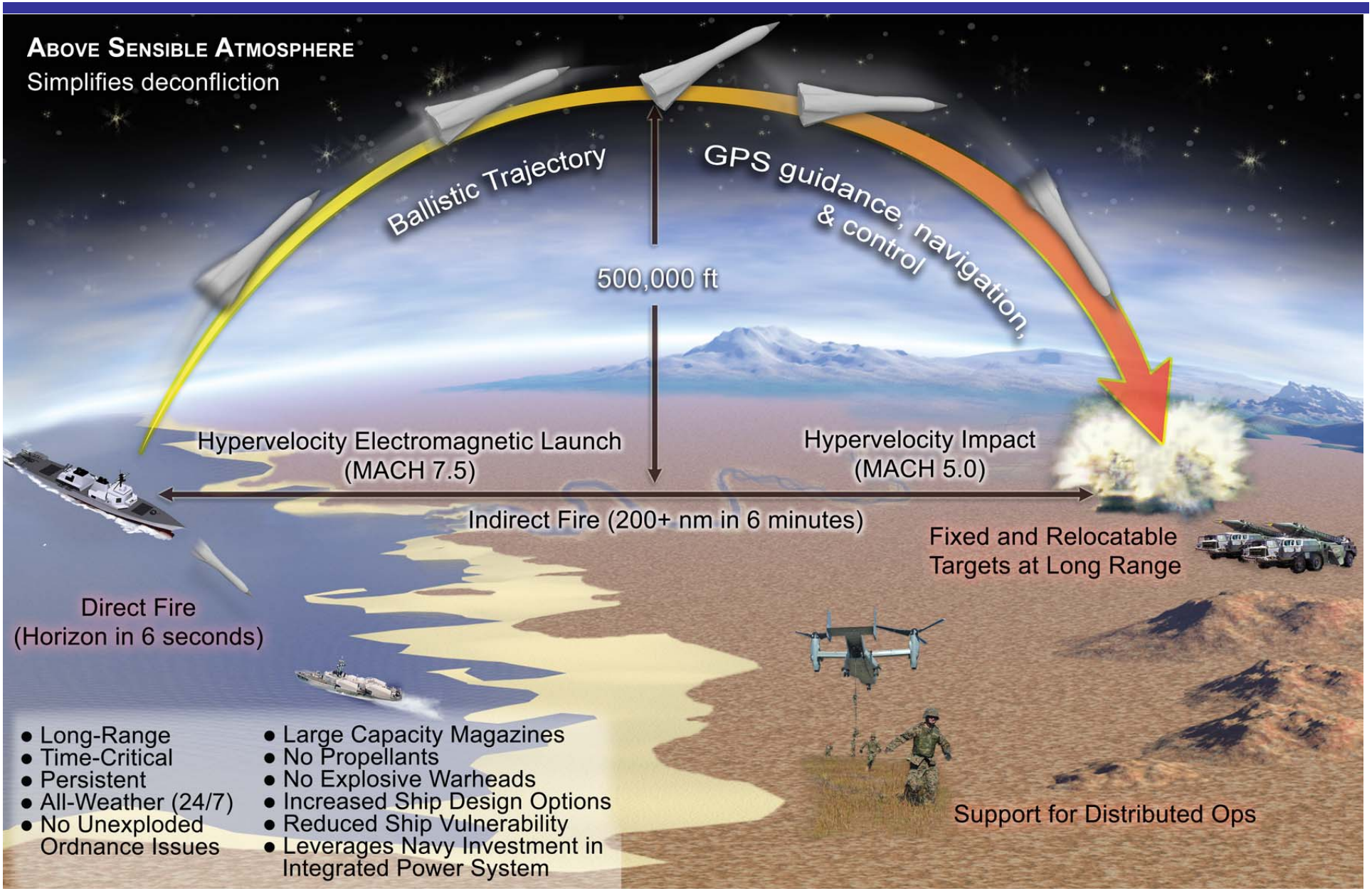
Revolutionary Research . . . Relevant Results

NAVSEA WARFARE CENTERS DAHLGREN

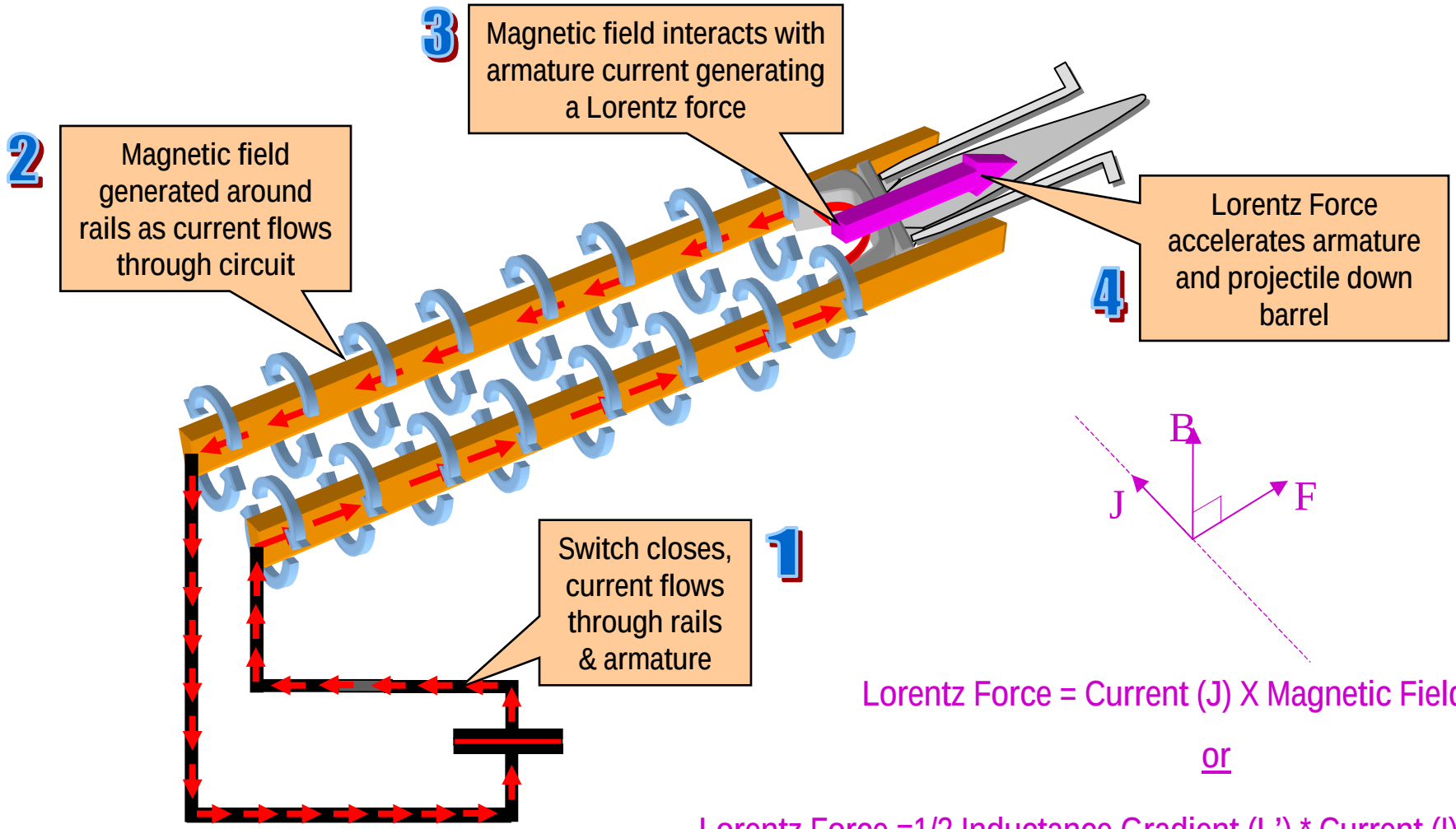
Test and Evaluation of Electromagnetic Railguns

NDIA T&E Conference
March 12-15, 2007

EM Railgun – Game Changing



How it Works

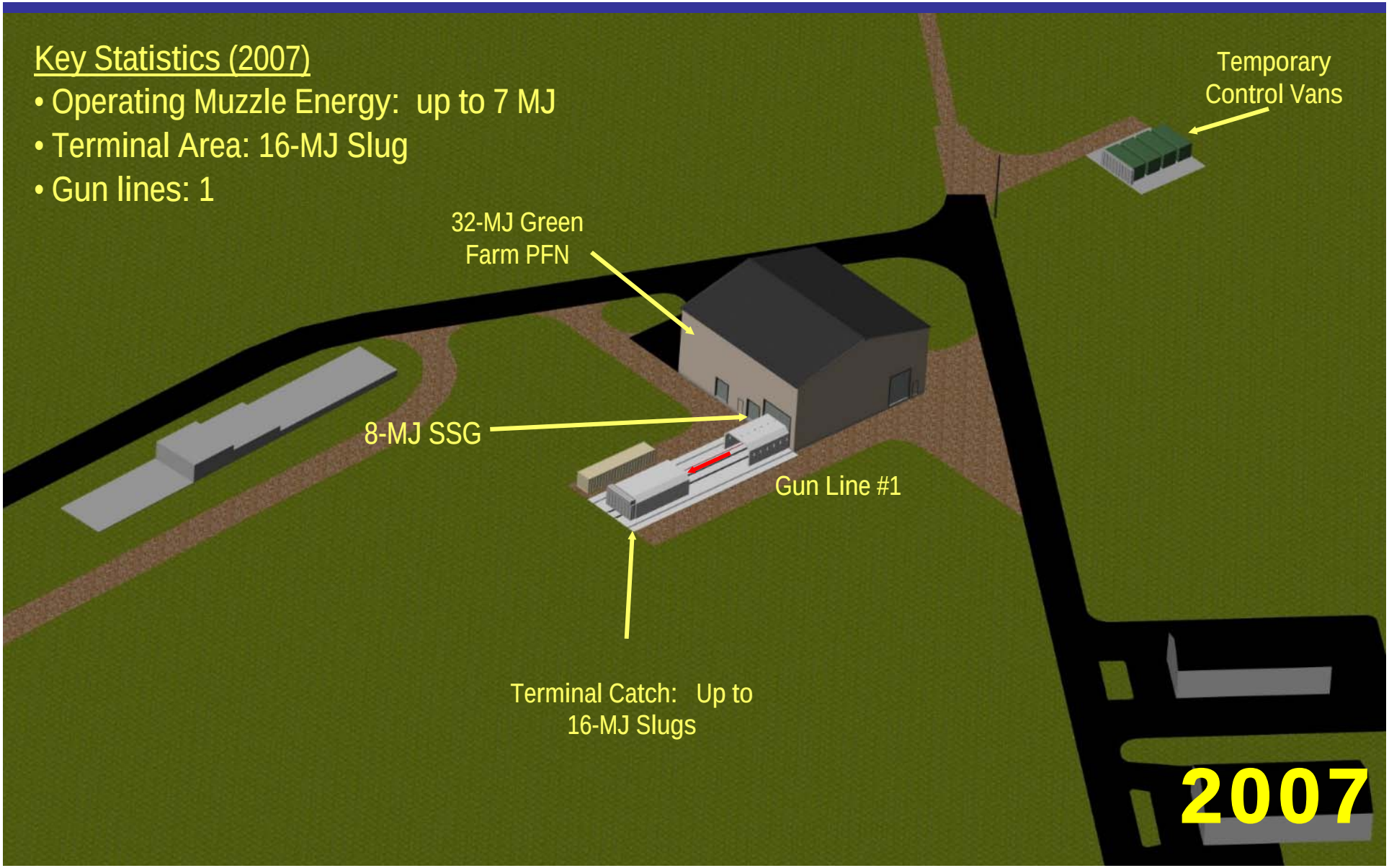


Lorentz Force = Current (J) X Magnetic Field (B)

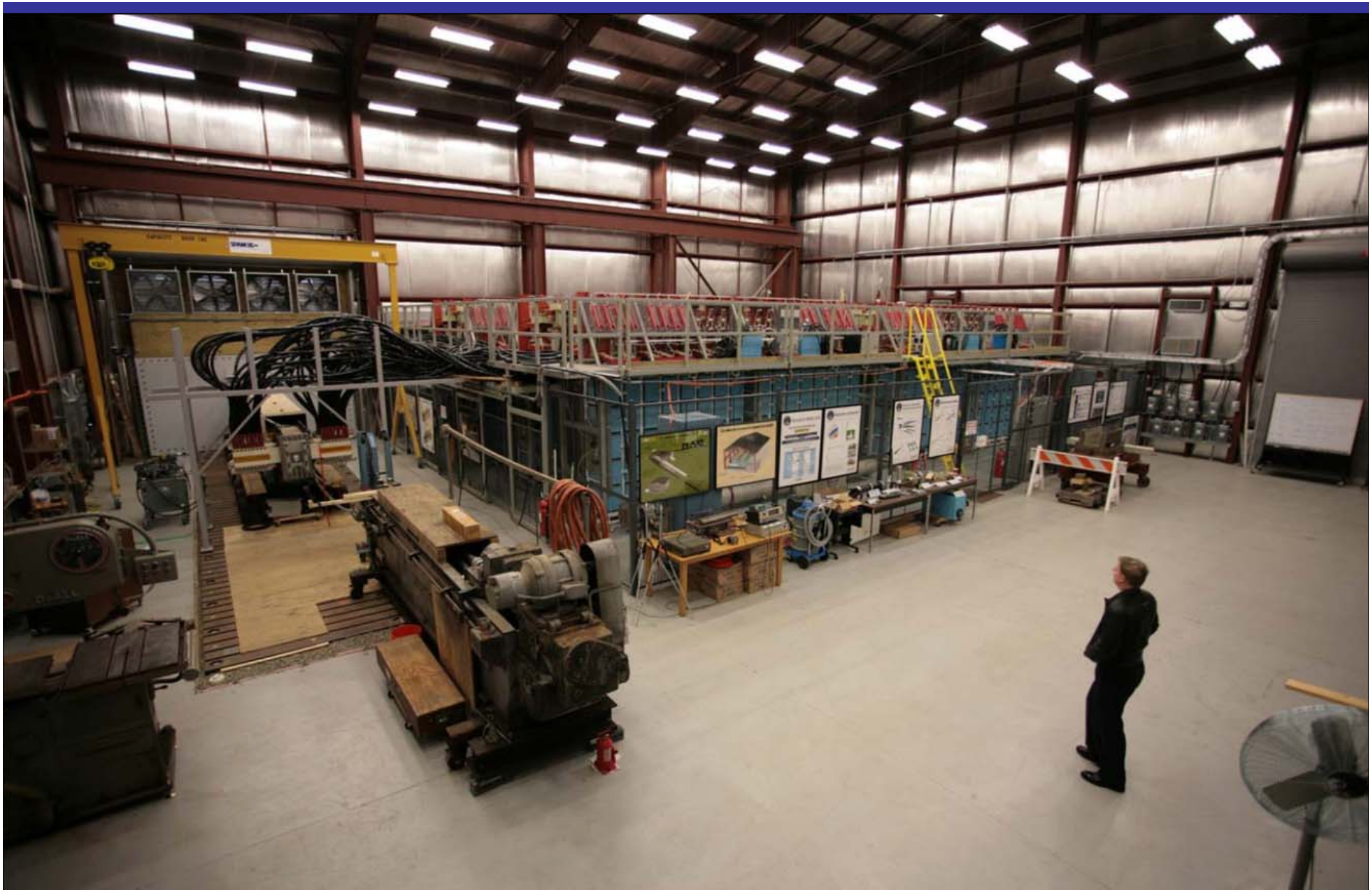
or

Lorentz Force =1/2 Inductance Gradient (L') * Current (I)^2

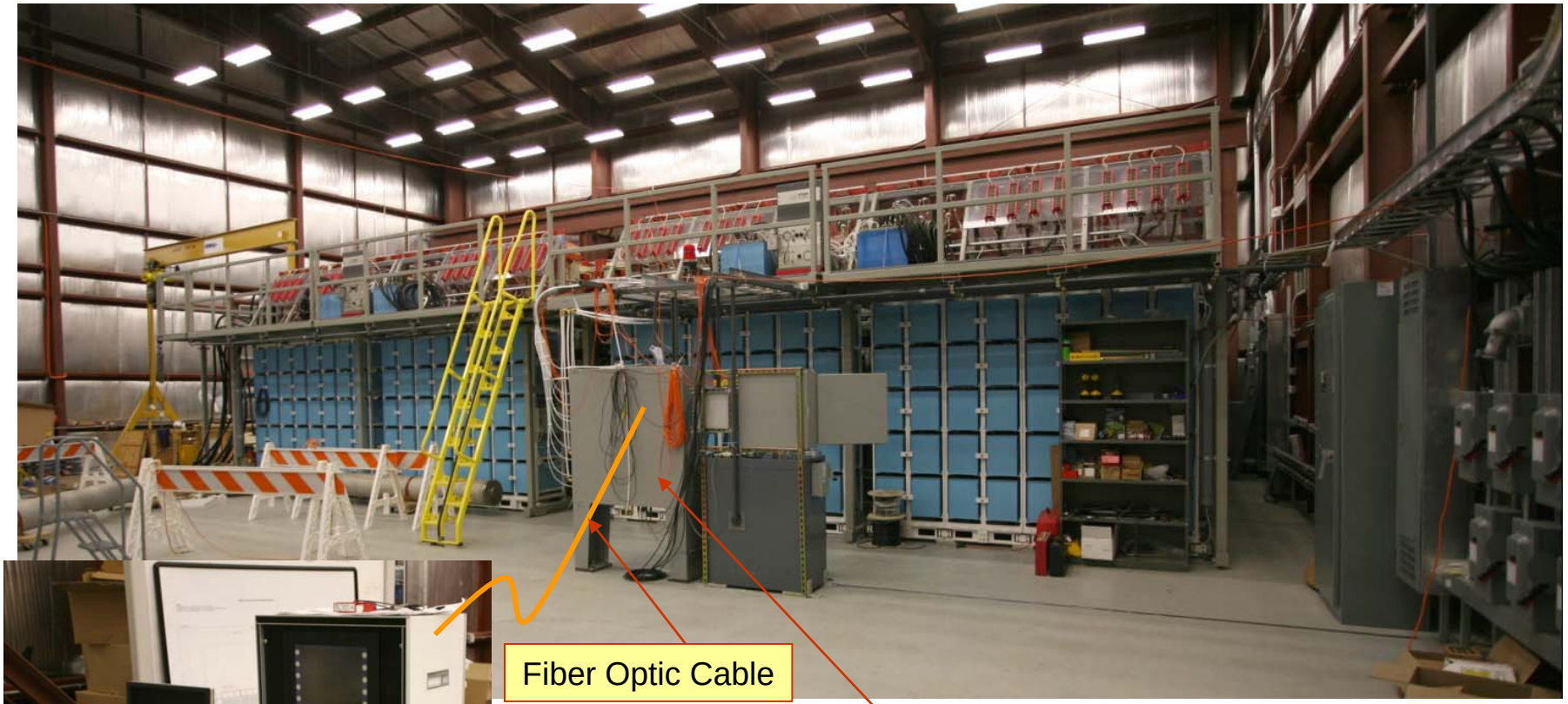
Current Facility



Current Facility



32-MJ PFN



Fiber Optic Cable

Controls Cabinets

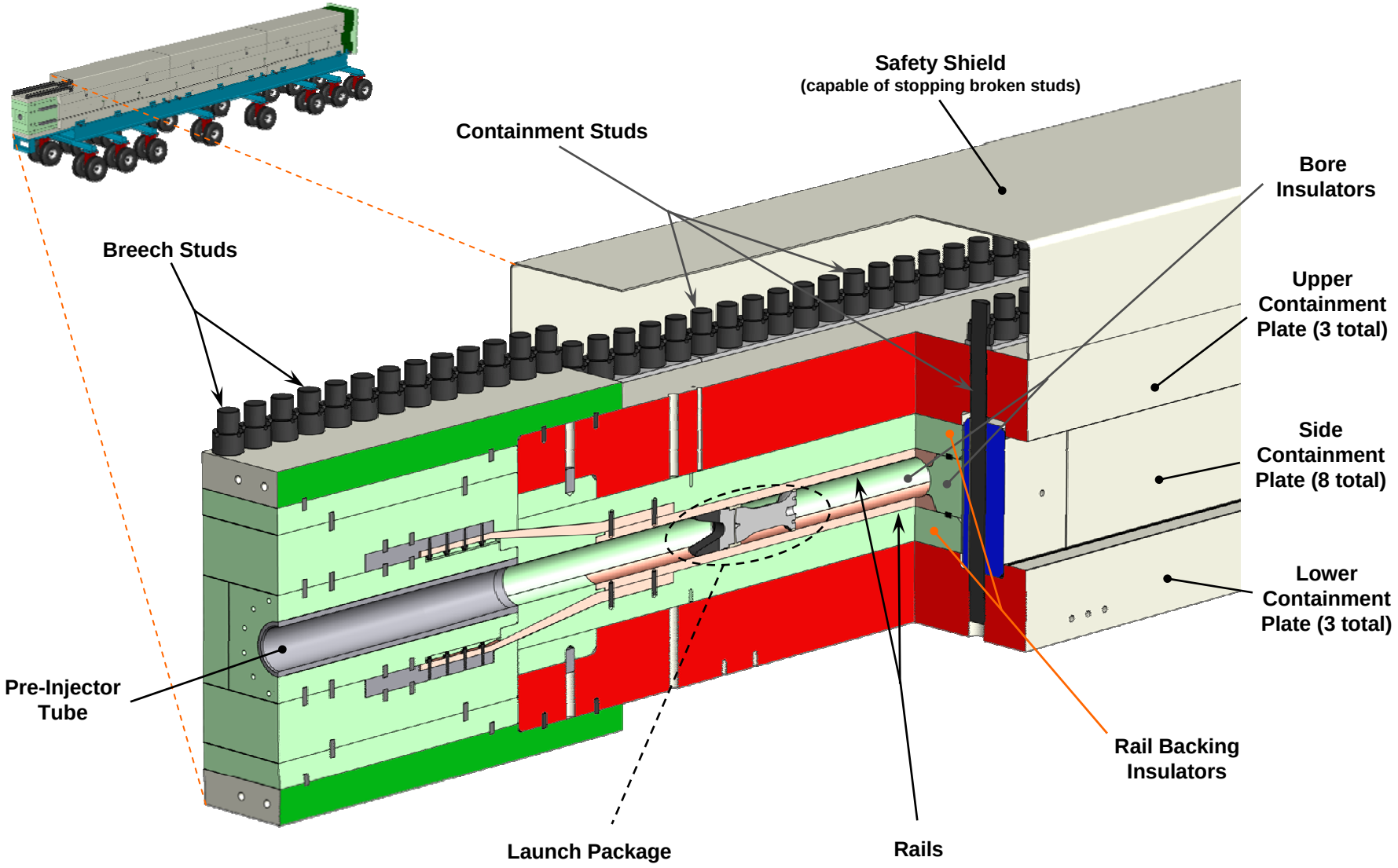
System Controller
(Located in Control Van)

Switching and Output Cables

350-MCM Coaxial Cable

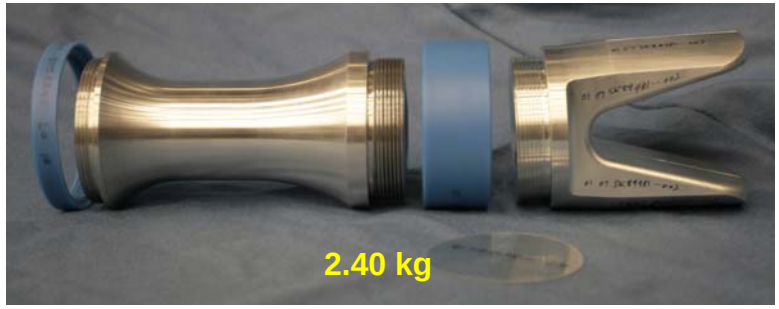
Spark Gap Switch

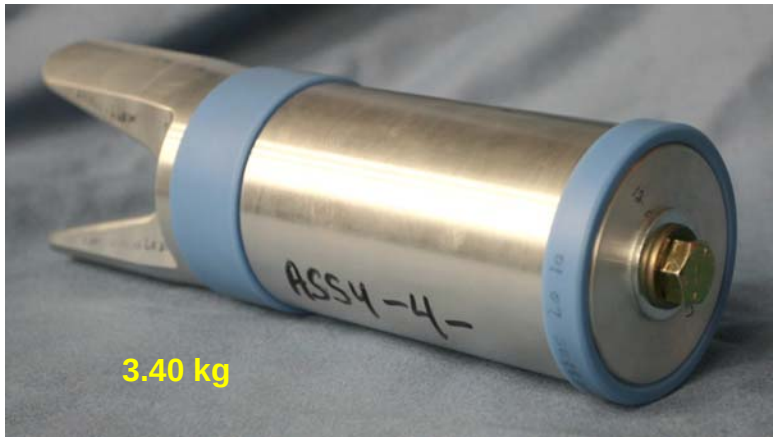
SSG Construction

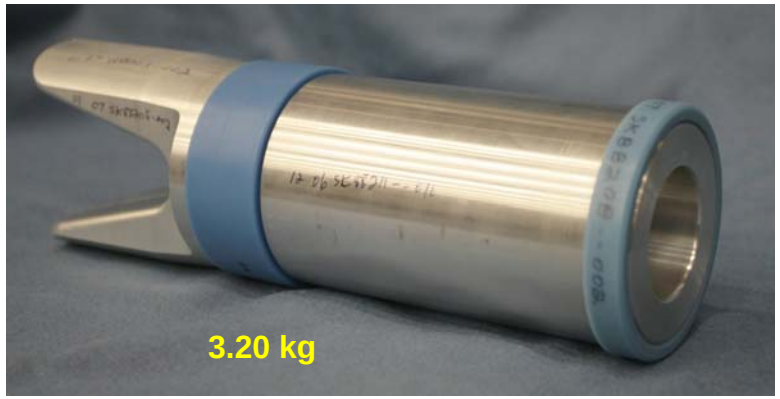


Launch Package

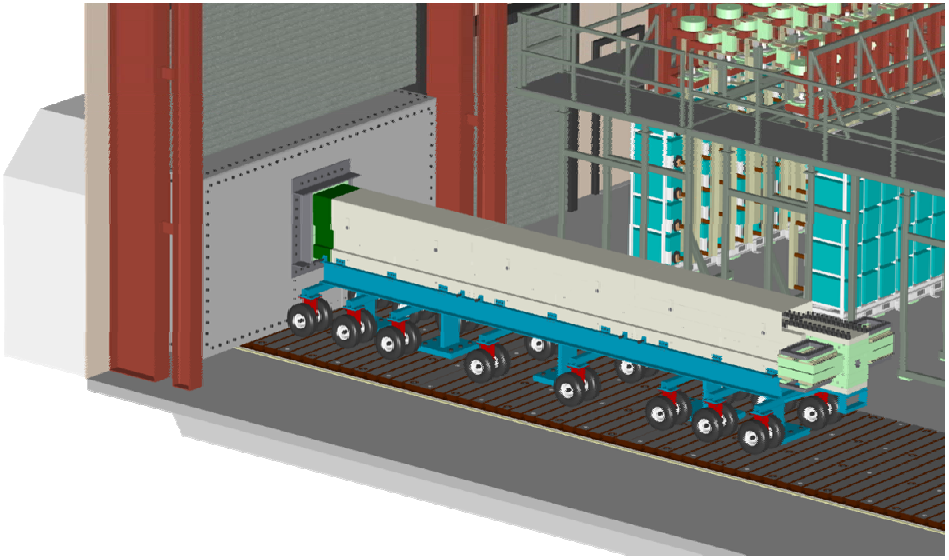
- Total Mass = 2.3-3.4 kg
- Aluminum Slug and Armature
- Nylon Bore Riders
- Design based on earlier work at Kirkcudbright and Greenfarm



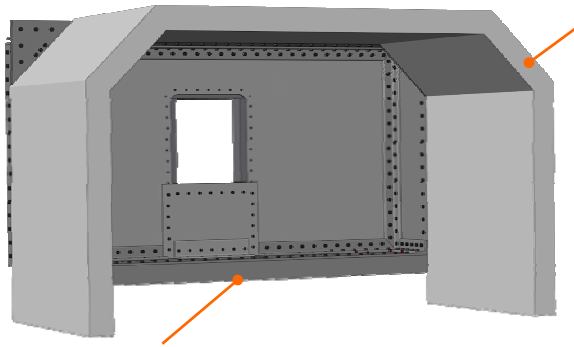




Gun - Facility Interfaces

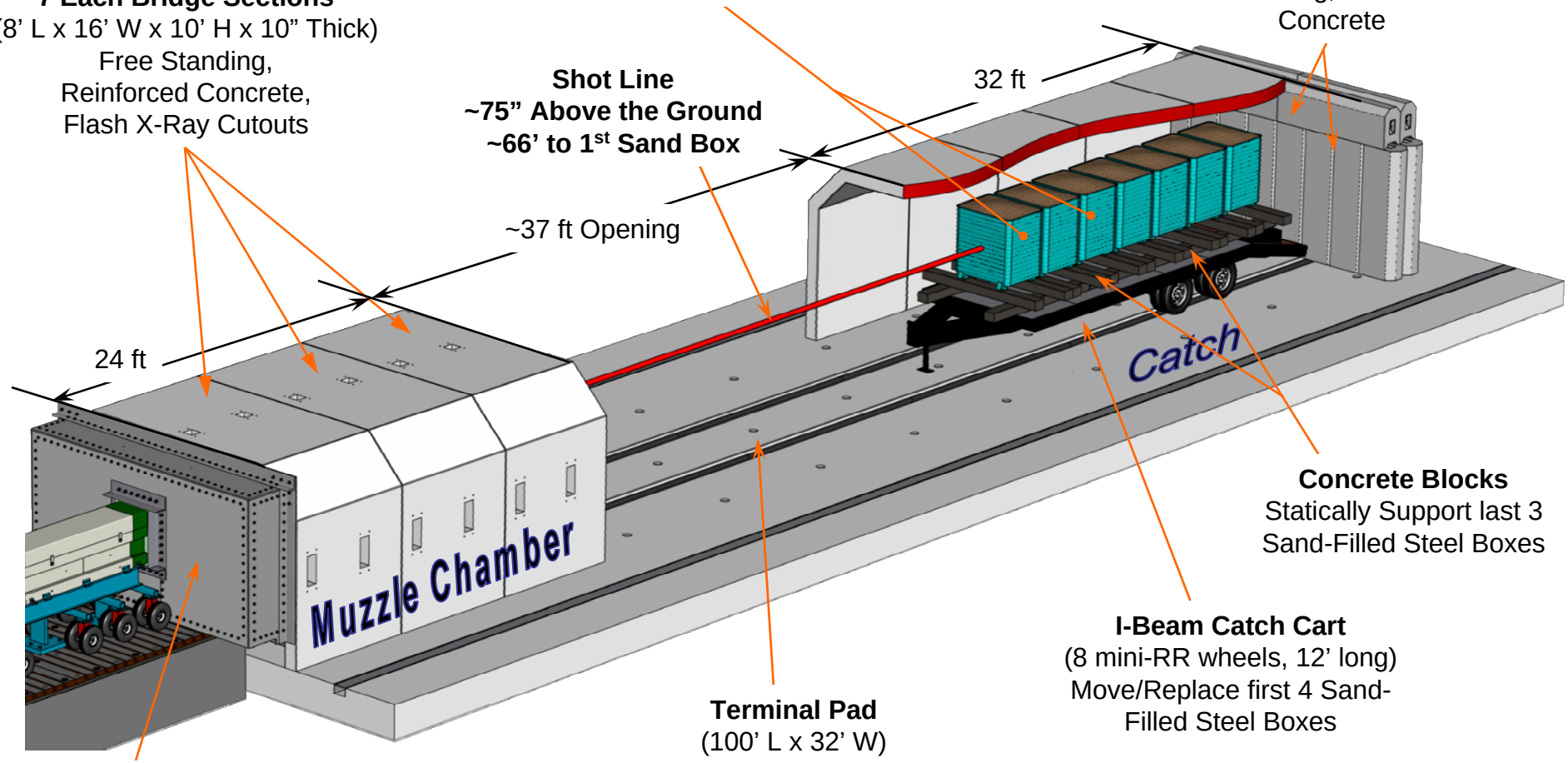


Muzzle Chamber
- 1" Thick A36 Steel Plate
- Bolts Directly to Gun Foundation
- Bolts Directly to Bridge Section
- Adaptable to Variety of Launchers



Recoil Plates
- 3" Thick A36 Steel Plate
- Bolt Directly to the Gun Foundation Plates
- Bolt Directly to Underside of SSG

Terminal Area Design



7 Each Bridge Sections
(8’ L x 16’ W x 10’ H x 10” Thick)
Free Standing,
Reinforced Concrete,
Flash X-Ray Cutouts

7 Each Sand-Filled Steel Boxes
(4’ x 4’ x 3’)
(21' of Sand Along Line of Fire)

Shot Line
~75” Above the Ground
~66’ to 1st Sand Box

20 Each NRL Shield Blocks – Double Course
(8’ L x 2.5’ W x 1.5’ Thick)
Interlocking, Reinforced Concrete

Concrete Blocks
Statically Support last 3 Sand-Filled Steel Boxes

I-Beam Catch Cart
(8 mini-RR wheels, 12’ long)
Move/Replace first 4 Sand-Filled Steel Boxes

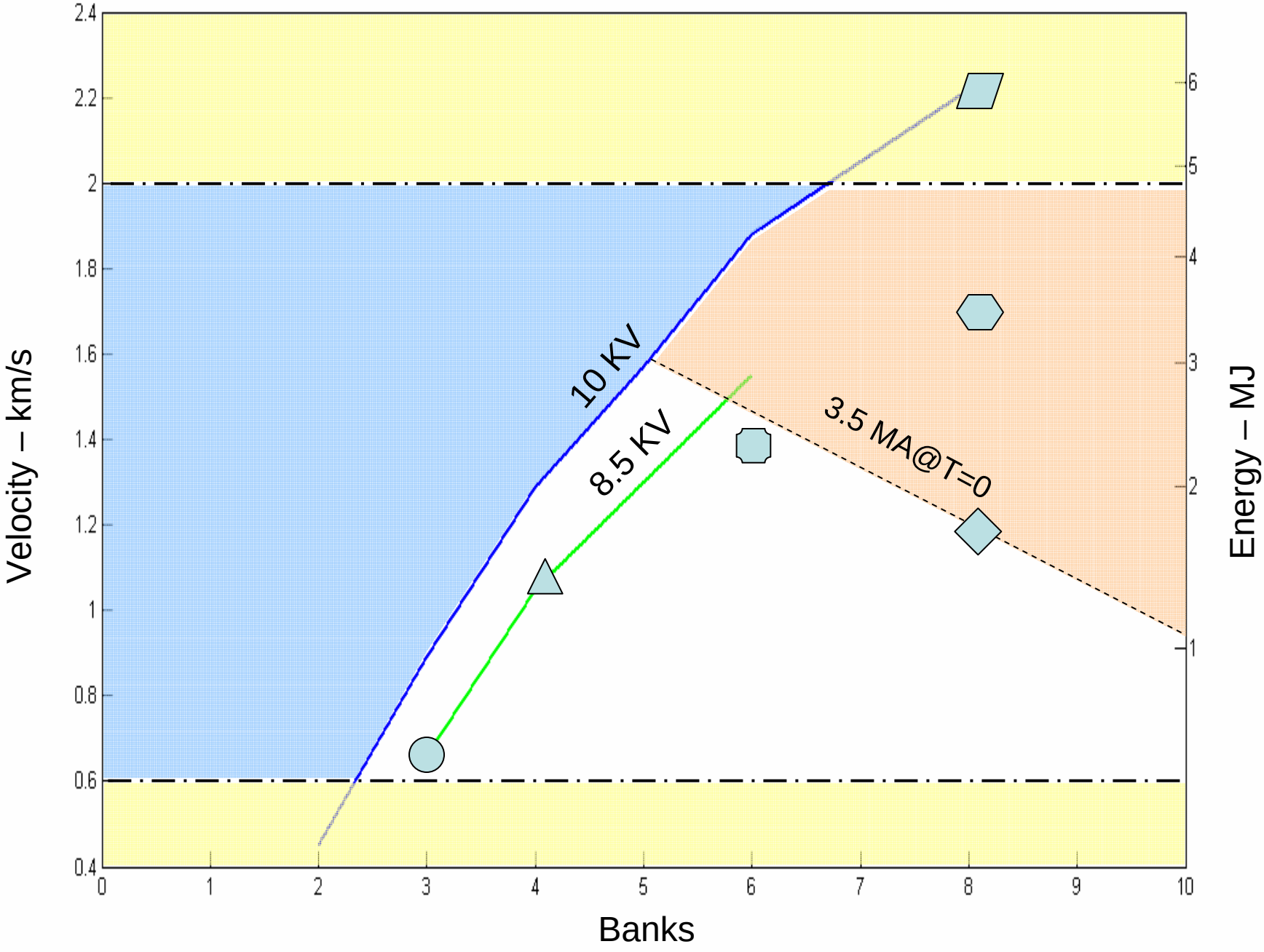
Terminal Pad
(100’ L x 32’ W)
Standard Gage Crane Rails,
3 Rows of Tie Downs every 8’,
2 Instrumentation Troughs

Steel Muzzle Chamber

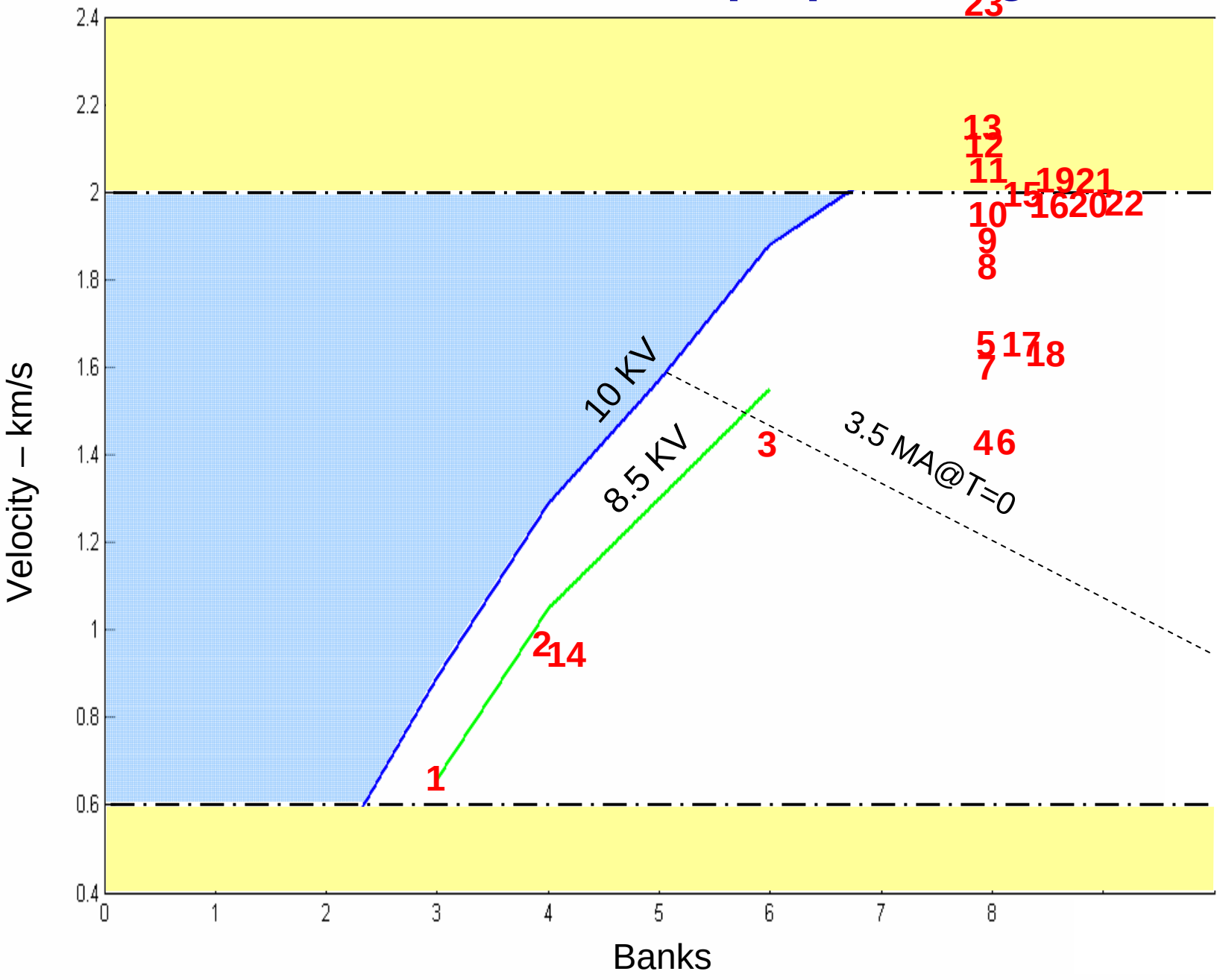
Catch Component

- 7 Each Sand-Filled Steel Boxes, Total of 14 On Hand
  - 4 ft x 4 ft x 3 ft
  - Wt 5740 lbs when Filled
  - 21 ft of Sand along Line of Fire
  - Open Top, Stackable, 4-Way Forklift Entry
- I-Beam Catch Cart
  - Support the First 4 Sand Boxes to Allow Quick Movement & Replacement
  - Runs on Crane Rails Using Mini-Railroad Wheels
- Concrete Blocks
  - Support the Last 3 Sand Boxes

Power Ramp Up Testing Plan (2.4kg)



Actual Power Ramp Up Testing



Test Results

Video of Test Results

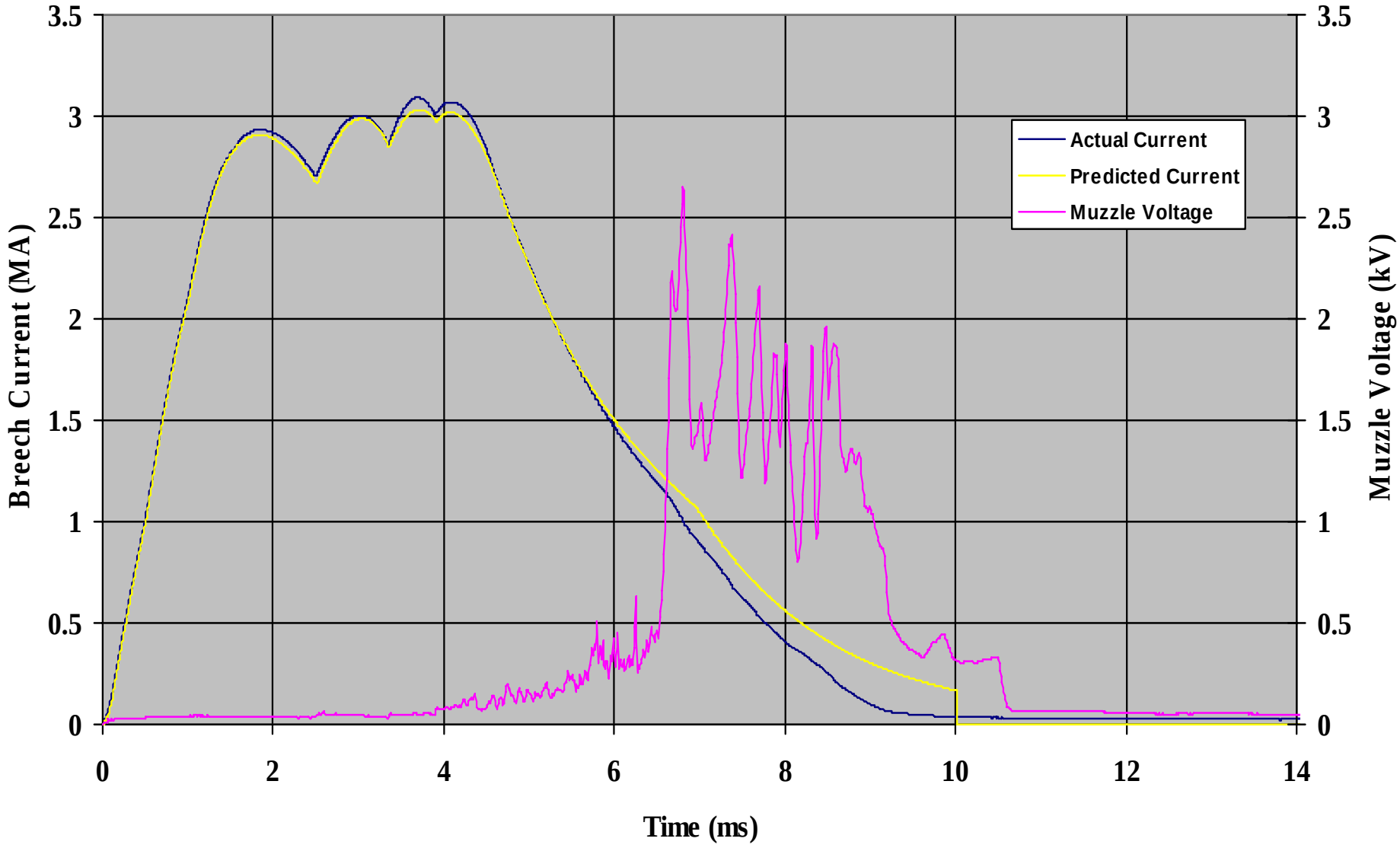
Test Results

Shot	Mass (KG)	Charge Voltage (KV)	Peak Current (MA)	Muzzle Velocity (m/s)	Muzzle Energy (MJ)	Efficiency (%)
1	2.4	8.2	1.7	837	0.841	12.6
2	2.41	8.18	1.8	1117	1.5	16.9
3	2.416	7.85	2.35	1560	2.94	24.5
4	2.456	6.25	2.79	1540	2.91	28.3
5	2.456	6.85	2.83	1760	3.8	30.7
6	3.29	6.9	3	1500	3.7	29.4
7	3.29	7.68	3.13	1680	4.64	29.8
8	3.288	8.3	3.09	1850	5.63	30.9
9	3.29	8.6	3.1	1920	6.06	30.9
10	3.29	8.9	3.09	1990	6.51	31
11	3.288	9.2	3.1	2070	7.04	31.4
12	3.346	9.68	3.13	2117	7.5	30.2
13	3.2	9.65	3.09	2146	7.38	29.8

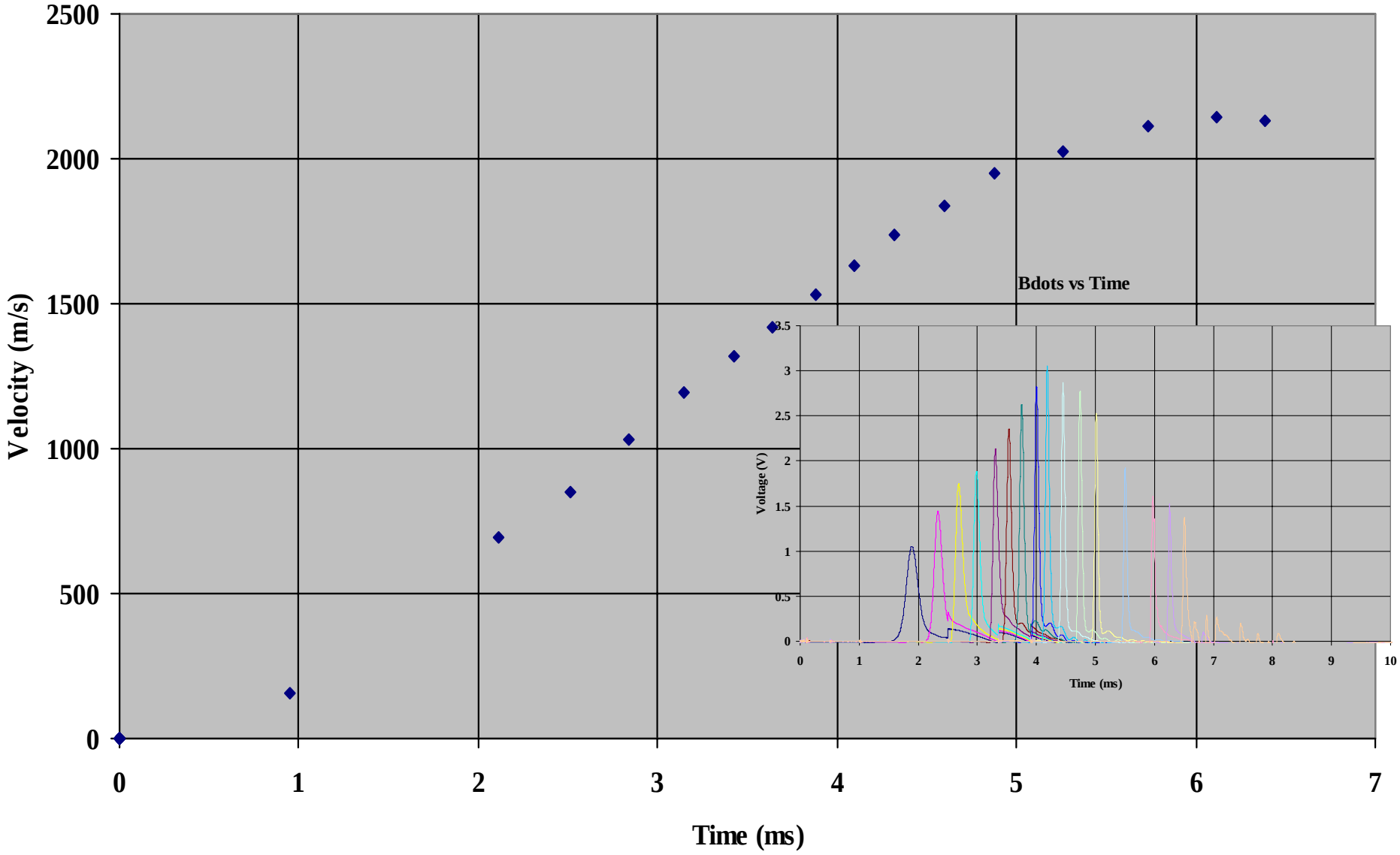
Test Results (continued)

Shot	Mass (KG)	Charge Voltage (KV)	Peak Current (MA)	Muzzle Velocity (m/s)	Muzzle Energy (MJ)	Efficiency (%)
14	2.46	8.2	1.87	1106	1.5	16.9
15	2.31	8.01	2.46	2005	4.65	27.4
16	2.89	8.89	2.75	2059	6.13	29.3
17	3.29	7.8	3.18	1722	4.87	30.3
18	3.29	7.8	3.18	1717	4.85	30.1
19	3.402	9.69	2.99	2053	7.17	28.9
20	2.892	8.9	2.75	2025	5.93	28.3
21	2.888	8.9	2.75	2019	5.88	28.1
22	2.89	8.9	2.73	2012	5.85	27.9
23	2.454	9.49	3.08	2519	7.79	32.7

Shot 13 Breech Current and Muzzle Voltage

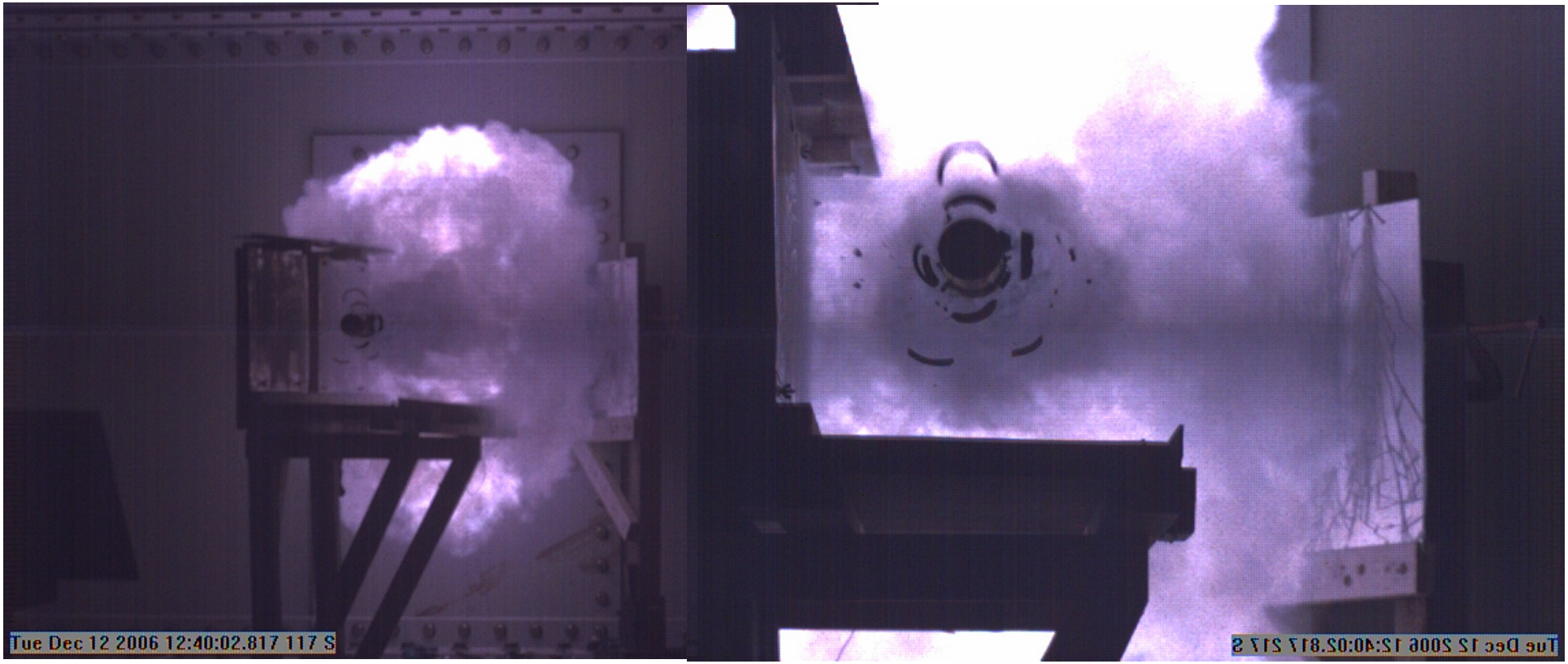


Shot 13 Velocity

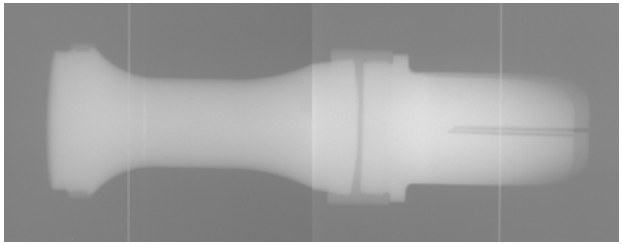
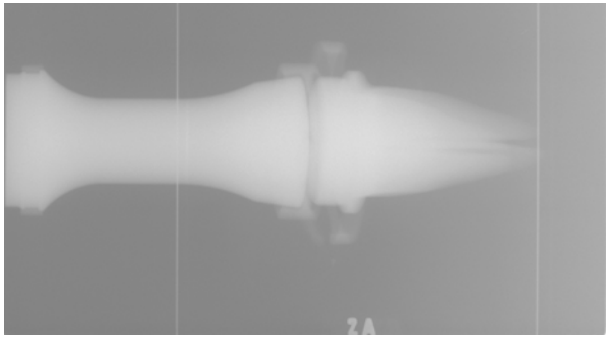
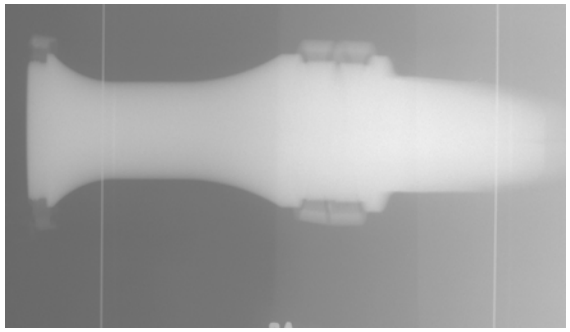
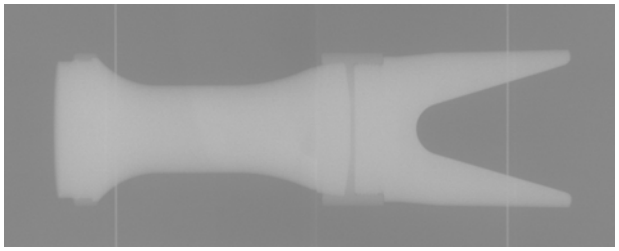
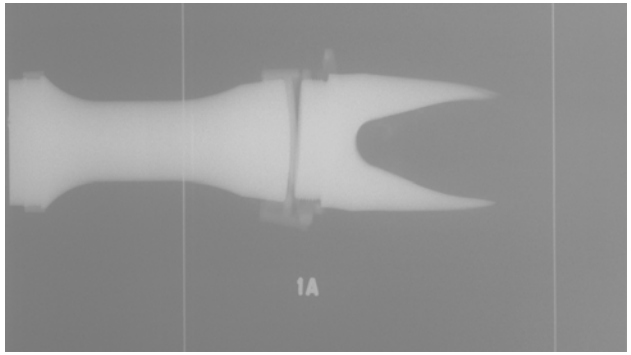
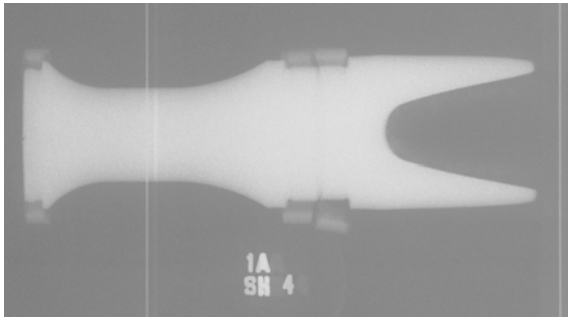


Muzzle Launch View

- Shot 7
- Muzzle Arc is 500K Amps at 2.3 KV
- 9 PSI Overpressure at 99” from muzzle



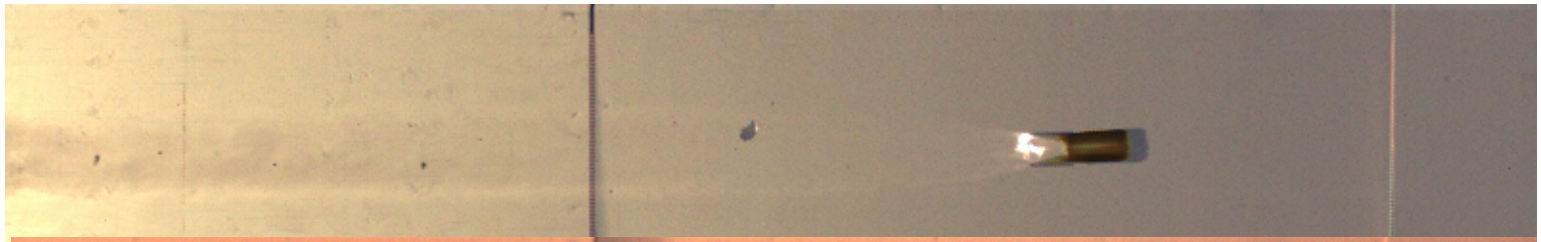
Flash X-ray Images

	Static Xray Image	Shot 2 Xray Image	Shot 4 Xray Image
Top View			
Side View			

All images are 3 feet from muzzle

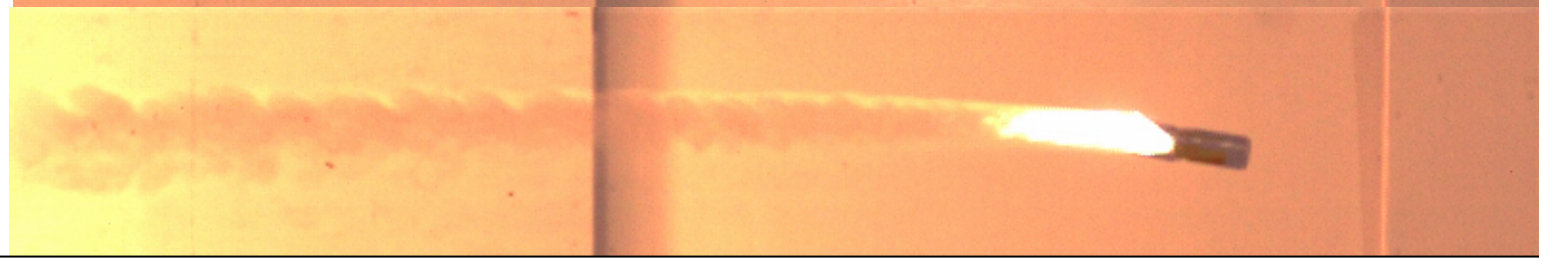
In-Flight Images

Shot 8:



Shot 9:

Shot 10:



Shot 21:

Tue Jan 30 2007 16:00:09.355 793

Target Impact

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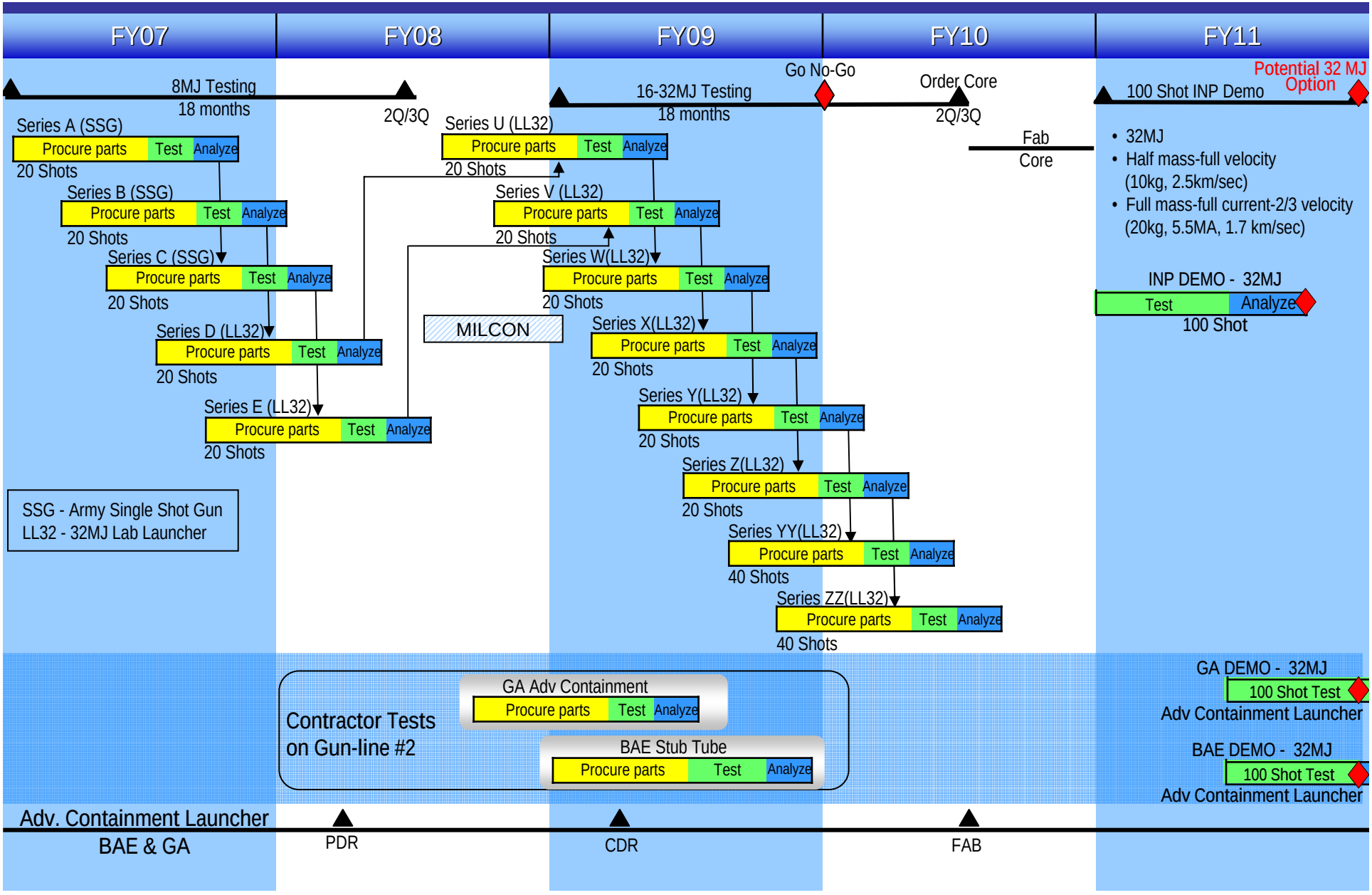
Launch Package Results

Original Launch Package

Recovered from Shot 1

Recovered from Shot 2

Bore Life
EMLF Testing Concept

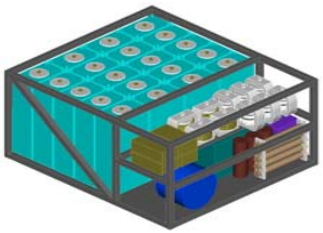


S&T Technology Challenges

- Launcher
  - Multi-shot barrel life
  - Barrel construction to contain rail repulsive forces
  - Scaling from 8MJ (state of the art) to 32MJ → 64MJ Muzzle Energy
  - Thermal management techniques

- Projectile
  - Gun launch survivability (45 kGee acceleration, Electromagnetic Interference Potential)
  - Hypersonic guided flight for accuracy
  - Lethality mechanics

- Pulsed Power System
  - Energy Density
  - Rep rate operation & thermal management
  - Switching
  - Torque management and multi-machine synchronization (rotating machine)



ONR INP Phase I Program

Revolutionary Research . . . Relevant Results

NAVSEA WARFARE CENTERS DAHLGREN

FY05	FY06	FY07	FY08	FY09	FY10	FY11

Executive Steering Committee Conclusion and Recommendation

Program Initiation Aug 05

Initial 8MJ Test Capability

Initial 32MJ Test Capability

Go – No Go Decision Point Aug 09

BAE

32MJ Lab Gun For Bore Life Development

Launcher Bore Life Development

32 MJ LAUNCHER 100 SHOT BORE LIFE DEMO

A

B

C

Exercise Options

General Atomics

BAE

Concept Design

Technology Development & Preliminary Design

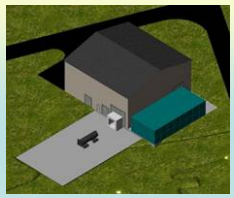
Advanced Containment

Detail Design & Fabrication

A

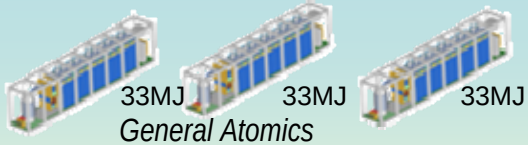
B

32 MJ ADVANCED CONTAINMENT DEMO



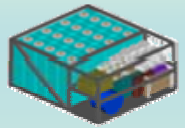
EMLF Test Facility NSWCDD

100MJ Capacitor Bank For Launcher Testing



33MJ 33MJ 33MJ

General Atomics



Advanced Capacitor Development

Rotating Machine Component Development

Multiple Awards

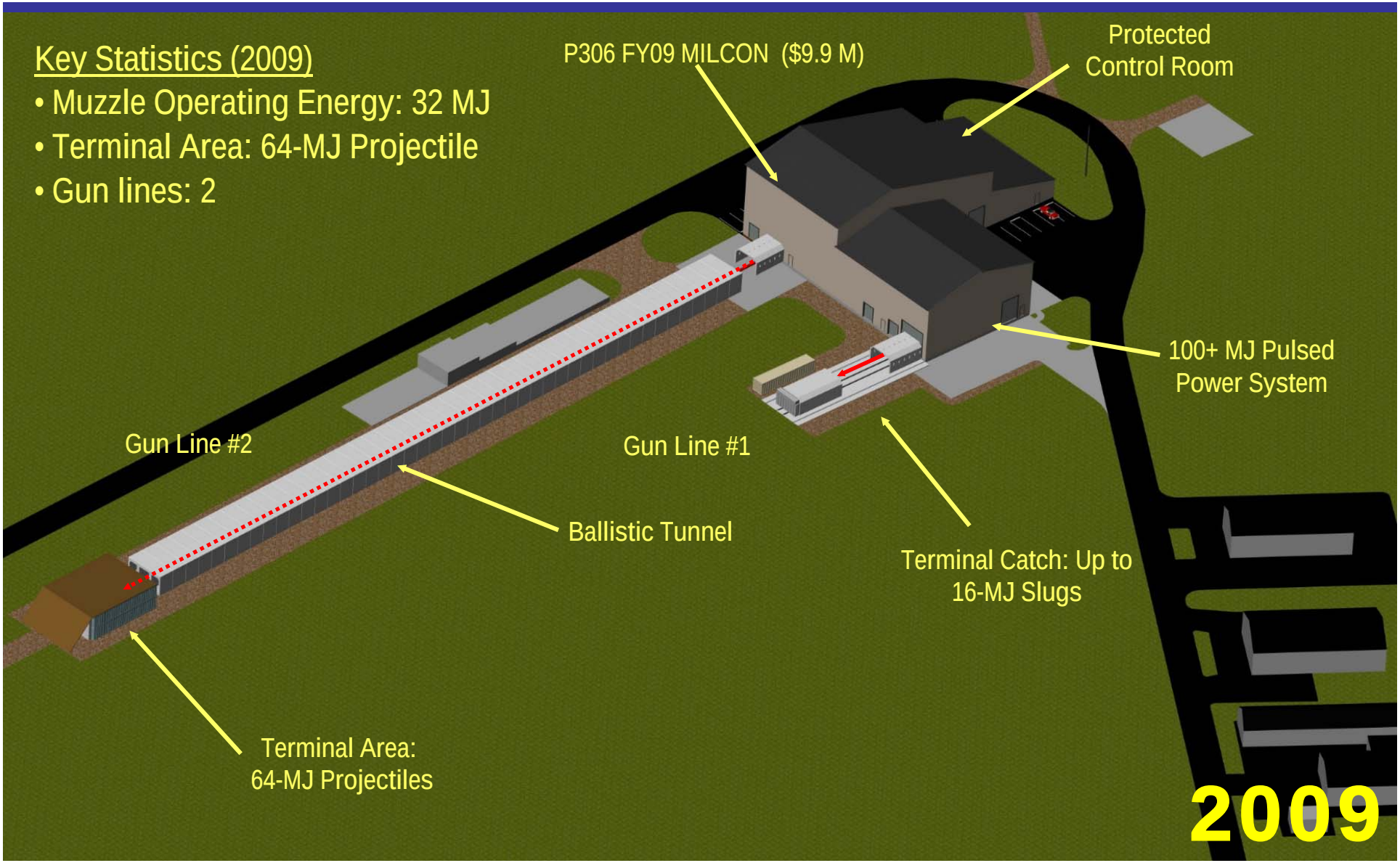
Boeing

Draper

Projectile Trades & Develop 4 Year Plan

Integrated Launch Package (ILP) Development

Milcon Addition



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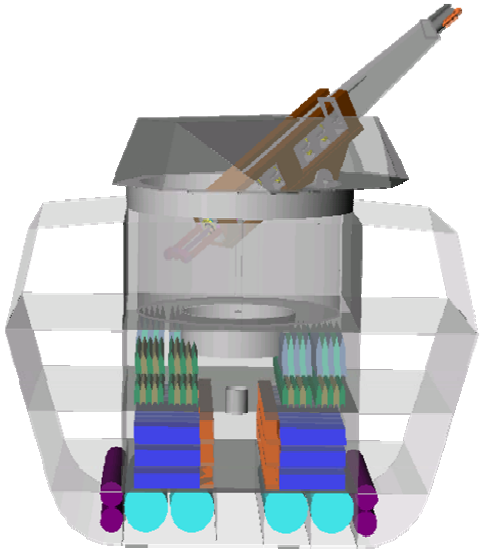
Back-up

Navy Electromagnetic Railgun



Why is it important?

- Volume & Precision Fires
- Time Critical Strike
- All weather availability
- Variety of payload packages
- Scalable effects
- Deep Magazines
- Non explosive round/No gun propellant
  - Greatly simplified logistics
  - No IM (Insensitive Munitions) Issues
- Missile ranges at bullet prices

What is it?

- Gun fired with electricity rather than gunpowder
- Revolutionary *250 mile range in 6 minutes*
- Mach 7 launch / Mach 5 hit
- Highly accurate, lethal GPS guided projectile
- Minimum collateral damage

Who needs it?

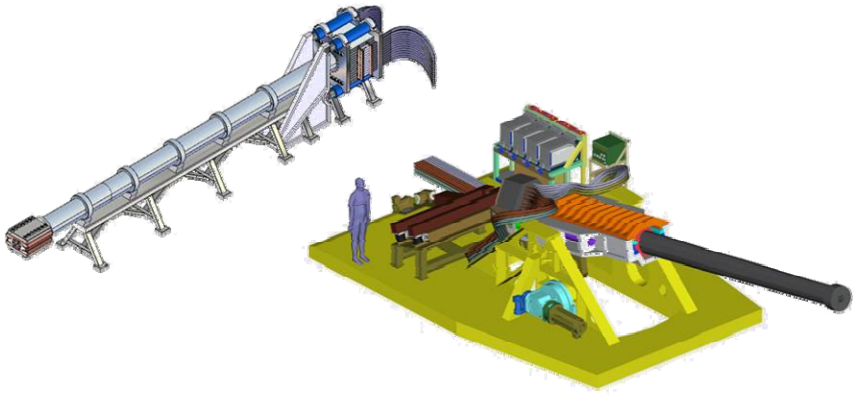
- Marines and Army troops on ground
- Special forces clandestine ops
- GWOT
- Suppress air defenses

When?

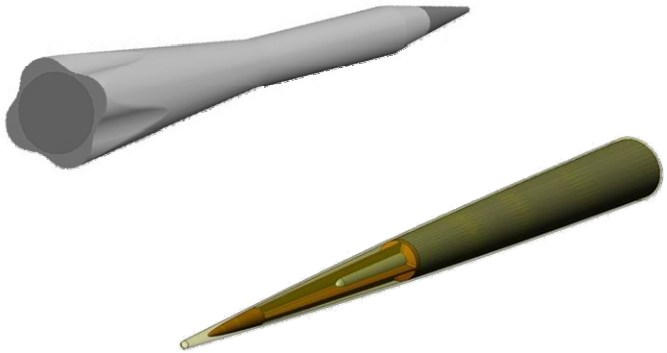
- Feasibility Demo 2011
- System Demo 2015
- IOC 2020-2025

Naval Railgun – Key Elements

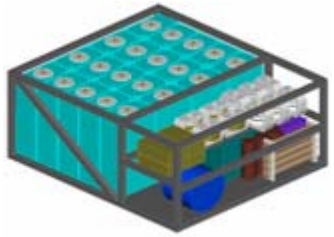
Launcher

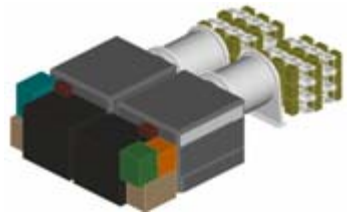


Projectile



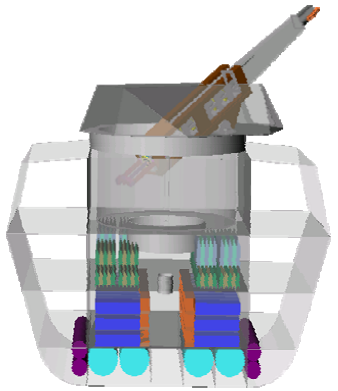
Pulse Forming Network (PFN)





Capacitors or Rotating Machines

Ship Integration

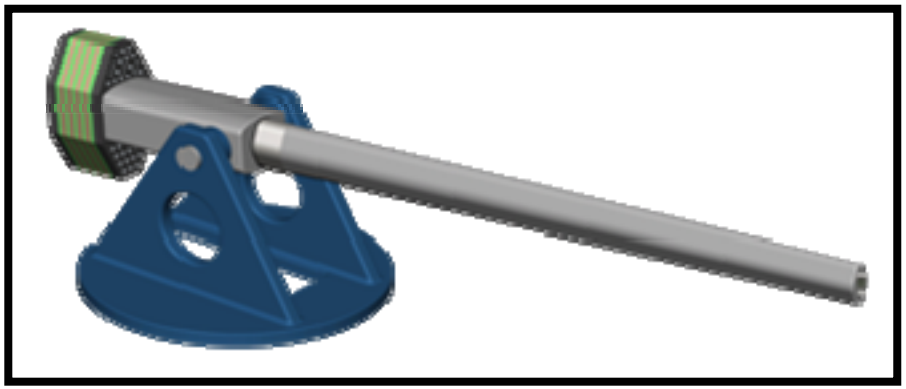


Key Parameters for Sizing a Naval EM Launcher

Pulse Forming Network Size

½ * Launch Mass * Muzzle Velocity^2

Desired Muzzle Energy



Current Profile

- Rail Separation Forces
- Transient Localized Heating

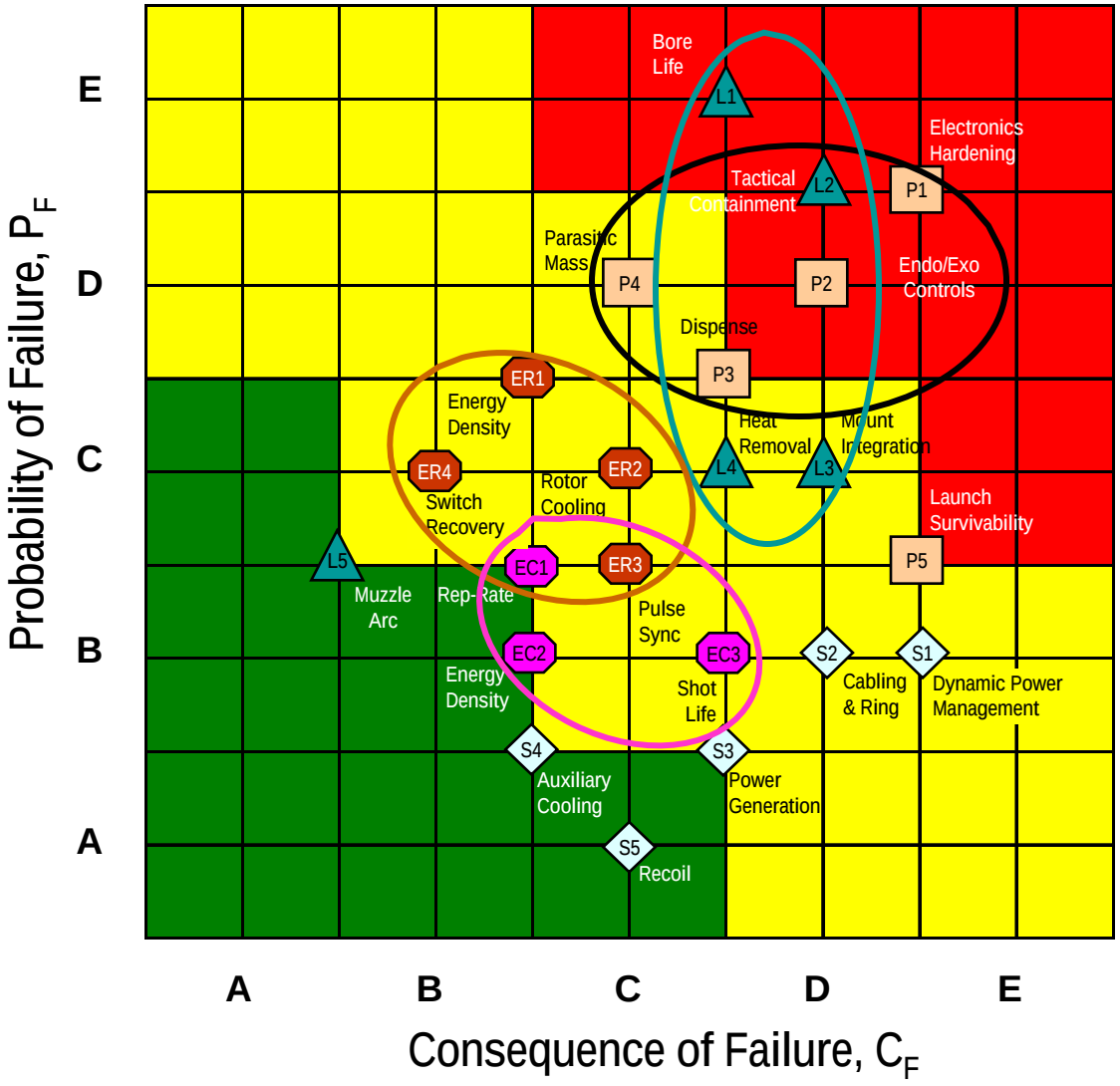
Bore Size & Shape

Launcher Efficiency

Barrel Length

- Max Projectile Acceleration
- Bulk Rail Heating

Risk Matrix Summary



Risk Ranking & Key Impacts

- L — Launcher
- P — Projectile

Failure Impacts Capability

- ER — Rotating Machine PPS
- EC — Capacitor PPS
- S — Ship Integration

Failure Impacts Volume, Weight & Cost

ONR INP Phase 1 Objectives

- Traceability to 64MJ, 6-10 round / min indirect fire weapon system
- Bore Life
  - 32 Mega-Joule (Muzzle Energy) EM Lab Launcher
  - 10kg launch package; full muzzle velocity of 2.5km/sec
  - 20kg launch package with full current of ~5.5MA
  - Demonstrate more than 100 shot bore life
- Containment
  - 32 Mega-Joule Advanced Containment Launcher
  - 10kg launch package; full muzzle velocity of 2.5km/sec
  - 20kg launch package with full current of ~5.5MA
  - 1000+ round predicted containment structural barrel life
  - Design for thermal management at a rate of 6 round / min
  - Design launcher for minimal round dispersion
  - Transportable on pallets and/or in sea containers,
  - Consider marine environment

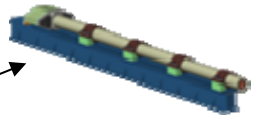
Integrated System Demo Strategy

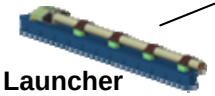
INP I 2005-2011

INP II 2011 - 2015

EM Lab Gun for Bore Life Development

INP Phase I EM Railgun Demonstration Launcher





Launcher Technology Dev.

Launcher Trades & Concept Dev.

INP Phase II EM Railgun Demonstration Launcher

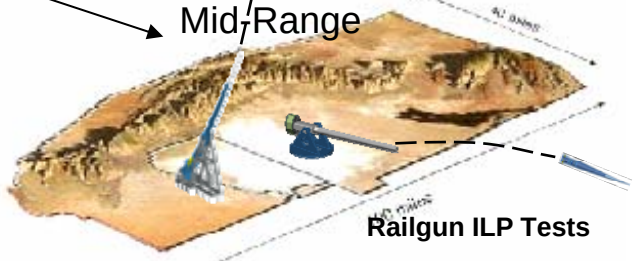
INP Phase II Long Range Integrated System Demo

Projectile Trades & Concept Dev.

ILP Interface in bore dynamics

Endo-Exo Testing

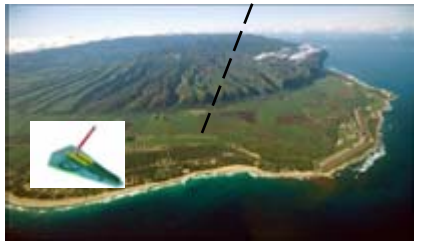
Mid-Range



Railgun ILP Tests

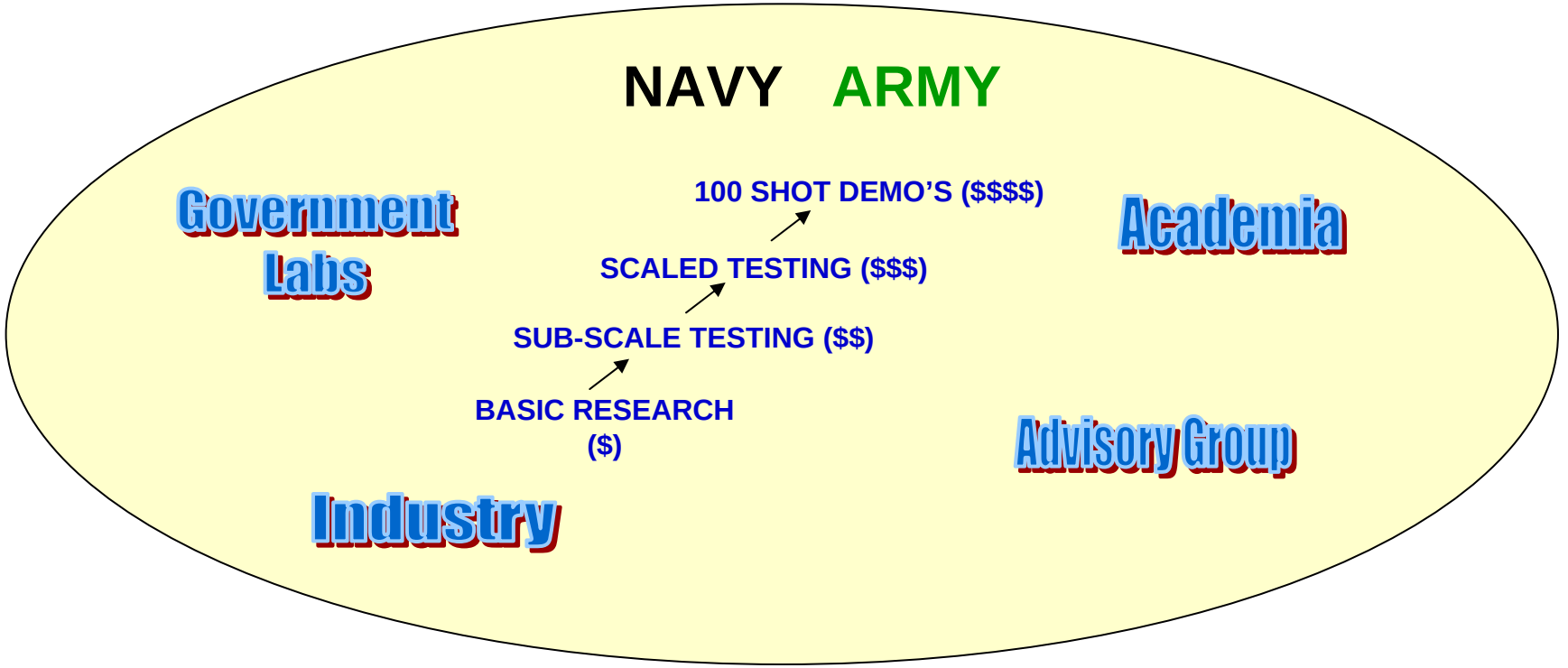
Terminal High Velocity Powder Gun

Long-Range



Electromagnetic Test Facility

Bore Life Consortium



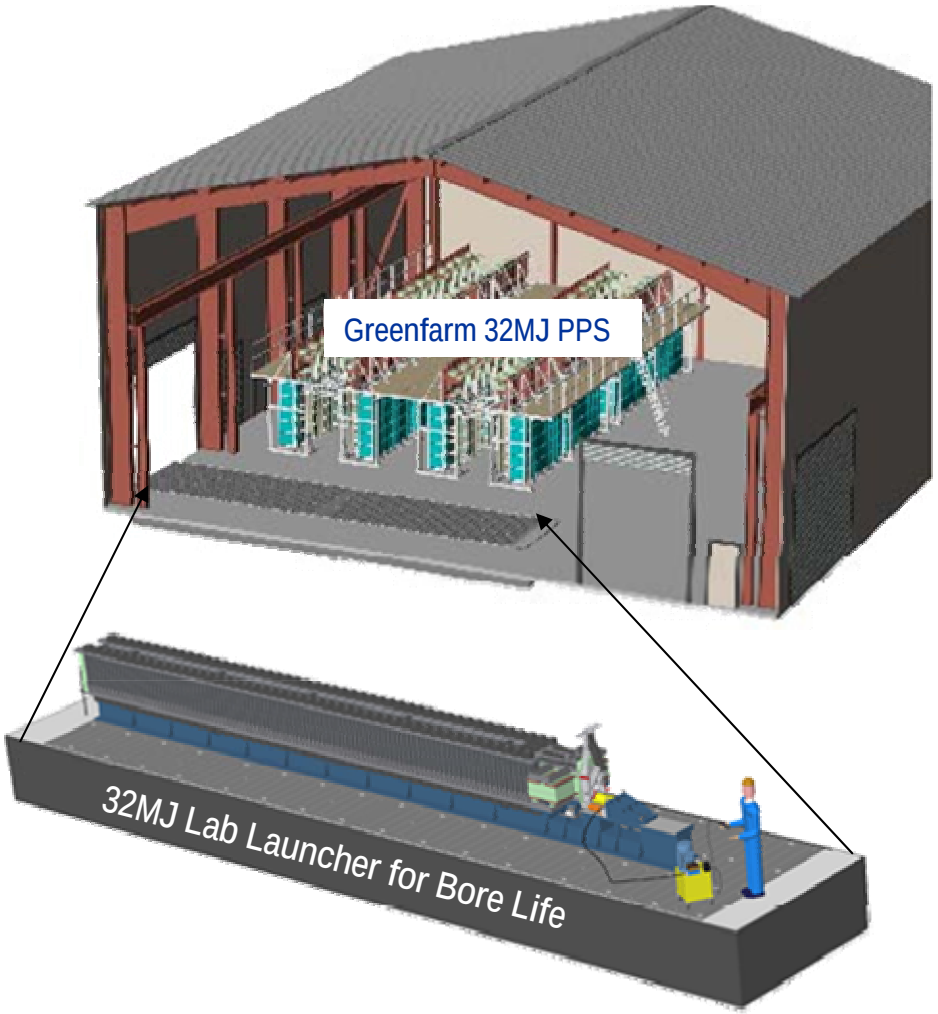
- Spans Basic Research to Full-Scale Demo's
- Parallel development paths via multiple research sites
- Avoids Duplication
- Efficient use of test resources

- Supports both Navy and Army EM Efforts
- Government purpose data rights to permit competition during the acquisition phase.

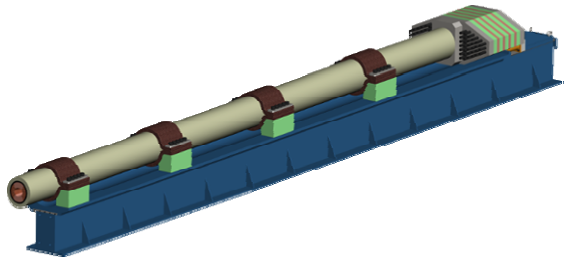
Coordinated Development!

Bore Life and Containment

Lab Launcher - EMTF



Advanced Containment Launcher



Phase	Phase of Project	Period
Basic	Conceptual Design Trade Studies	7 mos.
Army Add	Trade Studies for Army Application	3 mos.
Option I	Technology Development and Preliminary Design	30 mos.
Option II	Detailed Design, Fabrication and Demonstration	29 mos.

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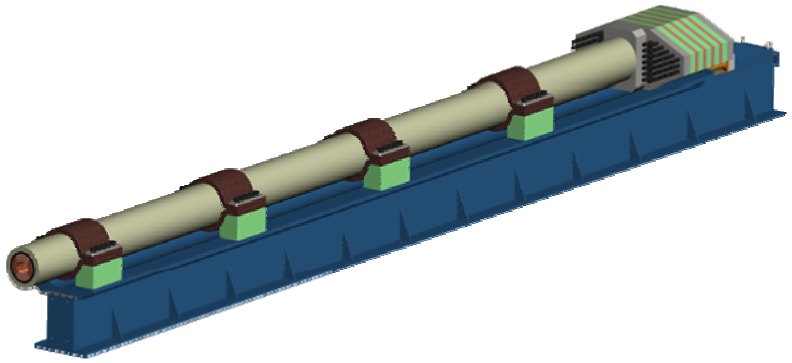


General Atomics Team

BOEING

L3 communications Applied Technologies Pulse Sciences

GENERAL ATOMICS

SPARTA

Jackson Engineering Engineering Technology and Development

Northrop Grumman Team

NORTHROP GRUMMAN

DRAPER LABORATORY

THE UNIVERSITY OF TEXAS AT AUSTIN

CEM

ATK ALLIANT TECHSYSTEMS

BAE Team

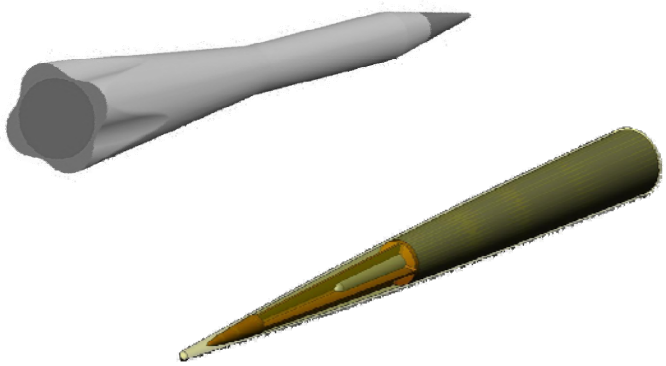
IAP

BAE SYSTEMS

SAIC

EMD

Projectile Concept Trades



Description of Effort

- Develop long range projectile concept
  - Lethal
  - Consistent with Navy CONOPS
  - Compatible with any EML gun development
- Identify critical development
  - GN&C
  - Aerobody (drag and thermal protection)
  - launched survivability
- Produce a development plan

The Boeing AASP Team

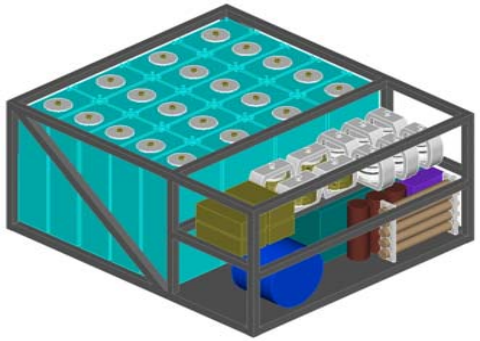
General Atomics, Honeywell, ARA, Boeing, ARL, Rockwell Collins, simulations

Draper Team

Draper Laboratory, TEXTRON Systems, ATK Alliant Techsystems, Mayflower Communications™

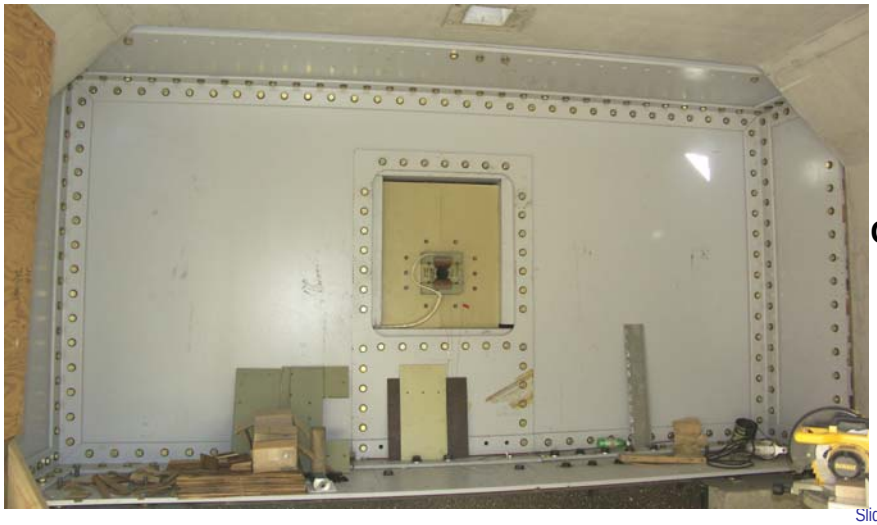
Advanced Pulsed Power

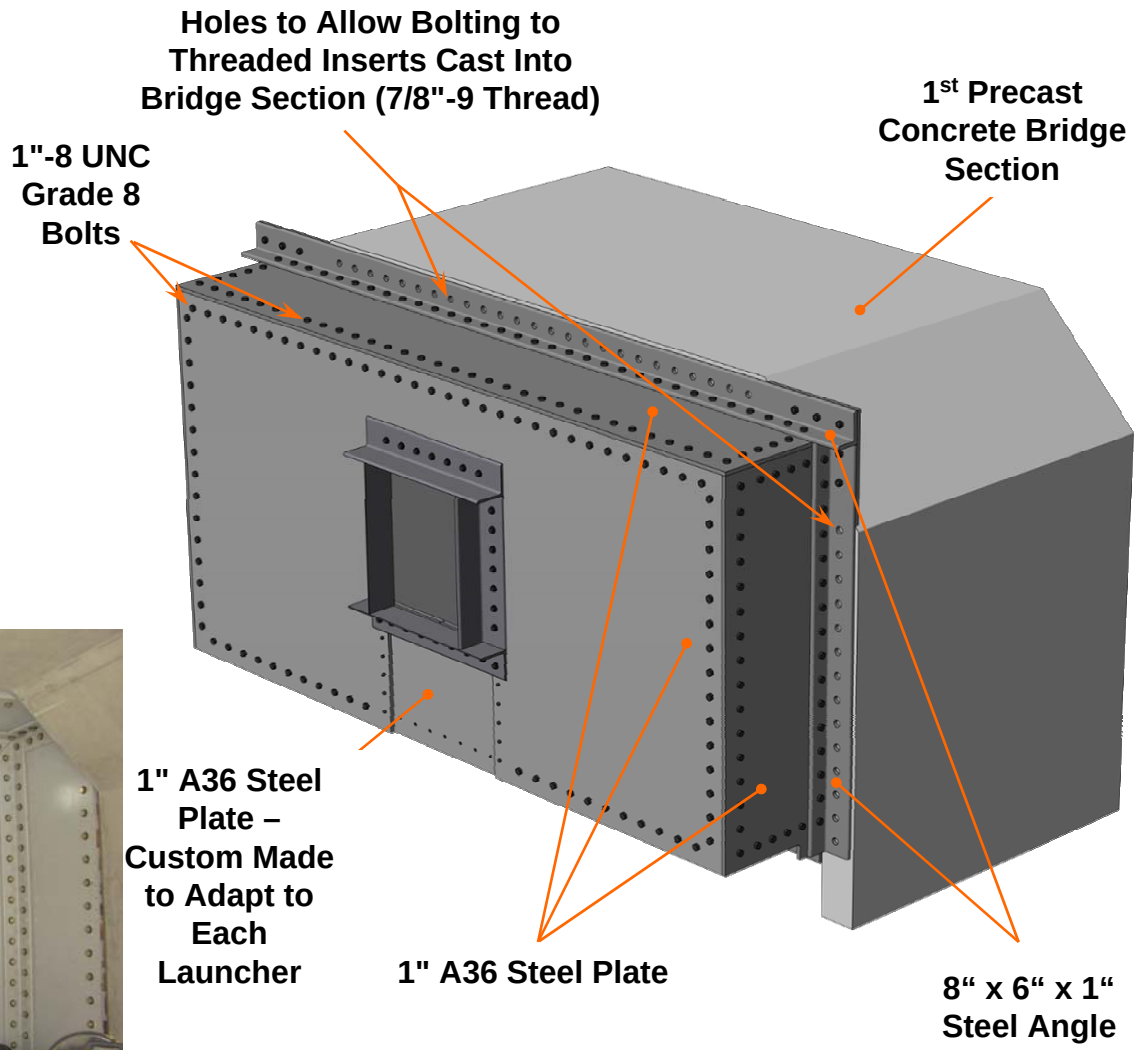
- Rotating Machine
  - Watch Army Effort (Demo in FY08)
  - Navy Specific Critical Component Development
- Advanced Capacitor
  - Increased Energy Density
  - Thermal Management for Multi Shot Operation



Steel Muzzle Chamber Component

- Steel Muzzle Chamber
  - Mates to both SSG & Lab Launcher
  - Bolts to 1st Concrete Bridge Section
- Collar Plates Seal Gaps between Launcher & Chamber





Vans on Van Pad