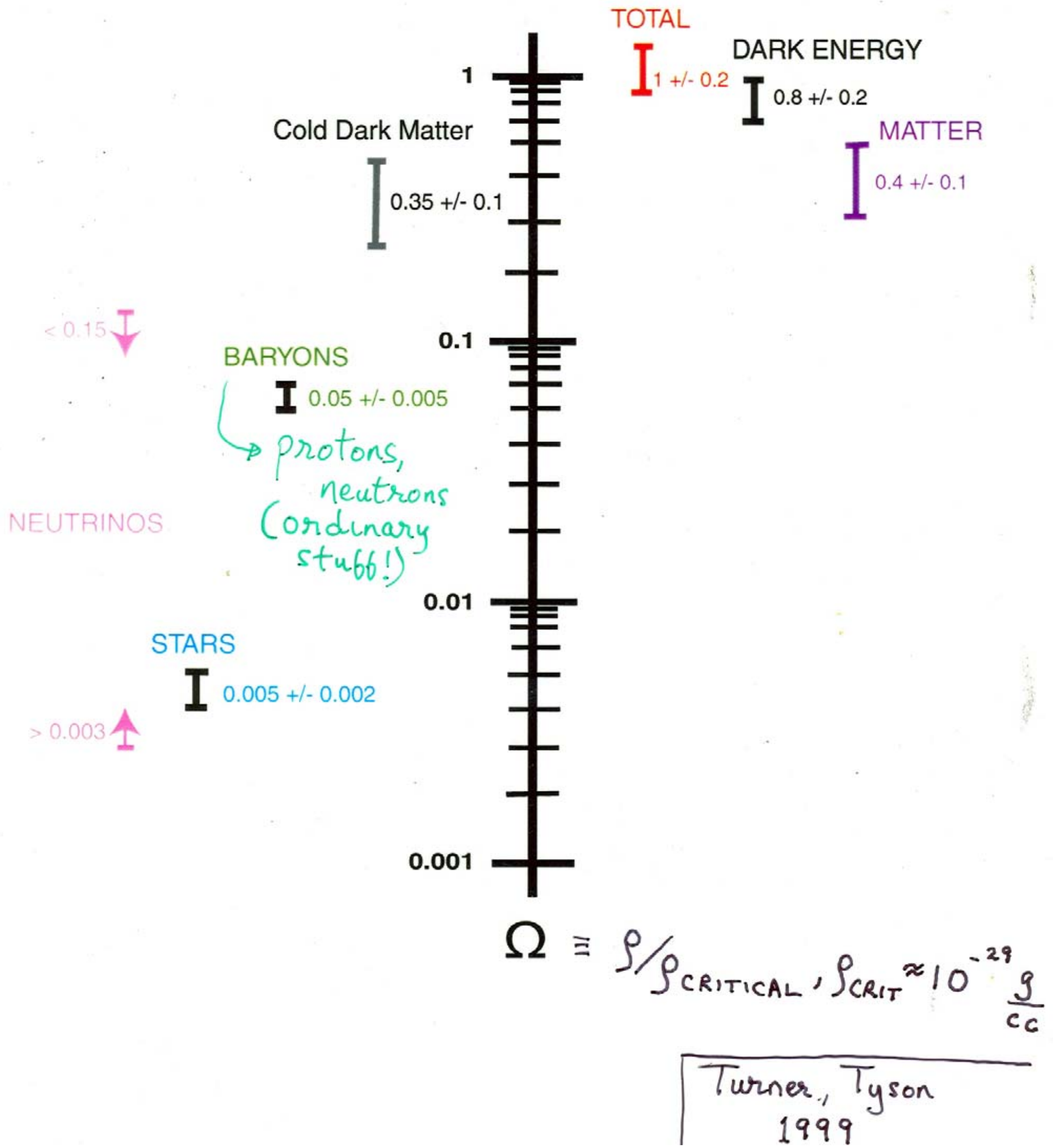
The DRIFT Dark Matter Search

D. Loomba
UNM

BNL August 3, 2006

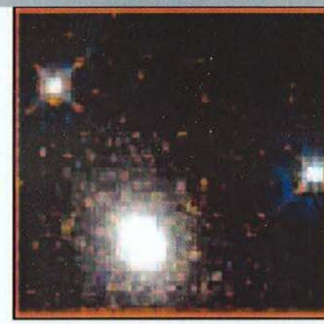
MATTER/ENERGY in the UNIVERSE



Post WMAP era ... Precision Cosmology! (~2003)

Knowing what we don't know! with great precision - matter and energy

heavy elements 0.03%



stars 0.5%

neutrinos 0.47%

free H and He 3.7%

dark matter 24.3%

dark energy 71.0%

if it isn't dark it doesn't matter!

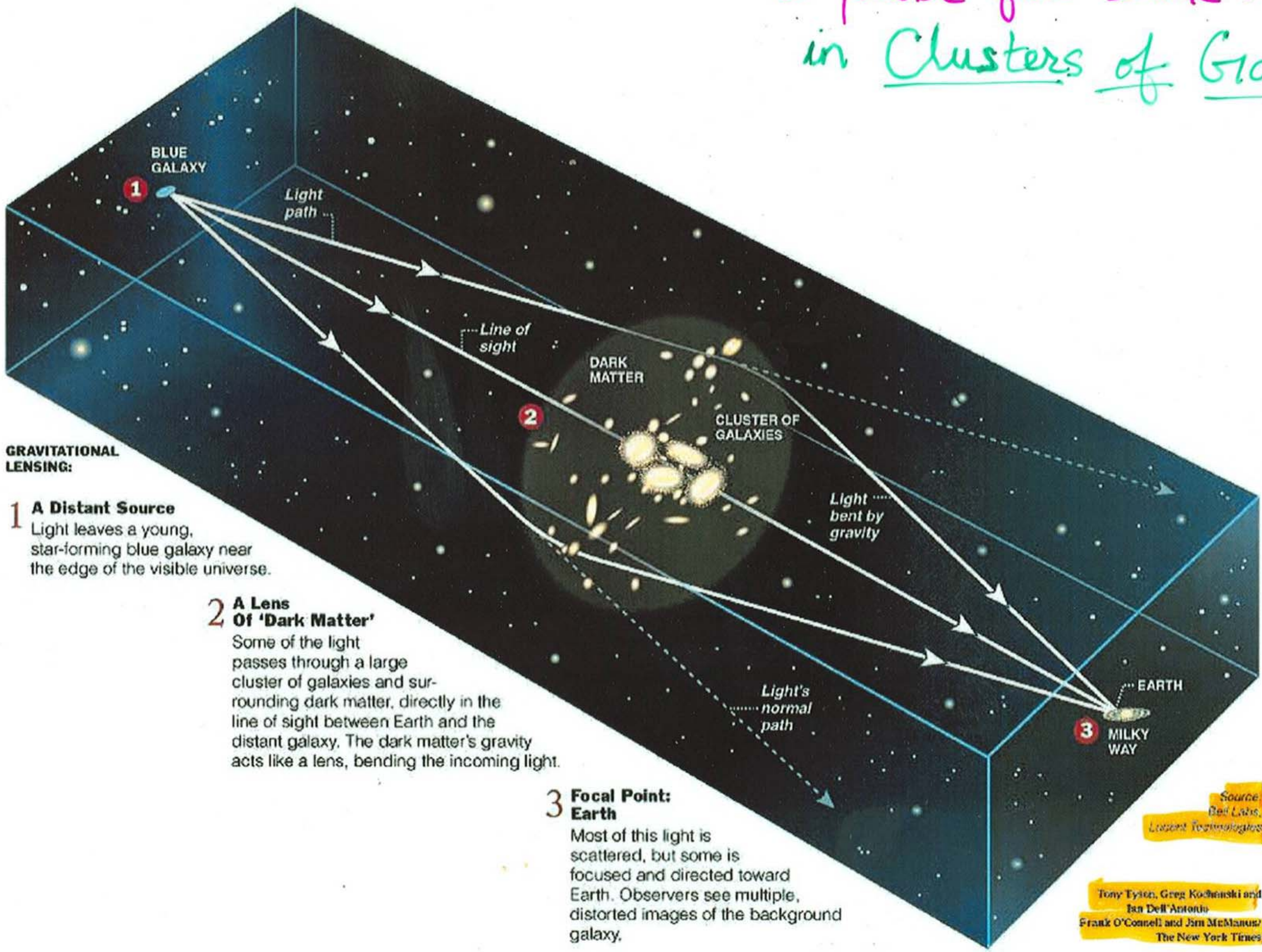
US0703 - all data shown is preliminary

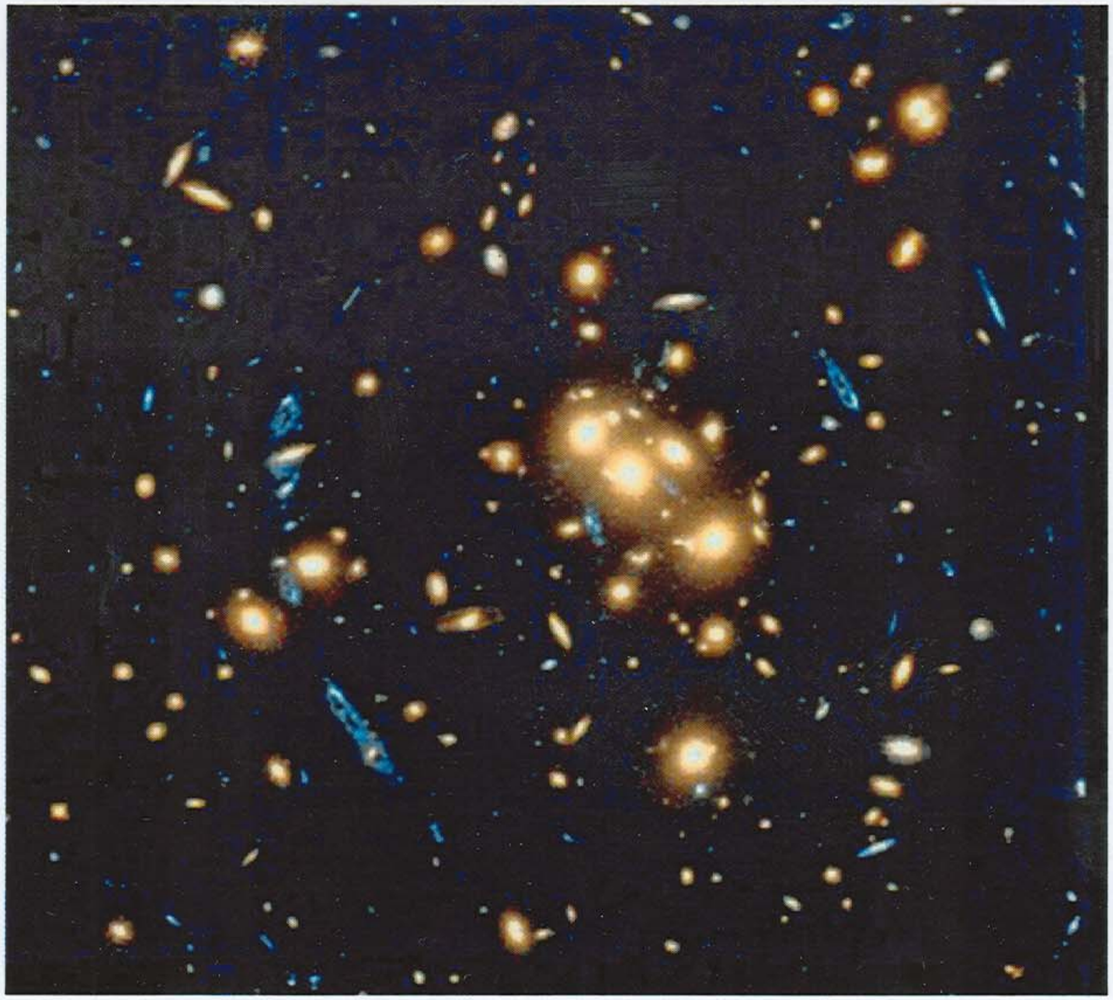
Gravitational Lensing:

Weighing the Universe with a

LENS

GRAVITATIONAL LENSING, a probe for Dark Matter in Clusters of Galaxies

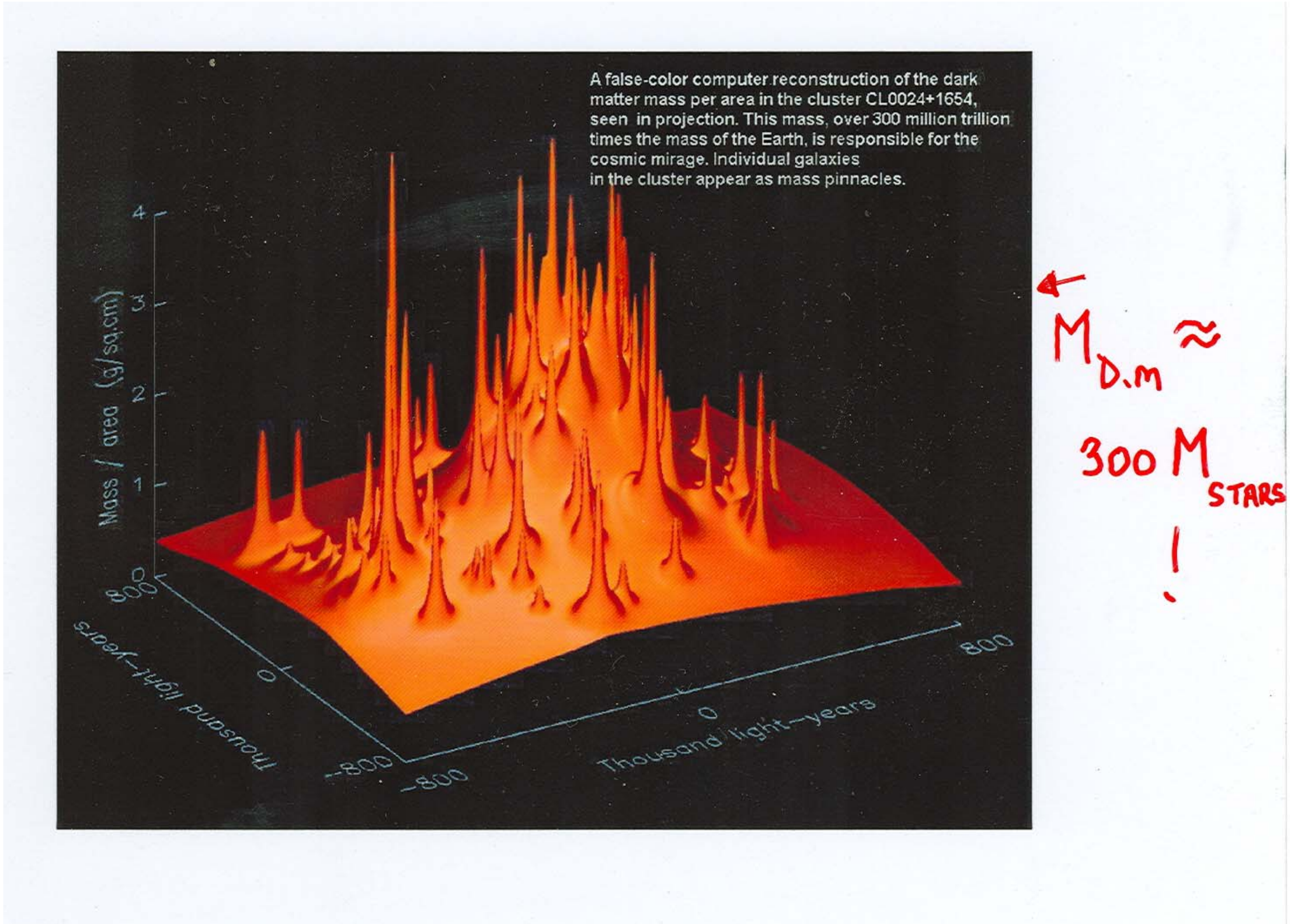




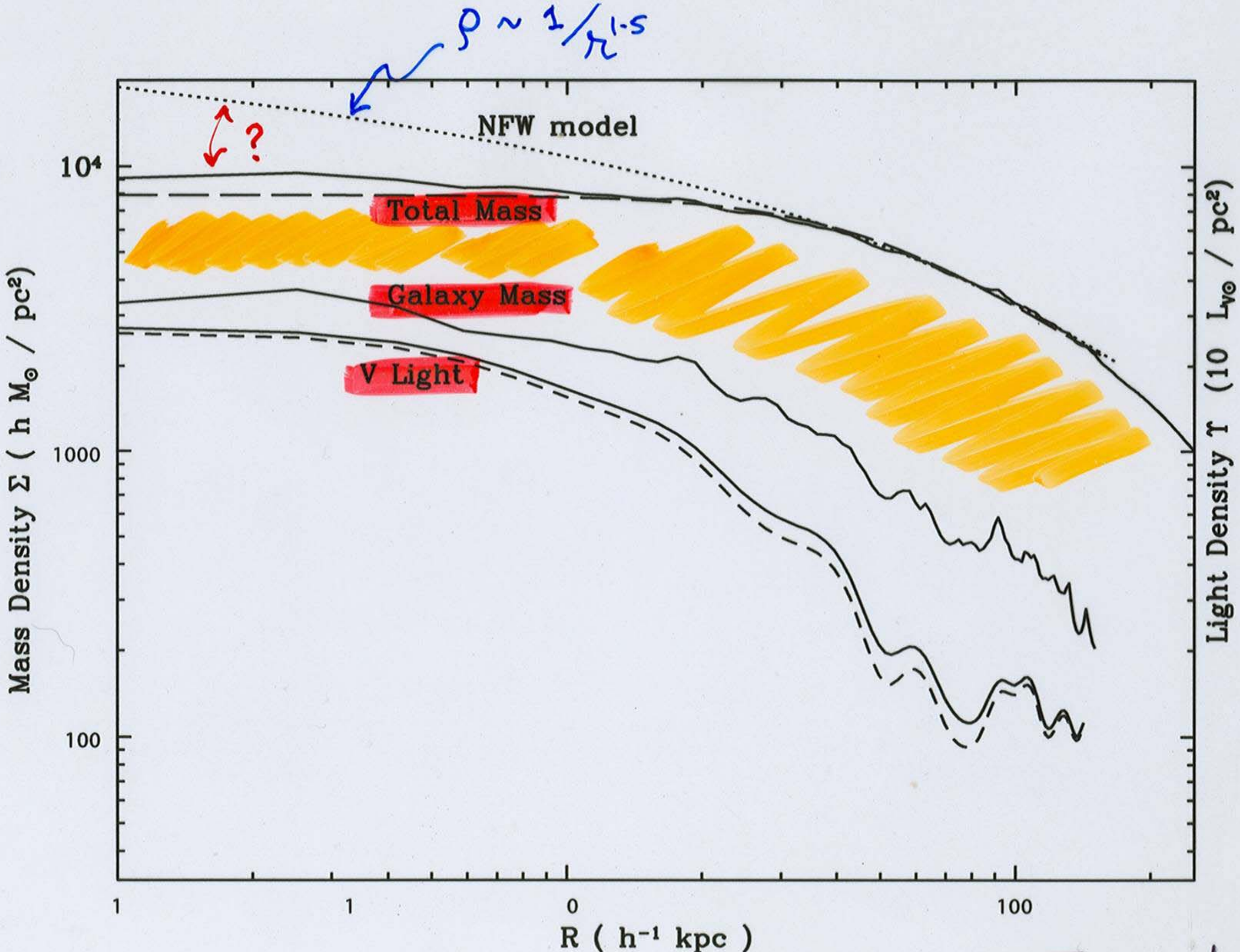
Foreground cluster at $z = 0.39$, lensed galaxy at $z \gtrsim 1.2$

A Hubble Space Telescope image of a gravitational lens formed by the warping of images of objects behind a massive concentration of dark matter. Warped images of the same blue background galaxy are seen in multiple places. (Colley, Tyson, Turner ApJ **461** L83 (1996)).

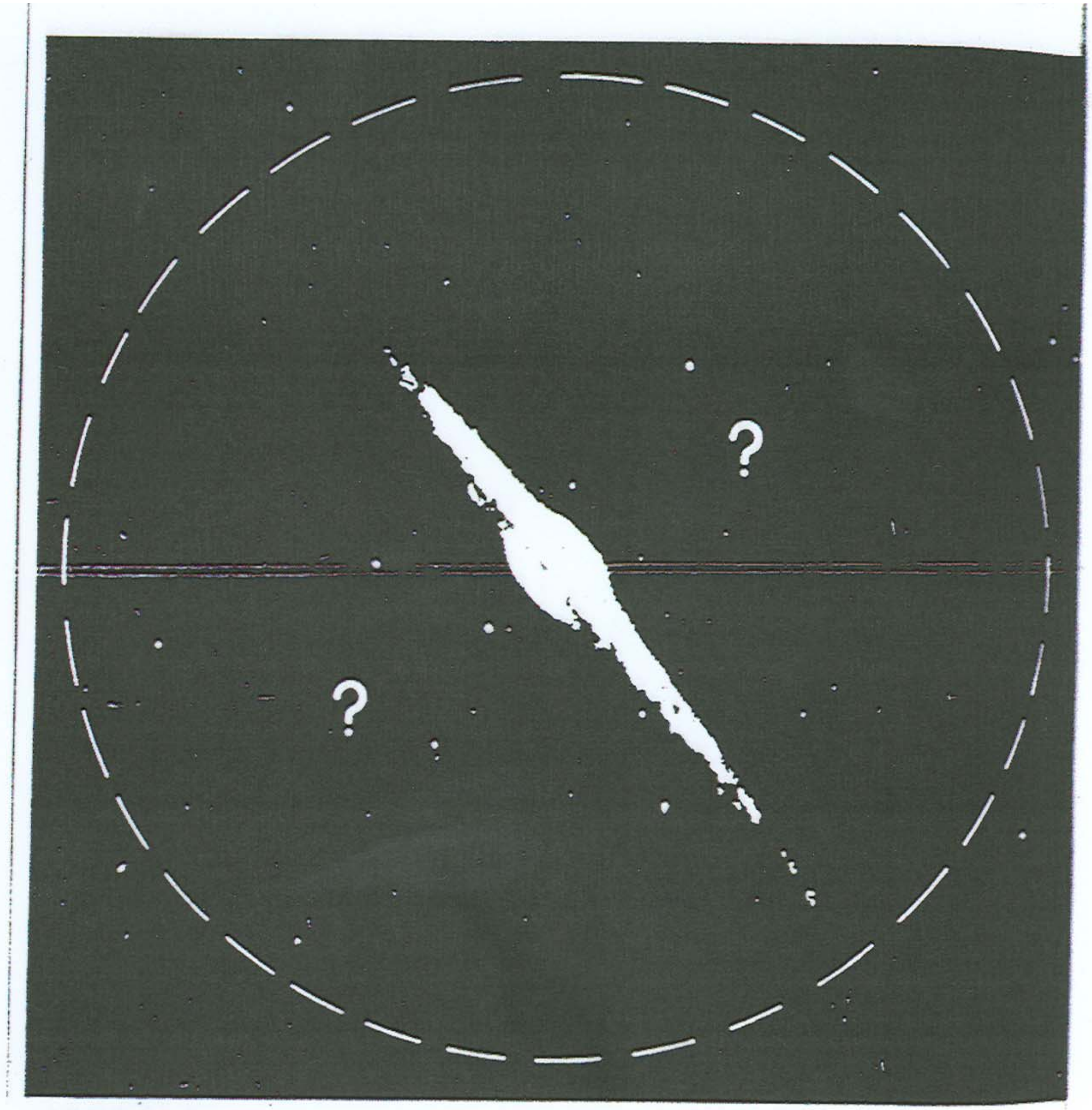
…and the resultant (2D) mass map



RESULTANT RADIAL MASS DISTRIBUTION



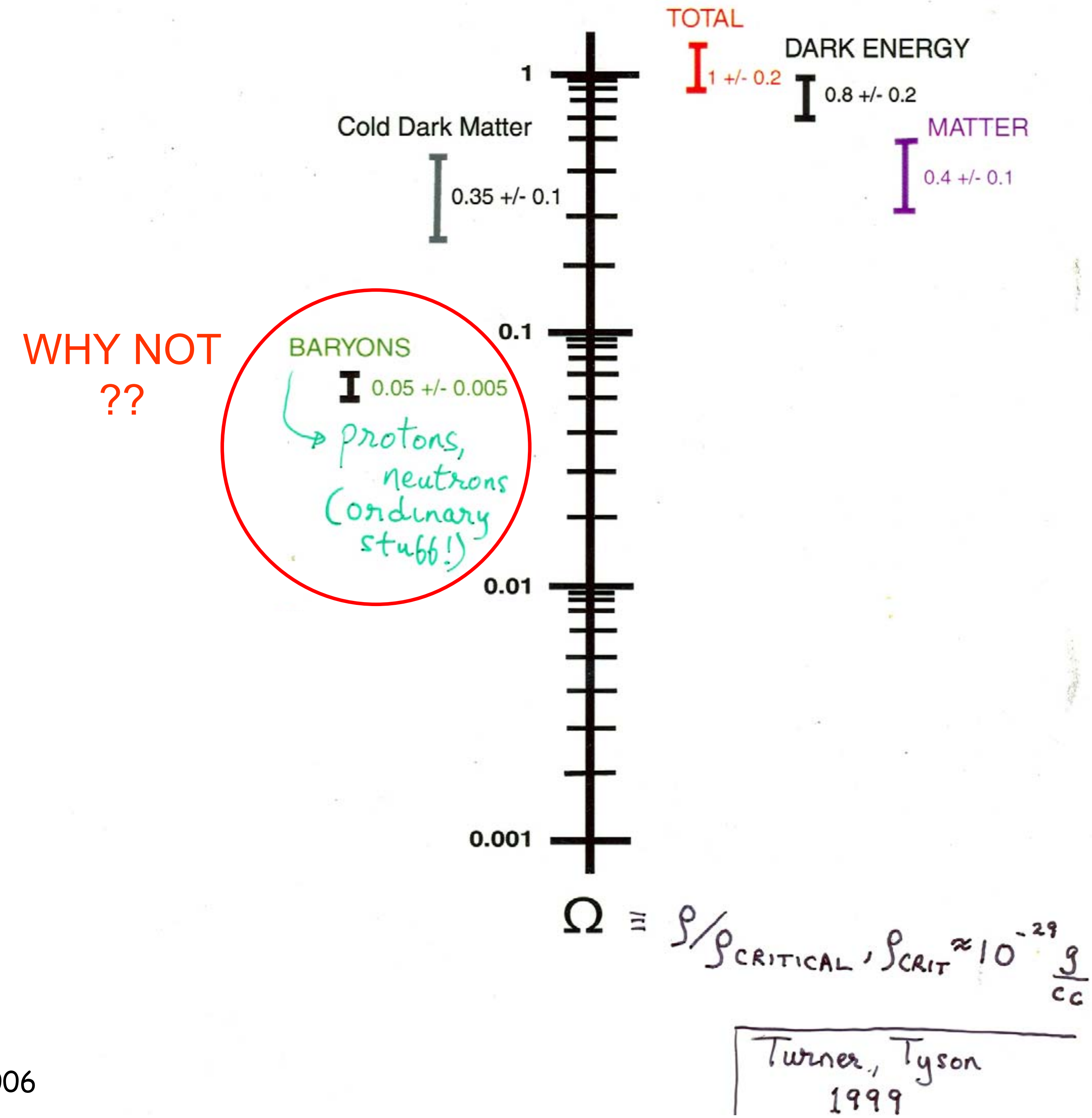
Tyson, et al (1998)



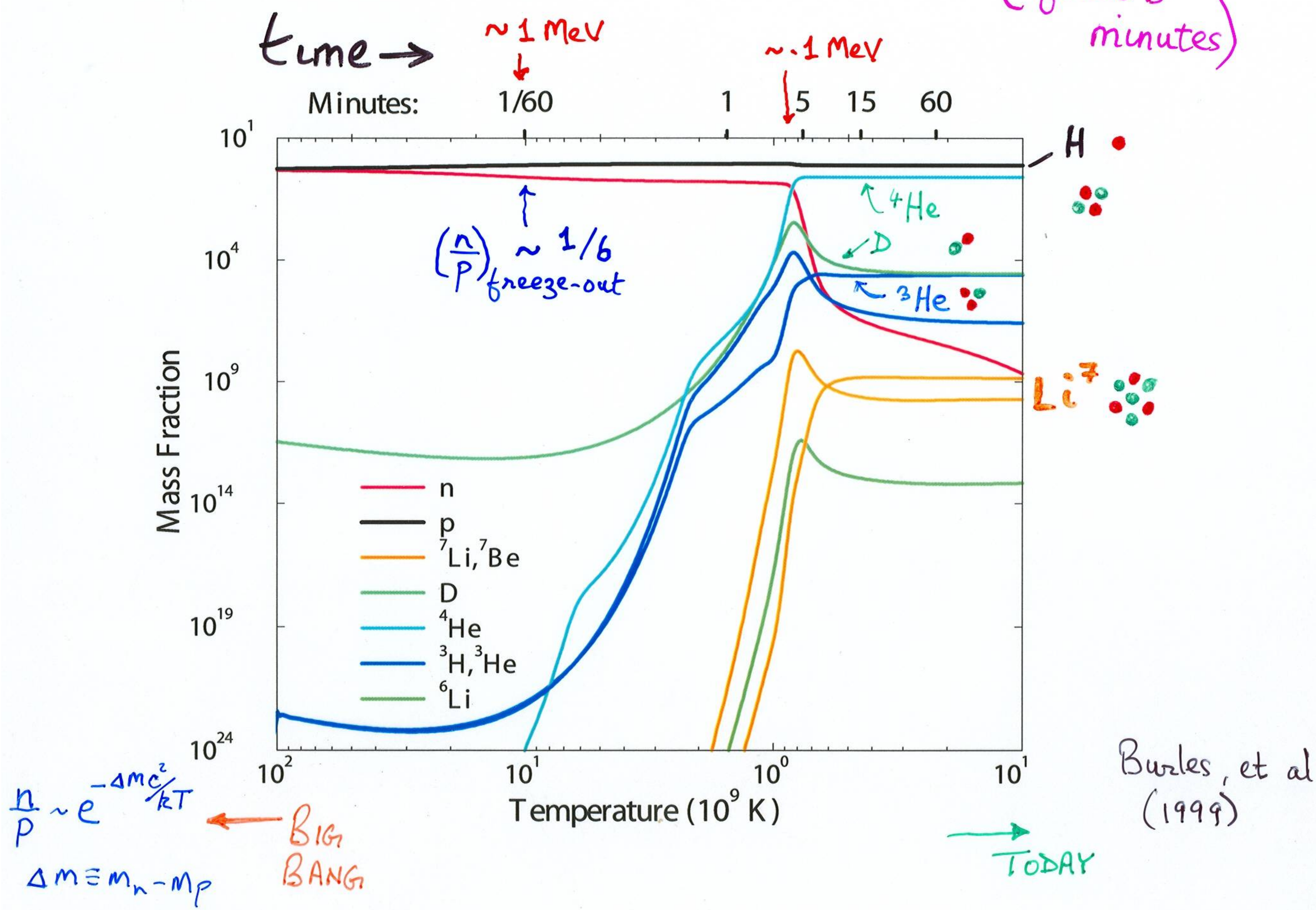
NGC4565

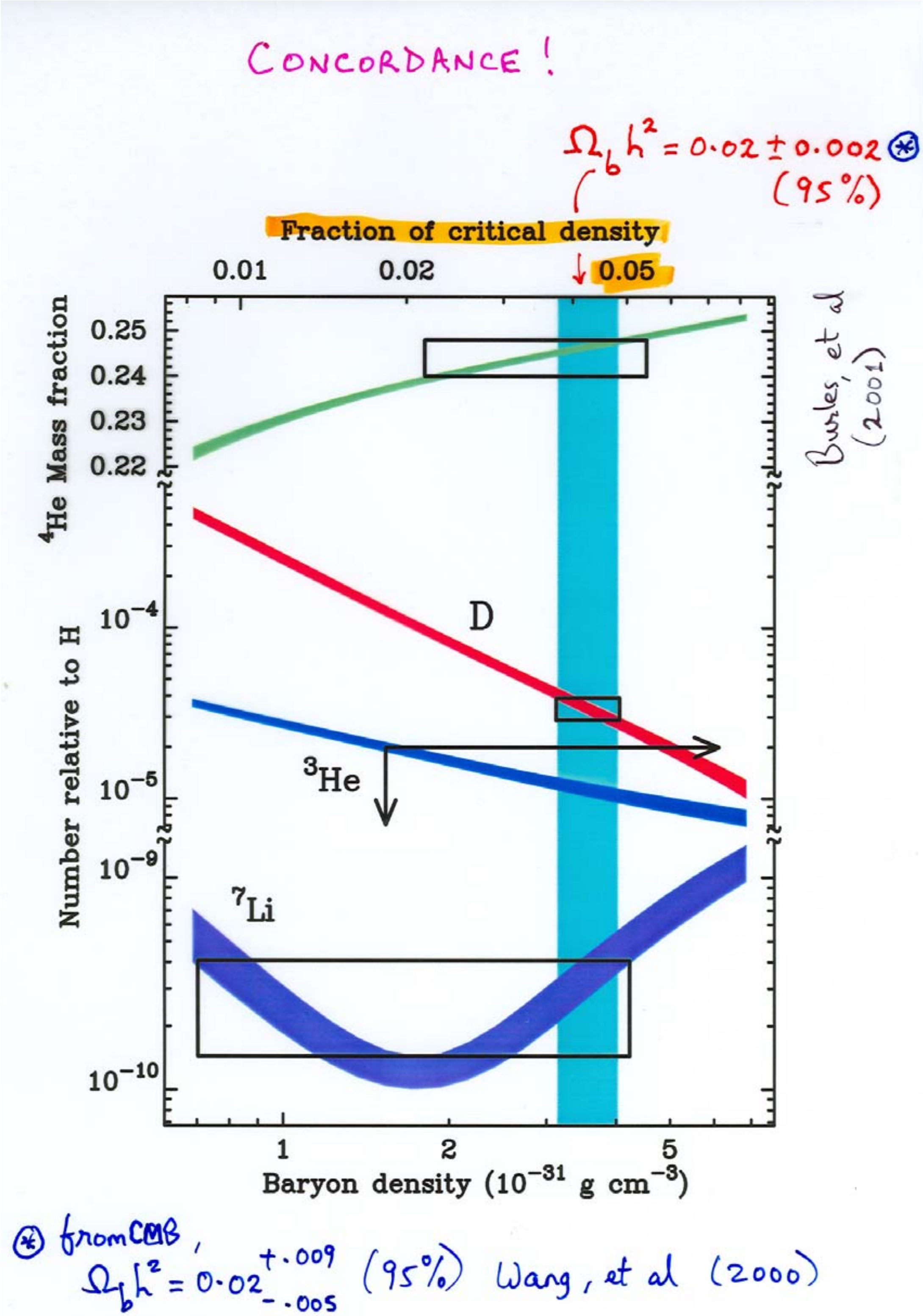
So, what is it??

MATTER/ENERGY in the UNIVERSE



BIG BANG NUCLEOSYNTHESIS (first 3 minutes)




CONCORDANCE!
$\Omega_b h^2 = 0.02 \pm 0.002$ (*)
(95%)
Fraction of critical density
0.01
0.02
0.05
0.25
0.24
0.23
0.22
^{4}He Mass fraction
10^{-4}
10^{-5}
10^{-9}
10^{-10}
Number relative to H
D
^{3}He
^{7}Li
Burles, et al (2001)
1
2
5
Baryon density (10^{-31} g cm^{-3})
(*) from CMB, $\Omega_b h^2 = 0.02^{+.009}_{-.005}$ (95%) Wang, et al (2000)

SOME (!) Candidates for DM

MACHOS

WIMPS

ν's

B-H's

Dwarfs

SIMPS^2

axions

MOND

Xtra Dimensions!

Fuzzy DM

CHAMPS

LEADING CANDIDATES FOR DARK MATTER:

WIMPs

Direct detection:

Astrophysics

$$\text{Rate} \propto \frac{N_T \, \rho_{DM} \, \sigma_0}{m_{wimp} \, m_n} \int_{v_{min}}^{v_{max}} \frac{f(v)}{v} \, dv$$

particle physics

Expected rate $\lesssim$ 1/day·kg, with $Q \sim 1$–100 keV

CONSTRAINTS ON DM PROPERTIES

- ASTROPHYSICS: COLD (non-relativistic), non-dissipative, and, at most, weakly-interacting

Galactic kinematics $\Rightarrow \rho_{DM,\odot} \sim 0.2-0.5 \frac{GeV}{cm^3}$

Halo Models $\Rightarrow \langle v^2 \rangle^{1/2} \sim 10^{-3} c$

} Flux if $m_\omega \sim 100 GeV$ $\sim 10^7$ thru your hand !!

- Particle Physics: beyond the Standard Model theories provide "natural" candidates for DM. Leading candidates:

  - axions
  - neutralinos from SUSY, $m_\chi \sim 10\text{'s} - 1000\text{'s}$ GeV

    $10^{-46} cm^2 \lesssim \sigma_{\chi p} \lesssim 10^{-42} cm^2$

    (maybe!)

OR: $\frac{1 \text{ event}}{kg \cdot day}$ down to $\frac{1 \text{ event}}{100 kg \cdot year}$!!!

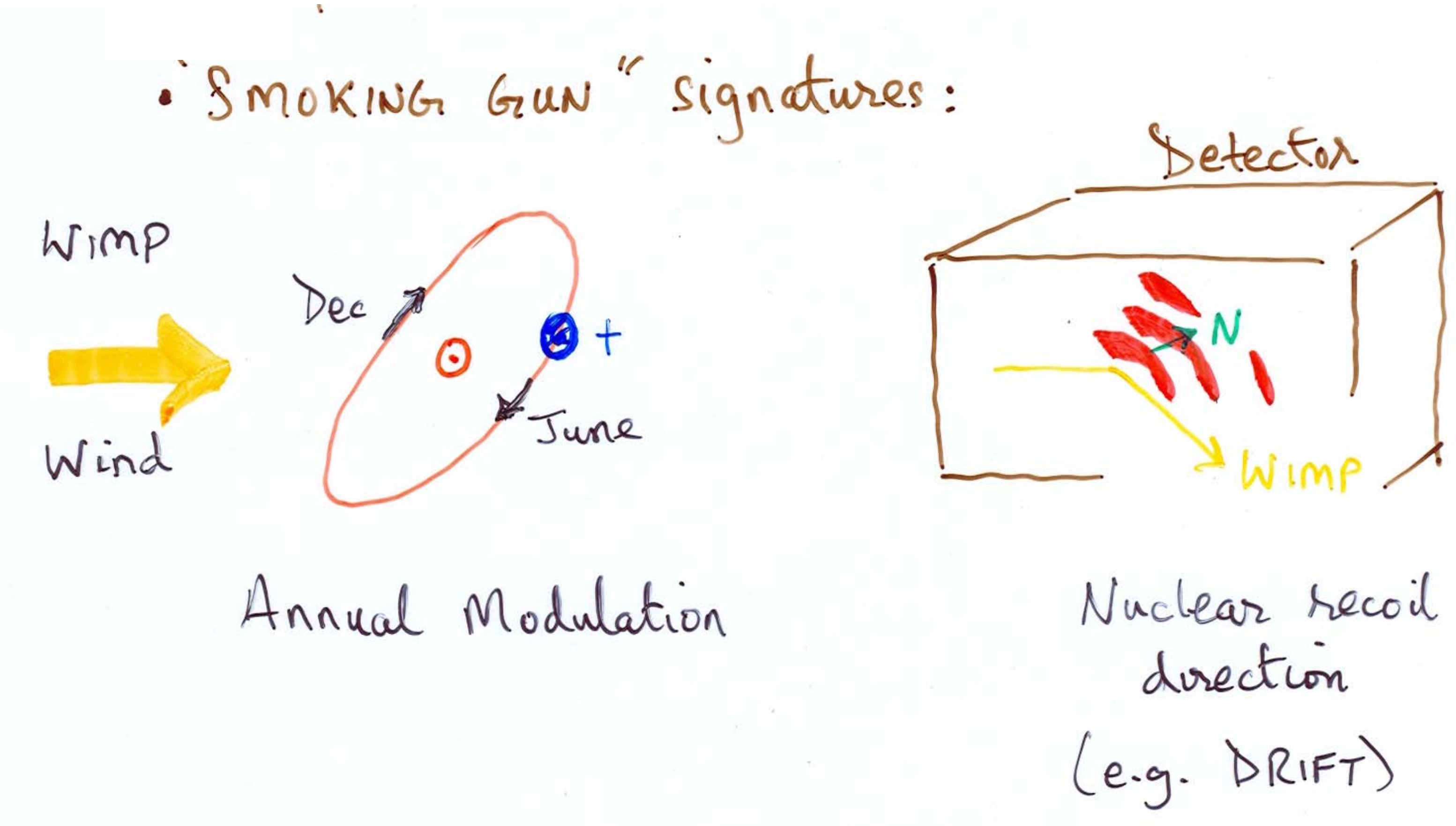
Background Projections - CryoArray (1 tonne)

	Event Rate [mdru]	Expose [1000 kg-day]	Raw Events [counts]	Reject [%]	Post rejection [counts]	Subtract 90% CL [counts]	Sys'tic 90% CL [counts]
GAMMA							
CDMS I *	800	0.011	254	99.85%	0.4	-	-
CDMS II	260	2.50	19,500	99.50%	98	16	5
Heidelberg-M *	40	0.25	0	n/a			
CryoArray	13	500	195,000	99.95%	97	16	5
BETAS							
CDMS I *	300	0.011	95	95.00%	5	-	-
CDMS II	20	2.50	1,500	95.00%	75	14	4
CryoArray	1	500	15,000	99.50%	75	14	4
NEUTRONS							
CDMS I*(Shield)	2201	0.011	700	99.90%	1	-	-
CDMS I*(Rock)	22	0.011	7	(multi)	n/a	4	-
CDMS II (Sh)	0.5	2.50	38	99.00%	0.4	-	-
CDMS II (Rk)	0.11	2.50	8	(multi)	n/a	6	1
CryoArray (Sh)	0.5	500	7,500	99.90%	8	-	-
CryoArray (Rk)	0.0055	500	83	(multi)	n/a	21	8

x20^{-1}

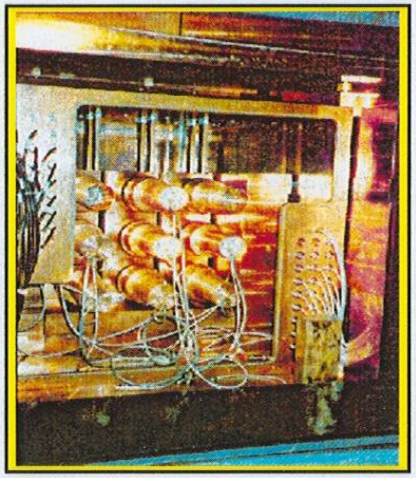
dru = 1 event keV^{-1} kg^{-1} day^{-1} Energy Range 10-40 keV

So you need…

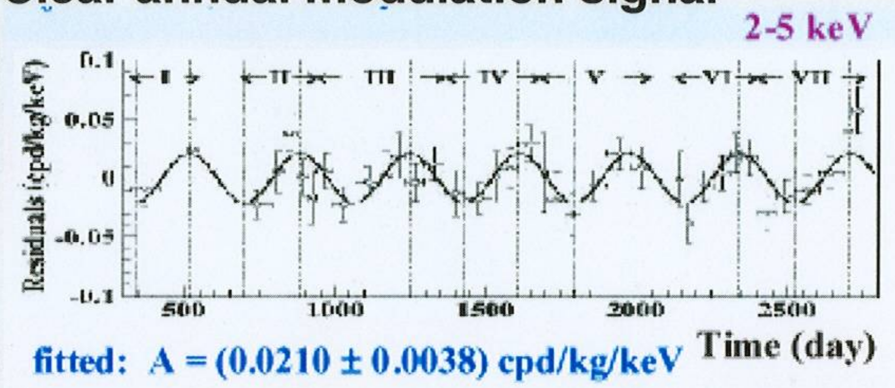


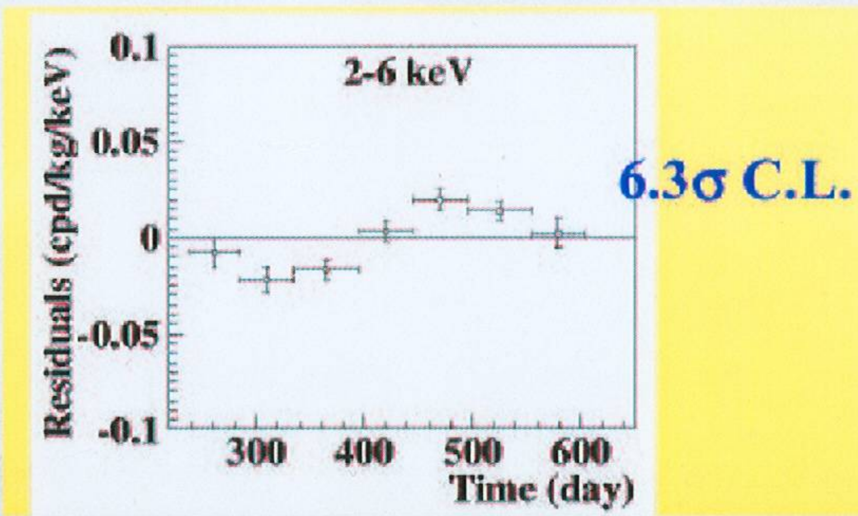
• "SMOKING GUN" signatures:
WIMP
Wind
Dec
June
+
Annual Modulation
Detector
N
WIMP
Nuclear recoil
direction
(e.g. DRIFT)

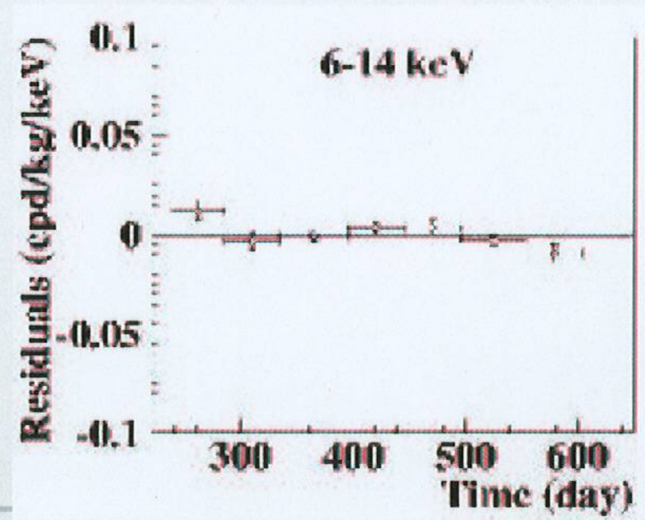
DAMA latest



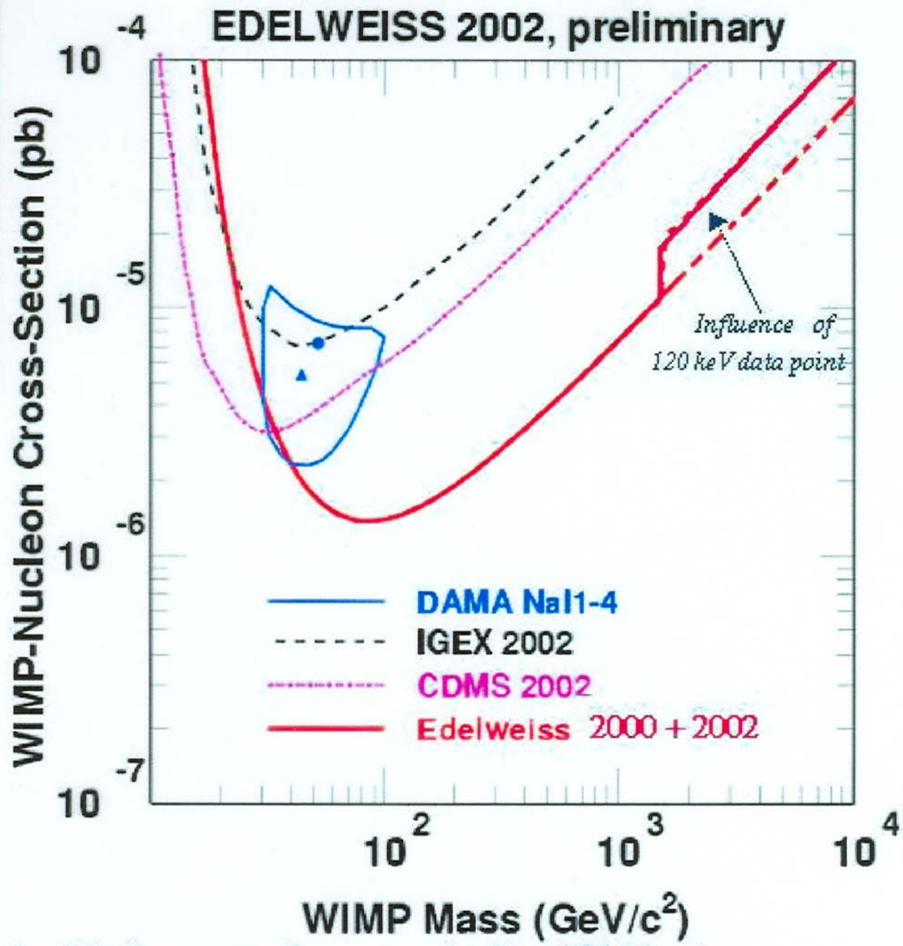
- DAMA - 100 kg of NaI(Tl)
- Annual modulation analysis
- 7 annual cycles analysed so far (latest 3 just released)
- Clear annual modulation signal







EDELWEISS-I 05/2002
Present sensitivity for spin independent WIMPs (bis)

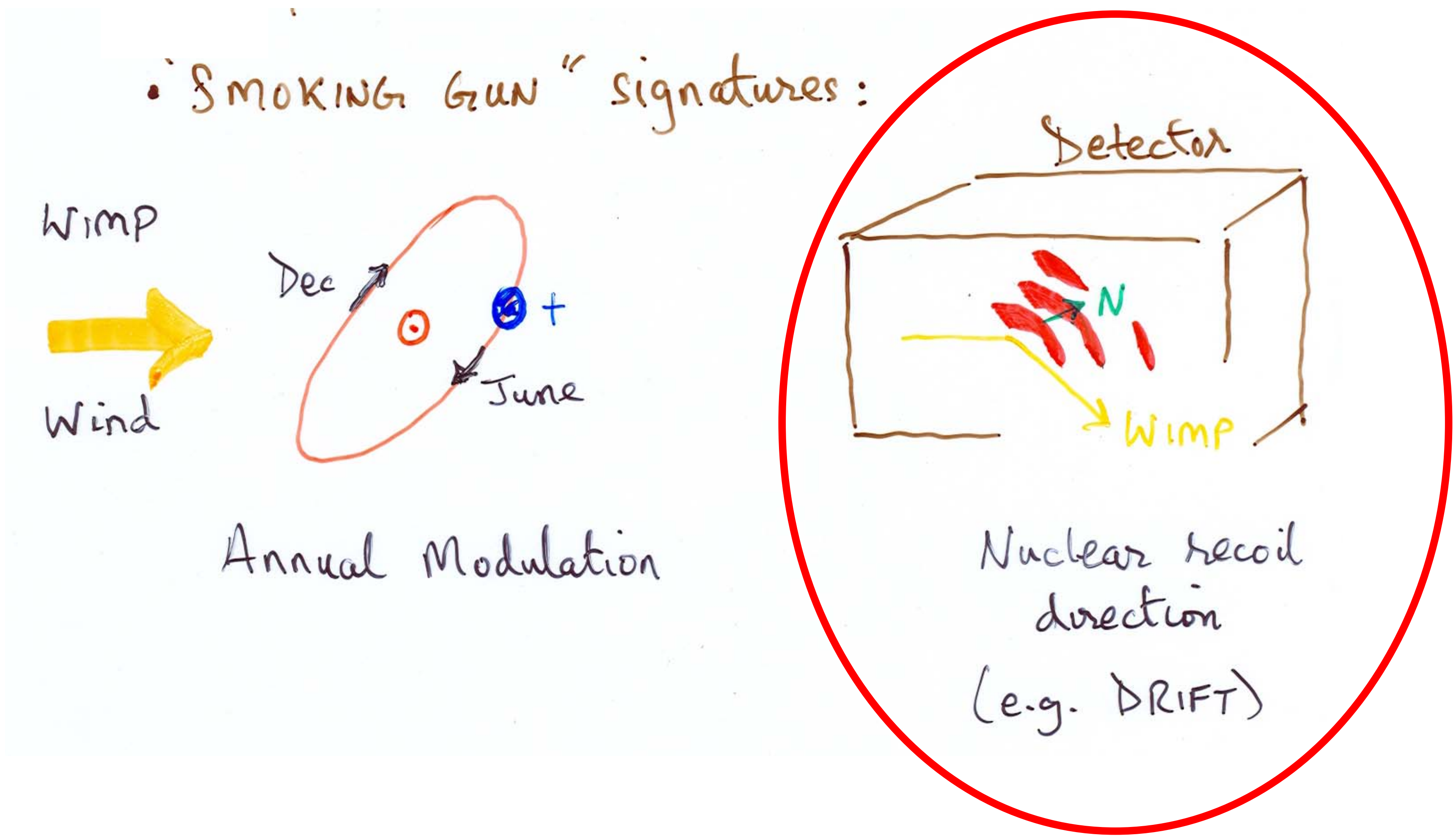


- ***Standard halo assumed, mean velocity of 220 km/s***
- ***WIMP signal acceptance = 95 %***
- ***Exposures (fiducial-corrected for recoil and WIMP acceptances) : 2000 data (5.0 kg.d- 4.3 kg.d) cumulated with 2002 data (8.2 kg.d-7.0 kg.d)***

Neutrino 2002

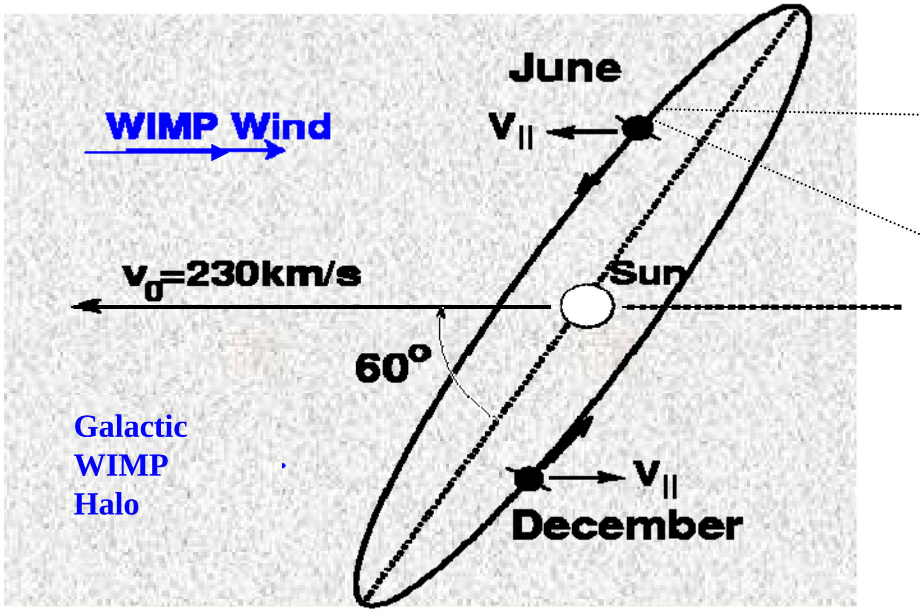
…but Edelweiss (and others now) ruled this out.

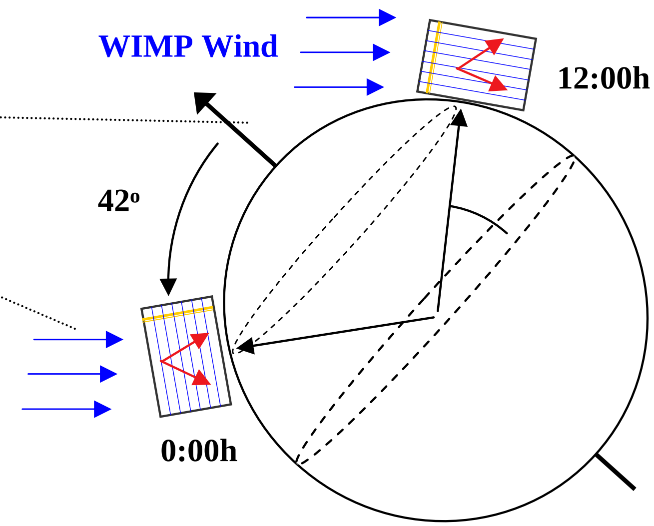
So you need…

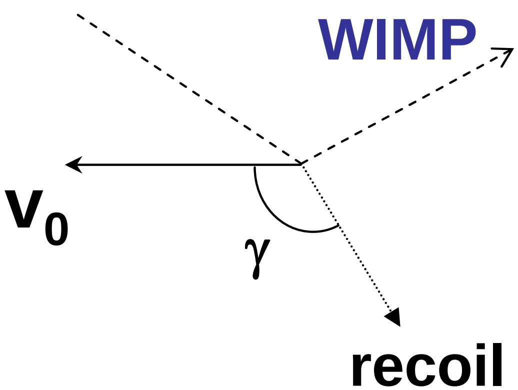


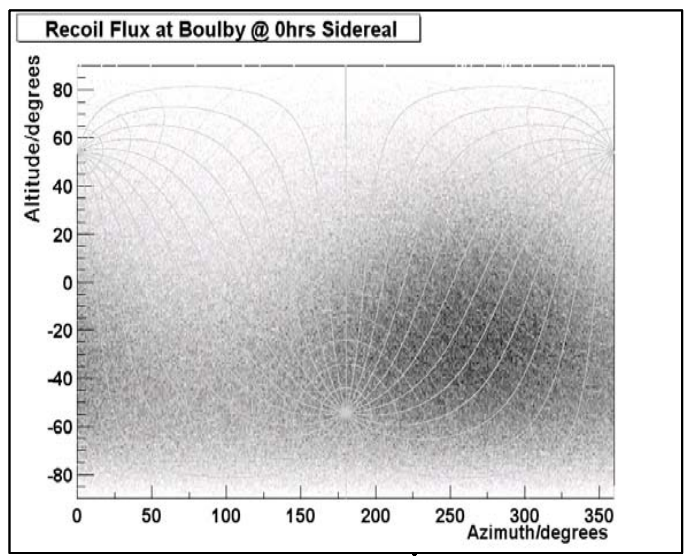
• "SMOKING GUN" signatures:
WIMP
Wind
Dec
June
+
Annual Modulation
Detector
N
WIMP
Nuclear recoil
direction
(e.g. DRIFT)

Nuclear recoil tracks yield WIMP direction

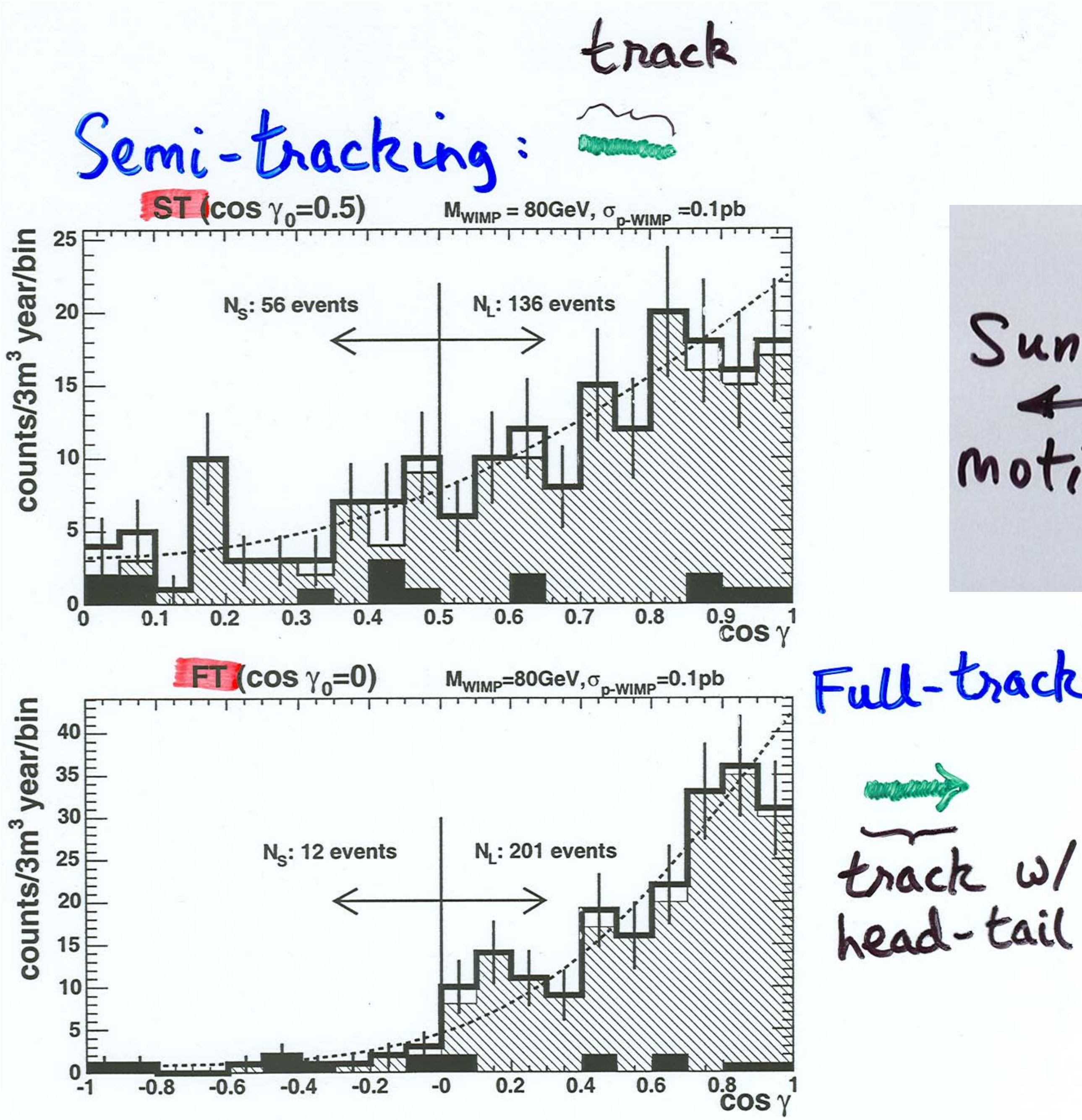


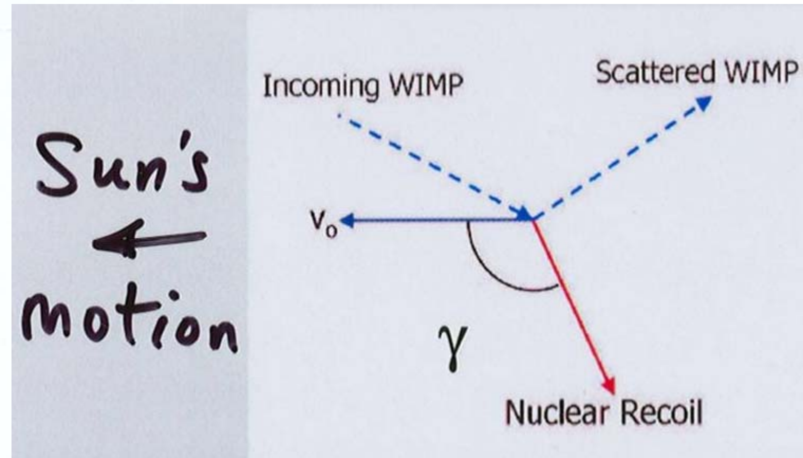






Identifying a signal





(astro-ph/0310638)

In fact, calculations indicate that there should be a head-tail signature in the ionization dE/dx!

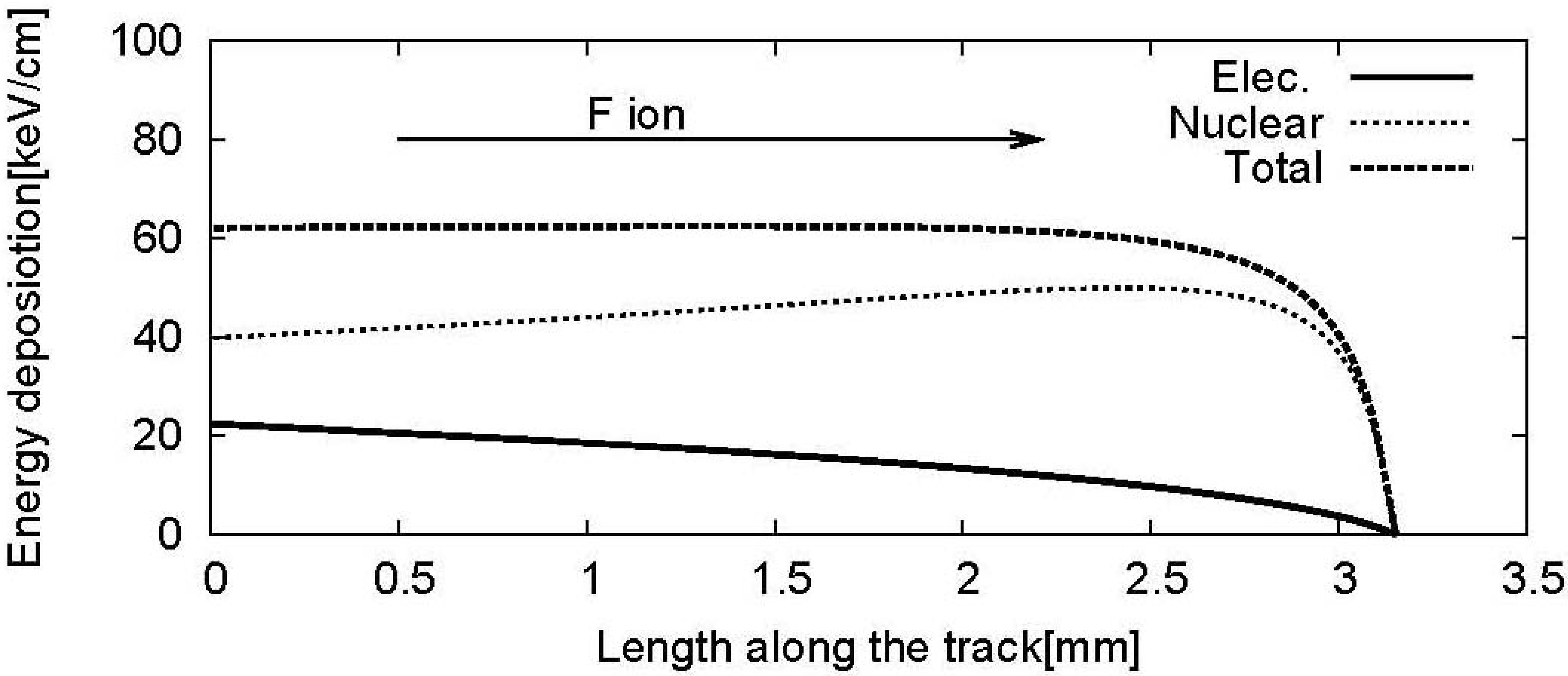


Fig. 2. Calculated energy loss of a F ion of 25 keV in 20 Torr CF_4 gas. The energy loss in the electron field, nuclear filed, and the total energy loss are shown by the solid, dotted, and dashed lines, respectively.

(astro-ph/0310638)

DRIFT

OCCIDENTAL COLLEGE

(SNOWDEN-IFFT + U.Gs)

UNM

(GOLD, HAGEMANN, SANGHI, TURK, LOOMBA)

SHEFFIELD

(SPOONER et al)

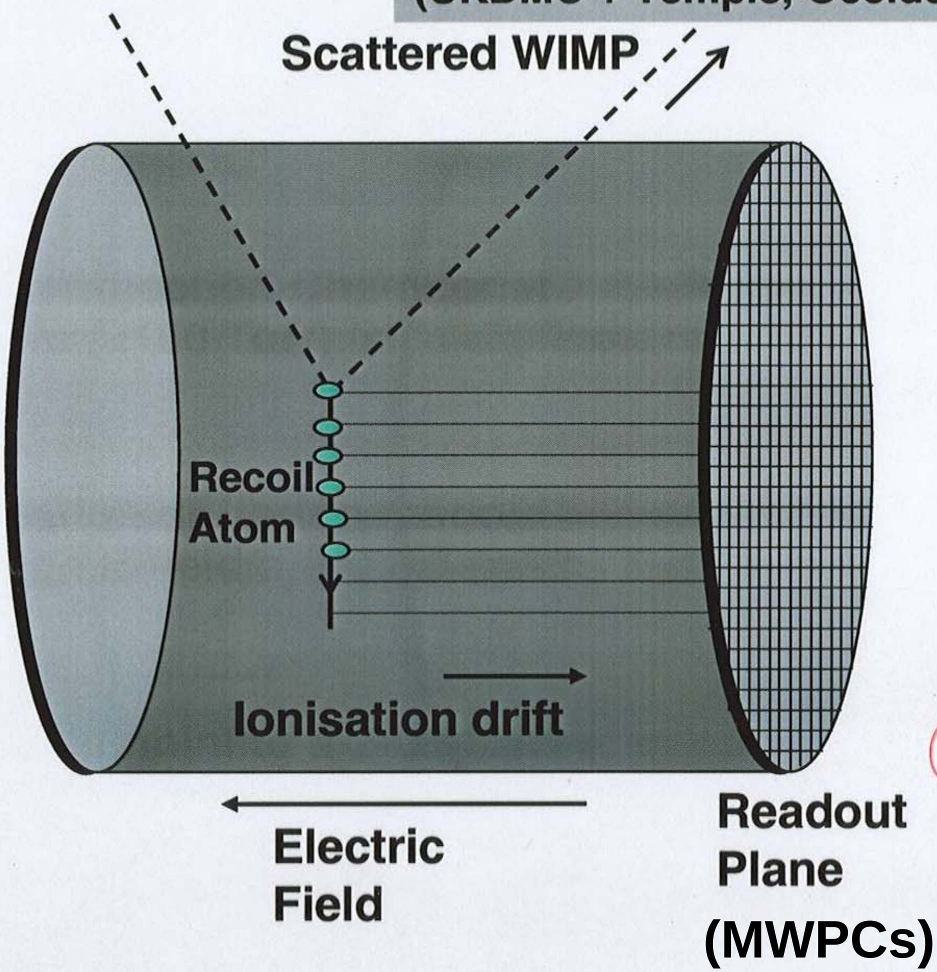
EDINBURGH

(MURPHY et al)

THE DRIFT CONCEPT : range vs. energy
→ tracking, tracking, tracking!

DRIFT - low pressure TPC

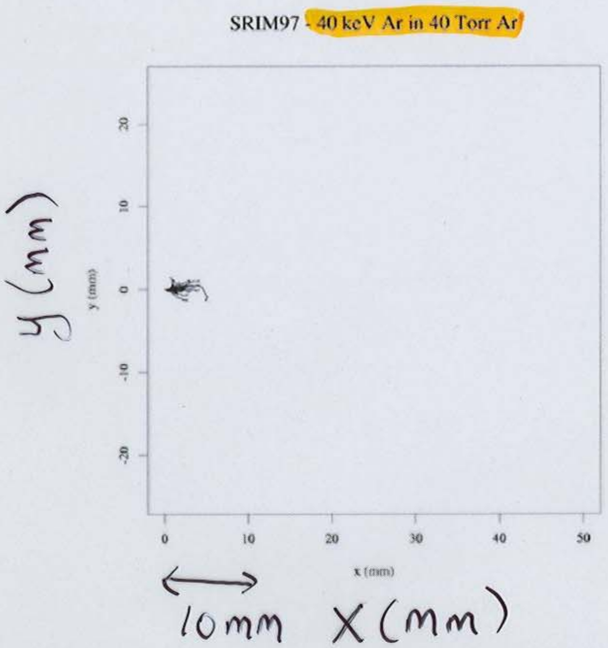
(UKDMC + Temple, Occidental College, LLNL)

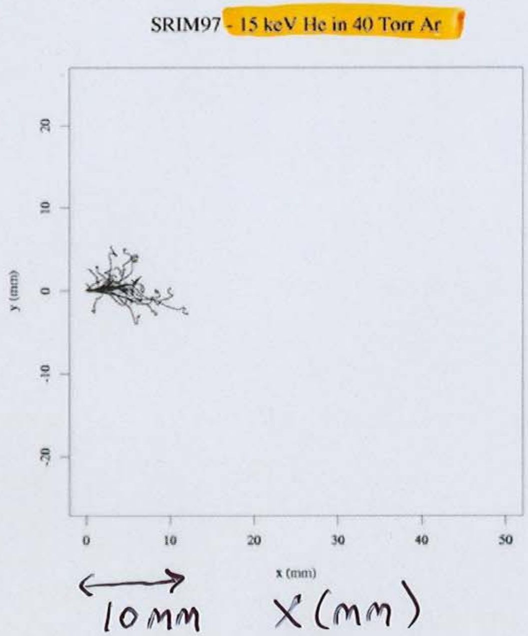


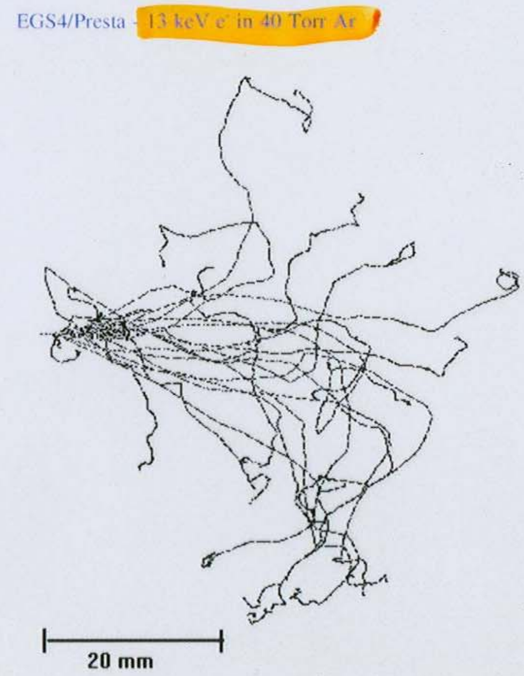
- Energy scale of nuclear recoils means recoil ranges very low
- Use a Time Projection Chamber at low pressure (<100 Torr) to extend recoil range to few mm
- Track ionisation drifted to readout plane by high E-field
- (*) Full 3-D reconstruction of track possible by combining a 2-D readout plane with timing information in the drift direction
- -ve Ion Drift with CS_2 (e.g.) idea by Jeff Martoff (Temple)

TRACKING IS ALSO KEY for DISCRIMINATION of BACKGROUNDS!

40 keV Ar recoils 500 electron-ion pairs	15 keV αs 500 electron-ion pairs	13 keV e⁻s 500 electron-ion pairs

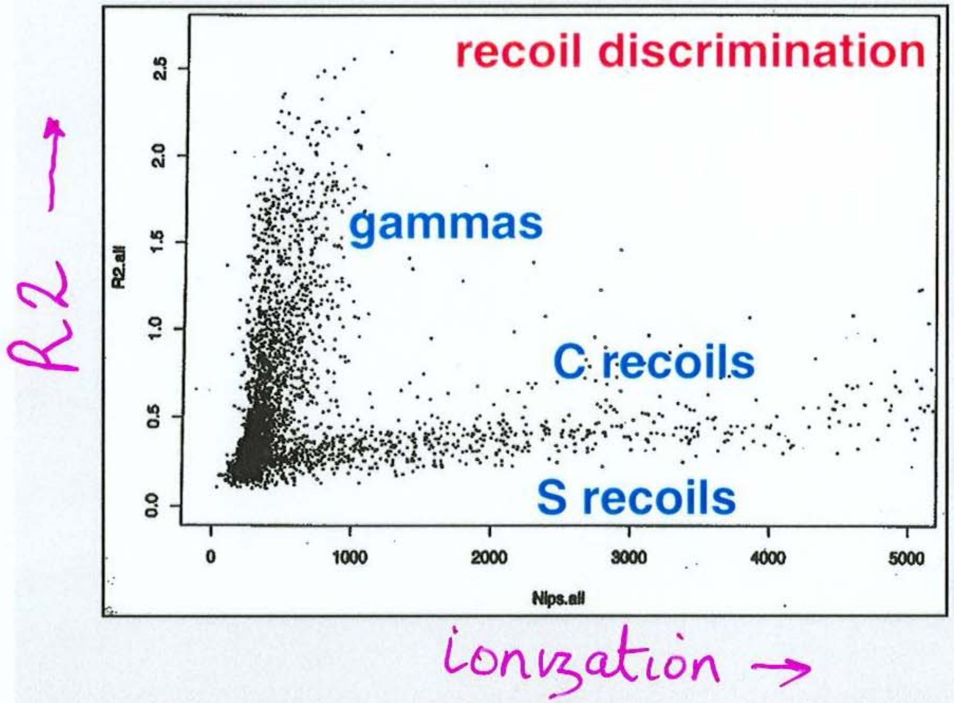


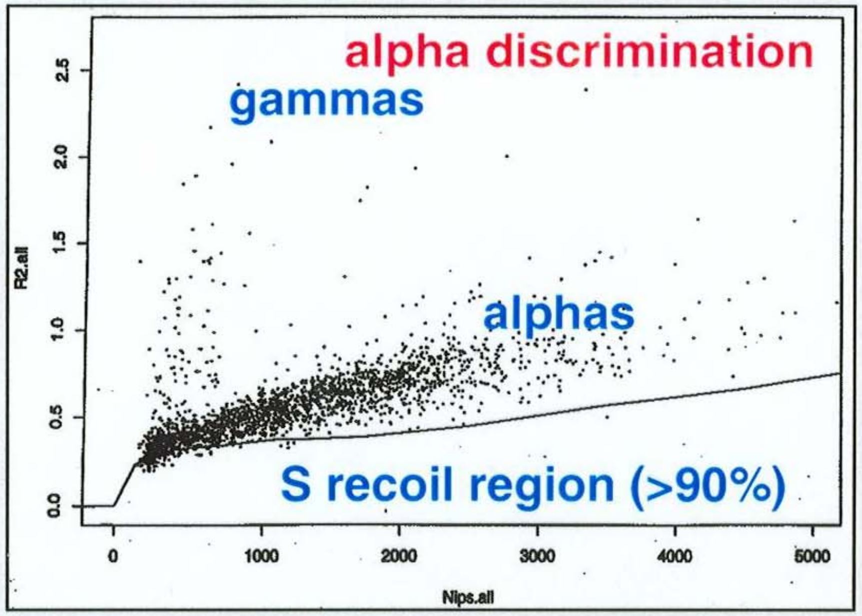




Note: discrimination still possible w/o true tracking!
(ala D-I)

1 ft^3 prototype tests (Occidental)

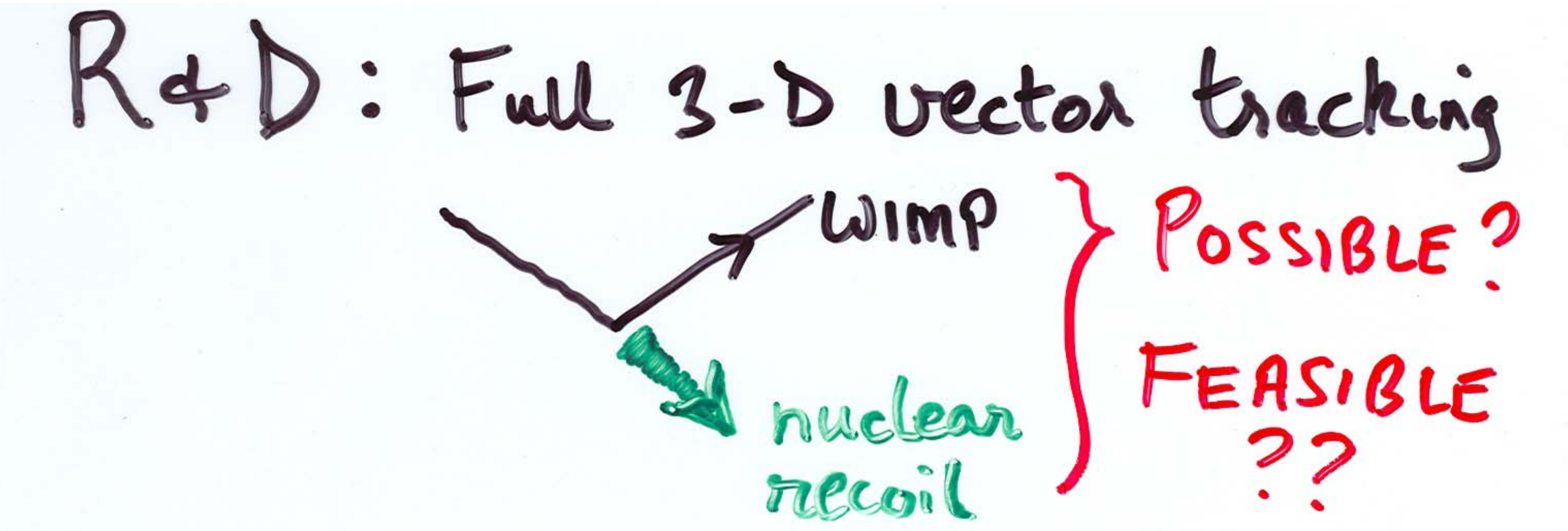




See Snowden-Ifft et al. IDM2000

US0703 - all data shown is preliminary

At UNM we are focusing on….



UNM R&D on Alternative Readouts (mainly GEM-based)

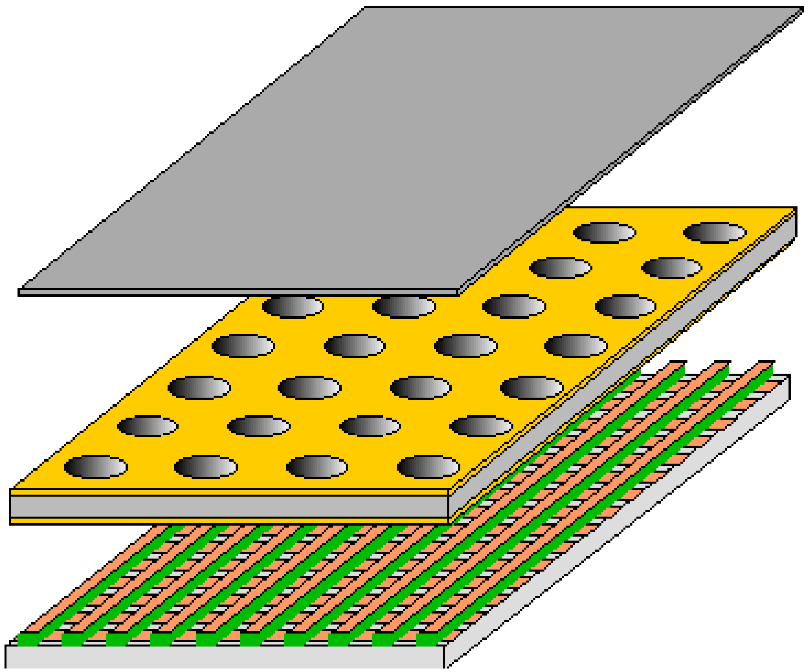
Goals are to achieve higher resolution (with $\sigma_x = \sigma_y$) and gain than current MWPC readouts used in DRIFT:

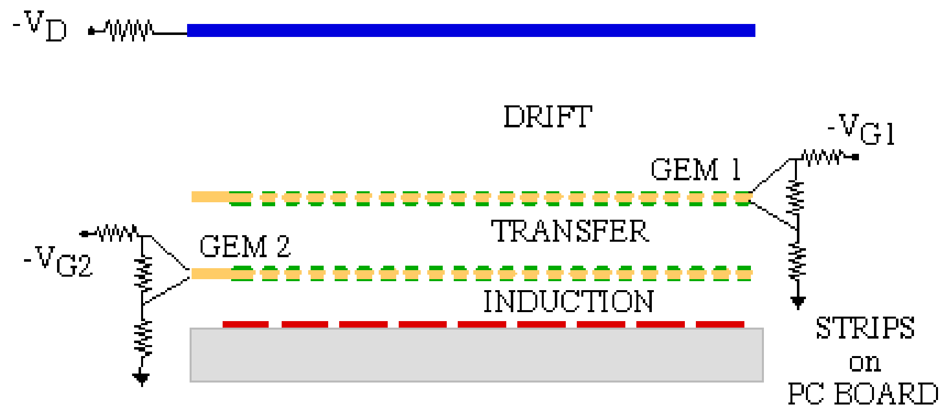
- Measure dE/dx along low-energy nuclear recoil track…is there a signal for head-tail discrimination?
- Achieve higher signal to noise (gains of >10,000 with multi-stage GEMs) to lower nuclear recoil energy threshold.
- Both should also allow better discrimination against backgrounds.

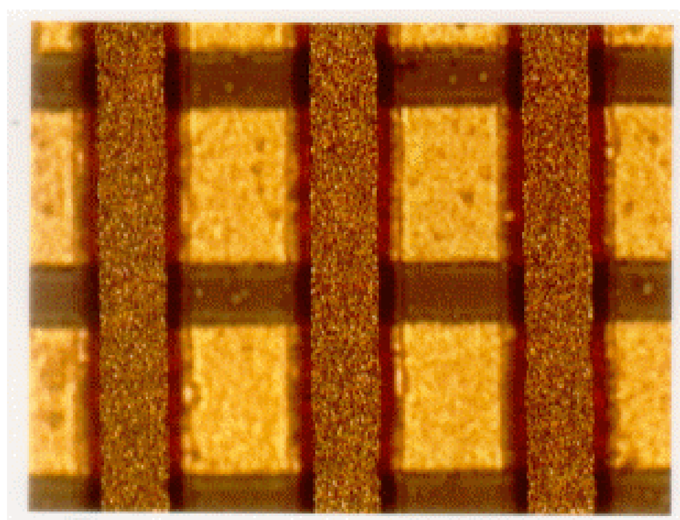
Initially the main focus is to study the fundamental properties of low-energy nuclear recoil tracks. Then we will study the feasibility of achieving these goals for a scaled-up DM detector.

UNM R&D Program

A) Start with GEMs + 2D readout boards (from CERN)







Immediate questions to be addressed:

- how much gain is needed and how many GEM stages do we need to achieve this gain? (will depend on signal-to-noise)
- what is the diffusion in between GEM stages and induction gap for CS_2? Magboltz says $\sigma \sim$ 100–150 um per stage, but we need to confirm.

We have acquired:

- 8 framed 10cm by 10cm CERN Ni-Au plated GEMs
- 4, 200 um pitch 1D readout boards (UNM) + 4, 200 um pitch, 2D readout boards (CERN)
- highly integrated preamp/shaper units from BNL with ~100 e- RMS noise, 4 us shaping time, 16 channels/board, ~$35/channel
- 10 boards of the MACRO 200 MHz WFDs loaned from BU (160 channels)
- vacuum vessel, pump, etc.

BTW, note that Shipsey, Martoff, et al have already tested GEMs with CS_2…

Shipsey, Martoff, et al work on GEMs and CS_2

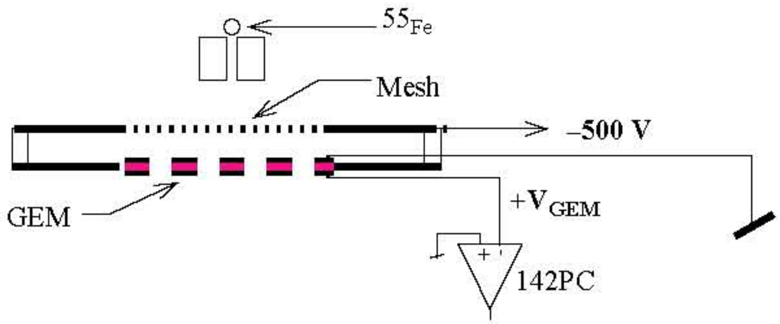


Fig. 1. GEM apparatus including drift mesh grid, GEM foil, collimated ^{55}Fe source, and bias voltages.

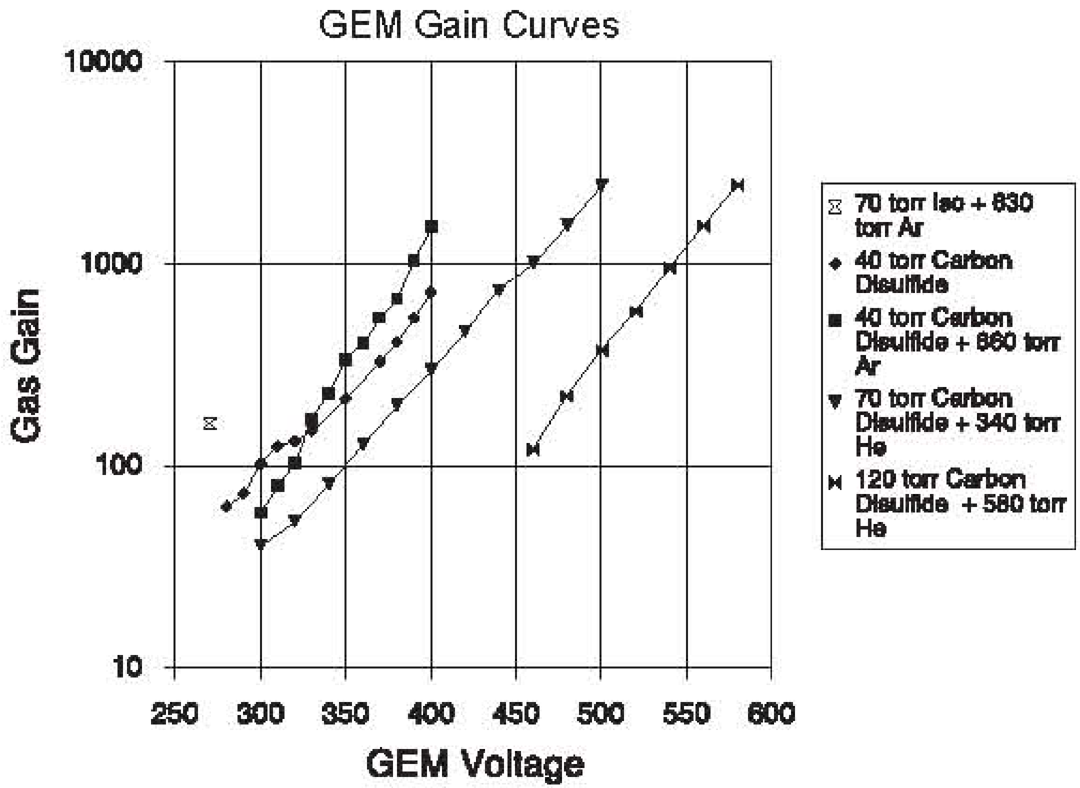
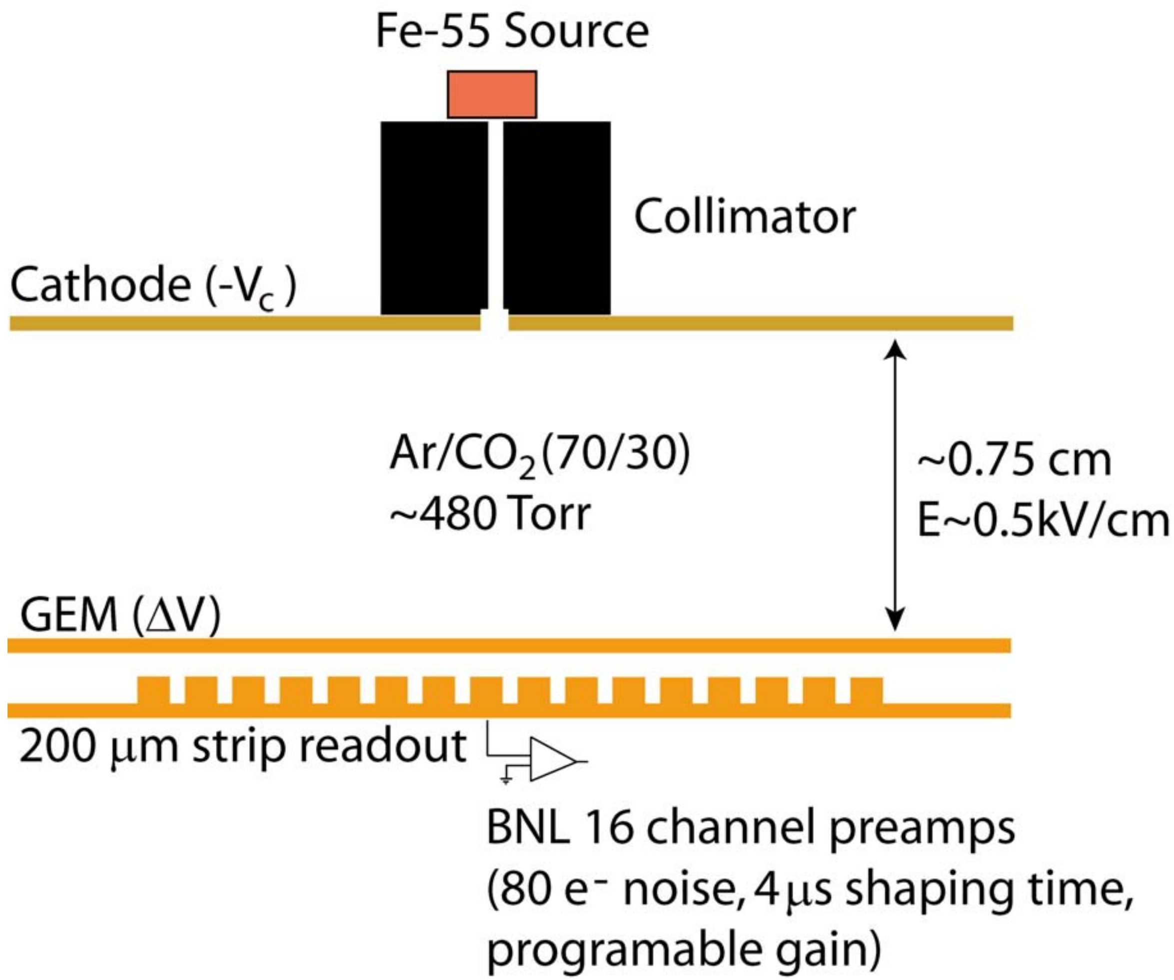


Fig. 2. Gain vs. V_{GEM} curves for 3M-GEMs exposed to collimated ^{55}Fe source. The single point at 270 V is for the e-gas Ar-Isobutane.

Basic Setup for GEM + 2D strip readout



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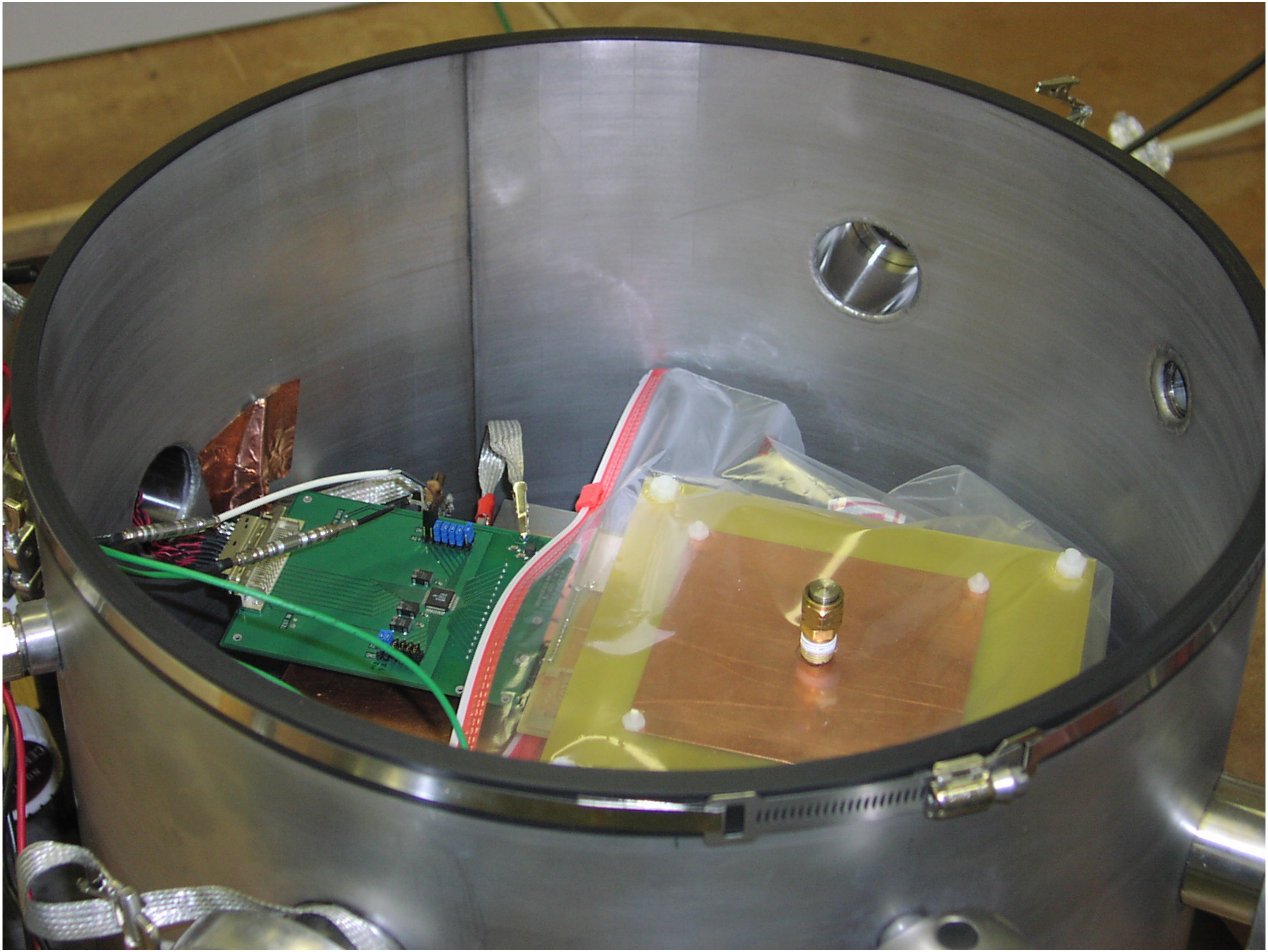

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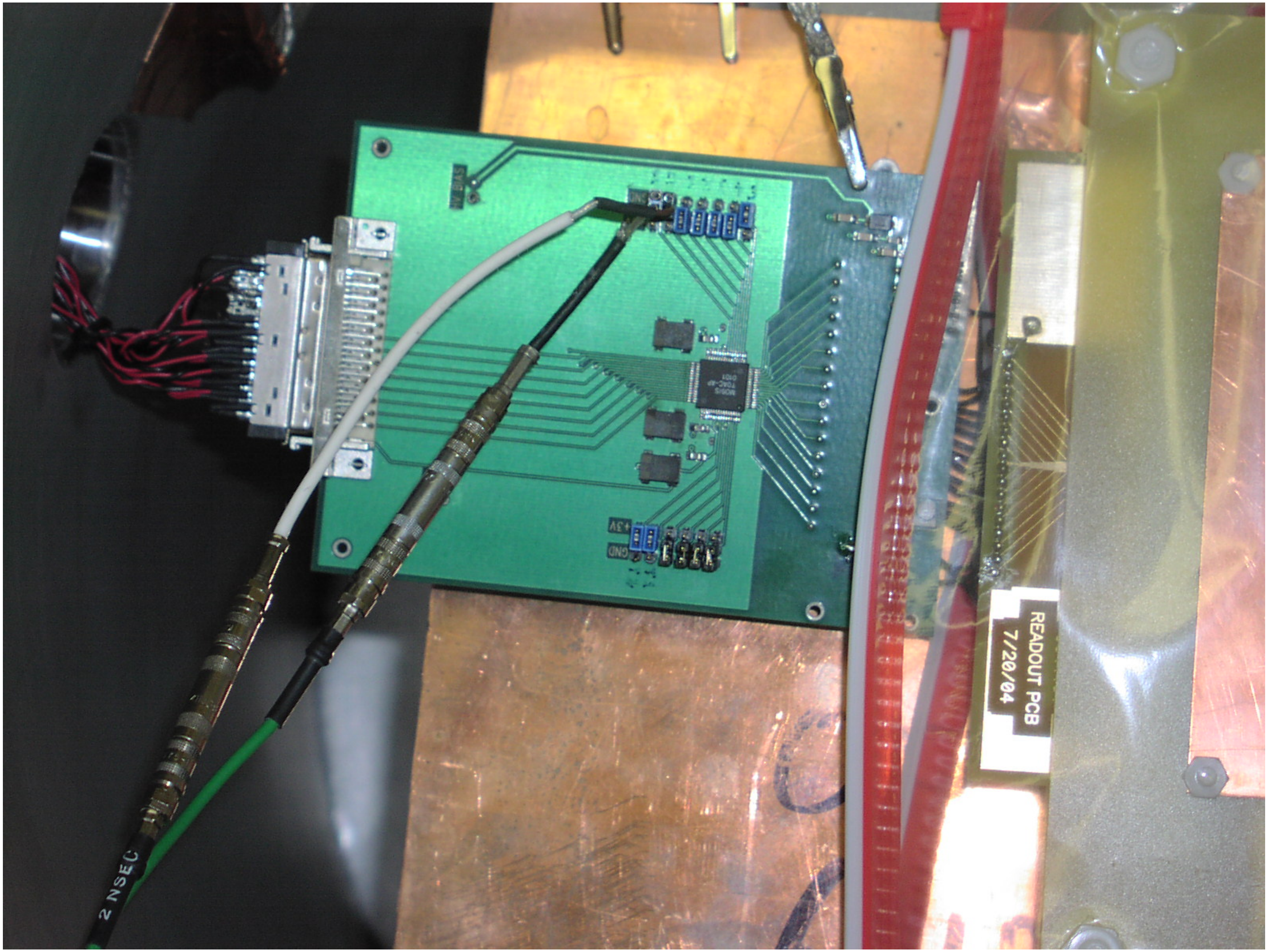
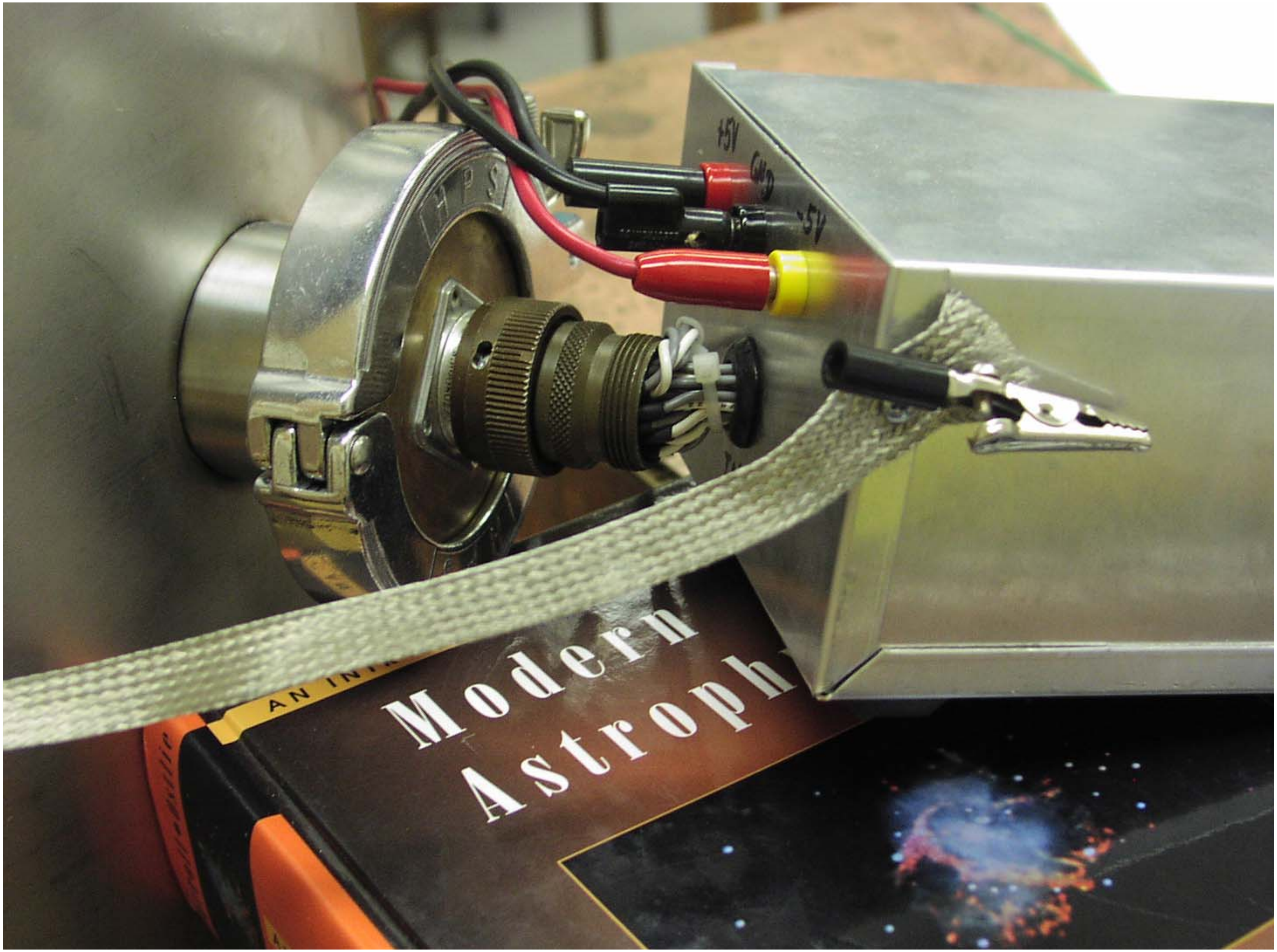
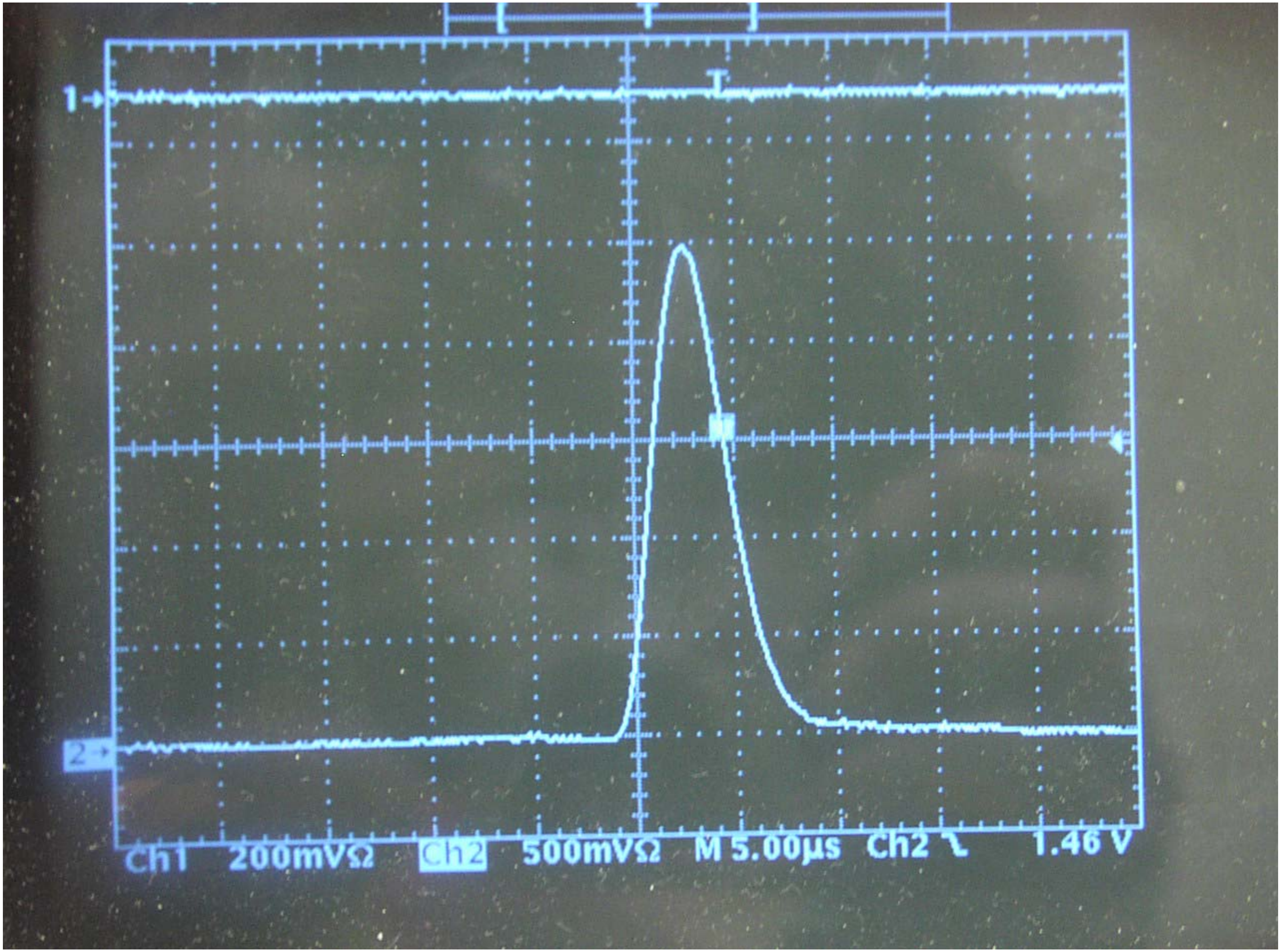
BNL 16-channel preamp/shaper



Signals passed thru vessel with Deteronix 30 pin feedthrough (cheap, robust)



Typical Fe-55 pulse from reading out sum of 4 strips with BNL preamp



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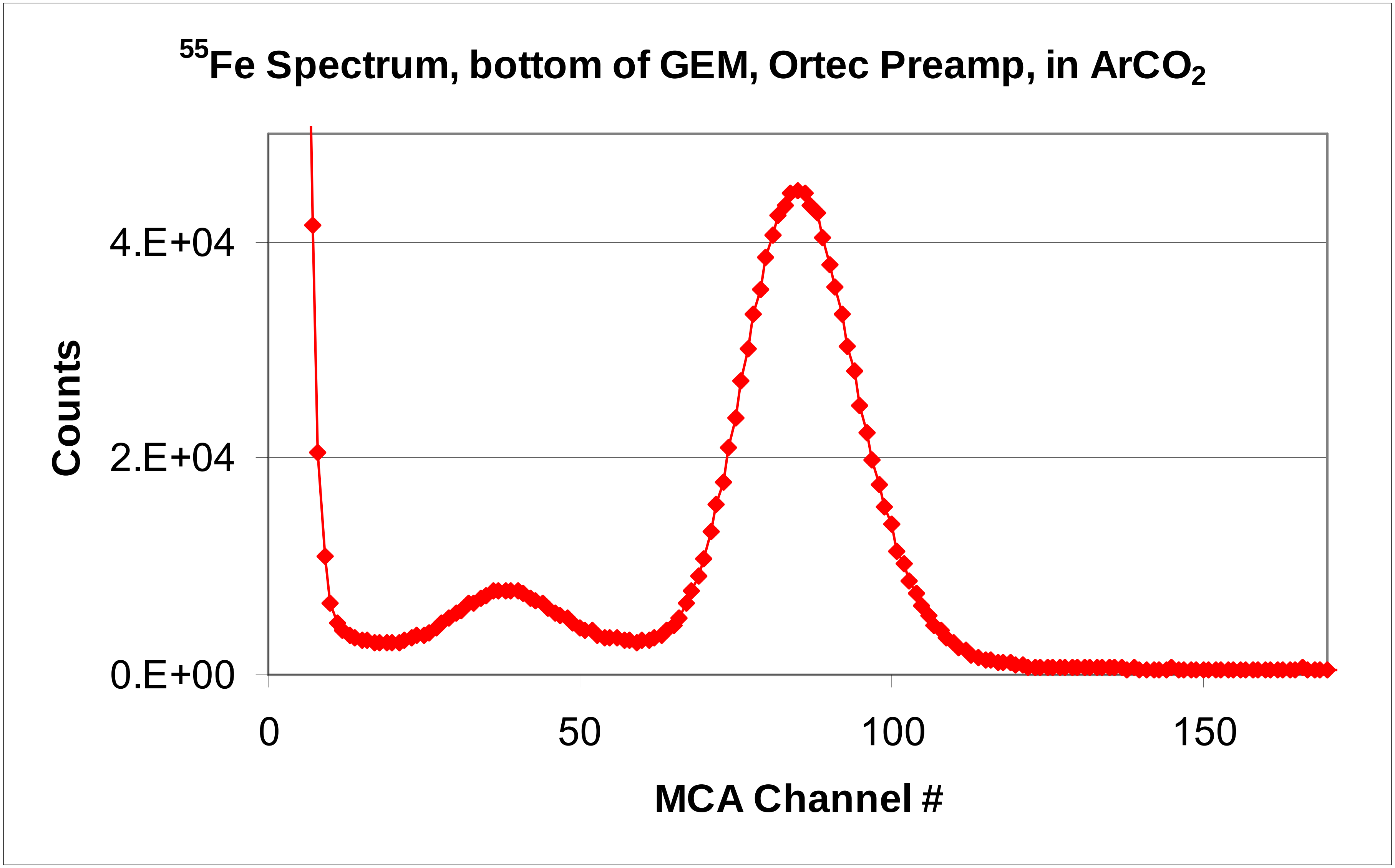
Results

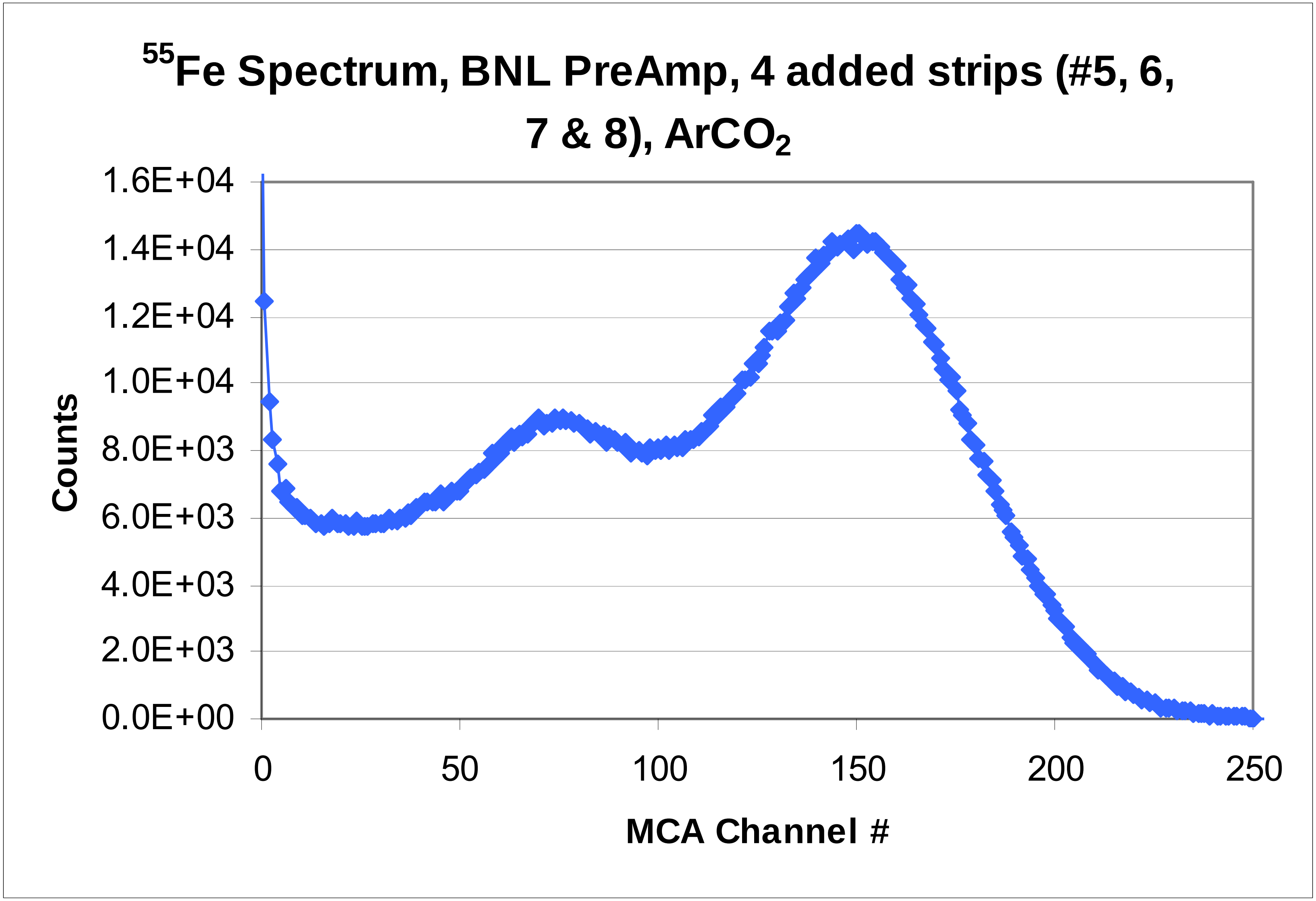
1) Picking signal off bottom of single GEM:

Estimated gain ~ 650, dE/E ~ 25-30% FWHM



Results

2) Picking signal off strips with collimated Fe-55 source (Note: FWHM of signal is about 4 strips wide)



Next steps

• Readout all 16 strips using the MACRO WFD + DAQ, ensuring that full signal is being added.

• Begin studies of diffusion in gap between GEM(s) & readout-strip using UV generated electrons from thin wire.

•Instrument 160 channels of the 2D readout strip (a 1.5cm X 1.5cm region) with BNL preamps with the aim of measuring tracks in the Fall.

• Address general electronics issues for a real DM detector with scale-up in mind. Are there better designs than 2D strips? How can we make use of the low rate and implement multiplexing while keeping noise down? Other ideas? We hope to interest BNL in collaborating with us on these and other R&D questions!

B) Study other readout schemes, such as GEM+CCD readouts:

CCD readout of GEM based neutron detectors

F.A.F. Fraga[1], L.M.S. Margato[1], S.T.G. Fetal[1], M.M.F.R. Fraga[1], R. Ferreira Marques[1], A.J.P.L Policarpo[1], B. Guerard[2], A. Oed[2], G. Manzini[2] and T. van Vuure[3]

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[3] *Delft University of Technology, IRI-ISO, Mekelweg 15, NL 2629 JB Delft, The Netherlands*

Abstract

We report on the optical readout of the GEM (gas electron multiplier) operated with a gaseous mixture suitable for the detection of thermal neutrons: $^3He\text{-}CF_4$. A CCD system operating in the 400-1000 nm band was used to collect the light. Spectroscopic data on the visible and NIR scintillation of $He\text{-}CF_4$ are presented. Images of the tracks of the proton and triton recorded with a triple GEM detector are also shown.

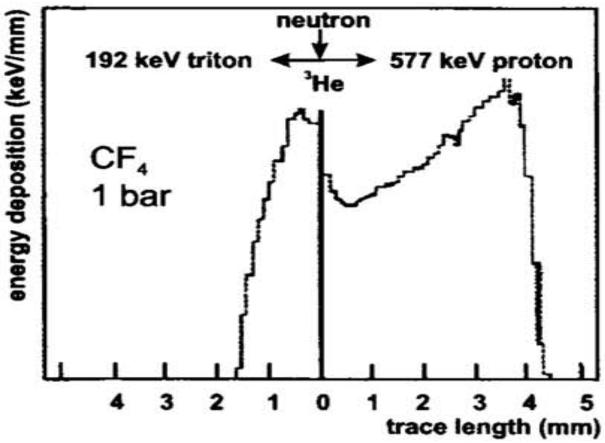


Fig. 4 The energy deposition along the proton and triton track in 1 bar CF_4.

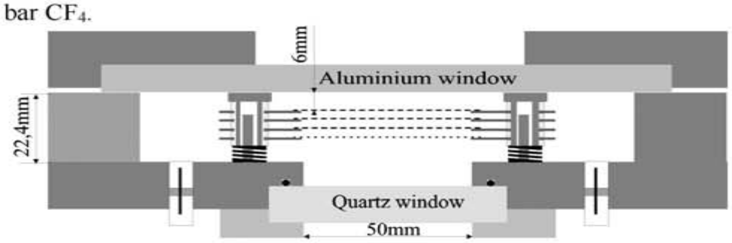


Fig. 5 Schematic cross-section of the detector. The CCD (not shown) was placed 30 cm away from the glass window.

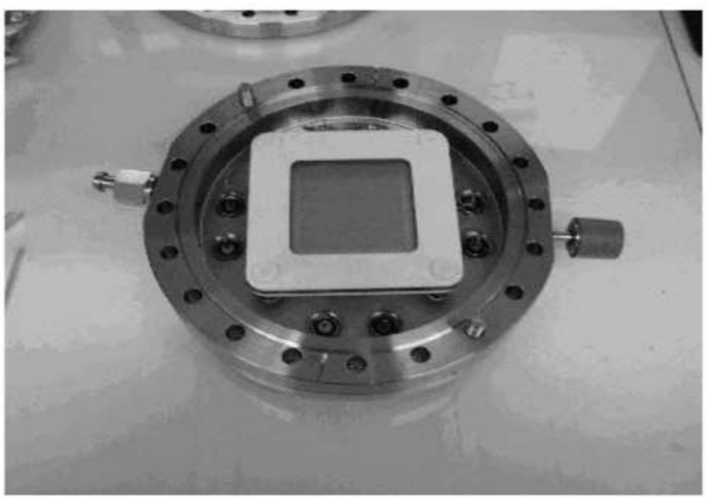


Fig. 6 Photograph of the detector with the entrance aluminium window removed, showing the stacked GEM assembly and transparent grid electrode.

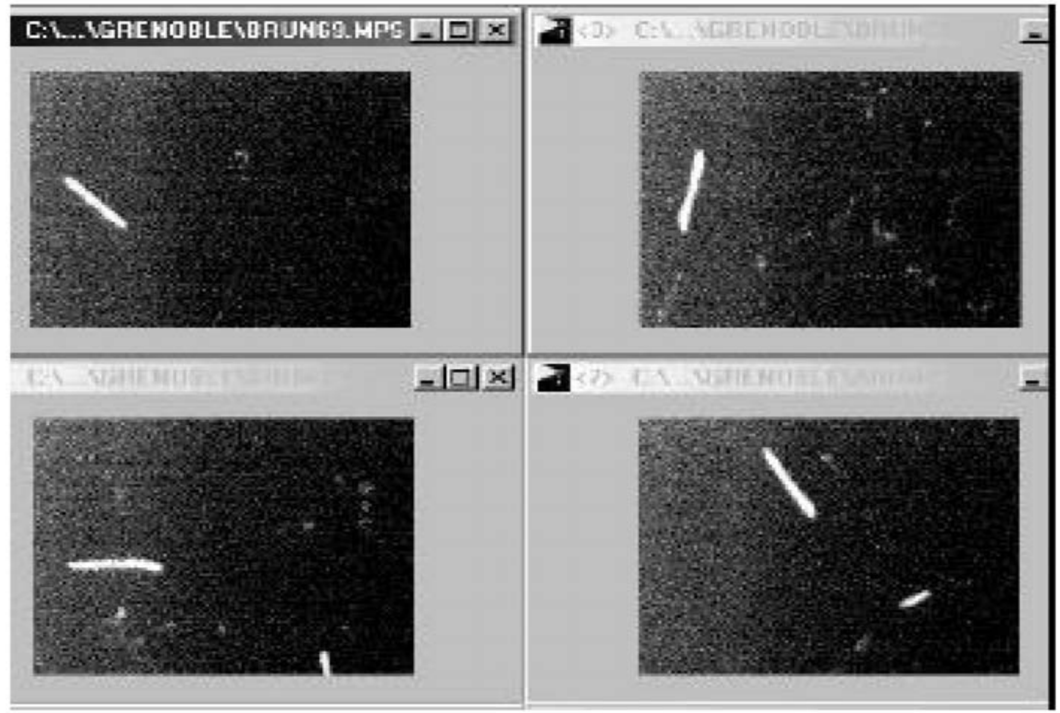


Fig. 7 Images of proton and triton tracks obtained with He(1bar)-CF_4 (400 mbar): V_{GEM1}=V_{GEM2}= V_{GEM3} =400V, E_D= 1kV/cm, E_T= 3 kV/cm, CCD Binning 7×7, Texp.=10ms.

Triton, proton tracks

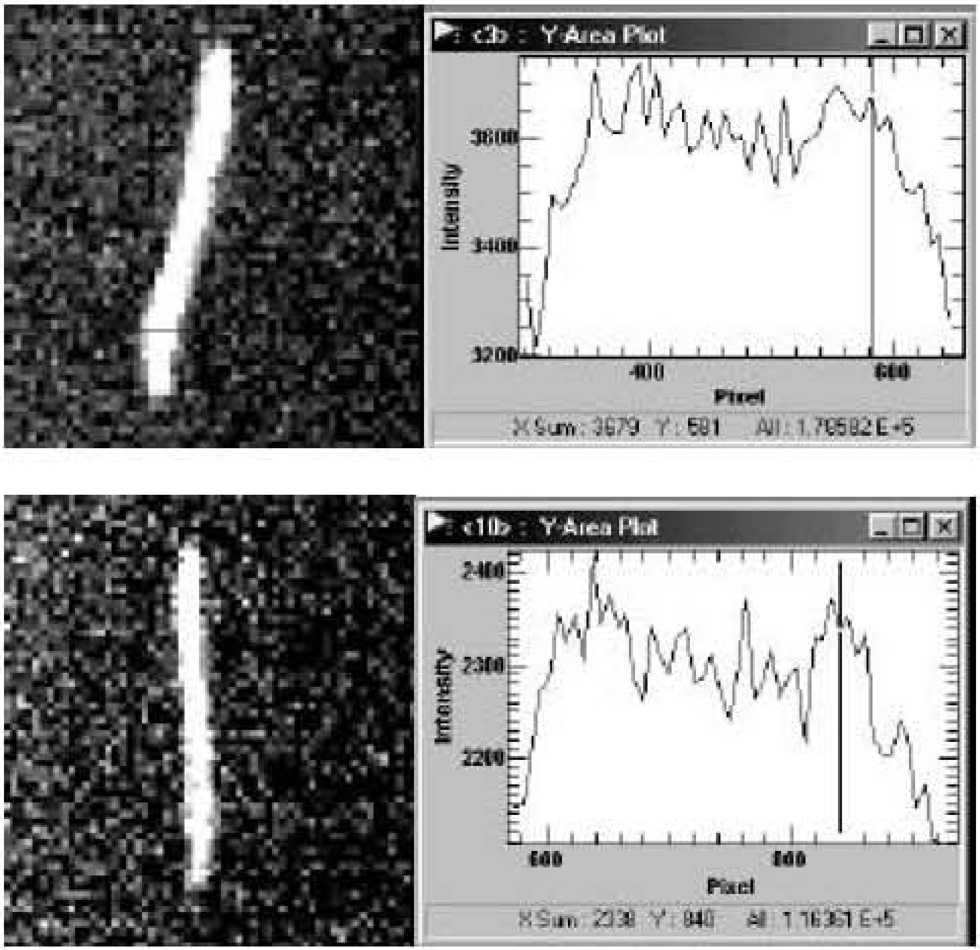
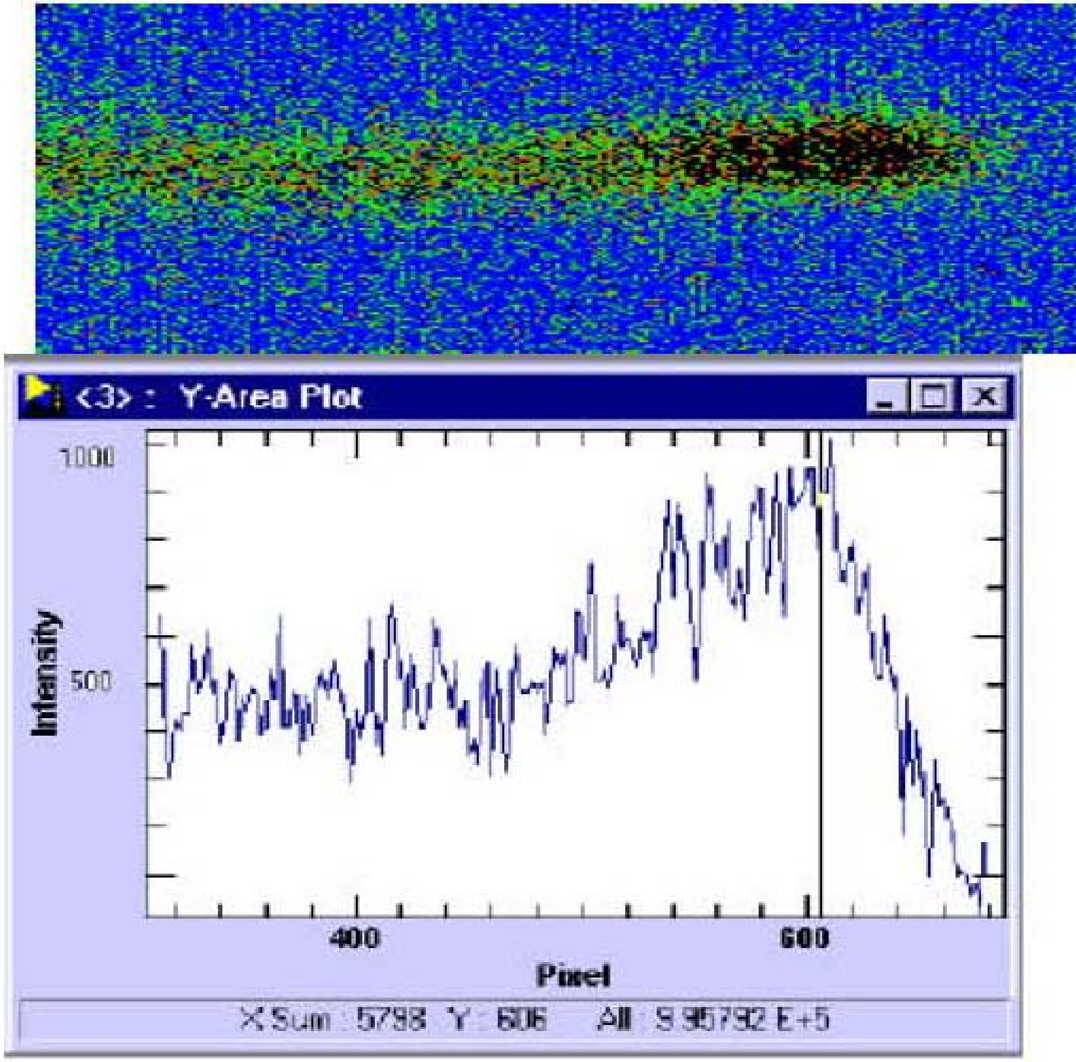


Fig. 8 Distribution of measured scintillation along tracks. The Bragg curves of the proton (left) and triton (right) are revealed.

Fig. 9 Superimposed proton-triton tracks obtained with an exposition time of 1s.

Alpha tracks



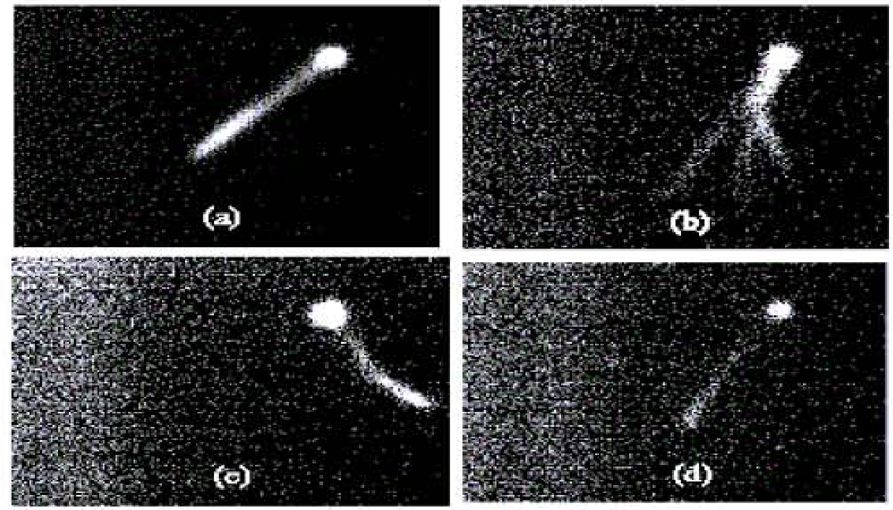


Fig. 5 Images of alpha tracks taken using the tracking chamber with Ar-%CF_4.: (a,b) $V_{GEM1}=V_{GEM2}=400V$ (Gain~140), $E_T=5.45KV/cm$, c=5.86KV/cm, CCD Binning 4x4, Texp.=10ms; (c,d) $V_{GEM1}=V_{GEM2}=430V$ Gain~300), $E_T=5.45KV/cm$, $E_C=0$, CCD Binning 7x7, T=10ms.

Fig. 6 Distribution of measured scintillation along an alpha track. The Bragg curve is revealed.