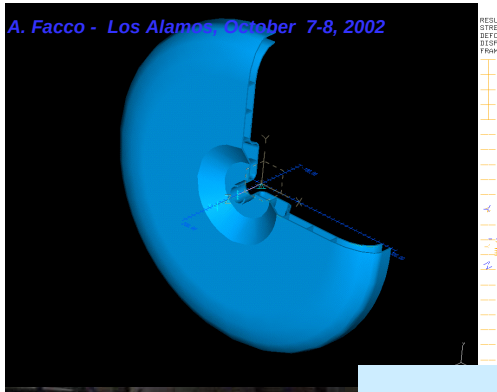
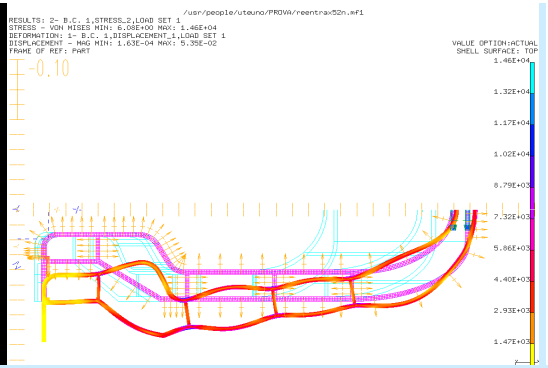
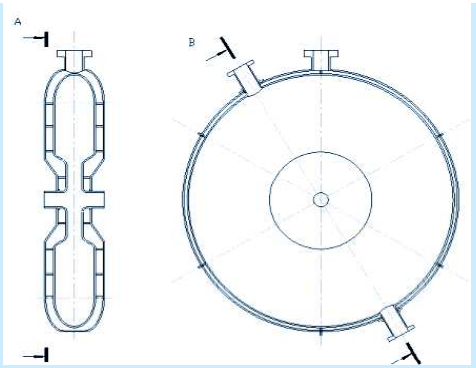
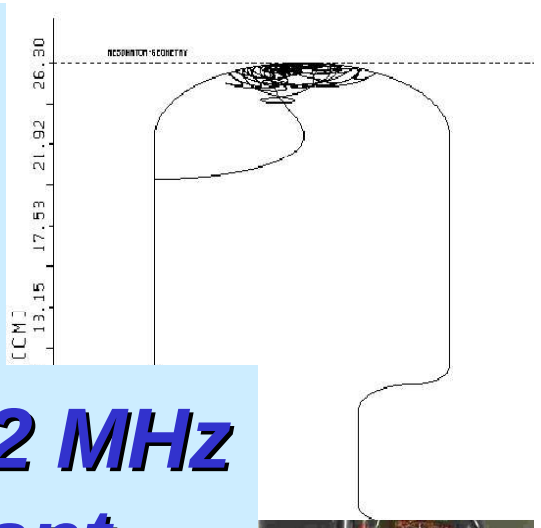
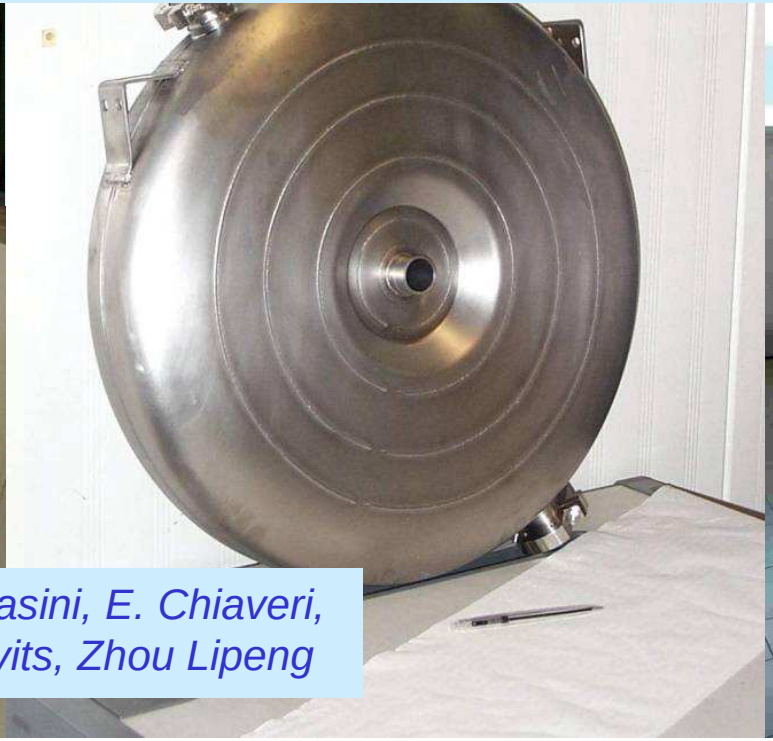








Development of a low-β, 352 MHz Superconducting Reentrant Cavity at LNL



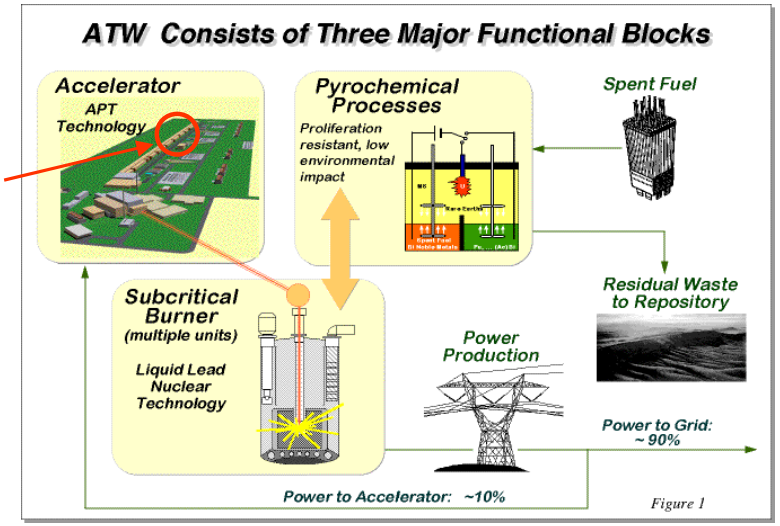
A. Facco, V. Zviagintsev, M. Pasini, E. Chiaveri, R.Losito, F. Scarpa, D. Berkovits, Zhou Lipeng

Introduction

- We are developing low-β superconducting cavities for ADS applications (TRASCO)
- The TRASCO accelerator is a 1 GeV, 30 mA proton linac
- The intermediate energy part, 5-100 MeV, works at 352 MHz

- Important constraint: ADS systems with sub-critical reactors do not tolerate beam interruptions longer than ~1 s

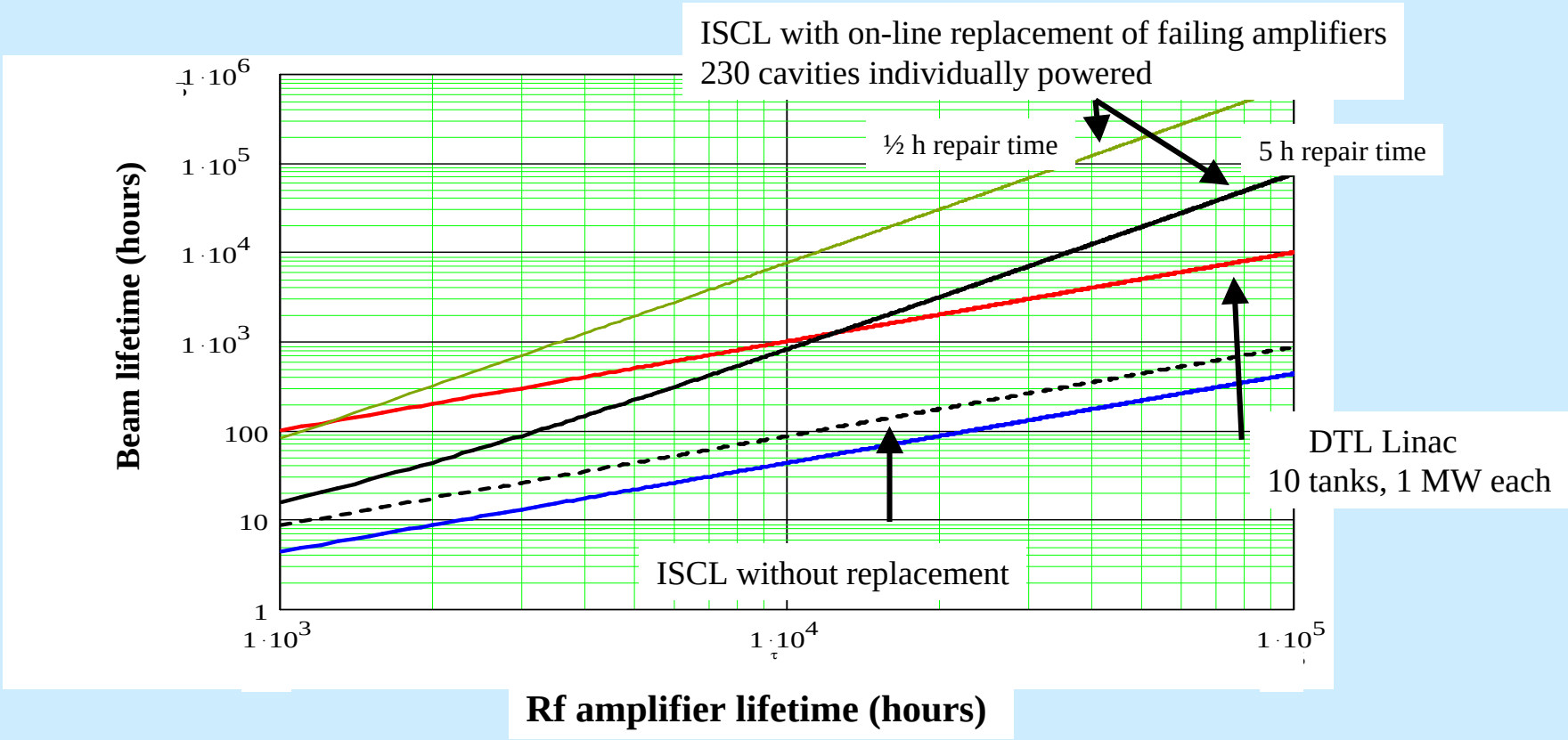
Accelerator Transmutation of Waste



Aim: Energy production and waste transmutation by means of an accelerator driven sub -critical reactor

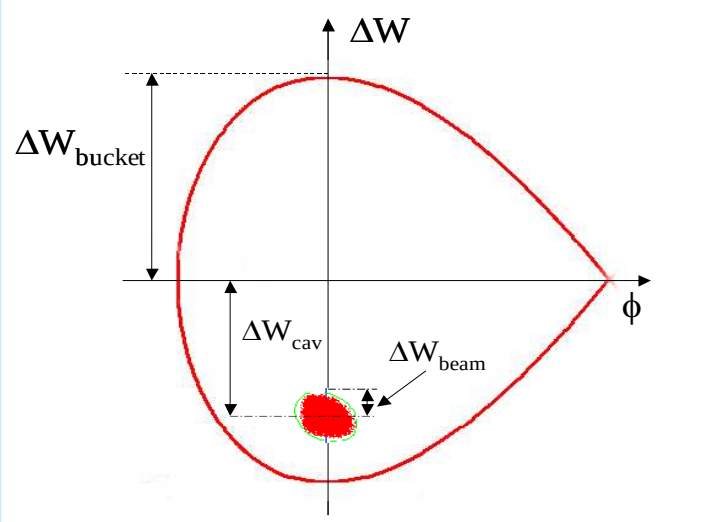
Beam lifetime in a repairable linac

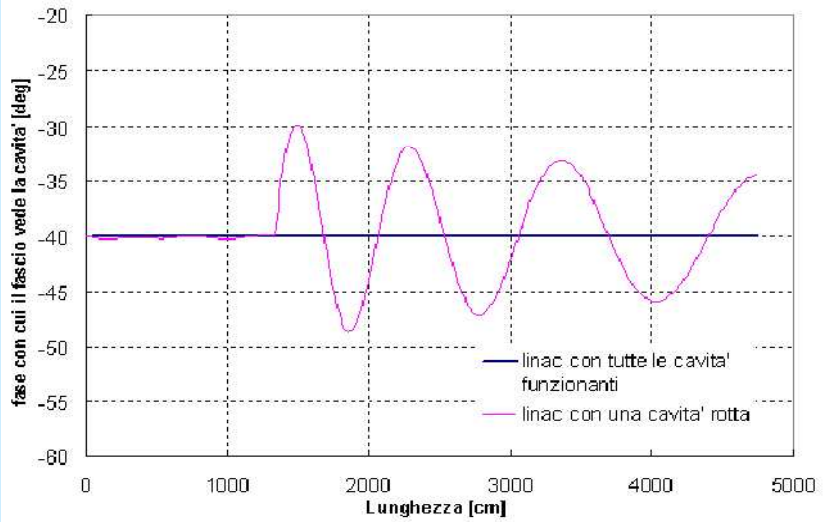
- Most beam interruptions come from failure of rf systems
- Beam lifetime can be improved significantly if the accelerator can tolerate the failure of one cavity and if this can be fixed on-line, e.g. replacing the power amplifier



Cavity constraints

- The linac can tolerate one cavity failure if the maximum energy gain per cavity is limited: $DW_{cavity} < DW_{bucket} - DW_{beam}$



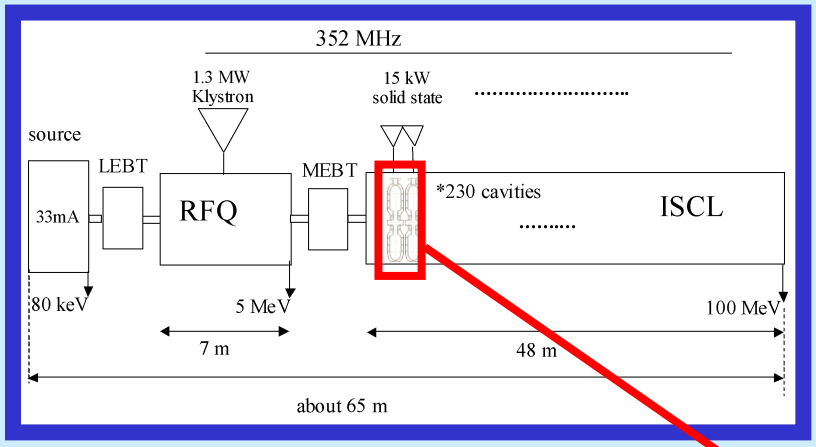


•Switching off one more cavity in the proper place allows to put back the beam in the center of the bucket

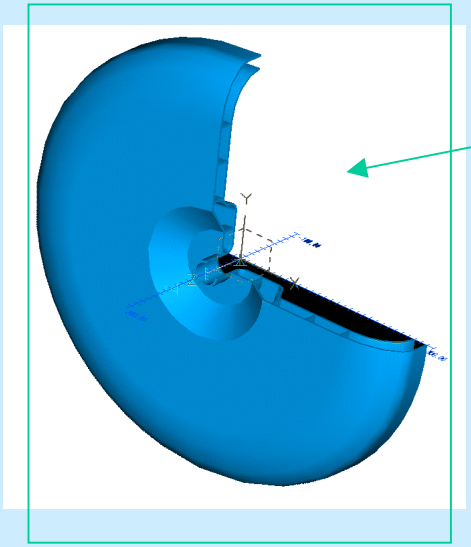
•Splitting the acceleration in many independent units, however, is not efficient in terms of R_{sh}: the superconducting solution is mandatory

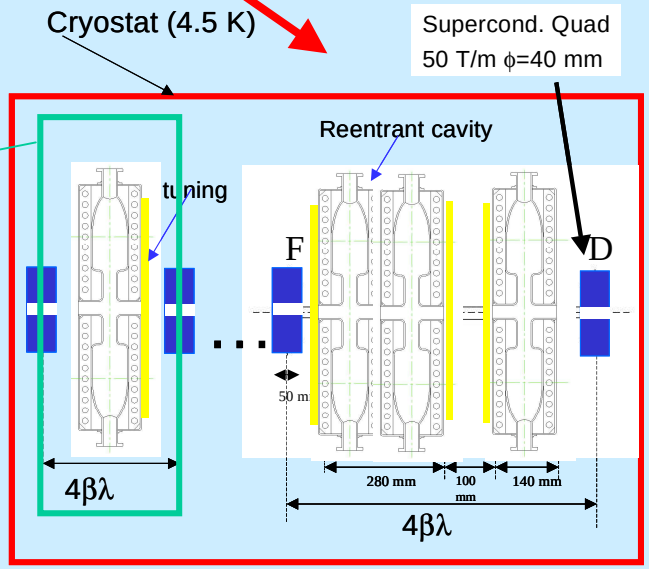
100 MeV TRASCO linac

tolerant of cavity failures



- 352 MHz, 30 mA proton RFQ
- 5-100 MeV ISCL
- FODO lattice
- wide-β SC cavities
- ΔW≤ 0.5 MeV/cavity
  (up to at least ~20 MeV)

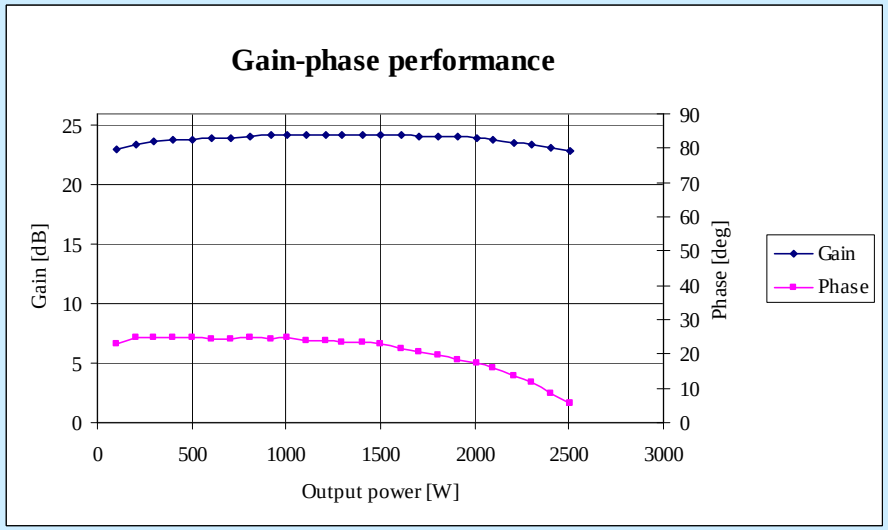


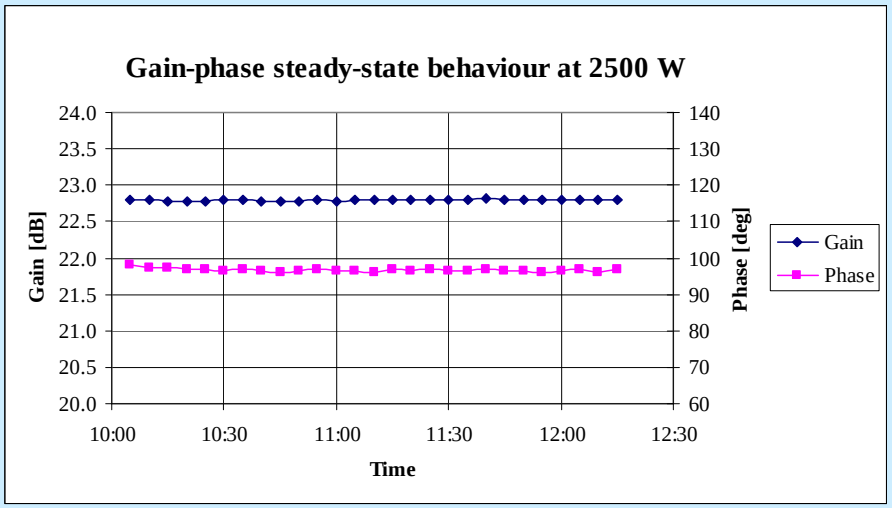


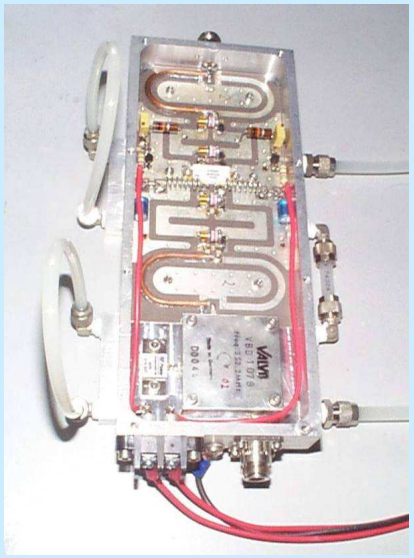
Required R&D:

- low cost - high reliability solid state amplifiers
- superferric quads
- cavities

Low cost - high reliability solid state amplifiers





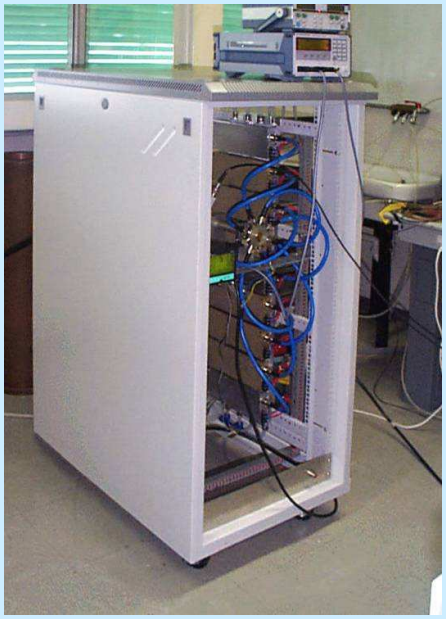


- **1st 2500 W amplifier constructed and successfully tested**

going on:

- Testing in severe conditions
- Engineering for production
- Design of 5-20 kW units

- **Modular construction**
- **MOSFET technology**
- **Circulators included**
- **Unconditionally stable**
- **Performance**
- **Reliability**



Superferric quadrupole magnet

- **Developed at MSU-NSCL in collaboration with INFN-LNL for superconducting linacs**
- **Very compact, to be used inside cryostats-magnetic shielding required**
- **tested at 300K; test at 4.2 K to be done**

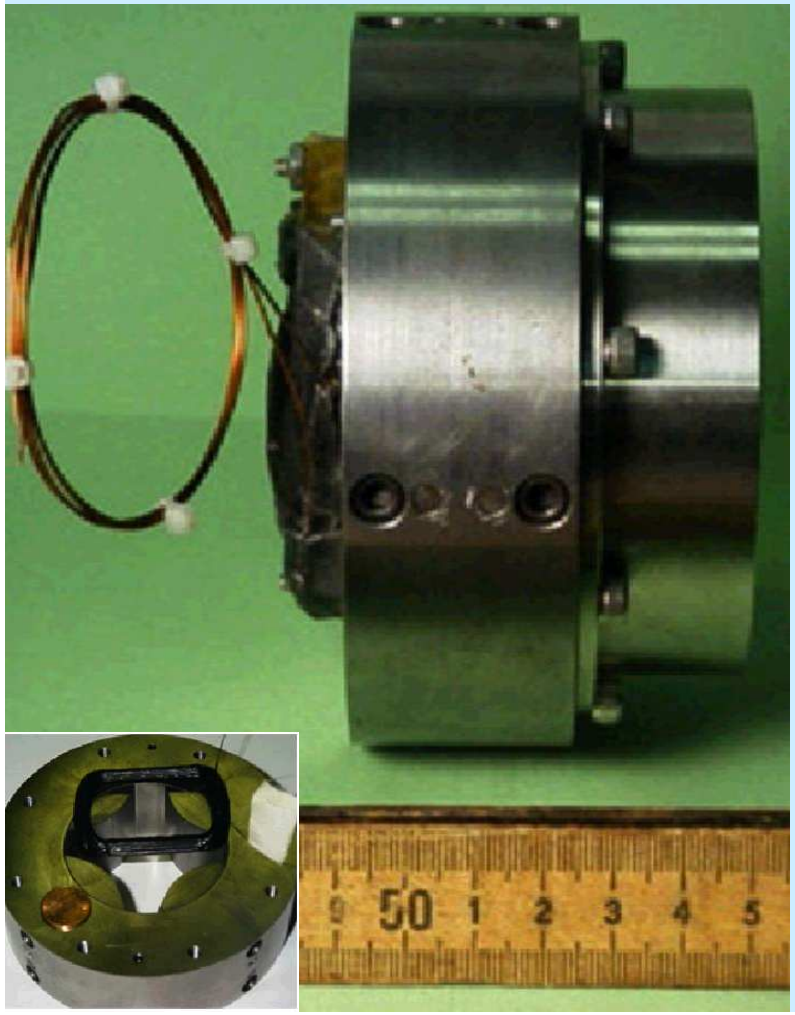
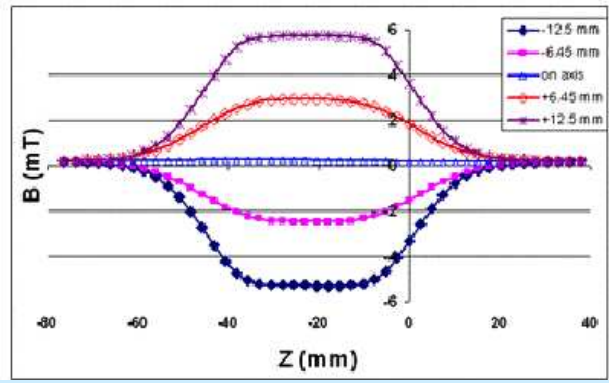
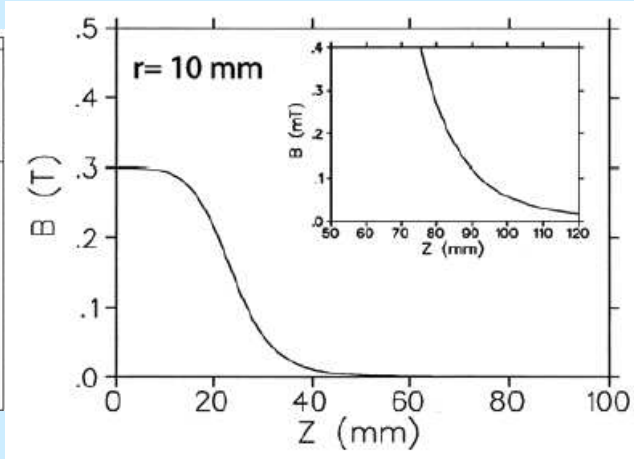


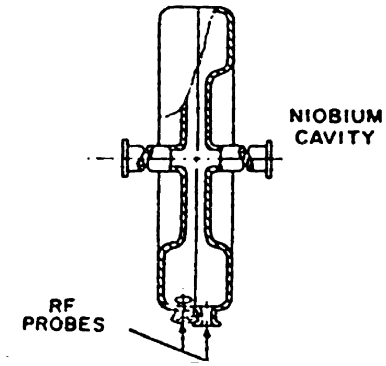
TABLE I
PHYSICAL PARAMETERS

Property	Specification
Effective length	50 mm
Radius	20 mm
Gradient	31 T/m
Turns of 0.431 mm wire	78
Current (2-D calculation)	63 A

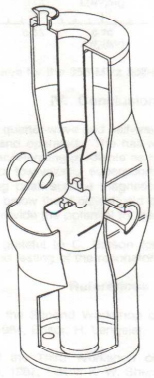


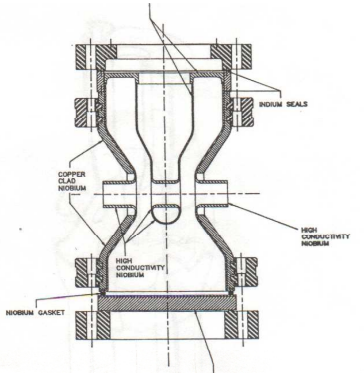


Examples of low-β cavities for proton beams

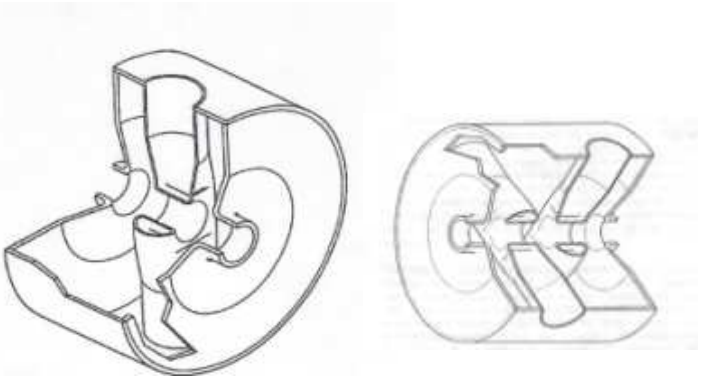


Stanford reentrant cavities (430 MHz)) -built and tested

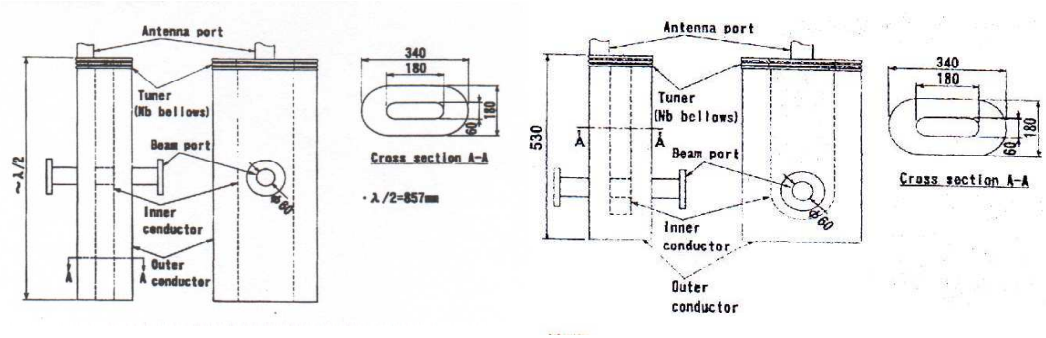




ANL λ/2 (355 MHz) and λ/4 (400 MHz)-built and tested

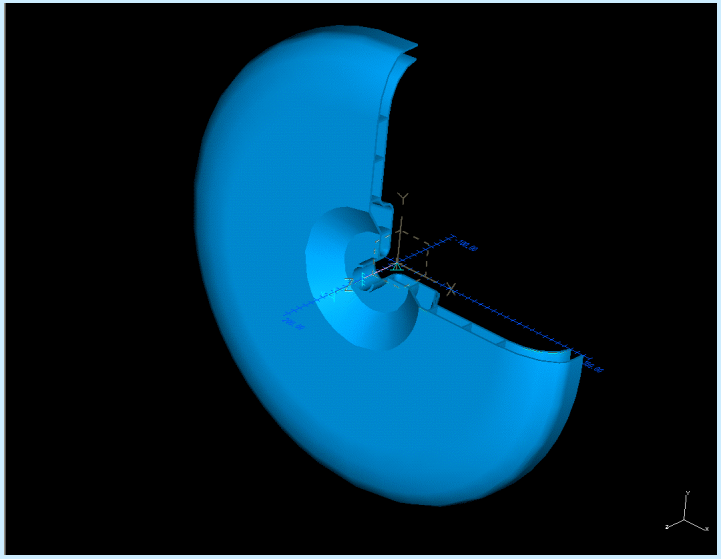


ANL 2-gap spoke (350 MHz) – built and tested
and 3 gap (850 MHz) spoke - proposed

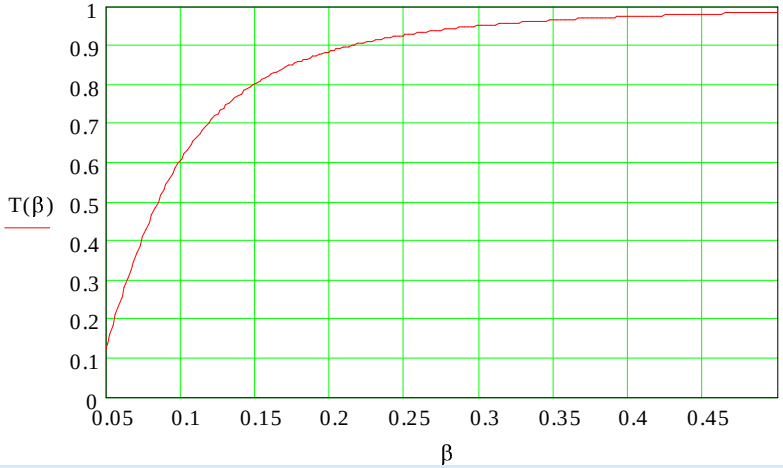


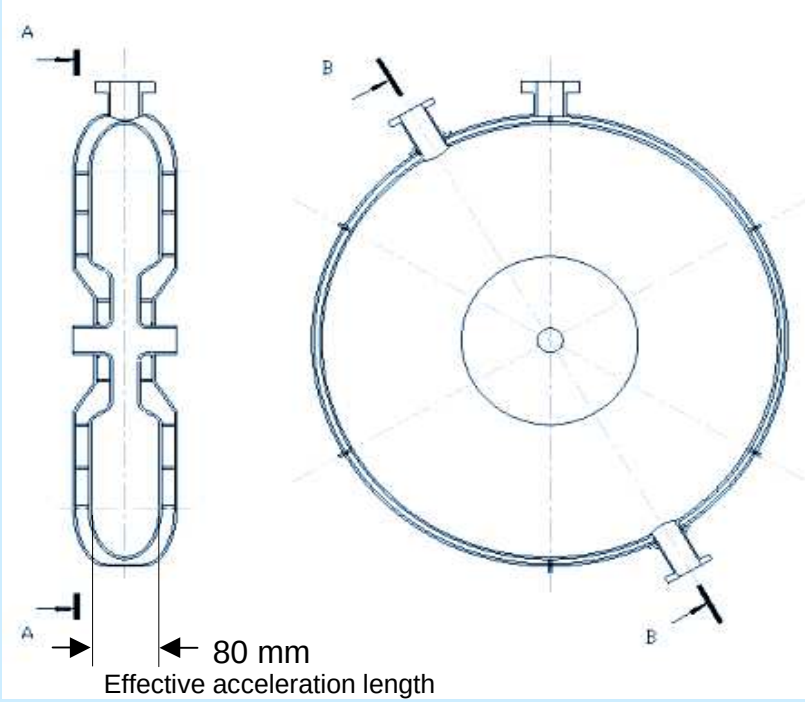
Toshiba λ/2 and λ/4 (175 MHz) - proposed

The TRASCO reentrant cavity

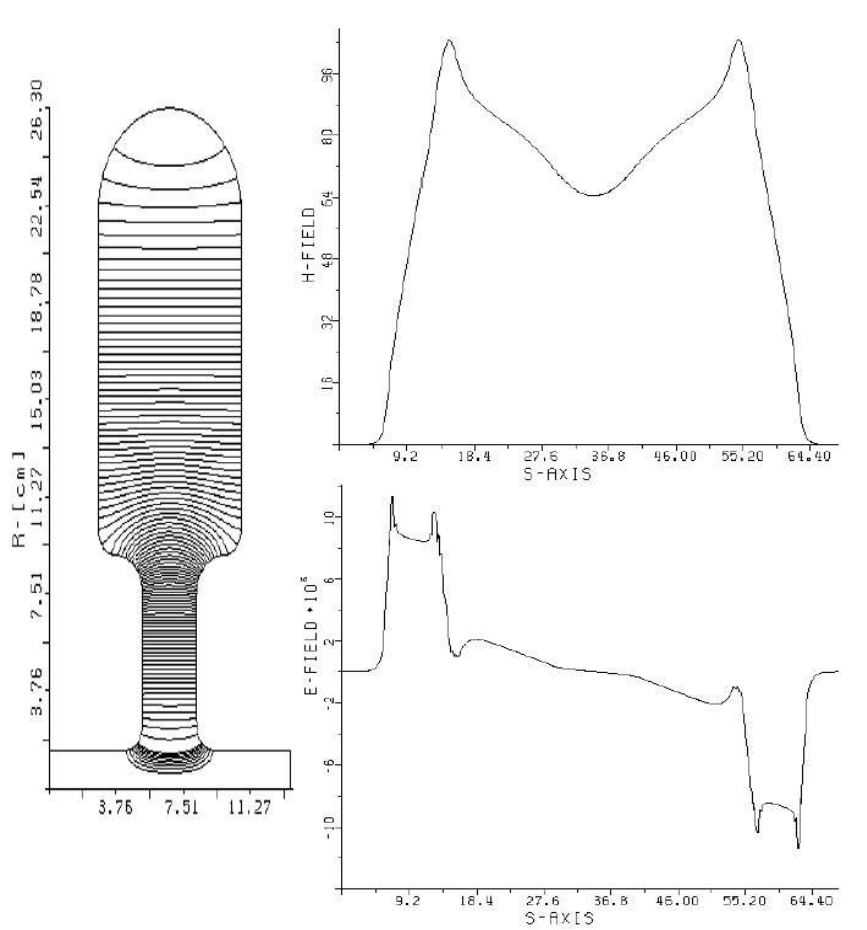


- 352 MHz cw
- single gap
- same cavity from 5 to 100 MeV
- Bore diameter 30 mm
- Field Axial symmetry





Rf design



In the final shape the intermediate step was smoothed to 60 deg

Main specifications:

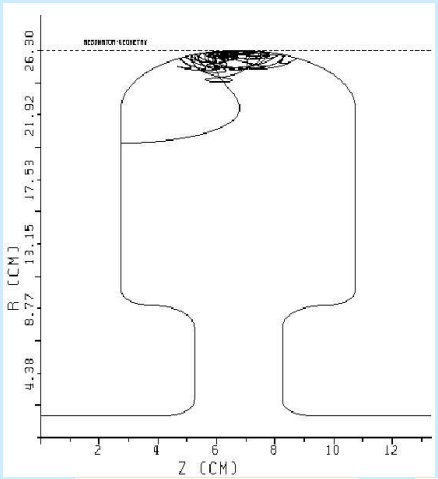
- 352 MHz, $\beta \geq 0.1$
- 30 mm bore diameter
- Inner length ≤ 80 mm
- $\Delta W \approx 0.5$ MV at 7W

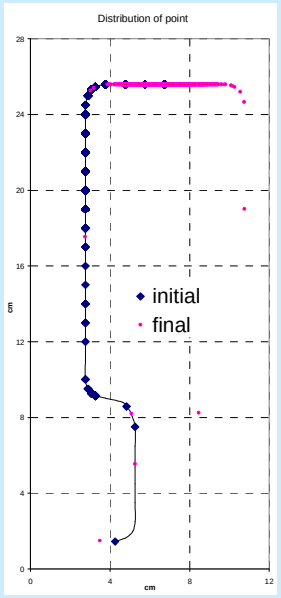
Rf codes used:

- Superfish, HFFS

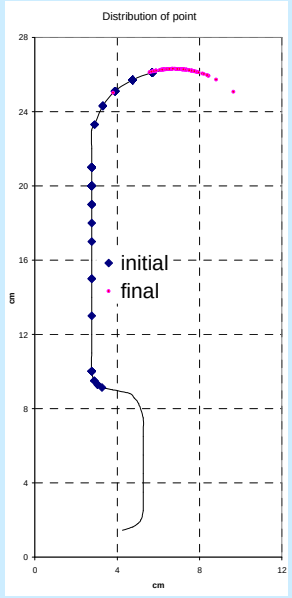
Cavity inner diameter	536	mm
Gap length	30	mm
Effective gap length	53	mm
Bore diameter	30	mm
Eff. acceleration length	80	mm
U/ E_a^2	0.034	J/(MV/m)
E_p/ E_a	3.0	
H_p/ E_a	3.1	mT/(MV/m)
$\Gamma = R_s \times Q$	83	Ω
R_{sh}/Q	84	Ω

Multipacting simulations

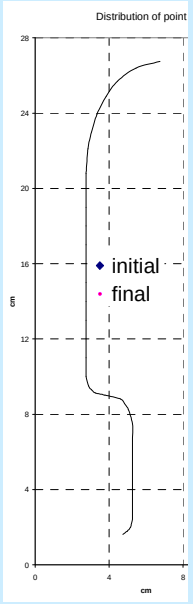




n. initial file 24020
n. selected file 1578
ratio 6.60%
range 0-25 MV/m



n. initial file 4840
n. selected file 95
ratio 2%
range 0-25 MV/m



n. initial file 16516
n. selected file 0
ratio 0%
range 0-25 MV/m

Total Number of runs with TVTRAG 45376

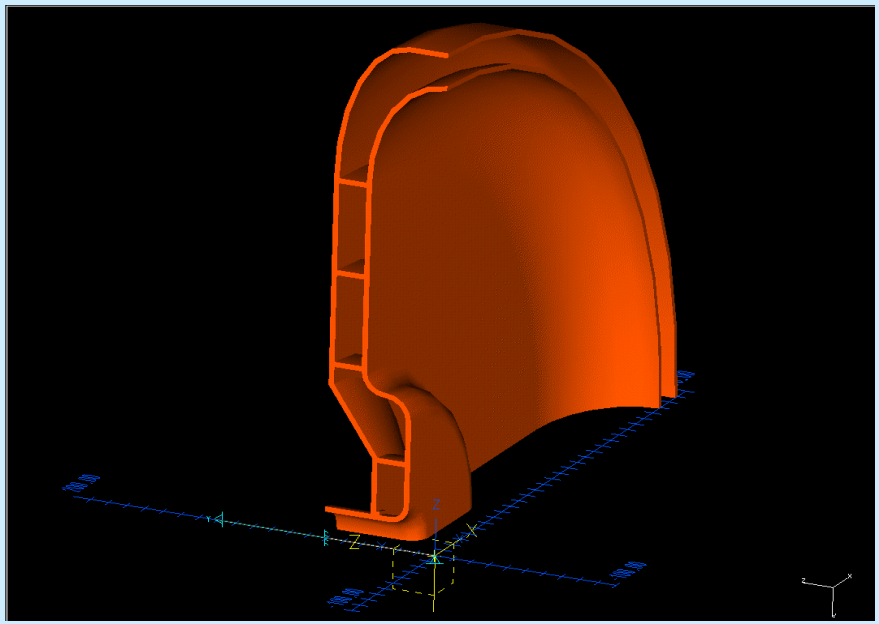
Simulation:

- code TWTRAJ (courtesy of R.Parodi, INFN Genova)
- ~60000 Runs
- 0.005 MV/m steps in E_a
- 5 mm steps in e^- starting position

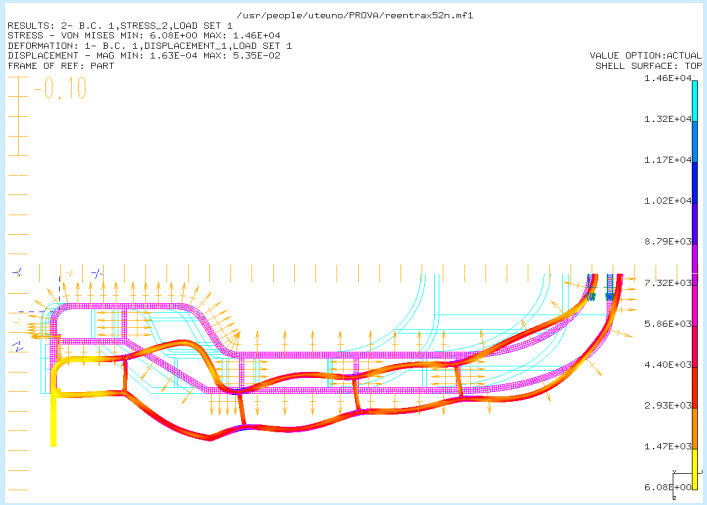
Results:

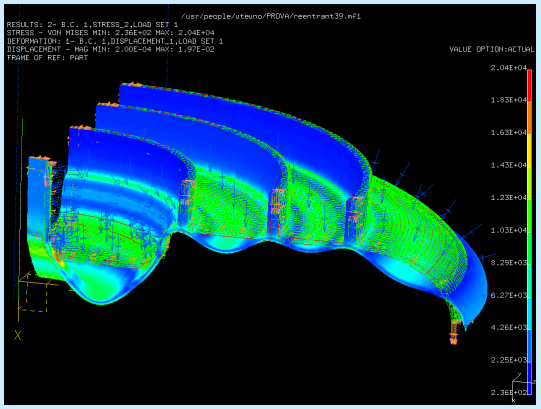
- MP negligible near the gap
- All levels at the equator: the equator profile is critical
- Ellipsoidal shape 1.5:1 free of MP

Mechanical design



- Main constraints:
  - -4 bar max pressure
  - -Physical length without tuner <130 mm
  - -Stability against He pressure fluctuations
  - -tunability
- Double wall structure with interconnecting rings
- 3 mm thick niobium sheet
  - -Inner shell: RRR>150 Nb
  - -Outer shell: normal grade Nb





- codes used:
  - Autocad (preliminary)
  - I-DEAS (main)

Mechanical construction

Inner shell

- Designed at LNL
- Built at Zanon, Schio (Vicenza) Italy
- CP treated at CERN
- Tested at LNL

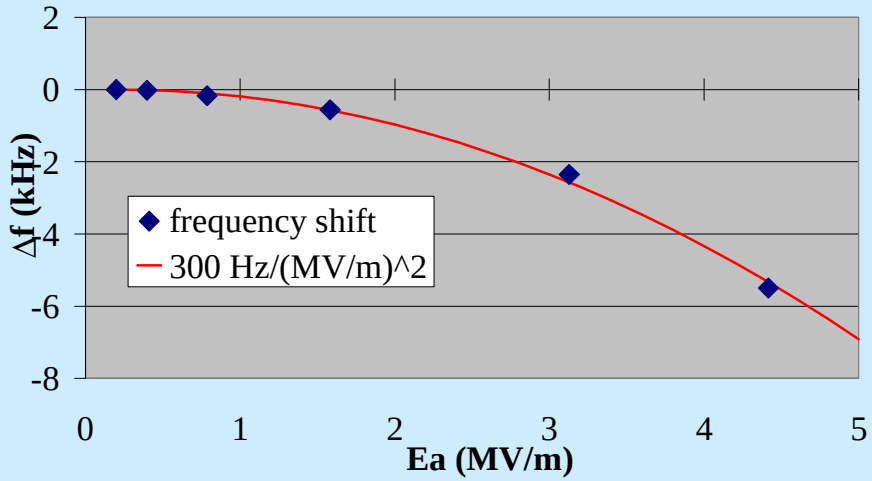
Detail of the interconnecting rings

Side view with rf ports

Final cavity after welding of the outer shell

Mechanical test results

(naked resonator - no tuner nor reinforcement)

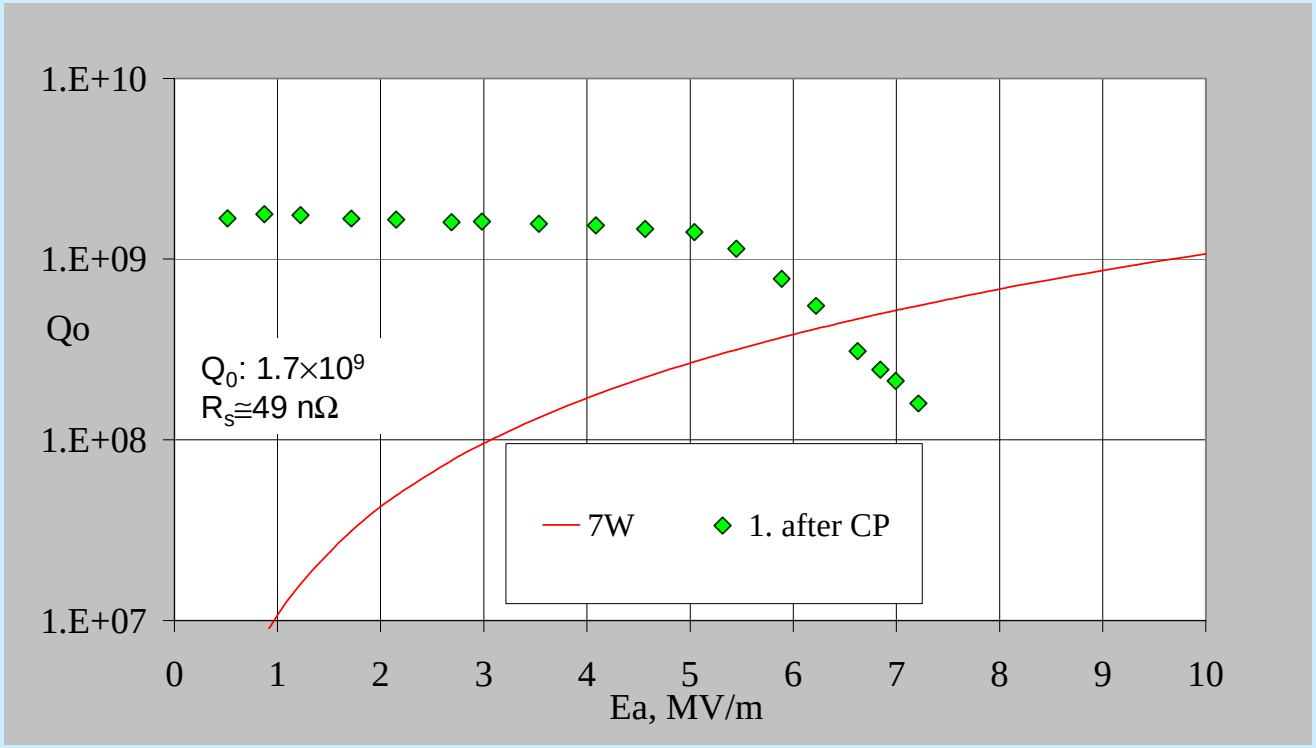


Lorenz force detuning test

parameter	measured	calculated	units
Rf frequency f final adjustment by plastic deformation foreseen	348.673	352	MHz
Frequency response to pressure df/dP from 0 to 1 bar in the helium vessel	~ -258	~ -140	Hz/mbar
Lorenz force detuning df/dE$_a$ measured from 0.2 to 4.4 MV/m	~ -300	~ -170	Hz/(MV/m)^2
Lower mechanical mode frequency f$_{mech}$	~ 195	~ 200	Hz

Superconducting Reentrant Cavity
1st Rf test at 4.2K

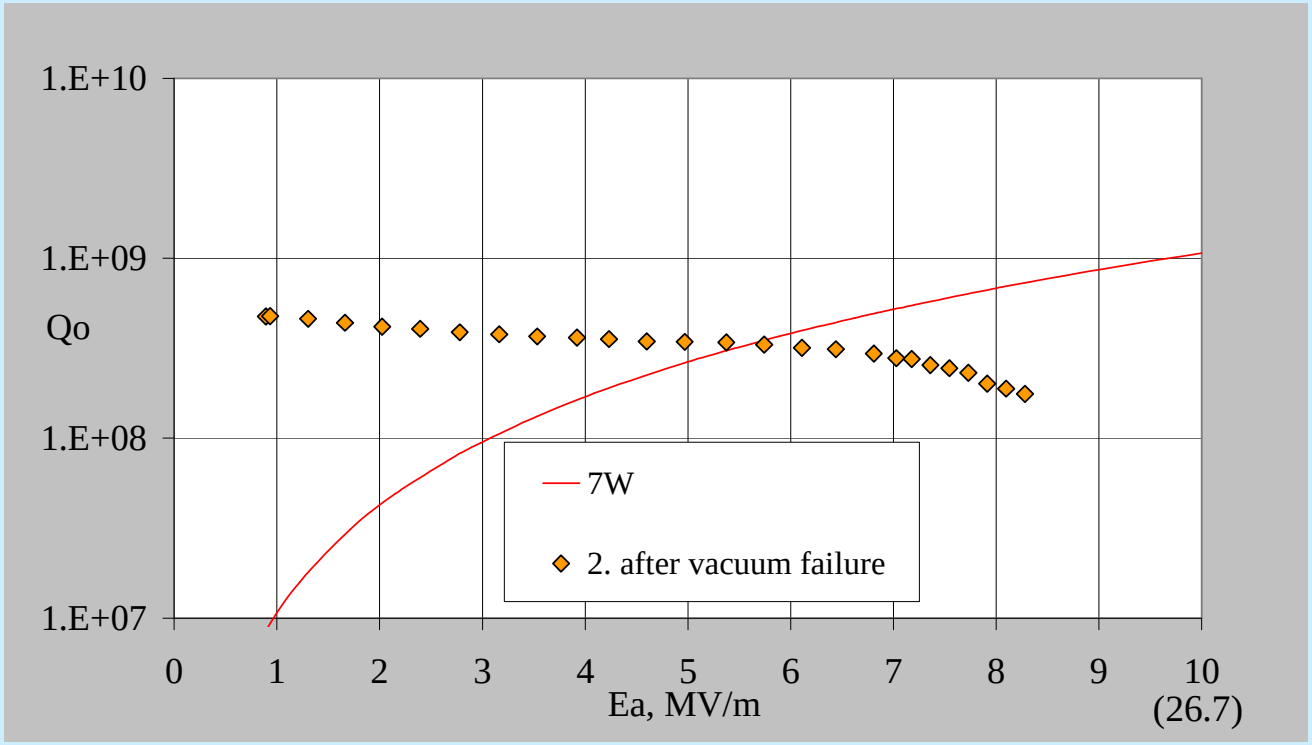
1st test (after CP): capacitive coupler at the beam port
insufficient coupling: MP and Rf conditioning impossible



- Low field MP disturbing the test
- **High Q_0: 1.7×10^9 Low field R_s≅49 nΩ (R_{res} ≅ 10 nΩ)**
- Strong field emission above 5 MV/m

Superconducting Reentrant Cavity
2nd Rf test at 4.2K

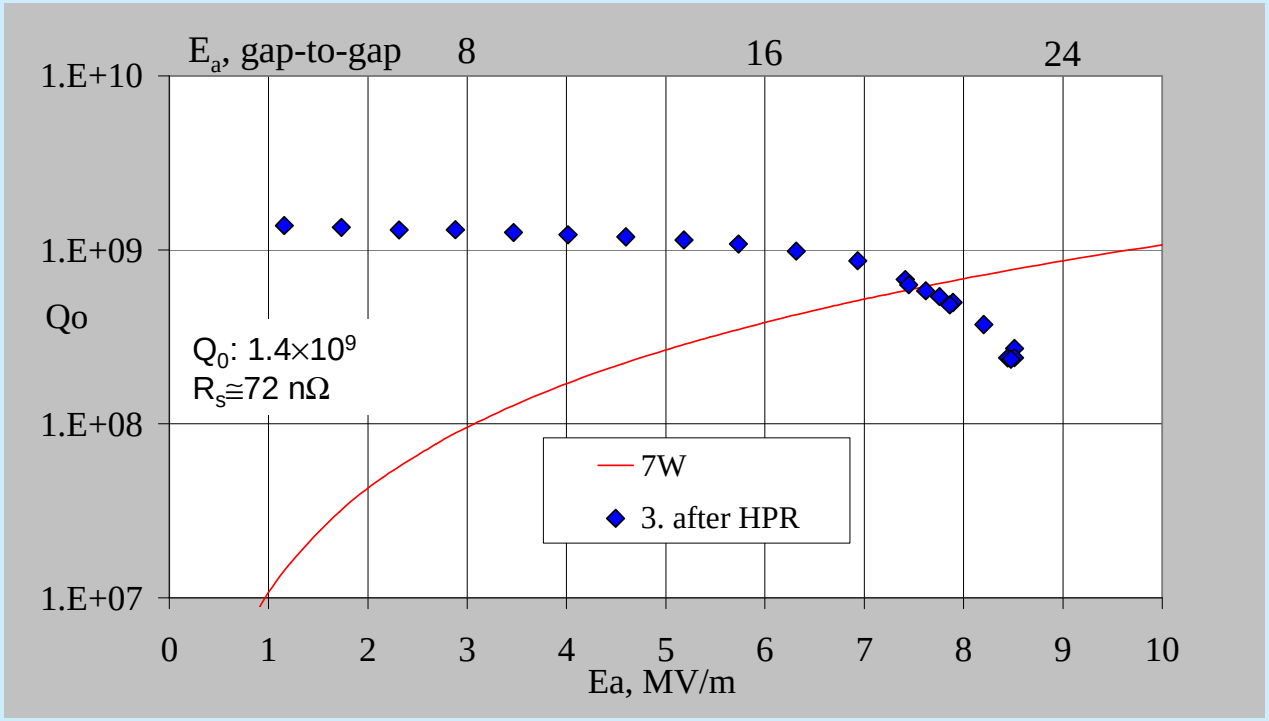
2nd test (after severe vacuum failure due to rf feedthrough burning; cavity exposed to dusty air during repair). Coupler problems fixed; MP and rf conditioning possible



- low field MP easily conditioned
- contamination with dust and burning residues: Q degradation
- Increased E_a, FE conditioned

Superconducting Reentrant Cavity
3rd Rf test at 4.2K

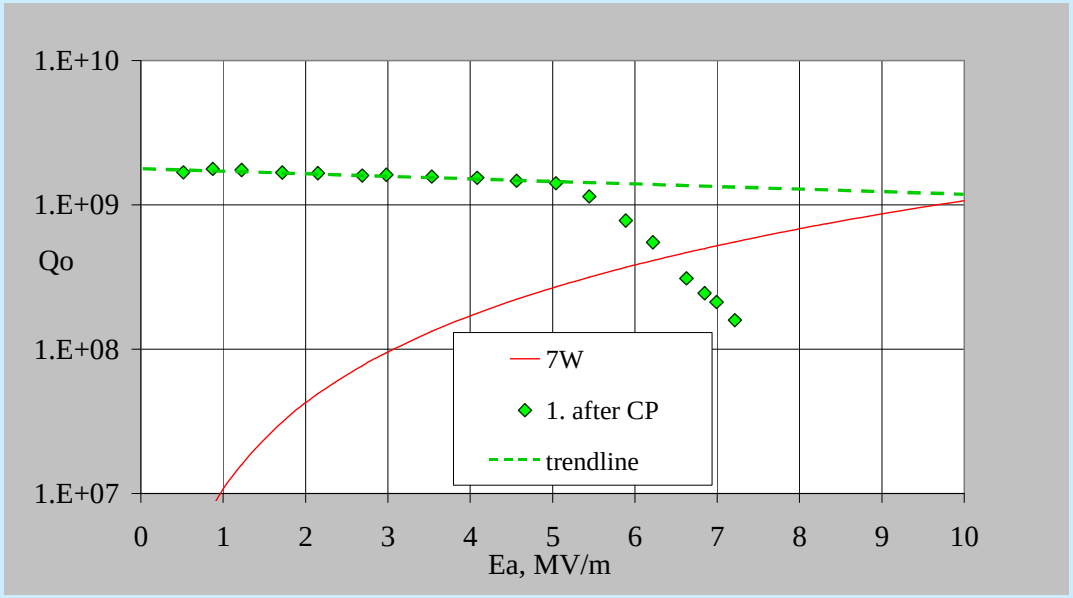
3rd test after HPR of the cavity from outside through rf- and beam- ports.



- no MP level above 0.03 MV/m; low field levels easily conditioned
- Q_0 partially recovered: $R_s \cong 72$ nΩ ($R_{res} \cong 33$ nΩ)
- E_a=7.5 MV/m @ 7W (0.6 MV)

Next steps

- HPR from inside and test again
- Build and test the tuner
- Build a 5 kW rf coupler for the SPES project



Considering the surface resistance measured in the first test, and the relatively low peak fields reached, we can expect further improvement of the 7 W gradient

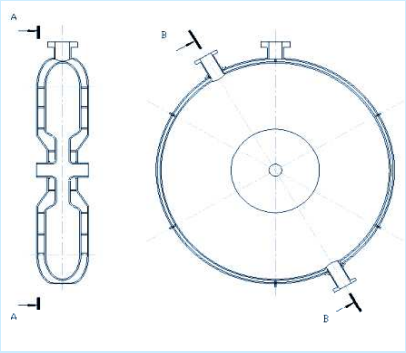
TRASCO Reentrant Cavity: advantages and drawbacks

Advantages:

- Short, compact and light, the He tank is part of the structure
- Relatively simple construction
- EM field perfectly symmetric
- very wide β acceptance
- Usable from very low energy (~5 MeV protons, β ~0.1)
- Low peak fields: possibility of high gradient

Drawbacks:

- not recommended for pulsed operation (Lorenz force detuning)
- relatively low energy gain/cavity
- Only inductive couplers to preserve compactness



Conclusions

•We have studied a high reliability design for the 30 mA, 5-100 MeV proton linac of TRASCO, based on reentrant cavities

- We have designed, built and tested a 352 MHz superconducting reentrant cavity
  - Short (13 cm without tuner) and very low β
  - free of dangerous multipacting
  - high gradient: 7.5 MV/m measured at the nominal power of 7 W
  - low peak fields: space for significant improvements

• Reentrant cavities possess some unique features that can be profitably used in low-β linacs, especially in the range $0.1 \leq \beta \leq 0.2$