Directional Detection with the Dark Matter Time Projection Chamber Experiment

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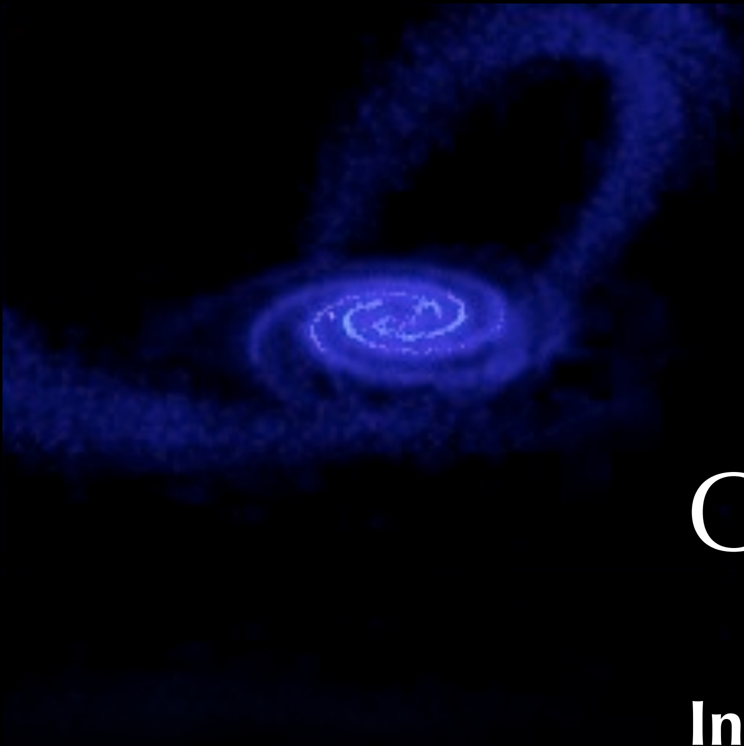
Rutherford Appleton Laboratory
Particle Physics Department Seminar
July 6, 2011



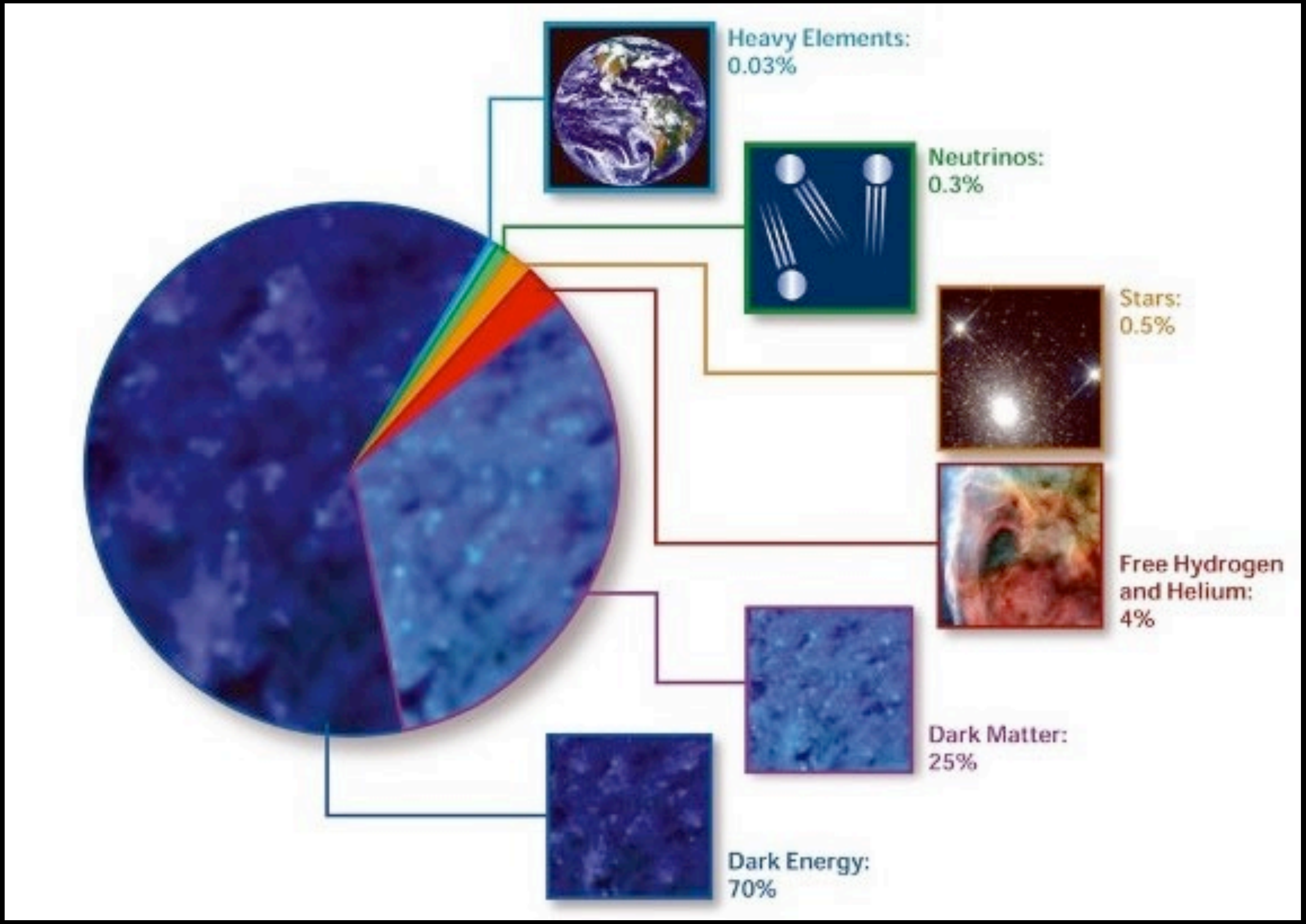
Outline

Introduction

Directional Dark Matter Detection

Recent Progress from DMTPC

Dark Matter is ~20% of the energy density of the universe.



Dark Matter Candidates

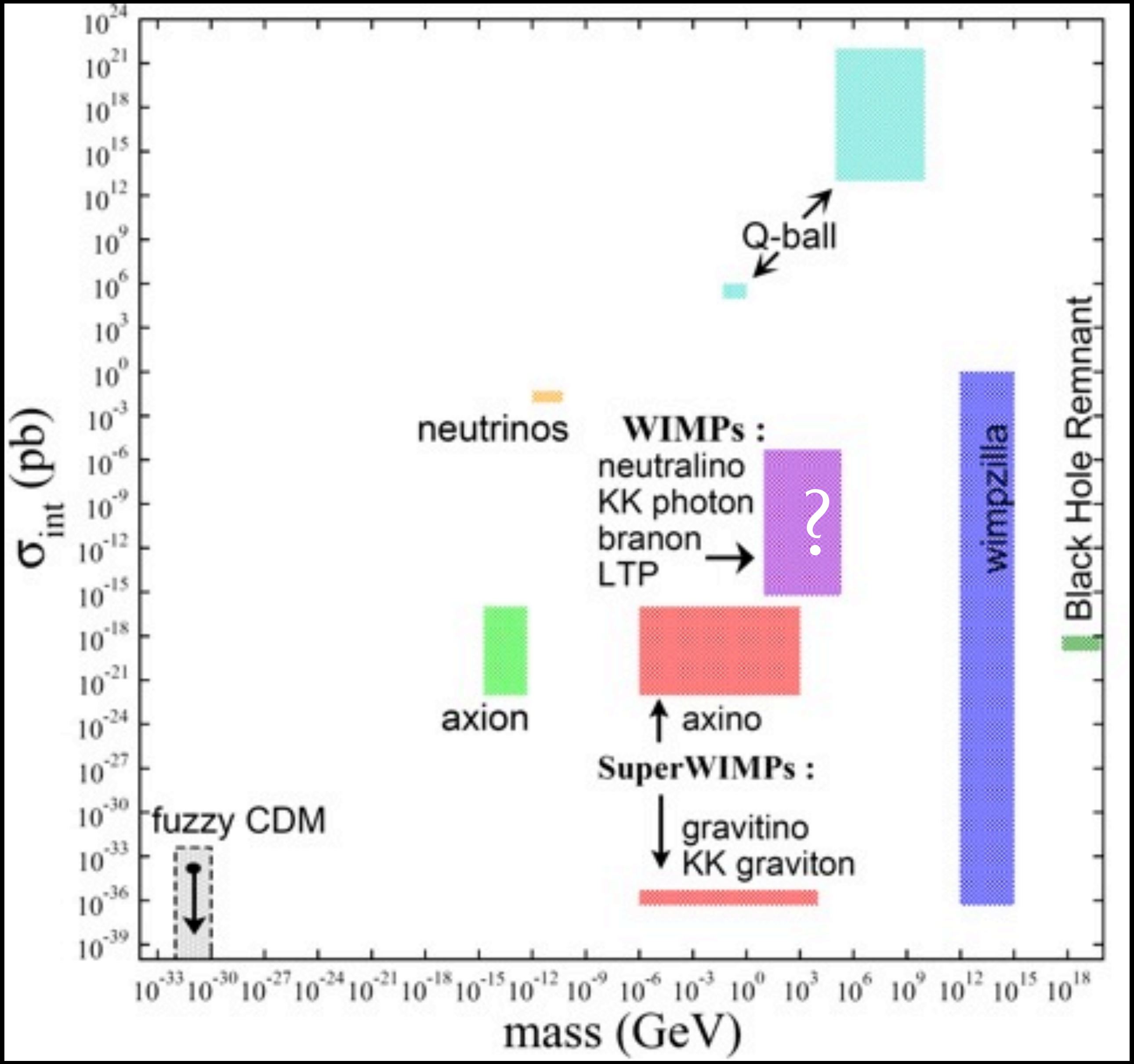
strong

e.m.

weak

interaction strengths

gravity



HEPAP/AAAC DMSAG Subpanel (2007)

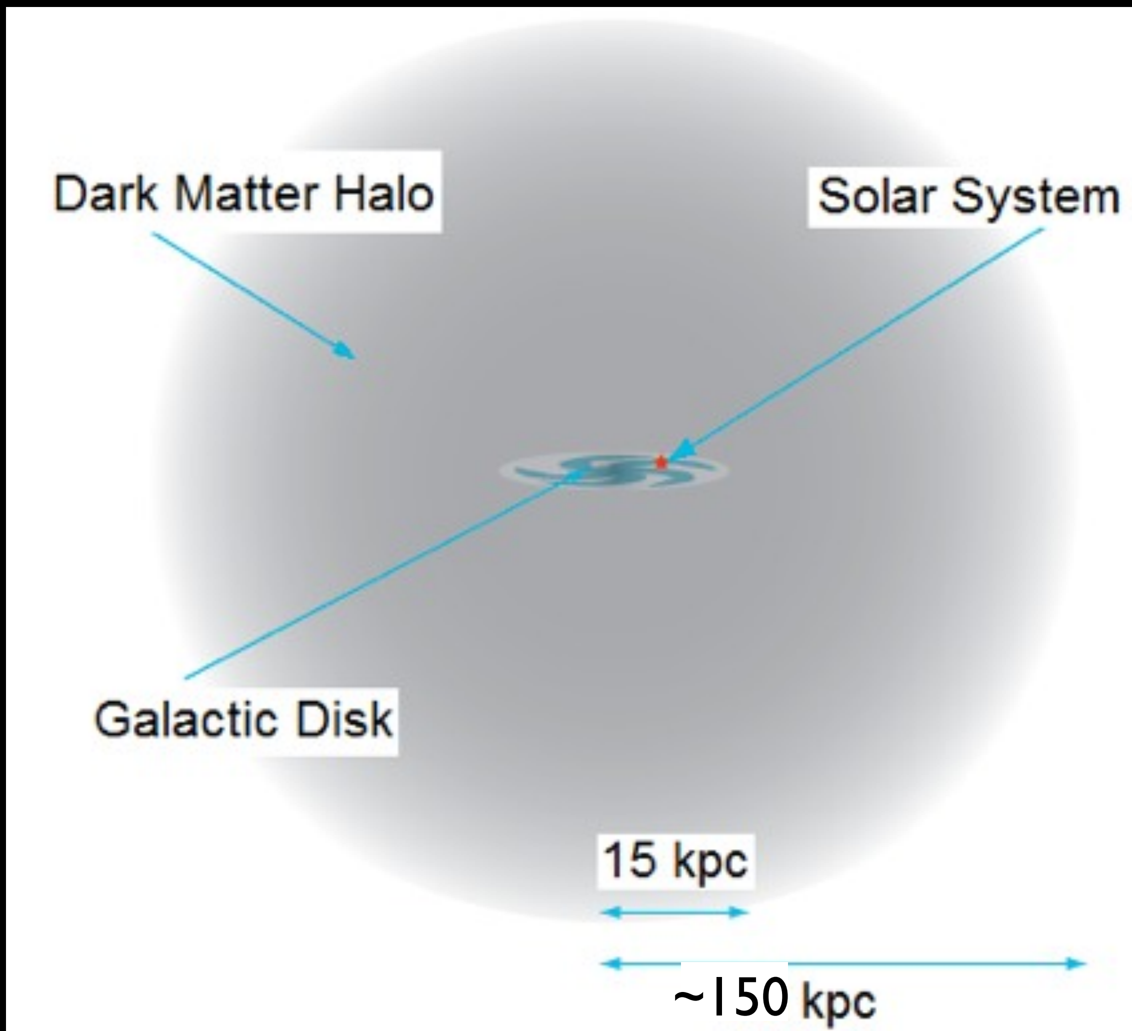
masses

neutrino ?

electron

t-quark

What do we know about Dark Matter?



optically dark

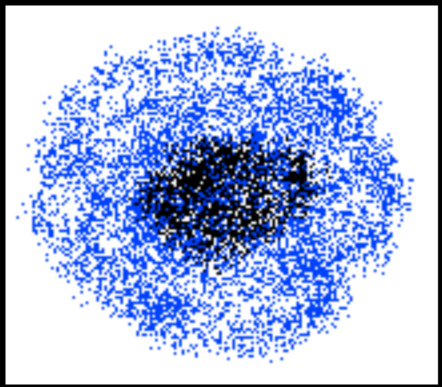
density ~ 0.3 GeV/cm^3

dark matter particle mass: ~unknown

interactions: very weak, ~collision-less

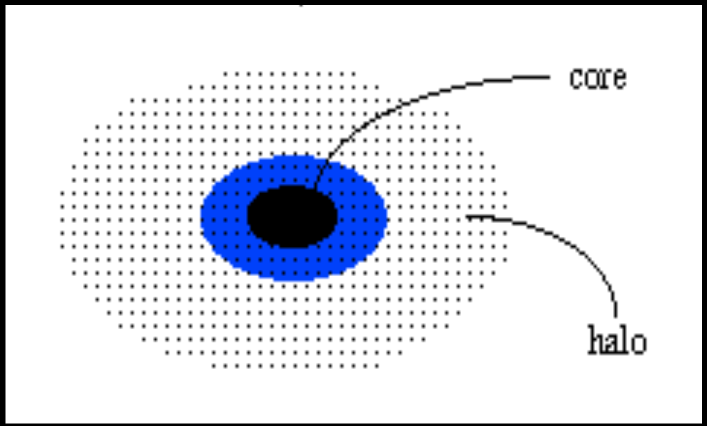
(J. Schombert)

Galaxy Formation

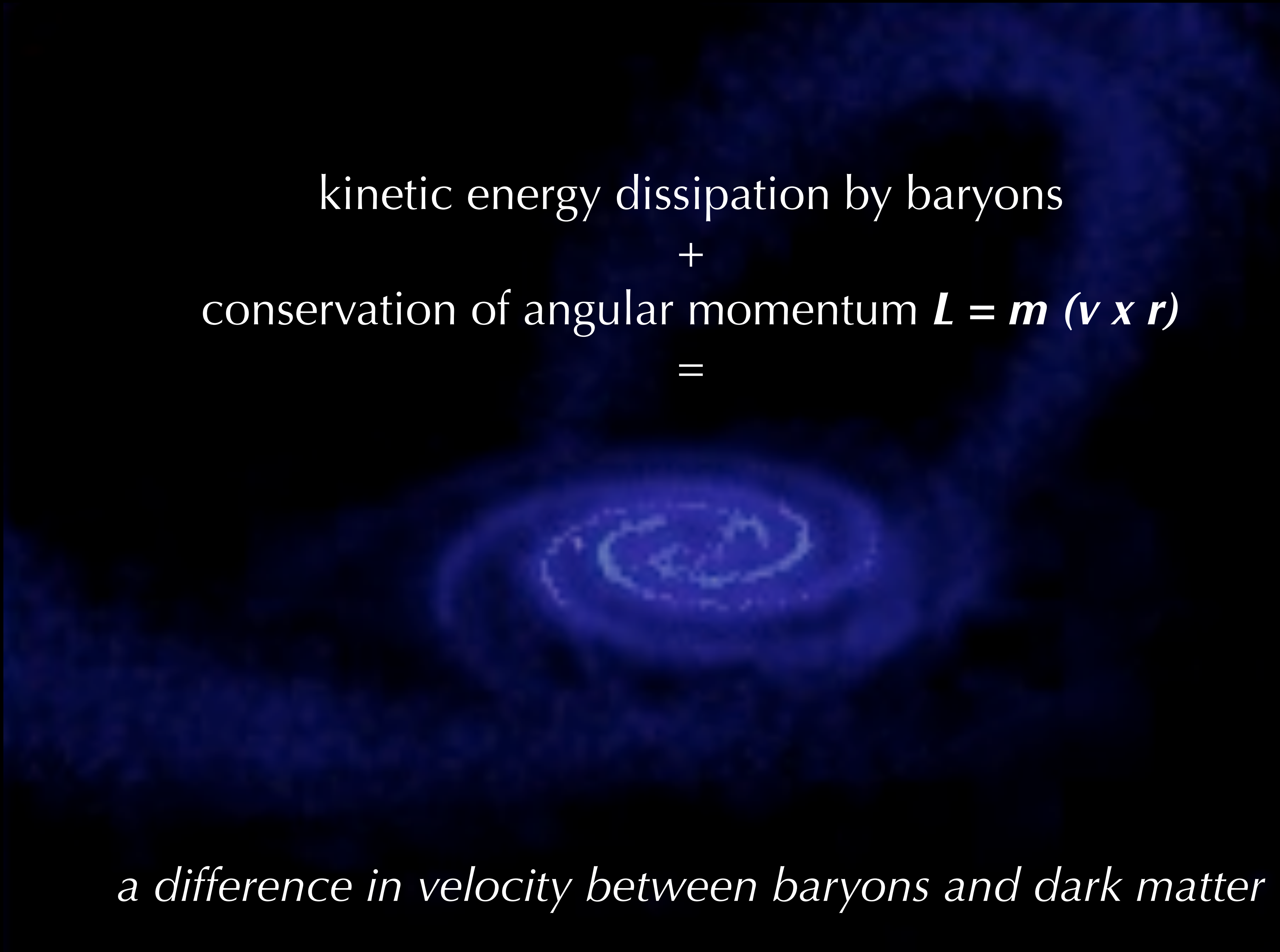


a lump of dark matter and gas collapses under its own gravity to form a protogalaxy

gravity separates out the protogalaxy into a core and halo. The baryons that make up the gas can interact to lose energy and fall to the core.



The dark matter, which only weakly interacts, remains in the halo.



kinetic energy dissipation by baryons

+

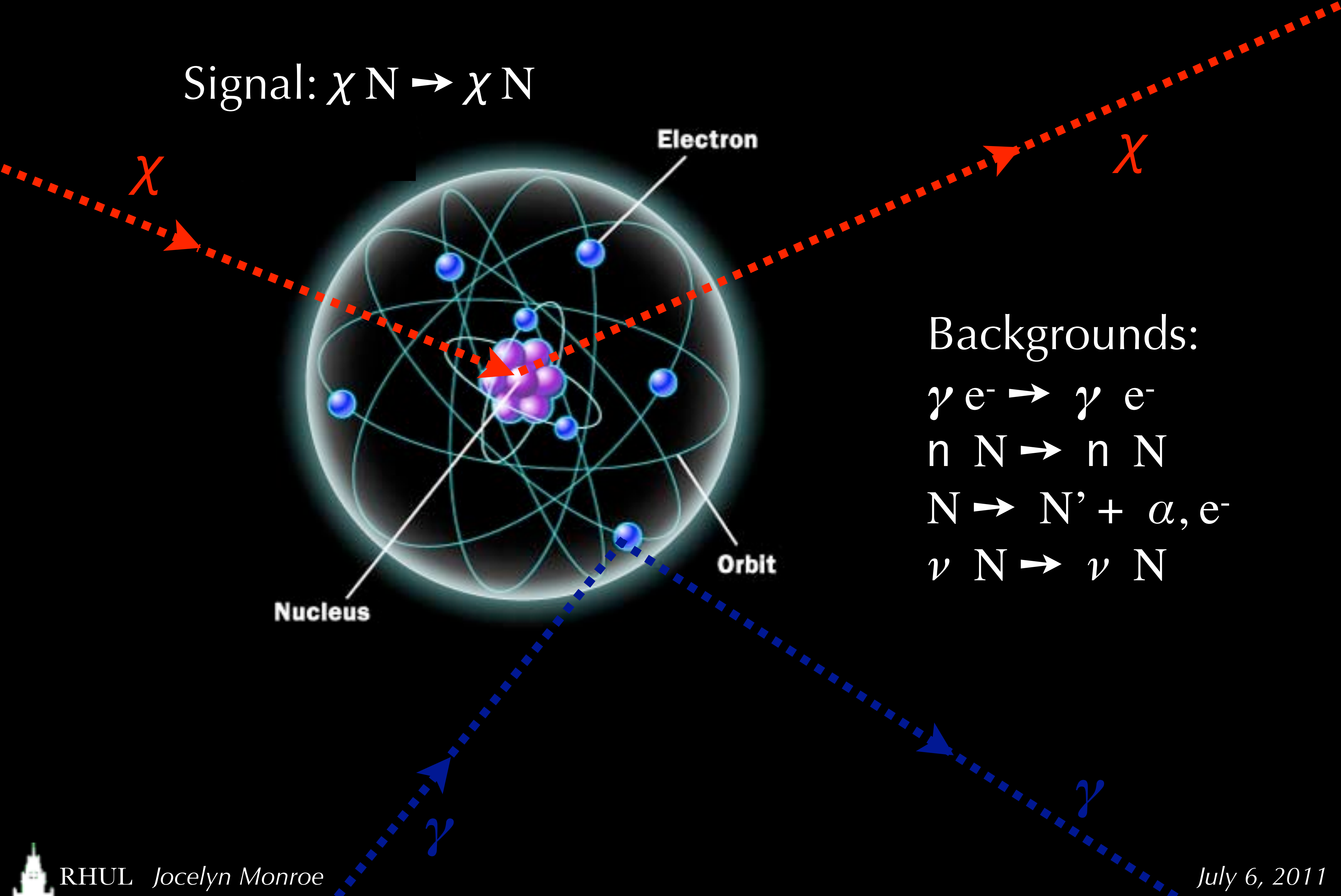
conservation of angular momentum $\boldsymbol{L = m\ (v \times r)}$

=

a difference in velocity between baryons and dark matter

Direct Detection

Signal: $\chi N \rightarrow \chi N$



Backgrounds:

$\gamma\ e^- \rightarrow \gamma\ e^-$

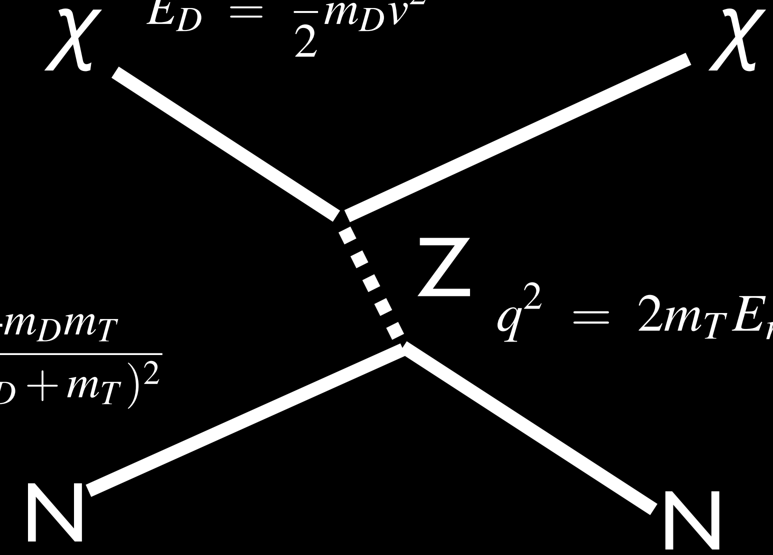
$n\ N \rightarrow n\ N$

$N \rightarrow N' + \alpha, e^-$

$\nu\ N \rightarrow \nu\ N$

WIMP Scattering

kinematics: *v/c ~ 8E-4!*



$$E_D = \frac{1}{2} m_D v^2$$

$$r = \frac{4 m_D m_T}{(m_D + m_T)^2}$$

$$q^2 = 2 m_T E_{recoil}$$

$$E_{recoil} = E_D r \frac{(1 - \cos\theta)}{2}$$

<u>Spin Independent:</u>

χ scatters coherently off of the entire nucleus A: $\sigma \sim A^2$

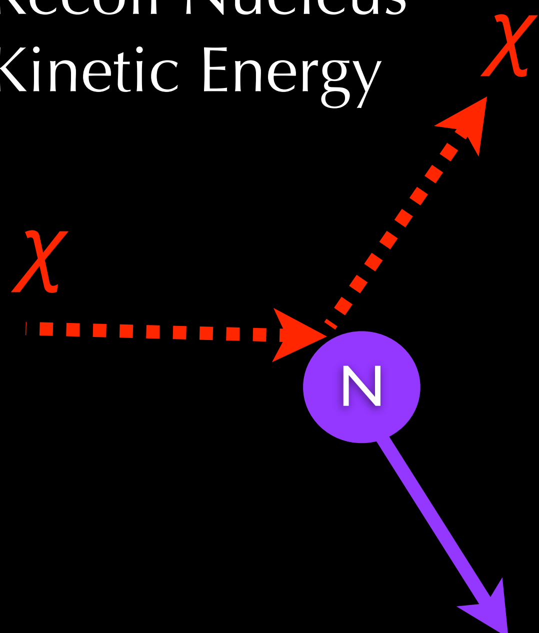
D. Z. Freedman, PRD 9, 1389 (1974)

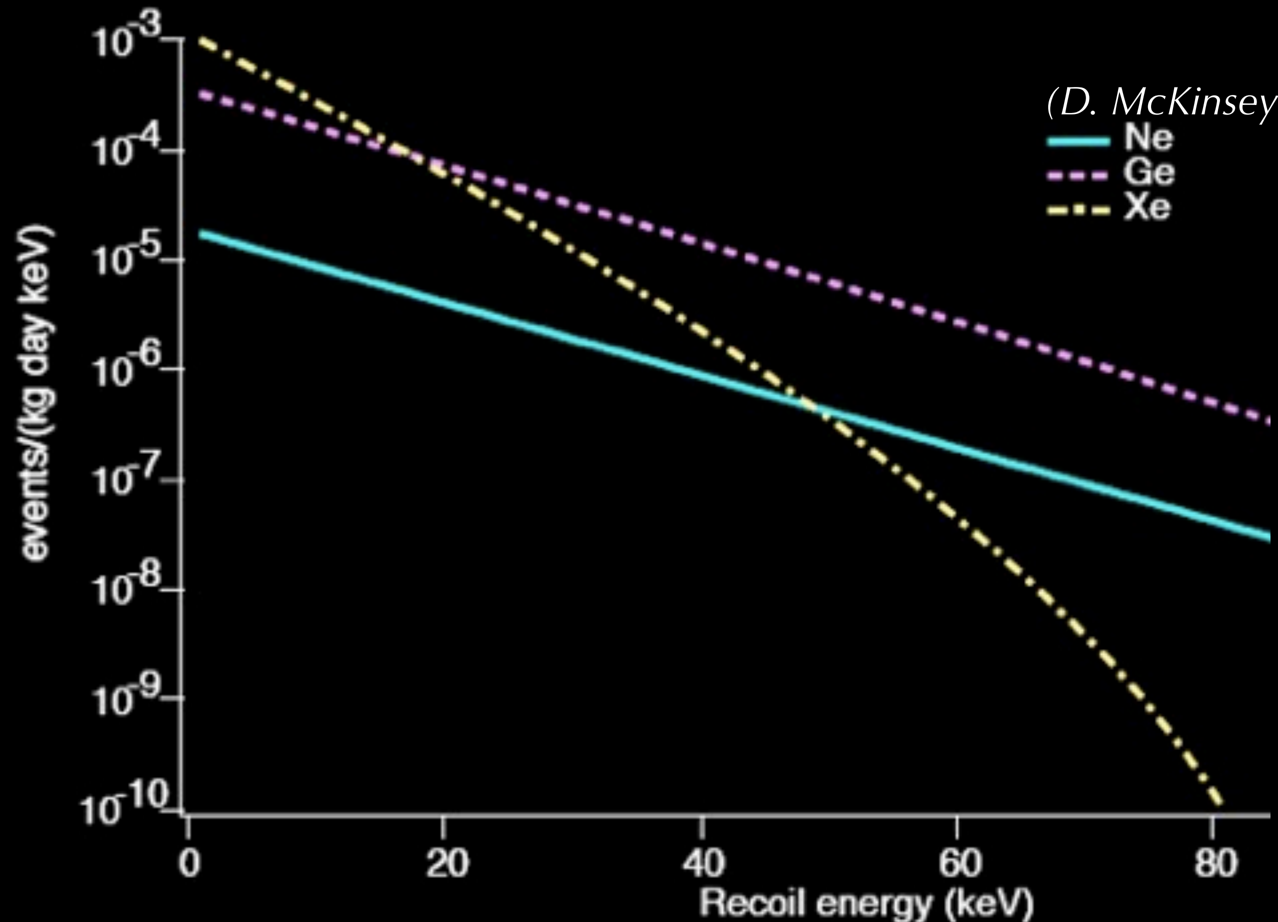
<u>Spin Dependent:</u>

only unpaired nucleons contribute to scattering amplitude: $\sigma \sim J(J+1)$

Measurement

Recoil Nucleus
Kinetic Energy





Scattering rate

Sun's velocity around the galaxy

WIMP velocity distribution

$$dR/dQ \sim (\sigma_0 \rho_0 / \sqrt{\pi}\, v_0 m_\chi m_r^2)\, F^2(Q)\, T(Q)$$

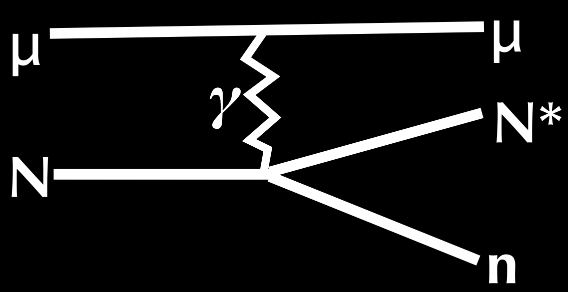
WIMP energy density, 0.3 GeV/cm³

Form factor

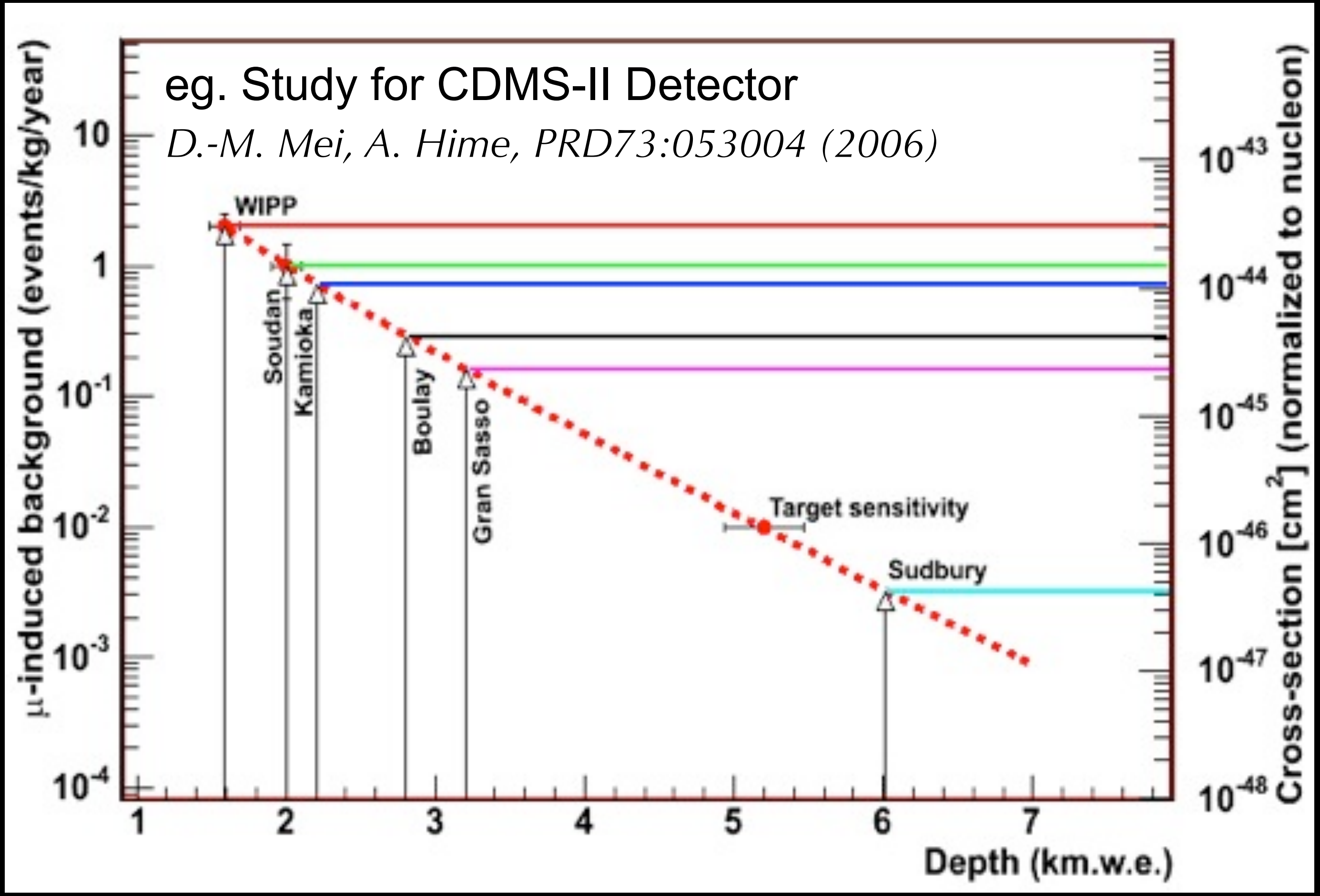
Backgrounds

Gamma ray interactions:
rate ~ N_e x (gamma flux), typically 10 million events/day/kg
Best dark matter detectors: sensitive to **0.01** events/day/kg

Neutrons:

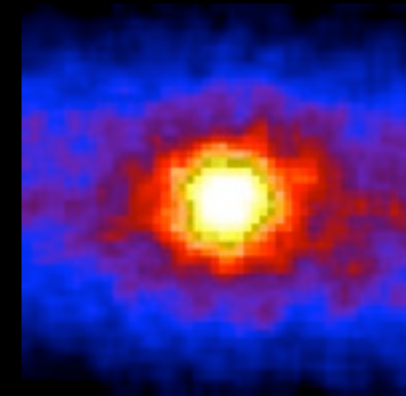


n: 10^{-8} - 10^{-10}/cm^2/s



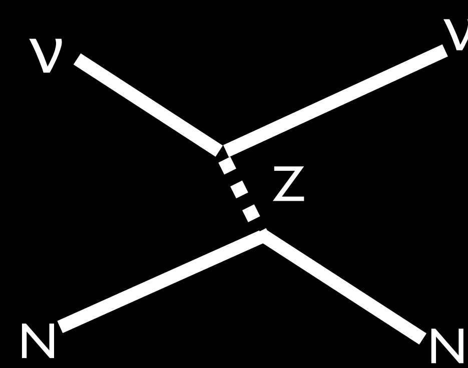
Contamination:
^{238}U and ^{232}Th chain decays, recoiling progeny

Irreducible Backgrounds

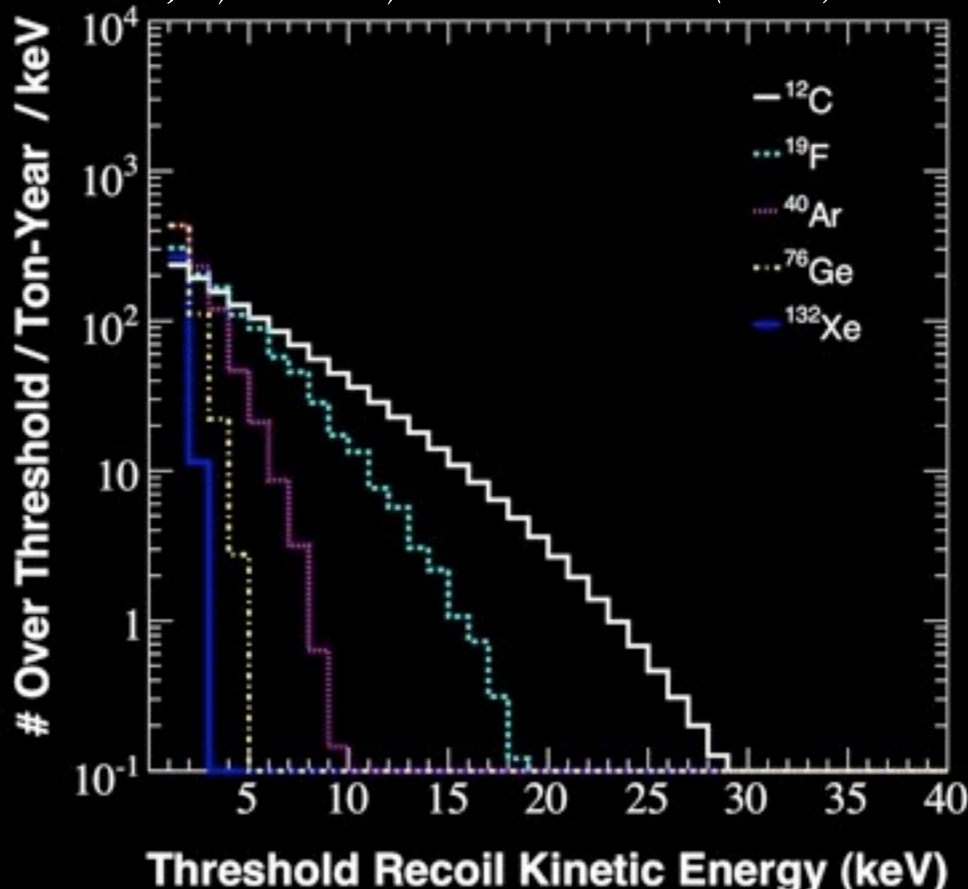


impossible to shield a detector from coherent neutrino scattering:

Φ(solar B⁸) = 5.86 x 10⁶ cm⁻² s⁻¹



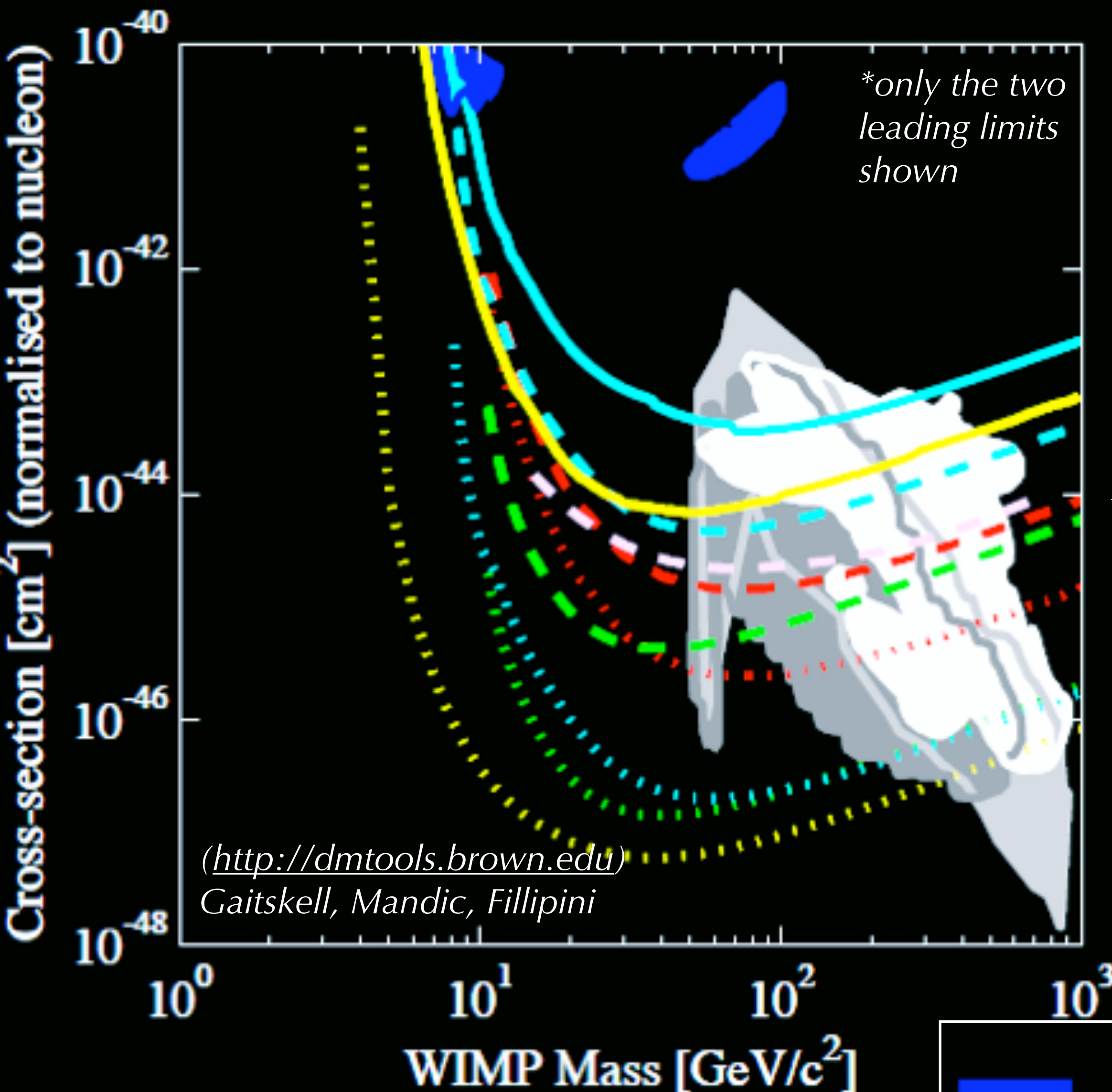
JM, P. Fisher, PRD76:033007 (2007)



1 event/ton-year = ~ 10^{-48} cm² limit

unless you measure the direction!

The Low Background Frontier



1 event/kg/day

1 event/100 kg/day

1 event/100 kg/100 days

so far: 3 years/
order of magnitude

10^4 is a lot of σ

10^{-24} cm^2: σ(neutron-A elastic scattering)

10^{-28} cm^2: σ(total inelastic pp at TeVatron)

10^{-35} cm^2: $\sigma(gg \rightarrow H)$ at LHC (Standard Model)

10^{-39} cm^2: σ(single top) at TeVatron

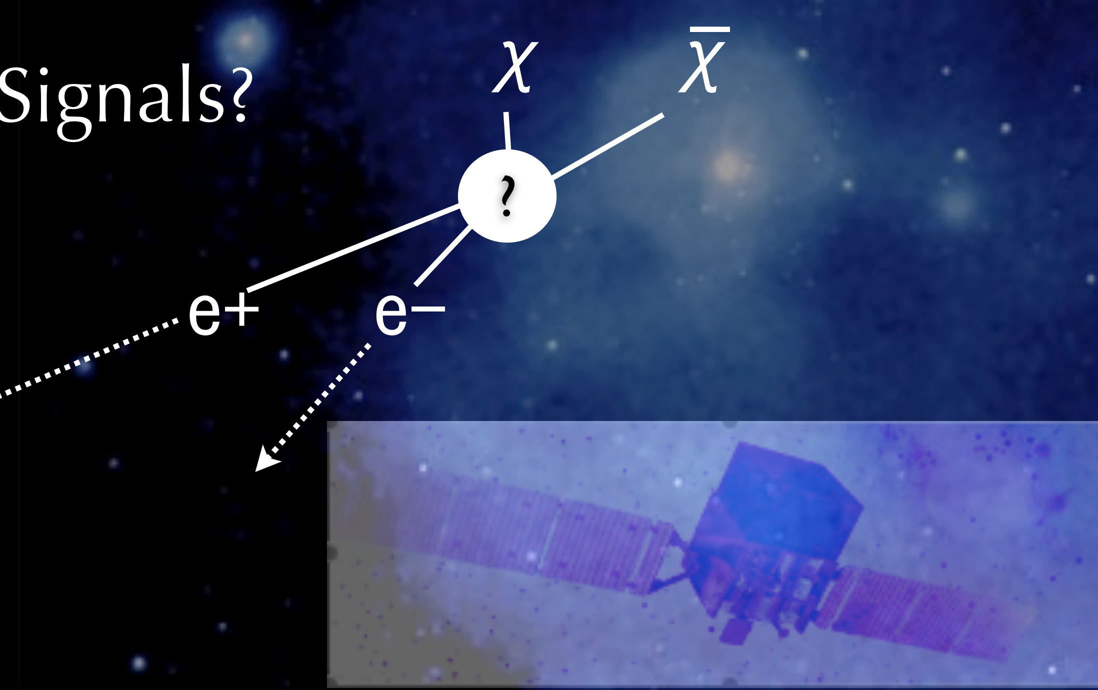
10^{-40} cm^2: $\sigma(\nu$ QE) at MINOS

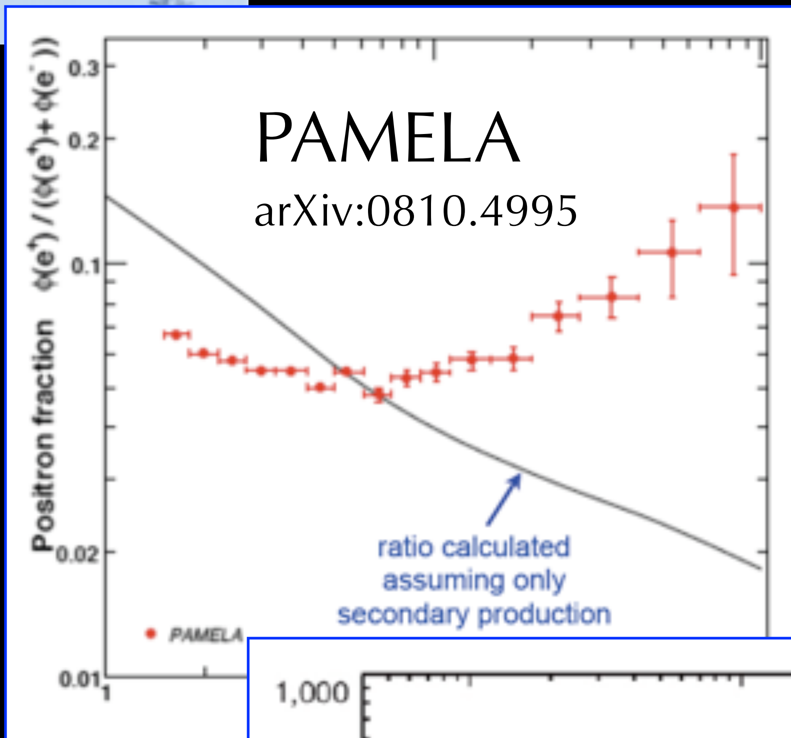
10^{-45} cm^2: $\sigma(\nu$-e Elastic) for solar ν

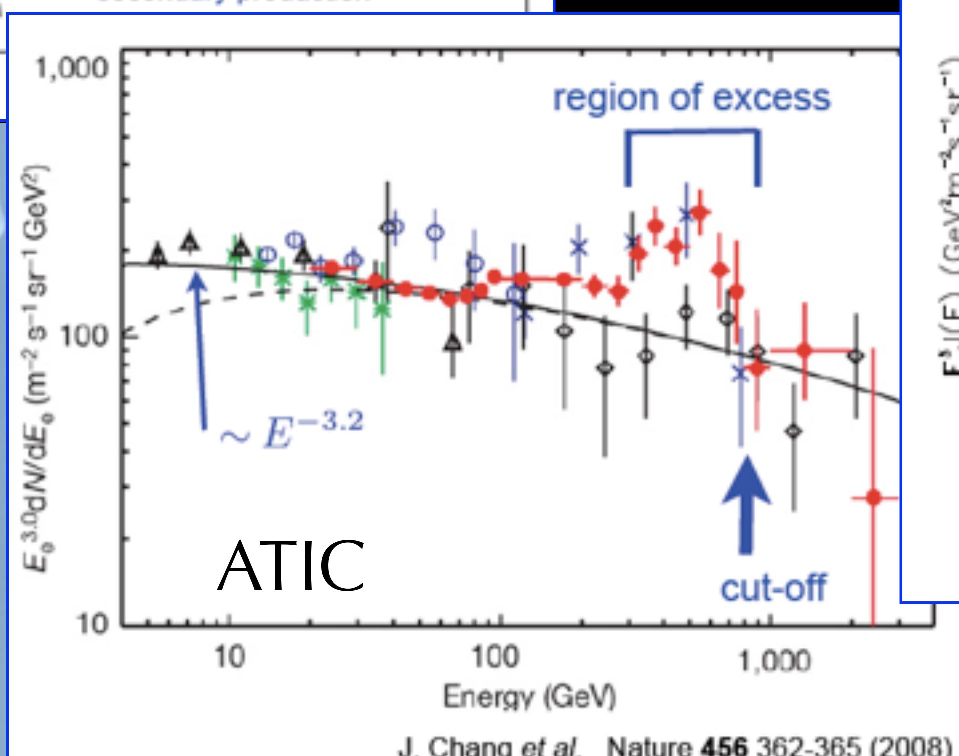
σ(DM coherent scattering)? 10^{-48} cm^2

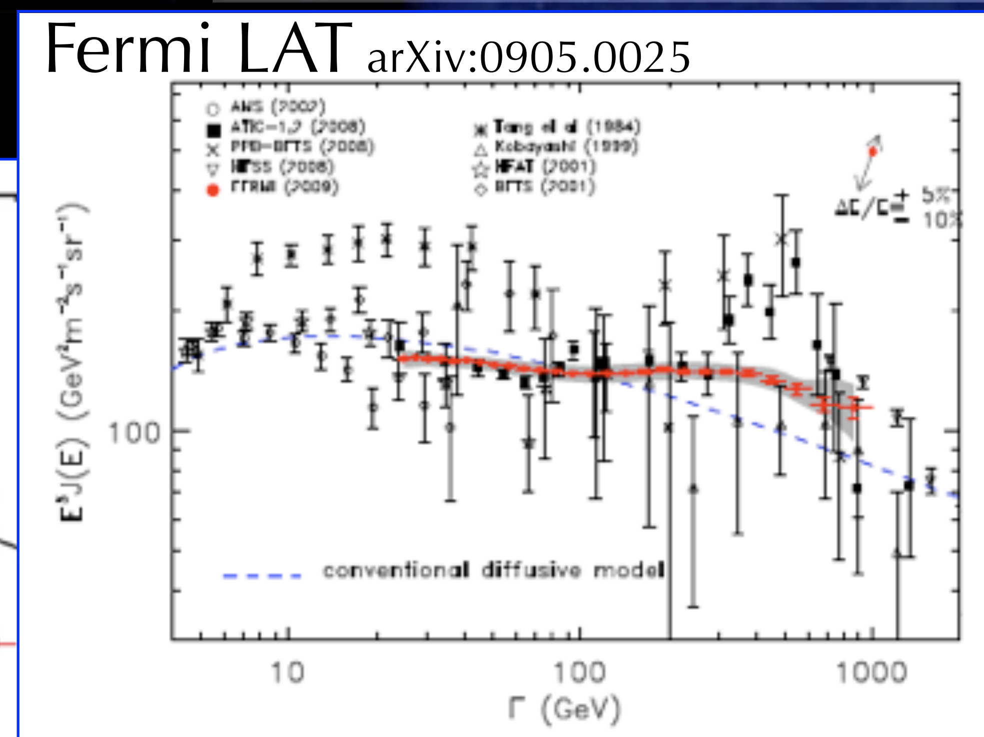
Not to Scale

Indirect Dark Matter Signals?









dark matter? local astrophysics?

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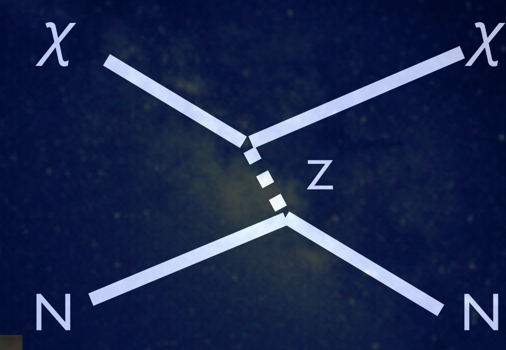
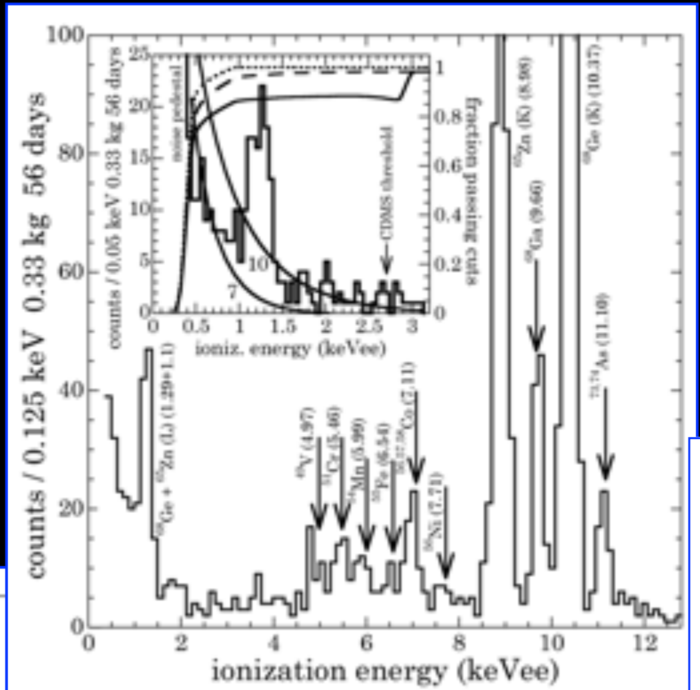
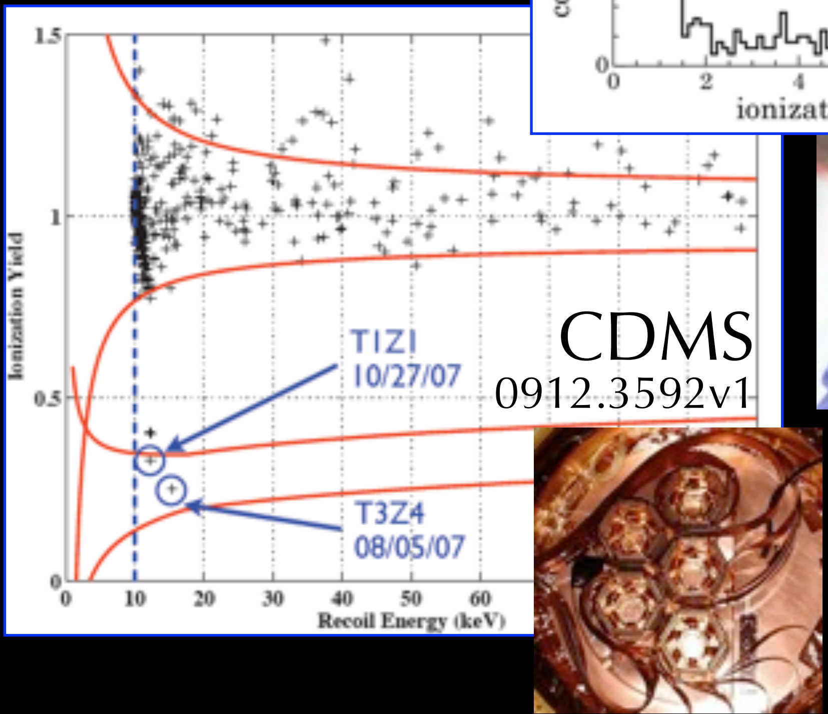
Direct Dark Matter Signals?



DAMA/Libra



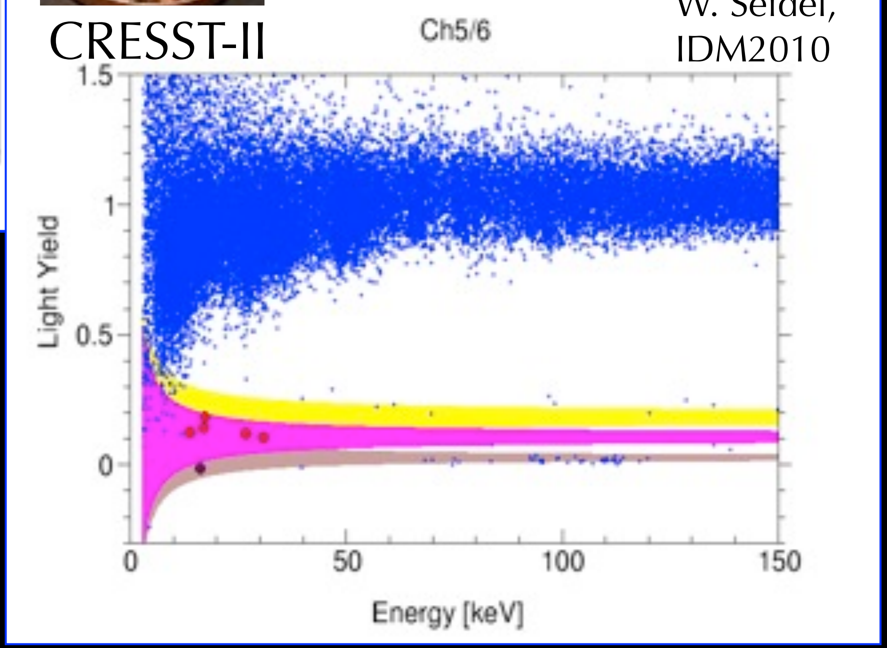


CDMS
0912.3592v1

COGENT
arXiv:1002.4703

CRESST-II

W. Seidel,
IDM2010

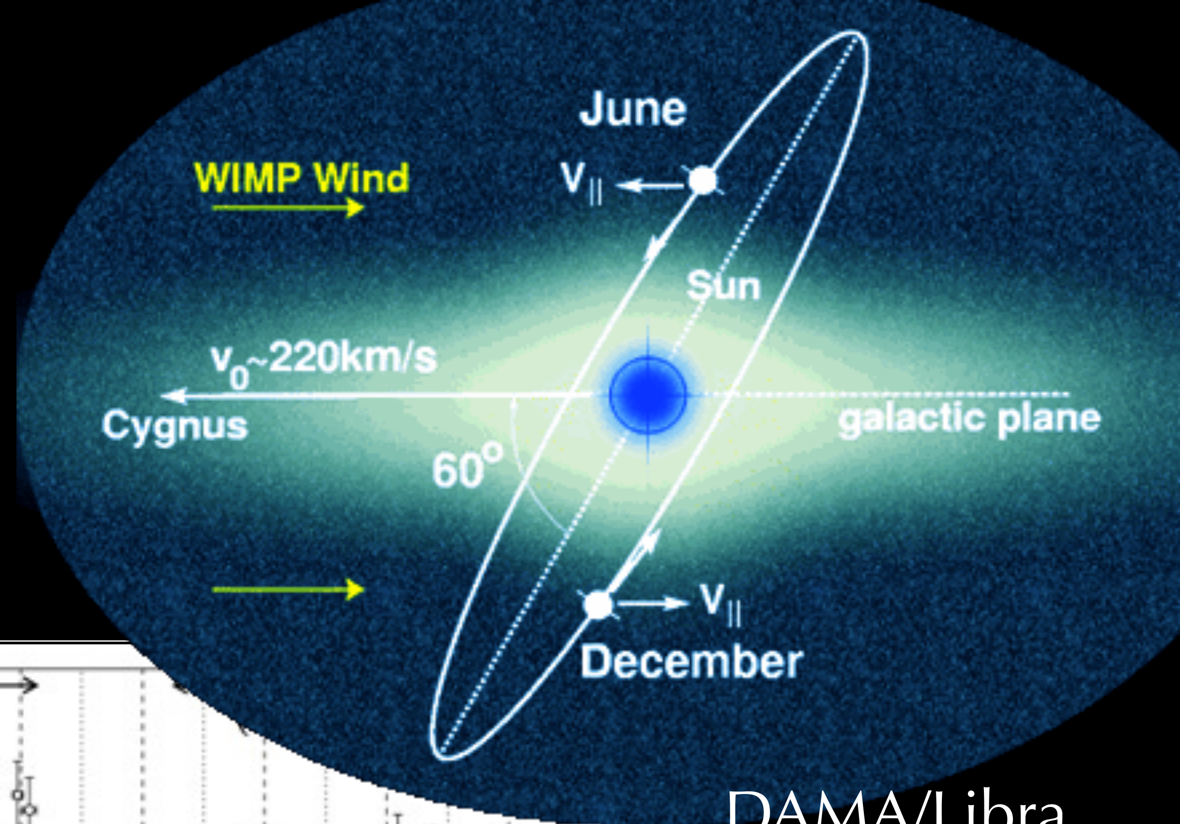


dark matter? new backgrounds?

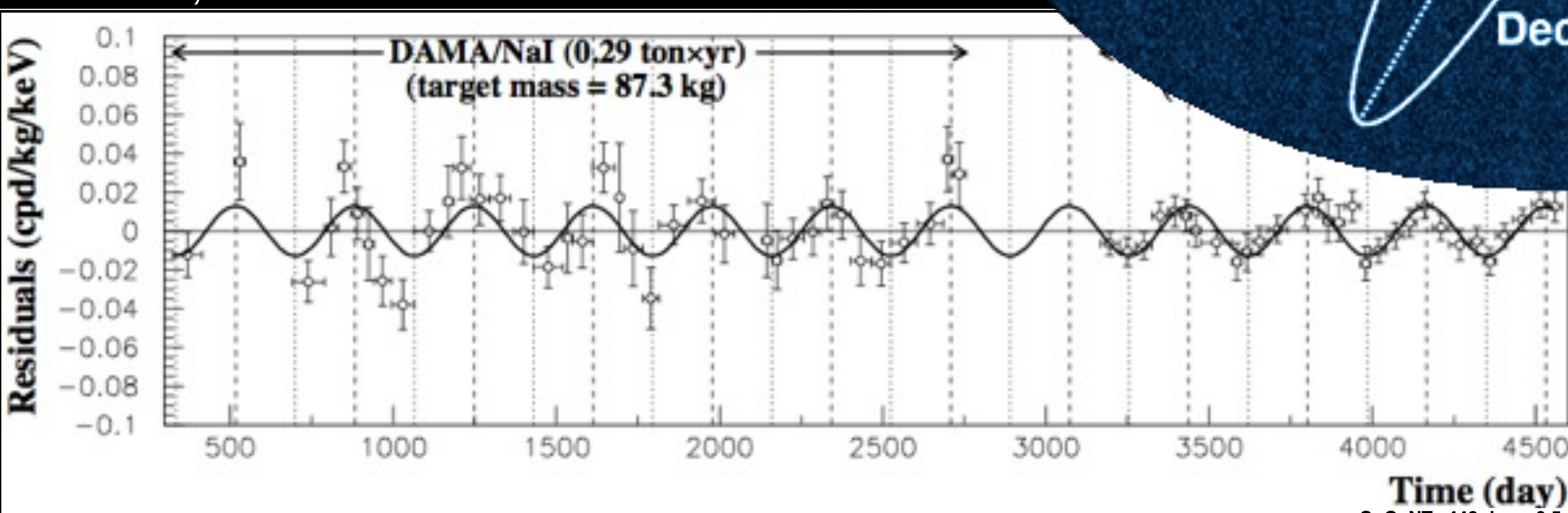
Annual Modulation

June-December event rate asymmetry ~2-10%

Drukier, Freese, Spergel, Phys. Rev. D33:3495 (1986)



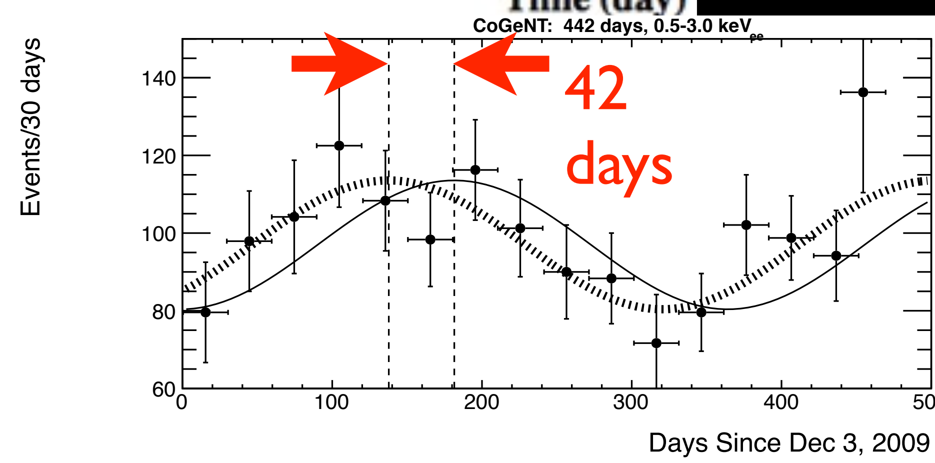
Eur. Phys. J. C56:333-355 (2008)



DAMA/Libra positive result, >8σ, *inconsistent with many expts*

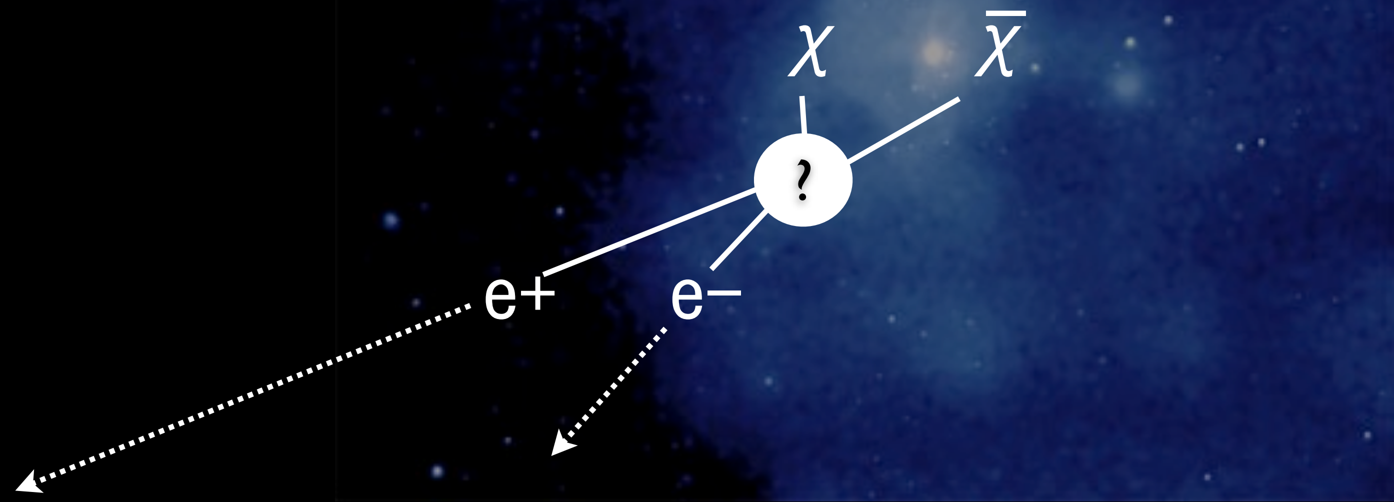
CoGeNT modulation result, 2.8σ, *consistent with DAMA/Libra*

J. Collar, STSI (2011), arXiv:1106.0650v1



CoGeNT (dashed line)

DAMA (solid line)



Motivation for Directional Dark Matter Detection:

The current experimental situation is inconclusive.
Recent anomalies...
- local astrophysics?
- new backgrounds?
- dark matter?

We need a definitive test of the astrophysical origin of a candidate dark matter signal.

Outline

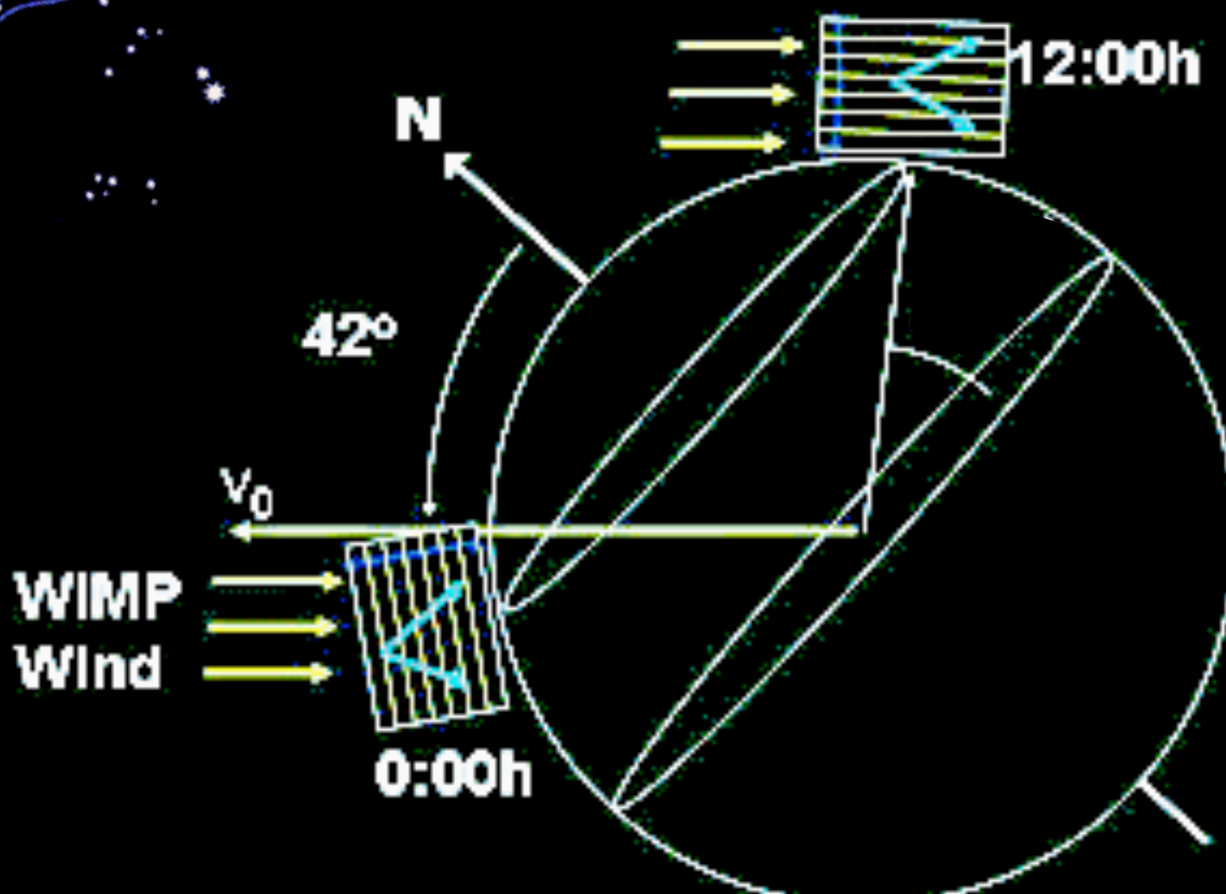
Introduction

Directional Dark Matter Detection

Recent Progress from DMTPC

The Dark Matter Wind apparently "blows" from Cygnus

directional detection: search for a dark matter source

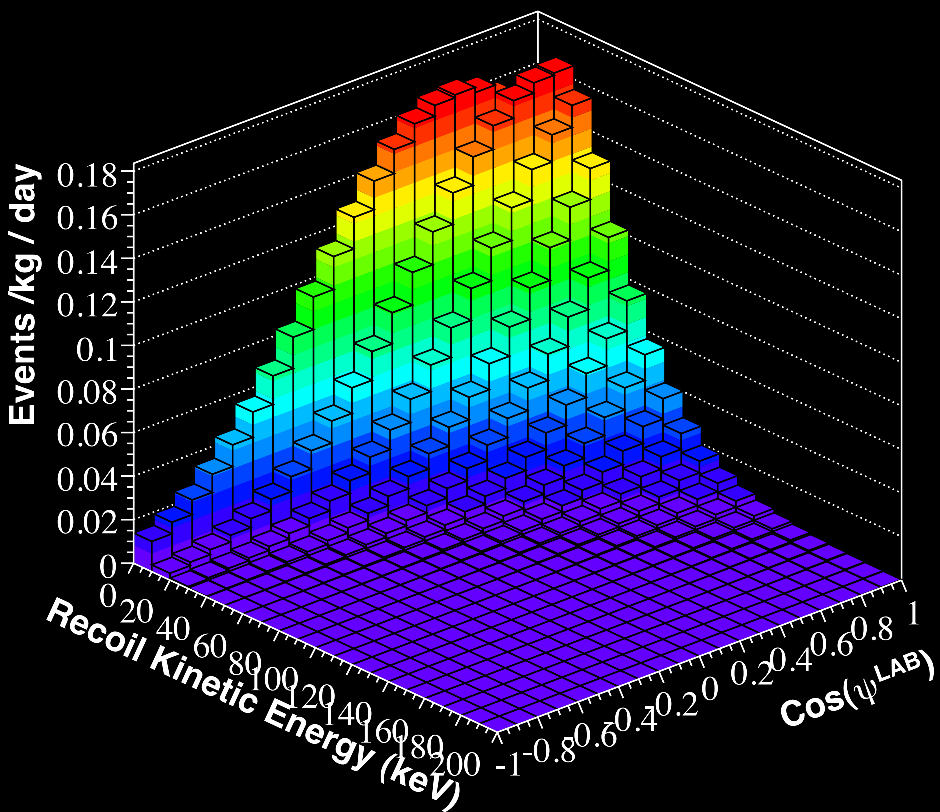


Daily direction modulation: asymmetry ~ 20-100% in forward-backward event rate.

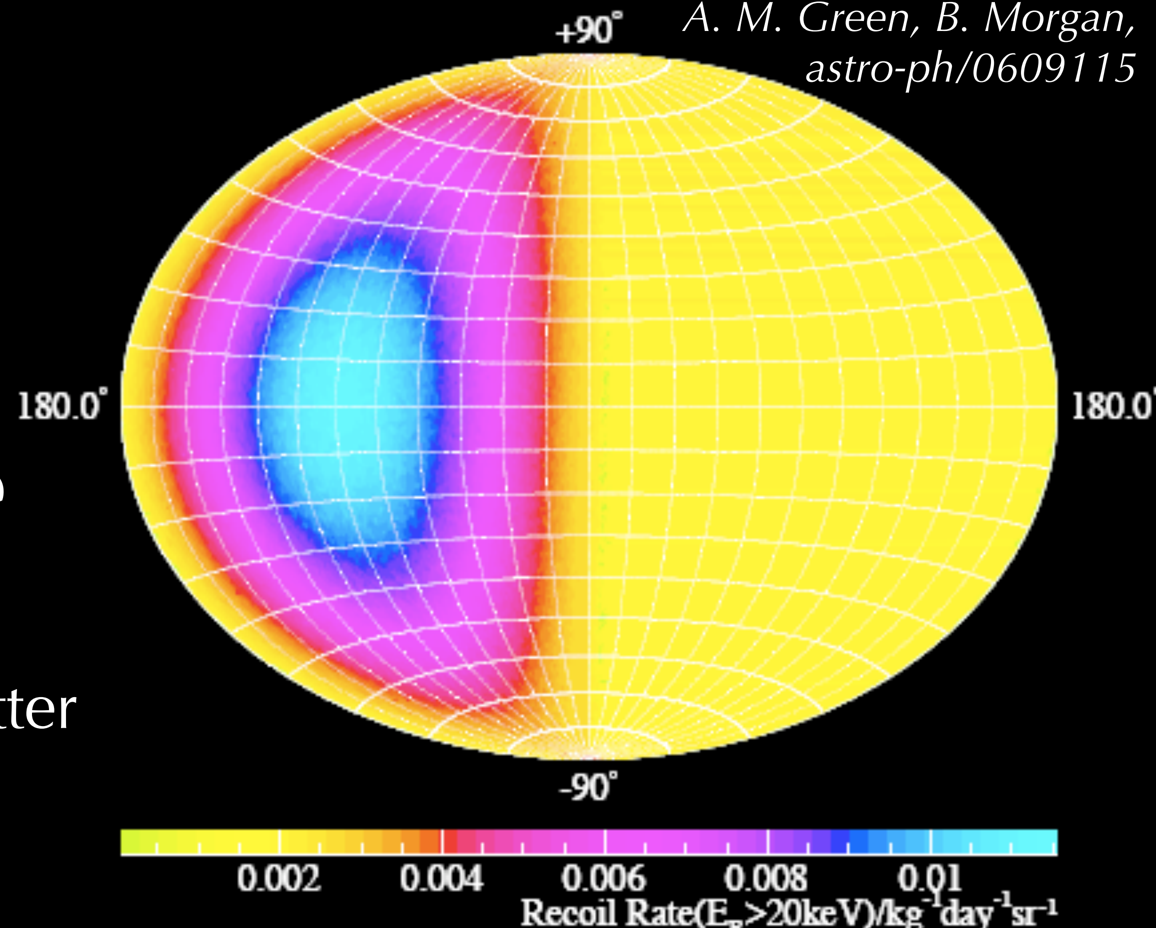
Spergel, Phys. Rev. D36:1353 (1988)

Directional Signal Prediction

if you can reconstruct the energy and <u>*angle*</u> of the recoil nucleus,
you have **a dark matter telescope**



A. M. Green, B. Morgan, astro-ph/0609115



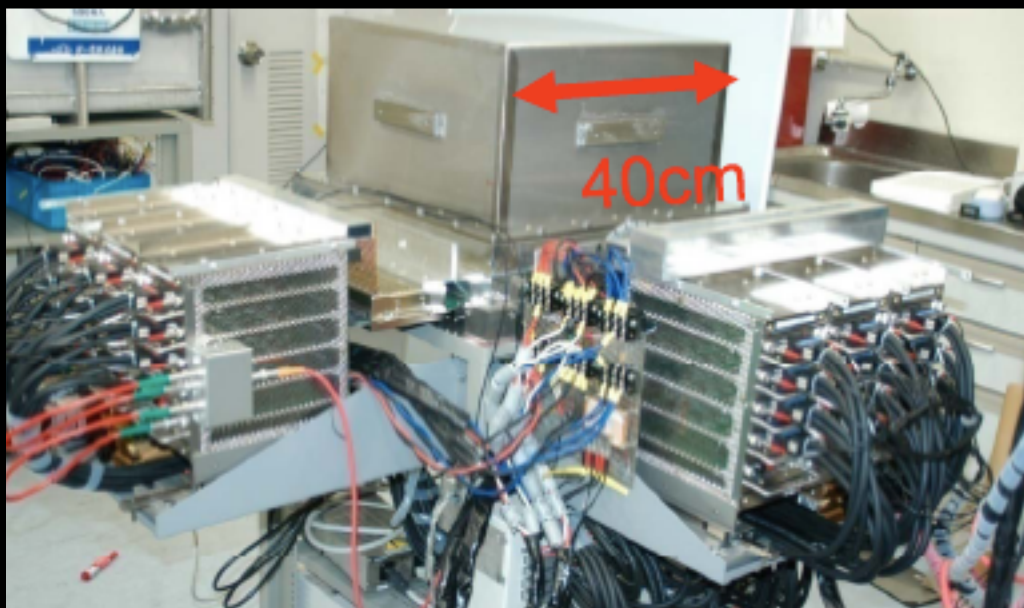
simulated reconstructed dark matter sky map: search for anisotropy

Unambiguous proof:
Correlation of WIMP-induced nuclear recoil signal with galactic motion

Directionality Around the World

DRIFT: in Boulby (UK), wire readout, CS_2 gas, negative ion drift, 16 kg-day exposure

S. Burgos et al., Astropart. Phys. 28, 409 (2007)

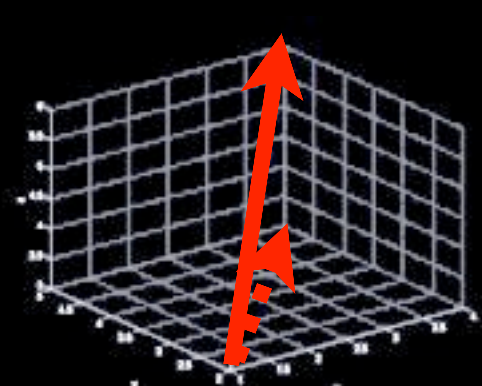


NEWAGE: in Kamioka, μ−pattern gas detector readout, CF_4 gas, *first* directional dark matter limit!

K. Miuchi, et al., Phys.Lett.B654:58-64 (2007)

MiMAC-He3: (ILL) above-ground R&D, He_3 gas, MicroTPC readout, A-dependence

D. Santos, et al., J. Phys. Conf. Ser. 65, 021012 (2007)

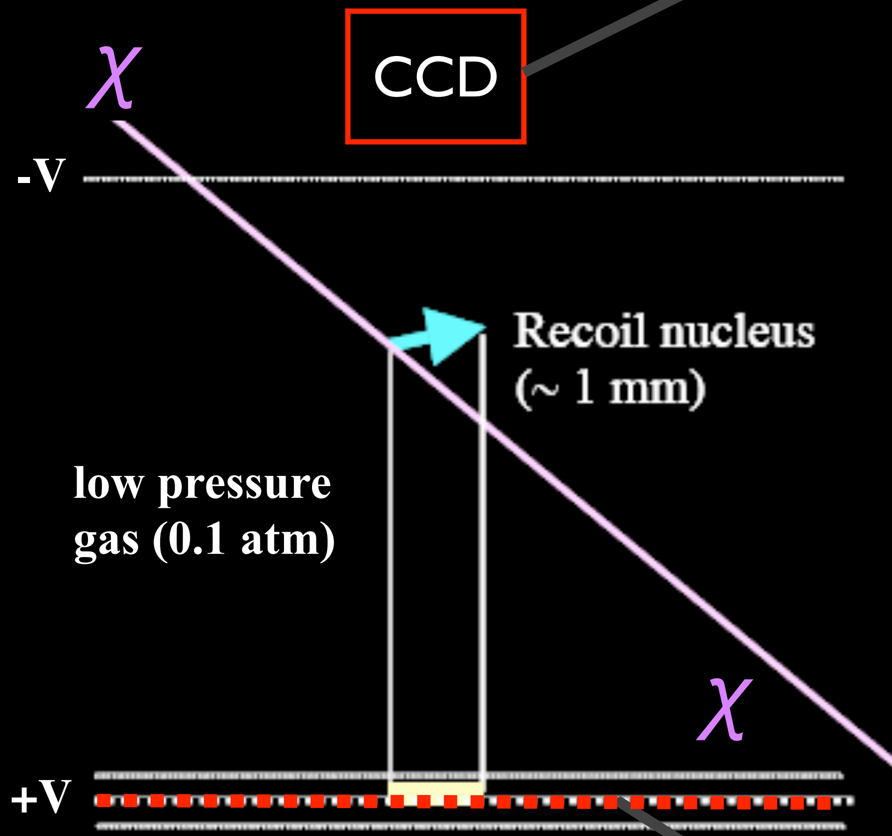


DMTPC: (Boston) in WIPP (US), CF_4 gas, CCD readout, direction tag

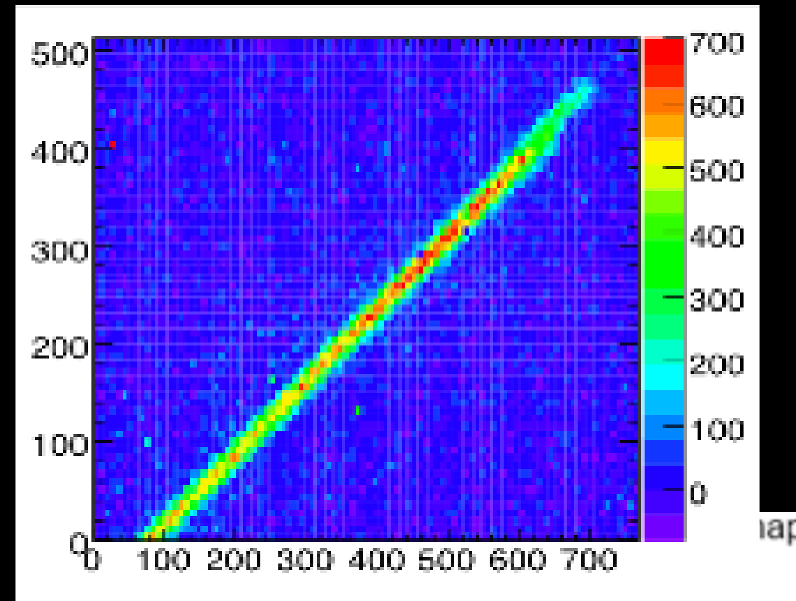
D. Dujmic, et al., NIM A 584:337 (2008)

Detection

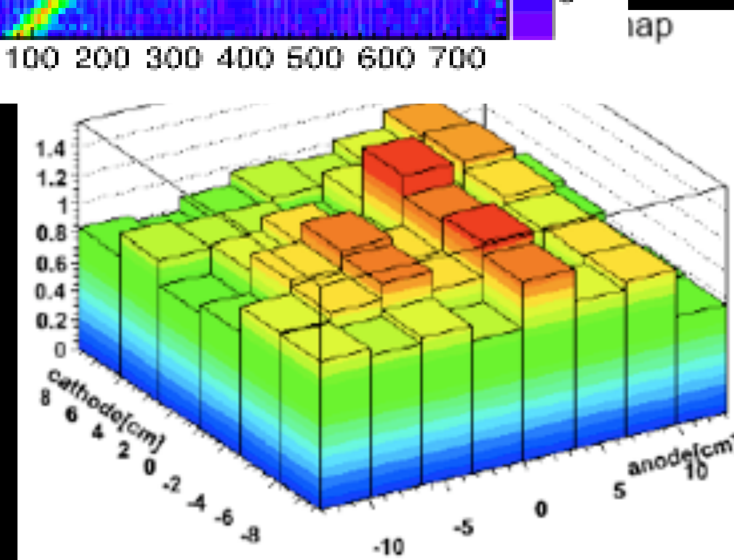
Photon Signal



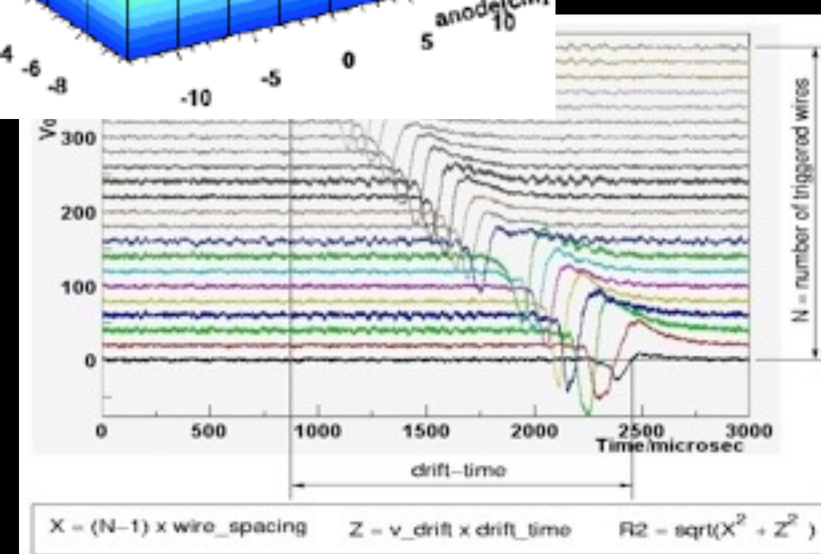
Electron/Ion Signal



(DMTPC)

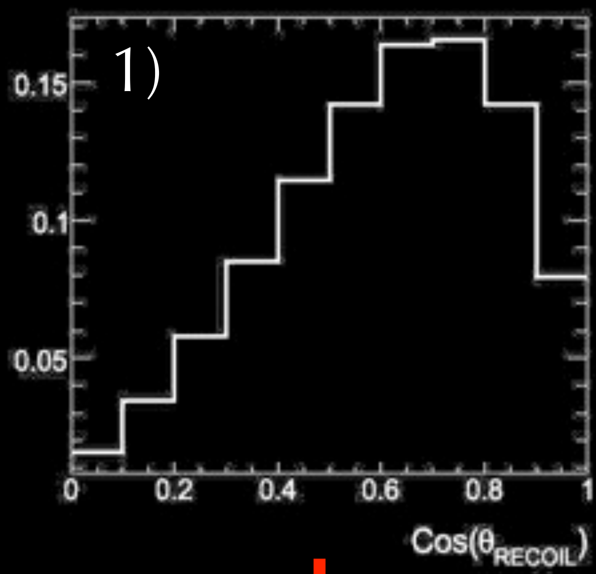


(NEWAGE)

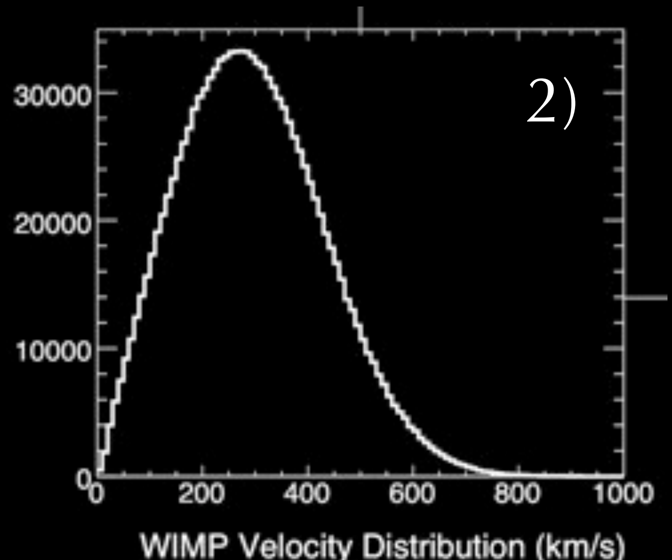


(DRIFT)

Signals in Directional Detectors



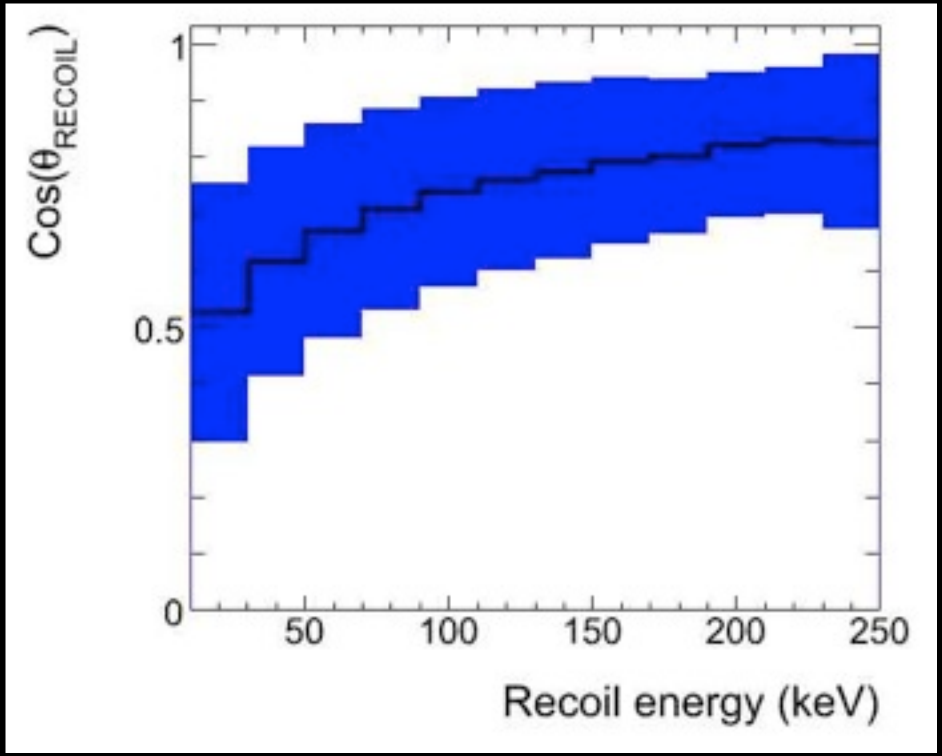
+



distribution of signal events determined by:

1. angular resolution of elastic scattering
2. dark matter velocity dispersion

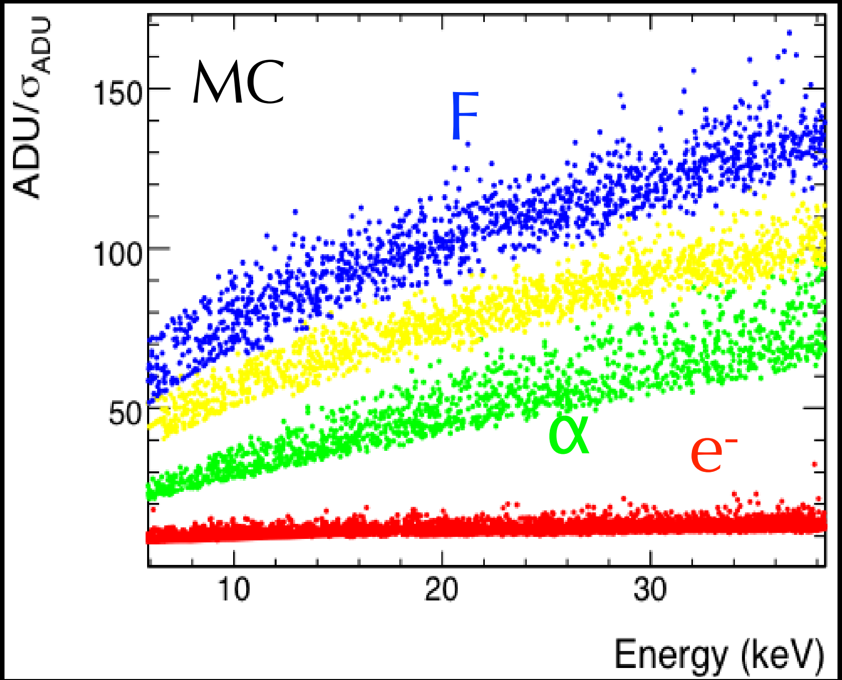
=

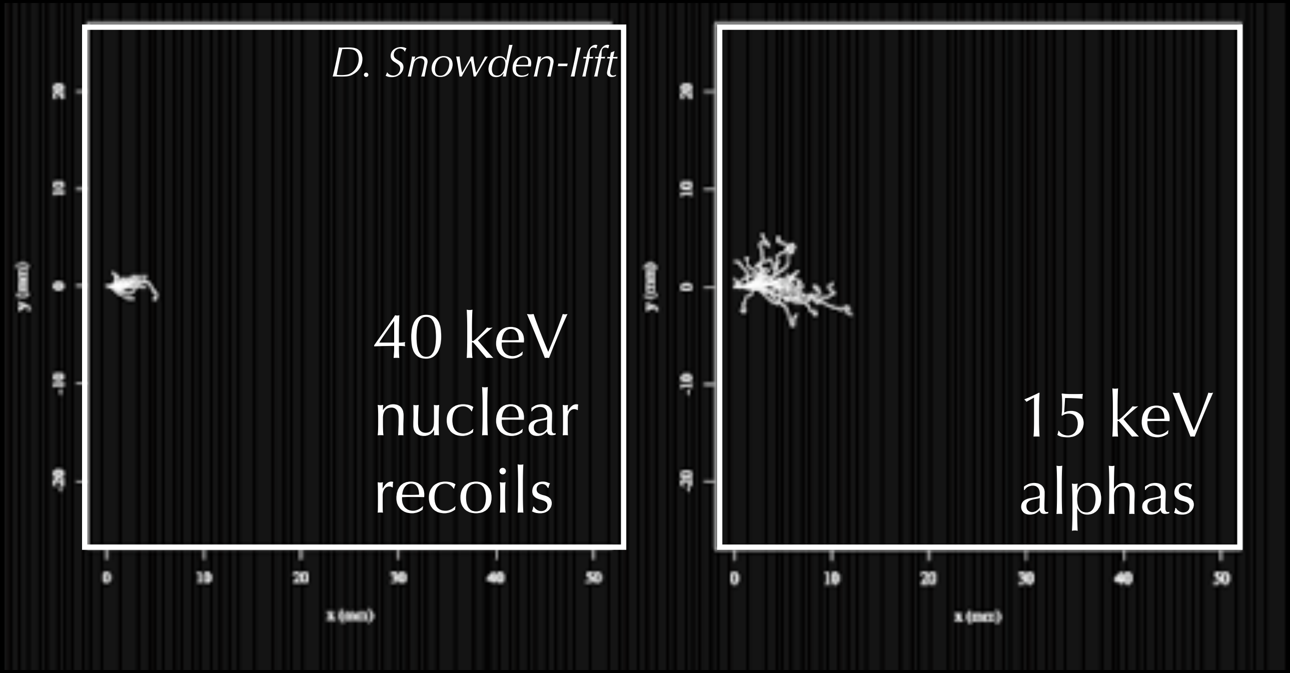


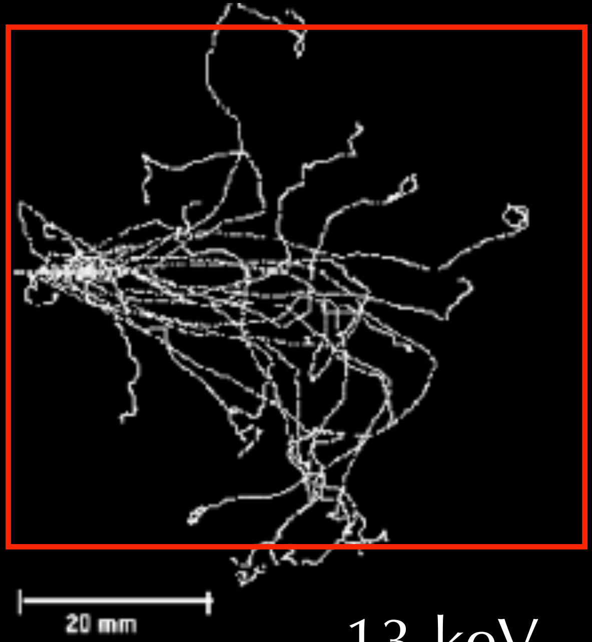
need ~50 keV threshold for directional detectors

Backgrounds in Directional Detectors

Three strategies:
1. tracking
2. range vs. energy
3. angular distribution







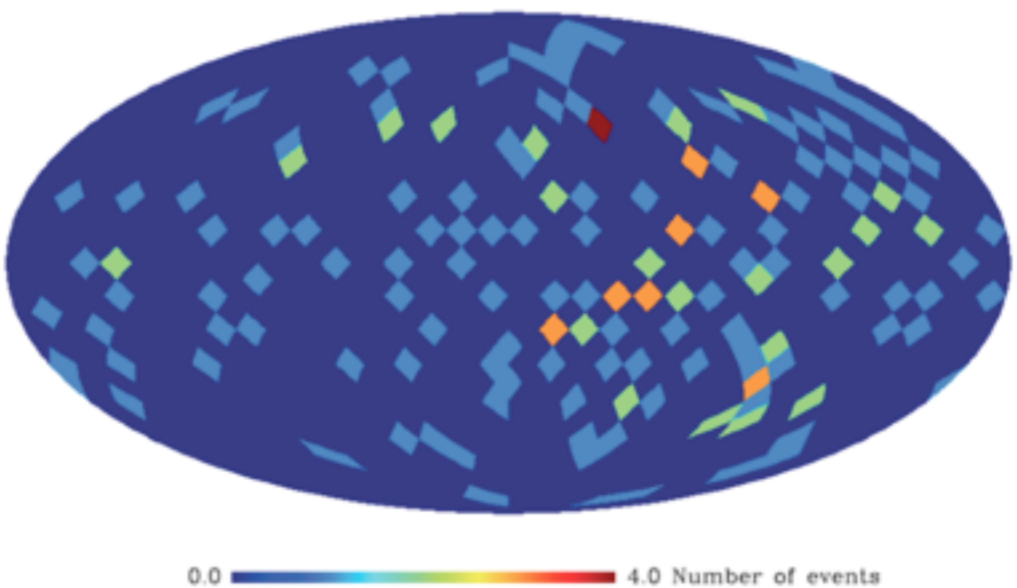
13 keV electrons

Optimization

how many events to detect the dark matter wind?

<u>Detector Properties:</u>
detector resolution
energy threshold
background
reconstruction
(2D vs. 3D)
vector or axial
reconstruction

No background, 3-d vector read-out, $E_T = 20$ keV	5
$E_T = 50$ keV	5
$E_T = 100$ keV	3
$S/N = 10$	8
$S/N = 1$	17
$S/N = 0.1$	99
3-d axial read-out	81
2-d vector read-out in optimal plane, reduced angles	12
2-d axial read-out in optimal plane, reduced angles	190



Billard et al. 2010

A. M. Green, B. Morgan,
Astropart.Phys.27:142-149,2007

J. Billard, F. Mayet, D. Santos,
arXiv:1009.5568

do not need "zero background" for directional detectors

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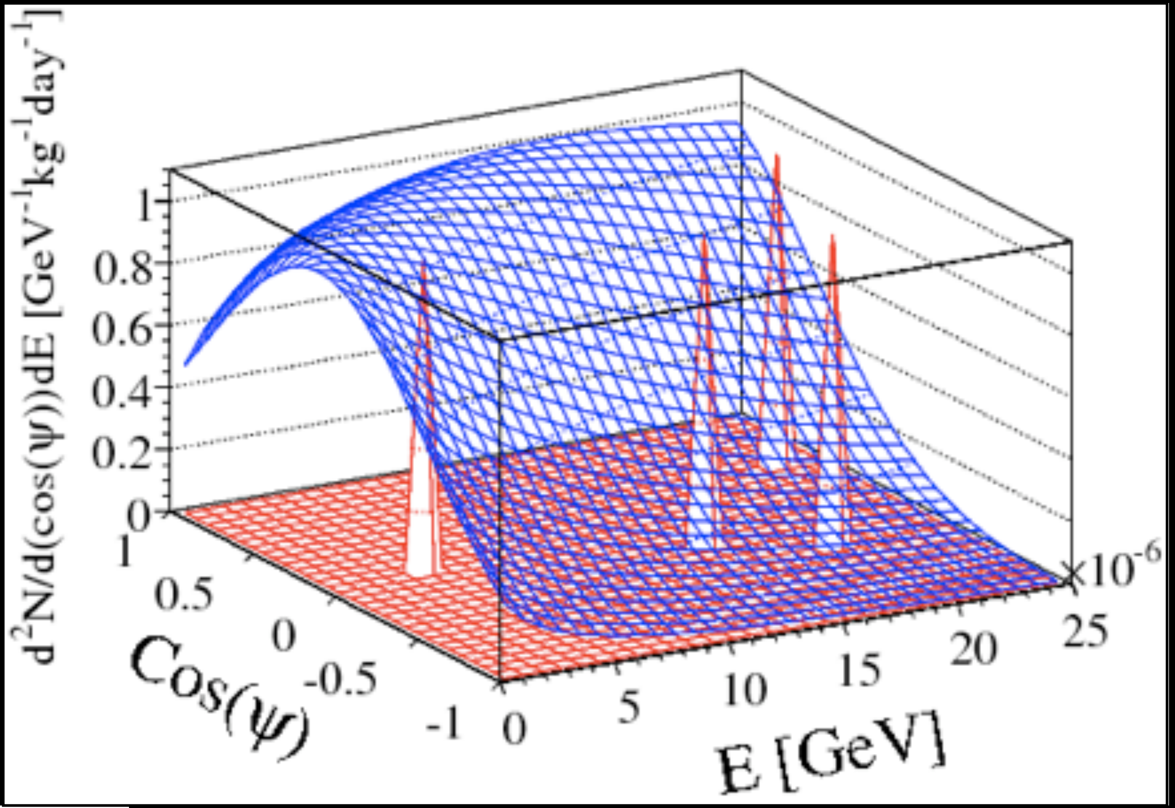
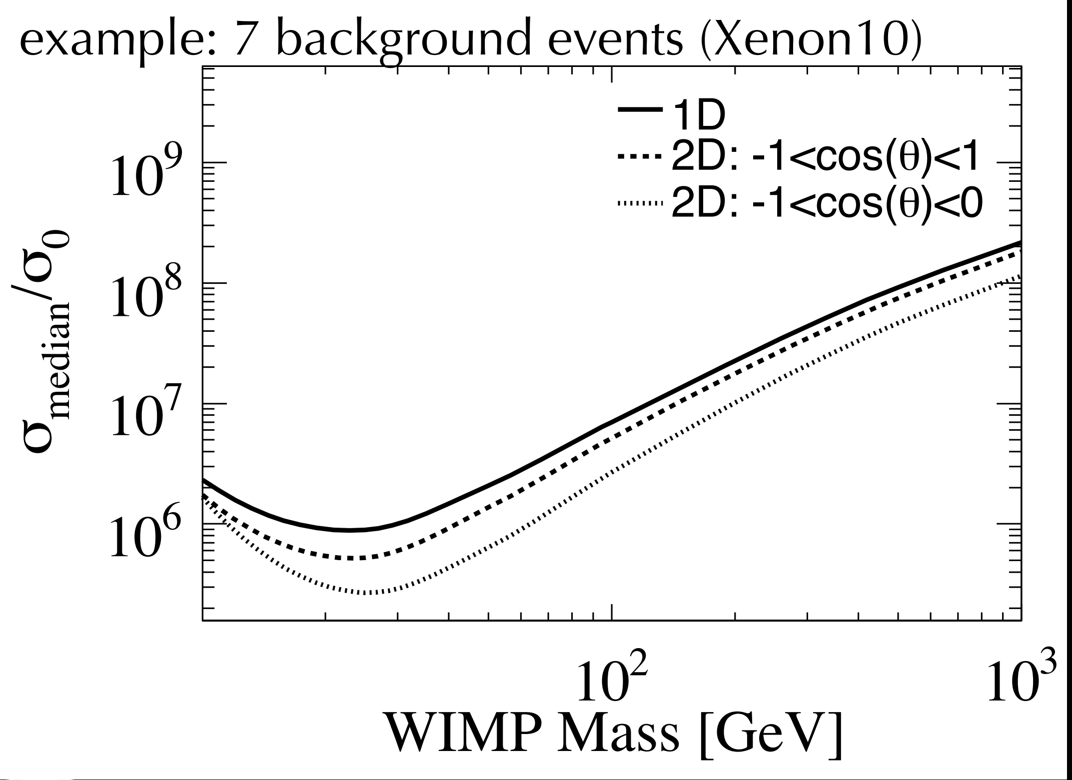
Sensitivity Example

in the presence of backgrounds

need to *measure* the neutron background energy, angle distributions (both ~unknown)





maximum patch method (based on Yellin gap)

S. Henderson, JM, P. Fisher, Phys. Rev. D 78:015020 (2008)

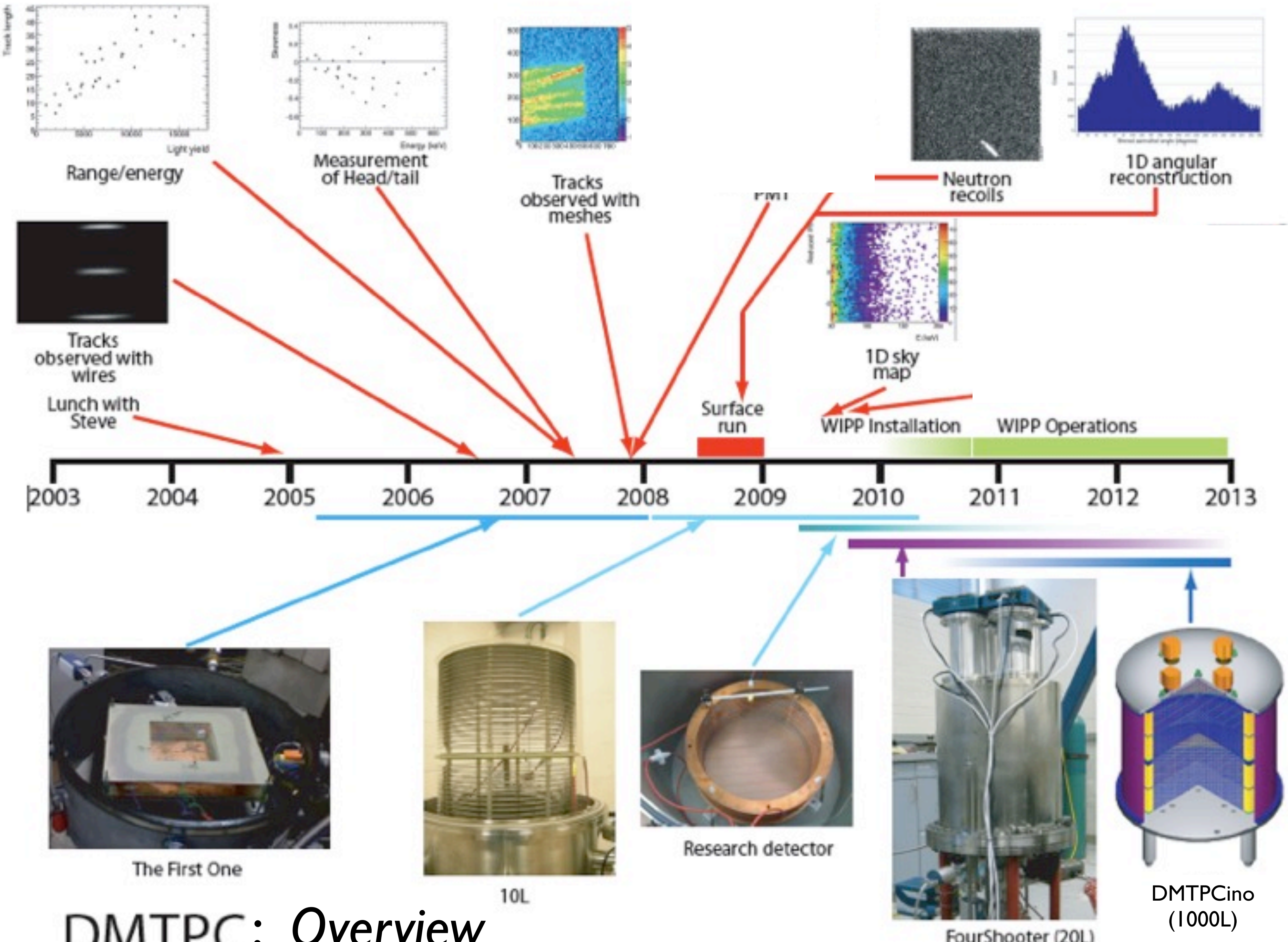
result:
with backgrounds, 2D dark matter detection can beat 1D by ~10x

Outline

Introduction

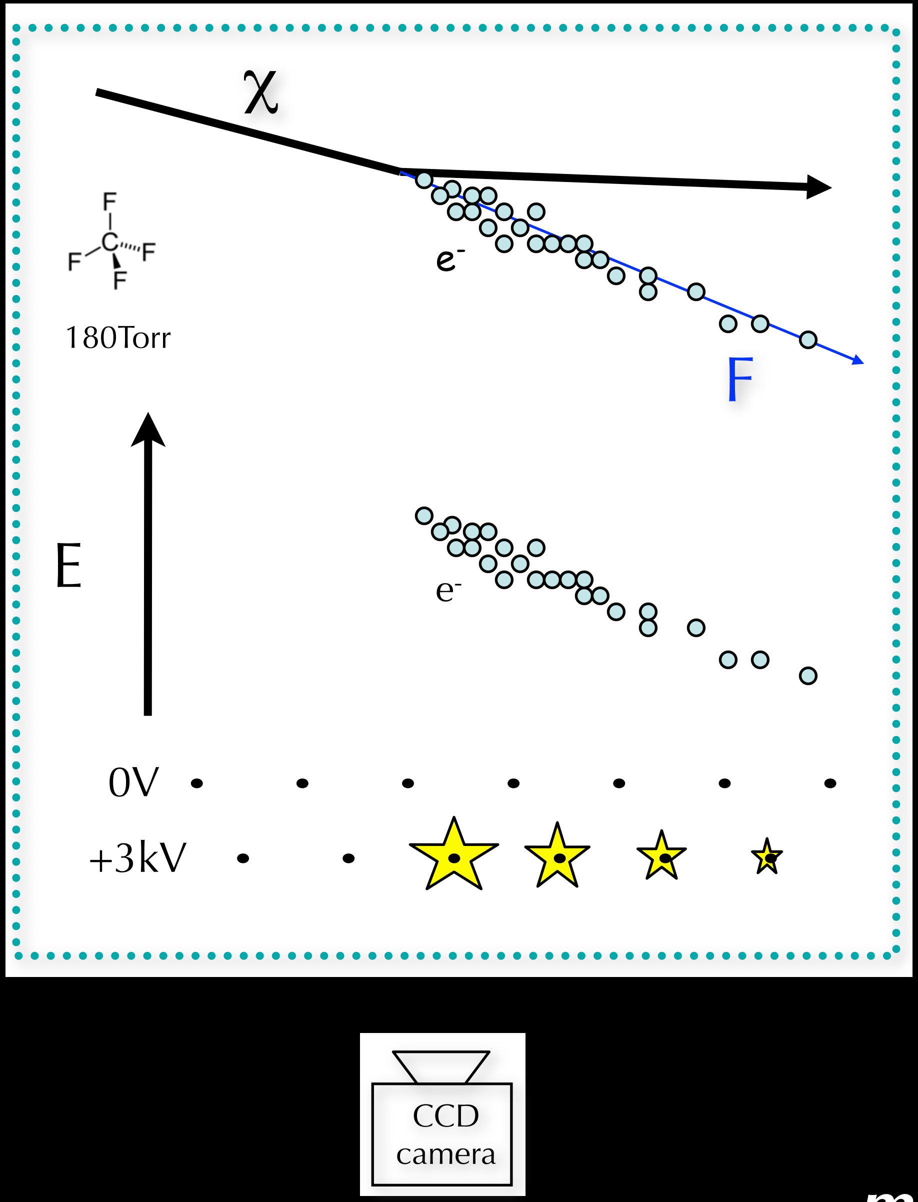
Directional Dark Matter Detection

Recent Progress from DMTPC

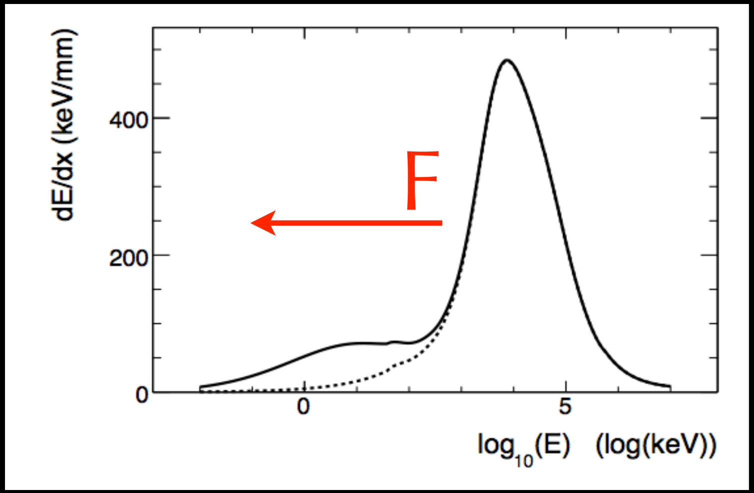


DMTPC: *Overview*

DMTPC Principle



1. primary ionization encodes track direction via dE/dx profile



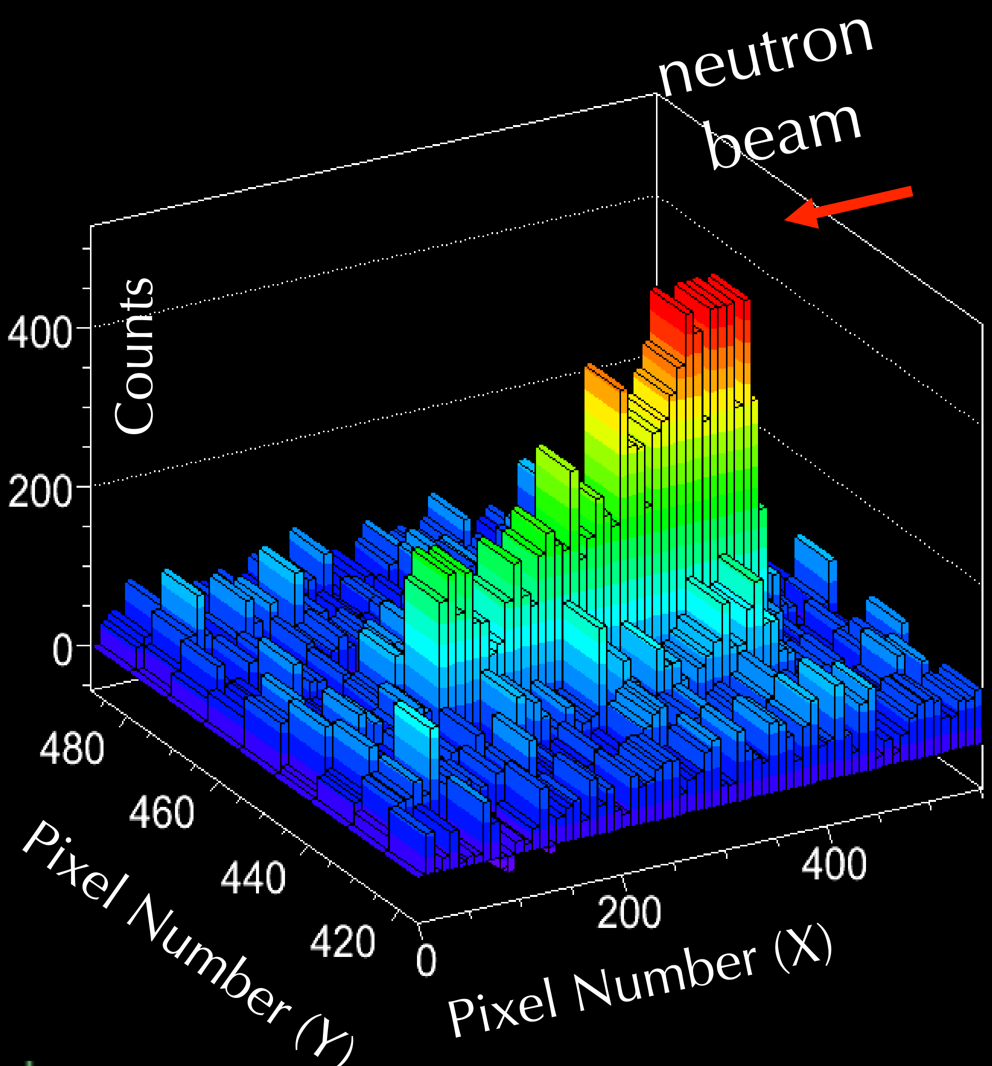
2. drifting electrons preserve dE/dx profile if diffusion is small

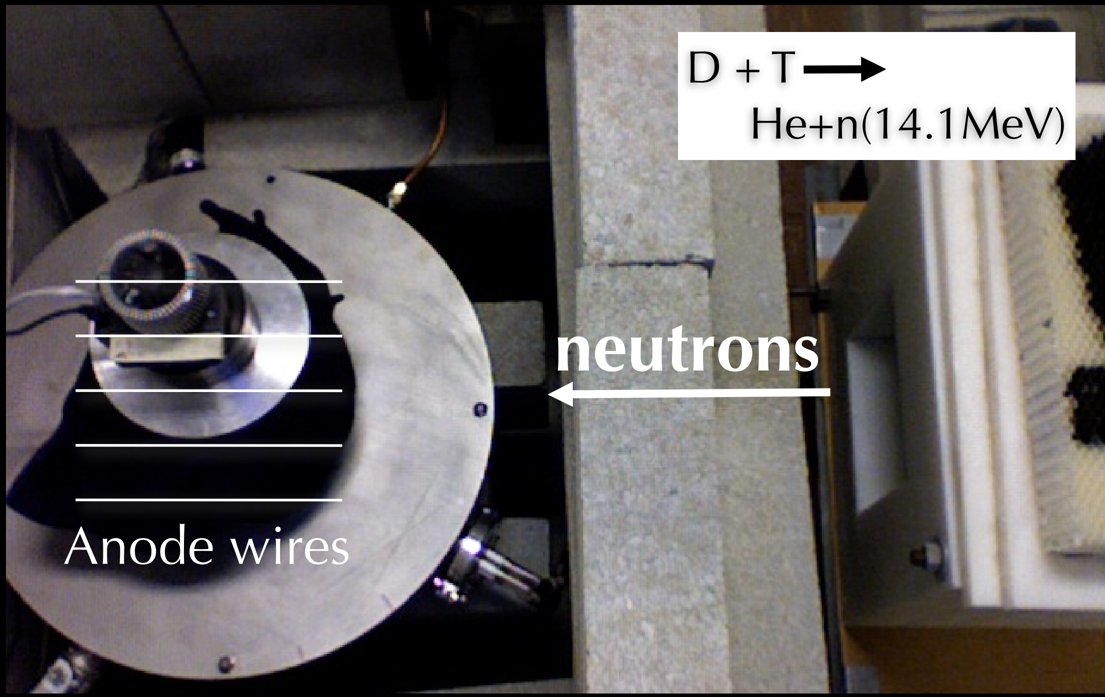
3. avalanche multiplication in amplification region produces gain, scintillation photons

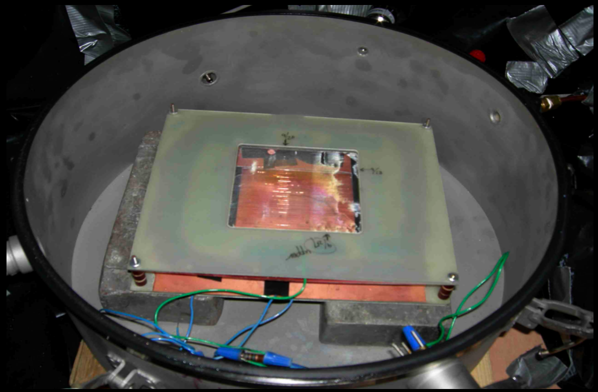
minimum wetted materials

DMTPC Proof-of-Principle

Neutron-fluorine elastic scattering mimics dark matter-induced recoils



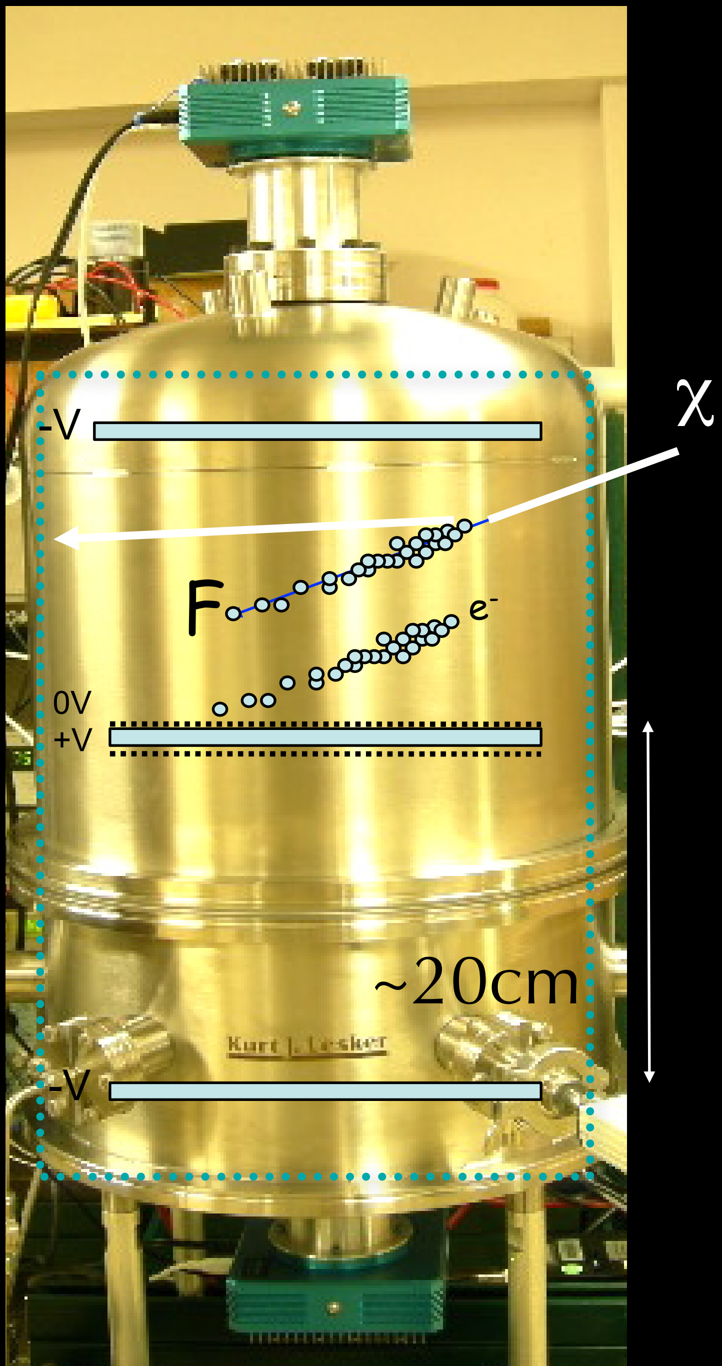




We can reconstruct the direction of ~100 keV fluorine recoil tracks!

D. Dujmic et al., NIM A584:327-333 (2008)

DMTPC Now



<u>Brandeis University</u>
A. Dushkin, L. Kirsch, *H. Ouyang*, G. Sciolla, H. Wellenstein*

<u>Bryn Mawr</u>
J. B. R. Battat*

<u>Boston University</u>
S. Ahlen*, ***M. Chernikoff***, A. Inglis, H. Tomita

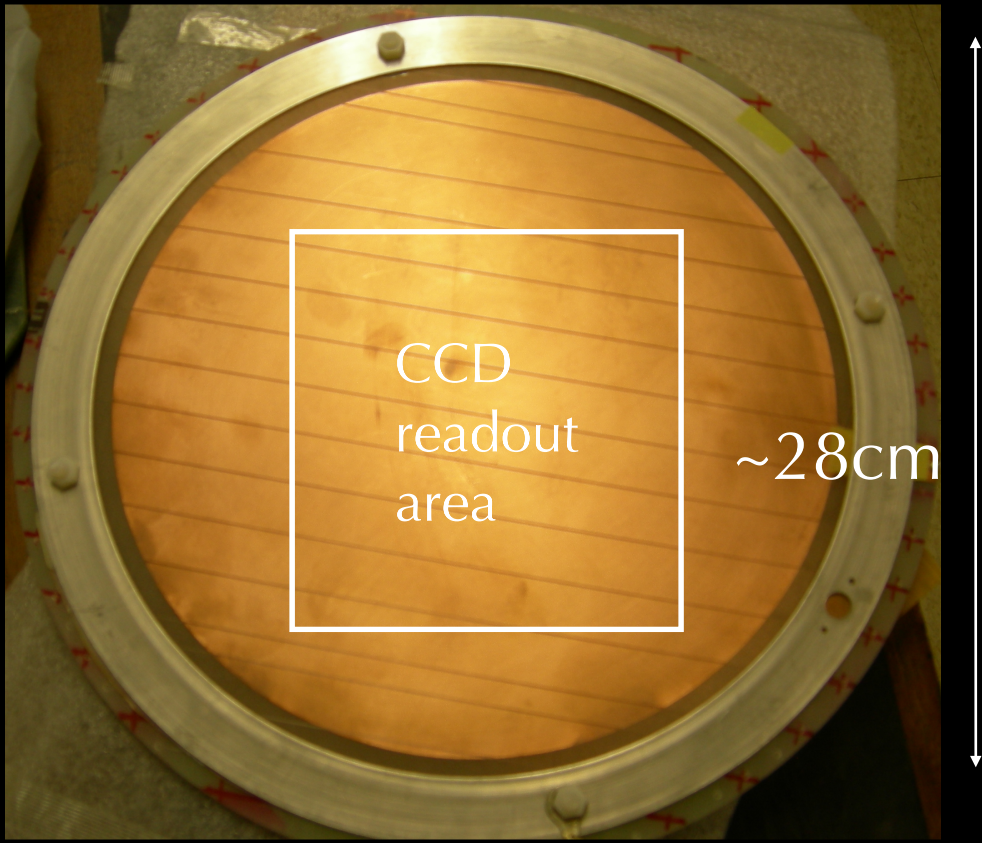
<u>MIT</u>
T. Caldwell, **C. Deaconu**, D. Dujmic, *W. Fedus*, P. Fisher*, ***S. Henderson, A. Kaboth***, G. Kohse, R. Lanza, *A. Lee*, ***J. Lopez***, *E. Nardoni*, *T. Sahin*, R. Vanderspek, *I. Wolfe*, R. Yamamoto, *H. Yegoryan*

<u>Royal Holloway University of London</u>
R. Eggleston, J. Monroe**

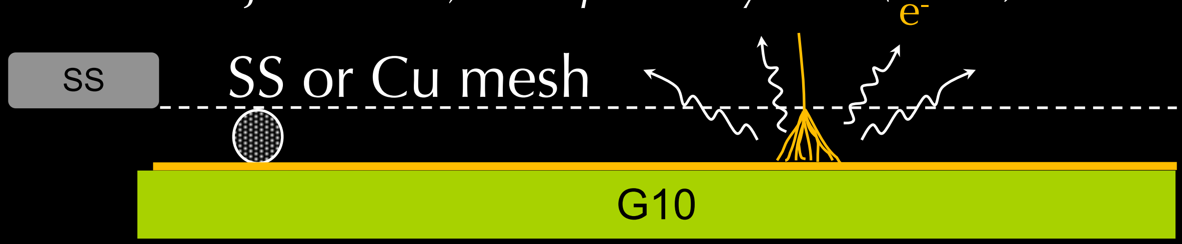
*) PI, **) spokesperson, *student*, ***PhD student***

Amplification Plane

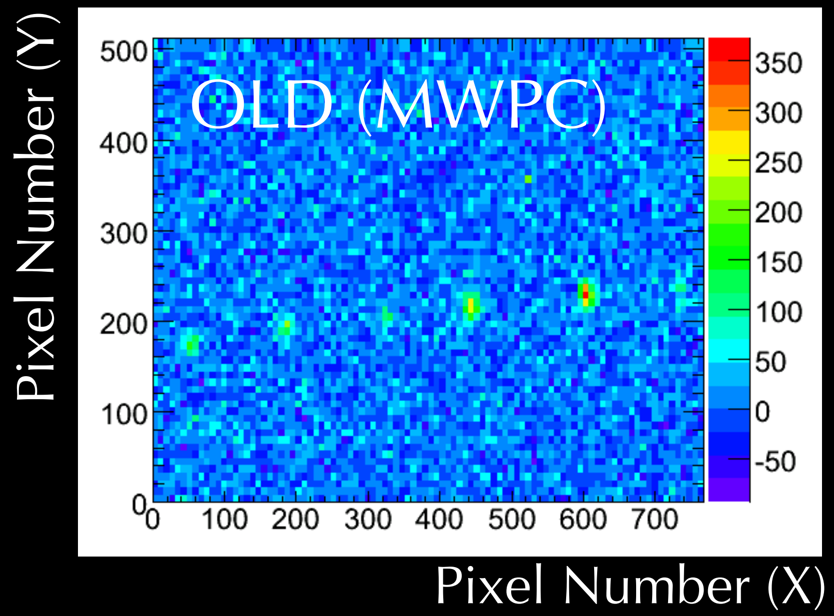
Copper Mesh, 256 um pitch

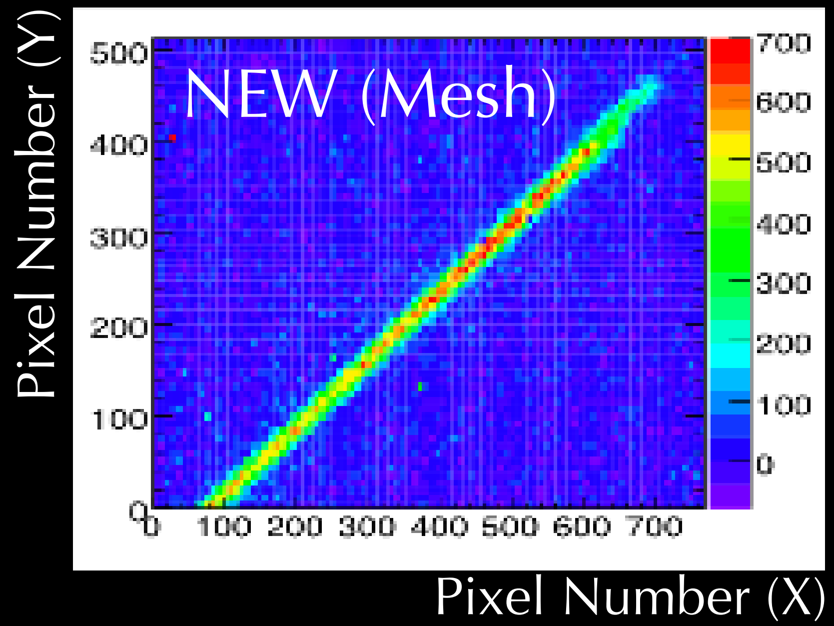


D. Dujmic et al., Astropart. Phys. 30 (2008)



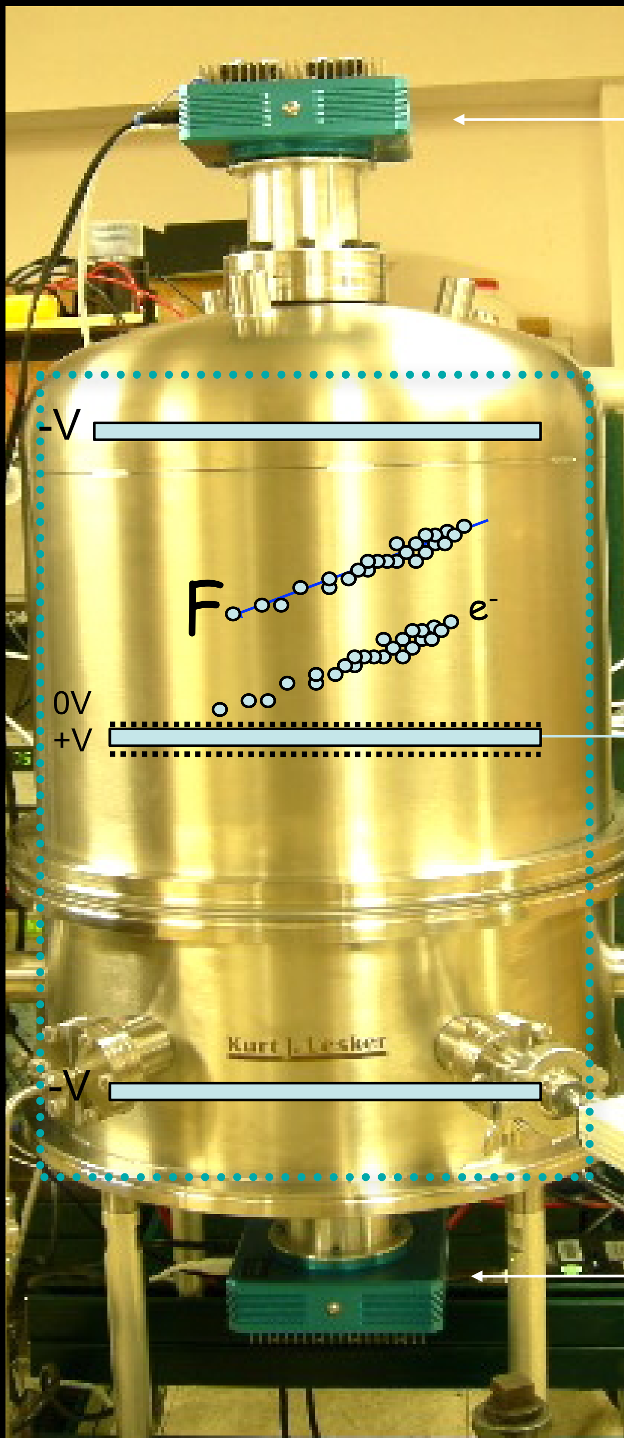
Resistive separators, dia=0.5mm, every 2.5cm

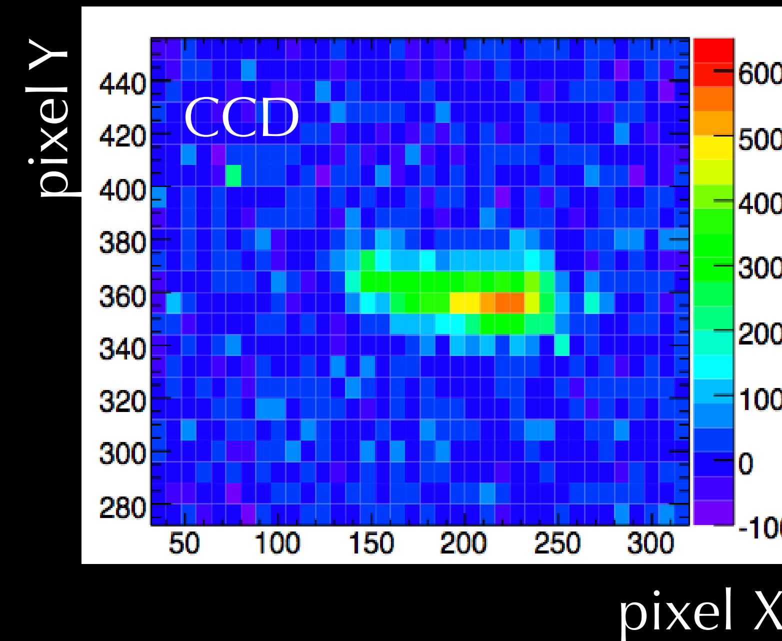


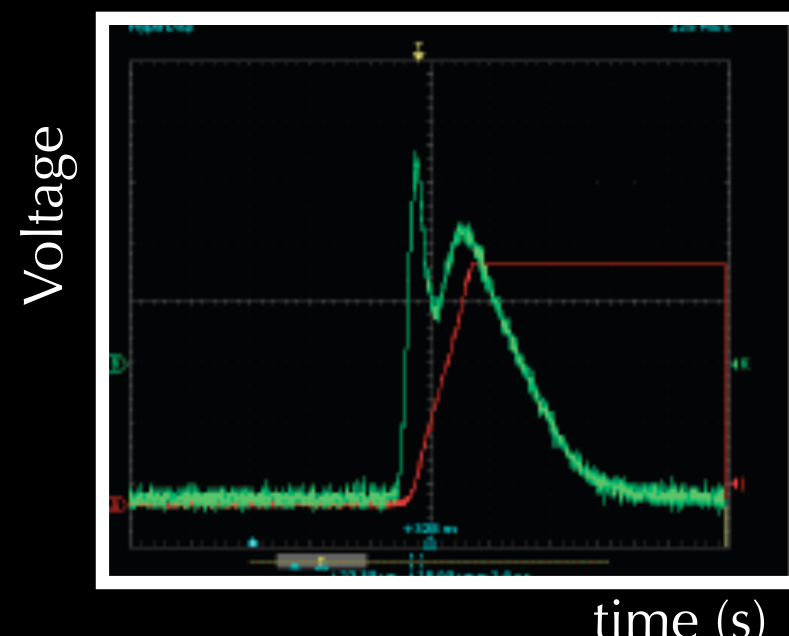


20x smaller pitch,
13x higher gain, 1->2D

TPC Readout

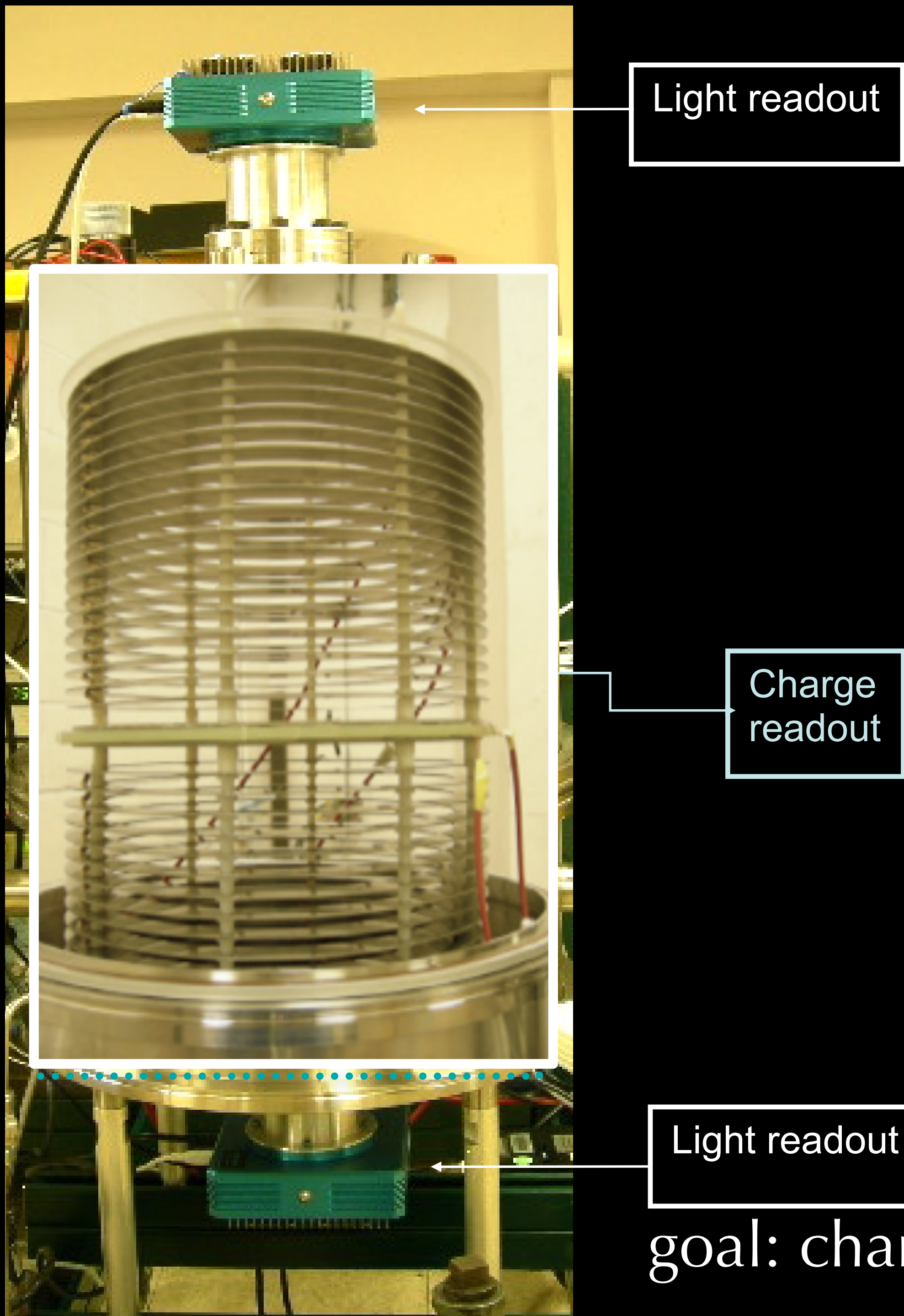


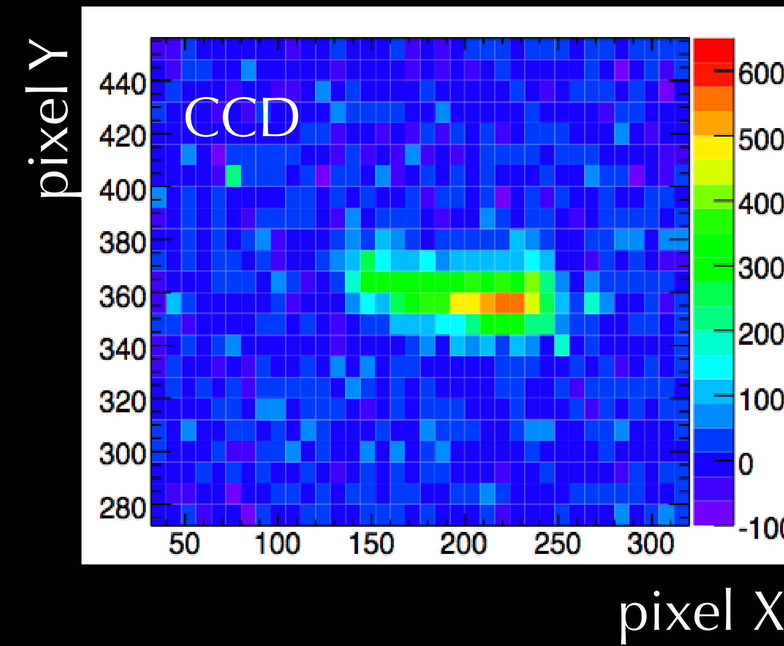


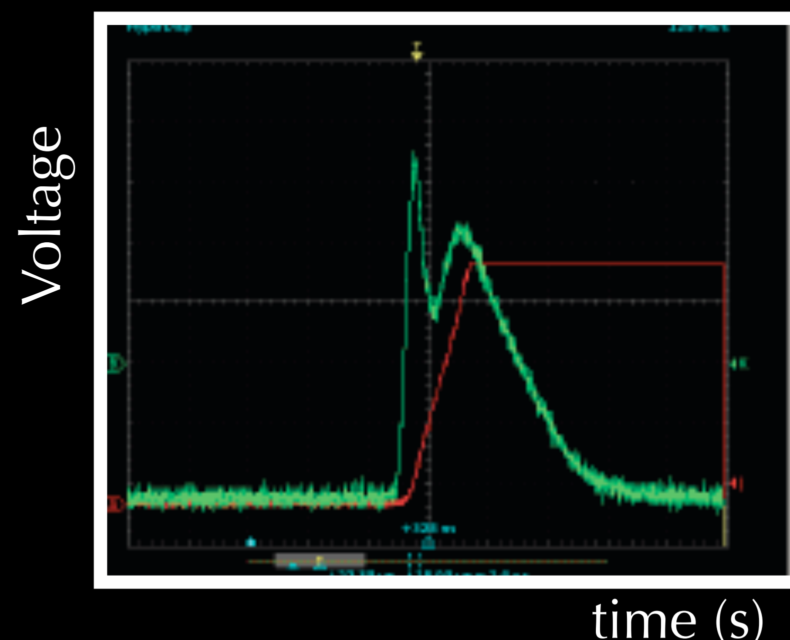


goal: charge and light= 2->3D *(J. Battat)*

TPC Readout







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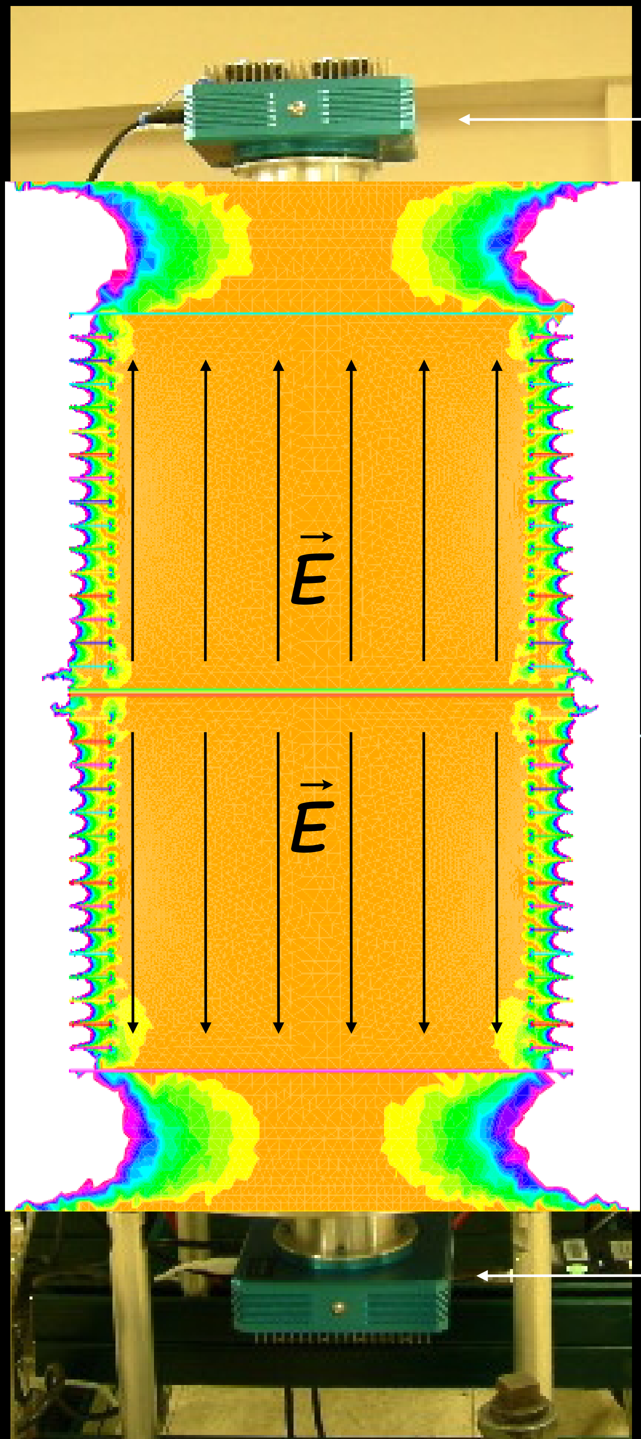
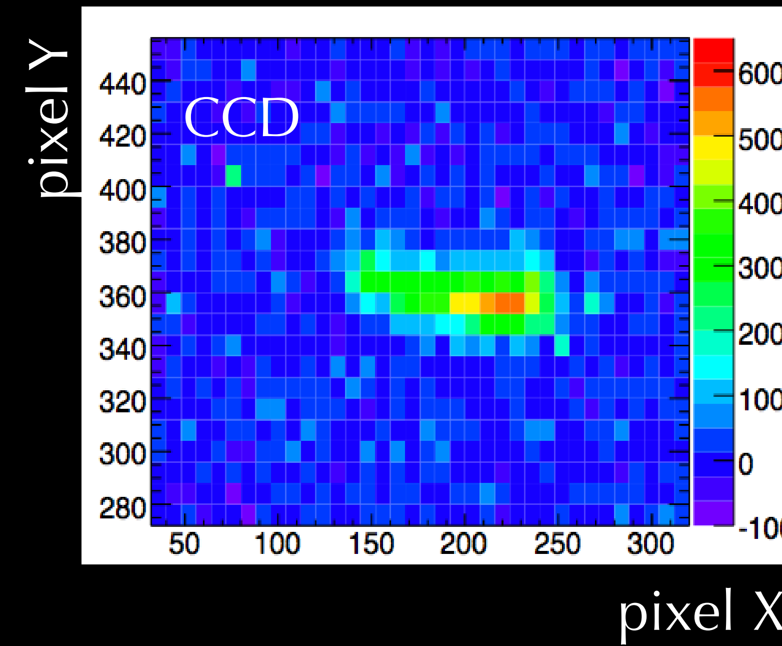
TPC Readout

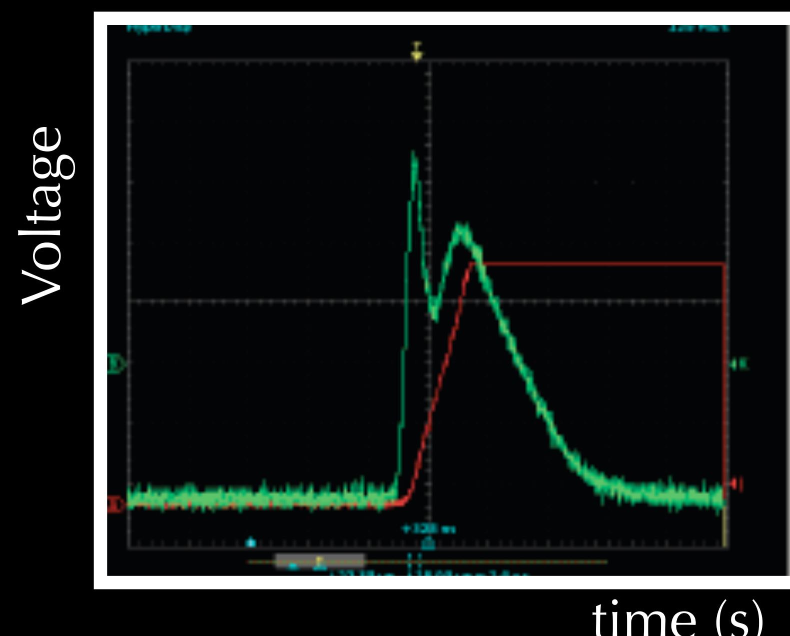


Light readout

Charge readout

Light readout





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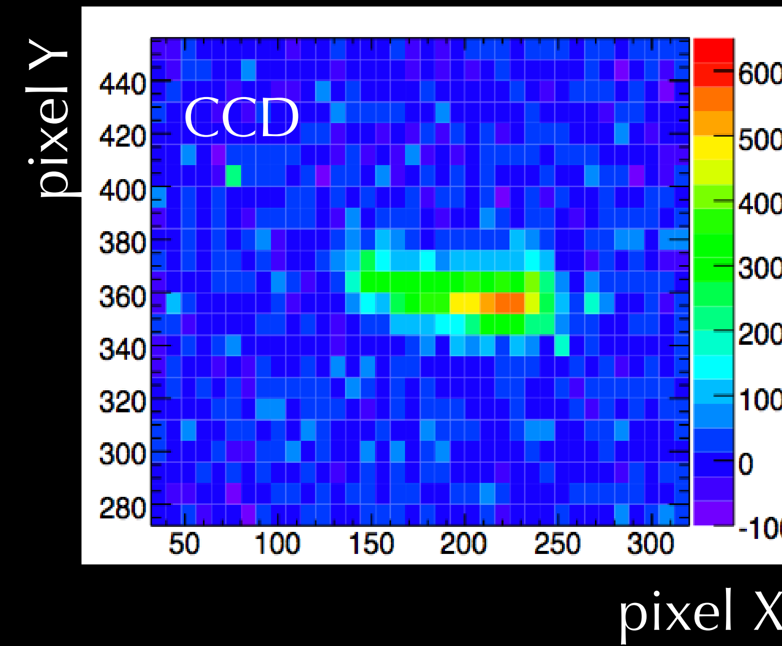
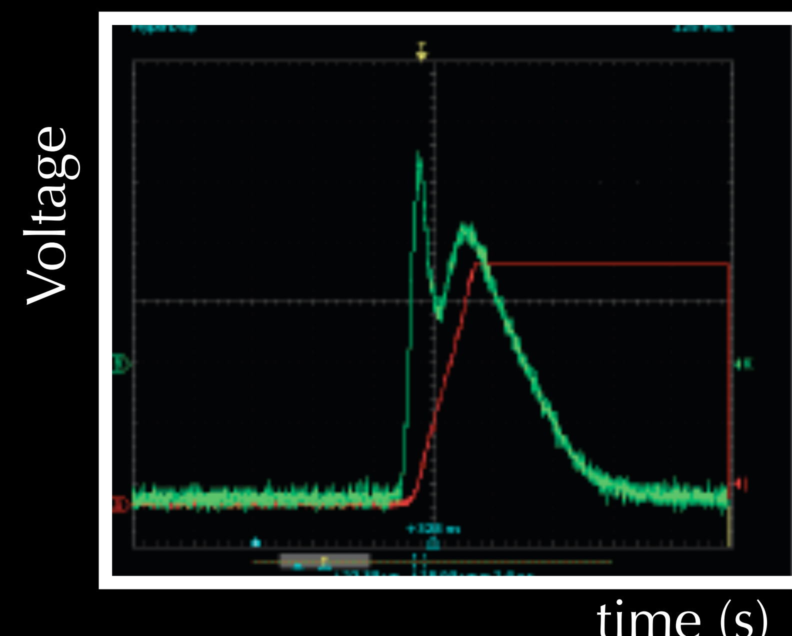
TPC Readout

Light readout

Charge readout

Light readout

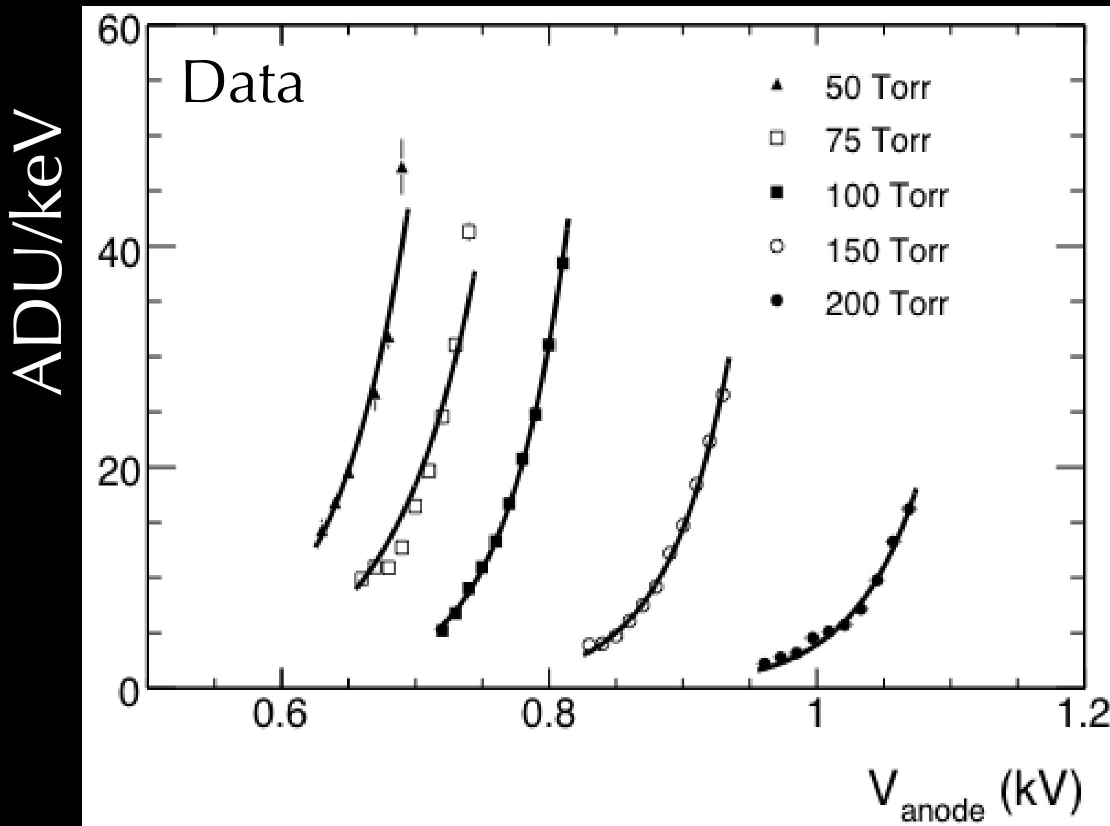




goal: charge and light= 2->3D *(J. Battat)*

CCD Readout

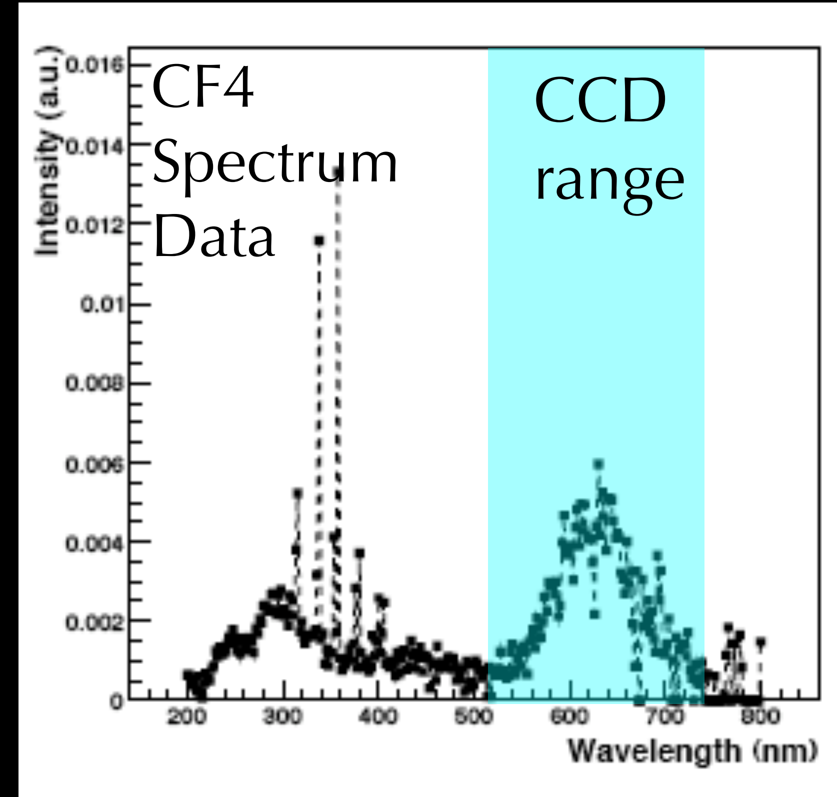
Total light output:

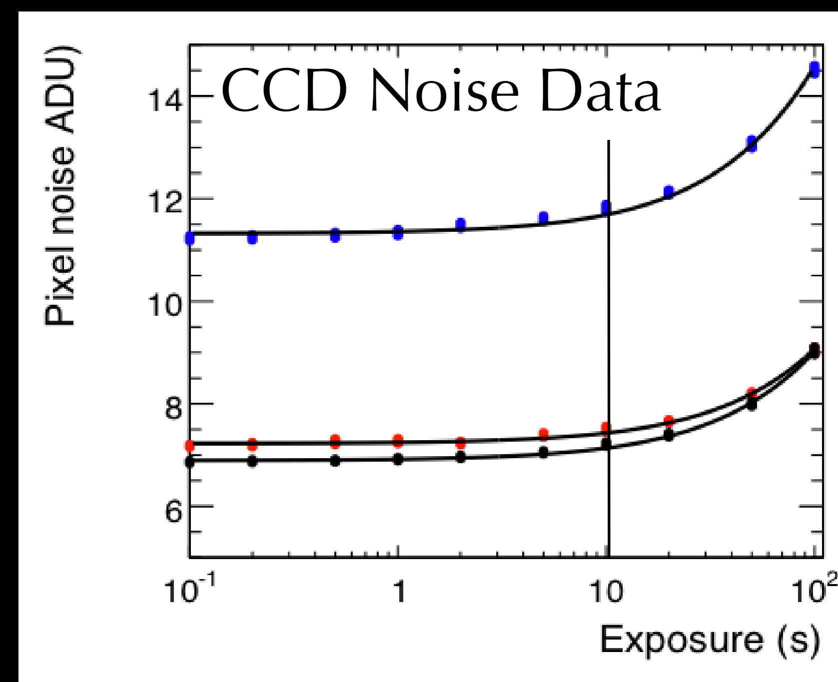


Increasing gain + track length with lower pressure, but decreasing mass!

CF4 scintillation: $\gamma/e^- = 0.38 +/- 0.04$

A. Kaboth, et al., NIM A 592:63-72 (2008)

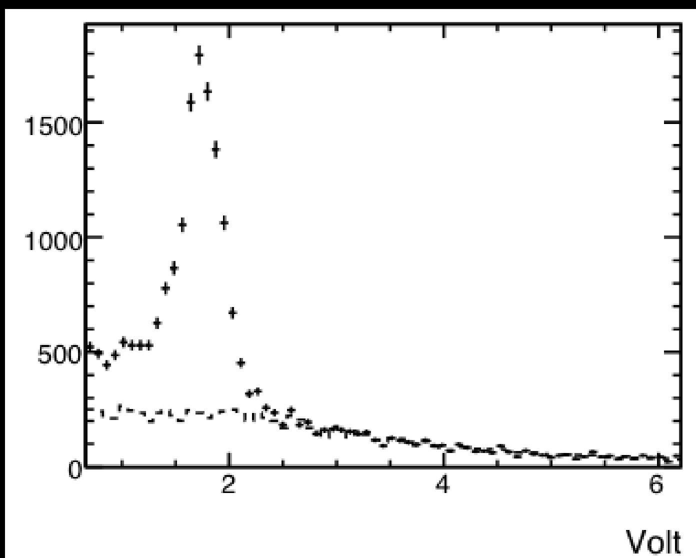


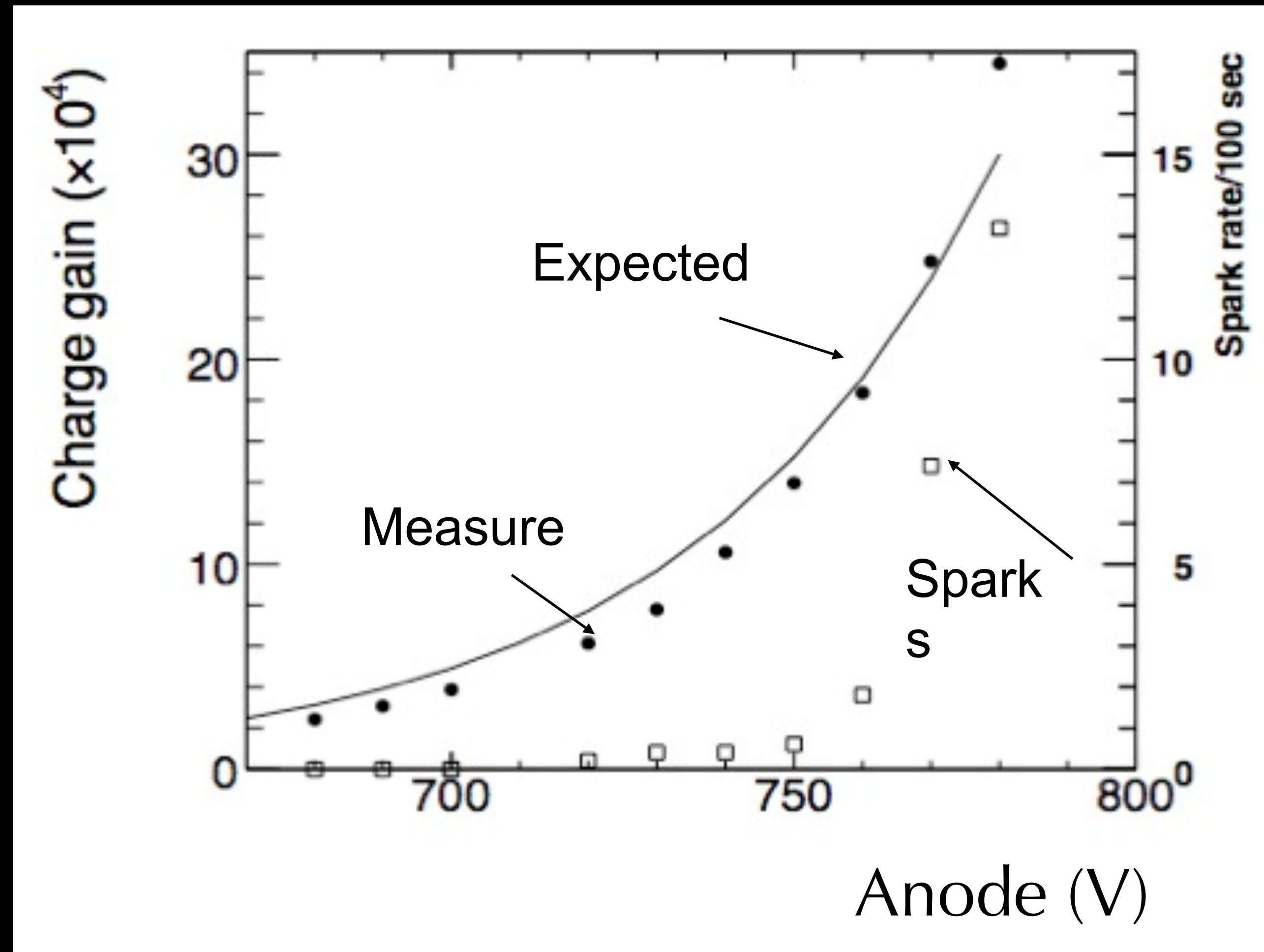


Charge Readout

(D. Dujmic, I. Wolfe)

Calibrate anode charge readout with Fe55 source





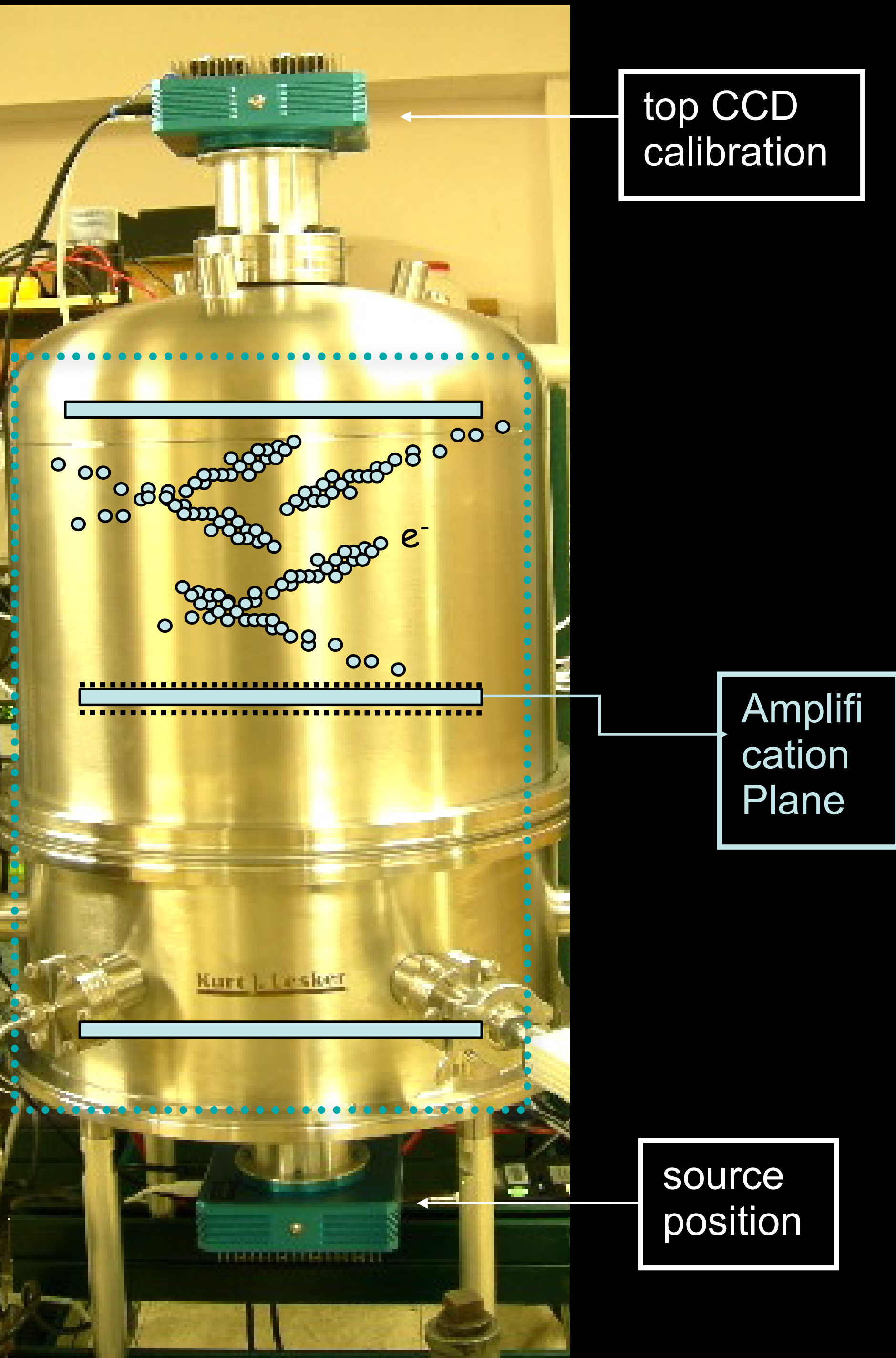
W = 33.8 +/- 0.4 eV (I. Wolfe)

Charge multiplication M = (V_{out} / 1.4pC/V) / (5.9keV / W)

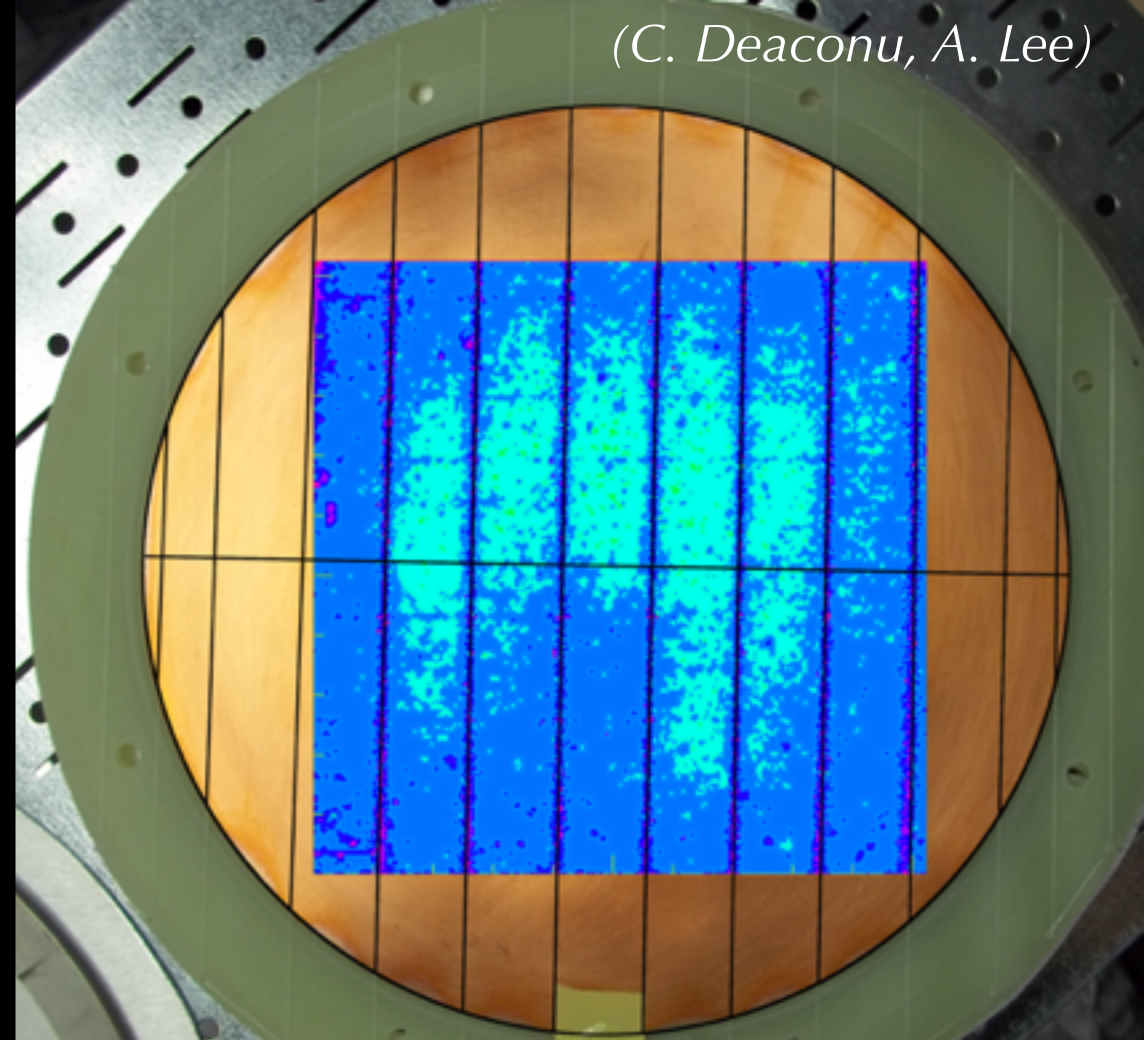
M >10^4 at operating pressure (60, 75Torr)

Determine anode operating voltage to maximize M, with <few% sparks

Length Calibration



(C. Deaconu, A. Lee)

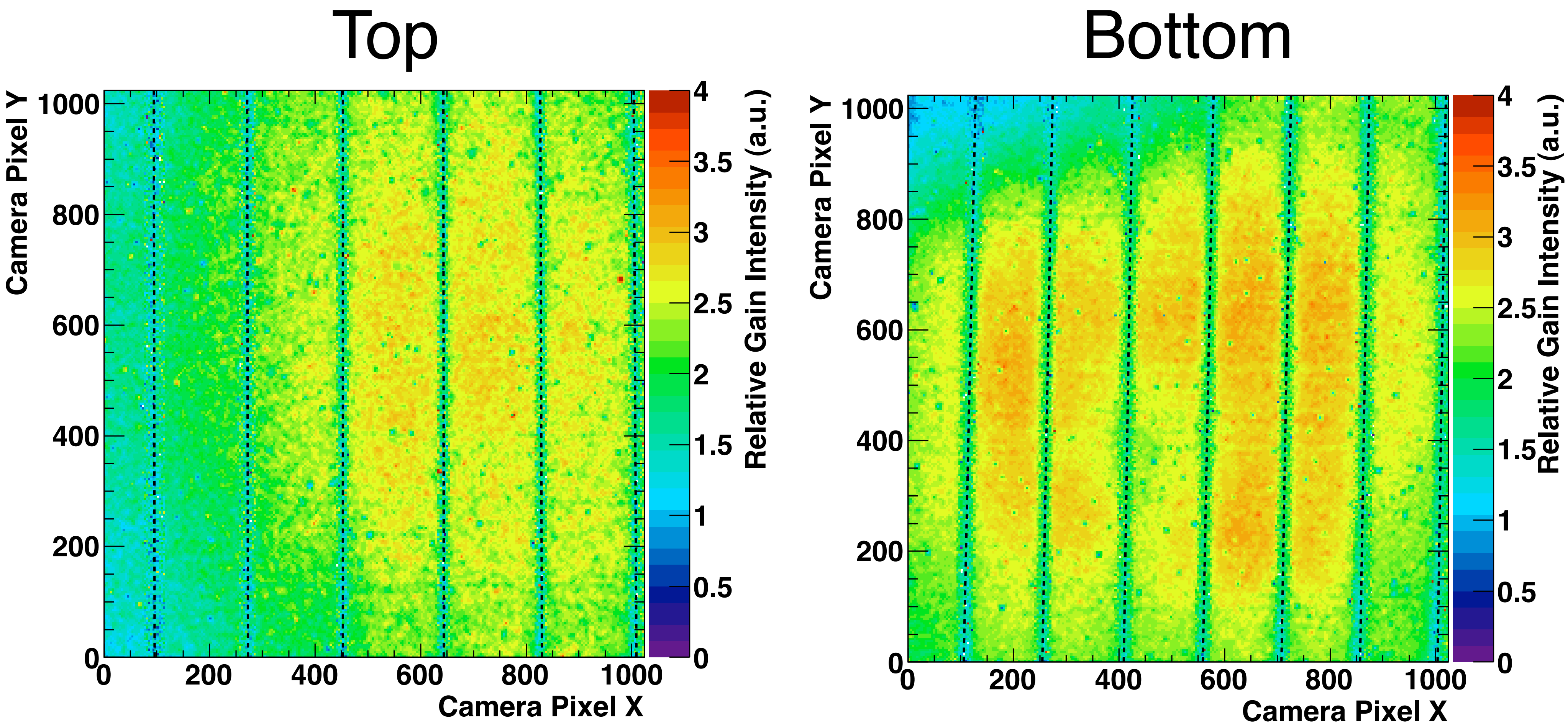


uniformly illuminate each TPC with gamma
from 31 uCi Co-57 (122,137 keV) and
9.5 uCi Cs-137 (662 keV) sources for 0.67 d

optical plate scale from comparing measure
spacer positions in gamma data with photo
= 136, 168 um/pixel (top,bottom)

10L Gain Maps

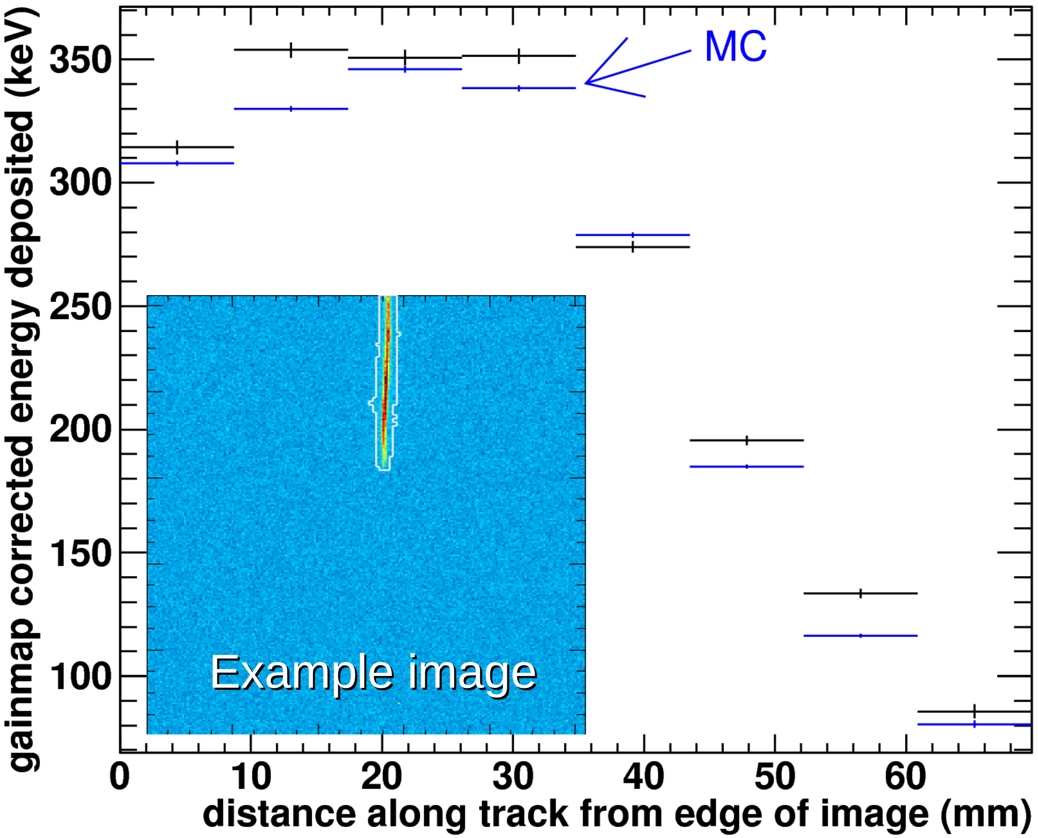
(A. Kaboth)



measured non-uniformity samples total system gain, can come from mesh-anode spacing, lens transmission, etc. Correct for this pixel-by-pixel in energy estimate.

CCD Energy Calibration

(C. Deaconu)

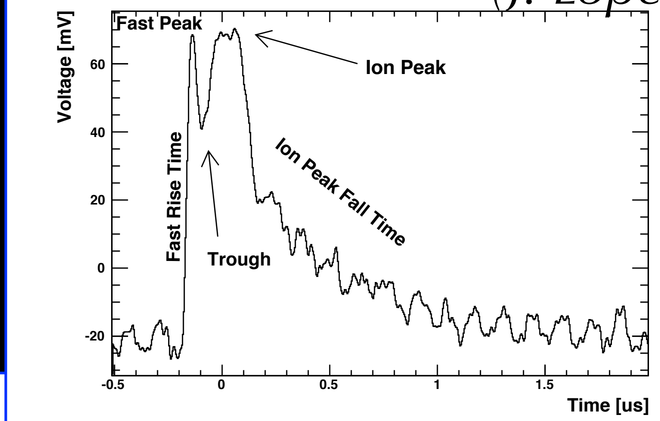


- Data taken with Am-241 source of known energy pointing towards image region.
- SRIM-based MC generates images with alphas of same energy and position and set gain (adu/keV).
- Reconstruct tracks in both sets of images to avoid any reconstruction bias.
- Project energy deposition along track axes, correct data for gain non-uniformity, and compare data vs. MC energy curves to figure out gain.

alpha energies measured in external solid sate detector (4.4 meV) compared to measured energy in CCD, at alpha track end: gain = 21,18 ADU/keV (top,bottom)

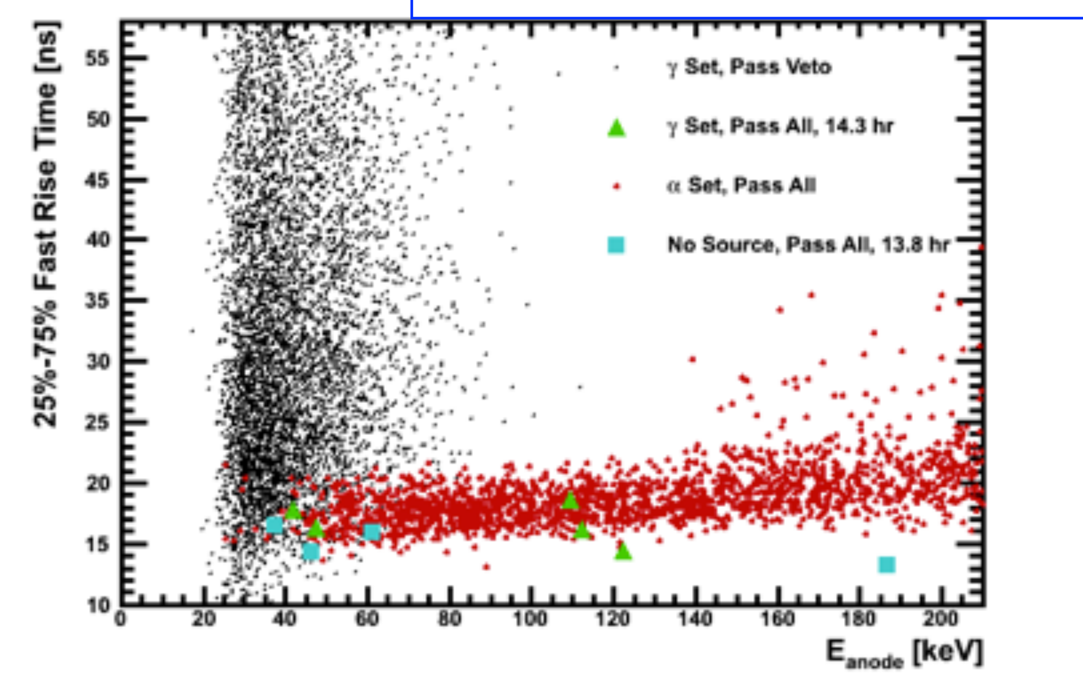
Charge Energy Calibration

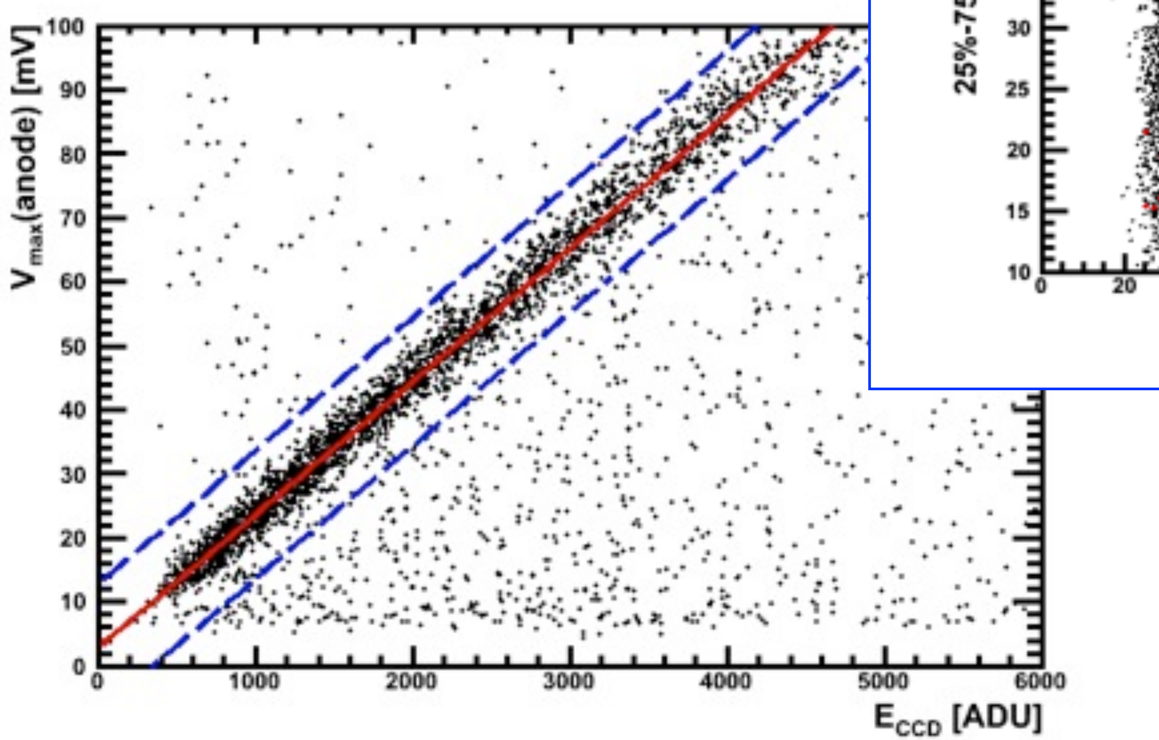
(J. Lopez)



Cut on mesh rise time vs. anode amplitude to reject gamma backgrounds in charge readout

Determine anode amplitude proportionality to CCD energy (calibrated with alphas)





$$V_{anode}[mV] = 2.82911 + 0.020814 N_{CCD}[ADU]$$

$$E_{anode}[keV] = 3.89 V_{anode}[mV]$$

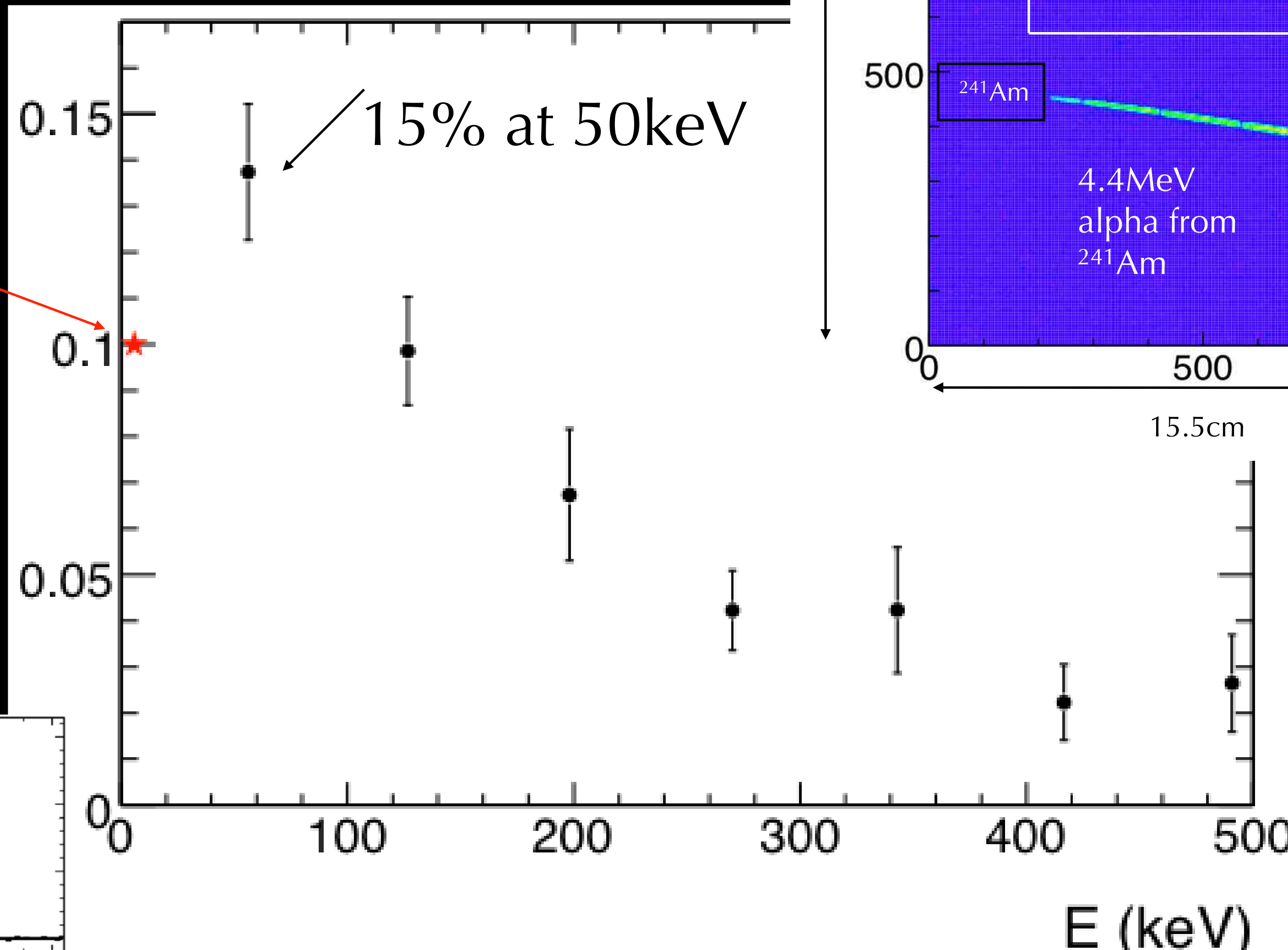
$$E_{CCD}[keV] = 11.0 + 0.08091 N_{CCD}[ADU$$

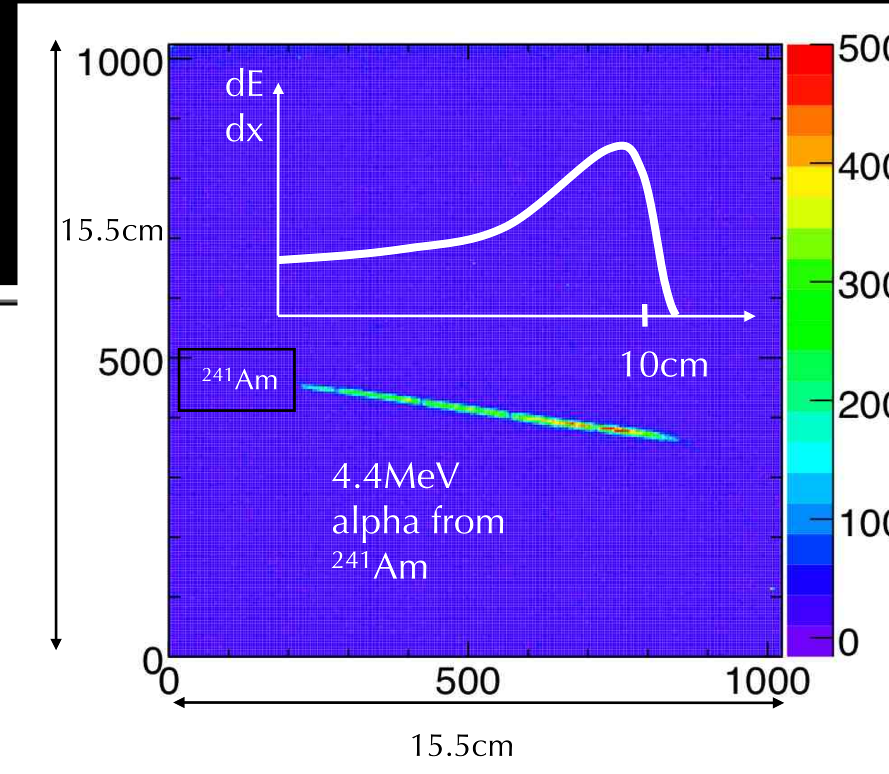
charge trigger threshold ~40 keVr

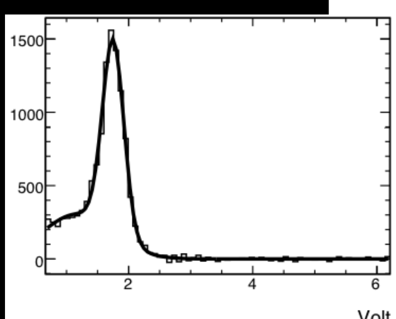
Energy Resolution

σ_E/E from CCD Readout:

~10% at 5.9keV for charge readout







(D. Dujmic)

Expected fluctuation (avalanche + primary) ~ 10%

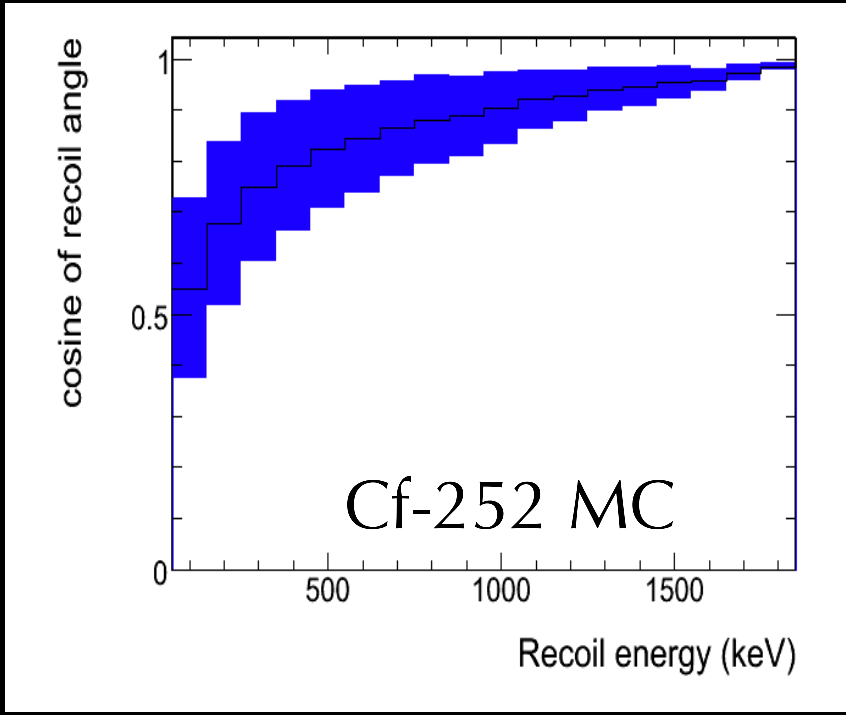
Avalanche=Alkhazov, NIM89 (1970) 155, primary=Poisson

"WIMP" Calibration

Neutron elastic scattering mimics dark matter recoils, and most neutrons below ~4 MeV alpha production threshold

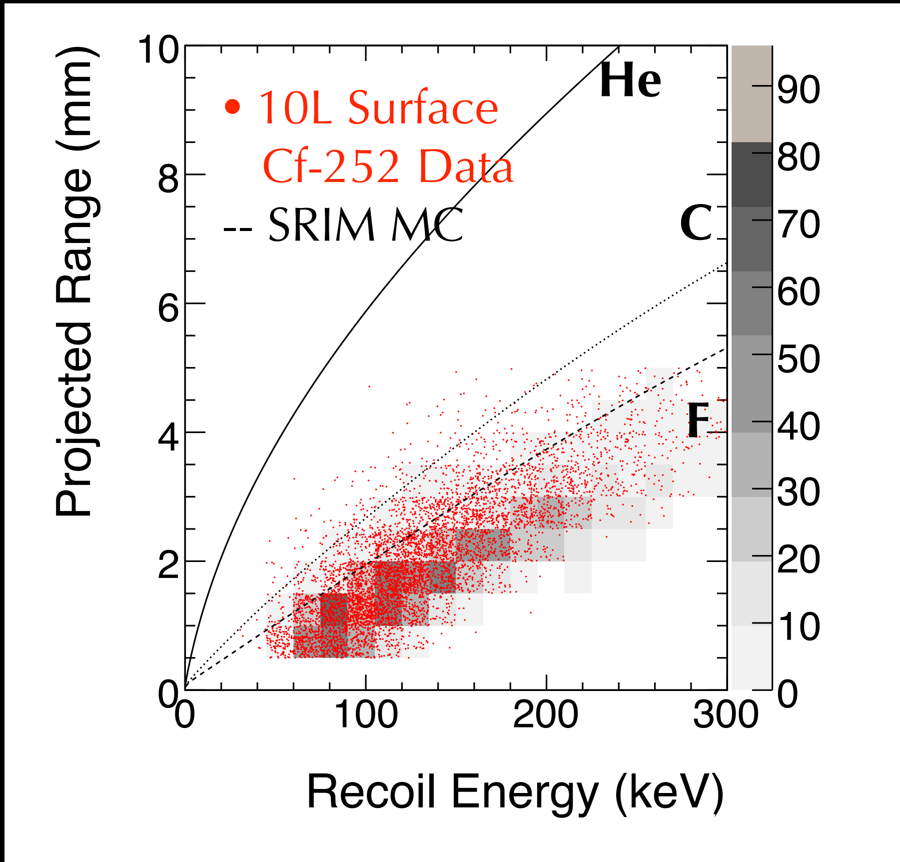
Cf-252 (~mCi) and d-t sources at surface, AmBe (8.9 uCi) source underground

100keV recoil angle	
Source	**Recoil angle**
14.1 MeV neutrons	80deg
Neutrons from AmBe	~68 deg (avg)
Neutrons from Cf252	~57deg (avg)
200GeV WIMP	~43deg (avg)



minimum recoil energy detected: ~50 keV

(Hitachi quenching)



Energy and recoil angle distributions similar to dark matter induced recoils

CF_4 Electron Attenuation

(D. Dujmic, T. Caldwell)

Attachment to CF_4:

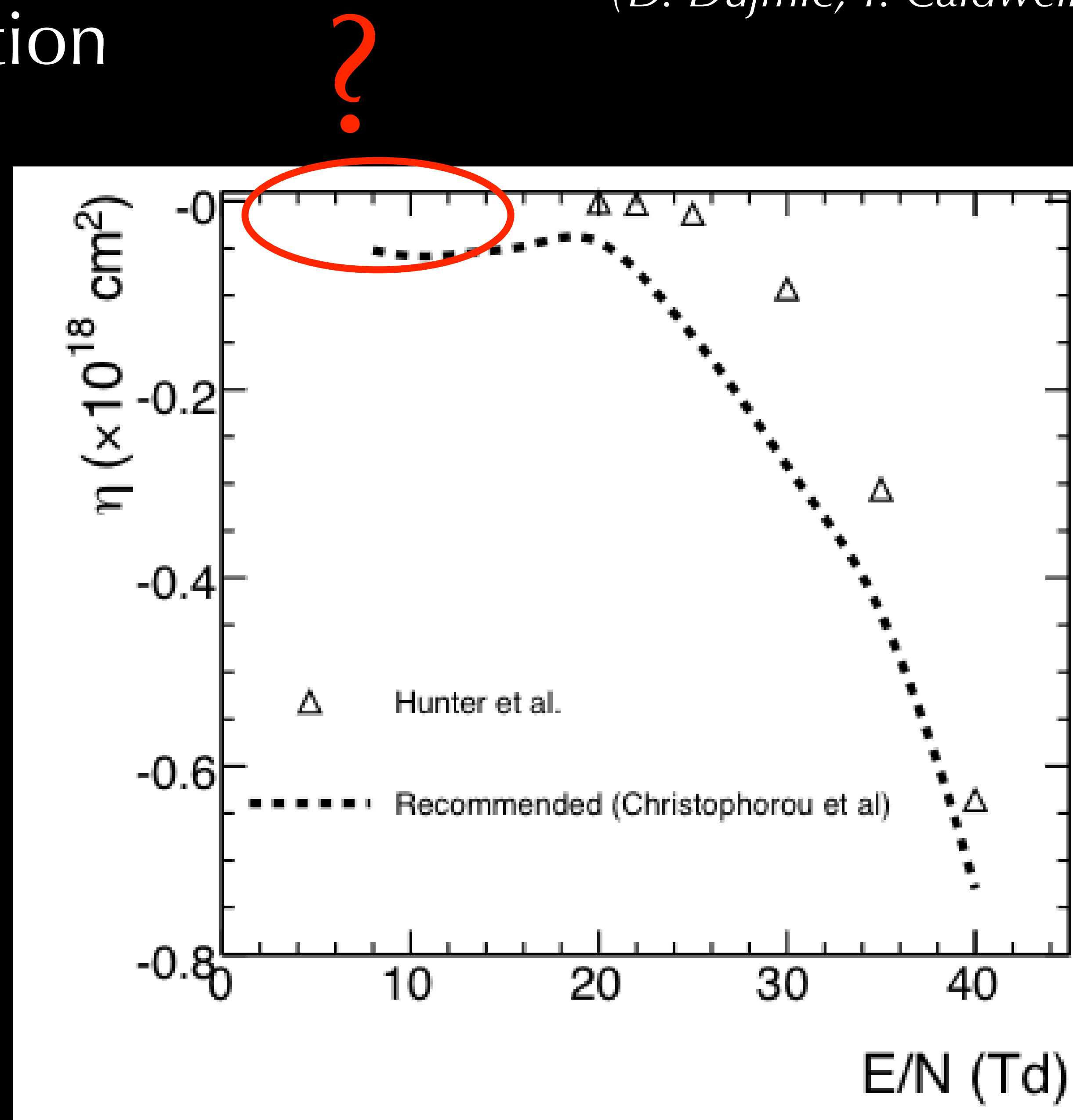
e.g.

$e^- + CF_4 \rightarrow CF_4^- \rightarrow CF_3 + F^-$

$e^- + CF_4 \rightarrow CF_4^- \rightarrow CF_3^- + F$

$e^- + CF_4 \rightarrow CF_4^{*-} \rightarrow F^- + CF_2 + F$

From previous measurements,
0% loss, or 70% loss after 20cm drift length?



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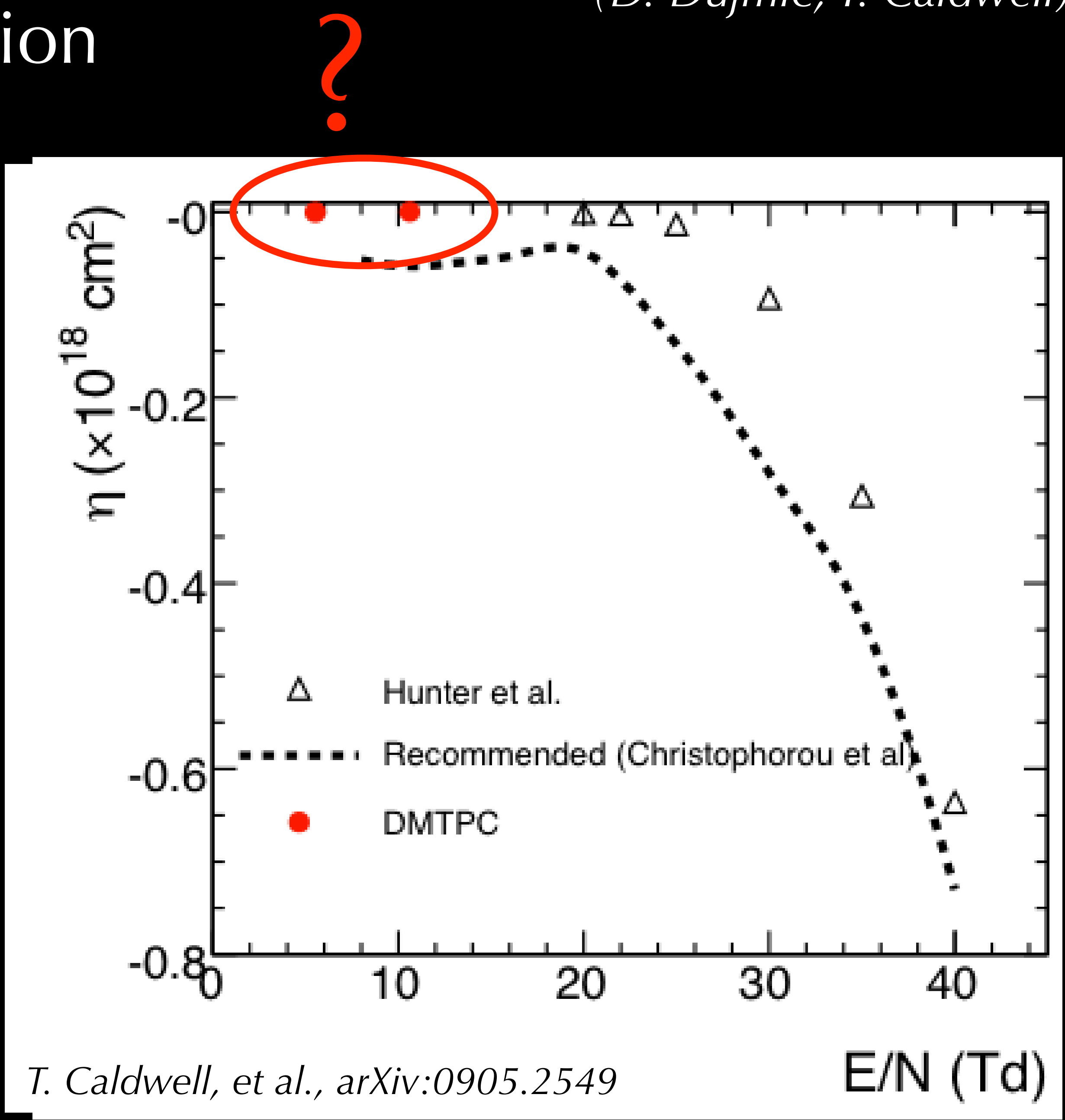


T. Caldwell, et al., arXiv:0905.2549

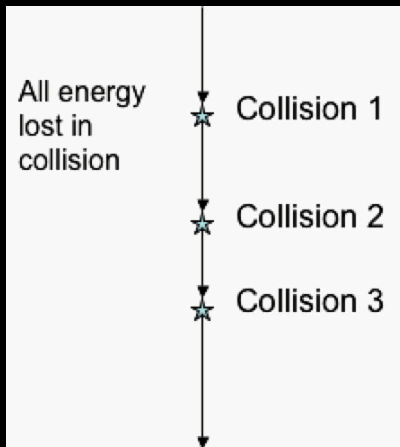
DMTPC measures ~0 charge loss over 20 cm drift length.

CF_4 Electron Diffusion

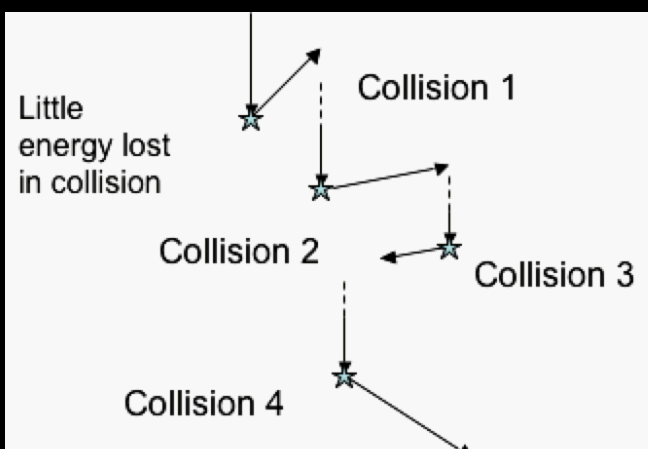
(D. Dujmic, T. Caldwell)

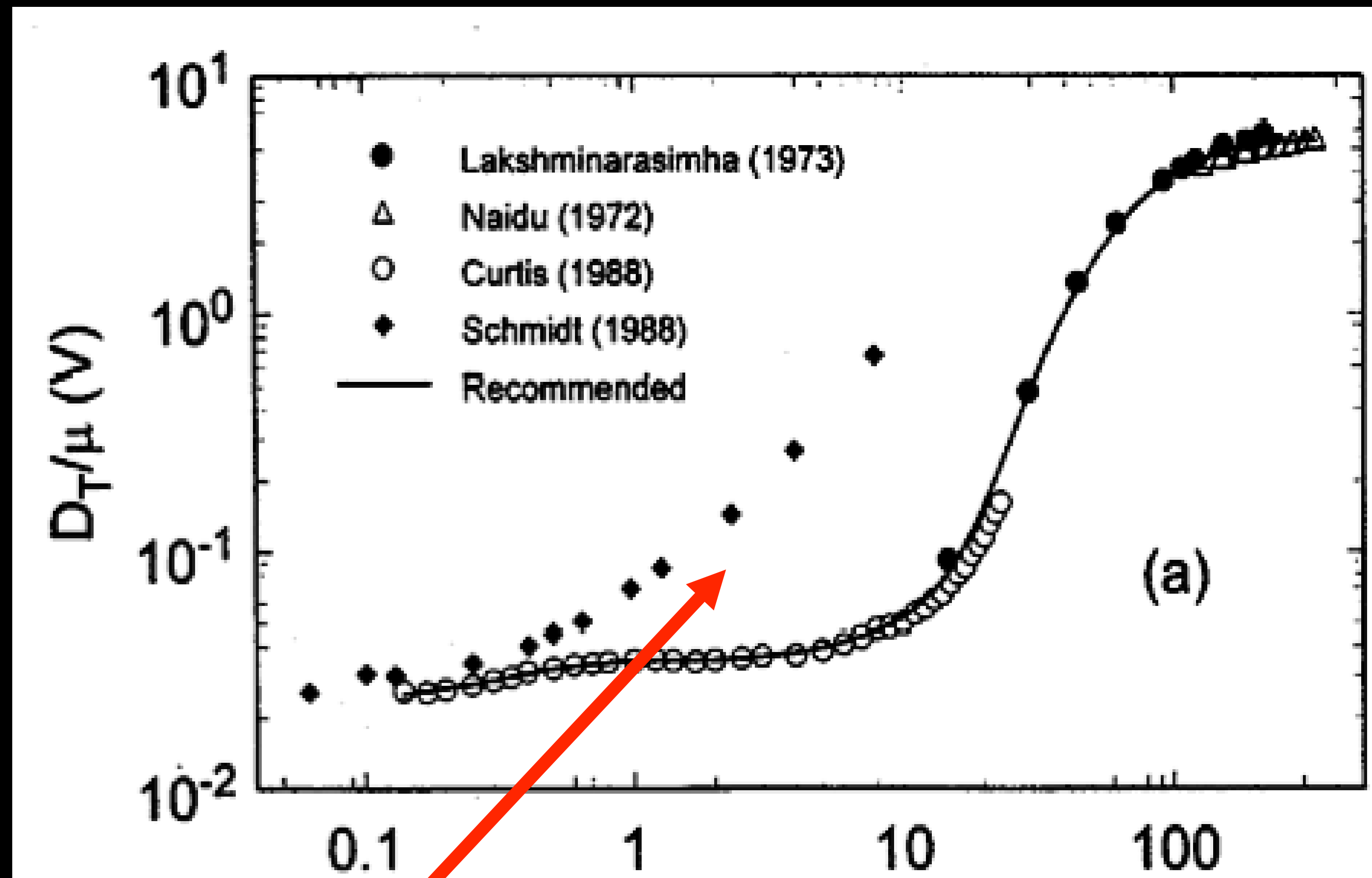
Large impact on spatial resolution:

$$\sigma^2 = (D/\mu)\ 2z/E$$



or?





E/N [Td]

>10x discrepancy in measurements in our range-of-interest

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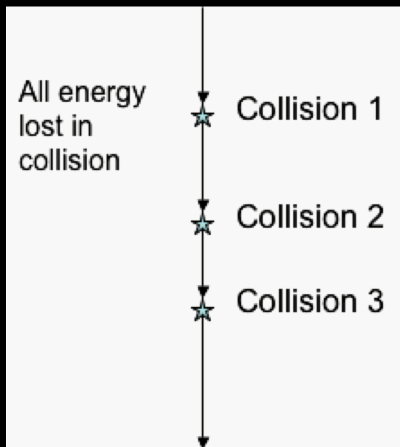

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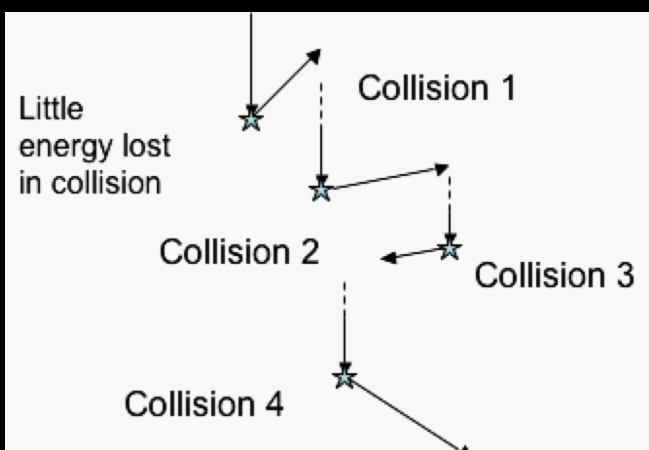

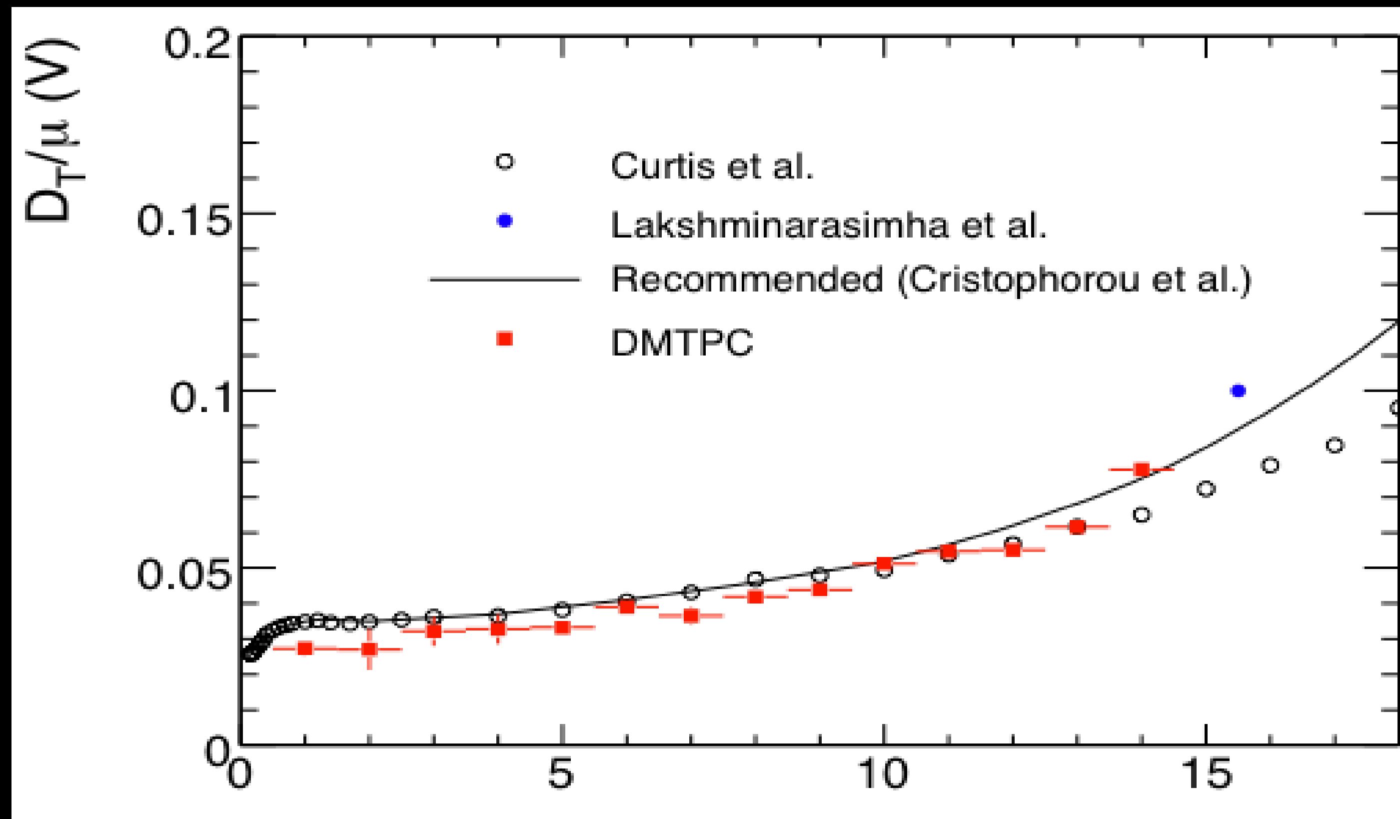

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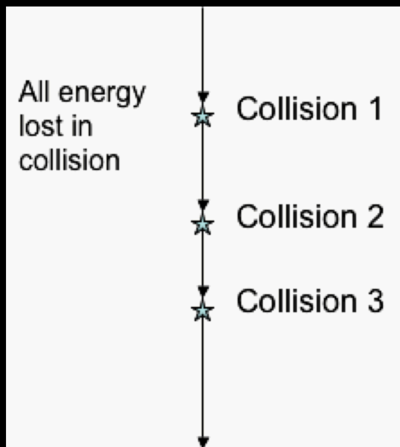

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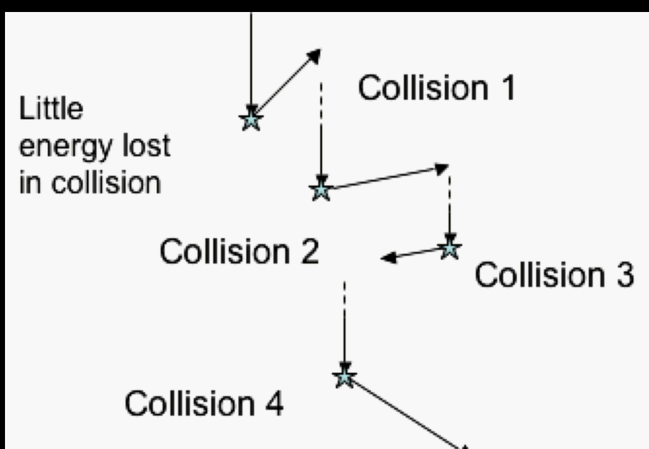
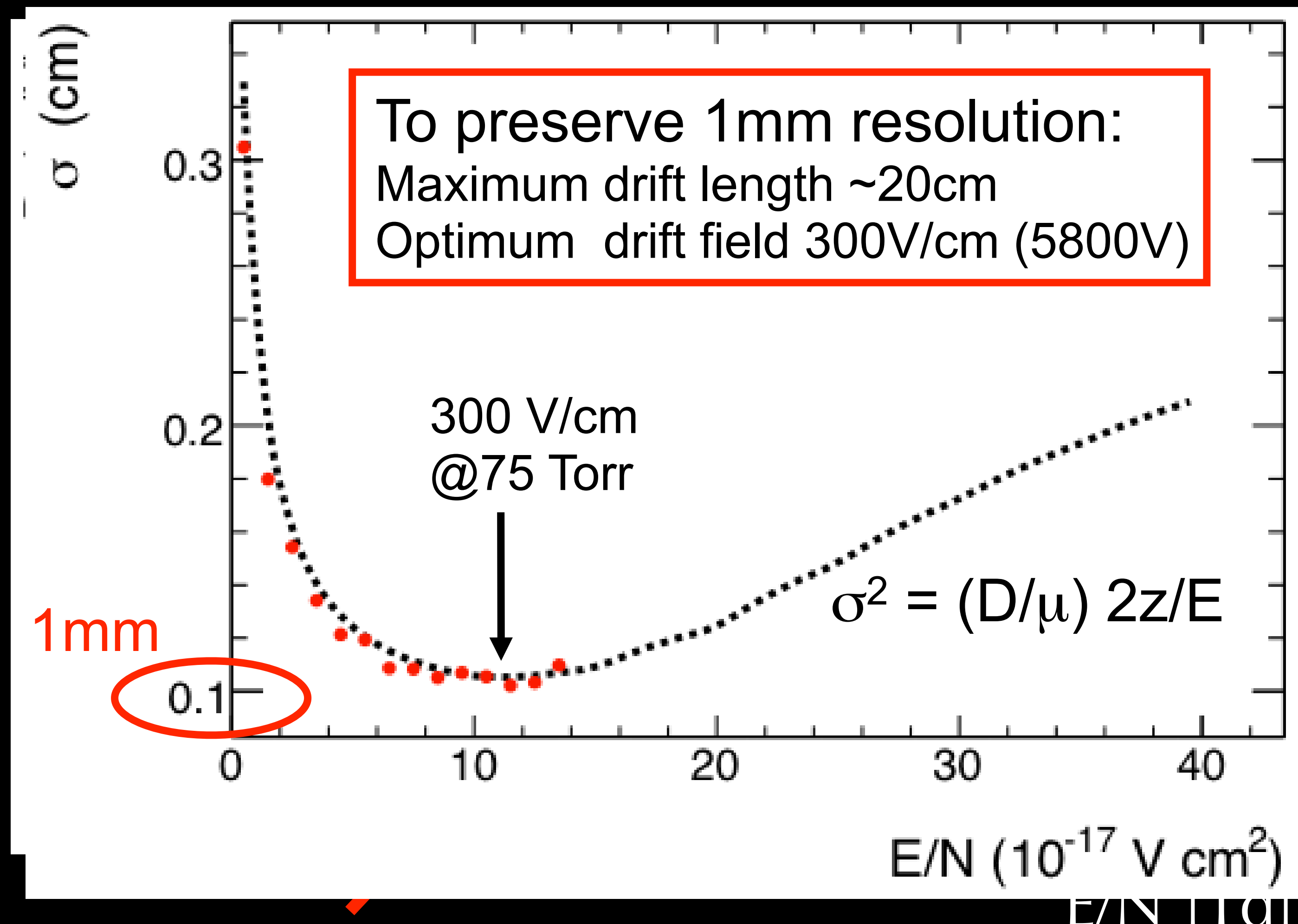


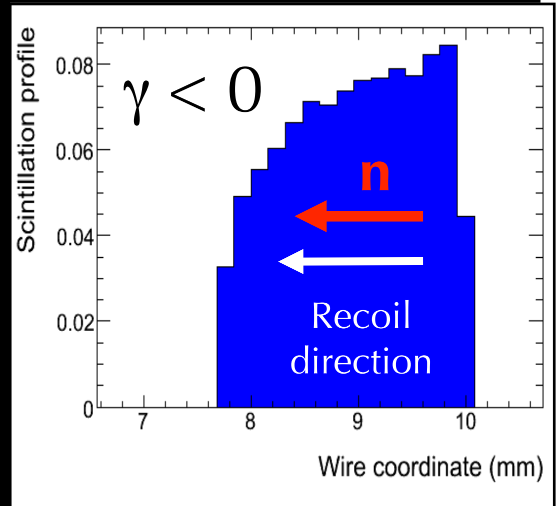


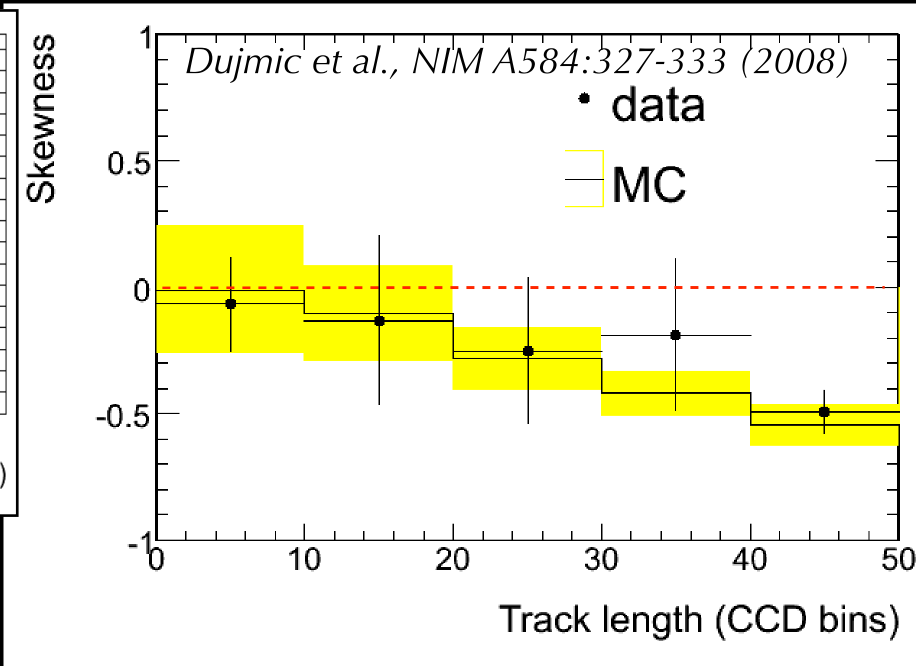
>10x discrepancy in measurements in our range-of-interest

DMTPC maximum drift length for <1 mm diffusion ~20 cm.

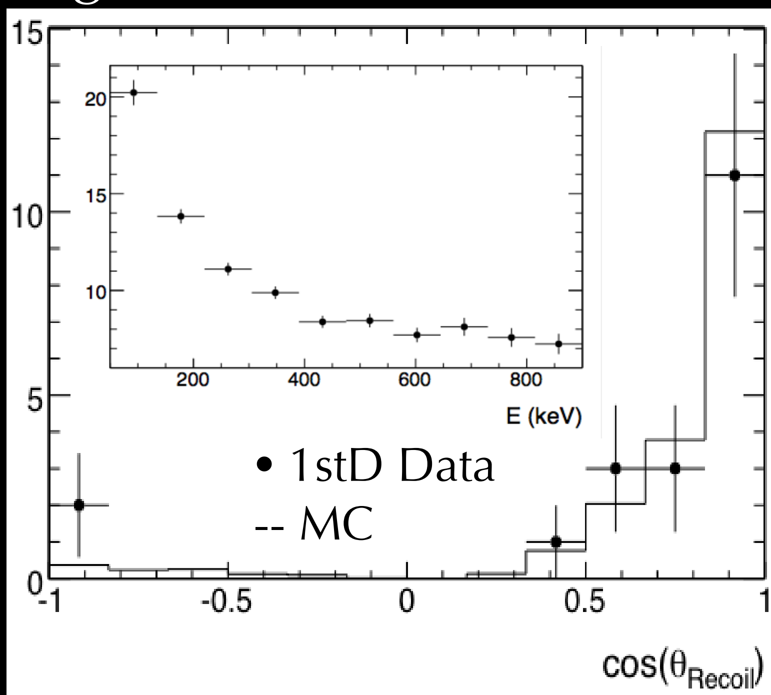
Directionality

2D angle + head-tail from light asymmetry (measure skewness)

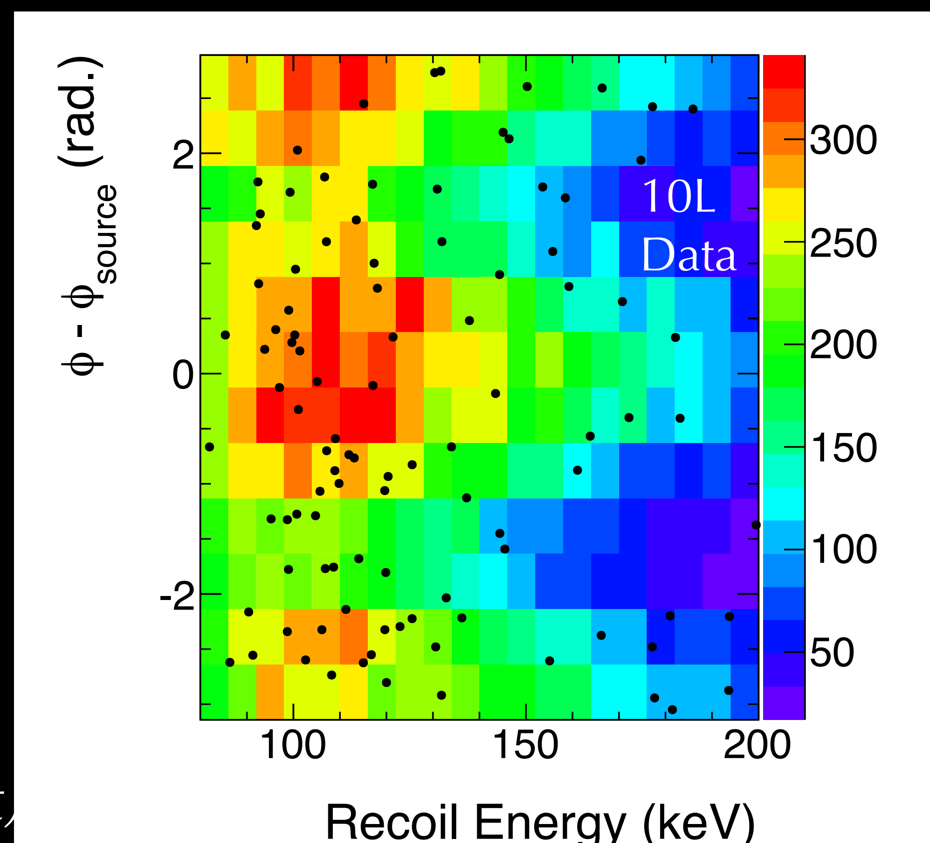




Signed cosine (E>200 keV), 5 cm drift



diffusion has a big impact on head-tail, working on 3D readout for 4-shooter *(J. Battat)*



Ahlen et al., Phys. Lett. B 695 (2011)

1D “sky map” for ^{252}Cf, and “WIMP ” data (E>80 keV),

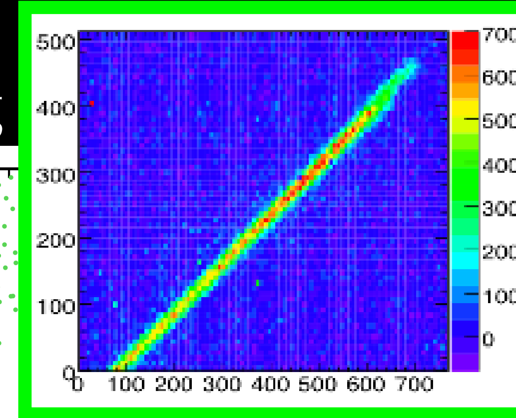
20 cm drift (10L detector)

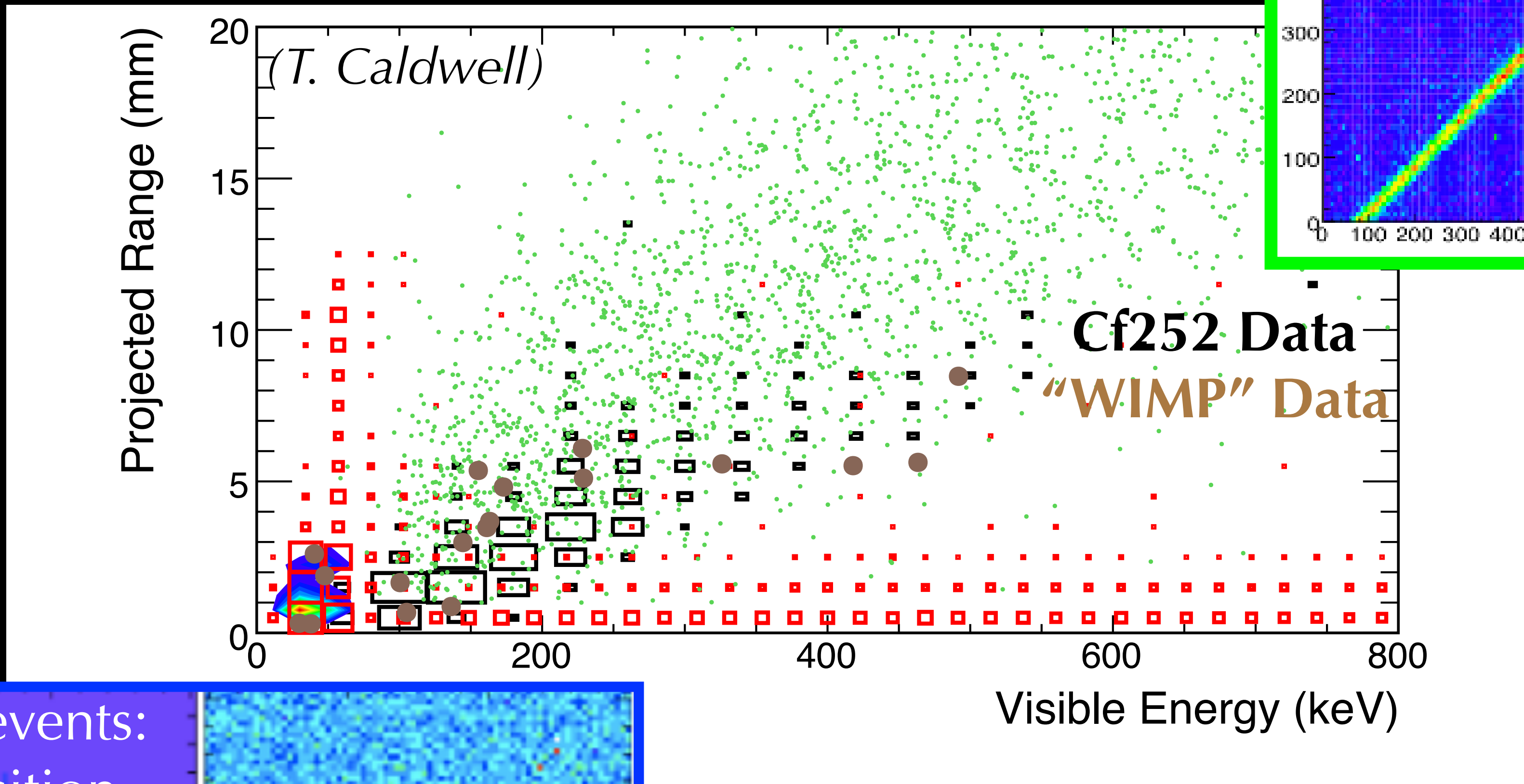
MC: 40° resolution at 80 keVr

(A. Kaboth)

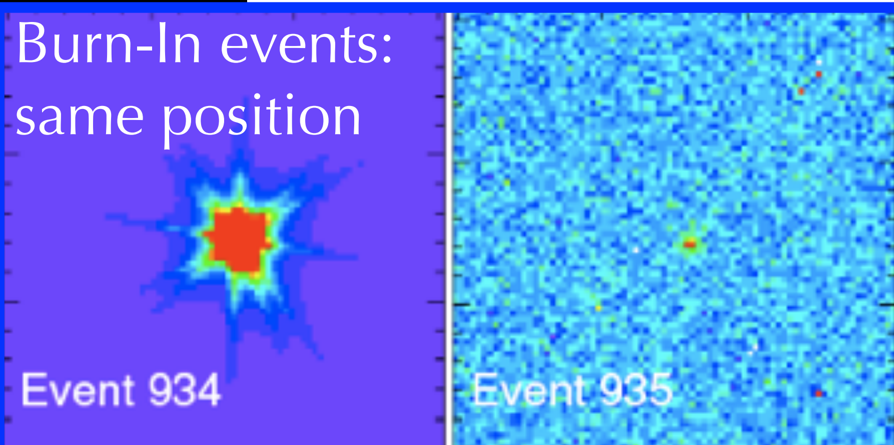
Surface Backgrounds

Alphas:
edge crossing

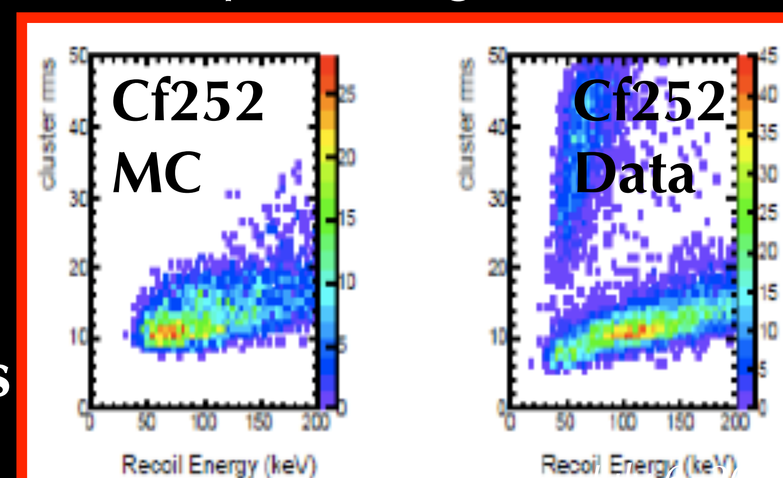




Burn-In events:
same position



"Worms": one hot pixel, large cluster rms

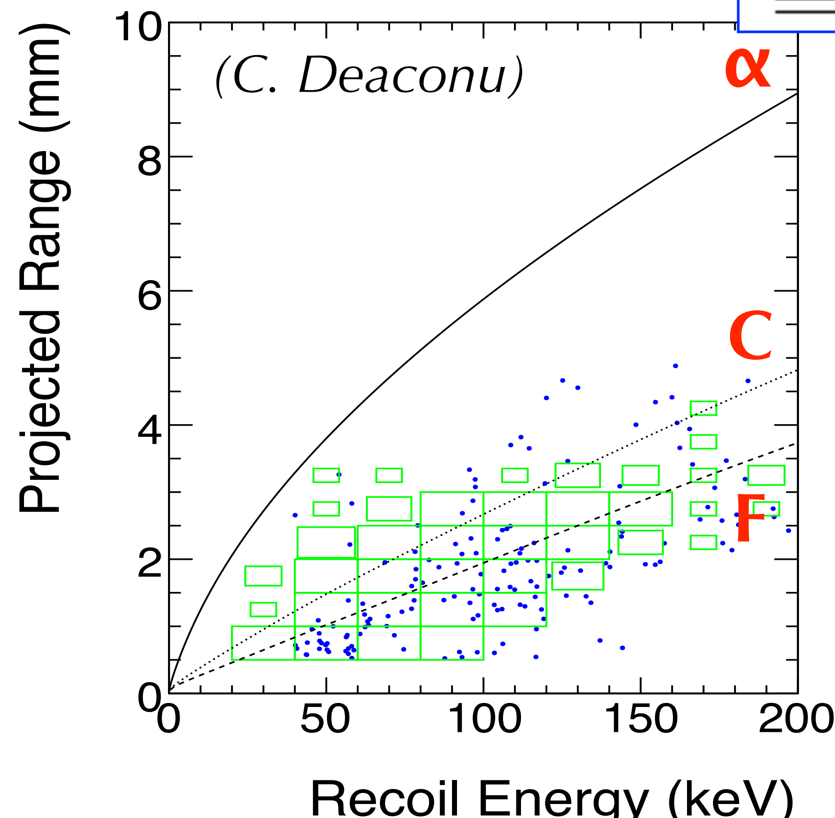


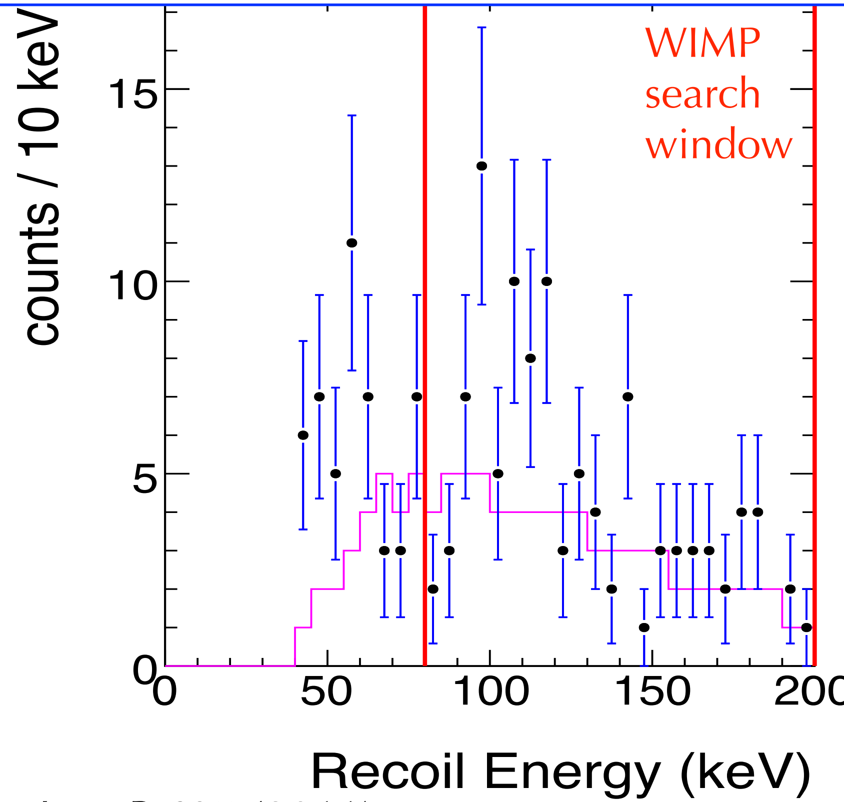
10^4 rejection of backgrounds from range vs. energy strategy, unique to directional detectors

Surface Run Results

nuclear recoil selection cuts set using calibration data

Event Selection Cut	Rate (Hz)
All Tracks	0.43
Residual Bulk Images	0.15
CCD Interactions	4.4×10^{-3}
Alpha Candidates	8.2×10^{-5}
Nuclear Recoil Candidates in $80 < E_R < 200$ keV	5.0×10^{-5}





S. Ahlen et al., Phys. Lett. B 695 (2011)

surface neutron flux measurement: T. Nakamura, T. Nunomiya, S. Abe, K. Terunuma, and H. Suzuki, J. of Nucl. Sci. and Tech. 42 No. 10, 843 (2005).

observed 105 events above 80 keV threshold chosen for dark matter search (threshold chosen for max. recoil efficiency), consistent with neutron prediction (74 events)

Surface Run Limit

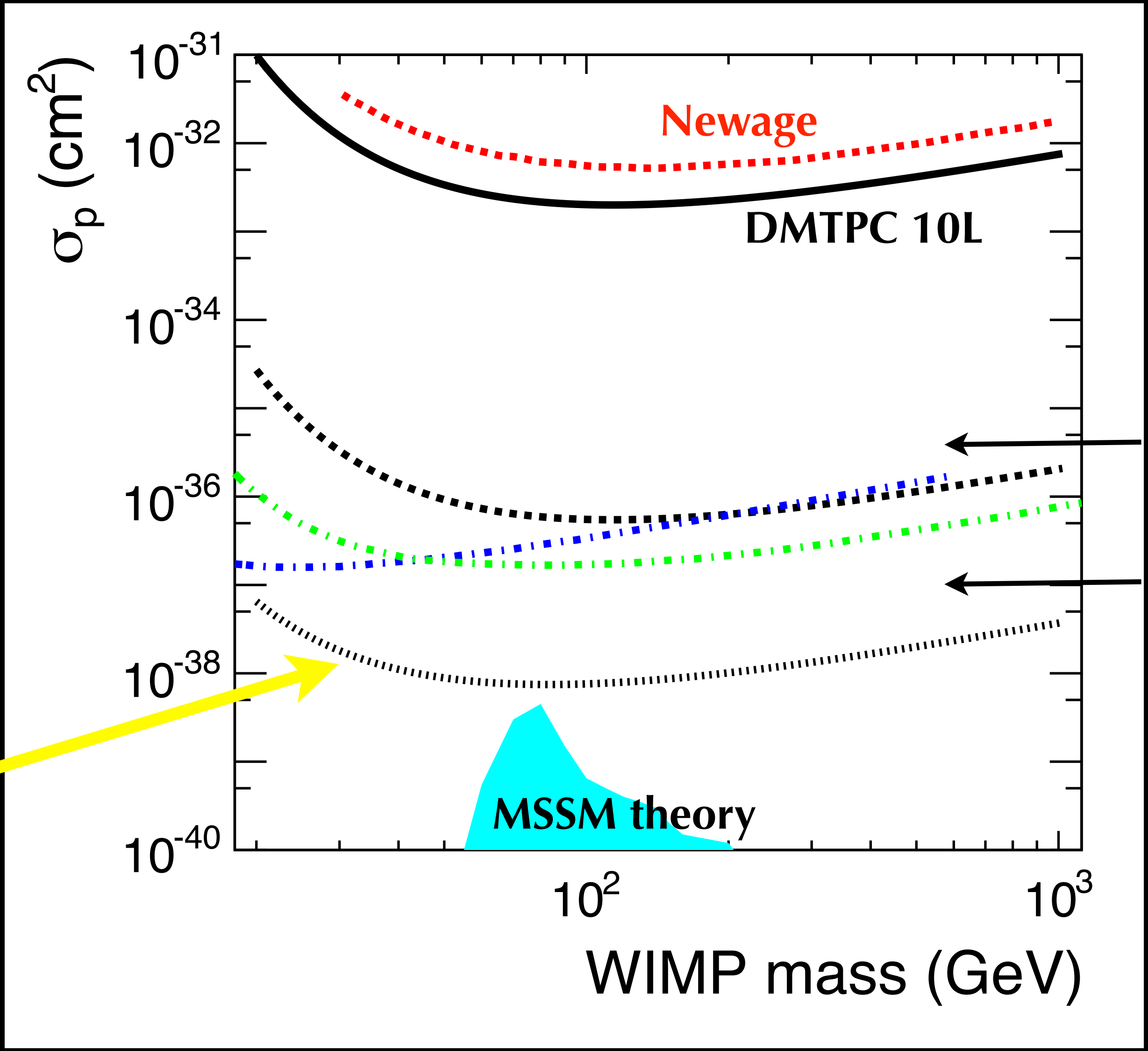
NEWAGE limit (Kamioka)

K. Miuchi et al., Phys.Lett.B686:11-17 (2010)

DMTPC limit (surface, 38 gm-day)

S. Ahlen et al., Phys. Lett. B 695 (2011)

$1m^3$ at WIPP (DMTPCino) projected sensitivity



directional results

DRIFT, *arXiv: 1010.3027*

1D results
COUPP, IDM2010

Next steps for DMTPC: low-background detector R&D, go 2150′ underground at WIPP, DMTPCino at WIPP ($1m^3$)


United States
Department of Energy
Waste Isolation Pilot Plant


2150 feet
underground


July 2010

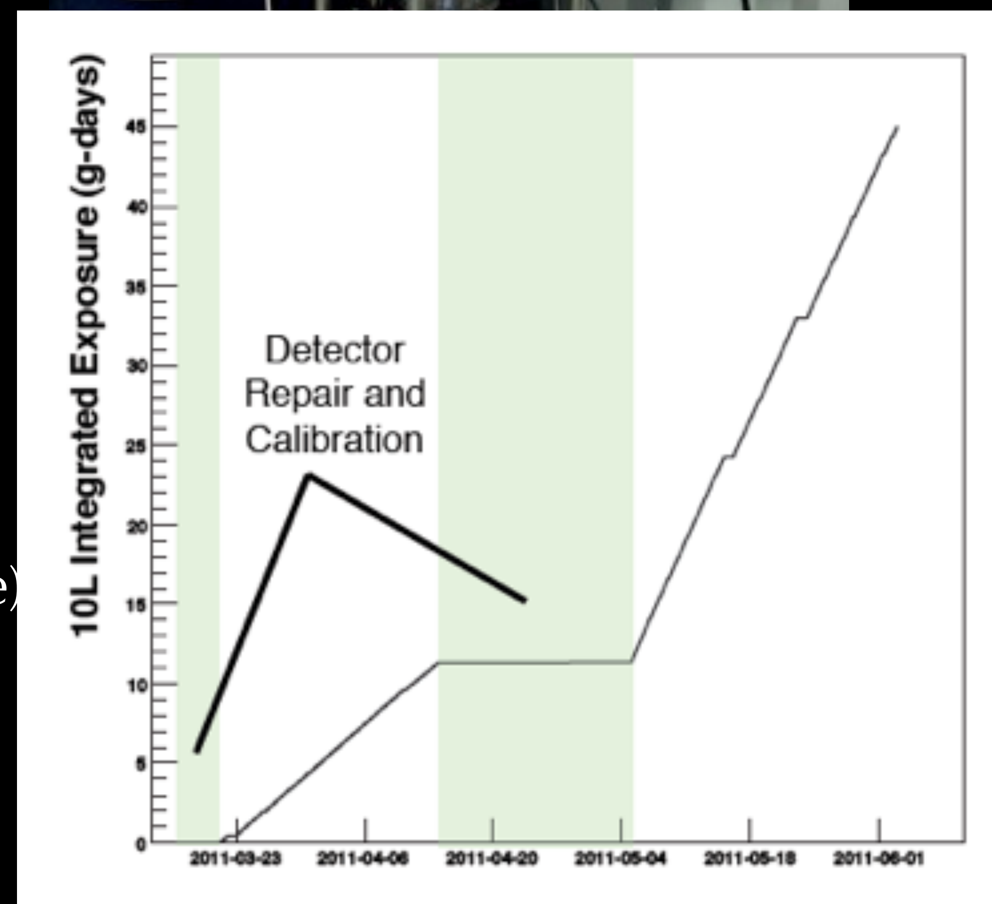
Yamamoto Laboratory at WIPP

October 2010

major effort at WIPP is to measure the in-situ detector backgrounds

“WIMP search” run started in March, typically 60-70% livetime (1 second exposure)

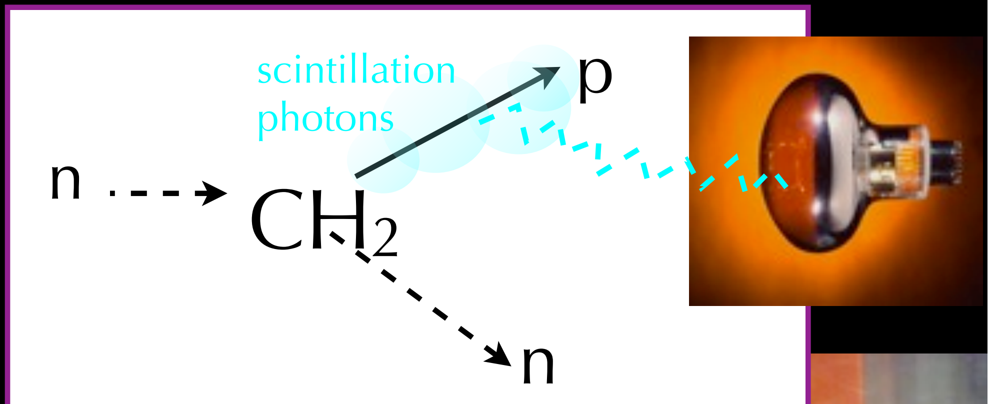
blind analysis, selection cuts defined on AmBe calibration data (Jan.-Mar.)

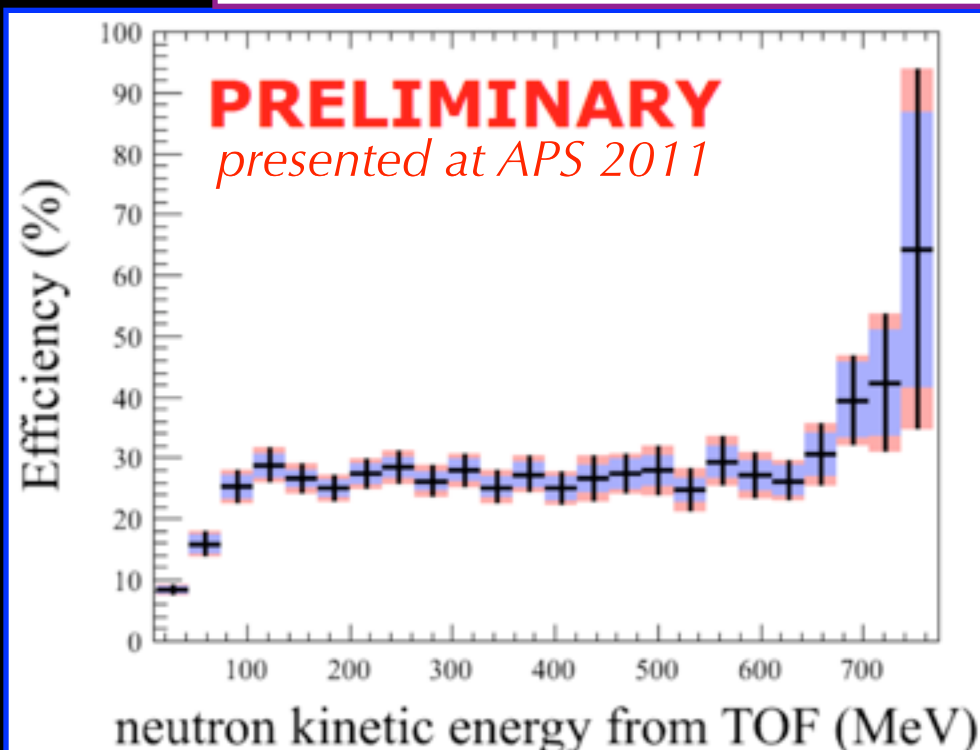


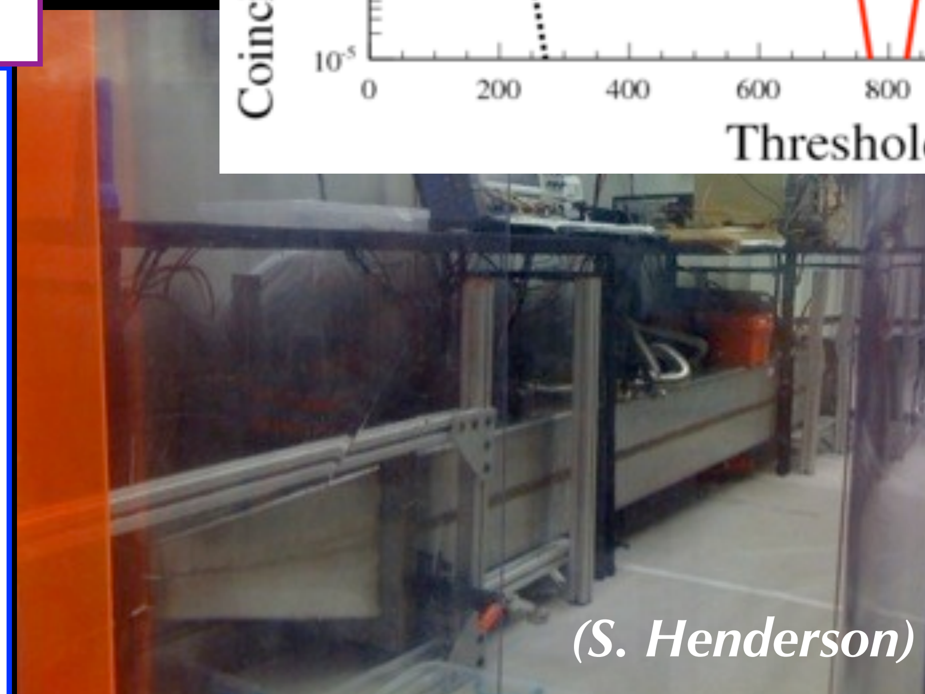
Active Neutron Veto Prototype

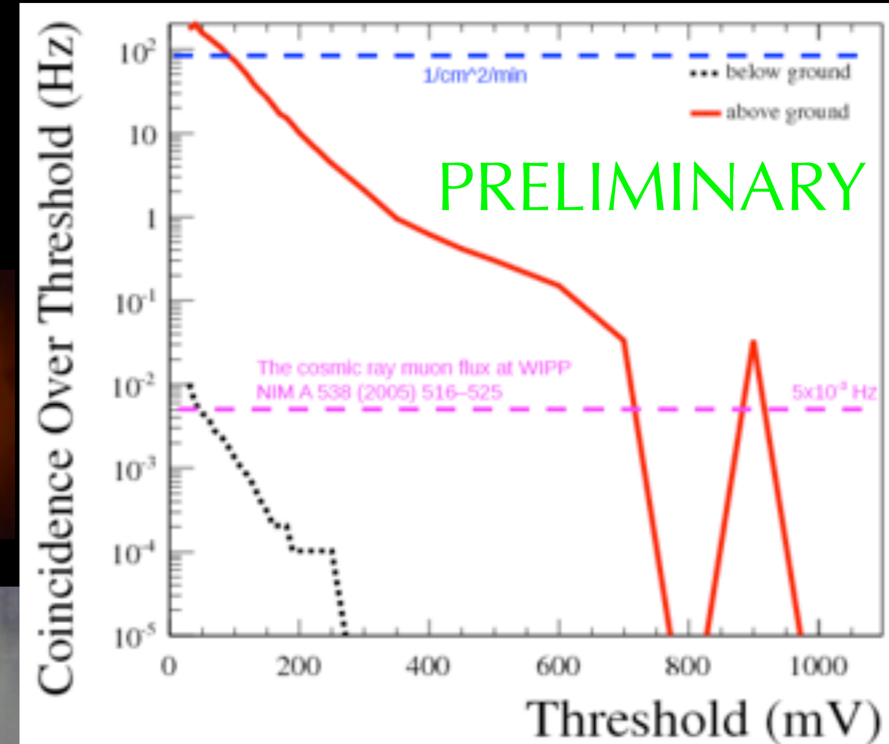
measure proton light, reconstruct neutron E

liquid scintillator active volume









prototype calibrated at LANL WNR beam test, deployed since August 2010

goals: *measure* high energy neutron flux+energy spectrum underground at WIPP

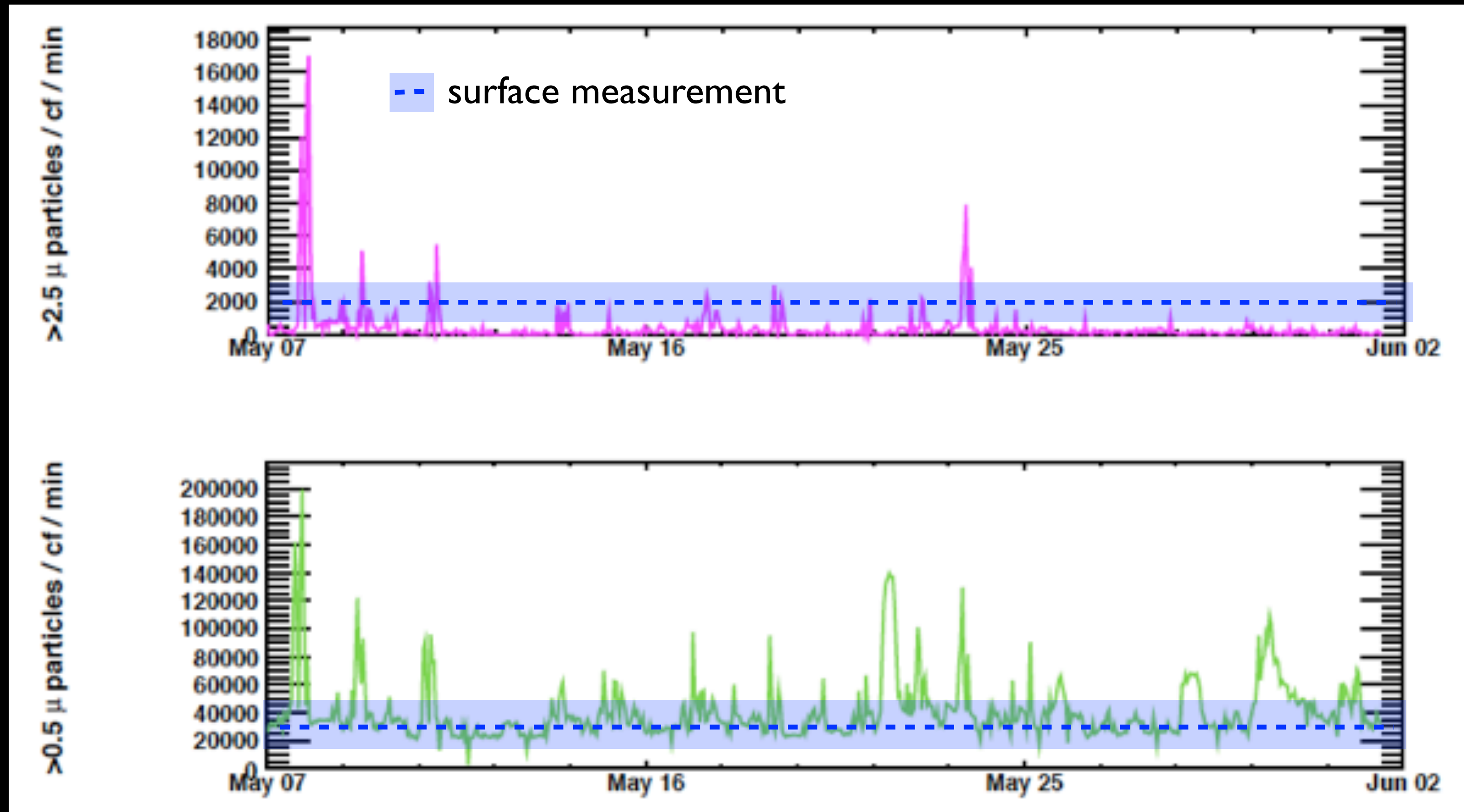
Underground Laboratory Conditions

WIPP measured background rates: *(I. Esch)*

- 21.6x lower gamma rate(25 -1600 keV) than surface
- lower limit of 415x lower neutron flux (predict x10^5)
- upper limit on Rn rate of <7 Bq/m^3
- muon flux reduction of 10^5 (1.6 km.w.e.)

NIM A 538 (2005)

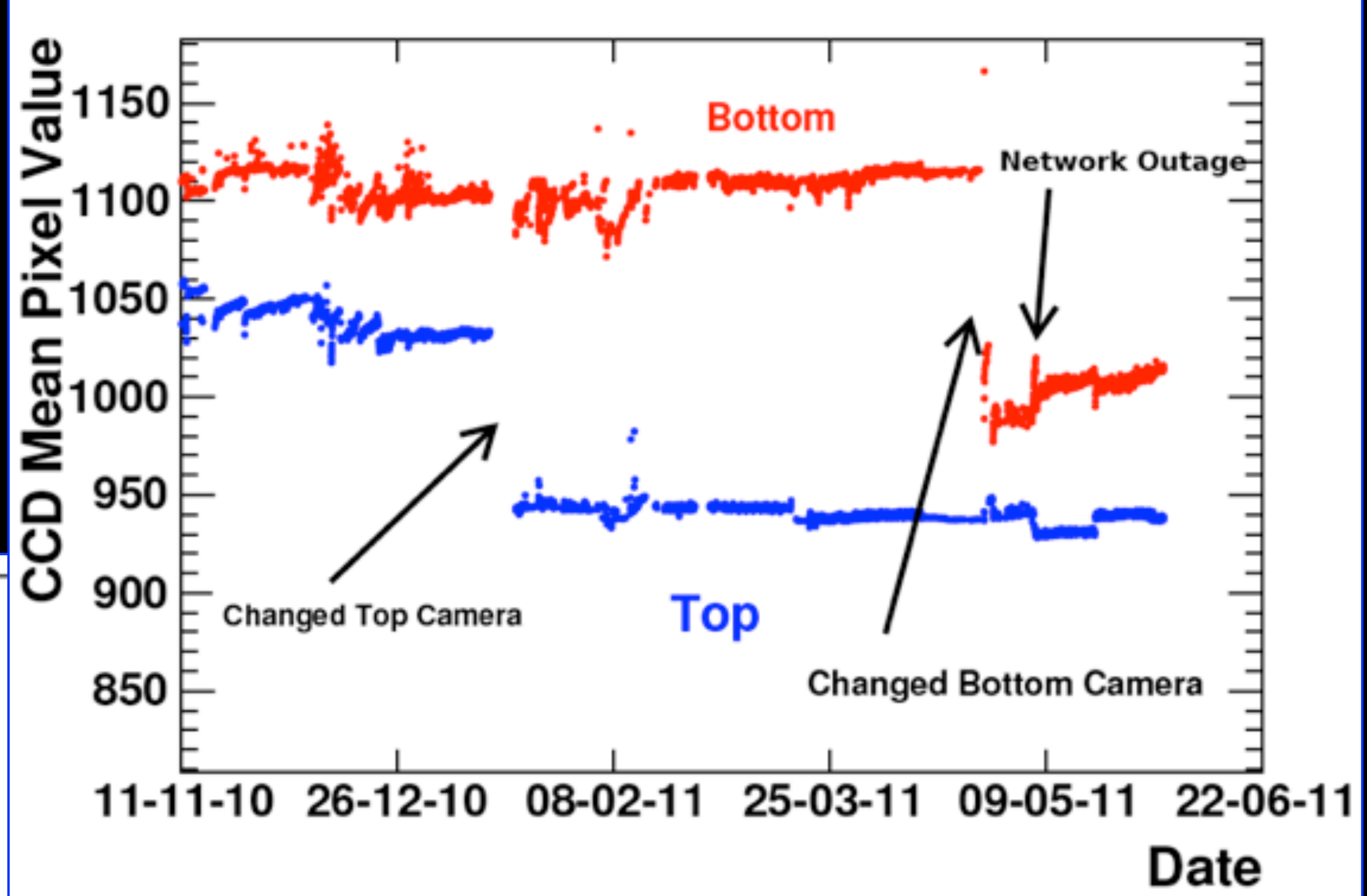
- lab particle count comparable to measured surface rate (at MIT)

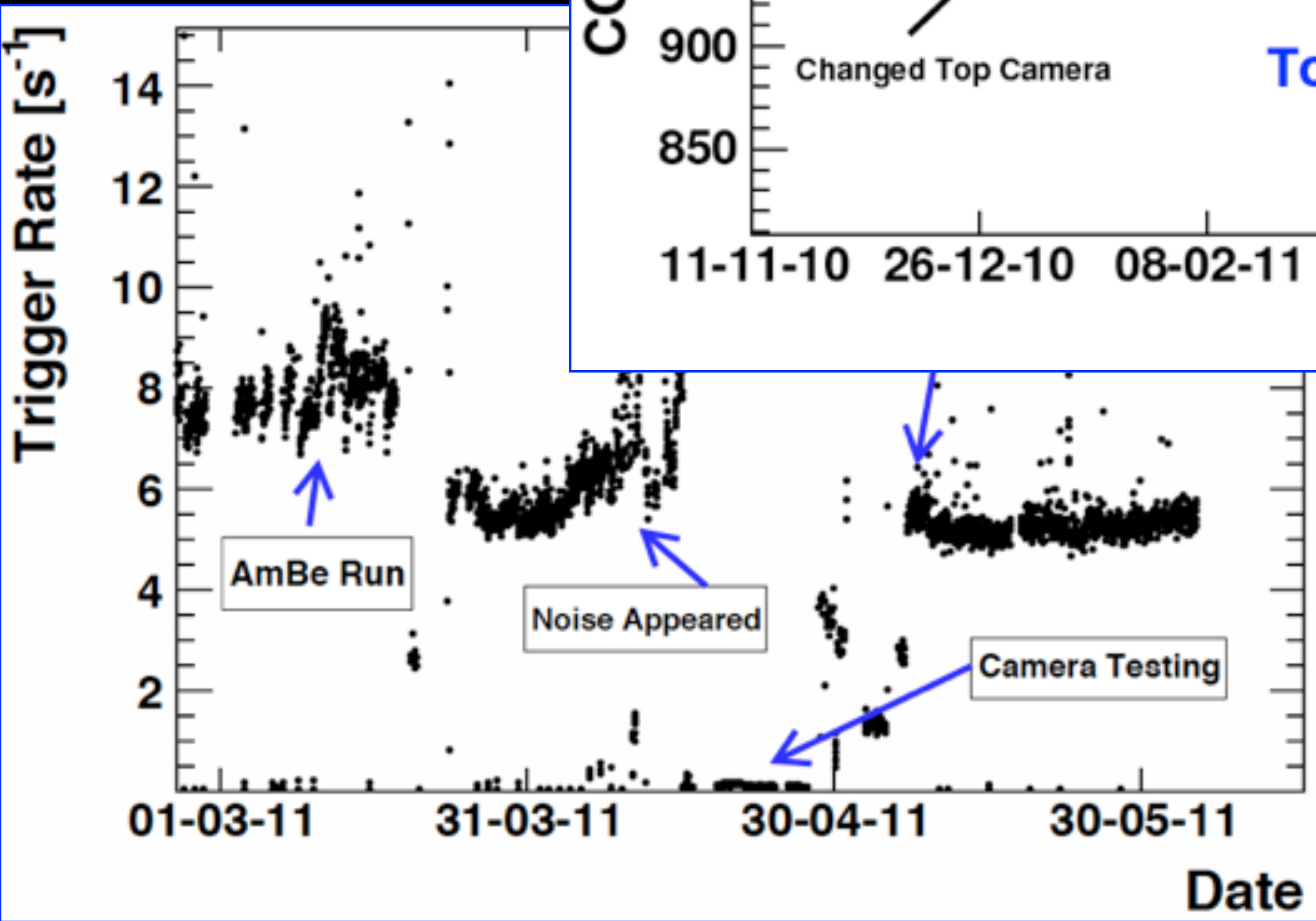


	at the WIPP			Range in Soil			Ratio
Element	Mass Spec. $[\frac{\mu g}{g}]$	Gamma Spec. $[\frac{\mu g}{g}]$	Avg $[\frac{\mu g}{g}]$	low $[\frac{\mu g}{g}]$	high $[\frac{\mu g}{g}]$	typical $[\frac{\mu g}{g}]$	Soil vs. WIPP
Uranium	0.048	<0.37	0.048	0.5	2.5	1.5	30
Thorium	0.08	0.25	0.25	1.2	3.7	2.4	10
Potassium	784	182	480	500	900	700	1.5

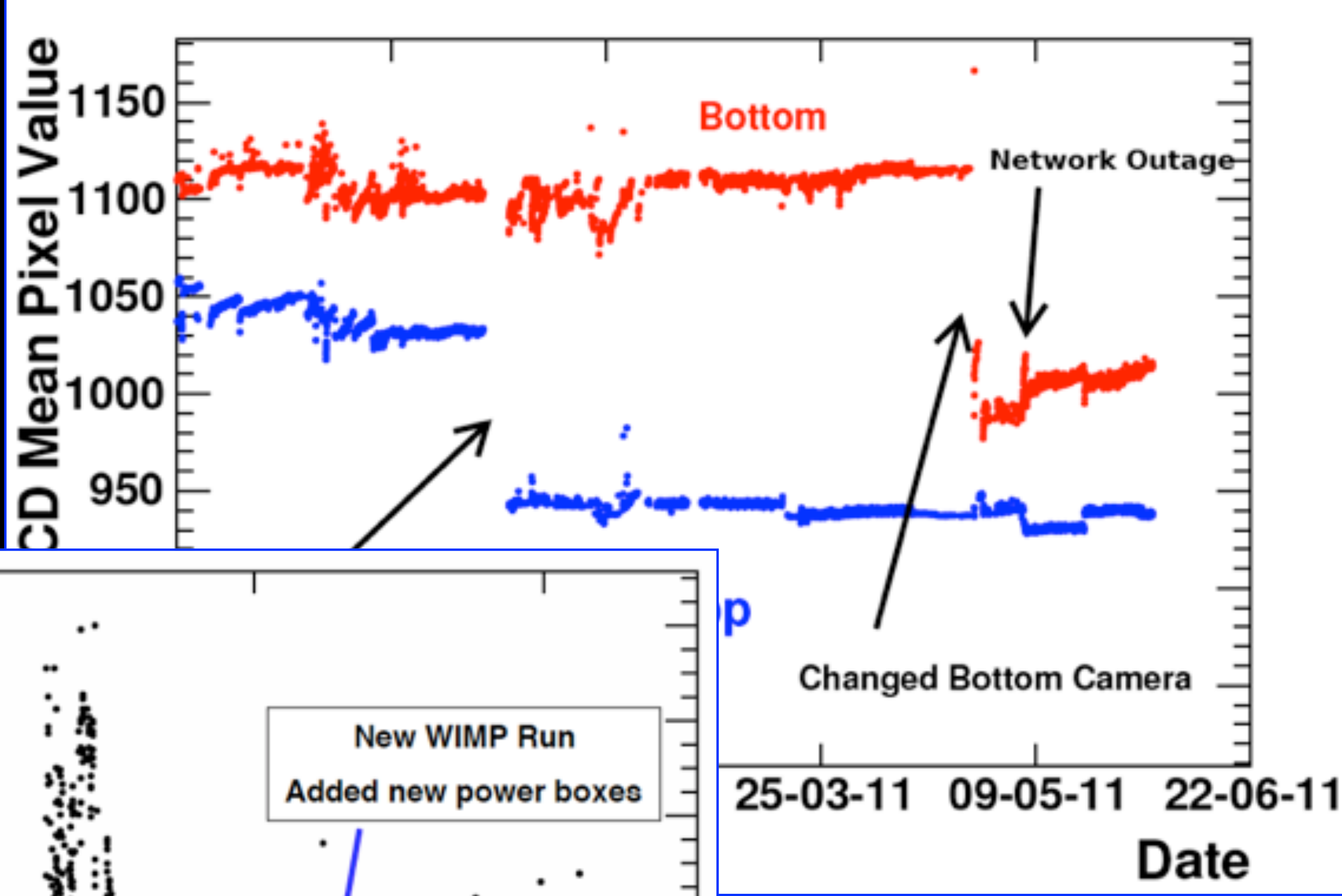
Table 4.21: Natural Radioactivity at the WIPP underground [WEB98].

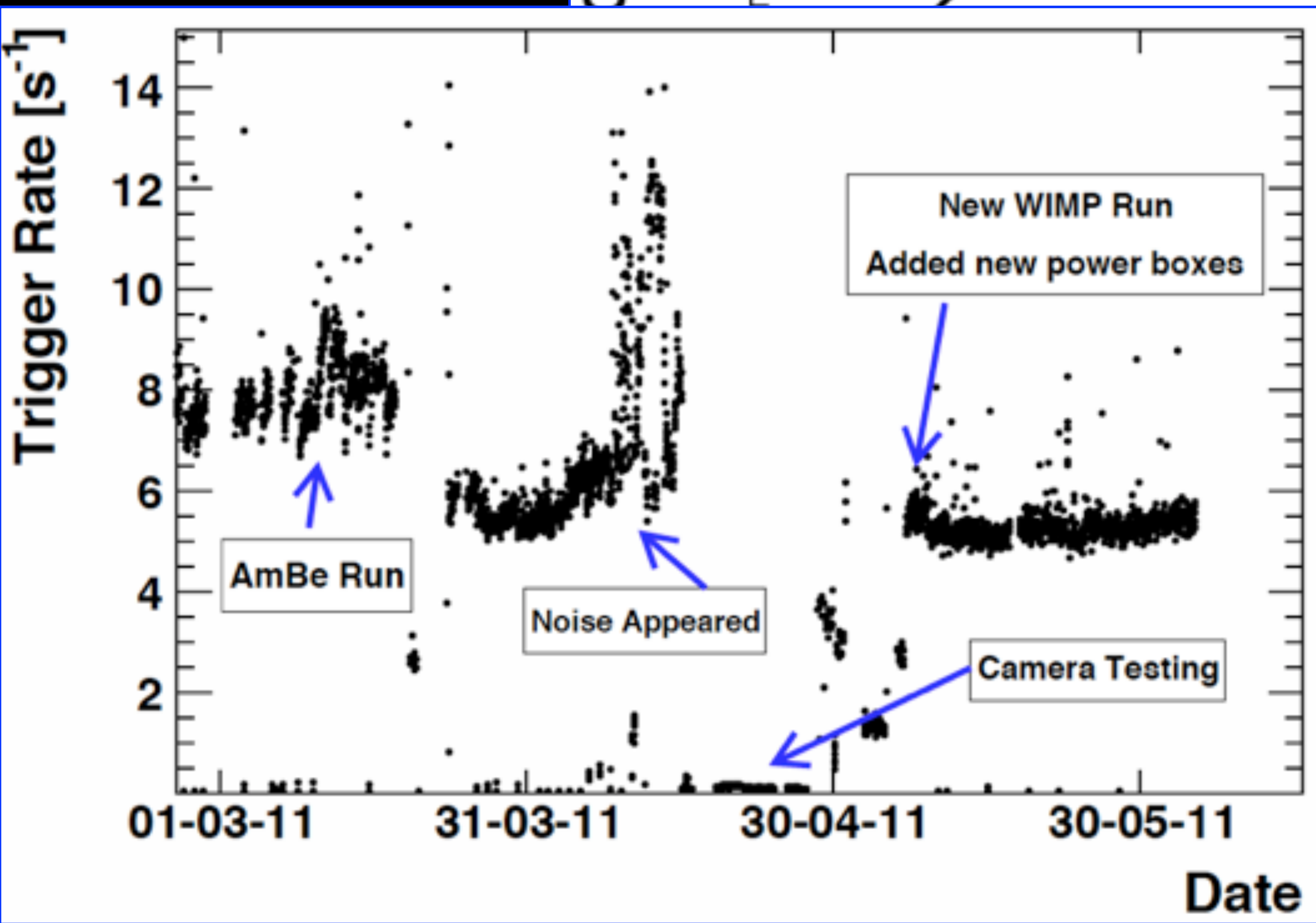
Detector Stability





Detector Stability

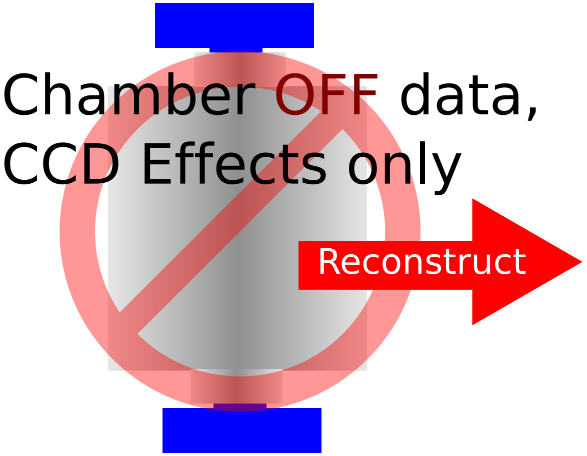


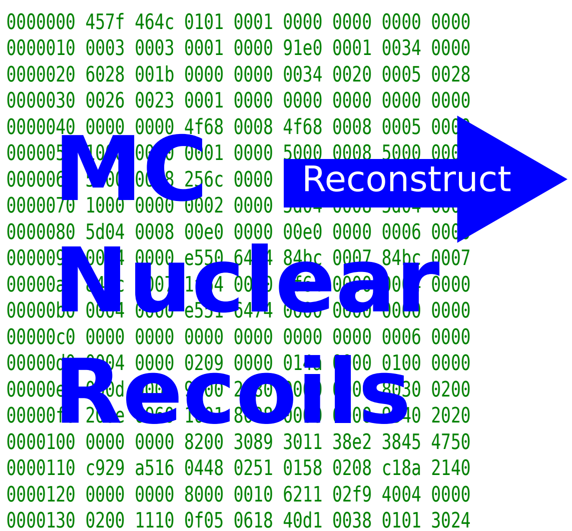


July 6, 2011

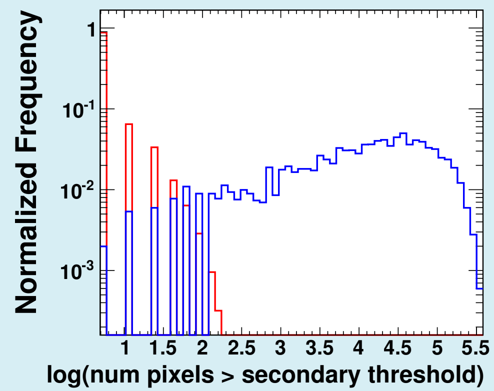
CCD Artifact Rejection Improvements

(C. Deaconu)





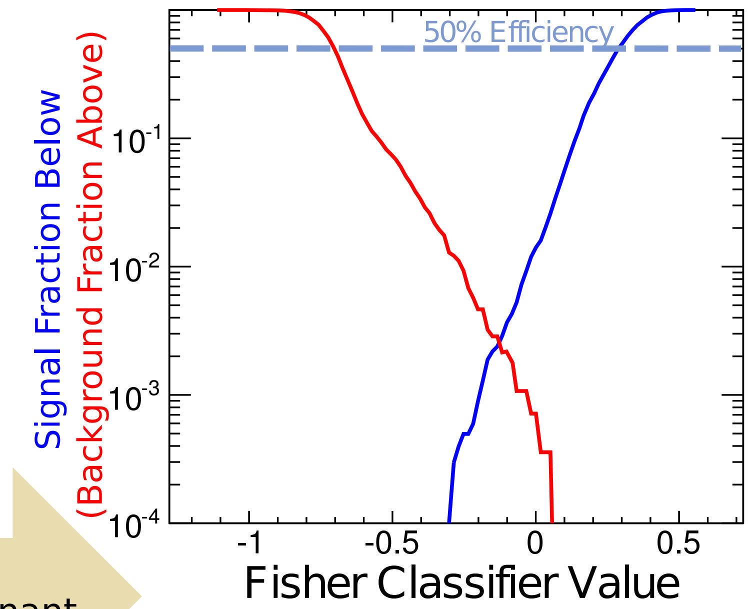
Discriminating Variables



- projected range
- pixel integral
- maxpixel
- pixel RMS
- num pixels
- num pixels > thresh
- num maxpixel neighbors > thresh

Fisher Discriminant

Discriminating Parameter

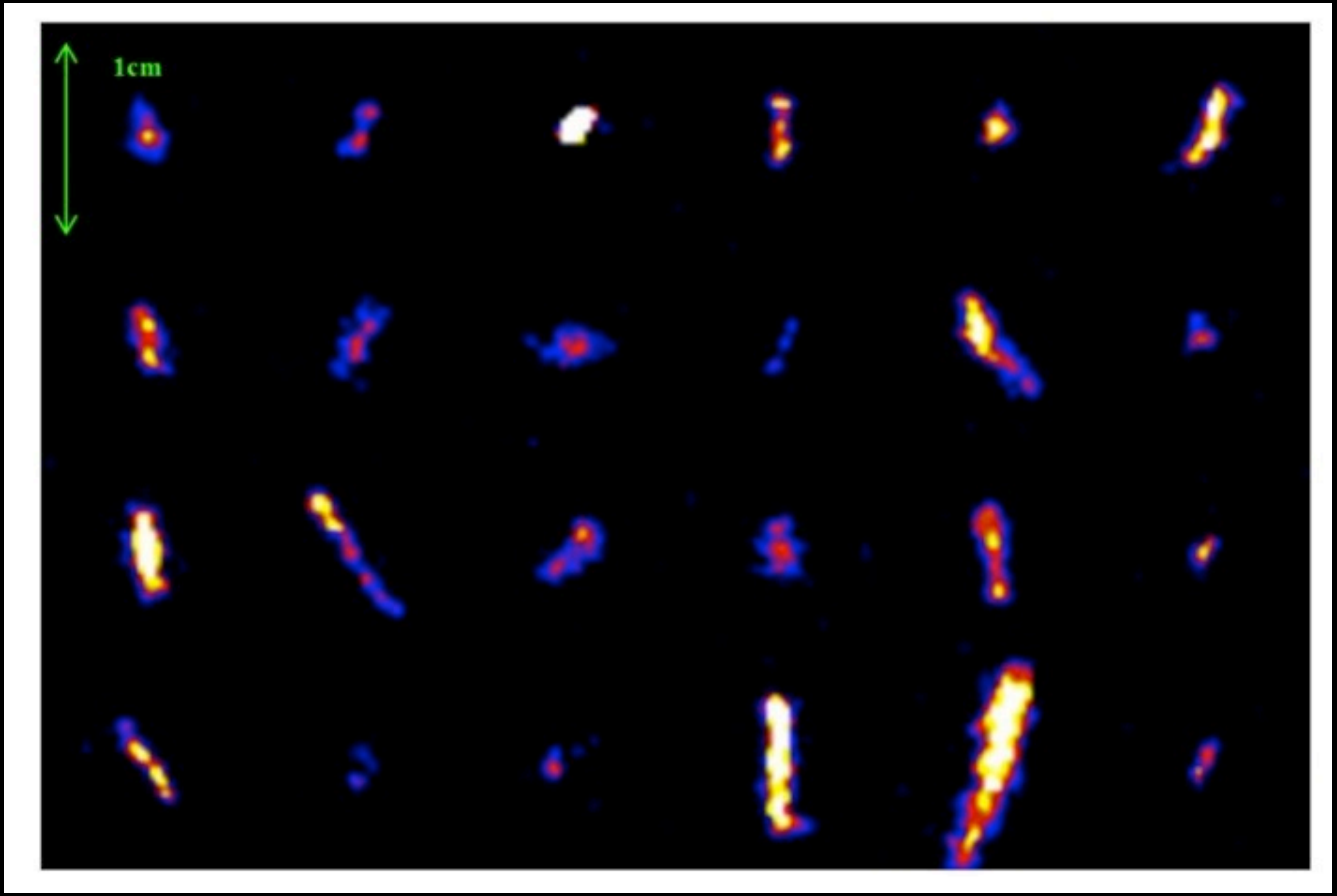


Fisher Discriminant is implemented with the ROOT TMVA framework, so can be easily swapped for a different multivariate algorithm if we find that necessary in the future.

now collect dedicated “cosmic” data set during gas re-fill for background calibration

CCD Artifact Rejection Improvement R&D

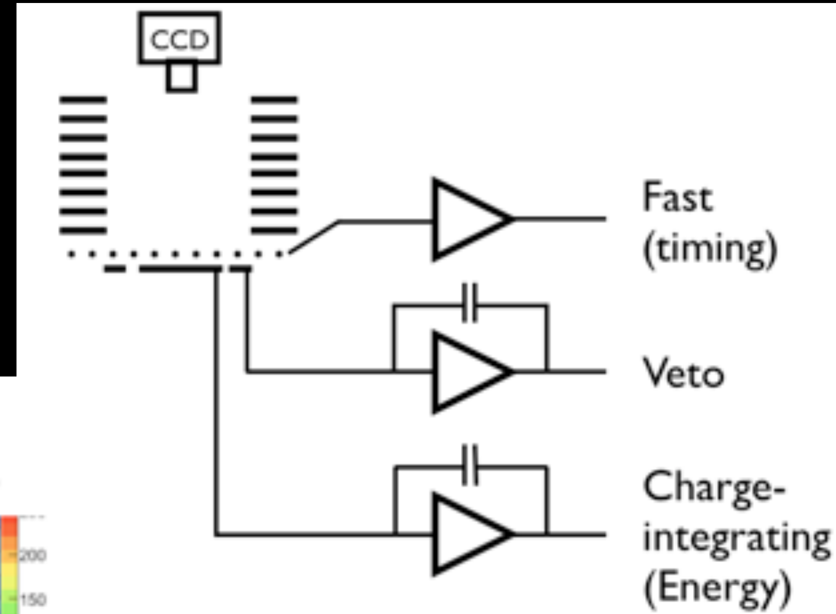
(H. Tomita, A. Inglis)

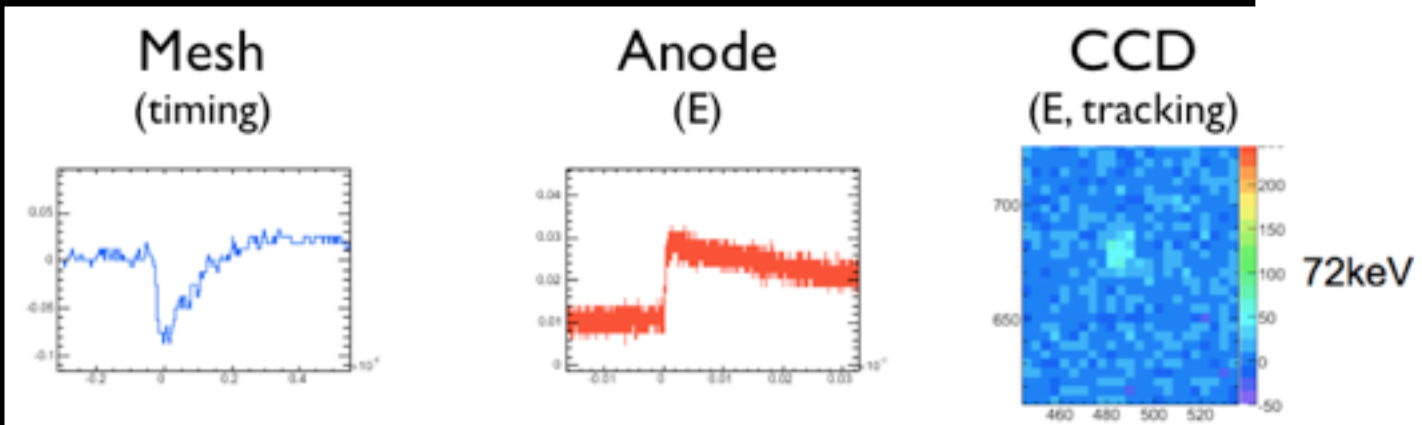


move to back-illuminated CCDs (EMCCD here) to eliminate RBIs

Redundant Readout R&D

for fiducialization, tracking in z (2D-> 3D) and background rejection

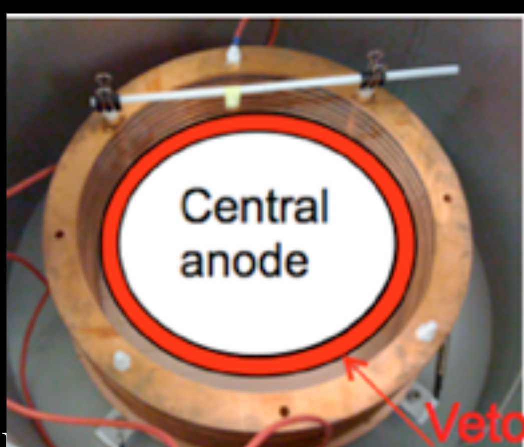


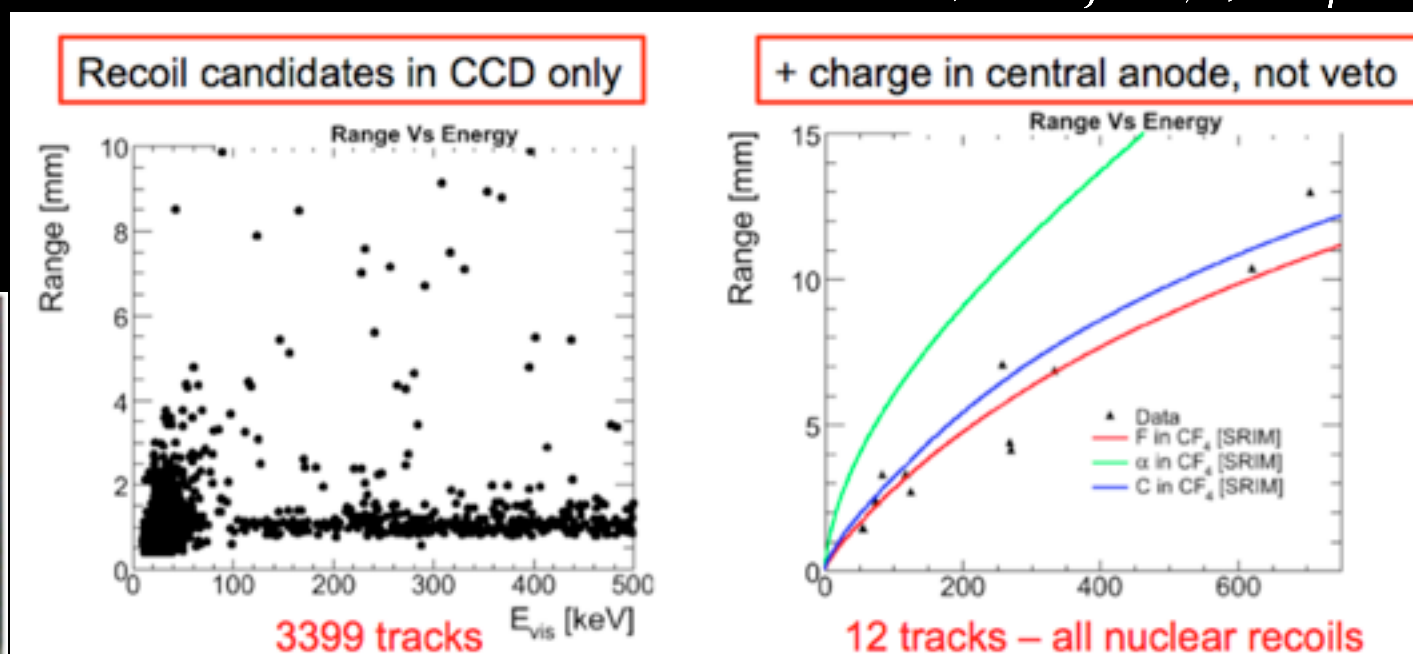


(D.Dujmic, J. Lopez)

1. x-y fiducialization

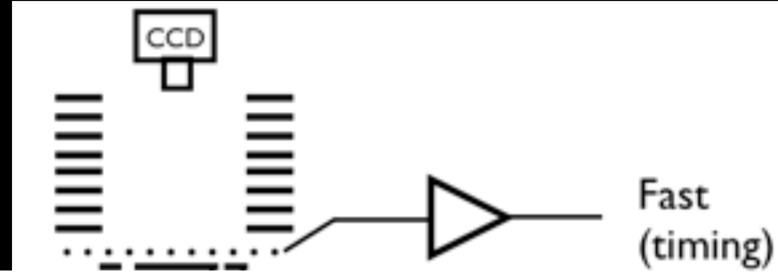
require no signal in veto ring of anode plane

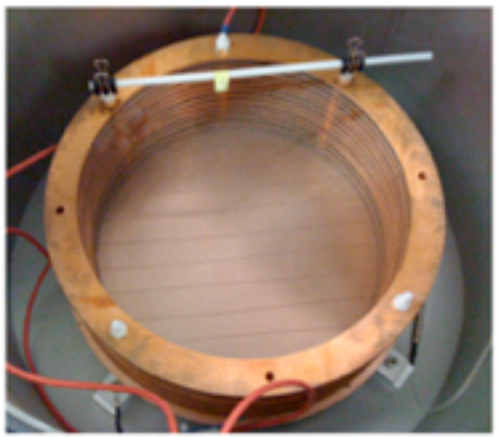




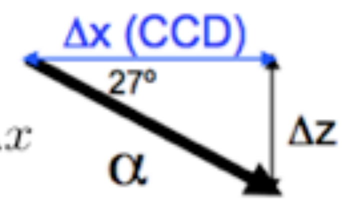
Redundant Readout R&D

2. tracking in z (drift direction)



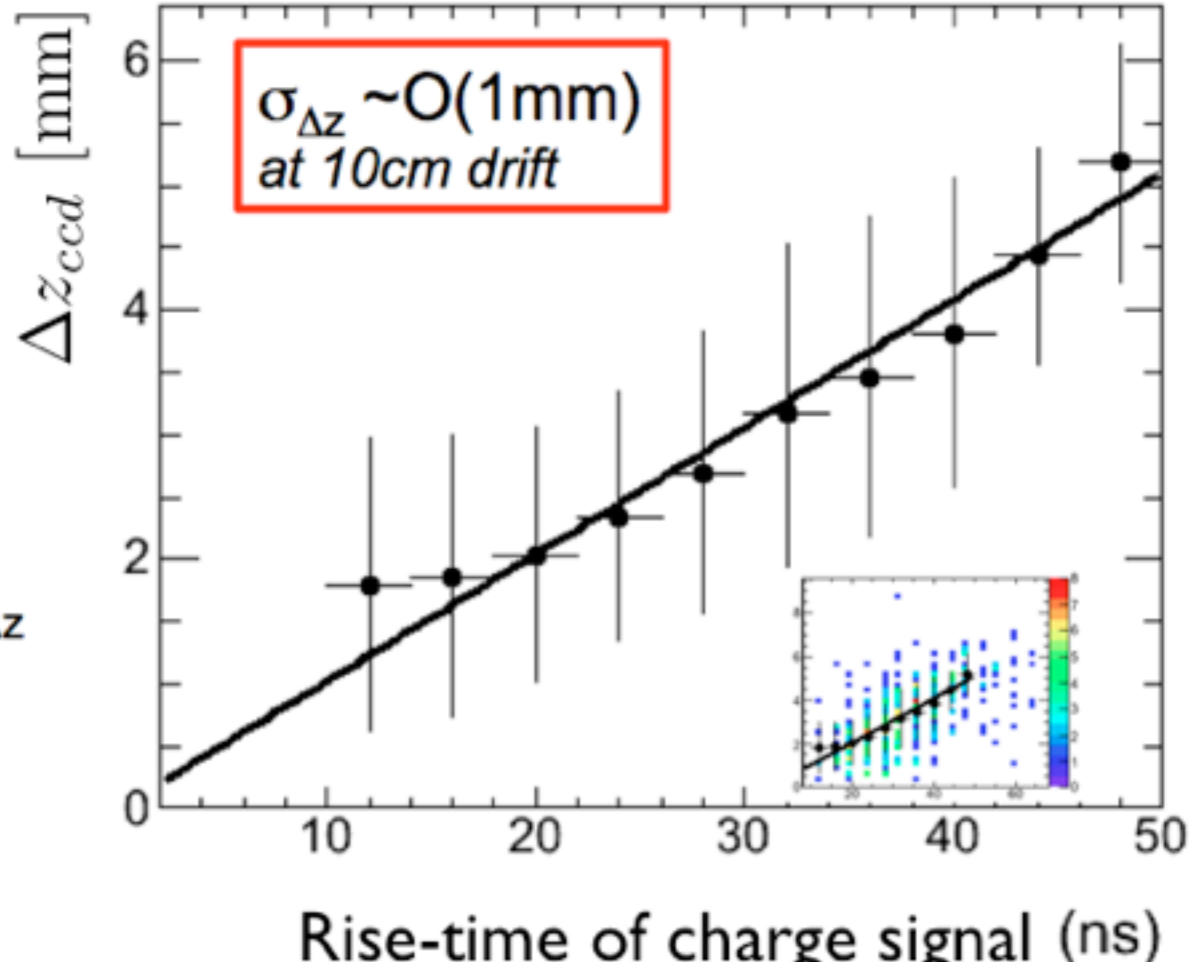


$$\Delta z = \tan(27^o)\Delta x$$



- vertical error bars = RMS (spread due to track angles + detector resolution)

- Bias toward longer tracks in CCD at small Δz (due to search algorithm in CCD - not Δt issue)



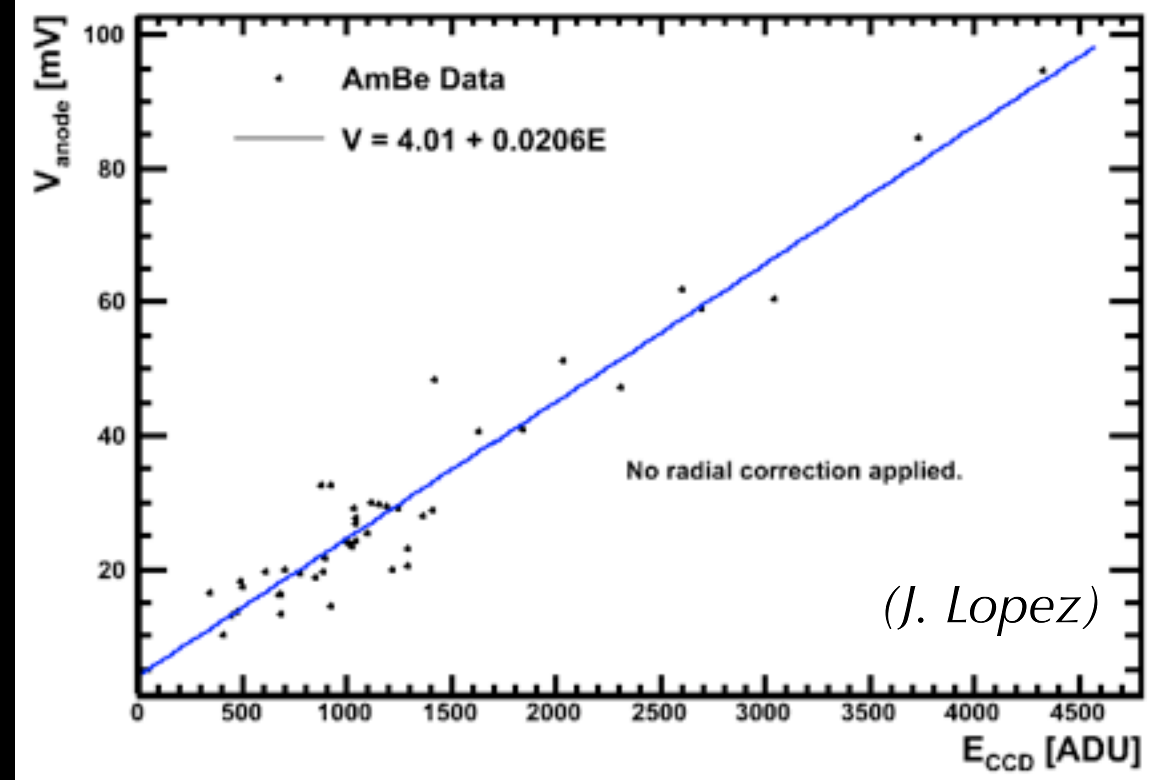
comparable tracking resolution in z (from charge) as in x-y (from CCD)

Redundant Readout R&D

3. background rejection

10L detector instrumented with charge readout of anode and mesh in December 2010 (WIPP)
(surface run analysis used no charge data)

(no veto ring on 10L anode)



preliminary bifurcated analysis result:

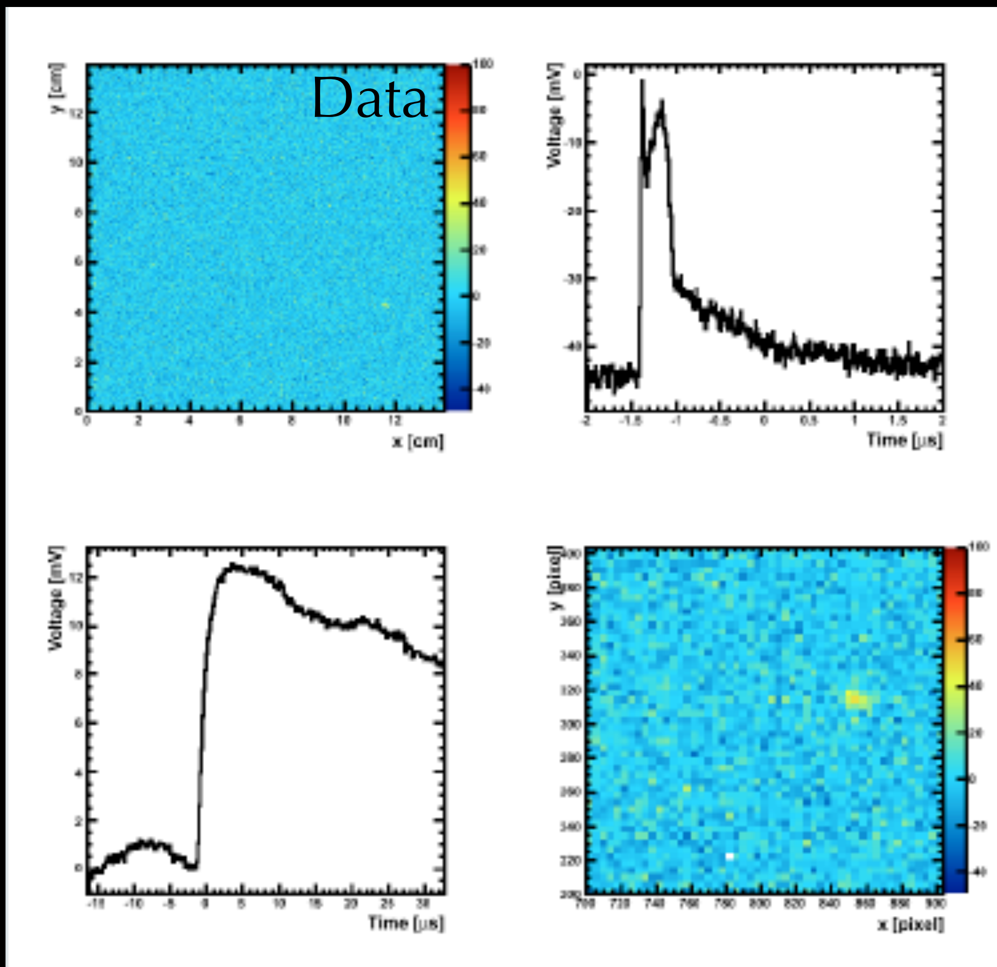
Cut	Pass CCD RBI	Pass CCD RBI & Artifact
Fail NR Charge	400	244
Pass NR Charge	4	2

require charge consistent with nuclear recoil in mesh rise time, and energy match to within 35 mV in anode amplitude, for 80 < E_recoil < 200 keVr

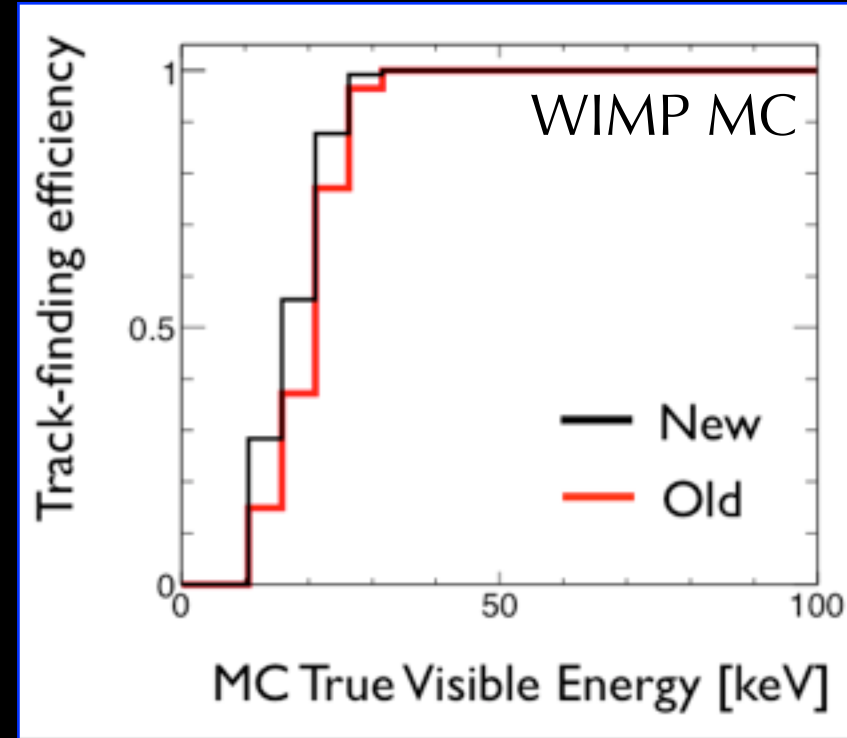
x100 rejection of non-nuclear recoil backgrounds from charge readout

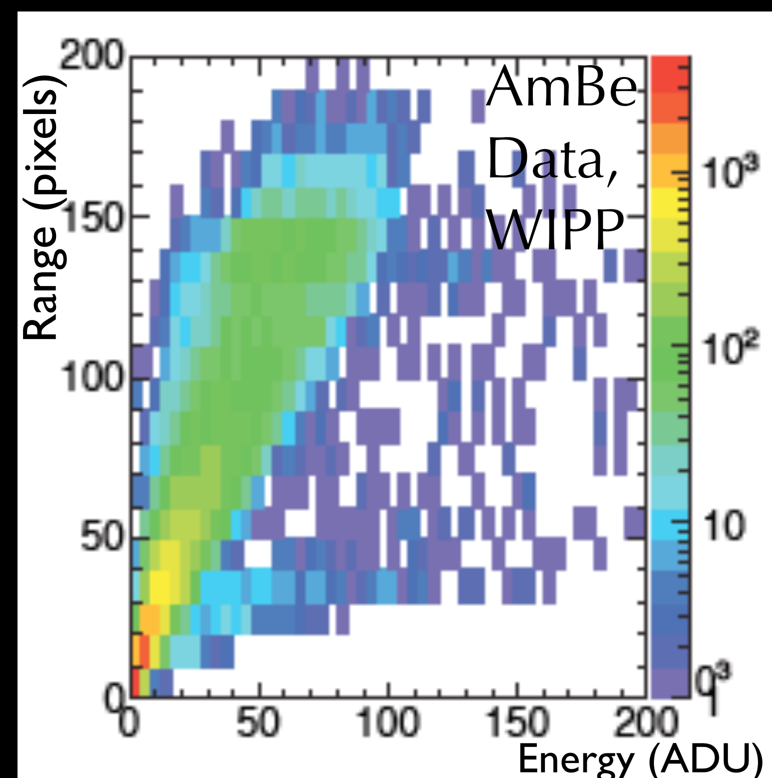
Energy Threshold Improvements

from analysis improvements to cluster-finding algorithm, and running at lower pressure (60 torr cf 75 torr), increased gain (~20 ADU/keV)



candidate **25 keV** nuclear recoil event from AmBe calibration data underground



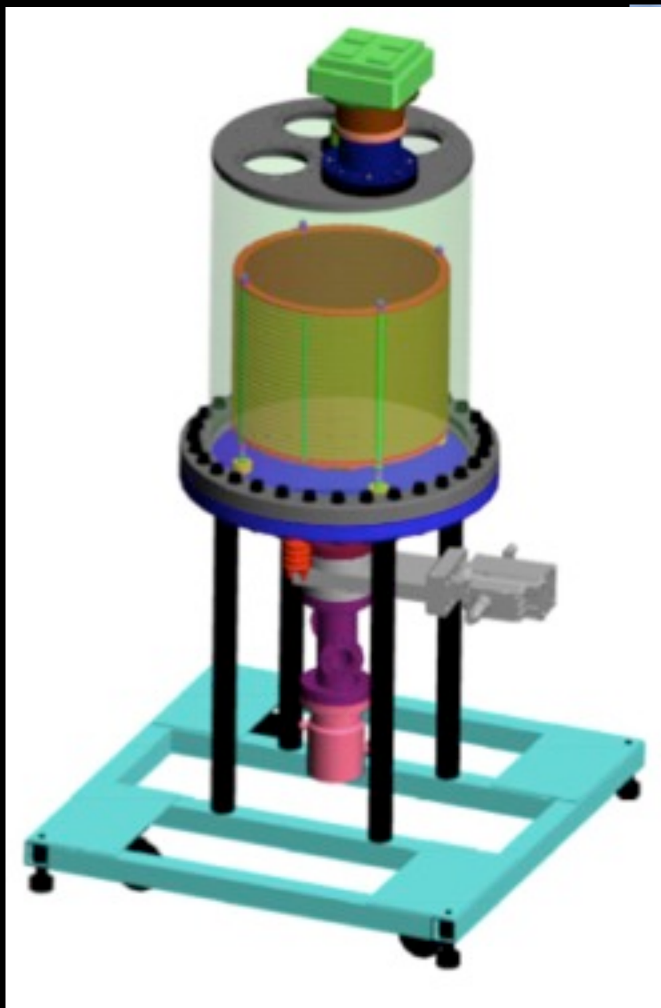


needed for low mass WIMPs!

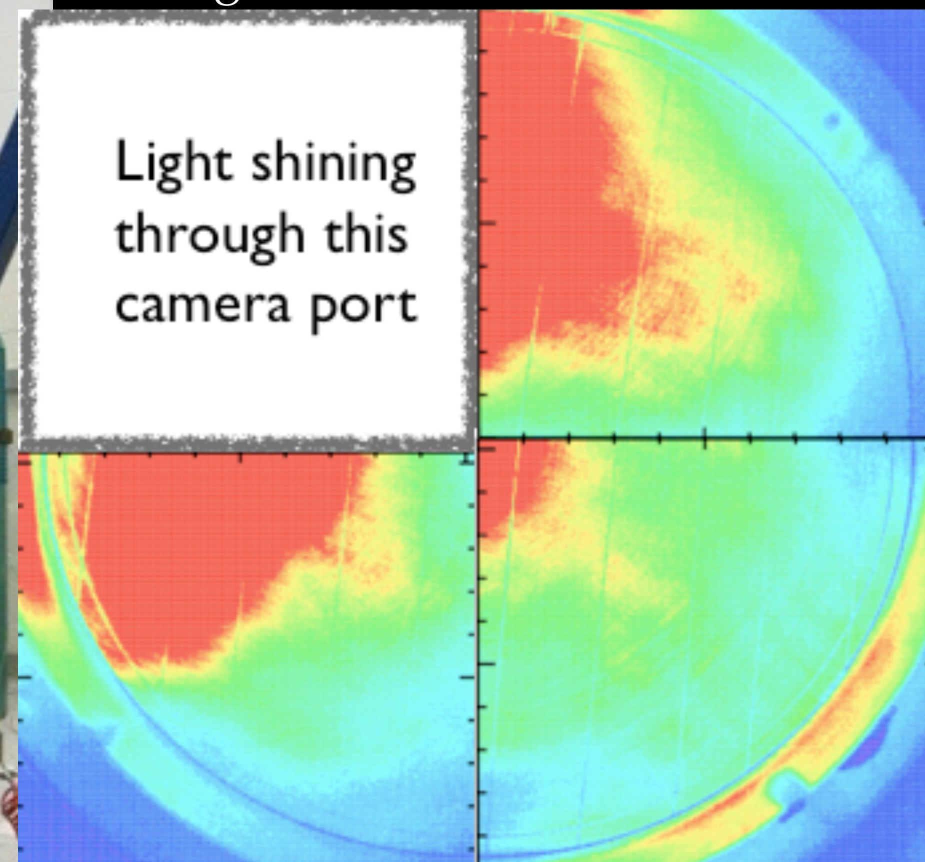
DMTPC Next Steps: Deploy 4-Shooter Detector at WIPP

Goal:

prototype for multi-camera readout, *with CCDs, charge readout+veto, PMTs (20L)*



first light:



(S. Henderson, J. Battat)

Installation Fall 2011 at WIPP, surface calibration run suite underway now (MIT).

DMTPC Next Steps: DMTPCino 1m^3 Detector at WIPP

Goal:

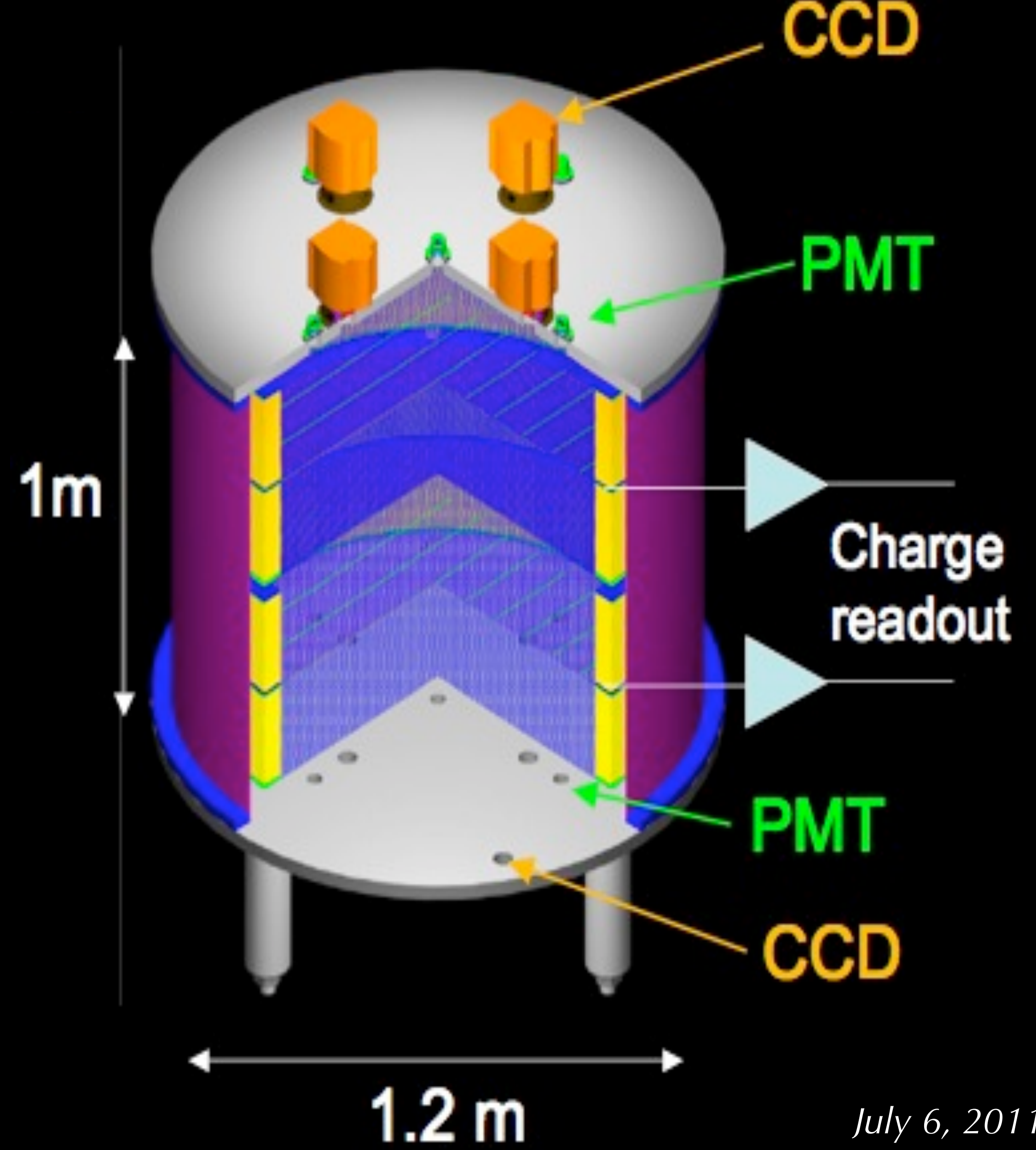
prototype for O(10 kg) fiducial mass detector, with 1 m^3 (0.25 kg) instrumented now

Require significant R&D on

(i) readout
(ii) optical system
(iii) directional
(iv) backgrounds
(v) scalability

Proposal for capital funded by NSF and DOE (2010).

Collaboration has realized we need to grow in order to field detectors at WIPP and build DMTPCino.



Directional Detection Future

Eventually: large detector, 10^{-46} cm^2 sensitivity,
what else can it measure?

MiniBooNE:
6 x 6 x 6 m^3

DMTPC Observatory
16 x 16 x 16 m^3

1 ton of CF_4
@50Torr

MINOS:
15 x 13 x 30 m^3

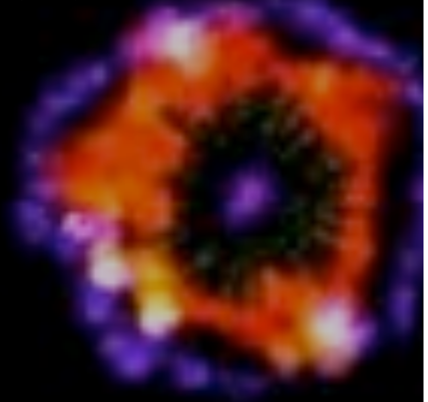
SNO:
21 x 21 x 34 m^3

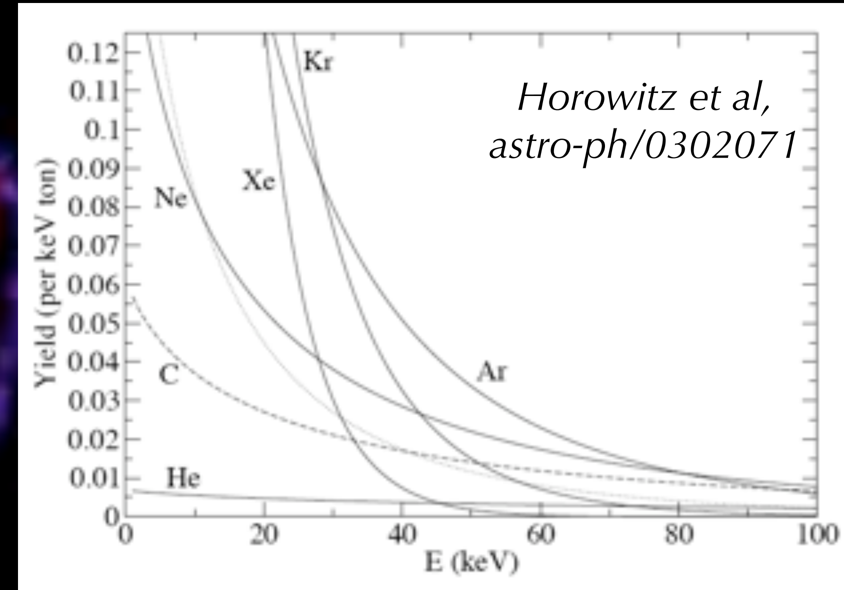
SuperK:
40 x 40 x 40 m^3

detector size for 10^{-44} cm^2 SI sensitivity

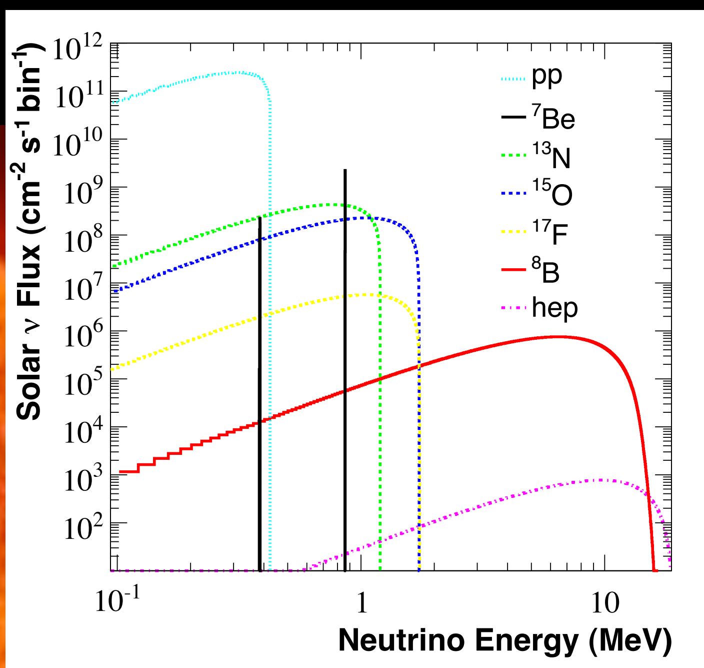
Low Background Frontier

tonne scale, keV threshold, low background detectors have potential for first observations of...



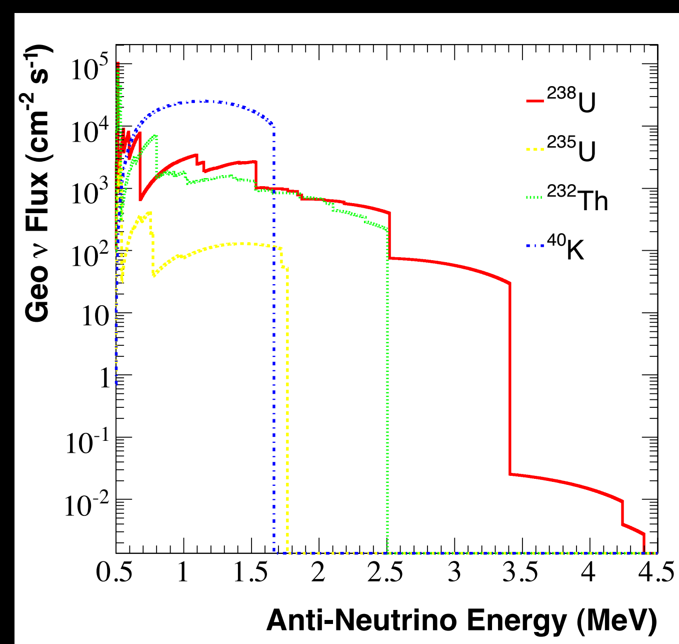


Supernova neutrinos in NC, flux and spectrum



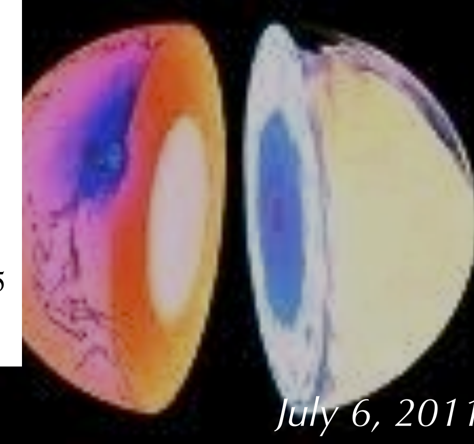
neutrino-nucleus coherent elastic scattering of solar neutrinos *JM, P. Fisher, PRD76:033007*

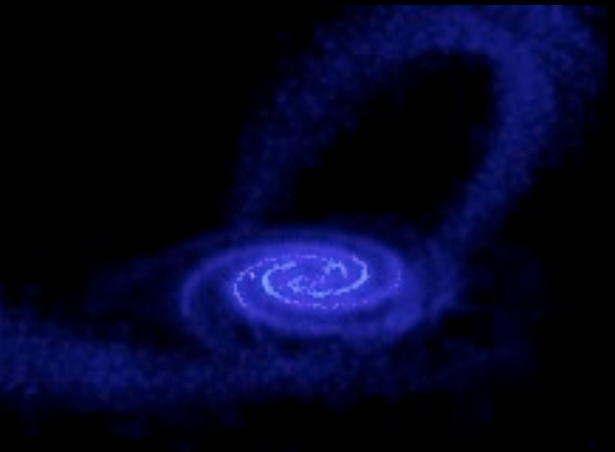
with direction measurement:



JM, S. Dye in preparation

^{40}K geo-neutrinos





Directional detection is a powerful new way to search for dark matter.

Backgrounds make directional detection very attractive.

Large low-energy, low-background tracking detectors have potential for *confirmation* of the astrophysical origin of a candidate direct detection dark matter signal, and fundamental physics at the low background frontier. The big challenge is scaling to competitive target masses. There has been great progress in last 5 years from DRIFT, NEWAGE, MiMAC, DMTPC... community needs to grow.

Dark matter telescope:
transition from discovery to observatory.

Backup Slides

CCD Readout

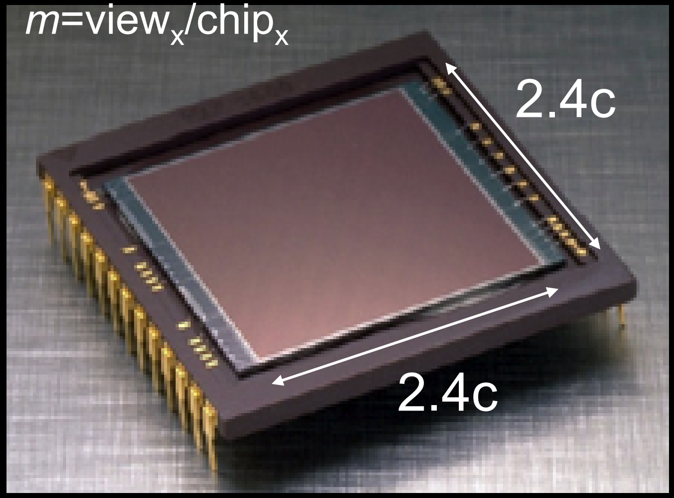
Vanderspek formula for light acceptance (thin-lens approximation)

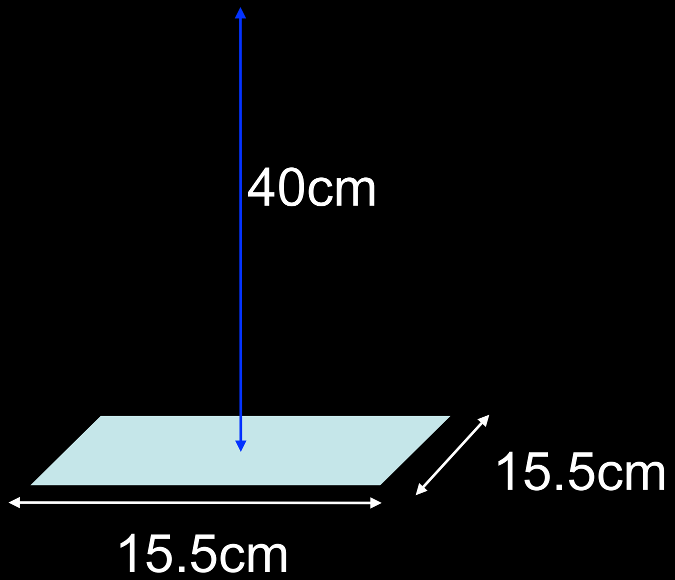
$$\Omega = \frac{1}{16(1+m)^2(f/\#)^2} \sim 10^{-3}$$

Favor large chip (small *m*), large pixel (faster readout)
Kodak KAF1001E, 1Mpixel
Binned pixel size ~560μm

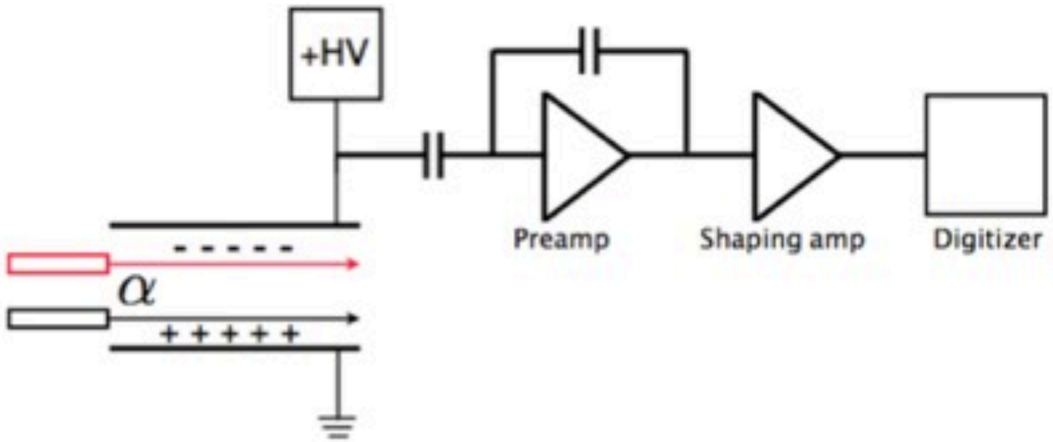
2 x Apogee ALTAU6:
- Noise 6.7ADU, gain 1.1e-/ADU
- Noise 11ADU, gain 1.8e-/ADU

Nikon 55mm, f/# 1.2 lens



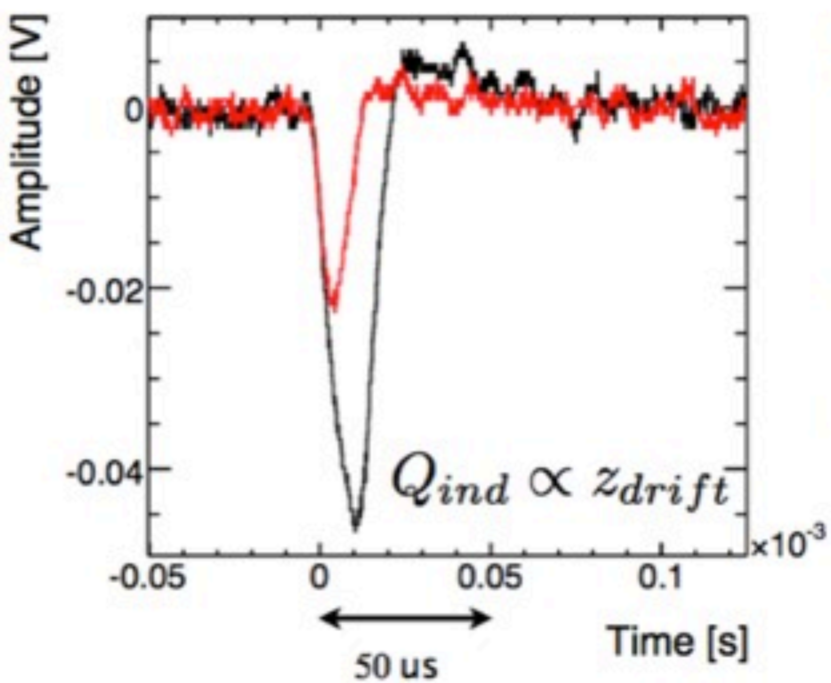


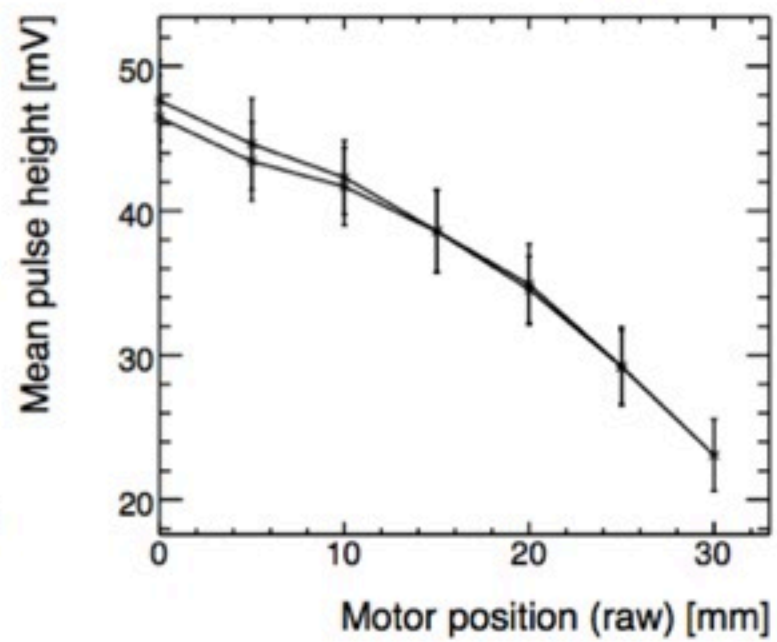
Fiducialization in z with charge



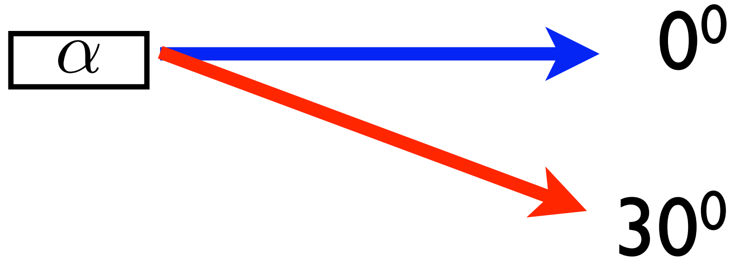
z coordinate from pulse height

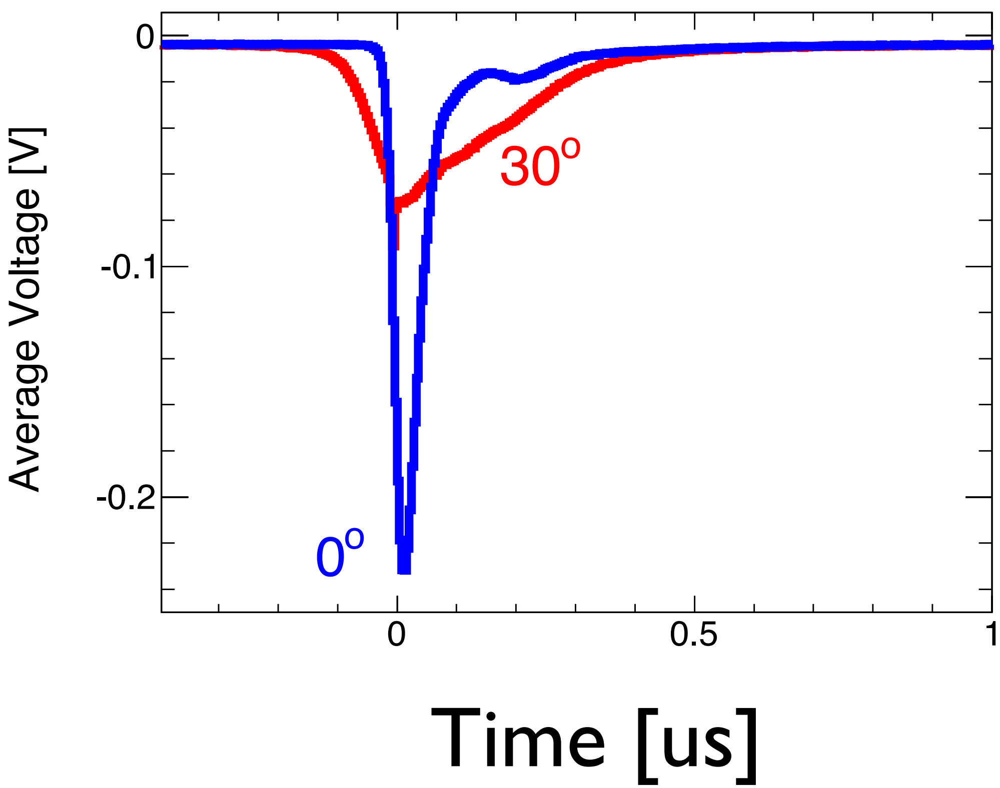
$$Q_{ind} = \int_0^T i_+ dt = Q_s \cdot \frac{z_{drift}}{d}$$

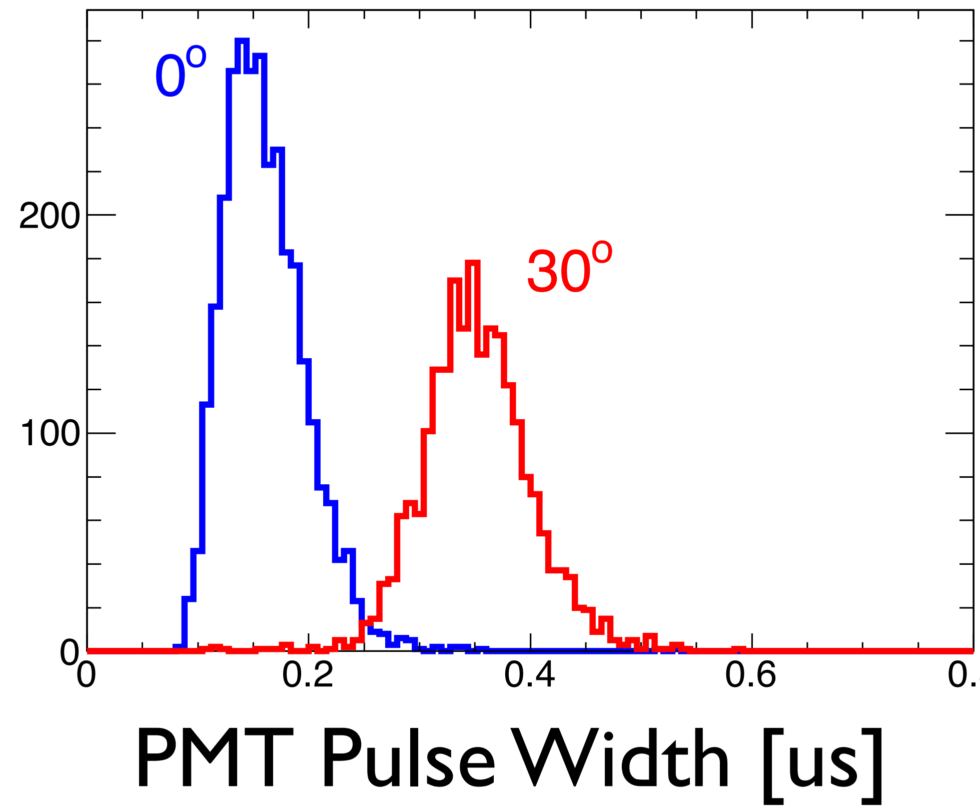




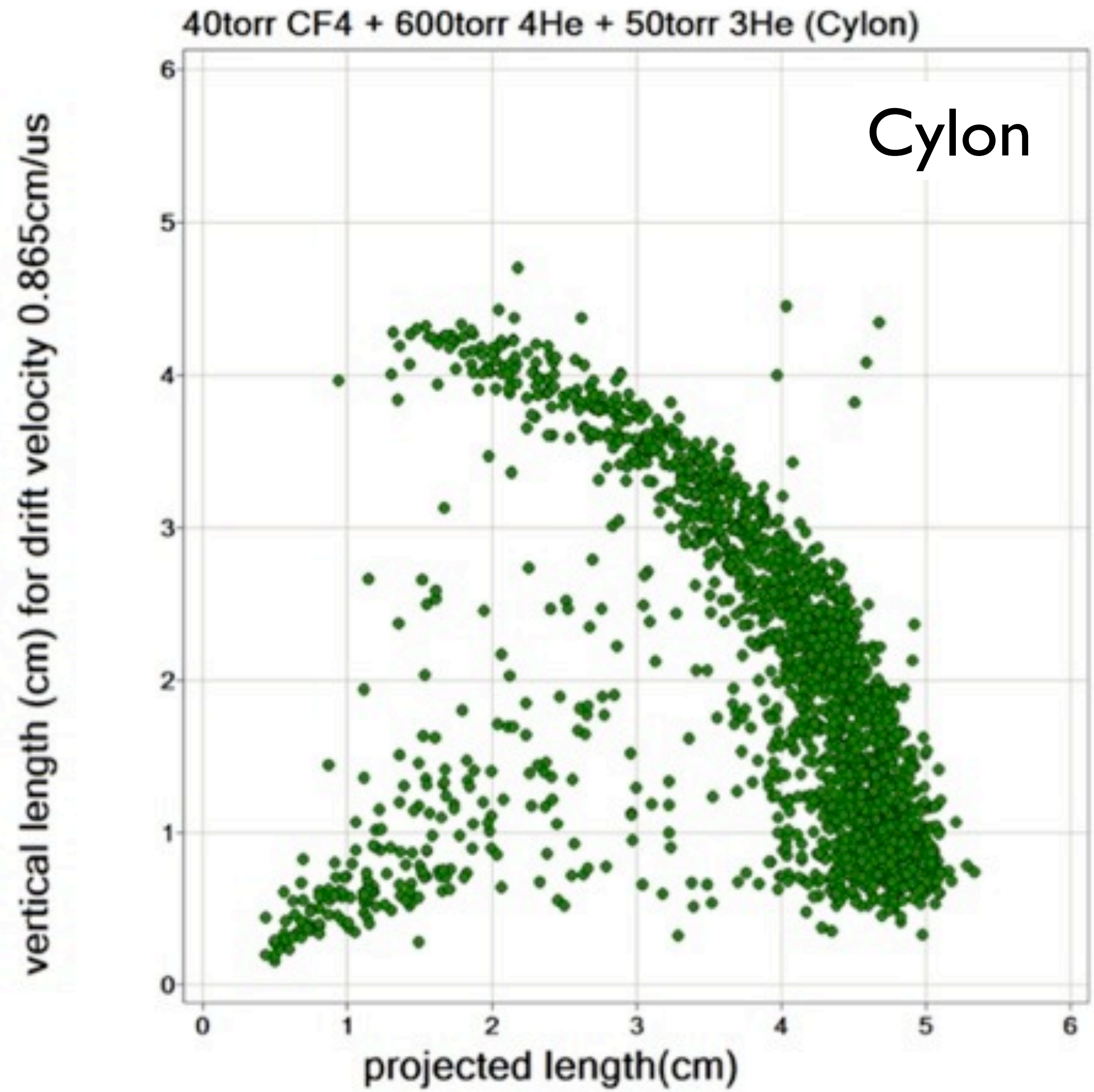
3^{rd} dimension from PMTs

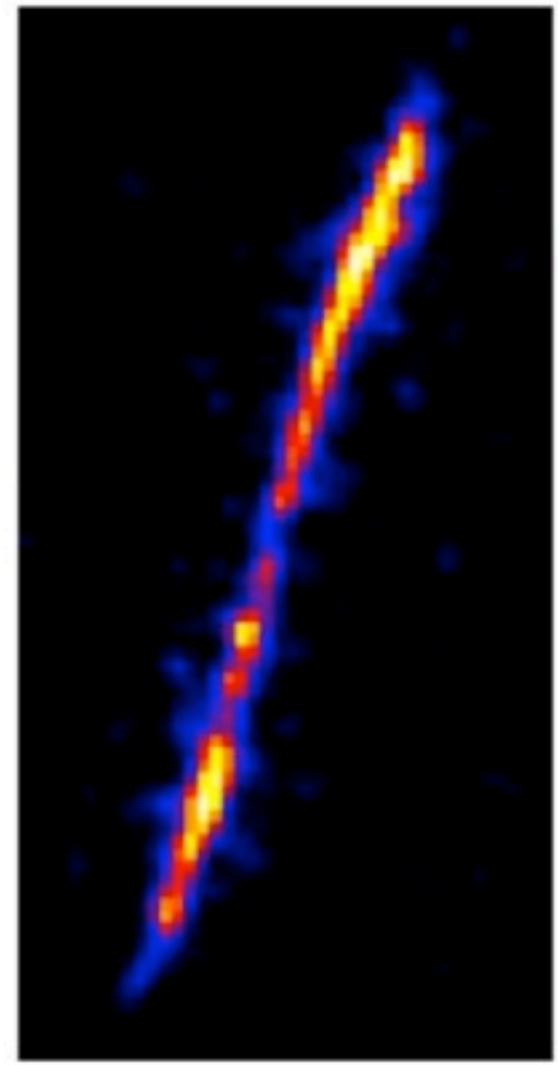






3rd dimension from PMTs





$$n +^3 \mathrm{He} \rightarrow \mathrm{T}(190\ \mathrm{keV}) + \mathrm{P}(570\ \mathrm{keV})$$