An independent analysis of CoGeNT

Christopher McCabe

with Celine Boehm and Jonathan Davis

JCAP 1408 014, arXiv:1405.0495

APS meeting, GRAPPA, UvA – 29th September 2014

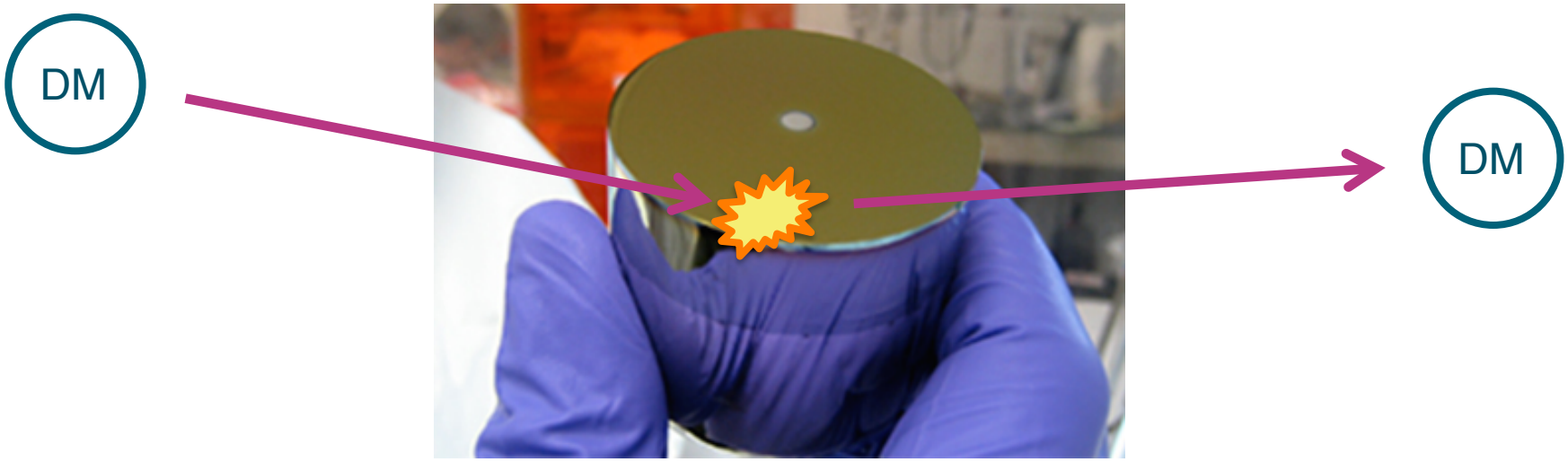
Plan

- Remind of you details about CoGeNT
- The importance of surface and bulk events
- Details of our analysis

What is CoGeNT?

CoGeNT:
1002.4703, 1106.0650,
1208.5737, 1401.3295

- Dark matter direct detection experiment



- P-type point contact Germanium detector
- Relatively small (~ 0.3 kg)
- Very low energy-threshold (~ 2 keV)
  - Beneficial for low mass DM searches

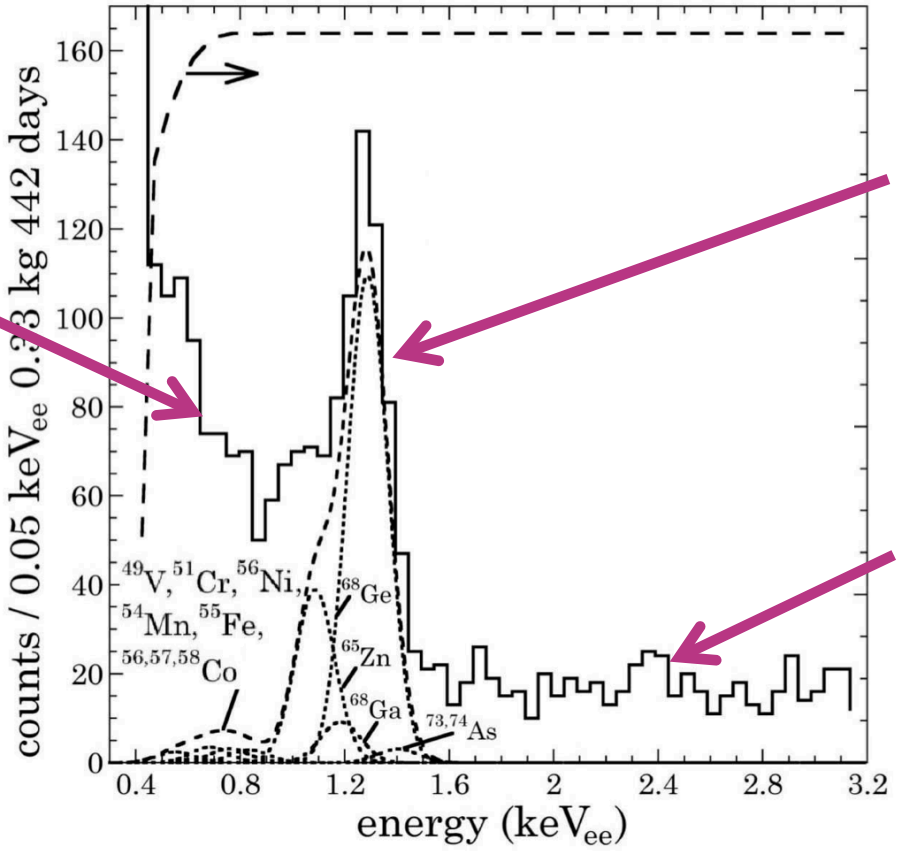
What do they measure?

CoGeNT:
1002.4703, 1106.0650,
1208.5737, 1401.3295

Unexpected

Expected

Irreducible excess of events at low energy



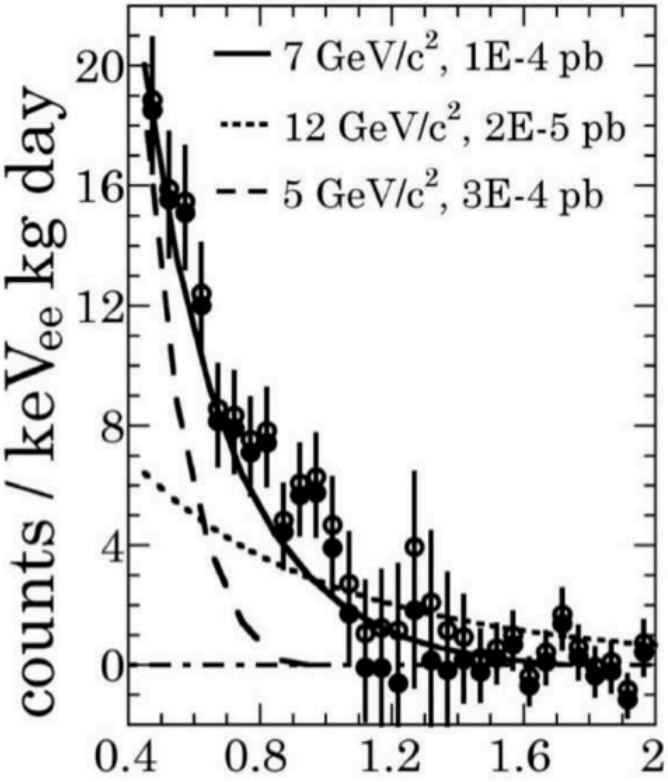
Cosmogenically activated ‘L-shell’ peaks

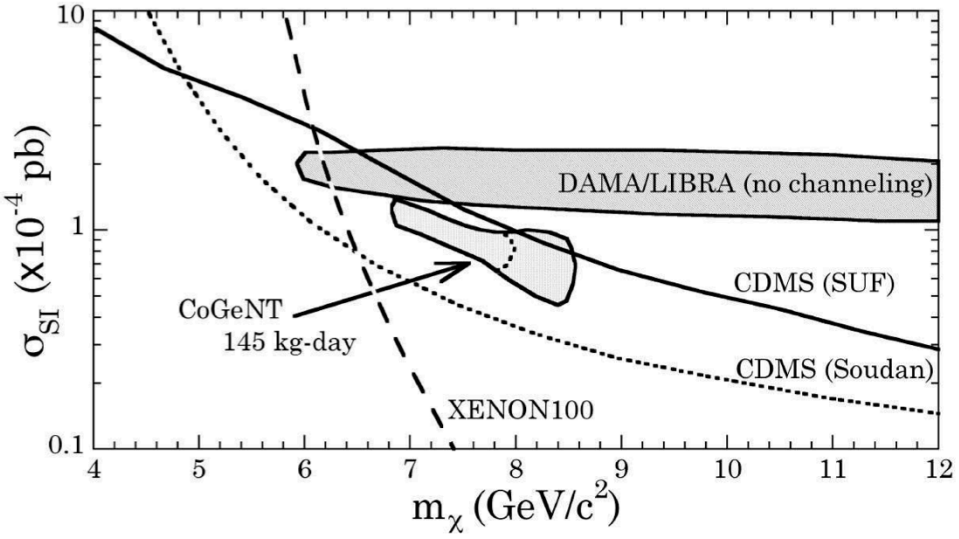
Flat background events from uranium, thorium, potassium, neutrons, muons, alphas, electrons…

Evidence for low mass DM?

CoGeNT:
1002.4703, 1106.0650,
1208.5737, 1401.3295

- 2010: low-energy 'irreducible excess' (650+ citations)
- Excess present in all subsequent results



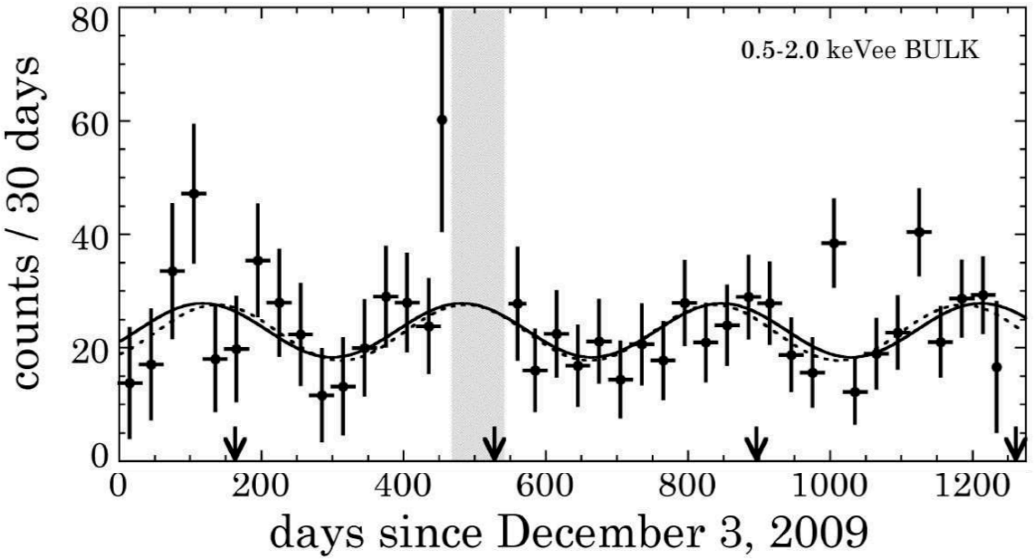


CoGeNT: 1106.0650

(Annual Modulation?)

CoGeNT:
1106.0650, 1401.3295

- Additionally, weak evidence for modulation $\sim 2.2\sigma$

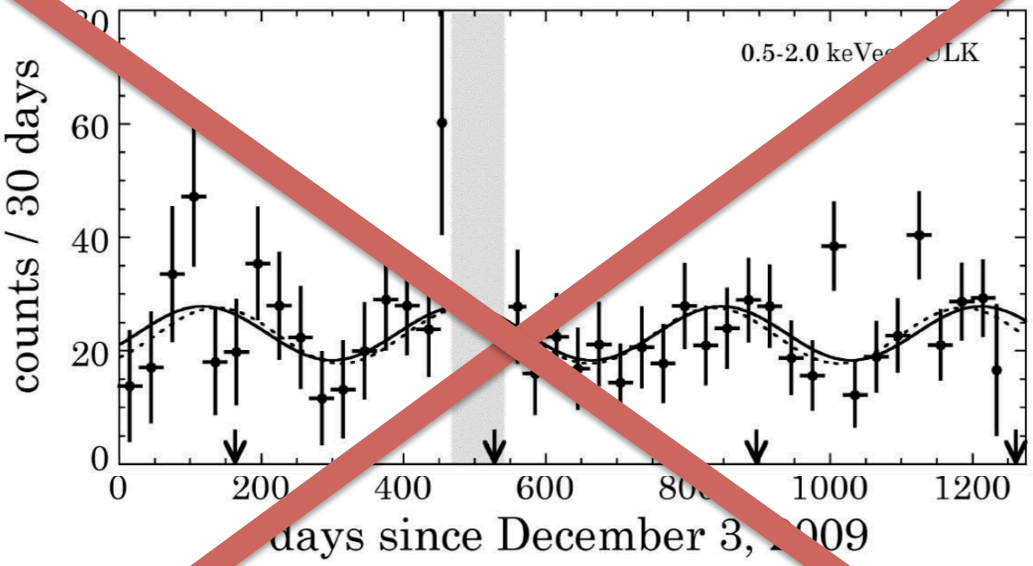


- Some usual features:
  - Not consistent with standard halo model eg peak day off
  - Modulated signal larger than expected/larger than what is possible (see Herrero-Garcia et al, arXiv:1112.1627)

(Annual Modulation?)

CoGeNT: 1106.065 , 1401.3295

- Additionally, weak evidence for modulation $\sim 2.2\sigma$



- Some usual features:
  - Not consistent with standard halo model eg peak day off
  - Modulated signal larger than expected/larger than what is possible (see Herrero-Garcia et al, arXiv:1112.1627)

Public data release

CoGeNT:
1106.0650, 1401.3295

- CoGeNT have publically released data twice

- 1st data release in 2011
  - Data included event energy and time
  - Various independent modulation studies performed

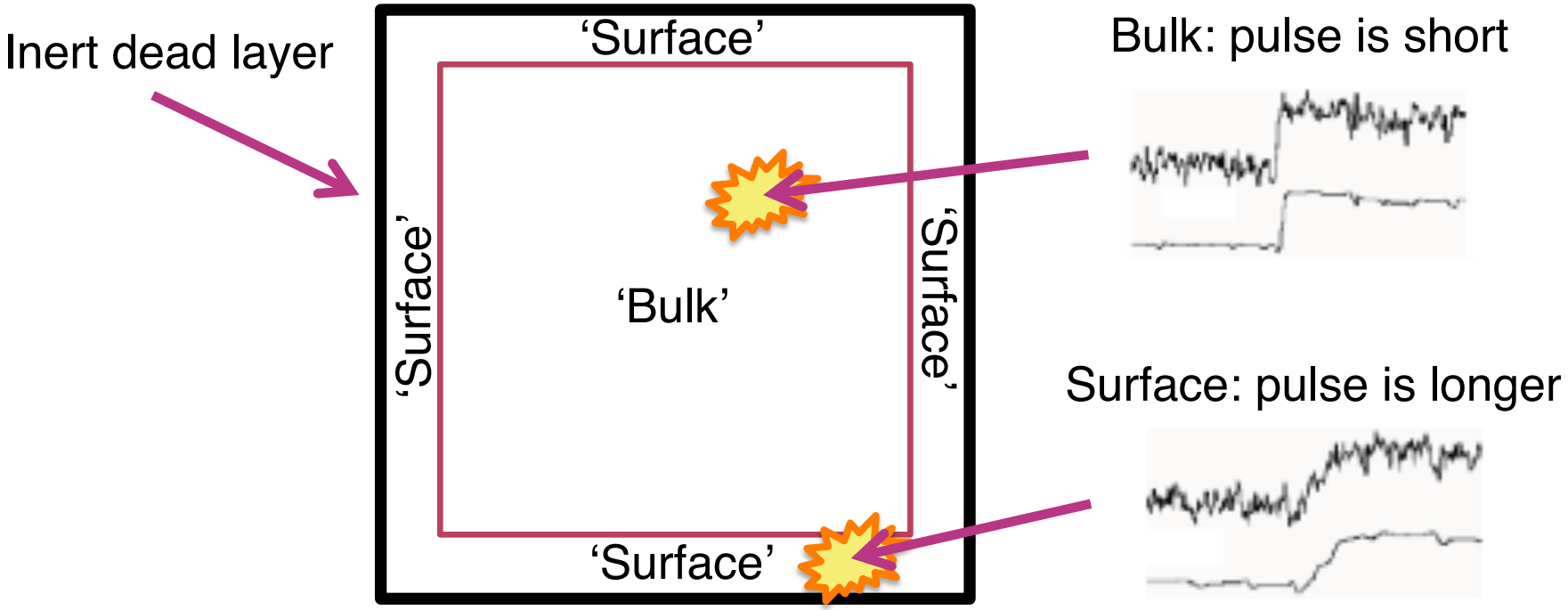
    Frandsen, Kahlhoefer, March-Russell, CM, McCullough;
    Kelso, Hooper, Buckley; Fox, Kopp, Lisanti, Weiner;
    Farina, Pappadopulo, Strumia, Volansky;
    Schwetz, Zupan;
    CM;

- 2nd data release in 2014
  - Data also includes the event 'rise-time'
  - 1 other (quasi-) independent analysis

    CoGeNT – Collar & Fields, arXiv:1401.6234
    (Collar & Fields + Kelso, Bellis to appear ????.????)

Why the rise-time is interesting

- Detector schematic

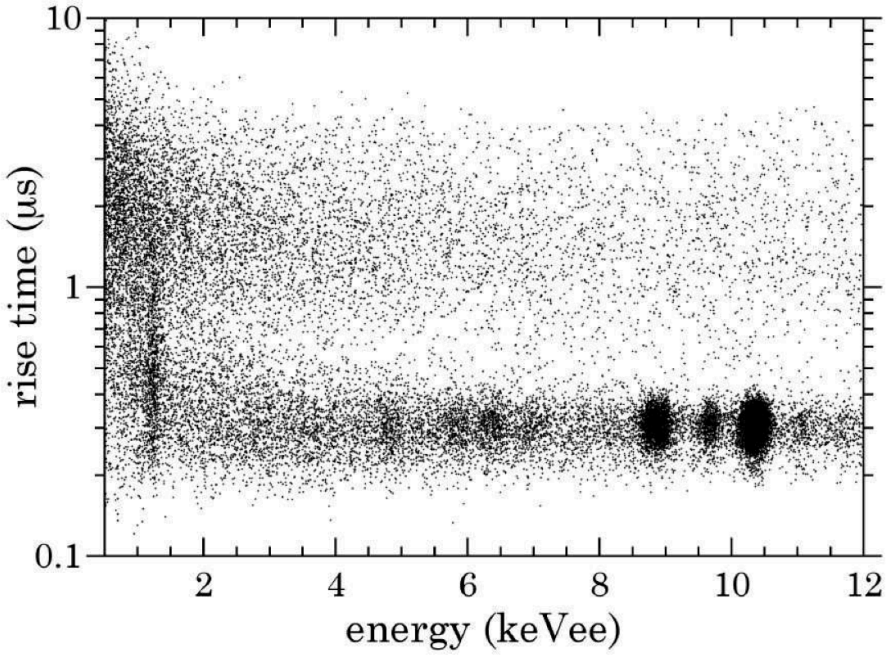


- Rise-time is the duration of the pulse – used to discriminate between bulk and surface events

Characterising the events

CoGeNT:1208.5737

- Events are characterised by the rise time



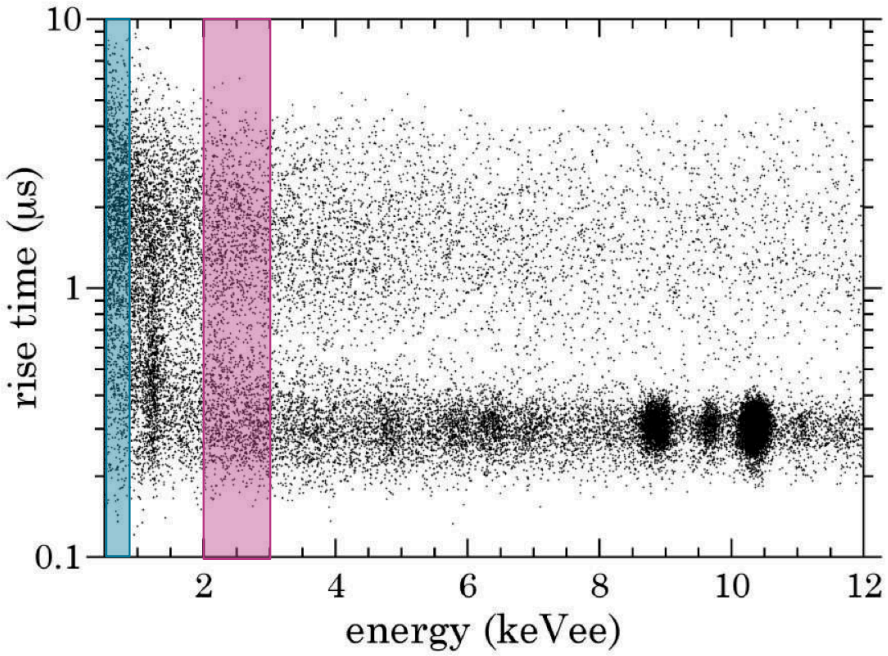
surface events

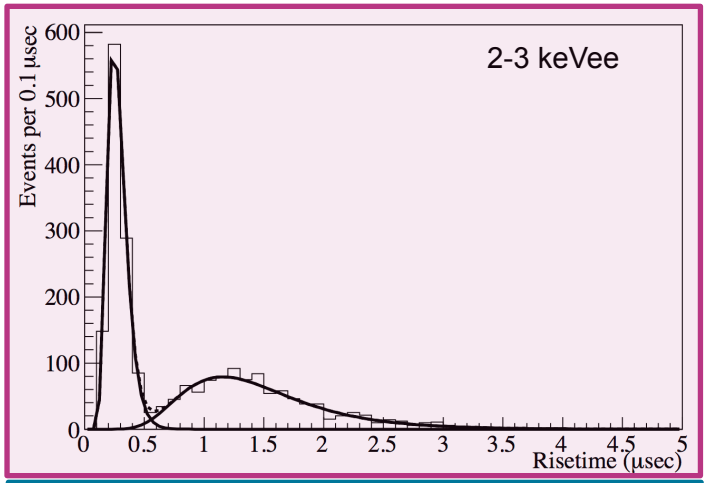
bulk events

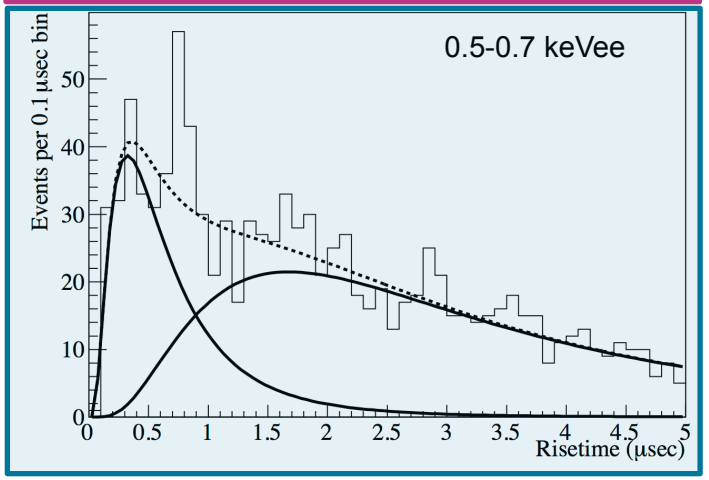
Characterising the events

CoGeNT:1208.5737

- Events are characterised by the rise time



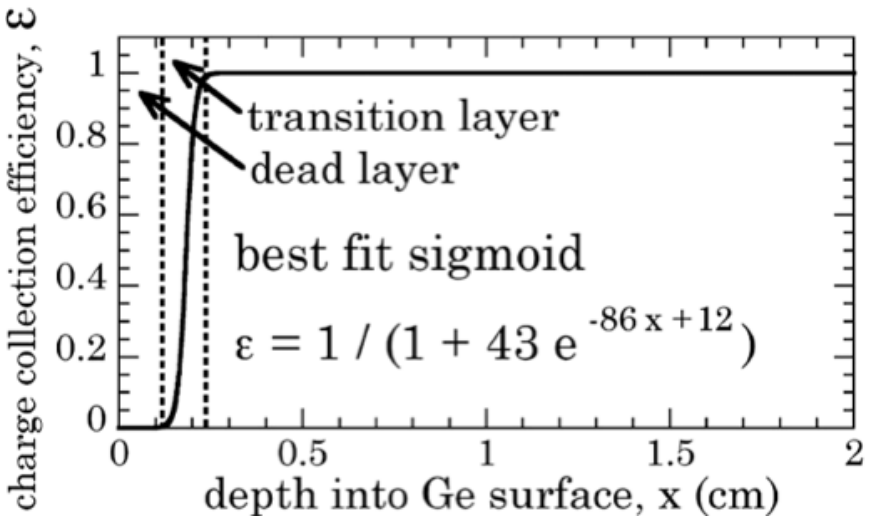


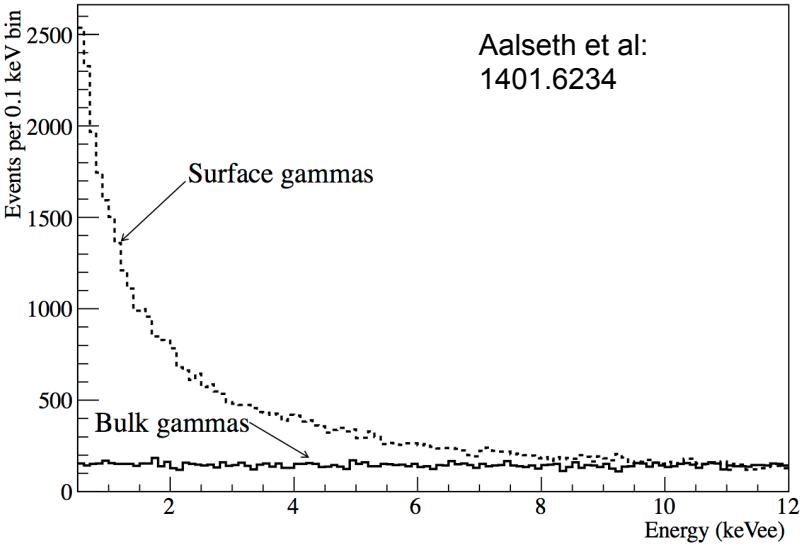


Difficult to separate at low energies:

The problem with surface events

- Partial energy (charge) collection



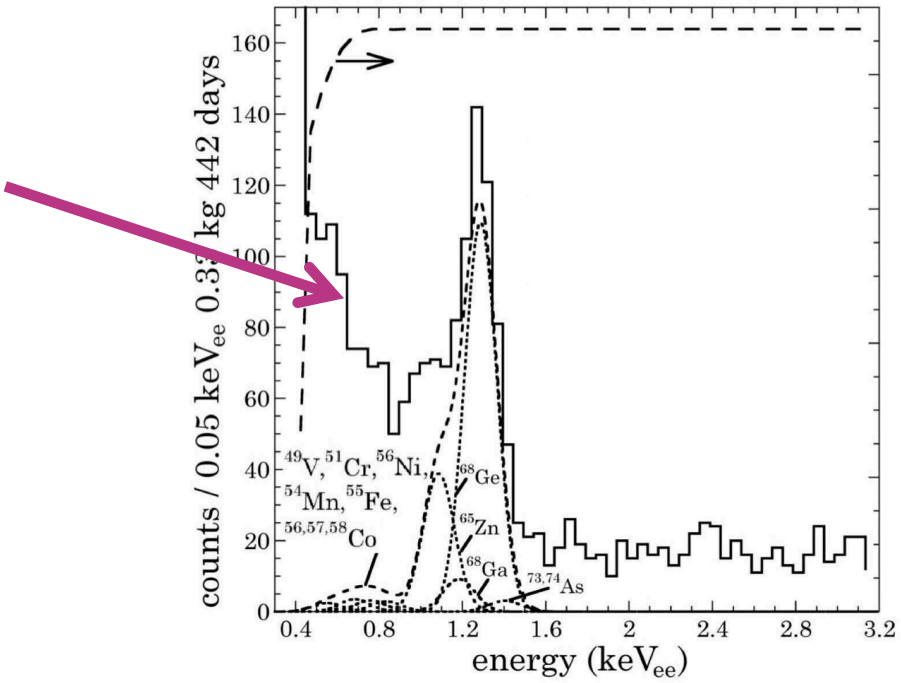


- Surface events can also give a low energy excess!
  - looks like the dark matter recoil spectrum

The punch-line

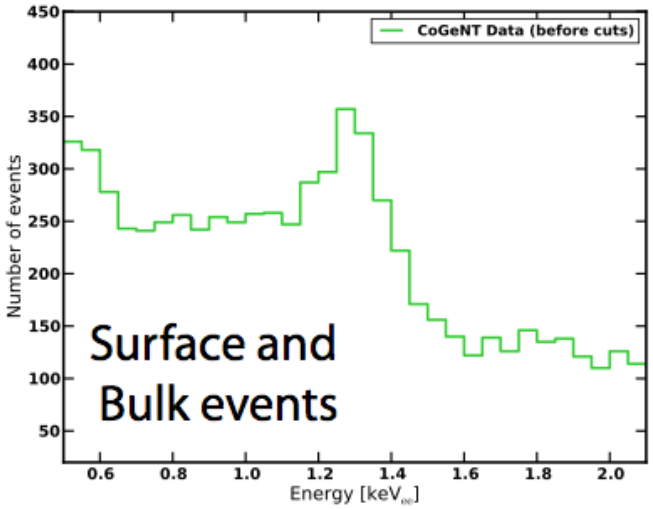
- All of the low energy irreducible excess can be accounted for by surface events

~~Dark matter~~
Surface events

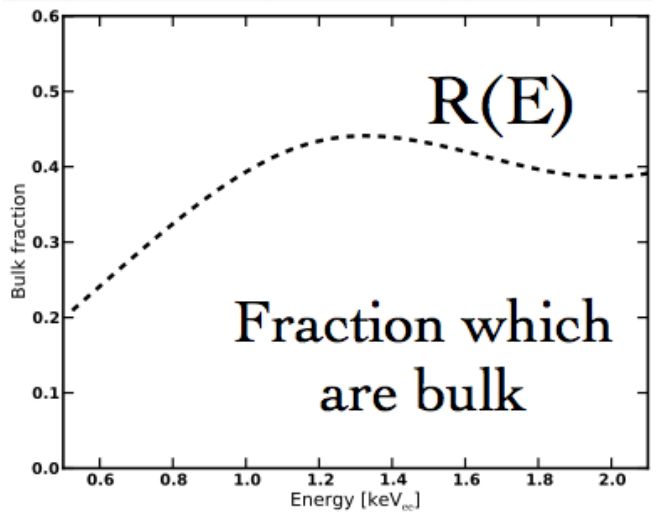


- Not possible to claim evidence for dark matter detection

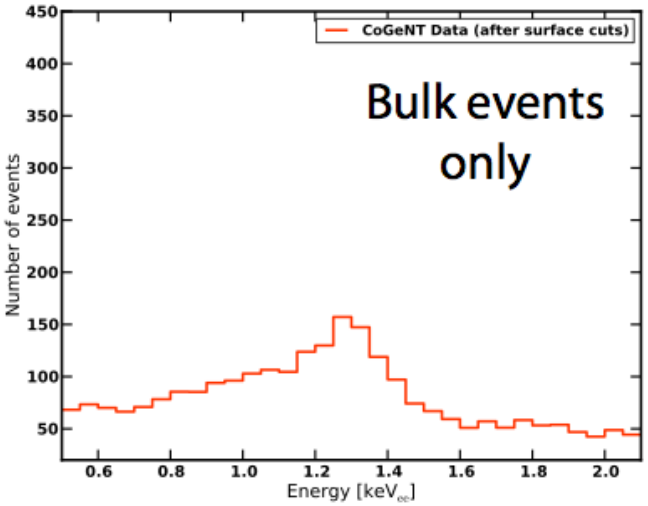
Cartoon of our analysis procedure



X

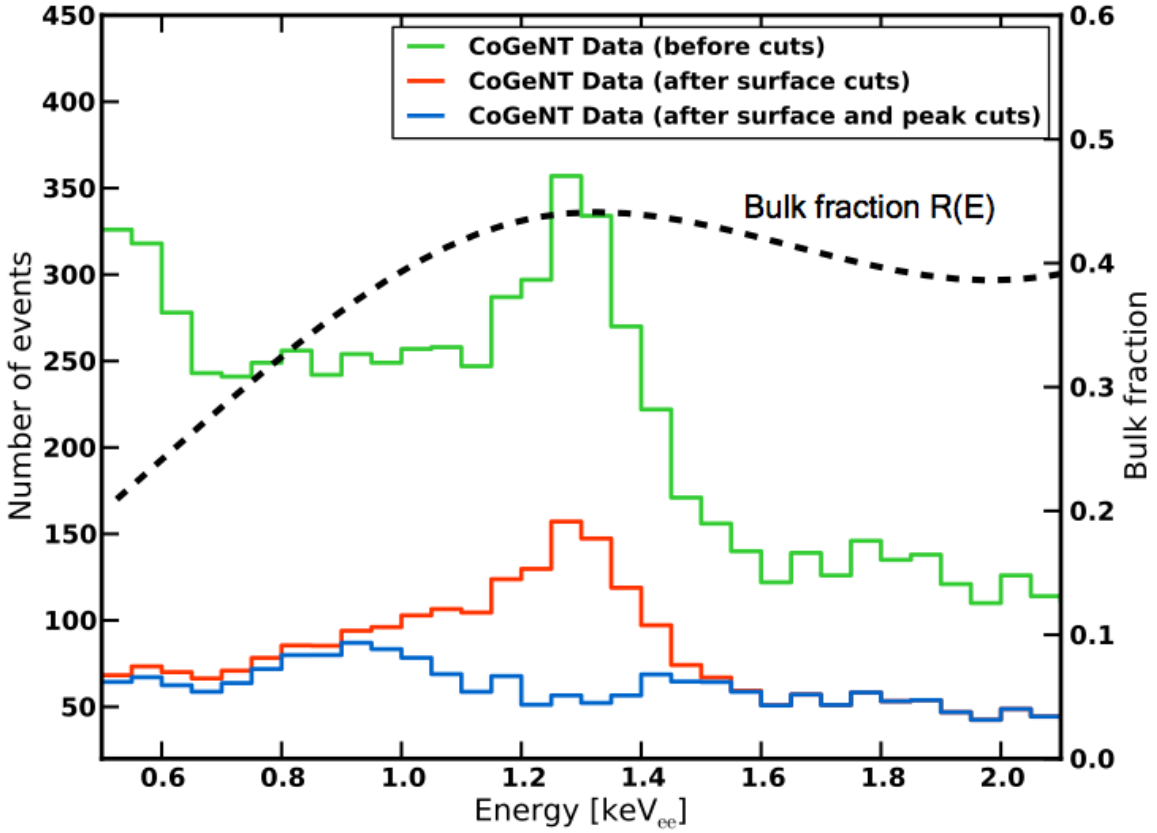


=



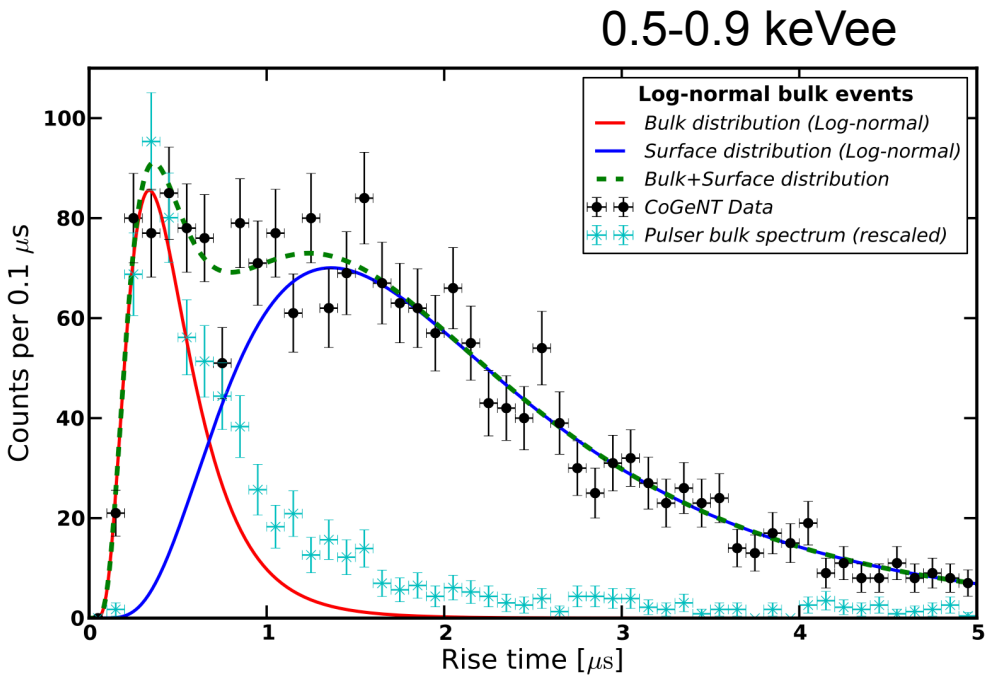
Cartoon of our analysis procedure

- Can also remove (known) L-shell peak (at ~1.3 keV_{ee})
- Search for dark matter in the remaining spectrum (in blue)



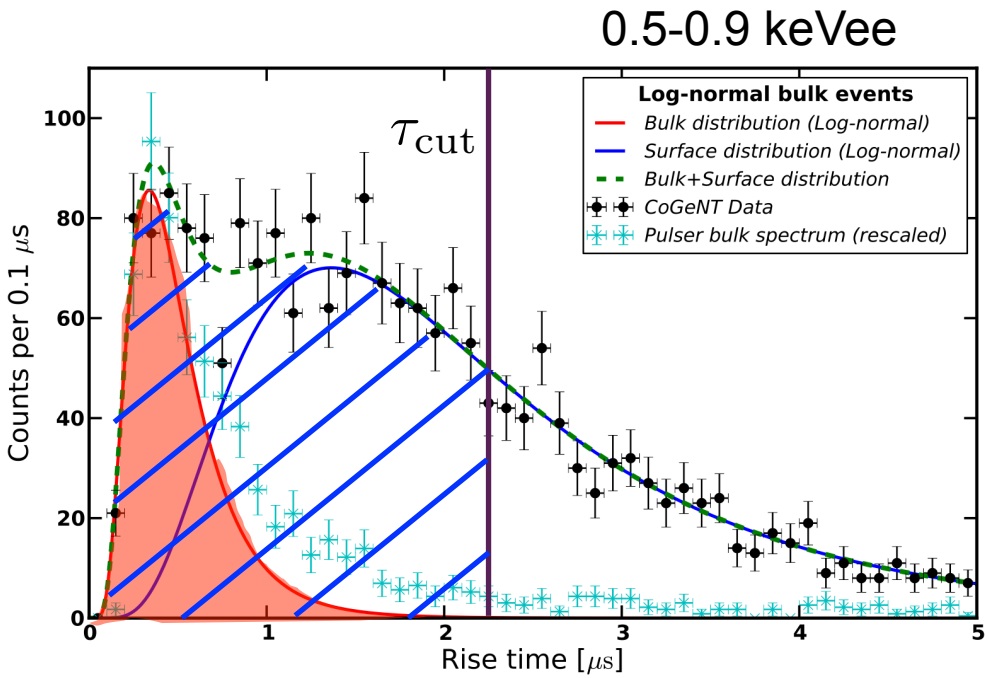
Finding the bulk fraction

- Fit to the rise time distributions
  - Two log-normal distributions fit the data well



Finding the bulk fraction

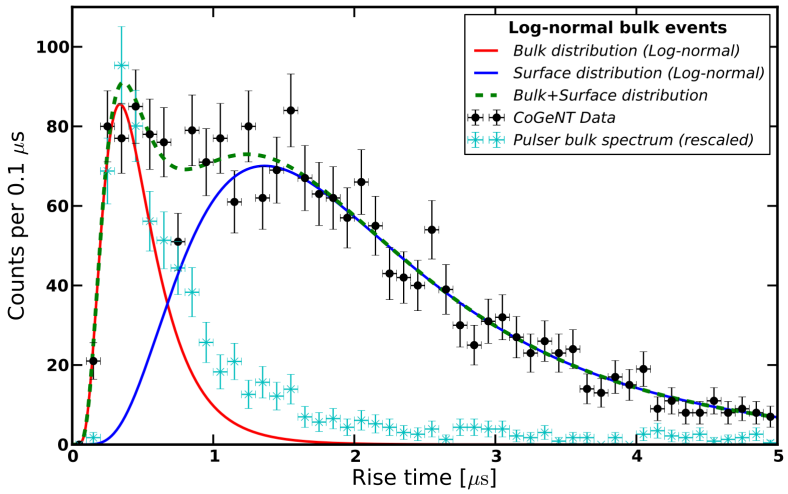
- Fit to the rise time distributions
  - Two log-normal distributions fit the data well

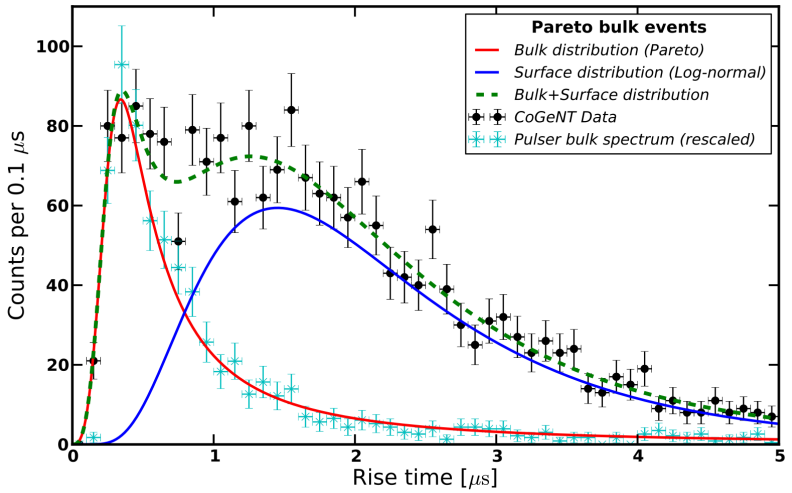


$$\mathcal{R}_j = \left[\frac{\text{Number of bulk events} < \tau_{\rm cut}}{\text{Total number of events} < \tau_{\rm cut}} \right]_j$$

Finding the bulk fraction

- Fit to the rise time distributions
  - Pareto distribution also gives a good fit

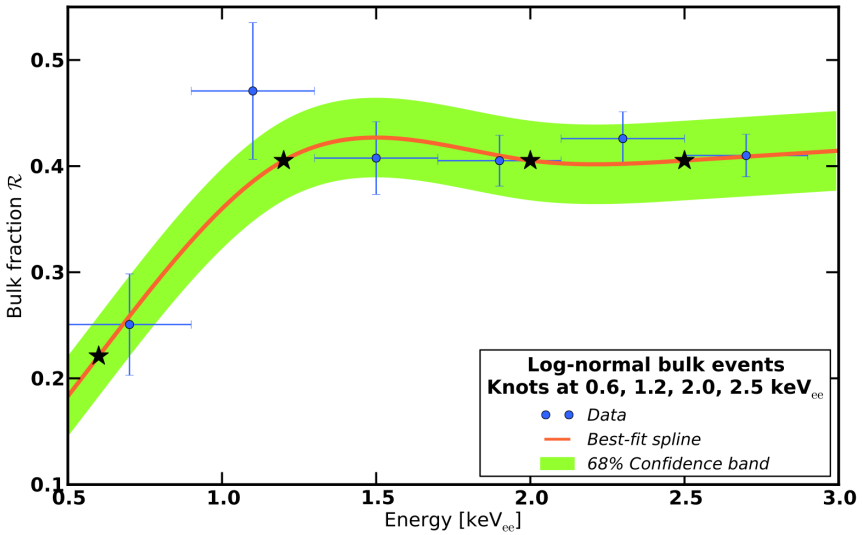


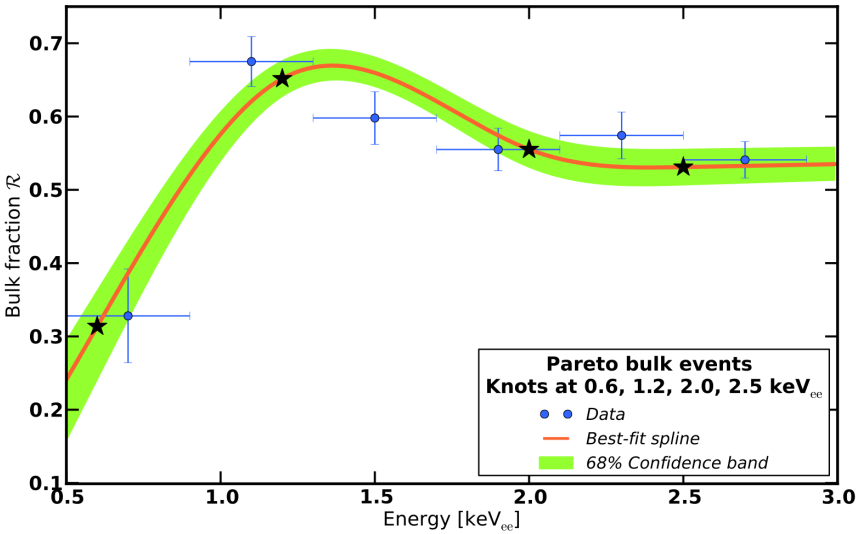


- Pareto gives better fit to “fast electronic pulser events able to mimic, to a good extent, a radiation-induced pulse taking place within the bulk of the crystal”

Finding the bulk fraction

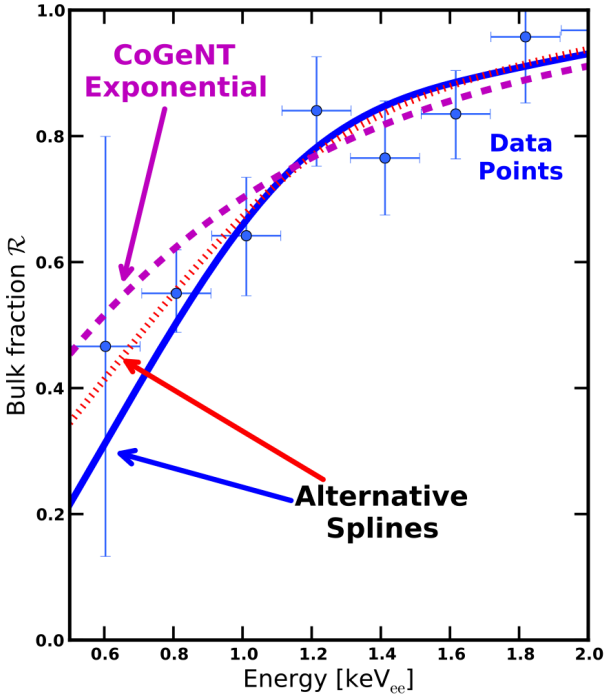
- Similar behaviour for both distributions

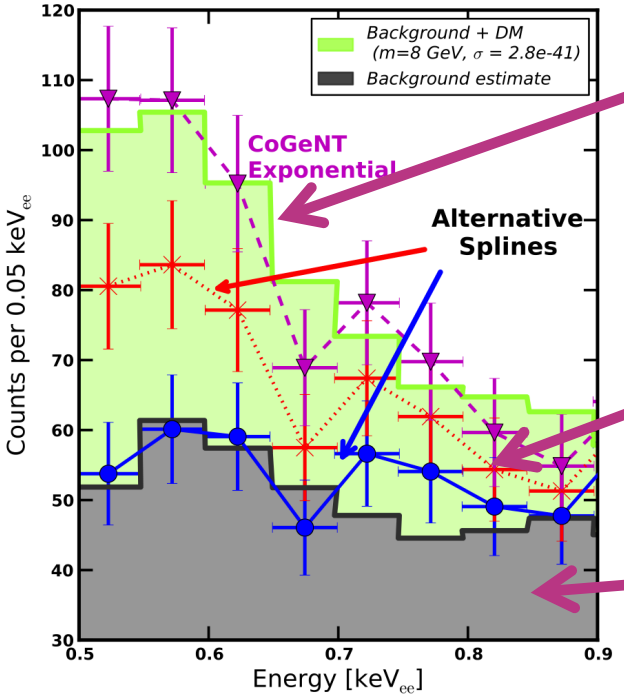




- Parameterise bulk fraction with cubic splines
  - Best choice as no theoretically motivated function

The bulk fraction matters





DM prediction

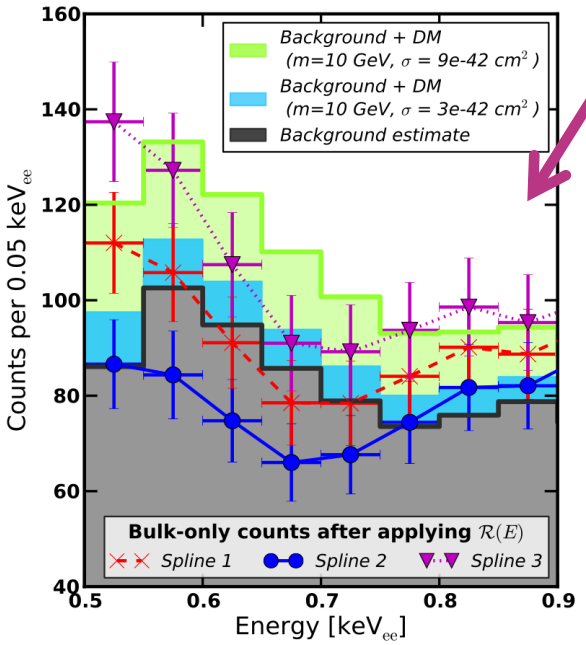
CoGeNT data
x bulk fraction
- L-shell peak

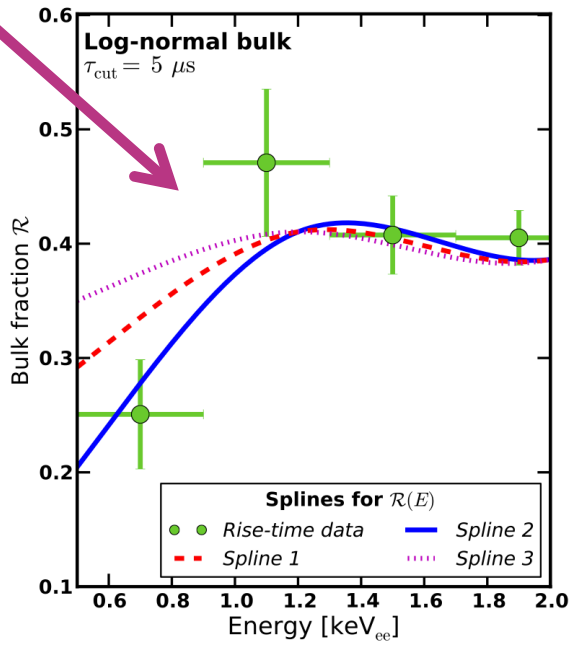
Bulk background

- Some spline fits result in preference for dark matter

Likelihood analysis

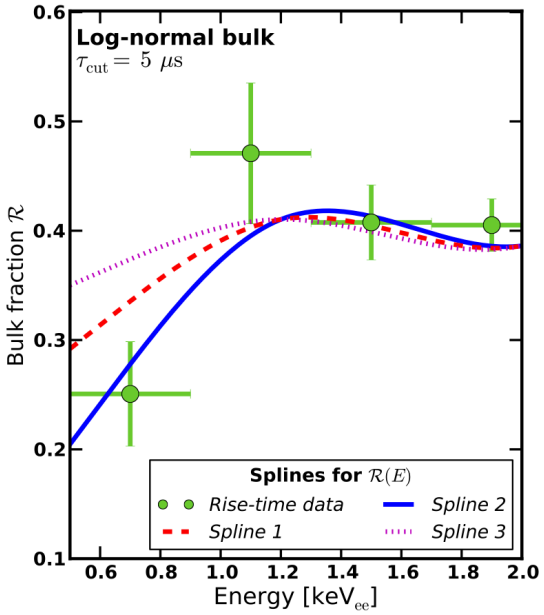
$$\lambda = -2\ln\left[\frac{\max \mathcal{P}(d_E|m,\sigma,\mathcal{R})\mathcal{P}(d_\mathcal{R}|\mathcal{R})}{\max \mathcal{P}(d_E|\sigma=0,\mathcal{R})\mathcal{P}(d_\mathcal{R}|\mathcal{R})}\right]$$

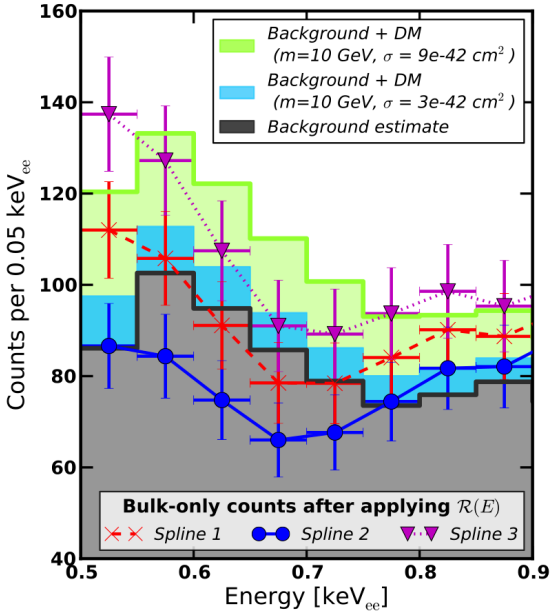


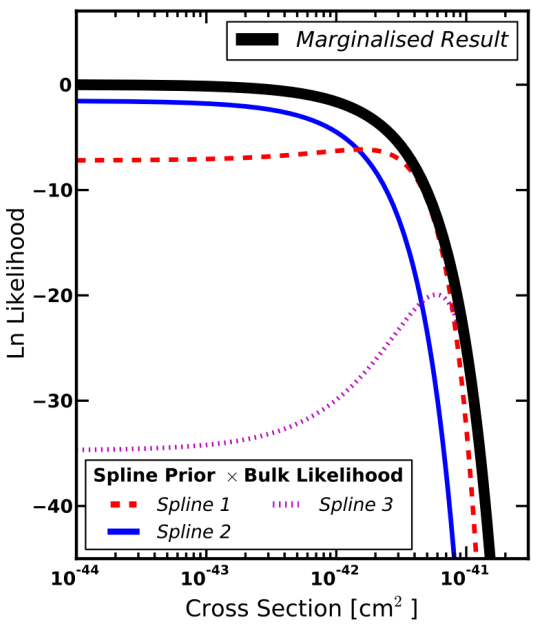


- Bulk background prediction from CoGeNT, arXiv:1208.5737

Likelihood analysis

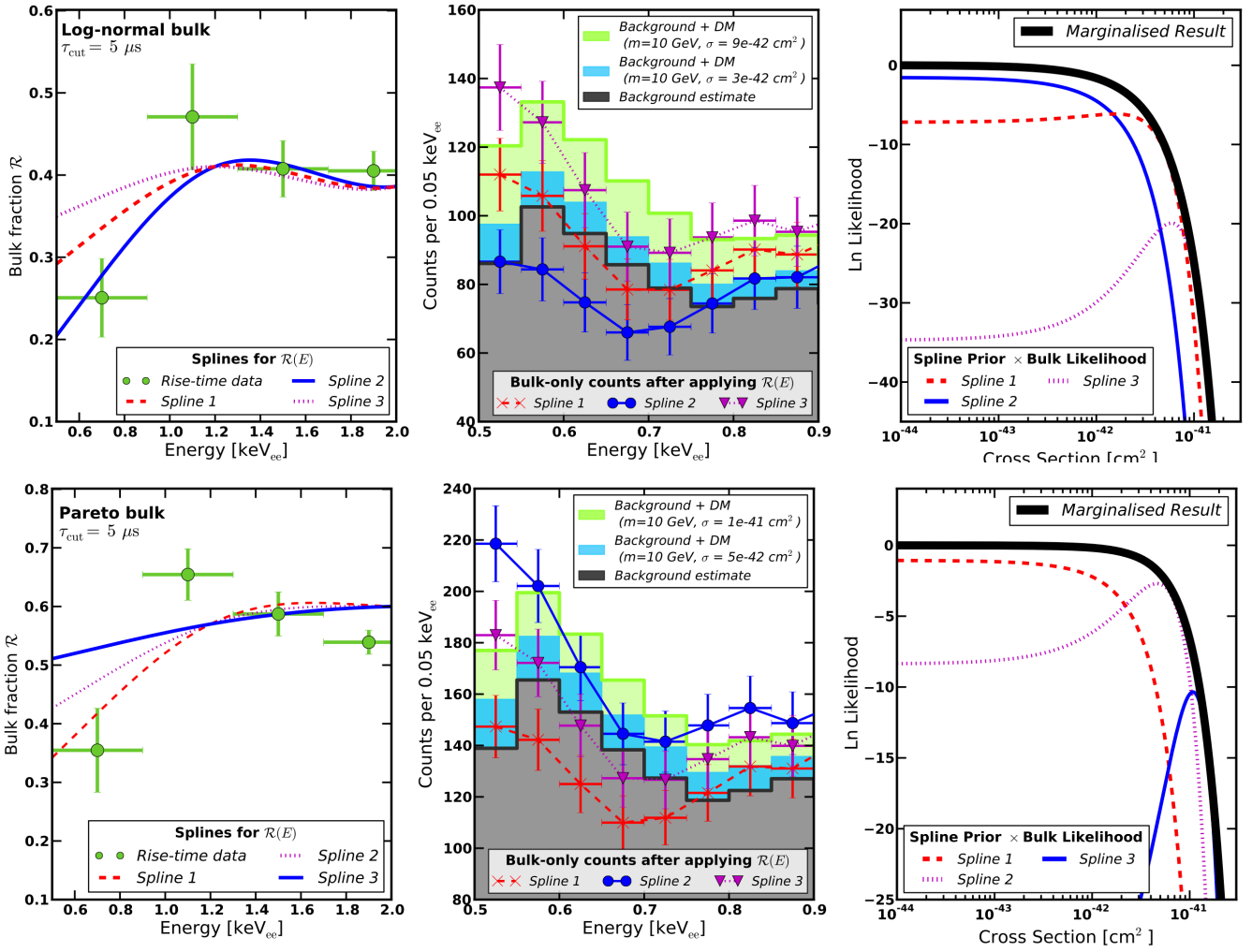




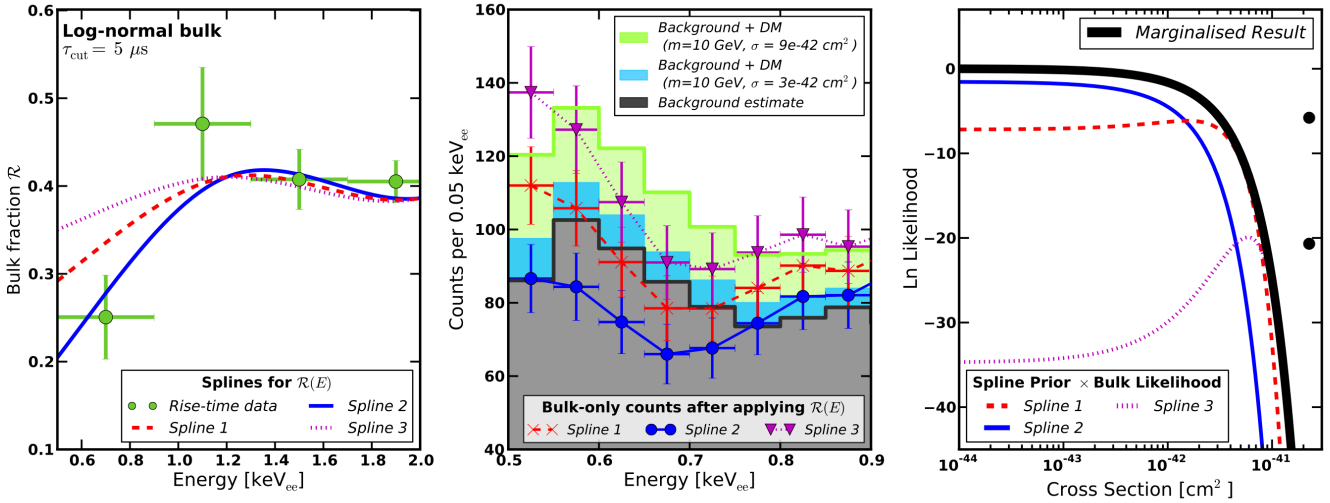


- We always find weak ($< 1\sigma$) preference for DM+background over fit to background only

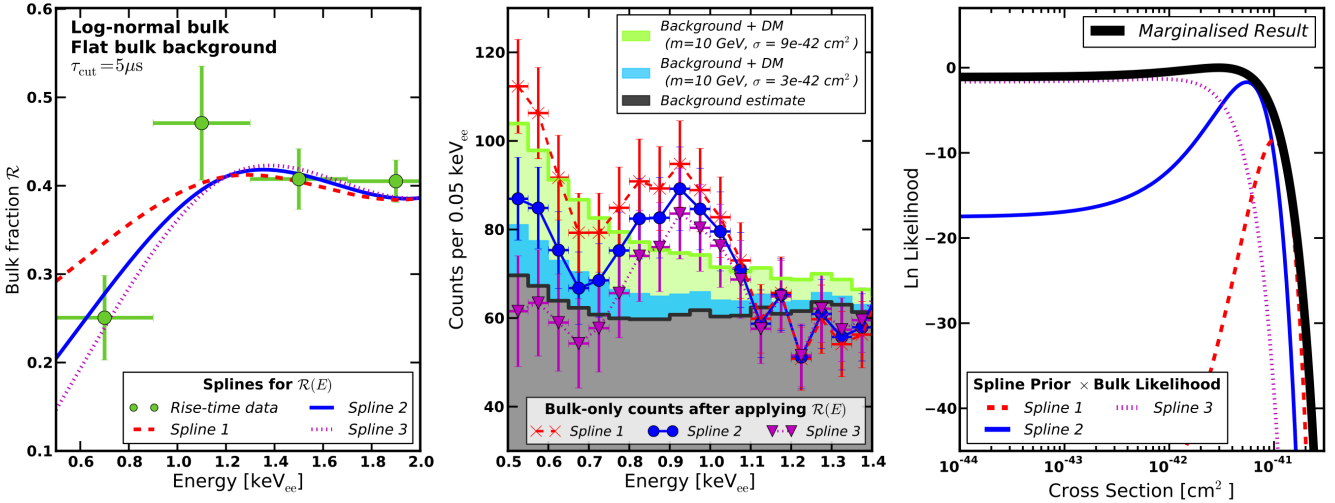
Log-normal vs Pareto



Varying the background model



Background from CoGeNT arXiv:1208.5737



Background from CoGeNT - Collar, Fields arXiv:1401.6234

Consistent results

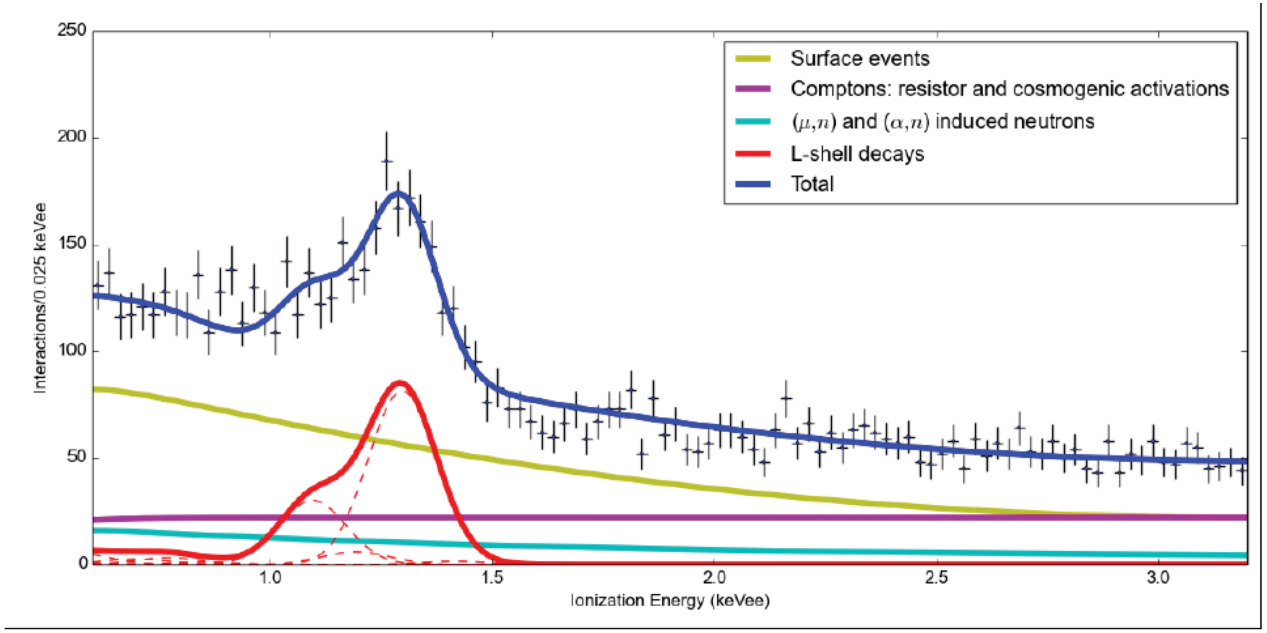
- We always find weak ($< 1\sigma$) preference for DM+background over fit to background only

Consistent results

- Juan Collar's analysis comes to a similar conclusion

Background Only Fit to the Data

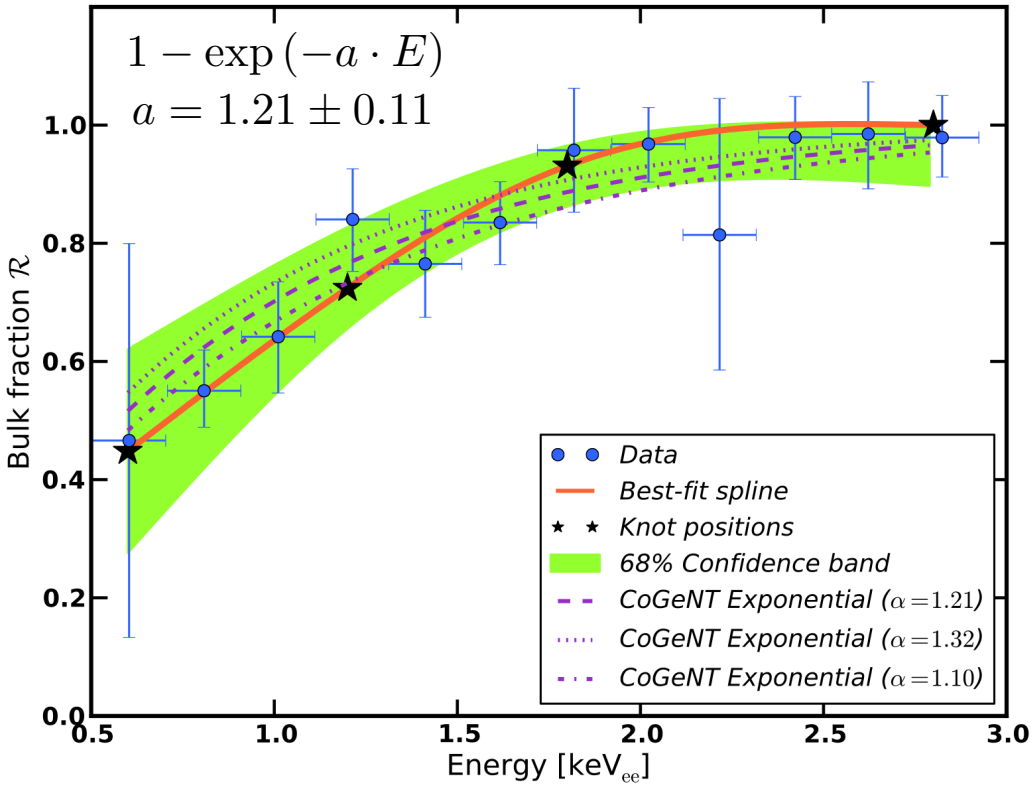
TeVPA/IDM 2014



Background model is good fit to the data

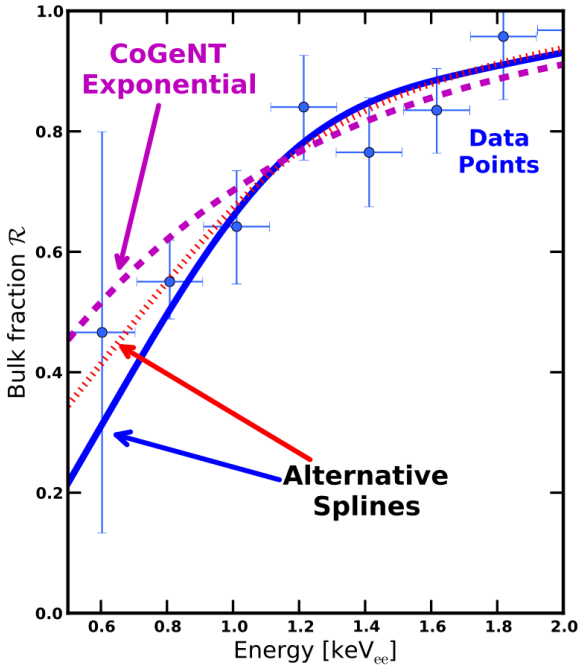
Difference to CoGeNT?

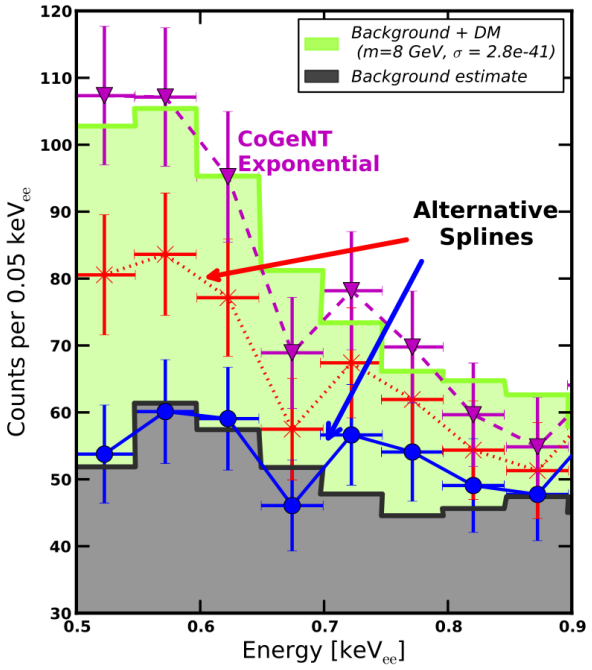
- Initial analyses assumed the bulk fraction is 1
- Later analyses fit with 1-parameter exponential – underestimate uncertainties

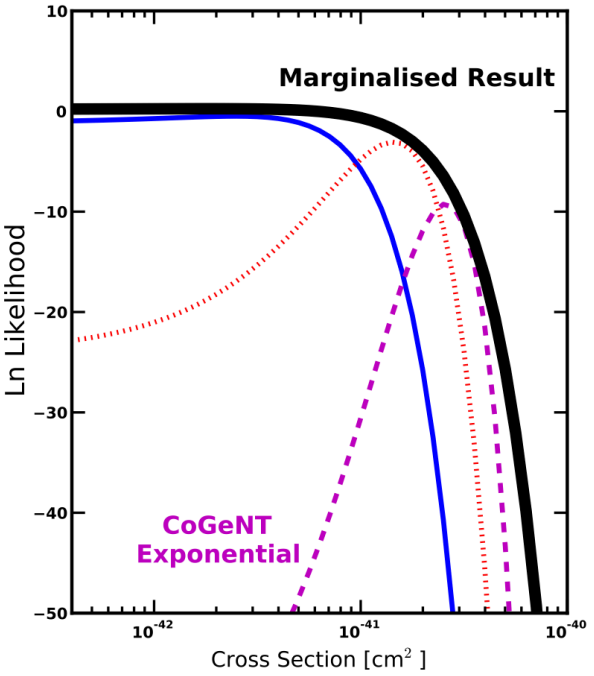


Difference to CoGeNT?

- Exponential leads to biased conclusion in favour of DM signal





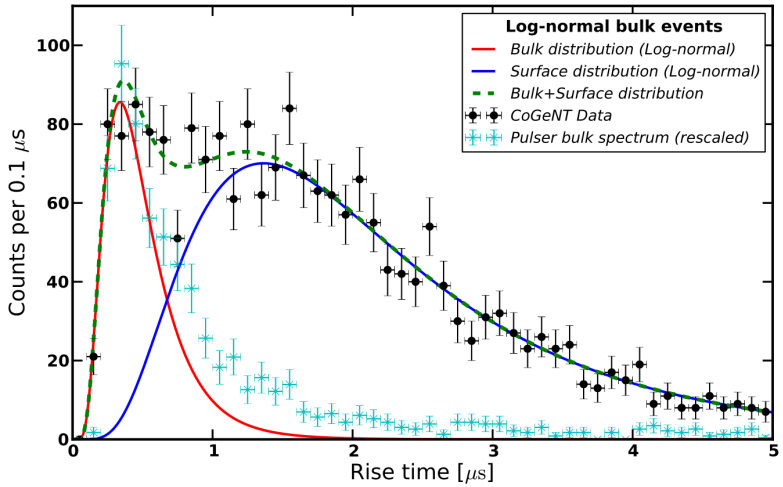


Summary

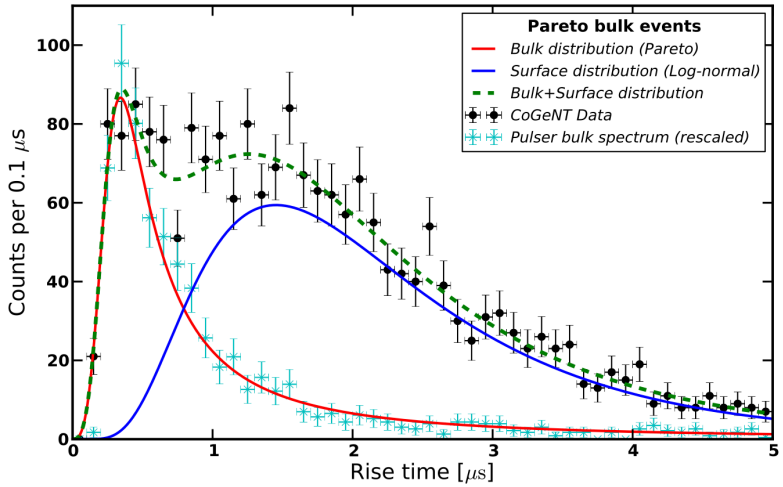
- CoGeNT signal has generated a lot of interest
- Full dataset released for public analysis
- Surface events can mimic dark matter signal (a rise at low energy)
- Surface event contribution is uncertain but it can account for all of the observed low energy excess

backup

Log-normal vs Pareto



$$f_{\text{total}}(\tau) = f_{\text{bulk}}(\tau) + f_{\text{surface}}(\tau)$$
$$= \frac{1}{\tau\sqrt{2\pi}}\left(\frac{A_b}{\sigma_b}\exp\left[-\frac{(\ln\tau-\mu_b)^2}{2\sigma_b^2}\right] + \frac{A_s}{\sigma_s}\exp\left[-\frac{(\ln\tau-\mu_s)^2}{2\sigma_s^2}\right]\right)$$



$$f_{\text{bulk}}(\tau) = \frac{A_b\alpha_b}{\gamma_b\kappa_b^{1/\gamma_b}}\tau^{1/\gamma_b-1}\left[\left(\frac{\kappa_b}{\tau}\right)^{-1/\gamma_b}+1\right]^{-\alpha_b-1}$$