Cosmic Explorer
Beamtube Experiment (CE-BEX):

Beam Tube Principal Cost Drivers

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

Caltech
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28-Sep-2025 v1

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LIGO-G2502099-v1

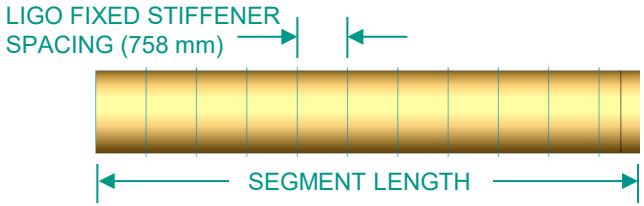
Scope

- Includes:
  - Beam Tube
  - Beam Tube Supports
  - design, materials, stiffening provisions, pump ports, supports, manufacturing, cleaning, transportation, and leak testing
- Does not include:
  - Baffles
  - Slab (foundation)
  - BT enclosure
  - BT insulation
  - BT vacuum bake
  - Vacuum equipment (gate valves, pumps, controls, gauges, etc.)
  - Overall management oversight, cost of money, etc.

Caveats & Sources

- Caveats
  - Based on 1994 cost data from CBI for the LIGO Beam Tube
  - While this data is "ancient", it may still provide relative measures of cost
  - In addition, this estimate (captured in a Mathematica notebook, LIGO-T2400377) may provide the template for updating to current cost information
  - Proper escalation would require different escalation factors for the various elements of the estimate – this has not been done
- Sources
  - LIGO-C1900321, “Final Design Review Data Package, Beam Tube Module: CDRL 09, DRD 04, Draft Detailed Design prepared by the contractor, CB&I
  - C-type documents in the LIGO DCC are generally restricted to LIGO Lab personnel, but can be made available to LSC and perhaps the public (TBD)
  - Document LIGO-T2400377 also compares the CB&I estimate to the LIGO cost book

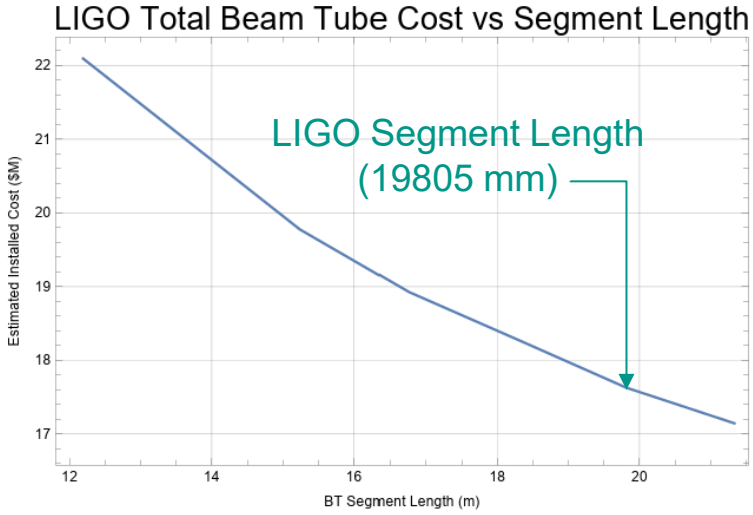
Tube Segment Length Impact on Cost (2 sites, 16 km, 1994 USD)

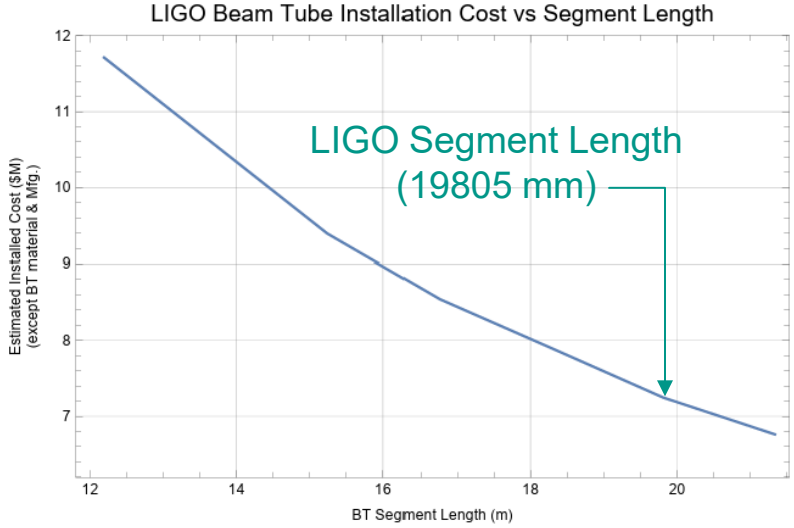


- Costs independent of tube segment length:
  - Coil mfg (average of 5 steel producers)
  - Spiral Welding manufacture
  - Stiffener costs (mfg and installation)
- Total Costs vs segment length:

- Install Costs dependent of tube segment length:
  - Short transport case (Portland, OR to Hanford, WA)

	40'	50'	55'	60'	65'	70'
Freight	74 714.5	59 956.1	71 930.3	74 928.7	72 741.9	91 927.6
Bellows	1 944 000	1 560 000	1 416 000	1 308 000	1 200 000	1 116 000
Supports	4 894 400	3 921 600	3 556 800	3 283 200	3 009 600	2 796 800
Tube Install	1 944 000	1 560 000	1 416 000	1 308 000	1 200 000	1 116 000
Leak Test	2 855 600	2 292 400	2 081 200	1 922 800	1 764 400	1 641 200





Tube Segment Length Impact on Cost (2 sites, 16 km, 1994 USD)

- Total Costs dependent of tube segment length:
  - Long transport case (Portland, OR to Livingston, LA)

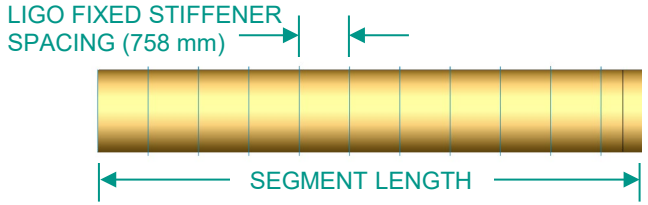
	40'	50'	55'	60'	65'	70'
Freight	4.3%	3.9%	4.8%	5.2%	5.2%	6.7%
Bellows	8.4%	7.6%	7.2%	6.8%	6.5%	6.1%
Supports	21%	19%	18%	17%	16%	15%
Tube Install	8.4%	7.6%	7.2%	6.8%	6.5%	6.1%
Leak Test	12%	11%	11%	10%	9.5%	9%
Stiffeners	4.4%	4.9%	5.1%	5.3%	5.5%	5.5%
Coil Mfg	24%	27%	28%	29%	30%	30%
Spiral Weld Mfg	17%	19%	19%	20%	21%	21%

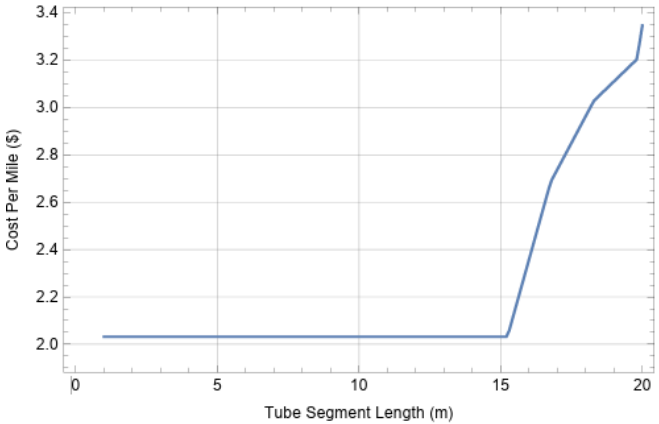
	40'	50'	55'	60'	65'	70'
Total Cost ($M)	23.0074	20.5084	19.8026	19.1943	18.5174	18.2669

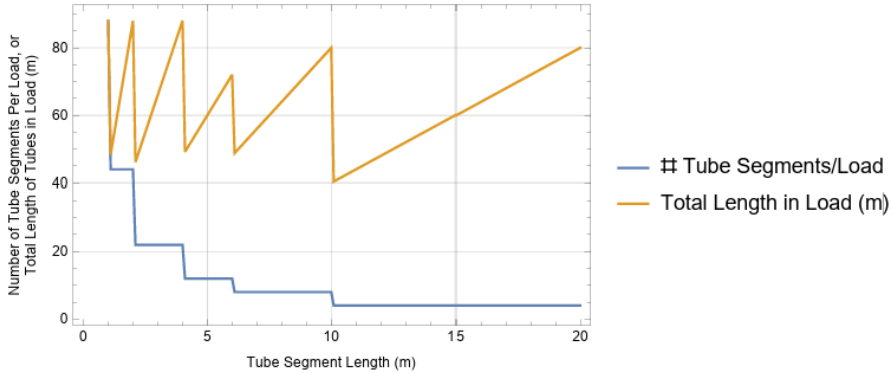
- Segment Lengths > ~20 m not considered because Freight costs rose dramatically

CE Cost (1994 USD) with LIGO Beamtube for varying tube segment length

- Freight
  - Heavy hauling (8.6x13.6x53 ft, <80,000 lb)
  - Packing density used to determine the number of transport loads:
    - > 4m long tubes, 2 rows x 2 levels)
    - ≤ 4m long tubes, stand up in 2 rows x 11

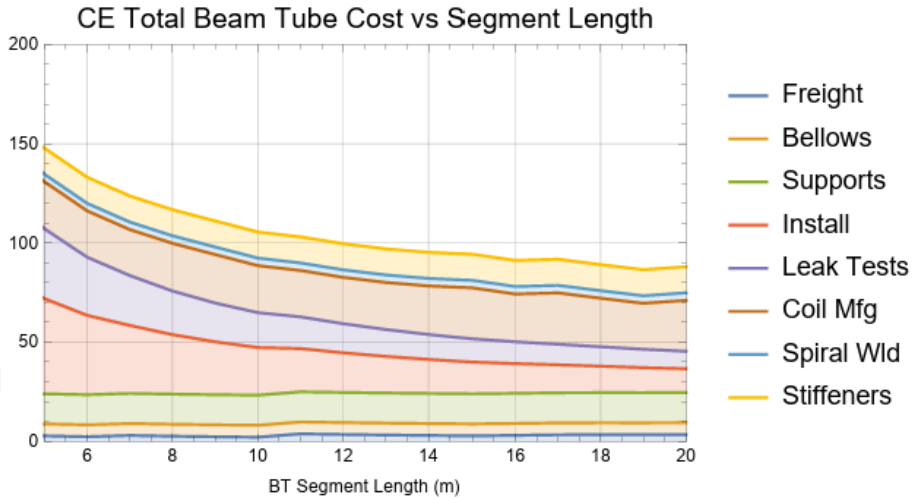






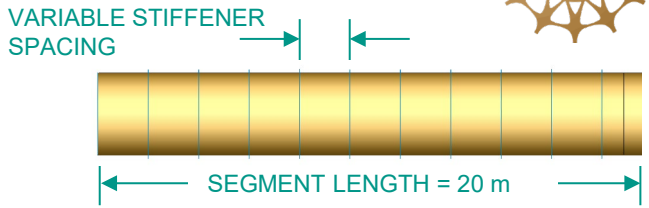
CE Cost (80 km, 1994 USD) with LIGO Beamtube for varying tube segment length (concluded)

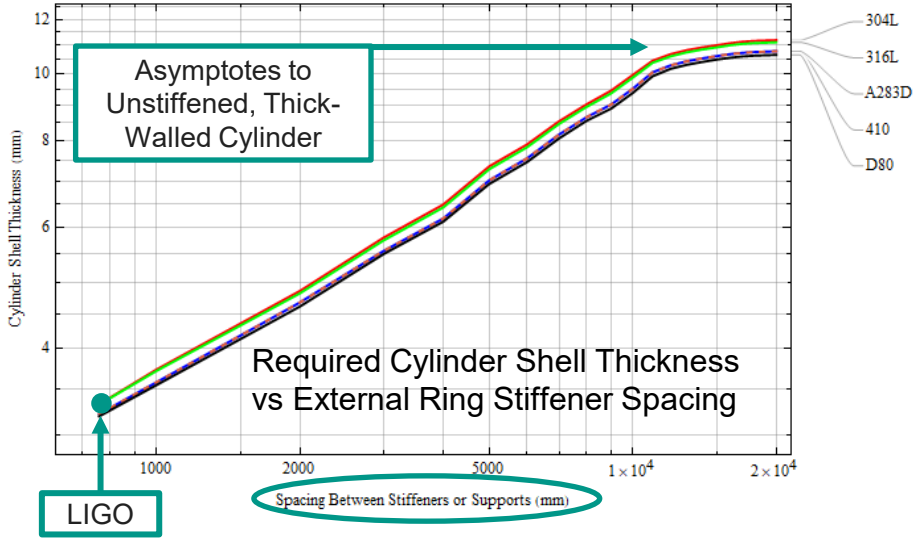
- Bellows (EJ)
  - In principle the EJ could be designed to handle the displacement of multiple BT segments, or optimized for shorter BT segments
  - I've estimated the number of EJs on the assumption that each EJ handles 40 m of tube
- Supports: Assumed 1 fixed & 1 guided support per EJ
- Pump Ports: Simply scaled by (CE Length)/(LIGO Length)
- Coil Mfg Costs (avg. of 5): coil material (304L), transport to/from bake facility, bake, transport to/from finishing mill, outgas test, level, slit, transport to tube mfg, less cost of 10% scrap steel
- Spiral Mill Costs (avg. of 3):
  - not quoted as a function of segment length
  - shorter segments would cost more due to the need to make more transverse cuts
- Stiffeners: material, fabrication, welding costs

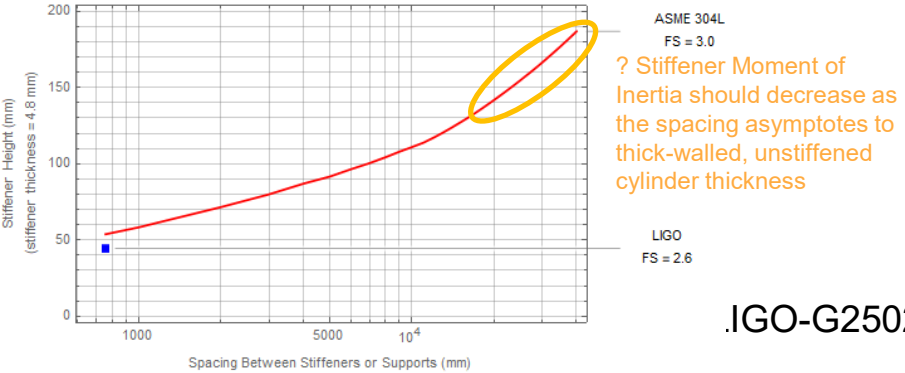


CE Cost (80 km, 1994 USD) with LIGO Beamtube for varying tube stiffener spacing

- Cylinder thickness and stiffener height (MOI) increases as stiffener spacing increases per ASME 2023.BPVC.VIII, Division 1
- Costs independent of stiffener spacing: Tube segment freight, Bellows, Supports, Leak Tests, Pump ports, Tube installation
- Assuming cylinder is formed by spiral welding (thick-walled is more likely slip rolled?)
- Assuming each 304L coil weight remains the same
- Stiffener
  - Material costs scaled by stiffener weight
  - Welding cost assumed constant per stiffener







? Stiffener Moment of Inertia should decrease as the spacing asymptotes to thick-walled, unstiffened cylinder thickness

CE Cost (80 km, 1994 USD) with LIGO Beamtube for varying tube stiffener spacing (concluded)

- The CB&I (LIGO) design seems optimal for a 304L ring-stiffened cylinder
- Corrugation fabrication cost (currently unknown) is offset by ~34% of baseline total
  - Stiffener cost of ~13.6%
  - Bellows cost of ~6.2%
  - Shell thickness reduction from 3.23 mm (LIGO) to 2.78 mm (CEBEX RFI) represents a cost of ~13.9%