Characterizing Cloud Distributions as Functional Forms for QUICR: Uncertainties due to Fitting Techniques and Shattered Artifacts

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4 November 2013

QUICR Breakout Session

Issues for QUICR

- **QUICR requires in-situ data on *N(D)*, *IWC*, β, N_T and functional fits for N(D) for developing & evaluating retrieval algorithms**

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- **QUICR requires in-situ data on *N(D)*, *IWC*, β, N_T and functional fits for N(D) for developing & evaluating retrieval algorithms**

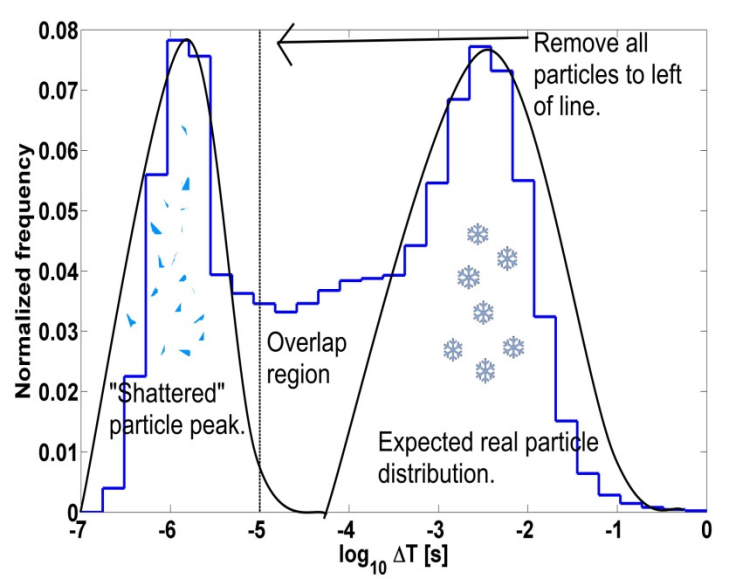
- **What is uncertainty on these bulk parameters induced by shattering of large ice crystals on inlets & tips of in-situ probes?**

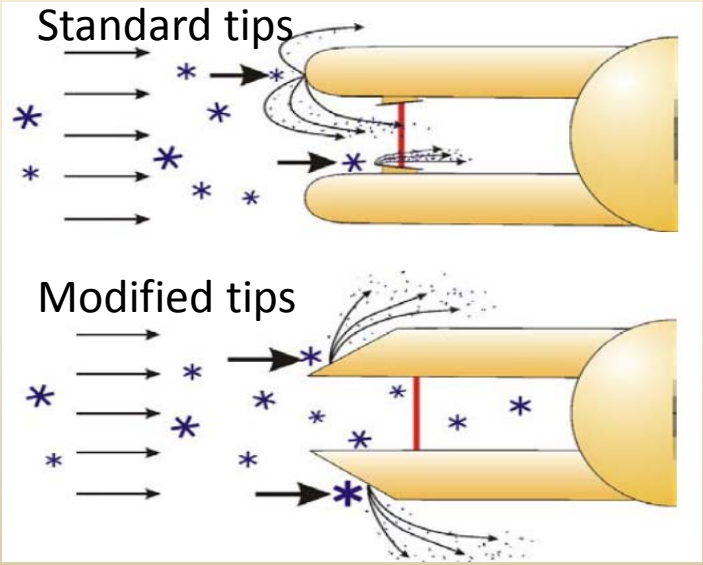
- **What is uncertainty induced by fitting algorithms on derived gamma fit parameters characterizing size distributions?**

Effect of Shattering

- **Ice crystal size distributions (SDs) from forward scattering and optical array probes (OAPs), like 2DC, may be biased by shattering**

- **Modified tips for OAPs & varying processing techniques based on particle interarrival distance (time) have been used to correct for artifacts**





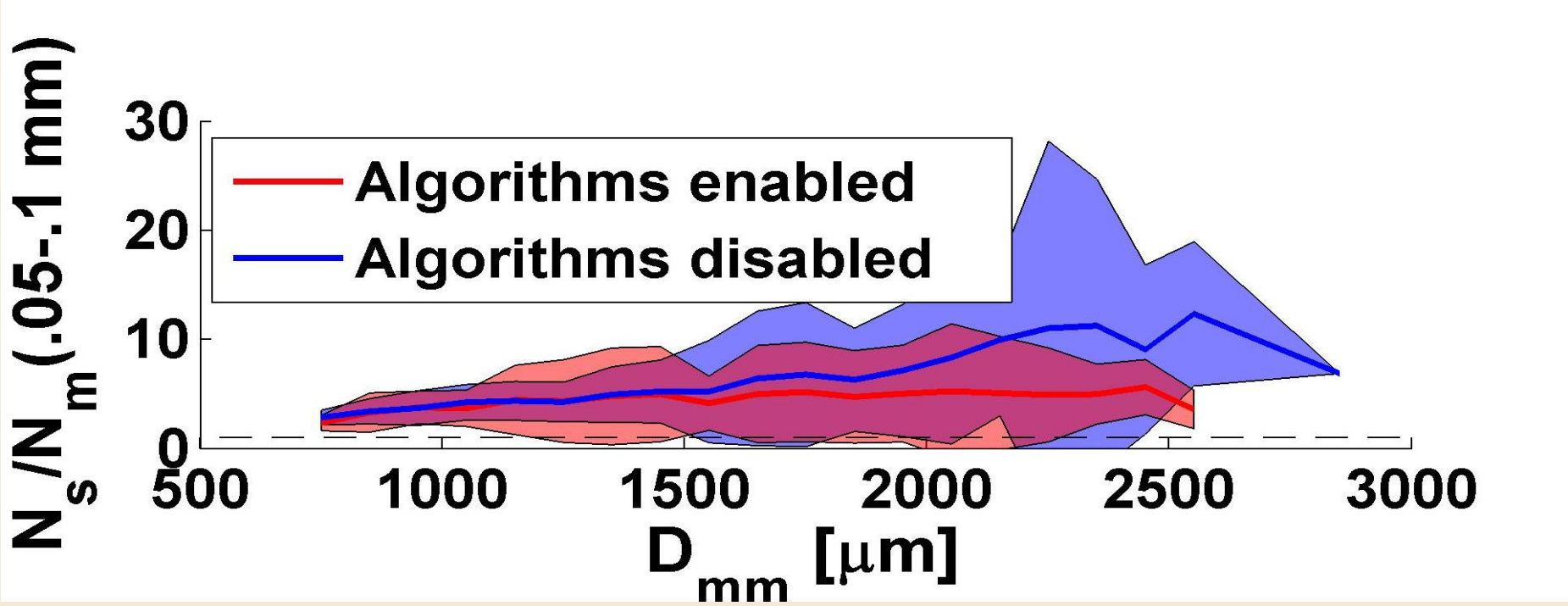
Korolev and Isaac (2006)

Last Spring

- **Showed data from 2 campaigns with co-located standard & modified 2DCs to investigate:**
  - **Identified conditions most conducive to shattering**
  - **Determined effect of shattering on bulk properties**

Campaign	Platform	Time + Location
Instrumentation Development and Education in Airborne Science phase-4 (IDEAS)	National Center for Atmospheric Research C-130	Research flight 3 (25 October) and 4 - 1 November 2011 near Cheyenne, WY
Indirect and Semi-Direct Aerosol Campaign (ISDAC)	National Research Council of Canada Convair-580	30 April near Fairbanks, Alaska

Compare Standard & Modified 2DC



Compare numbers of particles from standard tips (Ns) with number of particles from modified tips (Nm) from IDEAS

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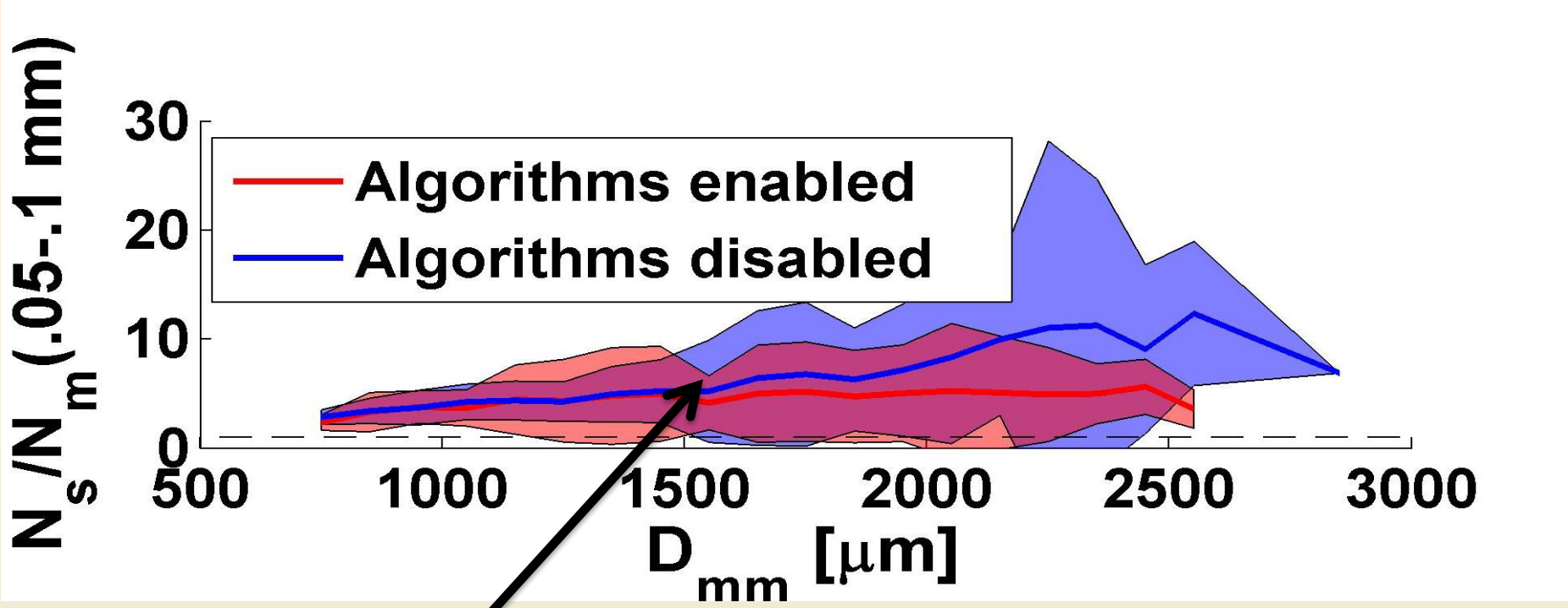

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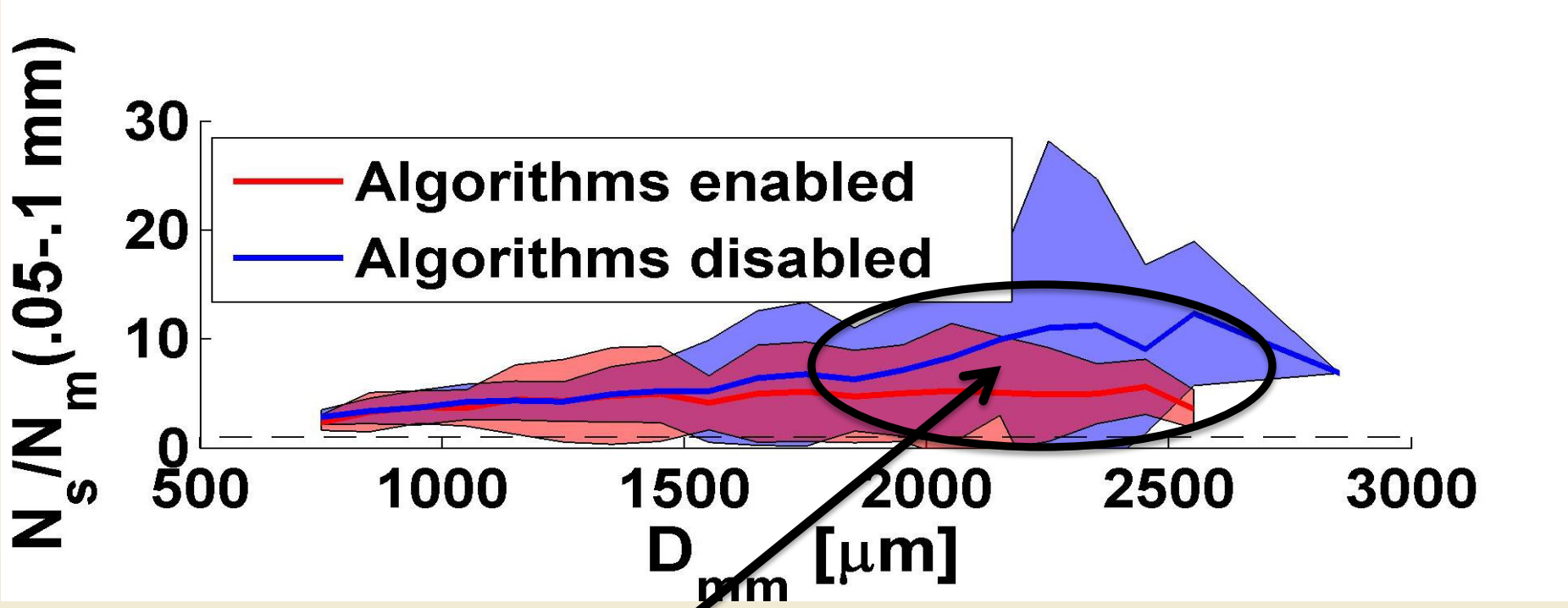
Fewer shattered particles with algorithms enabled

Compare Standard & Modified 2DC



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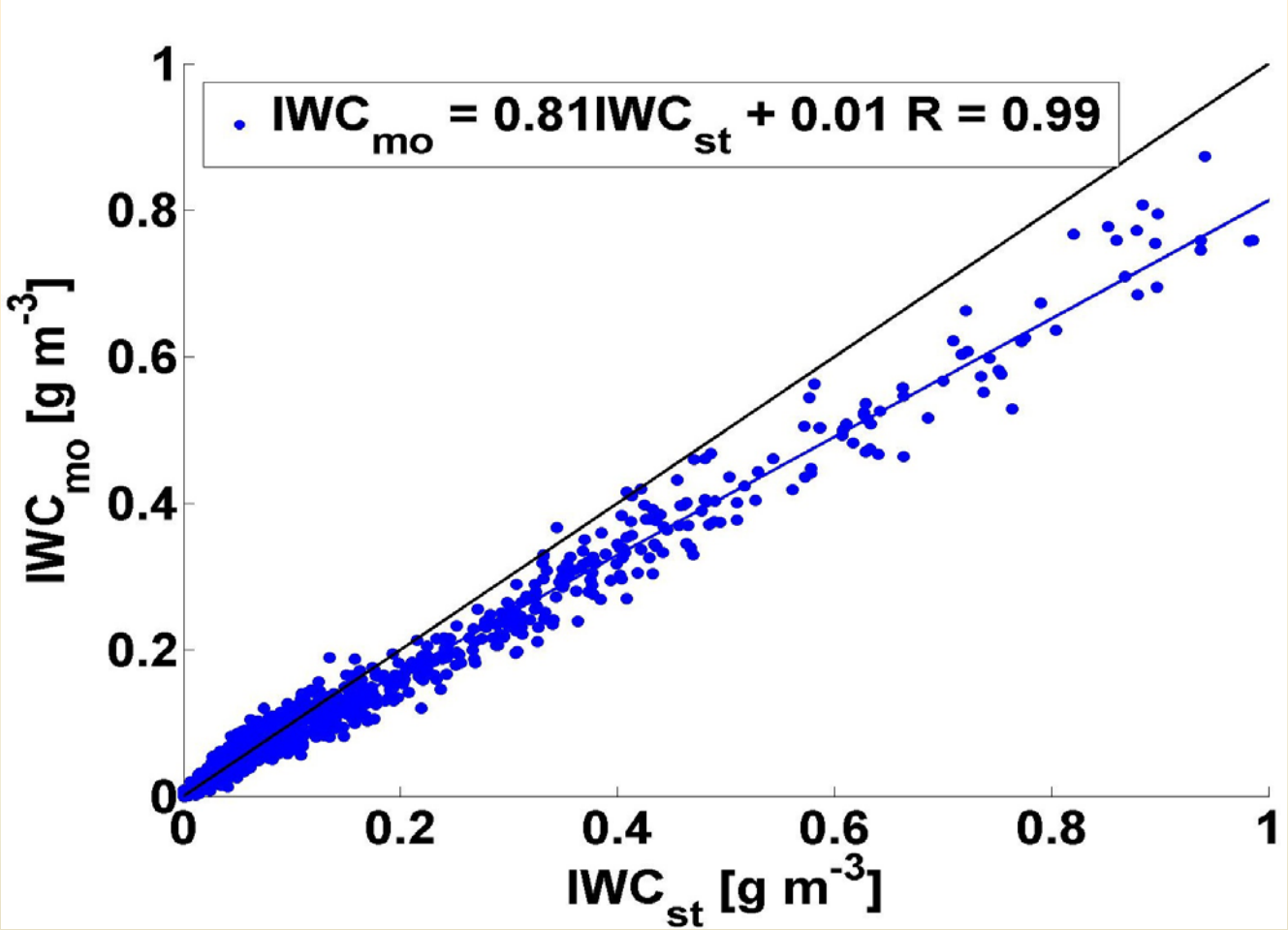
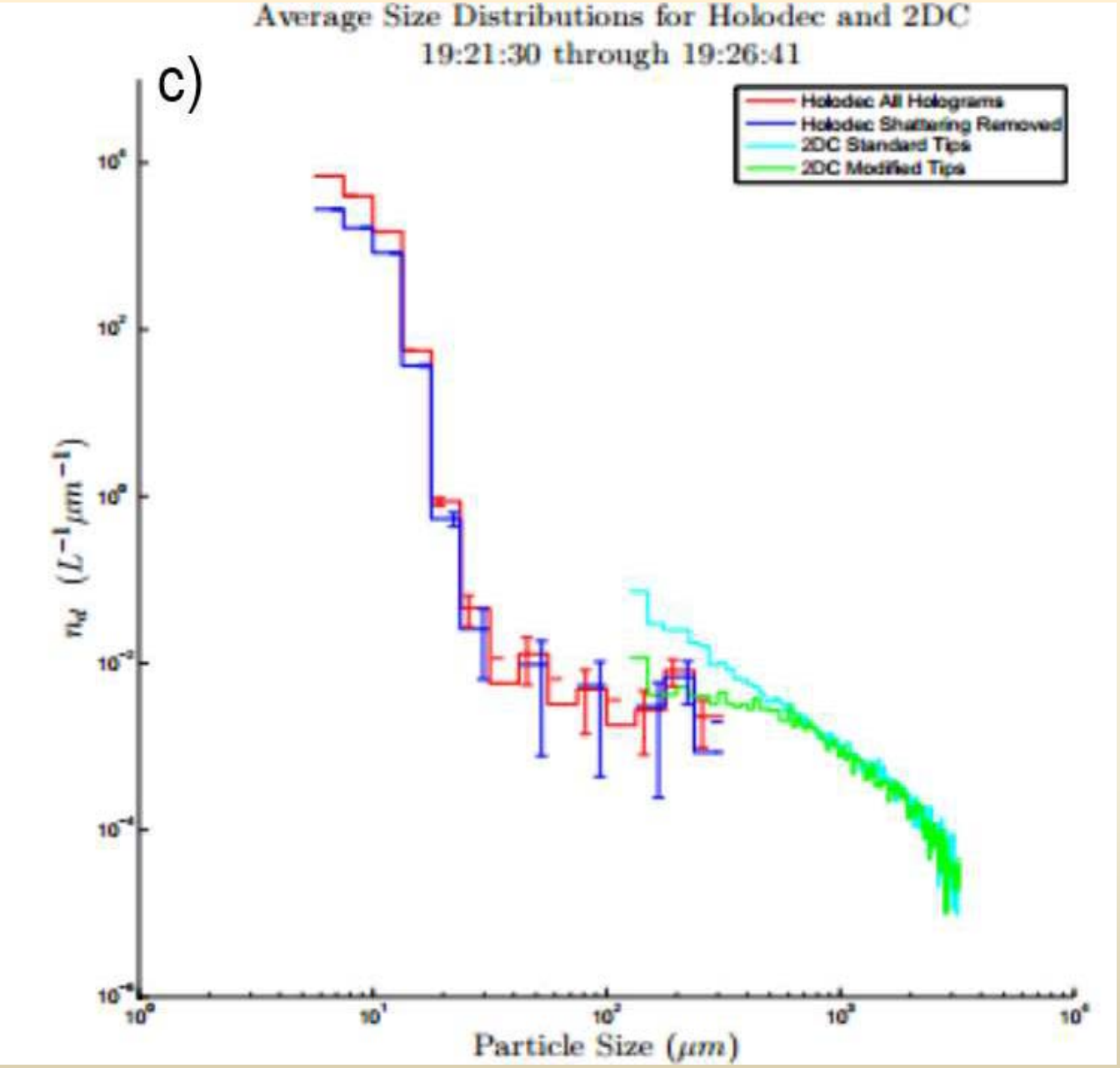
Ratio of N_s/N_m increases with median mass diameter D_{mm}

Impact on bulk parameters

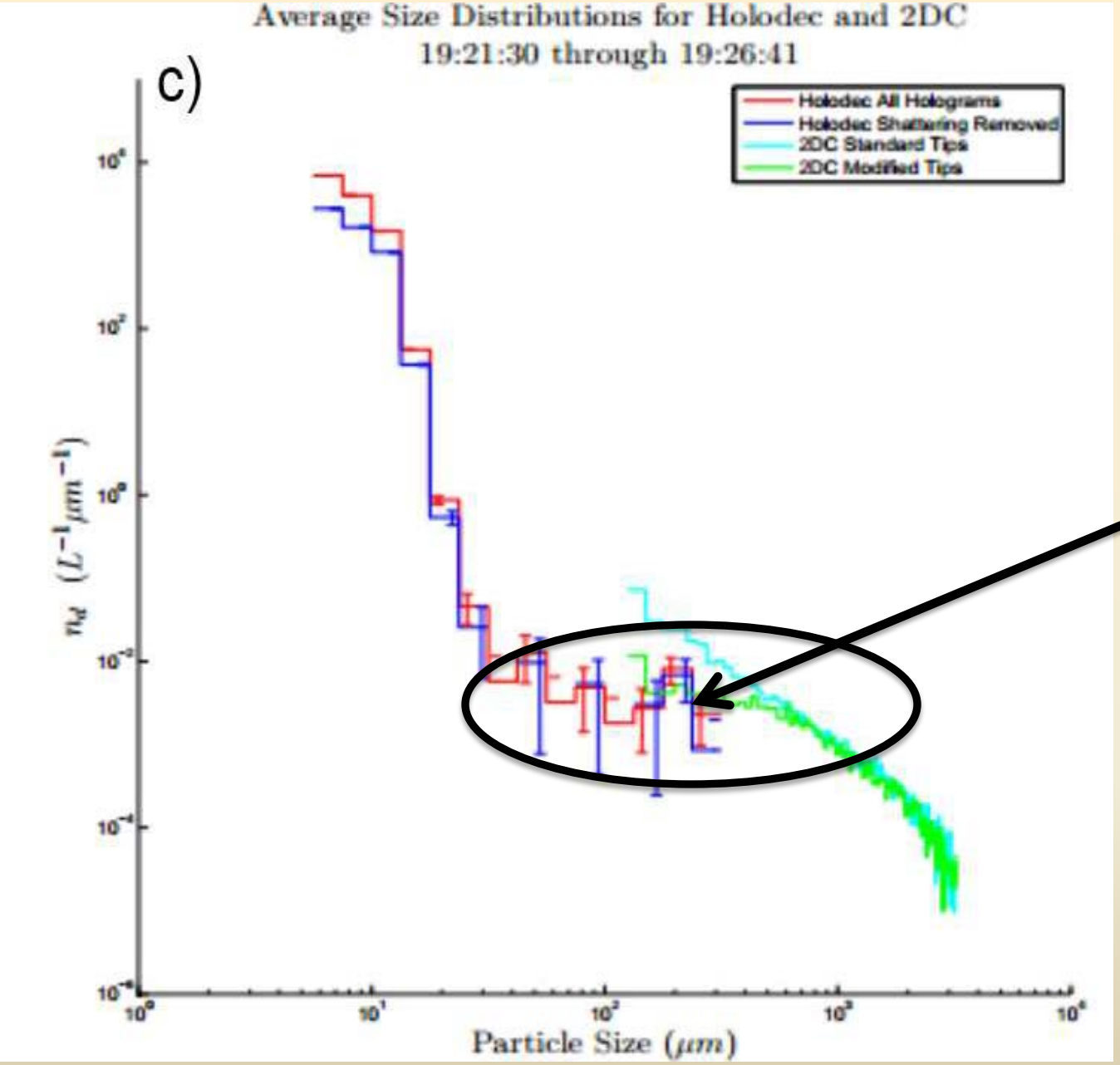


IWC_{mo} vs. IWC_{st} for IDEAS+ISDAC shows ~20% difference, which is less than uncertainty in IWC due to m-D relation

In –situ data provide reasonable IWC estimates



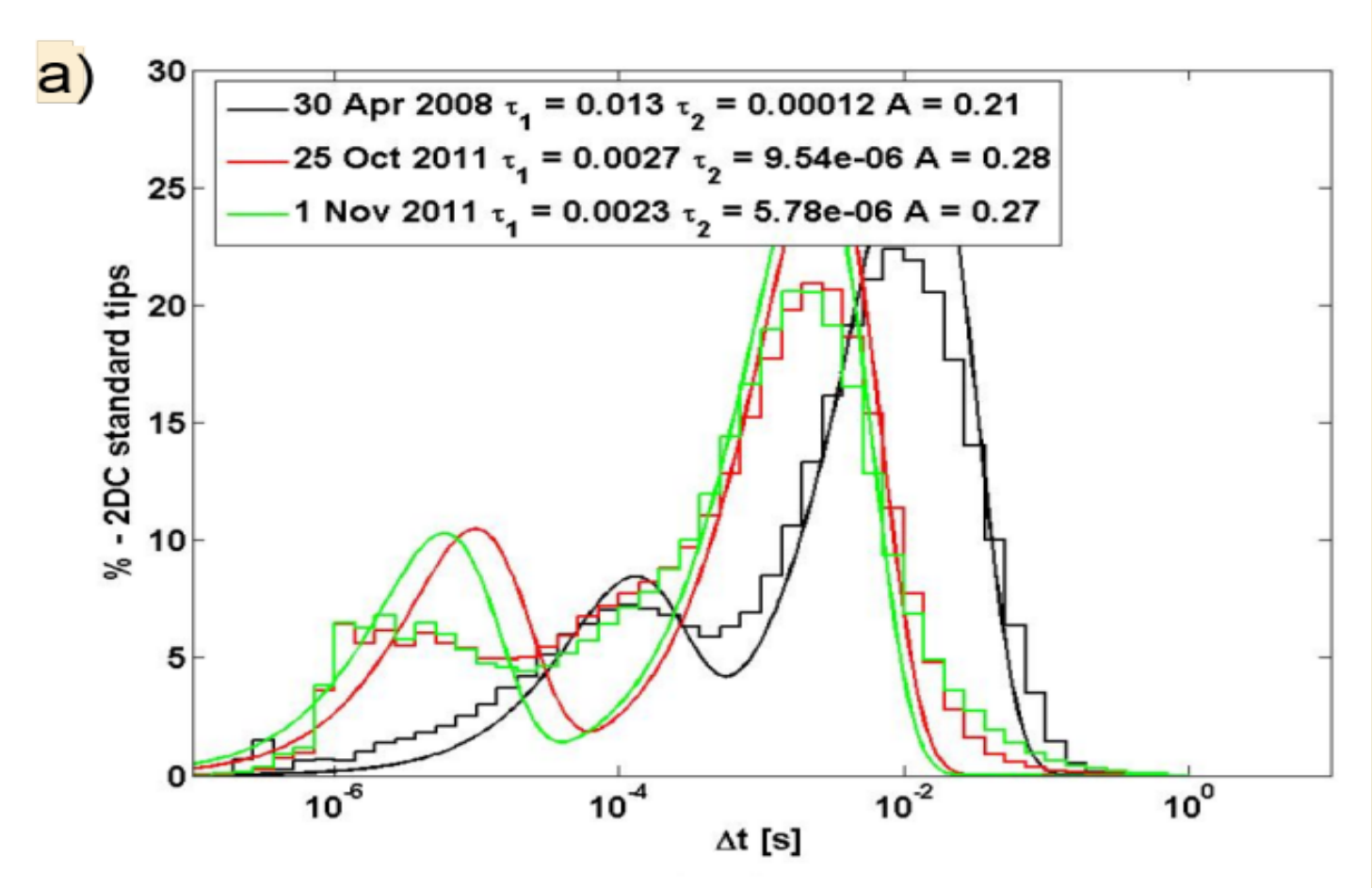
Comparison of 2DC/ HOLODEC during IDEAS shows good agreement



Comparison of 2DC/ HOLODEC during IDEAS shows good agreement

→ Suggests algorithms + tips does reasonable job removing artifacts

Efforts to Understand Shattering



- **Look at distribution of interarrival times on probe**

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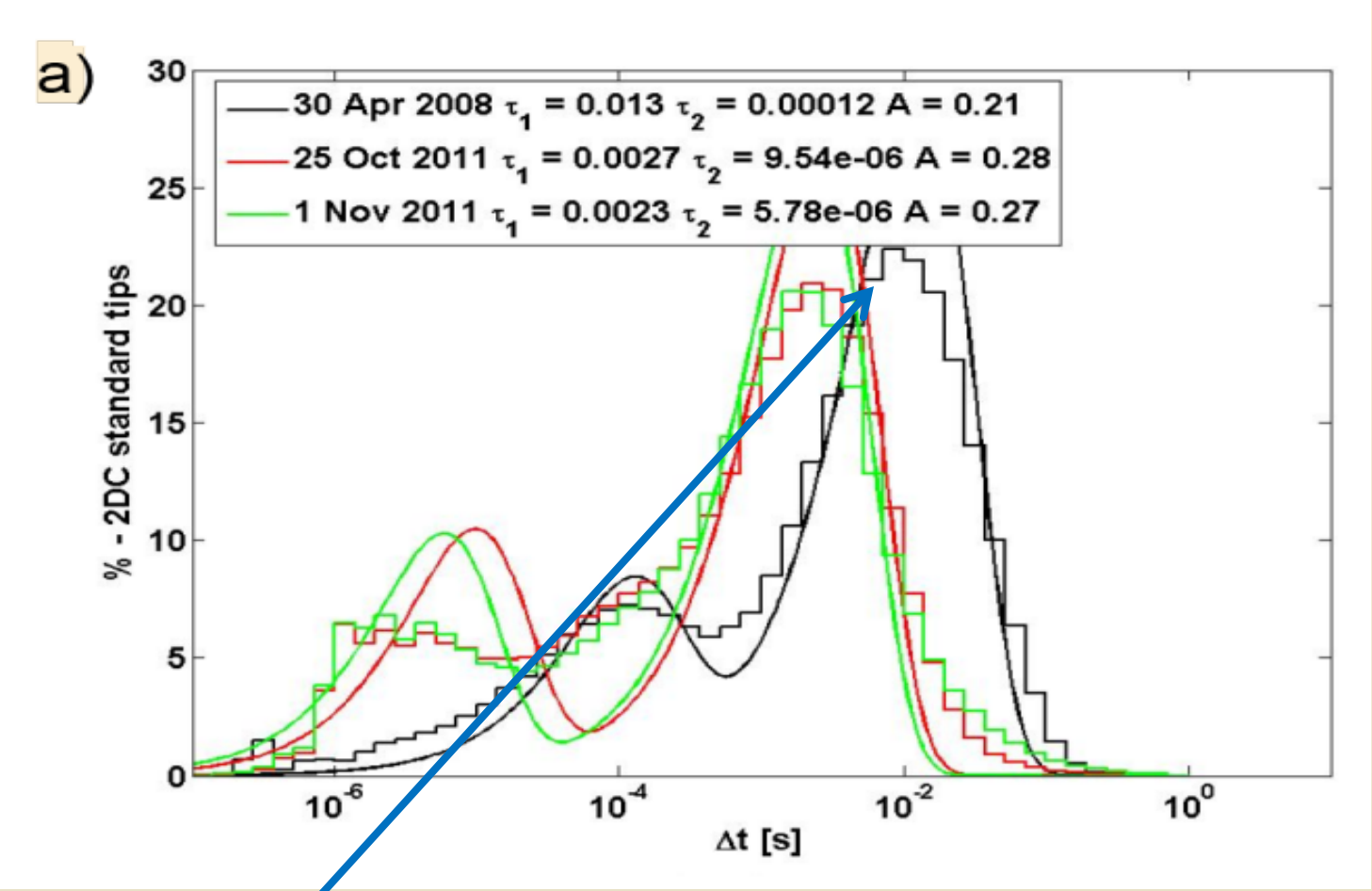
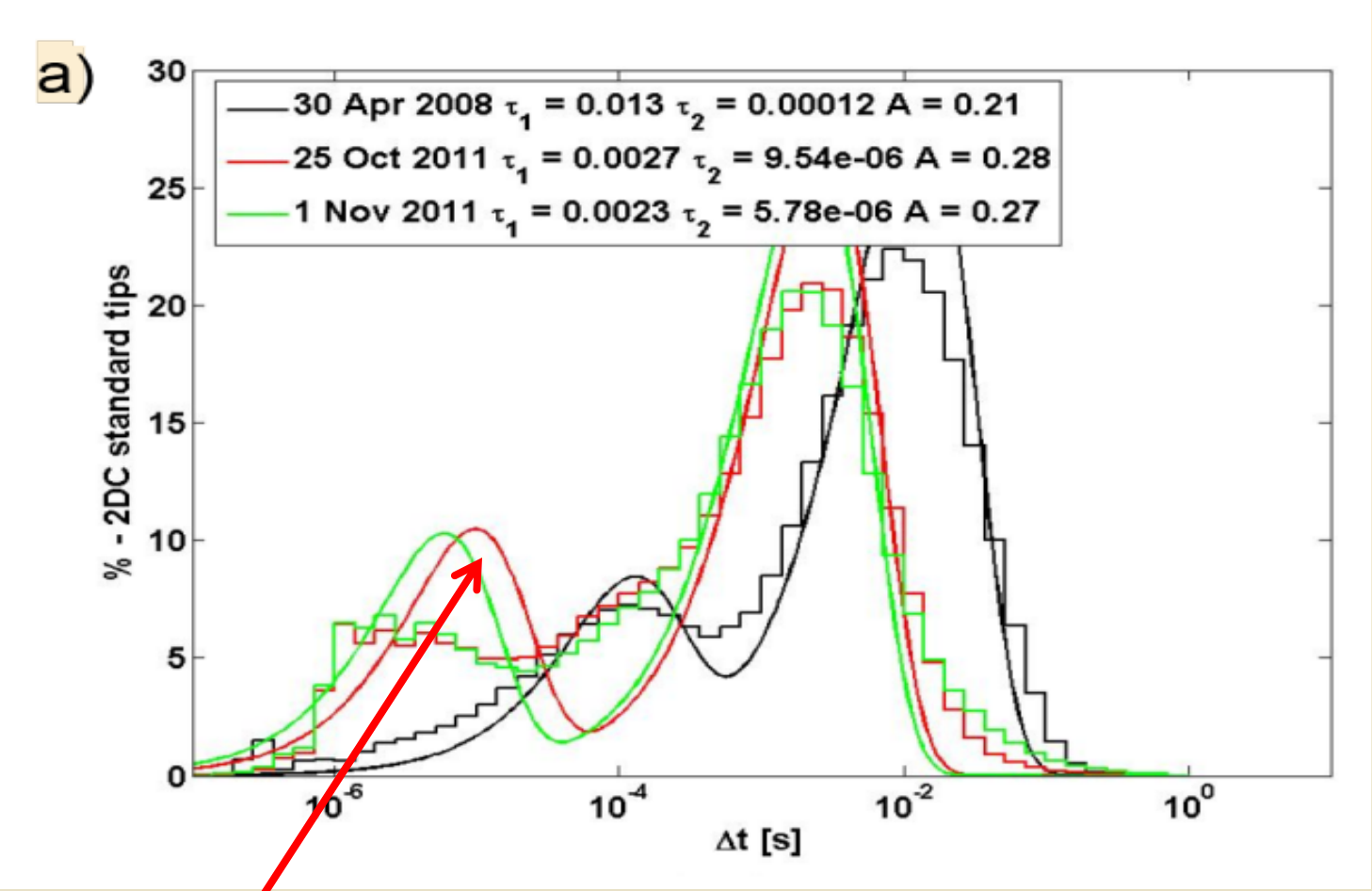


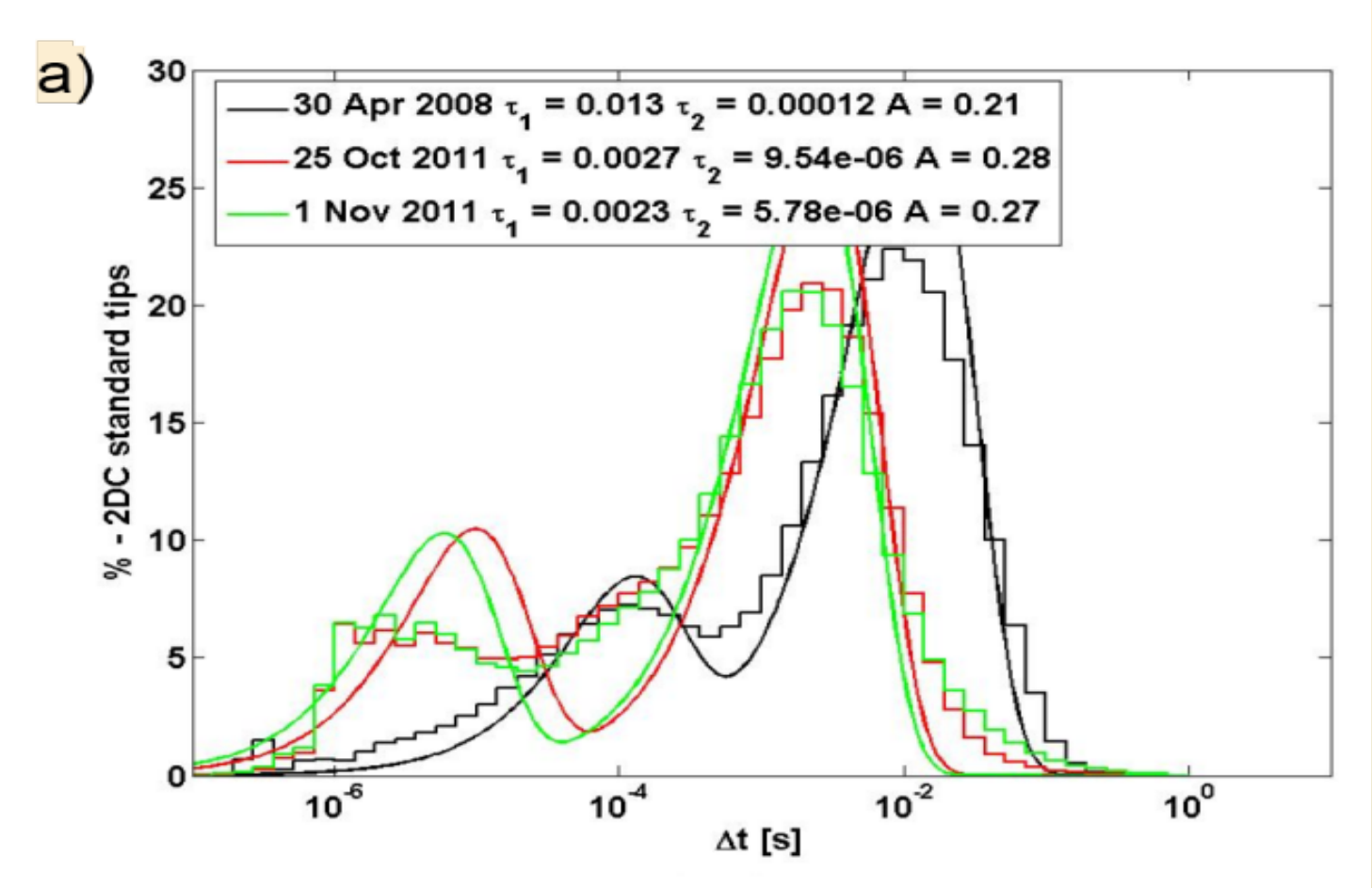
- **Look at distribution of interarrival times on probe**
- **Larger interarrival times correspond to naturally occurring particles (τ_1)**

Efforts to Understand Shattering



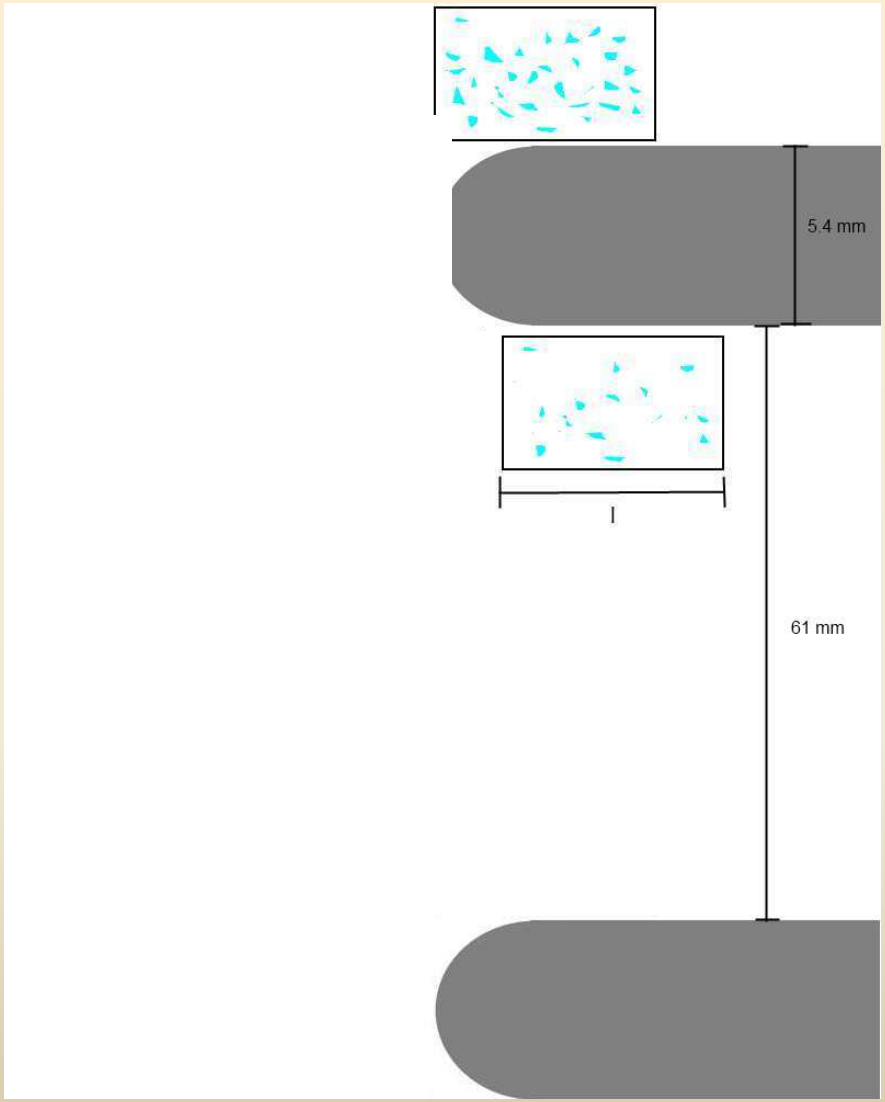
- Look at distribution of interarrival times on probe
- Smaller interarrival times correspond to shattered artifacts (τ_2)

Efforts to Understand Shattering



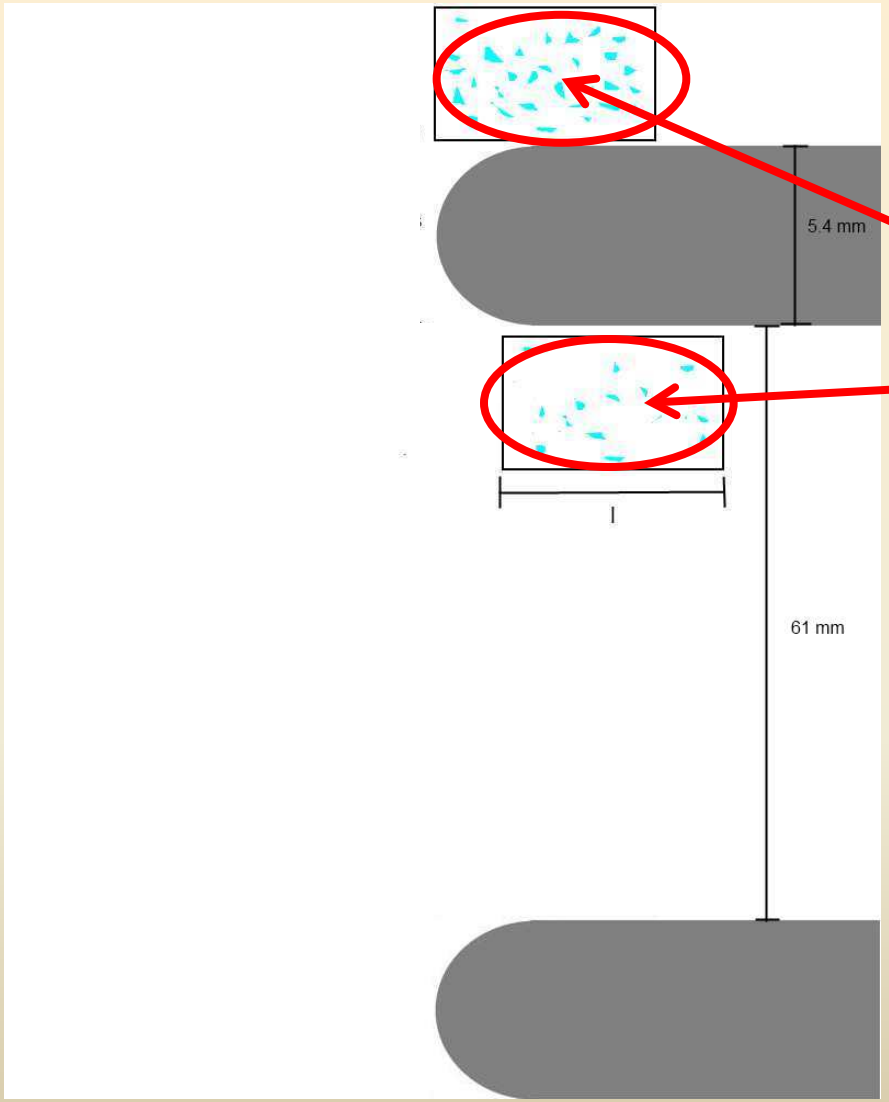
- Look at distribution of interarrival times on probe
- Why is there a difference in location of peaks between ISDAC/IDEAS?

Modeling Shattering



- **Develop model to characterize shattering on probe tips**

Modeling Shattering



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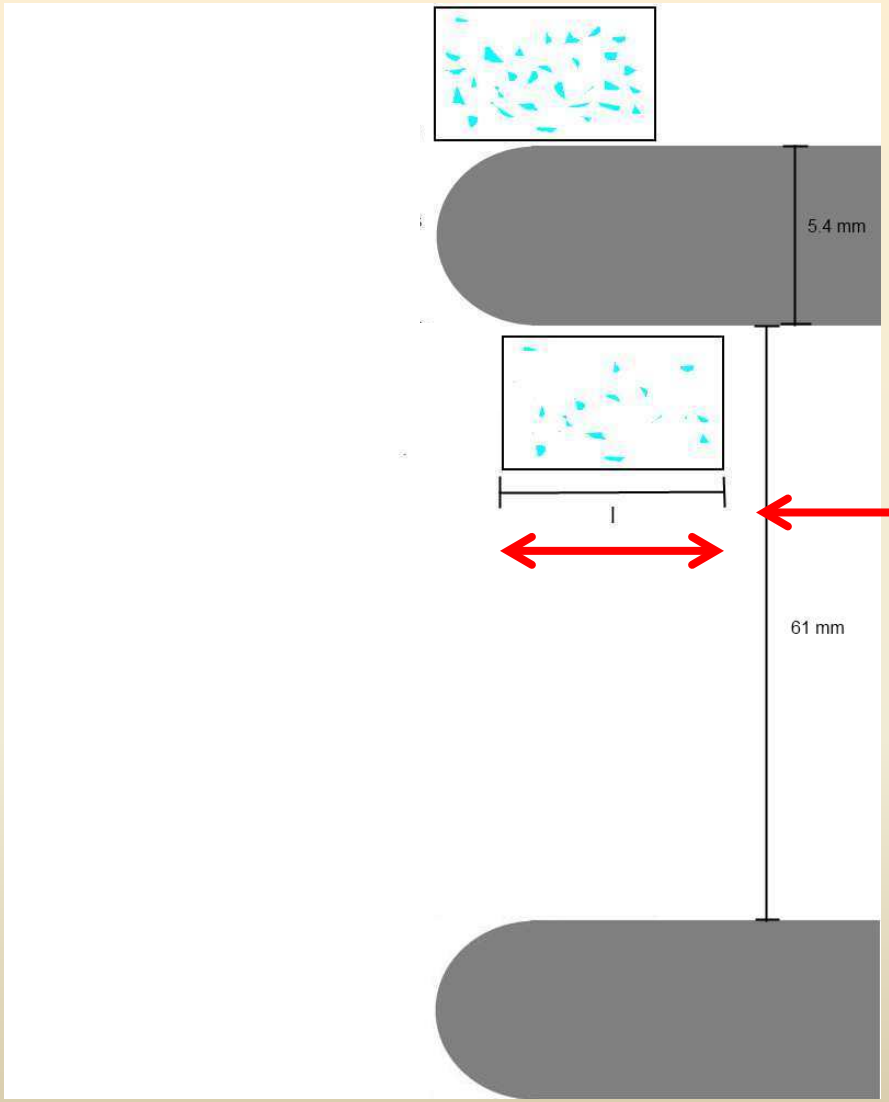

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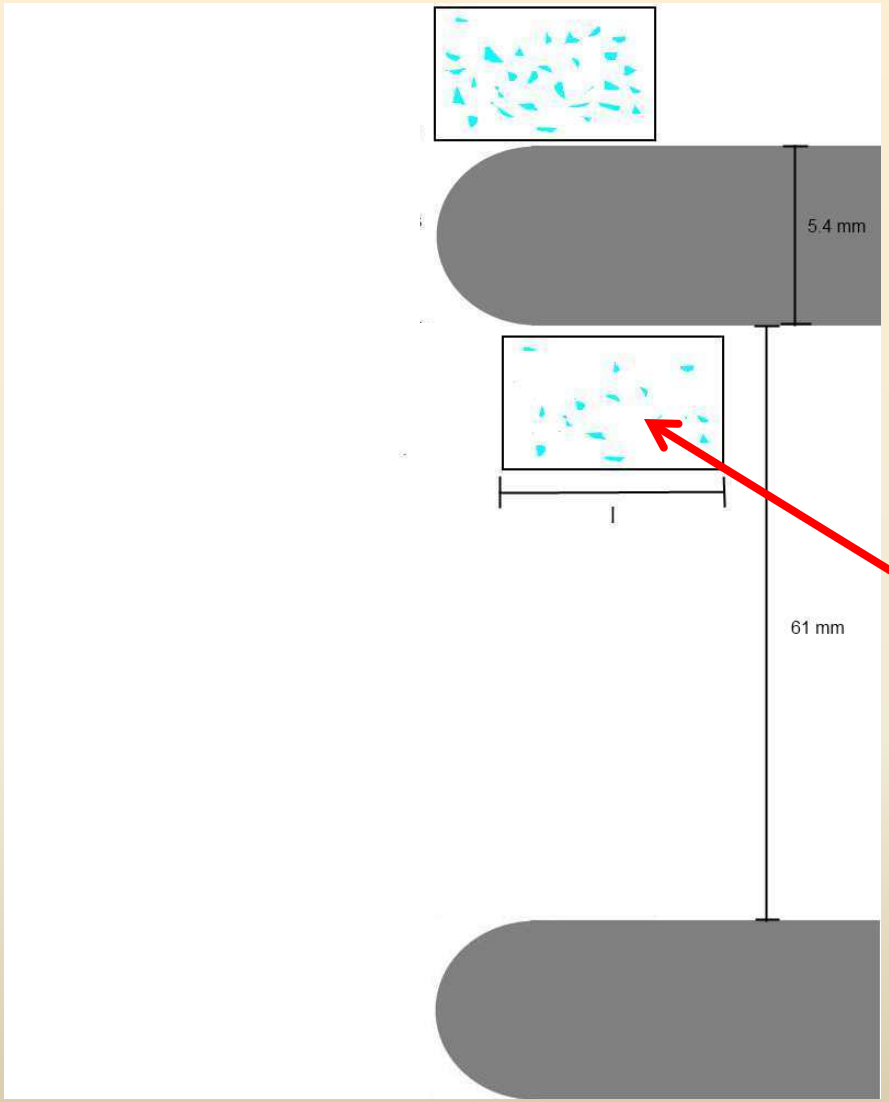

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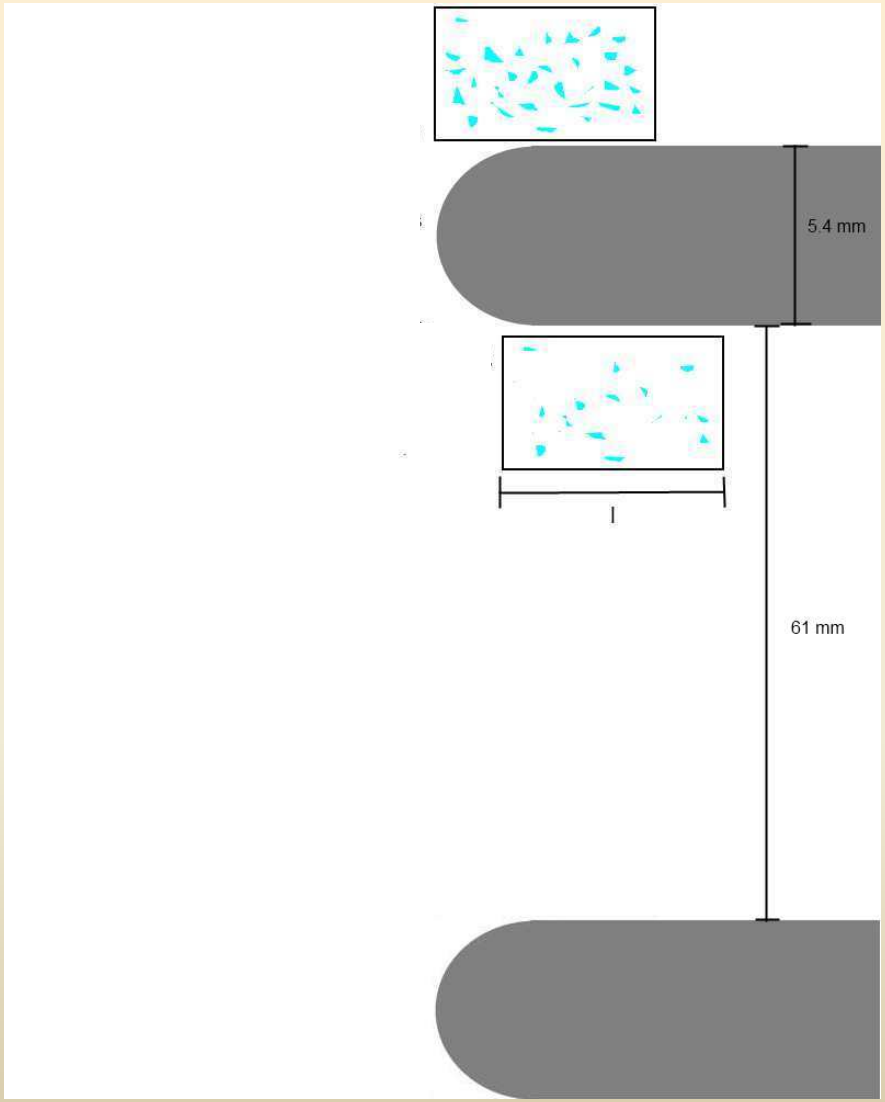
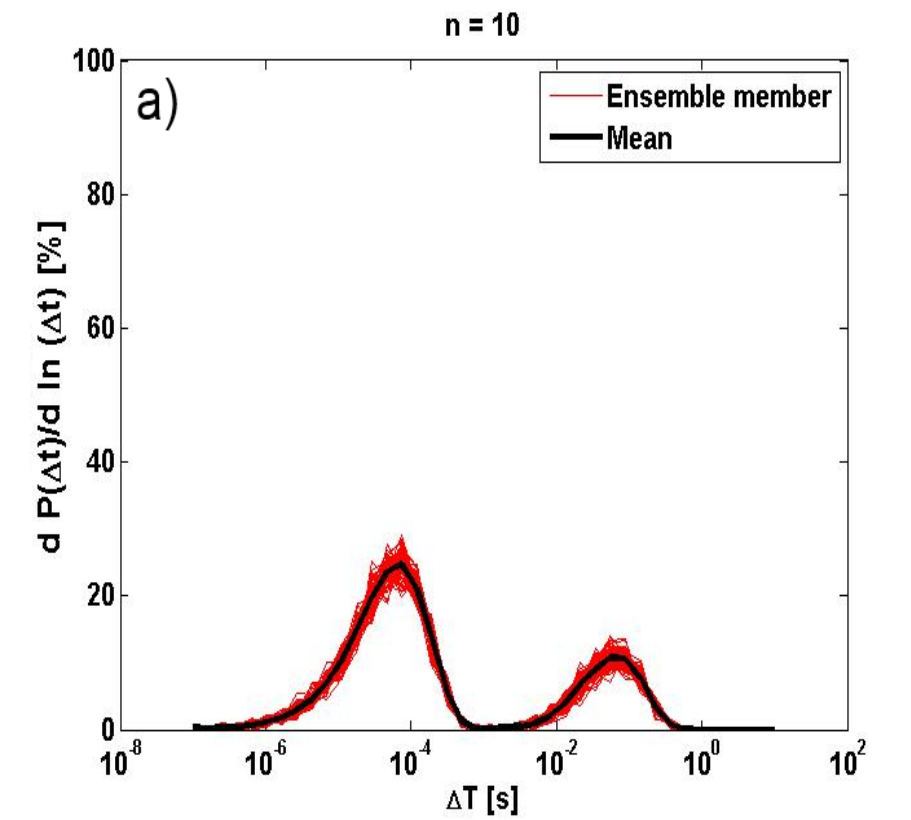


- **Develop model to characterize shattering on probe tips**
  - **Particles hitting tips shatter into n fragments distributed by Poisson statistics across length l in direction of flight**
  - **Probability of single fragment entering sample volume is k**
- **Compute distribution of interarrival times for IDEAS/ISDAC using observed concentrations**

Modeling Shattering



- **Example of calculation for $N=1\ L^{-1}$, n=10, l = 1 cm, k=5%**

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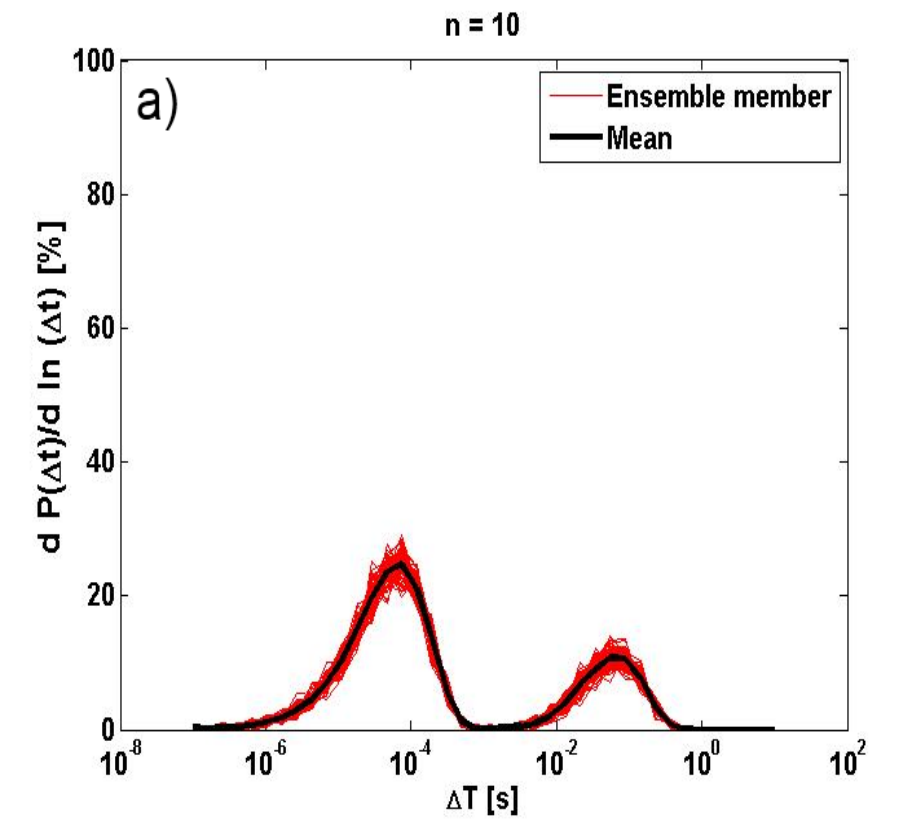

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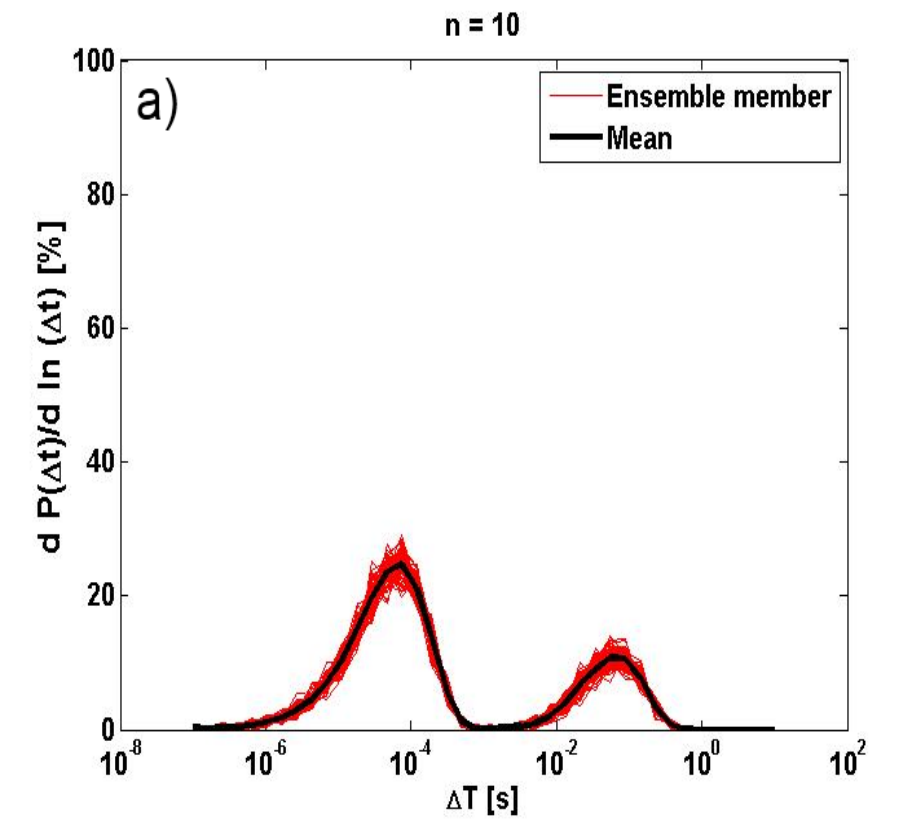

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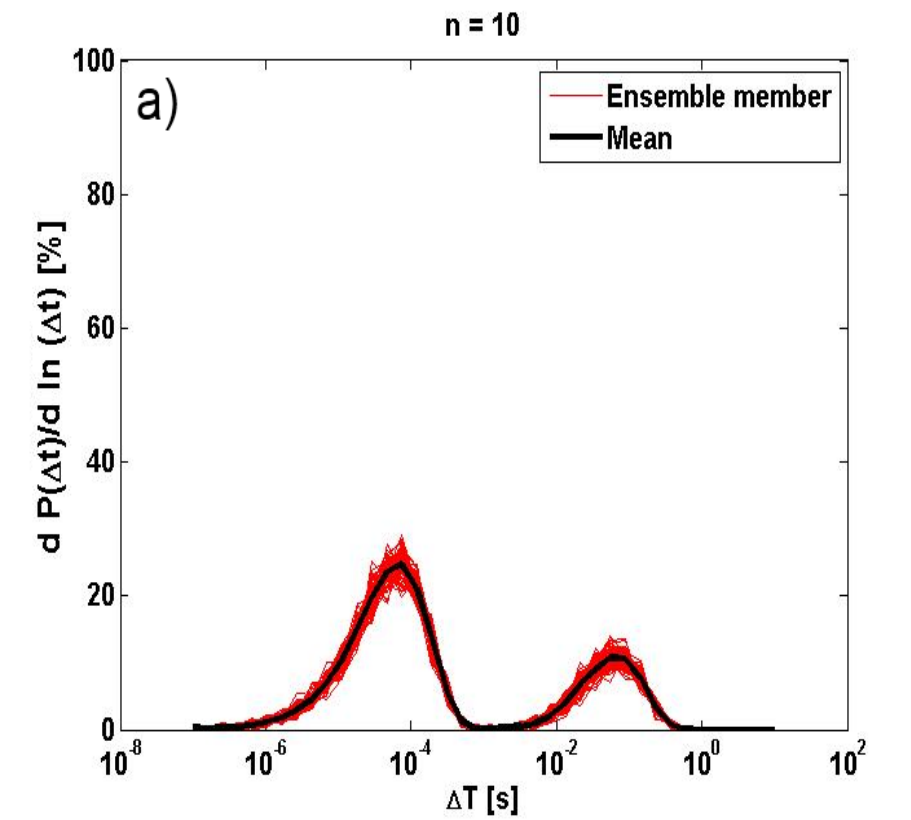

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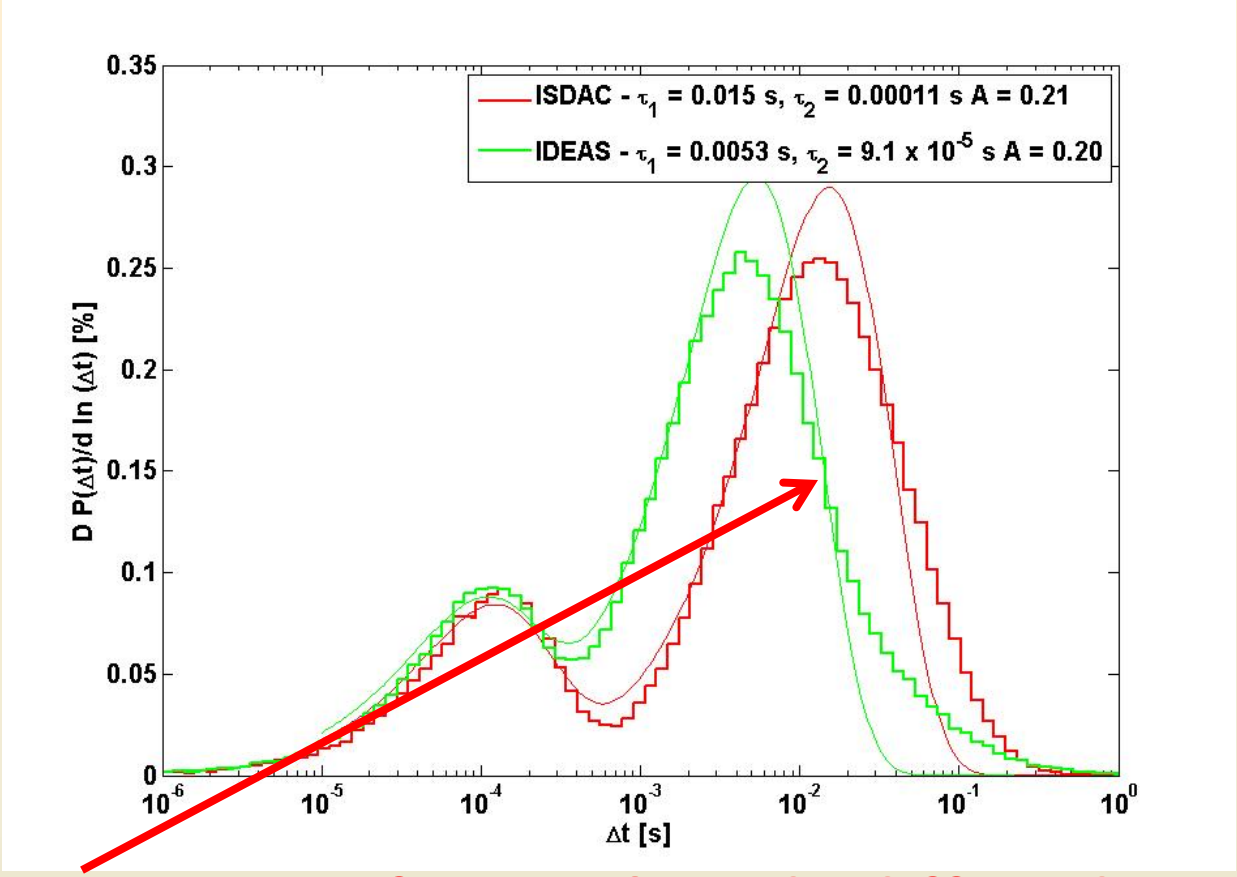
- τ_1 (natural particles) inversely correlated with N, TAS but not l or n
- τ_2 (artifacts) correlated with l, and inversely correlated with TAS, N and n

Simulation of ISDAC/IDEAS



- **Location of natural mode differs due to varying concentration between project**

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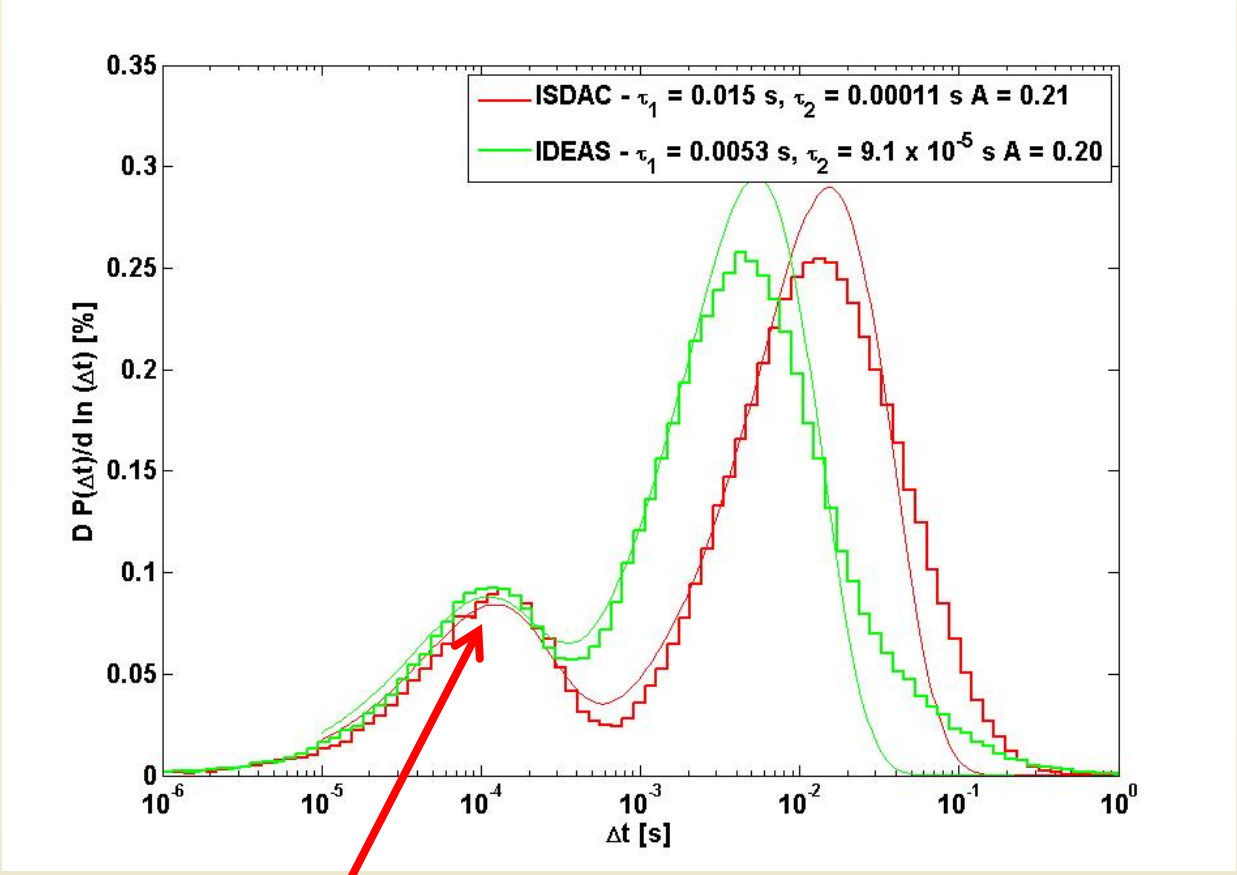

- **Location of natural mode differs due to varying concentration between project**
- **Location of shattered mode similar (but differed in observations): perhaps l, k or n differed due to variations in characteristics of crystals**

Gamma Distribution:

Mathematical Representation of Size Distributions

$$N(D) = N_0 D^{\mu} \exp(-\lambda D)$$

- N(D) = Number Distribution Function
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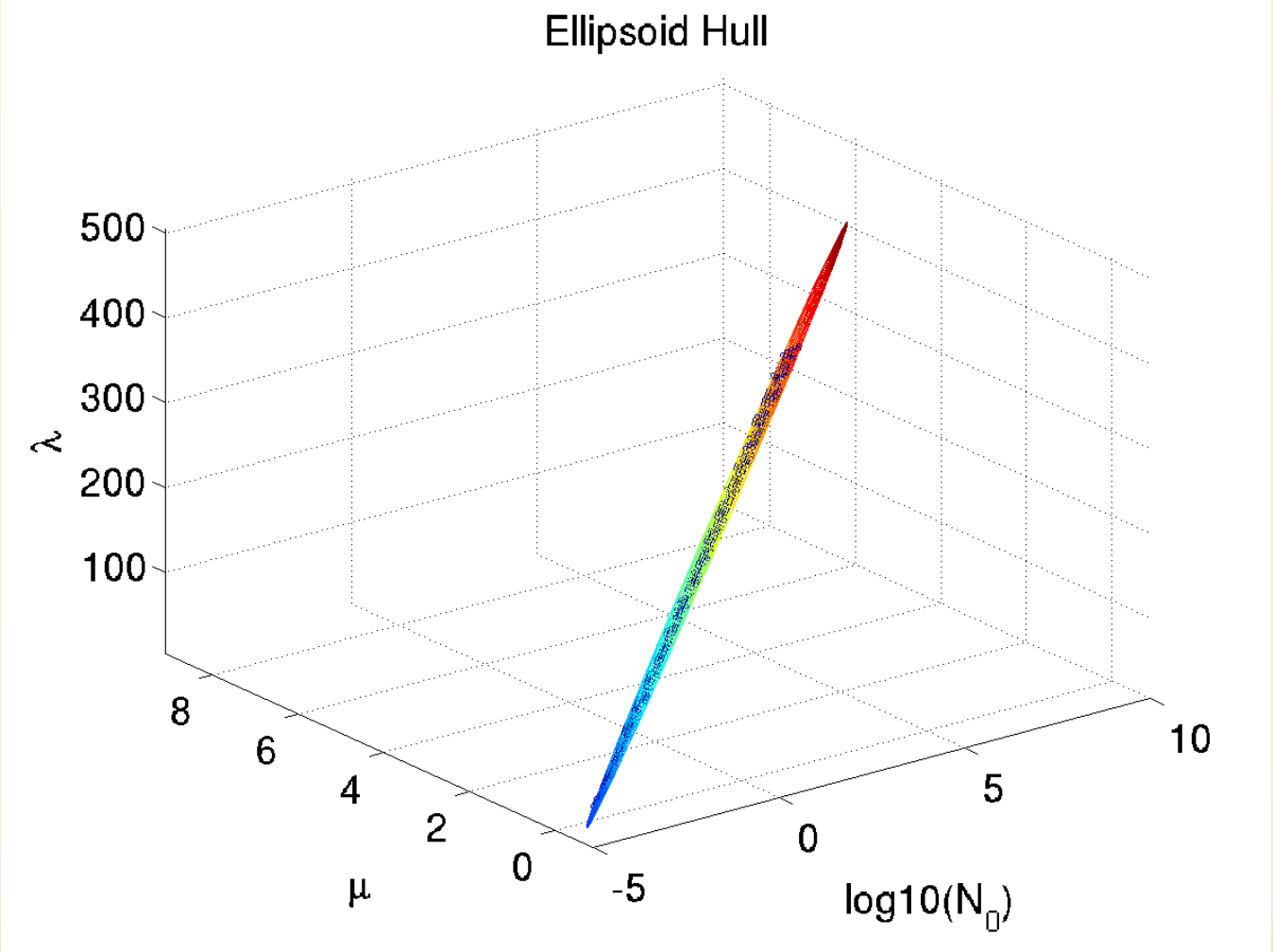
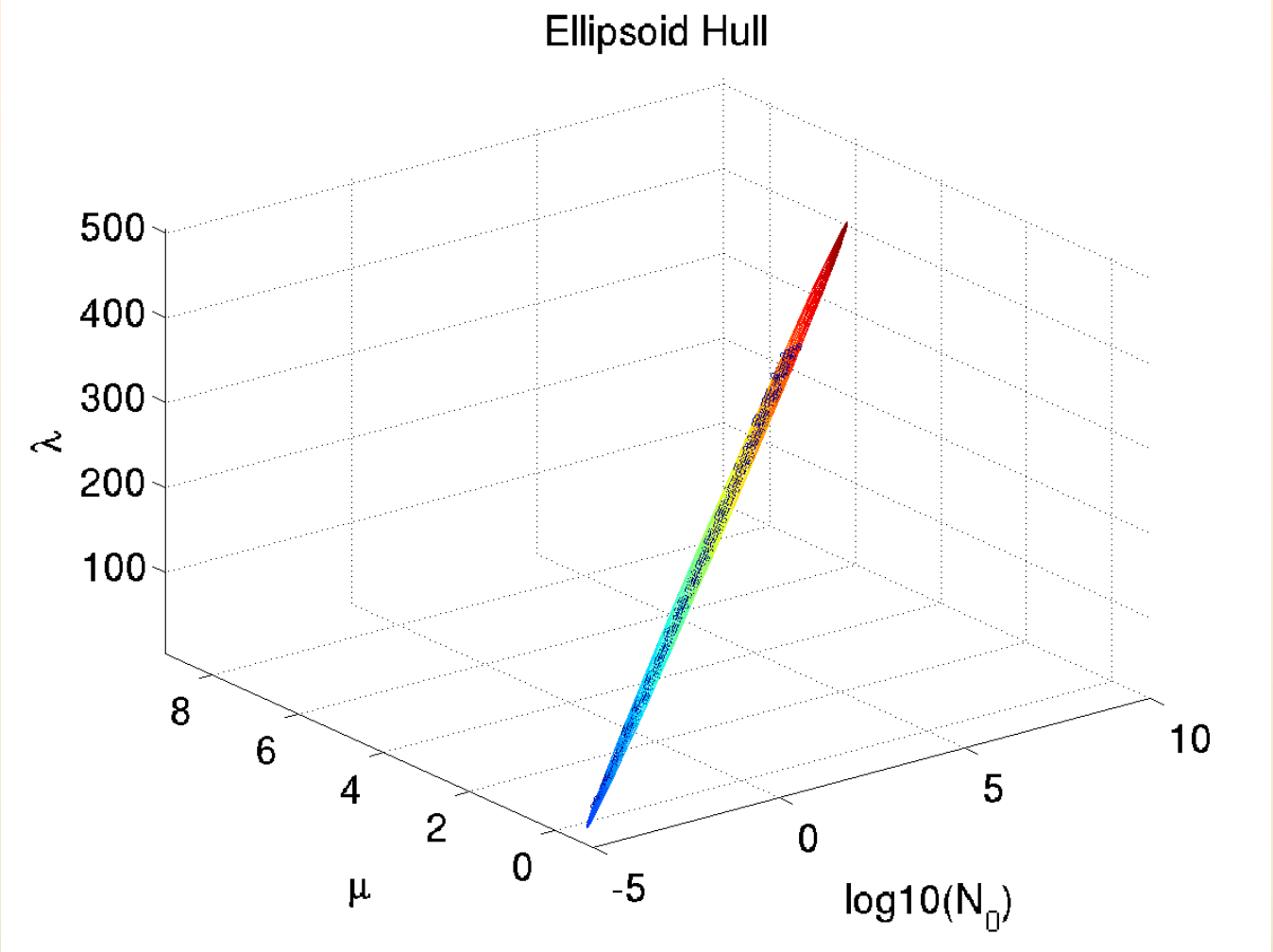
Have determined methodology for quantifying uncertainties in N_0, μ, and λ based on uncertainties in measured size distributions



There is broad range of $N_0/\mu/\lambda$ that fit SD well

→ Range determined by IGF technique that allows derived/observed moments to differ by $\Delta\chi^2$

→ Can't represent by single $N_0/\mu/\lambda$ value



But how big is $\Delta\chi^2$?

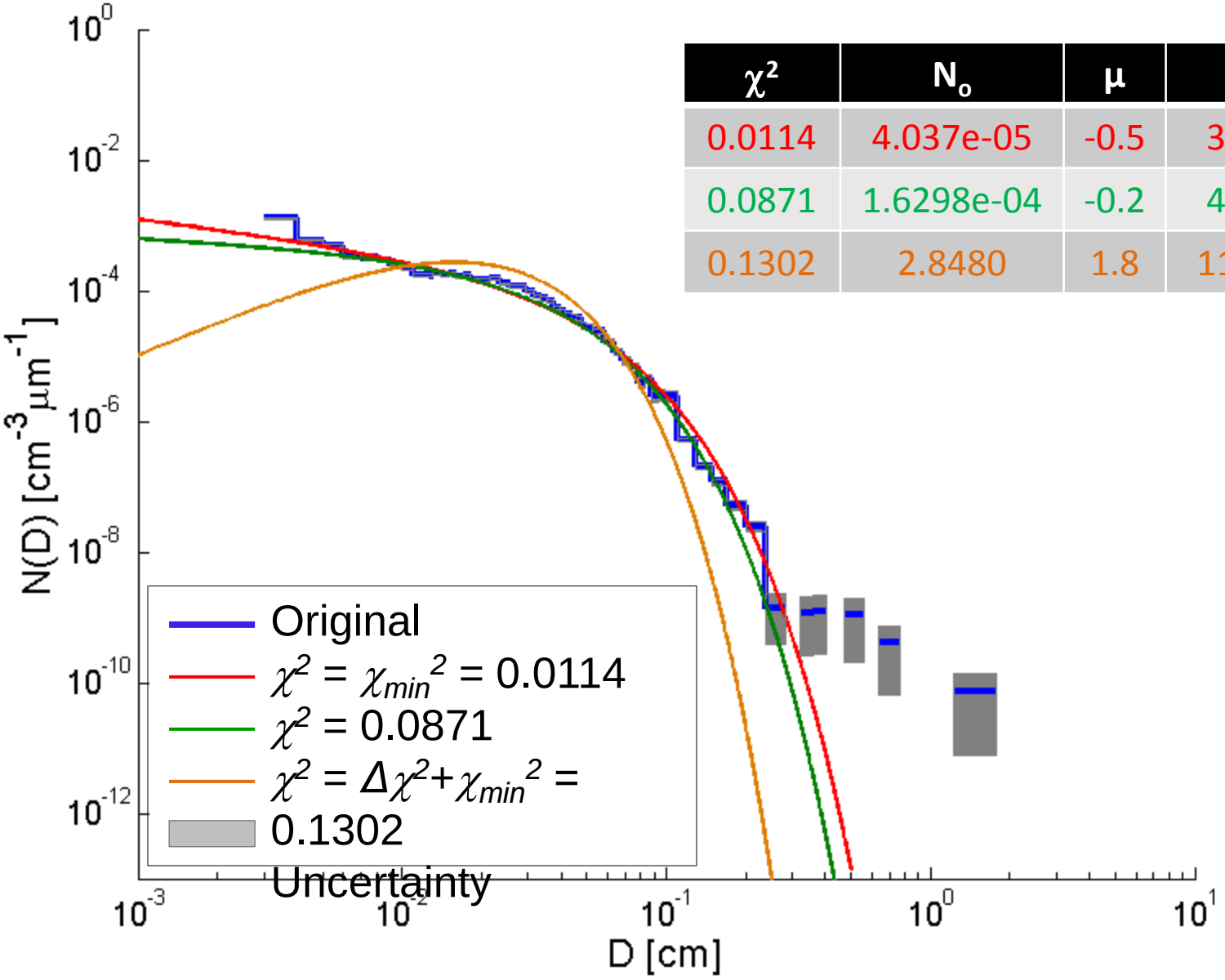
$N_0/\mu/\lambda$ determined depend on tolerance allowed

Determination of $\Delta\chi^2$

- Uncertainty in measured SD determined by square root of # of particles in each bin, gives $\Delta\chi^2$
- If $\Delta\chi^2 < \chi_{min}^2$ for fit then $\Delta\chi^2 = \chi_{min}^2$

1 SD Example: Aug. 20, Time: 170840

χ^2	N_o	μ	λ
0.0114	4.037e-05	-0.5	39.6535
0.0871	1.6298e-04	-0.2	49.5545
0.1302	2.8480	1.8	113.9109



Conclusions

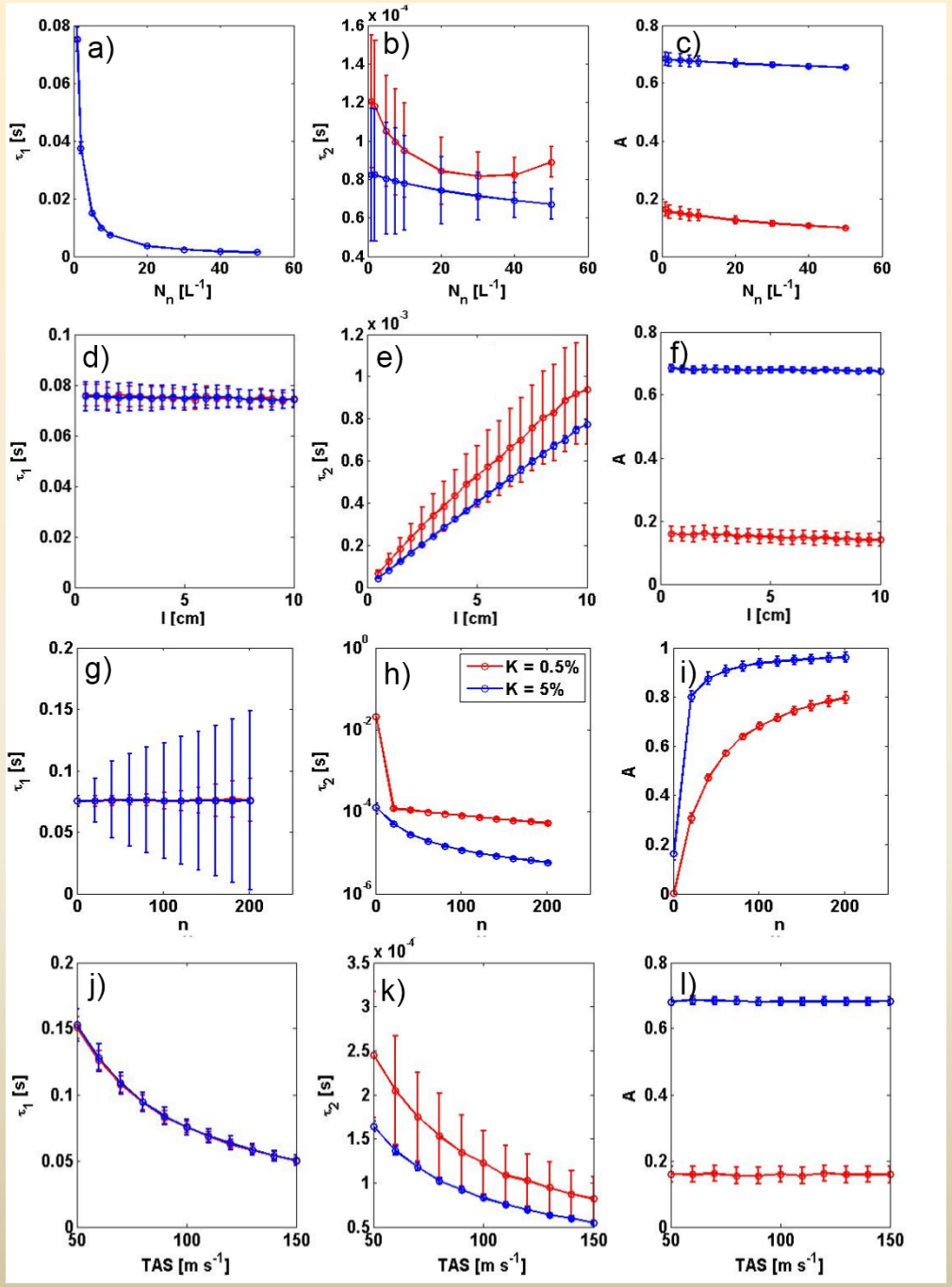
- Modified tips & processing algorithms combined best mitigate existence of shattered particles
- Modified tips reduce β, IWC by ~20%, no systematic bias in r_e
- Theoretical model does reasonable job describing shattering, but still unclear on what basis of shattering depends on
- Quantitative basis for determining range of N_0, μ, λ describing gamma fit distribution established

Next Steps

- **Conduct fits to SDs measured during past campaigns:**
  - **Currently working on MC3E/SPARTICUS data**
  - **IGF can accommodate for missing crystal ranges due to shattering**
- **QUICR ramifications:**
  - **Level of uncertainty in bulk parameters different (determined on parameter by parameter basis)**

Determination of $\Delta\chi^2$

- Calculate uncertainty in each 10-s *N(D)* → create $N(D)_{min}$($N(D)_{max}$) from $N-\sqrt{N}$ ($N+\sqrt{N}$)
- Compute 3 moments for each *N(D)* uncertainty
- Calculate χ^2 (comparing to moments of original N(D)) for each uncertainty → $\chi^2{}_{N(D)_{min}}$; $\chi^2{}_{N(D)_{max}}$
- $\Delta\chi^2$ = average of both χ^2
- If $\Delta\chi^2 < \chi_{min}{}^2$ for fit then $\Delta\chi^2 = \chi_{min}{}^2$



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1. Showed shattering increased with D_{mm} & amount of riming
2. Both modified tips & algorithms needed to remove artifacts
3. Tips more effective than algorithms for removing artifacts
4. Bulk IWC, b could be estimated within about 20%