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Institute of Theoretical and Experimental Physics of NRC " Kurchatov Institute",

Moscow , Russia

Normally conducting linacs in Russian accelerator projects

Layout of NC linac

IS – Ion Source

LEBT – Low Energy Beam Transport

RFQ – Radio Frequency Quadrupole

MEBT – Medium Energy Beam Transport

DTL – Drift Tube Linac

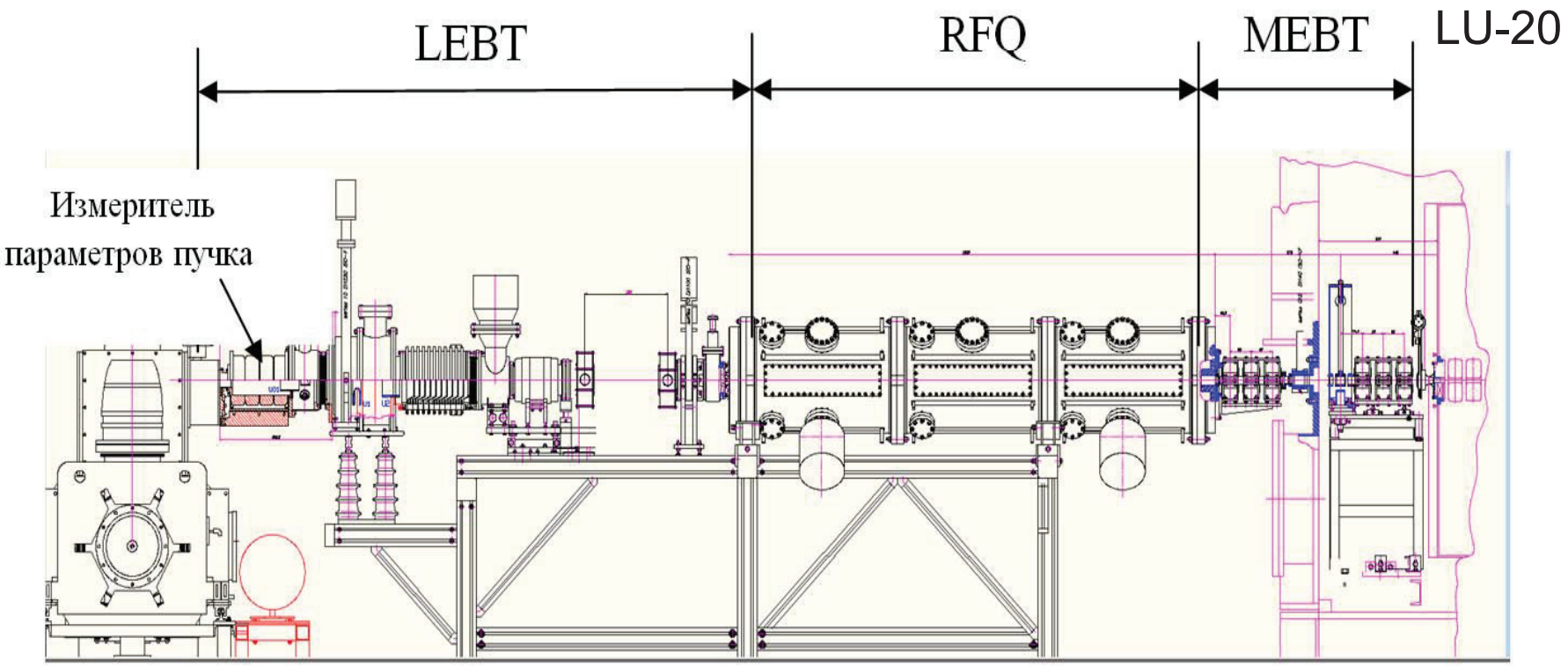
Choice parameters RFQ&DTL

Parameters	Pulse	CW
E_{smax}	Kp=1.7÷2.0	Kp=1.3÷1.6
V_k/ε	≥3	≥10
Transmission	≥ 90%	≥ 95%

RFQ: И.М.Капчинский & В.А.Тепляков 1969. Впервые в мире реализован в ИФВЭ в1975. В 1977 УРАЛ-15. В ИТЭФ в 1982г. рекордный ток ~200мА. LASL в 1980 (Proof of Principle)

- Низкая энергия инжекции
- Большой коэффициент захвата в режим ускорения
- Не требуется предварительной группировки
- Обеспечивает большой аксептанс и высокое значение предельного тока

RFQ for-injector
(LEBT&RFQ&MEBT)

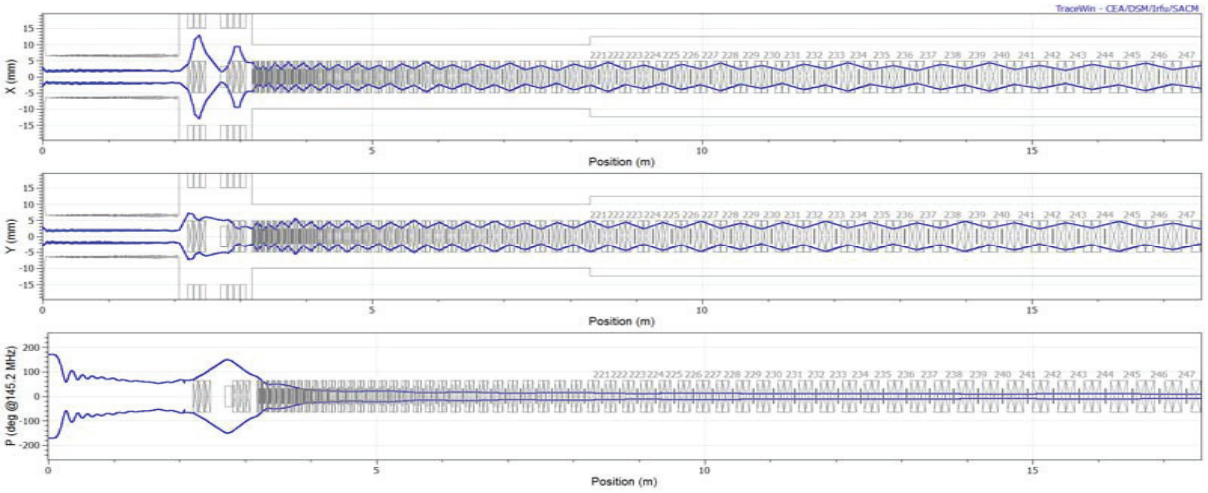


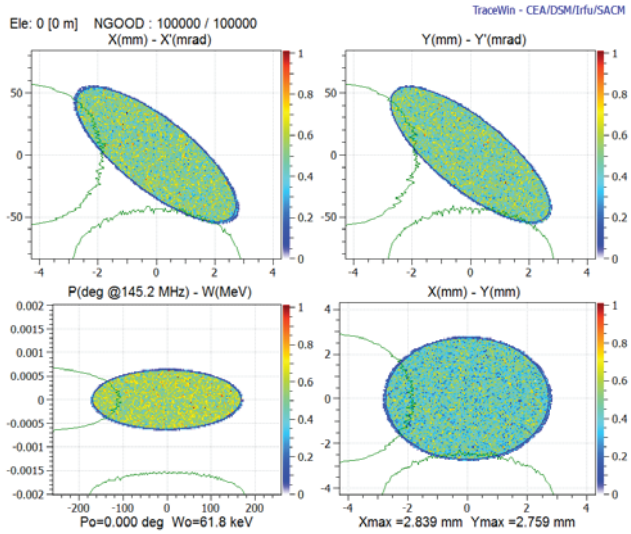
NICA: RFQ for-injector for LU-20

Main RFQ parameters

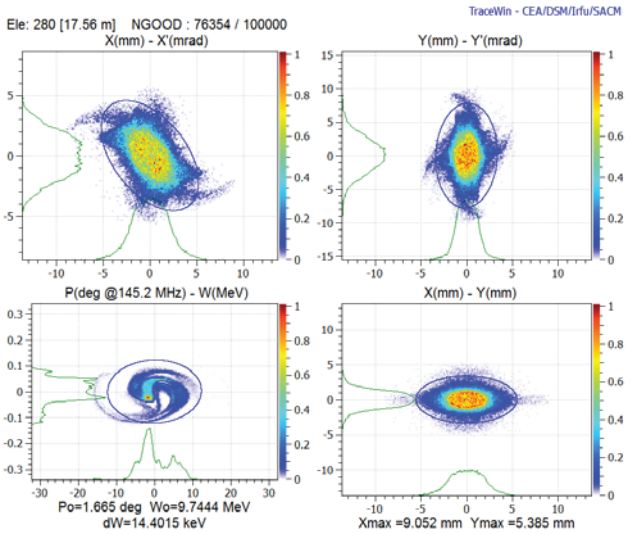
Operating frequency, [MHz]	145.2	
Z/A	0.3	0.5
Injection voltage, [kV]	103	61.8
Injection current, [mA]	10	20
Normalized emittance, [π·mm·mrad]	1.5	2
Normalized acceptance, [π·mm·mrad]	6	
Beam energy, [keV/u]	31÷155	
Synchronous phase,[deg]	-90÷-40	
Intervane voltage, [kV]	142	85
Maximum field strength, [Kp]	1.8	1.2
Average radius, [mm]	6.5	
Maximum vane modulation	1.3	
Length, [m]	2.07	
Transmission RFQ&MEBT&DTL, [%]	81	76
The RF power losses, [MW]	~ 0.5	

d+ Beam envelopes for RFQ&MEBT&DTL(Alvarez)



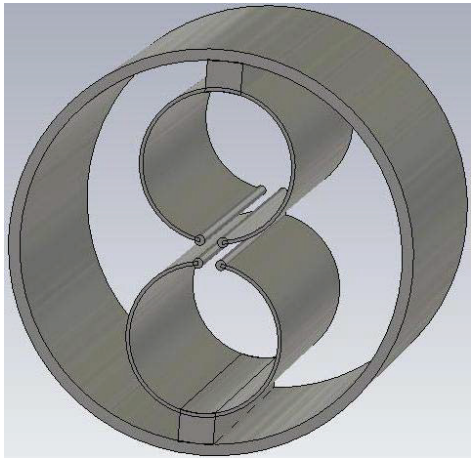


RFQ Input phase portraits

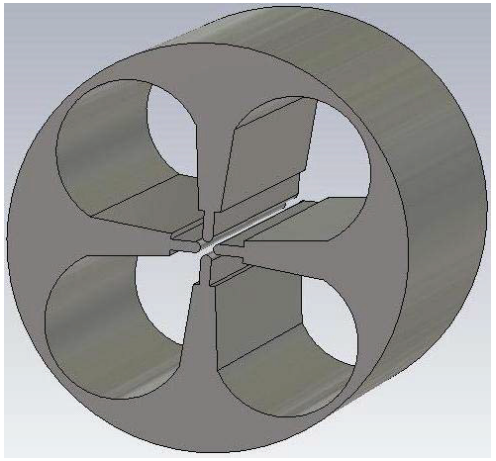


DTL Output phase portraits

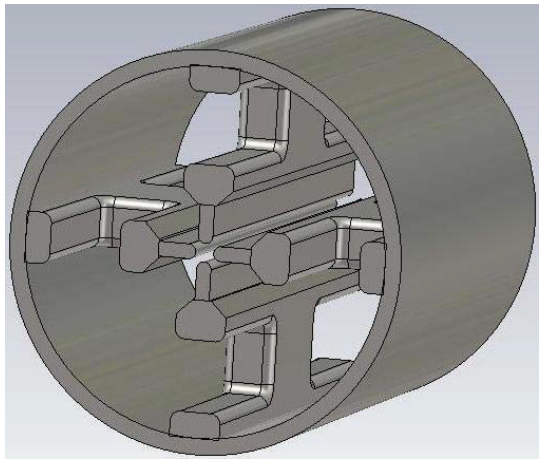
RFQ resonant structure



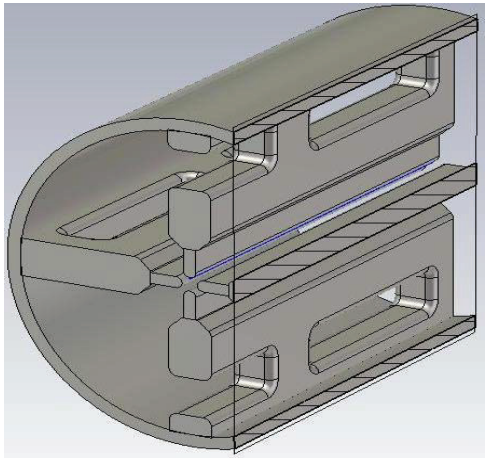
2H – резонатор Теплякова



«Клеверный лист»

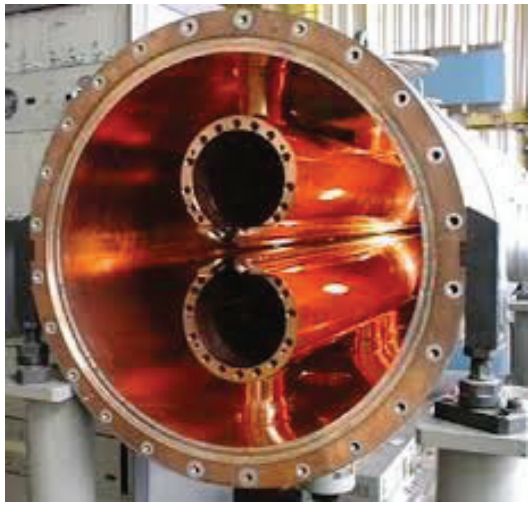


4-х камерный резонатор RFQ с окнами связи без смещения

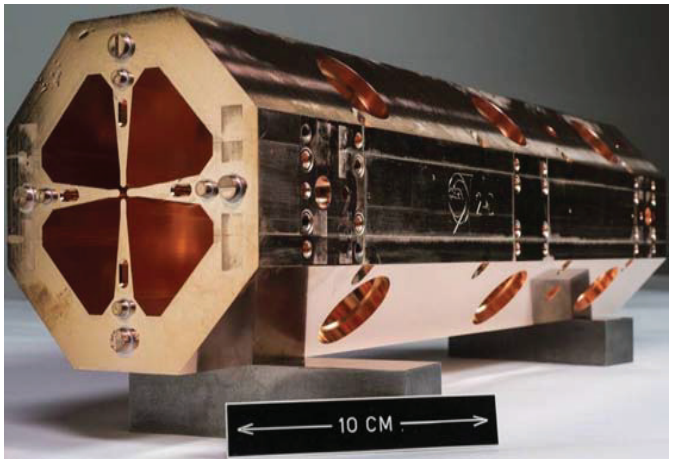


4-х камерный RFQ со смещенными окнами связи

RFQ resonant structure

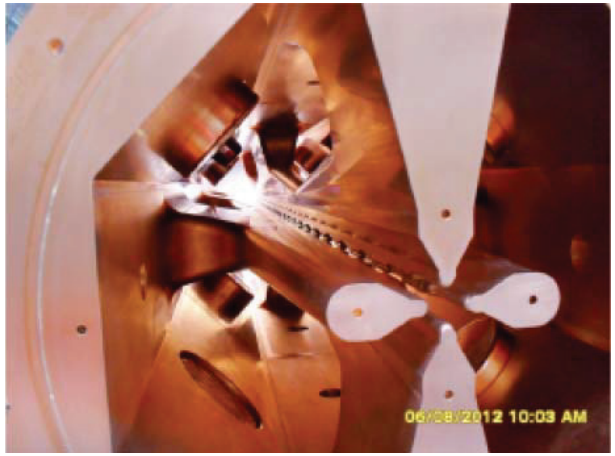


2H – резонатор Теплякова (URAL)



"клеверный лист“

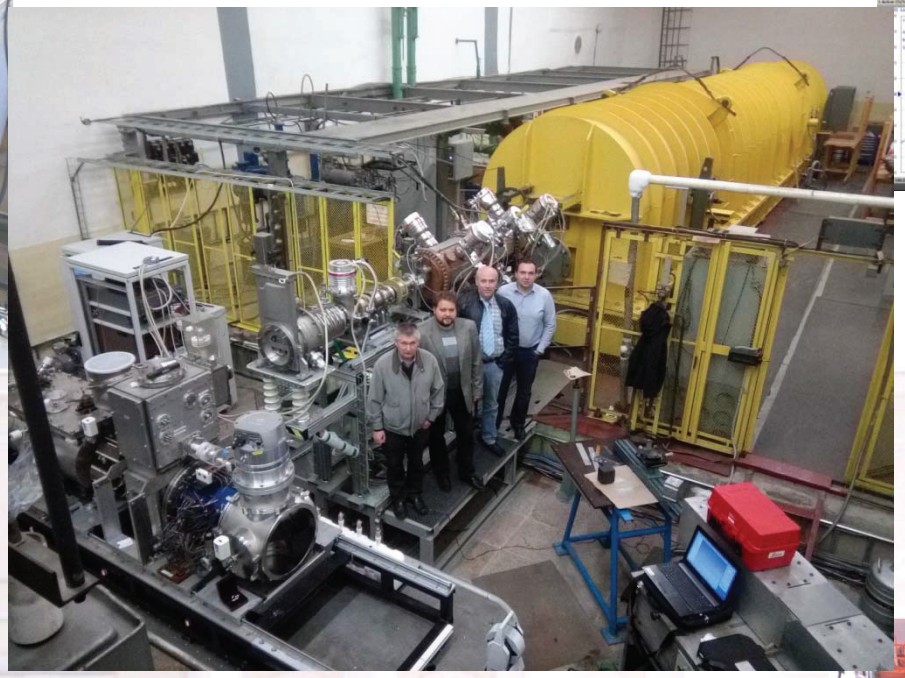
Структура типа "4-vanes“
со ссмещенными окнами (NICA)

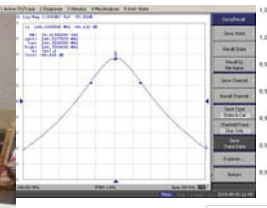


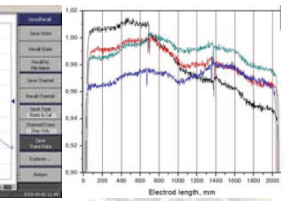
ATLAS RFQ (P. Ostroumov) cw linac

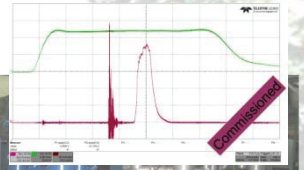
Project NICA (JINR)

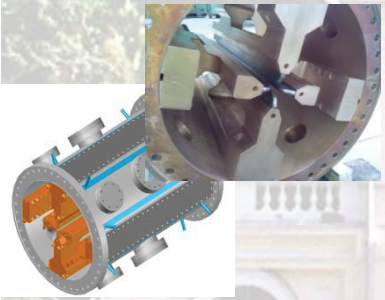
RFQ for-injector Nuclotron

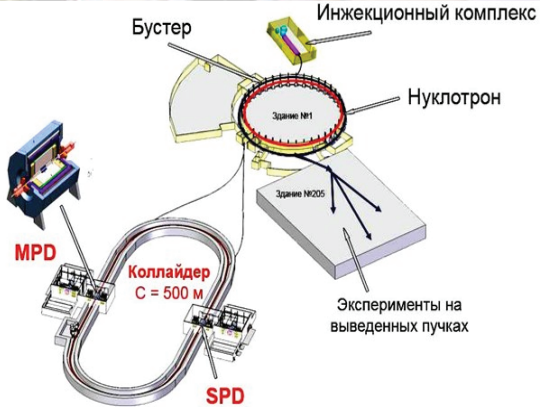








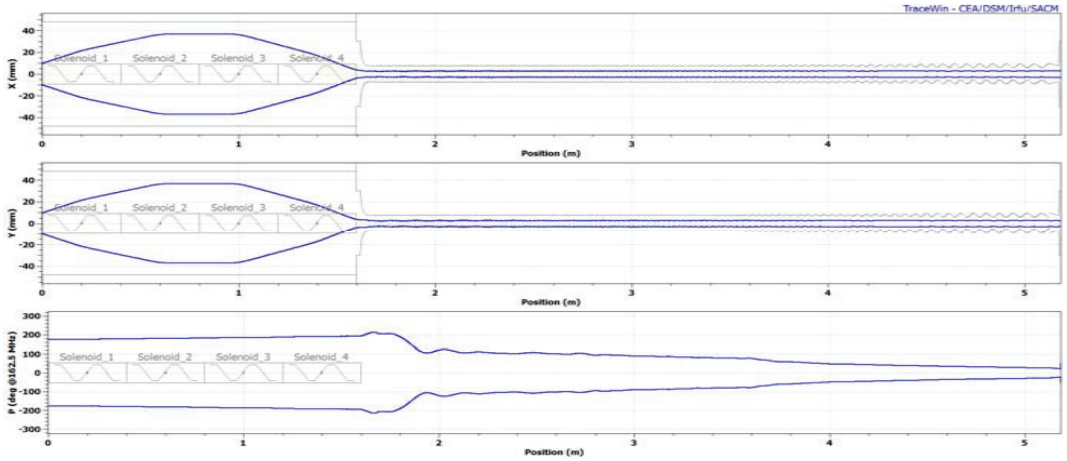




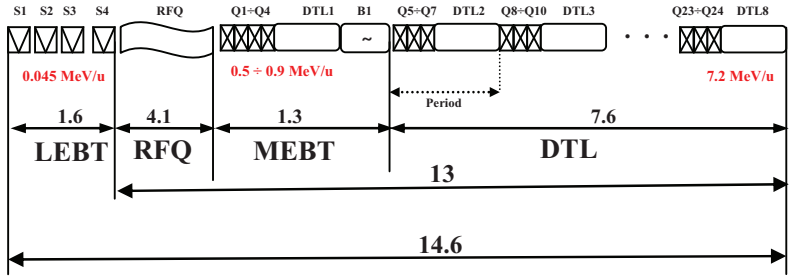
Transmission, %					
Z/A=0.5; I_{inj}=20 мА			Z/A=0.3; I_{inj}=10 мА		
RFQ (out)	MEBT (out)	ЛУ-20 (inp)	RFQ (out)	MEBT (out)	ЛУ-20 (inp)
89	81	75	93	92	80

New injector for Nuclotron

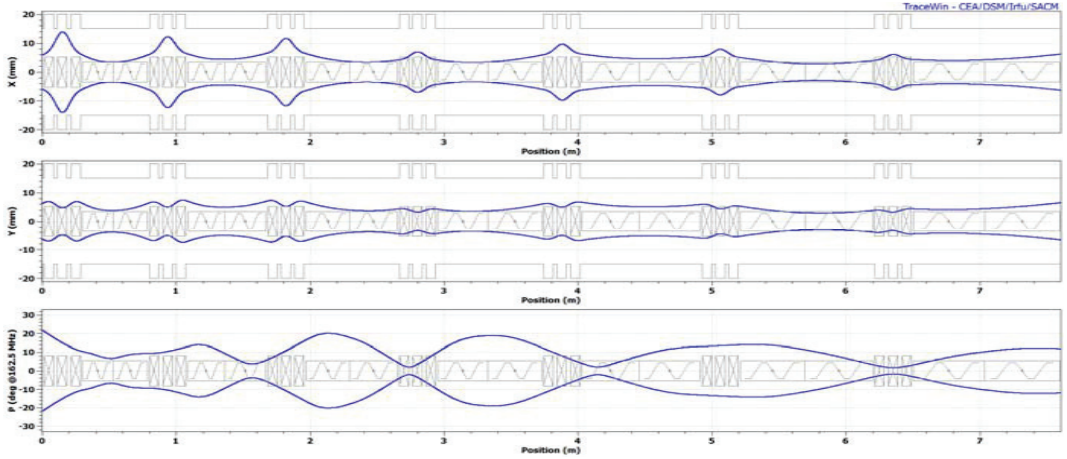
LEBT&RFQ envelopes



Layout of Linac



DTL envelopes

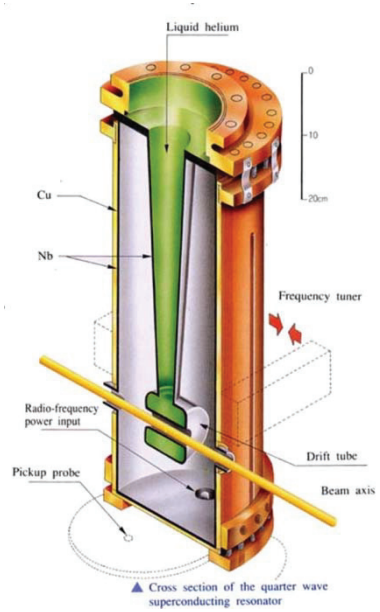


Main RFQ&DTL parameters

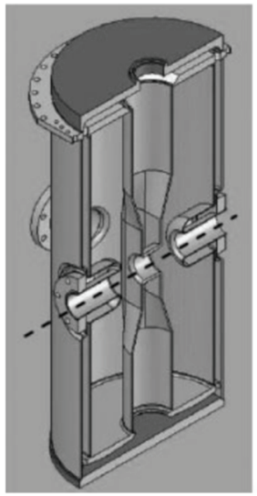
Operating frequency, MHz	162.5		
A/Z	1	2	3
Injection voltage, [kV]	45	90	135
Injection current, [mA]	5	10	15
Structure	RFQ	DTL	
Beam energy, [MeV/u]	0.045 ÷ 0.5	0.5 ÷ 7.2	
Maximum field strength [Kp]	1.8		
Normalized acceptance, [π mm mrad]	6	7	
Synchronous phase, [deg]	-90÷-35	-30	
Length, [m]	4.1	7.6	
Aperture radius, [mm]	19.0 ÷ 6.0	15.0	
Transmission, [%]	94.5	100	
RF power losses, [MW]	~0.5	~1	

Q_0

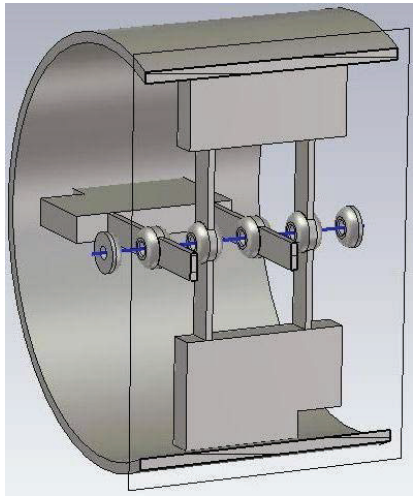
DTL Cavities



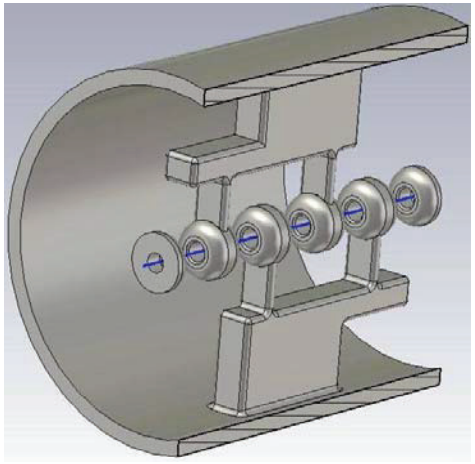
QWR (λ/4)



HWR (λ/2)



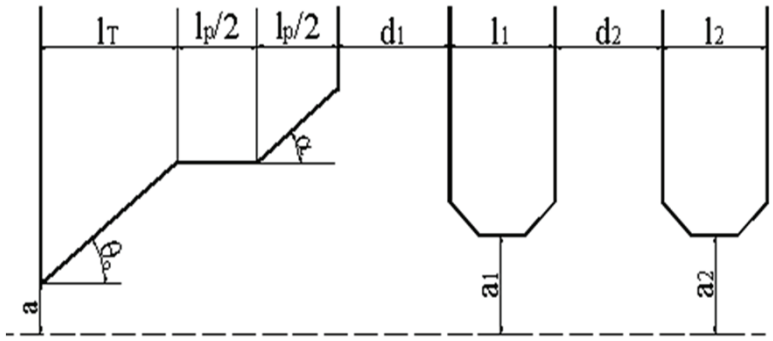
CH-cavity



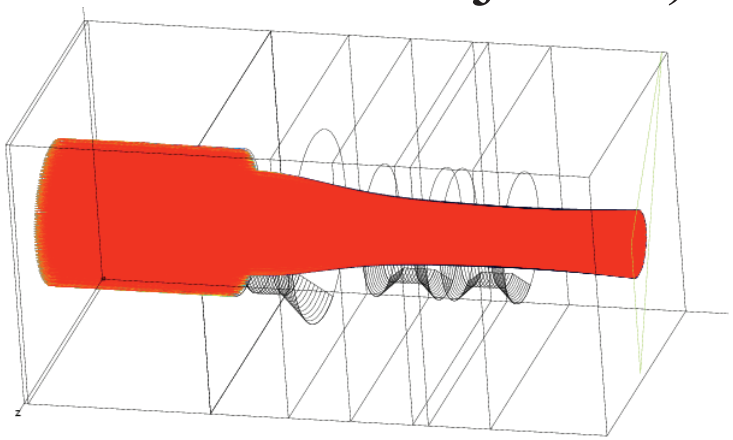
IH-cavity

Тип ускоряющей структуры	Мощность ВЧ потерь, кВт/м (экономичность)	Собственная добротность (степень надежности)	Сложность системы охлаждения(проста в эксплуатации)	Сложность изготовления (стоимость)
λ/4	656	7300	средняя	простая
λ/2	1120	7800	простая	простая
CH	380	11500	сложная	сложная
IH	275	9900	сложная	сложная

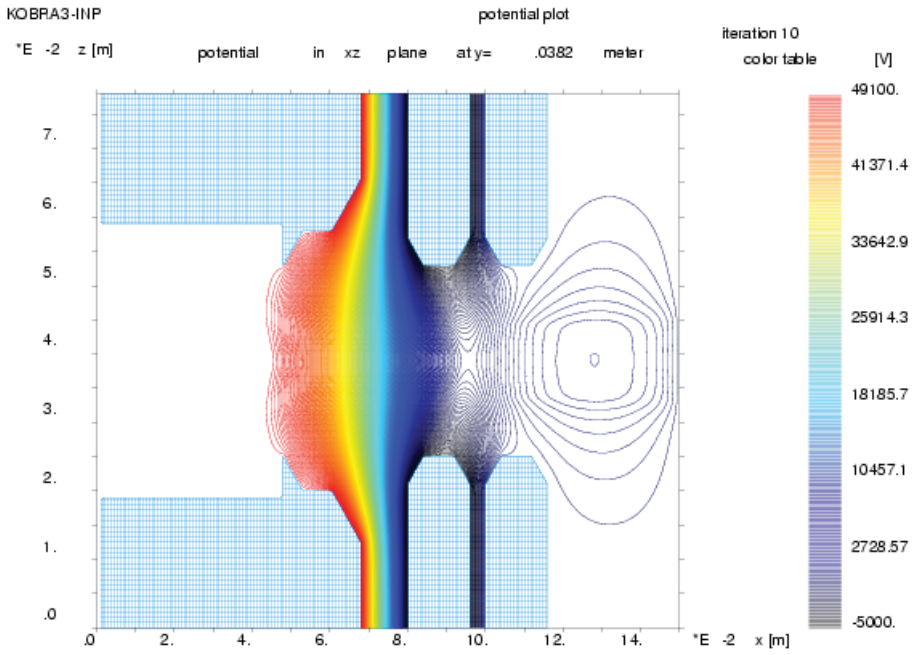
Simulation of ion source extraction system by code Kobra3-INP (laser ion source for TWAC Injector)



Geometry of 3-electrode extraction system

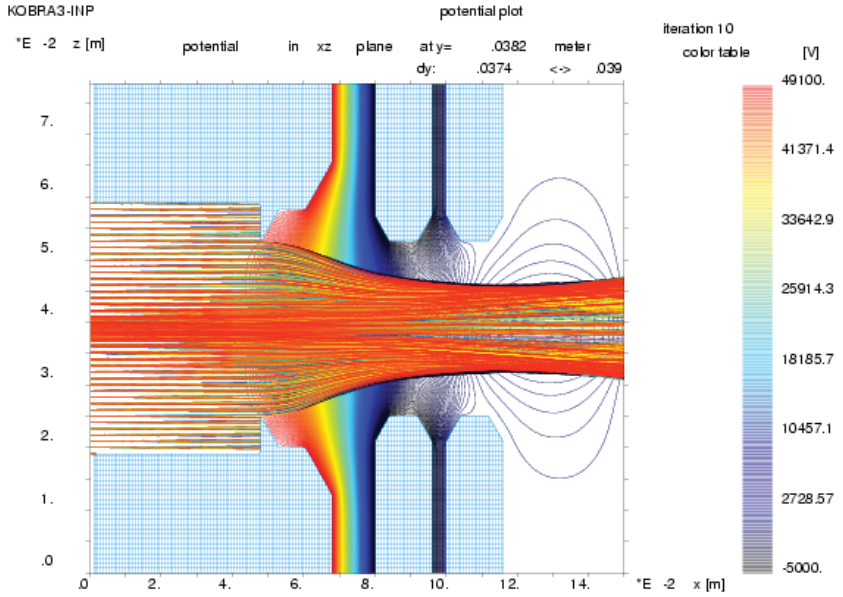


3-dim extraction system



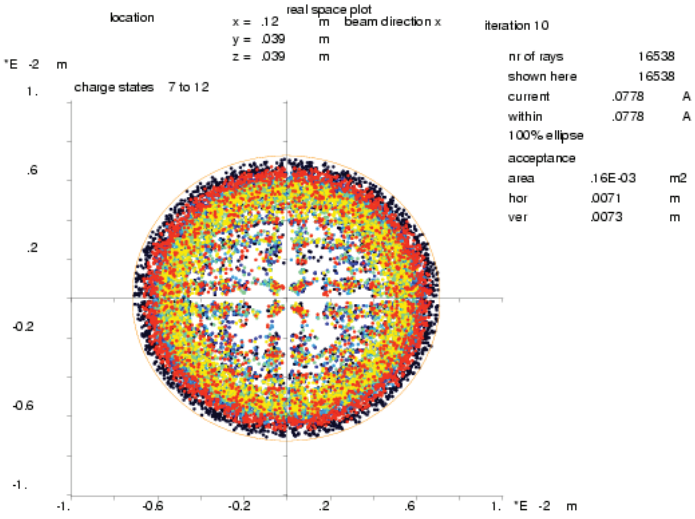
Potential distribution (plasma boundary)

Trajectories of Al^{7+}…Al^{12+} ions and output phase portraits

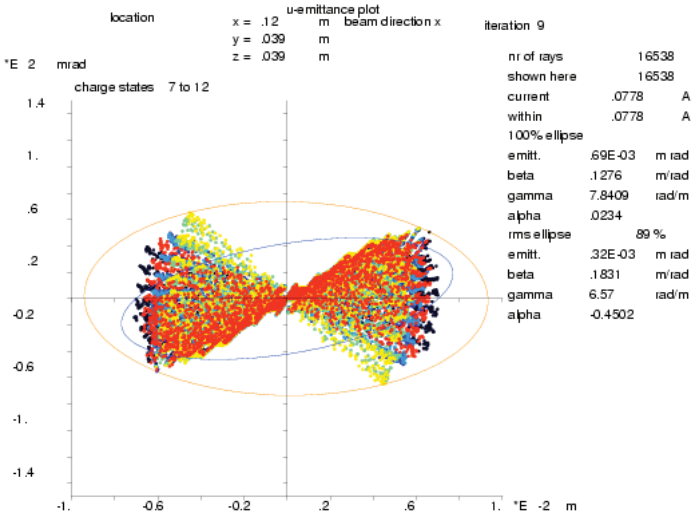


Trajectories of Al^{7+}…Al^{12+} ions

Beam profile

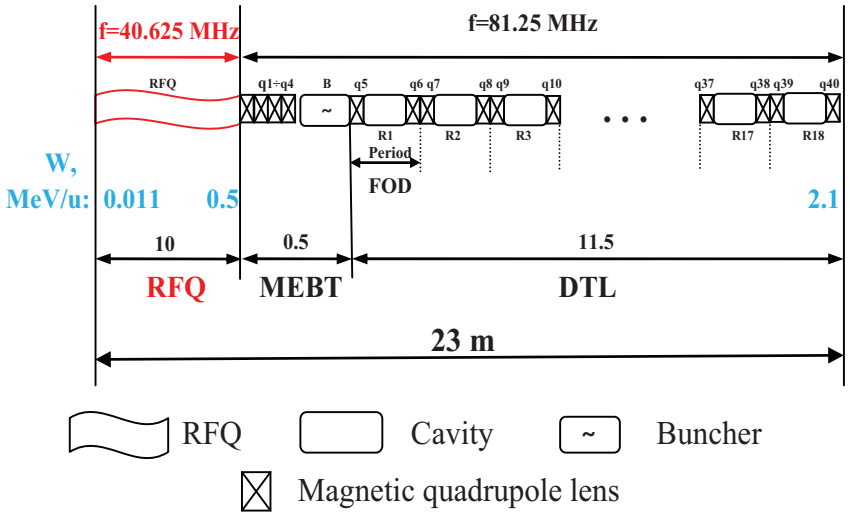


Output phase space

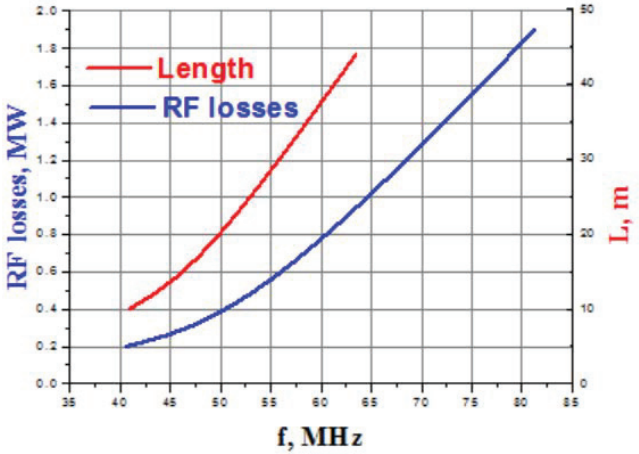


CW linac for project DERICA
(for the study of radioactive isotopes)

Layout of NC linac



Choice of frequency



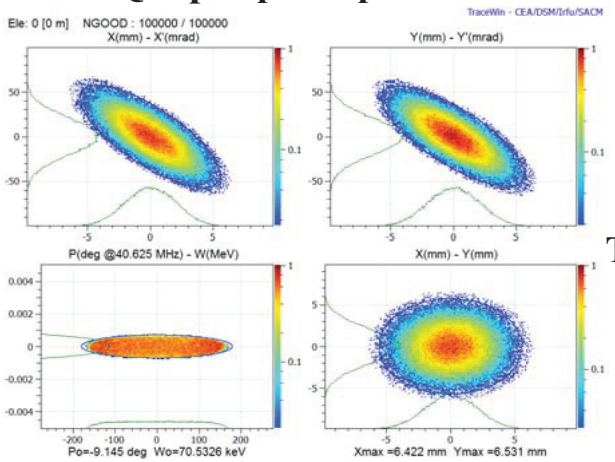
Main parameters

A/Z	≤ 6.5	
Normalized emittance, [π mm mrad]	1	
Injection current, [mA]	1	
Maximum field strength [Kp]	1.5	
Structure	**RFQ**	**DTL**
Operating frequency, MHz	40.625	81.25
Beam energy, [MeV/u]	0.011 ÷ 0.5	0.5 ÷ 2.1
Normalized acceptance, [π mm mrad]	10	12
Synchronous phase, [deg]	-90÷-35	-50÷-30
Length, [m]	10	11.5
Aperture radius, [mm]	19.0 ÷ 6.0	15.0
Intervane voltage, [kV]	203	-
Maximum gap field, [kV/cm]	-	90
Average radius, [mm]	19	-
Vane radius of curvature, [mm]	15.2	-
Maximum modulation	1.65	-
Number of magnetic lenses	-	36
Maximum field gradient, [T/m]	-	70
Number of cavity	-	18
Length of cavity, [mm]	-	350 (const)
Transmission, [%]	99	100

RFQ for 4-dim matcher (standard):

Transport =97.6% ; Transmission = 92.7% ; $\varepsilon_{n\ out}$ (99%) / $\varepsilon_{n\ out}$ (99%) = 1.57

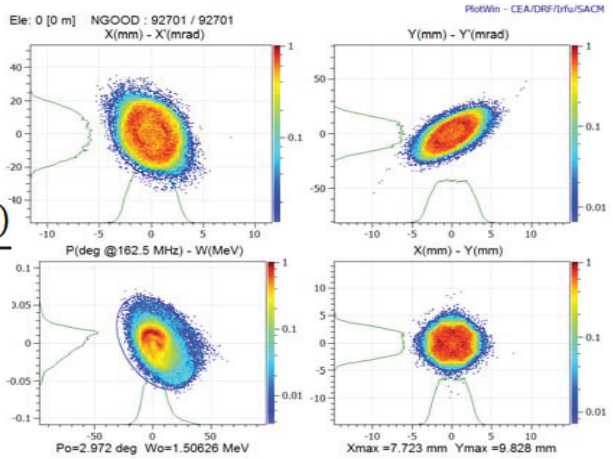
RFQ input phase portraits



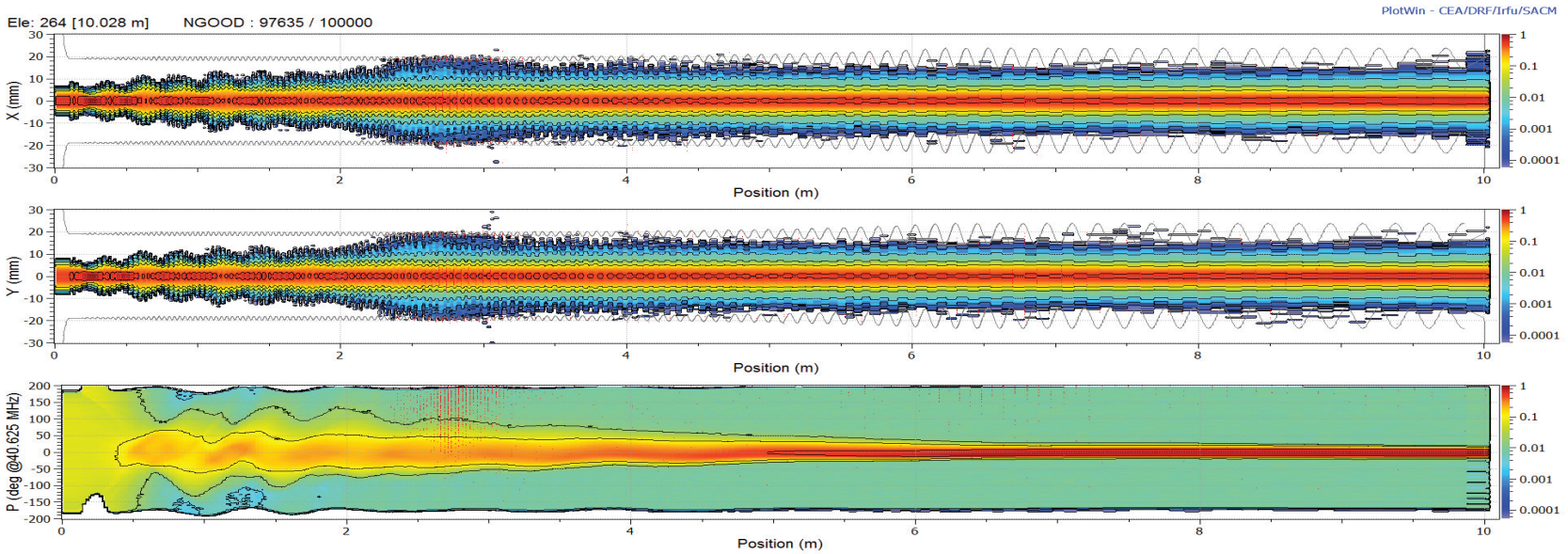
Transport= $\frac{Nout}{Ninj}$

Transmission= $\frac{Nout(accel)}{Ninj}$

RFQ output phase portraits



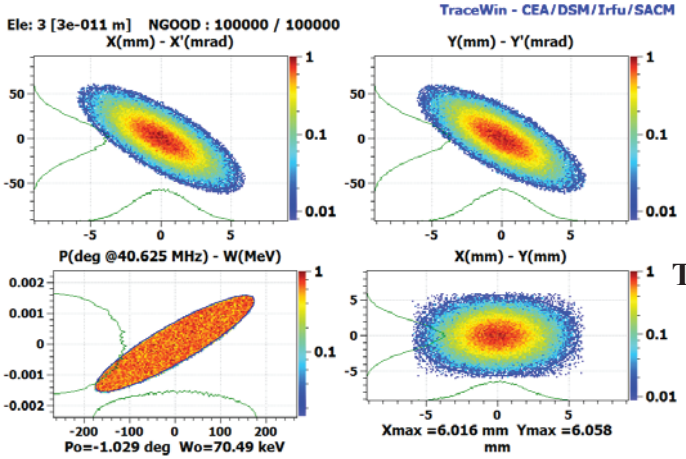
RFQ beam profile



RFQ for 6-dim ideal matcher:

Transport =100 % ; Transmission = 100 %; $\varepsilon_{n\ out}$ (99%) /$\varepsilon_{n\ inp}$ (99%) = 1.05

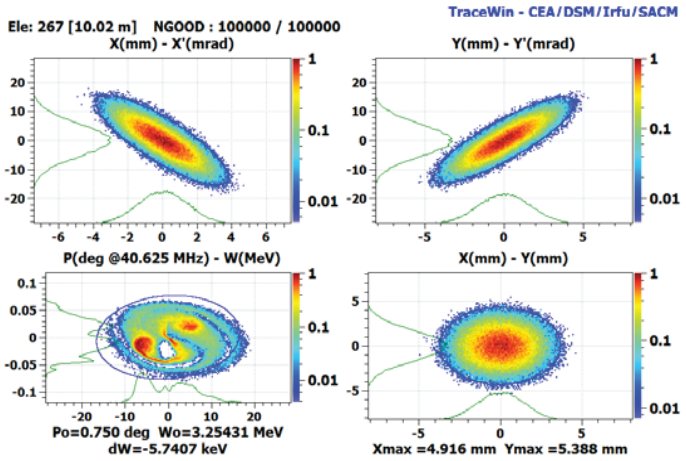
RFQ input phase portraits



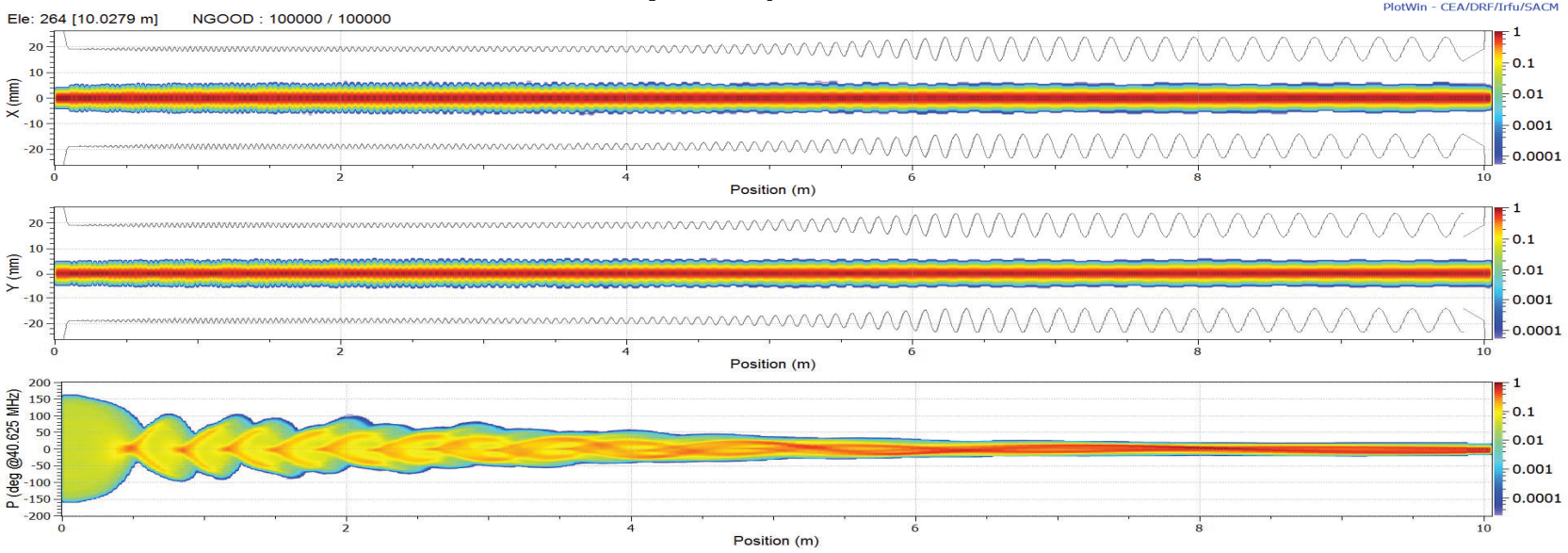
Longitudinal : uniform

Transverse : Gaussian 3σ

RFQ output phase portraits



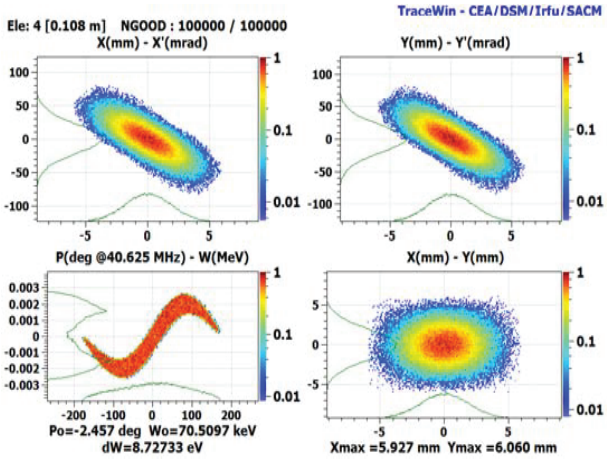
RFQ beam profile



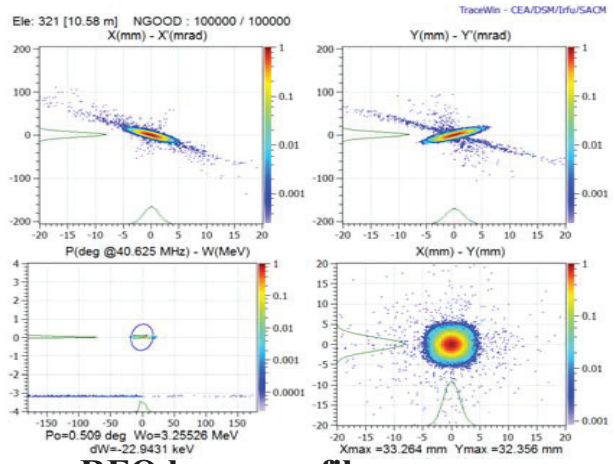
RFQ for 6-dim real matcher:

Transport =100 % ; Transmission = 99.7%; : $\varepsilon_{n\ out}$ (99%) /$\varepsilon_{n\ inp}$ (99%) = 1.21

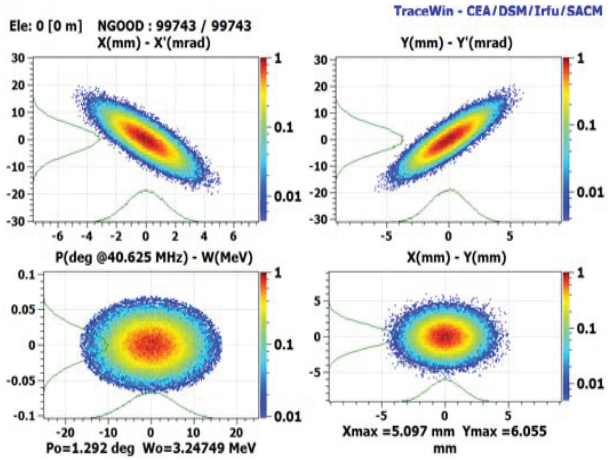
RFQ input phase portraits



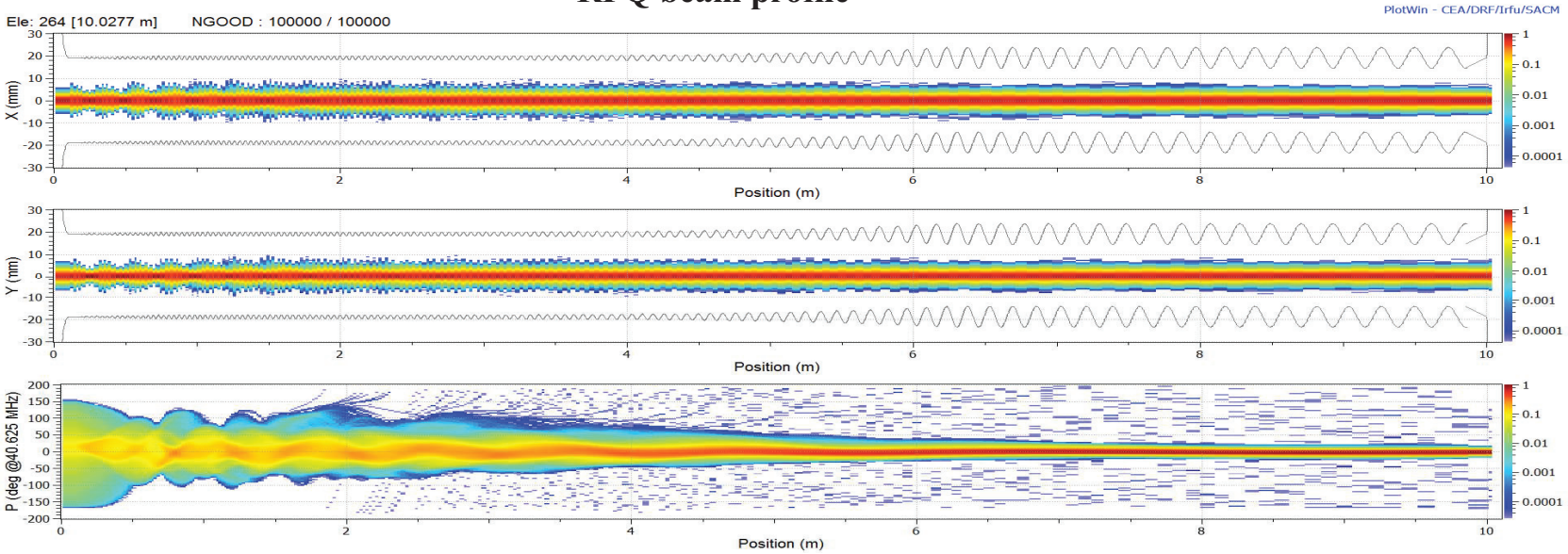
RFQ output phase portraits (total)



RFQ output phase portraits (accelerated)



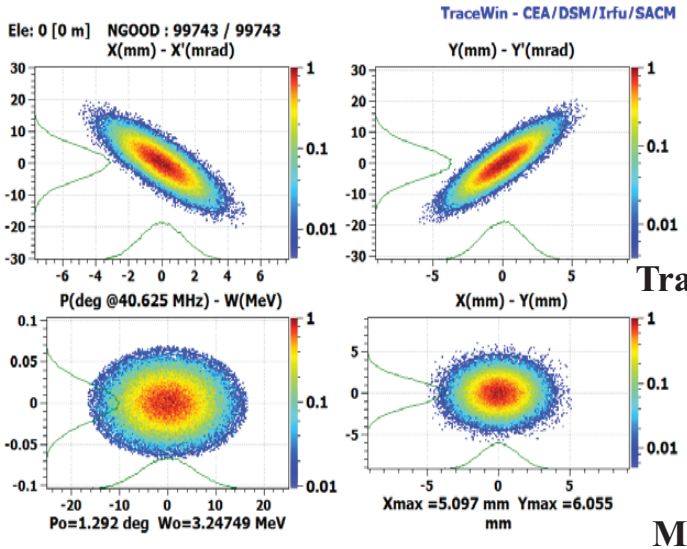
RFQ beam profile



DERICA: MEBT & DTL for 6-dim real matcher:

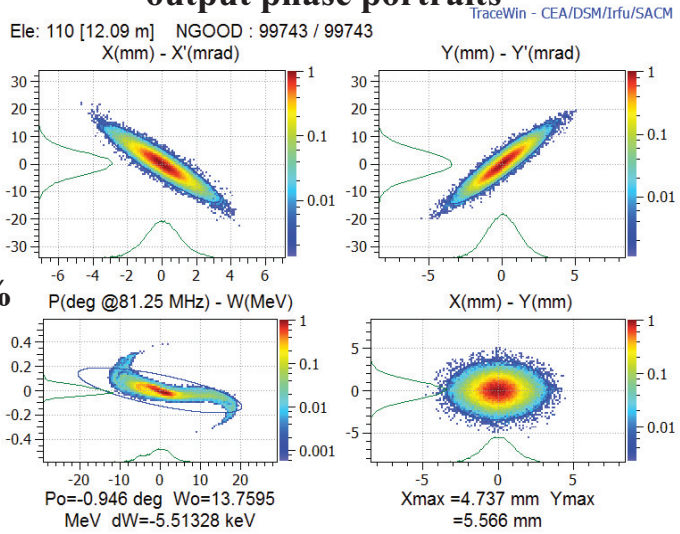
Transmission = 100%; : $\varepsilon_{n\ out}$ (99%) /$\varepsilon_{n\ inp}$ (99%) = 1.48

input phase portraits

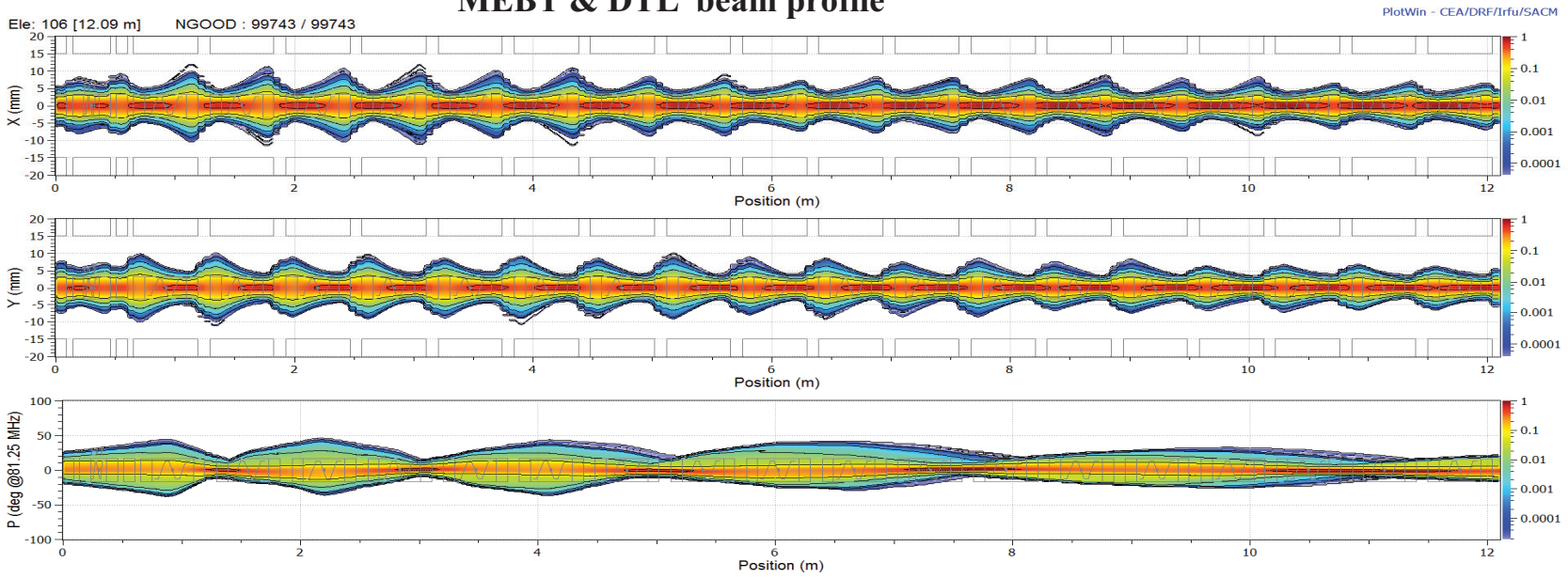


Transmission(RFQ&DTL)=99.7%

output phase portraits



MEBT & DTL beam profile



NC linac for project NEPTUN

pulsed neutron source of the 4-th generation (Spallation Source) on the basis proton accelerator and Np-237

Main parameters

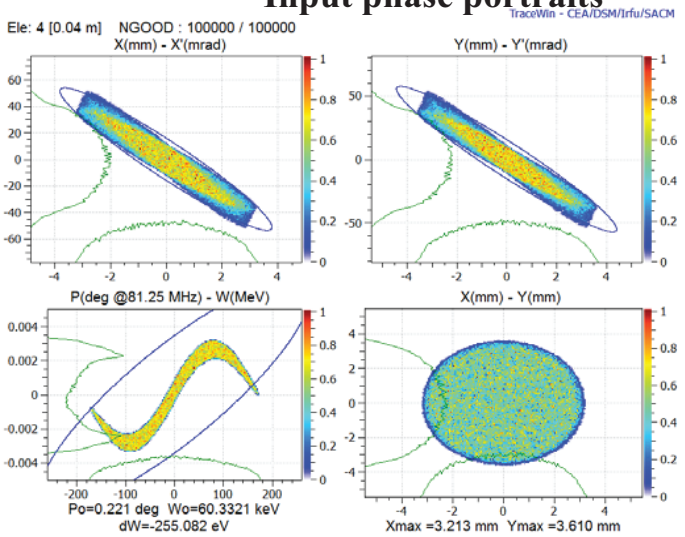
Ions	**H^+**
Operating frequency	**81.25 MHz**
Beam energy	**0.06÷4.8 MeV**
Velocity	**0.01131÷0.10076**
Injection current	**50 mA**
Normalized beam emittance	**1 π mm mrad**
Normalized acceptance	**15 π mm mrad**
Maximum field strength	**1.5 Kp**
Synchronous phase	**-90÷ -35 deg**
Intervane voltage	**210 kV**
Average radius	**16 mm**
Maximum vane modulation	**2.2**
Length	**8 m**
Transmission	**> 95 %**
Pulse power losses	**~ 1 MW**

Transport=99.994%

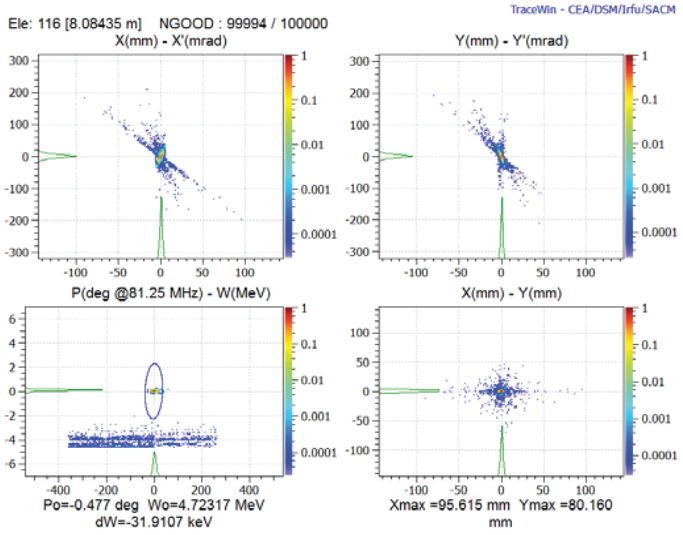
Transmission= 97.6%

$\varepsilon_{n\ out}$ (99%) /$\varepsilon_{n\ inp}$ (99%) = 3.8

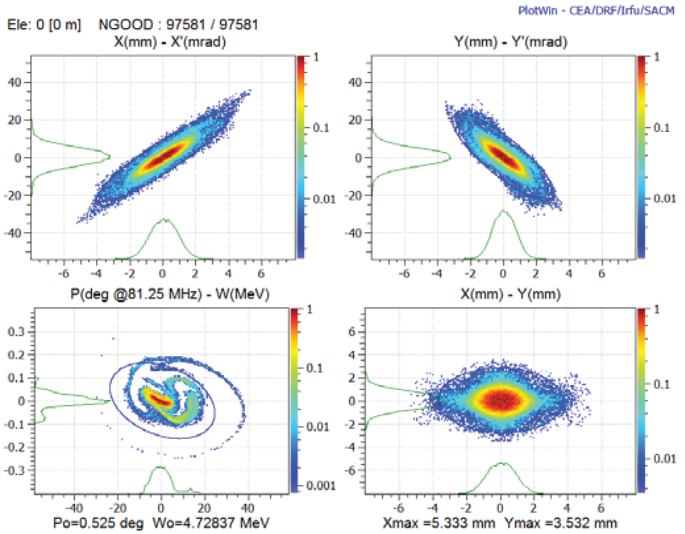
Input phase portraits



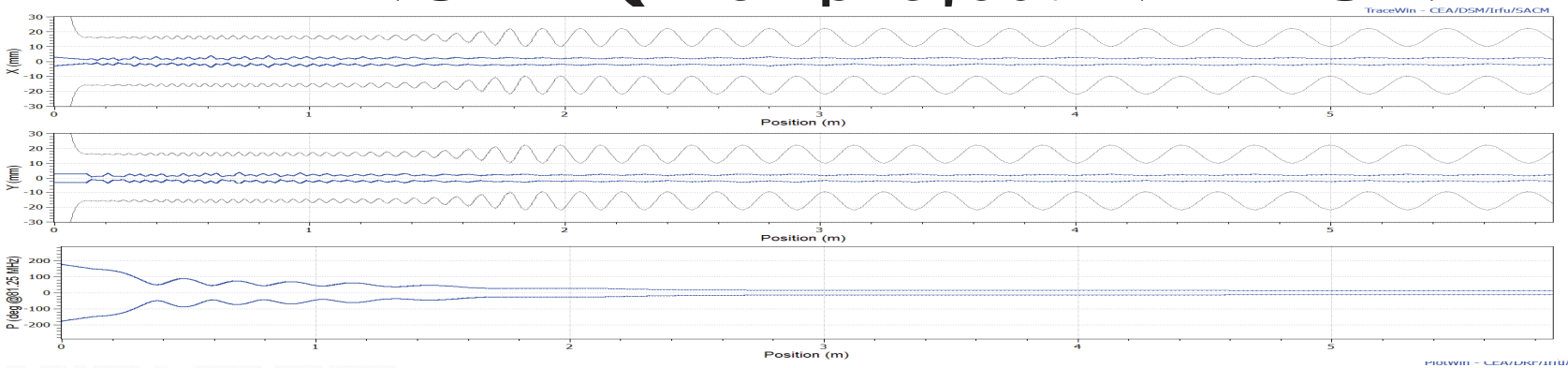
Output phase portraits (total)



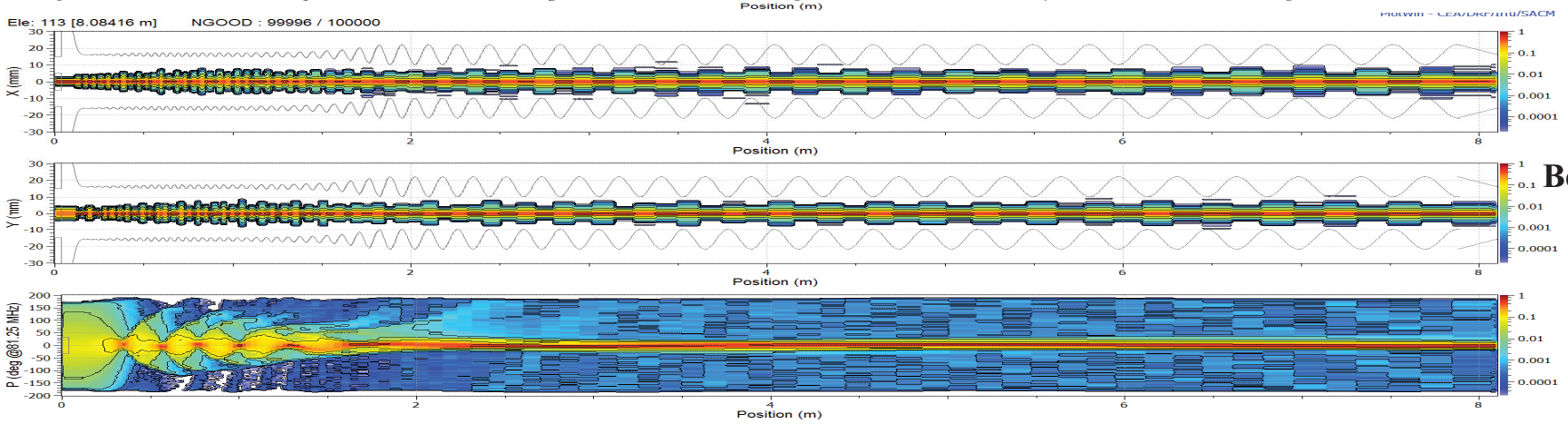
Output phase portraits (accel)



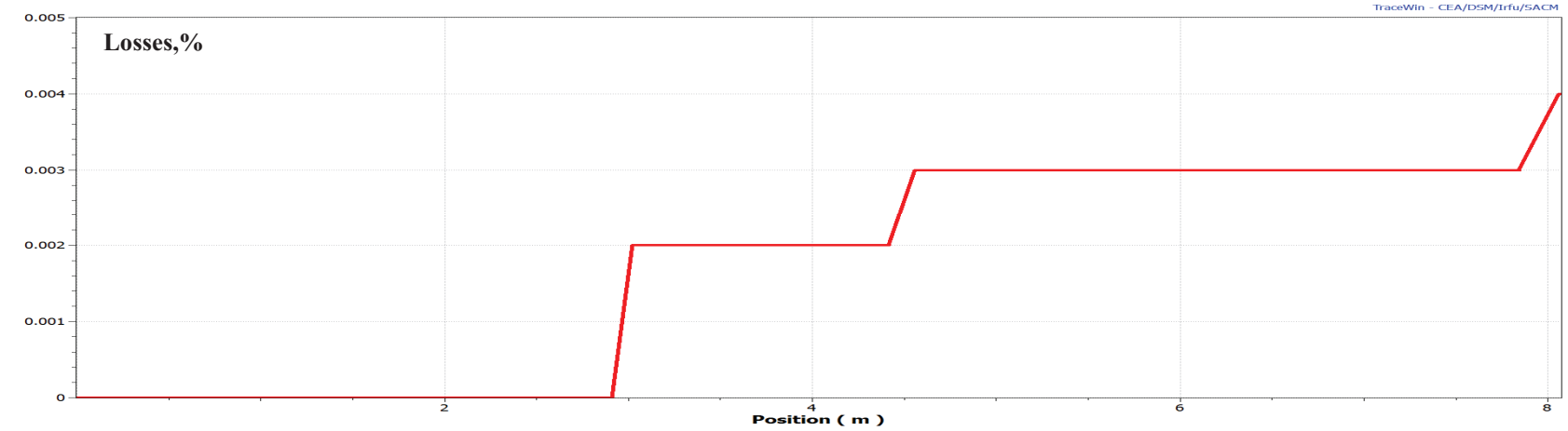
NC RFQ for project NEPTUN



Envelopes

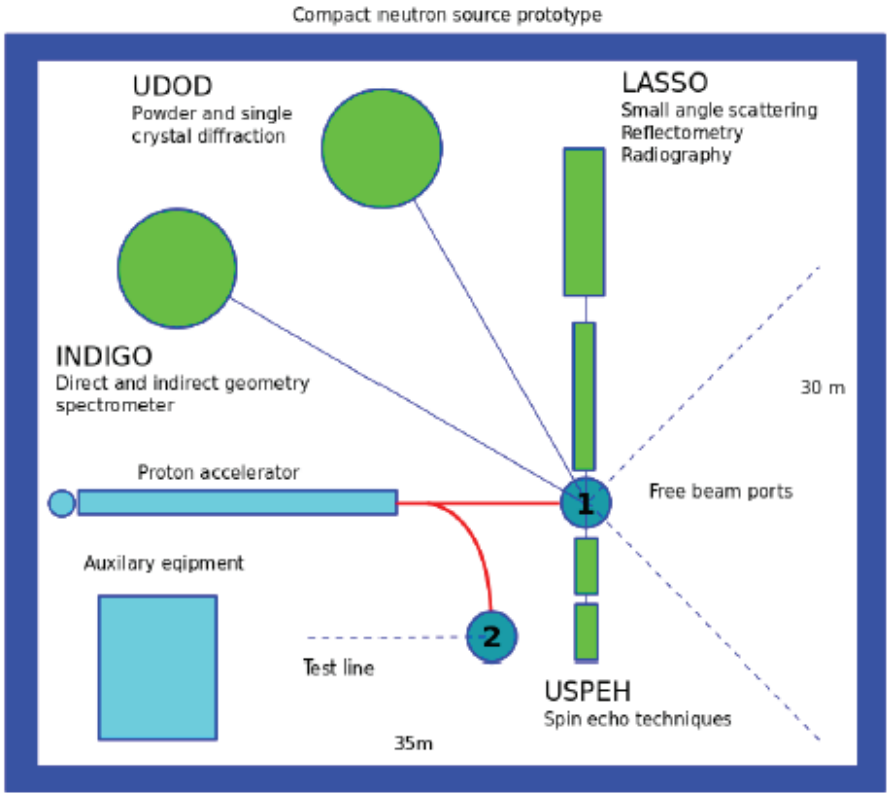


Beam profile



Losses

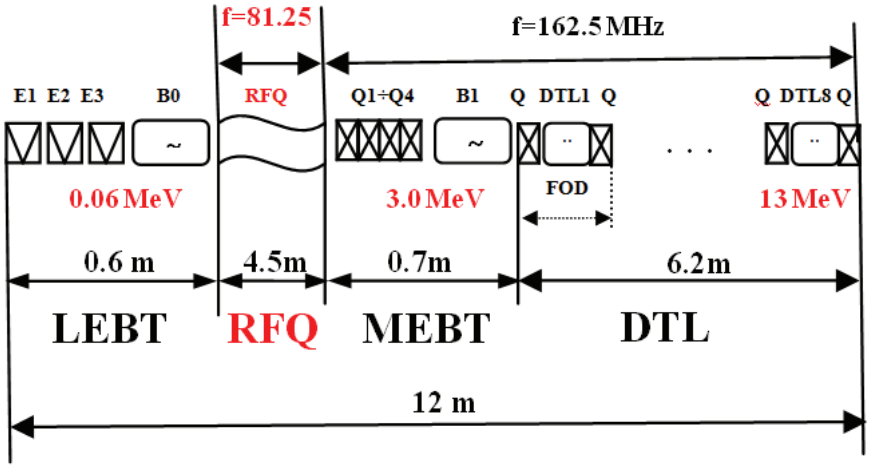
NC linac for project DARIA
(compact neutron sources)



p (13 MeV) → Be

W=3… 7… 10… 13 MeV

I max=83 mA



Layout of NC linac for project DARIA

BELA

Project of Multidiscipline Facility Based on ECR Ion Source and Linear Accelerator

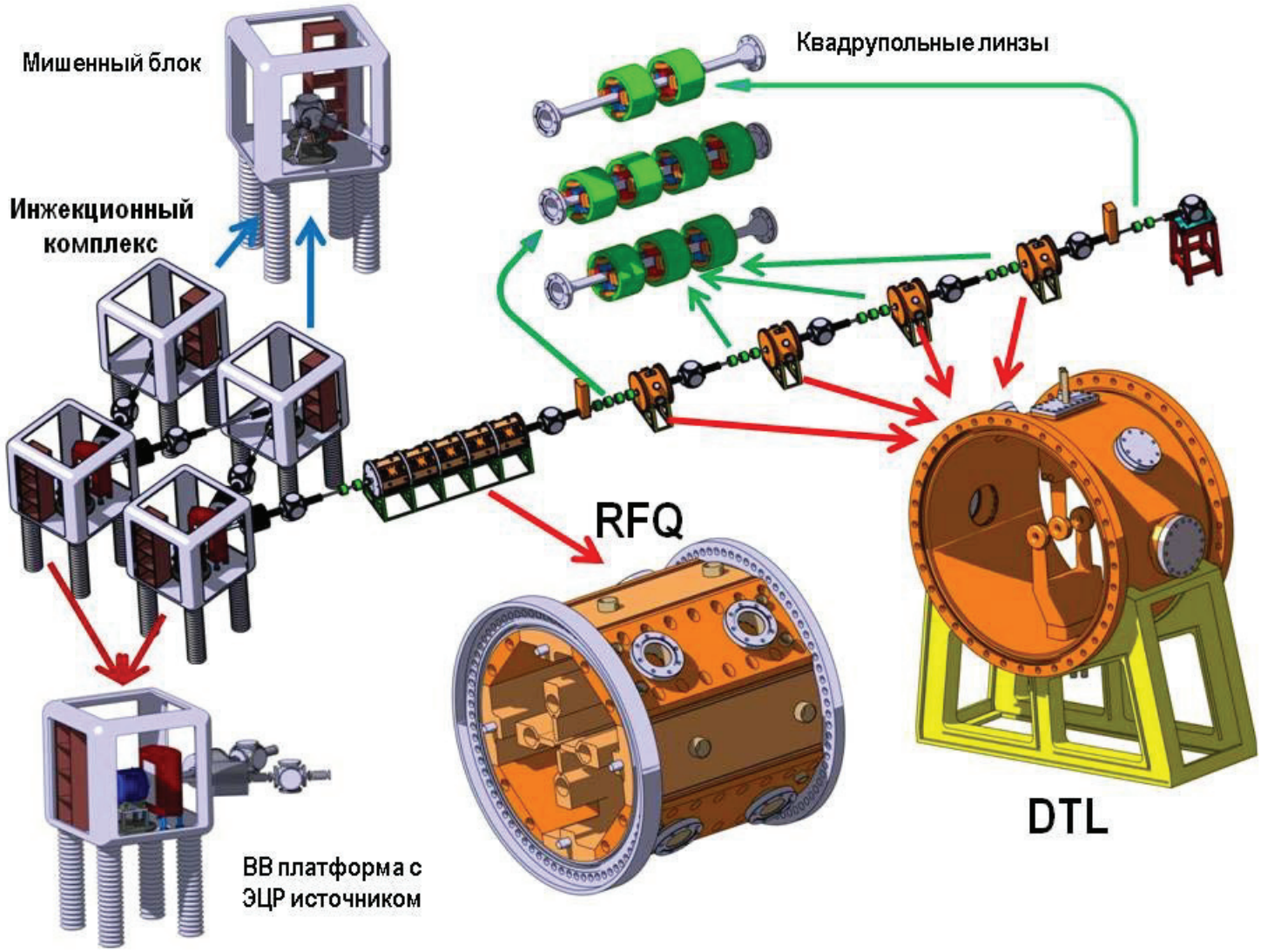
NRC "Kurchatov institute"-ITEP

ION BEAMS APPLICATION

- ✓ Material science – materials modification, fusion and fission reactor materials investigations;
- ✓ Facility for semiconductor industry – improvement of power electronics units by proton/ion beam irradiation;
- ✓ Neutron generator;
- ✓ Medicine (BNCT, Radiopharmaceutical for PET);
- ✓ Astrophysics;
- ✓ ....
- ✓ **Spallation Source**
- ✓ Accelerator Driving Ssytem

BELA

New “basic facility” for researches with neutron and ion beams



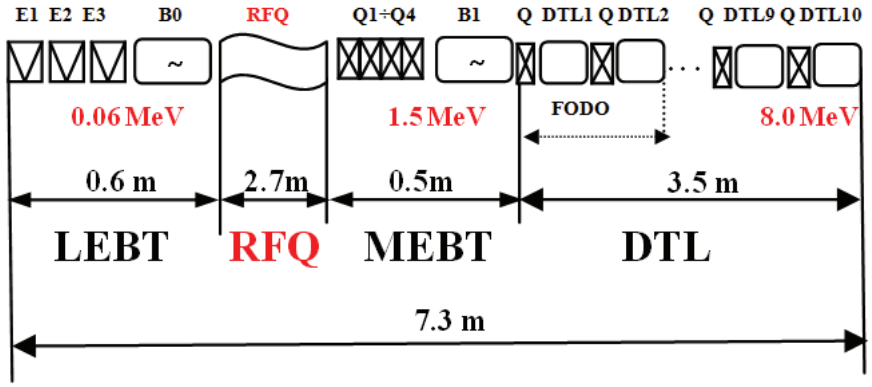
BELA: RFQ & DTL

Main RFQ parameters

Ions	H^+
Operating frequency	162.5 MHz
Beam energy	0.060÷1.5 MeV
Injection current	10 mA
Normalized emittance	1 π mm mrad
Normalized acceptance	10 π mm mrad
Synchronous phase	-90÷-35 deg
Intervane voltage	155 kV
Maximum field strength	1.6 Kp
Average radius	9 mm
Vane radius of curvature	7.2 mm
Maximum vane modulation	1.8
RF power losses	225 kW
Length	2.7 m

Main DTL parameters

Parameters	FODO
Ions	H^+
Operating frequency	162.5 MHz
Beam energy	1.5÷8.0 MeV
Normalized acceptance	15 π mm mrad
Injection current	10 mA
Number of focusing periods	4
Maximum on-axis field	110 kV/cm
Maximum field strength	1.6 Kp
	222 kV/cm
Aperture radius	10 mm
Length of channel	3.552 m
Number of cavity	8
Length of cavity	350 mm
Synchronous phase	-30 deg
Maximum magnetic field gradient	16 T/m
Number of magnetic lenses	8

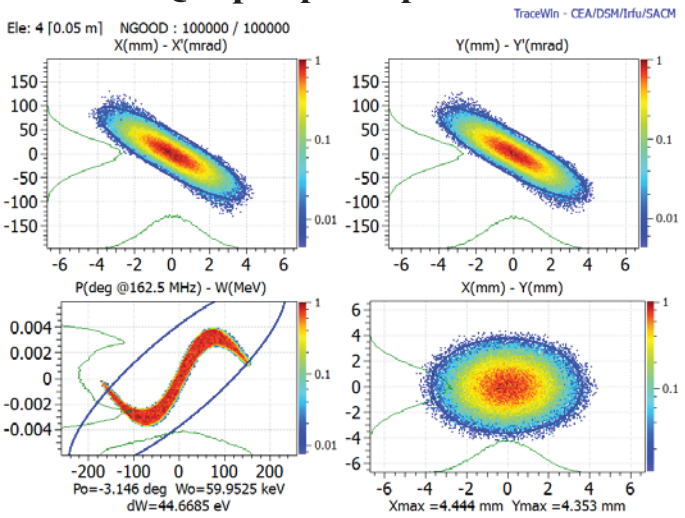


Layout of cw BELA

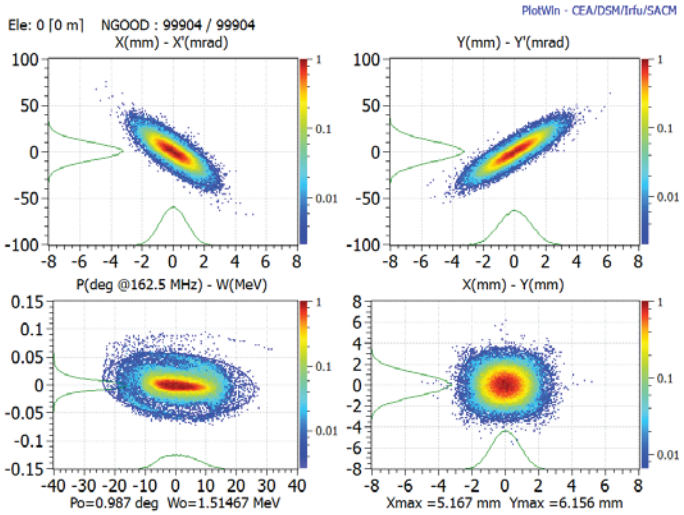
BELA: real 6-dim matching for RFQ

Transport = 100% Transmission = 99.9%

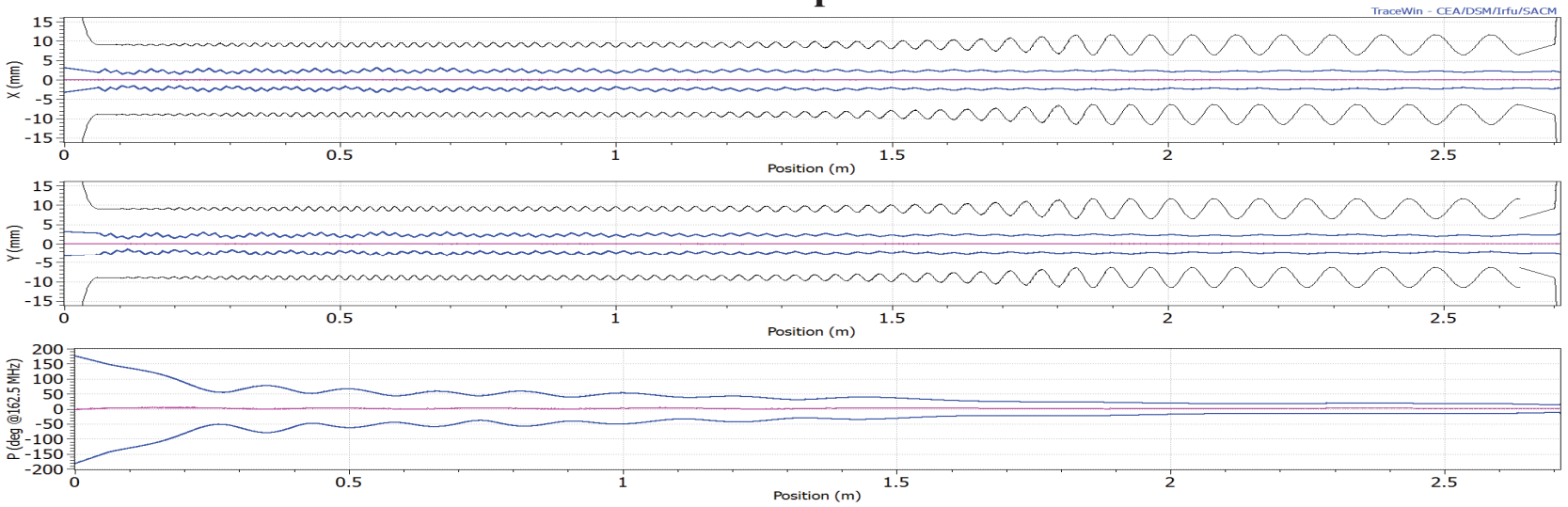
RFQ input phase portraits



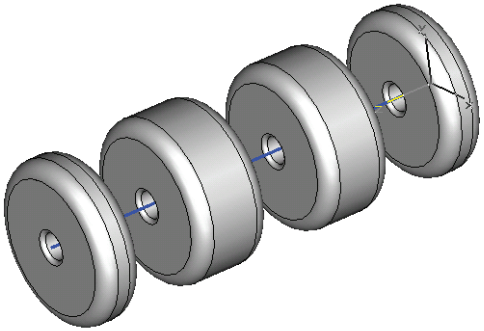
RFQ output phase portraits

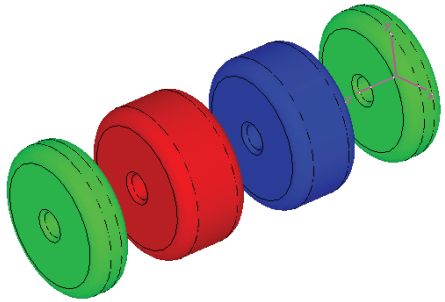


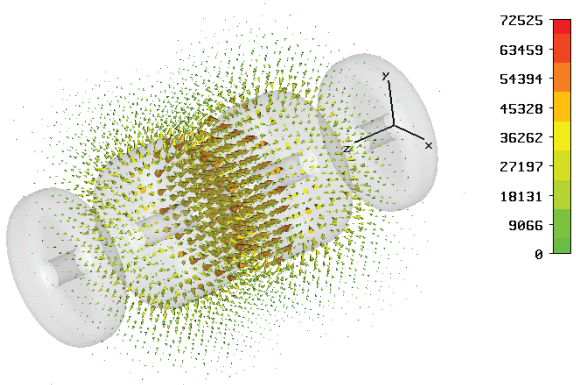
Envelopes

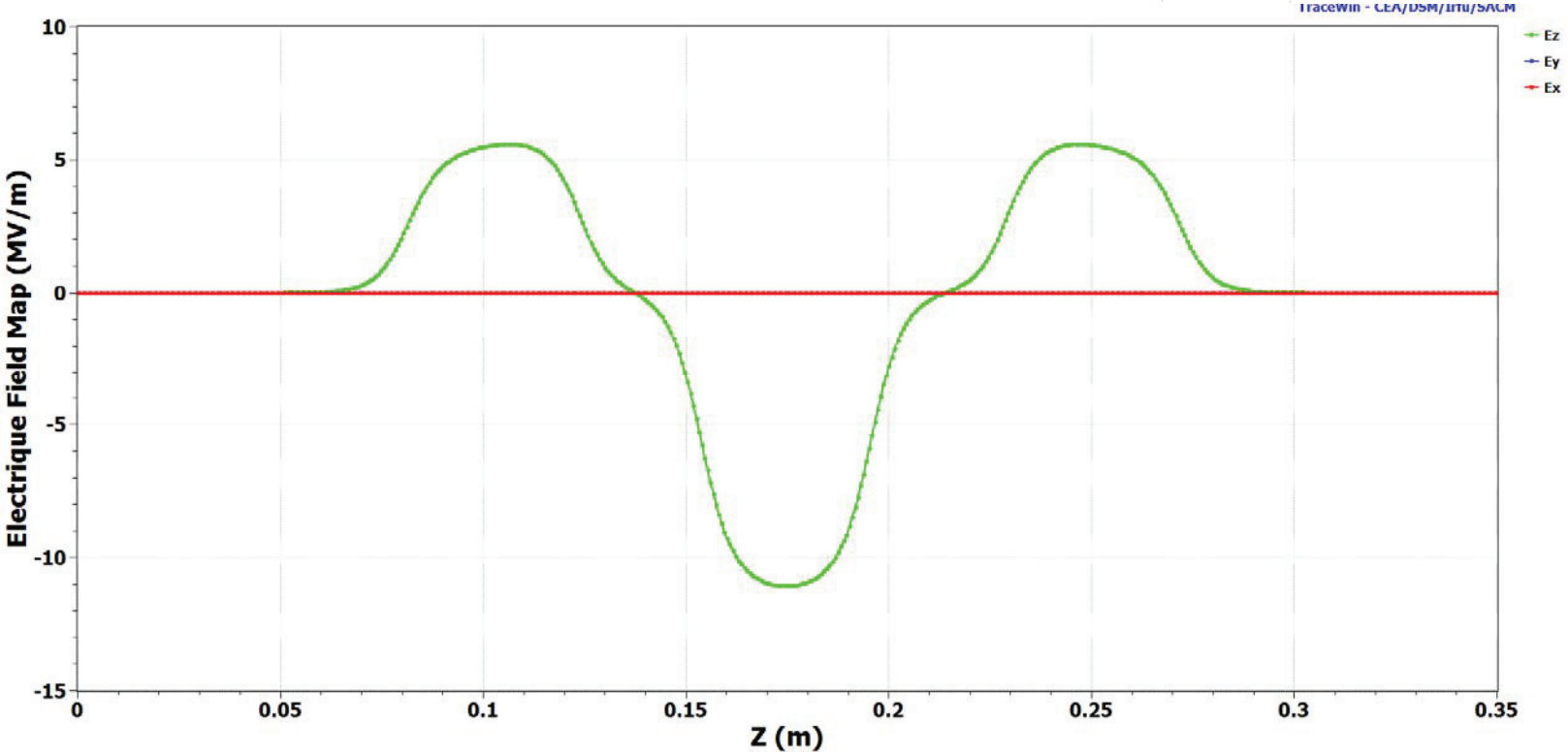


3-gap Cavity for DTL





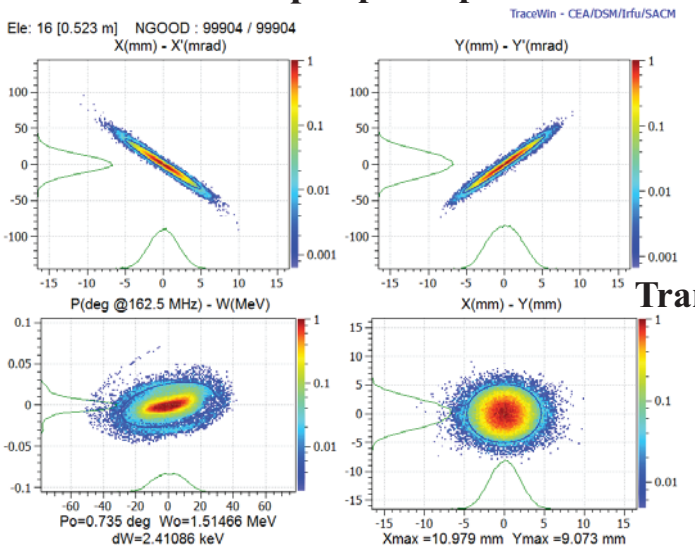




BELA: DTL with FODO period (3-gap cavity)

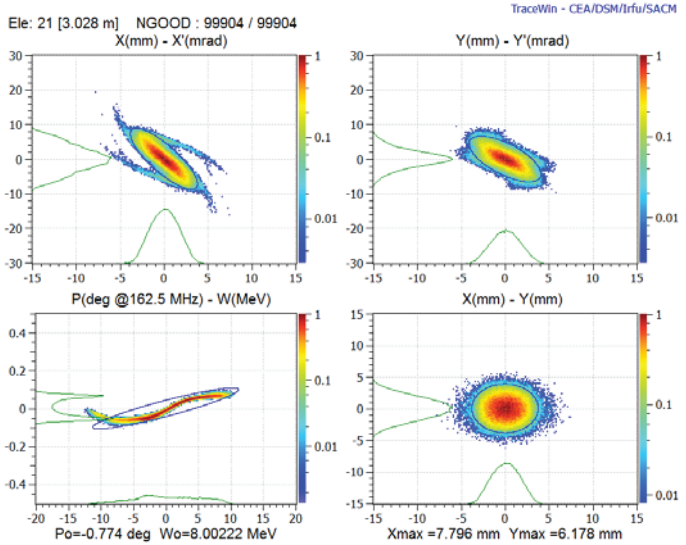
Transport = 100% Transmission = 100%

DTL input phase portraits

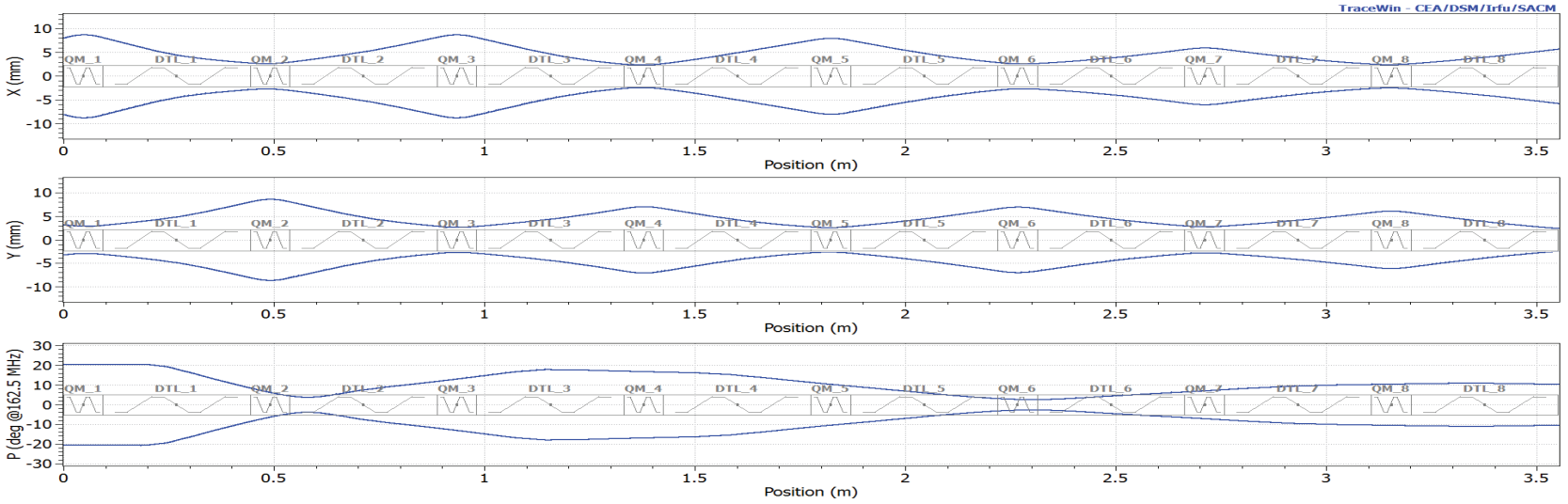


Transmission(RFQ&DTL)=99.9%

DTL output phase portraits



Envelopes



Conclusion for NC linac

LEBT:

1. Extraction system
2. 6-dim matching

RFQ:

1. Choice of Operating frequency
2. E_{smax} (Kp)
3. V_k/ε

DTL:

1. E_{smax} (Kp)
2. V_k/ε
3. Separatrix and transverse accetance
4. Structure of periods (focusing & phasing in agreement with RFQ)