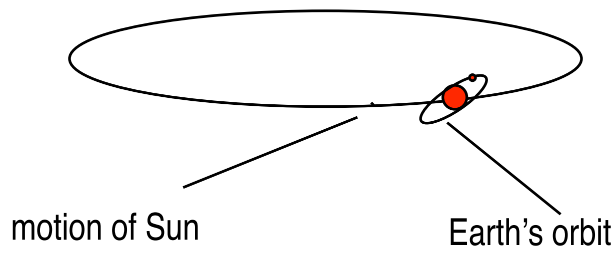
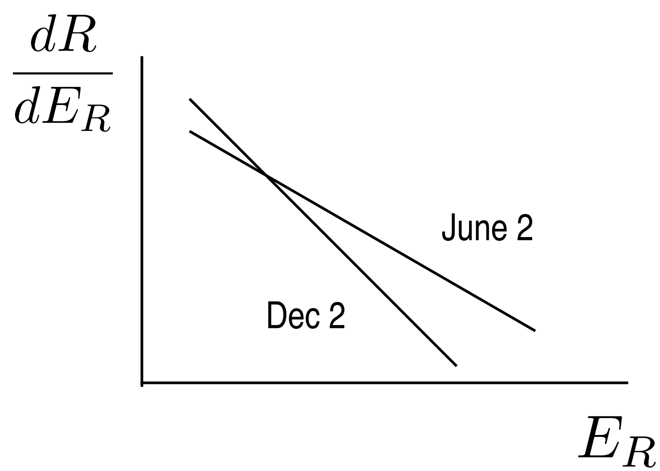
WIMP Direct Searches

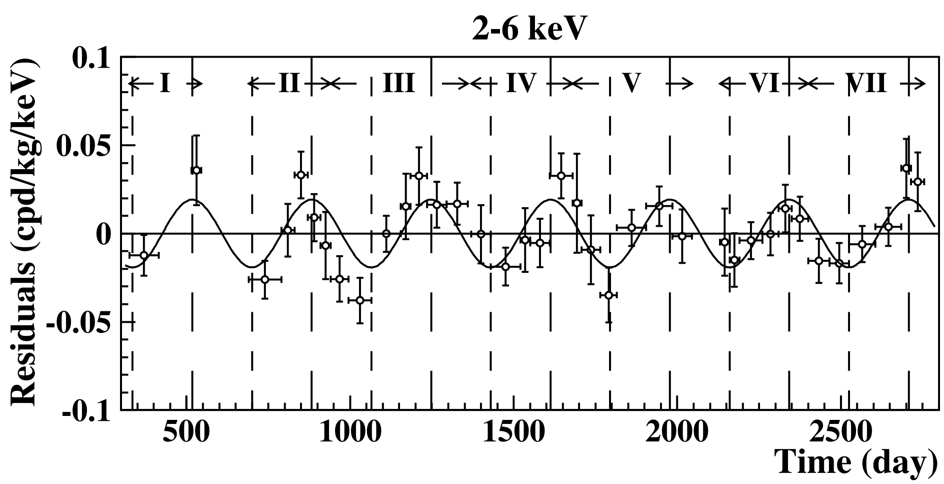
- Fundamental goal: See a very small WIMP signal in presence of many other particles interacting in detectors (photons, electrons, alpha particles, neutrons)
- Many different techniques:
  - Reduce backgrounds
    - HDMS/GENIUS, IGEX: Ge γ spectrometers
  - Reduce backgrounds + annual modulation
    - DAMA: NaI scintillator
  - Statistical nuclear recoil discrimination
    - DAMA, UKDMC: pulse-shape analysis in NaI, LXe
  - Event-by-event nuclear recoil discrimination
    - phonons + ionization/scintillation: EDELWEISS, CRESST, CDMS
    - LNobles: direct electronic excitation + ionization: XENON, ZEPLIN, WArP, etc.
    - SIMPLE, PICASSO: superheated droplets: bgnd-insensitive threshold detectors
    - DRIFT: (CS_2) high-pressure negative-ion TPC
  - Diurnal modulation
    - DRIFT

Annual Modulation



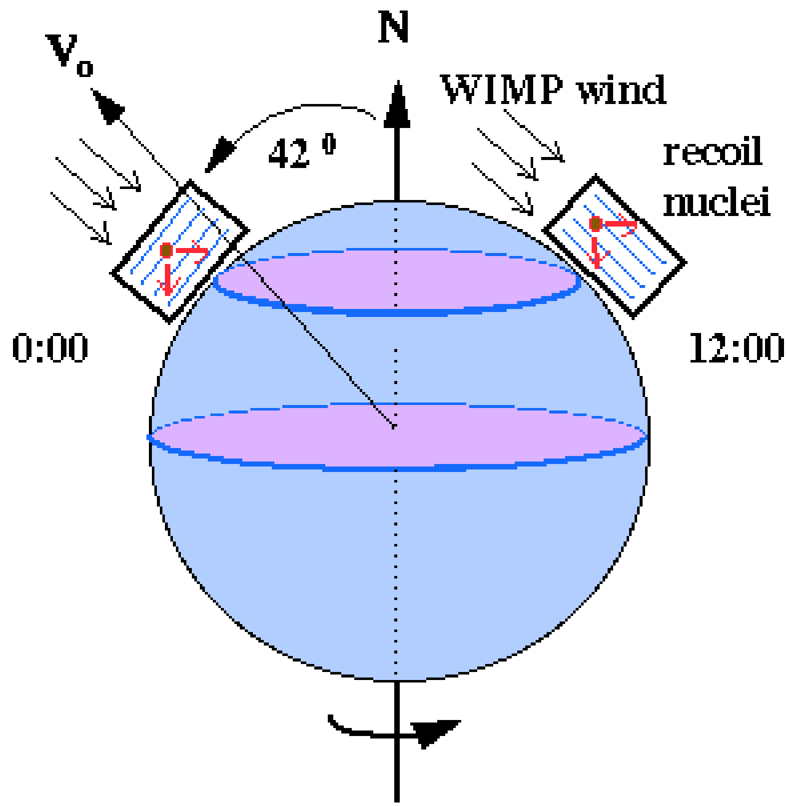


- WIMP wind ~ isotropic in halo frame, v_{rms} ~ 270 km/s
- Sun travels through this cloud at 232 km/s
- Earth adds or subtracts 15 km/s (= 30 km/s X cos 60^0) to solar velocity
- Expect ± 1-few % modulation in rate, energy deposition, depending on target and threshold
- DAMA: possible signal? Now running LIBRA

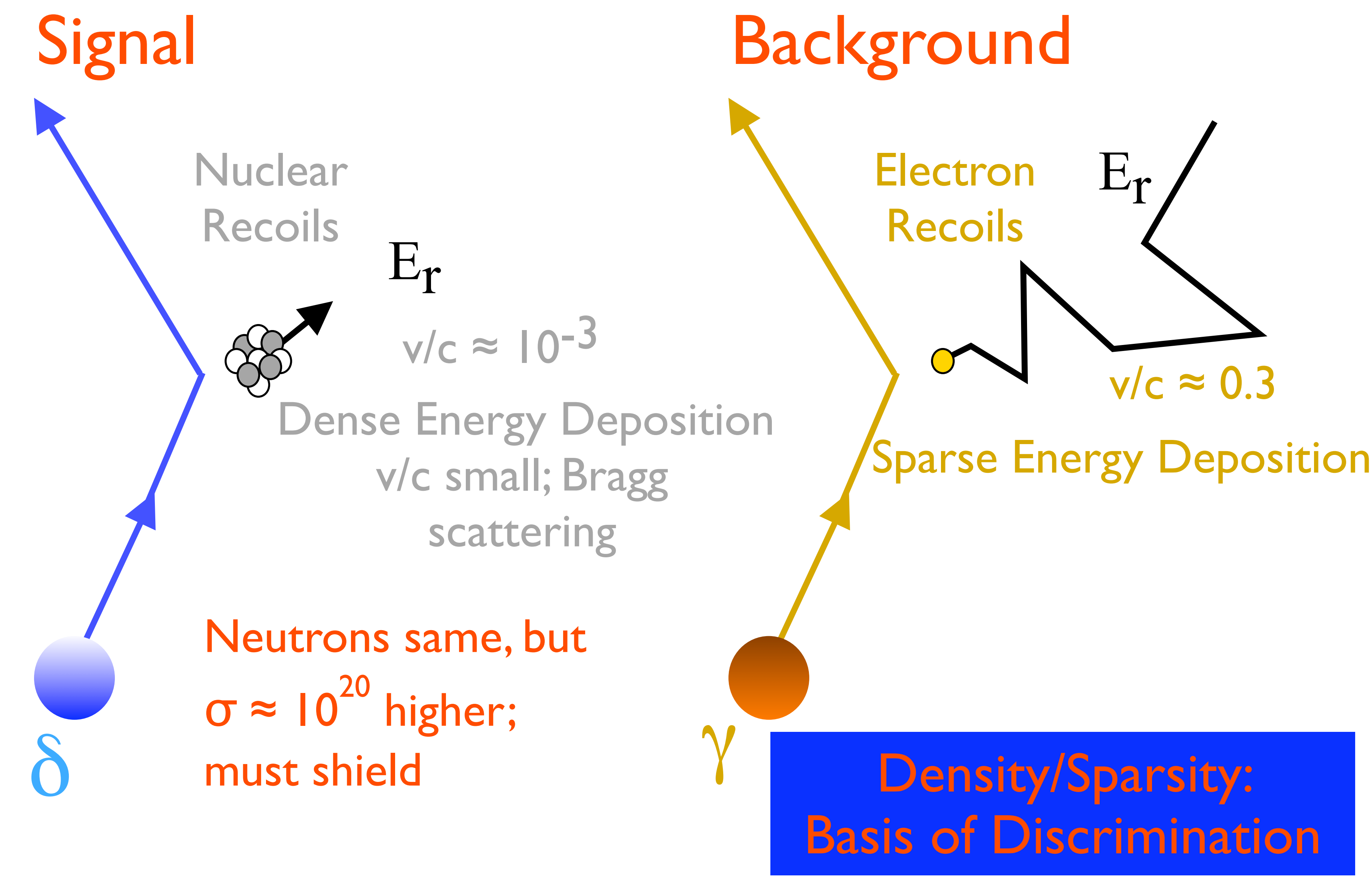


Diurnal Modulation

- Because of motion of solar system through galaxy, WIMPs are very directional in terrestrial frame (from Cygnus)
- Direction of WIMP wind varies diurnally due to Earth's rotation
- Recoiling nucleus will to a large extent preserve this directionality
- Large modulation (~ DC signal) possible in theory
- Backgrounds will be unmodulated
- Demonstrator experiment running (DRIFT), large masses still a challenge



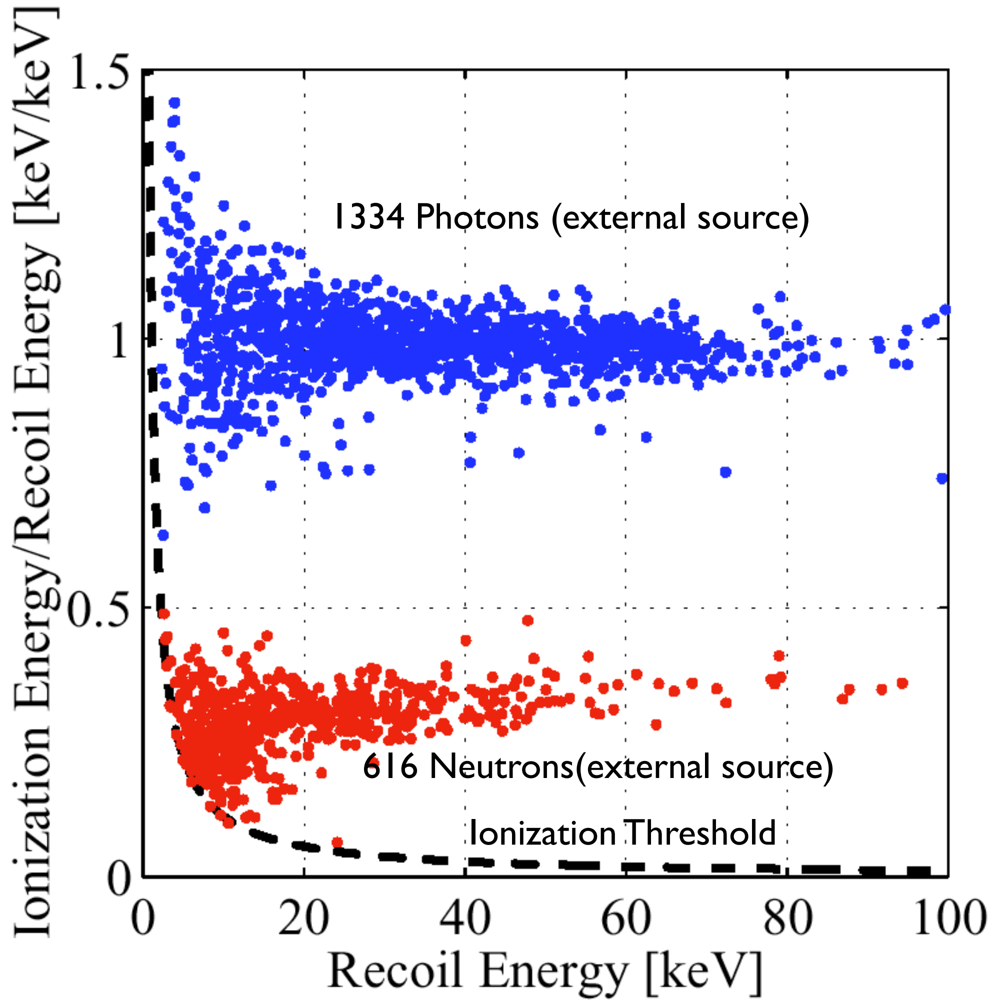
Nuclear Recoil Discrimination



Phonons + Ionization/Scintillation

- Nuclear recoils arise from
  - WIMPs
  - Neutrons
- Electron recoils arise from
  - photons
  - electrons
  - alphas

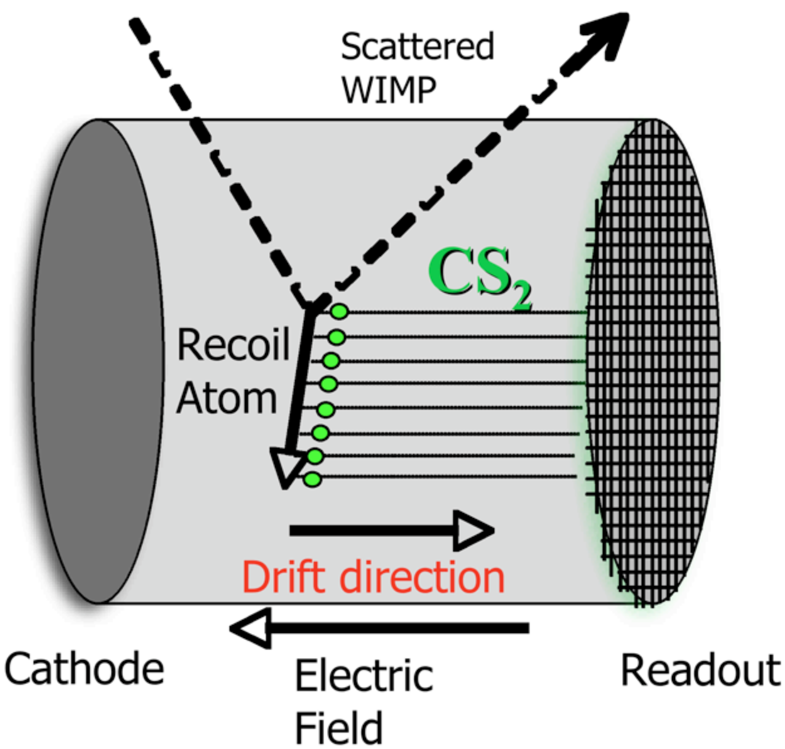
  (dominant background)



- Ionization yield
  - ionization/recoil energy strongly dependent on type of recoil (Lindhard)
- Recoil energy
  - Phonon (acoustic vibration, heat) measurements give full recoil energy
- Intrinsic event-by-event discrimination

DRIFT Time Projection Chamber

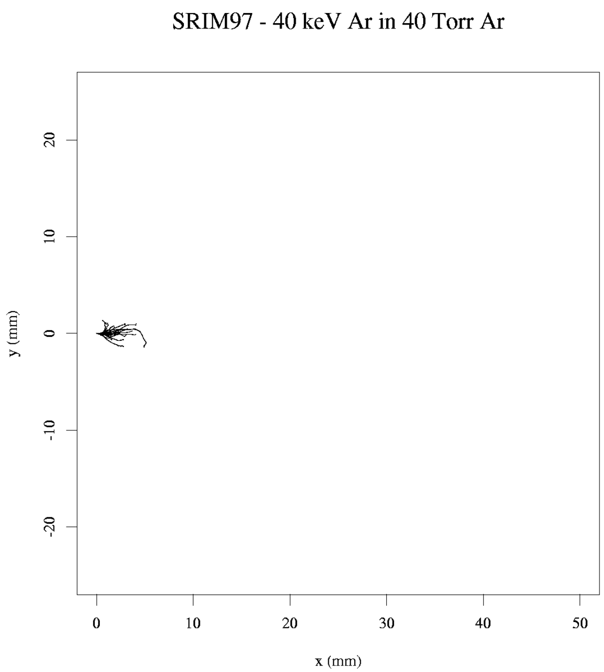
- DRIFT collaboration:
  - e^- + CS_2 → CS_2^-: drifting of heavy ion suppresses charge diffusion
  - 1 m^3 40 Torr CS_2 gas (0.17 kg)
  - underground in Boulby (UK)



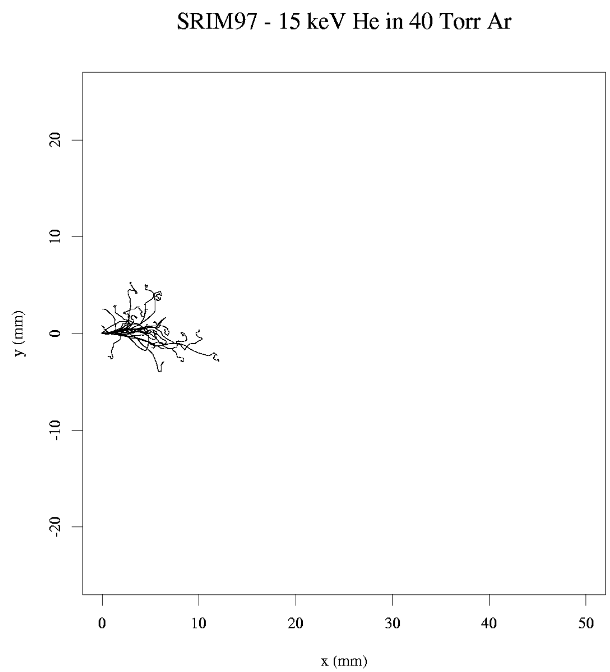
DRIFT Time Projection Chamber

Nuclear Recoils

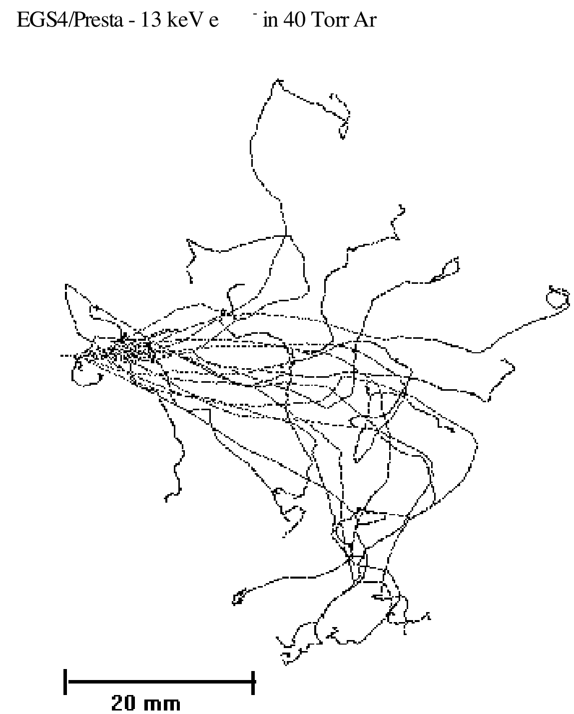
40 keV nuclear recoils
500 electron-ion pairs



15 keV αs
500 electron-ion pairs



13 keV e⁻
500 electron-ion pairs



… Maybe even the direction of the recoil can be reconstructed

DRIFT Time Projection Chamber

Nuclear Recoils

40 keV nuclear recoils
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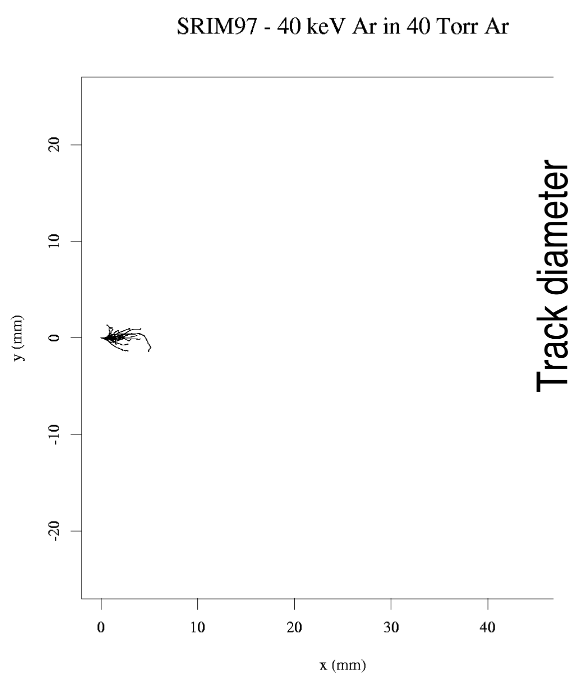

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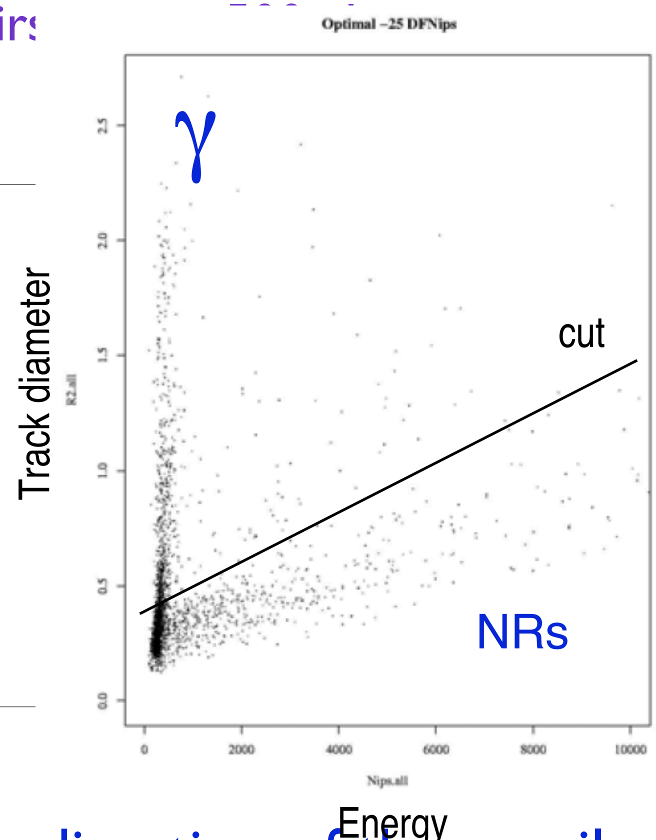

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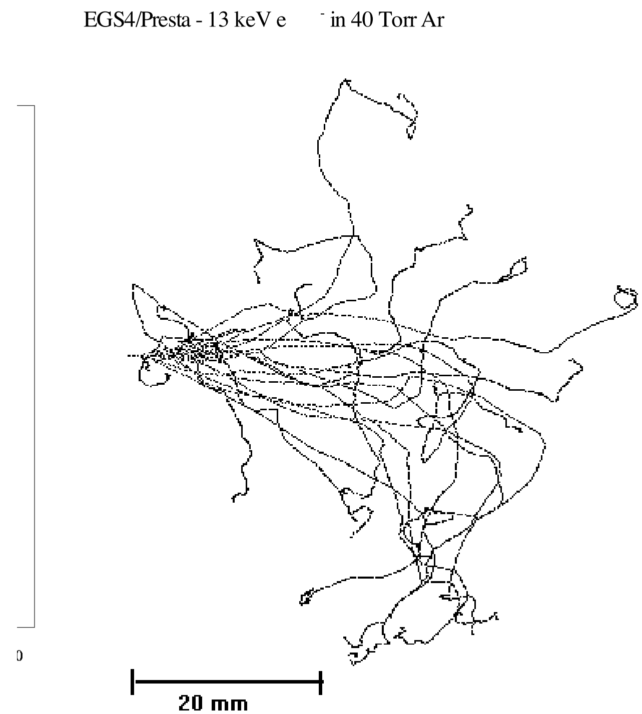
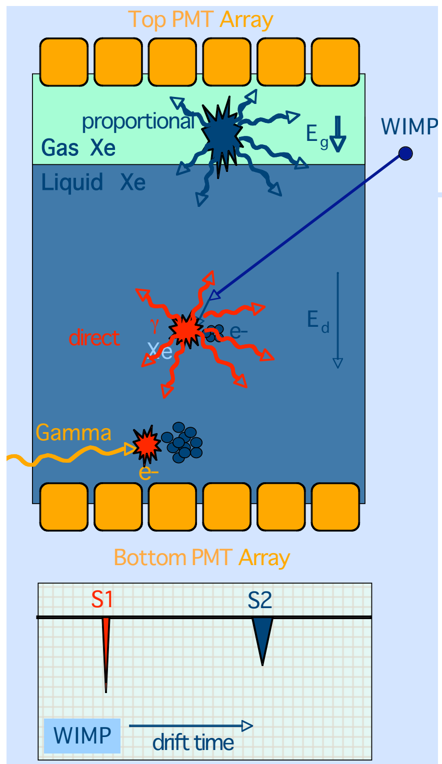
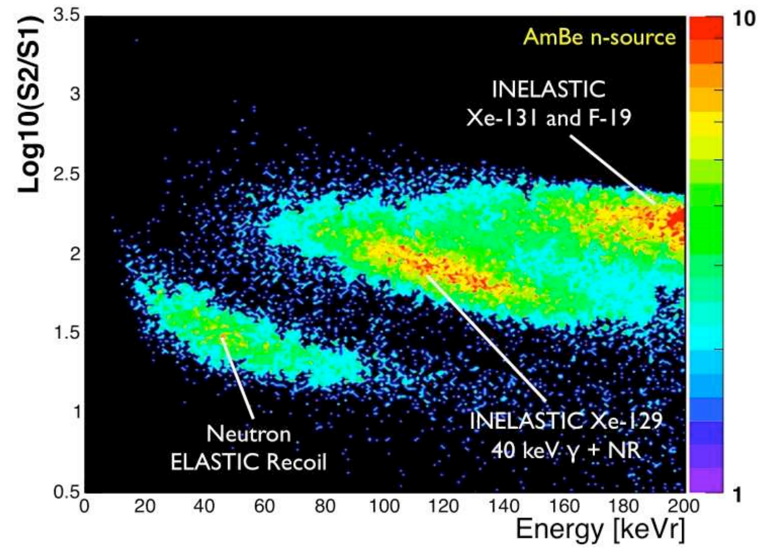


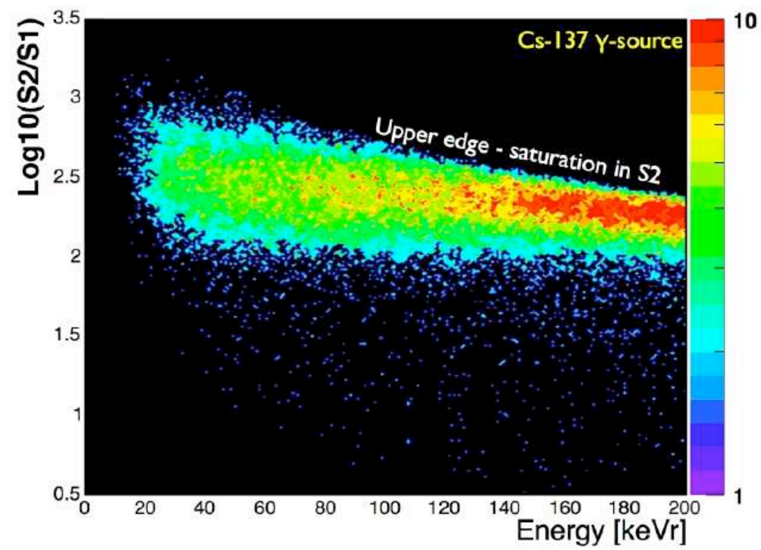
… Maybe even the direction of the recoil can be reconstructed

Liquid Xenon

- Recoils produce scintillation and ionization signal via production of excited states in Xe
- Can measure ionization directly by drifting it out and multiplying in gas or by awaiting recombination to get secondary scintillation
- For NRs, ionization is depleted by prompt recombination due to high ionization density

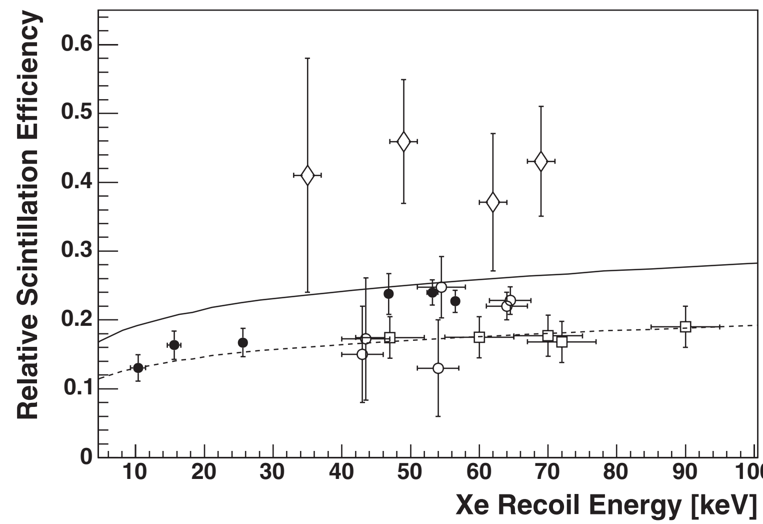


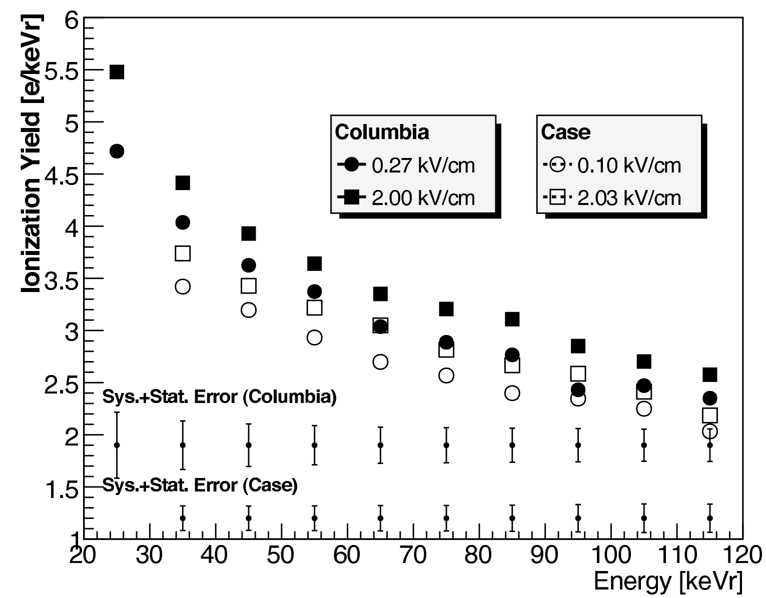




Liquid Xenon

- Serious experiments are beginning
  - XENON (Columbia, Brown, CWRU, Florida, LLNL, Rice, Yale)
    - much prototyping/basic measurement work done
    - quenching: 10-25% primary light scintillation efficiency for NRs relative to ERs
    - ionization efficiency:
      5 e-/keVr at 20 keVr
      3 e-/keVr at 100 keVr
    - 10 kg experiment being deployed at LNGS
  - ZEPLIN II and III
    - II: 2-phase, like XENON, ~10 kg deployed at Boulby
    - III: 2-phase with better light collection, ~10 kg, tested above ground, soon to enter Boulby

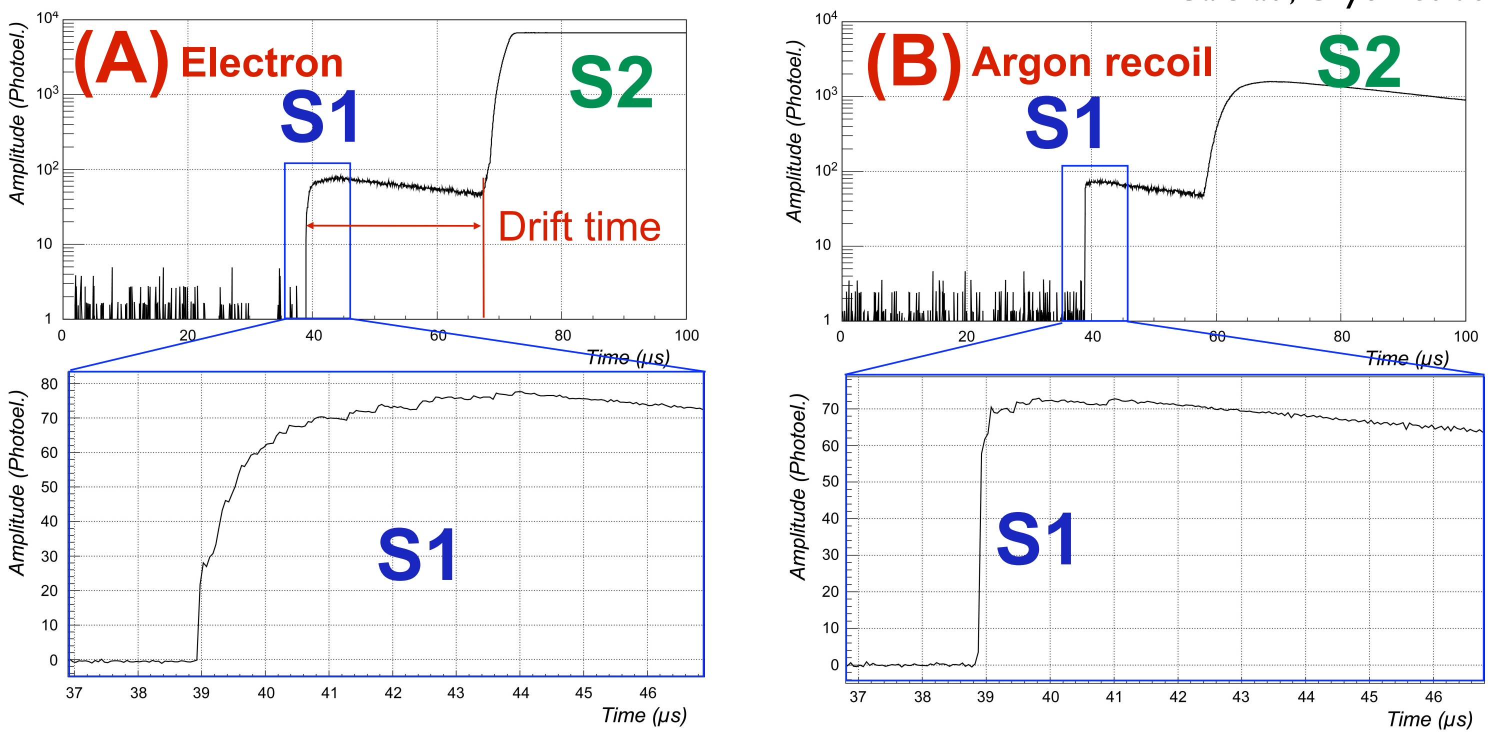




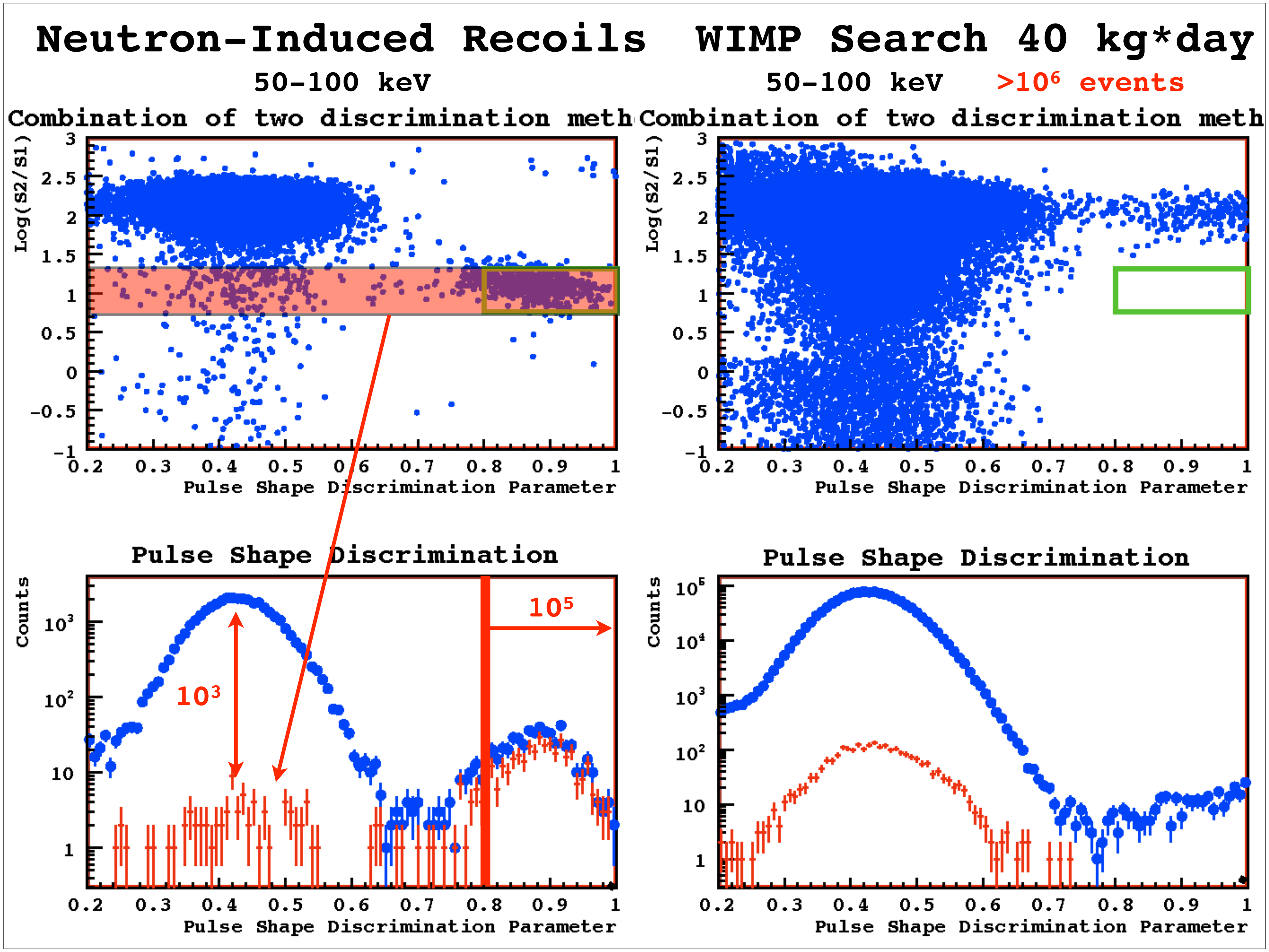
Liquid Argon

- You might think this is a bad idea...
  - ^{39}Ar: 565 keV beta, 0.8 Bq/kg natural: Need 10^7 rejection for 100 kg experiment to reach even 1/kg/day WIMP sensitivity; best sensitivities now are 0.1/kg/day
- But:
  - 2 independent rejection methods: S2/S1 (like LXe) and S1 rise time
  - No quenching of NRs relative to ERs, confirmed by D. McKinsey (CLEAN)

Galbiati, CryoDet 06



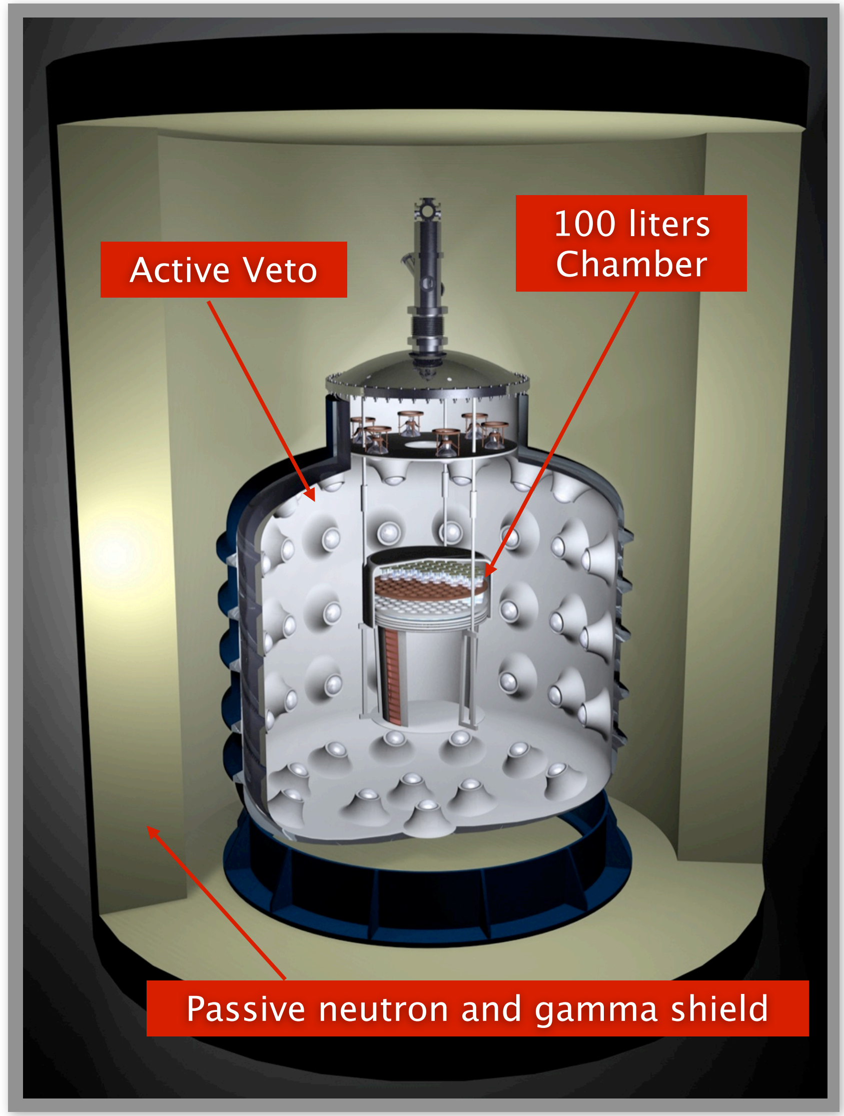
Liquid Argon



Galbiati, CryoDet 06

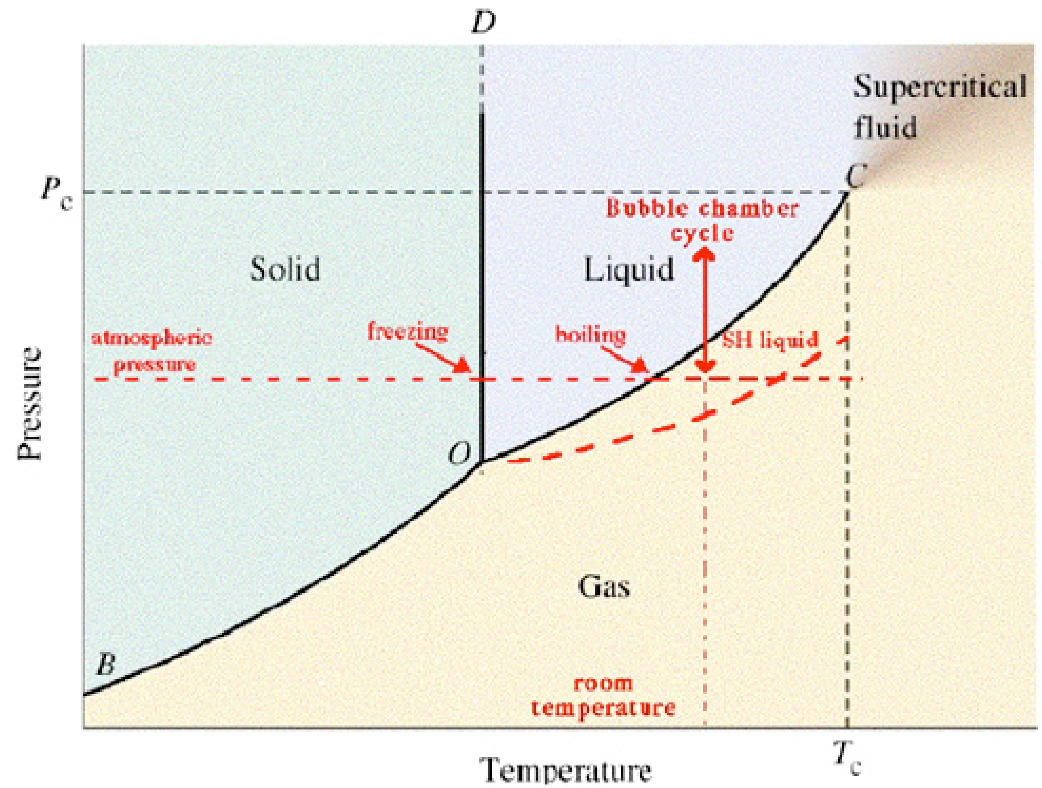
Liquid Argon

- WArP 2.3 L (3.2 kg) prototype:
  - INFN Pavia (incl. Rubbia), INFN Napoli, LNGS, Princeton (Calaprice, Galbiati)
  - 8 events 12-40 keVr in 34.3 kg-d, no events above 40 keVr
  - lower limit on rejection:
    10^7 for > 40 keVr
    10^8 for 60-120 keVr
- 140 kg experiment to be deployed at LNGS in coming year
- Could be a spoiler but:
  - Need to determine ultimate limit of rejection (10^8 gets you to current best limit)
  - ^{39}Ar removal?



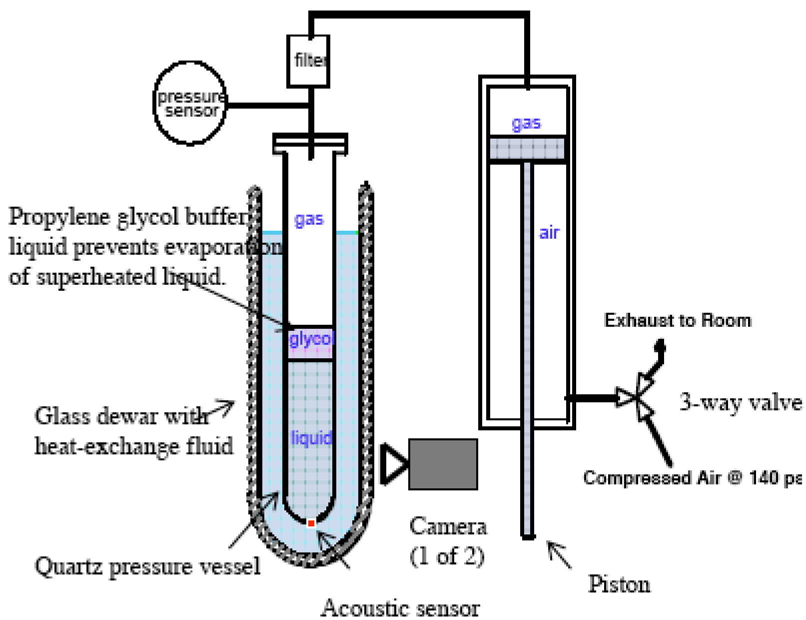
NR Discrimination in Bubble Chambers

- Superheated liquid
- Energy density effect: ER energy deposition density too small to nucleate bubbles
- Excellent rejection of ER backgrounds (lower limit of 10^9 demonstrated))
- Threshold detector, controlled by temperature & pressure

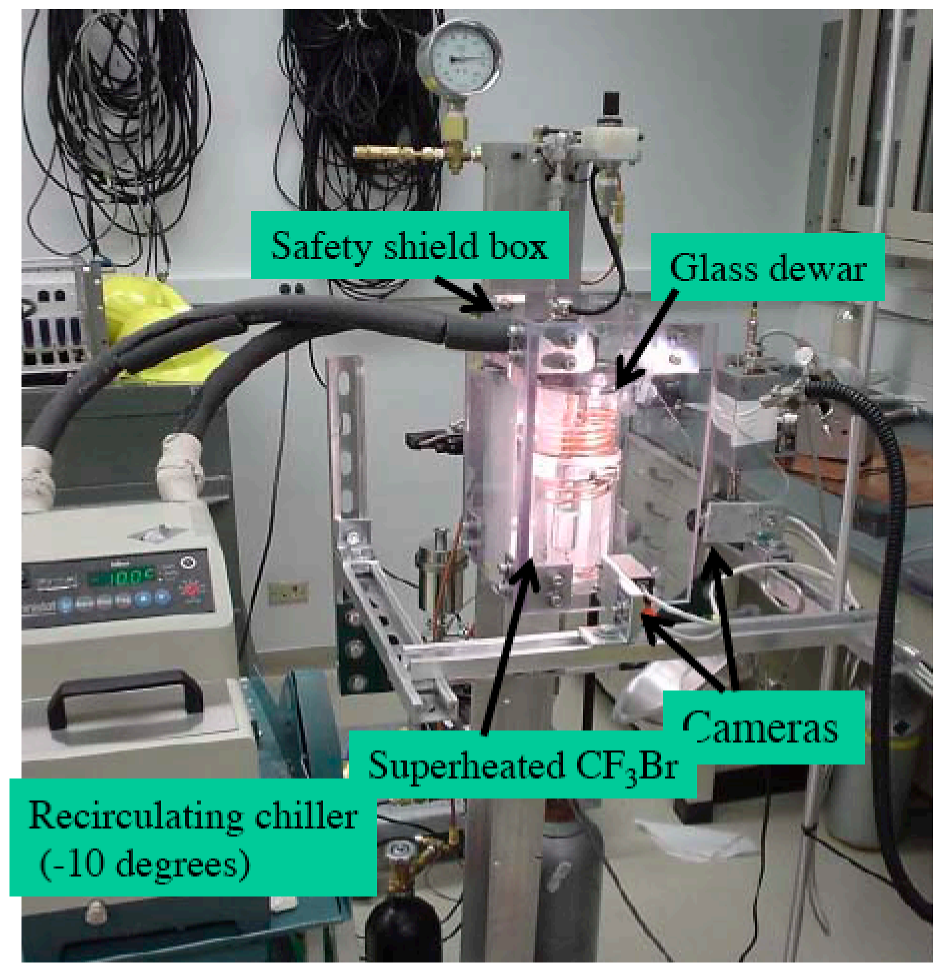


- Spin-independent (I and Br) and spin-dependent (F) targets work
- Scalable
- Many inexpensive modules to do energy scan
- COUPP: Collar (Chicago), Sonnenschein, Crisler, et al (FNAL) SIMPLE, PICASSO

NR Discrimination in Bubble Chambers



Collar group, Chicago



NR Discrimination in Bubble Chambers

- COUPP 1 kg prototype experiment being deployed in shallow site at FNAL (MINOS near detector hall)

Collar group, Chicago