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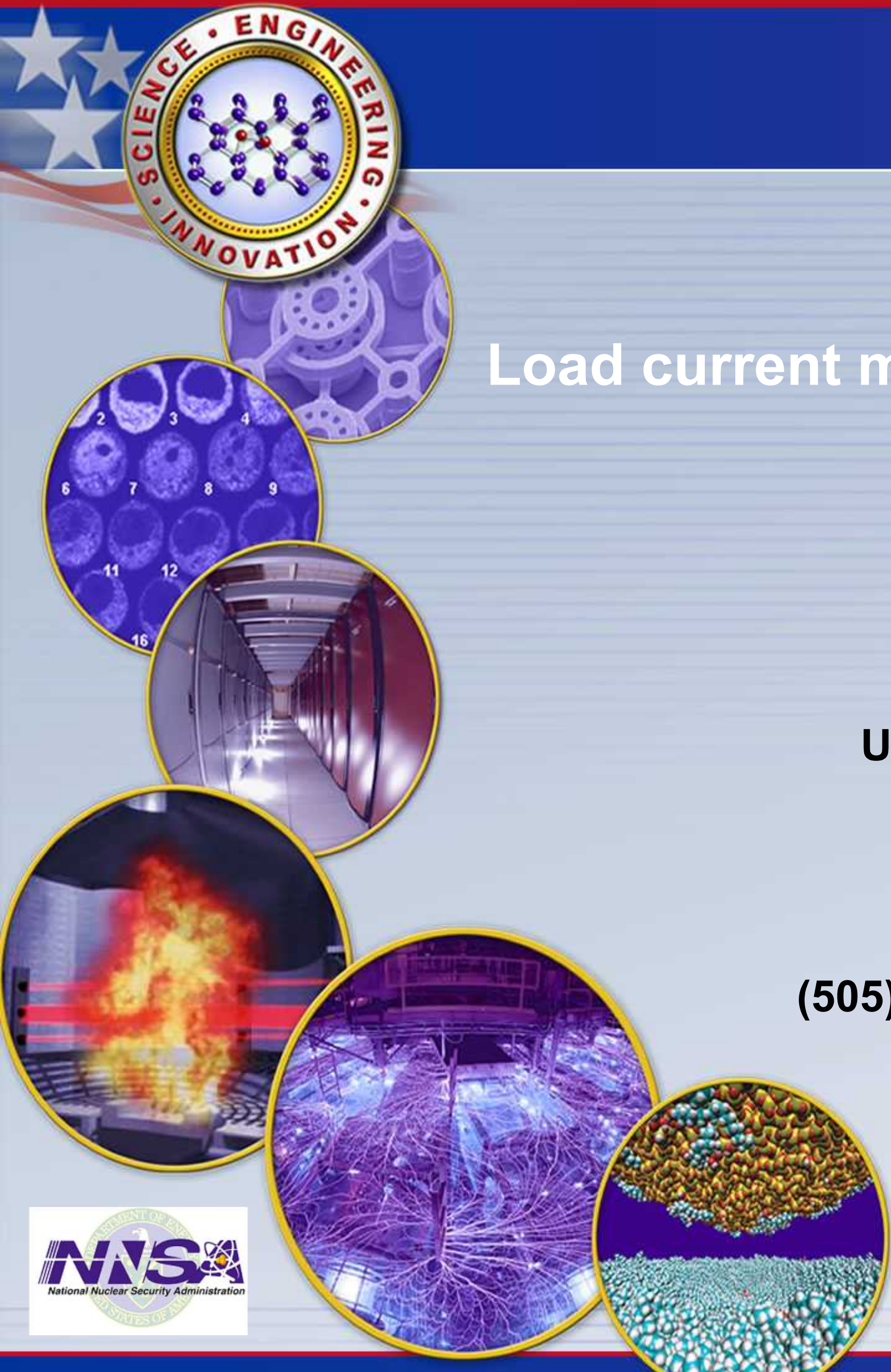

# Load current multiplier development at Reno and Sandia

US DOE/French DGA Workshop

April 25th, 2008

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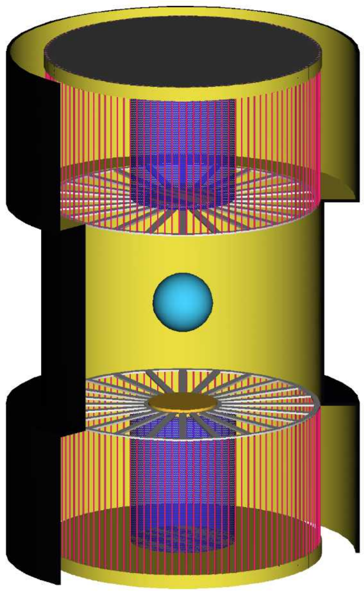
# Load current multiplier development at Reno and Sandia

- Reno Experiments:
  - A. Chuvatin (Ecole Polytechnique)
  - V. Kantsyrev (UNR)
  - L. Rudakov (Icarus)

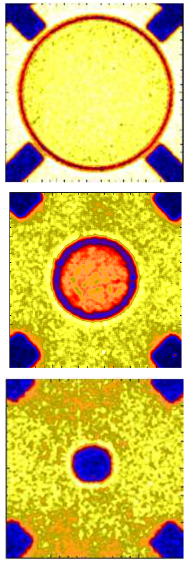
- Sandia Z Plans
  - A. Chuvatin (Ecole Polytechnique)
  - M. E. Cuneo (SNL)
  - T. D. Pointon, T. Haill, R. W. Lemke, W. Langston, M. Savage, W. A. Sygar, E. M. Waisman, K. Mikkelson, A. Owen (SNL)
  - D. V. Rose, D. Welch (Voss)

# We need validated, predictive pinch designs for pulse shaping, energy and power scaling for double pinch ICF

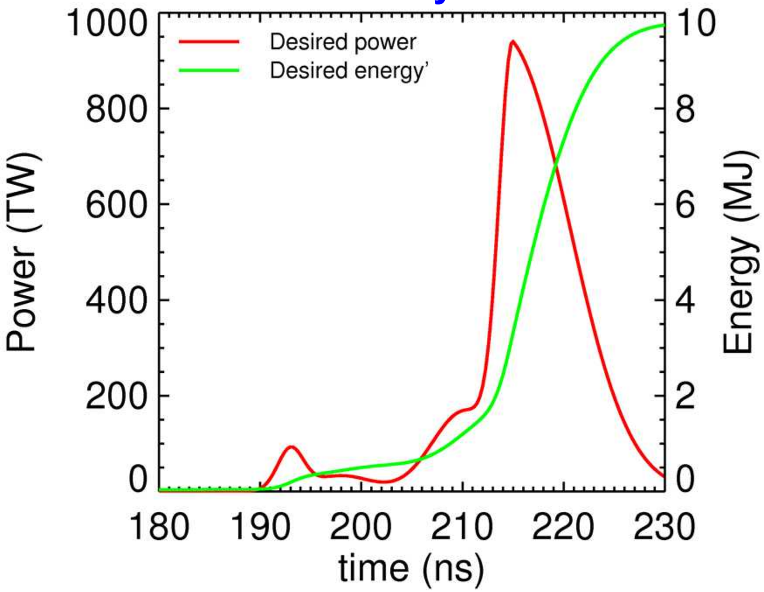


**250 eV Primary Hohlraums**

**210-225 eV secondary**



**R.A. Vesey et al**




- **Power scaling (1 PW/pinch @ 20-mm-diam.)**
- **Energy scaling (8 MJ/pinch)**
- **Capsule acceptance (9 to 14 ns)**
- **Radiation pulse shaping (3 steps)**
- **Shot-to-shot variations (2.5 to 5%)**
- **AK gap feed closure scaling (250 eV feed)**

**Possible implosion times:**

**60, 120, 240 ns**

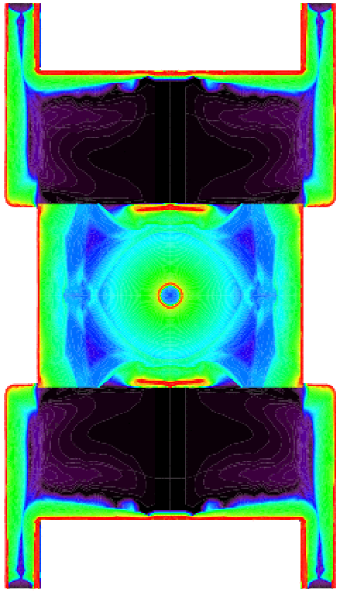
**Possible architectures:**

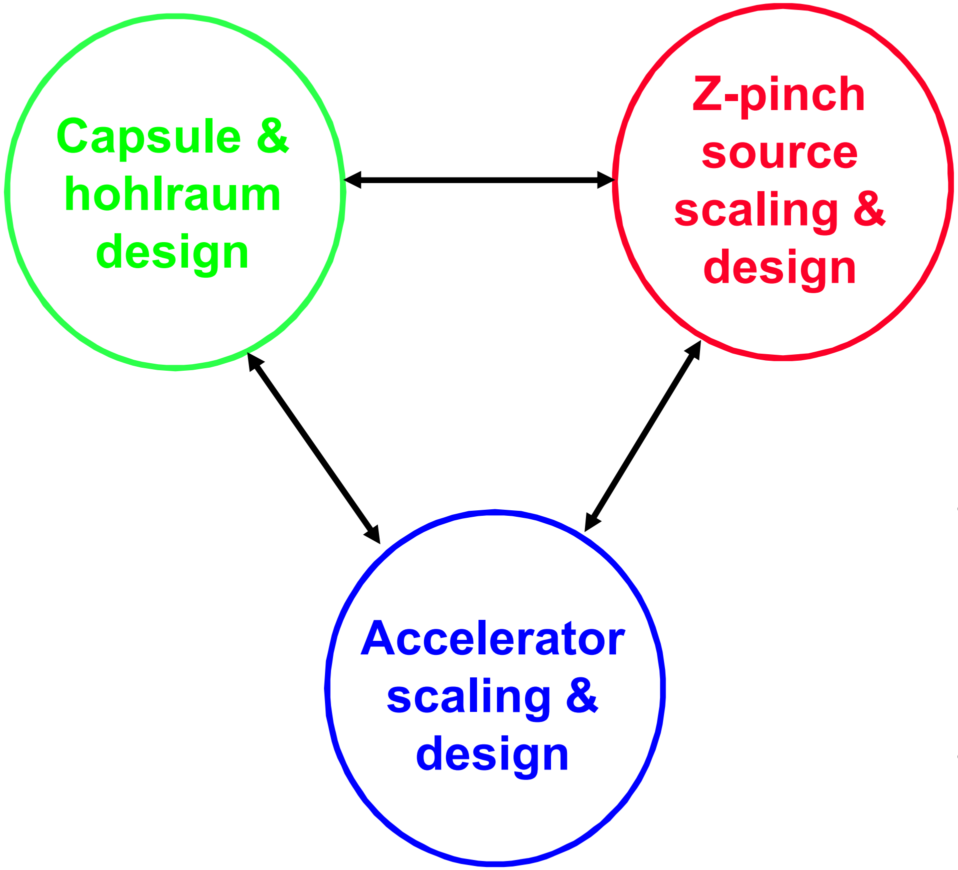
**Array on array**

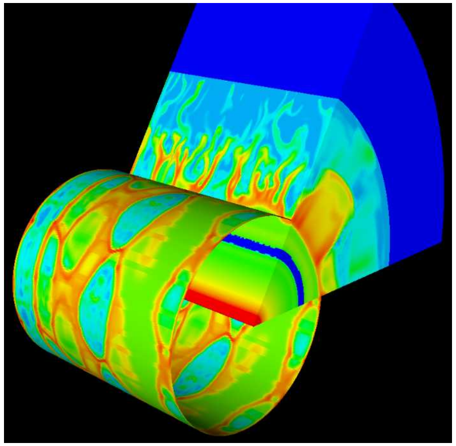
**Array on foil**

**Foil on foil**

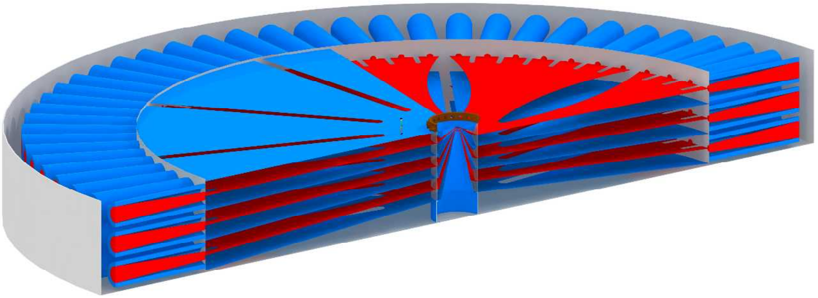
# Our goal is a validated high yield indirect drive ICF design





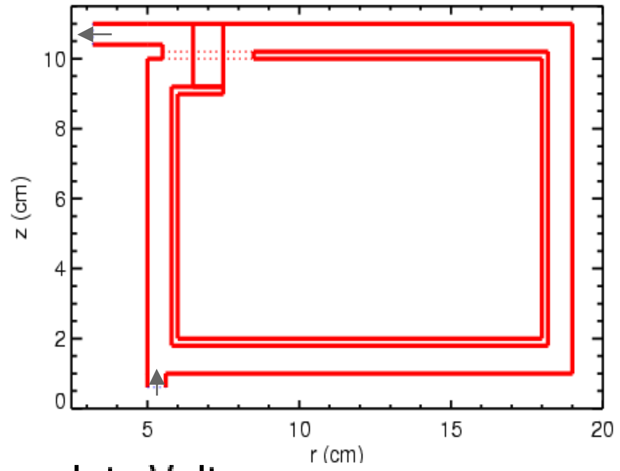
- Z-pinch design is the most uncertain aspect of a validated high yield design
- Designs must explore capsule, pinch and accelerator performance, cost and technology tradeoffs



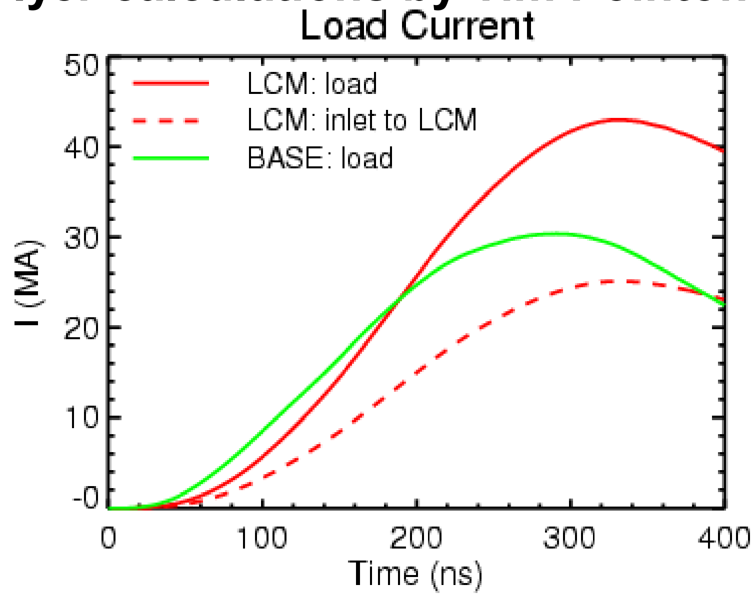
# High risk/high payoff development

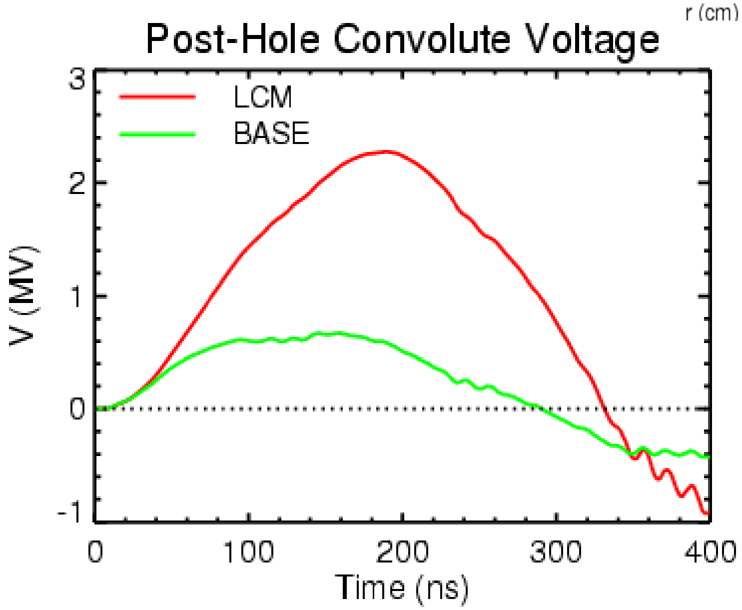
- Saturn and Z design show convolute current loss possible fatal flaw for short pulse low impedance drivers
- Load current multiplier pulsed power and load designs
  - Larger diameter, optimized current convolutes
  - Convolute cleaning techniques
  - Optimized LCM designs
  - Optimized low inductance ICE loads
  - Low inductance z-pinch loads

**Early non-optimal design (Chuvatin)**




**LCM/Flyer calculations by Tim Pointon**

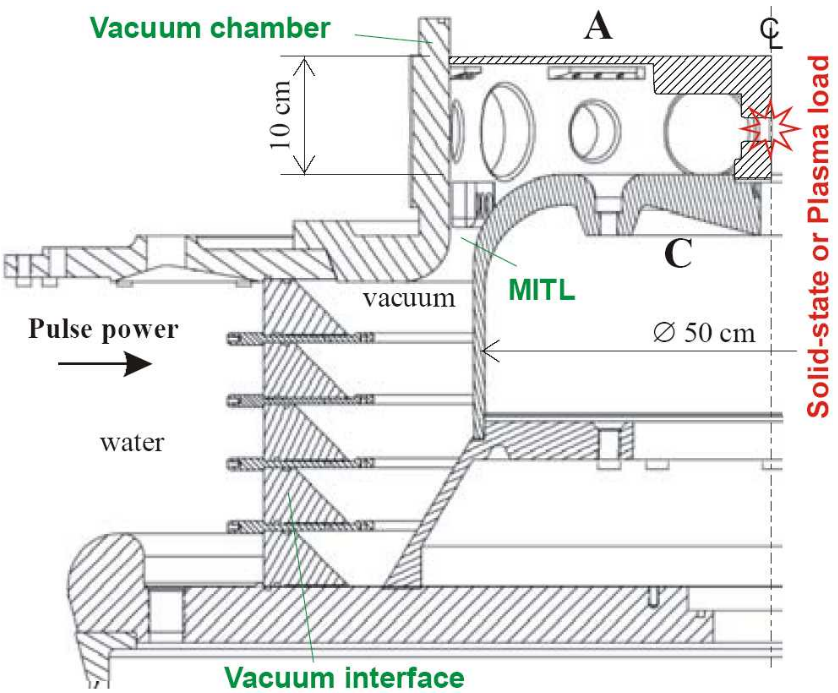


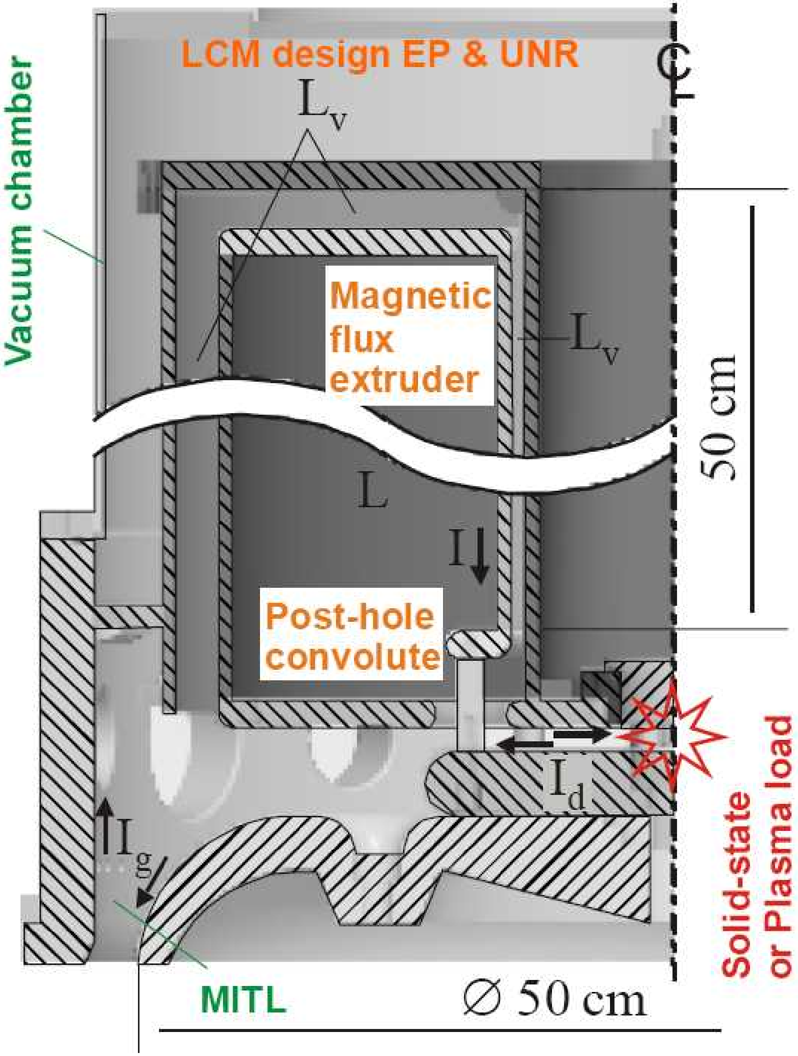




**Convolute voltage with LCM in long pulse is as high as convolute voltage in short pulse without LCM - so there is some hope this is possible**

# High electric field at the convolutes in short pulse were recognized as the most serious limitation

Chuvatin design




- Validate LCM concept on a short pulse generator - UNR Reno on ZEBRA at (1.9 W, Voc ~ 2 MV, 100 ns)
- Sandia sponsored collaboration with Victor Kantsyrev (UNR), Sasha Chuvatin (Ecole Polytechnique) and Icarus (Leonid Rudakov)

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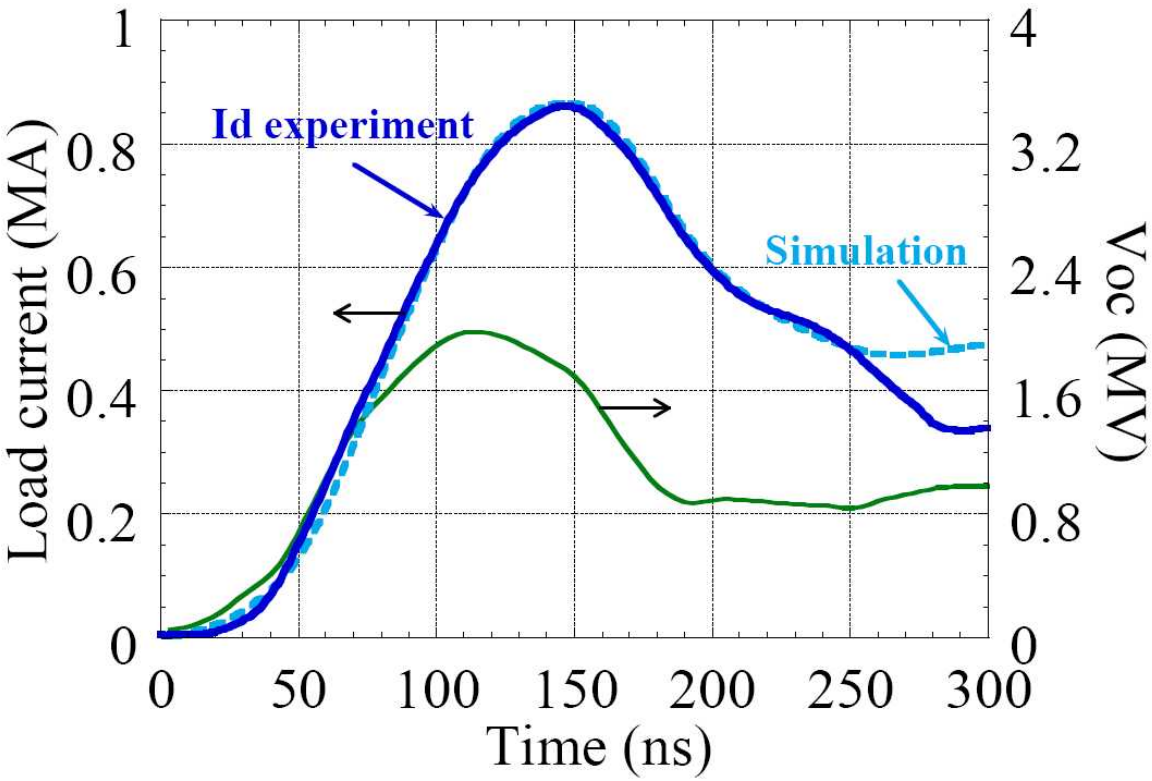
# This is the nominal performance of ZEBRA

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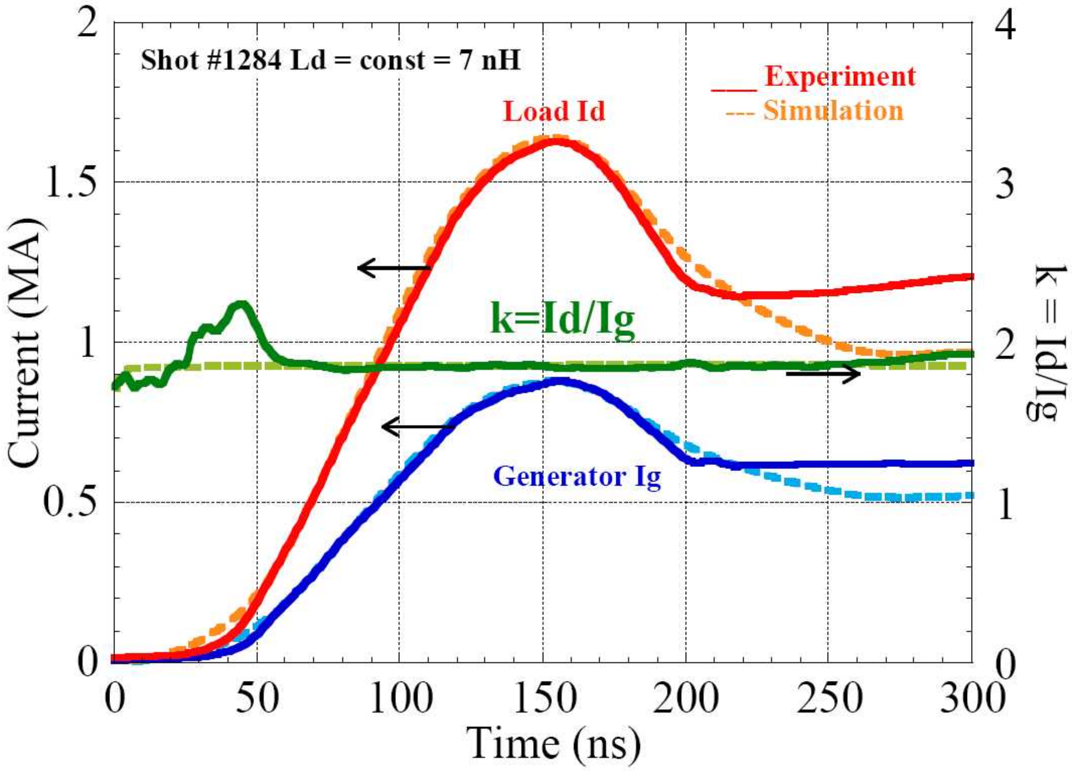
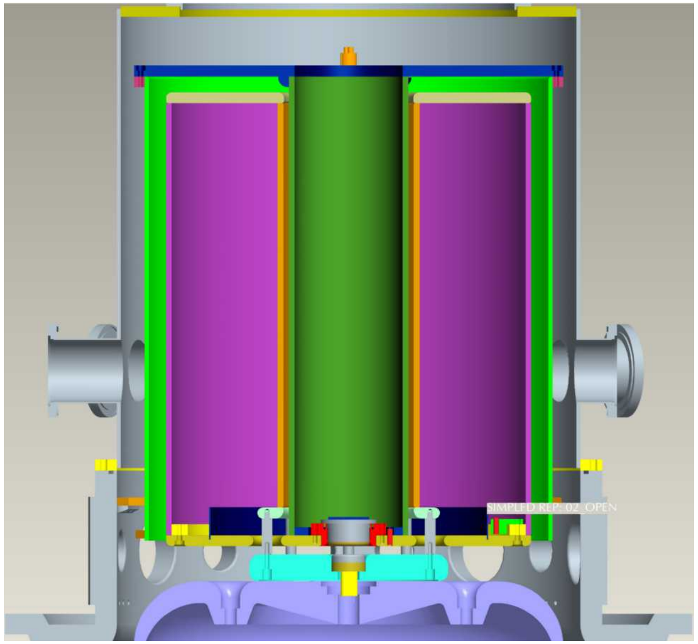
# Joint LCM experiments (June 2007, Oct 2007) @ UNR

**Chuvatin et al, to be published**

**Shot #1284: 6 mm diameter rod, constant load inductance Ld ≈ 7 nH**



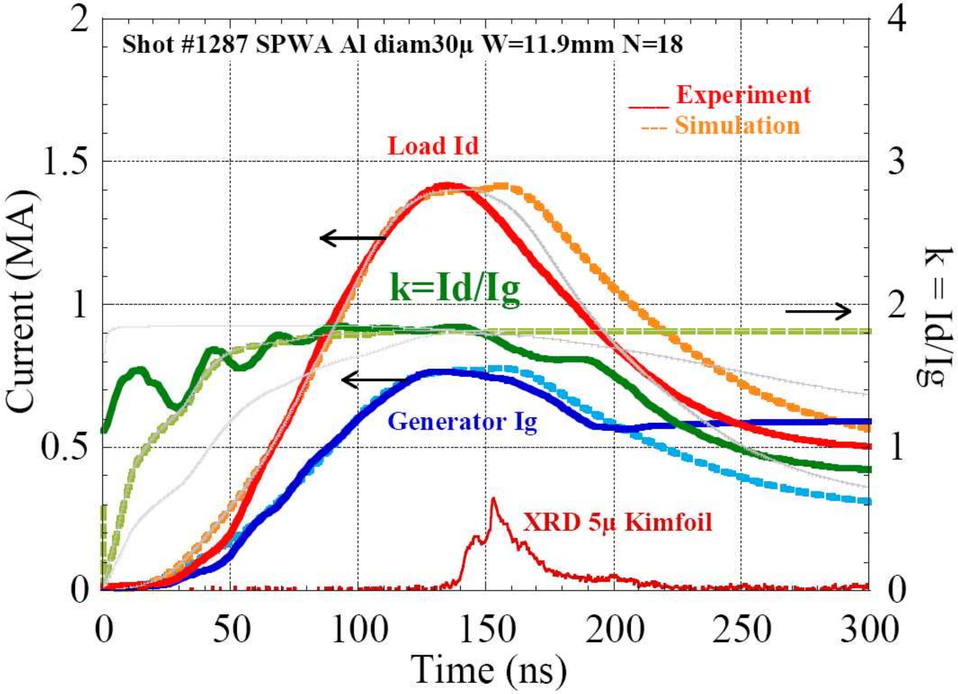



**Load current amplitude increased from nominal 0.8-0.9 MA to 1.62 MA in this shot, ± 0.05 MA uncertainty/ asymmetry**

# Joint LCM experiments (June 2007, Oct 2007) @ UNR

**Chuvatin et al, to be published**

**Shot #1287: z-pinch SPWA, 18 Al wires, 30 μ diameter, width = 11.9 mm**




**In this SPWA shot: Generator current is lower due to non-nominal Zebra operation, NOT DUE TO LCM**

**▷Load current multiplication coeff. k = Id/Ig ~ 1.8 0.1 at peak current, close to theory/simulations**

**▷ => lossless LCM design: MITL's and PHC at high electric fields (> 1 MV/cm) and plasma radiation**

**▷ SPWA k drops below $k^{theor}$ after first XRD peak w/o current assymetry => pinch resistance of 0.1-0.2 Ohm**

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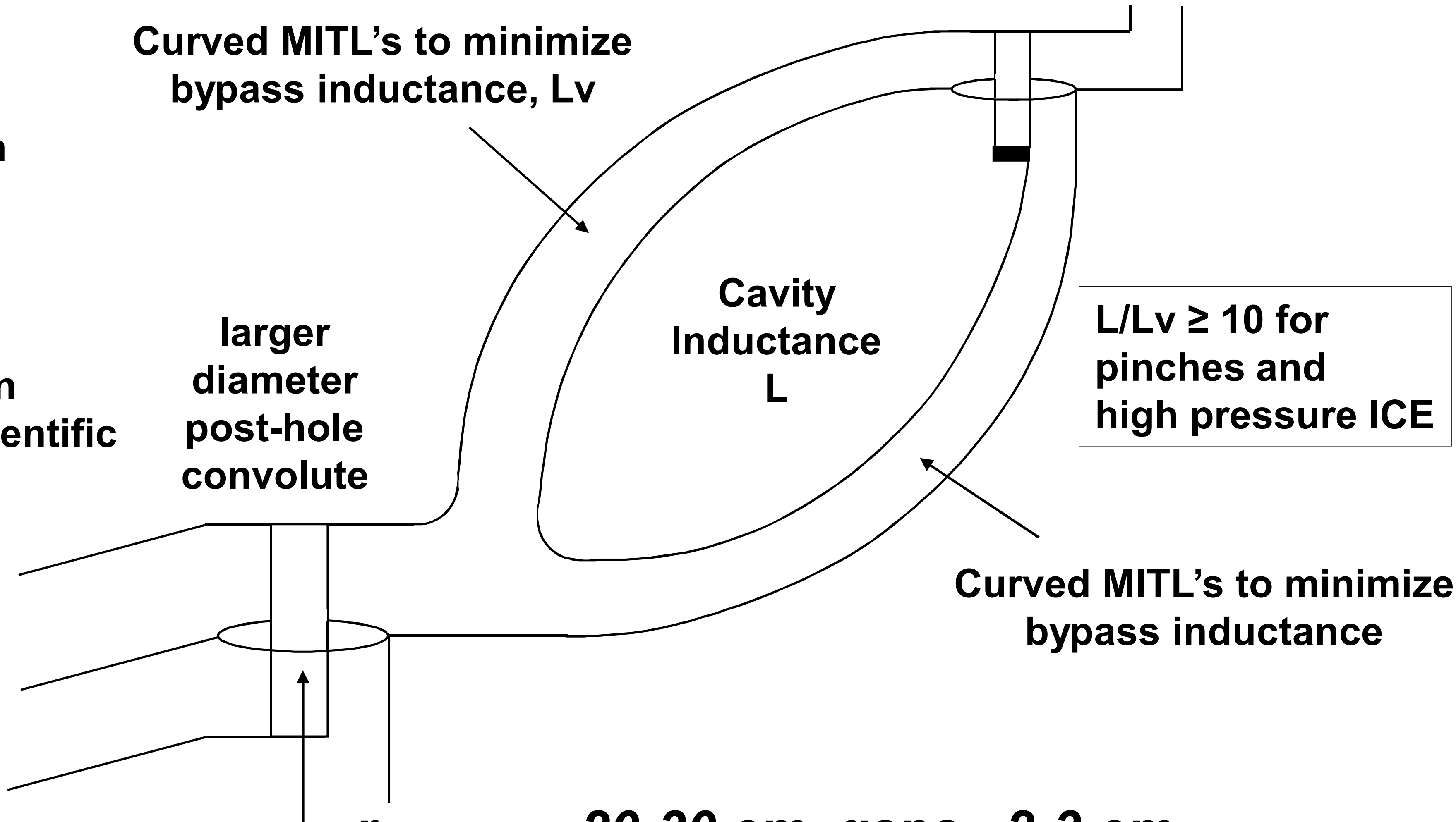
# We are designing an optimum LCM for Z to minimize Lbypass and maximize Lcavity/Lbypass

- Large convolute to increase gaps, reduce convolute losses and still achieve current gain
- First application is to ICE experiments

Chuvatin
Cuneo
Savage
Owen
Pointon
Langston
Voss Scientific
Davis
Lemke

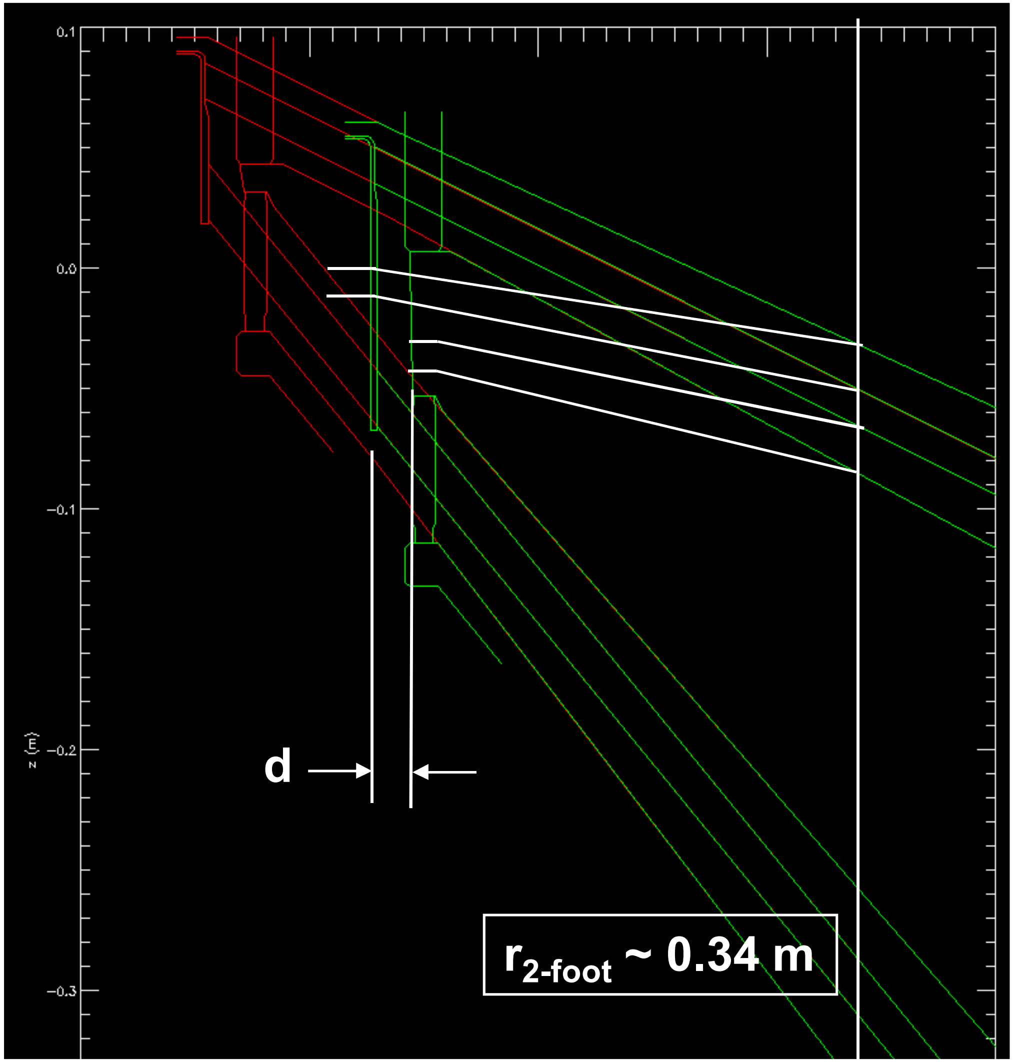



***$r_{optimum}$ ~ 20-30 cm, gaps ~2-3 cm***

# Optimal design of larger radius, low current loss convolutes needs to be addressed for LCM's

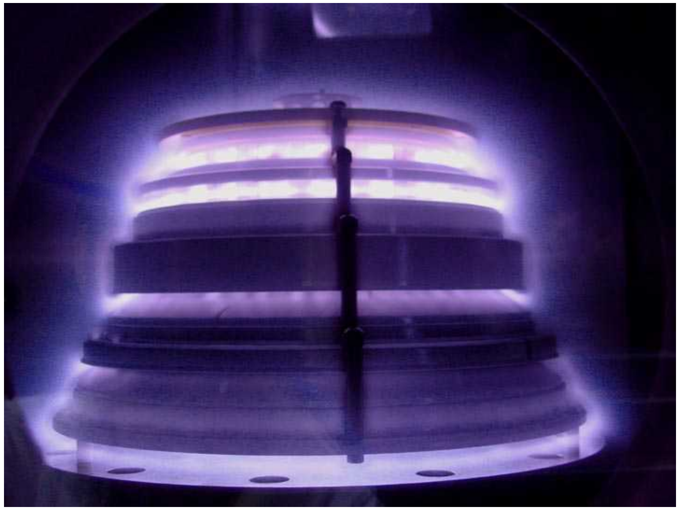
Langston, Pointon

$r_{conv}$=7.5 cm $r_{conv}$=15 cm

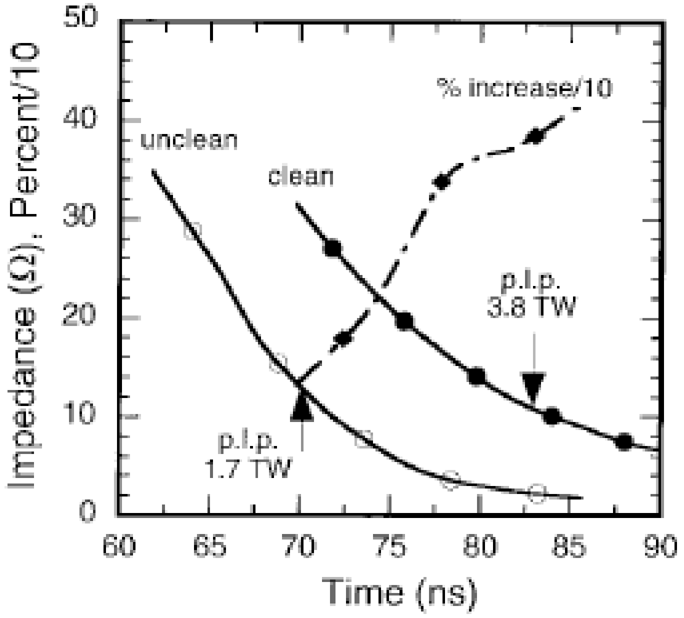



- The gap "d" may play an important role in determining the electron loss characteristics of the convolute. We may want to treat this as a parameter to be studied:
  - d ~ $r_{conv}$ (this allows the hole diameter to be increased proportional to $r_{conv}$ even with fixed numbers of posts?)
  - Change d so that V^1.5/d^2 is a constant - this is a weaker scaling

# Load current multipliers may only be possible in long pulse with active cleaning of convolutes



- Discharge cleaning with reactive gases have shown a factor of 100% to 400% increase in diode impedances over 85 ns
- Discharges increased Zflow in the MITL by 25% in this experiment, even at a 9 cm AK feed gap!




**225 W, 13.5 MHz, 110 mTorr Ar/10% $O_2$ discharge**

**Likely requirements: 1 kW, 40 MHz, 25 mTorr Ar/10% $O_2$ discharge**

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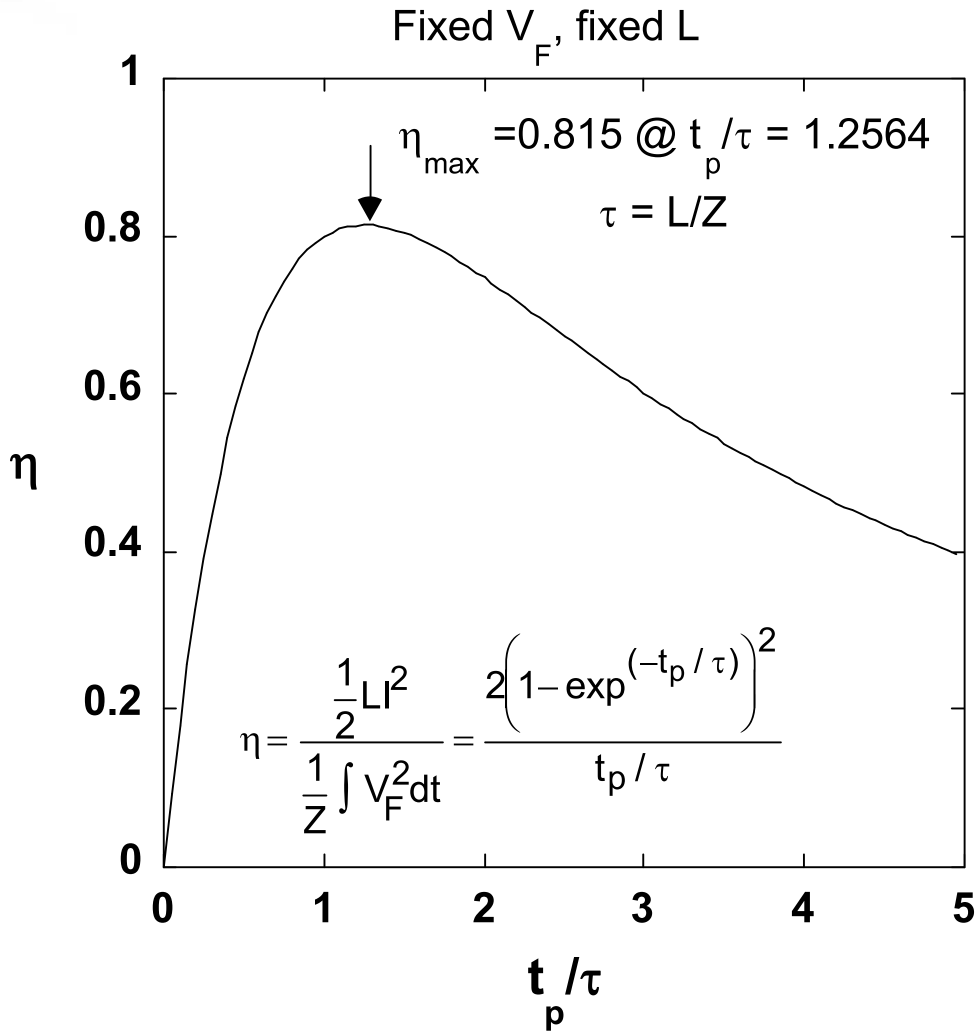
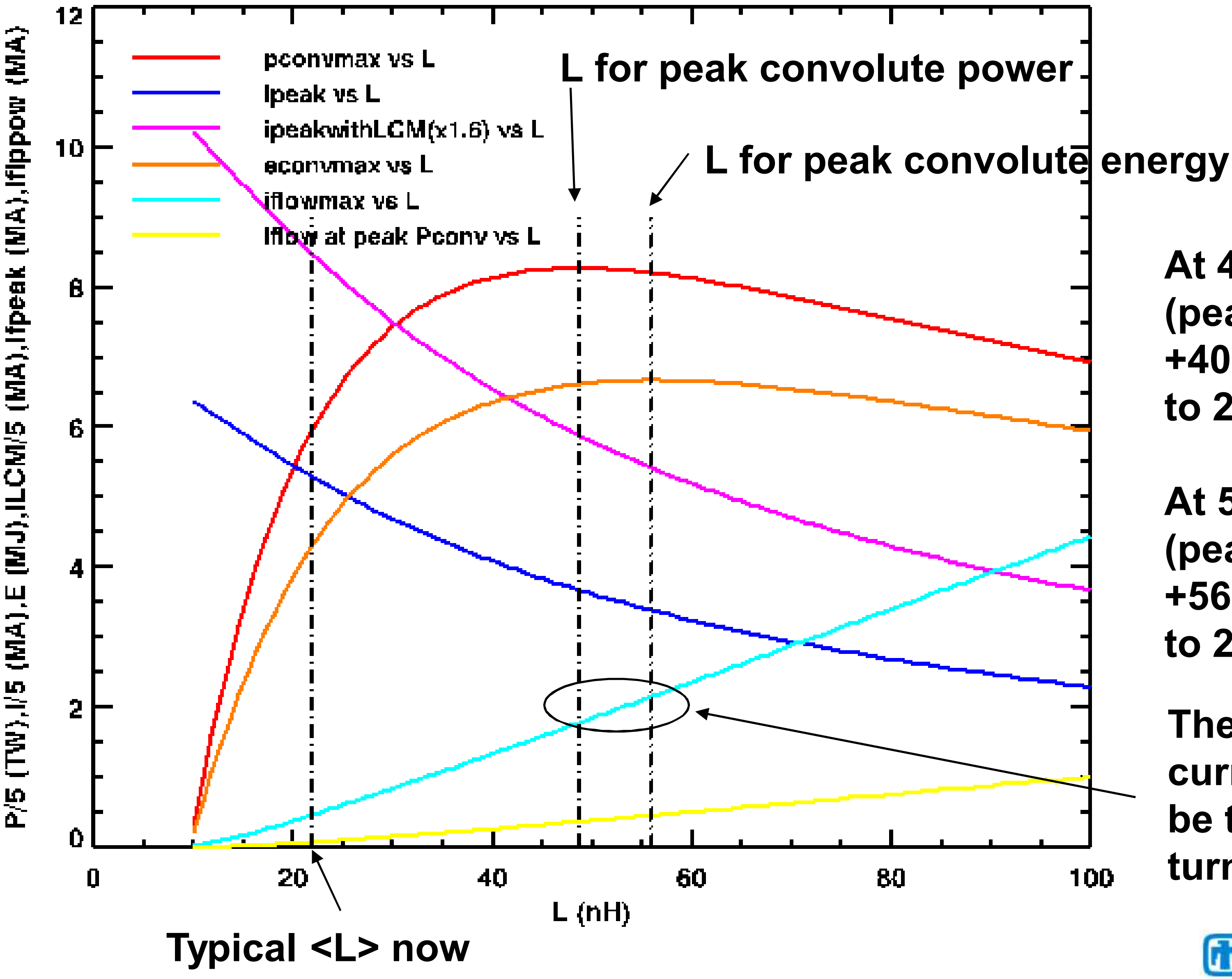
# Inductor coupling model problem, fixed V, fixed L




- **Two questions**
  - **Improve the coupling of energy from the stack (longer pulses better)**
  - **Optimize power of loads in configurations with highest energy coupling**

# Long pulse Z Voc, vary fixed L from 10 to 100 nH and find optimum vs L




At 48.7 nH (peak power) +40% compared to 22 nH

At 55.9 nH (peak energy) +56% compared to 22 nH

These flow currents could be too large and turn on convolute

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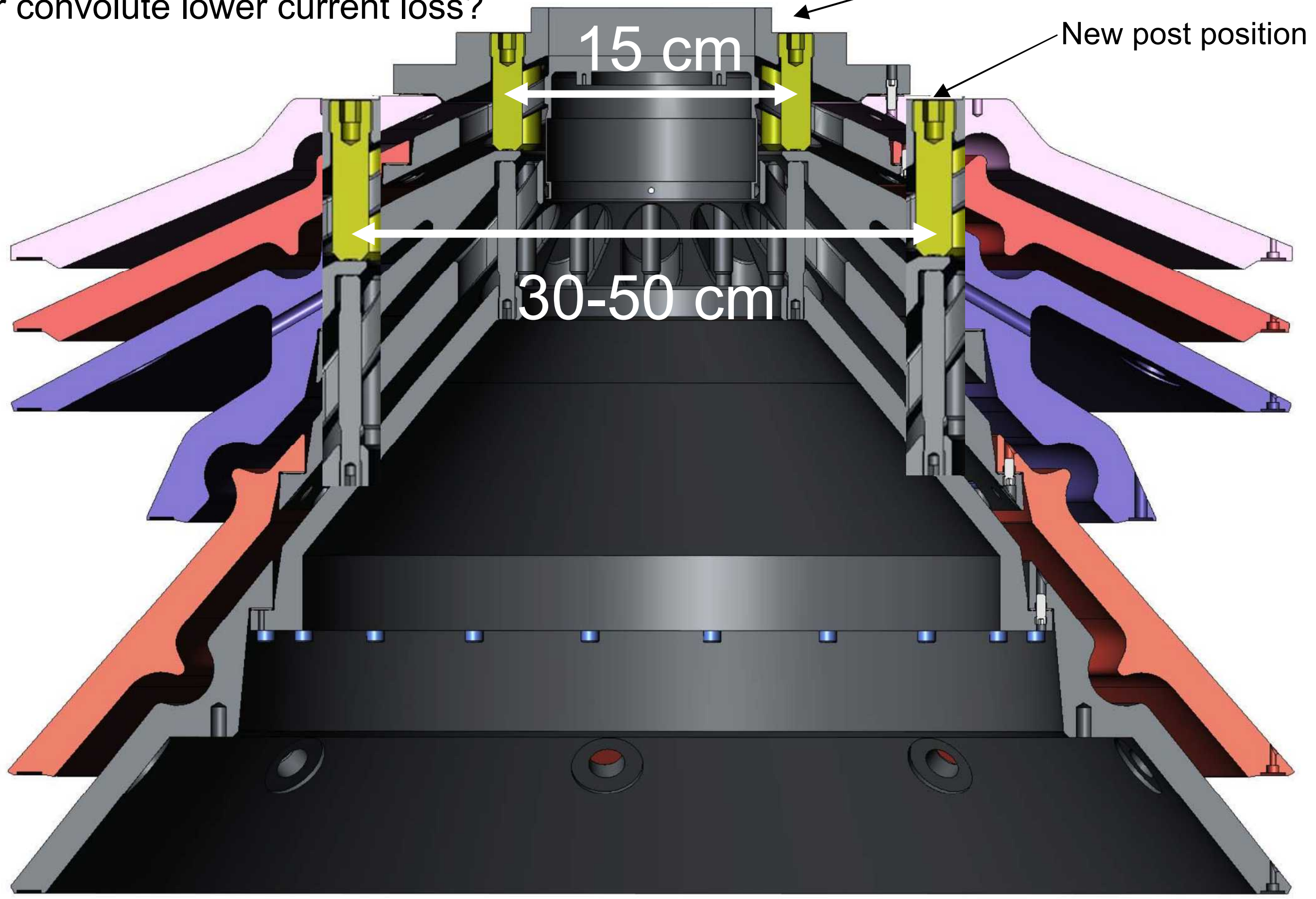
# This exercise gives an estimate of the total inductance budget

- Ltotal = 49 to 56 nH
- Ltotal = Lgen + Lconv + LLCM = 49 to 56 nH
  - $L_{LCM}$ = Lbypass + 4 Lload
  - Lgen + Lconv = 11 to 13.1 nH
  - Lbypass = 10 nH
- 4 Lload = 25.9 nH to 32.9 nH
- $\Delta$Lload = 6.5 nH to 8.2 nH
- These $\Delta$L are still a little high compared to what we believe our pinches achieve, but are in the ballpark
- Conclusion:
  - The LCM as an impedance transformer could be beneficial to allow greater energy coupling to the loads

# We are now designing the experiments for Z starting with a new convolute design

There are multiple reasons a large diameter convolute is needed

1) improved compatibility with load current multipliers
2) allows wire array or other load diameters of greater than 80 mm needed for Cu K-shell work (a Kr gap puff would require a 40-45 cm post diameter convolute)
3) larger convolute may decrease damage and lower operational costs
4) could larger convolute lower current loss?



# Not yet optimized, for low pressure ICE

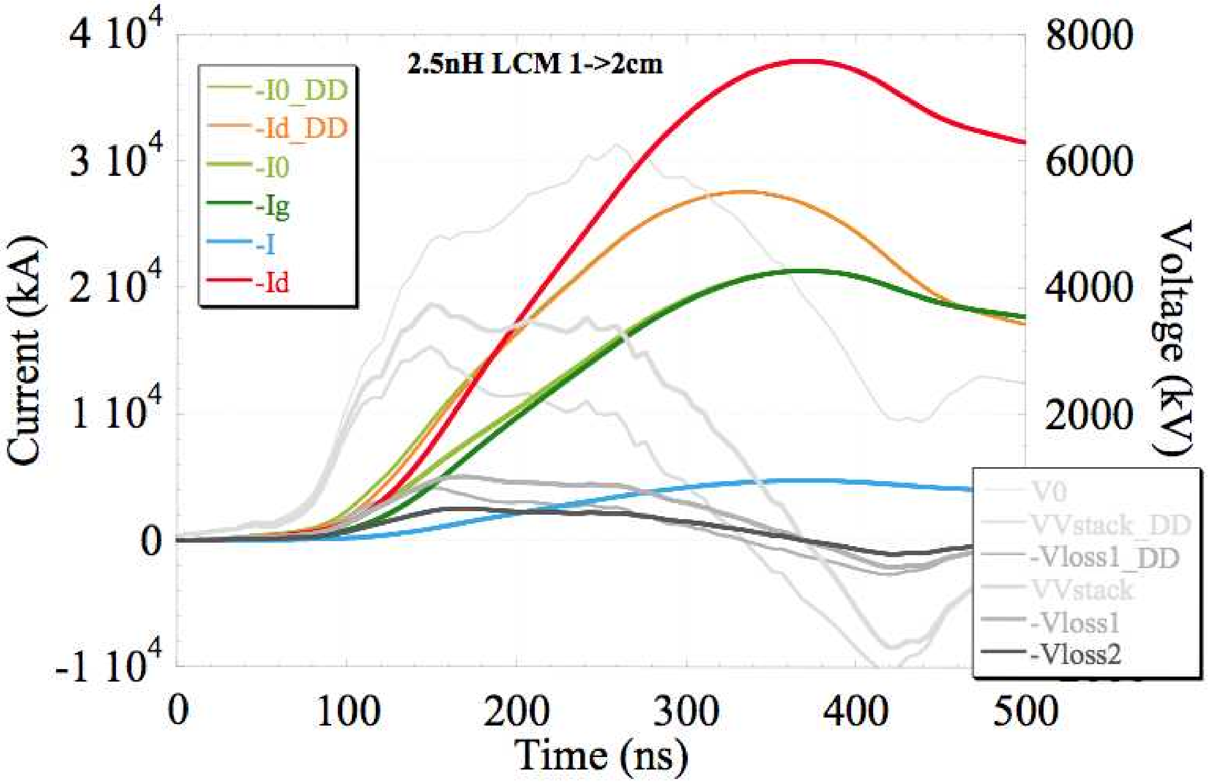
**Chuvatin design**

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

- **L/Lv ~ 2, not high enough for high pressure ICE or z-pinches**
- **Requires negative polarity posts. Normal Z convolute operation is positive polarity posts**

# This design shows 38 MA into a low pressure ICE load with Lfeed = 1 nH and Lload = 1.5 nH

**Chuvatin models**

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# Summary

- LCM concept in short pulse will require an understanding and minimization of loss in convolutes, at high voltages. Convolute loss on Z is currently too high, even without LCM
  - 3D LSP simulations (Voss Scientific - Rose)

- Discharge cleaning will be implemented on the Z facility for improving impedance behavior of the convolute

- A large diameter convolute will be developed for several programmatic needs by Q4 of next year

- Designs for LCM's with L/Lv~10 still need to be developed

- Integrated LCM - convolute - load designs in 3D ALEGRA with LCM circuit model (Haill)

- Once these 5 preconditions are satisifed we will test LCM's starting with low pressure ICE, followed by high pressure ICE and z-pinch loads, presumably in FY2010-11