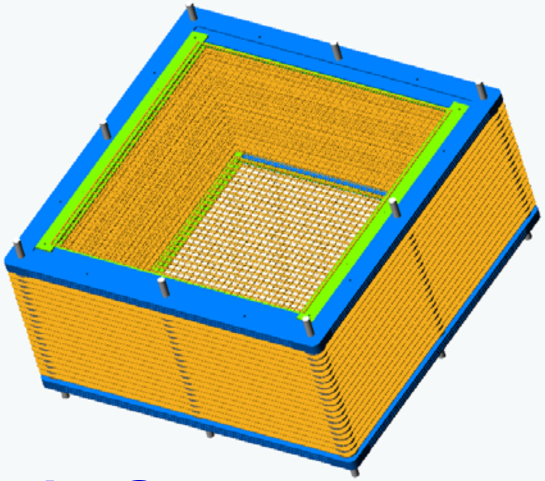
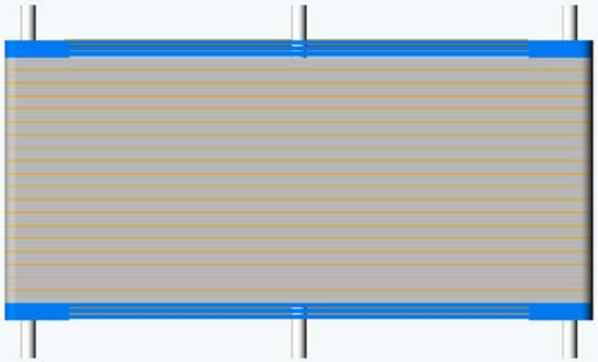
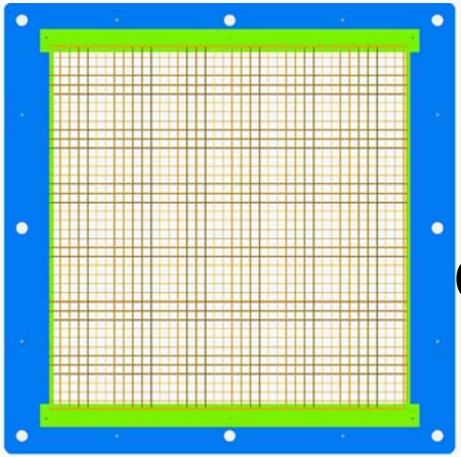
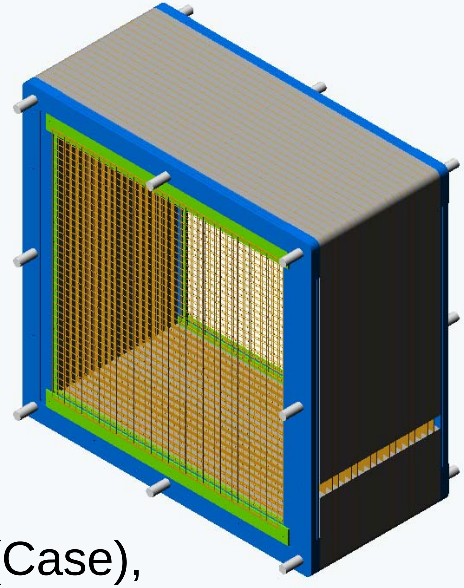




Beta Cage

A Screener of Ultra-Low-Level Radioactive Surface Contamination





Richard Schnee

Case Western Reserve University

In collaboration with

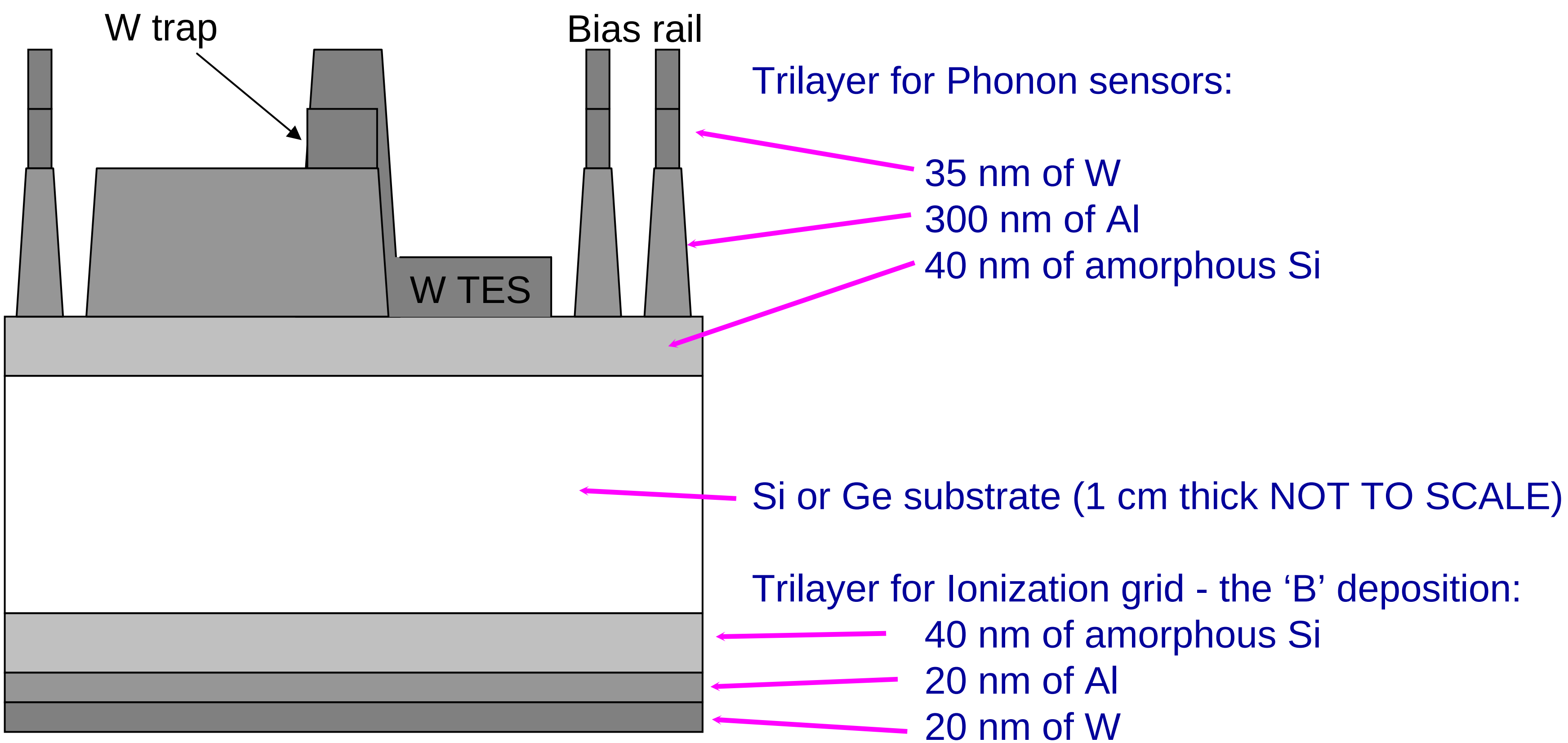
Dan Akerib, Darren Grant, Kristin Poinar, Tom Shutt (Case),

Sunil Golwala, Zeesh Ahmed (Caltech)

(and with work from others who have moved on)

Original Motivation: CDMS

- CDMS experiment limited by beta contaminants on surface or in thin films of detectors
  - Projected 150 kg SuperCDMS experiment could be background free if beta contamination kept < 6 m^{-2} day^{-1} in WIMP energy region



Need for Beta Screening Facility

- Better sensitivity to some beta-emitting isotopes than Ge γ detectors or other techniques (ICP-MS, α screeners, etc.)
- Some beta-emitting isotopes can be probed only by their beta emission

Method	Applicable Isotopes
ICP-MS (1 ppb)	^{40}K ^{48}Ca ^{50}V ^{87}Rb ^{92}Nb ^{98}Tc ^{113}Cd ^{115}In ^{123}Te ^{138}La ^{176}Lu ^{182}Hf ^{232}Th ^{235}U ^{238}U ^{236}Np ^{250}Cm
ICP-MS (1 ppt)	^{10}Be ^{36}Cl ^{60}Fe ^{79}Se ^{93}Zr ^{94}Nb ^{97}Tc ^{99}Tc ^{107}Pd ^{126}Sn ^{129}I ^{135}Cs ^{137}La ^{154}Eu ^{158}Tb ^{166m}Ho ^{208}Bi ^{208}Po ^{209}Po ^{252}Es
γ	^{40}K ^{50}V ^{60}Fe ^{60}Co ^{93}Zr ^{92}Nb ^{94}Nb ^{93}Mo ^{98}Tc ^{99}Tc ^{101}Rh ^{101m}Rh ^{102m}Rh ^{109}Cd ^{121m}Sn ^{126}Sn ^{125}Sb ^{129}I ^{134}Cs ^{137}Cs ^{133}Ba ^{138}La ^{145}Pm ^{146}Pm ^{150}Eu ^{152}Eu ^{154}Eu ^{155}Eu ^{157}Tb ^{158}Tb ^{166m}Ho ^{173}Lu ^{174}Lu ^{176}Lu ^{172}Hf ^{179}Ta ^{207}Bi ^{208}Bi ^{232}Th ^{235}U ^{238}U ^{236}Np ^{241}Pu
α	^{210}Pb ^{208}Po ^{209}Po ^{228}Ra ^{227}Ac ^{232}Th ^{235}U ^{238}U ^{236}Np ^{241}Pu ^{250}Cm ^{252}Es
β only	^{3}H ^{14}C ^{32}Si ^{63}Ni ^{90}Sr ^{106}Ru ^{113m}Cd ^{147}Pm ^{151}Sm ^{171}Tm ^{194}Os ^{204}Tl **^{10}Be ^{36}Cl ^{79}Se ^{97}Tc ^{107}Pd ^{135}Cs ^{137}La ^{154}Eu ^{209}Po**

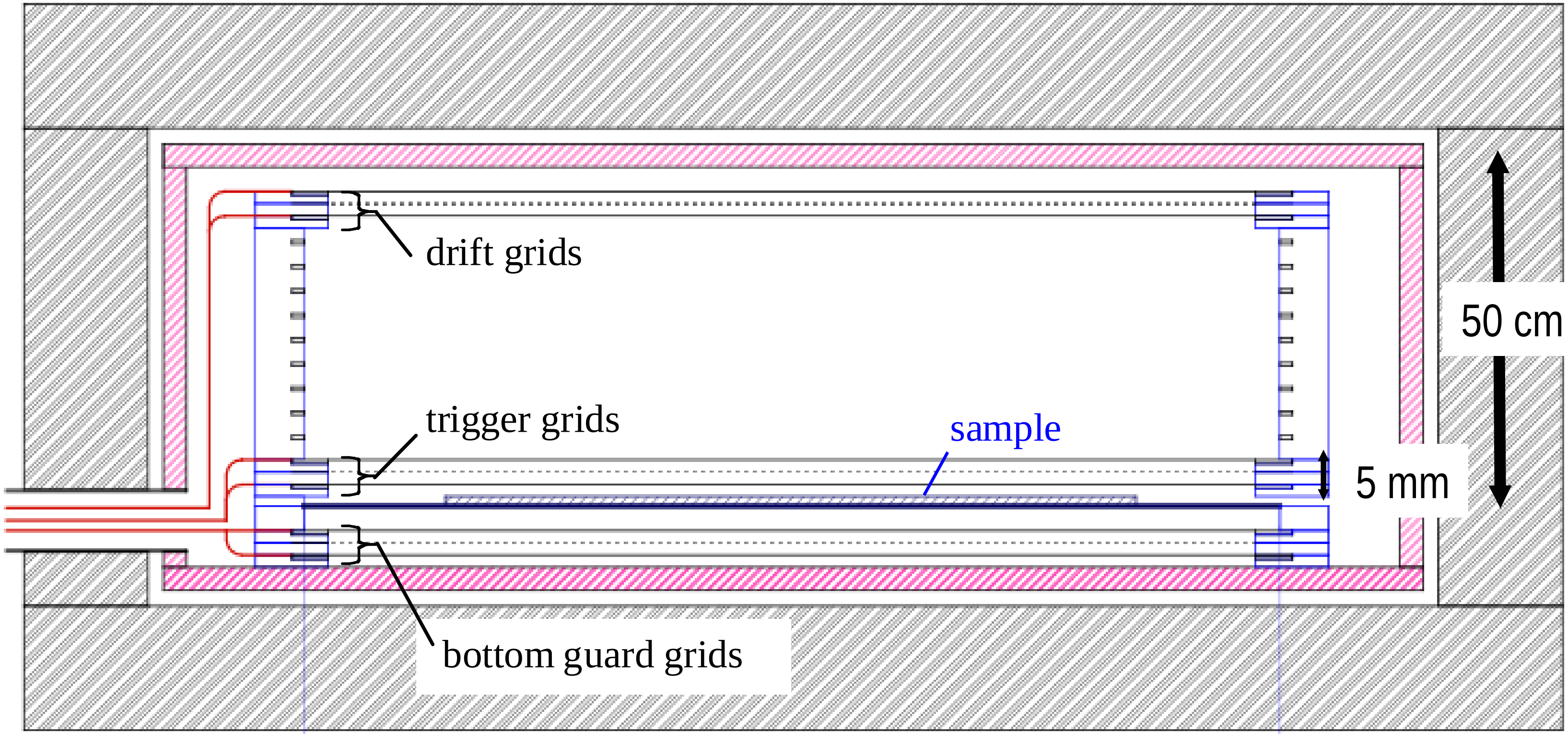
H. Nelson, UCSB

Basic Design Principles

- Backgrounds are proportional to mass of detector
  - Ultraclean materials to minimize internal contamination
  - Underground, shielded apparatus to minimize external backgrounds
- Deploy minimum material needed to stop βs.
  - Gas is best method to achieve this low mass
  - 150 keV e^- $\approx$ 30 cm Ne (1 atm)
  - Can identify betas with 300 keV endpoint with 50 cm height
  - Could Use Xe (1 atm) for higher-energy betas (range ~7x less)
    - Not for now (requires vacuum chamber); may try with prototype
- Maximize counting statistics
  - Large surface area (horizontal dimension) ~1 m^2
- Guard region to reject events emitted from outside chamber

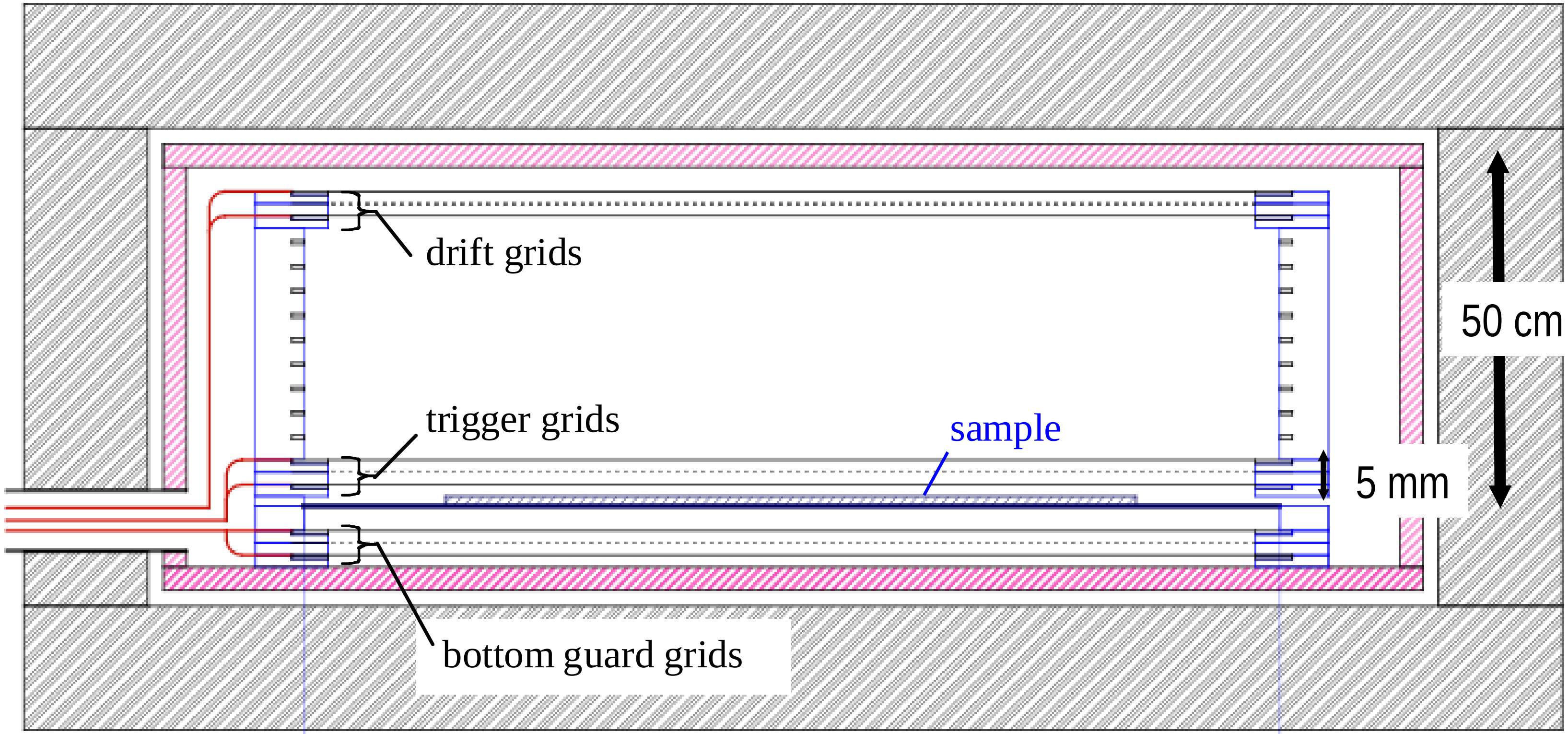
BetaCage

- Multiwire proportional counter
- Wires provide minimum surface area for emissions
  - 25 µm Ø, 1/2 cm spacing - 0.5% coverage
- Crossed grids could yield ~mm xy position information
  - Identify source position of contamination



BetaCage

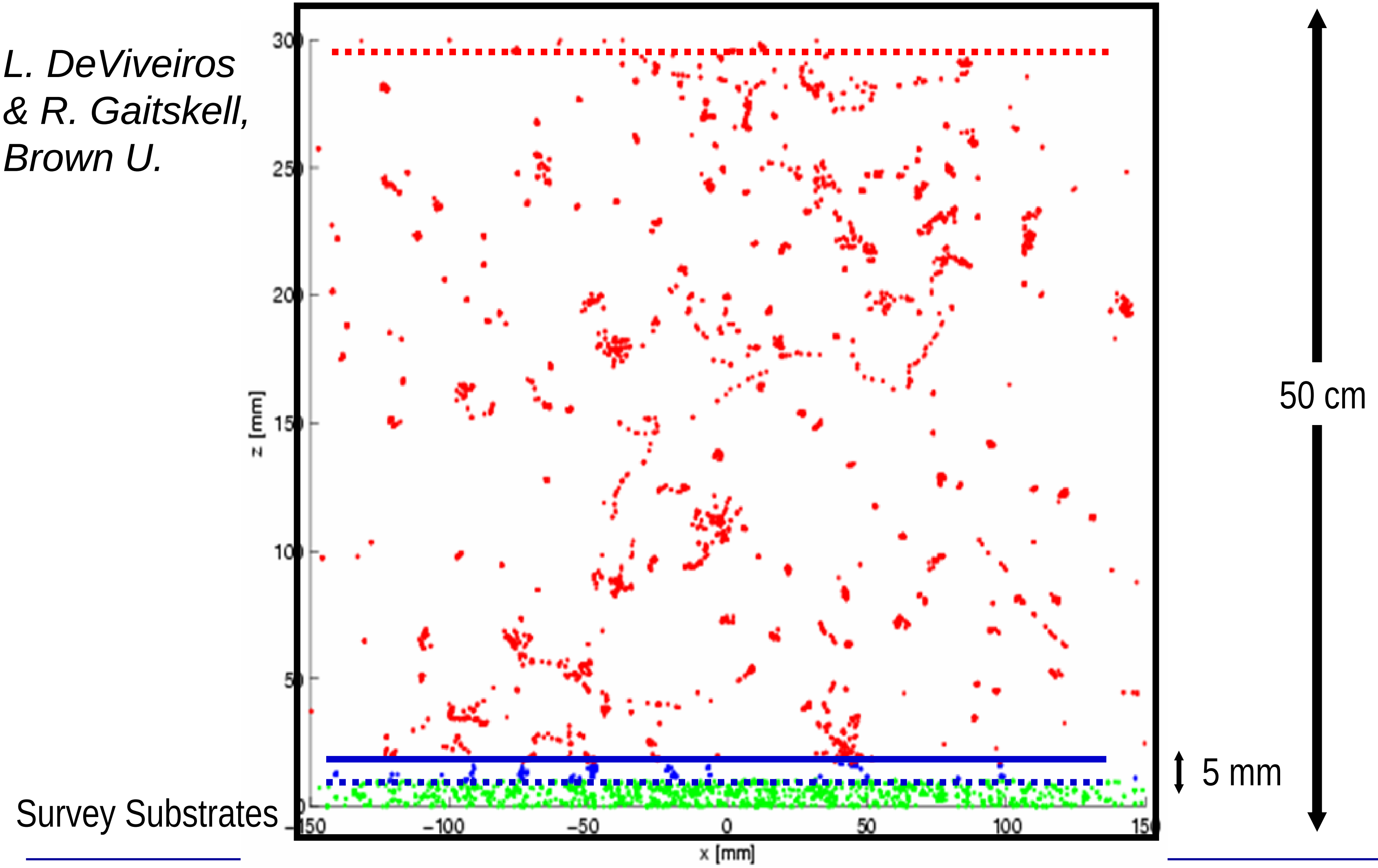
- Reject background interactions in bulk of gas by creating narrow (5 mm) “trigger region” near samples
  - Most gamma interactions in gas don’t cause trigger
  - Reduces backgrounds in gas to 15% of unrejectable total due to gamma interactions in sample that eject electrons into trigger region (these look exactly like beta emission)



Results of Monte Carlo Simulation

- Gamma Background equivalent to 1 event/(kg keV day)

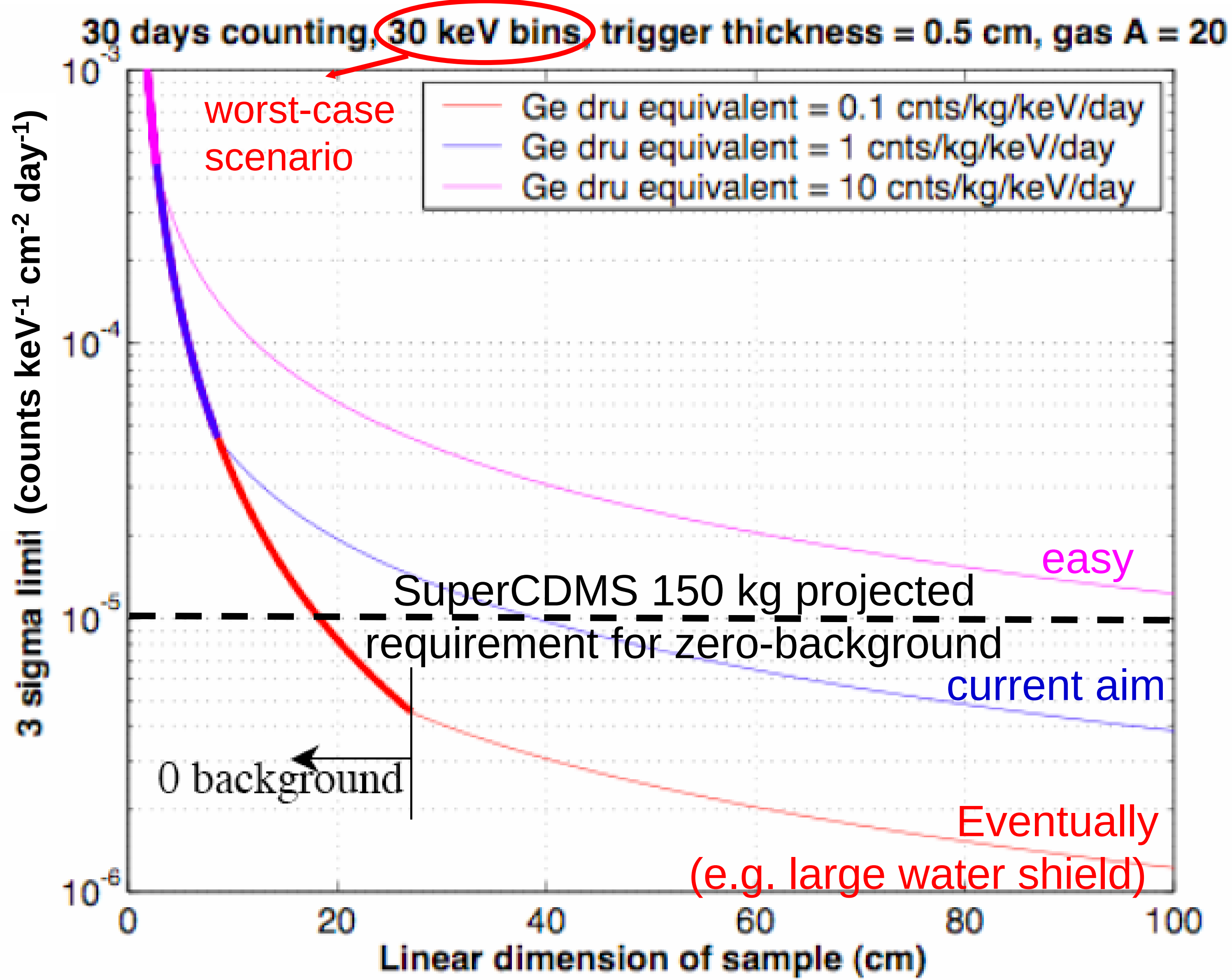
L. DeViveiros
& R. Gaitskell,
Brown U.



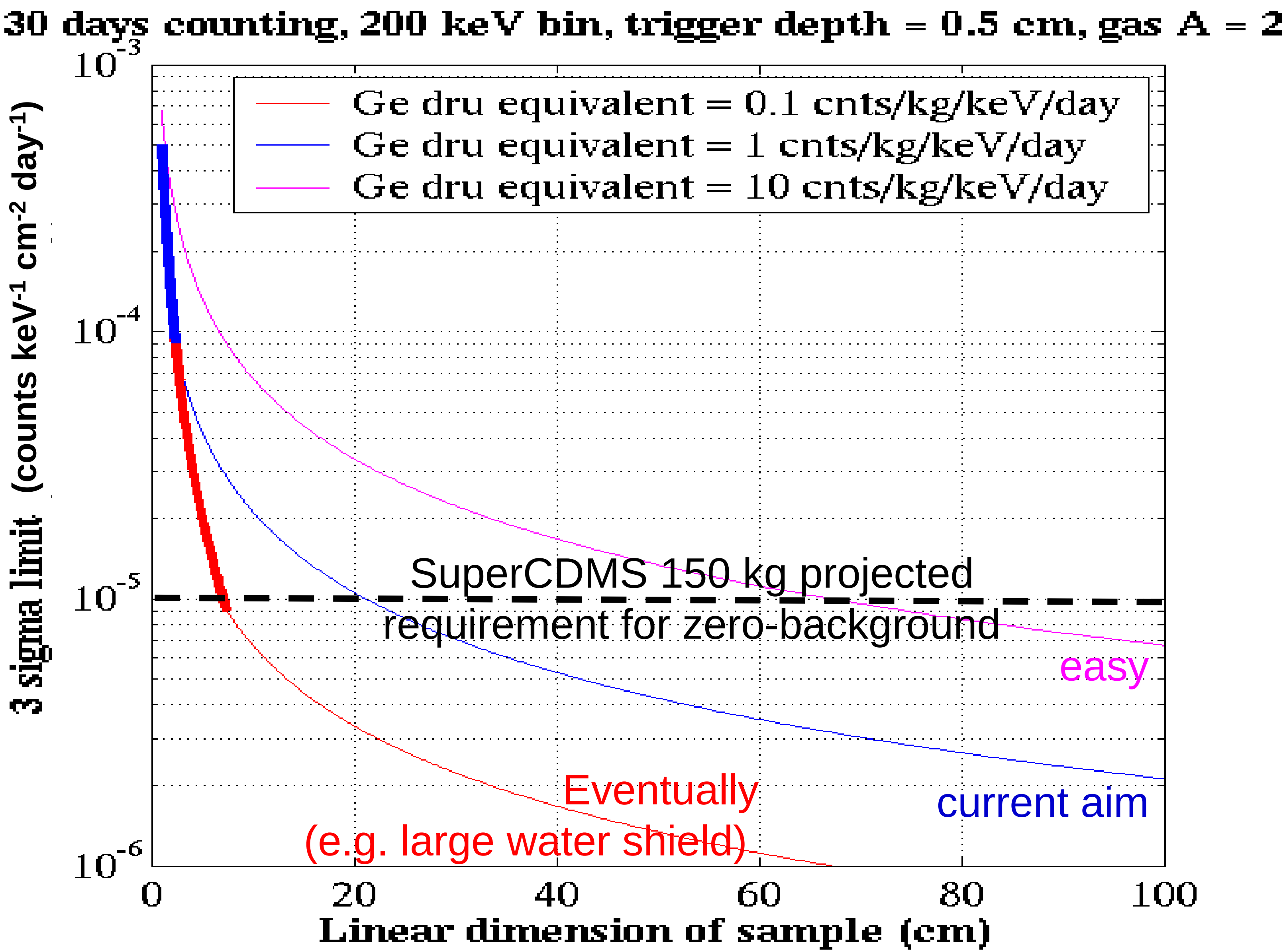
Backgrounds

- Dominated by external gammas (3 x 10^{-5} keV^{-1} cm^{-2} day^{-1})
  - Backgrounds of 1 event/ (kg keV day) straightforward with simple lead shield (including ancient lead liner)
  - Factor of 10 possible with better shield (e.g. clean water)
- Other:
  - ^{14}C in quench gas (5 x 10^{-6} keV^{-1} cm^{-2} day^{-1})
    - 5% methane, 10^{-16} g/g $^{14}C/^{12}C$
    - Evaluating impact & alternatives (pure gas), may ultimately limit
  - Wires
    - Bulk: negligible (10^{-13} keV^{-1} cm^{-2} day^{-1})
    - Surface: at 25 µm Ø, 0.5 cm spacing -> 200x smaller than sample
      - May have to clean wires (expect 10^{-8} keV^{-1} cm^{-2} day^{-1})
  - Additional Construction: Plastics / Cu (negligible gammas), minimize number of resistors inside chamber (10^{-6} keV^{-1} cm^{-2} day^{-1})
    - Operate at 1 atm - no pressure vessel
    - Neon gas can be vented (rather than recovered) after counting

Sensitivity (with background subtraction)



Sensitivity (with background subtraction)



Additional Uses: α, β, X-rays

- Would be world's most sensitive screener for all non-penetrating radiation
  - More samples and higher efficiency than Ge detectors
- Low energy x-rays will provide a background for solar neutrino experiments and large-cryogen dark matter experiments
  - CLEAN program wants to screen to ~0.03 X-rays/cm^2/day (amount produced by ^{40}K in PMT glass)
- Screen for ^{210}Pb via α and β emissions (negligible γ)
  - Potential applications to Si-chip industry
    - ^{210}Po (Pb daughter) is an α emitter that can cause single-event upset
  - A need exists to screen for ^{210}Pb-^{210}Bi-^{210}Po at a rate of ~0.02 α/cm^2/day
- Sensitivity might be more important than diagnostic capability
  - Majorana wants to count 10^4 resistors (10 g, 50 cm^2 total) to sensitivity of ~0.02 /cm^2/day
  - Ge counting would require at least 10 kg (expensive!) and extended counting

Carbon or Tritium Dating

- Questions on efficacy of chemistry, processing of sample
  - Introduction of contamination?
  - Losses when converting sample to assayable form?
- Method 1: Thin sample (solid or deposited onto planchet)
- Method 2: Fill counter with sample made into CO_2 or CH_4 (methane) to be used as active gas
  - Removes advantage of background discrimination using trigger region
  - Assume assay in 1 m^3 chamber with conservative background of 1 event keV^{-1} kg^{-1} day^{-1} (may expect 10x better)

	Background	3σ limit (1 day)	3σ limit (month)
$^{14}C/^{12}C$ in CO_2	300 events/day	6×10^{-18}	10^{-18}
$^{14}C/^{12}C$ in CH_4	100 events/day	4×10^{-18}	6×10^{-19}
$^{3}H/H$ in CH_4	100 events/day	2×10^{-20}	3×10^{-21}

Potentially competitive with AMS

Additional Uses Beyond Physics

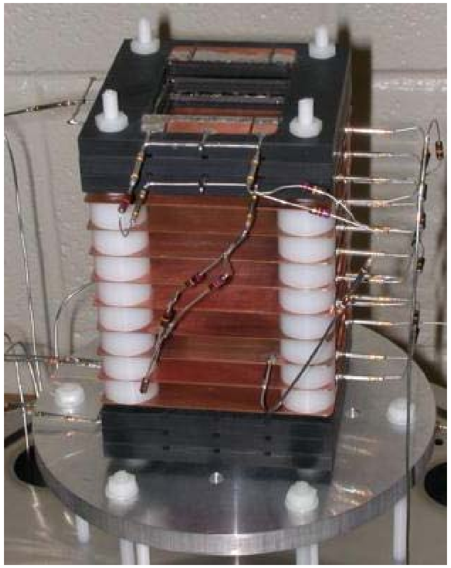
- Discussions at Boulder DUSEL conference and subsequent Minnesota Workshop on Synergies in Low-Background Ultra-Sensitive Radiation Techniques identified many user communities outside physics (cf. Wednesday's session here)
  - Tritium and ^{14}C in groundwater
  - Radioactive environmental sampling (accidental release of radioisotopes)
  - Exposure assessment studies (^{14}C as a tracer of particulate lung burden)
  - Use of short-lived isotopes for sediment dating
  - Tracers in uptake and transport (geomicrobiology)
  - Bioremediation studies
- These "other" users could use better beta-counting applications (^{14}C, ^{3}H, ^{40}K)

P. Cushman, UMinn

BetaCage Timeline

(many discussions)

2002 T. Bowles, LANL, sparks discussions at Aspen workshop on underground physics

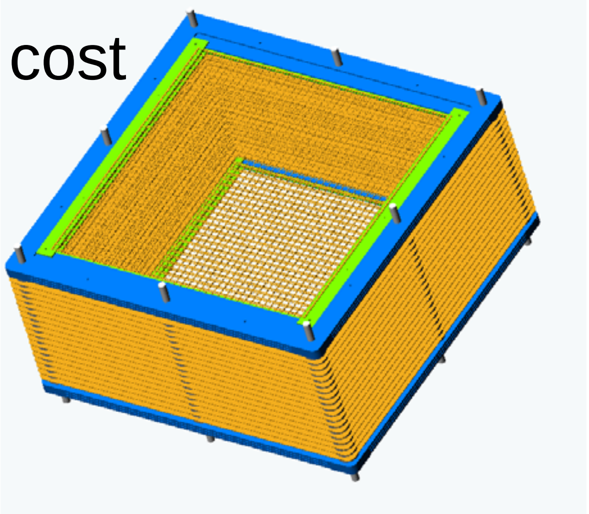


2003 T. Shutt & E. Dahl, Princeton, design, build, and operate 4 cm x 4 cm x 10 cm prototype

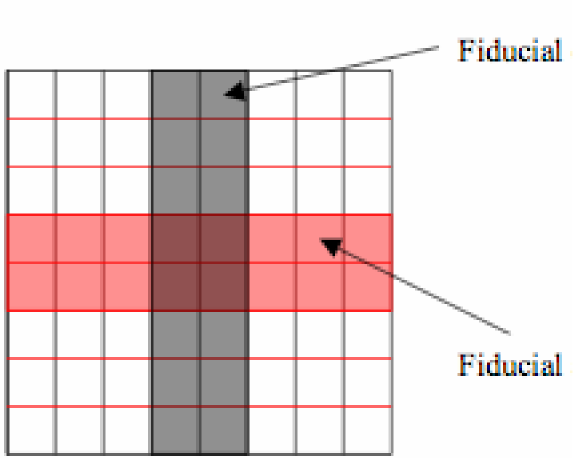
2006 Our group (Case and Caltech) building 40 cm x 40 cm x 20 cm prototype (not radiopure), proposing 100 cm x 100 cm x 50 cm detector

2007 We plan to run the prototype and hope to start construction on the full detector

BetaCage Prototype

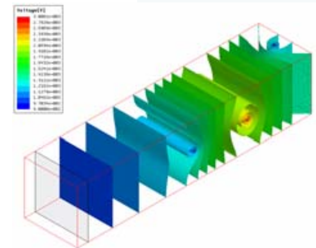


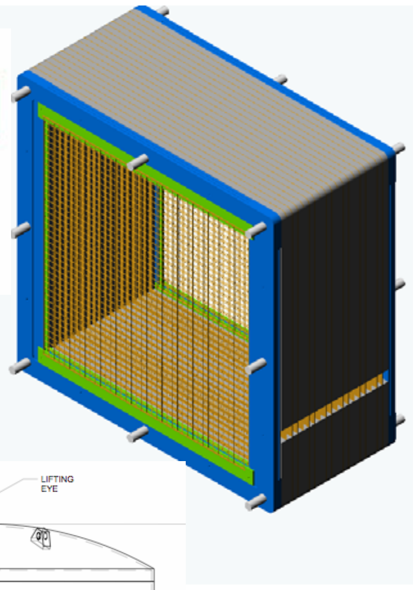
- Purpose: demonstrate functionality at low cost
  - Basic MWPC construction
  - Beta identification via endpoint energy
  - Alpha identification
  - Some vetoing of gamma-induced events
- Cut costs by not being radiopure, using simplified simple DAQ
  - Aluminum vacuum chamber
  - Use argon gas not neon
    - Less expensive, simple gas handling
    - Also allows prototype to be half size of final instrument (since electron ranges in Ar are half that in Ne)
  - Use few channels (trigger, bulk, and veto regions

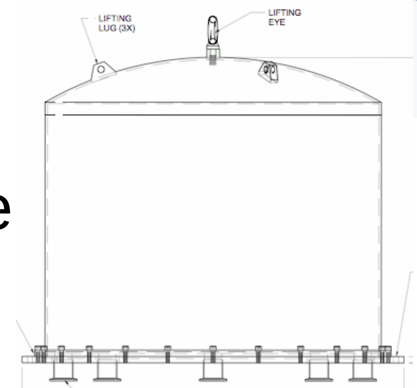


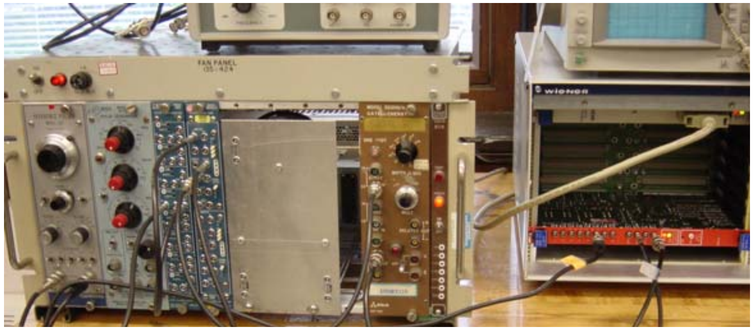
BetaCage Prototype Status

- Mechanical design done
- Electromagnetic simulations done
  - Wiring pad system and wires in hand.
  - Prototype frames and field shapers should arrive at Caltech today.
  - Test assembly this month at Caltech
- Vacuum chamber due mid-October
- DAQ and gas handling systems done
- HV system in progress
  - Almost all parts in hand
- Full assembly at Case Western in November

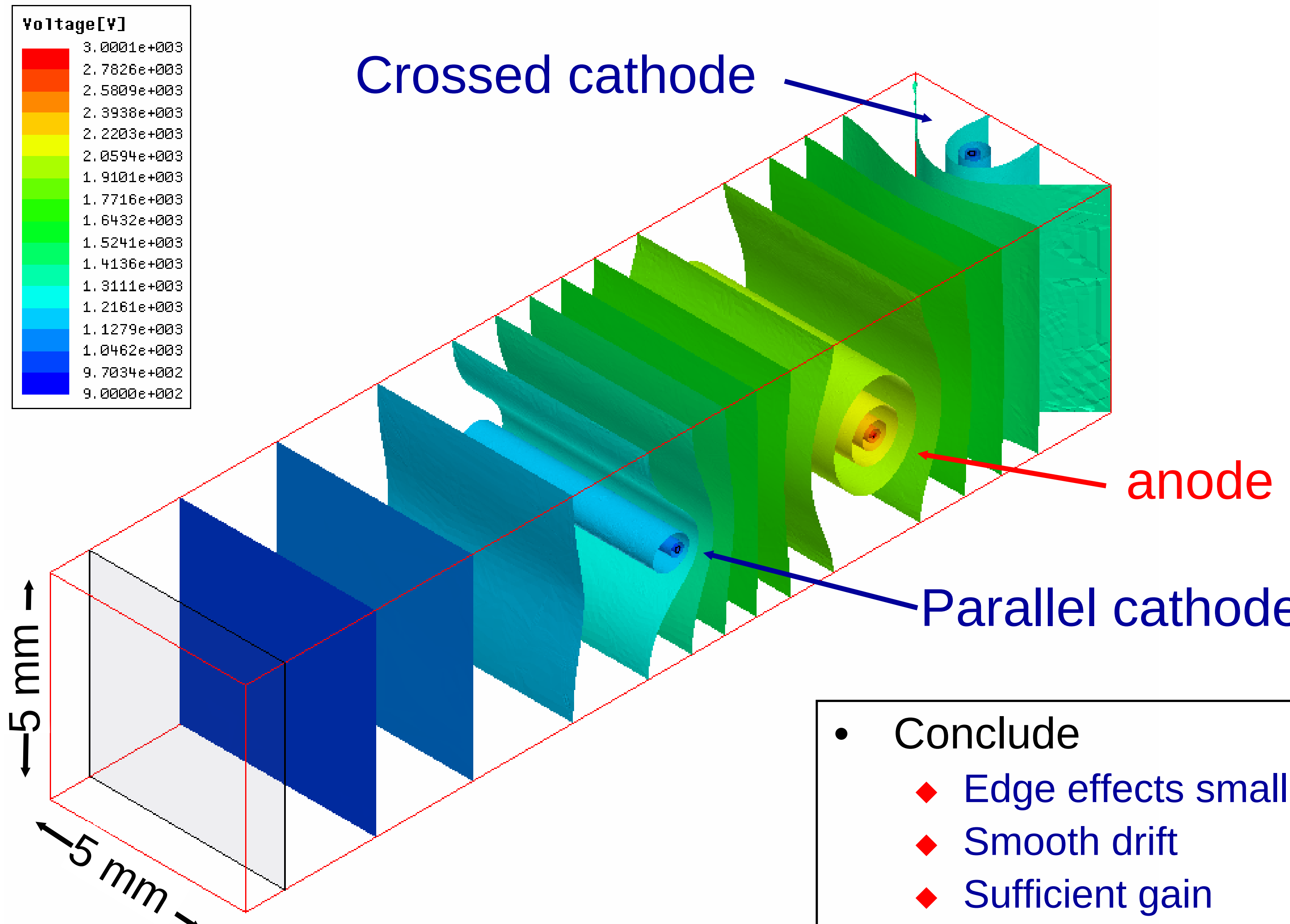








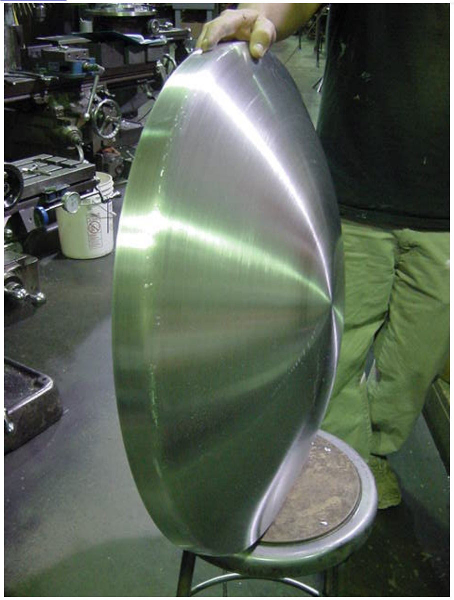
Simulation of Electric Fields in Maxwell-3D

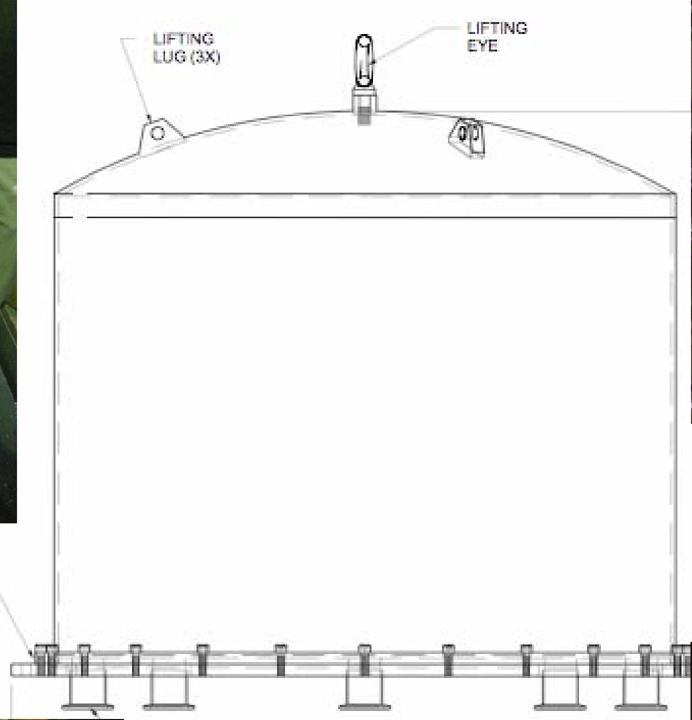


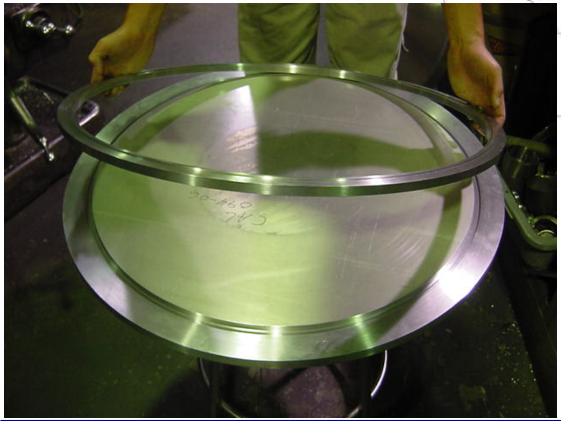
- Conclude
  - Edge effects small
  - Smooth drift
  - Sufficient gain
  - No breakdown

Z. Ahmed, Caltech

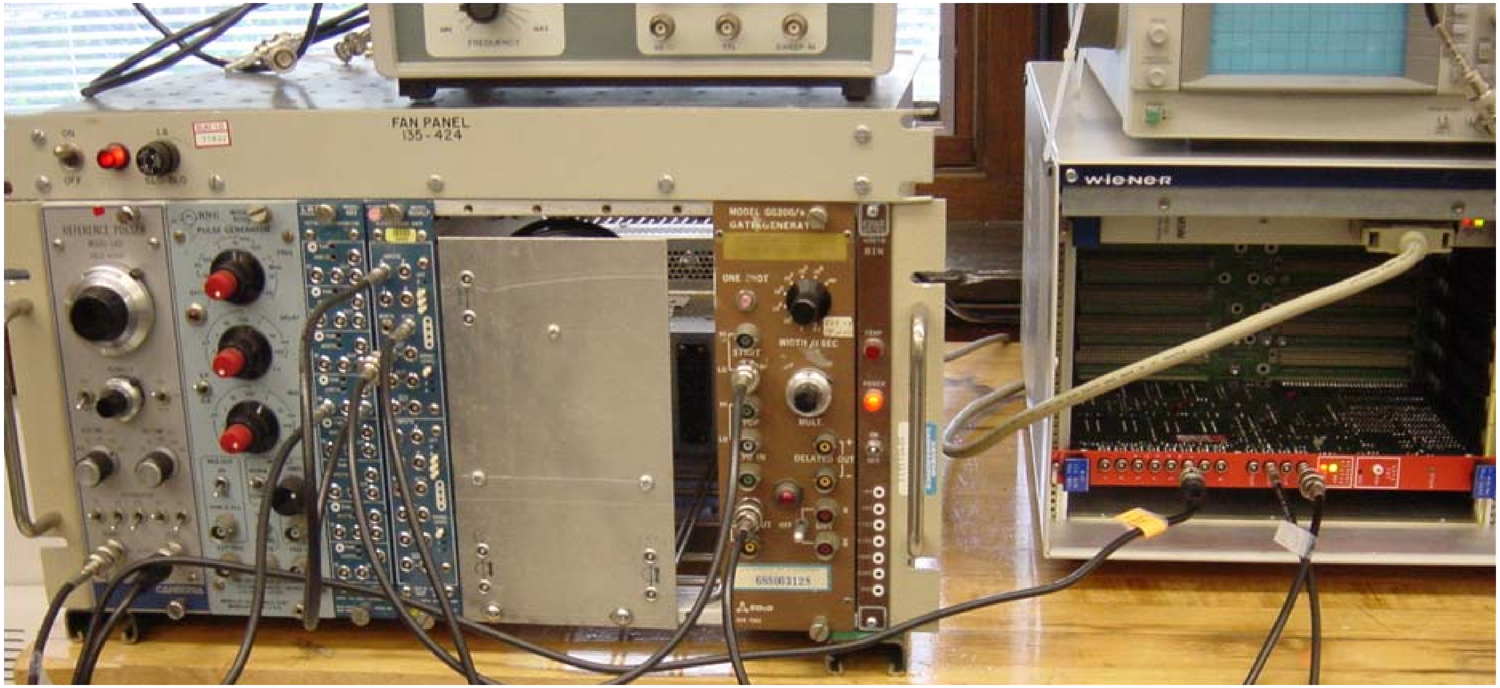
Vacuum Chamber Under Construction

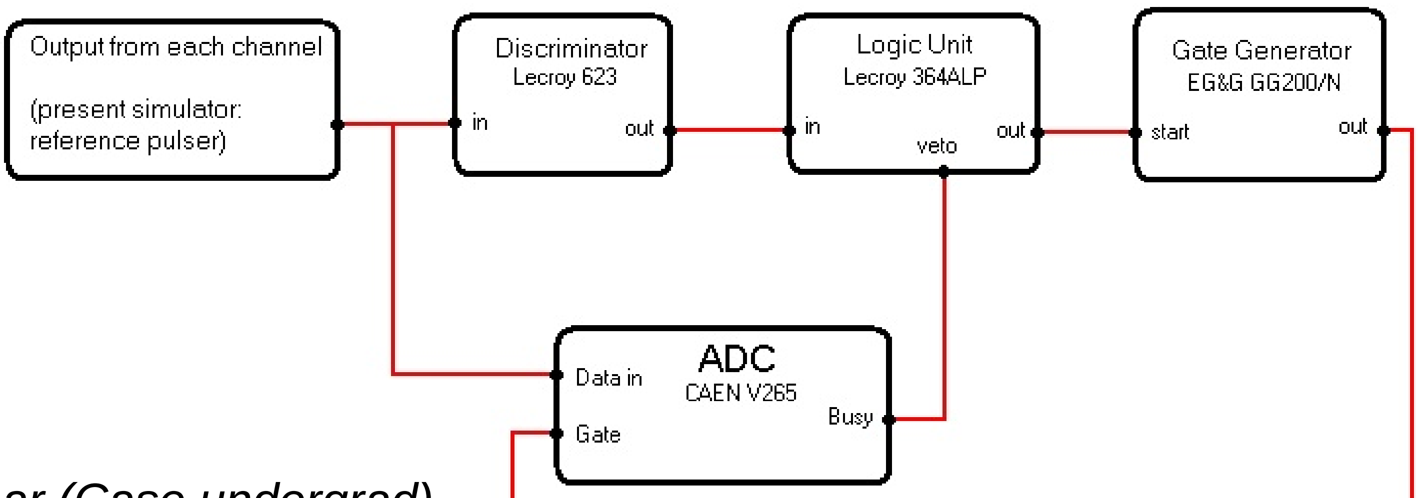






Prototype DAQ Ready





K. Poinar (Case undergrad)

BetaCage Proposal

- Switch to neon from argon, switch to all radiopure materials
  - Switch to neon requires doubling detector size
- Detector Development
  - Manpower: $200k
  - Plastic chamber and MWPC assembly construction $120k
    - Since not vacuum chamber, using Xe would be too expensive
- DAQ
  - $50k for middle end system - not full x-y
- Shield (1 dru) to be provided by Soudan Low-Background Counting Facility
  - Saves $55k
    - Uses ultra-low-radioactivity Cu as an alternative to ancient Pb
- Possible Upgrades
  - Improved shielding to improve sensitivity
  - Copper vacuum chamber to allow Xe for identification of high-energy endpoints

Conclusions

- Proposed BetaCage: Large, clean, shielded, underground multiwire proportional chamber could be world's most sensitive screener for all non-penetrating radiation
- Needed for screening CDMS detectors' thin films for beta contaminants
  - Potentially broad applications to rare-event searches
- Expect virtually no background for alphas
  - Presumably dominated by U/Th in wires, radon/dust on sample surface
- Excellent sensitivity for carbon or tritium dating
- Prototype screener to demonstrate operation, energy reconstruction, some background rejection in 2007