New 27-mm period undulator for APS-U

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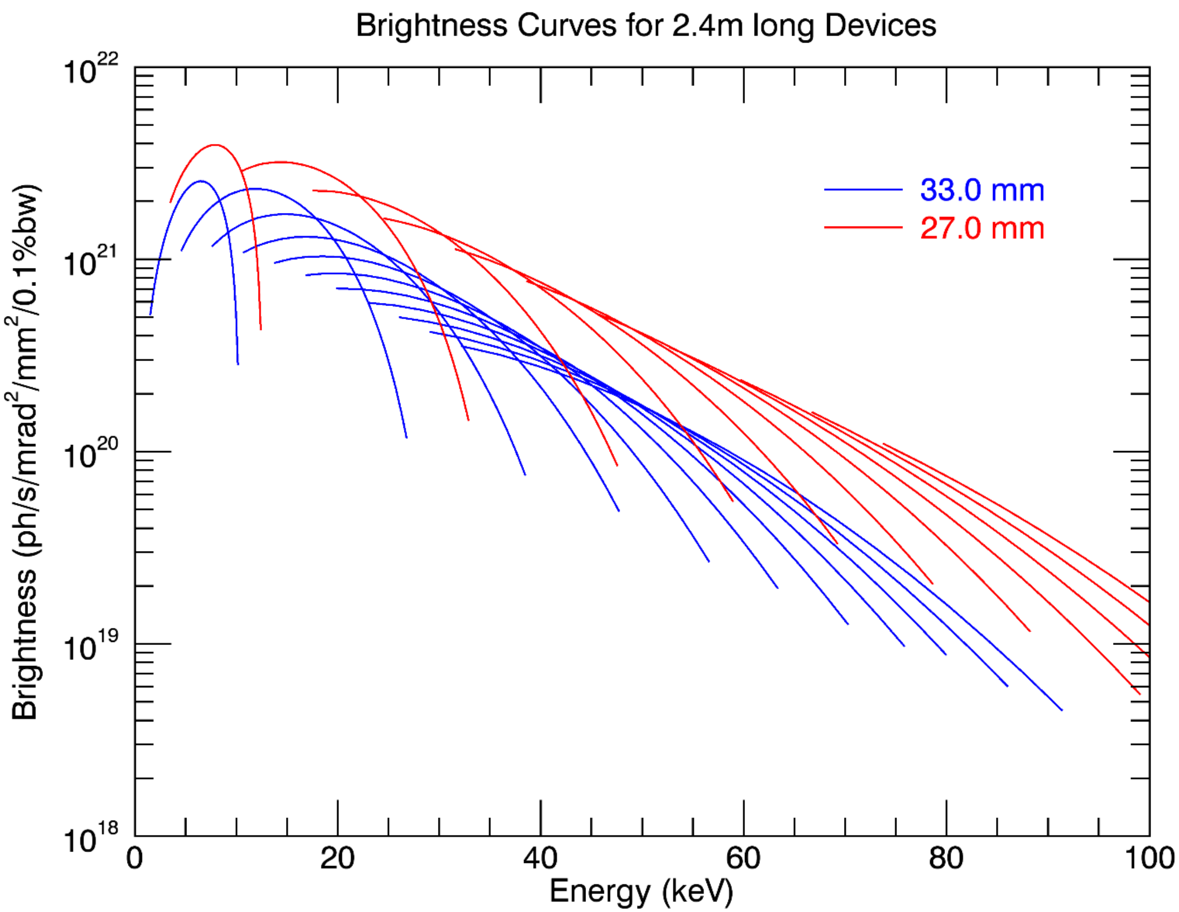
Outline

- Motivation
- Specifications
- Dimensions of the existing and new design
- Field, magnetic force, and roll-off of the existing and new design
- Electron beam trajectory of the new design
- Conclusion

Motivation

1. The new MBA lattice reduces the storage ring energy from 7 GeV to 6 GeV
2. The new MBA lattice will allow the lower limit of ID gaps to be reduced from 11mm to 8.5 mm
3. Need to use shorter undulator periods to take advantage of higher brightness

Tuning Curves of Typical Undulator for MBA lattice



The 2.7 cm period device provides full tuneability and increased brightness at lower power and power density than the 3.3 cm device

Comparison of Insertion Device Periods

The reduction of Storage Ring energy from 7 GeV to 6 GeV requires the reevaluation of undulator periods for APS-U

Source (period)	Maximum K	Minimum ID Gap (mm)	Minimum Energy (keV)	Power (kW)
APS* 3.3cm	2.60	11.0	3.22	5.45
APS-U 3.3cm	3.39	8.5	1.53	14.01
APS-U 2.7cm	2.28	8.5	3.51	9.34

All ID are 2.4 m long APS*: 7 GeV 100 mA APS-U : 6 GeV 200 mA

The 3.3 cm device exceeds front end power limit and pushes the lower limit of the 1st harmonic to very low energies

Motivation

- A two-headed revolver design exists and is in current operation
- Existing magnets can be used in the two headed revolver
- A new three-headed revolver is planned for the MBA lattice, to use multiple smaller-period devices to enhance brightness
- A three-headed revolver will require newer magnet arrays with smaller transverse dimensions

1) Explore smaller magnet design while meeting the storage ring requirements
2) Smaller magnets will also result in reduced forces for the magnet gap separation mechanisms

⇓

Investigate the 2.7 cm period device as a test case….

2 Headed Revolver

3 Headed Revolver

Specifications

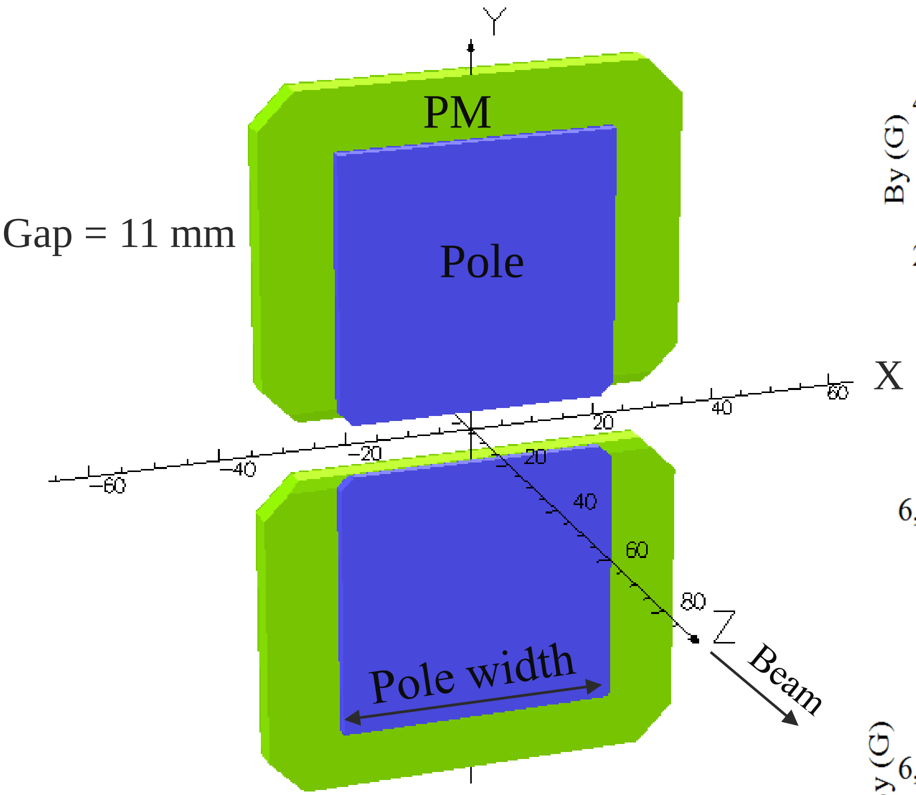
Magnetic field roll off specifications as a function of gap derived from the third harmonic.

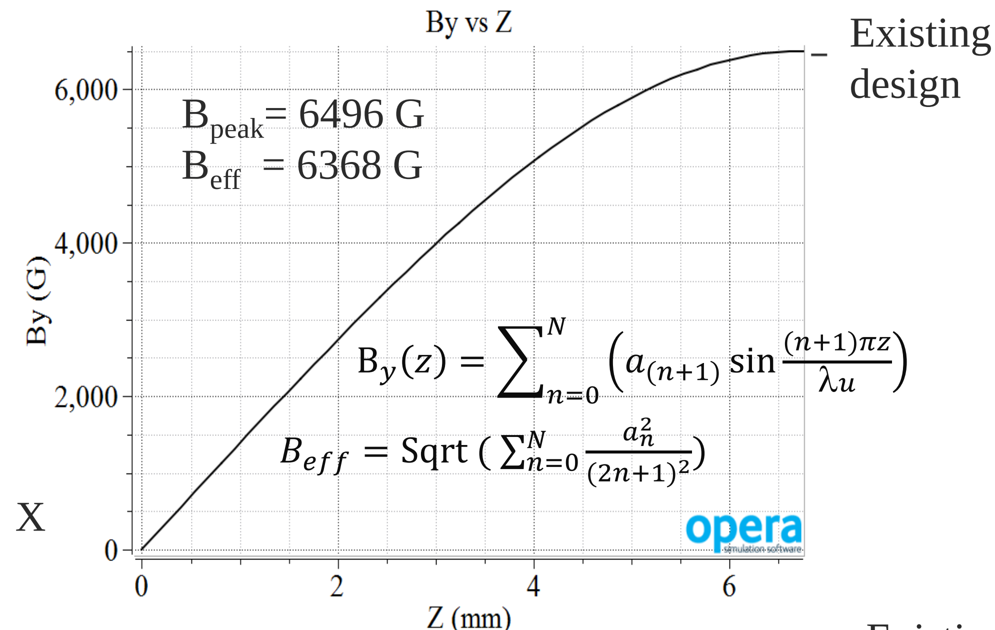
Gap (mm)	K value	Energy 3rd harmonic (keV)	FWHM (eV)	ΔE/E	K-factor	ΔB/B
8.5	2.282	10.54	54	5.15e-3	1.45	3.55e-4
11.0	1.664	15.92	84	5.26e-3	1.16	4.53e-4
13.5	1.221	21.75	116	5.33e-3	0.85	6.27e-4
15.5	0.959	26.00	141	5.42e-3	0.63	8.60e-4
18.5	0.671	30.97	171	5.52e-3	0.37	14.9e-4
24.5	0.333	35.95	202	5.61e-3	0.11	51.0e-4
30.0	0.178	37.35	211	5.65e-3	0.03	188.e-4

Existing 27-mm Period Undulator quarter period long

PM: NdFeB: N42SH

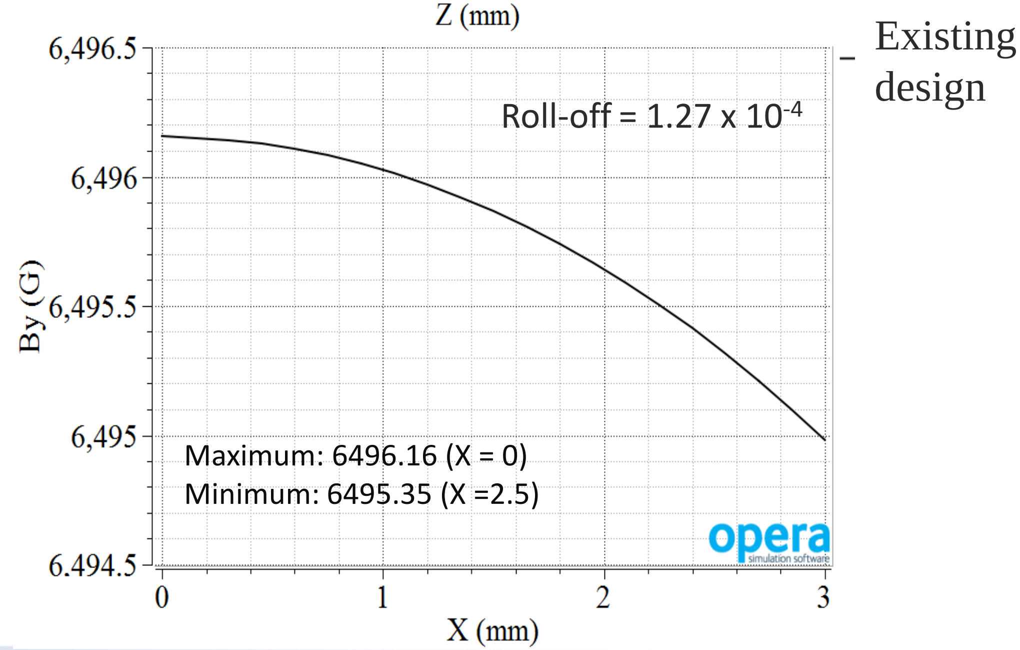
Pole: Vanadium Permendur





$\Delta B = B(x=2.5mm) – B(x=0 mm) = 0.81$ G

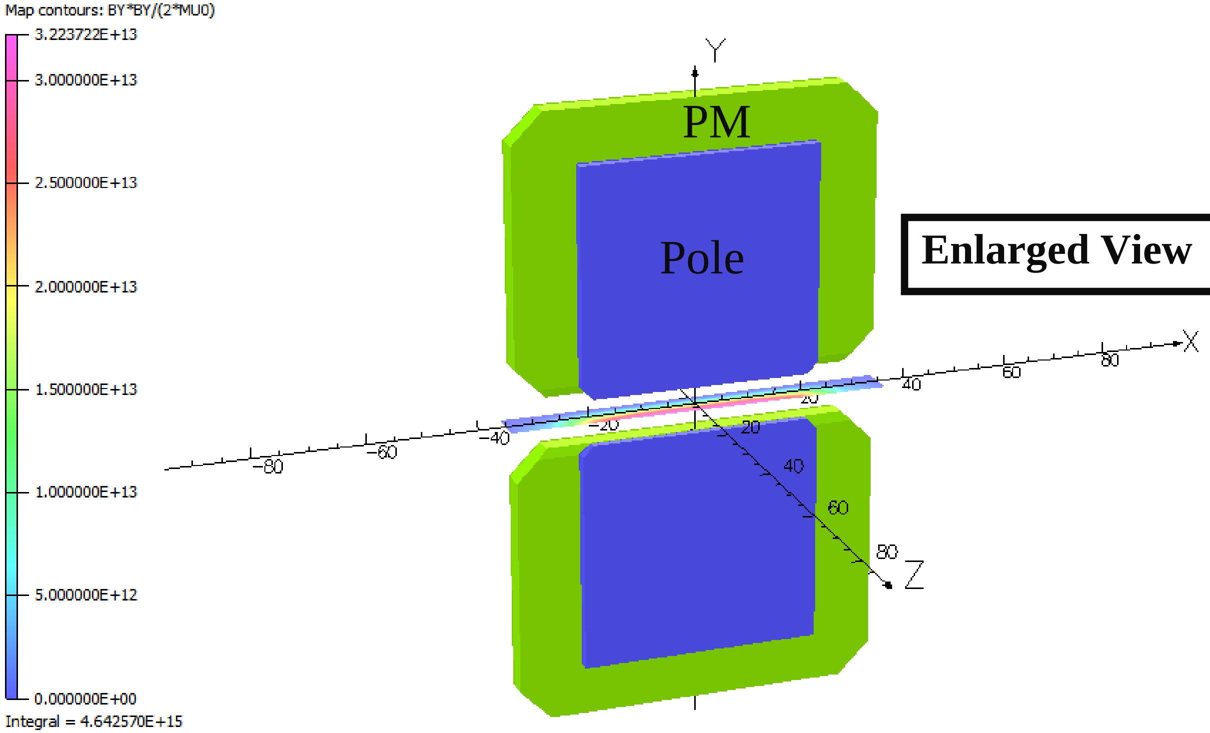
Roll-off = $\Delta B/B_{eff} = 1.27 \times 10^{-4}$

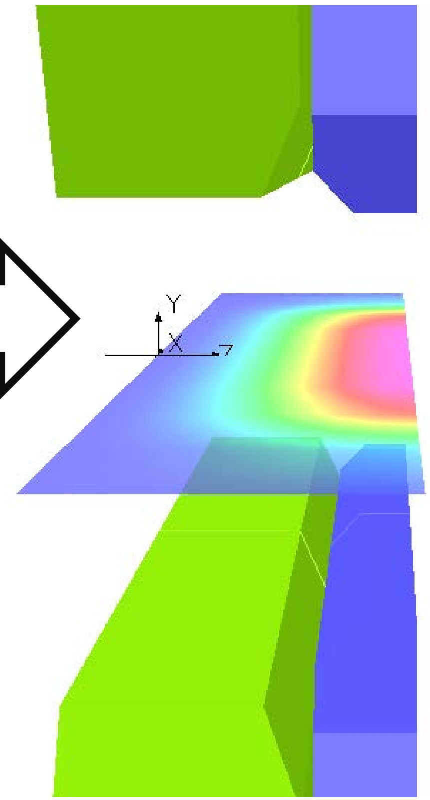


Small roll-off due, in part, to the wide pole width of 44 mm

Magnetic Force Analysis with the Existing Design

Gap = 8.5 mm



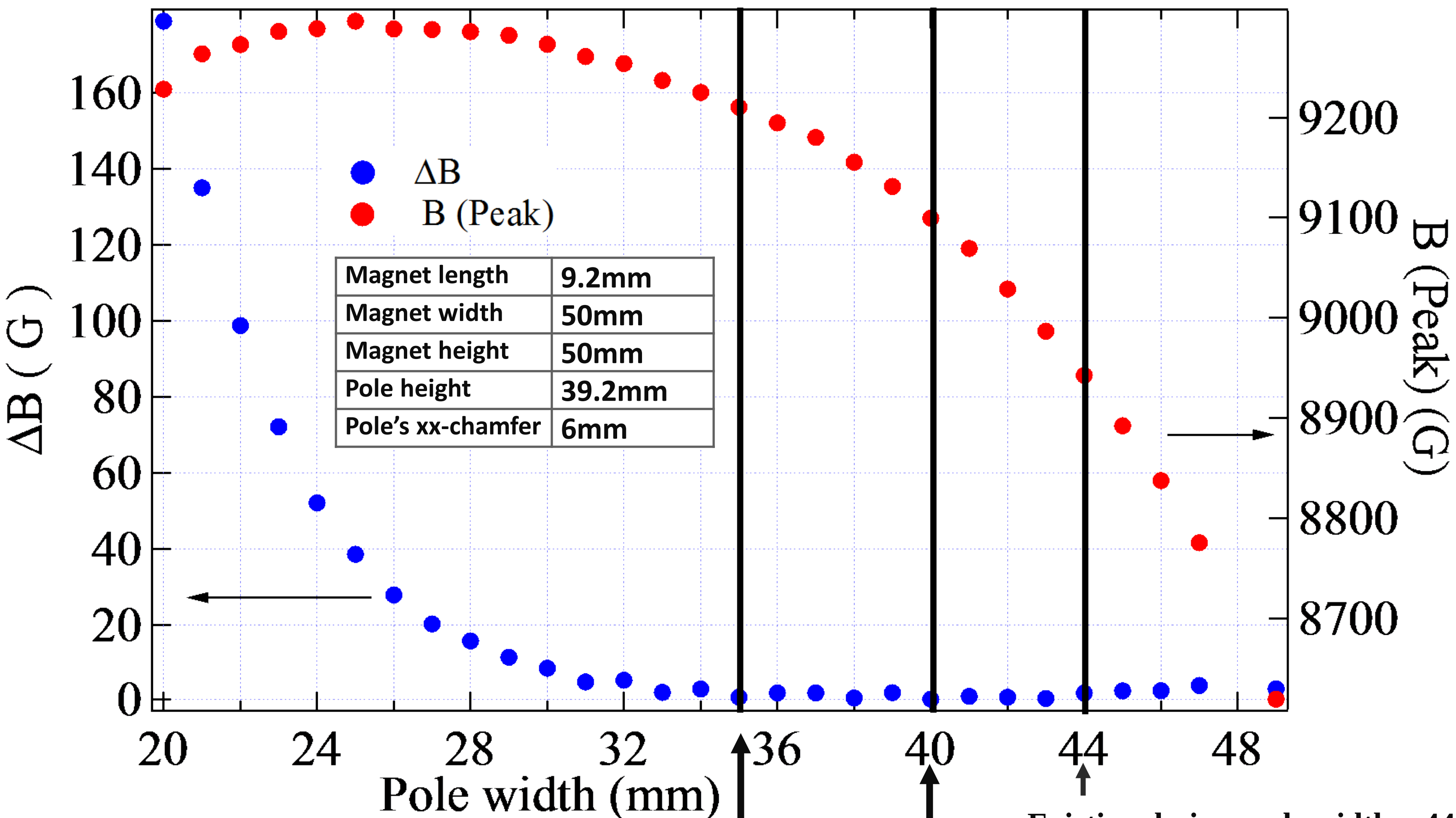


Force = 93 N (half period)
~16,500 N total force for 2.4 m undulator

opera simulation software

27mm period
44mm pole

Peak Field & Roll-off Vs Pole width at 8.5 mm gap



Magnet length	9.2mm
Magnet width	50mm
Magnet height	50mm
Pole height	39.2mm
Pole's xx-chamfer	6mm

Existing design: pole width = 44 mm

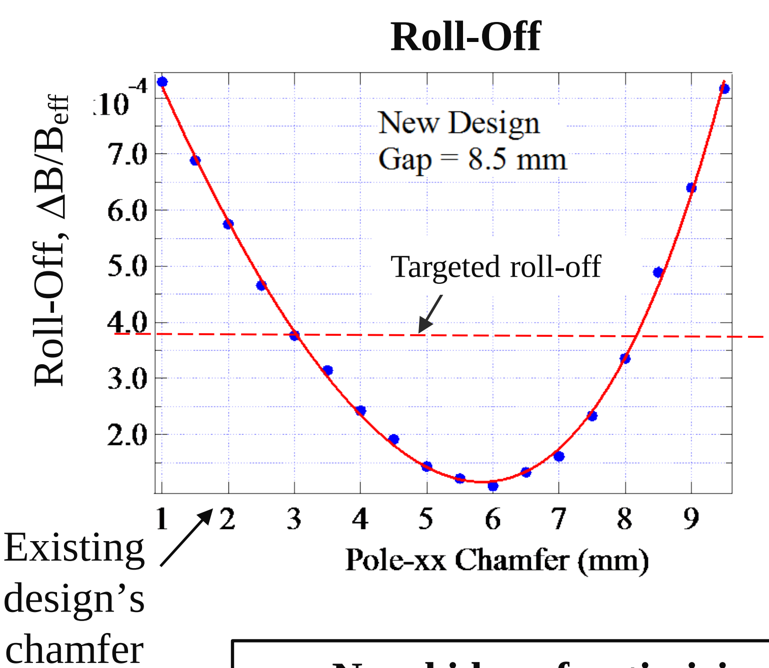
New Design: pole width = 40 mm

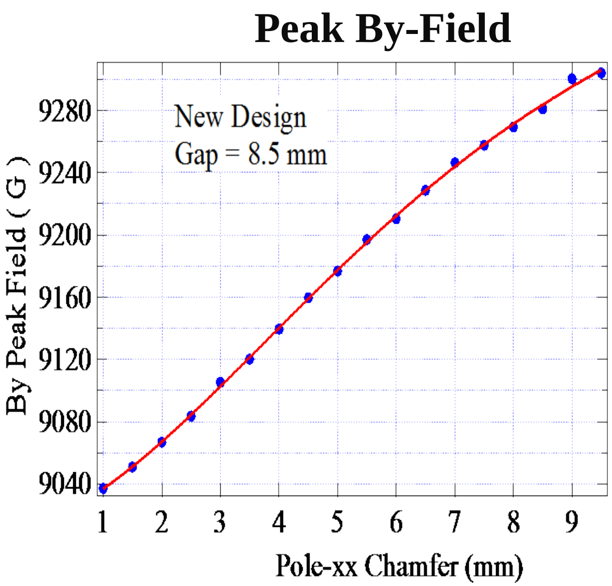
Future redesign: pole width = 35 mm

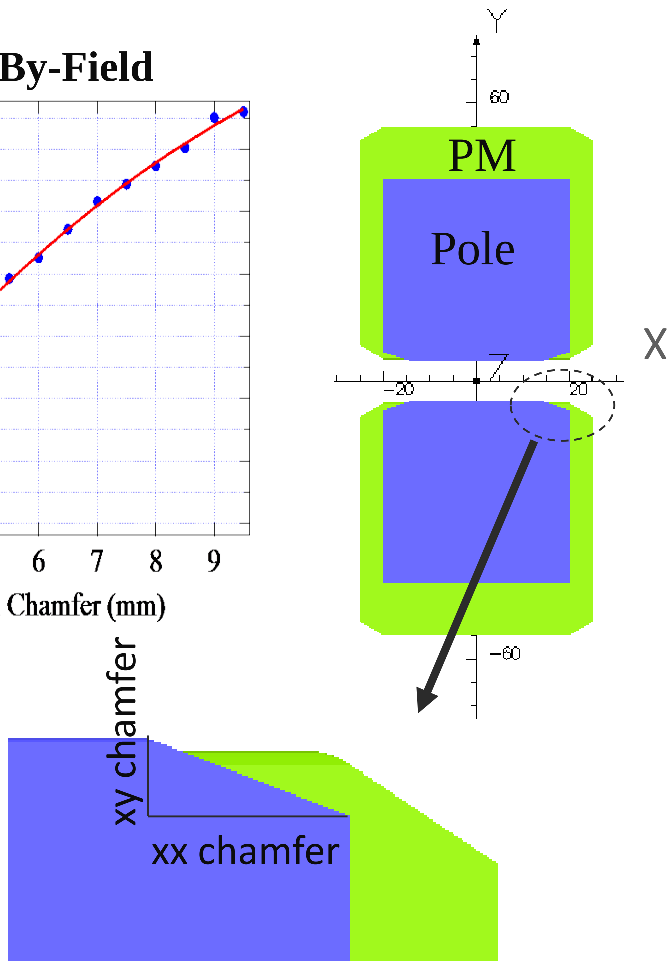
Roll-off gets worse as gap increases
(8.5mm gap shown)

Achieved the allowable roll-off field

Peak Field and its Roll-off Vs Pole's-xx Chamfer
Pole width = 40 mm







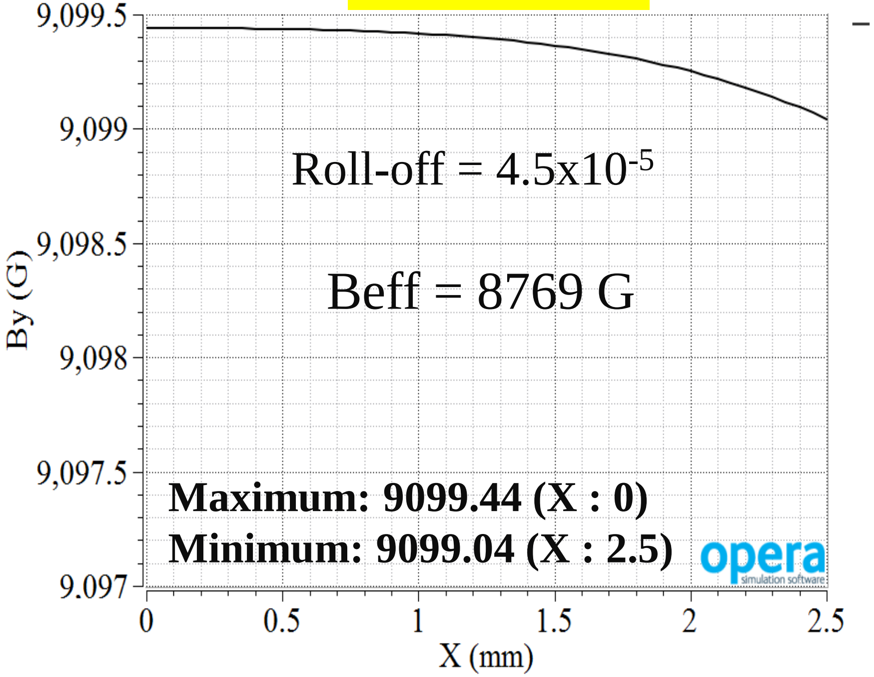
Novel idea of optimizing chamfer increases flux density at pole tip.

Chamfer improves performance and enables pole width to be reduced

By vs X fields of new and existing design (8.5 mm gap) (I)

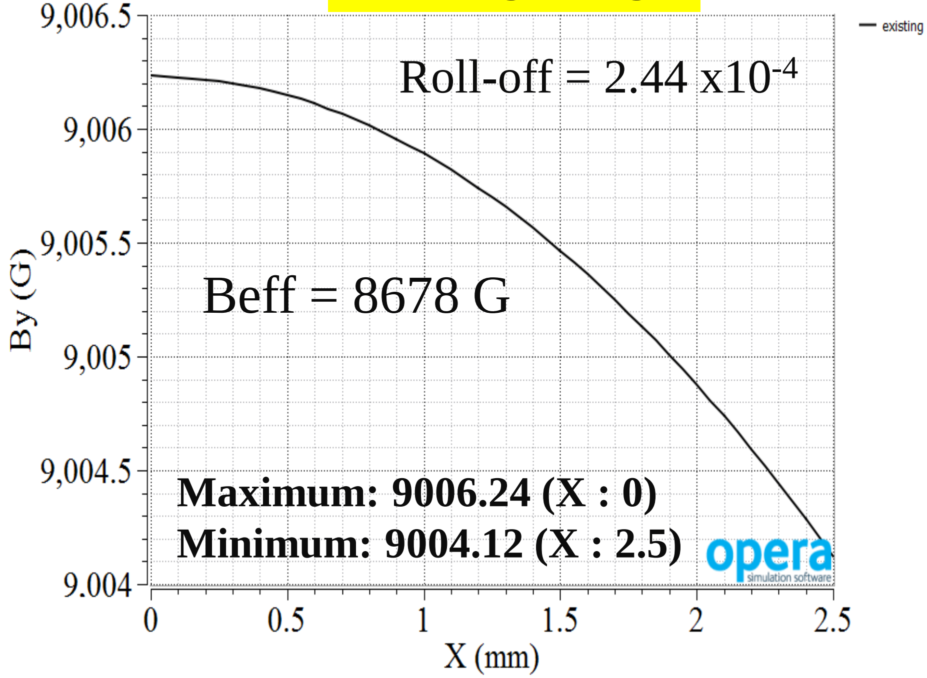
Range in X: -2.5 mm to 2.5 mm (Proposal APS-U)

New design



27mm period
40mm pole

Existing design

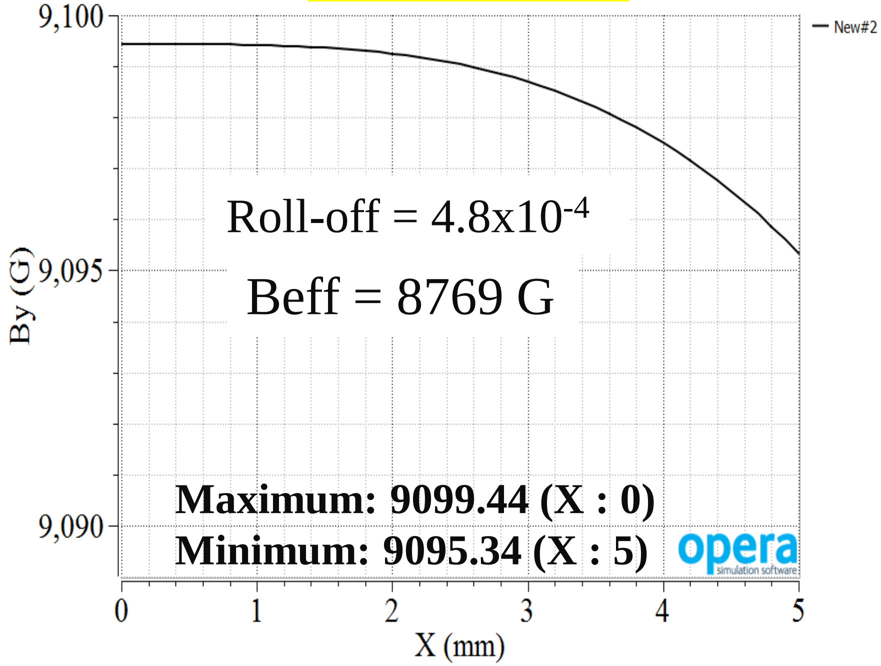


27mm period
44mm pole

By vs X fields of new and existing design (8.5 mm gap) (II)

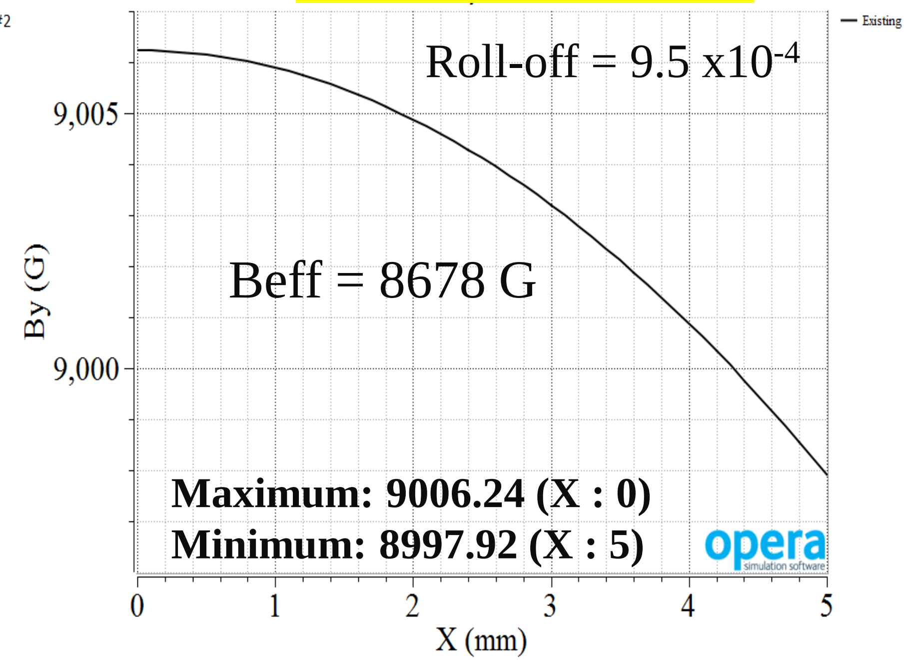
Range in X: -5 mm to 5 mm in X (current APS)

New design



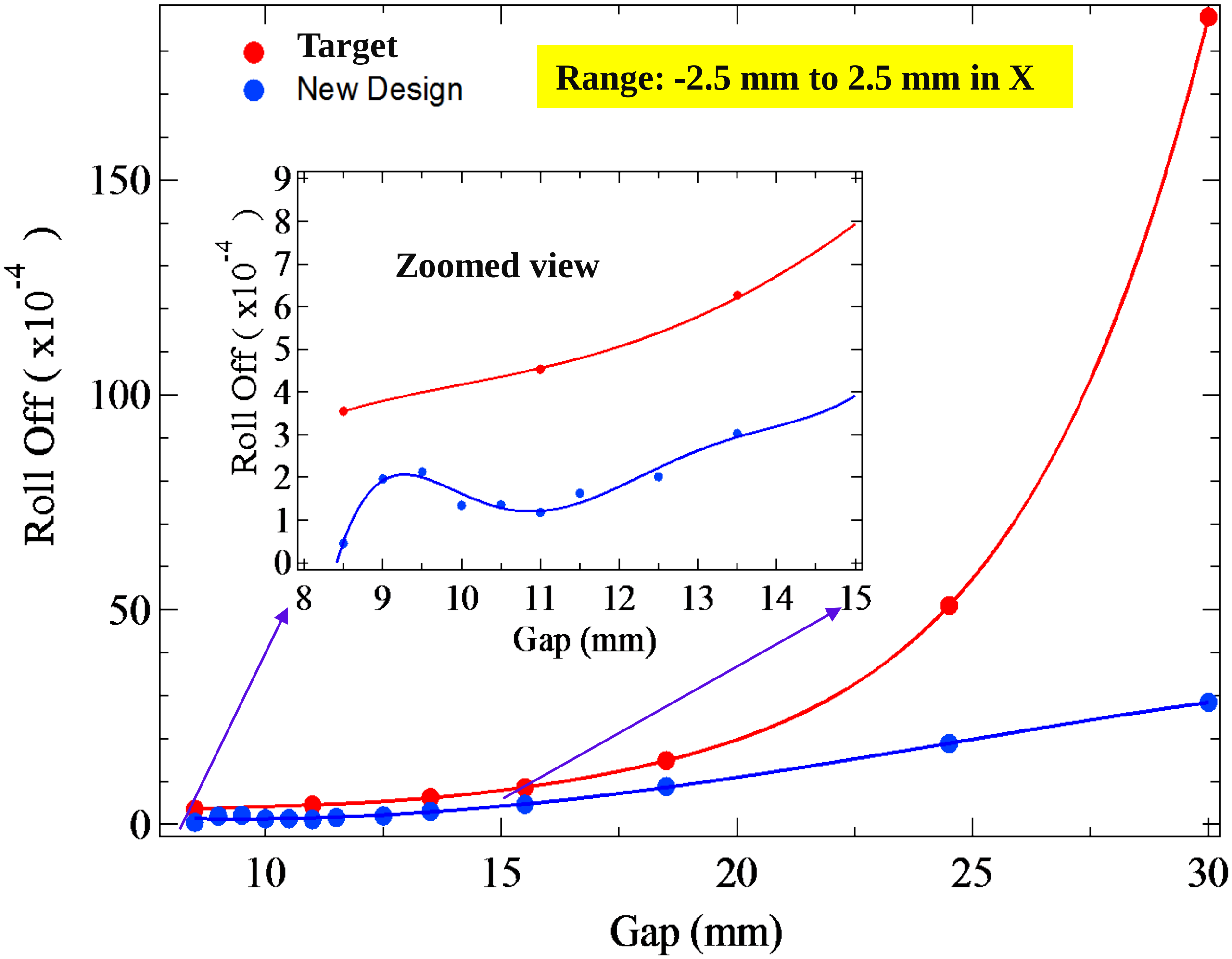
27mm period
40mm pole

Existing design



27mm period
44mm pole

Achieved targeted roll-off across the usable gap range



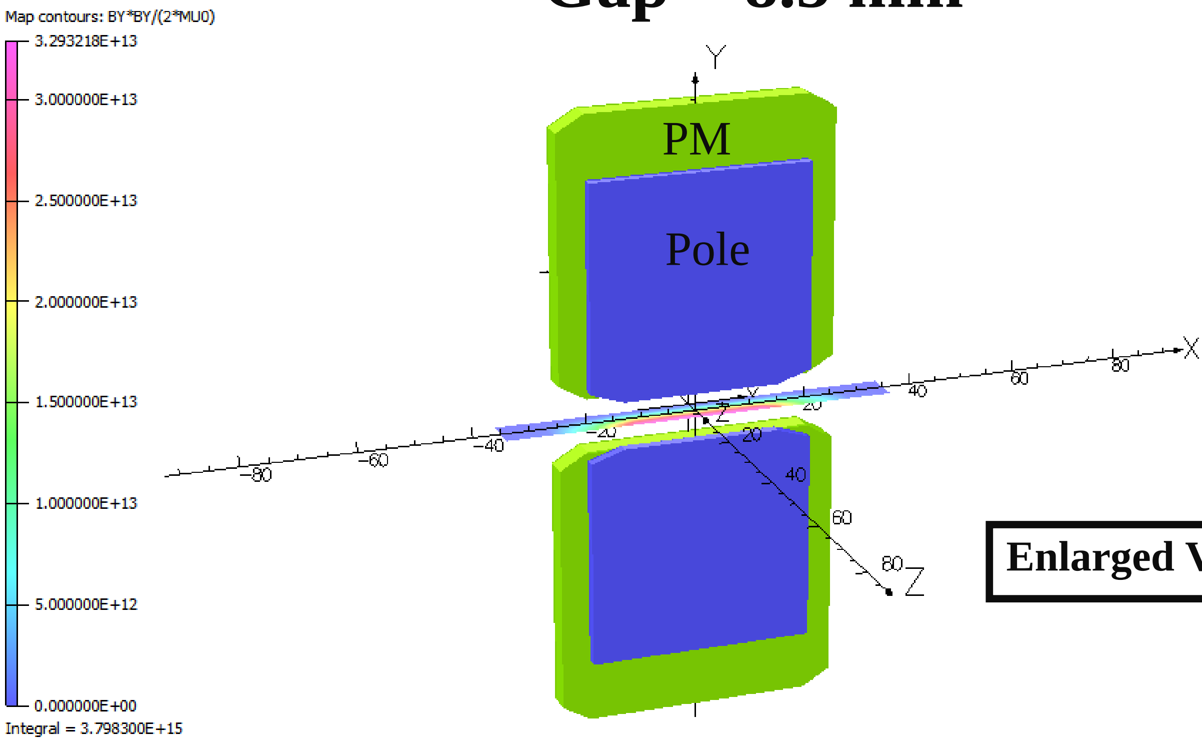
Gap(mm)	Peak By (G)	Roll-off (G)
8.5	9099.44	0.397564
9	8512.11	1.61723
9.5	7957.94	1.64716
10	7435.02	0.973871
10.5	6946.17	0.919809
11	6497.85	0.748918
11.5	6082.41	0.970257
12	5695.86	1.23966
12.5	5339.29	1.06
13	5005.7	1.01292
13.5	4701.02	1.40663
14	4415.02	1.9731
14.5	4144.87	1.4789
15	3897.78	1.85642

The roll-off is even less than 1G at 8.5 mm gap.

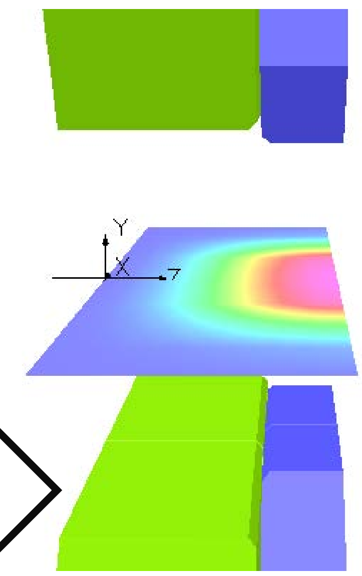
27mm period
40mm pole

Magnetic Force Analysis with the New Design

Gap = 8.5 mm



Enlarged View

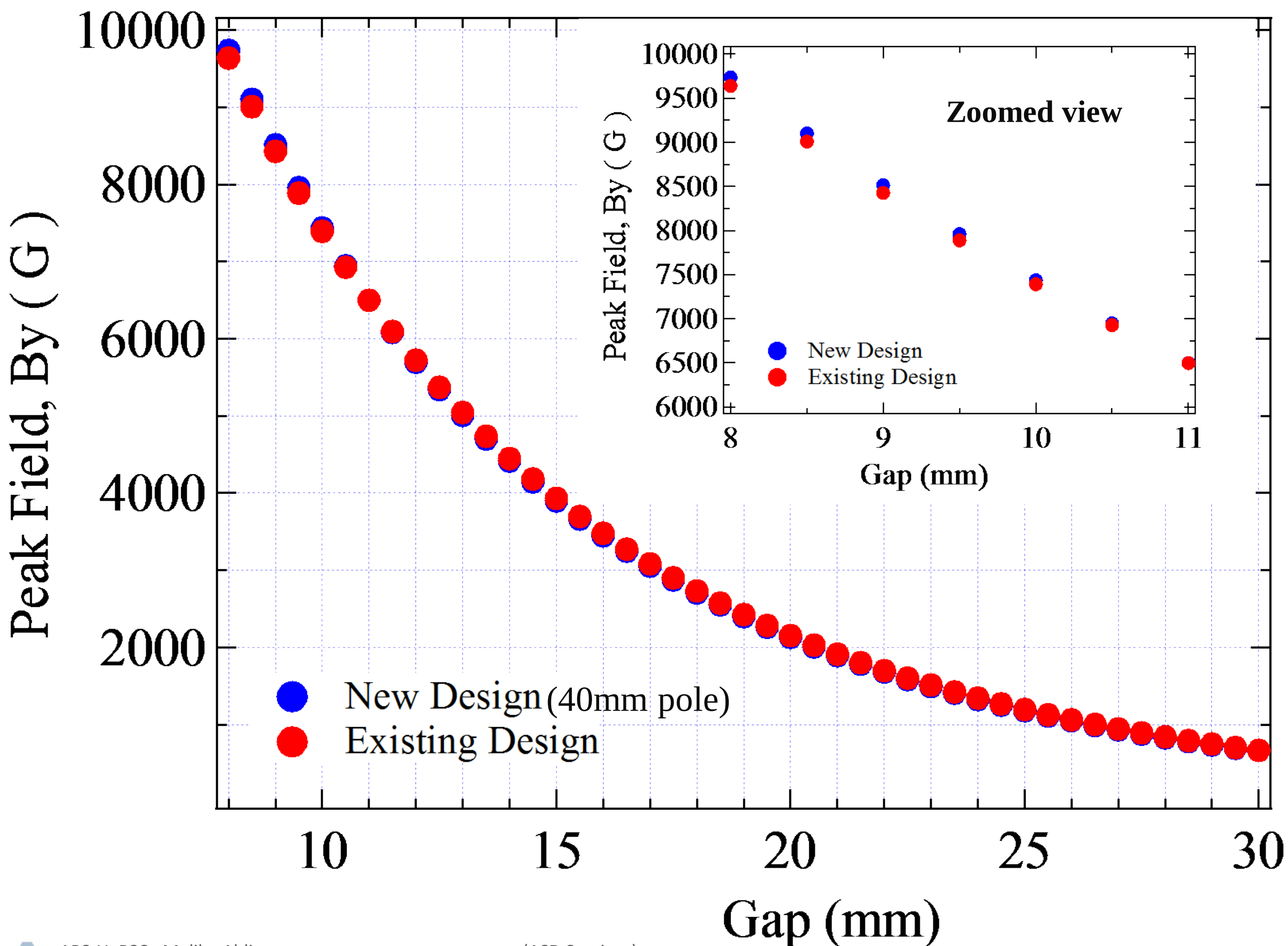


opera simulation software

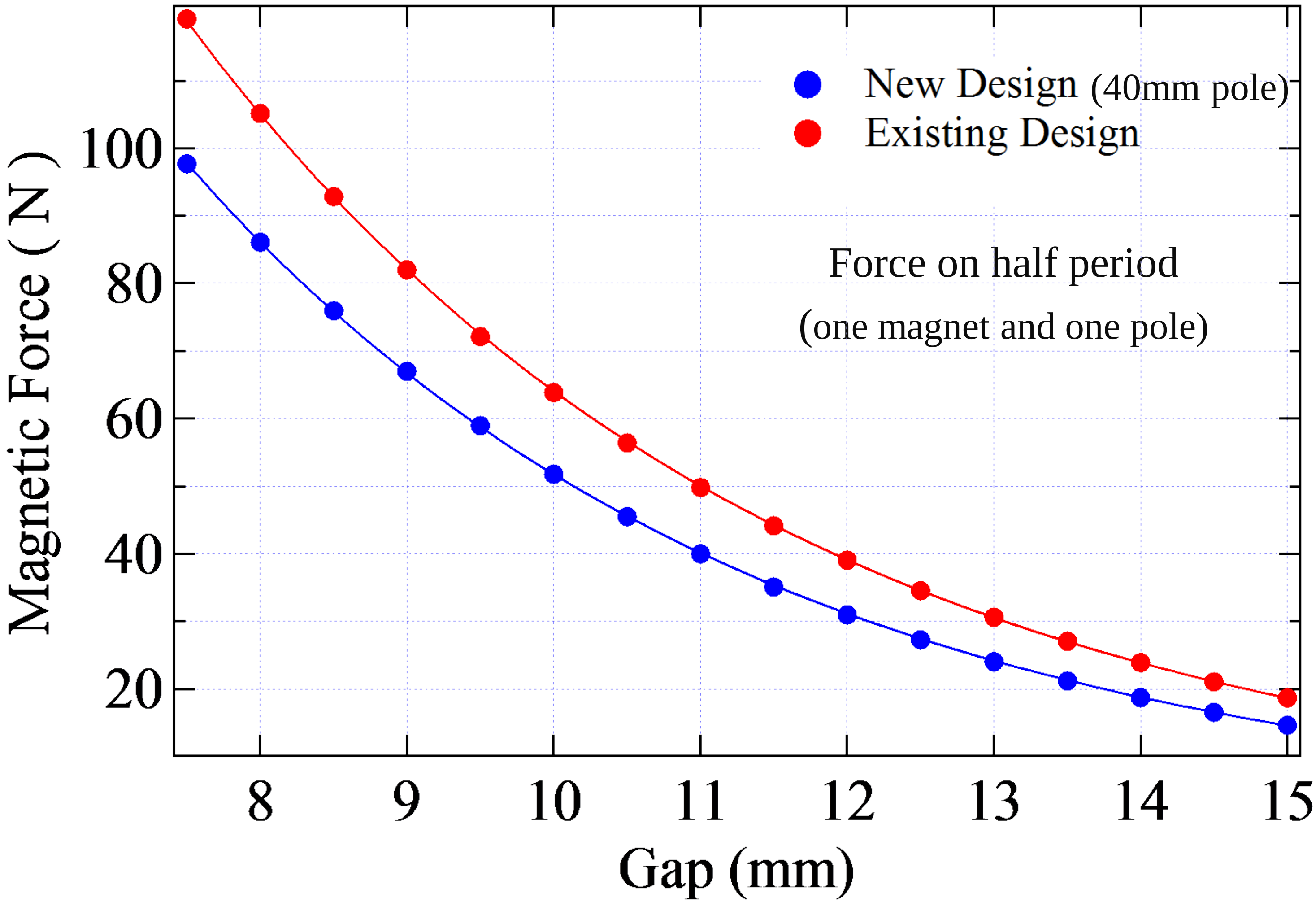
Magnetic force = 76 N (half period)
~13,500 N total force for 2.4 m undulator

27mm period
40mm pole

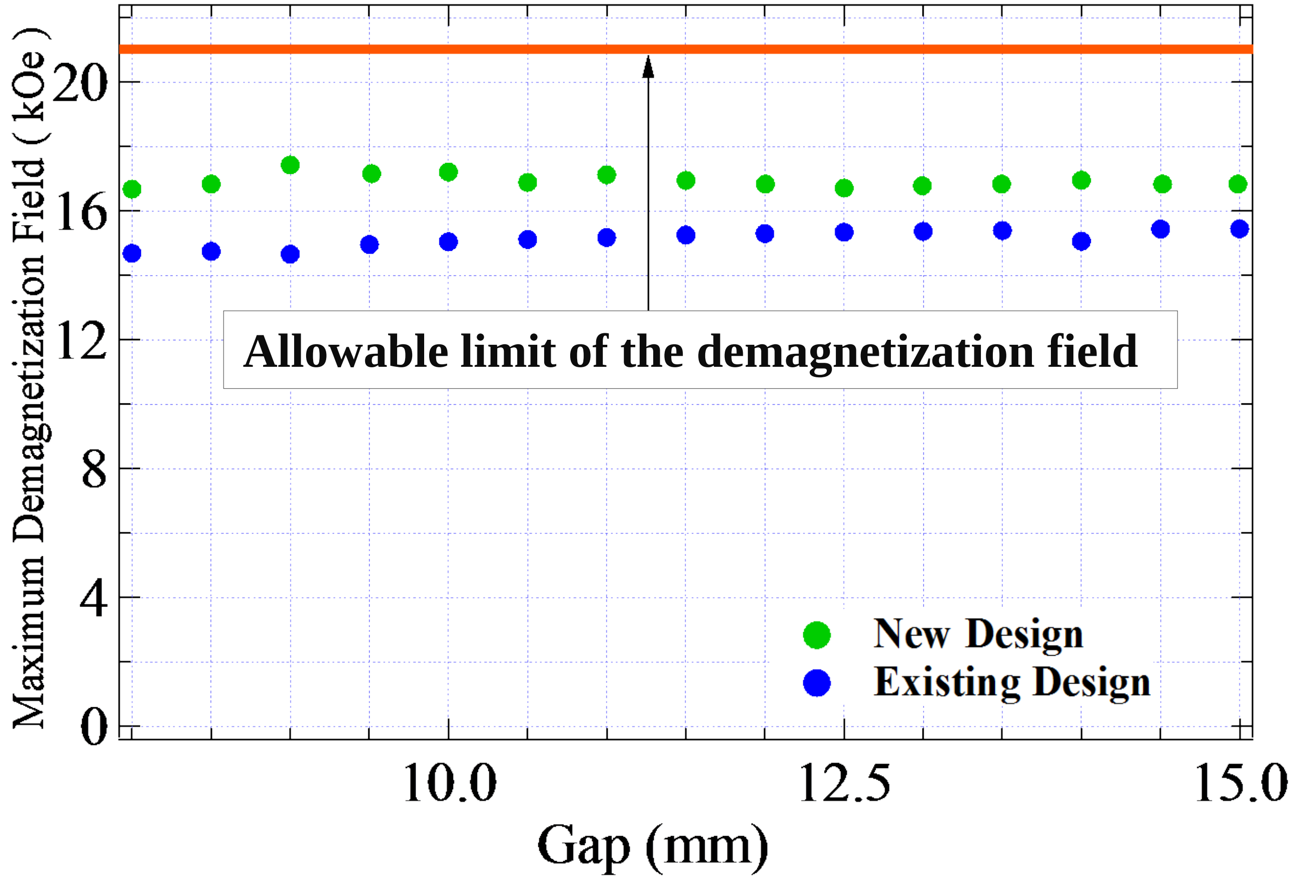
Peak Field Vs Gap of the new and existing designs



Gap dependence of the magnetic force



Gap dependence of demagnetization field on the PMs

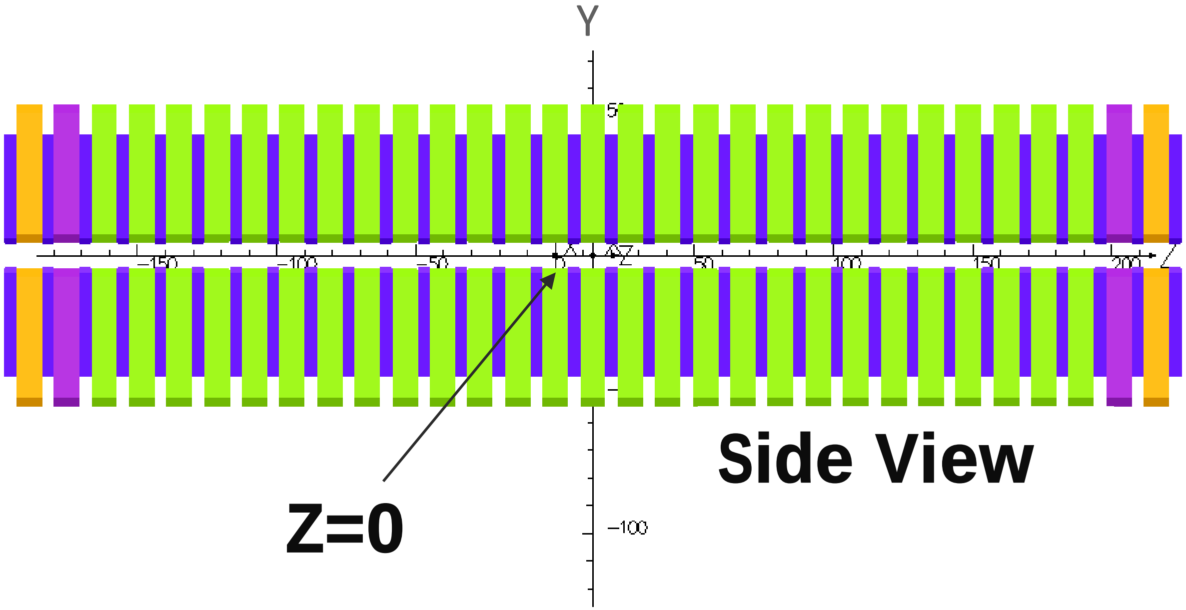


The maximum demagnetization field is still well below the allowable limit of < 21 kOe (25°C)

Design Results

27-mm period undulator	Existing Design	New Design	Difference	Unit
Magnet Material-NdFeB (NH42S)	---	---		---
Temperature	25°C	25°C		---
Pole Material- Vanadium Permendur	---	---		---
Gap	8.5	8.5		mm
Peak By field	9006 G	9099 G	**93**	G
Effective By field	8678 G	8769 G	**91**	G
Maximum demagnetization field	14.8	17.6	**2.8**	kOe
Magnetic Force (per half period)	93 N	76 N	**-17**	N
Field roll_off (+/-2.5 mm in X)	2.44×10^{-4}	4.5×10^{-5}	**-1.99×10^{-4}**	---
Magnet length	9.149	9.2	**0.051**	mm
Magnet width	67	50	**-17**	mm
Magnet height	51.41	50	**-1.41**	mm
Pole length	4.3	4.2	**-0.1**	mm
Pole width	43.99	40	**-3.99**	mm
Pole height	42.24	39.2	**-3.04**	mm
Pole's xx chamfer	2.03	6	**3.97**	mm
Pole's xy chamfer	2.03	2		mm
Pole's zz chamfer	0.89	0.2		mm
Pole's zy chamfer	0.81	0.2		mm
Magnet's xx chamfer	5.72	5		mm
Magnet's xy chamfer	5.72	2.9		mm
Magnet's zz chamfer	1.7	0.2		mm
Magnet's zy chamfer	0.76	0.2		mm
Tolerance between PM and pole	0.05	0.05		mm

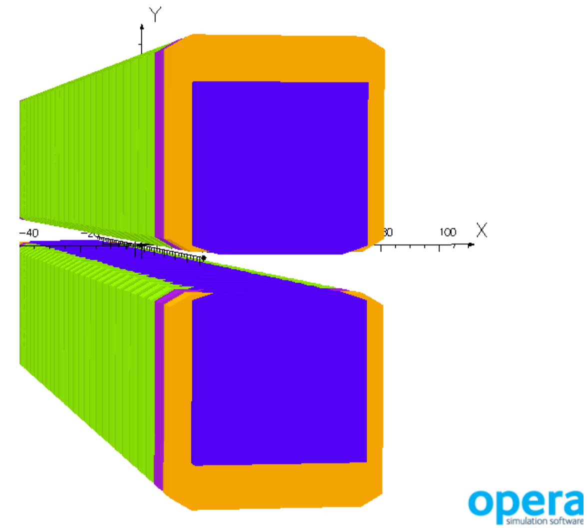
16 period long undulator
New Design (unit: mm)

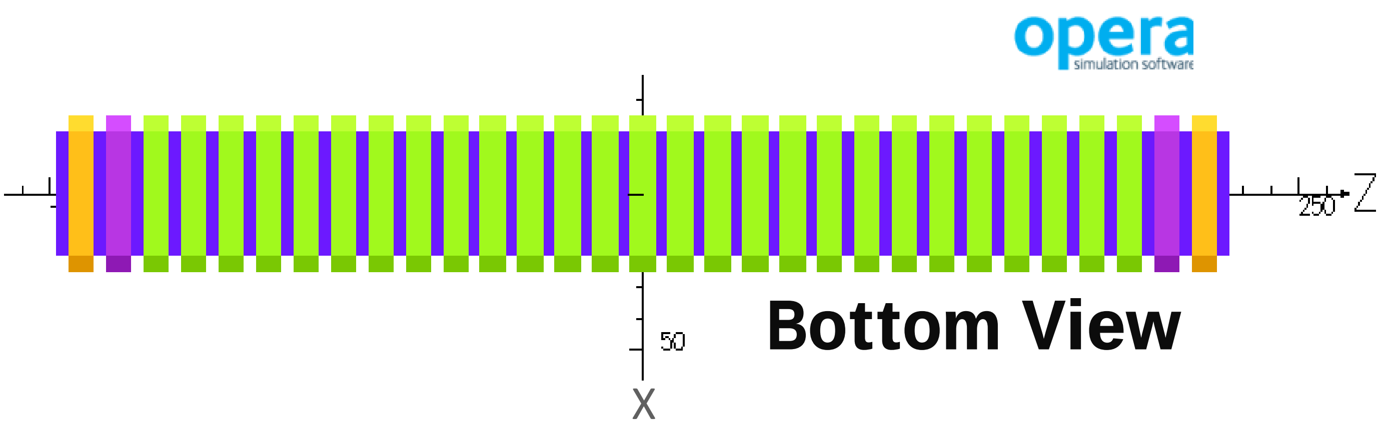


Z=0

Side View

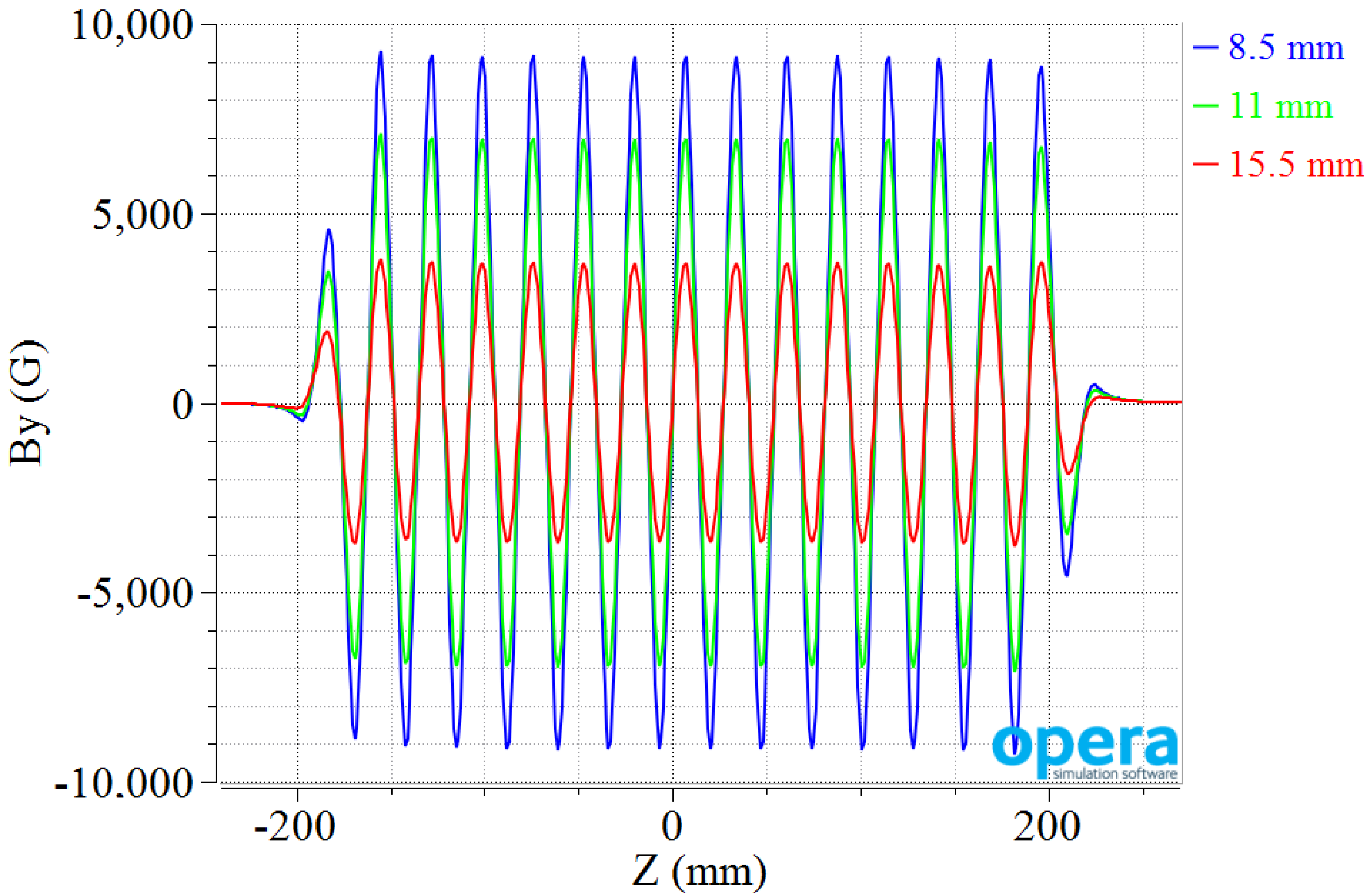
3D View





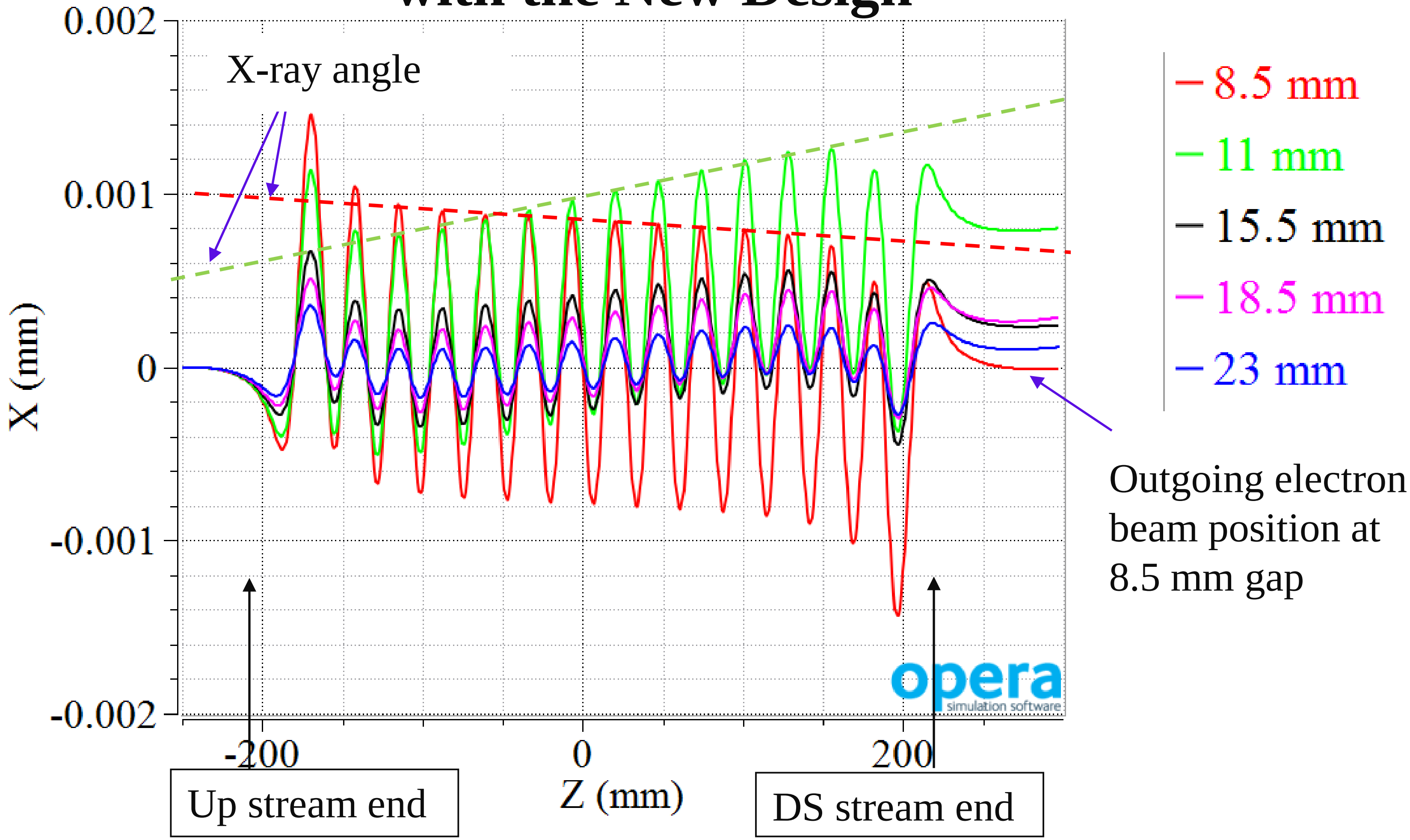
Bottom View

By vs Z of the new design at different gaps



16 period model shows end effects; can be scaled to full undulator length

Trajectories at different gaps at 6 GeV with the New Design



Maximum outgoing beam position differences ~ 0.8 μm

Maximum X-ray angle difference over the gap will be < 2.5 μrad

Conclusion

1. Investigated design goal for the APS-U to produce a 27mm period undulator with a higher field and lower magnetic force with a narrowed pole and narrowed magnet.
2. Optimized the chamfer of the xx-portion to reduce the roll off and modestly increase the field strength. Increasing field flux at the pole tip was critical to meet the design goals.
3. New Design is a viable option for the APS-U undulator layout and outperforms the existing design in the following areas:
   a) Reduced the total volume of the magnet and pole by 28%
   b) Increased the Beff field by 91 G (1.1%)
   c) Reduced the magnetic force by 18%
   d) Improved the roll-off field
4. New design meets all the required physical parameters and reduces the material used.
5. The moments of the magnets for the 1st and 2nd end poles was reduced by 25% and 73.5%, respectively.
6. The X-ray angle is smaller than 2.5 μrad with the gaps ranging from 8.5 mm to 23 mm.

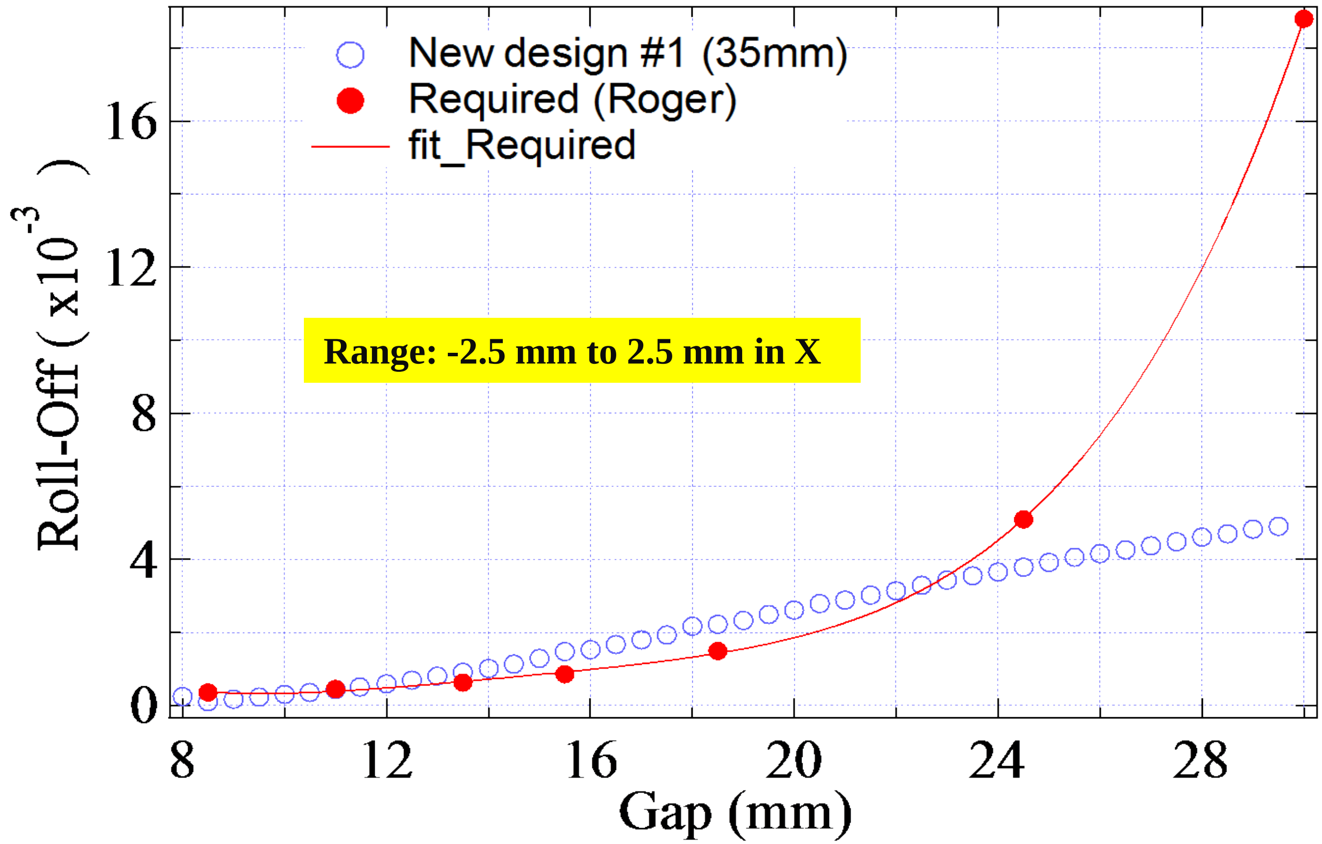
Acknowledgements

- Roger Dejus
- John Grimmer
- Jim Kirby
- Mohan Ramanathan
- Shigemi Sasaki
- Marion White

Compared to the existing design: less magnetic force, higher fields, and less material

27-mm period undulator	Existing Design	New Design	Difference	Future Design	Difference	Unit
Magnet Material-NdFeB (NH42S)	---	---		---		---
Temperature	25°C	25°C		25°C		---
Pole Material- Vanadium Permendur	---	---		---		---
Gap	8.5	8.5		8.5		mm
Peak By field	9006 G	9099 G	**93**	9210 G	**204**	G
Effective By field	8678 G	8769 G	**91**	8876 G	**198**	G
Maximum demagnetization field	14.8	17.6	**2.8**	17.6	**2.8**	kOe
Magnetic Force (per half period)	93 N	76 N	**-17**	70 N	**-23**	N
Field roll_off (+/-2.5 mm in X)	2.44×10^{-4}	4.5×10^{-5}	**-1.99×10^{-4}**	1.08×10^{-4}	**-1.36×10^{-4}**	---
Magnet length	9.149	9.2	**0.051**	9.2	**0.051**	mm
Magnet width	67	50	**-17**	50	**-17**	mm
Magnet height	51.41	50	**-1.41**	50	**-1.41**	mm
Pole length	4.3	4.2	**-0.1**	4.2	**-0.1**	mm
Pole width	43.99	40	**-3.99**	35	**-8.99**	mm
Pole height	42.24	39.2	**-3.04**	39.2	**-3.04**	mm
Pole's xx chamfer	2.03	6	**3.97**	6	**3.97**	mm
Pole's xy chamfer	2.03	2		2		mm
Pole's zz chamfer	0.89	0.2		0.2		mm
Pole's zy chamfer	0.81	0.2		0.2		mm
Magnet's xx chamfer	5.72	5		5		mm
Magnet's xy chamfer	5.72	2.9		2.9		mm
Magnet's zz chamfer	1.7	0.2		0.2		mm
Magnet's zy chamfer	0.76	0.2		0.2		mm
Tolerance between PM and pole	0.05	0.05		0.05		mm

Future Design (35mm)



The roll-off is in the requirement at closed gap. However, it becomes bigger than the requirement between 11 mm – 23 mm gap. However, the magnetic force can be reduced by 28%, and the field will be increased by 2.3% at a gap 8.5 mm