A PHYSICAL MODEL FOR THE DEPOSITION OF ENERGY VIA COSMIC RAYS IN SUBKELVIN BOLOMETRIC DETECTORS

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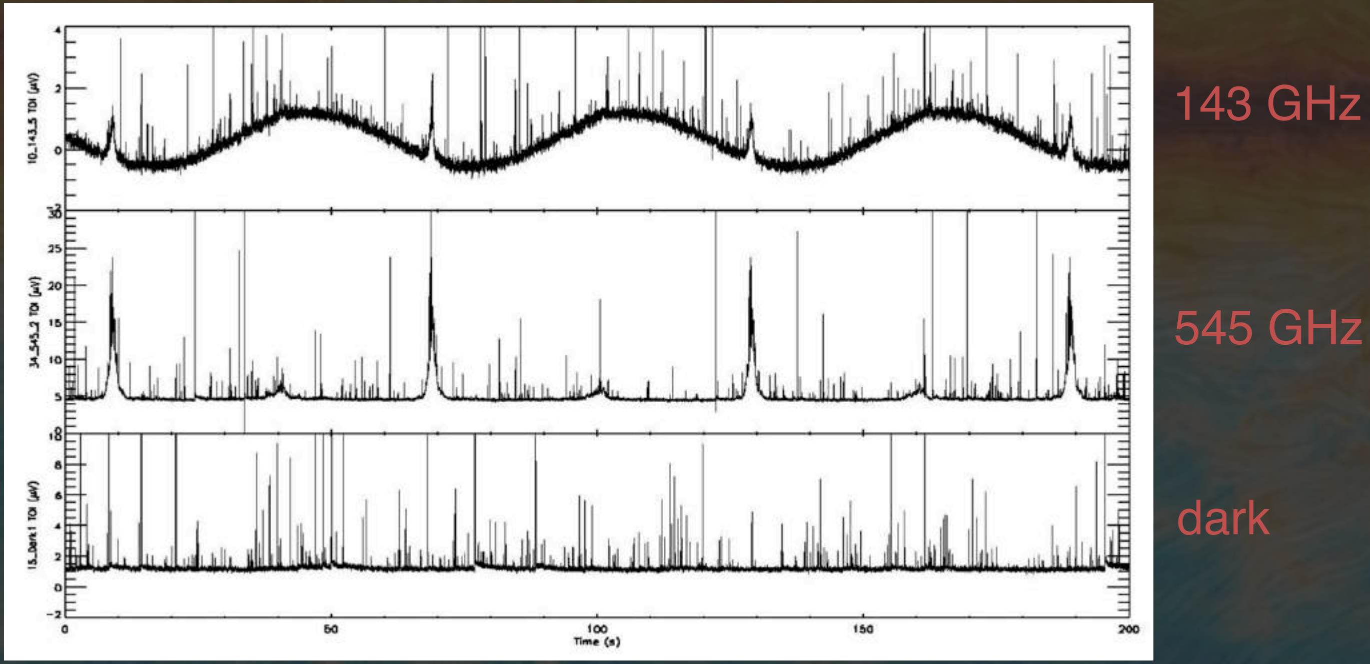
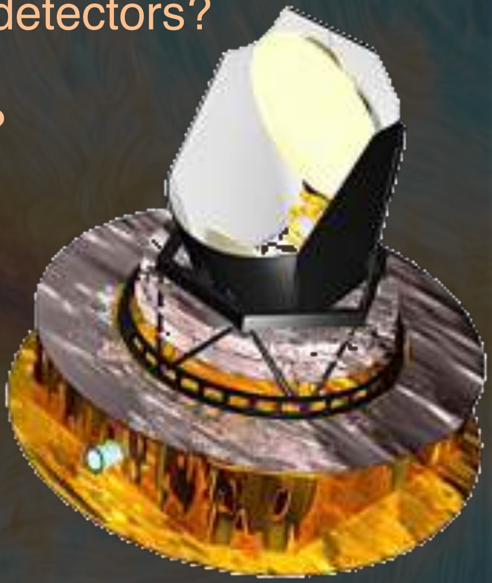
The Cosmic Ray Problem

The Question: CMB space missions are particularly sensitive to interactions with cosmic rays, owing to their detector sensitivity and their location in a high-radiation environment – as was the case with *Planck*.

What are the physical mechanisms of these disturbances in the detectors?

How will they affect the next generation of CMB space missions?

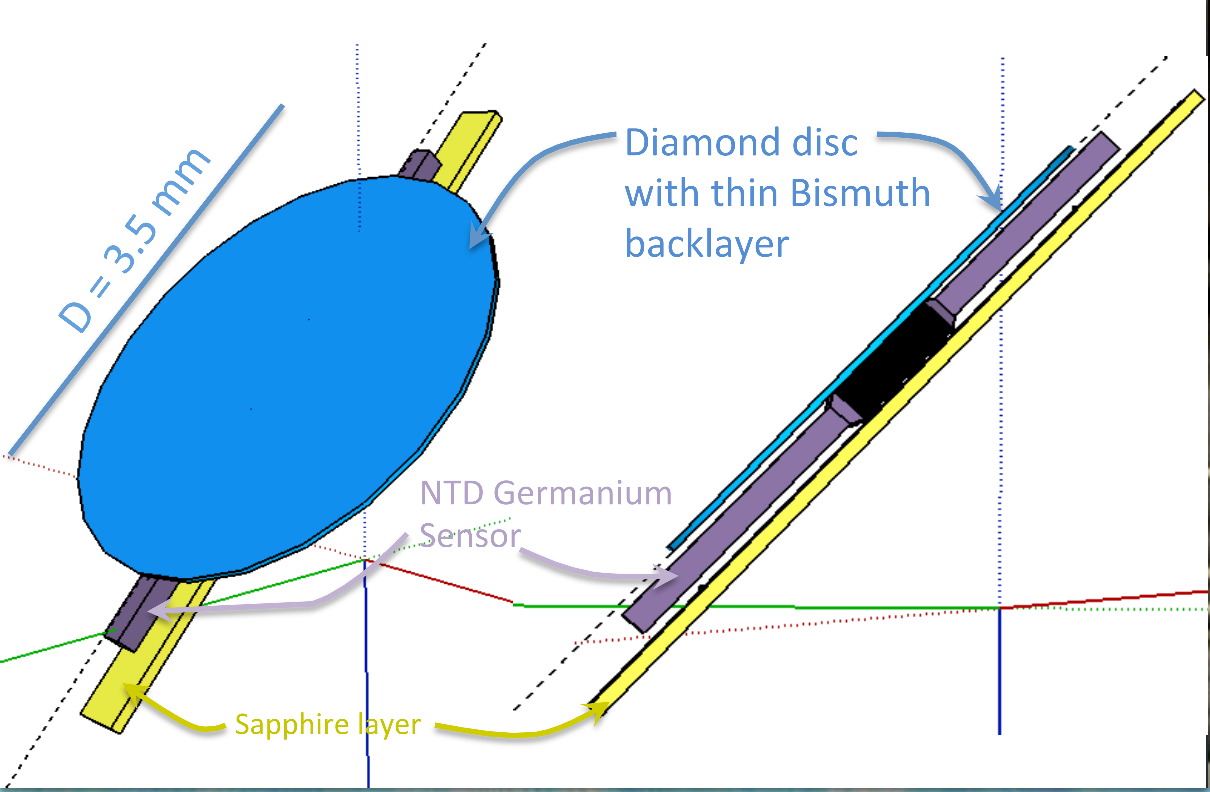


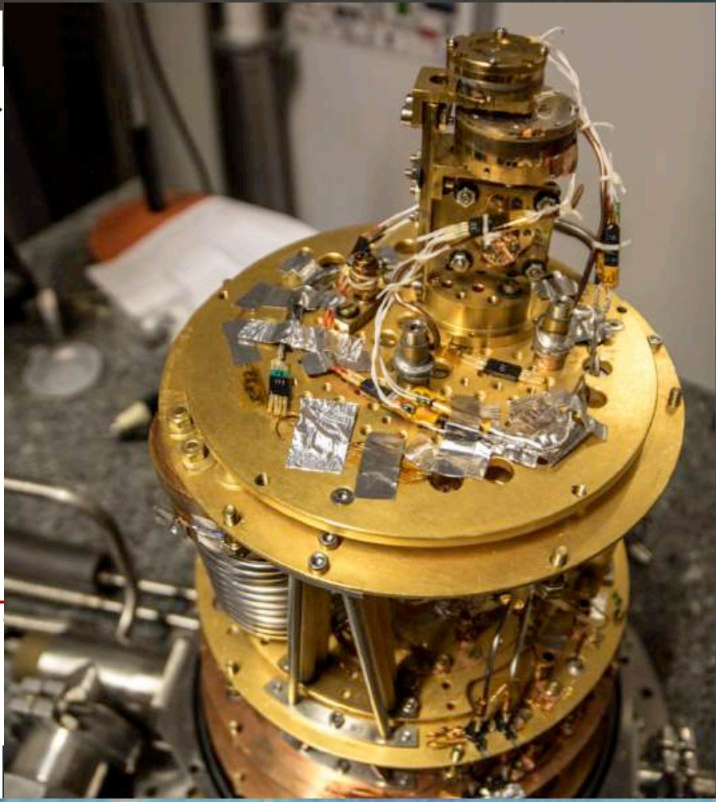


A Catalano, Planck Collab, J. Low Temp. Phys. 2013

Bolometer Measurements

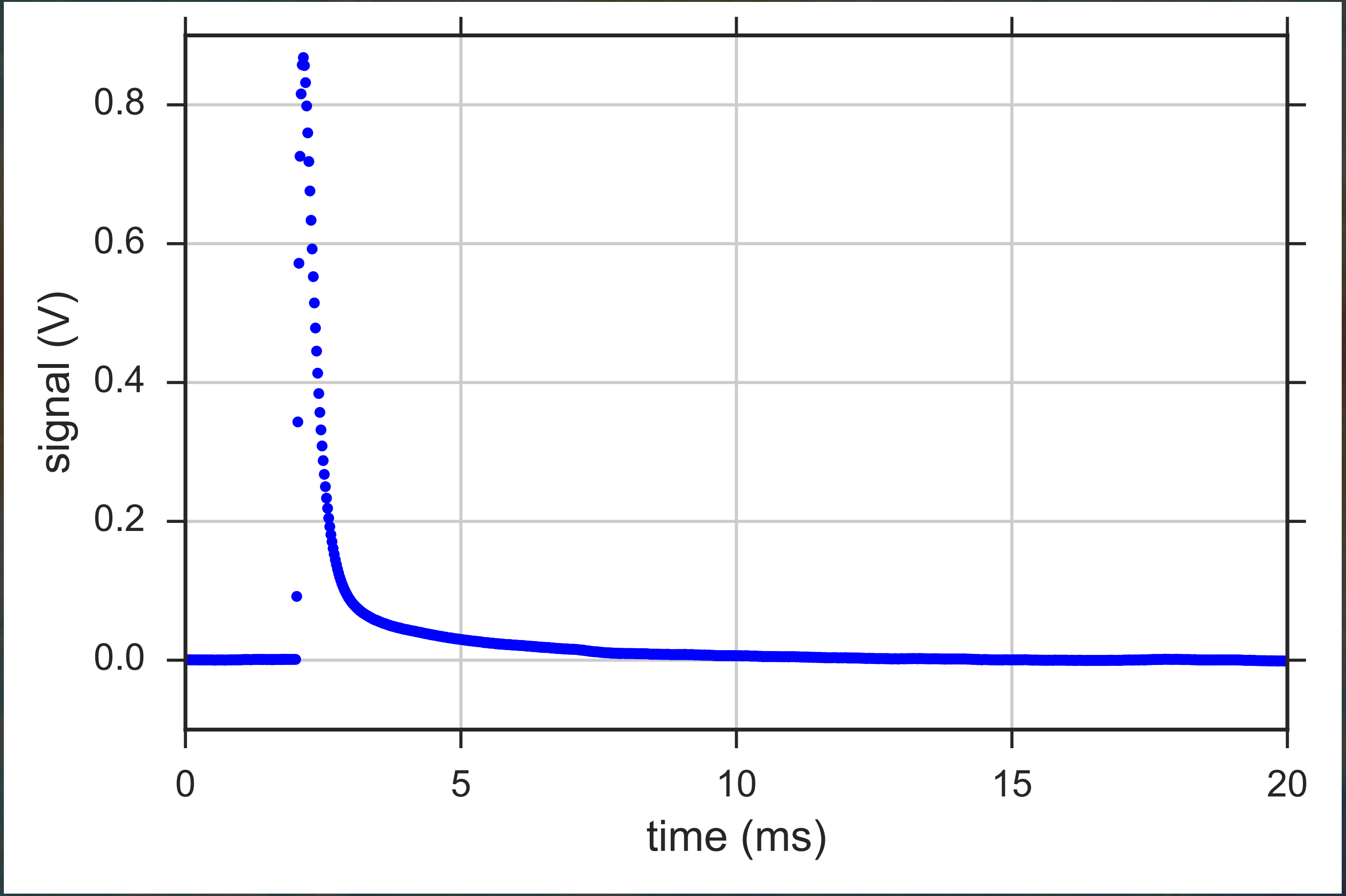
- Irradiated bolometers with ^{241}Am → 5.6 MeV alpha particle source
- Worked with DIABOLO, developed at IAS for a ground-based telescope
- Measurement campaigns on DIABOLO composite NTD Ge semiconductor bolometer
- 3000+ glitches, sampling rate @20µs (50kHz), dedicated detector development readout system





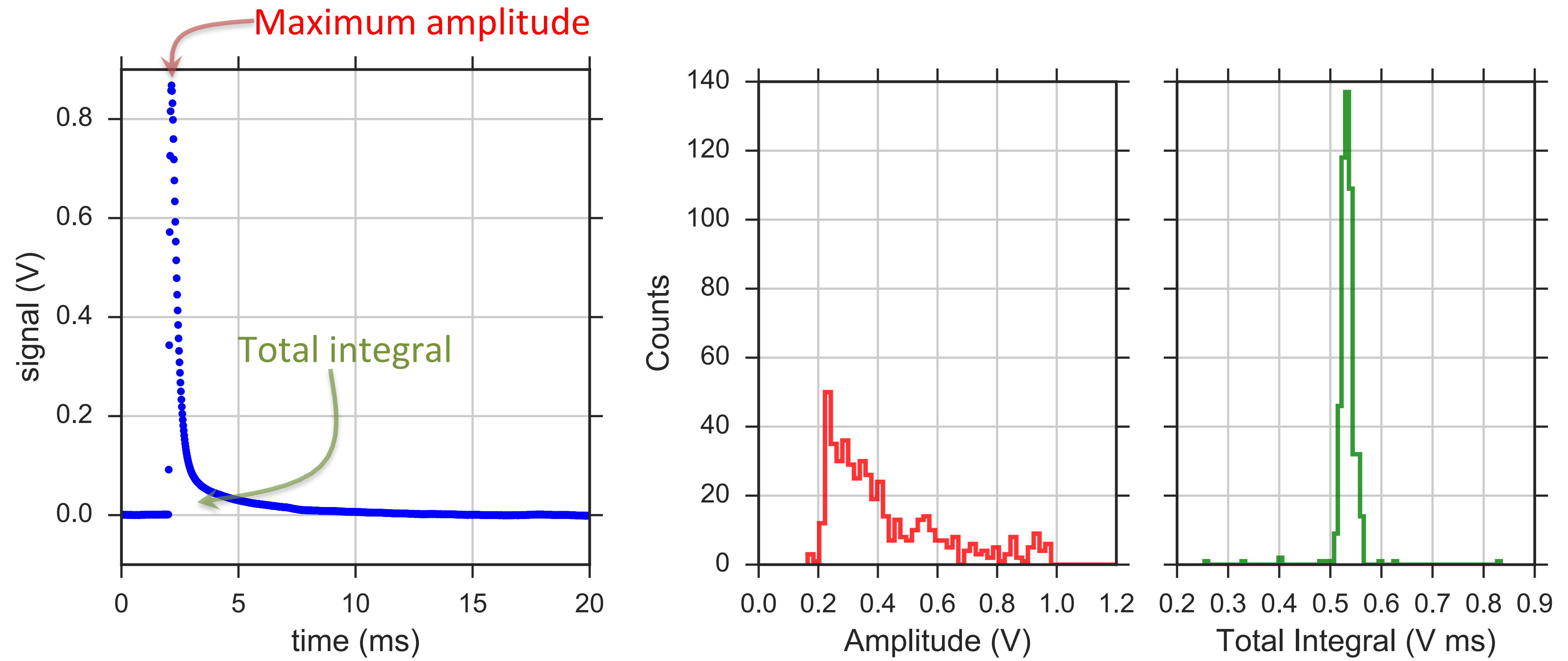
Introducing the Glitch

- Particle impacts create energy spikes in the bolometer signal; “glitches”.
- Energy rise is very sudden, dissipates with time
- Shape depends on many factors



Glitches: A first look

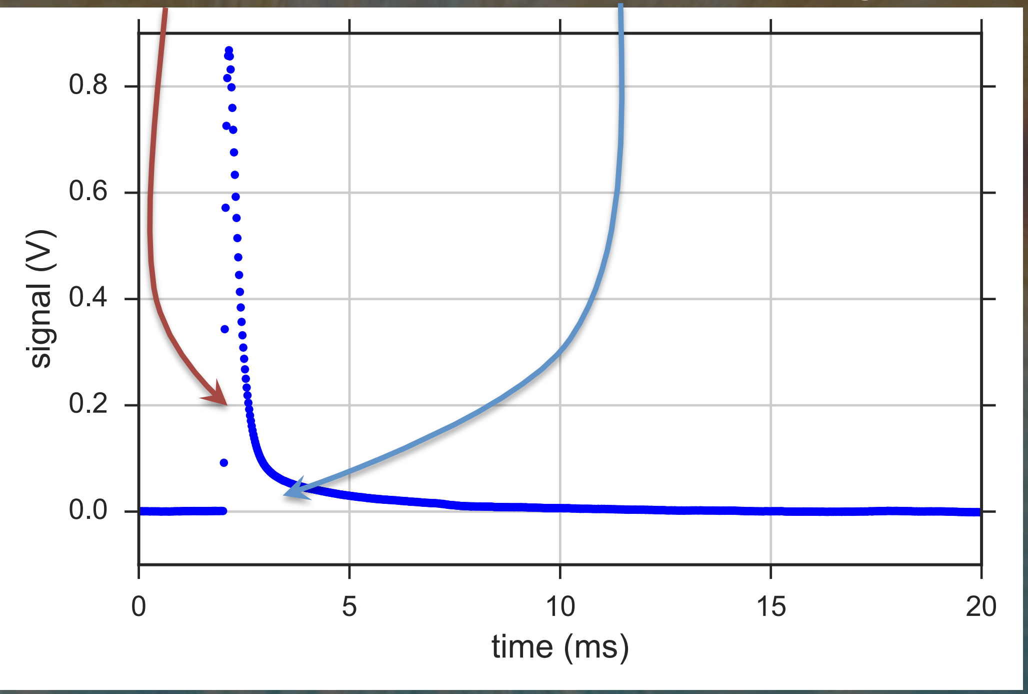
- Energy spectra of glitches:
  1) Which is a better representation of total energy deposited into bolometer from a cosmic ray; maximum glitch amplitude, or total integral of the glitch?

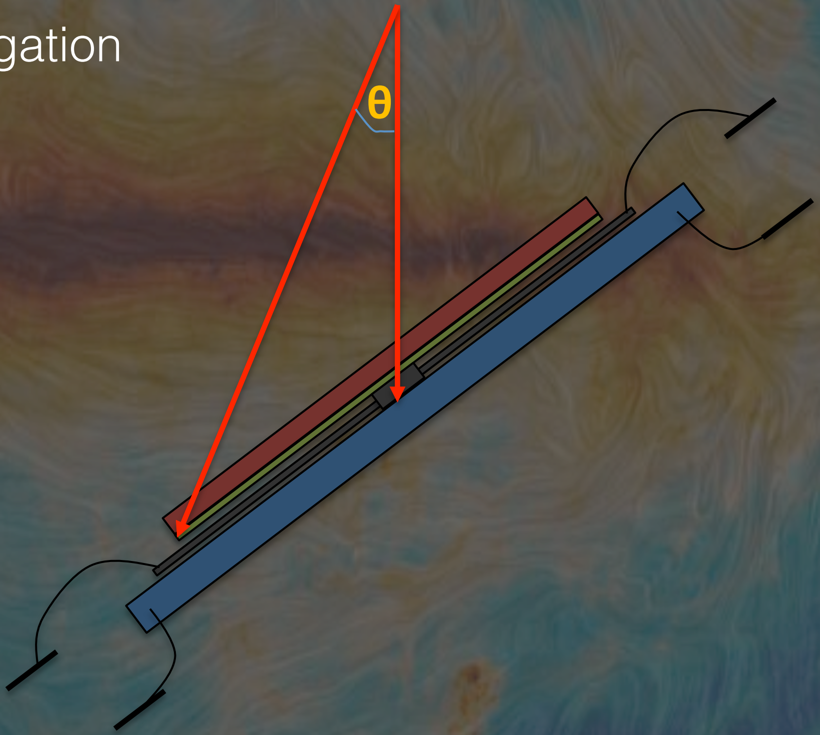


DIABOLO: What we have learnt

- Glitch shape depends on ratio of energy propagation types, which is based on position of impact of alpha particle.

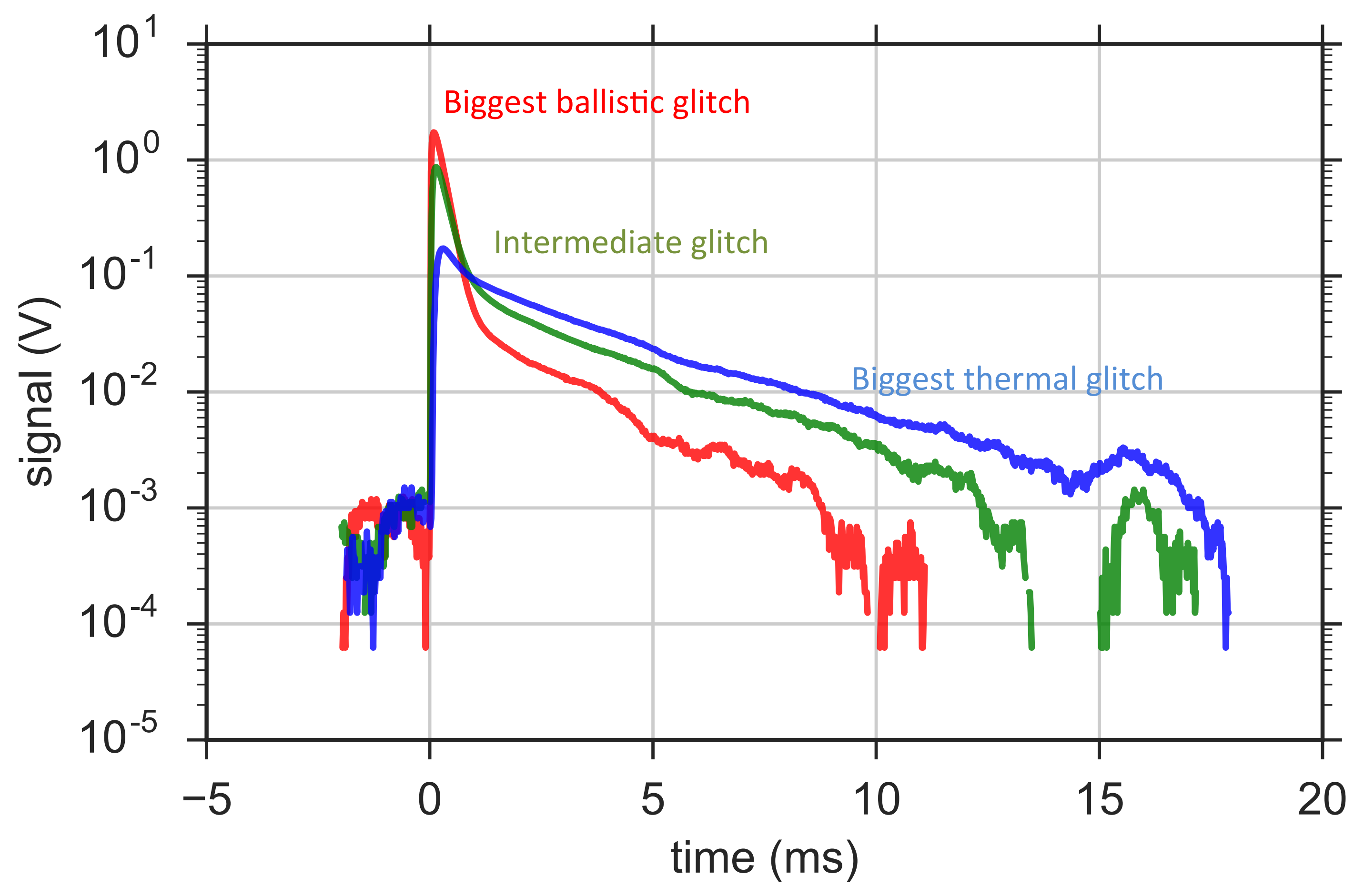
Ballistic Phonon and Thermal energy propagation





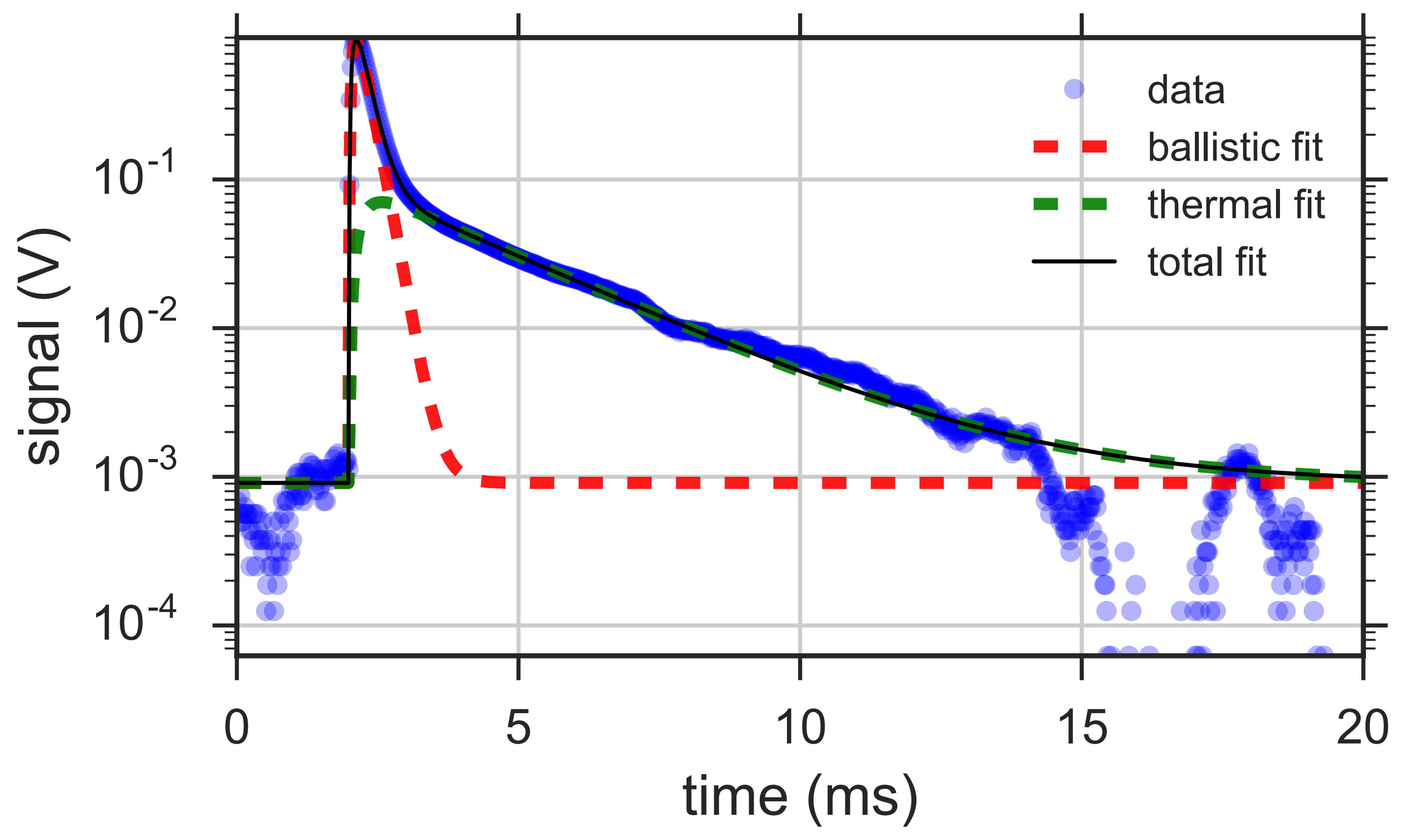
DIABOLO: What we have learnt, part II

- Ratio of these components depends upon where the α strikes the detector…



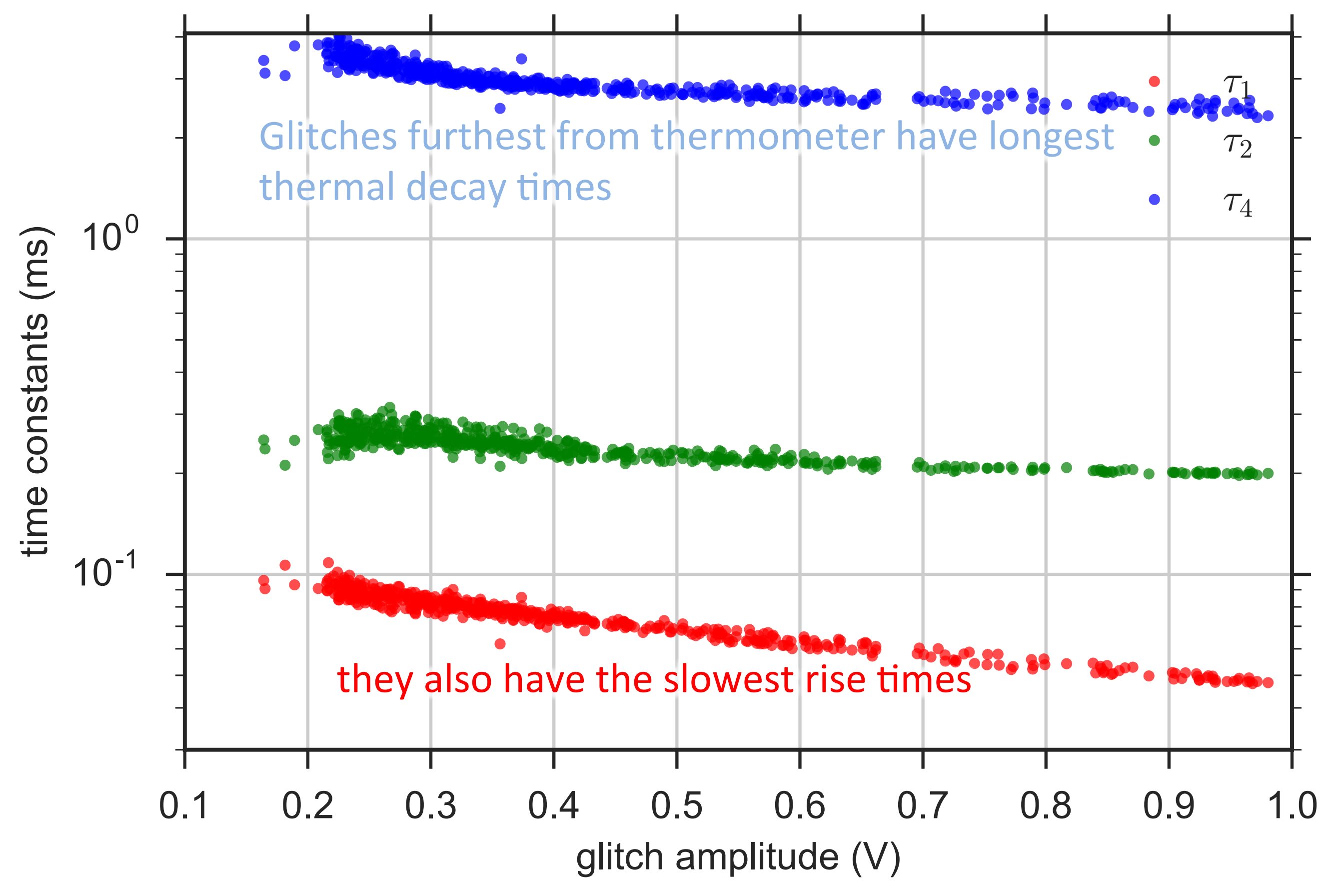
DIABOLO: What we have learnt, part III

- We can separate the ballistic and thermal components via fitting algorithms



DIABOLO: What we have learnt, part IV

Rising and decaying time constants vary as a function of the glitch amplitude, but thermal decay constant τ_4 has a wider spread.



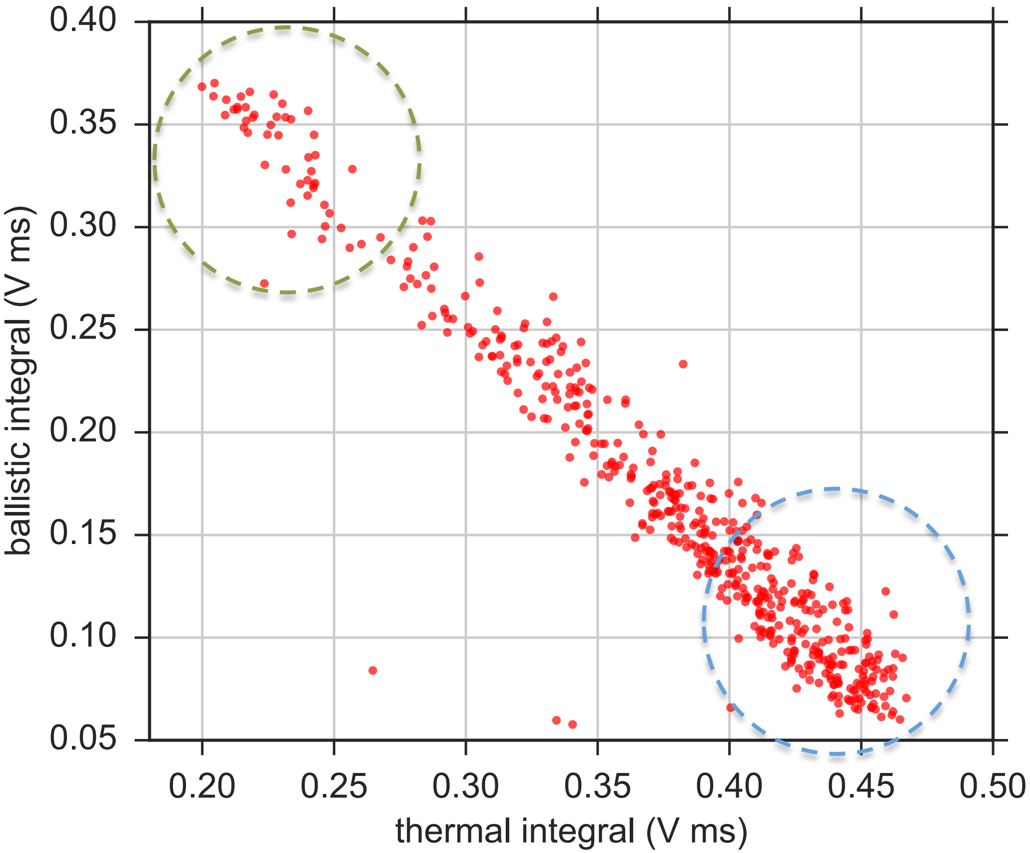
Glitches furthest from thermometer have longest thermal decay times

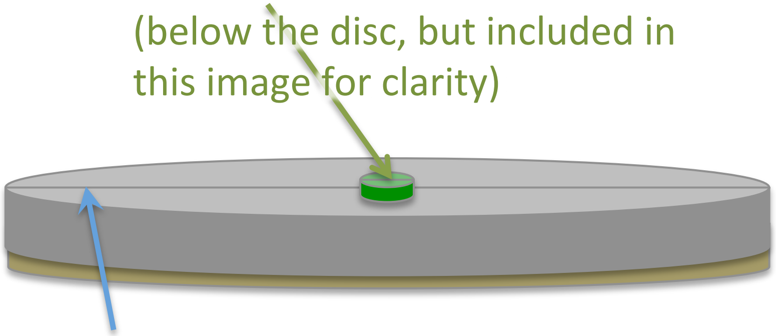
they also have the slowest rise times

DIABOLO: What we have learnt, part V

Integrating the separated curves, we see the 5.6 MeV line and the distribution of alpha particle impacts across the disc.

However, **total energy is always conserved due to having a single-energy alpha particle source.**



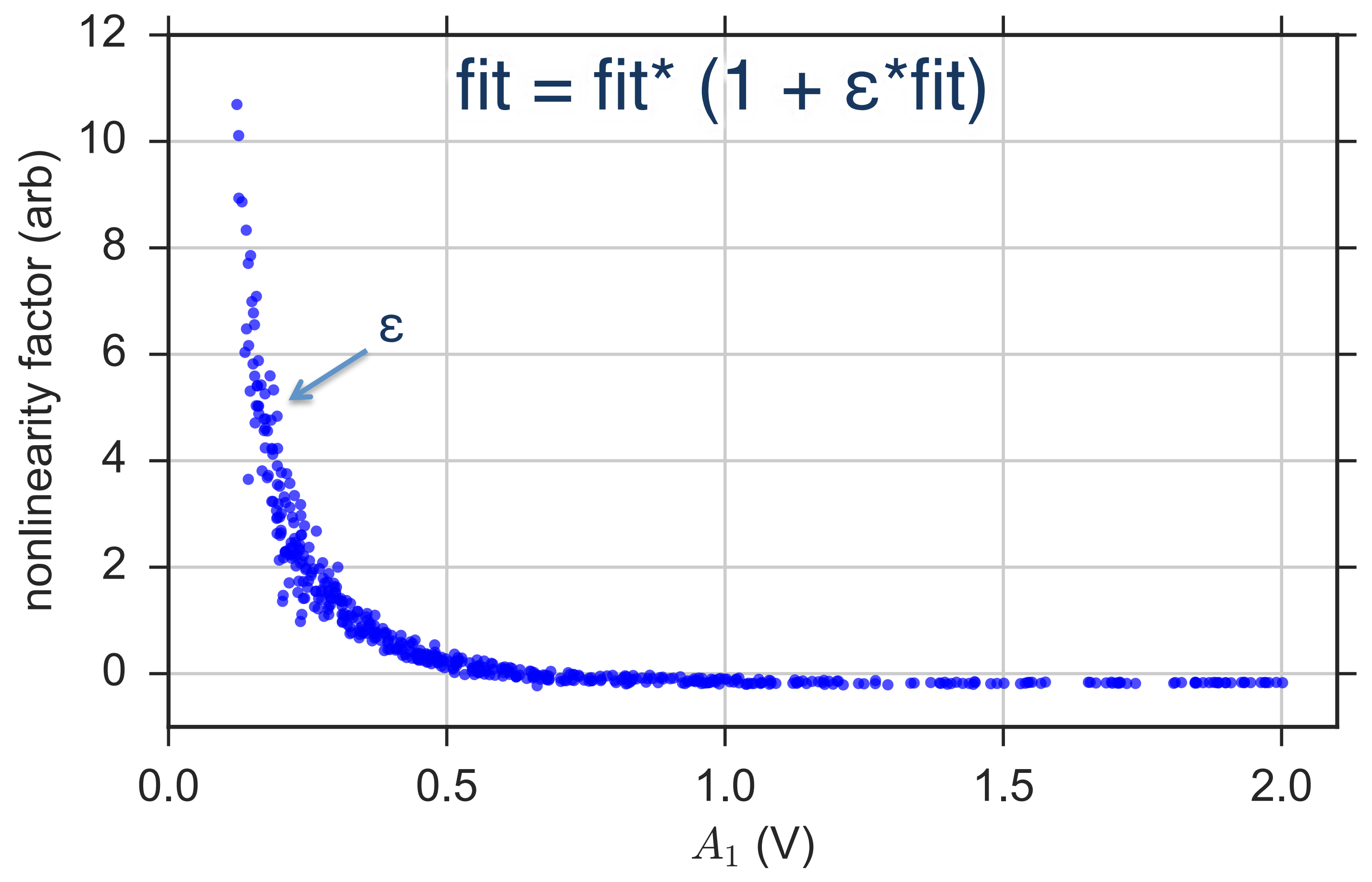


Direct hit to thermometer (below the disc, but included in this image for clarity)

Particle hit to absorber, far away from thermometer

DIABOLO: What we have learnt, part VI

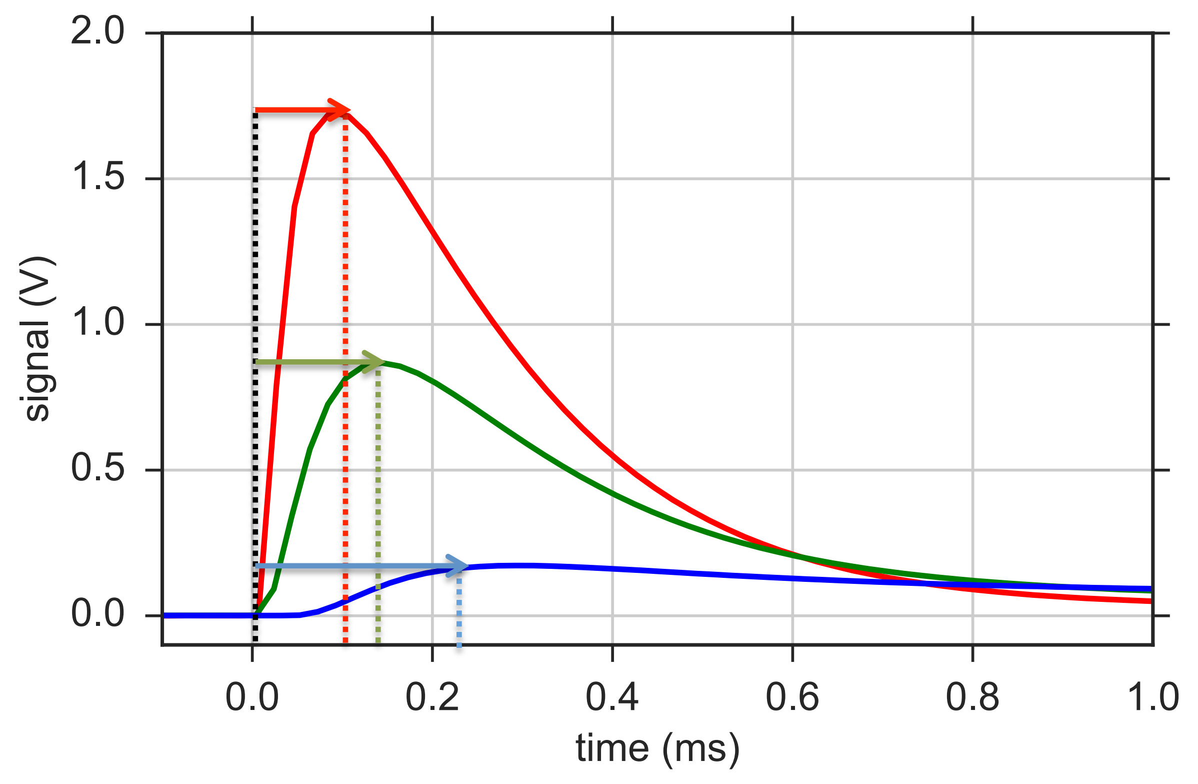
Quadratic nonlinearity ‘fudge factor’ increases goodness of fit. Must be explained by modelling of nonlinearities in transient state of bolometer.



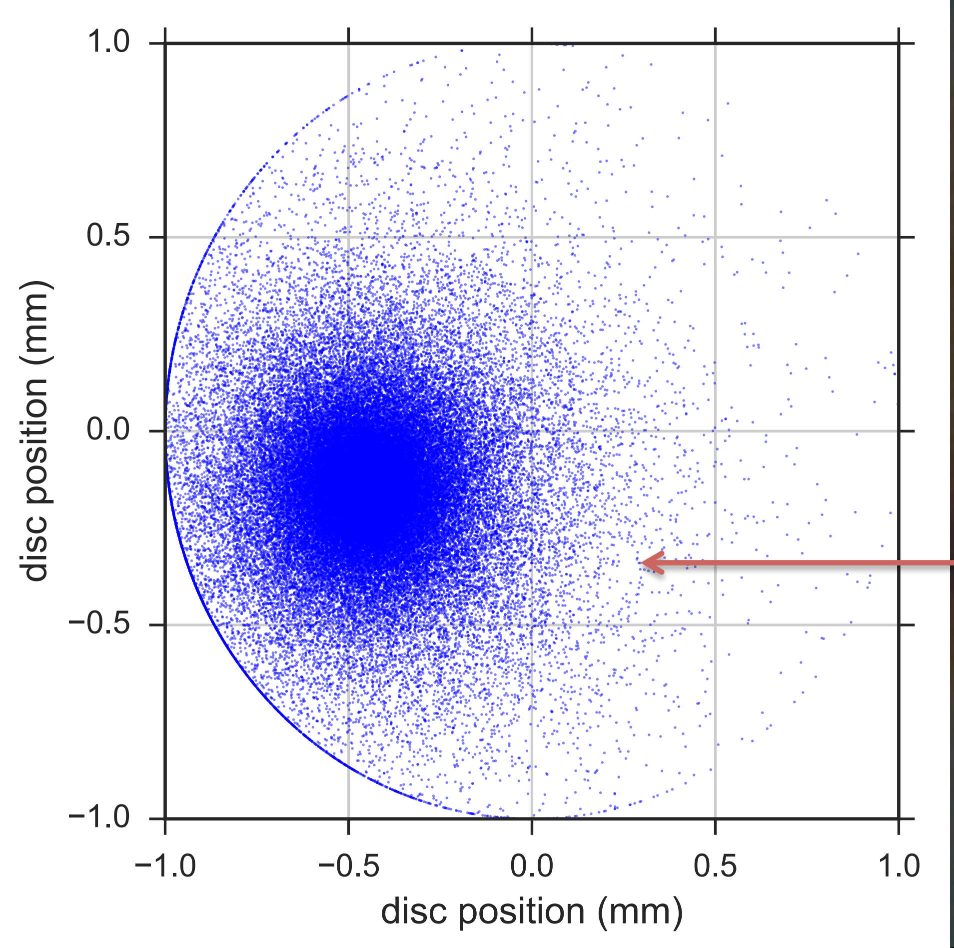
5.6 MeV alpha particles – what happens?

Rise time varies with starting amplitude. Why?

1) Impacts closer to the thermometer deposit a greater percentage of heat (translating into a hotter initial state) directly above the thermometer. This happens more quickly the closer the alpha hit is to the thermometer because the energy has less distance to travel.
2) Absorber acts as a capacitor for heat, results in change in glitch rise times as a function of hit distance from thermometer. Ballistic phonons in diamond bounce off polished interfaces and thermalise in Bismuth. Results in dramatic rise in T just above the thermometer.



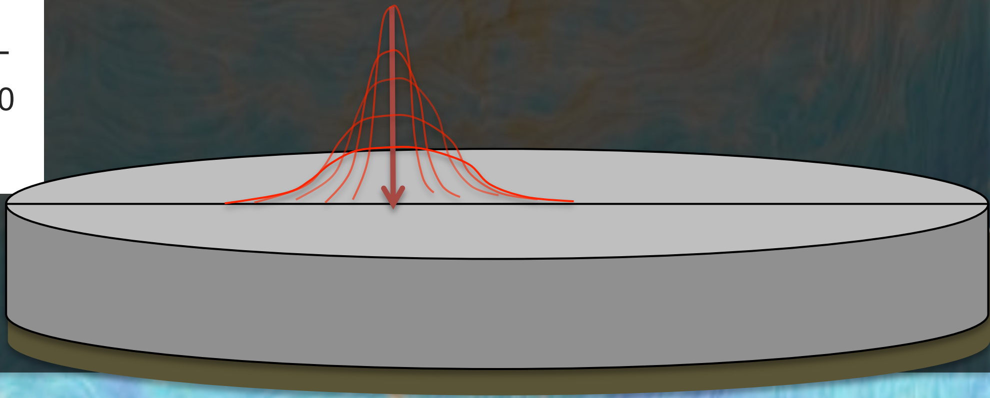
Modelling the disc



C_p and G of bismuth is higher than diamond, results in 90 – 95% of heat going to Bismuth with an initial temperature profile and with a time propagation (rise time) depending on particle impact point.

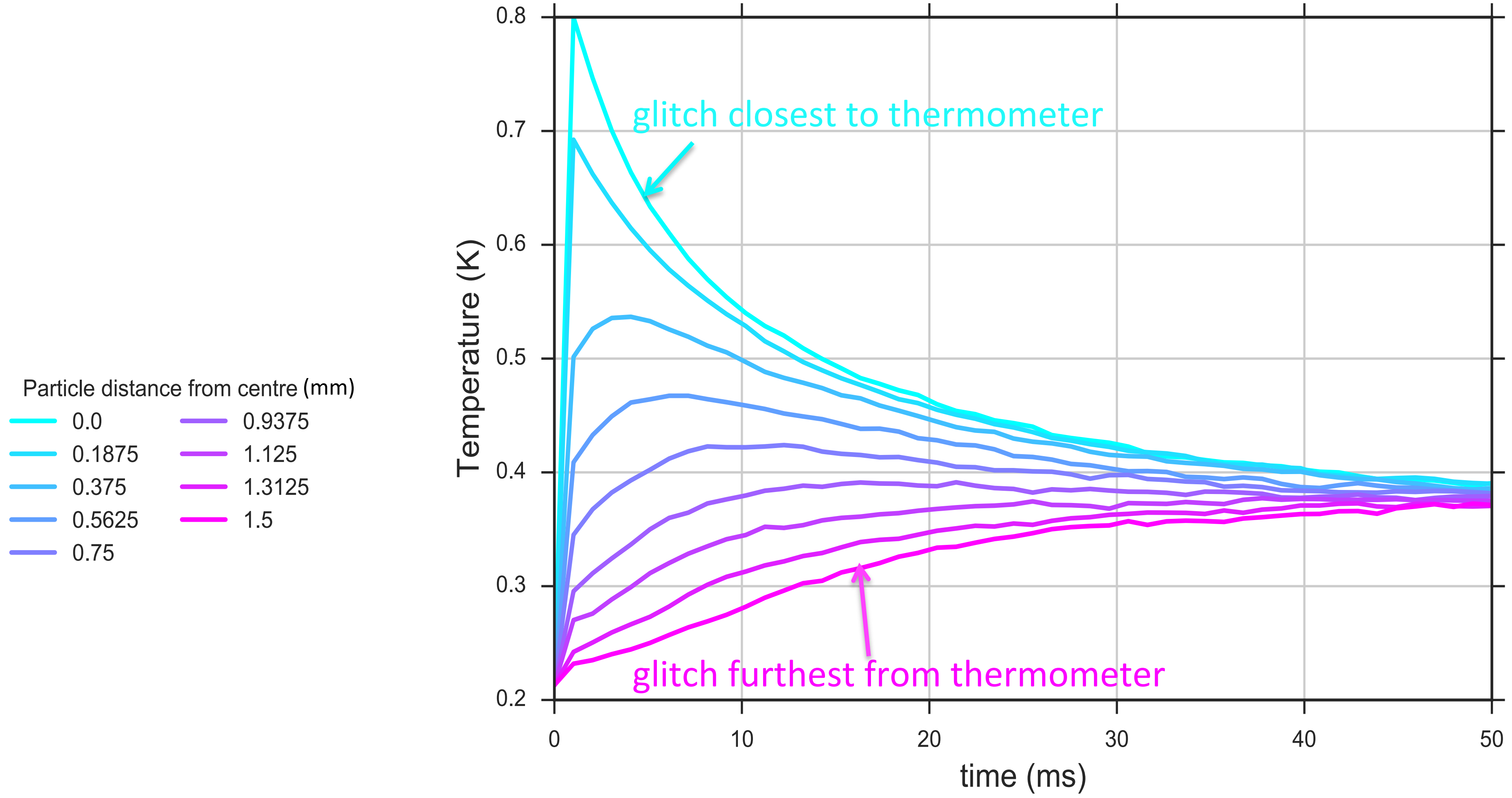
Energy propagation happens in 2 domains and we must simulate both to reproduce glitch:

- Monte Carlo [heat] particle propagation in the disc
- Distributed thermal model for lower thermometer layers



5.64 MeV = .9 pJ
.9 pJ in 100 μs = 10^4 pW!

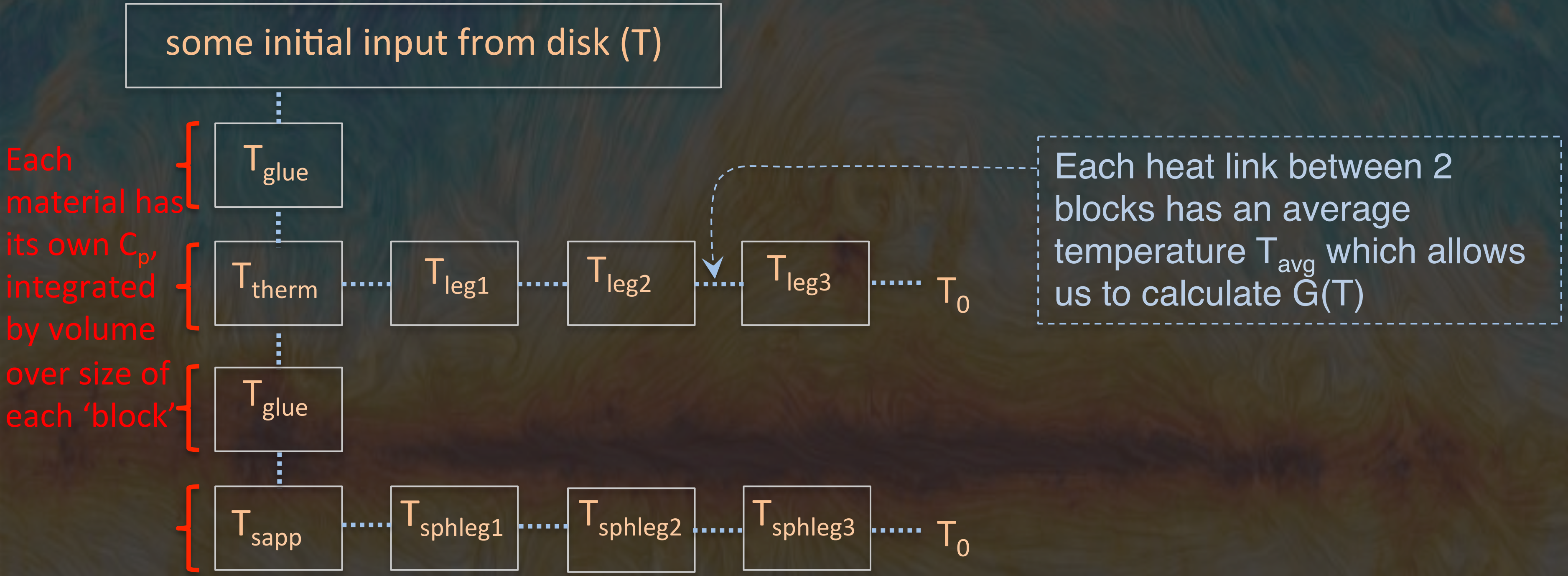
Modelling the disc



glitch closest to thermometer

glitch furthest from thermometer

Modelling the lower layers



some initial input from disk (T)

T_{glue}

T_{therm} …… T_{leg1} …… T_{leg2} …… T_{leg3} …… T_0

T_{glue}

T_{sapp} …… $T_{sphleg1}$ …… $T_{sphleg2}$ …… $T_{sphleg3}$ …… T_0

Each material has its own C_p, integrated by volume over size of each 'block'

Each heat link between 2 blocks has an average temperature T_{avg} which allows us to calculate G(T)

Starting from T0, we allow the bolometer to reach a steady state. At 200 mK working temperature, ΔT = ~15 mK due to Joule effect.

→

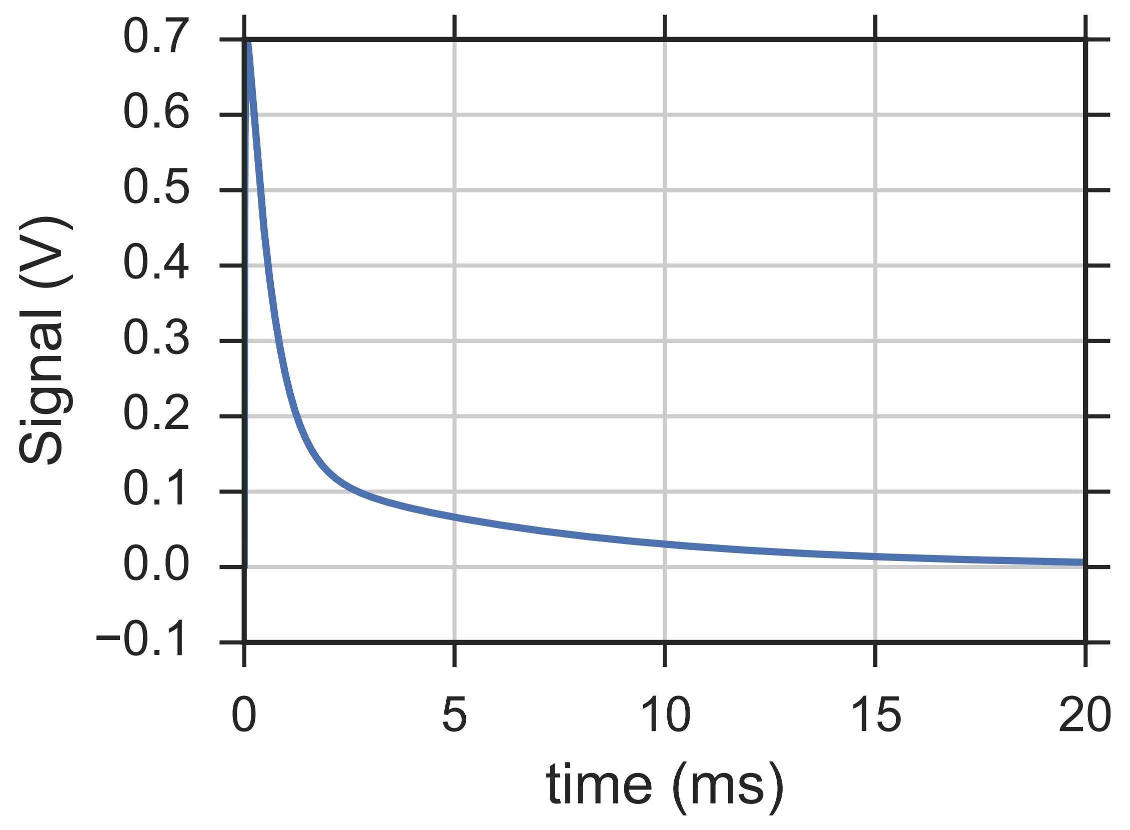
At SS, inject dT from disc input, and allow it to thermalise with time.

Modelling the lower layers: Results

Distributed heat model of thermometer, legs, glue, and sapphire reproduces double exponential decay in signal.

Once convoluted with the temperature curves as a function of particle hit distance, can reproduce glitch, including ballistic peak (even at far particle hit distances).

Needs fine tuning before more analysis is possible.



Next steps and conclusions

- Fine-tuning is necessary to couple the disc heat model with the distributed thermal model, and to get results to agree with experimental data.
- There any many uncertainties in these models which arise from the physical parameters. It is necessary to understand these and treat them as boundary conditions.
- This analysis is expandable to other semiconductor bolometers, and (with the addition of specific physics) to KIDs or TES.
- Reproducing data allows for a powerful tool for 1) understanding the impulse response of detectors; 2) predicting the topology of glitches in the next generation of space missions.
- New cryogenic test facility in development to take measurements at wider range of energies.
- To do this kind of analysis, we first need measurements with a high sampling rate.