DM-TPC

A Direction Sensitive Detector to Search for Dark Matter

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Moriond EW

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The DM-TPC Collaboration

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A DIRECT EMPIRICAL PROOF OF THE EXISTENCE OF DARK MATTER[1]

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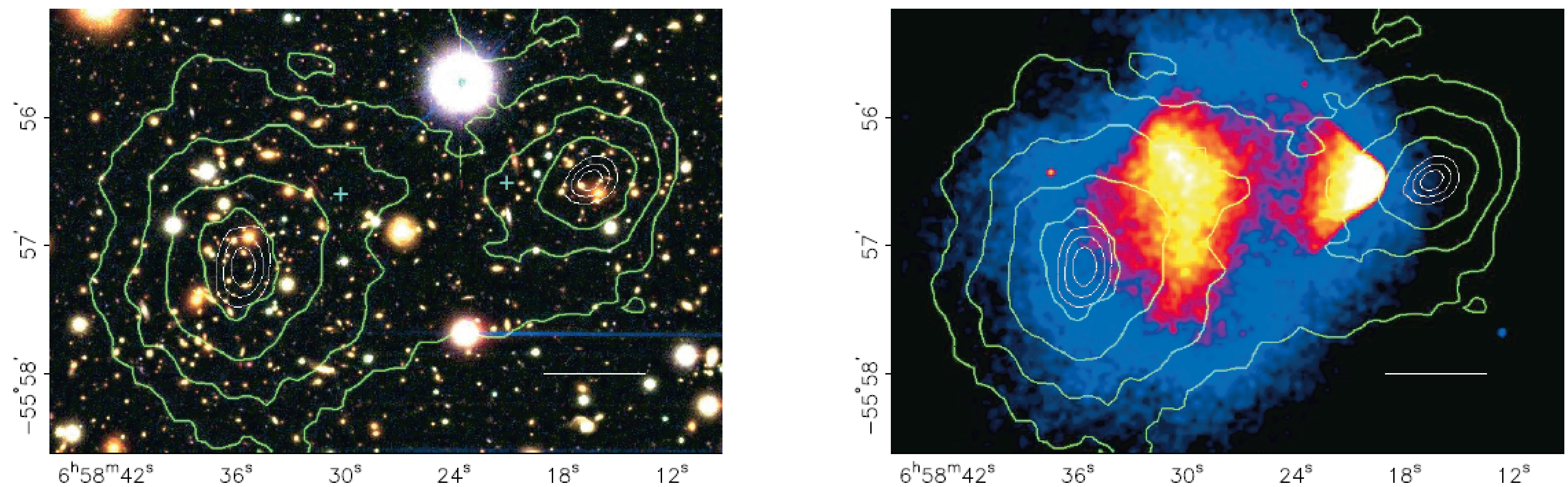
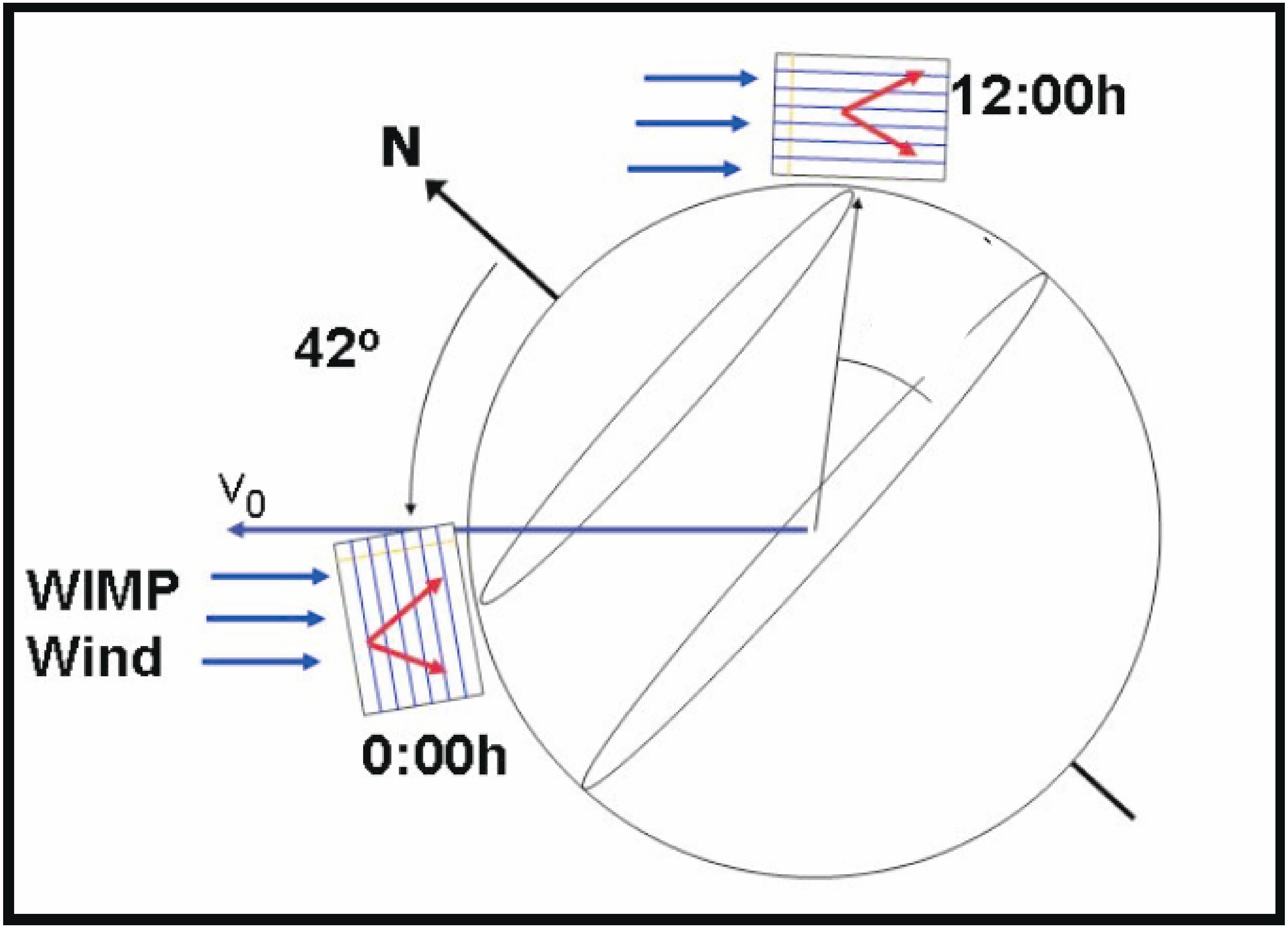


Fig. 1.—*Left panel*: Color image from the Magellan images of the merging cluster 1E 0657−558, with the white bar indicating 200 kpc at the distance of the cluster. *Right panel*: 500 ks *Chandra* image of the cluster. Shown in green contours in both panels are the weak-lensing κ reconstructions, with the outer contour levels at $\kappa = 0.16$ and increasing in steps of 0.07. The white contours show the errors on the positions of the κ peaks and correspond to 68.3%, 95.5%, and 99.7% confidence levels. The blue plus signs show the locations of the centers used to measure the masses of the plasma clouds in Table 2.

What is this stuff?

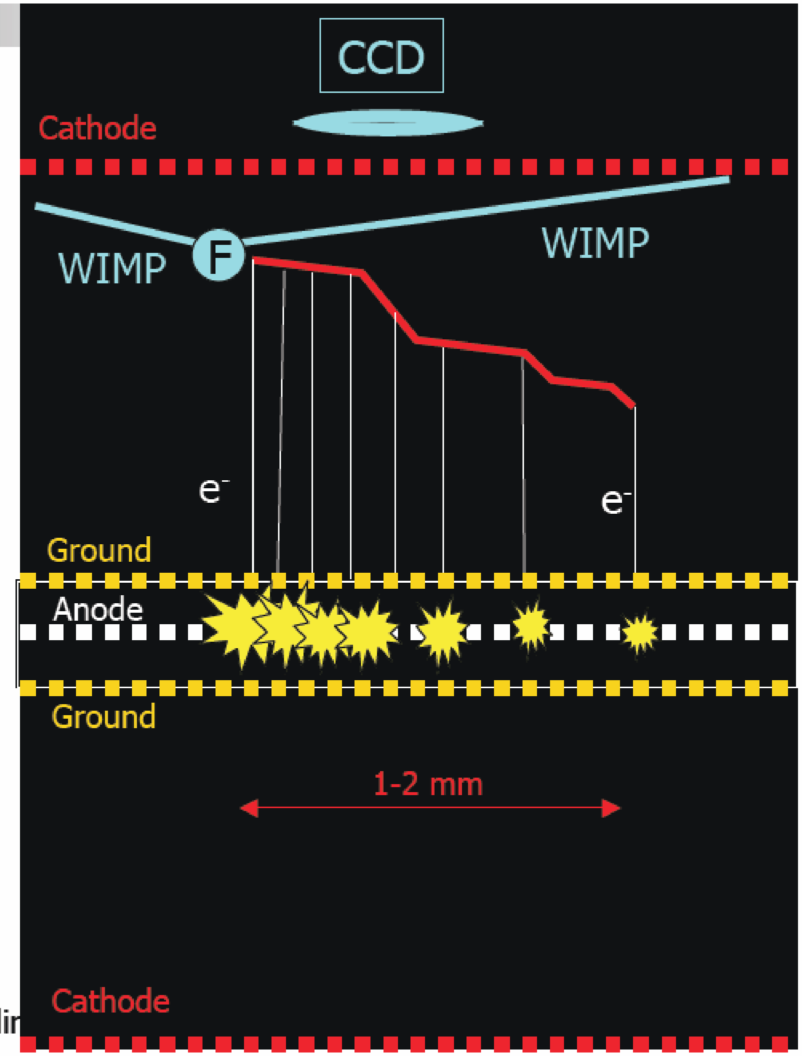
It may consist of massive neutral particles that scatter elastically off nuclei

- There are many candidates for this
- Dark matter particle rms speed of ~ 0.001c
- Recoil nuclear energies 1 to 100 keV
- Sun orbits galactic center at 230 km/s
- Dark matter probably forms large halo of our galaxy with smaller rotational velocity than sun
- Dark matter particles would appear to come from Cygnus if we could measure their direction of motion – a relative "wind" of dark matter


12:00h
N
42°
v_0
WIMP
Wind
0:00h

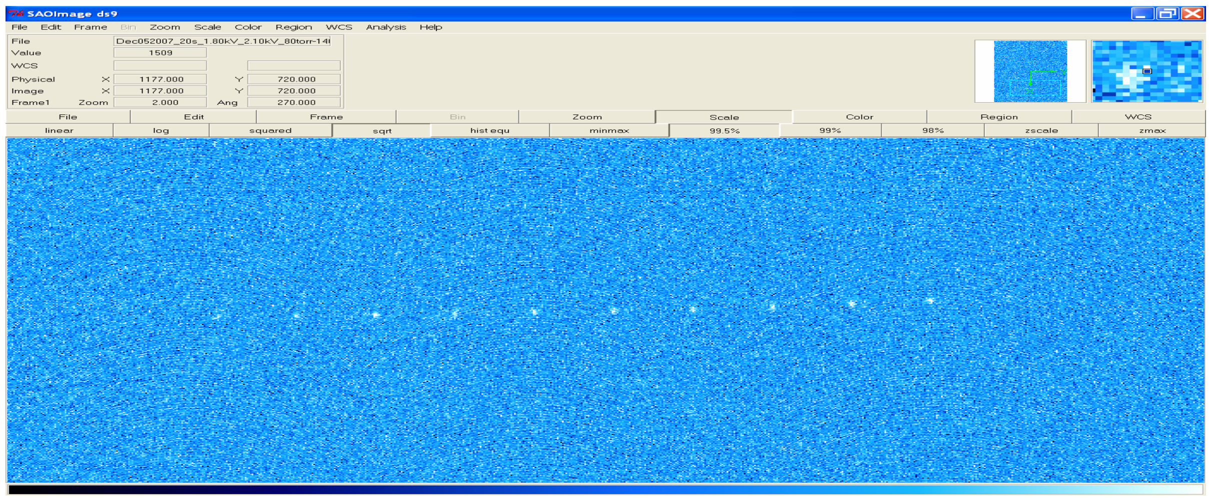
DM-TPC: detector concept

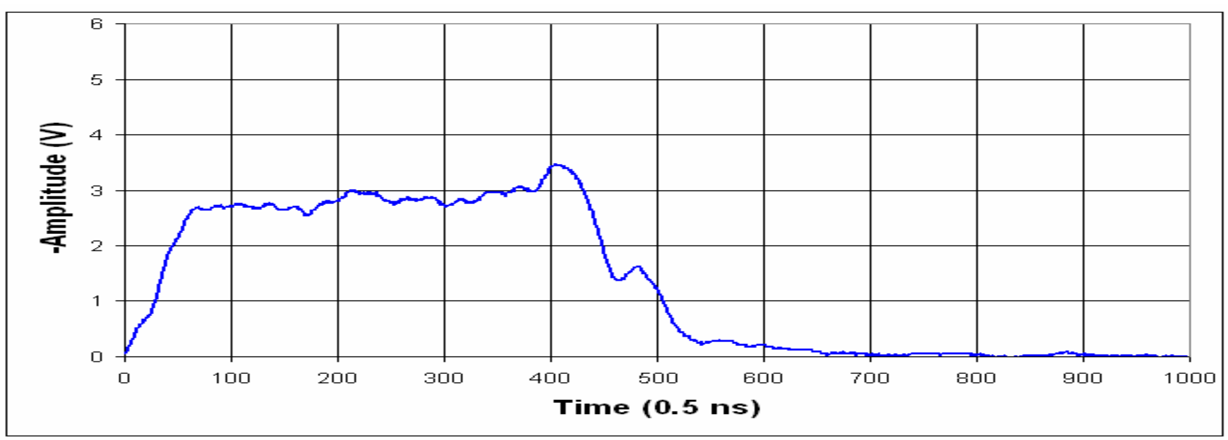
- Low-pressure CF_4 TPC
  - 50-100 torr→F recoil ~1-2mm
- CF_4 is ideal gas
  - F: spin-dependent interactions
  - Good scintillation efficiency
  - Low transverse diffusion
  - Non flammable, non toxic
- CCD readout
  - Image scintillation photons produced in avalanche
    - $\# \gamma_{\text{scintillation}} \propto \# e_{\text{ionization}}$
  - Low-cost, proven technology
- Amplification region (camera) serves 2 drift regions



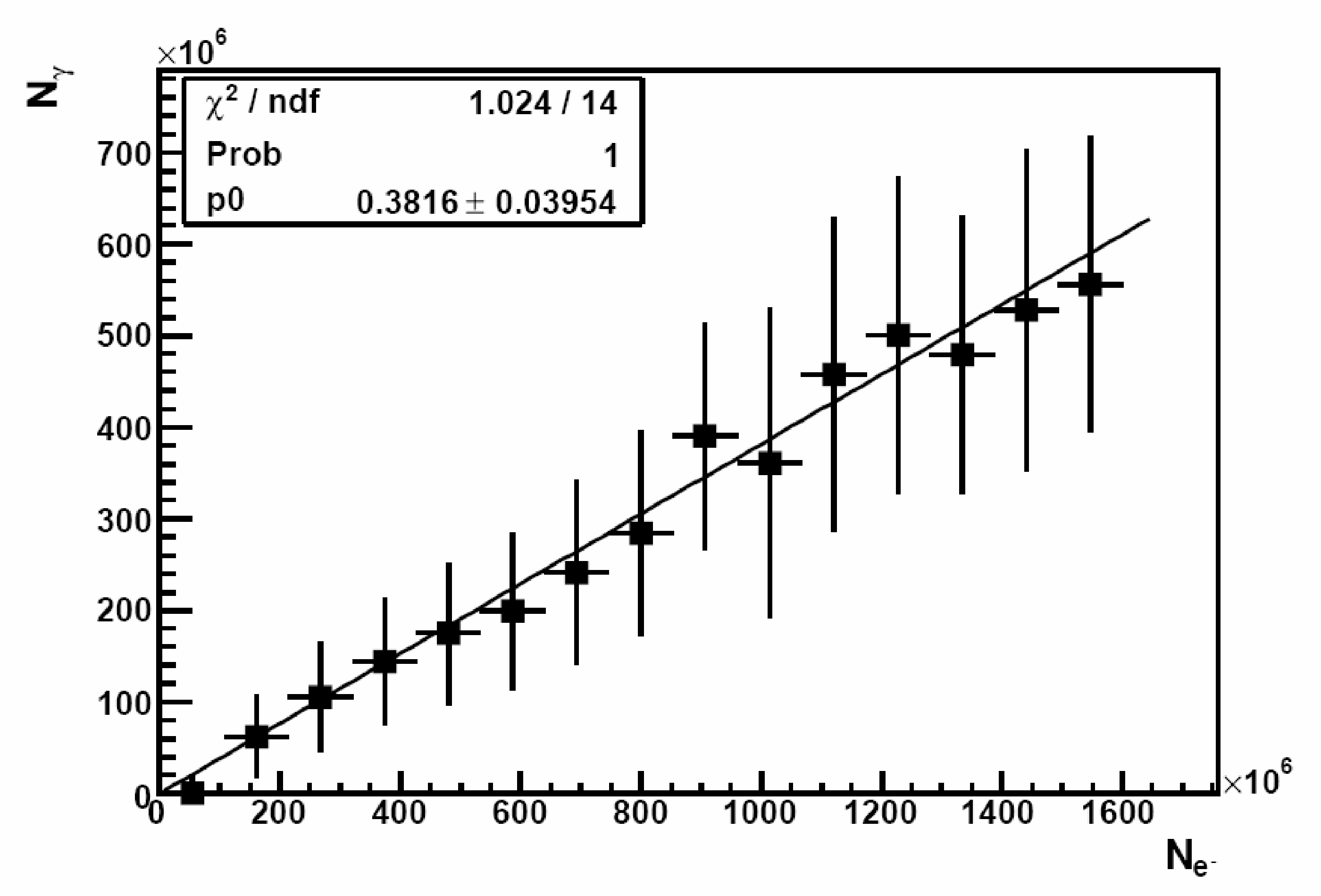
Photomultiplier gives third component

- Wire readout
- Background alpha particle
- Drift velocity = 10 cm/microsecond
- X = 7.5 cm, Y = 0, Z = 2.0 cm

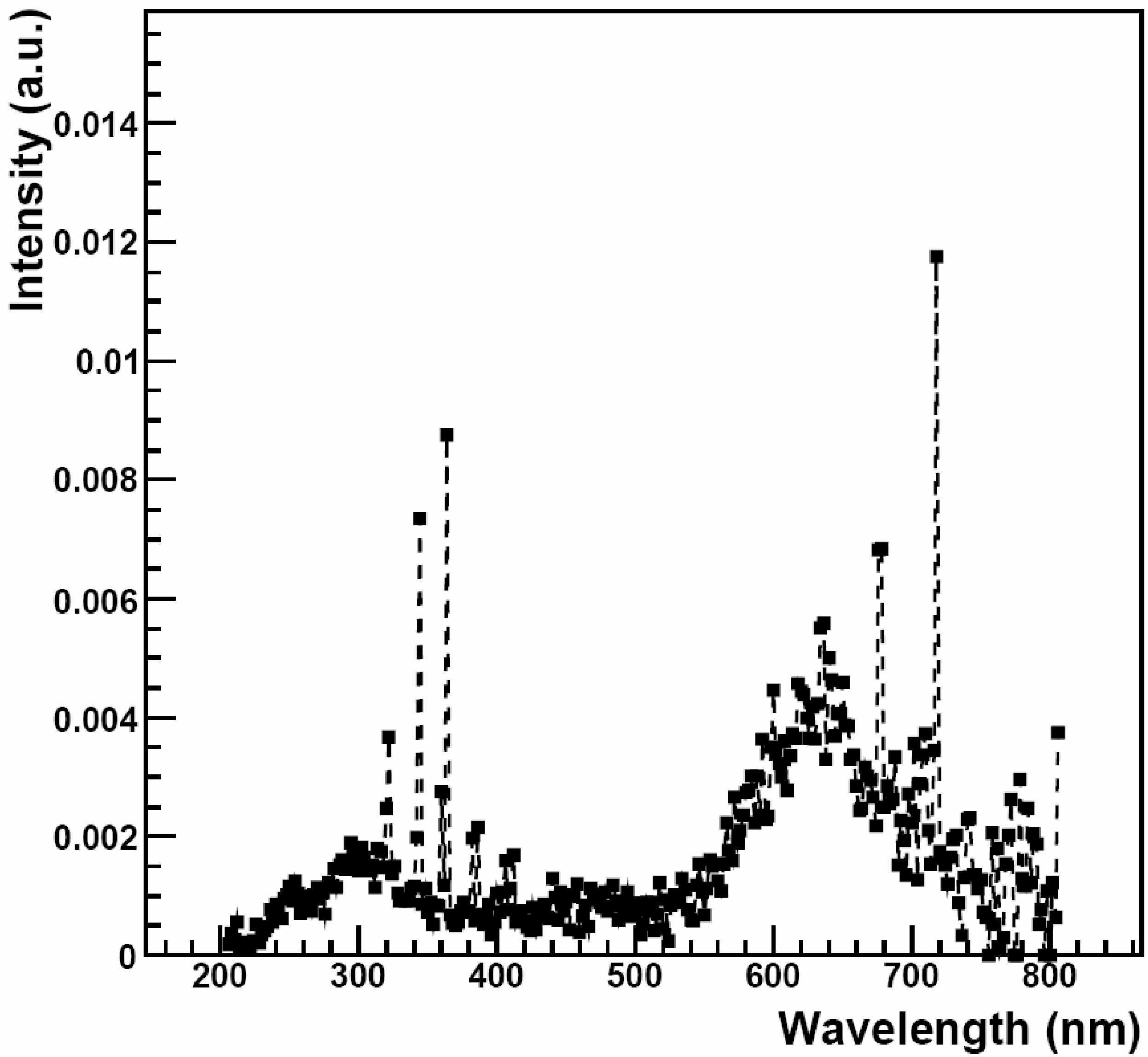




We have measured photon to electron ratio:
0.4 photons per electron in CF4



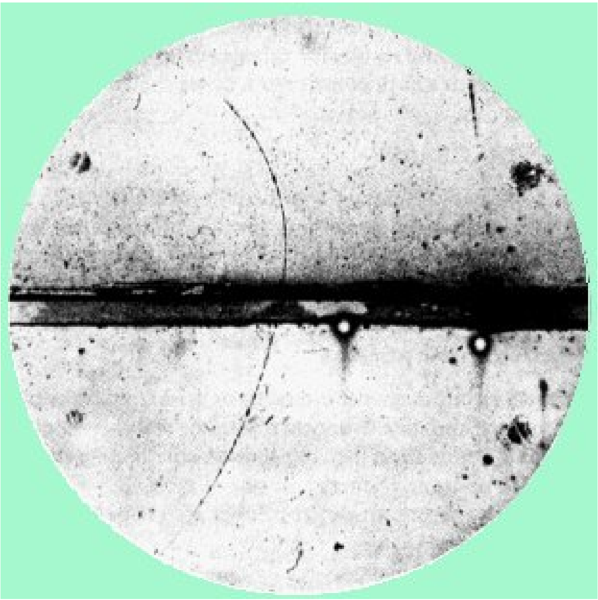
We have measured CF4 spectrum

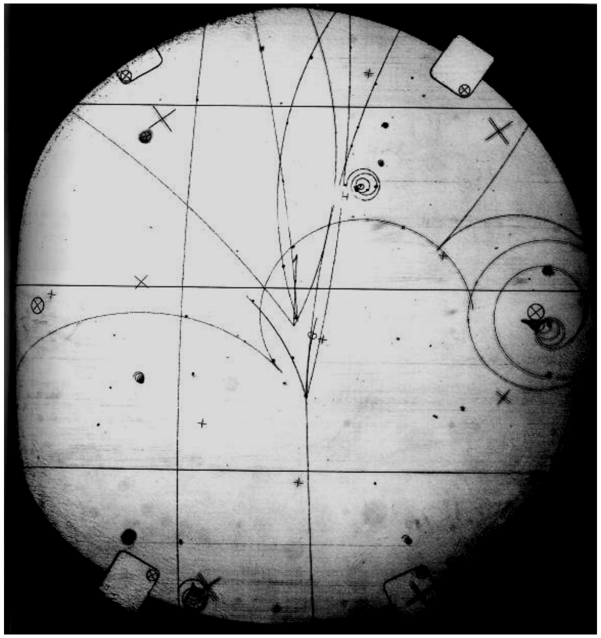


Tracking detectors have always led the way in making fundamental discoveries in particle physics

- **Modern trackers have thousands to millions of channels with individual electronic readout, while "classical" trackers used photographic readout:**
  - **Cloud chamber**
  - **Nuclear emulsion**
  - **Bubble chamber**

- Cloud chamber (radioactivity, Auger emission, positron, muons)
- Nuclear emulsion (pion, strange quark, heavy nuclei in cosmic rays)
- Bubble chamber (hadron resonances)





2nd generation DM-TPC prototype

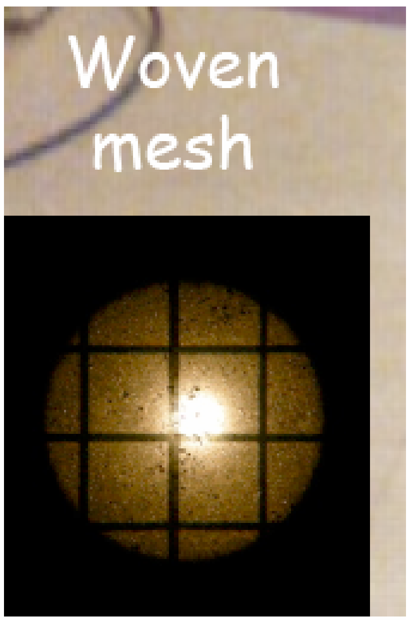
nothing inside except gas, 24 cm diameter mesh/0.5 mm gap amplification plane, field cage

GEM's did not work (too thin for avalanche to form at low P)

Wires work well but difficult to get small pitch, granularity

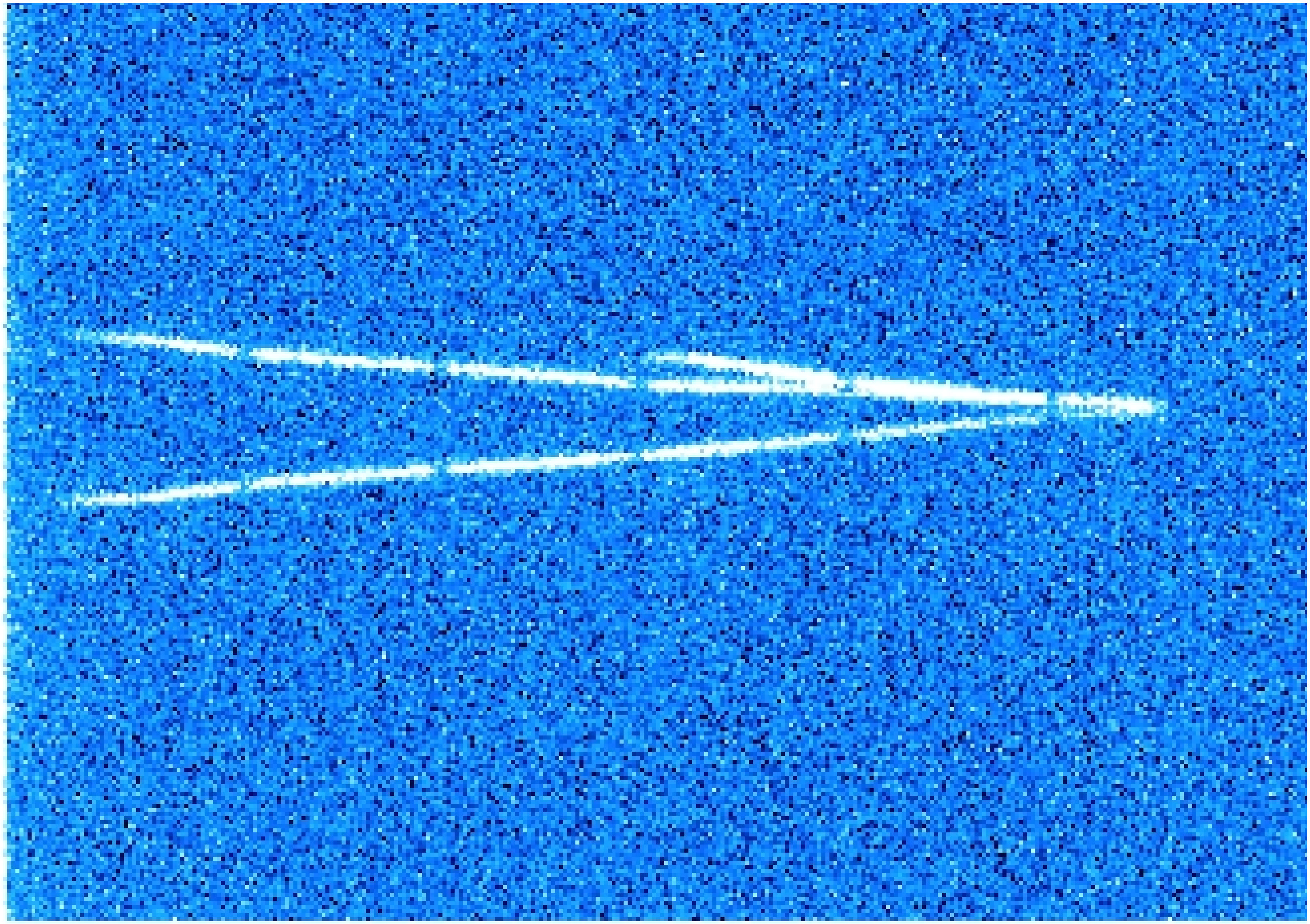
Mesh is essentially cost free and works very well

Micromegas are expensive (we will try for comparison)

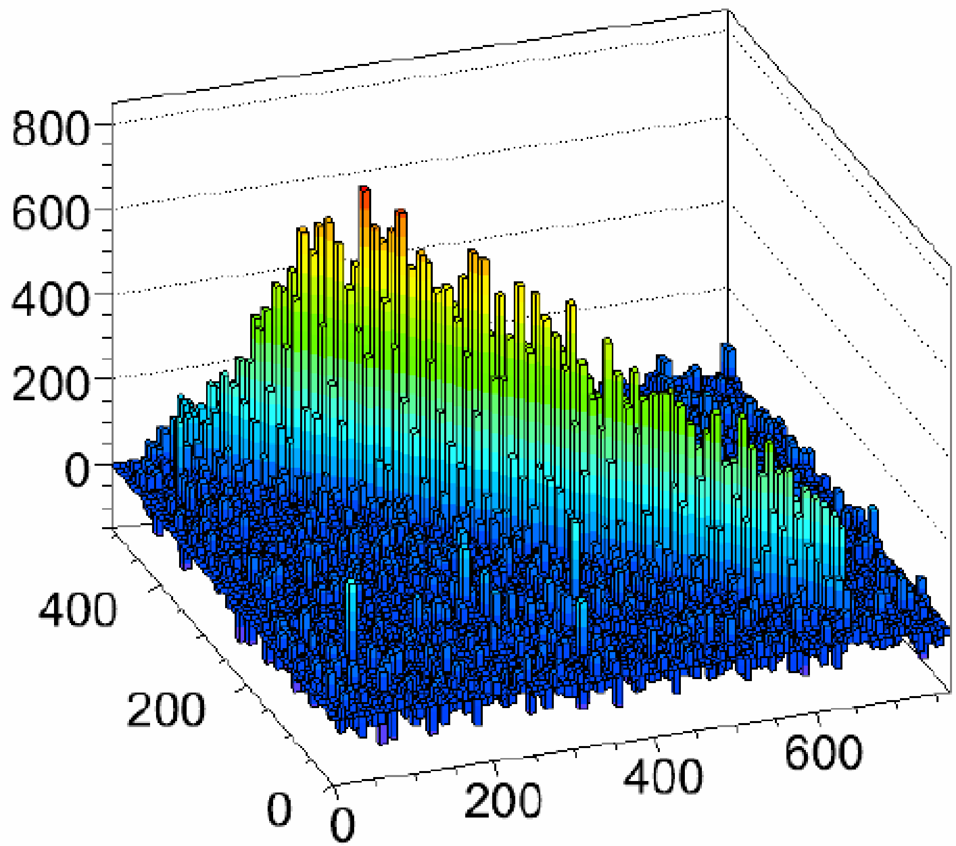


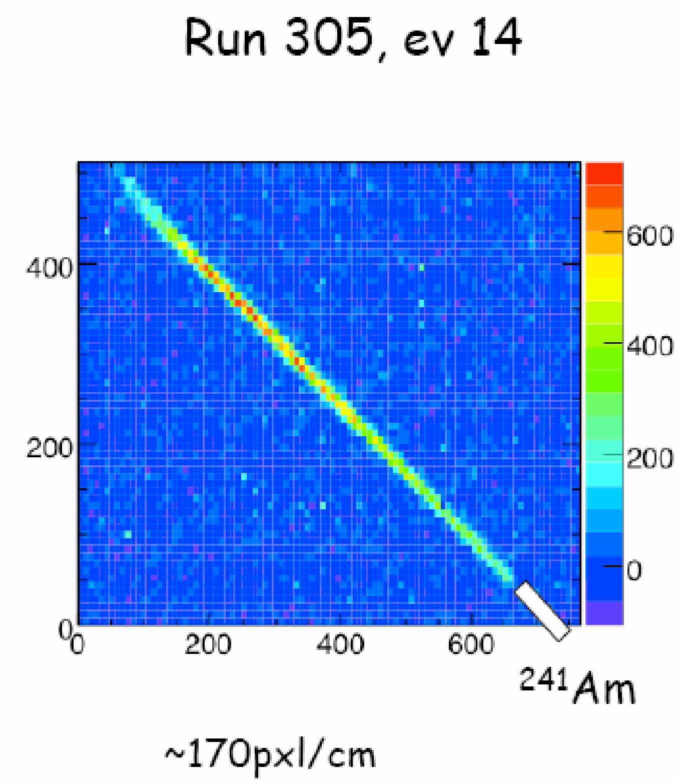
- 320 micron pitch
- 30 micron wire diameter
- 81% transparency

14 cm, 5 MeV alpha tracks with 2nd generation prototype in 80 torr with mesh amplification plane

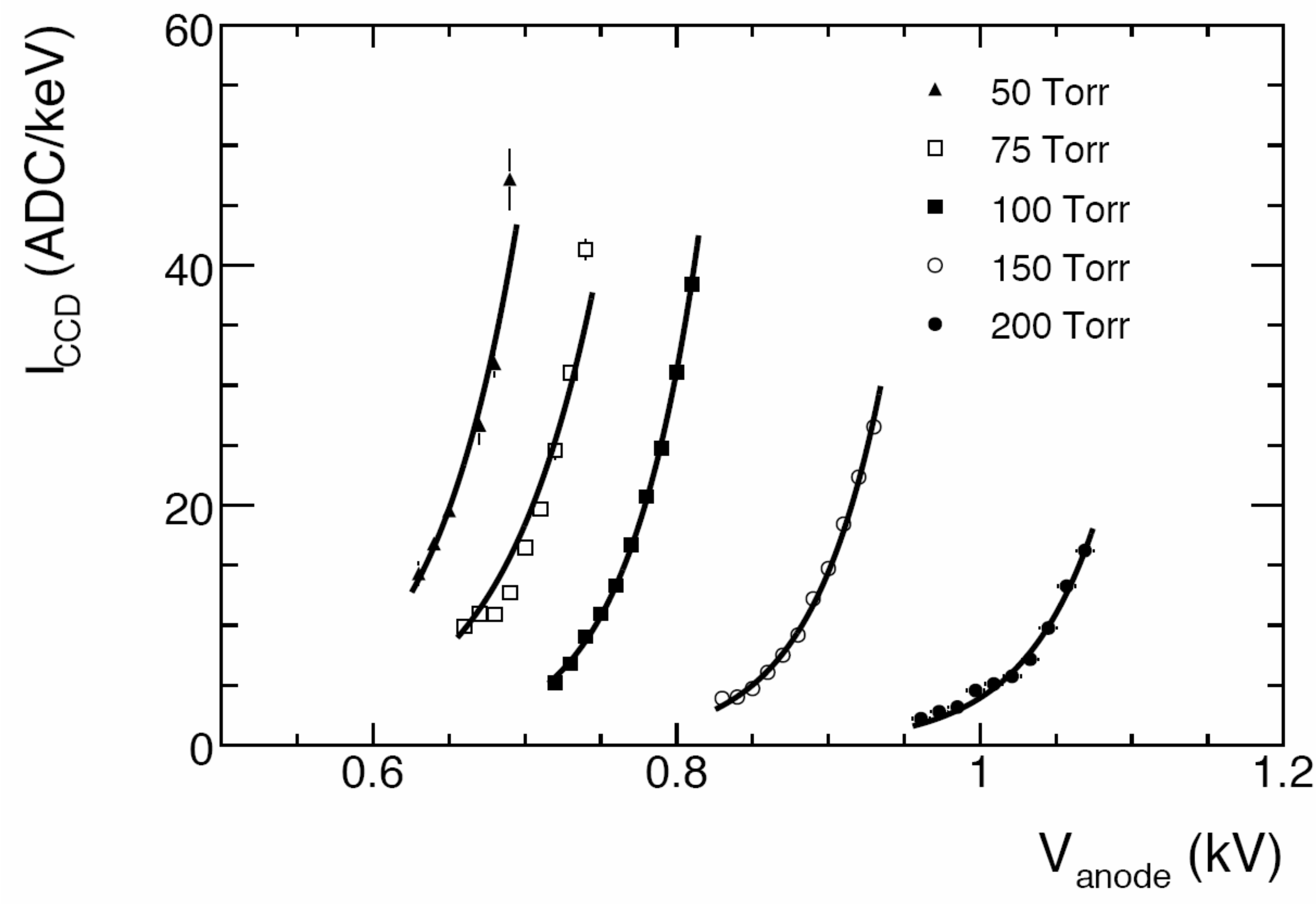


Frame III: Bragg Peak

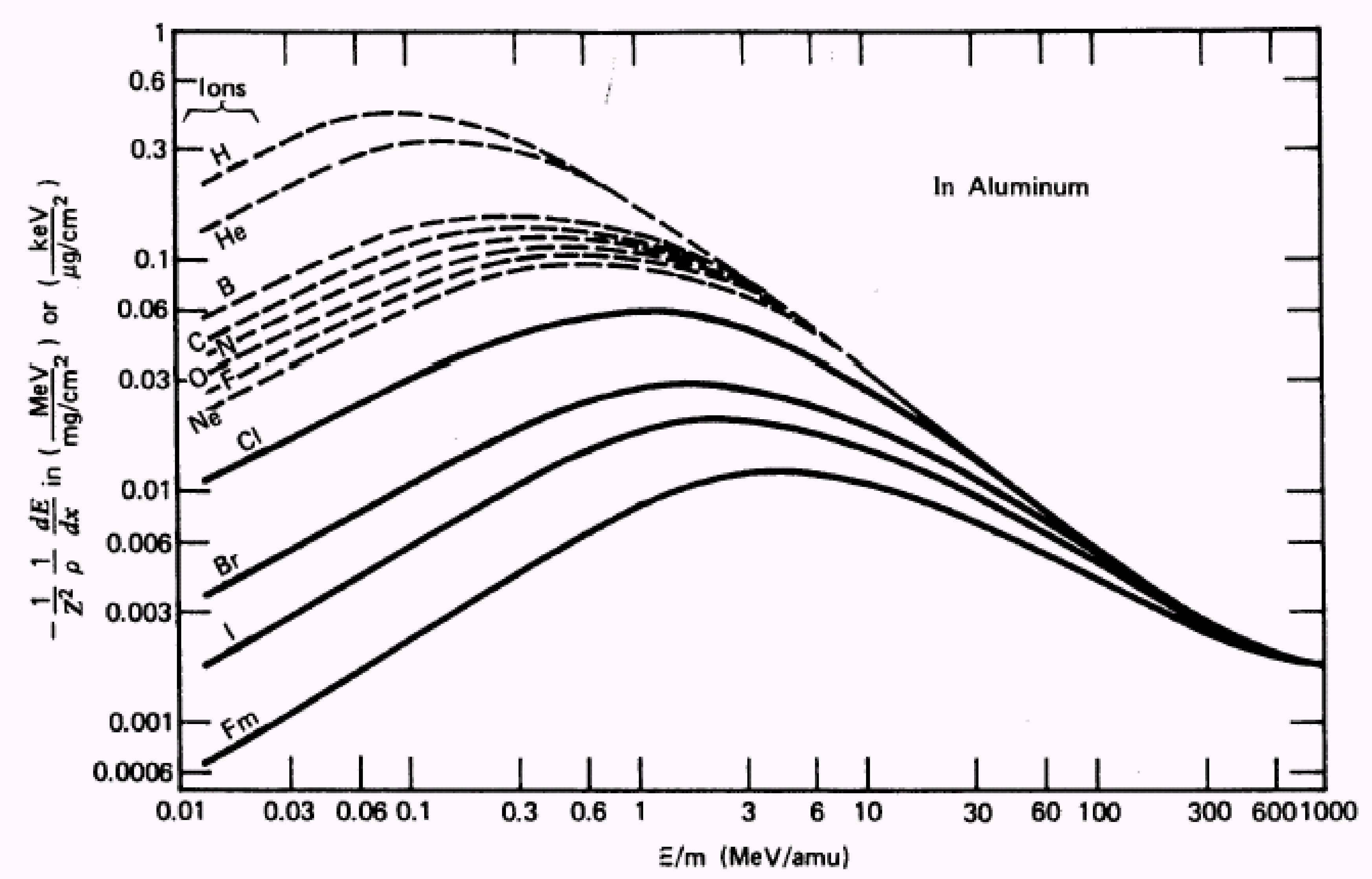




For 30 keV F recoil, dE/dx = 600 keV/(mg/cm2); 1mm range in 40 torr CF4, 16 pixels, 50 ADU/pixel (noise = 7 ADU)



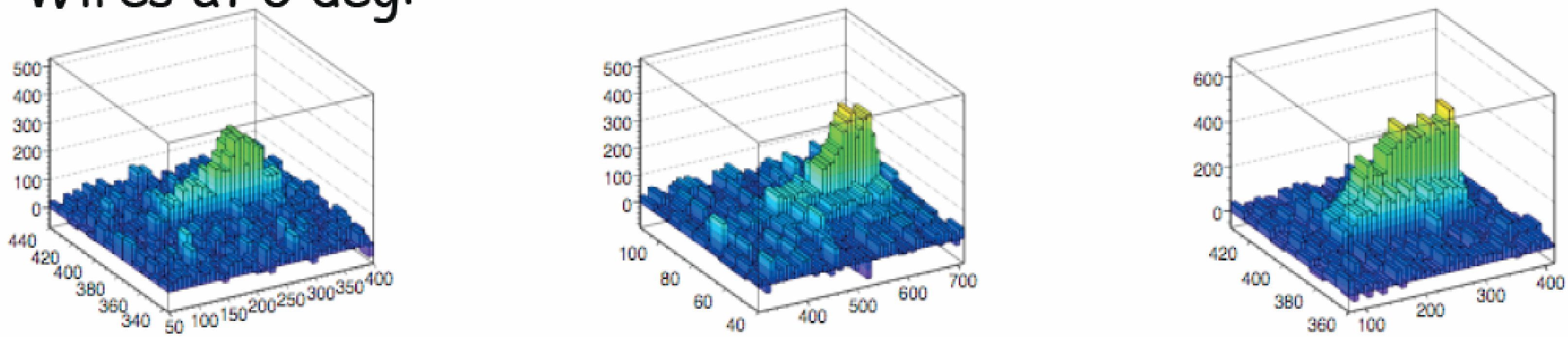
Direction can be measured from ionization profile below the Bragg peak



NIM A584:327-333,2008

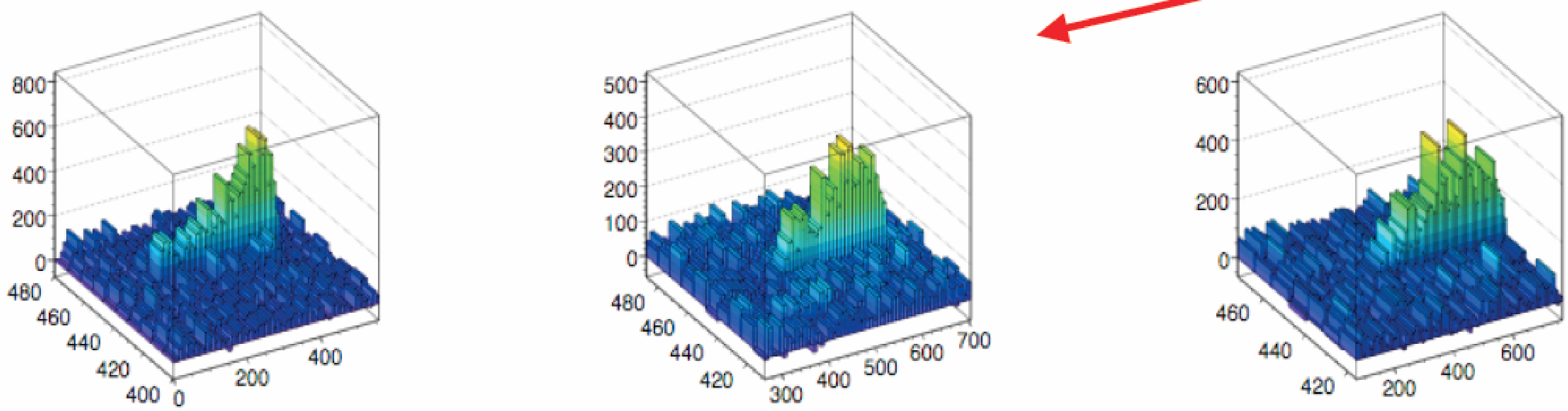
Observation of “head-tail” in F recoils

Wires at 0 deg:



Wires at 180 deg:

Direction of neutrons

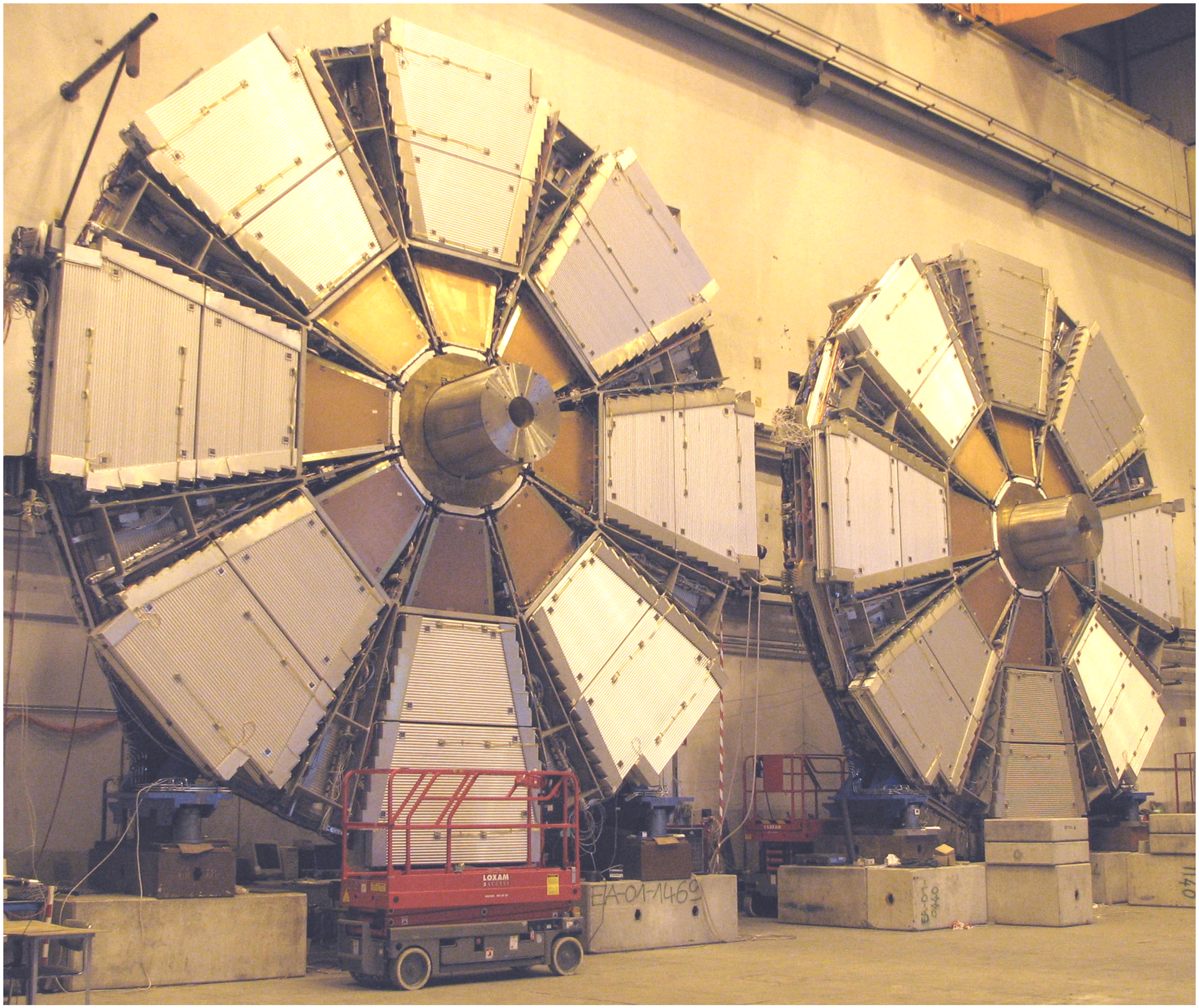


There is much background radiation that complicates search for dark matter

Excellent background rejection is another important feature of the DM-TPC

ATLAS Small Wheel Monitored Drift Tube muon chambers

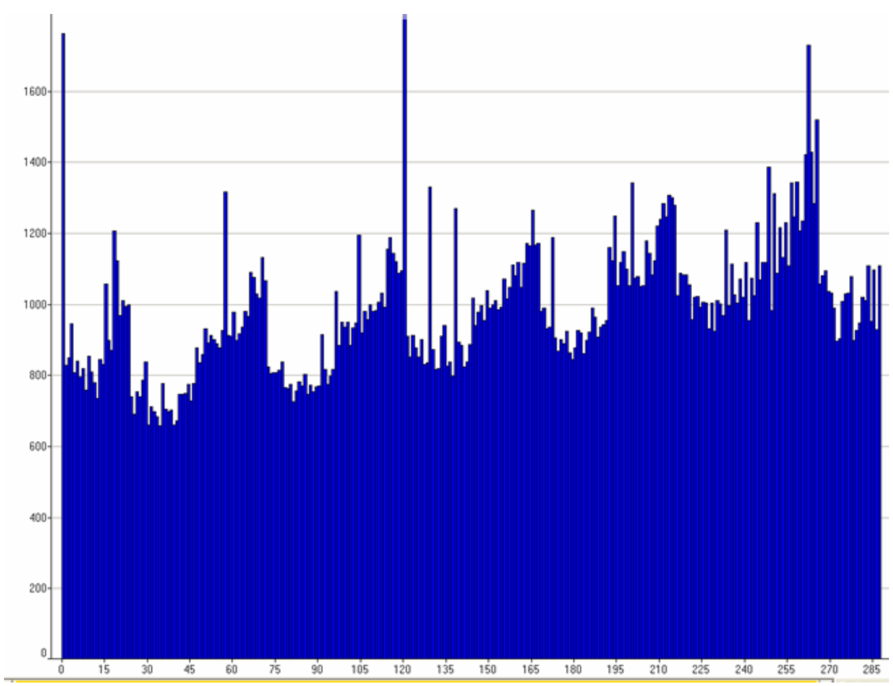
steel shielding disk on back side



Calibrate with background radiation
15 hr commissioning runs – 3 minutes live time
Rates for one chamber (2 square meters)

- 1500 Hz external x-rays
- 100 Hz βs from Al tubes
- 5 Hz αs from Al tubes
- 150 Hz cosmic ray e, mu

Hits/tube for events with 1 tube (x-rays)



Tube number for a chamber

Low background double beta decay experiments played important role in early dark matter searches

0.7 kg Germanium diode detector in Homestake mine for double beta decay search

Journal of Radioanalytical and Nuclear Chemistry, Articles, Vol. 124, No. 2 (1988) 513–521

ACHIEVING ULTRALOW BACKGROUND IN A GERMANIUM SPECTROMETER

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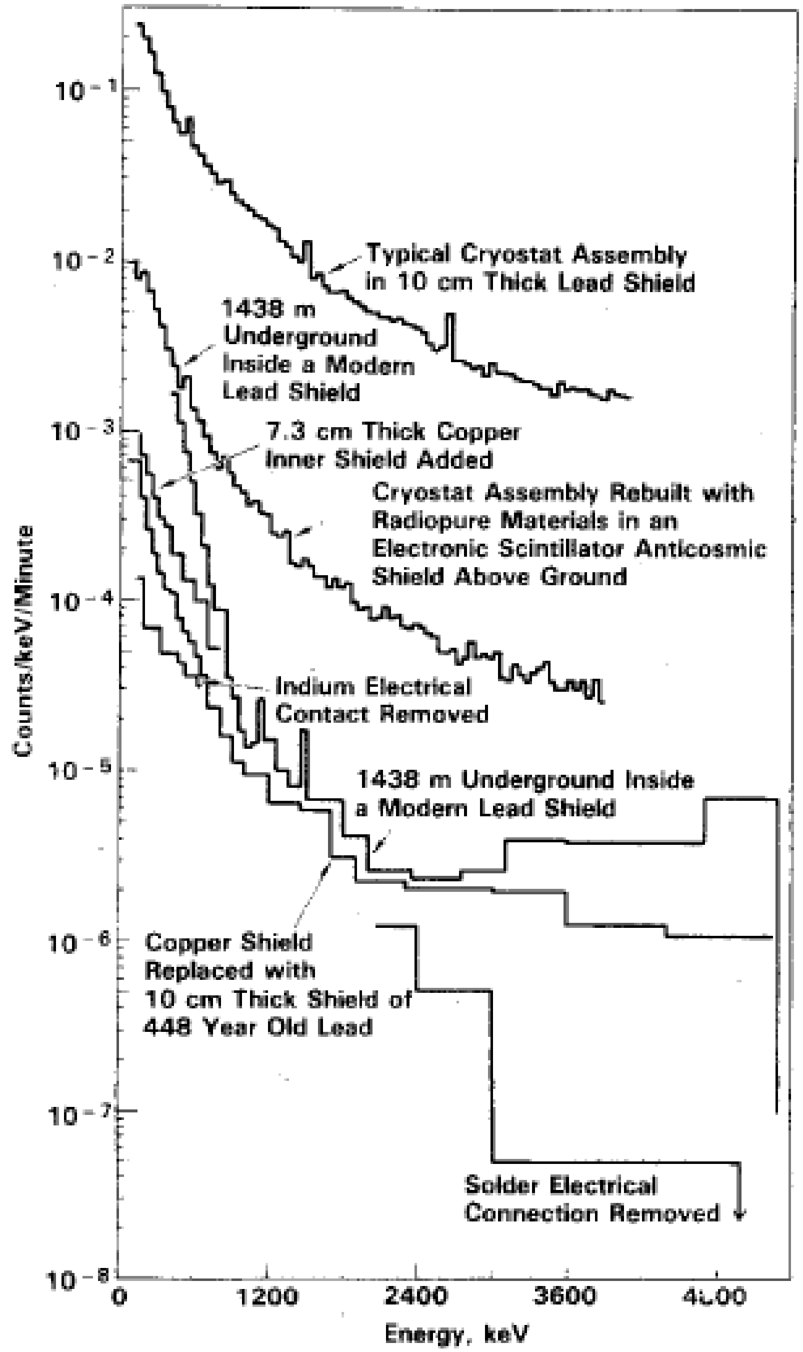
A germanium diode gamma-ray spectrometer has been constructed that exhibits background levels three orders of magnitude lower than conventional low-background laboratory spectrometers in the energy region around 100 keV and five orders of magnitude lower in the energy region above 3 MeV. The steps necessary to achieve this reduction are described, and the application of this technology to construction of ultralow background laboratory based germanium diode gamma-ray spectrometers is discussed.



Typical Cryostat Assembly in 10 cm Thick Lead Shield
1438 m Underground Inside a Modern Lead Shield
7.3 cm Thick Copper Inner Shield Added
Cryostat Assembly Rebuilt with Radiopure Materials in an Electronic Scintillator Anticosmic Shield Above Ground
Indium Electrical Contact Removed
1438 m Underground Inside a Modern Lead Shield
Copper Shield Replaced with 10 cm Thick Shield of 448 Year Old Lead
Solder Electrical Connection Removed
Counts/keV/Minute
Energy, keV

Heavy, Standard, Dirac Neutrinos ruled out in 1987

electronic threshold = 4 keV for minimum recoil of 15 keV

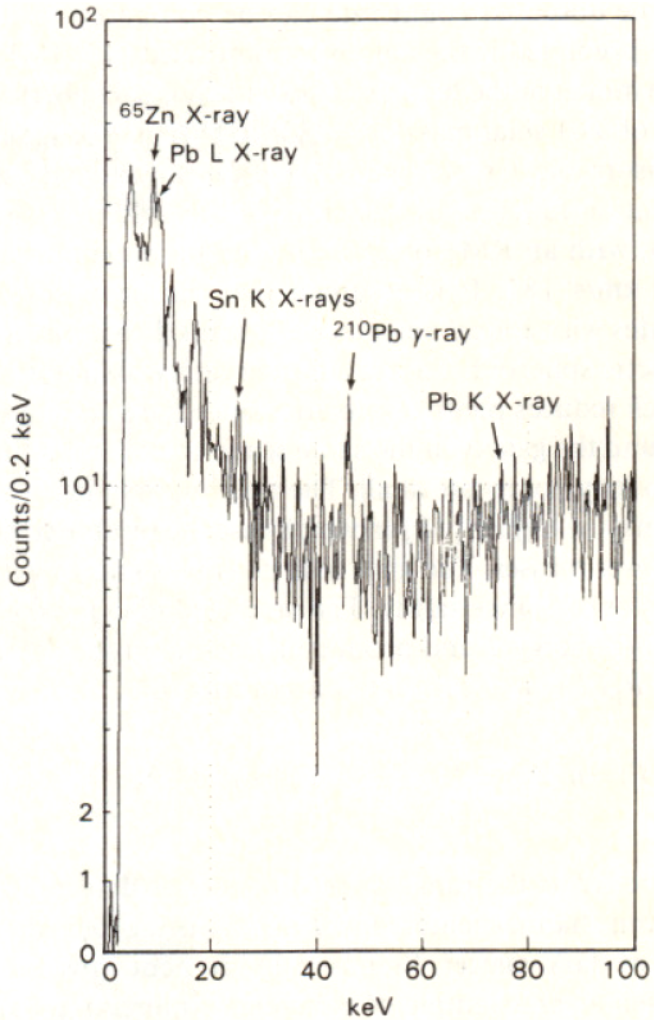
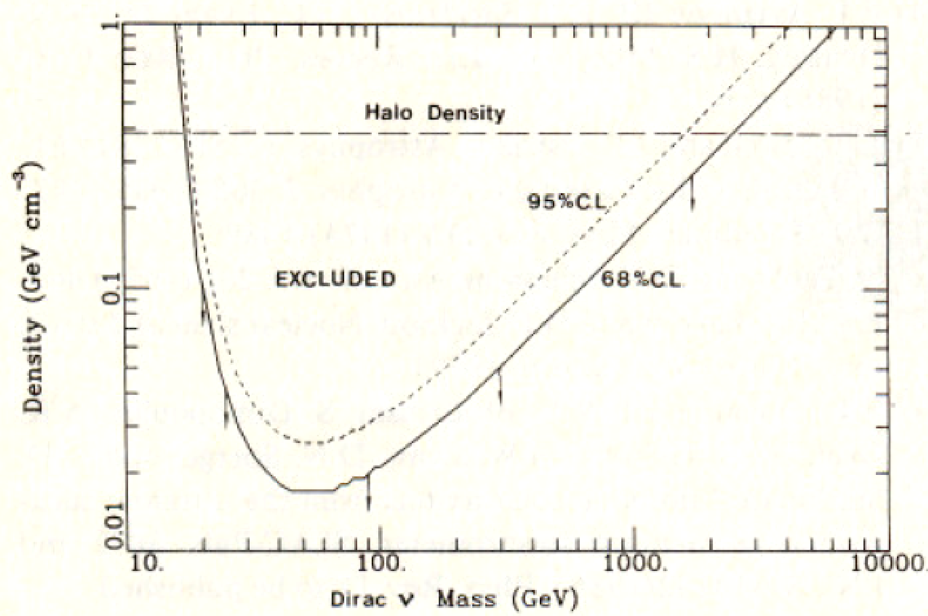


Fig. 2. 1000 h of data from the Ge spectrometer are shown. The width of each channel is 0.2 keV. The identified peaks result from the decay products of radioactivity in the exposed solder.



LIMITS ON COLD DARK MATTER CANDIDATES FROM AN ULTRALOW BACKGROUND GERMANIUM SPECTROMETER

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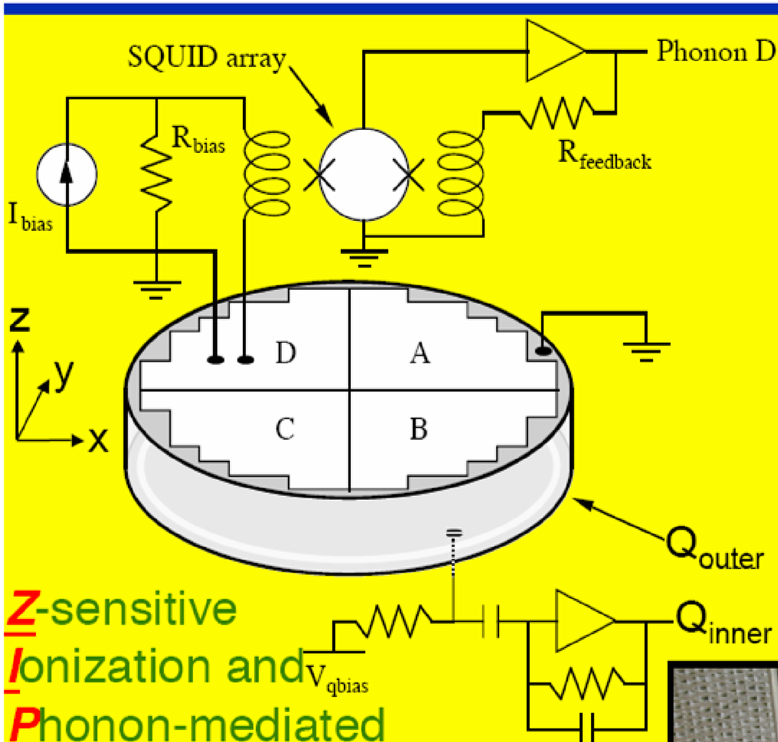
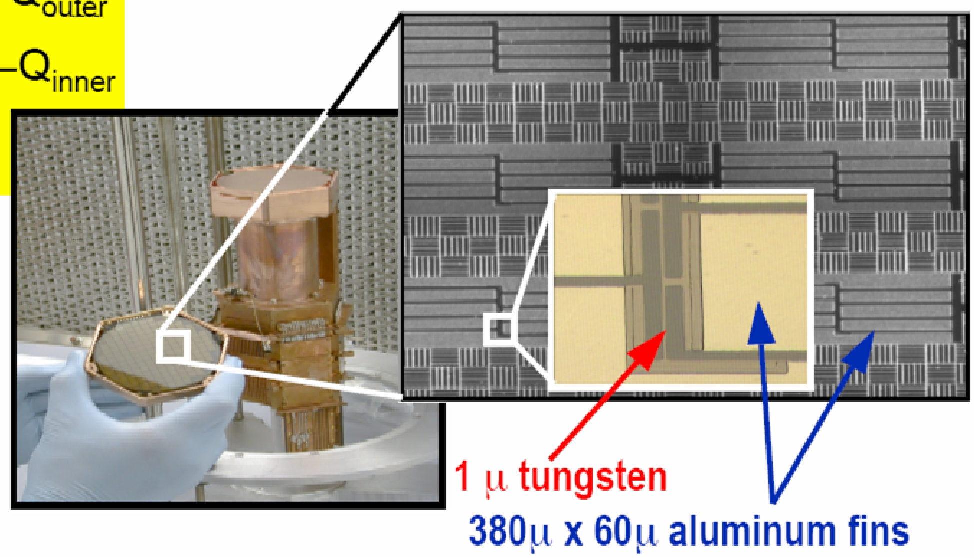
CDMS added phonon detection to reject gamma rays, x-rays, beta particles, and charged cosmic rays

CDMS

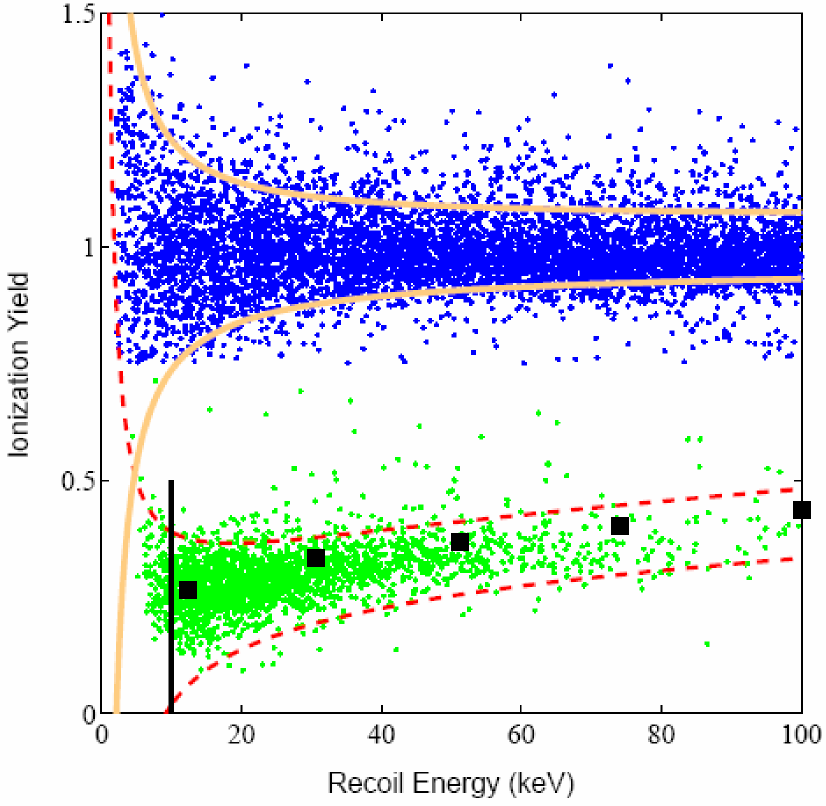


- 250 g Ge or 100 g Si crystal
- 1 cm thick x 7.5 cm diameter
- Photolithographic patterning
- Collect athermal phonons:
  - XY position imaging
  - Surface (Z) event veto based on pulse shape risetime

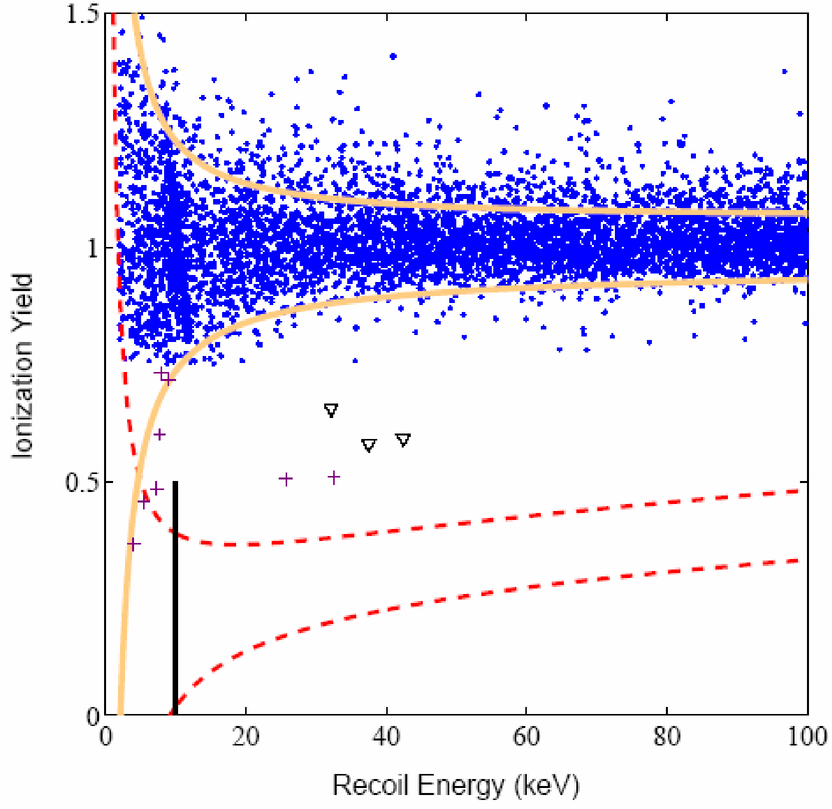
Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer edge



Calibration with gamma and neutron sources



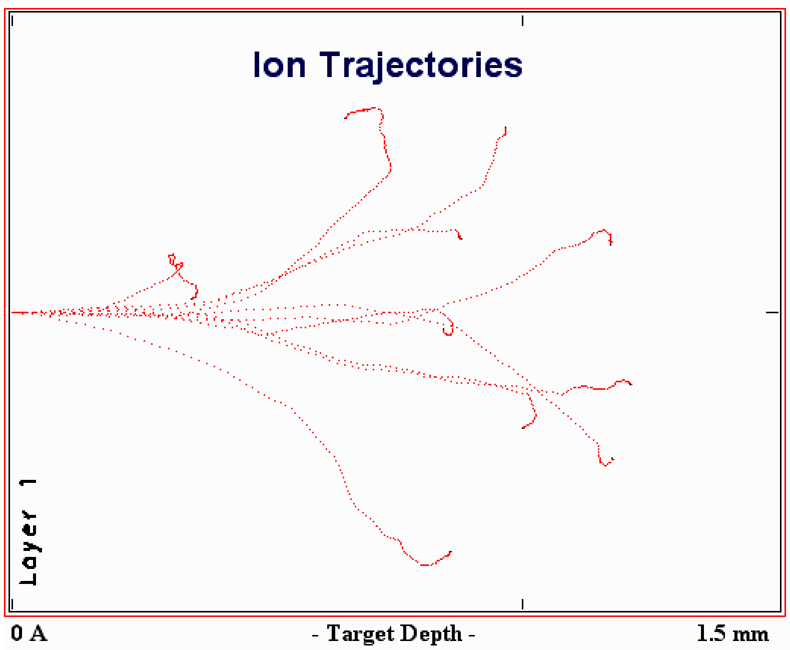
Search at Soudan mine in Minnesota



DM-TPC uses Range vs Energy for particle ID

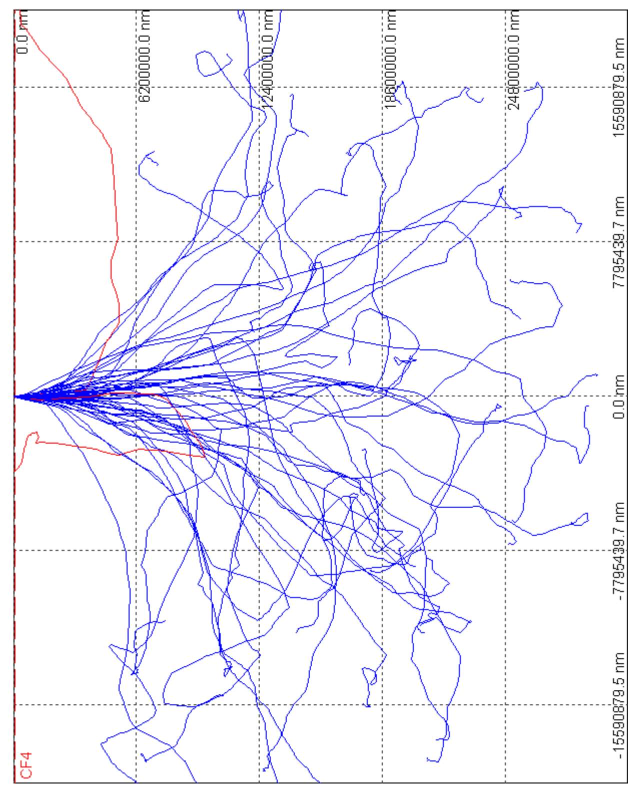
Electron dE/dx = 25 keV/(mg/cm2), below detection threshold

1.5 mm



30keV F ions in 50mbar CF4. Typical ion range is about 1mm. These produce same ionization as 15 keV electrons.

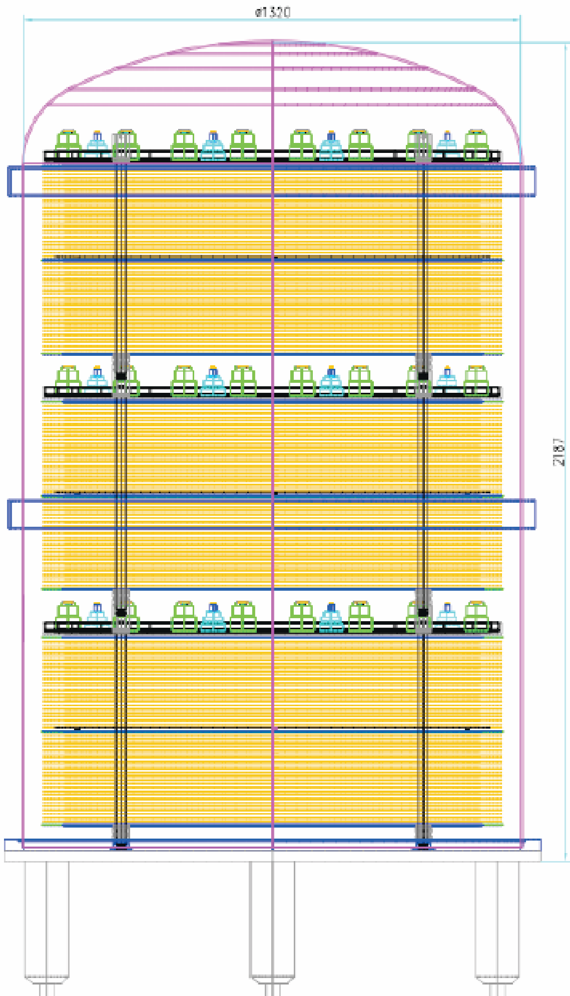
31 mm

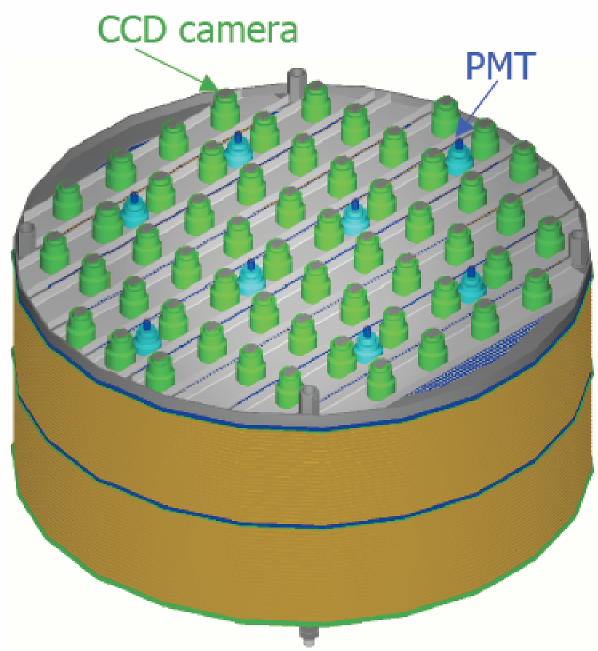


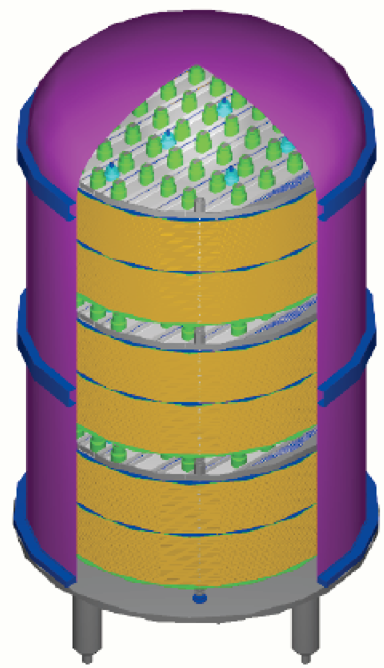
15keV electrons in 50mbar CF4. Typical electron range is about 30mm.

Preliminary

Example: 1.5 m^3 detector



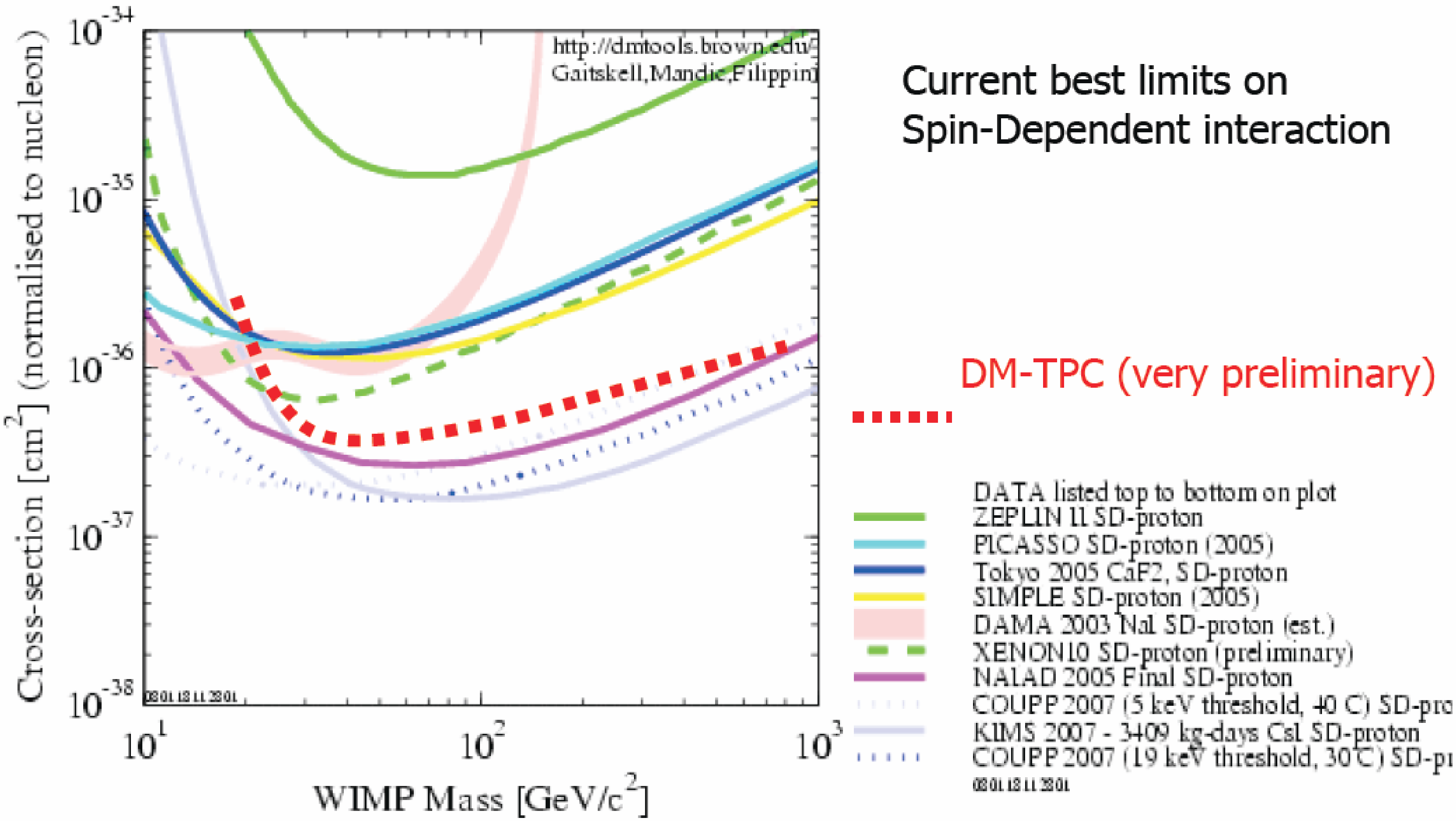




- 3 units --> 3 x (2 x 25) cm drift regions
  - 1m^2 triple mesh circular frames; V_{active}~ 1.5 m^3
- Low-cost CCD cameras inside active volume (20^{o}C)
- 25-50 cameras/plane; KAI220 chip & 0.95/25 lens

Very preliminary

Sensitivity of 1.5 m^3 DM-TPC prototype



Current best limits on Spin-Dependent interaction

DM-TPC (very preliminary)

Conclusions

Much progress so far

- Head-tail effect observed at 100 keV
- Low cost mesh readout with excellent performance
- Development of low cost ccd camera (10% commercial cost)
- Use of photomultiplier for third component

- **Much R&D remains**
  - Optimizations to be done
    - Gain, diffusion, cost, low background materials
  - Dealing with "worms" (direct interactions with ccd chip – eliminate with overlapping fields or with PMT)
  - Development of PMT trigger
  - CCDs, PMTs inside or outside?
- **We are looking forward to contributing to dark matter discovery program, either as follow-up to confirm and measure directional properties, or to make first detection**
- **Goal is to develop low cost reliable units that can be mass produced, to get up to 100 kg or more of detector mass, with about 300 chambers**