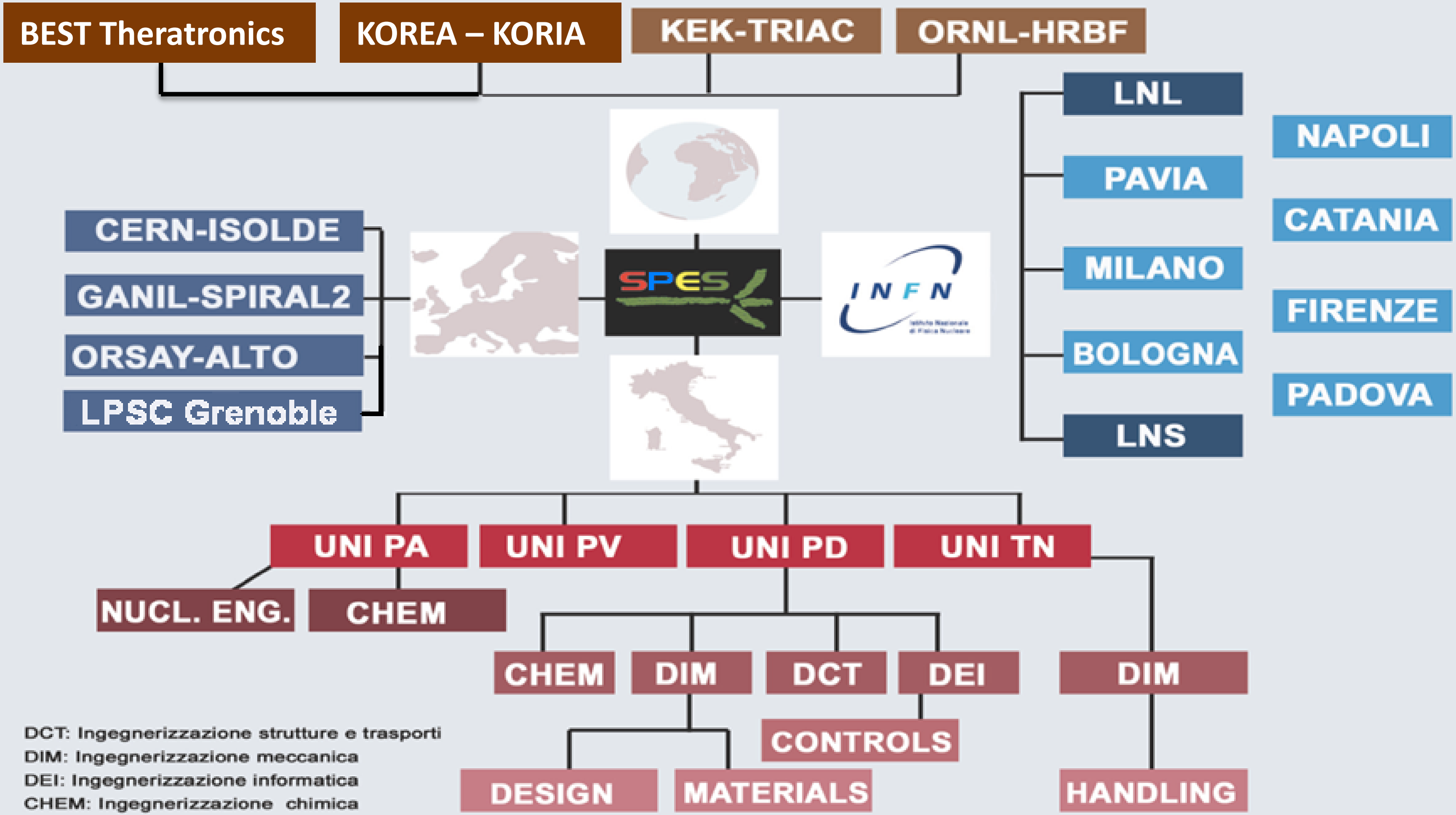
SPES Physical Design & Status

M. Comunian,
on behalf of SPES design group

Outline

- SPES Project:
- Cyclotron Driver
- RIB Production Target
- RFQ Cooler
- High Resolution Spectrometer
- Charge Breeder
- NEW RFQ injector for ALPI
- ALPI Linac by using the new RFQ as injector
- Upgrade scenario for ALPI

SPES collaborations network



BEST Theratronics
KOREA – KORIA
KEK-TRIAC
ORNL-HRBF

CERN-ISOLDE
GANIL-SPIRAL2
ORSAY-ALTO
LPSC Grenoble

SPES

INFN

LNL
PAVIA
MILANO
BOLOGNA
LNS

NAPOLI
CATANIA
FIRENZE
PADOVA

UNI PA
UNI PV
UNI PD
UNI TN

NUCL. ENG.
CHEM

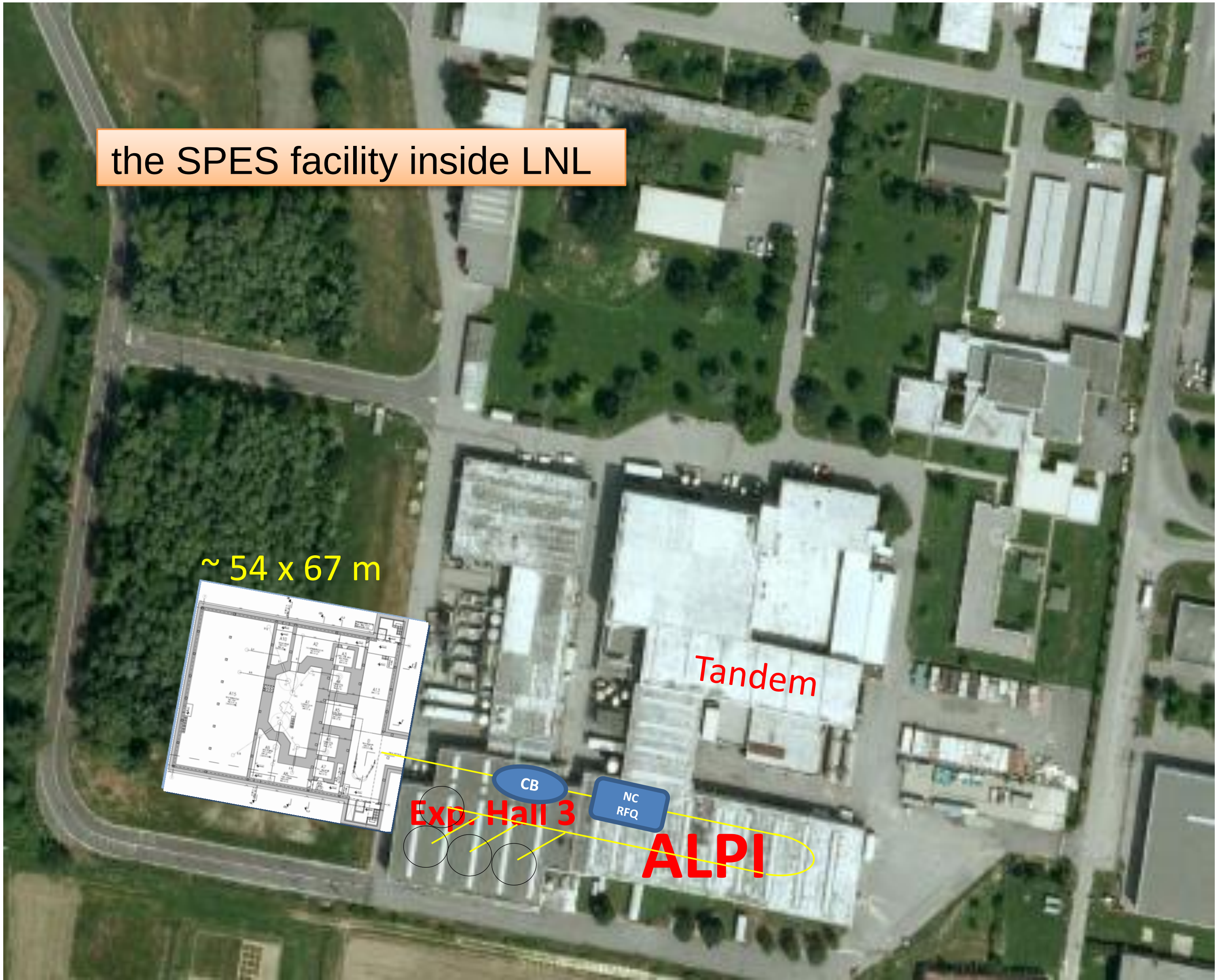
CHEM
DIM
DCT
DEI
DIM

CONTROLS

DESIGN
MATERIALS
HANDLING

DCT: Ingegnerizzazione strutture e trasporti
DIM: Ingegnerizzazione meccanica
DEI: Ingegnerizzazione informatica
CHEM: Ingegnerizzazione chimica

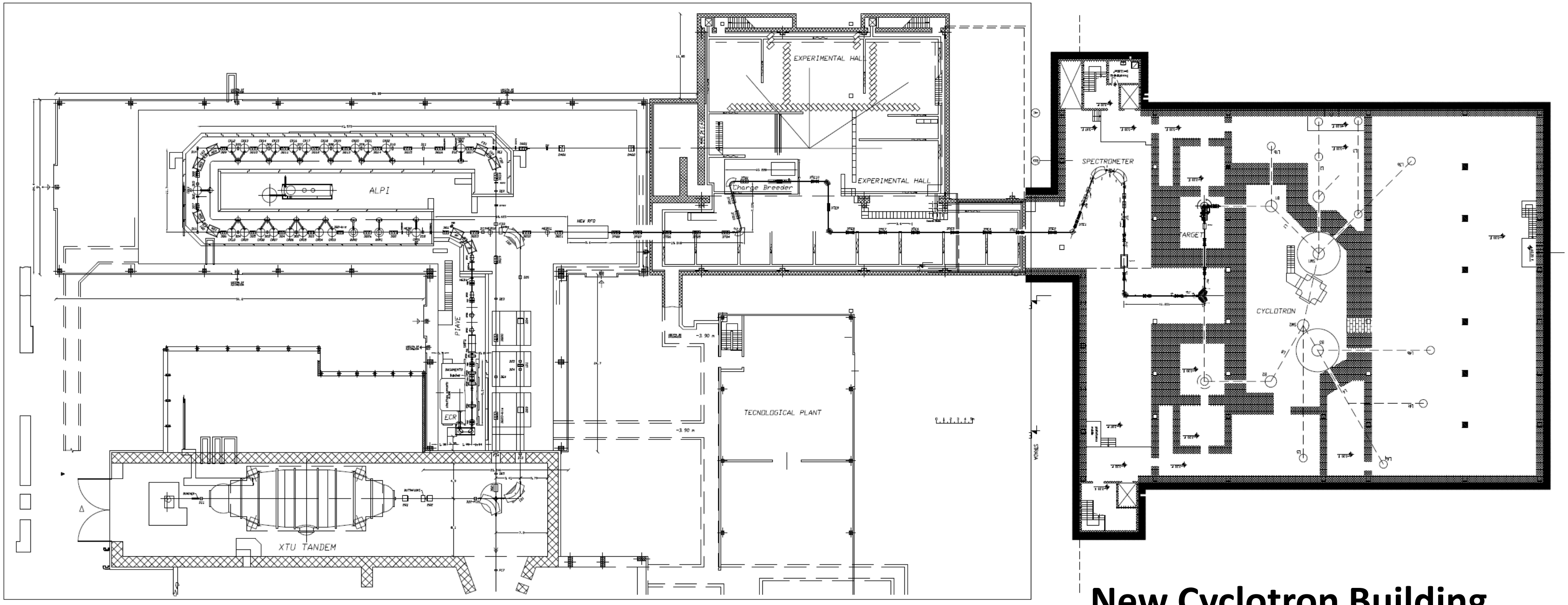
SPES Facility Layout



the SPES facility inside LNL

SPES Facility Layout

215 meters

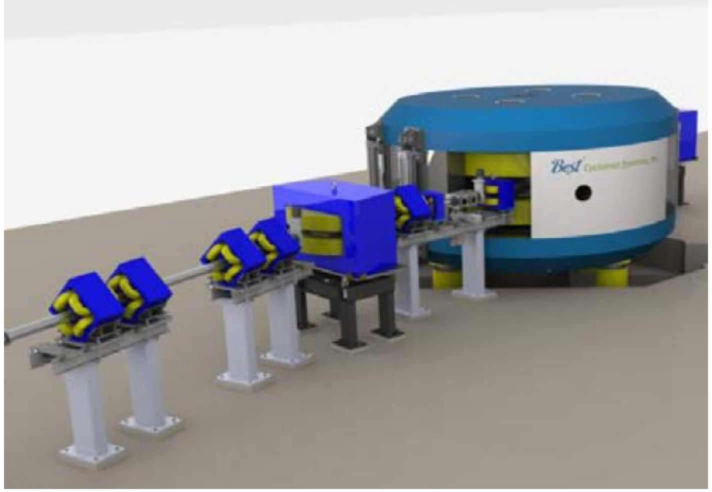


83 meters

New Cyclotron Building

BEST Cyclotron parameters

Total Costs:
cyclotron and 1 beam line 10 M€
Delivery 3-4 years (start 28 Oct '10)

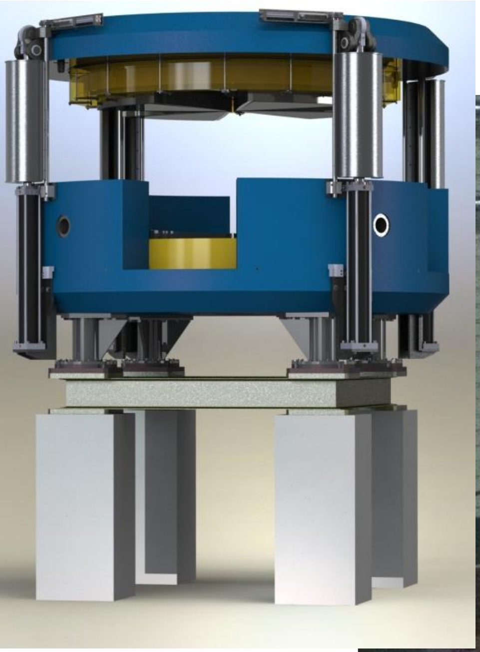


Main Dimensions
Diameter = 4.5 m
Height= 1.7 m
Weight = 210 tons

Best Theratronics

BEST 70 MeV Cyclotron	
Accelerated Particle	H-
Extracted Particle	Protons
Energy	35-70 MeV (variable)
Current	> 700 uA (variable)
Extraction System	**By stripping → simultaneous dual beam extraction**
Injection System	Axial Injection → External Multicusp Ion Source 15-20mA DC
Main Magnet	B_{max} = 1,6 T Coil current = 127 kAt Power supply = 30 kW 4 sectors, deep valley
RF System	2 resonators Frequency= 58 MHz Harmonic mode=4 Dissipated Power=15 kW per cavity DEE voltage=60-80 kV
Operational Vacuum	2 e -7 mbar

BEST 70p Model & Magnet



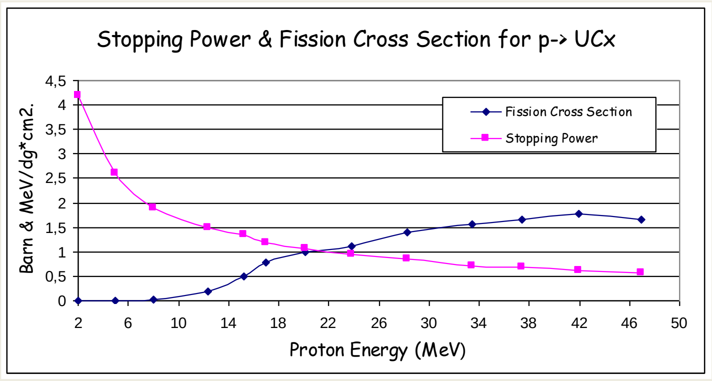
70p Model.

70p Magnet in Japan,
now is in Canada

Best® Theratronics

2007

SPES Multiple Target



Fission efficiency → 100p per 1.5 Fission Fragments

200 μA → 10^{13} fissions/sec

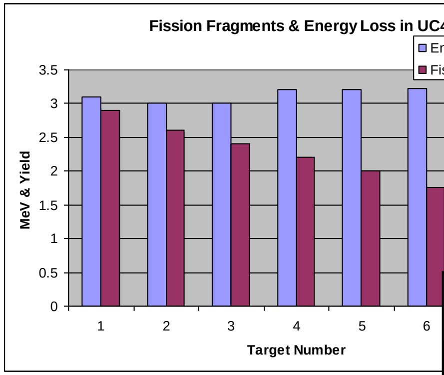
Beam power = 40 MeV p x 200 μA = 8 KW

Power distribution:

Direct target→ **7 disks 4 cm ϕ** ~1 mm thick

Energy loss UCx (30gr) **23 MeV** → 4.2 KW

(140W/gr)

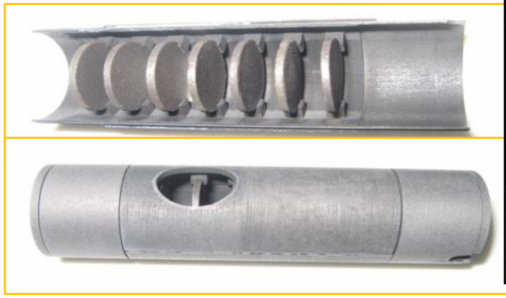


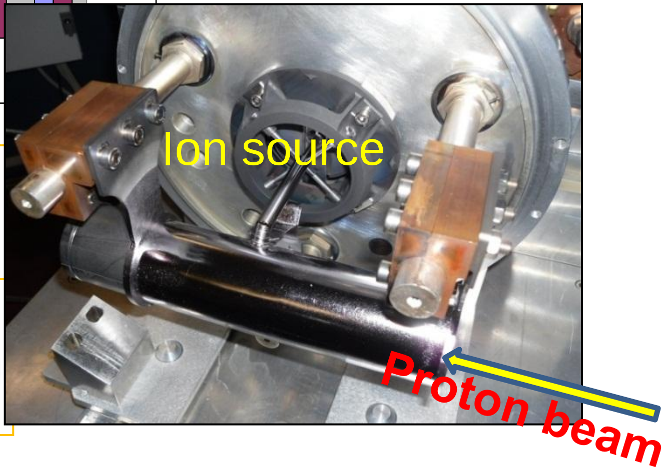
Operating temperature 2000°C

Stefan-Boltzmann law

$$P = \varepsilon \cdot \sigma \cdot S \cdot T^{4}$$

Target designed for optimized power dissipation by **radiative emission** and **fast release time** (minimum number of bunches N)



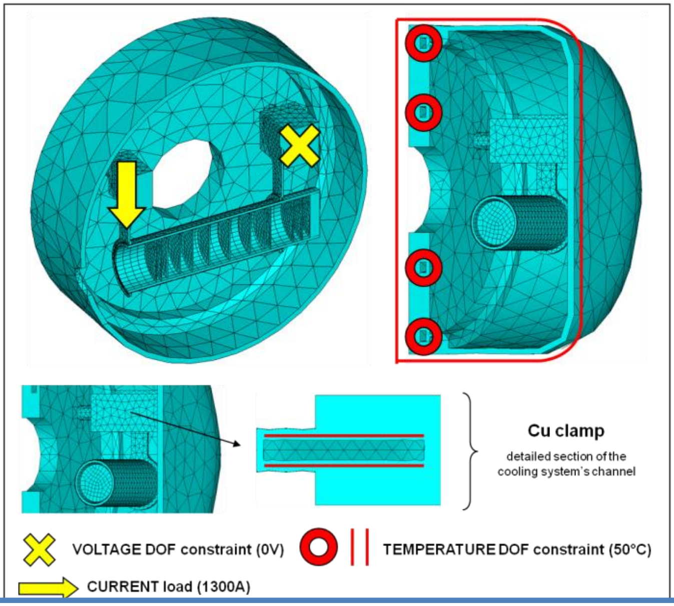


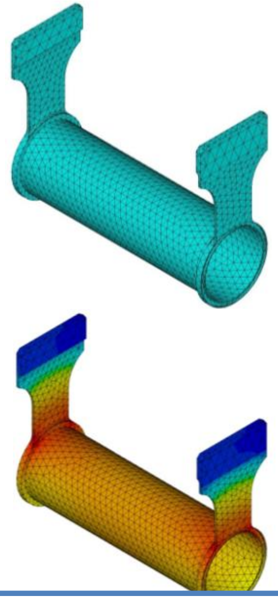
Release time = $\tau = T_{diff} + T_{eff} + N \times T_{Sticking}$

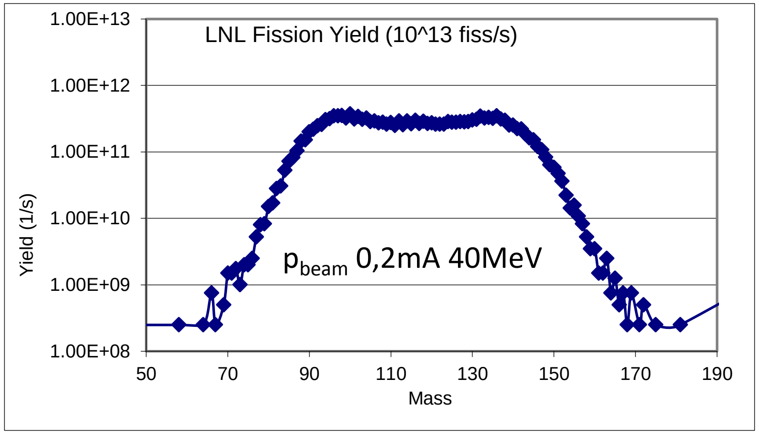
$\tau_{SPES} = 1 + 0.4 + 0.1 = \mathbf{1.5}$

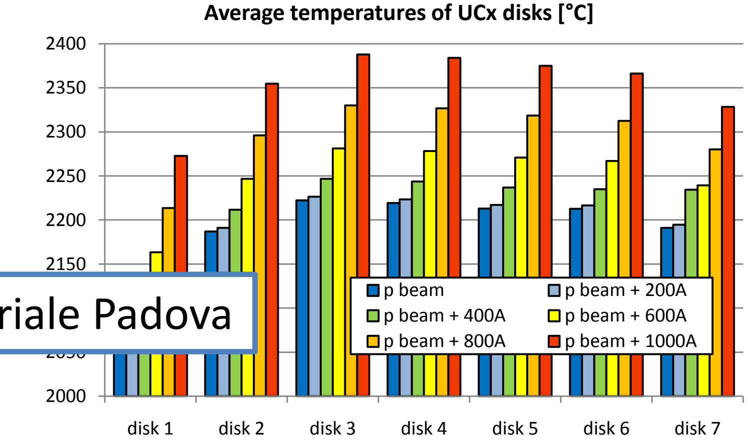
NEW DIRECT TARGET CONCEPT to operate with 10kW proton beam

The SPES choice: optimize the Direct Target design and material production to reach 10^{13} fissions/s

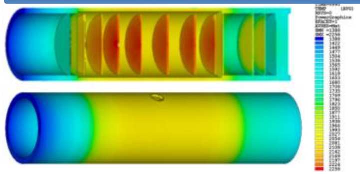


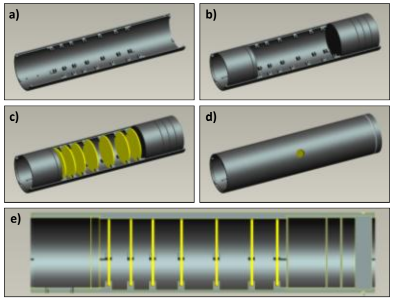


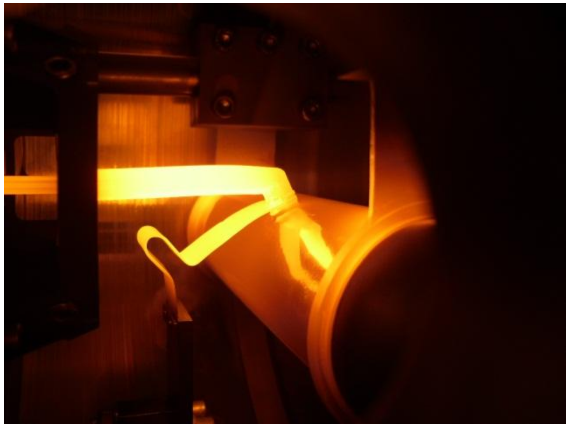


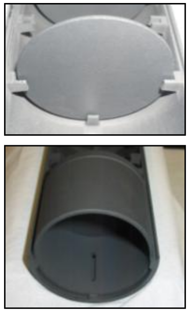


Collaboration with ENEA-Bologna and Ingegneria Industriale Padova

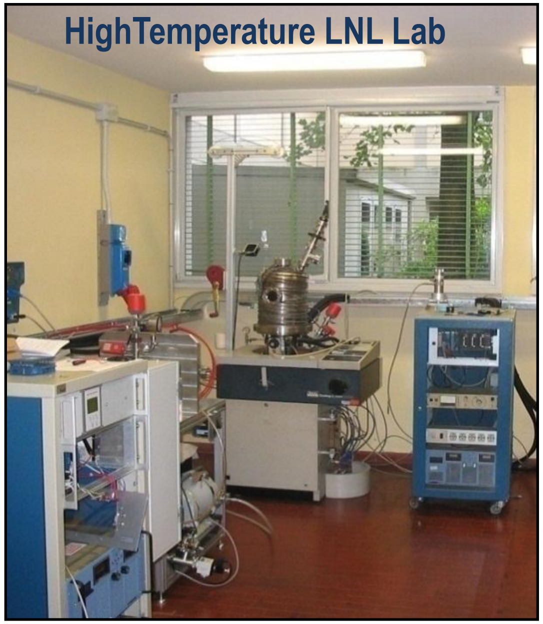








The ISOL SPES Laboratories

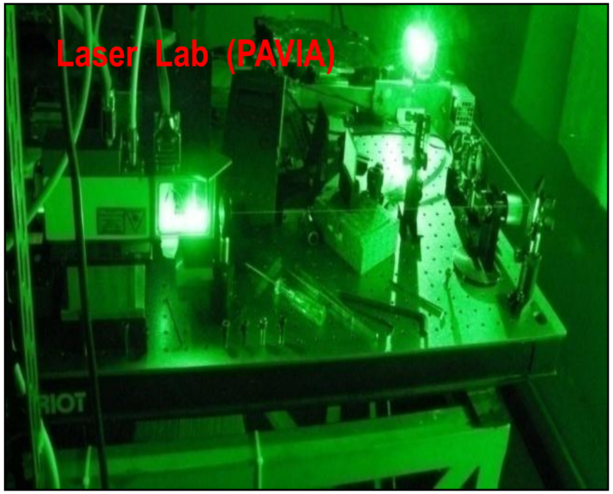

HighTemperature LNL Lab


Test Bench LNL Lab


UCx Chemistry Lab (PADOVA)

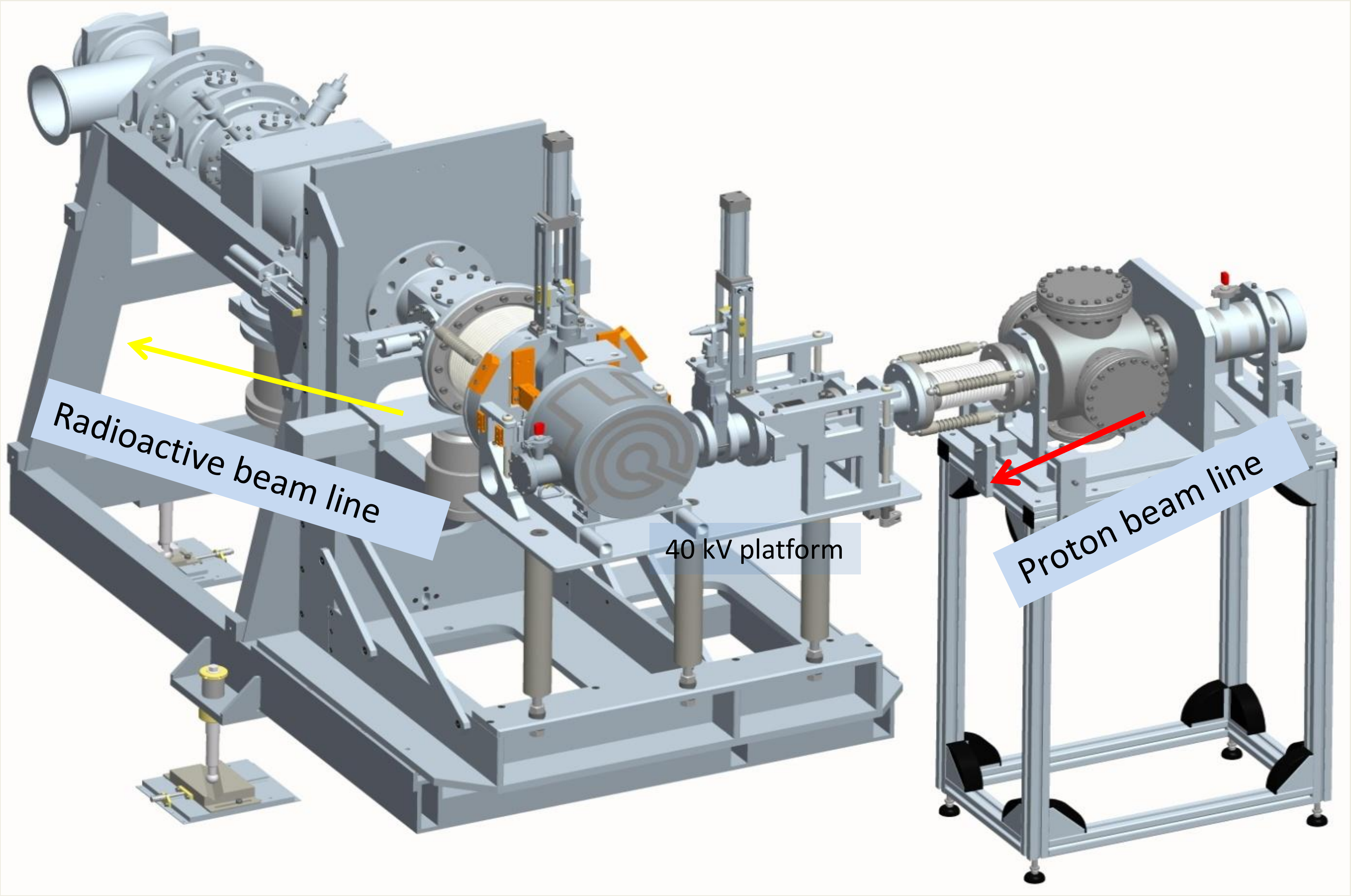

Carbide Chemistry Lab (LNL)

To be upgraded to UCx lab


Laser Lab (PAVIA)

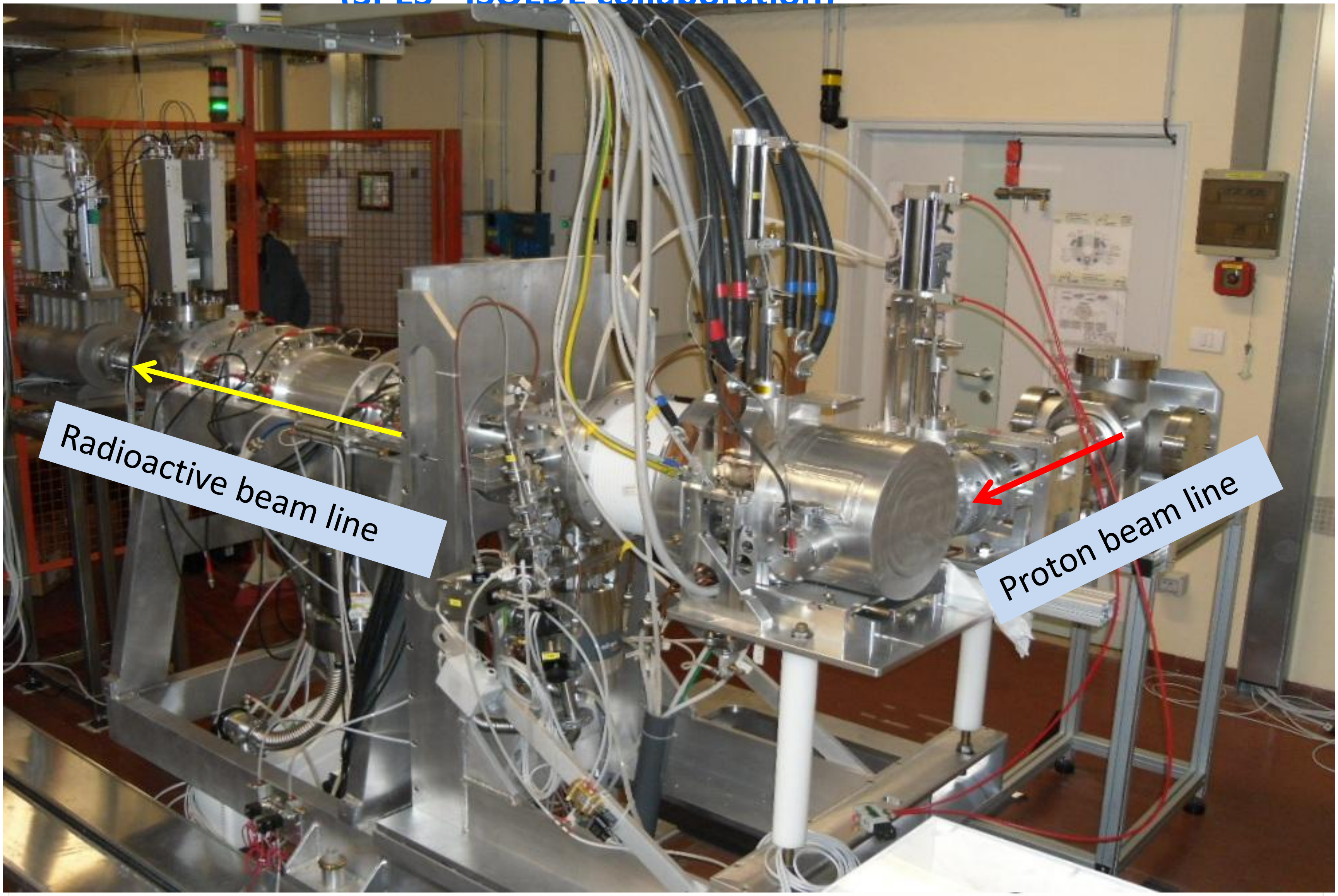
The SPES Front end

(SPES - ISOLDE collaboration)



The SPES Front end

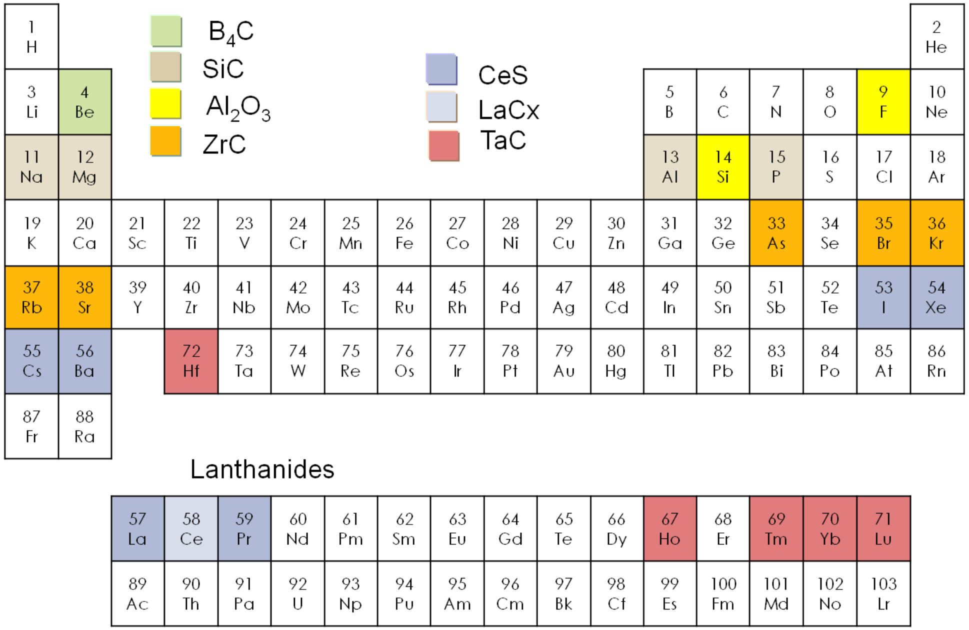
(SPES - ISOLDE collaboration)



Radioactive beam line

Proton beam line

Targets developed for SPES ISOL facility allow to produce a variety of beams in the proton-rich and neutron-rich area


🟩 B_4C

▨ SiC

🟨 Al_2O_3

🟧 ZrC

🟦 CeS

⬜ LaCx

🟥 TaC

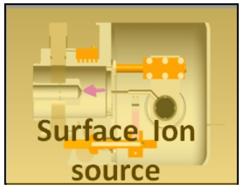
UCx

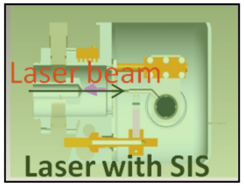
🟦 Elements with bad volatility (NOT EXTRACTED)

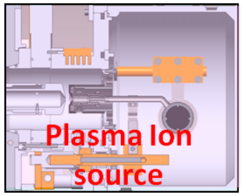
🟨 Surface Ionization Method

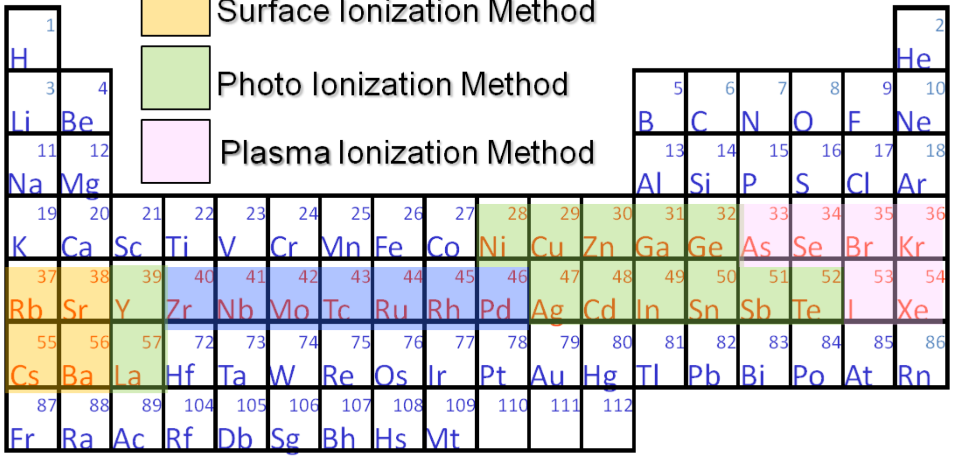
🟩 Photo Ionization Method

🟪 Plasma Ionization Method









Main fission (p-> ^{238}U) fragments

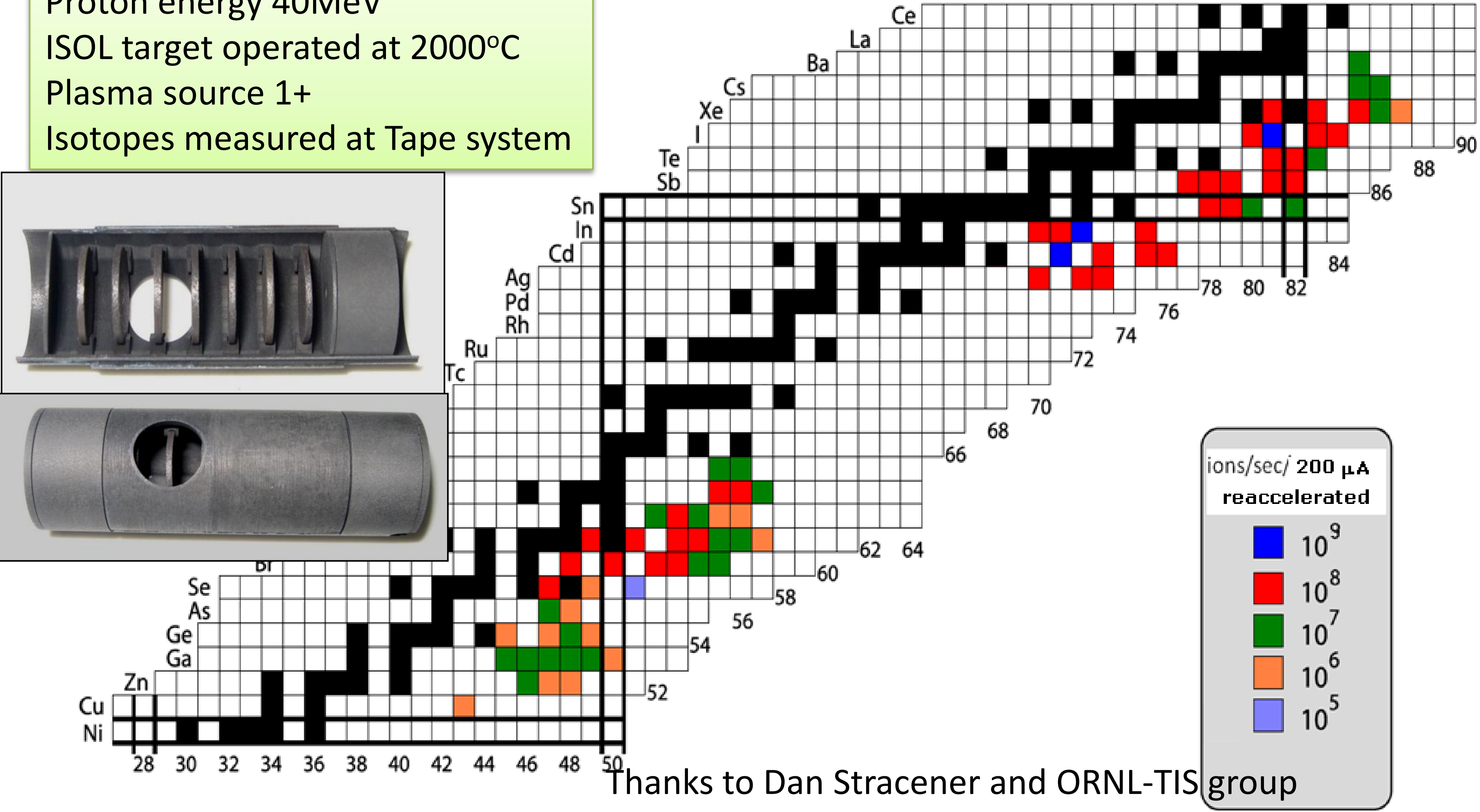
The BAD VOLATILITY elements are produced and trapped in the target. These elements are highly required for nuclear medicine applications.

On-line SPES Target
Test experiment at HRIBF

Experiment March 2010

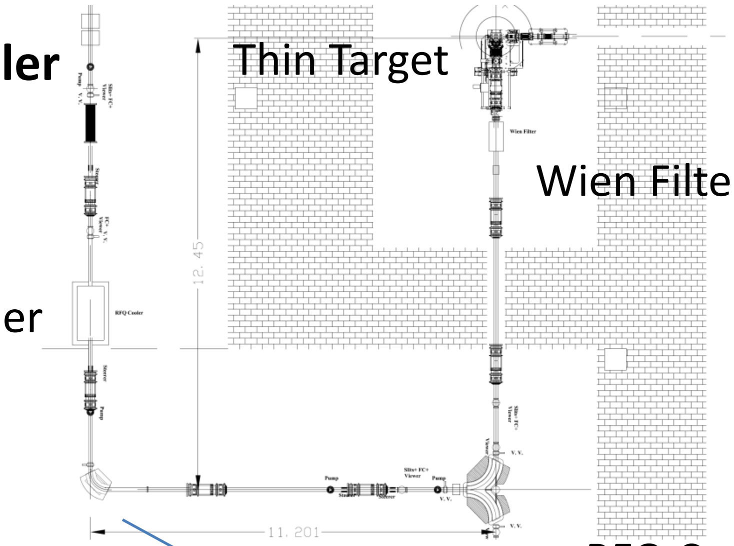
Proton energy 40MeV
ISOL target operated at 2000ºC
Plasma source 1+
Isotopes measured at Tape system

For **expected beam on target,** data are scaled to:
200 microA proton current
2-5% transport efficiency



Thanks to Dan Stracener and ORNL-TIS group

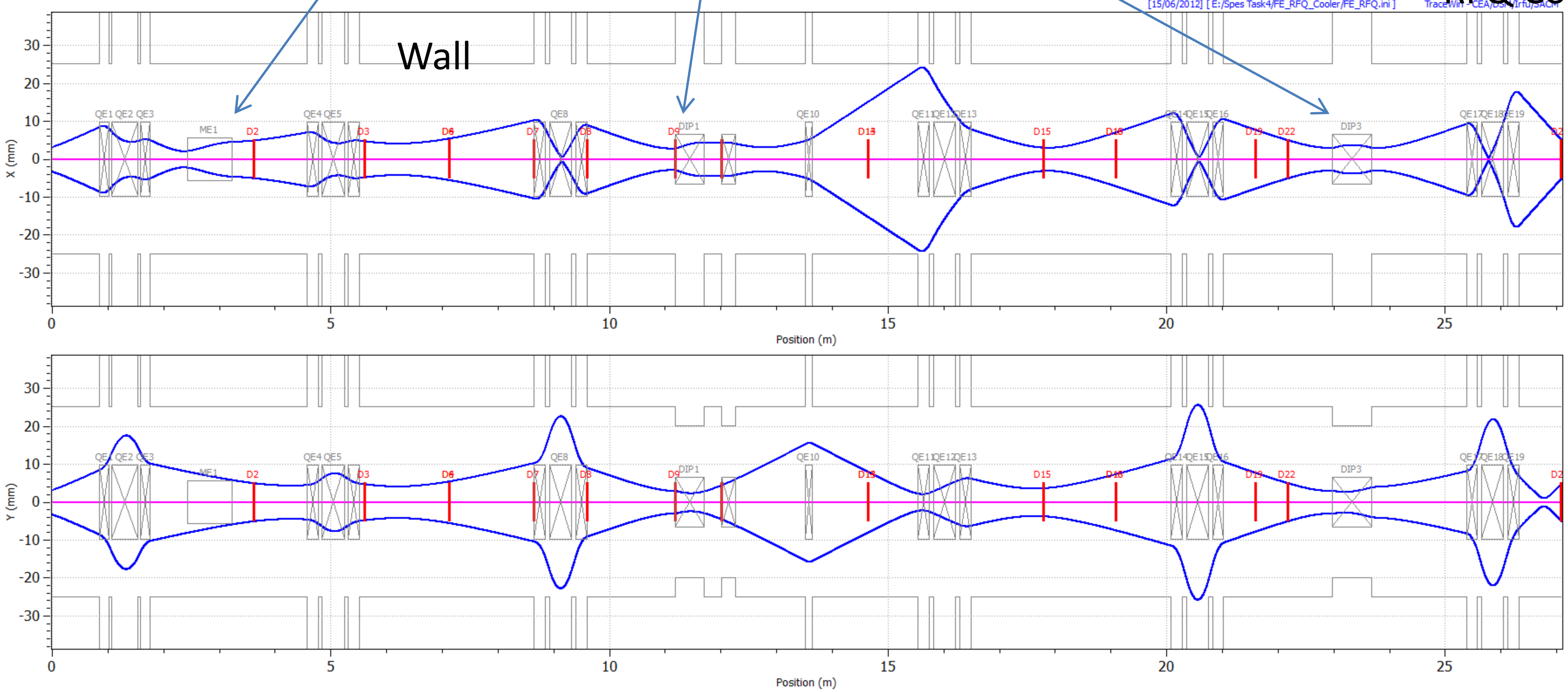
Beam transport from the Target to the RFQ cooler
Extraction Voltage of 40 kV.



Thin Target

Wien Filter

RFQ Cooler



Thin Target

Wien Filter

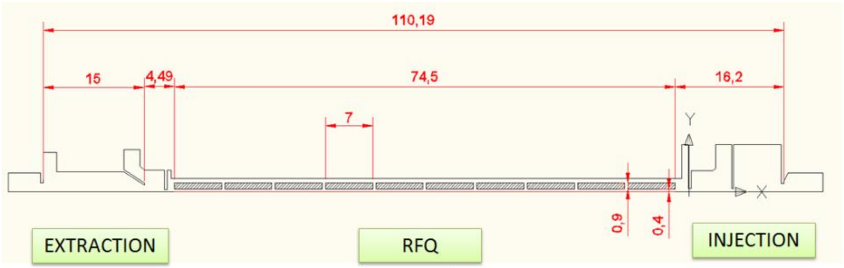
Dipole

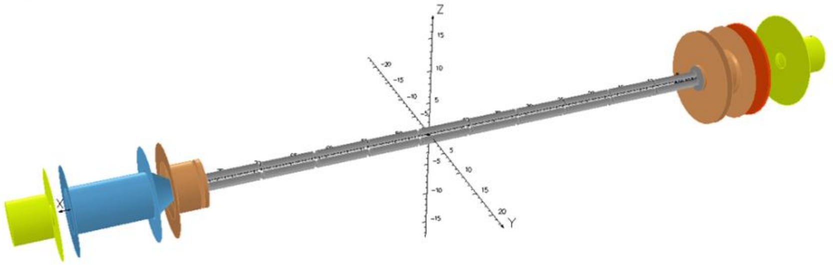
Wall

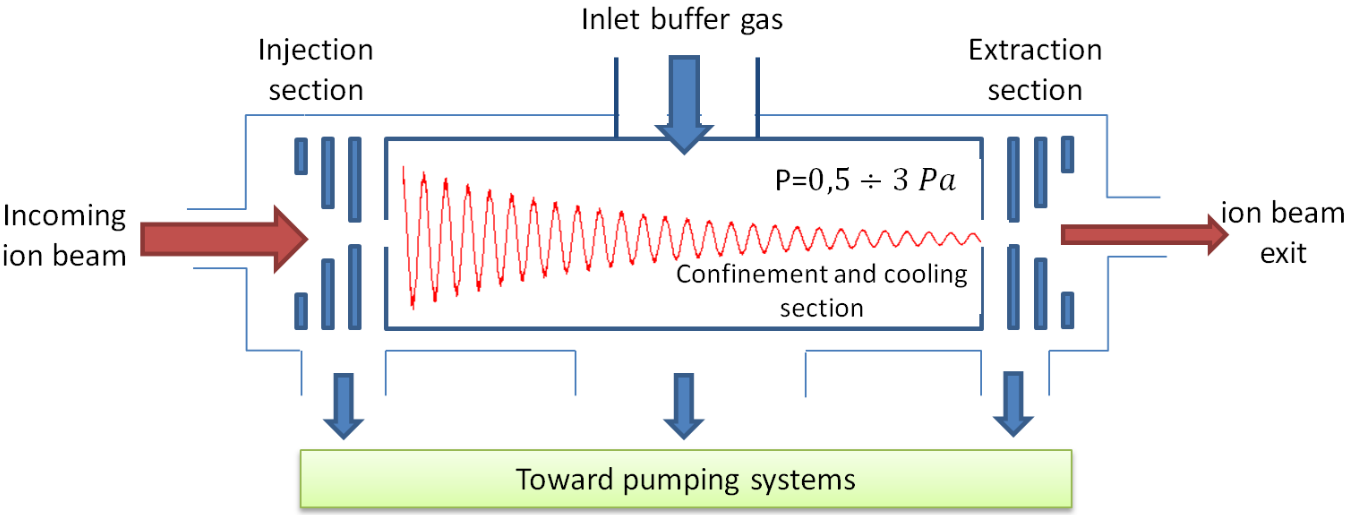
RFQ Cooler

SPES RFQ Beam Cooler parameters

Mass Range	5-200 amu
Transverse Emittance Injected beam	30 π mm mrad @ 40 keV
Emittance Reduction factor	10 (max)
Buffer Gas	He @ 273 K
Beam Intensity	50-100 nA → x10^{11} pps
Energy spread	< 5 eV
RF Voltage range	0.5 – 2.5 kV (1 kV at q=0.25)
RF Frequency range	1 -30 MHz (3.5 – 15 MHz at q=0.25)
RFQ gap radius (ro)	4 mm
RFQ Length (total)	700 mm
Pressure Buffer Gas (He) range	0.1 – 2.5 Pa
Ion energy during the cooling	100 -200 eV







Inlet buffer gas

Injection section

Extraction section

Incoming ion beam

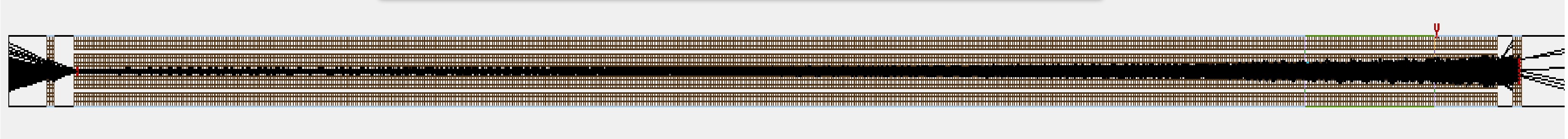
$P=0{,}5 \div 3\ Pa$

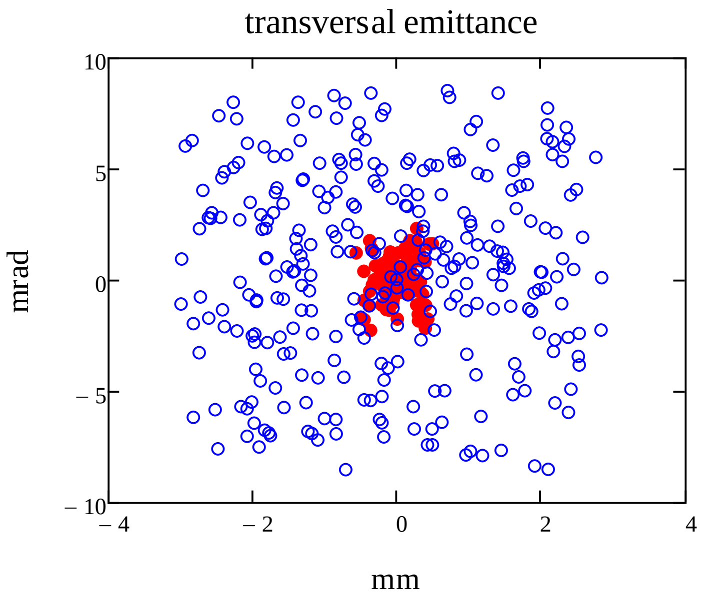
Confinement and cooling section

ion beam exit

Toward pumping systems

RFQ dynamics with SIMION code simulation





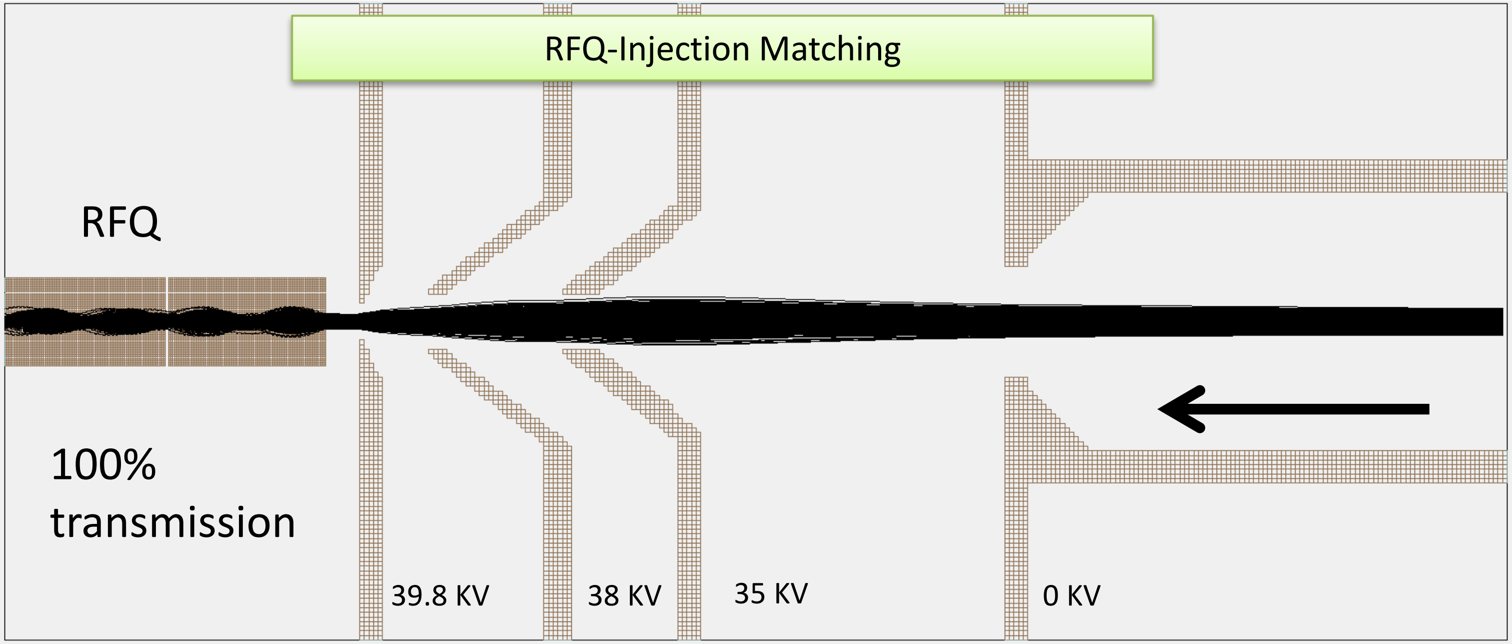
Input (blu) and output (red) transverse emittance: from 30 mmmrad to about 3 at 40 kV.

Cs+, A=133
Einj=200 eV
Vq=1500 volt
frf=5.57 MHz
V1=100 Volt
dV=10 Volt
He pressure =2.5 Pa
q=0.22 (Mathieu param.)

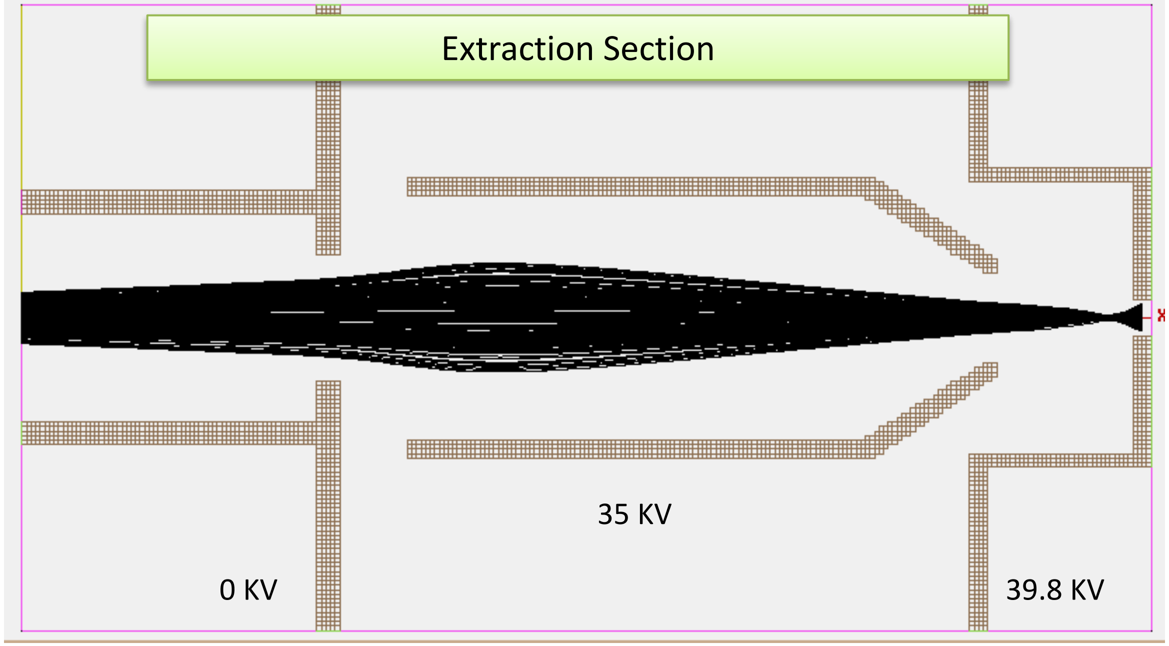
$$\frac{d^2u}{d\tau^2} - (2q_u \cos 2\tau)u = 0$$

$$q = q_u = q_x = -q_y = \frac{4eU_{RF}}{m\omega_{RF}^2 r_0^2},$$

POSTER ON BEAM COOLER: PO09



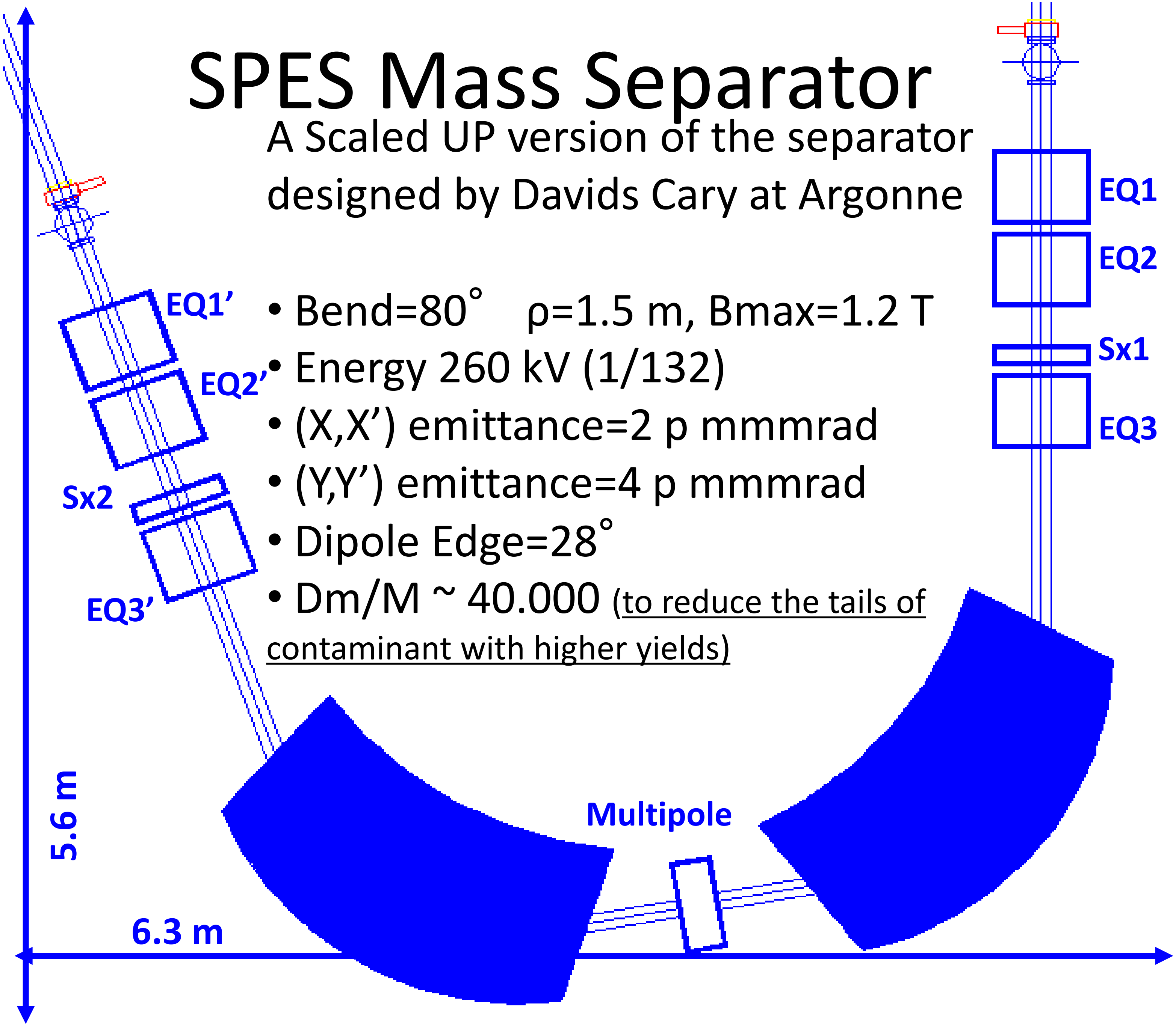
RFQ-Injection Matching



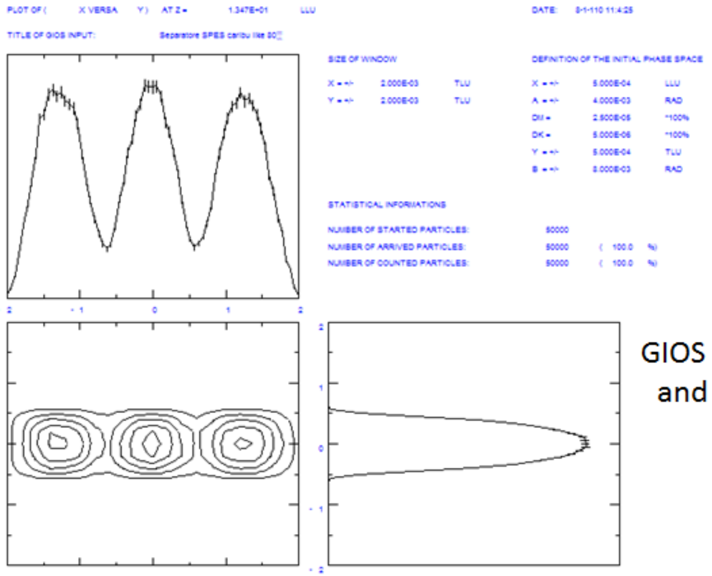
Extraction Section

SPES Mass Separator

A Scaled UP version of the separator designed by Davids Cary at Argonne

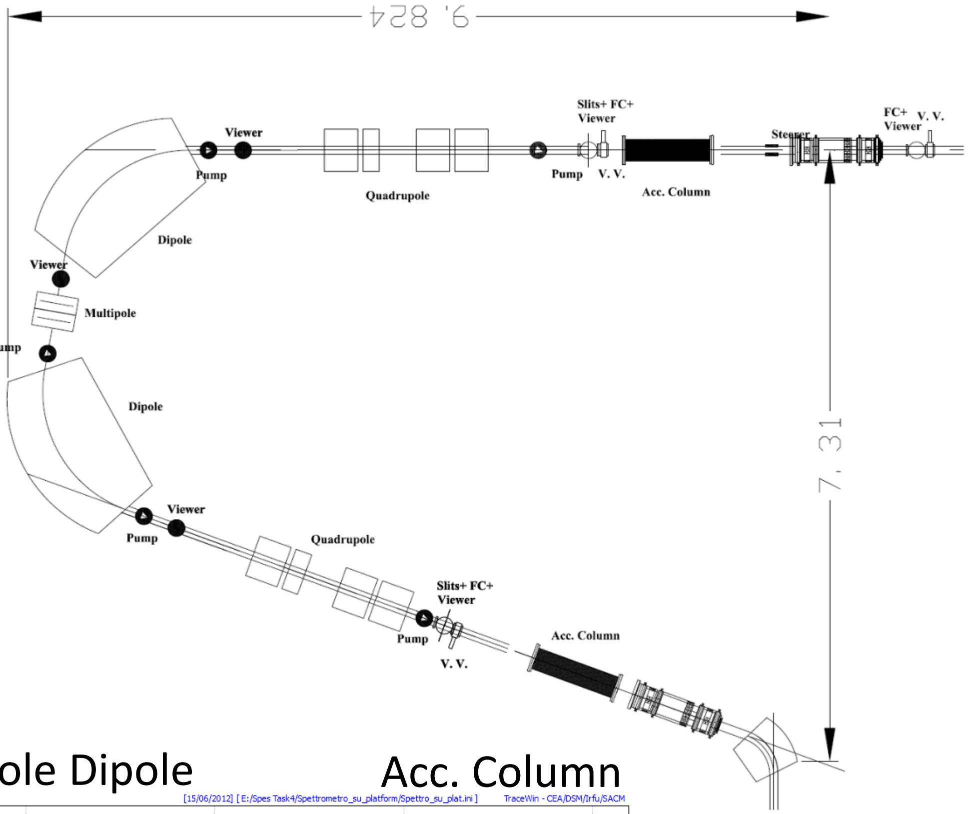


- Bend=80˚ ρ=1.5 m, Bmax=1.2 T
- Energy 260 kV (1/132)
- (X,X’) emittance=2 p mmmrad
- (Y,Y’) emittance=4 p mmmrad
- Dipole Edge=28˚
- Dm/M ~ 40.000 (to reduce the tails of contaminant with higher yields)



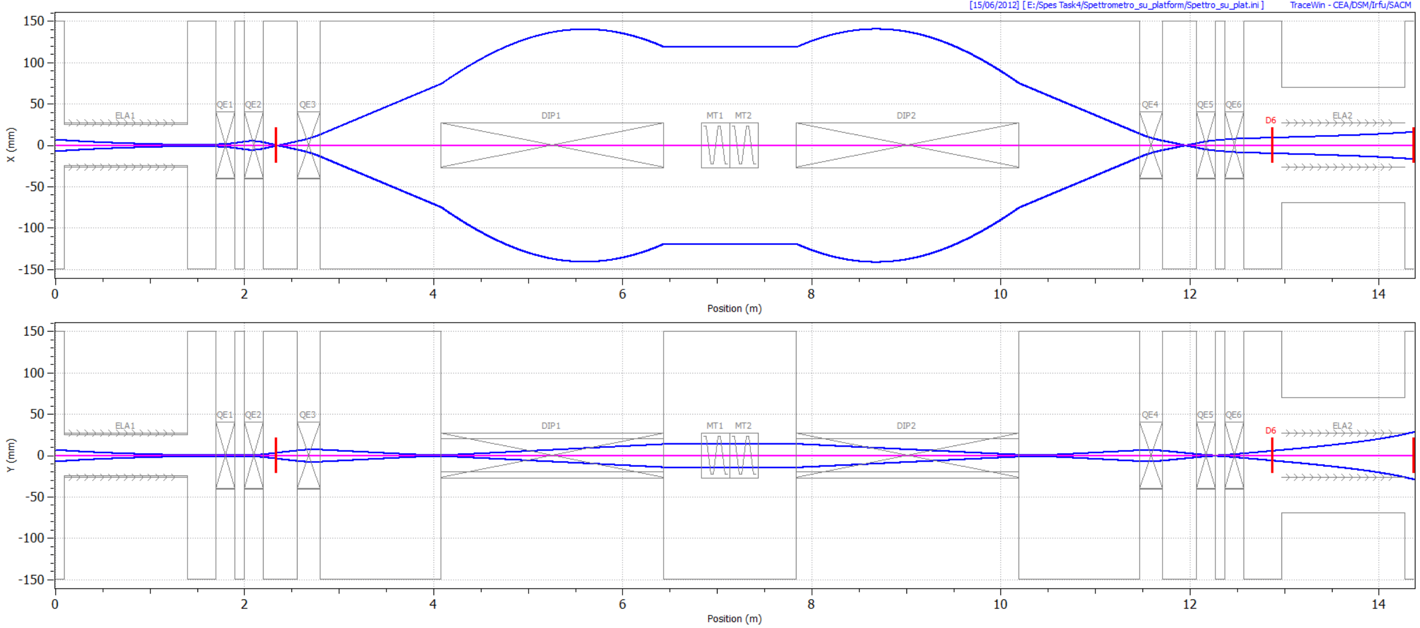
```
PLOT OF (      X VERSA      Y )    AT Z =        1.347E+01        LLU                    DATE:     8-1-110 11:4:25

TITLE OF GIOS INPUT:              Separatore SPES caribu like 80

                        SIZE OF WINDOW                              DEFINITION OF THE INITIAL PHASE SPACE

                        X = +/-      2.000E-03      TLU             X = +/-      5.000E-04      LLU
                        Y = +/-      2.000E-03      TLU             A = +/-      4.000E-03      RAD
                                                                    DM =         2.500E-05      *100%
                                                                    DK =         5.000E-06      *100%
                                                                    Y = +/-      5.000E-04      TLU
                                                                    B = +/-      8.000E-03      RAD

                        STATISTICAL INFORMATIONS

                        NUMBER OF STARTED PARTICLES:      50000
                        NUMBER OF ARRIVED PARTICLES:      50000     (   100.0   %)
                        NUMBER OF COUNTED PARTICLES:      50000     (   100.0   %)
```

GIOS up to 3° order
and DE= ± 1.3 eV



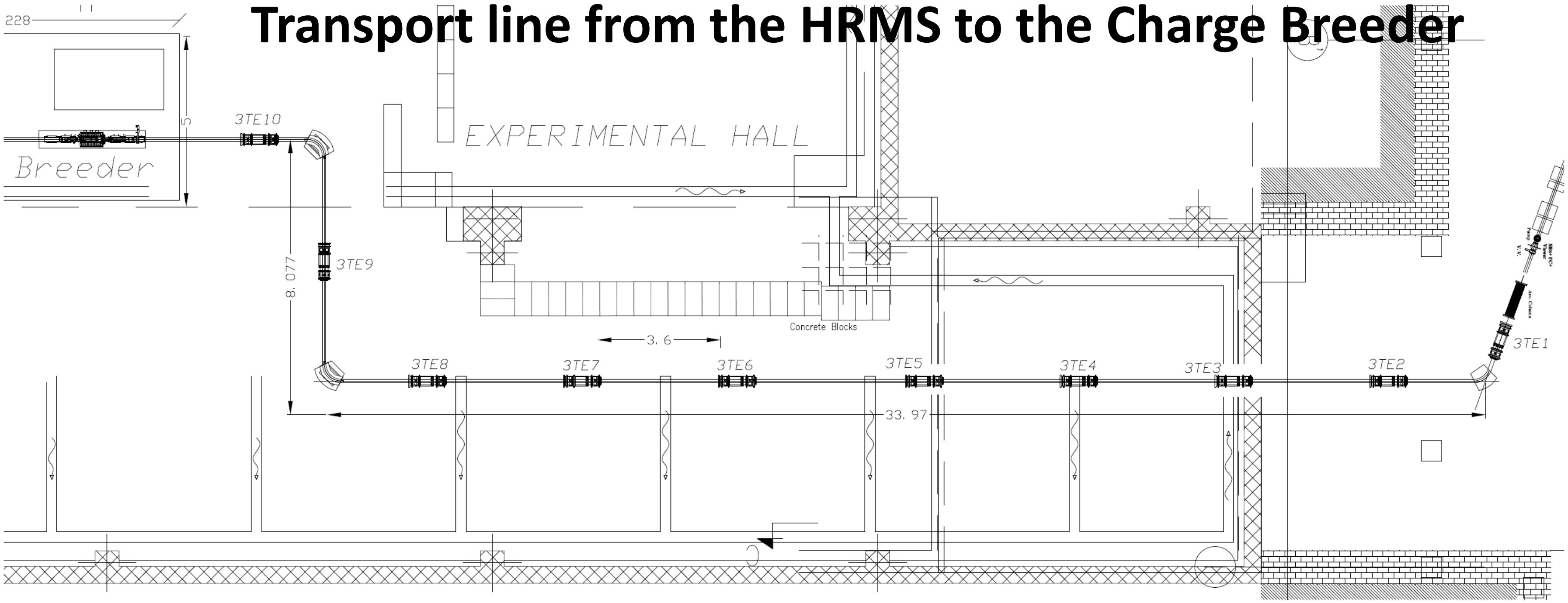
P X 0.0005 0.004 ; P Y 0.0005 0.008 ;
DM 0.000025; DE ± 0.0000005 → ΔE =2.6 eV;

Acc. Column   Dipole Multipole Dipole   Acc. Column

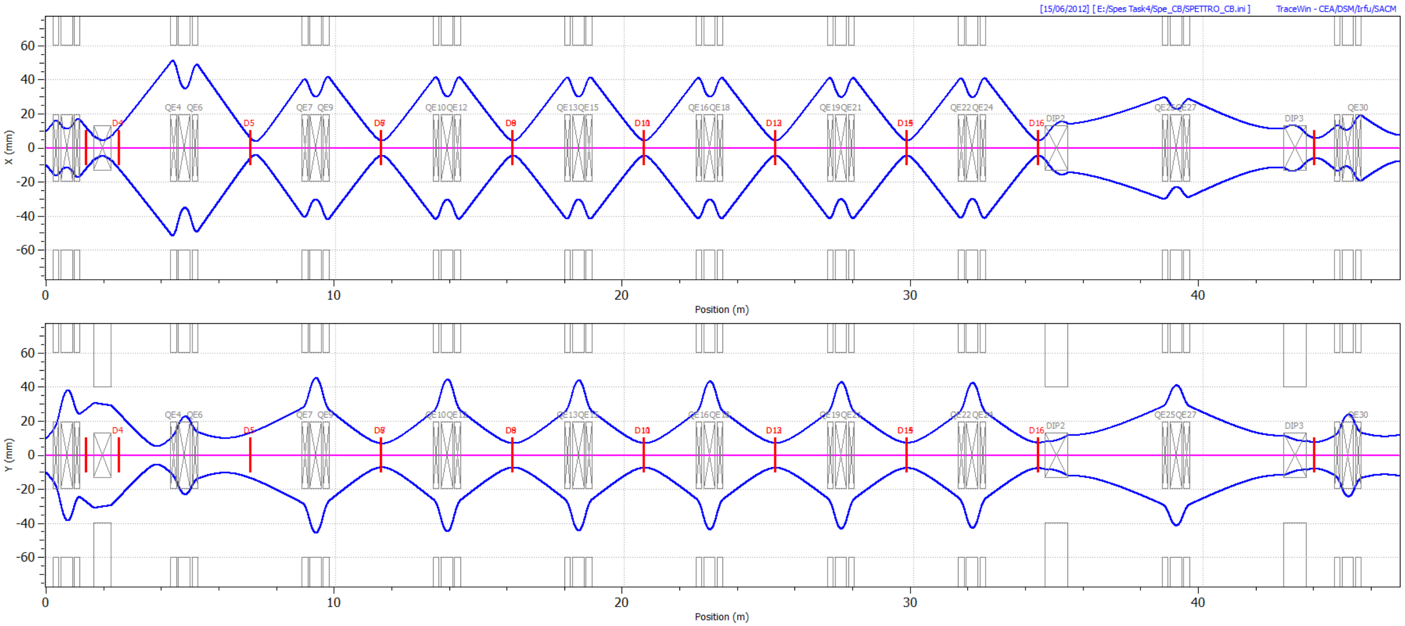


[15/06/2012] [E:/Spes Task4/Spettrometro_su_platform/Spettro_su_plat.ini]   TraceWin - CEA/DSM/Irfu/SACM

Transport line from the HRMS to the Charge Breeder



HRMS



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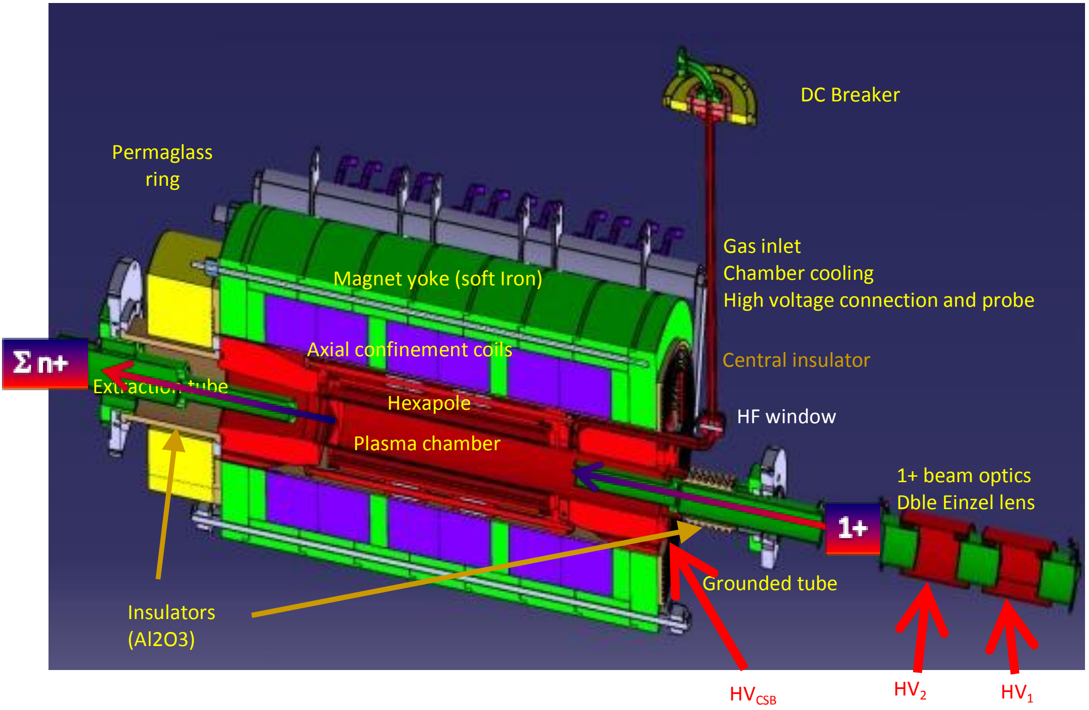
Charge Breeder (collab. LPSC_Grenoble)



Schematic drawing of the PHOENIX Charge Breeder

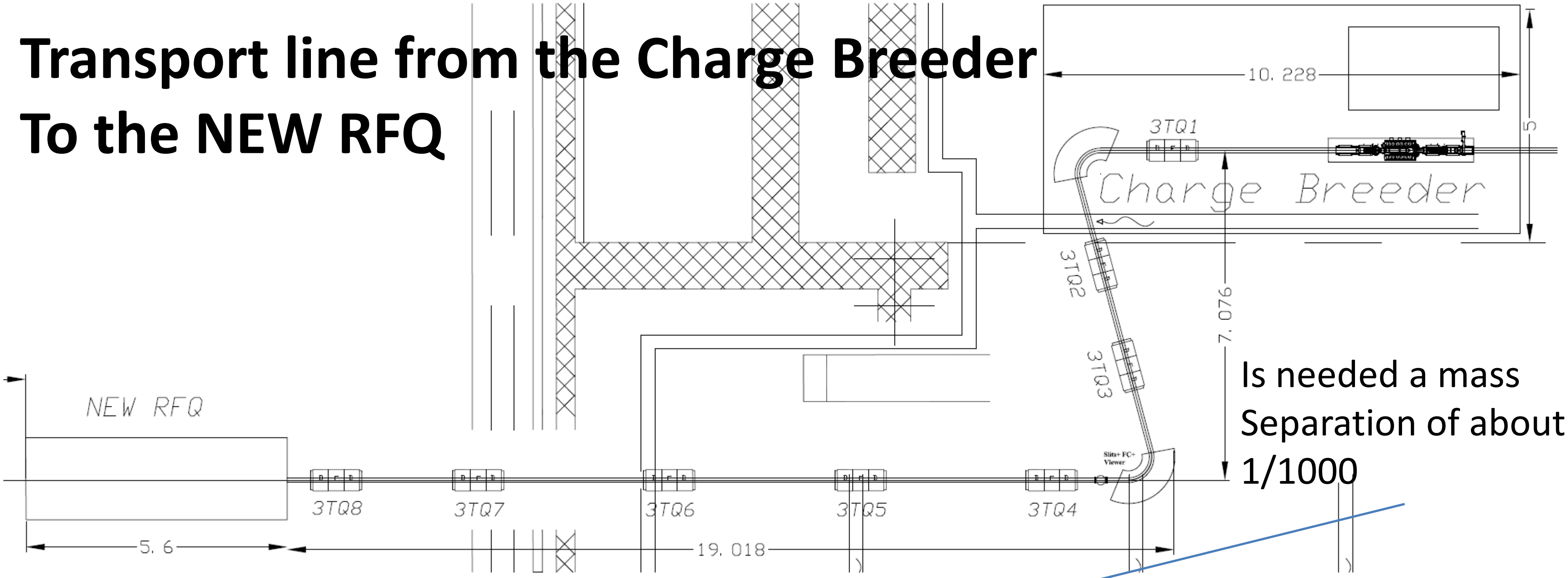
R&D on:

- New exapole -> higher charge states
- Trap process understanding -> improve efficiency
- Removal of grounded tube -> higher efficiency

Phoenix Charge Breeder Parameters	
f[GHZ]	14.5
P_max[W]	1000
B_inj [T]	1.5
B_ext[T]	1
B_rad[T]	1.35
eff_max for gas [%]	8-10
eff_max for metals [%]	3-5
Charge breeding time	3-4 to 10-15 ms/q

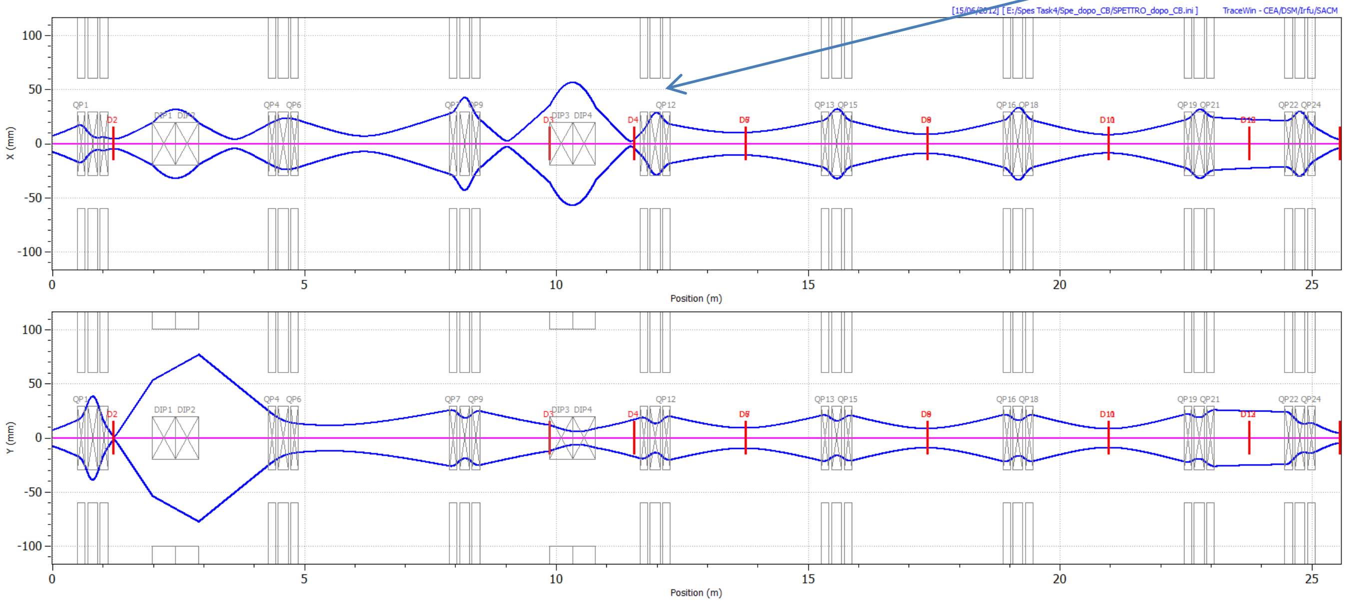
SIMION 3D Calculations

Transport line from the Charge Breeder To the NEW RFQ



Is needed a mass Separation of about 1/1000

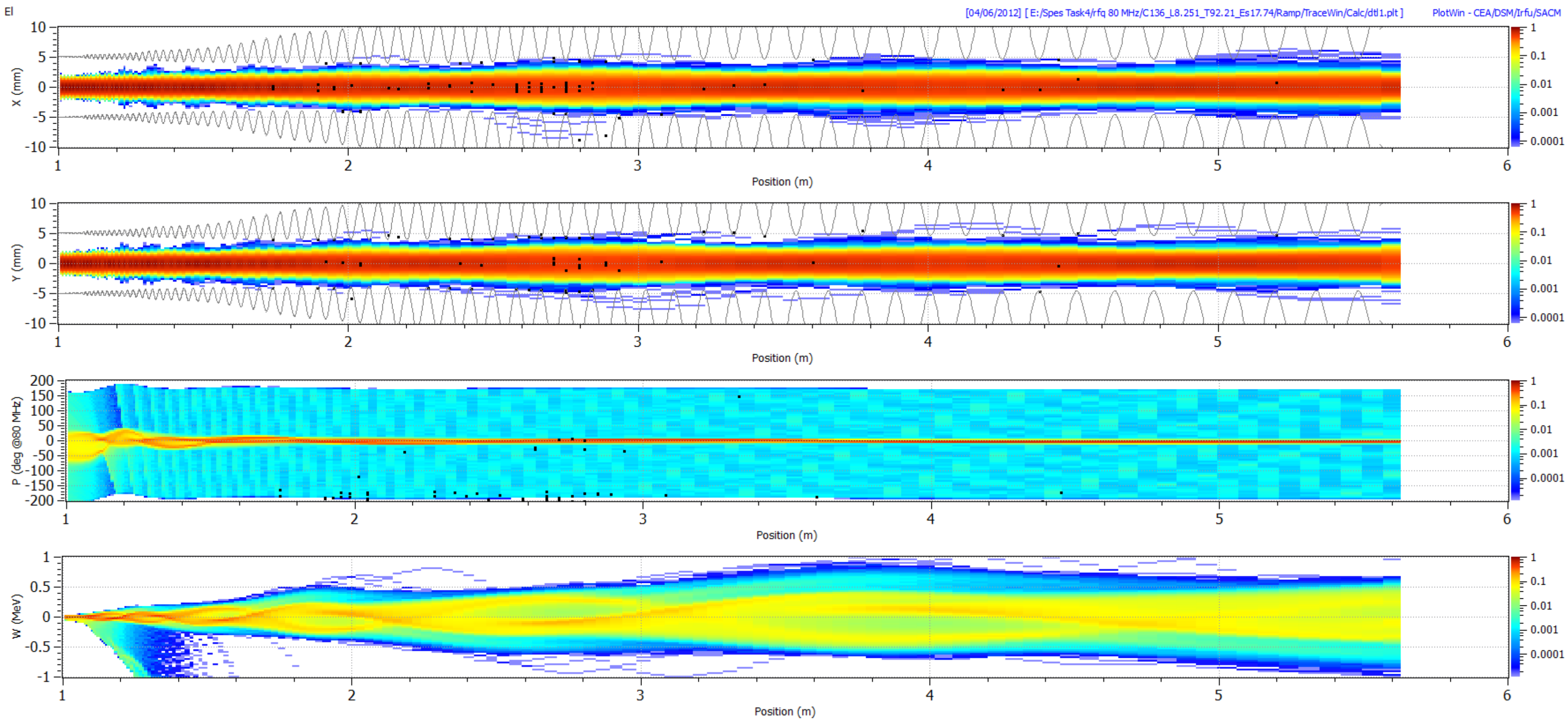
CB



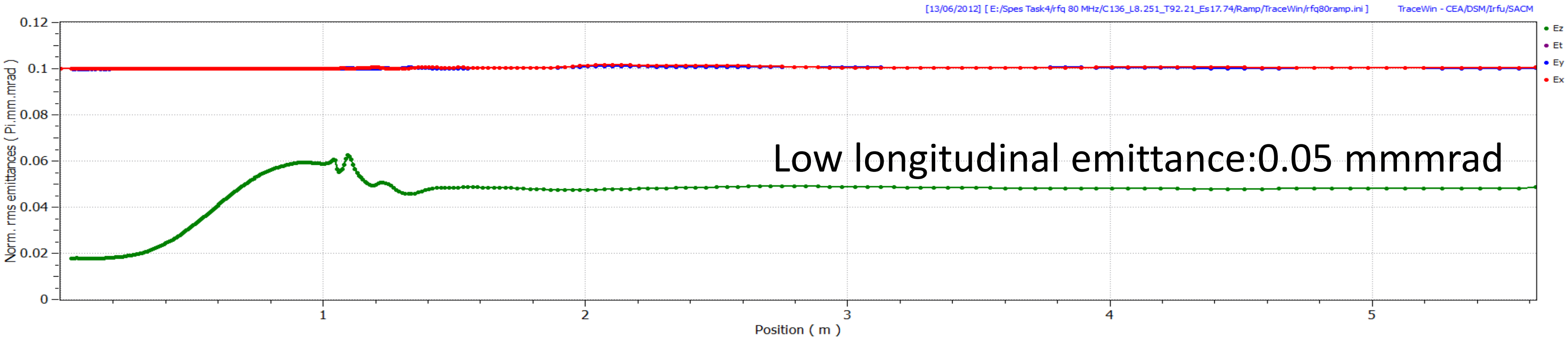
NEW RFQ

NEW RFQ injector for ALPI

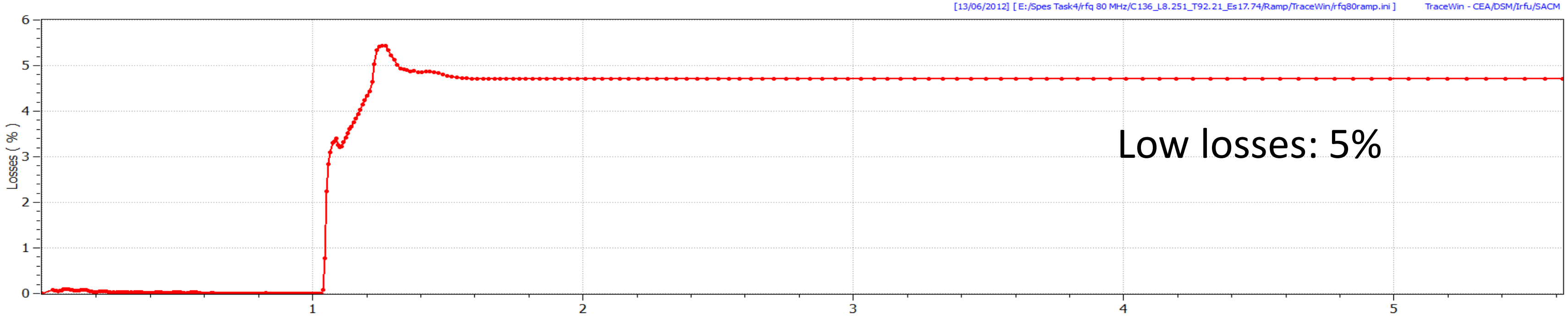
- Energy 5.7 –> 727.3 [β=0.0395] KeV/A (A/q=7)
- Beam transmission >94%
- Length 562 cm intervane voltage from 63.7kV to 120 kV (1.7 kp)
- RF power (four vanes) 180 kW.
- Mechanical design and realization, taking advantage of IFMIF experience.



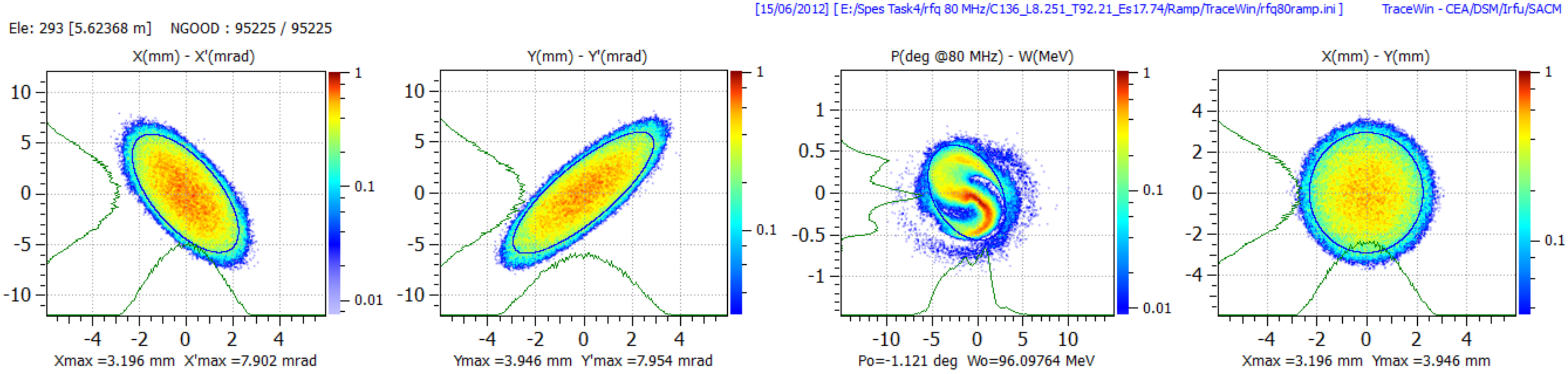
NEW RFQ injector for ALPI



Low longitudinal emittance:0.05 mmmrad

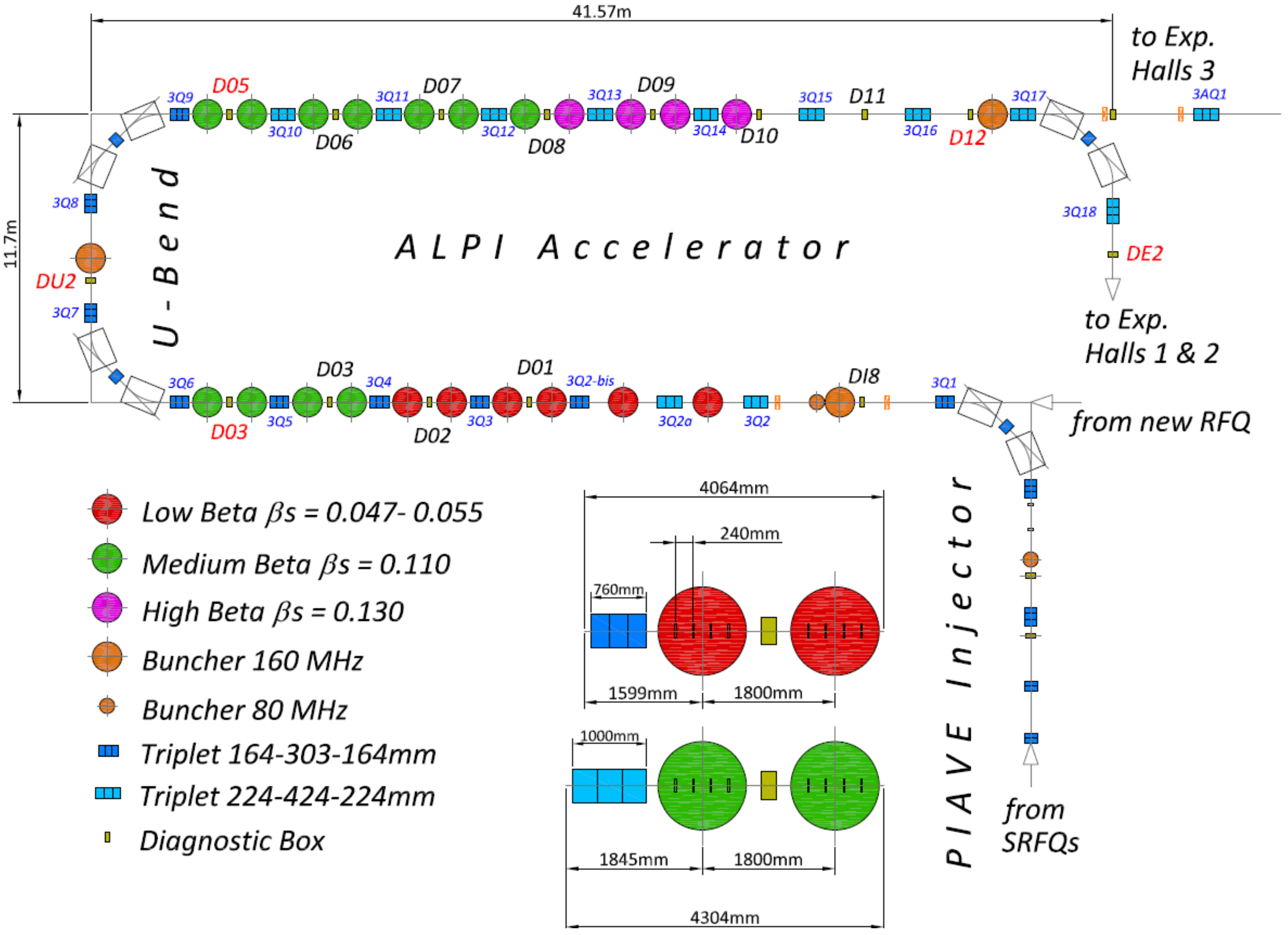


Low losses: 5%



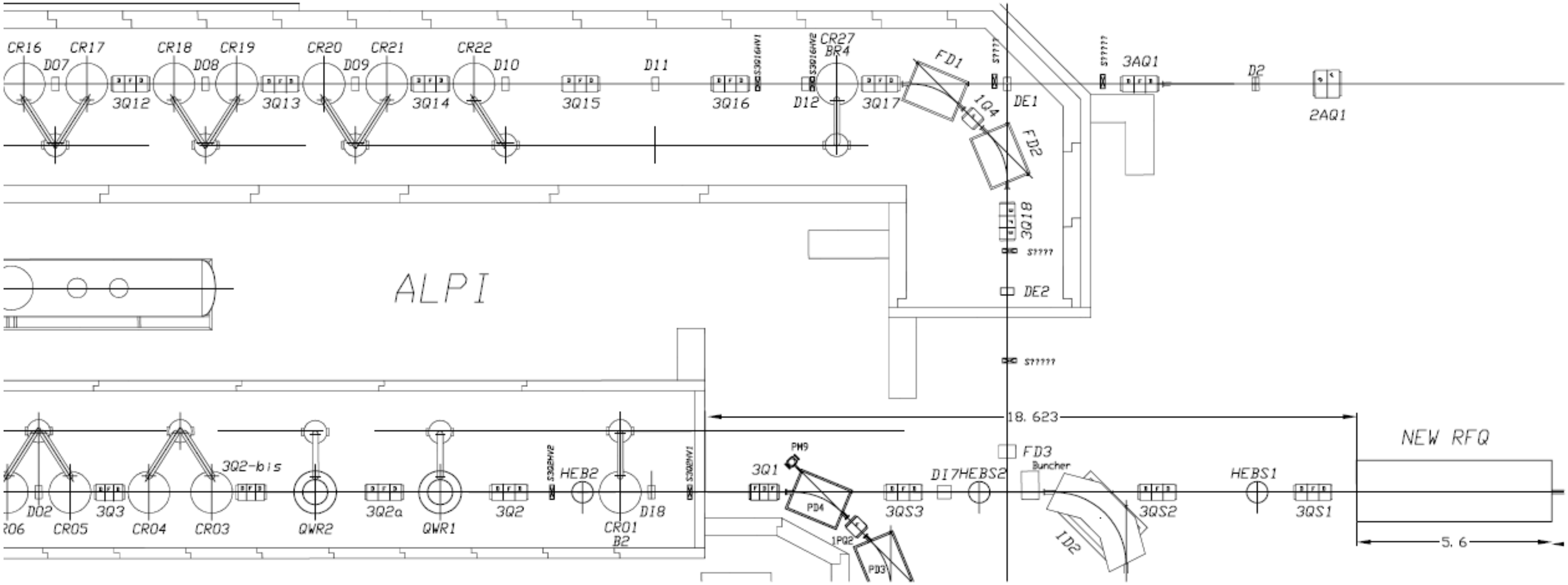
ALPI with the maximum cavity performance

- All Cavities from CR03 to CR07 at 4.5 MV/m.
- Medium beta CR07 to CR18 at 4.5 MV/m.
- High beta 6.5 MV/m for CR19-CR22.
- **Final Energy of 10 MeV/A (A/q=7)**

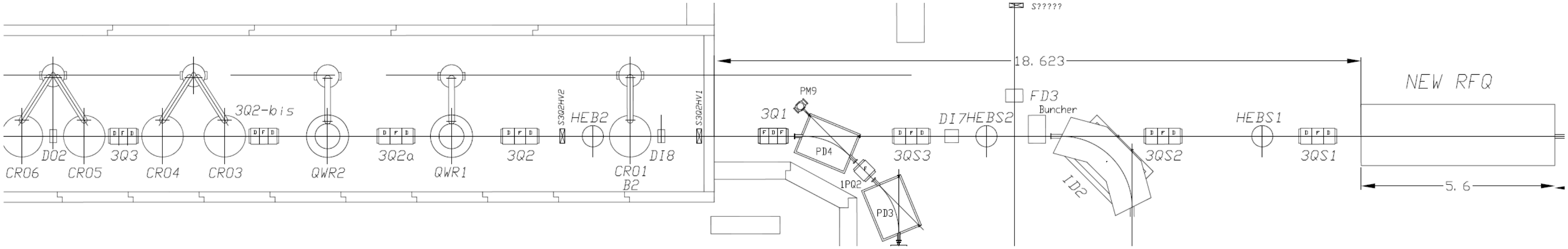


NEW RFQ injector into ALPI

Actual transmission= (70% PIAVE RFQ)*(60% ALPI)=42%
With the new RFQ=(94% NEW RFQ)*(80% ALPI)=75%
NEW RFQ Improvement:
higher output energy 727.3 [β=0.0395] KeV/A vs 587 [β=0.0355] KeV/A
Internal bunching section
Same longitudinal emittance as PIAVE: about 4 degKeV/u

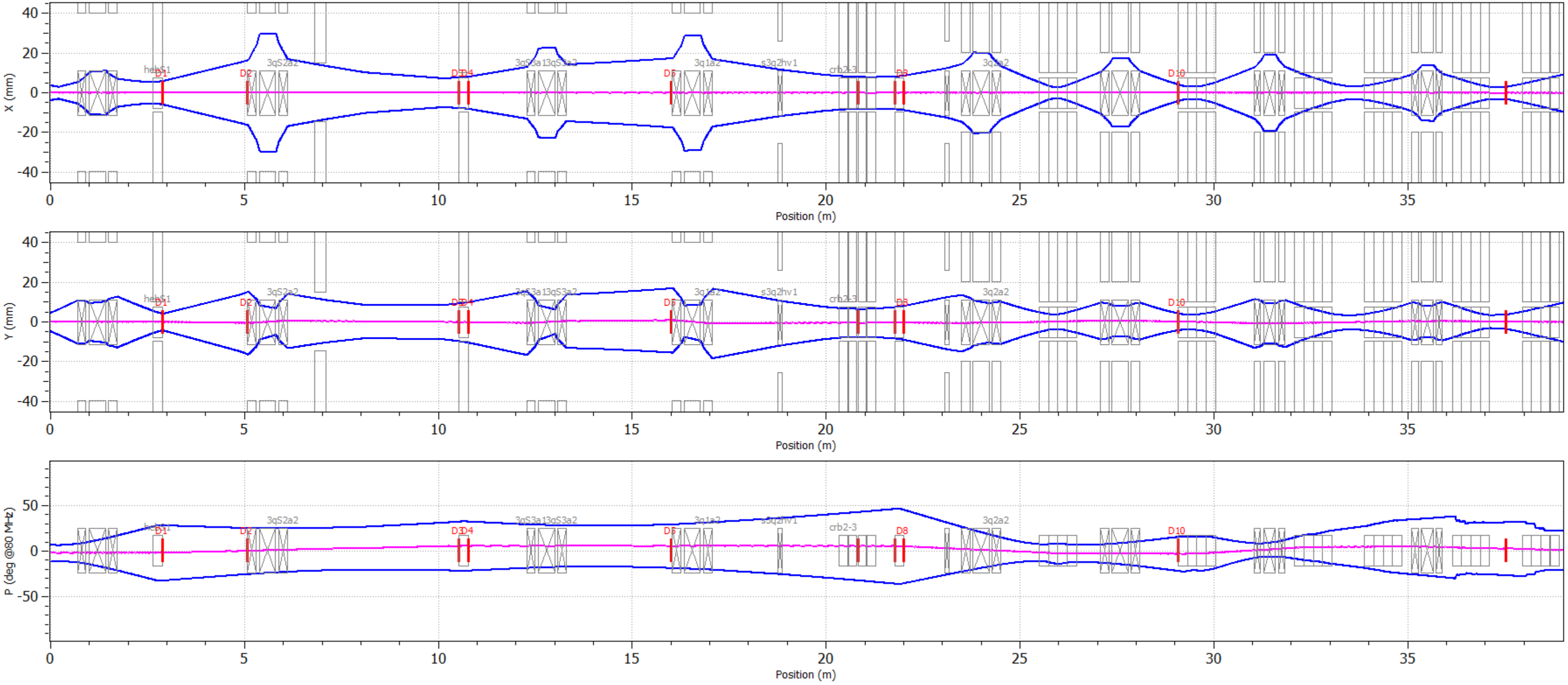


NEW RFQ injector into ALPI



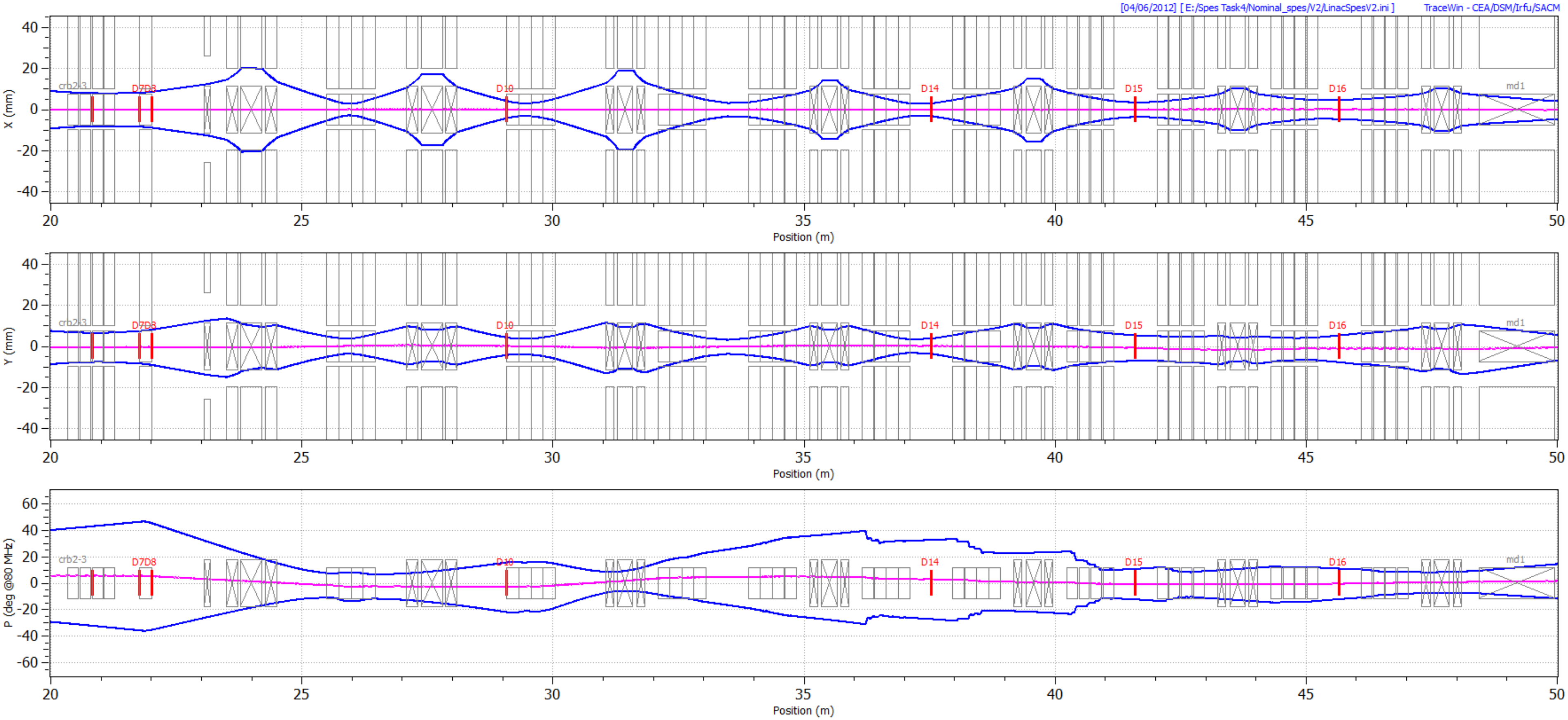
RFQ

QWR1 QWR2 CR3-CR4



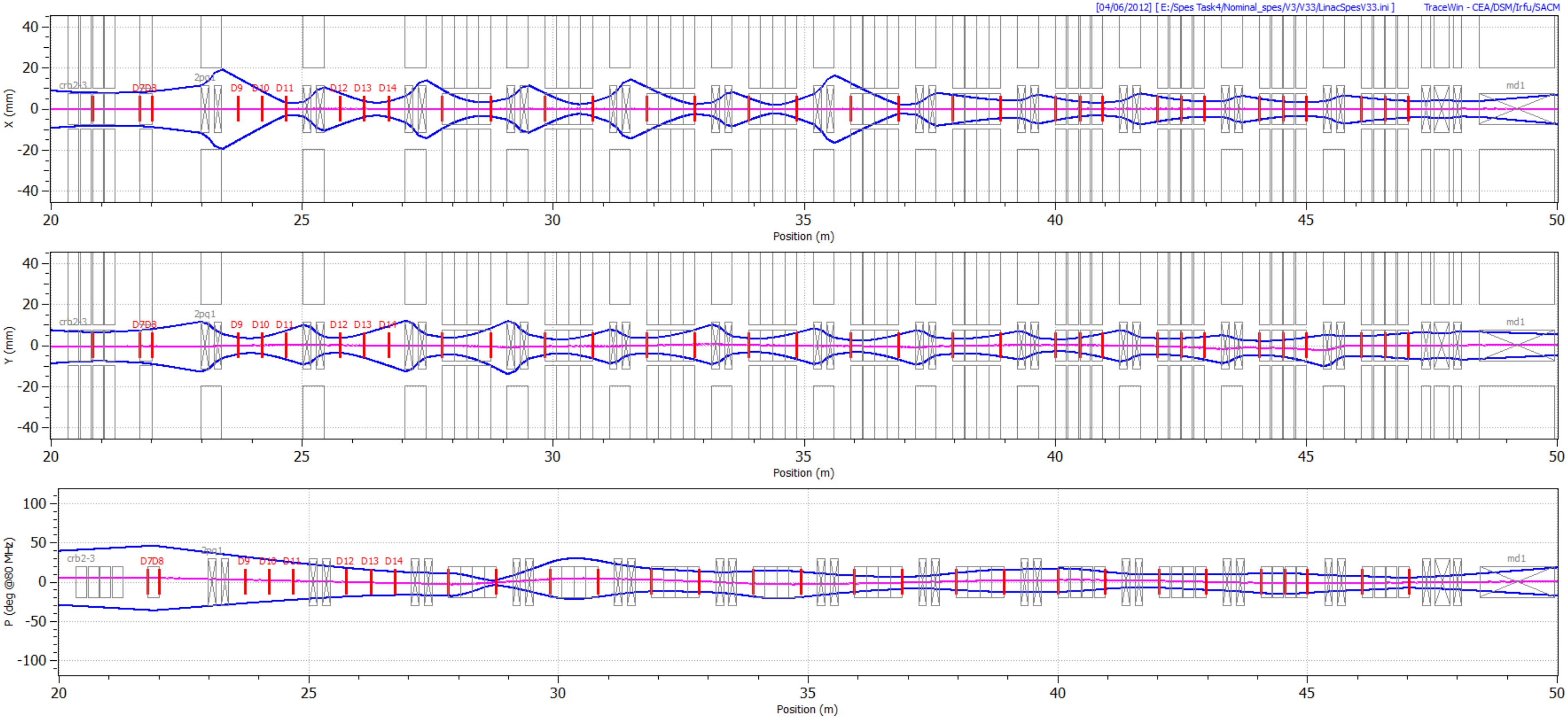
Actual ALPI Performance

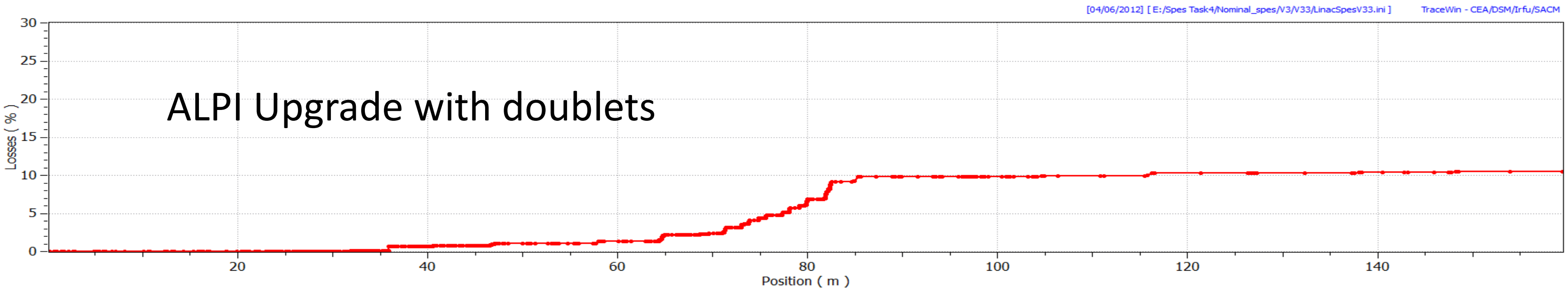
- ALPI all made by triplets (triplet QWR1 triplet QWR2), the period is DFD-CR-CR.
- Cavities Phases +/-20°.
- All cryostats conserve the position.
- 12% losses, for each branch.

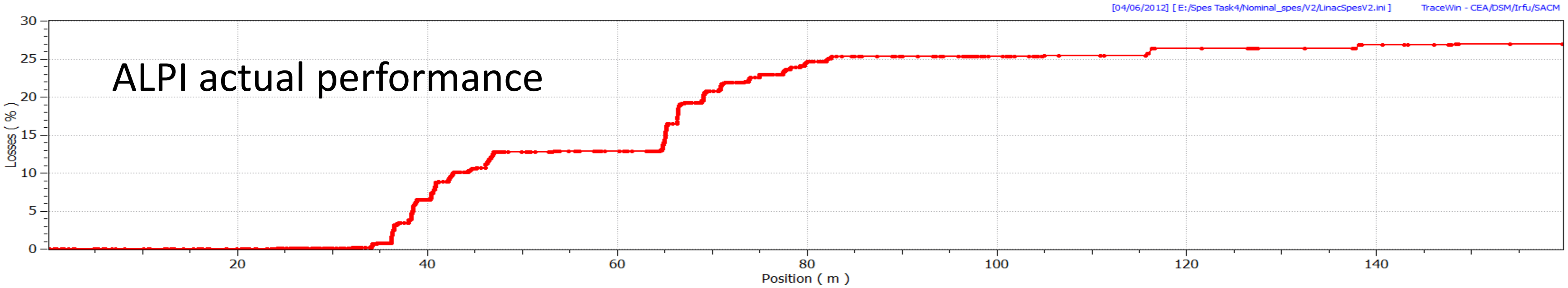


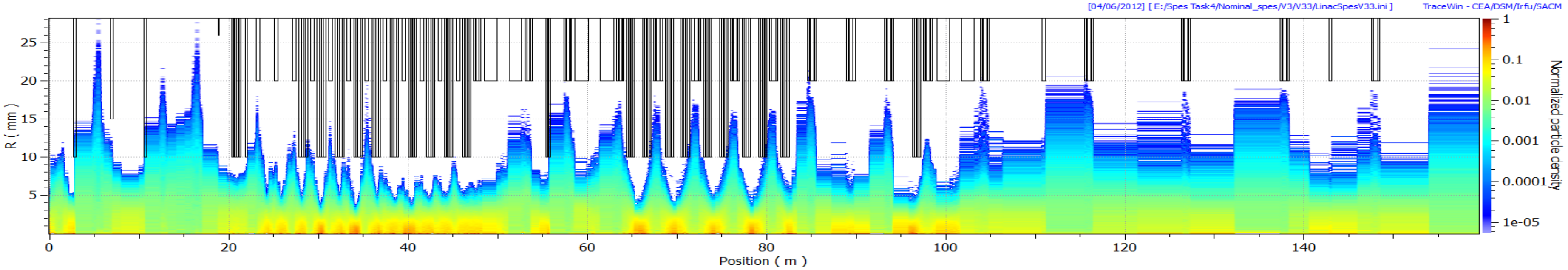
ALPI Upgrade Scenario

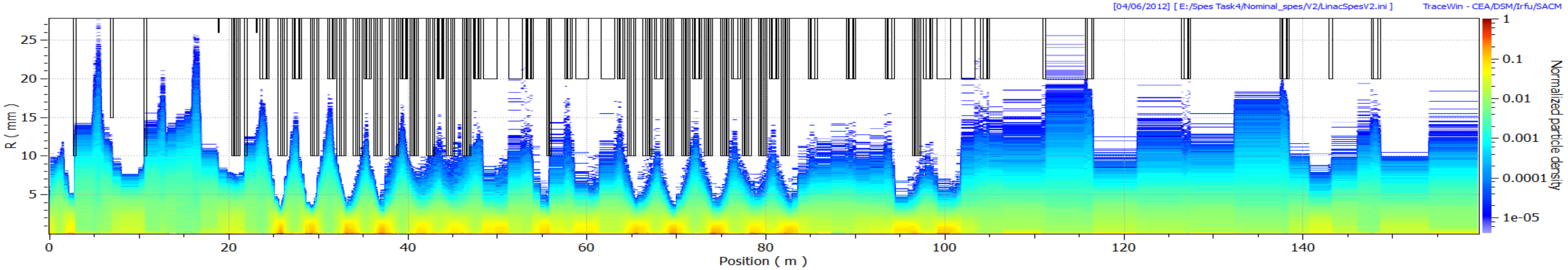
- ALPI with low energy part made by Doublets (12) the period is DF-CR.
- all cavities phases -20°.
- CR9, CR7, CR5, CR3 change the position.
- No losses, on the low energy branch.
- One steerer used before 3Q6, to compensate Cavities Steering effects.



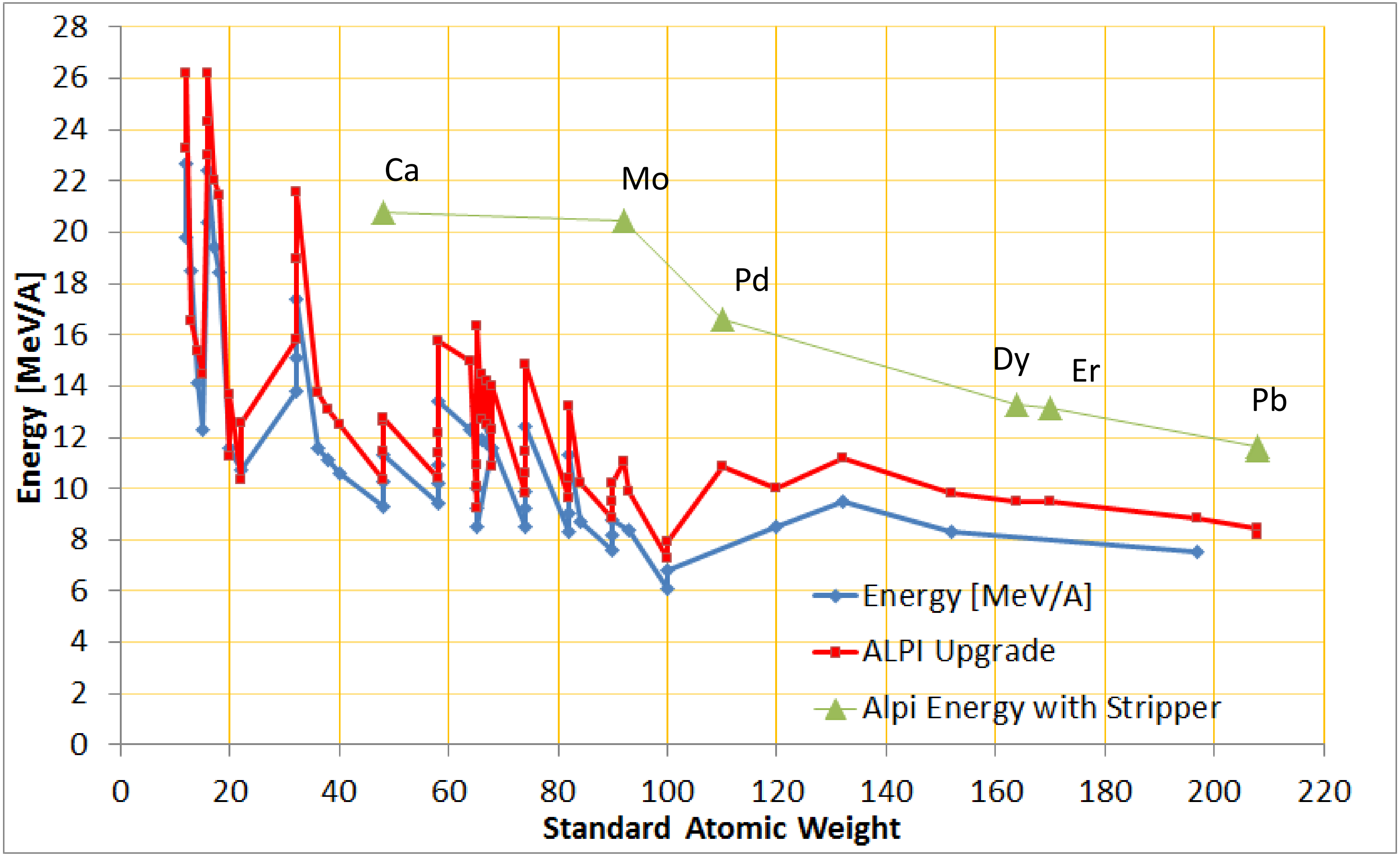

ALPI Upgrade with doublets


ALPI actual performance





Energy upgrade of ALPI for SPES



Status of the SPES Project

Phase α

α **Infrastructures** Executive Design done; construction follows;

α **Safety** report for cyclotron operation approved by Italian safety agencies;

α **Cyclotron** realization by BEST Theratronics on time;

α The **ISOL Target and Ion Source** are under characterization;

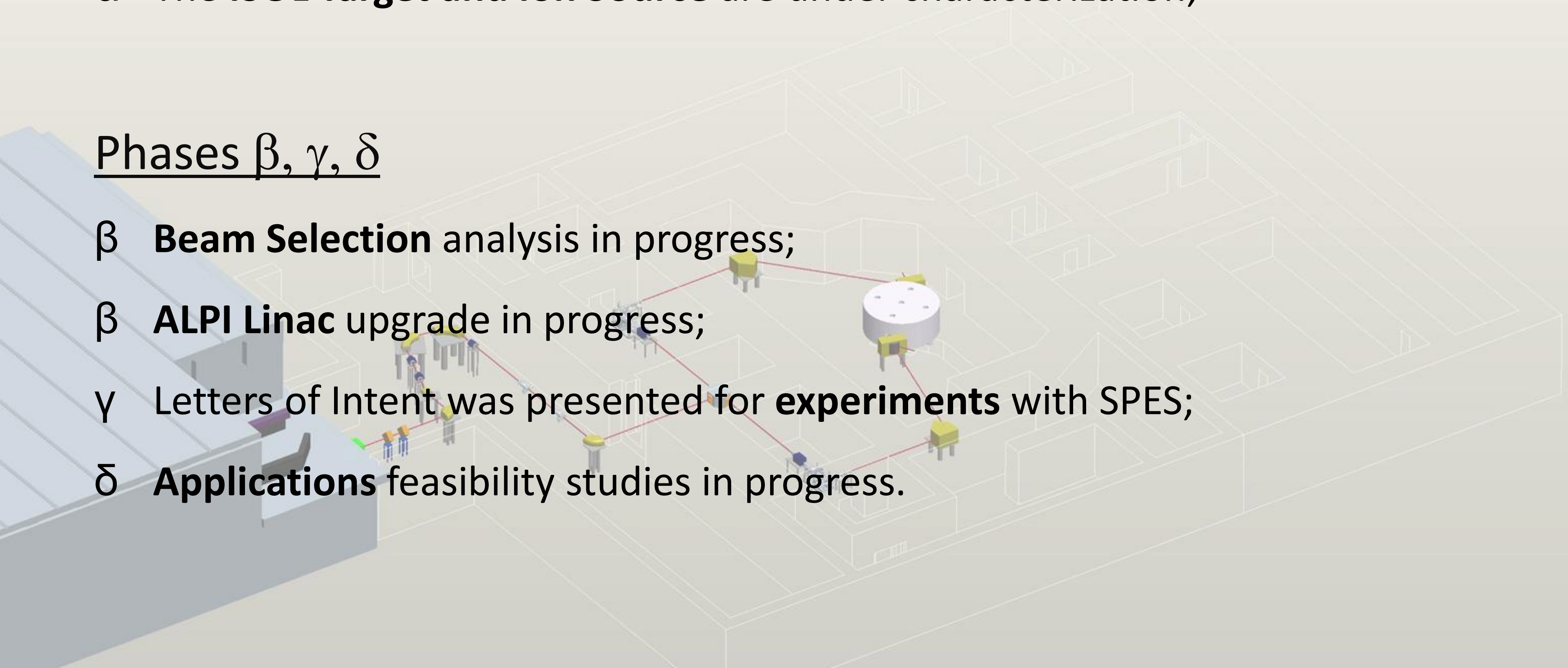
Phases β, γ, δ

β **Beam Selection** analysis in progress;

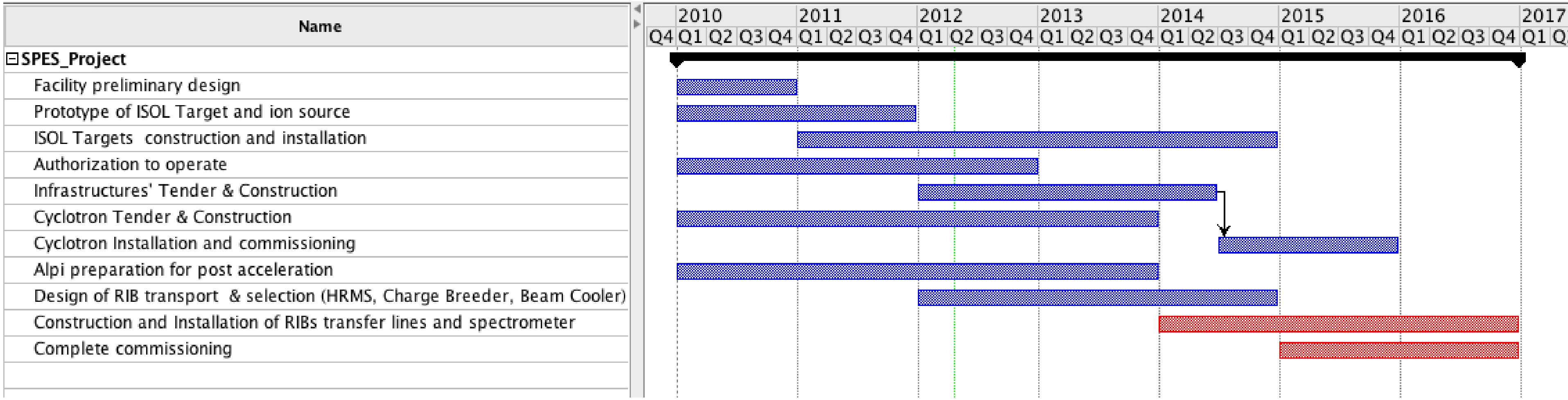
β **ALPI Linac** upgrade in progress;

γ Letters of Intent was presented for **experiments** with SPES;

δ **Applications** feasibility studies in progress.



SPES possible Schedule



Name

⊟ **SPES_Project**
- Facility preliminary design
- Prototype of ISOL Target and ion source
- ISOL Targets construction and installation
- Authorization to operate
- Infrastructures' Tender & Construction
- Cyclotron Tender & Construction
- Cyclotron Installation and commissioning
- Alpi preparation for post acceleration
- Design of RIB transport & selection (HRMS, Charge Breeder, Beam Cooler)
- Construction and Installation of RIBs transfer lines and spectrometer
- Complete commissioning

New Schedule after Infrastructures bid assigned

Conclusion

- The SPES project is an on-going activity.
- The final design for the re-accelerator part is almost ready.
- We “hope” for the assignation of the founds.