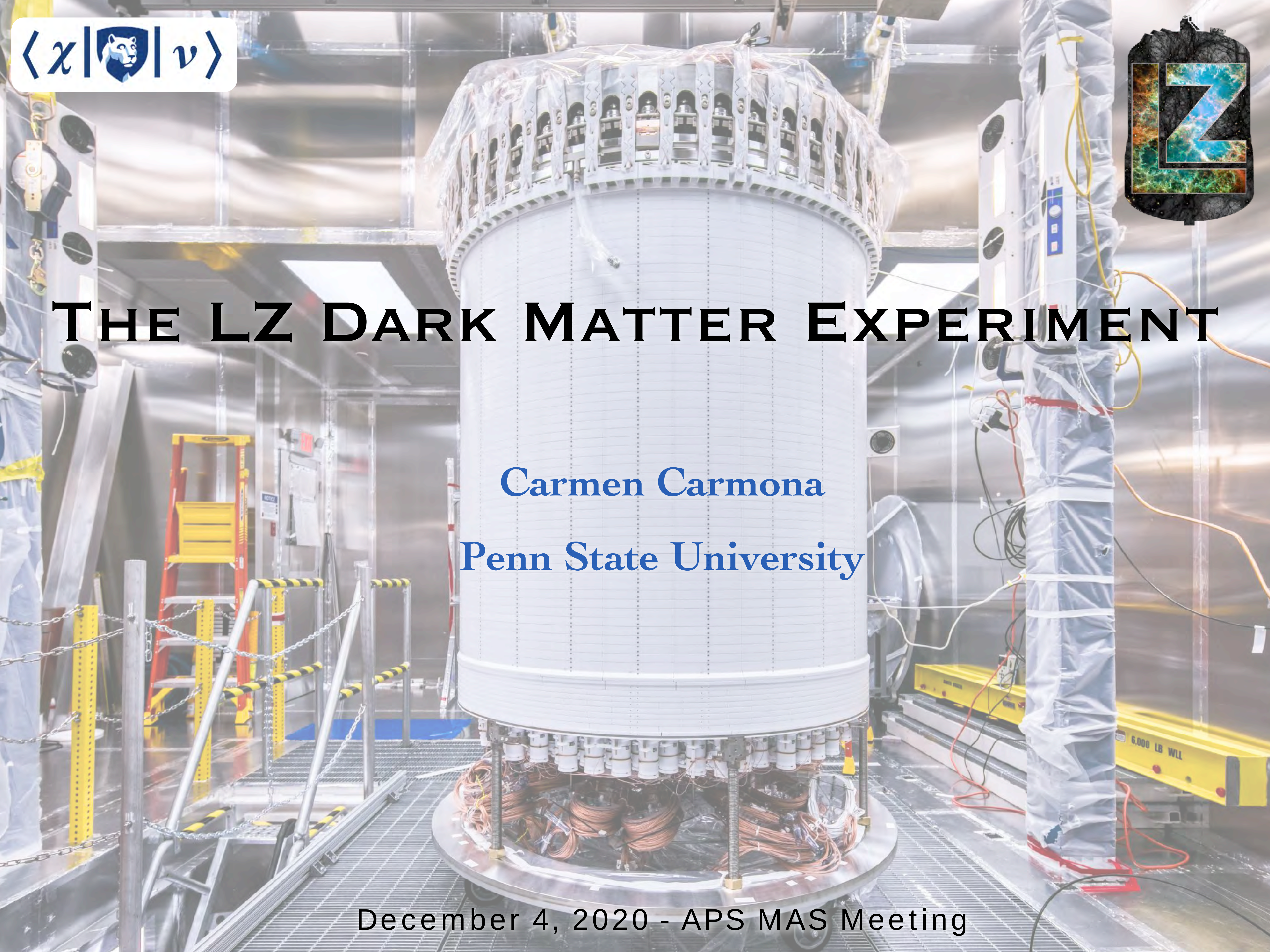


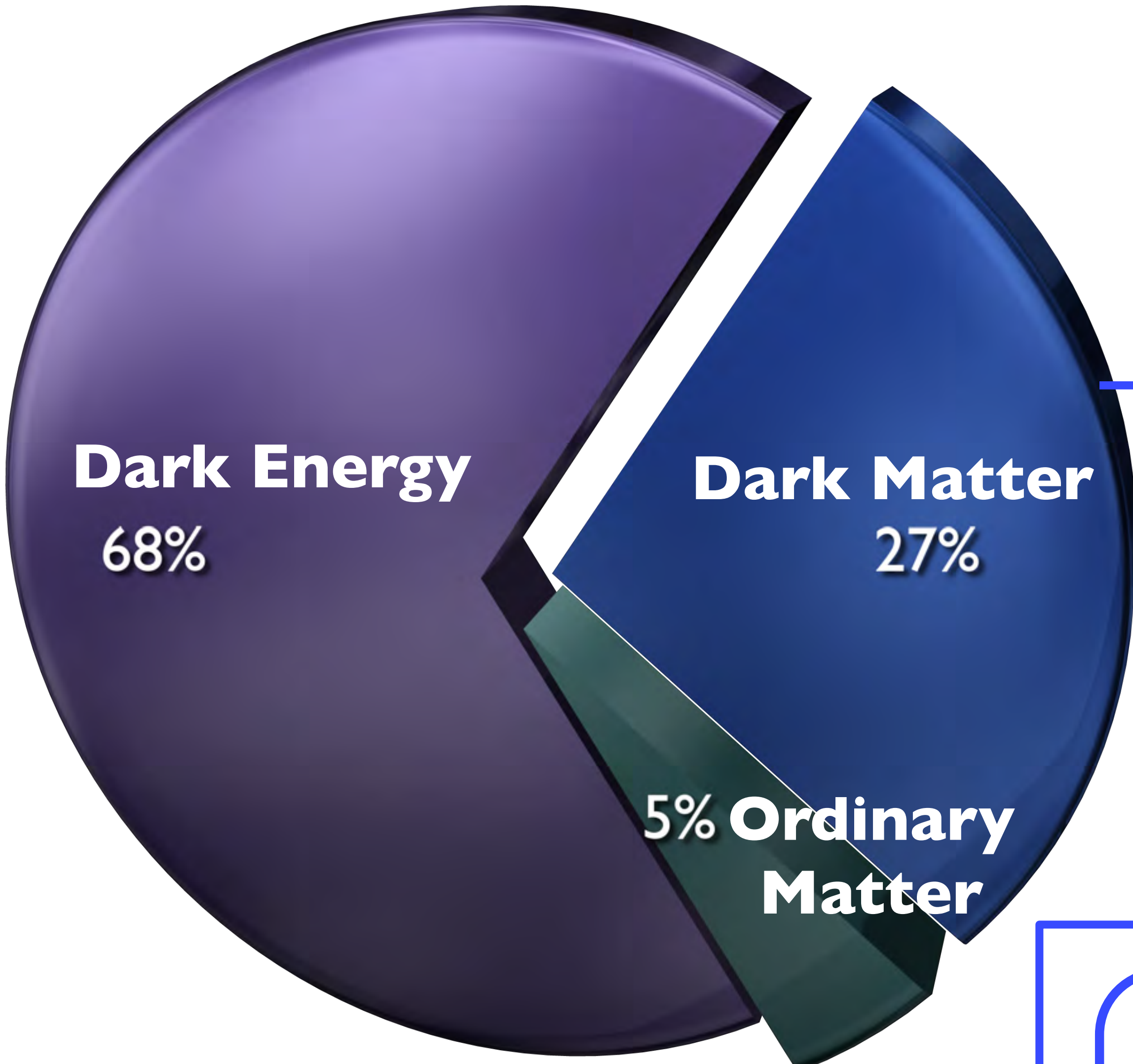
The LZ Dark Matter Experiment

Carmen Carmona

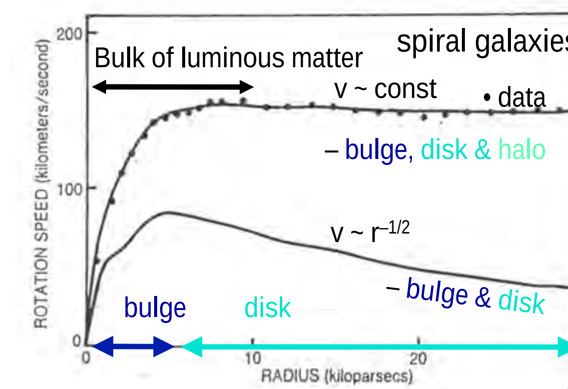
Penn State University

December 4, 2020 - APS MAS Meeting

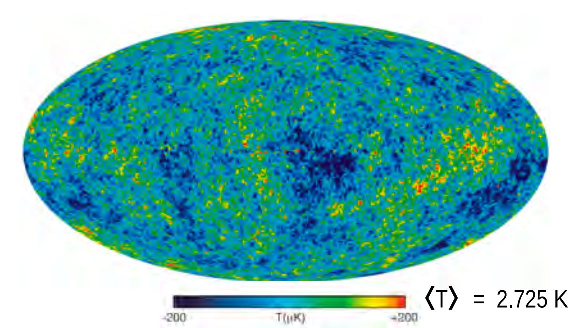
Dark Matter Evidence

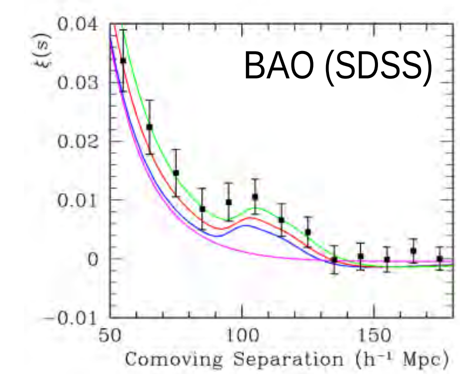


Motion of galaxies and galaxy clusters

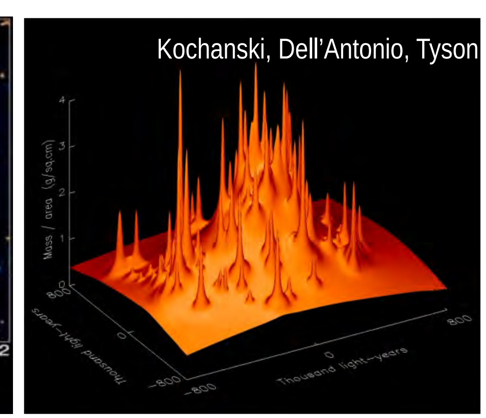


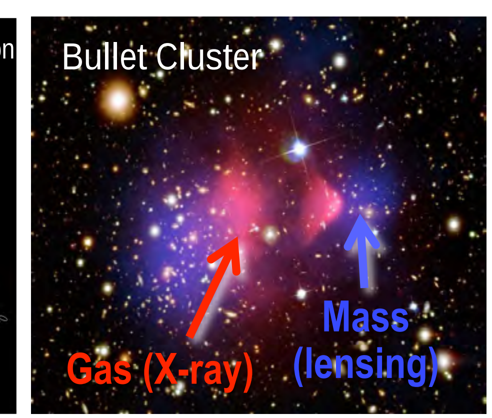
Cosmological Evidence (CMB, BAO, Supernovae…)



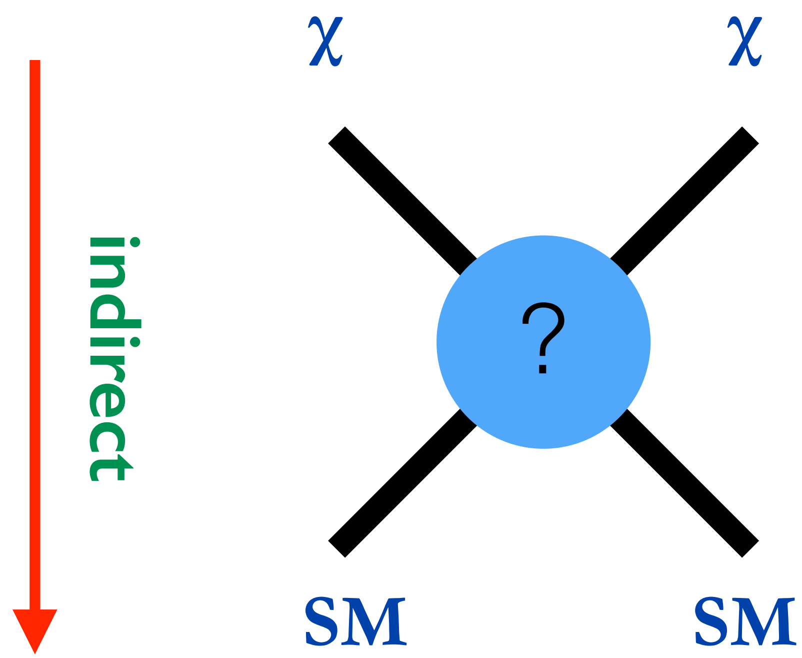


Gravitational Lensing (weak/strong)



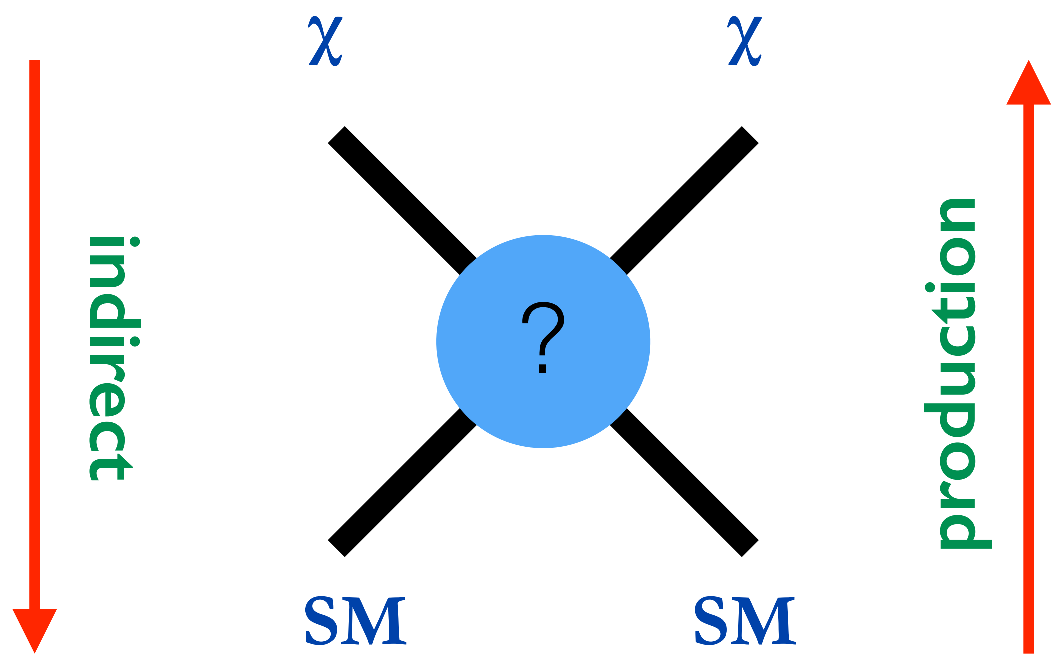


Dark Matter Detection



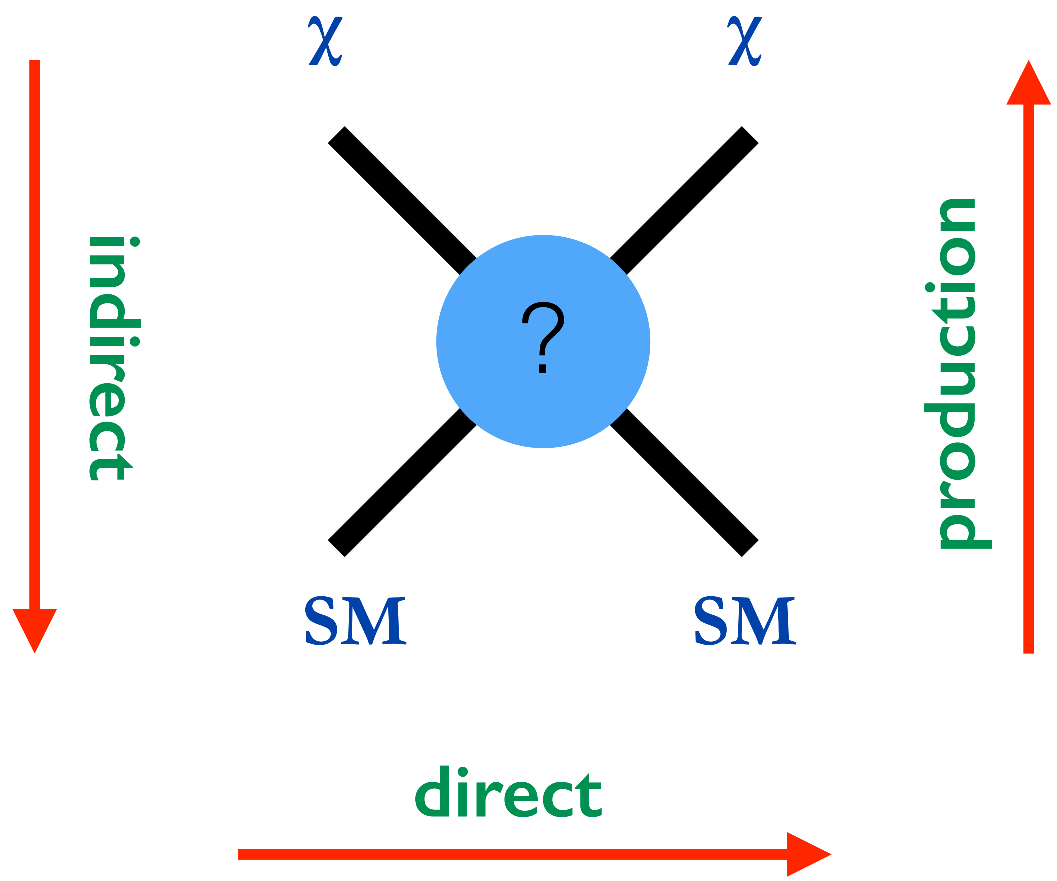
Indirect Detection
(DM annihilation)
HAWC, ANTARES,
Fermi, IceCube,
MAGIC, CTA, AMS,
HESS, VERITAS, GAPS…

Dark Matter Detection



Accelerator Searches
(DM production)
LHC, LDMX

Dark Matter Detection



Direct Detection

Different Targets / Technologies:

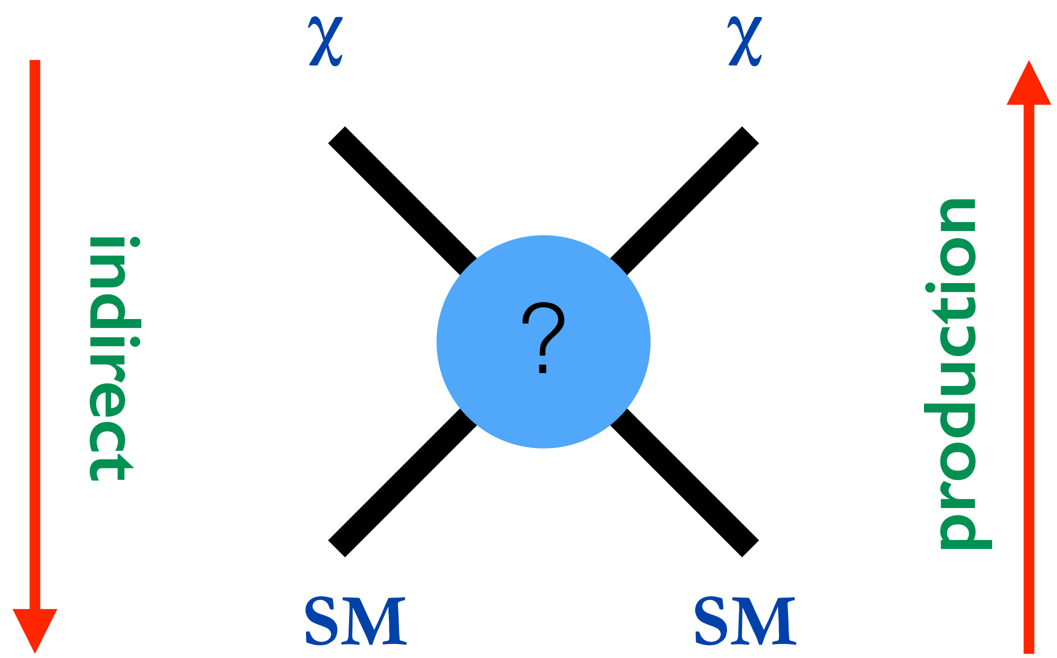
NaI, Ge, Si, Ar, Xe, RF

and many more…

Generally model independent

- can search for a variety of candidates

Dark Matter Detection



direct

Direct Detection

Different Targets / Technologies:

NaI, Ge, Si, Ar, Xe, RF

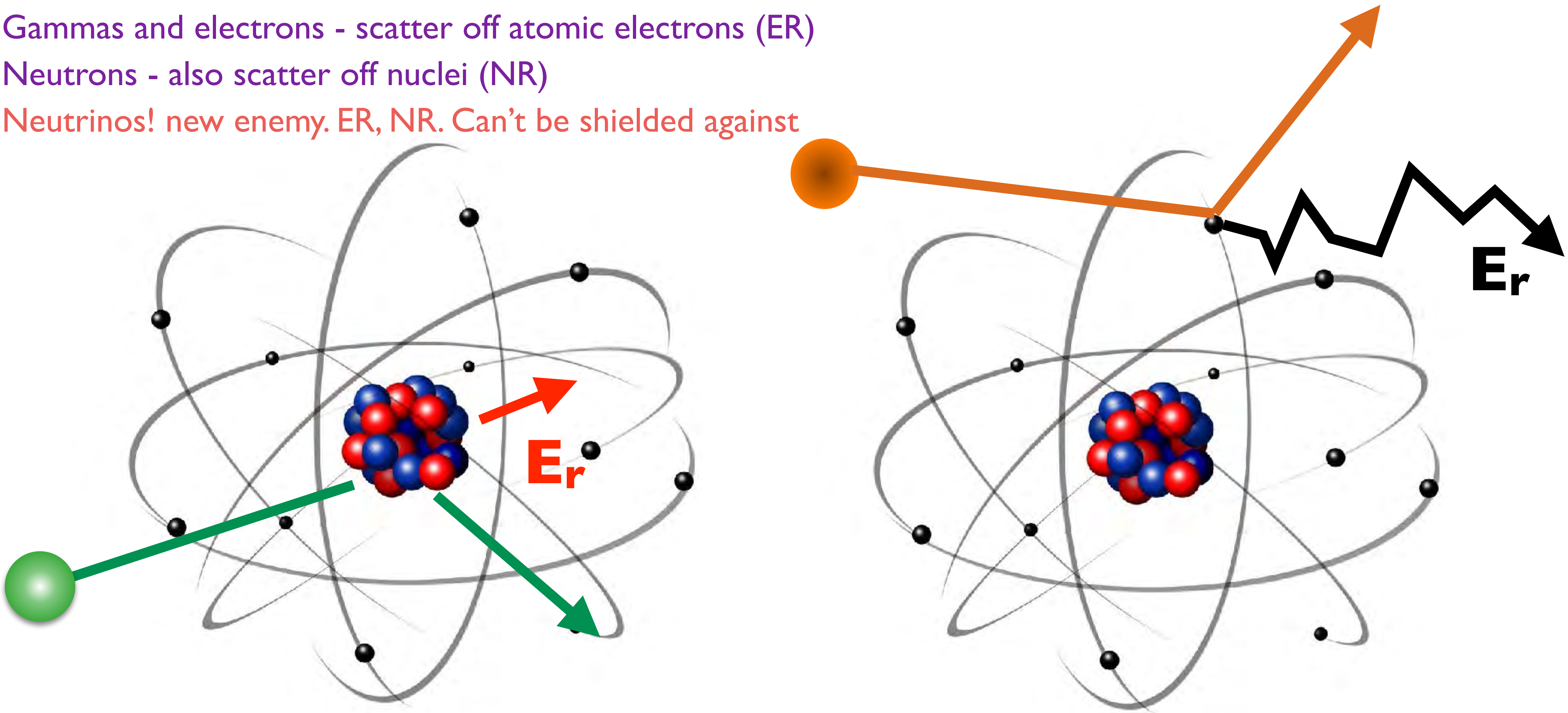
and many more…

Generally model independent

- can search for a variety of candidates

WIMPs Direct Detection

- WIMPs scatter off nuclei (NR)
  - Expect recoils O(10 keV)
  - Expect < 1 event / tonne / year
- Backgrounds
  - Gammas and electrons - scatter off atomic electrons (ER)
  - Neutrons - also scatter off nuclei (NR)
  - Neutrinos! new enemy. ER, NR. Can't be shielded against

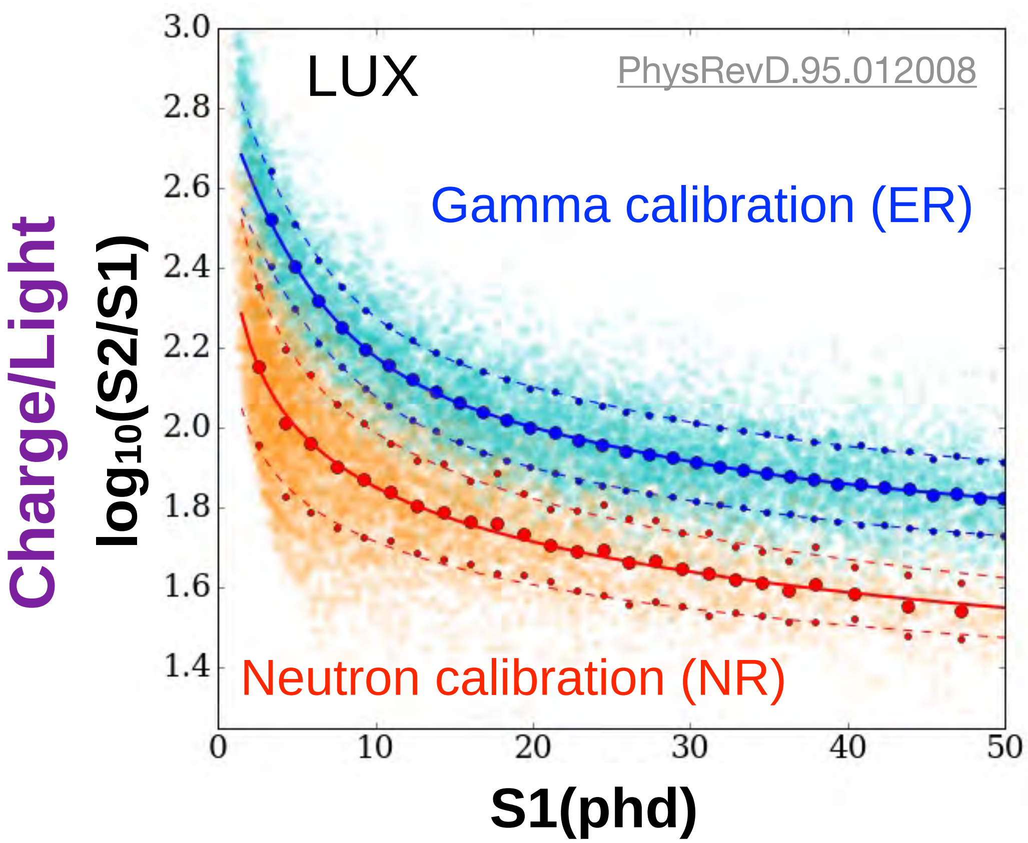


Signal: Nuclear Recoil (calibrate with neutrons)

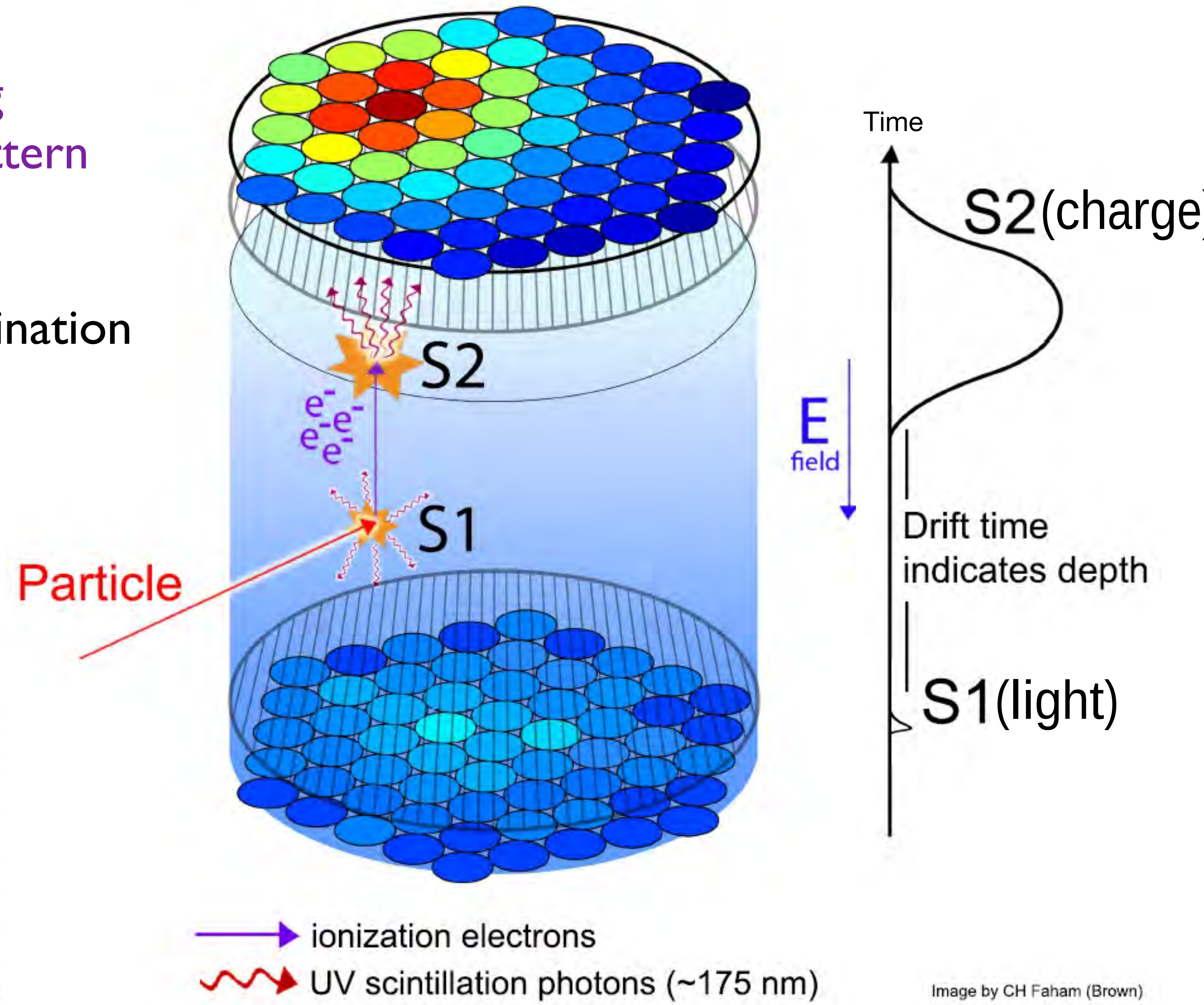
Background: Electron Recoil

Dual Phase Noble Liquid TPC

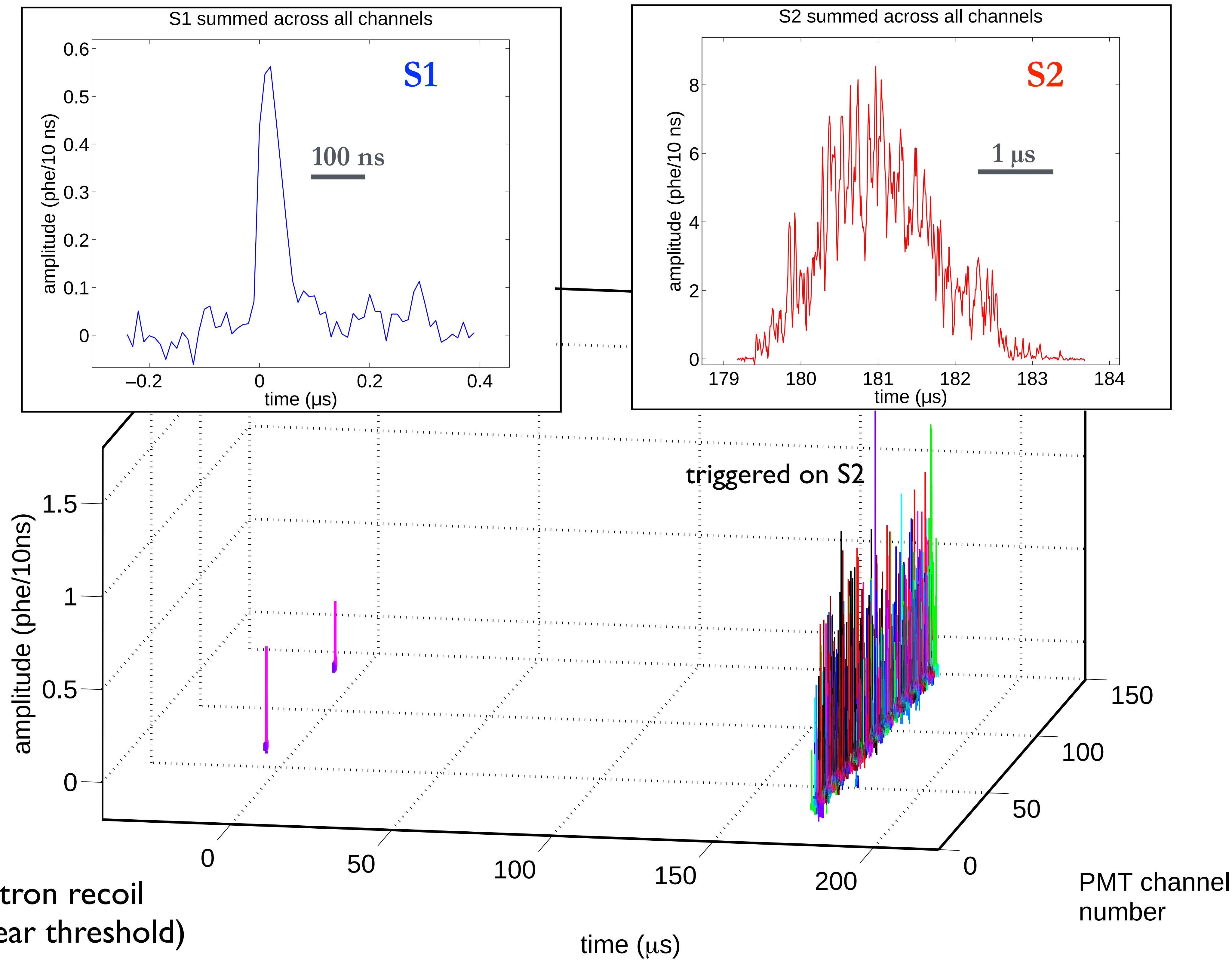
- Excellent 3D imaging capability
  - ✦ Z position from S1 - S2 timing
  - ✦ XY positions from S2 light pattern
- Ratio of charge (S2) to light (S1)
  => Signal vs Background discrimination



99.8% discrimination, 50% NR acceptance



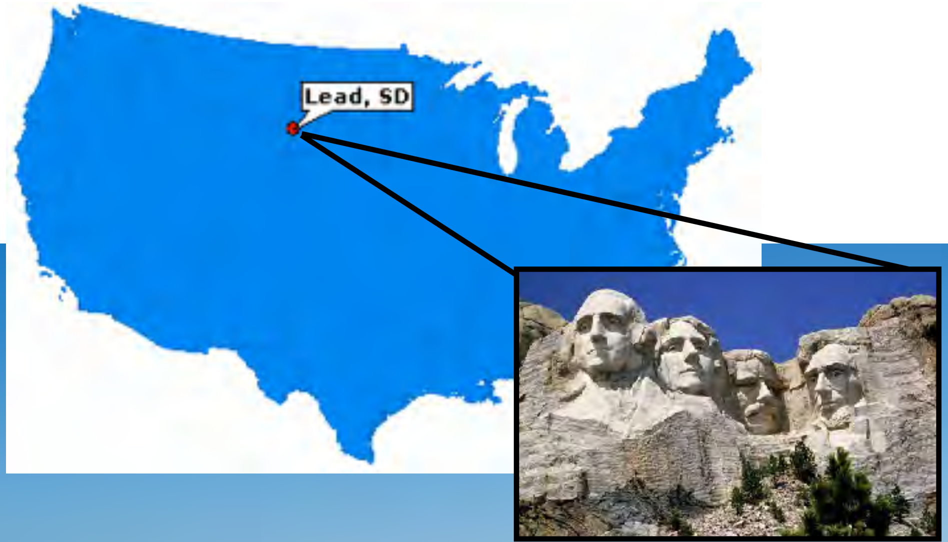
A Typical Event

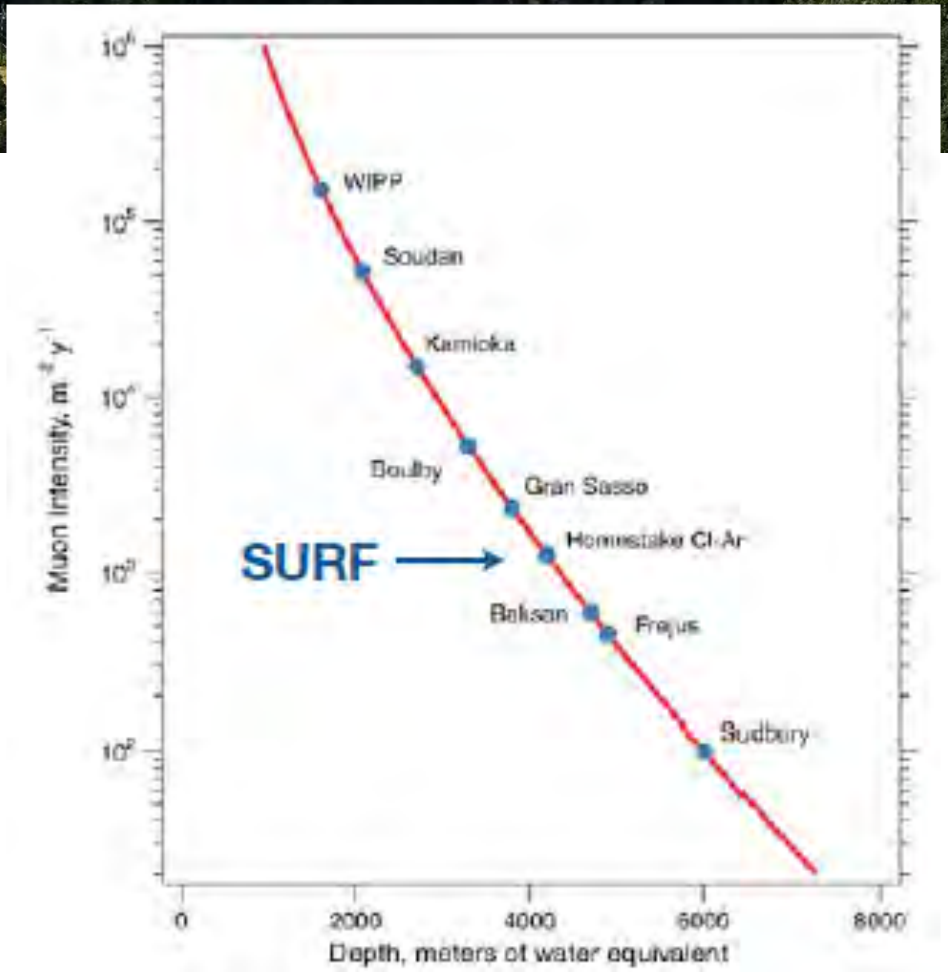


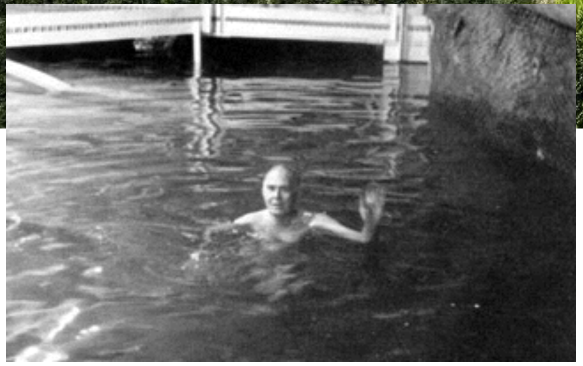
LUX

1.5 keV electron recoil
(2 phe S1, near threshold)

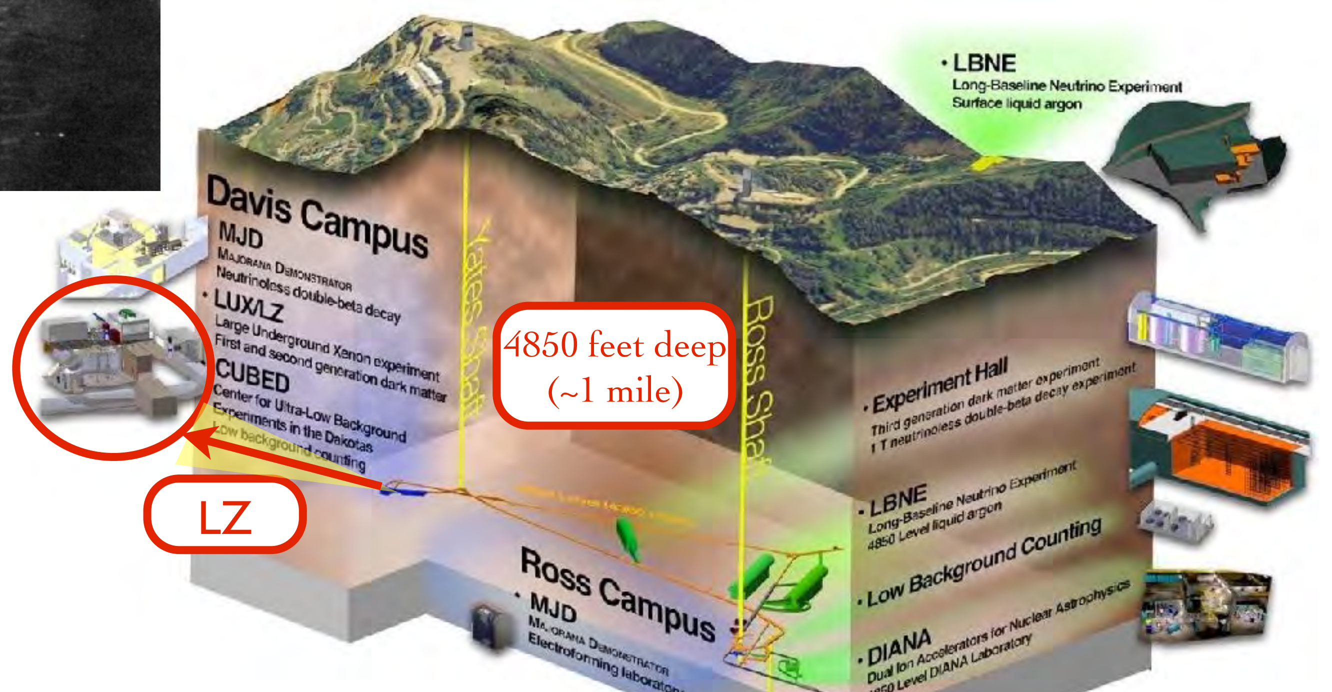
Sanford Underground Research Facility (SURF) in Lead, SD







Ray Davis, noble prize winner

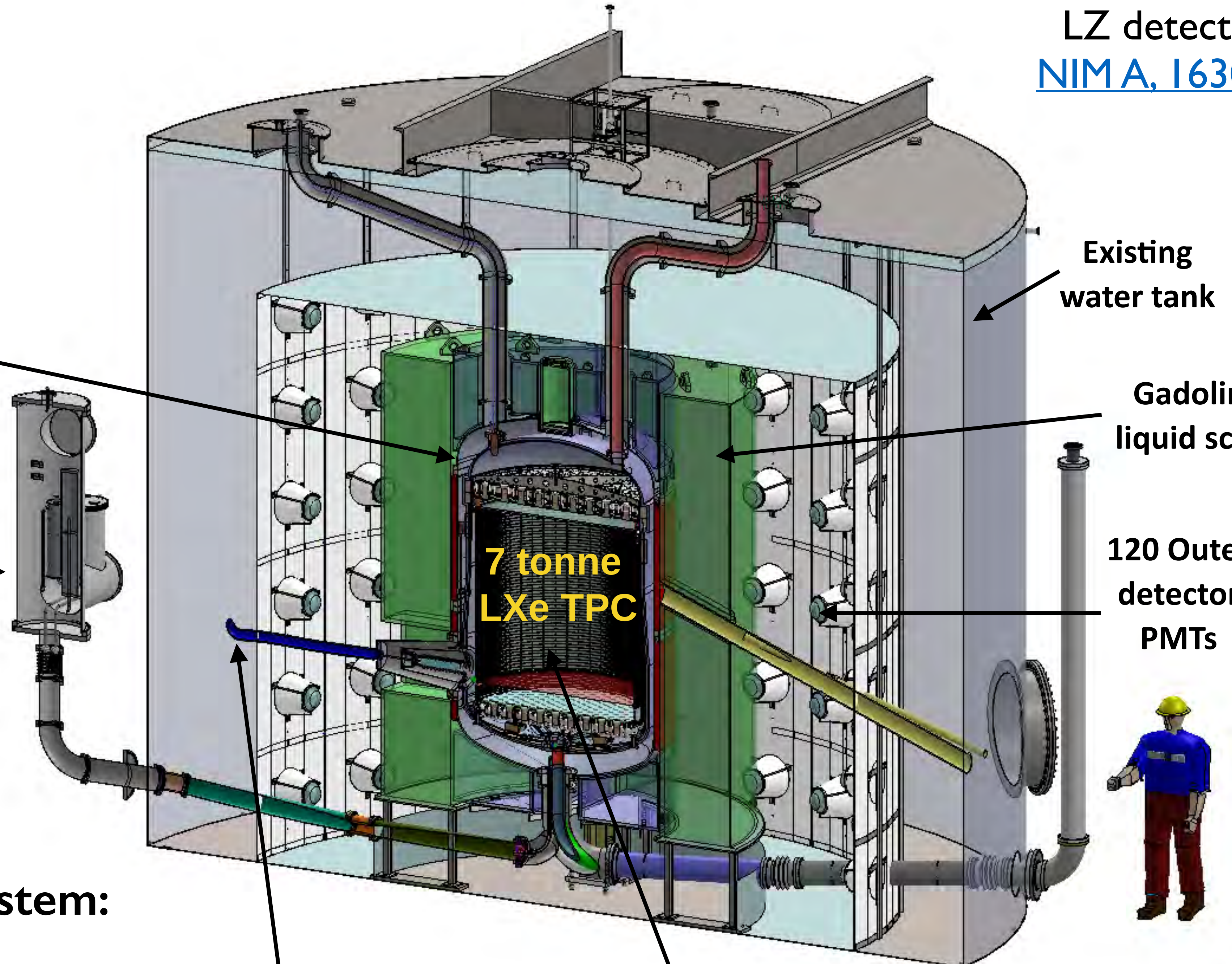


Muon flux reduced by 10^7 (4.3 km.w.e)

LZ Detector Overview

- **Xenon TPC**
  - ✦ Total mass: 10 T
  - ✦ Active mass: 7 T
  - ✦ Fiducial: 5.6 T

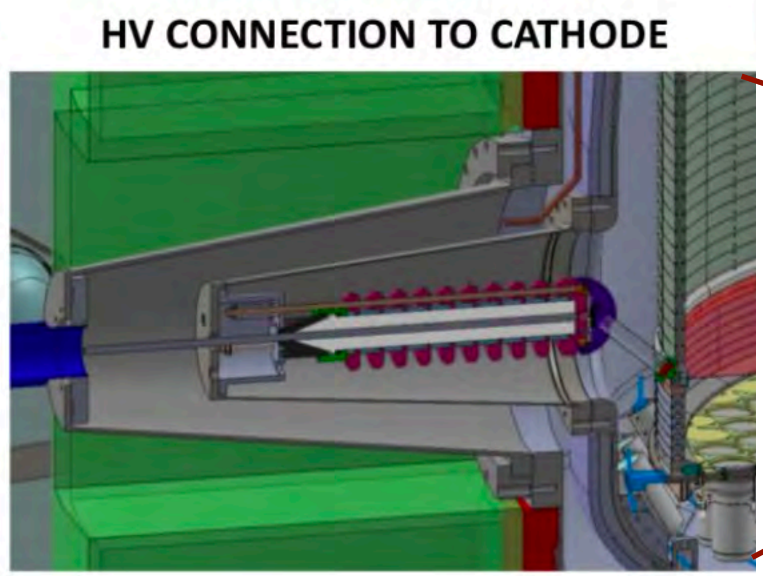
LZ detector paper:
[NIM A, 163047 (2019)]

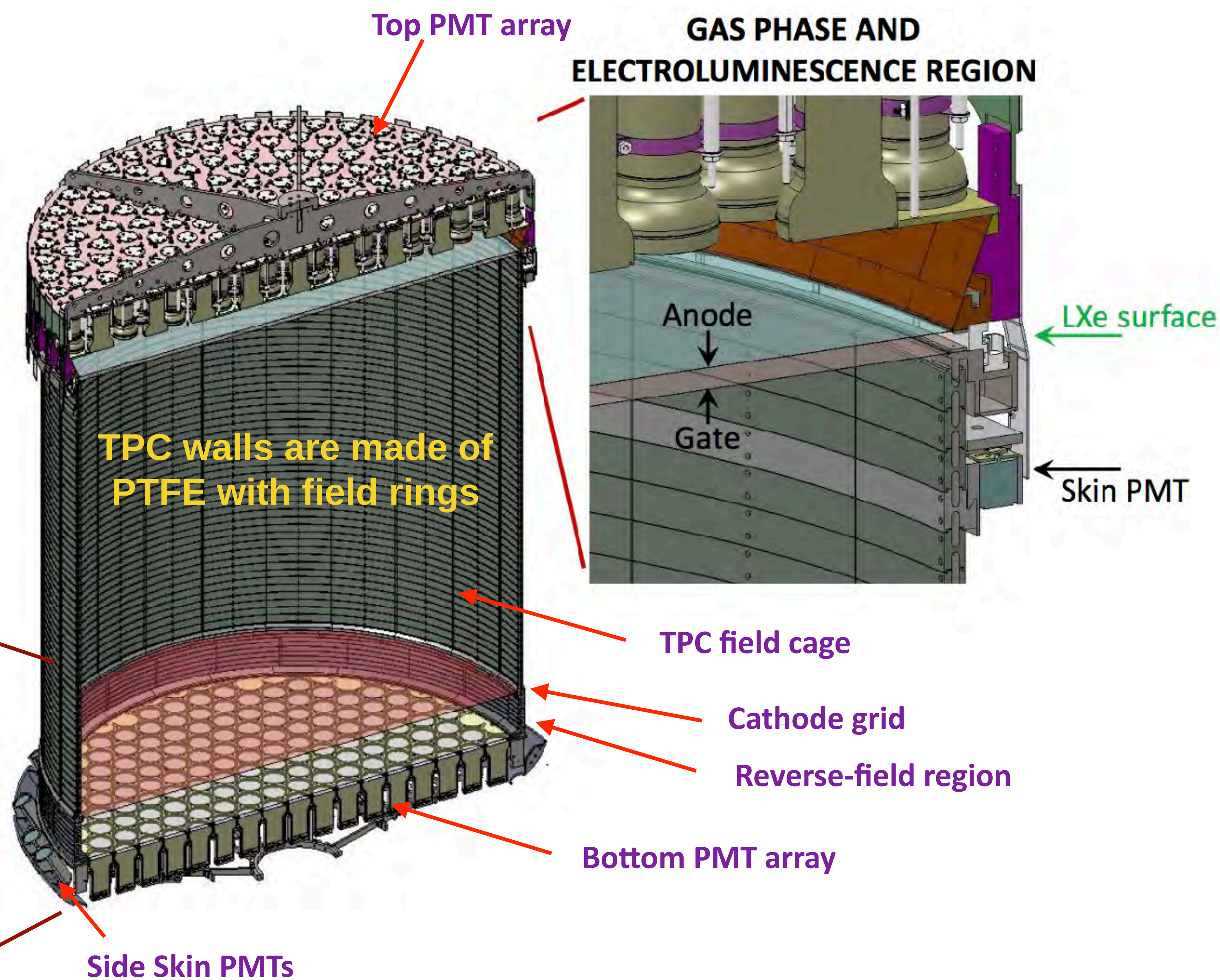


- **3-component veto system:**
  - ✦ Water tank
  - ✦ Gd-loaded scintillator
  - ✦ Instrumented LXe Skin

Xenon TPC

- 1.5 m diameter x 1.5 m height
- 7T active LXe (5.6T fiducial)
  - x50 more than LUX
  - x6 XENON1T
- 50 kV cathode HV
- 494x 3” PMTs
- Gas circulation @ 500 slpm (turnover full mass in 2.4 days)
- Instrumented Xe skin region, outside the field cage

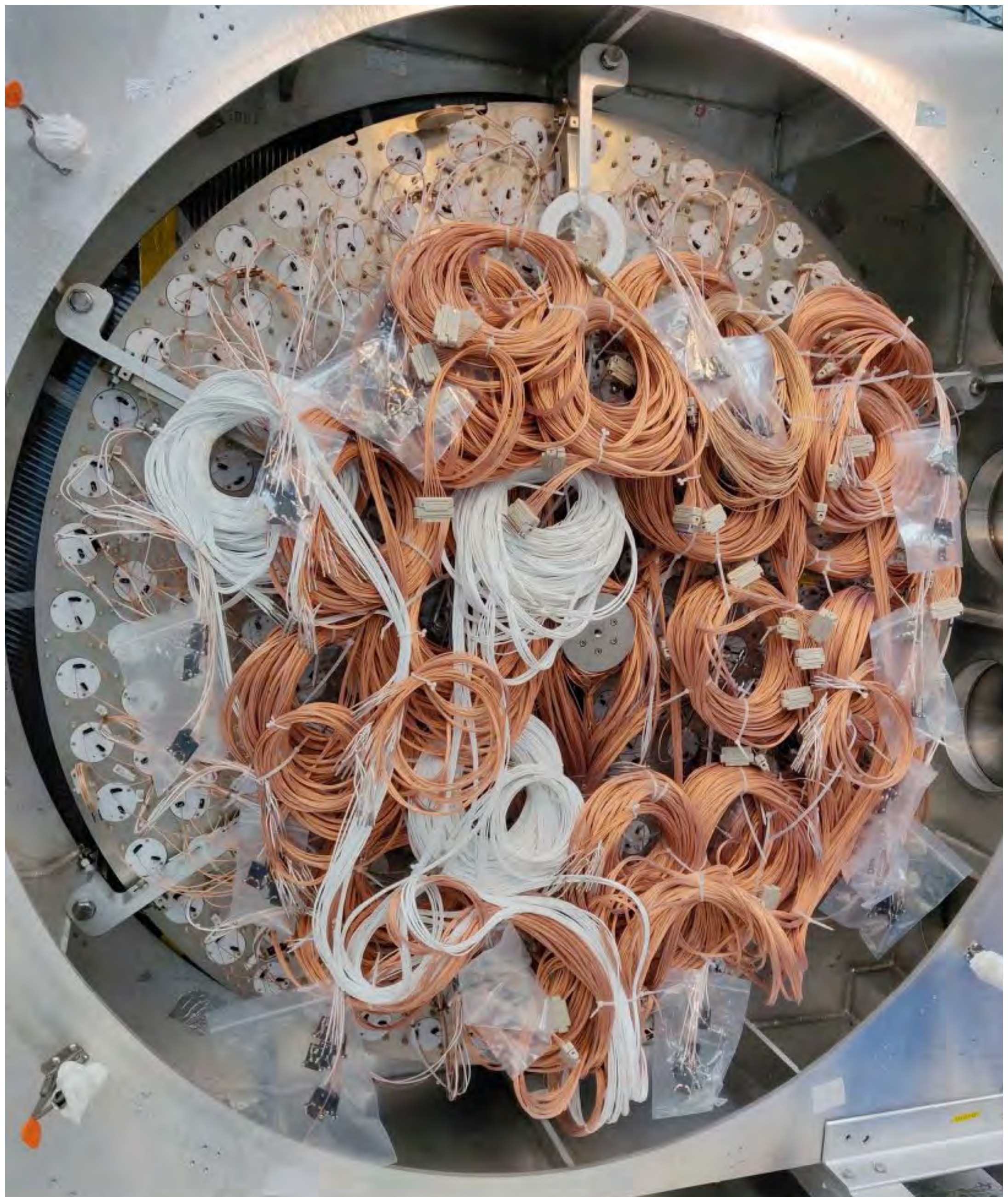


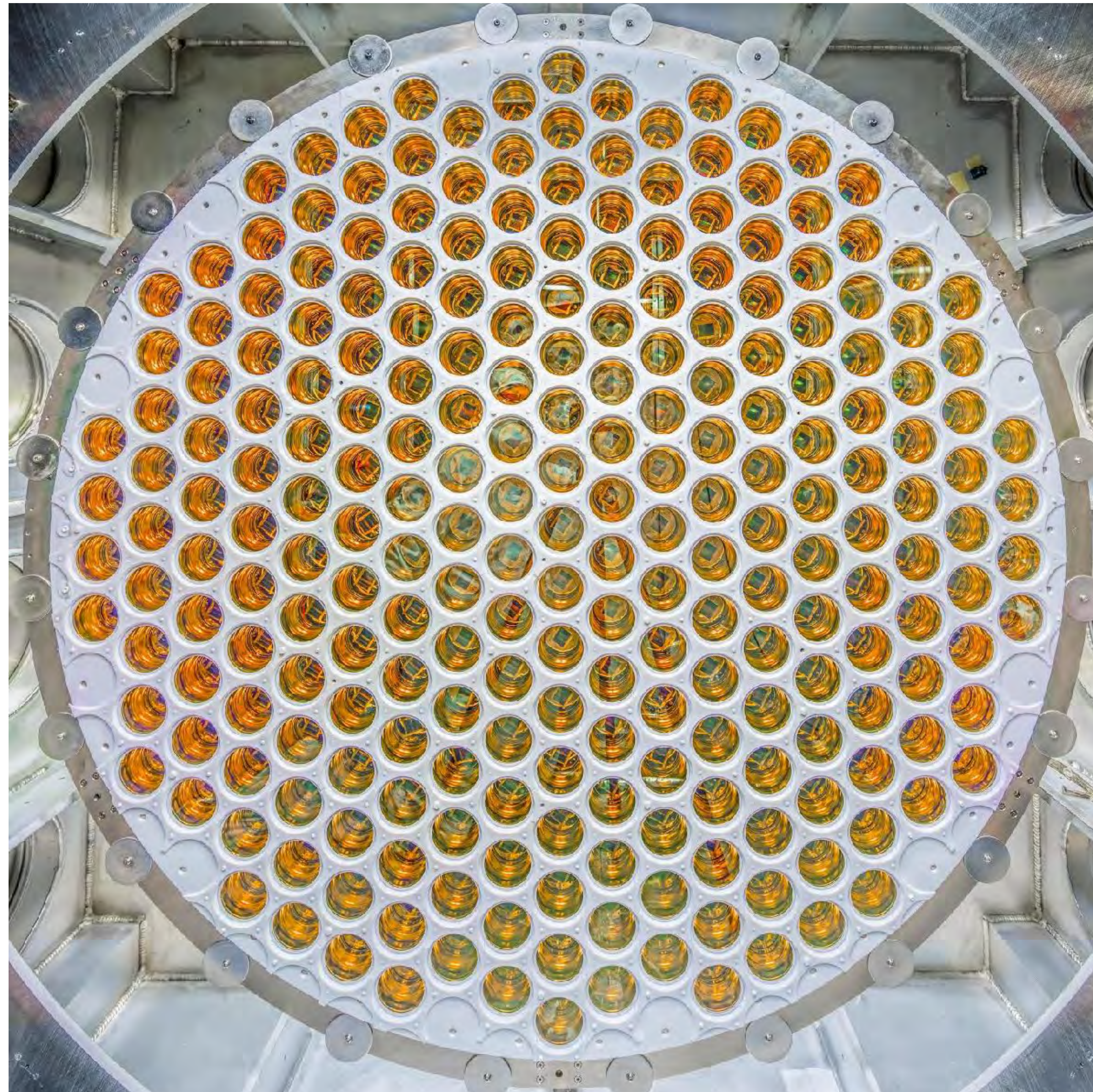


PMT arrays

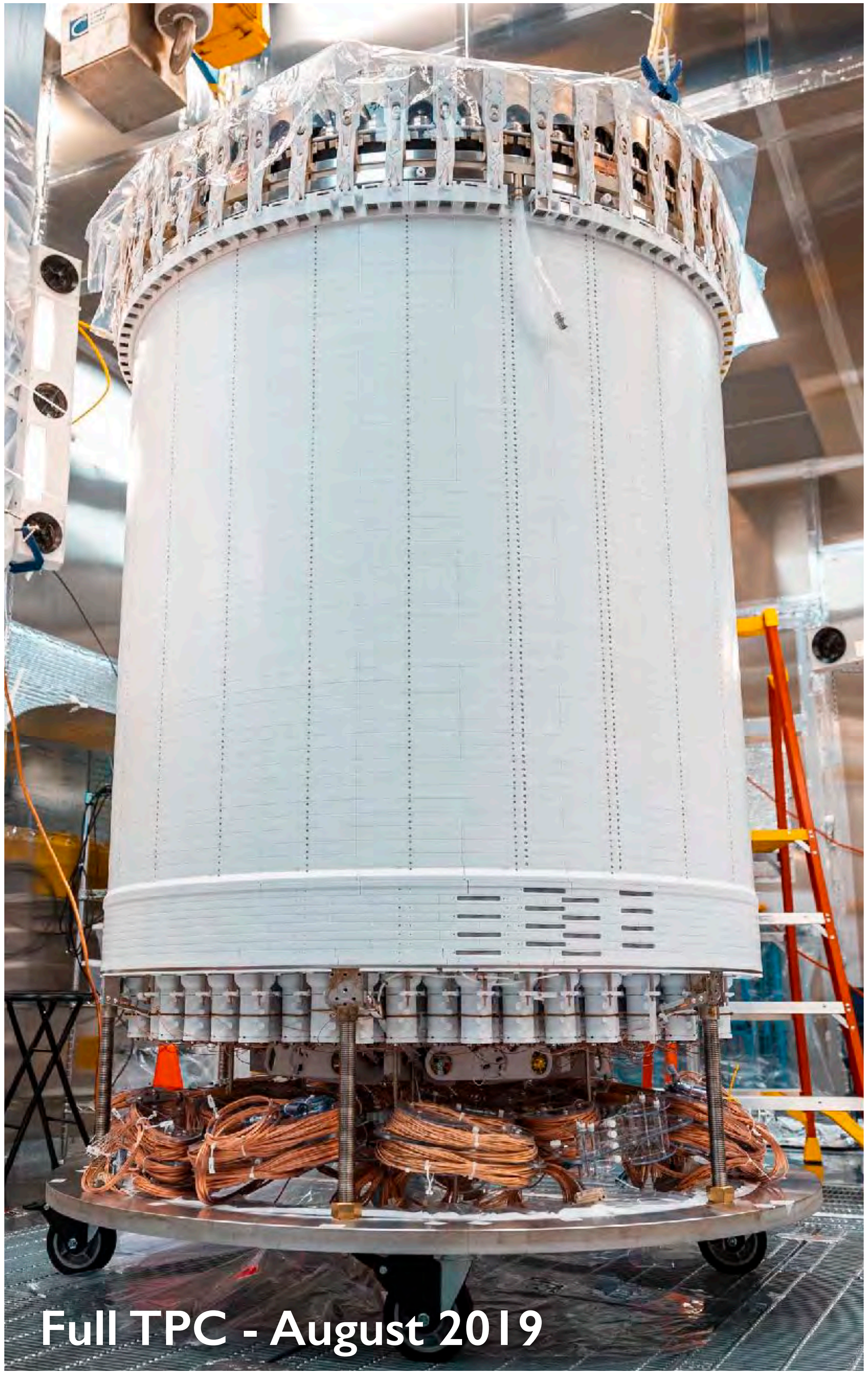
Hamamatsu R11410 (3”)

- Top array: 253 PMTs
- Bottom array: 241 PMTs





Assembled TPC

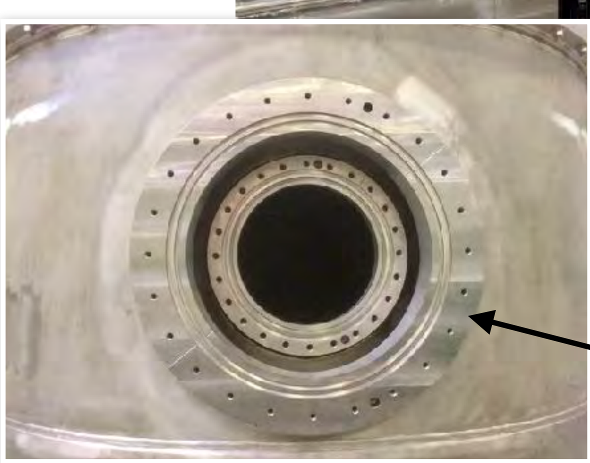


- Detector integration started in December 2018 at Surface Assembly Laboratory (SURF) ~13,500 working hours

Insertion into inner cryostat vessel

Ti Cryostat

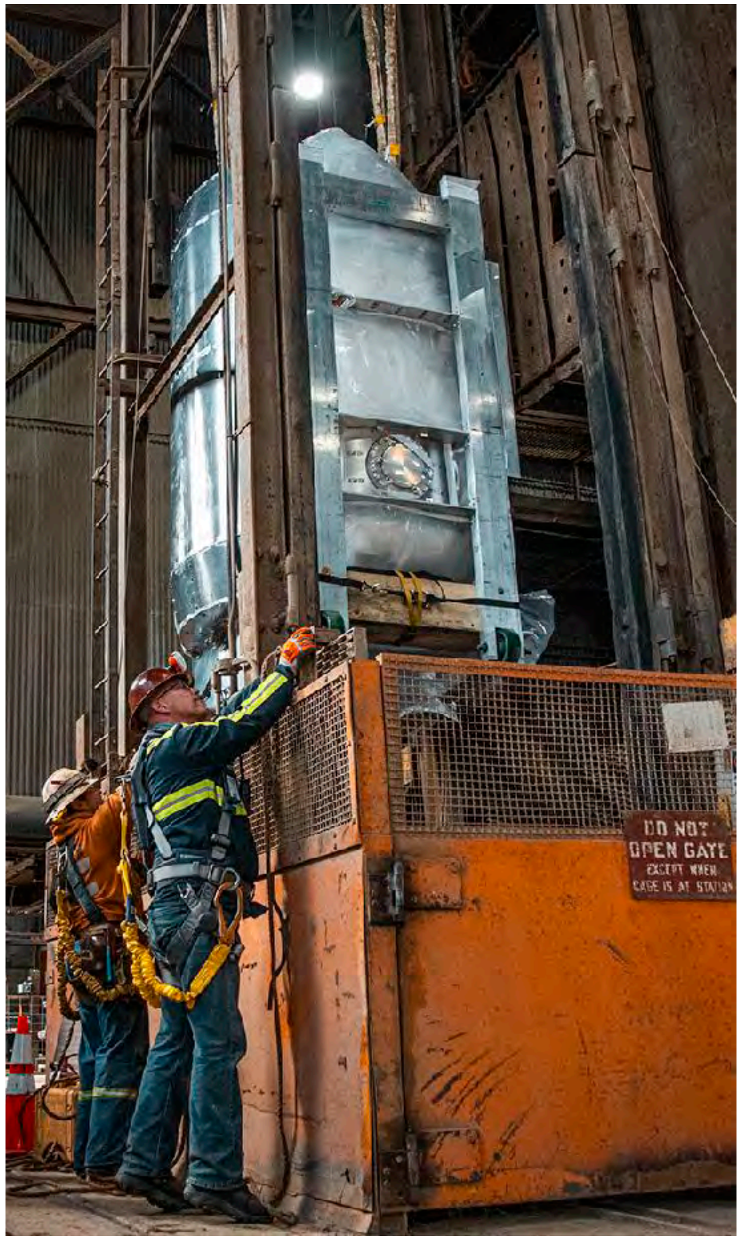
- Intensive R&D program identified low activity titanium material (Astropart. Phys. 96, 1-10 (2017))
- Arrived at SURF May 14, 2018



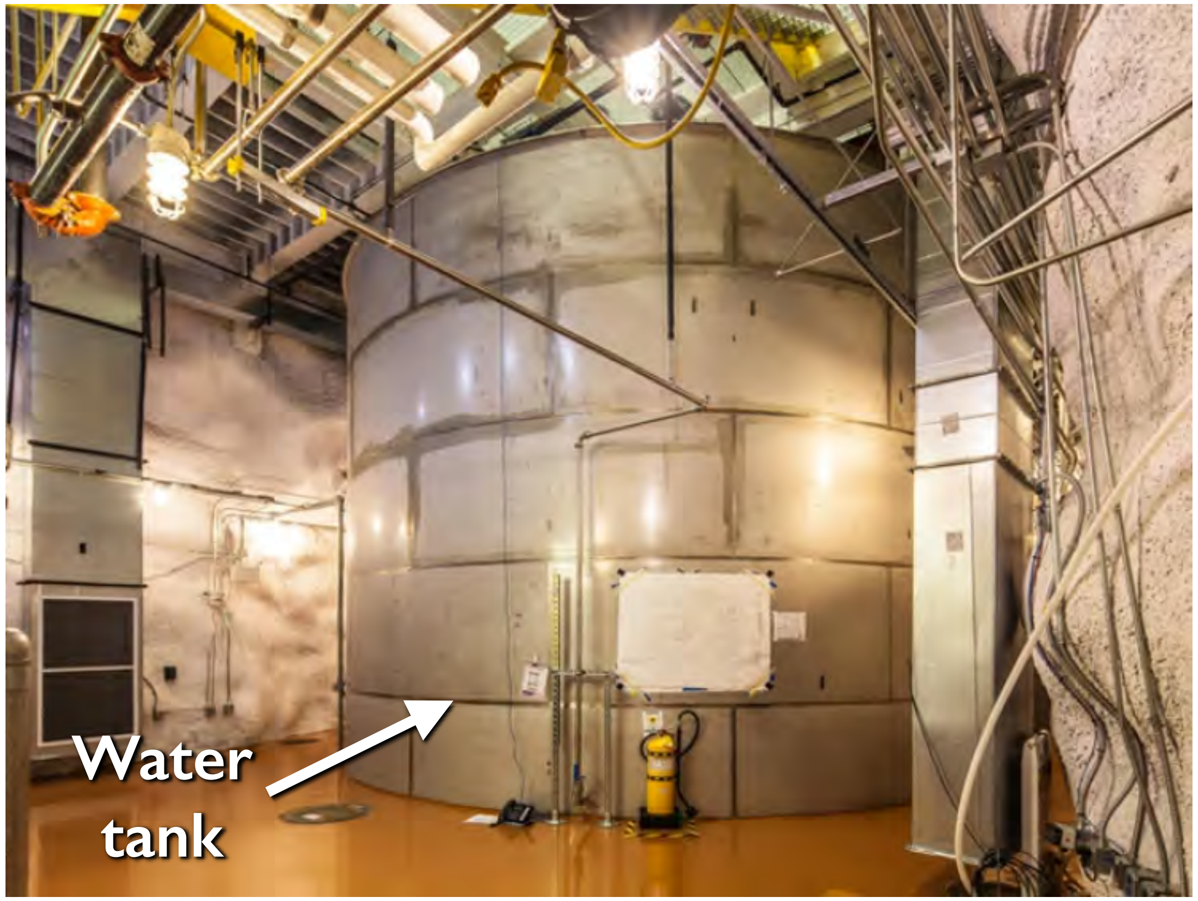
ICV and OCV HV ports alignment and parallelism < 1 mm

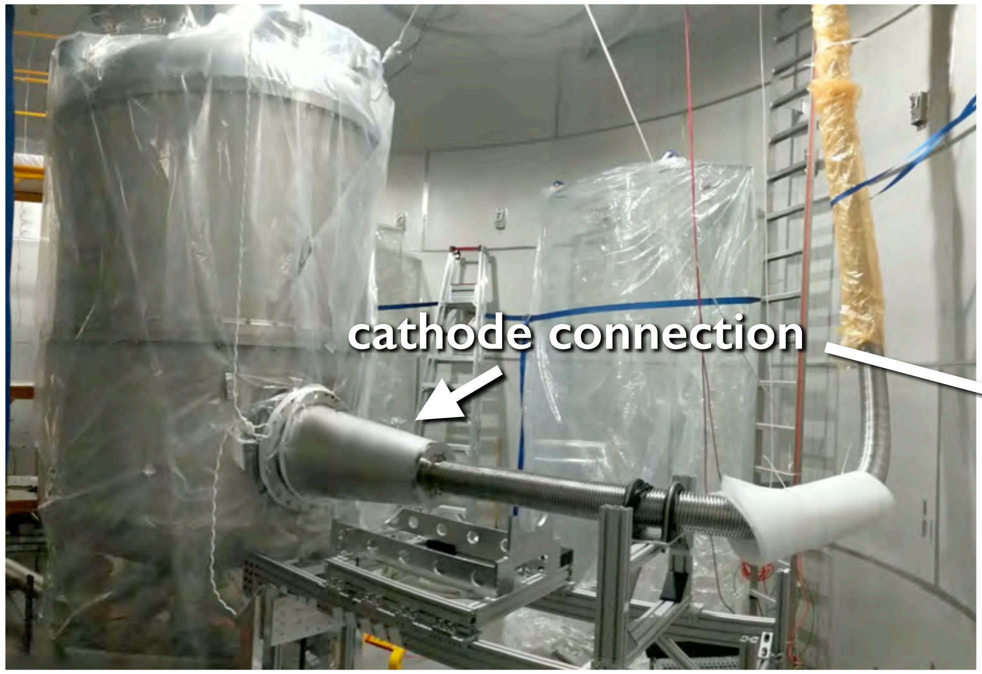
Transport of TPC Underground

October 2019



Underground deployment

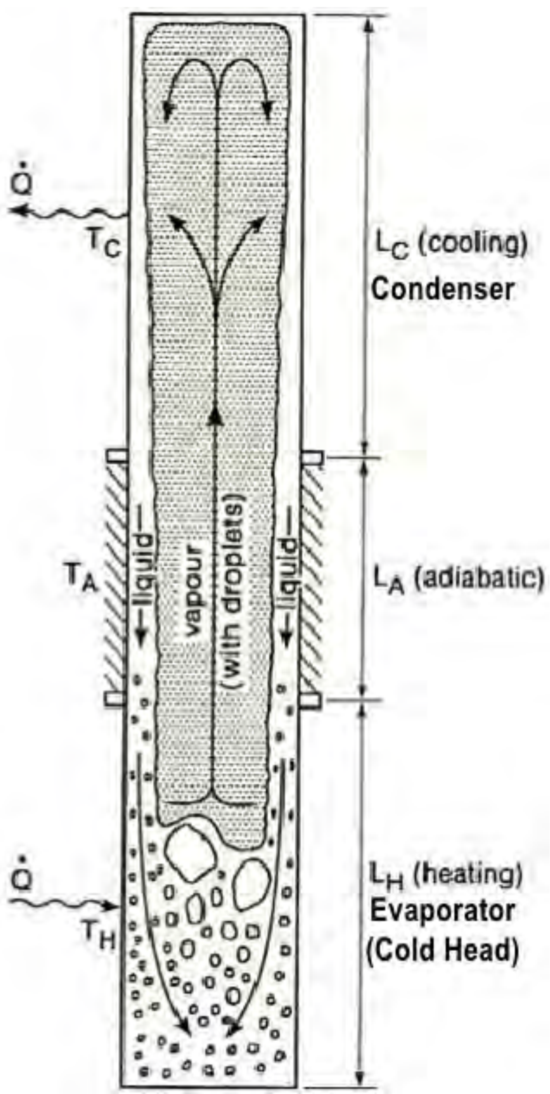




Making up cathode connections (under N2 purge)

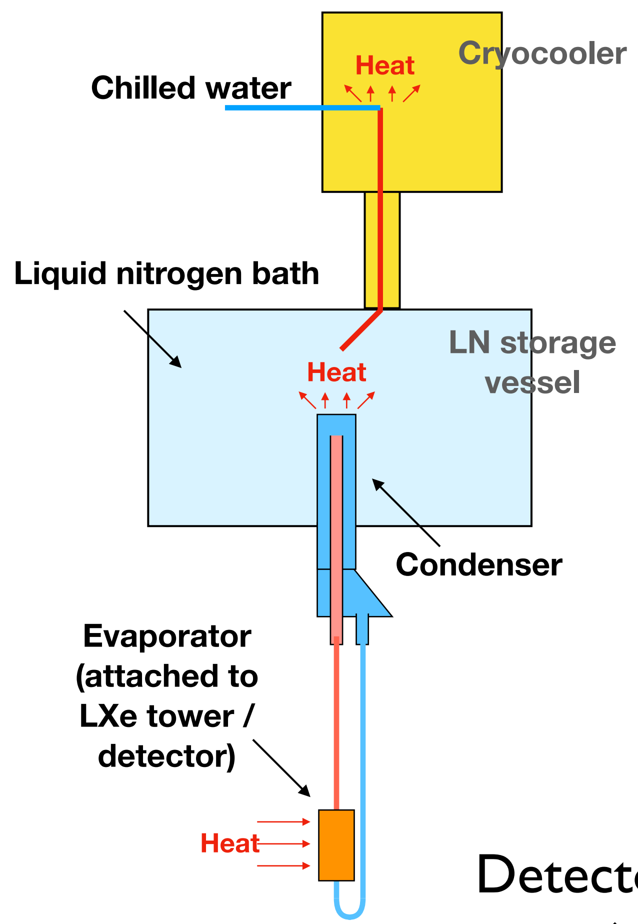
LZ Cryogenics

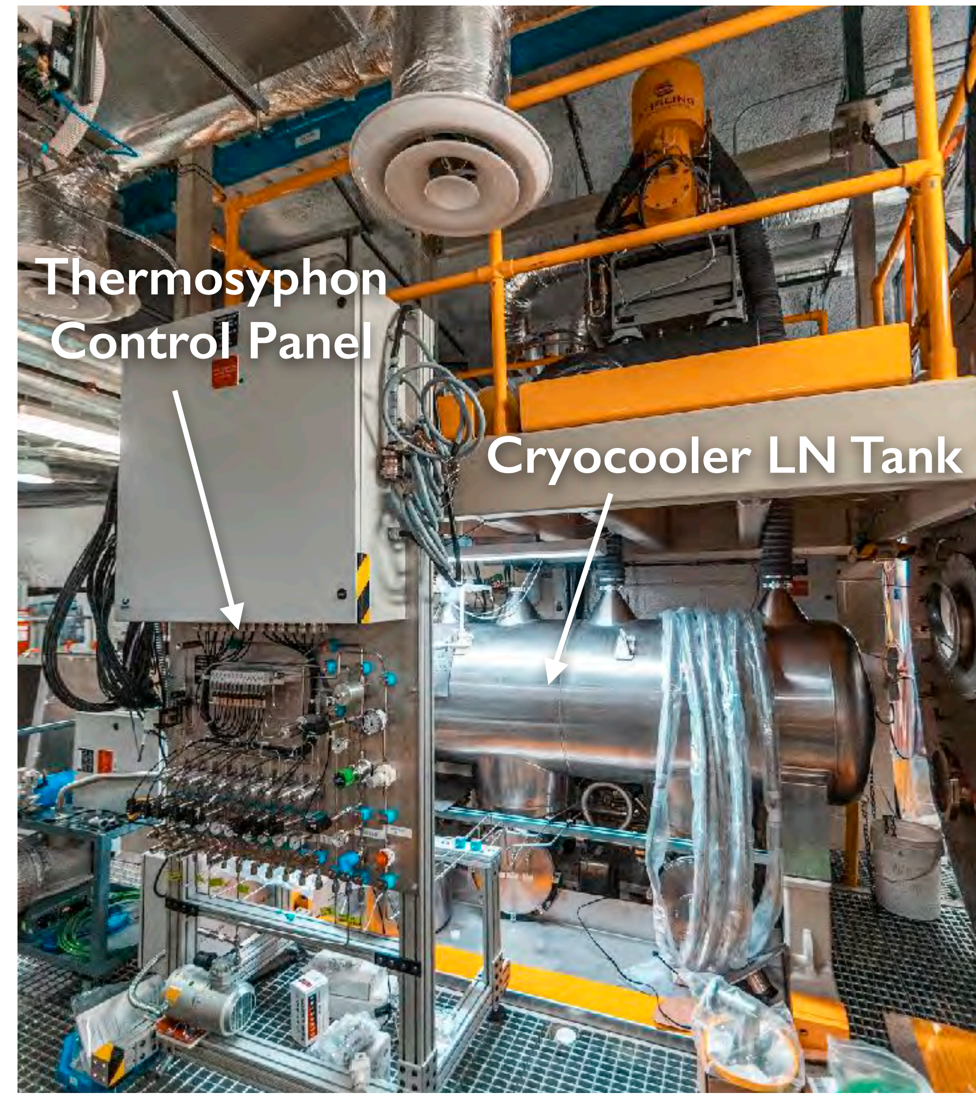
- Cooling provided by thermosyphon technology (also used in LUX)



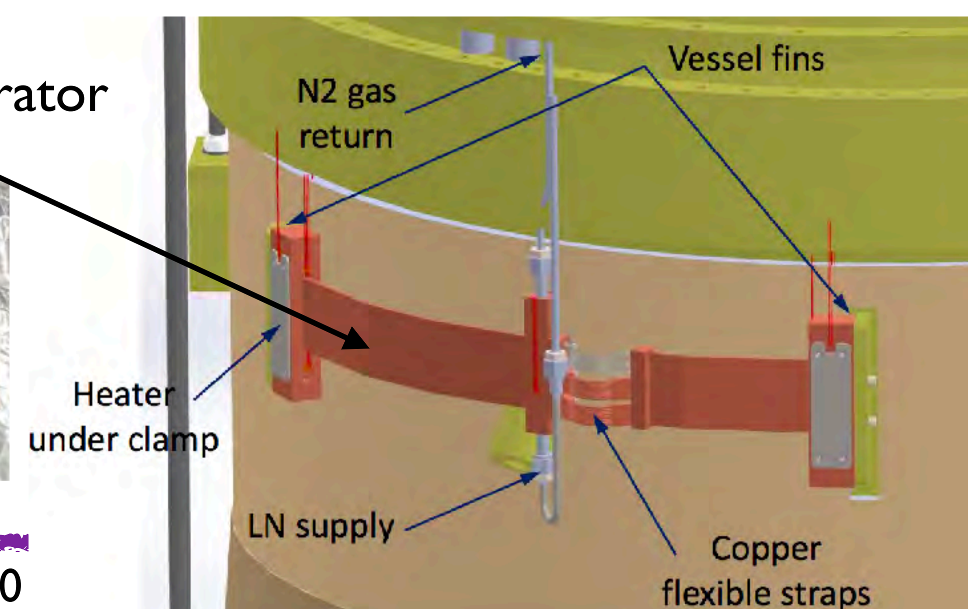
Thermosyphon principle

Sketch of cooling system

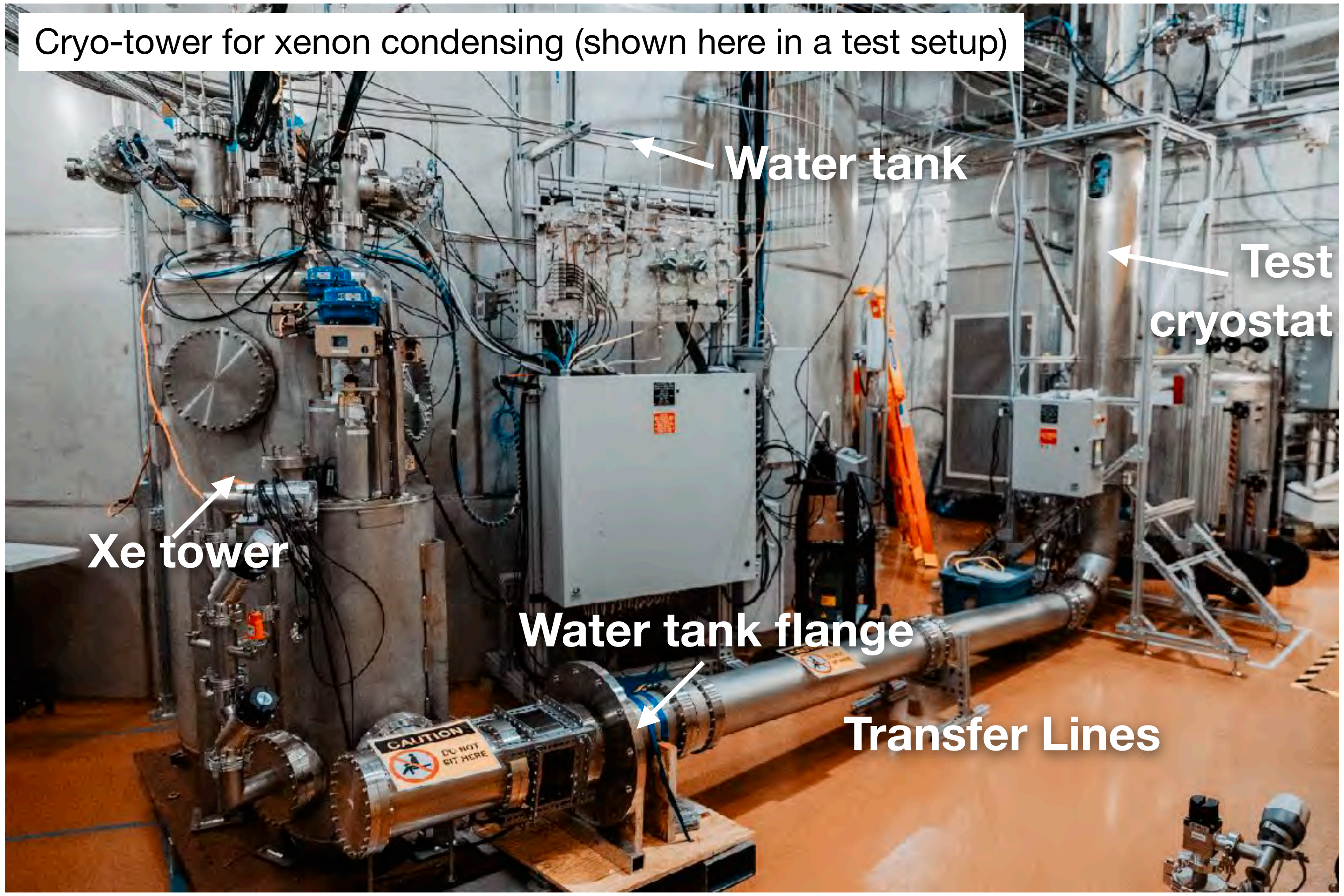




Detector evaporator



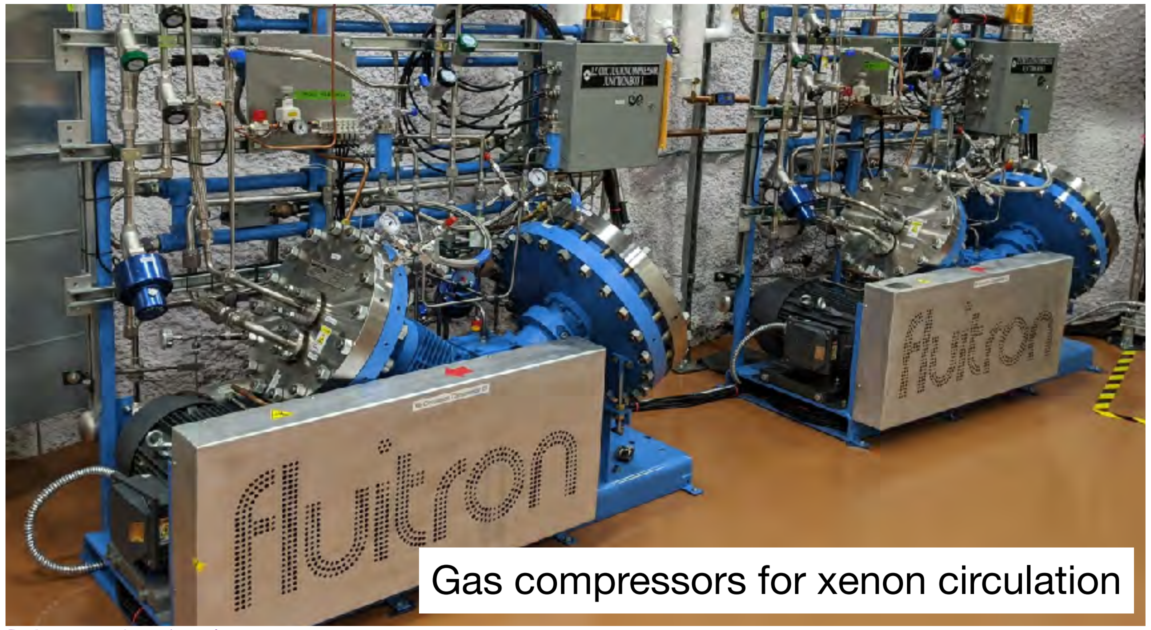
Circulation System



Cryo-tower for xenon condensing (shown here in a test setup)

Xenon purification unit from SAES using hot zirconium getter

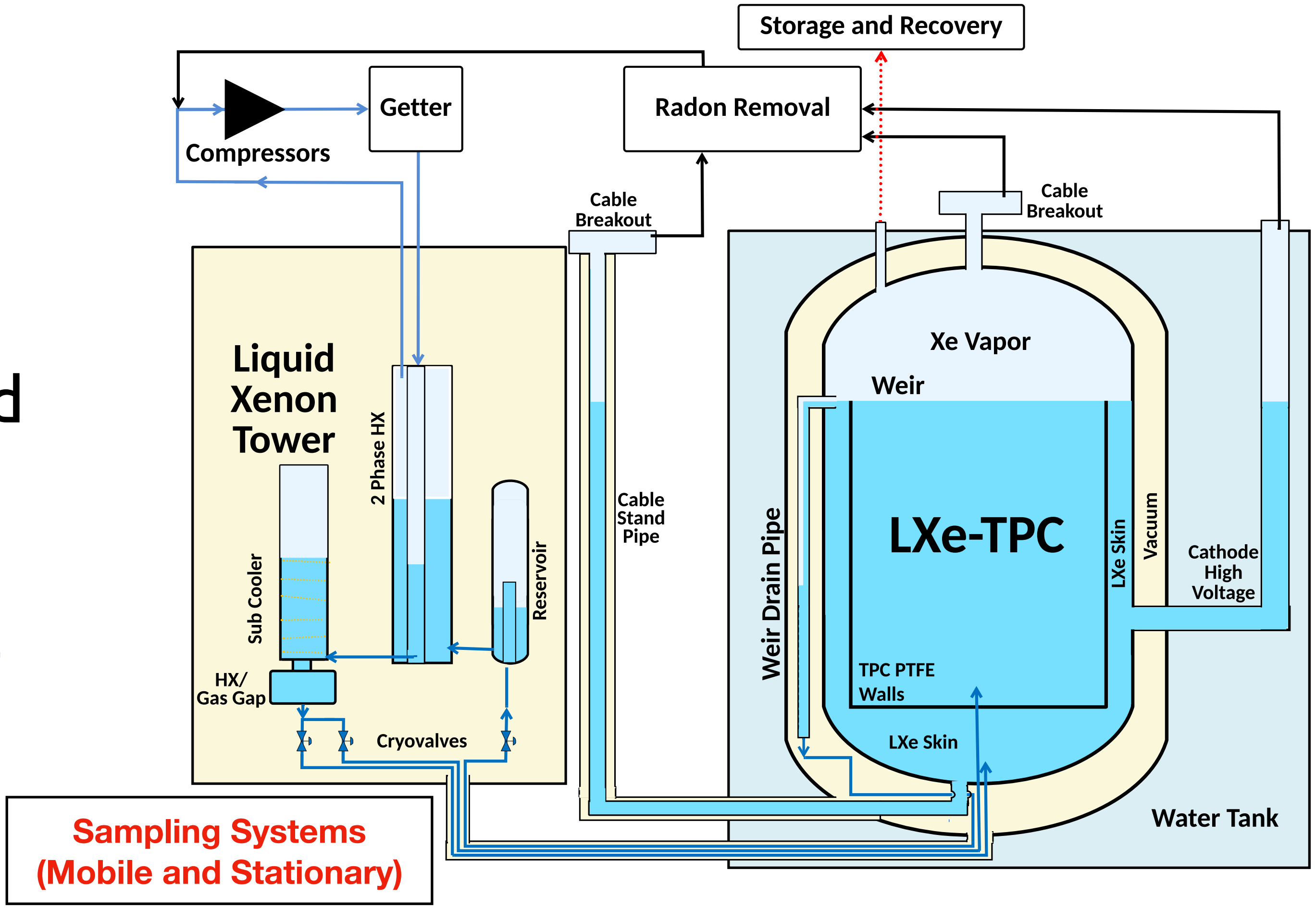

Xenon storage in underground alcove at SURF



Gas compressors for xenon circulation

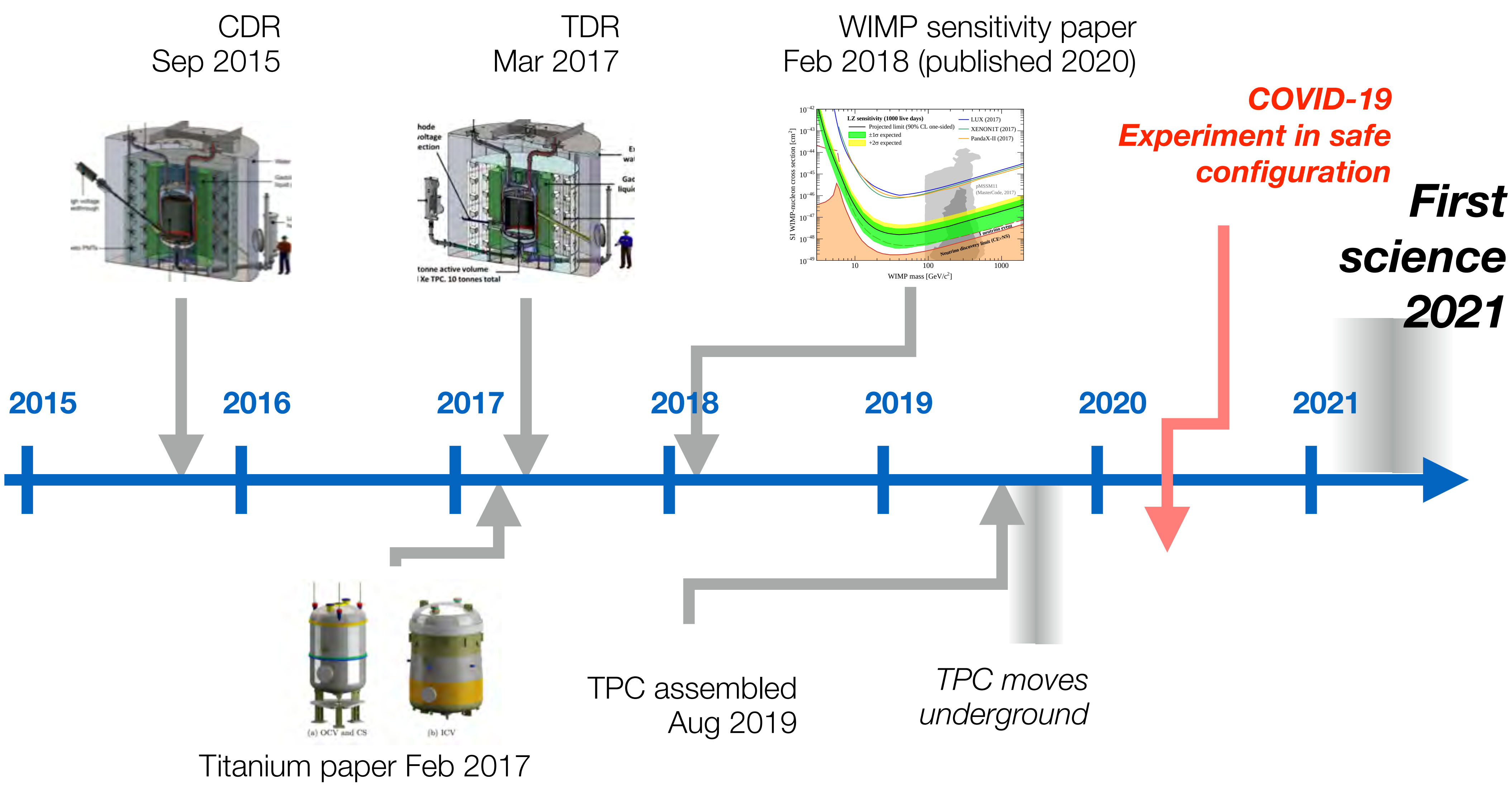
Circulation System & Commissioning

- Design gas circulation rate: 500 slpm
  - ✦ Turnover full xenon mass every 2.4 days
- Purification using hot zirconium getter
  - ✦ Removes non-noble impurities
- Underground commissioning completed
  - ✦ Exercise xenon delivery, circulation, and recovery systems with a modest liquid xenon payload in a full-height test cryostat prior to the installation of the LZ TPC
  - ✦ Up to 600 slpm demonstrated



Current Status

- Significant progress in the assembly of the TPC and associated systems
  - TPC complete and moved underground; HV cathode connection installed; Circulation testing complete
- Out of concern for the health of our staff and to slow the spread of the COVID-19 virus:
  - Shut down in mid-March; Reopened at reduced capacity in the summer
- Work continues while following institutional, local, and national guidelines
  - LZ construction almost complete!

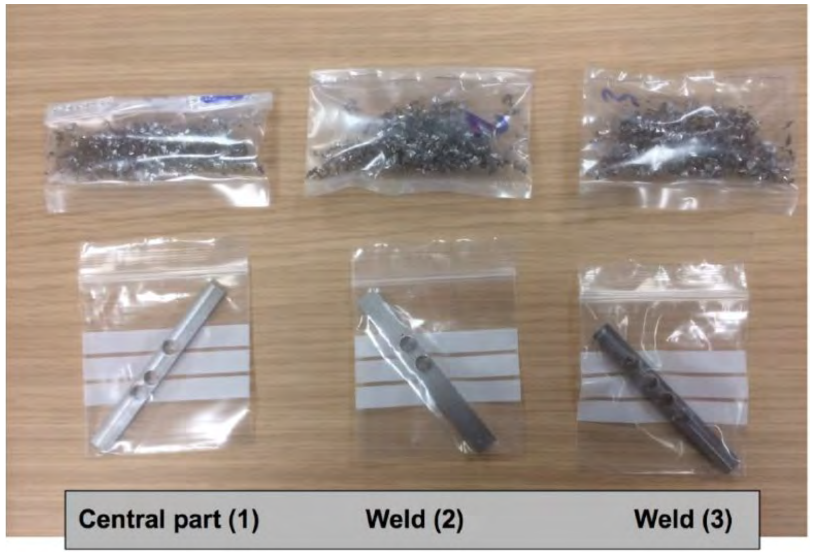


Background sources and mitigation

- Detector materials
  - ✦ Nothing went into the detector without screening
  - ✦ Radio-assay campaign with 13 HPGe detectors, ICPMS, neutron activation analysis
- Rn emanation
  - ✦ Four screening sites
  - ✦ All major parts emanated before assembly
  - ✦ Target Rn activity: 2 μBq/kg
- Rn daughters and dust on surfaces
  - ✦ TPC assembly in Rn-reduced cleanroom
  - ✦ Dust <500 ng/cm^2 on all LXe wetted surfaces
  - ✦ Rn-daughter plate-out on TPC walls <0.5 mBq/m^2
- Xenon contaminants — ^{85}Kr, ^{39}Ar
  - ✦ Charcoal chromatography at SLAC
- Cosmogenics and externals
  - ✦ 4300 m.w.e. underground at SURF in Lead, SD
  - ✦ Instrumented Xe skin region
  - ✦ Gd-LS outer detector
  - ✦ High purity water shield

Many sources of BG

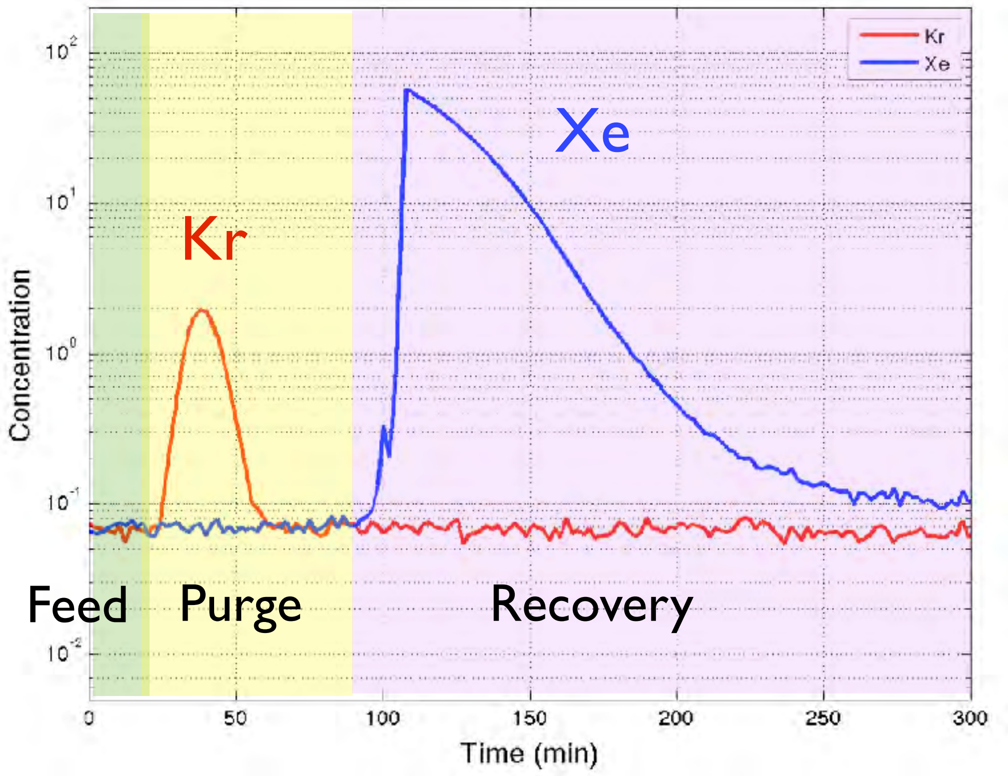
Many methods for BG mitigation

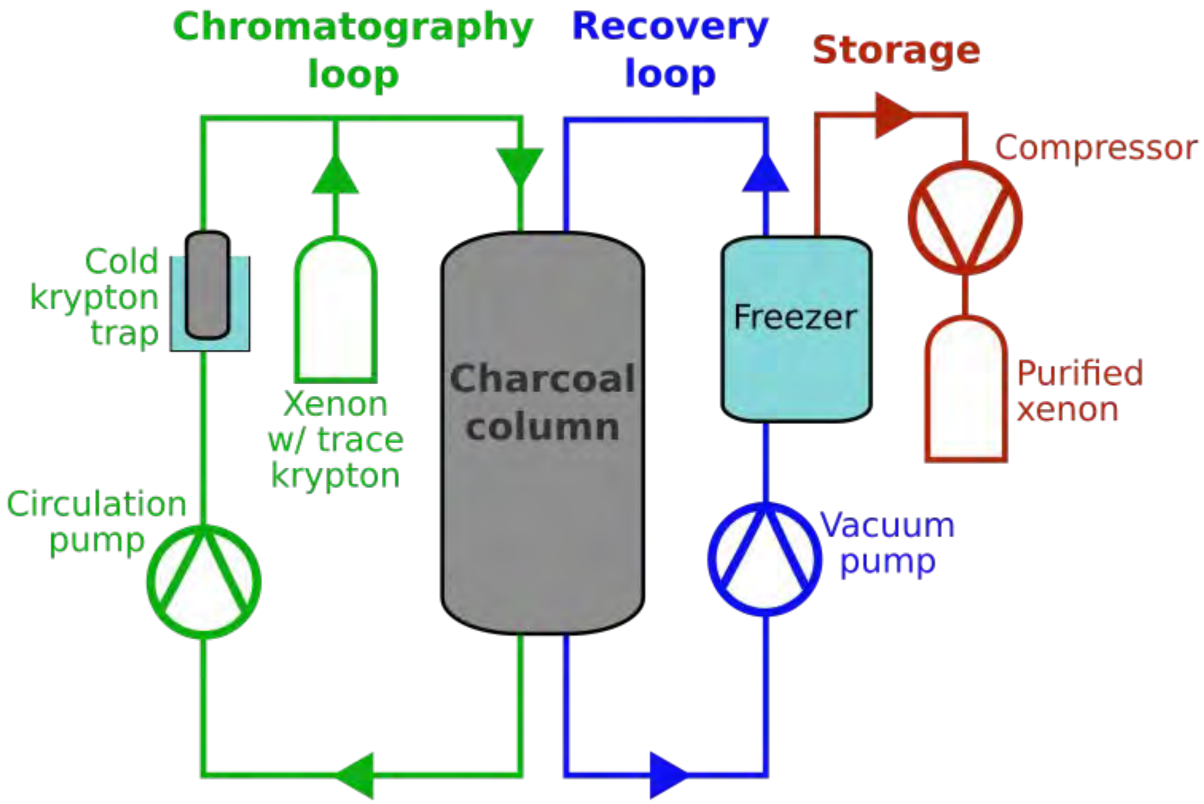


Eur. Phys. J. C, 80: 1044 (2020)

Kr Removal System

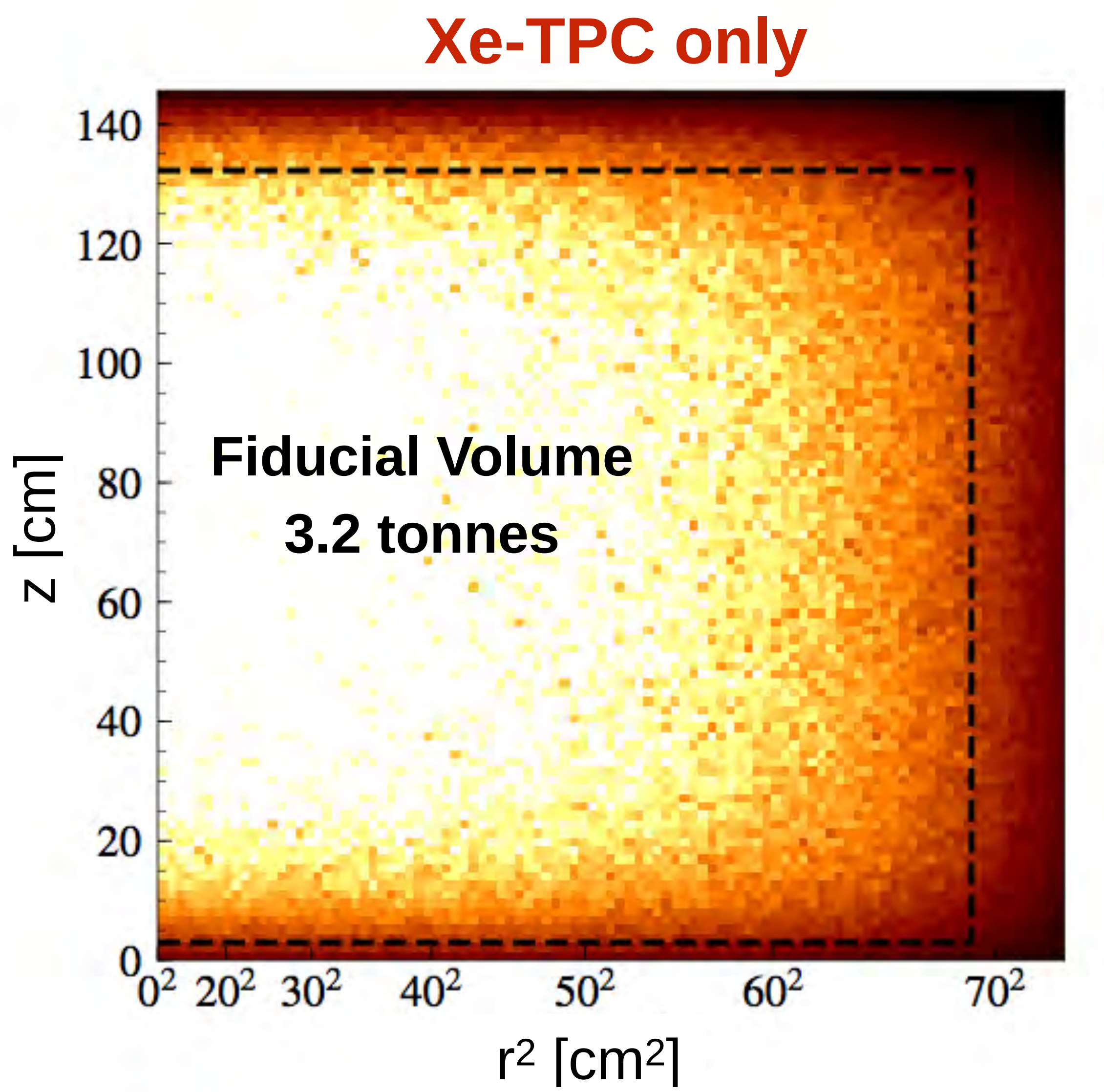
- 10 tonnes of Xe in hand
- Gas chromatography to remove Kr from Xe
  - Demonstration of 0.06 ppt in R&D at SLAC
- Production in progress





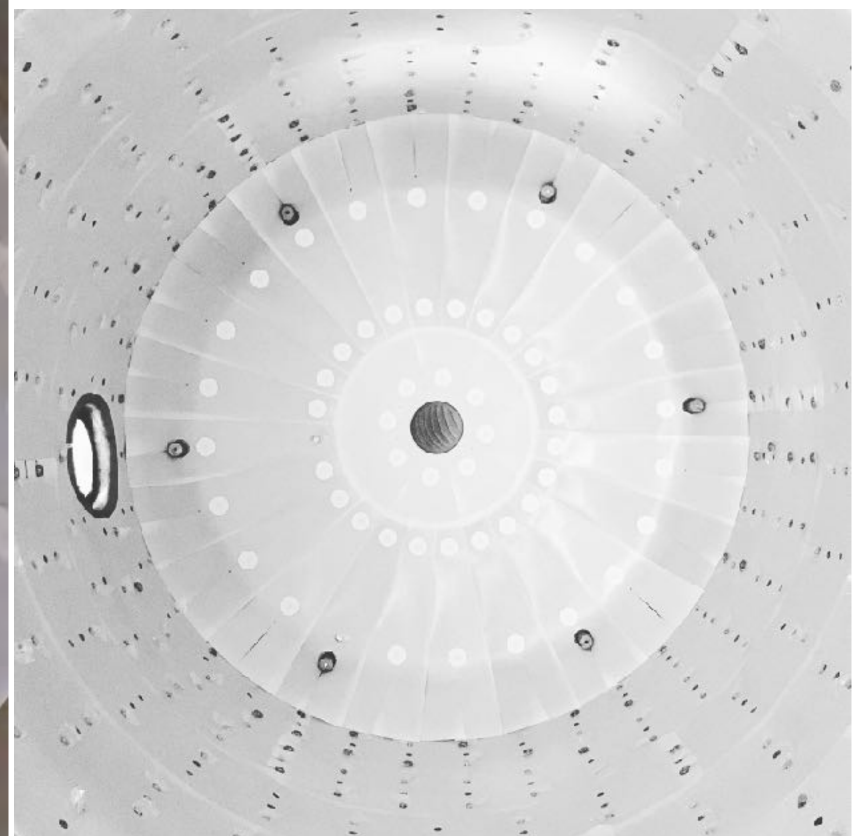
How to maximize the WIMP target mass?

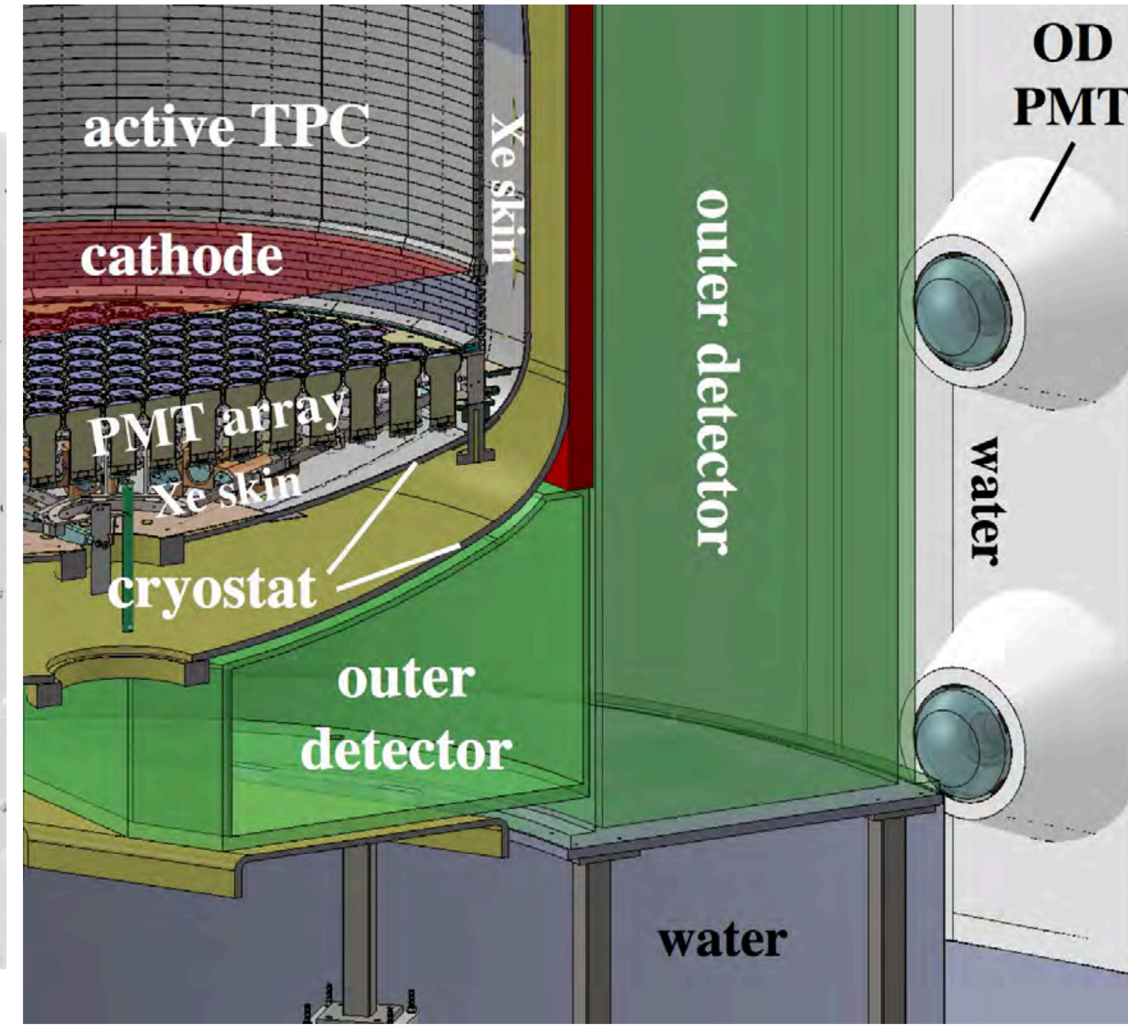
- No veto



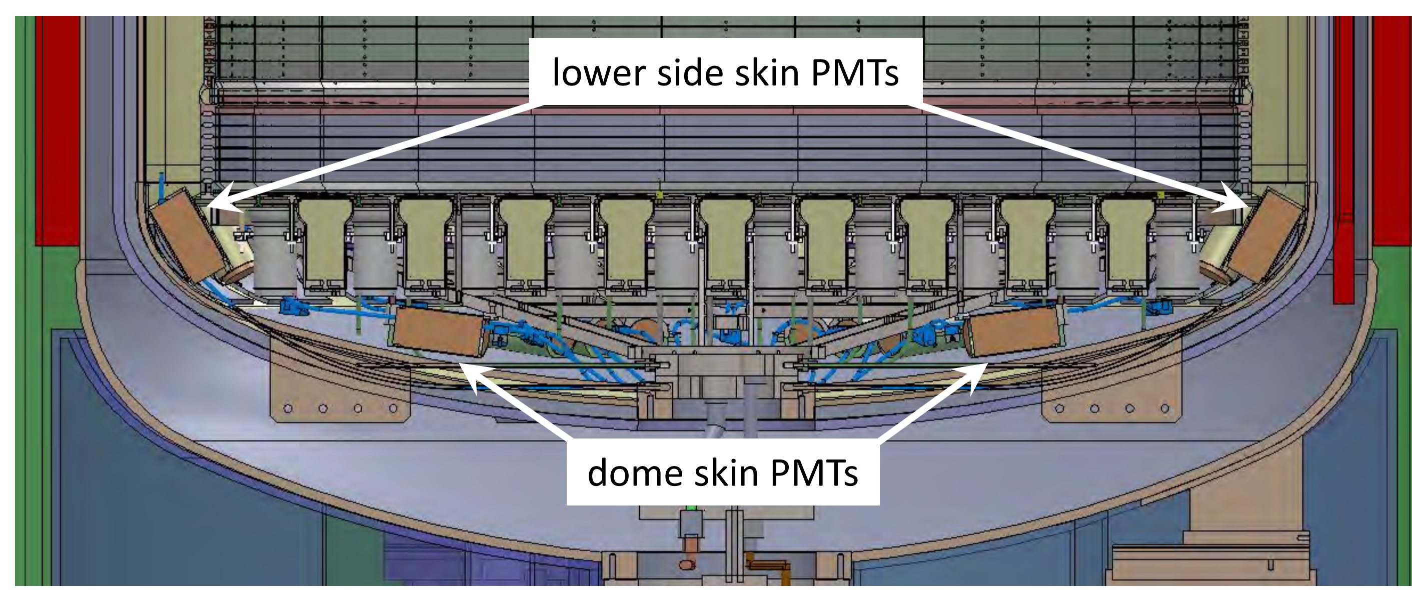
Xenon "Skin" veto

PTFE tiling in ICV & Bottom side skin assembly



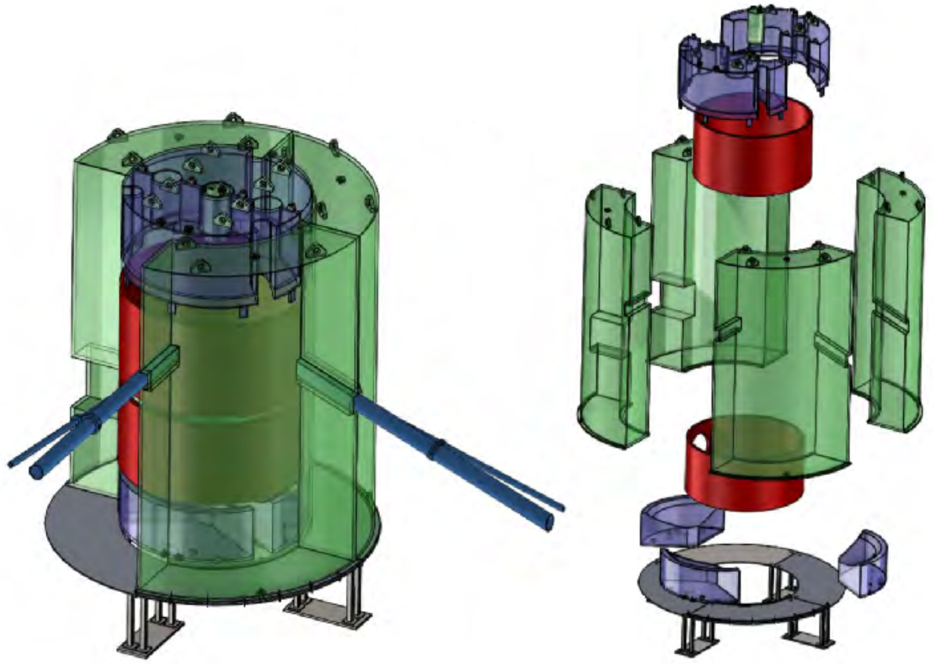


- Anti-coincidence detector for γ-rays
- 2 tonnes of LXe surrounding the TPC
- 1" and 2" PMTs at the top and bottom of the skin region
- Lined with PTFE to maximize light collection efficiency



Outer Detector

- Suppression of neutron-induced nuclear recoil rate ⇒ maximize fiducial volume.



- 17 tonnes Gd-loaded liquid scintillator in acrylic vessels
- 120 8" PMTs mounted in the water tank
- Observe ~8 MeV γ-rays from thermal neutron capture
- >95% efficiency for tagging neutrons
- Draw on experience from Daya Bay

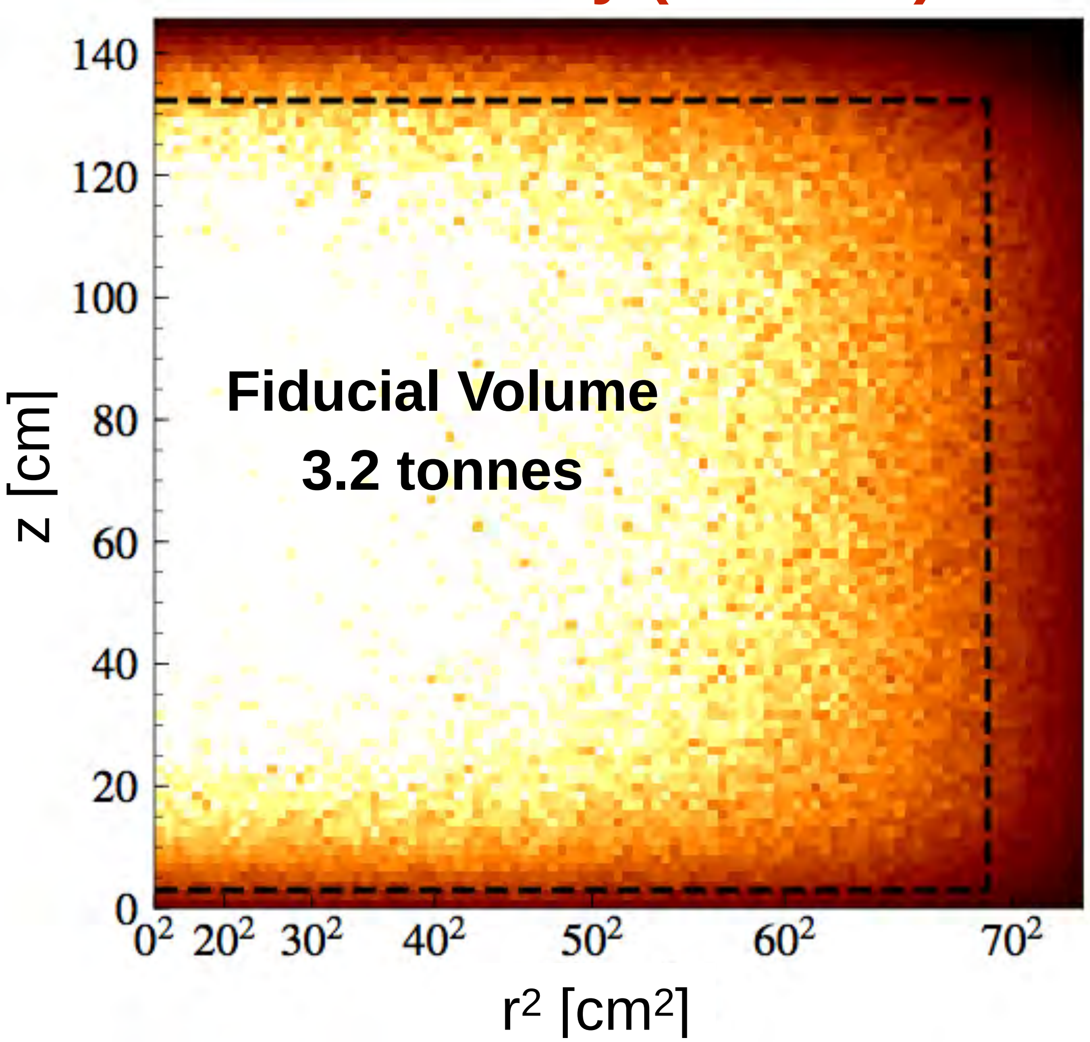
How to maximize the WIMP target mass?

- Three-component veto system:
  - ✦ Water tank
  - ✦ Xenon "skin"
  - ✦ Gd-loaded scintillator

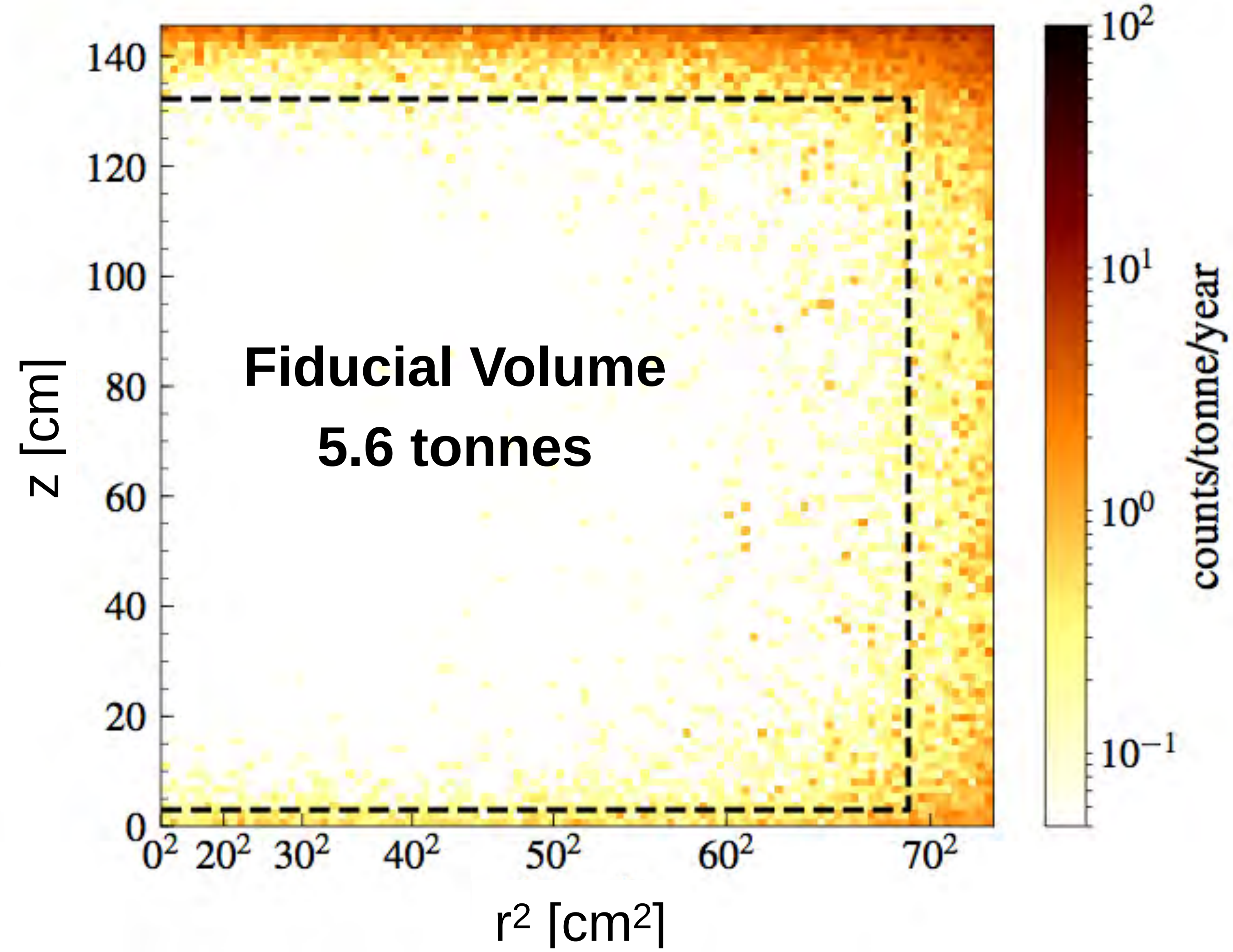
}

- Tag individual neutrons and gammas
  >95% efficiency for tagging neutrons
- Characterize backgrounds *in situ*
  → Enables discovery potential

Xe-TPC only (No veto)



TPC + skin + Gd-scint.



Combined veto system allows to define fiducial a volume of 80% of active volume

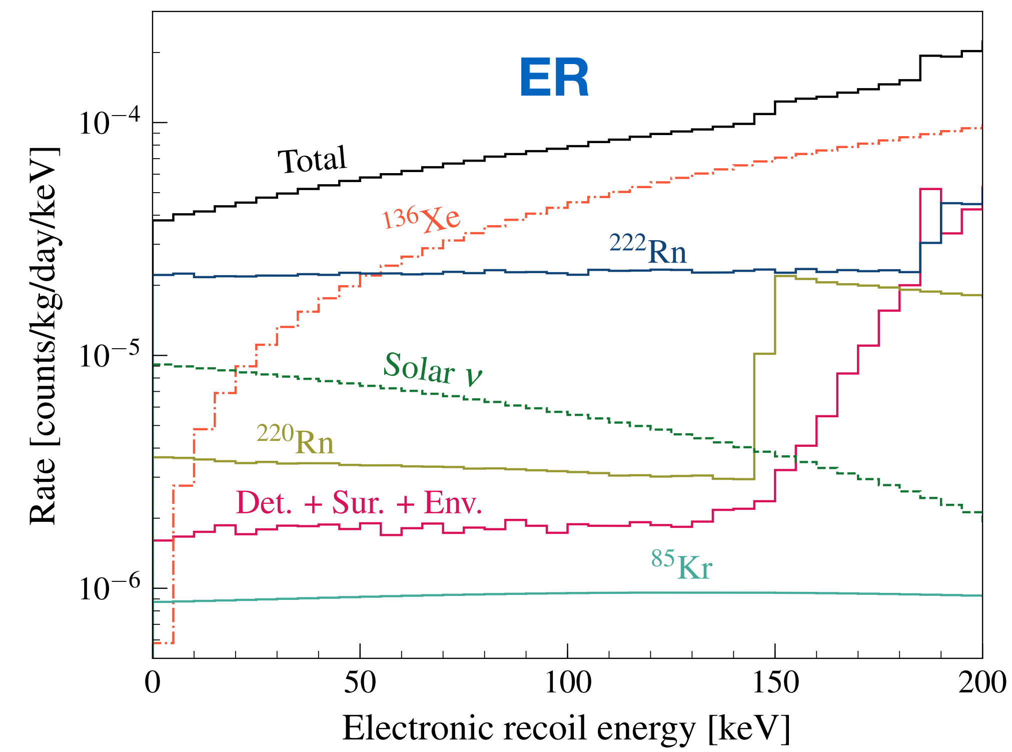
Expected backgrounds for 5.6 T fiducial - 1000 days

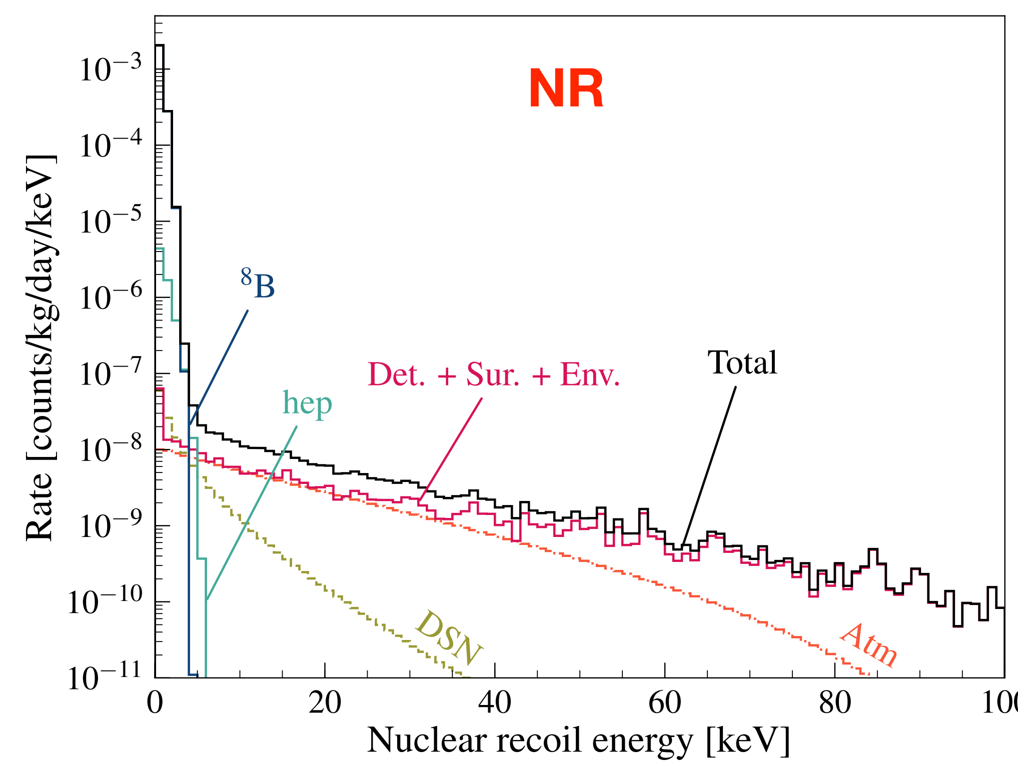
Background Source	ER (cts)	NR (cts)
Detector Components	**9**	**0.07**
Surface Contamination	**40**	**0.39**
Laboratory and Cosmogenics	**5**	**0.06**
Xenon Contaminants	**819**	**0**
^{222}Rn	681	0
^{220}Rn	111	0
^{nat}Kr (0.015 ppt g/g/)	24.5	0
^{nat}Ar (0.45 pub g/g)	2.5	0
Physics	**258**	**0.51**
^{136}Xe 2νββ	67	0
Solar neutrinos (pp+^{7}Be+^{13}N)	191	0*
Diffuse supernova neutrinos	0	0.05
Atmospheric neutrinos	0	0.46
Total	**1131**	**1.03**
with 99.5% ER discrim., 50% NR eff.	**5.66**	**0.52**

Radon is the dominant background!

*Not including ^{8}B or hep

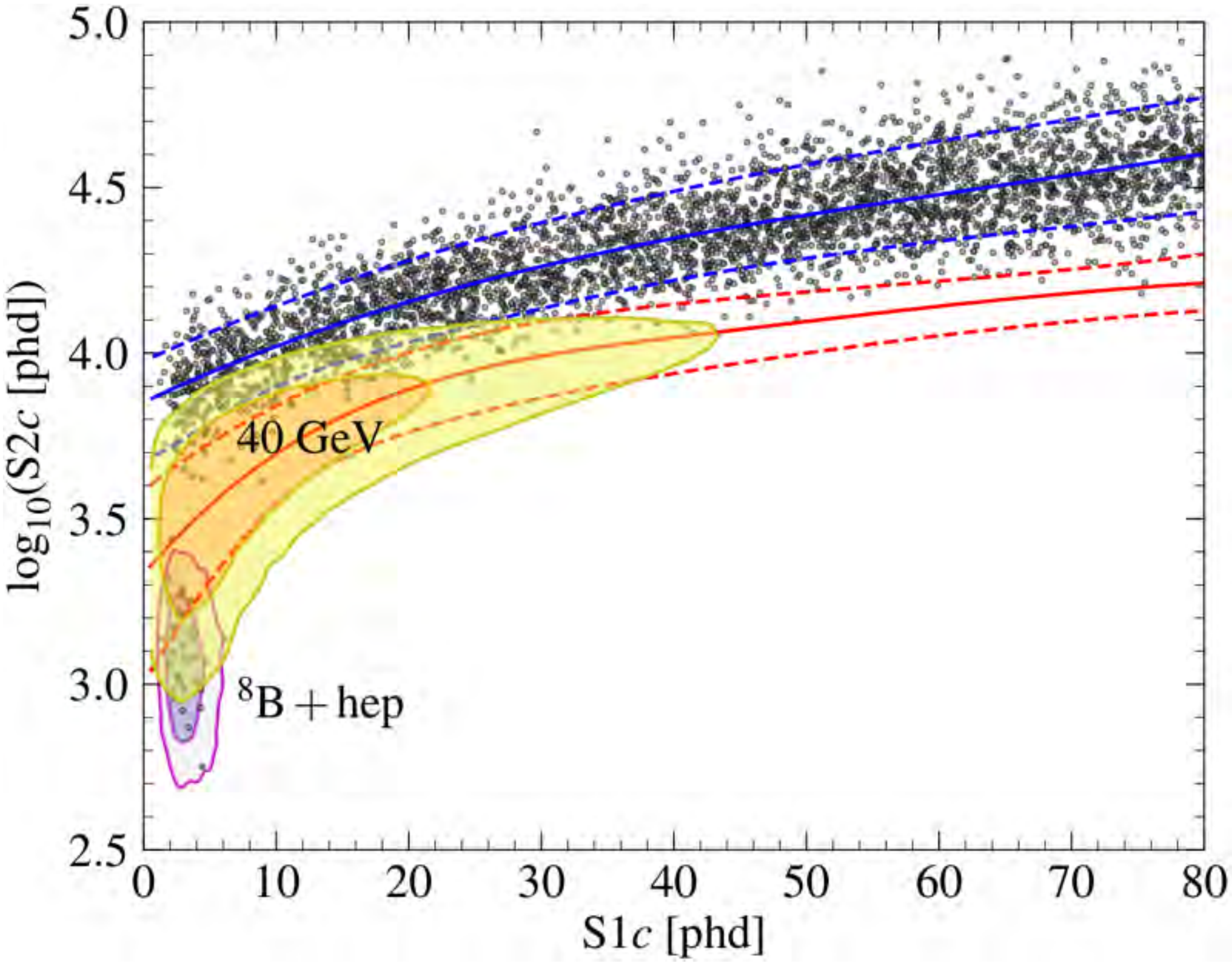
Phys. Rev. D 101, 052002 (2020)





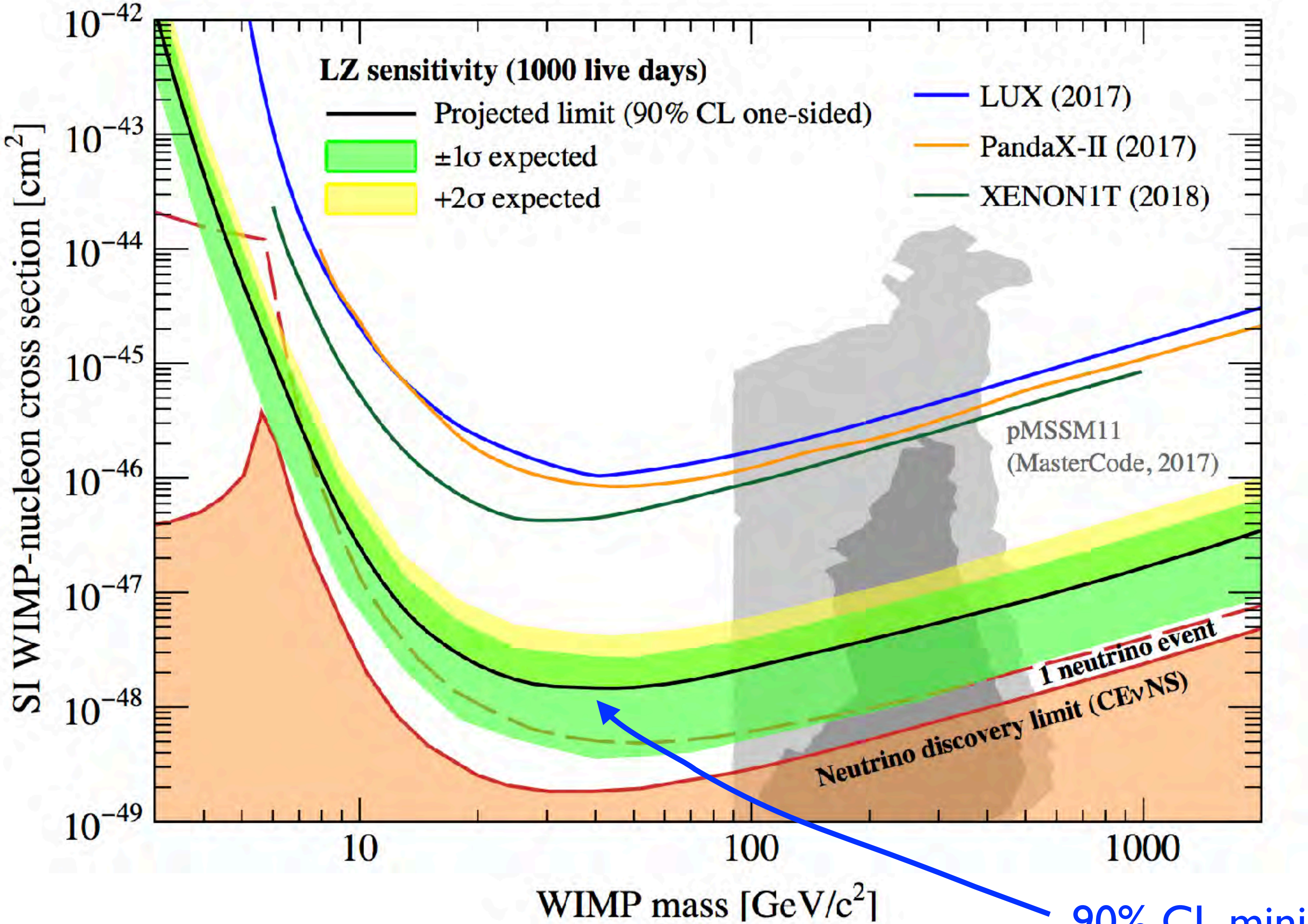
Expected backgrounds for 5.6 T fiducial - 1000 days

- Simulation of a 1000 day run of LZ



Phys. Rev. D 101, 052002 (2020)

Projected Sensitivity (5.6 T exposure, 1000 live days)



Phys. Rev. D 101, 052002 (2020)

90% CL minimum of
1.4×10^{-48} cm^2 at 40 GeV/c^2

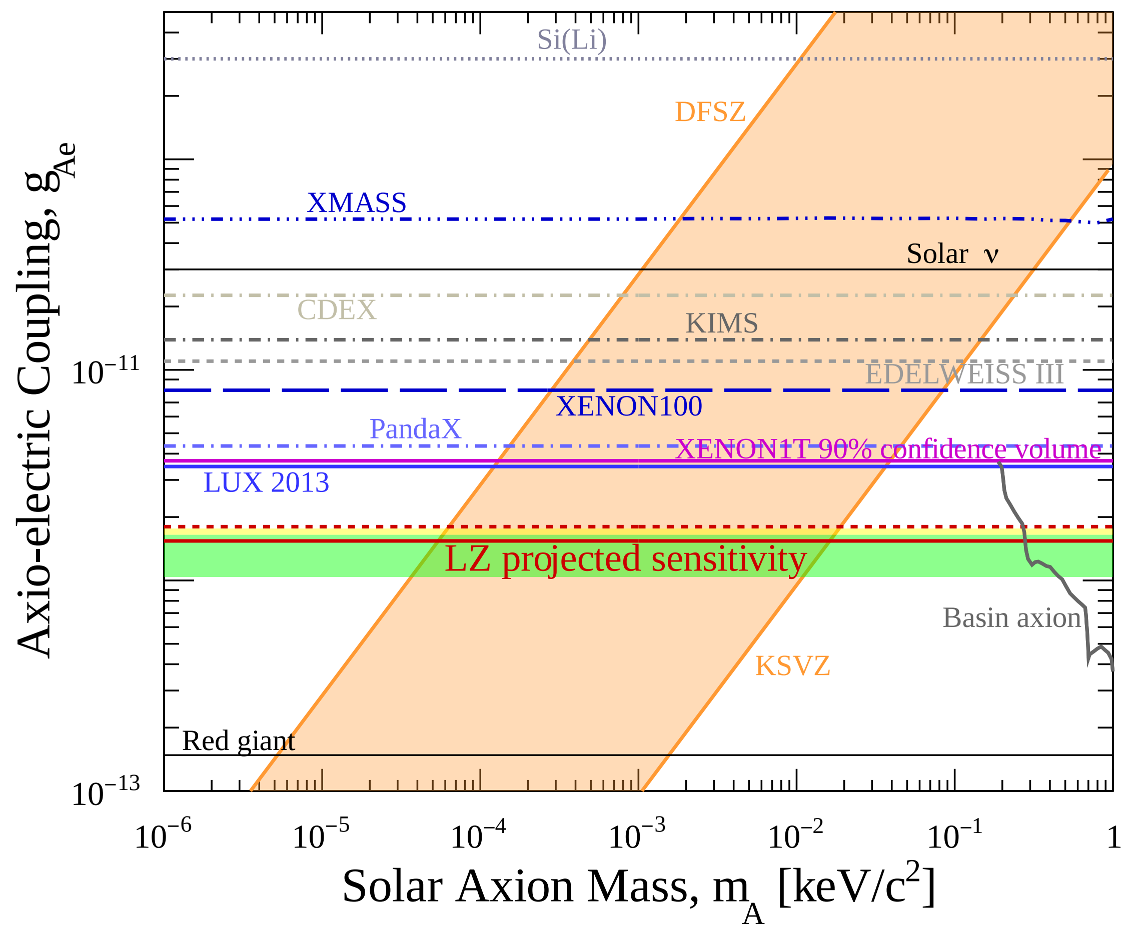
Thank You!

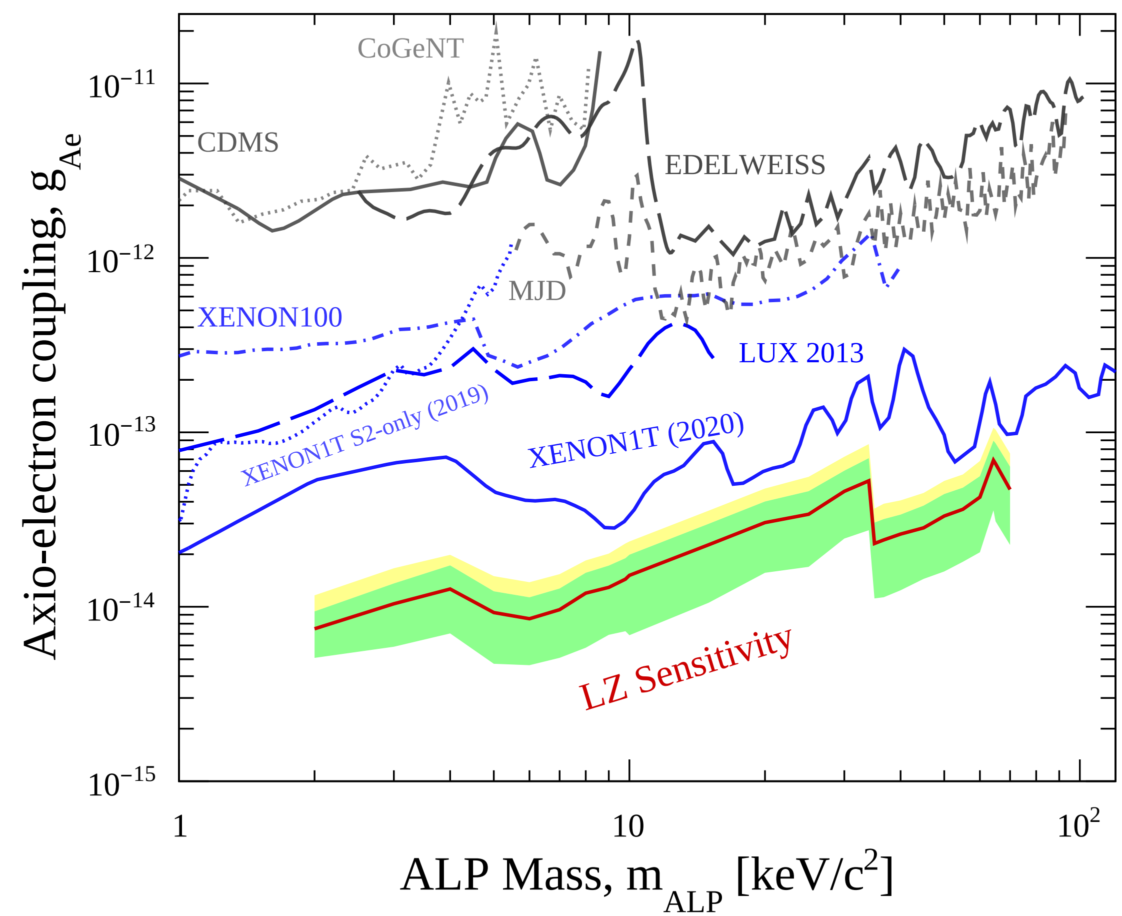
2021 will be an exciting year for direct detection!

~36 institutions, 250 scientists, engineers, technicians

Backup Slides

ER searches

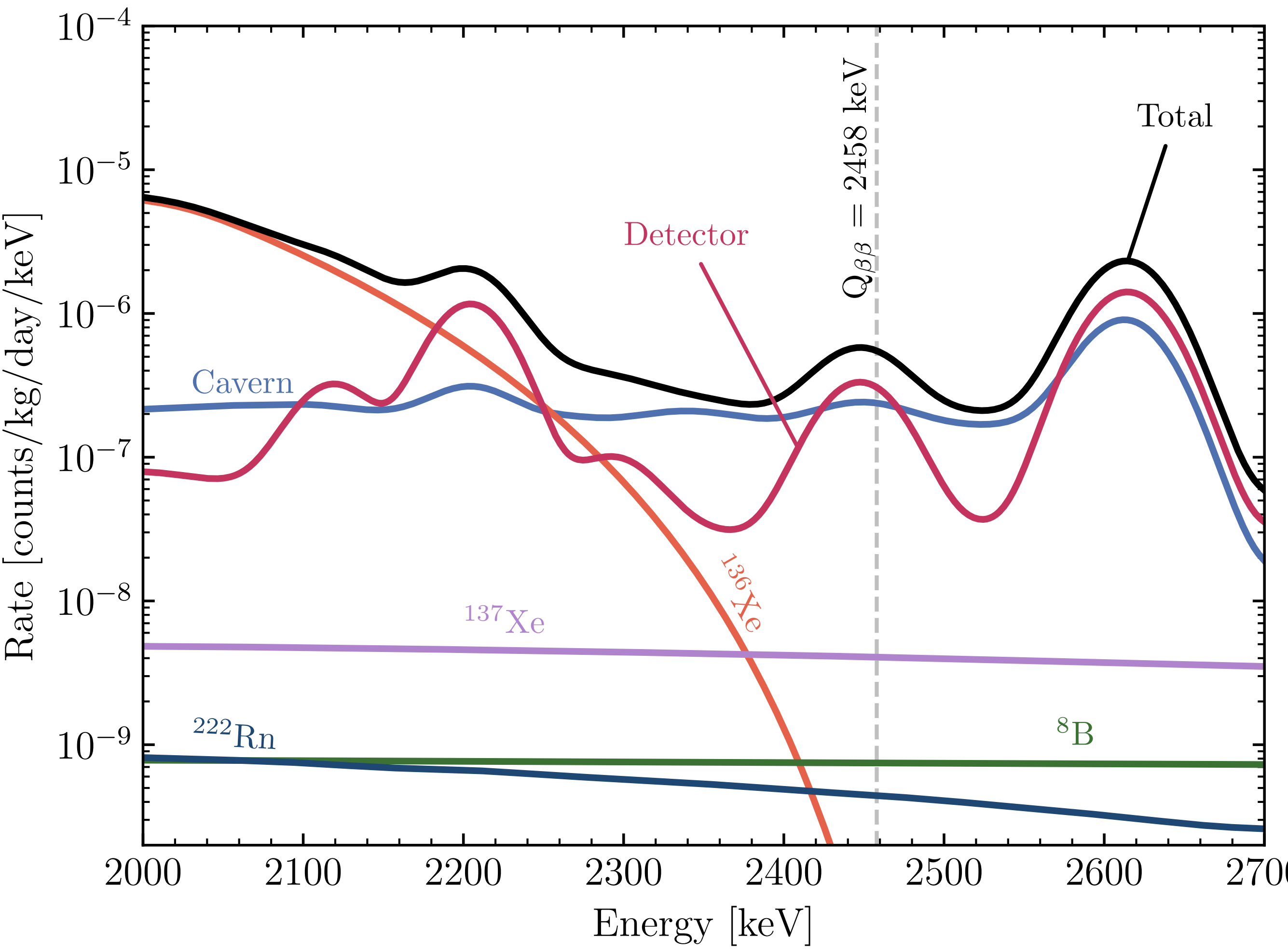


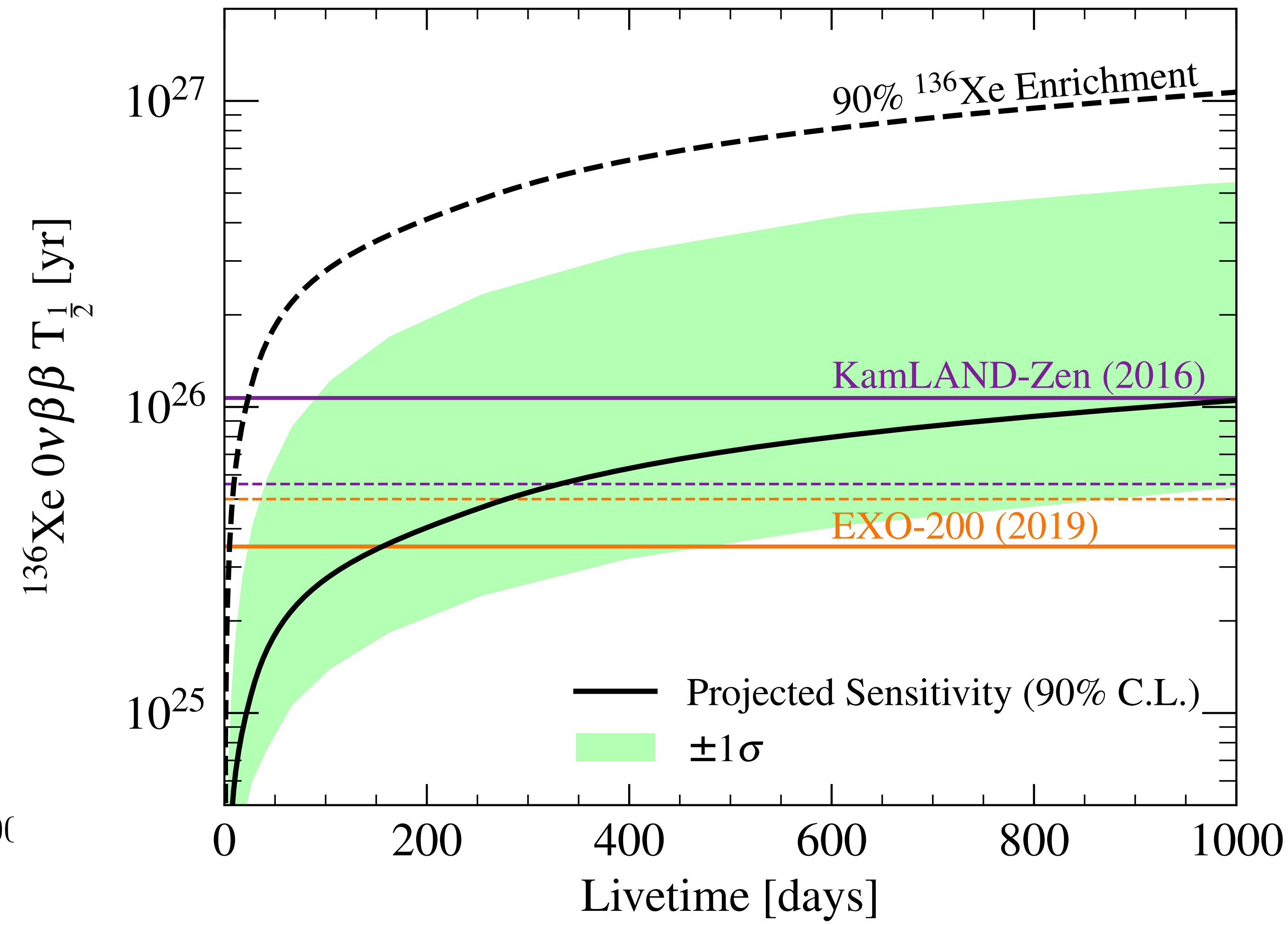


- Sensitive to electron recoils from many types of new physics including
  - Neutrino magnetic moment
  - Solar axions (axio-electric effect)
  - Axion like particles
- Paper in preparation describing LZ sensitivity to these signals

Non-WIMP sensitivity - 0νββ

Phys. Rev. C 102, 014602 (2020)





- ^{136}Xe Q value at 2458 keV
- Nominal 1% energy resolution at Q value
- $T_{1/2}$ (90% C.L.) > 1 x 10^{26} years in 1000 live days, inner 1 tonne fiducial mass