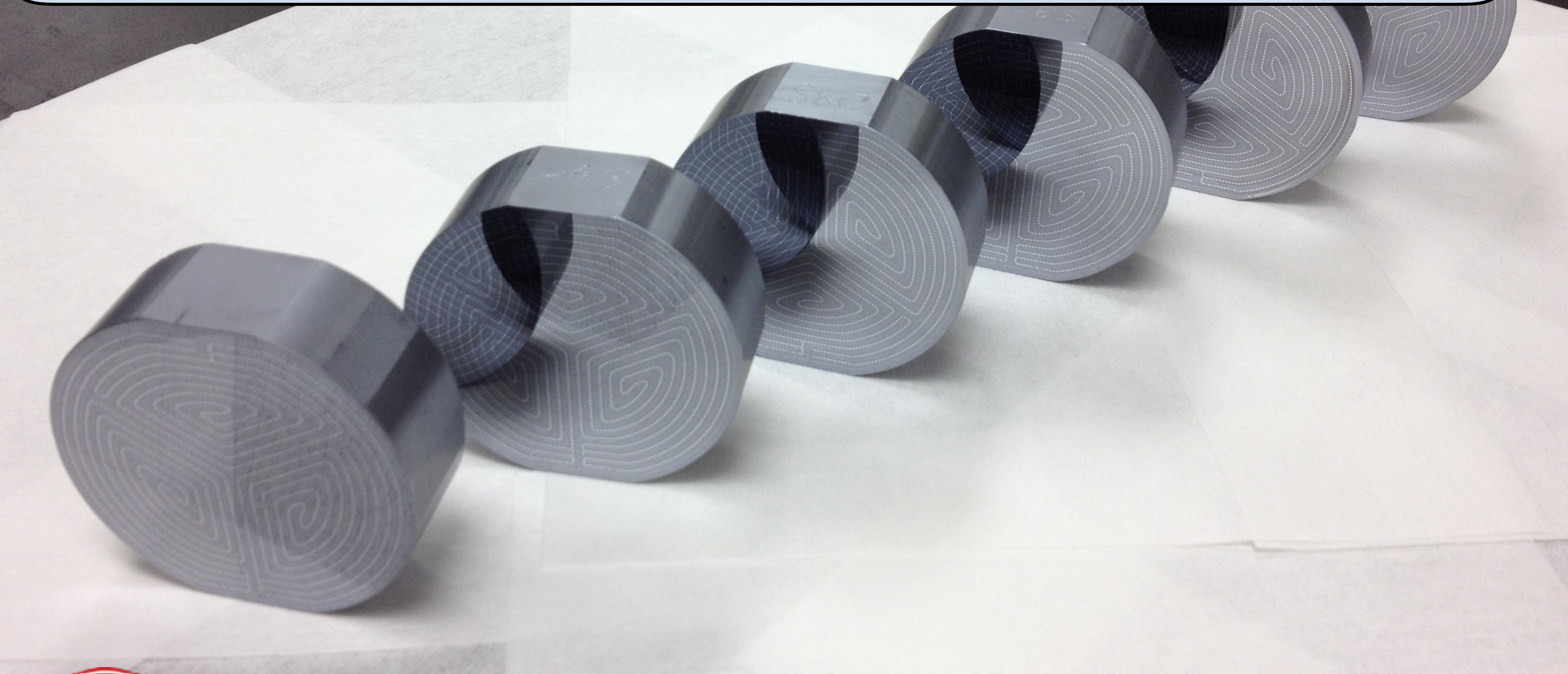
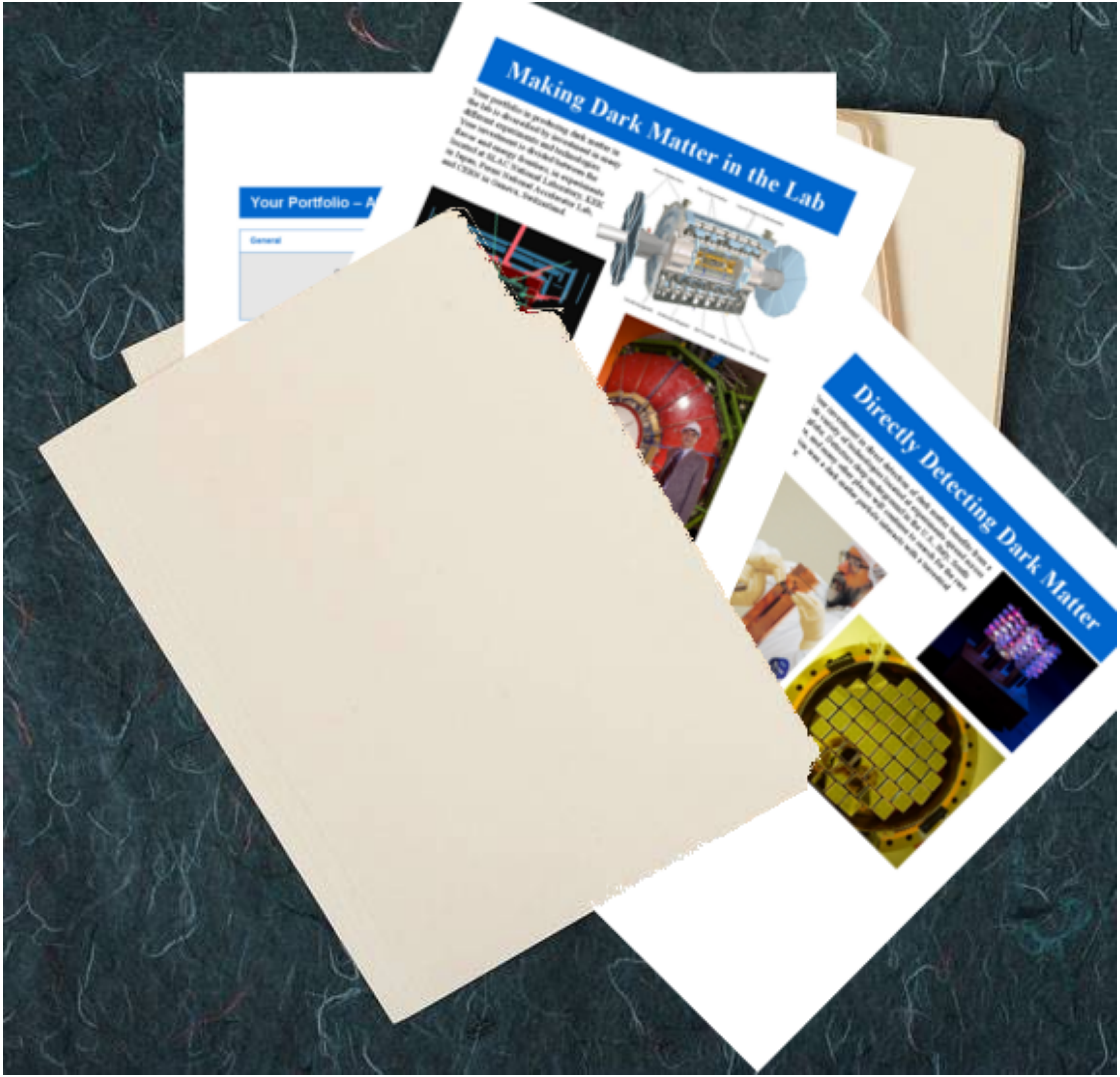
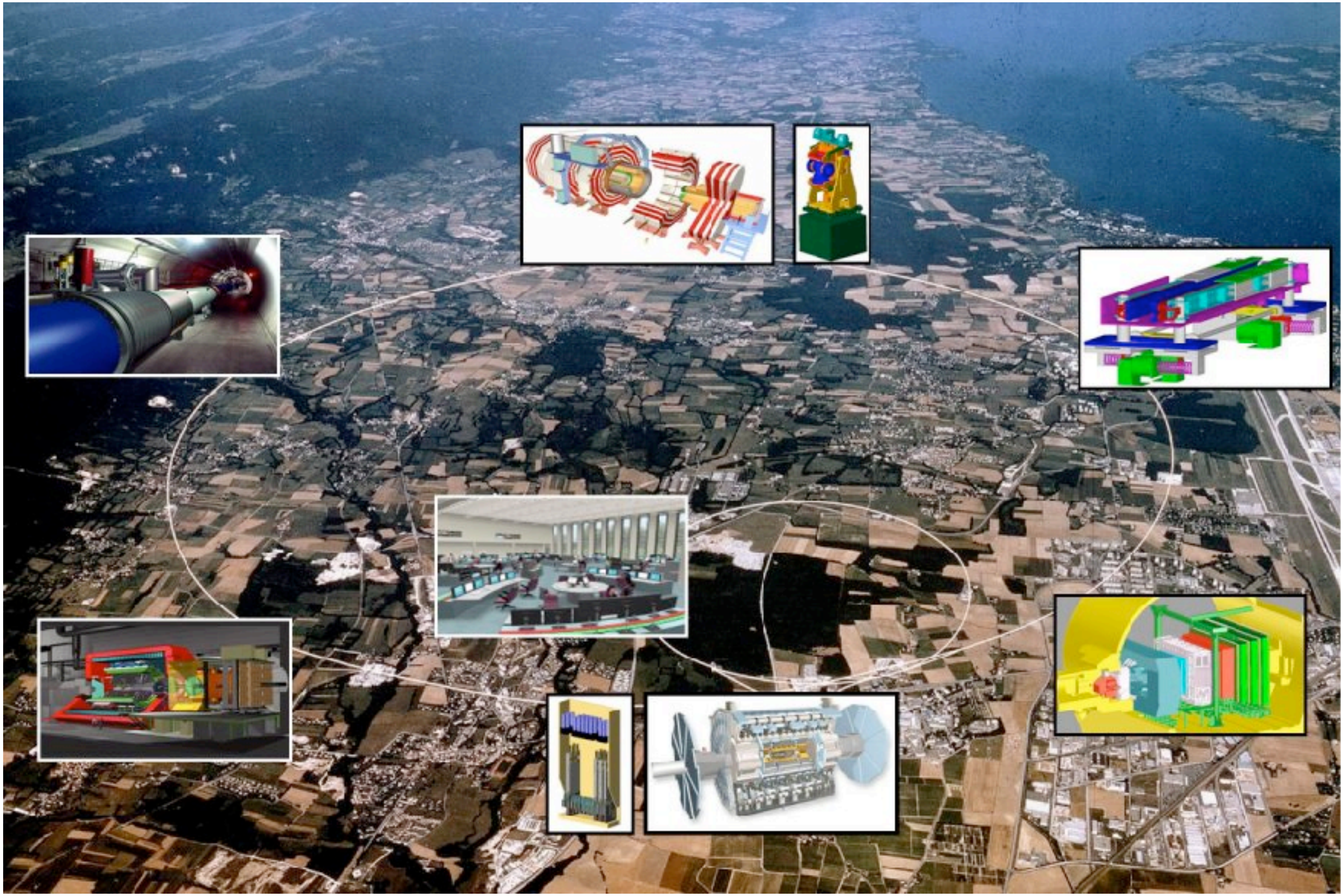
Detecting Weakly Interacting Massive Particle (WIMP) Dark Matter



Jodi Cooley
Southern Methodist University

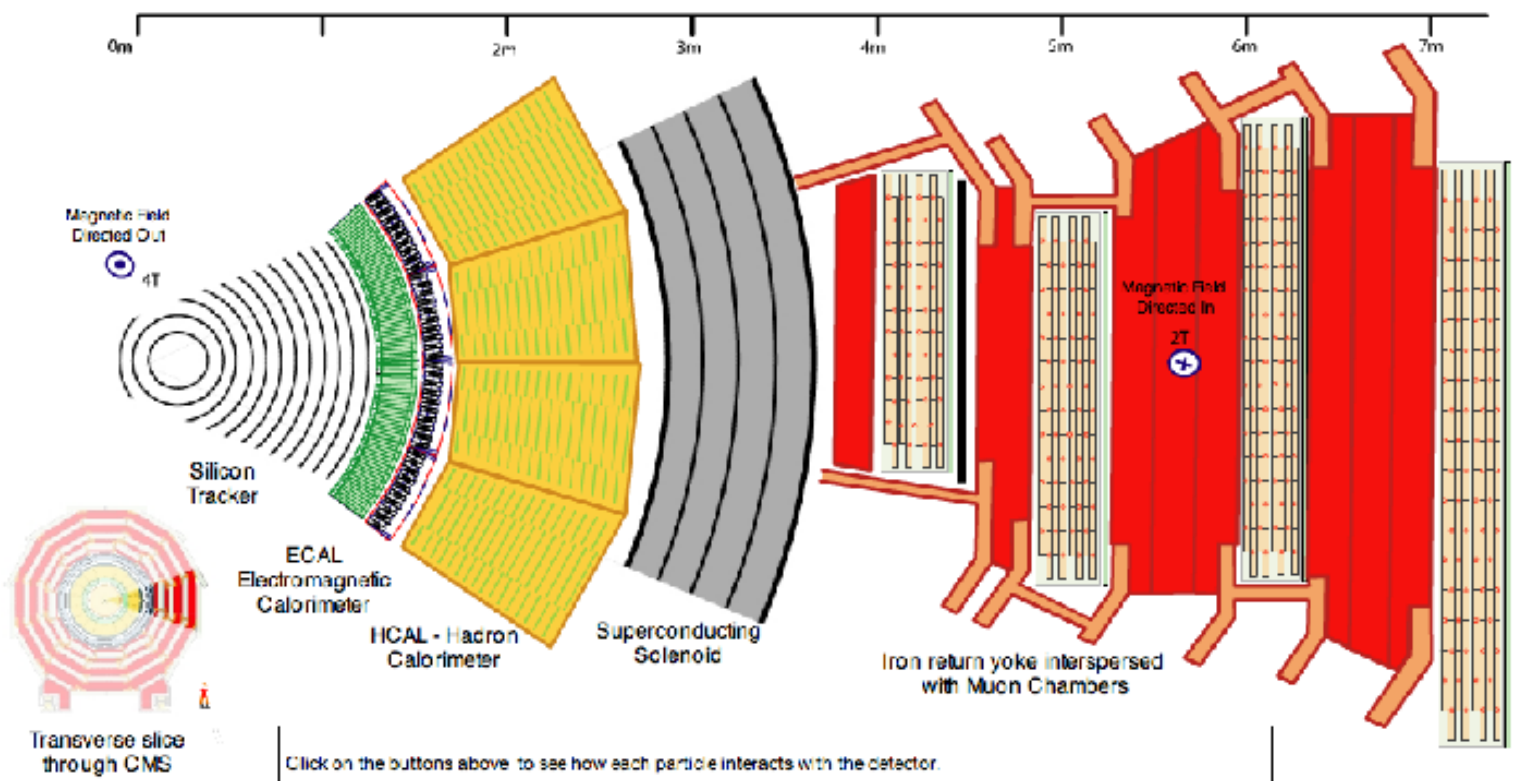

Making Dark Matter in the Lab
Directly Detecting Dark Matter
Your Portfolio –
General

Make It!



Colliders as DM Hunters

- WIMPs do not interact in LHC detectors.
  - Signature is missing transverse energy in the detector.
  - DM can be produced directly or in decays.



Steven Lowette, Rencontres de Blois 2017

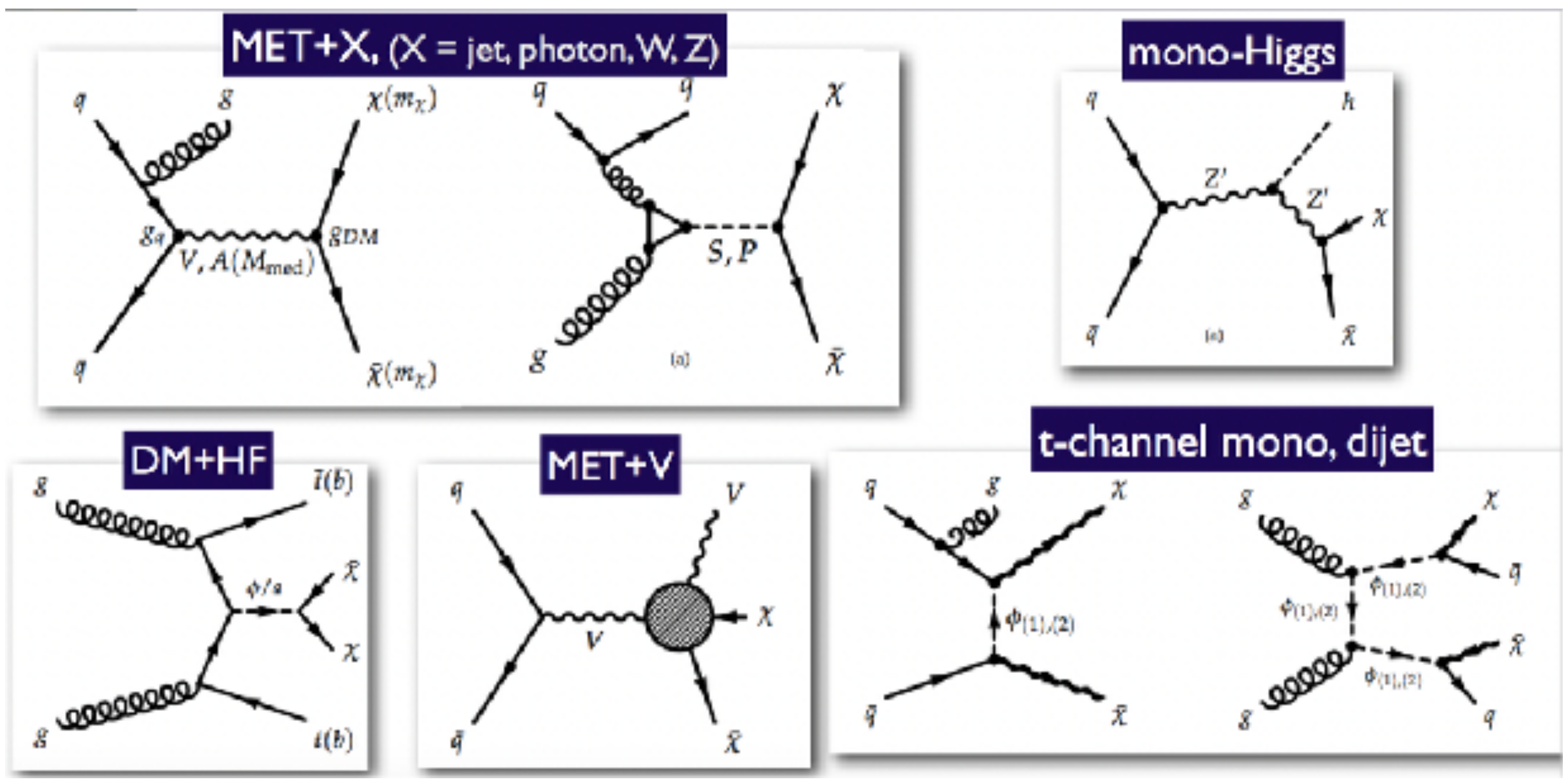
Some Current Searches

Collider physicists are looking everywhere:

Some Current Searches

Collider physicists are looking everywhere:

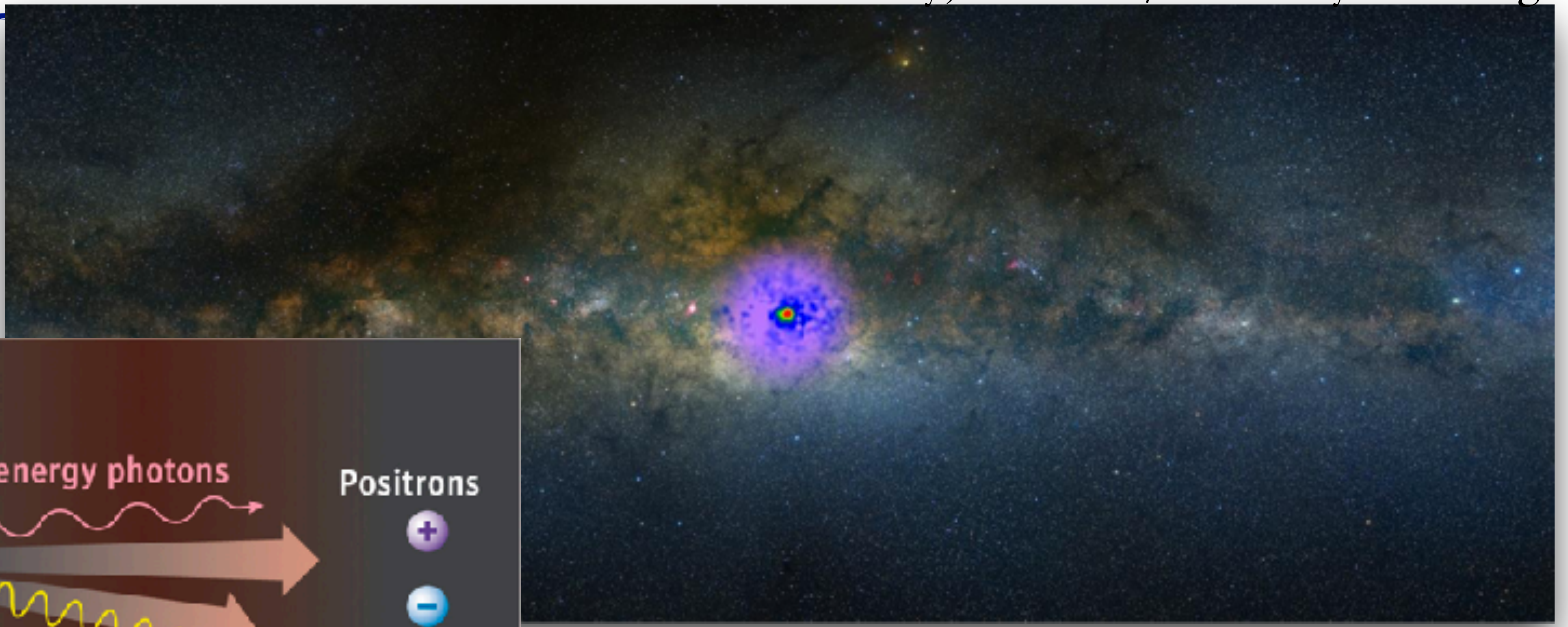
- Missing energy (dark matter) escaping the detectors
- Dark matter mediator searches in di-jet events



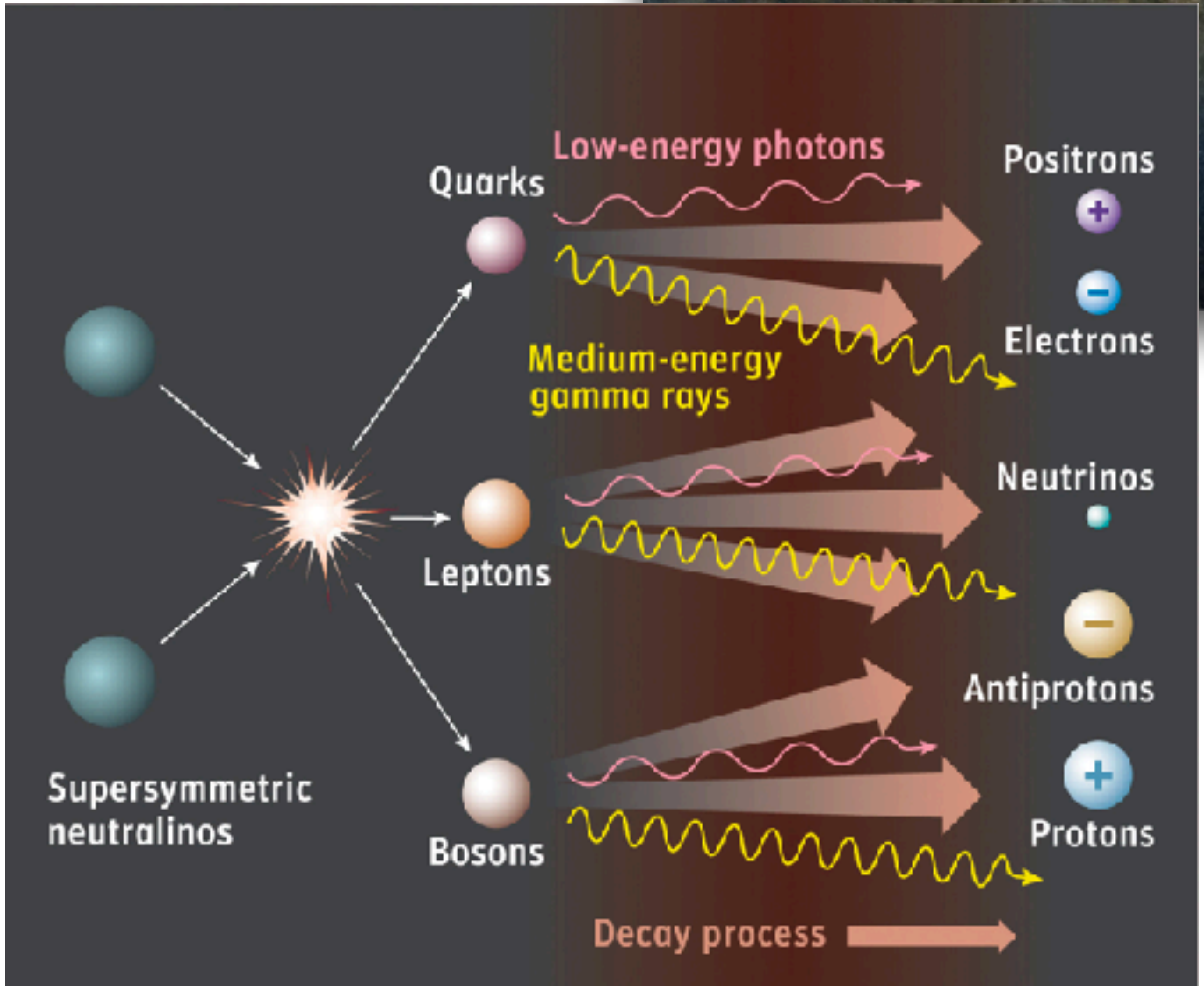
So far, no evidence of dark matter has been found!

Break It!

Credit: NASA; A. Mellinger/Central Michigan University; T. Linden/University of Chicago

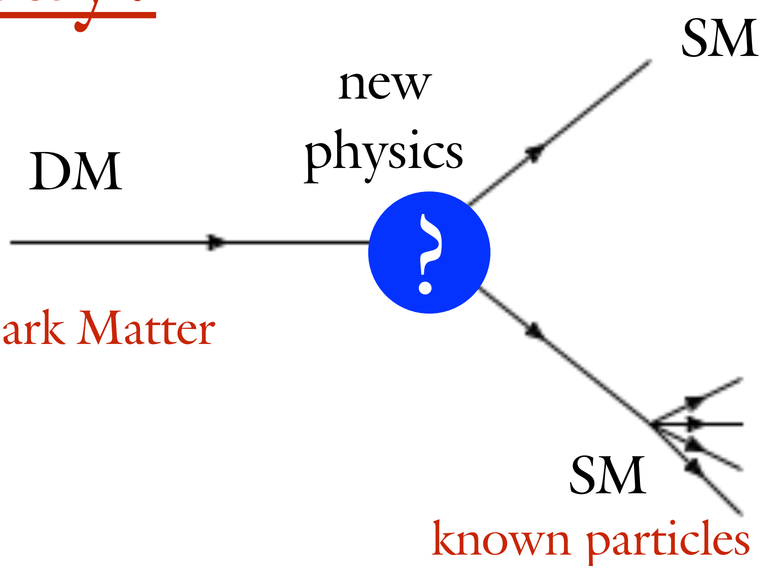


Annihilation:



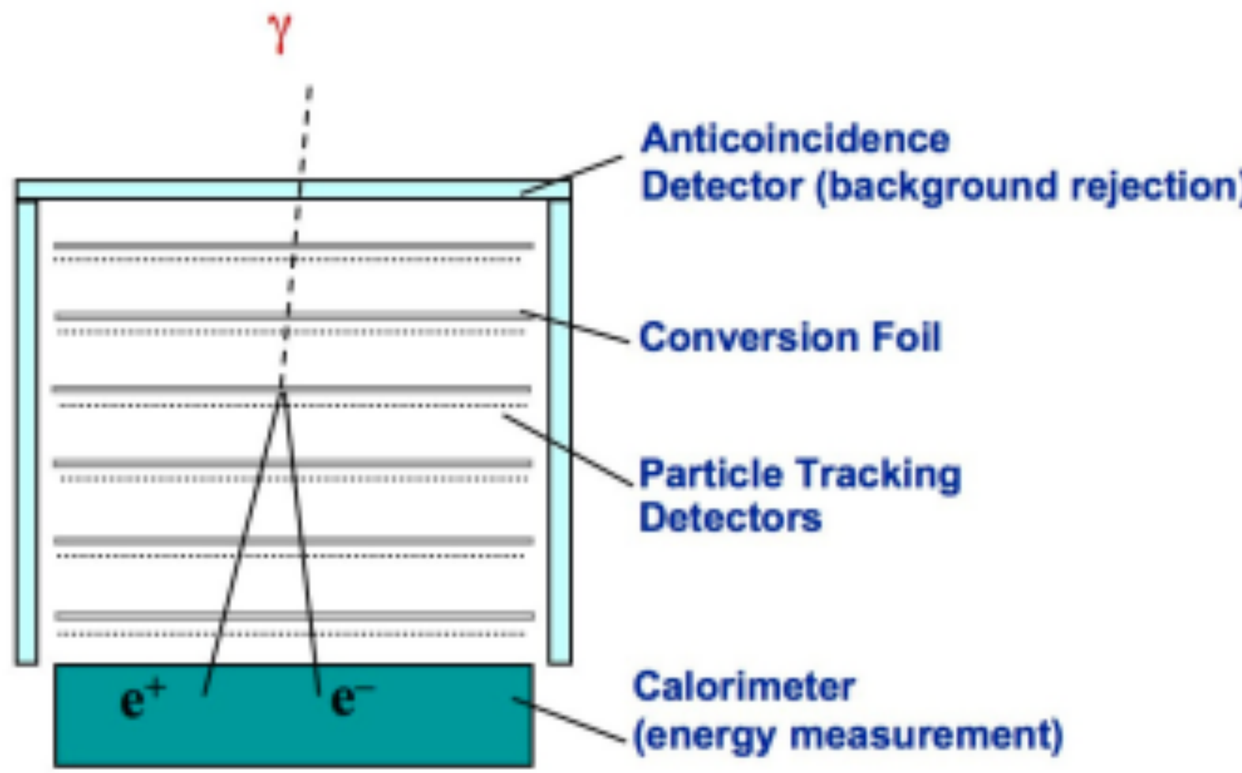
Credit: Sky & Telescope / Gregg Dinderman

Decay:



Gamma Rays

http://mediaarchive.ksc.nasa.gov/detail.cfm?mediaid=36076



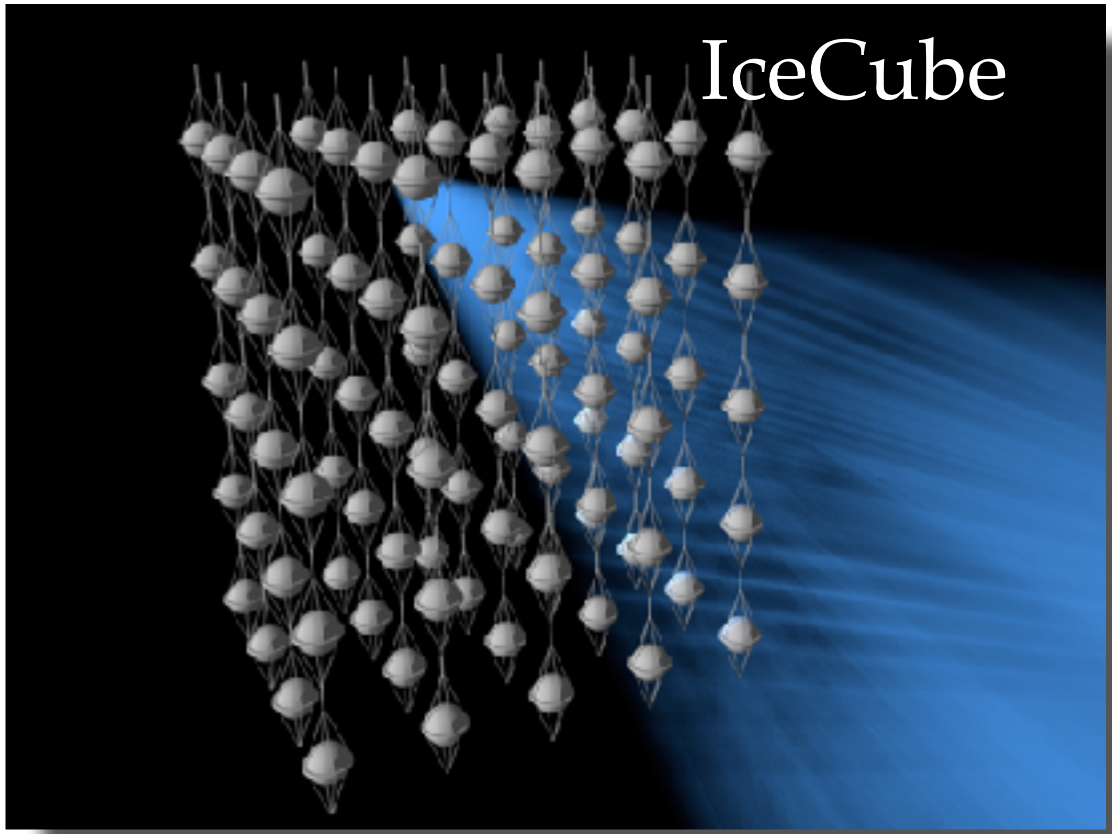
- Photons detected via pair production in high Z converter material.
- Cosmic rays are tagged by anti-coincident detector.
- Detects energies ~ 20 MeV to more than 300 GeV.

Gamma Rays

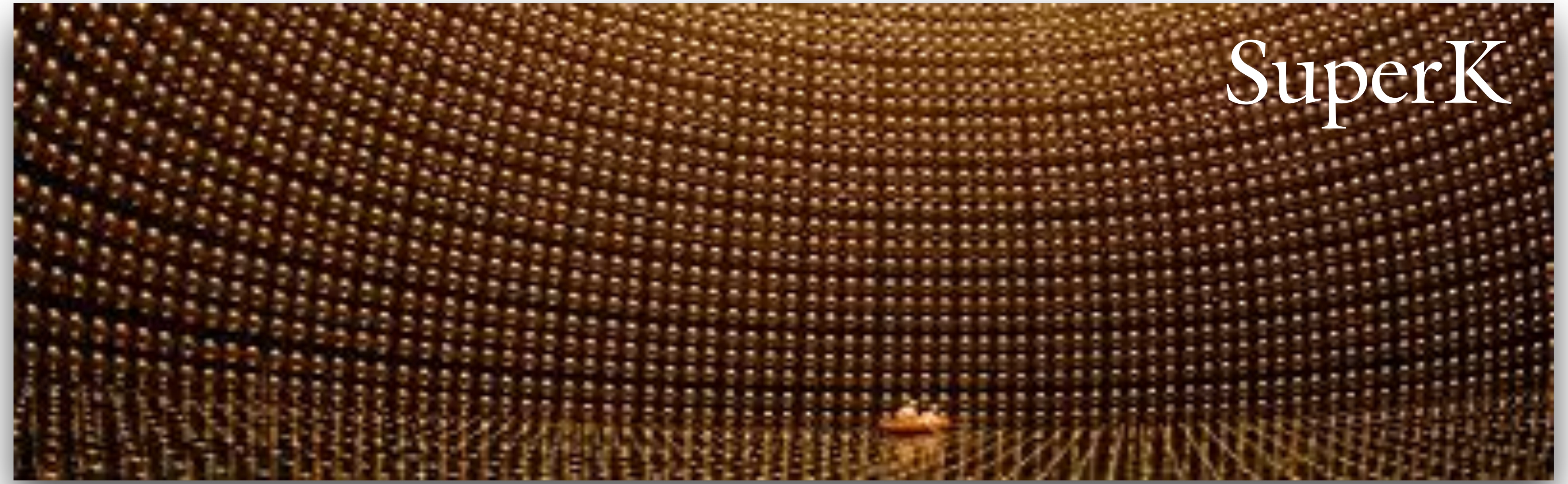
- Flux decreases quickly with energy for gamma rays.
- To reach the highest energy gamma rays large area Cherenkov detectors are necessary.

- Pros: point back to source and spectral information.
- Cons: backgrounds & attenuation

Neutrinos

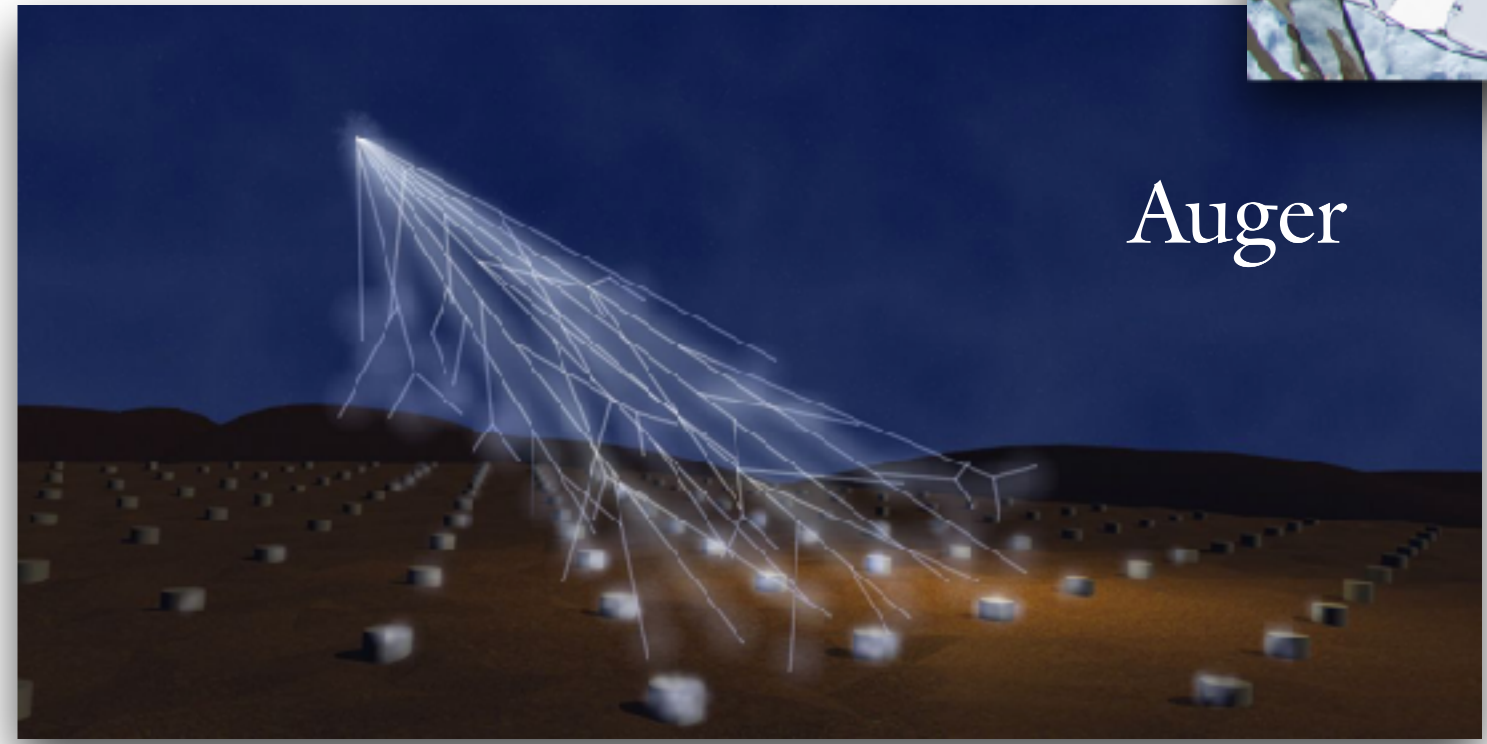


- Detect neutrinos produced in dark matter annihilations in the sun, center of Earth or galactic center.
- Pros: point back to source and spectral information, more directly comparable to direct detection σs.
- Cons: backgrounds & low stats



Cosmic Rays

- Detect charged particles produced in dark matter annihilations and decays in the cosmos.



- Pros: spectral information and low background for antimatter searches.
- Cons: diffusion and do not point back to sources.

Current Limits in a Nutshell

- Thermal annihilation cross-section benchmarks either rule out or are in tension with dark matter with masses below 10 - 100 GeV (depends on final state).
- Decay lifetimes below ~ $10^{27\text{-}28}$s ruled out for most final states and keV - EeV dark matter masses; for MeV-GeV dark matter decaying to e^+e^- lifetimes can be as short as $10^{24\text{-}25}$s.

Tracy Slatyer, Rencontres de Blois 2017

Anomalies in a Nutshell

- The 3.5 keV Line:
  - First seen in XMM-Newton data at ~4σ level *(PRL 113, 251301)*
  - Simplest DM solution is 7 keV sterile neutrino, in tension with some observations.
  - Possible astrophysics backgrounds: atomic lines (K,Cl, Ar, ?), charge exchange with heavy nuclei and neutral gas. Future instruments (MacroX) may help resolve situation.

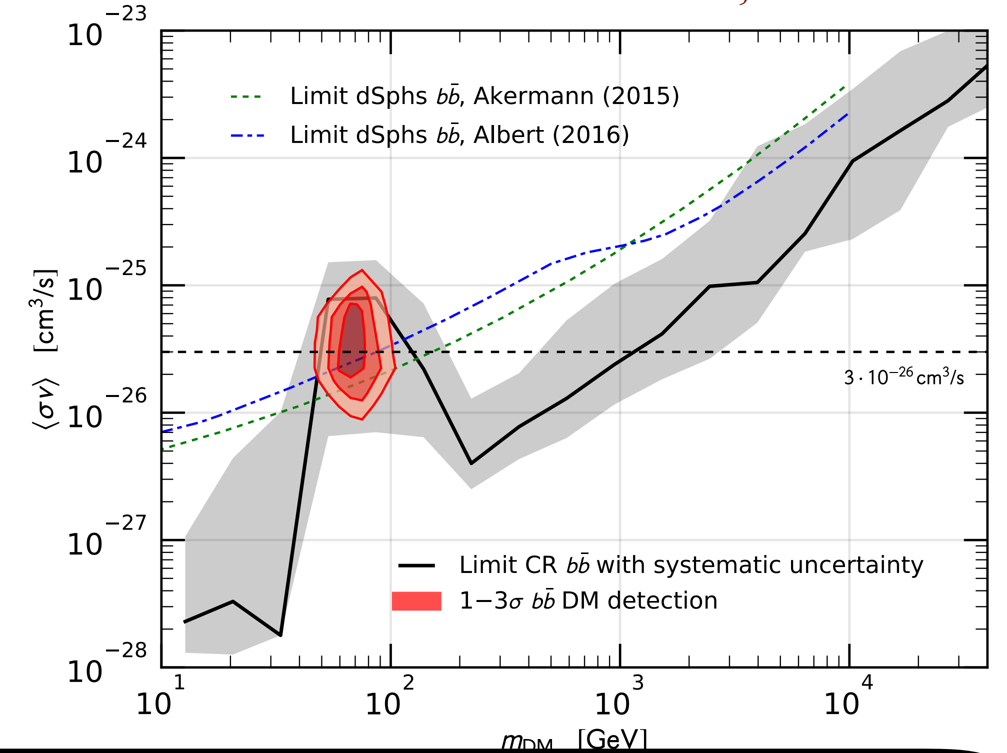
- The GeV excess @ Galactic Center:
  - First claimed in 2009 with Fermi data *(arXiv:0910.2998)*
  - Many studies suggesting ~10-100 GeV DM
  - Tension with non-detection in dwarf galaxies
  - Mounting evidence of large contribution from pulsars *(arXiv:1706.01199, PRL 116, 051102, arXiv:1412.6099)*

More Anomalies in a Nutshell

- AMS Antiprotons

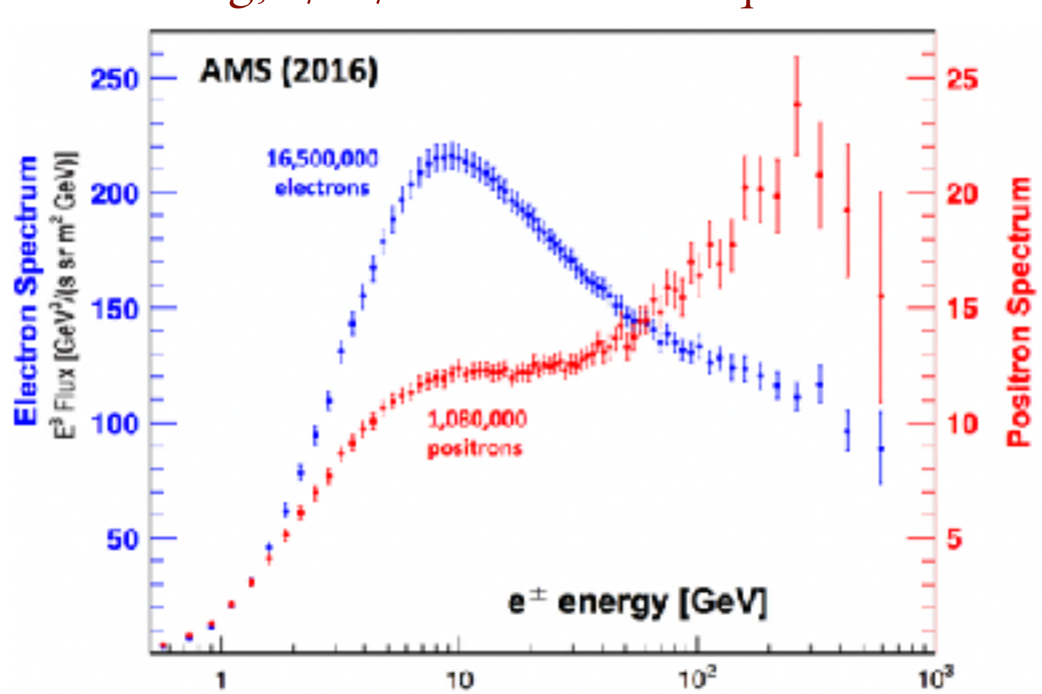
- Excess ~4.5σ possibly attributed to DM *(PRL 118, 191102; PRL 118, 191101)*
- Significant uncertainties: modeling of antiproton production cross section, cosmic-ray propagation, solar modulation.

Cuocu PRL 118, 191102



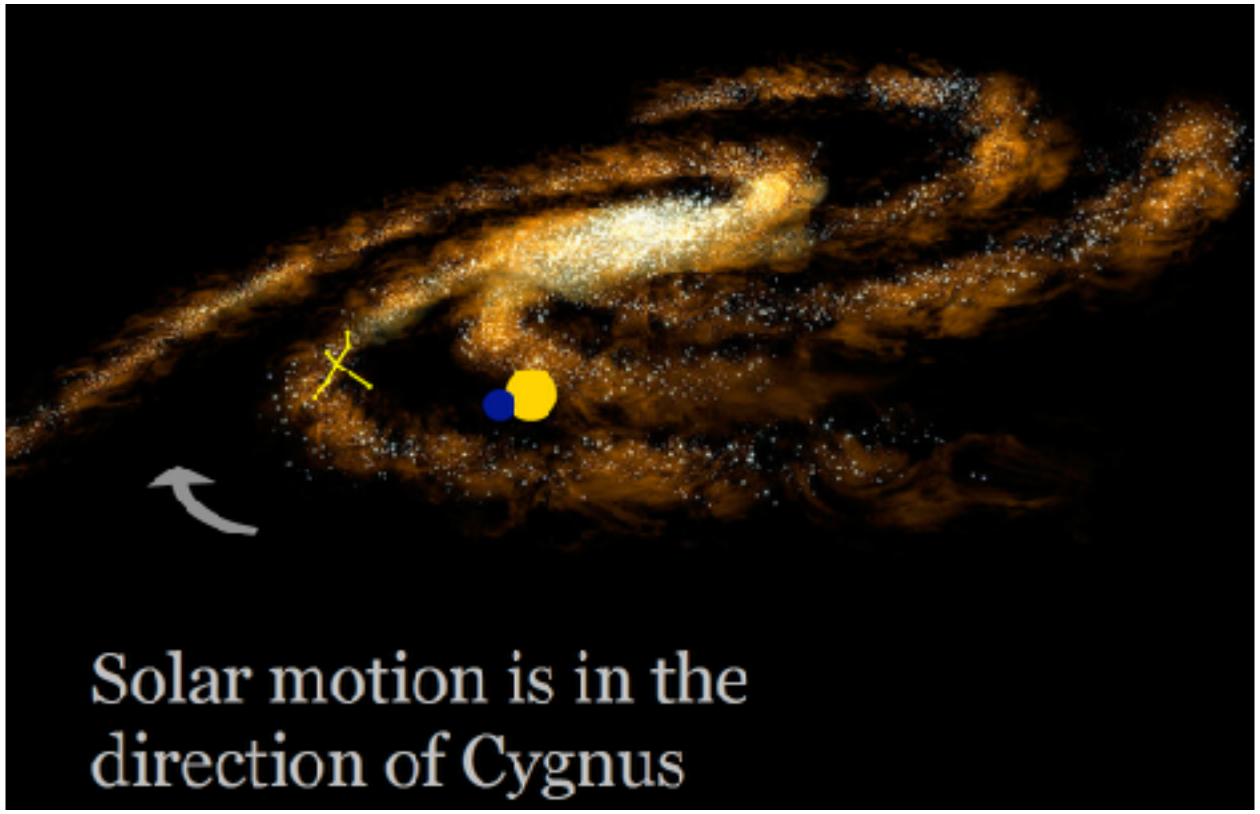
- AMS Positrons

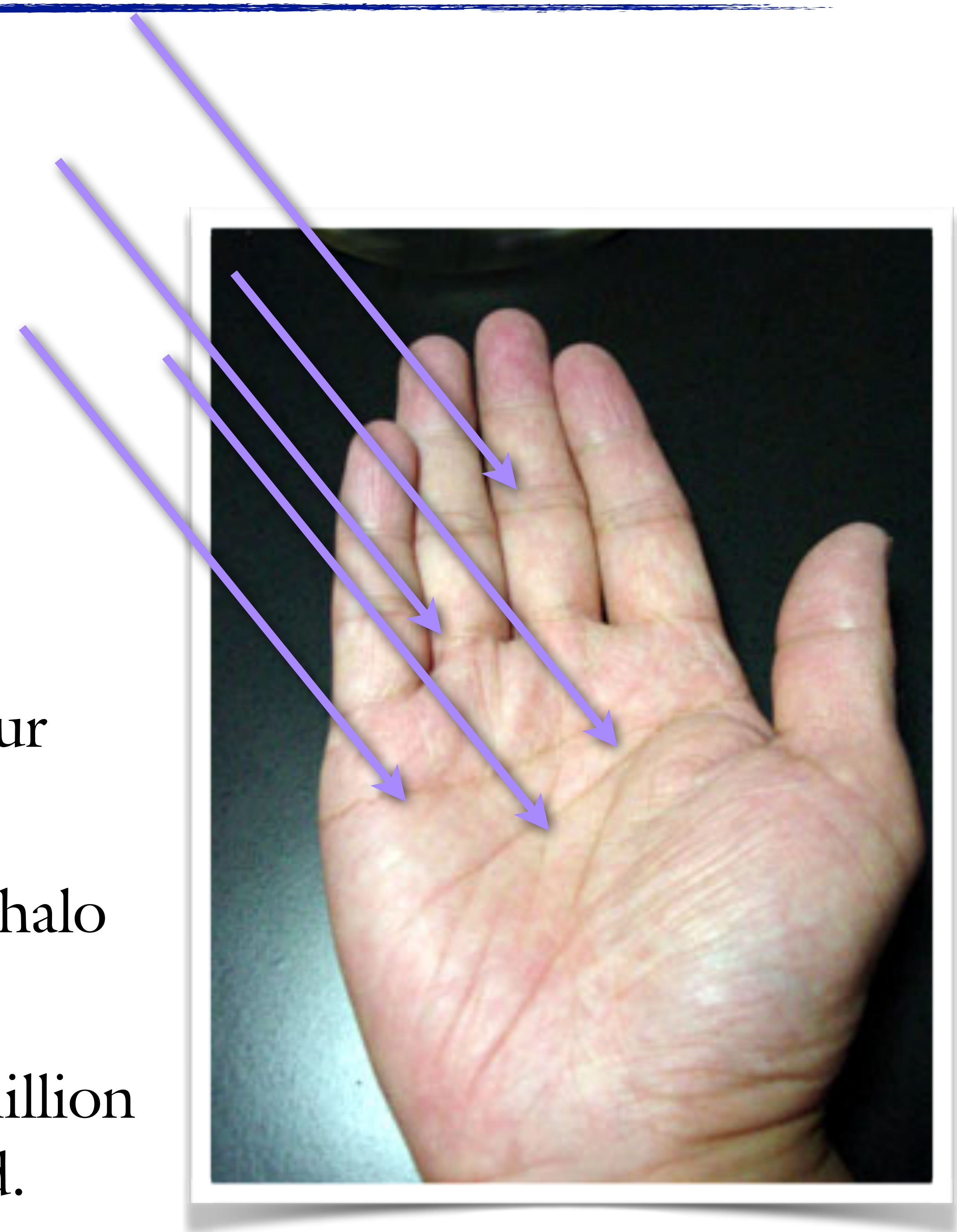
Ting, 8/12/16 CERN Colloquium



- Large excess of e⁺ > 10 GeV inconsistent with expectations for secondary e⁺ from proton collisions with interstellar medium.
- DM interpretation of signature for annihilation or decay in tension with other measurements.
- Potential for large pulsar contribution to signal. (arXiv:1702.08436)

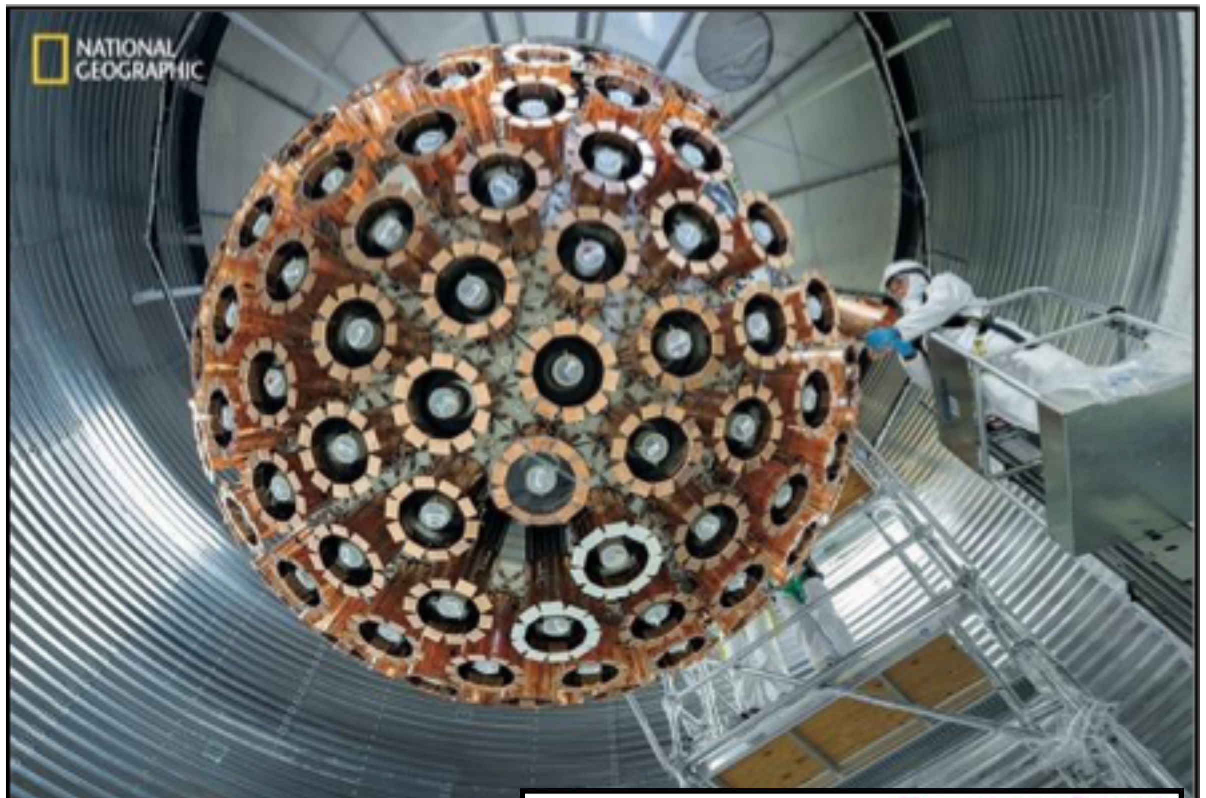
WIMP Interactions





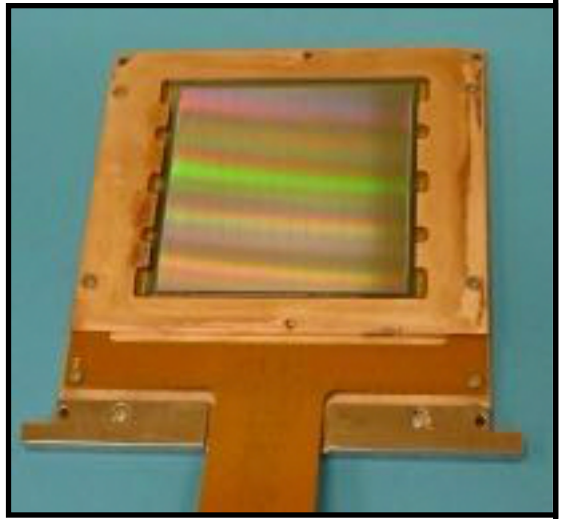
- Dark Matter exists in a halo around our galaxy.
- Our speed relative to the dark matter halo is ~220 km/s.
- If the dark matter is a WIMP, ~ 10 million would go through a hand each second.

Shake It!

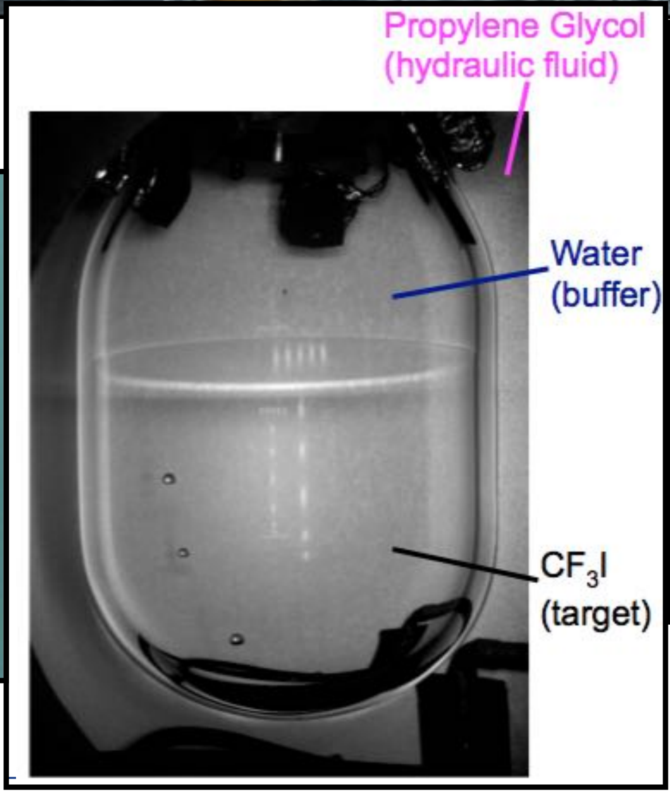


DEAP-3600

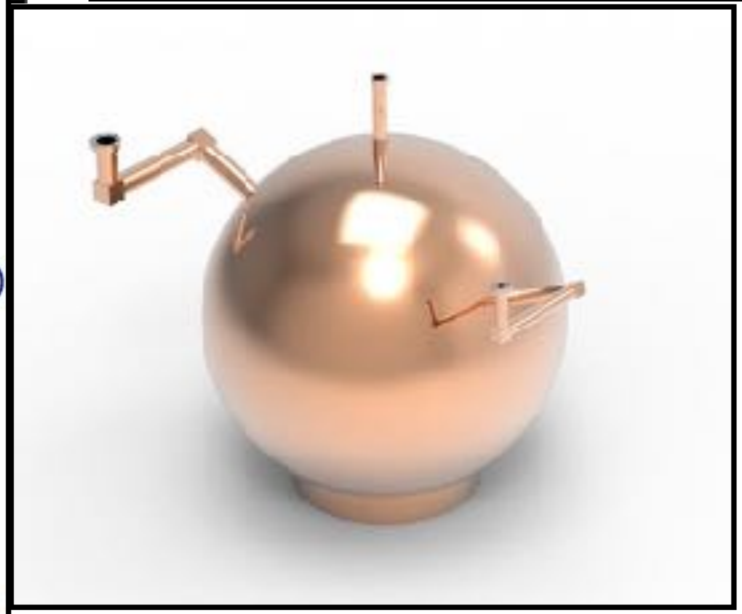
COSINE-100



DAMIC

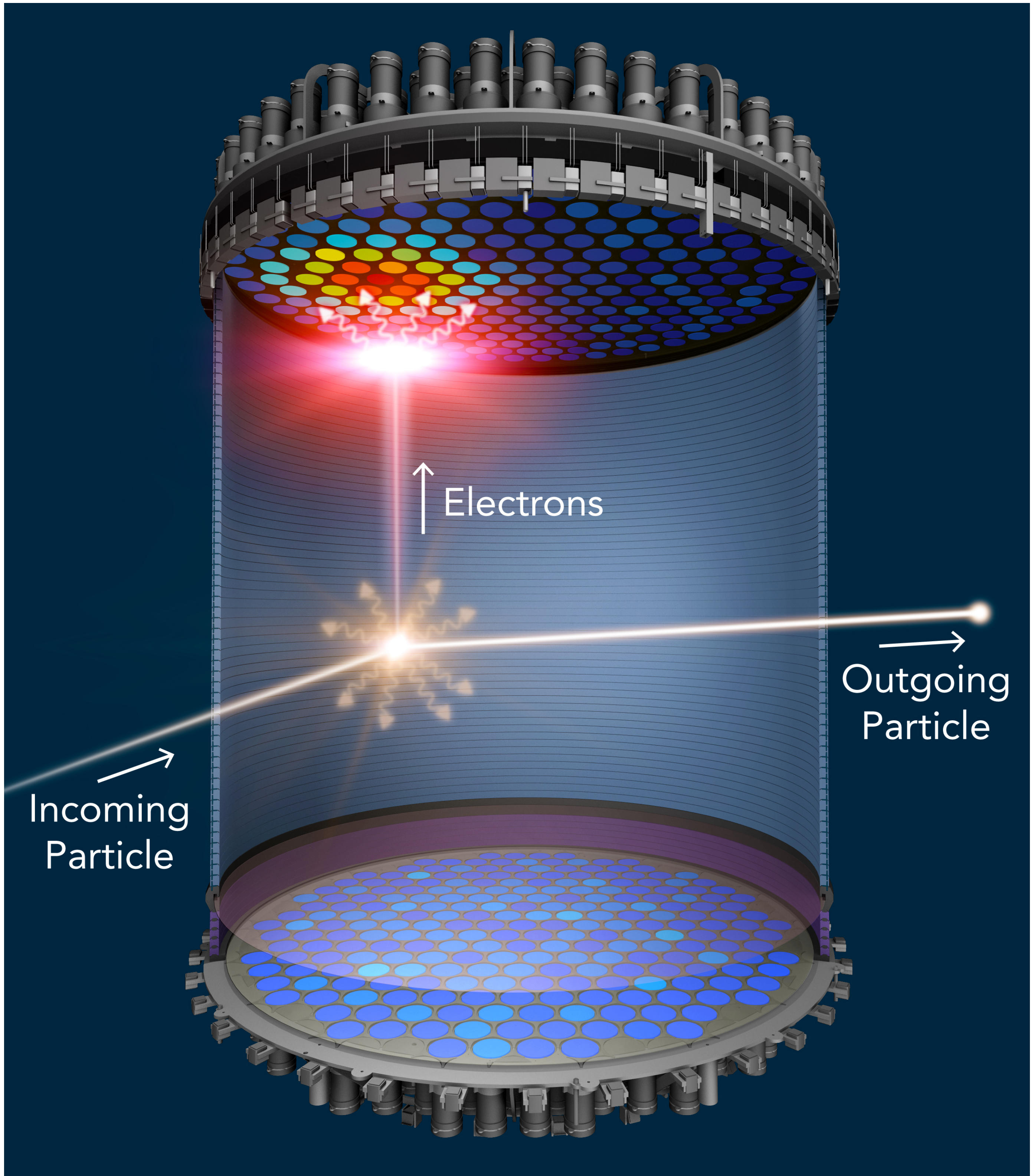


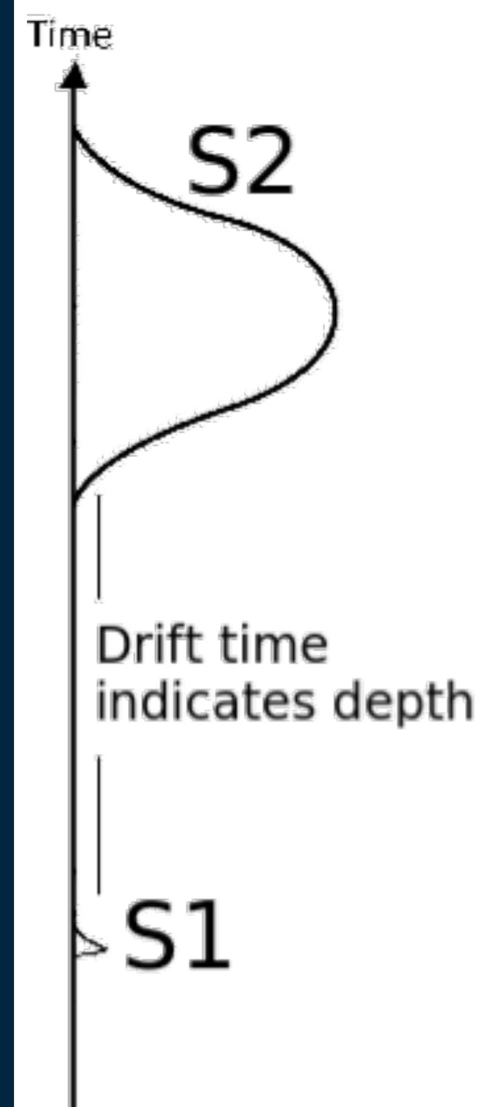
PICO



NEWS

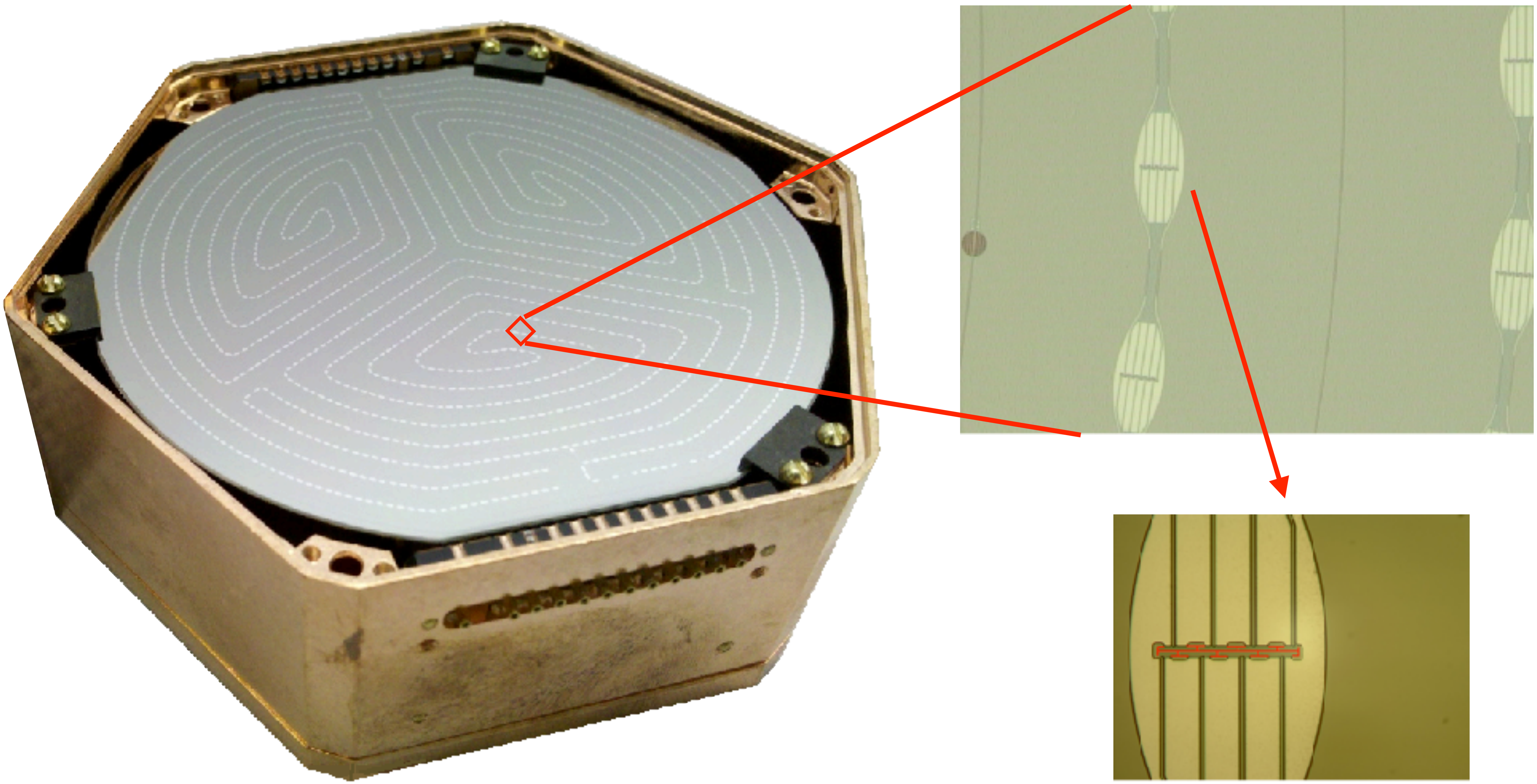
Noble Liquid Time Projection Chambers



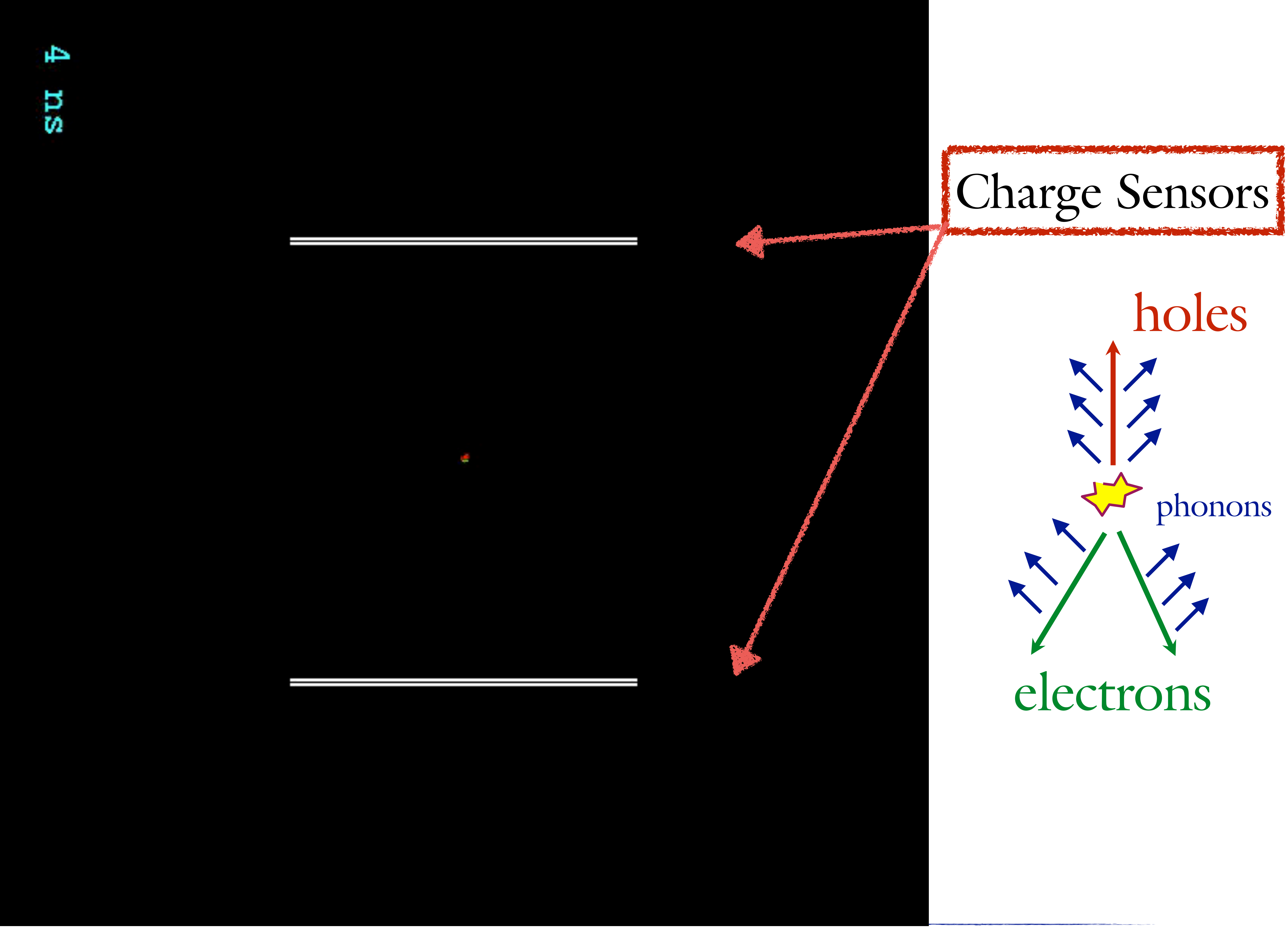


DarkSide
LUX/LZ
PandaX
XENON

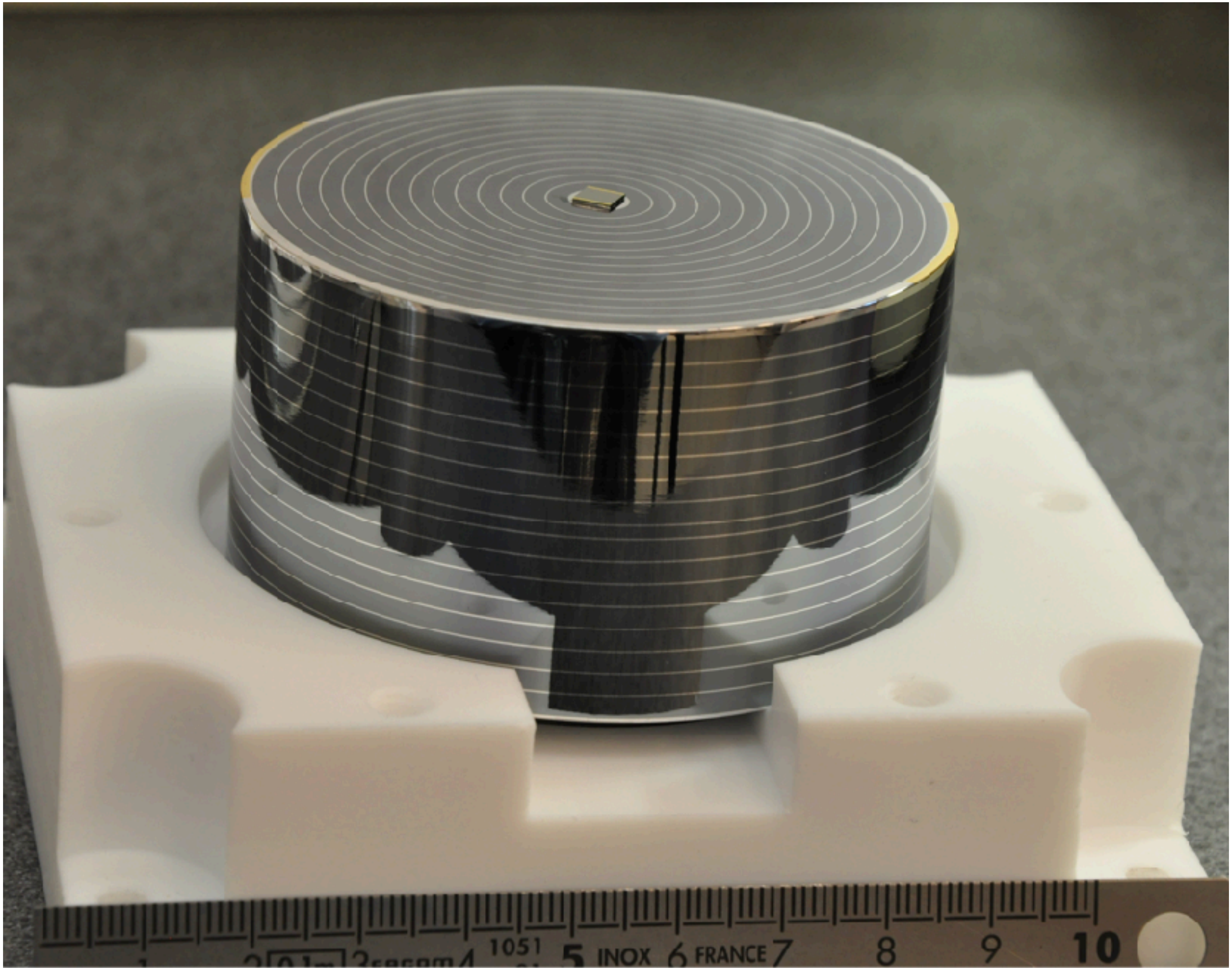
Solid State Devices



SuperCDMS Detector

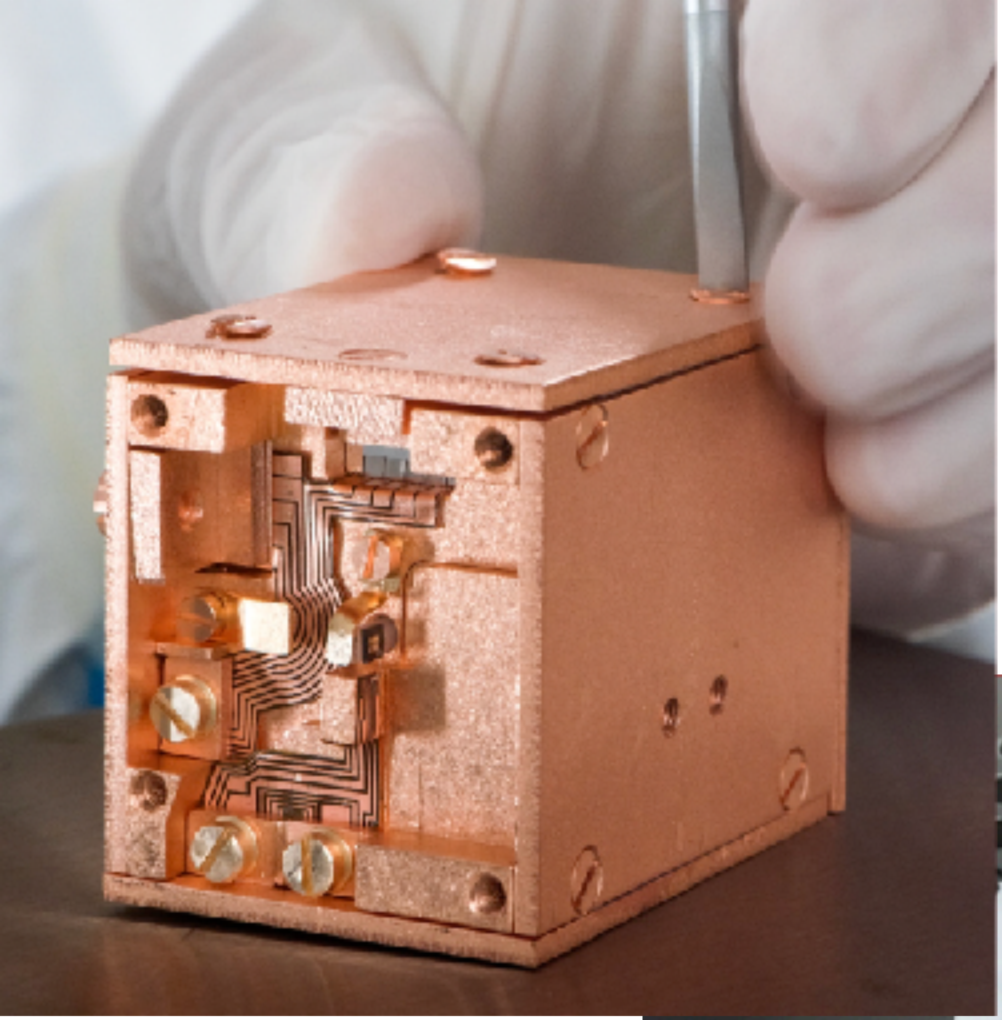


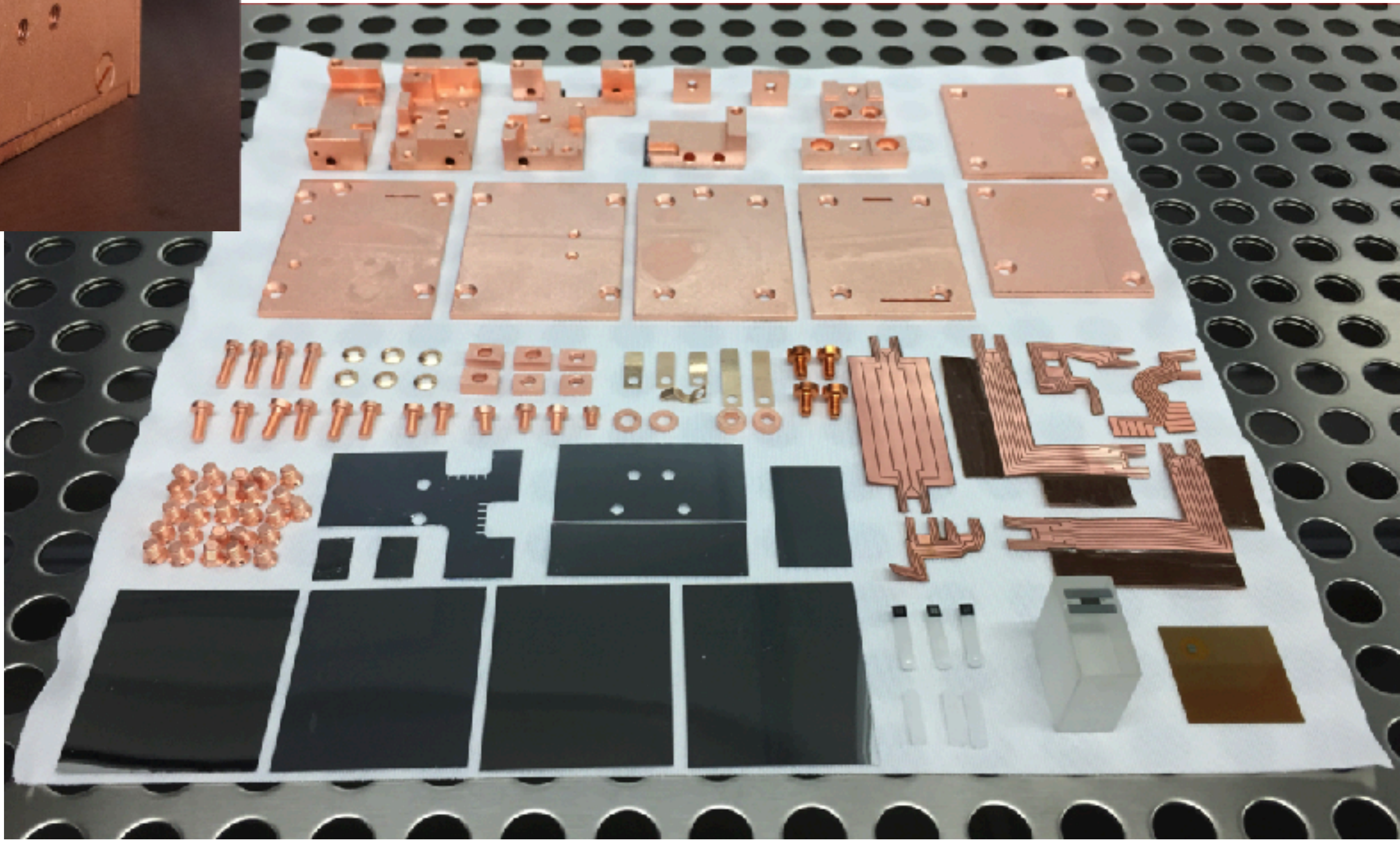
credit: SuperCDMS Collaboration



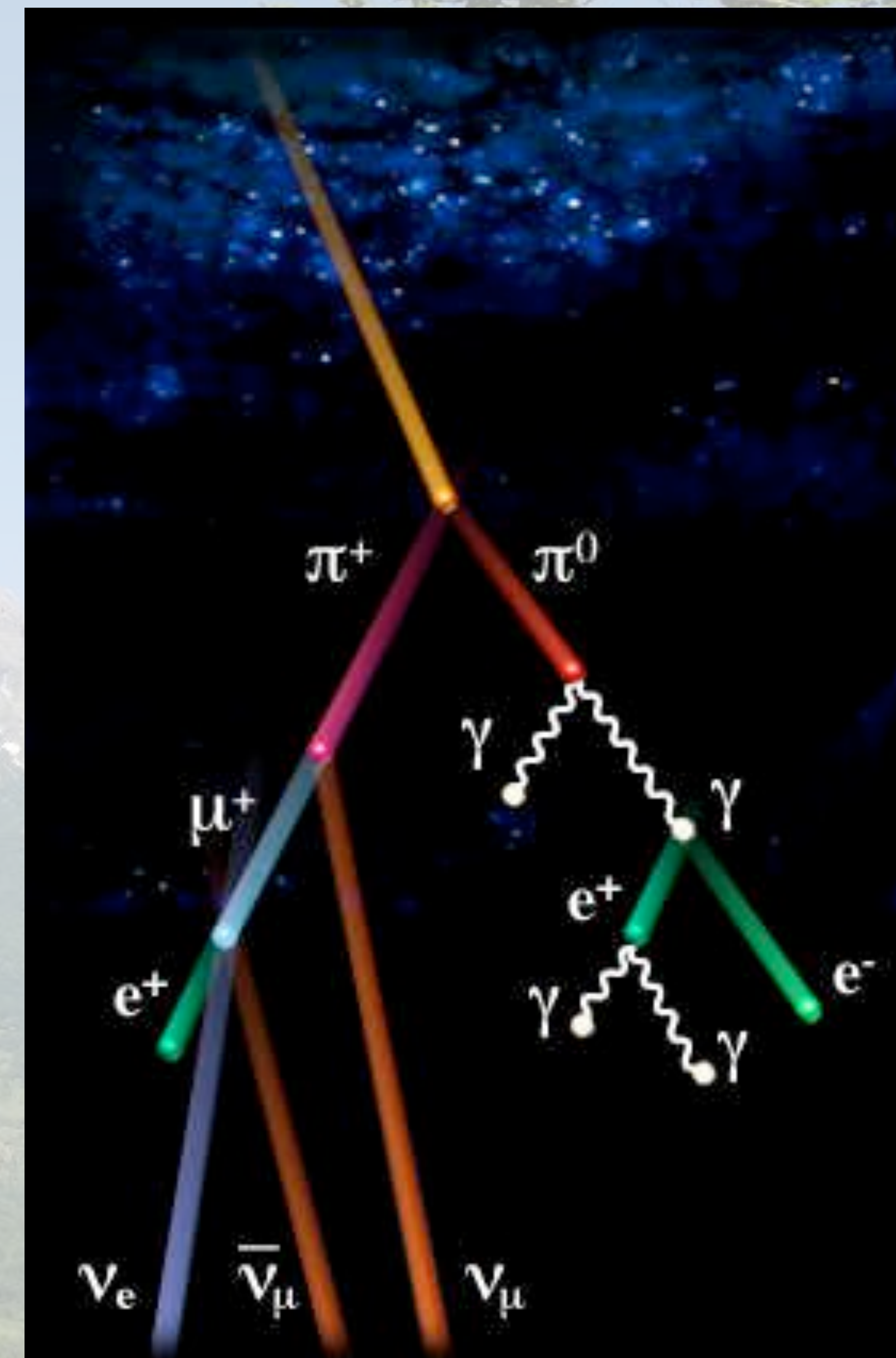
Edelweiss Detector

CRESST III Detector





Cosmic Rays:



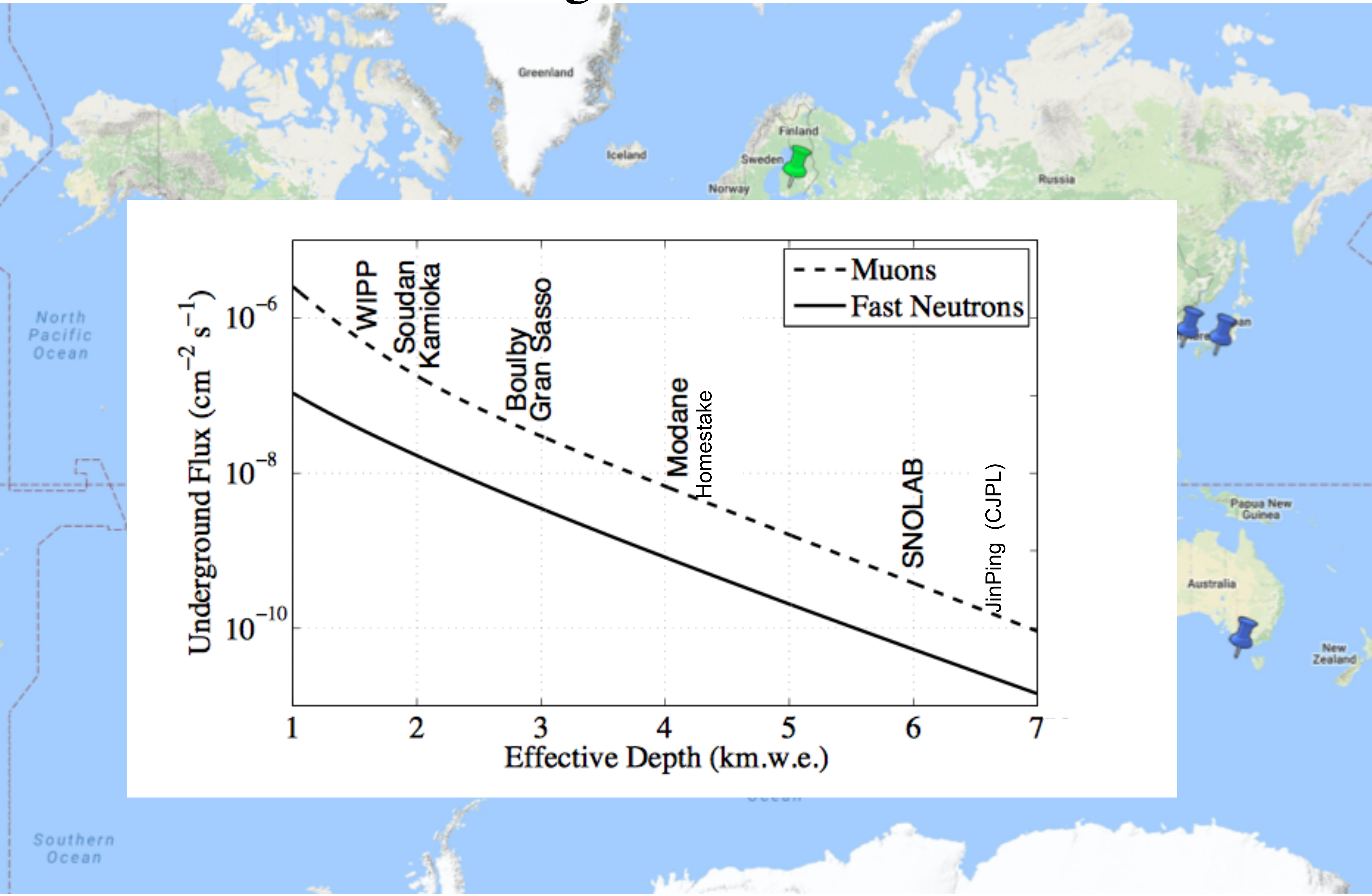
livefromcern.web.cern.ch

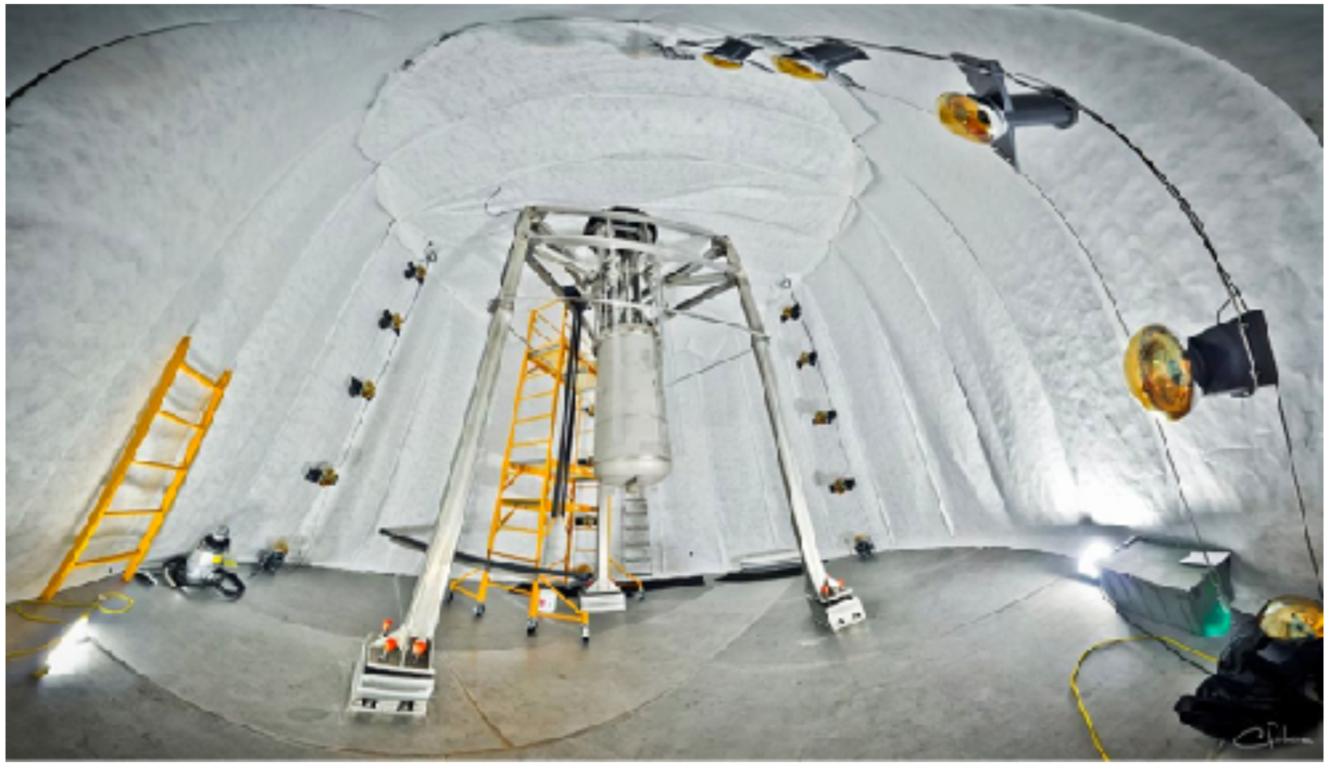
Experiments are sited underground to reduce the number of cosmic ray particles that reach detectors.

Gran Sasso, Italy

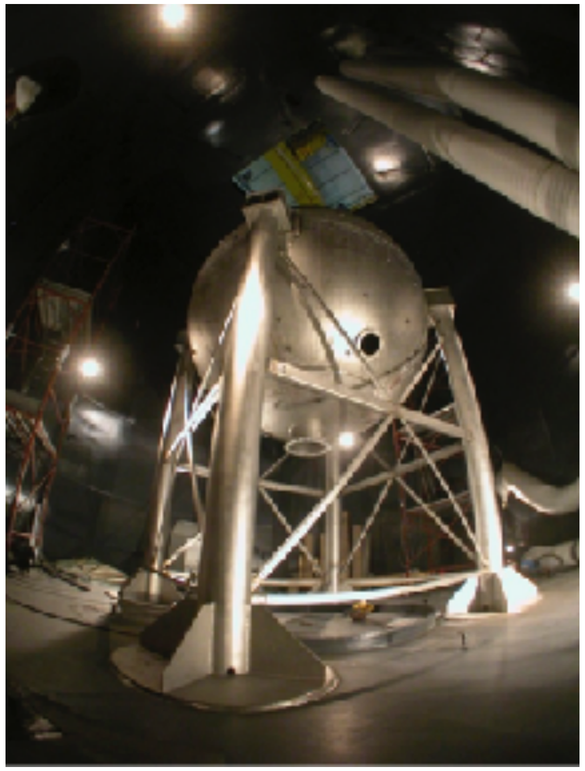
Underground Facilities

Underground Facilities

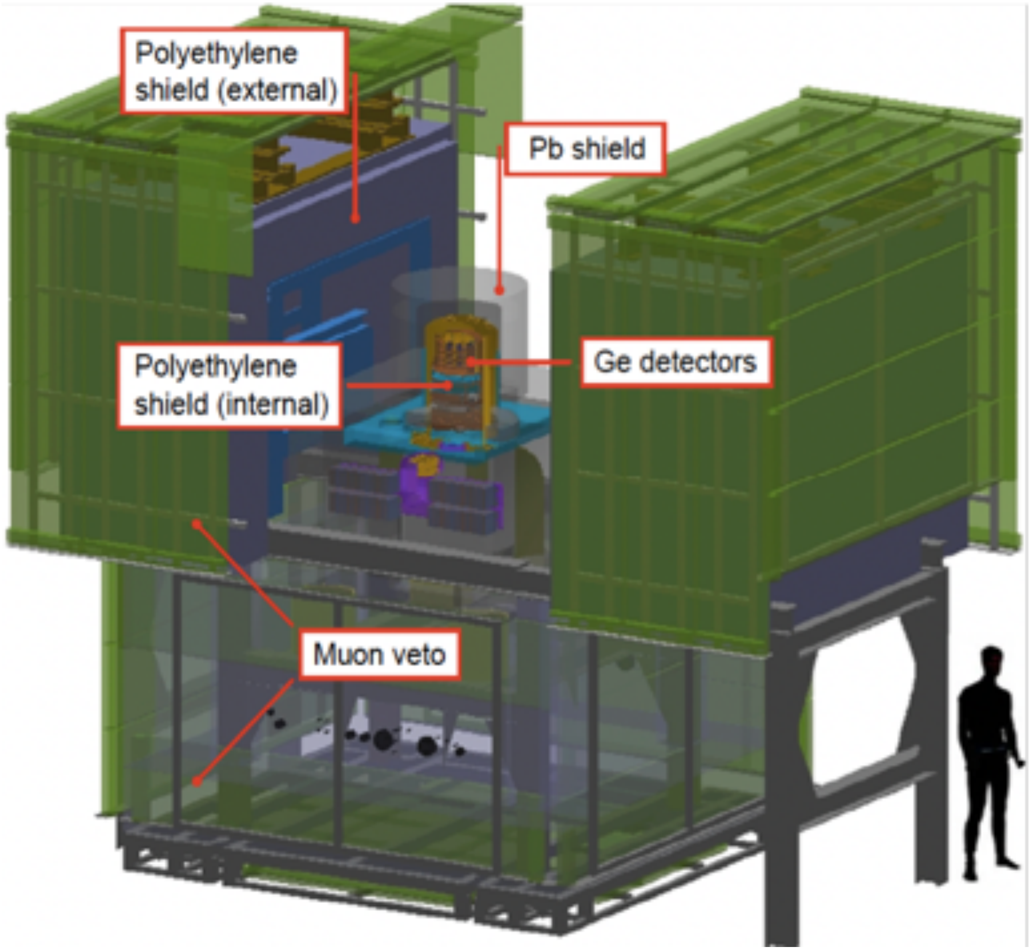




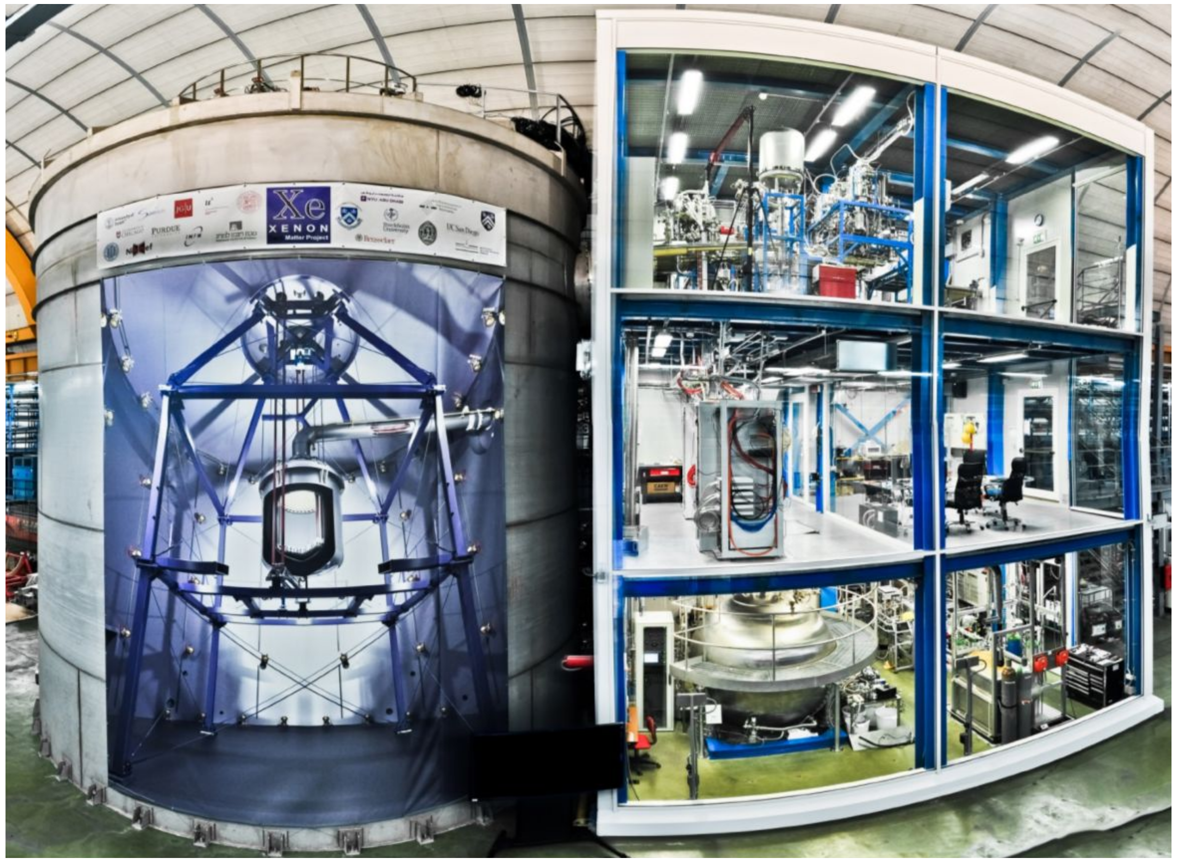
LUX/LZ Muon Veto



DarkSide Neutron Veto

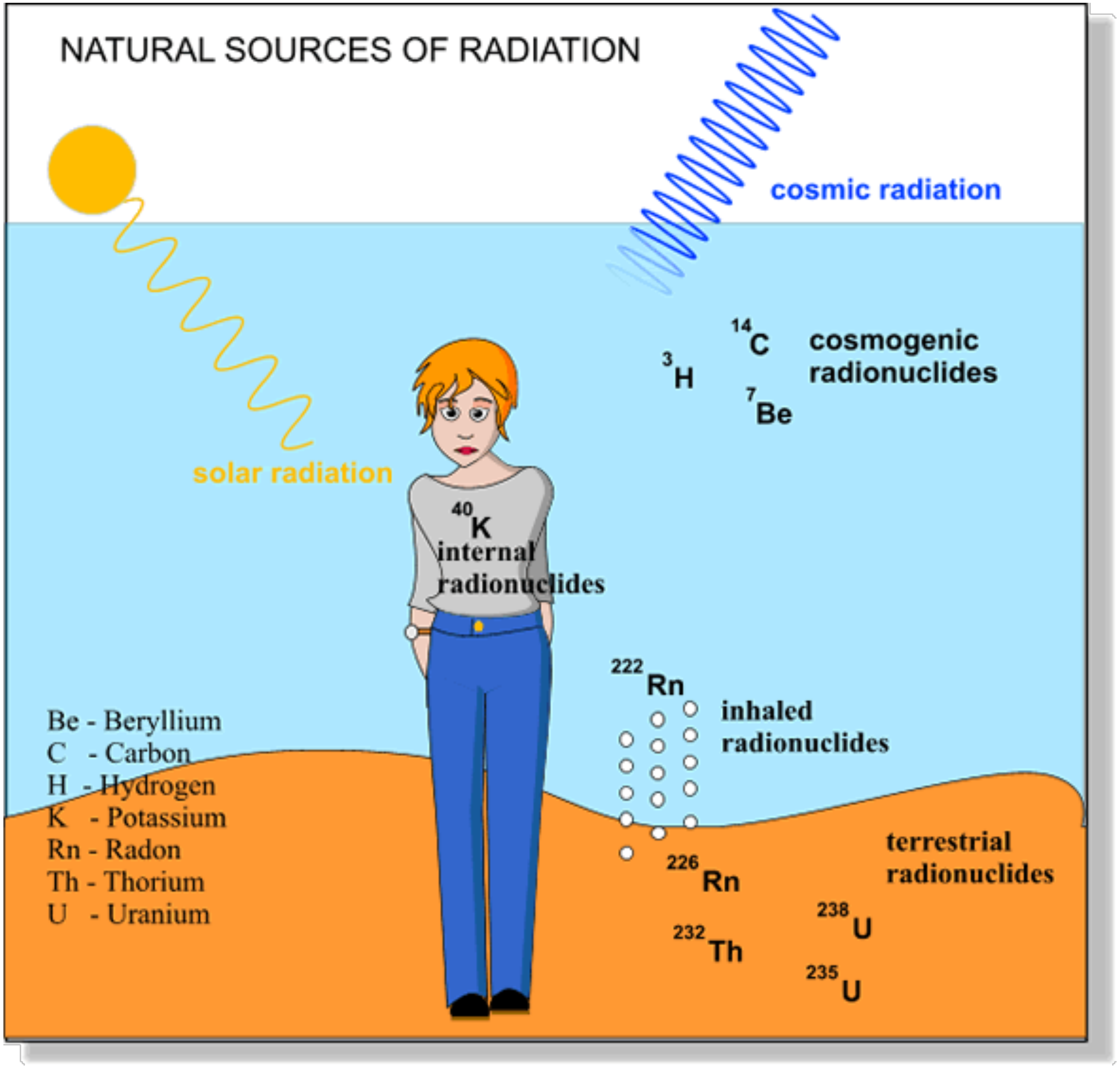


Edelweiss Active Muon & Passive Shield



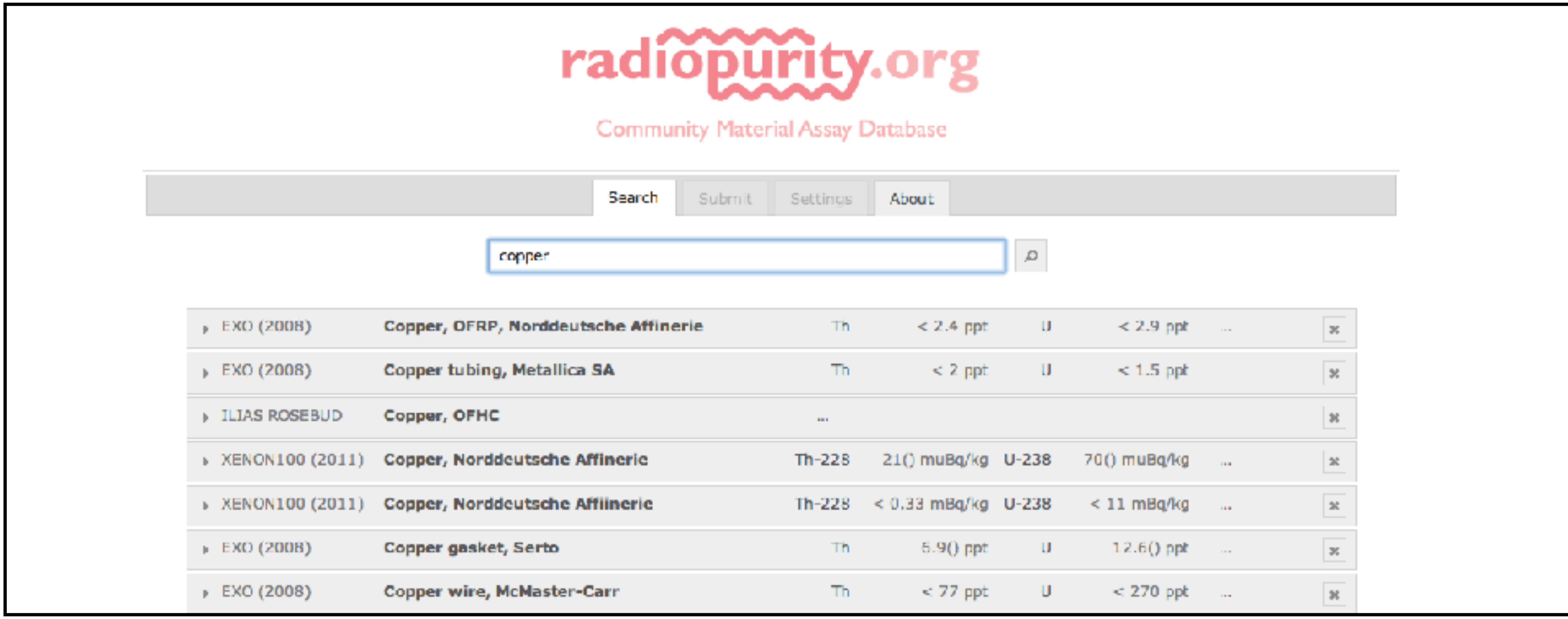
XENON1T water shield & infrastructure

Natural Radioactivity:



Community Assays Database

Use Clean Materials


radiopurity.org

Community Material Assay Database

Search | Submit | Settings | About

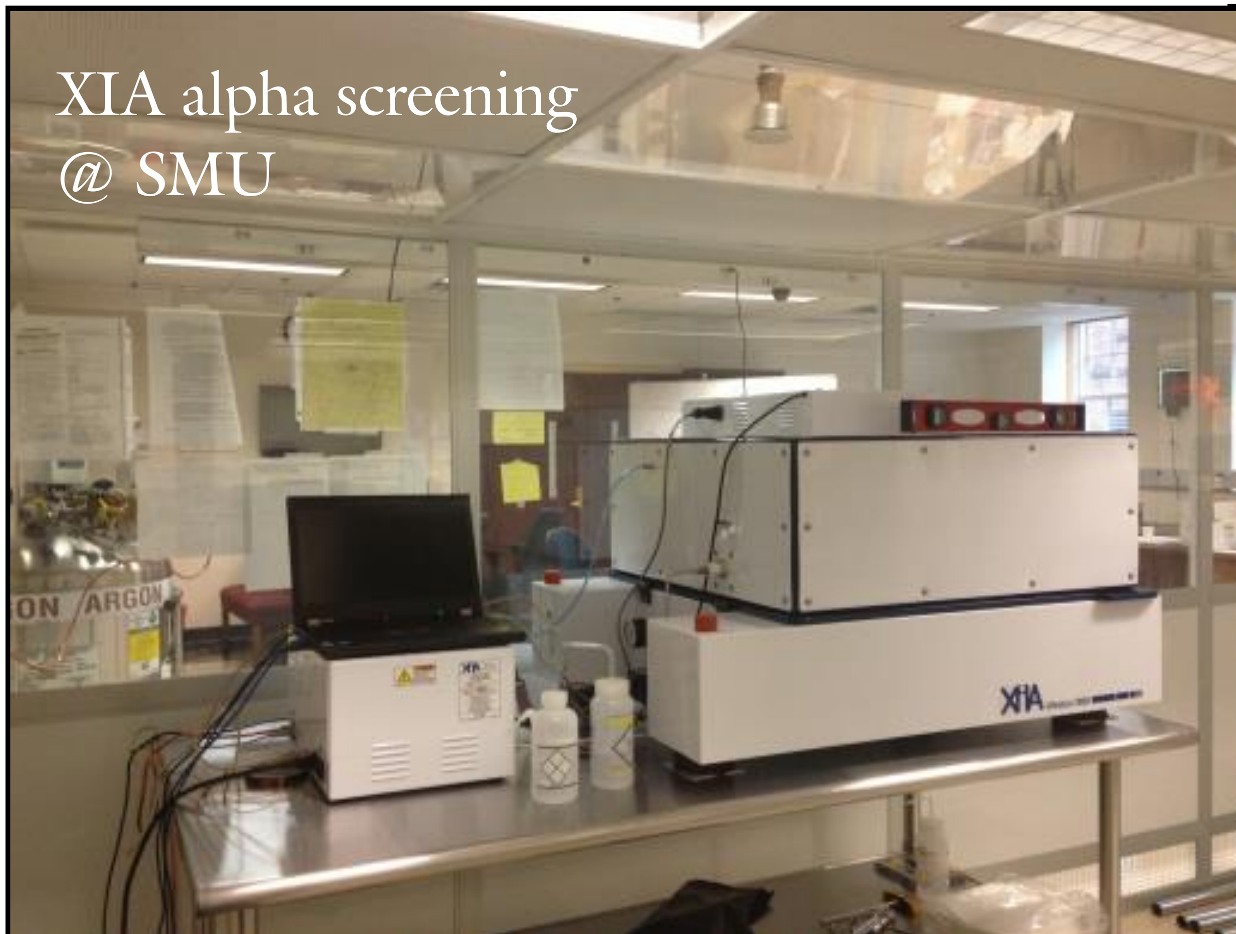
copper

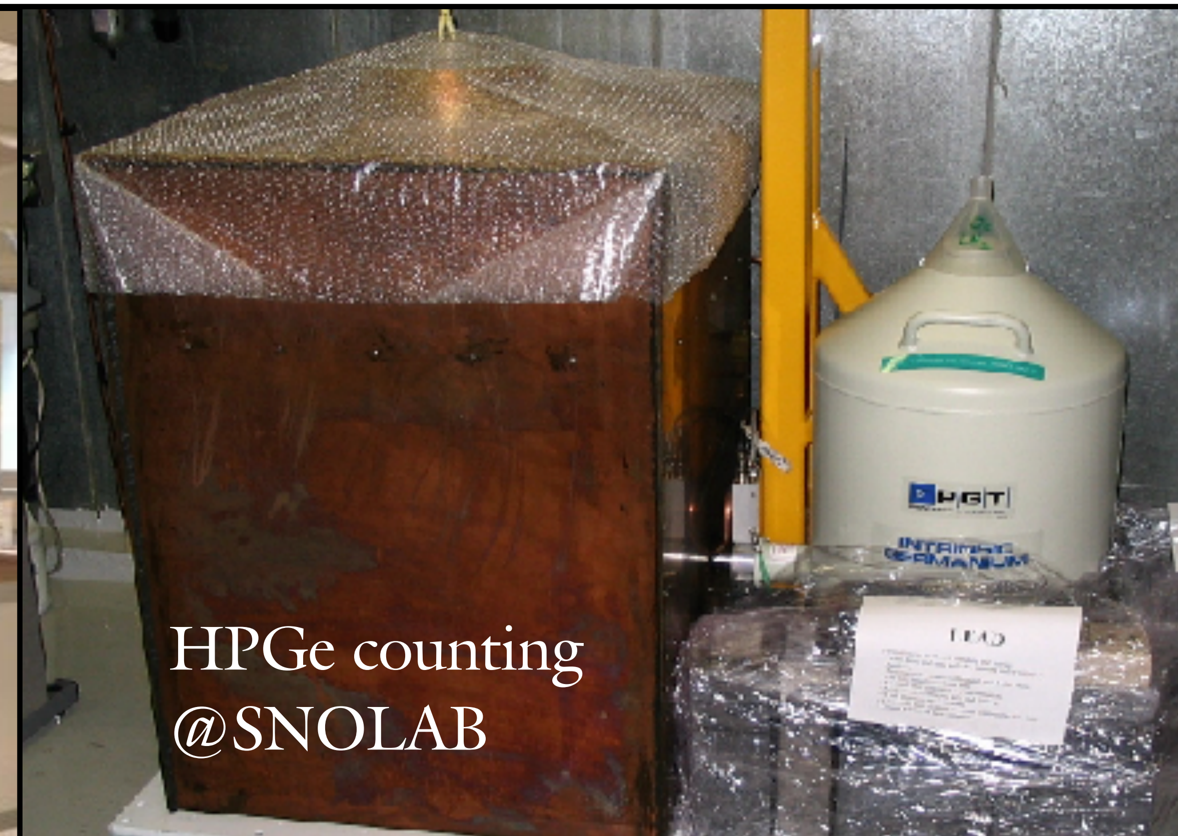
EXO (2008)	Copper, OFRP, Norddeutsche Affinerie	Th	< 2.4 ppt	U	< 2.9 ppt	...	
EXO (2008)	Copper tubing, Metallica SA	Th	< 2 ppt	U	< 1.5 ppt		
ILIAS ROSEBUD	Copper, OFHC	...					
XENON100 (2011)	Copper, Norddeutsche Affinerie	Th-228	21() muBq/kg	U-238	70() muBq/kg	...	
XENON100 (2011)	Copper, Norddeutsche Affinerie	Th-228	< 0.33 mBq/kg	U-238	< 11 mBq/kg	...	
EXO (2008)	Copper gasket, Serto	Th	5.9() ppt	U	12.6() ppt	...	
EXO (2008)	Copper wire, McMaster-Carr	Th	< 77 ppt	U	< 270 ppt	...	

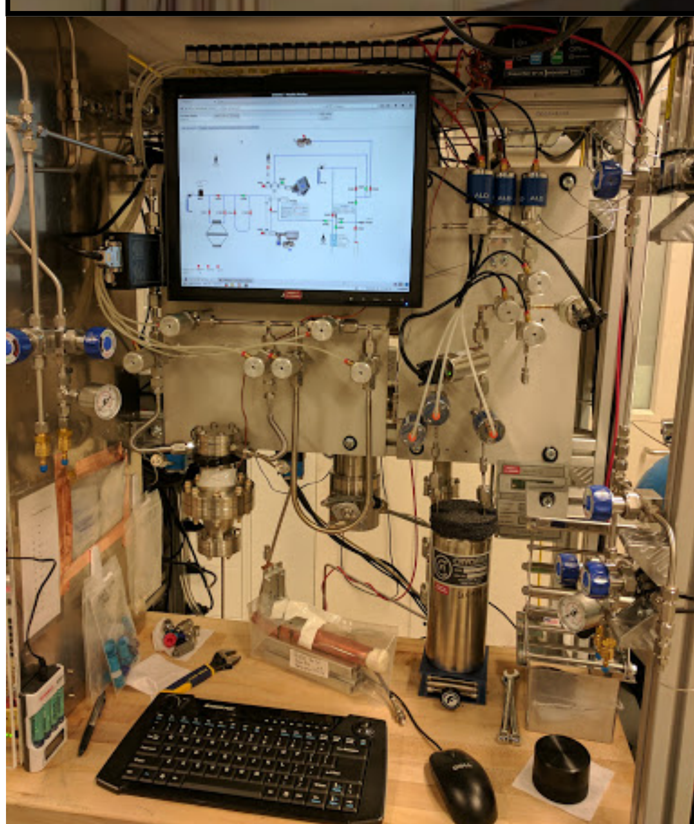
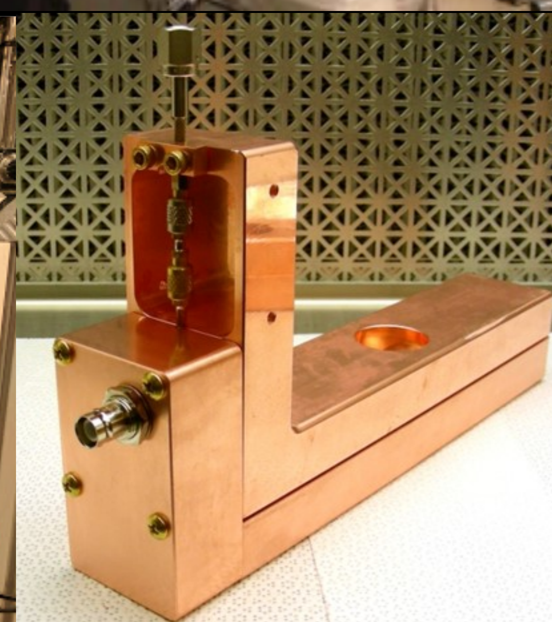
http://radiopurity.org

Supported by AARM, LBNL, MAJORANA, SMU, SJTU,SNOLAB & others

Materials Assay & Screening


XIA alpha screening @ SMU


HPGe counting @SNOLAB

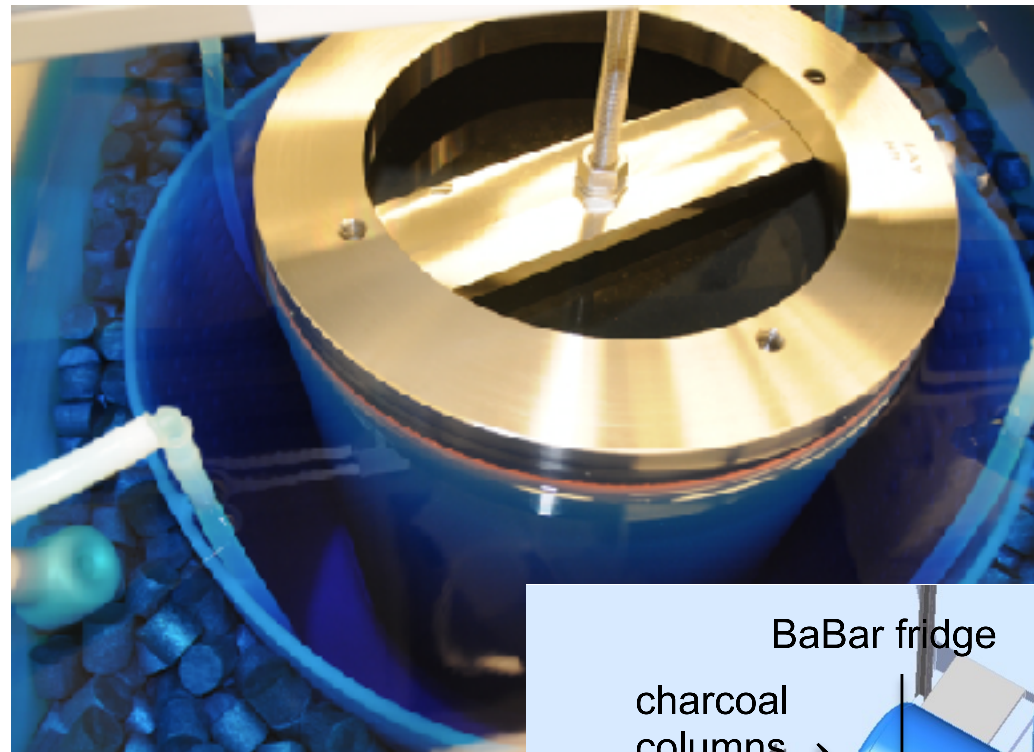


Radon Emanation @ PNNL


ICPMS @LNGS

In most cases, looking for materials at levels of < 1 ppb.

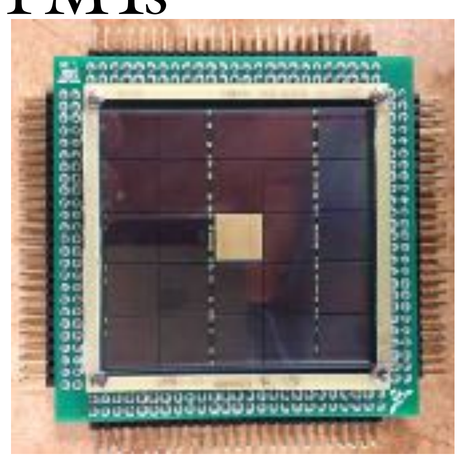
Make what you can't find!

Cryogenic distillation column for purification of ^{39}Ar

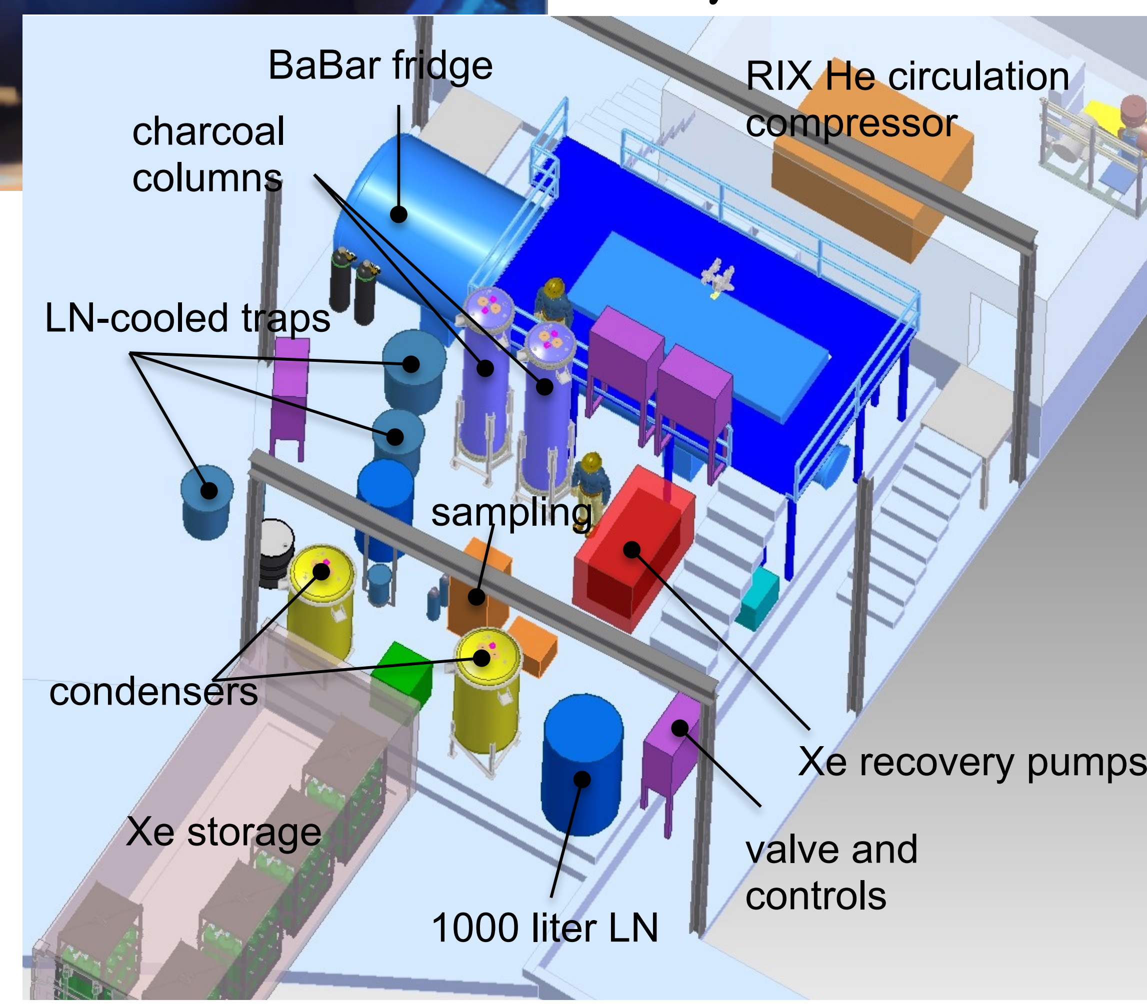


Electroforming of copper at PNNL

SiPMs replace PMTs

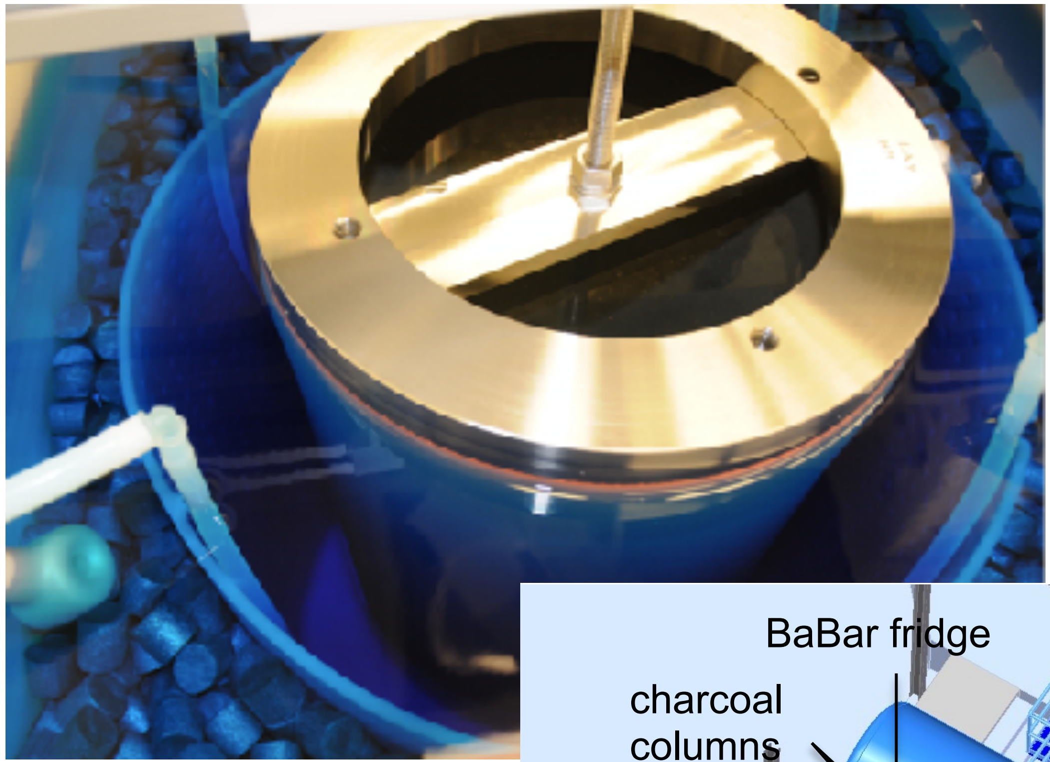


LZ Kr removal system at SLAC



Make what you can't find!

Future experiments will require a massive effort to extract and distill ^{39}Ar — plans are underway.



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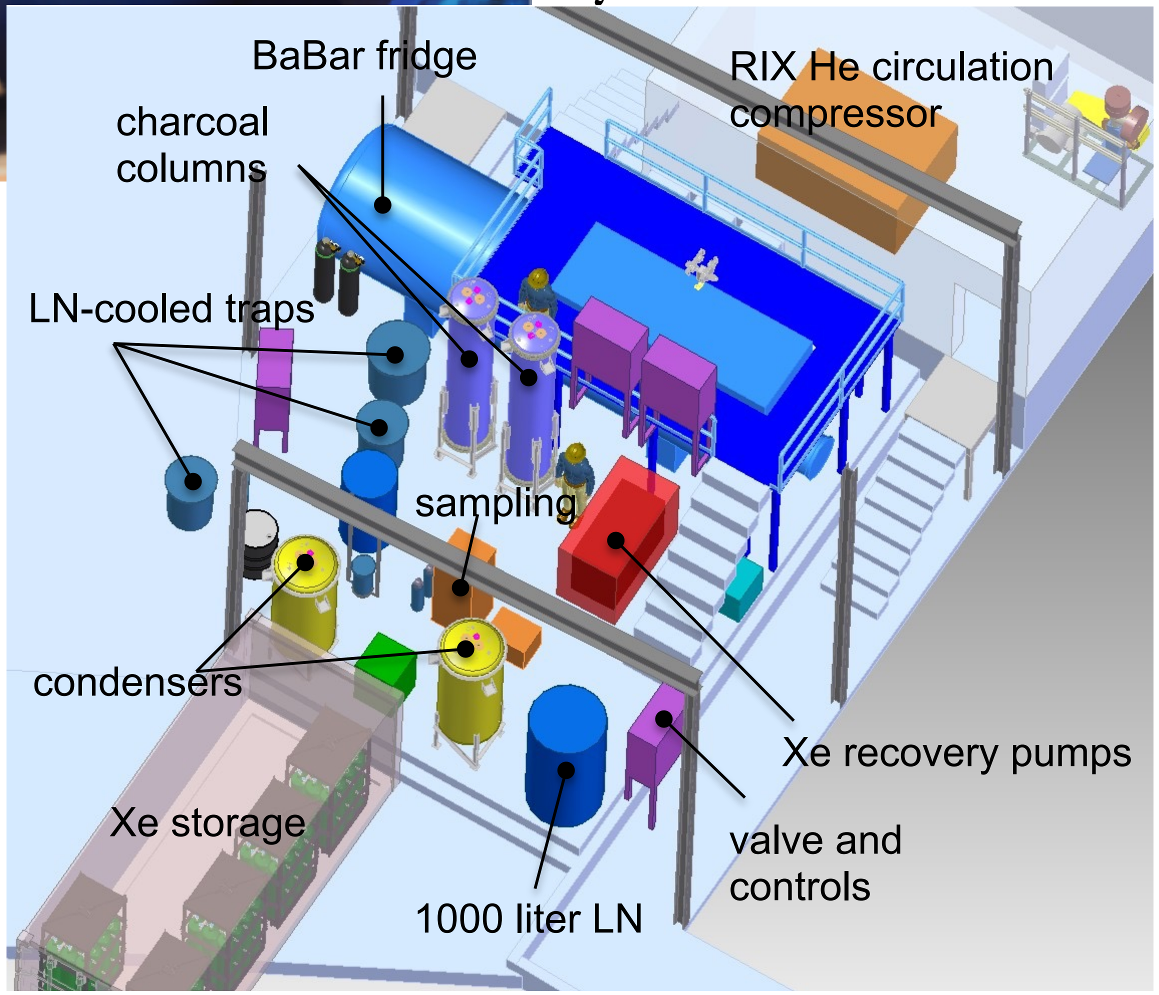
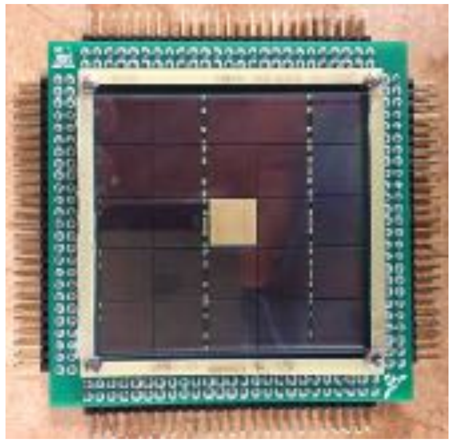
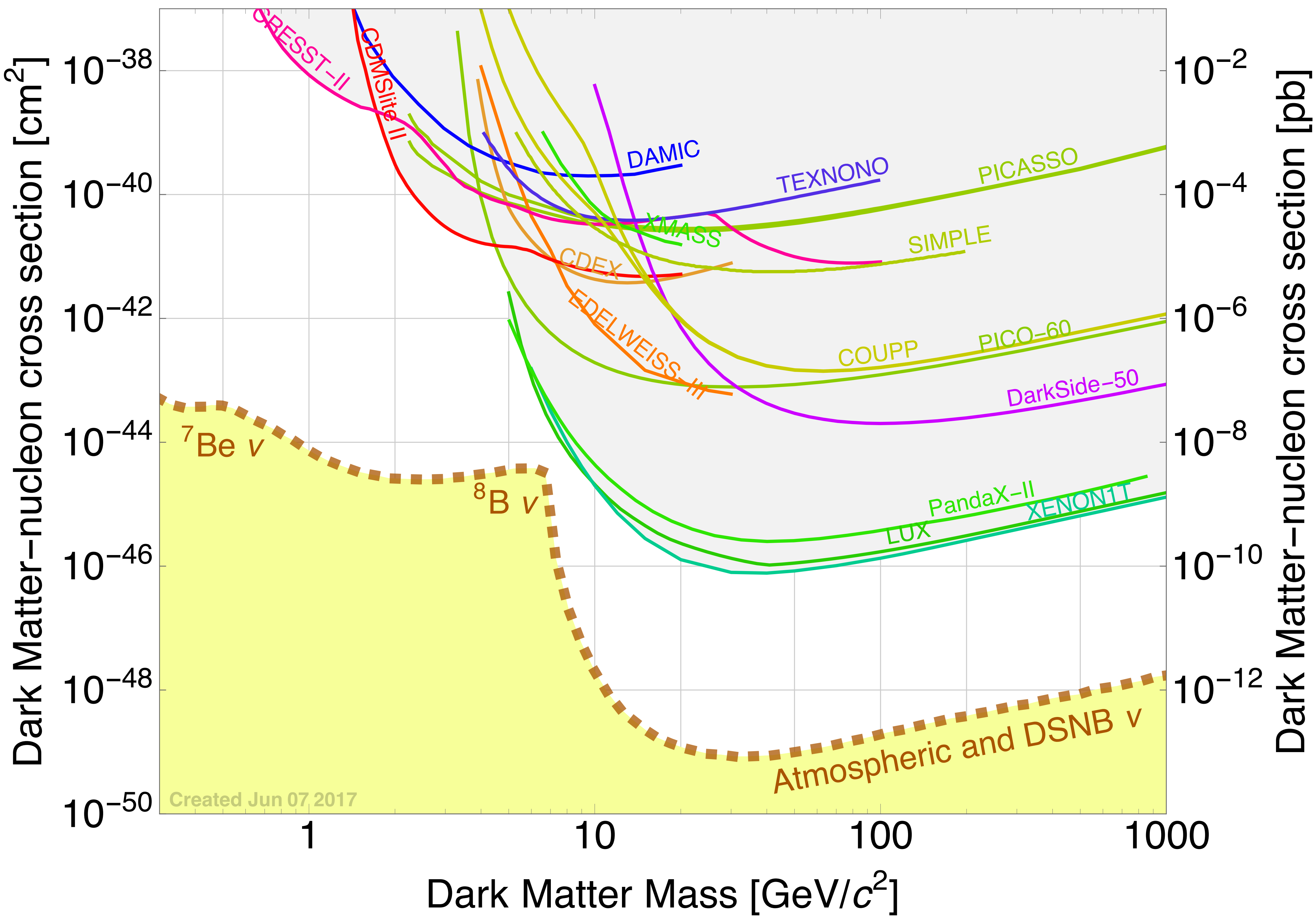


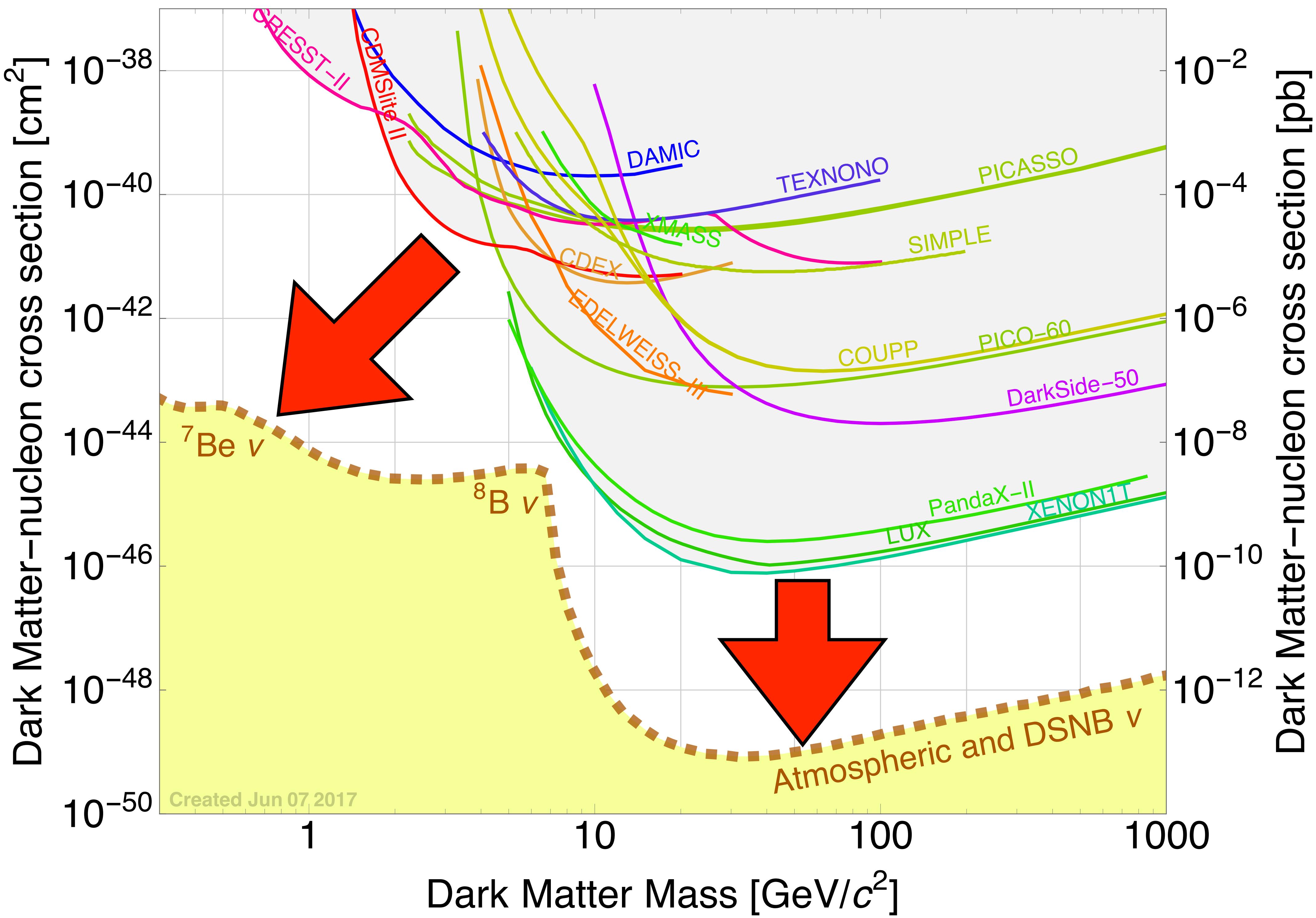
SiPMs replace PMTs



Current Landscape

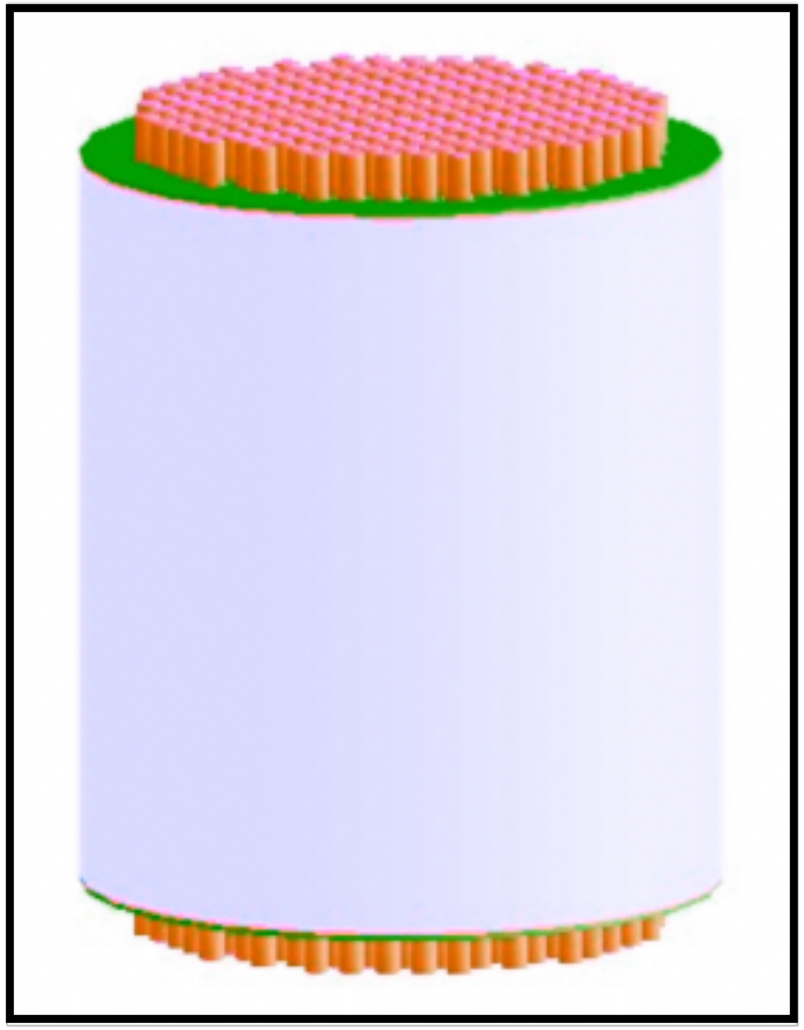


Current Landscape



Panda-X

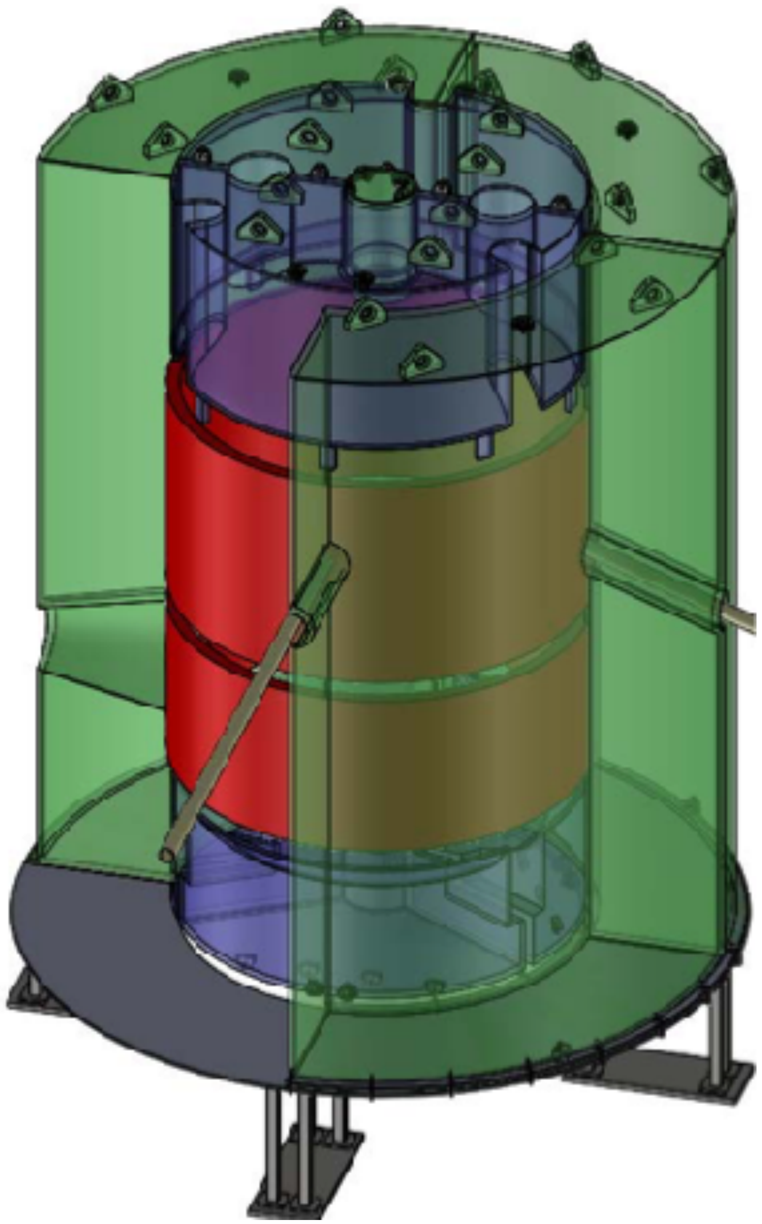
New Experiment Hall
at CJPL-II



PandaX-xT:
future multi-ton (~4-T) DM experiment - sensitivity to ^{8}B neutrinos, ~10^{-47} cm^{2} w/ 6 ton-yr exposure

LZ

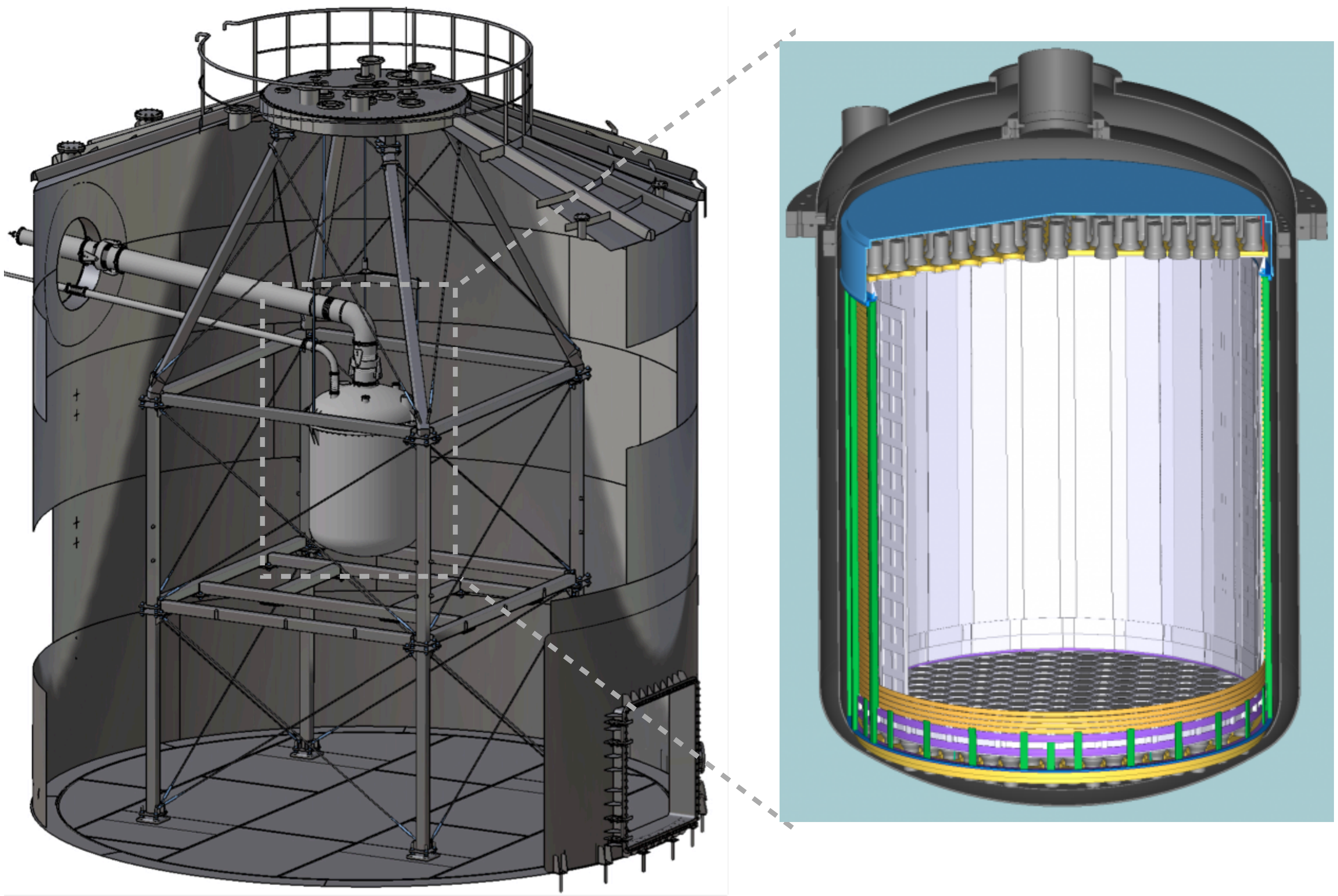
5.6 ton fiducial mass LXe TPC detector to be sited in the Davis Cavern at SURF, South Dakota.



Year	Month	Activity
2012	March	LZ (LUX−ZEPLIN) collaboration formed
2014	July	LZ Project selected in US and UK
2015	April	DOE CD-1/3a approval, similar in UK
		Conceptual Design Report arXiv: 1509.02910
2016	August	DOE CD-2/3b approval
2017	February	DOE CD-3c approval
		Technical Design Report arXiv: 1703.09144
2017	March	LUX removed from underground
2017	June	Begin preparations for surface assembly
2018	July	Begin underground installation
2020		Begin commissioning
2021		Begin data taking for WIMP search
2024+		5+ years of operations

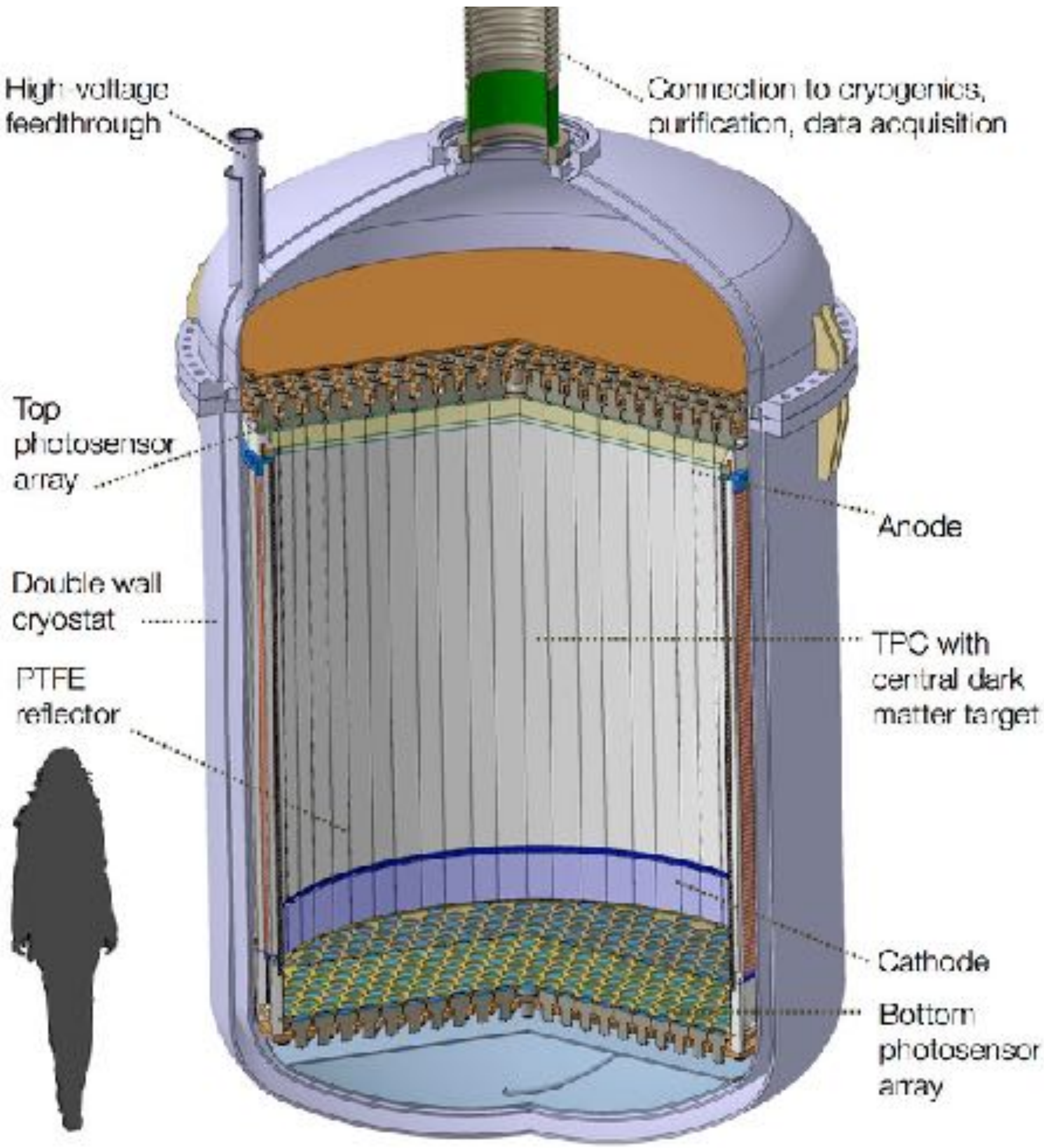
XENONnT

XENONnT proposal to LNGS submitted, work on site at LNGS to start in late 2018.



8 ton total LXe mass, 6 ton active (x3 compared to XENON1T)

DARWIN



- International collaboration (previously a consortium) of 24 groups.
- 40 ton LXe TPC detector with a goal of being sensitive to the coherent neutrino background.
- Plan to begin after completion of XENONnT
- Active R&D supported by the ERC.

The Global Argon Dark Matter Collaboration

ArDM
DarkSide
DEAP
MiniCLEAN

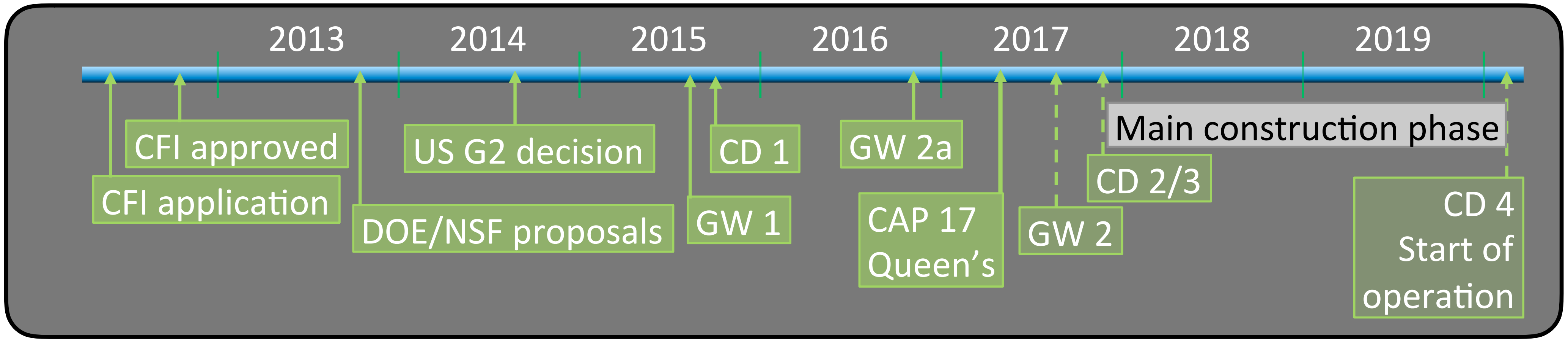
A Single Global Program for Direct Dark Matter Searches

- Currently taking data: ArDM, DarkSide-50, **DEAP-3600**
- **Next step: DarkSide-20k at LNGS (2021-)**
- Last Step: **300 tonnes detector**, location t.b.d **(2027-)**

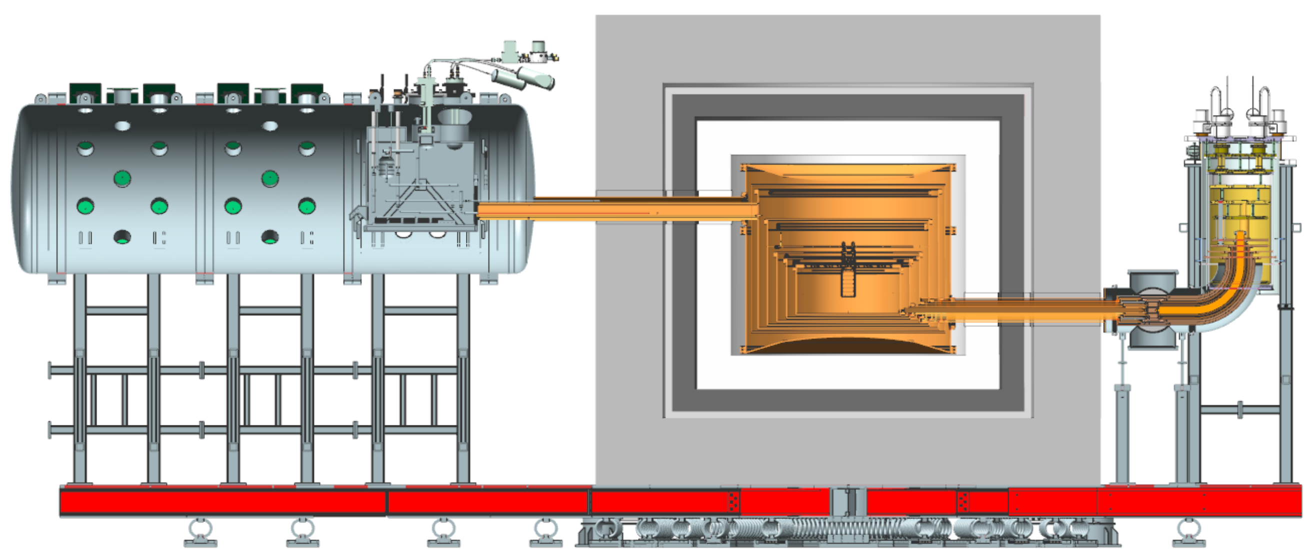
- Status:

- DarkSide-20k approved by INFN and LNGS in April 2017 and by NSF in Oct 2017
- Officially supported by LNGS, LSC, and SNOLAB
- 30 tonnes (20 tonnes fiducial) of low-radioactivity underground argon
- 14 m^2 of SiPM coverage

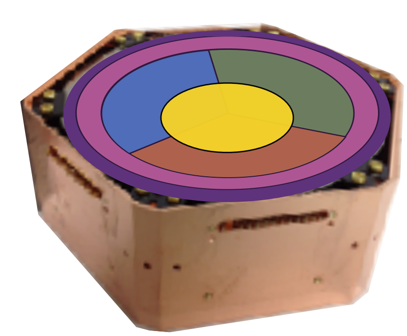
SuperCDMS



- SuperCDMS SNOLAB cryostat designed to hold 31 towers.



- Initial Payload:
  1 Ge iZIP tower (6 Ge)
  1 Ge/Si iZIP tower (4 Ge/ 2 Si)
  2 HV towers (4 Ge/ 2 Si each)

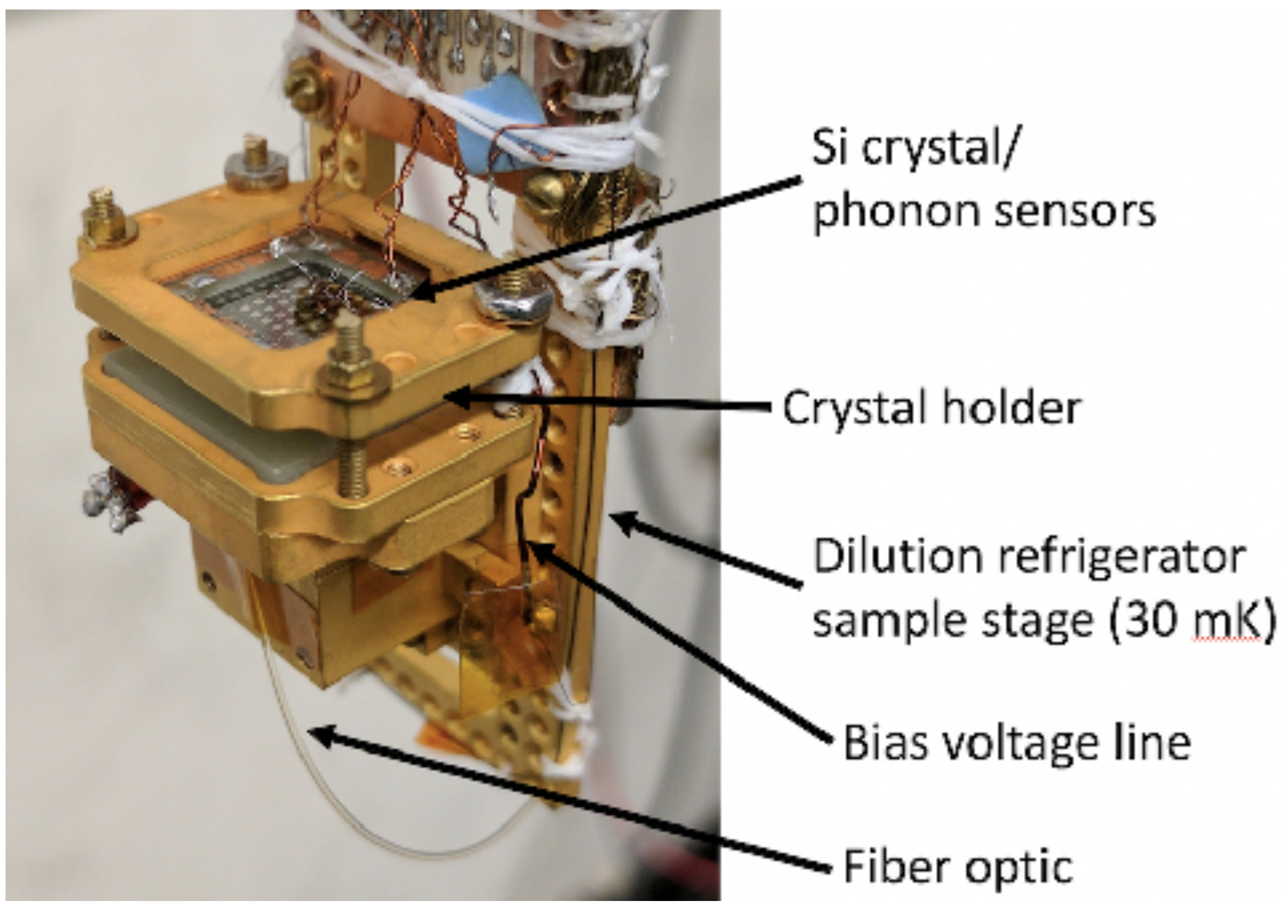


HV detector

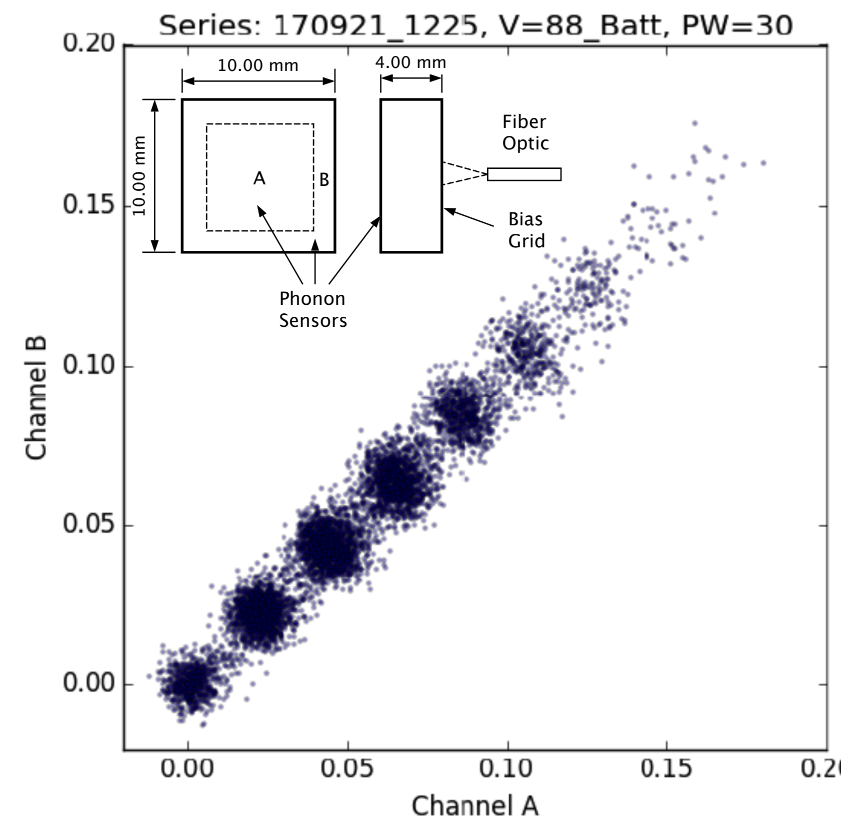
iZIP detector

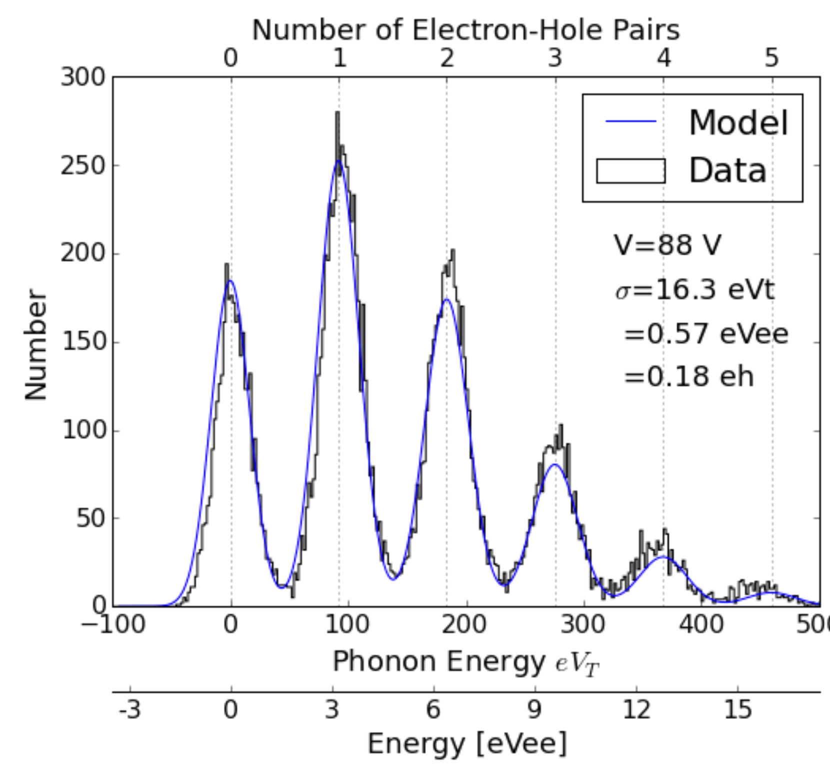
SuperCDMS R&D

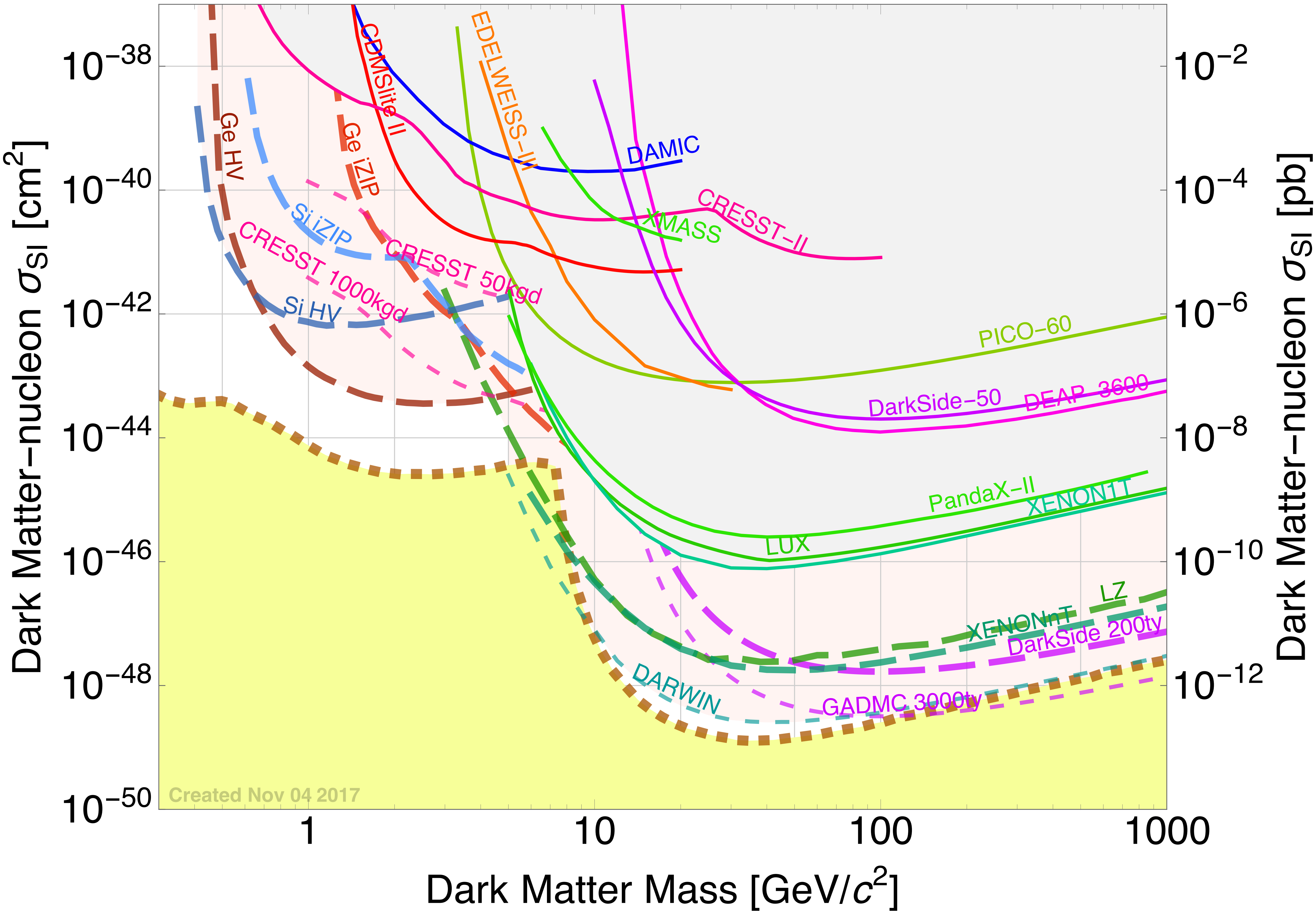
- Seeing e-h quantization: proof of principle in Si detector
- Enables thresholds down to one e-h pair enabling future searches down to solar neutrino background!



arXiv:1710.09335





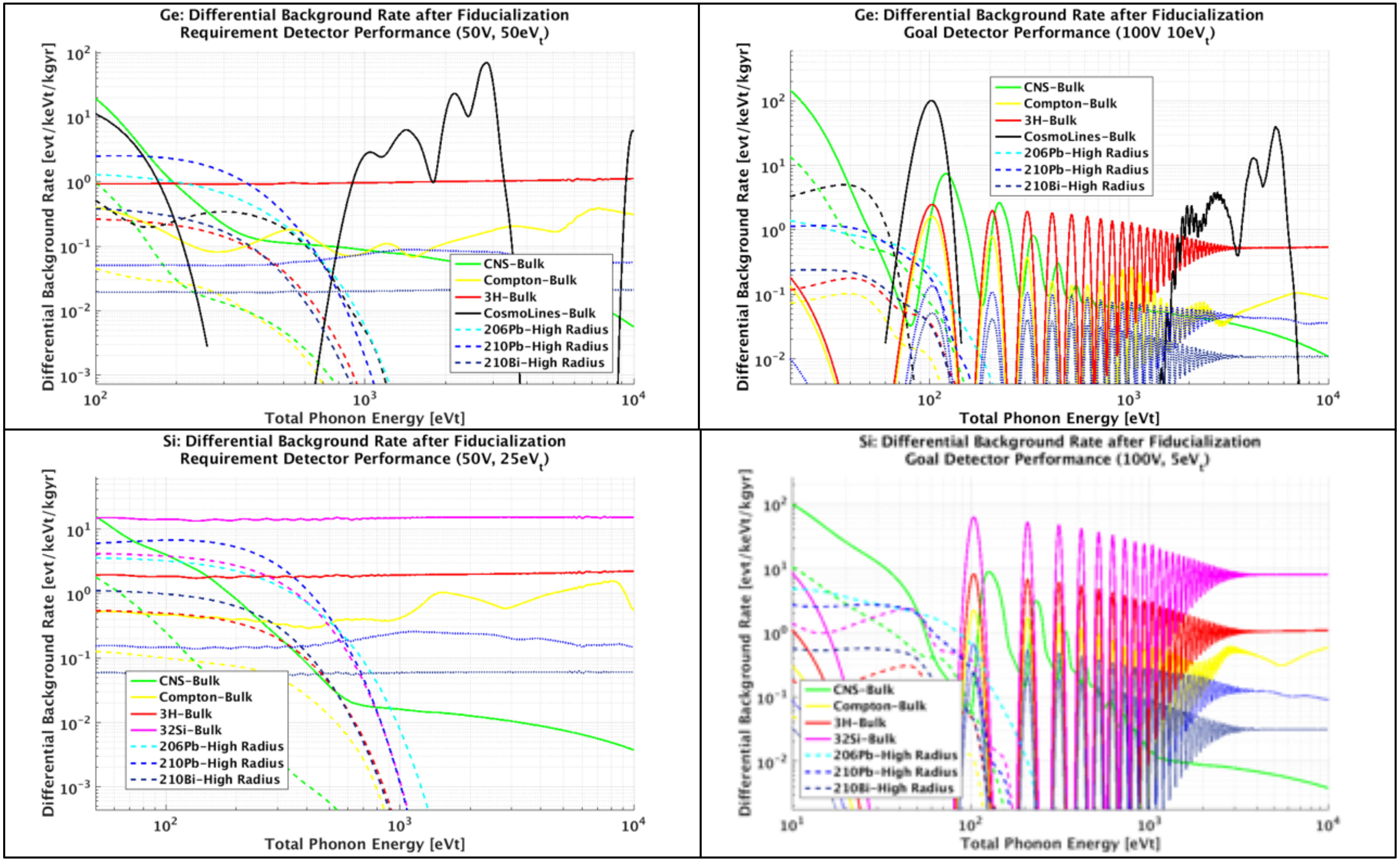

Dark Matter–nucleon σ_{SI} [cm^2]
Dark Matter–nucleon σ_{SI} [pb]
Dark Matter Mass [GeV/c^2]
10^{-38}
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
1
10
100
1000
CDMSlite II
EDELWEISS-III
DAMIC
CRESST-II
XMASS
Ge HV
Ge iZIP
Si iZIP
CRESST 50kgd
CRESST 1000kgd
Si HV
PICO-60
DarkSide-50
DEAP-3600
PandaX-II
XENON1T
LUX
LZ
XENONnT
DarkSide 200ty
DARWIN
GADMC 3000ty
Created Nov 04 2017

Conclusions

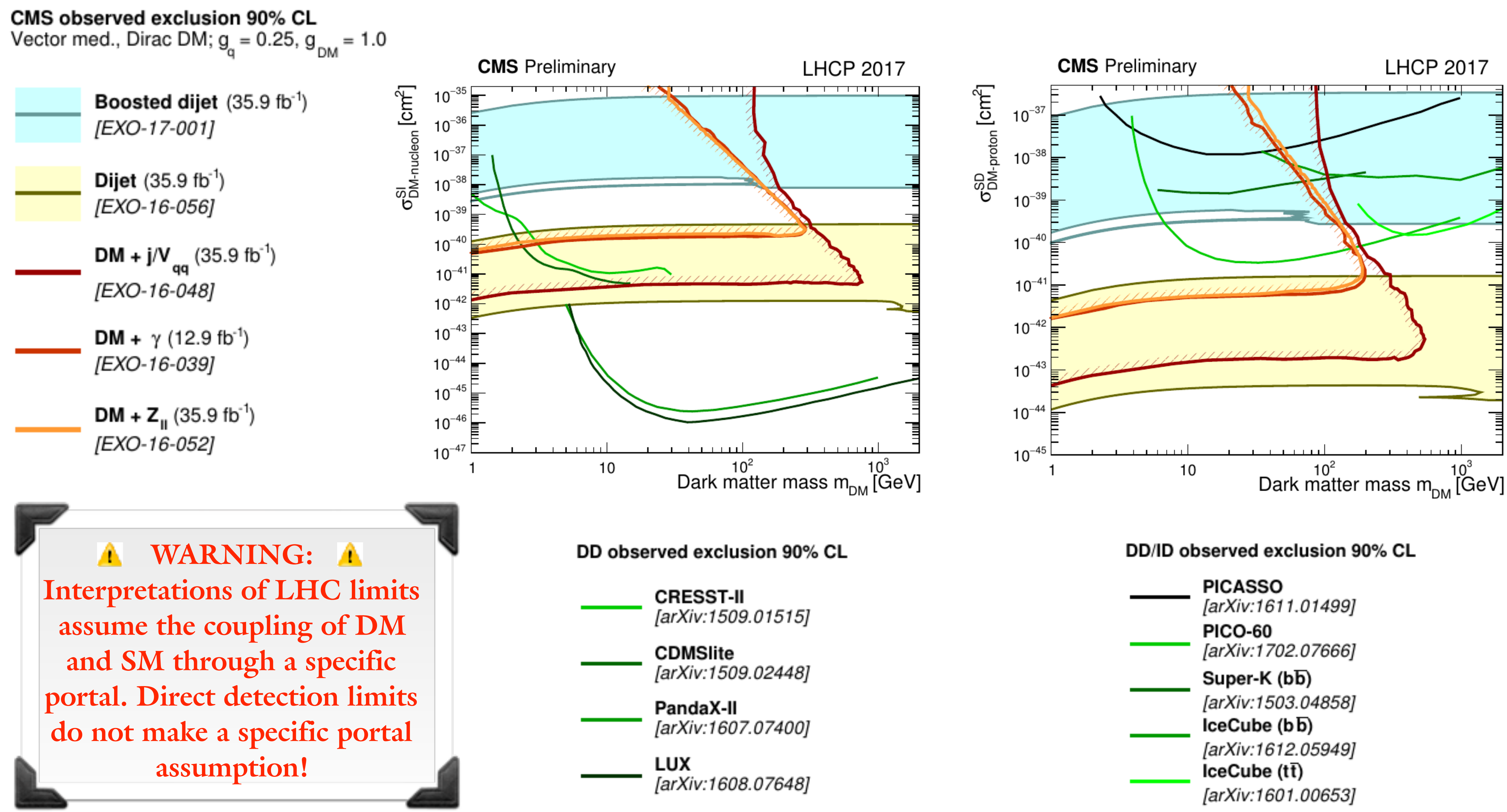
- There is a very large world-wide, multi-pronged approach for experimentally trying to detect the constituents of dark matter that includes direct detection of DM-nucleon scattering, indirectly detecting products of annihilation or decay of DM and producing DM in a collider.
- Dark matter search experiments have been very successful in ruling out a number of favored candidates. No compelling evidence for the detection of DM currently exists. However, there are perhaps tantalizing "hints" from indirect detection searches and the DAMA/LIBRA anomaly is not yet fully explained.
- A diverse set of experiments and target materials are needed. All three approaches are complementary and are making fast headway in exploring new parameter space.
- Stay tuned! Current experiments are producing results at a fast pace and larger, more sensitive experiments are soon to come online.

Back-up Slides

Simulated Spectra for HV Ge & Si detectors – showing future reach to solar neutrino floor enabled with e-h quantization



CMS & Direct Detection



⚠ **WARNING:** ⚠

Interpretations of LHC limits assume the coupling of DM and SM through a specific portal. Direct detection limits do not make a specific portal assumption!