Summary: NSF Workshop on Large Ultrahigh-Vacuum Systems for Frontier Scientific Research Instrumentation*

LIGO Livingston Observatory, Livingston, LA, USA
January 29-31,2019

Workshop co-chairs: H.F. Dylla (MIT/LIGO Consultant), R. Weiss (LIGO/MIT) and Michael Zucker (LIGO/MIT)

* Supported by the US National Science Foundation

"Blue Sky" Large Ultrahigh Vacuum Workshop

- Goals - examine vacuum design concepts & technologies to aid detailed design & engineering studies for the Cosmic Explorer[2] and Einstein Telescope[3] projects
  - associated benefits to other frontier fields; i.e., accelerators
- Held at LIGO Livingston on January 29-31, 2019; 38 attendees
- Sponsored by NSF & Caltech/MIT LIGO Lab
- Proceedings available[1] @ https://dcc.ligo.org/**LIGO-P1900072**/public

Credit: LIGO, LLO

Workshop Working Groups

1. Conventional single-wall vacuum systems

   - Cost reduction options of single wall beamtube technology and material options

2. Non-conventional vacuum technology

   - Cost reduction options including nested vacuum tubes with thin, bakeable, UHV shell inside robust outer wall

3. Novel surface treatment for conventional and UHV materials

   - Surface modifications and coatings to meet UHV and optical requirements

4. Vacuum pumping for conventional and nested systems

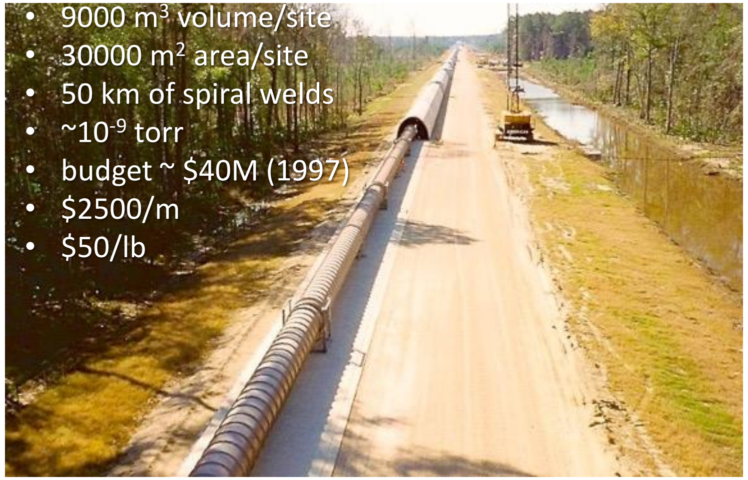
   - Pumping schemes and scenarios for obtaining UHV for both conventional single wall and nested vacuum vessels

WG1: Single Wall Beamtubes

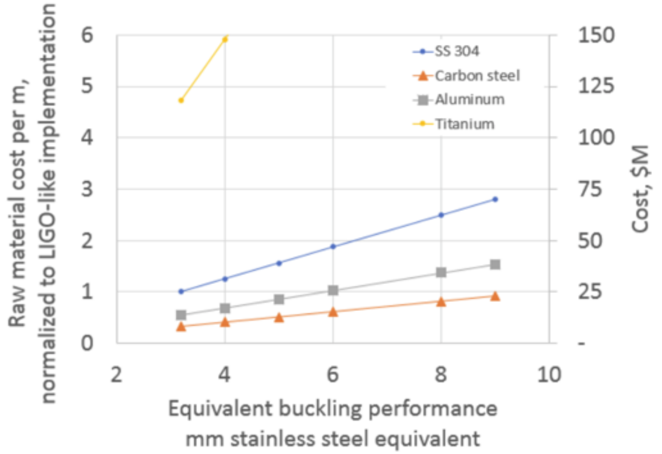
Chairs, C. Baffes (FNAL) & D. Henkel (Material Forensics)

- Material evaluation
  - 304L SS well understood
  - Al offers low H_2 outgassing and relatively low cost; dissimilar metal welding a challenge – ~4000 bellows w/40 mm stroke for 120C bake
  - Mild steel lower cost alternative offering low H_2 outgassing through Ruhrstahl-Hausen processing
- Fabrication Techniques
  - Spiral vs longitudinal welding
  - Seamless and Al extrusion
  - Explosion bonding vs hot isostatic pressing vs adhesive bonded transition
- Surface & Bakeout
  - Reflective surface bad; smooth surface good
  - 100C bakeout via iterative traveling 'hot tent' and ppb ultra dry viscous air flow – no isolation valves needed

LIGO Beamtube



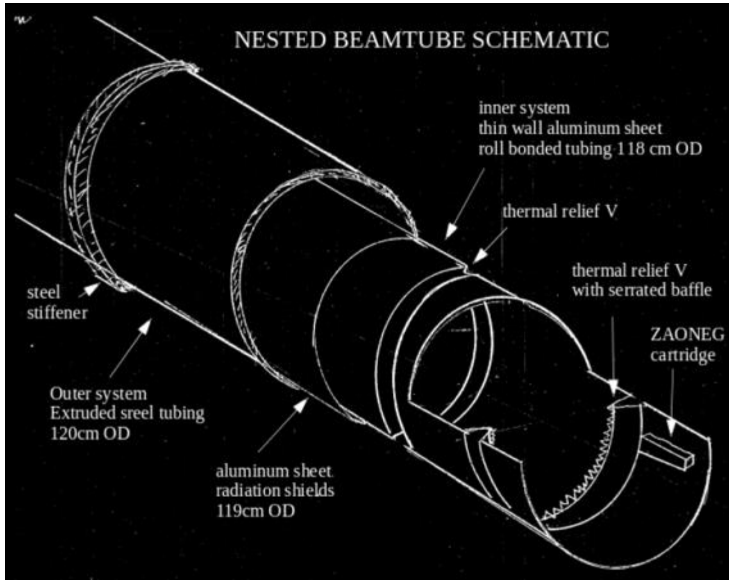
Credit: LIGO,LLO

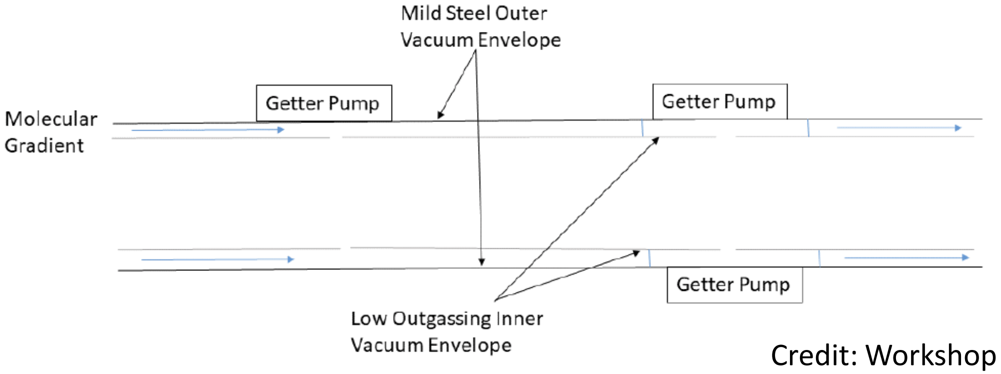


Credit: Workshop Report, Ref.1

WG2: Nested Beamtubes, Chairs: J. Noonan (ANL) & D. Manos (W&M)

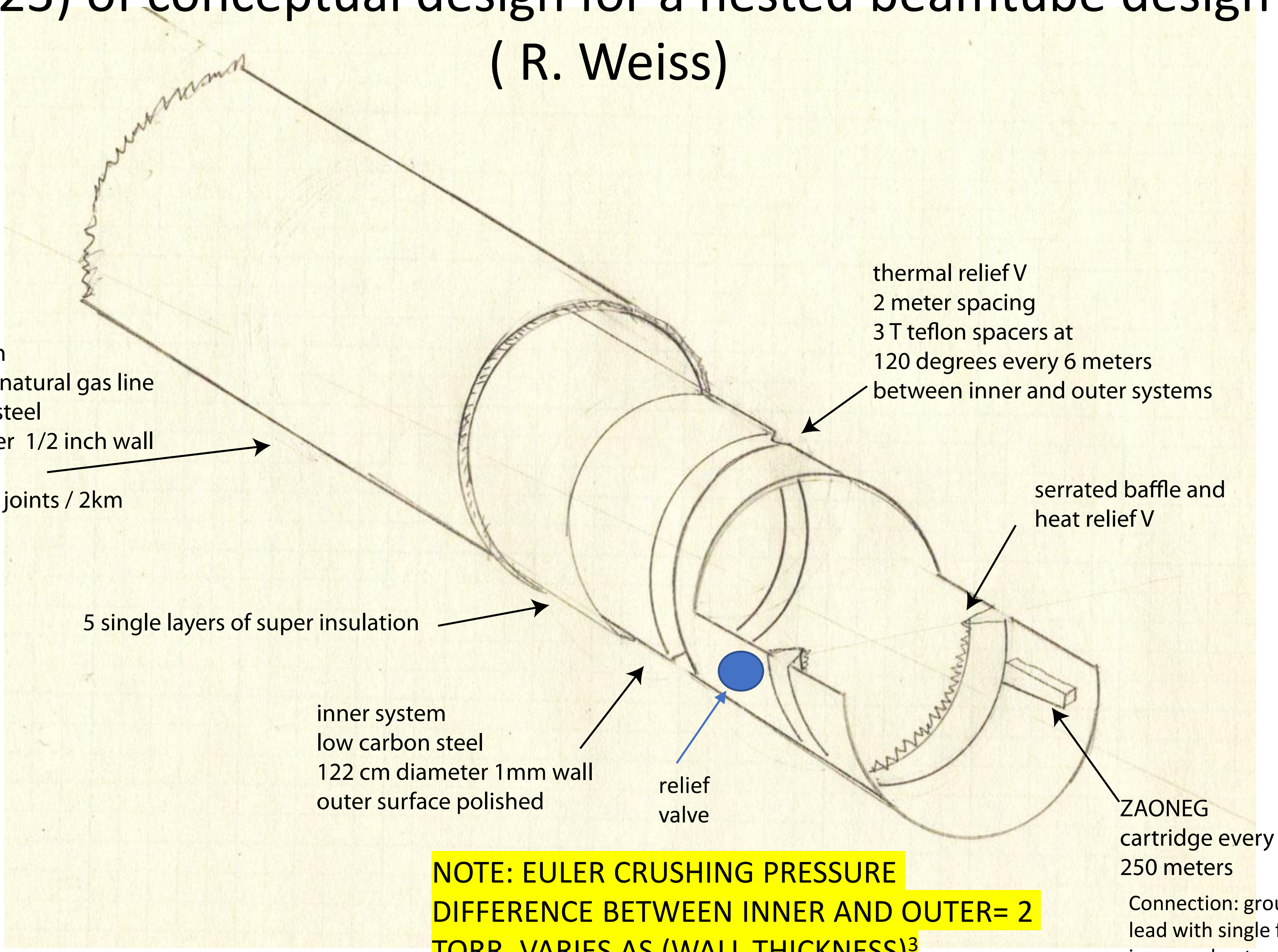
- Nested design conceived by R. Weiss (Vers. A)
- Concentric tubes
  - Thin, bakeable inner shell ½-1.5 mm thick Al with vibration dampening
  - Robust outer tube holds rough to HV; mild steel or FRP
  - Sealed or shared volumes
  - Annulus or soft sealing valves/shutters
- Still a viable option; trades complexity in design with simplicity of bakeout and leak detection





Credit: Workshop Report,Ref.1

Vers. B (2023) of conceptual design for a nested beamtube design
(R. Weiss)

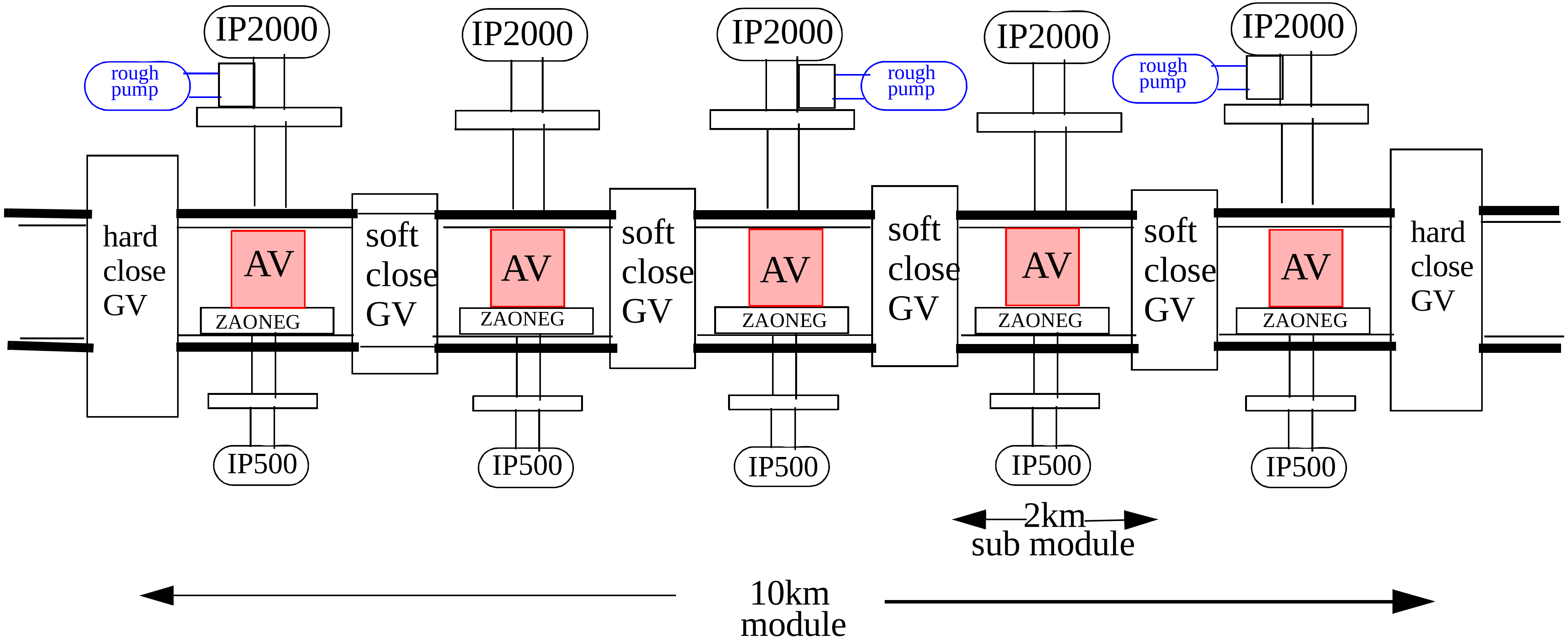


Credit: R. Weiss, MIT,2023

NOTE: EULER CRUSHING PRESSURE DIFFERENCE BETWEEN INNER AND OUTER= 2 TORR, VARIES AS $(\text{WALL THICKNESS})^3$

Connection: grounded to inner shell hot lead with single feedthroughs through both inner and outer systems

Basic 10 Km Module Schematic for Vers. B design (R. Weiss)



Credit: R. Weiss, MIT,2023

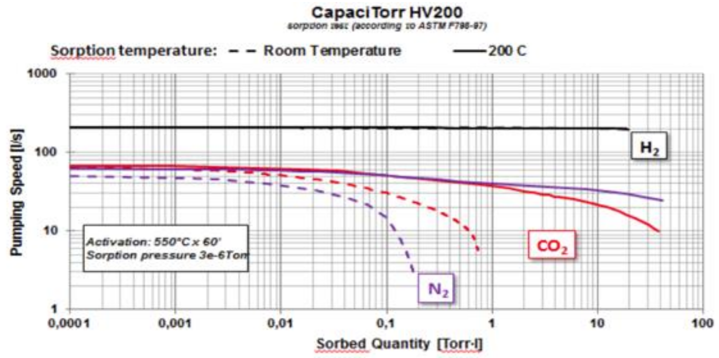
WG3: Novel Surface Treatments, Chairs, J. Fedchak (NIST) & J. Feicht (LIGO)

- Vacuum degassing at foundry reduces H_2 in mild steel[4]
- Magnetite (Fe_3O_4) on mild steel to prevent corrosion
- 1 µm TiN coating on SS to minimize water adsorption[5]
- Diamond-like carbon (DLC) coating
- Amorphous silicon (a-Si)
- Electrochemical conversion for low-reflection surface (blue/black surface)
- UV light sources and ozone considered
- Dry purge cleaning and “cycle purge” method
- NIST will perform outgassing measurements using SRG technique of mild steel and TiN, DLC coated chambers

WG4: Vacuum Pumping, Chairs, Y. Li (Cornell) and P. Chiggiato, (CERN)

- 40 km sectored into 10 km segments for independent pump down
- 10 km segments reduced to 2 km sections for installation intervals and bake out
- Automated venting for nested system to avoid buckling
- Rough to 10^{-2} Torr → turbo to 10^{-5} Torr → cryopumps or ZAO NEG+IP to trap $H_2 0$ during bake
- Ne-He cryo cycles to condense N_2, O_2, Ar
- Ti sublimation pumping for distributed getter pumping
- Pump interval ~ 250 m during bake and 1000 l/s per 1 km during operation
- Pressure gauges every 100-250 m to localize leaks

(Data Credit: SAES)



Path Forward [as projected in March 2019]

- Carry single wall and nested beamtube concepts to next level of detailed design, engineering, and cost studies
- Consider mild steel alloys and Al in addition to SS, detailing surface treatment, coatings, and material transitions
- Study best options for outer vessel material in nested system
- Quantify TiN, DLC, a-Si, Fe_3O_4 coating effectiveness for H_20 adsorption, scale and particulate, welding interference, and optical characterization
- Collaborate with NIST, JLab, and CERN on outgassing studies
- Follow-up workshop was planned for April 2020 at CERN:
  - Research agenda layout for short-term R&D to quantify cost-benefit of material choices and surface treatments identified

Path Forward [suggestions for this workshop and ahead]

- Carry single wall and nested beamtube concepts to next level of detailed design, engineering, and cost studies
- Consider mild steel alloys in addition to SS, detailing surface treatment, coatings, and material transitions
- Conceptual designs for novel valves: soft close and annular
- Quantify Fe_3O_4 coatings on mild steels (and others?) for H_20 adsorption, scale and particulates, and optical characterization
- Expand worldwide collaboration as design efforts for ET and CE proceed

Acknowledgements

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- Thanks to all attendees of the 2019 "*Large Vacuum Workshop*" with special thanks to the co-chairs for leading working groups and composing reports.
- Thanks to Paolo Chiggiato who helped organize international teleconference calls at typical bimonthly intervals from 2021-2023 to keep the collaboration moving forward that was initiated by the 2019 NSF "Large Vacuum" workshop at the LIGO Livingston site.

References

1. H. F. Dylla, R. Weiss, M. E. Zucker (eds), *NSF Workshop on Large Ultrahigh-Vacuum Systems for Frontier Scientific Research Instrumentation*, LIGO Livingston Observatory , Livingston, LA, USA, January 29-31,2019; see https://dcc.ligo.org/public/0158/P1900072/001/P1900072-v1.pdf

2. The Cosmic Explorer: http://www.cosmicexplorer.org

3. The Einstein Telescope: http://www.et-gw.eu

4. C. Park, T. Ha, and B. Cho, JVST **A34**, 021601 (2016).

5. Y. Saito, Y. Ogawa, G. Horikoshi, N. Matuda, R. Takahashi, and M. Fukushima, Vacuum **53**, 353 (1999).