



DoD MEMS Fuze Reliability Evaluation

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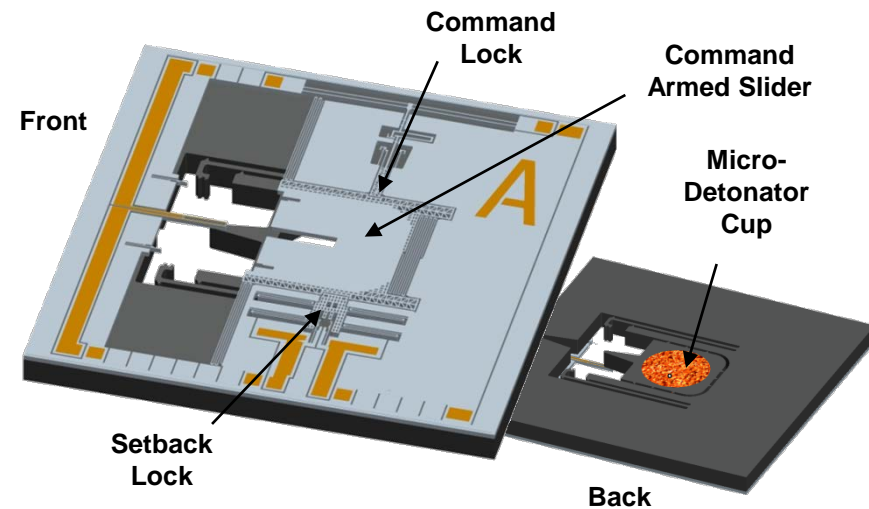
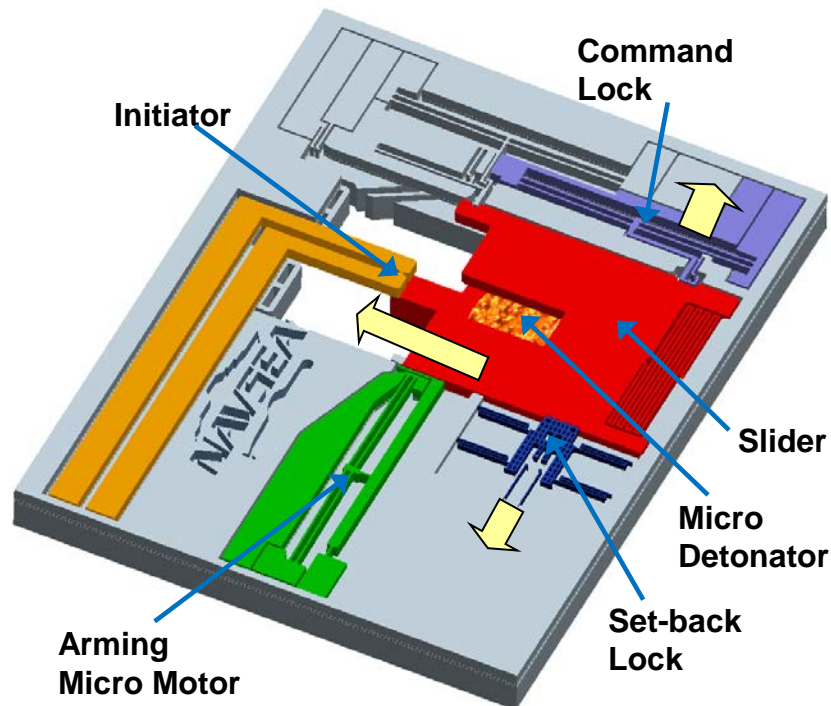
MEMS Safe and Arm Chip

MEMS based fuzing offers the potential for small volume, low cost, and low energy.

NSWC IHEODTD has been investigating silicon based MEMS for over a decade.

Can use either command arm/lock release motors or built in environmental sensors.

All non-explosive components fabricated on SOI wafers using established semiconductor processes.

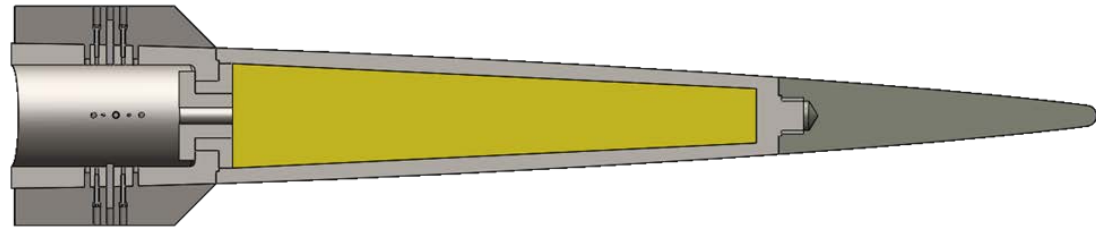


MEMS Applications

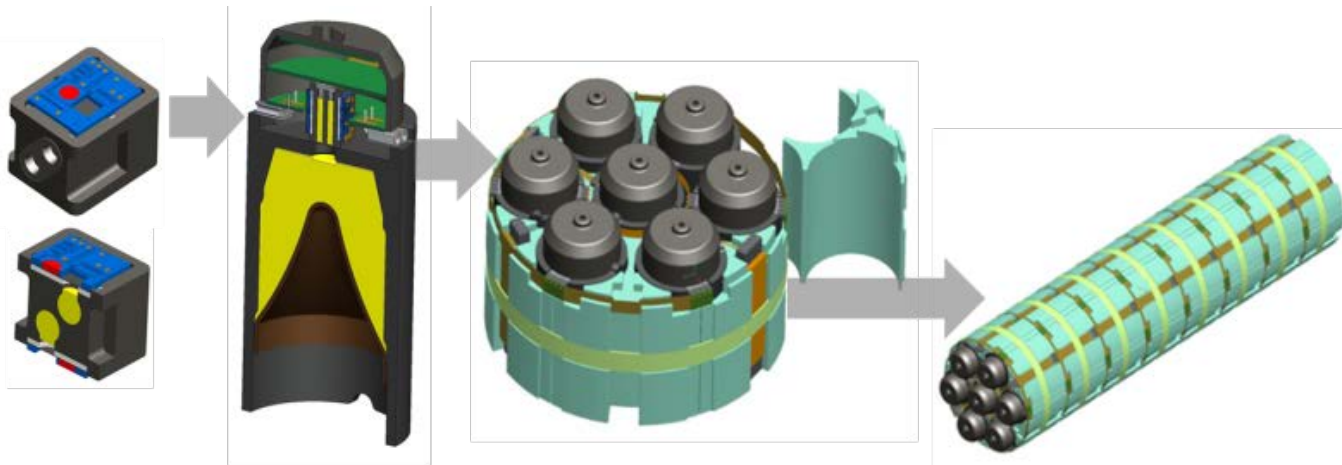
40 mm Grenade



Hypervelocity Projectile



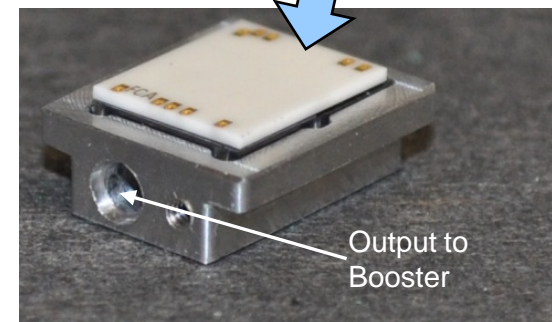
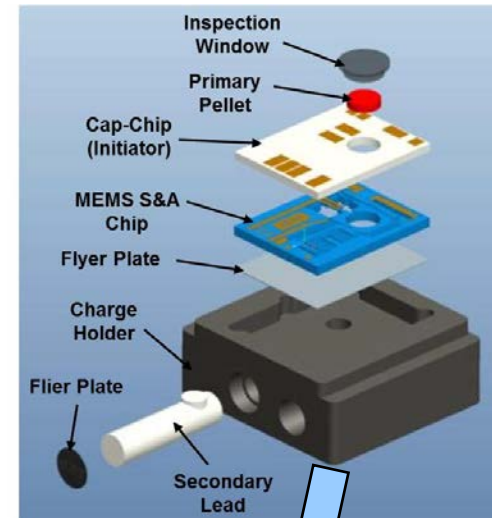
High Reliability DPICMS Replacement (HRDR)



HRDR brief by Daniel Pines at 4:40 today in US only session

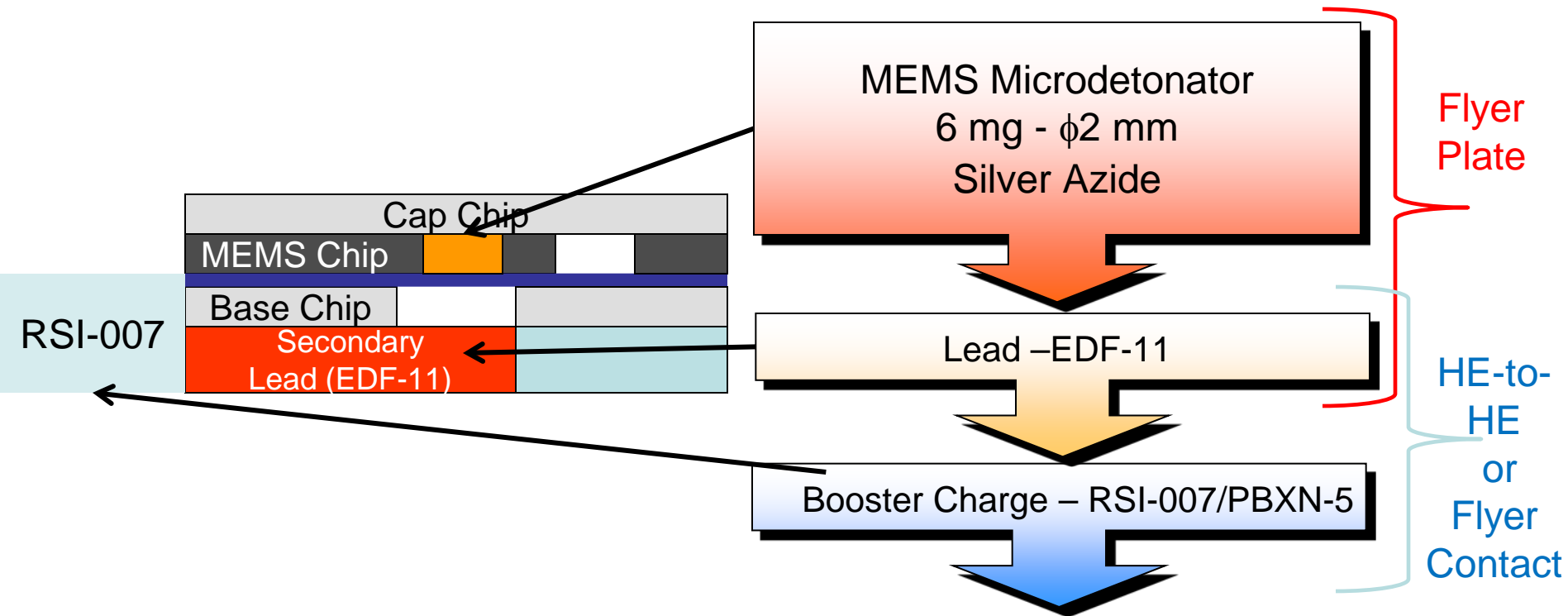
Explosive Train Overview

- Based on micro-detonator technology developed at NSWC IHEODTD
 - Demonstrated to TRL6 in 40 mm Grenade configuration
- Initiator fabricated onto the cap chip
 - Vaporizing metal foil bridge
- Pressed silver azide pellet assembled with the MEMS S&A chip
- Silver azide drives a flyer to initiate a lead
- Lead make 90° turn and initiates a booster
- Energetic components packaged in a metal fixture that is attached to an electronic PCB



μDetonator Package

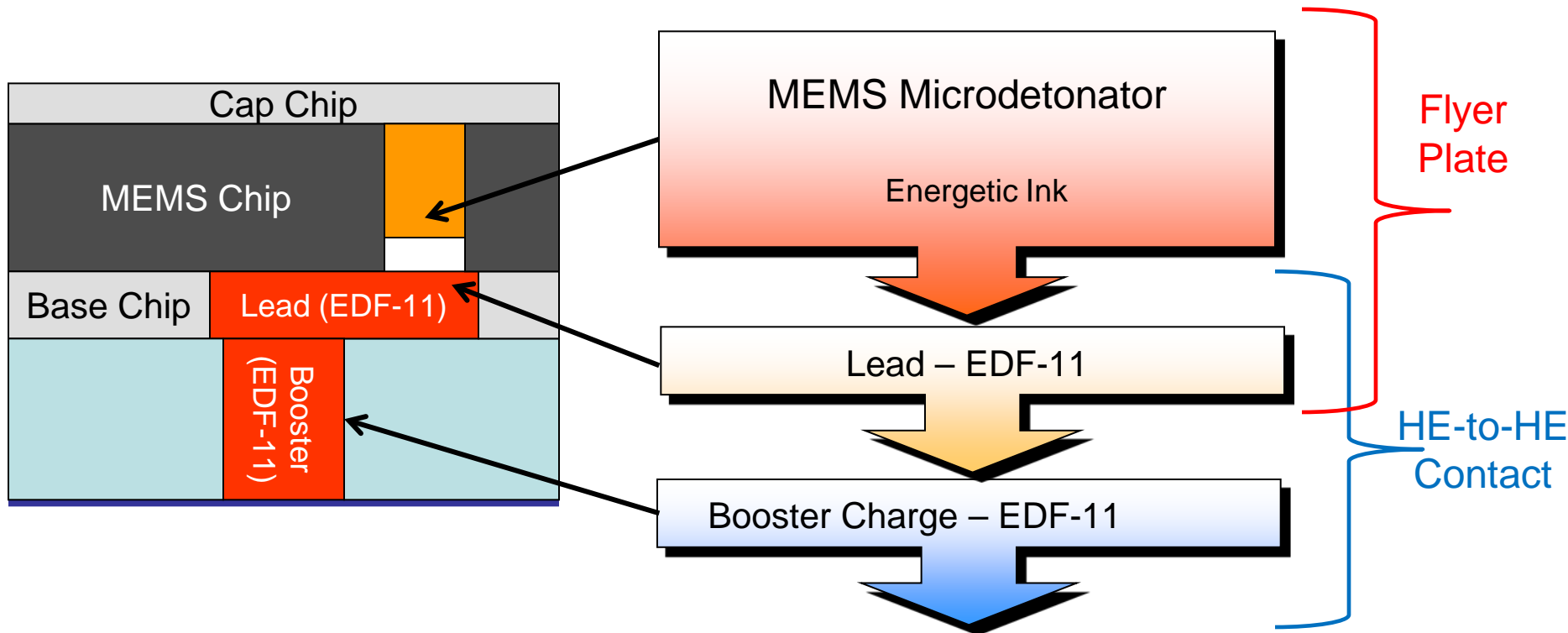
Navy Explosive Train (Basics)



Army Explosive Train (Basics)

US Army AREDEC also has a MEMS Fuze effort.

Uses LIGA metal MEMS processes.



Both detonators use stainless steel flyer plates

Explosive Train Reliability

- MEMS intentionally pushes the lower limits of explosive component size. We want the smallest size detonators and leads that will work reliably.
- Target programs have strict reliability requirements. This is particularly true for HRDR which must comply with OSD's policy of >99% reliability for cluster munitions.

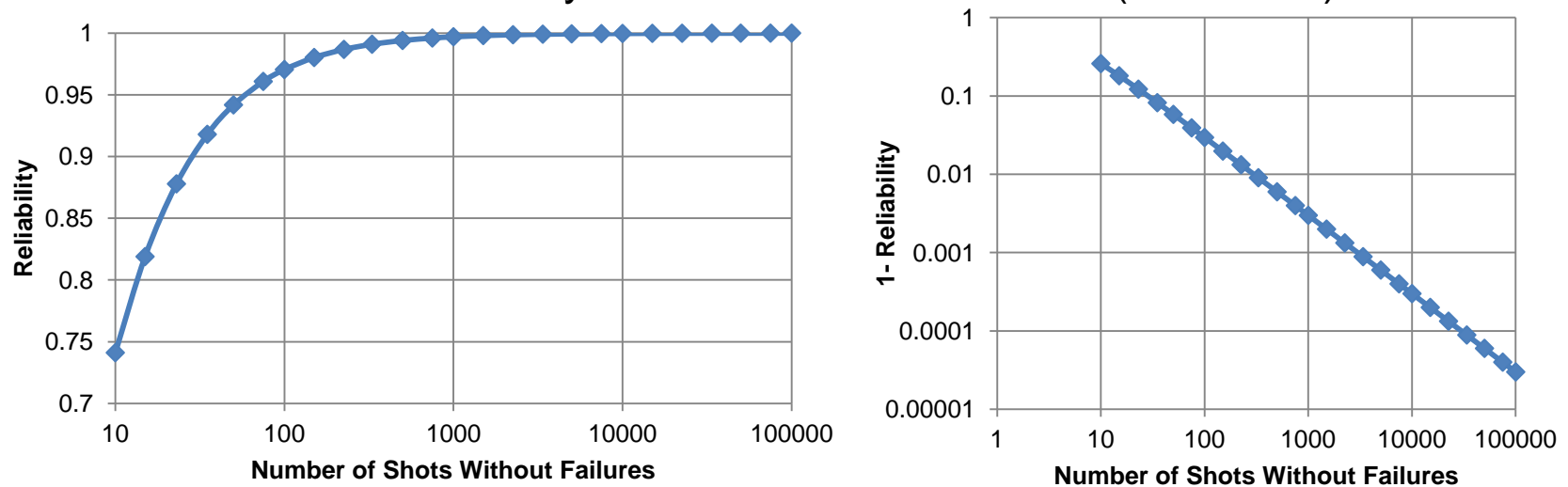


Brute force methods

Brute force demonstrations requires excessive number of shots to prove reliability.

99.9% Reliability @ 95% CL: 3000 Shots

Binomial Reliability at 95% Confidence Level (one sided)



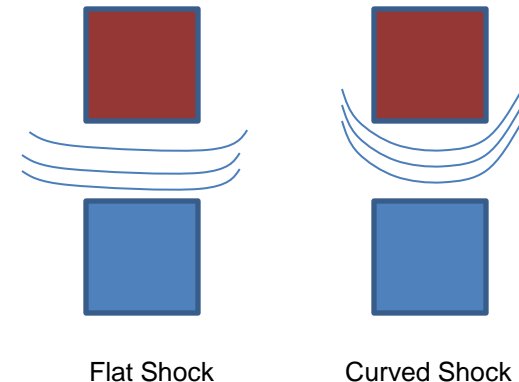
100 shot test series only demonstrates reliability to 97% (@ 95% CL)

Background – Traditional Estimation Methods

Traditional Reliability Methods have imposed penalties on the system. These penalties are large enough to produce an observable failure rate. Reliability is obtained by extrapolating to zero penalty.

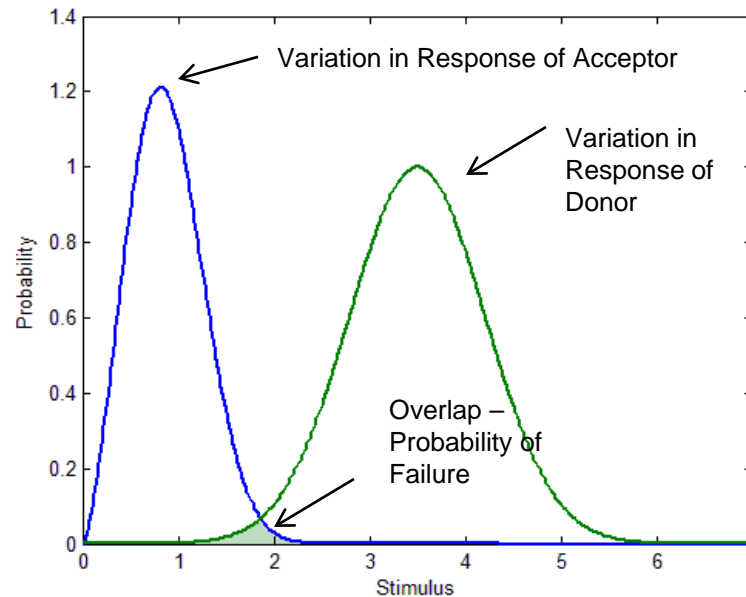
Penalties take the form of gaps (Varigap testing), reductions in donor output either through reducing its density or using less powerful explosives (Varidrive testing) or using less sensitive acceptor explosives (Varicomp testing).

All of these methods are problematic at the MEMS scale. Varidrive and Varigap change the shock curvature generated. Changes to explosives in Varidrive and Varicomp are not advisable since MEMS systems are near critical diameter.



Background – A New Approach

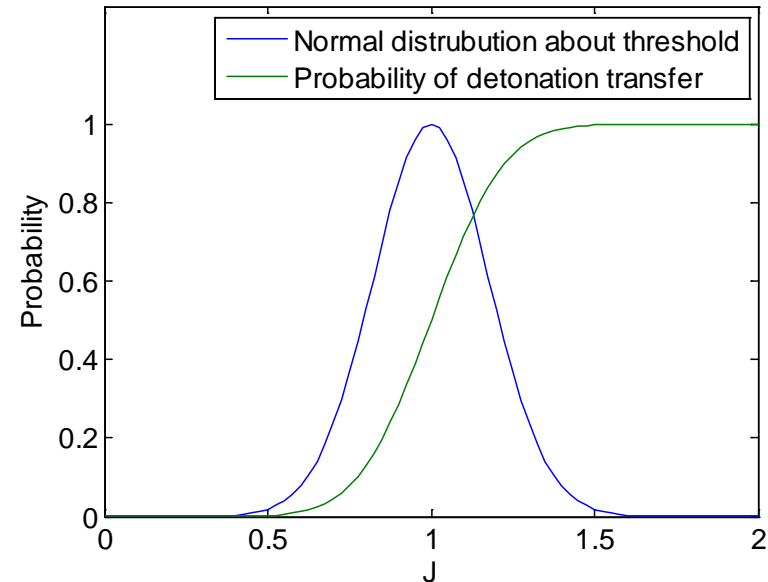
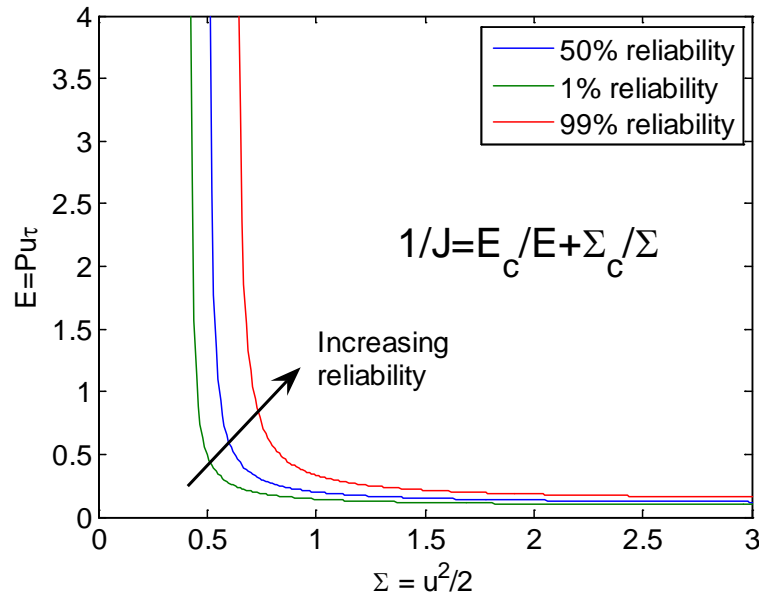
- Separate response of donor and acceptor at each interface.



- Data can better be used to evaluate a family of similar designs.
- Data also provides more insight into the system and can be used to optimize design

Background – Probabilistic Hugh James Space

Hugh James formalism can be used to map out statistical response of acceptor explosive

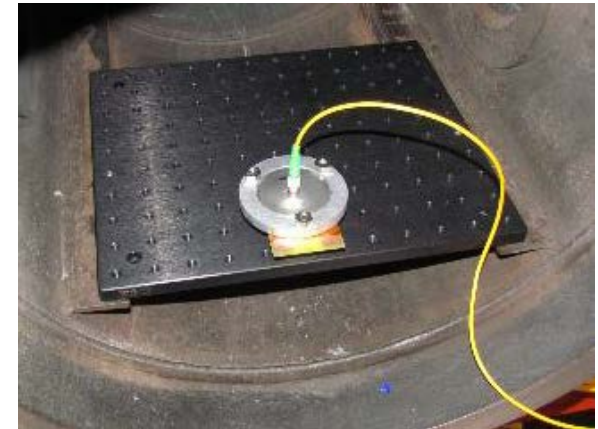
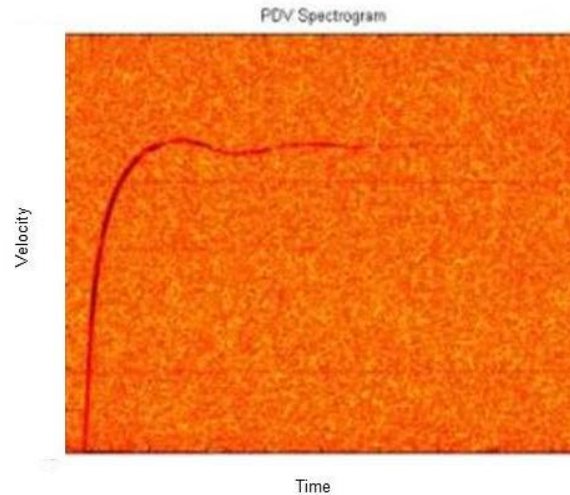
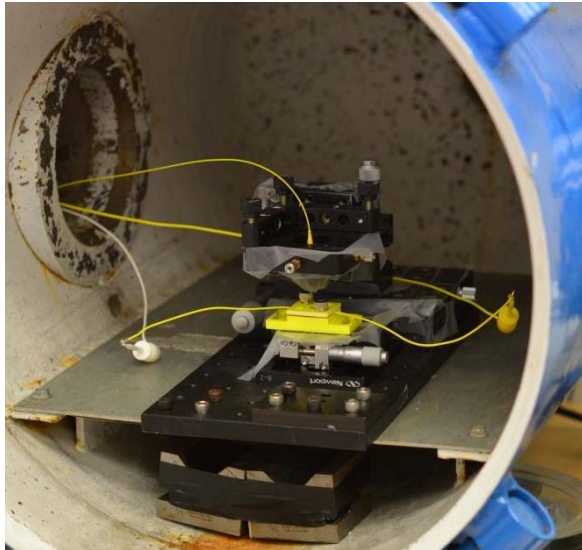


E_c (critical minimum energy) & Σ_c (critical minimum 'power') are defined by the acceptor explosive material. E & Σ can be calculated from variable flyer and gap tests and inherent explosive properties.

These methods were developed at AWE and LLNL and implemented at AFRL.

Detonator Characterization

MEMS flyer velocities can be measured with PDV

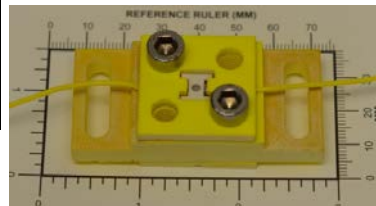
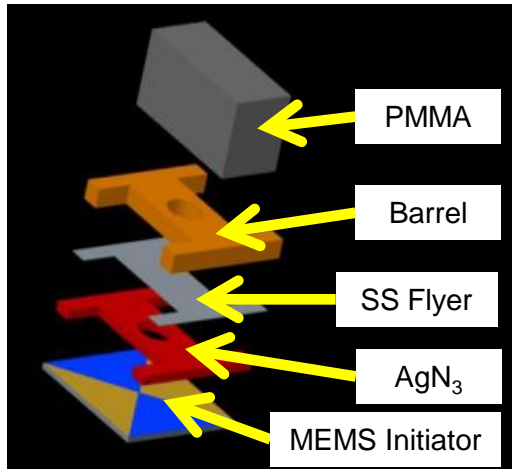
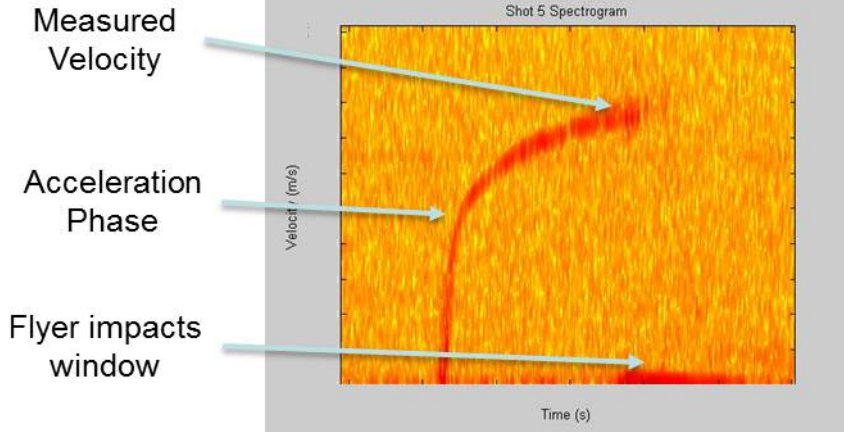


Variability will be present in any system → Need to shoot a sufficient number (100+) to fit to a statistical distribution.
Exact number of shots needed depends on how quickly tails of distribution die off.

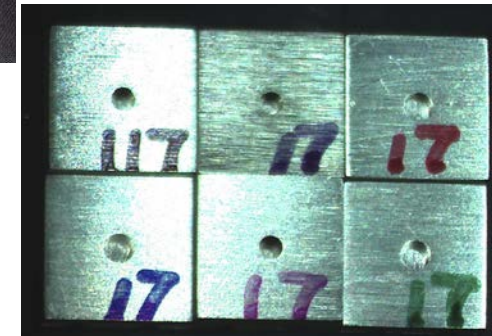
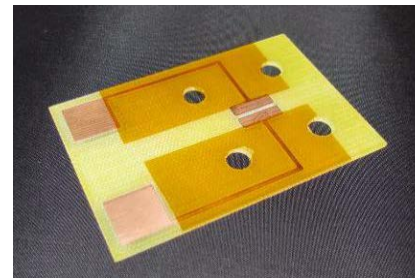
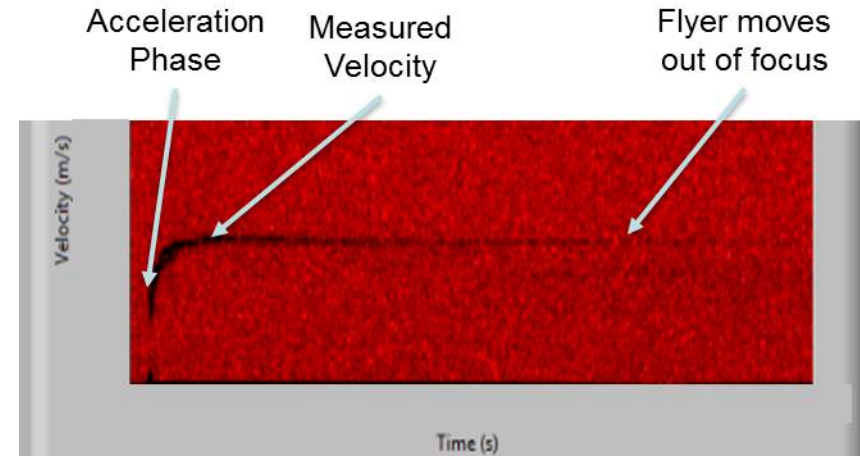
PDV system can also be used to measure pressure time histories for contact detonation interfaces.

PDV Measurements

Navy

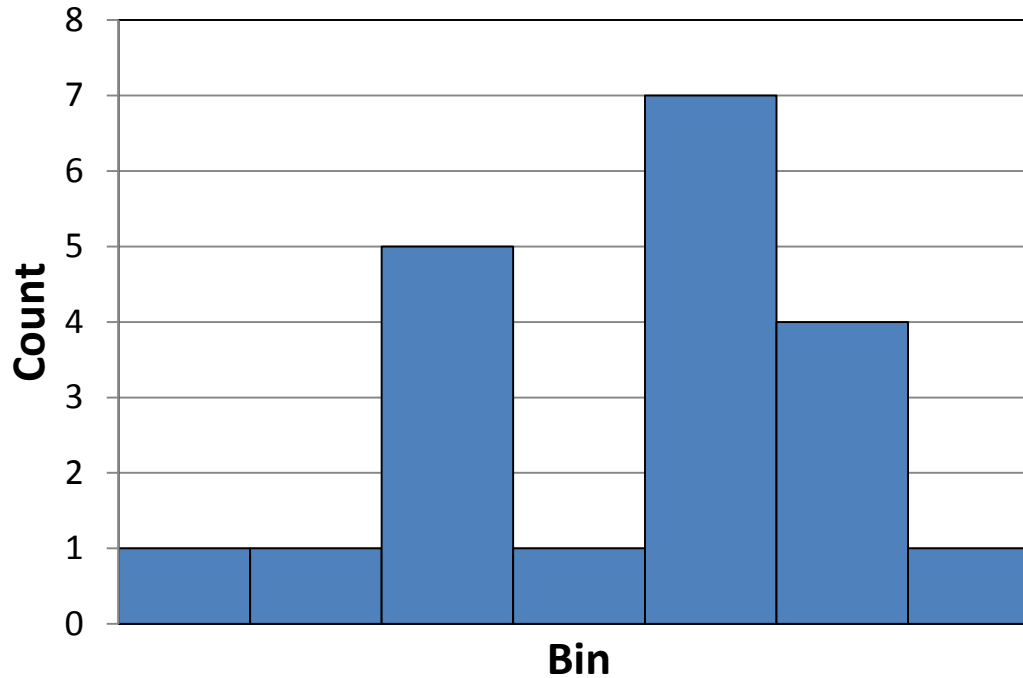


Army



PDV Results - Navy

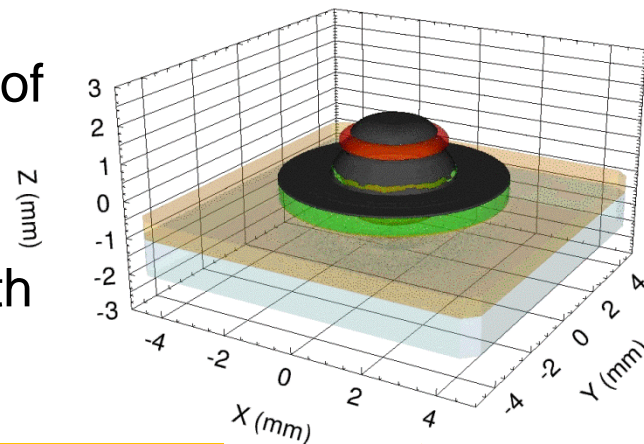
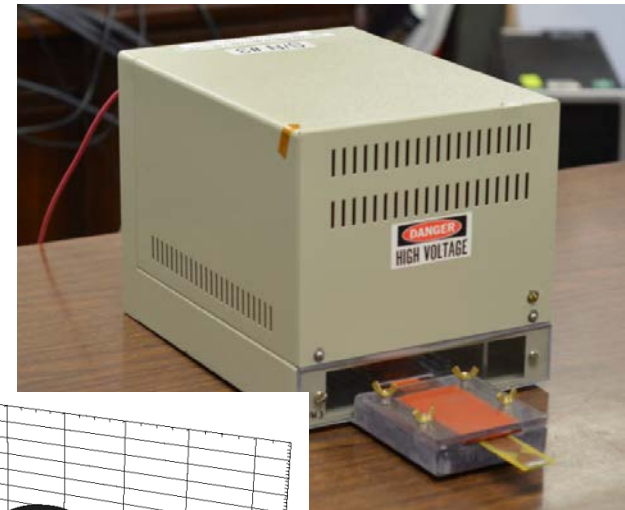
20 shots analyzed to date. Additional shots planned.



Standard deviation 4.7% of mean value.

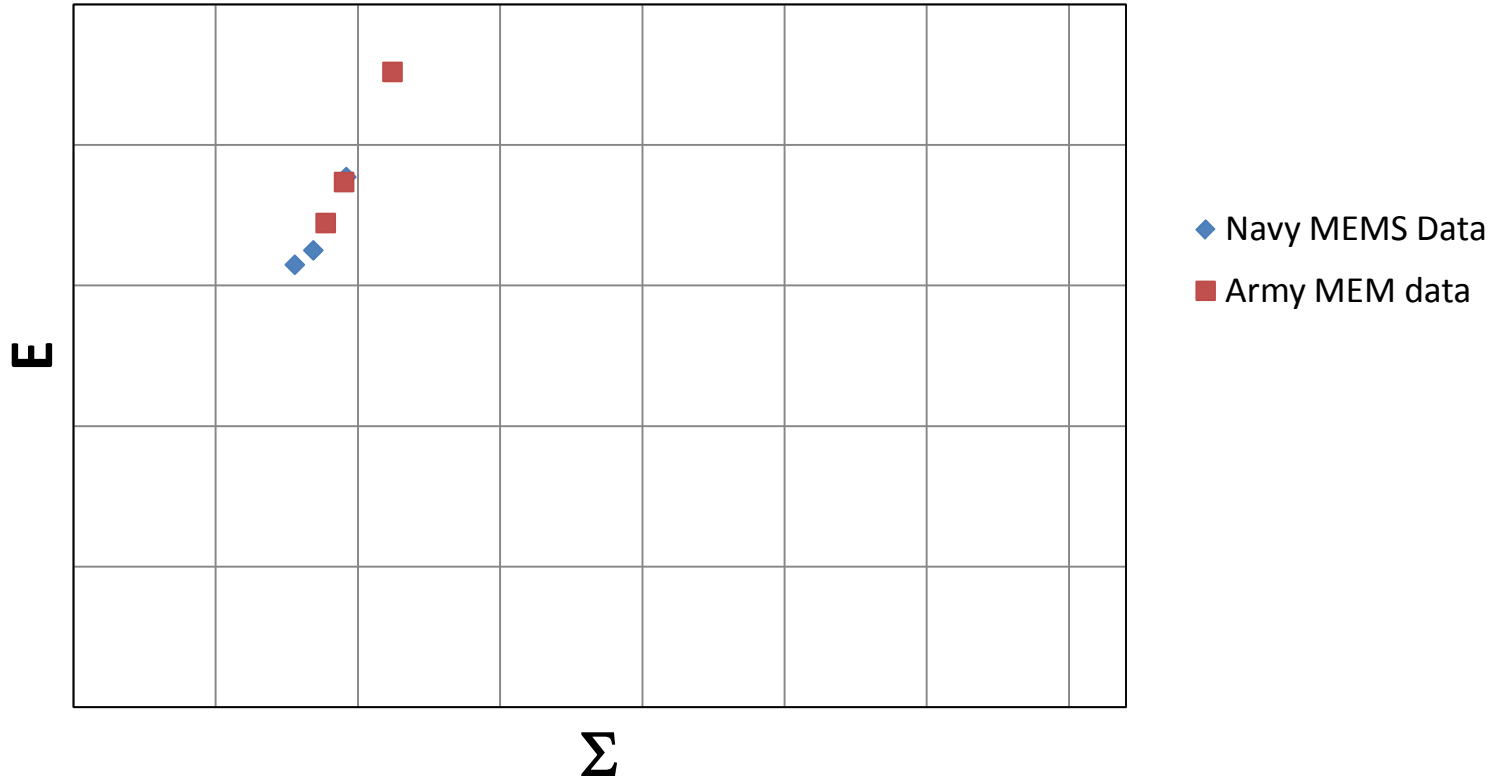
EDF-11 HJ Parameterization

- Electric gun will be used to make EDF-11 sensitivity measurements.
- Conduct threshold testing at several flyer thicknesses (0.5, 1, 2 & 3 mils Kapton)
- 1.6mm square flyer. Based on computer models of the flat section of MEMS flyer.
- Limited number of previous measurements at EFI relevant length scales, but spot size dependent.



Need to have Hugh James Initiation data at MEMS scales

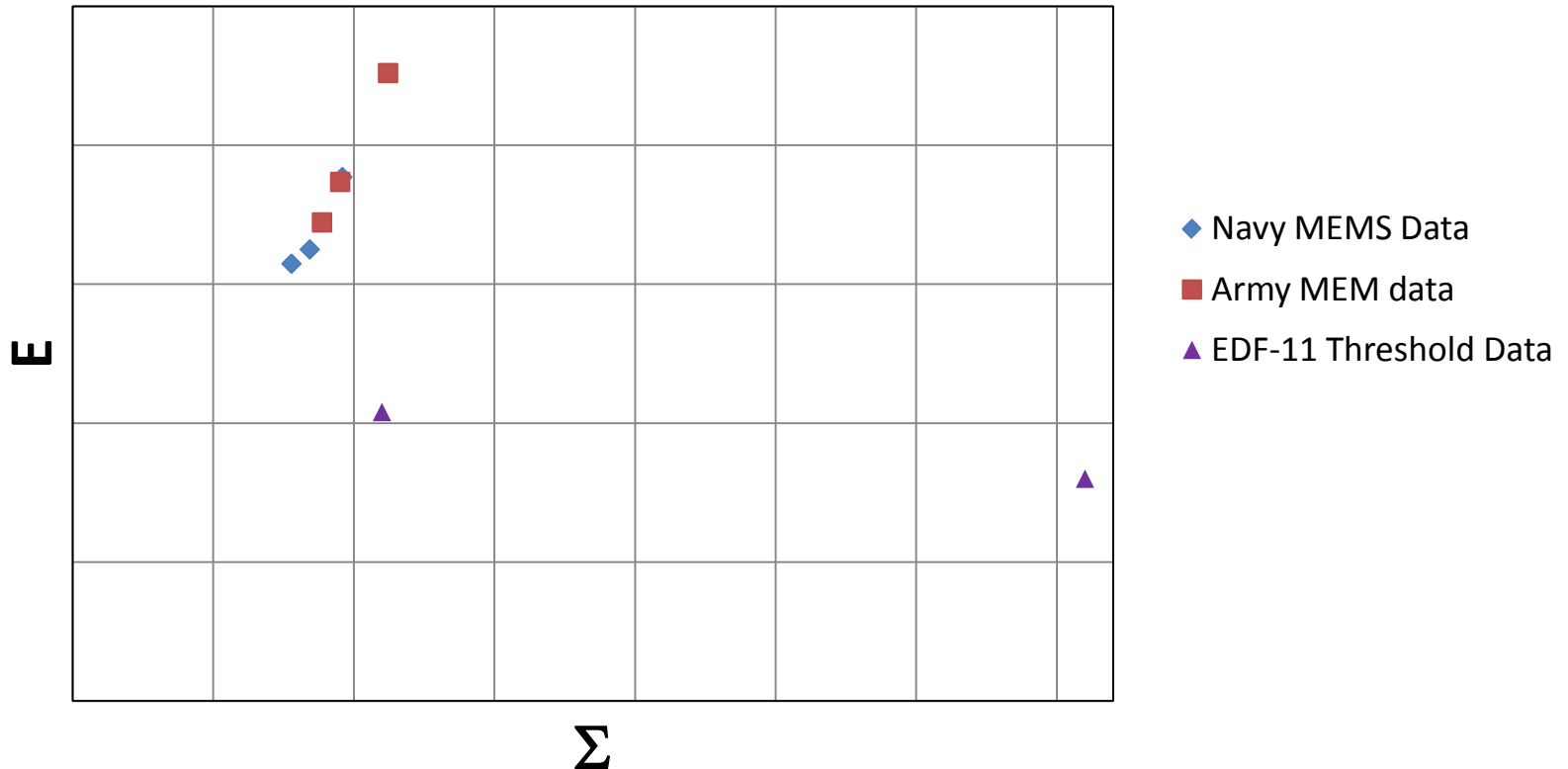
Flyer Measurements in HJ Space



Remember: the Navy design uses a larger diameter flyer

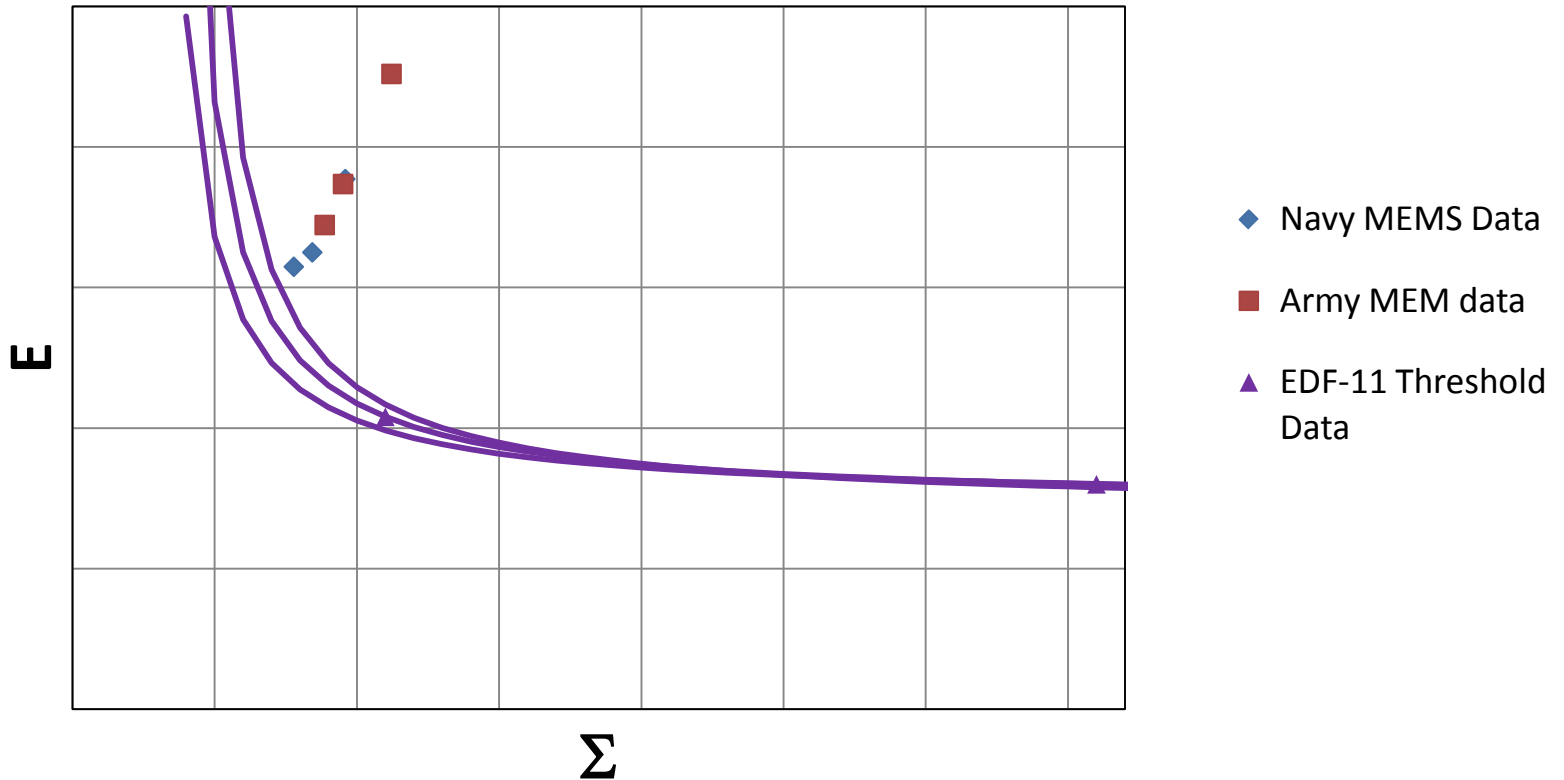
Previous EDF-11 Threshold Measurements

LLNL has made previous threshold measurements on EDF-11



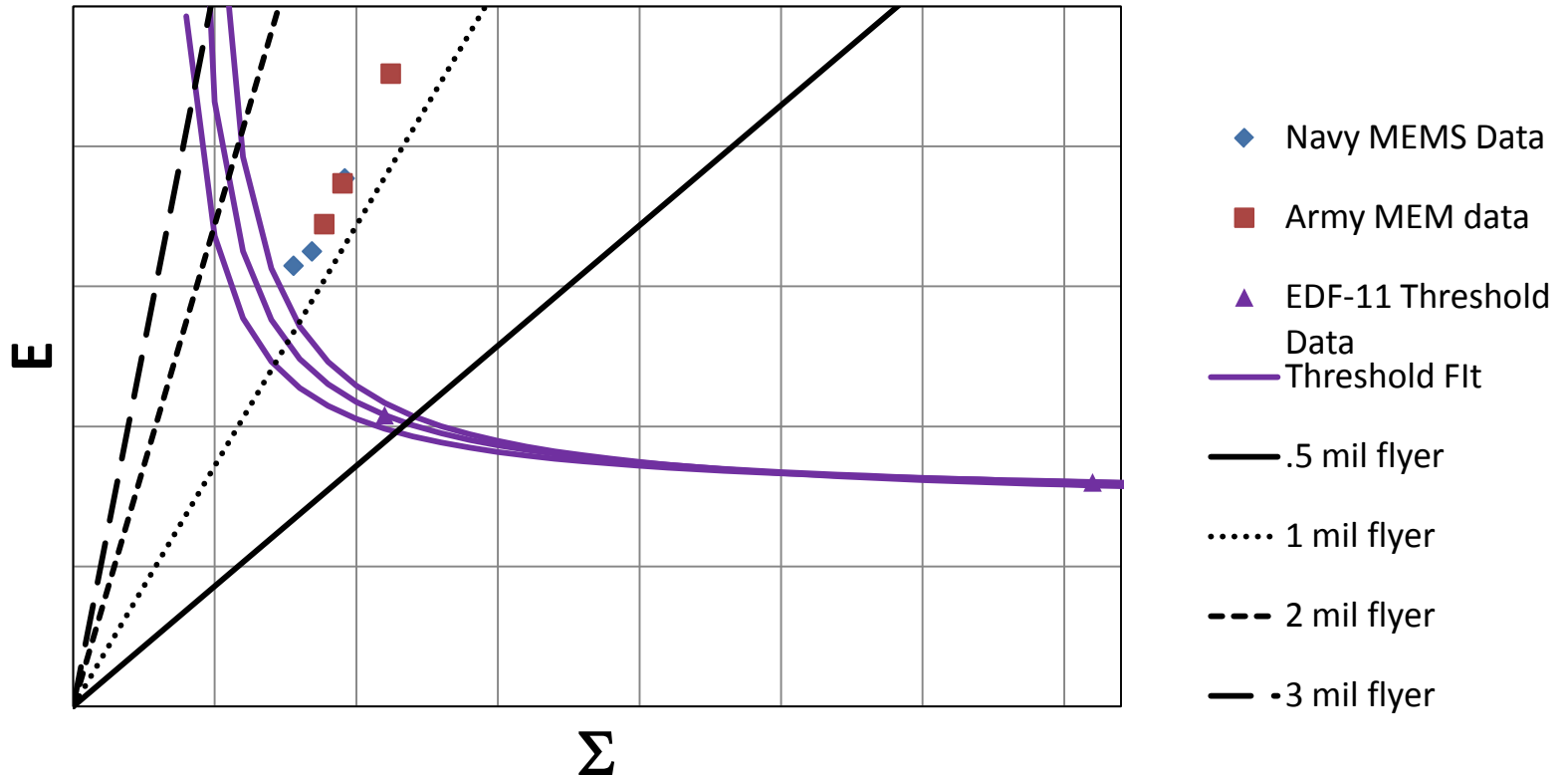
These measurements were made at EFI length scales, and would be lower at larger spot sizes.

Fit ill-defined



These two points do not well define a hyperbolic fit.

Proposed Measurement Paths



Each flyer thickness defines a path through HJ space.

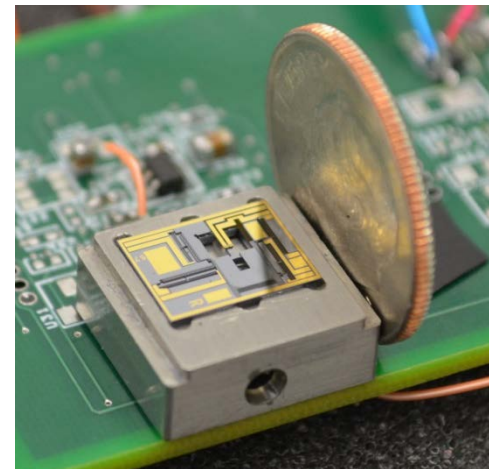


Upcoming

- Finish detonator experiments and fit distribution function
- Multiple threshold test series of EDF-11 in a MEMS relevant Hugh James Space
 - 0.5, 1, 2, and 3 mil thick Kapton
- Transfer lead output test series
 - PDV measurements of lead output

Conclusions

- New explosive trains require new methods of analysis.
- These new methods can better aid intelligent design.
- We believe we have a reasonable path to demonstrate reliability.
- Both the Navy and Army are committed to ensuring that MEMS fuzing achieves the highest degrees of reliability possible.





Acknowledgments Section:

Thanks to the Joint Fuze Technology Program (JFTP) for funding this work.

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Thanks to those who have helped work on the project:

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Questions?