SRF Accelerator for Indian ADS Program: Present & Future Prospects

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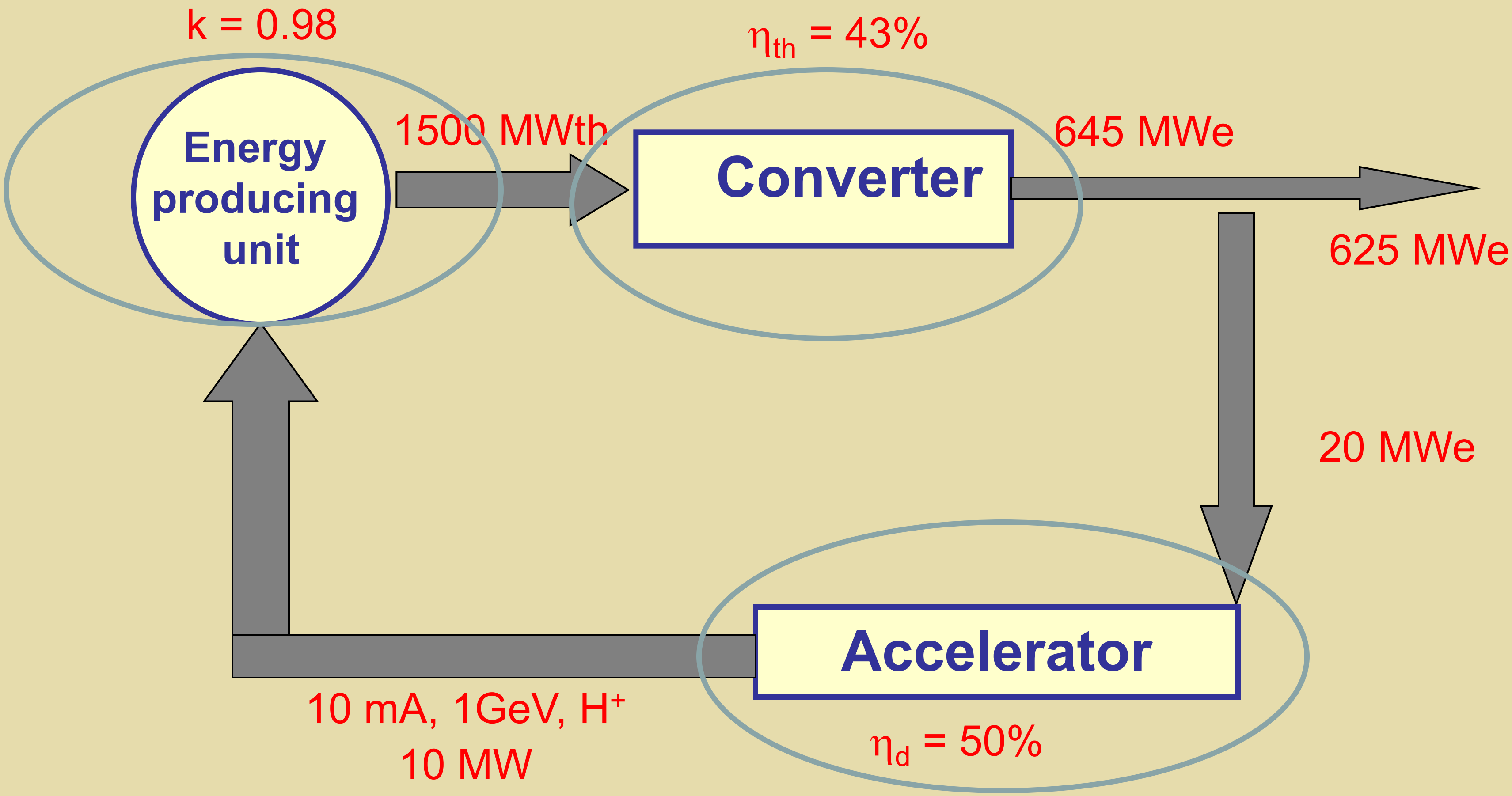
ACCELERATOR DRIVEN ENERGY AMPLIFIER

(Carlo Rubia)

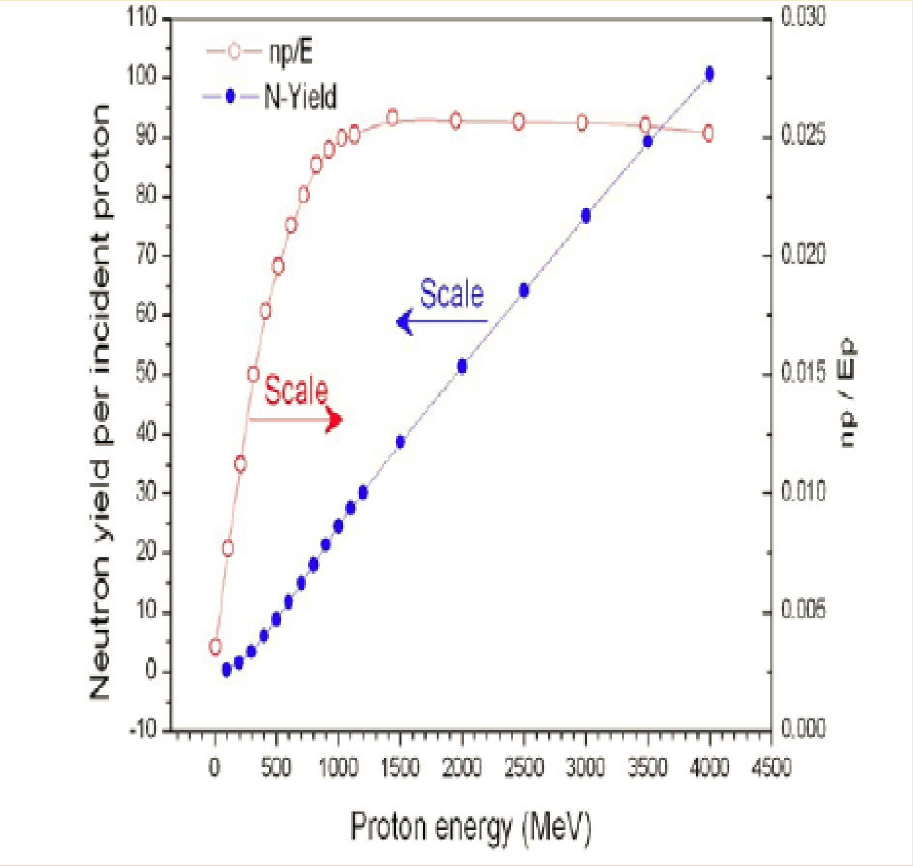


Y. Kadi and J.P. Revol

ADS

- ➢**Energy generation using Thorium**
- ➢**Transmutation**
- ➢**Incineration**

Most cost effective way to produce neutrons



✓By Spallation process with GeV energy protons striking on high Z target.

✓Number of neutrons per proton per Watt of beam power reaches a plateau just above 1 GeV.

Beam current requirement

$$P_{thermal}(MW) = E_{fission}(MeV) I(A) \frac{\nu_s}{\nu} \frac{k}{1-k}$$

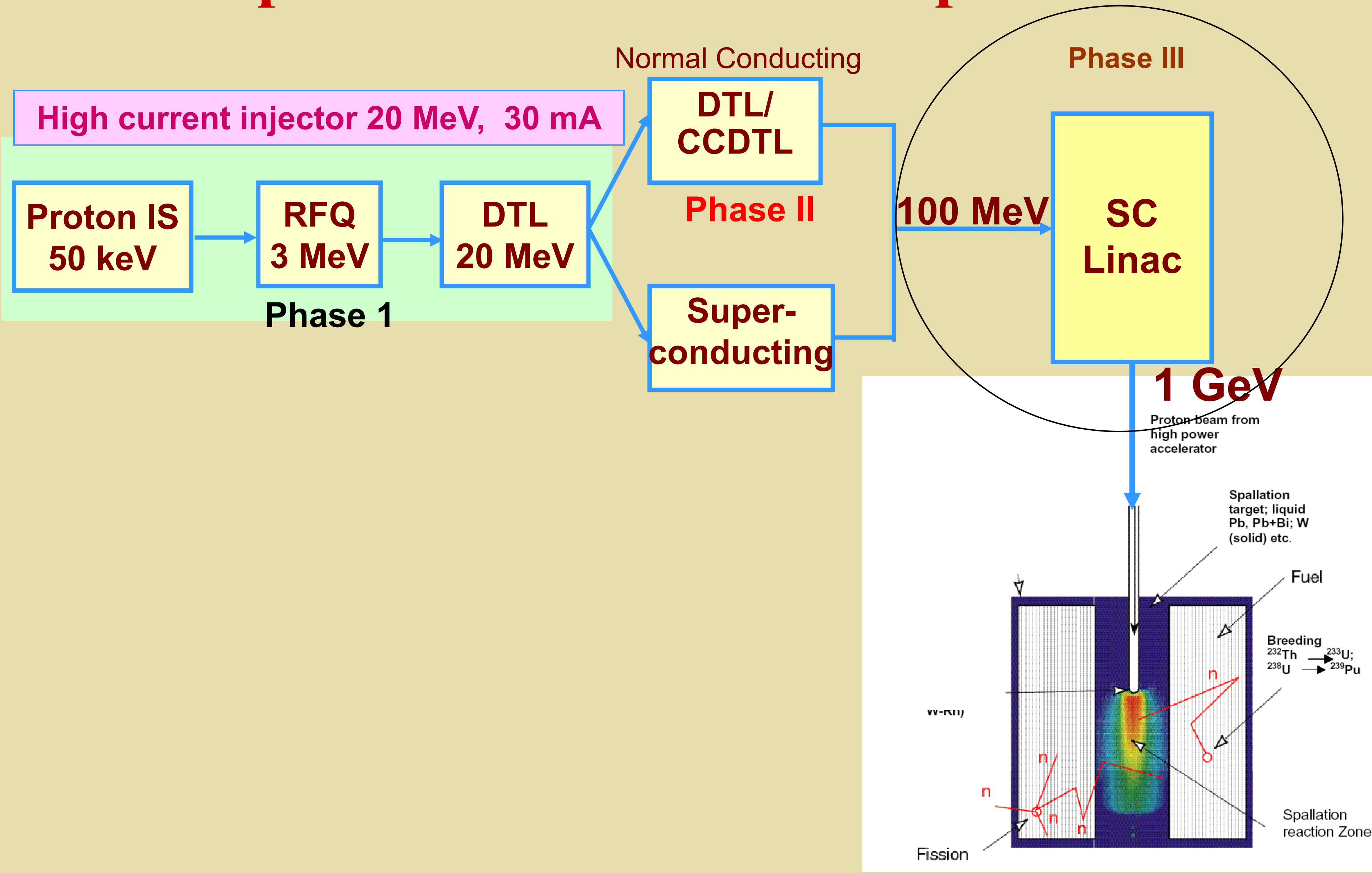
Proton Energy : 1 GeV
ν_s = 25 neutrons/proton
ν = 2.5 neutrons/fission

P_{th} (MW)	I (mA) *k=0.95*	I (mA) *k=0.98*
1000	29.2	10.2
1500	43.9	15.3
2000	58.5	20.4
2500	73.1	25.5
3000	87.7	30.6

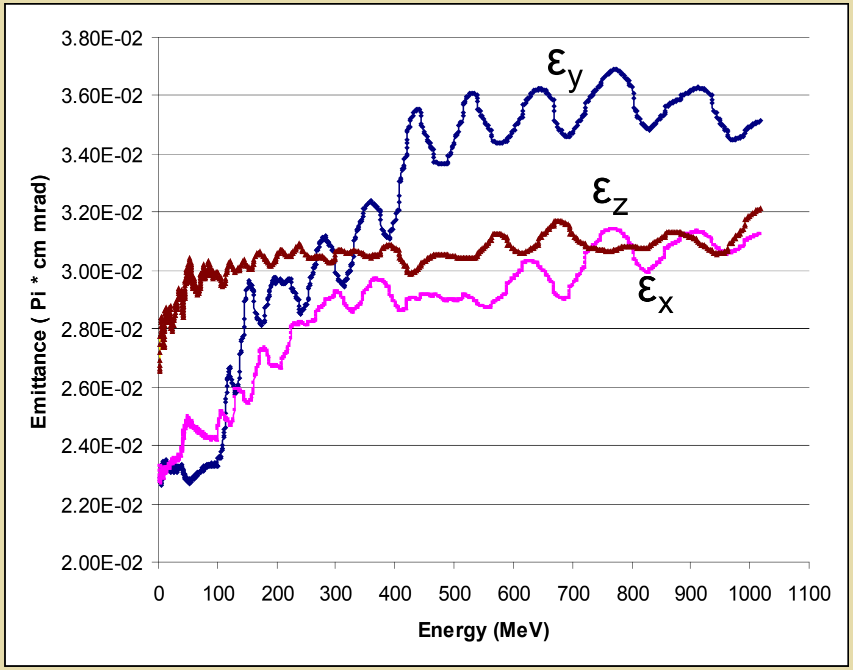
World Thorium Resources

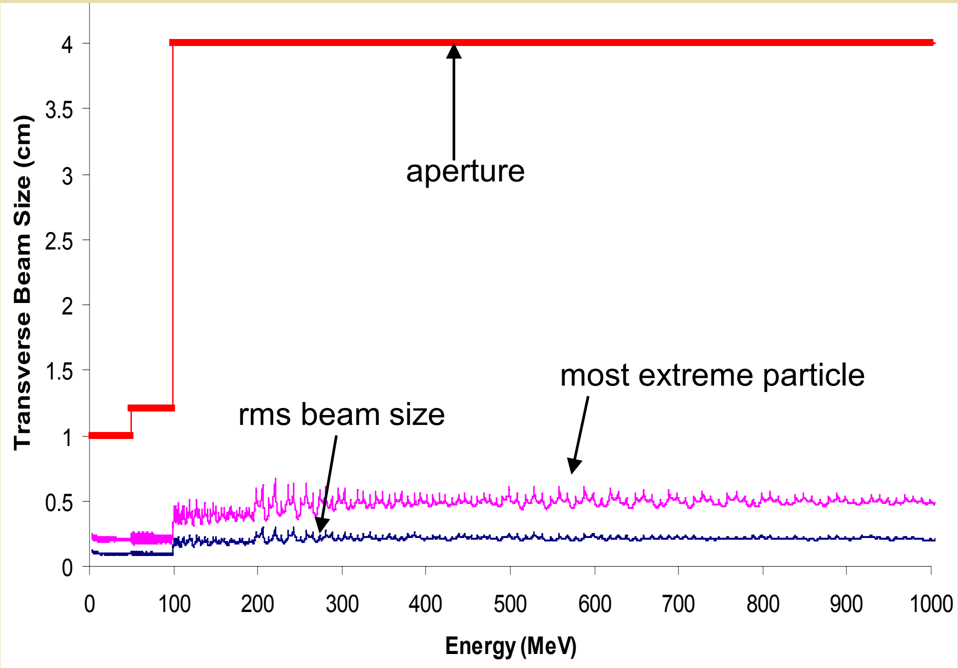
Country	Reserves (tons)
Australia	300,000
India	290,000
Norway	170,000
USA	160,000
Canada	100,000
S. Africa	35,000
Brazil	16,000
Other Countries	95,000
World total	1,200,000

Roadmap for Accelerator Development for ADS



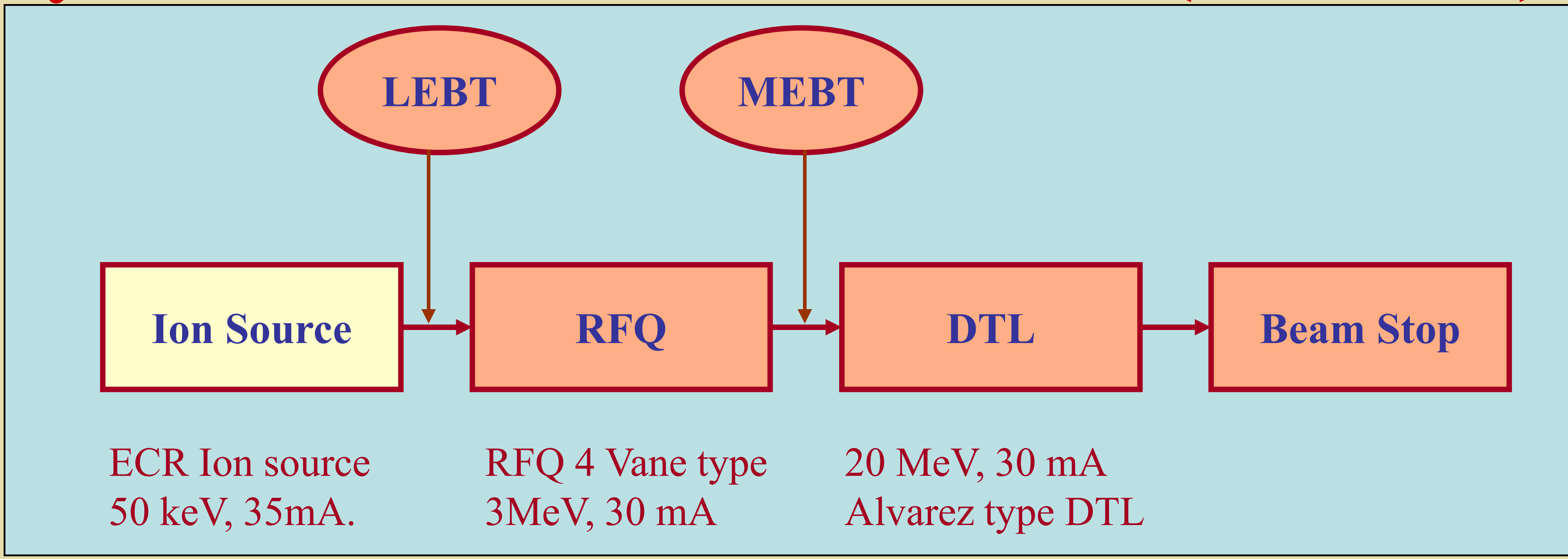
Beam Dynamics



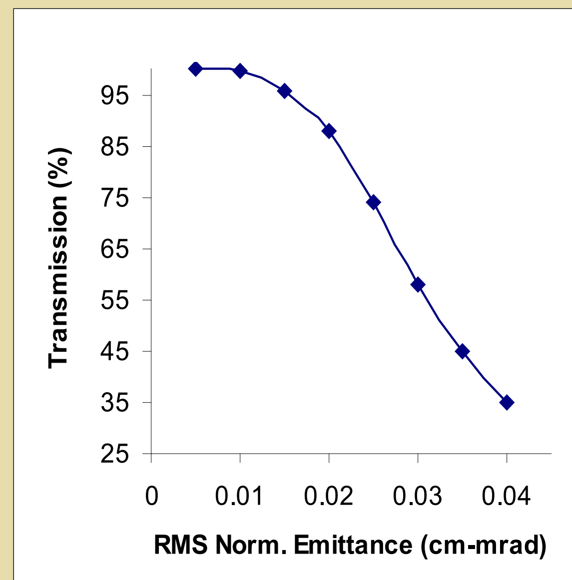


- Aperture is more than 16 times the rms beam size in the SC Linac
- Emittance growth is very small
- Transmission through the linac = ~97% (loss ~ 3% loss-RFQ).

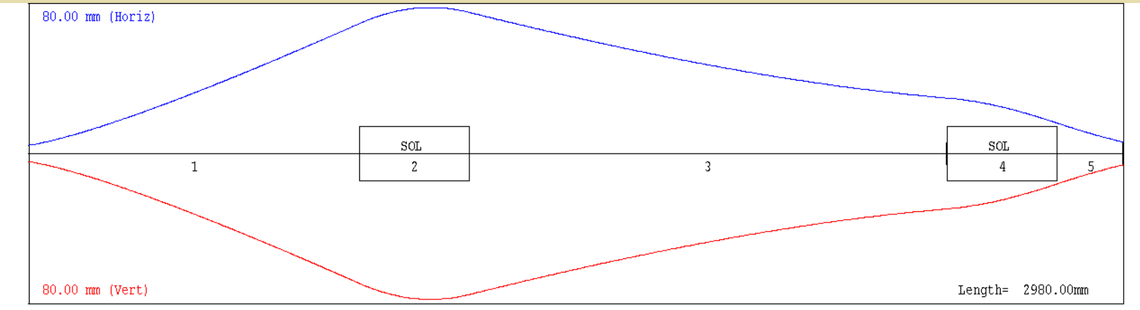
Layout of 20 MeV Linac Section (LEHIPA)



- High Current CW Linac.
- **Space charge forces** are strongest here.
- Main Design issue is **beam loss control & emittance growth.**
- Thermal management.



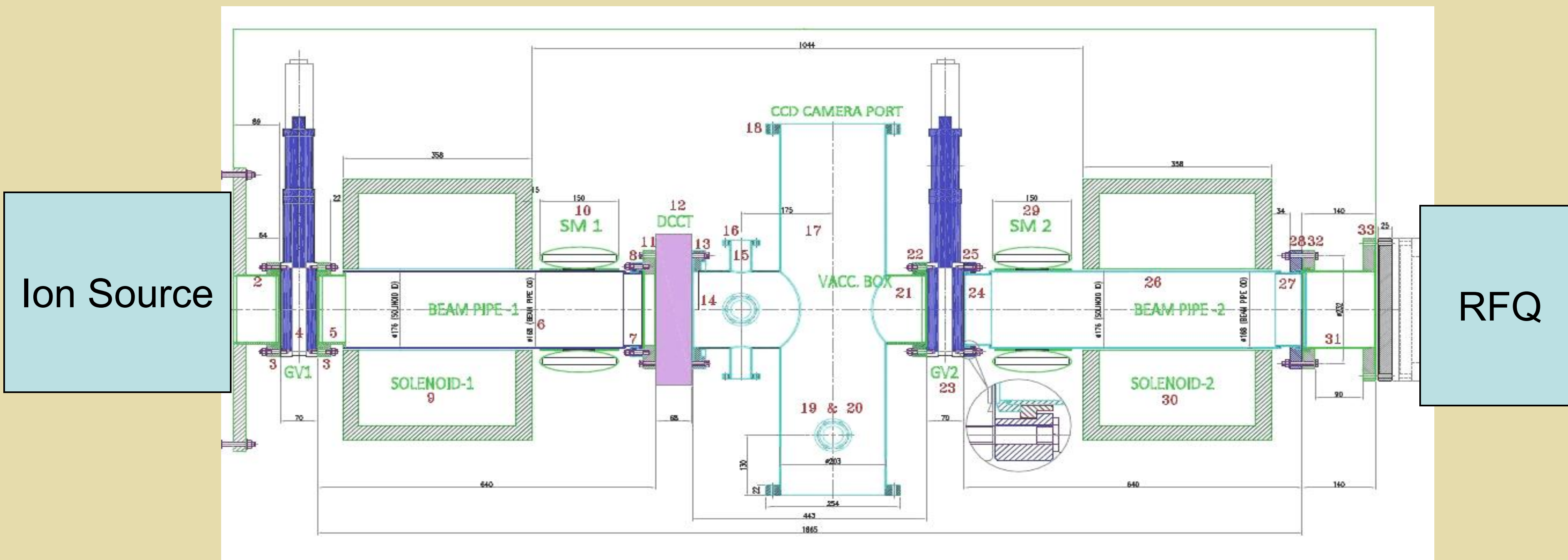
LEBT



Element	Length (cm)	Strength (G)
Drift	90	
Solenoid	30	1604
Drift	130	
Solenoid	30	1903
Drift	18	

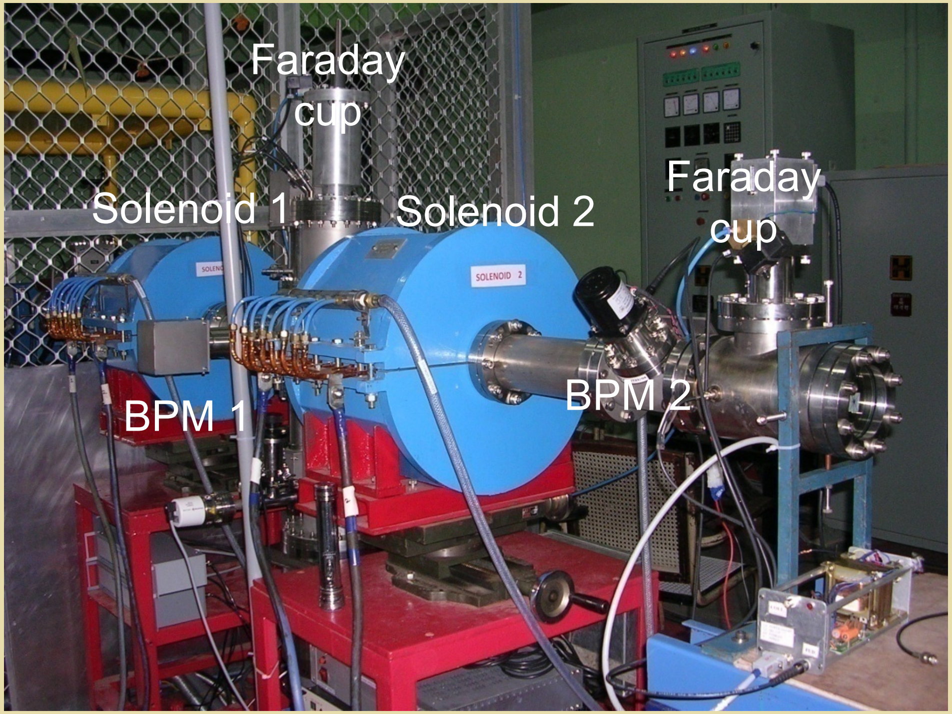
LEBT Components

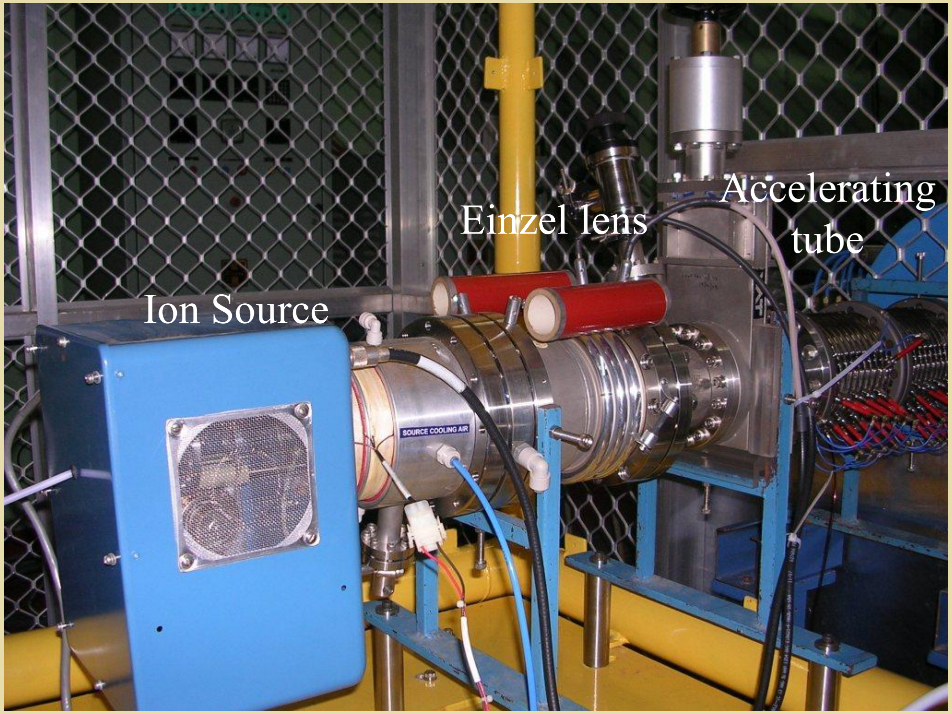
Solenoids	Designed, Fabricated & Tested.
Steering Magnets	Designed. To be fabricated.
Electron Trap	Designed. To be fabricated.
Diagnostics	DCCT, ACCT, RGBPM, Faraday Cup, …

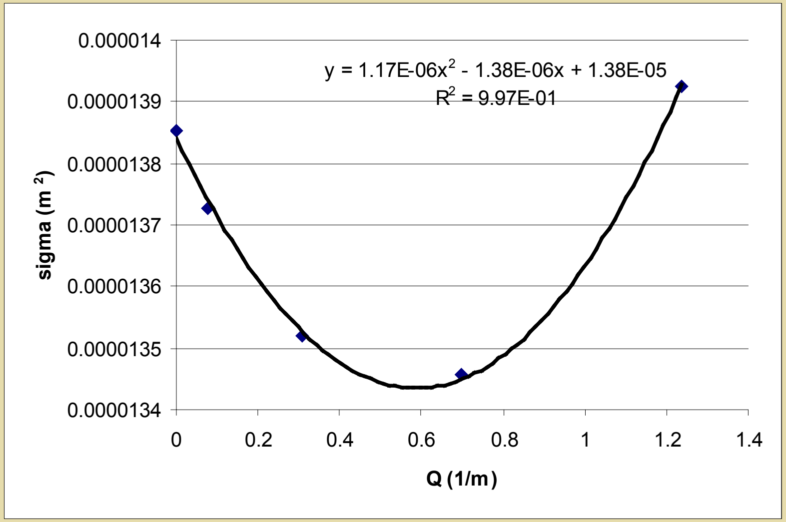


Layout of LEHIPA LEBT (Low Energy Beam Transport) Line

Test Bench for LEBT using Alphatros Ion Source







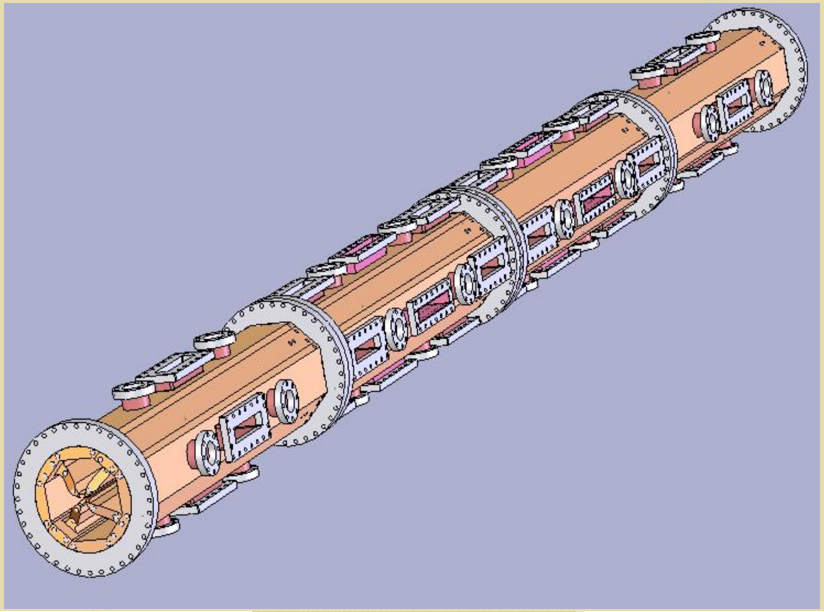
Emittance measurement using solenoid scan method

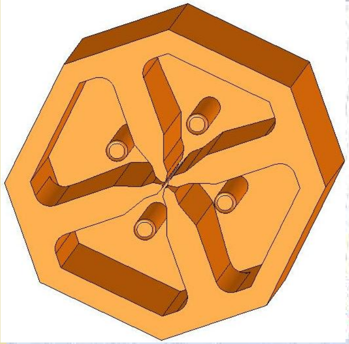
$$\sigma_{11}{}^{1} = \sigma_{11}{}^{0} L^2 Q^2 - 2(L\sigma_{11}{}^{0} + L^2\sigma_{12}{}^{0})Q + (\sigma_{11}{}^{0} + 2\sigma_{12}{}^{0} L + L^2\sigma_{22}{}^{0})$$

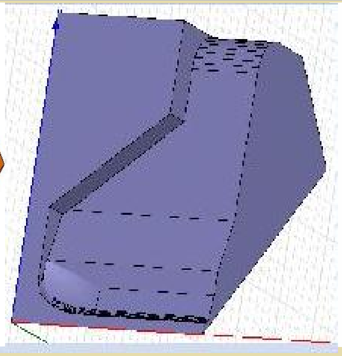
Normalized rms emittance is calculated to be 0.18 π cm mrad

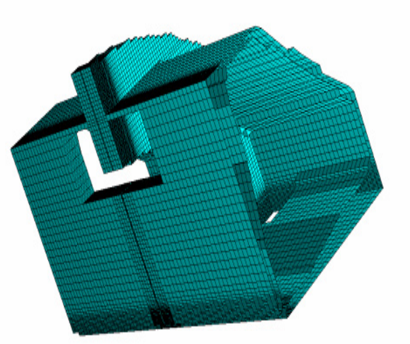
3 MeV RFQ

Parameters	Value	Units
I/O energy	0.05/3.0	MeV
Frequency	352.21	MHz
R_0	0.3556	cm
Rho	0.283	cm
Synch. phase	-30	deg
Vane Voltage	85	kV
Modulation	1.96	
Es	32.9	MV/m
Total length	4	m
RF power	550	kW
Transmission	98	%







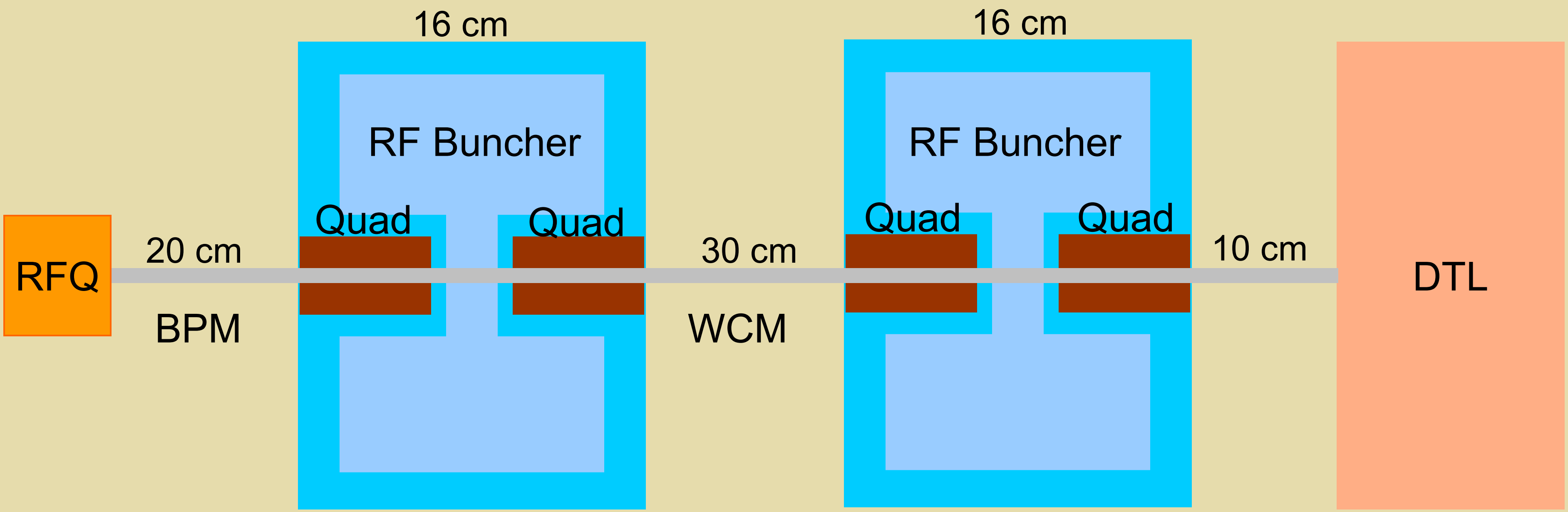


- ❖ It is planned to have it in 2 sections of 2 m each coupled via coupling cell.
- ❖ Planned to use Dipole stabilizer rods.
- ❖ Undercuts in the end regions to get the desired mode.

- ❖ 16 wall coolant channels and 8 vane cooling channels in a segment.
- ❖ Detailed Cooling requirements near the undercuts and Vacuum ports are in progress

MEBT

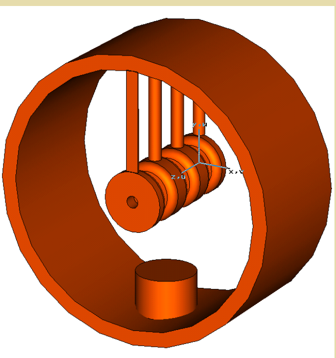
- Used for matching the beam from the RFQ to DTL
- 4 quadrupoles & 2 rf bunchers for matching the beam
- Quadrupole gradient: 20-40 T/m, Eff. Length = 7cm, aperture ~ 3 cm (dia)
- RF Bunchers @ 352.2 MHz, Rf Power = 5-6 kW
- Total length ~ 1 m.
- Provision for BPM and Wall Current Monitor

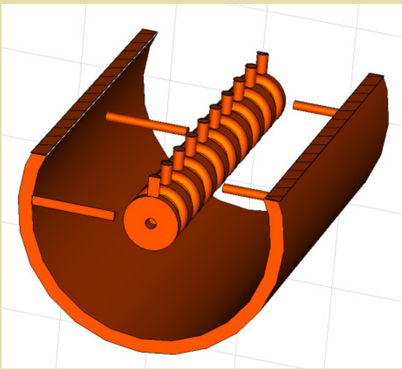


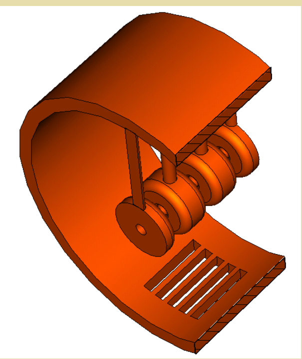
Layout of MEBT

Drift Tube Linac

Parameters	Tank 1	Tank 2	Tank 3	Tank 4
Input Energy (MeV)	3.11	6.85	11.26	15.75
Output Energy (MeV)	6.85	11.26	15.75	20.23
Quad grad. (T/m)	47-46	45-44.5	44.5-43	43
Aperture radius (cm)	1.2	1.2	1.2	1.2
Acc. Field grad. (MV/m)	2.14	2.14	2.14	2.14
Total Power (kW)	396.8	417.5	414.5	412.2
Tank Length (m)	3.05	3.26	3.27	3.28







Tolerances

- ✓ Quadrupole displacement along the transverse direction: ≤ 100 μm
- ✓ Quadrupole tilt ≤ 0.6 deg.
- ✓ Quadrupole field ≤ 0.7 % of the designed value.
- ✓ Beam axis misalignment with respect to the DTL axis ≤ 0.5mm
- ✓ Beam tilt ≤ 3 mrad

Tuners

- ❖6 Tuners of dia. 12 cm in each tank.
- ❖Maximum Depth : 11 cm
- ❖Nominal Position : 5.5 cm inserted
- ❖Tuning range: 2.28 MHz (using all tuners)

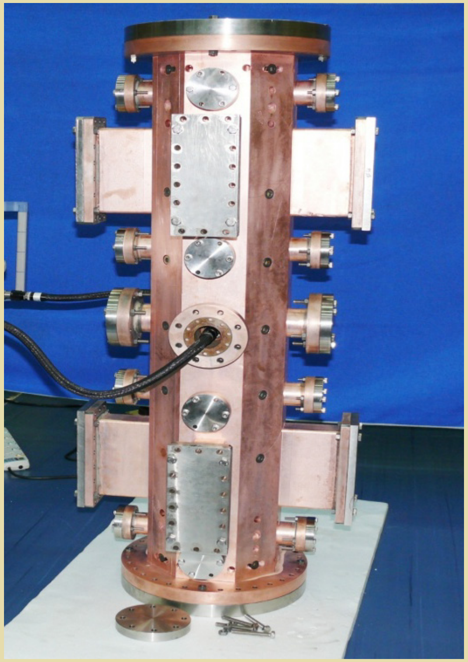
Post couplers

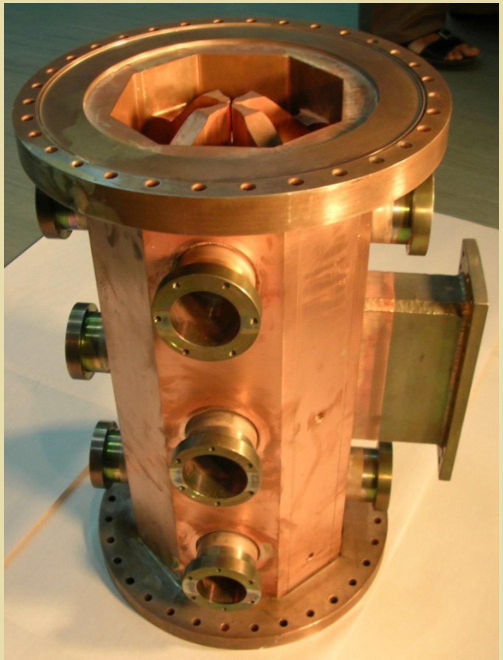
- ❖One Post Coupler every third DT in Tank 1 and 2 and every second DT in Tank 3 and 4.
- ❖Diameter: 2.5 cm

Vacuum Ports

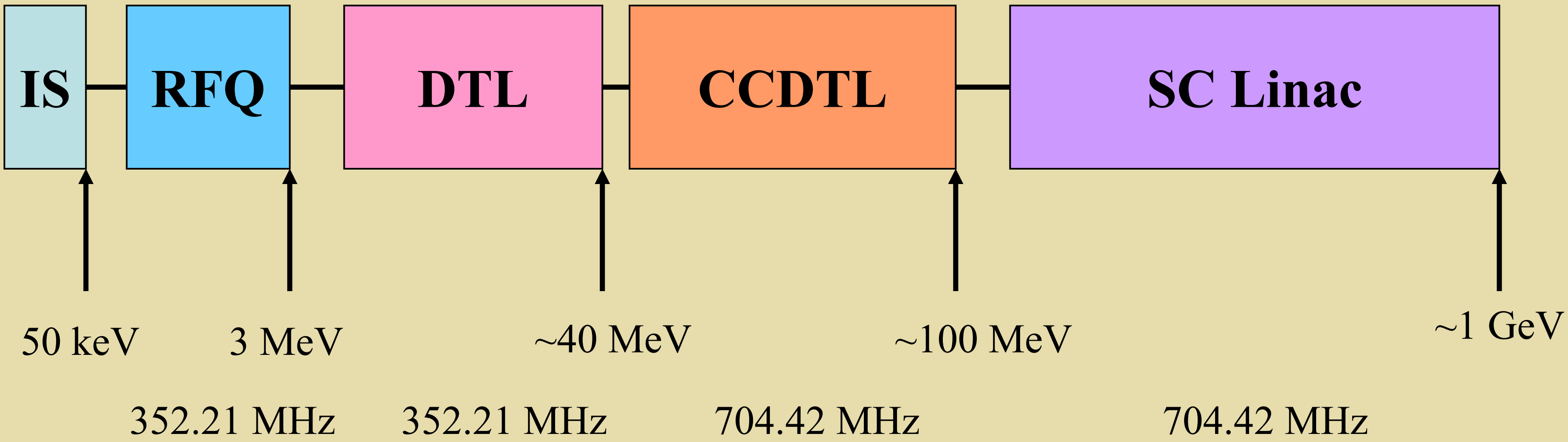
- ❖5 rectangular slots per vacuum port
- ❖No. of vacuum ports in first tank: 2

RFQ (400 keV) & DTL Prototypes





Layout of the 1 GeV Linac



Design Philosophy

- Match the beam from one structure to the next.
- Smooth phase advance per metre across all transitions for current independent matching.
- Avoid instabilities by keeping the zero current phase advance per period in all planes below 90 deg.

Roadmap for Accelerator Development for ADS

Modified

High current injector 20 MeV, 30 mA

Proton IS 50 keV → **RFQ 3 MeV** → **DTL 20 MeV**

Phase 1

Normal Conducting

DTL/ CCDTL

Phase II

Super-conducting

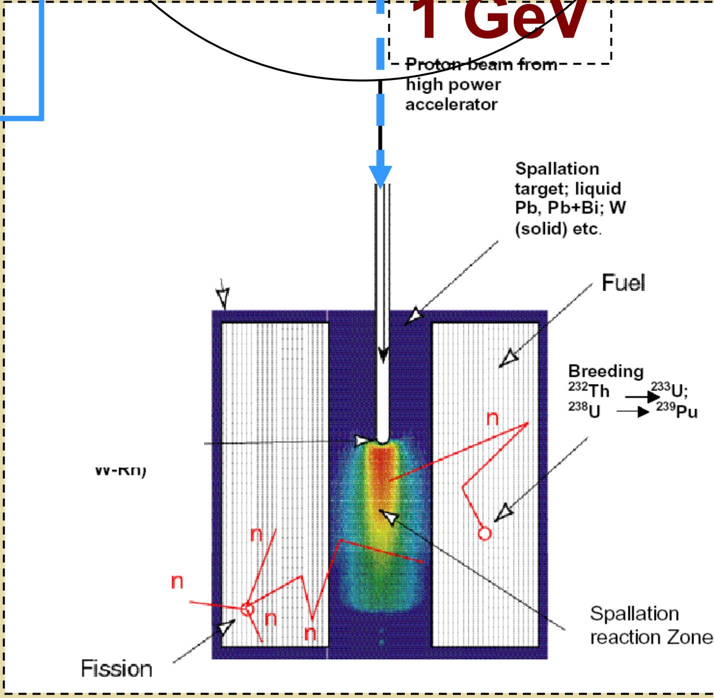
Phase III

100 MeV → **SC Linac**

1 GeV

Super-conducting

Spoke cavities

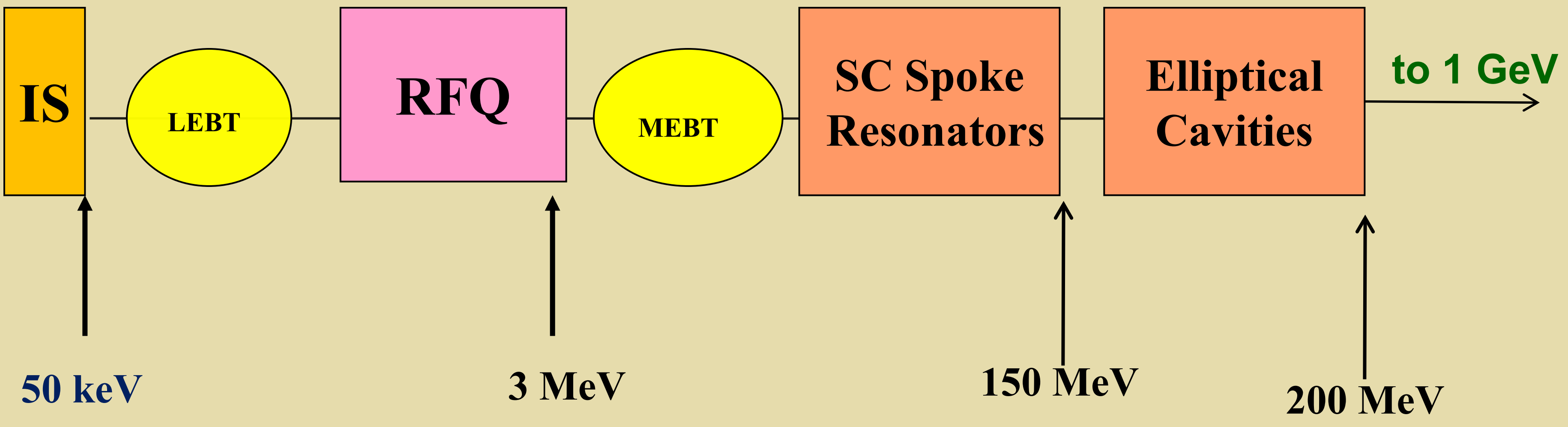


325 and 650 MHz

Being discussed under Indian Institutions and Fermilab Collaboration

Frequency: 325 and 650 MHz

Scheme for 200 MeV High Intensity Proton Accelerator (a front end of the 1 GeV Linac)



Current : 30 mA

We may go in steps but the design needs to be done for 30 mA

Comparison between NC & SC linac (200 MeV)

NC Option			SC Option		
RFQ	0.5 MW	3 MeV	**RFQ**	0.5 MW	3 MeV
DTL	3.0 MW	40 MeV	**Spoke/Ellip cavities**	6.0 MW	200 MeV
CCDTL	6.4 MW	100 MeV			
SC Linac	3.0 MW	200 MeV			

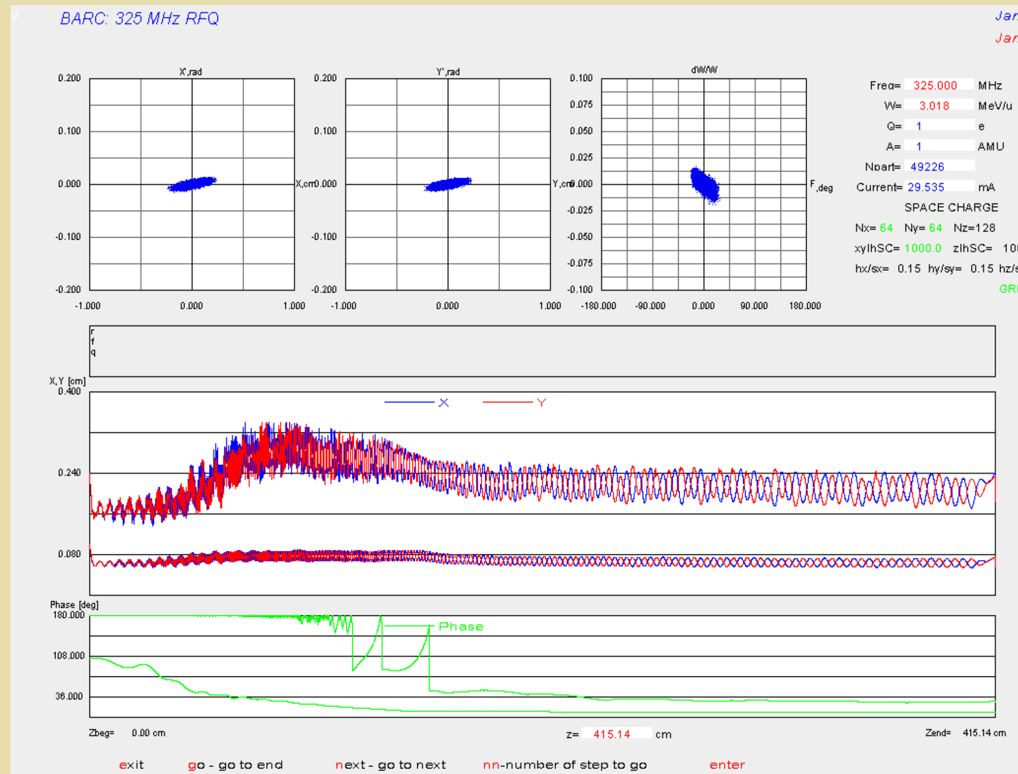
Total RF Power : ~13 MW
Length : ~ 140 m

Total RF Power : ~6.5 MW
Length : < 80 m

We save 6.5 MW of RF Power!
Length is only 100 m !!
Less number of components !!!

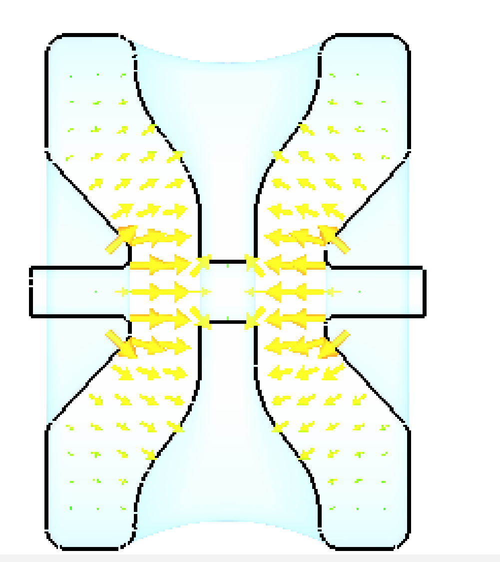
Preliminary RFQ Design (200 MeV Linac option)

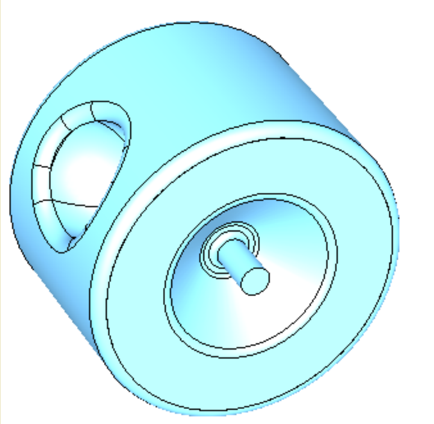
Energy	**35 keV-3 MeV**
Frequency	325 MHz
Current	30 mA
Vane Voltage	78 kV
Length	4.15 m
R_0	3.634 mm



Preliminary SSR2 ($\beta = 0.4$) Design

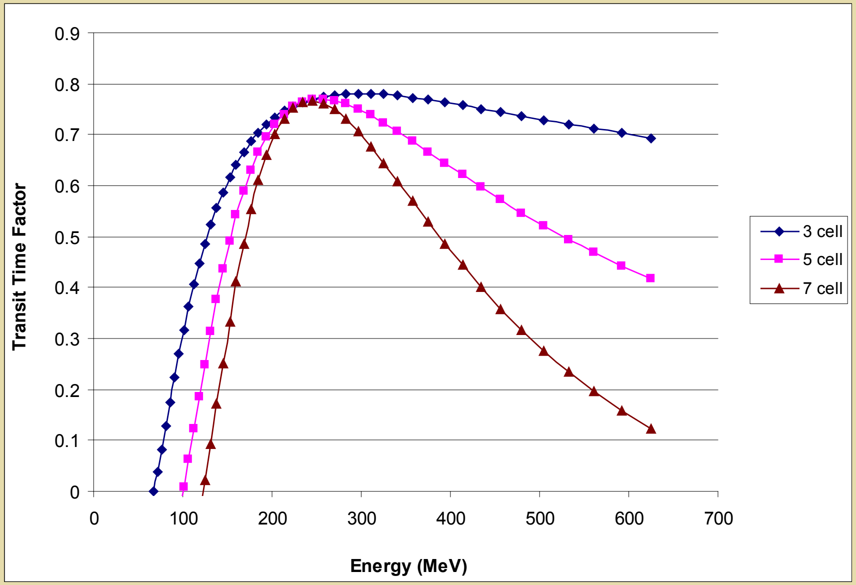
Optimization of SSR2 cavity





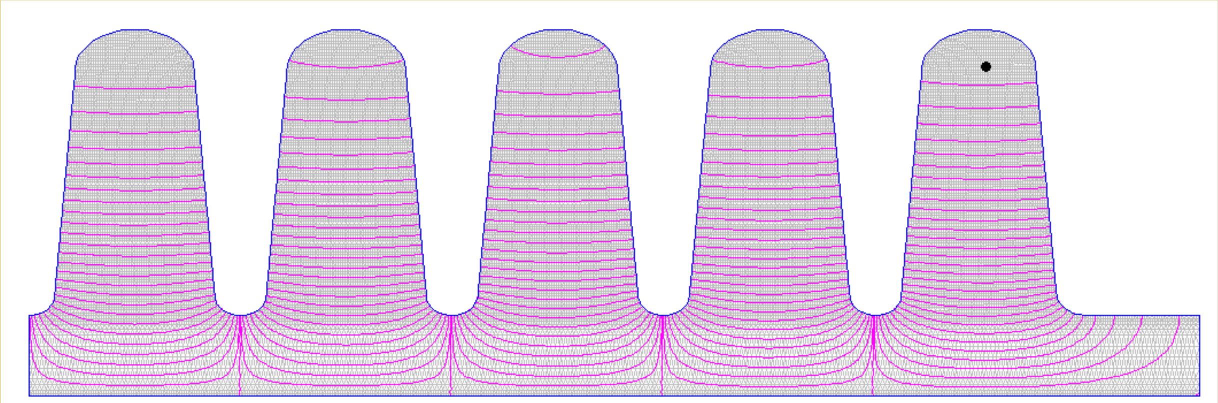
Parameter	Values
Geometrical beta	0.4
frequency	323.92 MHz
Peak electric field	9.15 MV/m
Peak Magnetic Field	13.66 A/m
Radius	26.13 cm
Cavity Length	36.81 cm

Elliptical Cavities 650 MHz



Parameters	$\beta_G = 0.6$	$\beta_G = 0.8$
No. of Cells	5	5
Diameter (cm)	39.34	38.54
Dome B (cm)	2	2
Dome A/B (cm)	1.9	2.4
Wall Angle (deg)	8	7
Iris a/b (cm)	0.8	0.6
Bore Radius (cm)	4.0	4.0
Equator Flat (cm)	0.5	1.2
Acc. Gradient (MV/m)	15	15

As the number of cells per cavity increases, the curves get narrower, and the velocity acceptance decreases.



Electric field profile in the 5 cell elliptical cavity.

Summary and Outlook

- **Physics Studies of a 1 GeV, 30 mA Proton Linac for IADS have been done (NC upto 100 MeV).**
- **Proposed to study 3-100/200 MeV using SC spoke resonators (collaboration with Fermilab under IIFC)**
- **R&D on RF systems, LLRF, RF Coulers, BPM, control systems, beam diagnostics, SRF cavity & cryomodule, test stands etc initiated.**
- **R&D part is funded.**

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Thank You