Magnetic Analysis Techniques Used at STI Optronics

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Outline

- Parametric analysis
- Global optimization

Parametric Analysis

- FEA
- PM Quad centerline adjustment
- Wiggler End Field
- Wiggler Ambient Field
- Eddy Current in PM Quad

FEA Developments

- Easy 3D modeling
  - CAD leveraged
- Easy parametric modeling
  - All models at STI are parametric
- Multi-physics Approach
  - Magnetic + Thermal + Structural
- Global Optimizers
  - Requires parametric
  - Multi-physics
  - Commercial codes OptiNet

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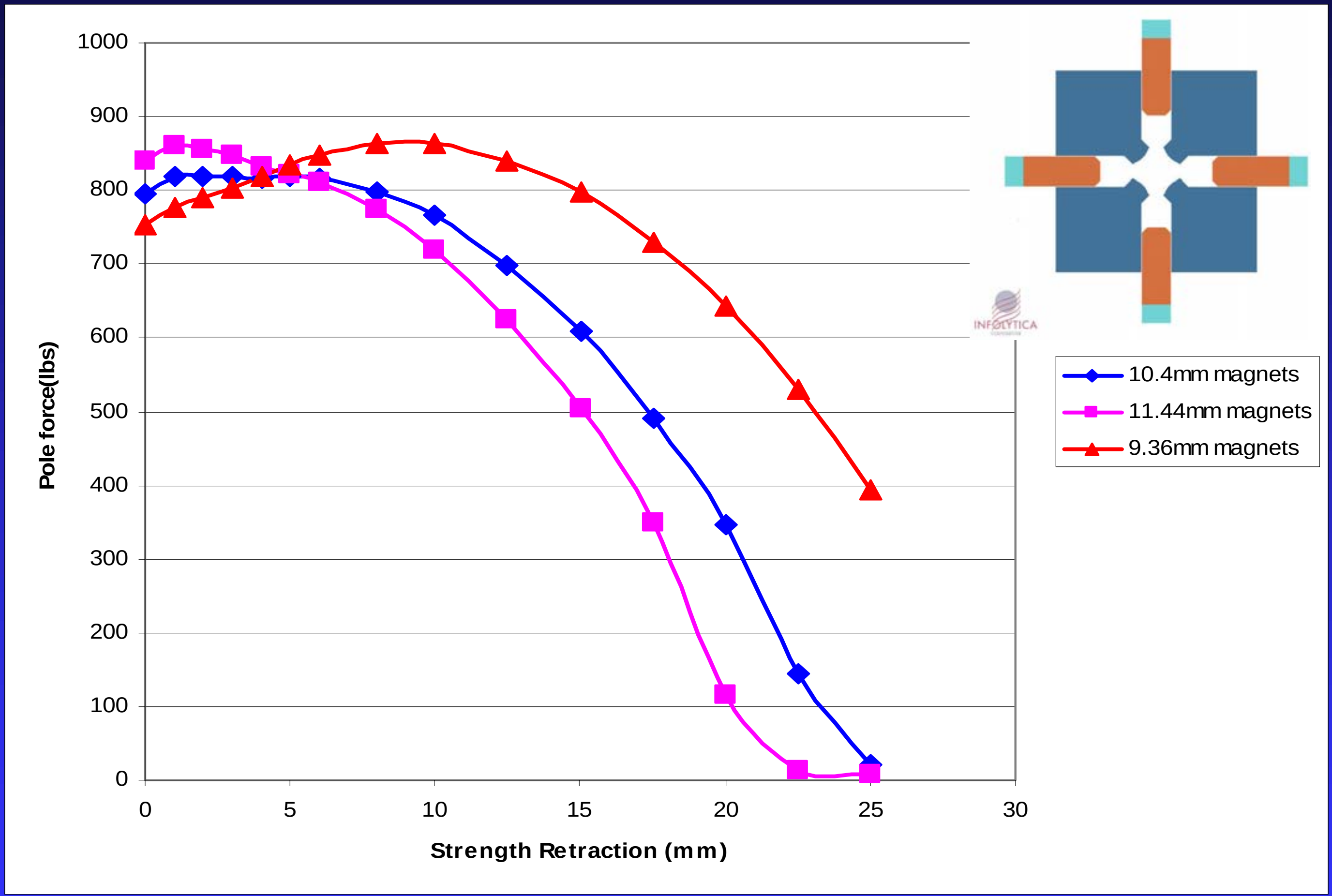
PM Quad Parametric Force and Strength Analysis



PM quad model has 92 parameters

Varied Magnet Thickness and strength

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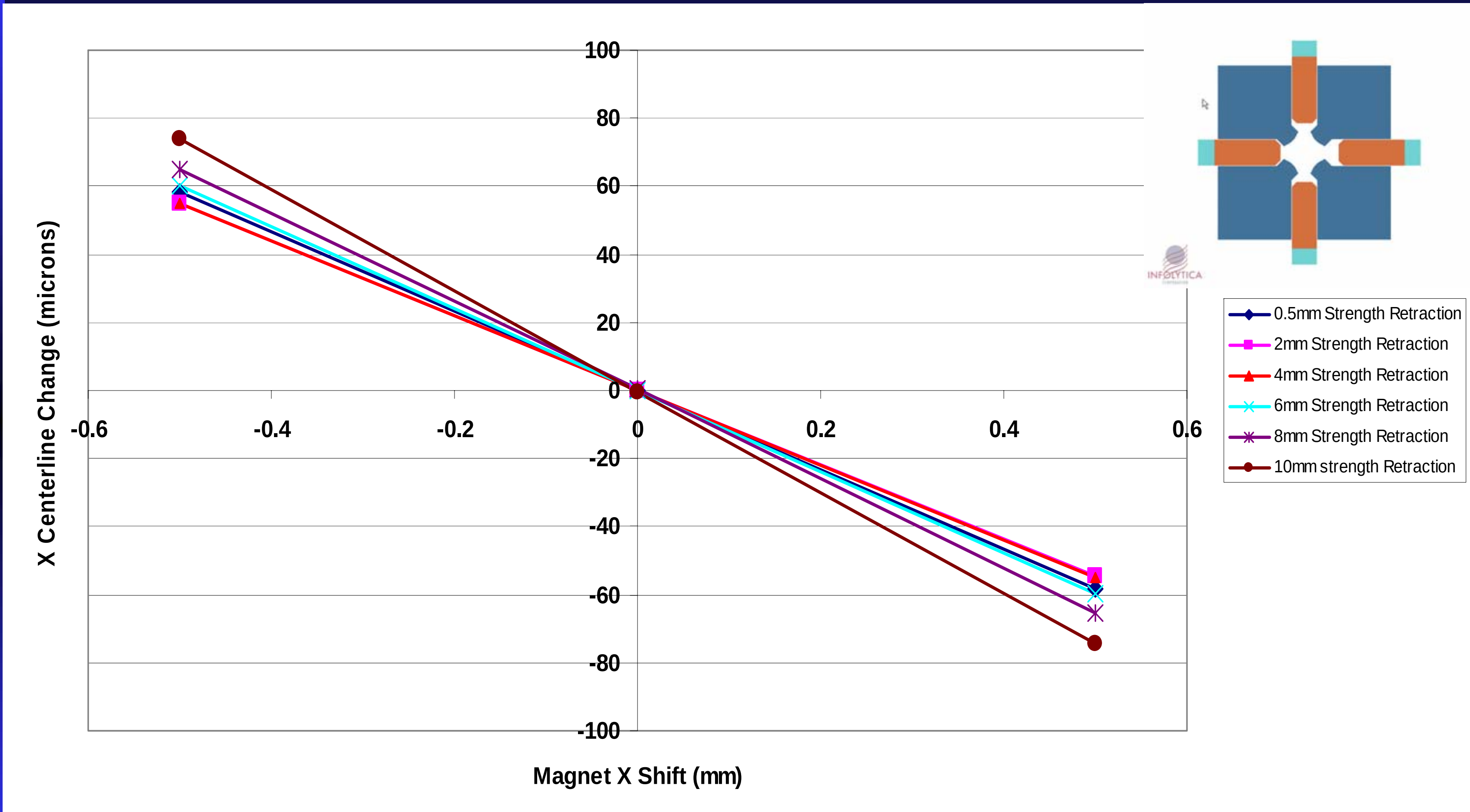
PM quad parametric analysis



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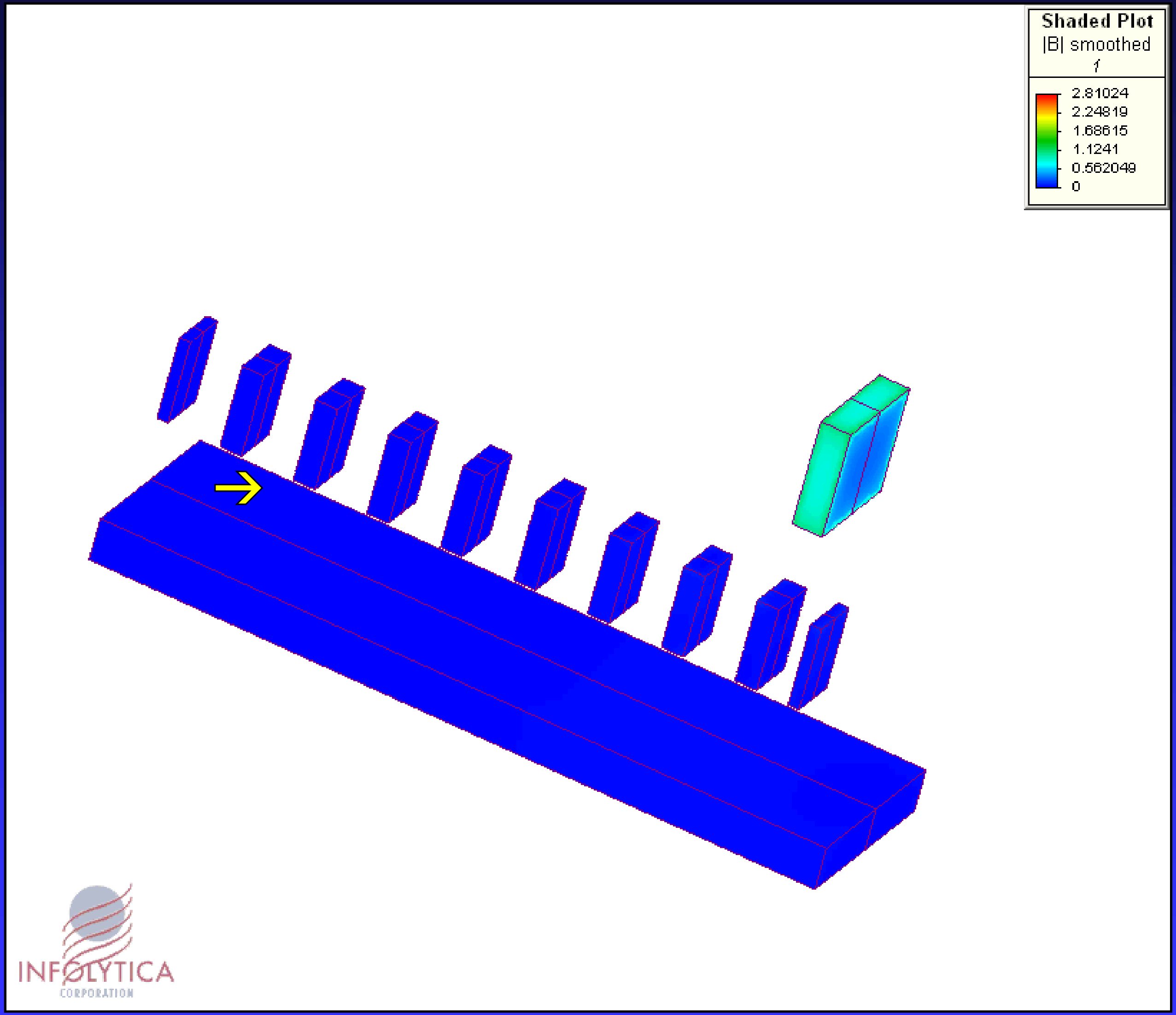
Magnetic Parametric Analysis and Modeling

Click the image to view animaton



Magnetic Parametric Analysis and Modeling

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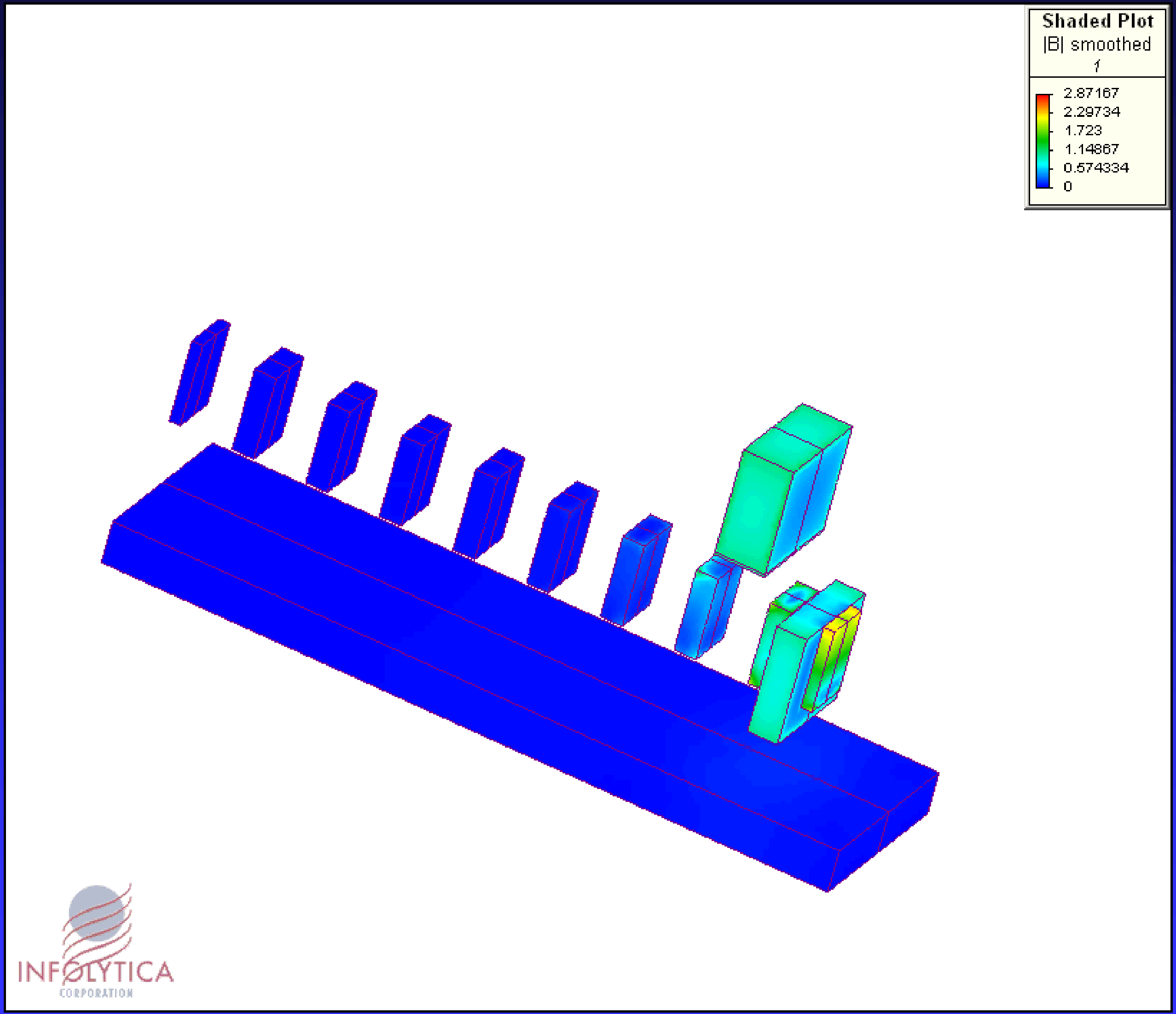

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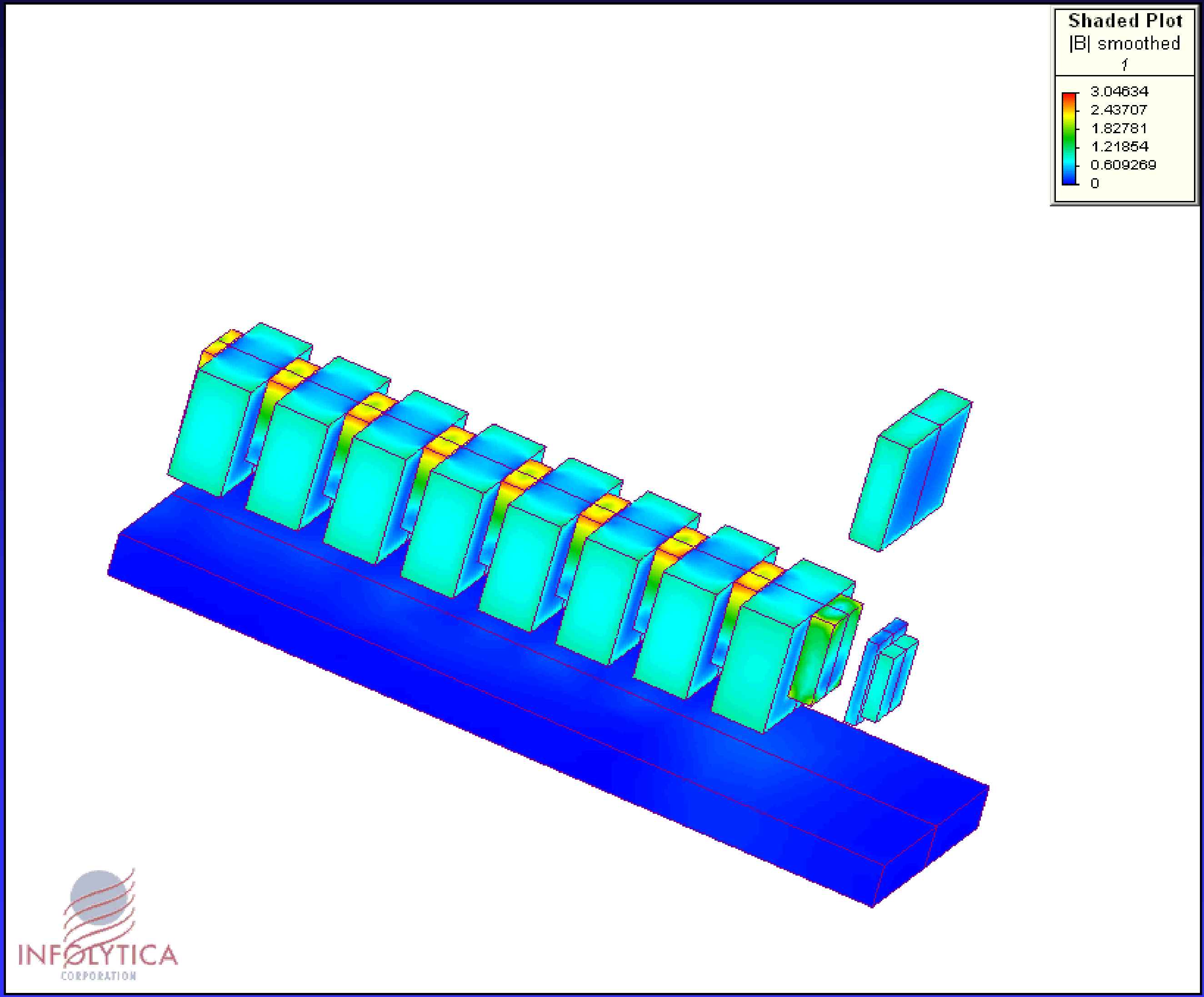
Magnetic Parametric Analysis and Modeling

Click the image to view animaton



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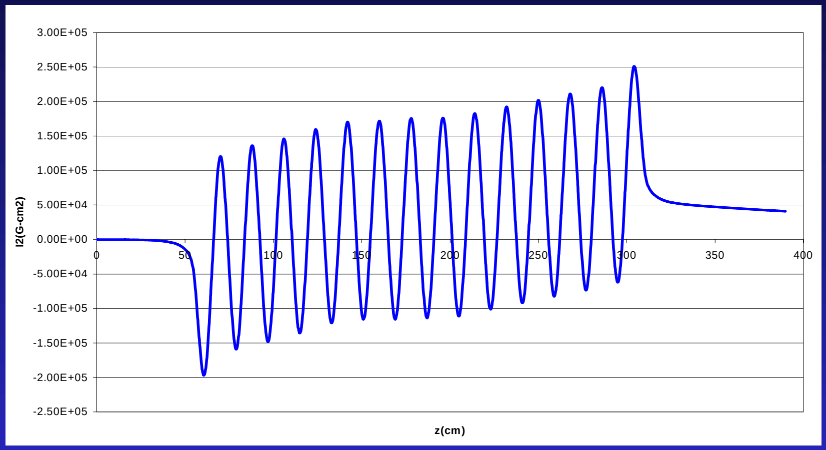
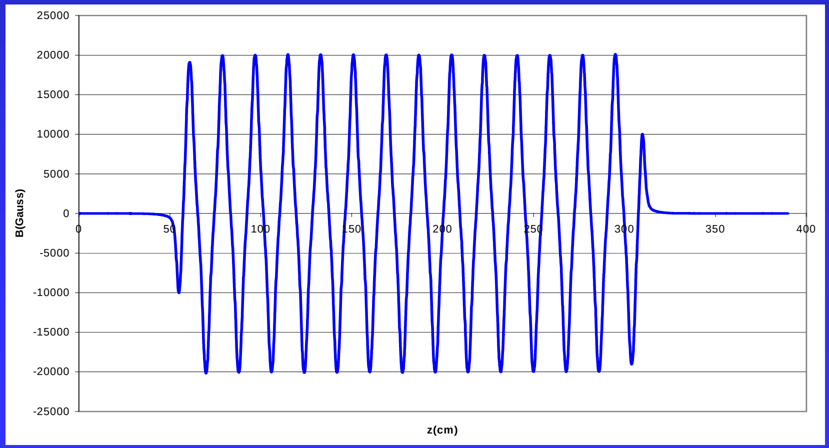
End Fields – Brazil Wiggler Example

Trajectory



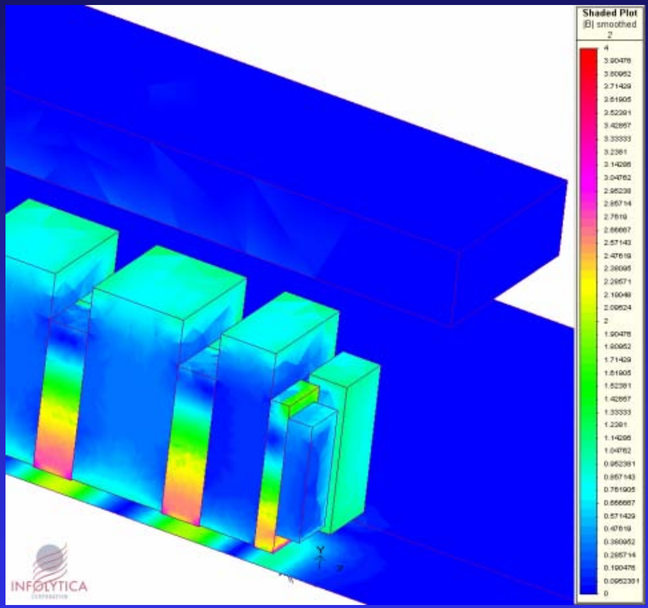
Entrance steering is 0.8% of a half-period kick.

B Field



The 2nd pole strength is 96% of nominal, while FEA calculation of 2nd pole strength gave 98% of nominal. B = 2.0T, λ_w = 18cm

End Field



The last pole and magnet are thinner.
A bias magnet is added to the end and a side magnet is also added.

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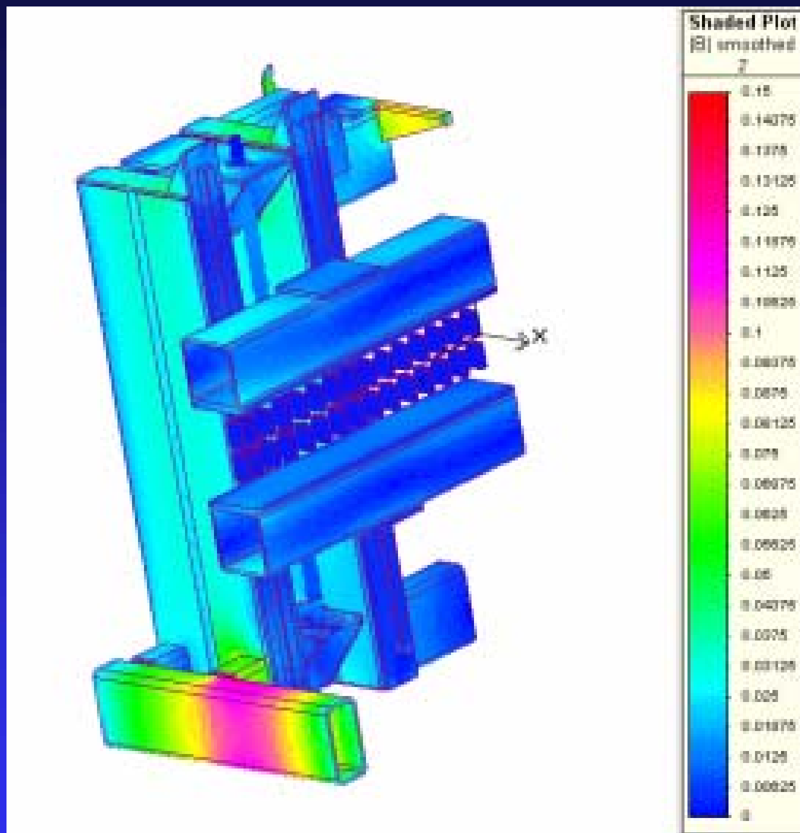
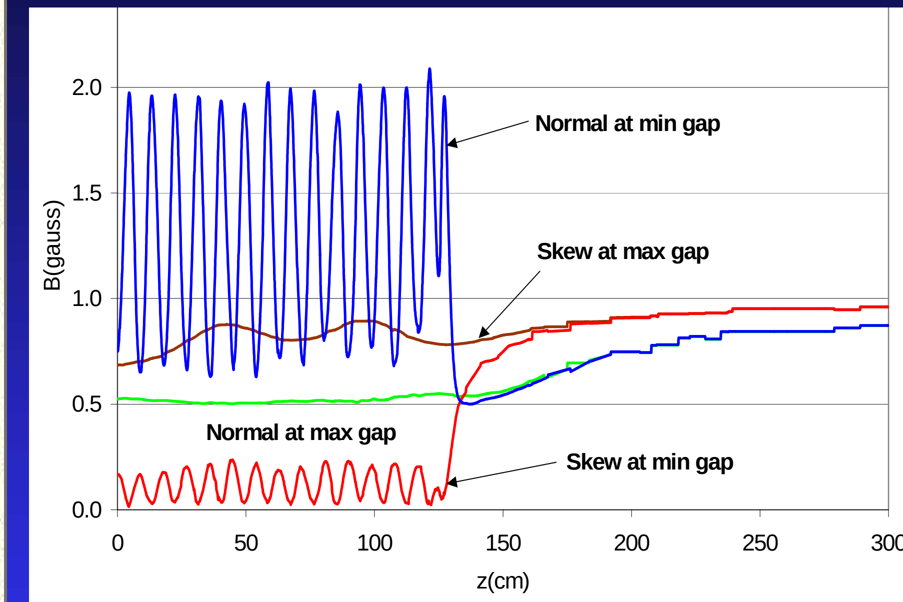
Ambient Fields – Brazil Wiggler



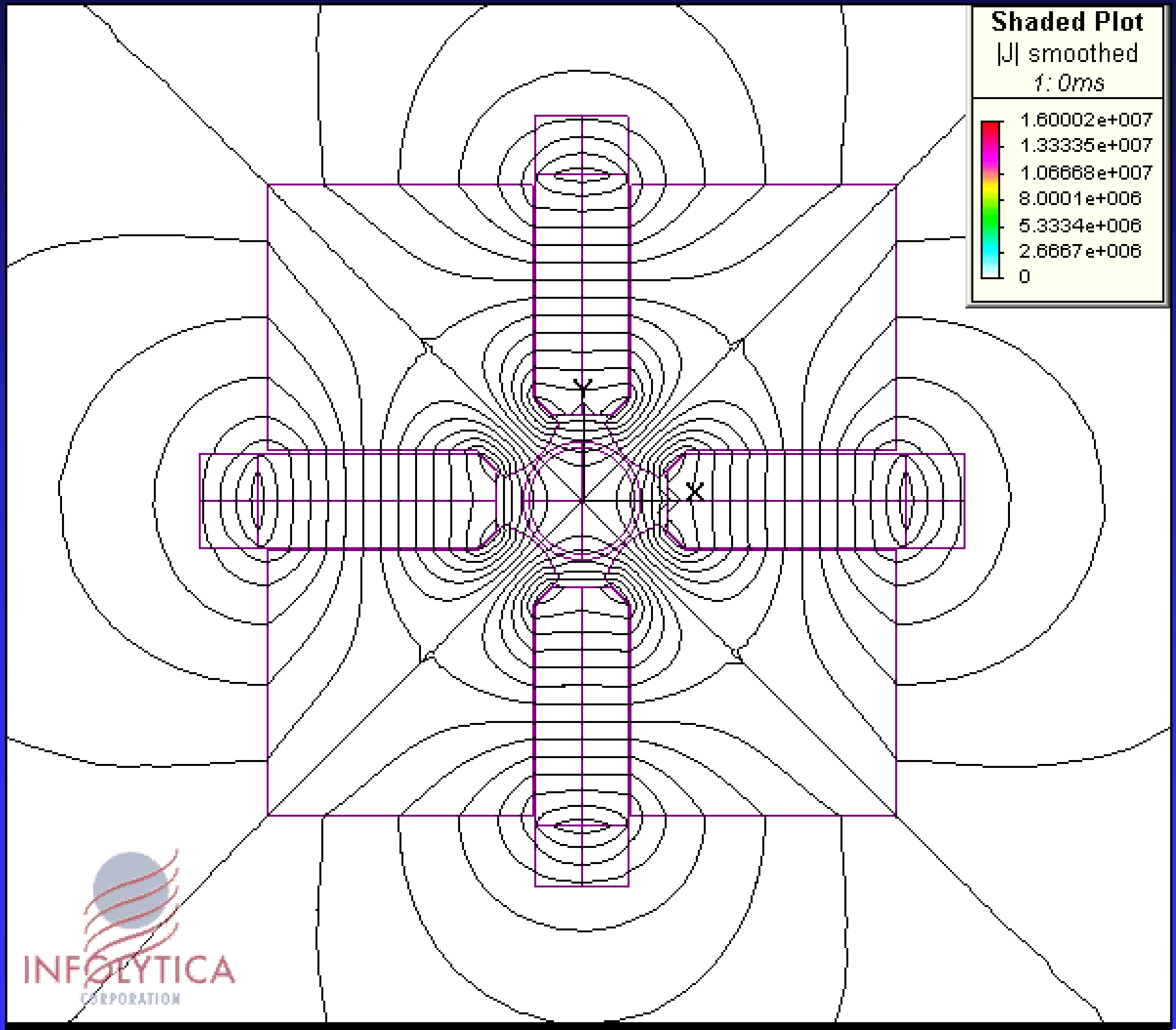
Magnitude of the wiggler magnetic field on the surfaces of the wiggler and poles in the presence of a horizontal 1 gauss ambient field.



Ambient field vs. Z with steel support structure.

Eddy Current in PM Quad

Click the image to view animaton



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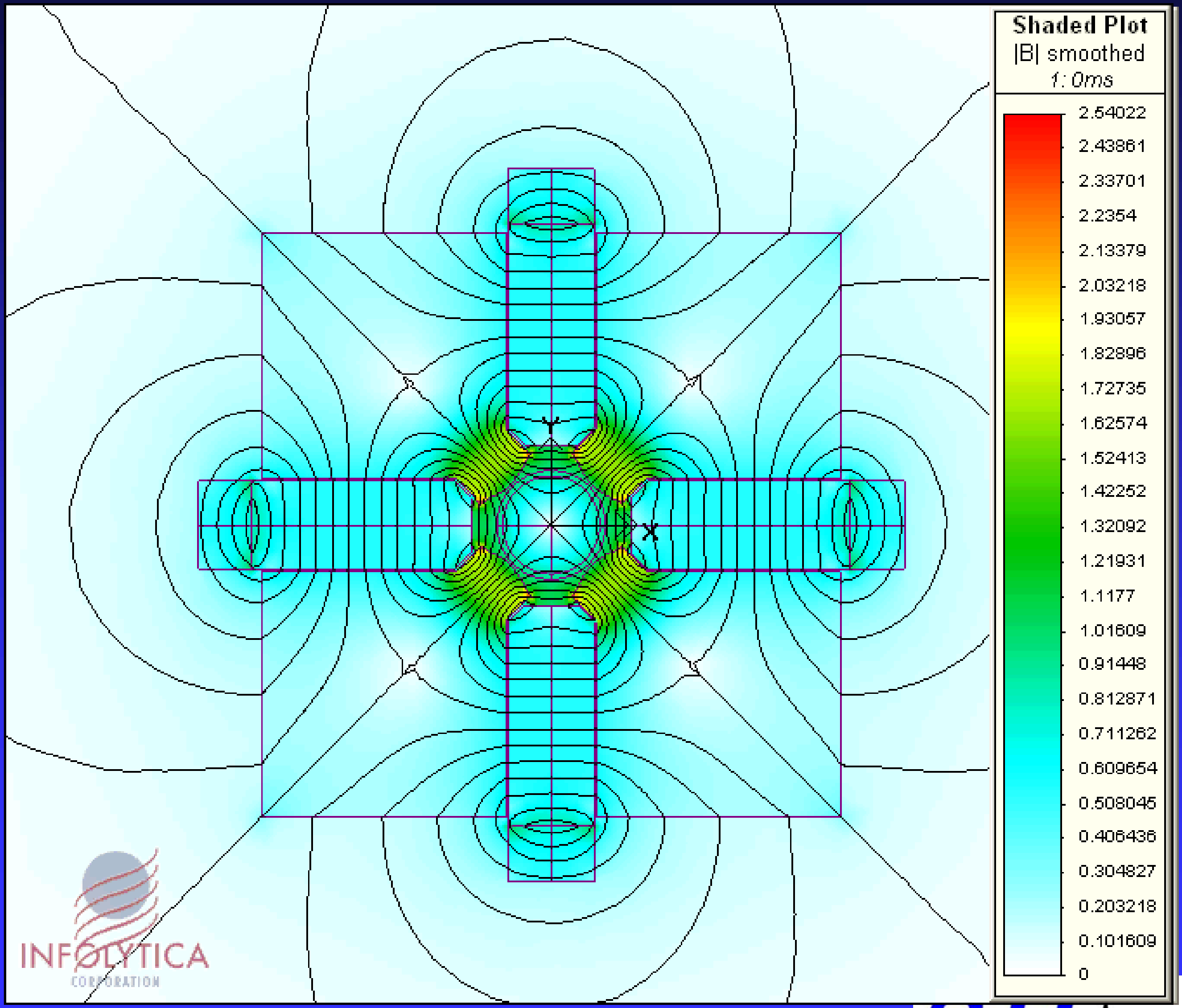
Time dependent B field in PM quad

Click the image to view animaton



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Global Optimizer

- Why?
  - Most of time is spent optimizing
  - Relatively easy to find local mins, hard for global ones
- Approaches
  - Simulated annealing
  - Genetic algorithms (encript floating point number as series of 0,1 ‘genes’). Bookeeping nightmare
  - Evolutionary
    - Similar to simulated annealing
- There’s a commercial code that does this, OptiNet

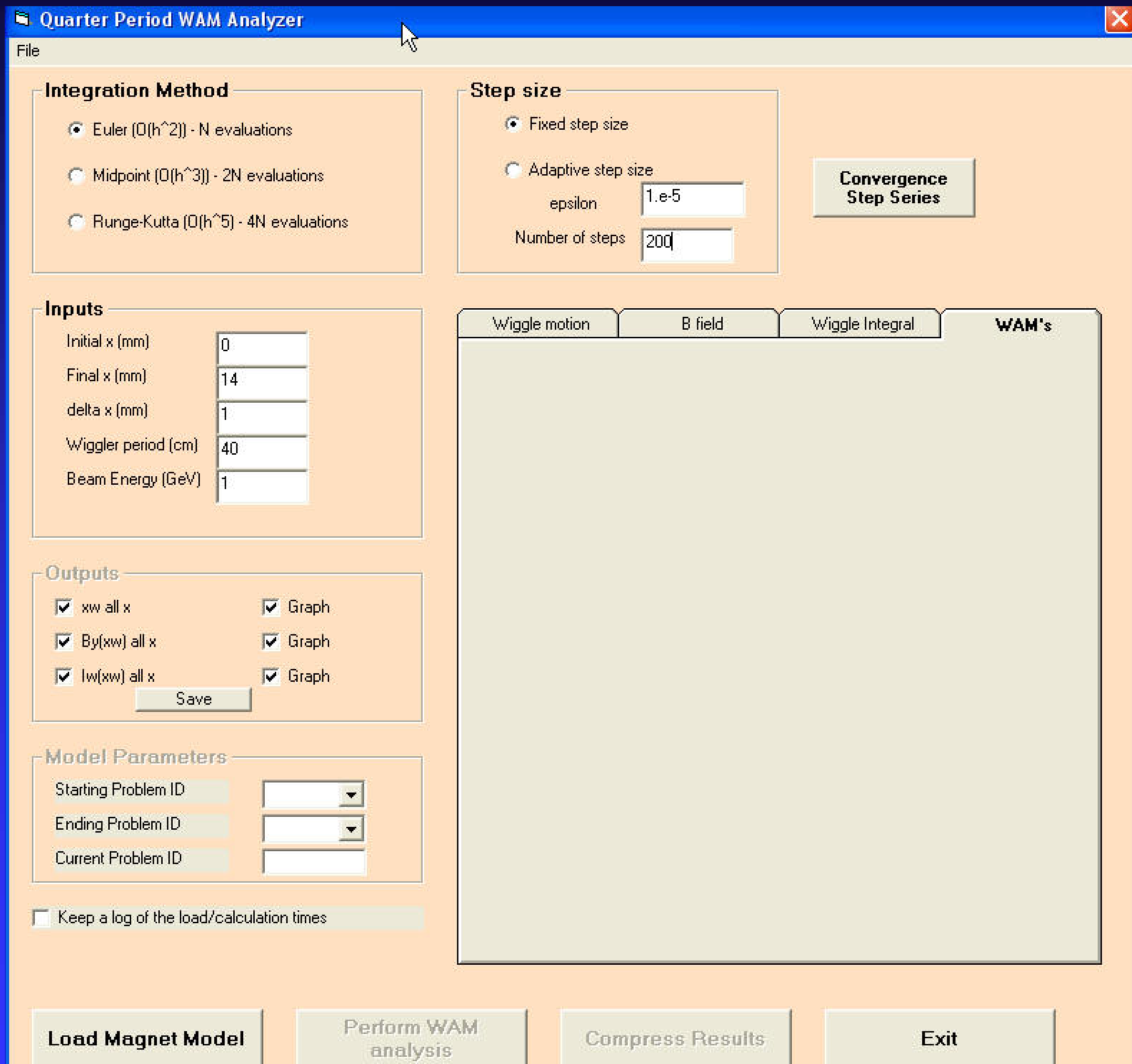
OptiNet example for damping ring wiggler

- ILC DR wiggler
  - 40 cm period!!!
  - B = 1.8 Tesla
  - E = 1 GeV
  - Wiggle amplitude is 0.5mm!!!
  - Wiggle averaged multipoles big problem

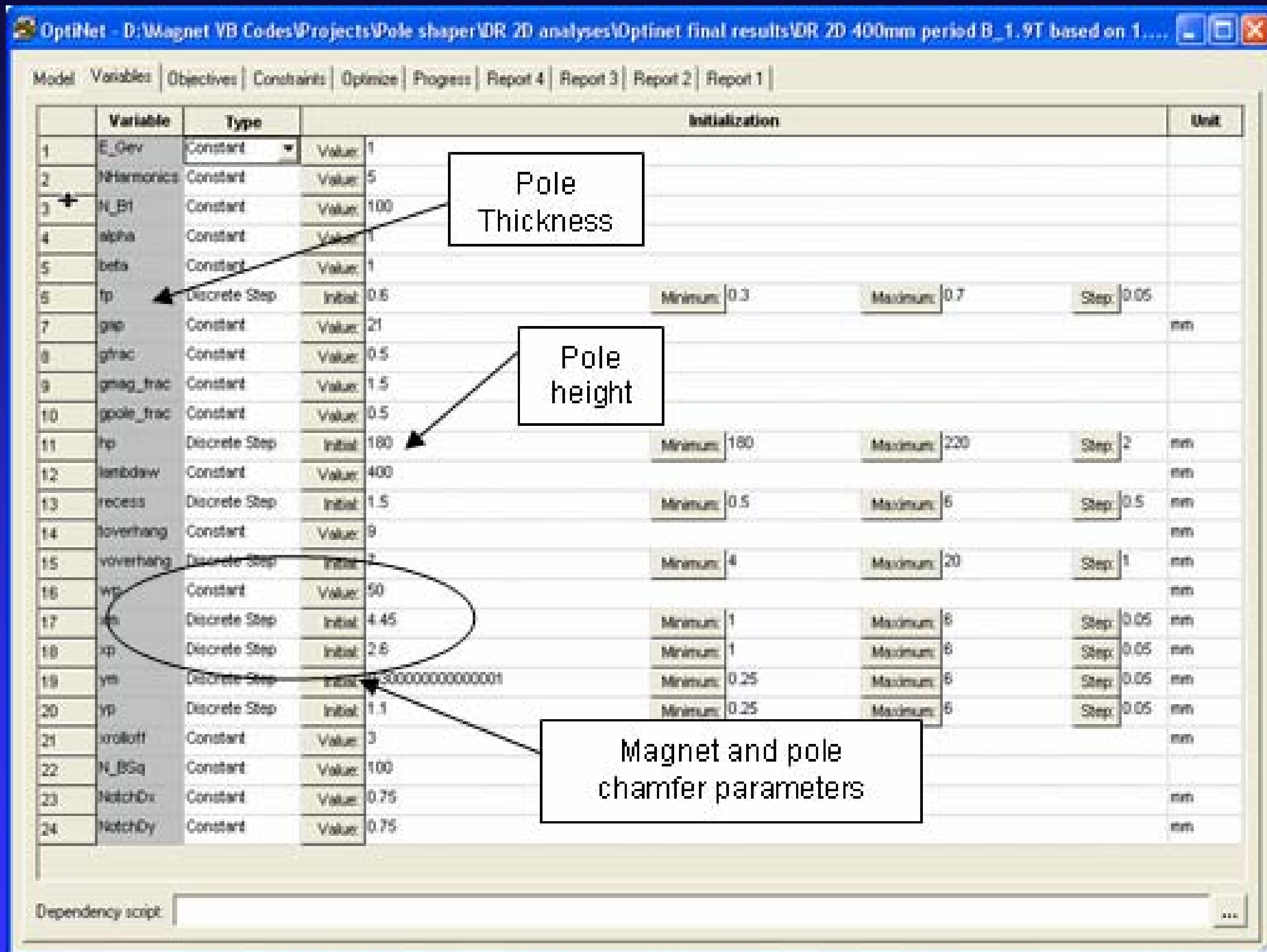
Outline of approach

- Make scripts
  - B^2 integrator
  - 3D pole shaper
  - WAM calculator
  - Rolloff calculator
- Make 'template' parametric model
- Perform 2D optimization
  - Demag, saturation, temp sens, etc, etc, etc using OptiNet
- Initial 3D scoping FEA to bound parameters
- Final 3D OptiNet runs

WAM Calculator Script



Set Optimization parameters



	Variable	Type	Initialization								Unit
1	E_Gev	Constant	Value:	1							
2	NHarmonics	Constant	Value:	5							
3	N_Bt	Constant	Value:	100							
4	alpha	Constant	Value:	1							
5	beta	Constant	Value:	1							
6	tp	Discrete Step	Initial:	0.6	Minimum:	0.3	Maximum:	0.7	Step:	0.05	
7	gap	Constant	Value:	21							mm
8	gfrac	Constant	Value:	0.5							
9	gmag_frac	Constant	Value:	1.5							
10	gpole_frac	Constant	Value:	0.5							
11	hp	Discrete Step	Initial:	180	Minimum:	180	Maximum:	220	Step:	2	mm
12	lambdaw	Constant	Value:	400							mm
13	recess	Discrete Step	Initial:	1.5	Minimum:	0.5	Maximum:	6	Step:	0.5	mm
14	toverhang	Constant	Value:	9							mm
15	voverhang	Discrete Step	Initial:	7	Minimum:	4	Maximum:	20	Step:	1	mm
16	wp	Constant	Value:	50							mm
17	[illegible]	Discrete Step	Initial:	4.45	Minimum:	1	Maximum:	6	Step:	0.05	mm
18	xp	Discrete Step	Initial:	2.6	Minimum:	1	Maximum:	6	Step:	0.05	mm
19	ym	Discrete Step	Initial:	[illegible]30000000000000001	Minimum:	0.25	Maximum:	6	Step:	0.05	mm
20	yp	Discrete Step	Initial:	1.1	Minimum:	0.25	Maximum:	6	Step:	0.05	mm
21	xrolloff	Constant	Value:	3							mm
22	N_BSq	Constant	Value:	100							
23	NotchDx	Constant	Value:	0.75							mm
24	NotchDy	Constant	Value:	0.75							mm

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Define constraints and objectives

OptiNet - D:\Magnet VB Codes\Projects\Pole shaper\DR 2D analyses\Optinet final results\DR 2D 400mm period B_1.9T based on 1...

Model | Variables | Objectives | Constraints | Optimize | Progress | Report 4 | Report 3 | Report 2 | Report 1

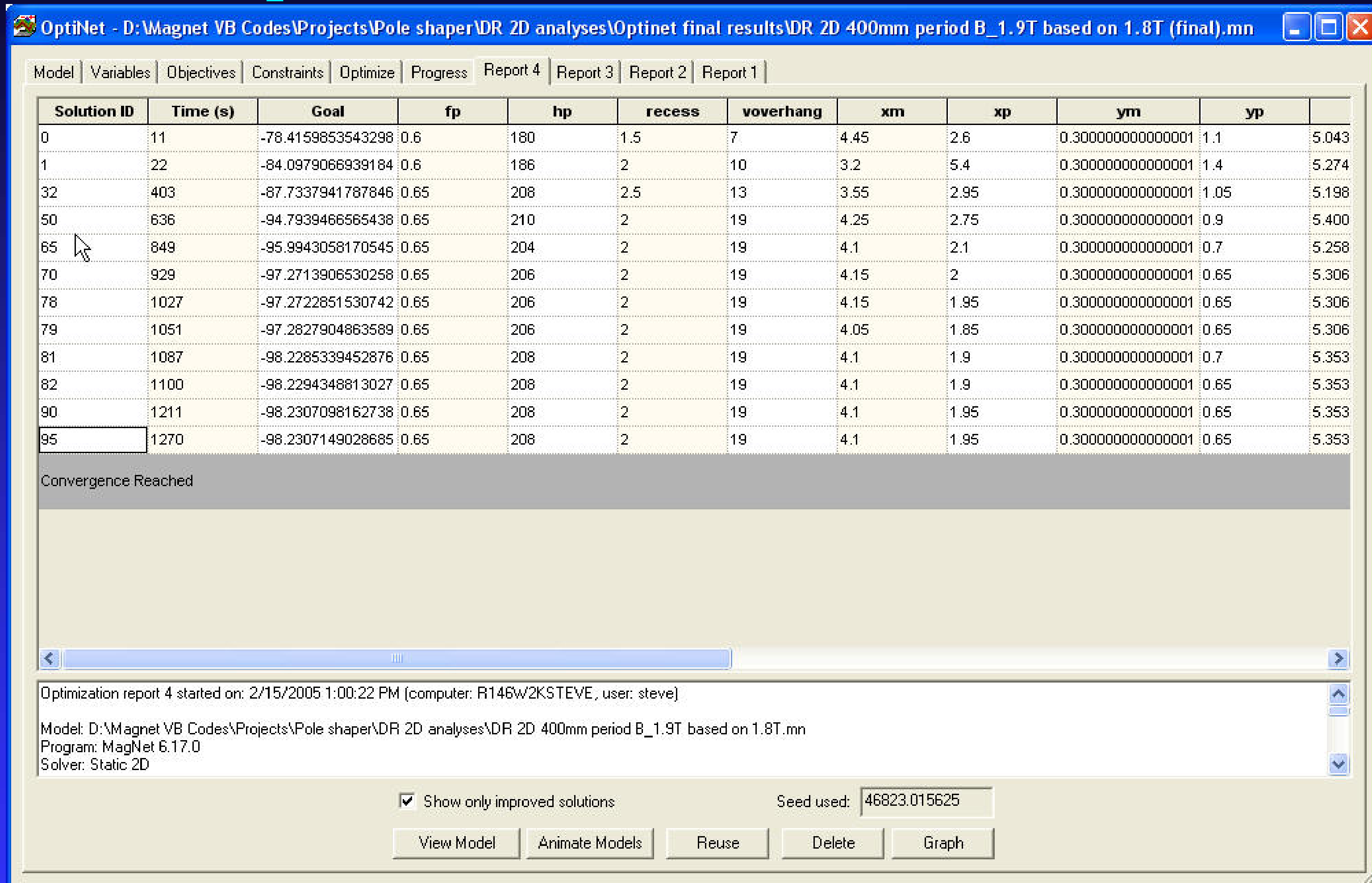
	Constraint	Argument(s)	Type	Value	Weight
1	Field at point	B y smoothed,0,0,0	Should be <=	1.91	500
2	Field in components - Minimum	H x smoothed,Mag1	Should be >	-1250495	0.0002
3	Field in components - Maximum	|B| smoothed, Pole1	Should be <	3.6	200
4	Field at point	B y smoothed,0,0,0	Should be >=	1.89	500

OptiNet - D:\Magnet VB Codes\Projects\Pole shaper\DR 2D analyses\Optinet final results\DR 2D 400mm period B_1.9T based on 1..

Model | Variables | Objectives | Constraints | Optimize | Progress | Report 4 | Report 3 | Report 2 | Report 1

	Objective	Argument(s)	Goal	Reference	Weight
1	Mass of component	Mag1	Minimize	0.0004	1
2	Script - Solution	BSquaredCalc.vbs	Maximize	0.25	50

Run the optimizer and examine solution



Solution ID	Time (s)	Goal	fp	hp	recess	voverhang	xm	xp	ym	yp	
0	11	-78.4159853543298	0.6	180	1.5	7	4.45	2.6	0.300000000000001	1.1	5.043
1	22	-84.0979066939184	0.6	186	2	10	3.2	5.4	0.300000000000001	1.4	5.274
32	403	-87.7337941787846	0.65	208	2.5	13	3.55	2.95	0.300000000000001	1.05	5.198
50	636	-94.7939466565438	0.65	210	2	19	4.25	2.75	0.300000000000001	0.9	5.400
65	849	-95.9943058170545	0.65	204	2	19	4.1	2.1	0.300000000000001	0.7	5.258
70	929	-97.2713906530258	0.65	206	2	19	4.15	2	0.300000000000001	0.65	5.306
78	1027	-97.2722851530742	0.65	206	2	19	4.15	1.95	0.300000000000001	0.65	5.306
79	1051	-97.2827904863589	0.65	206	2	19	4.05	1.85	0.300000000000001	0.65	5.306
81	1087	-98.2285339452876	0.65	208	2	19	4.1	1.9	0.300000000000001	0.7	5.353
82	1100	-98.2294348813027	0.65	208	2	19	4.1	1.9	0.300000000000001	0.65	5.353
90	1211	-98.2307098162738	0.65	208	2	19	4.1	1.95	0.300000000000001	0.65	5.353
95	1270	-98.2307149028685	0.65	208	2	19	4.1	1.95	0.300000000000001	0.65	5.353

2D model so several parameters are not properly analyzed. They were adjusted for 3D analysis

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Summary of Optinet features

- Intuitive and easy to use
  - Lots of tools included to make it easy to see what you're asking for
- Flexible
  - User can determine goals, constraints, monitor progress
- Powerful
  - We have used VBS, VB, our own ActiveX classes, IDL, Fortran95 dll's, standalone EXE's for custom goals and objectives
  - Others have used Matlab
  - In general any ActiveX server app (or wrapper app) can be used
- It is not a substitute for thinking! It will do EXACTLY what you tell it to do. You must insure that you are asking for the right thing.
- You must have Magnet (or Elecnet or ThermNet).
- It can be used for non FEA problems

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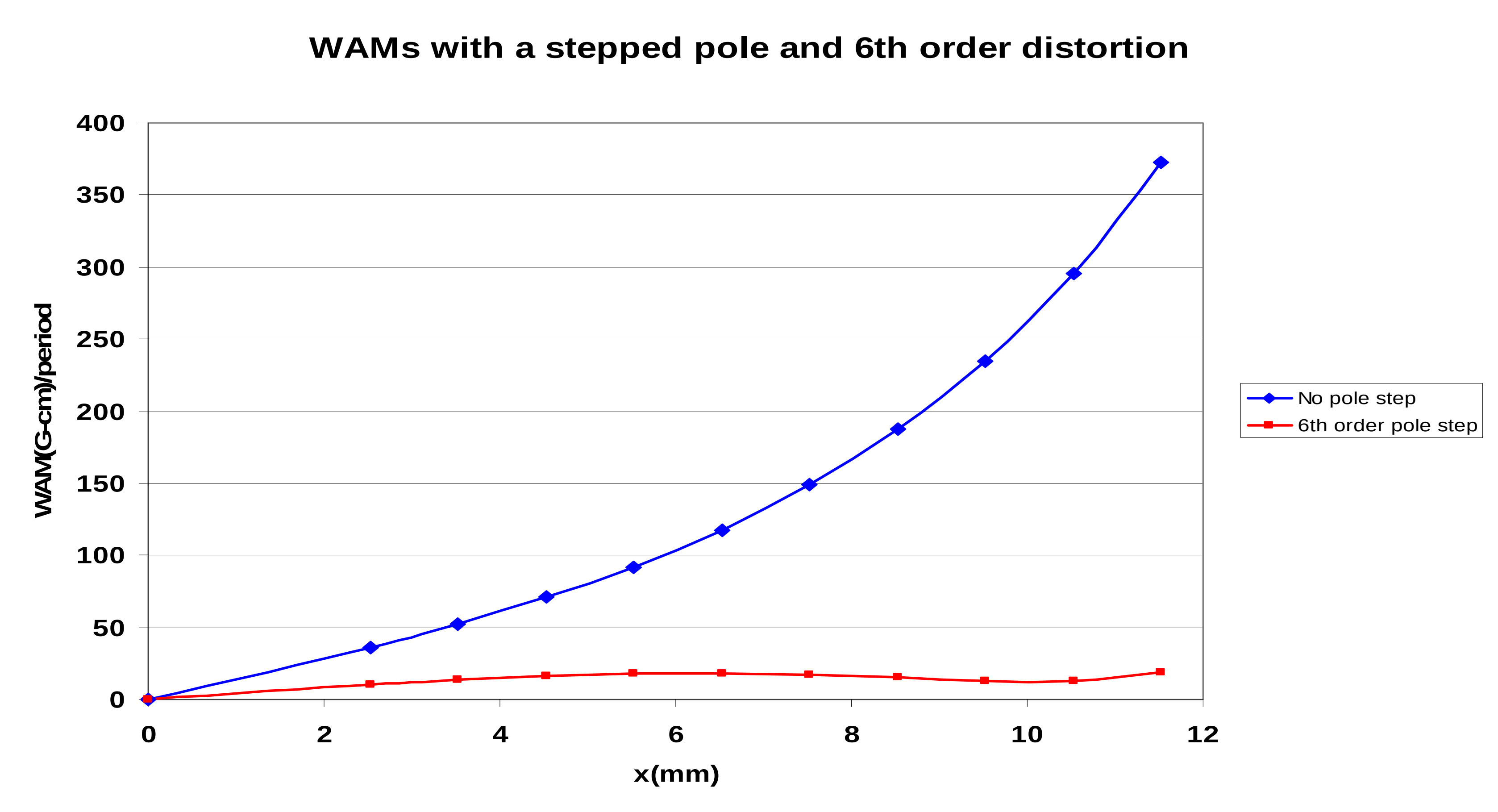
Results for 3D Optimization



WAM's reduced by a factor of 40

Optimization has worked very well

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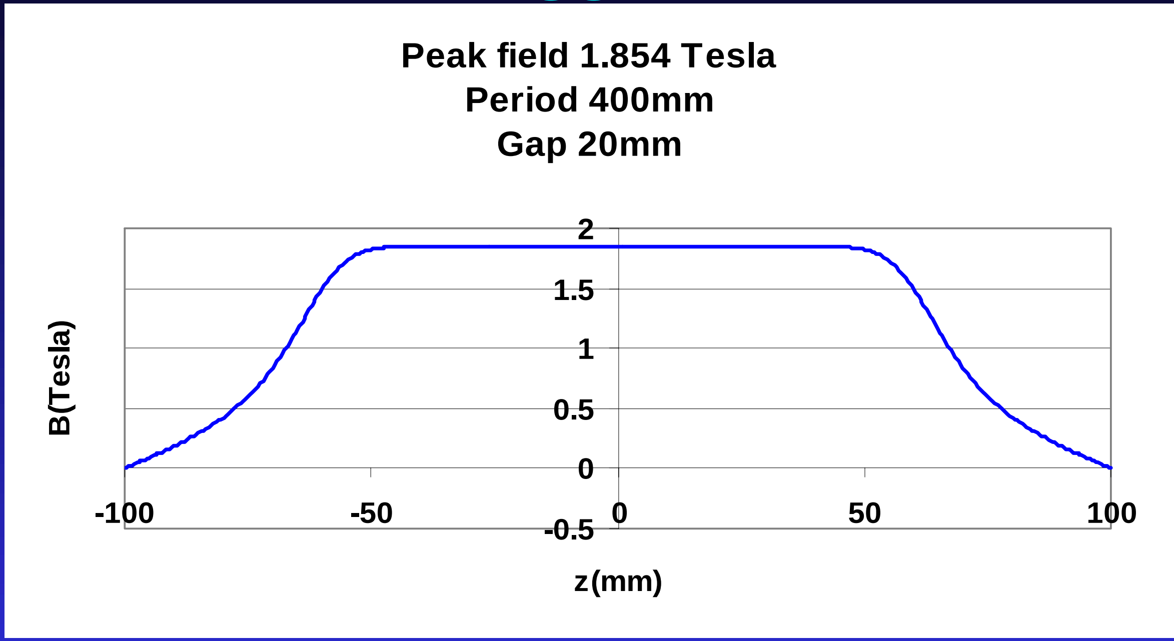
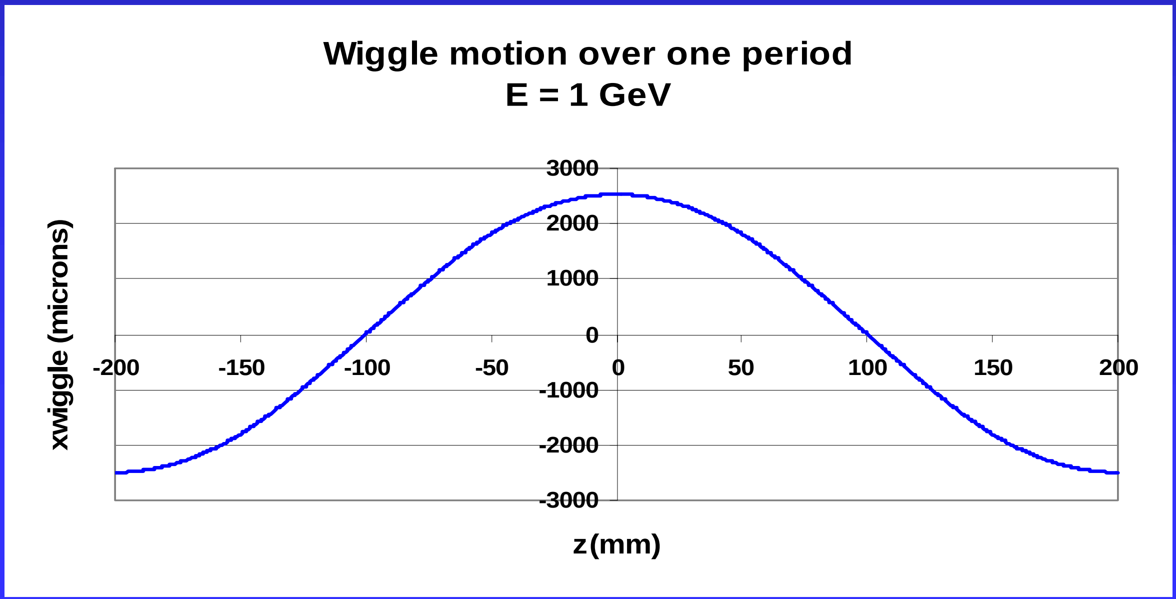
B fields and wiggle motions



B Field



Wiggle motion

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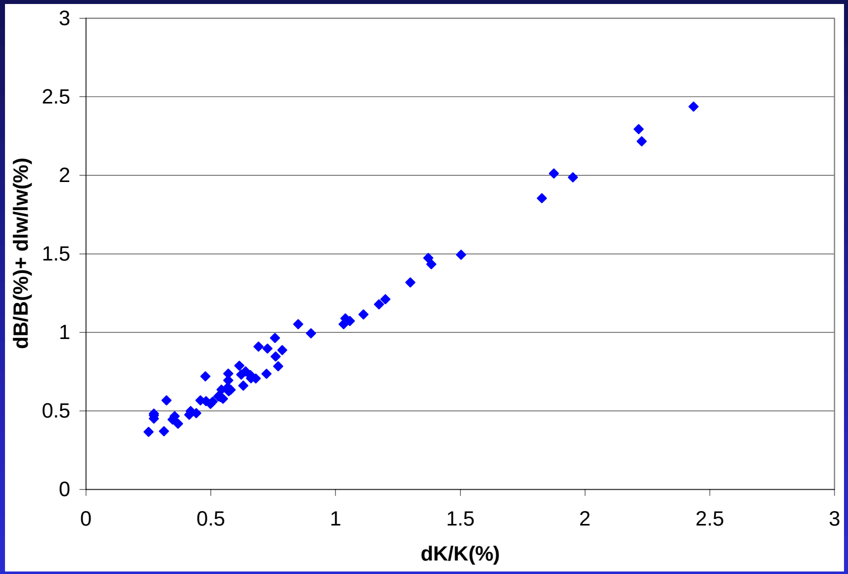
What's next for DR wigglers?

- Won Phase II SBIR to continue this work
  - Analysis
    - Repeat this for standard wigglers by including 3D magnet profiles or other exotic features
    - Series of optimizations for other DR wiggler configurations
    - Add FFT based optimization
  - Trade studies
    - Engineering and manufacturing trades
    - Cost trades
  - Prototype tests
    - Fabricate poles using different manufacturing methods
    - Build half period DR wigglers with shaped poles
    - Build half period standard wigglers with shaped poles
    - Build nine period prototype of one DR or standard wiggler configuration

Don’t forget that analysis only gets you part way there

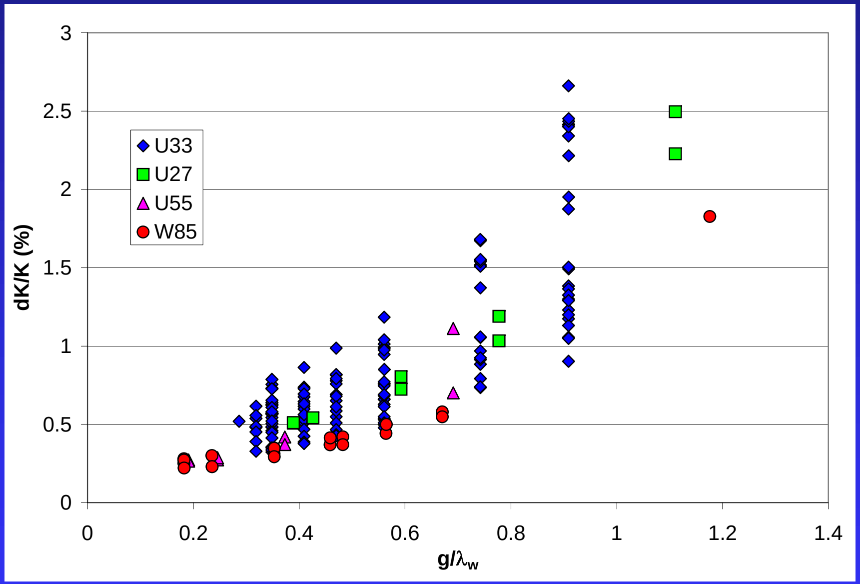


Correlation between half-period kick errors and field + period errors before tuning 19 undulators with periods 18mm - 85mm

$g/\lambda_w = 0.18\text{-}1.18$

$(dB/B) + (d\lambda_w/\lambda_w) = 0.13\% + 0.95 * (dK/K)$

Half period kick errors vs. g/λ_w 19 undulators with periods 18mm-85mm $g/\lambda_w = 0.18 - 1.18$



- Low half period kick errors require careful control of both the magnetic period and the peak field