Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

Traveling wave SRF cavity status and R&D plan

Vyacheslav Yakovlev, *et al.*

May 16, 2023

The 2023 International Workshop on Future Linear Colliders (LCWS2023)

Session

Accelerator: Superconducting RF

LCWS2023

INTERNATIONAL WORKSHOP ON LINEAR COLLIDERS

On behalf of SRF TW collaboration:

P. Avrakhov [1], A. Kanareykin[1], R. Kostin[1], S. Belomestnykh[2], F. Furuta[2] , S. Kazakov[2], G. Romanov[2], N. Solyak[2], T. Khabiboulline[2], G. Wu[2], V. Yakovlev[2], J. Rathke[3], H. Padamsee[4], V. Shemelin[4]

[1]Euclid Techlabs LLC, Rockville, MD
[2]Fermilab, Batavia, IL
[3]AES Inc, NY
[4]Cornell University, Ithaca, NY

Outline

- Introduction
- Advantages of TW
- Challenges for TW structure
- One-cell cavity with feedback waveguide
- 3-cell TW cavity status
- R&D plans
- Summary

Introduction

Present Limits of SRF:

- The Standing Wave (SW) TESLA Niobium-based structure is limited to a gradient of about 50 MV/m by the critical RF magnetic field (200 – 210 mT).

- Advanced shape cavities will be limited by the critical RF magnetic field to about 60 MV/m

  Re-entrant, Low-Loss, Ichiro, Low Surface Field

  For advanced shape, we lower *Hpk/Eacc* (by10-20%)

  but we raise *Epk/Eacc* (15-20%)

- How to break through the gradient barrier with Niobium?

- **Explore the option of Niobium Traveling Wave (TW) structures**

Advantages of TW Structures

- ❑ Travelling wave improves transit time factor and therefore allows lower <u>BOTH</u> B_{pk}/E_{acc} and E_{pk}/E_{acc}
  - RF power returns not through the accelerating structure (to form a standing wave with harmful peaks), but through a separate feedback Nb waveguide

- ❑ Travelling wave cavities operate at maximal group velocity in contrast to SW operating at zero group velocity, and therefore allow
  - Longer cavities → smaller gaps between cavities → higher average gradient;
  - Smaller aperture → additional increase in gradient because smaller B_{pk}/E_{acc} and E_{pk}/E_{acc}
  - Field profile tuning easier,

- ❑ Travelling wave $\pi/2$ structures offer higher G**R/Q* → lowers Cryo power.

- ❑ By choosing the Low-Loss cell shape + reduced aperture it is possible to lower B_{pk}/E_{acc} by 48% over the TESLA structure!

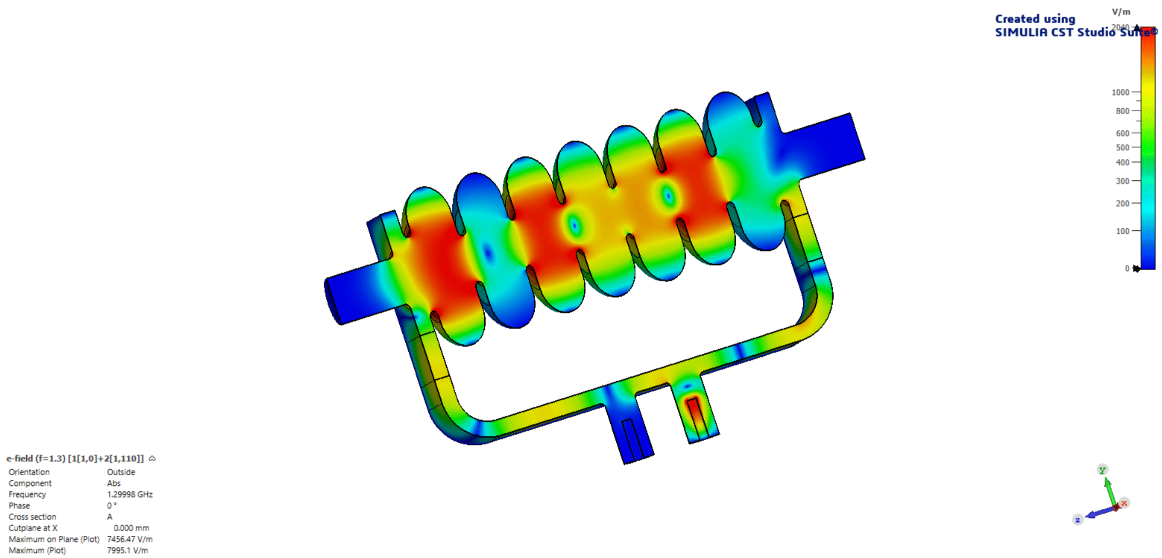
- ❑ **Opening the door to E_{acc} > 70 MV/m !!**

Advantages of TW Structures (cont)

- ❑ Smaller aperture (see above) is allowed because bunch charge for 3 TeV ILC upgrade will about 3 X less to get acceptable IP background…

- ❑ Putting SRF on the Road to ILC – 3 TeV with Niobium

- ❑ No need to struggle with exotic new superconductors or overlayers



Challenges for TW Structures

- ❑ Requires twice the number of cells per meter to provide the proper phase advance (about 105 degrees)

- ❑ Cavity fabrication and surface processing procedures and fixtures must deal with (roughly) double the number of cells per structure.

- ❑ A feedback waveguide for redirecting high power from the end of the structure back to the front end of accelerating structure.
  - The feedback requires careful tuning to compensate reflections along the TW ring to obtain a pure traveling wave (a special “matcher “ in addition to a main tuner to reach partial standing wave degeneracy)

Path for TW cavity for ILC

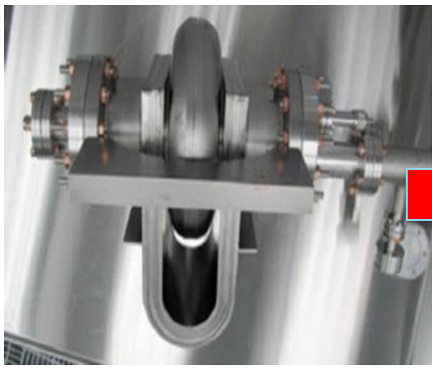
❑ General studies:

- New approach of multi-parametric optimization developed, which takes into account both maximally possible fields, *E* and *H*.
- Optimization shows that TW structure can have the accelerating gradient above 70 MV/m with the same critical magnetic and electric fields that in the SW structure.
- No multipactor in the cavity and in a feedback waveguide
- No cavity length limitation by a coupling between cells
- Tuning and “matching” (achieving of travelling wave) procedures are developed
- High-power coupler concept is developed
- TW RF diagnostics is developed

Path for TW cavity for ILC

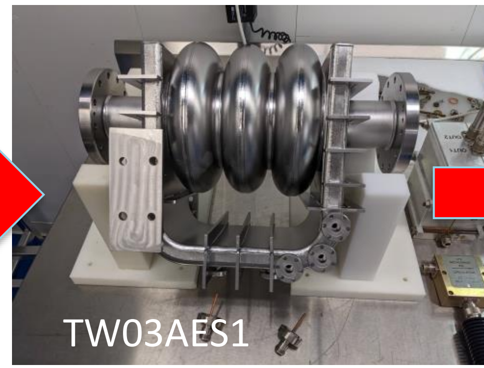
❑ Strategy of technology development for TW: step-by-step approach

HG tests of a single cell cavity with feedback WG*:



- Designed, manufactured (**AES**), processed;
- Reached 26 MV/m with inferior (easier) treatment of BCP

HG tests of a 3- cell TW cavity with feedback WG*:



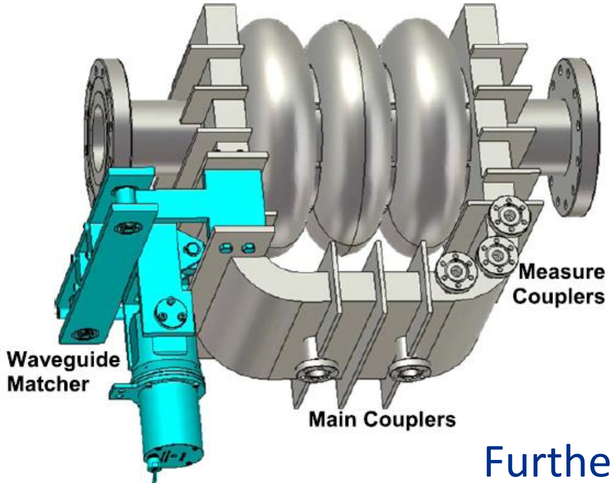
- Designed, manufactured (**AES**), processed (BCP);
- Tuning is in a process
- HG tests are scheduled for summer 2023

HG tests of a 0.5 m- long TW cavity with feedback WG, HP couplers, tuners and diagnostics (in collaboration with Cornell):

- The cavity cell RF optimization is **OK**
- Cavity-WG transition RF design is **OK**
- TTF-III HP coupler are supposed to be used.
- He vessel design – not started yet
- Tuners design – not started yet

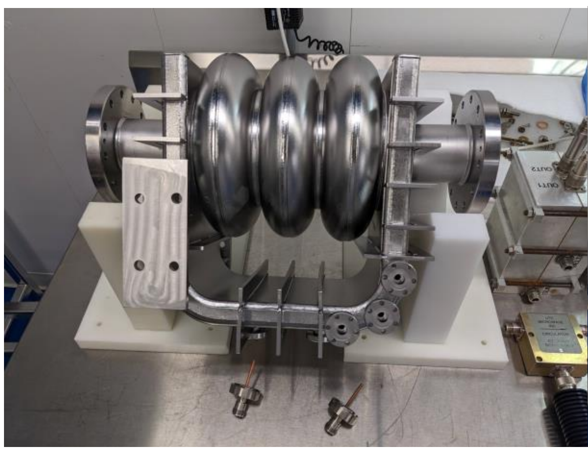
*Euclid Techlabs DOE SBIR DE-FG02-06ER84462 and DE-SC0006300.

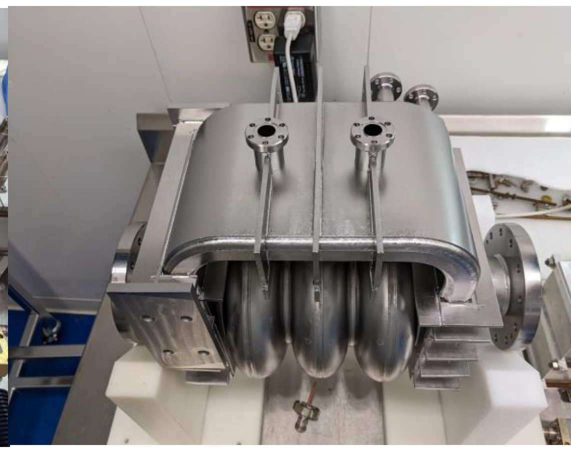
Status of the 1.3 GHz, 3-cell TW cavity HG tests:

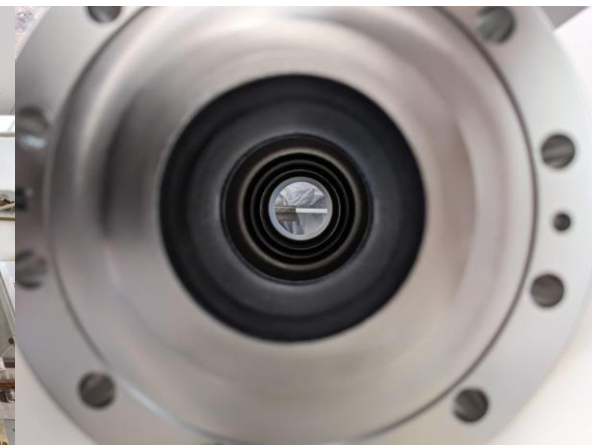


Cavity Parameters	TTF	LL60	RE70	STWA-105°
Aperture, mm	70	60	70	60
$k_{cc}(*)$, %	1.9	1.52	1.57	3.35
E_{peac}/E_{acc}	2.0	2.36	2.4	1.94
H_{peac}/E_{acc}, mT/(MV/m)	4.15	3.61	3.78	3.05
R_{sh}/Q, Ω	1036	1206	1140	1808
GR_{sh}/Q, Ω^2	30800	37970	33762	39075

Further optimization has been performed - H. Padamsee, et all, SRF21



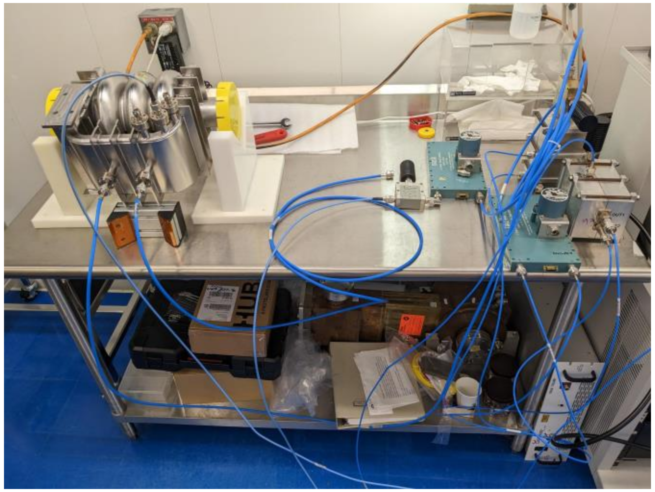


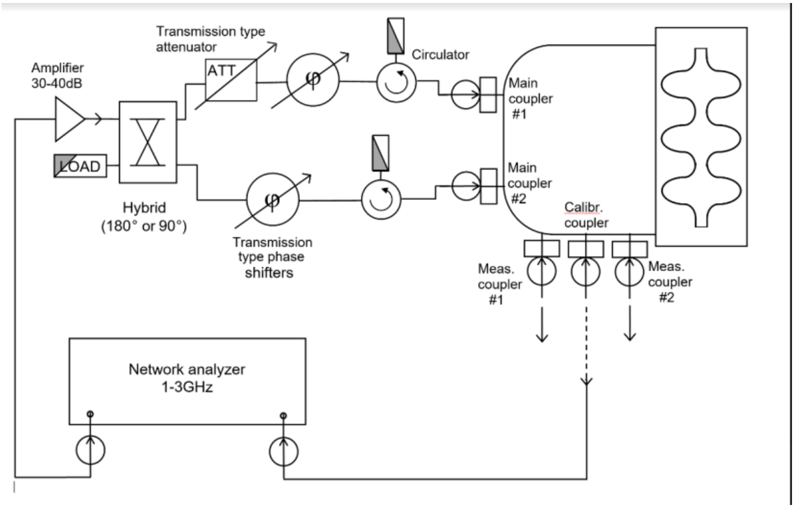


- The cavity – OK
- The “matcher” -OK
- Diagnostics – OK
- The input couplers - OK
- Processing fixtures – OK
- The cavity processing* - OK

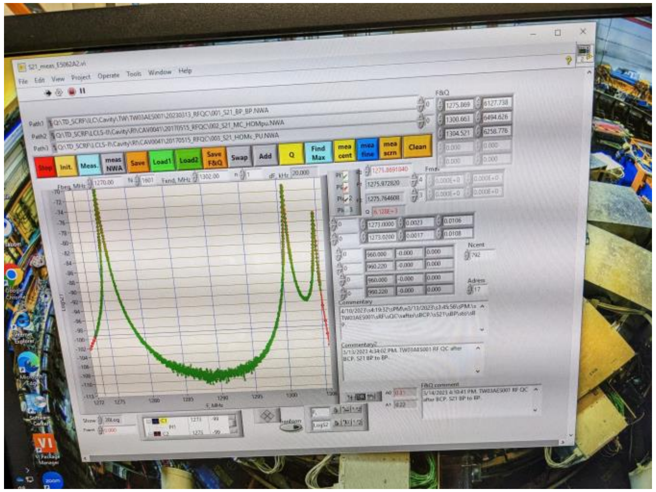
*120um rotational BCP, 800c bake, external BCP to remove oxides

3-cell TW cavity tests. RF measurements





Setup 1



3 modes

3-cell TW cavity tests. RF measurements

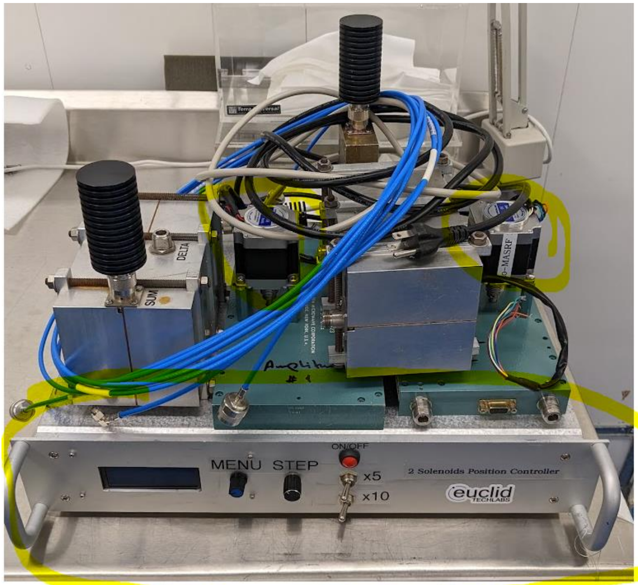
date	mode 1	mode 2	mode 3	mode 4	mode 5	mode 6	BCP	Temp	Vac/Air	Ribs
Fsol CST				1284	1302.1	1302.1	N	RT	Air	-
Fsol CST				1281.54	1297.9	1301.7	BCP	RT	Air	-
Fsol CST				1283.9	1300.82	1303.8	BCP	COLD	VAC	-
HFSS Eigen		1037.1	1165.32	1274.28	1301.17	1301.24	N	RT	Air	-
CST Eigen	961.785	1037.3	1165.45	1274.23	1301.03	1301.19	N	RT	Air	-
CST Eigen	**959.692**	**1035.23**	**1163.27**	**1271.26**	**1298.83**	**1299.03**	**BCP**	**RT**	**Air**	**-**
CST Eigen	961.376	1037.05	1165.31	1273.49	1301.1	1301.33	BCP	2K	Vac	-
2016		1044.5	1173.65	1277.91	1303.47	1305.77	N	RT	Air	N
9/23/2022	968.192	1038.59	1166.26	1277.78	1302.16	1305.68	N	RT	Air	Y
3/14/2023				1275.87	1300.67	1304.52	BCP	RT	Air	Y
4/10/2023				1275.73	1300.52	1304.42	BCP	RT	Air	Y

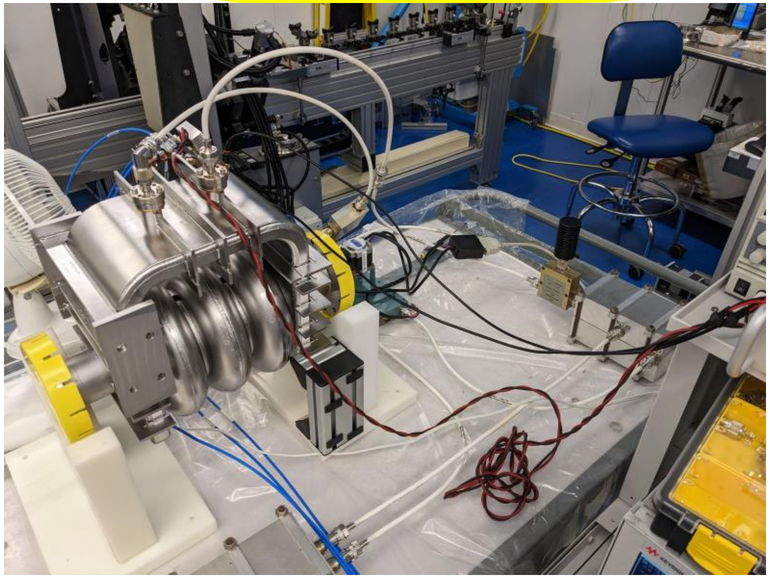
Fermilab

3-cell TW cavity tests. RF measurements

New setup

- New short cables
- Actuated phase shifters by EUCLID control box and stepper motors

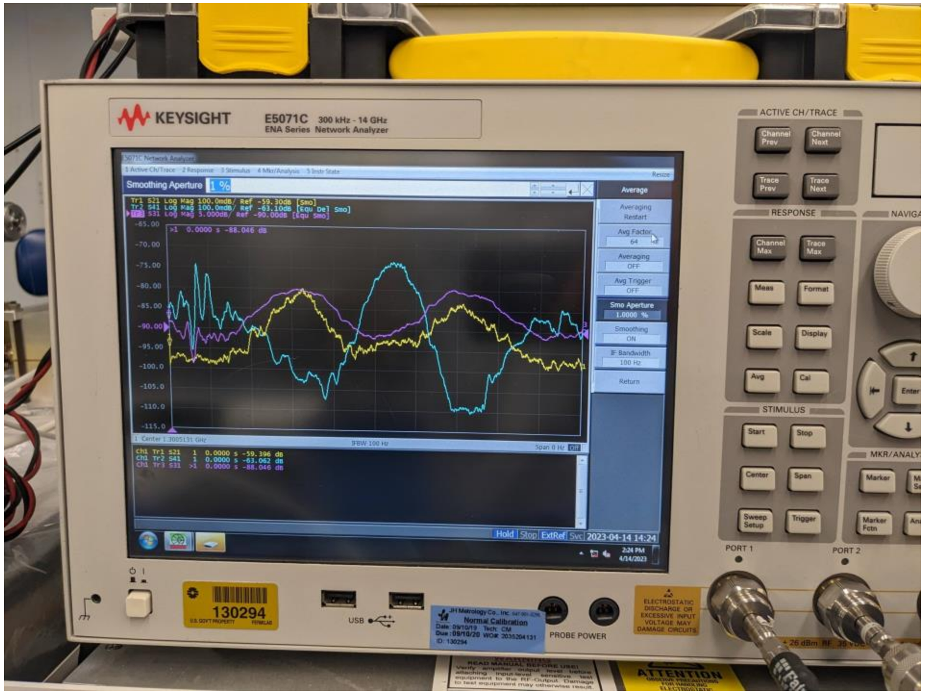




Fermilab

3-cell TW cavity tests. RF measurements

- ❑ Yellow – clear signal from middle
- ❑ Blue and Magenta – FW and BW
- ❑ Mathcad model predicts similar behavior:
  - FW changes both directions following phase
  - BW only on and repeats SW signal.

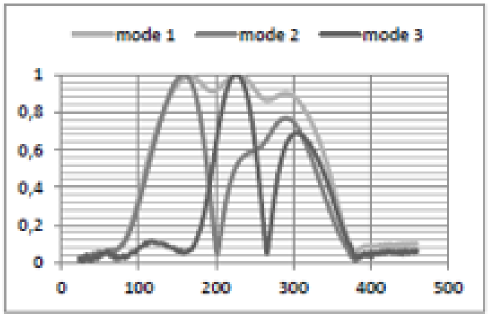


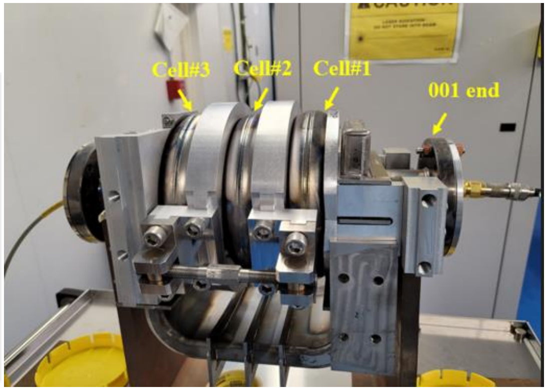
3-cell TW cavity tests. RF measurements

Tuning SW to get symmetrical distribution of TW03AES1

- First attempt
  - Push cell3 by 20kHz
  - Negative frequency shift expected but behaved opposite
  - Frequency increased anc field in cell 3 increased
- Second attempt
  - Push cell 2
  - Same opposite behavior
- Problem with tuning split ring discovered (next slide)

TW03AES001

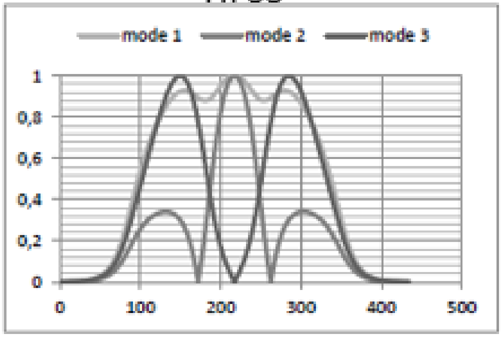




a

б

HFSS



в

3-cell TW cavity tests. RF measurements

Tuning fixture problem

- Split rings should contact the cavity close to the stiffening ring to deform the length
- In our case the point of contact is at the equator and cavity shape is deformed. The cavity is more rigid there.
- New split rings have been designed and fabricated.
- Tuning is continuing.

Further R&D plans

❑ Nearest plan:

- Complete the 3-cell cavity tuning – field flatness and TW (May-June 2023)
- Demonstration of a HG TW in the 3-cell cavity at VTS (summer, 2023)
- Achieving maximal acceleration gradient in this cavity (fall and winter 2023)

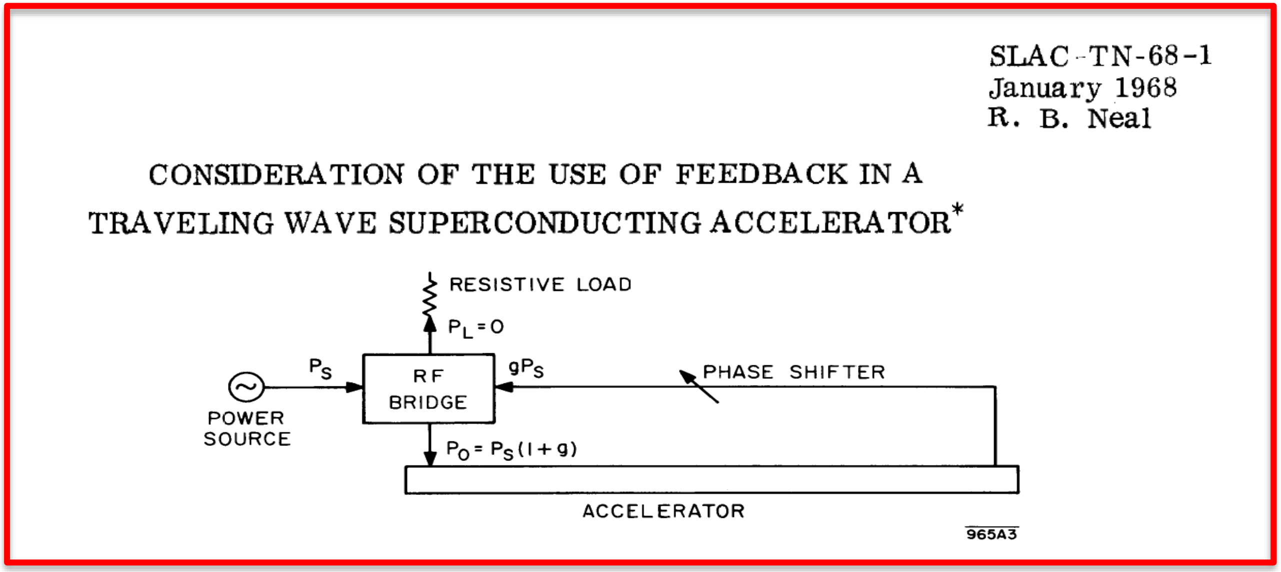
❑ Further development:

- Design of the 0.5 m long TW SRF structure and its components including
  - The cavity;
  - Tuners (the main tuner and the "matcher");
  - He vessel
  - Diagnostics probes
- Manufacturing, processing and HG tests of the bare TW cavity (3 years).
- Manufacture and tests of the dressed cavity with the main tuner and TTF-III couplers.

Summary

- TW Nb cavity with feedback waveguide potentially may allow acceleration gradient up to 70 MV/m
- R&D plan includes step-by –step experiments from a one-cell cavity with the feedback WG to a full –scale cavity.
- One-cell SRF cavity with the feedback WG is successfully designed, manufactured and tested, that showed the possibility of the feedback WG processing.
- Basing on this experiment the next step is planned: a 3-cell TW SRF cavity, which should demonstrate a HG TW wave in a SRF cavity.
- The 3-cell cavity and its components are designed and manufactured.
- The cavity is processed and under the tuning.
- The HG tests are scheduled for summer 2023.
- The next step – 0.5 m long TW SRF structure is under design .

❑ TW SRF cavity has a long story


SLAC-TN-68-1
January 1968
R. B. Neal

CONSIDERATION OF THE USE OF FEEDBACK IN A TRAVELING WAVE SUPERCONDUCTING ACCELERATOR*

❑ and, we are sure, a bright future!

MANY THANKS!