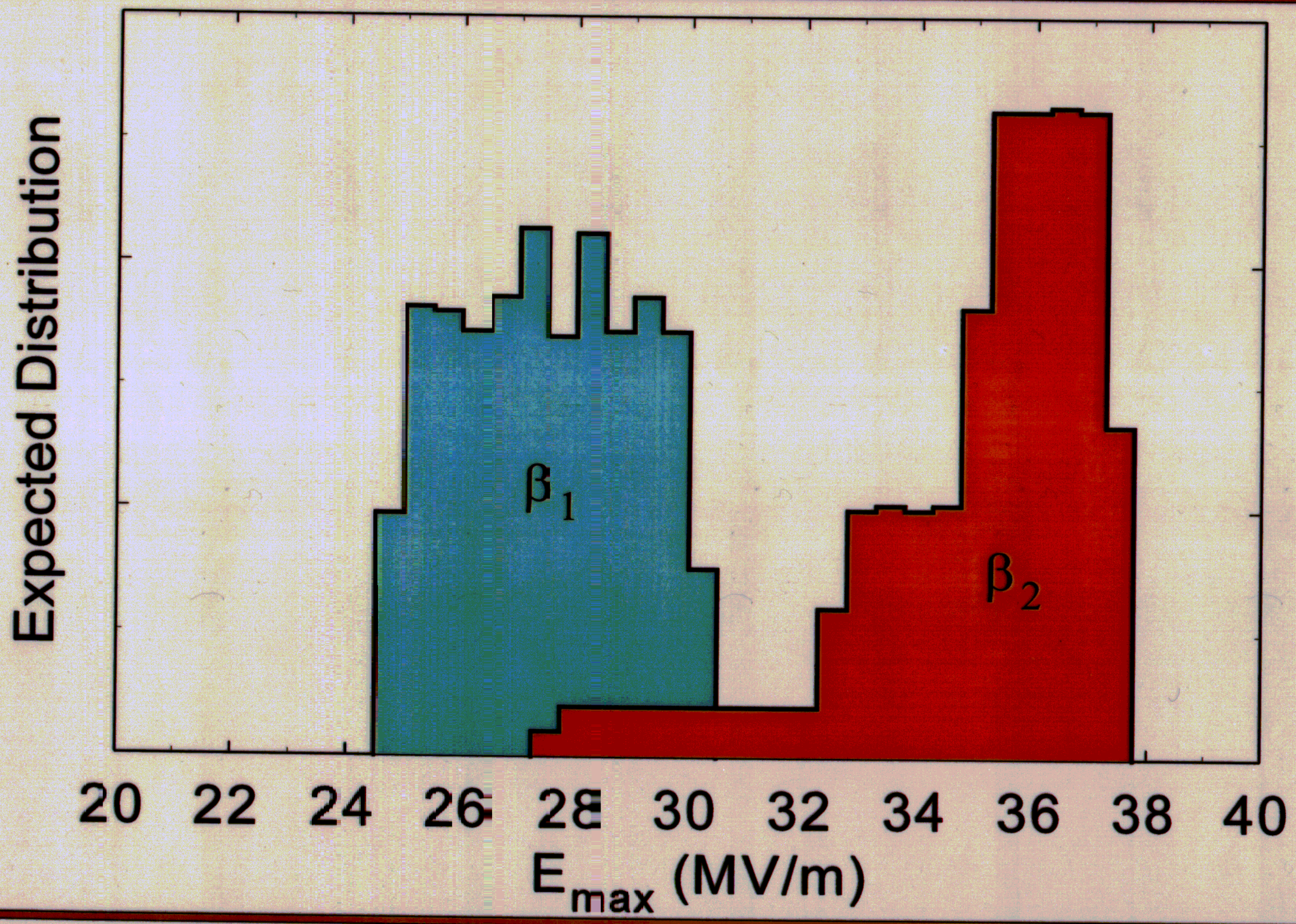
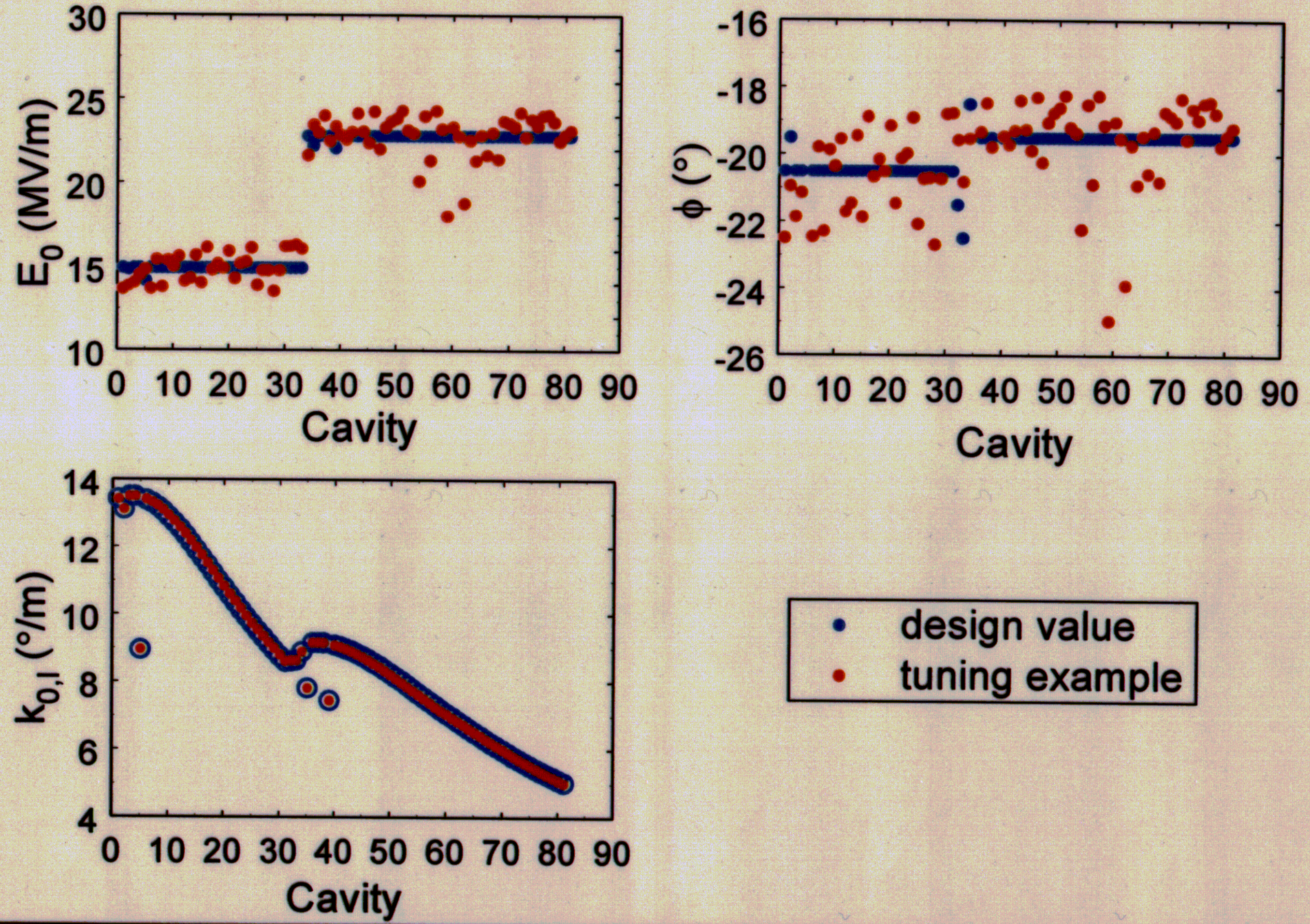
Expected (a la TJNAF) SRF-Cavity Design β Distributions



Design Philosophy: Set $\phi_s = \phi(E_0)$ for Each Cavity to Preserve $k_{0,l}$



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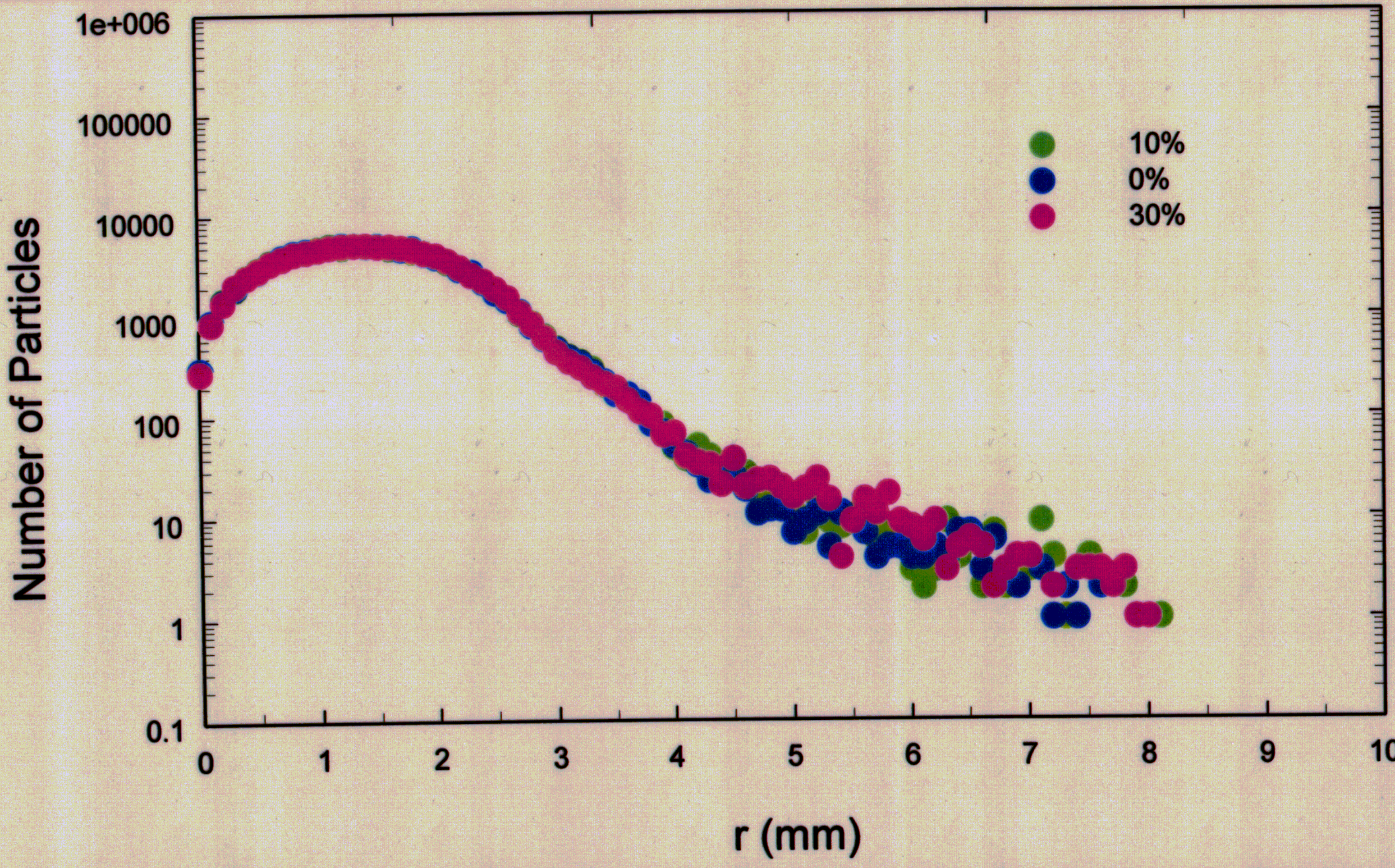
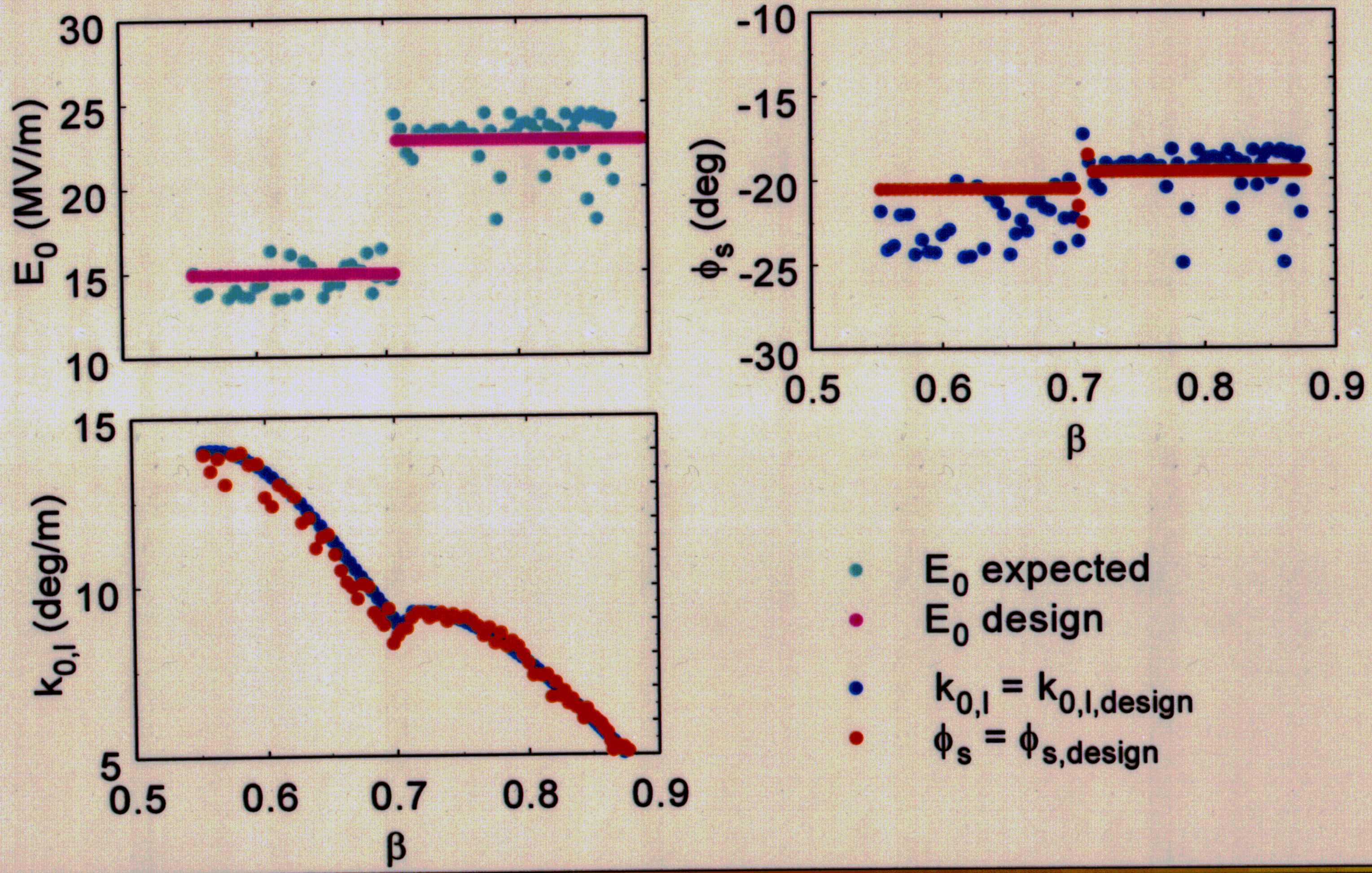
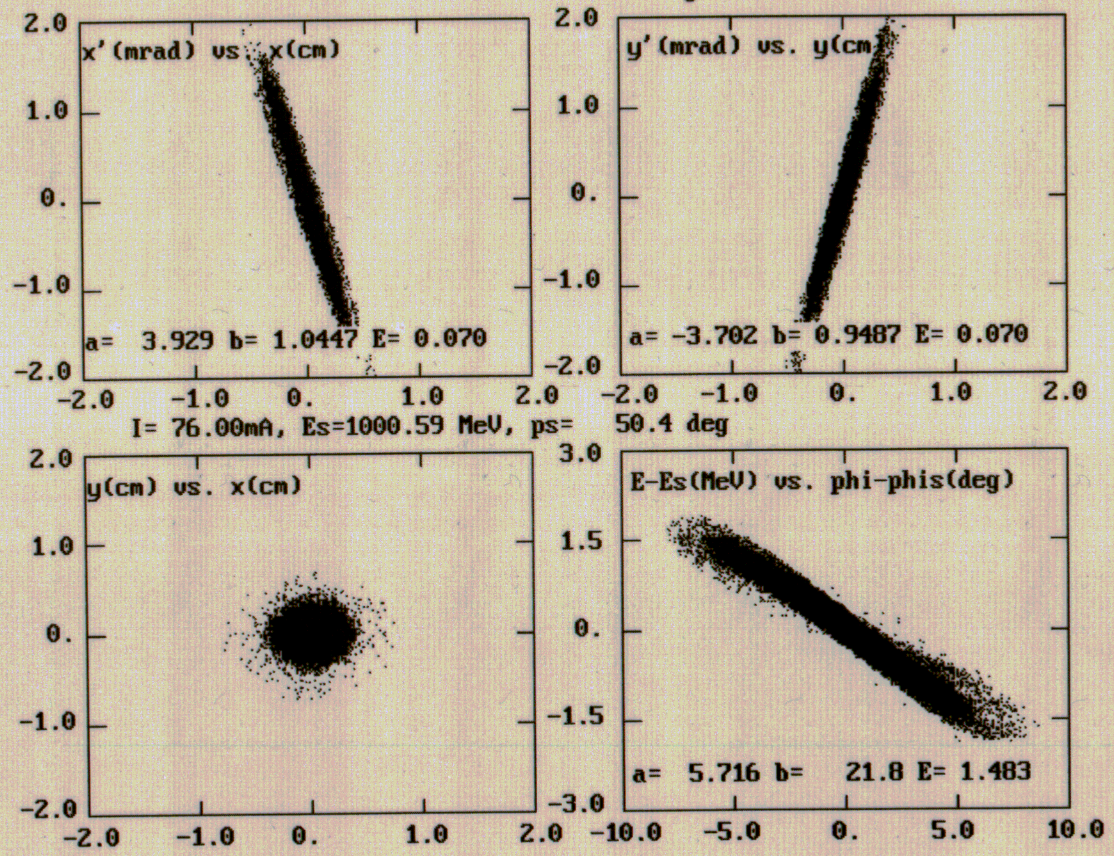
Radial Distributions at the End of SRF Linac for E_0, E_0 ±10%, E_0 ±30% are Barely Distinguishable



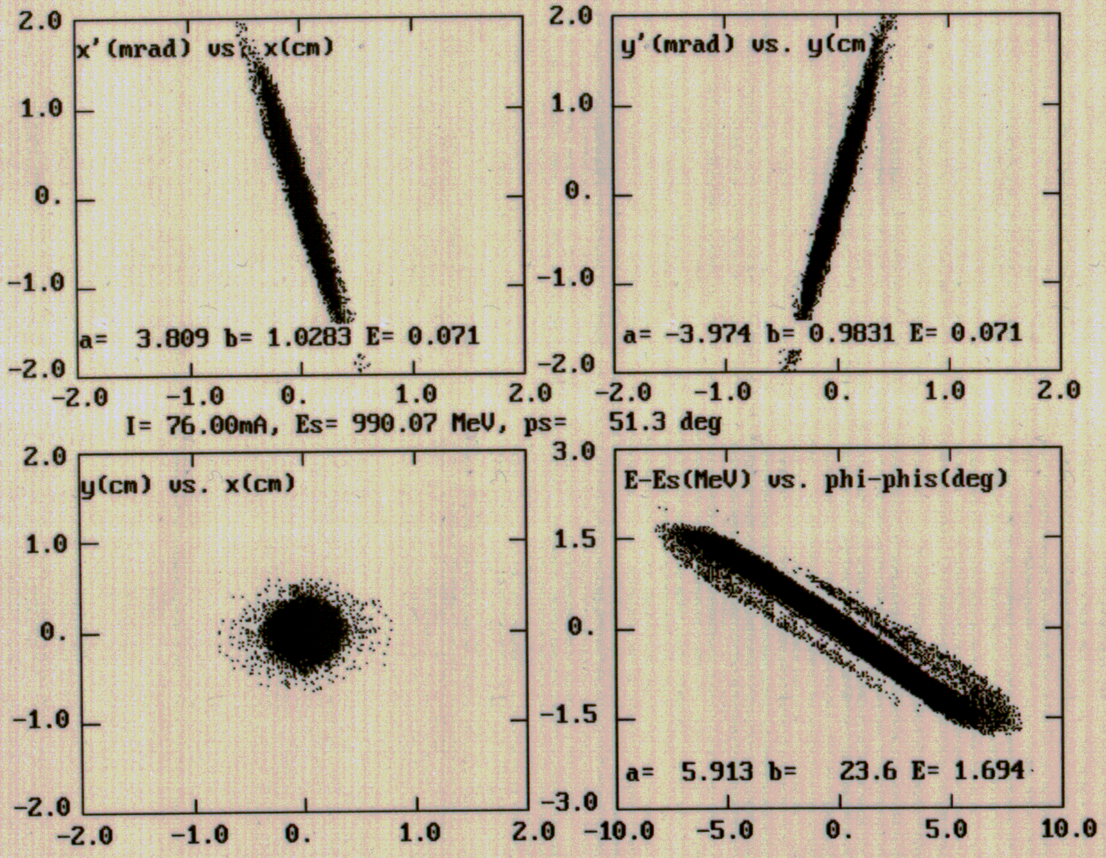
Constant ϕ_s is a Deviation from Design Tune -- Results in a Distributed Longitudinal Mismatch



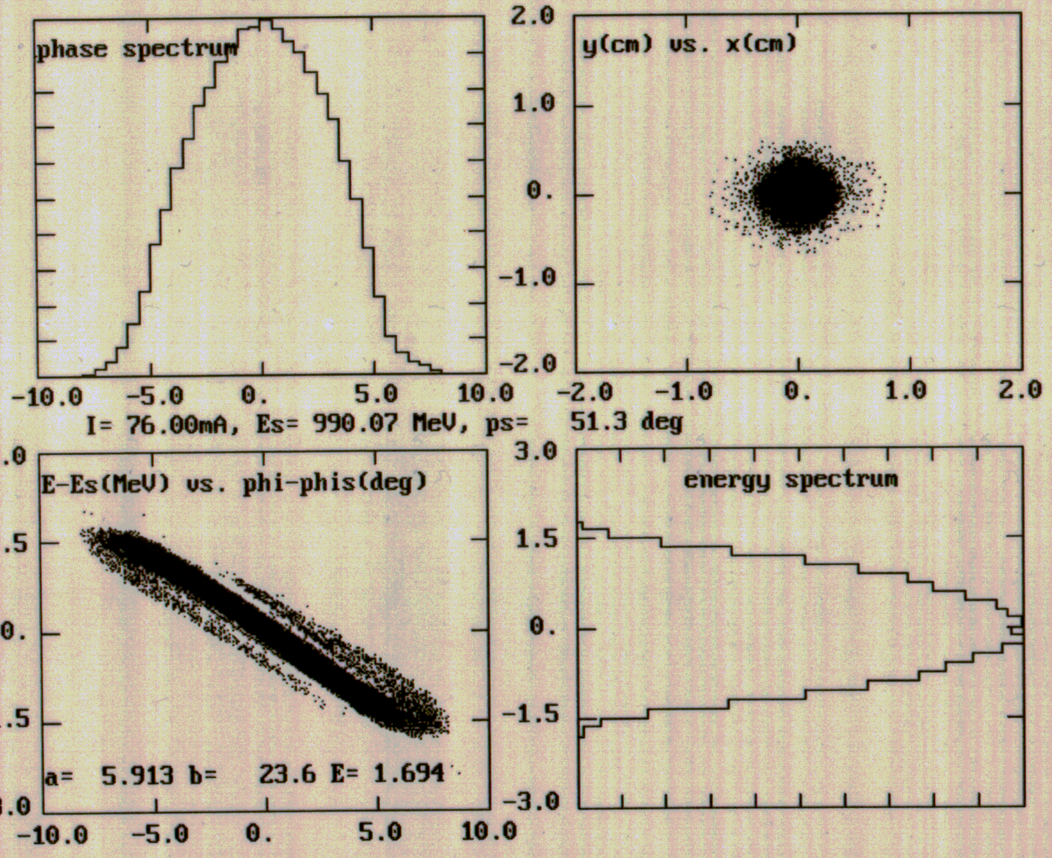
Phase Space Projections at Linac End for the Design Case



Phase Space Projections at Linac End for the $E_0 \pm 30\%$ Case



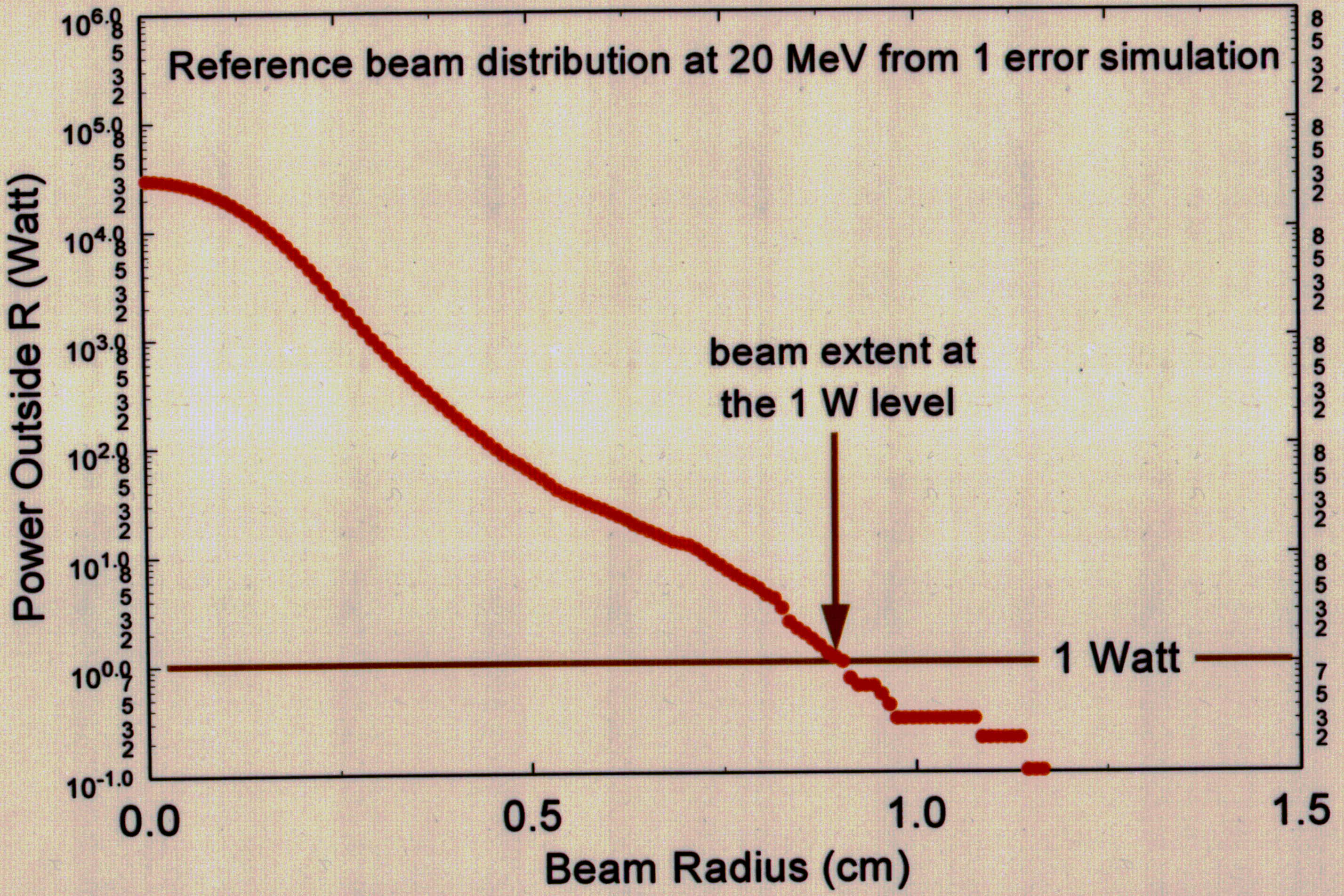
Phase Space Projections at Linac End for the $E_0 \pm 30\%$ Case



Implication of the Results

- The SRF linac structure in its present rf powering scheme is surprisingly tolerant to large variation in E_0
- Constant ϕ_s for varying E_0 is a deviation from the design tune
  – Results in a distributed longitudinal mismatch
- Longitudinal mismatch has little effect on transverse dynamics
  – the same cannot be said about conventional coupled cavity linac layout
- Has significant impact on commissioning; provides considerable leeway in setting phase and amplitudes
  – Has to meet requirement on W- and ϕ-spread for injection into ring
- Strongest of all the arguments in favor of a using SRF linac structures at higher energies

A Radial Power Distribution Defines the Beam Edge at the 1 Watt Level



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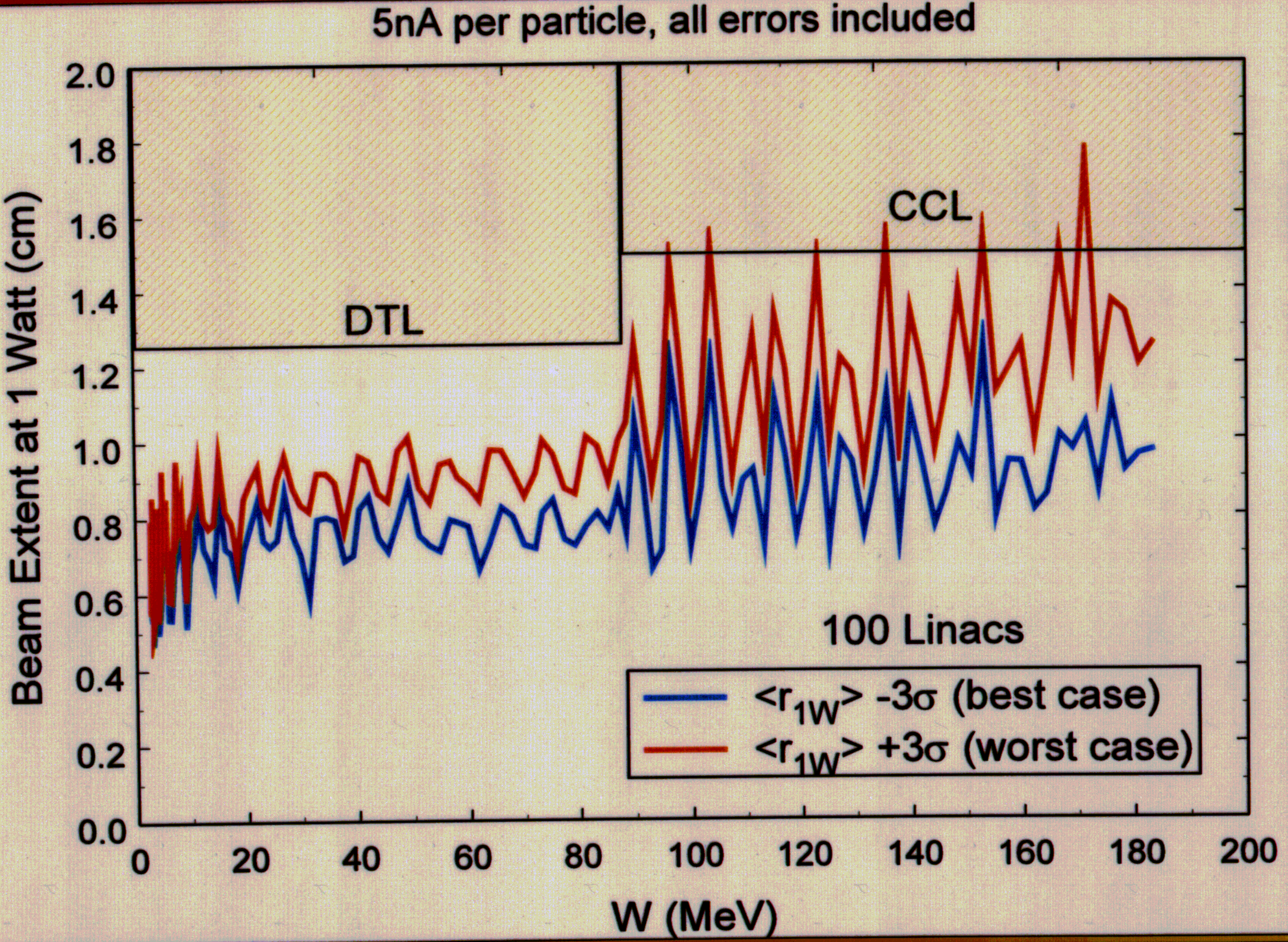
Maximum Expected Beam Extent at the 1- Watt Level Occurs in the CCL

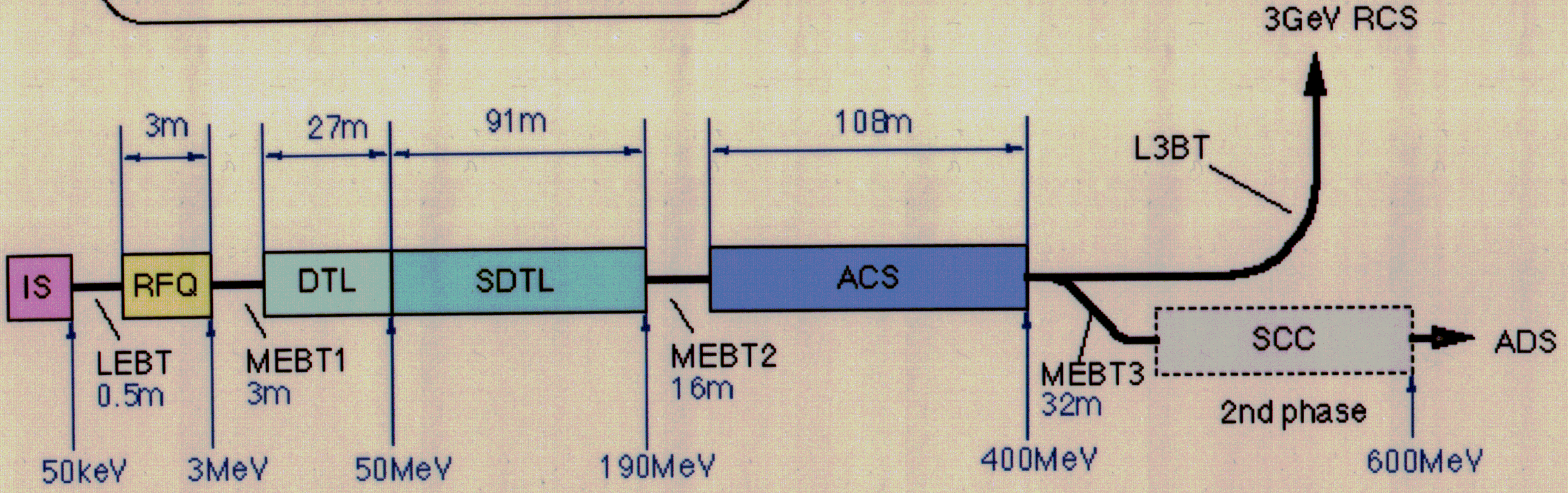


Requirements

- Current
  - Average: 675 μA
  - Peak: 50 mA
- Pulse
  - Pulse width: 500 μsec
  - Repetition: 50 Hz
  - Chopping ratio: 56 %
  - RF duty (600 μsec): ~ 3%
- Beam
  - Energy: 400 MeV
  - Momentum width: $\Delta p/p$ = +/- 0.1% (100%)
  - Emittance: 3 ~ 5 π mm-mrad (99%)

Linac layout

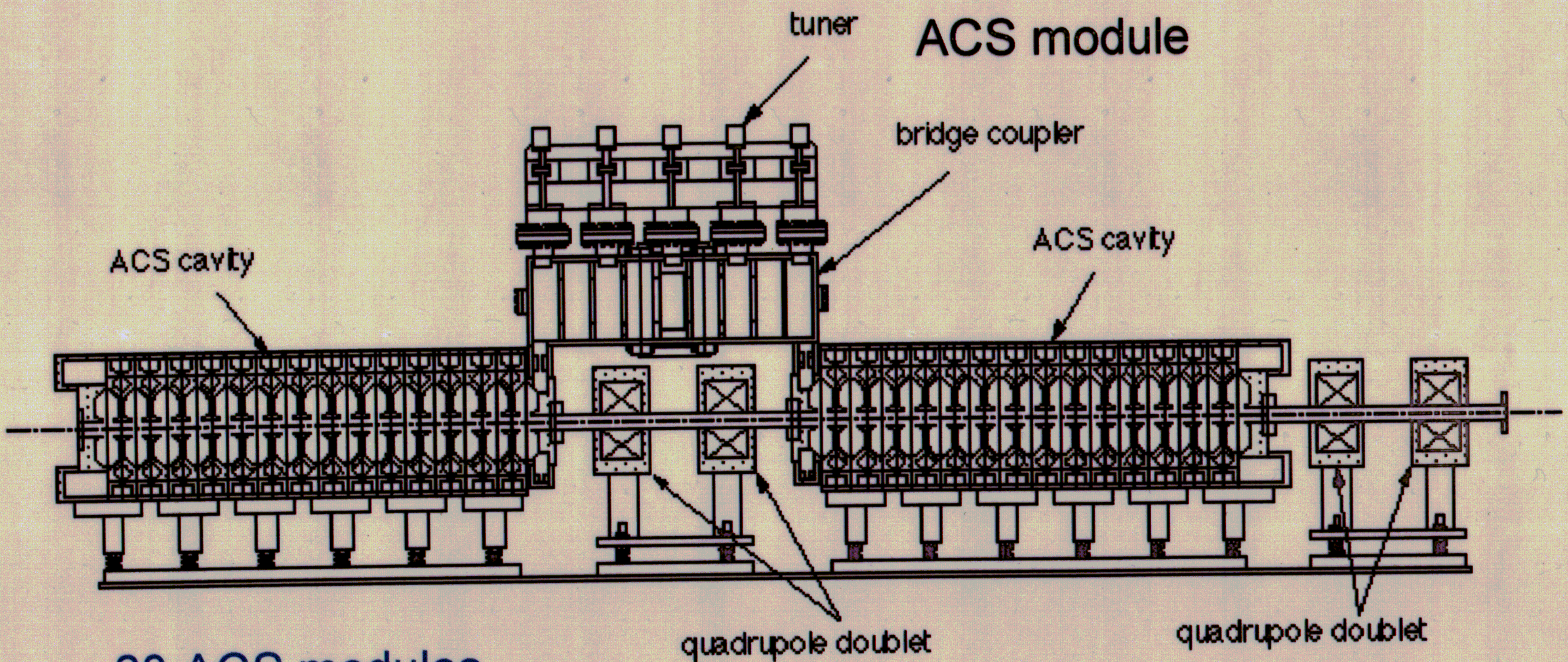
IS: Ion Source
RFQ: Radio Frequency Quadrupole linac
DTL: Drift Tube Linac
SDTL: Separate-type Drift Tube Linac
ACS: Annular Coupled Structure linac
SCC: Super-Conducting Cavity linac
RCS: Rapid Cycling Synchrotron



Main parameters

	RFQ	DTL	SDTL	ACS	
Output energy	3	50	191	400	MeV
Frequency	324	324	324	972	MHz
Total length	3.1	27.1	91.2	108.3	m
Structure length	3.1	26.7	65.7	68.2	m
Number of tanks	1	3	32	46	
Number of cells		146	160	690	
Number of klystrons	1	3	16	23	
E0		2.5-2.9	2.5-3.7	4.2-4.3	MV/m
Vane voltage	1.8				Ek
Stable phase	-30	-30	-27	-30	degree
Peak wall loss	0.336	3.3	16.6	33.3	MW
Peak beam power	0.148	2.4	7.0	10.5	MW
Peak total power	0.484	5.7	23.6	43.8	MW

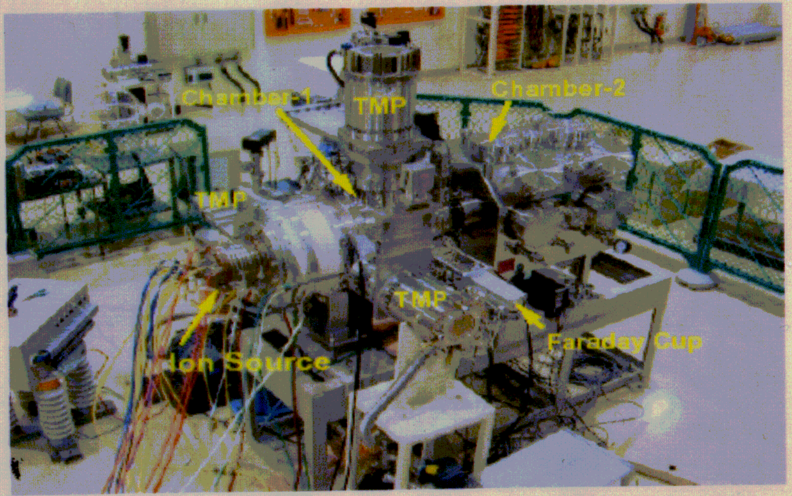
ACS

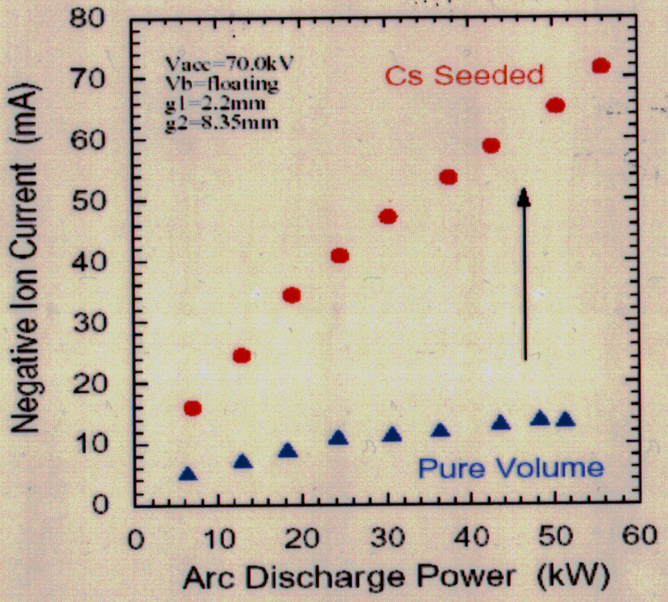


23 ACS modules
One ACS module = Two ACS tanks + One bridge coupler
One klystron per one ACS module
15 cells in an ACS tank
Doublet focusing

Cs-seeded Ion Source

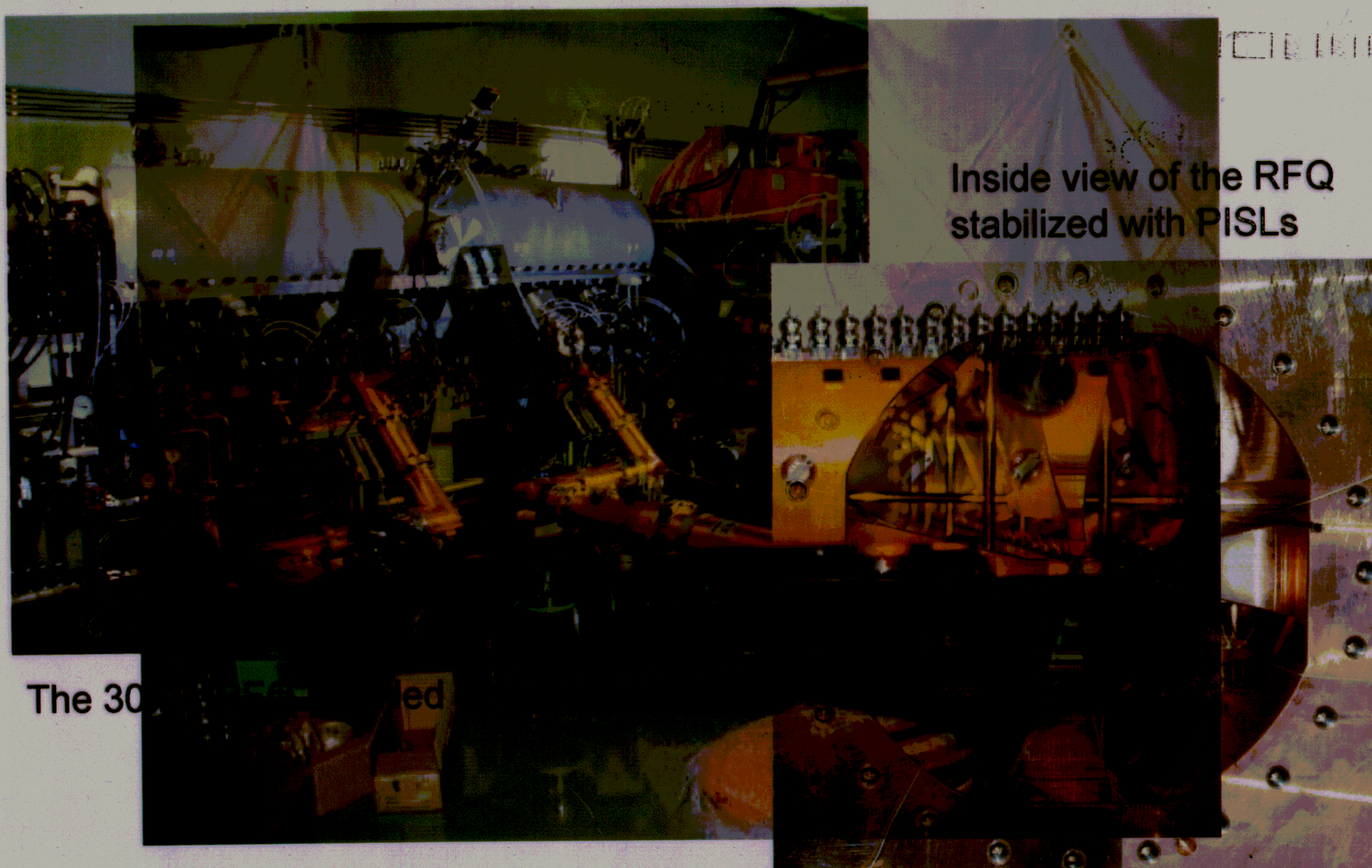
KEK/JAERI
The Joint Project Team





Volume Production Type Negative Ion Source

DTL #1 with D[illegible] RFQ Installed



Inside view of the RFQ stabilized with PISLs

The 30 [illegible] ed

Time Table

Beam test at KEK (Tsukuba) site:

- Beam test of RFQ and MEBT1 has been started.
- DTL#1 installation completion: December, 2002
- DTL#1 beam test start: December, 2002
- Beam test up to 60 MeV (SDTL#2) is planned.

Construction at JAERI (Tokai) site:

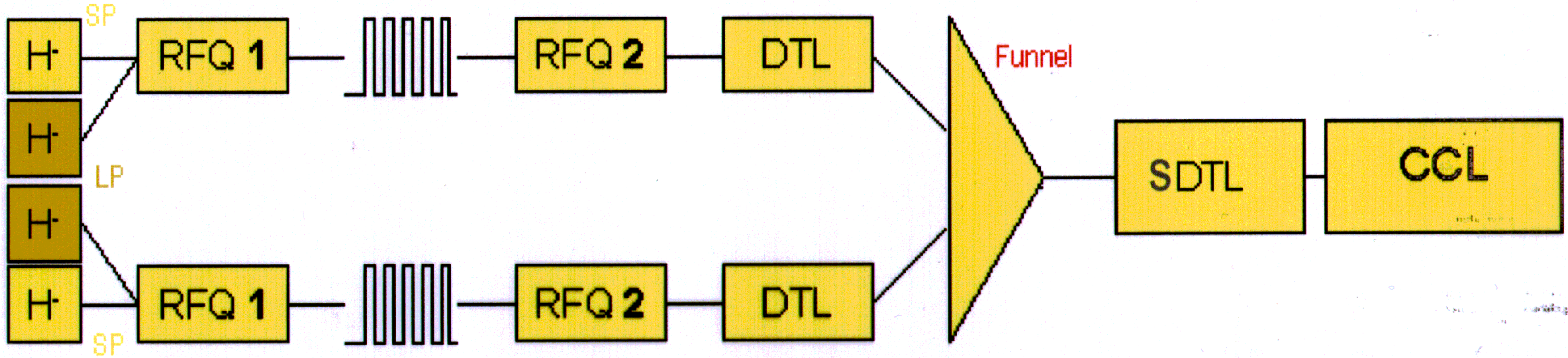
- Linac building completion: August, 2004
- Linac installation completion: March, 2006
- First beam to 3 GeV RCS: September, 2006
- First 50 GeV beam: March, 2007

ESS requirements

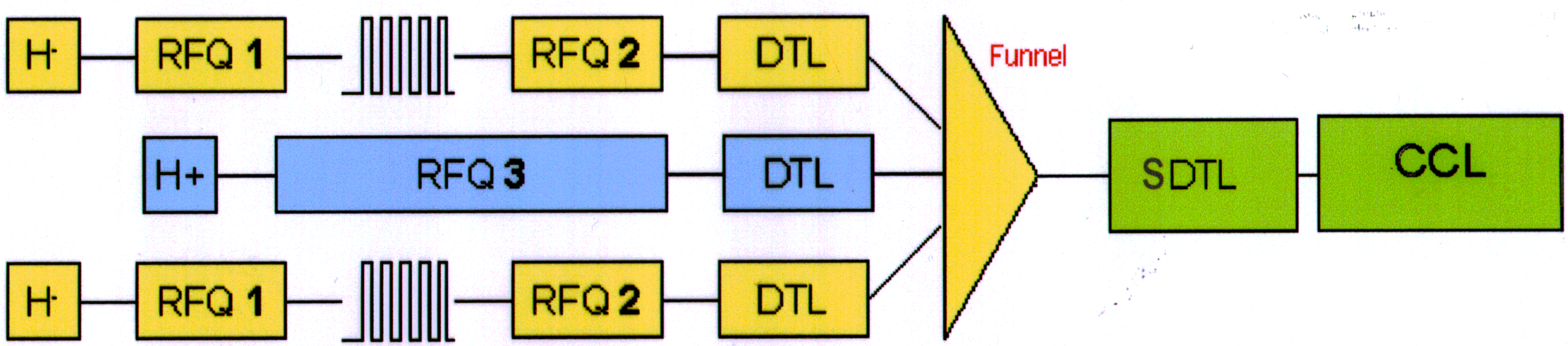
- 10 MW beam power: 5 MW at 50 Hz plus 5 MW at 50/3 Hz, Short pulse and Long pulse
- Consider the most efficient and reliable option
- Maintenance and repair require that high-energy beam losses be kept below 1 nA/m

	SP	*LP*	
PRF (pulses per second)	50	50/3	
Beam pulse width, 1 ring (ms)	2×0.50	2.5	
Beam duty factor	5.0%	4.2%	
Non-chopped beam current (mA)	114	114	
Chopping factor	2/3	2/3	100%
Final energy (MeV)	1334	1334	
Peak beam power (MW)	101	101	152
Mean beam power (MW)	5.07	4.22	6.34
Pulse gaps, ring separation (ms)	0.10		

The 2 options of the LE RT linac



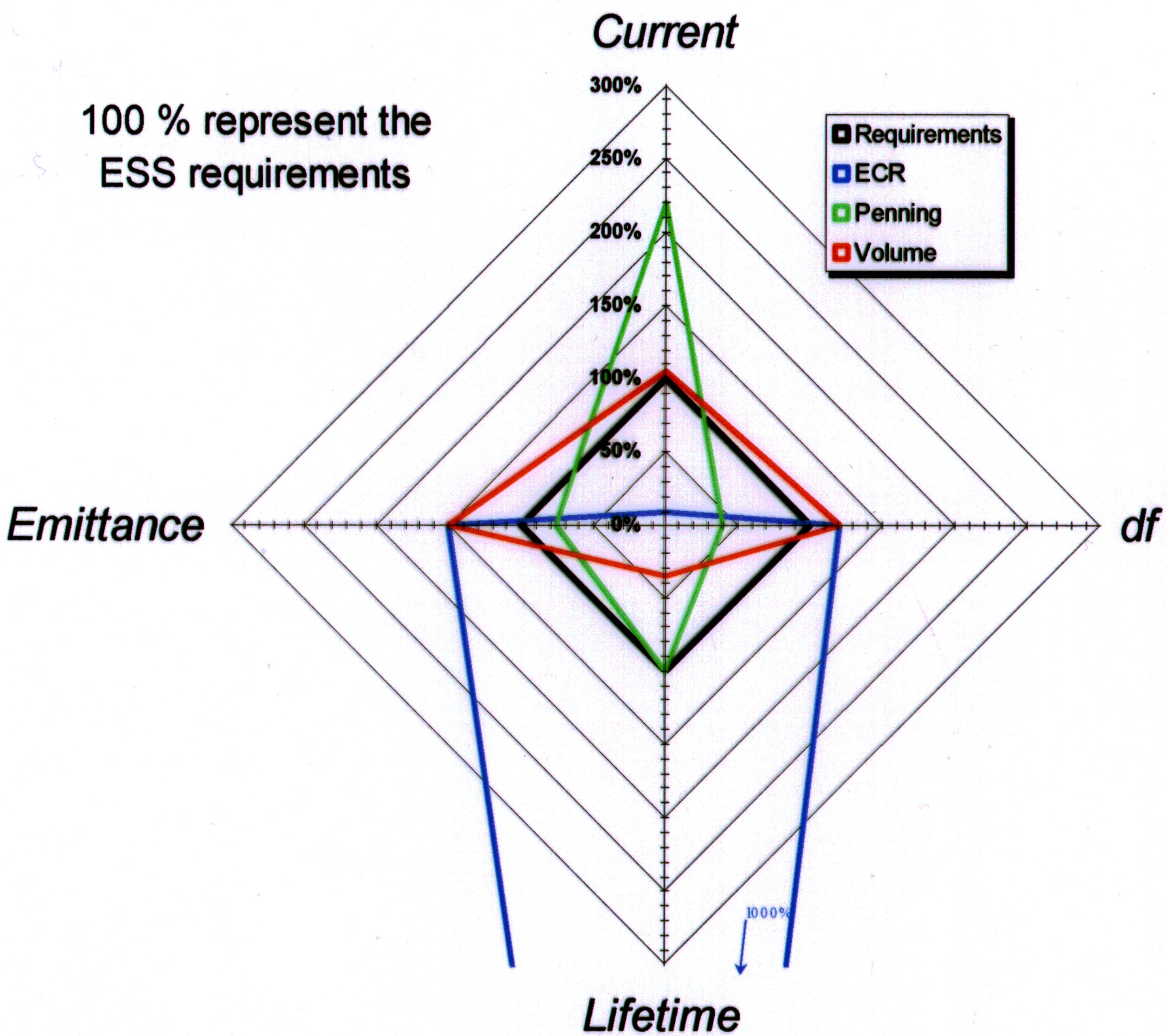
Reference design

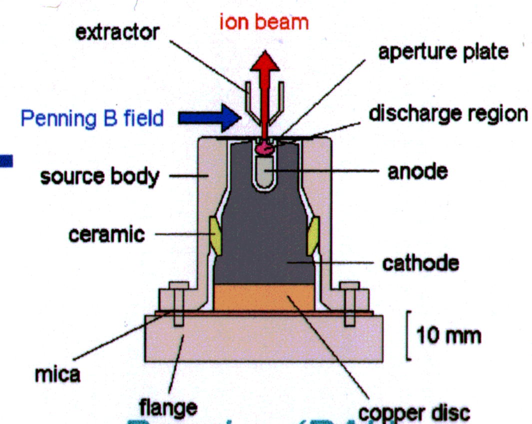


Fallback solution to ensure LP 5 MW on Day 1

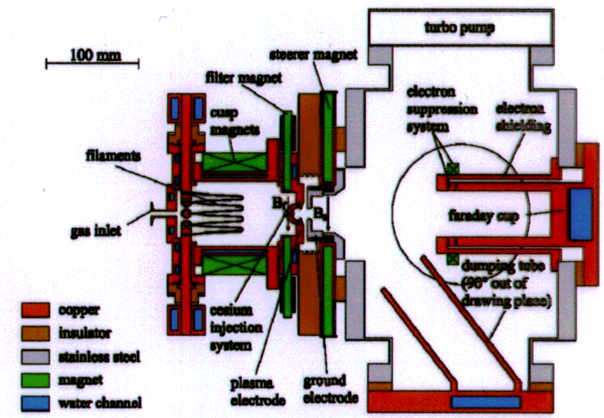
Different source type

100 % represent the ESS requirements

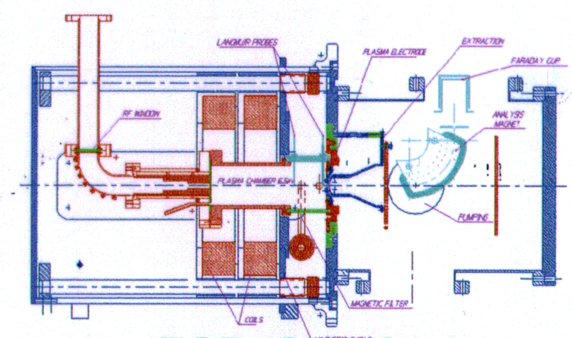




Penning (RAL)



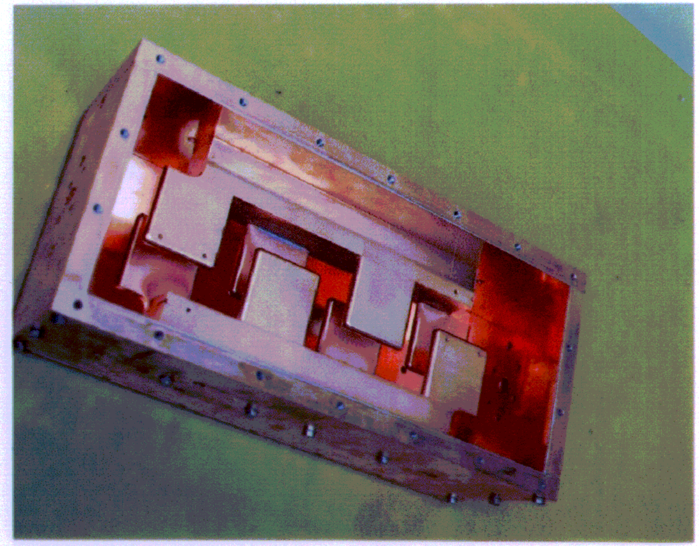
Volume (IAP-Frankfurt)



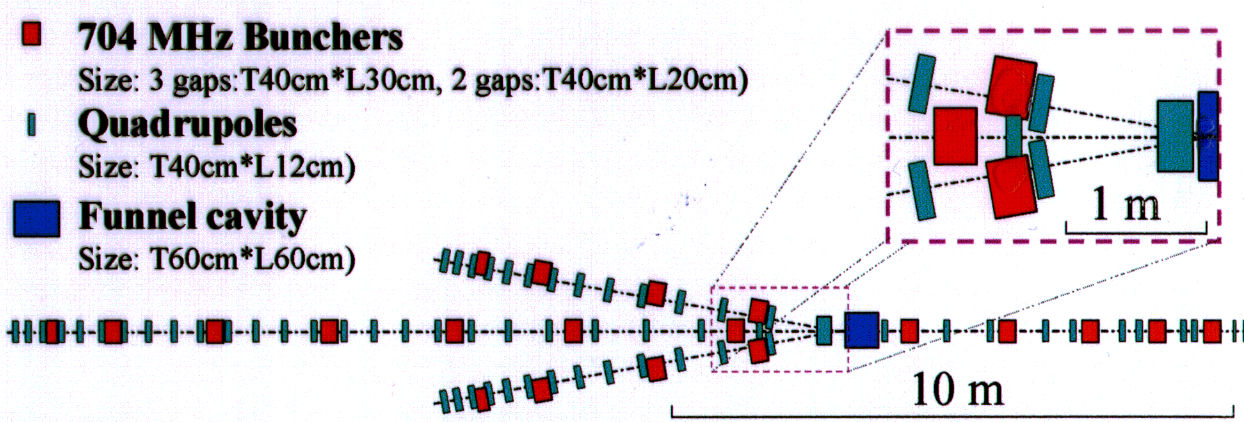
ECR (CEA-Saclay)

Funnel line

- Funnel cavity give about ±5° deflection angle
- Multicell cavity type (Y. Senichev), no dipole magnet needed
- Allow insertion of the H^+ line
- ±10.9° obtained with Quadrupoles
- 10% emittance growth (1% due to space-charge, 2% due to line non-chromaticity, rest due to phase-dependent particle transverse deflection

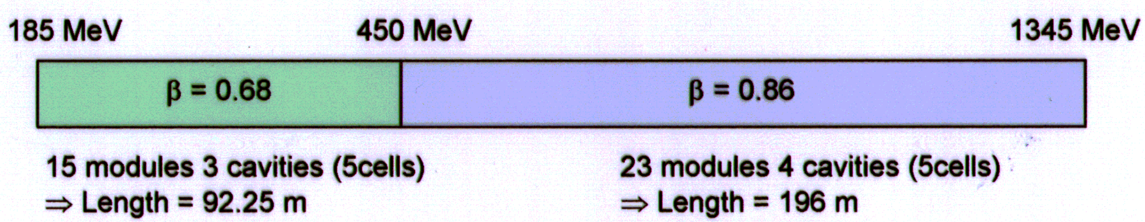


- non-chromaticity effect seems marginal



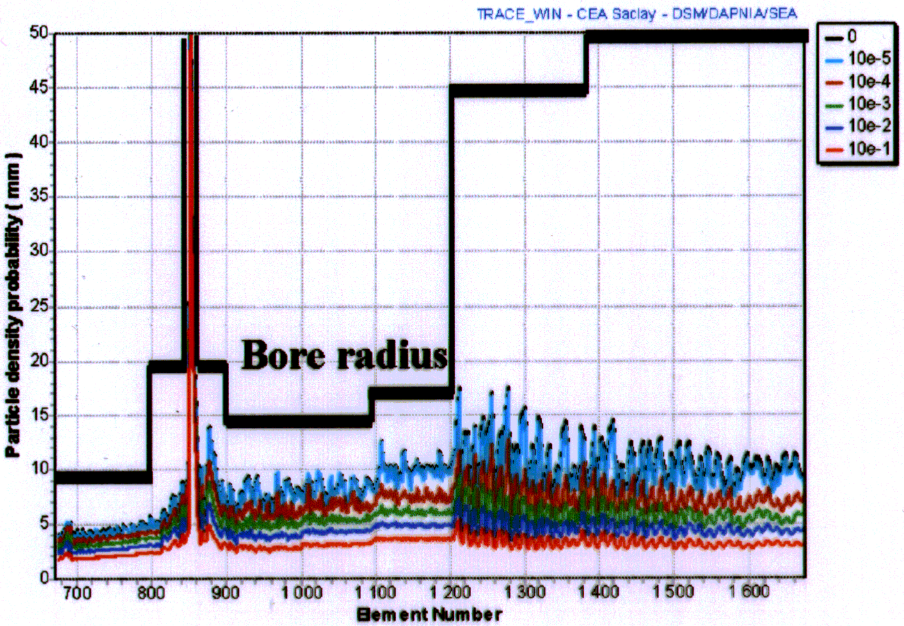
SCL from 184.5MeV to 1348MeV

- Two 5-cell cavity families, geometric β of 0.66 and 0.85
- Length = 290m
- B_p = 50 mT (about Ep = 27.5 MV/m, 2 times lower than TESLA)
- 2x800 kW rf power coupler per cavity

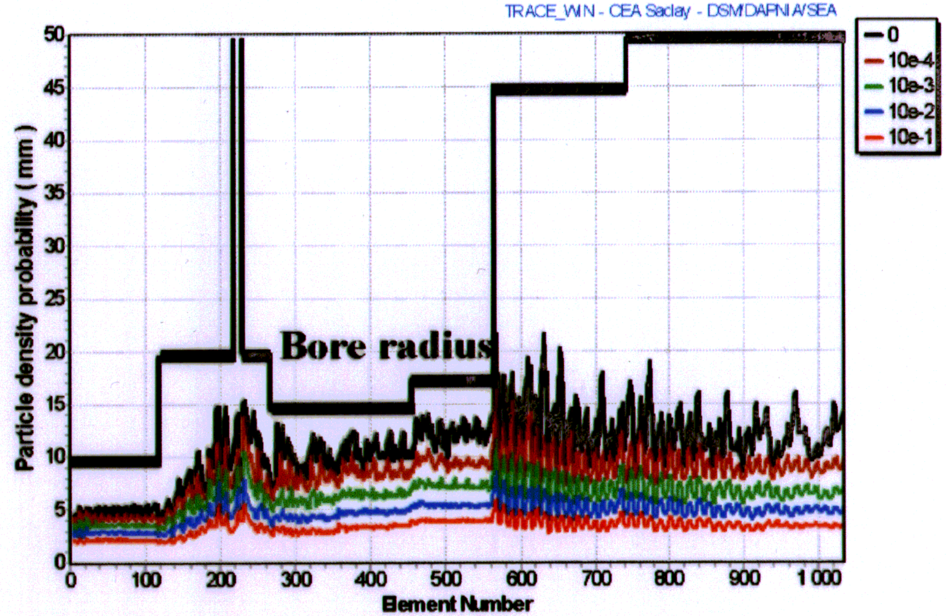


End to End simulations 3/4

H⁻



H⁺

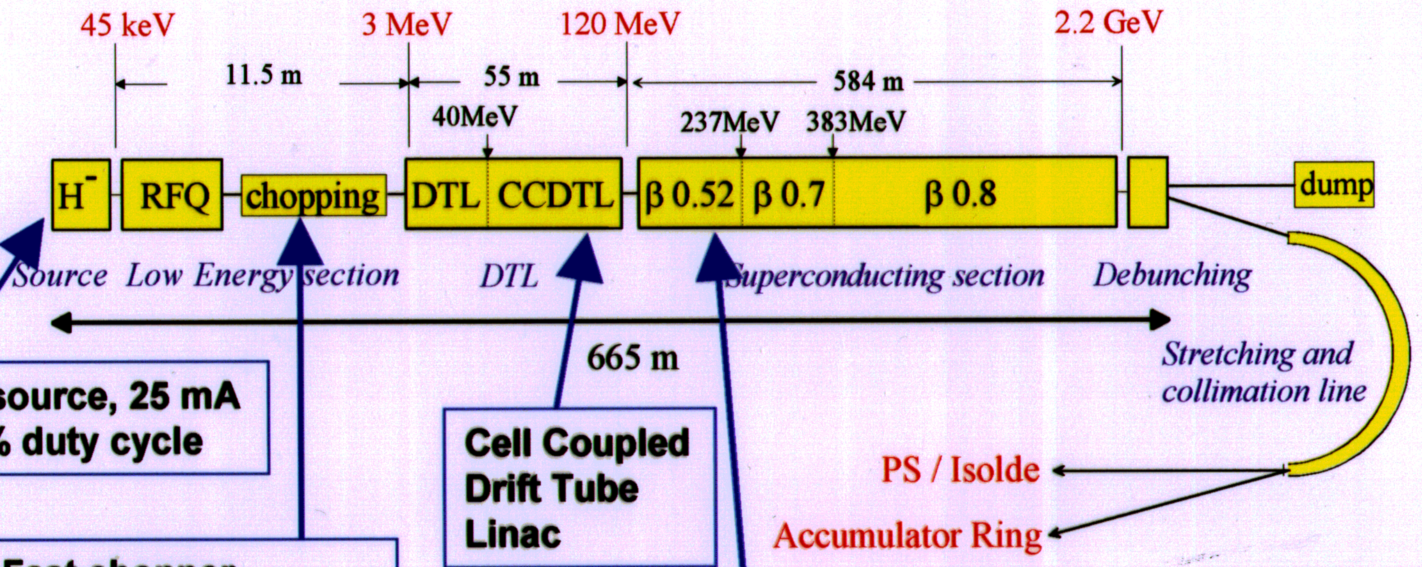


The minimum ratio between the bore radius and the 10^{-5} level is about:
- 1.45 in nc linac for H^-,
- 2.55 in sc linac for H^-,
- 1.15 in nc linac for protons,
- 2.1 in nc linac for protons.

Superconducting linac has much more margin than normalconducting one.

Dynamic errors do not lead to significant beam radius increase

The Superconducting Proton Linac: Design (1)



H- source, 25 mA
14% duty cycle

Cell Coupled Drift Tube Linac

Fast chopper
(2 ns transition time)

new SC cavities: β=0.52,0.7,0.8
5-cell β 0.8 cavities replacing 4-cell β 1 cavities in the LEP cryostat

2.2 GeV energy:
- **direct injection into PS**
- **threshold for π production**

RF system:
- **freq.: 352 MHz**
- **amplifiers: tetrodes and LEP klystrons**

SPL Beam Specifications

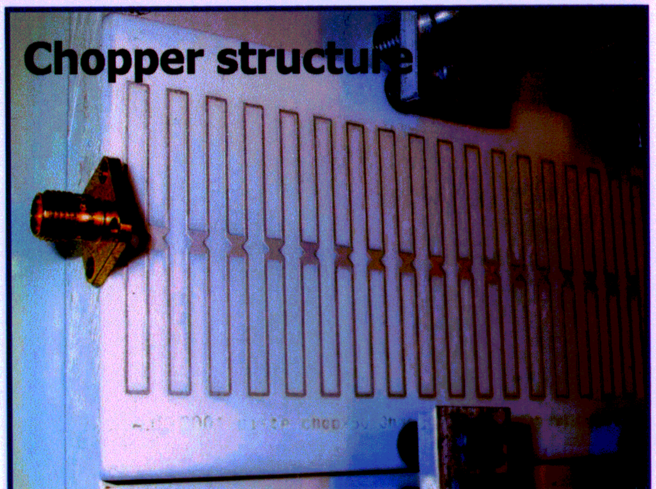
	Parameter	Value	Unit
MEAN PARAMETERS	Ion species	H-	
	Kinetic energy	2.2	GeV
	Mean current during the pulse	13	mA
	Duty cycle [mean beam power]	14 [4]	% [MW]
	Pulse frequency	50	Hz
	Pulse duration [number of H- per pulse]	2.8 [2.27 E 14]	ms [H^-/pulse]
FINE TIME STRUCTURE	Bunch frequency [minimum distance between bunches]	352.2 [2.84]	MHz [ns]
	Duty cycle during the beam pulse [number of successive bunches/number of buckets]	61.6 [5/8]	%
	Number of bunches in the accumulator [total number of buckets – empty buckets]	140 [146-6]	
	Maximum bunch current [maximum number of charges per bunch]	22 [3.85 E 8]	mA [H^-/bunch]
BUNCH CHARACTERISTICS	Bunch length (total)	0.13	ns
	Energy spread (total) [relative momentum spread (total)]	1.2 [~ 0.42 E-3]	MeV
	Normalised horizontal emittance (1σ)	0.6	µm
	Normalised vertical emittance (1σ)	0.6	µm
	Energy jitter during the beam pulse	< +- 0.5	MeV
	Energy jitter between beam pulses	< +- 2	MeV

Revised parameters are in red

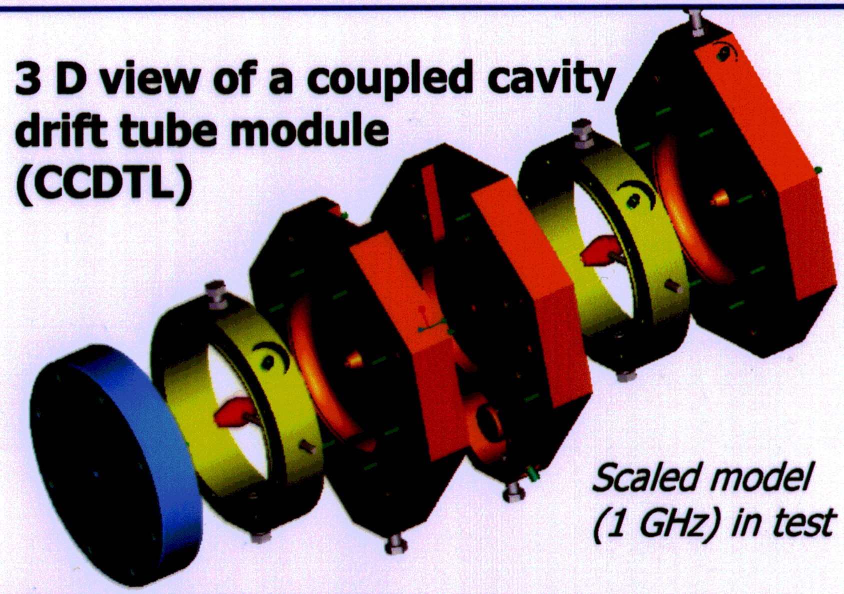
SPL R&D Topics

- Minimise beam loss to avoid activation of the machine (loss<1 W/m)
  - ***Beam Dynamics studies, optimise layout and beam optics***
- Chopper structure to create a time distribution in the beam that minimises losses in the accumulator
  - ***Travelling wave deflector with rise time <2 ns***
- Efficient room-temperature section (W<120 MeV)
  - ***CCDTL concept***
- Development of SC cavities for $\beta<1$
  - ***Sputtering techniques***
- Pulsing of LEP klystrons
  - ***Built for CW, operated at 50 Hz, 14% duty***
- Pulsing of SC cavities and effects of vibrations on beam quality
  - ***Low power (feedback), high power (phase and amplitude modulators) and active (piezos) compensation techniques***

SPL R&D – Low Energy



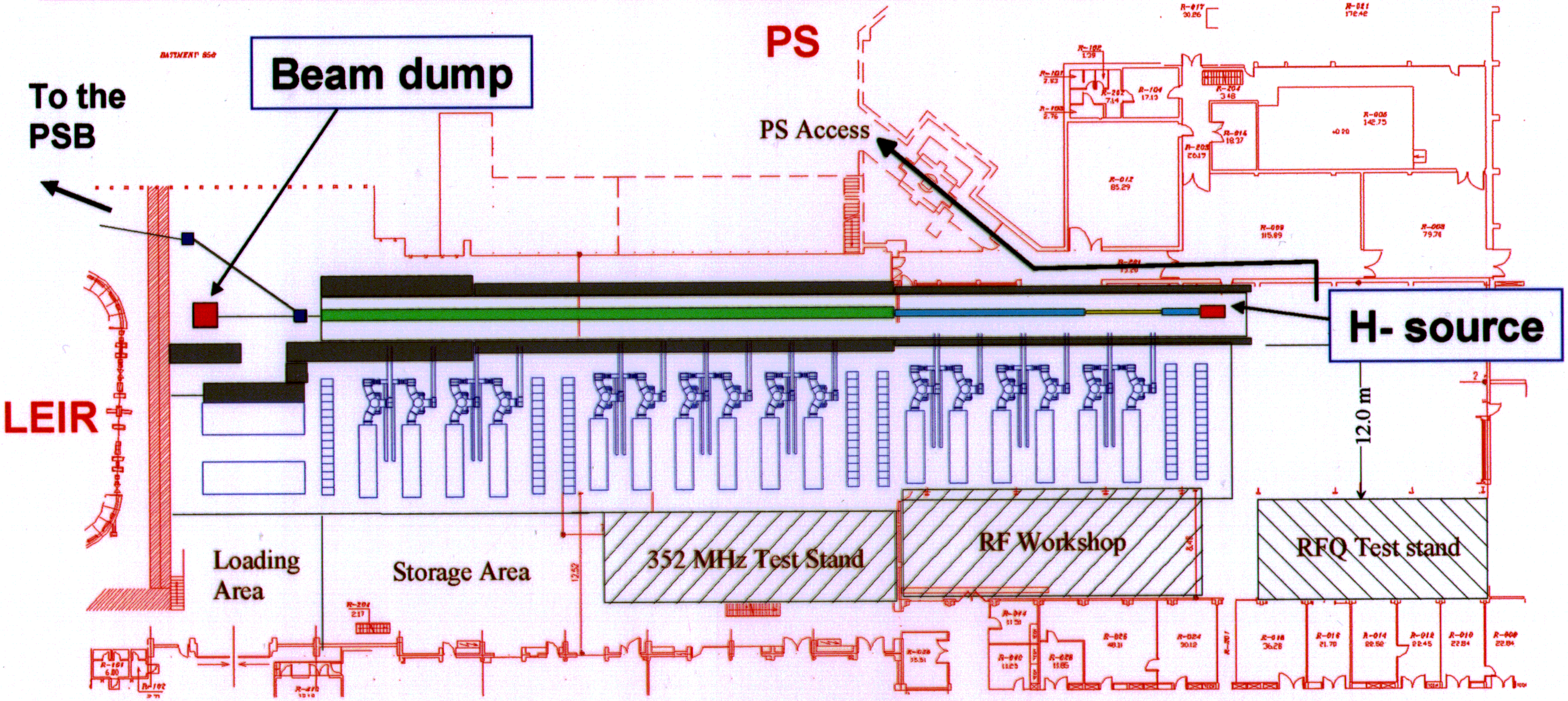
- Full performance prototype tested
- Driver amplifier in development



Collaboration on RFQs with CEA-IN2P3 (IPHI) and INFN Legnaro

352 MHz test place prepared (planned tests of CEA-built DTL structures in 2002)

The SPL Front-end (120 MeV) in the PS South Hall (intermediate proton intensity increase)



⇒ Increased brightness for LHC, × 1.8 the flux to CNGS & ISOLDE, ... (with upgrades to the PSB, PS & SPS)

⇒very cost-effective facility: hall and infrastructure are available in the PS
all the RF is recuperated from LEP
shielding is done with LEP dipoles!

The TRASCO Program

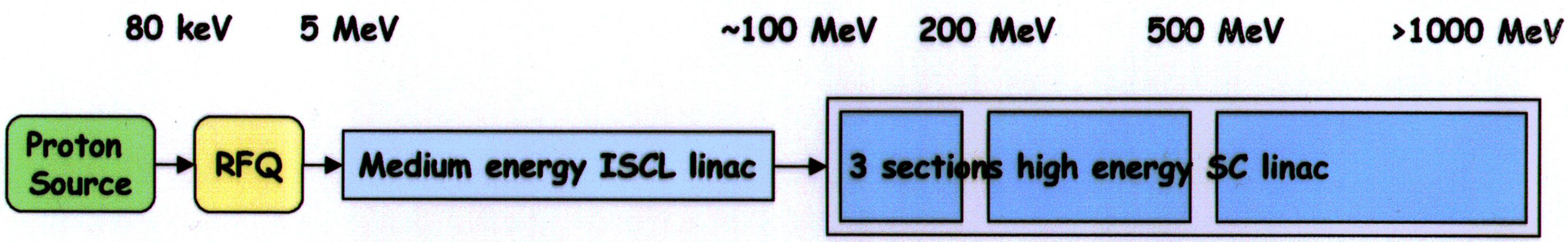
TRASCO is devoted to the conceptual study and the prototyping of components for an accelerator driven system for nuclear waste transmutation, and involves research agencies and Italian companies

- 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 $\beta = 0.47$ 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) 8βλ 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

Status of the Source

Design completed in 1999

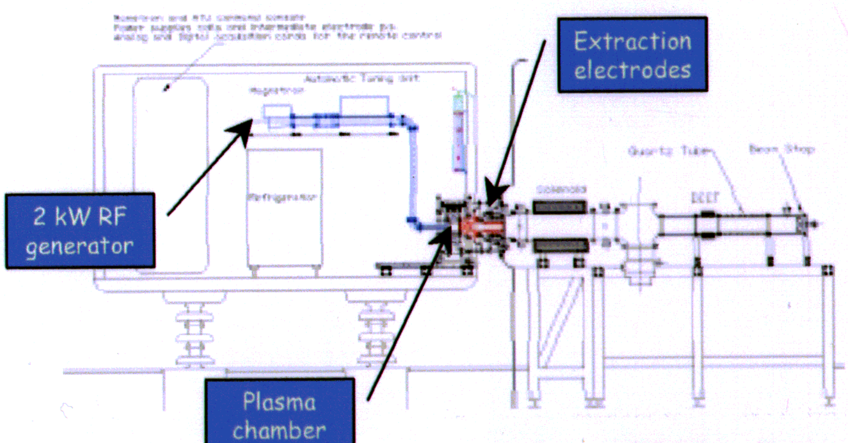
Source assembled in LNS in May 2000

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



RFQ Design

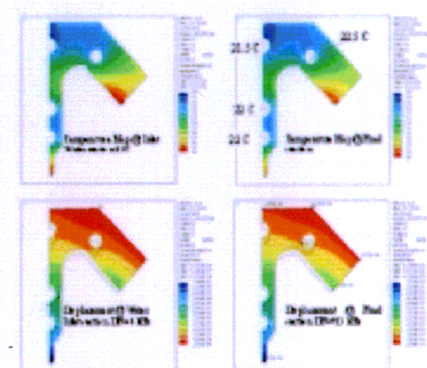
Different optimization procedure for TRASCO RFQ w.r.t. LEDA

- 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

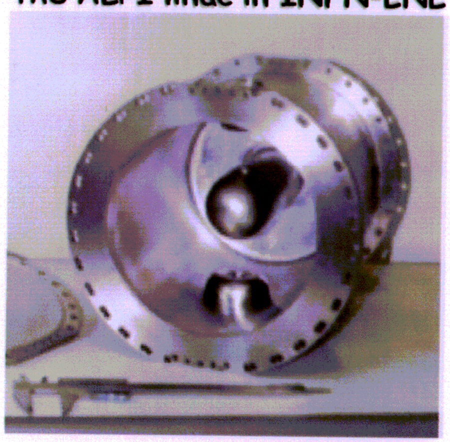


Superconducting low energy linac

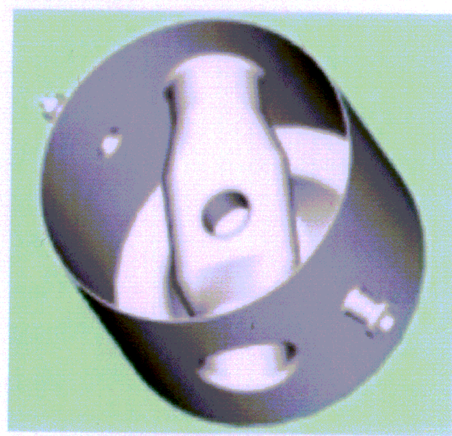
Single or two-gap structure linac
- Moderate energy gain per cavity
- 8 $\beta\lambda$ focussing lattice

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



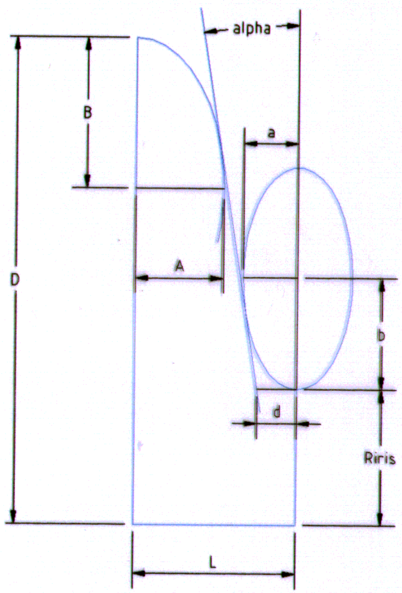
Spoke cavity

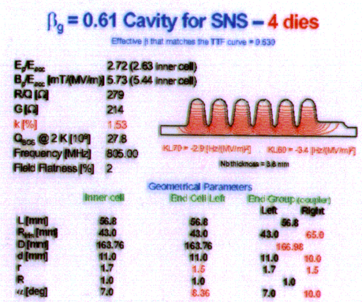


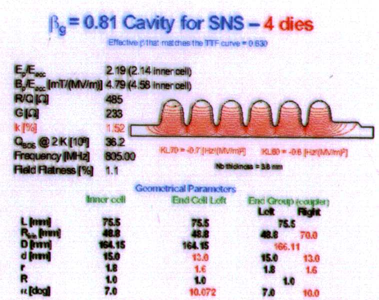
Reentrant cavity single gap structure. He Vessel integrated in the cavity

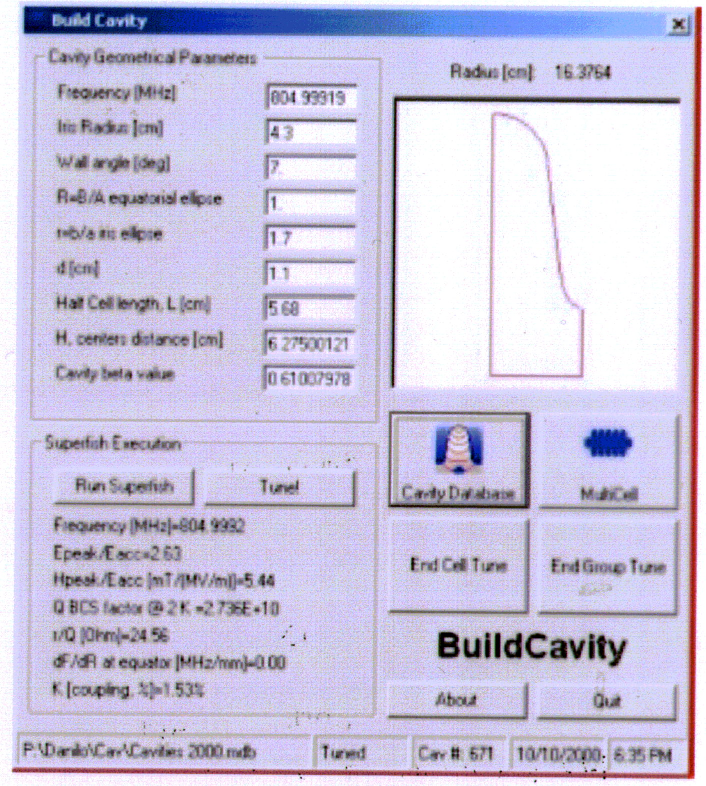
Some useful tools: for cavity design

- 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





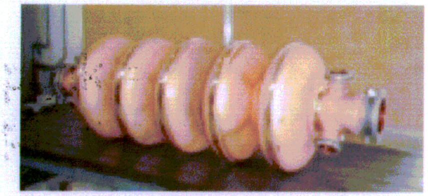




- Inner cell tuning is performed through the cell diameter, all the characteristic cell parameters stay constant: R, r, α, d, L, Riris
- End cell tuning is performed through the wall angle inclination, α, or distance, d. R, L and Riris are set independently
- End groups for a 4 die cavity can be tuned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

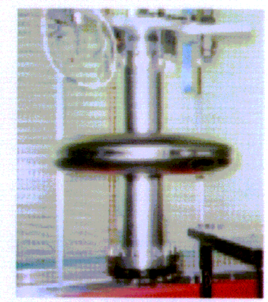
Cavity prototypes: program and results



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

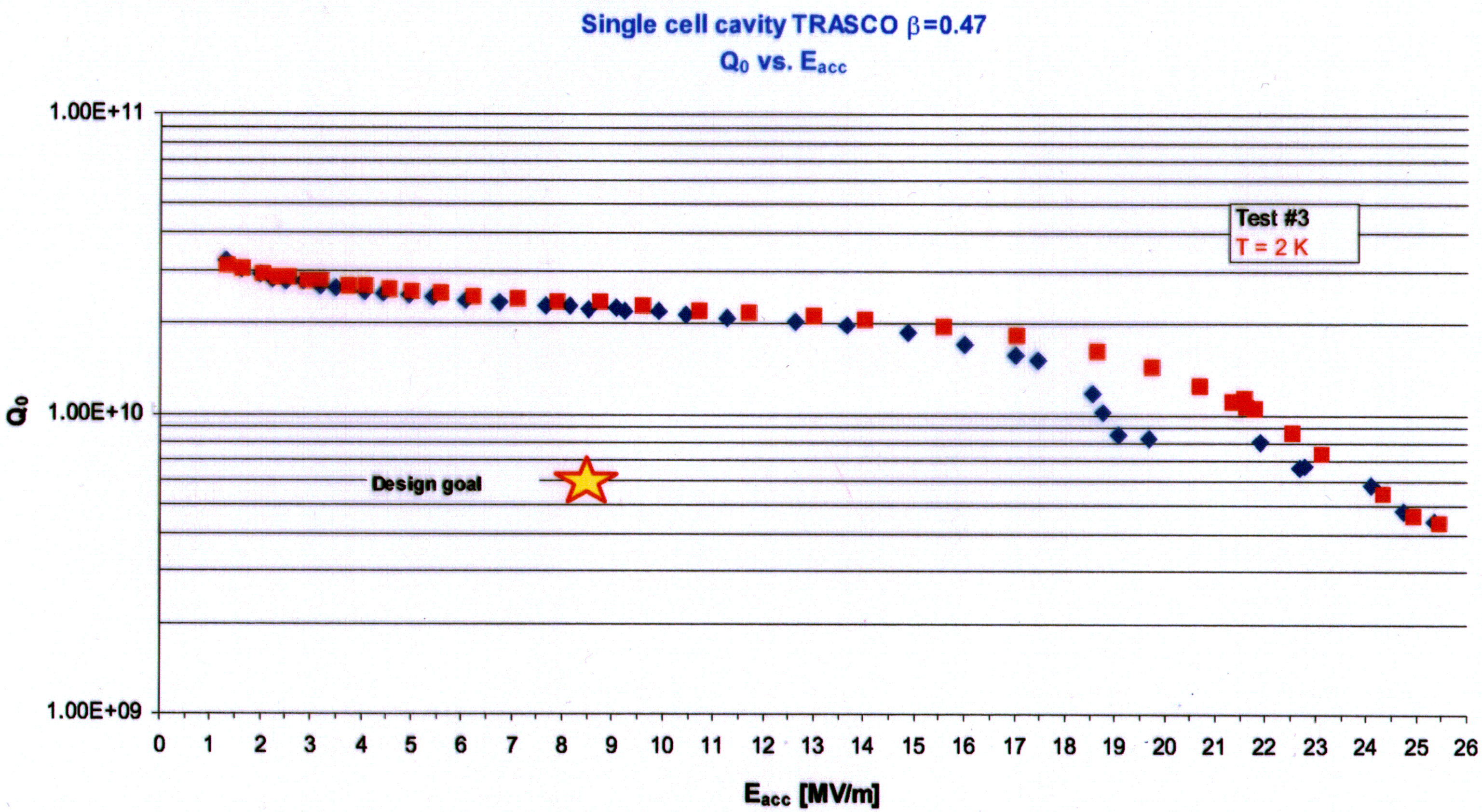
In progress:

- Two 5-cell full cavities

Z104 - Tested at TJNAF @ T = 2 K

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

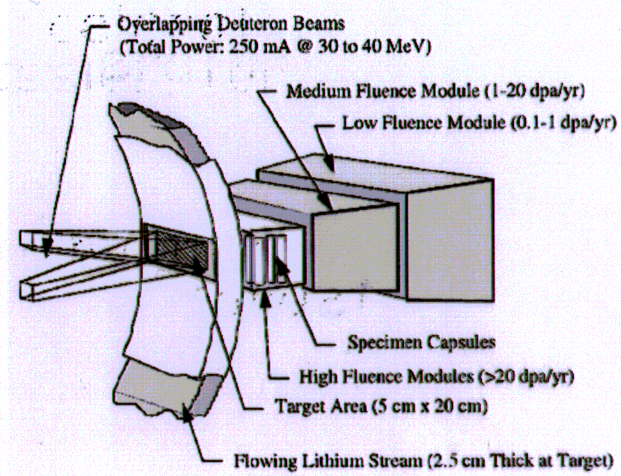
Max Epeak = 74 MV/m
Max Bpeak = 138 mT



Description

- IFMIF : accelerator-based D-Li neutron source
  - production of an intense flux of high energy neutrons
  - sufficient irradiation volume for realistic testing of materials and components up to about a full lifetime of their anticipated use in DEMO and beyond.
  - Must survive exposure to damage from neutrons with energy spectrum peaked near 14 MeV with annual doses of ~20 dpa (displacement per atoms), and total fluences of ~200 dpa.

IFMIF SCHEMATIC LAYOUT



Neutron Flux	$\geq$ 2 MW/m^2 (@ 500 cm^3)
Operation Availability	70 %
D^+ Beam Current	250 mA (CW, 2 x 125 mA)
D^+ Energy	40 MeV
D^+ Beam Size	200 mm (width) x 50 mm (height)
Li Jet Thickness	19, 25 mm (resp. for 32, 40 MeV D^+)
Li Jet Width	260 mm
Li Jet Velocity	10-20 m/s

Test facility	97.5%
Target facility	95.0%
Accelerator	88.0%
Conventional	99.5%
Central CS	99.5
Total (product)	80.7%
online/year	70%

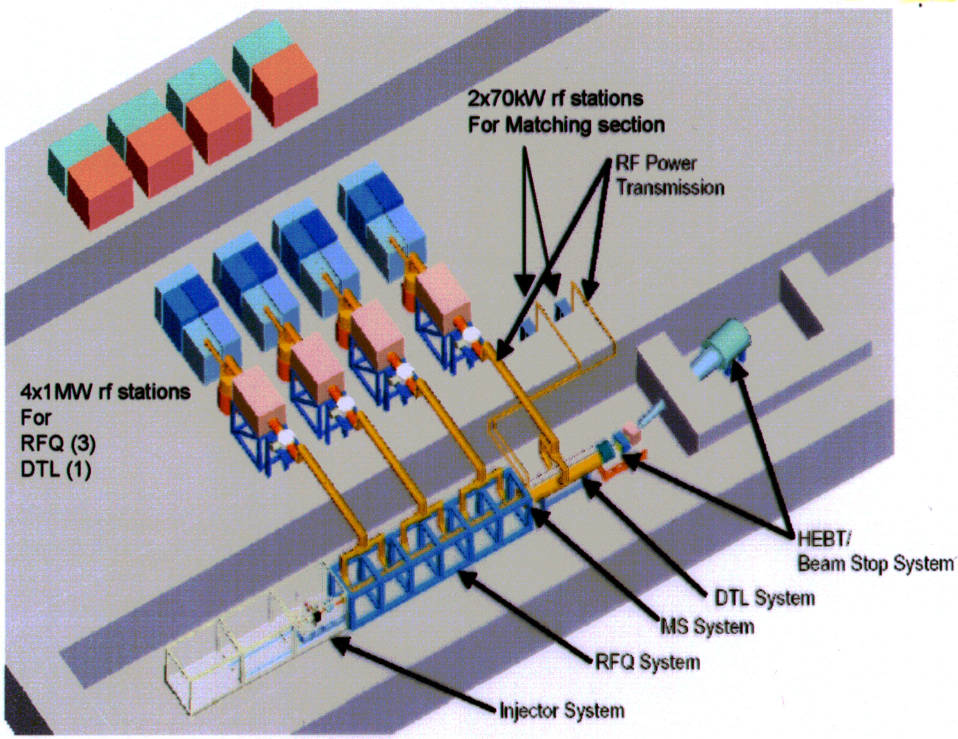
Accelerator facility

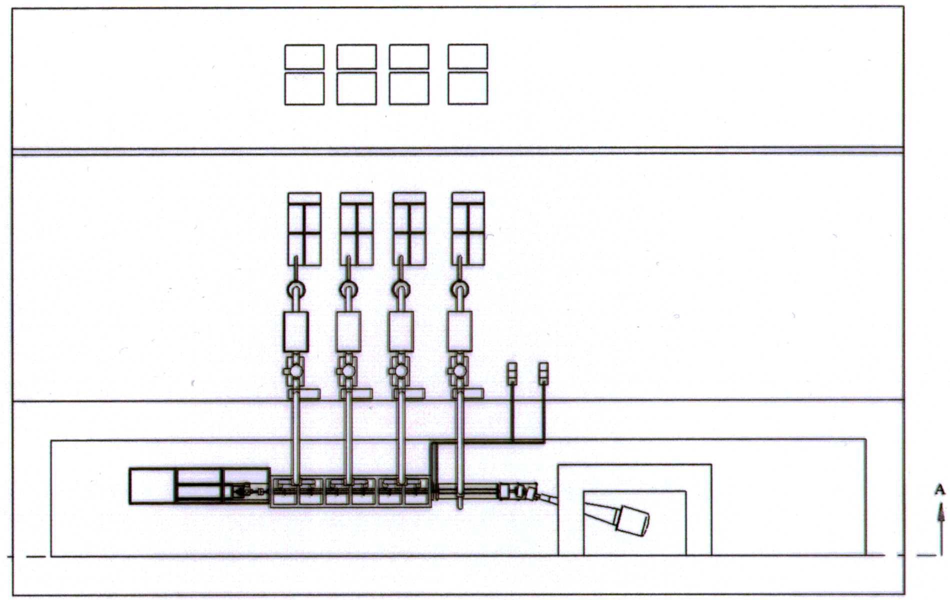
- D^+ beam current generated by two accelerator modules operating in parallel. **RAM is a major concern**
- The two D^+ beams converge on the Lithium target
- 2 modules composed of
  - D^+ source, 150 mA CW @ 95keV
  - RFQ up to 5MeV, CW, 125 mA
  - DTL up to 32 or 40 MeV
  - High Energy Beam Transport
- IFMIF needs 12×2 1MW rf station @ 175MW
- Development and testing of a RF system was identified as the highest impact development item
  - The diacrode will deliver 1 MW CW @ 175 MHz
  - Monitoring of long diacrode test tube (1000h) is under going with success (90hours up to now, CW @ 200MHz, 1MW)

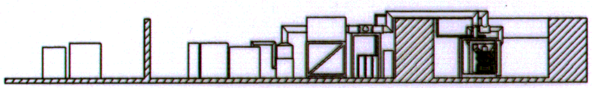
Phasing - Schedule

- KEP (Key Element technology Phase)
- EVEDA (Engineering Validation, Engineering Design Activities) 5 years, could start in 2004 (FPF6 start in 2003)
  - Need a central design team and a site
  - Prototype?
    - Full Performance Accelerator through the first DTL Tank
    - IFMIF Designs have been pursued at Frankfurt and Saclay
    - Best effort to integrate the "most favorable" design into the IFMIF prototype
- Highly depend on ITER decision
- More or less ready to build with a phase I completion in 2010 (50mA)

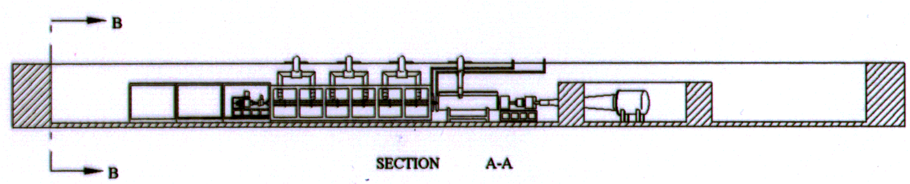
IFMIF Prototype concept



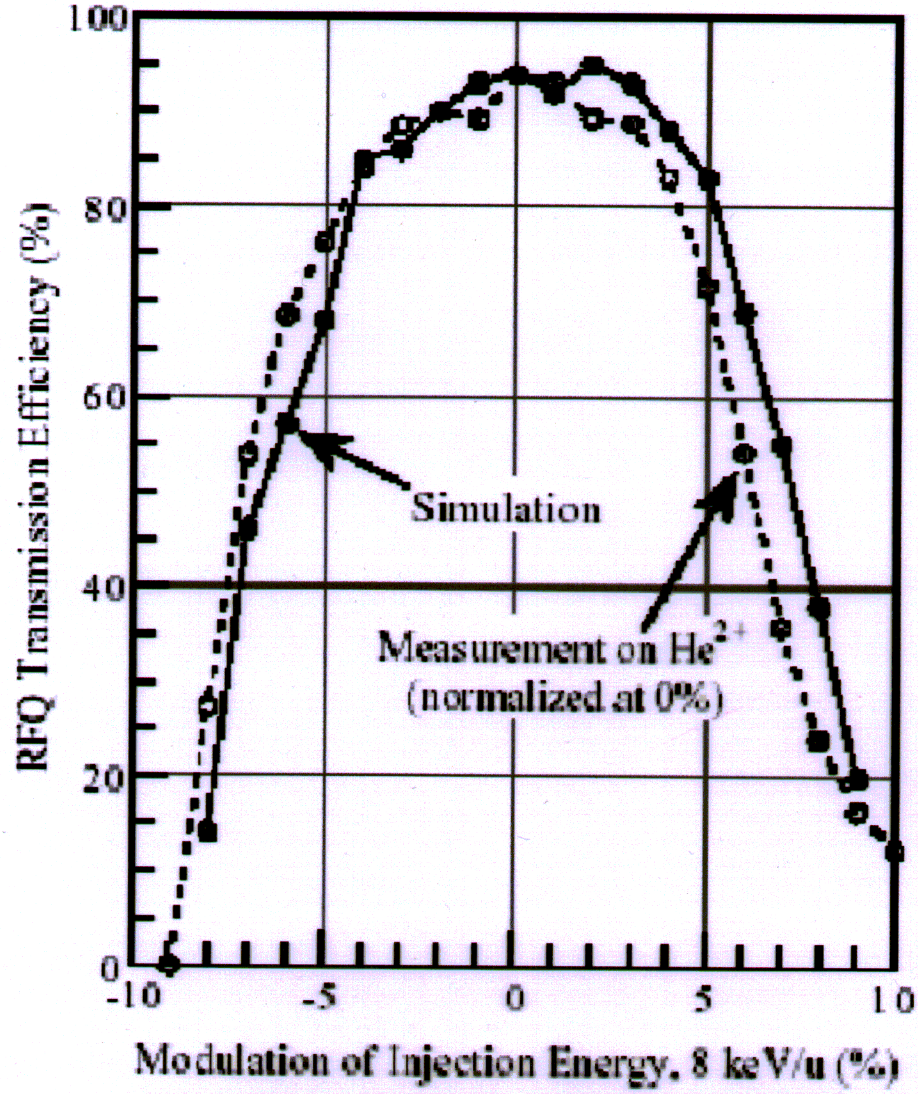




SECTION B-B



SECTION A-A



Simulated and measured RFQ transmission efficiency as a function of the injection energy modulation. Since the measured values contain a certain transport loss, they are normalized so that the measurement agrees with the simulation at the 0% modulation.

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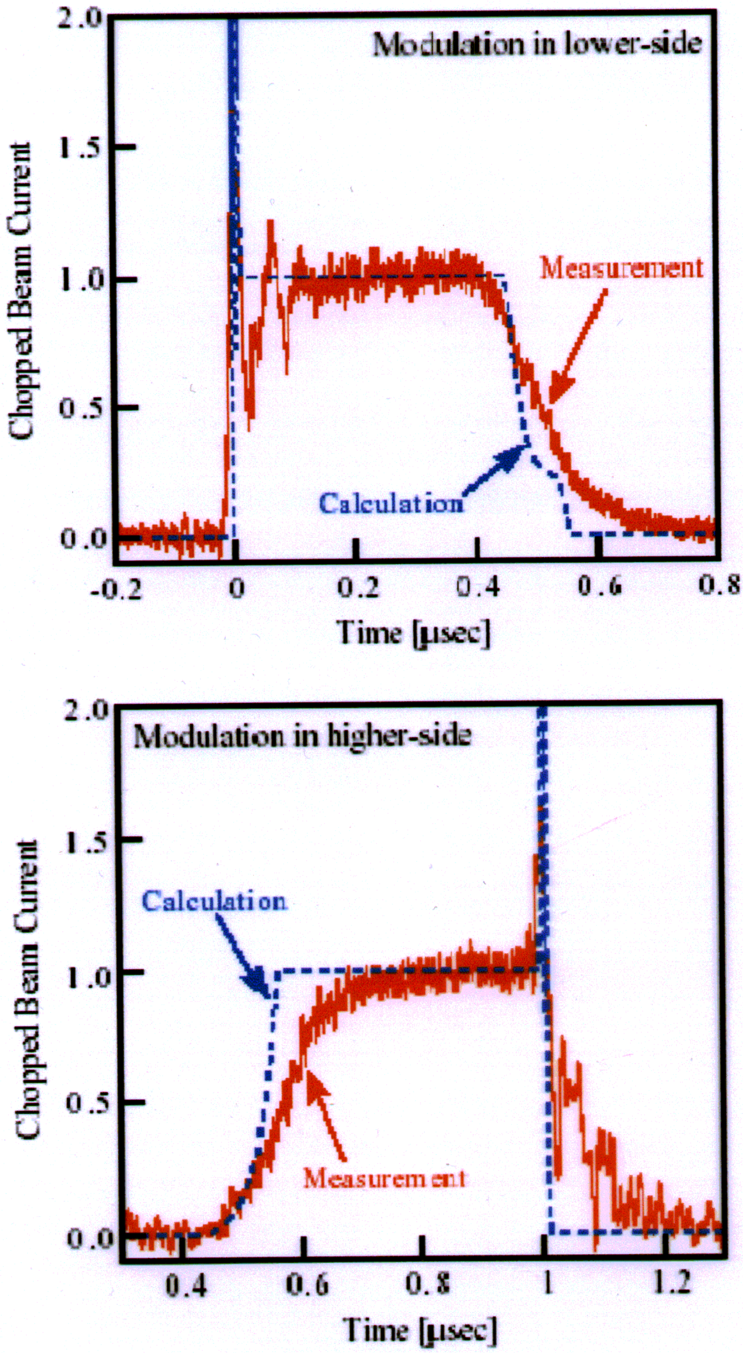

Measured and calculated results of chopped beam currents. When the chopping is done with the lower-side modulation, the spike appears at the front edge of the pulse (top), and with the higher-side modulation, at the rear edge (bottom). These spikes are caused with the bunching of beams due to the finite rise and fall speed of the chopper voltage. Numerical calculation was carried out, with a simplified assumption of a sinusoidal voltage rise- and fall-time of 50nsec (broken lines).

ICFA – HB2002, Takagi

High Power Linac Survey (H^+,H^-,D^+) *

* Based on T. Wangler's original table & updated during sessions of W.G. 2

W.G. II

Name	Ion	Pulse length (ms)	F_{Rep} (Hz)	Duty factor (%)	I_{Bunch} (mA)	$I_{Average}$ (mA)	Energy (GeV)	$P_{Average}$ (MW)	Start date …
LANSCE	H^+/H^-	0.625	100/20	6.2/1.2	16/9.1	1.0/0.1	0.8	0.8/0.08	On
* **SNS**	H^-	1.0	60	6.0	38	1.4	1.0	1.4	2006
* **CERN SPL**	H^-	2.8	50	14	22	1.8	2.2	4.0	?
* **ESS Short Pulse**	H^-	1.2	50	6.0	114	3.75	1.33	5 + 5	2010
ESS Long Pulse	H^- or H^+	2/2.5	16.67	4.2	114/90				
FNAL 8 GeV	H^+/H^-/e	1.0	10	1.0	25	0.25	8.0	2.0	?
* **JKJ 400 MeV**	H^-	0.5	50/25	2.5	50	0.7	0.4	0.28/0.14	2006
JKJ 600 MeV			25	1.25		0.35	0.6	0.21	?
* **TRASCO**	H^+	∞	CW	100	30	30	≥1.0	≥30	?
* **IFMIF**	D^+	∞	CW	100	2x125	2x125	0.040	10.0	2010

April 12, 2002

20th ICFA BD Workshop
8-12 April 2002