Shedding Light on Dark Matter

Dinesh Loomba
UNM

SMU Sept 17, 2007

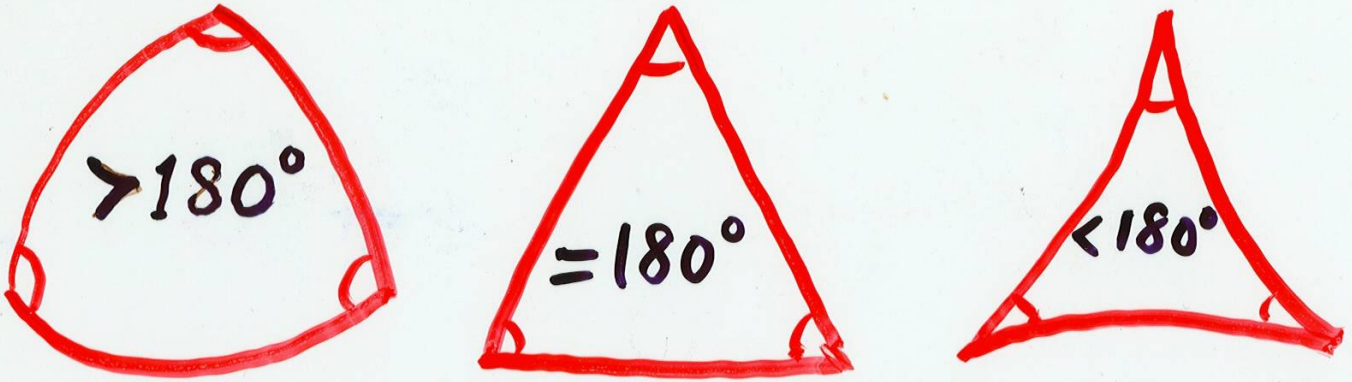
Einstein's GR Equations for Expanding Universe

GEOMETRY ⟷ ENERGY

(matter, radiation, ...)

$$\left[K = H^2 (\Omega - 1) \right]$$

$$\Omega = \frac{\varepsilon}{\varepsilon_{CRIT.}}$$



|| /\ || \/

RAYS: CONVERGE STAY || DIVERGE

$\Omega > 1$ $\Omega = 1$ $\Omega < 1$

$(\varepsilon > \varepsilon_c)$ $(\varepsilon = \varepsilon_c)$ $(\varepsilon < \varepsilon_c)$

Note: $\varepsilon_c \approx 10^{-29}$ g/cc or ~10 H atoms/m^3!

SKIP TO mid-1990's...

LOTS OF CONFUSION !

Theorists : "the World is FLAT!"
($\Omega = 1$)

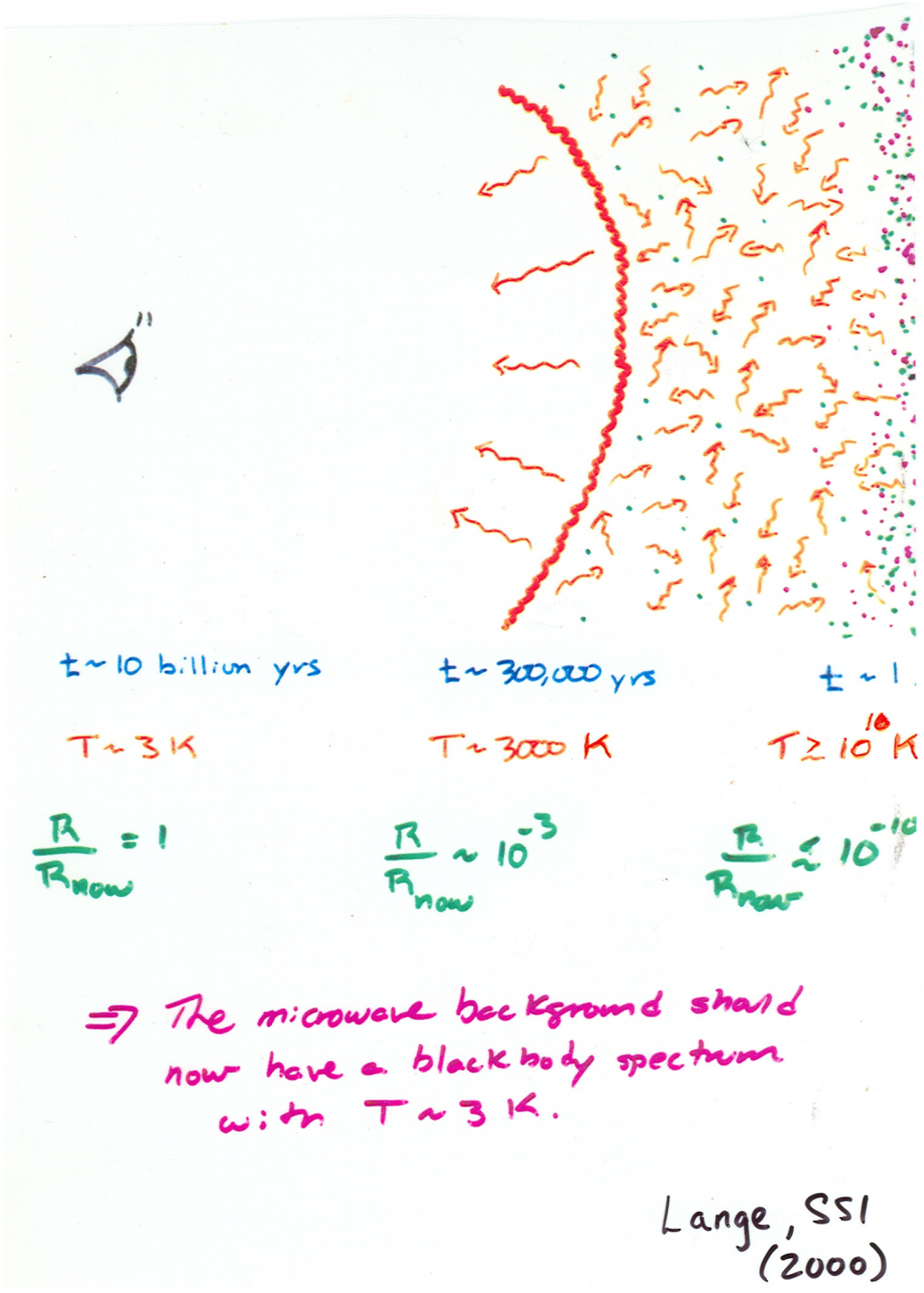
Astronomers: "no, it's open"
($\Omega \sim \frac{1}{3}$)

+ AGE CRISIS (again!)

then...

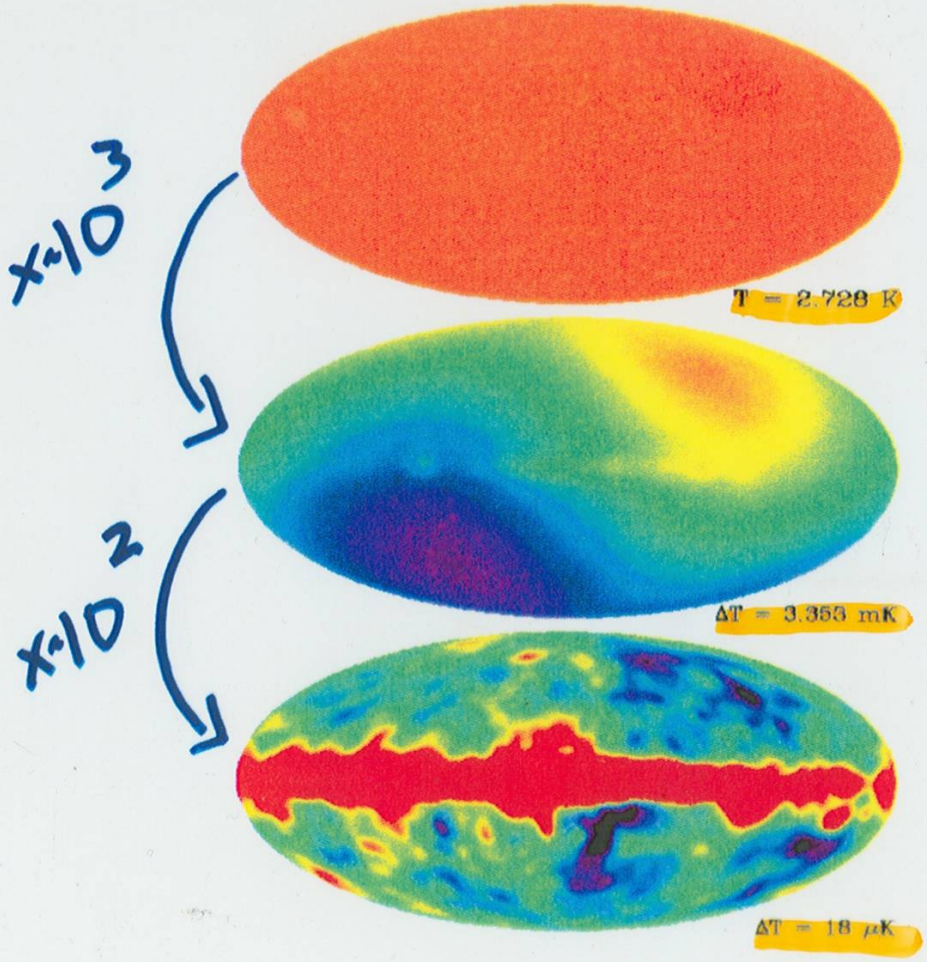
? Λ, Quintessence, Dark Energy,
"Funny" Energy ??
...

Cosmic Microwave Background Radiation



Cosmic Microwave Background

The Microwave Sky Seen by COBE-DMR:



$\times 10^3$

$\times 10^2$

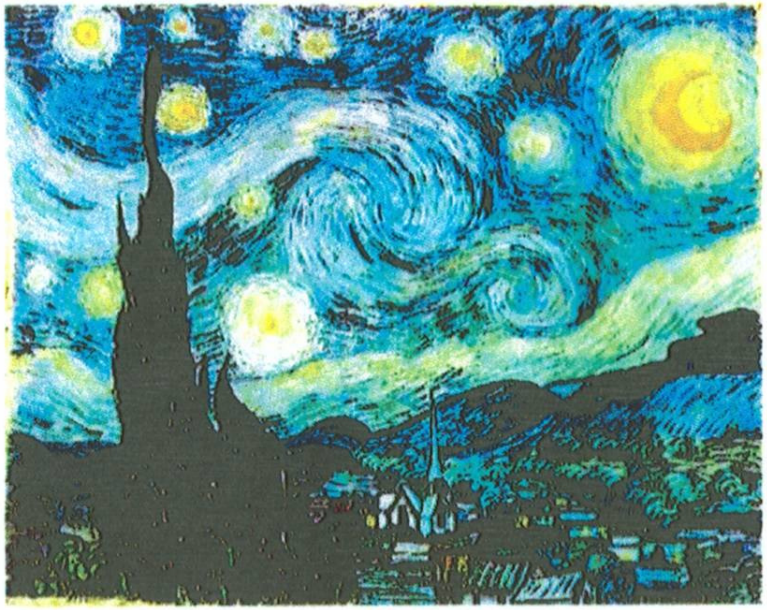
Isotropy $\left(\frac{\Delta T}{T} \sim 10^{-5}\right)$

Velocity

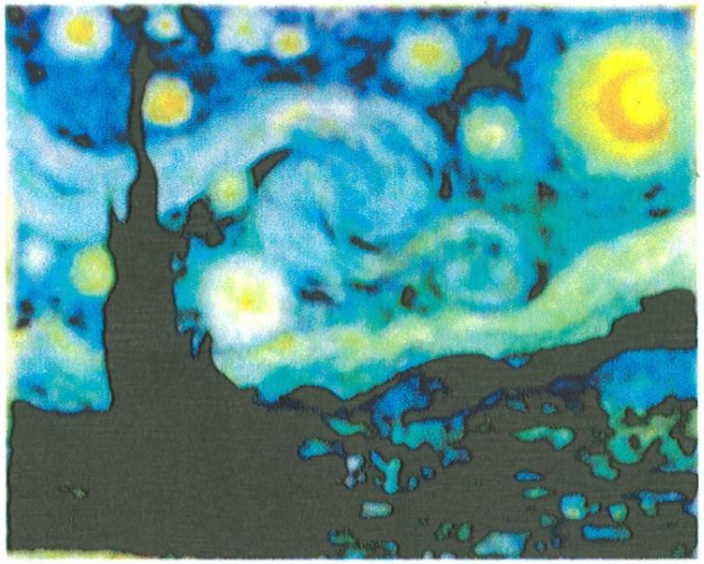
Inhomogeneity

(+Galaxy)

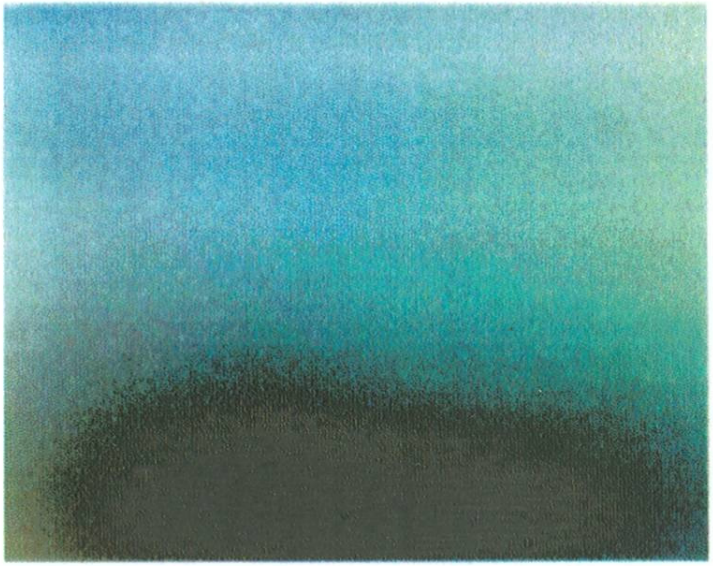
"Starry Night" as Seen by:



Van Gogh

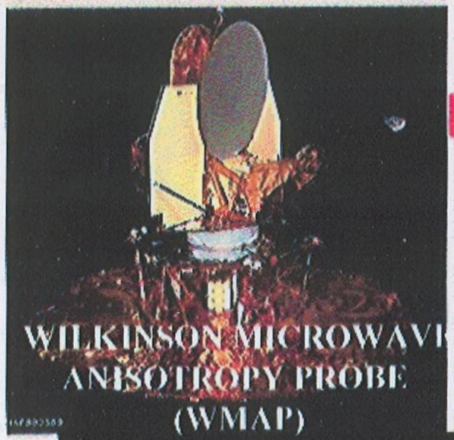


BOOMERanG

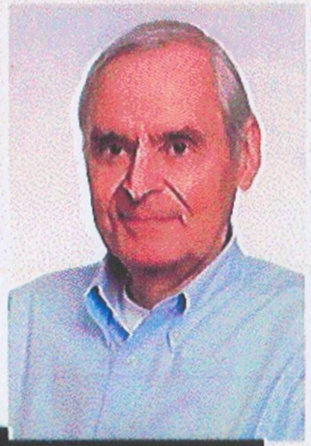


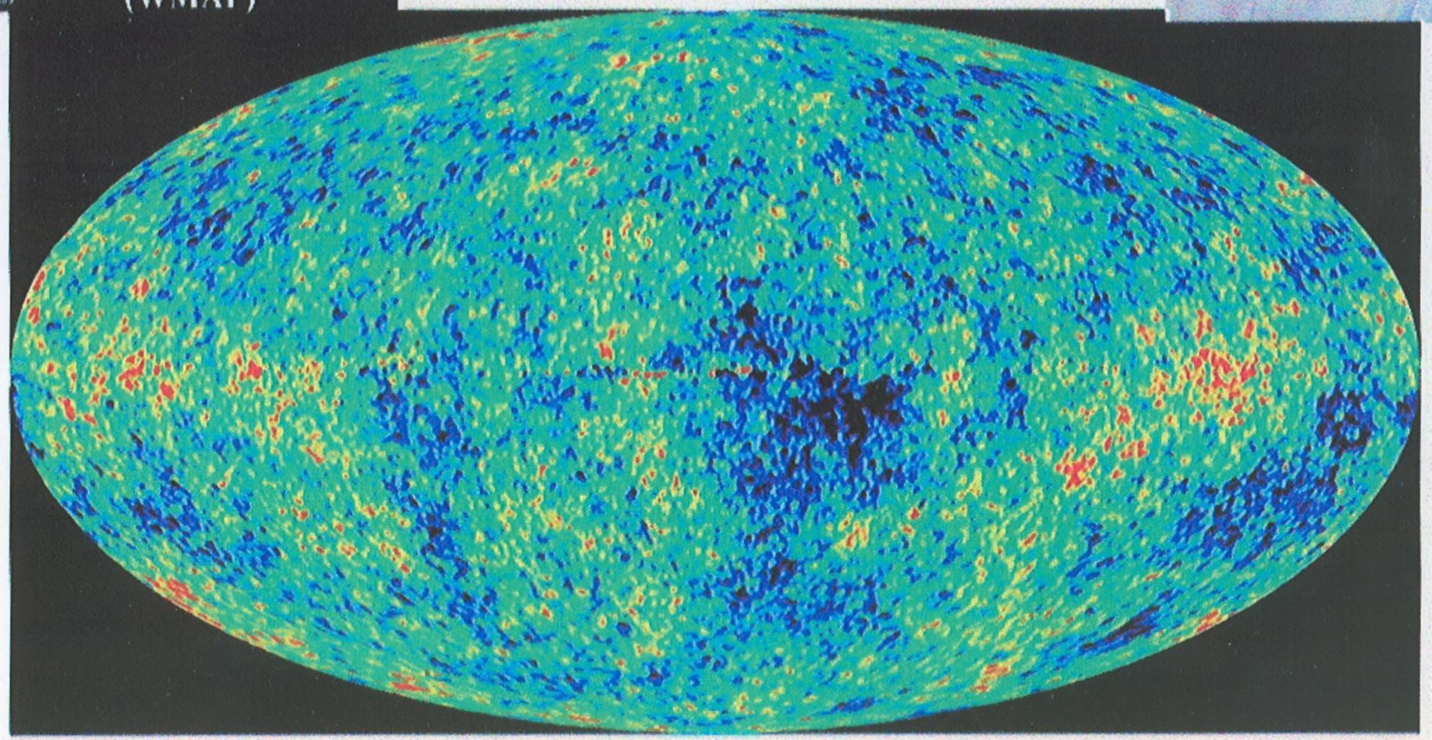
COBE

Lange, SSI (2000)

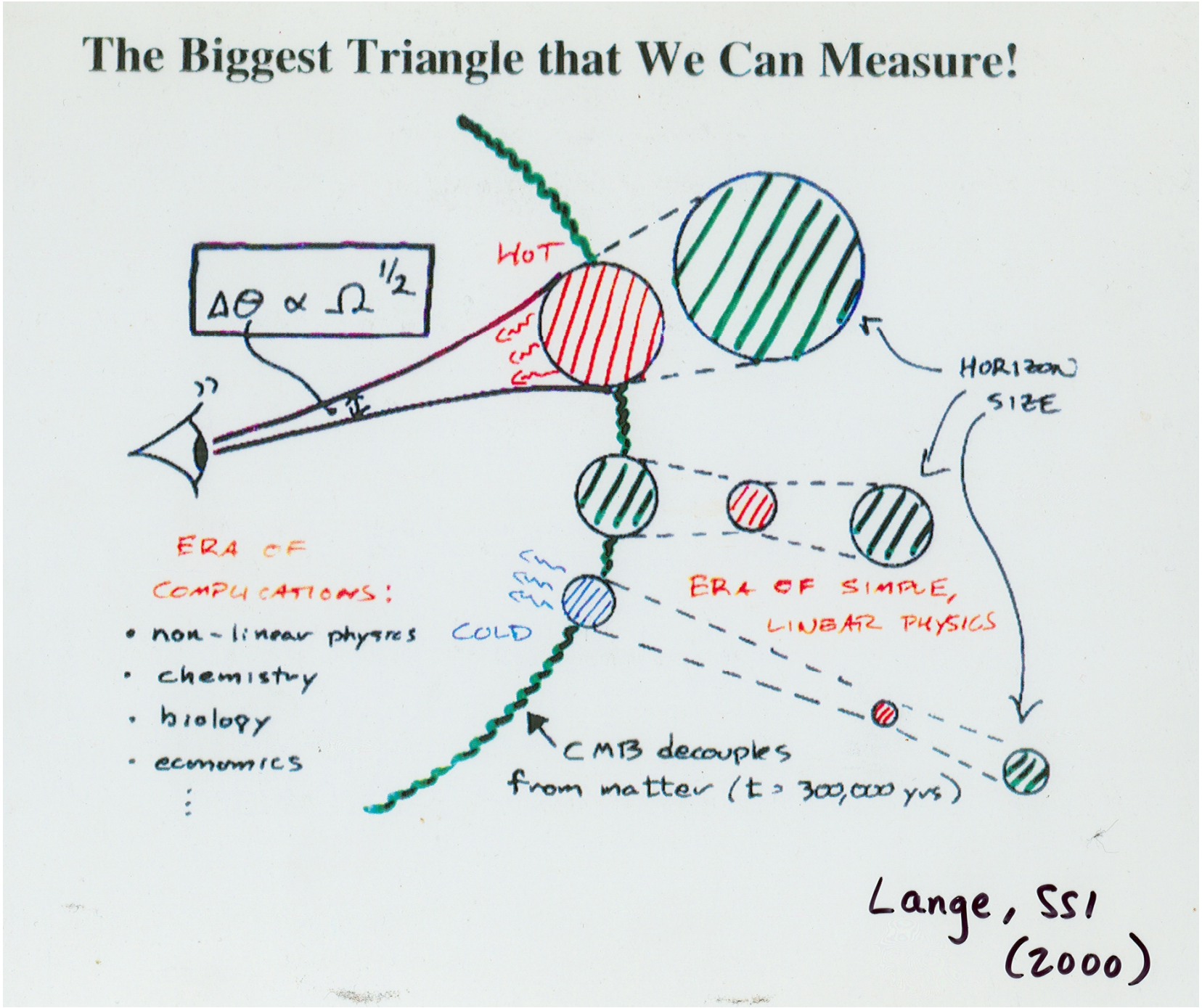


MAP OF THE UNIVERSE AT A SIMPLER TIME (400,000 YRS)



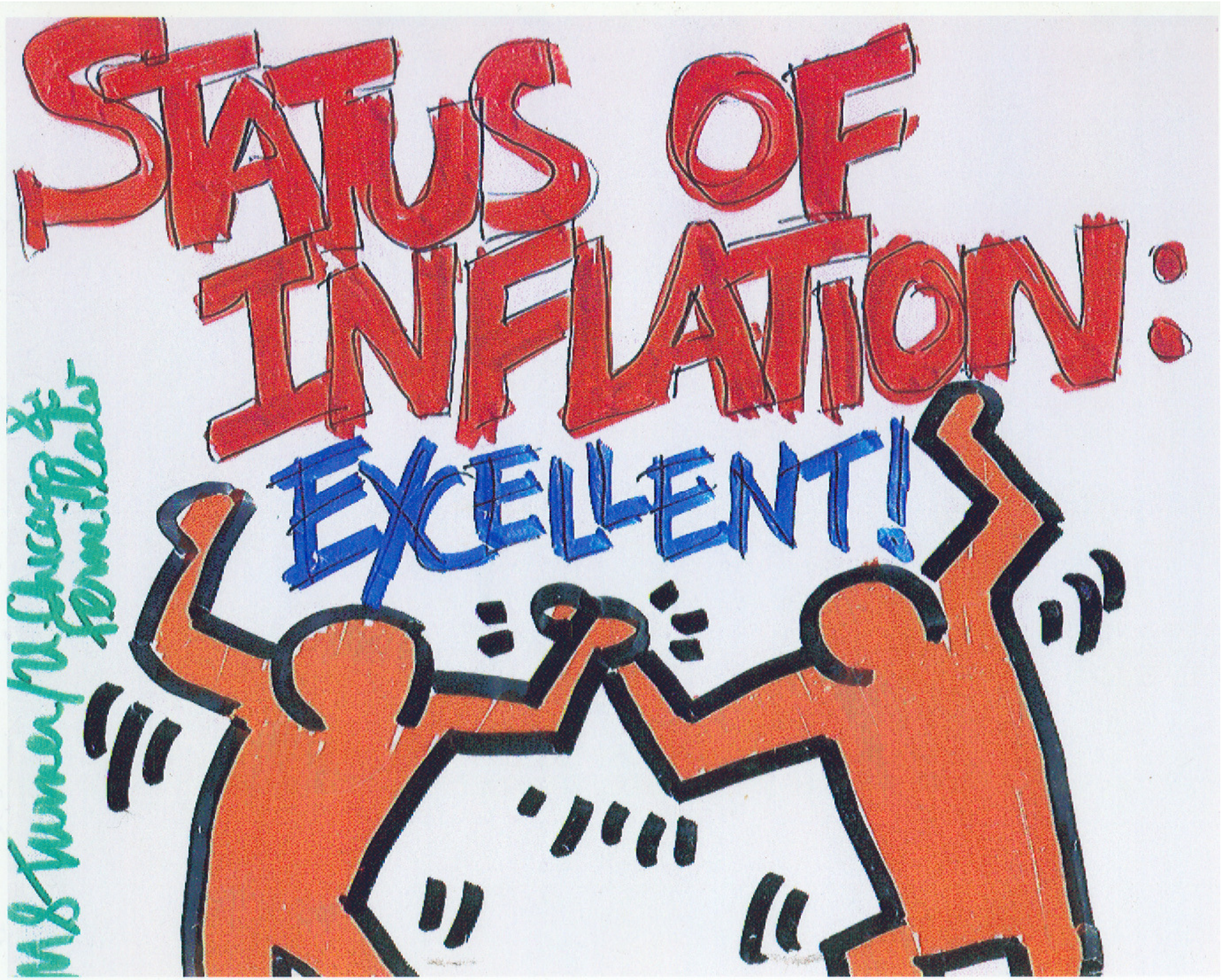


The Biggest Triangle that We Can Measure!

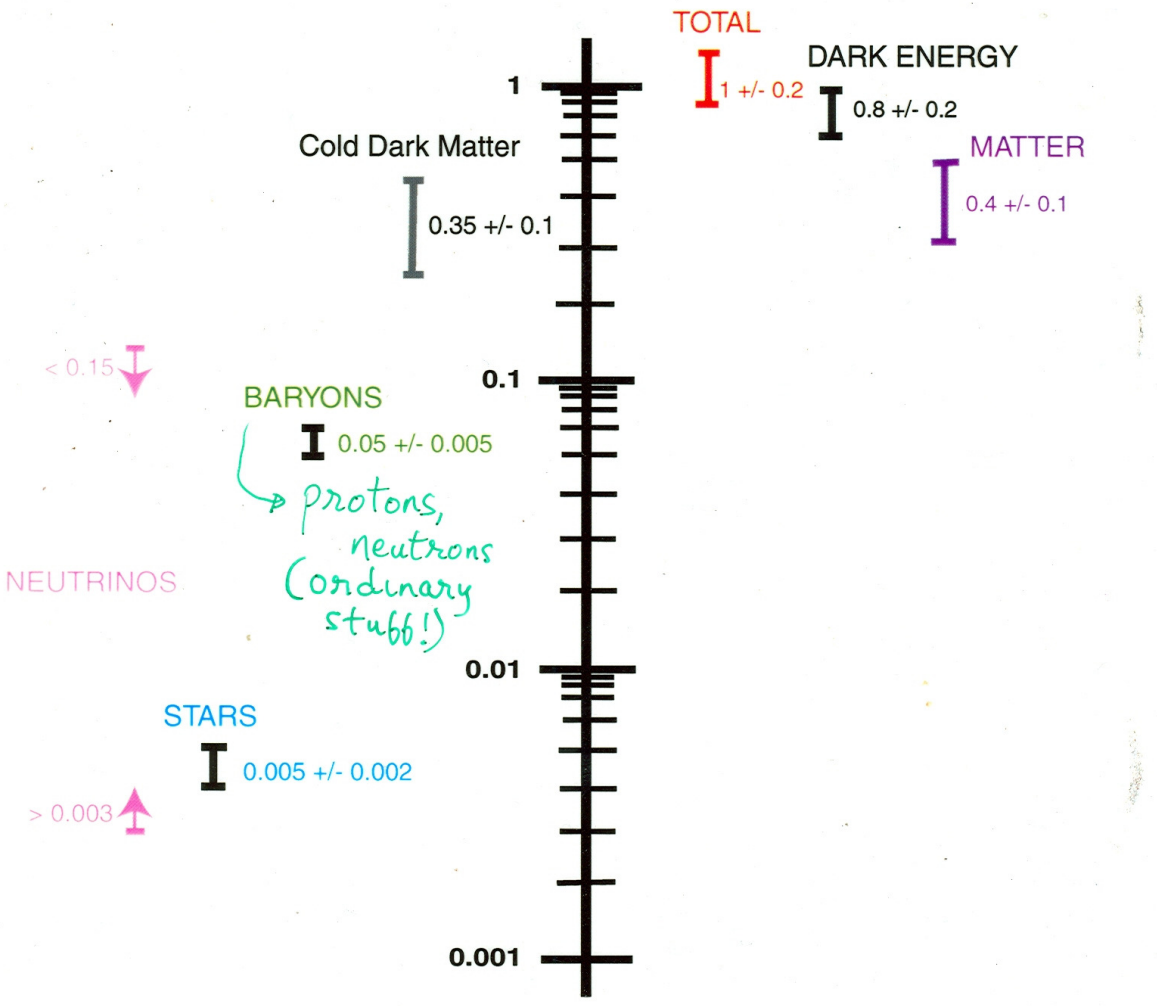


$$\Omega = \Omega_{\text{matter, radiation}} + \Omega_{\Lambda} = 1$$

$$\sim \frac{1}{3} + \frac{2}{3}$$


STATUS OF INFLATION:
EXCELLENT!

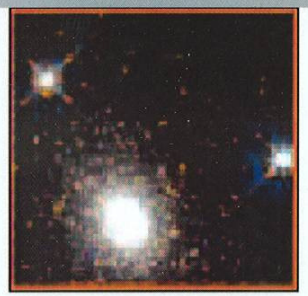
MATTER/ENERGY in the UNIVERSE



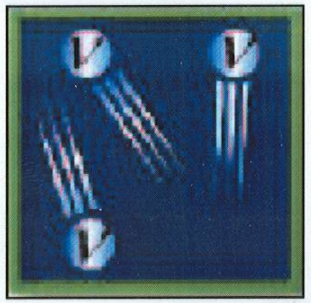
POST WMAP era ... PRECISION COSMOLOGY! (~2003)

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

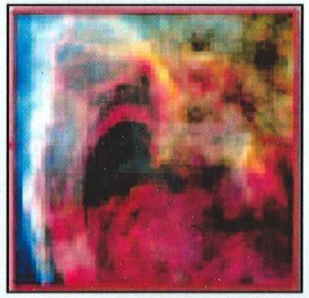
heavy elements 0.03%



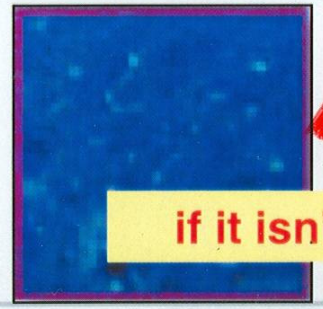
stars 0.5%



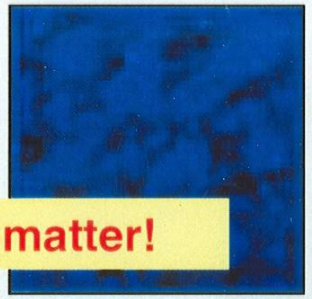
neutrinos 0.47%



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 Unwerse with a

LENS

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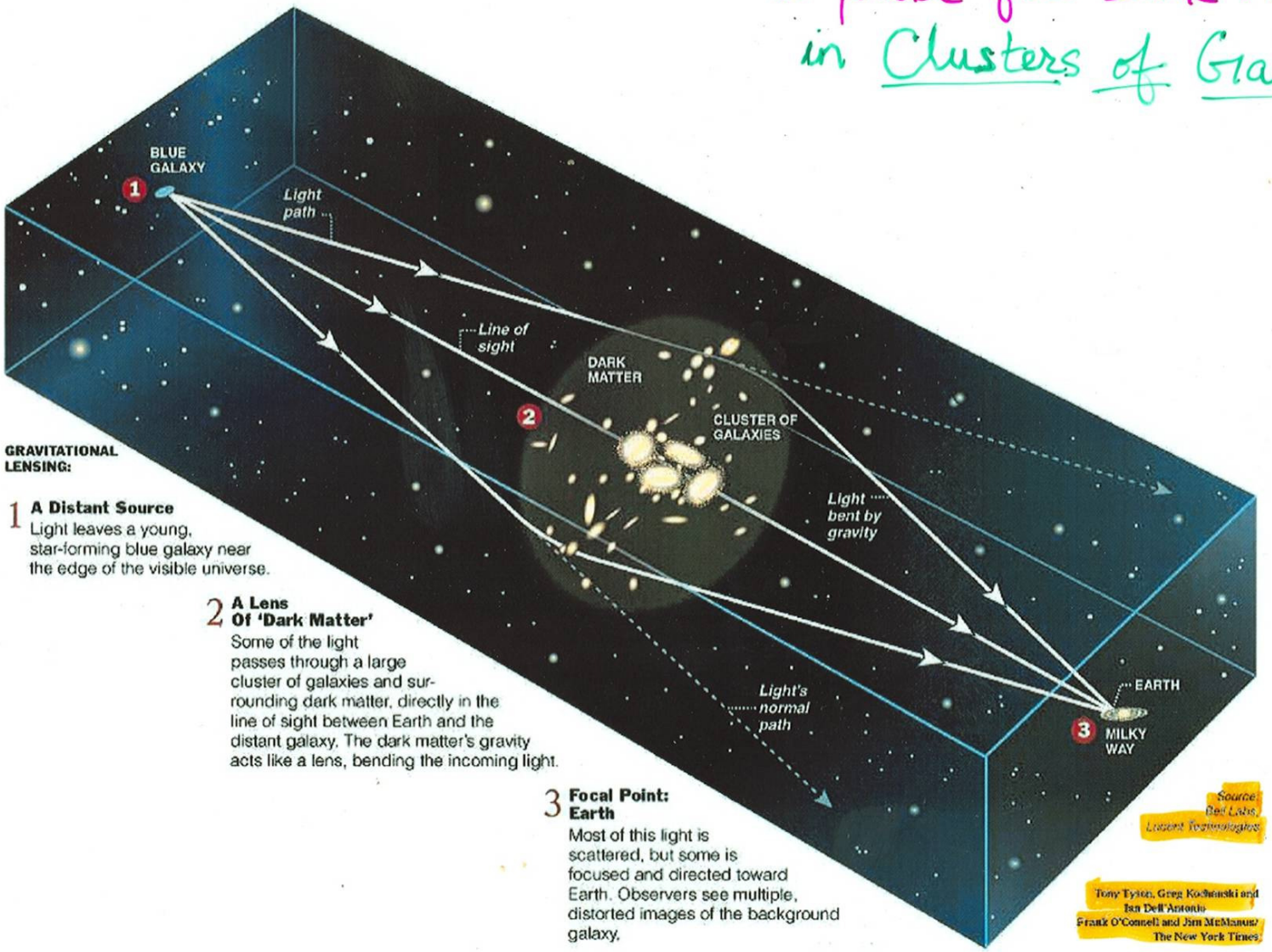
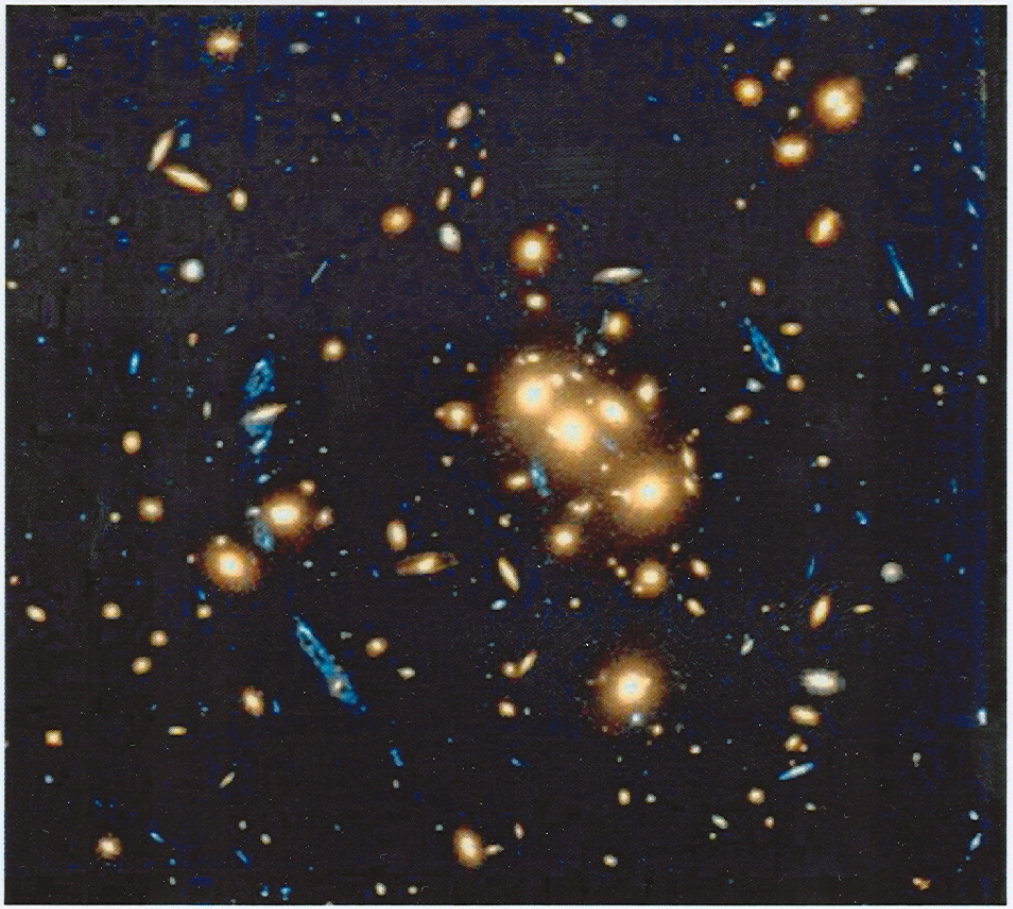
Gravitational Lensing, a probe for Dark Matter in Clusters of Galaxies

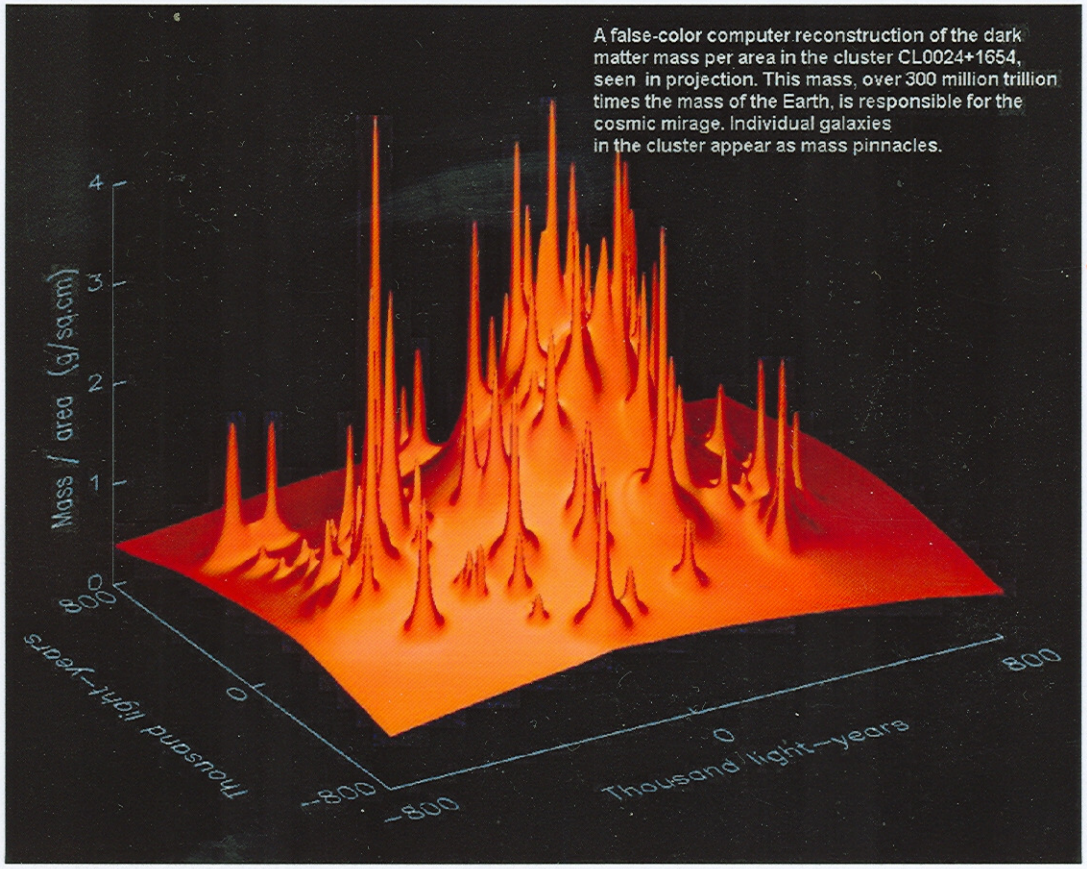




Foreground cluster at $z = 0.39$, lensed galaxy at $z \gtrsim 1.2$

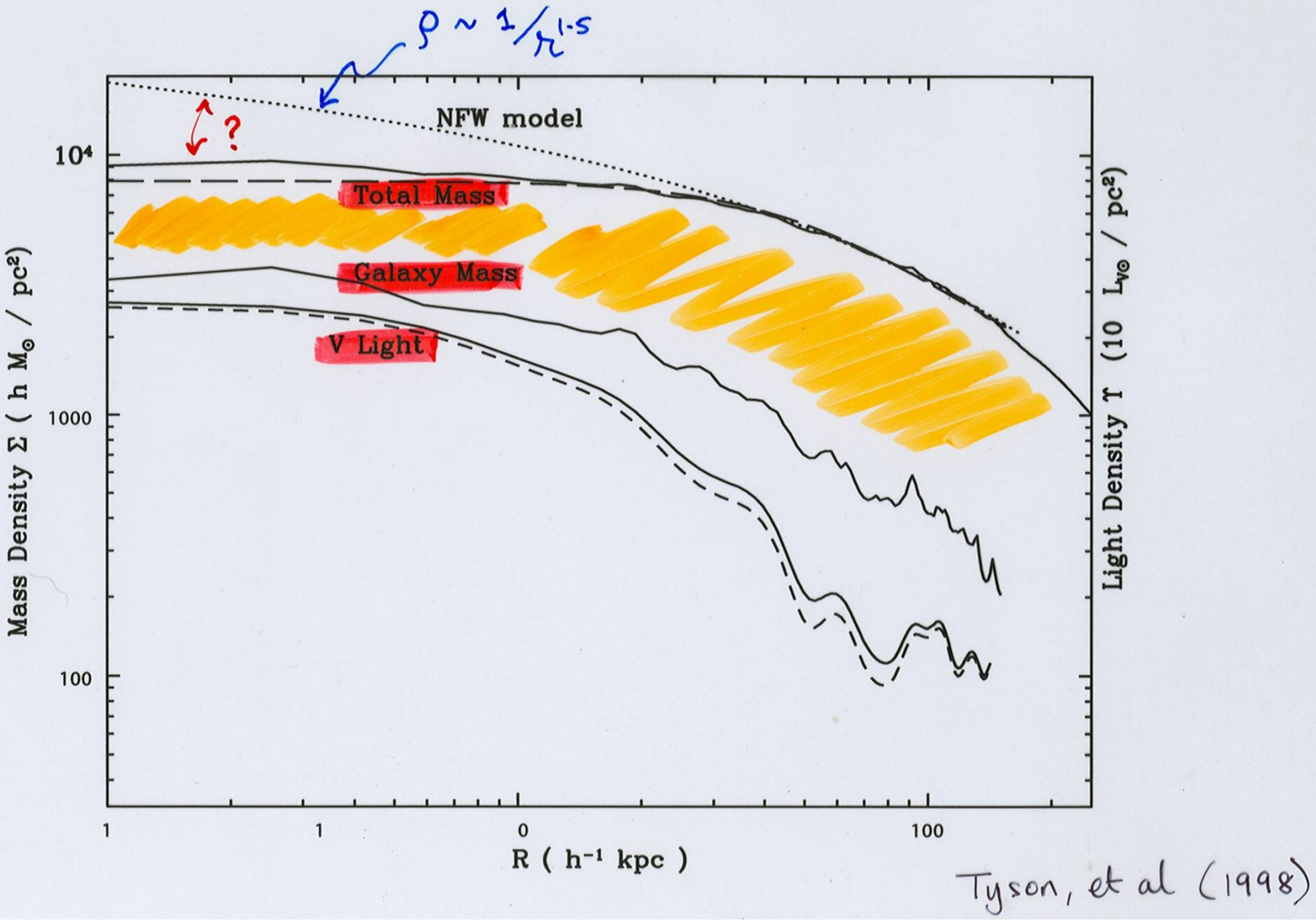
A Hubble Space Telescope image of a gravitational lens formed by the warping of images of objects behind a massive concentration of dark matter. Warped images of the same blue background galaxy are seen in multiple places. (Colley, Tyson, Turner ApJ **461** L83 (1996)).

…and the resultant (2D) mass map

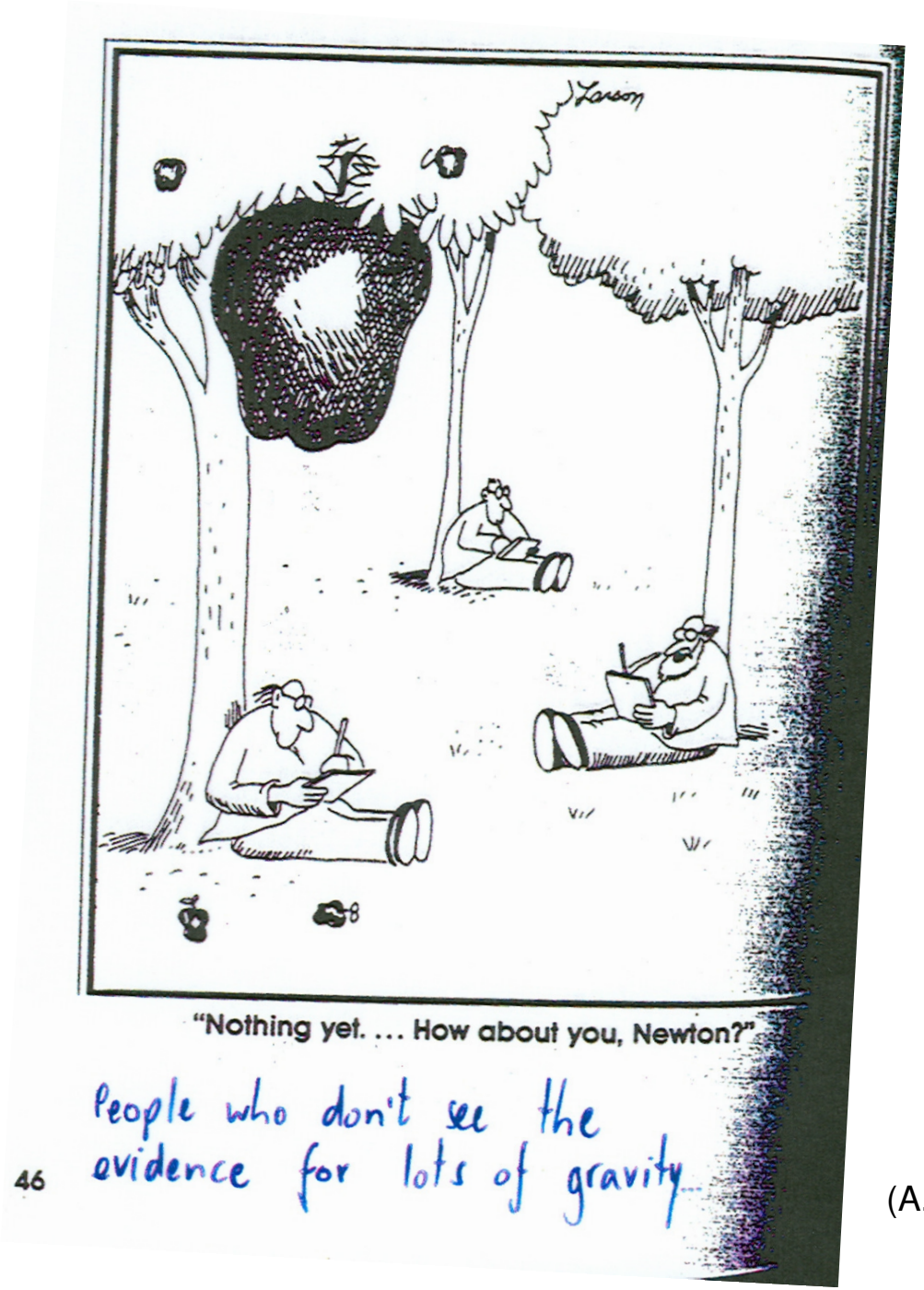


$M_{D.M} \approx$ 300 M_{STARS} !

Resultant Radial Mass Distribution



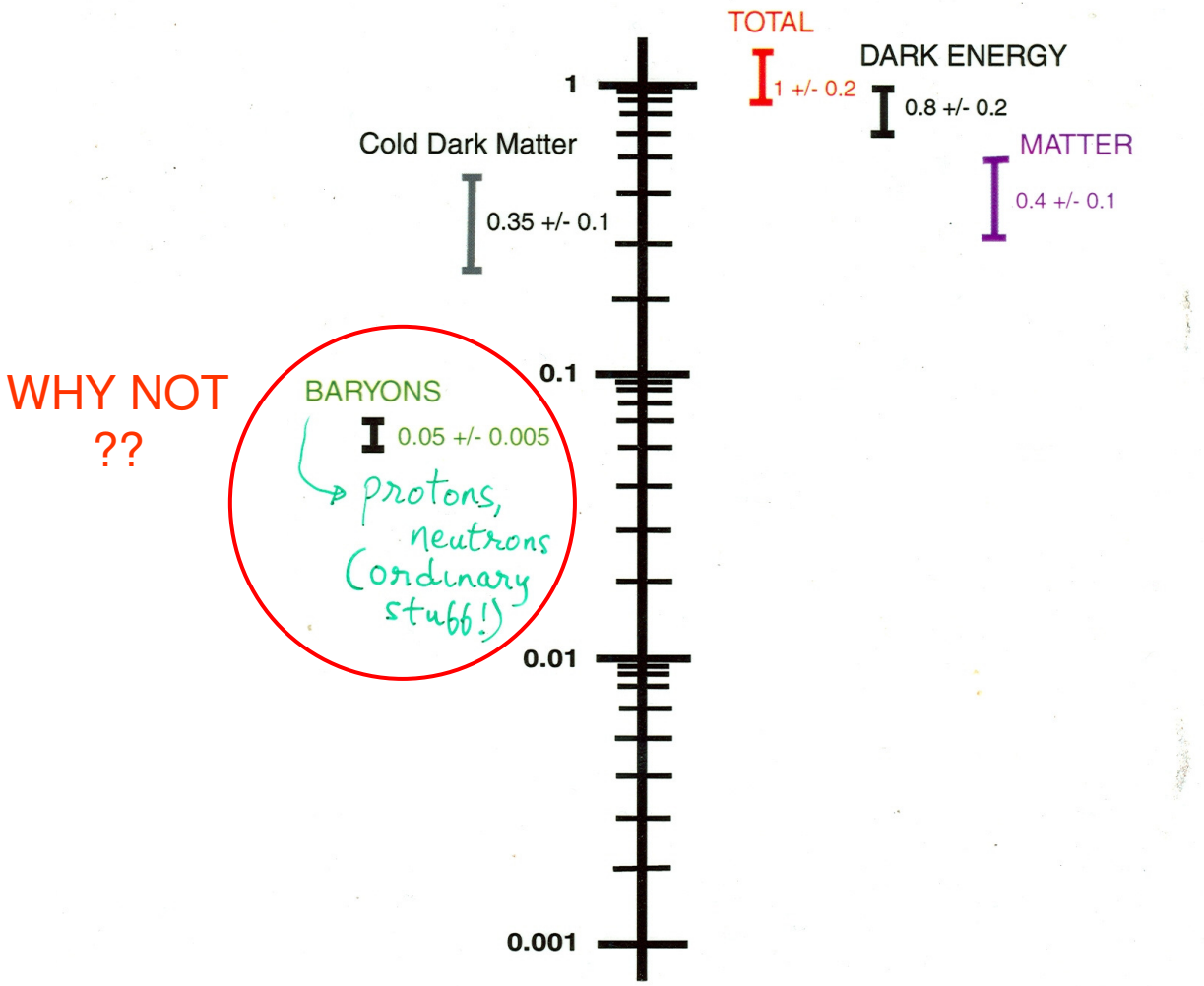
Tyson, et al (1998)



(A. Dekel, SSI 1998)

So, what is it ??

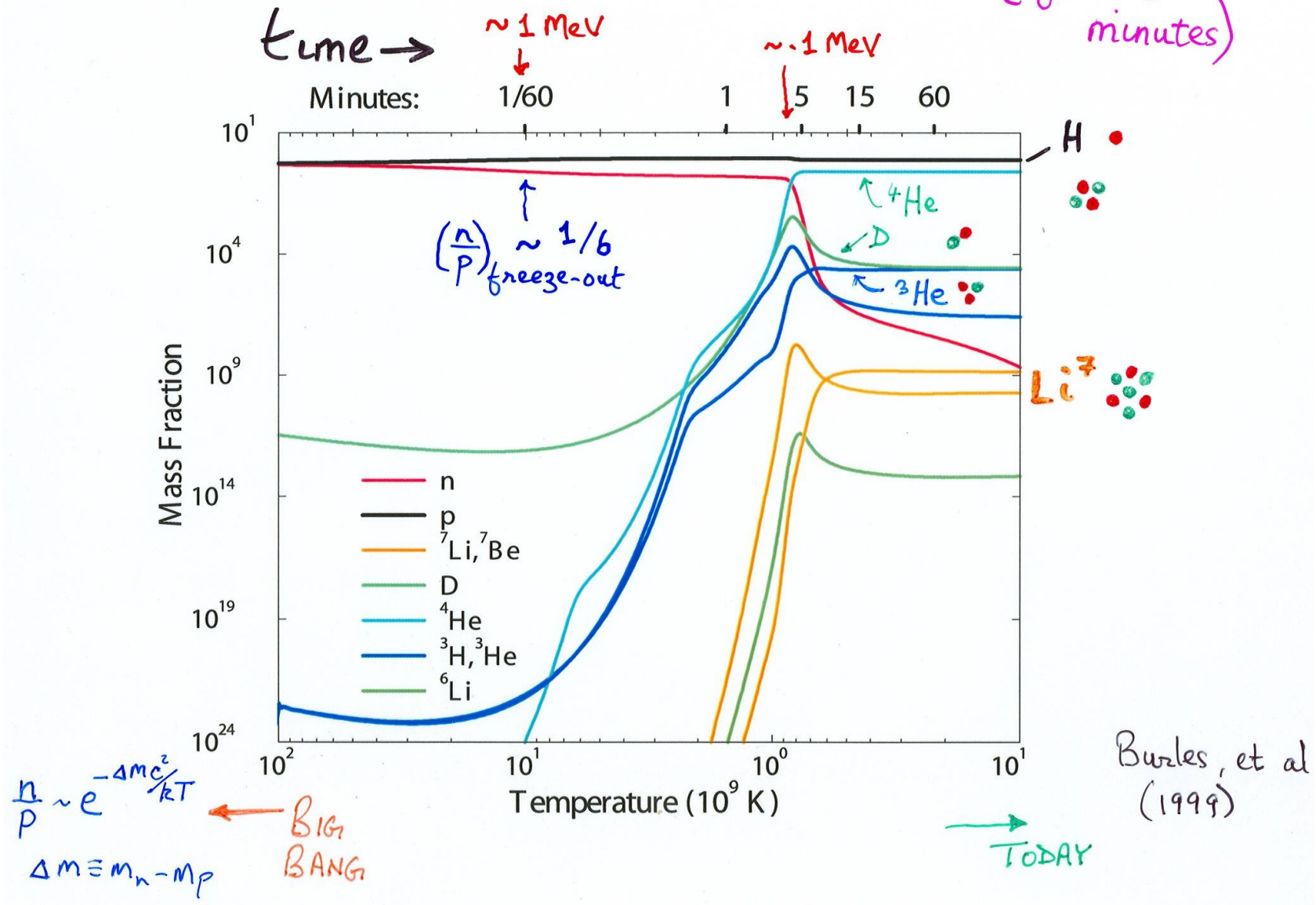
MATTER/ENERGY in the UNIVERSE



WHY NOT ??

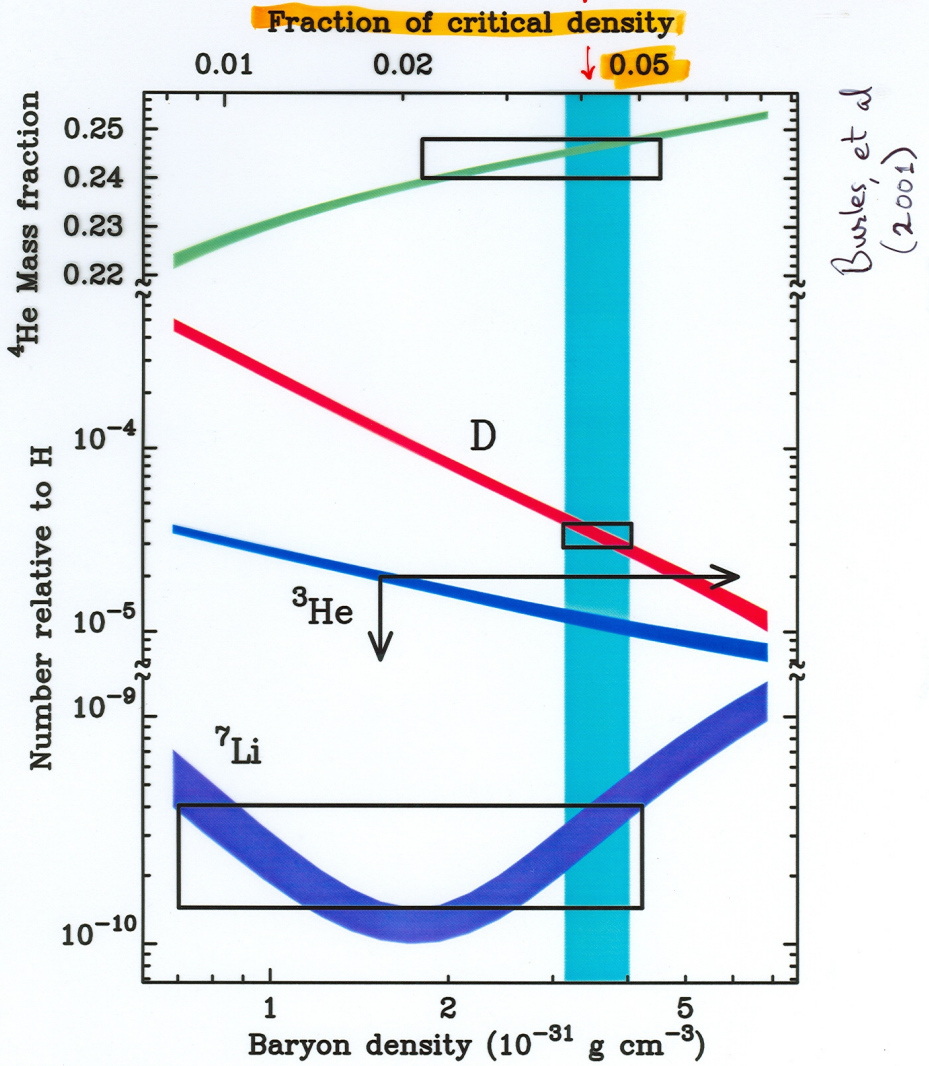
Turner, Tyson 1999

Big Bang Nucleosynthesis (first 3 minutes)



CONCORDANCE !

$\Omega_b h^2 = 0.02 \pm 0.002$ (*) (95%)



(*) from CMB, $\Omega_b h^2 = 0.02^{+.009}_{-.005}$ (95%) Wang, et al (2000)

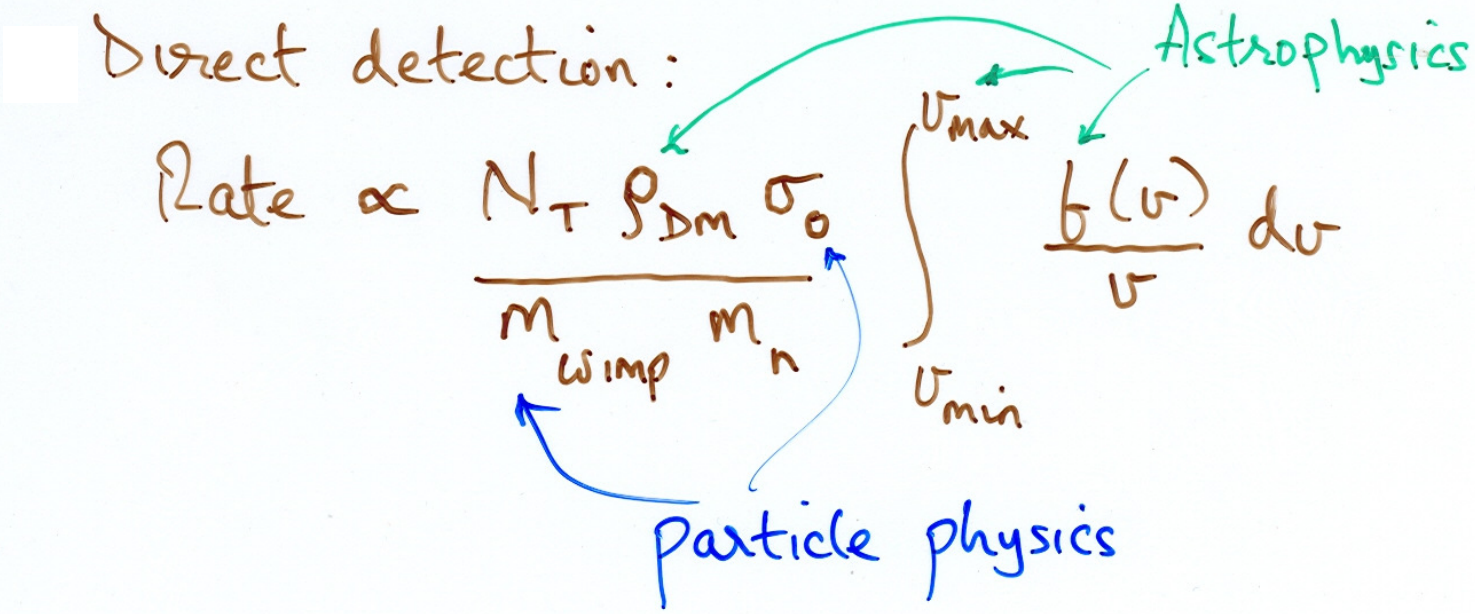
So, what is it ??


Some (!) Candidates for DM
MACHOS
WIMPS
ν's
B-H's
Dwarfs
SIMPS²
axions
MOND
Xtra Dimensions!
FUZZY DM
CHAMPS

LEADING CANDIDATES FOR DARK MATTER:

WIMPs

Direct detection:



Expected rate $\lesssim$ 1 /day.kg, with Q ~ 1-100keV

Constraints on DM Properties

- **Astrophysics:** cold (non-relativistic), non-dissipative, and, at most, weakly-interacting

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

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's – 1000's GeV

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

(maybe!)

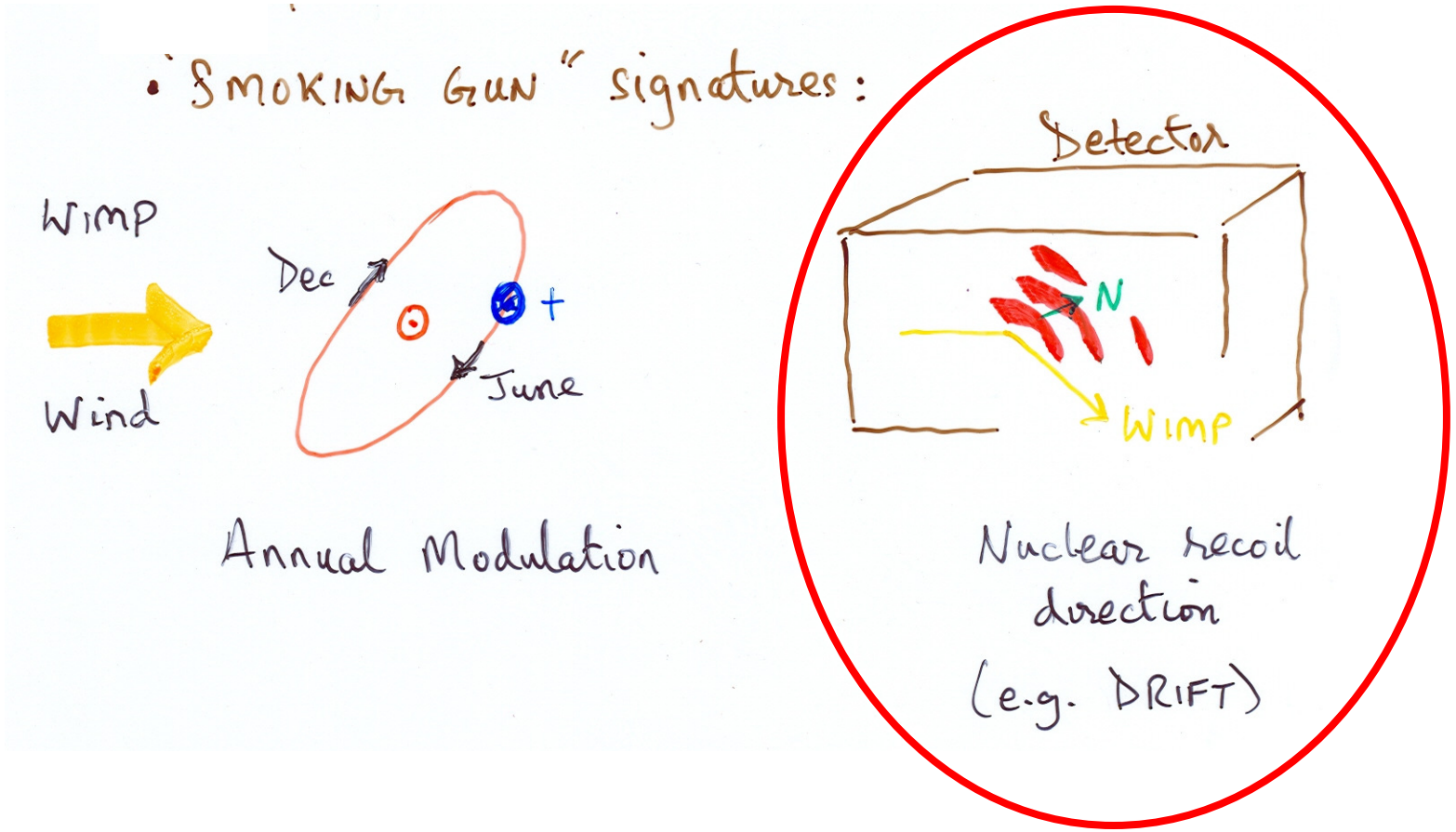
OR: $\frac{1 \text{ event}}{kg \cdot day}$ down to $\frac{1 \text{ event}}{100\,kg \cdot year}$!!!

Background Projections - CryoArray (1 tonne)

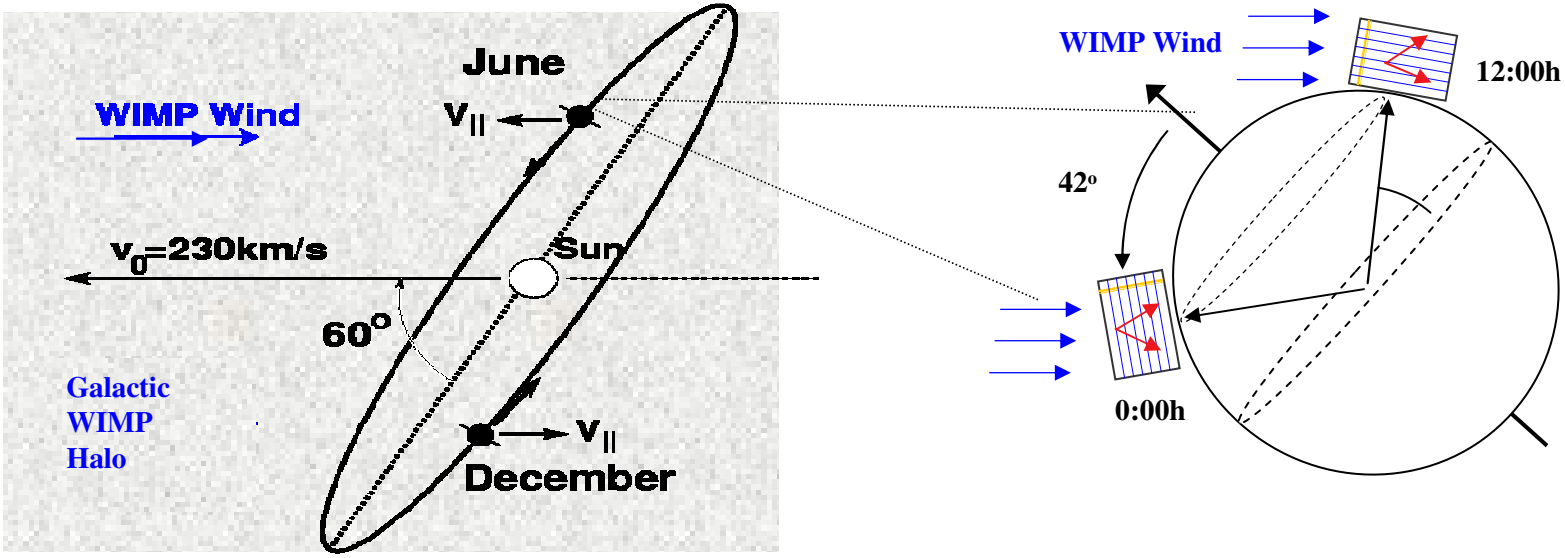
	Event Rate [mdru]	Expose [1000 kg-day]	Raw Events [counts]	Reject [%]	Post rejection [counts]	Subtract 90% CL [counts]	Sys'tic 90% CL [counts]
GAMMA							
CDMS I *	800	0.011	254	99.85%	0.4	-	-
CDMS II	260	2.50	19,500	99.50%	98	16	5
Heidelberg-M *	40	0.25	0	n/a			
CryoArray	13	500	195,000	99.95%	97	16	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 x20^{-1}	0.5	500	7,500	99.90%	8	-	-
CryoArray (Rk)	0.0055	500	83	(multi)	n/a	21	8

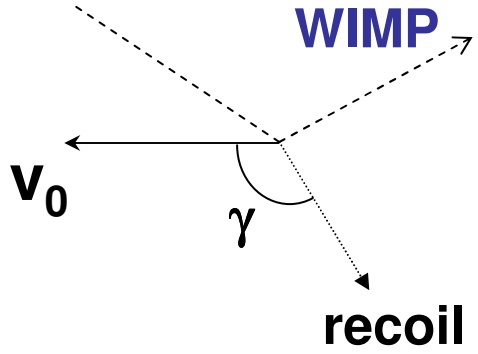
dru = 1 event keV^{-1} kg $^{-1}$ day $^{-1}$ Energy Range 10-40 keV

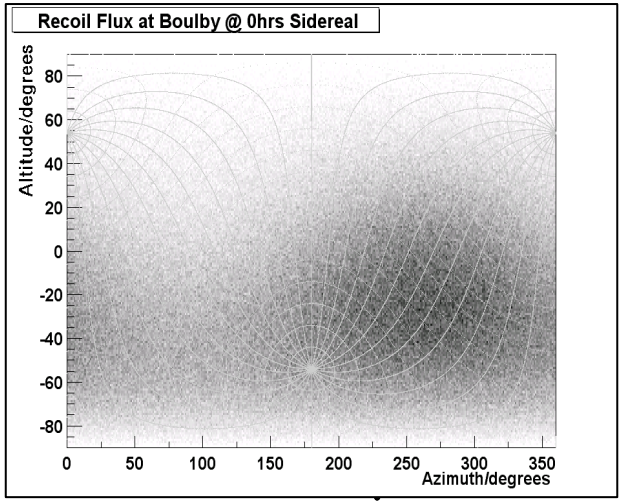
So you need…


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

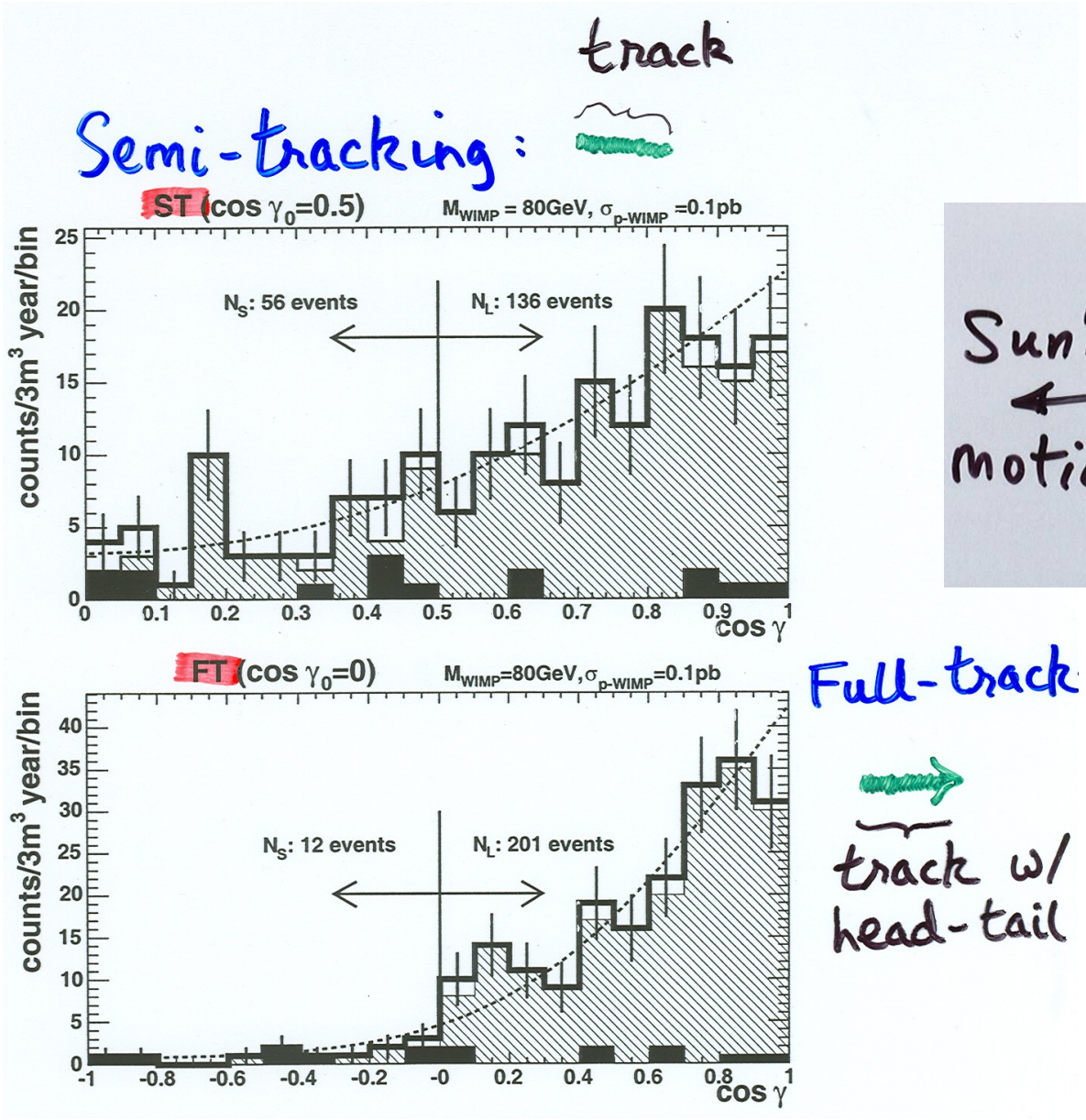
Nuclear recoil tracks yield WIMP direction

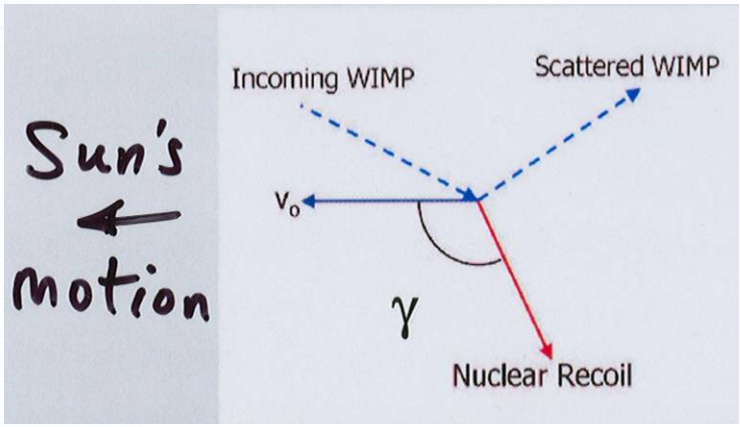






Identifying a signal





(astro-ph/0310638)

THE DRIFT DARK MATTER SEARCH

SMU Sept 17, 2007

DRIFT

OCCIDENTAL COLLEGE
(SNOWDEN-IFFT + U.Gs)

UNM
(GOLD, HAGEMANN, SANGHI, TURK, LOOMBA)

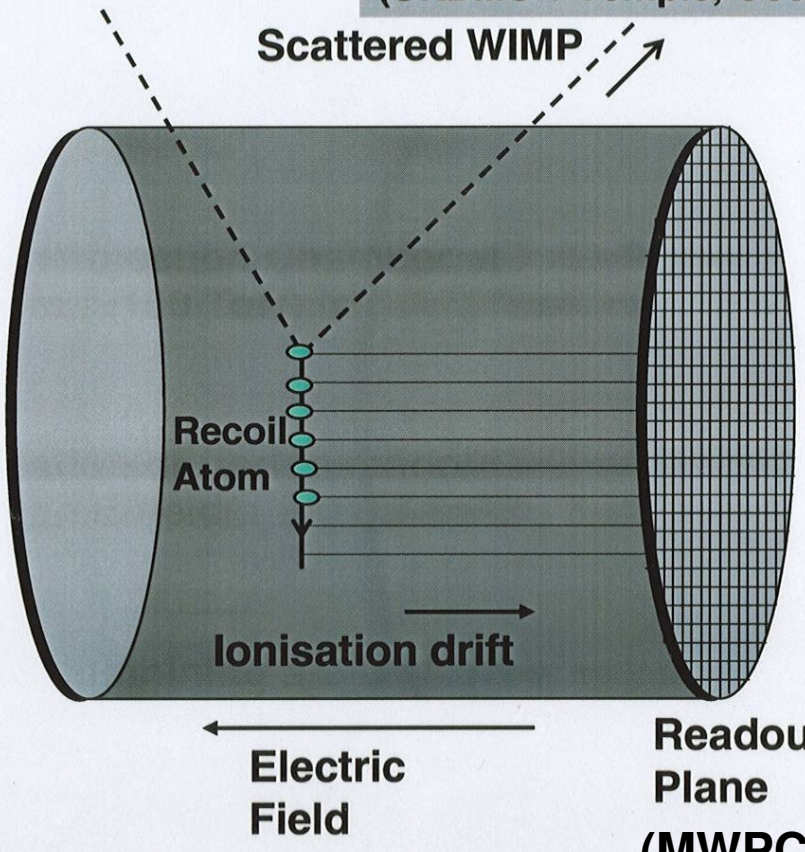
SHEFFIELD
(SPOONER et al)

EDINBURGH
(MURPHY et al)

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

DRIFT - low pressure TPC

(UKDMC + Temple, Occidental College, LLNL)



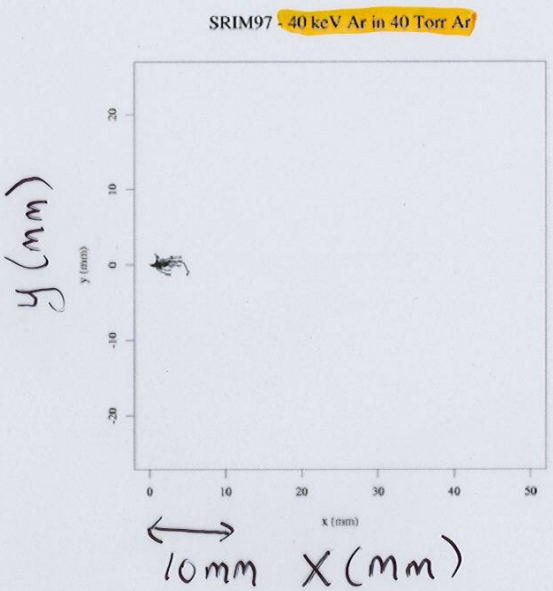
- Energy scale of nuclear recoils means recoil ranges very low
- Use a Time Projection Chamber at low pressure (<100 Torr) to extend recoil range to few mm
- Track ionisation drifted to readout plane by high E-field
- Full 3-D reconstruction of track possible by combining a 2-D readout plane with timing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

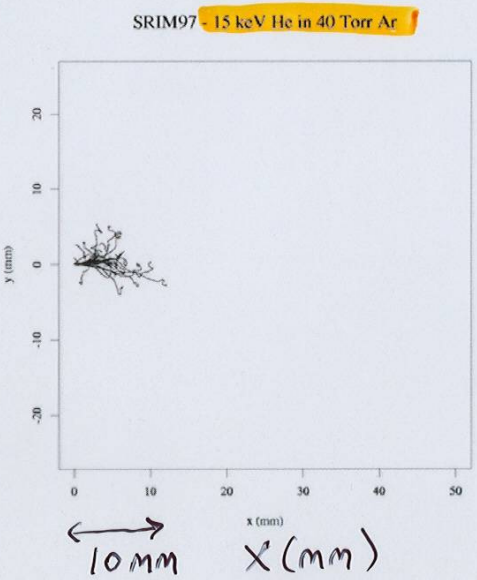
TRACKING is ALSO KEY for DISCRIMINATION of BACKGROUNDS!

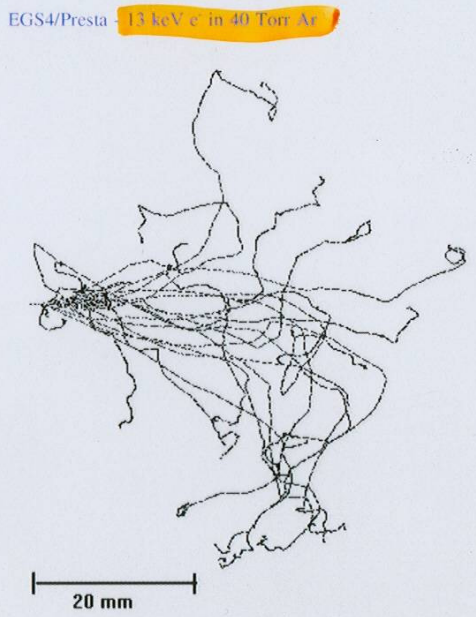
40 keV Ar recoils
500 electron-ion pairs

15 keV αs
500 electron-ion pairs

13 keV e^-s
500 electron-ion pairs

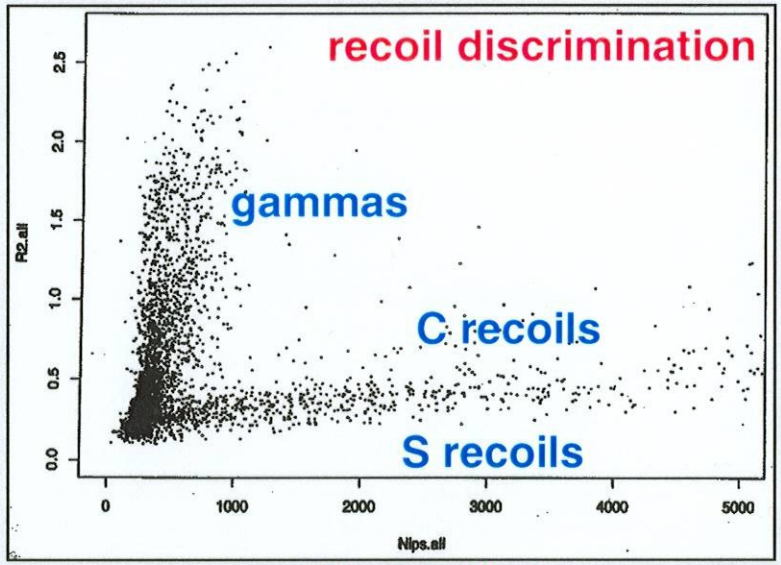






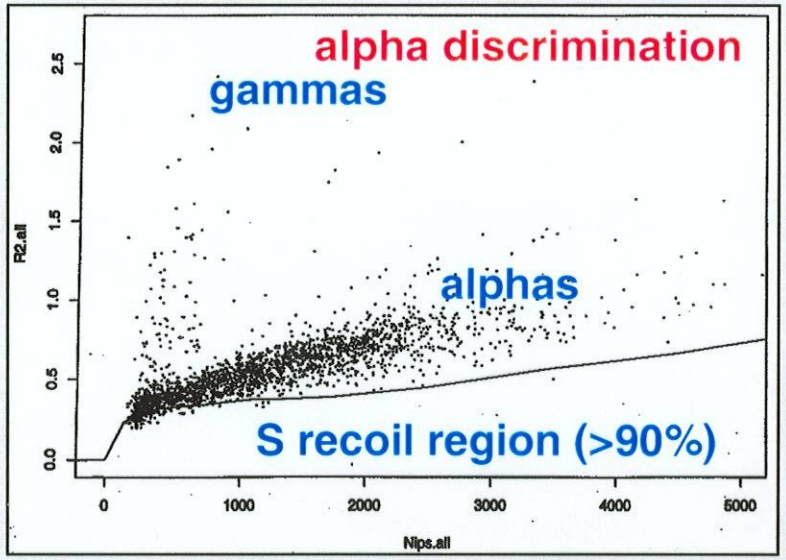
Note: discrimination still possible w/o true tracking!
(ala D-I)

1 ft^3 prototype tests (Occidental)



R2 →

ionization →

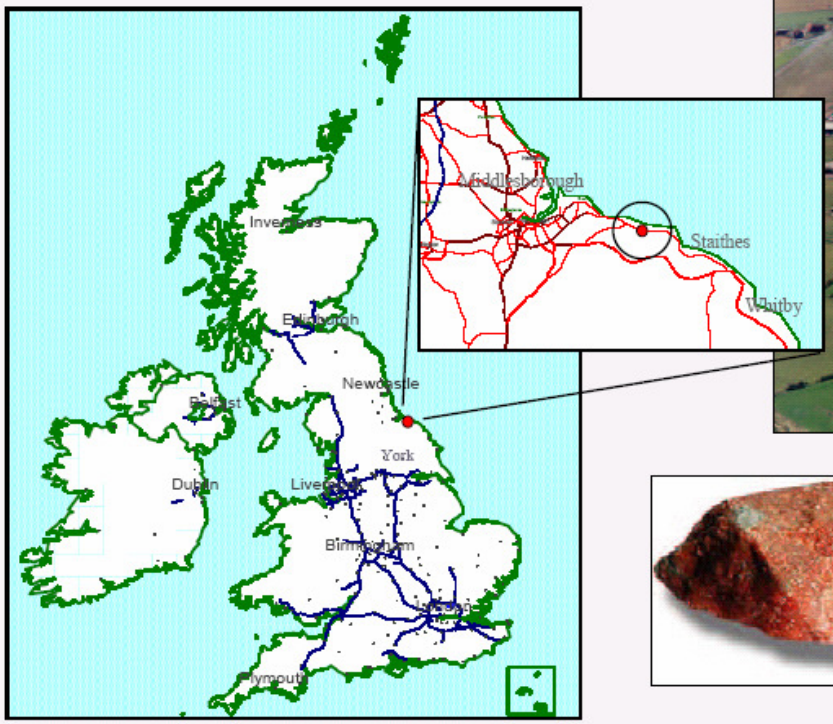


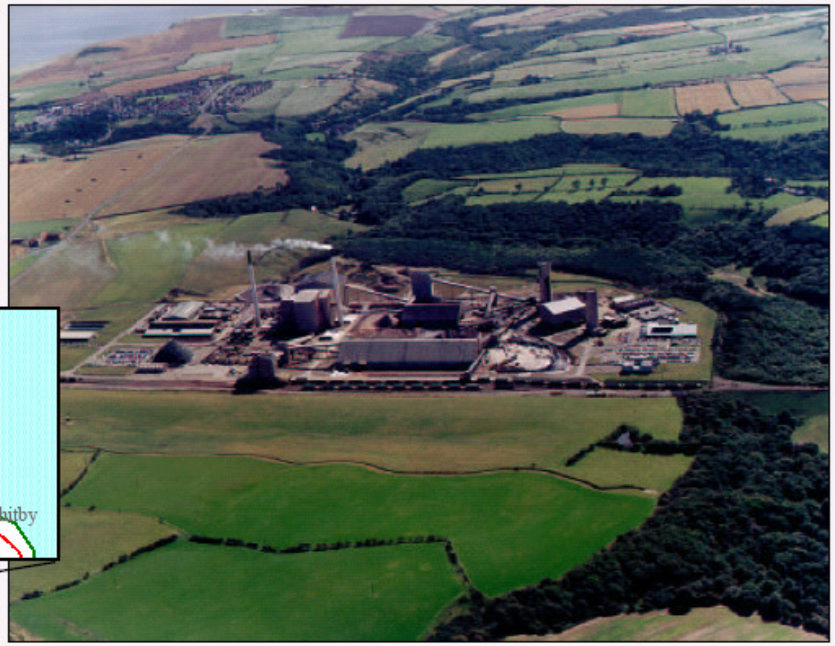
See Snowden-Ifft et al. IDM2000

US0703 - all data shown is preliminary

Boulby mine

- Working Potash mine
- Deepest mine in Britain
- 850m to 1.3km deep



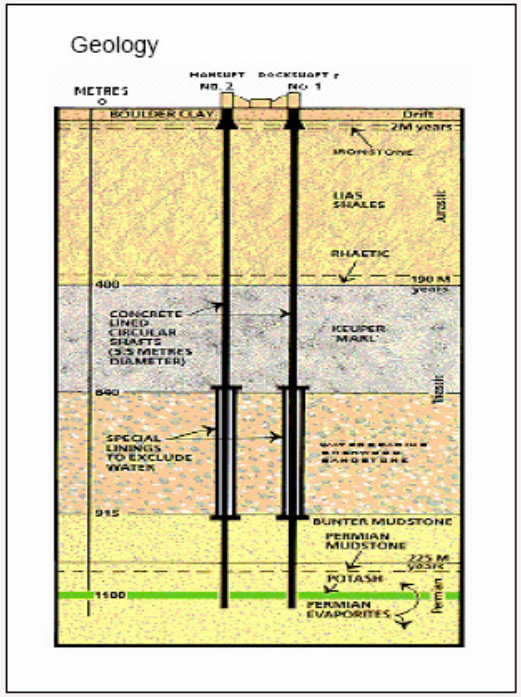


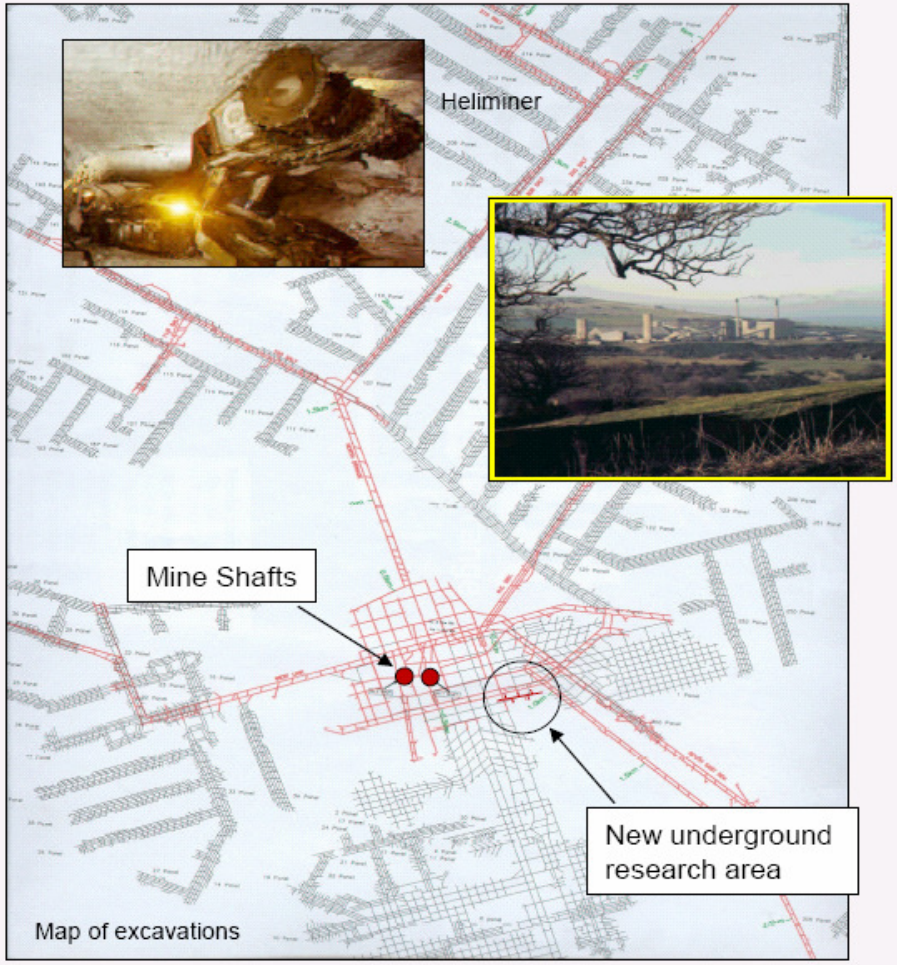
Sylvanite

CLEVELAND POTASH

Boulby mine

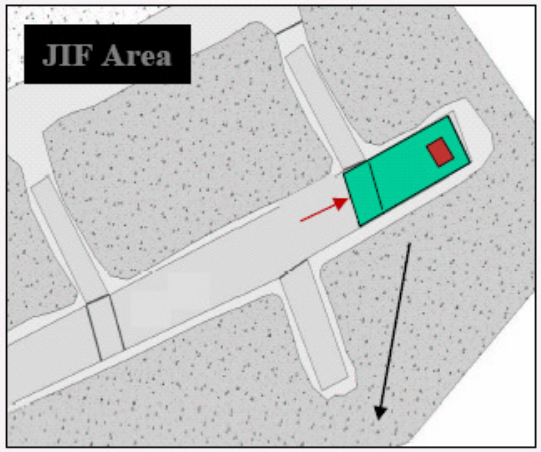
- Roadways & cavern excavated in Potash & Rock salt layer
- Over 40kms of Tunnel dug each year (now >1000kms in total)





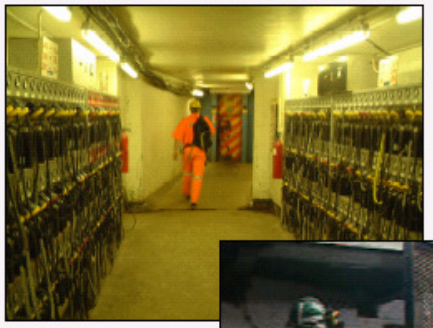
No infrastructure (1989)

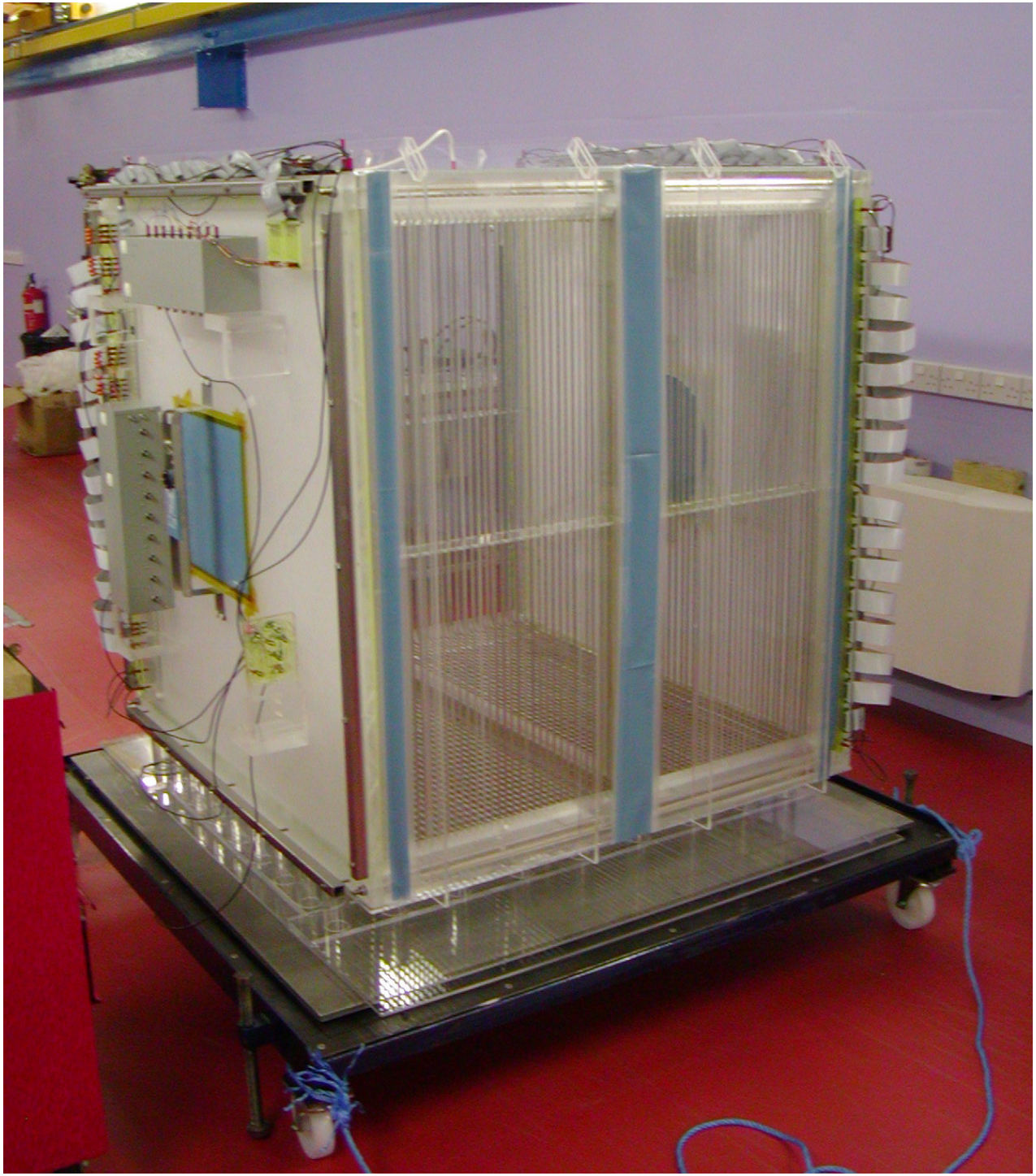
The JIF area now



1000m^2 of supported lab space available for next generation Dark Matter experiments…

Working underground





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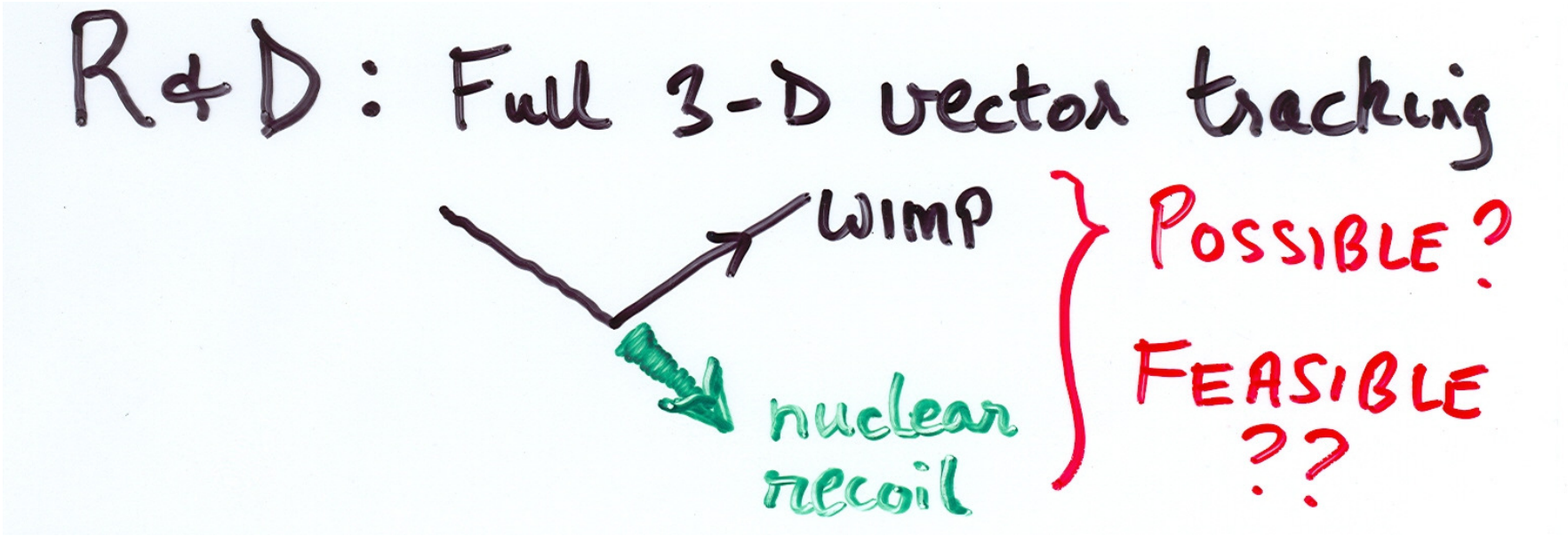
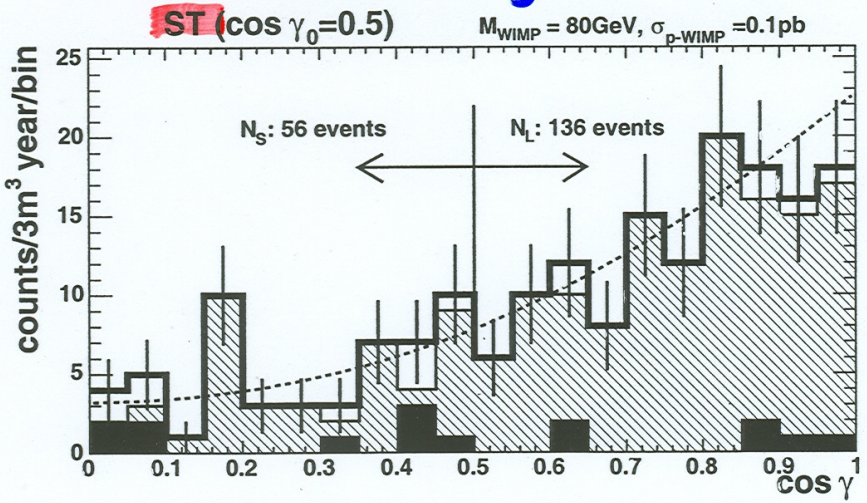
At UNM we are focusing on….

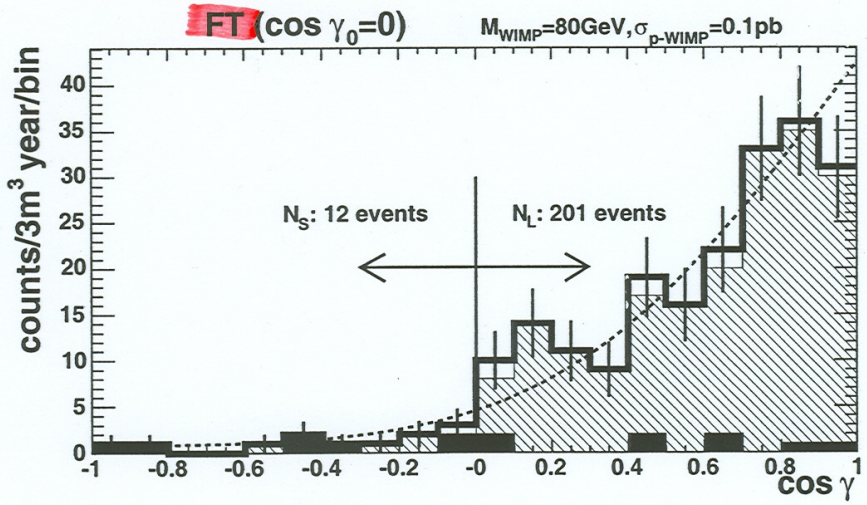


Recall the advantages of full 3D tracking

track

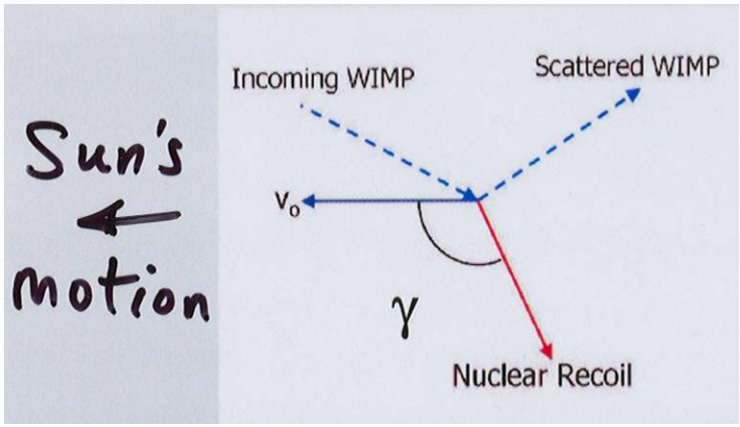
Semi-tracking :





Full-track

track w/ head-tail



(astro-ph/0310638)

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

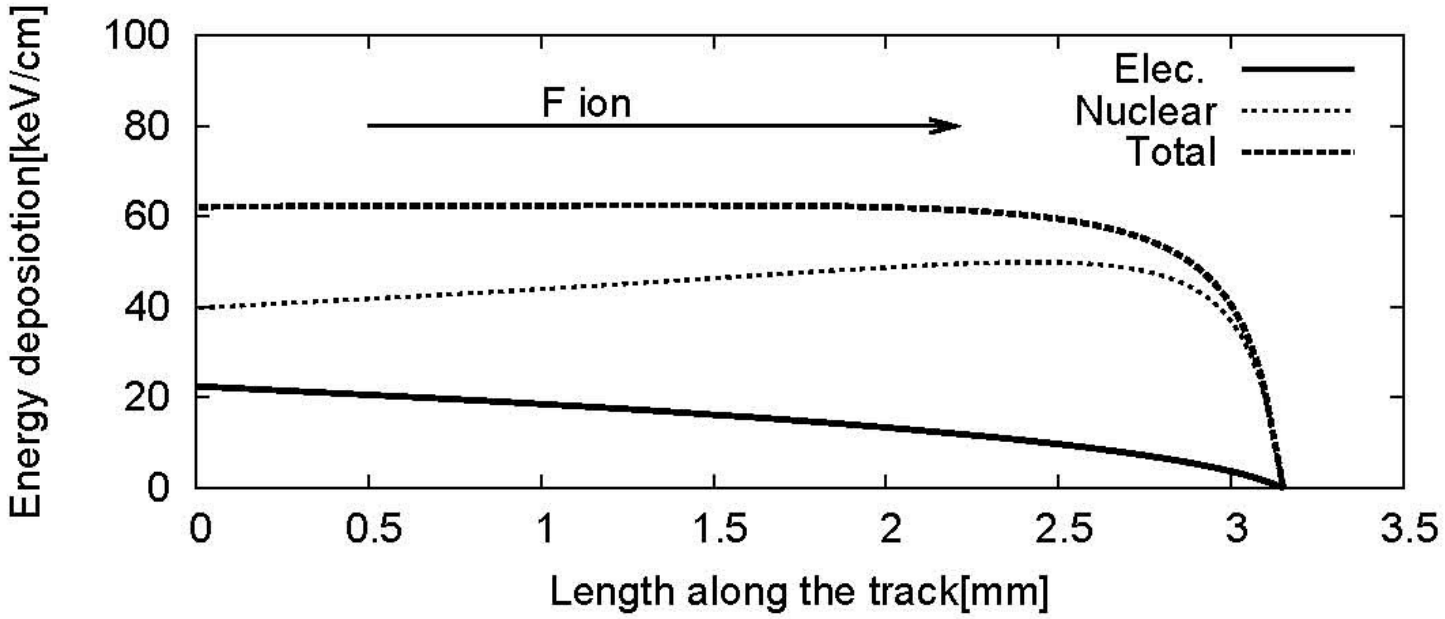
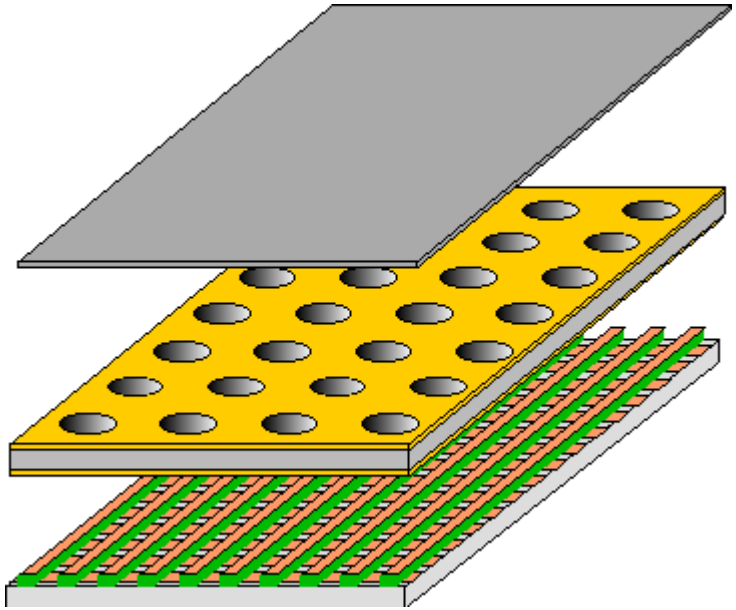


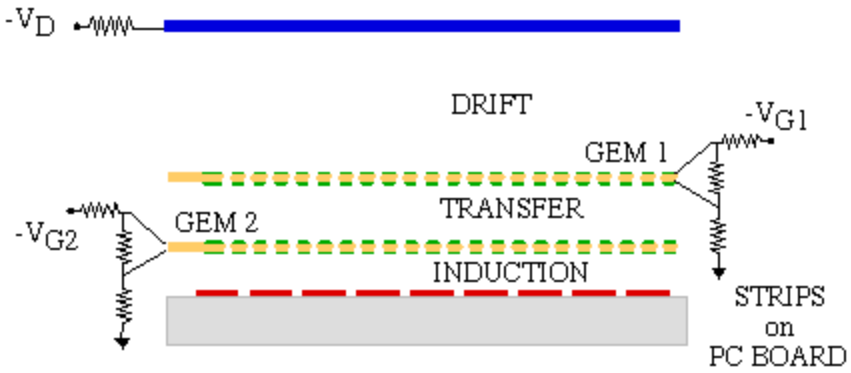
Fig. 2. Calculated energy loss of a F ion of 25 keV in 20 Torr CF_4 gas. The energy loss in the electron field, nuclear filed, and the total energy loss are shown by the solid, dotted, and dashed lines, respectively.

(astro-ph/0310638)

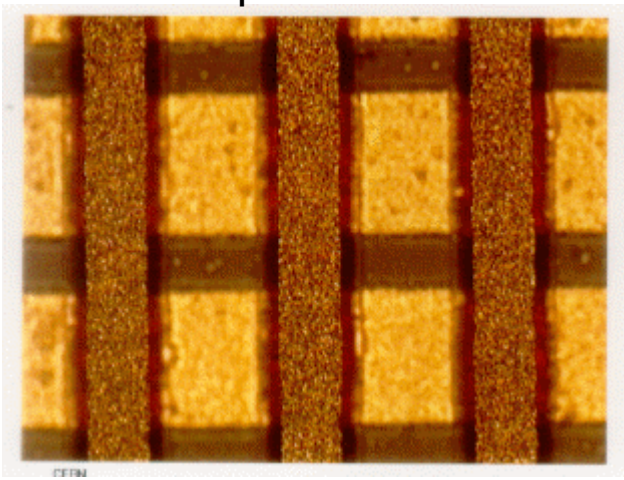
UNM R&D Program

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





200 um pitch



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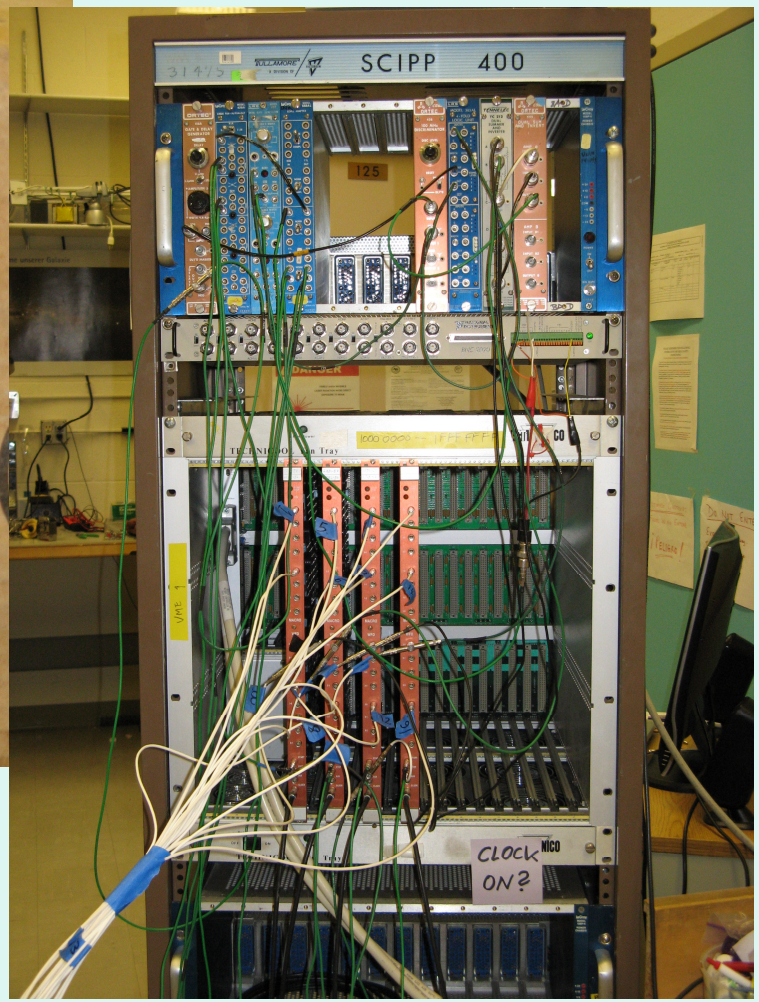
Measuring low energy nuclear recoils

Reading out 16 strips in 1D into 16 separate WFD channels giving us 200μm strip pitch



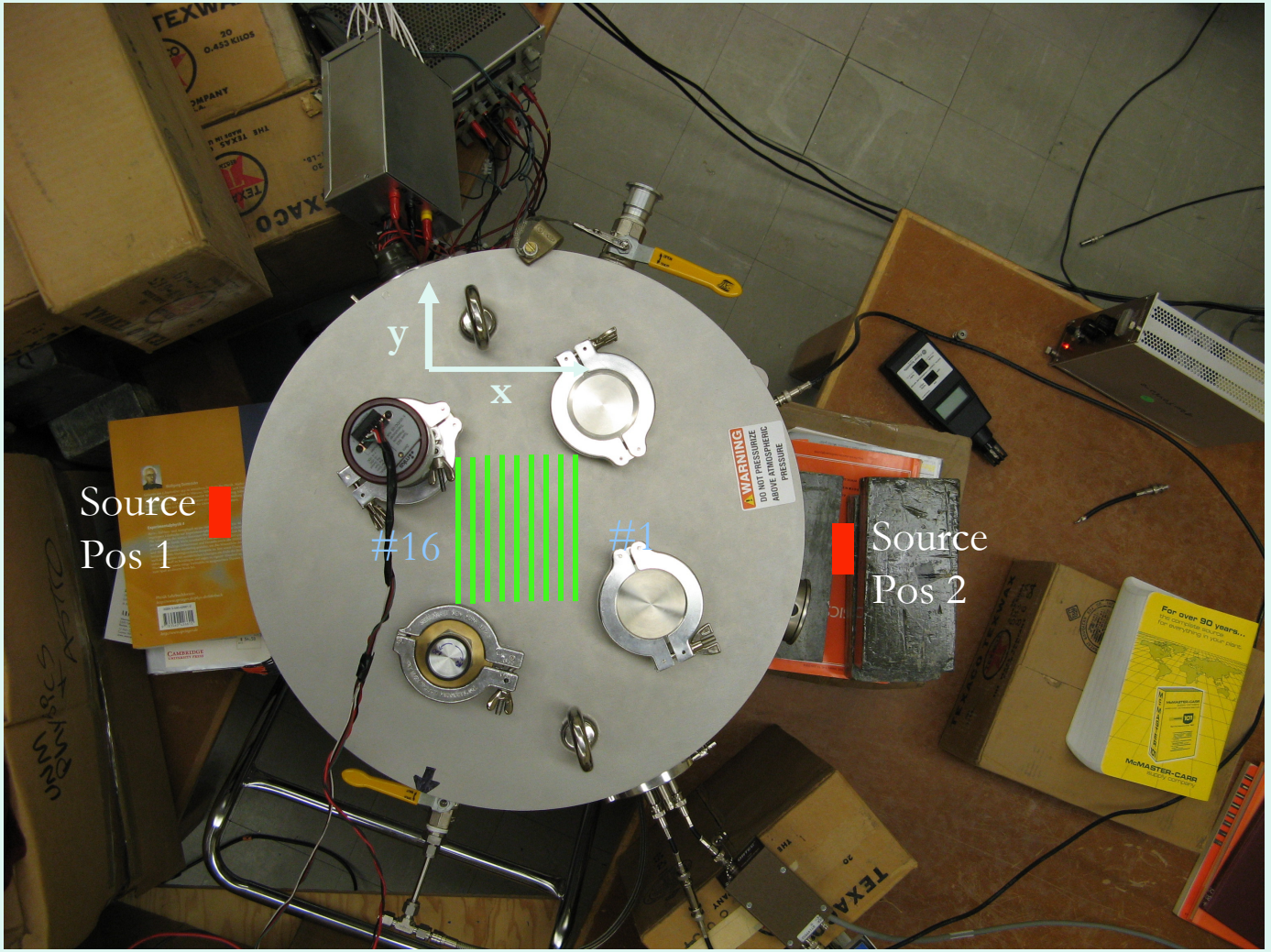
Digitizers have digitization rate of 200MHz and were designed and built for MACRO experiment;

on loan from Ed Kearns (Boston University)

Measuring low energy nuclear recoils

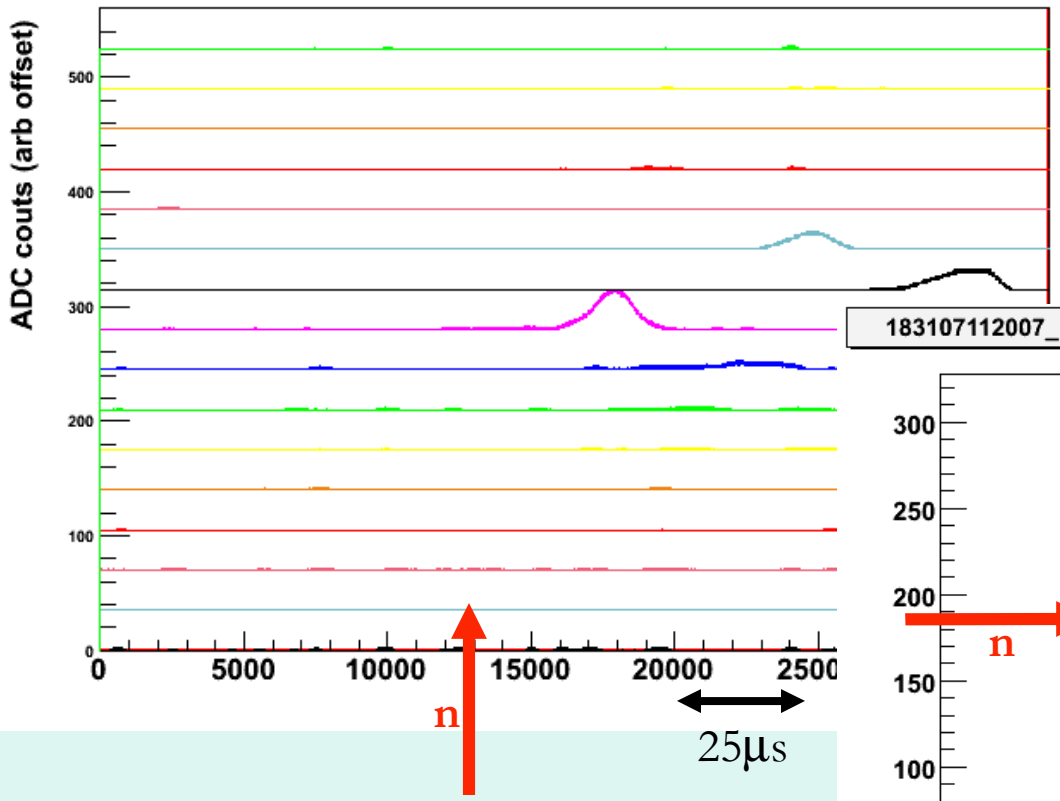
Neutron source: ^{252}Cf, activity of <20μCi in Jan 2007 (expected: few events per minute in active detector volume)

SETUP:



Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:

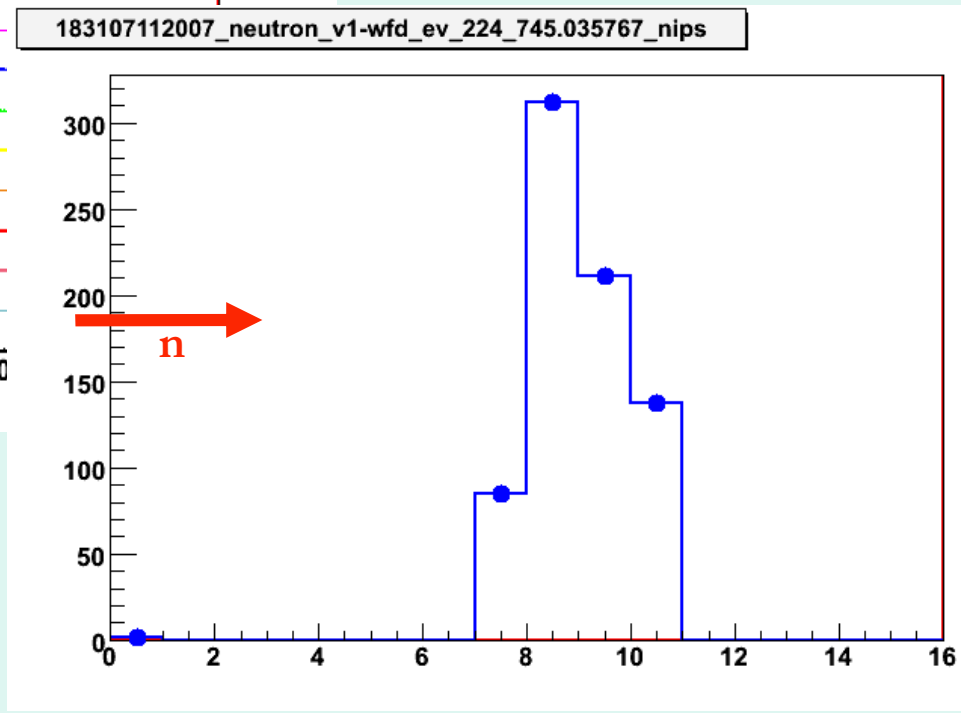


Event has ~745 NIPs

$\Delta x \sim 0.4$ mm

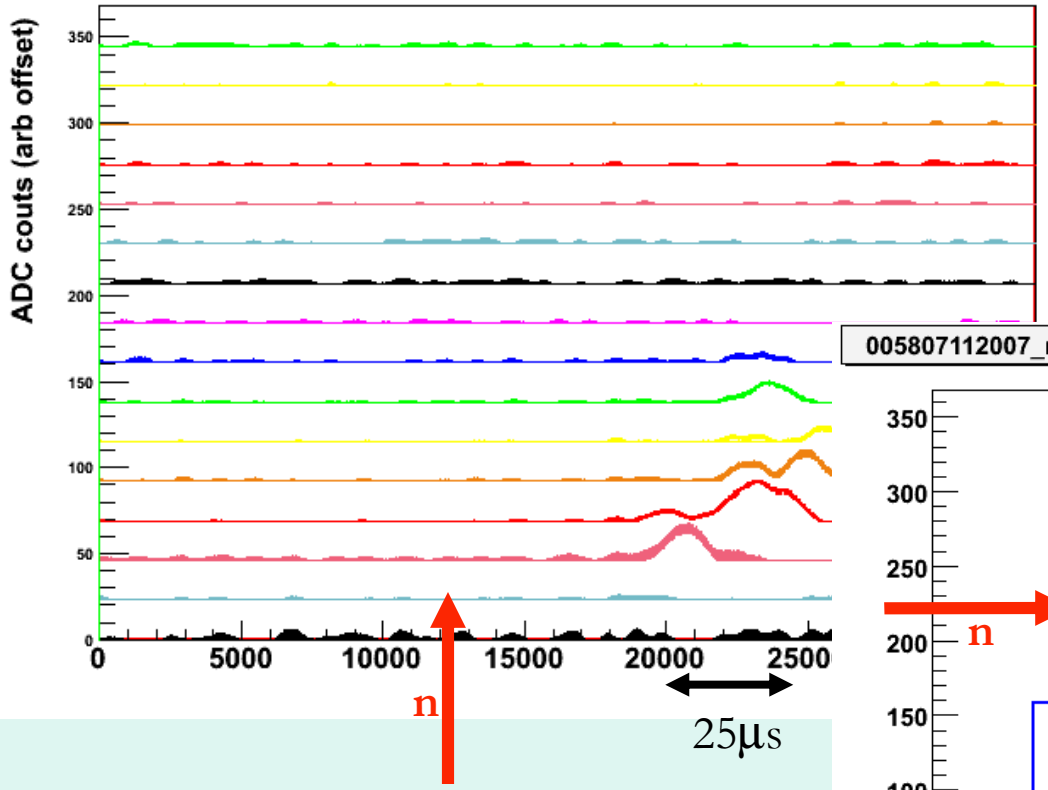
$\Delta z \sim$?

[35keV Sulfur recoil]



Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:

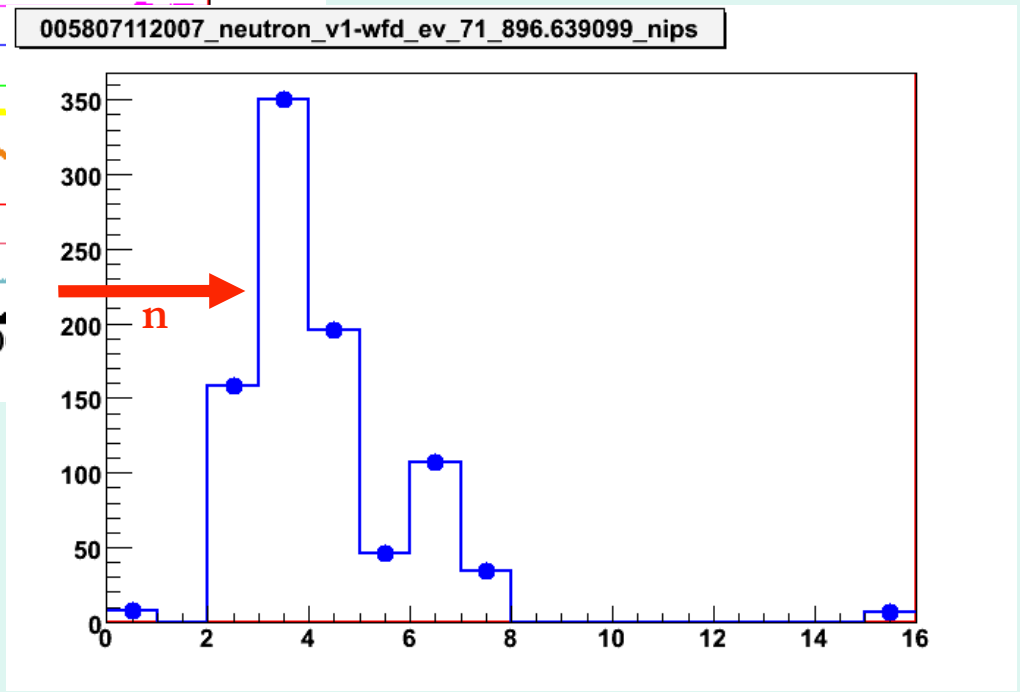


Event has ~900 NIPs

$\Delta x \sim 1$ mm

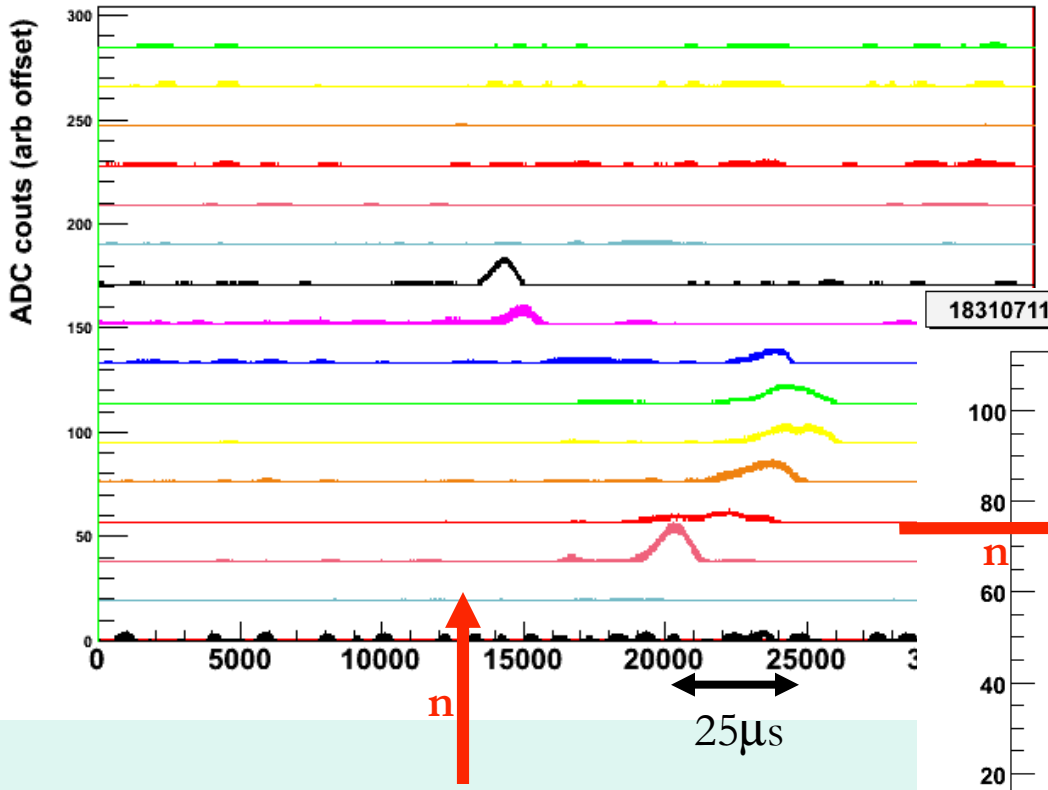
$\Delta z \sim 0.7$mm

[25 - 30keV Carbon recoil]

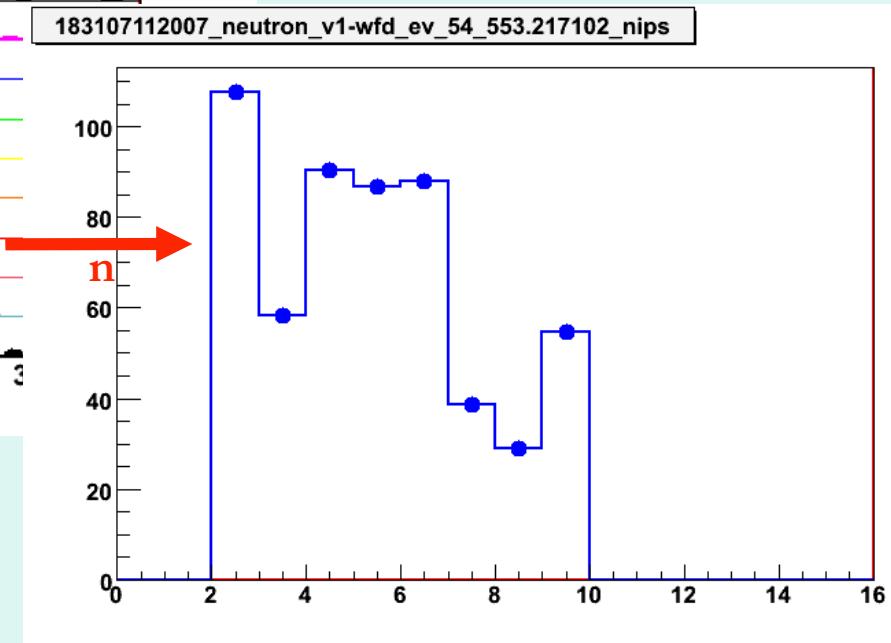


Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:

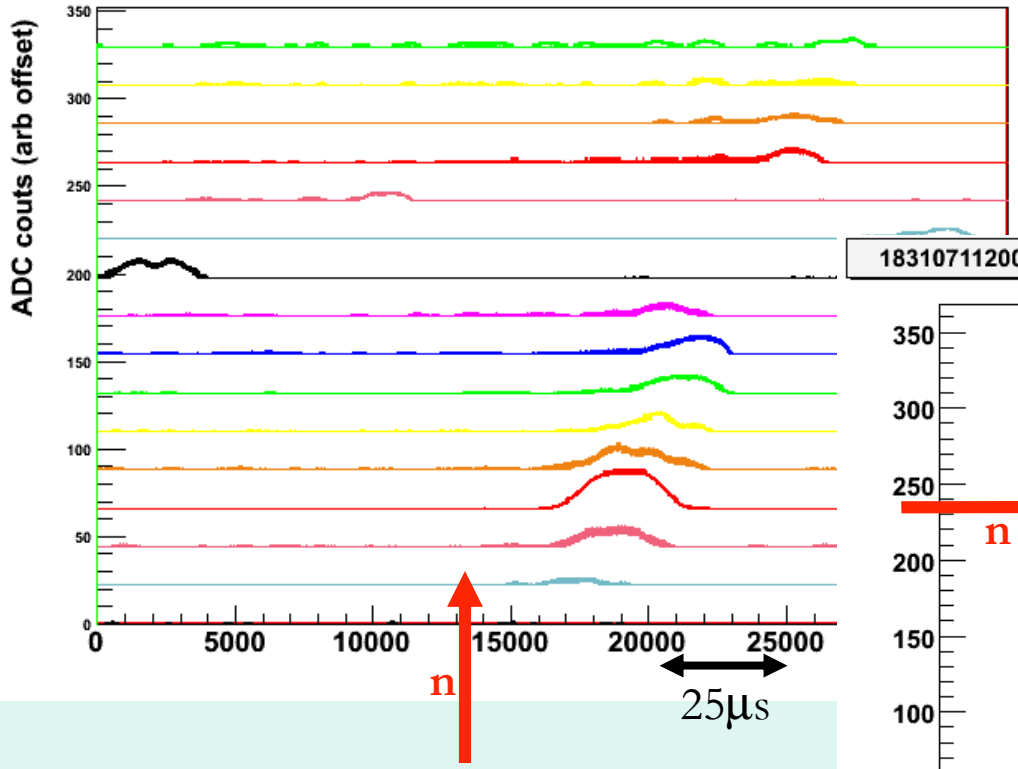


Event has ~550 NIPs
Δx ~ 1.2 mm
Δz ~ 0.8mm
[20keV Carbon recoil]

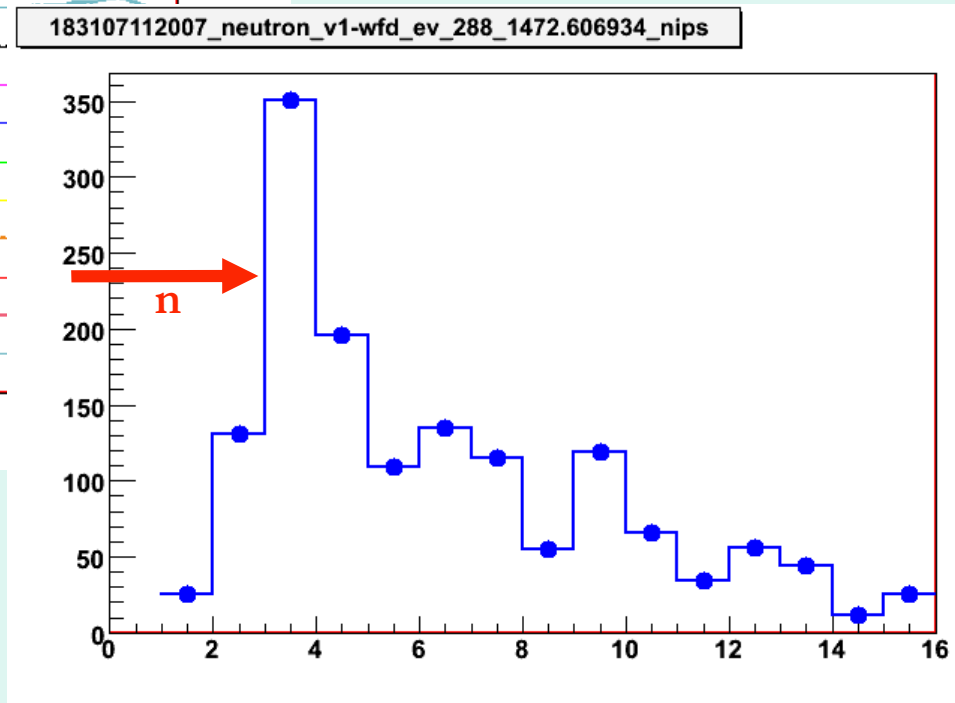


Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs > 1000:

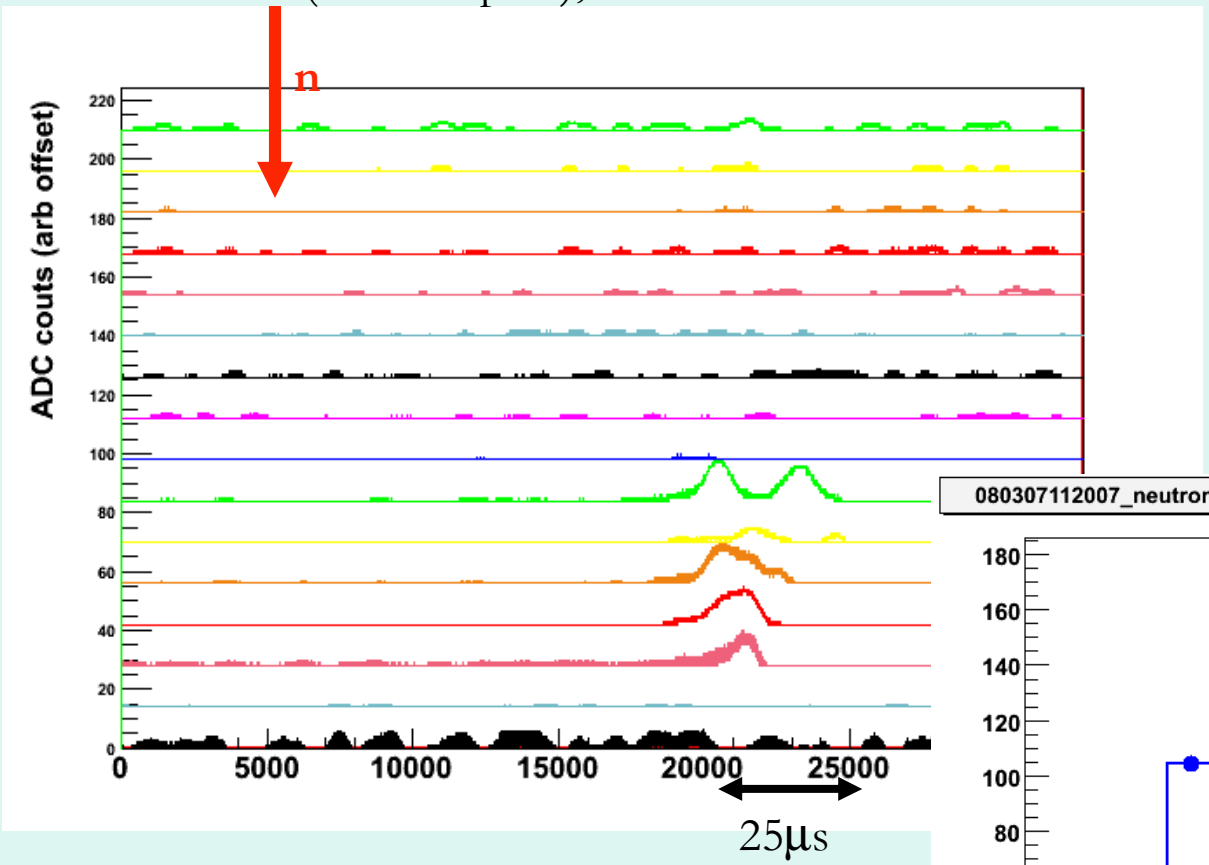


Event has ~1500 NIPs
Δx ~1.2-1.4 mm
Δz ~ 1.2mm
[40keV Carbon recoil (?)]

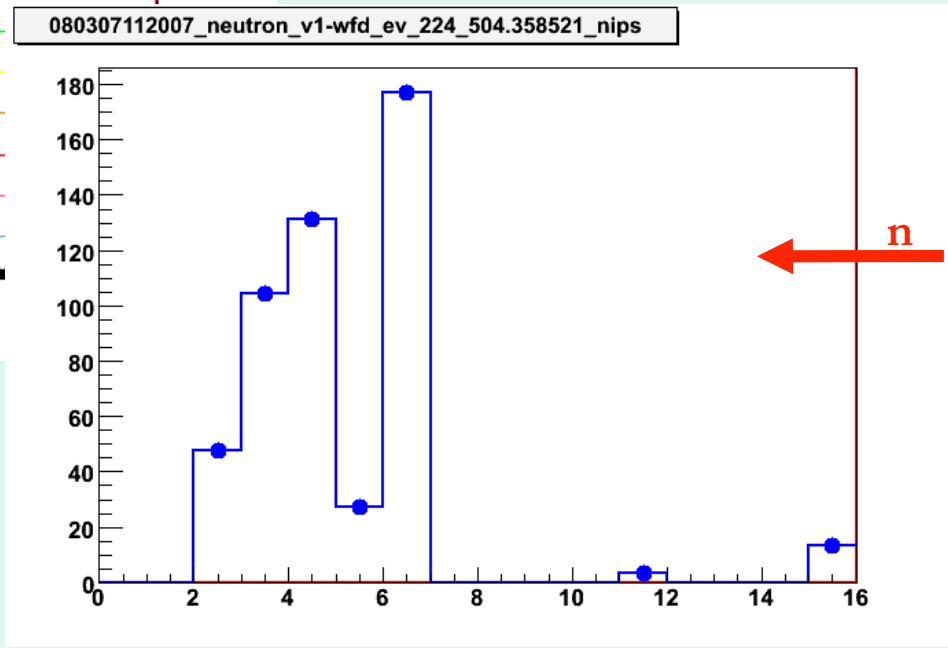


Measuring low energy nuclear recoils

Position 1 (from strip 16), NIPs < 1000:

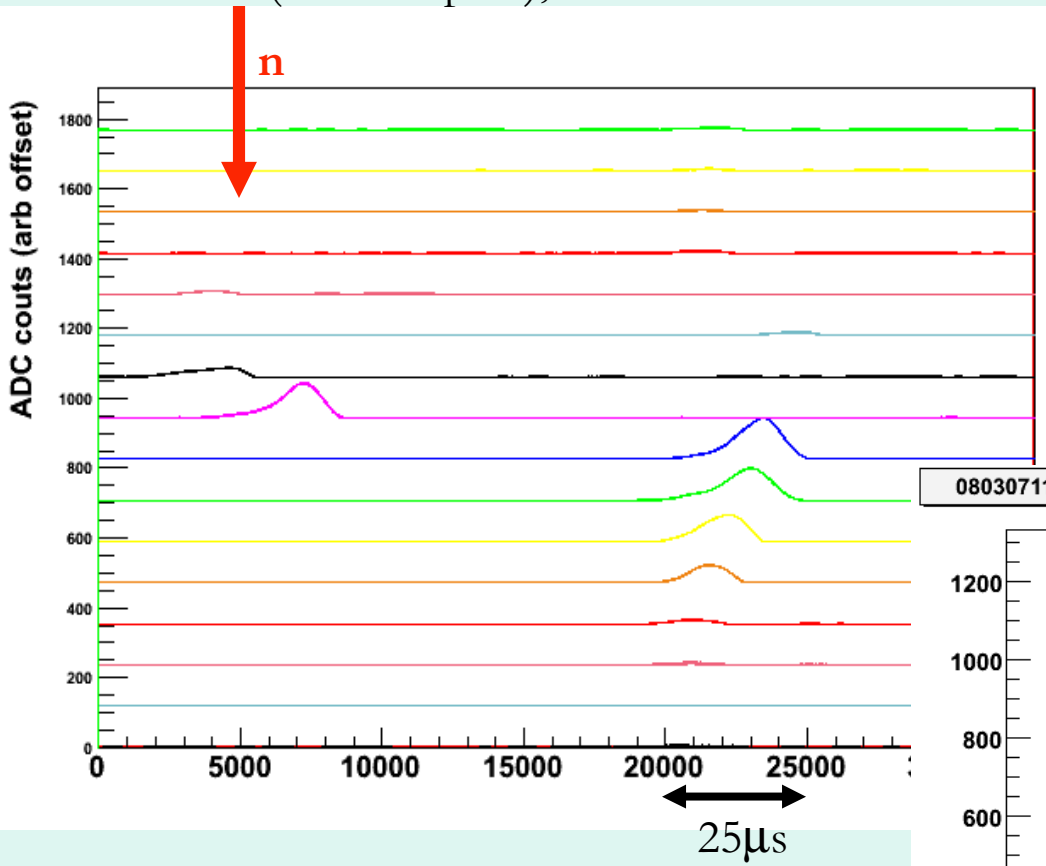


Event has ~500 NIPs
$\Delta x \sim 0.8$ mm
$\Delta z \sim 0.5$mm
[17keV Carbon recoil]

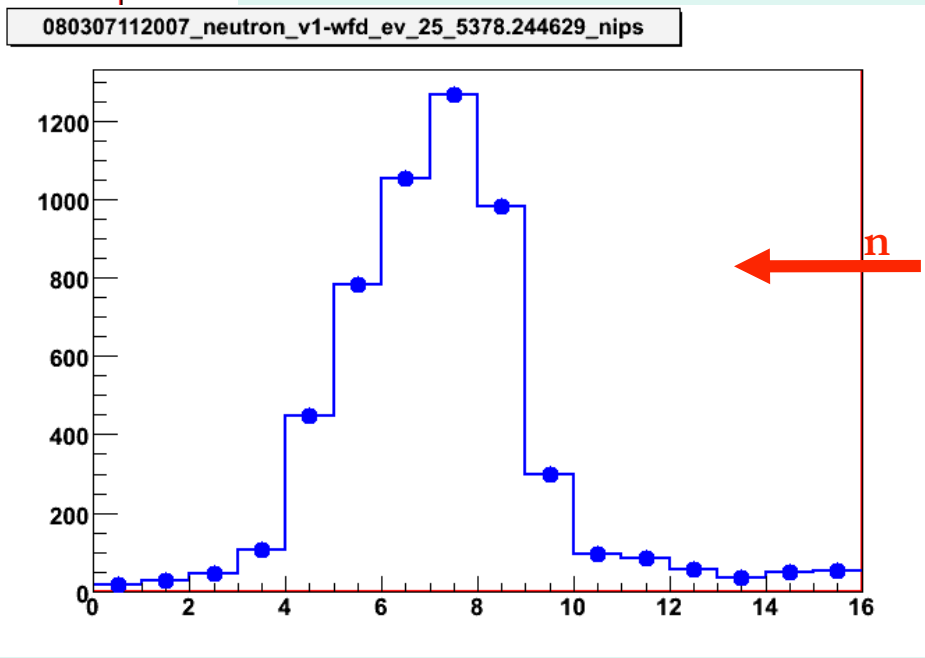


Measuring low energy nuclear recoils

Position 1 (from strip 16), NIPs **> 1000**:

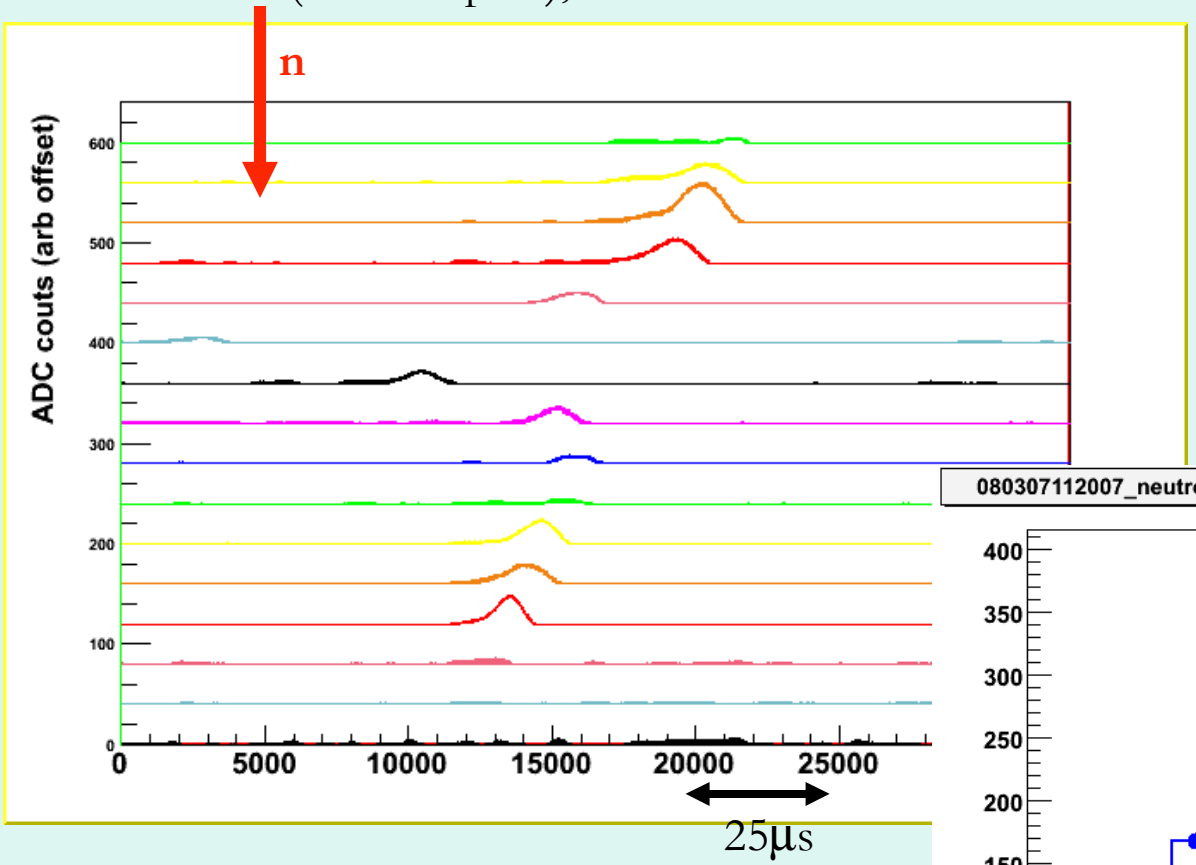


Event has ~5400 NIPs
$\Delta x \sim 1.2 - 1.4$ mm
$\Delta z \sim 0.2$mm
[200keV Sulfur recoil]

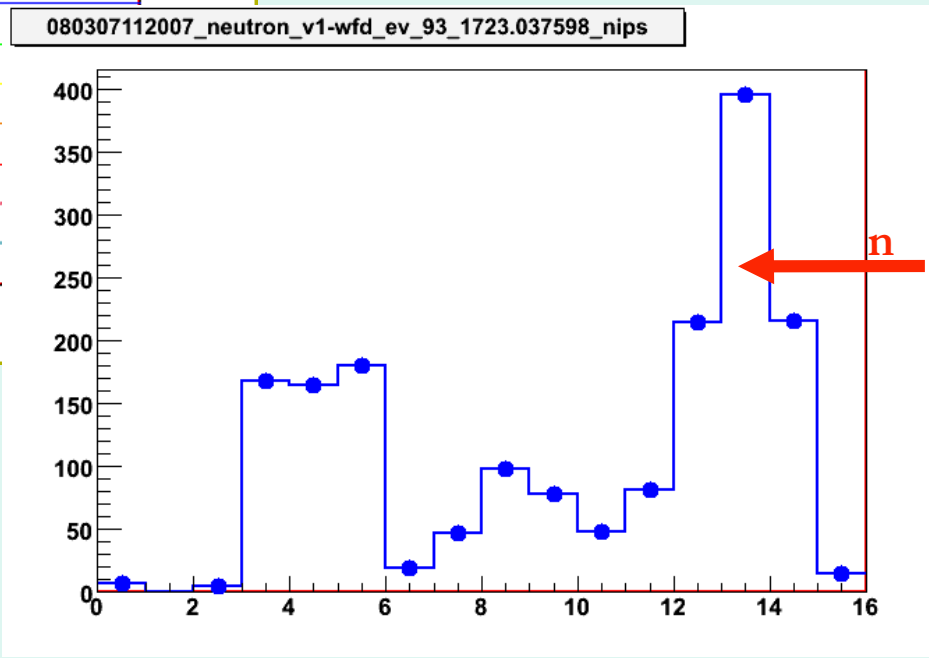


Measuring low energy nuclear recoils

Position 1 (from strip 16), NIPs > 1000:



Event has ~1700 NIPs
$\Delta x \sim 1.2 - 1.4$ mm
$\Delta z \sim 0.2$mm
[48keV Carbon recoil]



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]

[1] *LIP - Coimbra and Departamento de Física da Universidade de Coimbra, 3004-516 Coimbra, Portugal*
[2] *Institute Laue Langevin, BP 156X, F-38042 Grenoble Cedex, France*
[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: ^{3}He-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-CF_4 are presented. Images of the tracks of the proton and triton recorded with a triple GEM detector are also shown.

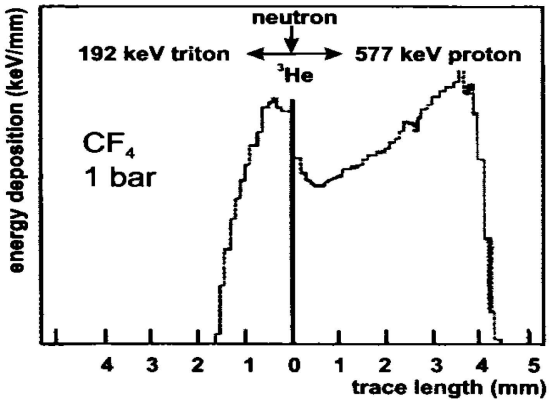


Fig. 4 The energy deposition along the proton and triton track in 1 bar CF_4.

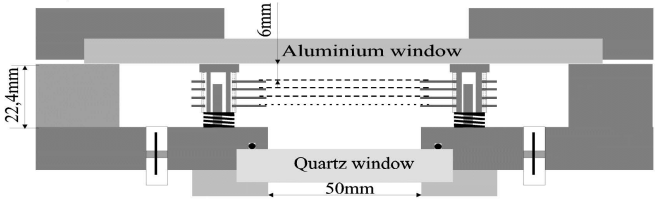


Fig. 5 Schematic cross-section of the detector. The CCD (not shown) was placed 30 cm away from the glass window.

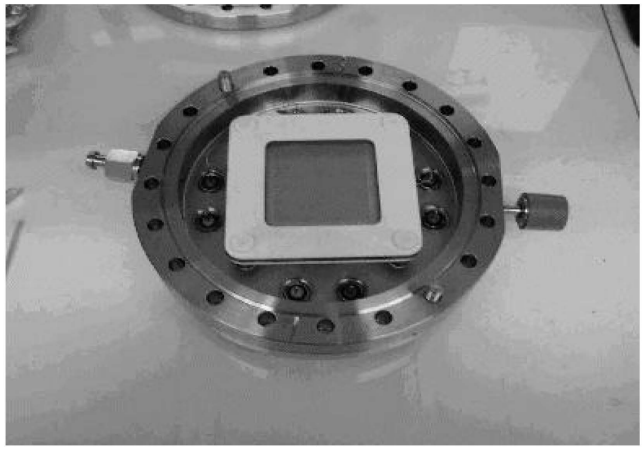


Fig. 6 Photograph of the detector with the entrance aluminium window removed, showing the stacked GEM assembly and transparent grid electrode.

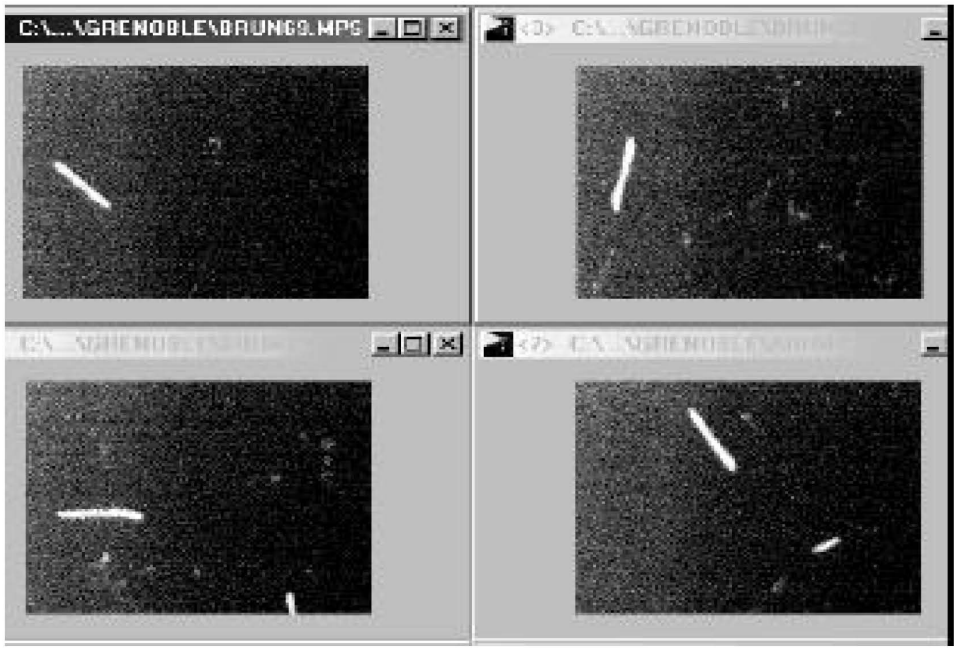


Fig. 7 Images of proton and triton tracks obtained with He(1bar)-CF_4 (400 mbar): V_{GEM1}=V_{GEM2}= V_{GEM3} =400V, E_D= 1kV/cm, E_T= 3 kV/cm, CCD Binning 7×7, Texp.=10ms.

Triton, proton tracks

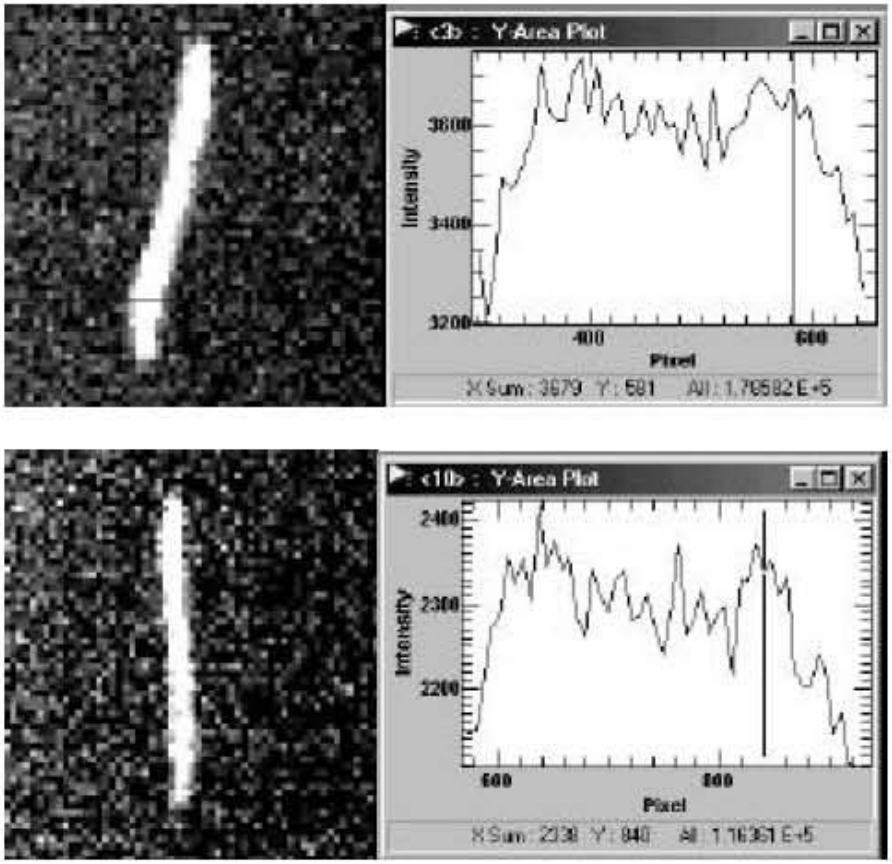


Fig. 8 Distribution of measured scintillation along tracks. The Bragg curves of the proton (left) and triton (right) are revealed.

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

Alpha tracks

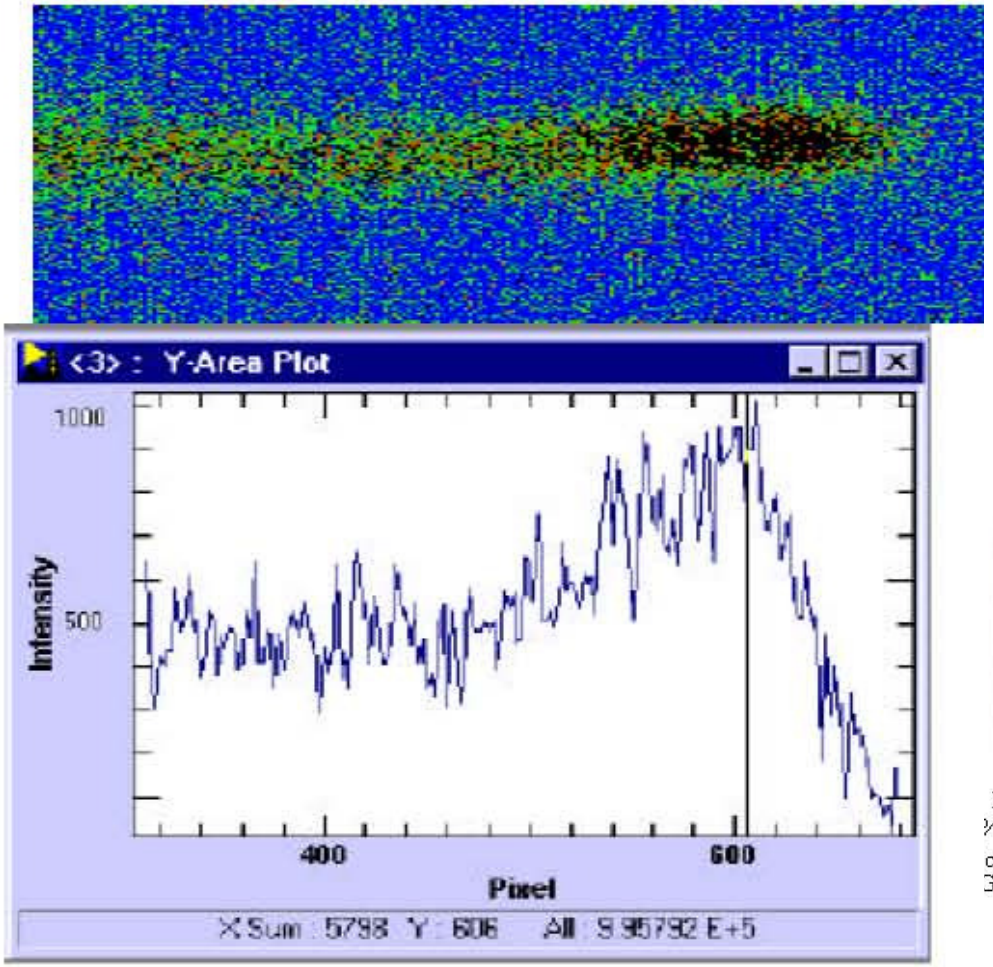


Fig. 6 Distribution of measured scintillation along an alpha track. The Bragg curve is revealed.

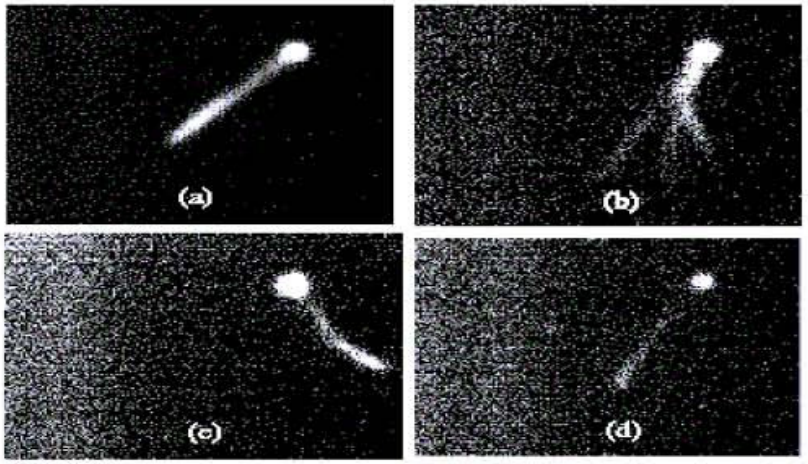


Fig. 5 Images of alpha tracks taken using the tracking chamber with Ar-%CF_4.: (a,b) $V_{GEM1}=V_{GEM2}=400V$ (Gain~140), E_T=5.45KV/cm, $_C$=5.86KV/cm, CCD Binning 4x4, Texp.=10ms; (c,d) $V_{GEM1}=V_{GEM2}=430V$ Gain~300), E_T=5.45KV/cm, E_C=0, CCD Binning 7x7, T=10ms.