Argonne NATIONAL LABORATORY

Impedance Optimization of Small Gap Chambers for the High Single Bunch Current Operation at the APS

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Impact of ID Chamber Impedance at the APS

- **The single bunch current is limited by the vertical impedances in the ring.**
- **The vertical impedance is dominated by the ID chambers**
  - 68% of total ring impedance (23x8mmE, 1x5mmE, 8x7.5mmR)
  - 34% by Geometric impedance
  - 34% by Resistive wall impedance
- **We like to keep 16 mA in the single bunch for the hybrid mode**
  - High chromaticity in x and y plane is required to store 16 mA in the single bunch.
  - If the impedance increases, we need to increase the chromaticity to keep 16 mA. However, the sextupole strengths are limited.

- **Prior to the MBA lattice based APS Upgrade, we had considered replacing the 8-mm gap chambers with 7.3-mm gap chambers**
  - It will increase the impedance significantly.
  - Can we do it without giving up 16-mA operation?
  - If possible, what engineering design change we need to make?

Motivation and Significance of 16-mA Operational Mode

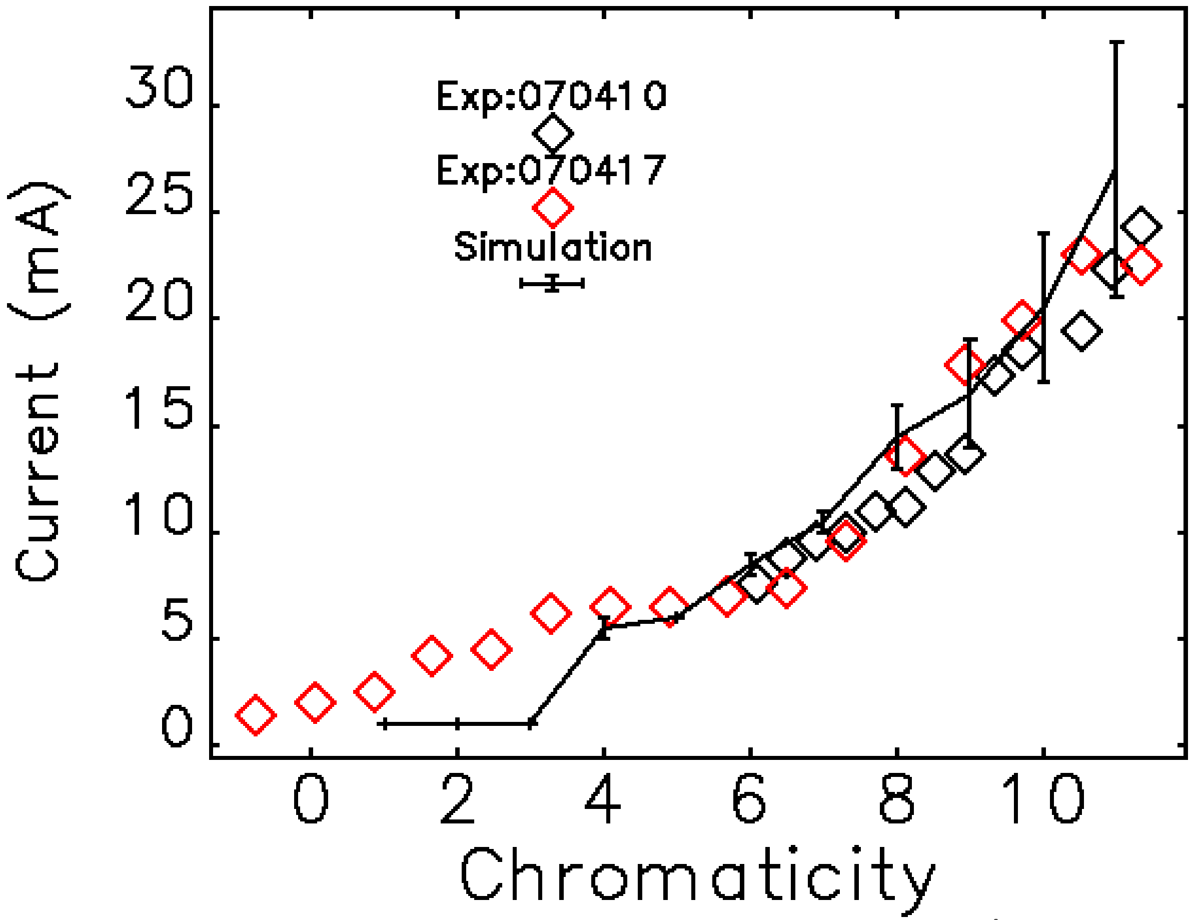
	Energy (GeV)	Size (m)	Total Current (mA)	Bunch Current (mA)	Bunch Charge (nC)
ESRF[a]	6	844.4	200	4	11
APS[b]	7	1104	102	16	59
Spring8[c]	8	1436	100	5~	24~

- The timing-mode users are very strong in the APS.
- The high-flux users have strong demands on the small gap chambers.
- So we have to optimize the small gap chambers to reduce the impedance to meet the both demands. This became the motivation of impedance optimization for the small gap ID chambers.

[a] http://www.esrf.eu/Accelerators/Operation/Modes
[b] http://www.aps.anl.gov/Accelerator_Systems_Division/Accelerator_Operations_Physics/SRparameters/node5.html
[c] http://www.spring8.or.jp/en/users/operation_status/schedule/bunch_mode

Impedance Effect on the Single Bunch Current

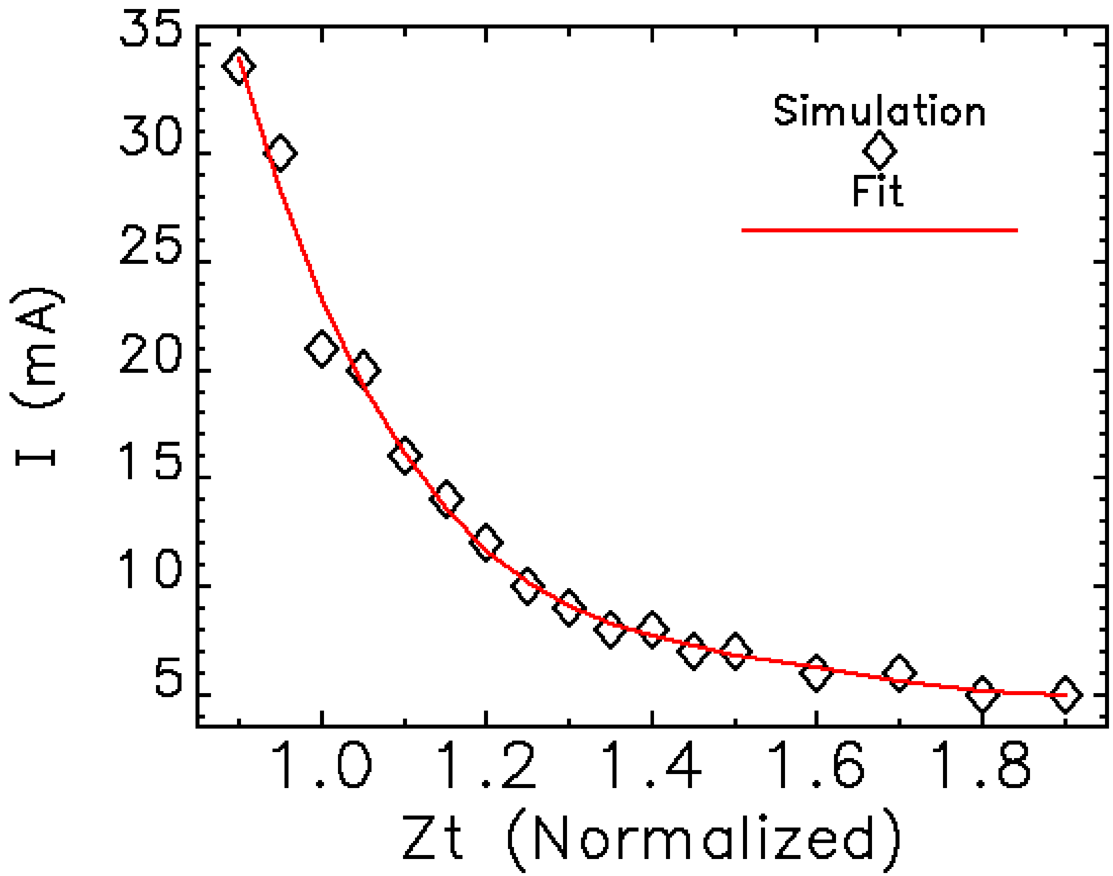
- The single bunch current is limited by the vertical impedances in the ring.



(Experiment by Chae, Emery, Yao)

Impedance Effect on the Single Bunch Current

- Shows the single bunch current as function of impedance in the current APS ring. Zt=1 is nominal APS.
- Can predict the current with the hypothetical increase and decrease of impedance in the APS-U

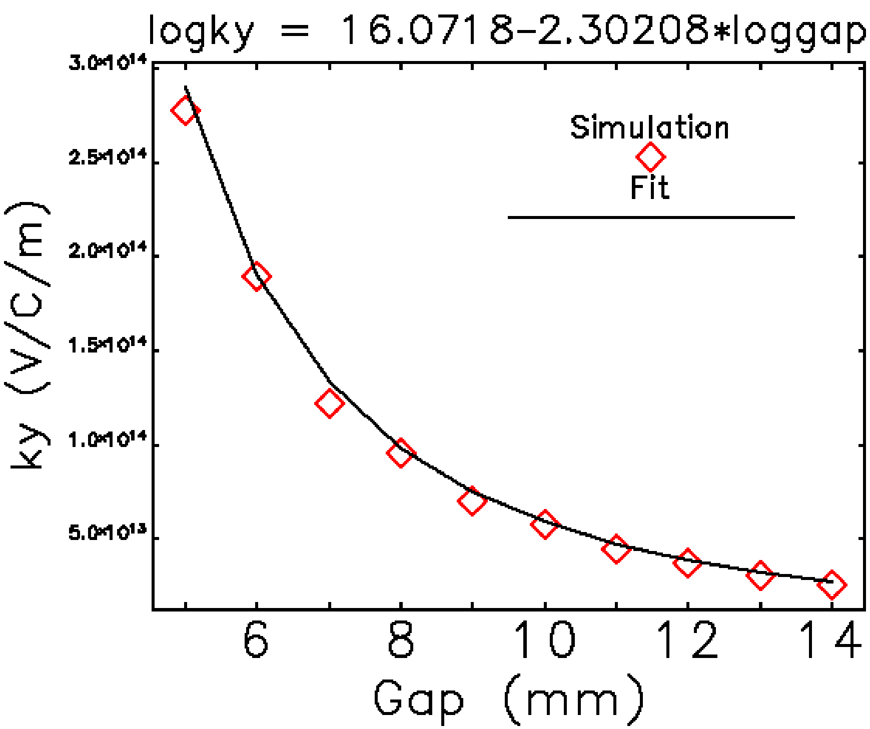


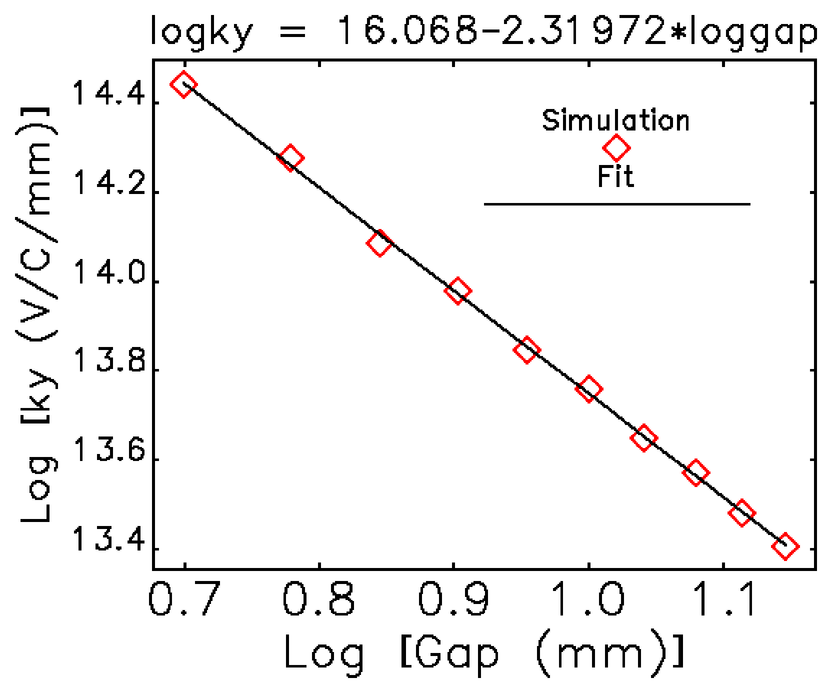
ID Chamber Optimization

- **ID Extrusion Chamber**
  - Gap
  - Width
  - Profile: Ellipse vs. Racetrack
- **APS-to-ID Chamber Transition**
  - Linear taper
  - Nonlinear taper
- **APS Extrusion Chamber**
  - Width
  - Height
  - New taper

ID Chamber Gap

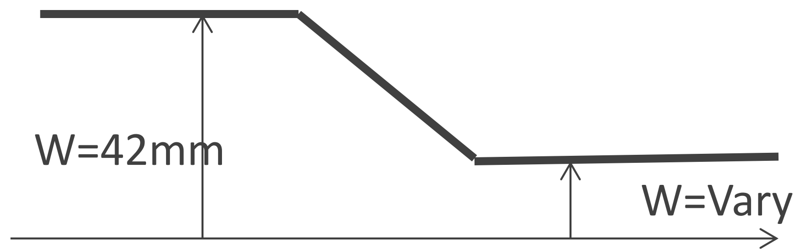
- $ky \propto {}^{1}/_{Gap^{\alpha}}$
- α = 2.1 ~ 2.4 for Gap = [4mm, 14mm]
    - Depends on ID width, transition length, beam offset

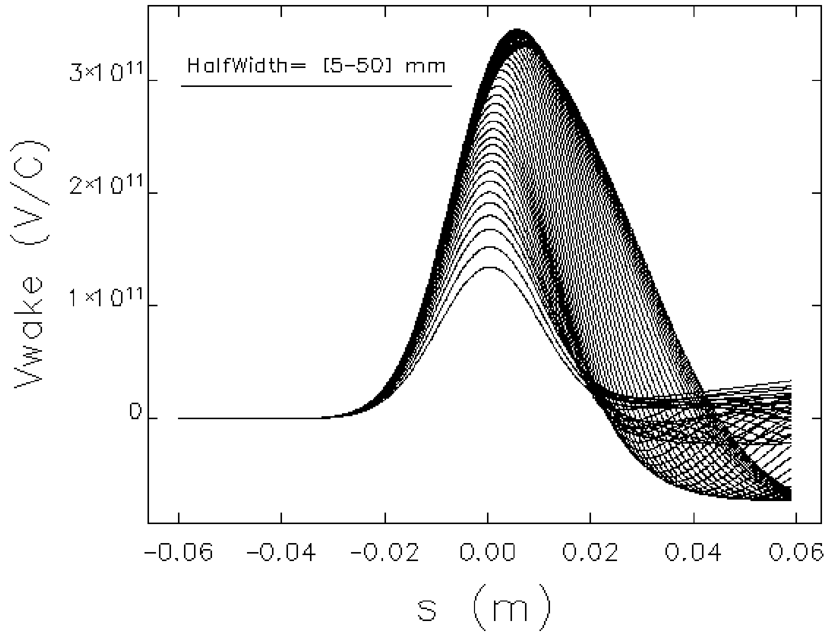


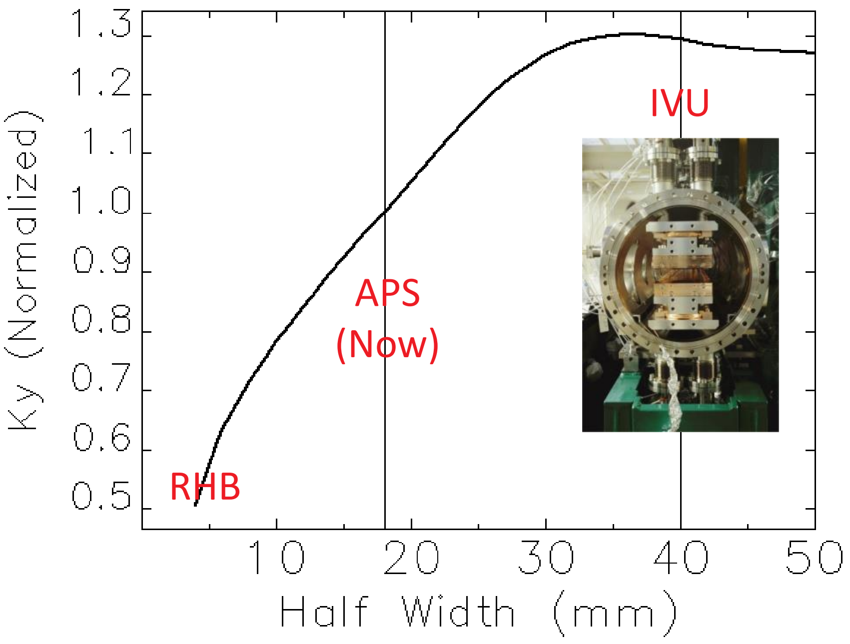


ID Chamber Width

- APS regular chamber has half width w=42 mm → **Fixed**
- APS undulator chamber has half width w=18mm → **Vary**



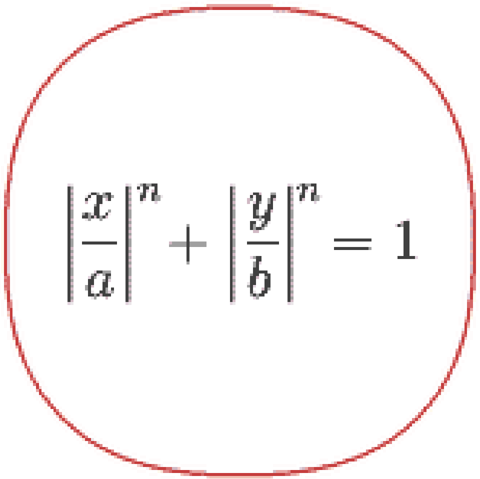




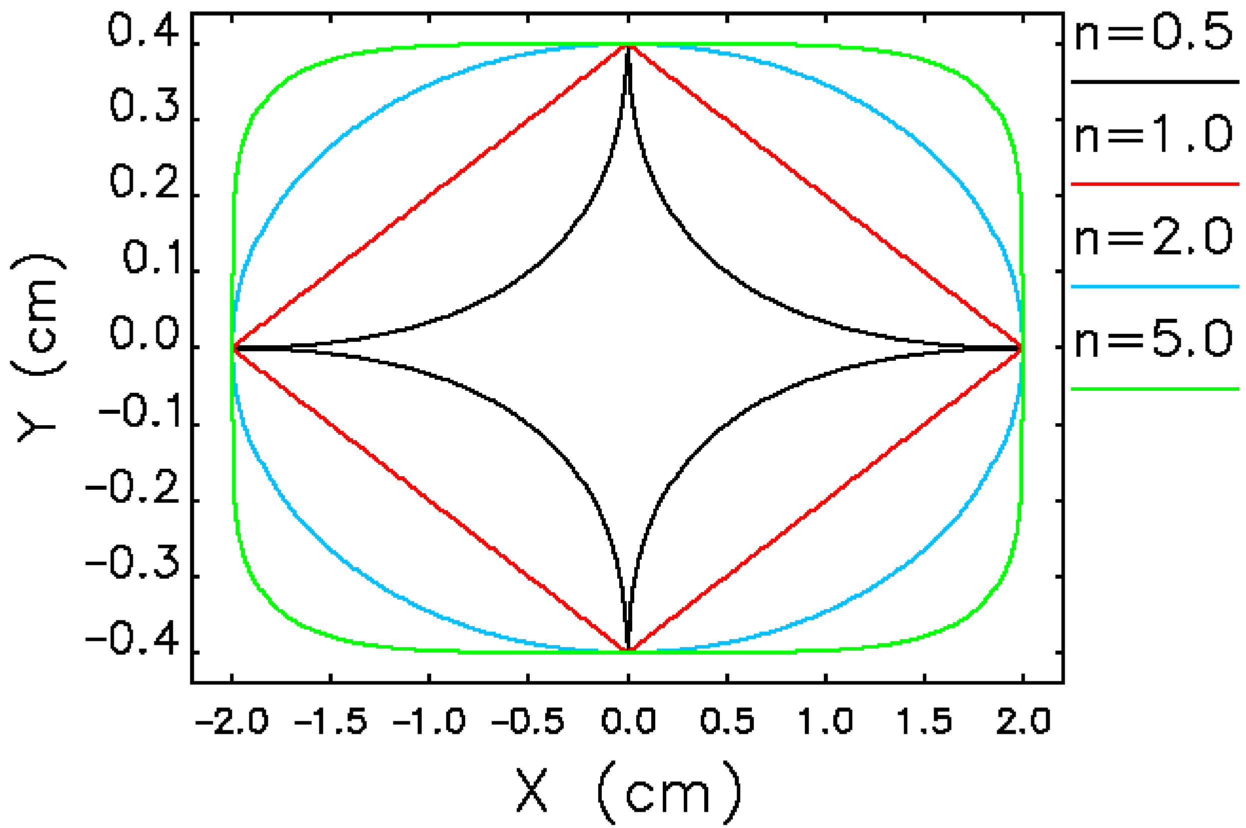
- **Smaller chamber width requires small beta-x for a good injection efficiency**

ID Chamber Profile: Superellipse

- Also called Lamé curve
- n < 2: hypoellipse
- n = 2: ellipse
- n > 2: hyperellipse

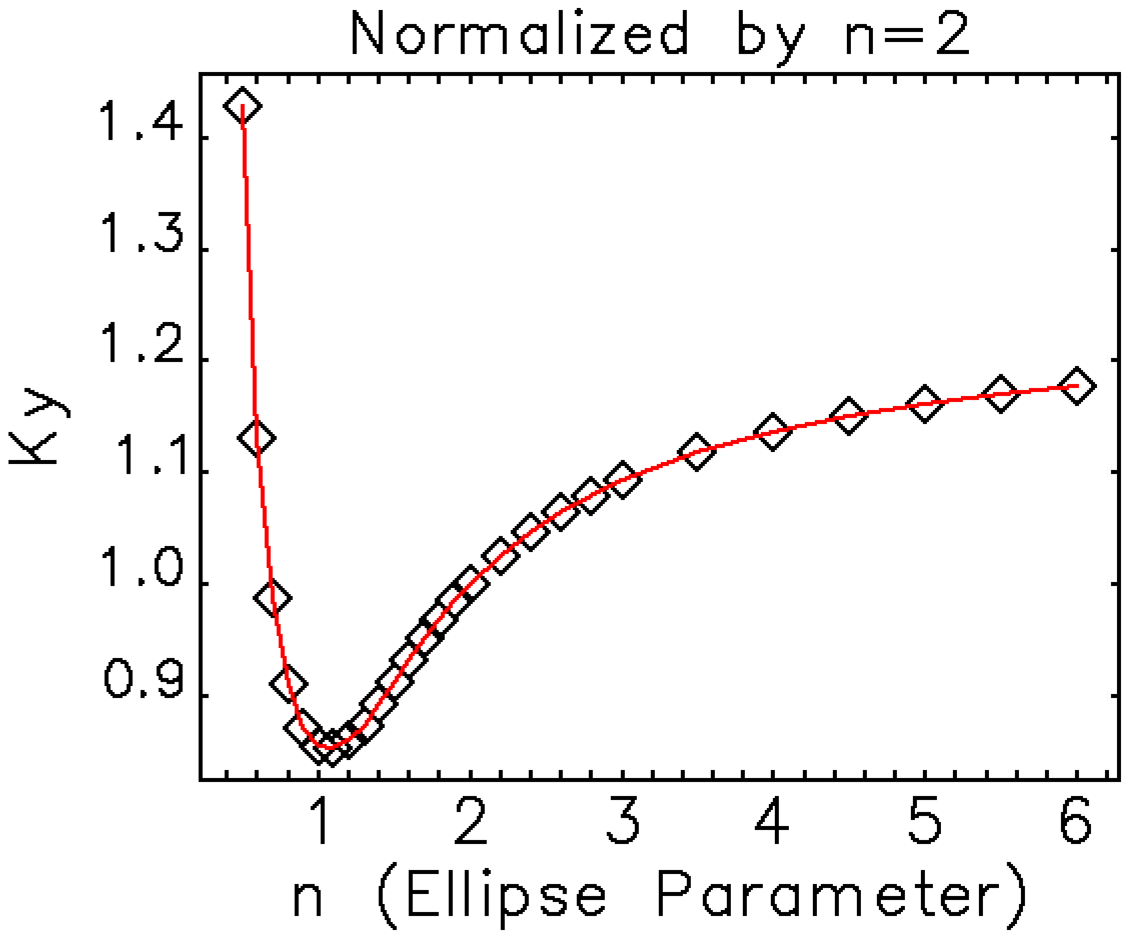


$$\left|\frac{x}{a}\right|^n + \left|\frac{y}{b}\right|^n = 1$$

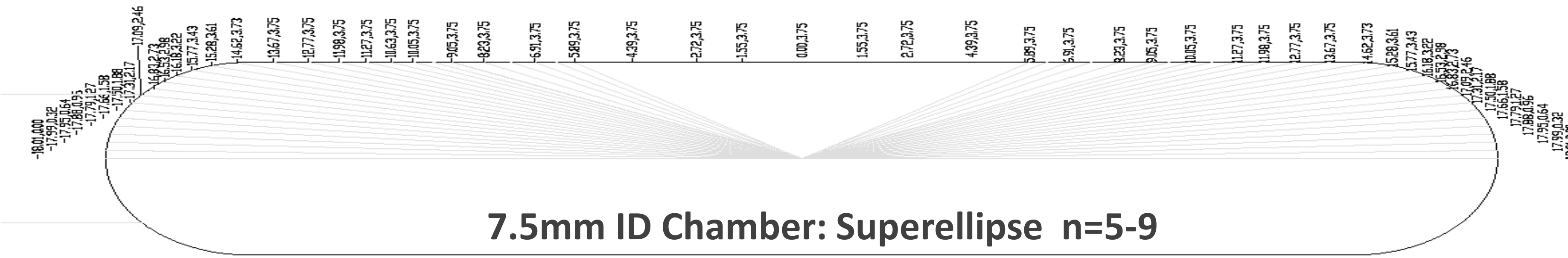


ID Chamber Profile: Superellipse (2)

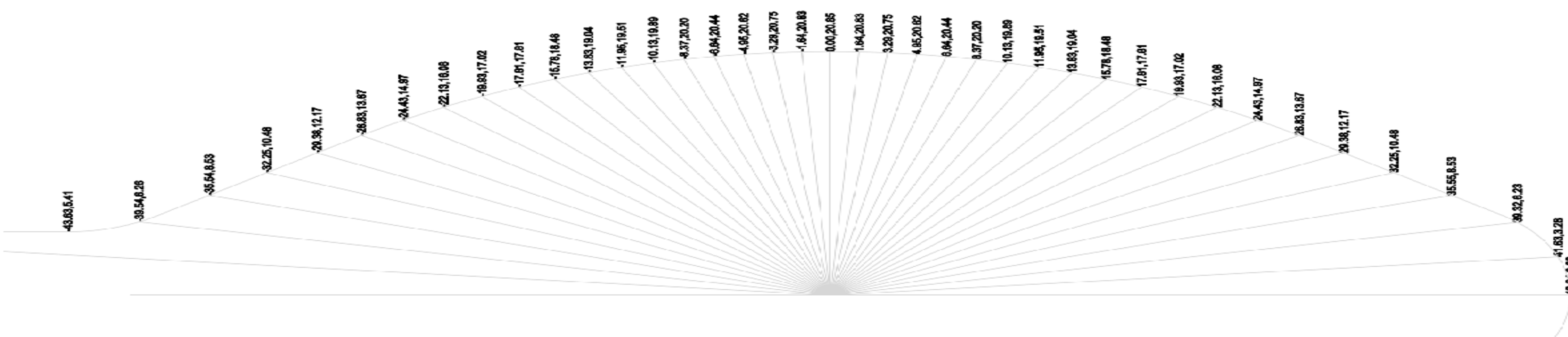
- Studied various ways of reducing the taper impedance



ID Chamber Profile: Superellipse (3)



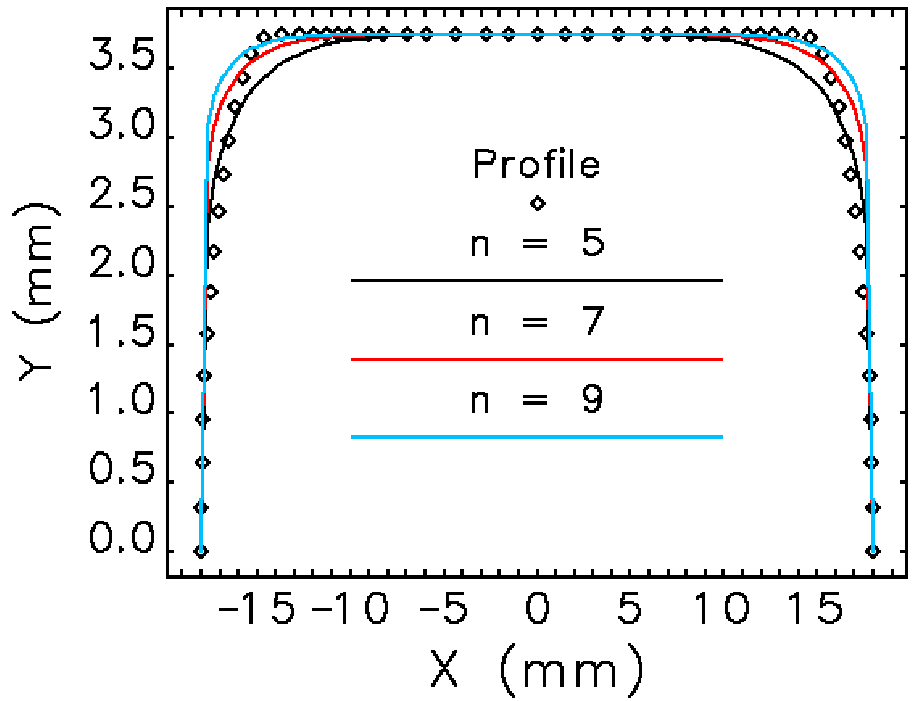
7.5mm ID Chamber: Superellipse n=5-9

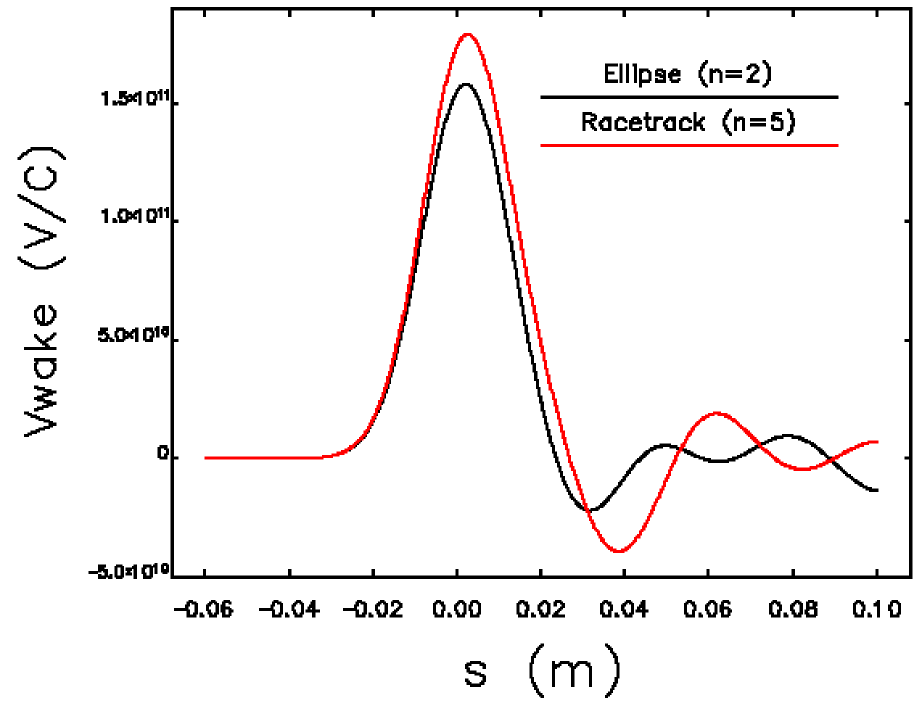


APS Extrusion: Superellipse n=2

- Profile data provided by B. Stillwell (AES-MED)

ID Chamber Profile: Superellipse (4)

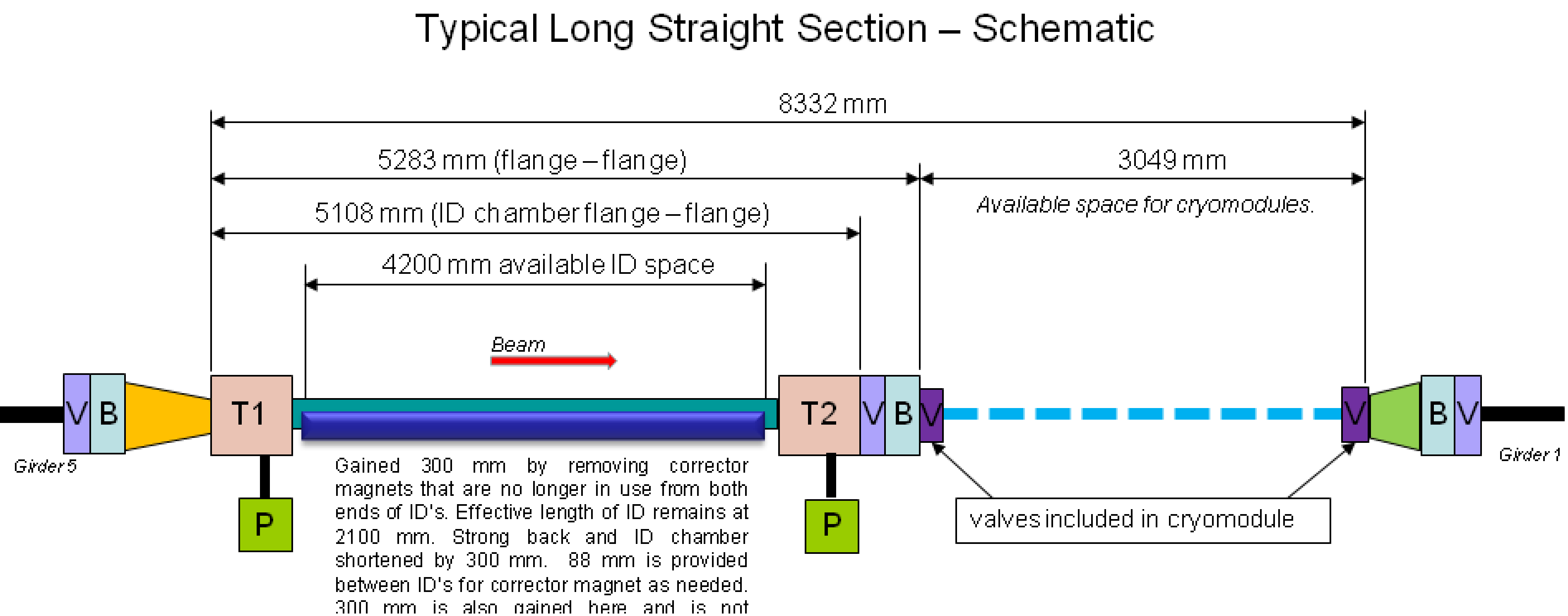




7.5mm ID Chamber: Superellipse n=5-9

- Profile data provided by B. Stillwell (AES-MED)

Transition

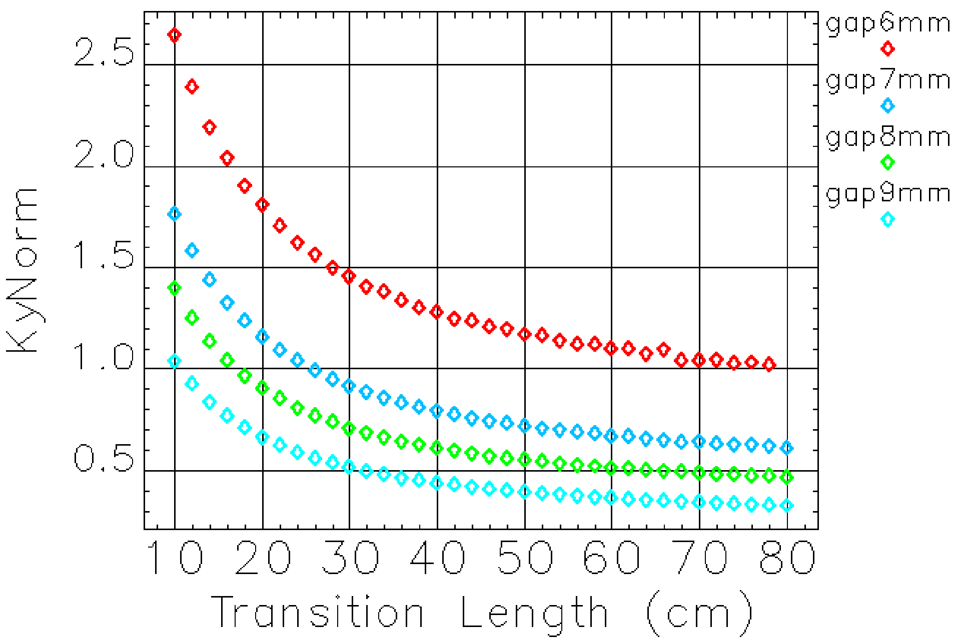


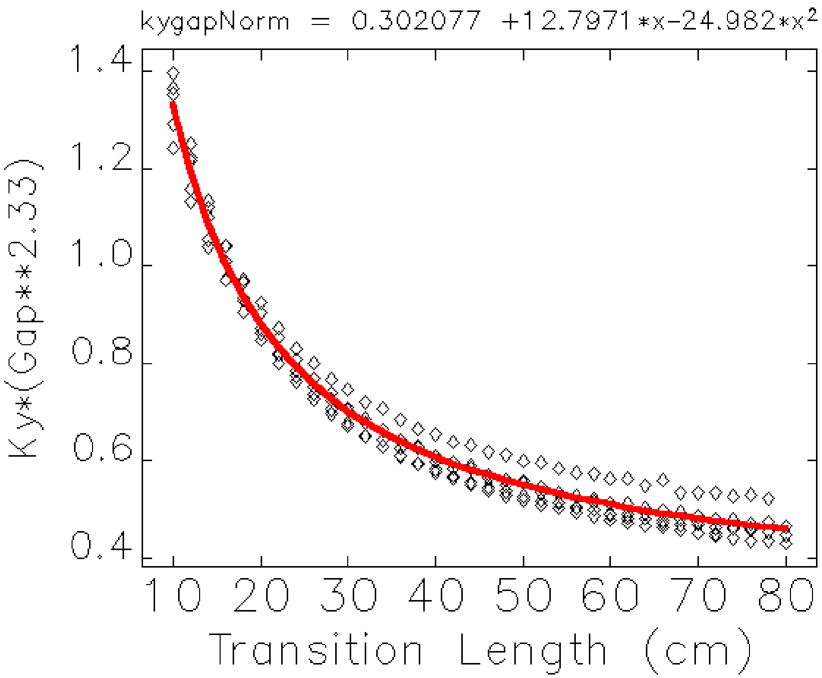
- Symmetric Transition
- Asymmetric Transition

- Nonlinear Transition
- Segmented Transition

Symmetric Transition

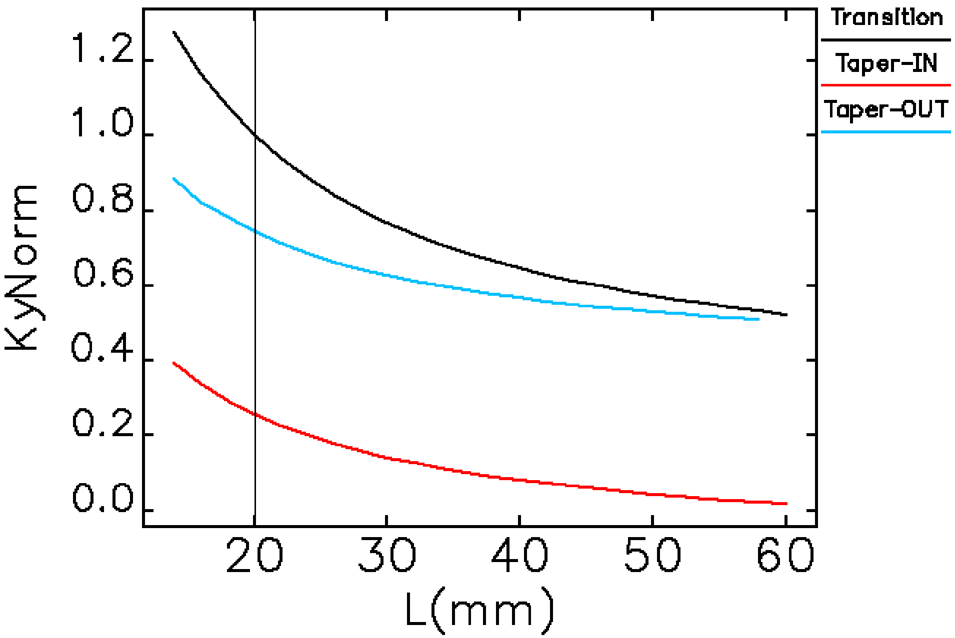
- Constraint: L=L1+L2 is fixed
- **L1=L2, β1=β2**

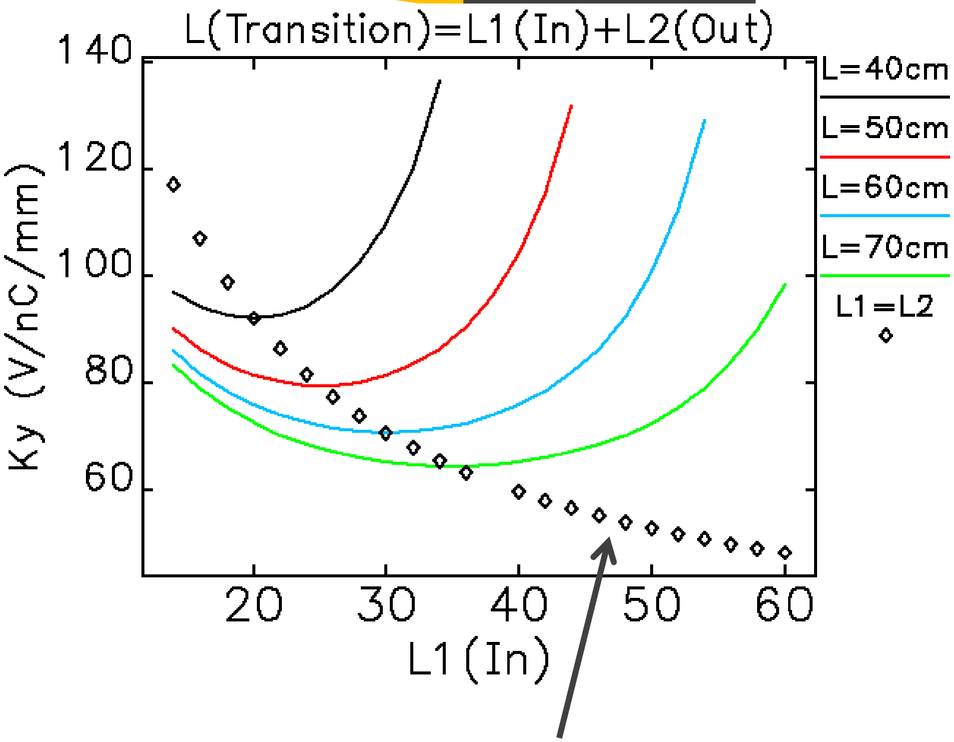




Asymmetric Transition

- Constraint: L=L1+L2 is fixed
- **L1≠L2, β1=β2**

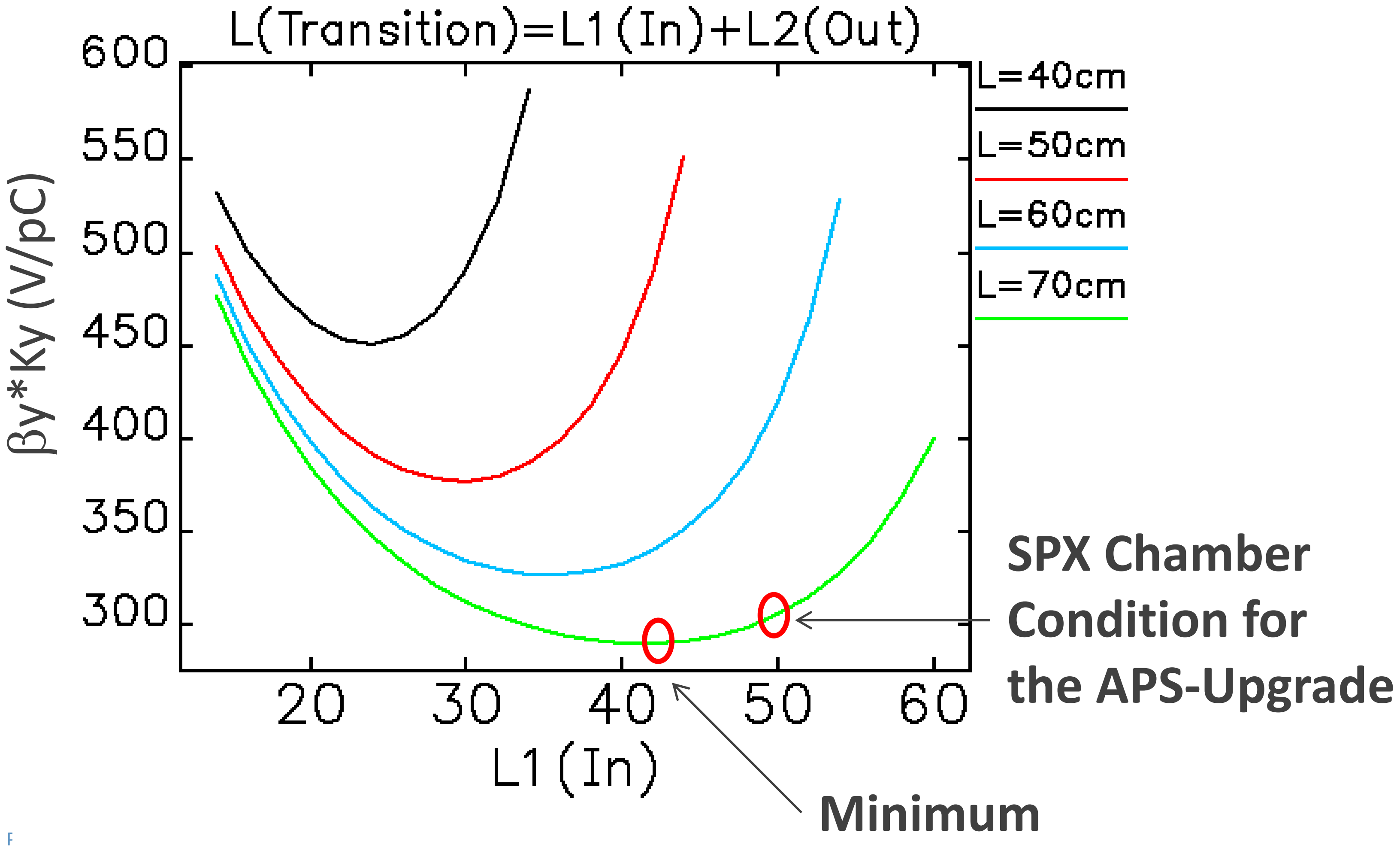




L1=L2 makes the minimum Ky

Asymmetric Transition (2)

- SPX Chamber: **L1=50cm, L2=20cm**, **β1=8m, β2=4m**
- **Optimize: β1*Ky1 + β2*Ky2**



Nonlinear Transition

Impedance Formula for constant width chamber*

$$Z_y^{rect} = j\frac{Z_0 w}{4}\int_{-\infty}^{\infty} dz \frac{h'(z)^2}{h(z)^3}$$

- Optimize w ➔ narrow horizontal aperture
- Optimize linear h'(z) ➔ long taper
- Optimize h(z) ➔ nonlinear taper

* G. Stupakov, Geometrical Wake of a Smooth Flat Collimator, SLAC-PUB-7167, 1996

Nonlinear Transition (2)

- Optimum profile found by B. Podobedov and I. Zagorodonov*

$$h(z) = \frac{h_{\min}}{\left(1+\left(\beta^{-1/2}-1\right)z/L\right)^2}, \quad \beta \equiv \frac{h_{\max}}{h_{\min}}$$

$$\frac{Z_y^{optimum}}{Z_y^{linear}} = \frac{8\beta}{(1+\beta)\left(1+\sqrt{\beta}\right)^2}$$

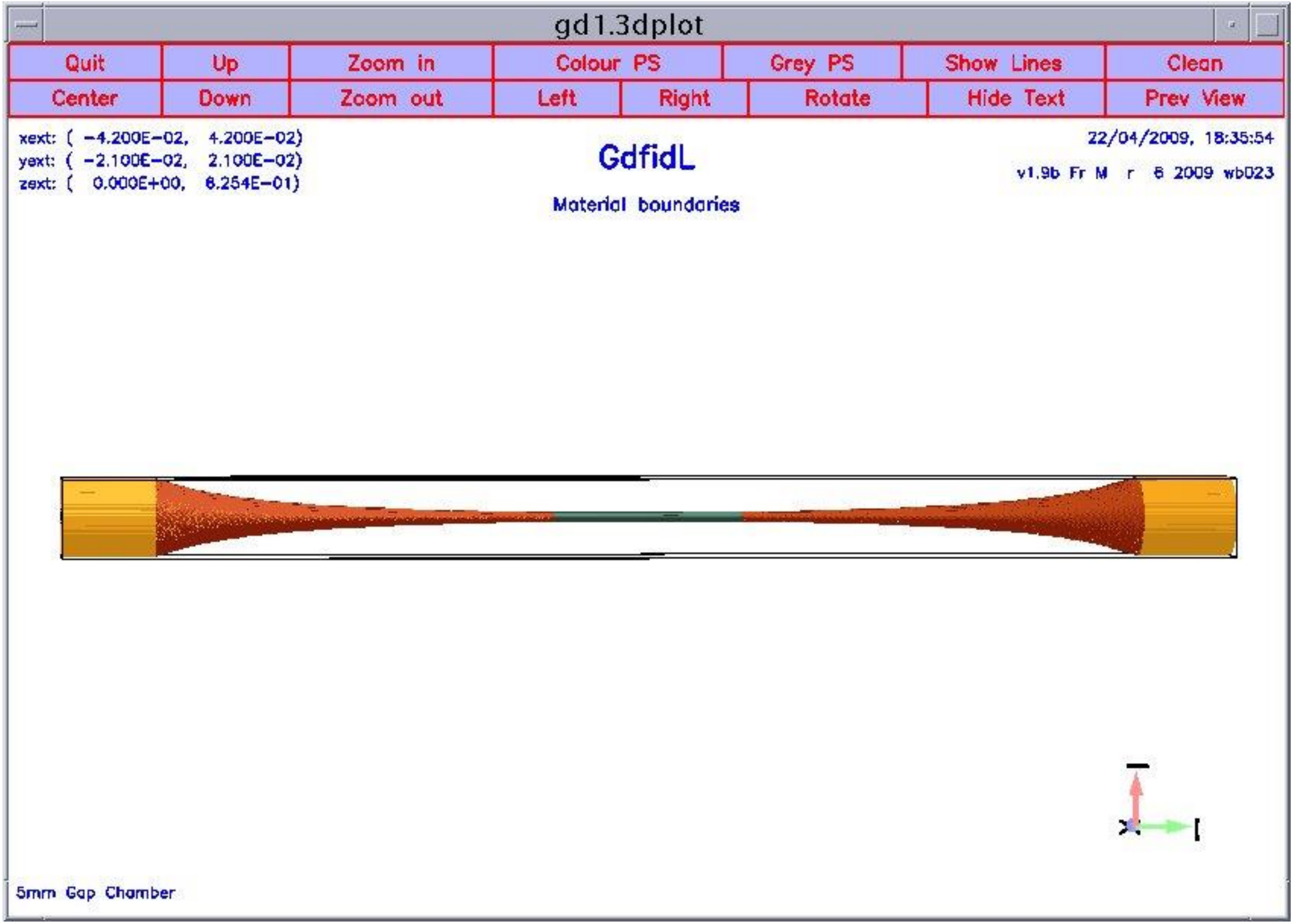
APS Chamber

hmax=21 mm, hmin=4 mm

Ratio=5/8

*B. Podobedov, I. Zagorodonov, "Impedance Minimization by Nonlinear Tapering," Proc. of PAC2007, p. 2006.

Nonlinear Transition (3)



1. ID Chamber

- Gap
- Width
- Profile

L1, $\beta 1$

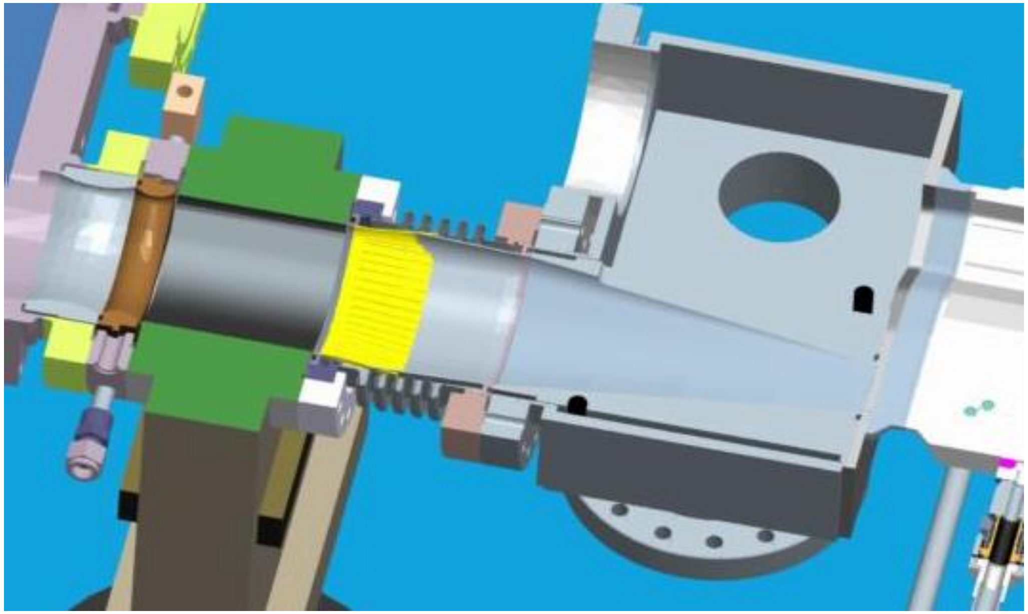
L2, $\beta 2$

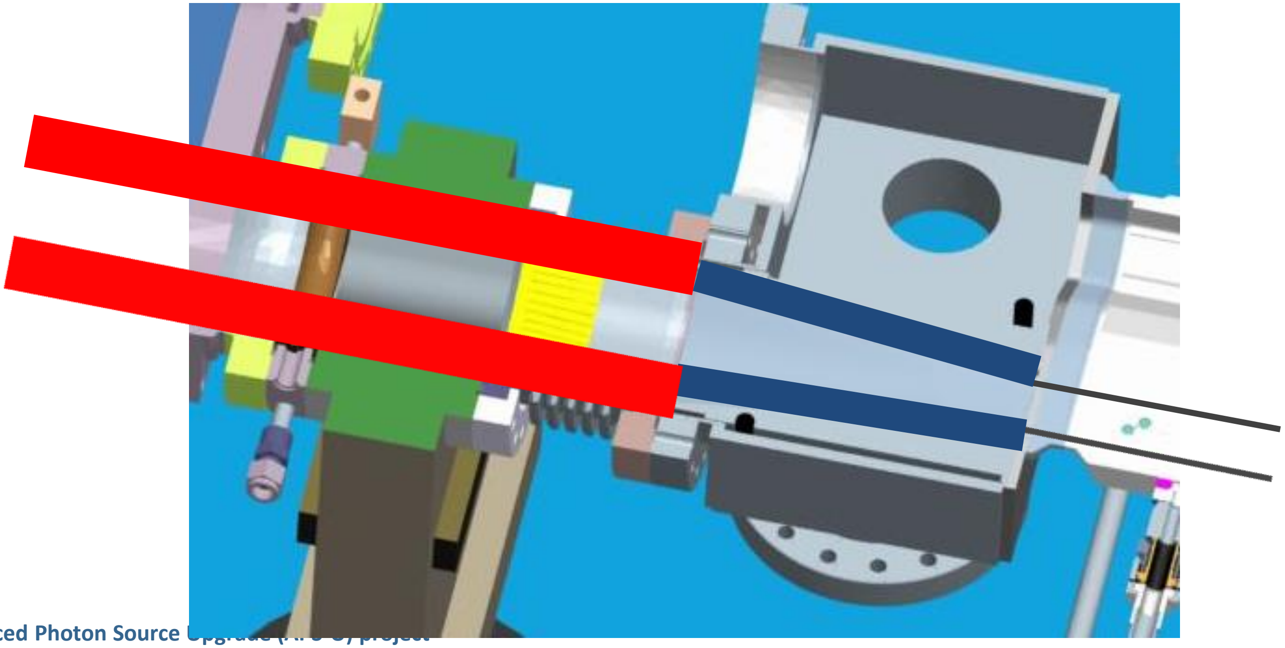
3. APS Chamber

- Width
- New Taper

2. Transition

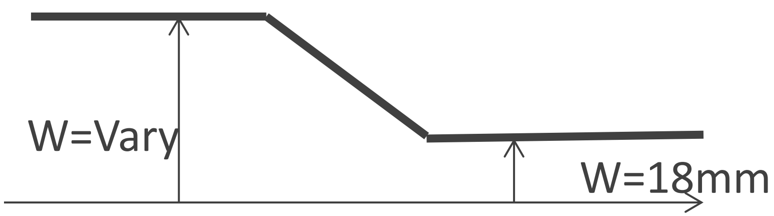
- Length
- Symmetric
- Asymmetric
- Nonlinear Taper

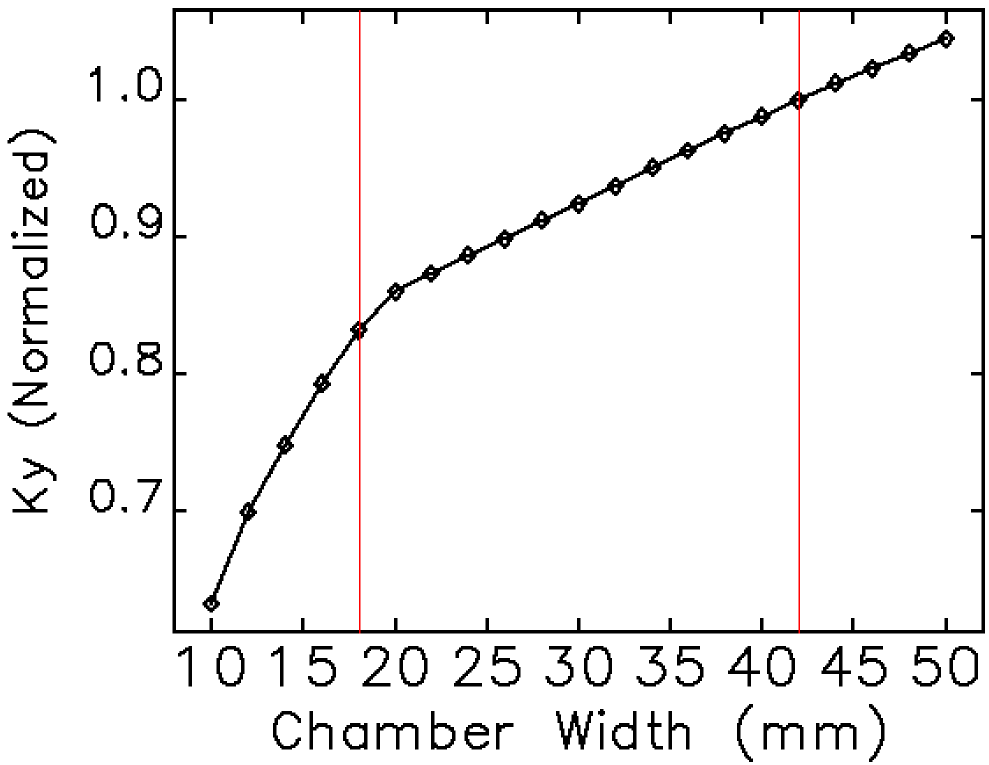




APS Chamber Width

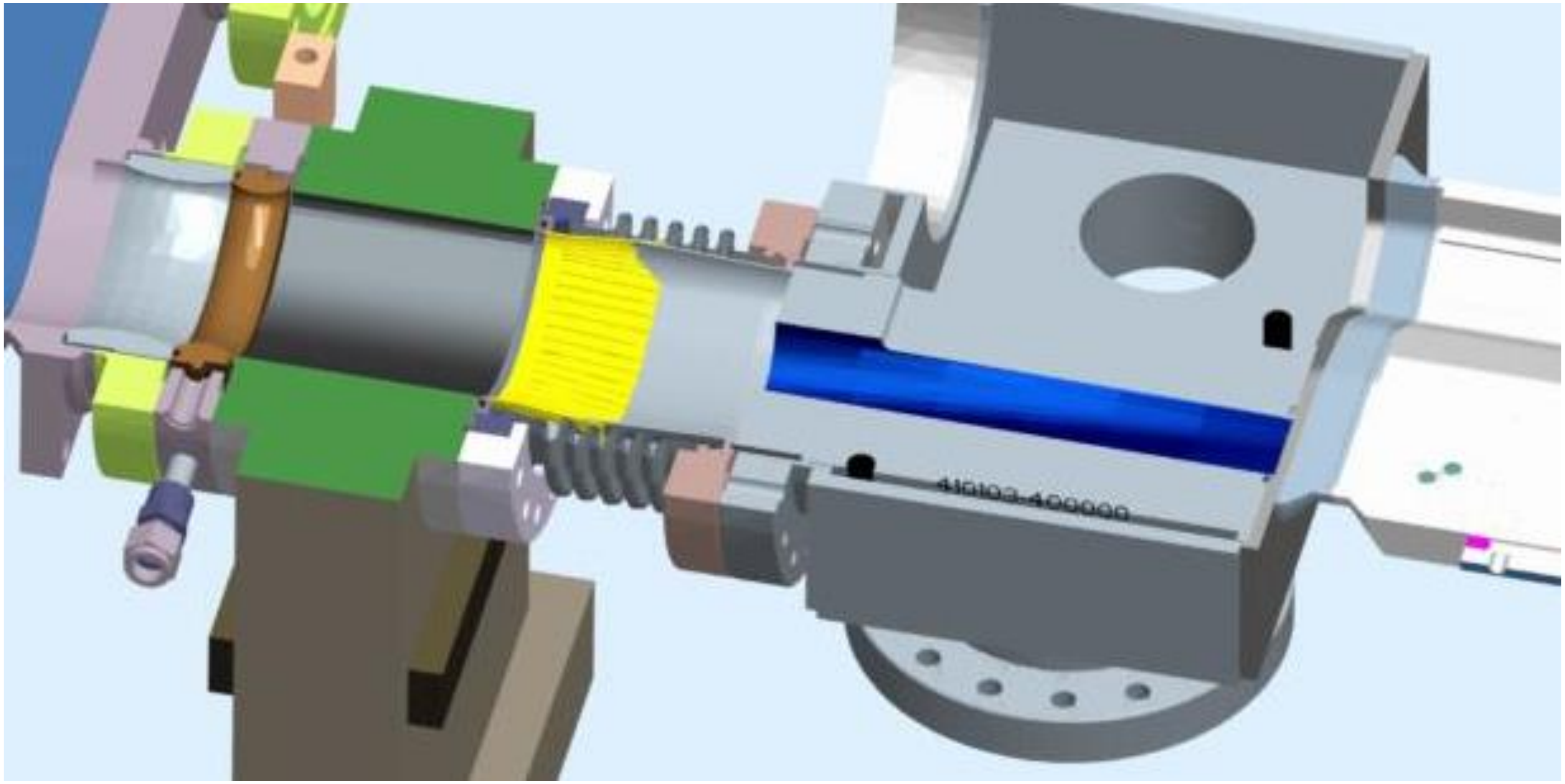
- APS undulator chamber has half width w=18mm ➔ **Fixed**
- APS regular chamber has half width w=42 mm ➔ **Vary**



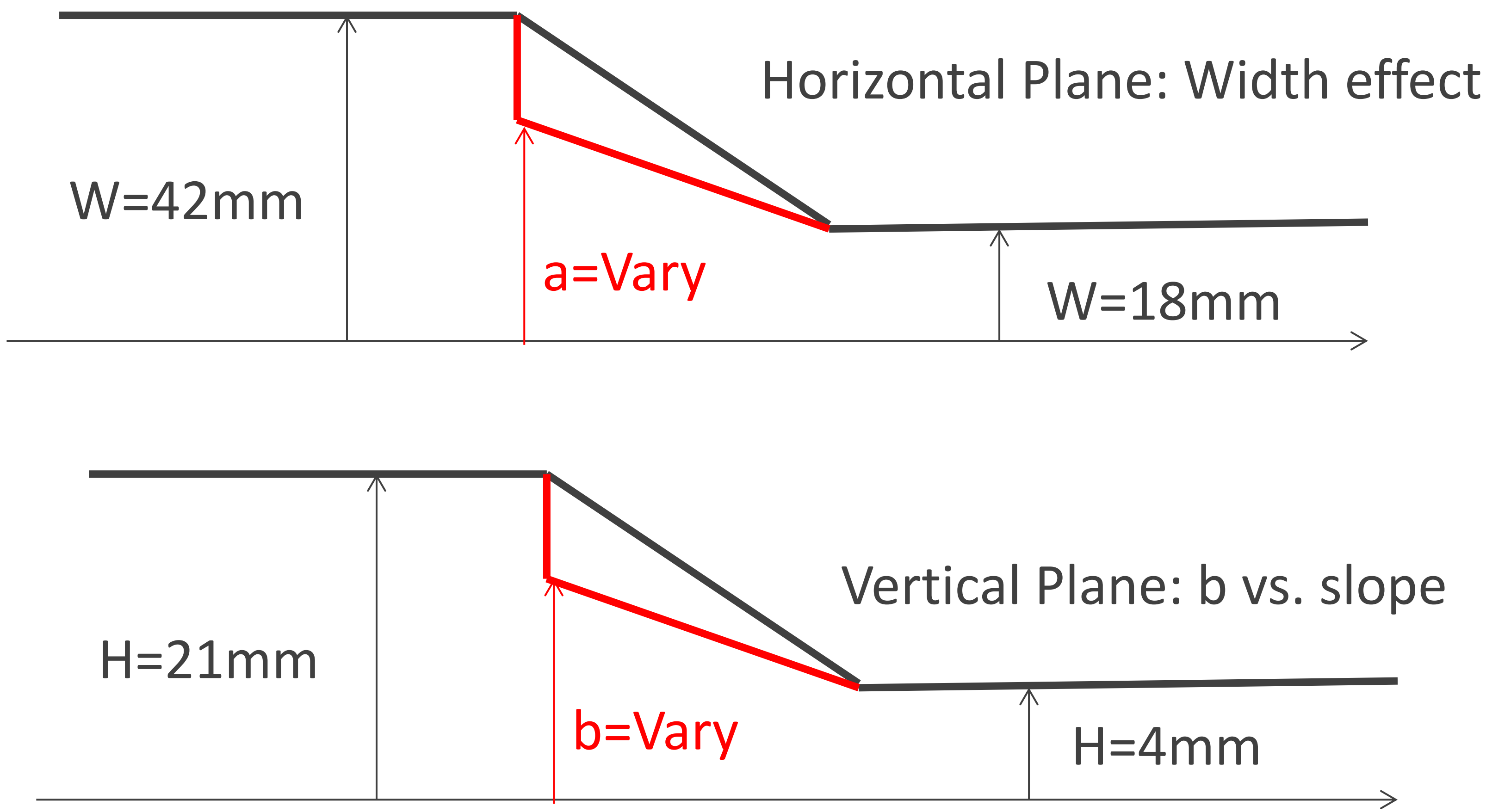


Very interesting,
But not practical

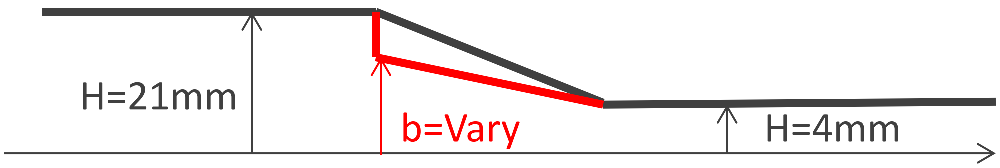
New Taper

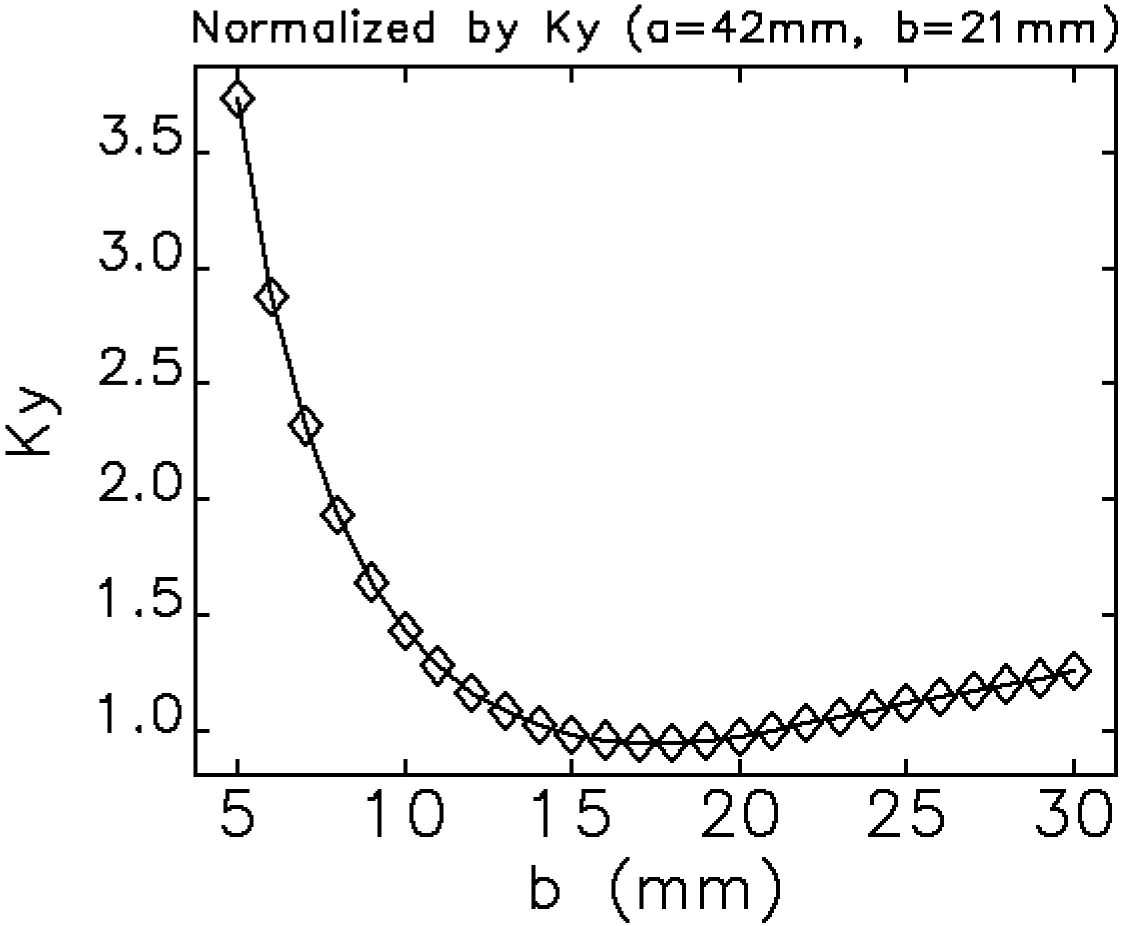


New Taper Optimization

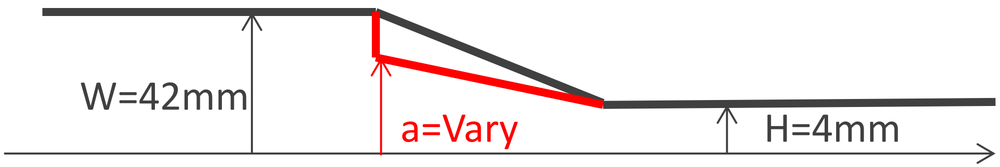


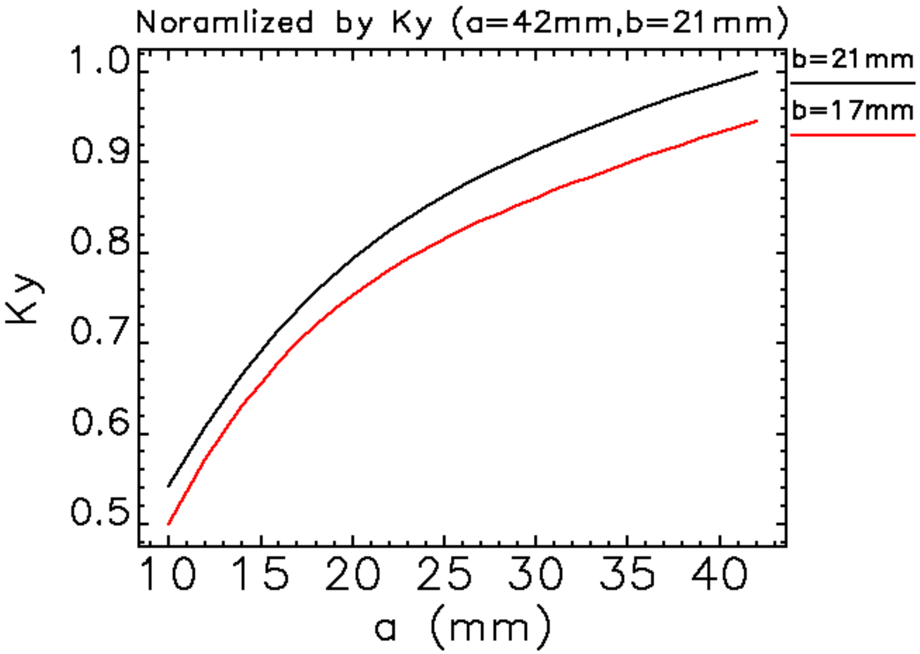
New Taper Optimization: fixed a

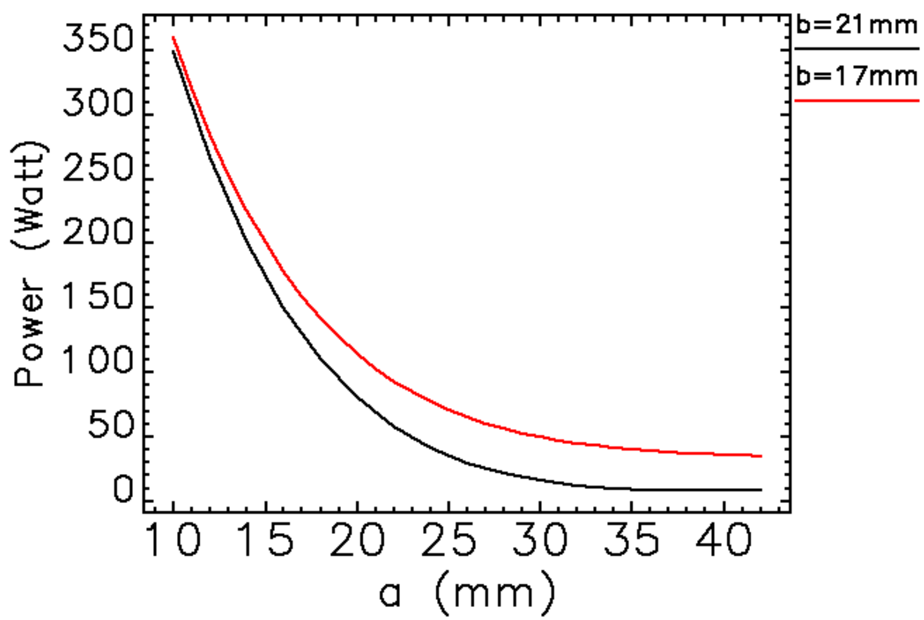




New Taper Optimization: fixed b

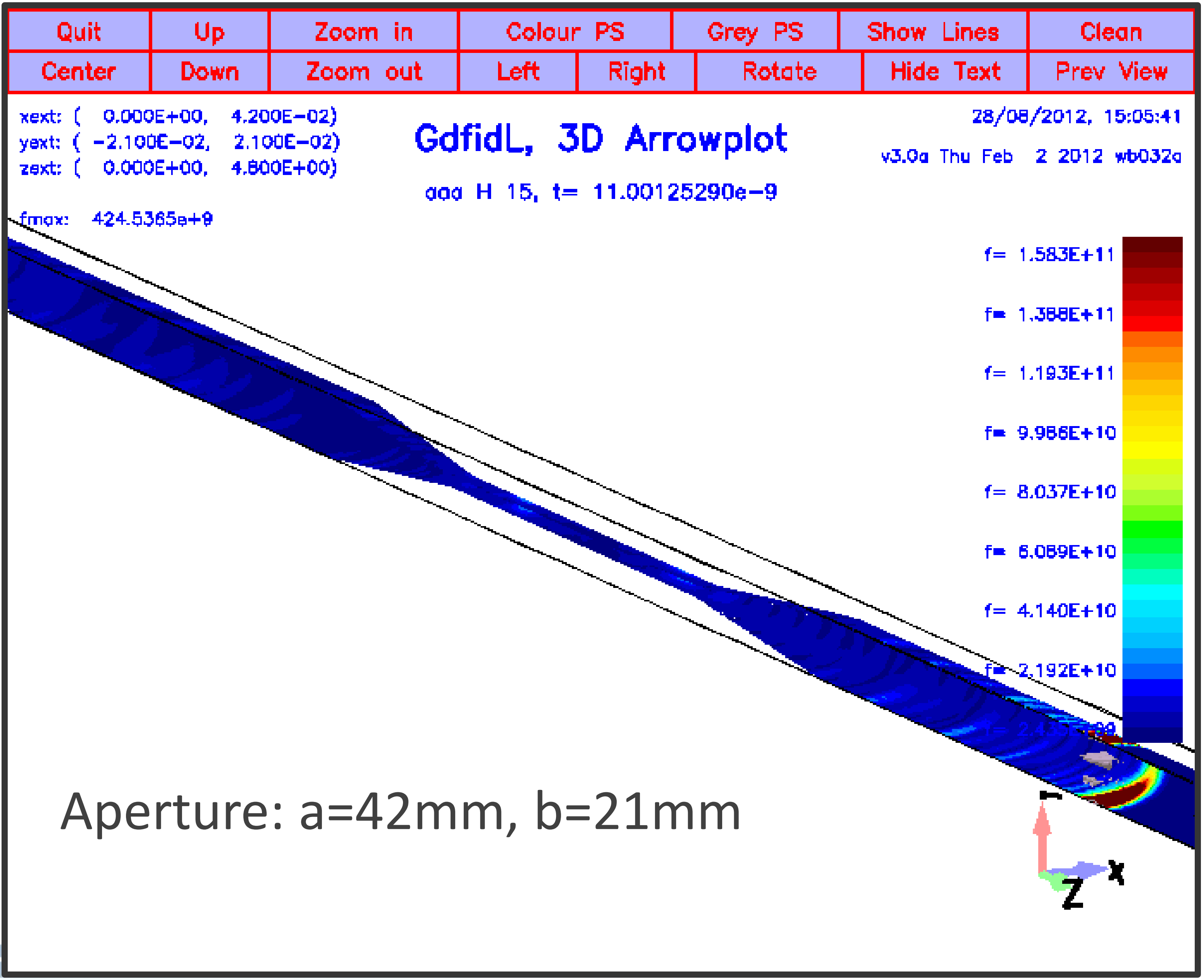






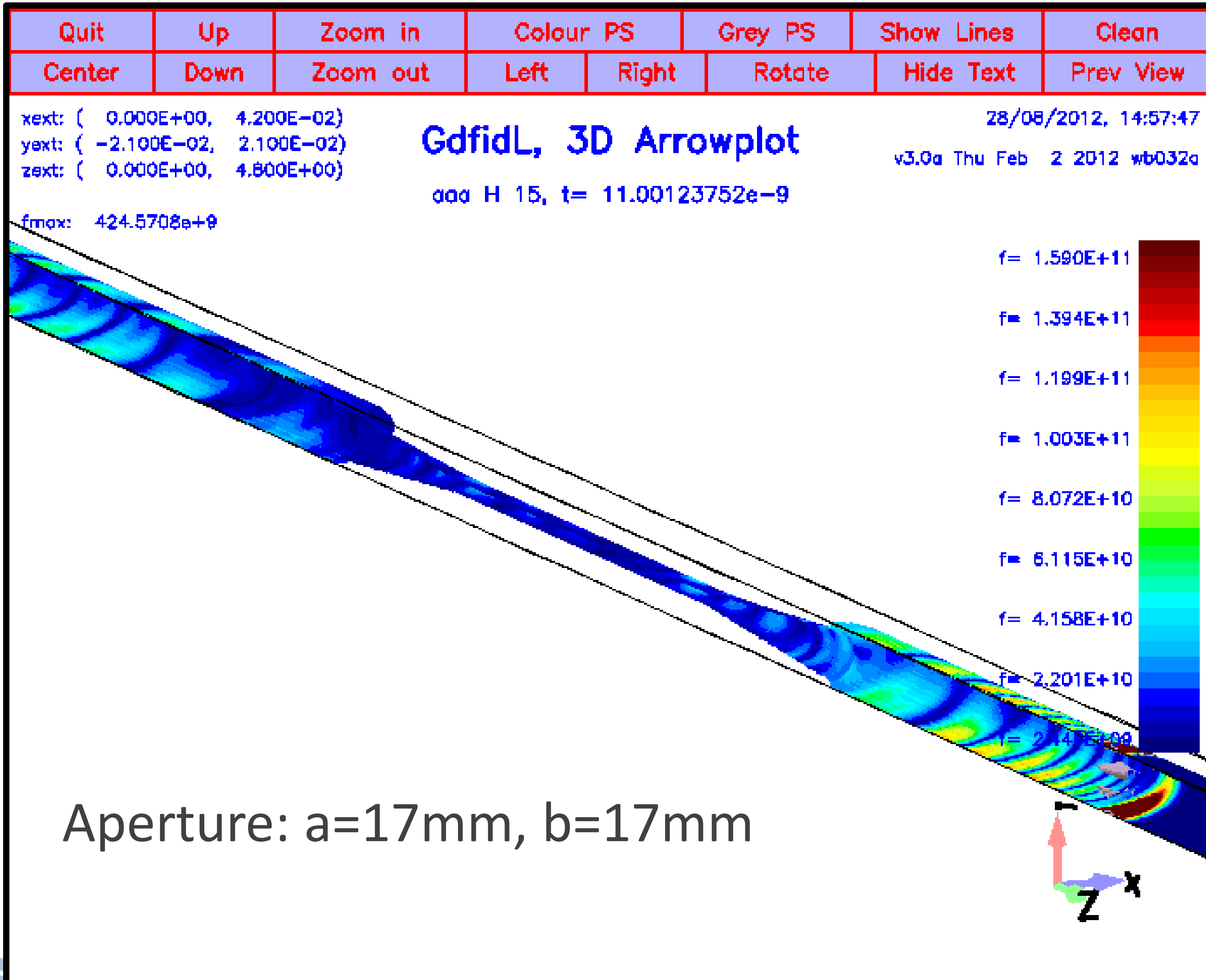
- As “a” decreases, Ky also decreases
- As “a” decrease, rf heat load increases
- **We determined that a=b=17 mm**

ID Chamber - Wakefield



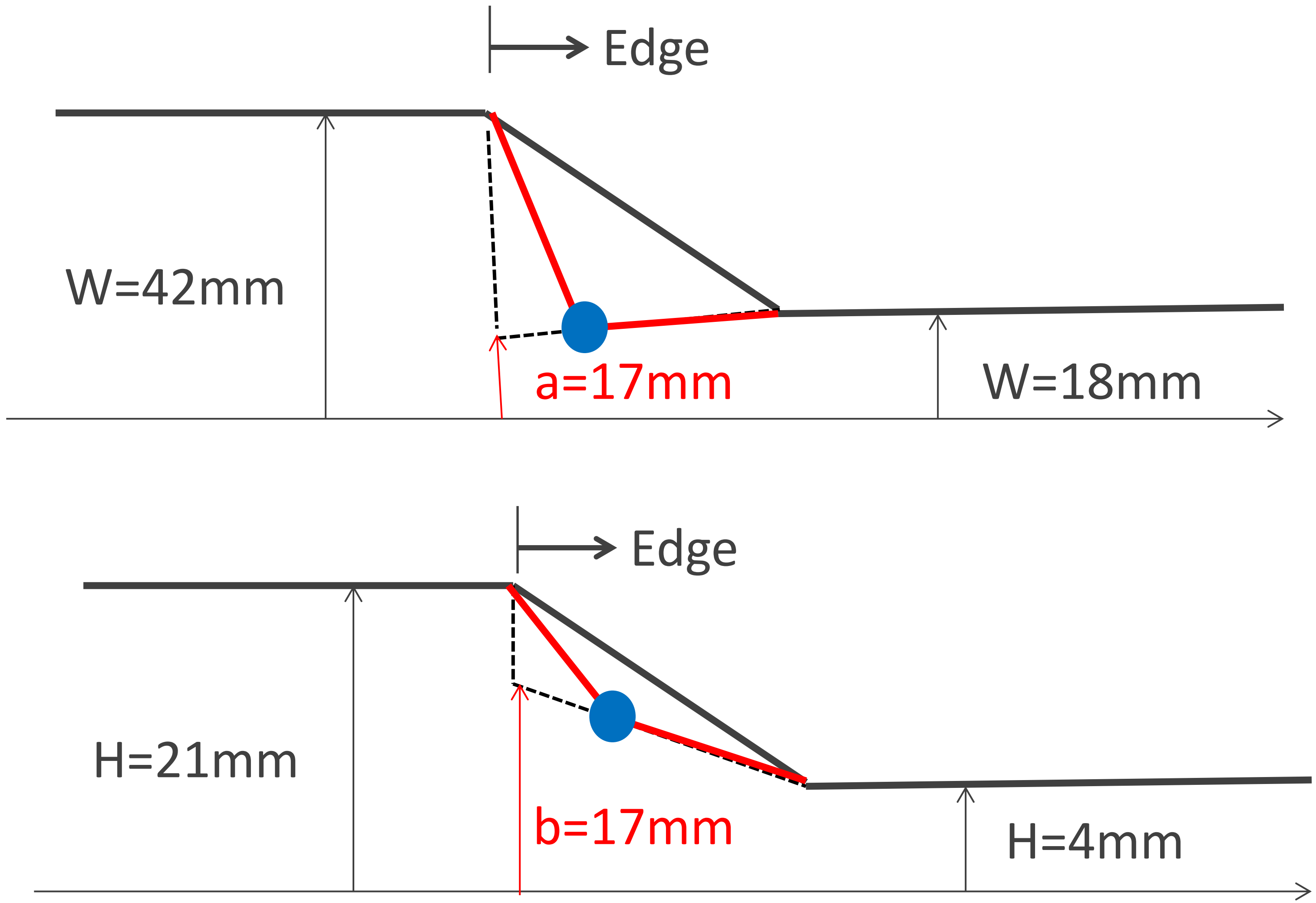
Aperture: a=42mm, b=21mm

ID Chamber with New Transition - Wakefield

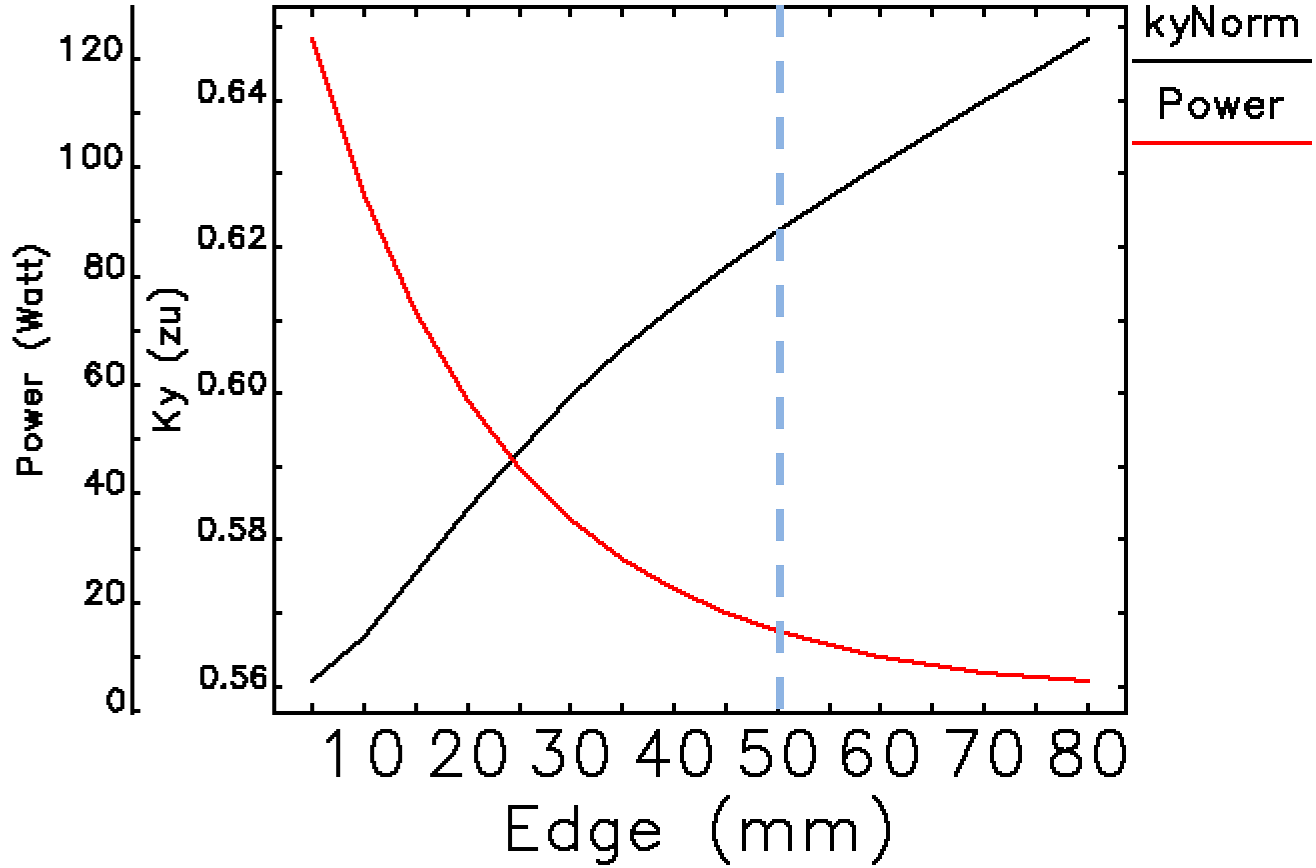


Aperture: a=17mm, b=17mm

Optimize the taper for Power & Ky (a=b=17mm)



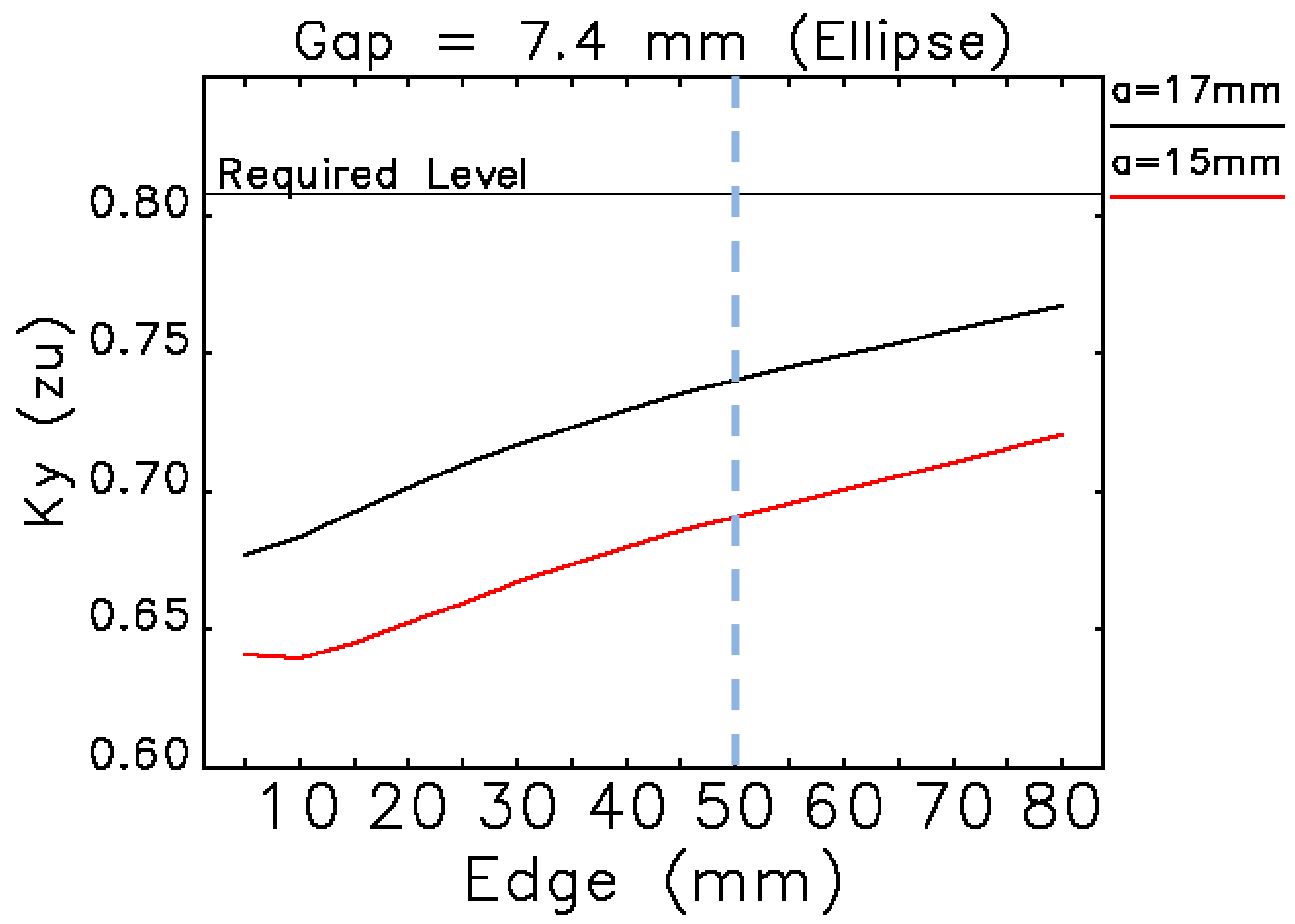
ID Chamber: Full Gap=8mm (Half Width=18mm)



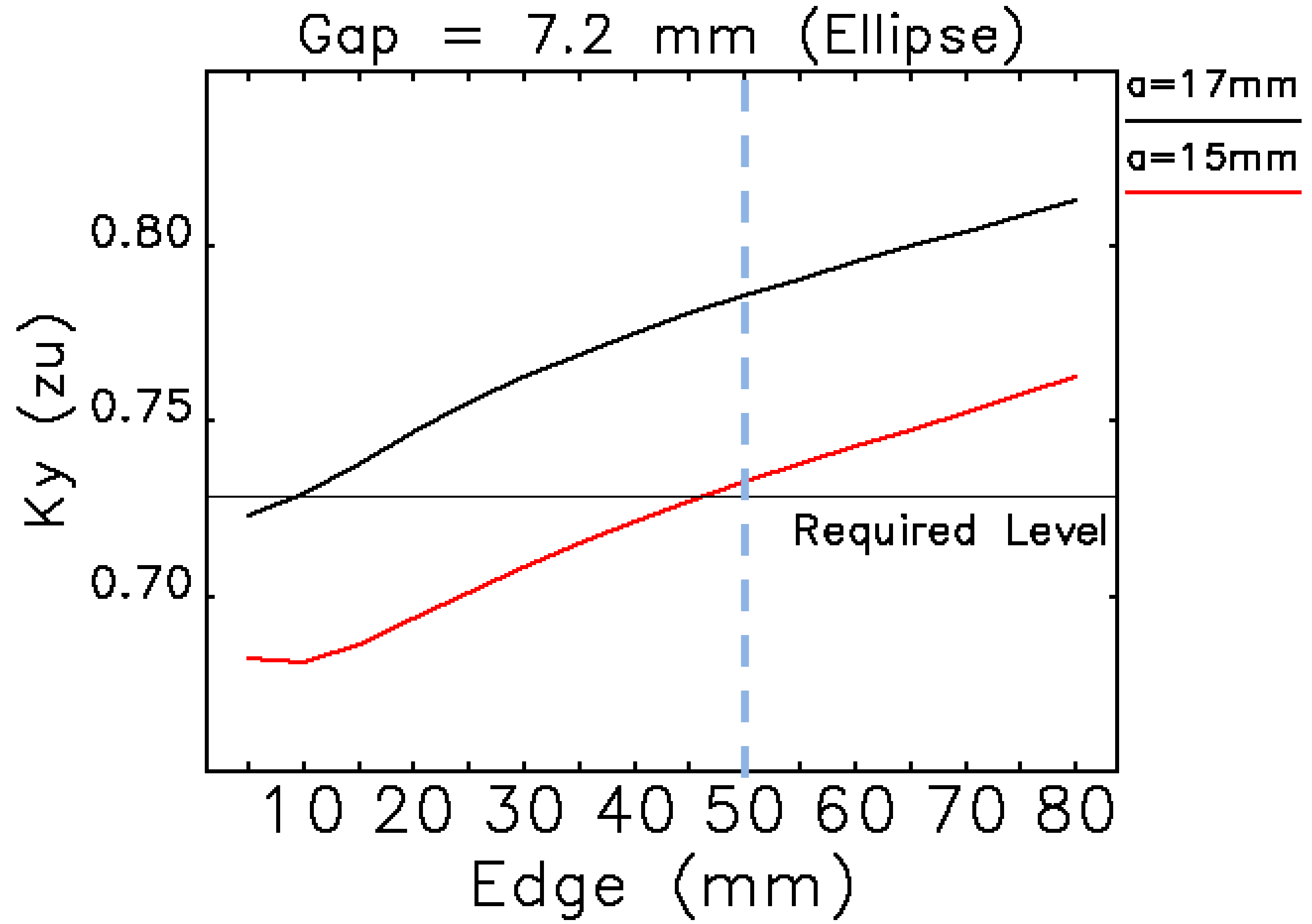
Required Impedance Level (Replacing 8.0mm Ellipse by smaller gap chamber)

Gap (mm)	Total Impedance (zu)	Resistive Wall Impedance (zu)	Geometric Impedance (zu)
8	1.73	0.730	1.0
7.8	1.73	0.788	0.942
7.6	1.73	0.851	0.879
7.4	1.73	0.922	0.808
7.2	1.73	1.001	0.729
7.0	1.73	1.090	0.640
	Condition for 16-mA	Analytic Estimate	Required to achieve by optimization

ID Chamber: Full Gap=7.4mm (Half Width=18mm)



ID Chamber: Full Gap=7.2mm (Half Width=18mm)



Possible Replacement by Using Optimized ID Chamber

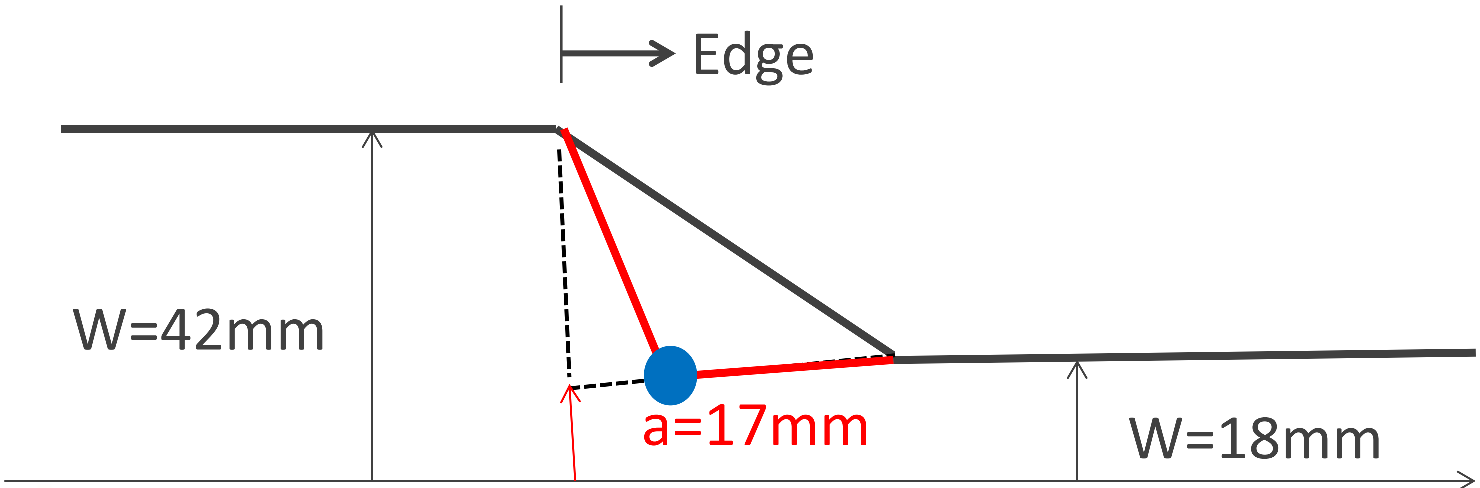
- We can replace each 8-mm gap elliptic chamber with NEW 7.3-mm gap elliptic chamber
- We can replace each 7.5-mm (Racetrack Chamber) with NEW 7.0-mm gap elliptic chamber
- We can replace 9x7.5-mm (Racetrack) and 24x8-mm gap elliptic chambers with NEW 33x7.2-mm elliptic chambers

Acceptable Chamber Replacements with New Taper for 16-mA Operation

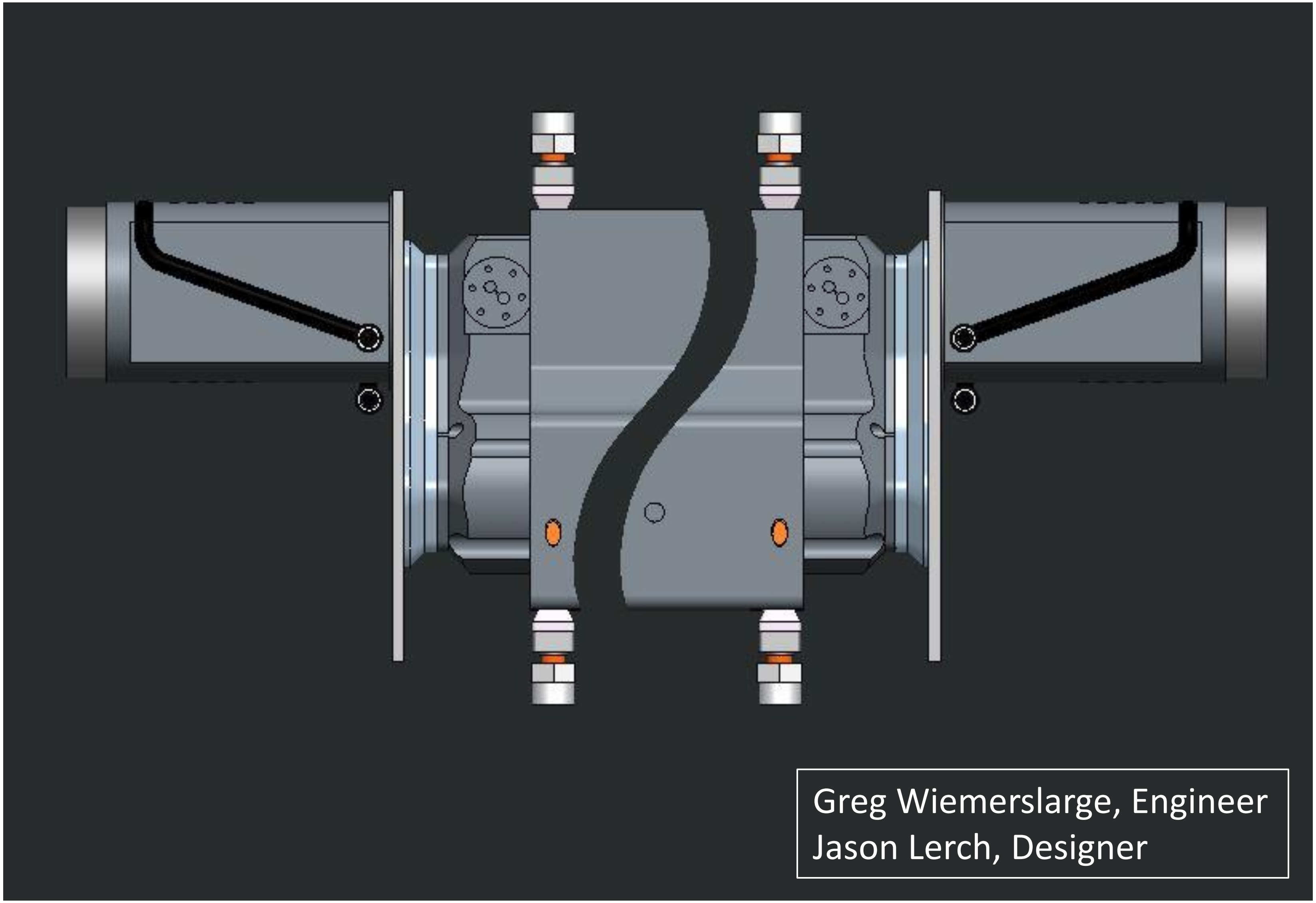
5.0 (#)	8.0 (#)	7.5R (#)	7.4	7.2	7.0	Total Impe	Imax (mA)	
1	24	9				1	23	2013 Run-2
1	33					0.848	42	NEW a=17mm
1			33			0.949	28	NEW a=17mm
1				33		0.989	24	NEW a=17mm
1					33	1.034	20	NEW a=17mm

The APS Specific Engineering Recommendation for New ID Chamber

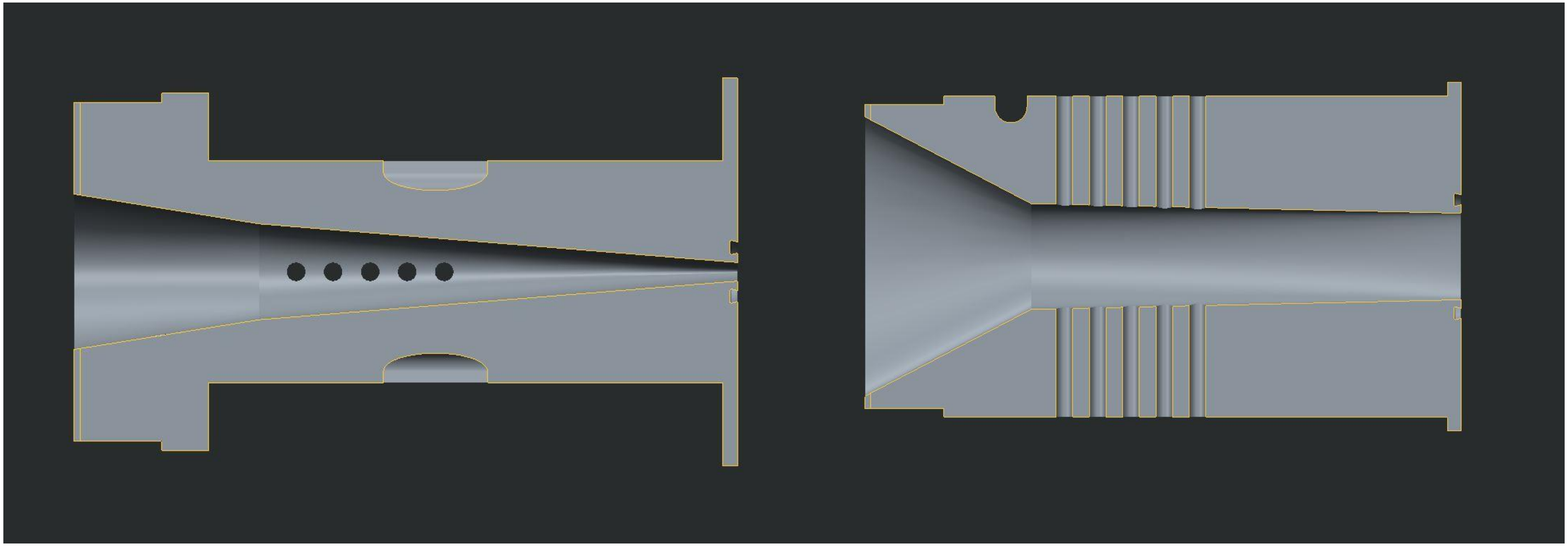
- ID Chamber
  - Use Elliptic Profile
  - Use Half Width 18 mm
- Transition
  - Use Symmetric Transition
  - Use Edge Length 50 mm
  - Use Edge Aperture 17 mm (a=b=17mm)
  - Replace the pumping slot with holes



As a result at the APS



As a result at the APS (2)



- A 5-mm gap chamber for 17-mm period undulator will be installed during the August shutdown in 2014 (G. Wiemerslarge , J. Lerch, Y. Chae).
- We will measure local impedance of two 5-mm gap chambers with new and old transition to compare each other. (V. Sajaev, Y. Chae)
- New chamber’s impedance should be < 60% of old one.

Summary

- We considered an ID vacuum chamber gap, width, and its profile as well as the taper transition for optimization.
- We found that the narrow aperture on the APS extrusion chamber side significantly reduced the impedance.
- With new chamber design principle, the 7.3-mm elliptic ID vacuum chamber can be used by replacing the existing 8.0-mm gap chamber for the 16-mA operation; the resultant undulator magnet gap will decrease from 11 mm to 10 mm.
- A 5-mm gap chamber with the new transition for short period undulator will be installed at the APS in September.
- We plan to measure the local impedances of two 5-mm gap chambers with new and old transition, respectively, located at different sectors in the ring. This will confirm the validity of design concept.