ICFA – HB 2002
20th ICFA Advanced Beam Dynamics Workshop
High Intensity High Brightness Hadron Beams

Fermilab
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The TRASCO Project

Carlo Pagani
University and INFN Milano - LASA

INFN
Istituto Nazionale
di Fisica Nucleare

The TRASCO Program

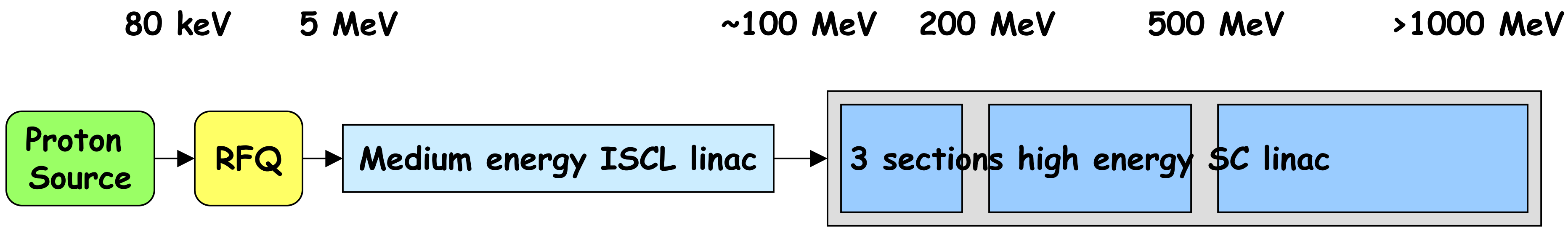
TRASCO is devoted to the conceptual study and the prototyping of components for an accelerator driven system for nuclear waste transmutation, and involves research agencies and Italian companies

- TRASCO/ACC
  - Accelerator studies: lead by INFN (Milano, LNL, LNS, ...)
- TRASCO/SS
  - Subcritical reactor studies: lead by ENEA

TRASCO/ACC (1998-2004, in three funding stages) is devoted to:

- Conceptual design of a high current superconducting proton linac
  - I=30 mA E> 1 GeV
- Construction of an 80 kV, 35 mA proton source
- Construction of a 5 MeV, 30 mA, CW RFQ
- Construction of superconducting cavity prototypes for low beta cavities (<100 MeV)
- Construction of superconducting cavity prototypes for β = 0.47 elliptical cavities
- Preliminary engineering of main linac components (cryomodules, cavity ancillaries, etc.)

The Reference Linac Design



Source	RFQ	ISCL	High Energy SC Linac
Microwave RF Source High current (35 mA) 80 keV	High transmission 90% 30 mA, 5 MeV (352 MHz)	5 - 85/100 MeV SC linac Spoke cavities (352 MHz) Lambda/4 cavities (176 MHz) Reentrant cavities (352 MHz) $8\beta\lambda$ focussing	3 section linac: - 85/100 - 200 MeV, β=0.47 - 200 - 500 MeV, β=0.65 - 500 – 1000/2000 MeV, β=0.85 Five(six) cell elliptical cavities Quadrupole doublet focussing: multi-cavity cryostats between doublets - 704.4 MHz

TRIPS: TRASCO Intense Proton Source

High intensity (several 10s mA) proton sources exist

- Chalk River
- Los Alamos
- CEA-Saclay

Critical problem for ADS is the source reliability and availability

Additional efforts with respect to state of the art are required for:

- Voltage and current stability
- Control of the low beam emittance

Subprogram is aimed at the source construction and operation

TRIPS Goals:		**Achievements**
Proton Beam current	35 mA	**55 mA (~90% p.f.)**
Beam emittance	0.2 π mm mrad	**To be measured**
Operating voltage	80 kV	**80 kV**

Status of the Source

Design completed in 1999

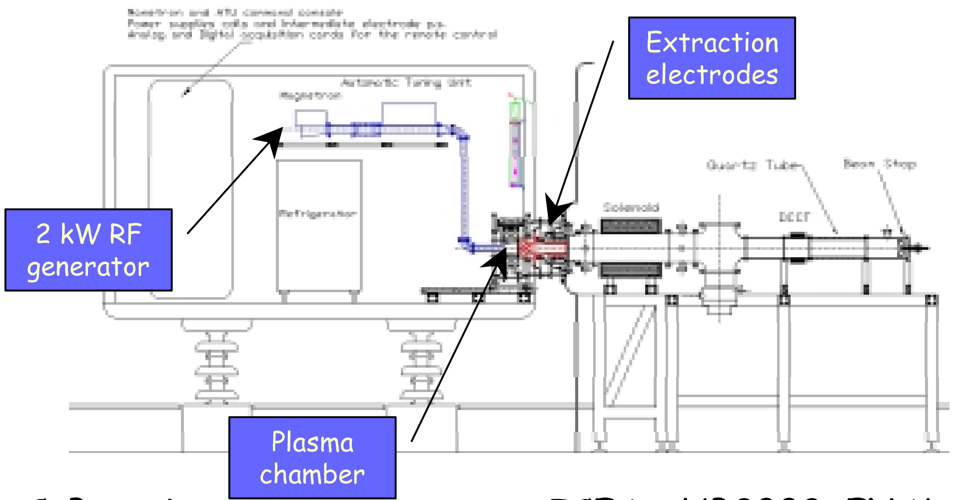
Source assembled in LNS in May 2000

Achievements:

- First beam of 20 mA @ 60 kV in Jan 2001
- 80 kV, 55 mA operation in Aug 2001

Off-resonance microwave discharge source (2.45 GHz)

- Based on SILHI (CEA/Saclay)
- Modifications focussed on increase of reliability and availability

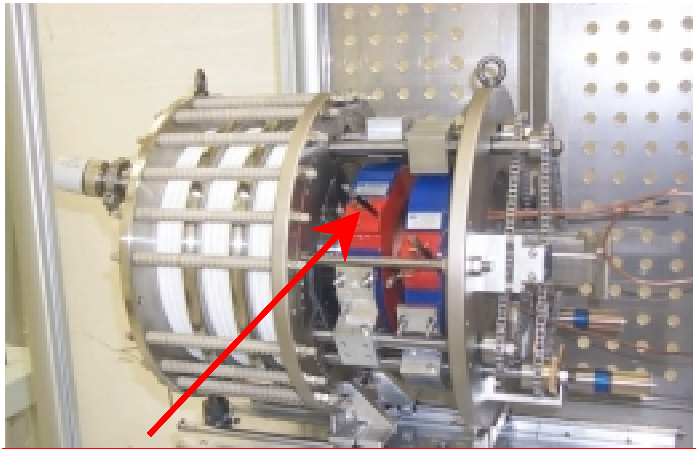


Design choiches

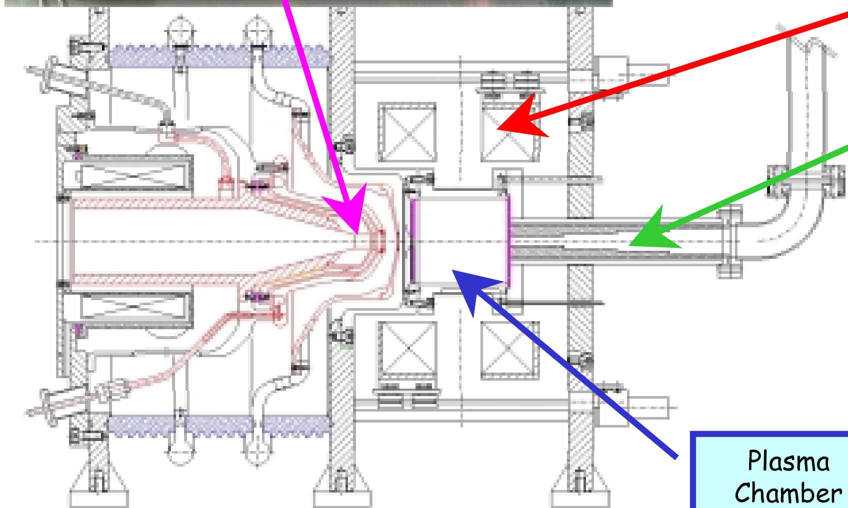
Studies on SILHI extraction system (with CEA and LANL) lead to:

- Pentode configuration with new geometry
- Lowered voltage: from 95 kV to 80 kV

4-step binomial transformer for waveguide to plasma impedance matching

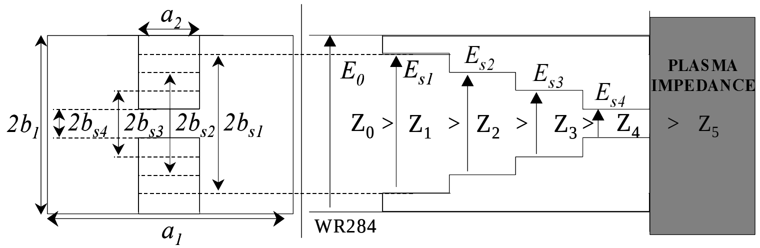


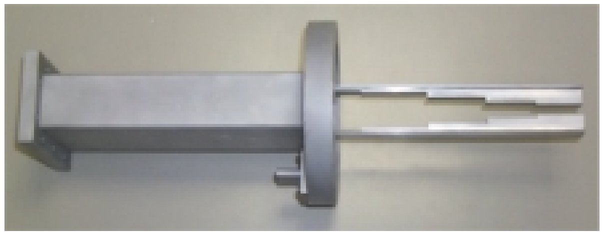
Moving coils to adjust ECR region



Plasma Chamber

Matching transformer (impedance match)





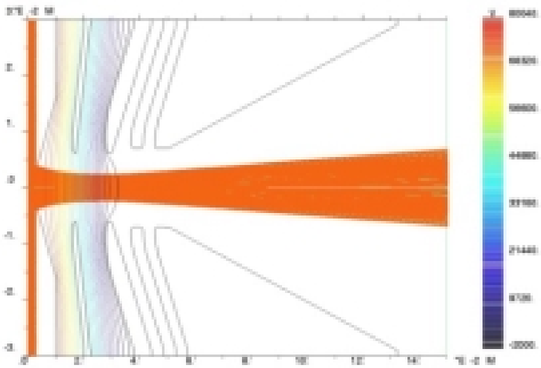
LEBT

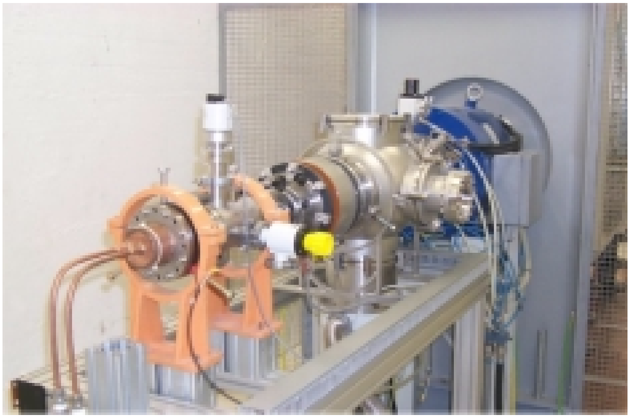
A rms emittance below 0.2 p mm mrad has been calculated with beam dynamics simulations, crosschecking different codes

Below: particle trajectories and lines of fixed electric potential in the extraction region

LEBT for beam analysis and characterization:

- Solenoid (focussing)
- Beam alignment monitor
- 2 current transformers for beam current measurements
- 10 kW **beam stop**



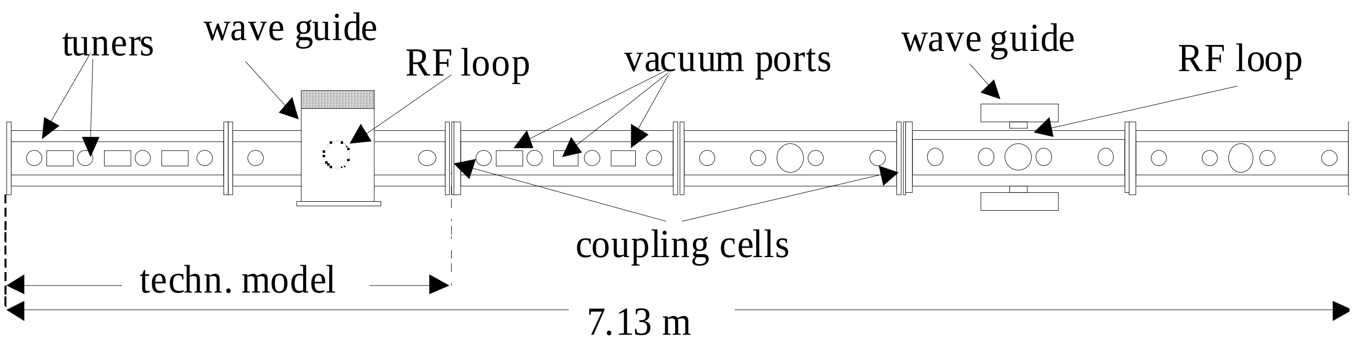


Reliability test at 65 kV/15 mA: 24 h with no beam interruptions
Reliability at 80 kV is not yet achieved, needs more work

Low Energy Linac

The low energy linac is split in two components:

- A normal conducting CW Radio Frequency Quadrupole (RFQ): from 80 keV to 5 MeV
  - Standard RFQ design with 3 resonantly coupled segments:
    - Radial match in the structure
    - Shaper
    - Gentle buncher (from CW to 352.2 MHz bunches)
    - Accelerator (boosts up to 5 MeV, longest portion)



- A superconducting linac (ISCL): from 5 MeV to 100 MeV
  - λ /4, λ/2 cavities at 176 MHz or 352.2 MHz
  - Spoke cavities @ 352.2 MHz
  - Reentrant cavities at 352.2 MHz

RFQ Design

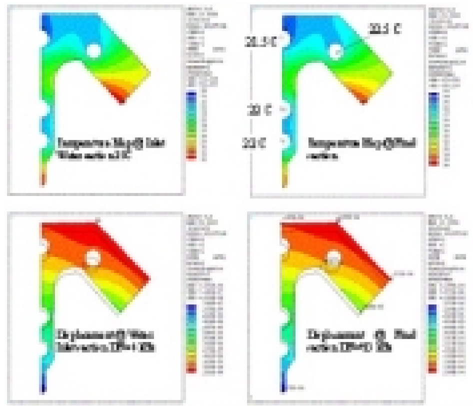
Different optimization procedure for TRASCO RFQ w.r.t. LEDA

- Limit to 1 RF source (1.3 MW CERN-LEP klystron)
- Lower design current of 30 mA (transmission of 96%)
- Peak surface electric field is 33 MV/m, 1.8 Kilpatrick limit
- Simplified engineering/manufacturing choices

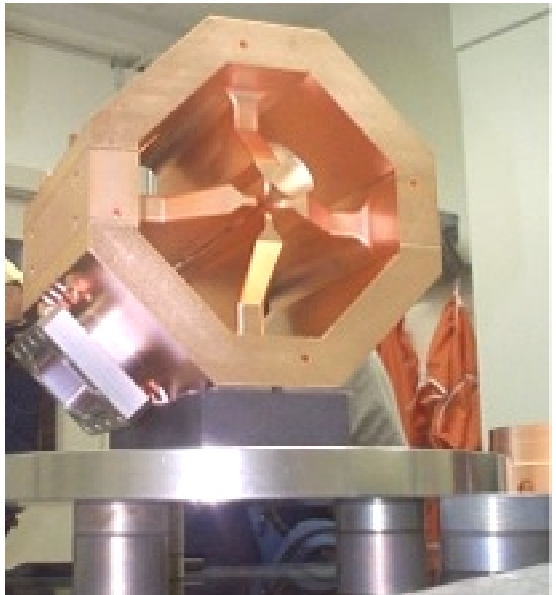
Substantial heat dissipation in the structure ~ 600 kW total

Three resonantly coupled segments

TRASCO RFQ:	
Beam current	30 mA (96 % transmission)
Beam emittance	0.2 π mm mrad T
	0.18 π deg MeV L
Final Energy	5 MeV
Length	7.13 m (3 sections)
RF Power	150 kW (beam)
	600 kW (structure)
Peak Field	1.8 Kilpatrick



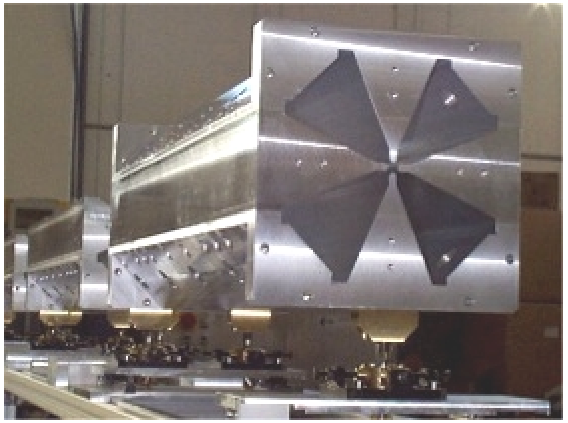
RFQ: fabrication tests

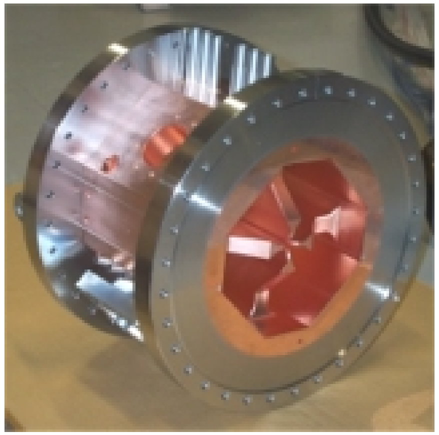


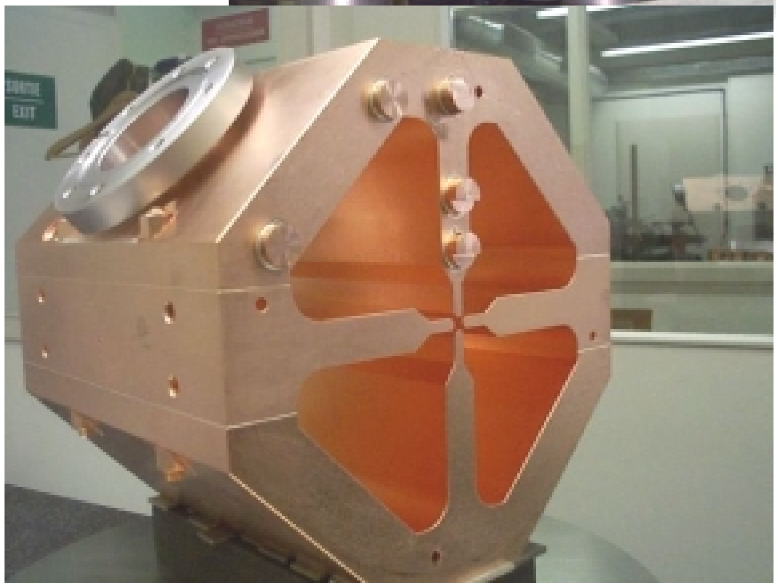
A 3 m Al model of the structure has been build and measured, and achieved the necessary field stabilization

A 220 mm part of the structure has been built to test the full fabrication procedures

- Brazing
- Water channels by long (1 m) drilling







Superconducting low energy linac

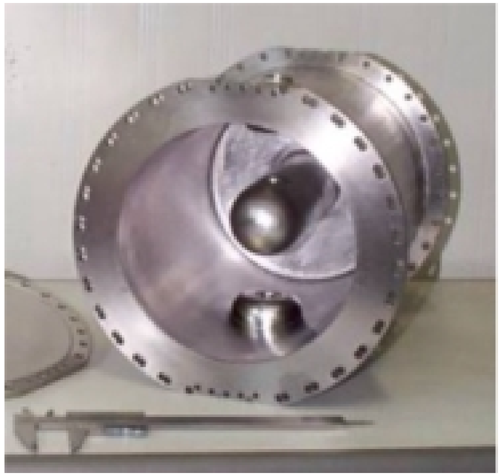
Single or two-gap structure linac

- Moderate energy gain per cavity
- 8 $\beta\lambda$ focussing lattice

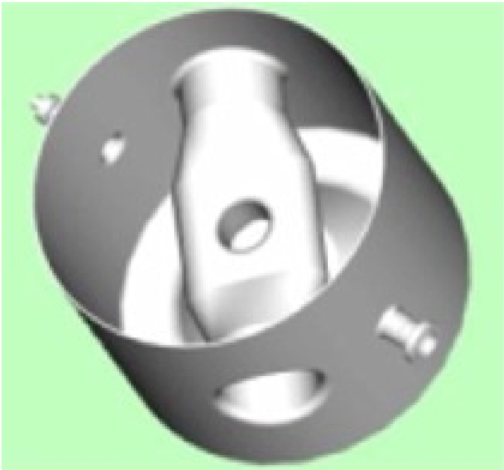
Various options are being considered

- Lambda/4 cavities (176 MHz)
- Spoke cavities
- Reentrant cavities

Quarter Wave resonator (QWR) 2 gap structure of the ALPI linac in INFN-LNL



Spoke cavity



Reentrant cavity single gap structure. He Vessel integrated in the cavity

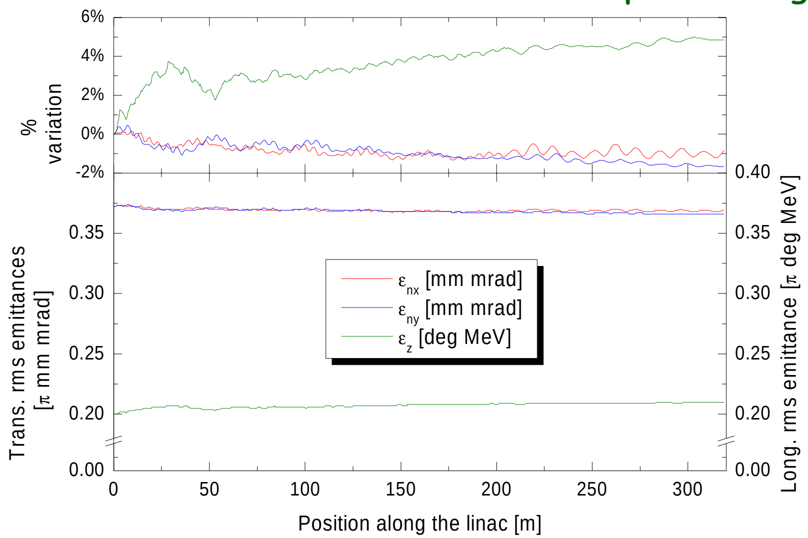
The high energy linac

Section β	0.47	0.65	0.85
# cells/cavity	5	5	6
Length	84 m	124 m	110 m
Initial/Final Energy	85 MeV	200 MeV	500 MeV
	200 MeV	500 MeV	1 GeV
Doublet period	4.2 m	4.6 m	8.5 m
# periods	20	27	13
# cavities in section	40	54	52
Max. Eacc (MV/m)	8.5 MV/m	10.2 MV/m	12.3 MV/m

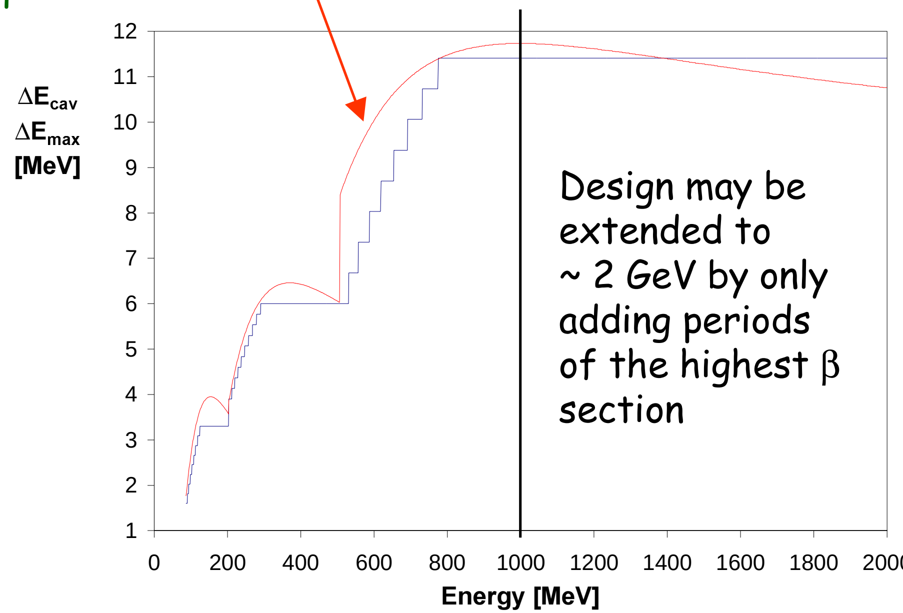
Approximately 320 m of linac are needed from 85 MeV to 1 GeV

Designed with high current beam dynamics criteria to avoid emittance growth (smoothness, tune resonances, ...)

Beam Dynamics calculations (fully 3D) predict small emittance variations due to nonlinear space charge

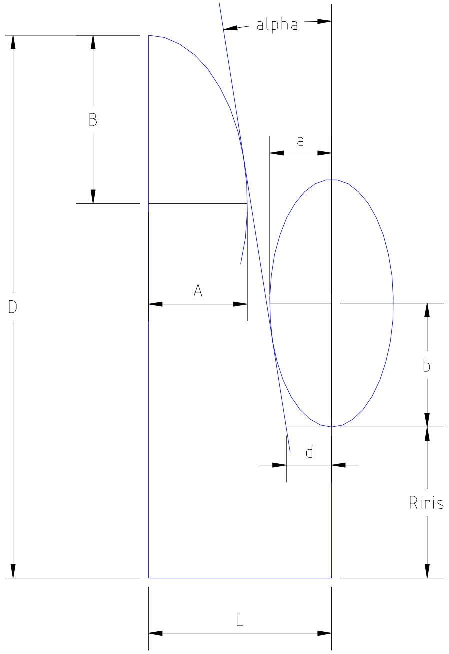


Maximum ΔE at conservative peak surface fields (50 mT)



Some useful tools: for cavity design

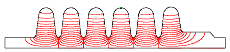
- We built a parametric tool for the analysis of the cavity shape on the electromagnetic (and mechanical) parameters
- All RF computations are handled by SUPERFISH



β_g = 0.61 Cavity for SNS – 4 dies

Effective β that matches the TTF curve = 0.630

E_p/E_{acc}	2.72 (2.63 inner cell)
B_p/E_{acc} [mT/(MV/m)]	5.73 (5.44 inner cell)
R/Q [Ω]	279
G [Ω]	214
k [%]	1.53
Q_{BCS} @ 2 K [10^9]	27.8
Frequency [MHz]	805.00
Field Flatness [%]	2



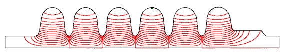
Geometrical Parameters

	Inner cell	End Cell Left	End Group (coupler) Left	End Group (coupler) Right
L [mm]	56.8	56.8	56.8	
R_{iris} [mm]	43.0	43.0	43.0	65.0
D [mm]	163.76	163.76	166.98	
d [mm]	11.0	11.0	11.0	10.0
r	1.7	1.5	1.7	1.5
R	1.0	1.0	1.0	
α [deg]	7.0	8.36	7.0	10.0

β_g = 0.81 Cavity for SNS – 4 dies

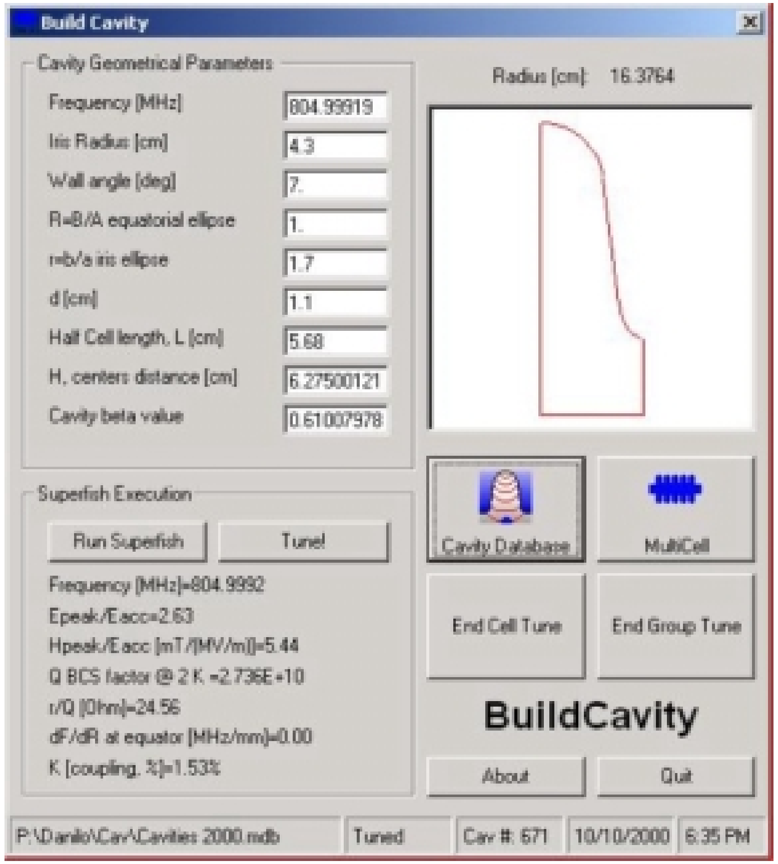
Effective β that matches the TTF curve = 0.830

E_p/E_{acc}	2.19 (2.14 inner cell)
B_p/E_{acc} [mT/(MV/m)]	4.79 (4.58 inner cell)
R/Q [Ω]	485
G [Ω]	233
k [%]	1.52
Q_{BCS} @ 2 K [10^9]	36.2
Frequency [MHz]	805.00
Field Flatness [%]	1.1



Geometrical Parameters

	Inner cell	End Cell Left	End Group (coupler) Left	End Group (coupler) Right
L [mm]	75.5	75.5	75.5	
R_{iris} [mm]	48.8	48.8	48.8	70.0
D [mm]	164.15	164.15	166.11	
d [mm]	15.0	13.0	15.0	13.0
r	1.8	1.6	1.8	1.6
R	1.0	1.0	1.0	
α [deg]	7.0	10.072	7.0	10.0

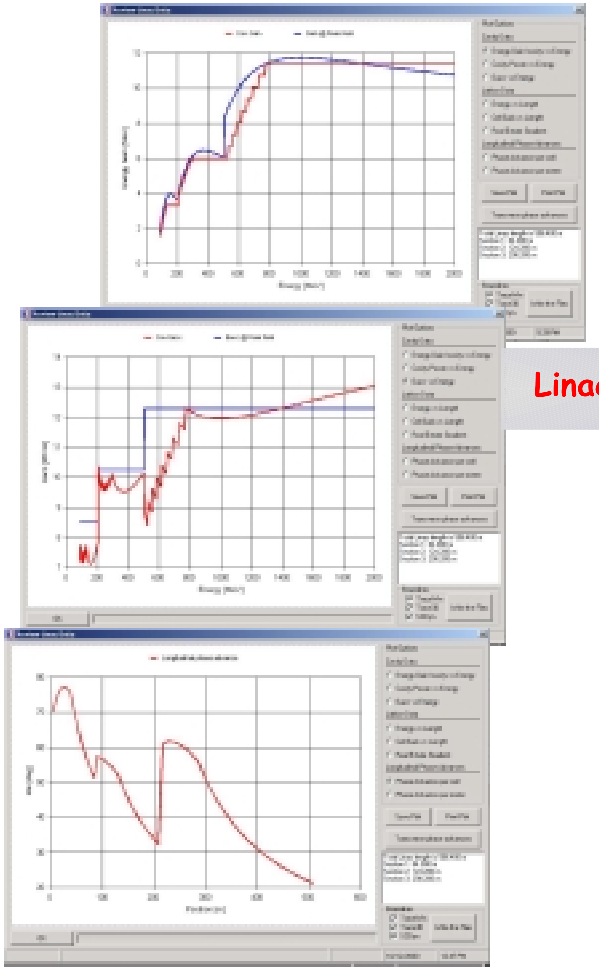


- Inner cell tuning is performed through the cell diameter, all the characteristic cell parameters stay constant: R, r, α, d, L, Riris
- End cell tuning is performed through the wall angle inclination, α, or distance, **d**. R, L and Riris are set independently
- End groups for a 4 die cavity can be tuned using the end cell diameter (and a,d,R,L, Riris are set independently)

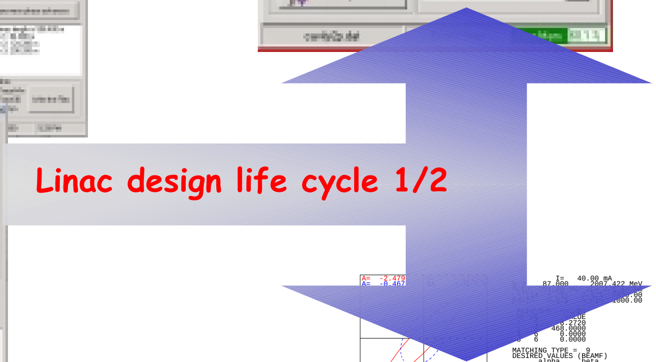
- All e.m. cavity results are stored in a database for futher parametric investigations.
- A proper file to transfer the cavity geometry to ANSYS is then generated

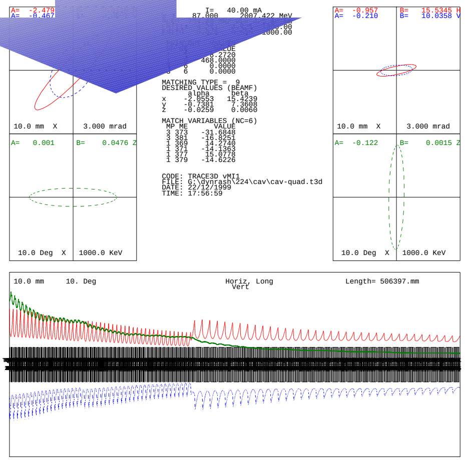
Some useful tools: for linac design

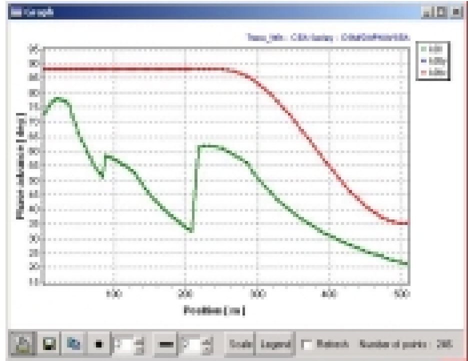
DoLinac (INFN, PP)
builds linac from simple rules, with control of longitudinal & transverse phase advances



TraceWin (CEA, Uriot & Pichoff)
Longitudinal plane in input
Lattice cell (Maille) based, very convenient to use
Very elaborate matching with great control over the transverse phase advance laws
Can directly give input and control multiparticle simulations with different codes



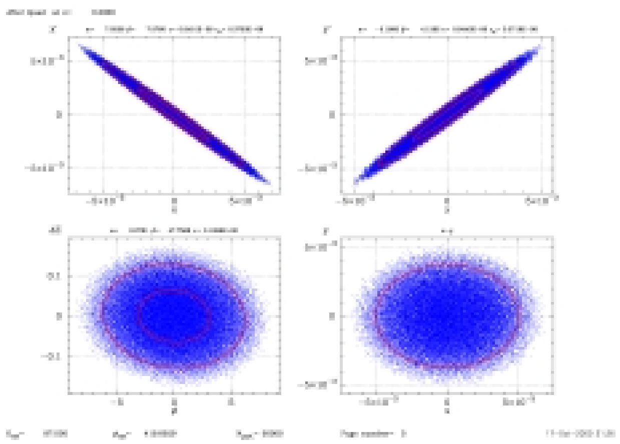


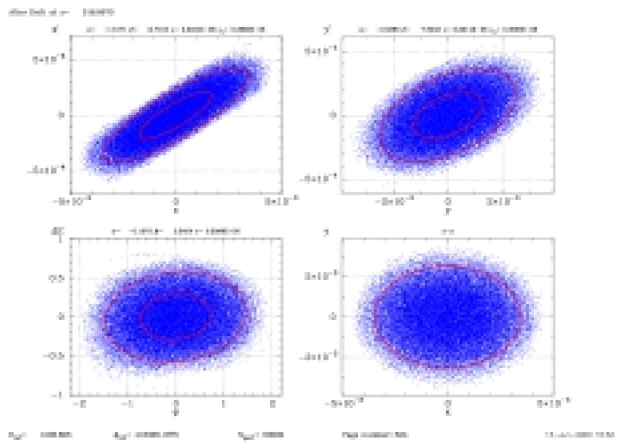


TRACE3D (originally by LANL)
Standard beam optics code
Awkward to use in this context, since it ignores the lattice periodicity
Difficult to implement transverse phase advance laws as TraceWin (so the two codes need to "talk")

Some useful tools: for PIC simulations

SCDyn (INFN/PP)
Multigrid space charge code
Cavities as on-axis "sin"-like field
t-dependent

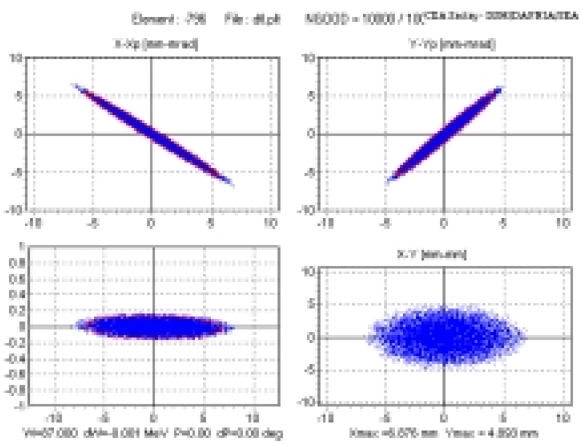


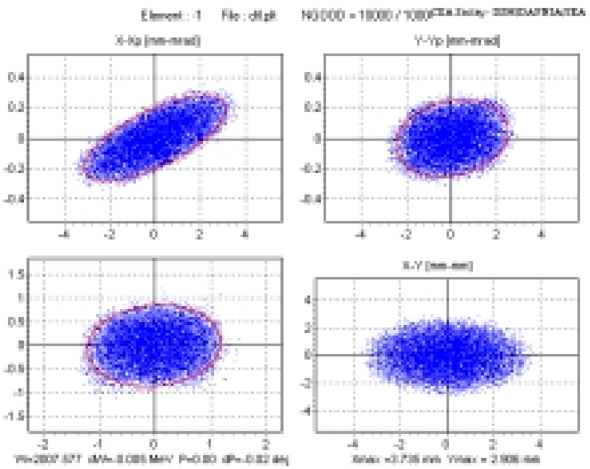


Linac design life cycle 2/2

Code Comparisons (by NP) INFN/CEA/IN2P3 Meeting Saclay, Oct 18-19, 1999

From: Workshop on R&D on SC Proton Linac Saclay, October 19-20, 2000





PARMILA/ (PARTRAN?) (CEA/Pichoff)
2D(scheff)/ 3D(PICNIC) space charge routines
Error studies
z-dependent
"Standard" code

Cavity prototypes: program and results

350 MHz cavities with CERN (MOU)

- Single cell sputtered – $\beta = 0.85$
- 5 cell sputtered – $\beta = 0.85$
- Cavity integration in a LEP type cryostat – done at CERN
- All tests reached the design goals, indeed performed as the best LEP batch

The 700 MHz activities are carried out in parallel with CEA/Saclay and IN2P3/Orsay, to optimise development efforts

- Milano works on prototypes of the lowest beta (0.47)
- Saclay/Orsay works on prototypes of the intermediate beta (0.65)

The design work is common between the labs

So far:

- Four β=0.47 single cell cavity has been built and tested with Zanon
  - Two with RRR>30 treated and tested at Saclay
  - Two with RRR>250 treated and tested at Saclay and TJNAF
- several β =0.65 single cell cavity have been built and tested by the Saclay group

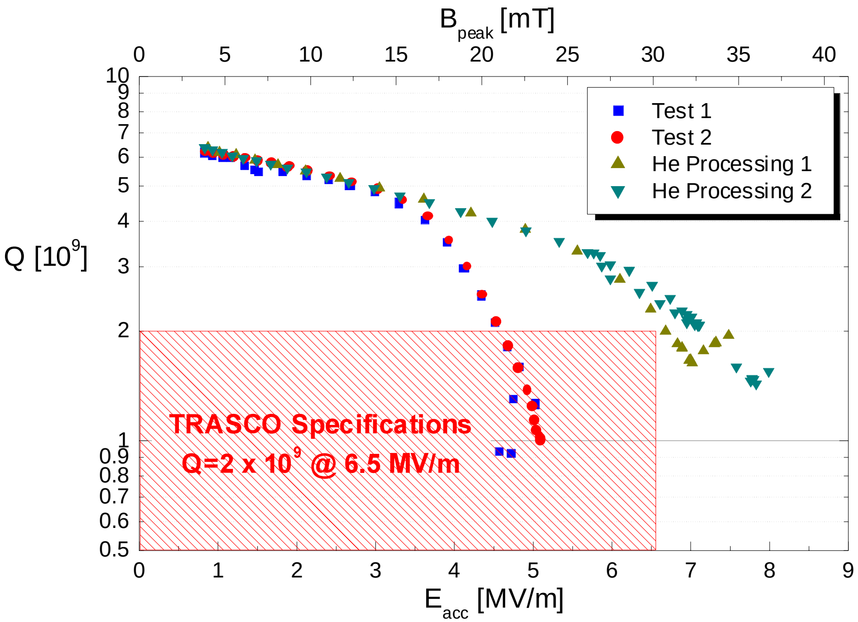
In progress:

- Two 5-cell full cavities

350 MHz prototypes with CERN

Prototypes of sputtered (Nb on Cu) cavities with the CERN 352.2 MHz technology for the LEP cavities

Single cell sputtered – $\beta = 0.85$
5 cell sputtered – $\beta = 0.85$
Cavity integration in a LEP type cryostat



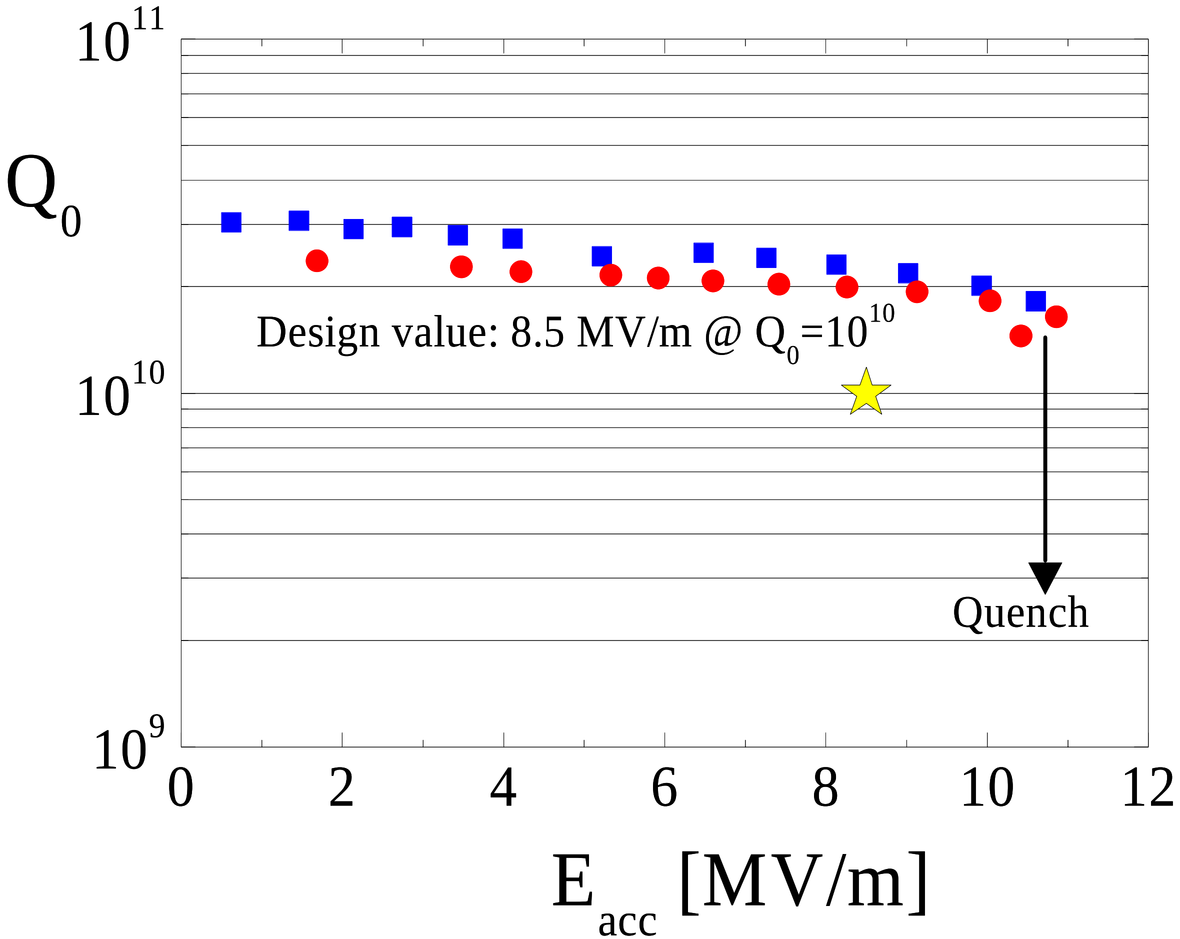
The cavities performed as the best LEP cavities, **but**

- bulk Nb needed at lower β
- moderate gradients w.r.t. 700 MHz
- longer linac

Z101 & Z102 Comparison

Fabricated with RRR>30 Niobium at Zanon

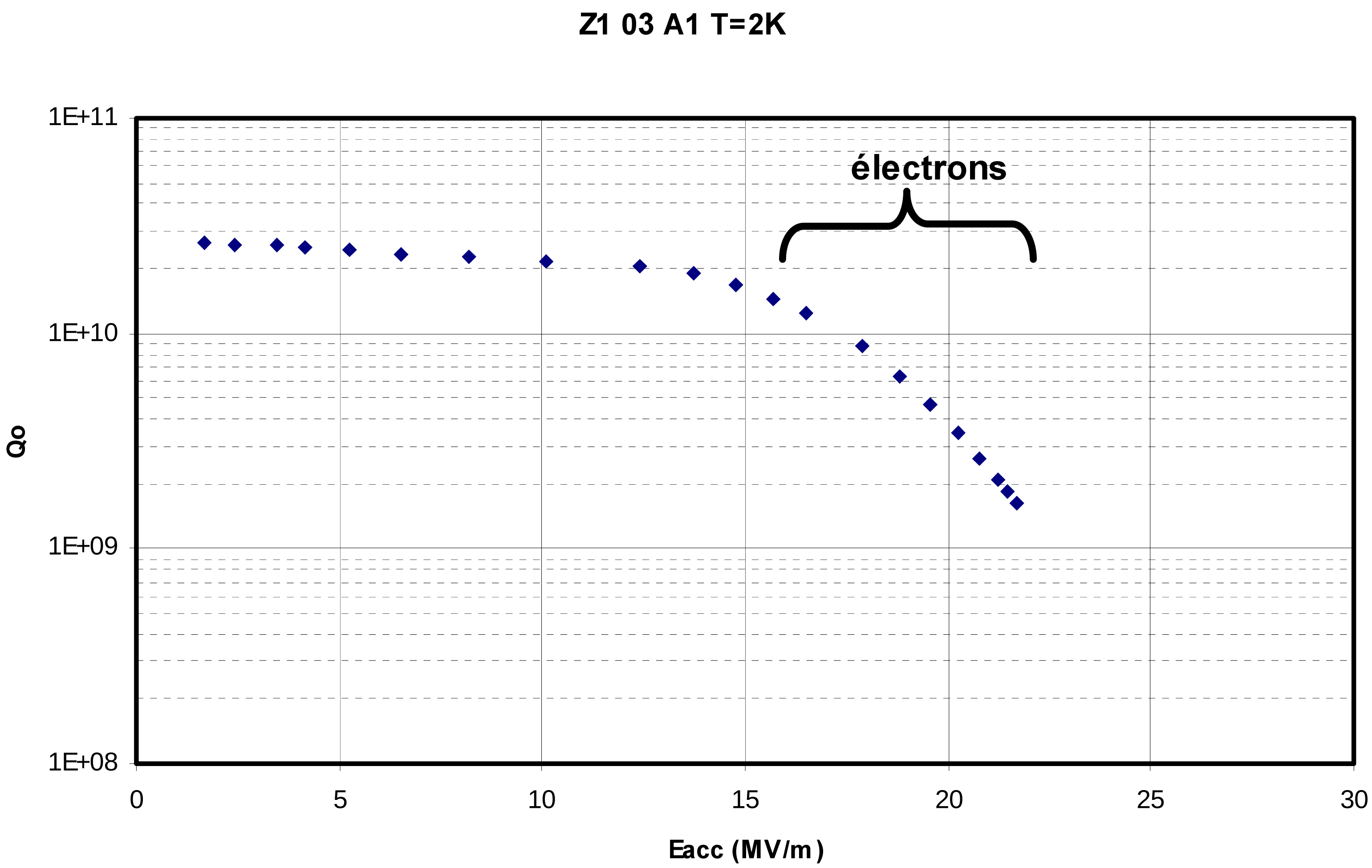
Chemical treatment, HPR and tests at Saclay



■ ■ ■ Z101 @ 1.5 K

● ● ● Z102 @ 2.0 K

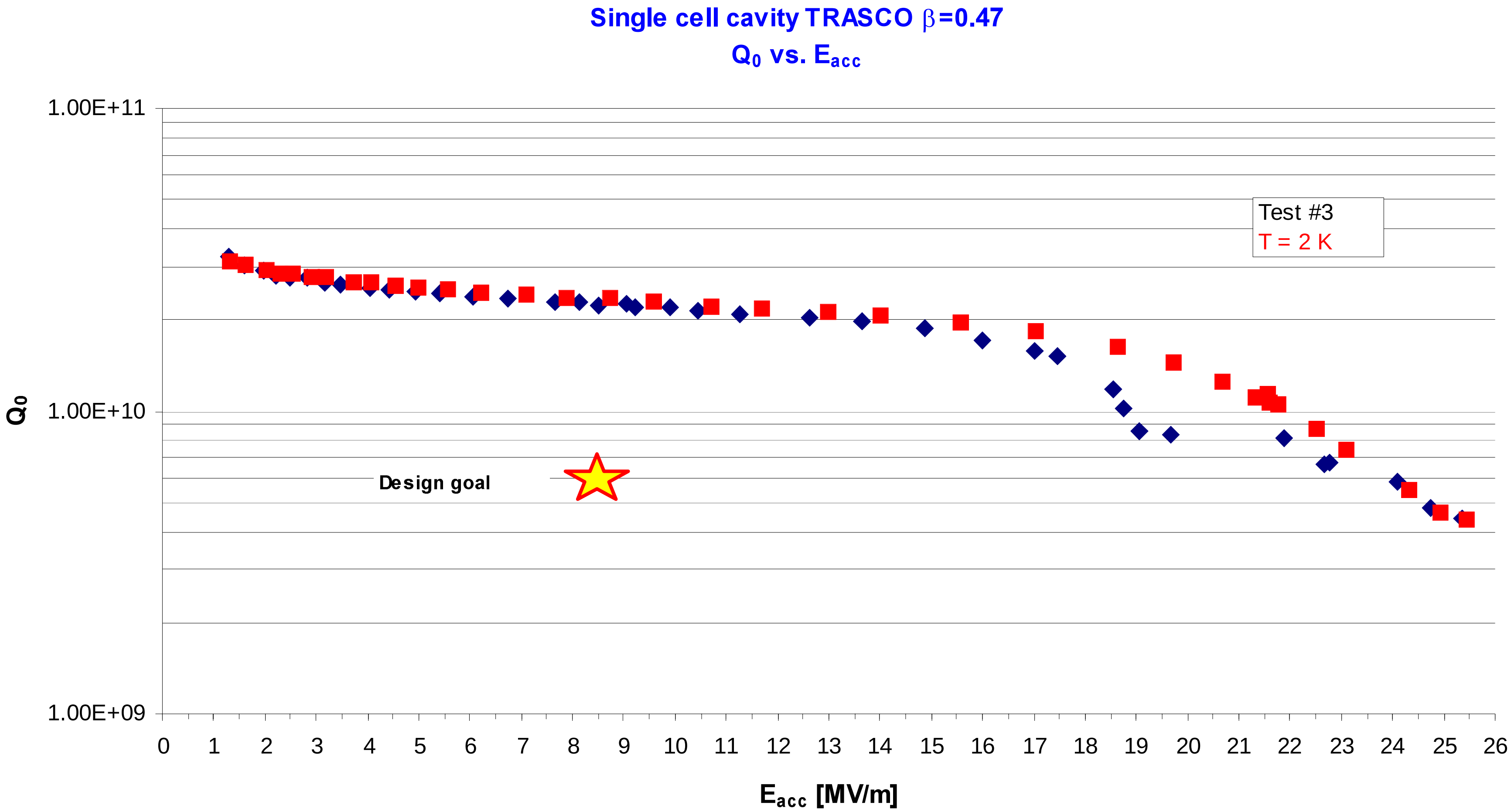
Z103 - Tested at Saclay @ T= 2 K



Z104 - Tested at TJNAF @ T = 2 K

Epeak/Eacc = 2.9
Bpeak/Eacc = 5.4 mT/(MV/m)

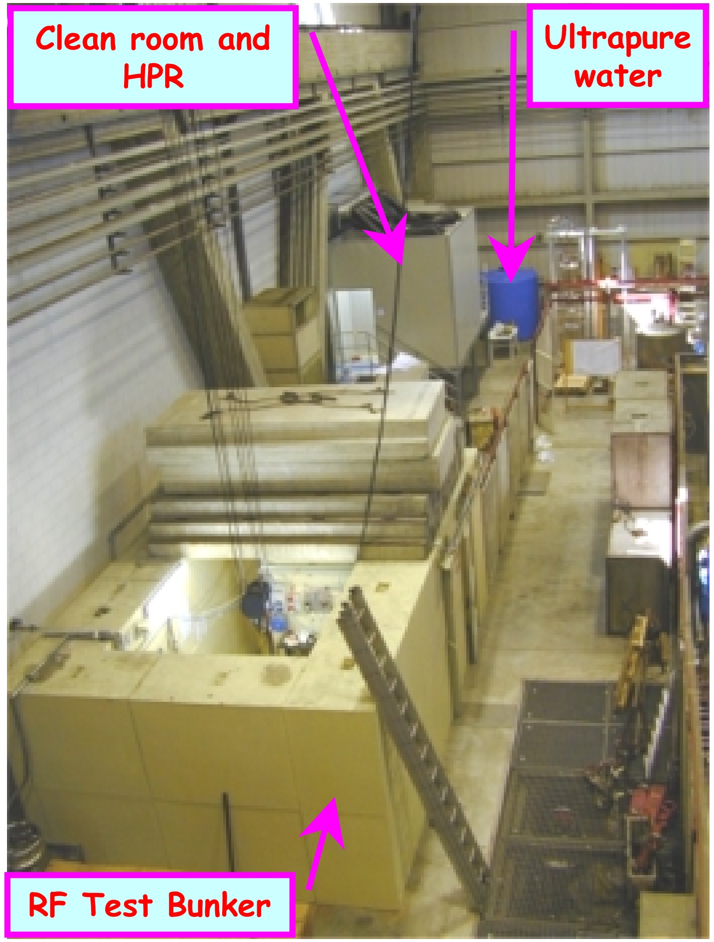
Max Epeak = 74 MV/m
Max Bpeak = 138 mT



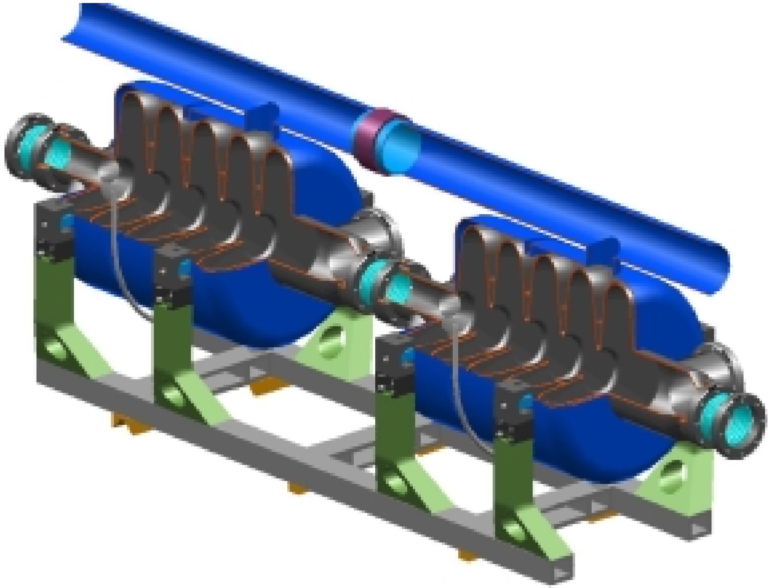
Cavity test infrastructure in Milano

Clean Room, HPR station & vertical cryostat

- HPR station in a class 100 clean room
- RF test bunker with a vertical cryostat



Other Activities in Milano



Cryomodule engineering studies

- Based on the TTF/TESLA experience
- Sliding cavity fixtures
- Single thermal shield with integrated cooling pipes: "finger welds"

Tests on piezo-tuner for Lorentz-forces and microphonics compensation

- Using the same piezo chosen at DESY for TESLA
- Static and dynamic piezo characterization
- Tests of an adaptive system for frequency stabilization