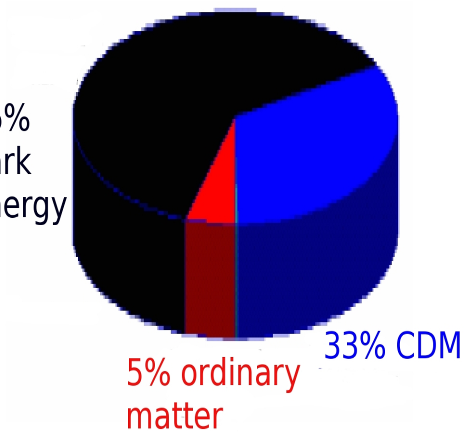
LAr for Dark Matter Detection



Everyone agrees we live in the best of all possible worlds...

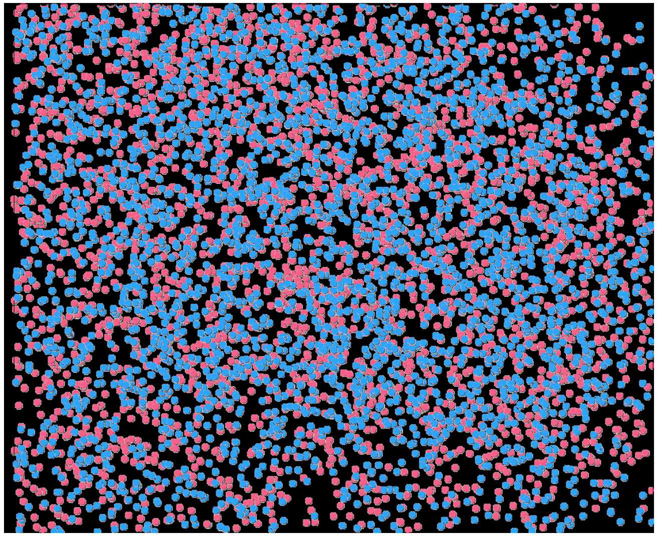
"Concordance Cosmology" (Spergel et al, 2003) - grand synthesis of observations on CMBR, galaxy clustering, distant SN, ...

Impressive agreement is obtained using a single set of cosmological parameters (Λ, Ω_m, Ω_b, H_0) ...

Leaving a universe which is totally dominated by undiscovered forms of matter, all of them seen only indirectly (DM, DE) !!

How can this new orthodoxy be experimentally tested?

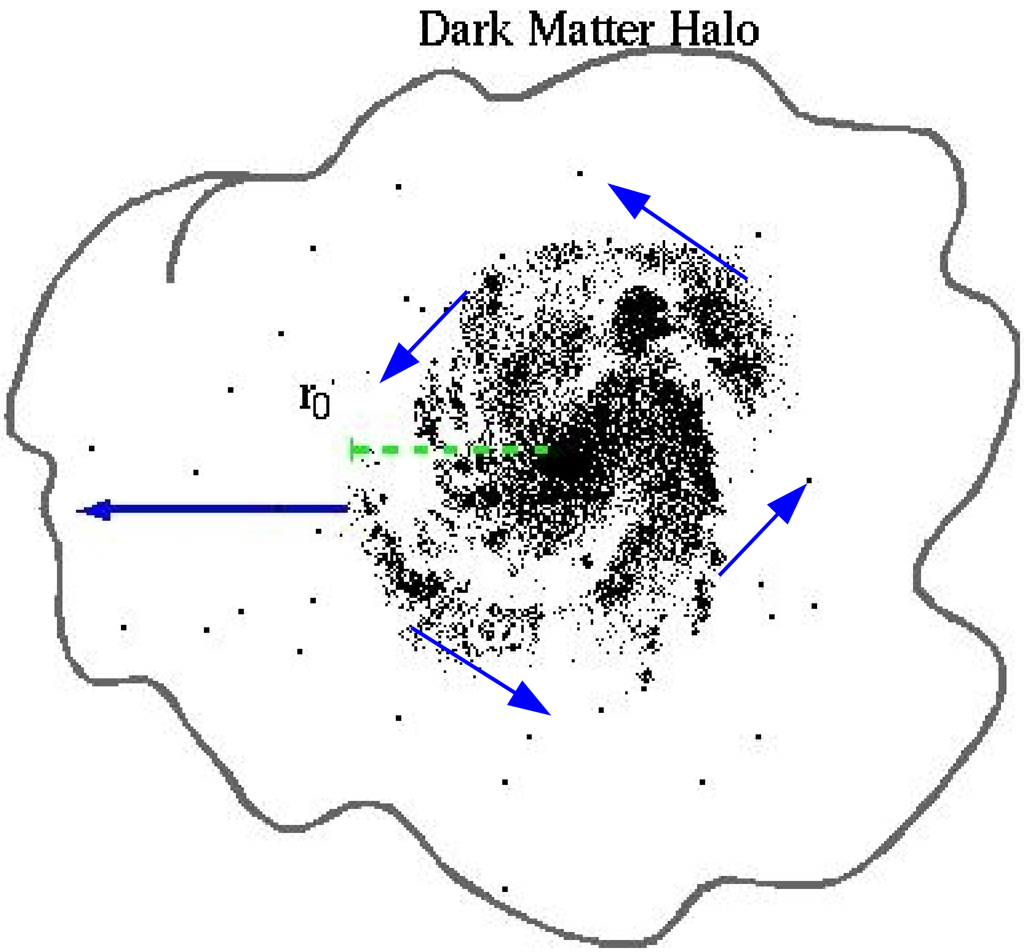
DM Dynamics for Dummies



- DM density fluctuations “seed” OM gravitational collapse.
- BUT Virial Theorem requires energy loss for cloud collapse
  - DM is ~ dissipationless while OM is not (BB radiation)
- Hence OM collapses (and flattens to disk) within large DM halo

(nice book, Galactic Dynamics, Binney & Tremaine)

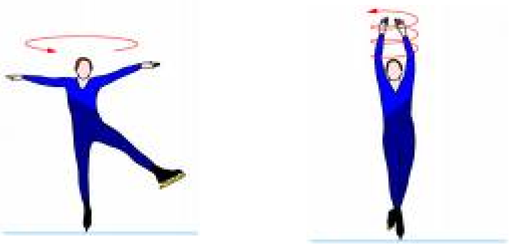
DM Dynamics for Dummies II



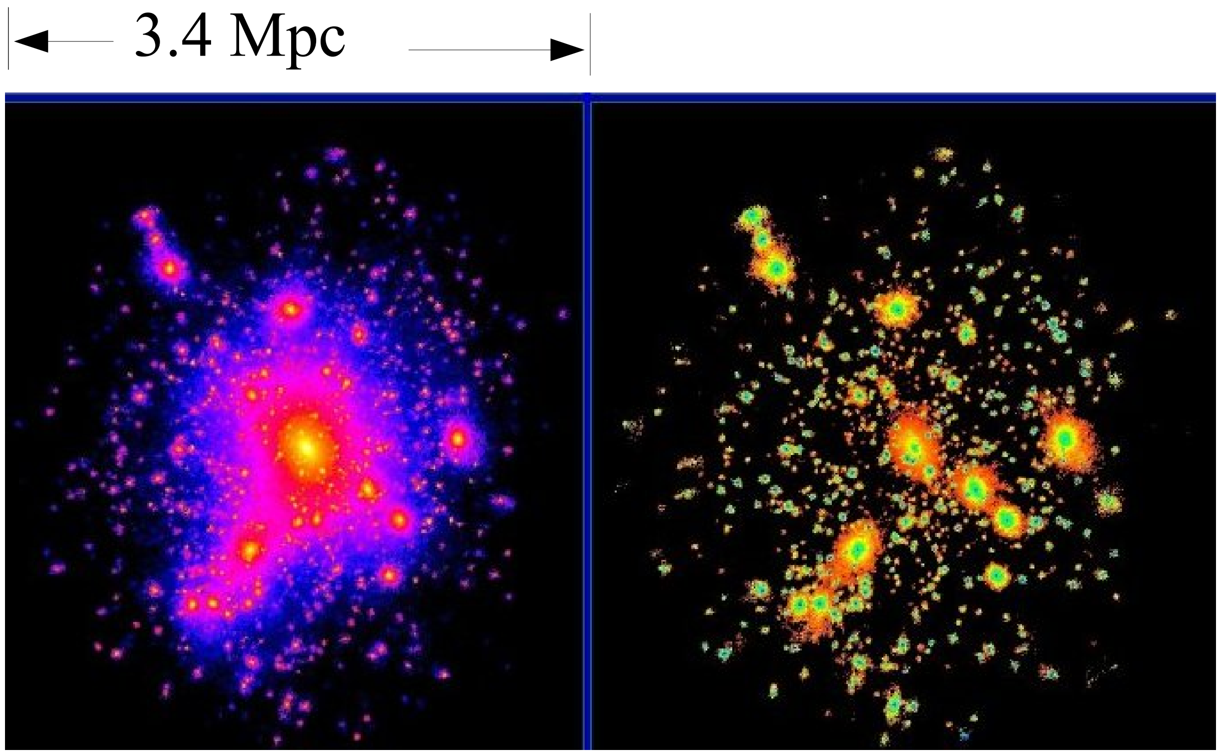
Another effect: rotation.

Energy can be radiated away by OM during collapse, but angular momentum cannot.

So, "Ice Dancer's Arms" effect leads to spin-up of collapsing galaxy within halo.



REAL DM DYNAMICS I



(Moore, 1998)

Large Numerical simulations show “hierarchical collapse” forming complex DM structures in phase space (energy loss by hot particle ejection)

Measuring Dark Matter WIMPS

WIMPs have v_{rms}~.001 c, scatter elastically from detector nuclei. Energy transfer spectrum:

$$\frac{dR}{dE_r} = \frac{R_0}{E_0 r} \exp\left(\frac{-E_r}{E_0 r}\right)$$

$E_o \sim 10^{-6} M_{DM}$

$$r = 4 \frac{\mu_{T,DM}}{m_T + M_{DM}}$$

Typical recoil energy is only 10-100 keV !

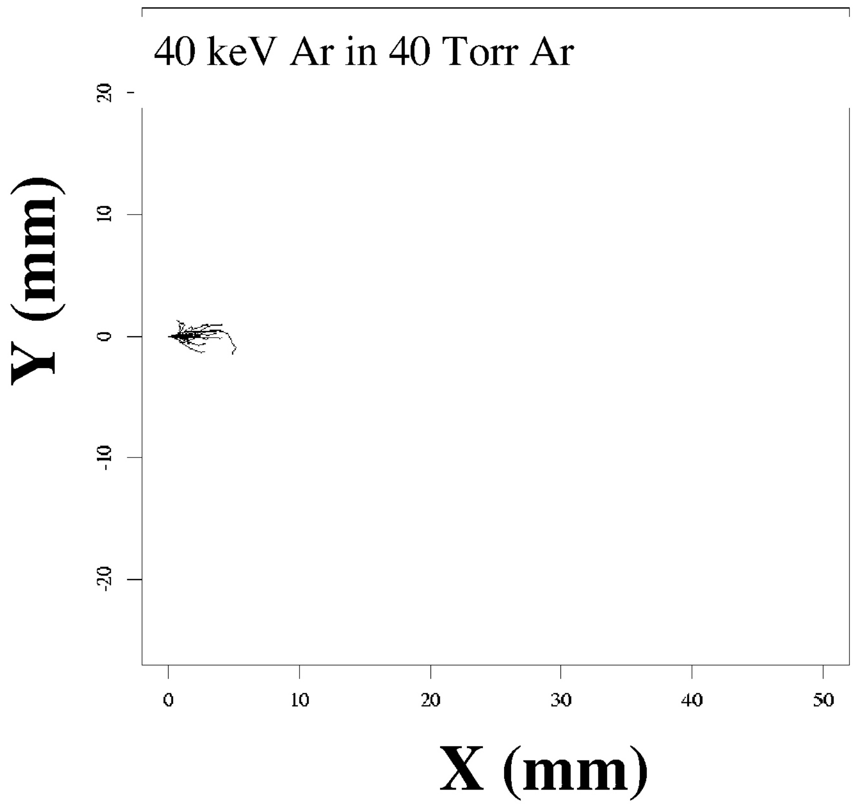
Rate from SUSY and present expt. limits -
< .1 event/kg day

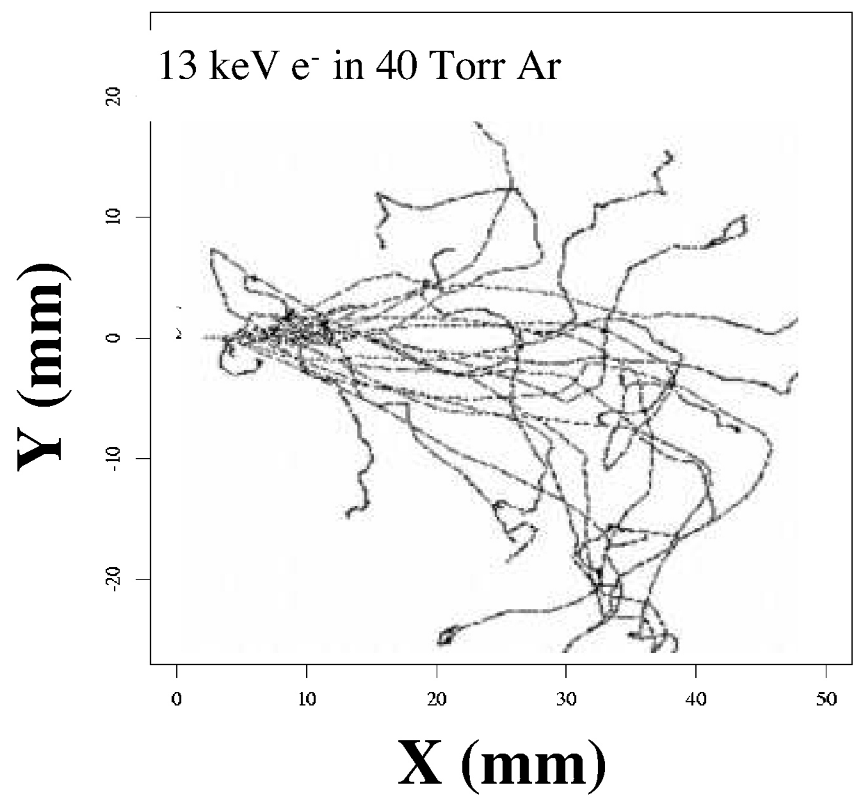
Name of the game- Make the biggest detector you can, put it in the deepest mine you can find, see if you can get zero nuclear recoil counts.

Backgrounds- Low LET

Long lived & induced radioactivity, penetrating cosmic rays, radon...very different energy density than recoil nucleus w/ same energy.

"Discrimination" methods exploit this to reject background that cannot be suppressed by materials selection, underground location, etc.





“Discrimination” Signatures

Cryogenic Semiconductors (CDMS, Edelweiss)	ioniz/phonons	~1e-3	$$$$$
LXe Scint/TPC (XENON, LUX)	ioniz/scint	~1e-2	$$$$
LNoble Scint only (DEAP, CLEAN)	pulse shape	1e-6-1e-8	$$
LAr Scint/TPC (WARP, ARDM)	ioniz/scint + pulse shape	<1e-8	$$$
Bubble Chamber (COUPP,Picasso)	threshold (beware alphas)	<<1e-8	$
Gas TPC (DRIFT, DMTPC,..)	range/ioniz directionality	~1e-5	??

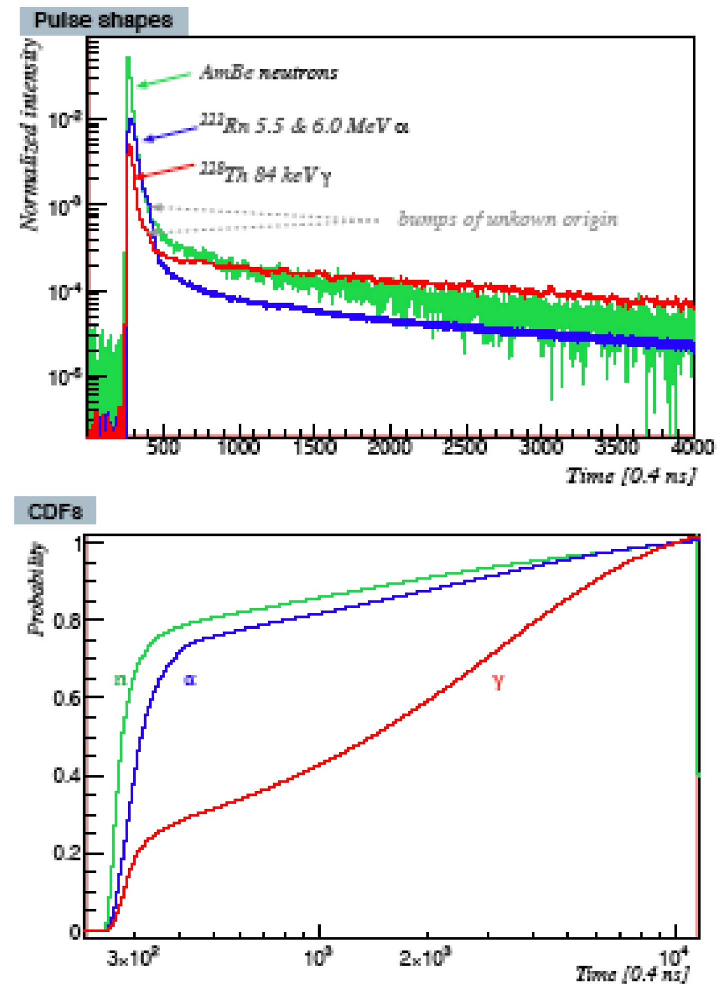
LAr Scintillation Discrimination

Time distribution of light* output from Liquid Argon for
γs, αs and neutrons

2 components:
τ(fast) = 7 ns
τ(slow) = 1600 ns

I(fast)/I(slow)
= 0.3(γ)
= 1.0(α)
= 3.0(neutrons)

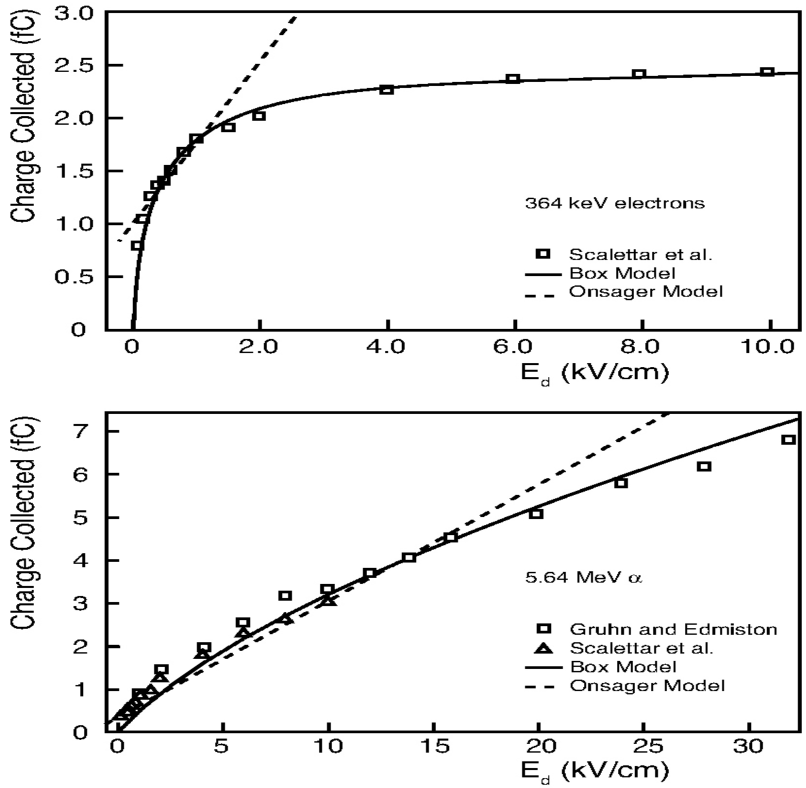
*convolved with waveshifter and PMT response



from T. Pollman

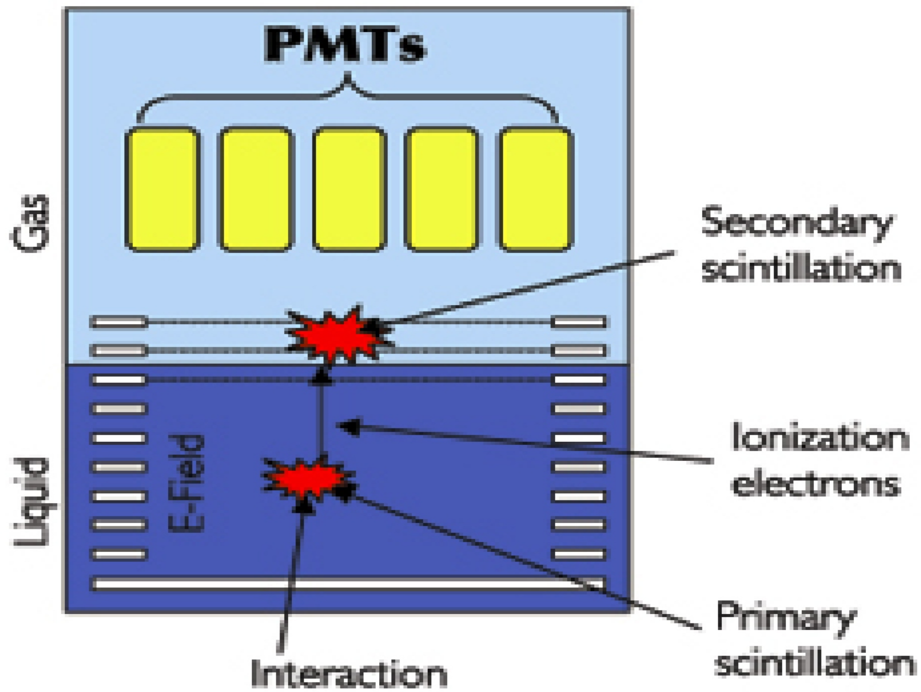
S. Pordes LiquidArgon@CDF 2/10/09 7

LAr Charge Collection Discrimination



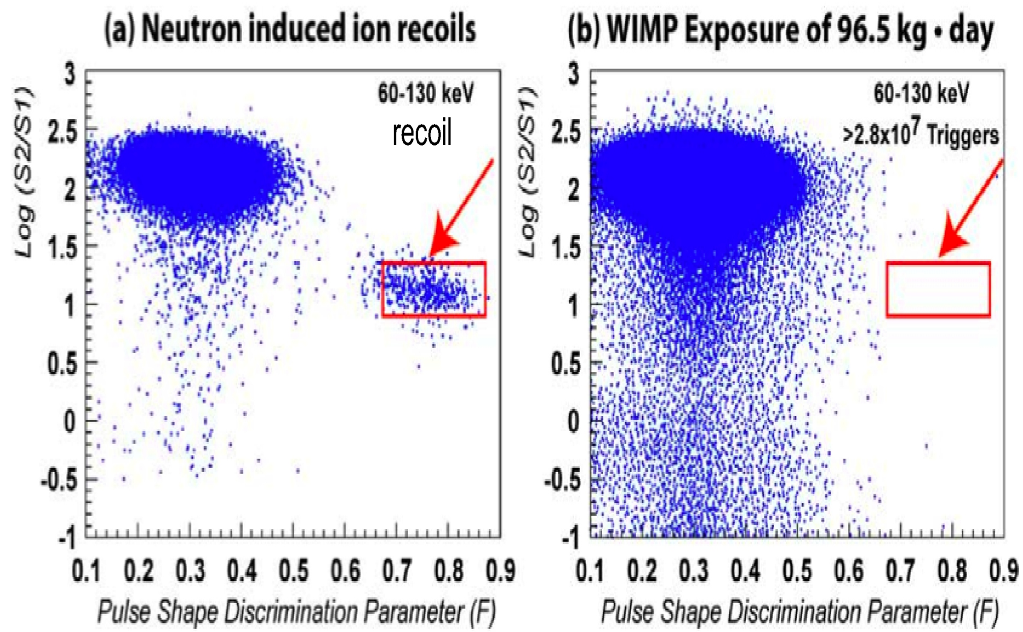
Dense ionization is hard to collect before recombination occurs.

LAr TPC Scheme



* Primary scintillation (128 nm) wavelength shifted & detected.
* Ionization drifted out, detected by electroluminescence light (128 nm, delayed by drift time ~ 1 us/1.5 mm).

Discrimination Results from WARP



~ 2 p.e./keVee WARP (Benetti et al. 2007)

* Two parameter BG rejection is more powerful than one.
* Primary scint. pulse shape & chg/scint ratio appear to be independent discriminants

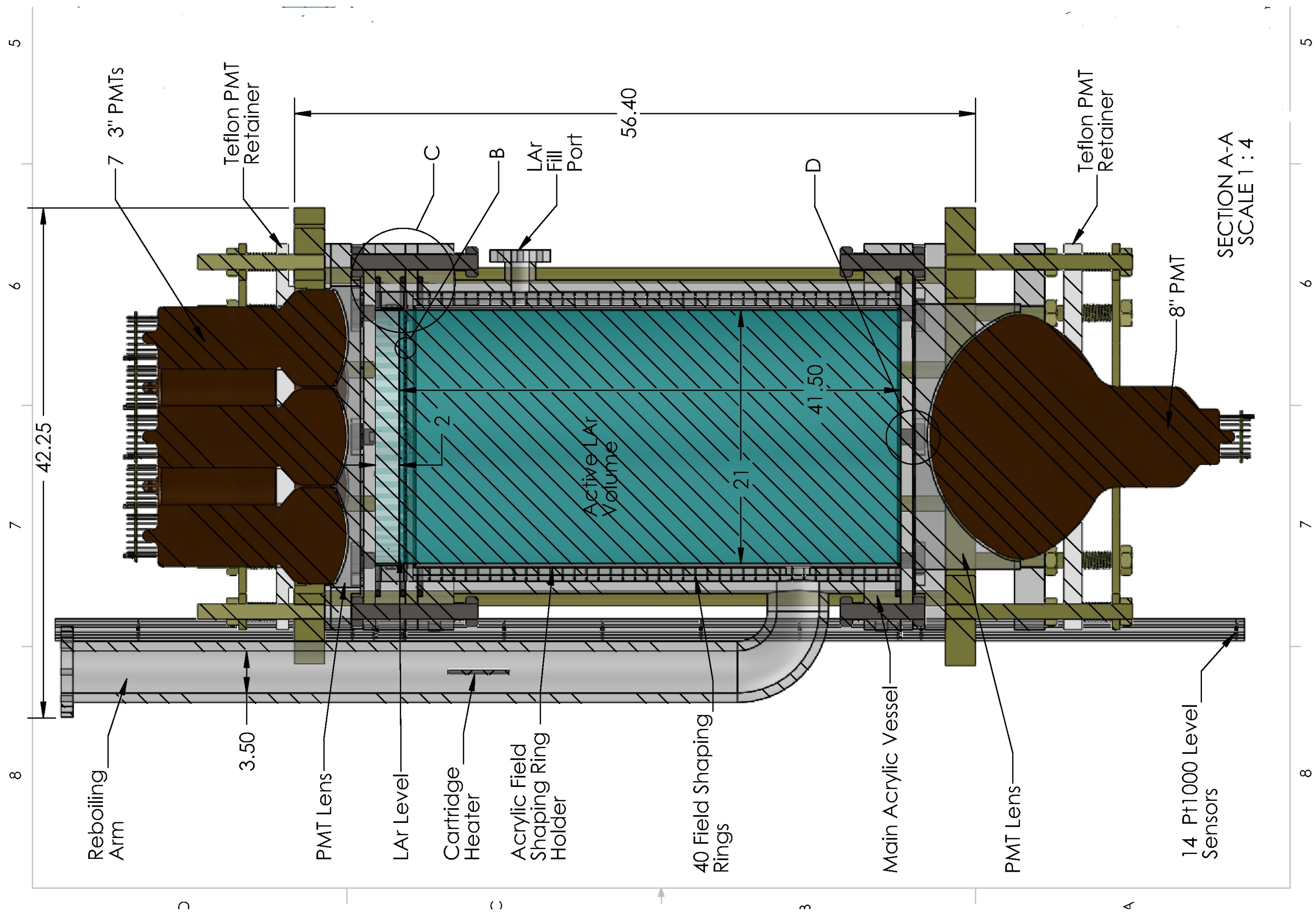
FNAL Program

* Context: 21-institute MAX proposal for NSF DUSEL-S4 detector engineering funds is funded acc'd to Program Officer.

* Essential R&D issues:
  - Low 39-Ar Argon collection and characterization
  - Zero dead volume TPC w/ wall event rejection
  - High primary scintillation detection efficiency (>~6 PE/keV)
  - Demonstrate acrylic containment scheme w/WLS films
  - Design DAQ with necessary dynamic range & speed
  - Achieve & maintain msec e- lifetimes (LAr purity)
  - ...

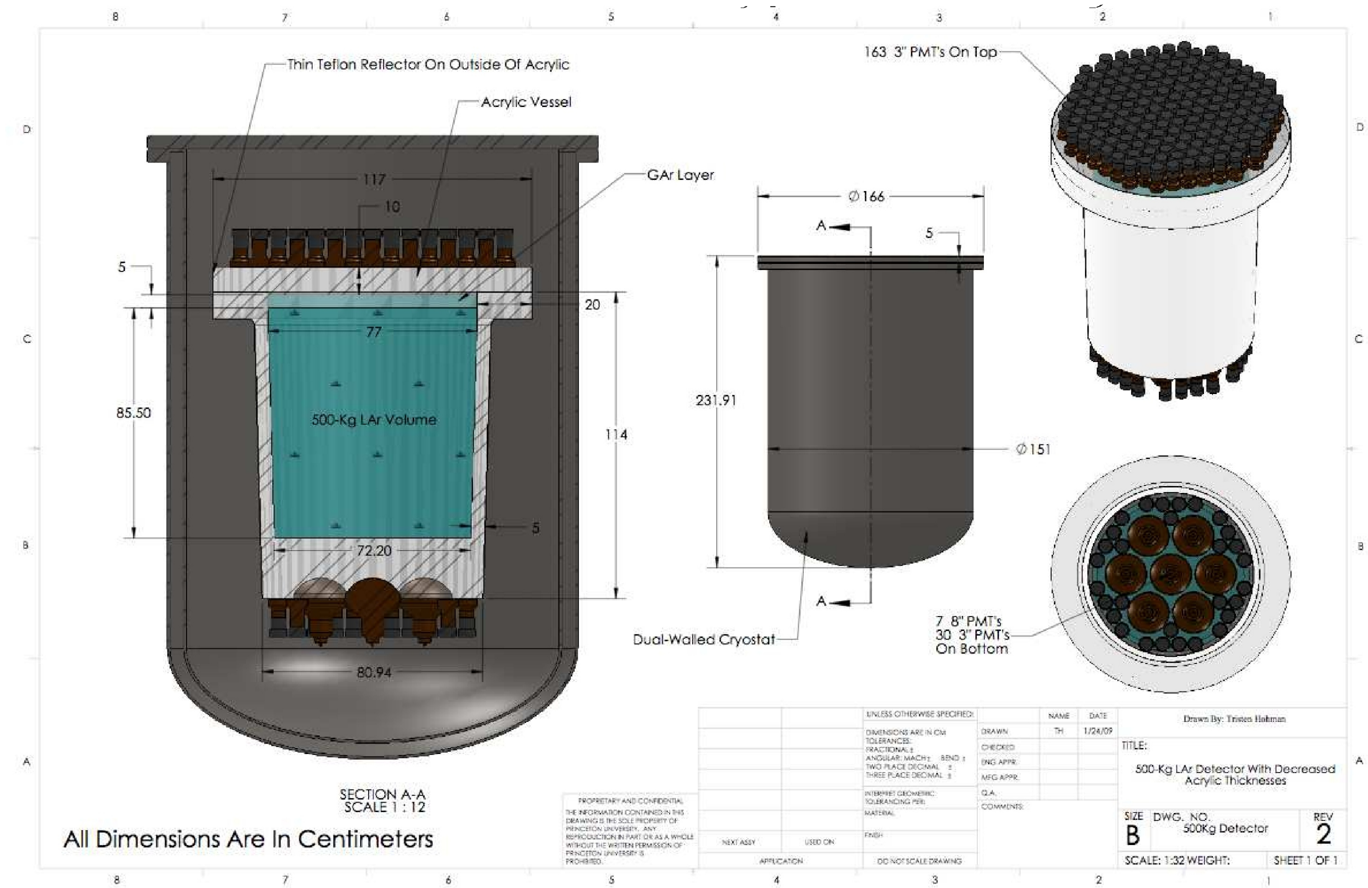
* Staged detector development:
  - 20 kg
  - 500 kg (MAX/10)
  - 5000 kg MAX

20 kg Detector



* 40 cm drift, 20 cm bore
* 8 + 1 PMT's
* Acrylic vessel inside metal cryostat

500 kg Detector (MAX/10)



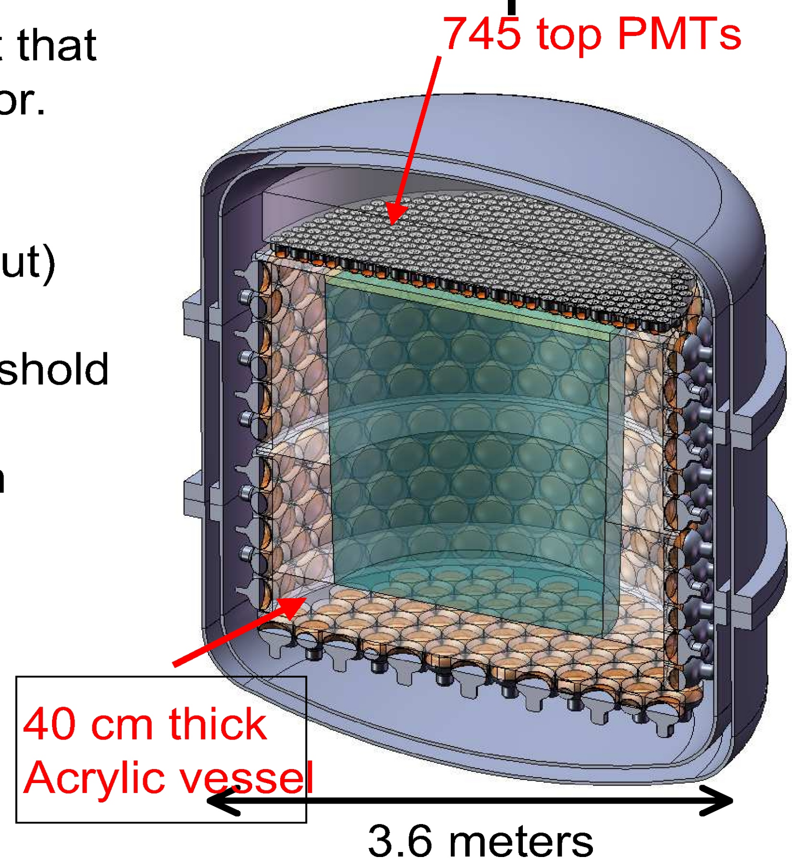
* 85 cm drift, 75 cm bore
* 193 + 7 higher performance PMT's
* Acrylic vessel, 75 KV drift voltage

5000 kg DUSEL Detector (MAX)

Argon Detector Concept

- Largest diameter cryostat that will fit down DUSEL elevator.
- 5 tons depleted argon
  (2.6 tons after fiducial cut)
- 30 keV recoil energy threshold
- ~ 2 cm position resolution
- 0.5 background events expected in 5-year run.

3 order of magnitude improvement over present CDMS/ XENON sensitivity



FNAL Activities

39-Ar assay work
- 1 liter, 8.5 bar prototype ion chamber
- 1 liter, 180 bar ion chamber

20 kg detector design work
- HHV schematics
- Drift field simulations
- Many technical synergies with FNAL LAr-neutrino program

Radioisotopes in Ar

37-Ar ($t_{1/2}$=35 d, EC, Q=815 keV)

cosmogenic; 40-Ar(n,4n) threshold 29 MeV
.01-10 Bq/kg atmospheric Ar
not a huge problem

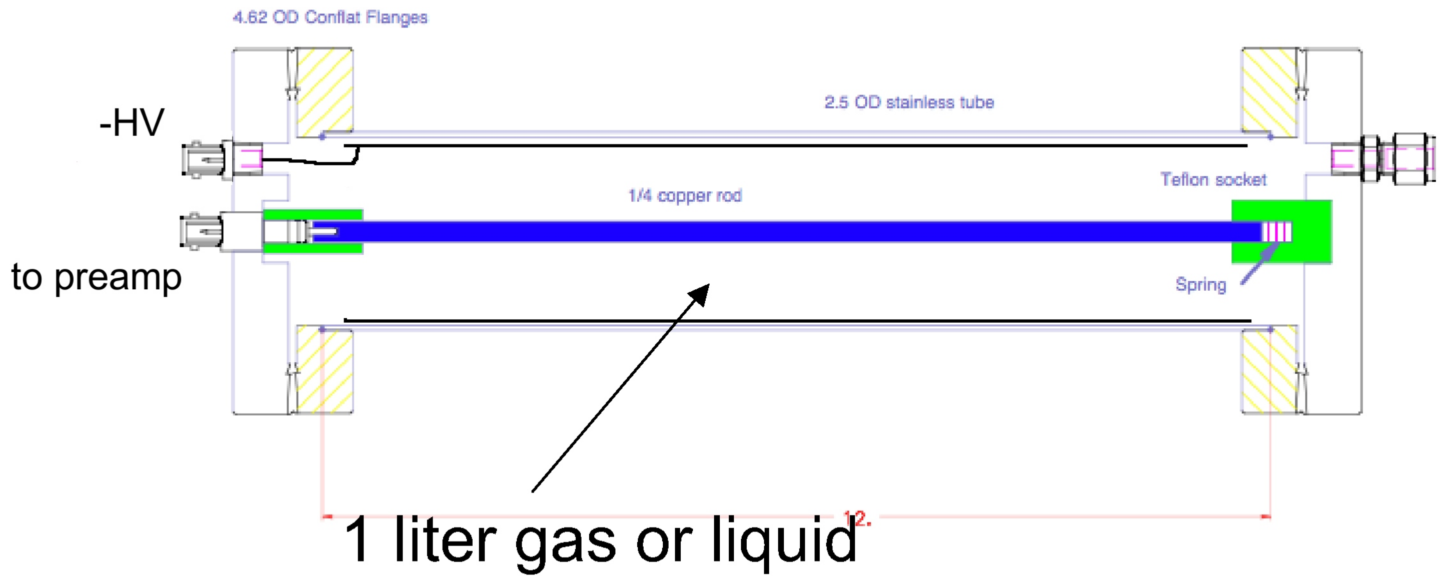
39-Ar ($t_{1/2}$=269 yr, beta-, Q=565 keV)

cosmogenic, 40-Ar(n,2n) threshold 10 MeV,
39-K(n,p) threshold 0!
1 Bq/kg atmospheric Ar
a huge problem! (raw rate, discrimination)

Solution:

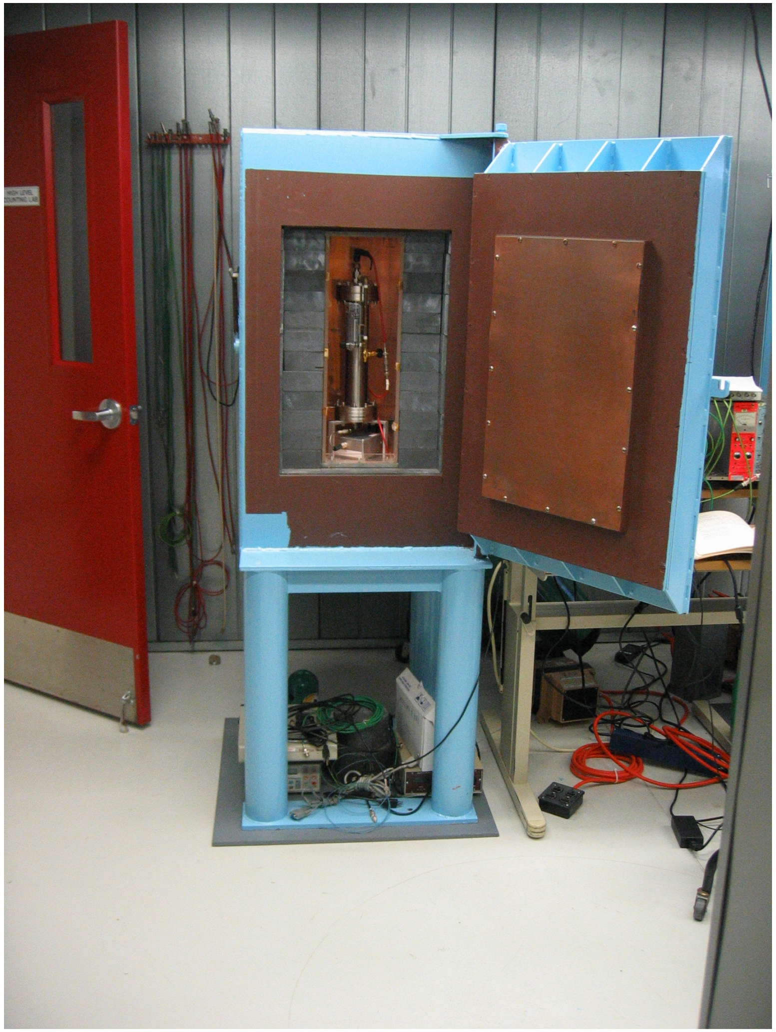
underground Ar (Galbiati et al, Princeton)
counted at upper limit .05 Bq/kg (=> 5 T MAX)
how low is it really?

Prototype 39-Ar Ion Chamber

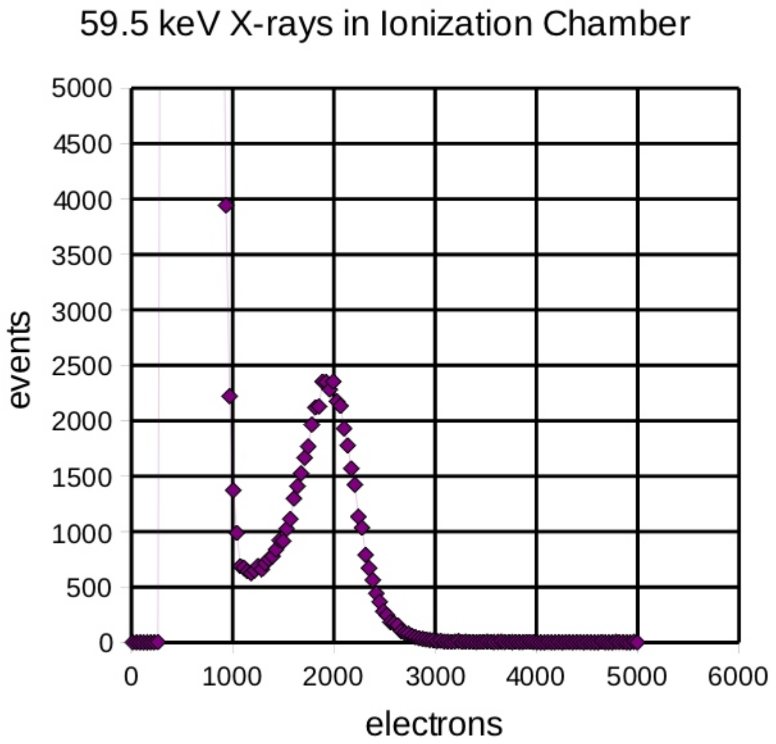


* Output to AMPTEK preamp taken near ground
* Tested mainly with 60 keV x-rays from 241-Am (39-Ar betas peak near 200 keV)
* AMPTEK 220 e- rms noise achieved

Prototype 39-Ar Ion Chamber



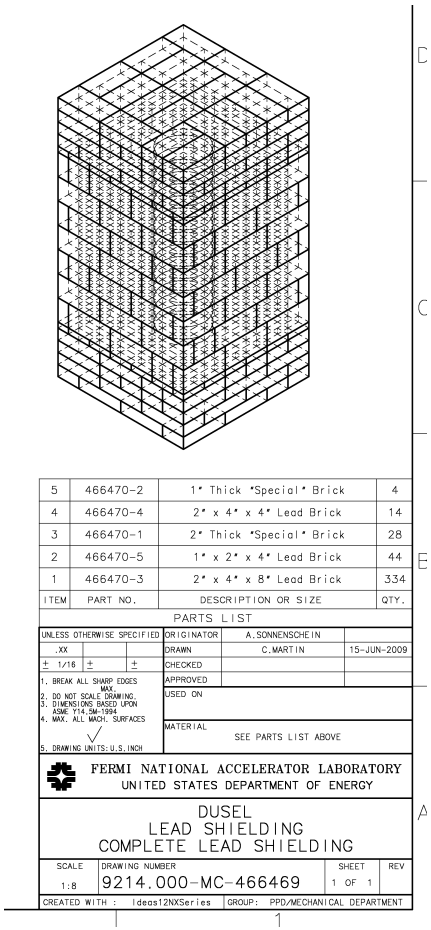
In Pb shield at Site 39 Counting Lab

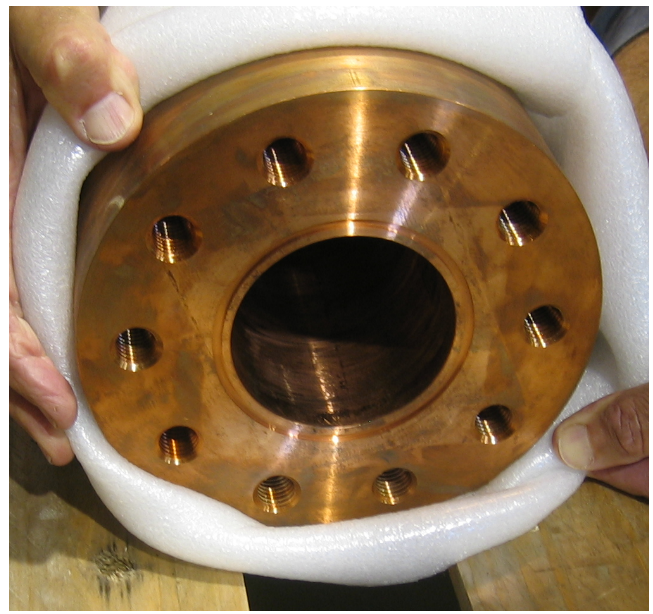


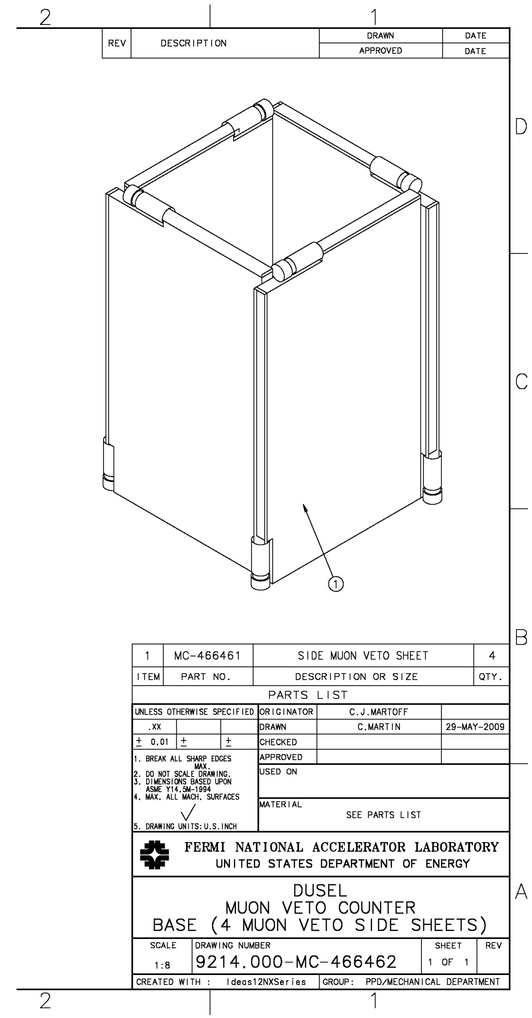
220 electrons rms noise

* Detector fully characterized & calibrated against Si diode
* 180 bar HV feedthru tested to 7.5 KV at 8.5 bar

Developing 180 bar Chamber

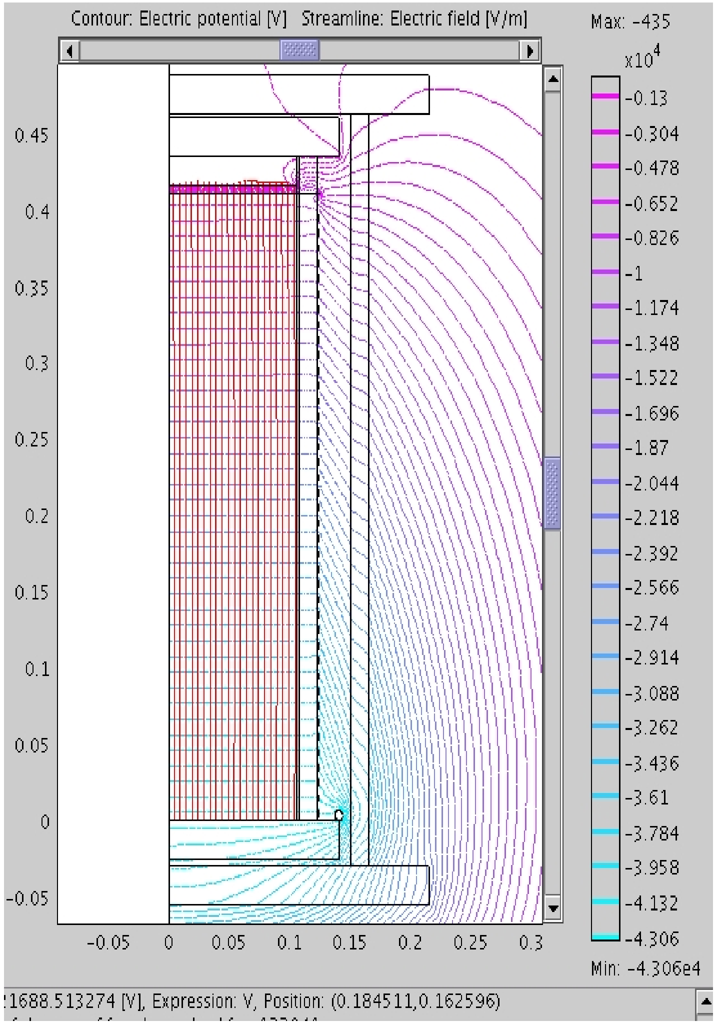


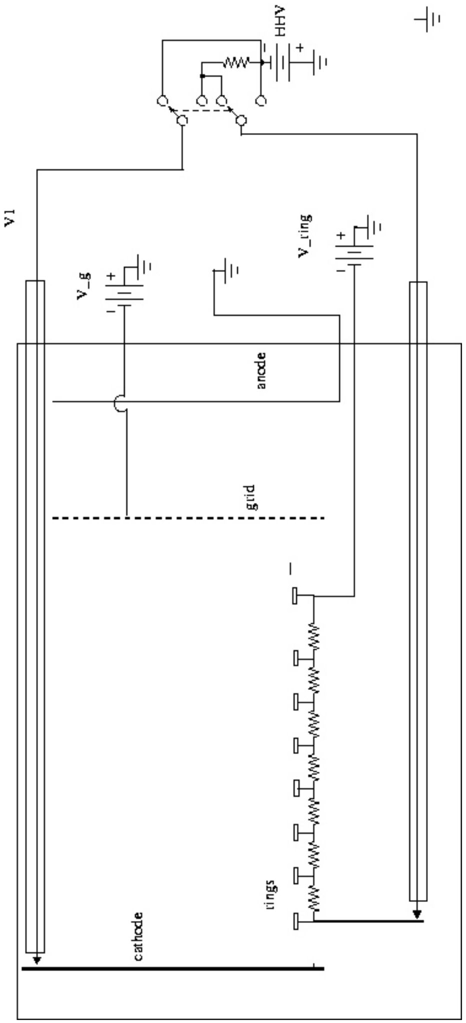




To achieve <.01 Bq/kg requires OFHC construction, Pb shield, muon vetoes, underground location.

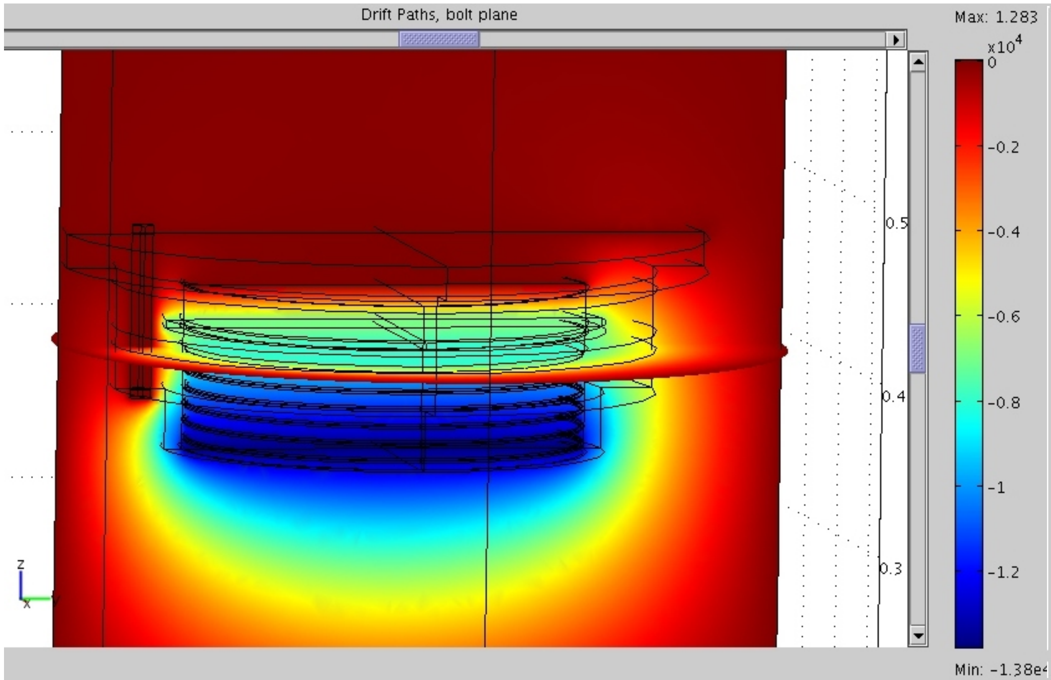
20 kg Detector Electrostatics

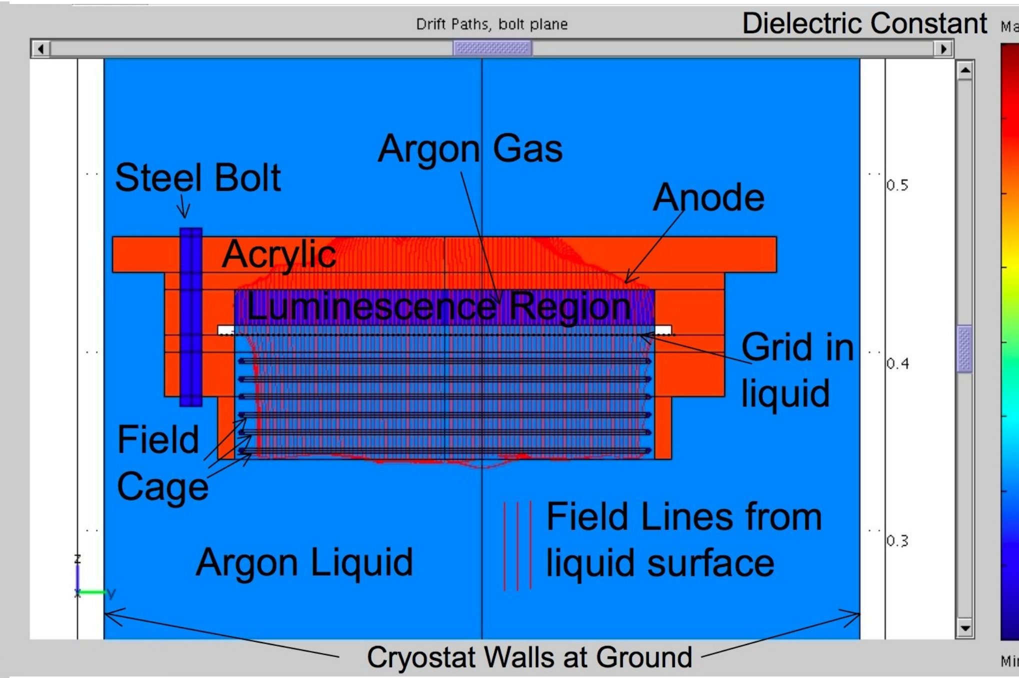




* Detailed 2-D models of field along walls & in EL region
* Devising flexible HHV system to allow field shape adj. while cold

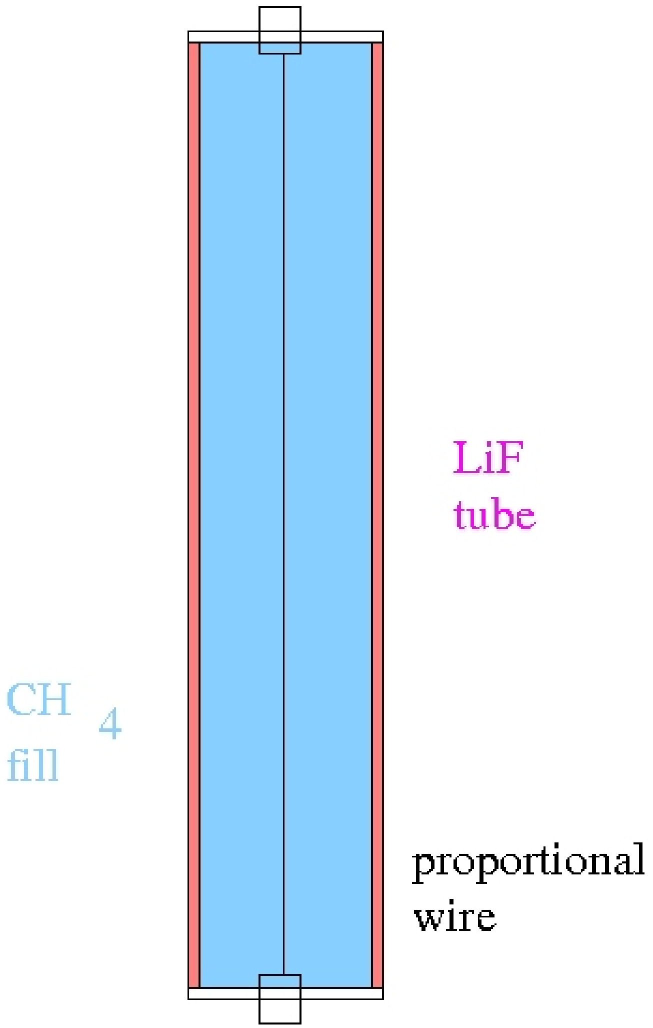
More 20 kg Detector Electrostatics





* Partial 3-D model (4x Xeon + 4 GB RAM constraint!)
* Allowed study of off-center cryostat location, lid bolts, feedthrus
* Further modeling by Z. Tang, PPD Mech. Dept.

Other Stuff

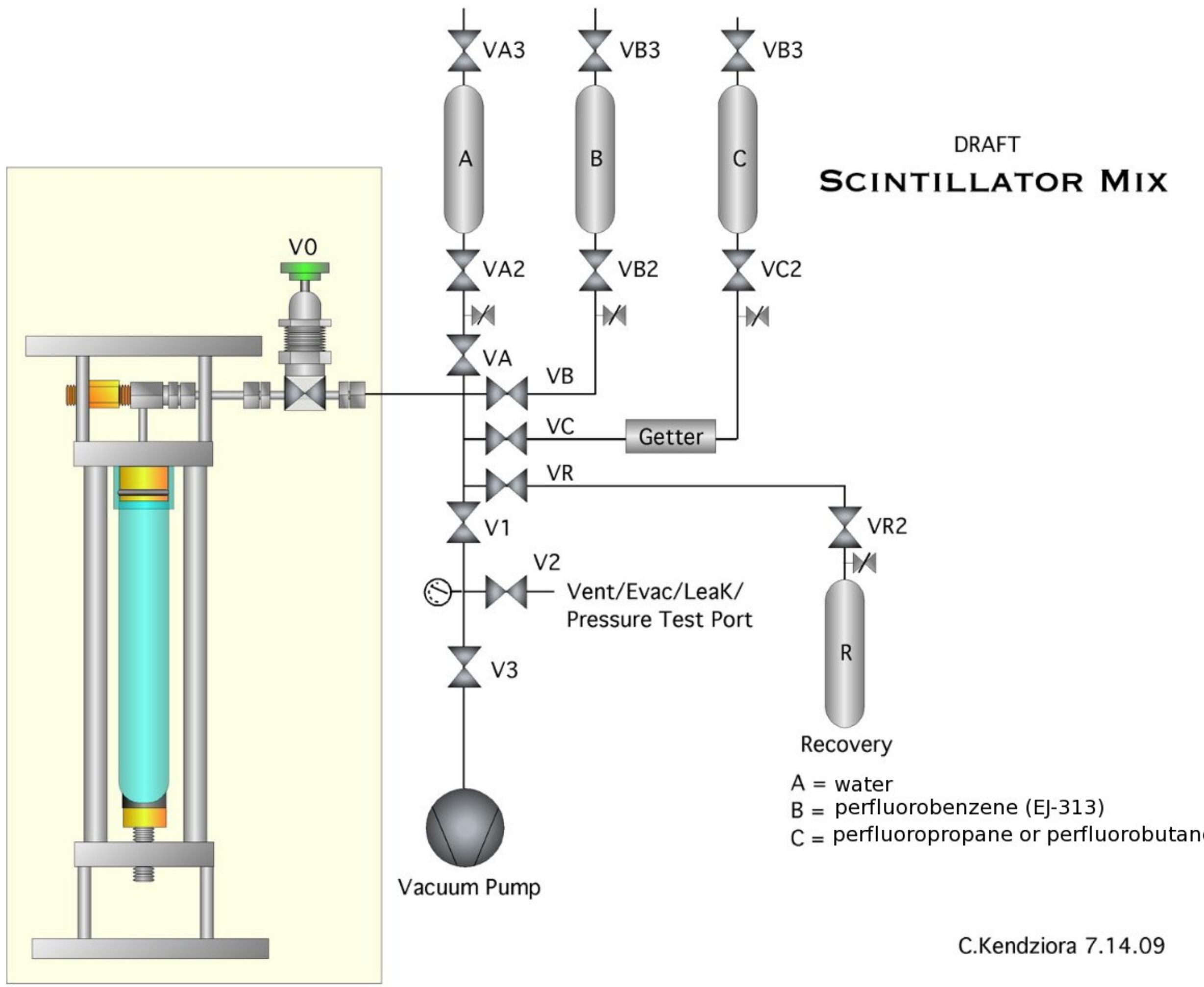


Advanced LAr scintillation light detector- CH_4 prop. ctr!

* P_{vap}= 45 Torr @ 87K
* Absorption length for 128 nm ~.3 mm
* Pretty good low pressure chamber gas

Questions:
* single-photon detection?
* radioactivity compared to QPIDs?
* efficiency compared to TPB + QPID?
* timing resolution?

Other Stuff

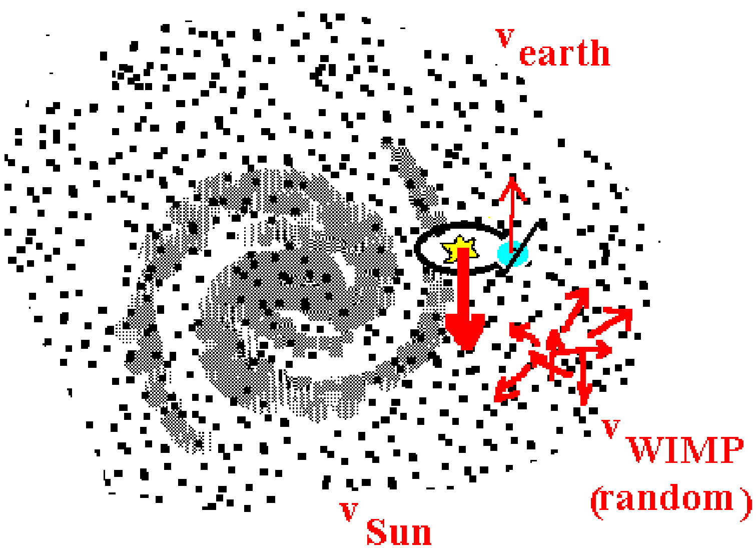


Scintillating Bubble Chamber for Dark Matter (with M. Crilser)

Challenge- eliminate alpha BG in COUPP by identifying event energy from scintillation

* Commercial C_6F_6 liquid scintillator
* Commercial C_4F_{10} base solvent
* NuPure getter
* Gas system being ordered!

More Other Stuff

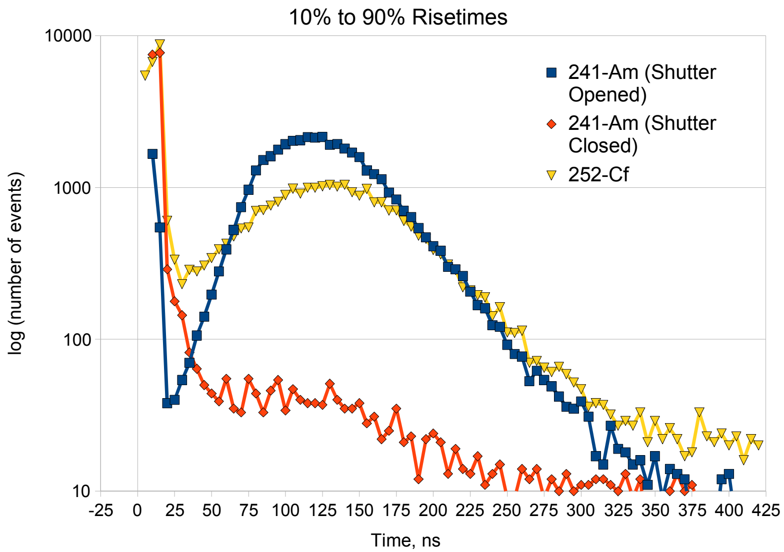


* G. Sciolla, C. J. Martoff, Gaseous Dark Matter Detectors, arXiv:0905.3675 [astro-ph] (invited by New Journal of Physics)

* M.P. Dion, C.J. Martoff, On the Mechanism of Townsend Avalanche for Negative Molecular Ions, submitted to PRA

* M. P. Dion, The Study of Negative Ion Gases for Time Projection Chambers, PhD Dissertation, Temple University May 2009. (Dion now at NASA-GSFC)
* C. J. Martoff, M. P. Dion, M. Hosack, D. Barton, New, Benign Electron Capture Agent for Negative Ion TPC , Nucl. Inst. Meth. A 598, 501 (2009).
* M.P. Dion, J. Tatarowicz, C.J. Martoff, Neutron recoils in a GEM-NITPC. (in preparation)
* C. Martin, D. Barton, C. J. Martoff, Pulse Shape Discrimination with GXe Scintillation (in preparation)

More Other Stuff



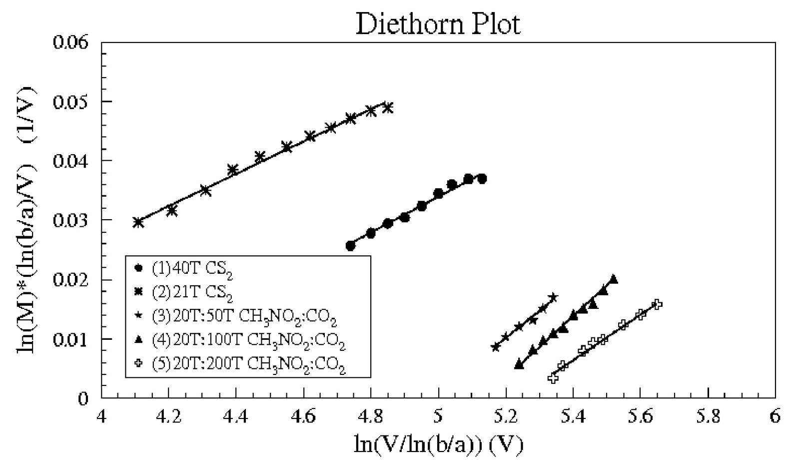


Figure 4.20: Diethorn plots for several negative ion gas mixtures studied in the present work.