Argonne NATIONAL LABORATORY

Small Aperture, Welded, Stainless-Steel Insertion Device Vacuum Chambers

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Why:

- Limitations of current designs
- What is to be gained with a new one

What:

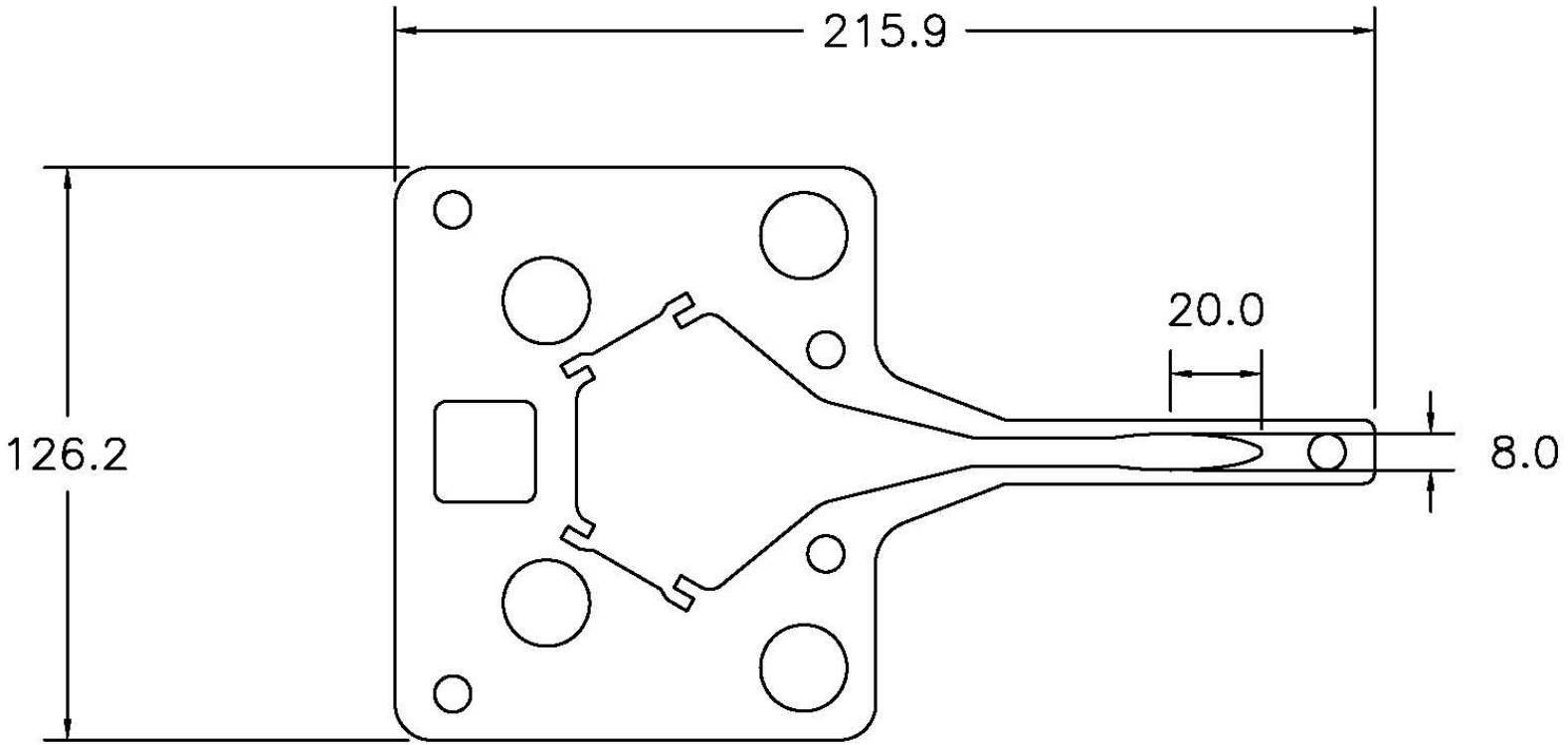
- Geometry
- Material
- Coating

How:

- Fabrication
- Testing

Original IDVC Construction

- Al 6063-T5 – Extruded then machined
- Elliptical aperture
- 5mm and 8mm vertical aperture versions (total heights of 7mm and 10mm)
- “Strongback” to maintain minimum flatness and twisting

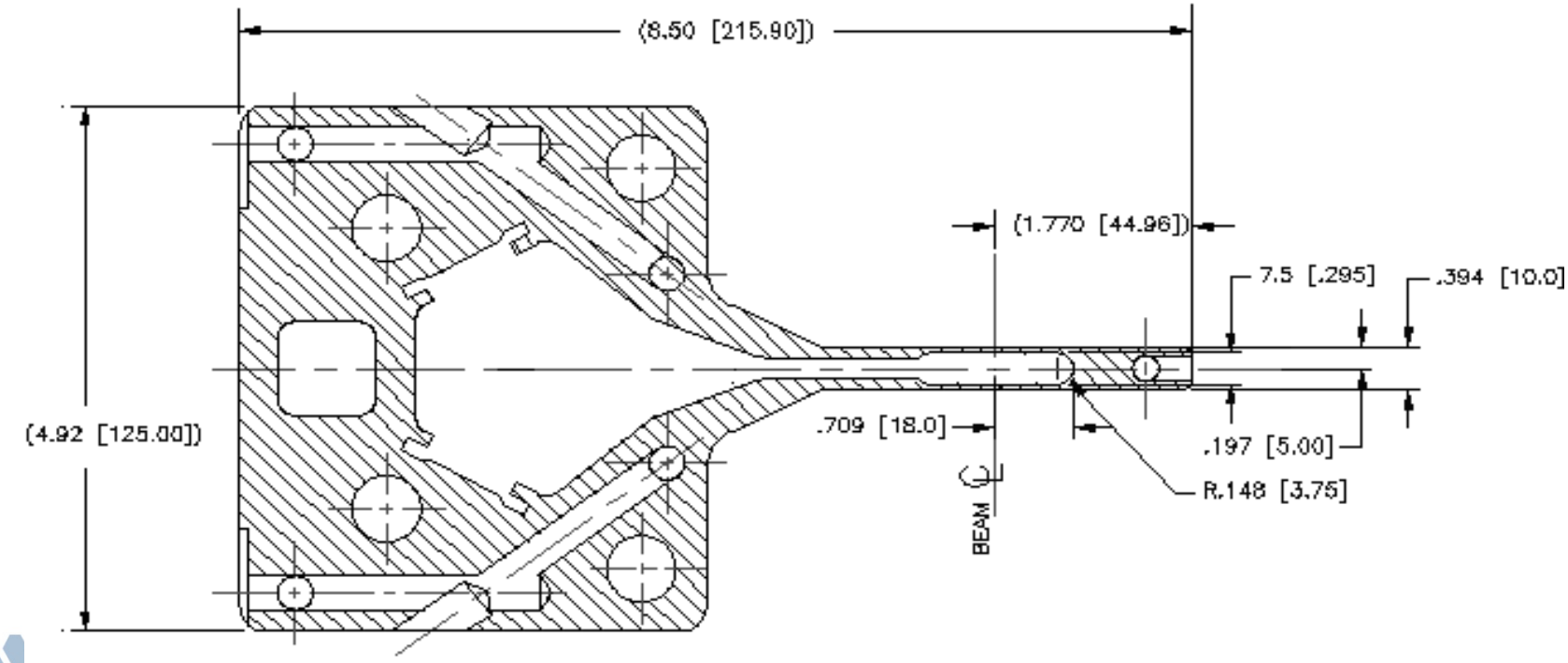


Most recent IDVC Design

•Aperture shape changed from elliptical to rounded-rectangular to reduce beam loss at corners, esp. during injection

• Wall thickness increased to keep deflection low, resulting in reduced vertical aperture (8mm → 7.5mm)

•Horizontal aperture reduced by 4mm



Limitations of most-recent designs

- Impedance due to surface resistance of Al
- Thicker walls are required to minimize deflection of rectangular aperture, reducing beam aperture for a given total height (min undulator gap)
- No access to interior surface
- Fabrication is tricky
- Bimetal required for welding to SS end-boxes

Proposed Design

Construction: Stainless steel to minimize deflection under vacuum
Milled and welded

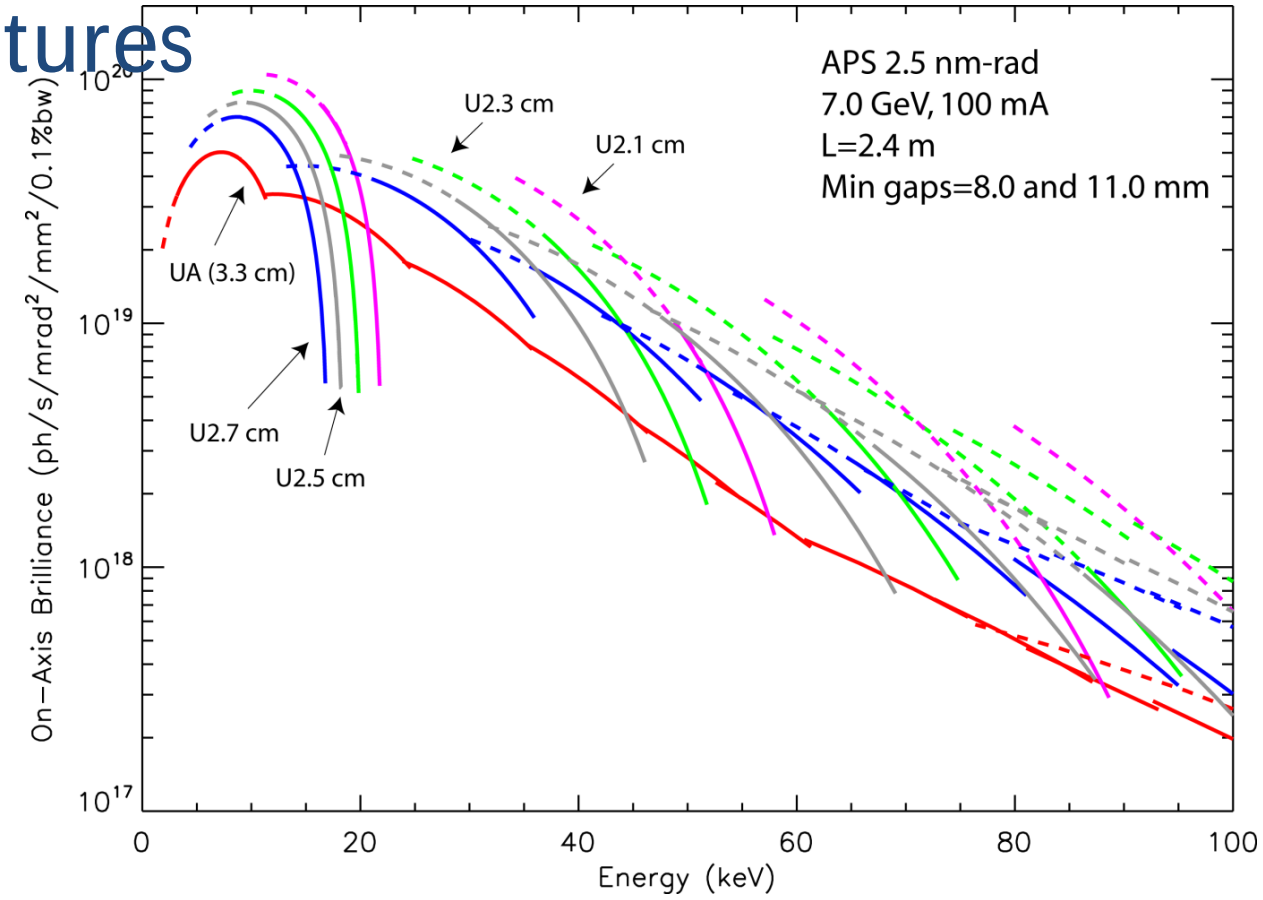
Plating: Cu plating to minimize resistive wall impedances

Geometry: Reduced wall thickness – 1mm

Challenges:

Staying within required tolerances (flatness <0.1mm, wall thickness ± 50µm)
Achieving a consistent and robust plating layer
Meeting required vacuum performance (< 2E-10 torr)

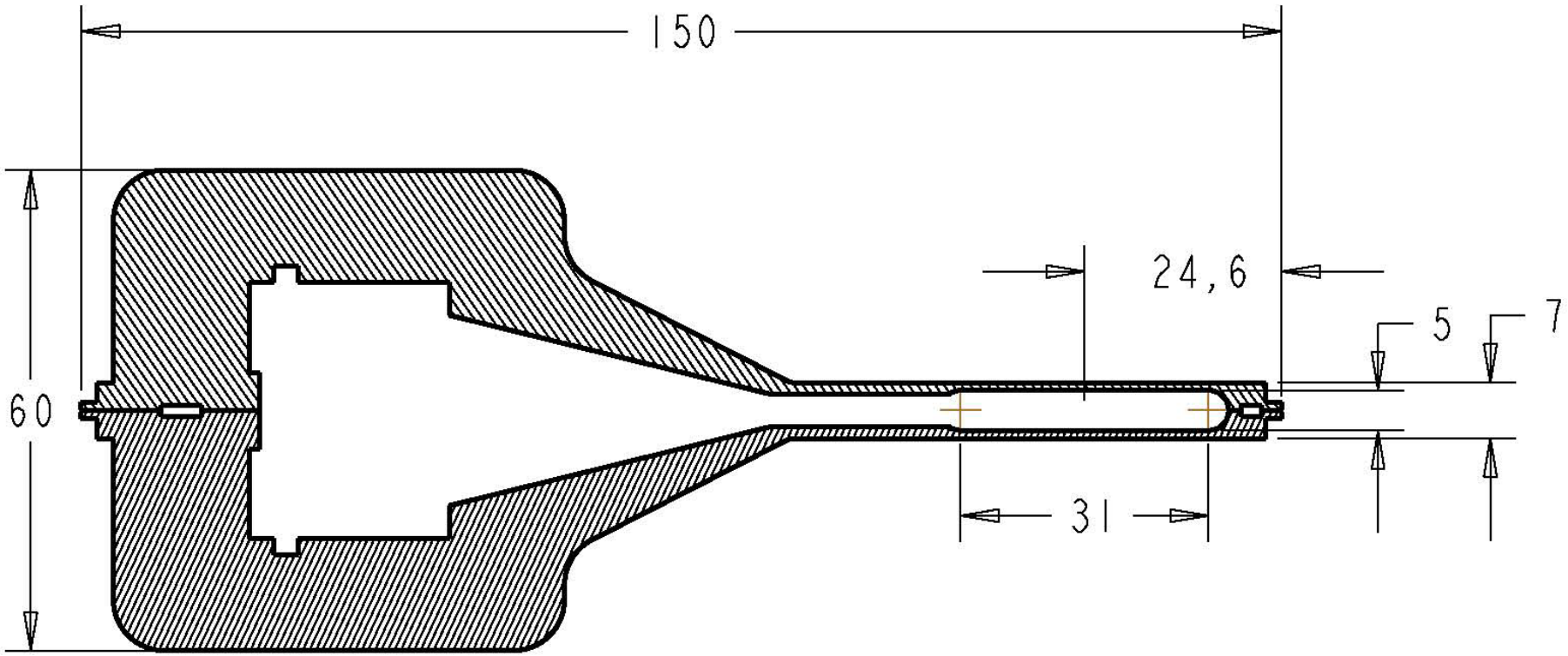
What is To Be Gained at Smaller Apertures



- The solid curves indicate the tuning coverage for a minimum gap of 11.0 mm. The extensions towards lower energies are shown by the dashed curves (8.0 mm minimum gap). All undulators are of the "generic" out-of-vacuum design and made of NdFeB magnets and vanadium permendur poles.
- The minimum reachable first harmonic energy goes from to 3.2 -> 1.9 keV (UA), 7.3 -> 4.4 keV (U2.7 cm),. 9.6 -> 6.0 keV (U2.5 cm), 12.5 -> 8.3 keV (U2.3 cm), and 16.4 -> 11.4 keV (U2.1 cm) when changing the gap from 11.0 mm -> 8.0 mm
- Reductions due to magnetic field errors were applied – estimated from one measured Undulator A.

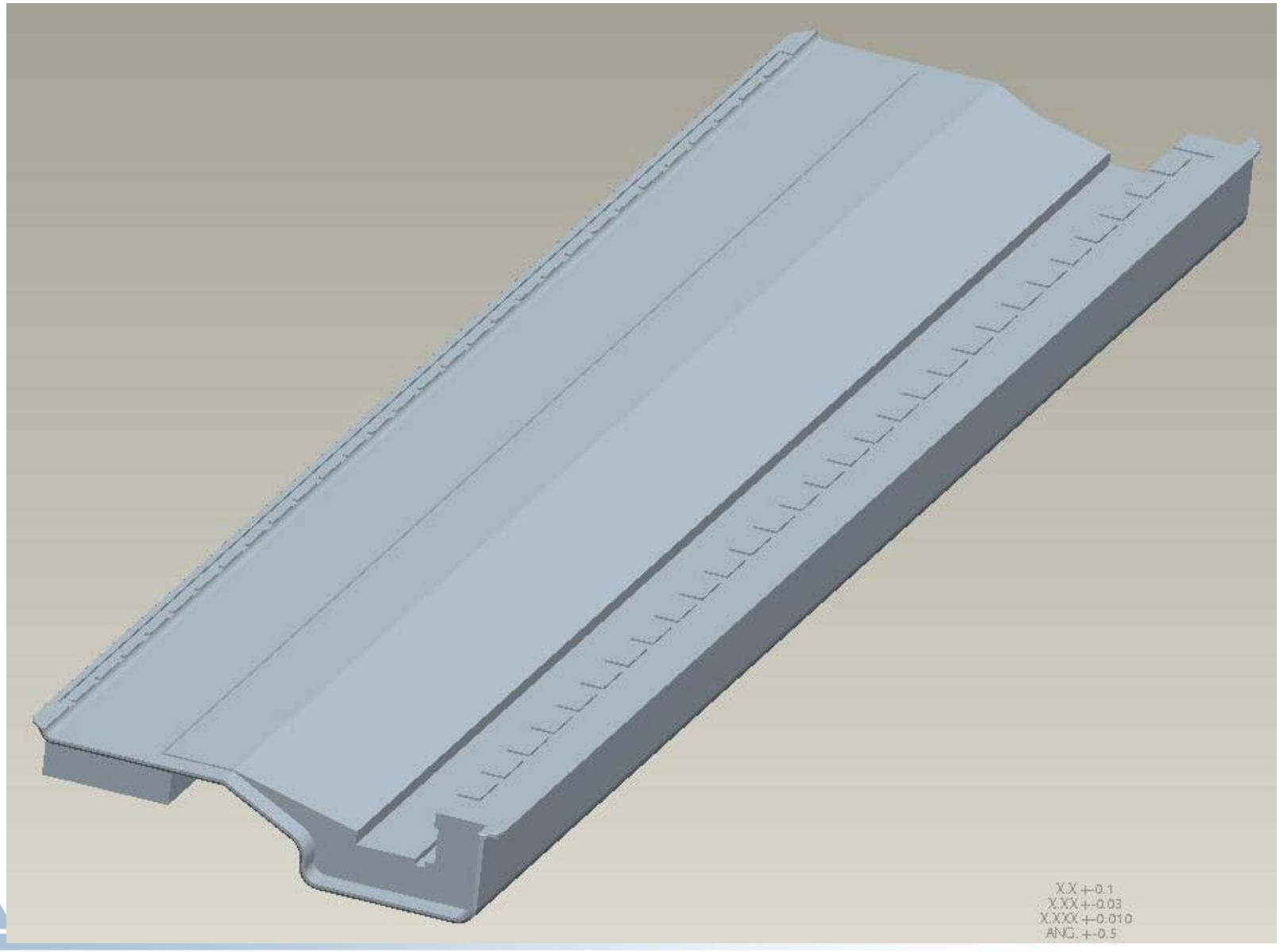
Courtesy R. Dejus

Proposed Design



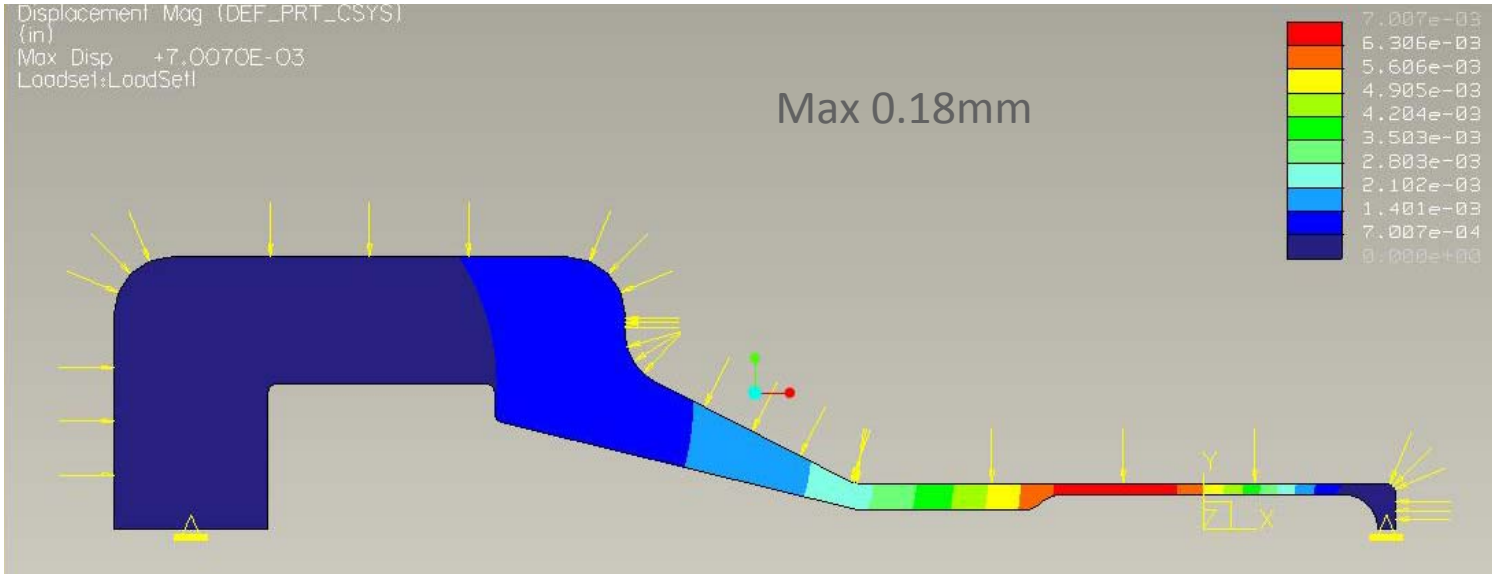
Reduced wall thickness
Protrusions at seams to minimize distortion caused by welding
Simplified NEG strip slots for easier insertion
Channels to vent trapped gasses between halves

Proposed Design (Test chamber)

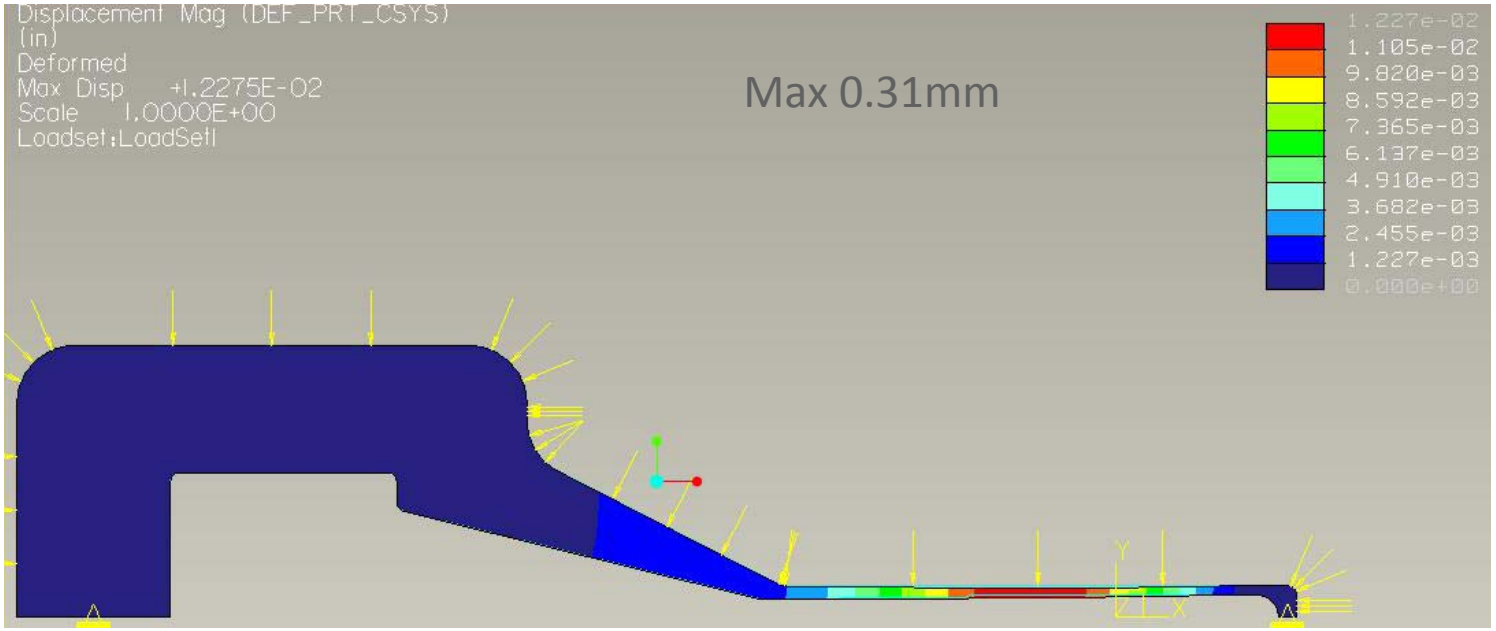


Deflection for Al 6063-T5

7.5 mm aperture w/ 1.25mm wall (current design)

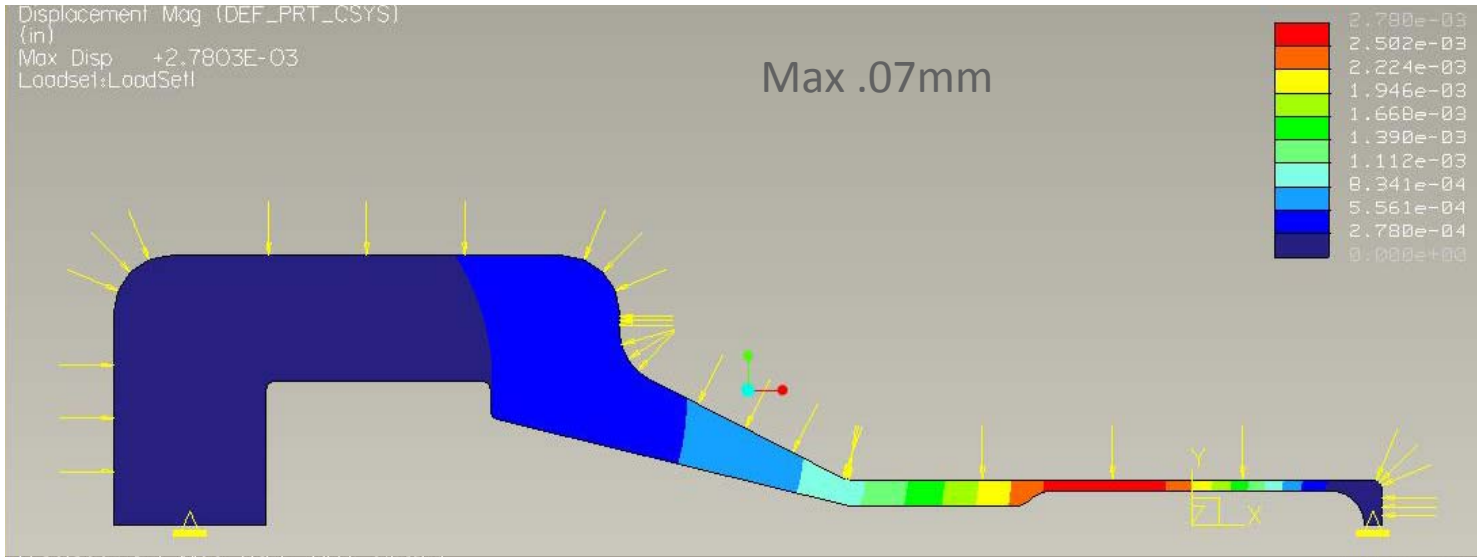


5 mm aperture w/ 1mm wall

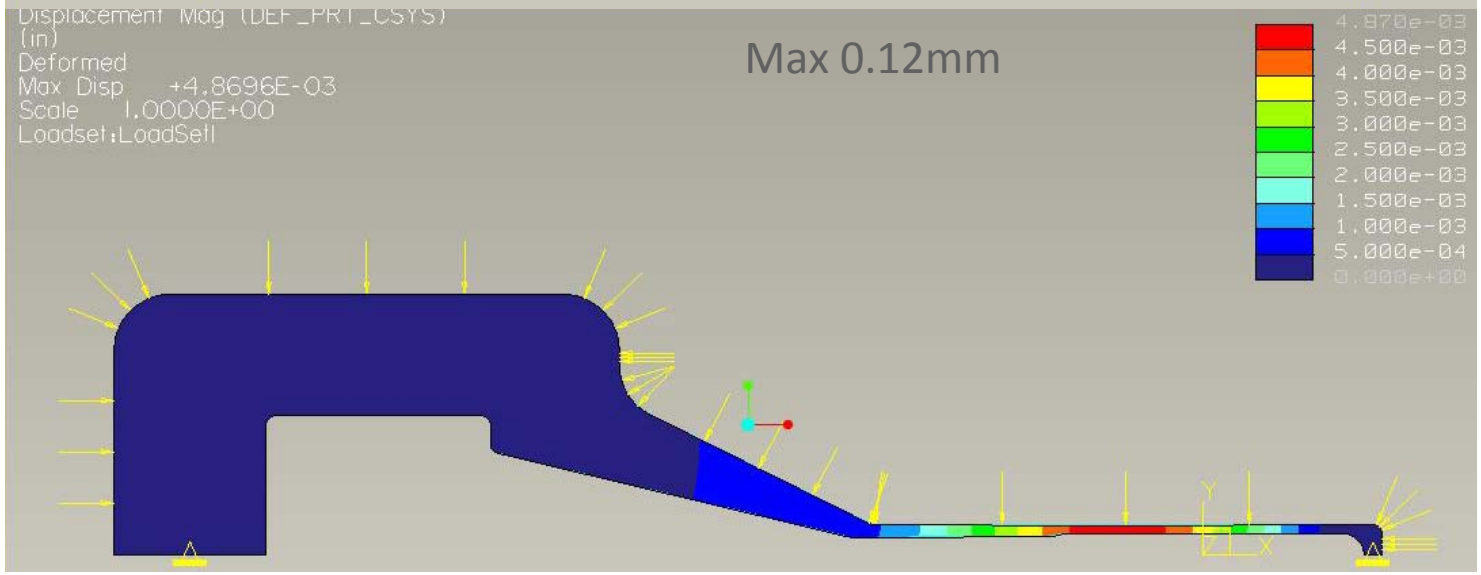


Deflection for SS 316LN

7.5 mm
aperture
w/ 1.25mm wall
(current design)



5 mm
aperture
w/ 1mm wall



Proposed Design - Material

Austentic Stainless Steel 316LN (annealed)
16% Cr, 10% Ni, 2% Mb
"L" Low carbon – reduces chromium carbide formation during welding
"N" Nitrogen containing - stabilizes austentic phase, increases strength

High strength
30ksi yield / 75ksi ultimate tensile

Lowest magnetic permeability, < 1.02
- Commonly used near sensitive electronics
- Only slight increases observed in machining and welding

Very easily welded

High resistivity

Ref: ATI Allegheny Ludlum Technical Data Blue Sheet – Stainless Steel Type 316LN, 2009

Proposed Design – Plating Material

Needed to reduce resistive wall impedances of SS chamber

Surface Resistance, $R_o = \rho/\delta_o$

Skin depth, $\delta_o \alpha \text{ sqrt}(\rho) \rightarrow R_o \alpha \text{ sqrt}(\rho)$

Surface resistance Cu / SS = 0.15
Cu / Al = 0.80
Ag / Cu = 0.97

Proposed Design – Plating thickness

Assuming copper, how much do we need?

Skin depth: $\delta = \sqrt{\frac{2\rho}{\omega\mu}}$

Assuming 24 bunch mode, lowest f= (24)(c/1104m)=6.5MHz
δ=25.7 µm

50 µm recommended by ASD

Require ± 5 µm consistency (important to minimize wake fields)

Intermediate plating layer required (Ni) but can be very thin

Machining / Plating

- Discussed work with Hi Tech Mfg / Schiller Park

- Body pieces to be milled from 1.25” thick bar stock
  Bending / twisting minimized with appropriate milling technique

- Standard electroplating
  Uniformity in plating thickness will require careful consideration of electrode placement

Welding

We have discussed E-beam welding with Sciaky (Chicago) and visited their facility.
Sciaky recommended by in-house welding expert

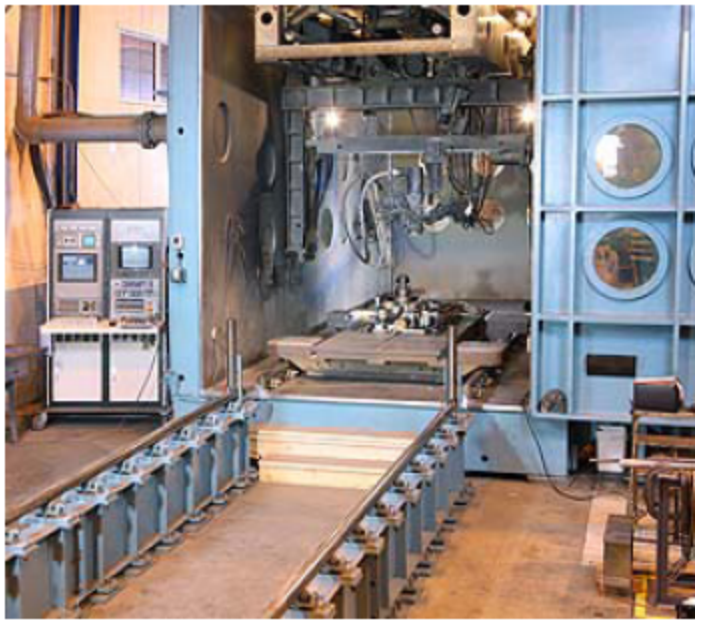
Known leaders in the field
Sciaky designs/builds welders and also provides welding services

E-beam welding offers:

- Highly-concentrated energy source, deep penetration, precise control
- Minimum total heat → minimum distortion

VX-300 Electron Beam Welder

Hard Vacuum (5 x 10-6 torr)
42 kW- 60 kV Gun with Optics
CNC Control - Joint Scanning and Digitizing System
Work Envelope - 248" x 70" x 54"
Chamber Interior Dimensions - 300" x 108" x 132"
(Includes Wire feed system)



http://www.sciaky.com

Precedent

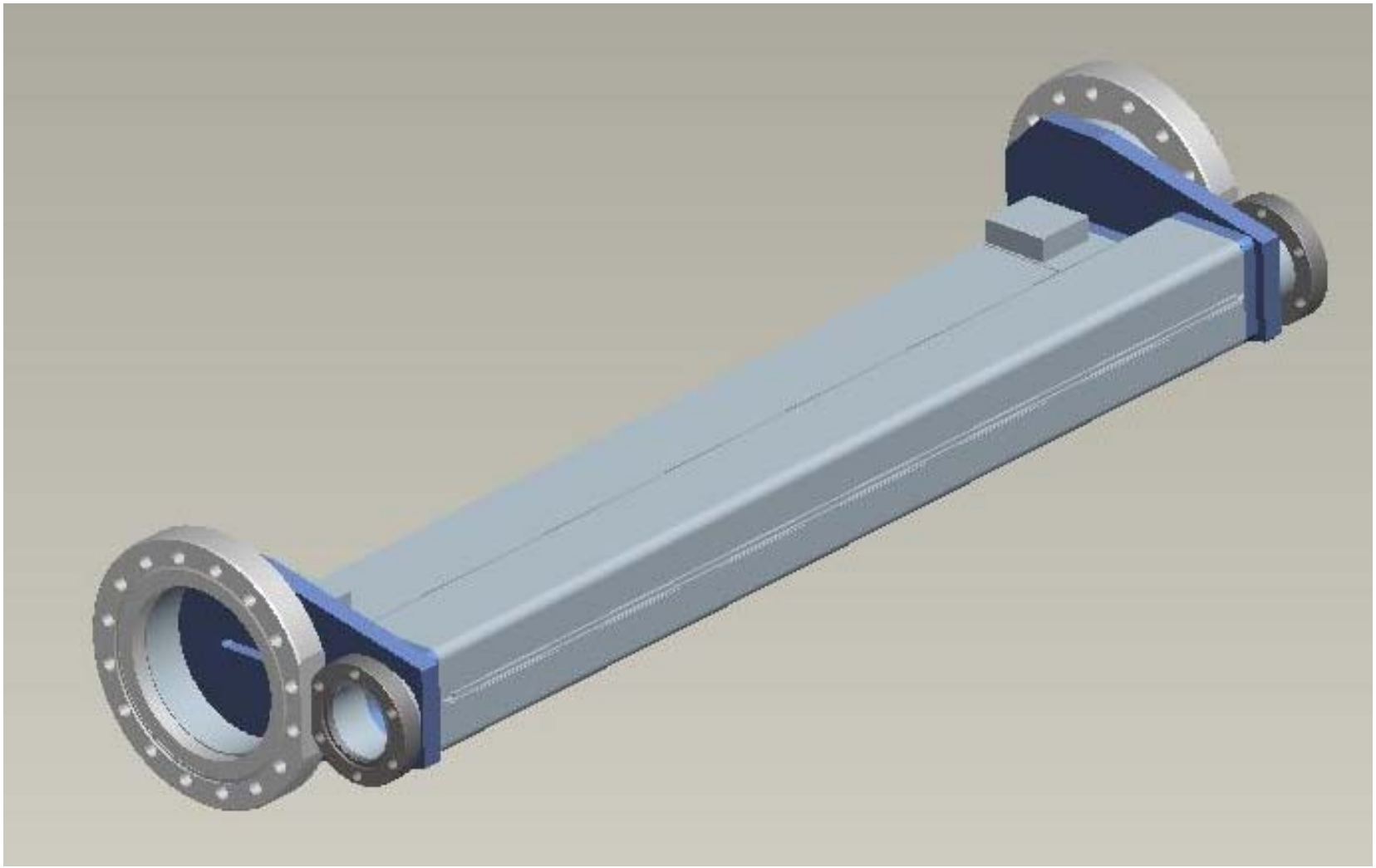
ESRF:

SS316LN
8mm aperture, 10mm total height
interior plated with 60µm copper
Electron beam welded

Aperture formed by two sheets of SS supported between two SS bars.
Less distortion from machining.
More distortion from welding.

Ref: N.Rouviere, “New Development of Undulator Vessels at E.S.R.F.,” EPAC 1998

Test Assembly



Test Assembly - Evaluation

Distortion resulting from machining process (bending and twisting)

Quality of plating (Is it going to flake off?)

Distortion resulting from welding

Effect of welding on plating

Magnetic properties (installed in an undulator using Hall probe)

Vacuum performance

Wall deflection under vacuum

Test Assembly - Estimated Cost for Two

Components procured and fabricated	$17,000
Welding fixtures procured and fabricated	$2000
Assemblies welded	$12,000
Total	$31,000

Acknowledgements

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