Recent Results on Dark Matter

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Princeton/FNAL

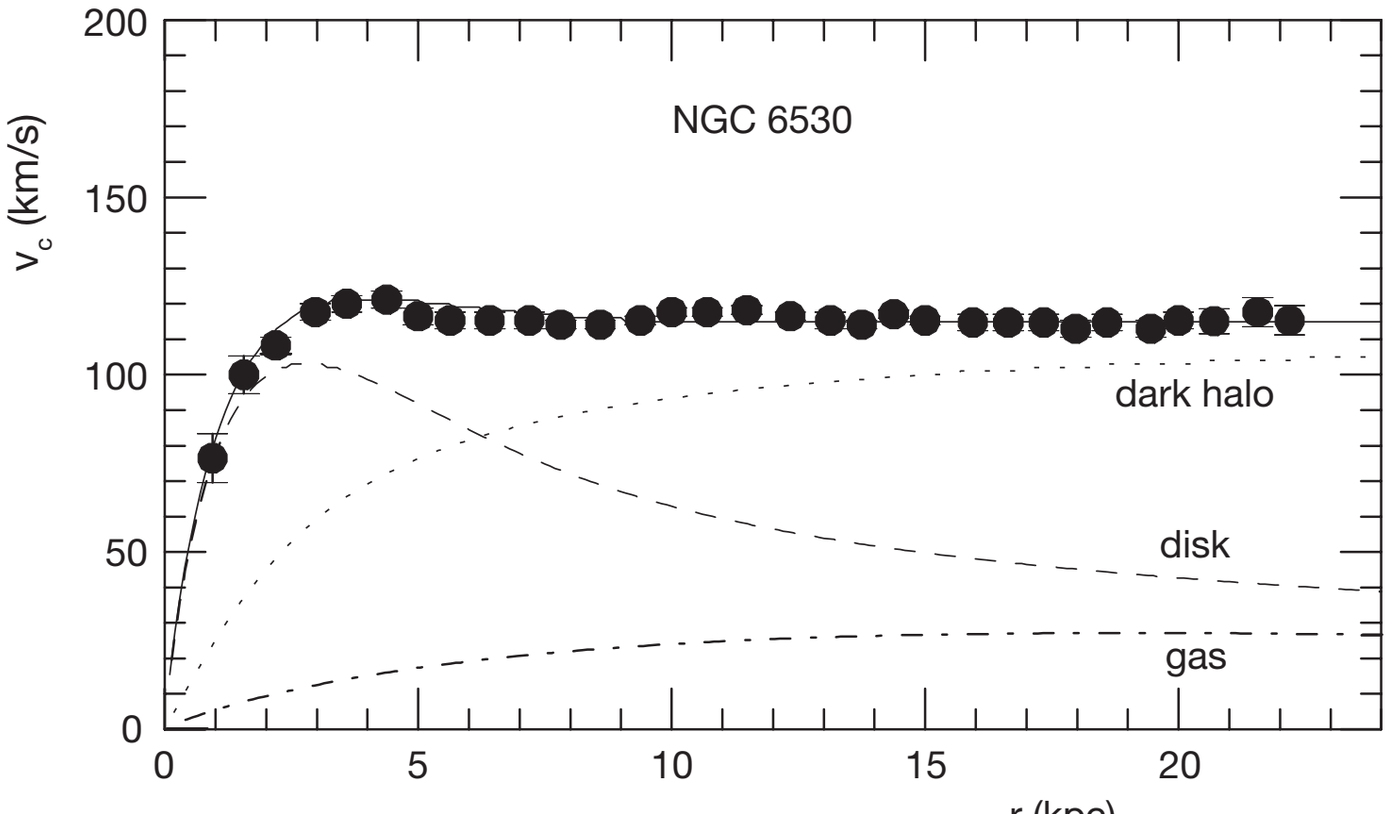
FNAL Users' Meeting
Batavia, IL

Jun 2, 2010

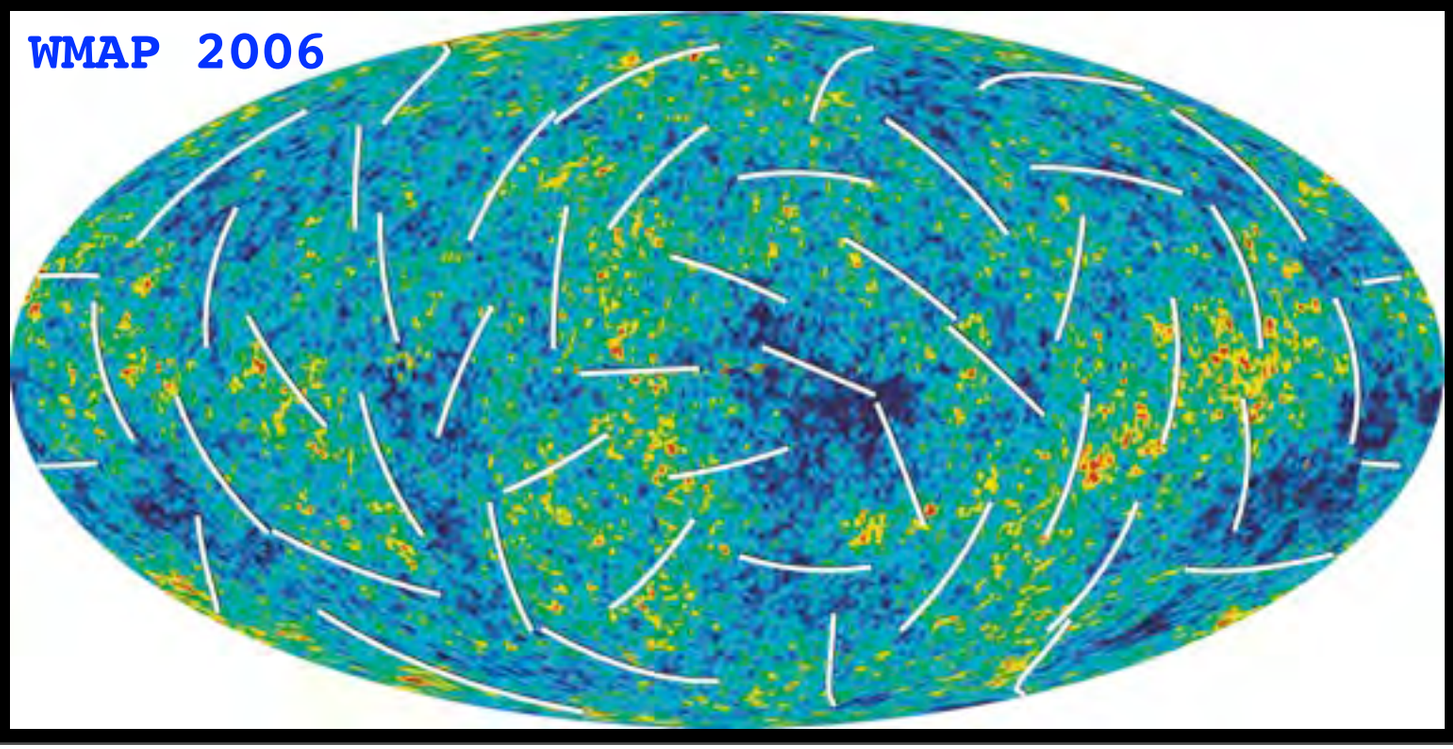
Plan of the Talk

- Evidence for dark matter
- Present results and claims
- The current Fermilab program on dark matter
- The role of Fermilab in the context of the future of US dark matter searches

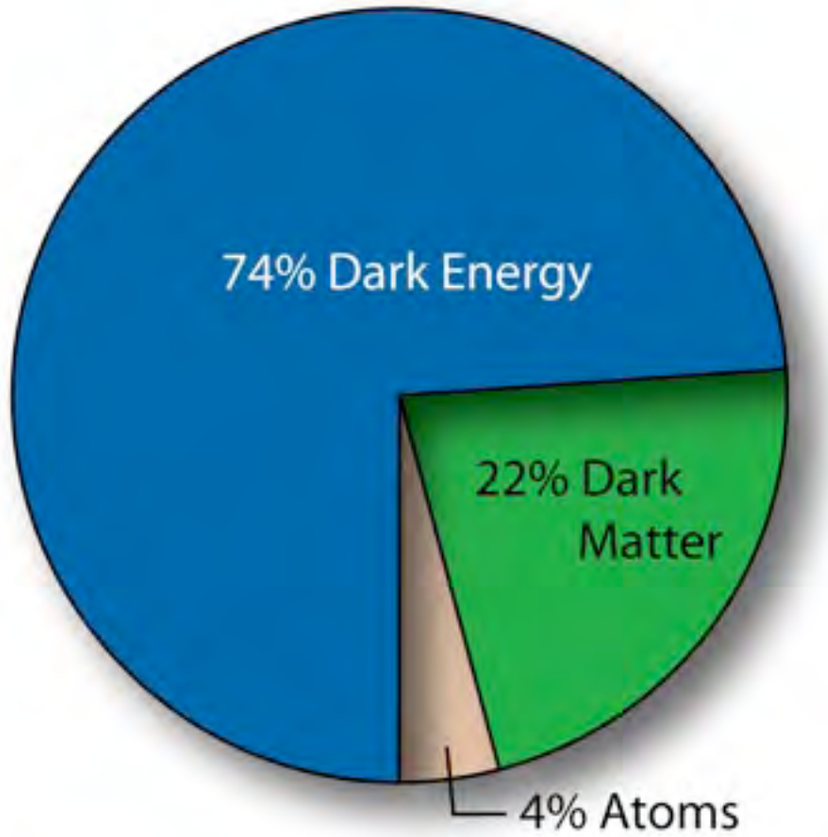
Dark Matter Evidence

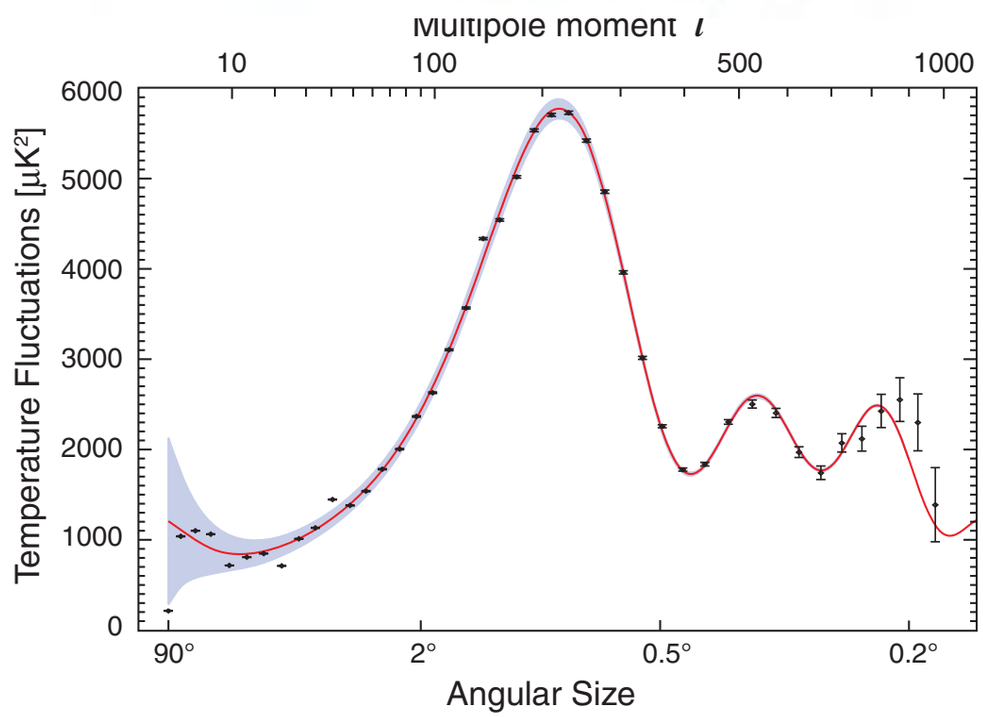


B. Fuchs astro-ph/9812048



WMAP 2006





Bullet Cluster

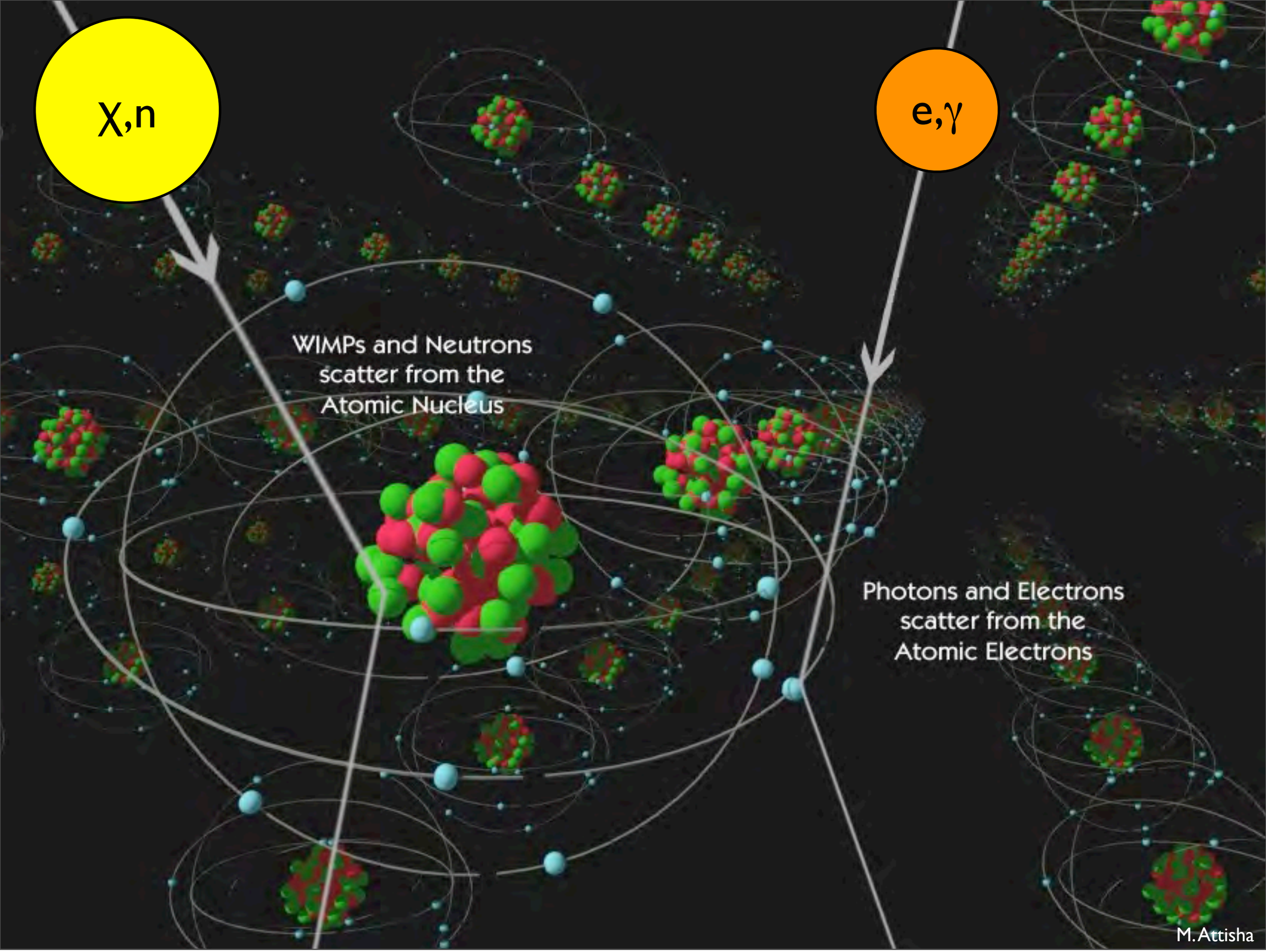
NASA

Bullet Cluster

NASA

Dark Matter

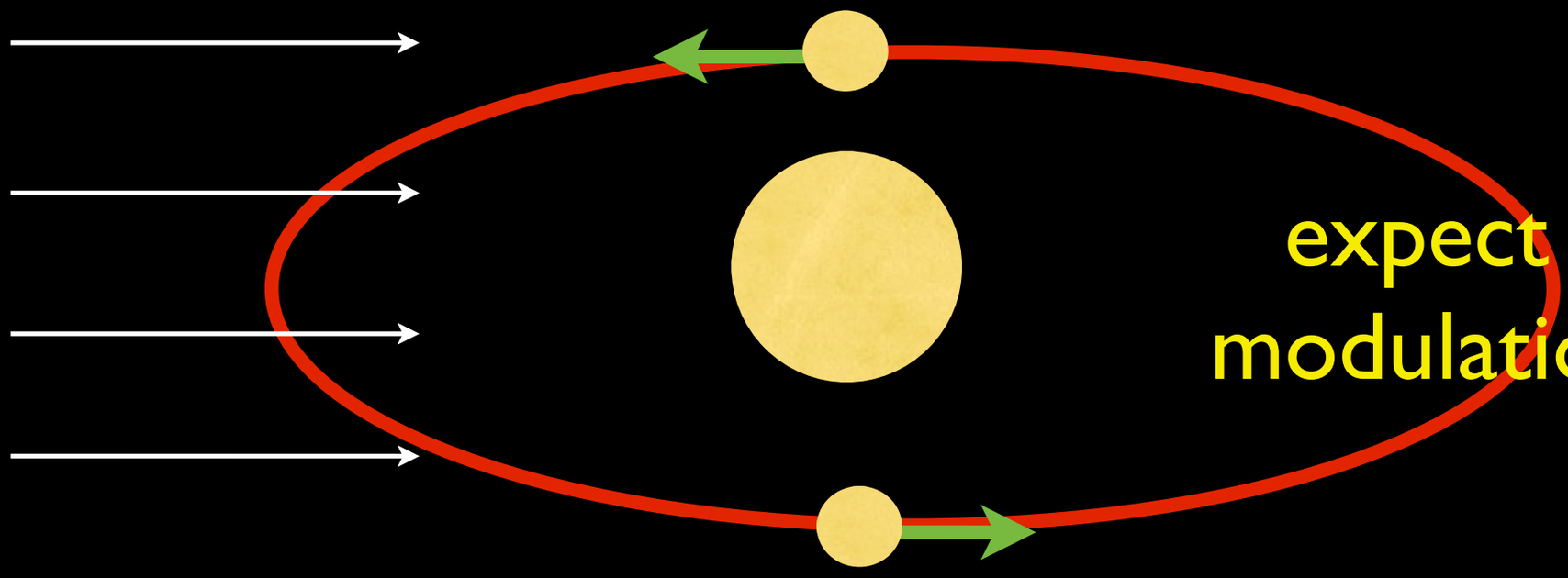
- New physics beyond Standard Model
  - Unambiguous evidence
  - Possibly connected with electroweak symmetry breaking, SUSY, and structure formation
- Very bright prospects for experimental observation
  - Astroparticle physics: direct and indirect searches
  - Particle physics: CMS and ATLAS at LHC
  - Cosmology: halo profiles, CMB, BBN
- Discovery of dark matter in nature with direct searches would be transformational for entire particle physics community


χ,n
e,γ
WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons
M. Attisha

WIMP Wind & Signatures

WIMP "wind"

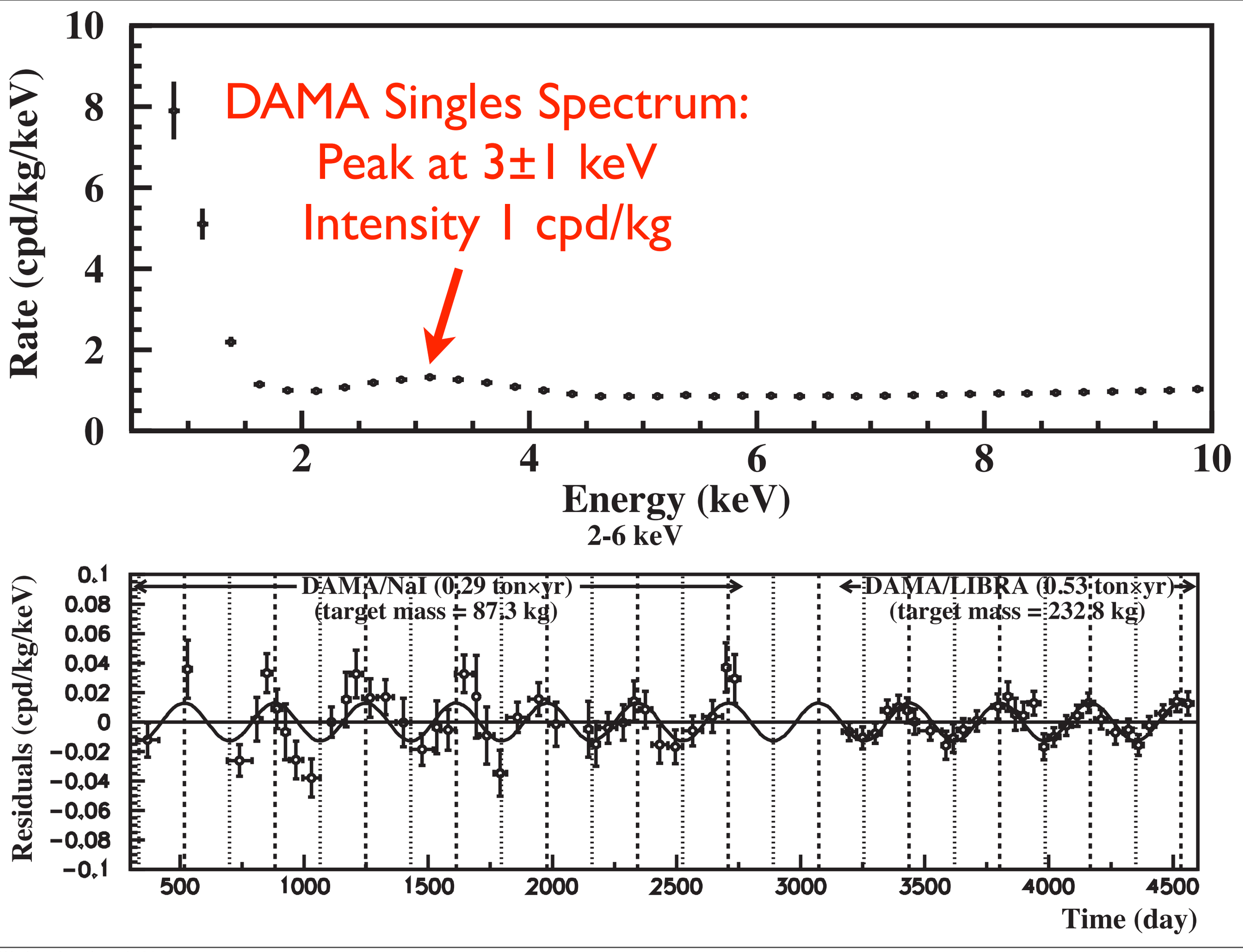
in the summer,
moving against wind



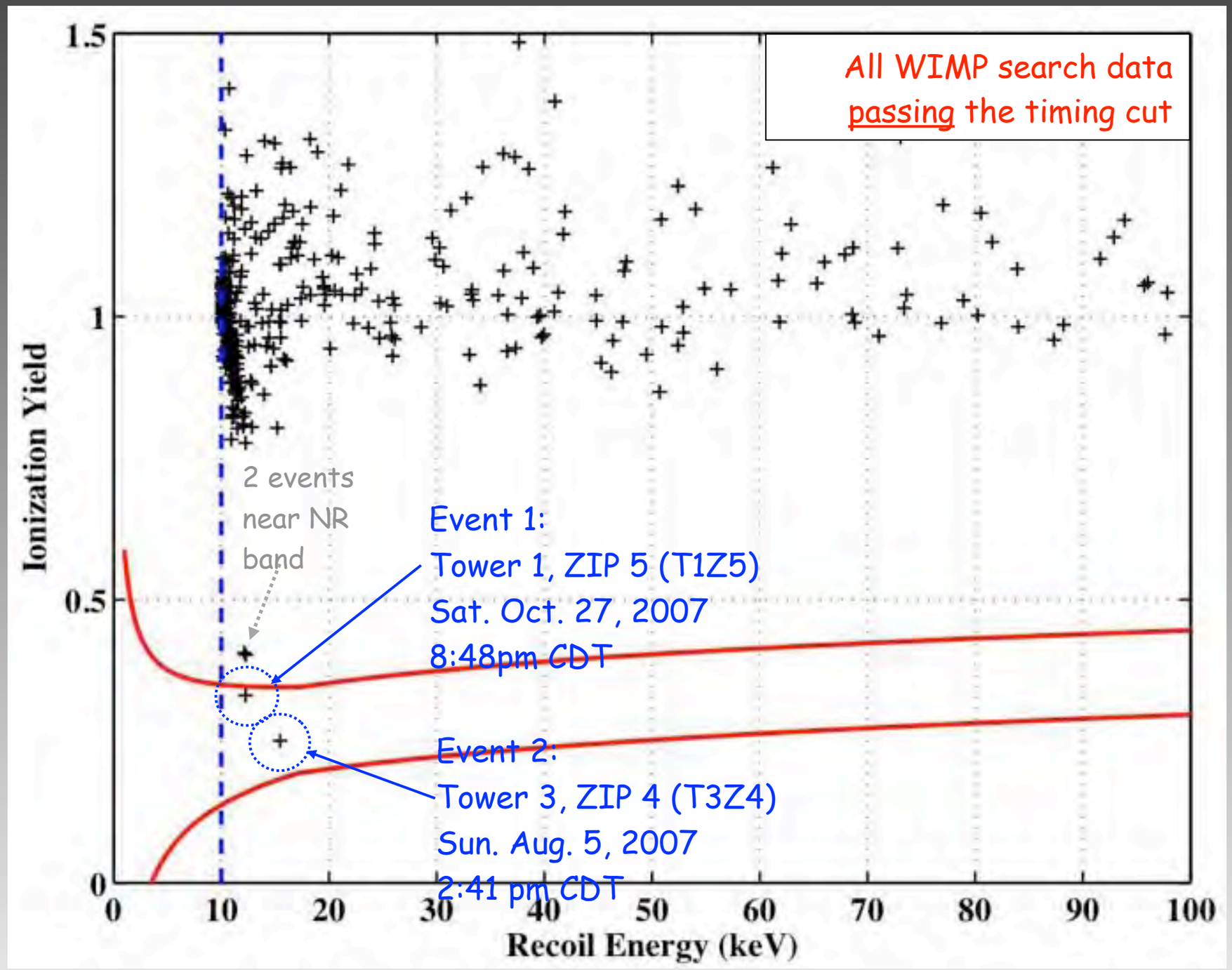
expect an annual
modulation in signal!

in the winter,
moving away from wind

Drukier, Freese, and Spergel Phys.Rev. D **33**, 3495 (1986)

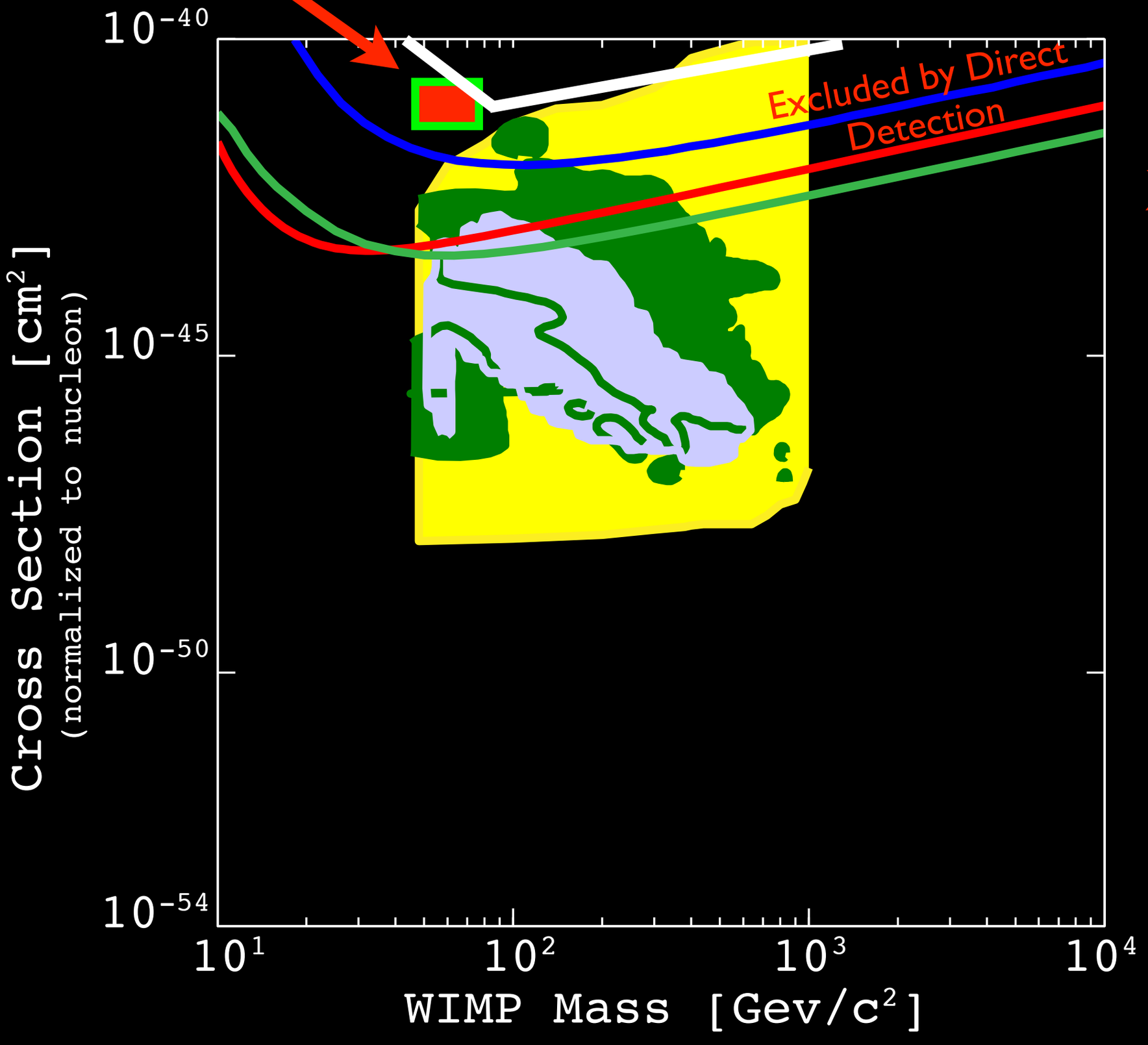

DAMA Singles Spectrum:
Peak at 3±1 keV
Intensity 1 cpd/kg
Rate (cpd/kg/keV)
Energy (keV)
2-6 keV
DAMA/NaI (0.29 ton×yr)
(target mass = 87.3 kg)
DAMA/LIBRA (0.53 ton×yr)
(target mass = 232.8 kg)
Residuals (cpd/kg/keV)
Time (day)

Unblind Events Passing Timing Cut



2 events in the NR band pass the timing cut!

DAMA Claim! SUSY Exploration



COUPP (4 kg)

WARP (3 kg Ar)

CDMS (6 kg Ge)

Xenon (100 kg Xe)

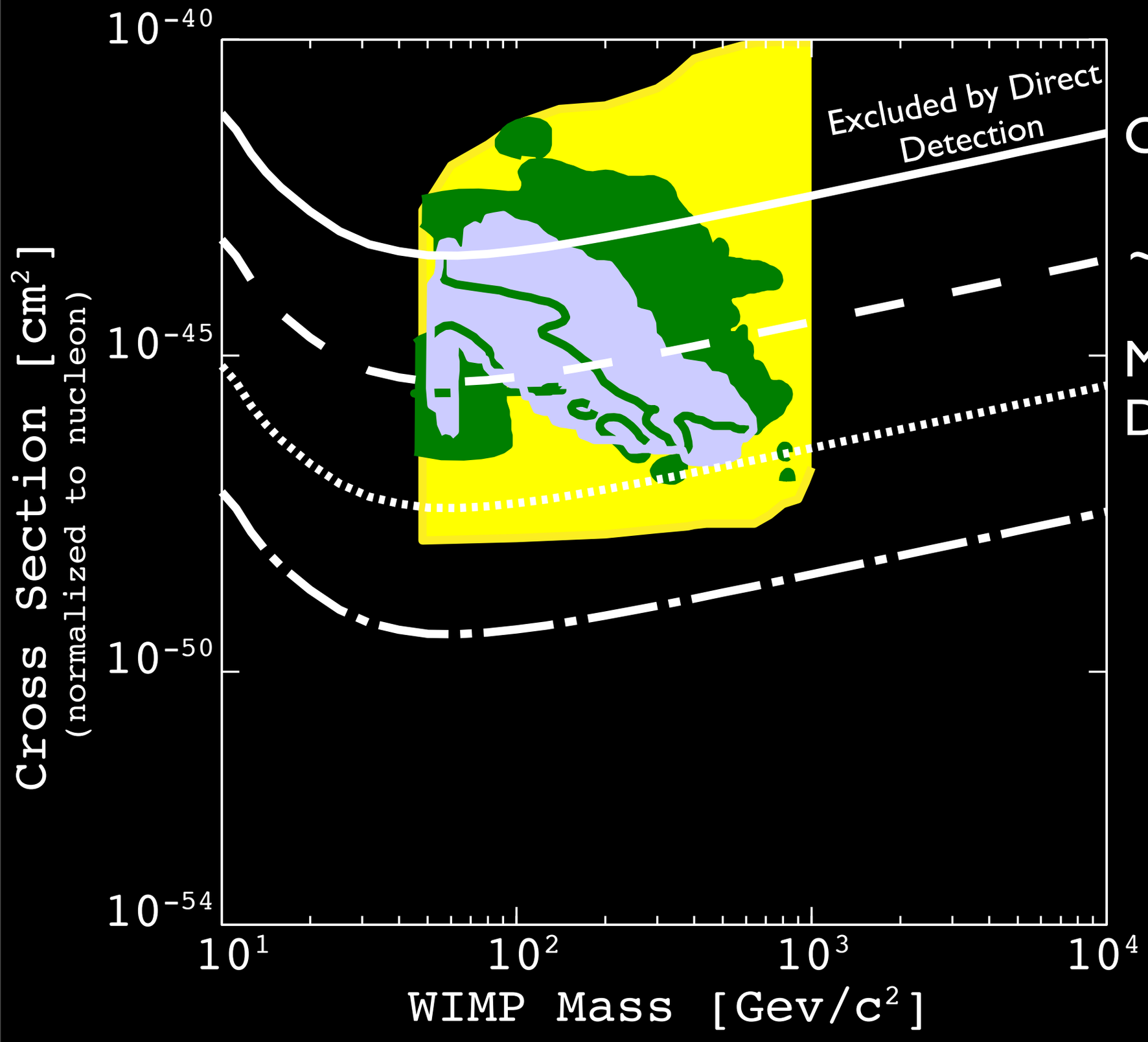
Kim, Nihei, Roszkowski, and Ruiz de Austri
JHEP 12, 034 (2002)

Baltz and Gondolo
JHEP 10, 052 (2004)

Roszkowski, Ruiz de Austri, Trotta
arXiv:0705.2012

R. Schnee

SUSY Exploration



Current Limit

~100 kg detectors

Multi-ton detectors @ DUSEL

Discovery possible at any time!

Sensitivity improved by 10^3-10^4 next decade

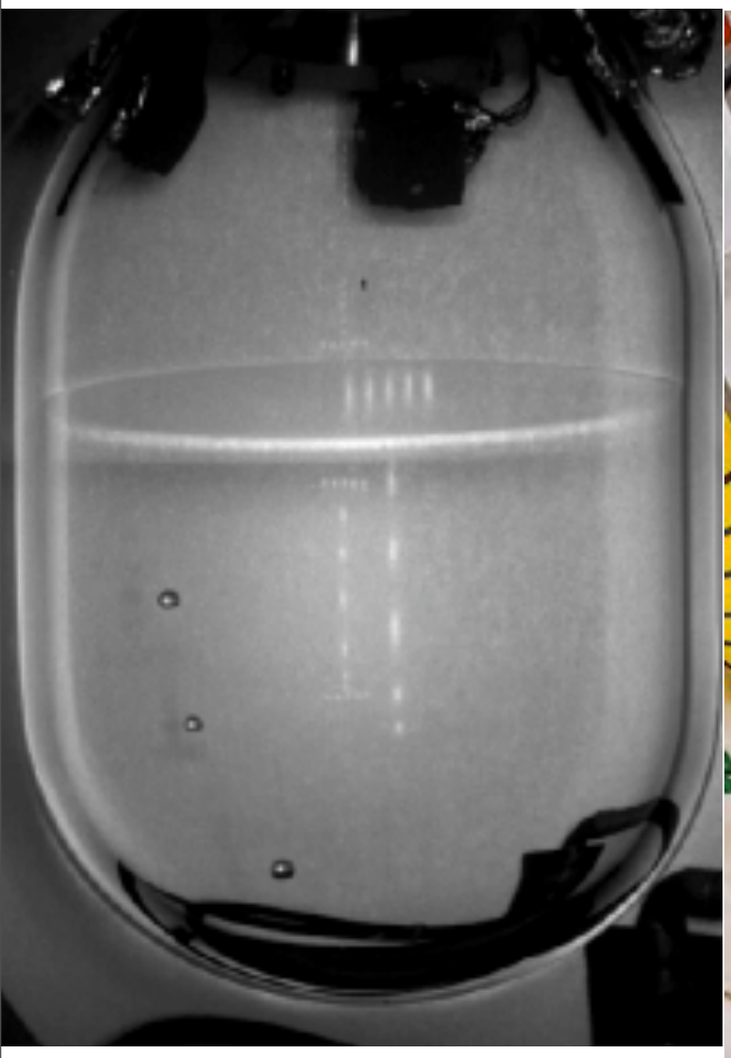
R. Schnee

The Fermilab Program on Dark Matter

- The CF_3I-based COUPP (E-961) detectors: a bubble detector for dark matter
- The Cryogenic Dark Matter Search - CDMS (E-891)
- The cryogenic noble liquid program: DarkSide (E-1000) and MAX (P-1001)

Searching for Dark Matter with Bubble Chambers (COUPP)

- Exploit physics of bubble nucleation to discriminate against background gammas and alphas: successful 2009 run of small chamber demonstrated potential to reach zero background.
- Scalable: 4-kg run in 2009, 60-kg being commissioned now; 500-kg and 16-ton (DUSEL) versions under discussion



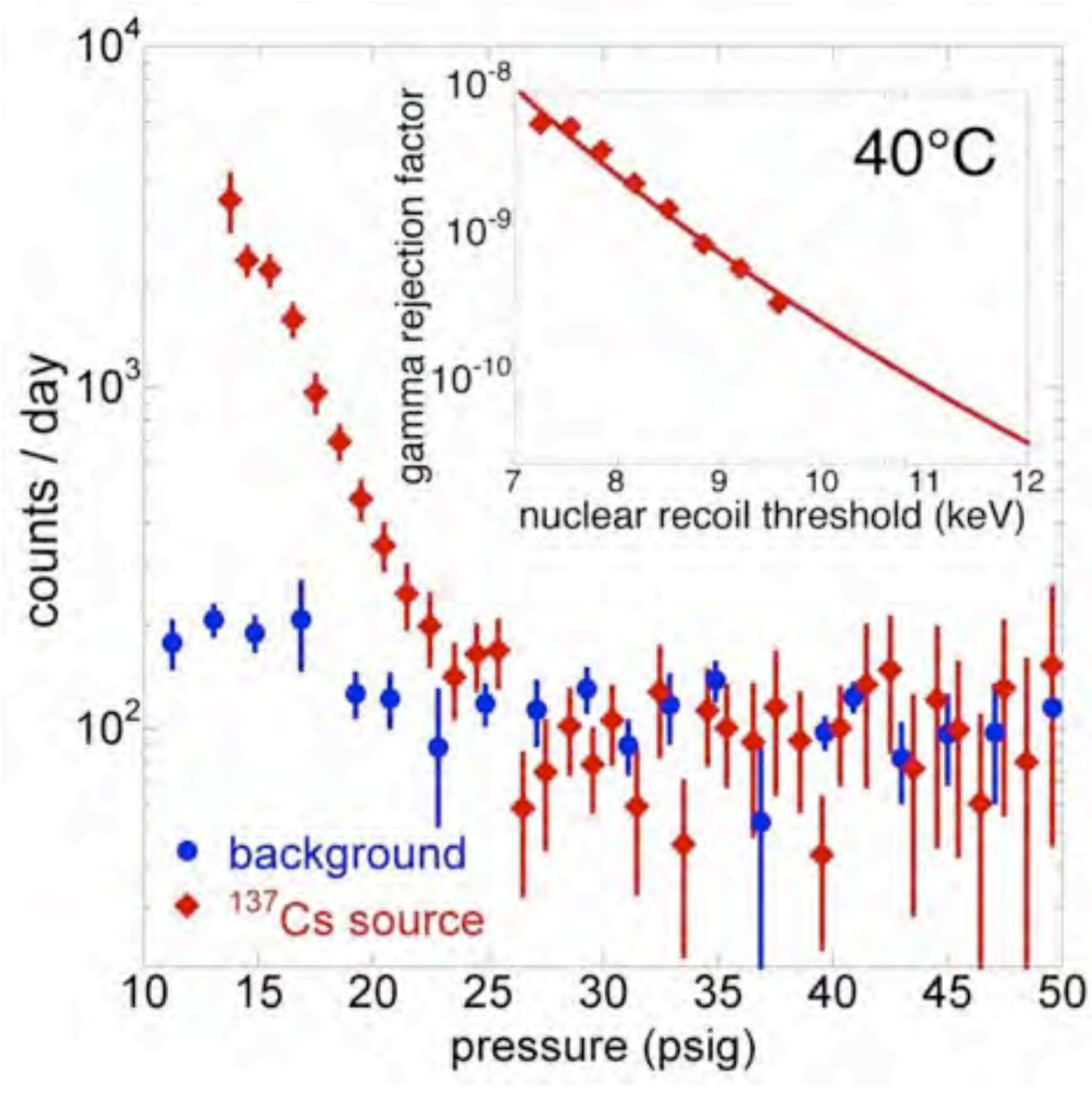
Neutron scattering background event in 4-kg chamber

Construction of 60-kg chamber

Fused silica inner vessel for 60-kg chamber. High purity construction techniques are used to reduce contamination by environmental radioisotopes

Background Discrimination

- Exploit remarkable features of bubble nucleation physics to discover dark matter:
  1. Insensitivity to γ and β backgrounds when pressure and temperature are tuned to require high dE/dx
  2. More acoustic emission from α events than nuclear recoils. ← New



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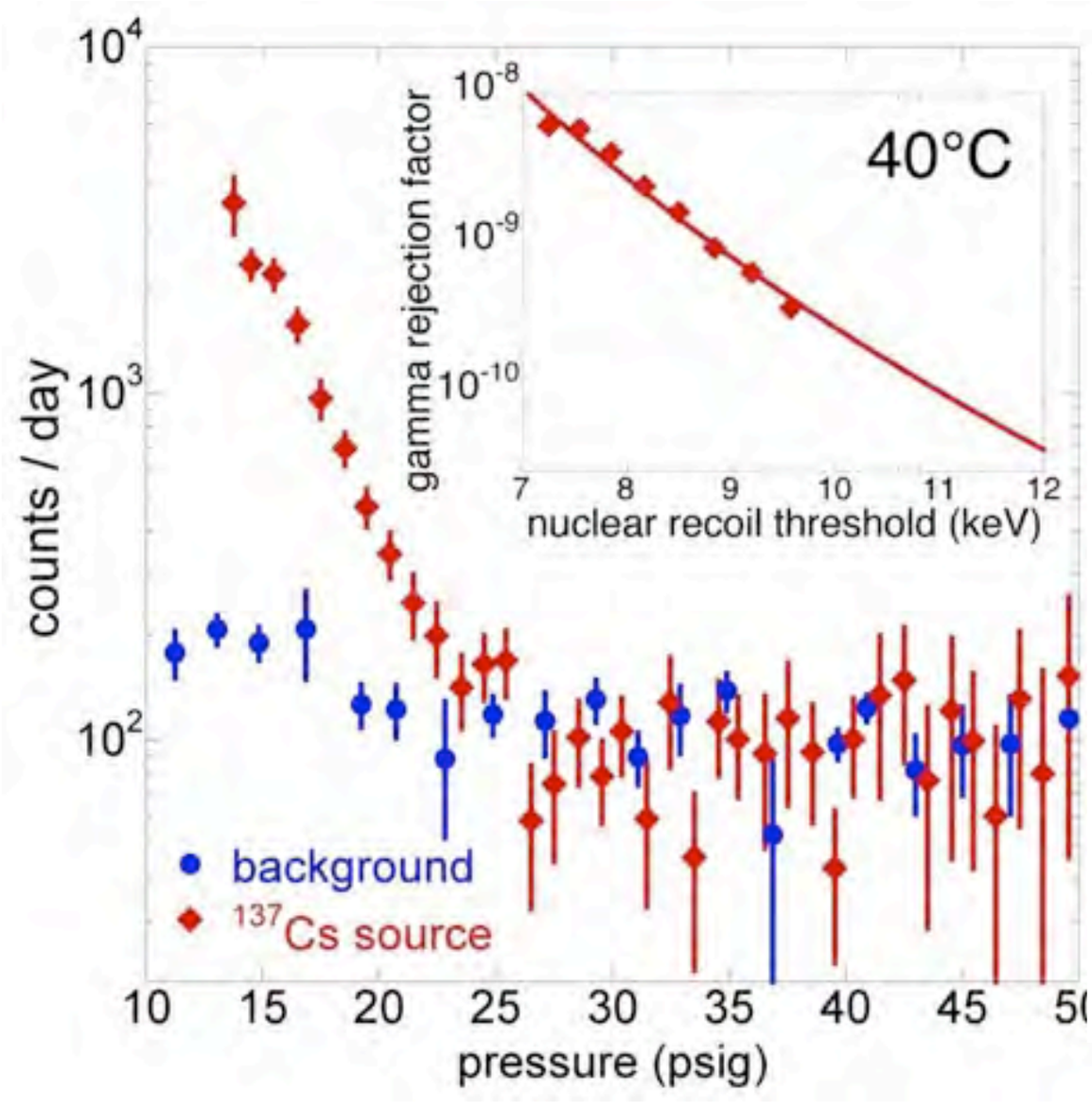
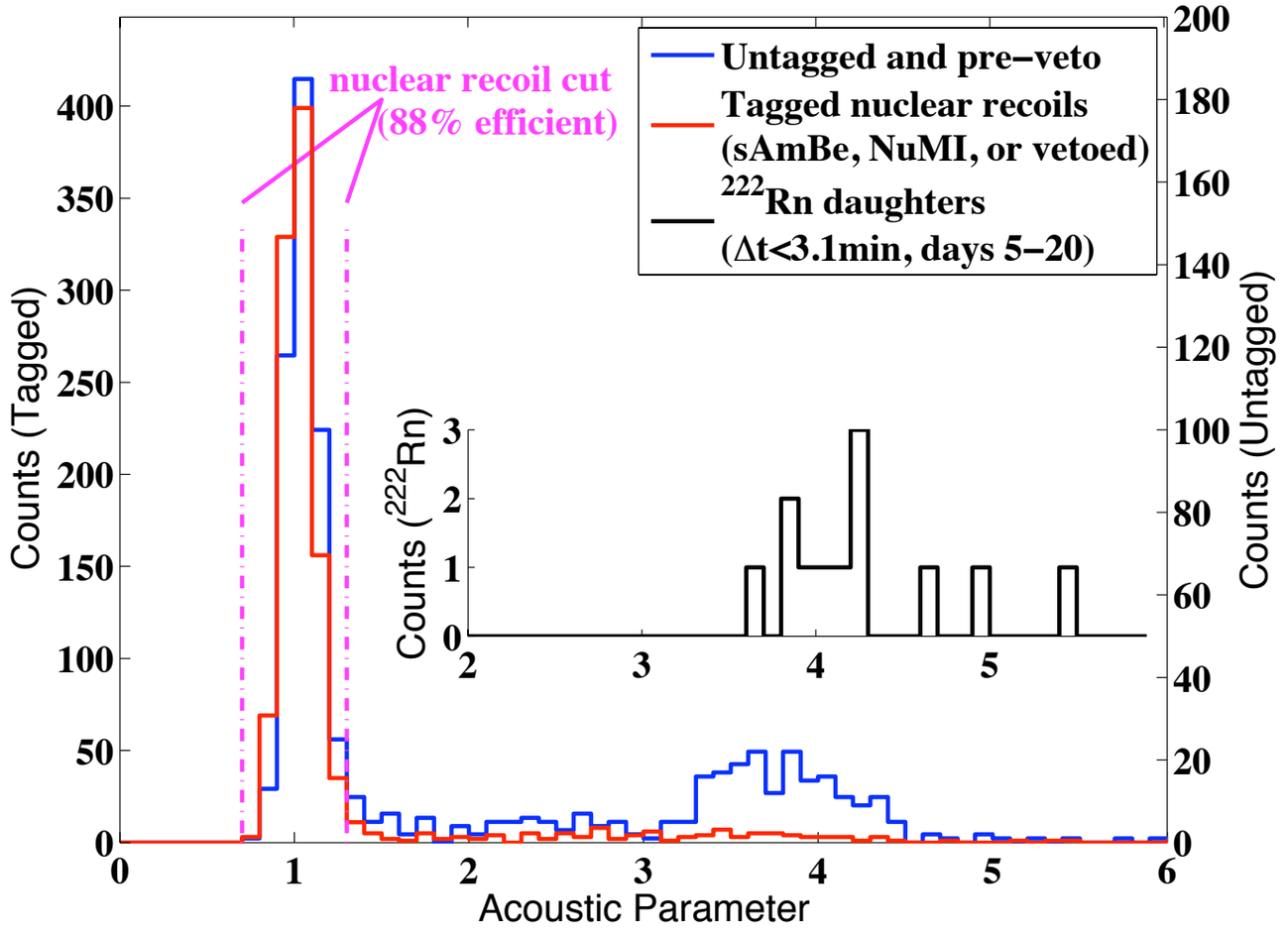




COUPP Sensitivity Goals

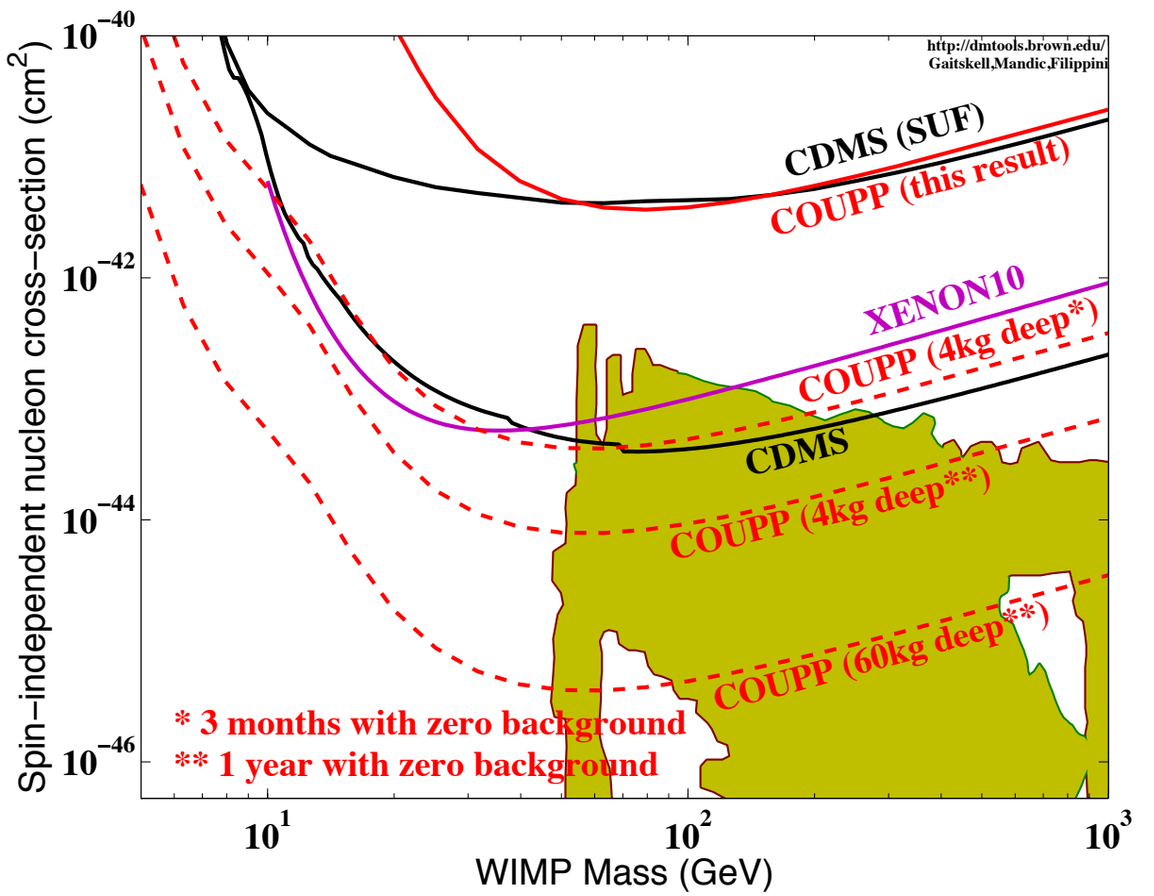
• In 2009, the COUPP 4-kg chamber reached the limit of sensitivity which can be achieved in the NuMI tunnel at Fermilab (300 m.w.e.), due to residual flux of cosmic-ray induced neutrons

• The 4-kg and 60-kg chambers will be deployed at Snolab (6000 m.w.e.) in 2010-2011. At this site, the neutron backgrounds can be reduced by more than 4 orders of magnitude.

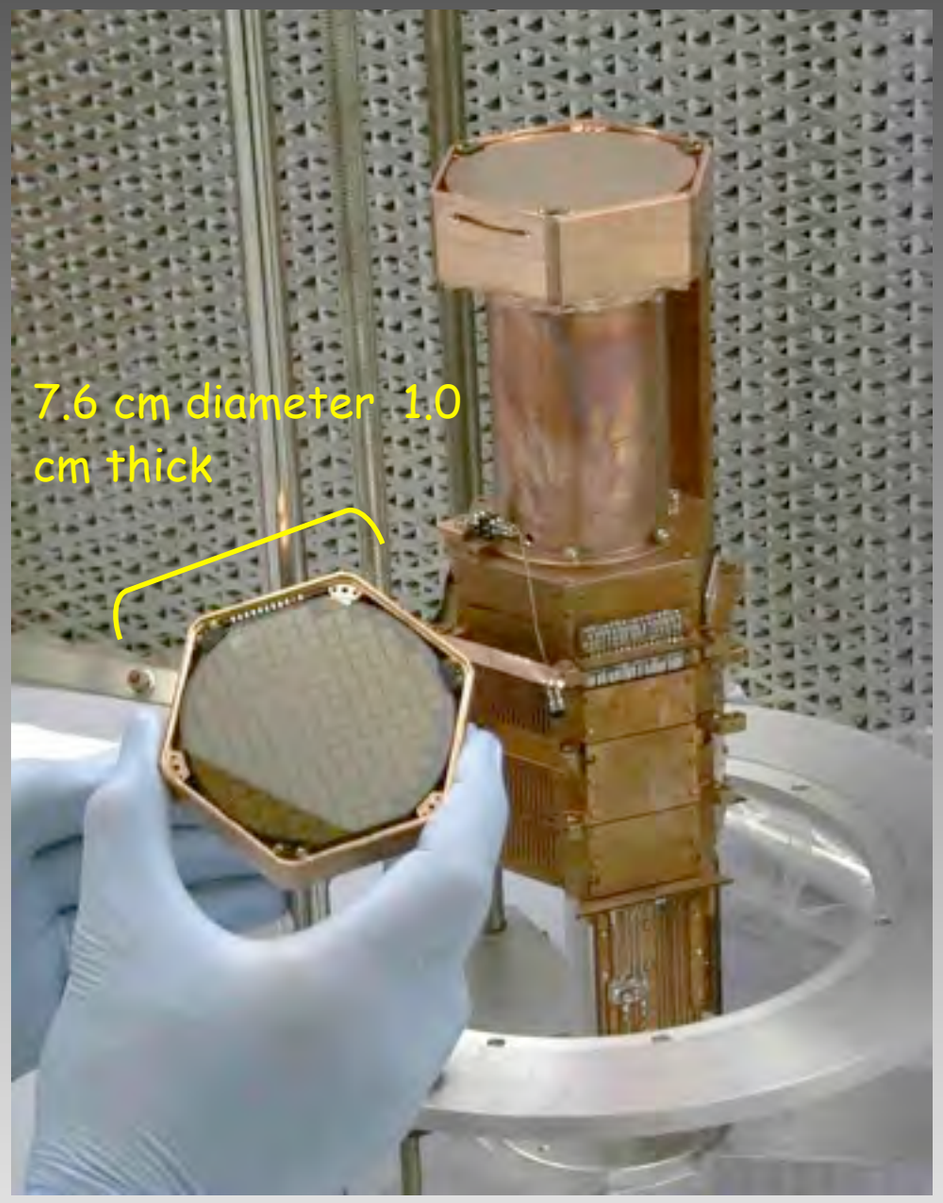
• If alpha rejection power is high, the bubble chamber technique will have competitive sensitivity to both spin-dependent and spin-independent couplings

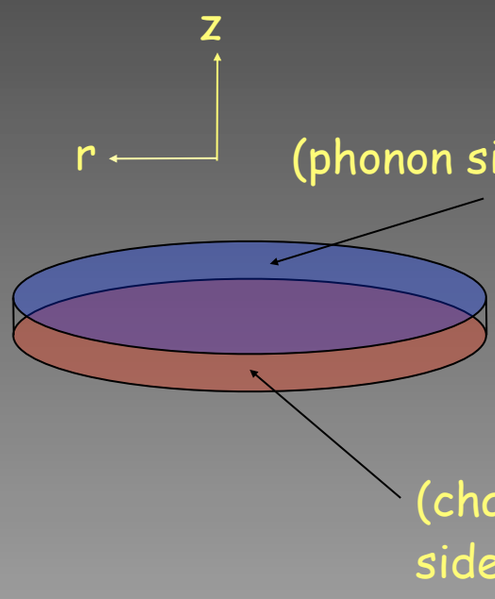
Spin-Dependent

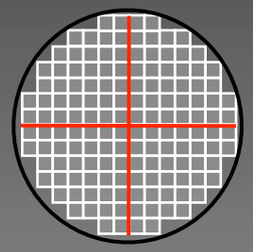
Spin- Independent



Z-sensitive Ionization and Phonon Detectors

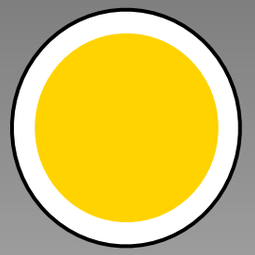




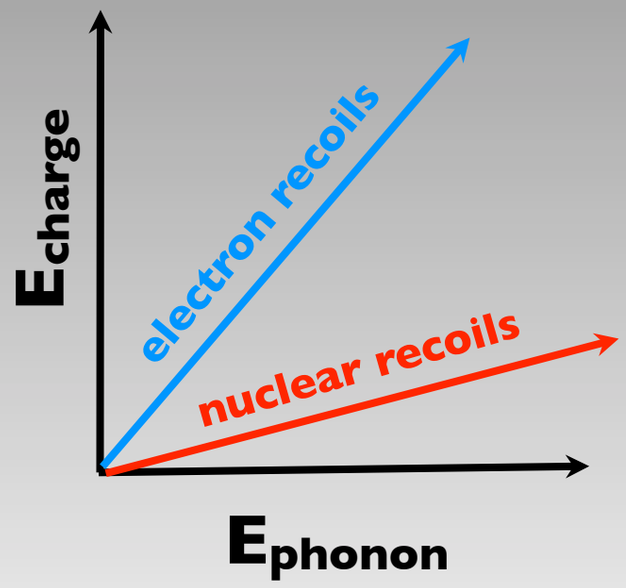


4 phonon channels

(each is 1036 TES sensors in parallel)



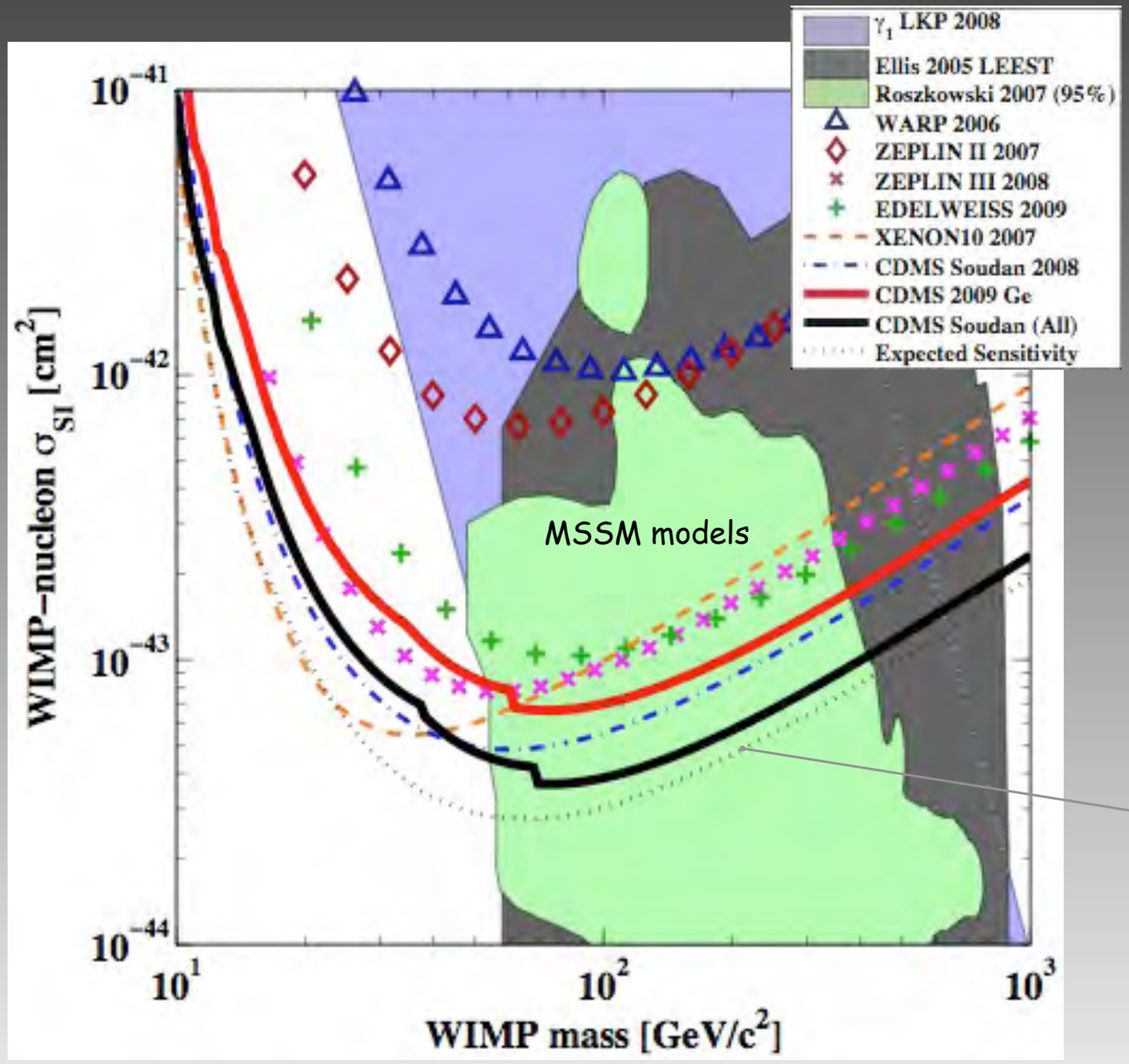
inner sensor
+
outer guard



Signature of a Nuclear Recoil

reduced ionization signal relative to phonon signal

90% C.L. Spin-Independent Limit



In the presence of 2 events (no background subtraction):

CDMS 2009

@WIMP mass 70 GeV

$\sigma = 7.0 \times 10^{-44}$ cm^2 (90% C.L.)

CDMS Combined Soudan Data

@WIMP mass 70 GeV σ

$= 3.8 \times 10^{-44}$ cm^2 (90% C.L.)

Sensitivity curve based on revised bg estimate:

$0.8 \pm 0.1(\text{stat.}) \pm 0.2(\text{sys.})$ surface events

$0.04^{+0.04}_{-0.03}$ cosmogenic neutrons

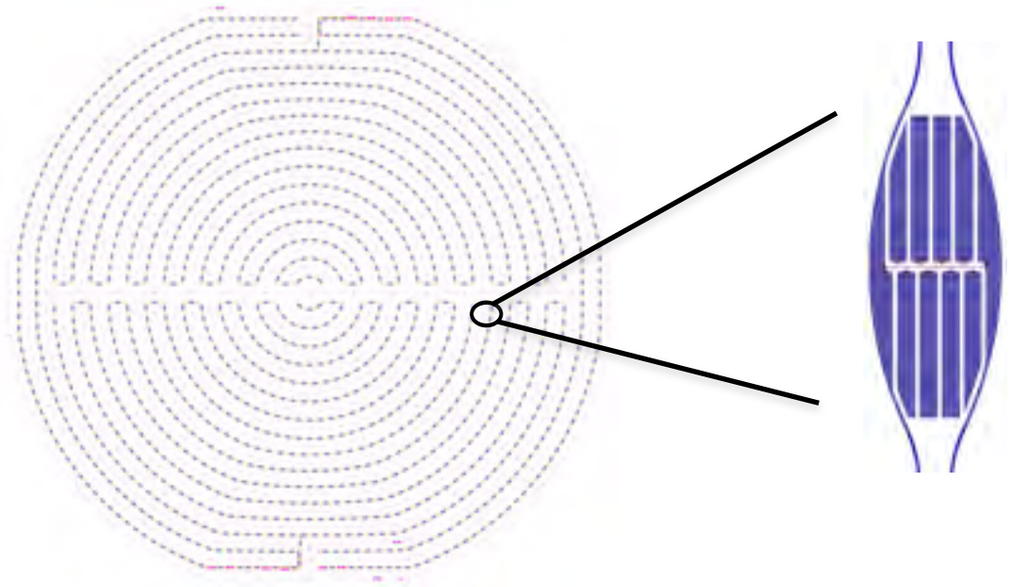
0.04 – 0.06 radiogenic neutrons

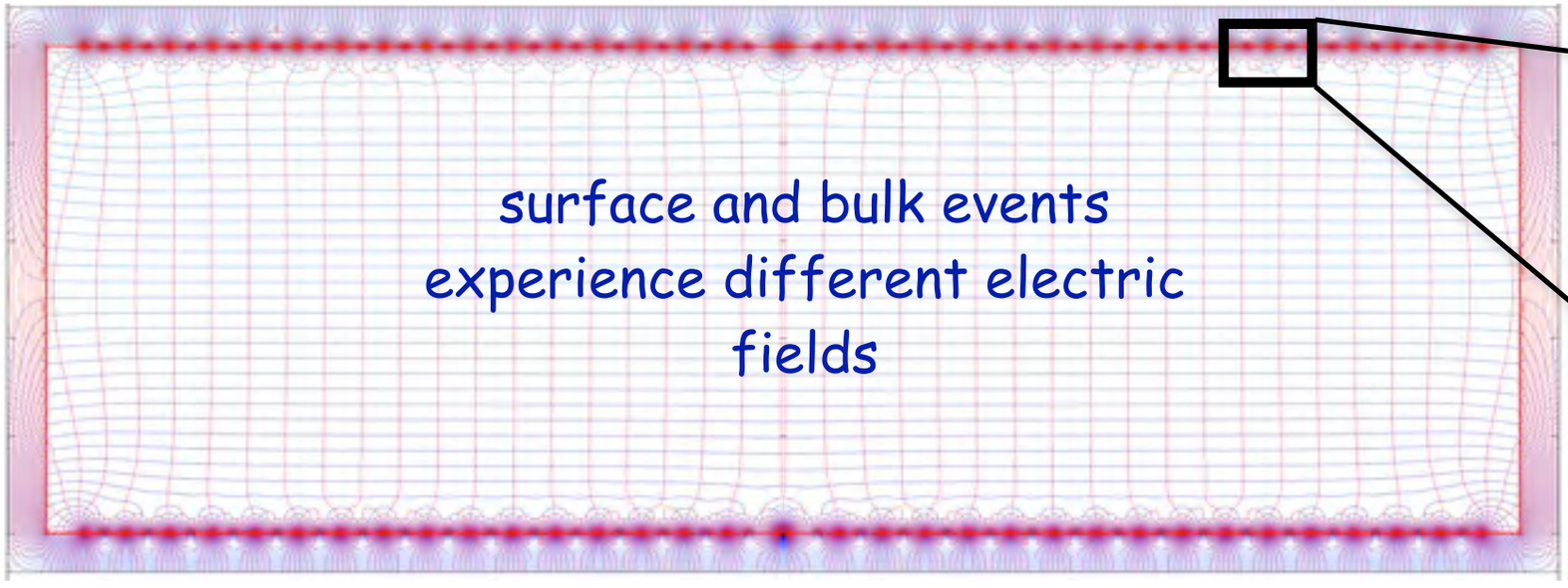
Breakthrough in detector technology

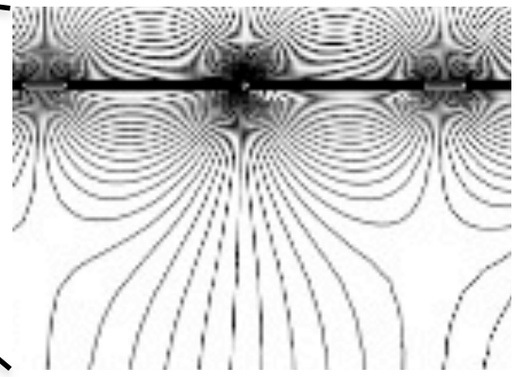
iZIP = interleaved charge and phonon channels

- rejection of surface events X10 better than CDMSII style detectors !

- efficiency for neutrons passing charge cut is ~55%







Charge near surface is collected by electrodes on only one side

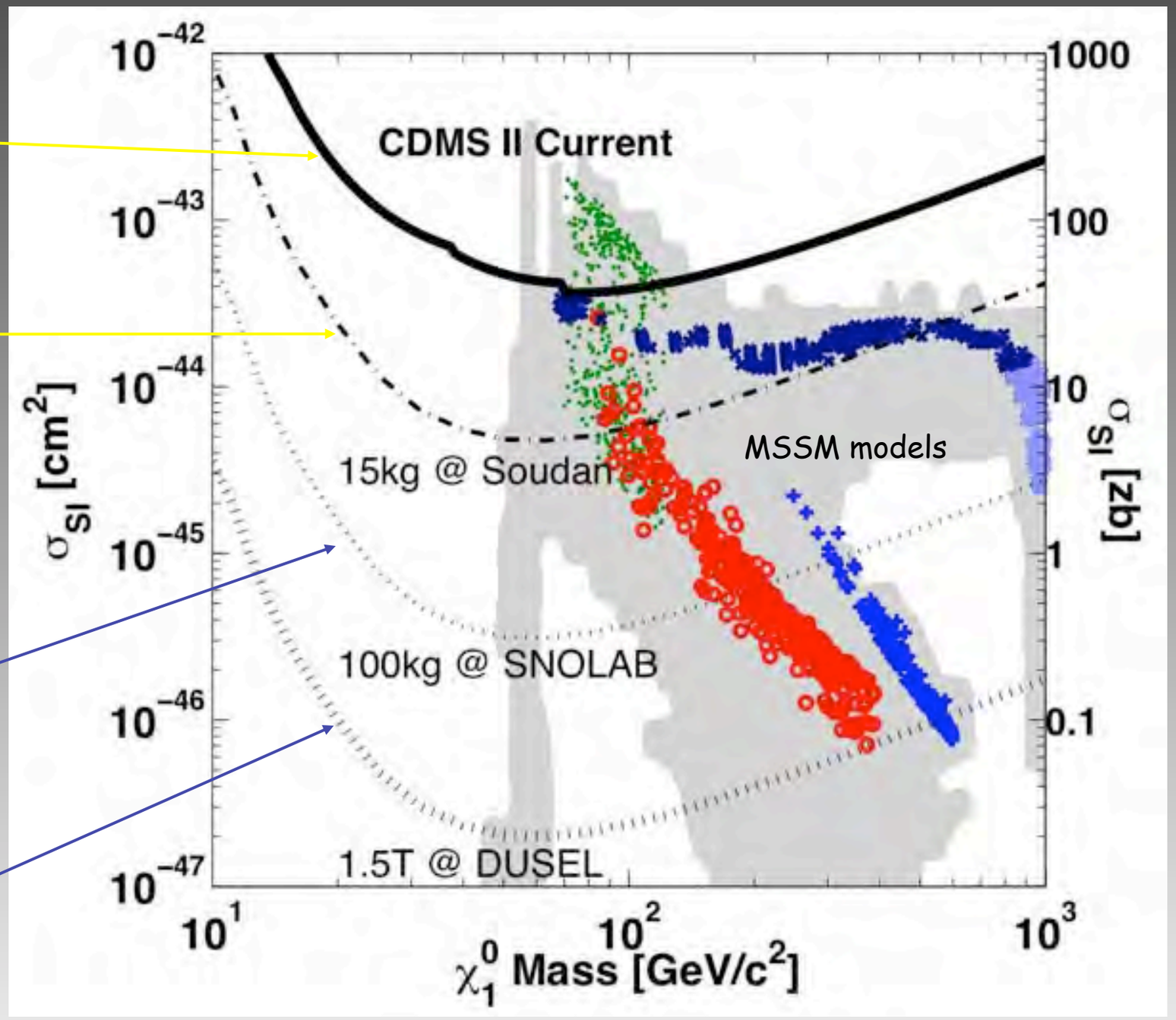
CDMS Future Projections

CDMS II
4 kg Ge
~ 2 yrs operation

SuperCDMS @ Soudan
15 kg Ge
~ 2 yrs operation

SuperCDMS @ Snolab
100 kg Ge
~ 3 yrs operation

DUSEL/GEODM
1.5T



Argon-based Search: DarkSide (E-1000)

- LAr is one of the brightest scintillators known. Pulse shape of primary scintillation provides very powerful discrimination for NR vs. EM events:

  Rejection factor exceeds 10^8 for > 60 photoelectrons (Boulay & Hime 2004; Benetti et al. (WARP) 2006)

- Ionization drift is well established technology on very large scale detector. Ionization:scintillation ratio is a strong and semi-independent discrimination mechanism:

  Rejection factor ~10^2 (Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006)

- Spatial resolution from ionization drift in a TPC detector localizes events within few mm, allowing rejection of multiple interactions, "wall events", etc.

Challenges for Future DM Searches

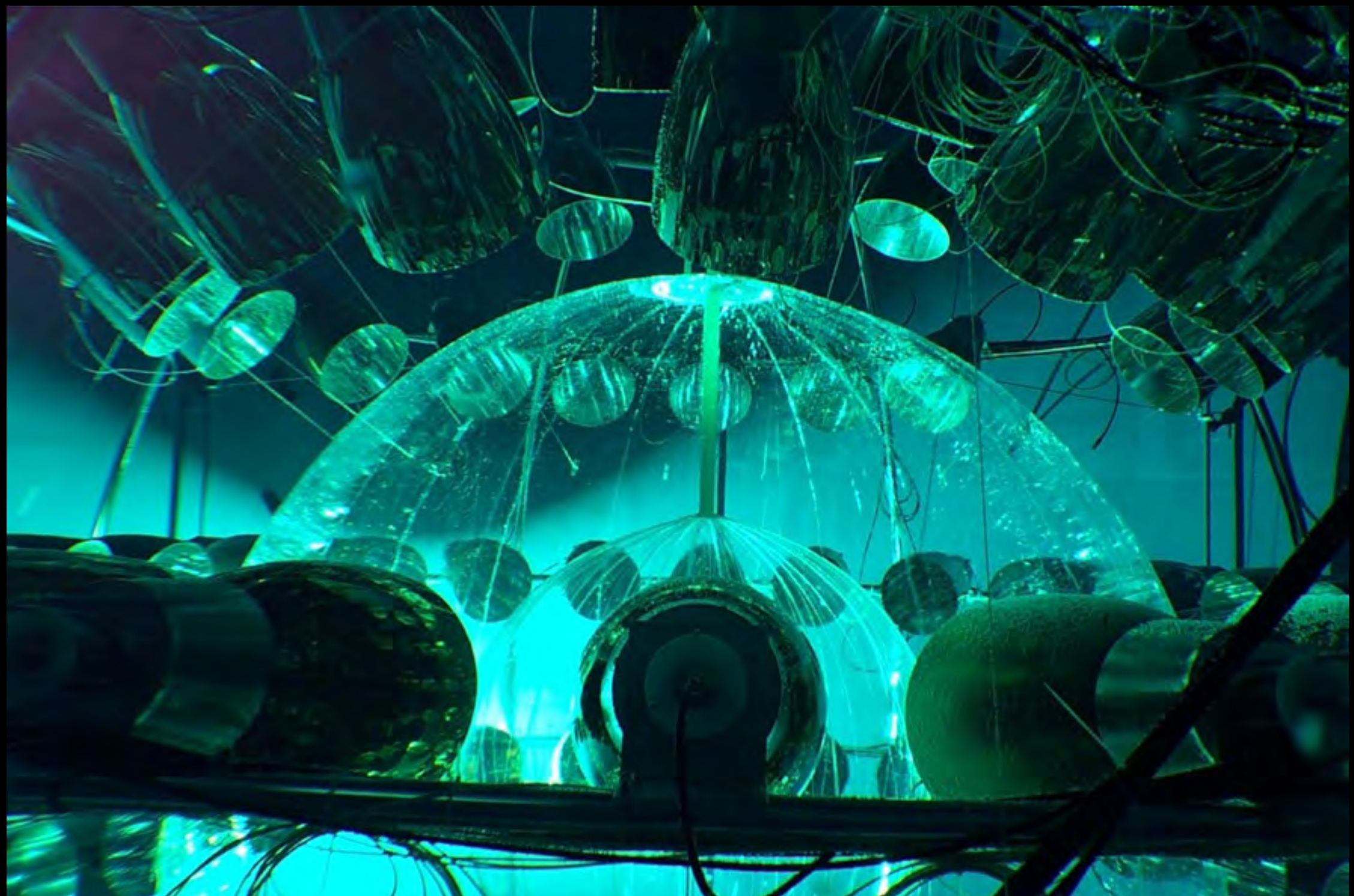
1. Radioactivity reduction in active and passive detector parts
2. Powerful discrimination against residual radioactivity
3. Reduction of internal neutron sources (*e.g.* photodetectors)
4. Mitigation of external neutron flux and rejection of residual external neutron events

New technologies introduced in E-1000

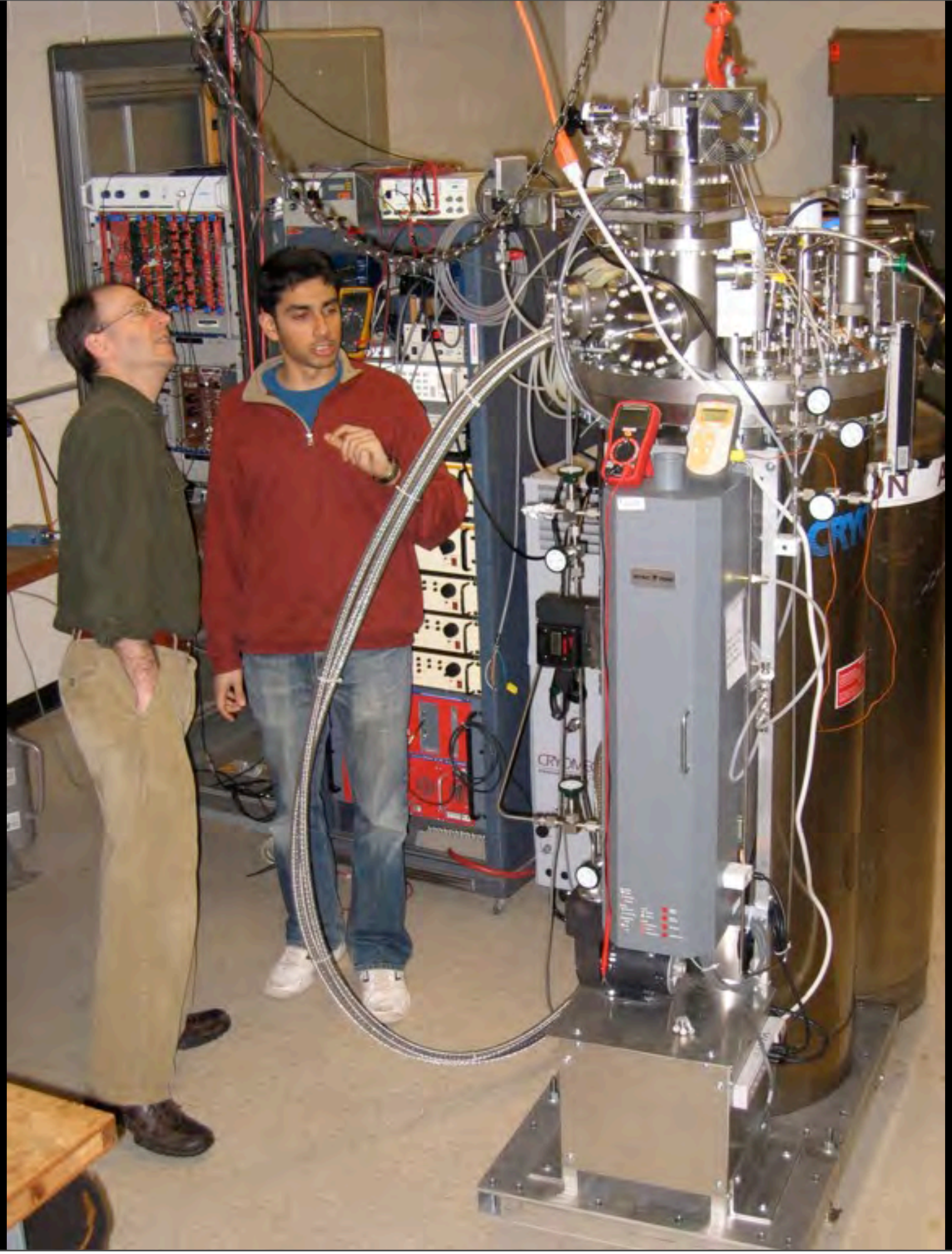
1. Depleted Argon from underground sources
2. High efficiency borated liquid scintillator neutron veto (>99.8% rejection efficiency for radiogenic neutrons)
3. QUPID photosensors
   - no background detected in best Ge
   - new photocathode with high QE at liquid argon temperature

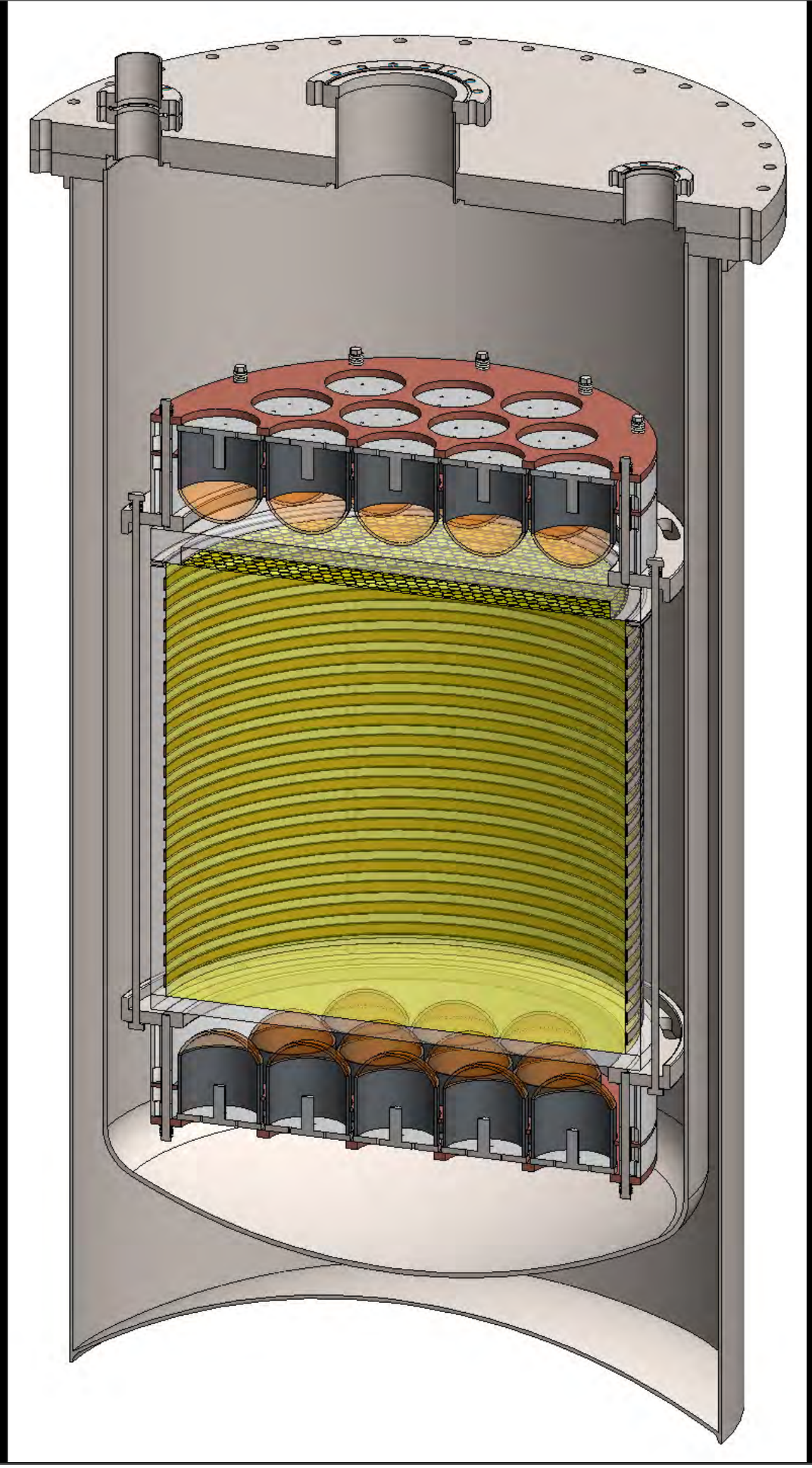
Princeton-Fermilab Cryogenic Distillation Column @ FNAL PAB

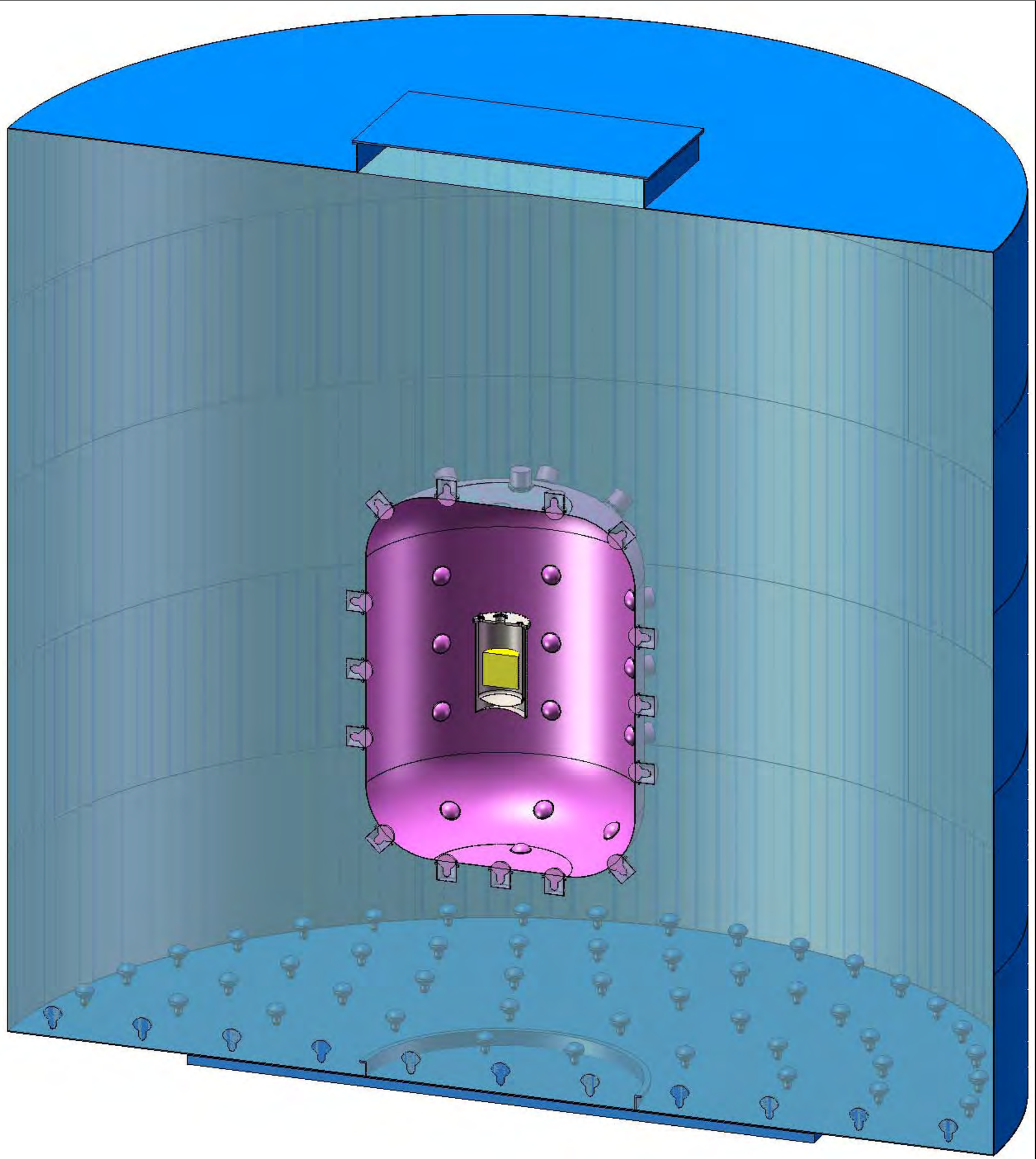
Proposal of DarkSide to Borexino



Conduct DarkSide Development Test within CTF tank







DarkSide Timeline

- DarkSide-50
  - Science starting 2011
  - projected sensitivity of 10^{-45} cm^2
- DarkSide ton scale
  - Science starting 2014-5
  - Projected sensitivity 5×10^{-47} cm^2
- MAX @ DUSEL
  - 20 ton DAr, 6 ton Xe
  - Projected sensitivity 10^{-48} cm^2

The Future of the US Dark Matter Effort

- Large number of US groups pursuing R&D towards design of detectors with timing of deployment compatible with DUSEL (2017 installation start - 2019 science start)
- Multi-ton detectors designed to probe range 10^{-47}-10^{-48} cm^2:
  - CLEAN - Ar
  - COUPP - CF_3I
  - GEODM - Ge
  - LZ - Xe
  - MAX - DAr and Xe

The Future of the US Dark Matter Effort

- The dark matter community fully recognizes that experiments of this scale should exploit the combined resources of existing collaborations, especially on the front of cryogenic noble liquids
- In a recent meeting in Berkeley, May 21-22 2010, we started important discussions on how to best implement this strategy of consolidation
- Fermilab currently supporting efforts on Ar, Ge, and CF_3I
- Fermilab in position to play significant role in the full range of future US dark matter searches

The End