WIMP detection with Liquid Rare Gasses - a race to large scales.

T. Shutt

Case Western Reserve University

Detecting galactic WIMP dark matter

Dark matter "Halo" surrounds all galaxies, including ours.

Density at Earth:

$$\rho \sim 300\ {m_{\text{proton}}}\big/\text{liter}$$

$$m_{wimp} \sim 100\ m_{proton.}$$

3 WIMPS/liter!

Typical orbital velocity:

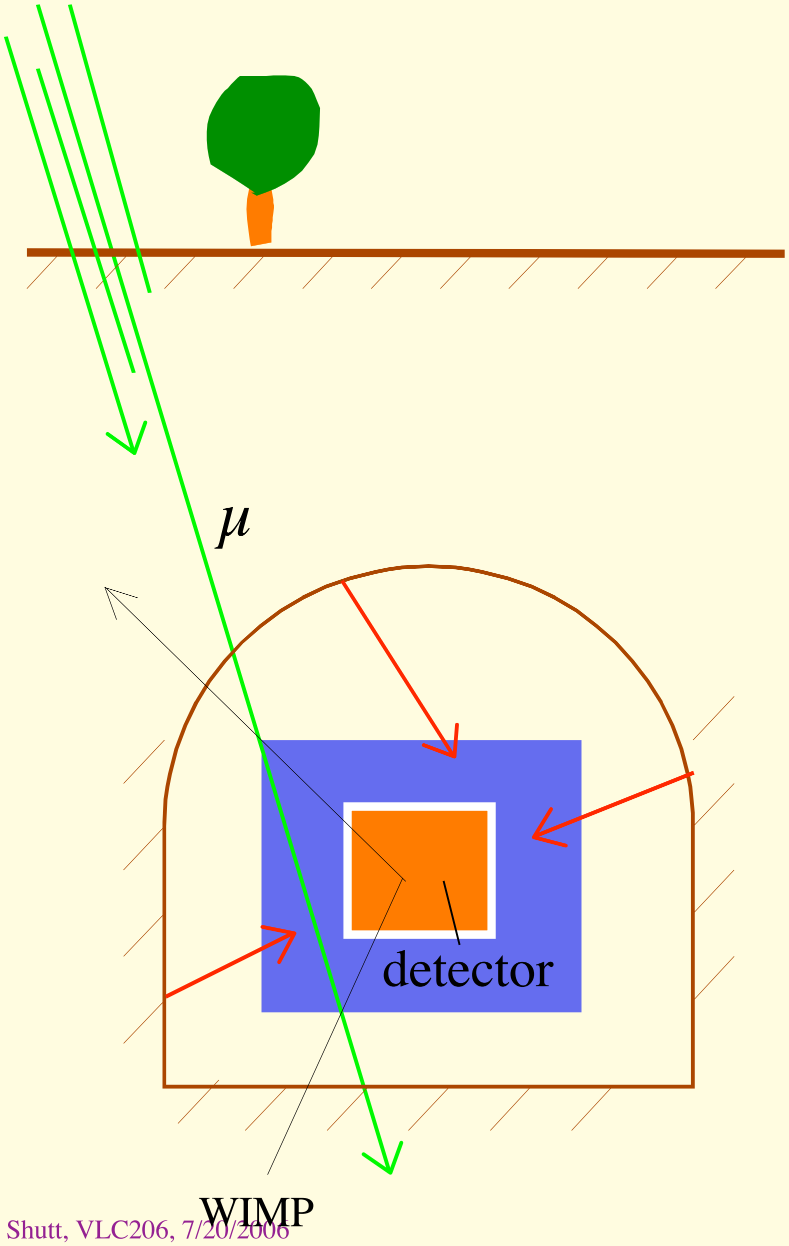
$$v \approx 230\ \text{km/s}$$

$$\sim 1/1000\ \text{speed of light}$$

Coherent scalar interactions: A^2

Rate: < 0.06 event/kg/day, or much lower

Detecting rare events.



- Problem: radioactivity
  - Ambient: 100 events/kg/sec.
  - Pure materials in detector
- Shield against outside backgrounds
- Underground to avoid muons

Why Roman lead is special.

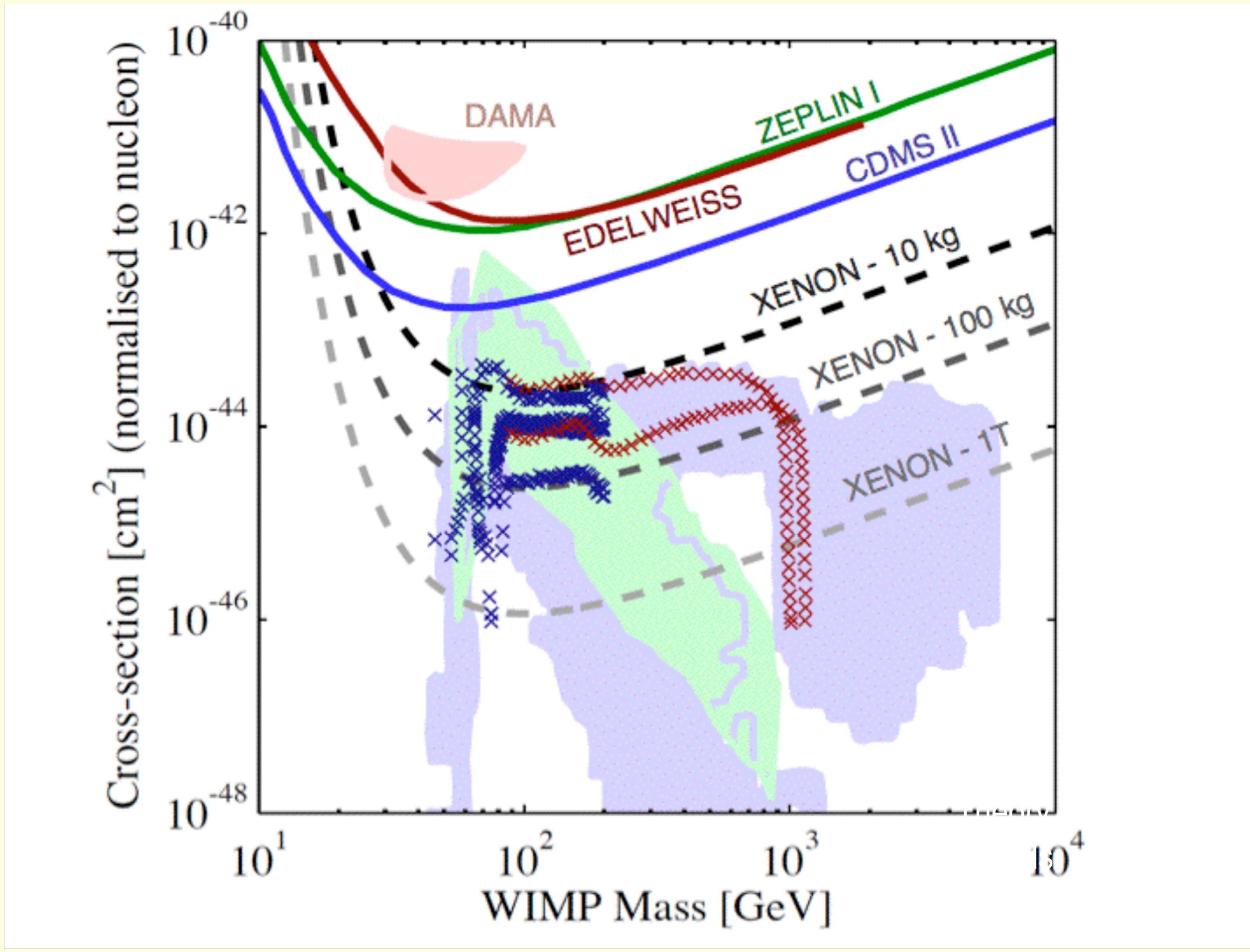
U, Th in rock: 2 ppm ≈ 10^7 decays/day/kg

Crude smelting removes U, Th from Pb.

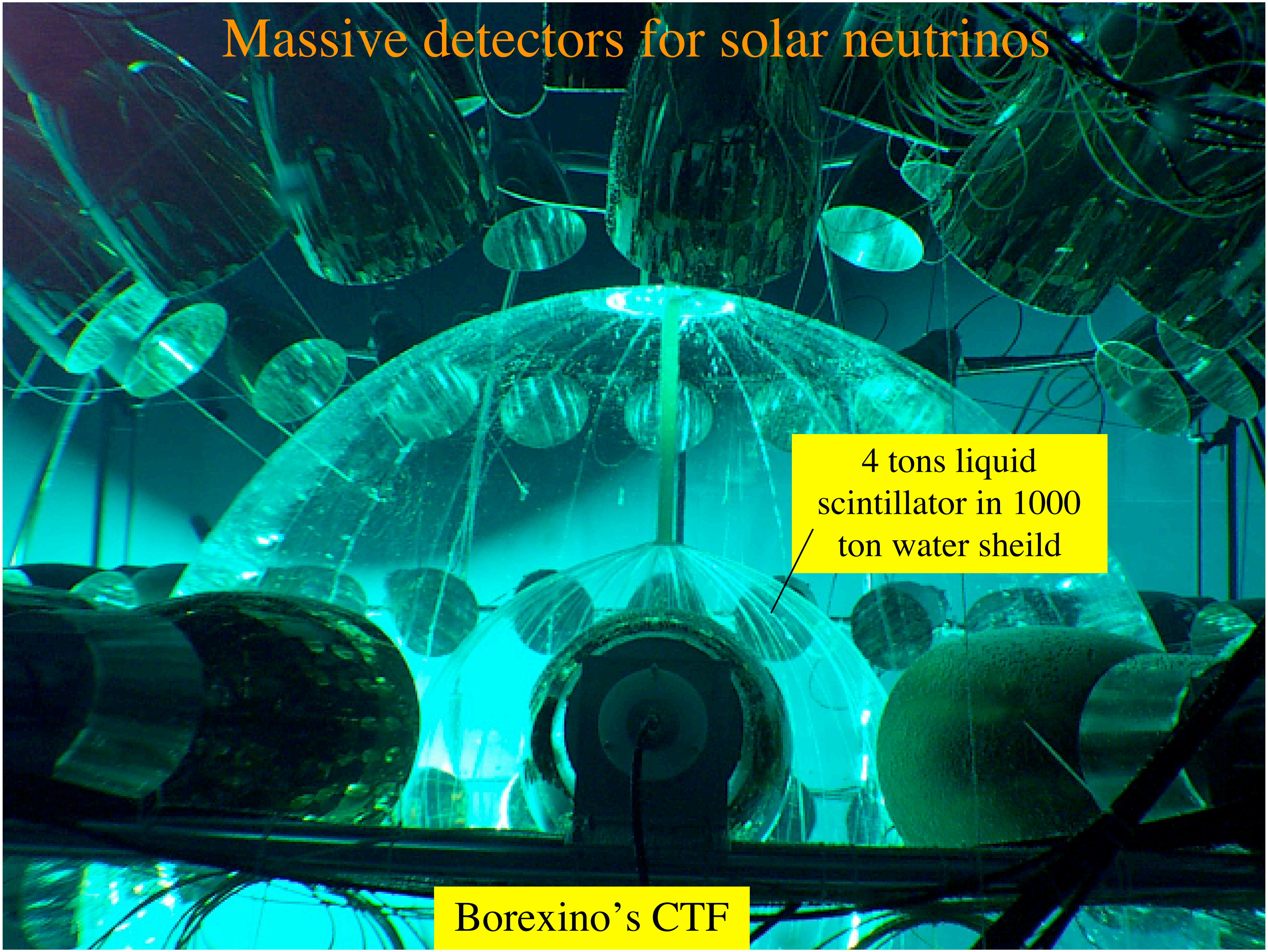
^{210}Pb at bottom of U decay chain remains.

$T_{1/2}$= 22 years

Current and needed sensitivity



- We have entered phase of testing SUSY.
- Need ton-scale detectors for full "generic" test.


Massive detectors for solar neutrinos
4 tons liquid
scintillator in 1000
ton water sheild
Borexino's CTF

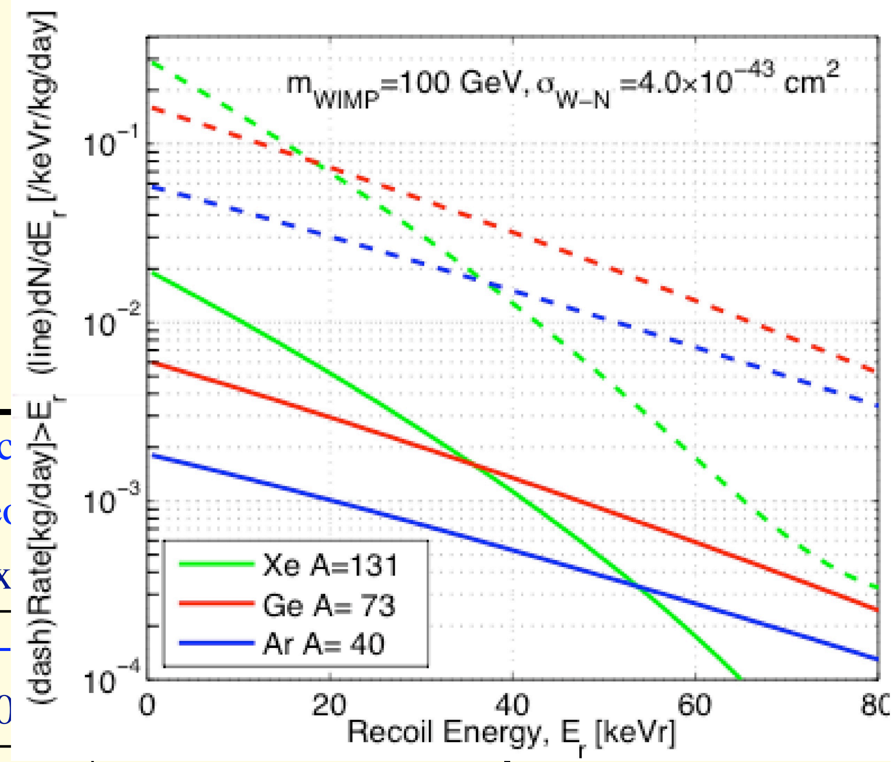
Liquid Noble-Gas Detectors

- Liquid target:
  - Readily purified
  - Scalable to large masses
- Liquid scintillator: ^{14}C fatal for dark matter
  - Even in petroleum - 10^{-18}
  - ^{14}C: U->a + rock -> n -> $^{14}N(n,p)^{14}C$
- Liquid noble gasses.
  - Easily purified.
  - Scintillation and Ioinization
  - Cryogenic PMTs exist.
- Drawback: small signals
  - $N_{ex}=E/W$, $W_{Ge} \approx 3$ eV, $W_{Xe} \approx 15$ eV
  - Cryo-cryogenic: E/kT maximized with $T \sim 0.020$ K
  - Rare gasses: High voltage boosts E (e.g., in PMT)

Scalable to large masses

Noble liquid properties

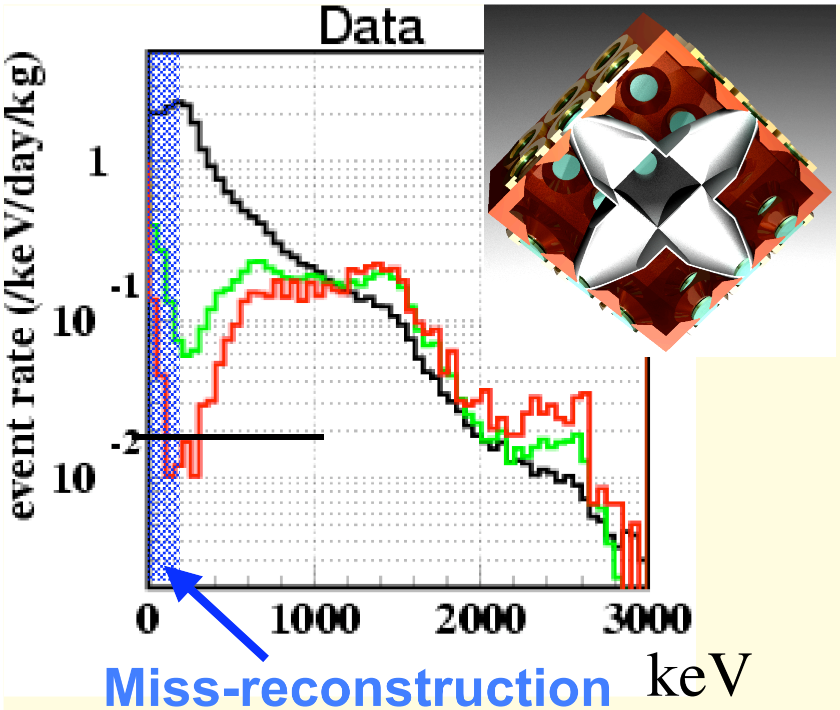
Element Z, A	ρ (g/cm^3)	Radio- activity (Bq/kg)	***T*** **(K)**	λ (nm) *E* (eV)	*L* (c theo Ex	
He 2, 4	0.125	-	4.2	78 15.9	- 60	
Ne 10, 20	1.205	-	27.1	80 15.5	- 60	electron bubbles
Ar 18, 40	1.39	^{39}Ar -1 ^{41}Ar - ?	87.3	128 9.7	90 66	
Kr 36, 83.8	2.41	^{85}Kr 3x10^5	120	147 8.4	60 82-100	
Xe 54, 131.3	2.94	-	165	175 7.1	50 30-50	~ $ 1M/ton; Need 40 keV thresh. Spin separable ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe



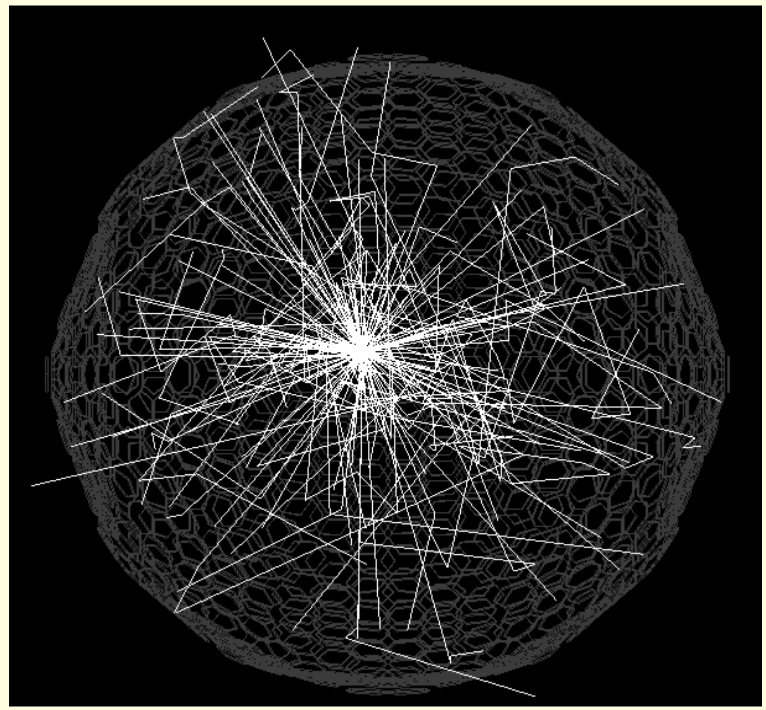
XMASS

- Large mass of liquid Xenon, rely on self shielding

XMASS



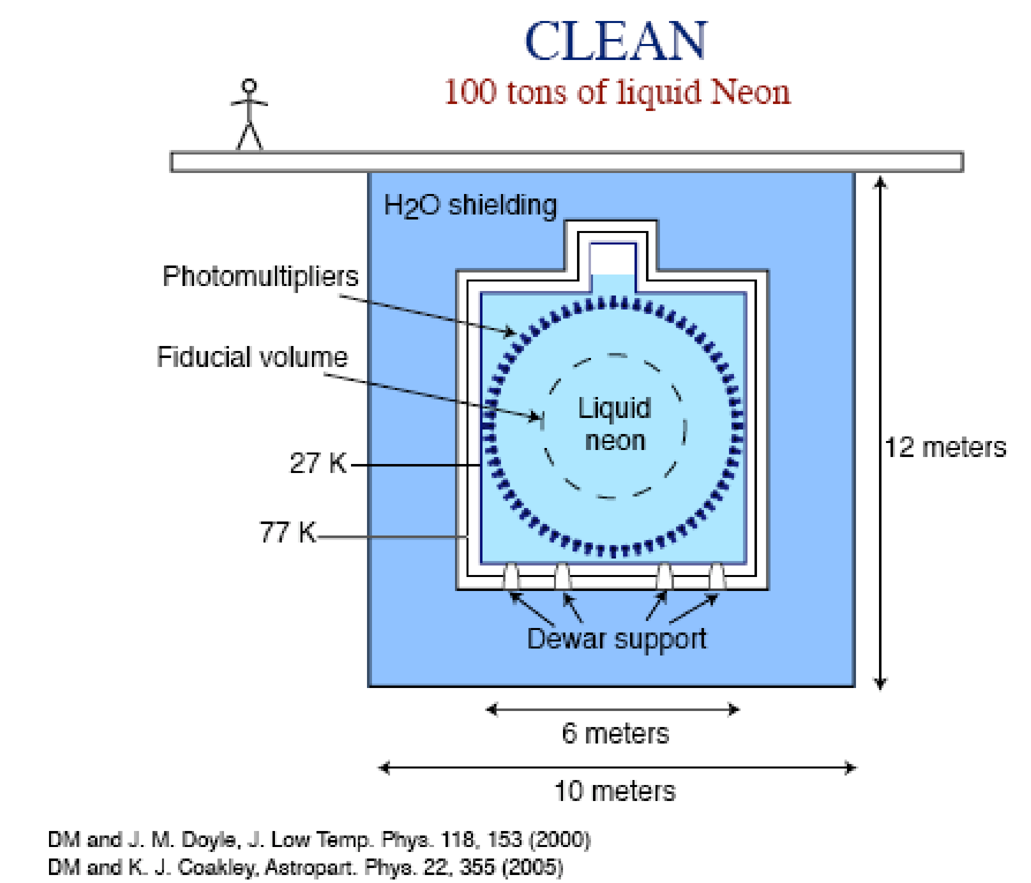
Rayleight scattering prevents timing-based position reconstruction



- 100 kg results: limited by events at edges
- Key question: position reconstruction at low energies.
- Rayleigh scattering

- Radioactivity
  - Kr removed by distillation - ppt achieved.
  - Radon emanation?

CLEAN



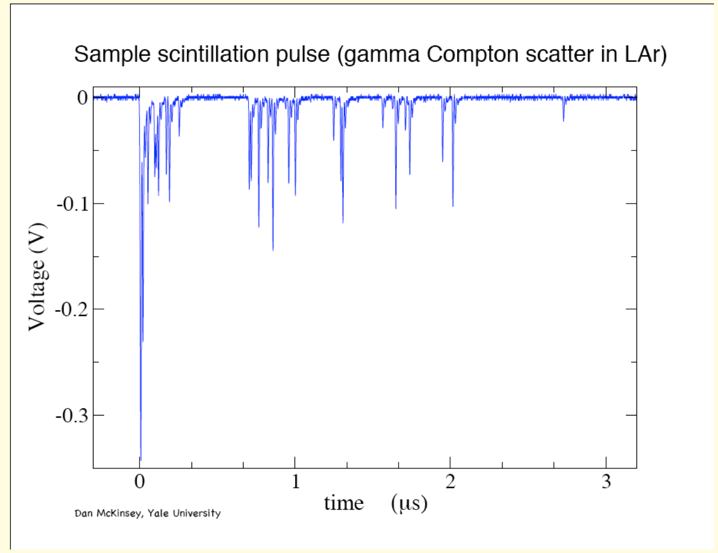
"pico-clean"

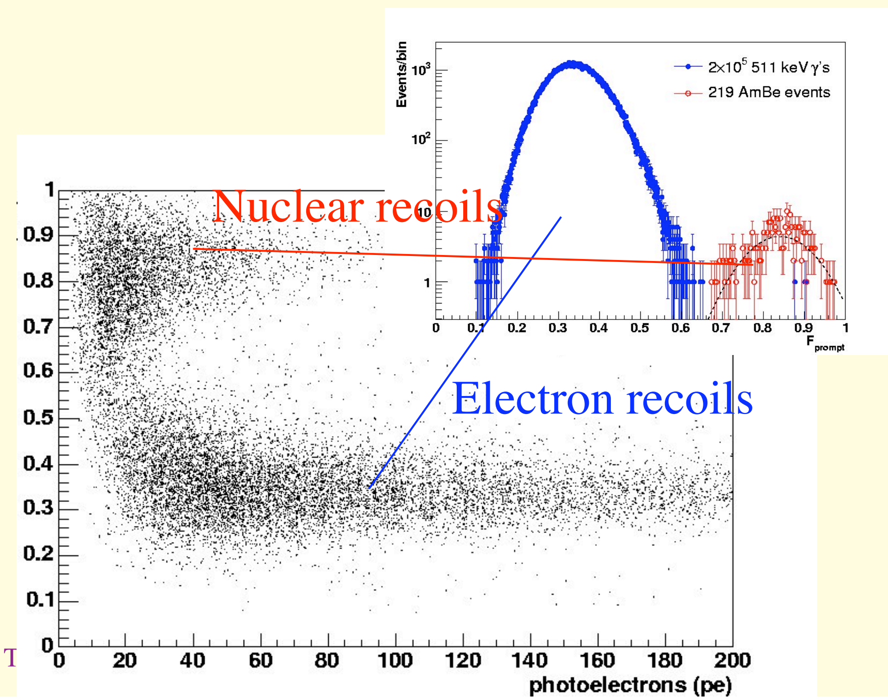
Includes liquid-phase purification on charcoal

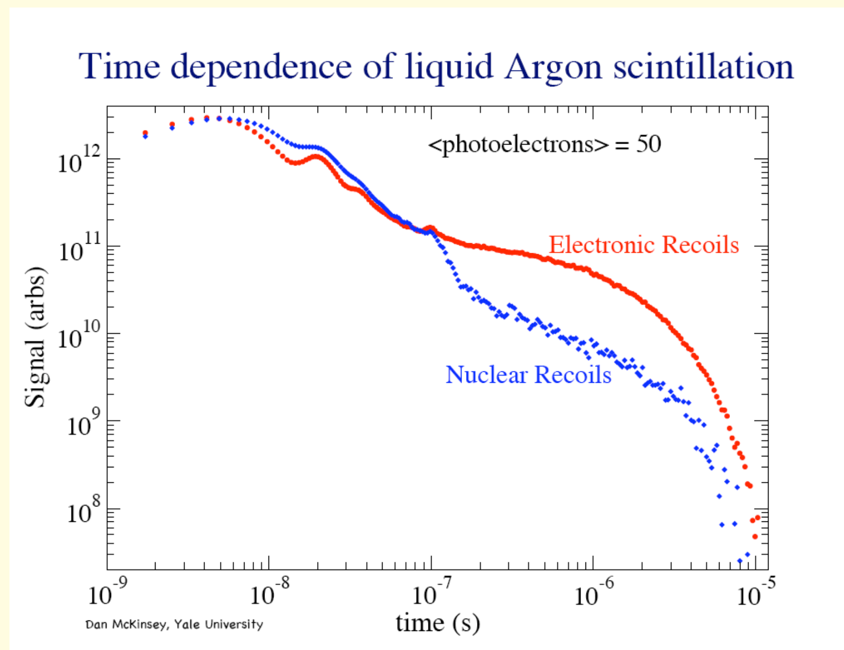
- Initially - pp-solar neutrinos with LNe
- Dark matter:
  – Ne: low rate, but use large mass.
- Powerful pulse-shape discrimination

Scintillation pulse-shape discrimination

- Ar - ^{39}Ar beta decay at 1 Bq/kg
- For ton-scale experiment, need ~10^8 or more rejection
- Boulay & Hime:
  - Pulse shape discrimination powerful enough to do it.



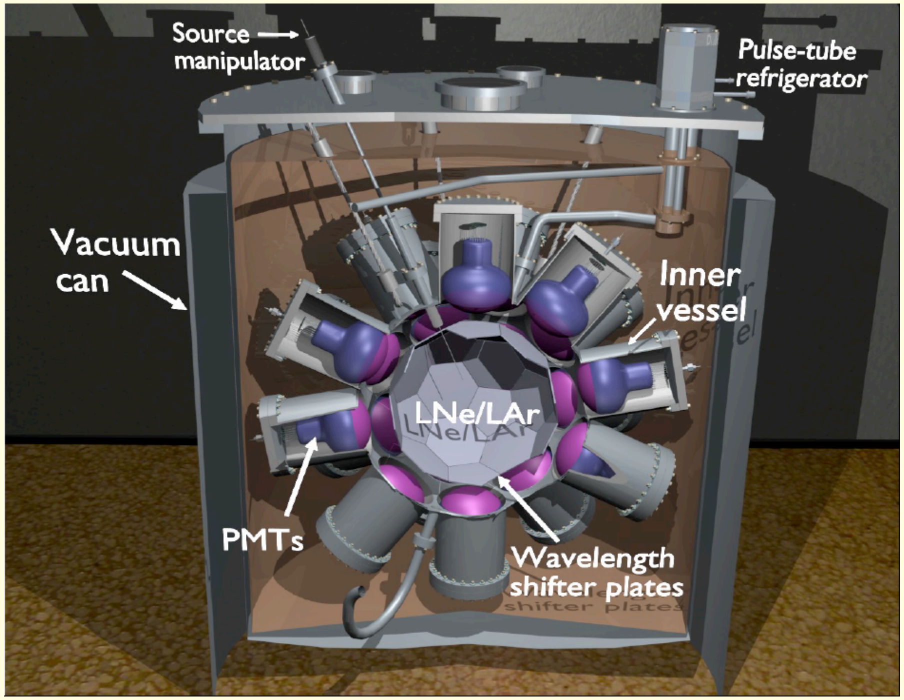




DEAP + Mini-CLEAN

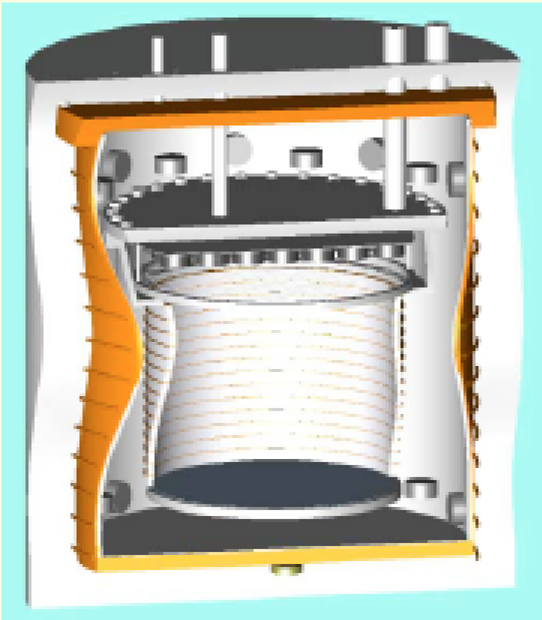
- DEAP - 10 kg detector - 06/07 in SNOLab
- Mini-CLEAN - 100 kg detector for ~08/09

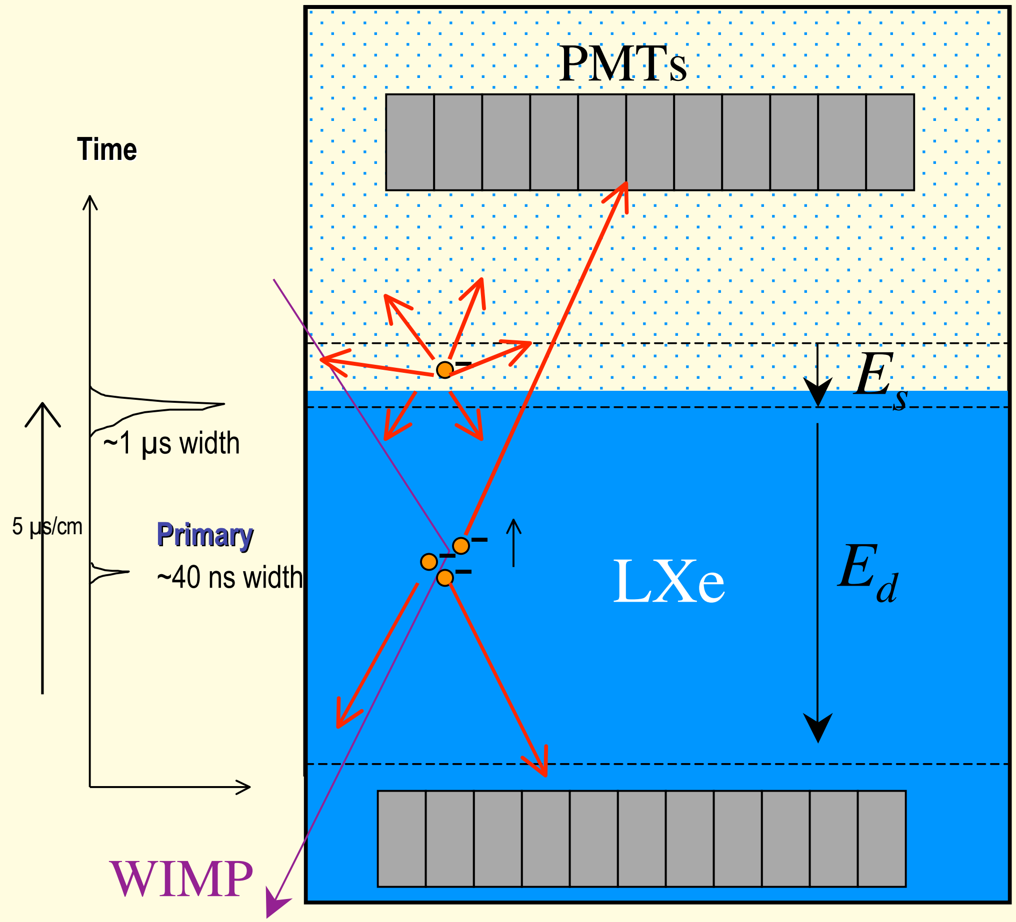
Mini-CLEAN



Outstanding question: factor of 3 in nuclear recoil light yield.

Dual phase time projection chamber

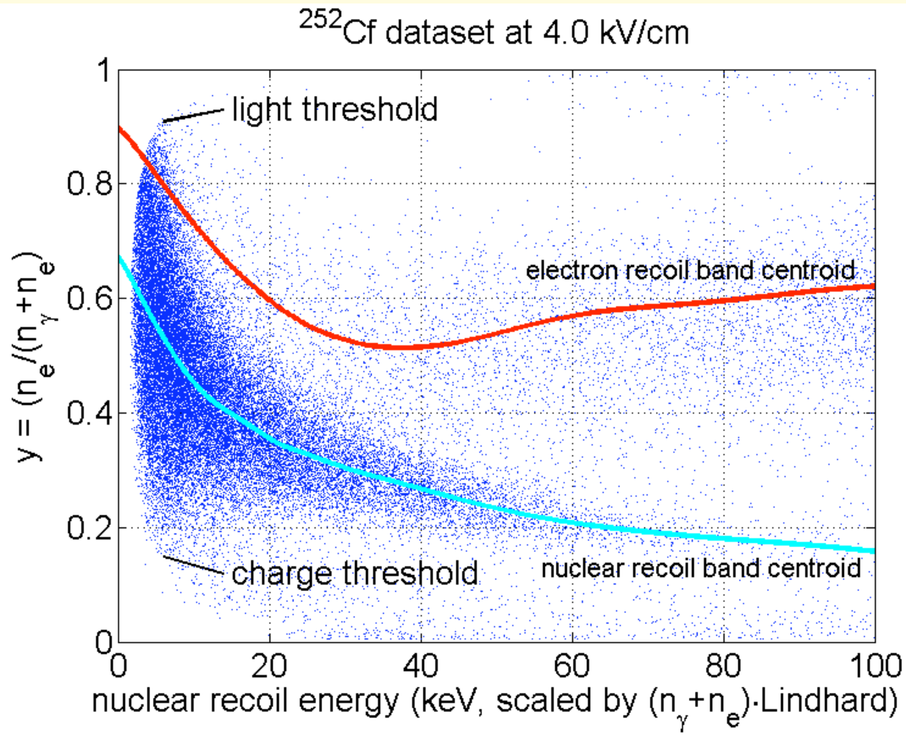


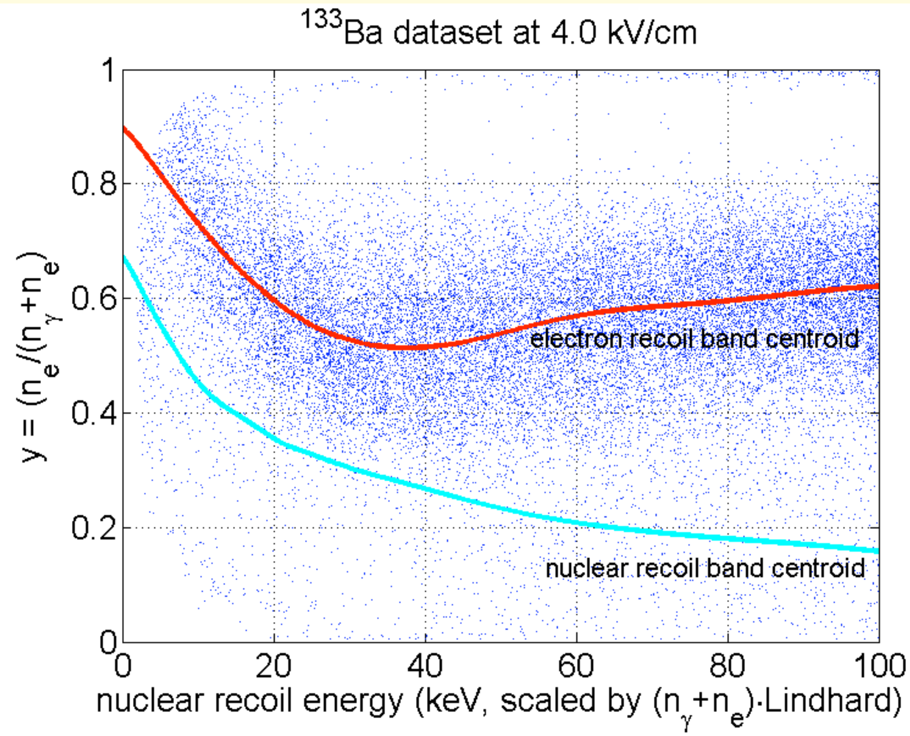


- Can measure single electrons and photons.
- Charge yield reduced for nuclear recoils.
- Good 3D imaging
  - Cutting edges crucial.

A. Bolozdynya, NIMA 422 p314 (1999).

Background discrimination

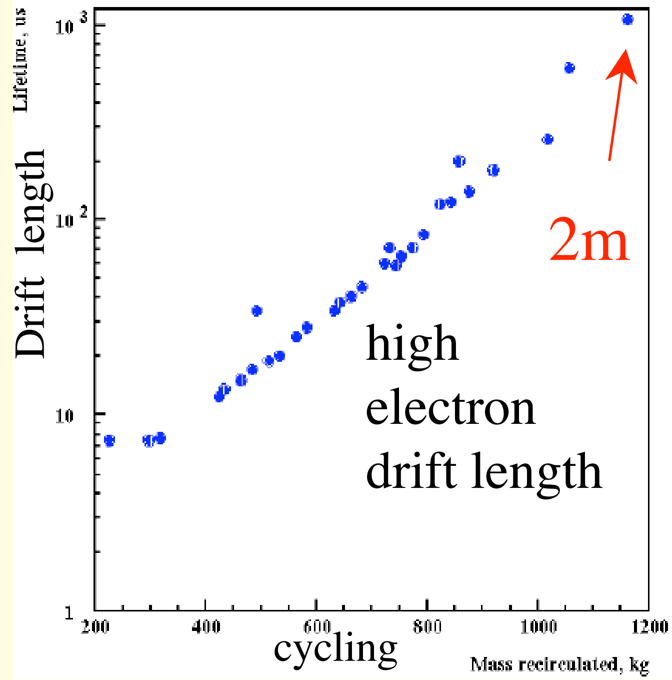


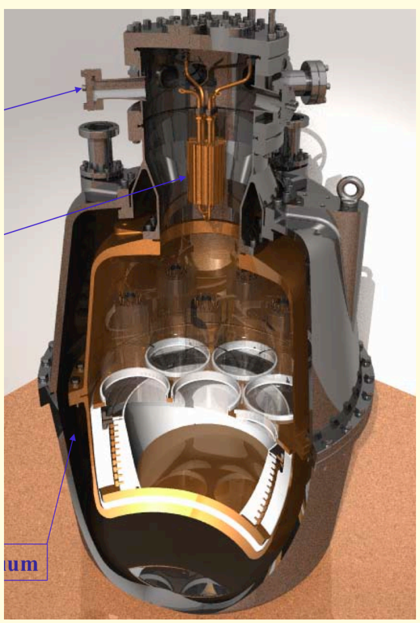


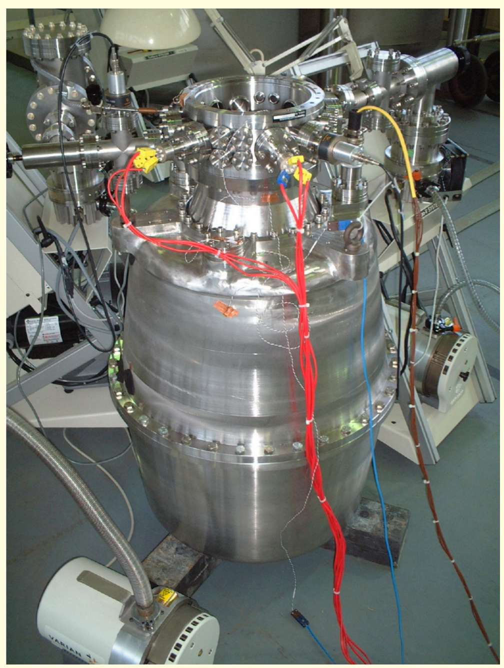
- Nuclear recoils: less charge than electron recoils: recombination
- Event-site physics well-characterized
  - Anti-correlation between charge and light.
- ~99% discrimination down to 5 keVr!

ZEPLIN II

- ~45 kg total liquid Xe, 30 kg fiducial
- Boulby deep site
- 7 large PMTs above liquid
  - ~ 3 x worse light collection than in liquid.
- Modest (~0.5 kV/cm) drift field.

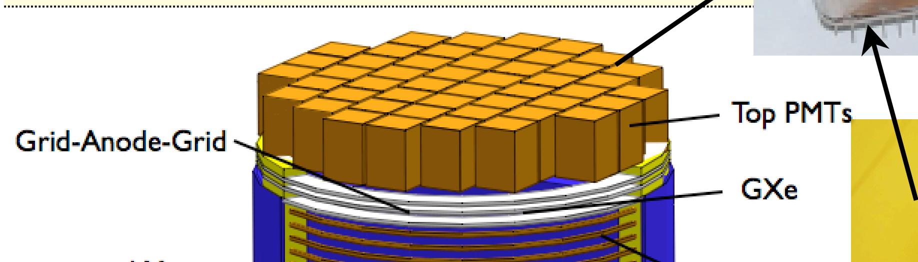


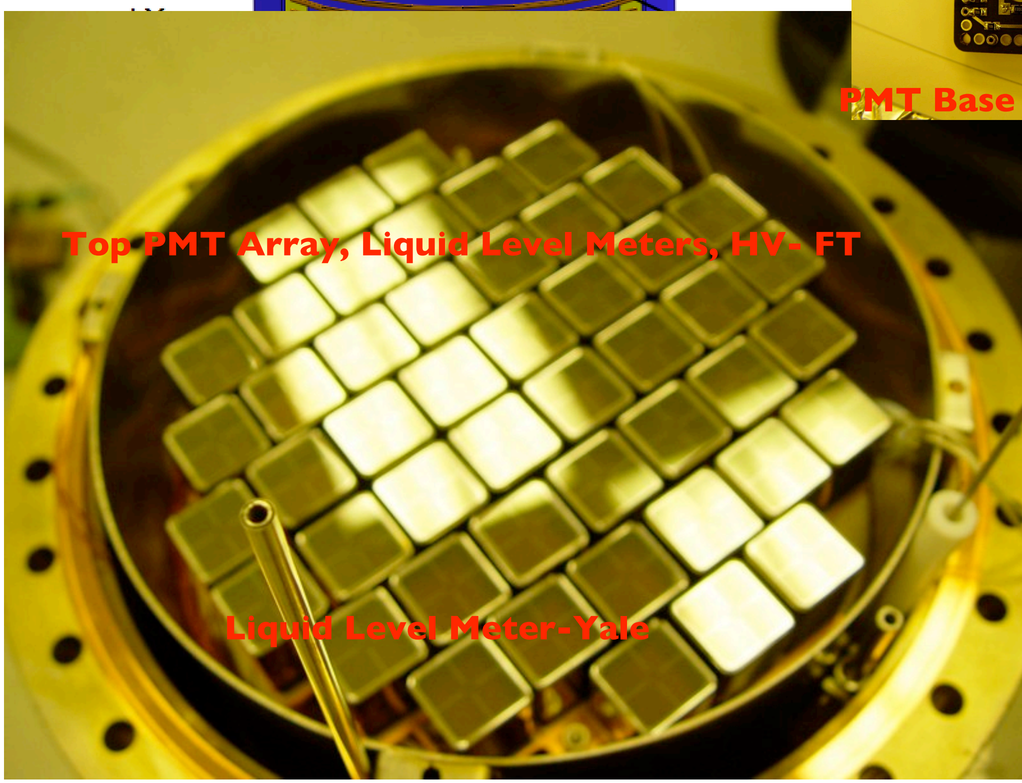


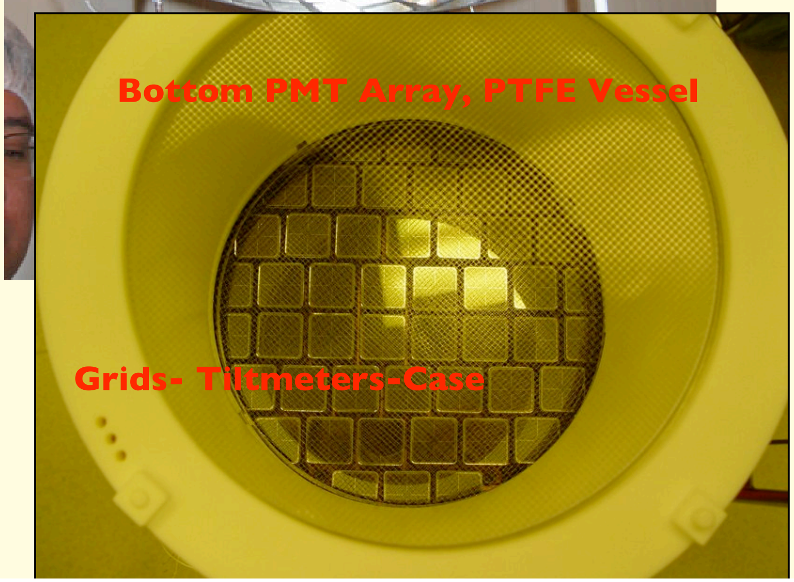


XENON10: Detector Assembly

89 Hamamatsu R5900 (1" square)
20 cm diameter, 15 cm drift length
22 kg LXe total; 15 kg LXe active

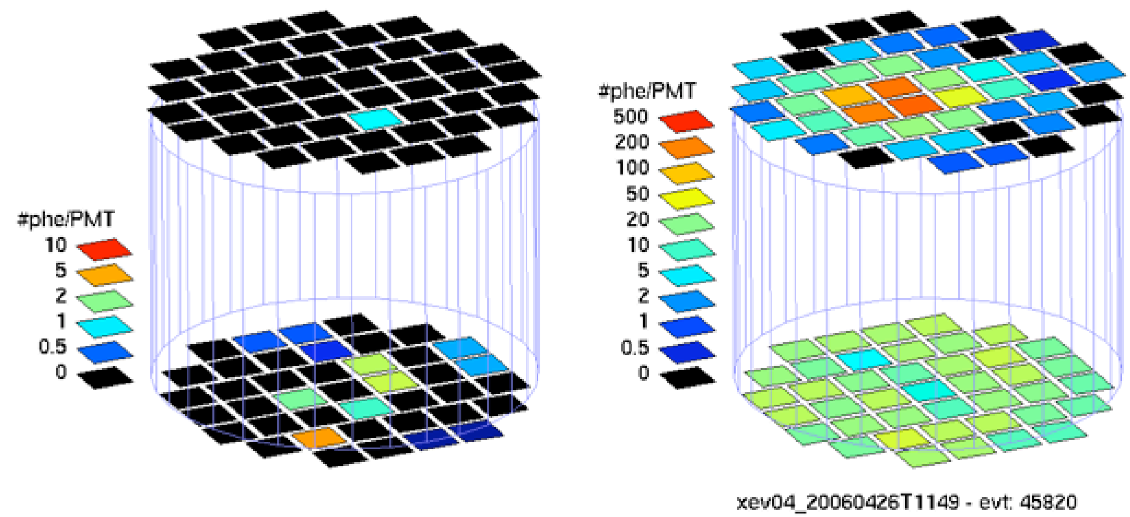


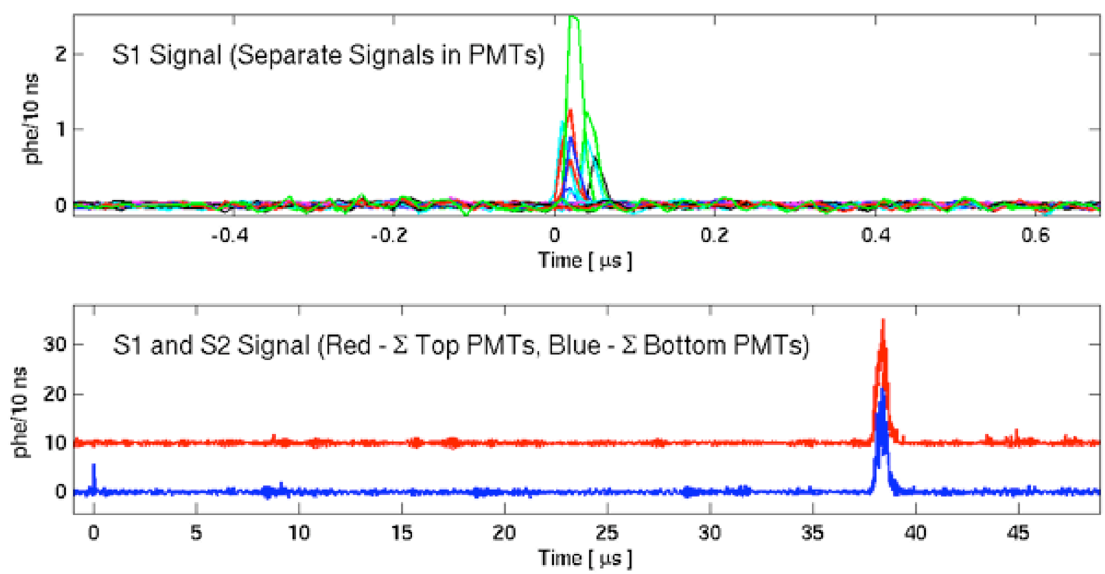




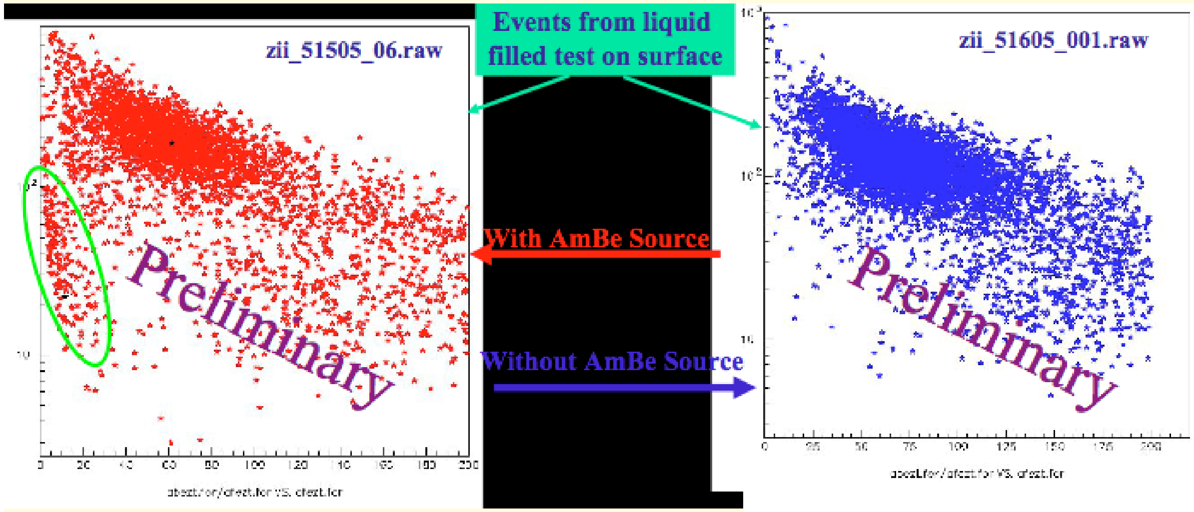
XENON10 Example Low Energy Event

- Low Energy Compton Scattering Event
  S1=15.4 phe ~ 6 keVee
  Drift Time ~38 _s = 76 mm
  (Max depth 150 mm)
- Bulk gamma calib shows avg S1
  2.3 phe/keVee
  0.9 phe/keVr
- Trigger n>=4 in 80 ns window
  - Able to trigger on S1 for 10 keVr with >90% eff
  - Also catching S2 triggers (with pretrigger look-back)
- Noise on separate PMT chans <<0.1 phe equiv



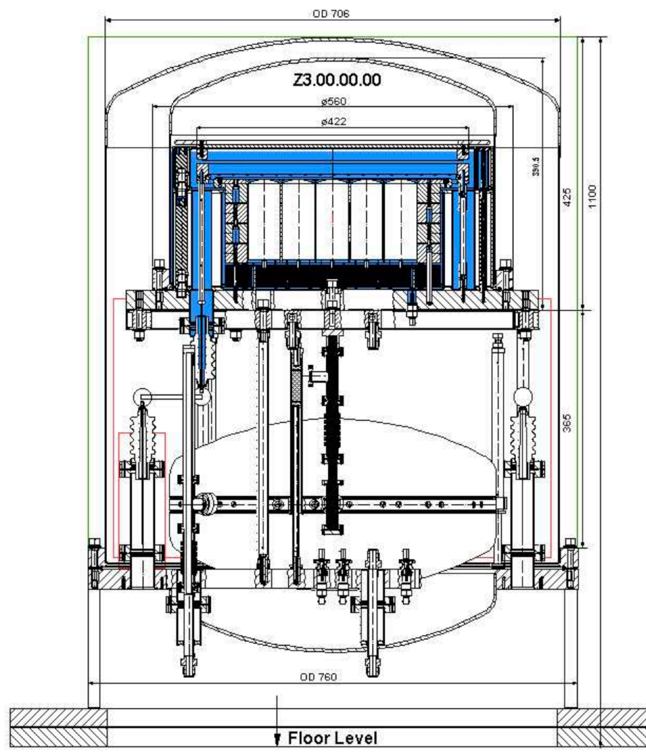


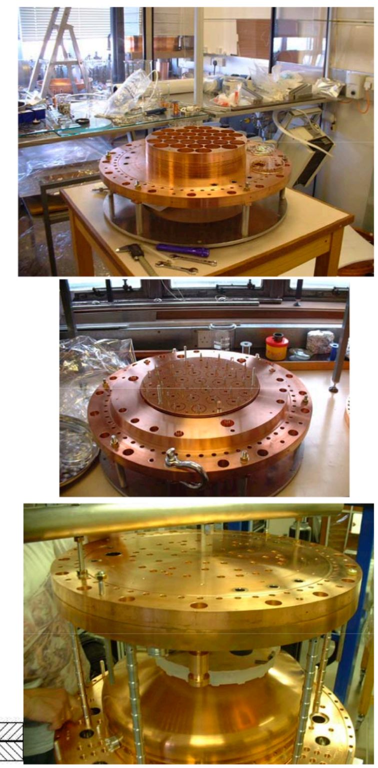
ZEPLIN



- Discrimination in ZEPLIN II
- Operating underground - Boulby mine, UK
- Results … stay tuned.

- ZEPLIN III
- PMTs in liquid
- High field - improved discrimination

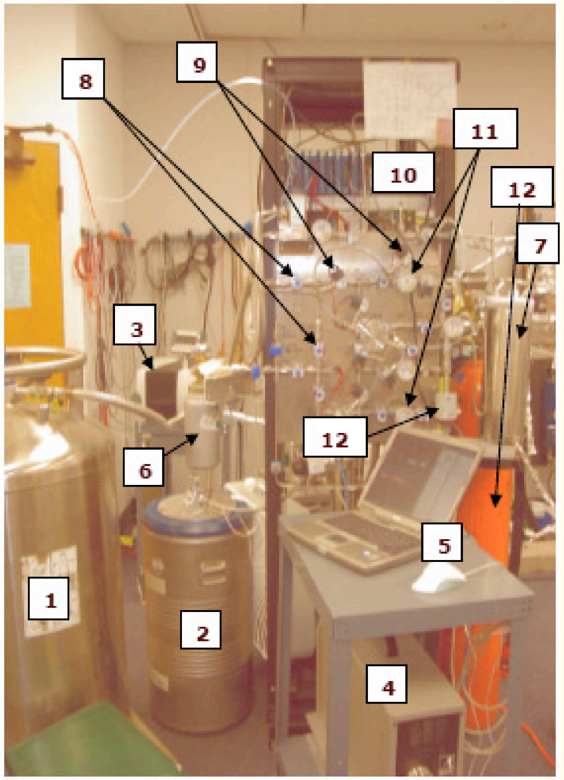




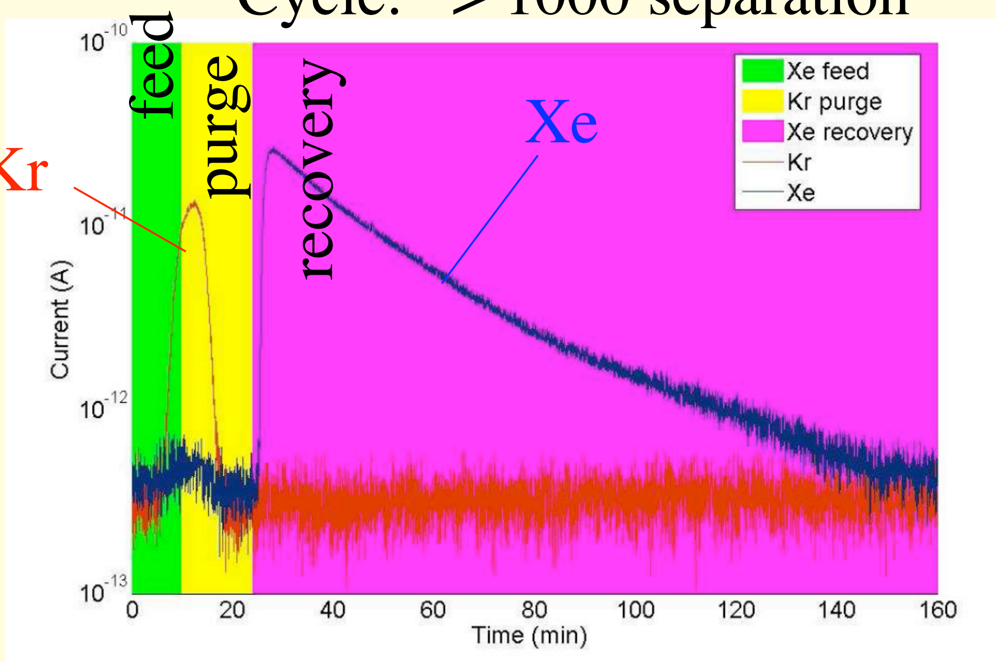
Kr removal

- ^{85}Kr - beta decay, 687 keV endpoint.
  - Goals for 10, 100, 1000 kg detectors: Kr/Xe < 1000, 100, 10 ppt.
  - Commercial Xe (SpectraGas, NJ): ~ 5 ppb (XMASS)
- Chromatographic separation on charcoal column

10 Kg-charocoal column system at Case



Cycle: > 1000 separation



200 g/cycle, 2 kg/day

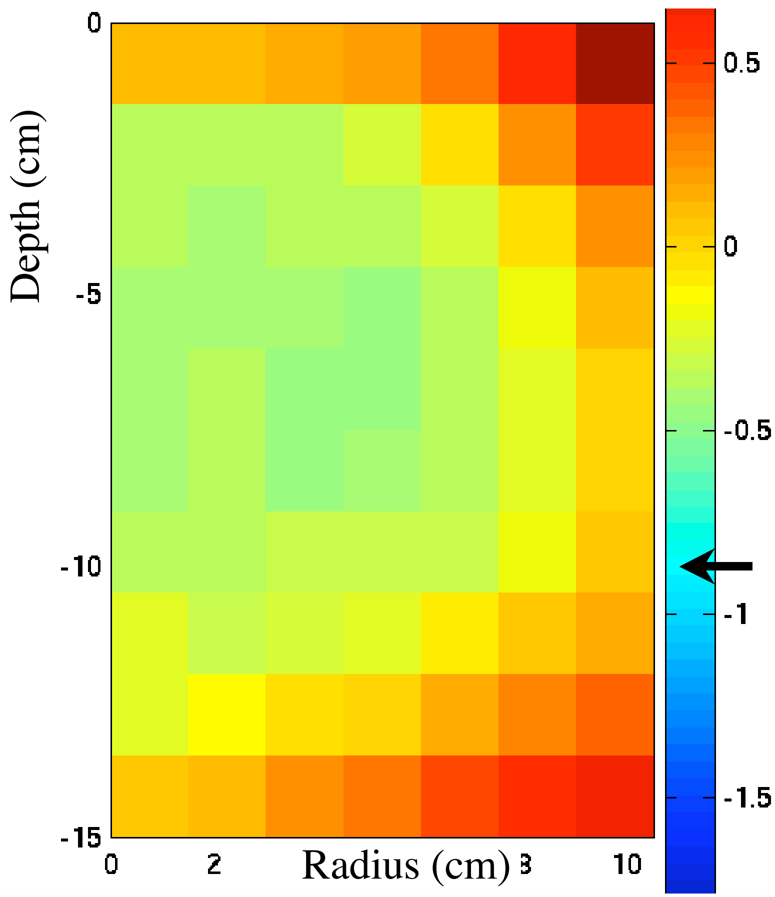
25 Kg purifed to < 10 ppt

XENON10 expected background

- Dominant background: Stainless Steel Cryostat & PMTs

Electron recoil background 5-25 keVee

(Brown)



Original XENON10 Goal <0.14 /keVee/kg/day

Current estimate: 2-3 x original goal

- Simple background problem.
  - Single, low-energy Compton scattering
  - Very forward peaked.
  - Probability of *n* scatters while traversing distance *L*:

$$P_n(L) \cong \frac{1}{n!}\left(\frac{L}{\lambda}\right)^n e^{-\frac{L}{\lambda}}$$

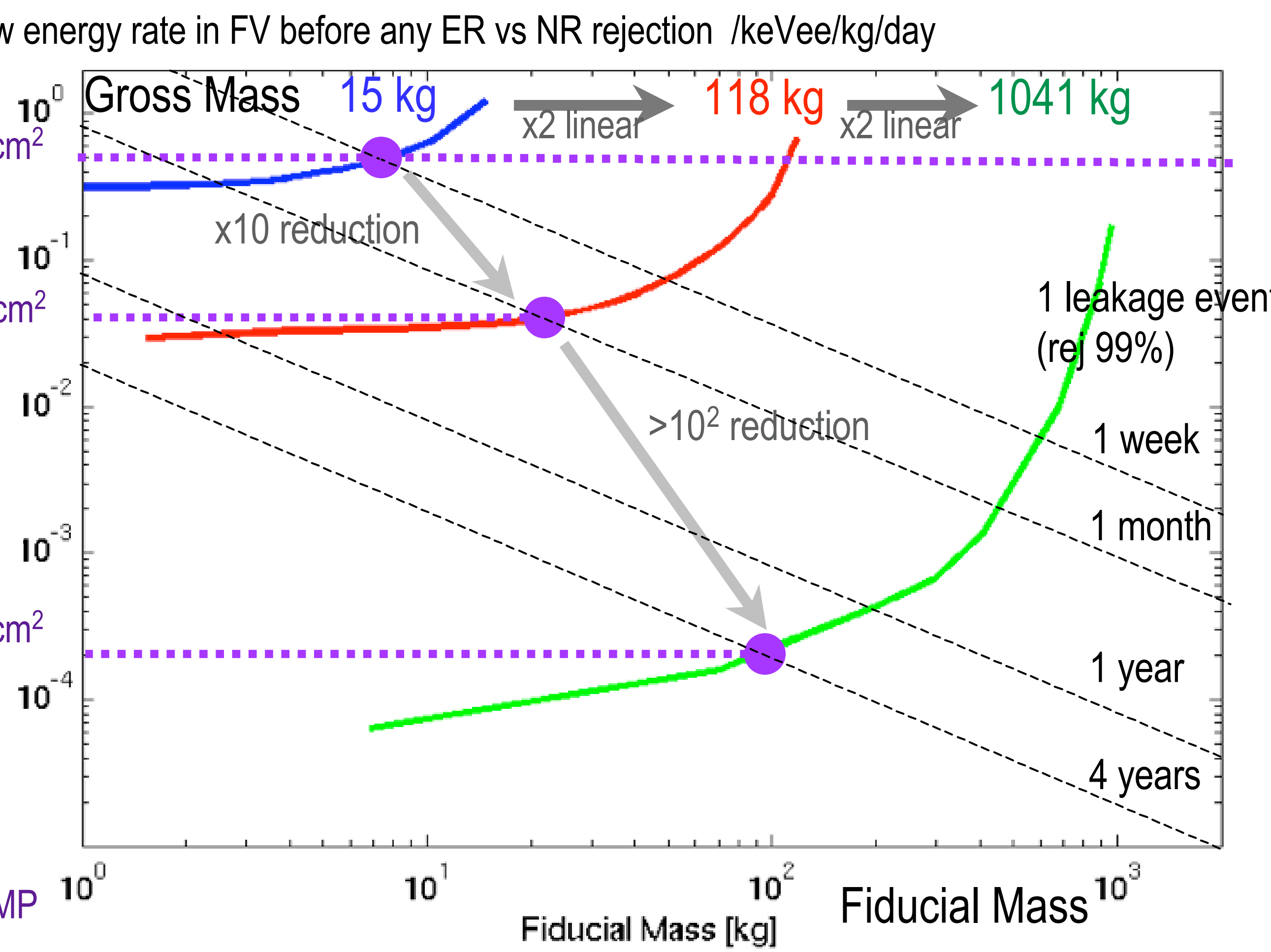
Scaling LXe Detector: Fiducial BG Reduction

- Assuming ER are rejected at 99% for 50% acceptance of NR
  - Diagonal dashed lines show background x exposure giving 1 event leakage
  - If rej. 99% -> 99.5% and acc. 50% -> ~100% then all _ are better by 4x

XENON10 - 400 mdruee _ = 4 10^{-43} cm^2
7 live-days x 8 kg fid

“118 kg” - 40 mdruee _ = 4 10^{-44} cm^2
30 live-days x 20 kg fid

“1041 kg” - 0.2 mdruee _ = 2 10^{-46} cm^2
1200 live-days x 100 kg fid



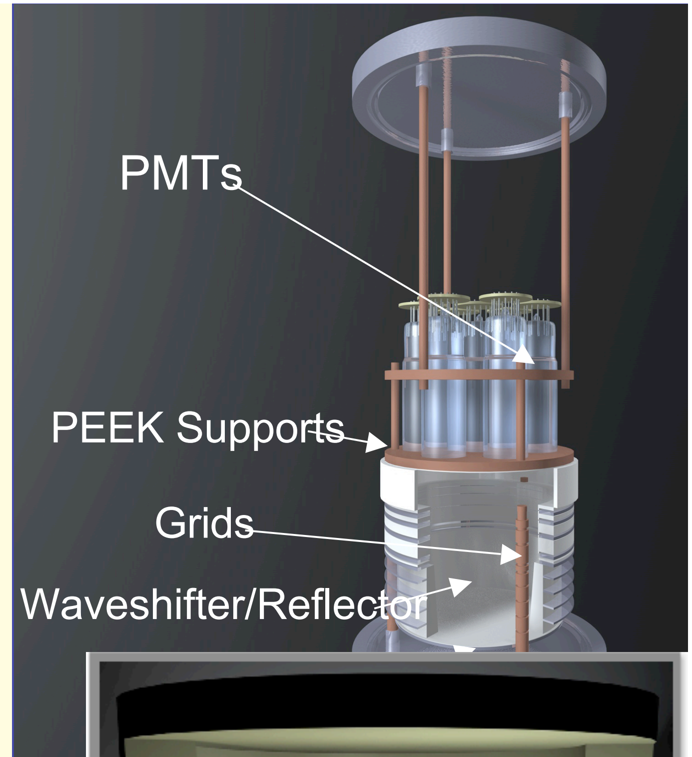
Reference: Current CDMS II
90% CL _ = 2 10^{-43} cm^2 for 100 GeV WIMP

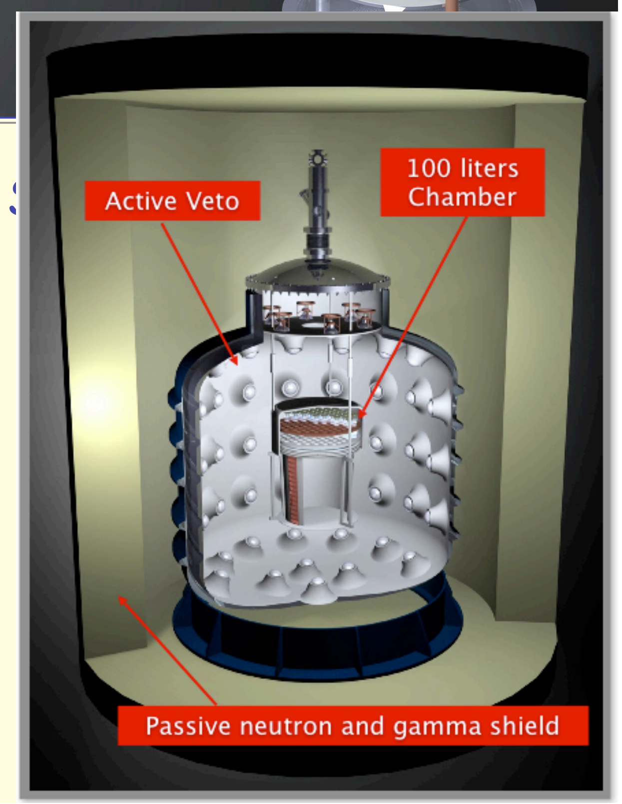
dru = cts/keVee/kg/day

WARP

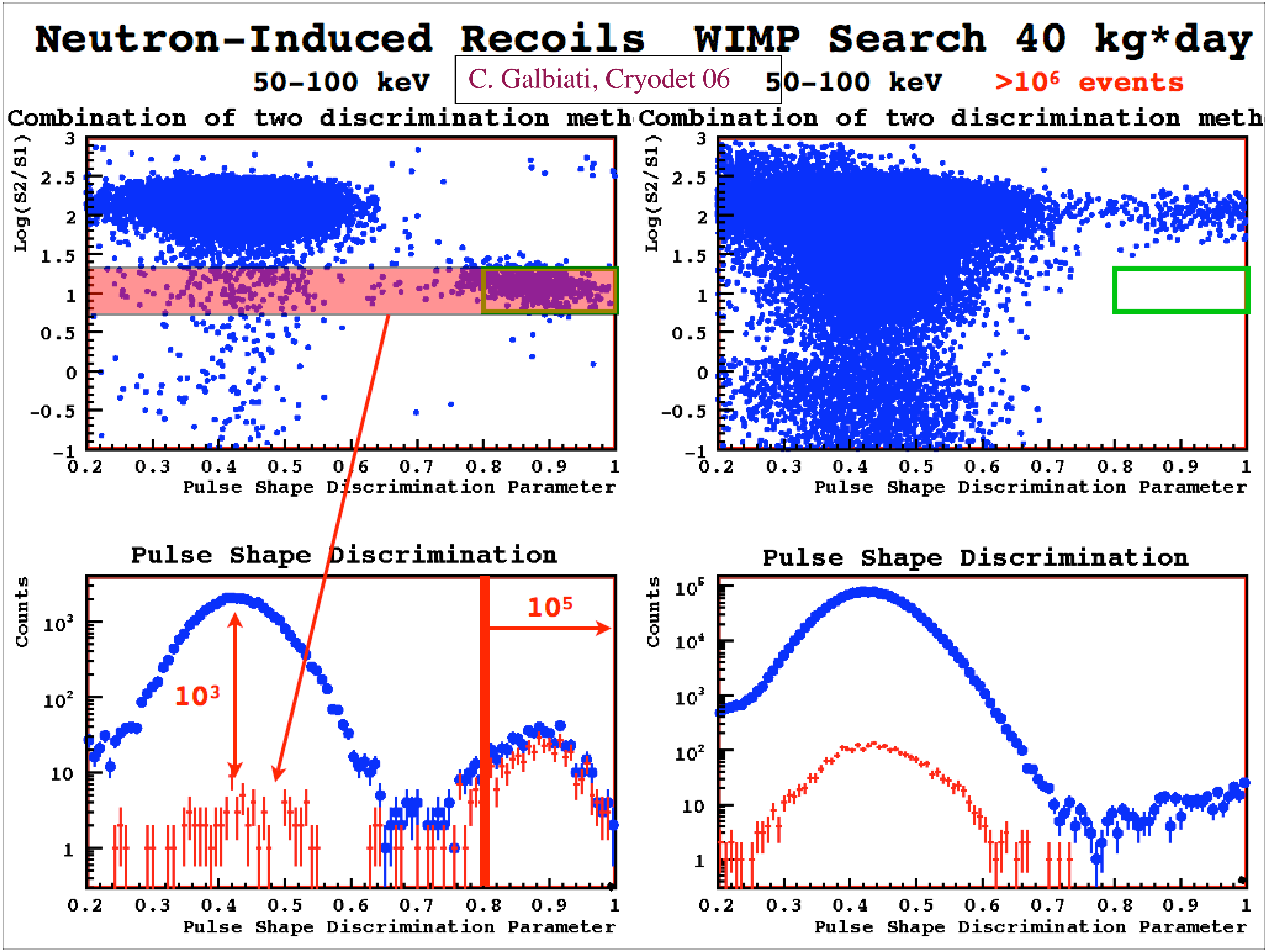
- Dual-phase, LAr
  - PSD discrimination
  - Charge yield discrimination
  - High-quality 3D-imaging
- Spin-off from Icarus program

- 3.2 kg prototype running - Gran Sasso
- ArDM (A. Rubbia, CanFranc, Spain)

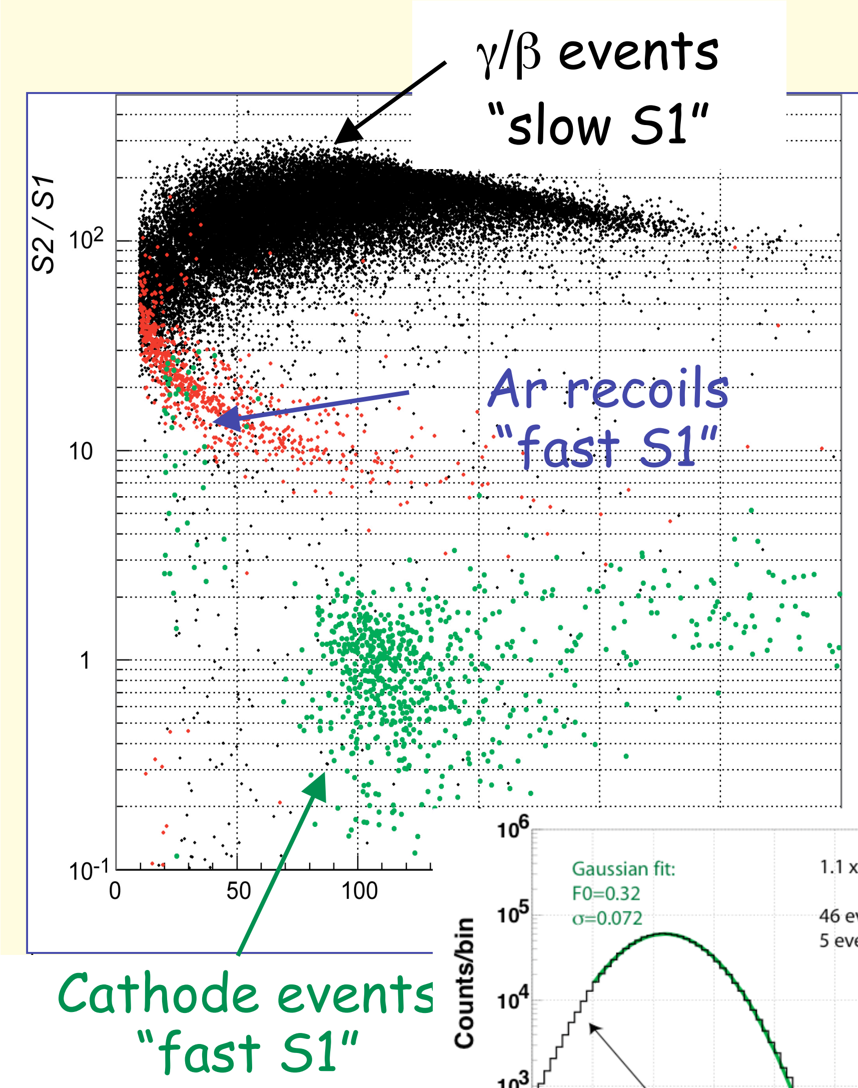


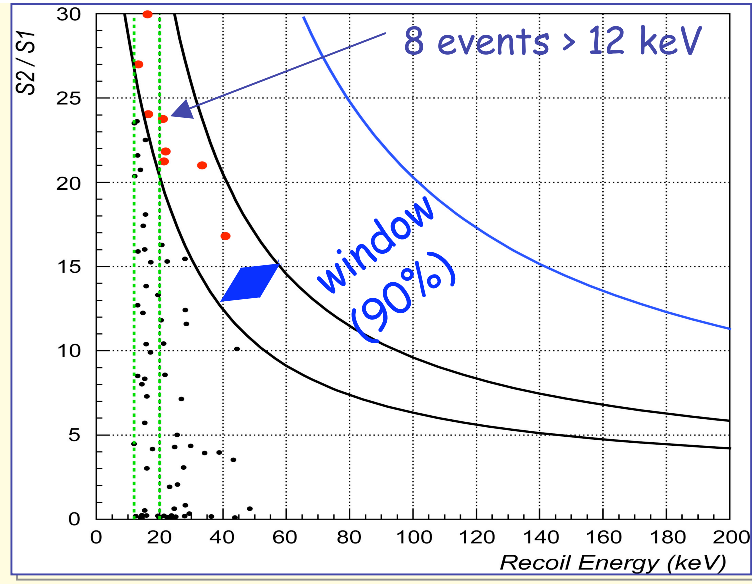


- 100 kg detector under fabrication
  - 800 kg active shield
  - Projected installation - late 2006.



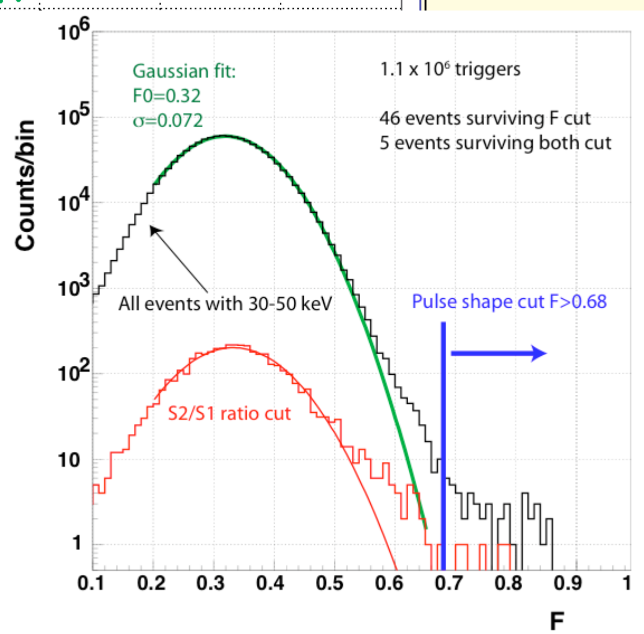
Neutron-Induced Recoils
WIMP Search 40 kg*day
C. Galbiati, Cryodet 06
50-100 keV
50-100 keV
>10⁶ events
Combination of two discrimination meth
Combination of two discrimination meth
Log(S2/S1)
Pulse Shape Discrimination Parameter
Pulse Shape Discrimination
Counts
10³
10⁵

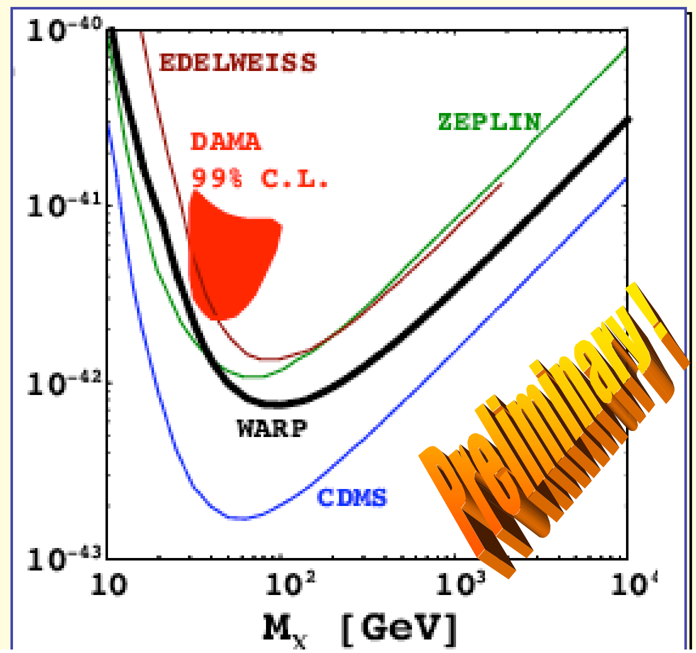




L. Pandola, Cryodet 06

- Preliminary analysis:
  - No events > 40 keV.



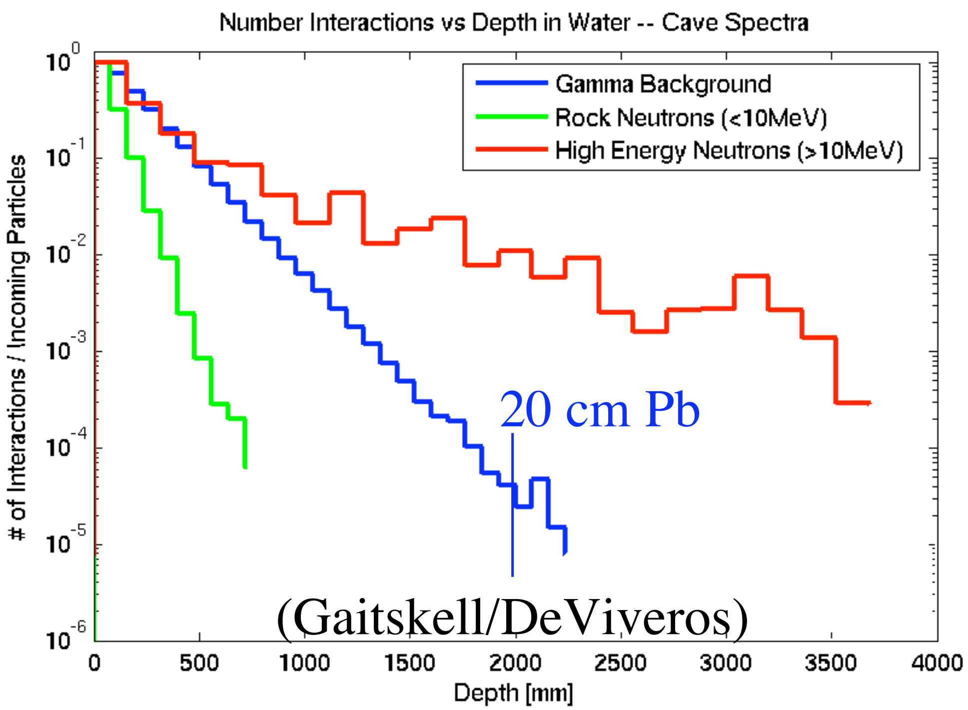


A large water-shield

- Ideal shield for large mass liquid noble gas detectors
- Standard shield:
  - Pb shield ancient Pb/Cu liner. $$
  - Polyethylene neutron moderator for DM.
- Water shield:
  - Low cost, flexible mechanics
  - Modular approach allow rapid detector evolution
  - Best-possible low-radioactivity shield
- Multiple applications:
  - other DM
  - $\beta\beta$ decay
  - advanced screening

Shielding and purity

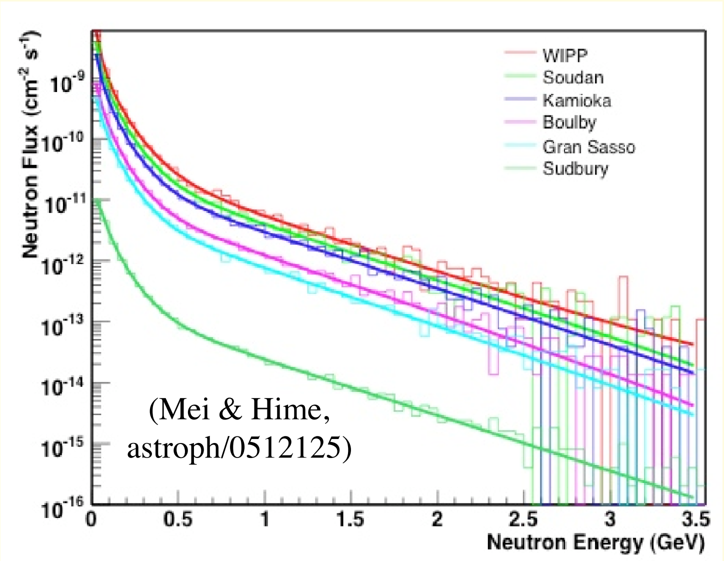
- Very good shield of gammas and neutrons.
- Thick water effective for high energy neutrons
  - Ok for 10^{-46} cm^2 at Homestake early site (4850 mwe), or even Henderson (~3000 mwe).
- Purity: Very good with minimal effort (apart from Rn)
  - ~ $ 50 K commerical system
  - Naively ~ 10,000 cleaner than Pb/Cu.
  - Radon: stable water; seal + purge; Ra removal in water system.

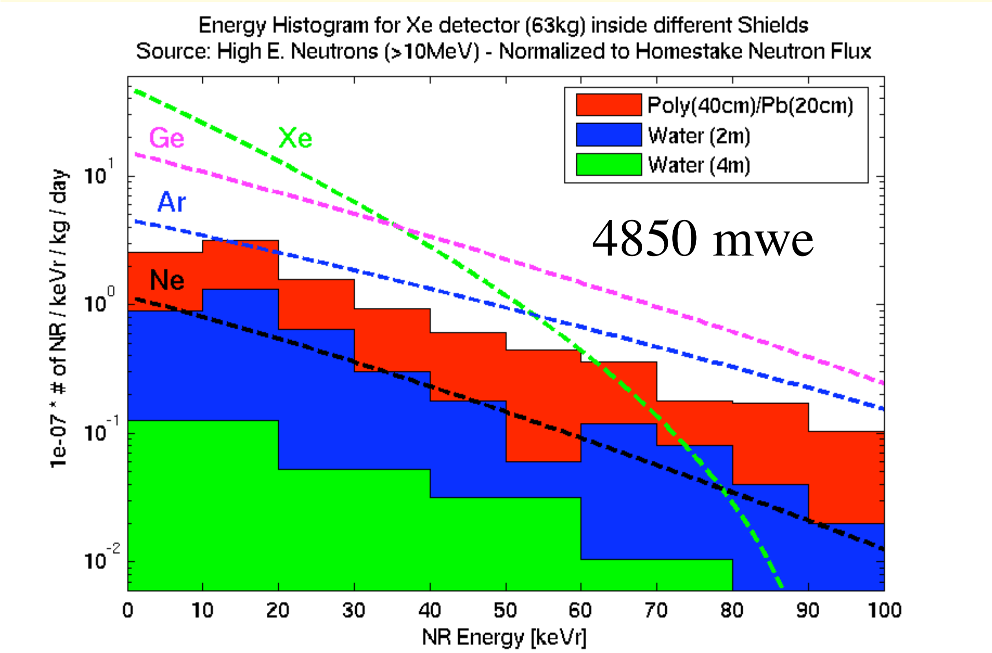


- Dark matter detectors with discrimination do not need high purity.
- Other applications could benefit enormously
  - Non-discriminating DM - XMASS
  - ββ decay
  - Advanced screening.

Water shield and ~100 MeV neutrons

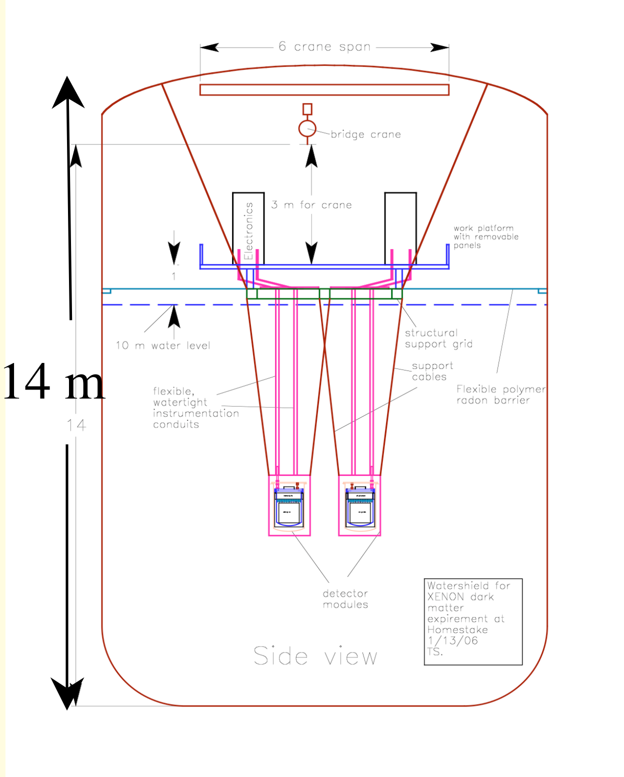
- Very high energy muons in rock, outside of any veto
  - Low rate, but important
- Very difficult to stop: cross section on hydrogen drops above 100 keV.
- Water shield:
  - Elastic scattering primarily on O.
  - Forward scattered
  - Overcome by simple thickness

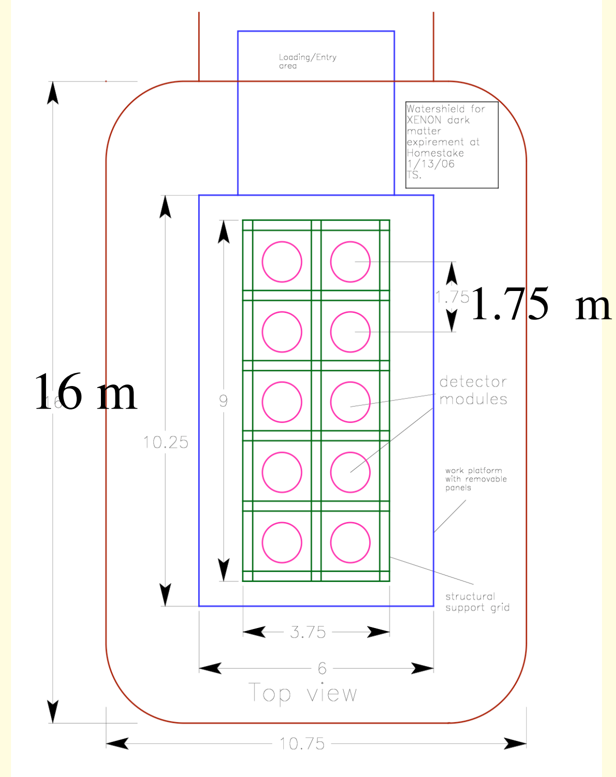




- 2m water better than feasible Pb/Poly shield
  - Pb multiplies neutrons by ~20.
- 4m water sufficient for 1 ton Xe exp (10^{-46} cm^2) sensitivity at Homestake 4850 mwe
- Allows very large experiments at early stage Homestake (or even Henderson).

Pre-DUSEL Homestake possibility





- DUSEL process for new national underground lab.
- 4850 mwe depth at Homestake - early program.
- 10 module system
- 4 m shielding
- Davis cavern +3m depth.

Conclusion

- A horserace to large scale.
  - XMASS - Xe single phase.   Large size not funded
  - CLEAN/DEAP
    - Can ^{39}Ar background be overcome?
    - What is the "quenching" factor?
    - Ne?
  - Xe dual phase: ZEPLIN II + XENON10
    - Results this fall
    - Large detectors to follow soon.
  - Ar dual phase: WARP + ArDM
    - Can ^{39}Ar background be overcome?
    - WARP results already - 100 kg under construction
- Current round of experiments should prove these technologies.
- Plans for large scale deployment underway.