EPAC 2002

Paris, 3-7 June 2002

Status of the High Current Proton Accelerator for the TRASCO Program

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on behalf of the TRASCO_ACC group

TRASCO_ACC

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Istituto Nazionale di Fisica Nucleare

The TRASCO Program

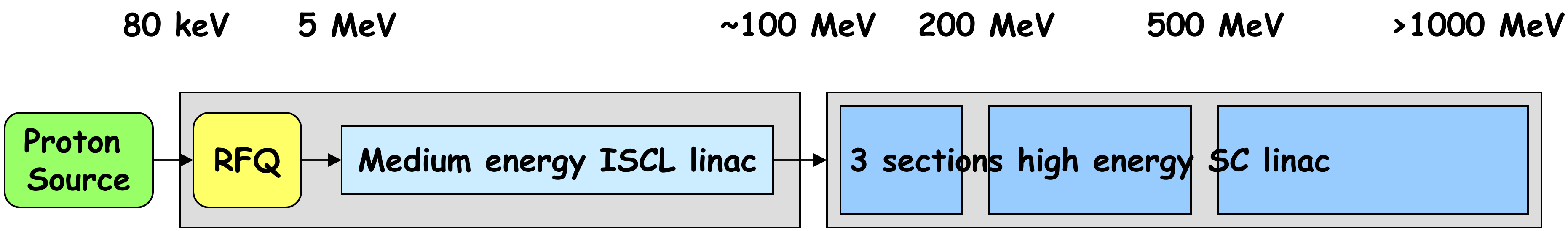
TRASCO: **conceptual study** and the **prototyping of components** for an **accelerator driven system for nuclear waste transmutation**, and involves research agencies and Italian companies

- TRASCO/ACC
  - **Accelerator studies**: lead by INFN
- 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 and R&D activities on key items:
  - an 80 kV, 35 mA proton source (**INFN - LNS**)
  - a 5 MeV, 30 mA, CW RFQ (**INFN - LNL**)
  - SC cavity prototypes for low β cavities (<100 MeV) (**INFN - LNL**)
  - SC cavity prototypes for β = 0.47 elliptical cavities (**INFN - MI**)
  - SC cavity prototypes for β = 0.85 sputtered cavities (**INFN - GE**)
  - engineering of elliptical SC linac components (cryomodules, etc.) (**INFN - MI**)

The Reference Linac Design



Source	RFQ	ISCL	High Energy SC Linac
Microwave RF Source High current (35 mA) 80 keV	High transmission 95% 30 mA, 5 MeV (352 MHz)	5 - 85/100 MeV SC linac Baseline design: Reentrant cavities (352 MHz) Alternative design: Spoke, λ/2, λ/4, ladder 8βλ FODO focussing with sc magnets	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

Beam Dynamics

TRIPS: TRASCO Intense Proton Source

High intensity (tens mA) proton sources exist
- Chalk River, Los Alamos, CEA-Saclay

ADS asks for high reliability and availability

Additional efforts are required for:
- Voltage and current stability
- Control of the low beam emittance

Design in 1999, source in LNS in May 2000

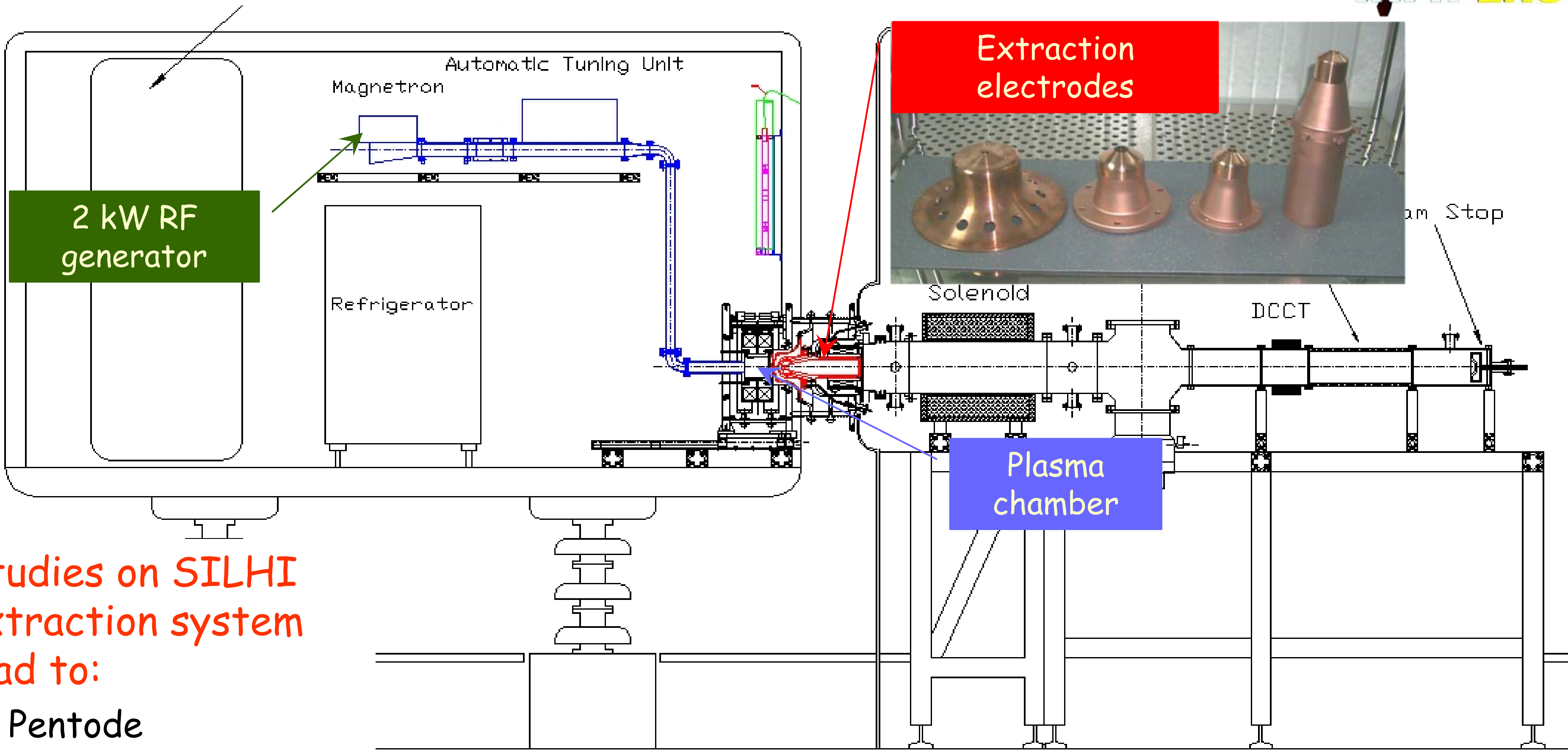
Achievements:
- First beam of 20 mA @ 60 kV in Jan 2001
- 80 kV, 55 mA operation in Aug 2001

Off-resonance microwave discharge source (2.45 GHz), based on SILHI (CEA/Saclay)

TRIPS Goals:		Achieved
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**

Reported at EPAC2000, PAC2001

Layout of the Source and LEBT



Studies on SILHI extraction system lead to:

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

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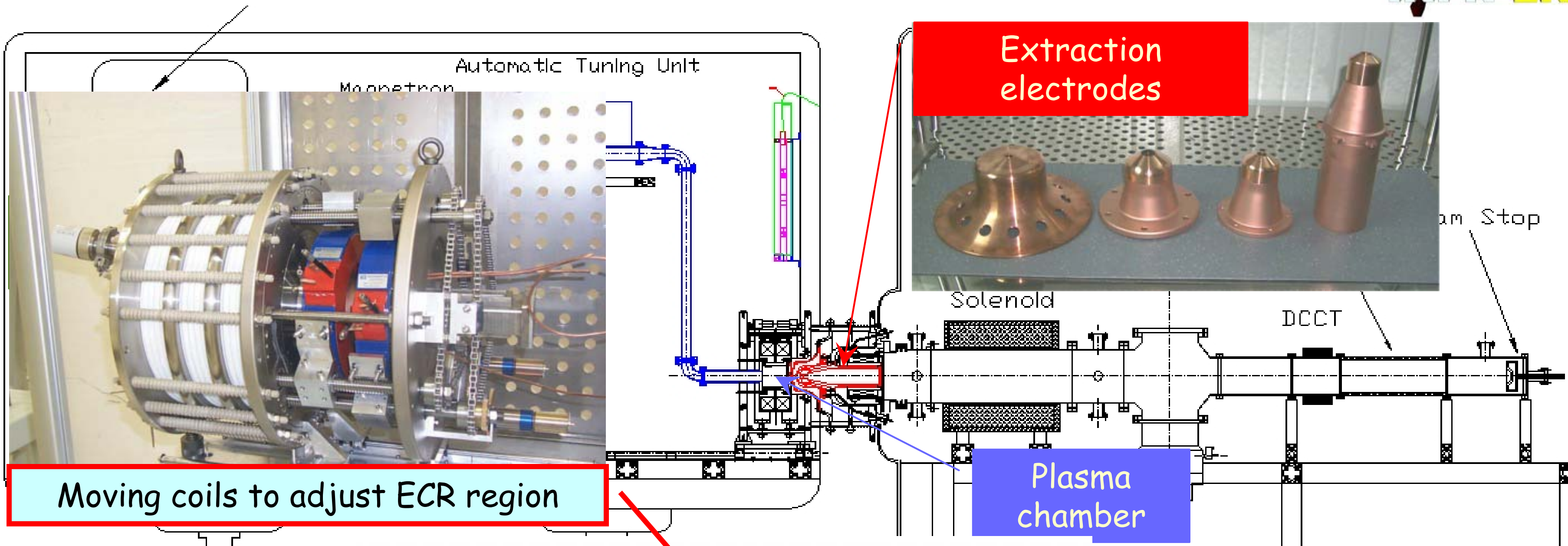

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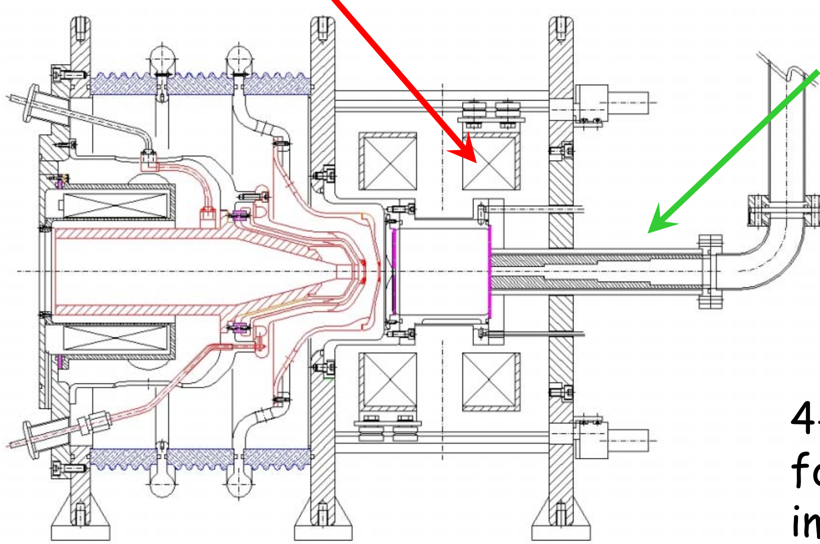


Matching transformer (impedance match)

4-step binomial transformer for waveguide to plasma impedance matching

Performances and recent development

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

- Emittance unit from CEA is being shipped to Catania for measurements

LEBT for beam analysis and characterization:

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

Reliability tests have been performed:

- **at 65 kV/15 mA: 24 h with no beam interruptions**
- **Tests at 80 kV are underway (improving)**

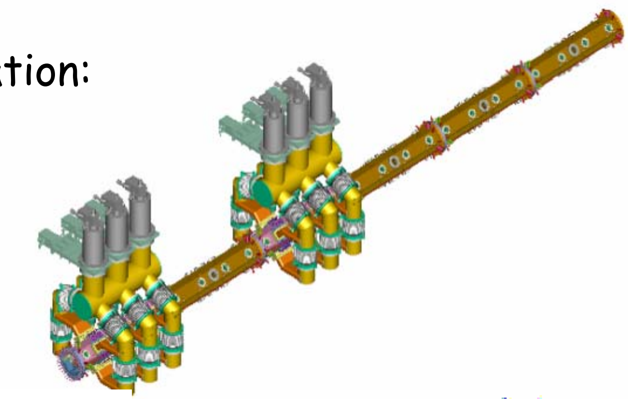
A new control system for automatic restart procedures after discharge is being implemented

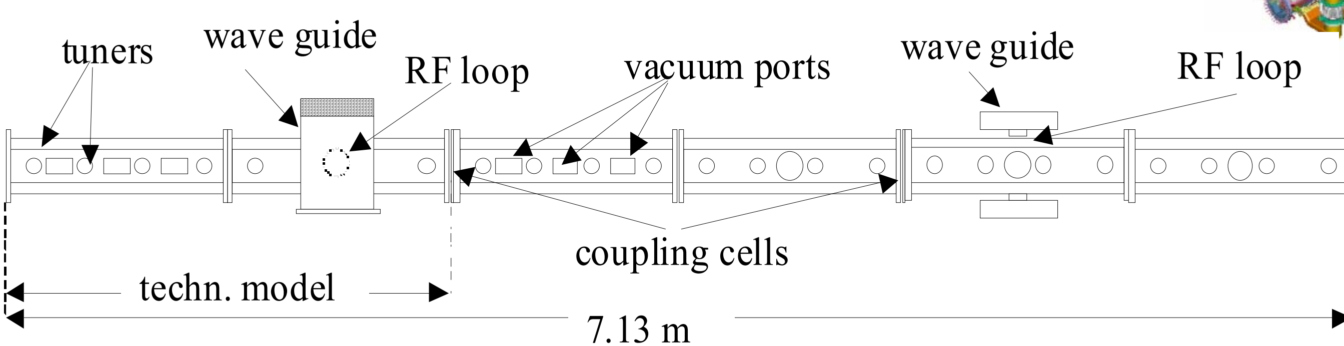
Low Energy Linac

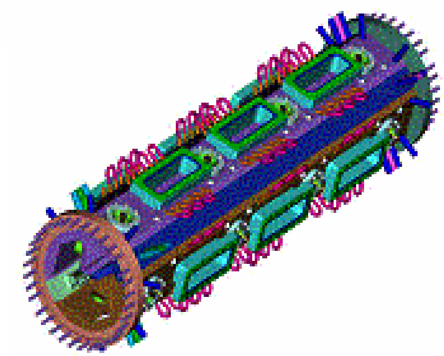
Papers contributed to this Conference (TU and TH)

The low energy linac is split in two components:

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







- A superconducting linac (ISCL): from 5 MeV to 100 MeV
  - Reentrant cavities for highest availability (allowing beam on with 1 cavity off)
  - $\lambda/4$, $\lambda/2$ cavities
  - Spoke cavities

RFQ Design

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

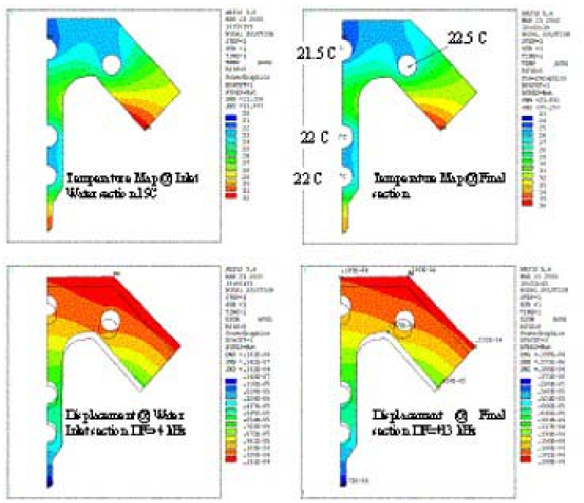
- Limit to 1 RF source (1.3 MW CERN-LEP klystron)
- Lower design current of 30 mA (transmission of 96%)
- Peak surface electric field is 33 MV/m, 1.8 Kilpatrick limit
- Simplified engineering/manufacturing choices

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

Poster THPLE083: Field tuning of the TRASCO RFQ



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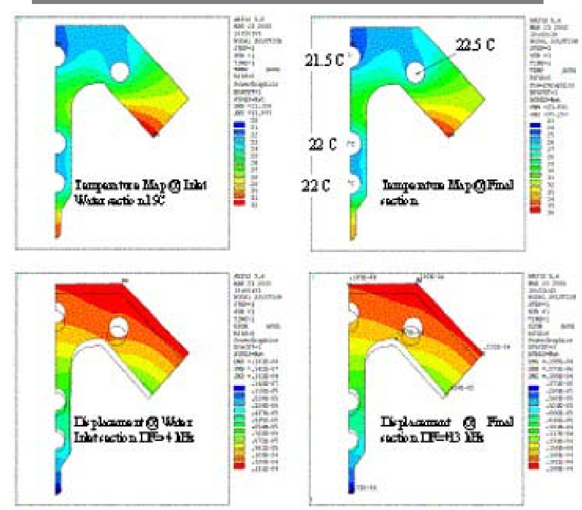
TRASCO RFQ:	
Beam current	30 mA (96 % transmission)
Peak Field	1.8 Kilpatrick

Copper dominated

- Not space charge limited
- Not beam loading limited
- 150 kW to beam
- 600 kW to copper

Poster THPLE083:
Field tuning of the TRASCO RFQ



RFQ: fabrication tests

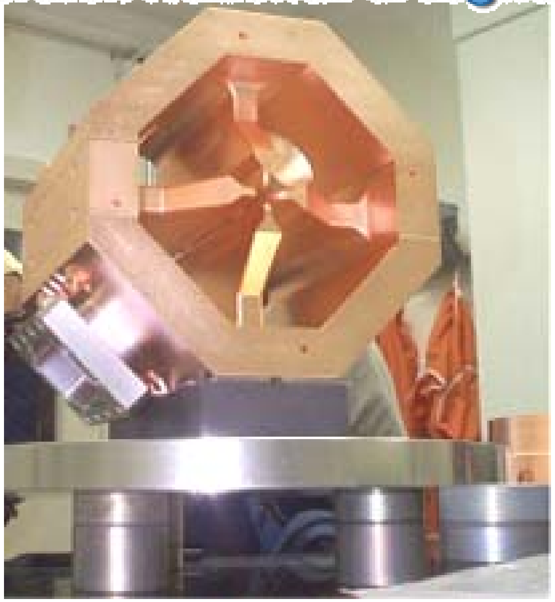
Laboratori Nazionali di Legnaro

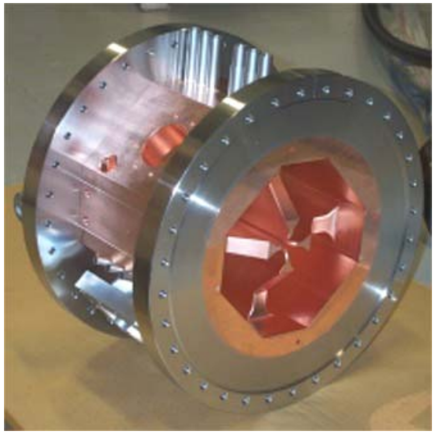
A 3 m Al model of the structure has been built and measured at LNL, and achieved the necessary field stabilization

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

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

Full structure is under fabrication





Superconducting low energy linac

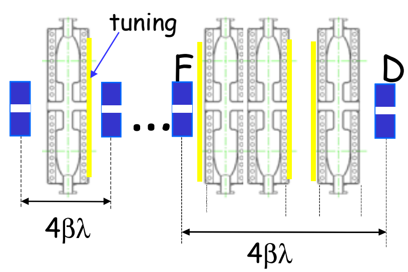
Single or two-gap structure linac

- Moderate energy gain/cavity
- Solid state RF amplifiers
- 8 βλ focussing lattice

Poster TUPLE121: A 2.5 kW, Low Cost 352 MHz Solid State RF Amplifier for CW and Pulsed Operation

Various options, are being considered

- Reentrant cavities
- Spoke cavities
- λ/4 cavities
- ladder



Poster THPDO022: RF testing of the TRASCO SC Reentrant Cavity for High Intensity Proton Beams

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

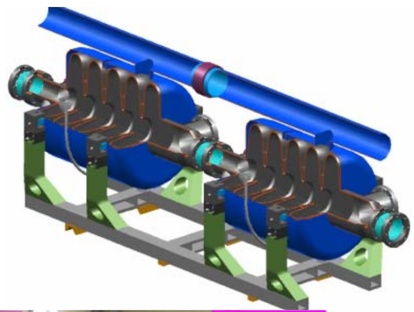
2 gap spoke cavity

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

The high energy linac

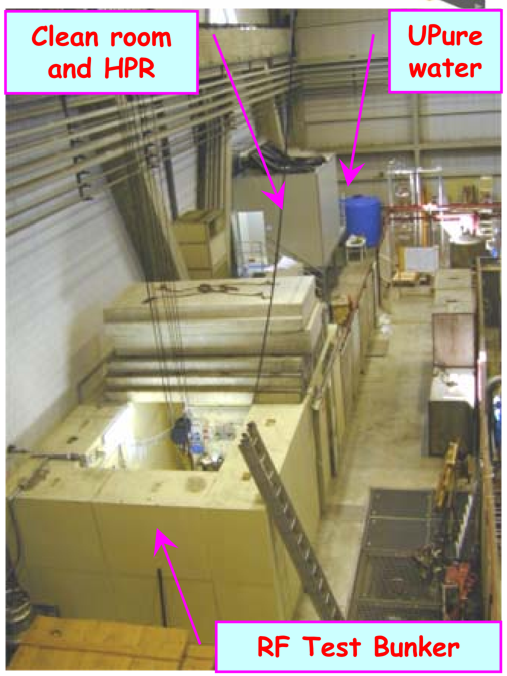
Papers contributed to this Conference (WE and TH)

- Conceptual design of the 3 section linac
- Development and test of prototype cavities
  - At 352 MHz with the LEP II sputtering technology
  - At 704 MHz, bulk niobium, for the lowest β
- Design and engineering of cavity components and ancillaries
  - Cryomodule, tuner system, piezo damping, …
- RF Test infrastructure



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

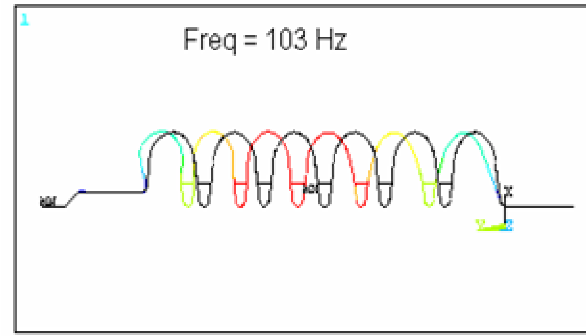
Section β	0.47	0.65	0.85
# cells/cavity	5	5	6
Length	50 m	93 m	102 m
Initial/Final Energy	100 MeV	190 MeV	480 MeV
	190 MeV	480 MeV	1 GeV
Doublet period	4.2 m	5.8 m	8.5 m
# periods	12	16	12
# cavities in section	24	48	48
Max. Eacc (MV/m)	8.5 MV/m	10.2 MV/m	12.3 MV/m

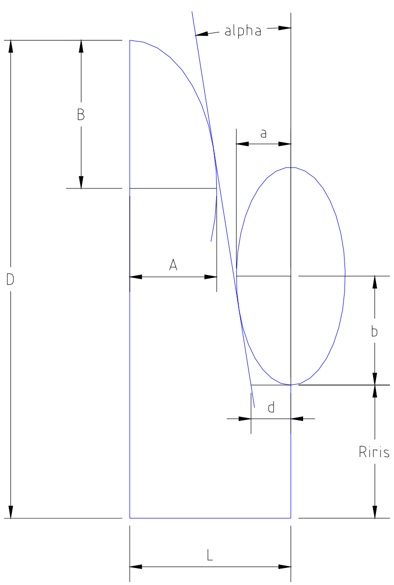


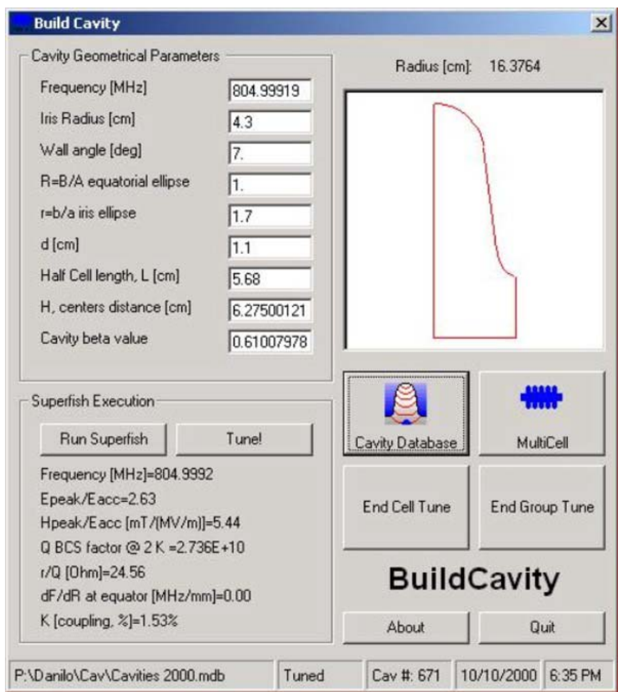
Conceptual design: cavity design

- Parametric tool for the analysis of the cavity shape on the electromagnetic (and mechanical) parameters
- Inner cell tuning is performed through the 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)

Longitudinal eigenmode analysis





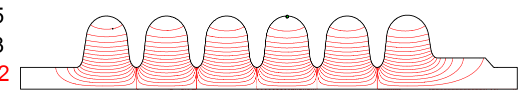


Tool used also for the **SNS** cavity design

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



KL70 = -0.7 [Hz/(MV/m)²] KL80 = -0.8 [Hz/(MV/m)²]

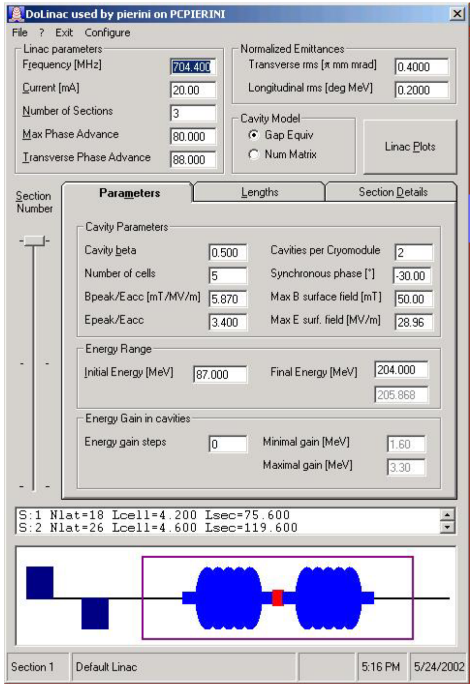
Nb thickness = 3.8 mm

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

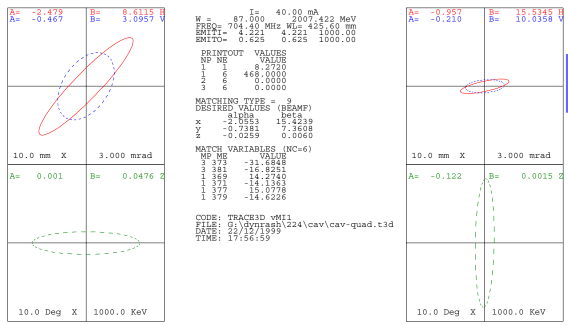
Conceptual design: linac design

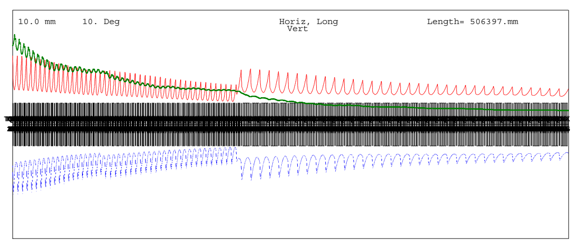
INFN Milano LASA



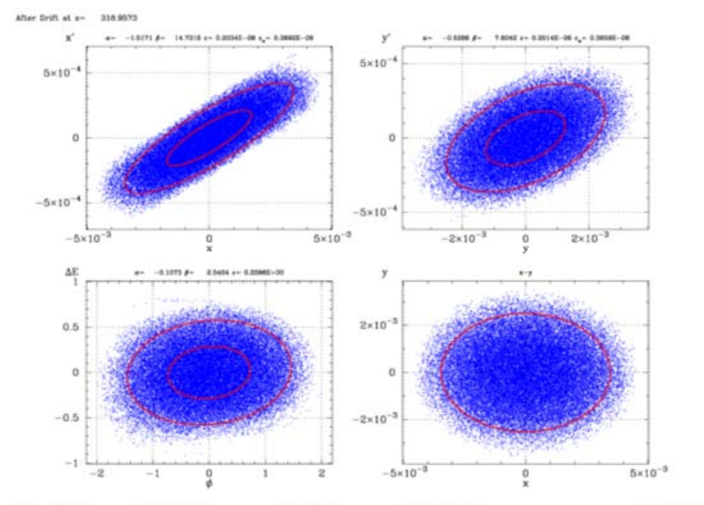
Build linac from **simple rules**, with **control of longitudinal & transverse phase advances**

Find **matched beam** solution in all linac





Run non-linear multi-particle simulations for confirmation of design



Poster WEPLE109:
Adiabatic Matching in Periodic Accelerating Lattices for Superconducting Proton Linacs

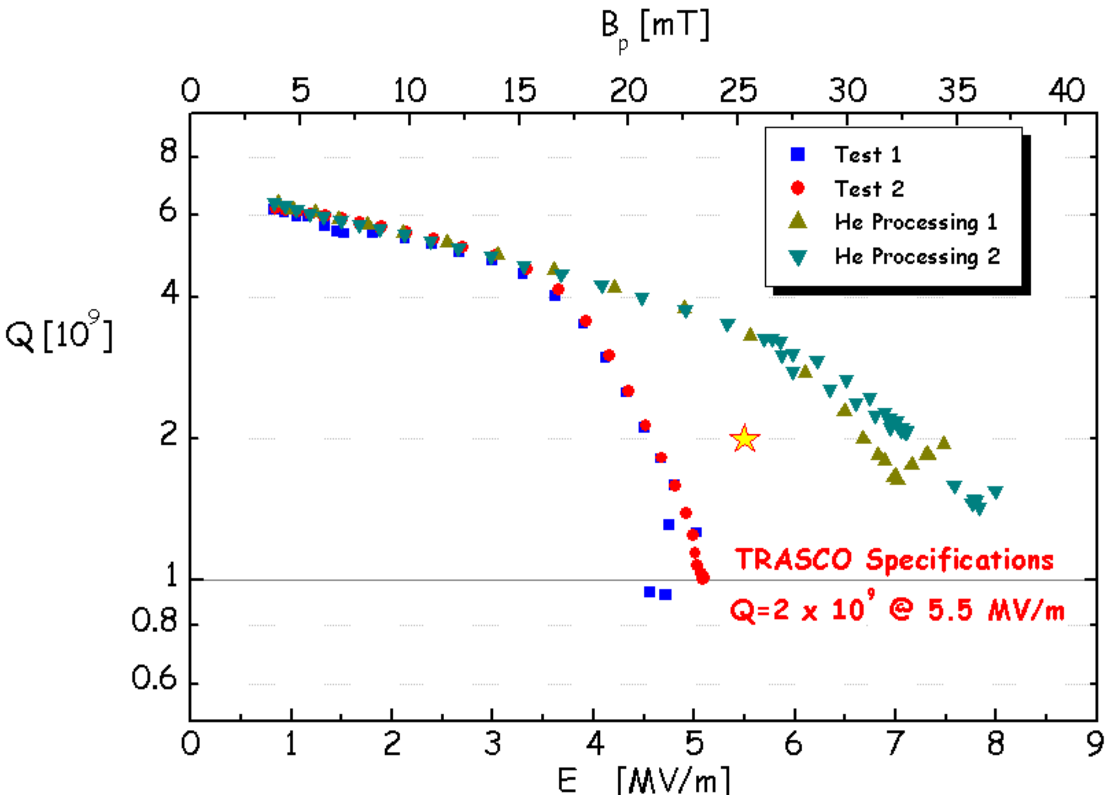
352 MHz β=0.85 prototypes with CERN

352 MHz cavities with CERN (MOU)

- Use LEP II sputtering technology
- Single cell and 5 cell sputtered – β = 0.85
- Cavity integrated in a LEP type cryostat

All tests reached the design goals, indeed performed as the best LEP batch

But: Bulk niobium is needed at lower β, and the gradient is moderate w.r.t 704 MHz



Test in a modified LEPII cryomodule (Aug. 2001)

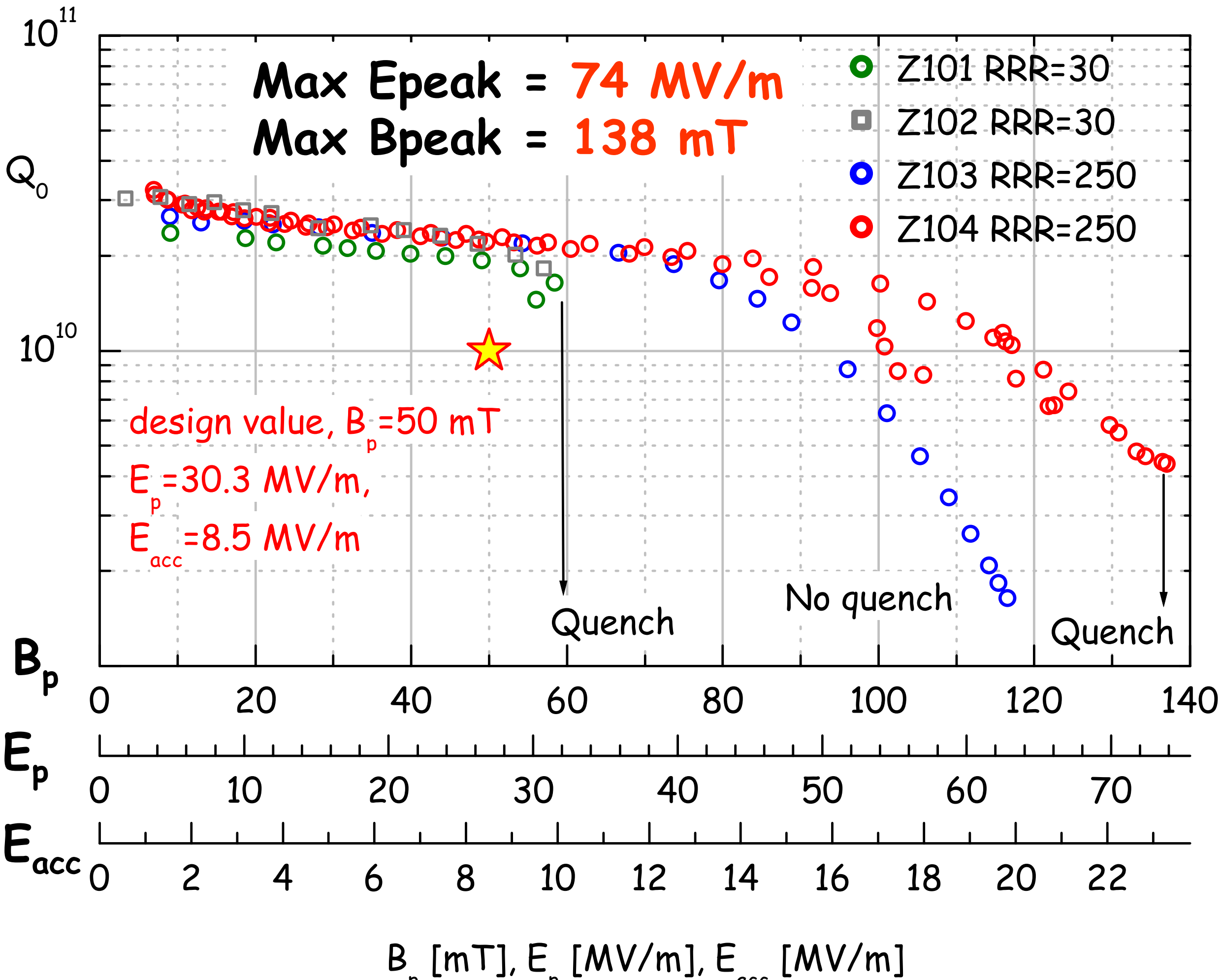
- Powered to 250 kW
- 7 MV/m

β=0.47 single cell cavities prototypes

INFN Milano LASA

Fabricated with RRR>30 & RRR>250 Niobium at Zanon

BCP, HPR and tests at TJNAF (Z104) and Saclay (Z101-Z103)



For 1-cell:

E_p/E_{acc} = 2.90

B_p/E_{acc} = 5.38 mT/(MV/m)

For 5-cell:

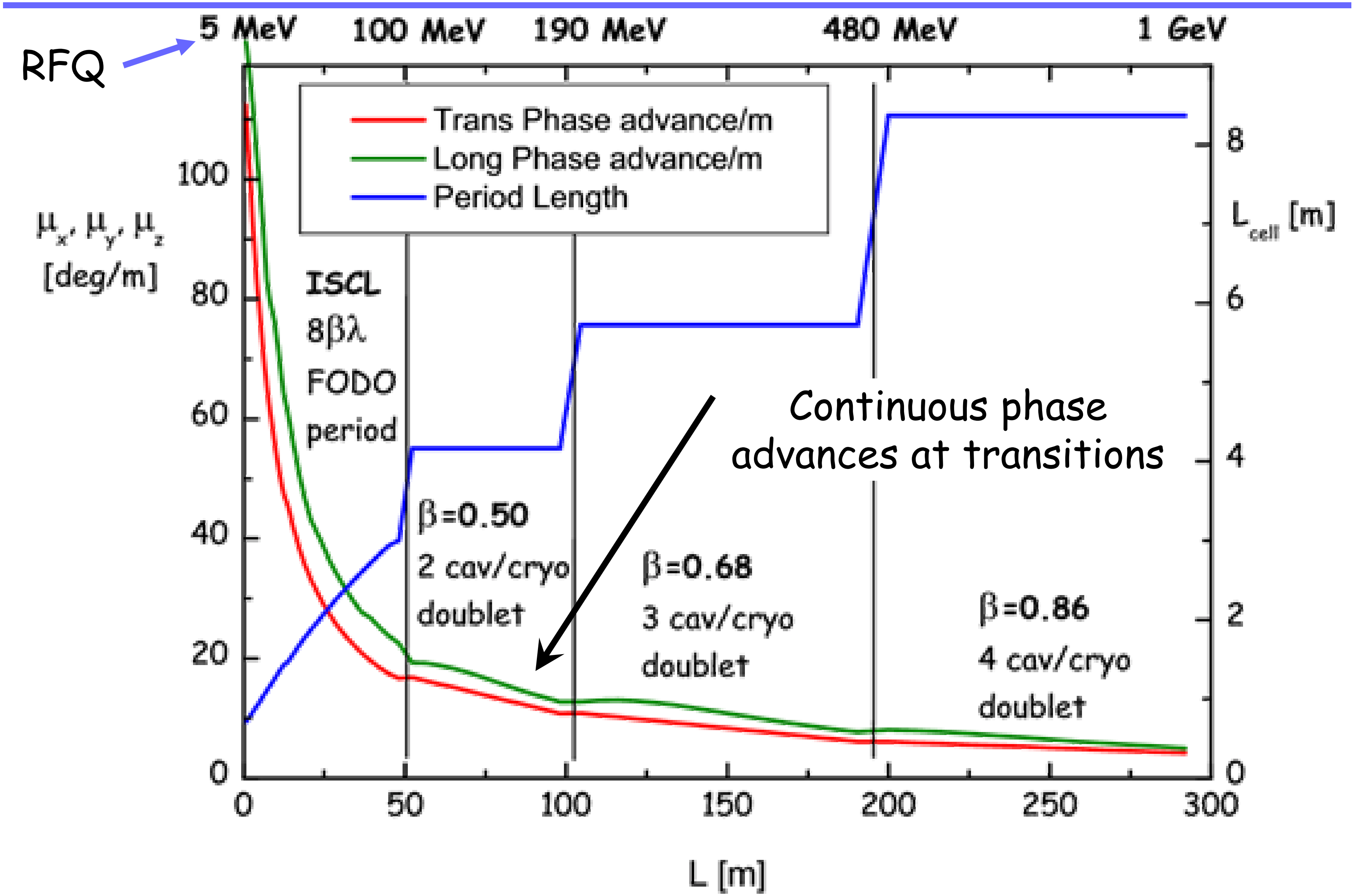
E_p/E_{acc} = 3.57

B_p/E_{acc} = 5.88 mT/(MV/m)

Two 5 cell cavities are under fabrication

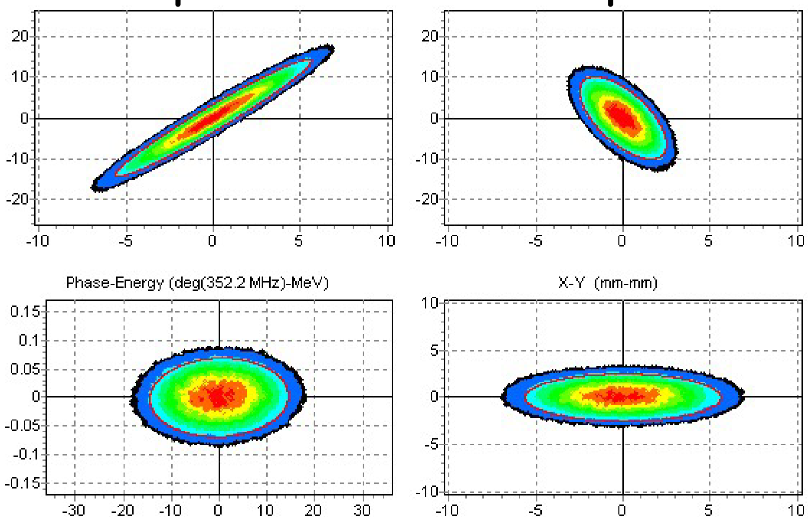
Poster THPDO023: RF Tests of the Single Cell Prototypes for the TRASCO β=0.47 Cavities

Baseline of the "smooth" linac design

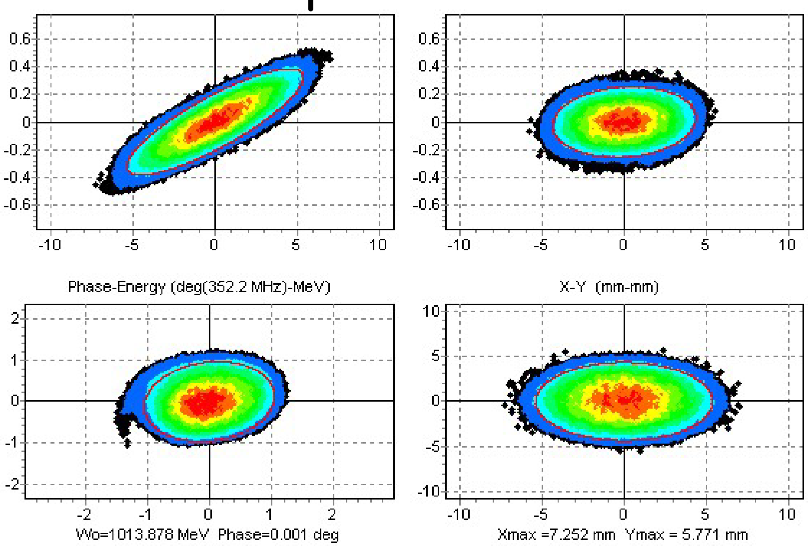


Full SC linac from 5 MeV to 1 GeV

Input @ 5 MeV 10^5 ptcl

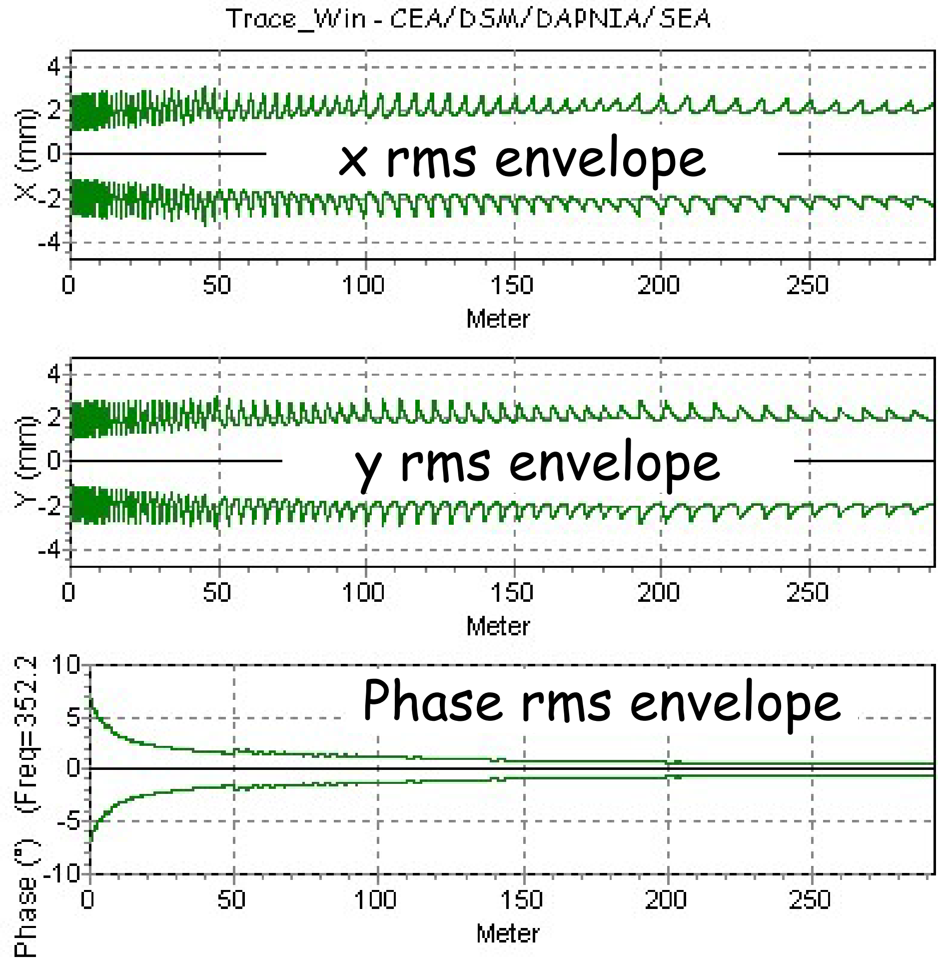


Output @ 1 GeV

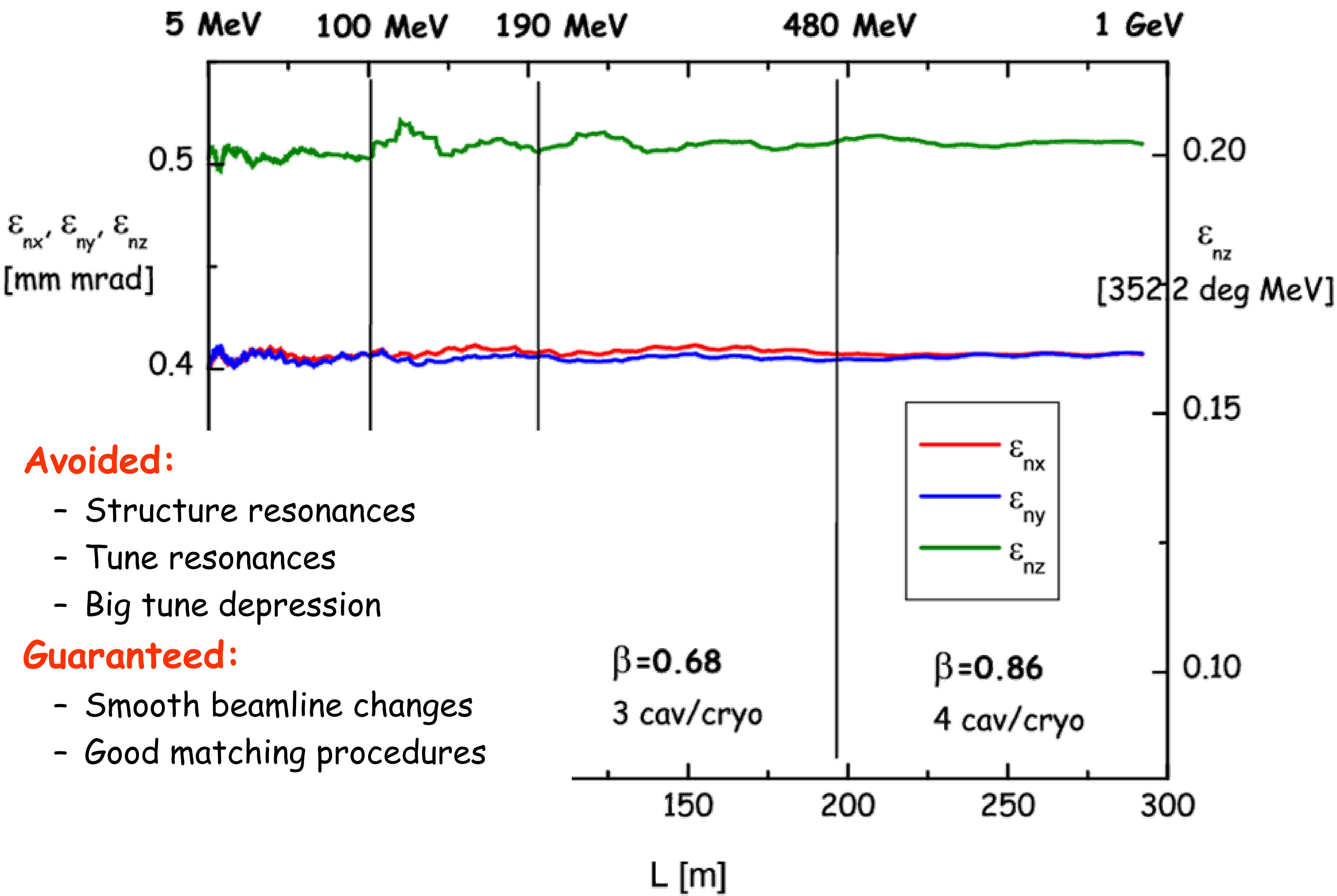


Results of non-linear simulations

No particle losses, beams well confined



Rms emittances growth (from end of RFQ to full energy) < 2%



Avoided:

- Structure resonances
- Tune resonances
- Big tune depression

Guaranteed:

- Smooth beamline changes
- Good matching procedures

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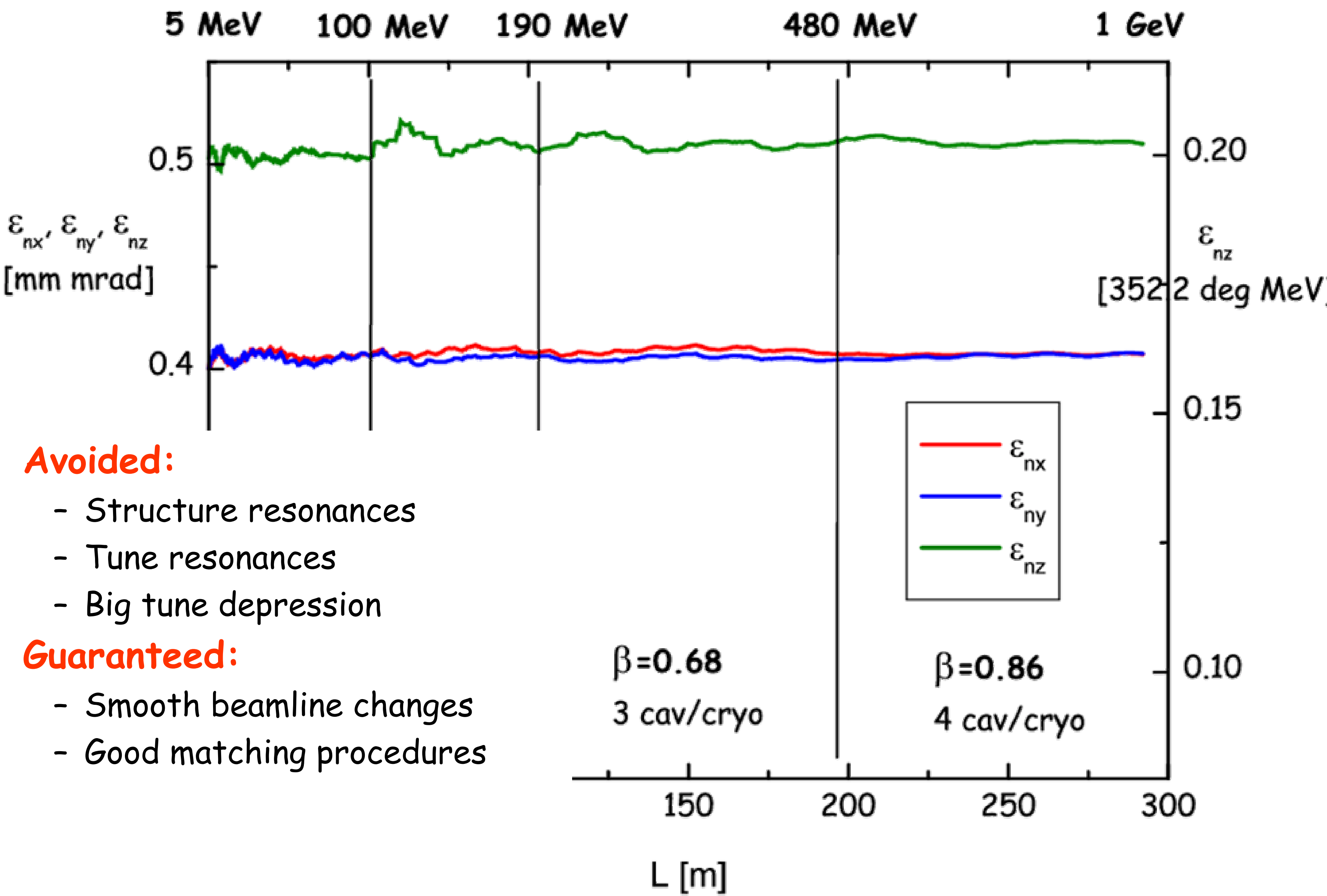

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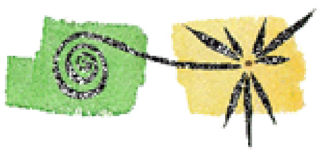
Perspectives

The effort to build a complete ADS system exceeds the capabilities (and the funding availability) of any national program like TRASCO

- TRASCO means to provide significant R&D and prototipical effort along the road to the design of a transmuter system
- cfr. "*A European Roadmap for Developing Accelerator Driven Systems (ADS) for Nuclear Waste Incineration*", by the European Technical Working Group on ADS, April 2001
(available in http://itumagill.fzk.de/ADS/)



Already in the FP5 of the European Commission a Program has been funded: "**PDS-XADS** – **P**reliminary **D**esign **S**tudies for an e**X**perimental **A**ccelerator **D**riven **S**ystem"

- 25 Partners, from Research Institutions to EU Industries
- 12 M€ Program (50% supported by the Commission)
- Several Working Packages, dealing with various aspects of an ADS
- WP3 is dedicated to the Accelerator

More to come in the FP6 …