A Direction Sensitive Dark Matter Detector

Steve Ahlen

Boston University

March 7, 2007

Evidence of Non-Baryonic Dark Matter

- Fritz Zwicky, 1933: large velocities of galaxies in Coma Cluster
- Gamow, Alpher, 1940’s and many since: big bang nucleosynthesis limits amount of baryonic matter
- Vera Rubin and others, 1970’s: flat rotation curves of essentially all spiral galaxies
- Bullet cluster, 2006: collision of two clusters of galaxies
  - Optical: galaxies pass through with small interaction
  - X-ray: hot gas (10 times mass of visible galaxies) pancakes due to large interaction
  - Weak lensing of background galaxies: most mass passes through with no interaction
- Concordance model (cosmic microwave background, dark energy, large scale structure, inflation, etc.)

ROTATIONAL PROPERTIES OF 21 Sc GALAXIES WITH A LARGE RANGE OF LUMINOSITIES AND RADII, FROM NGC 4605 ($R = 4$ kpc) TO UGC 2885 ($R = 122$ kpc)

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Department of Terrestrial Magnetism, Carnegie Institution of Washington
Received 1979 October 11; accepted 1979 November 29

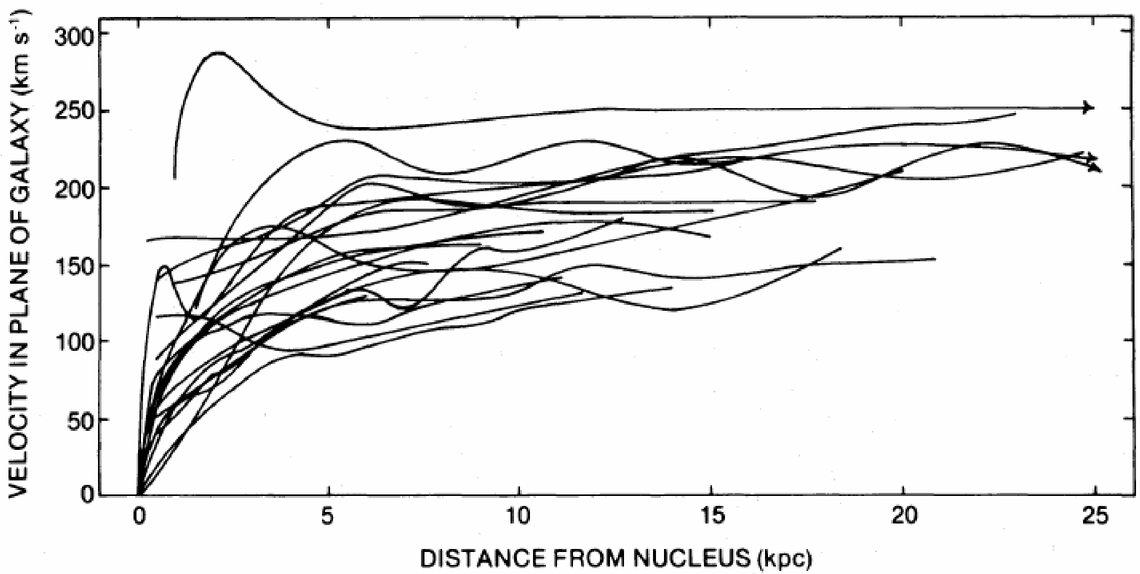


FIG. 6.—Superposition of all 21 Sc rotation curves. General form of rotation curves for small galaxies is similar to initial part of rotation curve for large galaxies, except that small galaxies often have shallower nuclear velocity gradient and tend to cover the low velocity range within the scatter at any R.

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

Douglas Clowe,[2] Maruša Bradač,[3] Anthony H. Gonzalez,[4] Maxim Markevitch,[5,6]
Scott W. Randall,[5] Christine Jones,[5] and Dennis Zaritsky[2]

Received 2006 June 6; accepted 2006 August 3; published 2006 August 30

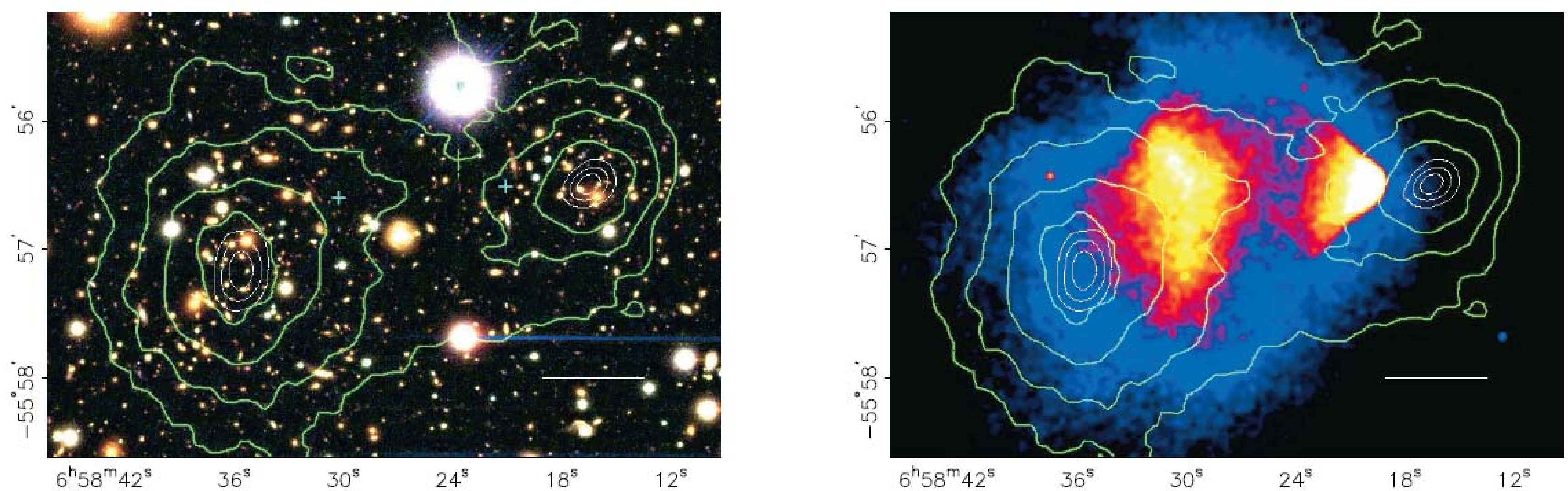


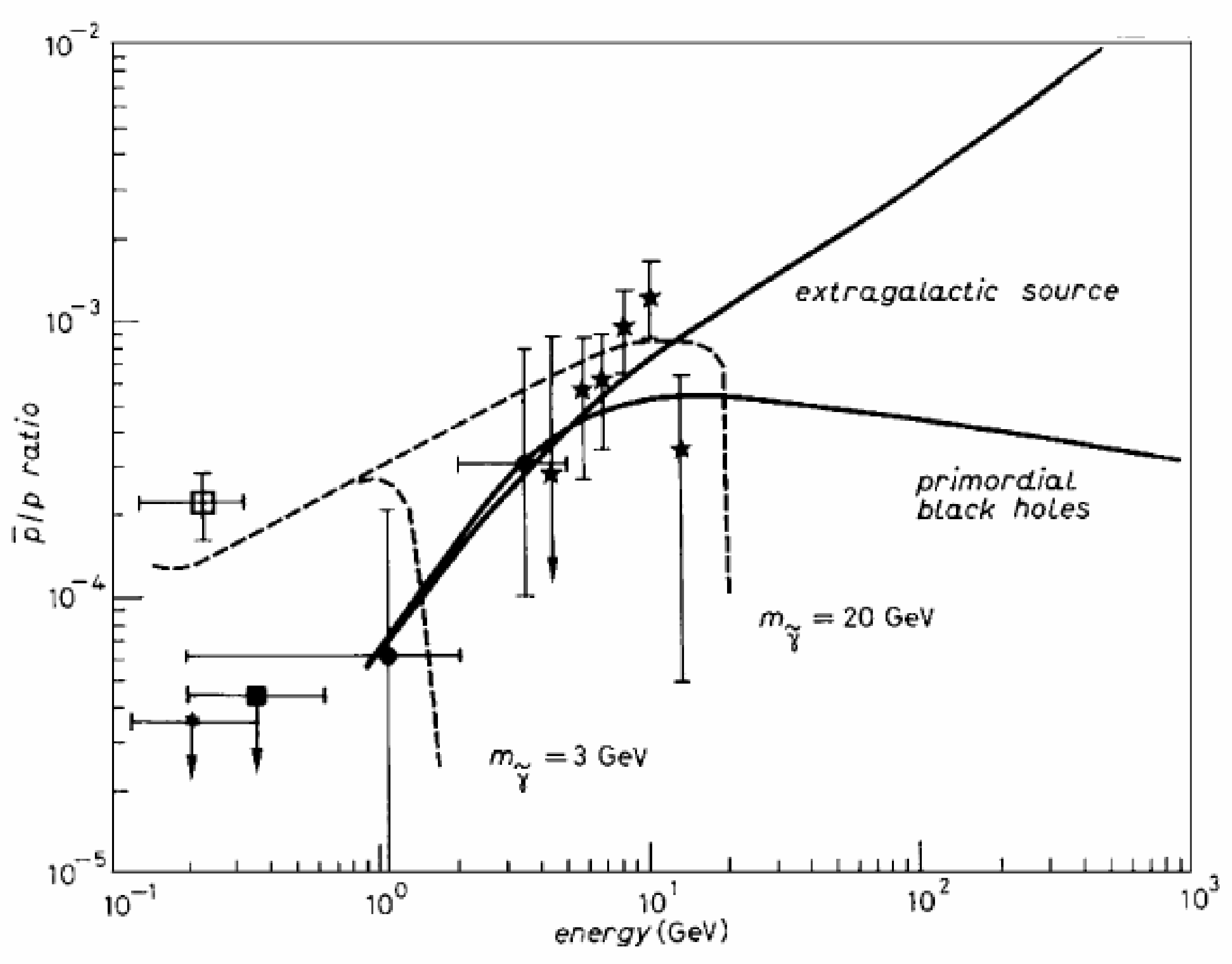
Fig. 1.—*Left panel*: Color image from the Magellan images of the merging cluster 1E 0657−558, with the white bar indicating 200 kpc at the distance of the cluster. *Right panel*: 500 ks *Chandra* image of the cluster. Shown in green contours in both panels are the weak-lensing κ reconstructions, with 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.

Weakly Interacting Massive Particles (WIMPs)

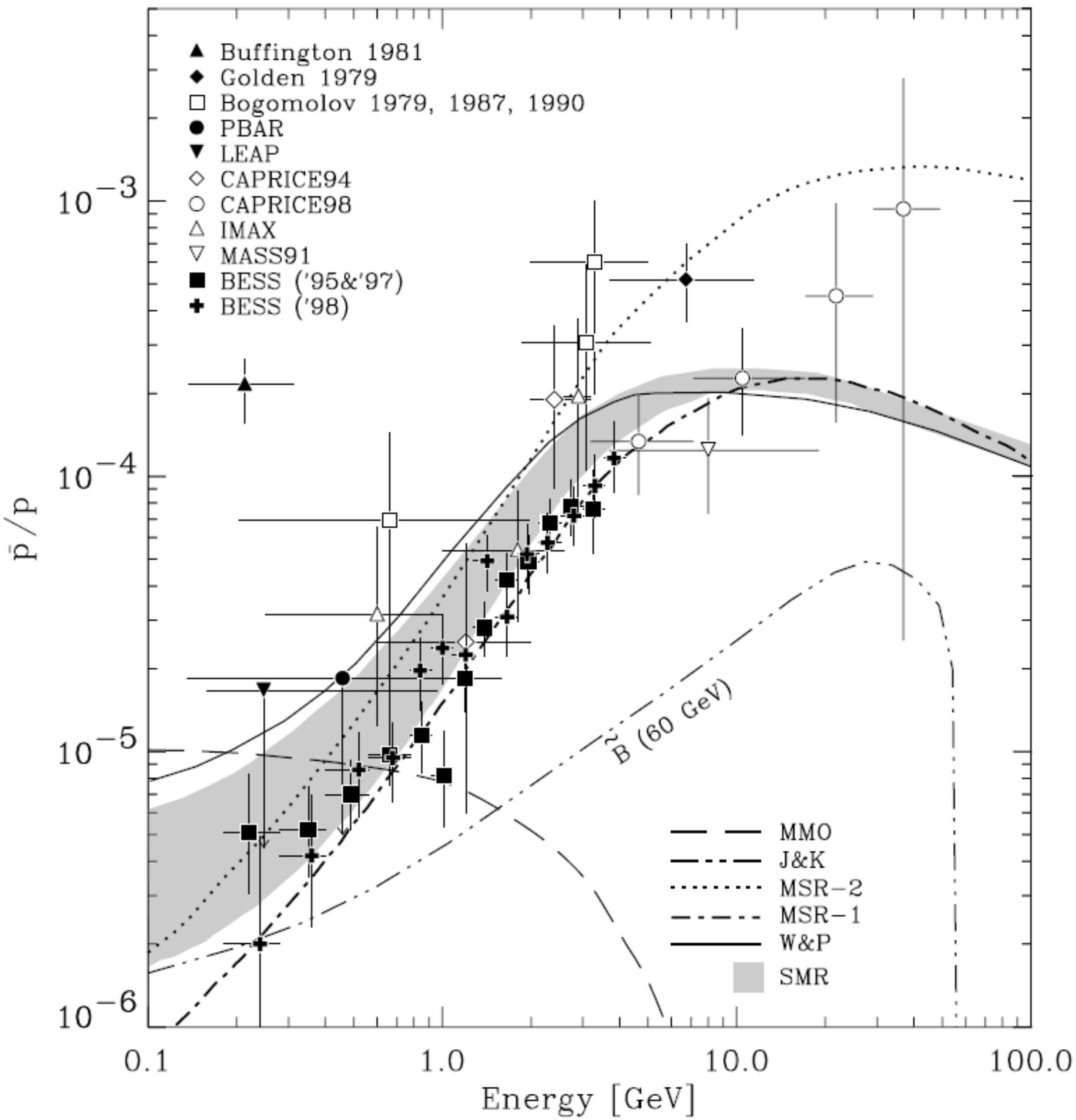
- Lightest supersymmetric particle is a leading candidate for dark matter
- Isothermal halo of our Galaxy (~ 0.001 c)
- Annihilation in Galaxy to make antiprotons
- Annihilation in Sun to make neutrinos
- Elastic interactions with nuclei
  - Many possible reactions (spin-dependent and spin-independent) and cross-sections
  - Recoil energy of tens of keV
  - Rate much less than 1 event / kg / day

Antiproton Excess in Cosmic Rays in 1981 was interpreted as neutralino annihilation in Galaxy

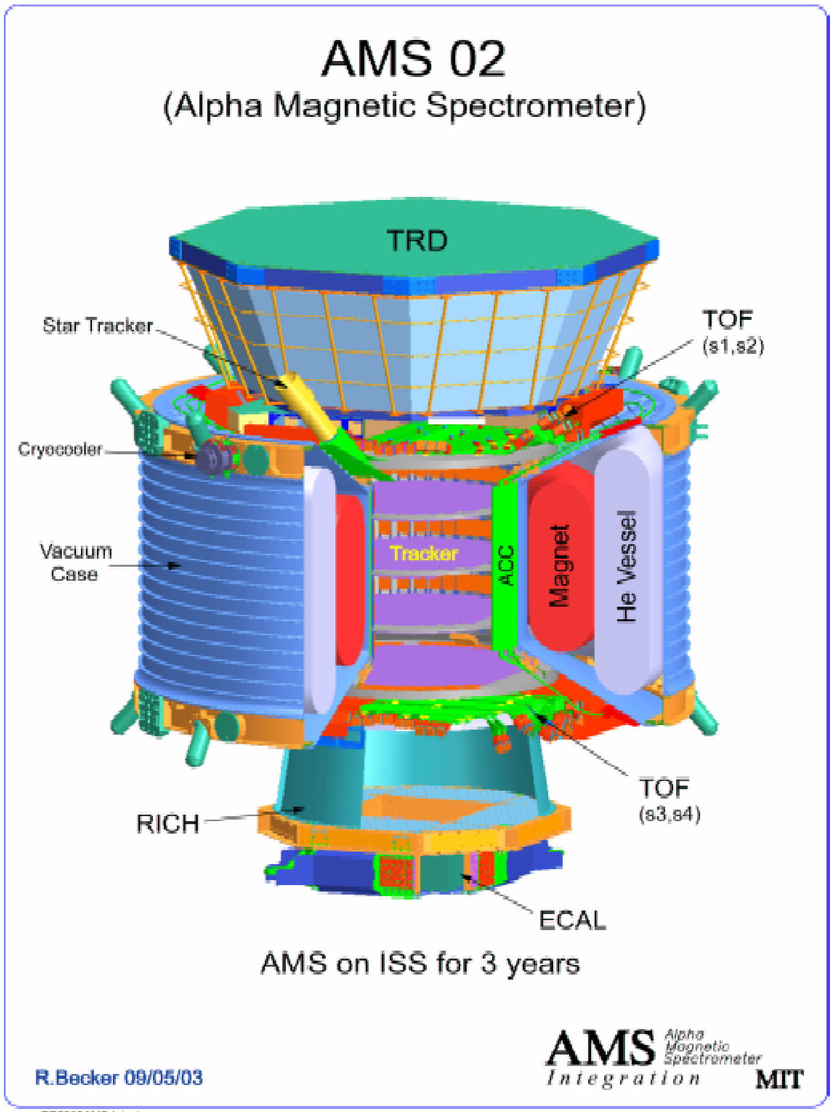
(Silk, J., Srednicki, M., 1984, Phys. Rev. Lett. 50, 624)

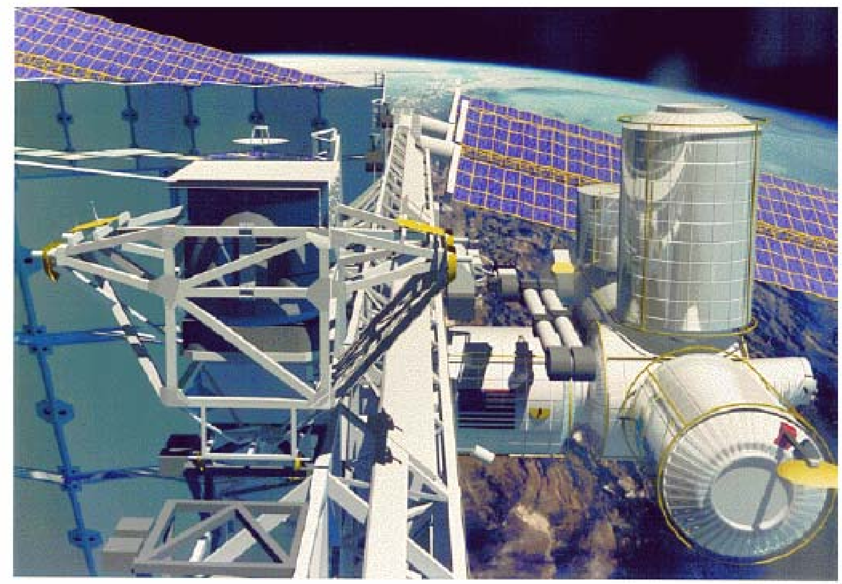


Space Science Reviews **99:** 95–104, 2001.

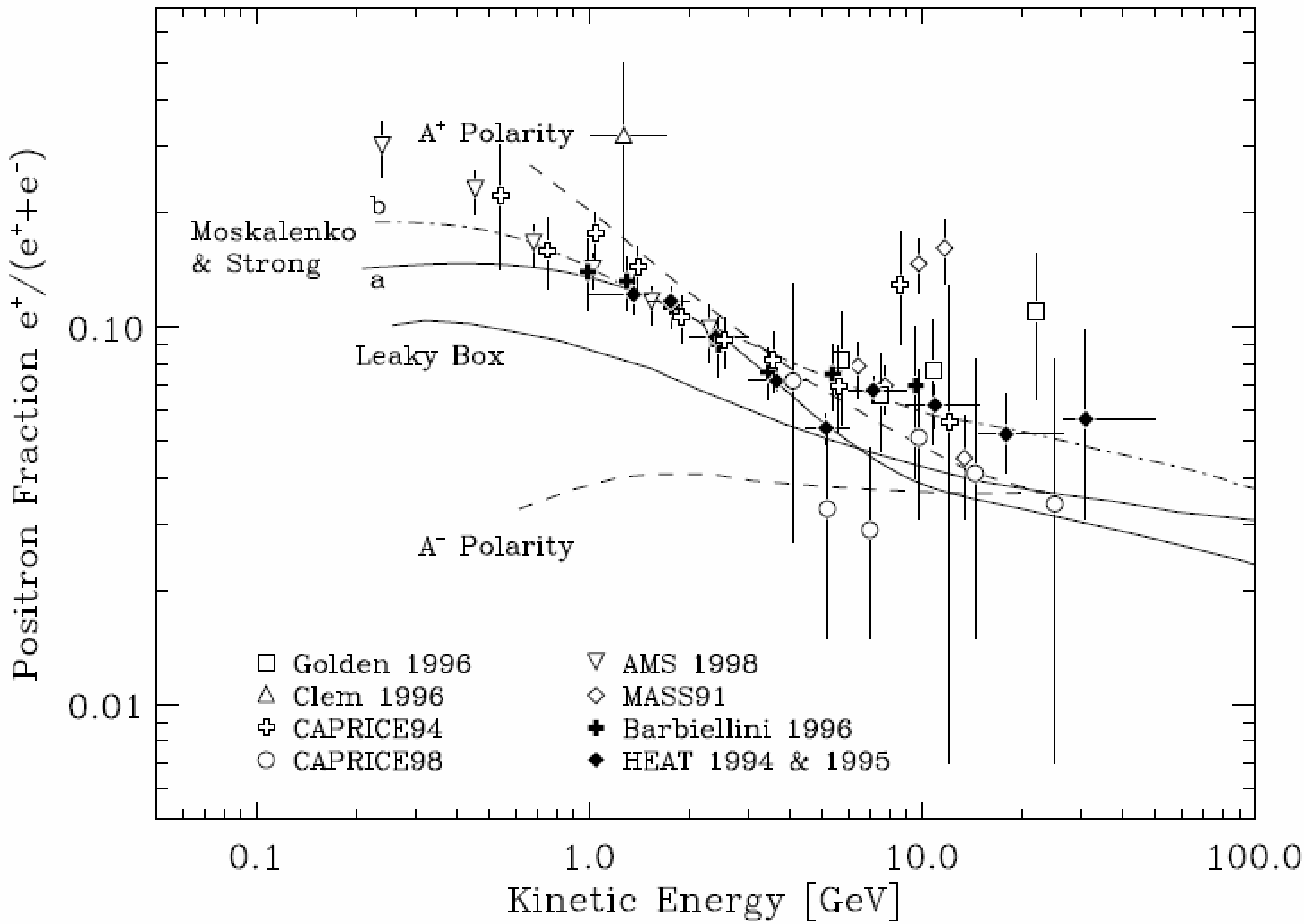


Alpha Magnetic Spectrometer

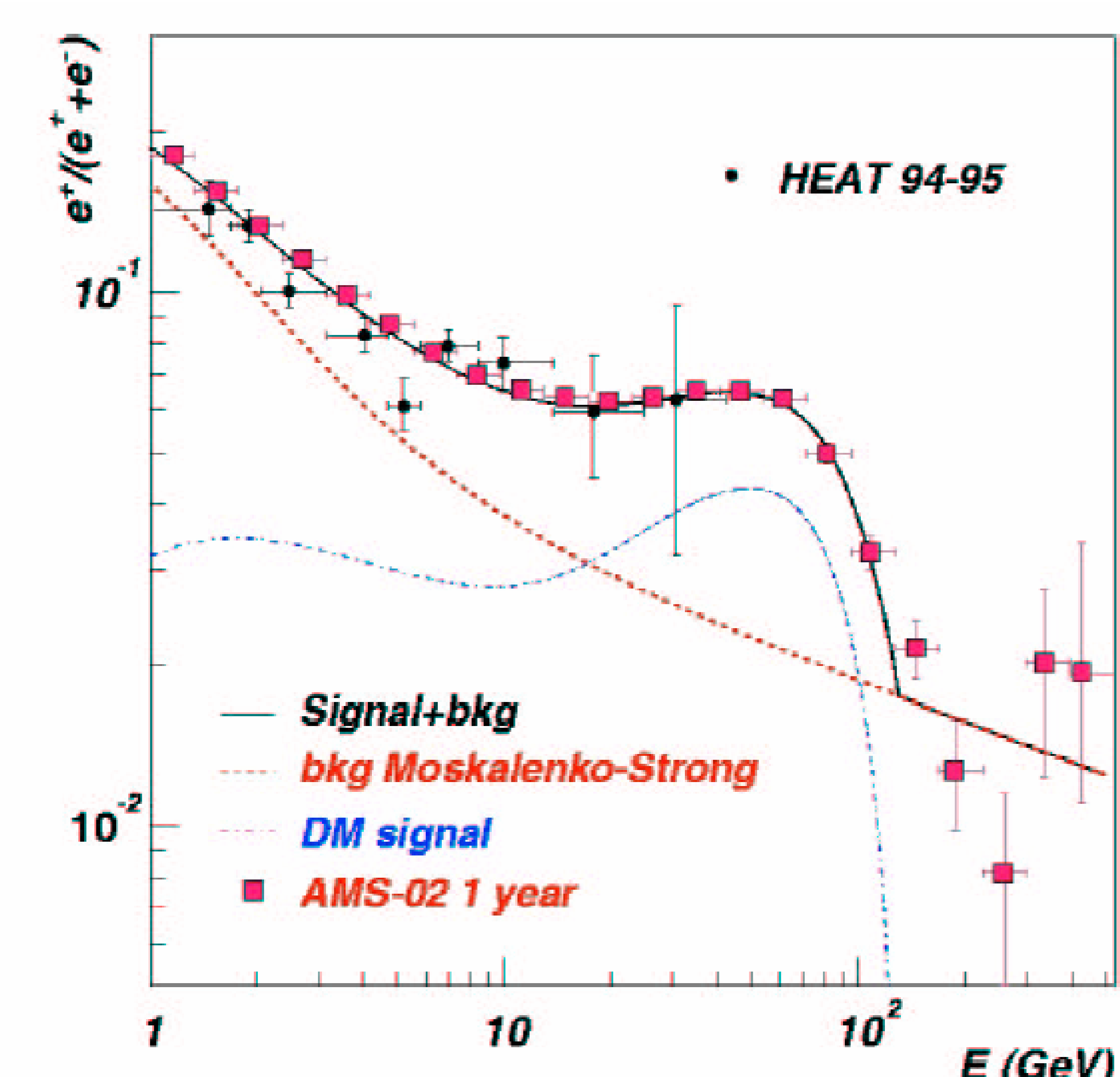




Positron Fraction

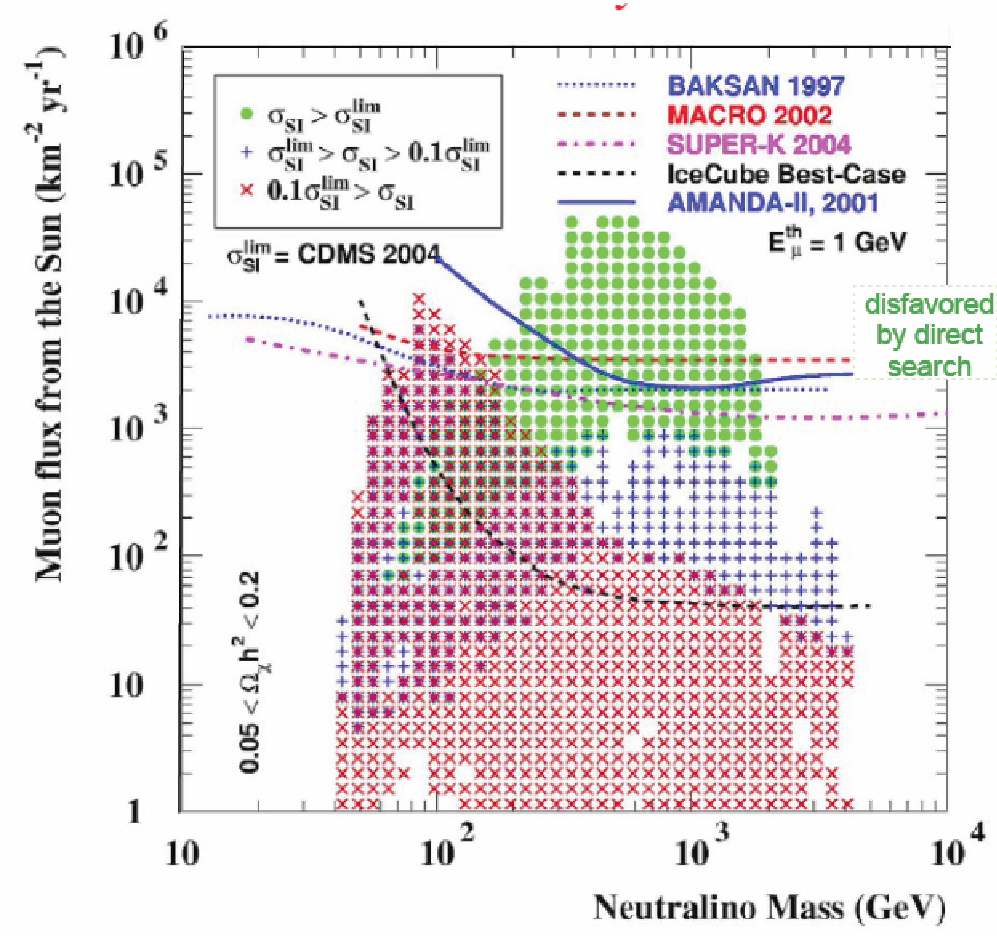


If AMS Attached to Space Station



Search for WIMPs caught in the Sun

Sensitivity to muon flux from neutralino annihilation $\chi\chi \rightarrow \ldots \rightarrow \nu$



First Direct WIMP Search in 1987

Volume 195, number 4 PHYSICS LETTERS B 17 September 1987

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

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[c] *Pacific Northwest Laboratory, Richland, WA 99352, USA*

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[e] *Applied Research Corp., 8201 Corporate Dr., Landover MD 20785, USA*

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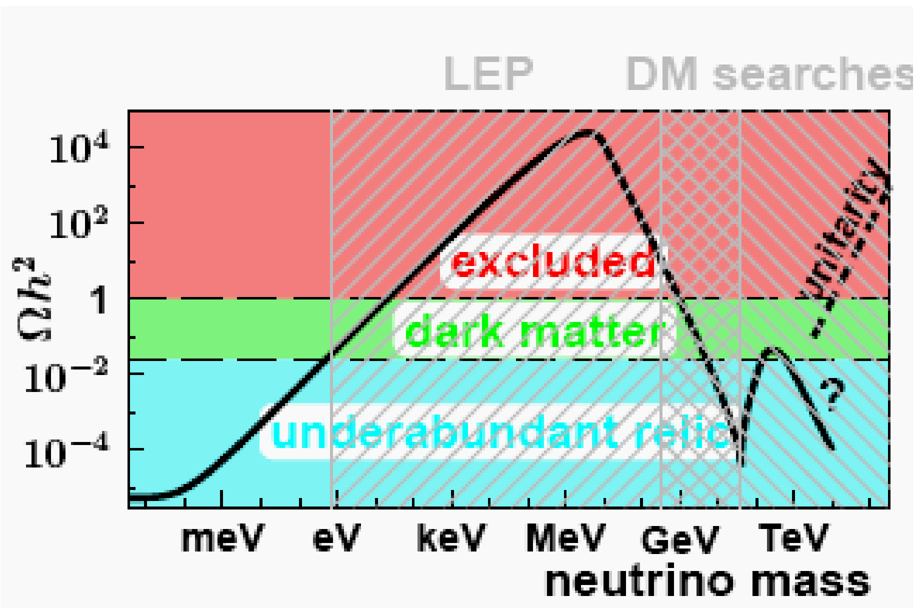
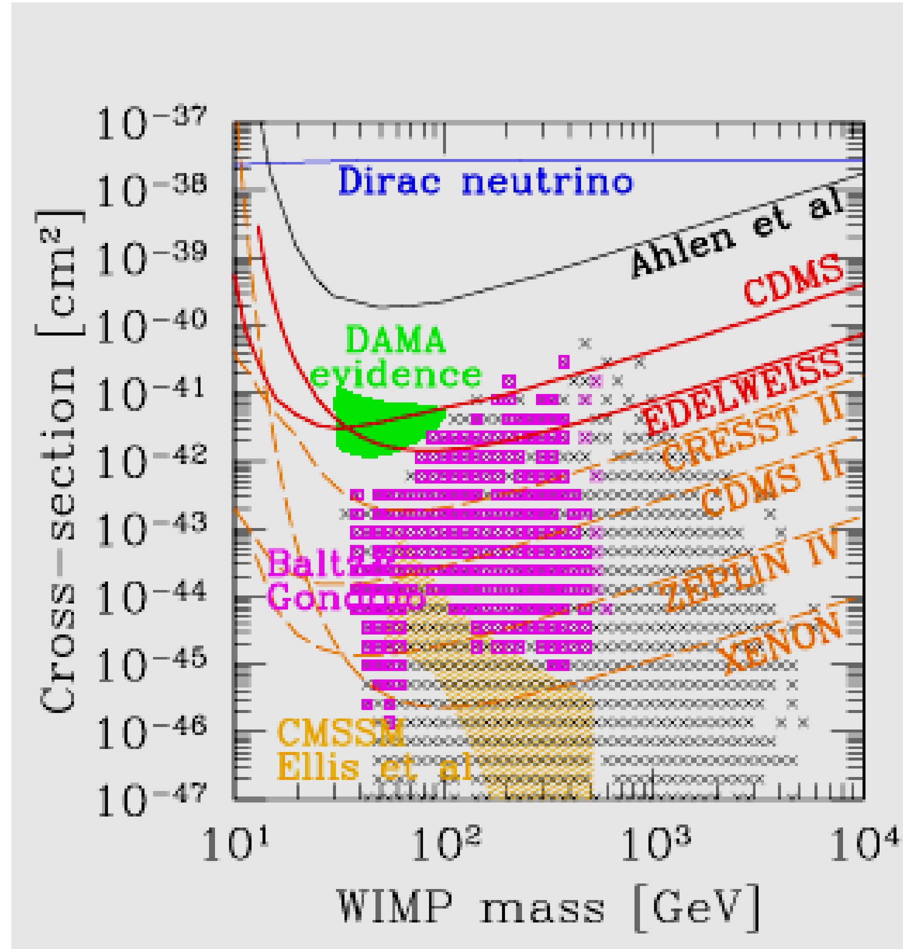
[h] *Institute for Advanced Study, Princeton, NJ 08540, USA*

An ultralow background spectrometer is used as a detector of cold dark matter candidates from the halo of our galaxy. Using a realistic model for the galactic halo, large regions of the mass–cross section space are excluded for important halo component particles. In particular, a halo dominated by heavy standard Dirac neutrinos (taken as an example of particles with spin-independent Z^0 exchange interactions) with masses between 20 GeV and 1 TeV is excluded. The local density of heavy standard Dirac neutrinos is <0.4 GeV/cm^3 for masses between 17.5 GeV and 2.5 TeV, at the 68% confidence level.

Non-Baryonic Dark Matter

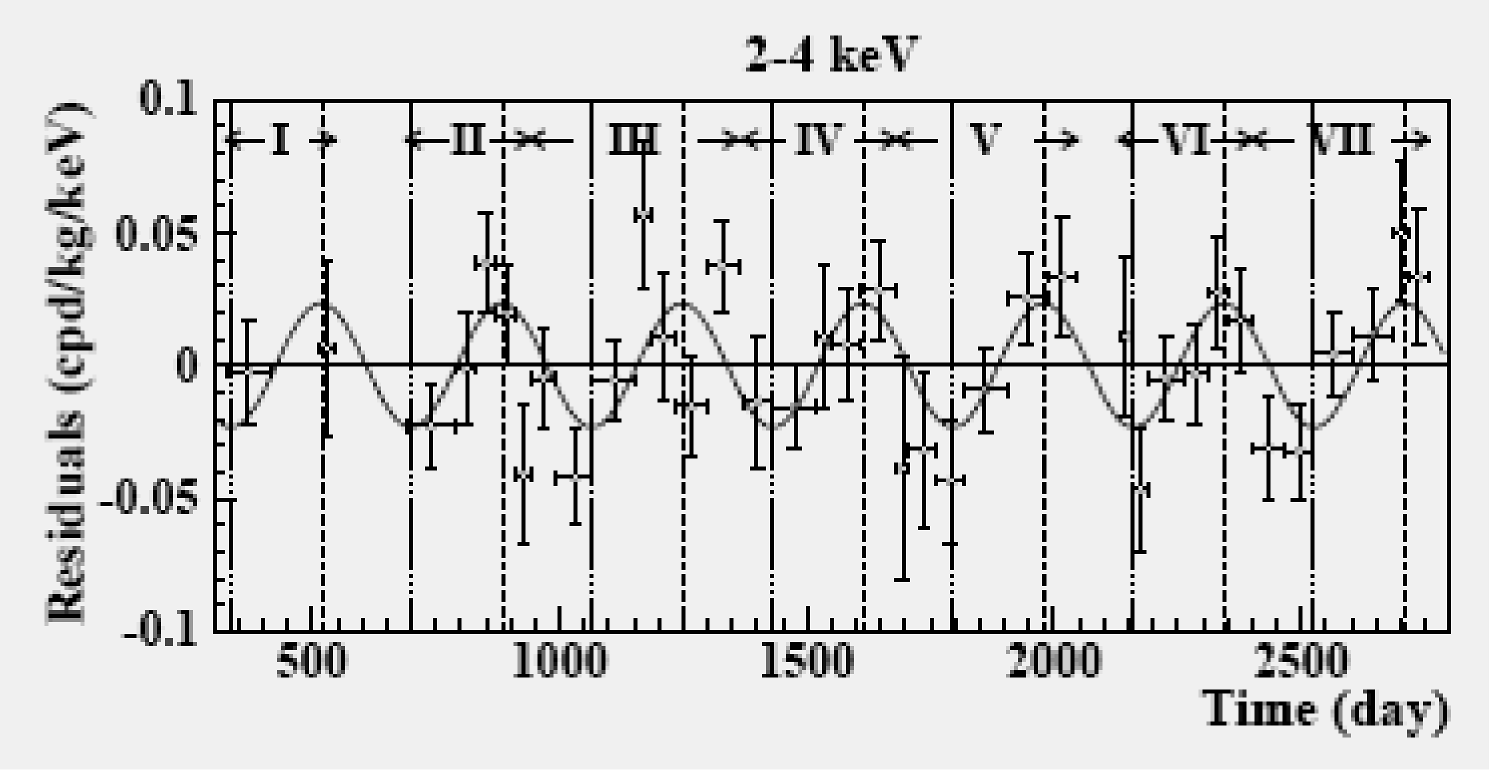
Paolo Gondolo
Department of Physics, University of Utah,
115 South 1400 East, Suite 201, Salt Lake City, Utah 84112, USA



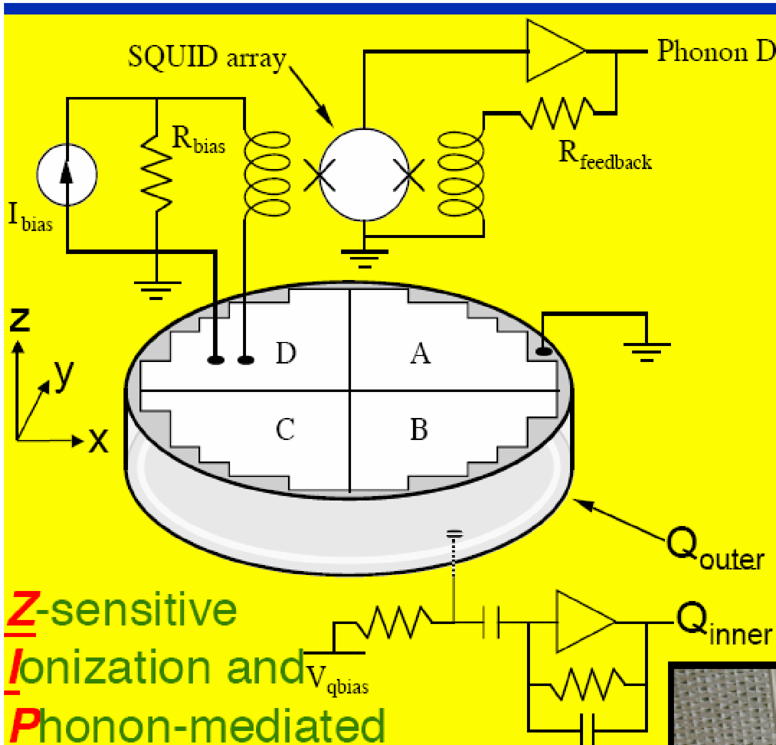


DAMA claimed discovery

- 100 kg NaI
- Pulse shape discrimination separates x-rays from recoils
- Annual modulation due to variations in relative velocity of dark matter particles

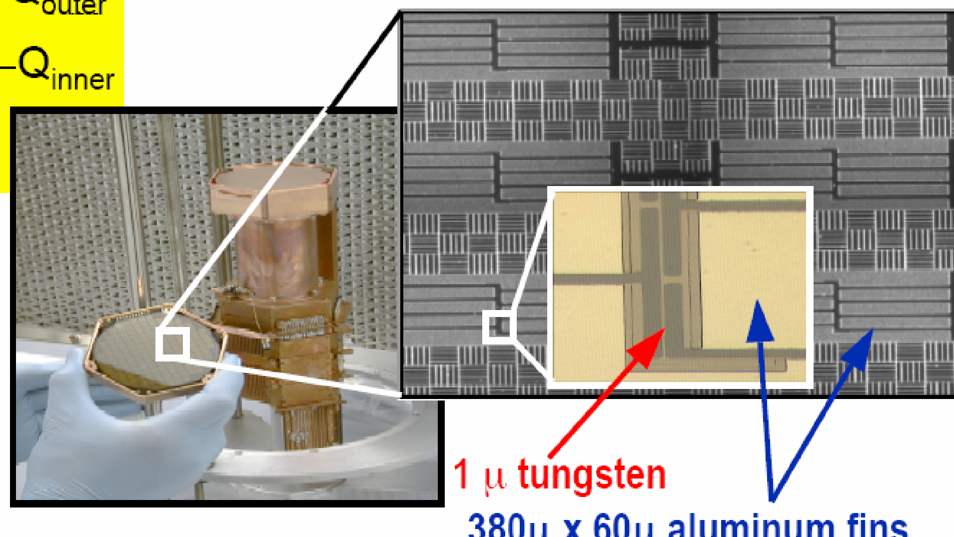


CDMS

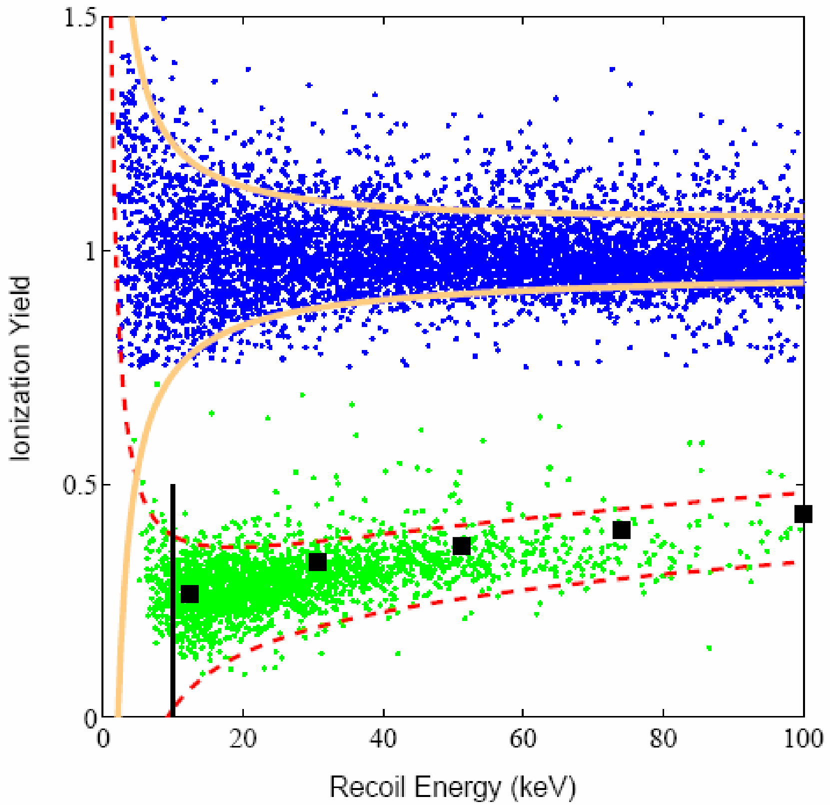


- 250 g Ge or 100 g Si crystal
- 1 cm thick x 7.5 cm diameter
- Photolithographic patterning
- Collect athermal phonons:
  - XY position imaging
  - Surface (Z) event veto based on pulse shape risetime

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

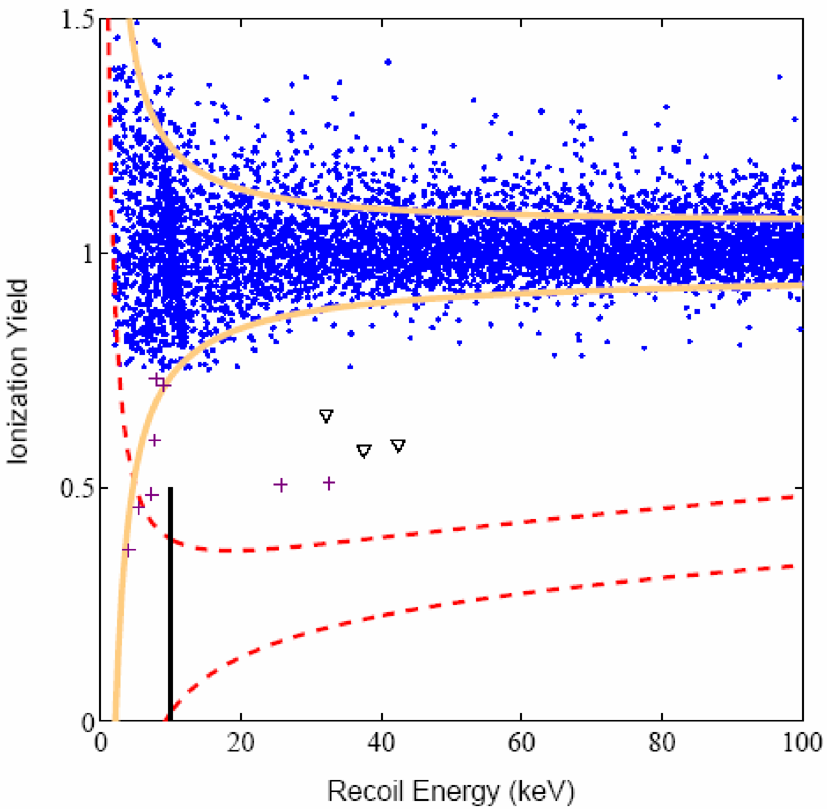


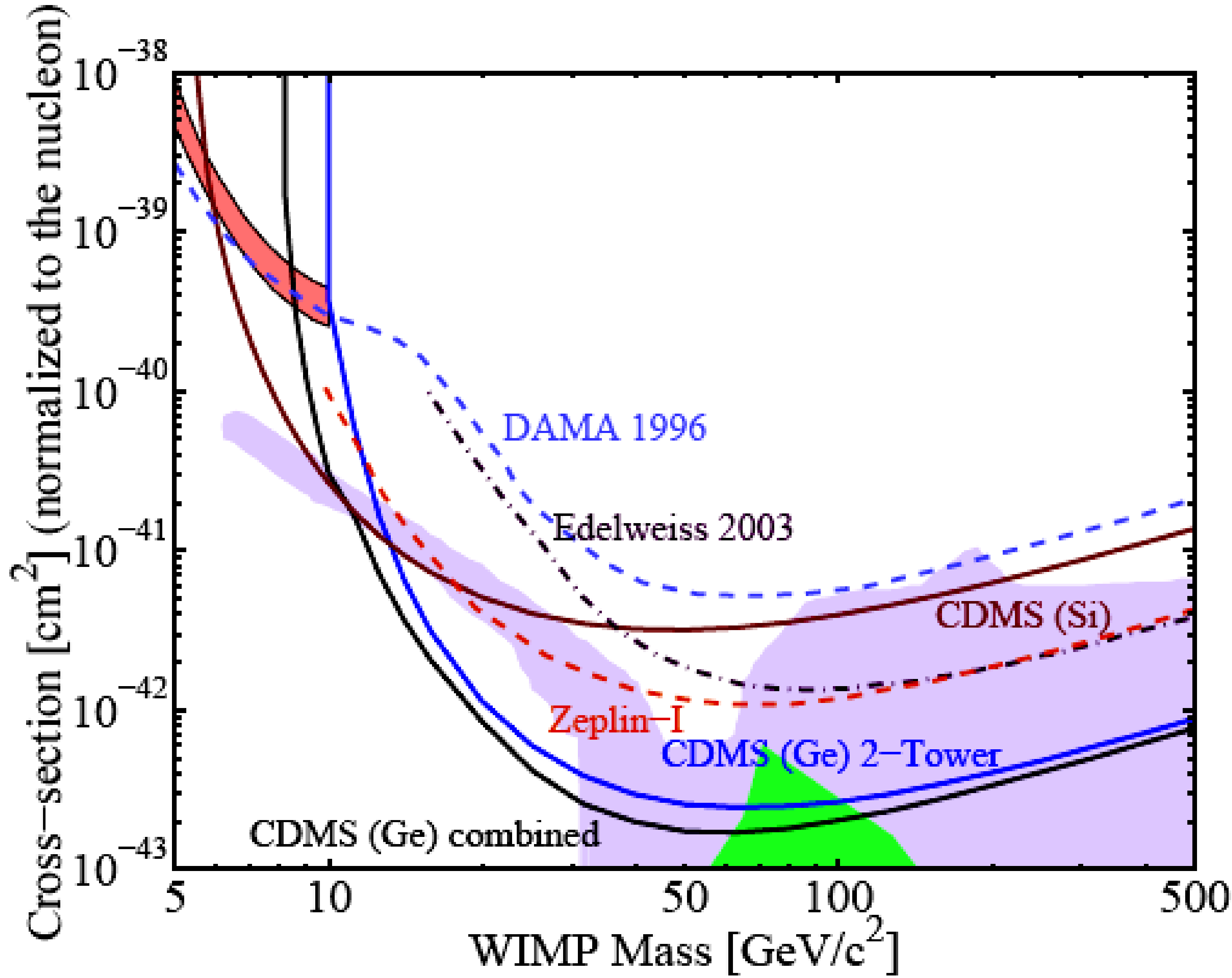
Calibration with gamma and neutron sources



■ Ahlen Calculation

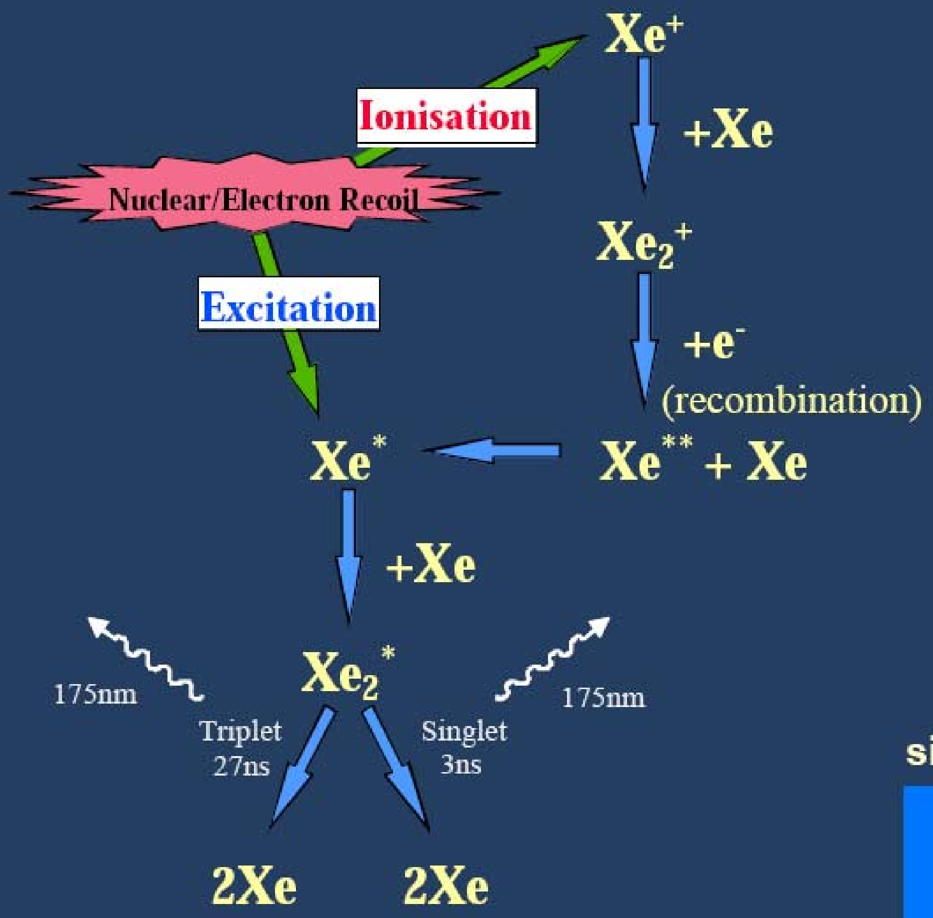
Search at Soudan mine in Minnesota





Limit based on 46 kg days exposure

Liquid Xe basics

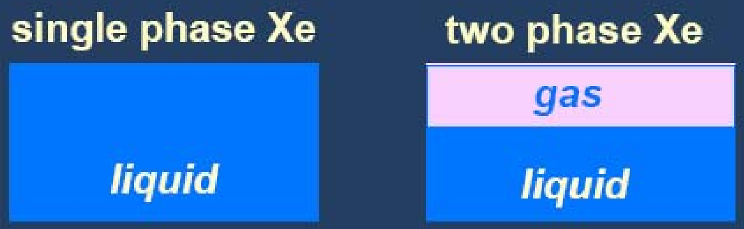


three discrimination techniques

(1) scintillation pulse shape
--> ZEPLIN I

(2) ionisation-scintillation
- low field- *--> ZEPLIN II*

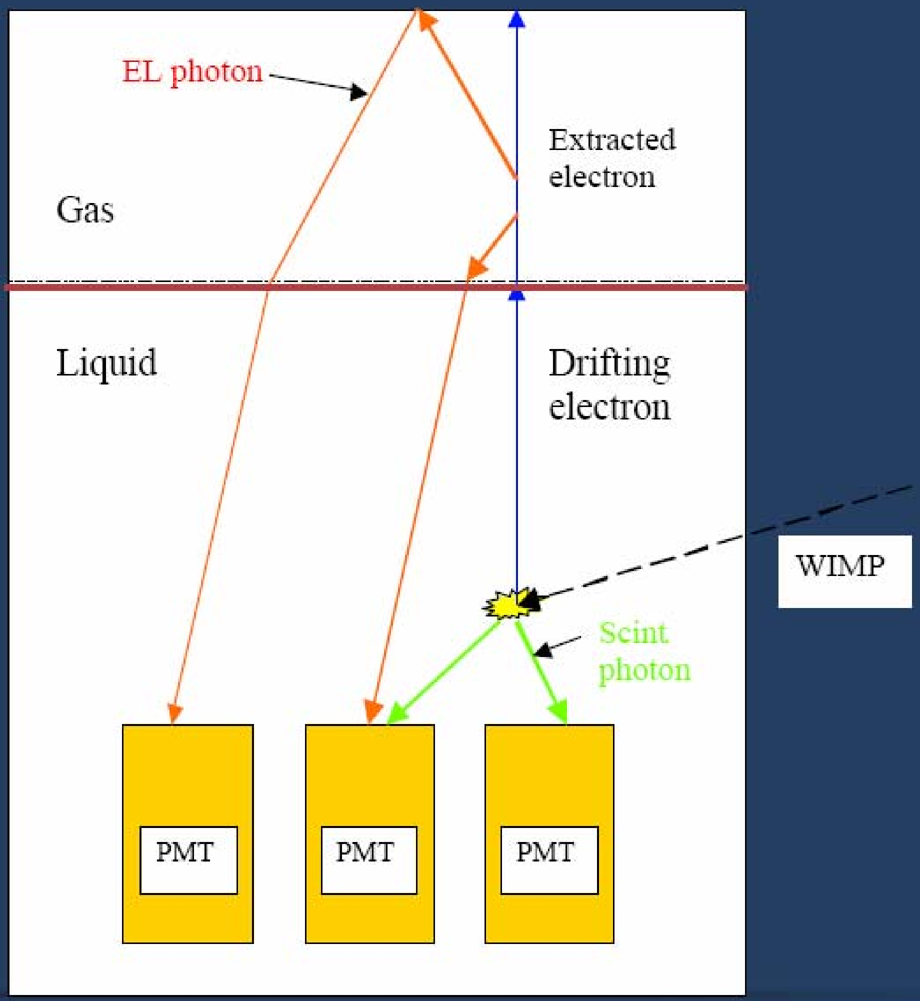
(3) ionisation-scintillation
- high field- *--> ZEPLIN III*



World expertise

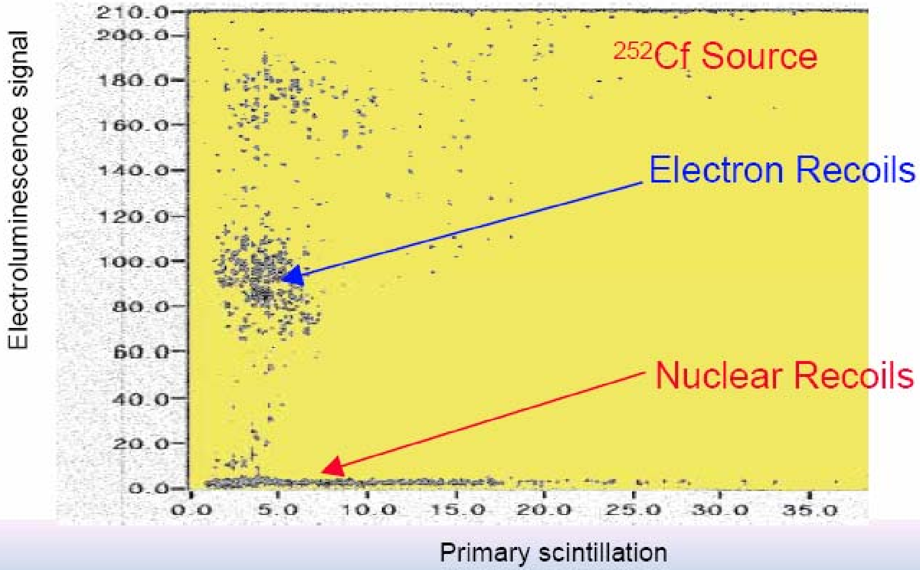
- ICARUS-UCLA • Doke group (Japan) • DAMA • Columbia • UKDMC • ITEP

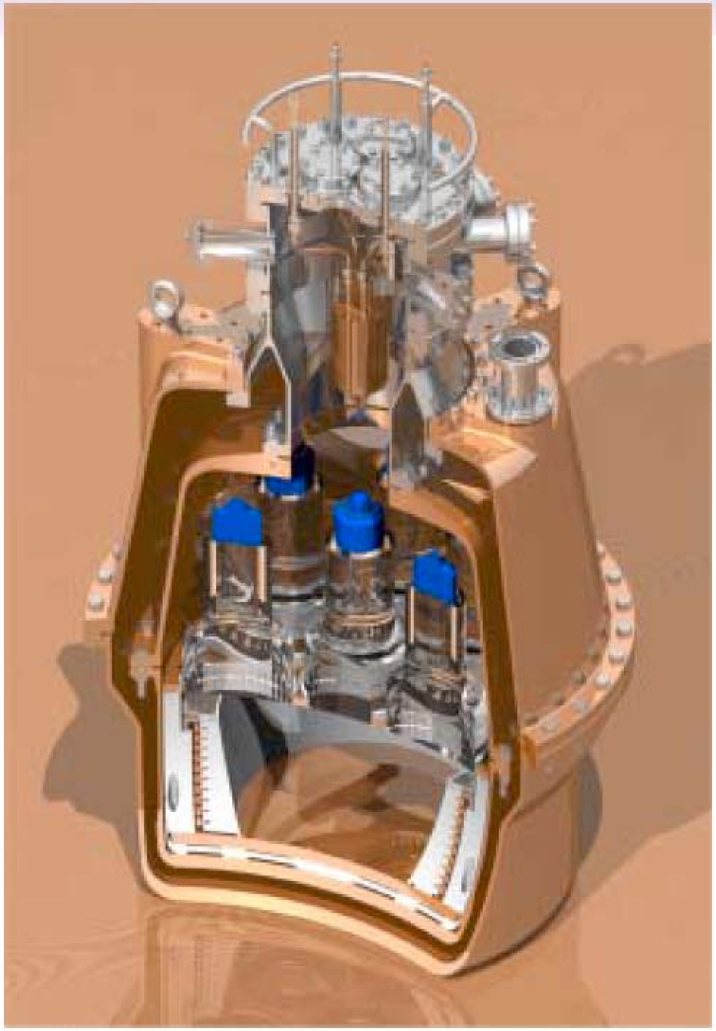
ZEPLIN II basics - two phase



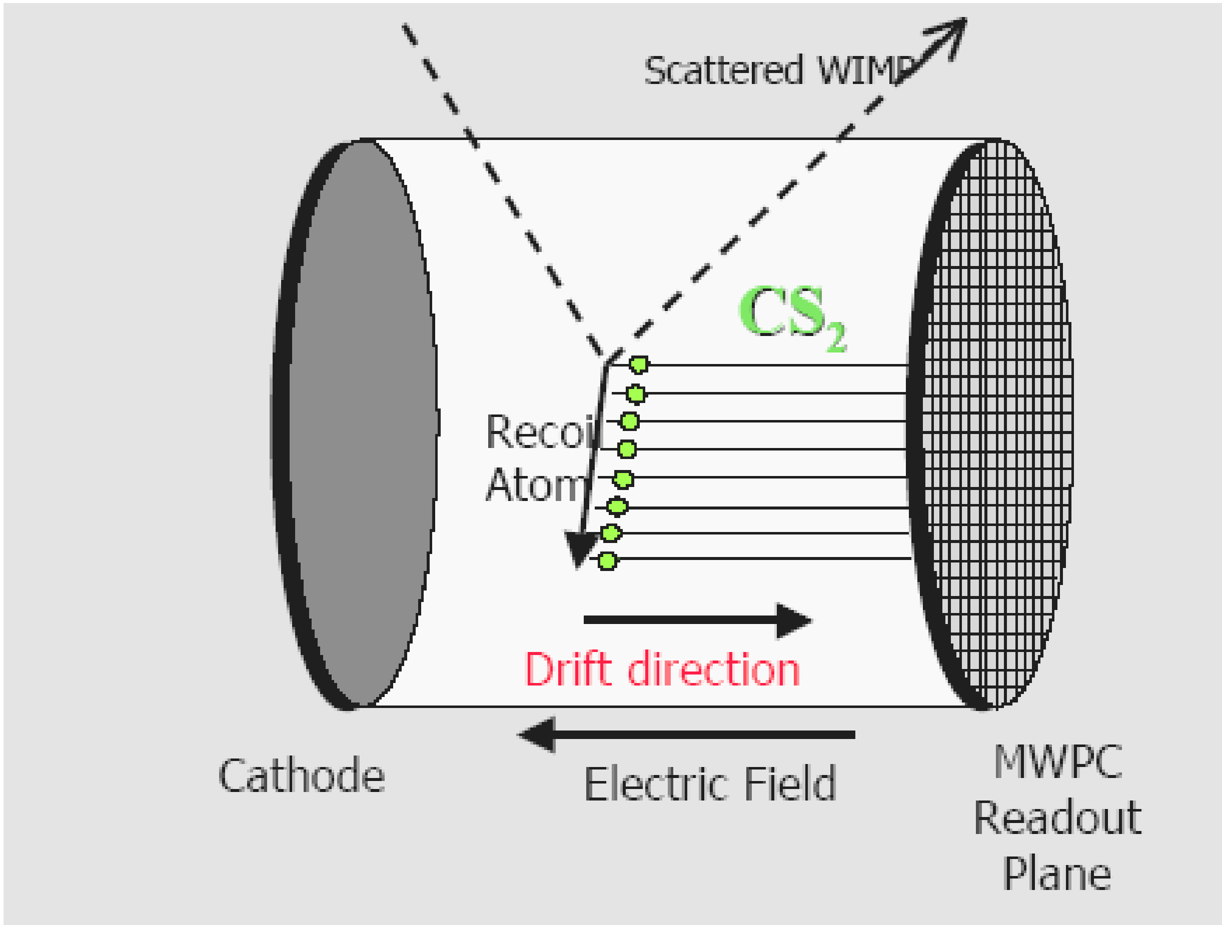
ZEPLIN II

- UKDMC/UCLA/Padova/Torino /Texas A&M currently constructing 30 kg ZEPLIN II module.
- Prototype indicates excellent discrimination properties.



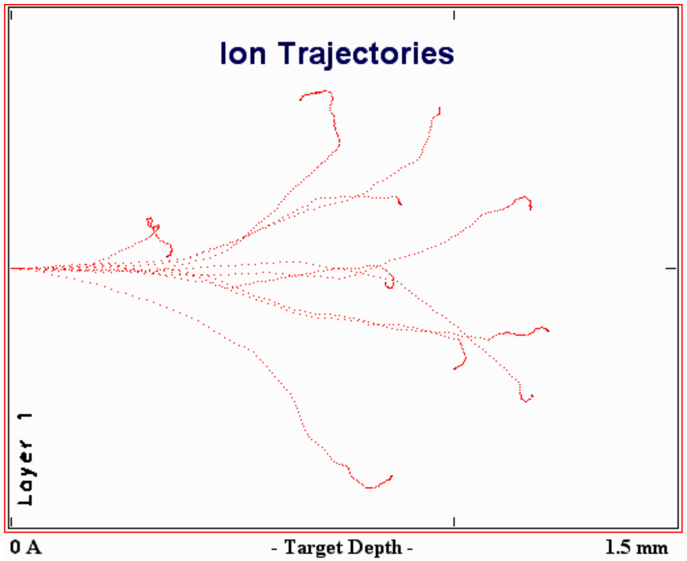


DRIFT - a directional DM detector

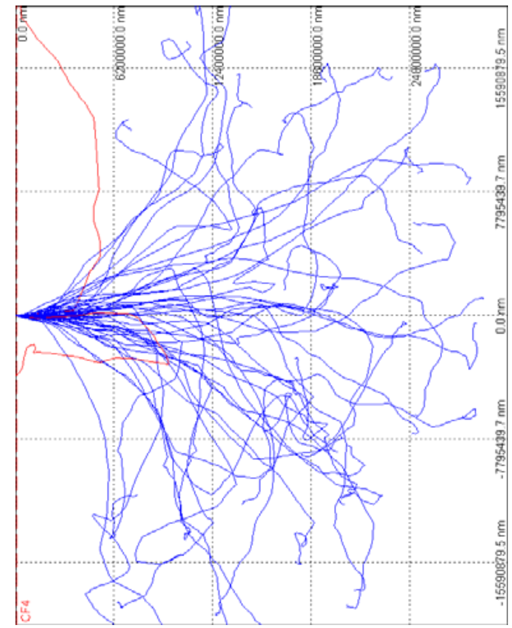


Occidental College, University of New Mexico, Sheffield University

Range vs Energy is powerful technique for particle ID



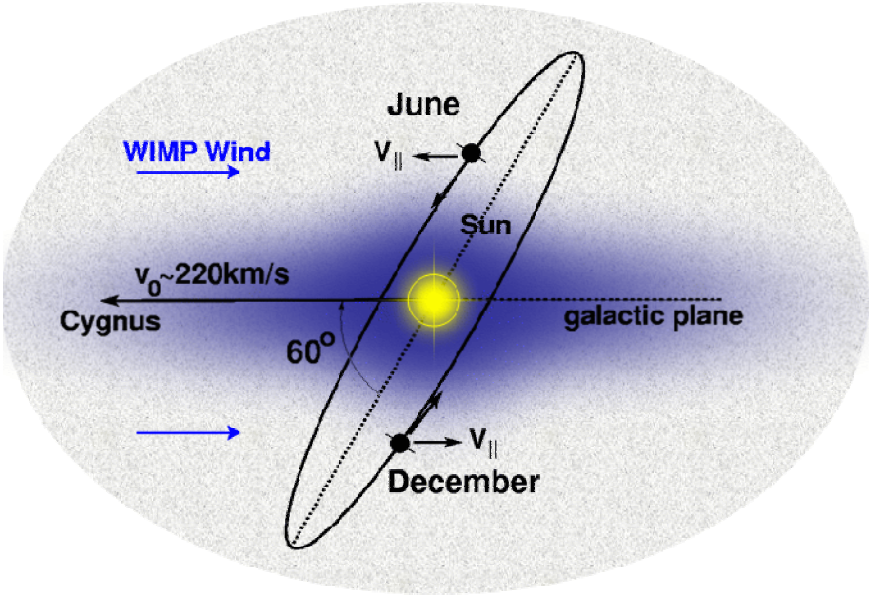
30keV F ions in 50mbar CF4 [15]. Typical ion range is about 1mm.

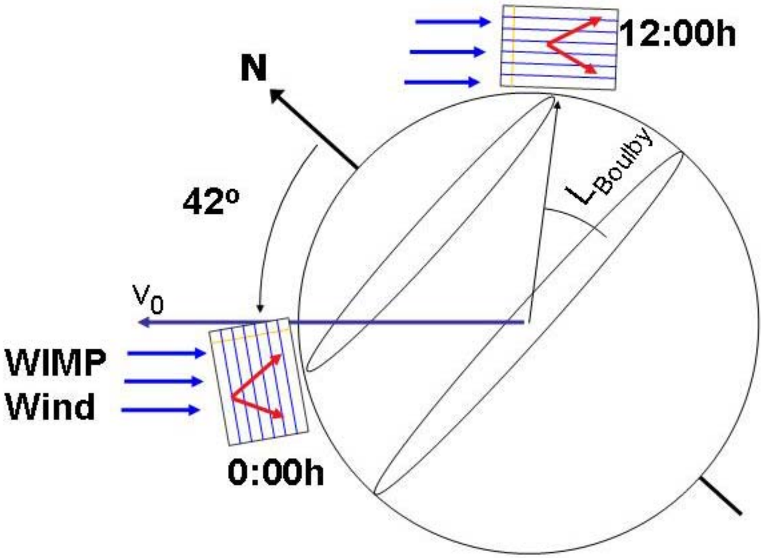


15keV electrons in 50mbar CF4 [16]. Typical electron range is about 30mm.

WIMP Wind in Our Galaxy

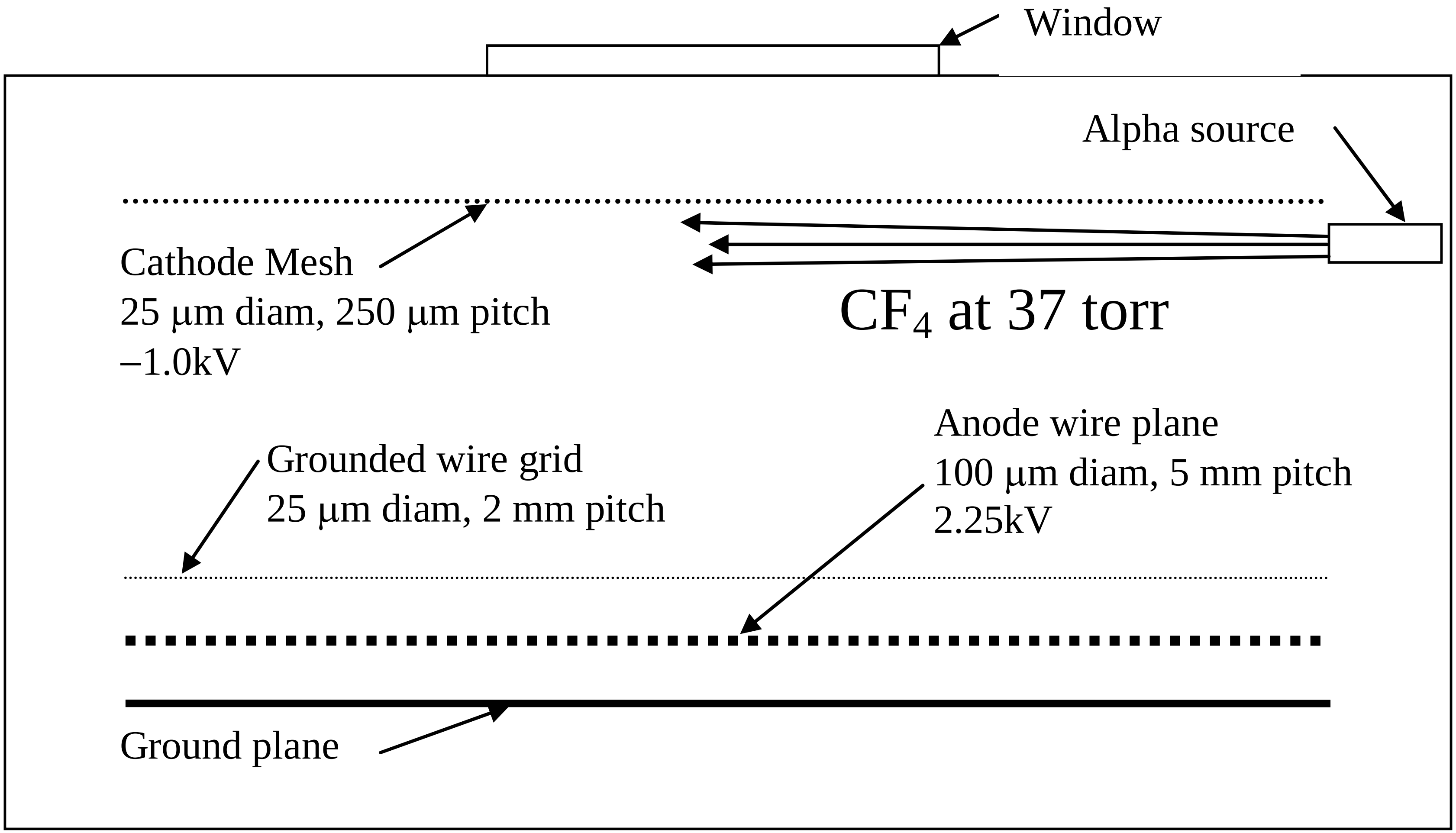
- **Dark matter halo large compared to baryonic matter in spiral galaxy**
- **Solar System rotates about galactic center with speed of 220 km/s**
- **Dark matter particles move isotropically with speeds of a few hundred km/s**



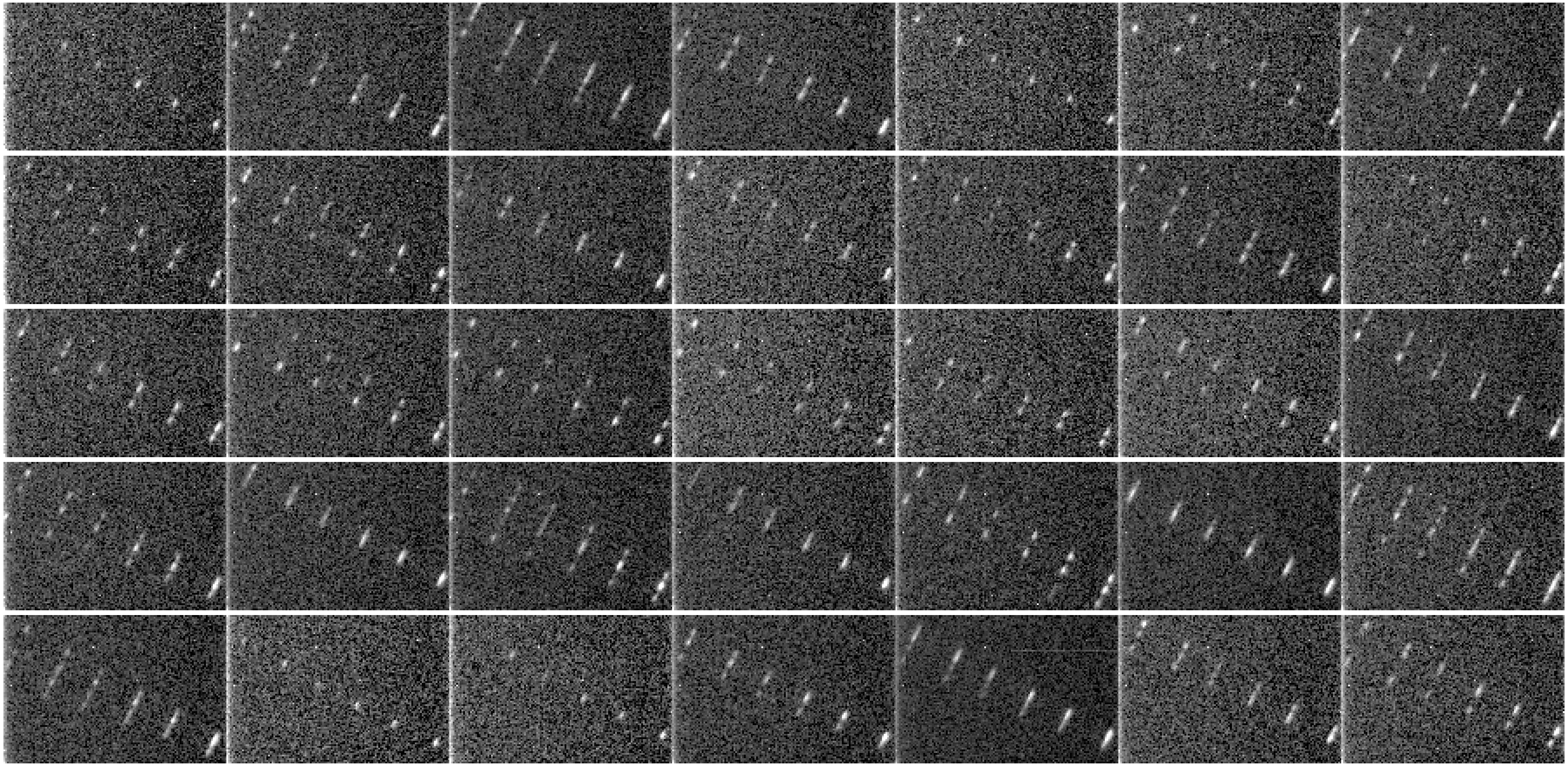


MIT/BU CF4 Prototype – Summer 2006

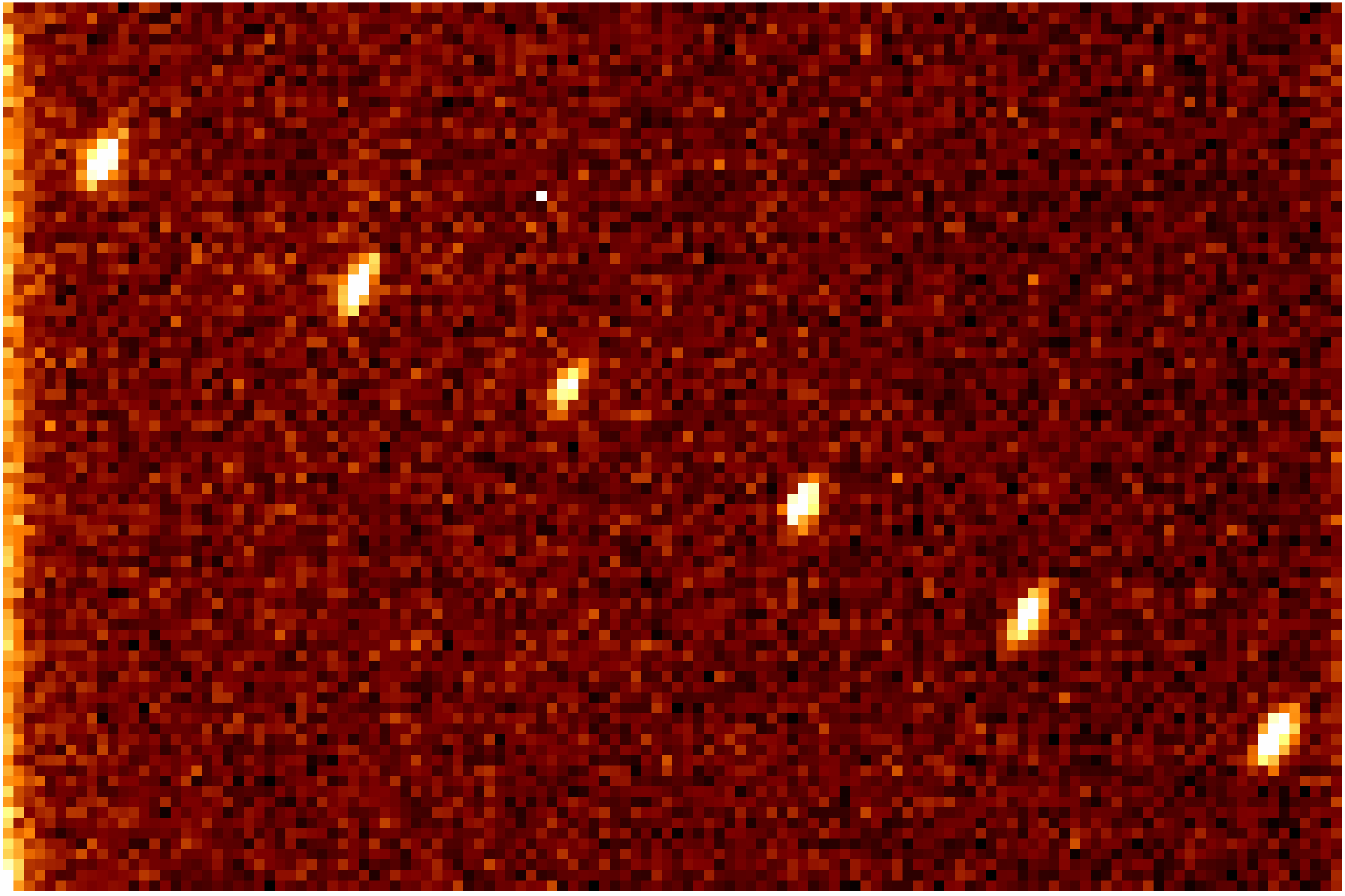
Peter Fisher, Marta Lewandowska, Steve Ahlen, Hidefumi Tomita



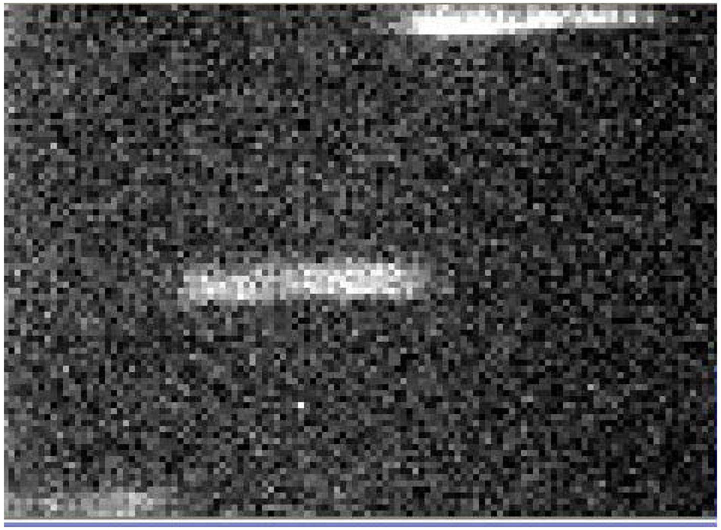
35 Successive Images for one second exposures



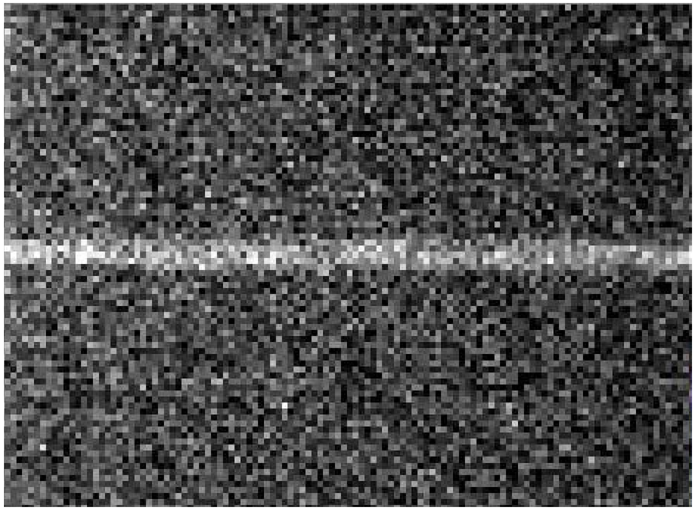
Alpha Particle Track
Diffusion = 275 microns, Gain = 30,000



45 degrees relative to wire direction



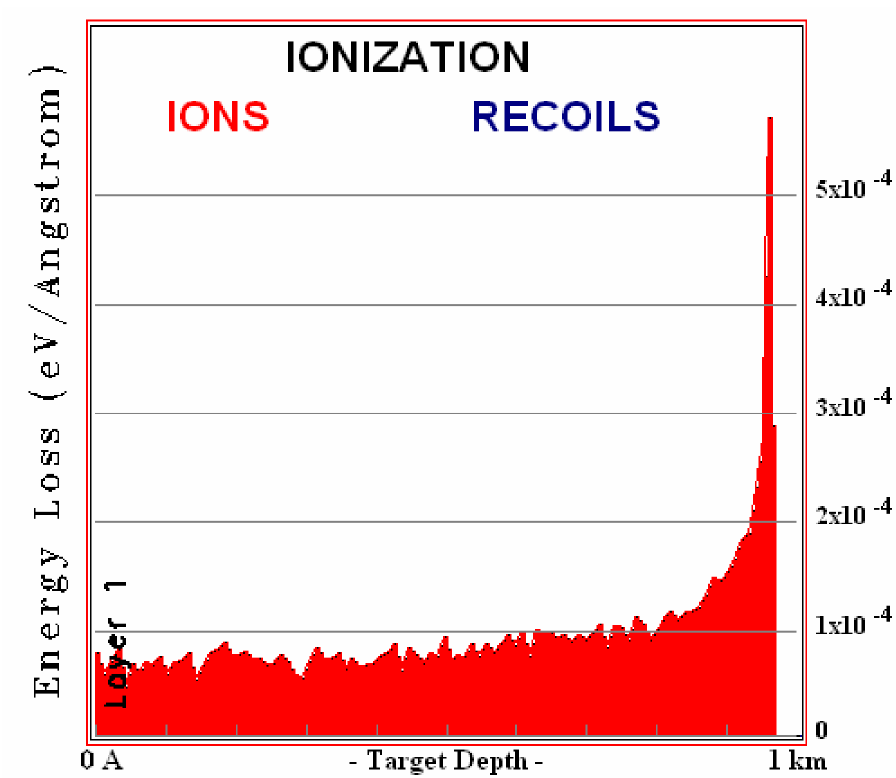
parallel to wire

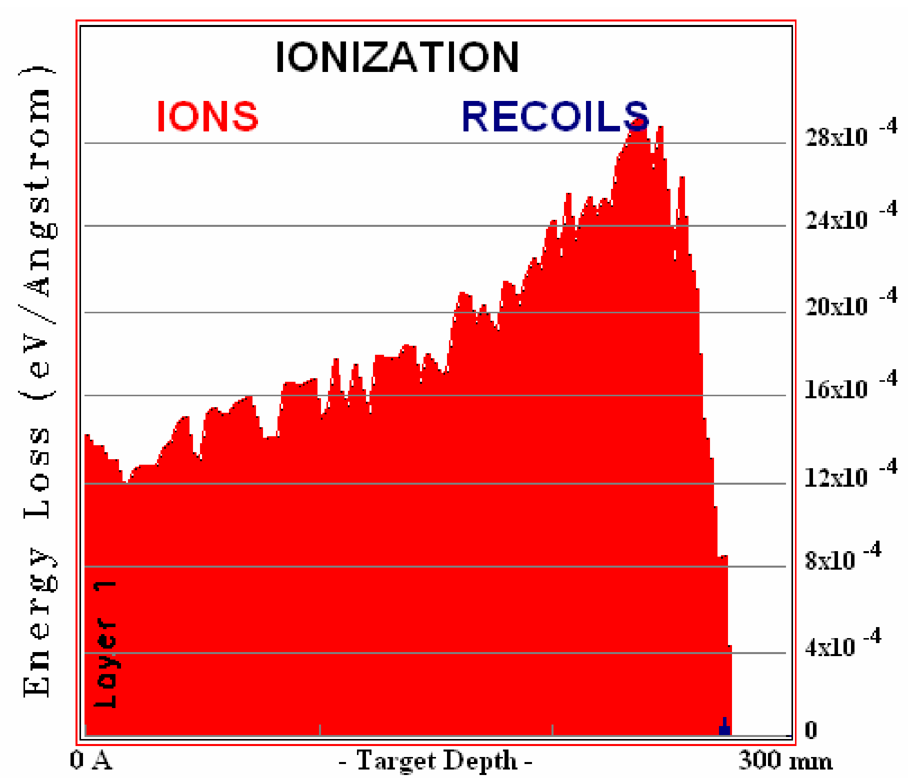


TRIM Calculations

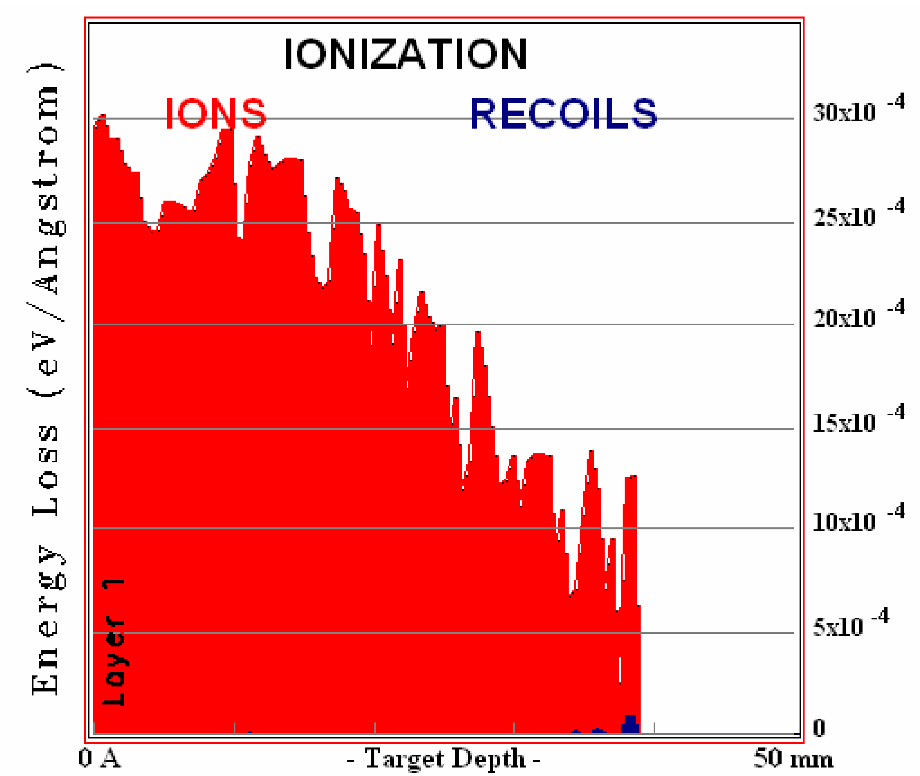
900 MeV proton
1 atm

5 MeV alpha
1/20 atm

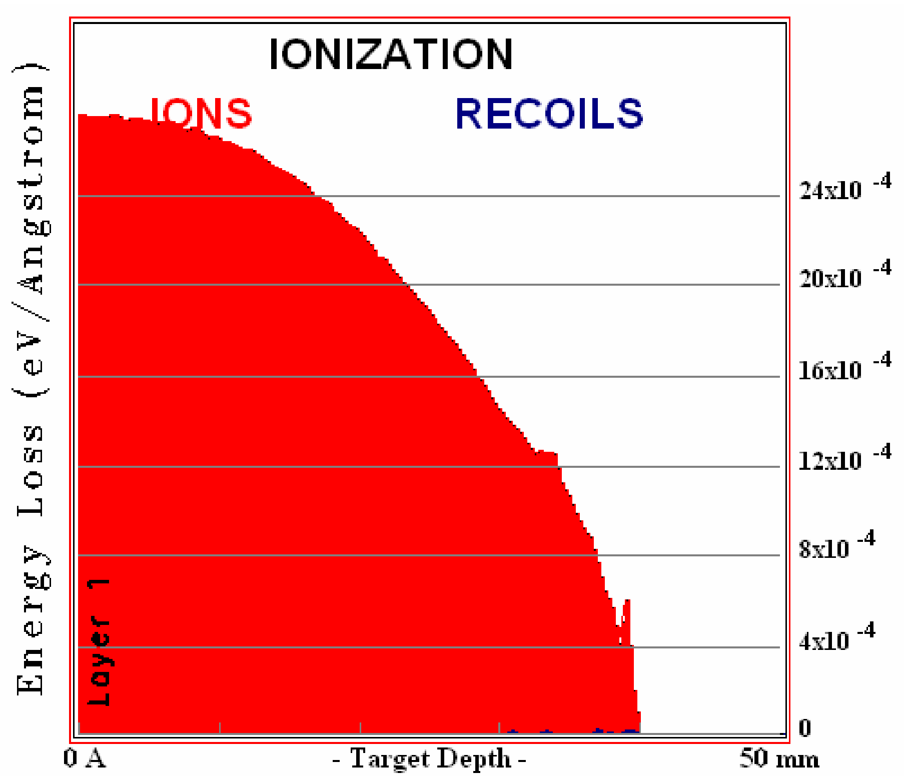




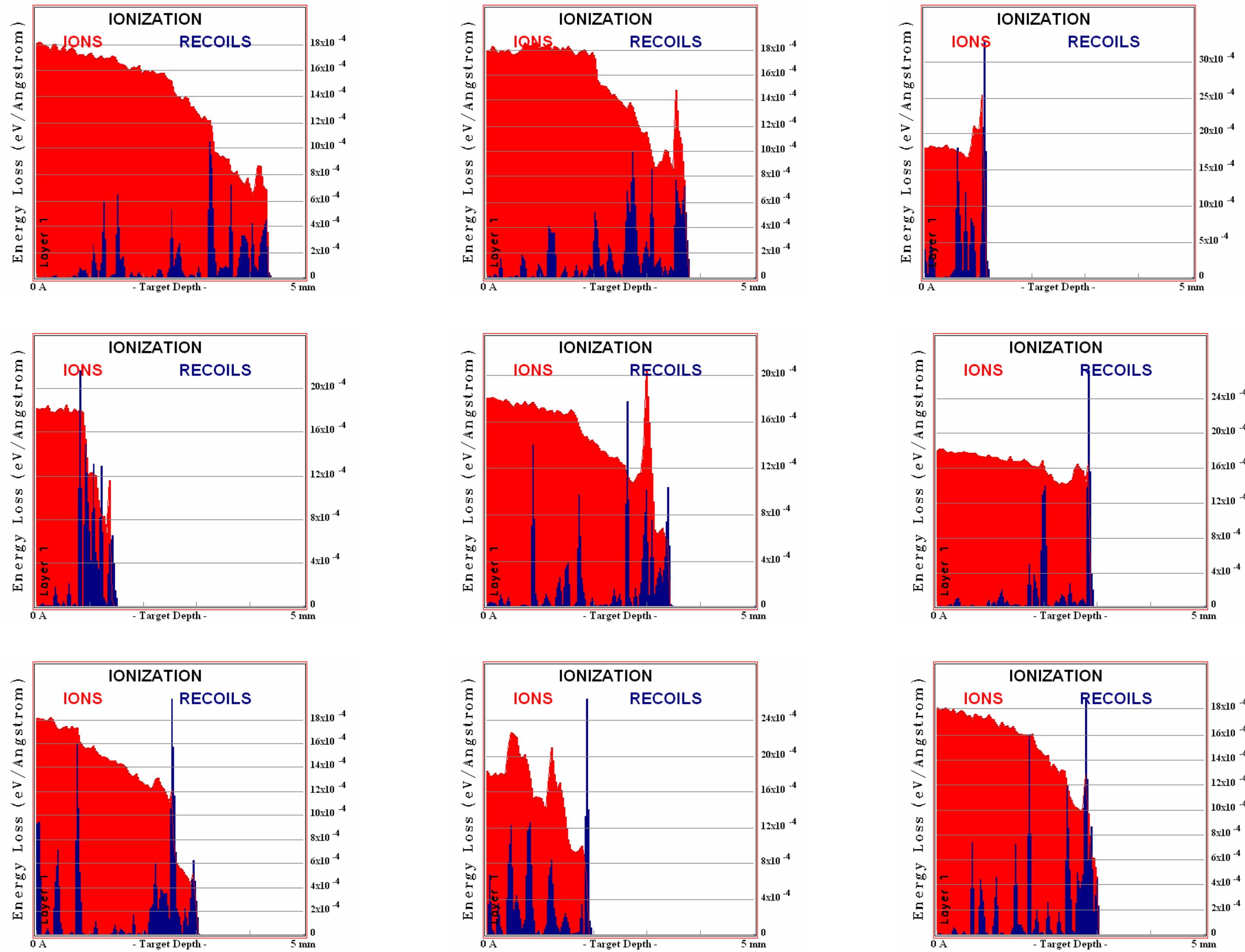
800 keV alpha
1/20 atm
Quick Calculation

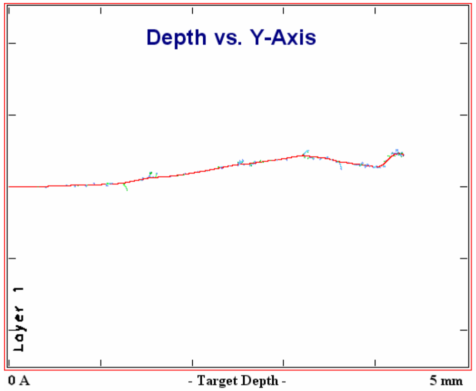


800 keV alpha
1/20 atm
Detailed Calculation



100 keV F ions in 50 mbar CF4




Depth vs. Y-Axis
Layer 1
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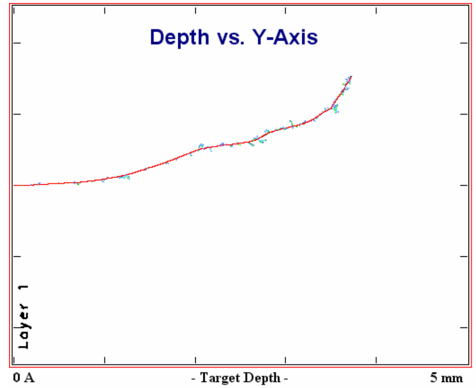
- Target Depth -
5 mm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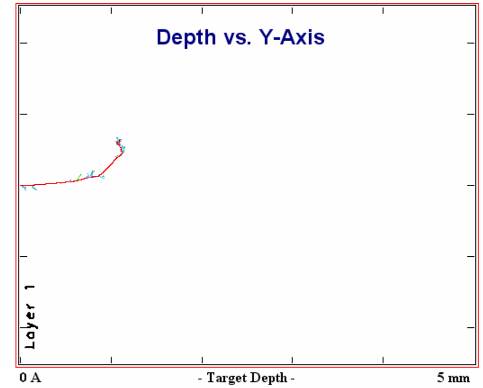
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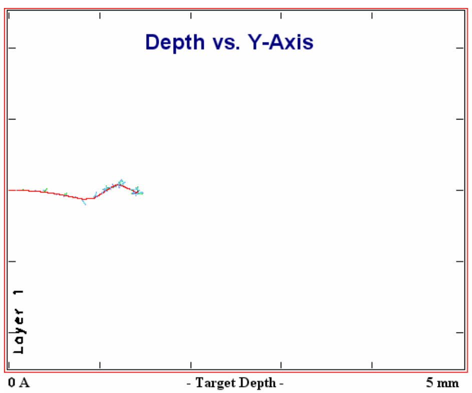
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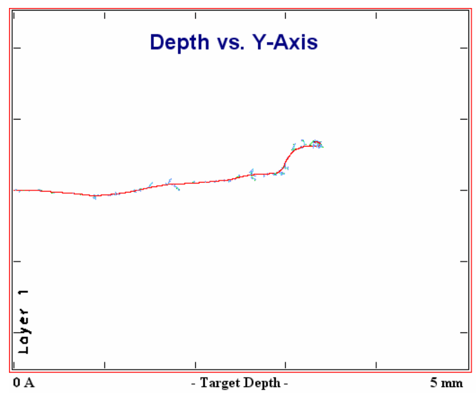
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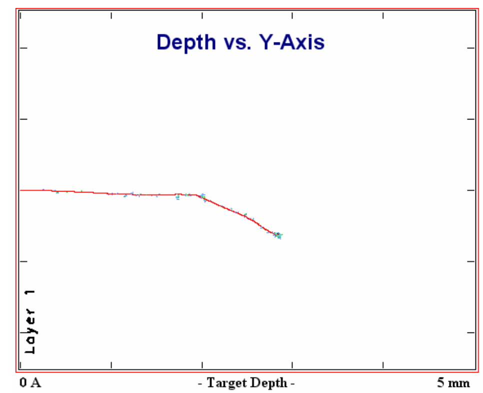
Depth vs. Y-Axis
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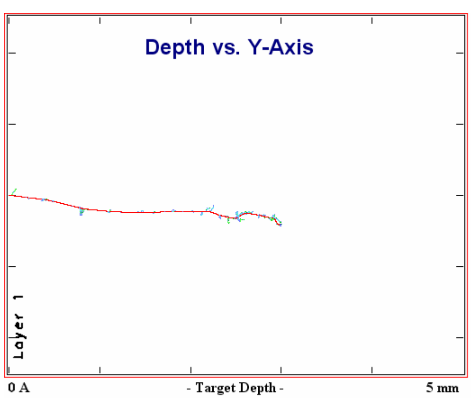
5 mm


Depth vs. Y-Axis
Layer 1
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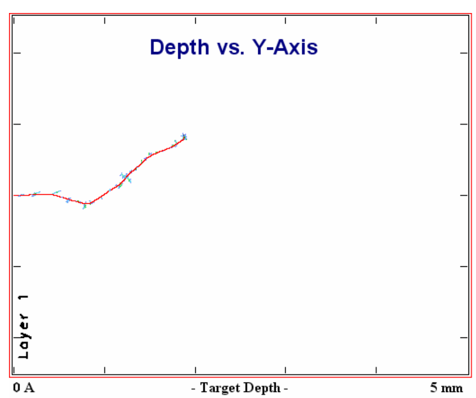
- Target Depth -
5 mm


Depth vs. Y-Axis
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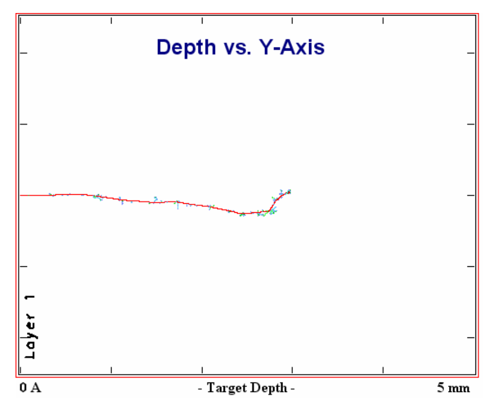
- Target Depth -
5 mm

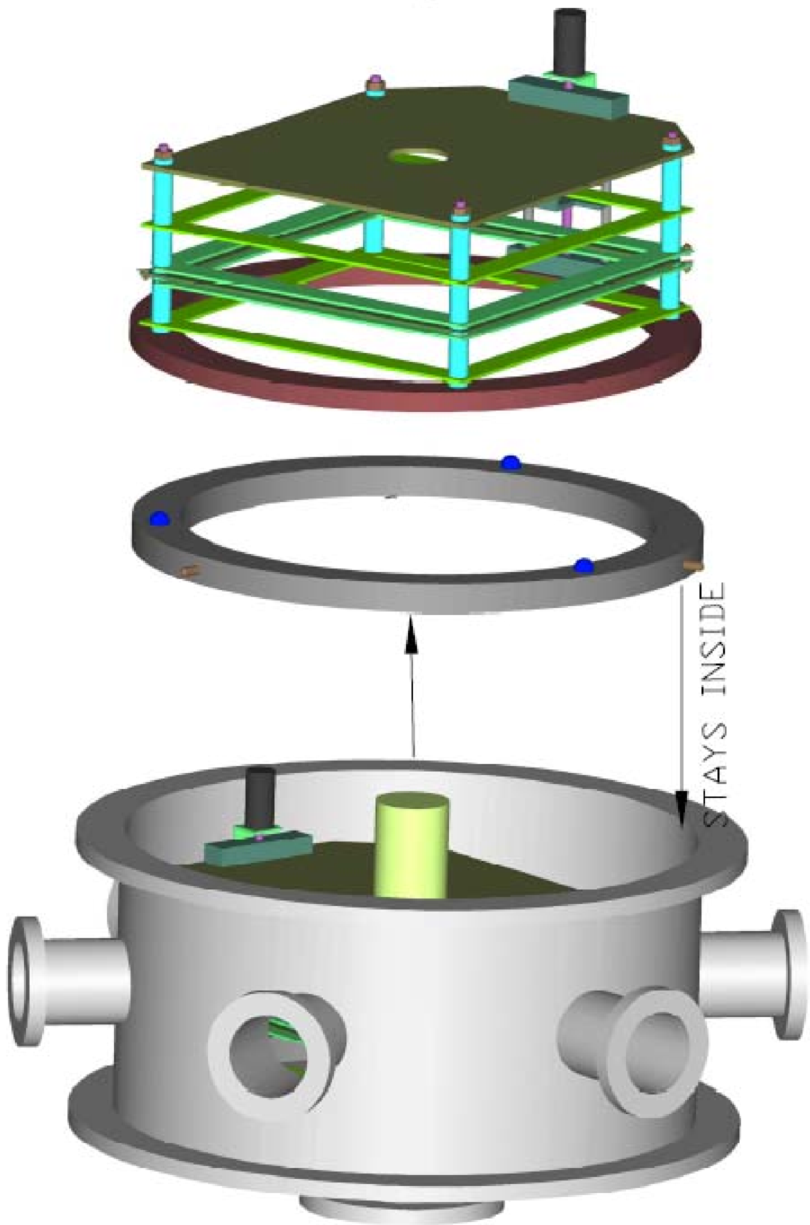

Depth vs. Y-Axis
Layer 1
0 A
- Target Depth -
5 mm

Next Generation Directional Prototypes

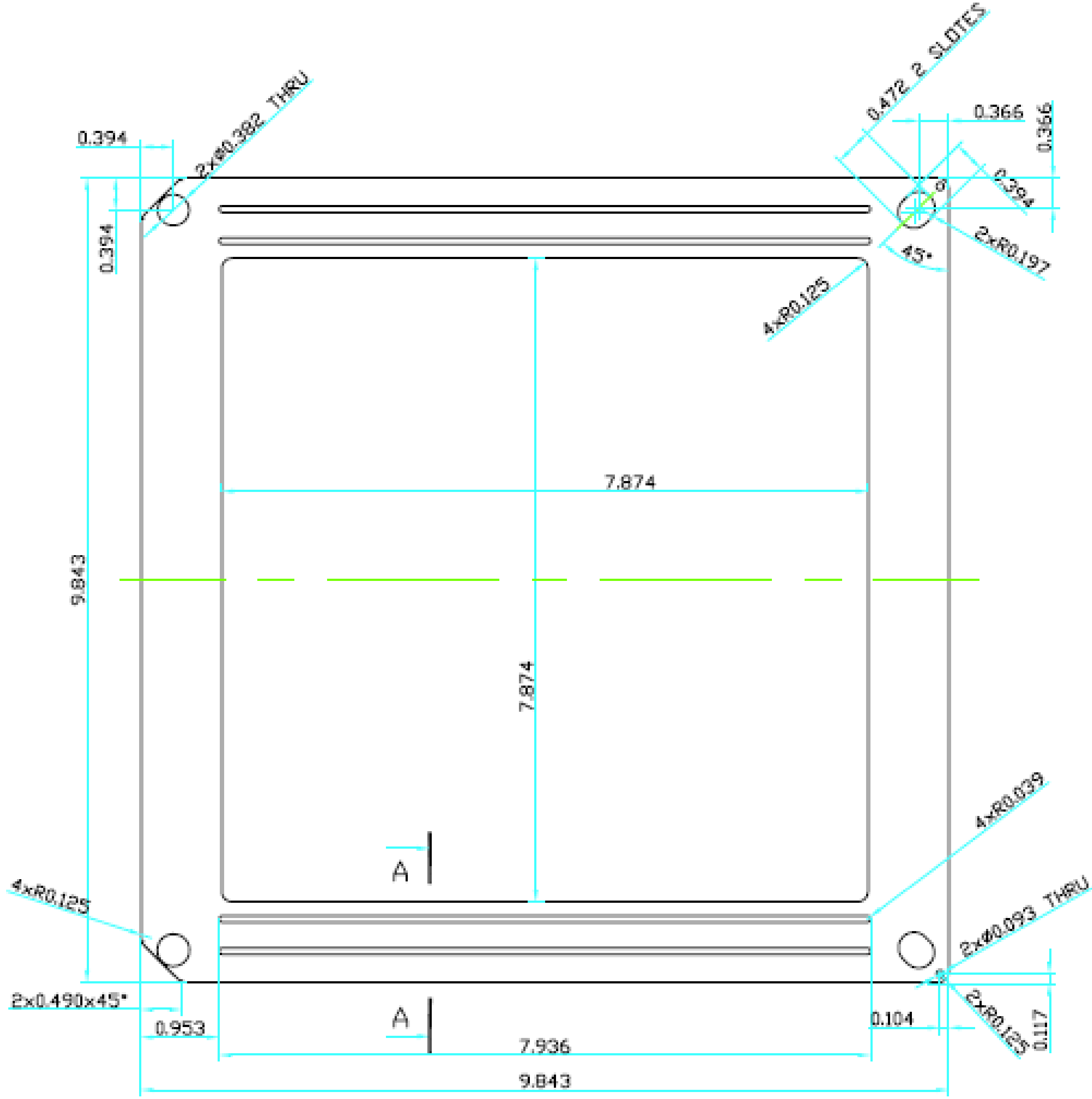
- Boston University
  - Steve Ahlen, Hidefumi Tomita, Debbie Avery, Eric Hazen
- MIT
  - Peter Fisher, Jocelyn Monroe, Gabriella Sciolla, Dennis Dujmic, Roland Vanderspek
- Brandeis
  - Hermann Wellenstein
- Will work with DRIFT collaboration to explore various designs with electronic readout and optical readout
- Head-tail direction sensitivity determined with neutron beams
- Supported by DOE Advanced Detector Research Program and the MIT Kavli Institute for Astrophysics and Space Research

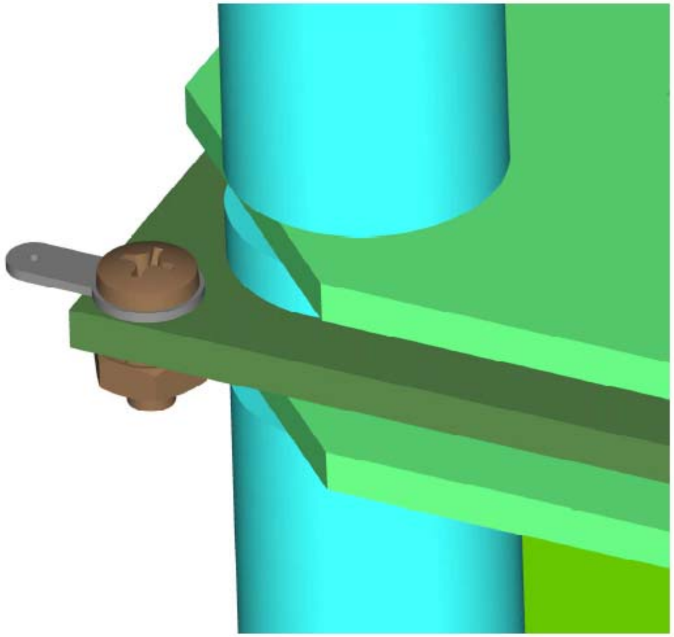
Optical Readout

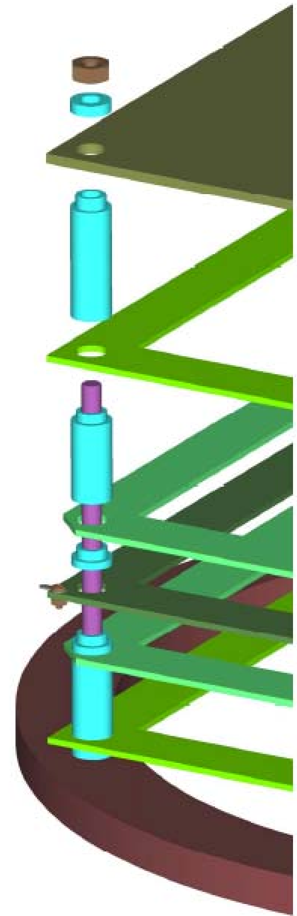
- **Two 25cm x 25cm x (2.5 to 25cm) drift cells**
- **Anode wire diameter 30 or 50 microns**
- **Wire pitch 2.5 mm**
- **Three Dimension Reconstruction:**
  - **In anode plane by scintillation profiles on one or more wires (1 mm by 0.5 mm resolution for track length)**
  - **Perpendicular to anode plane by phototube pulse shape (1 mm resolution for track length)**

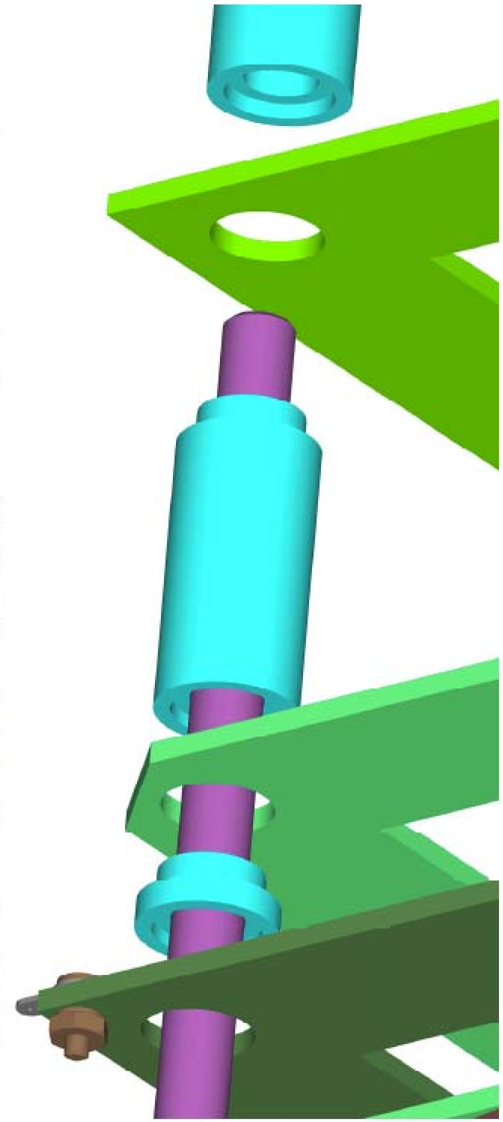

STAYS INSIDE


Kurt J. Lesker


0.472 2 SLOTES
0.366
0.366
0.394
2xØ0.382 THRU
0.394
0.394
2xR0.197
45°
4xR0.125
7.874
9.843
7.874
4xR0.039
A
2xØ0.093 THRU
4xR0.125
2x0.490x45°
A
0.953
7.936
0.104
2xR0.125
0.117
9.843

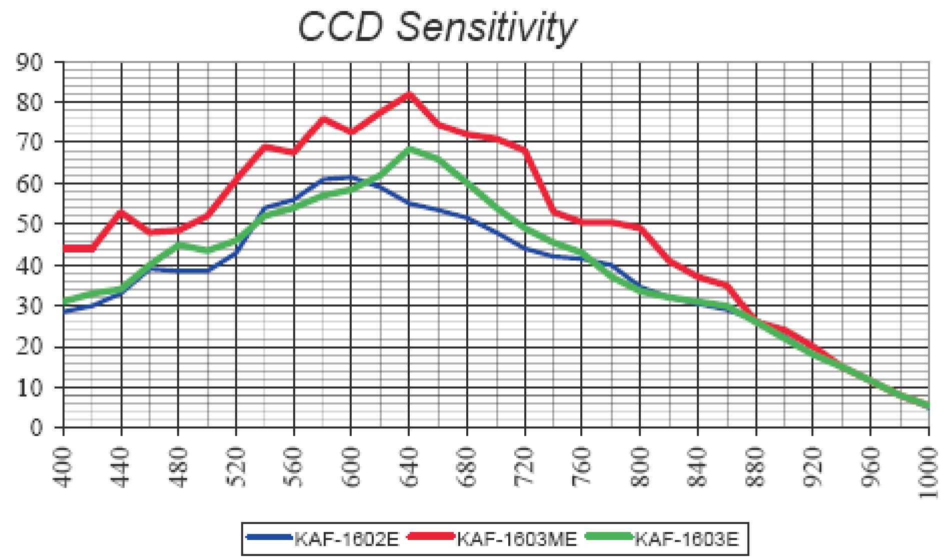






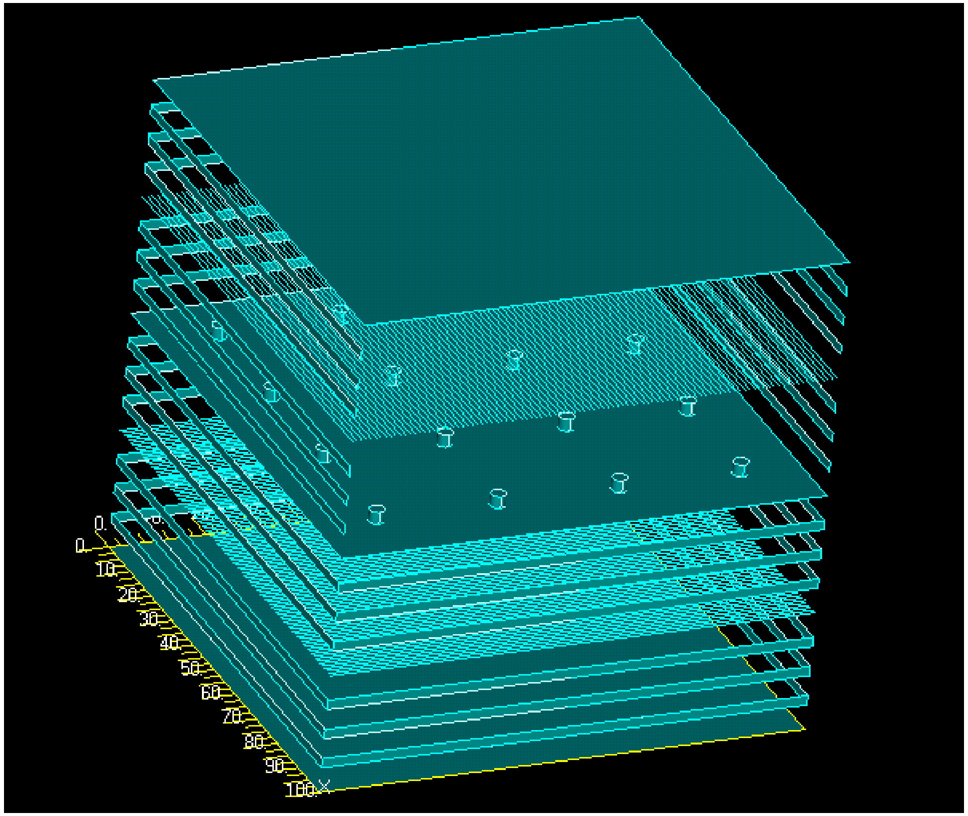
Alta® U2
High Performance Cooled CCD Camera System

CCD	Kodak KAF-1602E, 1603E, 1603ME
Array Size (pixels)	1536 x 1024
Pixel size	9 x 9 microns
Imaging area	13.82 x 9.22 mm (127.4 mm^2)
Imaging diagonal	16.61 mm
Linear Full Well (typ.)	100,000 e^-
Dynamic Range	76 dB



Cubic meter prototype to follow

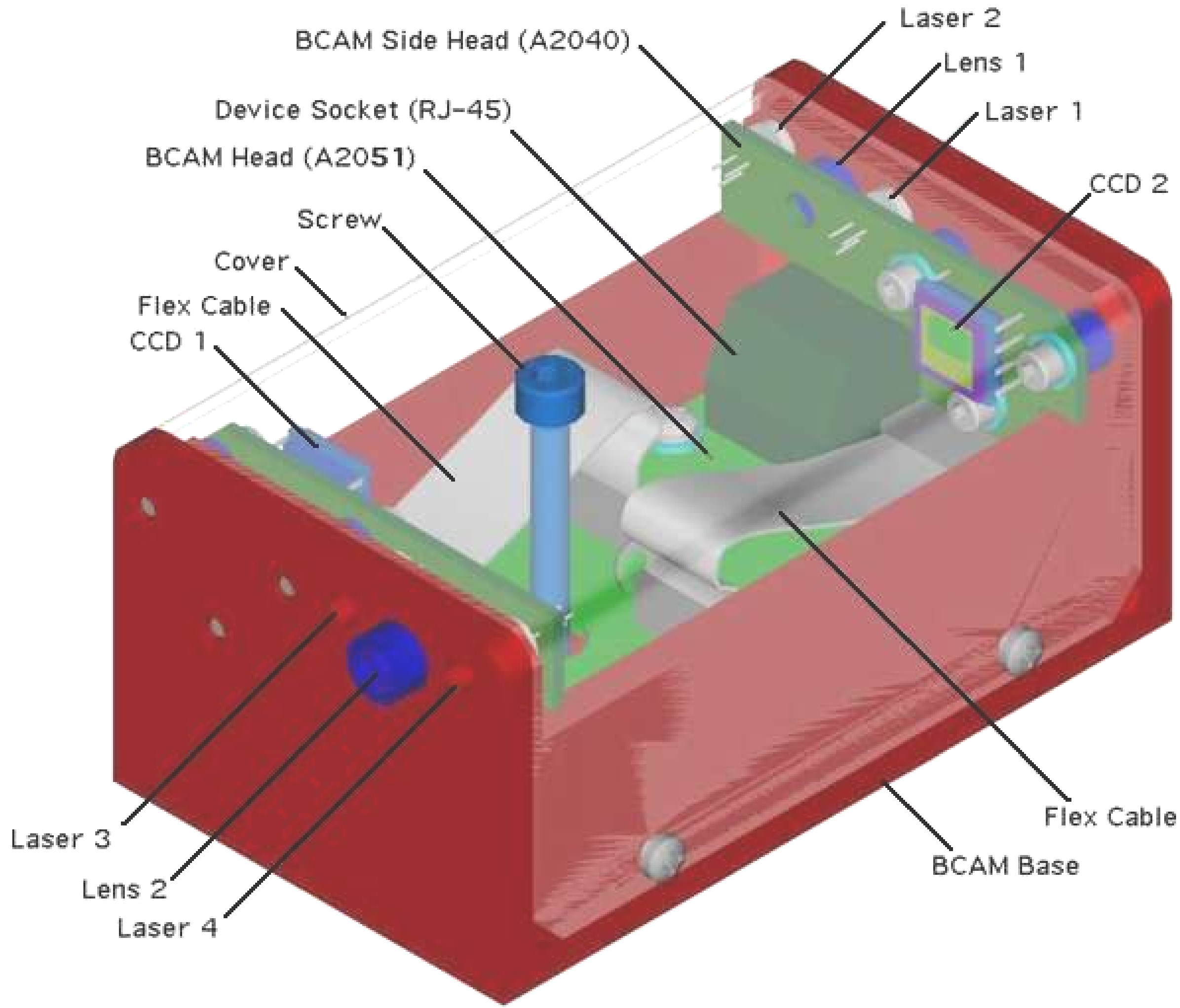
- **180 grams CF4**
- **32 low cost (non-cooled) ccds with fast readout and lenses inside vacuum chamber**
- **4 drift zones: each 1 meter by 1 meter by 25 cm**



The BCAM Camera

Kevan S Hashemi[1], James R Bensinger

Brandeis University



DMSAG Draft Report

Steve Elliott

HEPAP Meeting

February 23, 2007

Panel

Hank Sobel, Chair (UCI)
Howard Baer (FSU)
Frank Calaprice (Princeton)
Gabriel Chardin (SACLAY)
Steve Elliott (LANL)
Jonathan Feng (UCI)
Bonnie Fleming (Yale)
Katie Freese (U. of Michigan)
Robert Lanou (Brown)

Charles Prescott (SLAC)
Hamish Robertson (UW)
Andre Rubbia (ETH-Zurich)
Kate Scholberg (Duke)
Yoichiro Suzuki (U. of Tokyo)
Michael Witherell (UCSB)
Jonathan Bagger, Ex-Officio (Johns Hopkins University)
Garth Illingworth, Ex-Officio (UCSC)

Recommendation 1: Program and Funding

We recommend that the U.S. advance the search for dark matter using a variety of physical and technical approaches. U.S.-led experiments currently lead the world in sensitivity of the direct detection searches for both WIMPs and axions. We recommend that this leadership be preserved. This requires, in addition to supporting the running and improvement of existing detectors, that the R&D for the next stage of technology development be strongly supported with a goal of steady progress towards ton-scale and larger detectors.

To realize this program on an optimal time scale, the committee recommends that DOE and NSF increase funding for the direct detection of dark matter from the present ~$2-3M to ~$10M annually. The prospect of detecting dark matter while the LHC is operating amply justifies this increase. Such a figure is also consistent with the recommendations of P5 and EPP2010.

Recommendation: Priorities (Further Discussion Planned)

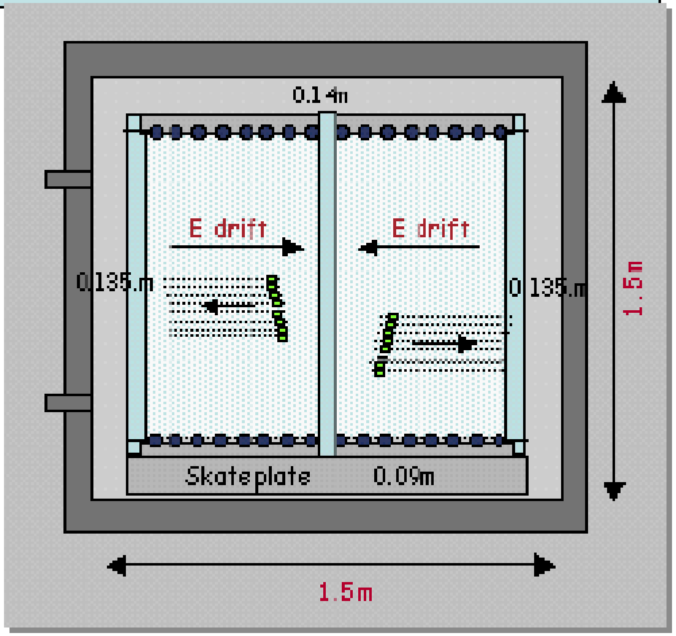
Following on the above recommendations, if the comprehensive program we have described is not able to be fully funded, then we recommend that the funding priorities during the next few years be aimed equally towards:

- continuing the on-going CDMS and ADMX experiments as indicated above and
- funding the expansion of the noble liquid experimental efforts to their next level.

During the same time period, the development of superheated liquid detectors and detectors capable of determining WIMP direction should be supported with a lower priority since, although they have great promise, they still have significant R&D questions remaining to be answered.

We believe that many of the questions associated with the longer-term direction of the experimental efforts will be resolved during the next few years and that a program review in or around 2009 will be necessary.

DRIFT-II (U.S.,G.B.)



- TPC filled with low-pressure electro-negative gas (CS_2) (electrons captured)
- Recoil tracks are ~few mm long, Ion drift limits diffusion in all 3 dimensions
- End planes allow determination of range, orientation & energy
- Excellent discrimination based on range and ionization-density
- Important R&D efforts by DRIFT groups and others, include improvements in readout sufficient for achieving full directionality…GEMs, Micromegas, combinations of wires and scintillation optics or isochronous cells and time-resolved pads.

Recommendation: Superheated liquids and Directional sensitivity

In addition to the above main lines of development,

- The sub-panel recommends the development of superheated liquid detectors. The program proposed by COUPP appears to be well balanced and has recently been approved by the Fermilab PAC.
- On the basis of the performance and background levels presented by the DRIFT collaboration, the sub-panel recommends the development of a single prototype detector module with the principal goal of demonstrating track reconstruction and directionality determination.