Excess Broadening Due to Diffusion in the Absorber

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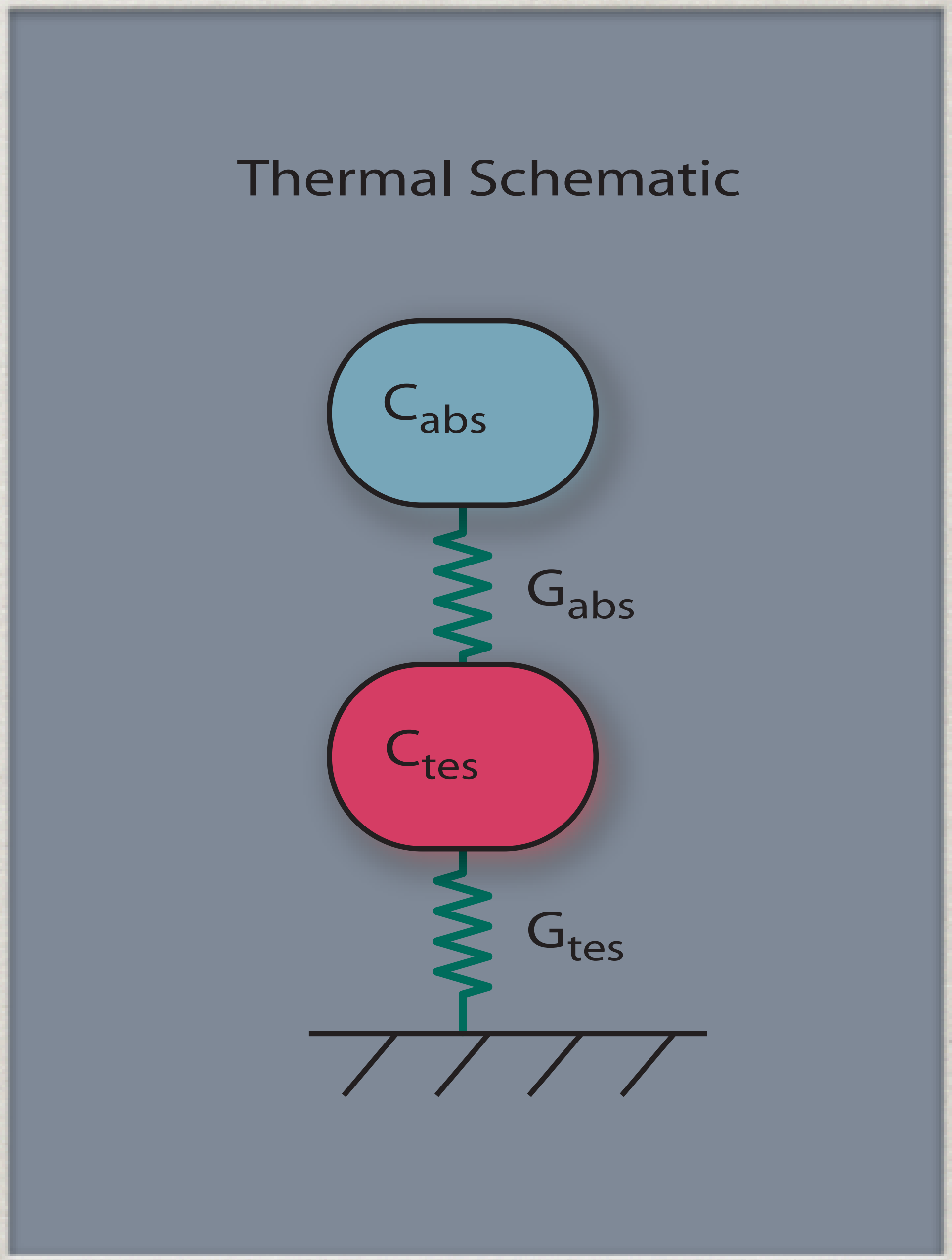
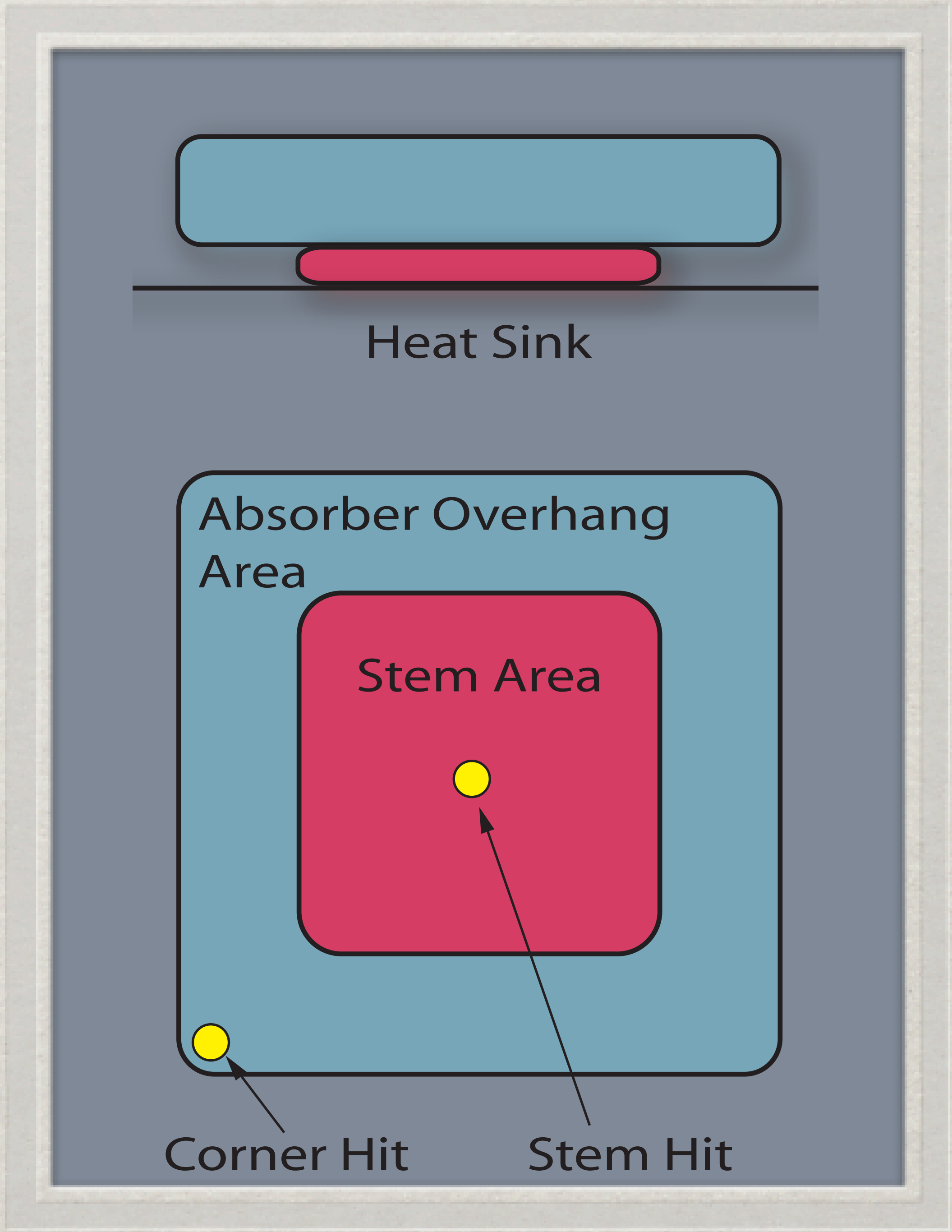
The Ideal MicroCalorimeter

- Absorber connected to TES connected to heat sink
- Assume <u>instant</u> thermalization in Absorber / TES
- Response / Resolution is determined by C_{abs} / G_{abs} / C_{tes} / G_{tes} and the R(T,I)



Practical µCal : The Mushroom Design

- Cantilevered design driven by practical considerations :
  - Maximizing focal plan area
  - Preventing wiring and substrate hits



Practical μCal : Physical Considerations

- The ideal microcalorimeter model no longer applies
- Diffusion time scales in the absorber, comparable to the thermal time scales, can affect detector response
- Different "path lengths" from interaction point to heat sink result in position dependent pulse shape
- This leads to a degradation in resolution that increases linearly with energy

Characterizing the Problem

- We did a numerical simulation of diffusion in a mushroom absorber

$$\frac{\partial E_{\mathrm{abs}}(x,y,t)}{\partial t} = D\,\nabla^2 E_{\mathrm{abs}}(x,y,t) - \frac{G_{\mathrm{abs}}}{C_{\mathrm{abs}}} E_{abs}(x,y,t) + \frac{G_{\mathrm{abs}}}{C_{\mathrm{tes}}} E_{\mathrm{tes}}(x,y,t)$$

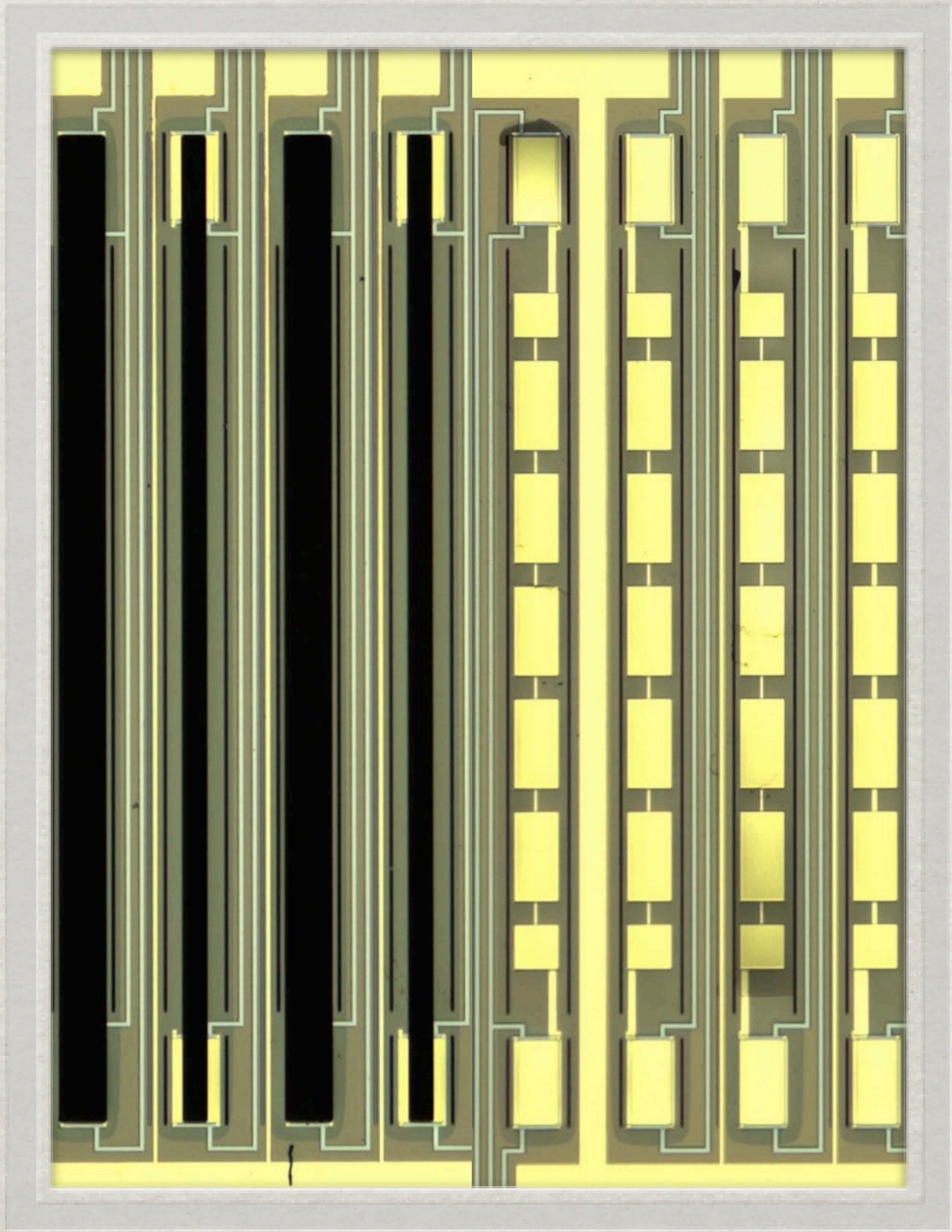
Details of Diffusion

Solved diffusion/detector model numerically.

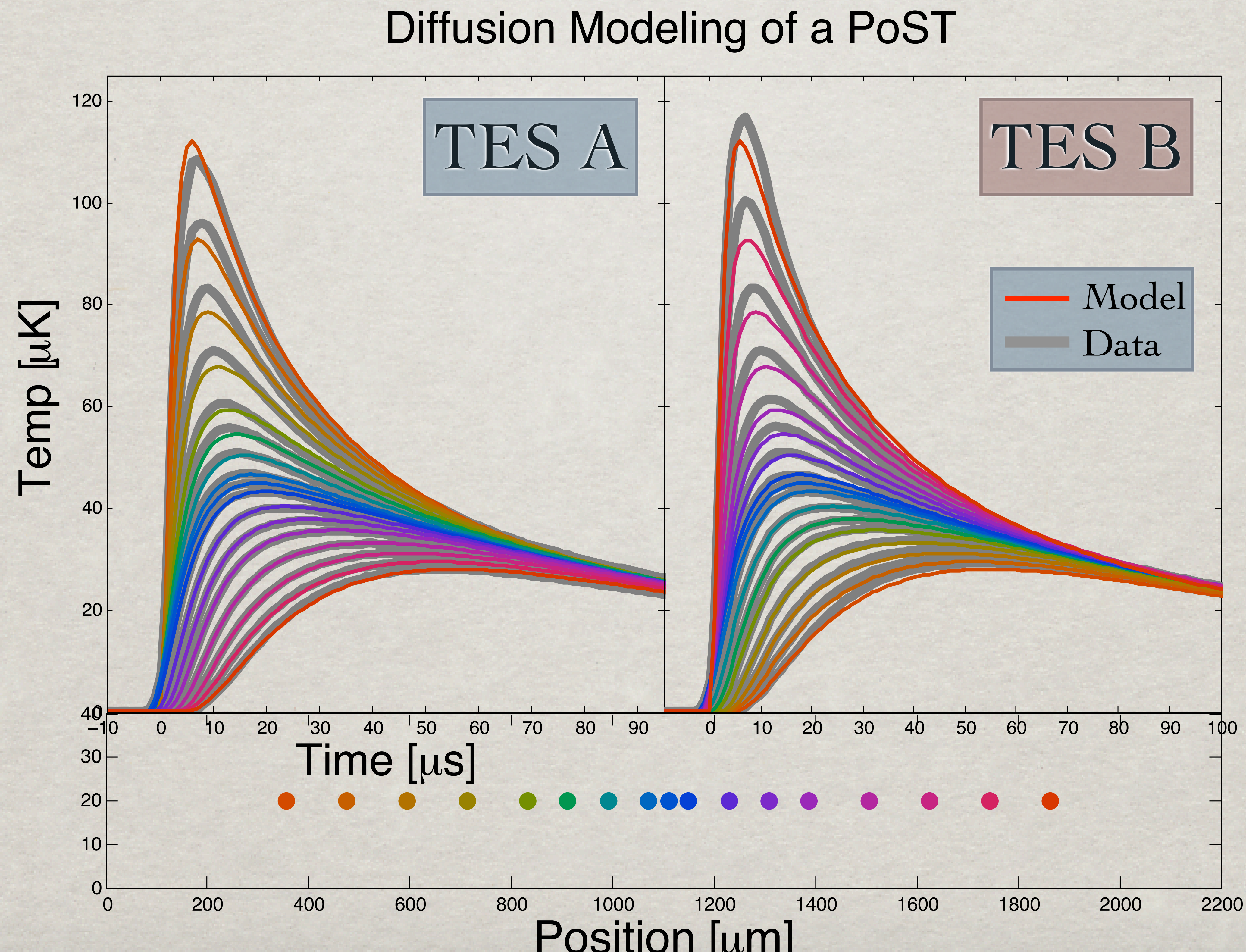
- Permits arbitrary definition of device geometry and edge conditions
- Used Forward Time Centered Space differencing method
  - Method allows us to solve for a given time step across the entire spacial grid simultaneously

Verification of Diffusion Model

- Applied the diffusion model to a continuous PoST geometry
- Compared to data obtained from PoST device
  - Defined pixels based on equal count bins



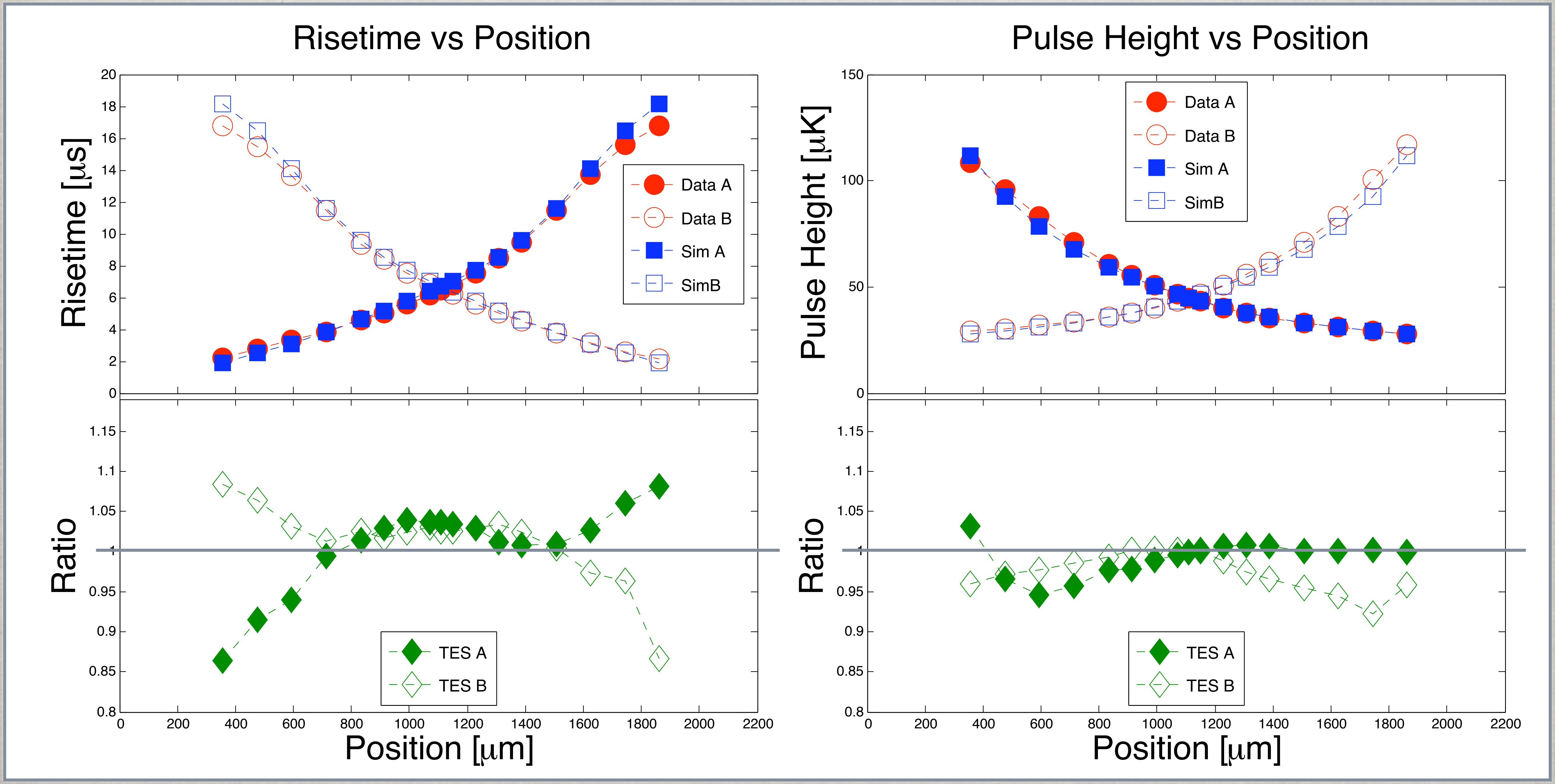
PoST Pulses



Diffusion Modeling of a PoST
TES A
TES B
Model
Data
Temp [μK]
Time [μs]
Position [μm]
120
100
80
60
40
20
0
−10
0
10
20
30
40
50
60
70
80
90
100
30
20
10
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200

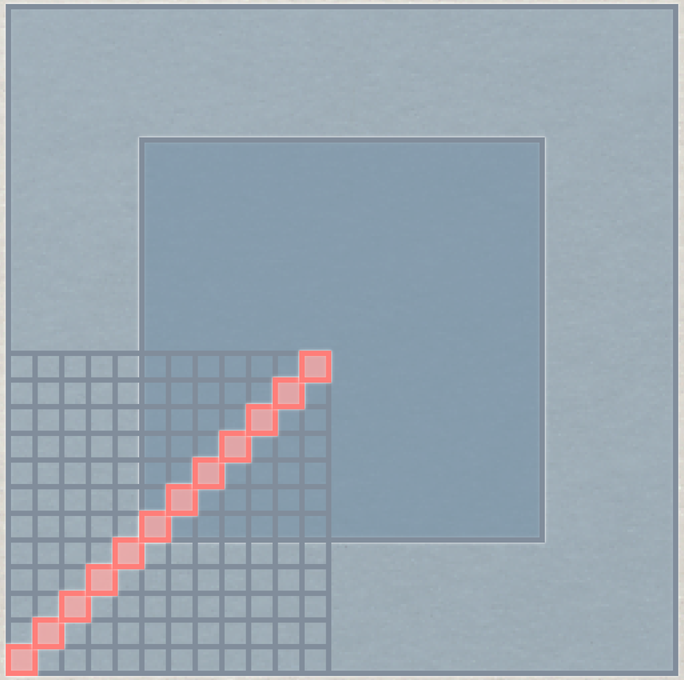
Validity of The Model

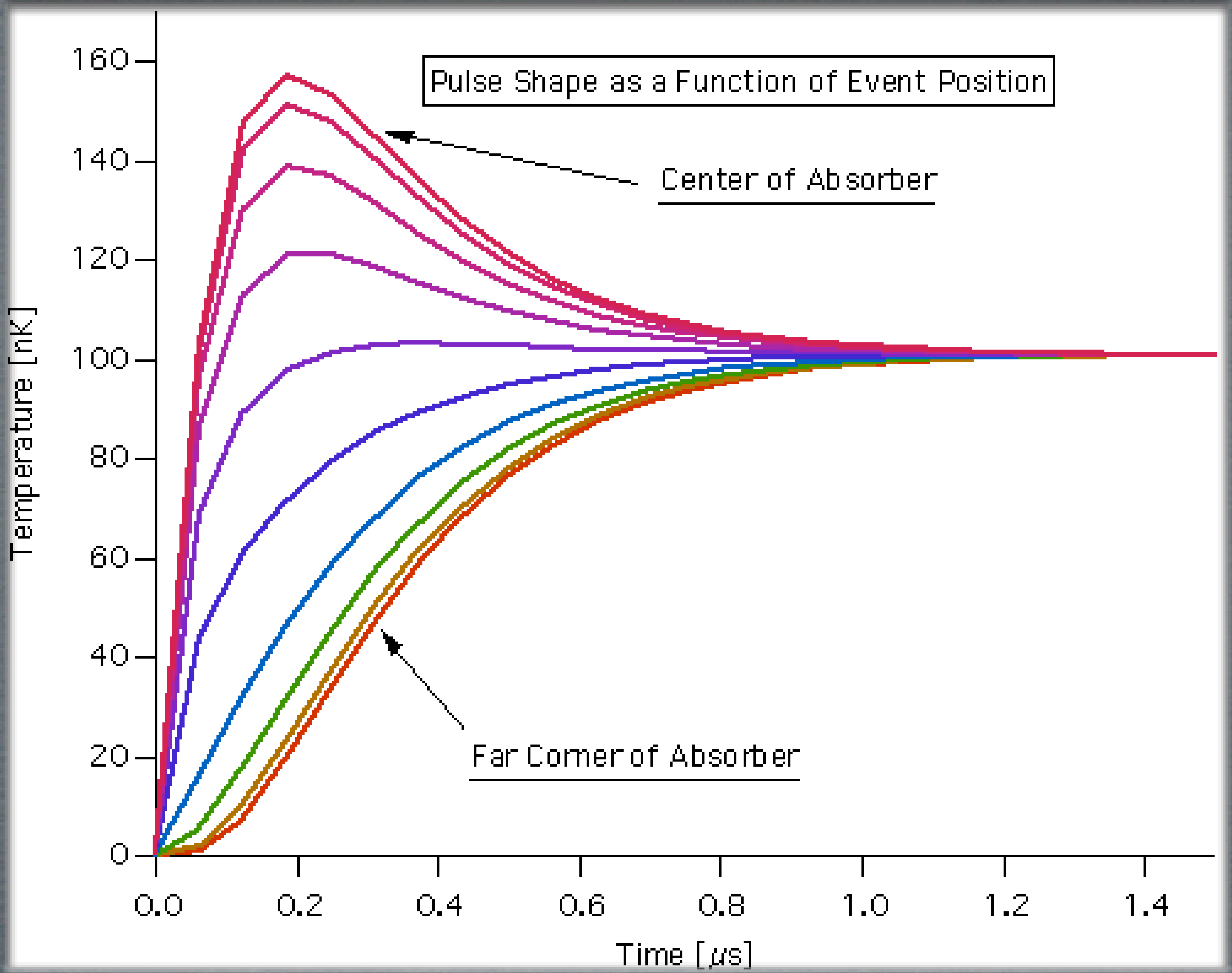
- Comparison of risetime and pulse height shows good agreement between data and model and indicate D ~ 3.2×10^4 $\mu m^2/\mu s$



Application to a Mushroom uCal

- Simulated pulses across the surface of a 250x250 μm absorber, attached to a 150x150 μm TES.
- Device parameters were chosen to give a nominal energy resolution of 2 eV.





Pulse shape variation across surface of absorber shows significant "peakiness" near TES contact area

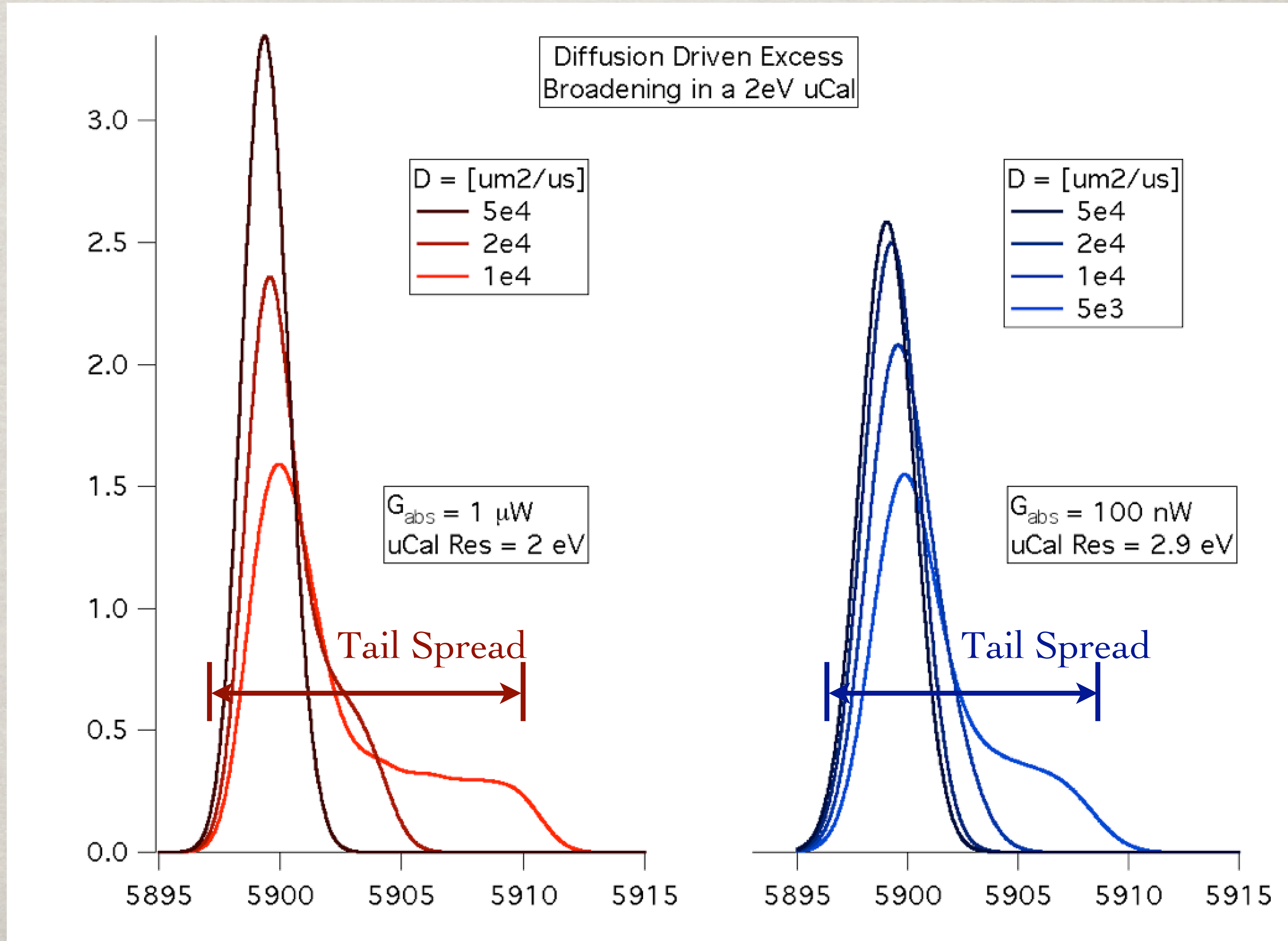
The Effect of Varying Pulse Shape

To determine the effect of diffusion on detector performance we :

- Constructed an average pulse to be used as a template for an optimal filter
- Used the appropriate noise PSD for the device parameters
- Applied the optimal filter to all simulated pulses
- Convolved results with a 2 eV (FWHM) gaussian

2 eV (FWHM)

δ-fn Response

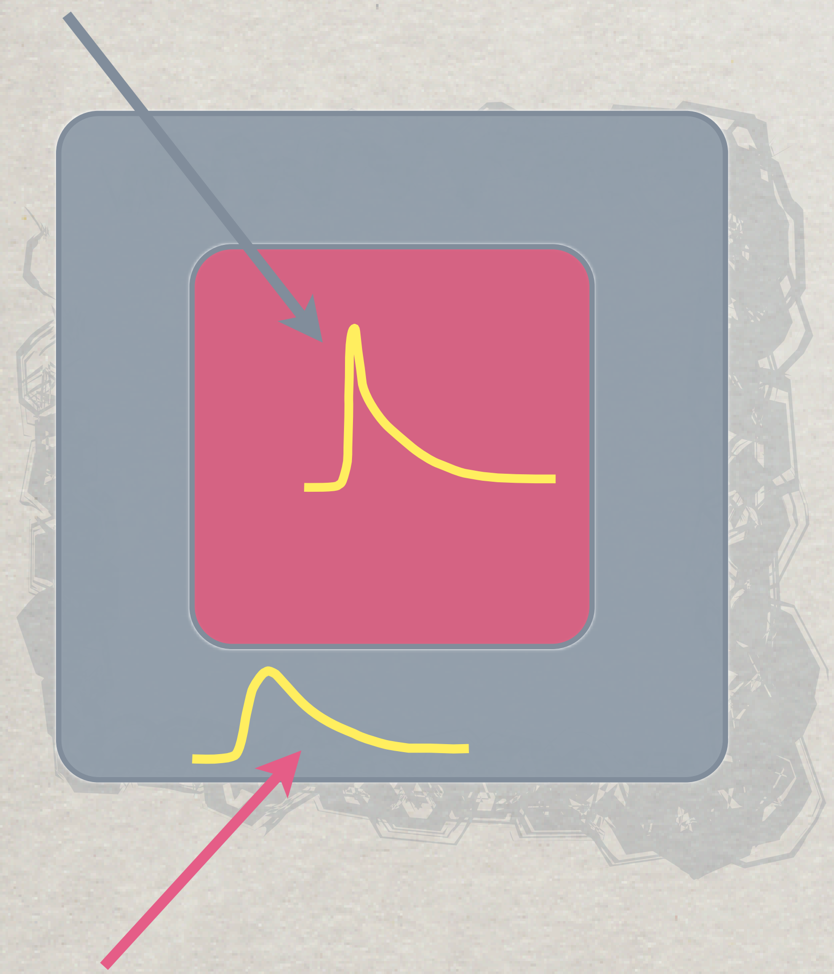


The High Energy Tail

- For this mushroom geometry, the presence of a finite diffusion time in the absorber leads to a high energy tail in the delta-fn response
- No energy is being lost in the absorber. It all goes through the TES eventually
- The tail can be understood based on a geometric areas argument

The High Energy Tail

Fast “peaky” pulses



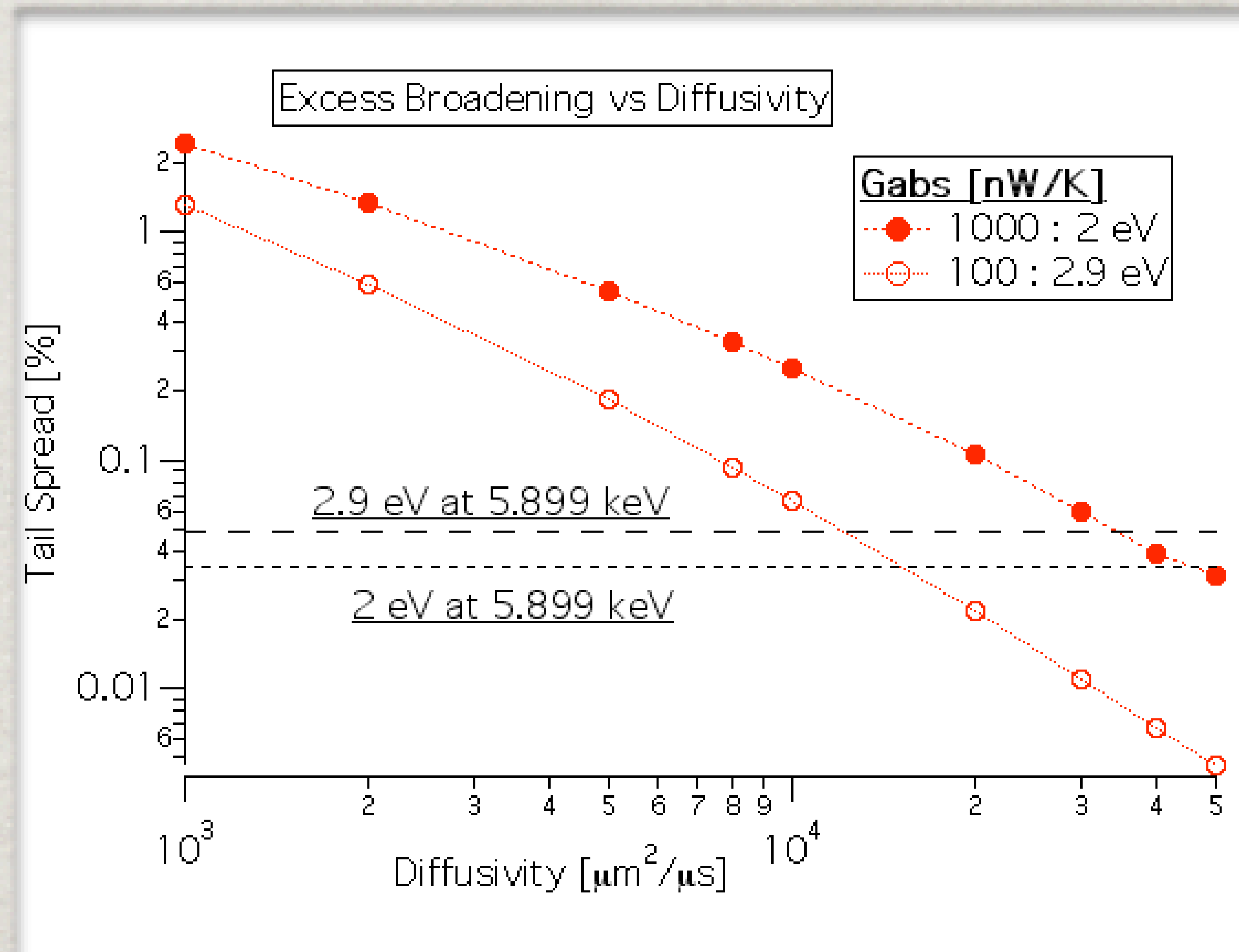
Slow pulses

- Area of mushroom overhang ~2x area of TES overlap.
- Template pulse is dominated by slower overhang pulse shapes
- Optimal filter operating on the central “peaked” pulses results in a larger reconstructed energy than for the slower pulses

Quantifying the Excess Broadening

- Diffusion broadening leads to a non-gaussian high energy tail. We characterize it by the % spread with respect to the input energy

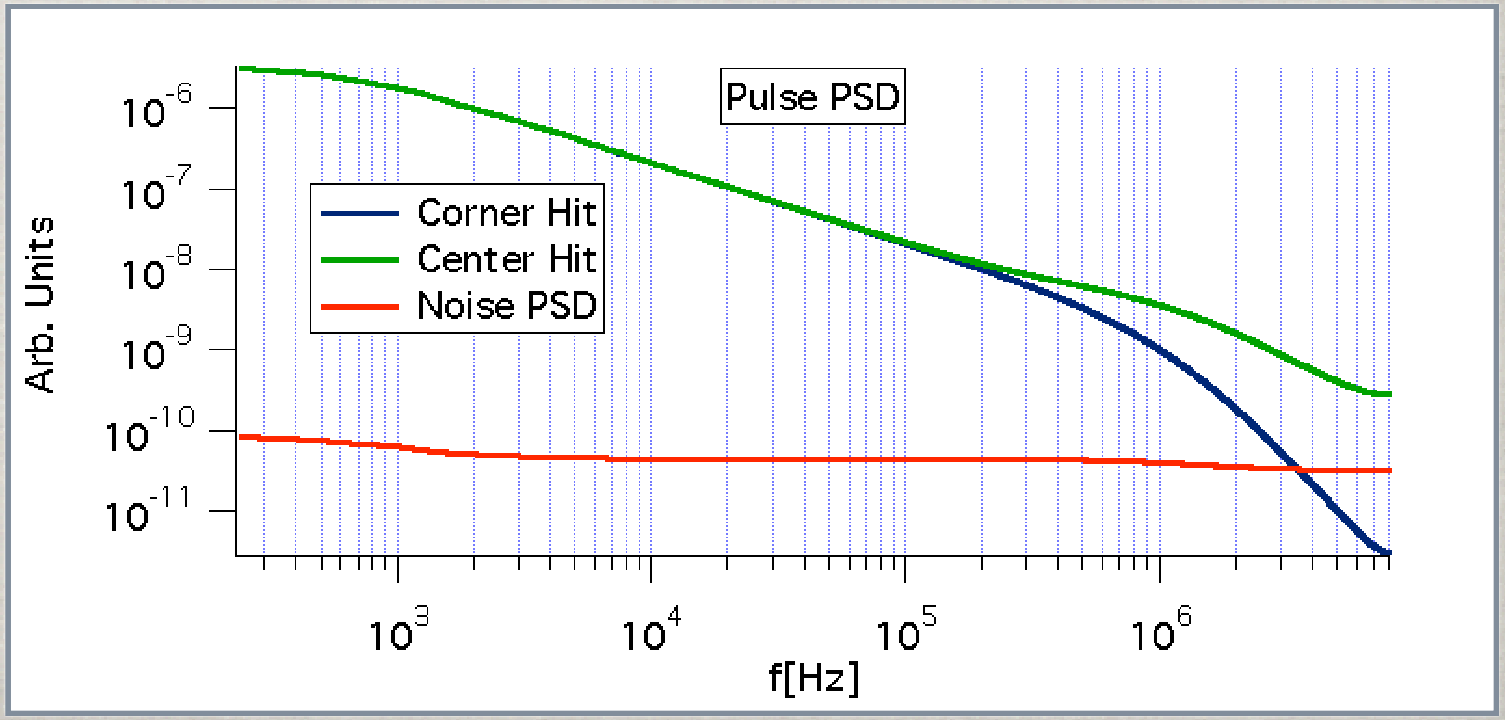
- Simulations spanning a factor of 10x in G_{abs} and 50x in D show that $D>10^4\ \mu m^2/\mu s$ is needed in order not to degrade the desired performance



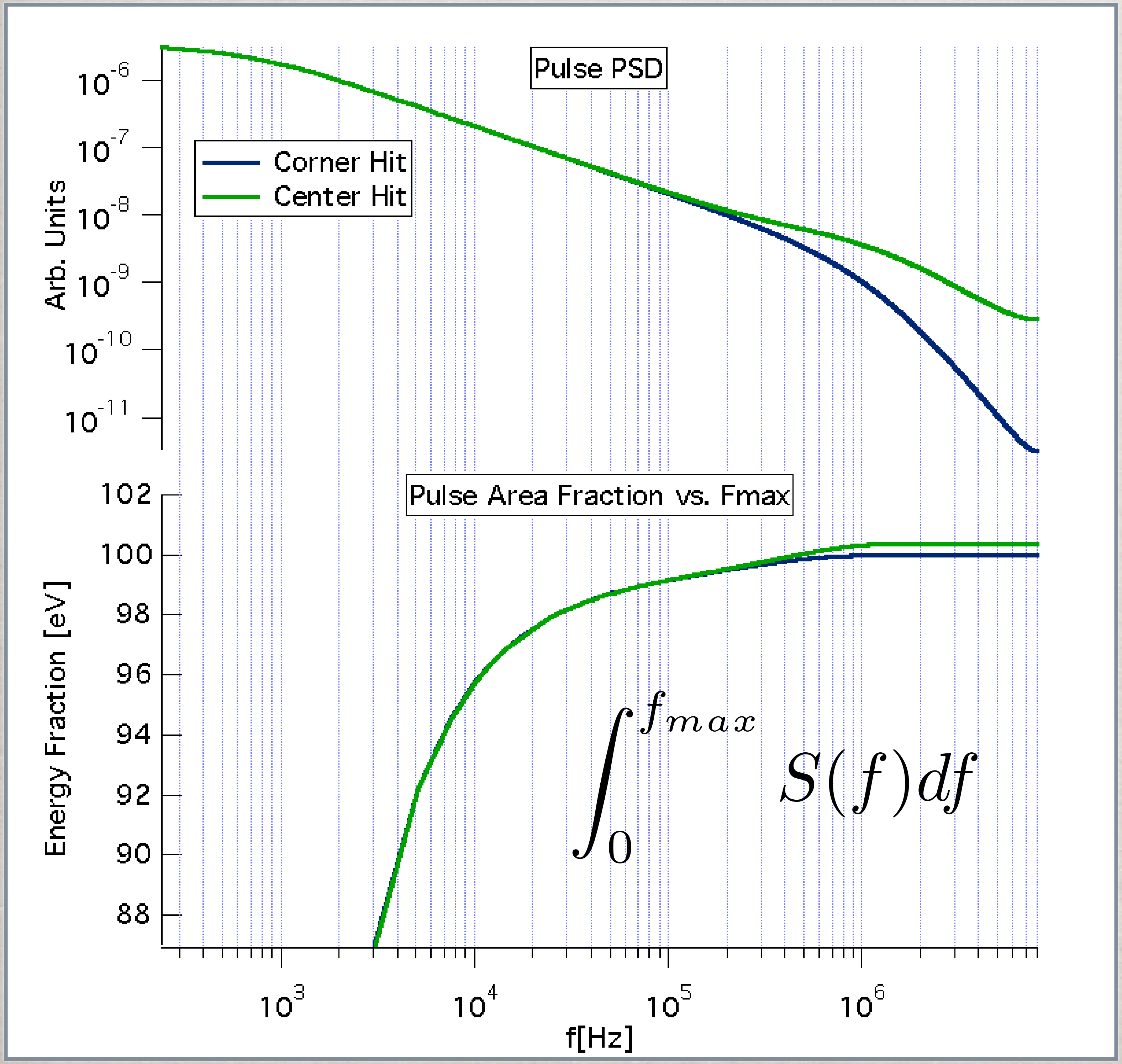
A Filtering Approach to Minimizing Broadening

- The effects of position dependence in pulse shapes lies in the short time scales / high frequency bins

- Applying a low pass filter to the data stream does not help, however, since the frequency content of all signals are changed in the same way

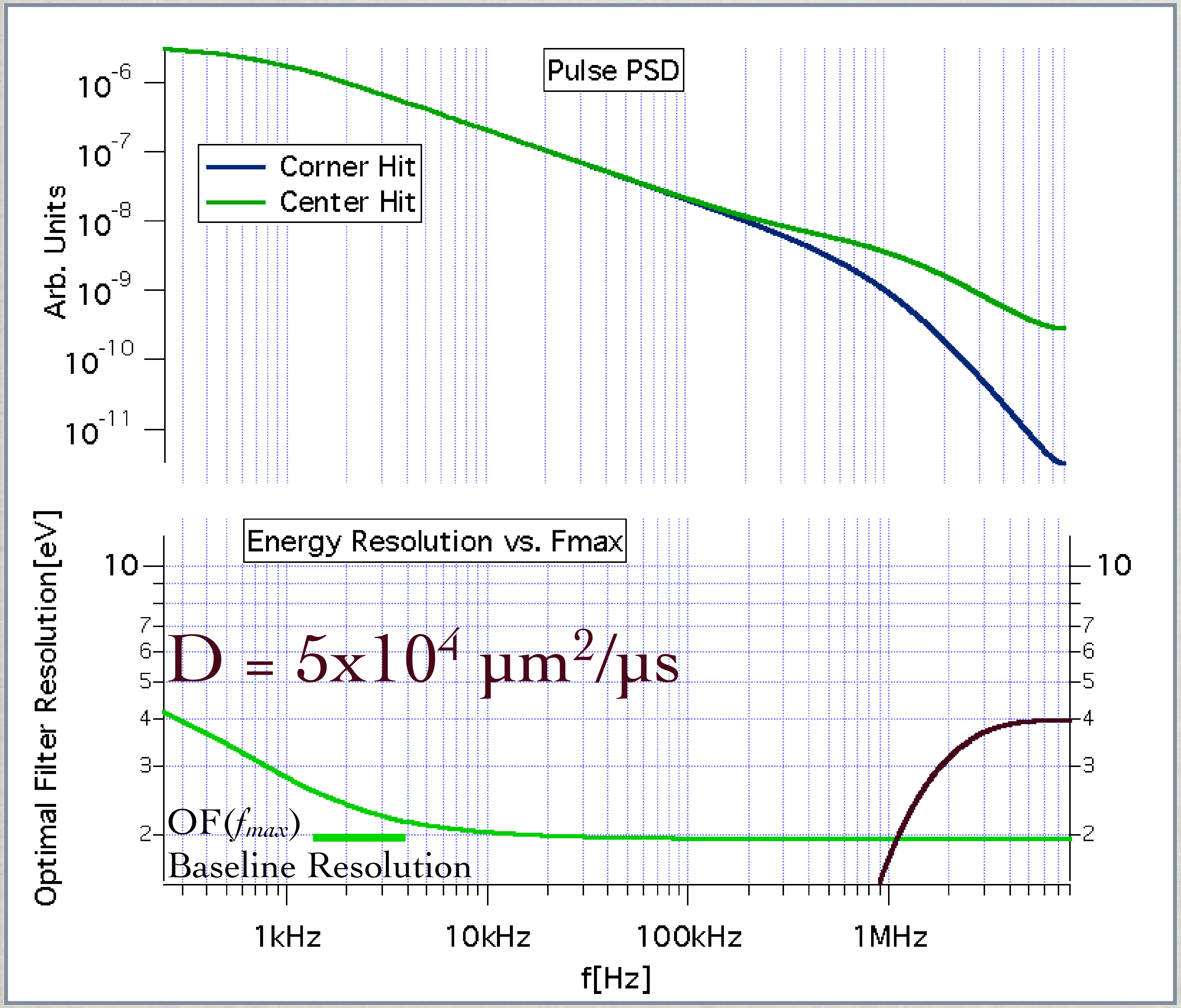


A Modified Optimal Filter



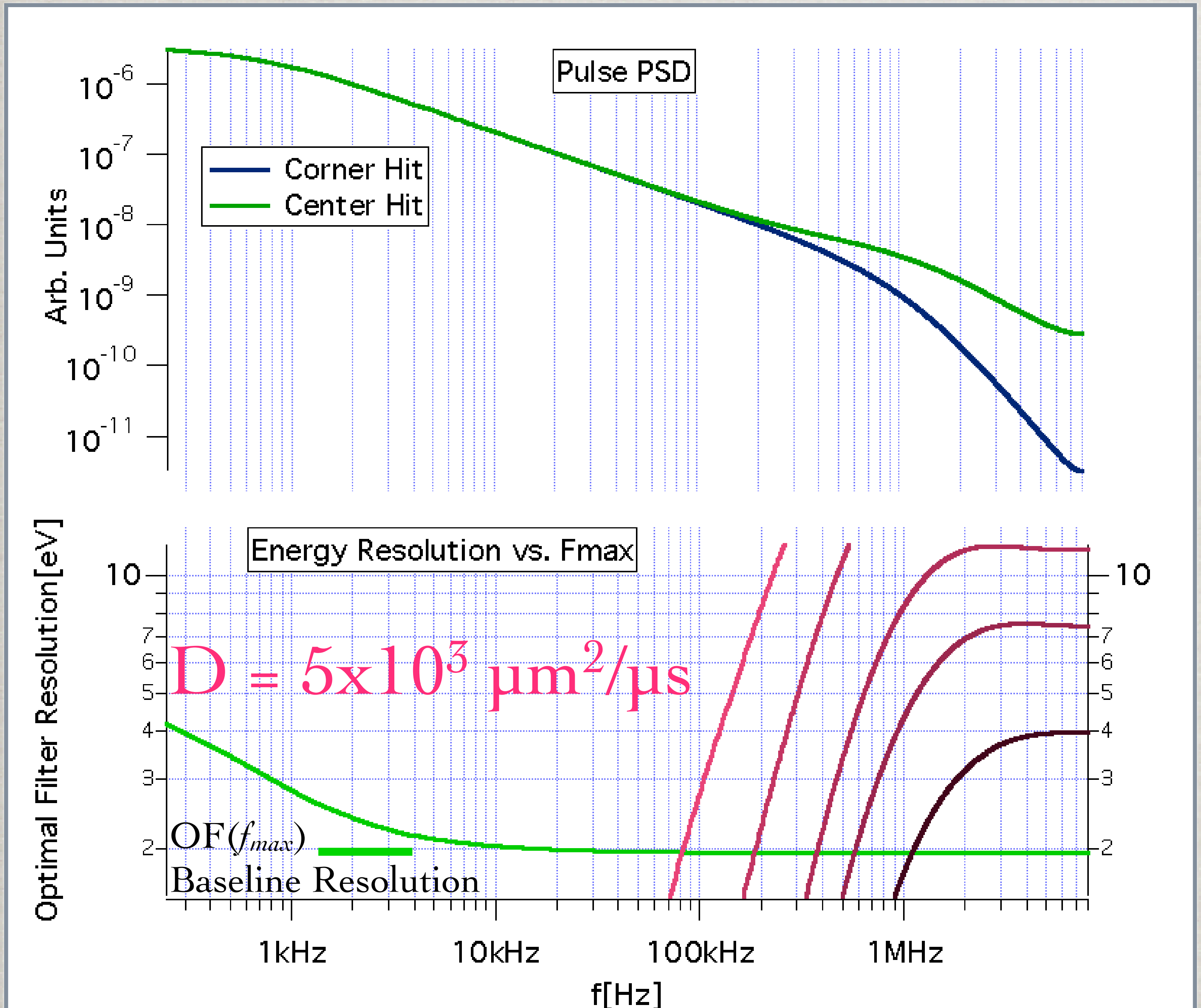
- The majority of a pulses area is contained within the lower frequency bins
- We construct a modified optimal filter that only considers the signal up to a frequency f_{max} : $OF(f_{max})$

Effect of OF(f_{max}) on Baseline Resolution



- Plotting :
  - Baseline resolution as a function of f_{max}
  - Diffusion tail spread as a function of f_{max}

Effect of OF(f_{max}) on Baseline Resolution



- Plotting :
  - Baseline resolution as a function of f_{max}
  - Diffusion tail spread as a function of f_{max}
- For f_{max} ~ 100 kHz tail spread practically eliminated, AND the baseline resolution is unchanged

CONCLUSION

- Diffusivity value in the absorber of ~< 1×10^4 $\mu m^2/\mu s$ leads to significant pulse shape variation for mushroom shaped devices

- The use of a modified optimal filter that only considers frequencies below a certain f_{max} can eliminate excess broadening for a modest cost

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