Status of the HAPL Program

Laser Fusion Energy
with lasers and direct drive targets

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Presented to Fusion Power Associates Annual Meeting
Oak Ridge, TN
Dec 5, 2007

Sponsored by DOE/ NNSA/ Defense Programs

The HAPL team is dedicated to developing inertial fusion as an energy source

14th HAPL meeting
March 21 & 22, 2006
Oak Ridge National Lab

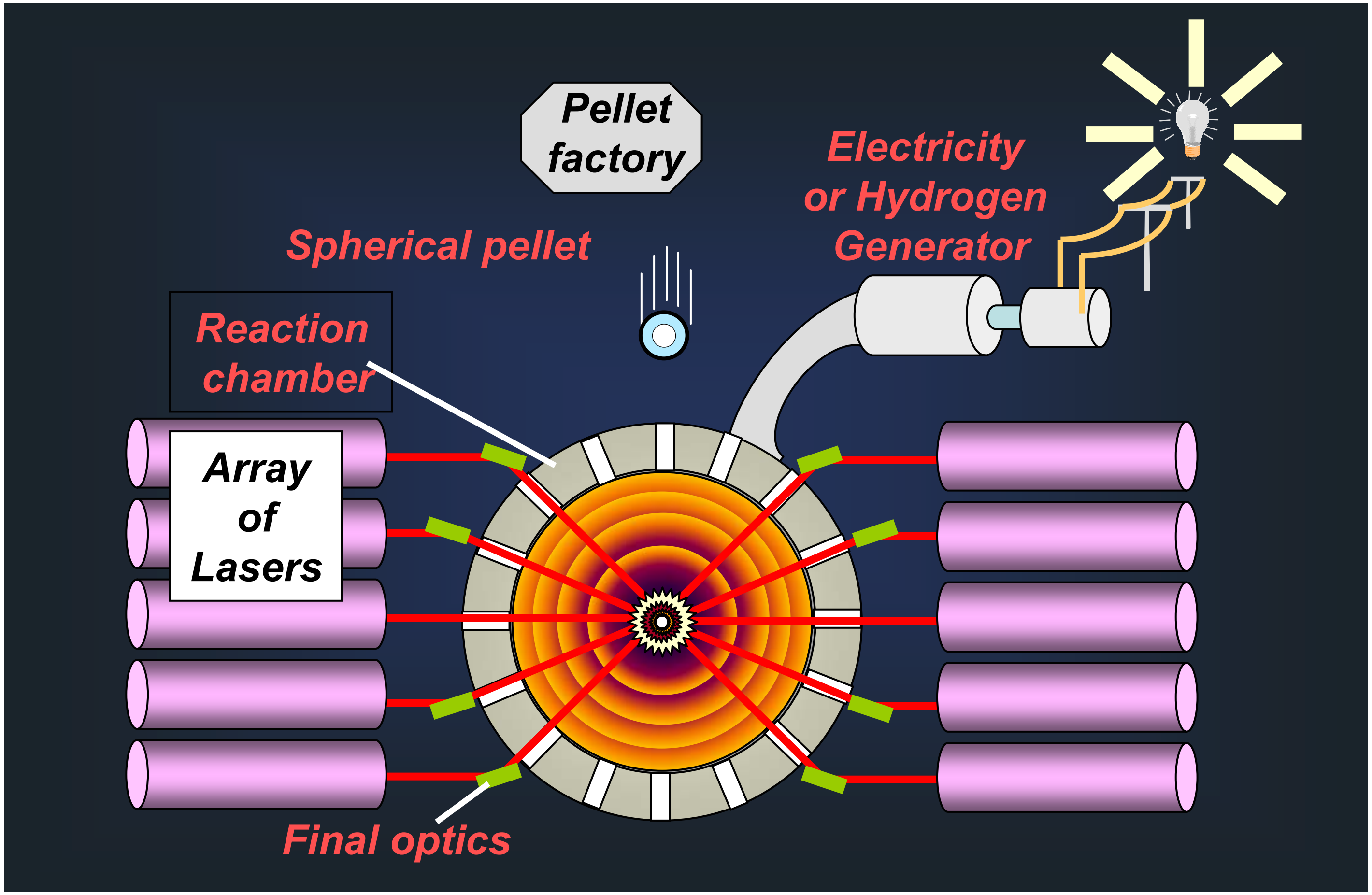
Government Labs
1. NRL
2. LLNL
3. SNL
4. LANL
5. ORNL
6. PPPL
7. SRNL

Universities
1. UCSD
2. Wisconsin
3. Georgia Tech
4. UCLA
5. U Rochester, LLE
6. UC Santa Barbara
7. UC Berkeley
8. UNC
9. Penn State Electro-optics

Industry
1. General Atomics
2. L3/PSD
3. Schafer Corp
4. SAIC
5. Commonwealth Tech
6. Coherent
7. Onyx
8. DEI
9. Voss Scientific
10. Northrup
11. Ultramet, Inc
12. Plasma Processes, Inc
13. PLEX Corporation
14. FTF Corporation
15. Research Scientific Inst
16. Optiswitch Technology
17. ESLI

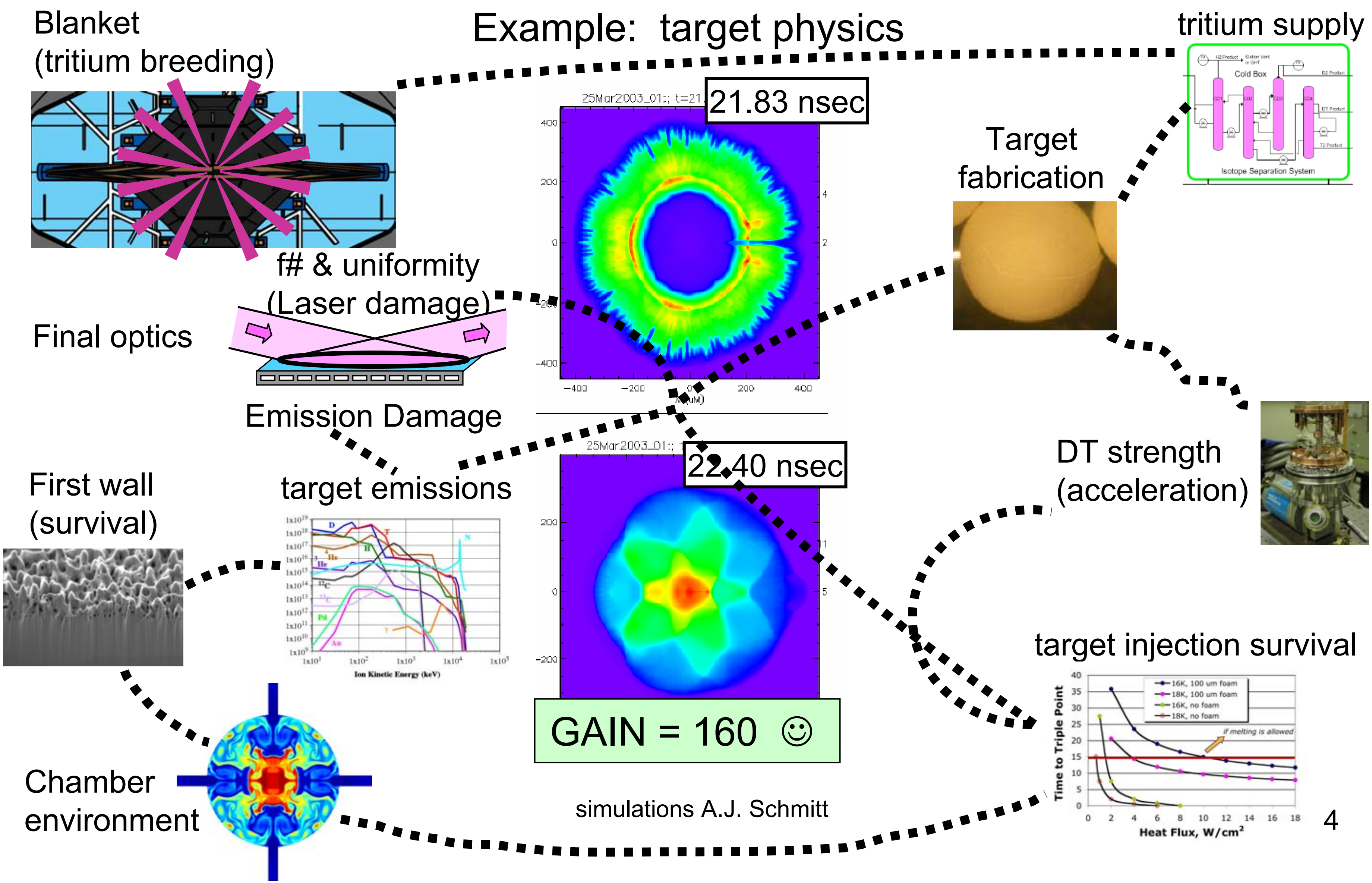
Progress Report: Basic S&T for laser fusion Energy

Where we started
Where we are now
What we still need to do



We take an "integrated system" approach

Much harder, but much more likely to yield something that works!



TARGET DESIGN

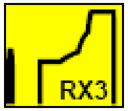
START 1999	What we have done	What we still need
1 D High gain DIRECT DRIVE target designs	**Energy:** Gain > 150 @ 2.4 MJ 3 different simulations* Threat spectra **Fusion Test Facility:** Gain > 50 @ 500 kJ 2 different simulations** **Simulations** Codes backed w/ expt's 2 D high resolution Realistic surface finish Sensitivity studies	Ignition on the NIF Thoroughly evaluate Direct Drive (DD) …Including experiments at prototypical energy / intensity Pursue advanced designs: Shock ignition

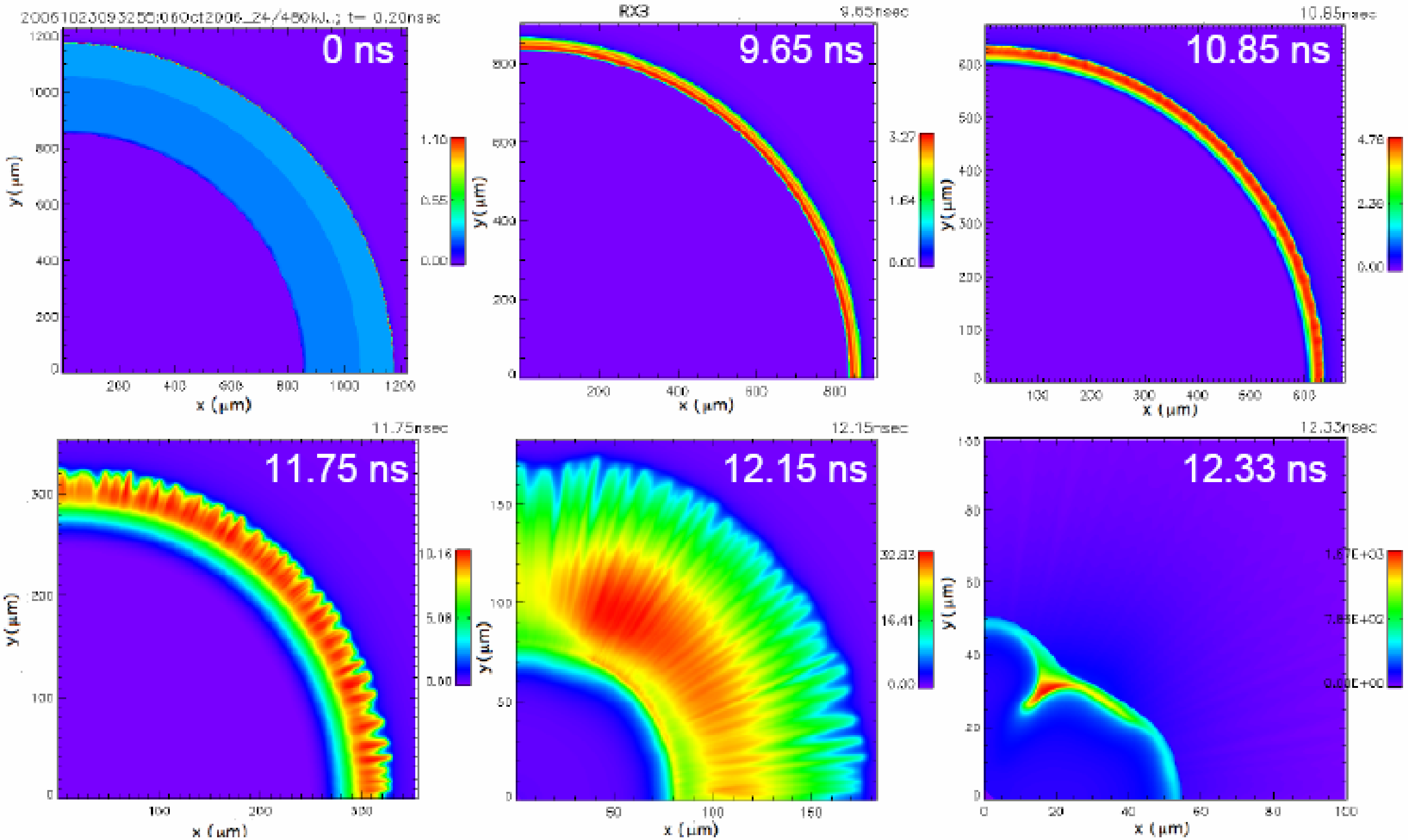
* NRL, LLE, LLNL ** NRL, LLE, LLNL

2 D high resolution simulations show gain of 56 for 480 kJ KrF Laser

Result: With NIF-spec.-equivalent outer surface finish, the RX3 pulse gives a yield of 27 MJ, ~90% of clean-1D yield

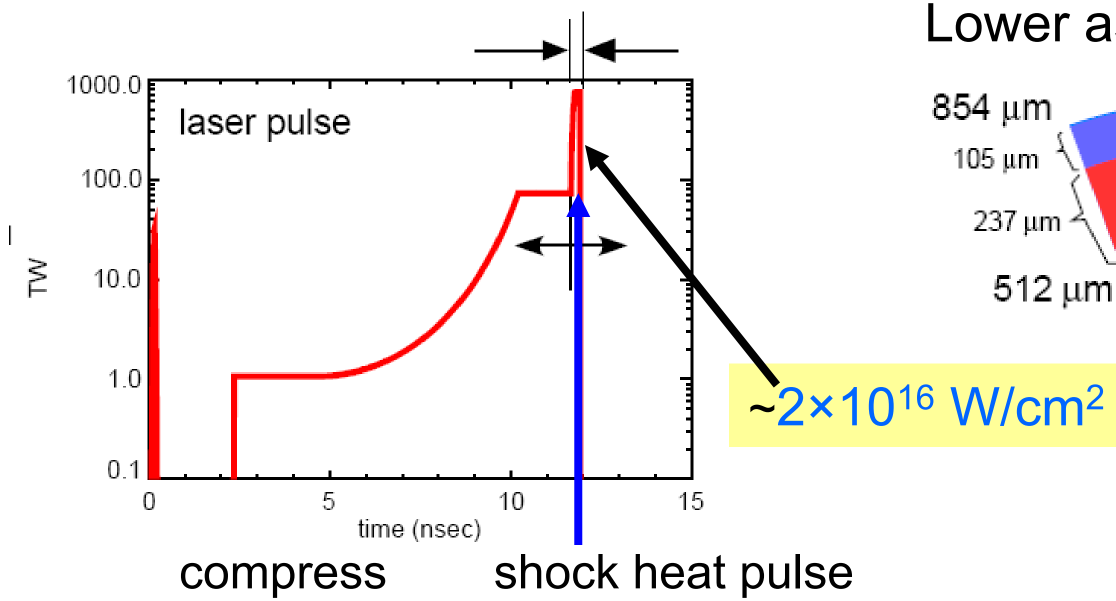
Simulations have 660 pts (r) X 2048 pts (θ) over a half sphere, and can resolve modes from 2-512.



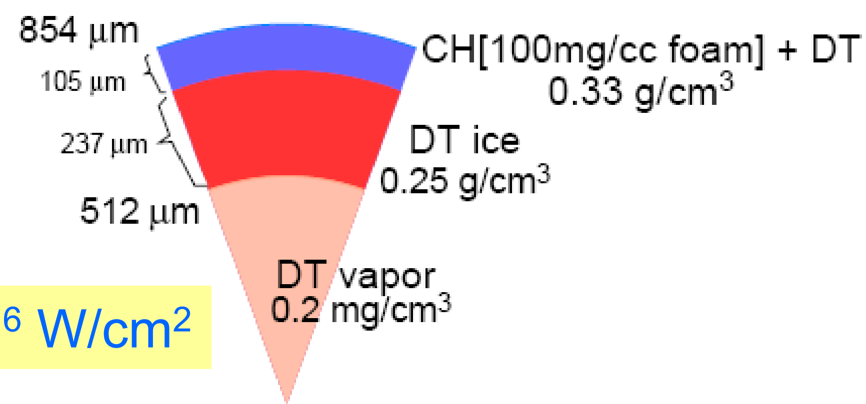


0.478 μm rms surface finish on DT/CHfoam

Shock Ignition (R Betti, LLE) shows promise for even higher performance: 1 D Gain = 100 @ 300 kJ KrF



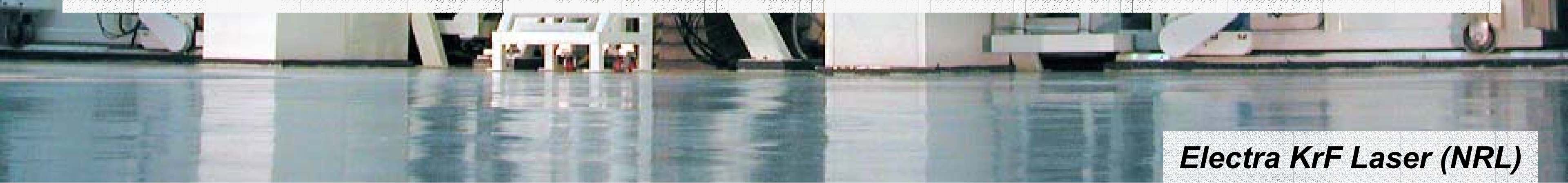
Lower aspect ratio target



2-D studies also give promising performance
Collaborations with NRL (Schmitt) & LLNL (Perkins)

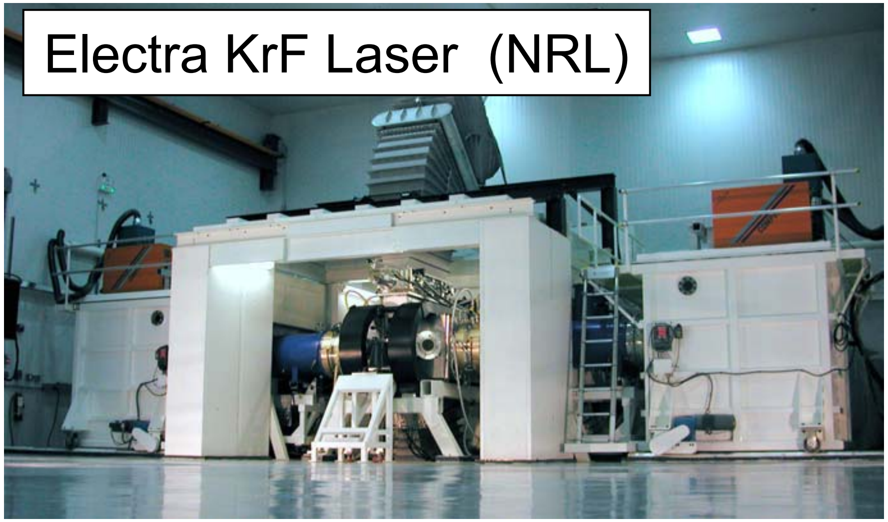
LASERS

START 1999	What we have done	What we still need
No high energy, rep-rate, Fusion-Class Laser existed	• Now have two lasers: ○ Energy (50-700 J) ○ Rep-rate (2 -10 Hz) ○ Long runs (10^4- 10^5) (several hours) ○ Low XDL ○ Predict efficiency ○ Scalability	• Integrated test: ○ Efficiency ○ Durability ○ Pulse shape ○ High uniformity ○ Wavelength

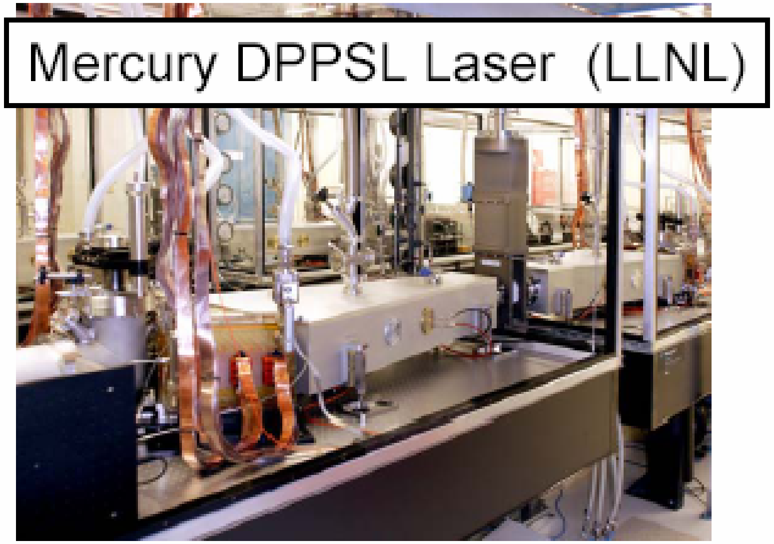


Electra KrF Laser (NRL)

Both HAPL Lasers have demonstrated high energy, rep rate, long duration, operation.

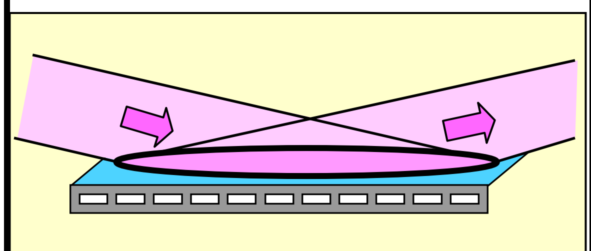


> 230,000 shots
300-700 J @ 248 nm
120 nsec pulse
2.5 - 5 Hz
Predict >7% efficiency
16 k shots, 270 J, 2.5 Hz, 2 hrs
Operate as complete laser system



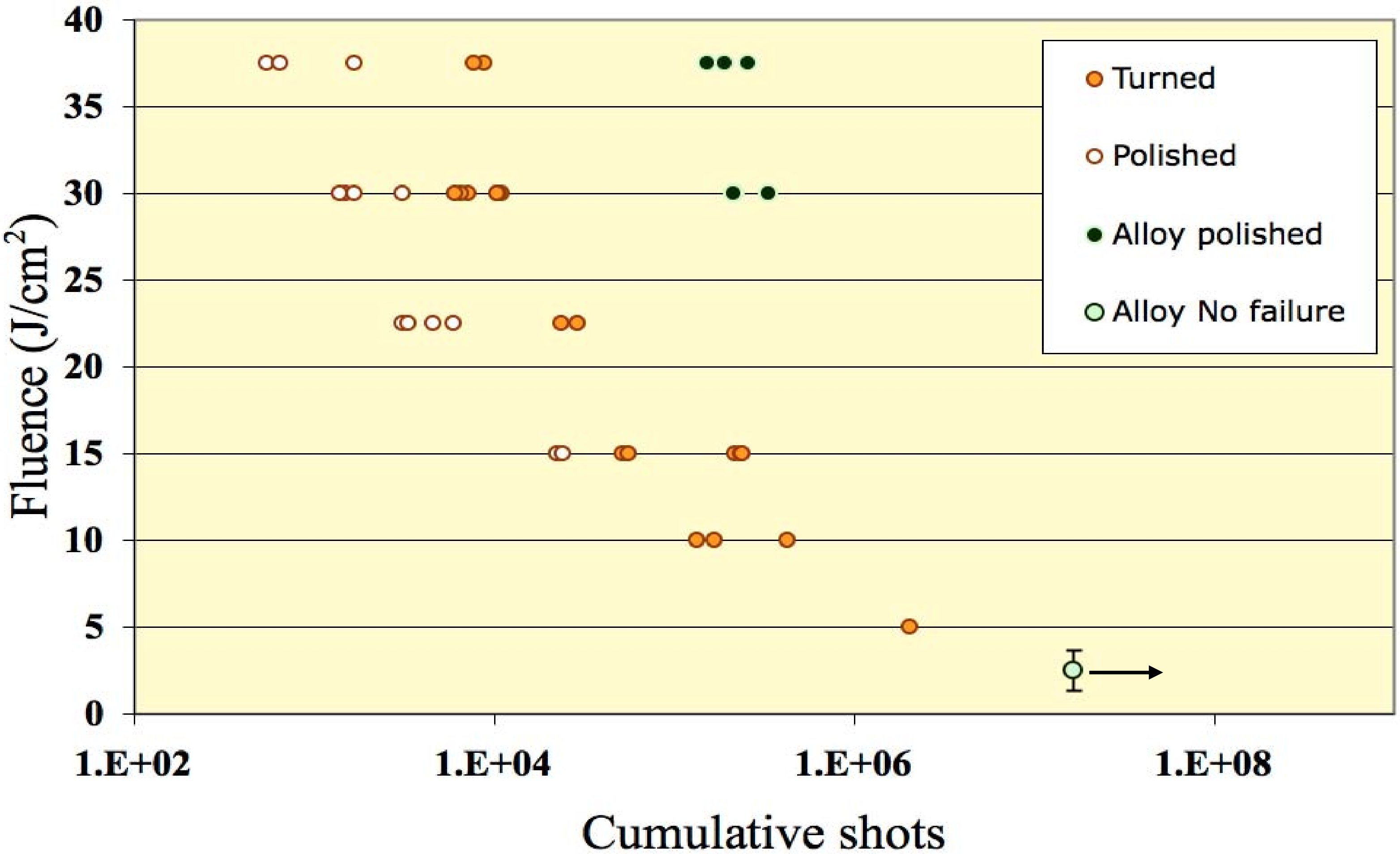
> 270,000 shots
55 J @ 1051 nm
15 nsec pulse
10 Hz
100 k shots continuous @ 10 Hz
73% Conversion to 2 ω
Installed advanced front end

FINAL OPTICS

START 2001	What we have done	What we still need
GIMM concept proposed… Not tested or evaluated 	• GIMM with solid solution Al shows high long term laser damage threshold. • 3 D neutronics show downstream optics lifetime components	• Large area test • Integrated design: ○ neutron ○ x-rays resistant • Revisit Dielectrics

Final Optics

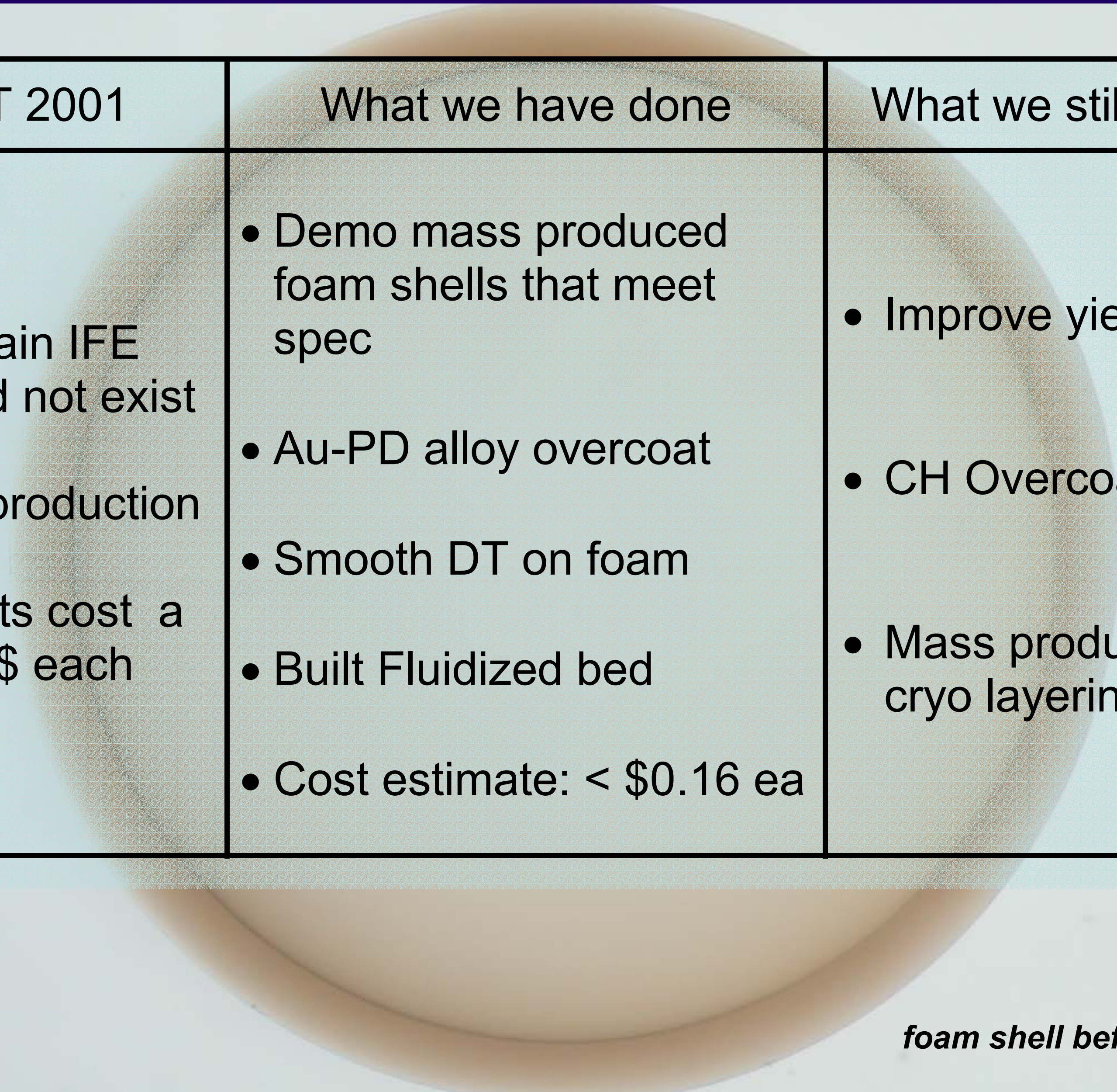
Developed high laser damage Grazing Incidence Metal Mirror (GIMM) using Polished, solid solution alloy, Al + 1% Cu*



*Alloy: 5-µm Al +1%Cu sputtered on 4” Si wafers, polished by CMP to < 1 nm RMS, < 10 nm PV

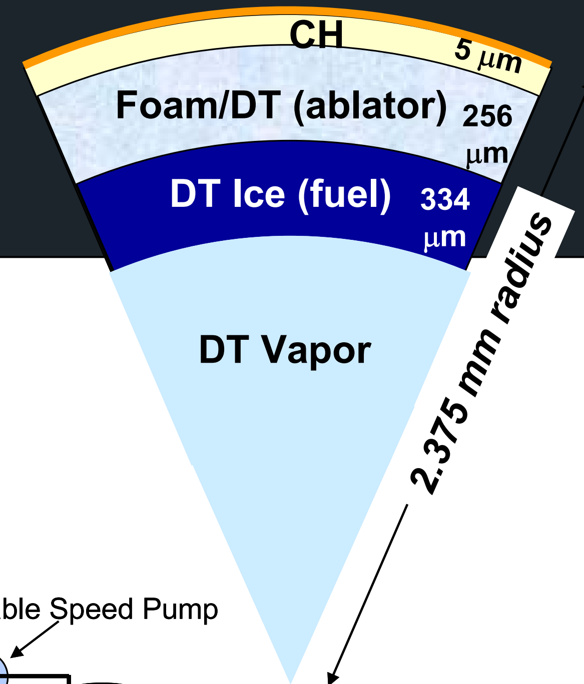
Target Fabrication

START 2001	What we have done	What we still need
High Gain IFE targets did not exist No mass production ICF targets cost a lot of $$ each	• Demo mass produced foam shells that meet spec • Au-PD alloy overcoat • Smooth DT on foam • Built Fluidized bed • Cost estimate: < $0.16 ea	• Improve yield • CH Overcoat • Mass production cryo layering

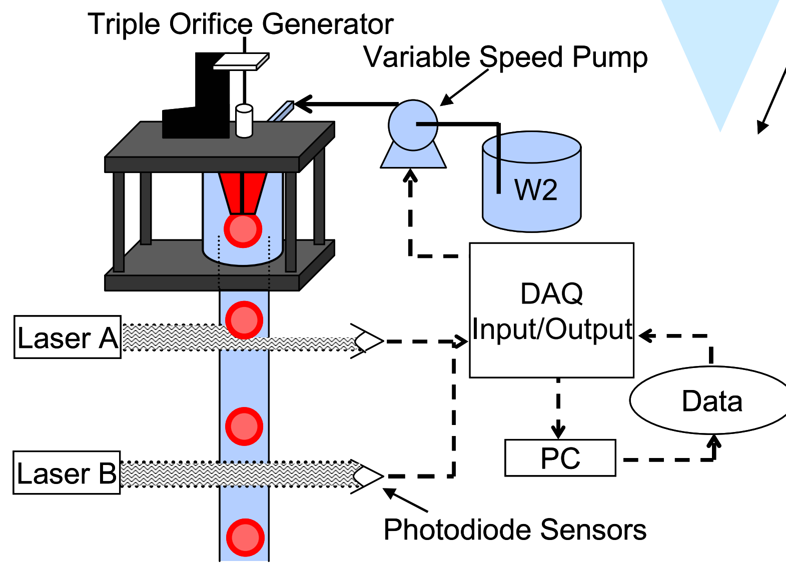


foam shell before drying

We can mass produce foam shells that meet specs

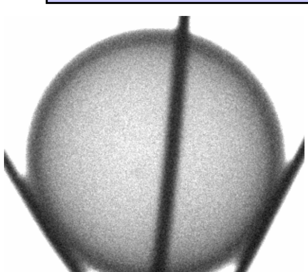


22 shells/min,
< 1% variation



Not to scale

Foam Shell:
100 mg/cc, up to 4mm dia



x-ray picture

Schaffer

"wet" shells

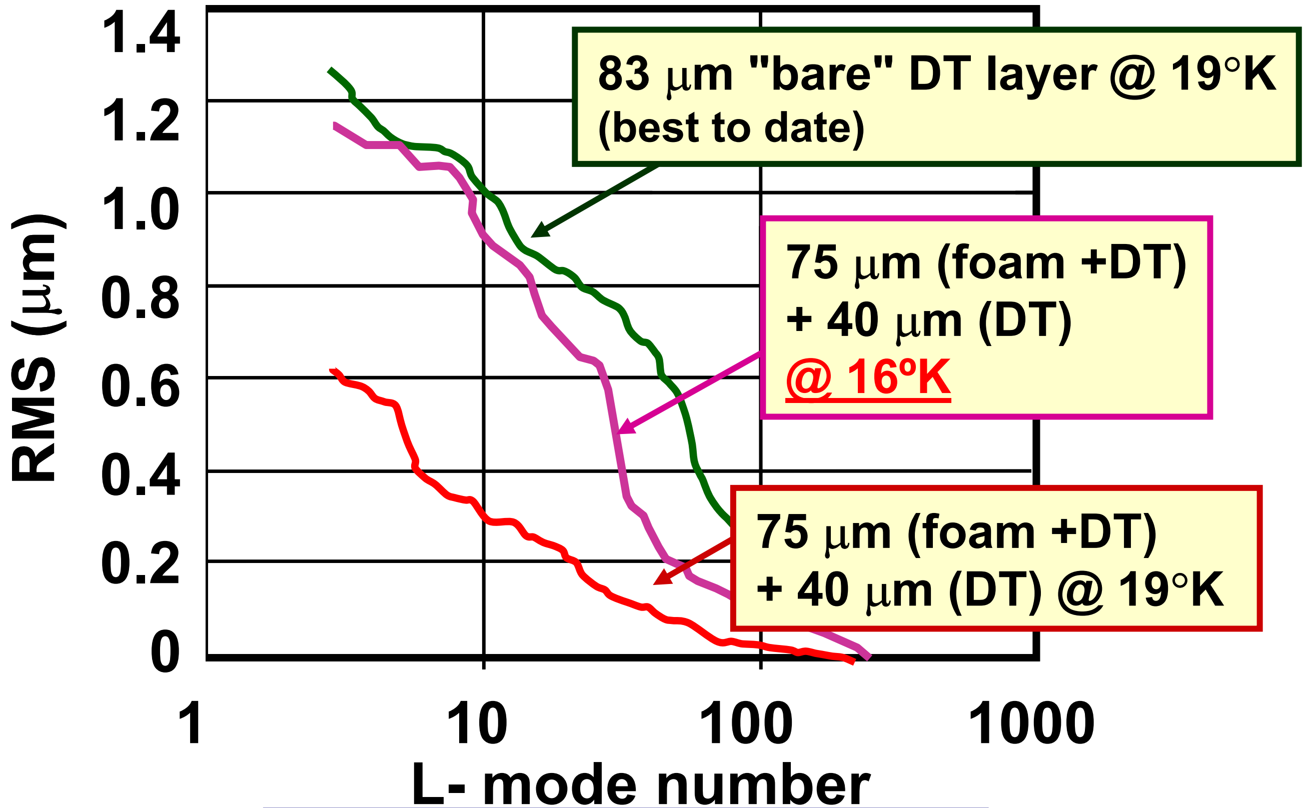
GA

GA, Schaffer

Target Survival into Chamber

START 2001	What we have done	What we still need
Target can not be placed accurately Target will not survive injection	• Gas free chamber designs allows target survival, accurate placement • Demo DT layer over foam more robust to thermal load. • Demo Au/Pd overcoat offers thermal protection	• Measure DT/foam: ○ thermal inertia, ○ mechanical strength

DT ice layers grown over foam base are smoother than pure DT ice…and are far more robust

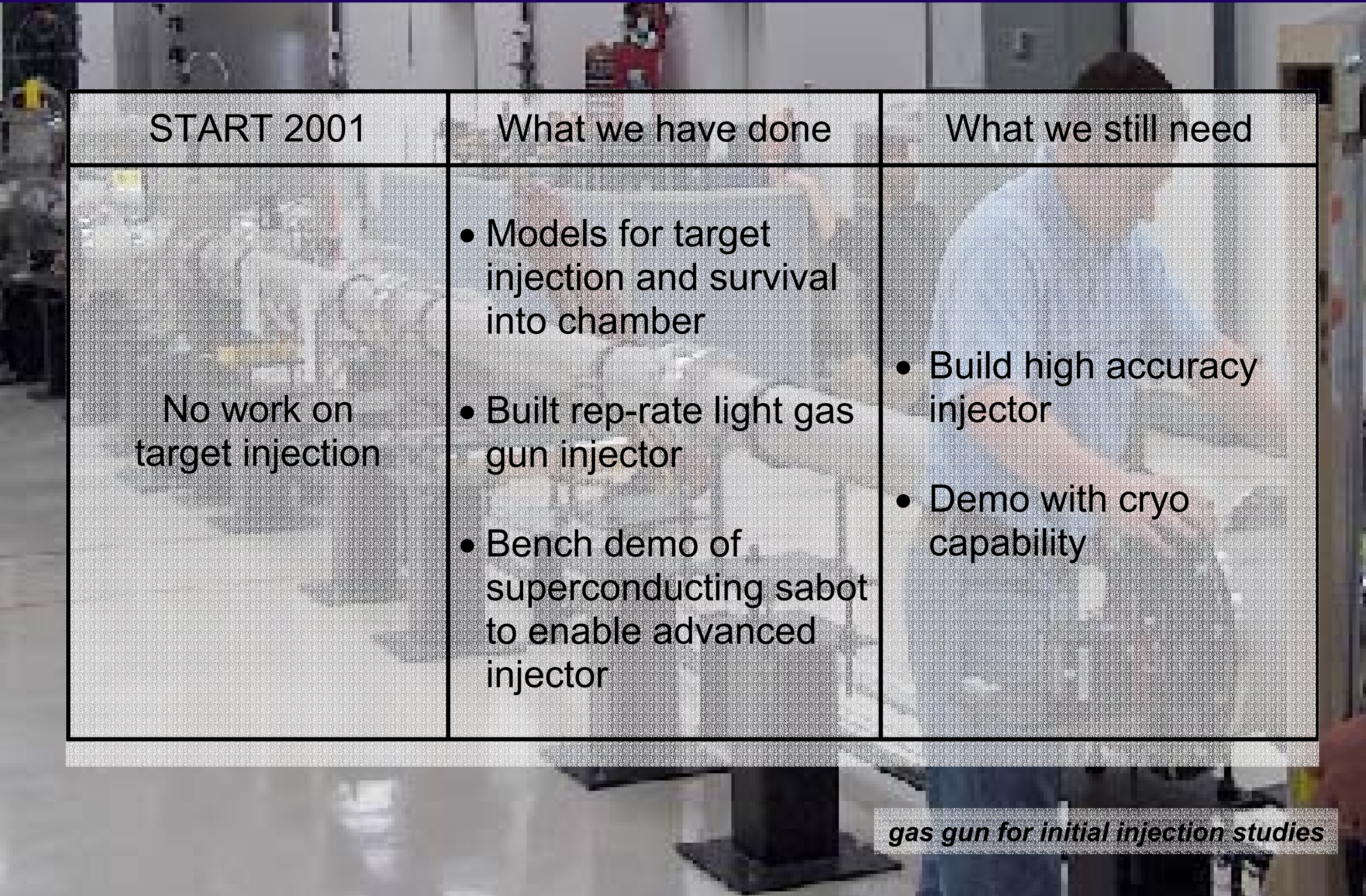


Cumulative Reverse Spectra RMS
Σ [L-mode (256-n)]
T = 19 °K

LANL, Schaffer

Target Injection into Chamber

START 2001	What we have done	What we still need
No work on target injection	• Models for target injection and survival into chamber • Built rep-rate light gas gun injector • Bench demo of superconducting sabot to enable advanced injector	• Build high accuracy injector • Demo with cryo capability



gas gun for initial injection studies

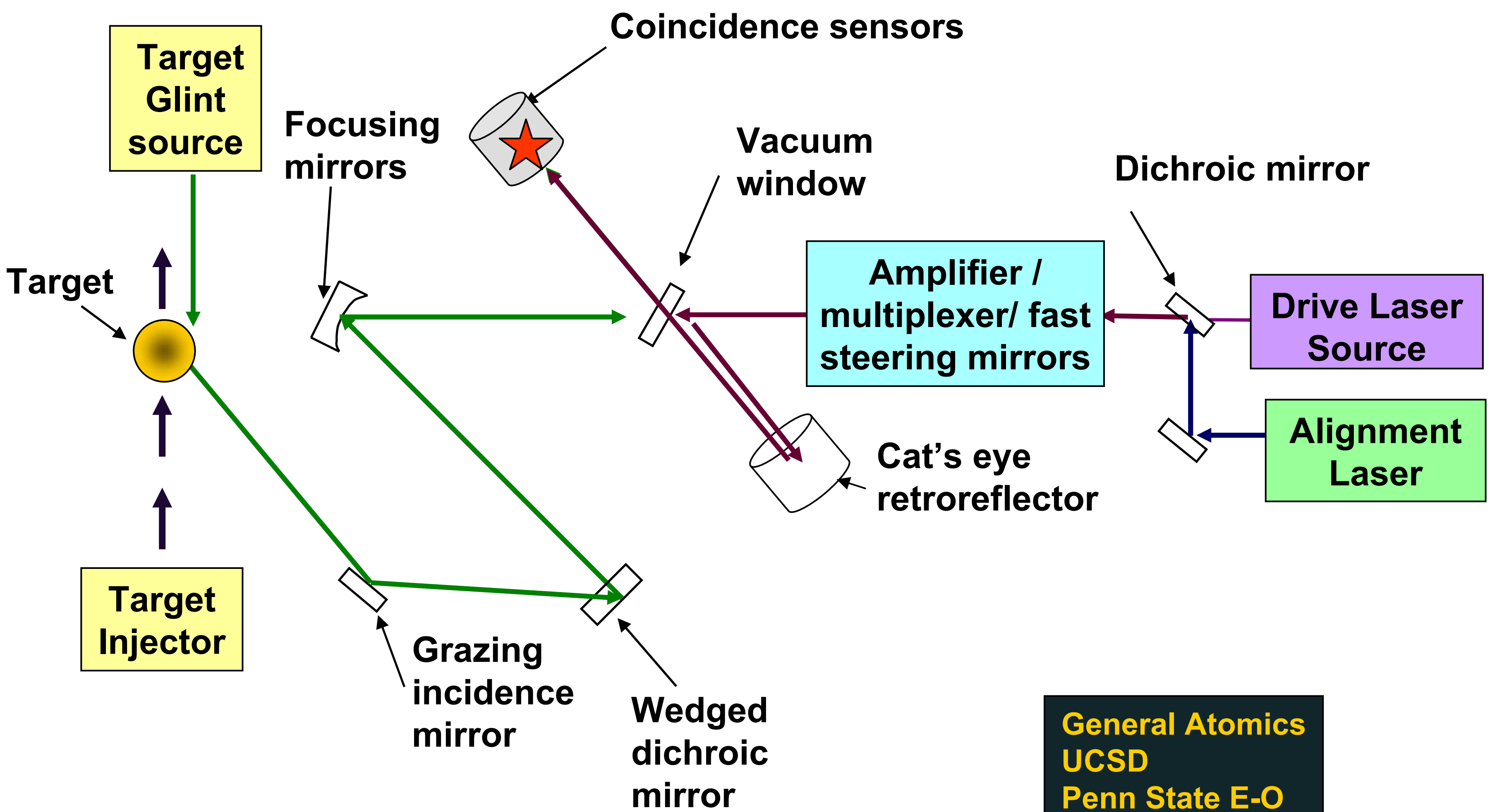
Target Engagement

START 2001	What we have done	What we still need
Minimal work on tracking of target or steering laser beams	• Bench demo of concept to track and engage target	• Improve engagement from 150 um to 20 um • Use a real target at right velocity • Full bench demo with injector

simulated driver beams steered to overfill target

Target engagement

- Concept: Use glint return off injected target to steer driver beams
- Bench tests: steered laser to hit falling target with 150 um accuracy (Need 20 um)



General Atomics
UCSD
Penn State E-O
A.E. Robson
NRL

Reaction Chamber

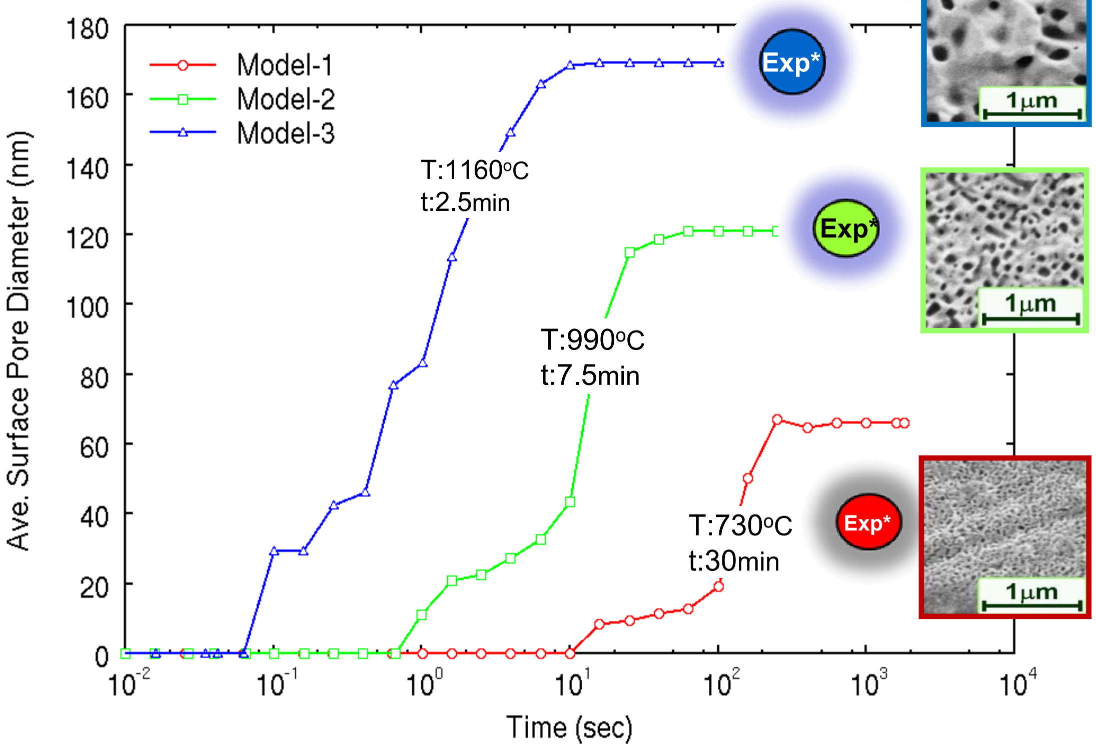
START 2001	What we have done	What we still need
Power Plant Studies to guide experiments	Tungsten armored LAF Steel wall concept Fielded many sources to study effect of emissions on wall Established: • Temperature limit • Armor/substrate bond • Conditions for target, wall, efficiency Unsolved: He ion exfoliation Possible Solutions: • Engineered materials • Magnetic Intervention to keep ions	Integrated chamber concept(s): • Engineered wall -and / or- • Magnetic Intervention

Tungsten sample irradiated with ions from the University of Wisconsin IEC Facility

An example of materials science performed in HAPL

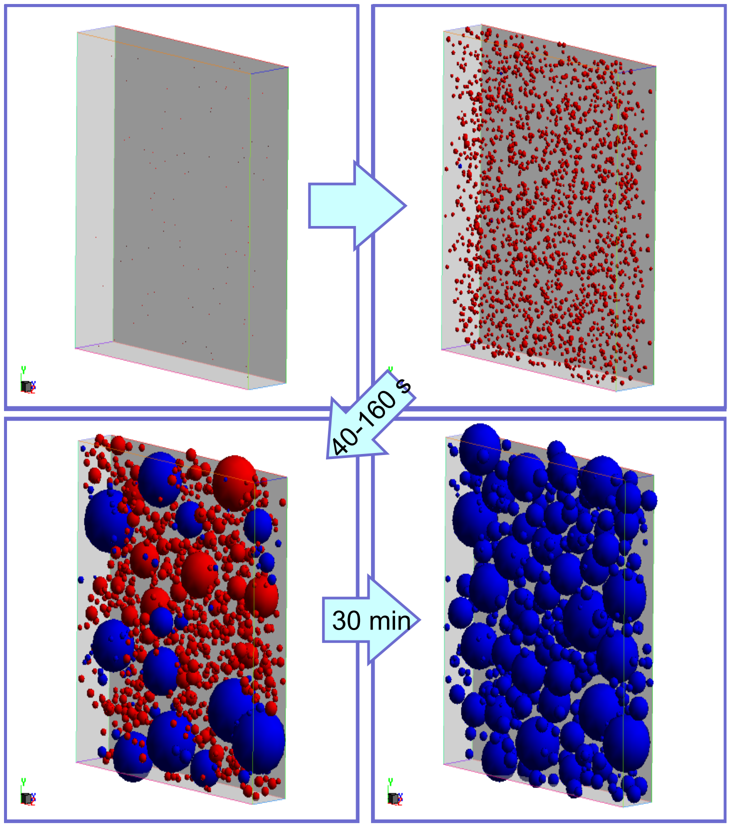
McHEROS Code Simulates IEC Surface Pores

	Temperature (°C)	Implantation Rate (He/cm^2-s)
Model-1	730	$2.2x10^{15}$
Model-2	990	$8.8x10^{15}$
Model-3	1160	$2.6x10^{16}$



UCLA, Wisconsin

$2.2x10^{15}$ He/cm^2-s; 730 °C; t:30min (IEC)

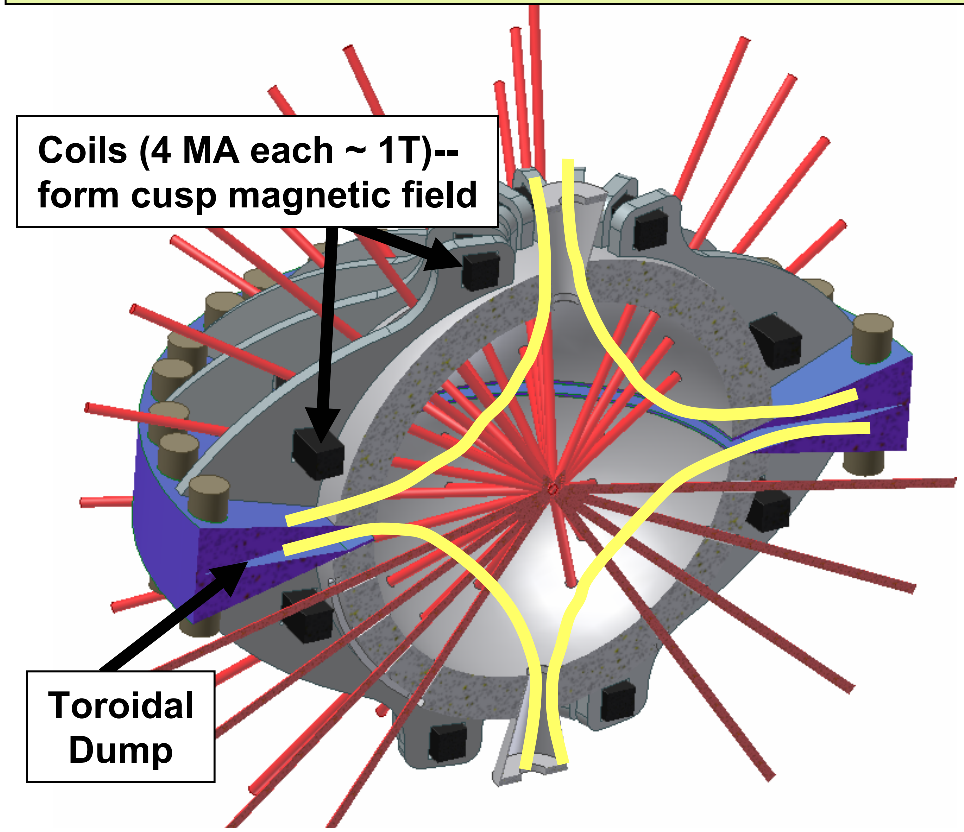


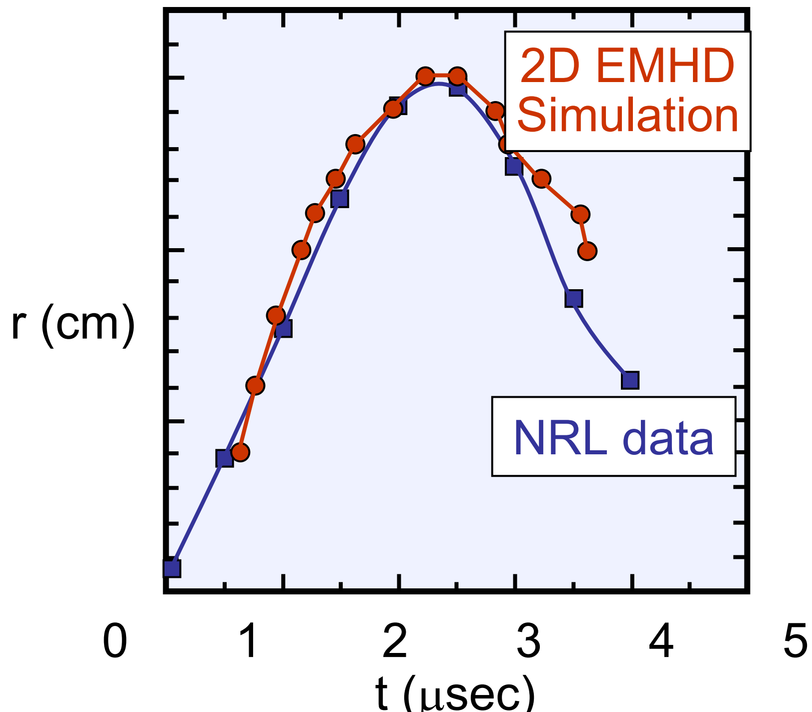
McHEROS Results:

- **Good Agreement between McHEROS Simulation and Experiment**
- **McHEROS provides an *EXPLANATION* for the oversized Surface Pores**

"Magnetic Intervention" offers a way to keep the ions off the wall

1. **Nuclear driven ions drag electrons, plasma stopped by magnetic pressure**
2. **Ions never hit the wall!**
3. **Ions, at reduced energy *and power,* escape cusp and absorbed in dumps**
4. **Physics demonstrated in 1979 NRL experiment***



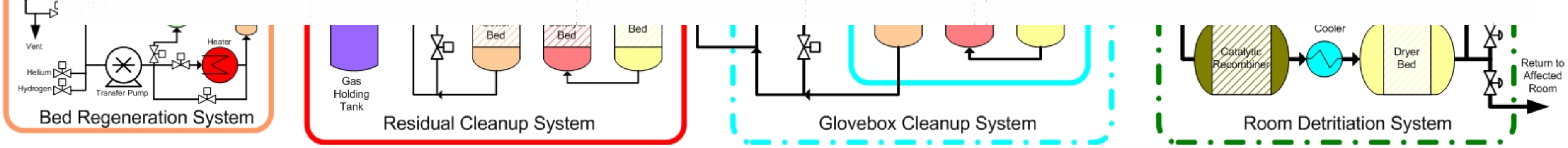


*R. E. Pechacek, *et al*., Phys. Rev. Lett. **45**, 256 (1980).

NRL, PPPL, UCSD, Wisconsin, Voss

Breeding, Pumping, Tritium handling

START 2001	What we have done	What we still need
Power Plant Studies	Designs for blanket using PbLi or FLIBE. • > 50% efficiency • sufficient T breeding Design for Tritium Handling System Design for Vacuum System Hydrogen production study	Power plant design study When we have an integrated picture. …and not before



PPPL Tritium Recovery System

Availability...or, just *how* robust is <u>*your*</u> concept?

Path to high availability:

- Simplicity
- Understress materials
- Robust design
- Test to destruction

And most importantly...

Have the attitude you <u>will</u> build something at the end of the day