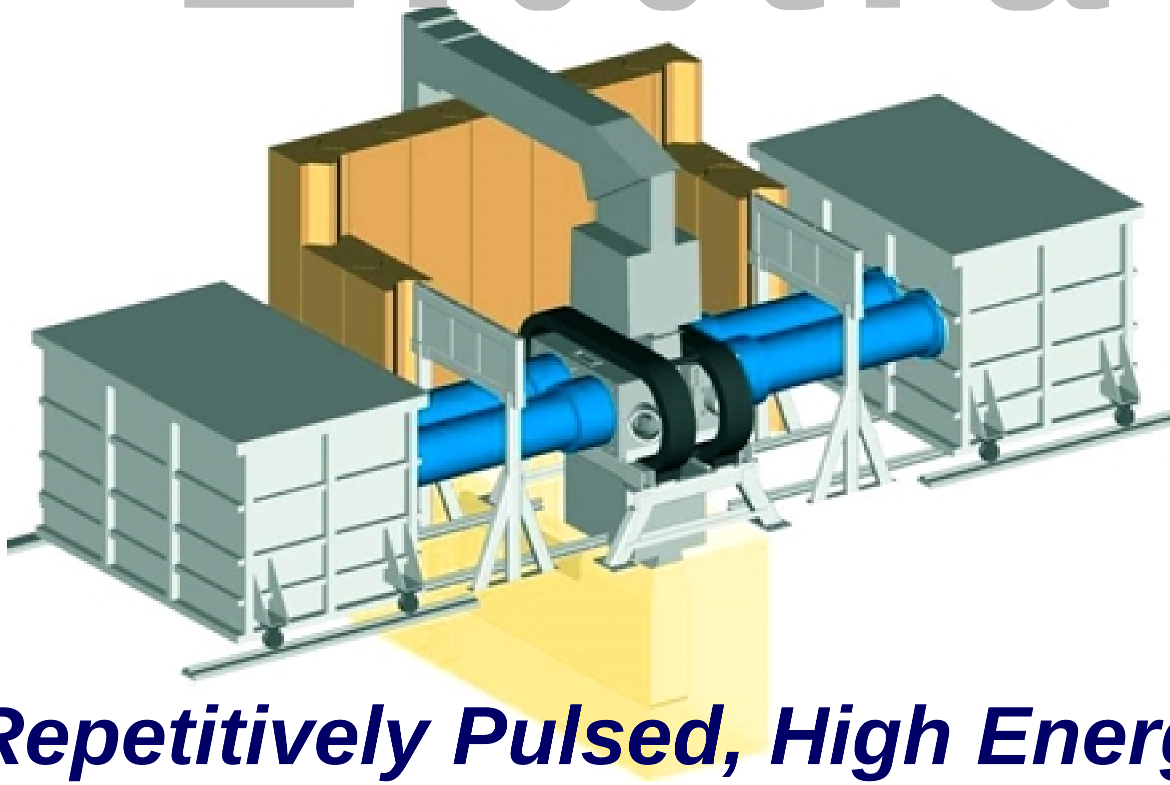
Electra



A Repetitively Pulsed, High Energy, Krypton Fluoride Laser for Inertial Fusion Energy

Naval Research Laboratory
November 13, 2001

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Work sponsored by DOE//NNSA/DP

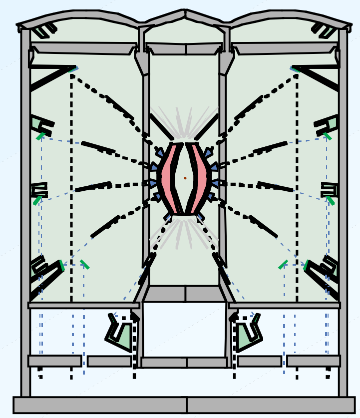
The Electra Program will develop the Science & Technology required to build a KrF Laser for Inertial Fusion Energy

Electra laser: 5 Hz, 30cm aperture, 400-600 J

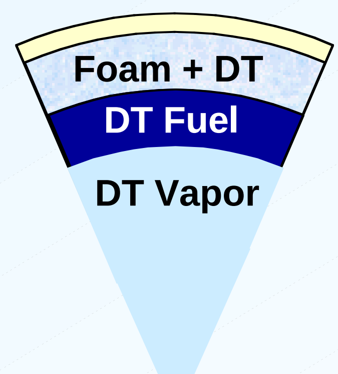
Build Electra by integrating each component as it is developed

Focus on technologies that can be scaled to ultimate goals*: determined by power plant studies and target designs*

laser energy	**50-150 kJ**
durability	**3 x 10^8 shots**
Rep-rate	**5-10 Hz**
efficiency	**6-7 %**
cost	**< $ 225/J**
beam non-uniformity	**< 0.2%**



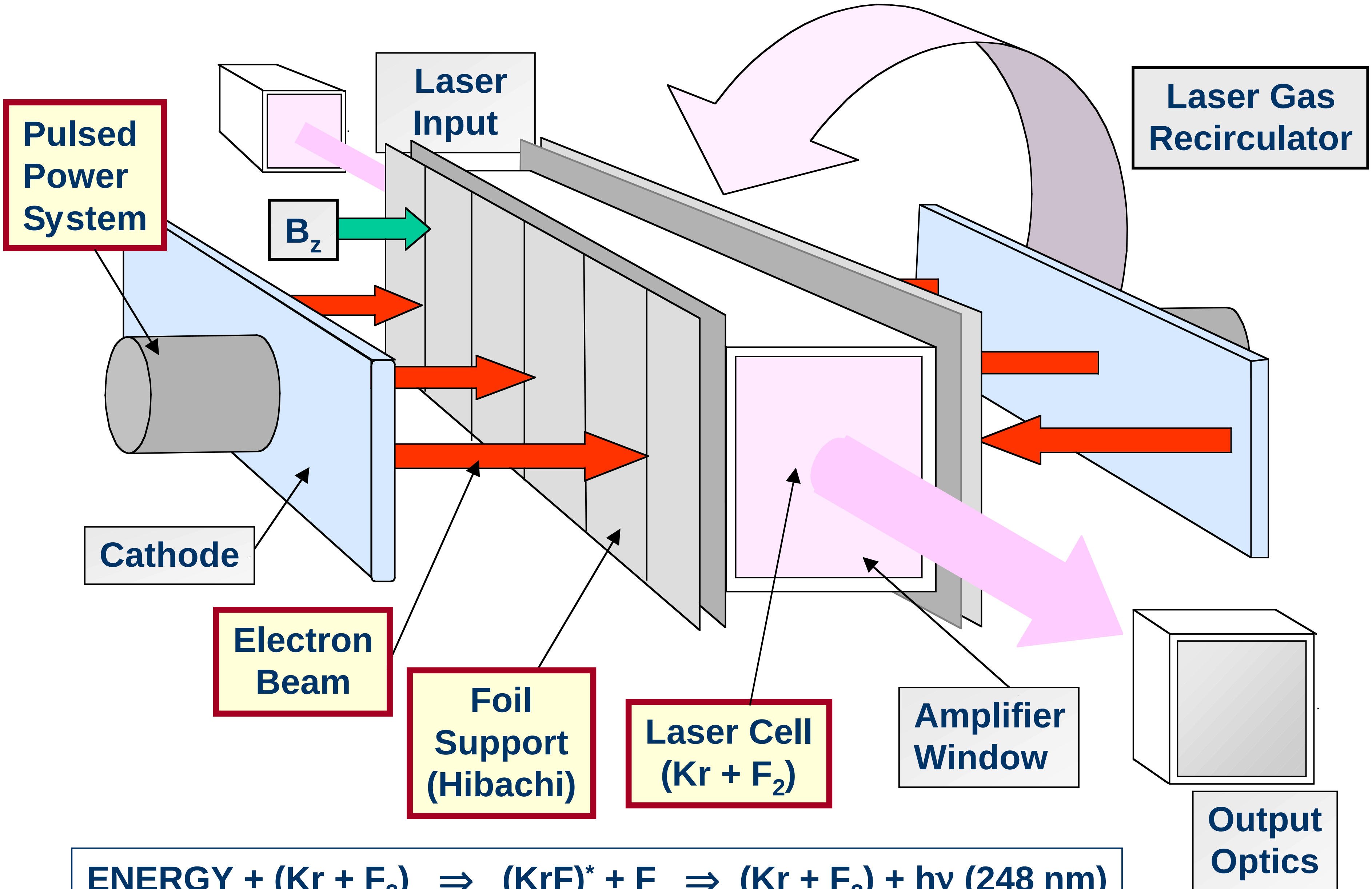
Power Plant Study [2]



Target Design (G >100) [1]

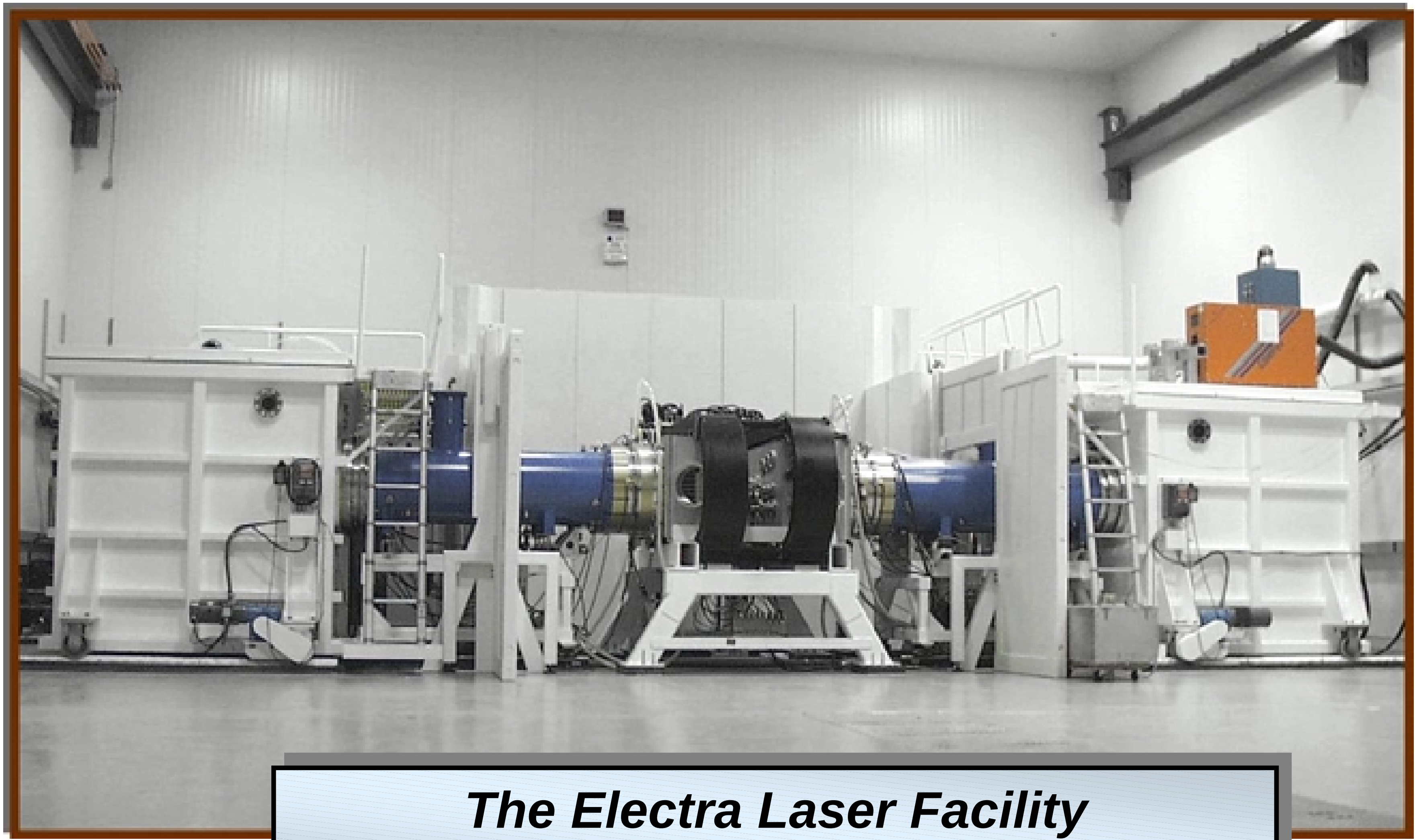
1. S.E. Bodner et al, ."Direct drive laser fusion; status and prospects", *Physics of Plasmas* **5,** 1901, (1998).
2. Sombrero: 1000 MWe, 3.4 MJ Laser, Gain 110; Cost of Electricity: $0.04-$0.08/kWh; Fusion Technology, **21**,1470, (1992)

The Key Components of a Krypton Fluoride (KrF) Laser



ENERGY + ($Kr + F_2$) $\Rightarrow$ $(KrF)^*$ + F $\Rightarrow$ ($Kr + F_2$) + hν (248 nm)

First Generation system can run 5 Hz for 5 hours
Excellent test bed for developing laser components



The Electra Laser Facility

500 keV, 100 kA, 100 nsec @ 5 Hz (x 2 sides = 50 kW)

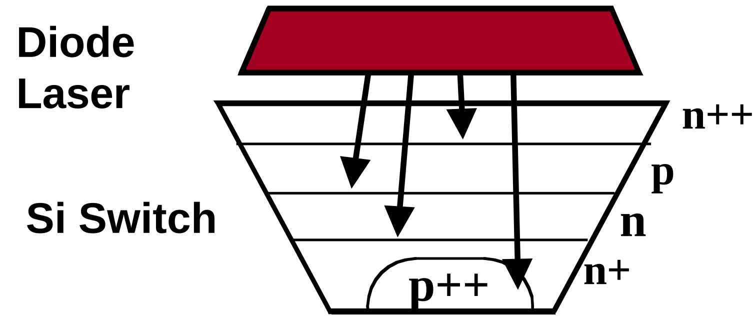
Advanced Pulsed power:
Proof of principle demo of laser gated solid state switch.
Can become basis for system that meets IFE requirements

Flood entire switch volume & junction with laser light.. Gives high turn-on (dI/dt)

Present hold-off > 3.2 kV,
advanced four layer device 16.7 kV

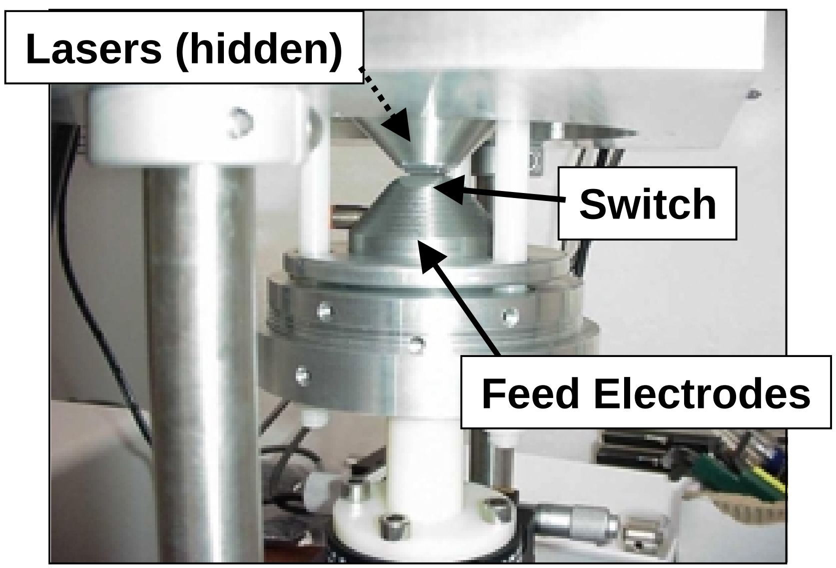
Series/parallel devices for higher V & I

Options for Electra System:
- Very fast Marx generators
- Marx/PFN

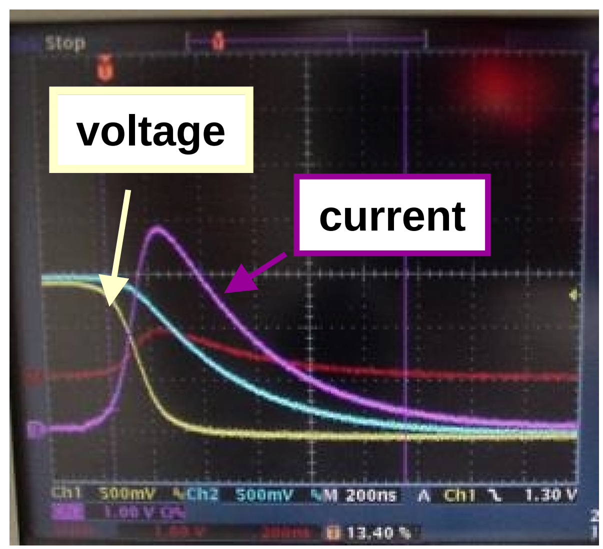


Photon λ ~ 1105 nm = 1.36 eV

I.E. Just above the band edge of the PN junction

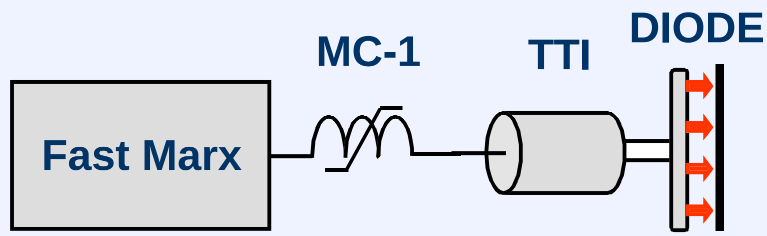


First switch results..it works!!!



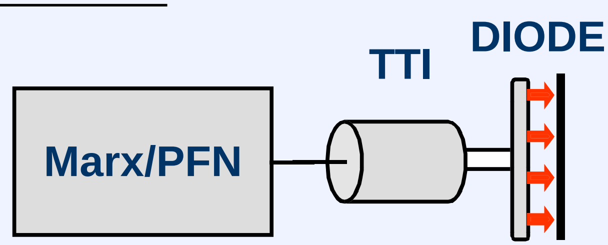
We are evaluating three pulsed power systems based on adv switch All have potential to meet IFE requirements (< $10.00/J, >80% eff)

Fast Marx w/ laser gated switches + 1 stage Magnetic Compressor



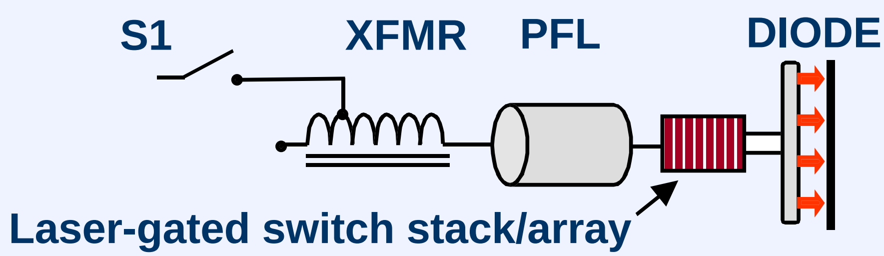
$ 7.15/J   85% eff

Marx / Pulse Forming Network



too new to evaluate cost and efficiency

Transformer + PFL + HV laser output switch

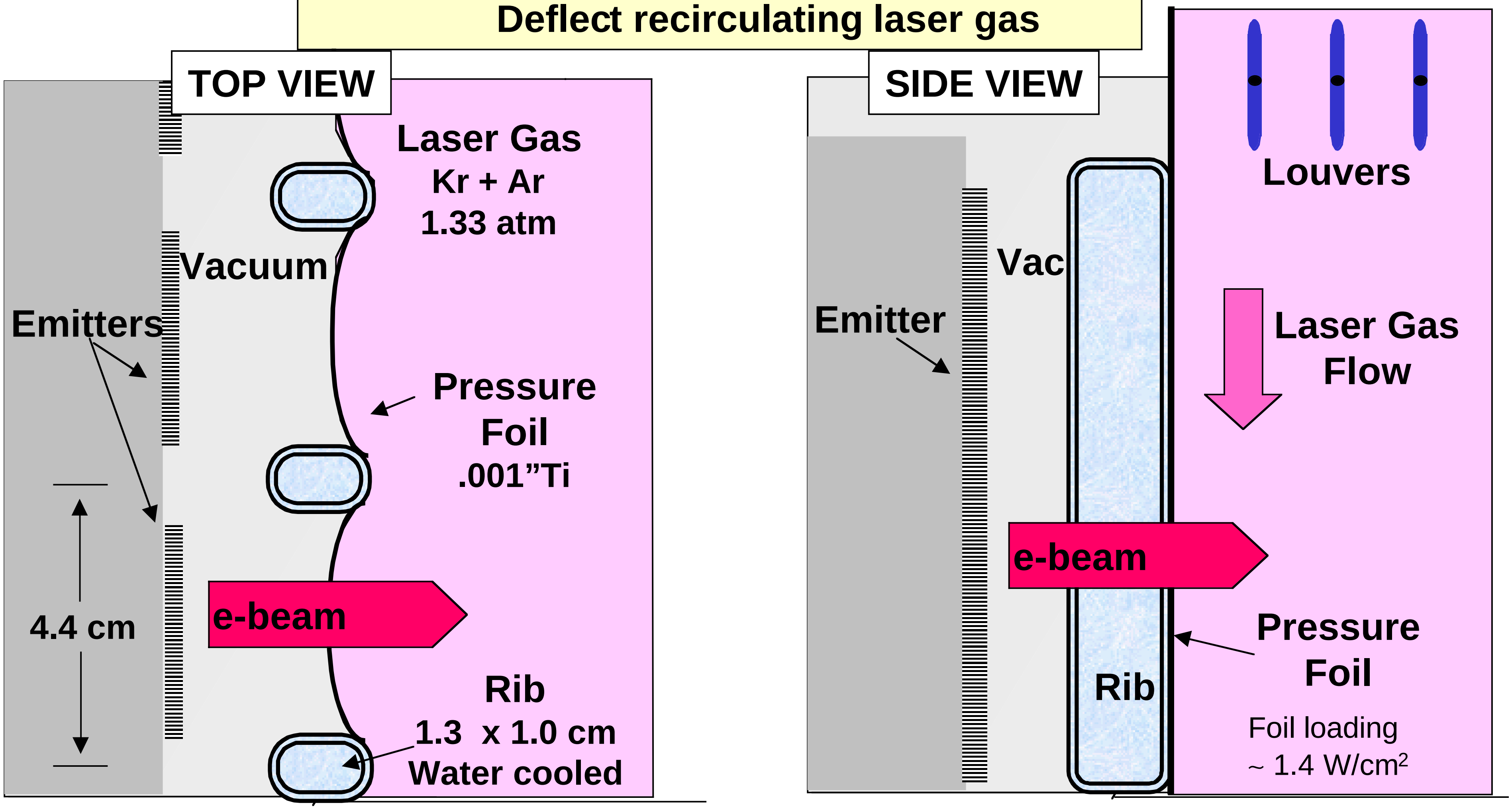


$ 8.35/J   87% eff

Notes:
Cost: $ / e-beam Joule, for 100 kJ systems in quantities, NOT Electra;
Efficiency: Flat top e-beam/wall plug

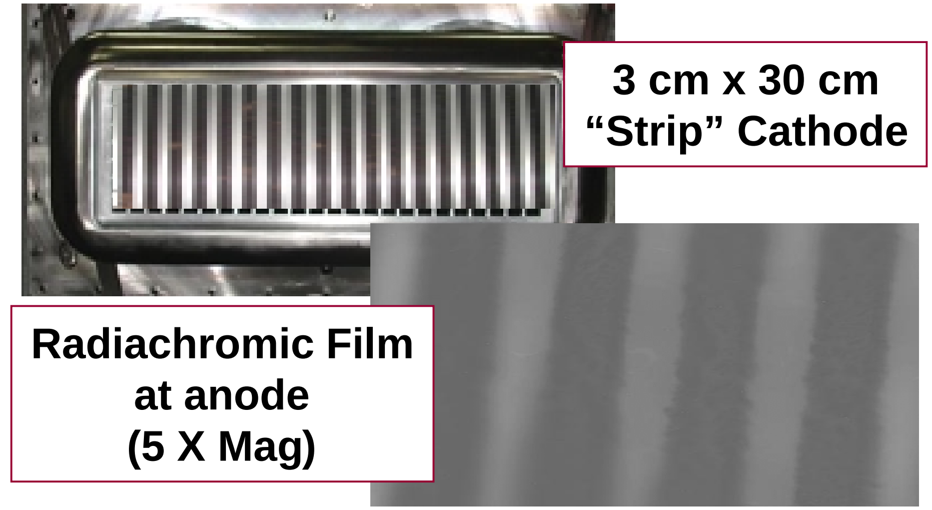
Hibachi:
We have identified a hibachi design that will allow high e-beam transmission, long life, and low power consumption

E-beam: Pattern emitter to miss hibachi ribs
Cooling: Flow water through ribs
Deflect recirculating laser gas

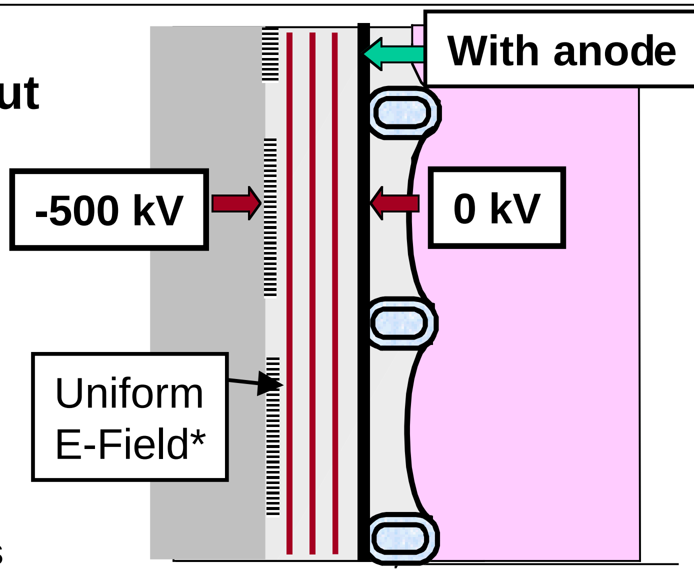


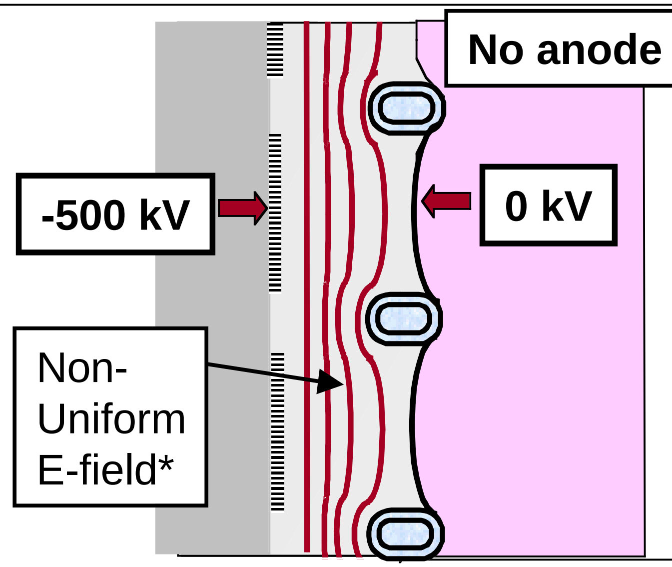
Hibachi concept has three main issues...

Can the beam be patterned and "rotation-compensated" to miss the ribs?



Can we run without an anode foil?



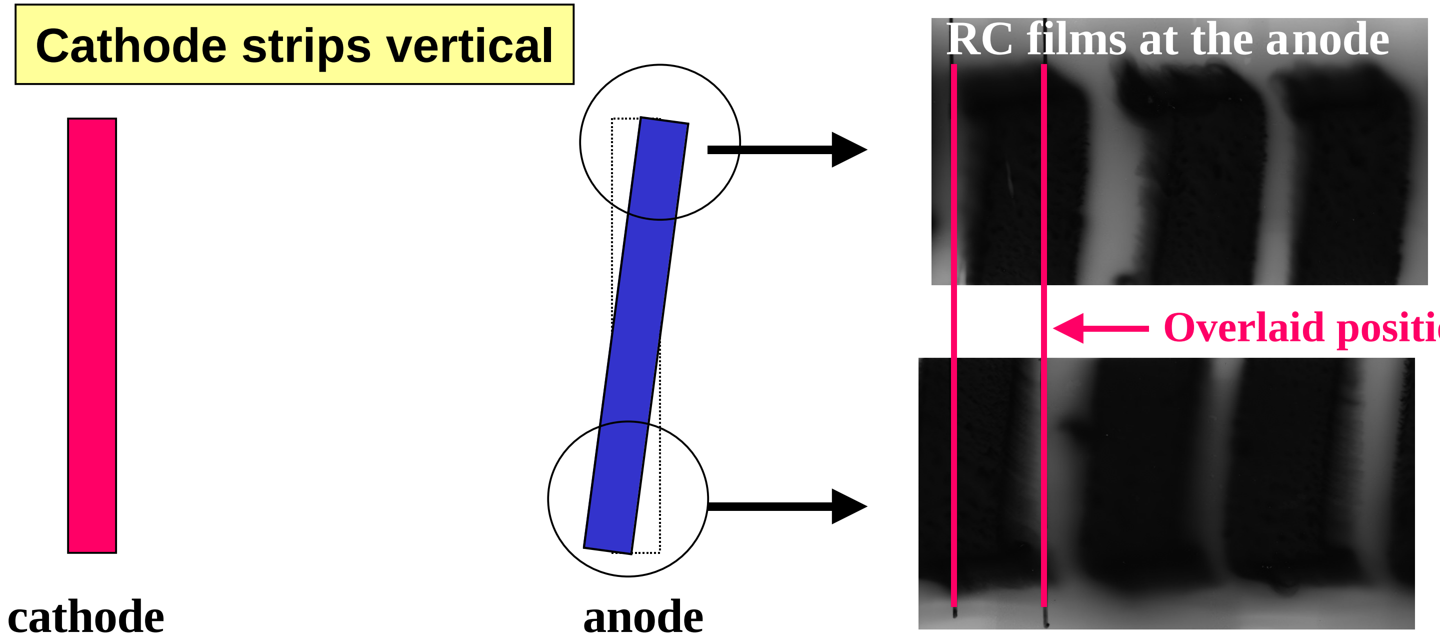


*lines show equipotentials

Can the laser gas be made to cool the hibachi foil?

We can get the beam through the ribs

Cathode strips vertical

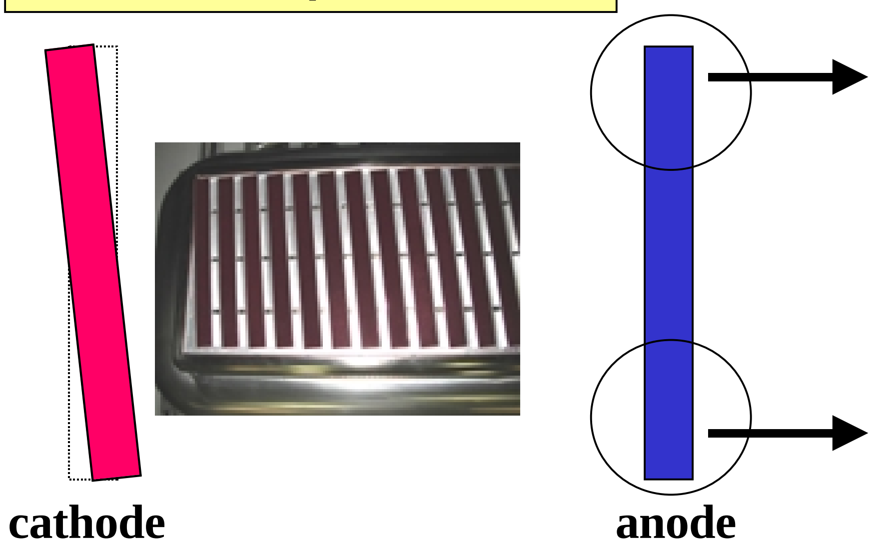


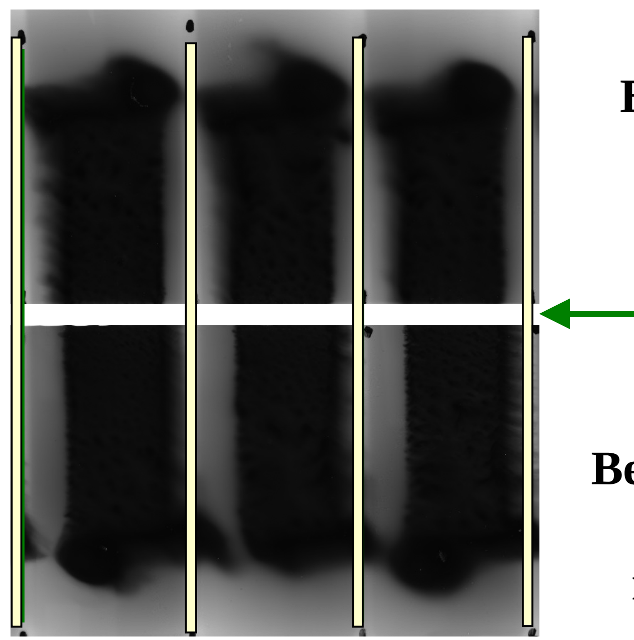
Overlaid position of a cathode strip

4° rotation at the anode

Part of the electron beam hits the ribs

Cathode strips rotated 4°





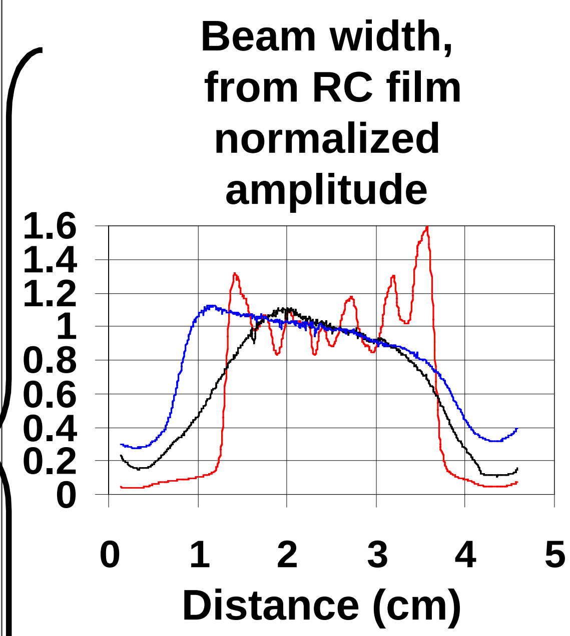
Beam enters the hibachi vertically

Rib positions

Beam losses at ribs are minimized

Current transmission through hibachi (I_{cell}/I_{diode}): *without* anode: 82% ---[effectively same as *with* anode (83%)]

	Anode	No anode
A. Total Diode Current [kA] (Current w/o anode lower-- larger A-K gap)	101	88.5
B. Allowance for beam "edge effect" (.92%)	92.9	81.4
C. Injected Beam current density [A/cm^2] (24 strips x 2.54 cm x 27 cm)	56.4	49.1
D. Width of beam into laser cell [cm]	2.61	3.15
E. Area correction factor (2.54/D)	.97	.81
F. Expected current density (C x E) [A/cm^2]	54.9	39.5
G. Faraday Cup expected current density (FC foil loses 5% current)	51.2	37.5
H. Measured current density	43.3	30.8
I. Hibachi current trans efficiency (H/I) (≡ Current into cell/diode current)	**83%**	**82%**



$J_{laser\ cell}$ (FWHM)	
at cathode (not shown)	2.54
into hibachi (red)	2.37
into cell	
with anode (black)	2.61
No anode (blue)	3.15

Expect higher transmission in final design:
1. shallower ribs (less rotation, more uniform E)
2. thinner pressure foil (1 mil vs 2 mil)

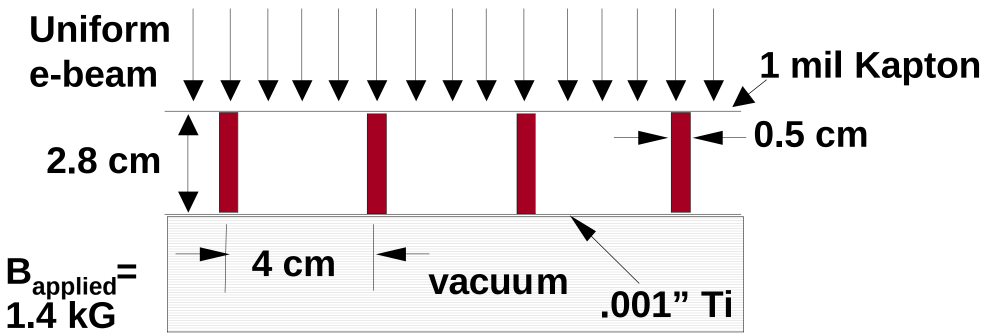
Modeling predicts energy deposition efficiency (e-beam into gas) is 74% @ 500 keV…(and greater than 80% at 750 keV)

Full 3-D Monte-Carlo Simulations,

…..includes losses due to beam rotation, ribs, back-scattered electrons

PART 1: BENCHMARK CODE WITH SIMPLE EXPT:

…..Uniform beam through hibachi



RESULTS:

Current Transmission Efficiency

Predicted: 76%

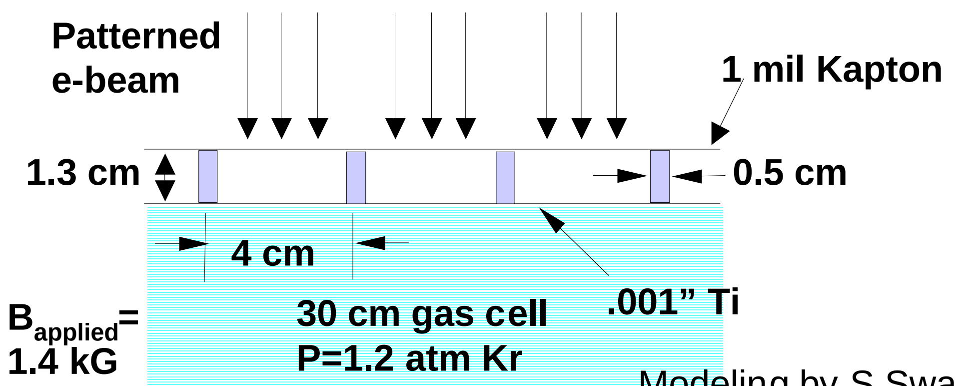
Measured: 76%

PART 2: MODEL THE WHOLE THING:

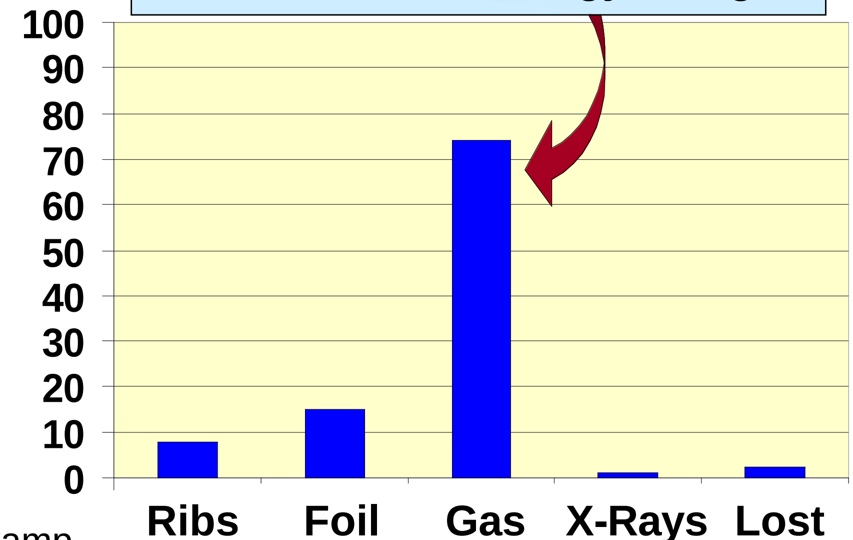
Transmission through hibachi

Patterned electron beam

Deposition in gas

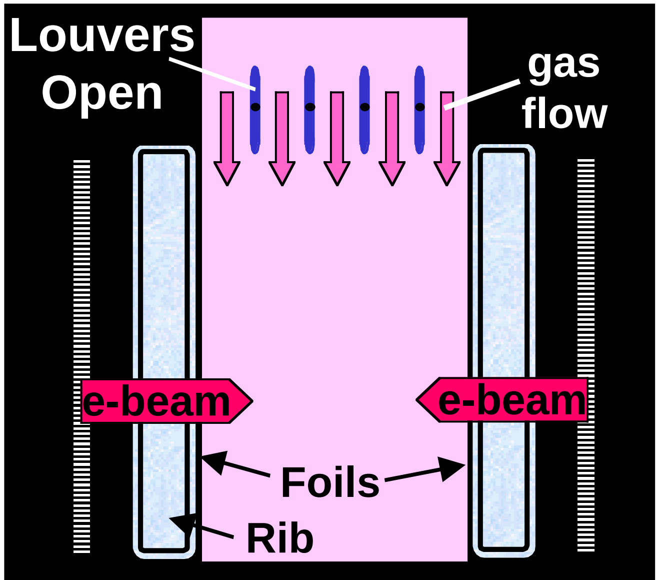


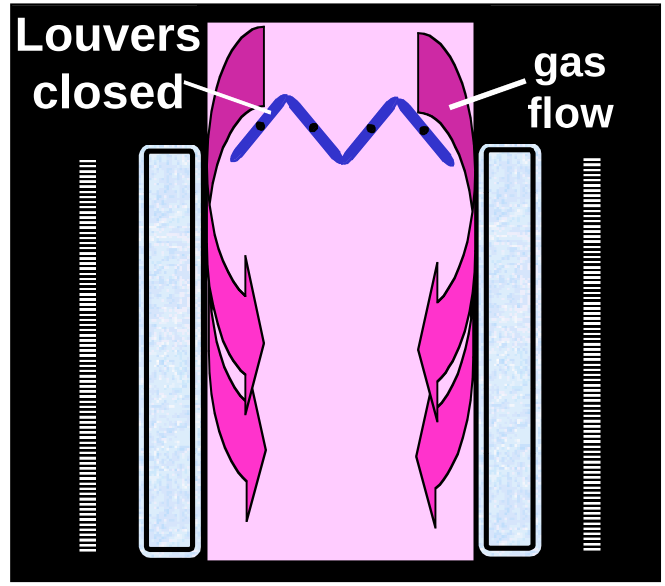
RESULTS: 74% energy into gas



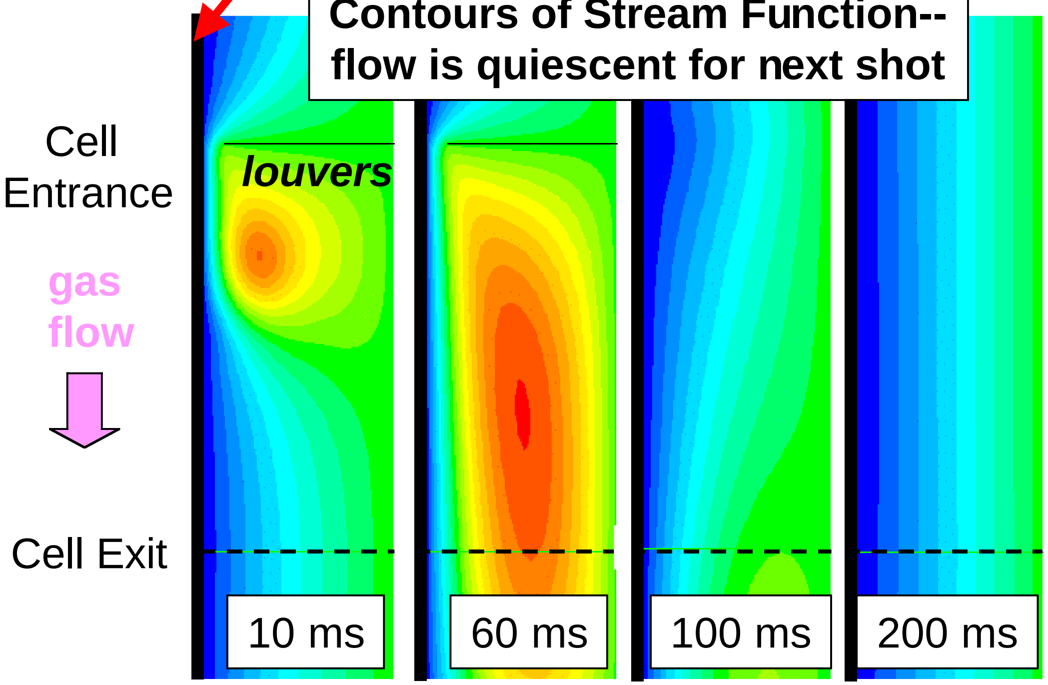
Modeling by S Swanekamp

The recirculating laser gas can be used to cool the Hibachi

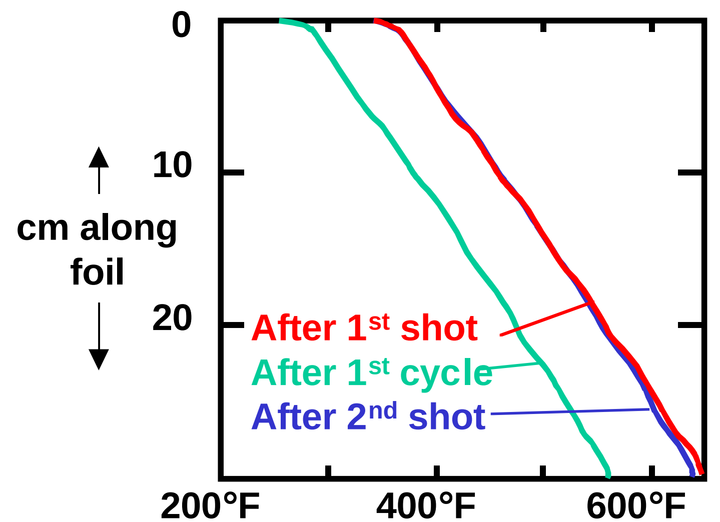




Contours of Stream Function-- flow is quiescent for next shot



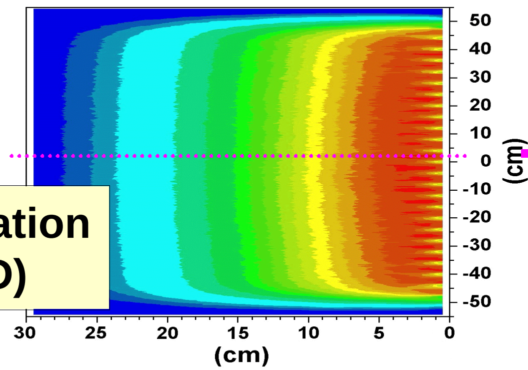
Foil Temperature below required 650°F



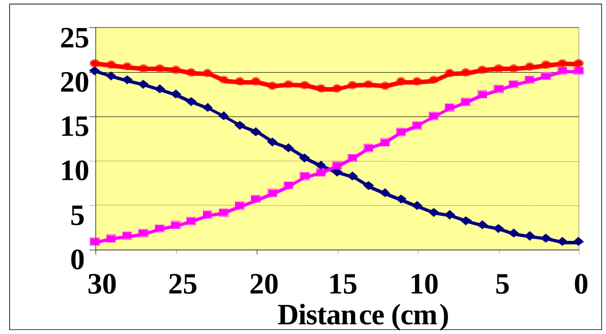
Concept & Modeling:
A.Banka & J.Mansfield, Airflow Sciences, Inc

Measured e-beam deposition in cell agrees with simulations

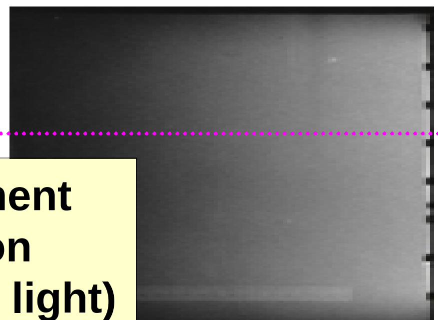
ENERGY



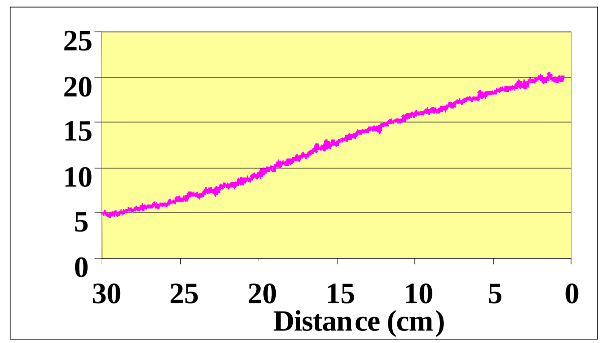
Simulation
(2-D)



Calculated Deposited Energy (eV/cm-electron)



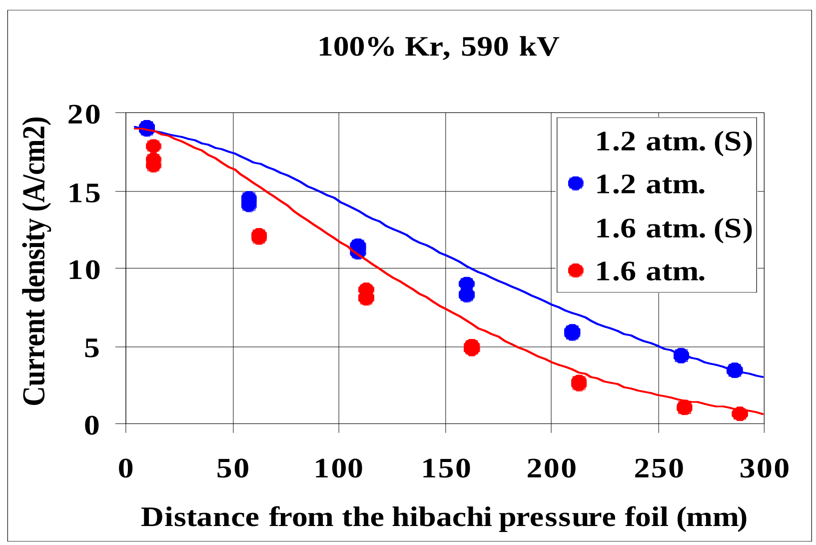
Experiment
(end on
integrated light)



Normalized Light Intensity

CURRENT

Comparison of measured and calculated (1-D) current vs distance across the laser cell



ORESTES: laser amplifier physics code

Radiation Hydrodynamics
NRL
Laser Physics

objectives.......provide reliable system scaling,
calculate pulse shaping,
understand & improve efficiency.

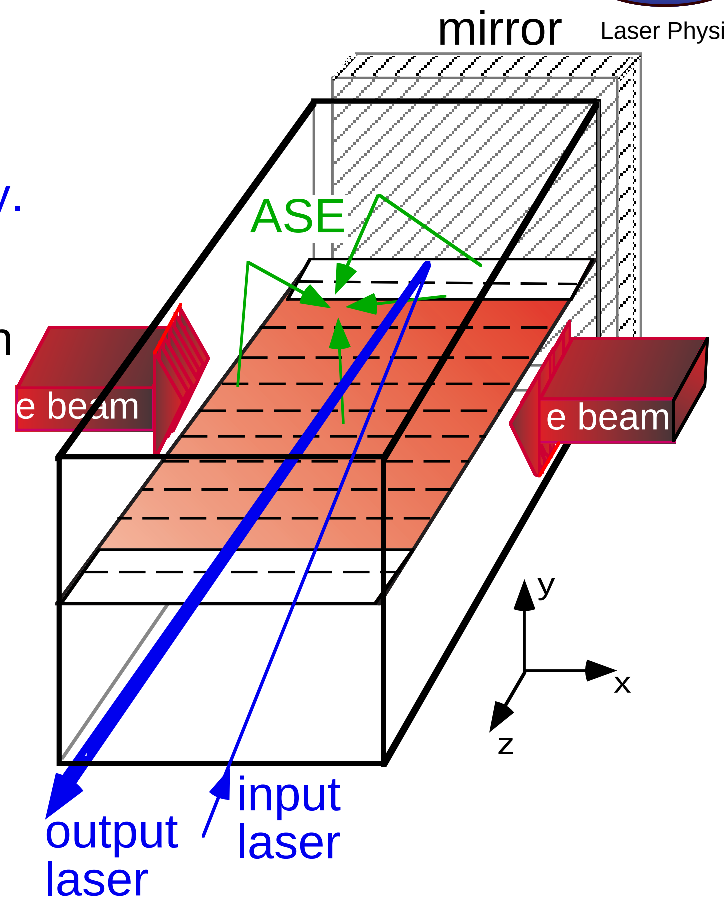
e-beam..........assume uniform deposition
Boltzmann analysis for ionization
and excitation.

plasma..........1-D axially resolved
complete energy accounting
T_e and T_g, n_e, species, ...

kinetics.........automated chemistry solver
e.g, 24 species + 20 KrF(v),
122 reactions.

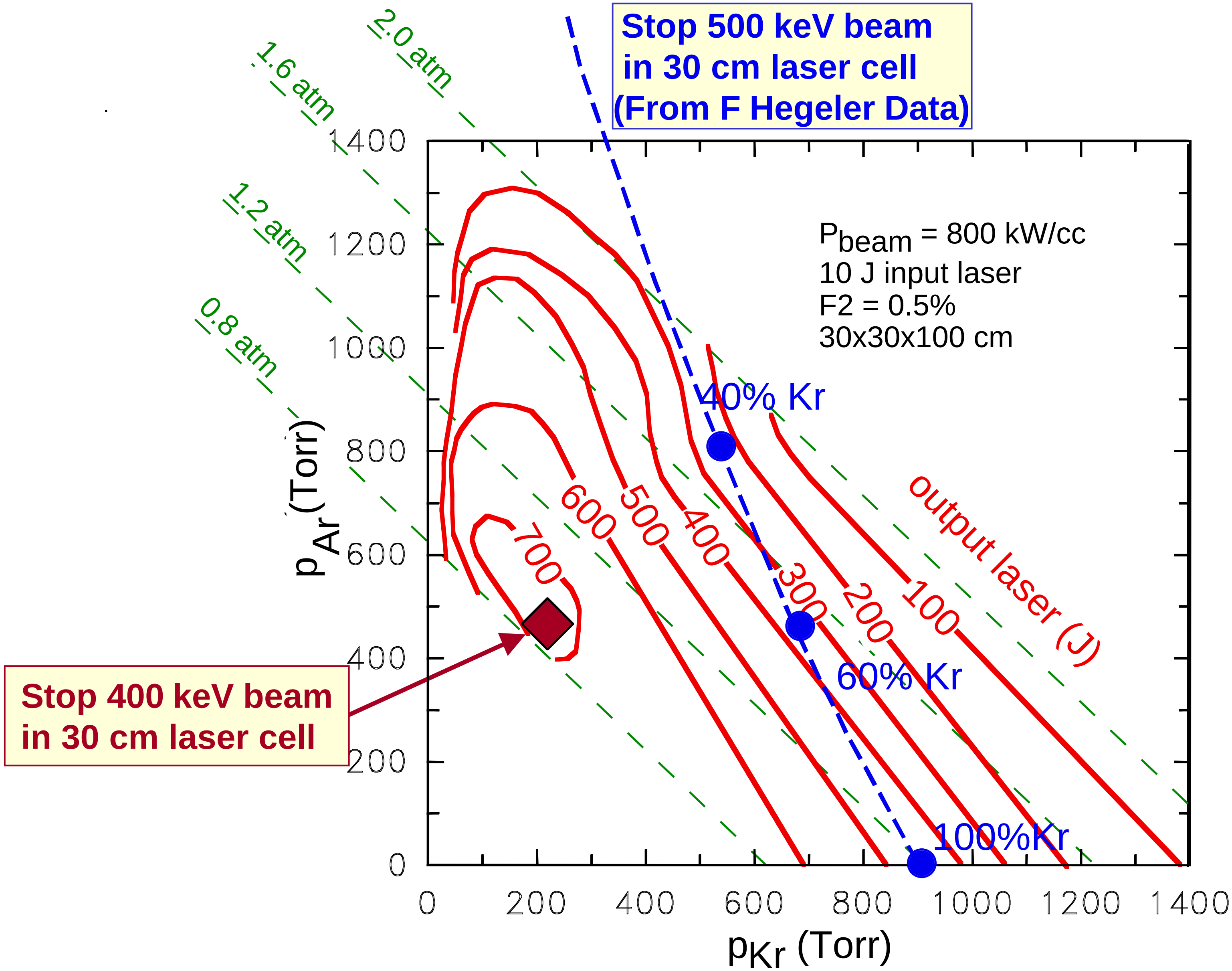
lasing............method of characteristics
for laser transport.

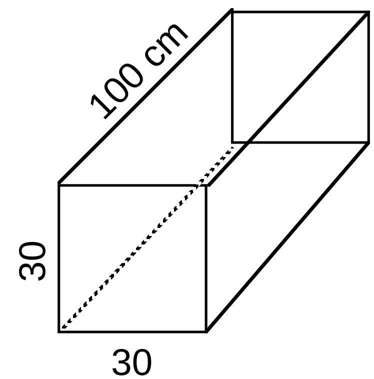
ASE..............3-D, discrete ordinate,
time dependent, local look-back approach
with 8 pt interpolator;
future --> FFT/FCT for parasitics.



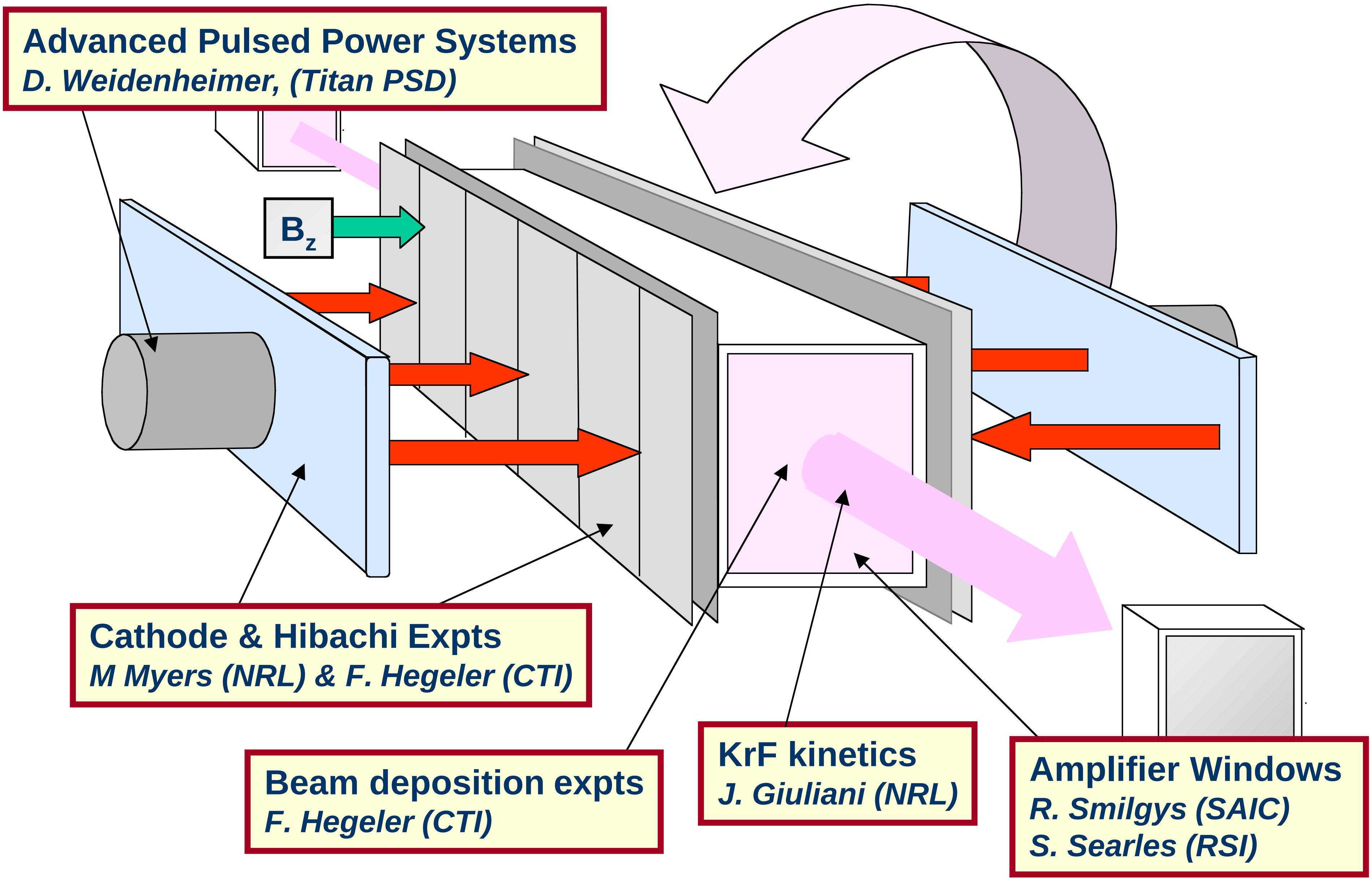
ORESTES predicted laser yield vs pressure and composition for ELECTRA.

Laser Physics
NRL
Radiation Hydrodynamics





Poster Presentations on Electra



Summary

Fully operating facility for laser component R & D

Advanced Pulsed Power switch demonstrated
  Can be basis for efficient, cost effective pulsed power

Viable hibachi design:
  Pattern beam to miss ribs,
  Use periodic deflection of laser gas for cooling
  Looks like it can meet transmission requirements

Electron beam deposition experiments agree with code

KrF Physics code "ORESTES" giving us tool for predicting and possibly improving laser output

Meeting the IFE efficiency requirements is a challenge… but achievable

Efficiency Goal: 6-7%

Efficiency allocation:		How we get there	Current status
Pulsed power	80%	Advanced PP design-- 87%	RHEPP 63%
Hibachi	80%	Cool Tube Hibachi-- 85%	Nike~ 50%
Ancillaries	95%	Electra + Study[1]	N/A
Intrinsic	10-12%	KrF physics[2] -- 12%	14-15%(small systems)[3,4] 12% predicted from Nike kinetics code[5]
TOTAL	6-7%		7% Nike (not optimal η)

1. Electra will validate technology. Efficiency and cost will be established with modeling from Electra results
2. $\eta_{intrinsic} = \eta_{formation}$ (25-28%) x $\eta_{extraction;}$ (40-50%) = (10-14%). Optimize extraction by increasing gain-to-loss
3. "KrF Laser Studies at High Krypton Density" A.E. Mandl et al, Fusion Technology 11, 542 (1987).
4. Characteristics of an electron beam pumped KrF amplifier with atmospheric pressure Kr-rich mixture in strongly saturated region", A. Suda et al, Appl. Phys. Lett, 218 (1987)
5. M.W. McGeoch et al, *Fusion Technology*, 32, 610 1997