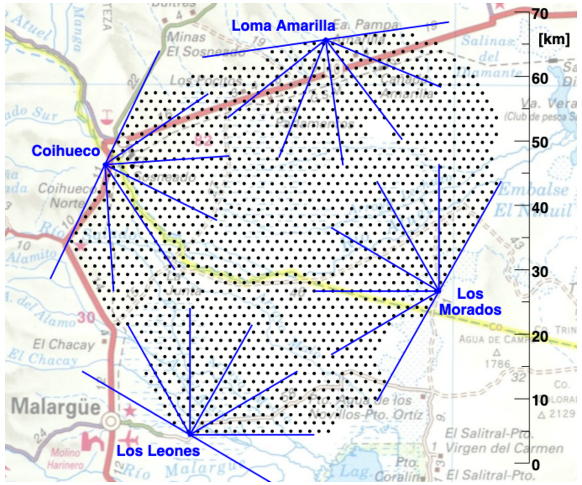
Slide from U. Barres Centro Brasileiro de Pesquisas Físicas | CBPF (2020)

The Core Science Case

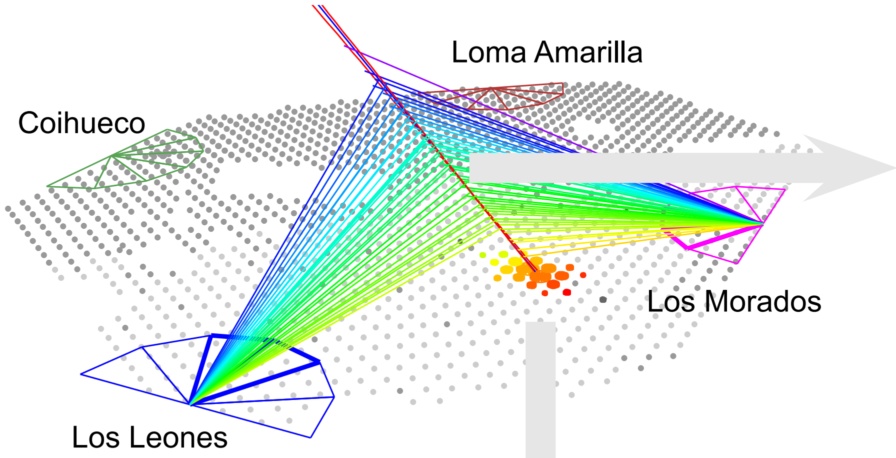
- Detection of short-timescale phenomena
  - Low-energy threshold for detection of short-timescale (< 1hr) transient events down to 100 GeV
- Search for PeVatrons
  - Improved sensitivity up to a few 100s TeV to search for PeV Galactic particle accelerators.
- PWNe and Gamma-ray Halos
  - Unique potential for accessing the high-energy end of the Galactic Population.
- Dark Matter and Diffuse Emission
  - Unique access to the Galactic Center and Halo at the high-energy end of the spectrum.
- Cosmic-rays
  - Unique complement to LHAASO for anisotropy studies, with capability to reach low-angular scale.
  - Good muon tagging implies good mass resolution for composition studies up to the knee.

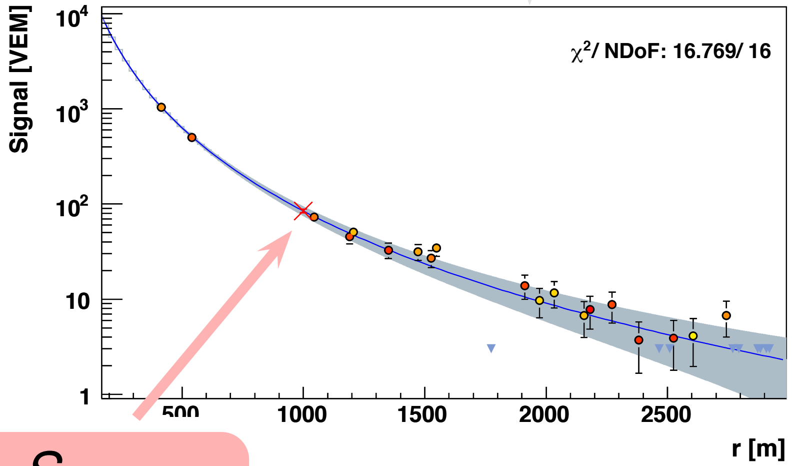
Slide from U. Barres Centro Brasileiro de Pesquisas Físicas | CBPF (2020)

The Pierre Auger Observatory



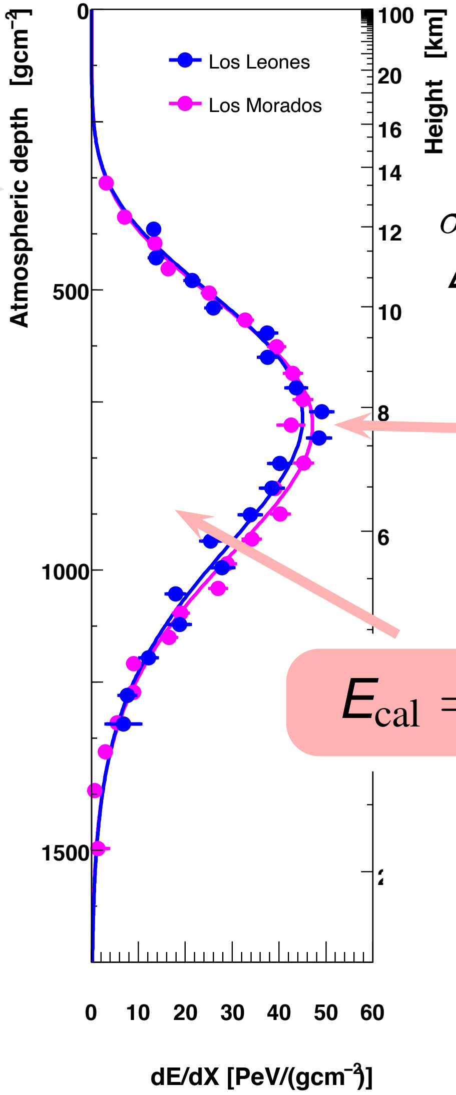
- 1660 water Cherenkov detector stations, spread out over 3000 km^2 (Surface Detector, **SD**)
- 27 fluorescence telescopes (Fluorescence Detector, **FD**)
- Taking data since 2004, currently undergoing a major detector upgrade (**AugerPrime**)
  - Plastic scintillators on top of each SD station
  - Radio upgrade
  - Main goal: enhance **composition sensitivity**





S_{1000}

$E_\text{surface} = f(S_{1000},\, \theta)$



X_max

$\sigma_{X_\text{max}} \leq 20\,\text{g/cm}^2$
$\Delta_\text{sys} \leq 10\,\text{g/cm}^2$

$E_\text{cal} = \int \frac{\mathrm{d}E}{\mathrm{d}X}\,\mathrm{d}X$

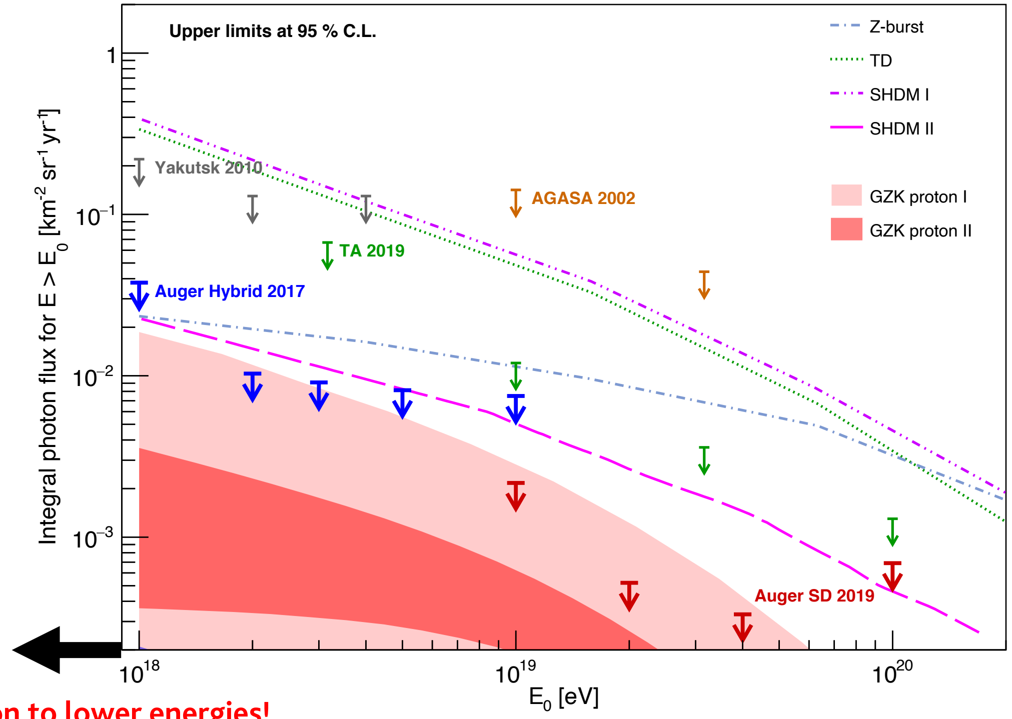
$\sigma_E/E \sim 8\,\%$
$\Delta_\text{sys} \approx 15\,\%$

Ultra-high-energy (UHE) photons at Auger: (some) scientific goals

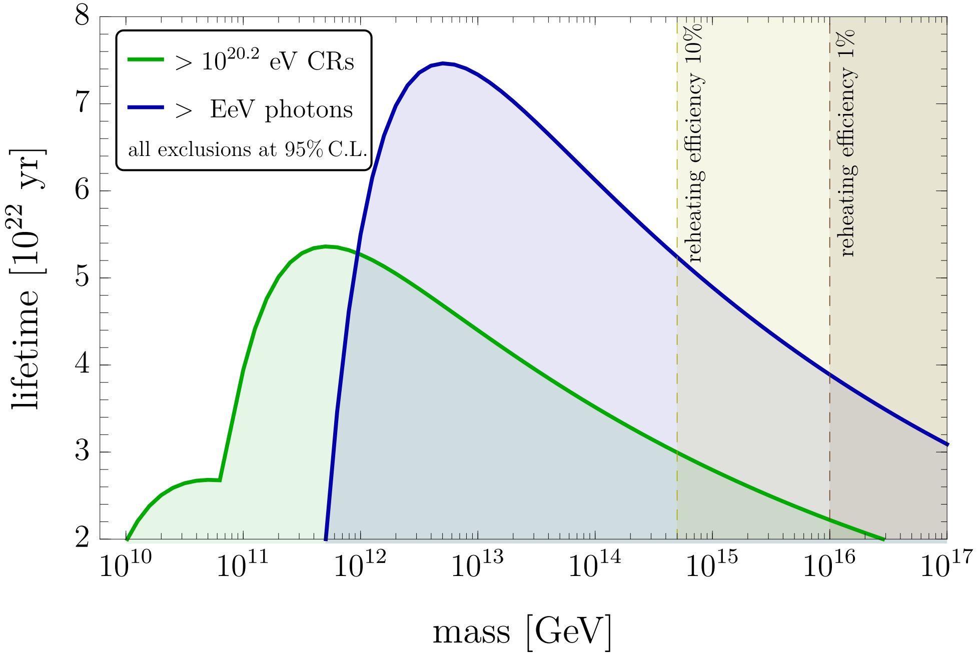
- Pose constraints on the **origin of UHE cosmic rays** and the **properties of their sources** in conventional *bottom-up* models: expected flux of **cosmogenic (GZK) photons** depends on e.g. primary composition and source properties

- Constrain **exotic *top-down* models** for the origin of UHECRs: **Super-heavy dark matter (SHDM)** provides a link between cosmology and astroparticle physics, relating the expected flux of UHE photons to the lifetime-and-mass parameter space of SHDM particles

- Test ***new-physics* scenarios**, e.g. Lorentz invariance violation



Extension to lower energies!



Auger Letters of Interest related to UHE photons:
SNOWMASS21-CF7_CF3-NF4_NF0_Jaime_Alvarez-Muniz-140
SNOWMASS21-CF1_CF7-203

Questions for Discussion

- Are there gamma-ray detectors that we missed?
- Focus on science capabilities and synergies, complementarities between experiments
  - What science advances can be driven by future observation of MeV, TeV and EeV photons?
  - Timeline for the different experiments, possibilities for multi-messenger and multi-wavelength observations
    - Want to make a matrix of experiments and science opportunities as a function of frequency band/messenger type
- How best to organize ourselves over the next 2-3 months so the community can start working on their contributed ”white” papers?