The SPES layout, construction and commissioning strategy

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Thanks to SPES Team: G. Prete, G. Bisoffi, E. Fagotti, P. Favaron, A. Andrighetto, A. Pisent, M. Comunian, A. Palmieri, A. Porcellato, D. Zafiropoulos, L. Sarchiapone, J. Esposito, C. Roncolato, L. Ferrari, M. Rossignoli, M. Calderolla, M. Poggi, M. Manzolaro, J. Vasquez, M. Monetti, L. Calabretta, A. Russo, M. Guerzoni

SPES, acronym of *Selective Production of Exotic Species,* is a CW radioactive ion beam facility under construction at LNL INFN in Italy.

Outline

- Functional elements of SPES post-acceleration
- The lay out.
  - New transfer line to experiment operational
  - Transport line from CB to ALPI →main elements under procurement.
  - The new RFQ as new ALPI LINAC injector (mechanical design going on).
- Transport line 1+ design to be frozen soon:
  - Low energy transport and selection;
  - RFQ cooler
  - High Resolution Mass Spectrometer;
- ALPI LINAC for SPES.
- Installation and beam commissioning sequence for the post accelerator.

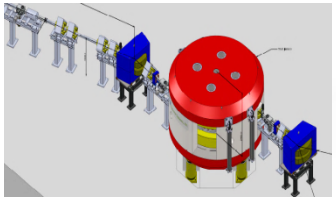
Computational approach

- The post acceleration of SPES requires extremely good magnetic selection, high transmission (precious beam) and very good knwoledge of the position, of amount and location of beam losses
- The approach, computational tools (TRACEWIN, 10^5 macroparticles, accurate field maps..) are almost the same as for high intensity linacs (IFMIF or ESS)
- 3° order matrix transport for separators optimization (GIOS).
- 3D field simulations with COMSOL and OPERA 3D for field map calculation.
- Sistematic error studies with massive computing parallelization….

The ISOL choice for SPES

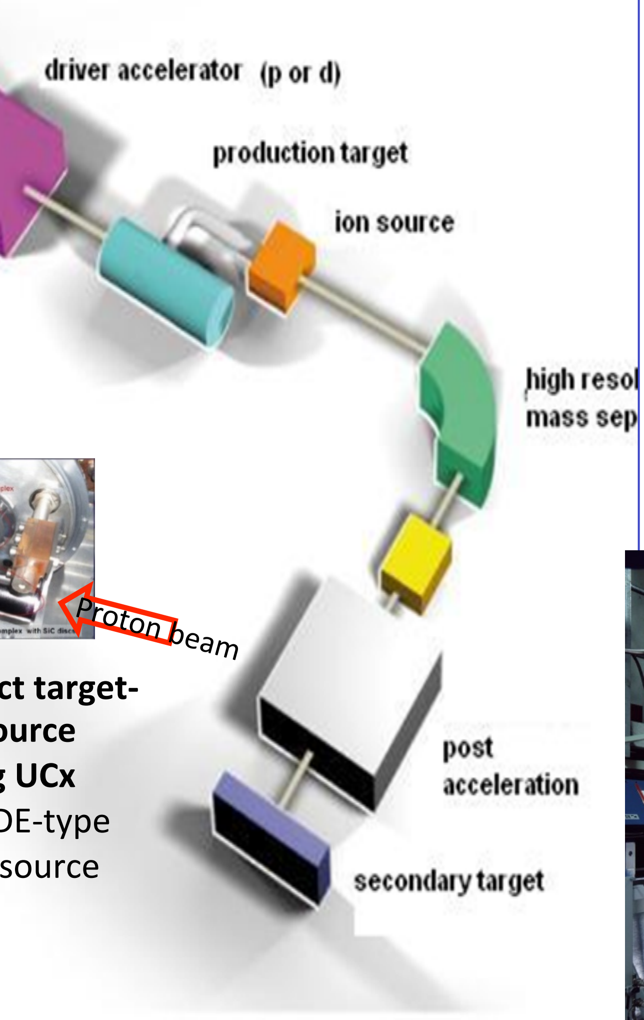
Cyclotron → Proton Driver:

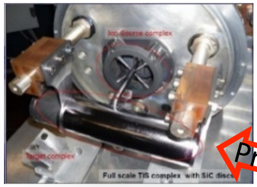
70MeV 0.75 mA 2 exit ports



<u>NEW CONCEPT</u>
direct target
Multi-foil UCx
designed to
reach **10^{13} f/s**
0.2 mA 40 MeV

Define a cost-effective facility in the order of **50 M€**





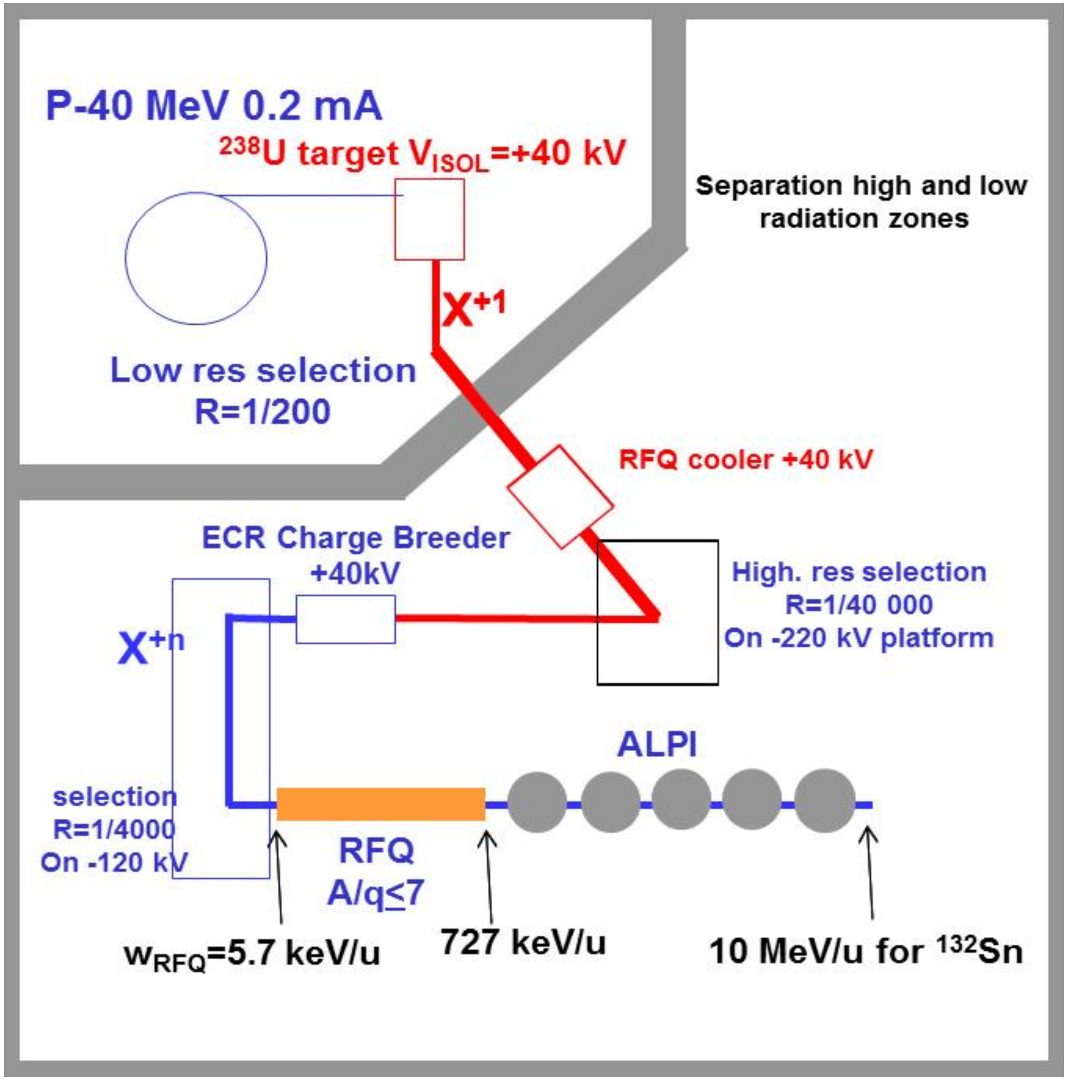
SPES direct target-ion source
30g UCx
ISOLDE-type target/source

ALPI tunnel

Functional scheme

- The use of the continuous beam from the +1 source (LIS, PIS, SIS) maximizes the RNB efficiency but need a CW post accelerator (RFQ and ALPI); this layout also needs a charge breeder chosen to be an ECR that woks in continuous.
- The energy on the transfer lines are determined by the chosen RFQ input energy (w_{RFQ}=5.7 keV/u); namely, all the devices where the beam is approximately stopped (production target, charge breeder and RFQ cooler) lay at a voltage:

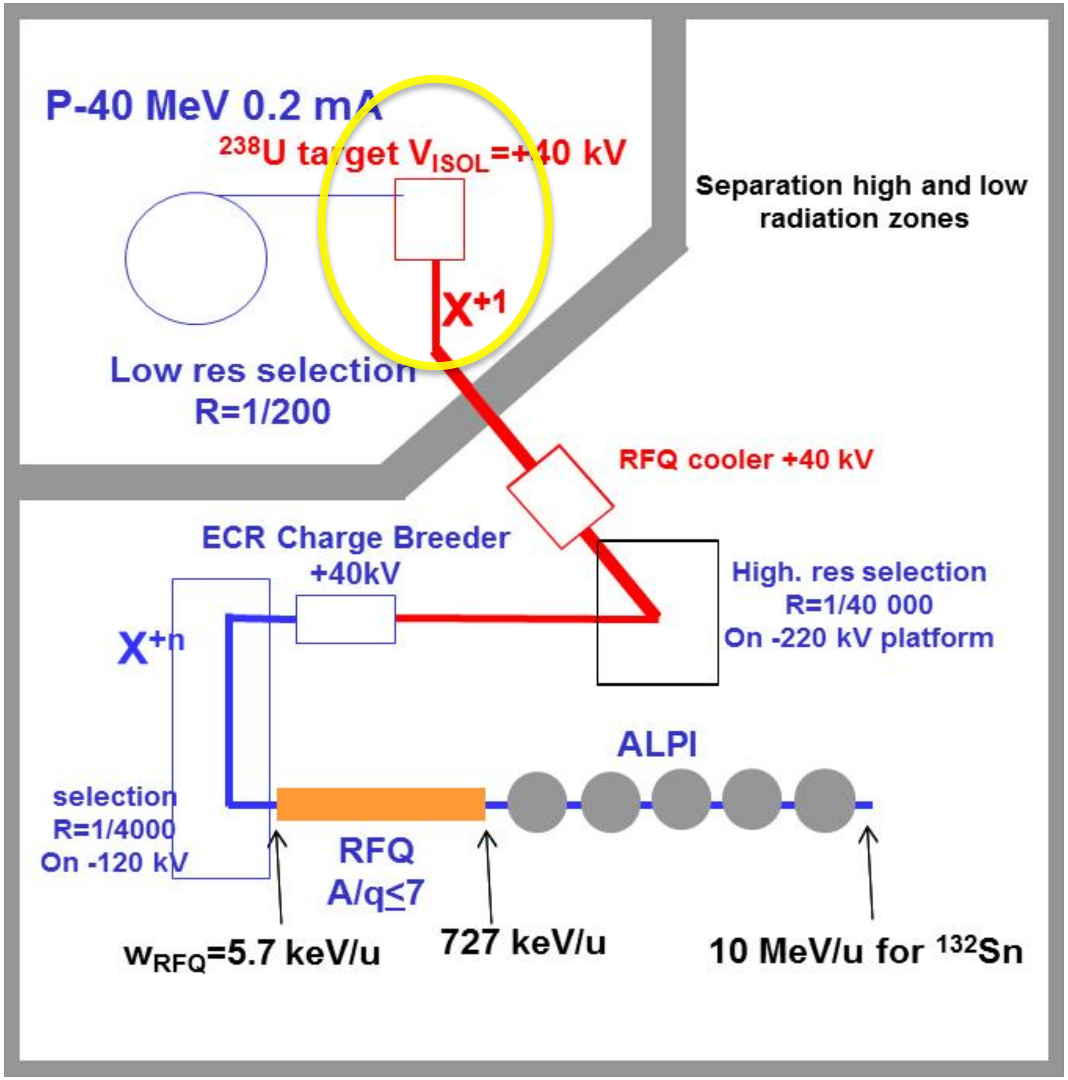
$$eV = (A/q) w_{RFQ}$$



Functional scheme

- The beam preparation scheme satisfies various requirements:

1. the zone with worst radiation protection issues is reduced by means of the first isobar selection (resolution R=1/200).



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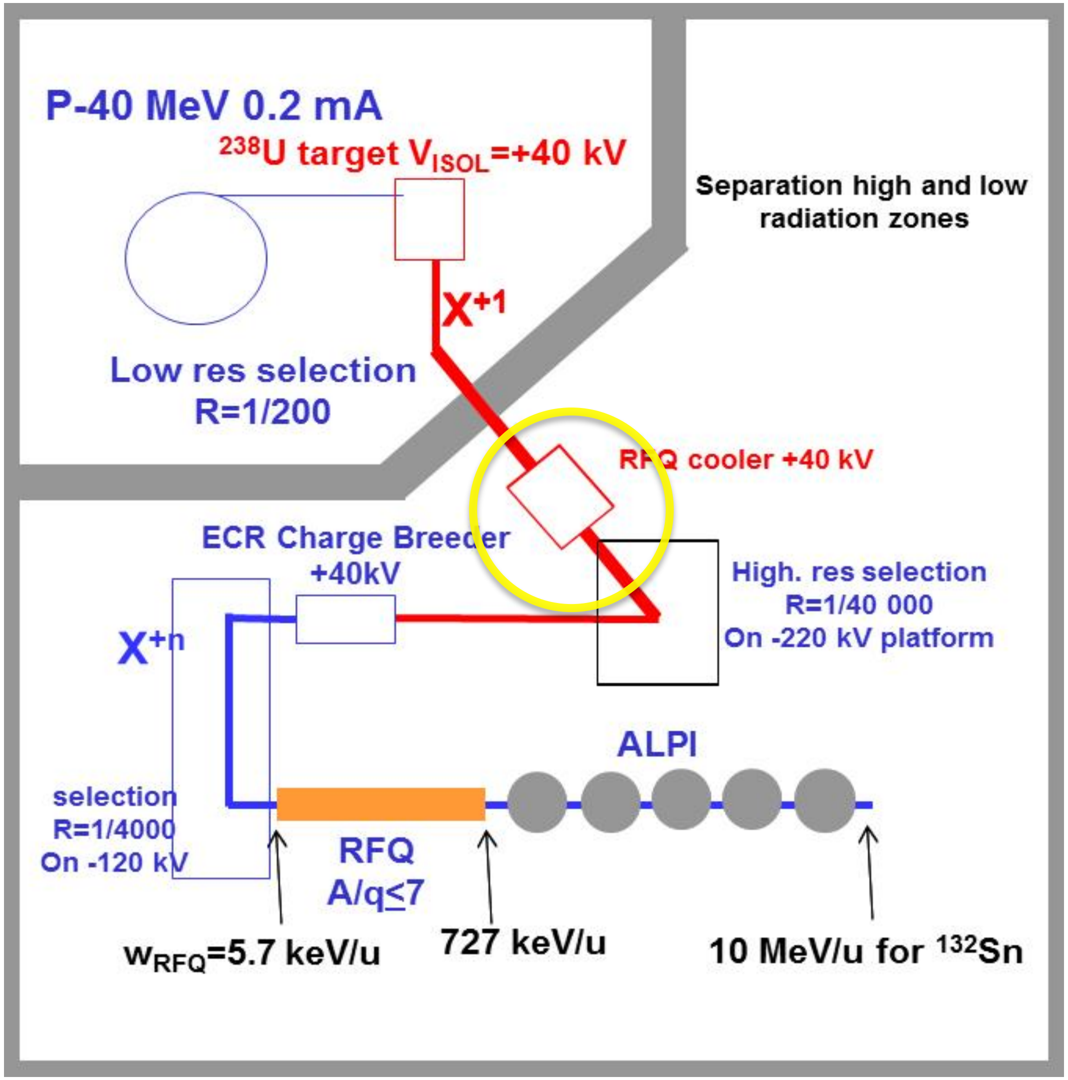

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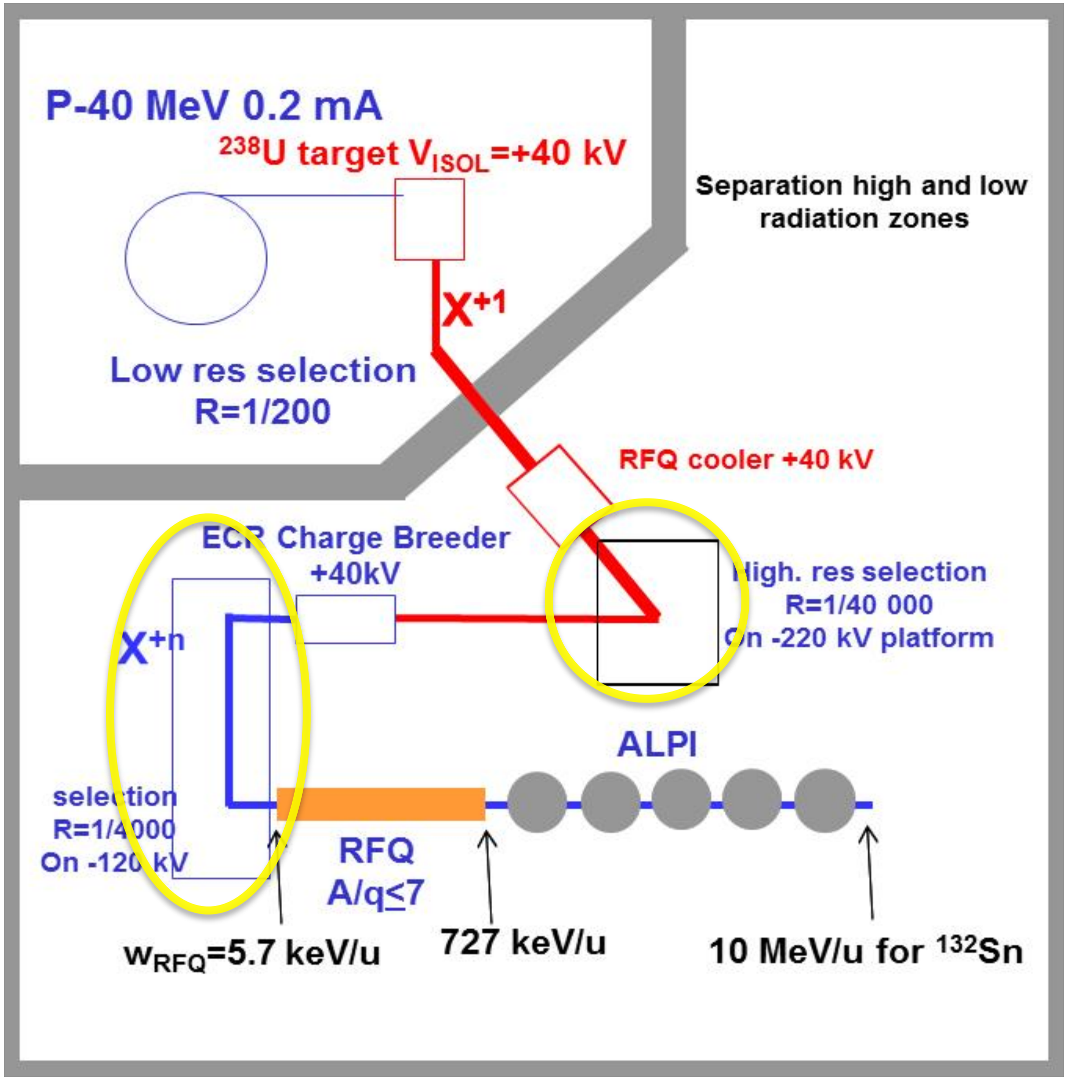

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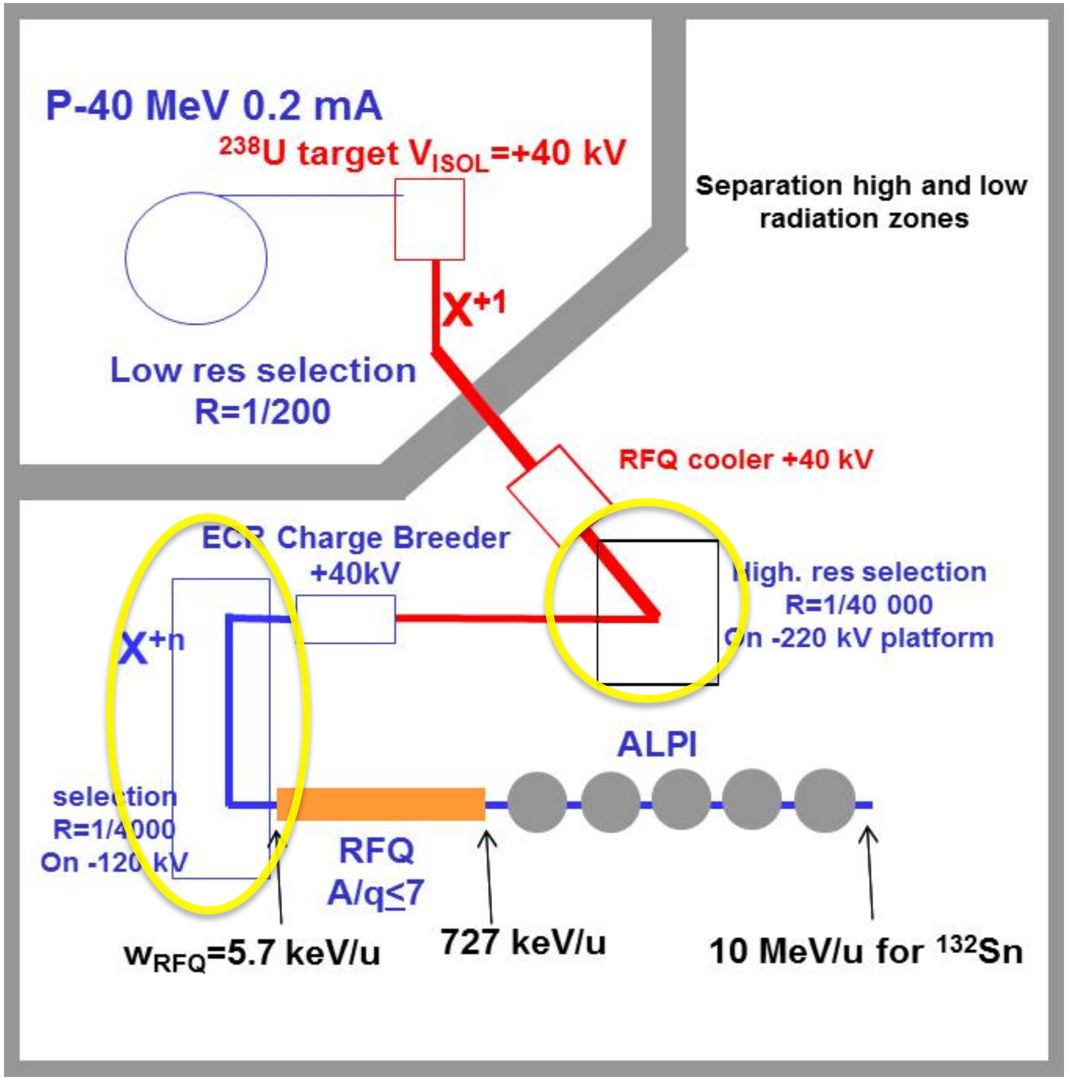

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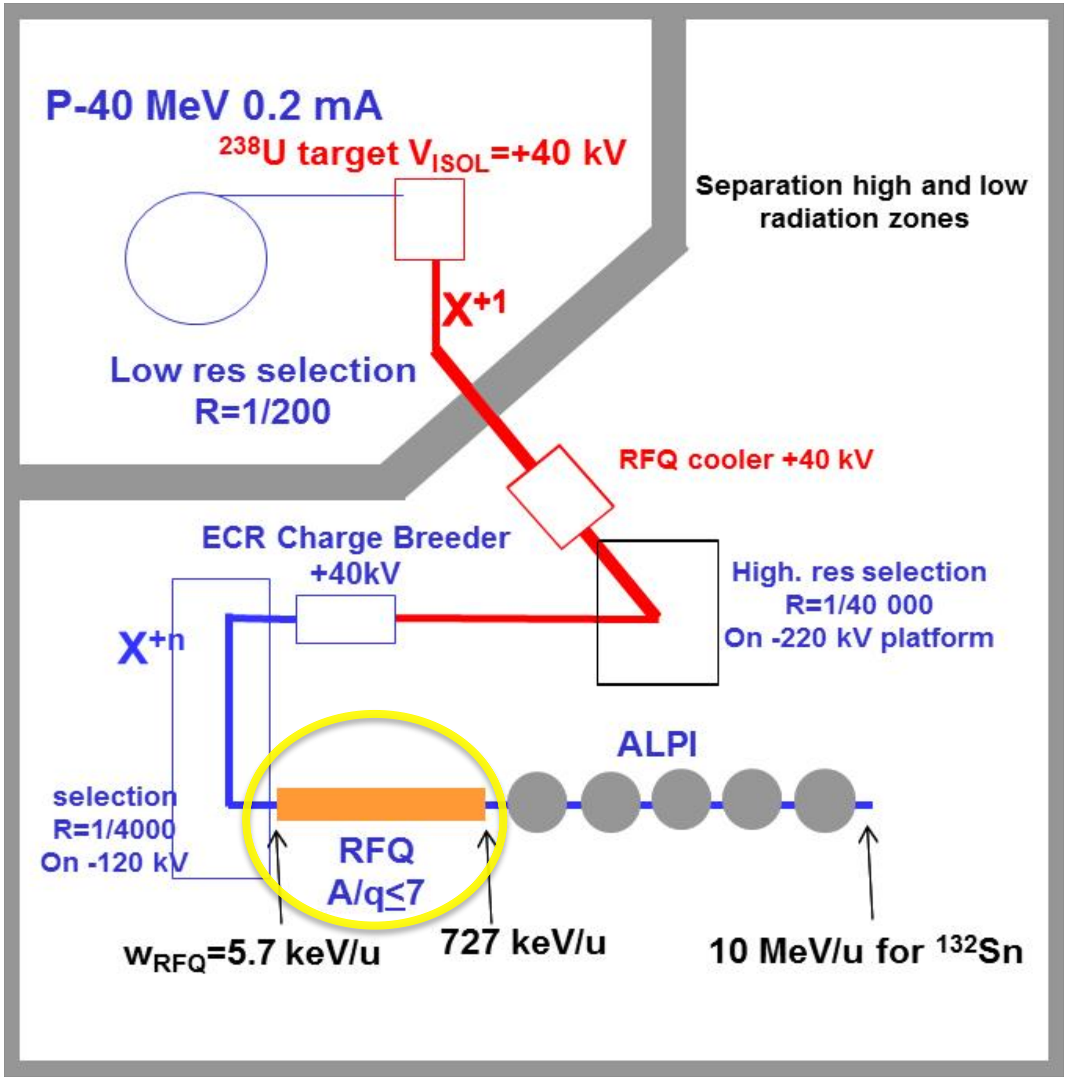

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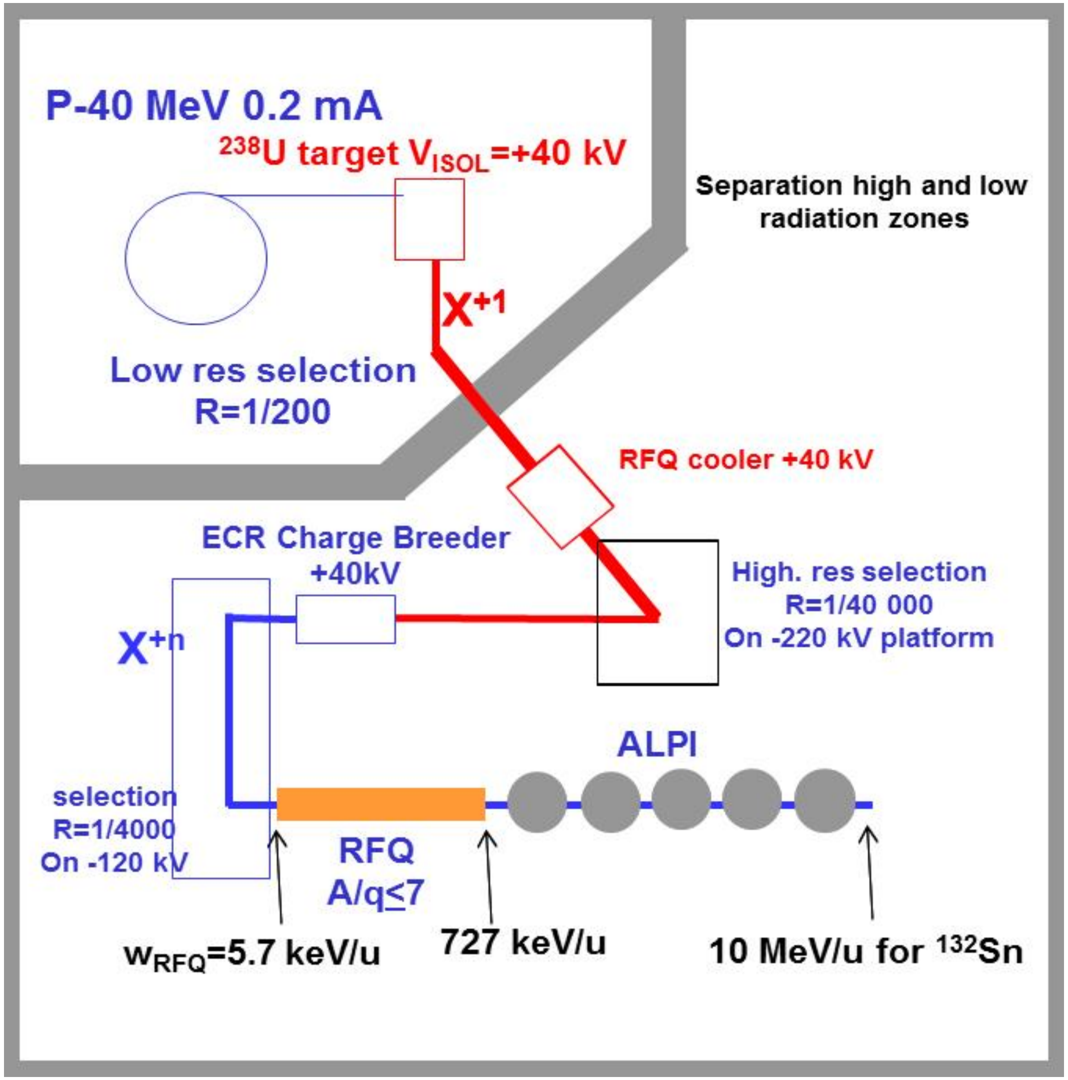
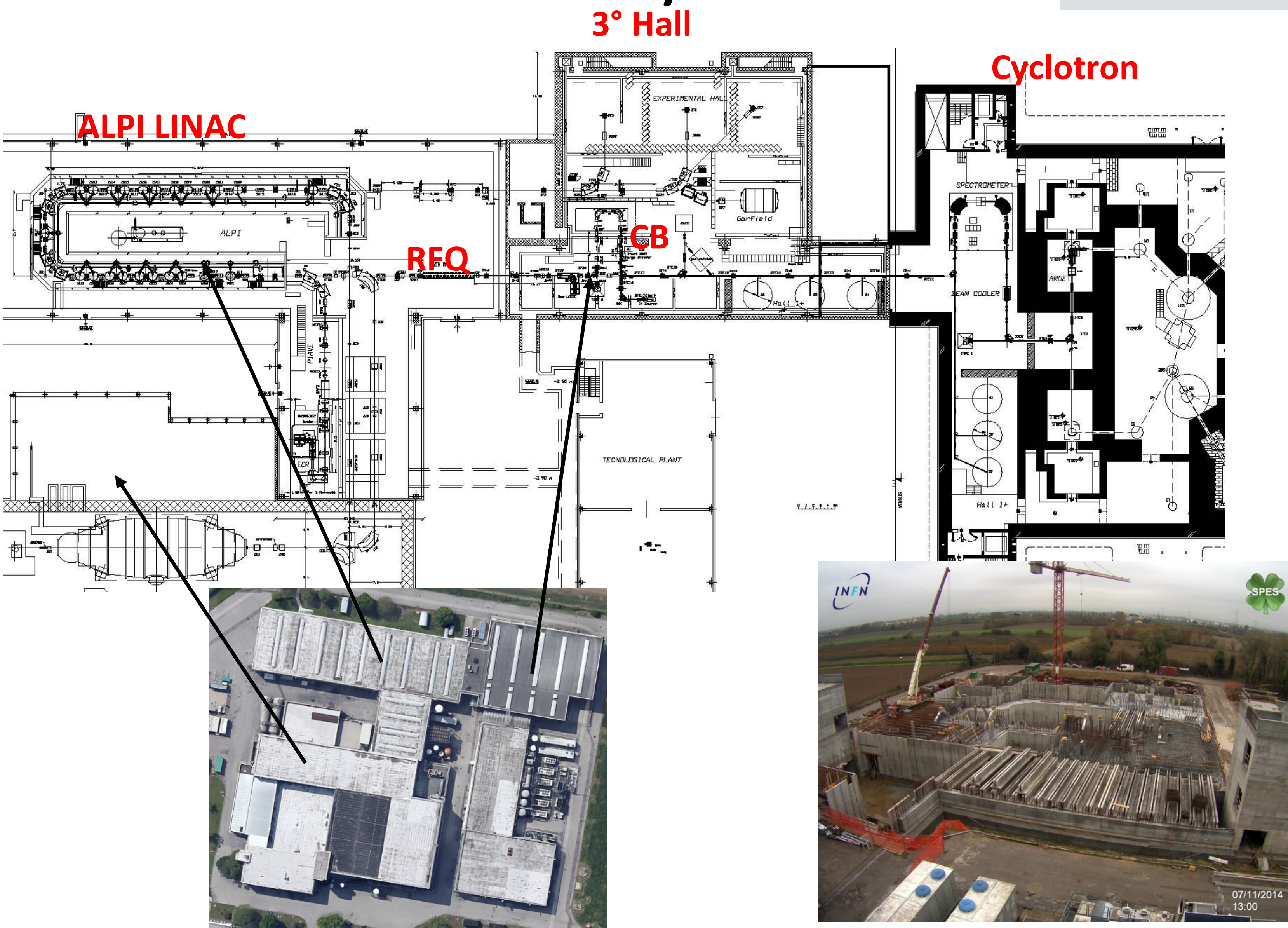
6. An external 5 MHz buncher before the RFQ will be available for specific experiments (at the price of about 50% beam transmission).
7. The dispersion function is carefully managed in the various transport lines; where possible the transport is achromatic, otherwise the dispersion is kept low (in particular at RFQ input D=0, D' is about 50 rad).



SPES Layout


3° Hall
Cyclotron
ALPI LINAC
RFQ
CB
EXPERIMENTAL HALL
ALPI
Garfield
SPECTROMETER
BEAM COOLER
Hall 1+
PIAVE
ECR
TECNOLOGICAL PLANT
INFN
SPES
07/11/2014
13:00

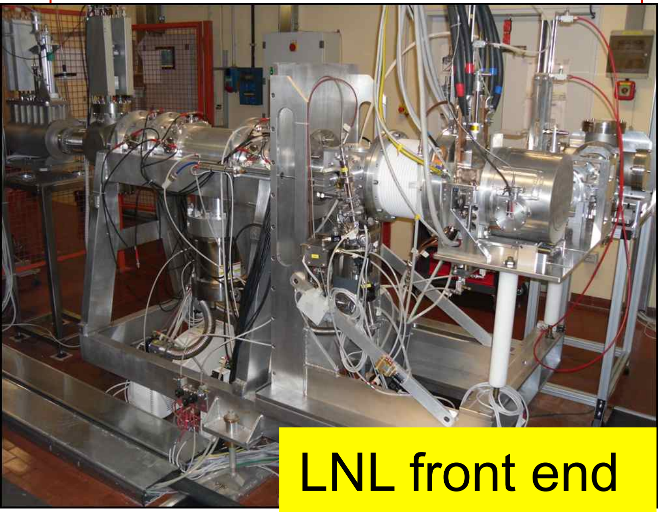
Key technologies and choices

- Vacuum (long lines <10-8 mbar), reliable control of residual gasses.
- Brazing (RFQ, bunchers….)
- Optics elements:
  - Electrostatic quads when possible (but we have to rescale with A/q)
  - Magnetic dipoles for momentum analysis and dispersion control
  - Magnetic lenses (solenoids and quads) for the line MMRMS RFQ with possible energy upgrade (low energy high charge state)
- Beam instrumentation for pilot beam, for low intensity (10-4 pps) and few tape station for species characterization

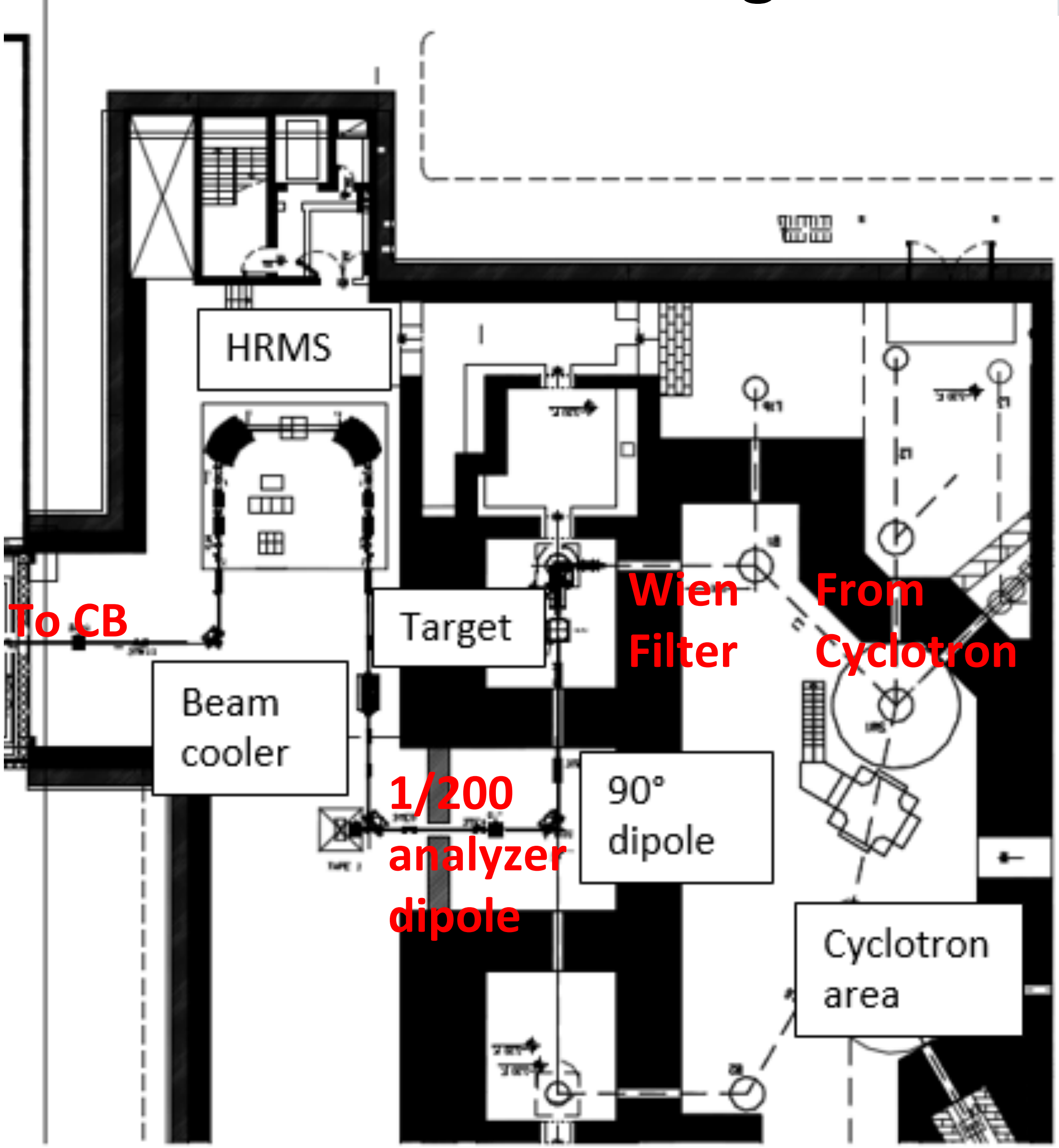
SPES Layout: zoom on new building

NEWS OF 1+ LINES

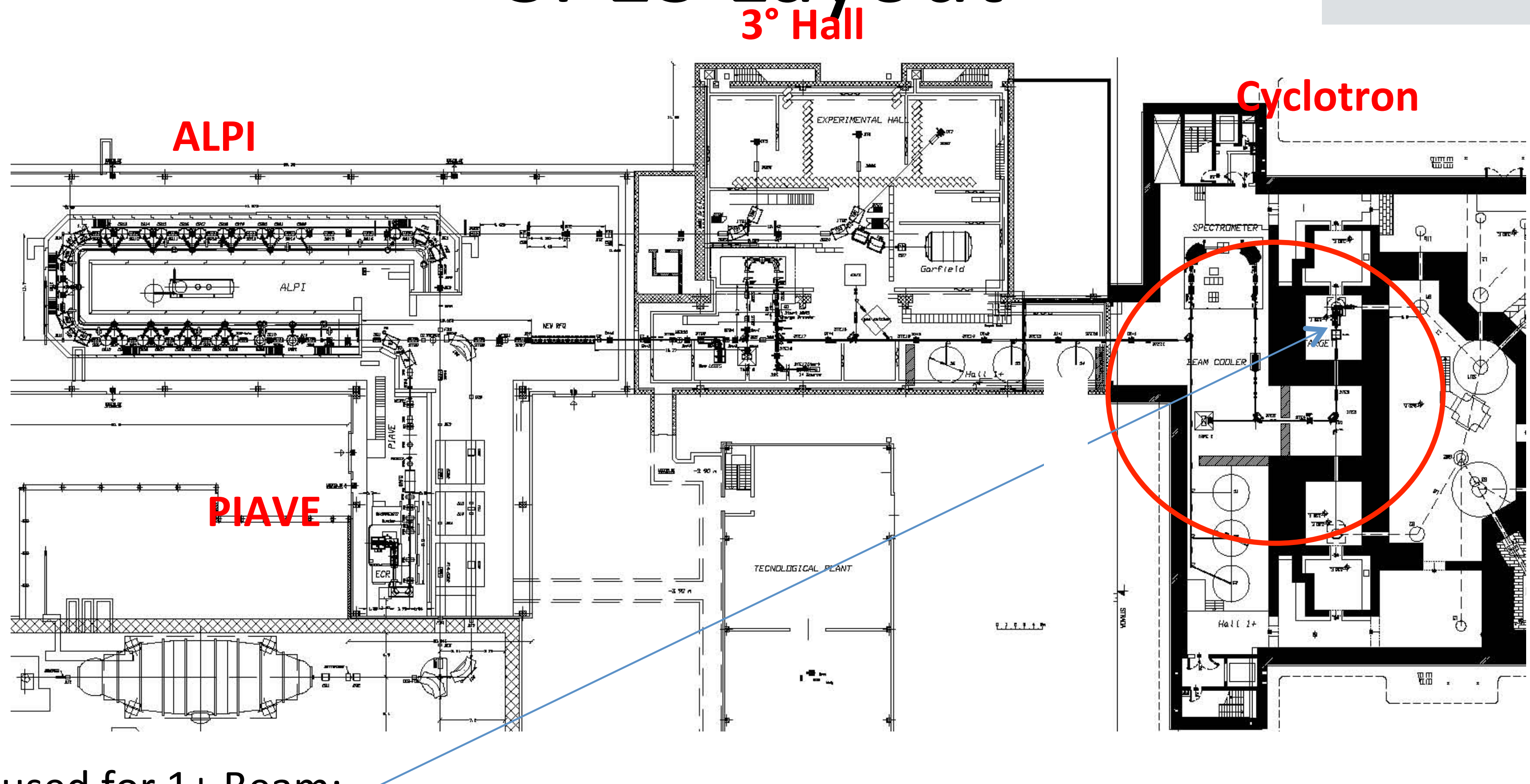
- Usage of short electrostatic triplets (for little areas)
- 1/200 via D1 dipole. Isotopes from isobars separation
- HRMS to CB
- Wien Filter as a pre-mass separator.
- Usage of dipoles for bending magnets in order to control the dispersion.



LNL front end

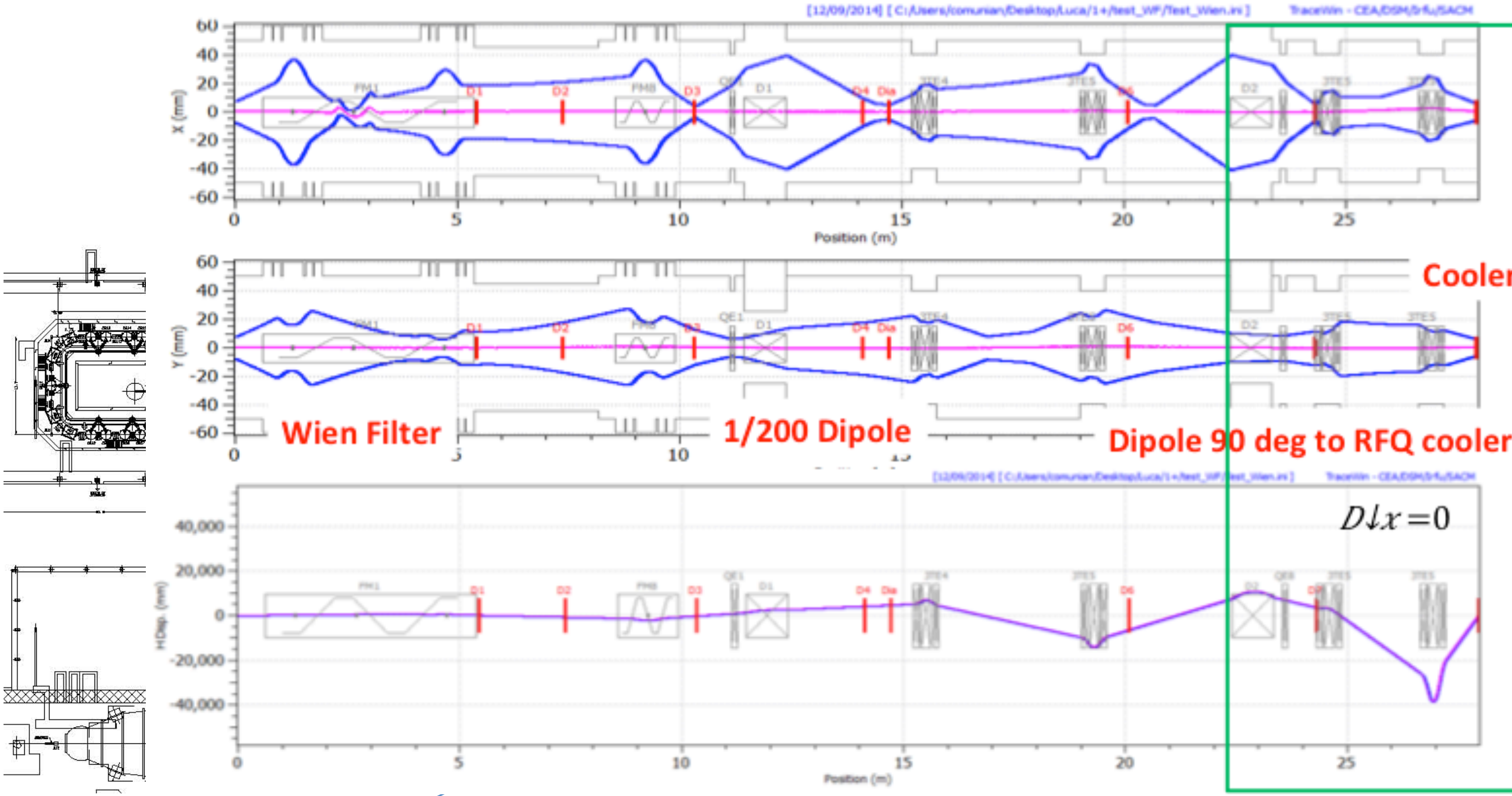


SPES Layout



Input used for 1+ Beam:

- Mass 132 A 1+
- Voltage 40 kV
- RMS norm. Emittance 0.007 mmmrad Geom=8.6 mmmrad, Geom 99%=70 mmmrad, $\Delta E = \pm 20$ eV. Brho=0.331 Tm
- CEA TraceWin code
- Fields Maps for long Electrostatic quads and Wien Filter. Short triplets with hard edges.



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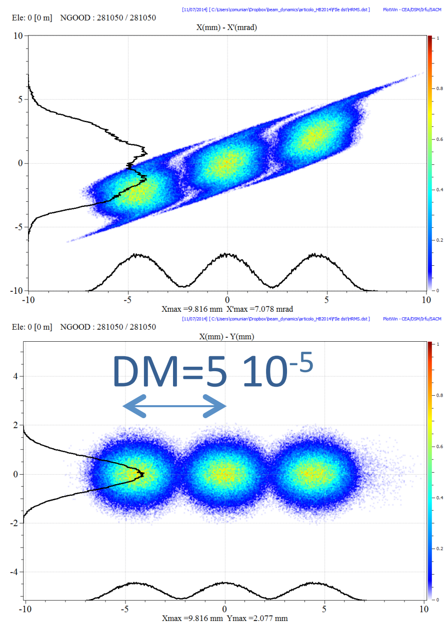
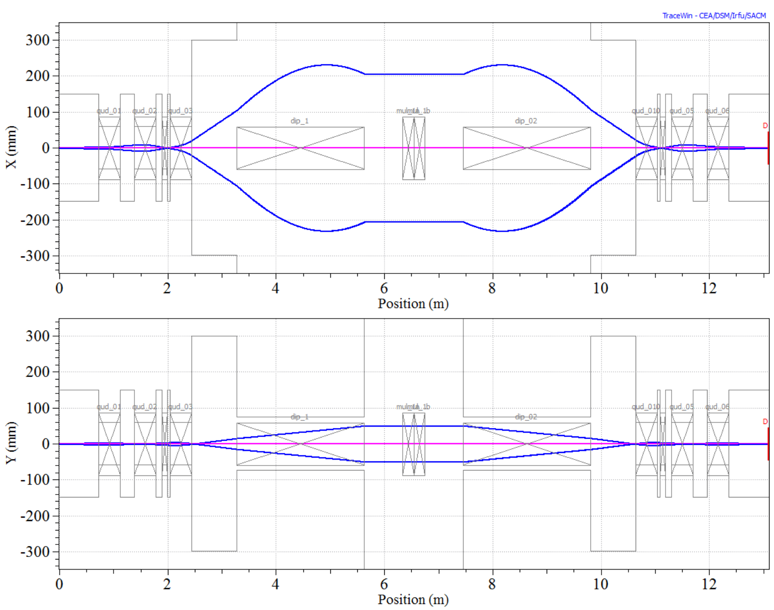
HRMS physics design

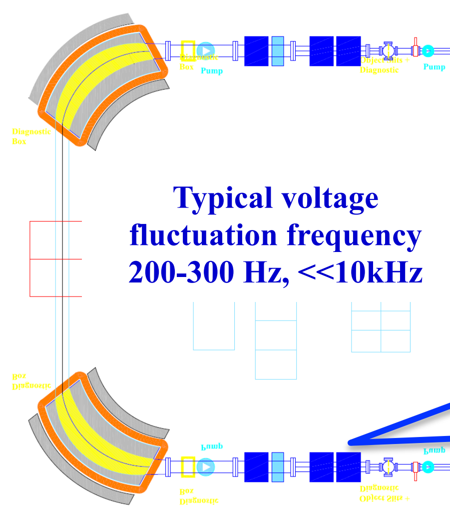


preliminary analysis (LNS-LNL)
Input parameters:
- Energy= 260 KeV
- $\Delta\theta$=4 mrad
- **ΔE= ± 5 eV**
- **Emittance99%=5.7π mm mrad**

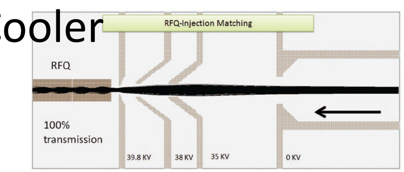
Linear Design Mass resolution: 1/60000
(eng. design: 1/25000)

Ispired to CARIBU-HRMS, ANL (USA)



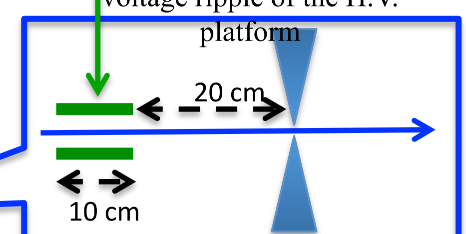


Cooler



Typical voltage fluctuation frequency 200-300 Hz, <<10kHz

Electrostatic Plates to correct the voltage ripple of the H.V. platform



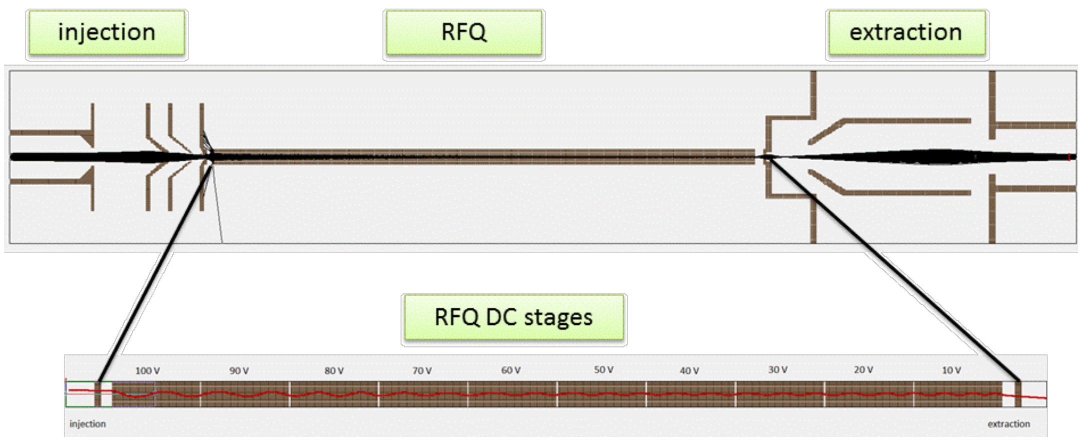
Plates gap 6 cm,
± 750 V to correct
± 5 V platform ripple

L. Calabretta, A. Russo

SPES RFQ Beam Cooler parameters

Mass Range	9-200 amu
Transv. Emitt. Injected beam (norm rms)	0.007 π. mm.mrad
Emittance Reduction factor	10 (max)
Buffer gas	He @ 300 K
Beam Intensity	50-100 nA → x10^{11} pps
Energy spread of extracted beam	≈ 1 eV
RF Voltage range	0.5 – 2.5 kV (1 kV at *q*(Mathieu)*=0.25)
RF Frequency range	1 -30 MHz (3.5 – 15 MHz at *q**=0.25)
RFQ gap radius (r_o)	4 mm
RFQ Length	700 mm
Pressure Buffer Gas (He) range	0.1 – 2.5 Pa
Average energy during the cooling	<10 eV

(*) max transmission efficiency (~80%)



M. Maggiore

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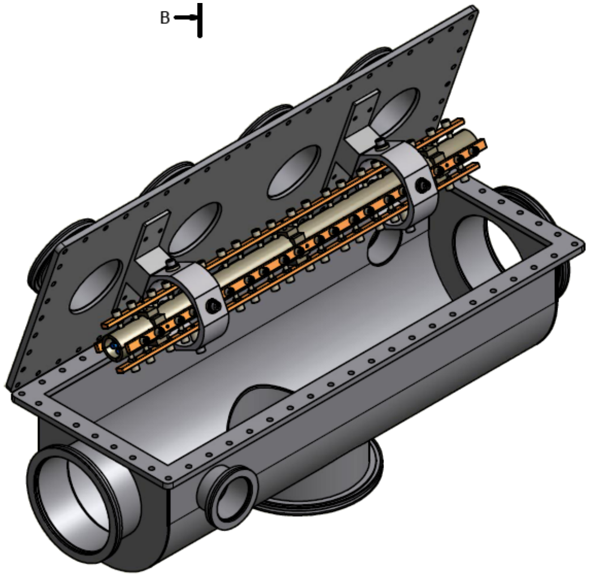
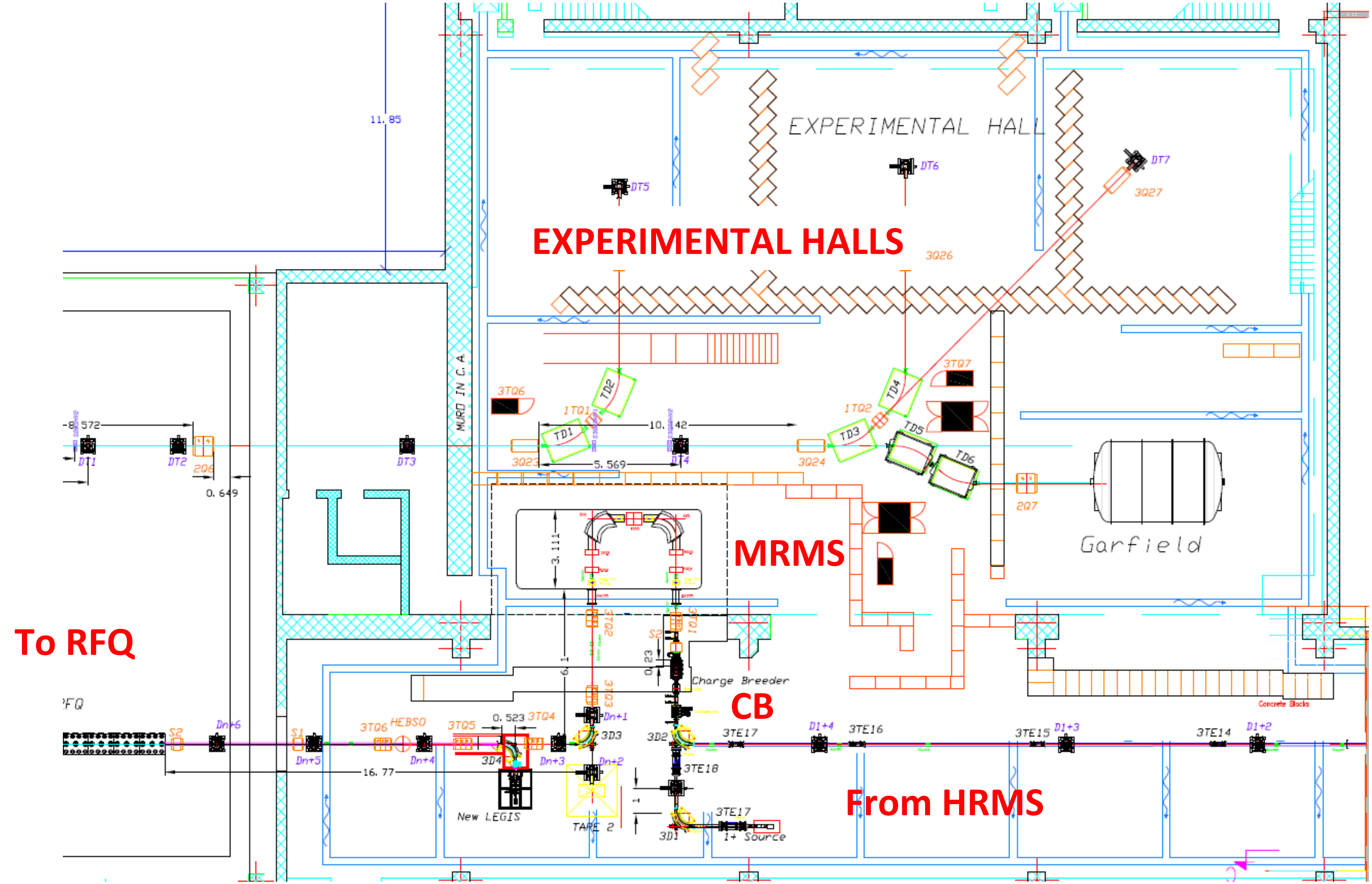


- Components are being finalized and next year (2015) all things should be carried out.
- Waiting for assignment of dedicated area (end of Dec 2014) for starting the assembly and testing of the whole equipment.
- Preliminary test of the RFQ device at Milan University (ELTRAP facility) expected for next year.

M. Maggiore

SPES Layout: zoom on 3° hall



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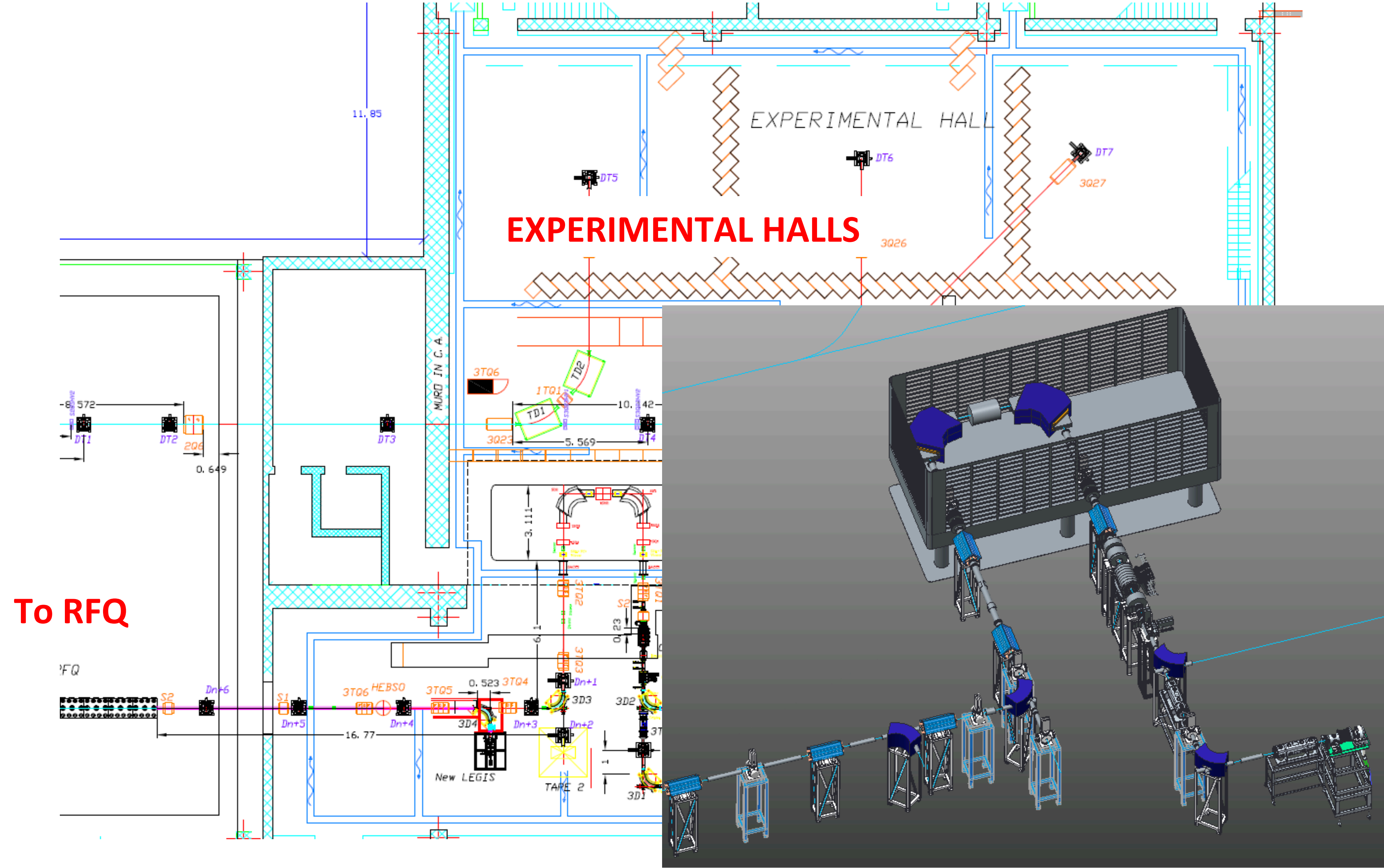
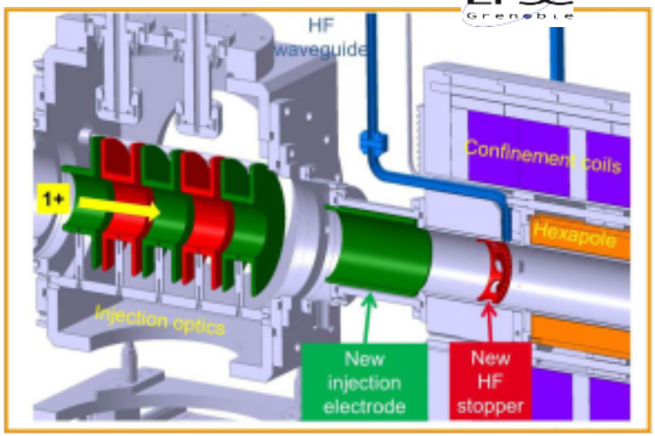


ECR-type Charge Breeder



- CB based on ECR technique
- Developed by LPSC (LEA-COLLIGA coll.)
- Design 2013, construction 2014

Features: 3 coils for axial magnetic field; permanent magnet 6-pole for the radial field (1.2 T at injection, 0.42 T minimum and 0.82T at extraction). Microwaves at ~14.5 GHz and a maximum power of 600 W; operation at 18 GHz also possible.

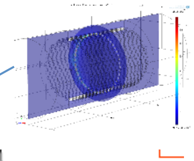
Mass Range			ION	Q	Efficiency [%]	Year Data Source	(M/q)_min	(M/q)_max
		138	Xe	20+ (21+)	10,9 (6,2)	2012 (2005)	6.57	6.90
130	132	134	Sn	21+	6	2005	6.19	6.38
		98	Sr	14+	3.5	2005	7	7
		94	Kr	16+(18+)	12(8,5)	2013	5.22	5.88
90	………..	99	Y	14+	3.3	2002	6.43	7.07
74	………..	80	Zn	10+	2.8	2002	7.40	8.00
	81	82	Ga	11+	2	2002	7.36	7.45
90	91	92	Rb	17+	7.50	2013	5.29	5.41
		34	Ar	8+(9+)	16,2(11,5)	2012 (2013)	3.78	4.25

A. Galatà

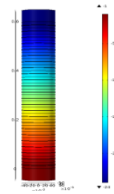
CB and Medium Resolution Mass Spectrometer (1/100)

Error study performed

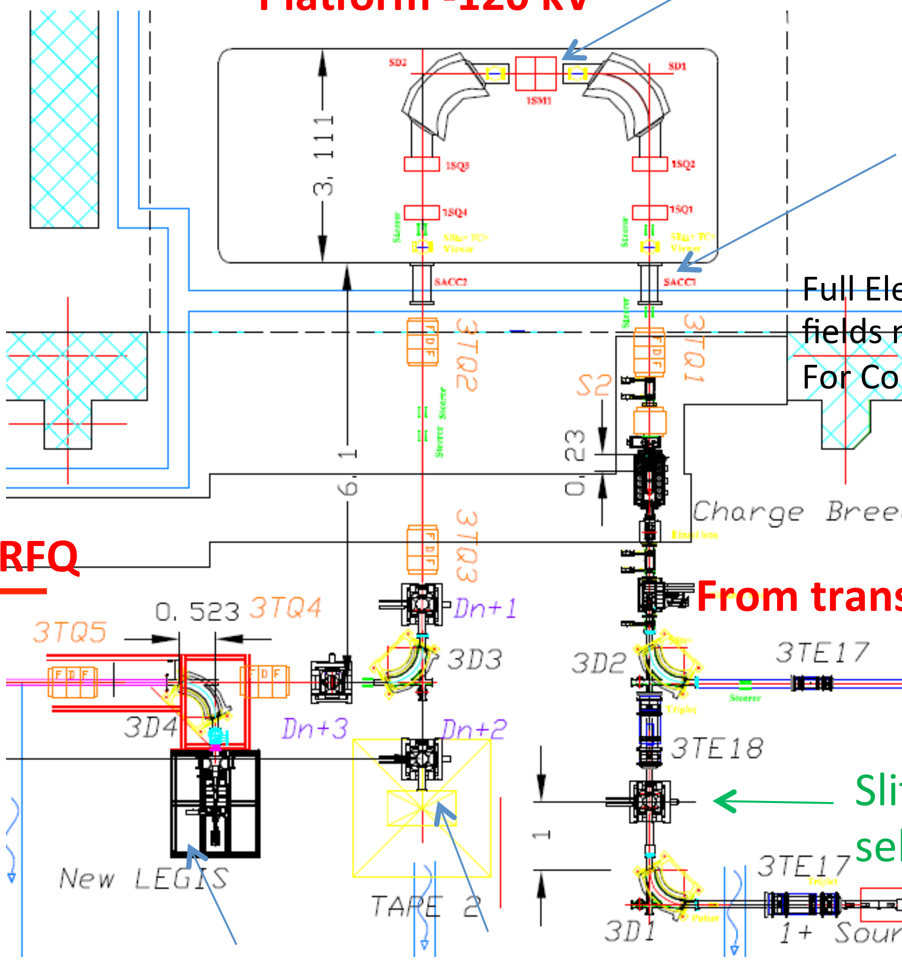
Platform -120 kV



Full Electrical fields maps for Multipoles



Full Electrical fields maps For Columns



RFQ

From transport line

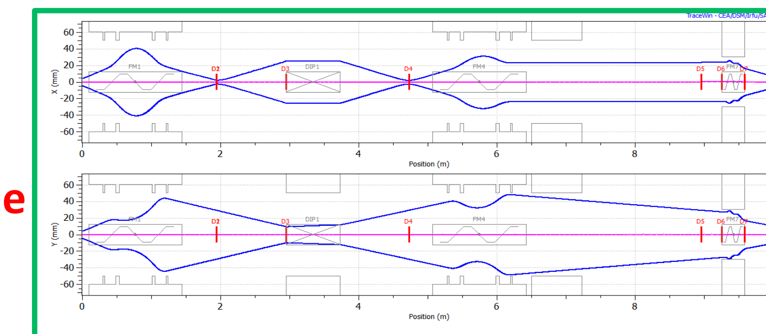
Slits for beam selection, 1/166 sep

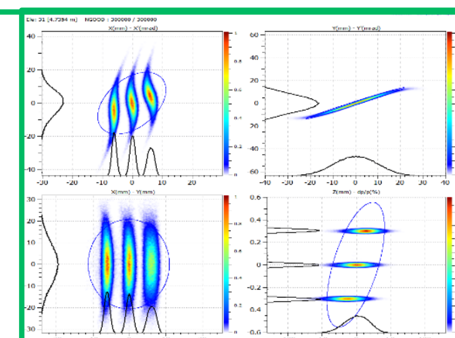
1+ Source for CB tests

Future Stable Source for ALPI

RIB Diagnostic with TAPE SYSTEM

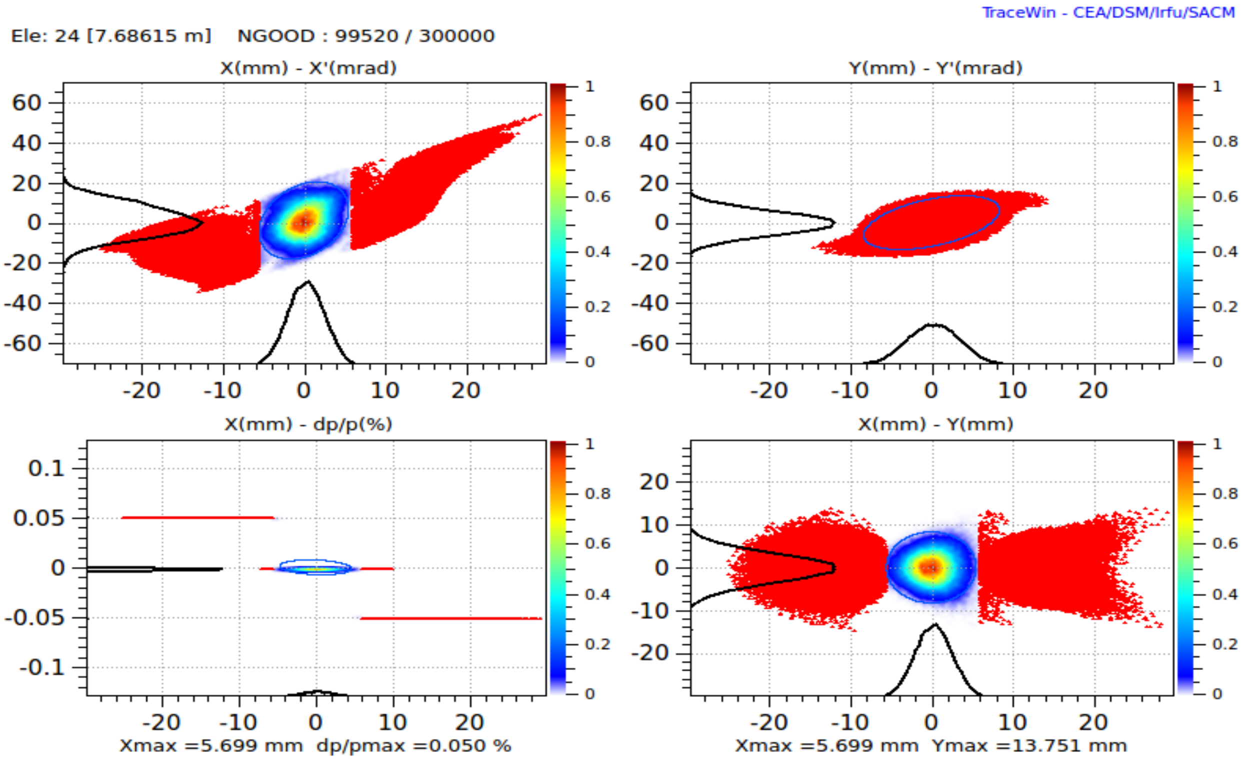
Input: 0.1 rms transverse norm., 28.44 rms geo. Tot geo emittance 222.7 pi mm mrad @ 40 kV. A/q=7.
Input Twiss parameters from simulation of CB. Spread of ±15 eV Brho = 0.076 Tm





A. Russo L. Bellan

Beam optics of MRMS



Dipoles

R=750 mm

$\Phi=90^0$

Edge=33.35 °

B=0.2 T

Gap=± 35 mm

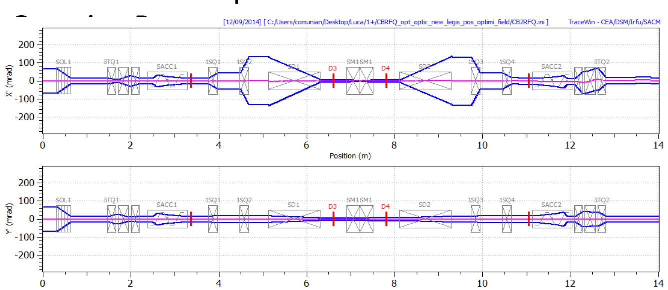
R_{sex}=1474 and 828 mm

Field homogeneity 10^{-4}

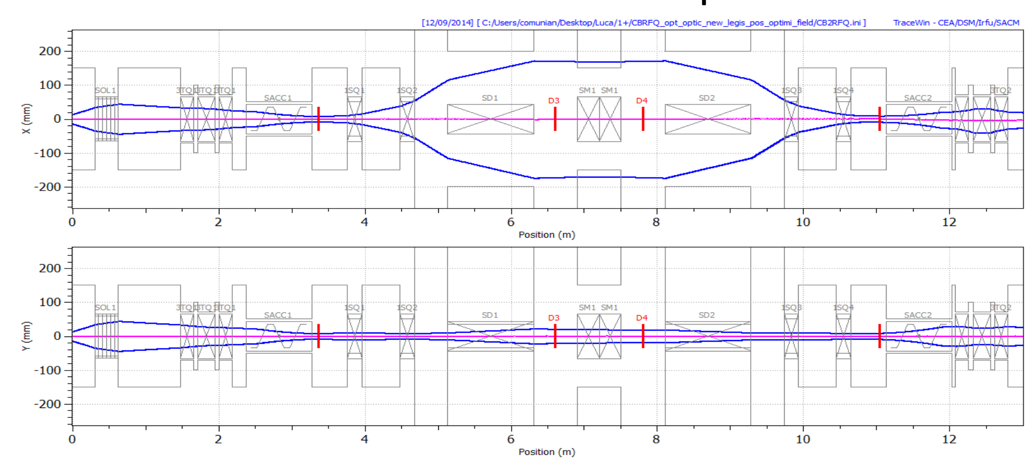
(in ± 180 mm hor, ± 35 mm ver)

Electrostatic multipoles elements
In the center (bore beam diameter=300 mm)

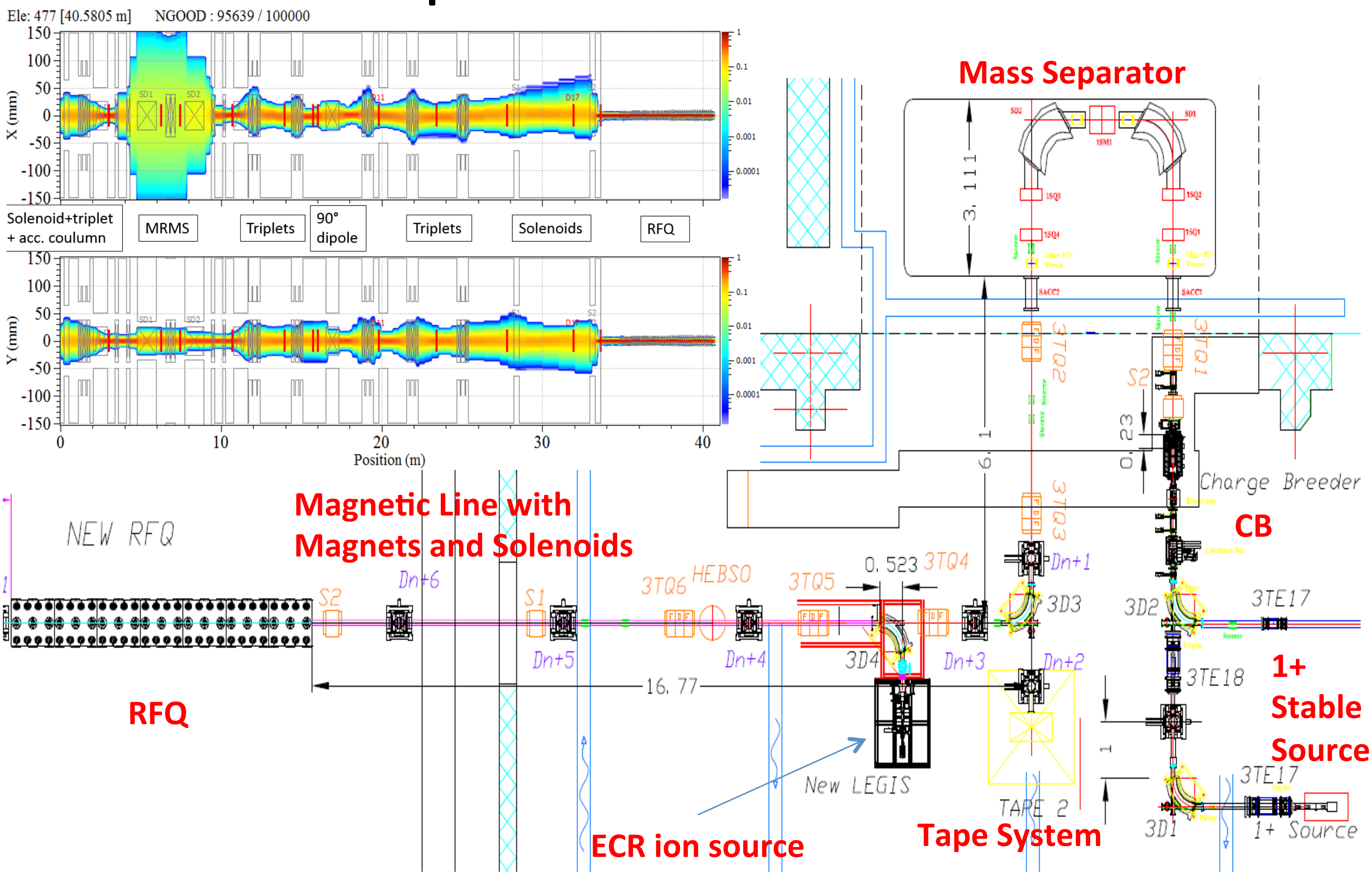
In figure are reported 3 beams, with the same emittance, injected separated by **1/1000** in mass.
After the MRMS the beams are fully separated in X.
RMS Tr. Norm. Input Emittance 0.1 mmmrad.



Beam Envelopes



Transport Line to SPES RFQ



Beam instrumentation

- Beam line to be built next: profiles (harps), slits, emittance, FC.
- Low intensity diagnostics (in the line and in ALPI).
- Gamma (tape system) characterization at specific locations after separators: LRMS, HRMS, MRMS.

Specs of the elements on CB-ALPI line

Comment	nome	slits	Faraday cup	profila tore	emittanc emeter	timing	X_max [mm]	Y_max[mm]	monitor range X,Y mm
MMRMS object	Dn-1						9	9	±16
MMRMS image	Dn+0						13,3	14	±10
MMRMS emittance	Dn+1						18,8	41	±35
tape system spot	Dn+2						17,3	21	±23
Input ALPI line	Dn+3						33	23	±20
pre-buncher	Dn+4						36,2	30	±30
pre-solenoids	Dn+5						34,2	45,8	±35
pre-RFQ	Dn+6						66	51	±40
Per RFQ comm.	Diagnostic plate (temporary)						5,9	5,1	±10

M. Poggi

SPES RFQ

Parameter (units)	Design Value
Operational mode	CW
Frequency (MHz)	**80.00**
Injection Energy (keV/u)	5.7 (β=0.0035)
Output Energy (keV/u)	727 (β=0.0395)
RF power dissipation (kW)	100

Table 2: RFQ design parameters

Parameter (units)	Design
Inter-vane voltage V (kV, A/q=7)	63.8 – 85.84
Vane length L (m)	6.95
Average radius R_0 (mm)	5.33 – 6.788
Vane radius ρ to average radius ratio	0.76
Modulation factor m	1.0 – 3.18
Min small aperture a (mm)	2.45
Total number of cells	321
Synchronous phase (deg.)	-90 – -20
Focusing strength B	4.7 – 4
Peak field (Kilpatrick units)	1.74
Transmission (%)	95
Input Tr. RMS emittance (mmmrad)	0.1
Output Long. RMS emittance (mmmrad) / (keVns/u)/(keVdeg/u)	0.055 / 0.15 / 4.35

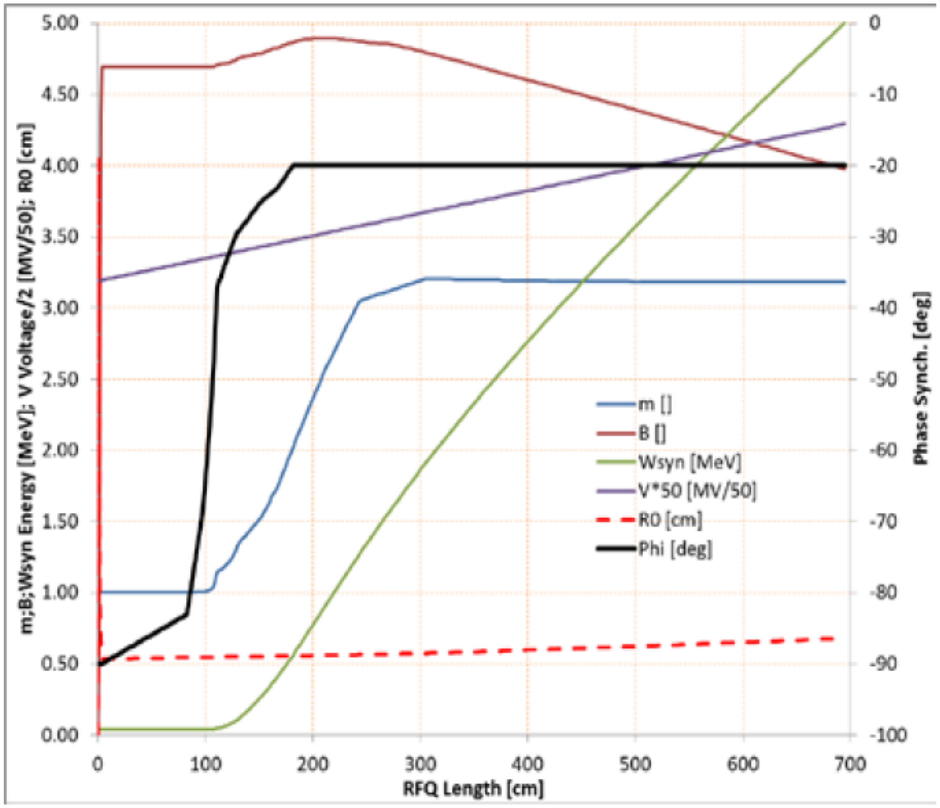
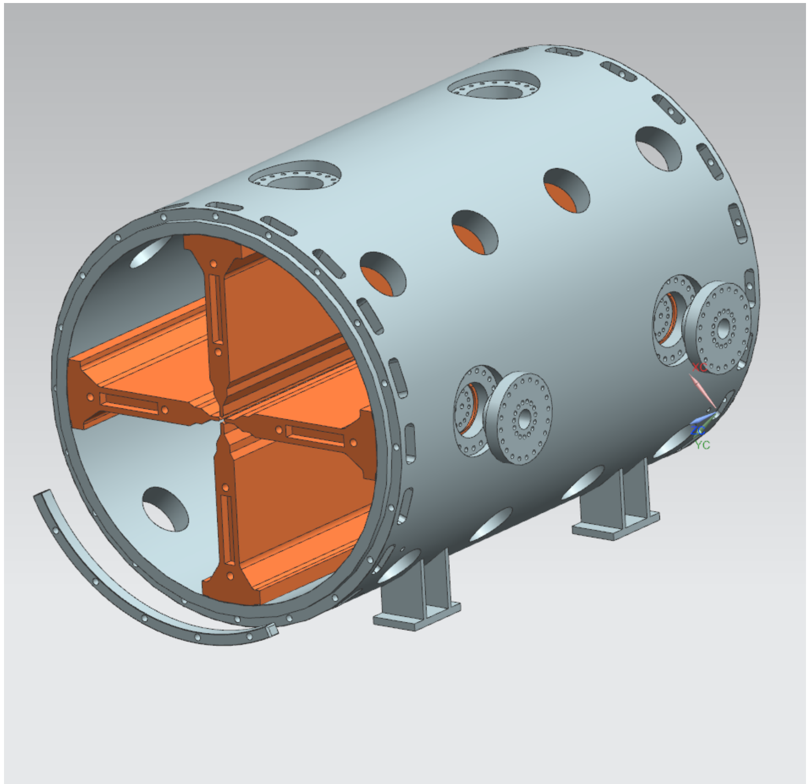
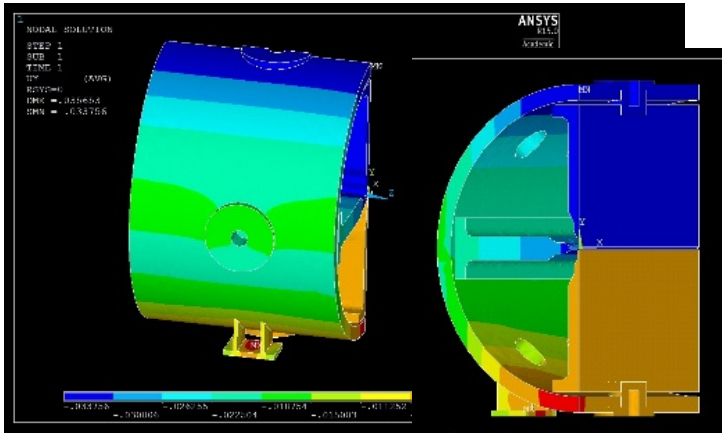


Figure 1: The main RFQ parameters vs. length.

RFQ Mechanical concept

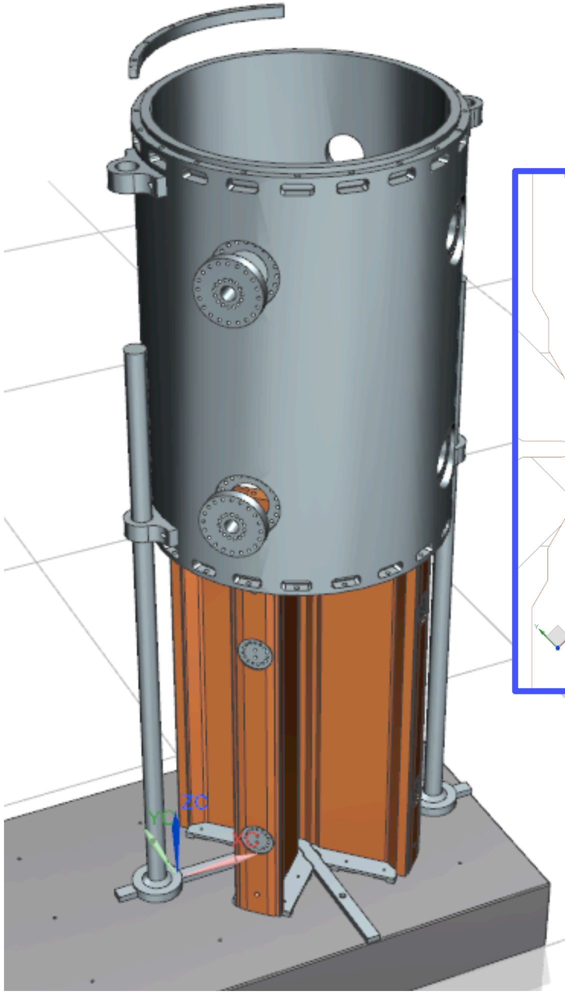


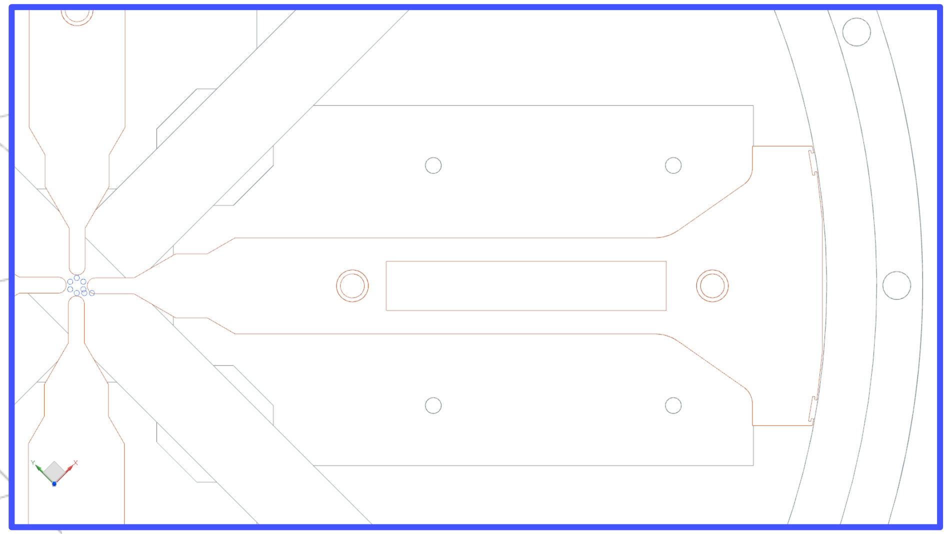


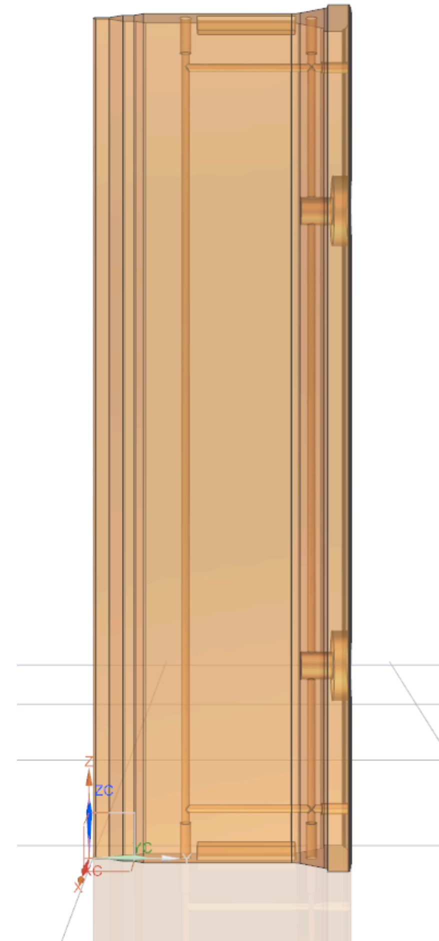
Bolted electrodes, copper plated 304L tank, metallic circular joints, brazing of electrodes and other components before assembly

Tank length 1200 mm, inner radius 375 mm, 40 mm thickness

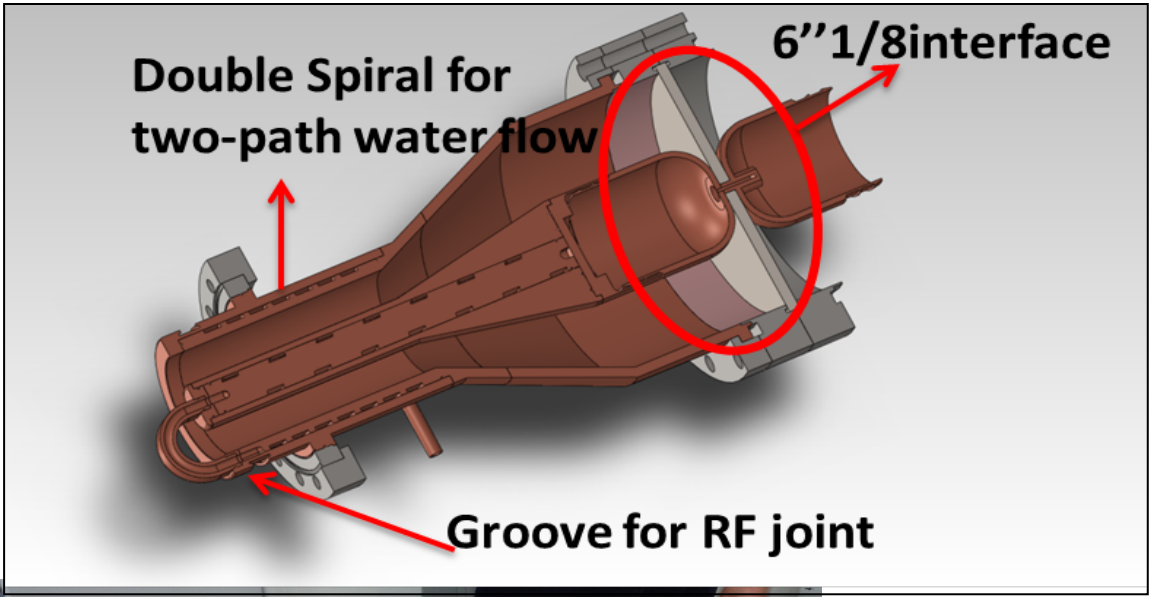
Electrode assembly concept







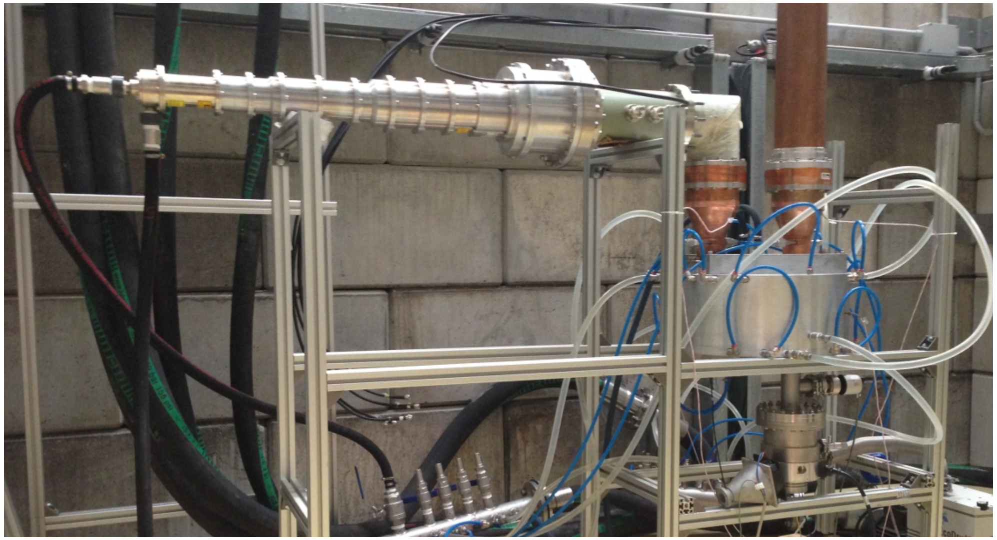
IFMIF coupler tested to 200 kW 175 MHz cw



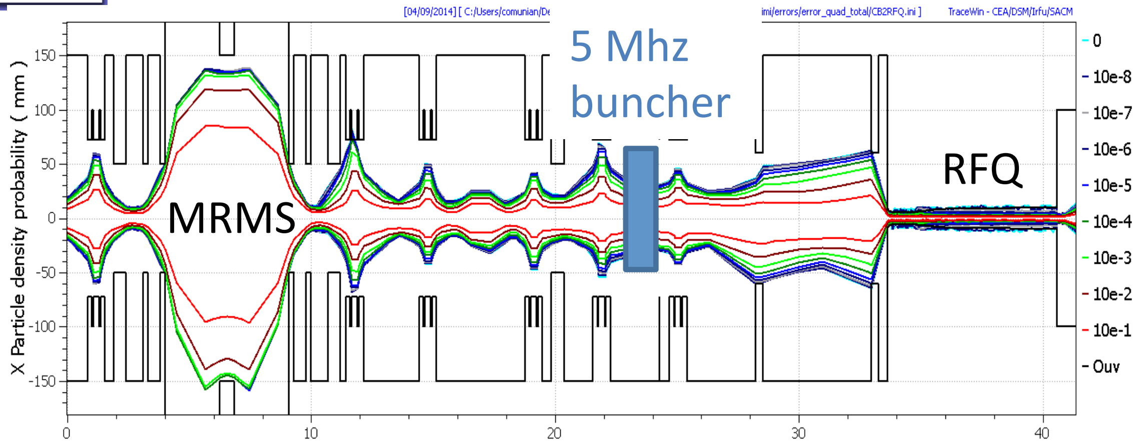
same coupler will be used 100 kW 80MHz

S_{12} = -0.34 dB (7.6% insertion loss) (with dummy couplers)

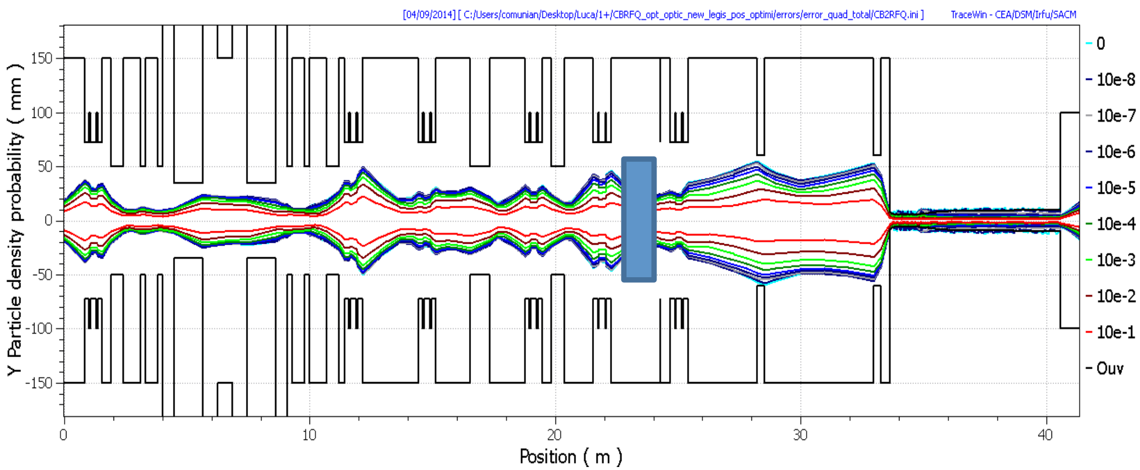
S_{12} = -0.44 dB (9.7% insertion loss)



BD from CB to end of RFQ

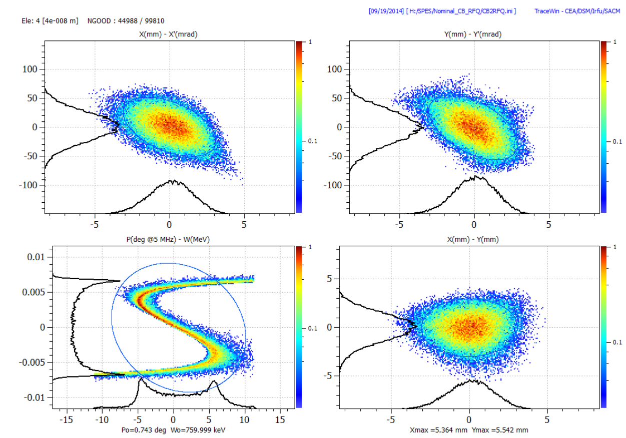


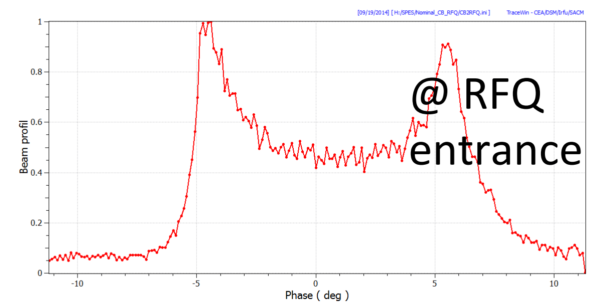
Total amount of space occupied by the beam due to quad errors



Without buncher: total losses 93-94 % after the RFQ, output longitudinal emittance 0.067 πmmmrad.

IF 5 MHz buncher on:



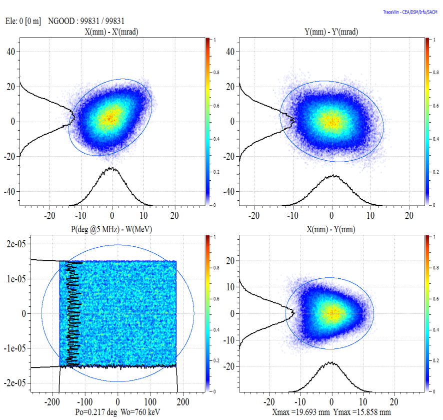


Transmission 45 % (chopping the satellite bunches) RFQ output emittance long rms 0.0371 πmmmrad

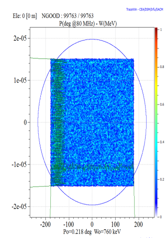
V. Andreev

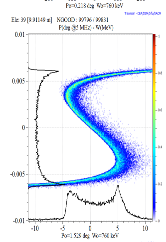
Buncher study

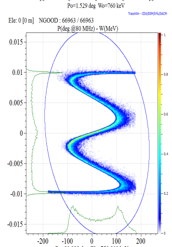
Input beam at the RFQ ± 15 eV, $^{132}Sn^{19+}$, 760 keV.
Continuous

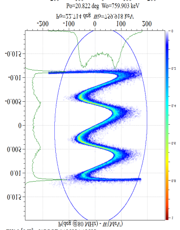


n. of harmonics	transmission	emittances (keV deg/ u)
no buncher	93%	5.15
1 harmonics	45%	2.3
2 harmonics	60%	3.36
3 harmonics	70%	4.5







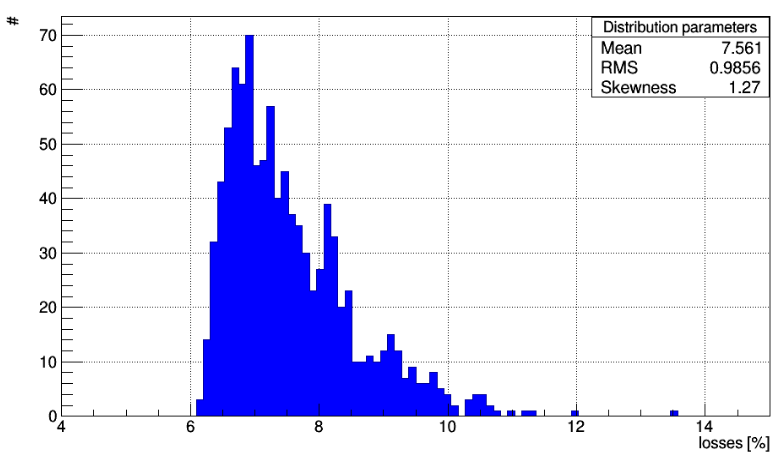


Beam Optics of Transport line from CB via RFQ with static errors study

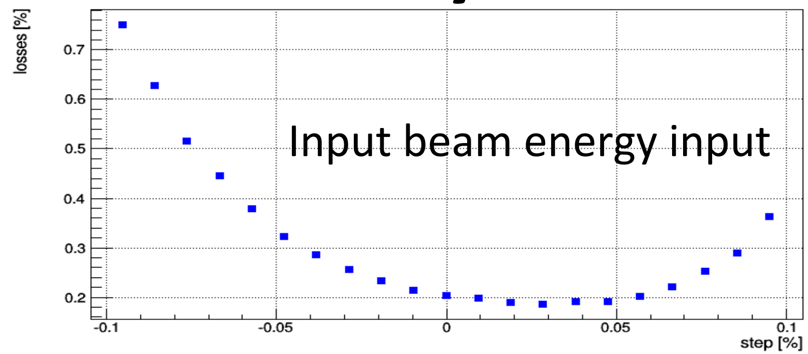
Quadrupoles errors	Sensibility required
Misalignment	0.1 mm
Tilt	0.15
Gradient error	0.3%
Dipoles gradient error	0.02%
Multipolar component	0.6%

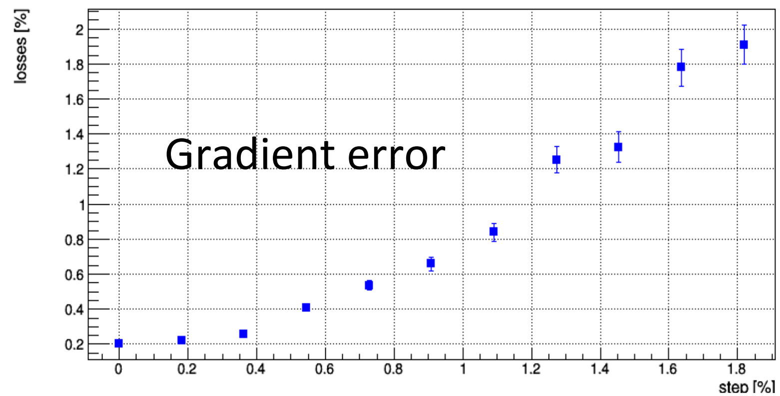
Input beam error	Applied errors
Mismatch	10%
Kinetic energy offset	0.1‰
X’	10 mrad
X	1 mm

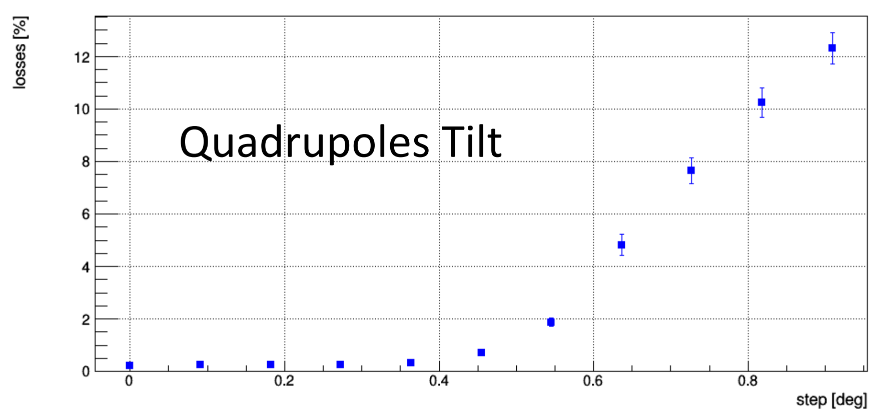
Total losses due to quadrupole errors



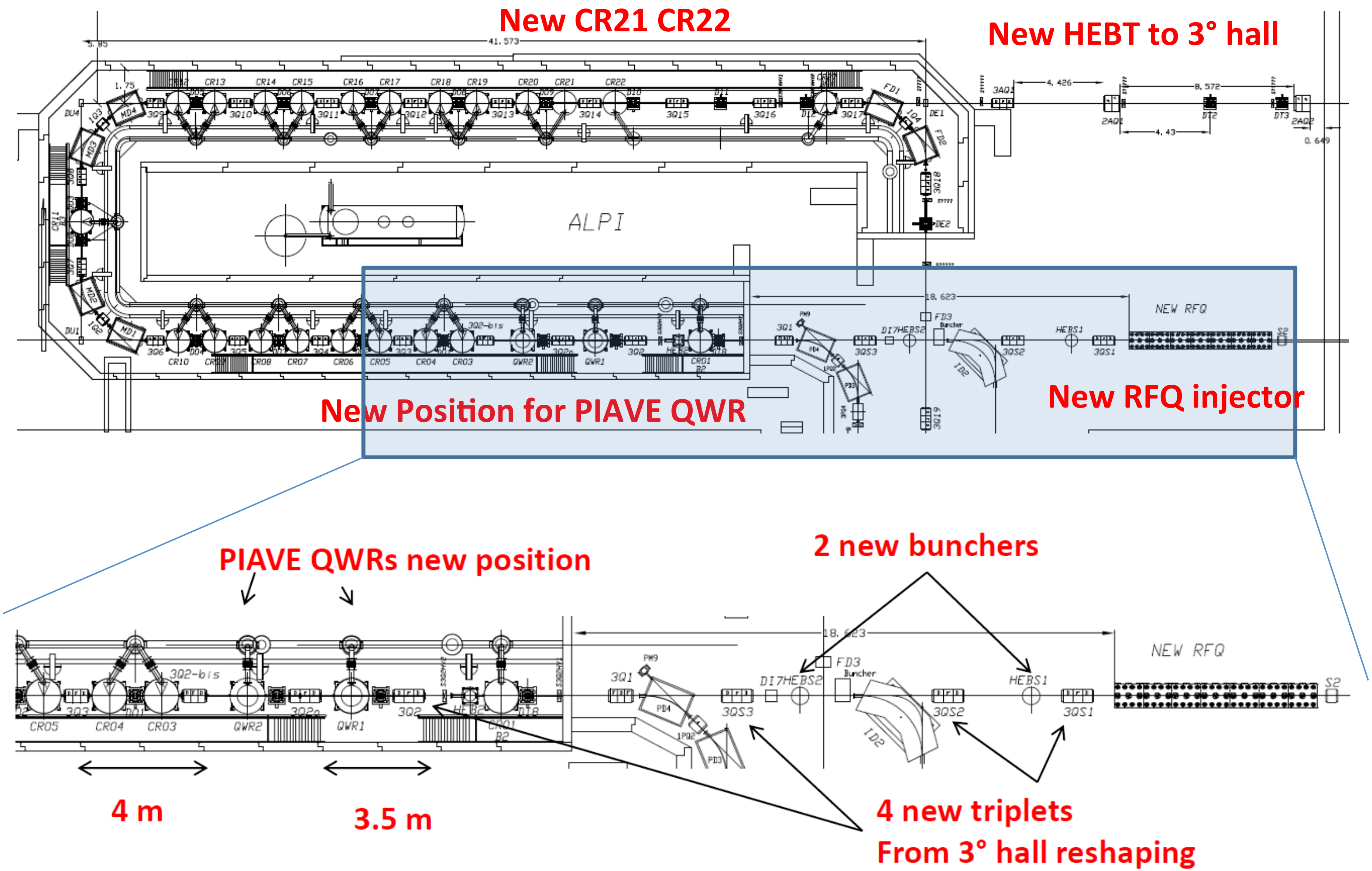
With this set of Errors we get an average of 7.4% of losses out of RFQ





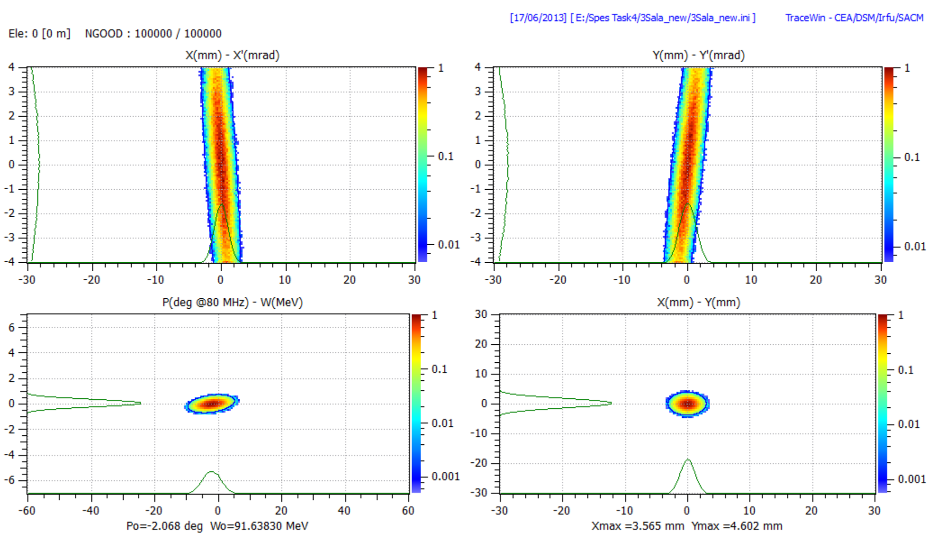


SPES Layout: zoom on ALPI LINAC

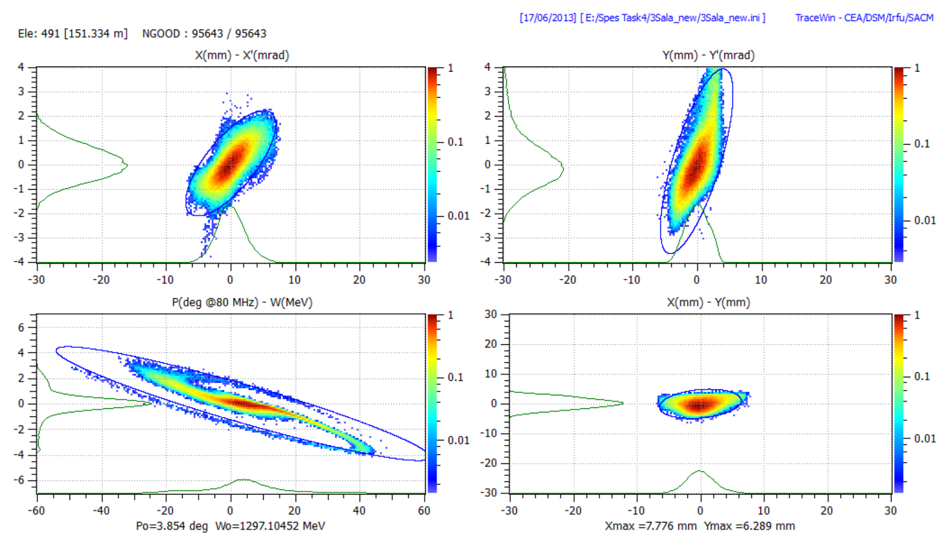


ALPI LINAC for SPES case A/q=7 $^{132}Sn^{19+}$

- Input energy from new RFQ: 93.9 MeV (β=0.0395) = 0.711 MeV/A.
- Output energy from CR21: 1285 MeV (β= 0.143) around 9.7 MeV/A.
- Input Transverse emittance of 0.12 mmmrad RMS norm. Long. 6.2 πdeg*KeV/u
- Global transmission from CB to Experimental Hall: 0.93 (RFQ)*0.97(ALPI)=0.9=90%.
- Simulation software: Tracewin with full RF fields Maps for cavities.

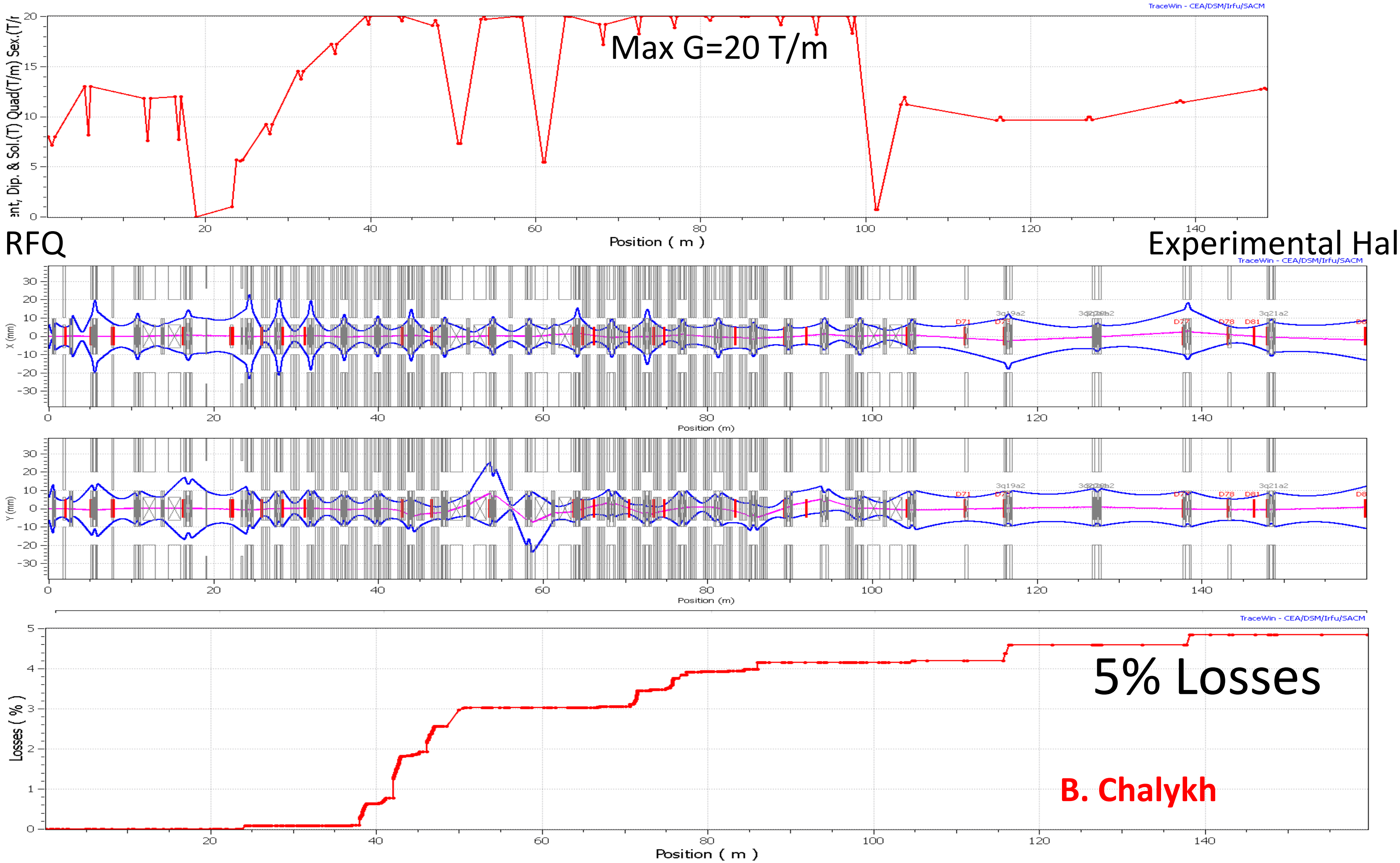


ALPI Input Phase Space

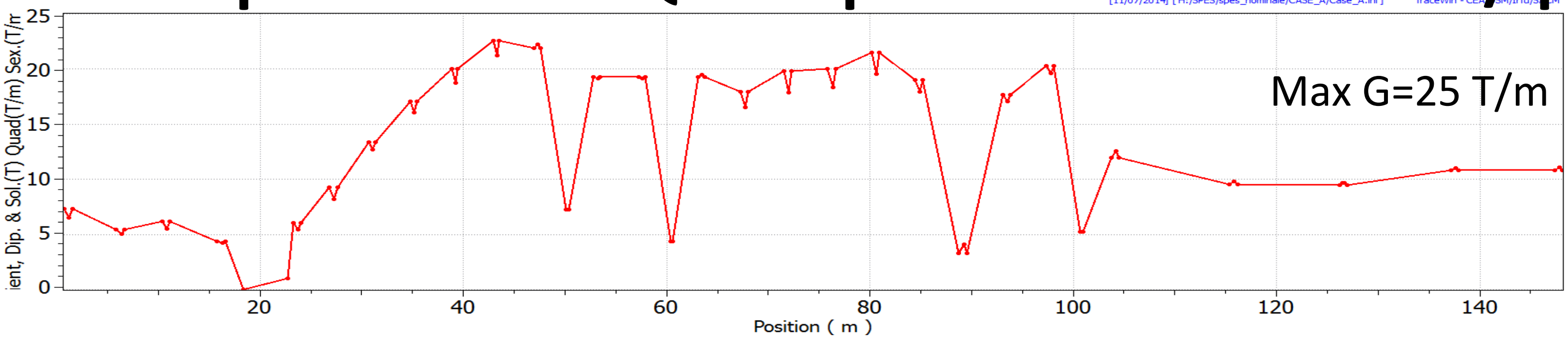


ALPI Output Phase Space

Beam Optics from RFQ to Experimental Hall for A/q=7

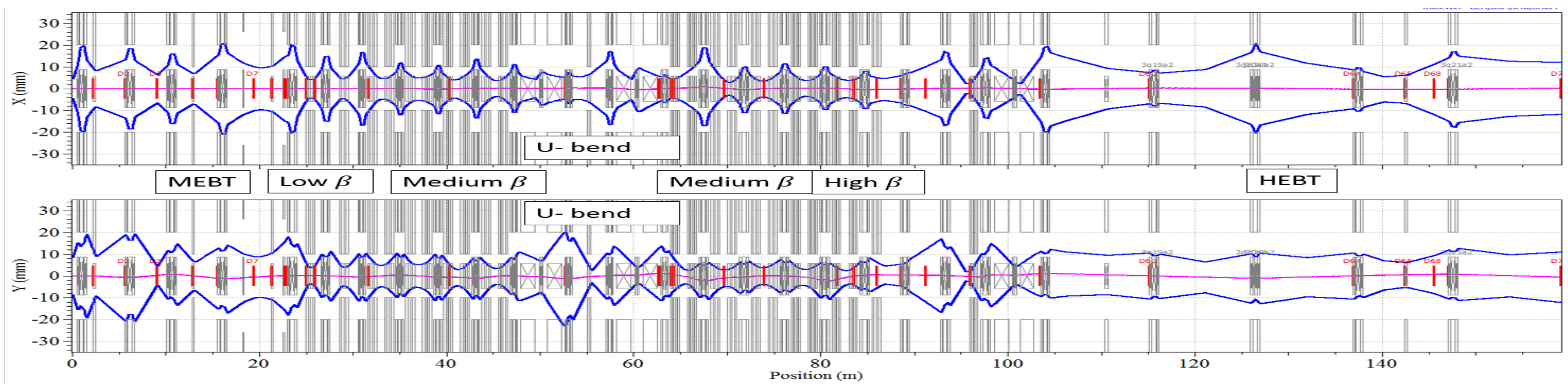


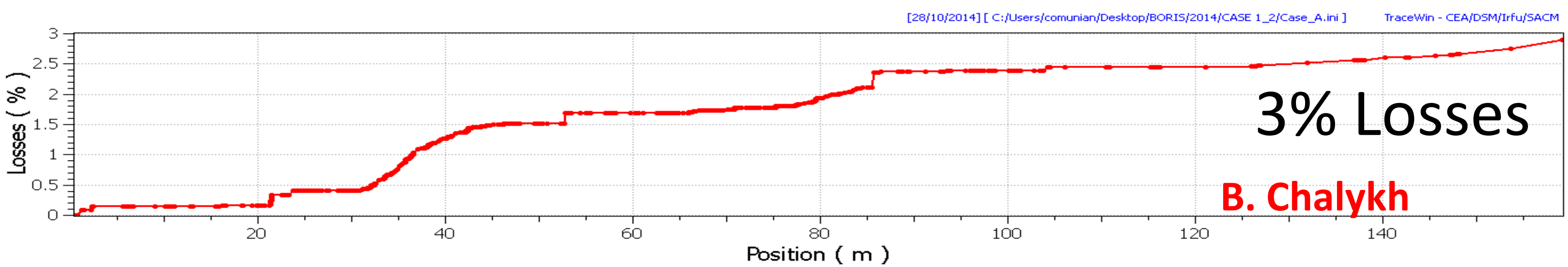
Beam Optics from RFQ to Experimental Hall for A/q=7



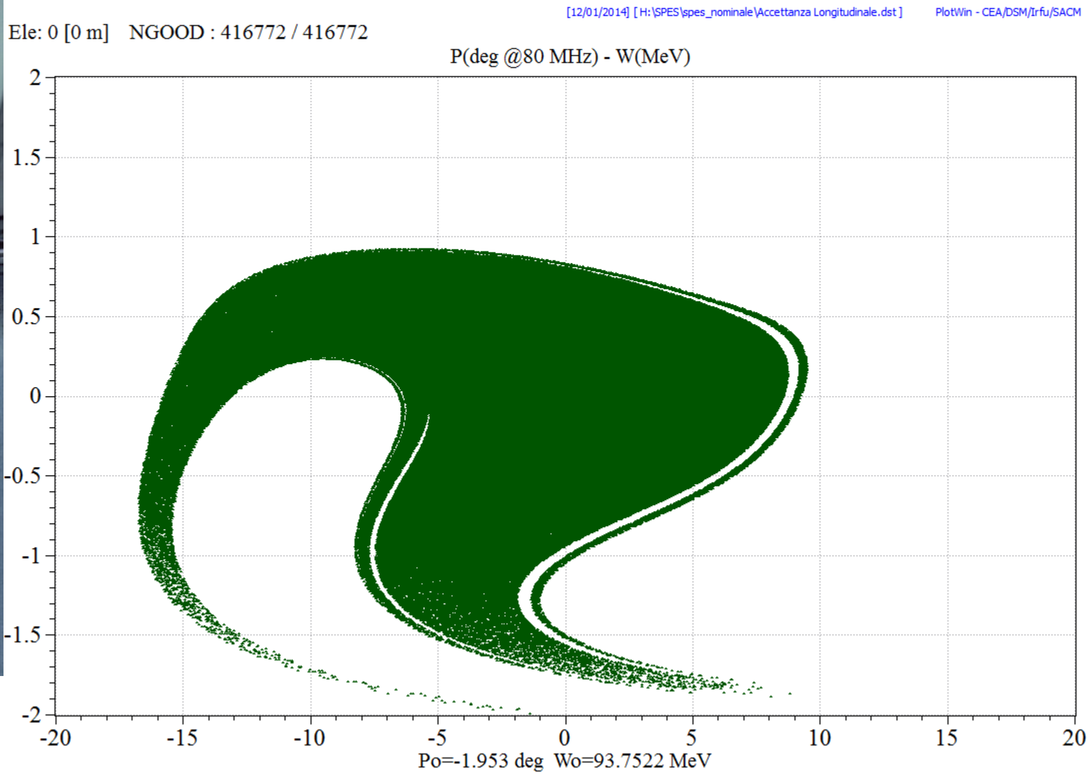
RFQ

Experimental Hall



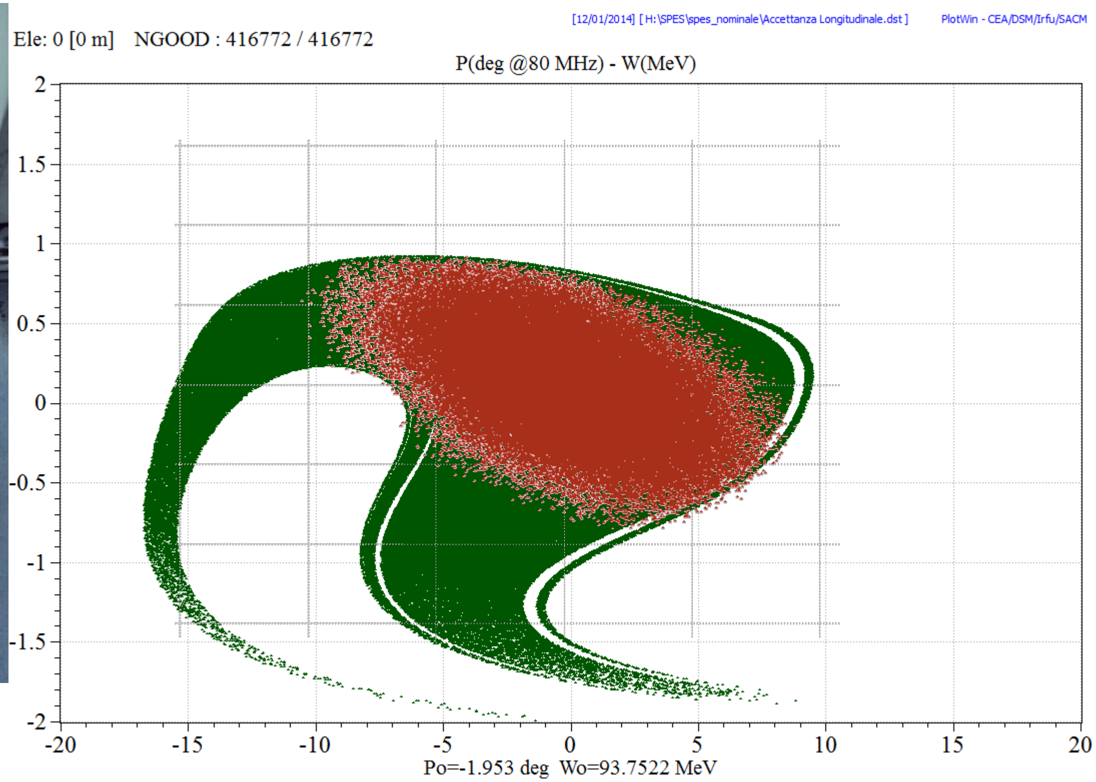


ALPI long acceptance plot



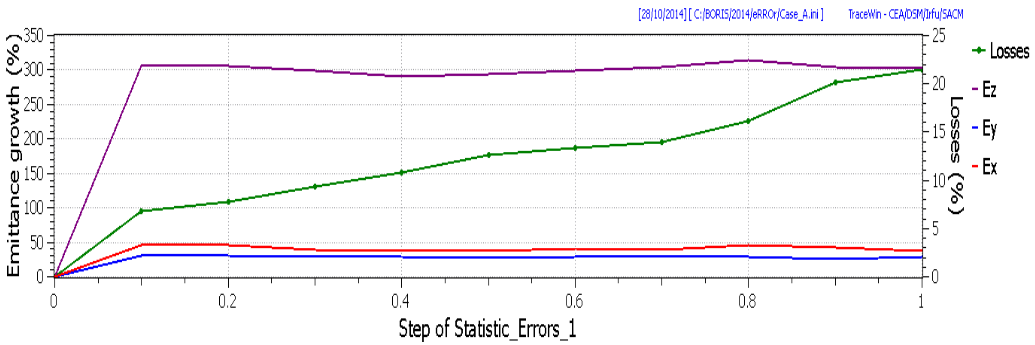
Total ALPI Acceptance=26 πdegKeV/u
Used Input Emittance long RMS=6.2 πdegKeV/u
RFQ output Emittance long RMS=4.5 πdegKeV/u

ALPI long acceptance plot

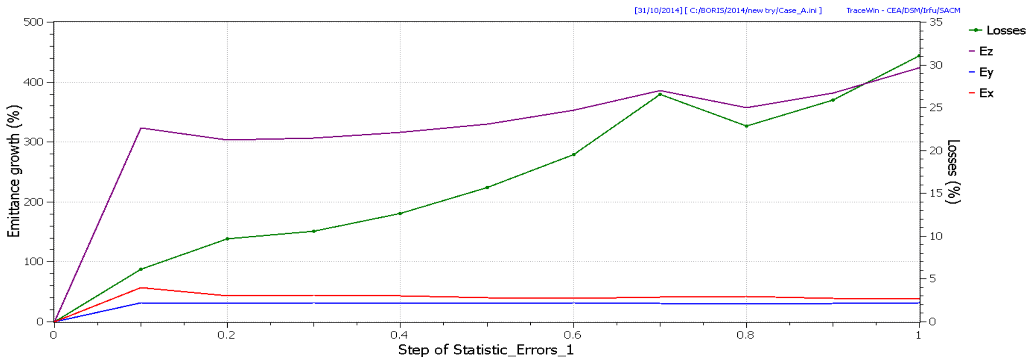


Total ALPI Acceptance=26 πdegKeV/u
Used Input Emittance long RMS=6.2 πdegKeV/u
RFQ output Emittance long RMS=4.5 πdegKeV/u

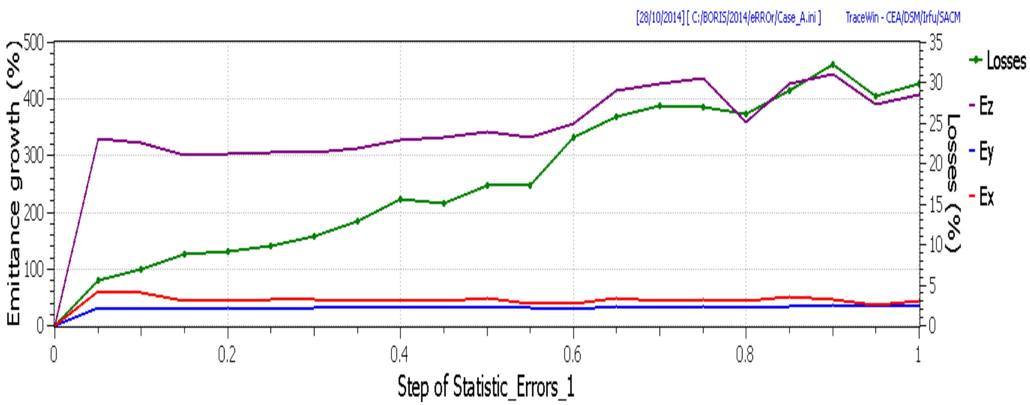
ALPI error study (ongoing)



Cavity misalignment max of ±2 mm:
with ±1 mm losses 12%



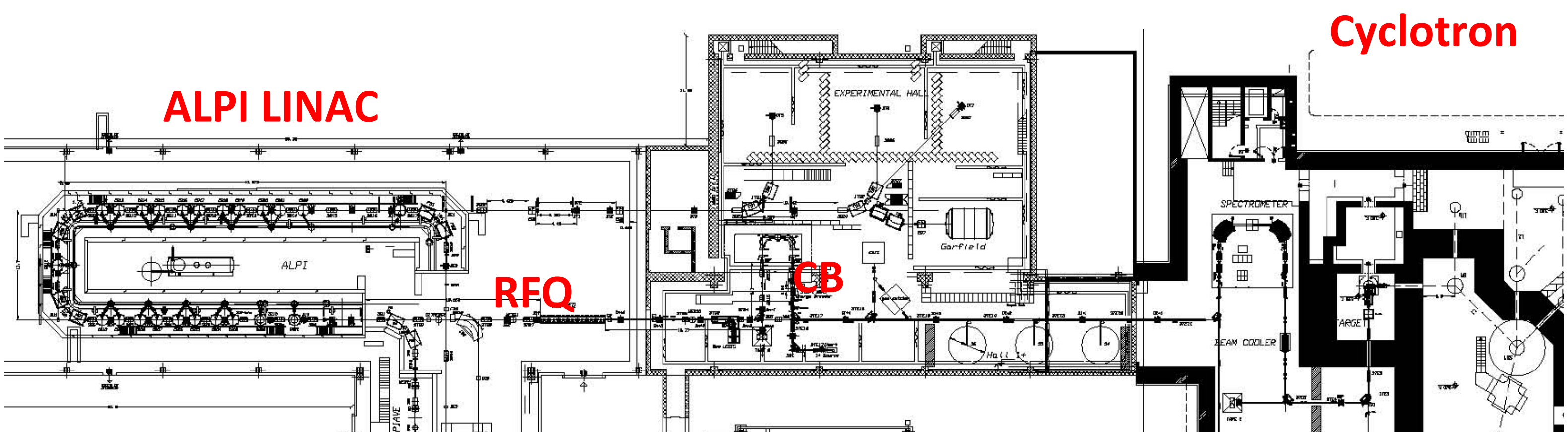
Cavity field change max of ±2%:
with ±1% losses 15%



Cavity phase change max of ±3 deg:
with ±1.5° losses 15%

Beam commissioning sequence

1. Source +1 (surface); CB; MRMS (2016)
2. Off line (high energy building) RFQ cooler (2015-16)
3. Source +1 (plasma); RFQ cooler; CB; MRMS; RFQ input line (2017)
4. CB; MRMS; RFQ; bunchers; ALPI (2018-19)
5. Source +1 (SIS-ISOL); wien filter; low resolution separator (2017) .
6. Source +1 (surface-bunker); wien filter; low resolution separator; RFQ cooler (2018).
7. 6.+HRMS+transport lines to low energy experiments. (2018)
8. 6.+HRMS+long transfer lines+CB (2019)
9. From production target to end of ALPI (2019)
10. First RIB trough ALPI to experiments (2019)



Conclusions

- SPES post accelerator beam design has involved the study of many critical devices, and the overall optimization to distribute the criticality.
- The beam transport lines from CB to ALPI are specified and we are tendering the magnets.
- The mechanical design of RFQ and HRMS will be completed during 2015; starting of procurement procedure will follow within 2015.

Beam characteristics and constrains

- Emittance from plasma source: 70 π mmmrad geom RMS @40 kV ($^{132}Sn^{1+}$), $\pm$ 40eV (laser and surface are better)
- After RFQ cooler and with platform 6 π mm mrad geom 99% @ 220 kV (132Sn1+), $\pm$2 eV. Resolution required for the 1/20000.
- Input acceptance of CB $\pm$5 eV, output 0.1 π mm mrad norm, +- 30 eV.
- MRMS with geometrical acceptance of 340 π mm mrad.
- ALPI longitudinal acceptance (26 πdegKeV/u) and RFQ output longitudinal rms emittance (4.3 πdegKeV/u).