Artist: Eddie Anaya (Cal State Fullerton)

Cosmic Explorer Beamtube Experiment (CE-BEX): Circumferential Joint Design

Beamtube Workshop #3 (29-Sep – 2-Oct 2025)

Caltech

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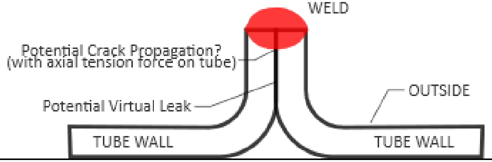
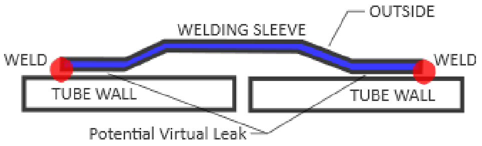
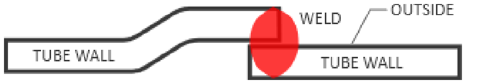
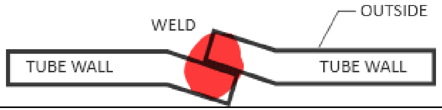
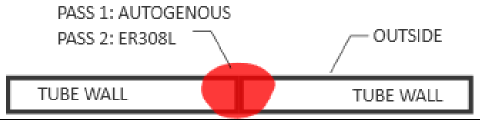
24-Sep-2025 v1

LIGO-G2502097-v1

Circumferential Welded Joint Taxonomy

Table 1 Taxonomy of Potential Welds

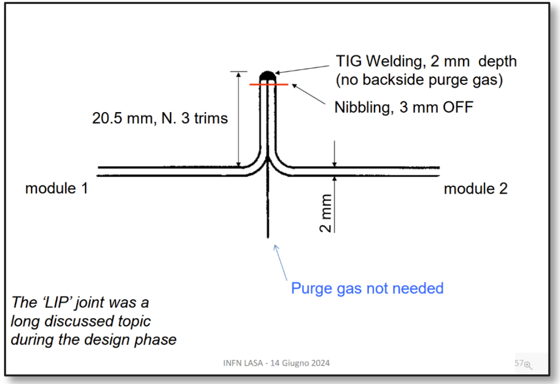
Description	Cross-Section Sketch	Advantages	Disadvantages	Example applications
Radial Lip Weld[1]		• Edge welding preferred by welders • No additional parts • Single weld bead • Can be cut and rewelded if needed	• High tensile stress (potential for limited fatigue life) • Requires lip formation operation on each tube end • Potential virtual leak	Virgo? GEO600
External Welded Sleeve[1]		• Low stress • Low welding particulate density in interior	• Additional part required • May require cylindricity operation on both ends of tube section? • Compliant joint? • Two weld beads required • Potential virtual leak? (unless intentional gap)	ET PS
Socket Weld (aka Bell & Spigot)		• Low Stress • No additional parts • Single weld bead	• Requires lip formation operation on one tube end • Requires cylindricity operation on one tube end • Requires welding particulate capture	
Conical Scarf Joint Weld		• Low Stress • No additional parts • Single weld bead • Tight registration of mating surfaces	• Requires different lip formation operation on each tube end • Requires welding particulate capture	
Butt Weld		• Low Stress • No additional parts • Single weld bead	• Requires cylindricity operation on both ends of tube section • Requires welding particulate capture	LIGO

[1] C. Garion, “Design of the ET beampipe pilot sector”, 22-Jan-2024, pg. 15

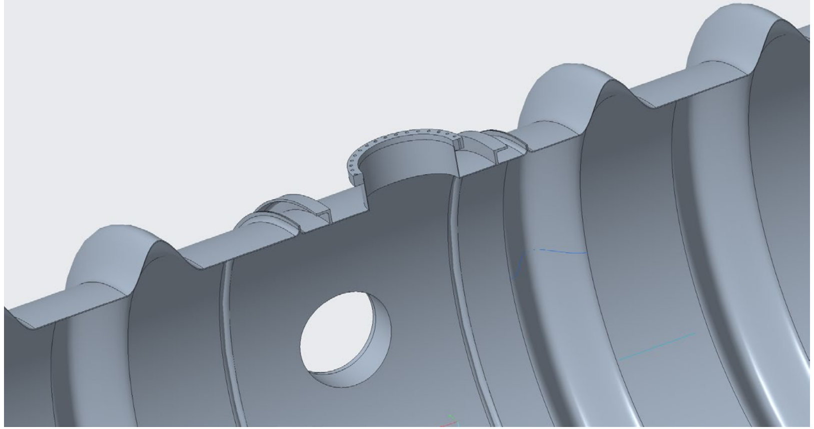
General Circumferential Joint Comments

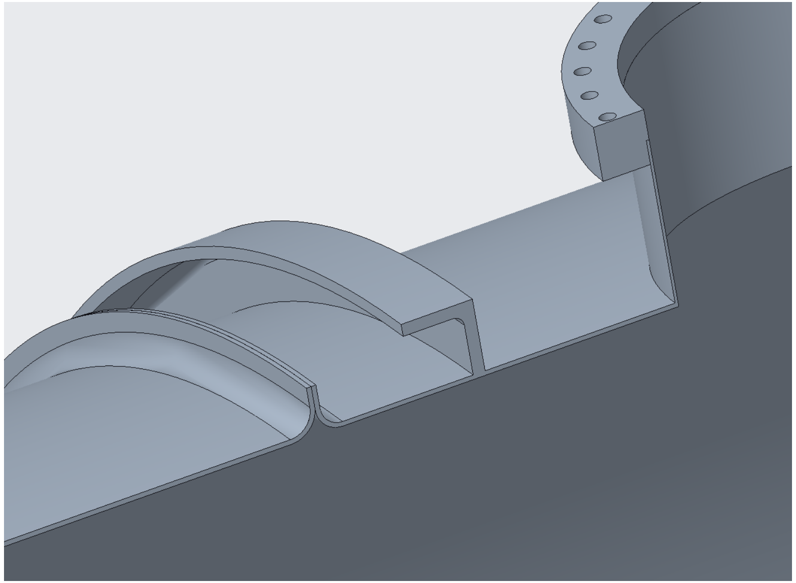
- Factory swage to precise end circumference seemeds relatively easy
- Fussy butt joint fitup in field dominated CBI time/joint
- Back shielding isn't "extra step" if a field He leaktest is needed in any case
- Virtual leak (of gas) a non-issue in volumetric perspective
- Trapping contaminants is only an issue if welding precedes final cleaning step; this does not seem practical in any scenario
- Welding generated particulates are not a significant concern:
  - Far from optics
  - Not a frangible surface layer that can "rain" down through the laser beam when excited by vibration
- Pre-formed "self-aligning" end features with no extra parts seems a good solution

Draft corrugated specification



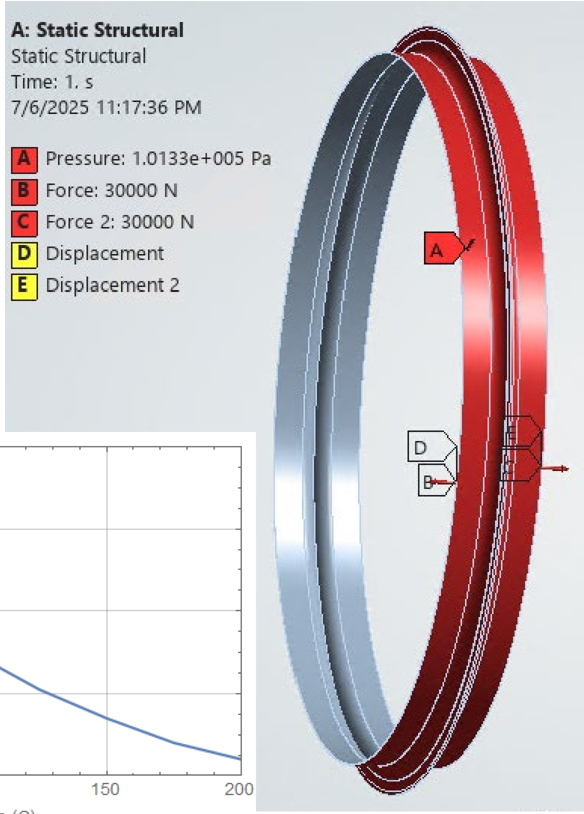
From A. Pasqualetti, **Corso Nazionale di formazione Vuoto Avanzato June 2024.**
https://agenda.infn.it/event/42143/contributions/237797/attachments/122532/179379/04_02_VirgoVacuum_ET_13_06_2024_Lasar2.pdf
Also the joining method employed by RAL and GEO600

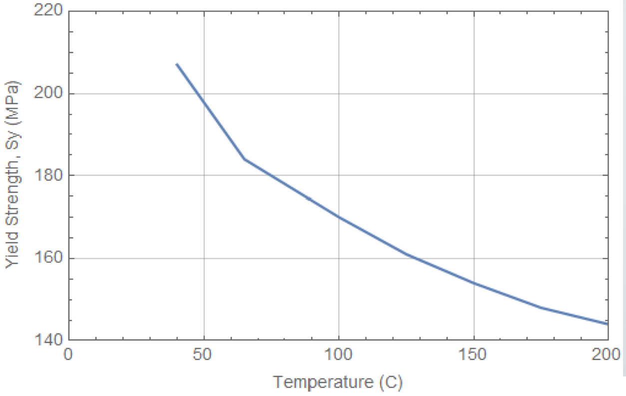




Welded Lip Joint

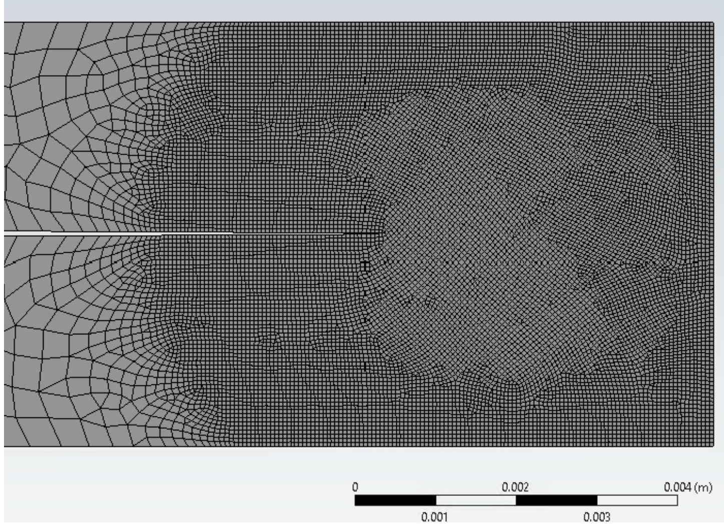
- Thermal expansion during a bakeout of a corrugated tube adds axial compressive loading
- Countered by the external atmospheric pressure when evacuated
- During normal operation the vacuum-induced axial tension load should not exceed the capacity of the fixed support stands
- LIGO BT Fixed Support maximum axial load is ~30 kN (a soft/suggested limit for CEBEX)
- The allowable stress for 304 and dual rated 304/304L is 138 MPa up to 150C

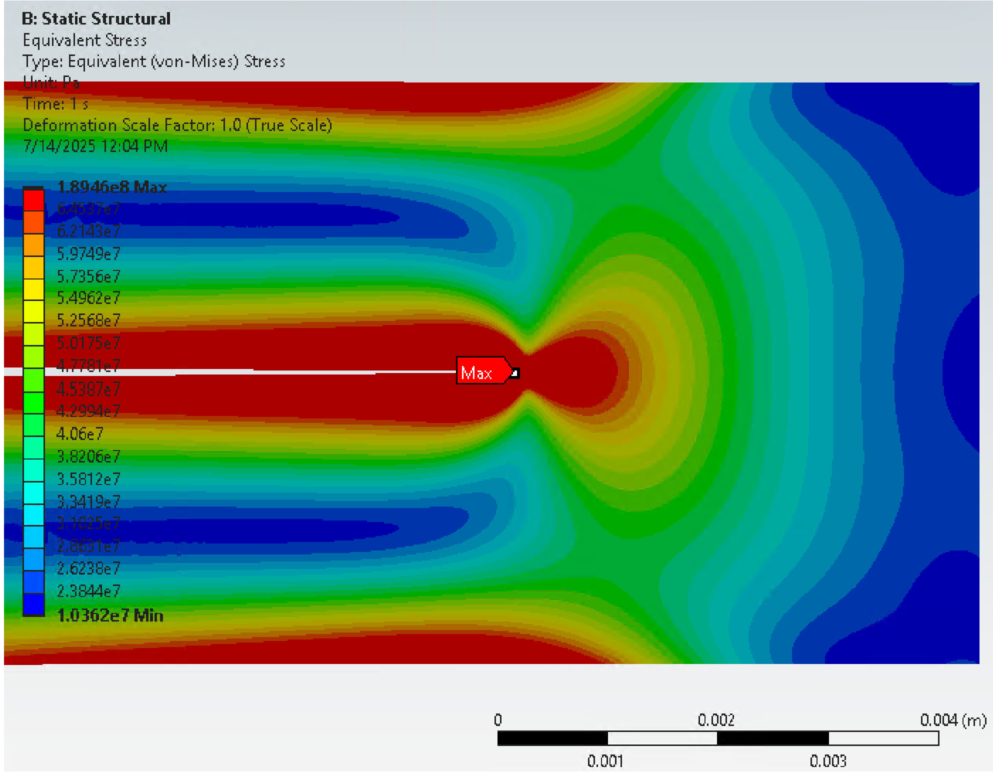




<u>Linear</u> Stress analysis of welded radial lip joint (2D, axisymmetric)

- As the mesh is refined a "singularity" at the “crack tip” becomes apparent (189 MPa)
- The material at the “crack tip” should yield and redistribute the stress …and the crack may grow

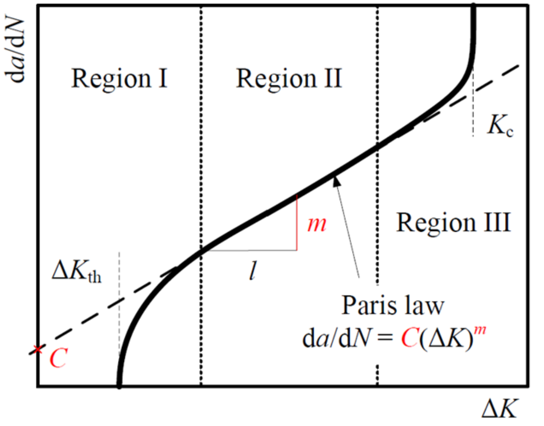




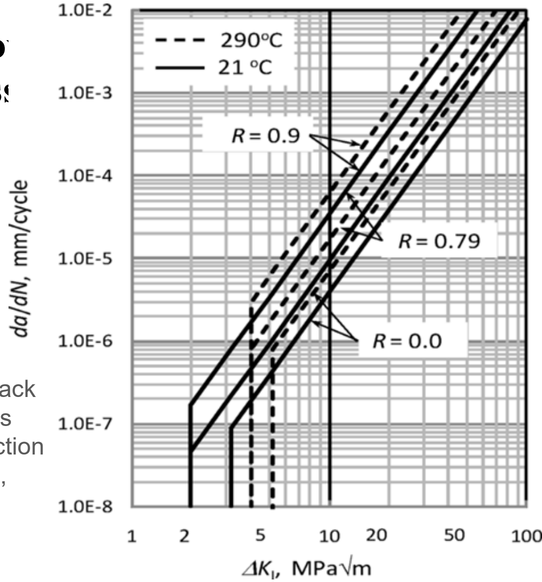
Crack propagation threshold

- Proposed addition (2018) of threshold stress intensity factors for ASME BPVC Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components"
- Ideally want K_I << 2 MPa √m
  - Otherwise must rely on crack cyclic fatigue lifetime calculation
  - … and hope stress field doesn’t promote UHV leaks

Paris’ law for crack grov per cycle (da/dN) as a function of Stress Intensi Factor (K)



Proposed fatigue crack gro rates for austenitic stainless steel exposed to air environment*

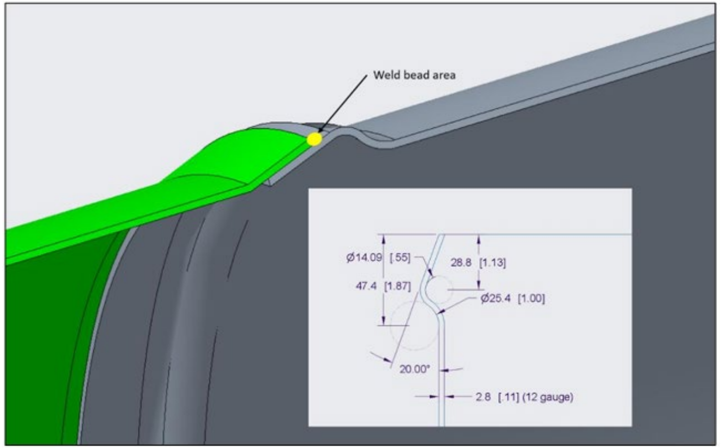


*Hasegawa, Usami, “Development of Fatigue Crack Growth Thresholds for Austenitic Stainless Steels Exposed to Air Environment for ASME Code Section XI”, J. of Pressure Vessel Technology, Jun 2018, Vol. 140

Welded Radial Lip Stress Intensity

- The stress intensity factor, K_I = 2.47 with a 20 mm high lip
  - > 2.0 MPa √m threshold for crack growth
- Could be reduced if:
  - Chosen corrugated design results in << 30kN axial force in operation
  - Can reduce the lip height (reduces bending stress), but this would only slightly decrease K
  - Could rely on long crack fatigue life but this seems risky/unwarranted
  - Could use a different material with higher threshold
    - However ferritic steel has ~same threshold
- Also not clear how much margin or safety factor we should have relative to this threshold value
- ∴ recommend using conical scarf joint

Stress Intensity Factor (K) contour integrals along the crack front - converge to 2.47 MPa √m
For lip height of 20 mm (beyond the bend radius)



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