Single Objective Genetic Optimization of an 85% Efficient Klystron

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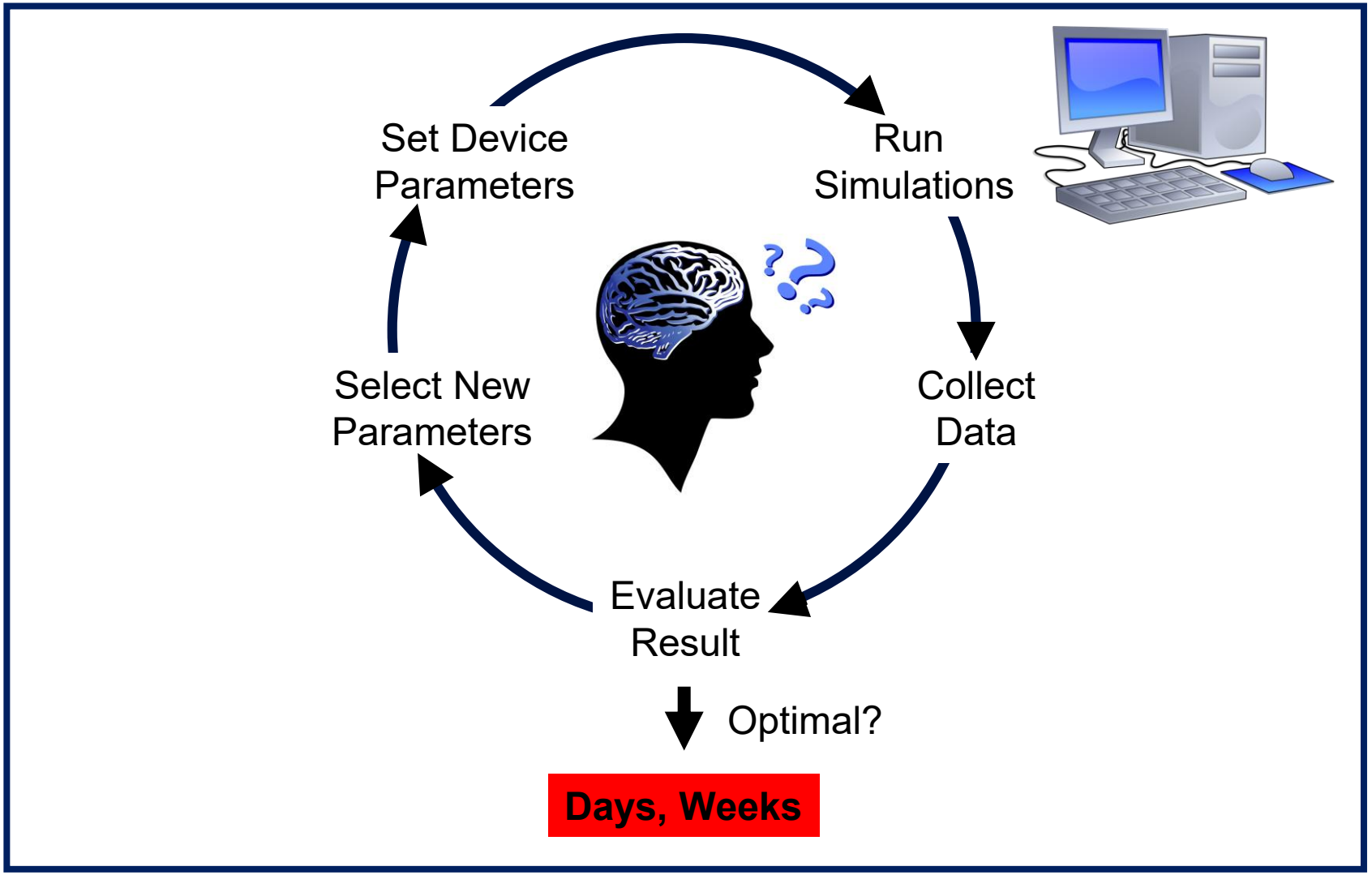
Motivation

- Overall efficiency is a critical priority for the next generation of particle accelerators as they push to higher and higher energies
- In a large machine, even a small increase in efficiency of any subsystem or component can lead to a significant operational cost savings
- Novel klystron cavity tuning schemes and modern optimization open the door to ultra high efficiency klystrons
- Target: 85% overall klystron efficiency
  (Calabazas Creek Research Phase I SBIR)

Outline

- The need for optimization
- Galaxy Simulation Builder (GSB) as a framework for design optimization
- How big of an optimization? *Collector Example*
- Optimization of an 85%+ efficient klystron

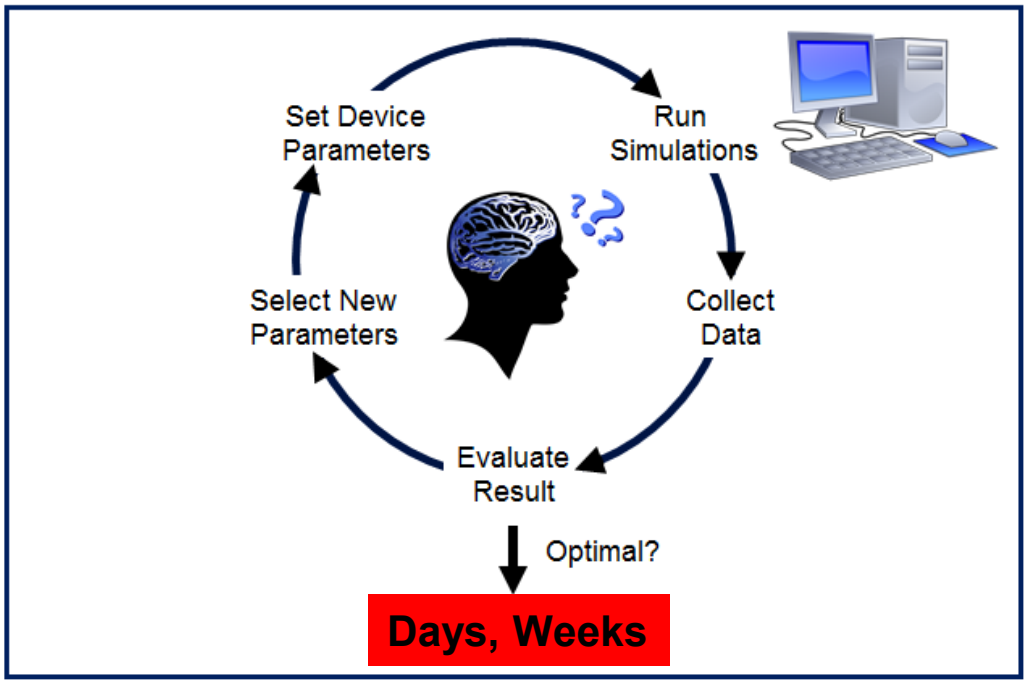
Human Based Optimization is Slow



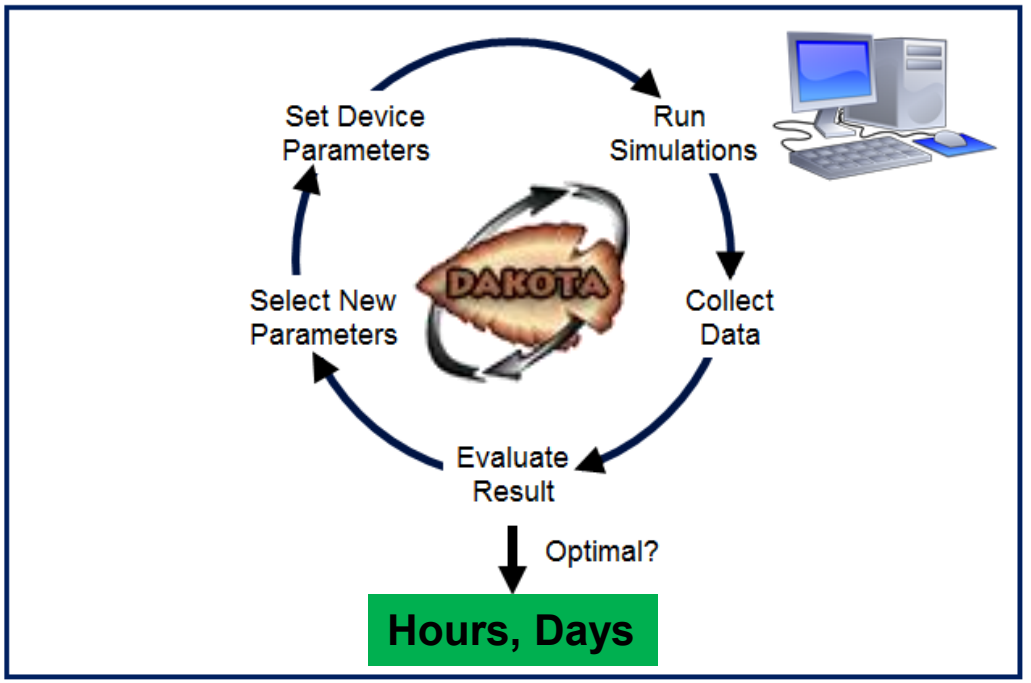
Typical Human Based Optimization Cycle

We Can Use Computers for Faster Optimization

Simulations Easily Run in Parallel



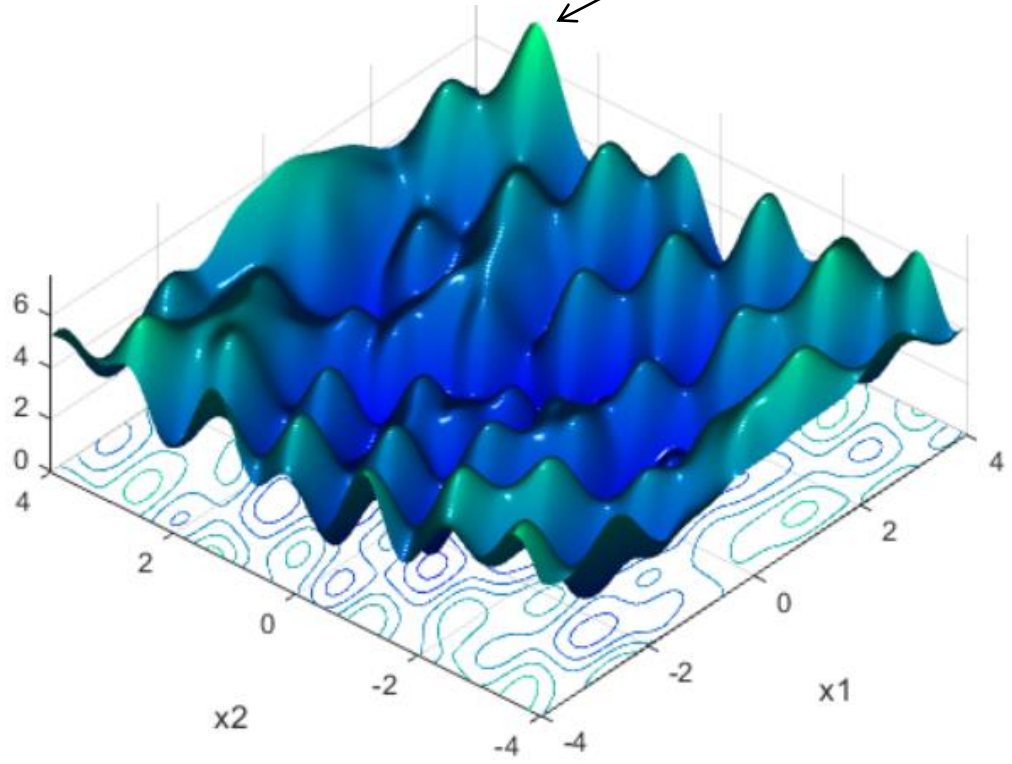
Human Optimization



Computer Optimization

Global Optimization

How do we find a global maxima or minima instead of a local maxima or minima?

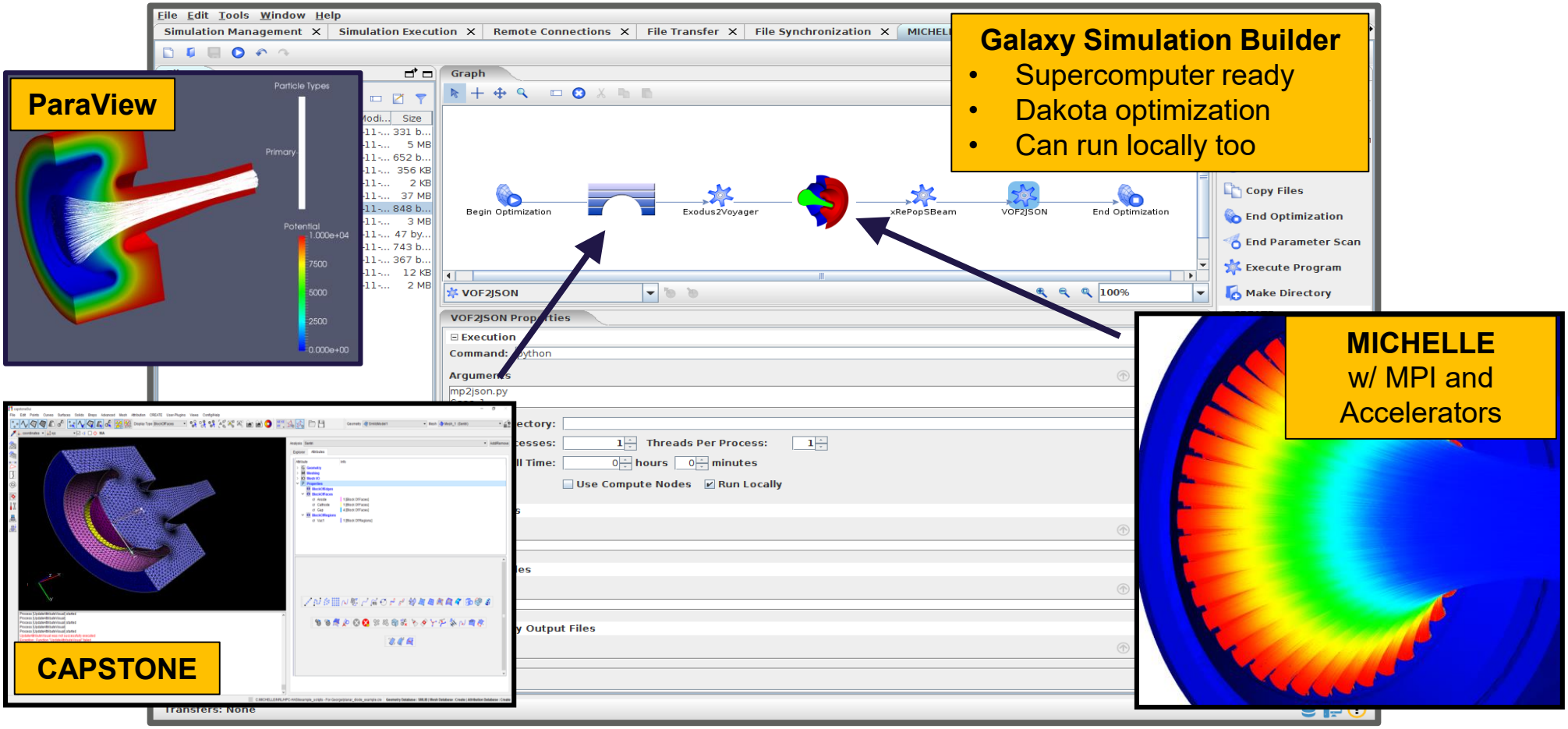


Many algorithms exist. We will focus on the genetic algorithm.

Galaxy Simulation Builder (GSB)

An Optimization Framework

Rapid 3D Design is Made Possible Using the Galaxy Simulation Builder Framework



Galaxy Simulation Builder builds and launches custom simulation pipelines on the Supercomputing Resource Centers and can optimize the results using Dakota.

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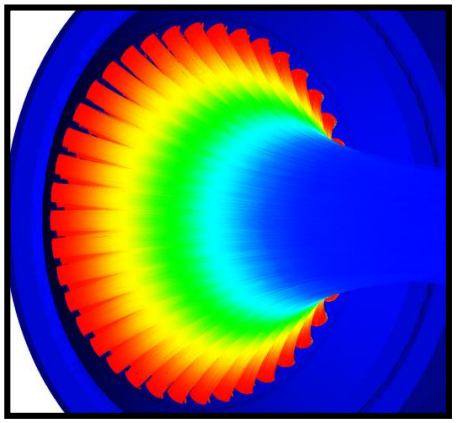
Engineers and Scientist Repeat Processes. GSB Sets it Up Once.

- "Once and done" simulation pipeline creation
- Cross platform environment
- Design optimization using Dakota
  - Local and global optimization options
  - Uncertainty quantification
- Tight HPC integration for execution on the DSRCs
- Executable on remote or local machines
- Supports MPI and serial modules
- Automatic parallel execution of parallel pipelines
- Easy to add any simulation software into the simulation pipeline

Thunder Supercomputer

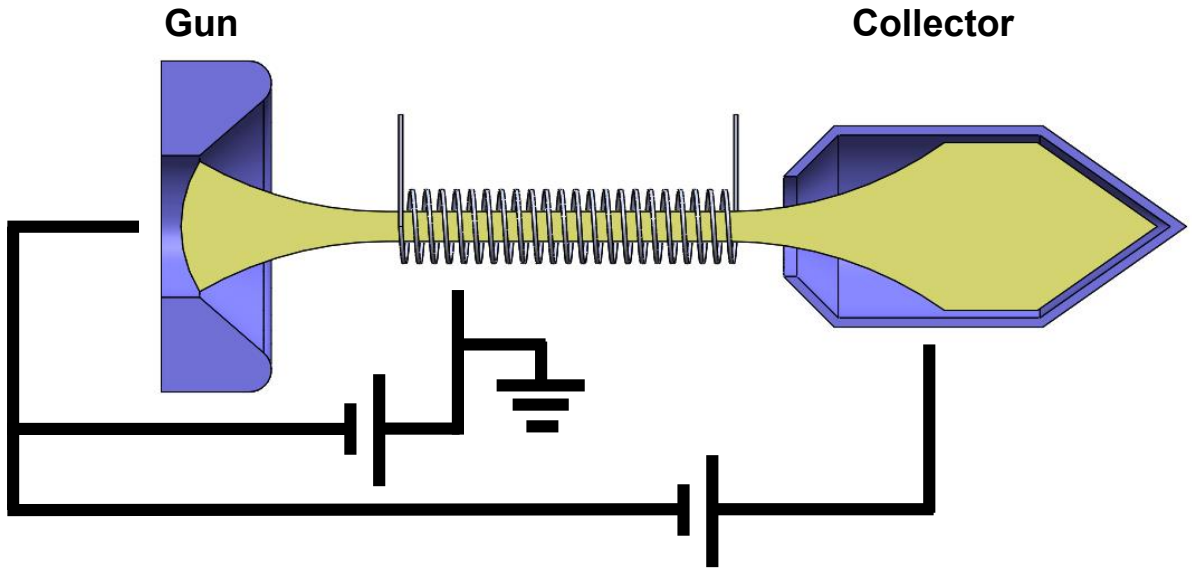


Electron Gun Simulation in MICHELLE

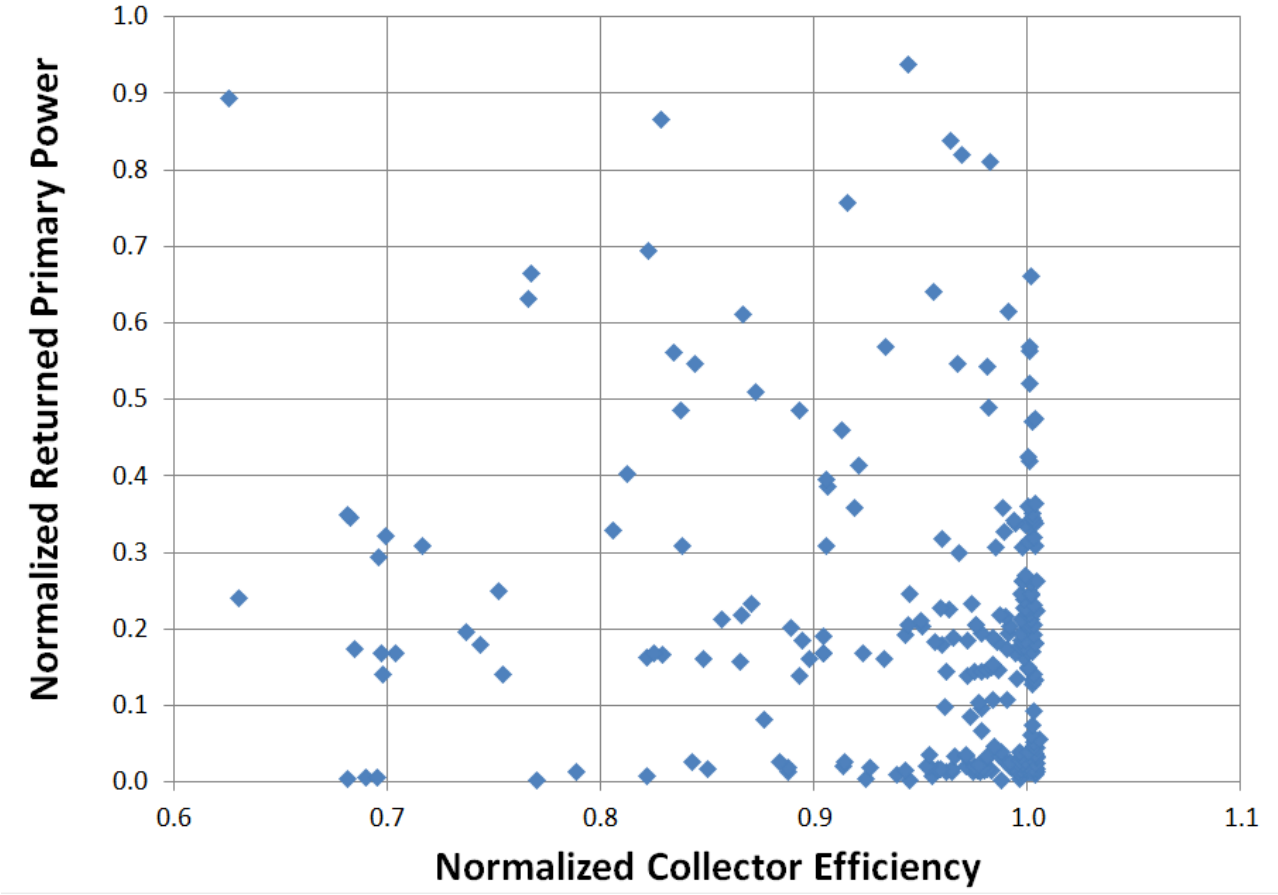
Running Large Optimizations

Collector Case Study

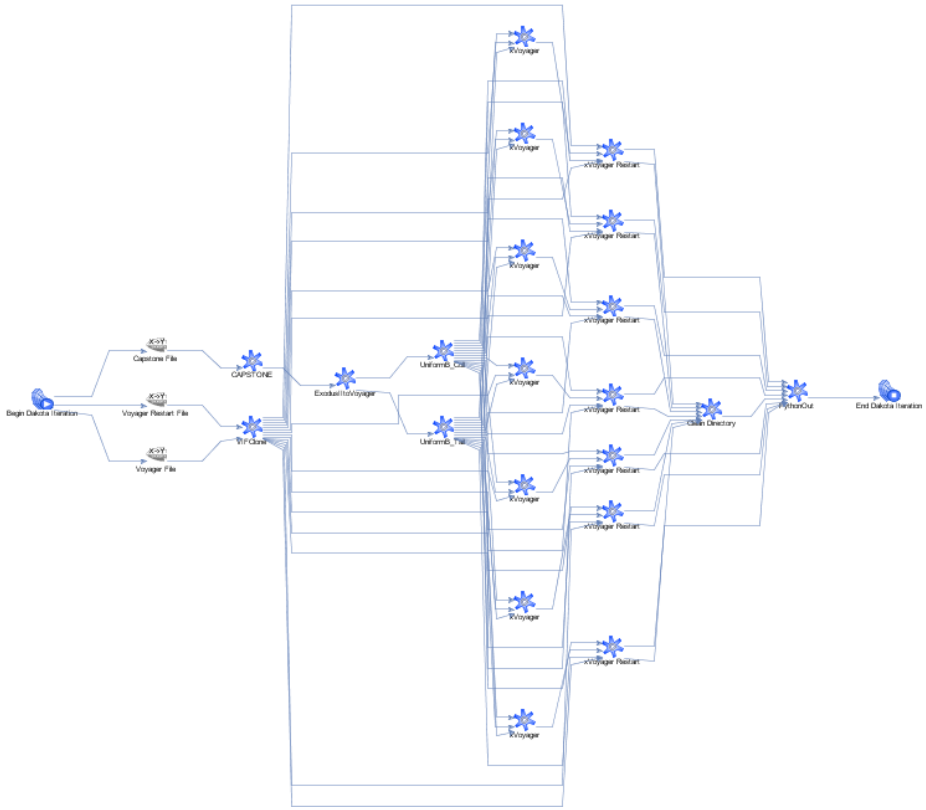
Depressed Collector Optimization: Setting the Stage



Optimization for Maximum Efficiency with Minimized Returned Primary Power



Collector Optimization at 7 Drive Points Even Bigger!



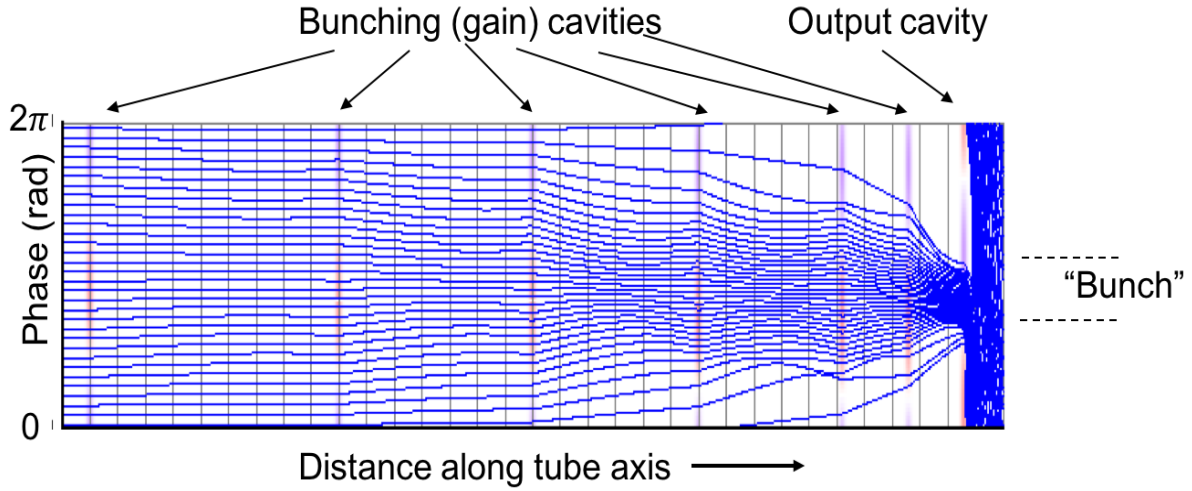
7 Drive Point MSDC GSB Pipeline

- **Simulated on Thunder (HPC)**, Excalibur (HPC), and Zeus (Leidos)
- Optimization setup to maximize efficiency at the operating point and minimize returned primary power at all drive levels
- 7 drive point optimization is as fast as single drive point optimization on the DSRC when drive points are run in parallel **(< 24 hours)**

High Efficiency Klystron Cavity Tuning: Core Oscillation Method (COM) Bunch-Align-Compress (BAC)

Core Oscillation Method (COM) Method

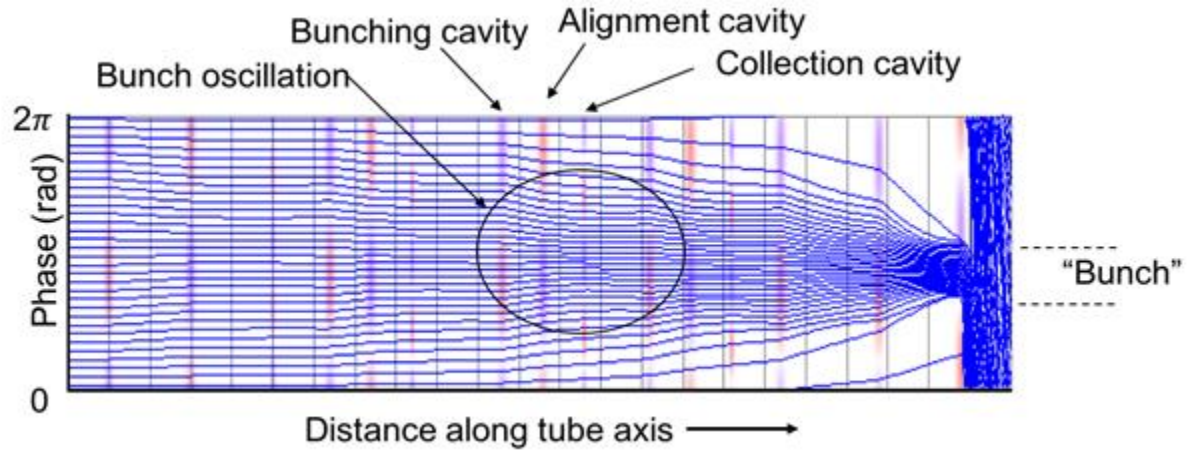
- Cavity spacing set wider than normal, set to bunch oscillation length
- Anti-bunch particles monotonically approach the central bunch
- Circuits are long



* A. Yu.Bajkov, D.M.Petrov "Problems of creation powerful and super- power klystrons with efficiency up to 90%", International University Conference "Electronics and Radio physics of Ultra-high Frequencies", St. Petersburg, May 24–28, 1999, pp. 5–8.

Bunch Align Collect (BAC) Method

- Uses cavity triplets
  - Bunching (accelerate and decelerate particles downstream and upstream of bunch center, respectively)
  - Align – shortens bunching distance (for triplet)
  - Collect – modifies anti-bunch particles velocities so they converge to bunch center (cavity is at second harmonic)
- Circuits have many cavities



I. A. Guzilov, I. A. "BAC method of increasing the efficiency in klystrons." Vacuum Electron Sources Conference (IVESC), 2014 Tenth International. IEEE, 2014.

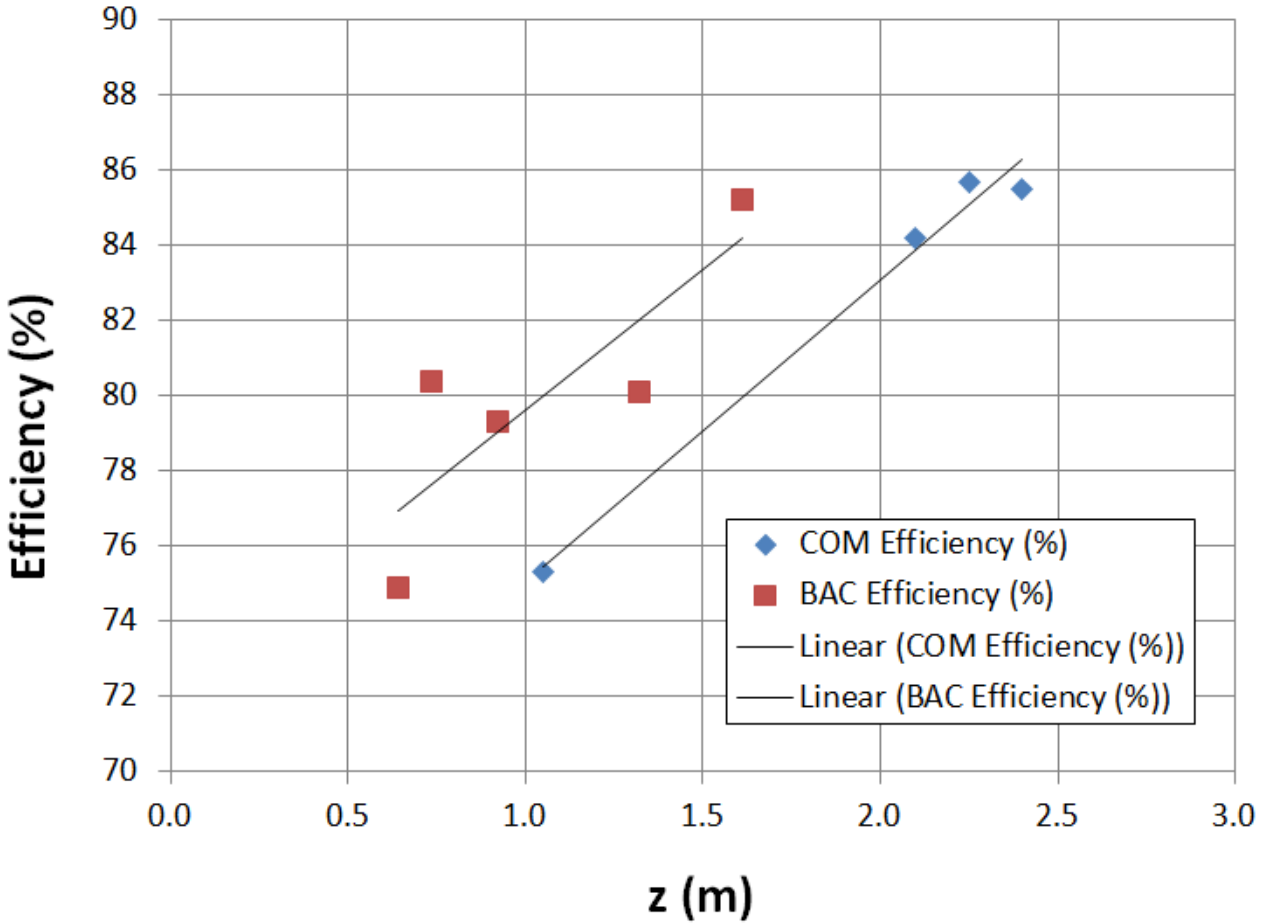
Klystron Optimization

Genetic Optimization Approach

- Hand optimize COM design
- Hand optimize BAC design based on COM design

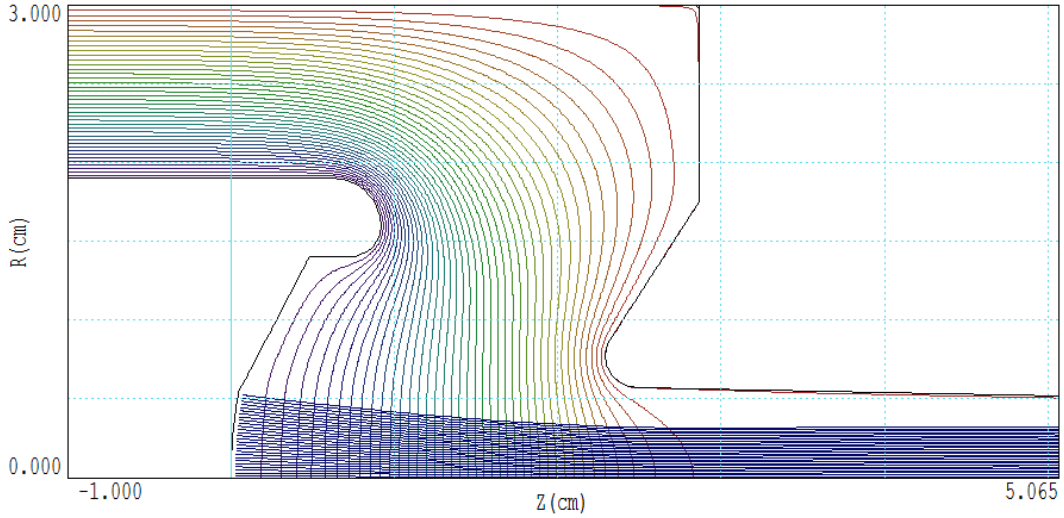
- Genetic Algorithm:
  - Cavity frequencies
  - Last cavity:
    - External Q
    - Frequency
    - Longitudinal location

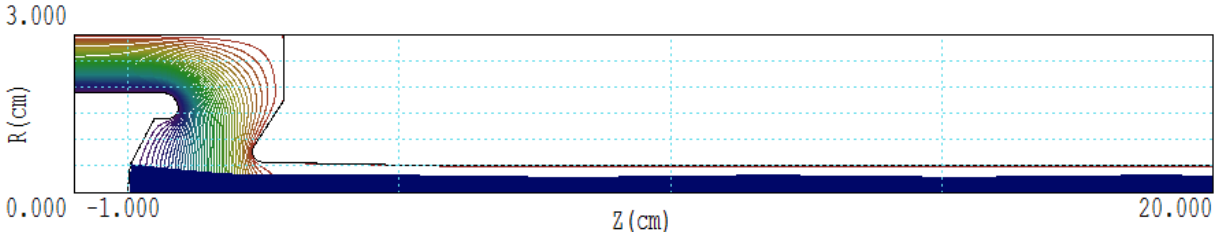
Genetic Optimization Results



- Population Size: 50
- ~ 5000 AJDISK Simulations per optimization

Including the Gun Model

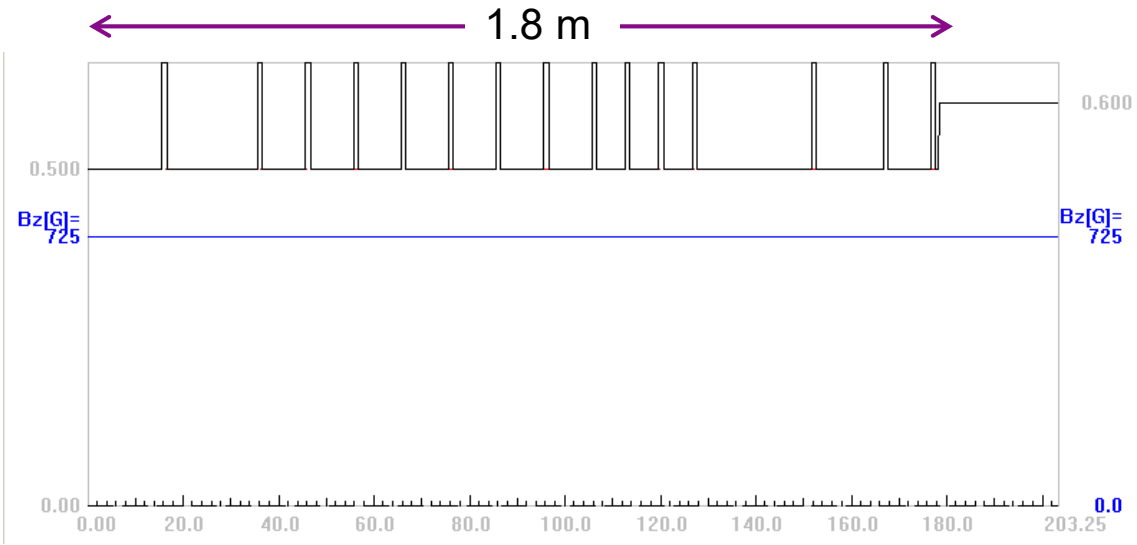


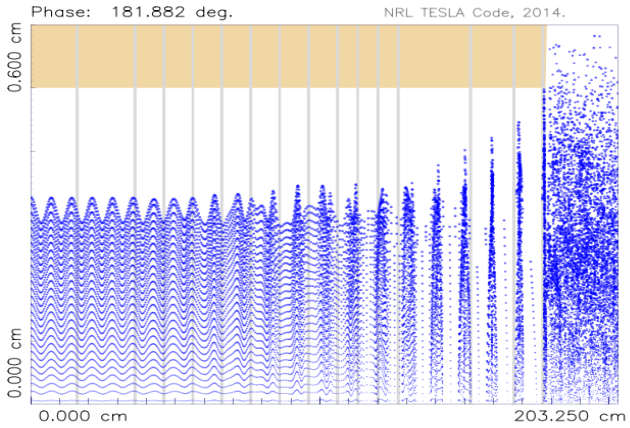


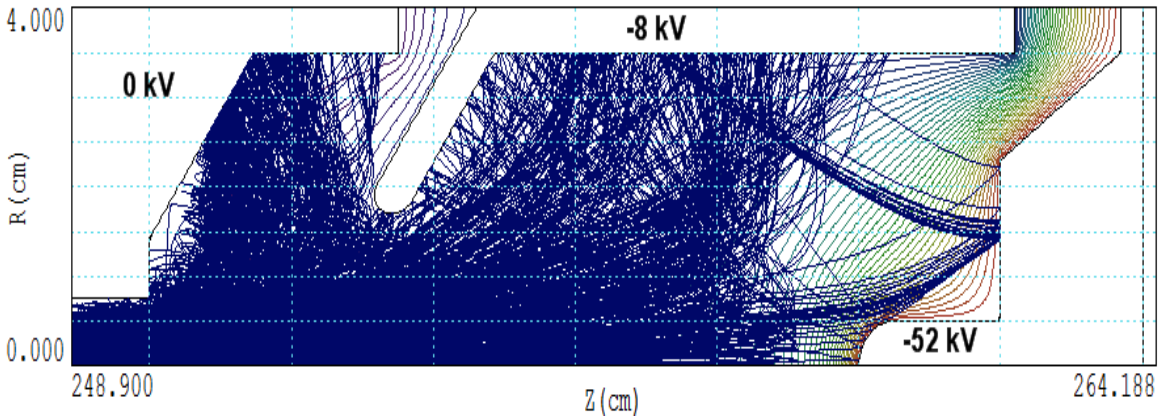
Ripple
+/- 5%

87% Efficient BAC Final Results

15 Cavities
P = 102 kW
η = 84%
87% with depressed collector







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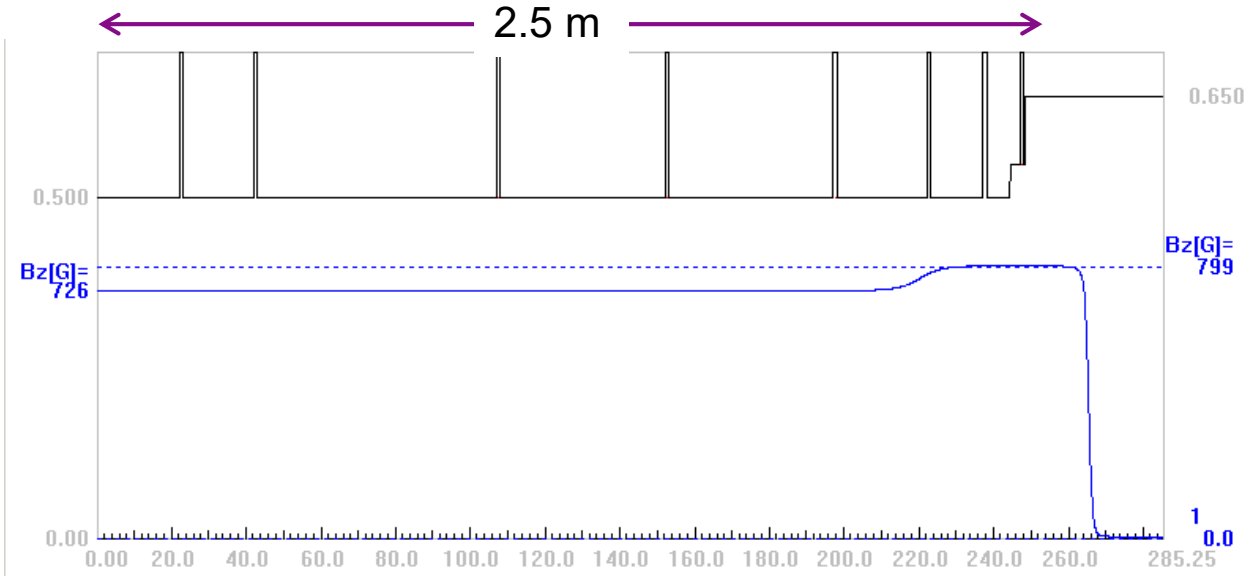
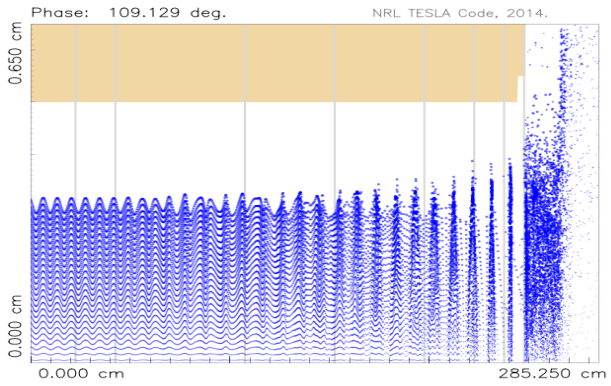
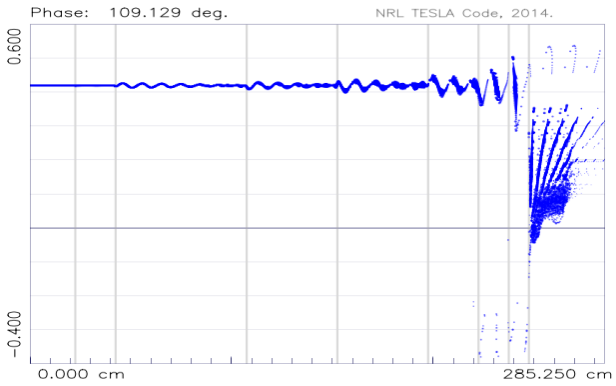
87% Efficient COM Final Results

8 Cavities
P = 104 kW
η = 87%







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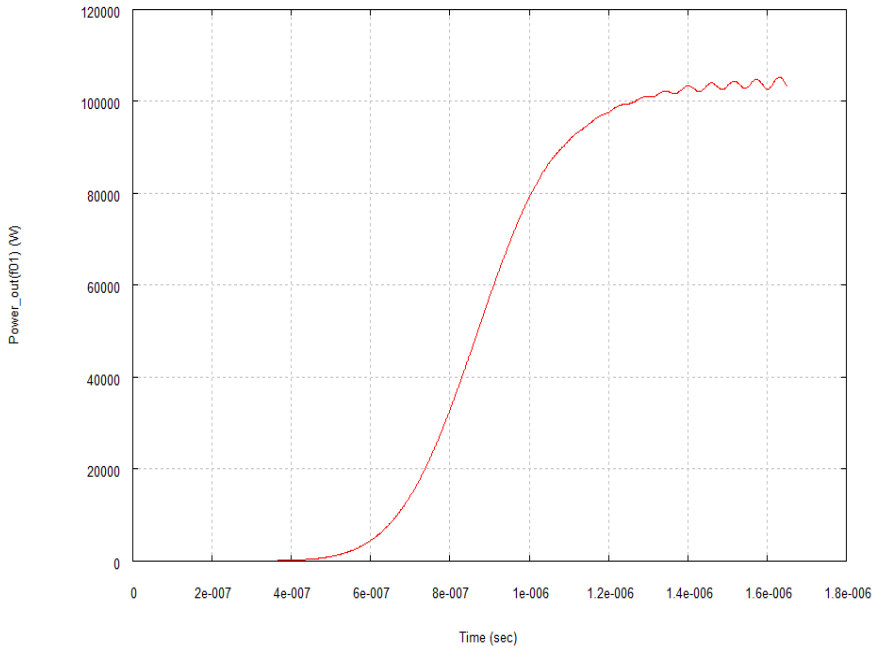
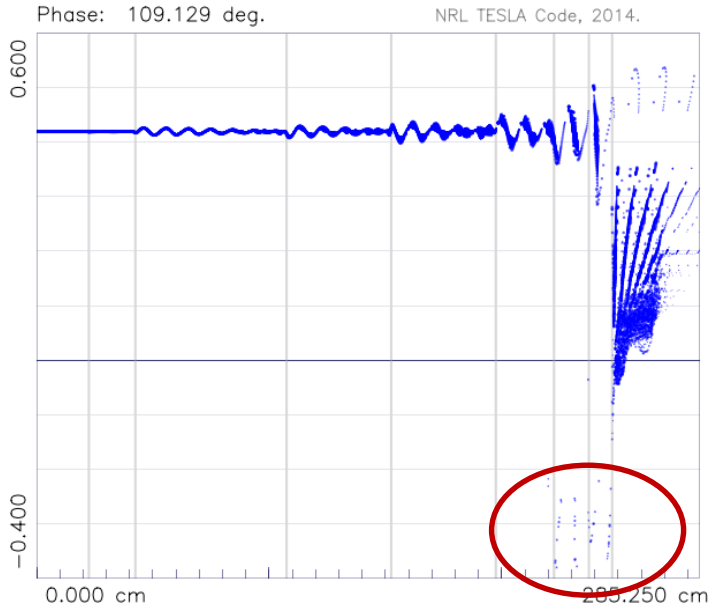
Final COM Results





- Small ripples are associated with reflected electrons
- Will refine the design to reduce (eliminate) these

Summary

- Galaxy Simulation Builder provides a framework for optimization of complex simulation pipelines
- The Single Objective Genetic Algorithm worked well for optimizing high efficiency COM and BAC klystron designs
- SOGA optimized COM and BAC klystrons both achieved 87% efficiency
  - BAC: 87% with depressed collector and 15 cavities
  - COM: 87% with 8 cavities, but 2.3m long (Phase II SBIR)
- Work done under subcontract to CCR, funded by the U.S. Department of Energy through a SBIR Grant, number DE-SC0017789.