The DAMIC dark matter experiment

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DAMIC

ICRC

The Astroparticle Physics Conference

34th International Cosmic Ray Conference

July 30 - August 6, 2015 The Hague, The Netherlands

DAMIC - Dark Matter In CCDs

★ Evidence from astrophysics and cosmology of cold dark matter
Leading candidate: hypothetical WIMPs

★ Could produce keV-energy nuclear recoils when scattering elastically off target nuclei in the detector
Coherent WIMP-nucleus elastic scattering

★ DAMIC: bulk silicon of scientific-grade CDDs as targets
- ★ Low readout noise of CCDs
- ★ Relatively low mass of the silicon nucleus

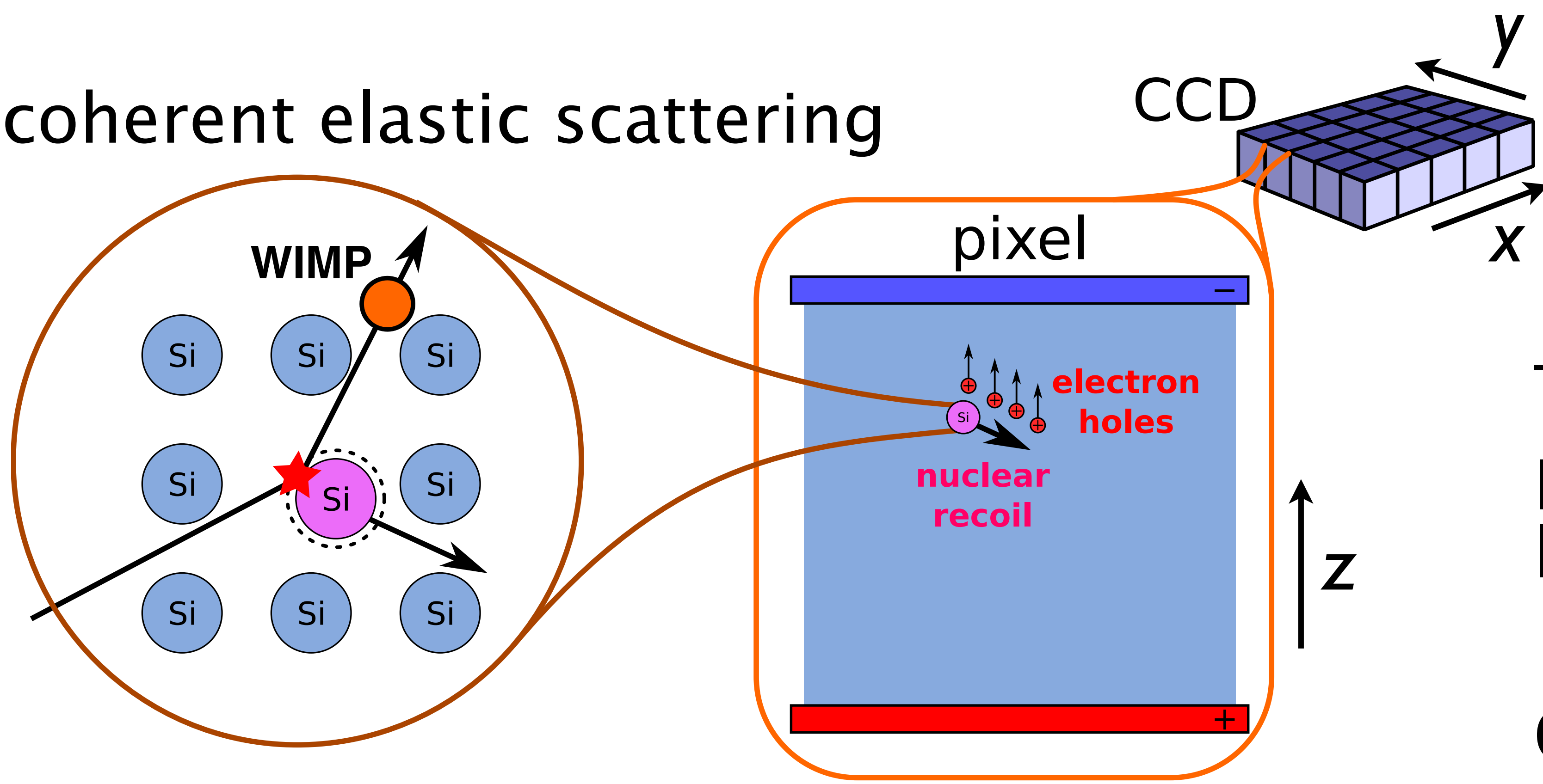
CCDS are ideal instruments for the identification of nuclear recoils from WIMPs < 10 Gev/c^2

Damic Collab., Phys Letters, 2012

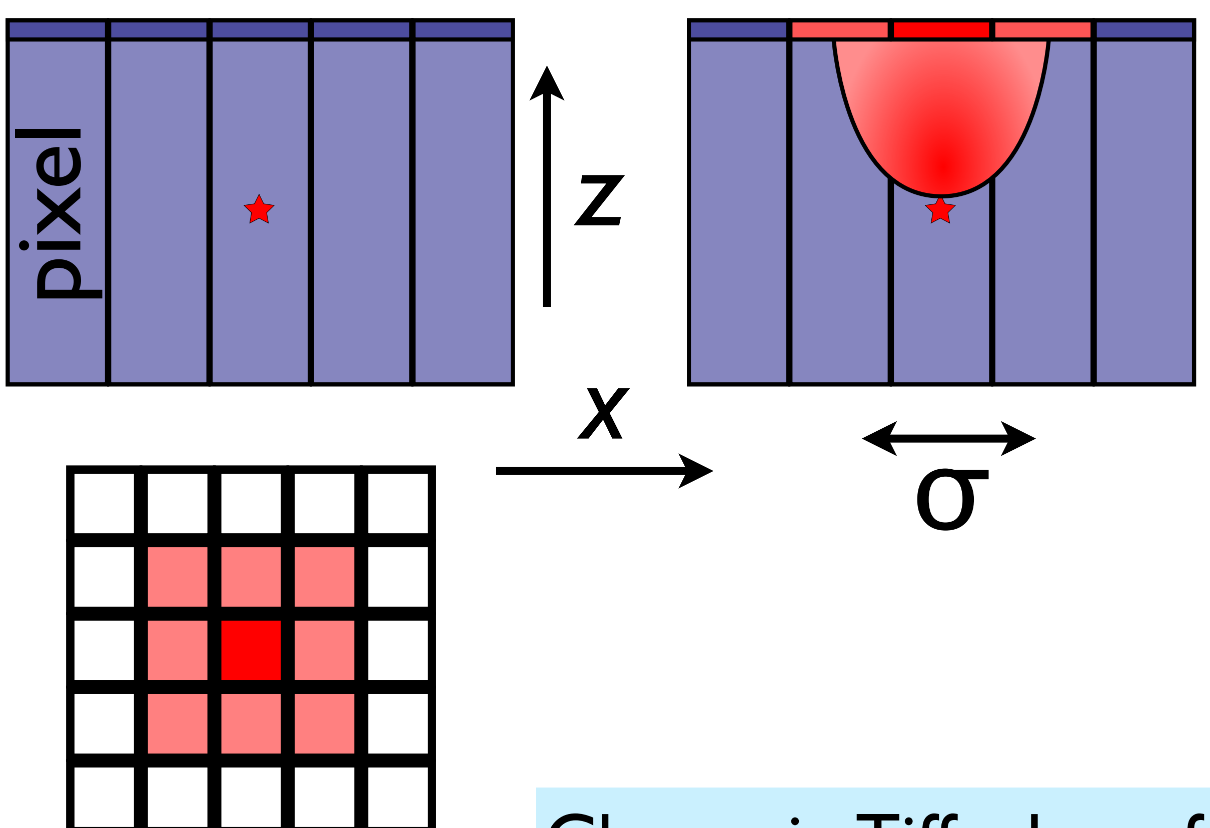
★ Explore new regions of the WIMP parameter space
Study other dark matter candidates

★ DAMIC100 will exclude/confirm hints of a 10 GeV mass WIMP without ambiguities on energy threshold

CCDs as WIMP detectors



The **scattering** of a DM particle with a SI nucleus leads to **ionization**



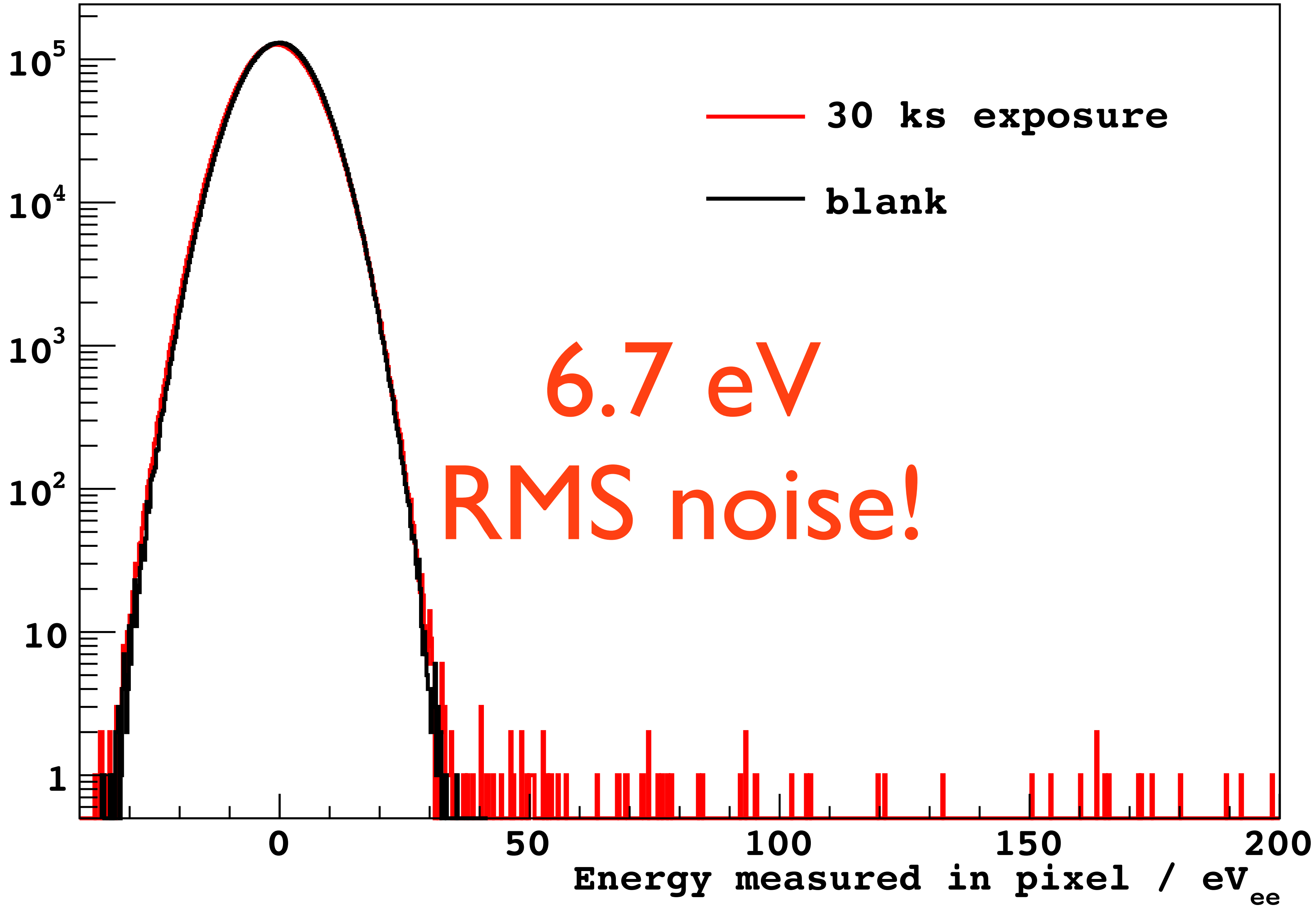
Charge carriers are **drifted** along z direction and collected at CCD gates

Charge **diffuses** as it travels

We fit to the radial spread of the cluster to estimate its **position in z** within the CCD bulk

Chavarria, Tiffenberg for Damic Collab., Phys. Procedia, 2014

CCD performance



Readout noise:
~2 e^- (3.6 eV e–h)

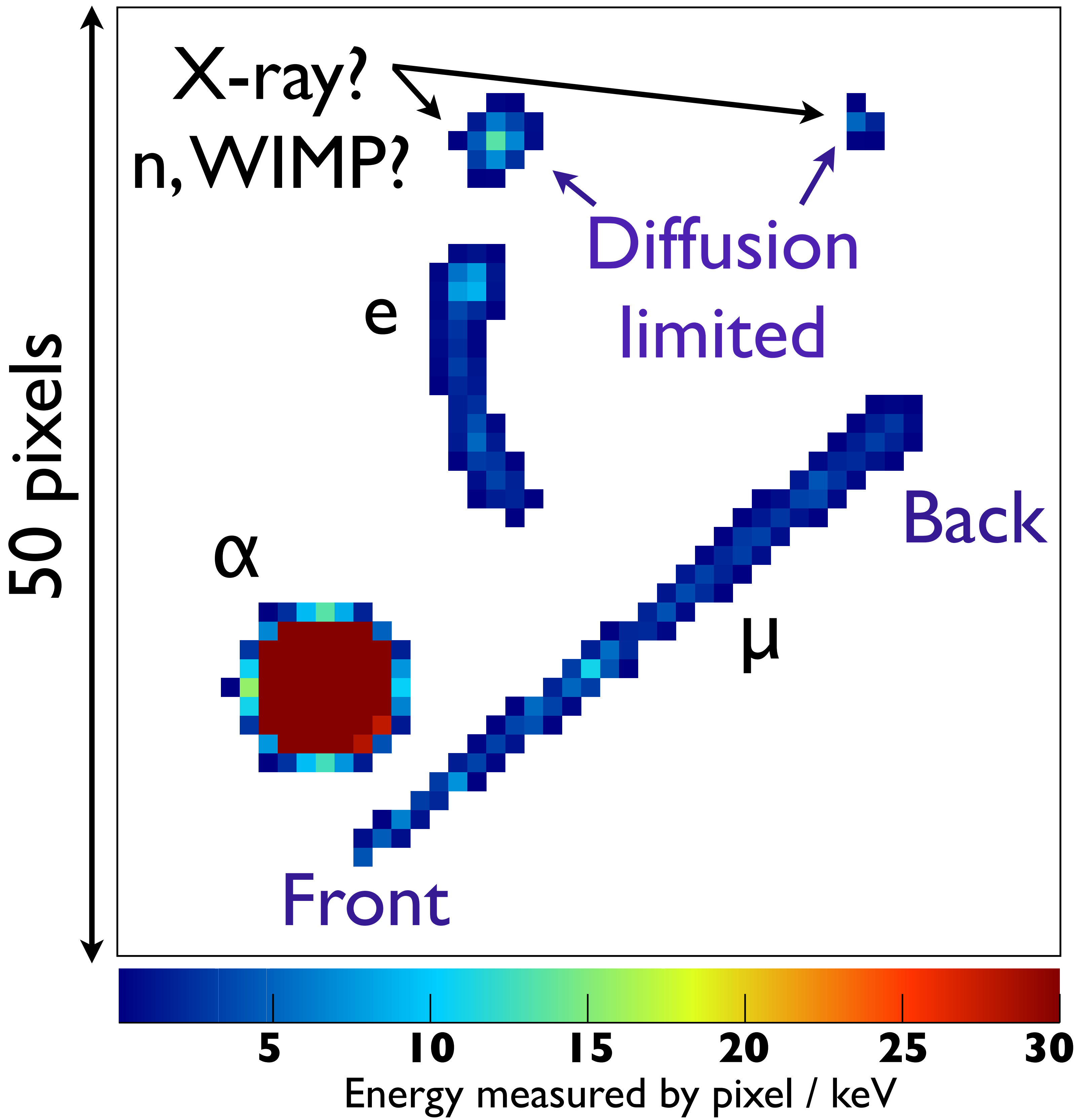
CCDs: very high **resistivity** silicon

- Low **radioactive** backg.
- Low **dark current** (0.1 e^- /pix/ day)
- Very few (if any) **defects** in silicon lattice

Histogram of all the pixel values in an image after the **median pixel** value over may images has been **subtracted**.

Blank exposure: zero-length exposures read out right after every data exposure, with **true readout noise patterns** but no physical tracks.

Particles detected (at ground level)



Low energy electrons and nuclear recoils: **diffusion limited clusters**

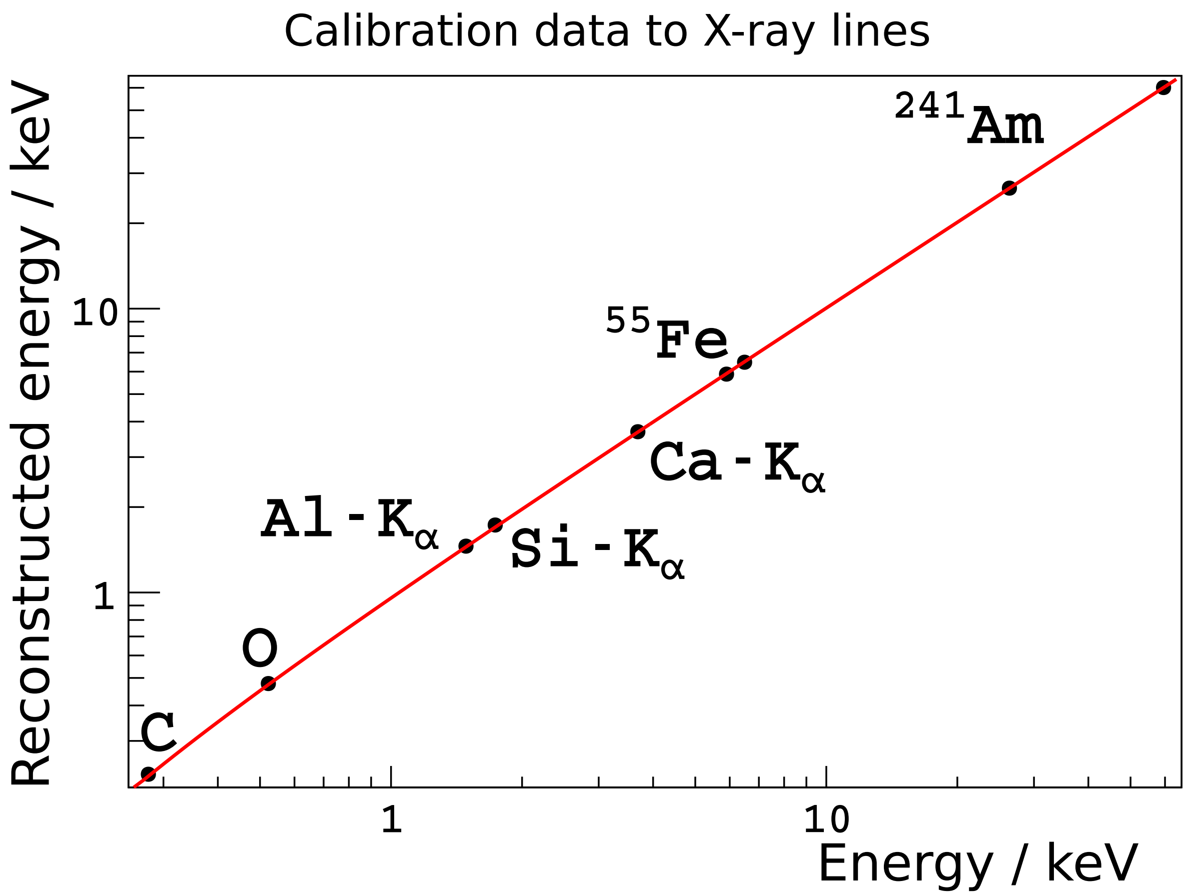
(their spatial extension is dominated by charge diffusion)

Higher energy **electrons** (Compton, β decay): extended tracks

α particles in the bulk or from the back: large round structures

cosmic **muons**: orientation of the track is evident

Calibration and energy resolution



Reconstructed x true energy

K$_\alpha$ fluorescence lines from Kapton target and other materials in the CCD setup

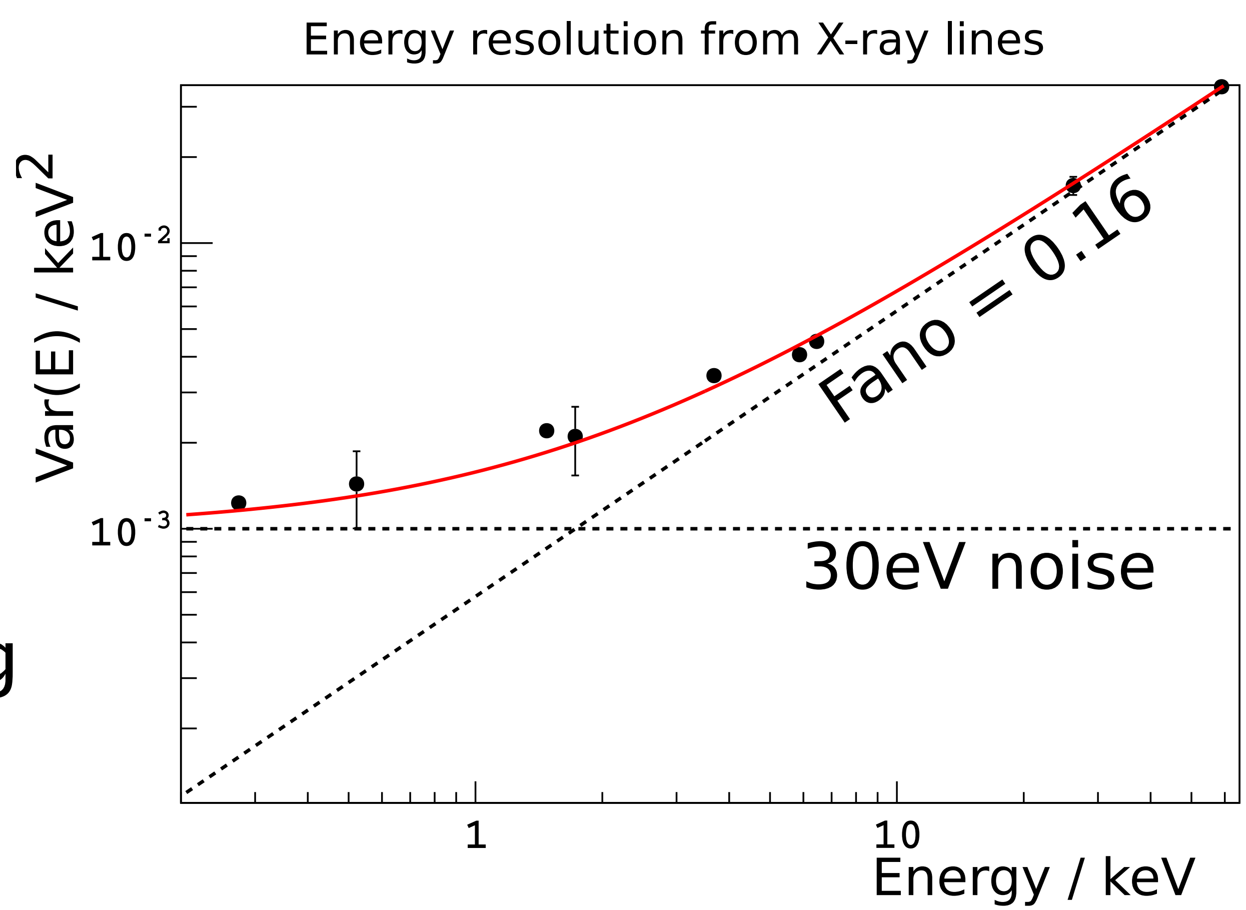
^{55}Fe and ^{241}Am X-rays by the radioactive sources

Linearity from 0.3 to 60 keVee

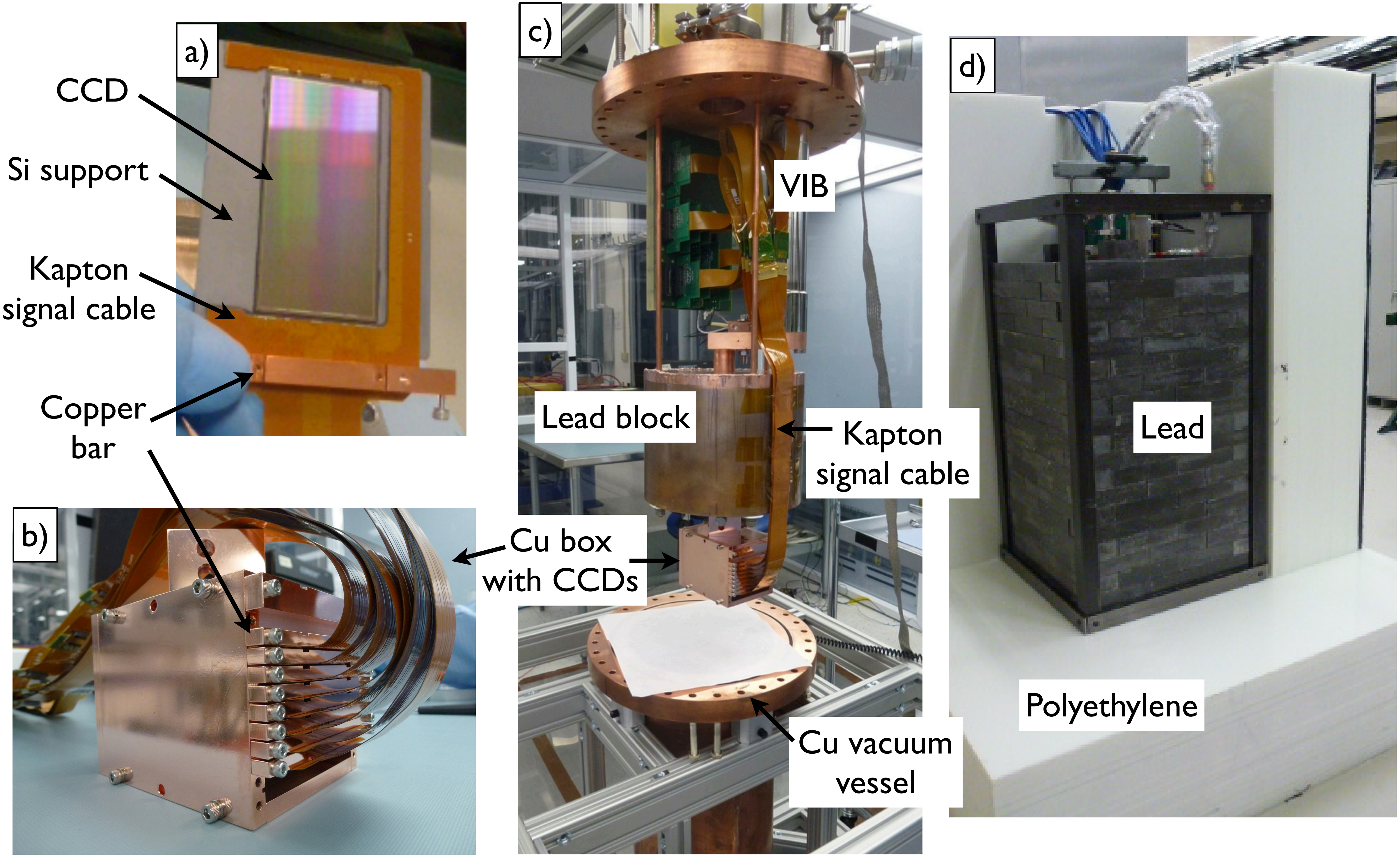
Energy resolution

Ilumination from backside, many pixels

Readout noise leads to a limiting resolution of 30 eVee.



DAMIC at SNOLAB



β - β coincidences

- ★ Ultimate **sensitivity** of the experiment: rate of the **radioactive background** that mimics the nuclear recoil signal from the WIMPs
- ★ The measurement of the **intrinsic contamination** of the detector is fundamental
- ★ For silicon-based experiments the **cosmogenic isotope ^{32}Si** is particularly relevant, its decay spectrum extends to the lowest energies and may become an irreducible background

$$^{210}\mathrm{Pb} \xrightarrow[64\,\mathrm{keV}]{\beta^-} {}^{210}\mathrm{Bi} \xrightarrow[1.2\,\mathrm{MeV}]{\beta^-} {}^{210}\mathrm{Po}$$

$$\tau_{1/2} = 5\,\mathrm{d}$$

$$^{32}\mathrm{Si} \xrightarrow[227\,\mathrm{keV}]{\beta^-} {}^{32}\mathrm{P} \xrightarrow[1.7\,\mathrm{MeV}]{\beta^-} {}^{32}\mathrm{S}$$

$$\tau_{1/2} = 14\,\mathrm{d}$$

Sequence of βs starting in the **same pixel** of the CCD in **different images**

Damic Collab., JINST, 2015

β - β coincidences

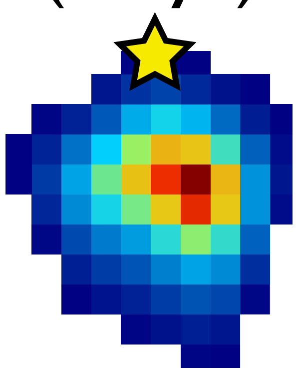
We have performed a search for ^{32}Si and ^{210}Pb in 57 days of data

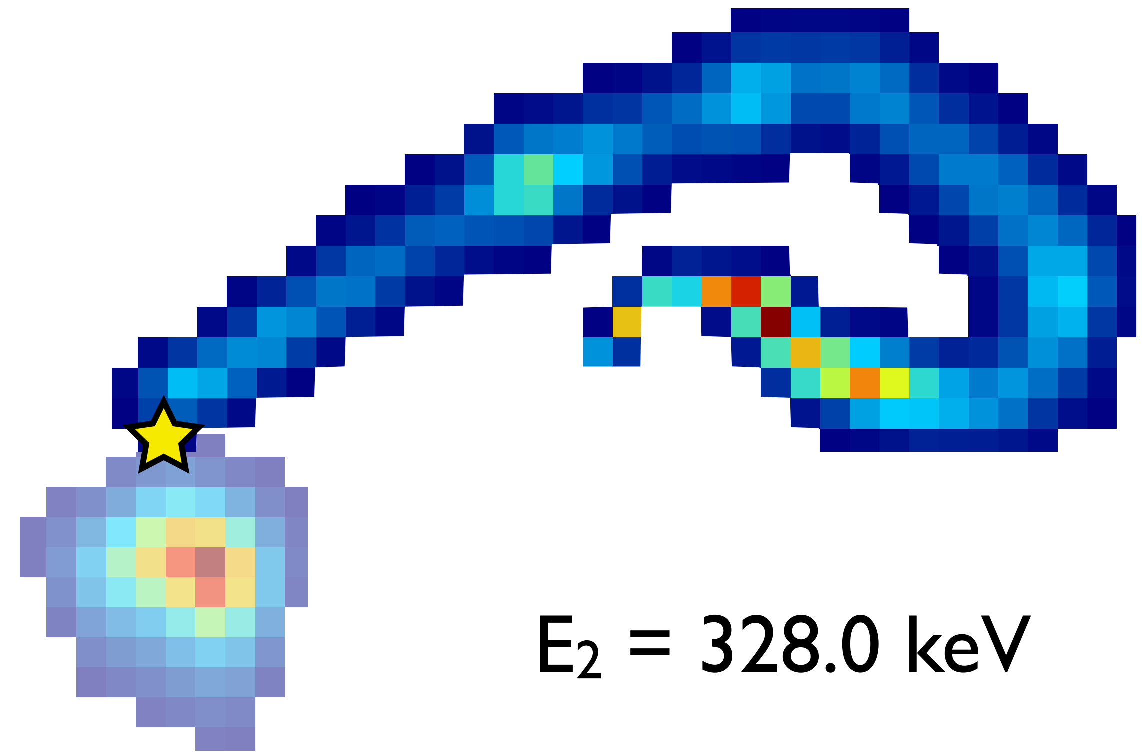
^{32}Si – ^{32}P candidate from data:

E_1 = 114.5 keV

Δt = 35 days

(x_o, y_o)





E_2 = 328.0 keV

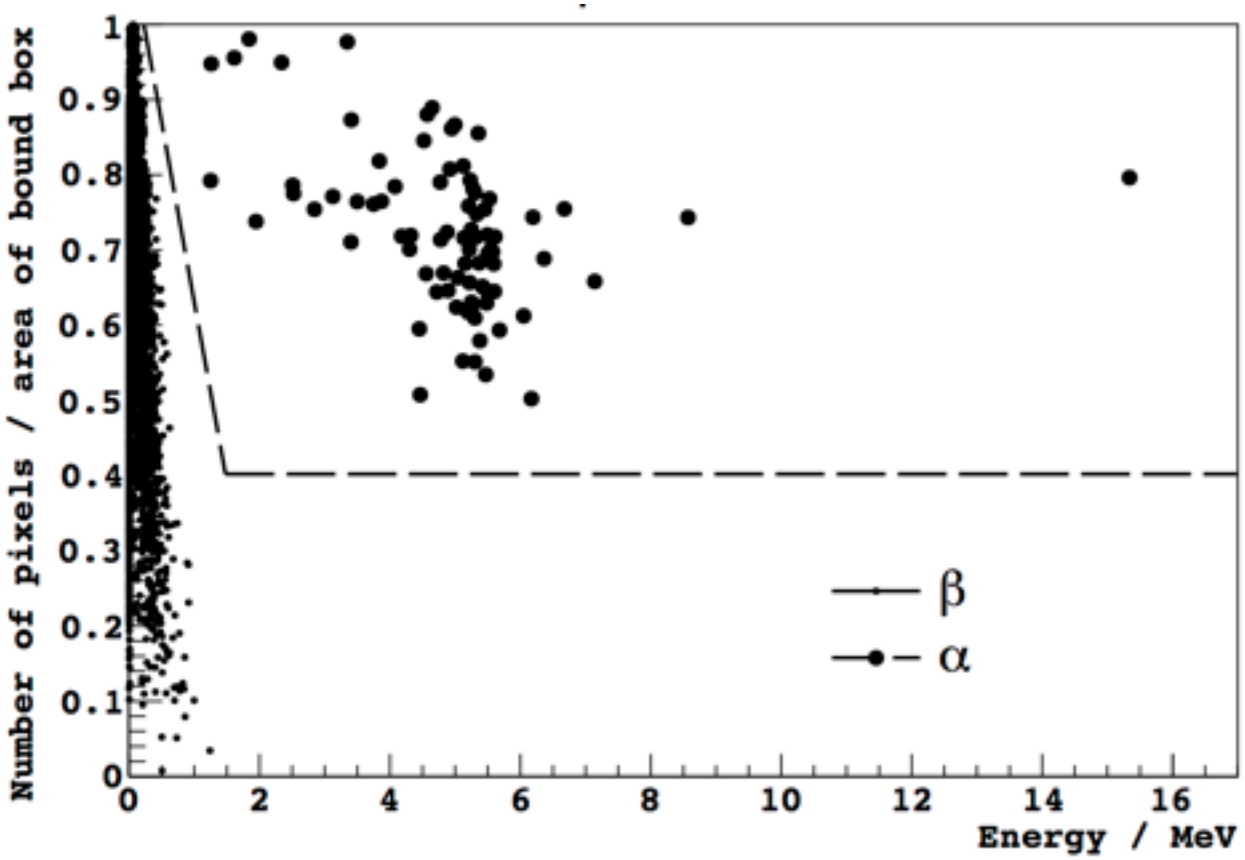
★ Efficiency and acidental pairs: detailed Monte Carlo simulations

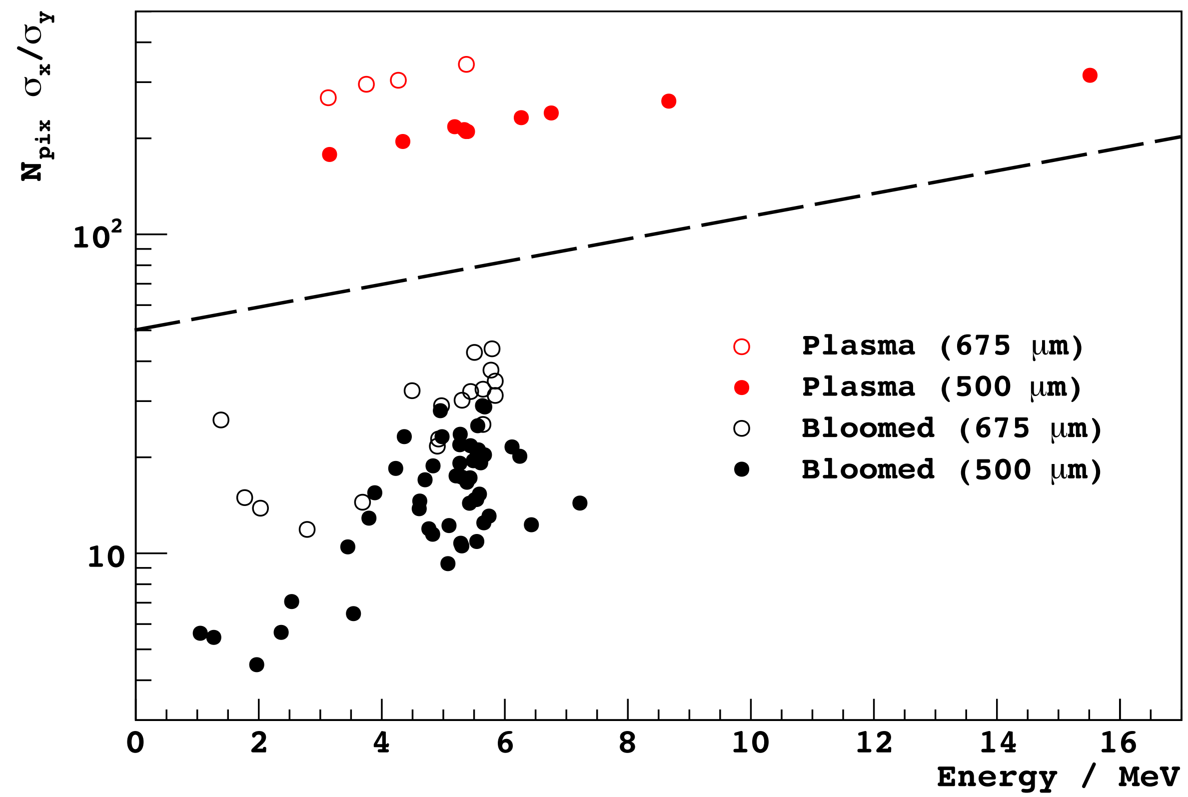
★ ^{32}**Si** decay rate was estimated to be $80^{+110}_{-65}\ \mathrm{kg}^{-1}\mathrm{d}^{-1}$ (95% CL)

★ Similar procedure: upper limit on the ^{210}**Pb** decay rate

$33\ \mathrm{kg}^{-1}\mathrm{d}^{-1}$ (95% CL)

α particles



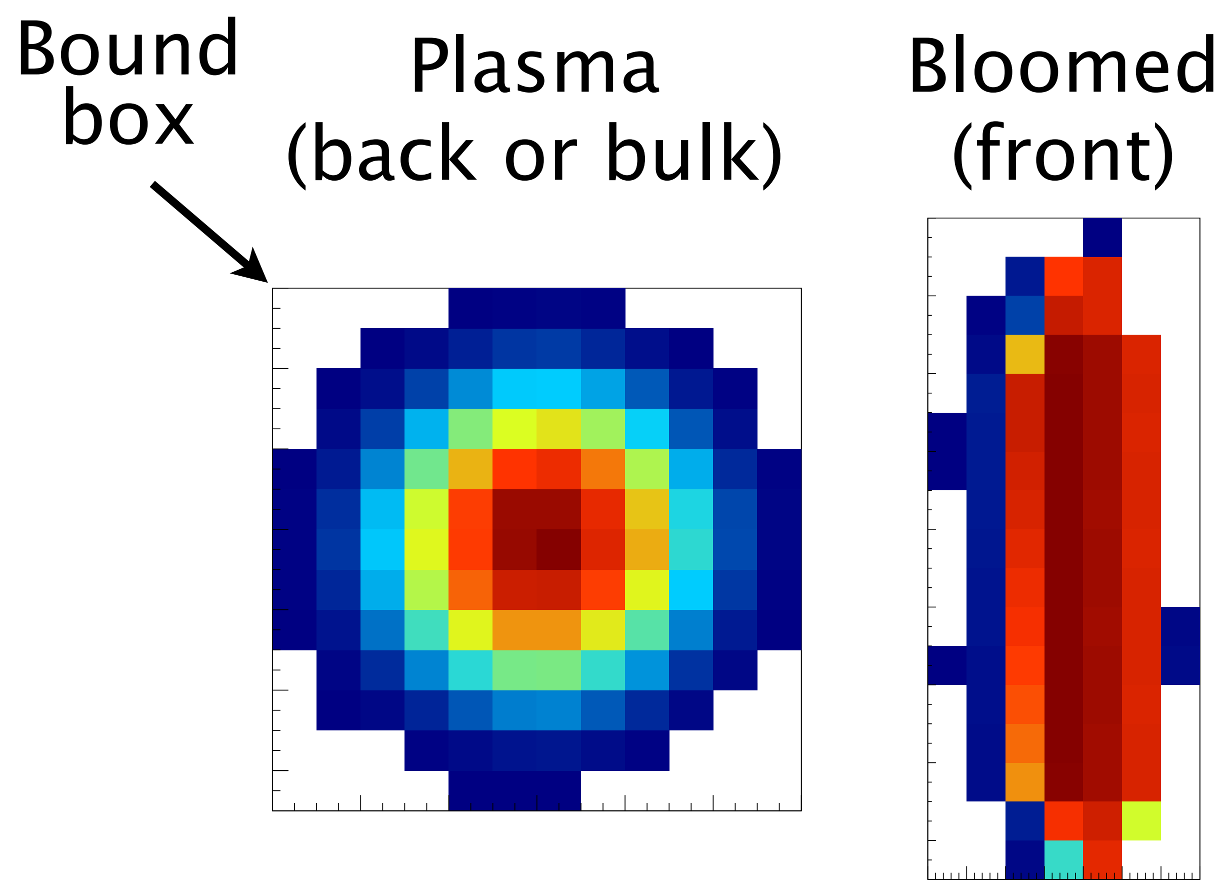


α–β **discrimination** based on shape of track.

Limits on contamination:

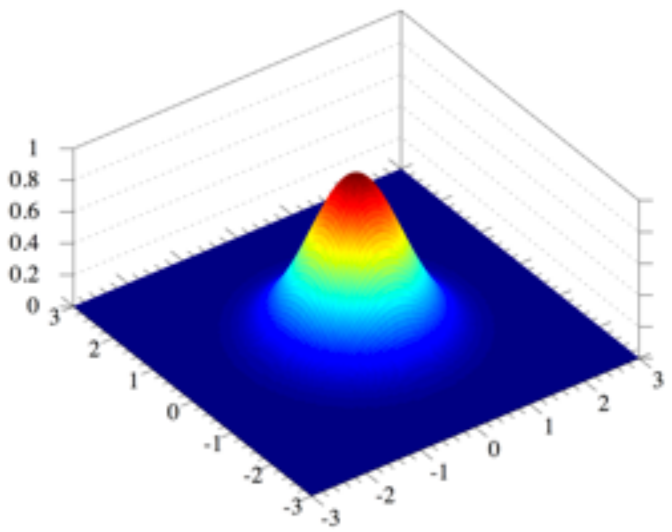
^{238}**U** < 5 kg^{-1} d^{-1} = 4 ppt
^{232}**Th** < 15 kg^{-1} d^{-1} = 43 ppt

Damic Collab., JINST, 2015



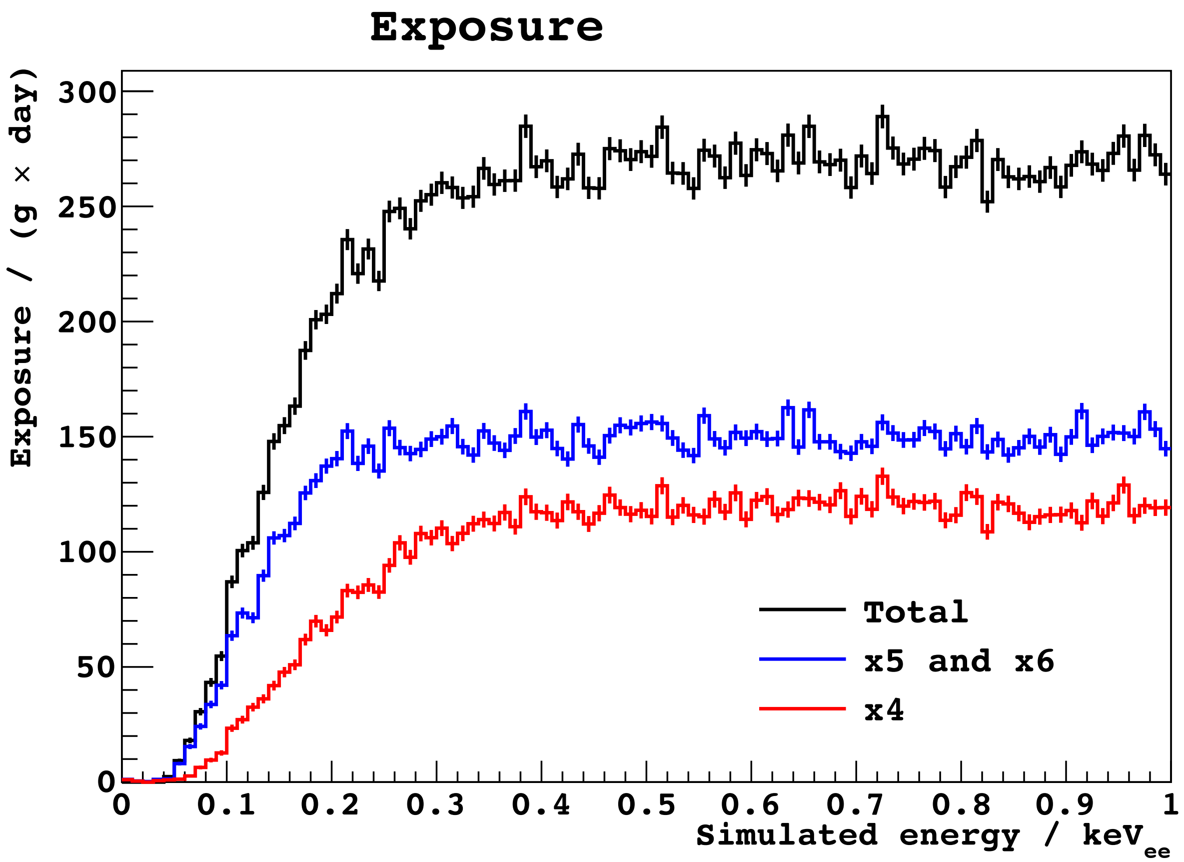
Dark Matter search analysis

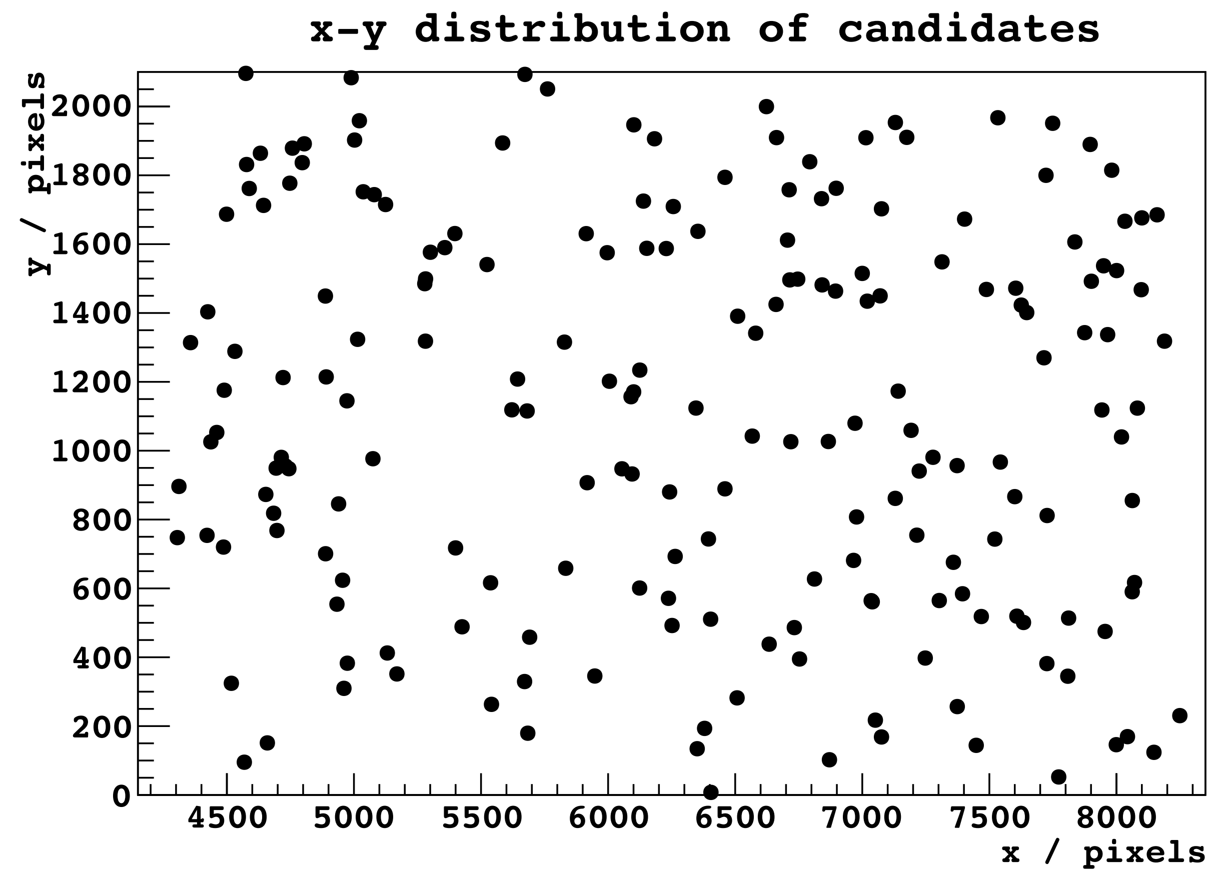
$$\underbrace{N_e(E)}_{\text{Number of ionized e-}} \times \texttt{Gaus}(x, y, \underbrace{\mu_x, \mu_y}_{\text{position of energy deposition}}, \underbrace{\sigma(z)}_{\text{lateral spread}}))$$



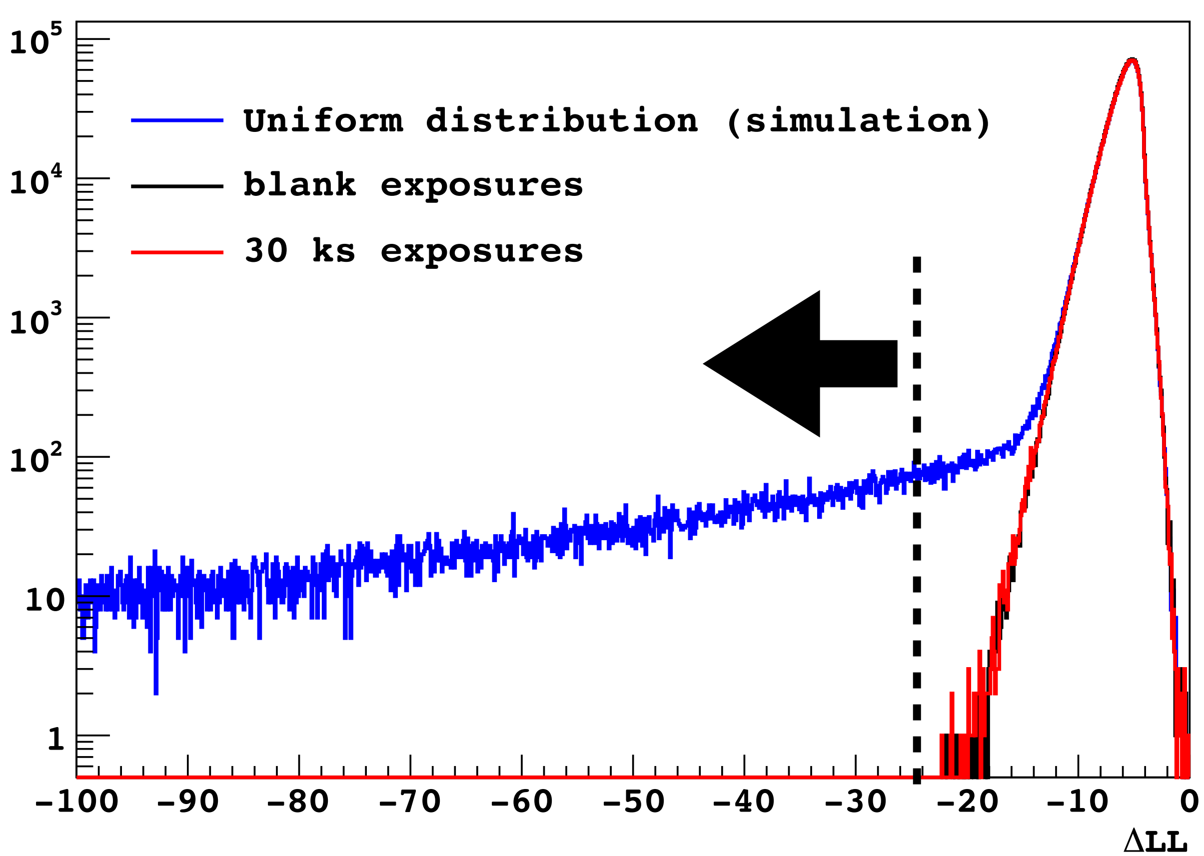
- ★ Fit 2D Gaussian in a moving 7x7 pixel window (baseline + peak)
- ★ Get LL of of best fit
- ★ Compare to fit to constant pixel values (null hypothesis)
- ★ Calculate $\Delta LL = LL_{BF} - LL_{const\text{-}pix}$
- ★ Good candidates: large negative values of ΔLL

Dark Matter search analysis



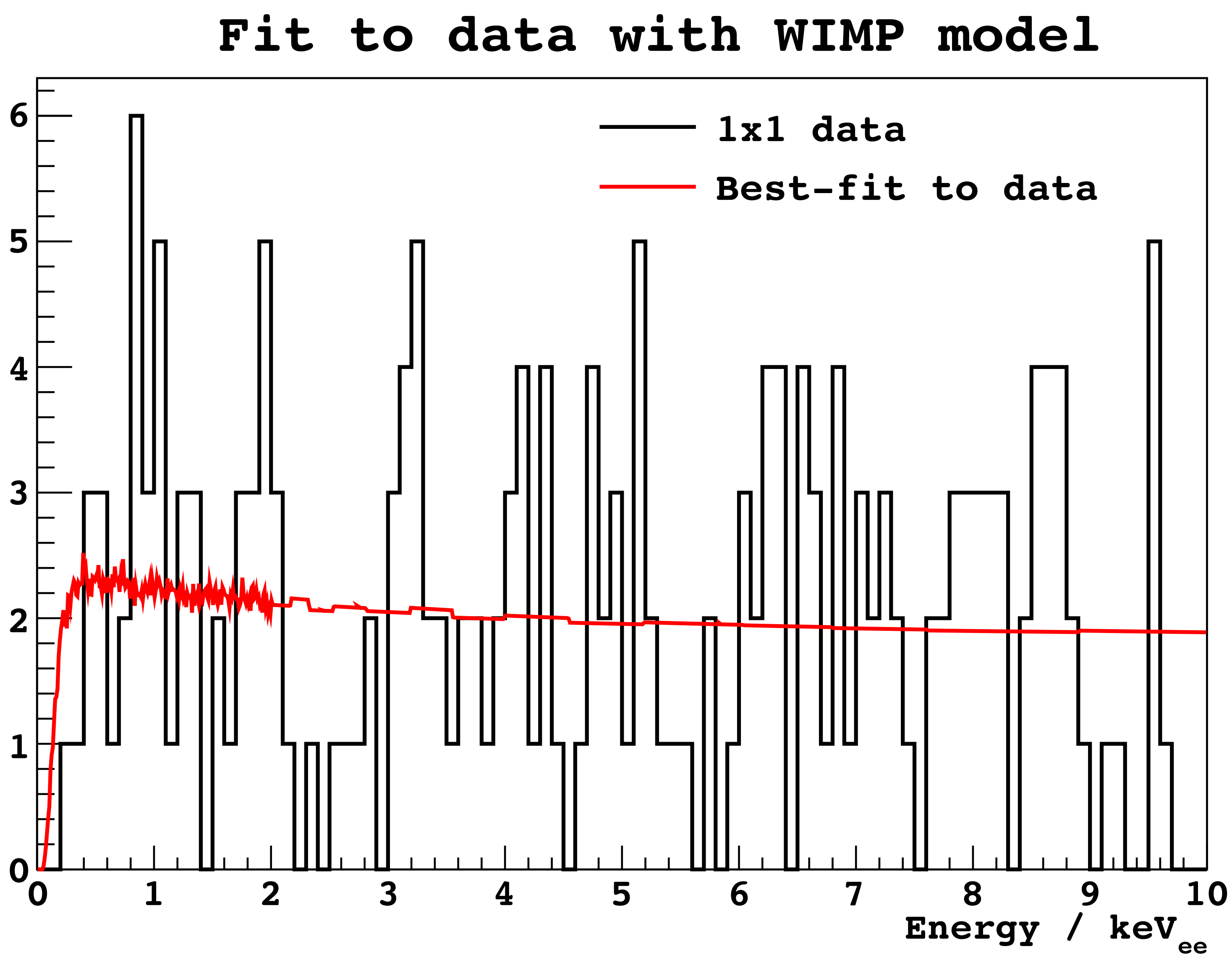


ΔLL distribution



Blanks, with no real hits, are used to determine the **cuts**

Dark Matter search analysis



Data used:
36 days with 3 CCDs
- 2 x 500 μm (2.2 g),
- 1 x 675 μm (2.9 g)

7 more days with 675 μm

Total exposure: ~0.3 kg.d

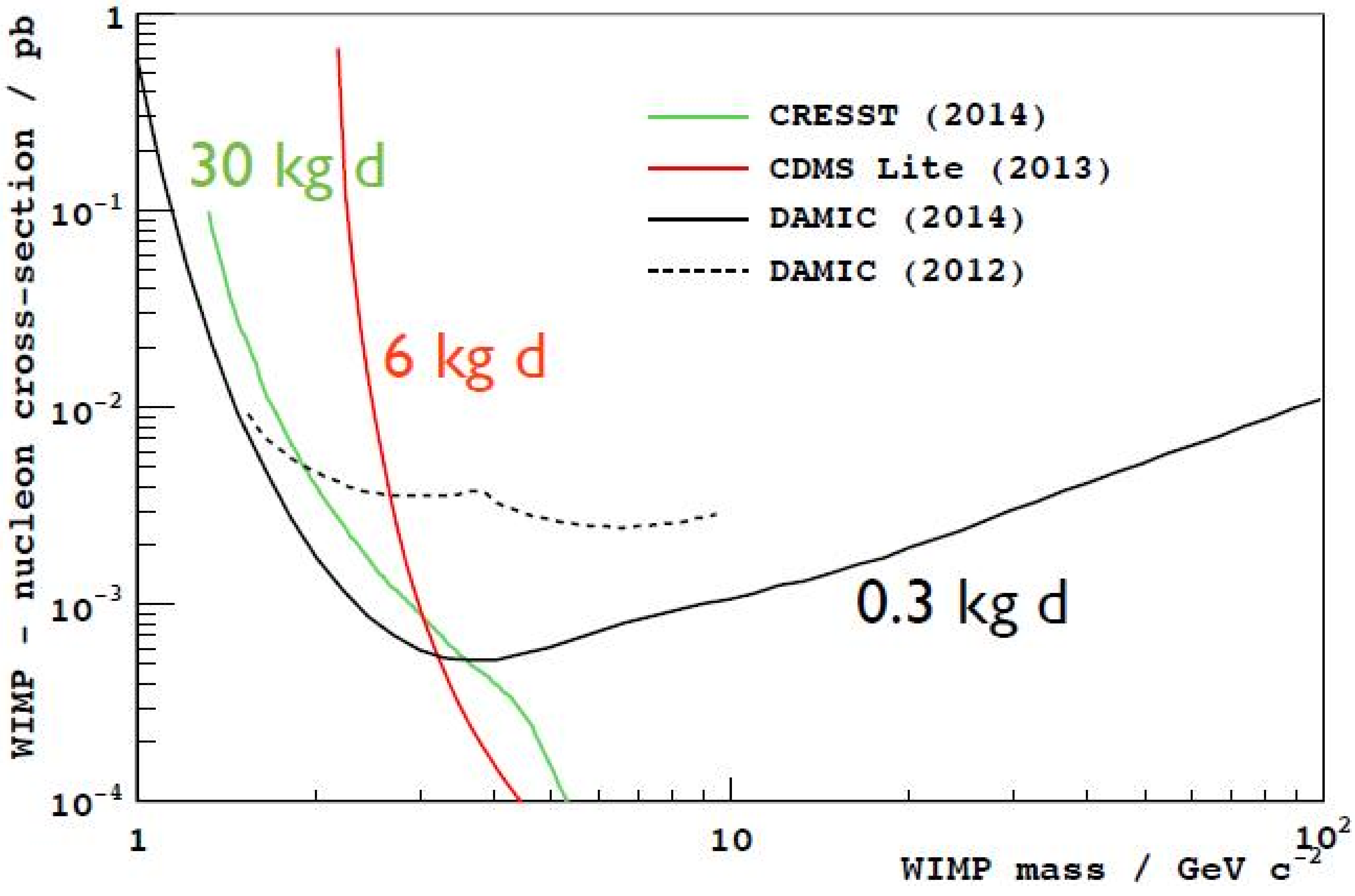
Best fit:

m_{WIMP} = 26 ± 46 GeV/c^2
σ_{WIMP} = (7 ± 16) x 10^{-4} pb
c_{bkg} = 67 ± 13 dru
min(–logL) = –396.5

Null hypothesis
c_{bkg} = 74 ± 5 dru
min(–logL)= –396.1

Dark Matter signal model;
Lindhard ionization efficiency: k=0.15
v_0 = 220 km s^{-1} v_{Earth} = 232 km s^{-1}
v_{esc} = 544 km s^{-1} ρ = 0.3 GeV c^{-2} cm^{-3}

Dark Matter search analysis

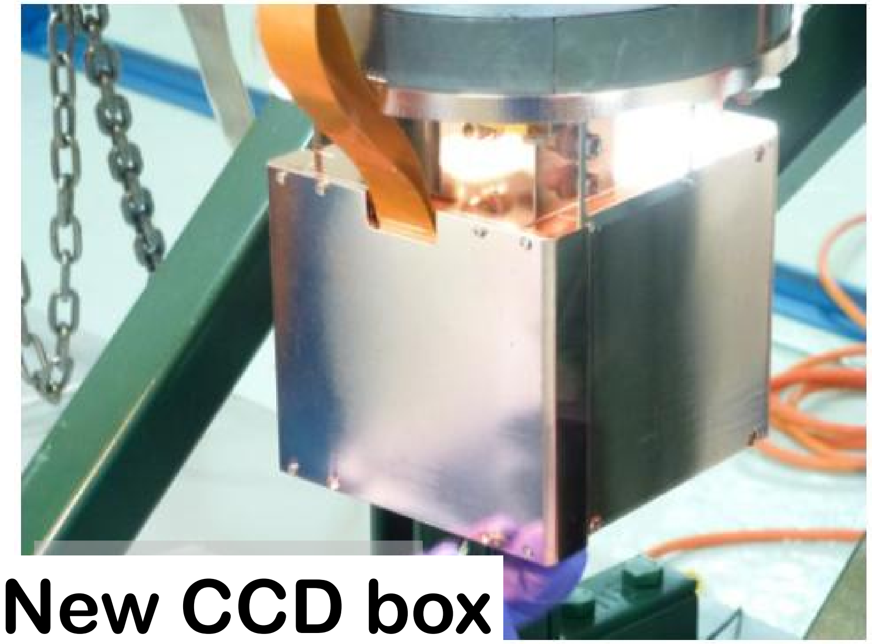


Towards DAMIC100

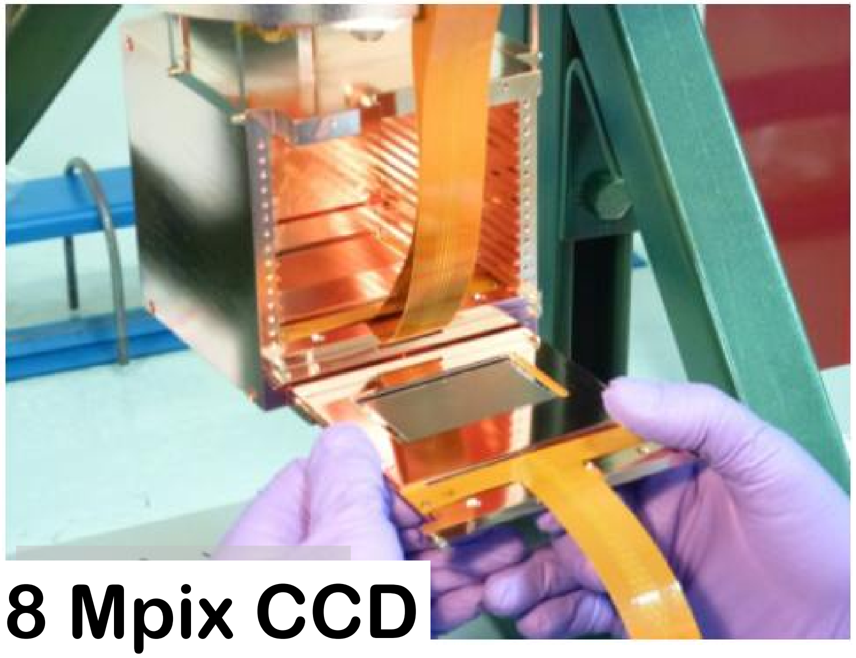
DAMIC100: 100g of active Si in low-noise package inside existent installation at SNOLAB

★ We have 24, 16 Mpix CCD's (675 μm, 5.9 g each)
★ **Dec 2014**: installation of the final DAMIC100 Cu box
- new box fits 18 CCD in current vessel
- Installed three 8 Mpix CCD's (675 μm) to study backgrounds

★ **Feb 2015**: Added N_2 box to remove radon. Cu vessel etching.
★ **Mar/Apr/May 2015**: +1 CCD (tot 4), modifications to internal CCD array to study backgrounds.
★ **July 2015**: first 16 Mpix DAMIC sensor packaged and tested

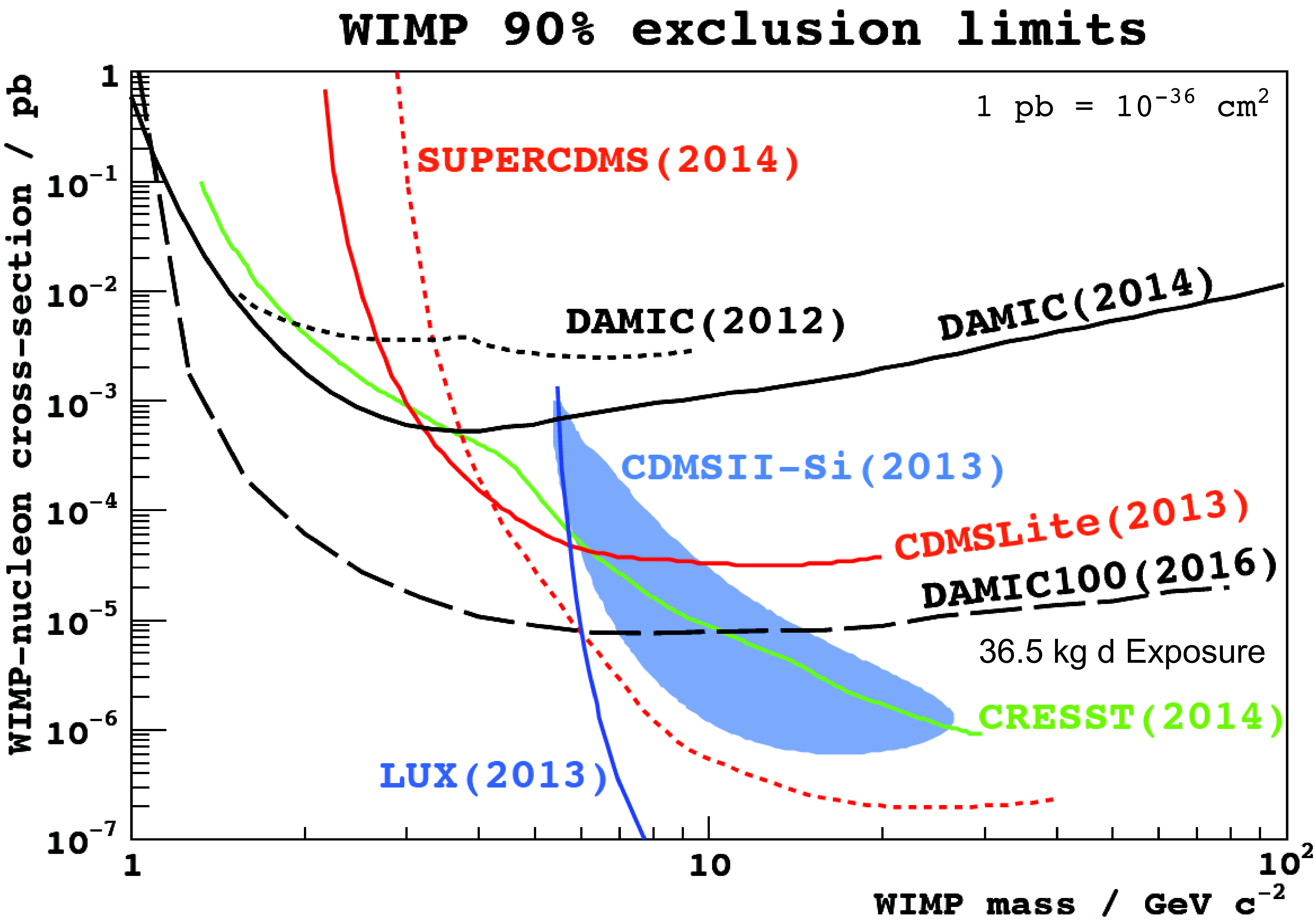


New CCD box



8 Mpix CCD

DAMIC100 sensitiviy

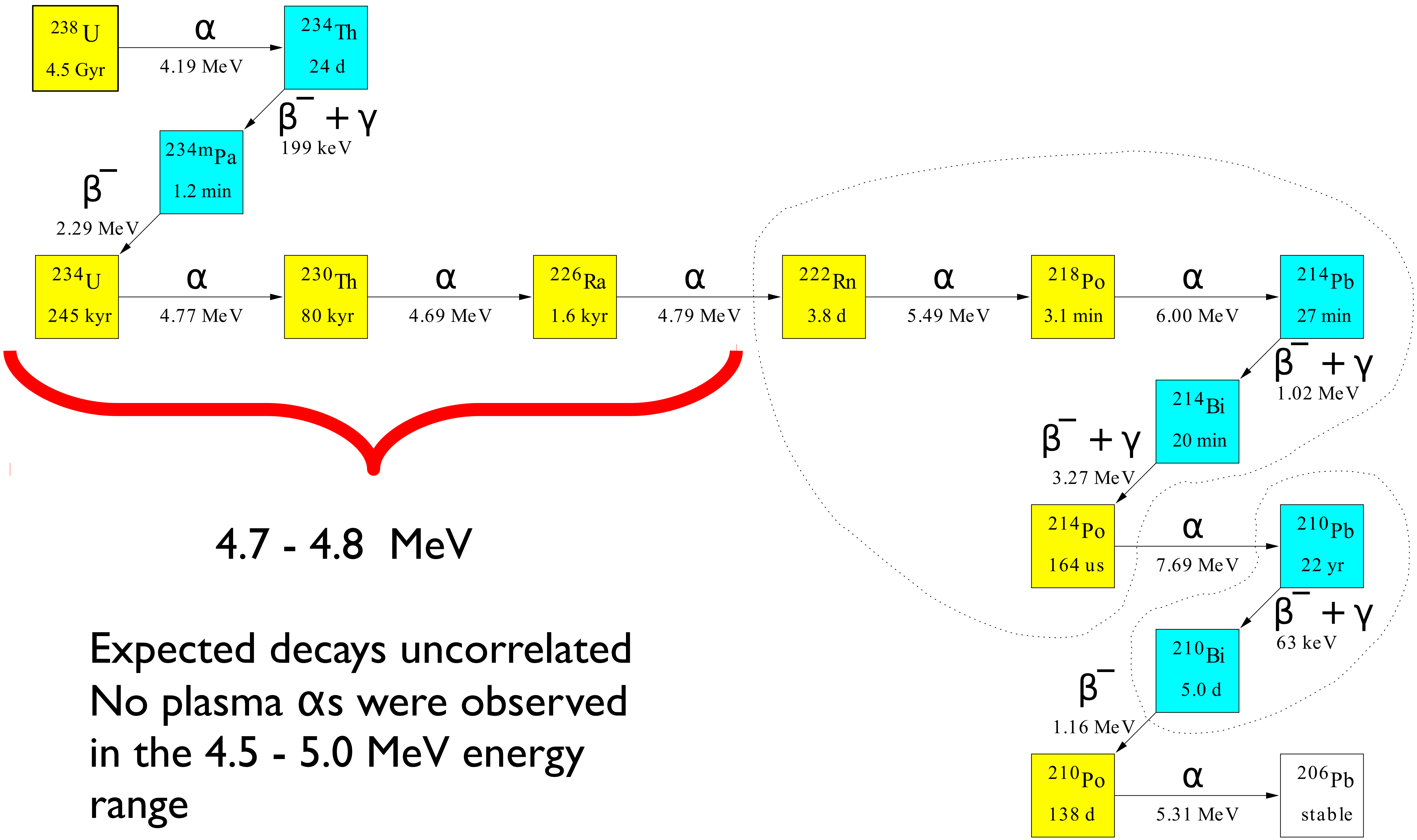


Summary

- ★ CCDs are excellent particle detectors with a **very low threshold** and **high spatial resolution**.
- ★ CCDs are well suited to identify and suppress **radioactive backgrounds**
- ★ DAMIC collaboration has used CCDs as **WIMP detectors** successfully.
- ★ Modest exposure (~ 0.3 kg d) can already probe **new regions** of WIMP parameter space.
- ★ Progressive **upgrades** to study performance and backgrounds yelded promising results
- ★ **DAMIC100** well underway and should begin data taking by the end of 2015.
- ★ Will be able to explore part of the **CDMSII-Si signal region**.

Backup slides

^{238}U chain

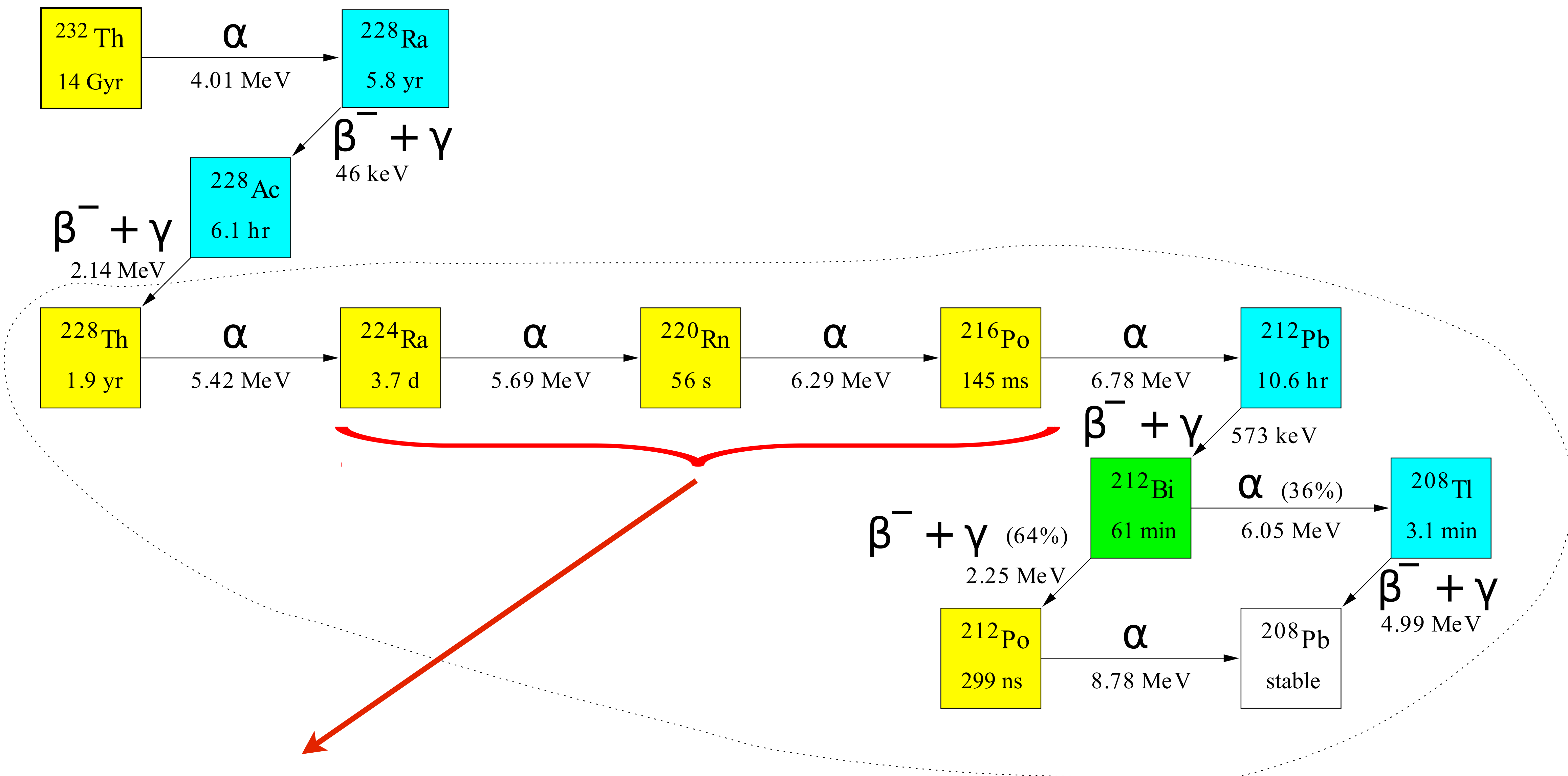


4.7 - 4.8 MeV

Expected decays uncorrelated
No plasma αs were observed
in the 4.5 - 5.0 MeV energy
range

$^{238}\mathrm{U} < 5\ \mathrm{kg}^{-1}\ \mathrm{d}^{-1} = 4\ \mathrm{ppt}$

^{232}Th chain



Timescale of short lived sequence ^{224}Ra ^{220}Rn ^{216}Po is ~ 1 min (much smaller than exposure time)

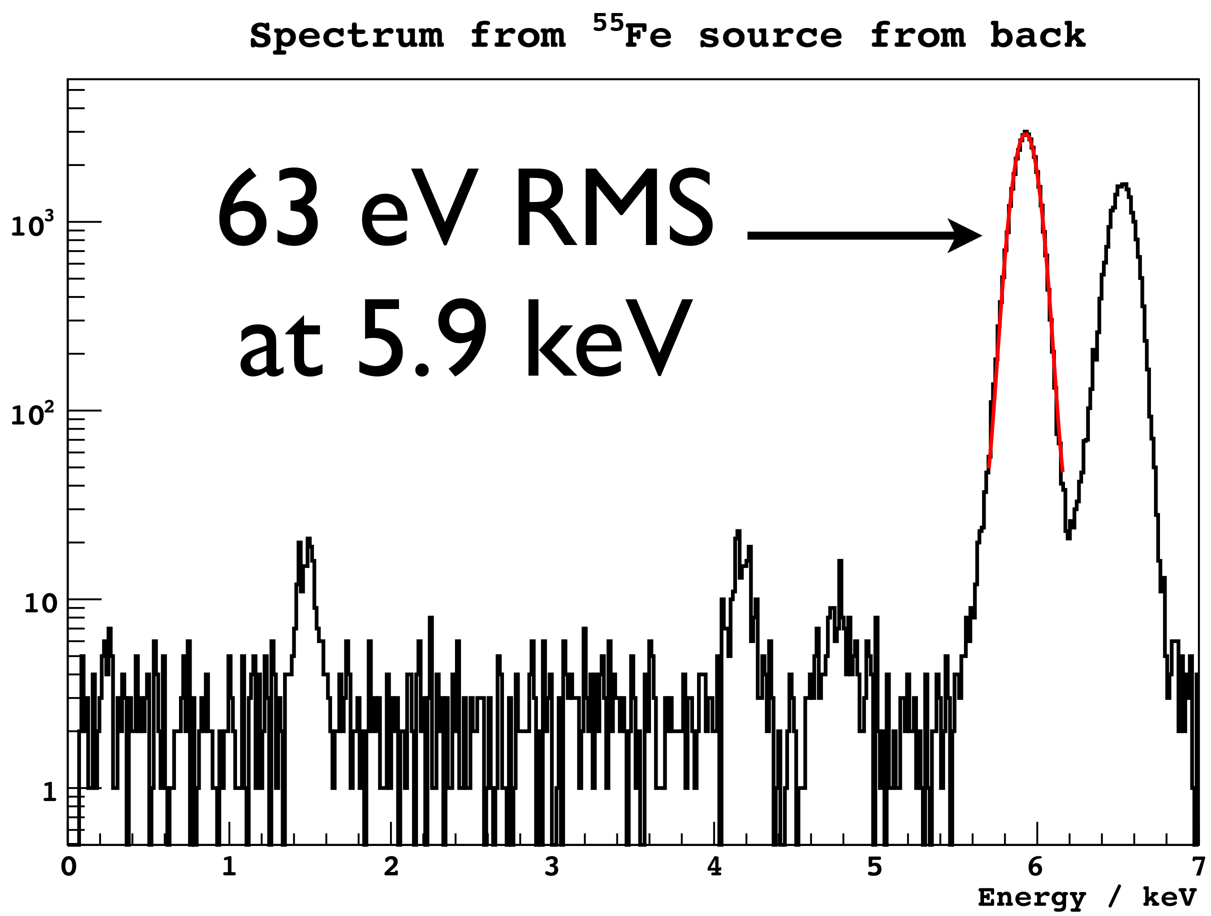
Single cluster (in the bulk) with 18.8 MeV

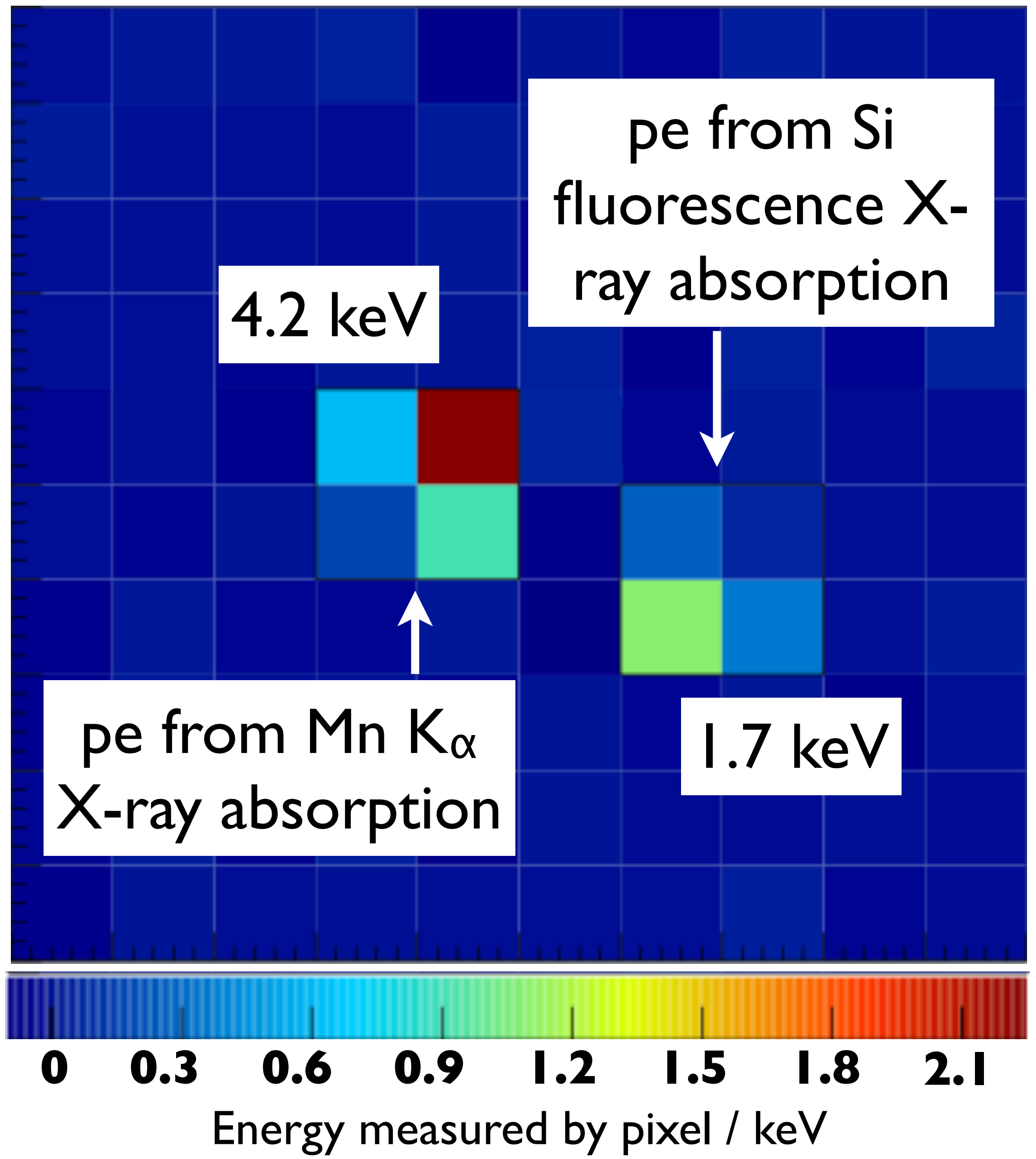
No cluster with energy > 16 MeV was observed

^{232}Th < 15 kg^{-1} d^{-1} = 43 ppt

Energy response

Mn Kα = 5.89 keV
Mn Kβ = 6.49 keV

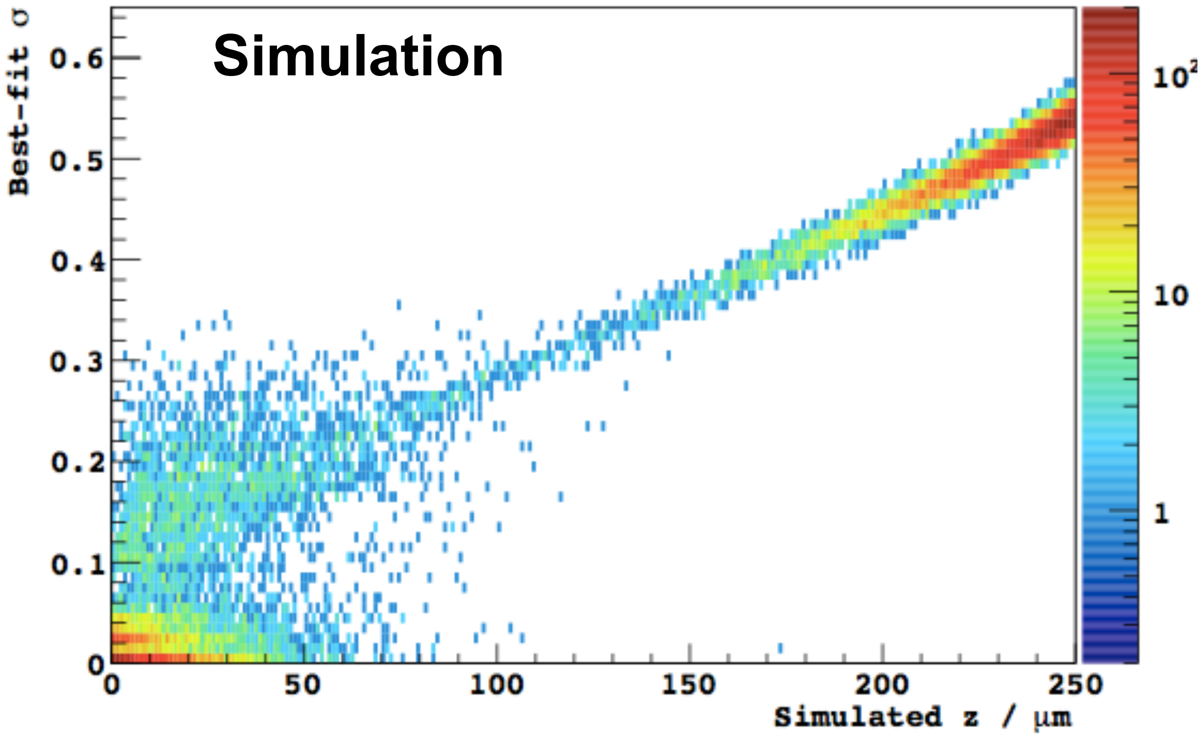




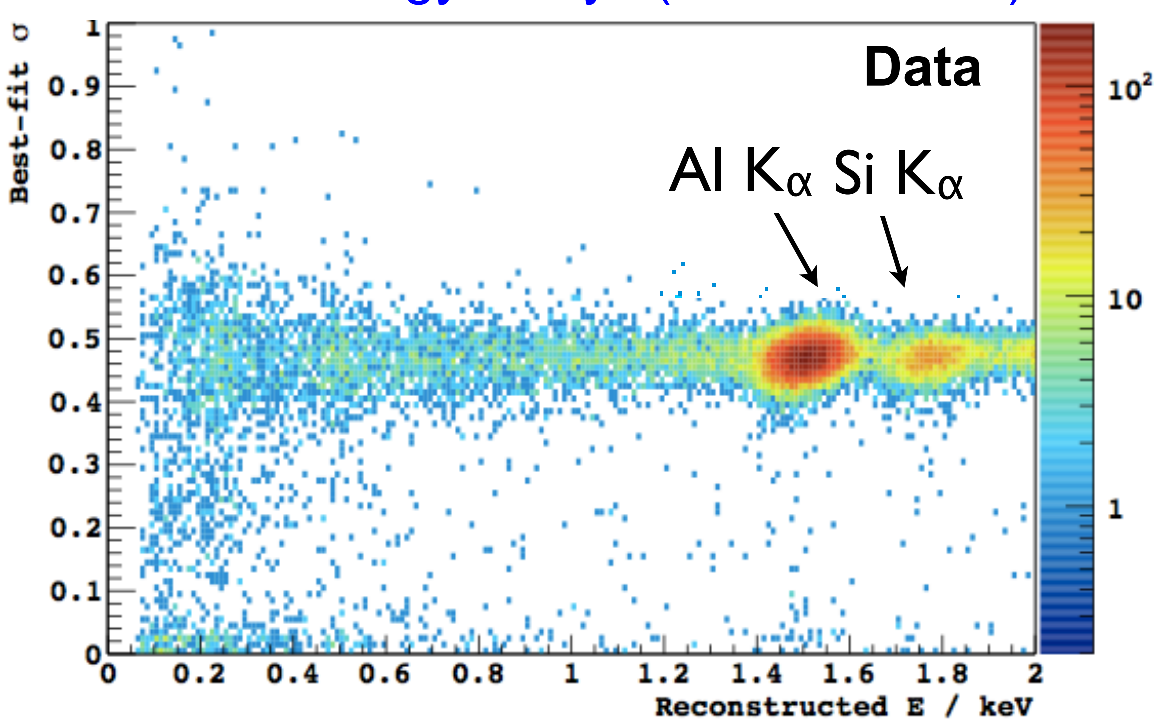
- ★ Main peaks: X-rays that deposit their full energy in the CCD, while the Mn escape lines are due to partial energy deposits, where the subsequent Si fluorescence X-ray (1.7 keV) escapes the CCD, absorption length 14μm.
- ★ Rarely: fluorescence X-ray travels far enough in the CCD (few attenuation lenghts) and leads to two distinguishable clusters.
- ★ Demonstration of capability to resolve energy deposits 10s of μm apart.

Diffusion and 3D reconstruction

^{55}Fe source 6 keV X ray (front and back)



Low energy X-rays (from the back)



250 µm thick CCD

^{252}Cf source (neutrons)