Direct Search for Dark Matter

Old and New Technologies

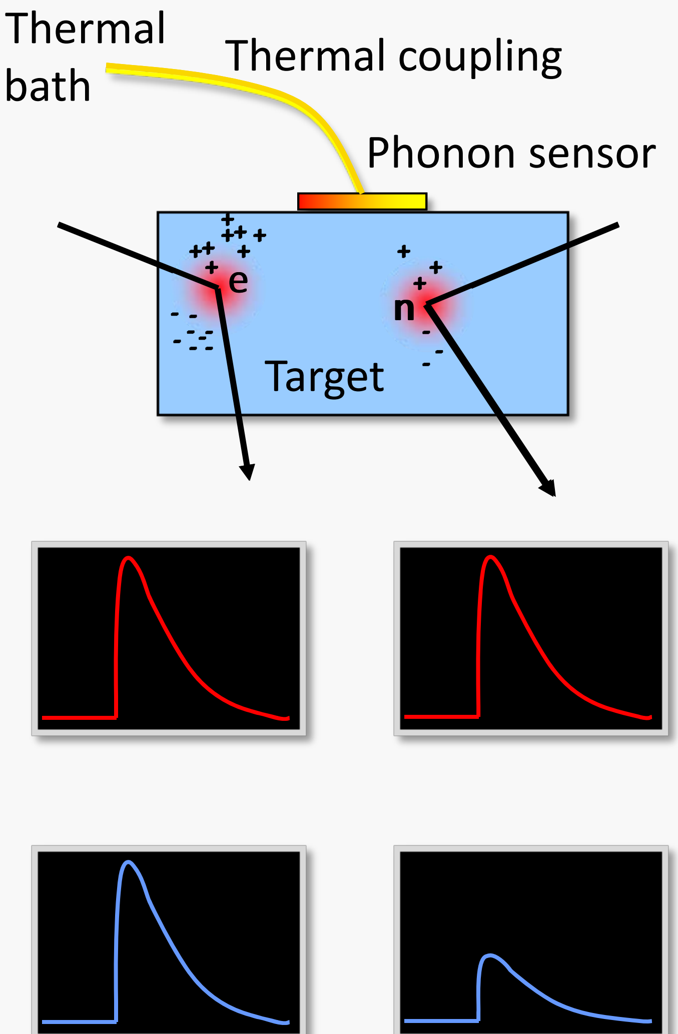
Wolfgang Rau, Queen's University

Overview

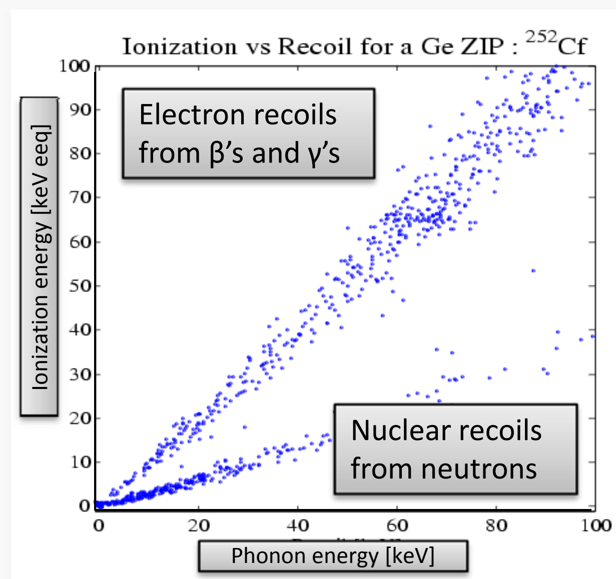
- Cryogenic Detectors
  - Some more Details and New Developments
- Superheated Liquids
  - PICASSO and COUPP
- Scintillators
  - DAMA/LIBRA, KIMS and DEAP/CLEAN
- Directional WIMP Detectors
  - Motivation, Prospects and Technologies

Cryogenic Detectors

Basics – Reminder



- Conventional detectors (ionization, scintillation): signal reduction for nuclear recoils (quenching)
- Most energy converts to thermal energy (lattice vibrations – phonons)
- Measure thermal signal
- Combine with conventional technology: discrimination of BG

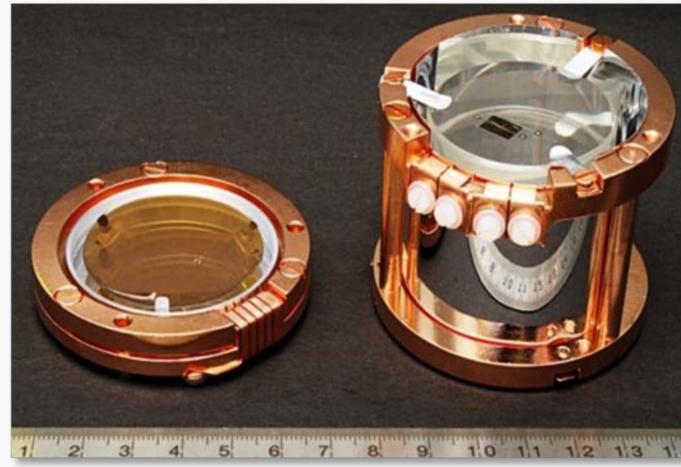


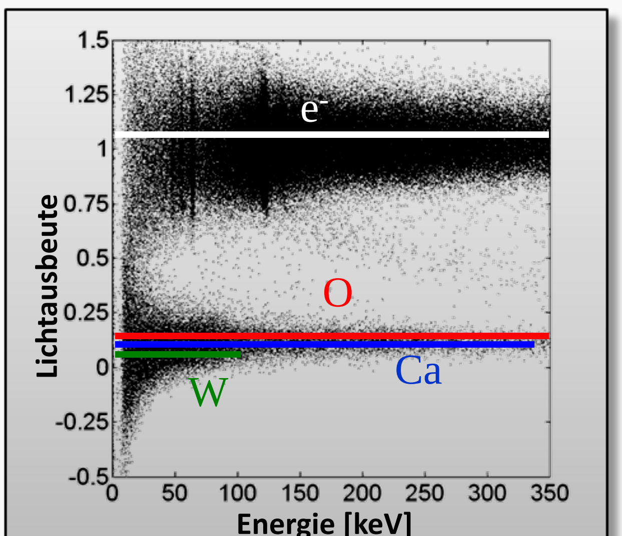
Cryogenic Detectors

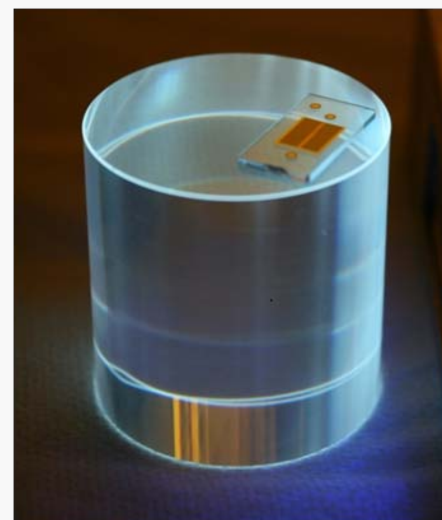
CRESST at Gran Sasso– glued Sensors

- $CaWO_4$ as WIMP target
- Scintillator, W TES for thermal readout
- Neutrons → O recoil; WIMPs → W recoil
- Less light from W recoil → can discriminate
- Need good light output/resolution
- Thin film deposition decreases light output
  → Deposit sensor on small substrate,
  glue to target

  Also simplifies detector production



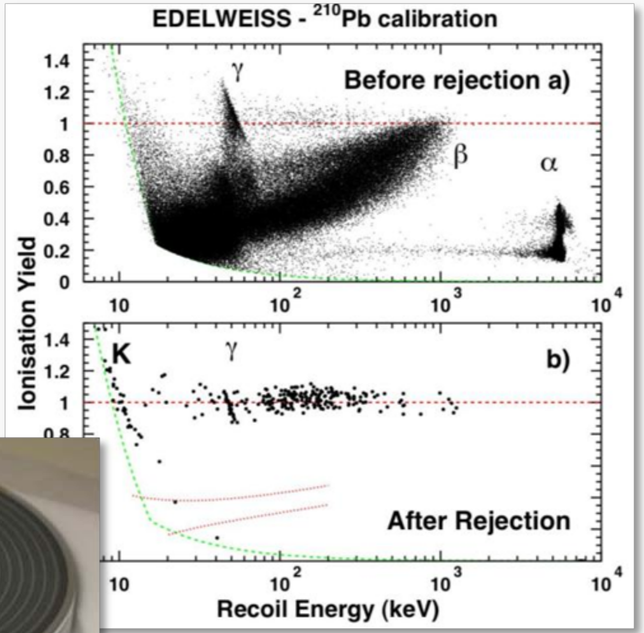




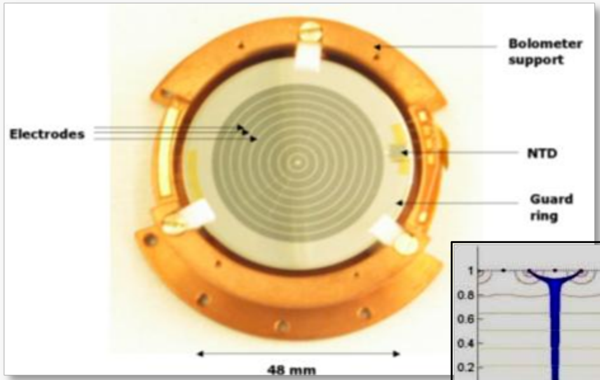
Cryogenic Detectors

EDELWEISS at Modane – Interleaved Electrodes

- Germanium as WIMP target
- Charge readout; thermal readout: NTD
- Surface ER have less charge → like NR
- New detectors with different electrode concept to remove surface events
  Surface events: charge on one side
  Bulk events: charge on both sides
- Very good performance
- Considerable improvement in sensitivity expected

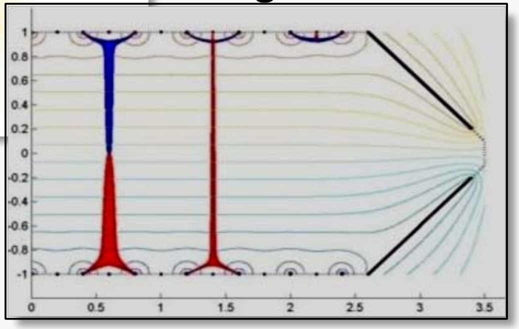


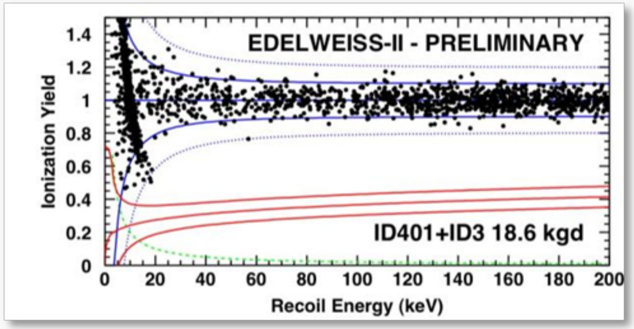
2nd prototype: Electrodes also at rim: 80 % fid vol



First Prototype

Charge collection

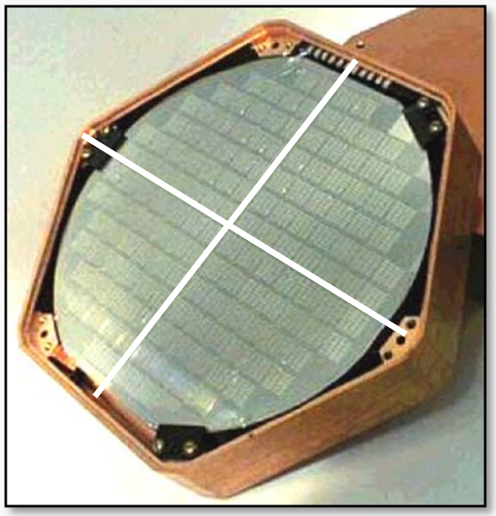




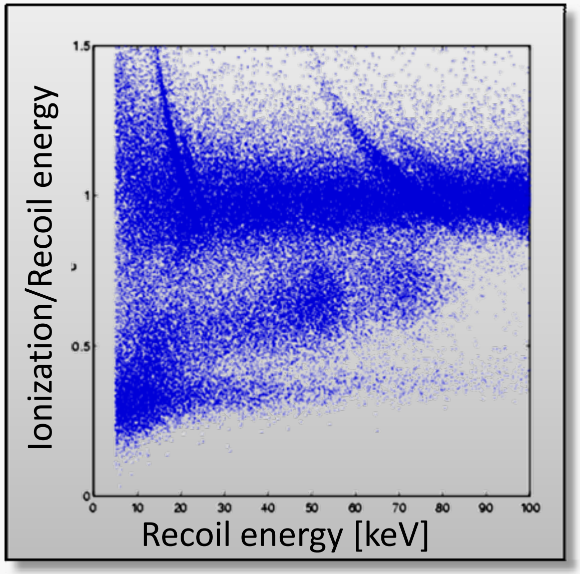
Cryogenic Detectors

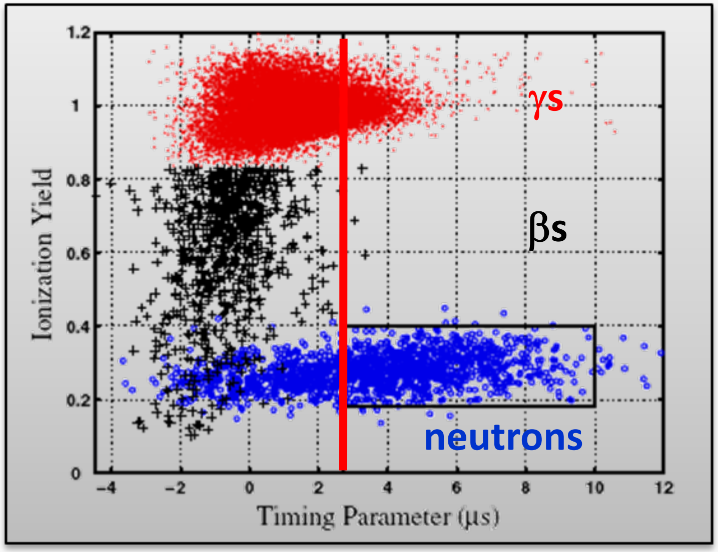
CDMS at Soudan – ZIP

- Germanium as WIMP target
- Charge and thermal readout (TES)
- 4 sensors/detector, fast signal (< ms) position reconstruction
- Identify surface events through timing (PSD) of thermal signal



Z-sensitive Ionization and Phonon detector





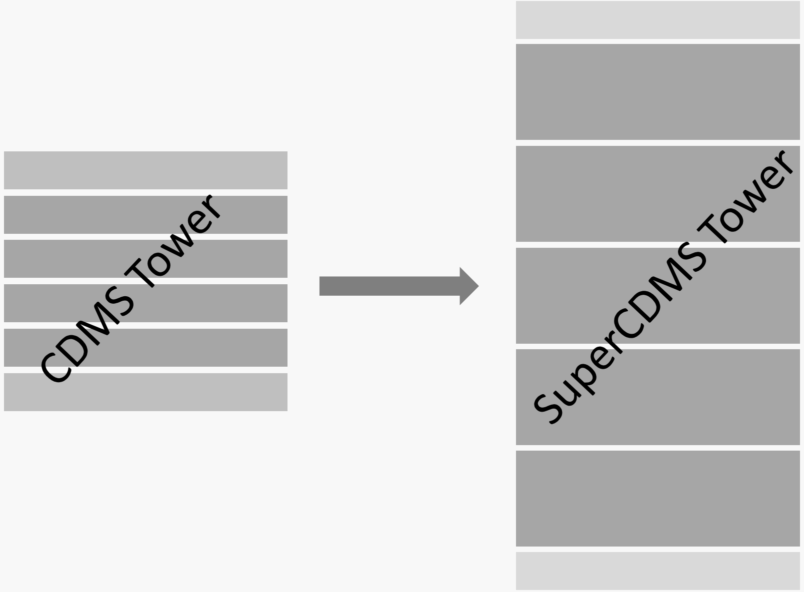
Cryogenic
Super-heated
Scintillator
Directional
Conclusion

Cryogenic Detectors

SuperCDMS – Mercedes (mZIP)

- Larger mass per module:
  ~250 g → 620 g
- Increased thickness
  → improved Bulk/Surface ratio
- Improved sensor design for better surface event rejection
- New geometry – "Mercedes"
  → better position reconstruction
  (better Position dependent calibration)

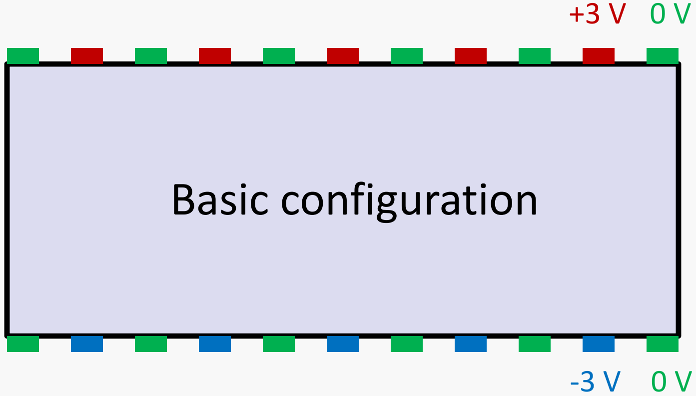
- New arrangement:
  5 full detectors; 2 "half" as veto
- First set installed; replace all old detectors by new ones by summer 2010 (→ ~15 kg Ge)
- First look at background: Surface events (traced by alphas) per mass reduced as expected

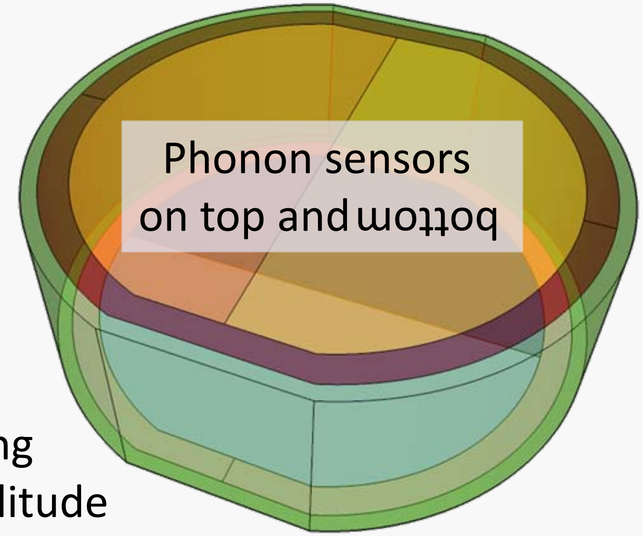


Cryogenic Detectors

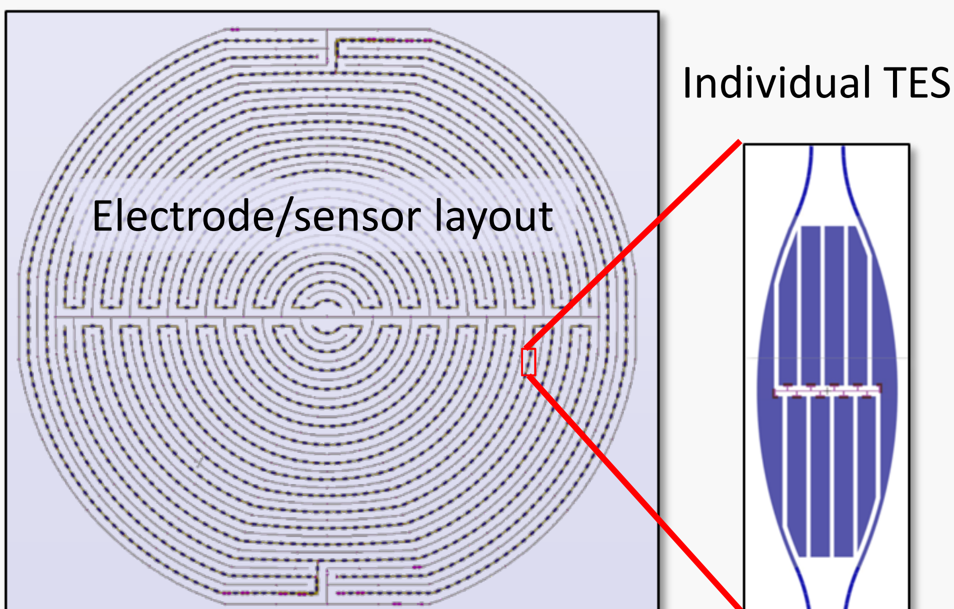
SuperCDMS – iZIP

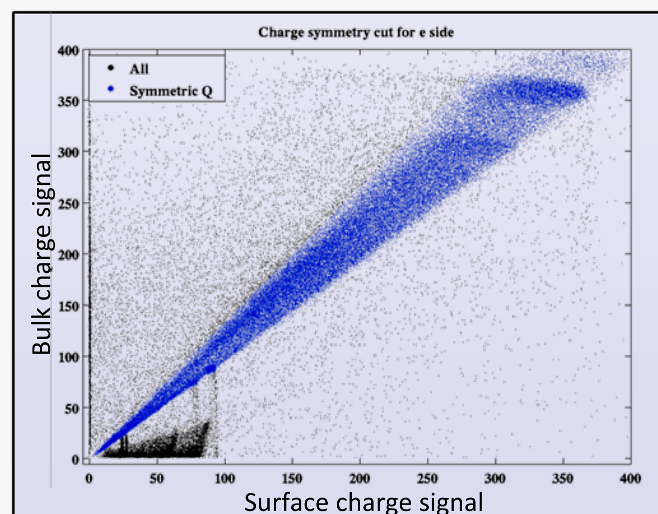
ZIP with interleaved electrodes:





Z sensitivity:
- Charge
- Phonon timing
- Phonon amplitude





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Cryogenic Detectors

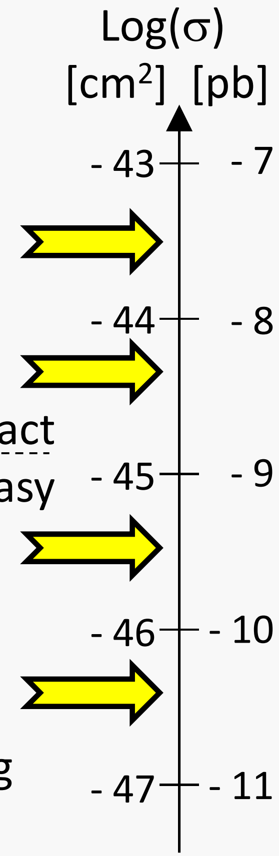
SuperCDMS at SNOLAB and beyond

CDMS II, oZIP	1 cm x 3", ~250 g	19 Ge detectors, ~5 kg
SuperCDMS Soudan, mZIP	1"x 3", ~630 g	25 detectors, ~15 kg

!! Fact

?? Fantasy

SuperCDMS SNOLAB, iZIP	3.3 cm x 10 cm ~1200 g	~100 detectors, ~120 kg
GEODM	6" x 2" ~5000 g	~300 detectors, ~1500 kg



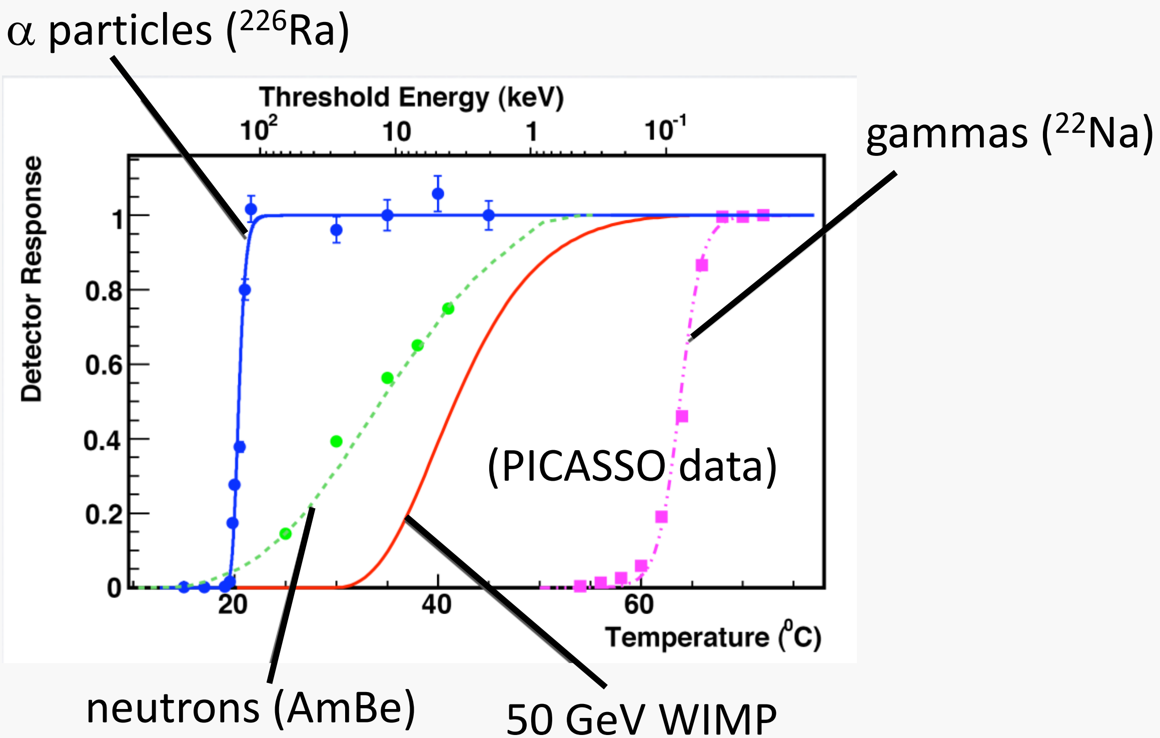
My personal guess: for ton scale we'll have one experiment world wide

Memorandum of understanding between EURECA and GEODM/SuperCDMS for exchange of information / collaboration in technical questions signed

Superheated Liquids

Basics

- Bubble chamber principle: liquid above evaporation temperature
- Particle interaction triggers nucleation, produces proto-bubble
- Small proto-bubbles collapses (surface tension)
- Need high ionization density to produce large enough proto-bubble
- Necessary ionization density depends on p and T
- Typical target: Fluor (^{19}F) in CF-compounds → low Z, but high spin



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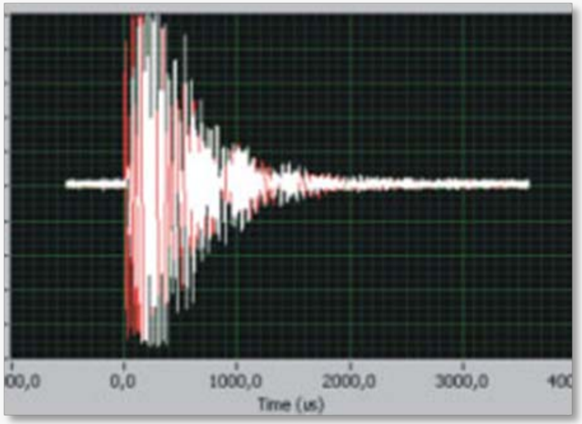
Superheated Liquids

PICASSO at SNOLAB

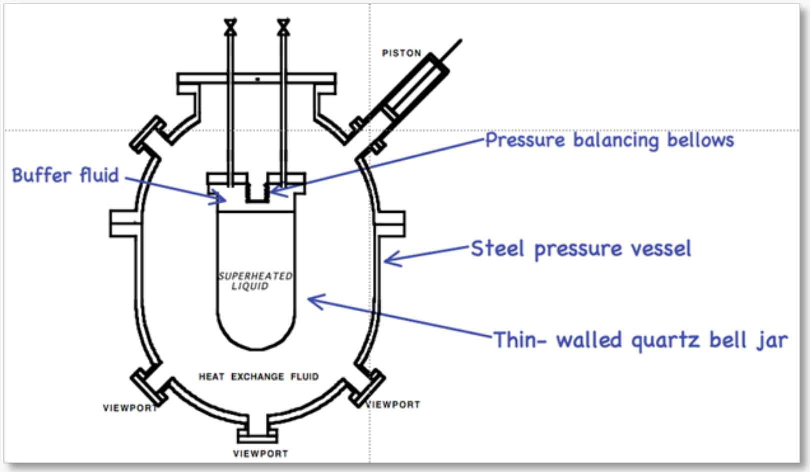
- Freon (C_4F_{10}) droplets in gel matrix
- Total active mass: 2.6 kg (32 detectors)
- Nuclear recoils and αs can evaporate droplets
- Acoustic readout
- Sensitive to spin-dependent interaction
- Recent development: PSD for α vs NR (single vs multiple proto-bubbles)
- 14 kg d (from 2 detectors) published in 2009

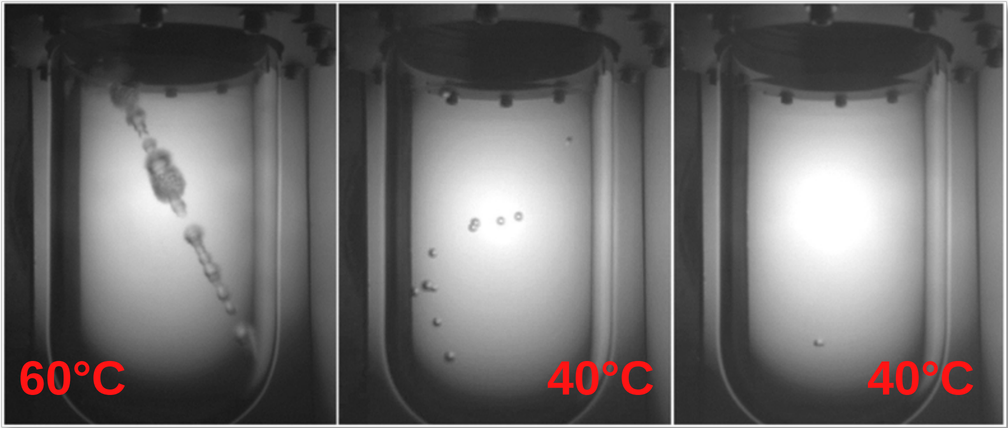


Superheated Liquids

COUPP

- Monolithic bubble chamber
- Target material: CF_3I (I for good SI interactions)
- Need to re-pressurize after each event
- Optical readout
- 1.5 kg chamber data published (shallow site at FNAL), 77 evt/kgd
- New 4 kg chamber operating
- 10 L chamber being commissioned
- 60 kg chamber produced (to be deployed at SNOLAB)
- Additional acoustic readout considered for α-NR discrimination



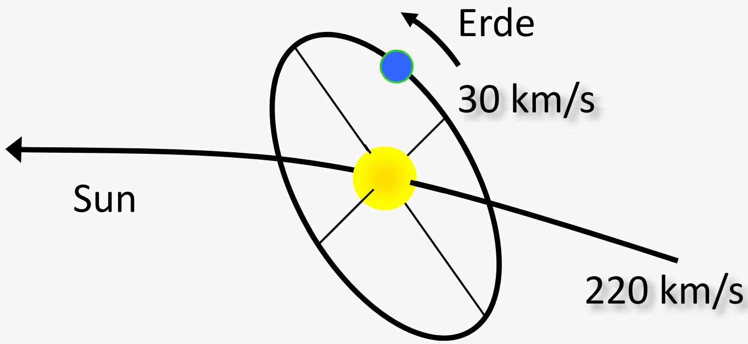


muon Neutron(s) WIMP

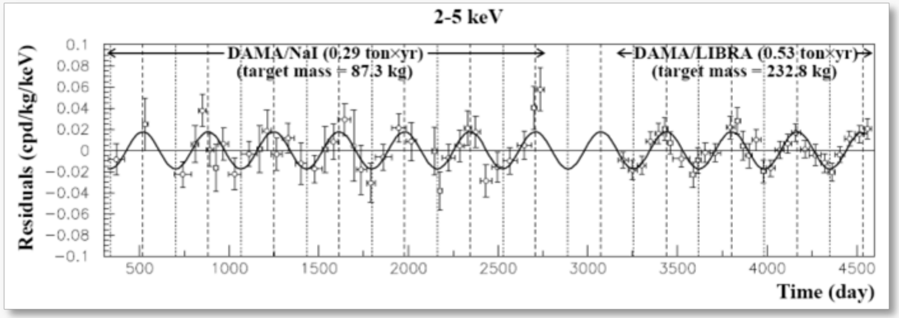
Scintillation Detectors

DAMA/LIBRA at Gran Sasso

- NaI scintillator, 9.7 kg single crystals
- Data: 7 years (1995-2002), 87 kg (DAMA) + 3.5 years (2003-2007), 240 kg (LIBRA)
- Obvious oscillation of the rate, correct phase
- Interpretation controversial

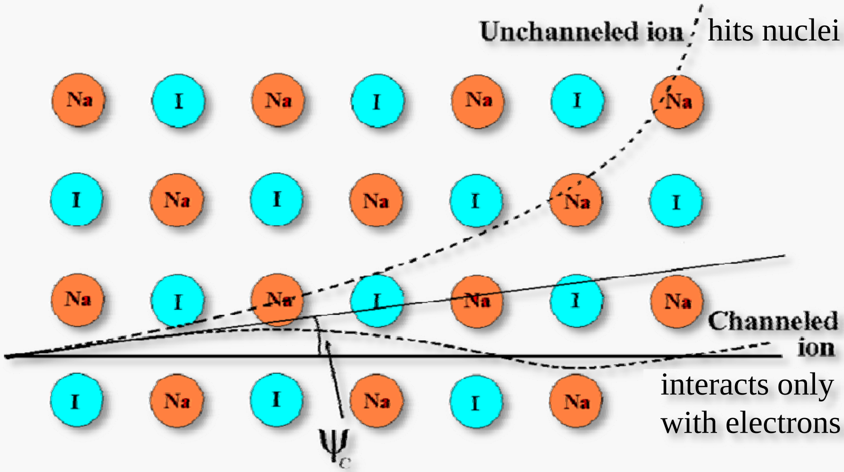


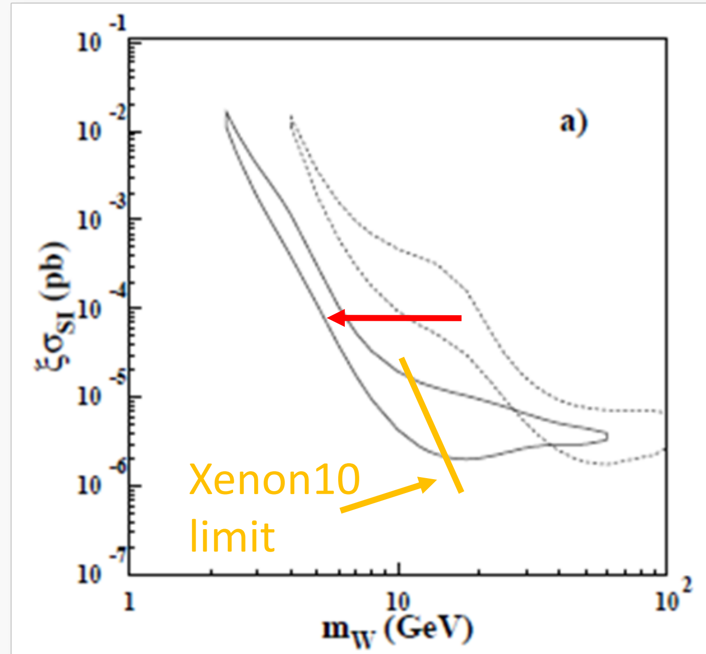
Source	*Main comment*	*Cautious upper limit (90%C.L.)*
RADON	Sealed Cu box in HP Nitrogen atmosphere	$<0.2\%\ S_m^{obs}$
TEMPERATURE	The installation is air-conditioned	$<0.5\%\ S_m^{obs}$
NOISE	Effective noise rejection	$<1\%\ S_m^{obs}$
ENERGY SCALE	Periodical calibrations + continuous monitoring of ^{210}Pb peak	$<1\%\ S_m^{obs}$
EFFICIENCIES	Regularly measured by dedicated calibrations	$<1\%\ S_m^{obs}$
BACKGROUND	No modulation observed above 6 keV; this limit includes possible effect of thermal and fast neutrons	$<0.5\%\ S_m^{obs}$
SIDE REACTIONS	Muon flux variation measured by MACRO	$<0.3\%\ S_m^{obs}$



Scintillation Detectors

DAMA/LIBRA – Channelling





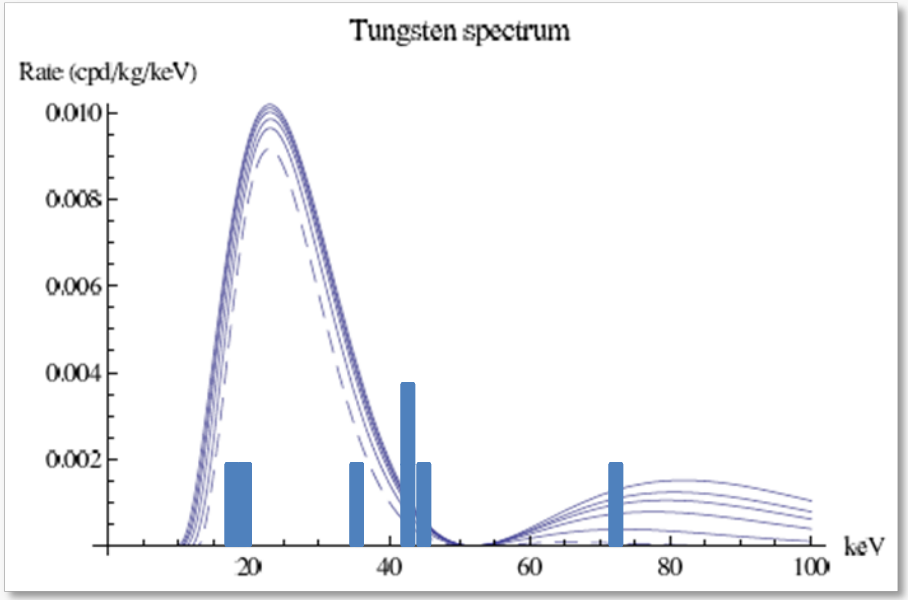
→ Channelled ions do not quench
→ Energy scale for NR equal to ER
→ Allowed signal region moves to lower masses

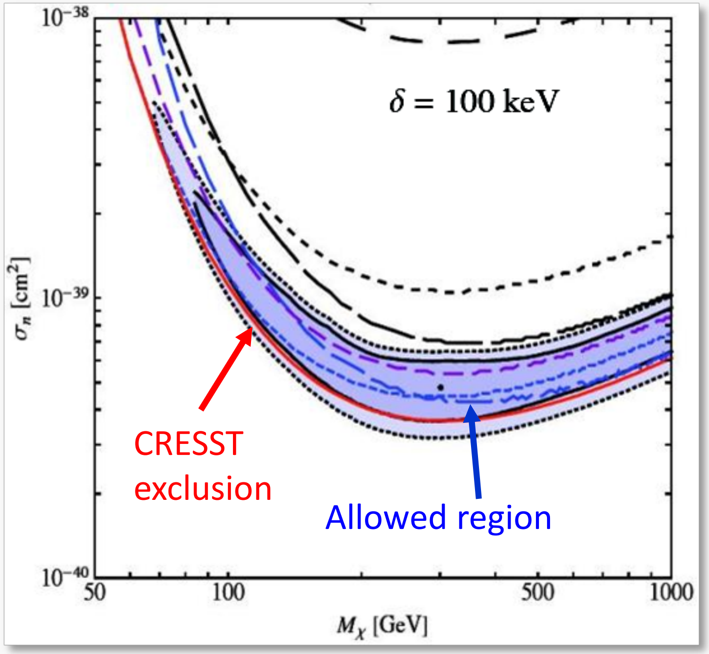
- Channelling model not fully worked out, effect probably (much?) smaller
- No indication for channelling in CDMS (needs more careful analysis!)
- Some experiments are starting to explore low mass region (CoGeNT, TEXONO, CDMS)

Scintillation Detectors

DAMA/LIBRA – Inelastic DM

- WIMP has low energy (~100 keV) excited state
- Lead to large oscillation fraction (up to 100 % instead of only a few % for standard WIMP interactions
- Makes it more difficult for some other experiments to detect
- High mass nuclei are more sensitive, e.g. W in CRESST

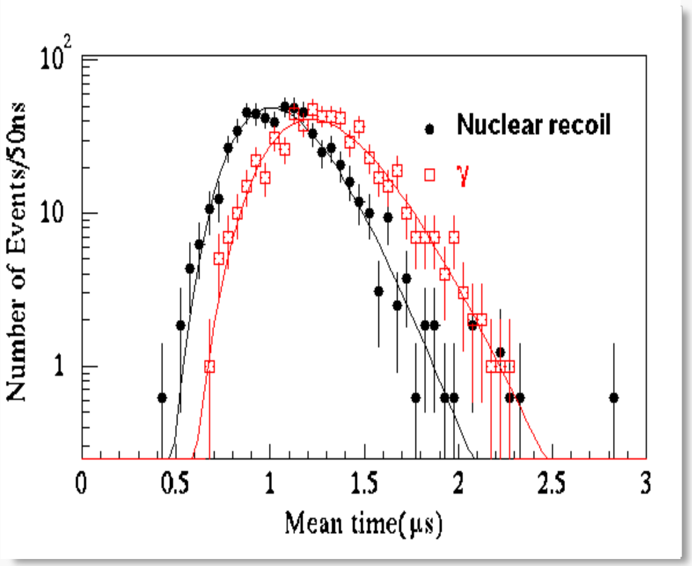




Scintillation Detectors

KIMS at Yangyang

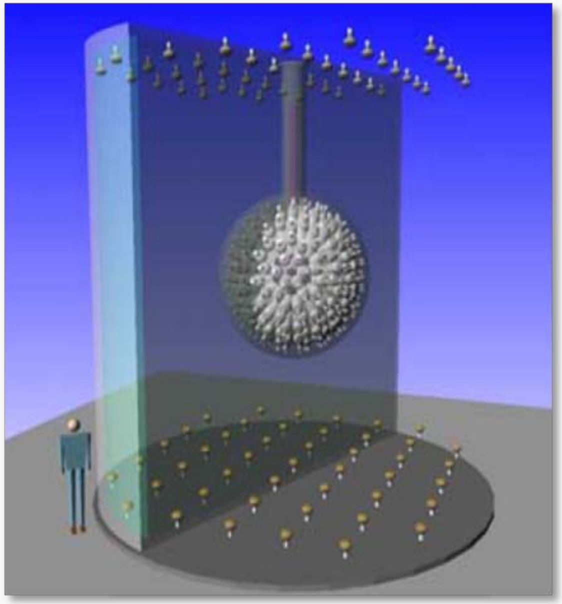
- CsI scintillator, 8.7 kg single crystals
- Big effort in reducing internal contamination
- 12 detectors (104 kg) operating
- Data from 2 detectors (3.4 ton d) published
- Searching for annual modulation – most direct check on DAMA (only for NR so far)

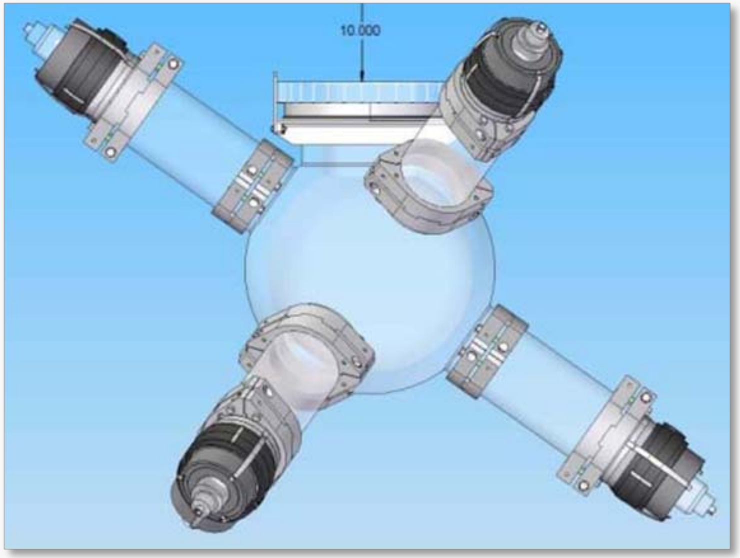


Scintillation Detectors

DEAP 3600 at SNOLAB

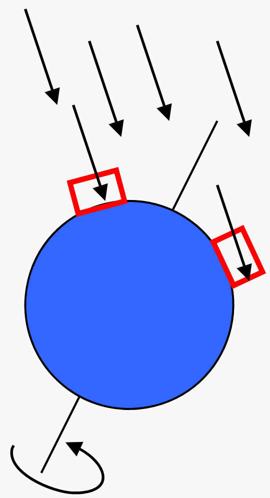
- Total target mass 3600 kg (1000 kg fiducial)
- Full scale is funded
- Installation at SNOLAB has started
- Ar with reduced ^{39}Ar content may be used
- Expected sensitivity ~10^{-46} cm
- R&D efforts include studying of new high QE PMTs, material tests (cryo, optical, contamination), background mitigation …



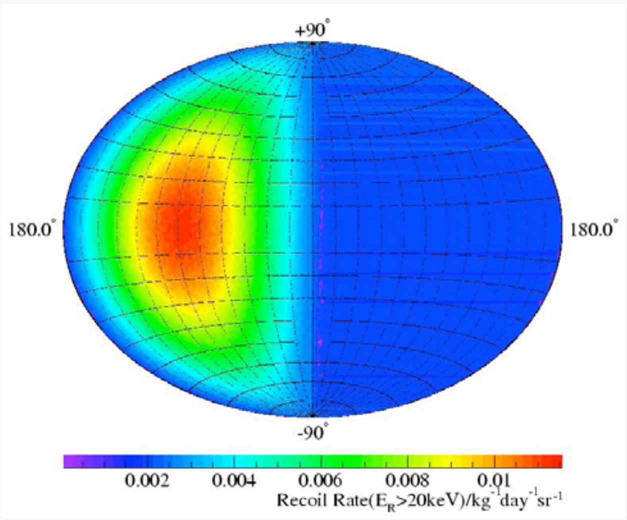


Directional Detection

Motivation, Challenges, Statistics



- Main Motivation
  Primary signature (direction of incoming particle) strong and unique:
  - direction changes by 90 ° during the day
  - direction constant in cosmic frame, changing in lab frame
- Main Challenges
  - correlation between incoming particle and scattered nucleus only moderate
  - recoils are low energy → tracks are short
  - non-trivial to distinguish between head and tail of track
- Statistics
  - For a perfect detector of order of 10 WIMP events are needed
  - For non-zero background this increases (~ x2 for S/B of 1)
  - If readout is only 2d numbers further increase (roughly x2 to x10)
  - If head/tail can partially/not be distinguished we need up to several hundred events

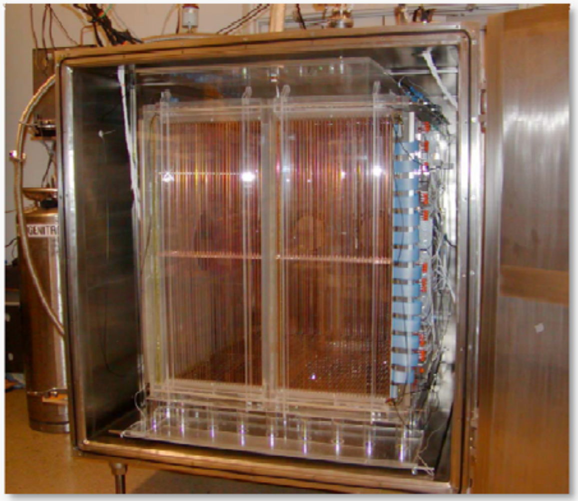


[A. Green, B. Morgan (Cygnus 2009 Workshop)]

Directional Detection

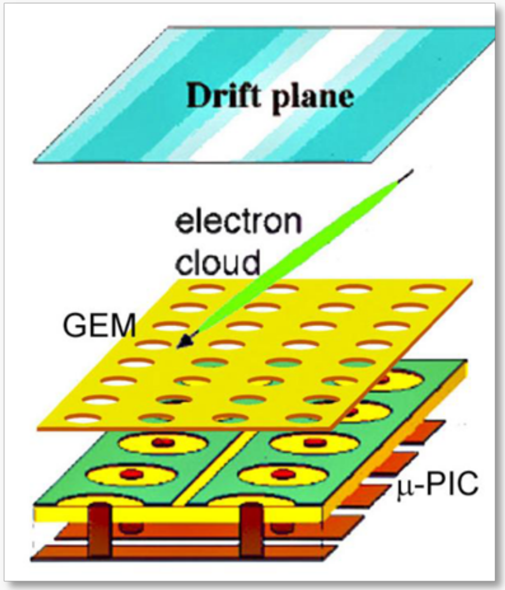
DRIFT at Bulby

- 1 m^3 gas TPC (CS_2, possibly with CF_4 fraction)
- MWPC readout
- Low pressure (40 Torr), ~200 g
- Negative Ion drift (reduce diffusion)
- Gamma discrimination by track length
- Several test runs in the past
- Presently 1 TPC running at Bulby



NEWAGE at Kamioka

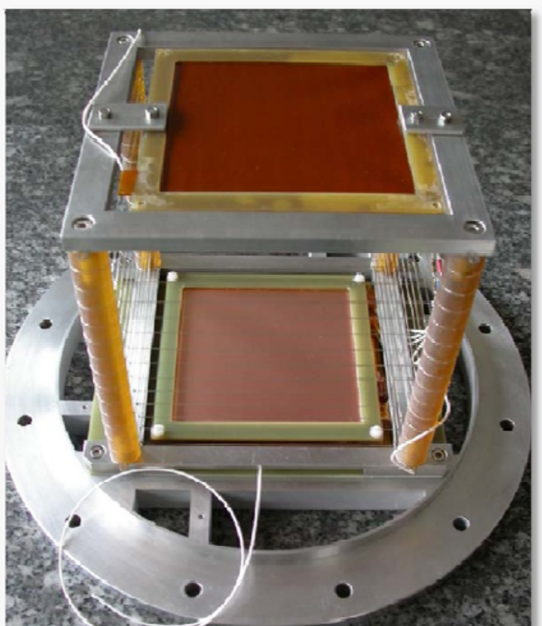
- 0.03 m^3 gas TPC (CF_4)
- Low pressure (152 Torr), ~11 g
- GEM + μPIC readout, 400 μ pitch
- Angular resolution ~45 °
- 0.5 kgd DM exposure
- Towards the future:
  larger detector, lower pressure



Directional Detection

DMTPC

- 10 L gas TPC (CF_4)
- Charge readout (mesh: 28 μm wire, 256 μm pitch)
- Scintillation readout (CCD)
- Low pressure (75 Torr), 3 g
- 2d readout
- Head-Tail discrimination shown for few hundred keV
- Collected data above ground (45 gd), moving to WIPP



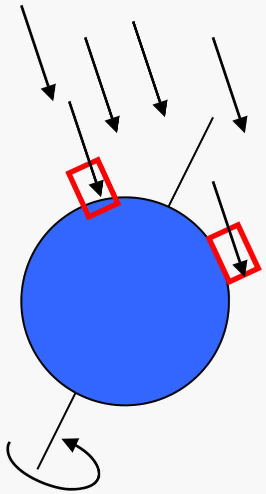
MIMAC

- (15 cm)^3 gas TPC (^3He or CF_4)
- Medium pressure (350 Torr)
- Micromegas readout (300 μm pitch)
- 3d tracks from 6 keV He recoil at 300 mbar shown

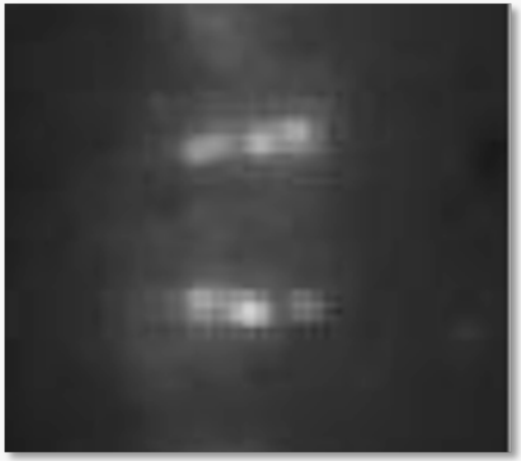
Directional Detection

Emulsion

- Keep direction relative to WIMP wind
- Emulsion with ultra fine grains (40 nm)
- Swell to make short tracks (~100 nm) visible to optical microscope, distinguishable from random 'fog'
- Develop 1 kg prototype (2010)



200 keV Kr



Original track
~200 nm, SEM

Expanded track
~ 4 µm, optical

[T. Naka et al. (Cygnus 2009 Workshop)]

Conclusion

Running experiments

- Cryogenic detectors: best sensitivity for spin independent interaction, very promising new detector technology
- Superheated liquids: best sensitivity for spin dependent interaction (specifically p-spin), relative low cost
- Scintillators:
  Annual oscillation from DAMA/LIBRA, tension with null-results from others → new possible explanations
  KIMS works towards test of annual modulation signal

Future Experiments

- DEAP/CLEAN: single phase liquid Ar (150 kg/ 1 ton)
- Directional detection: needs large number of WIMP events
  Gas TPCs with different readout being developed
  Emulsion as new idea in this game