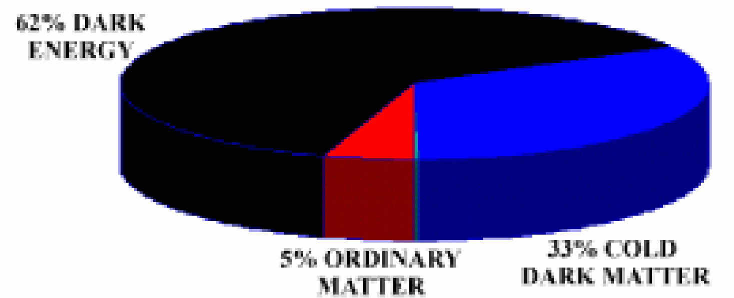
Toward WIMP Astronomy



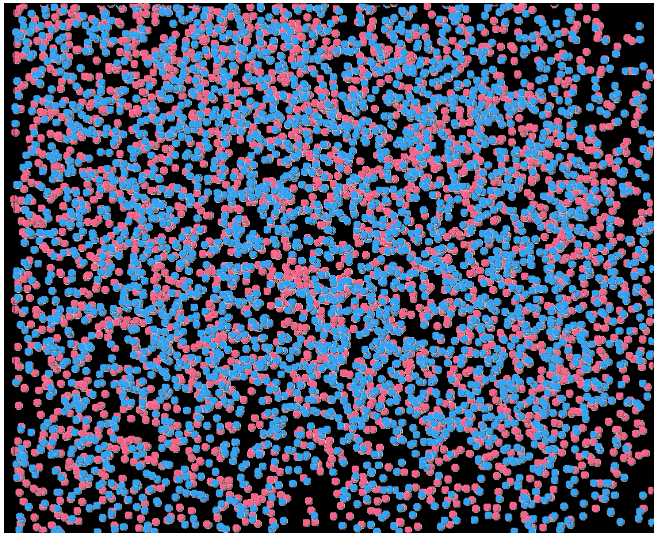
"Concordance Cosmology" (Spergel et al, 2003) - synthesis of observations on CMBR, galaxy clustering, distant SN, ...

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) !!

What direct measurements can be made on these?

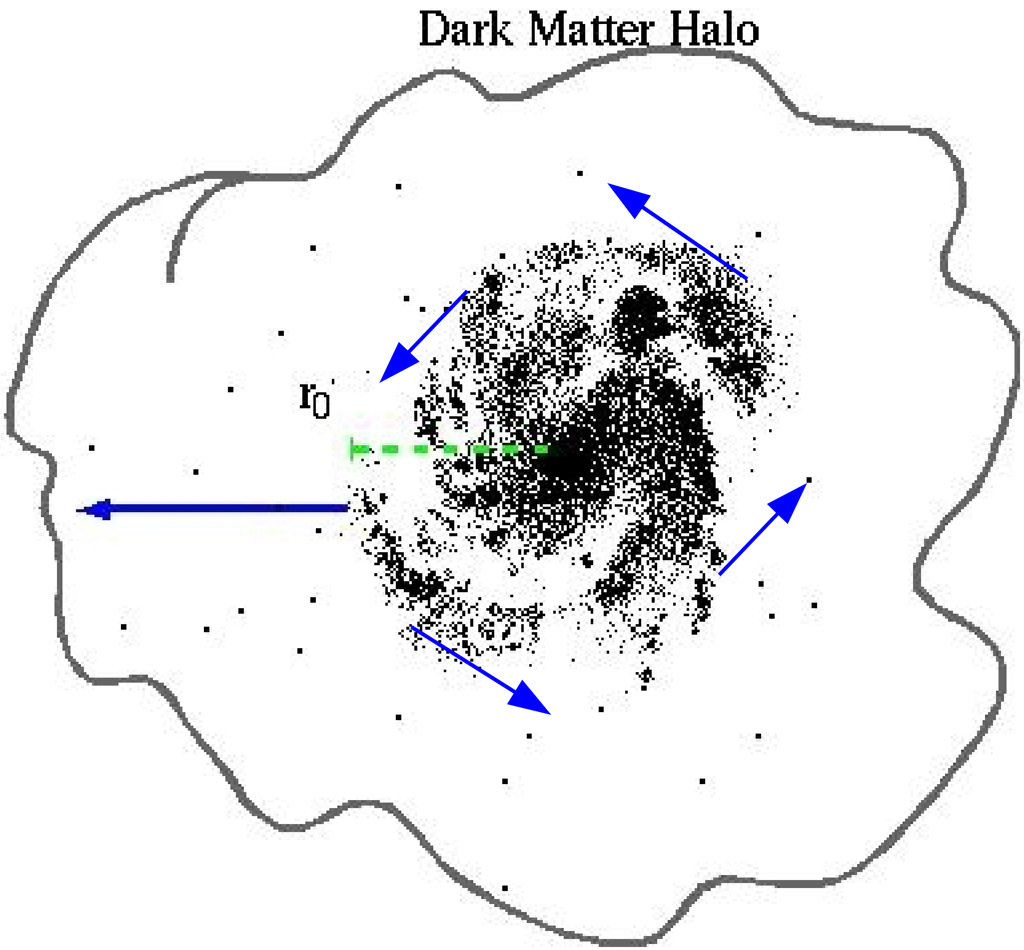
DM Dynamics for Dummies



- 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)

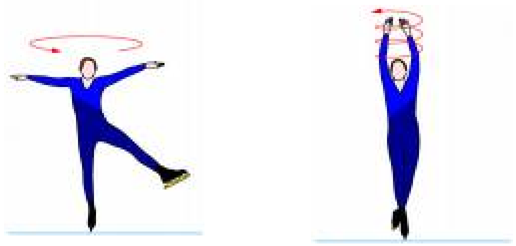
DM Dynamics for Dummies II



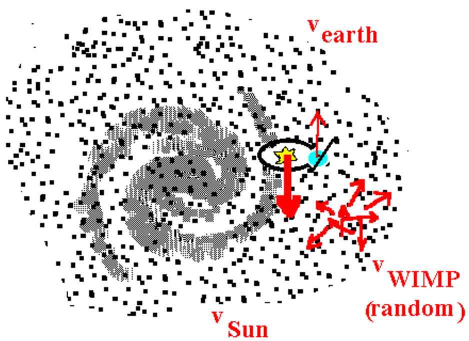
Another effect: rotation.

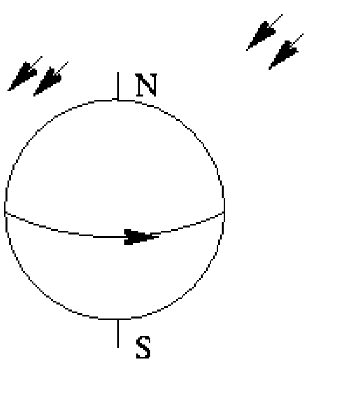
Energy can be radiated away by OM during collapse, but angular momentum cannot.

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



The WIMP WIND
BLOWS FROM CYGNUS





- Solar system follows galactic rotation with $v \sim v_{rms,\ WIMP}$

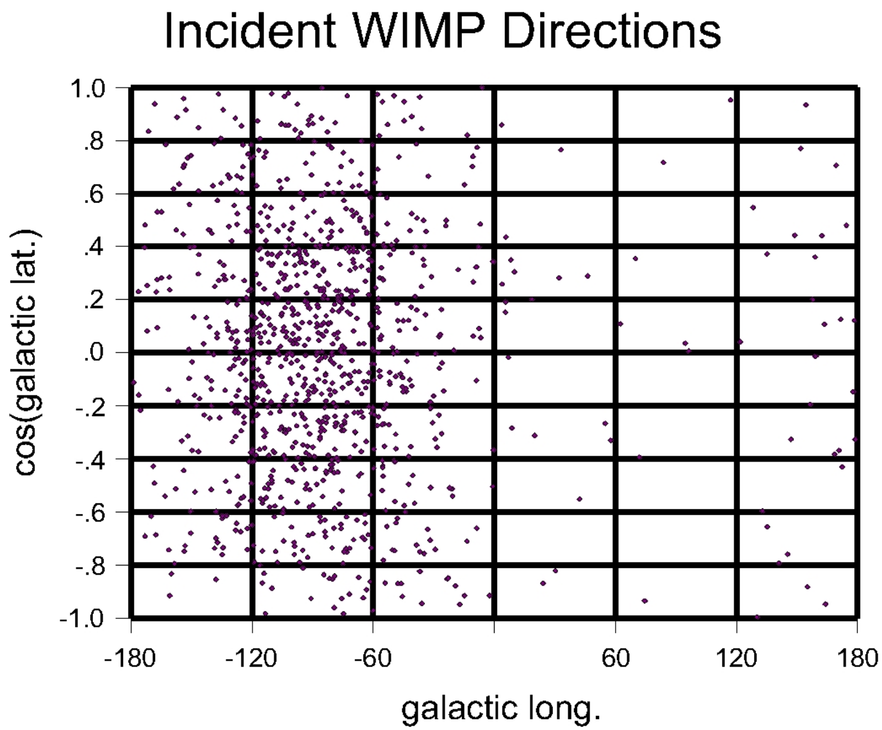
- So WIMPs tend to come from a particular direction on the sky (Cygnus)

- Just like constellations, source point of WIMP wind rises and sets each (sidereal) day!

"Because WIMPS should have a strong directional asymmetry due to the movement of the Sun with respect to the galaxy frame, the directional information can confirm that the events are due to WIMPs."

- The NUSEL at Homestake Science Book, nucl-ex/0308018

WIMP ARRIVAL DIRECTIONS

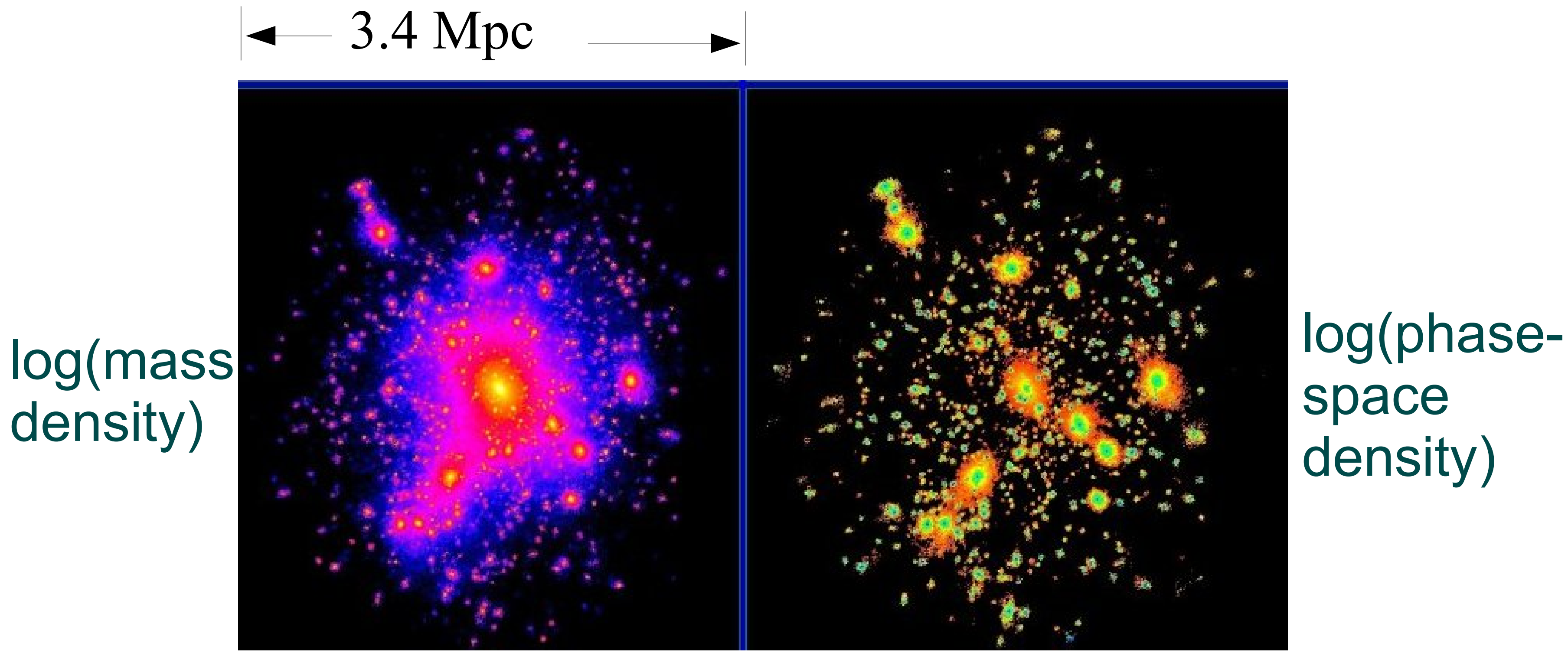


For “usual” parameters:

$v_{rms,\ WIMP}$ = 260 km/s, Boltzmann with cutoff

|v_sun| =220 km/s

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)

REAL DM DYNAMICS II

- Sagittarius dwarf galaxy: Milky Way companion at ~16 kpc
- "Tidal streams" of matter are seen falling into the MW
- One stream probably strikes Solar System
- Dark Matter should accompany ordinary matter in stream

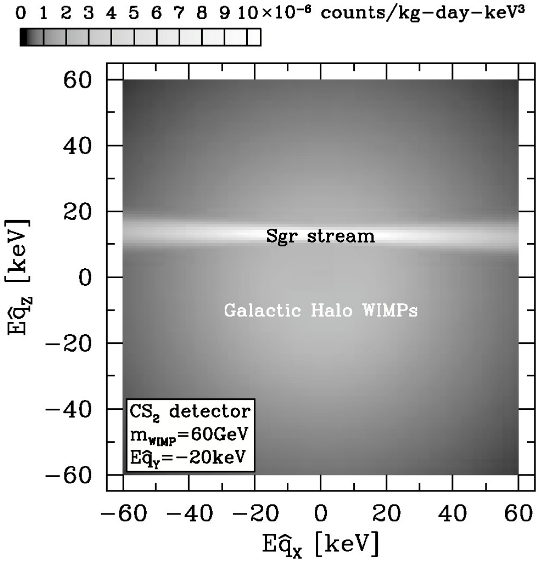
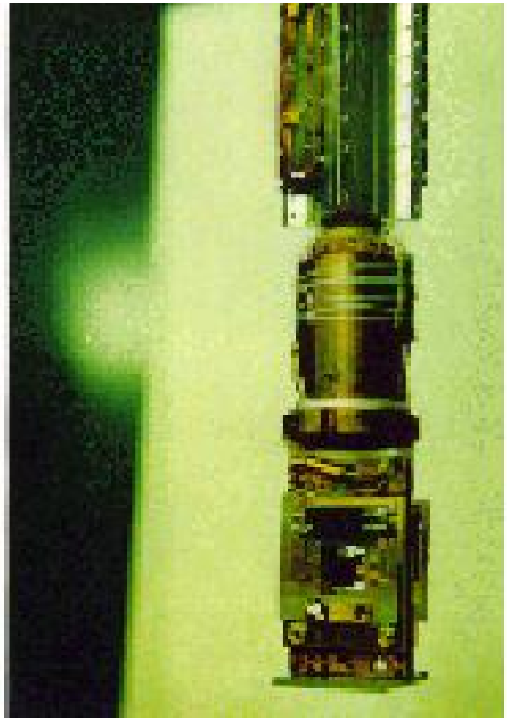


FIG. 3. Count rate of 60 GeV WIMPs in a CS_2 detector (DRIFT) as a function of recoil energy and direction of the nuclear recoil. (Freese, Gondolo, Newberg 2005)

How to Do Direction Sensitive Dark Matter Search?



My first direction-sensitive DM detector prototype-
CJM et al, Phys Rev. Lett. **76**, 4882 (1996)

- Basically a recoil telescope using cryogenic GeAu thin film thermistors to detect recoil Si (range ~1000 Å !)
- Worked, but achieving kilograms of sensitive mass this way would have been a challenge (!)

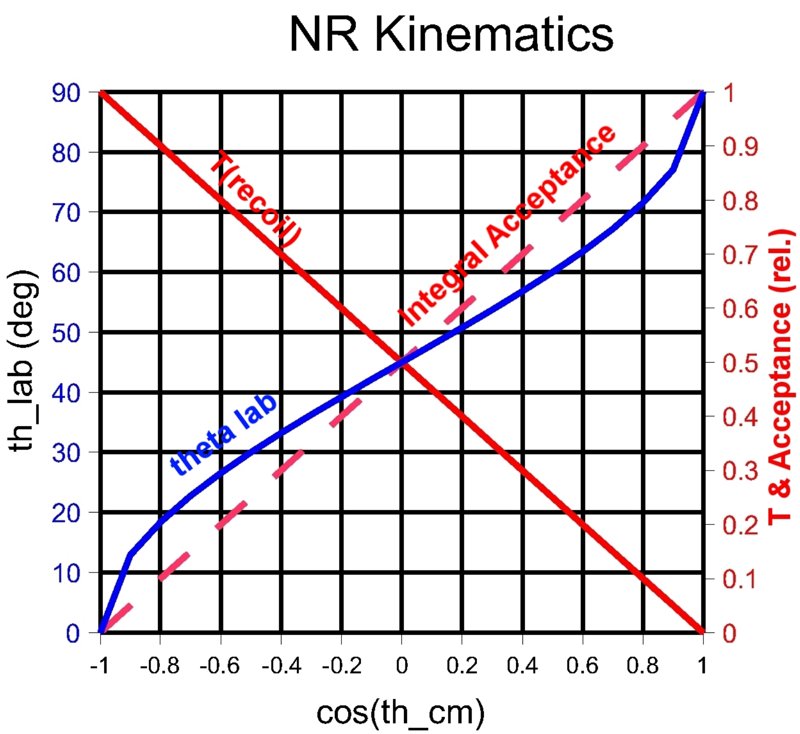
Natural medium for direction-sensitive detection of low energy recoil atoms is low pressure gas.

Advantages for Dark Matter:

- Gas is pure (TPC geometry)
- Tracking gives powerful and well understood particle identification
- Gas can be changed to check A-dep.

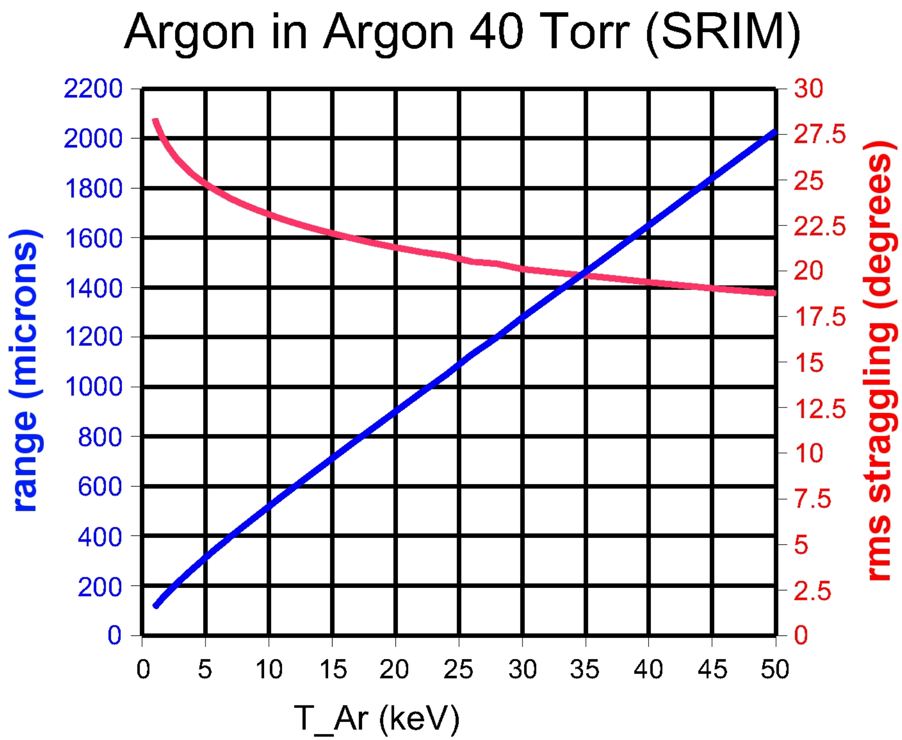
BUT- low pressures and large, high resolution gas detectors do not go together!

KINEMATICS OF DIRECTIONALITY



- NR kinematics of recoil nucleus is basically independent of m_W/m_A
- $0^o < \Theta_{lab} < 90^o$; half acceptance $\Theta_{lab} < 45^o$
- Better pointing costs dearly in acceptance
- No help anyhow if v_{rms} is appreciable

MEASUREMENT OF DIRECTIONALITY

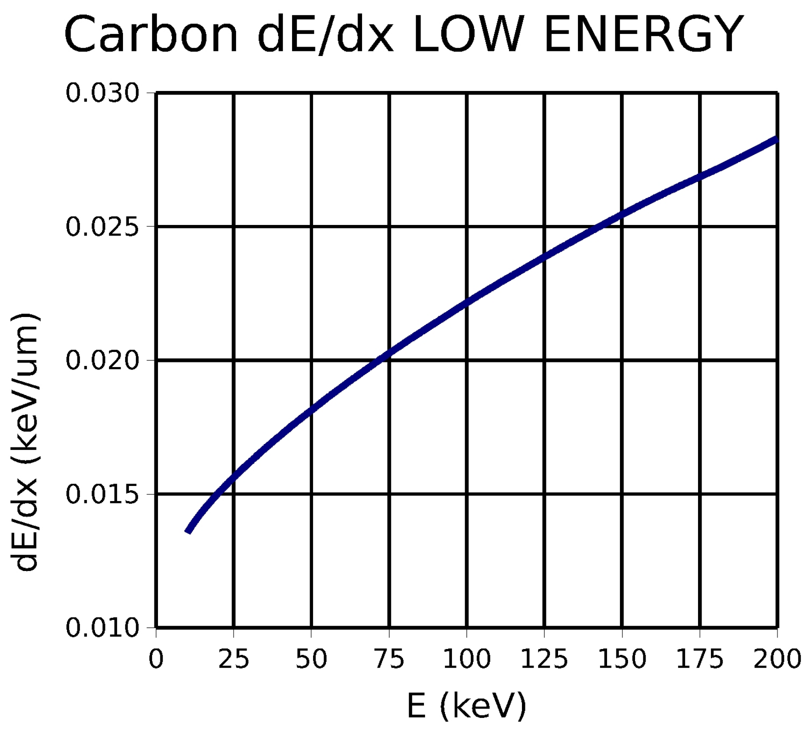


SRIM program (Ziegler, IBM) widely used to simulate stopping of ~keV particles.

Transverse multiple scatter predicted to be not so bad.

Caveat- SRIM optimized for solids, not gases

“Head-Tail” Discrimination



- H/T orientation of tracks is as important as direction
- Change in dE/dx along track offers a possible signature
- With <~mm tracks, diffusion and readout quantization are serious issues

“Head-Tail” Discrimination

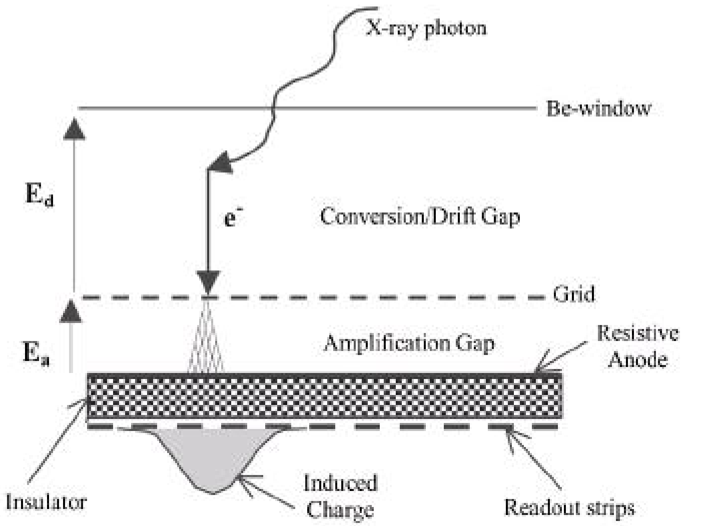
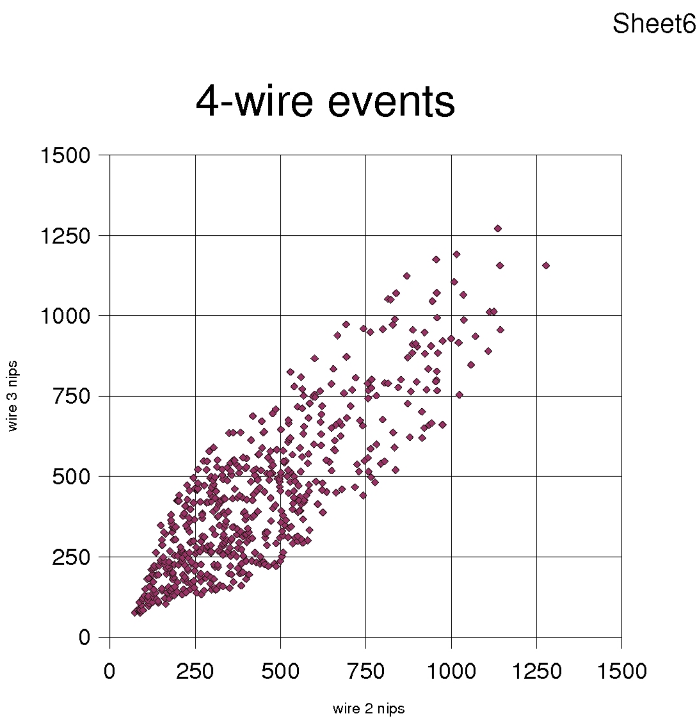


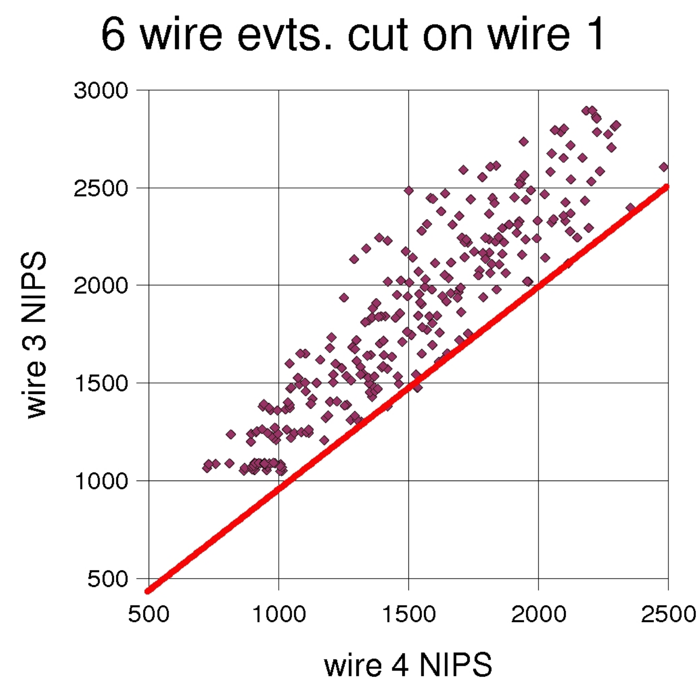
Fig. 1. Schematic of the parallel-plate resistive-anode chamber with the readout electrode separated from the anode. Details are not in scale.

D.M. Khazins et al,, IEEE TNS 51, 943 (2004)

- Micropattern detectors quantize tracks only at ~100 micron scale
- Low occupancy allows simple crossed-strip readout rather than pixels
- Bruker Corp. patented bulletproof readout scheme seems to offer good solution for large scale detectors- to be tested at Temple.

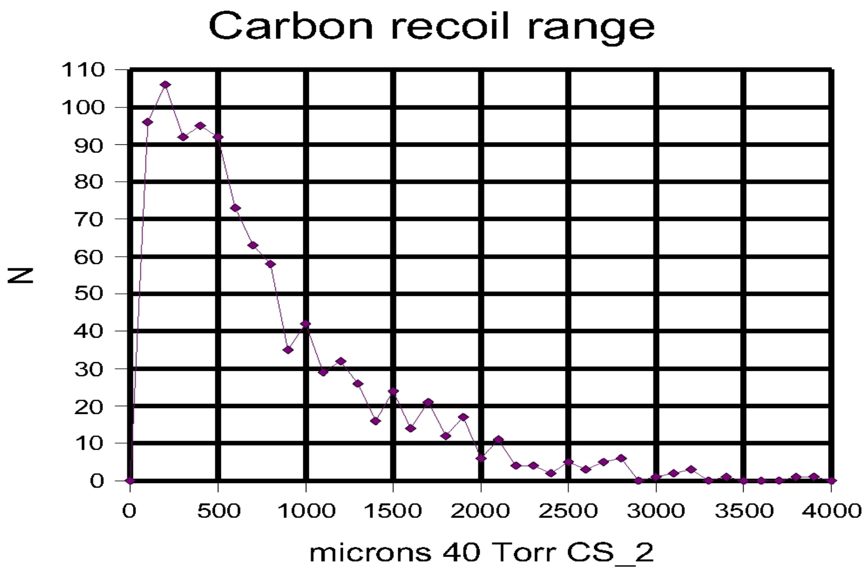
“Head-Tail” Simulation

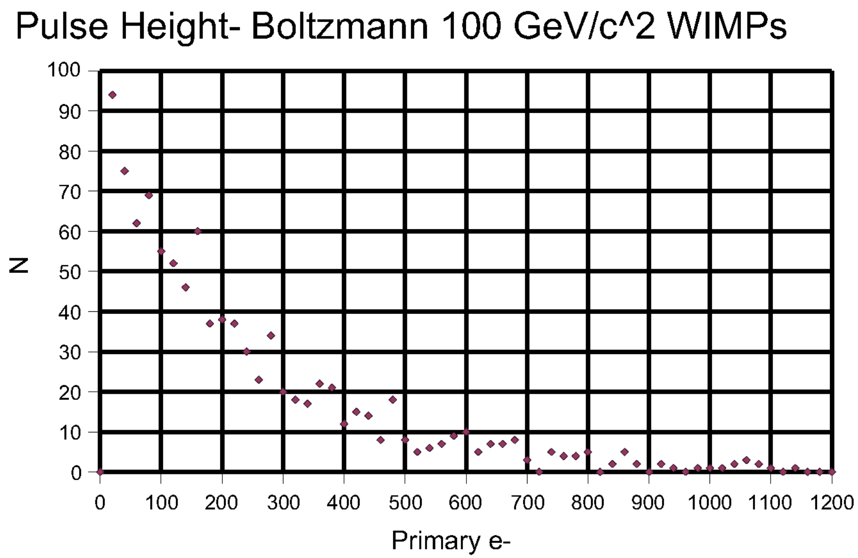




Start-point fluctuations + diffusion require 4-6 hit resolution elements for dE/dx discrimination. (200 keV C in DRIFT I)

Tracking Requirements for WIMP Recoils





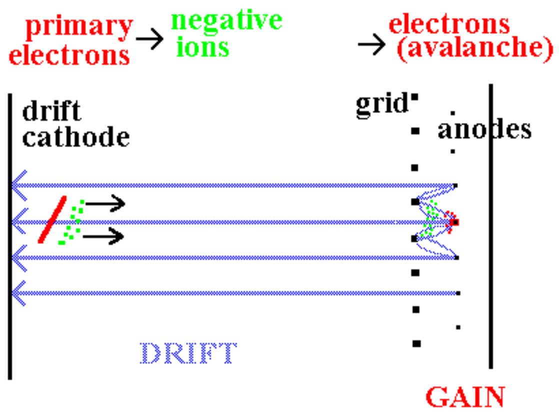
The instrumentation challenge is to measure and reconstruct sub-mm tracks from few-tens-keV recoil atoms.

High Accuracy TPC at Low Pressure

Diffusion must be controlled (both ⊥ and ∥) to resolve short tracks

$$\sigma_d = L\sqrt{(\epsilon / eEL)}$$

At low pressure, increasing E causes ε to run away when drifting electrons.



Solution: Negative Ion TPC
Allows such low pressure detectors to be built and operated with drift fields ~2 KV/cm at .05 bar and **thermal-limit diffusion ~500μm / √m in all 3-D.**

Negative Ion TPC pubs: Martoff et al, NIM **A 440**, 355 (2000) Ohnuki et al, NIM **A 463**, 142 (2001); Miyamoto et al, NIM **A 526**, 409 (2004) Martoff et al, NIM **A 555**, 55 (2005)

NITPC Capture Agent

Capture agent should:

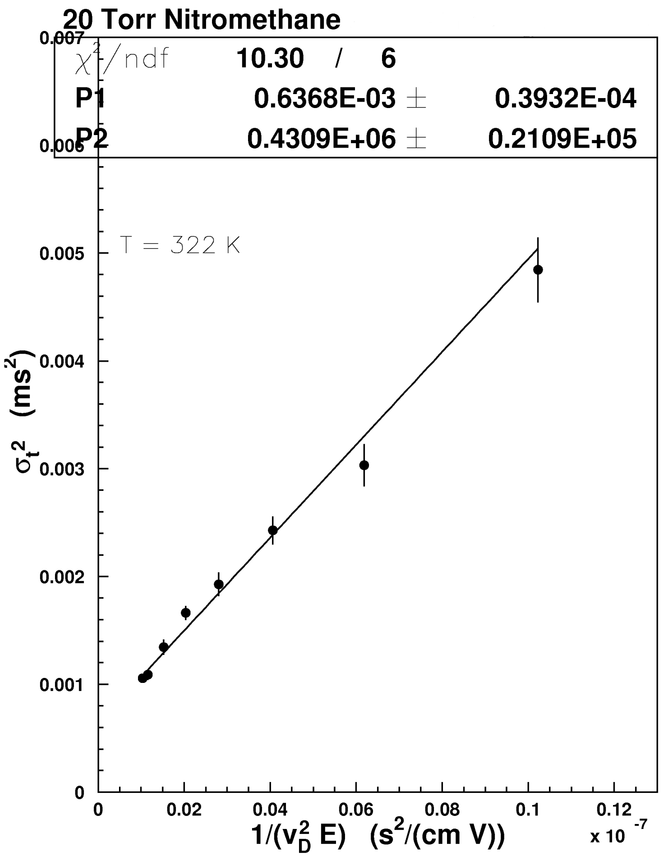
- Capture efficiently even in drift fields >~25 V/cmTorr
- Not dissociate upon capture to form corrosive/polymeric products
- Avalanche with satisfactory gain at attainable fields

First and most efficient agent: CS_2 (carbon dislufide; Crane, 1953)

Properties::

- ✓ Electron binding energy 0.6 eV
- ✓ Negative ion mobility ~ 1/4000 that of electron
- ✓ Gains >~ 10^3 attainable in MWPC and GEM (NIM **A 526**, 409 (2004))
- ✓ L_{cap} <~ 100μm for E/p <~ 40V/cm Torr
- ✗ Explosive mixtures with air 0.5%-50%
- ✗ Highly toxic by inhalation and absorption
- ✗ Teratogen, probable carcinogen, smells bad

New, Green(er) Capture Agent

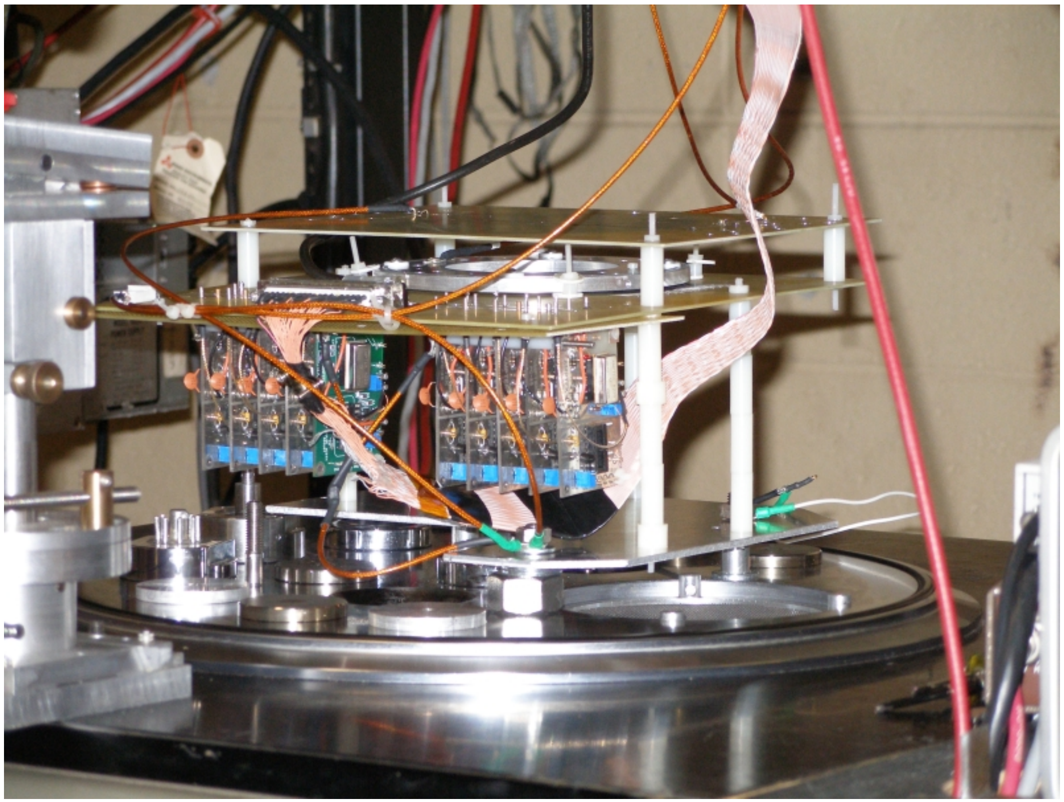


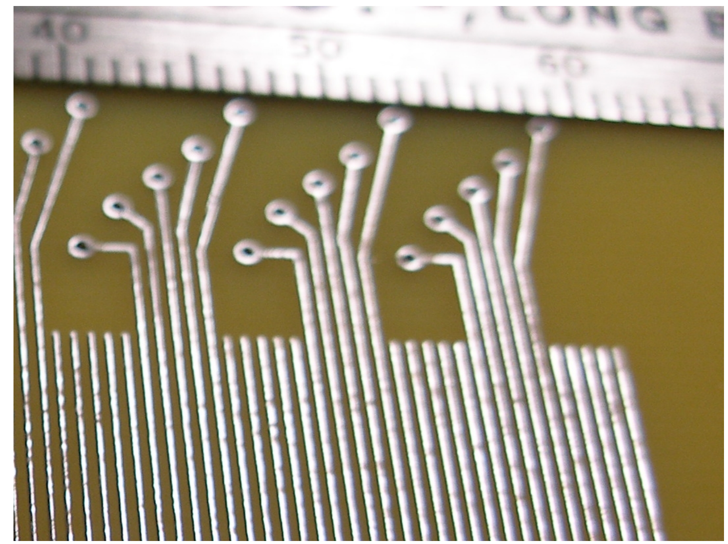
CH_3NO_2 (nitro-methane; race car fuel)

- ✓Drift velocity ~ 0.8 x CS_2
- ✓Linear to at least 6 V/cm Torr
- ✓Diffusion stays thermal to at least 6 V/cm Torr
- ✓MUCH less toxic/flammable than CS_2

(Developed at Temple for x-ray polarimetry < 3 keV in NASA-GSFC collaboration)

CURRENT TEST RIG

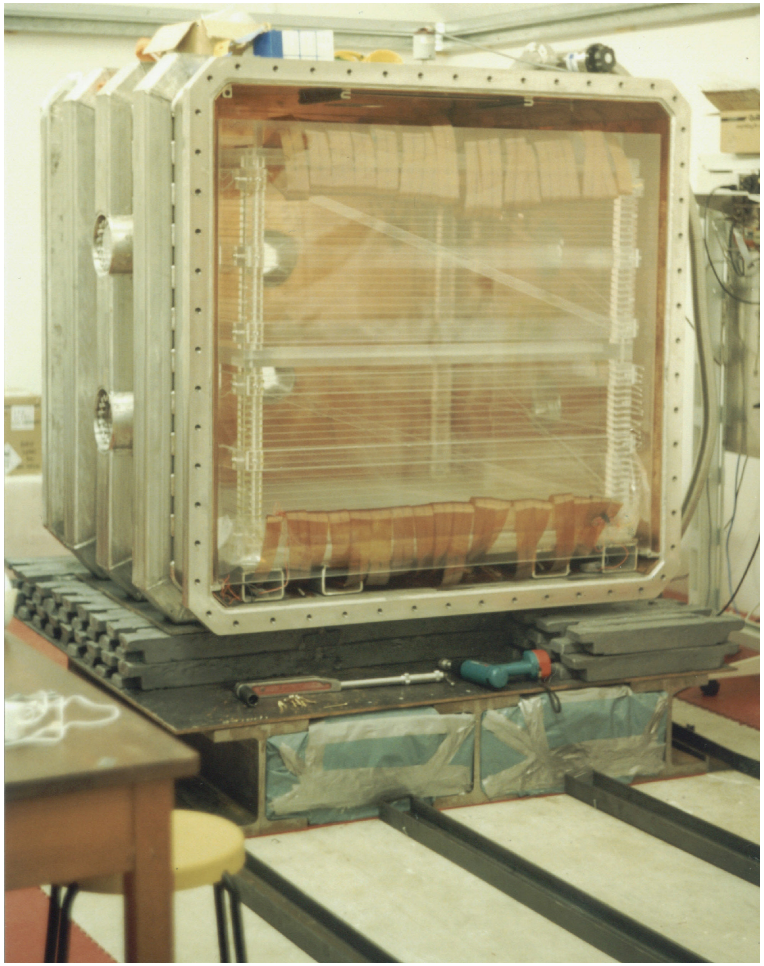




- 140 mm pitch NASA “GEM-like device”
- 600 um pitch anode
- 10 AMPTEK amplifiers
- easily sees 55-Fe photoelectron tracks

Built for:
- high-field diffusion measurements
- recoil track calibration in DM energy range using TUNL 1-10 MeV neutron beam

LARGE UNDERGROUND NITPC



DRIFT I- Directional Recoil Identification from Tracking
Temple-Occidental-UKDMC

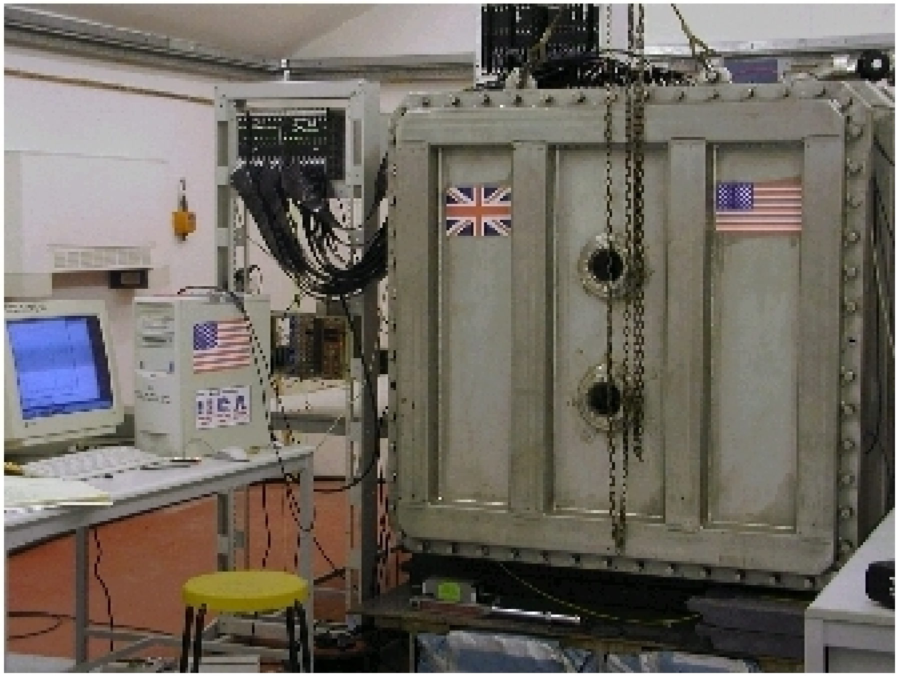
Lessons Learned from DRIFT I in Boulby:

- Underground safety & reliability issues are tractable- even in working mine and even with CS_2
- NITPC sees ~ no gamma backgrounds
- NITPC can detect neutron background underground via differential shielding expt.
- LXe background suppression improved fast!

DRIFT I pubs:

Snowden-Ifft et al, NIM **A 498**, 155 (2000)
Alner et al, NIM **A 535**, 644 (2004)

DRIFT I DIFFERENTIAL SHIELDING



50 cm-thick polyethylene pellet shield box
Reported to SAGENAP (2004)
Note no Pb shielding (gamma rays) needed

WIMP OBSERVATORY DESIGN

Competitive experiment will require:

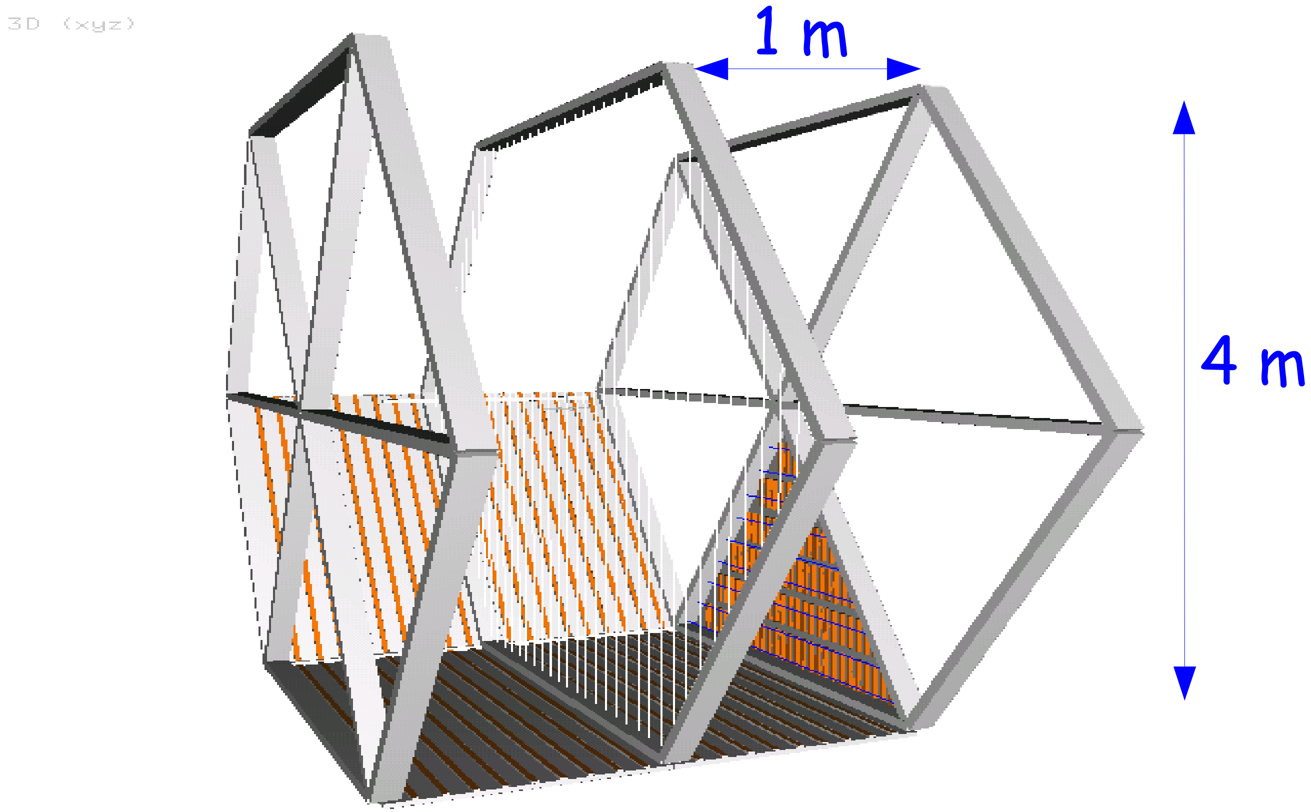
- Energy threshold as low as possible (< 5 keV = 100 primary e-)
- Tracking threshold < 1 mm
- Drift field 1-2.5 kV/cm
- Active mass > 10 kg and scalable to 100's of kg

Constraints:

- Low density gas required for track length => 50 m^3 NITPC
- Neutron Shielding and veto required at any depth
- Size of modules/parts constrained by underground lab access:

WIPP: < 2.9 x 2.9 x 4.7 m   Homestake: < 1.4 x 3.7 x 2.2 m

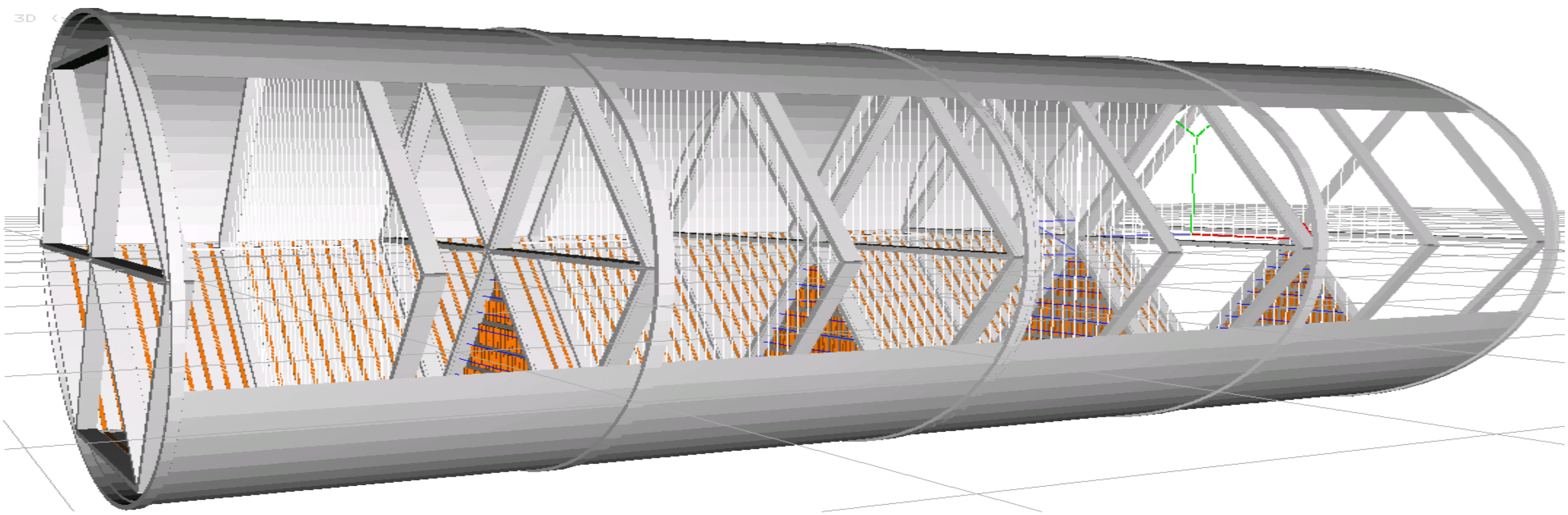
Modular WIMP-TPC



- Hex-prism, 4 m diameter, 2 x 1 m drift spaces
- 40-80 Torr CS_2 (or Nitro)
- 4-8 kg active target per module

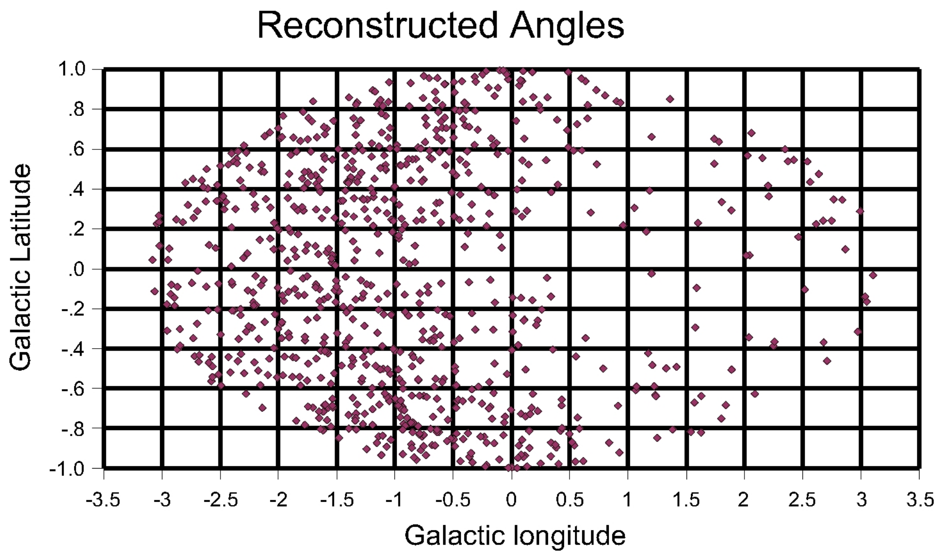
- 2 kV/cm drift field, v_{drift} = 200 m/s (Neg. ions drift SLOWLY)
- σ_{diff} = 500 μm/$\sqrt{}$m in all 3 dimensions
- Micromesh gain structure with 350 um crossed strip readouts (Khazins, IEEE TNS 2004)

Multiple Modules



- Don't forget necessary local shielding (see below)
- 4-8 kg/module => 100 kg easily accommodated in WIPP

SIMULATED DETECTOR

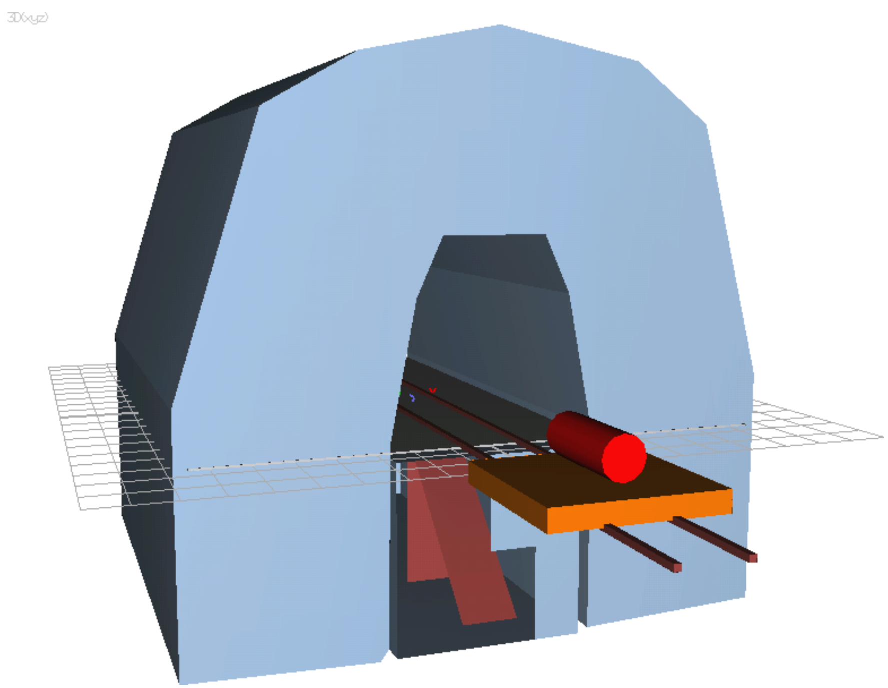


Simulation for C in 40 Torr CS_2

- diffusion $\sigma = 475\ \mu m$
- SRIM stopping
- drift distance bin 570 μm
- transverse readout pitch 350 μm
- readout threshold 6 <u>initial</u> electrons

LAB INFRASTRUCTURE SHIELD

(Every expt needs electricity & shielding! DUSEL should provide both.)

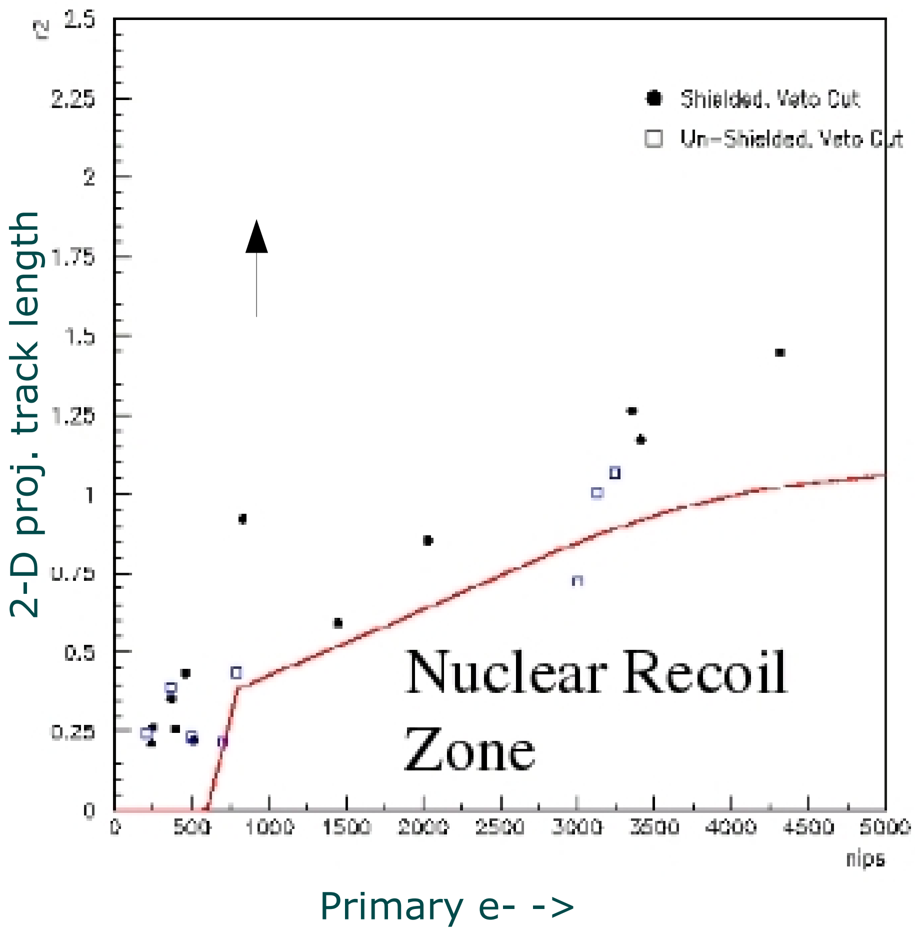


- This is my imagination talking
- Civil engineering & railway project
- Lab space is a tunnel-within-a-tunnel with overhead water 5 m thick
- Beneath the floor is another tank 5 m deep containing a railway trestle
- Lab floor and detectors supported by the trestle
- Transfer cars move in & out of shield
- Not shown: 125 ton water end-plug (typical freight-car load)
- Very flexible multi-user system
- Tunnels can be as long as you want

Summary

- If WIMP DM exists, it is possible to measure its direction of incidence
- Elastic scattering kinematics severely constrain the pointing accuracy
- The only clear way to measure this is with an NITPC of ~100 m^3
- DMSAG FINAL REPORT: “As we have discussed, we do not yet have detectors with this directional capability; however, there are interesting ideas for reaching the directionality goal and they constitute one of the important R&D goals. Seeing these periodicities will be a significant confirmation of the source of any signal as being due to WIMPS, for establishing other WIMP properties and for aiding in measuring properties of the WIMP relic distributions. “

NEUTRON BG AT 3000 MWE



DRIFT I experience showed the power of tracking for eliminating background from radioactivity