SPES BEAM DYNAMICS

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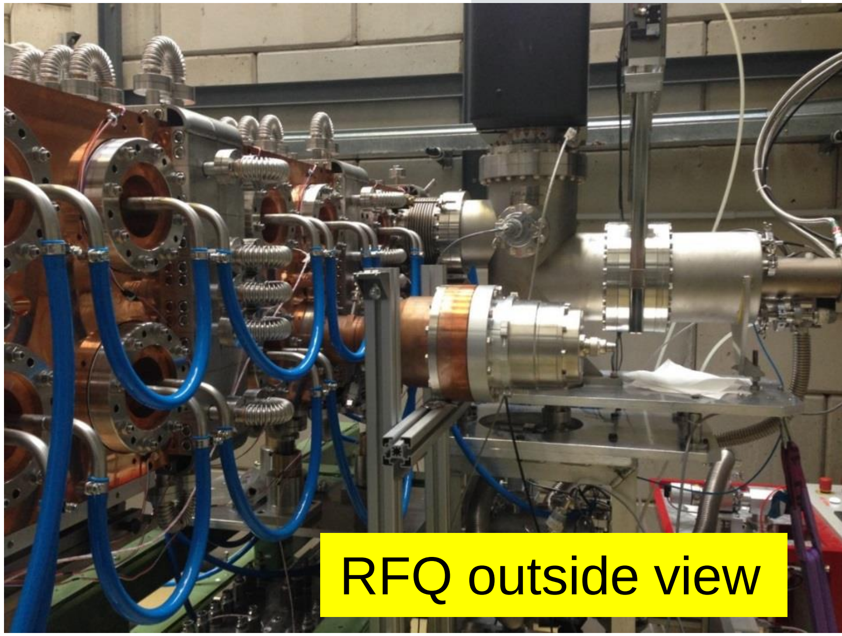
SPES, acronym of *Selective Production of Exotic Species,* is a CW radioactive ion beam facility under construction at LNL INFN in Italy.

Outline

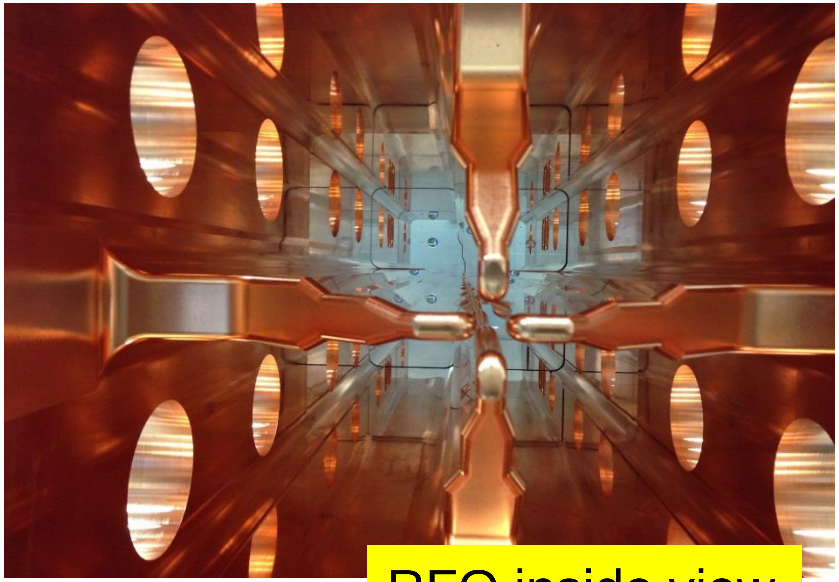
- Overview of SPES Project.
- Transport line 1+:
  - Low energy transport and selection;
  - High Resolution Mass Spectrometer;
  - Charge Breeder.
- Transport line n+:
  - Clean the contaminants from CB with MRMS.
  - The new RFQ as new ALPI LINAC injector.
- ALPI LINAC for SPES.

Premise

- The LNL group has designed the RFQ for IFMIF EVEDA and the DTL for ESS (more in the main stream of this workshop).
- 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
- Contaminants give similar problems for radiation protection (MPS and activation in the beam settingsteps)
- The approach computational tools (TRACEWIN, 10^5 macroparticles, accurate field maps..) are almost the same.



RFQ outside view

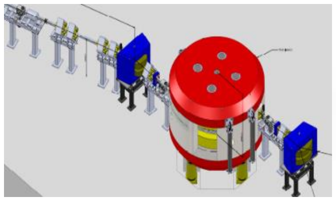


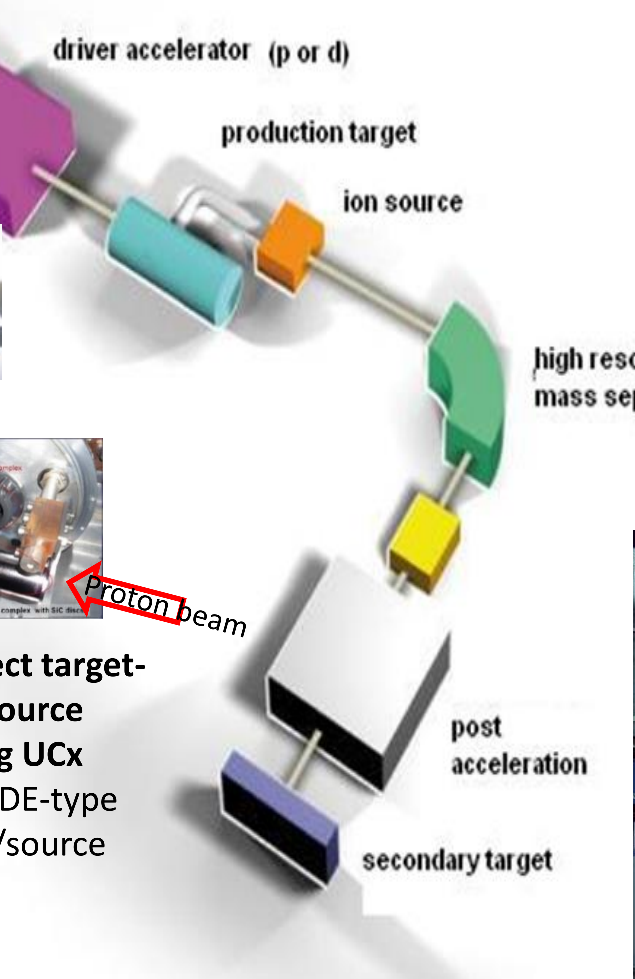
RFQ inside view

The ISOL choice for SPES

Cyclotron → Proton Driver:

70MeV 0.75 mA 2 exit ports





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

NEW CONCEPT
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€

ALPI SC LINAC

SPES scientific and technical collaboration

INTERNATIONAL LEVEL

EUROPE

LEA Colliga → France-Italy
(SPES, SPIRAL2,**ALTO**,EXCYT,FRIB, Coll. on Det.)

ISOLDE (CERN)→SPES (Italy)

LEA (signed May 2014)**→ Poland-Italy**

MoU (in preparation)**→ ELI-np - SPES**

Second Generation ISOL facilities

European ISOL Roadmap toward

EURISOL

NATIONAL LEVEL SPES collaboration

Acc.Techologies & Mechanics
(INFN divisions and Universities)
Milano, Bologna, LNS, LNL, Pavia, Trento, Palermo.

Physics Programs & Detectors (INFN)
(Bari, Bologna, Catania, Firenze, Milano, LNL, LNS, Padova, Trento, Napoli)

International collaboration on **Innovative Itinerant Detectors & on experimental proposals** to keep a **qualified** & **competitive level**
AGATA, FAZIA, PARIS, NEDA, GASPARD
Italy → France, England, Spain, Poland, Romania, Bulgaria, Turkey, Germany, Croatia, Sweden, Finland, Denmark.

WORLD

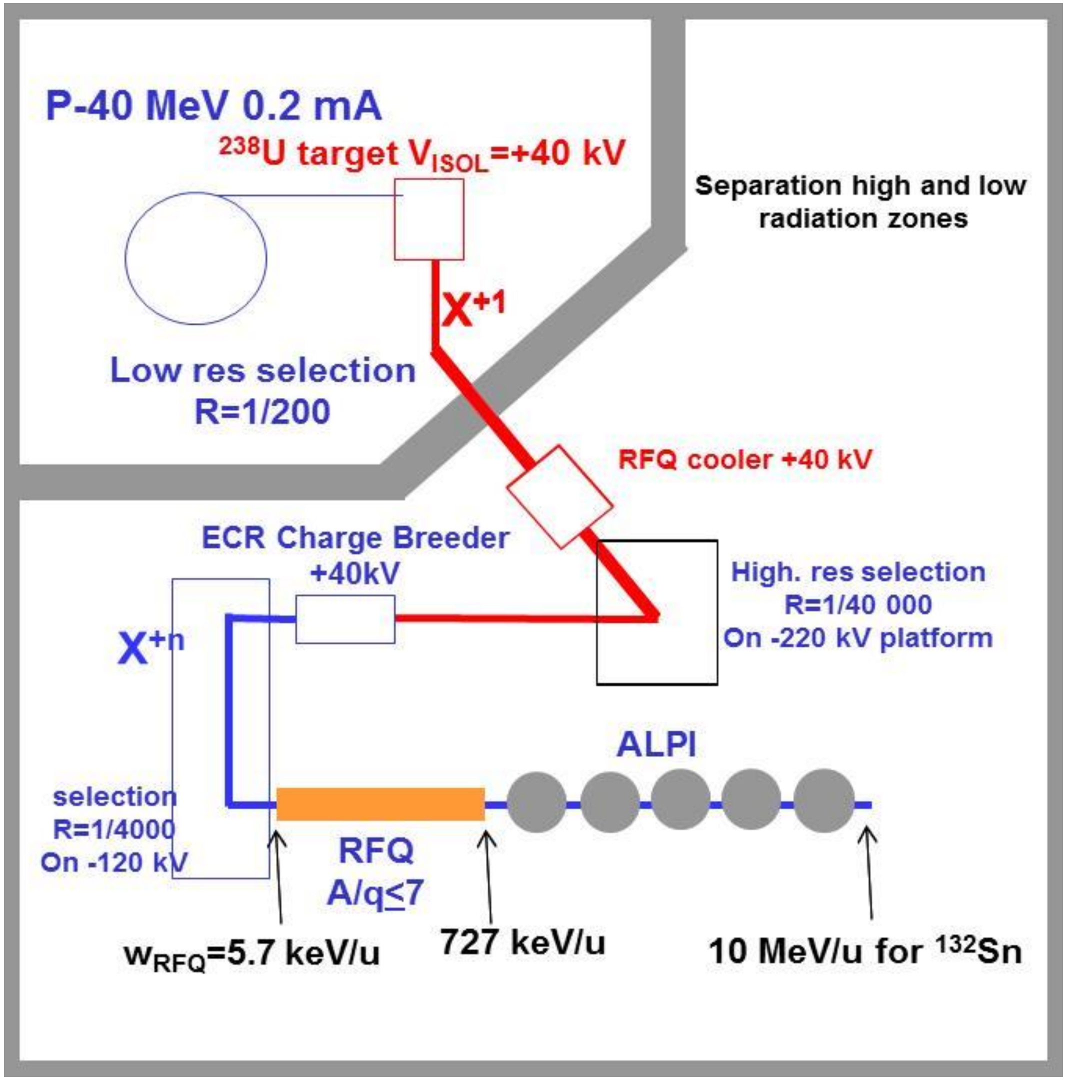
MoU (signed) → iTHEMBA-Labs - INFN
HRIBF (ORNL)

RIKEN, MSU-FRIBS, RISP-KOREA, BARC, NEW DEHLI, DUBNA, MOSCA

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:

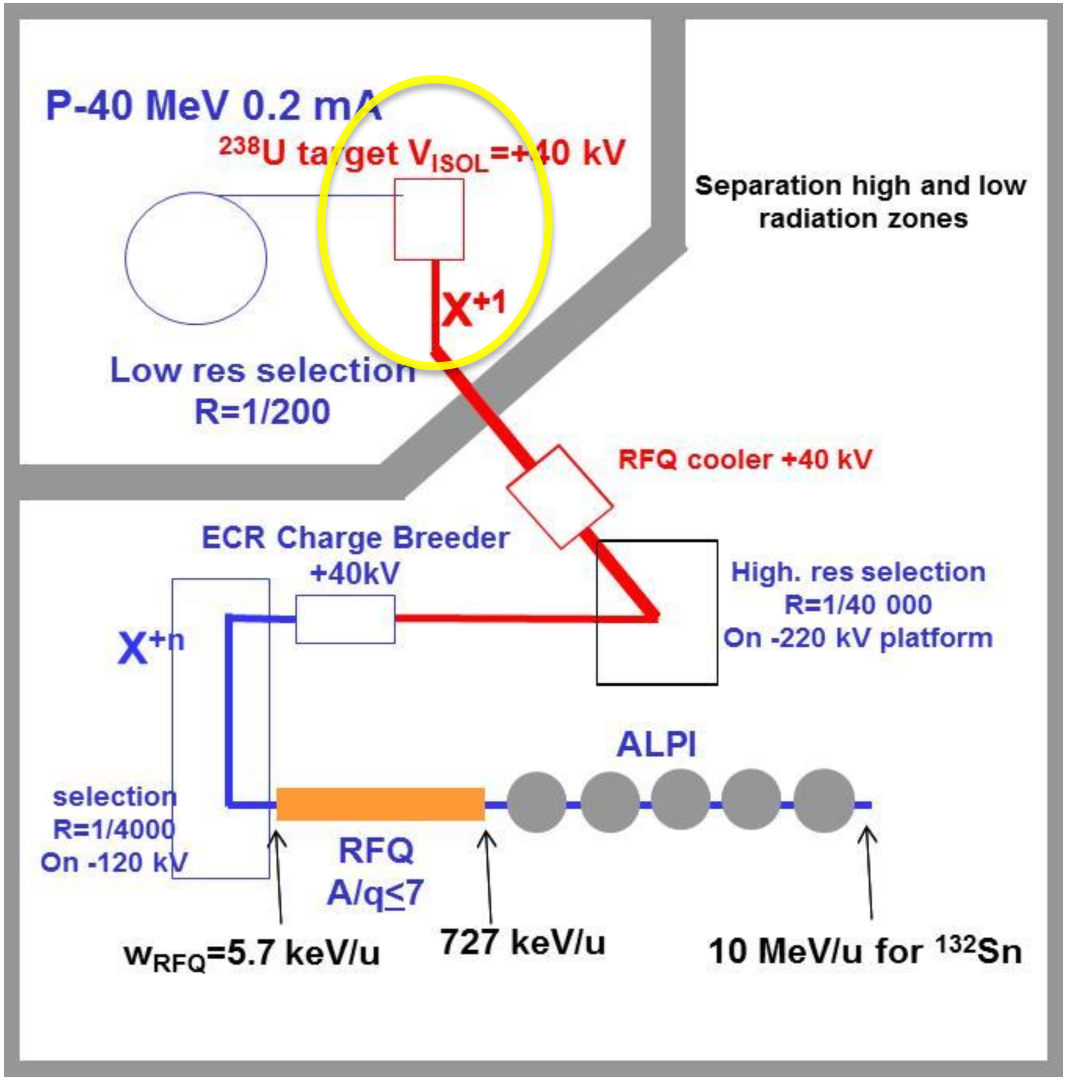
$$eV = (A/q)\, w_{RFQ}$$



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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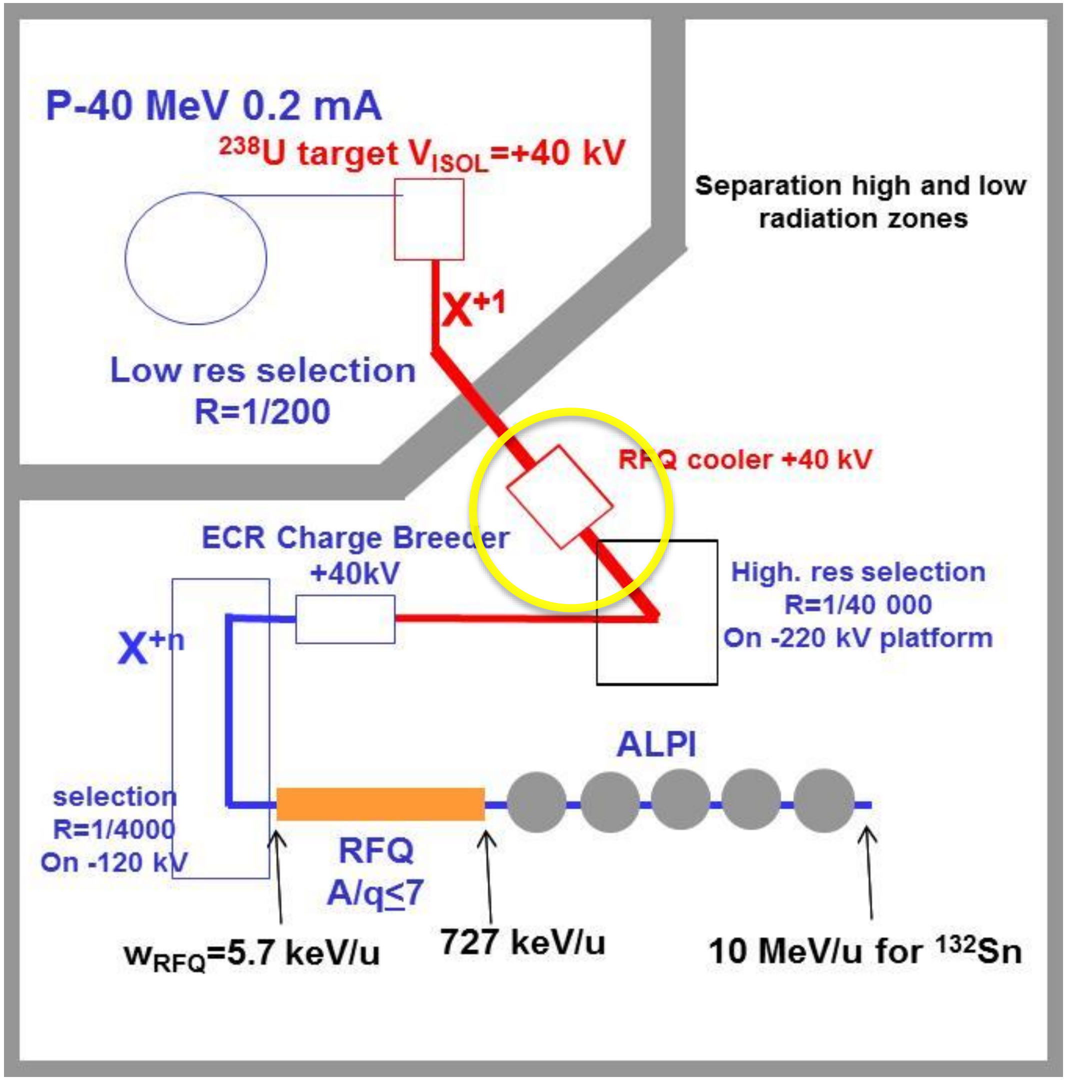

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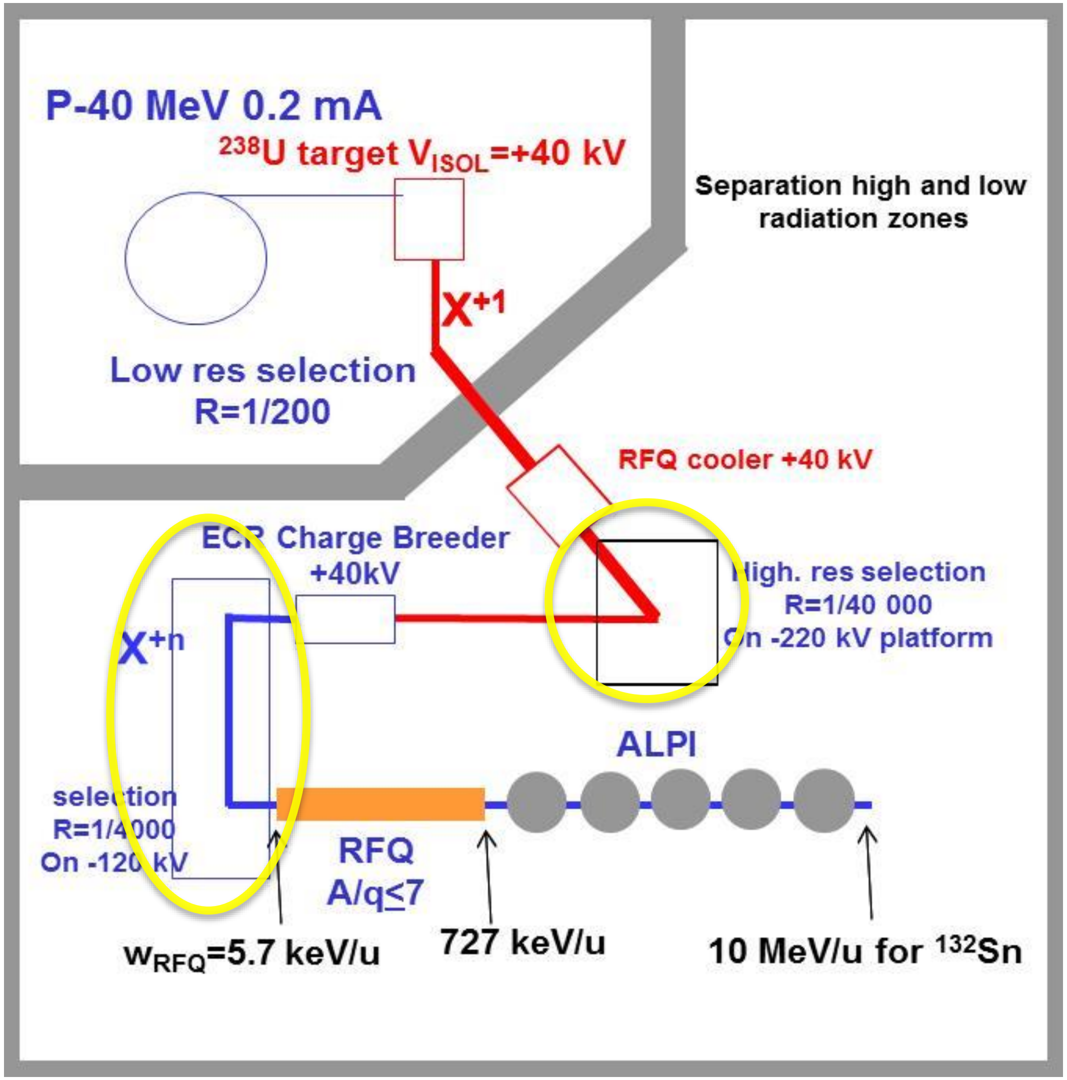

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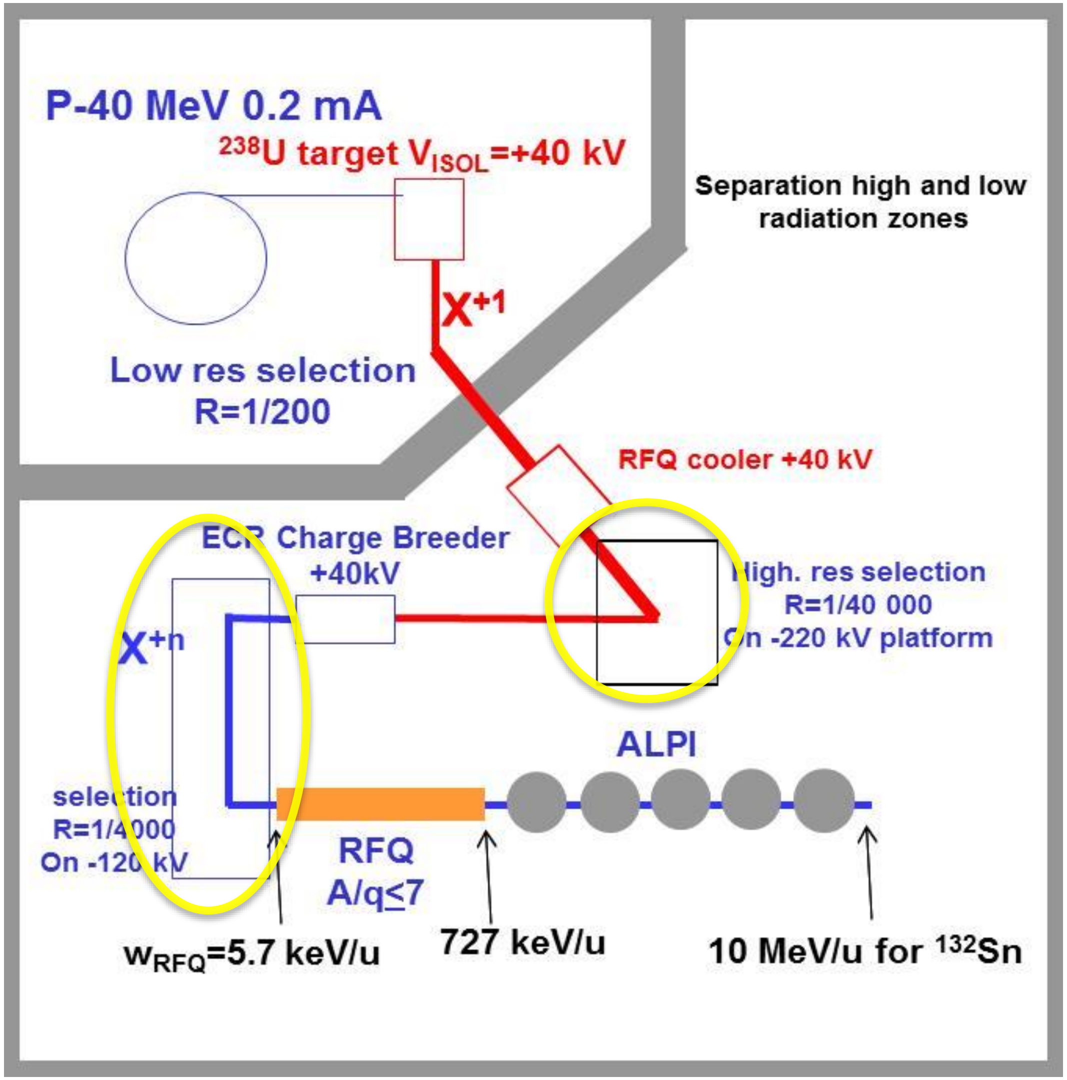

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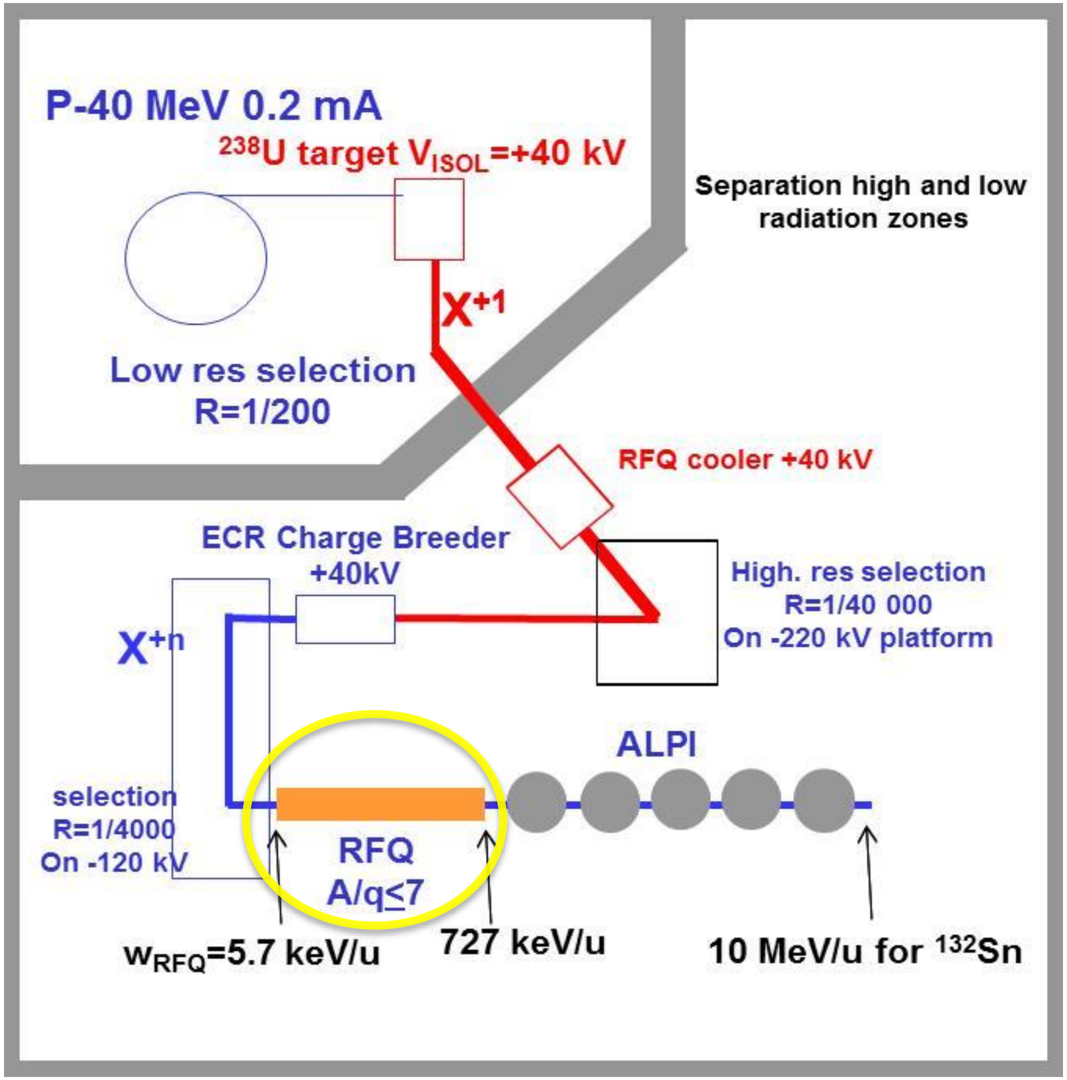

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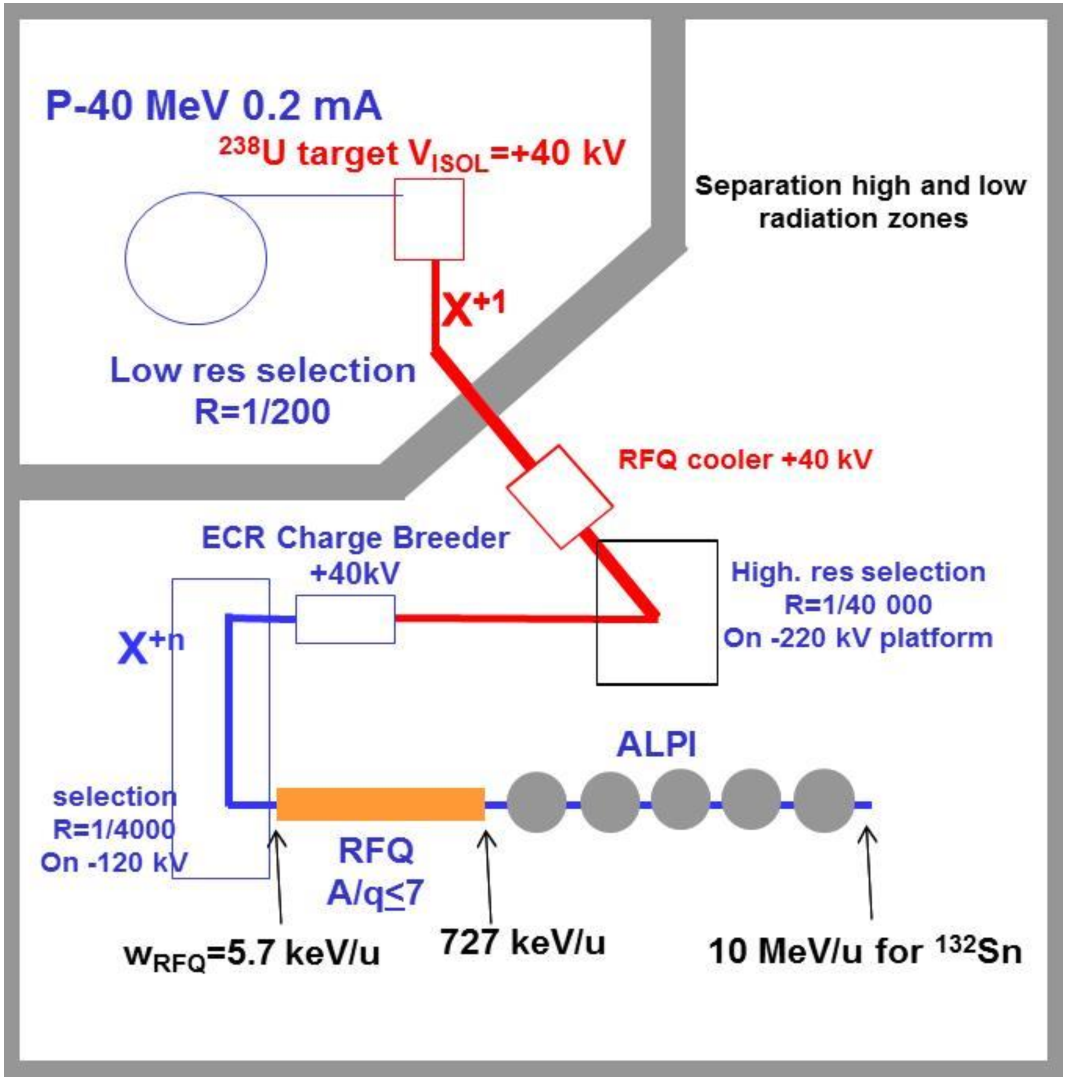
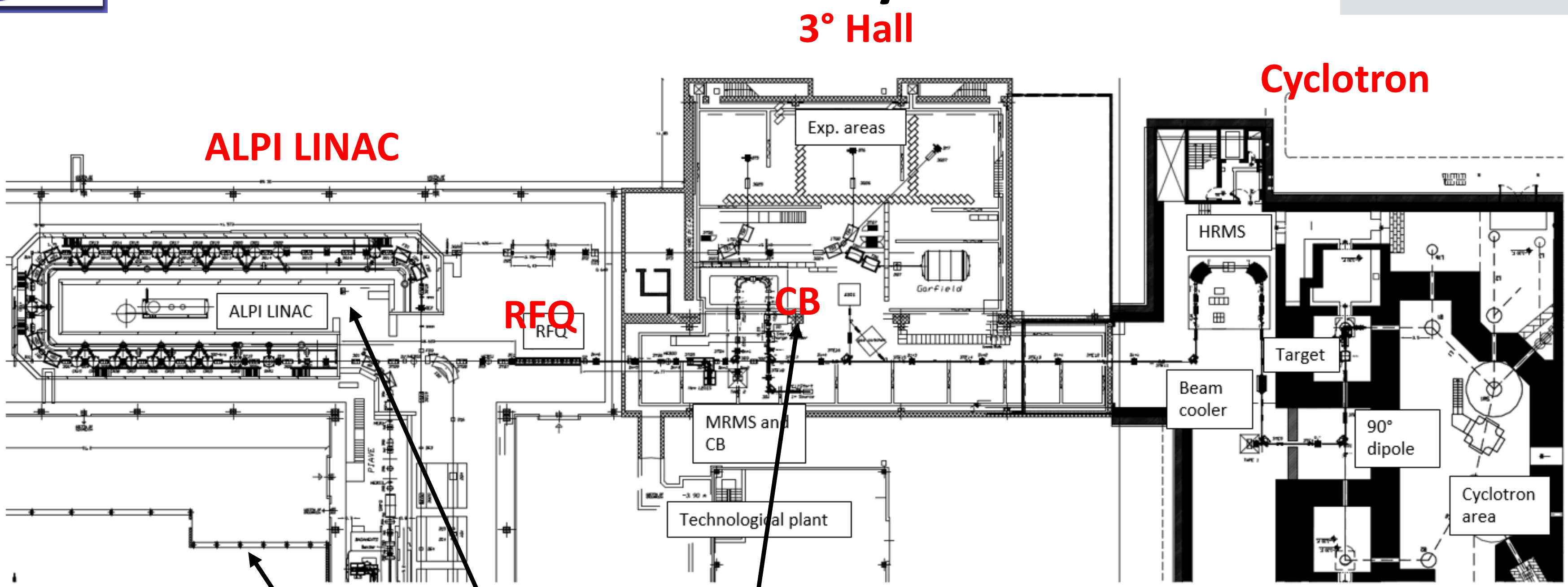
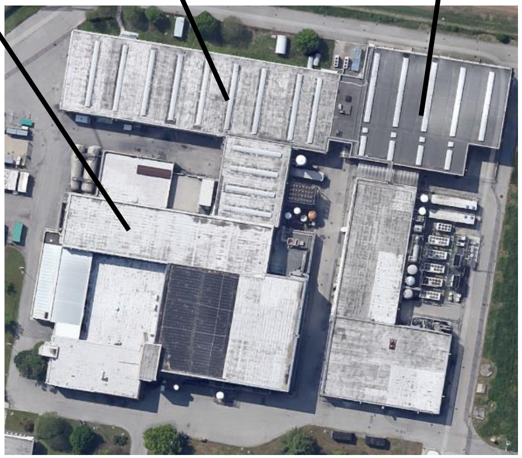
6. An external 5 MHz buncher before the RFQ will be available for specific experiments (at the price of about 50% beam transmission).
7. The dispersion function is carefully managed in the various transport lines; where possible the transport is achromatic, otherwise the dispersion is kept low (in particular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



SPES Layout

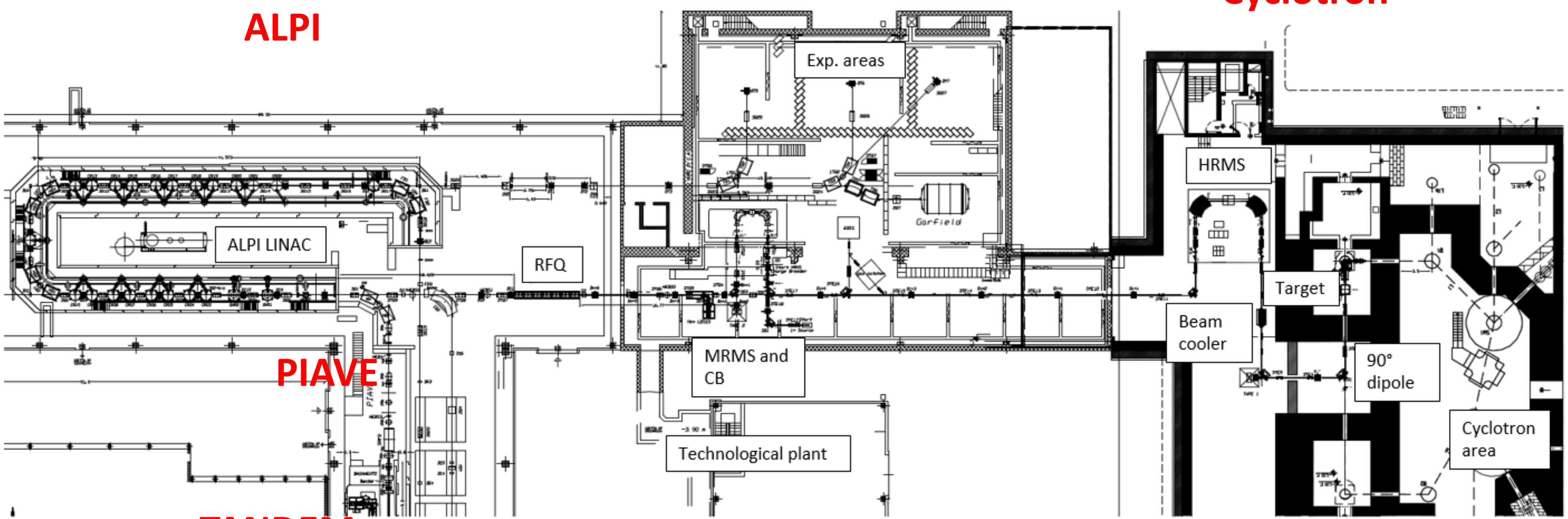

3° Hall
Cyclotron
ALPI LINAC
Exp. areas
ALPI LINAC
RFQ
RFQ
CB
Garfield
HRMS
Target
Beam cooler
MRMS and CB
90° dipole
Cyclotron area
Technological plant




INFN
SPES
07/11/2014
13:00

SPES Layout

3° Hall



ALPI UPGRADE

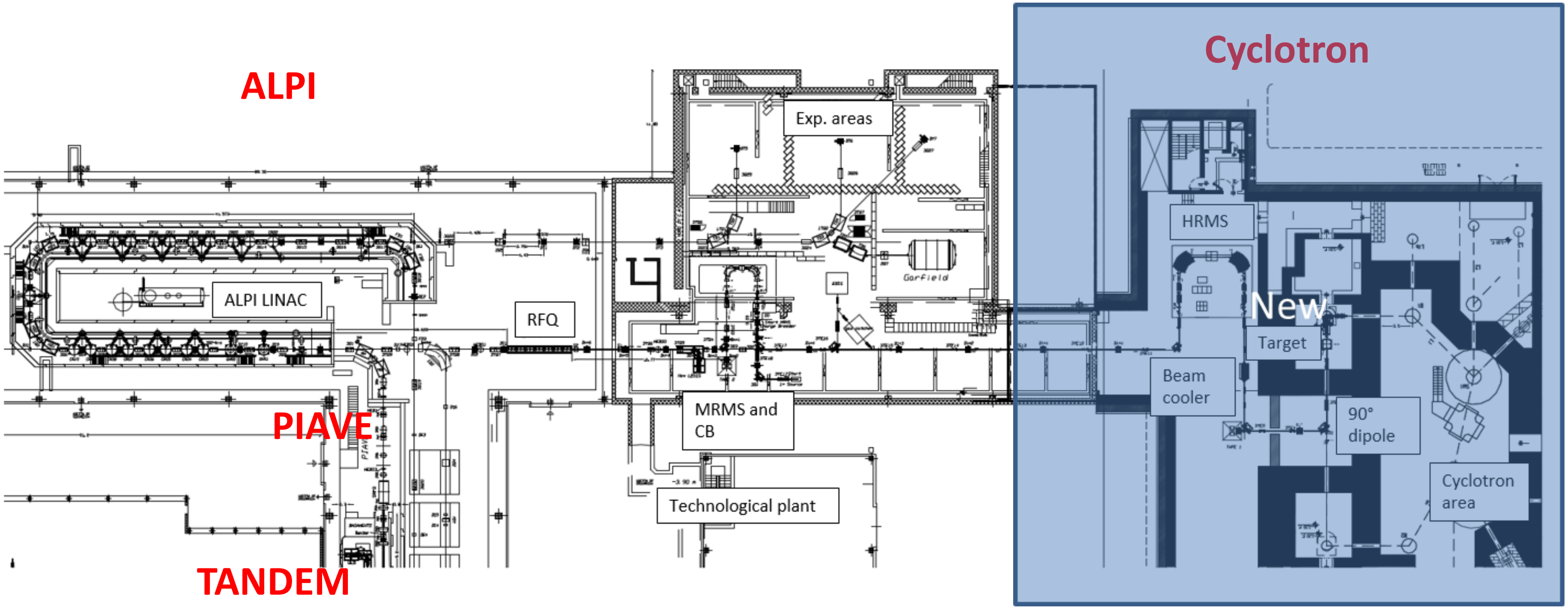
- Resonators: low-beta upgrade and E-Upgrade (+2 high-b cryostats)
- New quads with higher gradient (20→25 T/m) to optimize T
- RN Beam Diagnostics
- Cryogenics and cryostats upgrades
- Vacuum system replacement
- New controls (RF, diagnostics, magnets, access, vacuum)

NEW INJECTOR AND LINES

- New HEBT to Hall III, low energy 1+ line, EXCYT spectrometer.
- Charge breeder and dedicated 1+ source
- MR Mass Spectrometer
- Transport to ALPI (lenses, bunchers, …)
- New NC RFQ

SPES Layout

3° Hall



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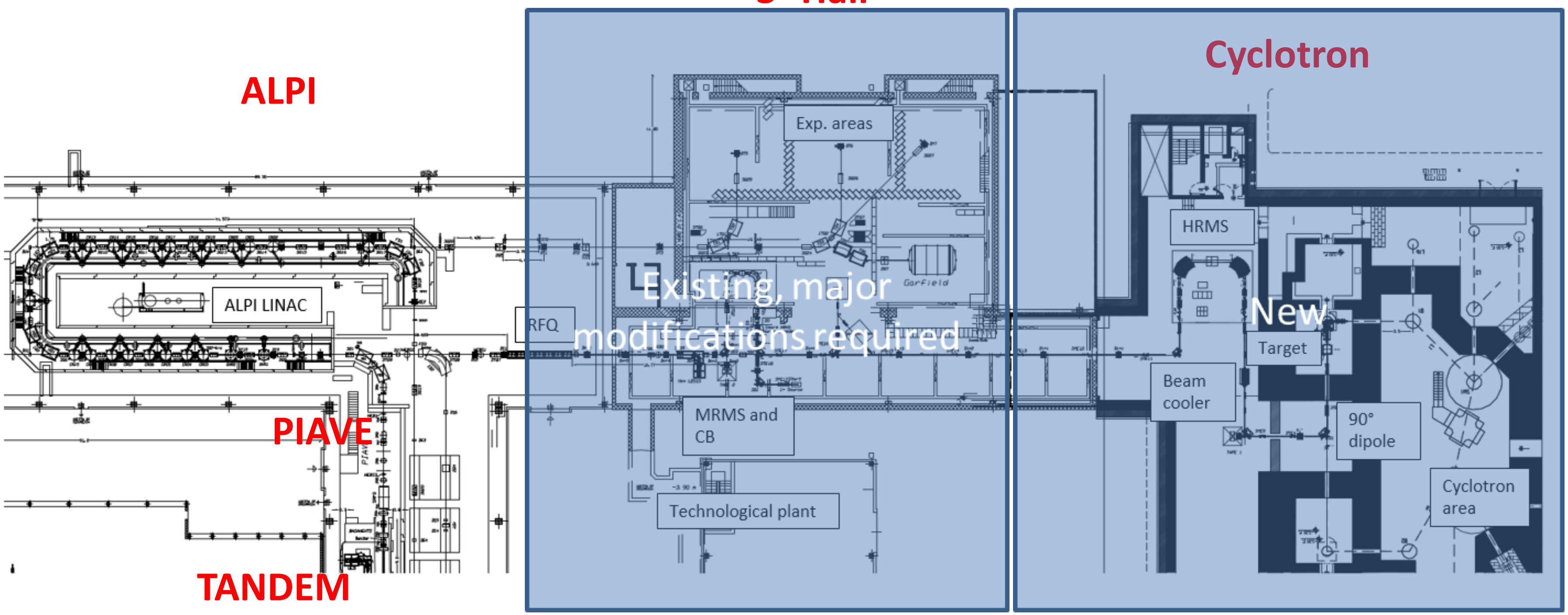

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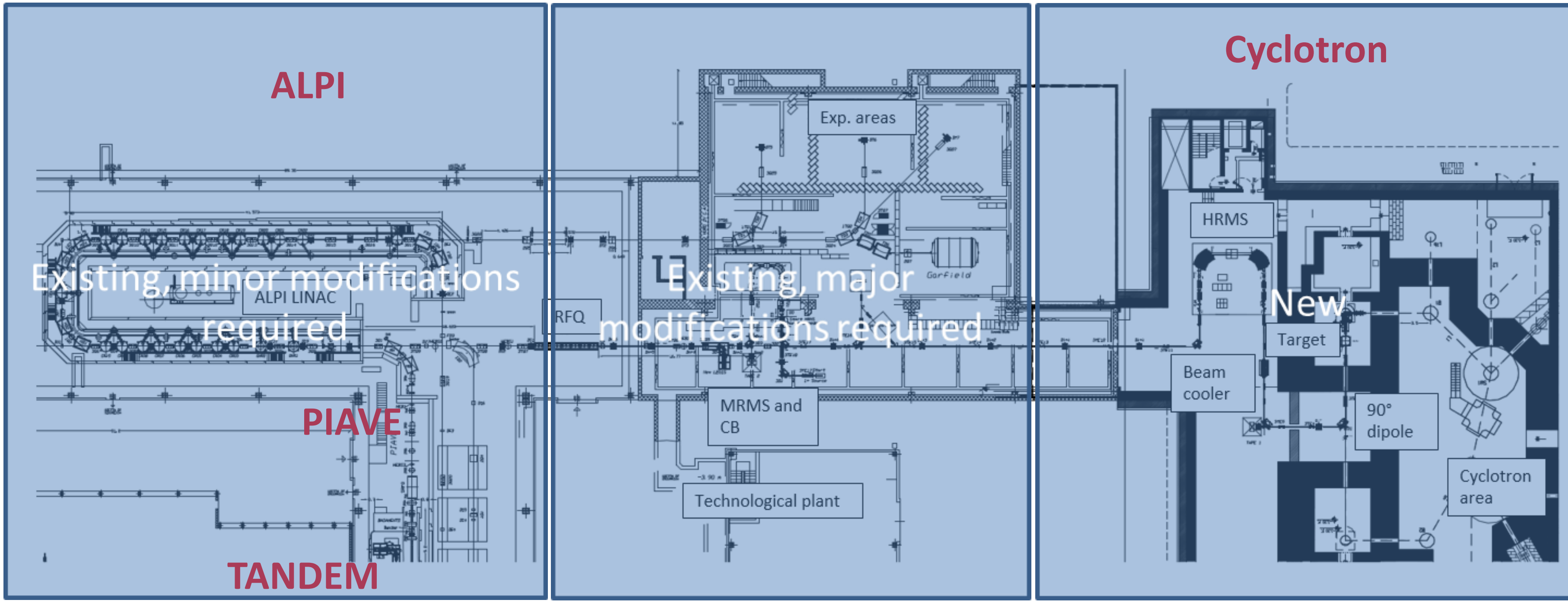

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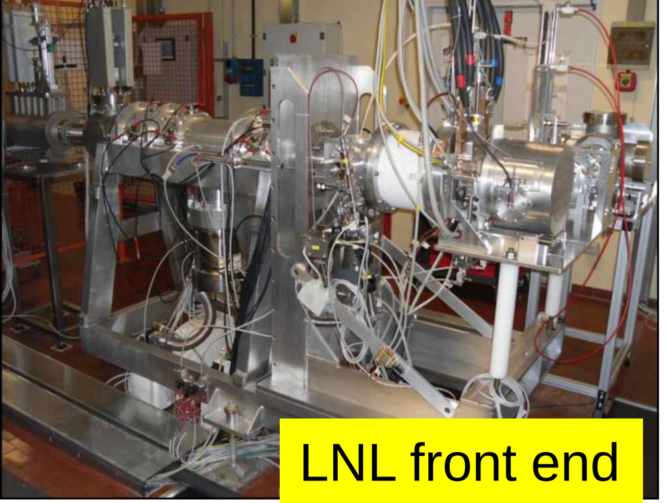
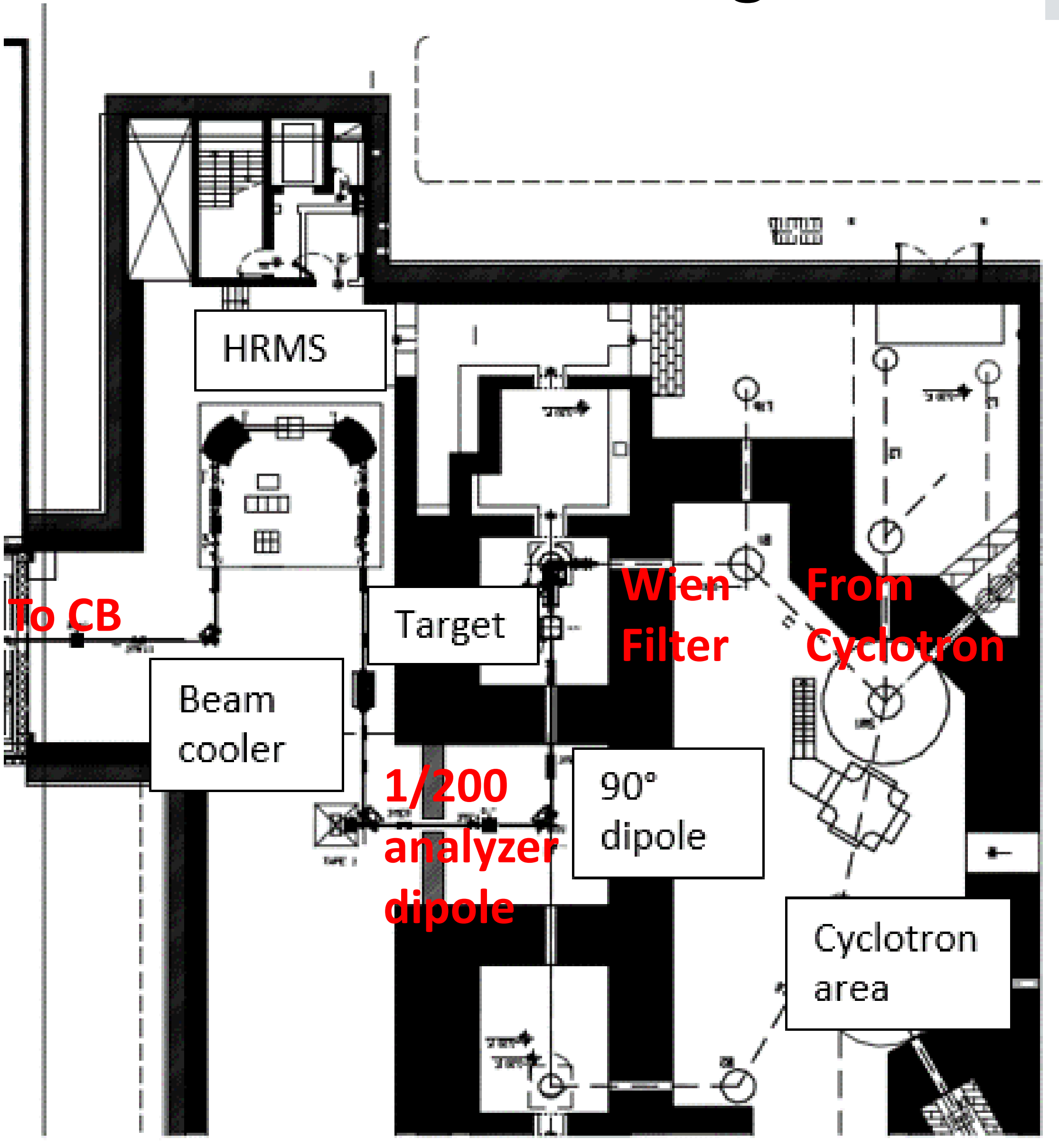
SPES Layout: zoom on new building

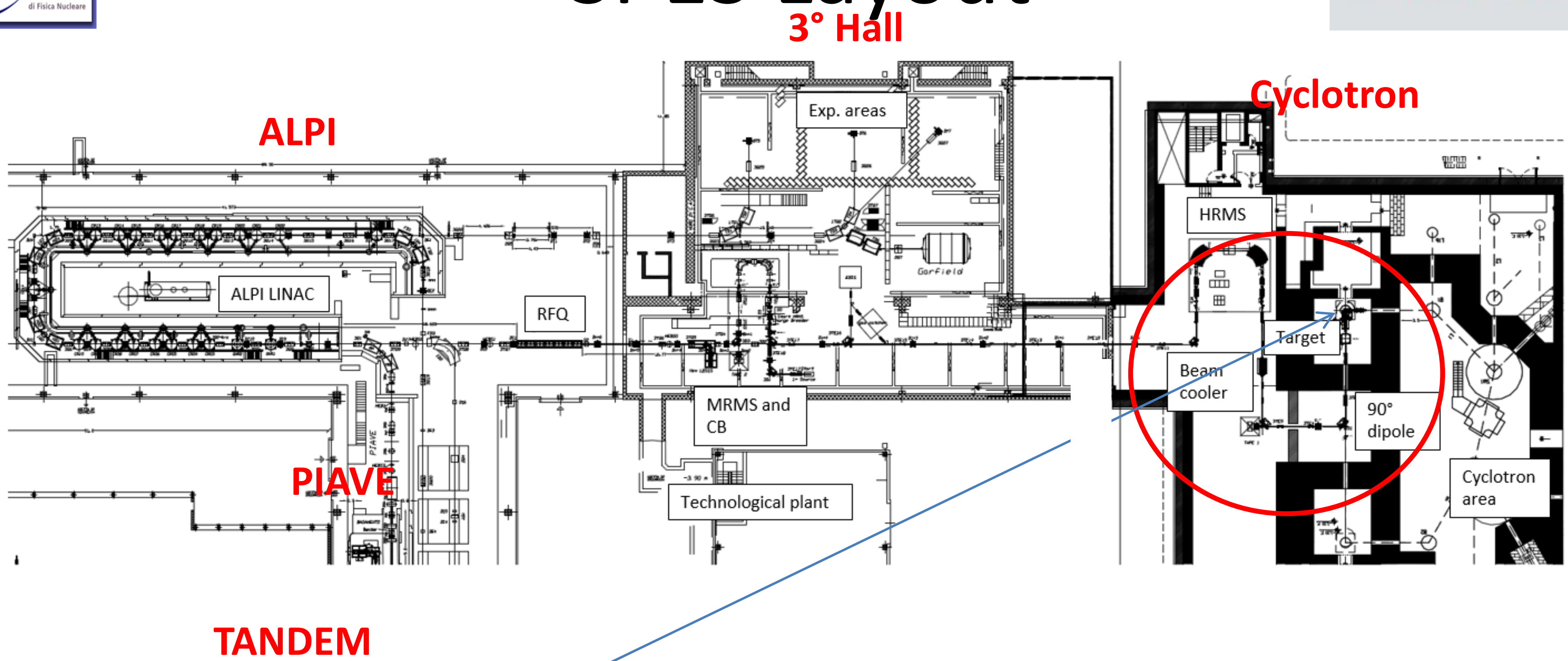
NEWS OF 1+ LINES

- 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.





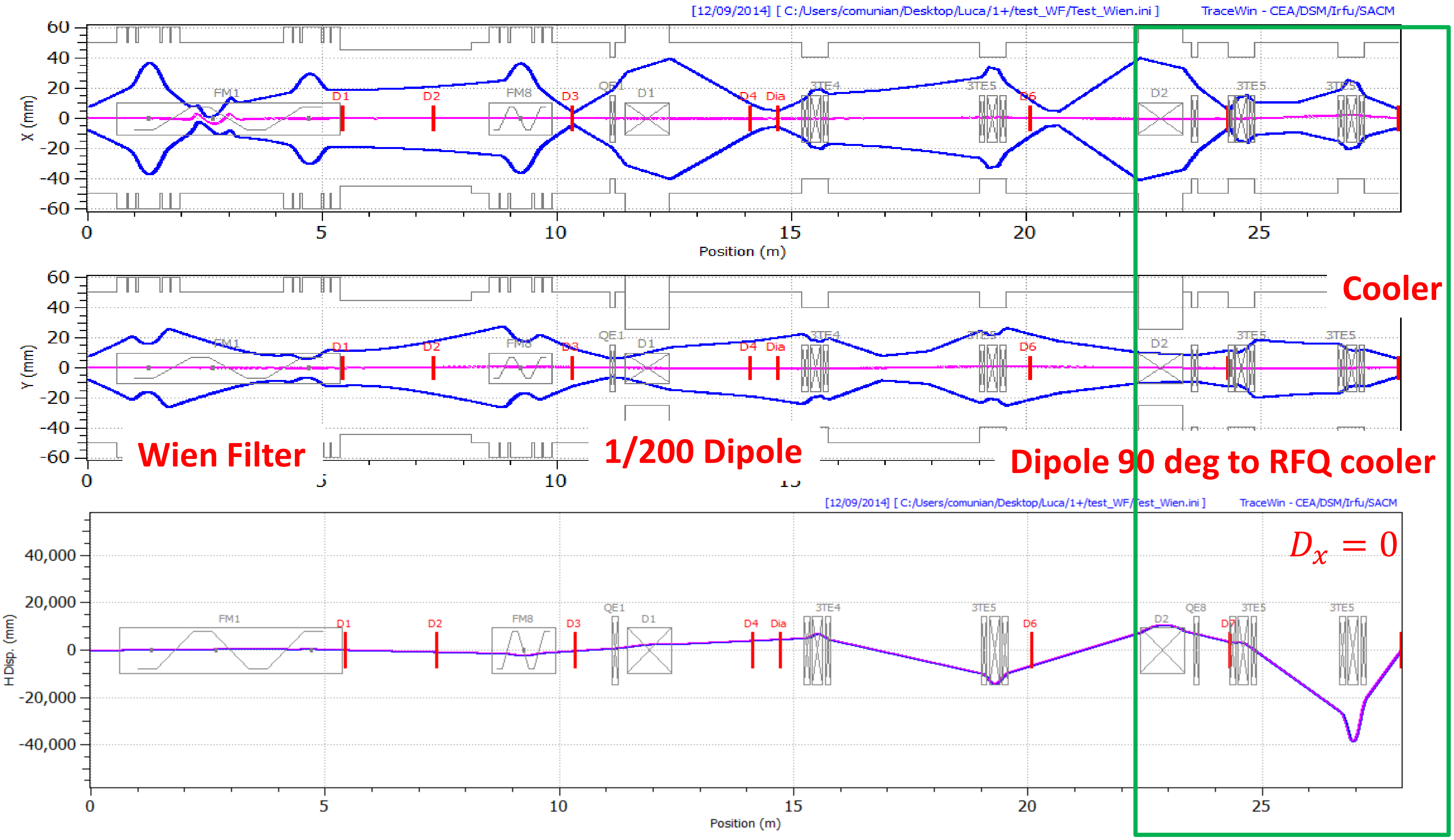
SPES Layout



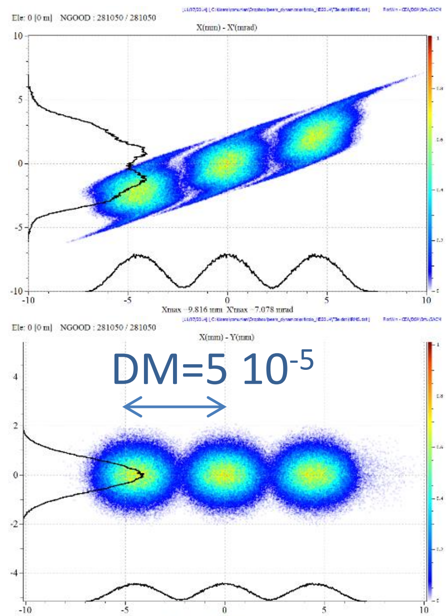
Input used for 1+ Beam:

- Mass 132 A 1+
- Voltage 40 kV
- RMS norm. Emittance 0.007 mmmrad Geom=8.6 mmmrad, Geom 99%=70 mmmrad, ΔE =±20 eV. Brho=0.33088485 Tm
- CEA TraceWin code
- Fields Maps for long Electrostatic quads and Wien Filter. Short triplets with hard edges.

From target to beam cooler



HRMS physics design



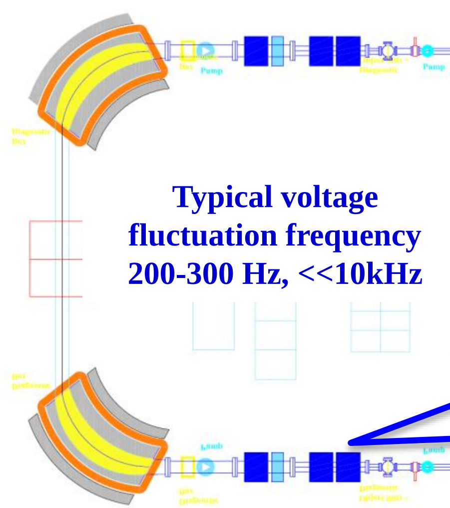
preliminary analysis (LNS-LNL)
Input parameters:
- Energy= 260 KeV
- $\Delta\theta$=4 mrad
- **ΔE= ± 5 eV**
- **Emittance99%=5.7π mm mrad**

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

Ispired to CARIBU-HRMS, ANL (USA)

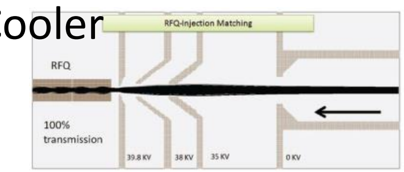
SPES RFQ Beam Cooler parameters

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

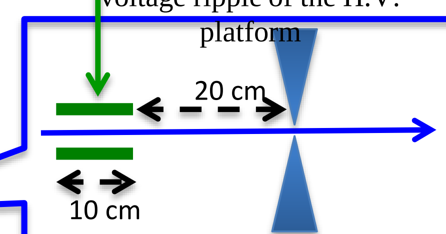


Typical voltage fluctuation frequency 200-300 Hz, <<10kHz

Cooler



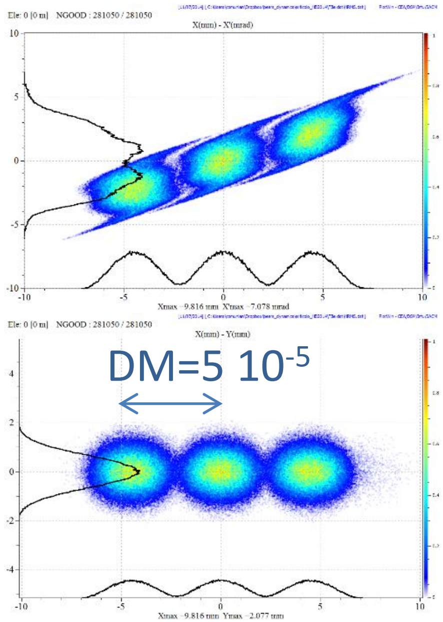
Electrostatic Plates to correct the voltage ripple of the H.V. platform



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

L. Calabretta

HRMS physics design



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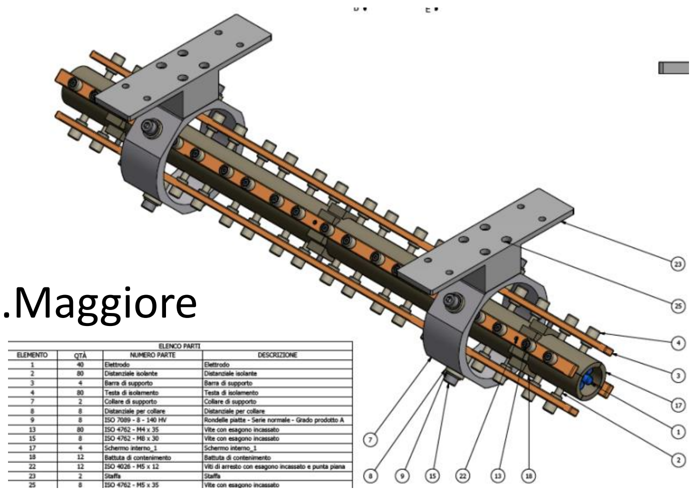
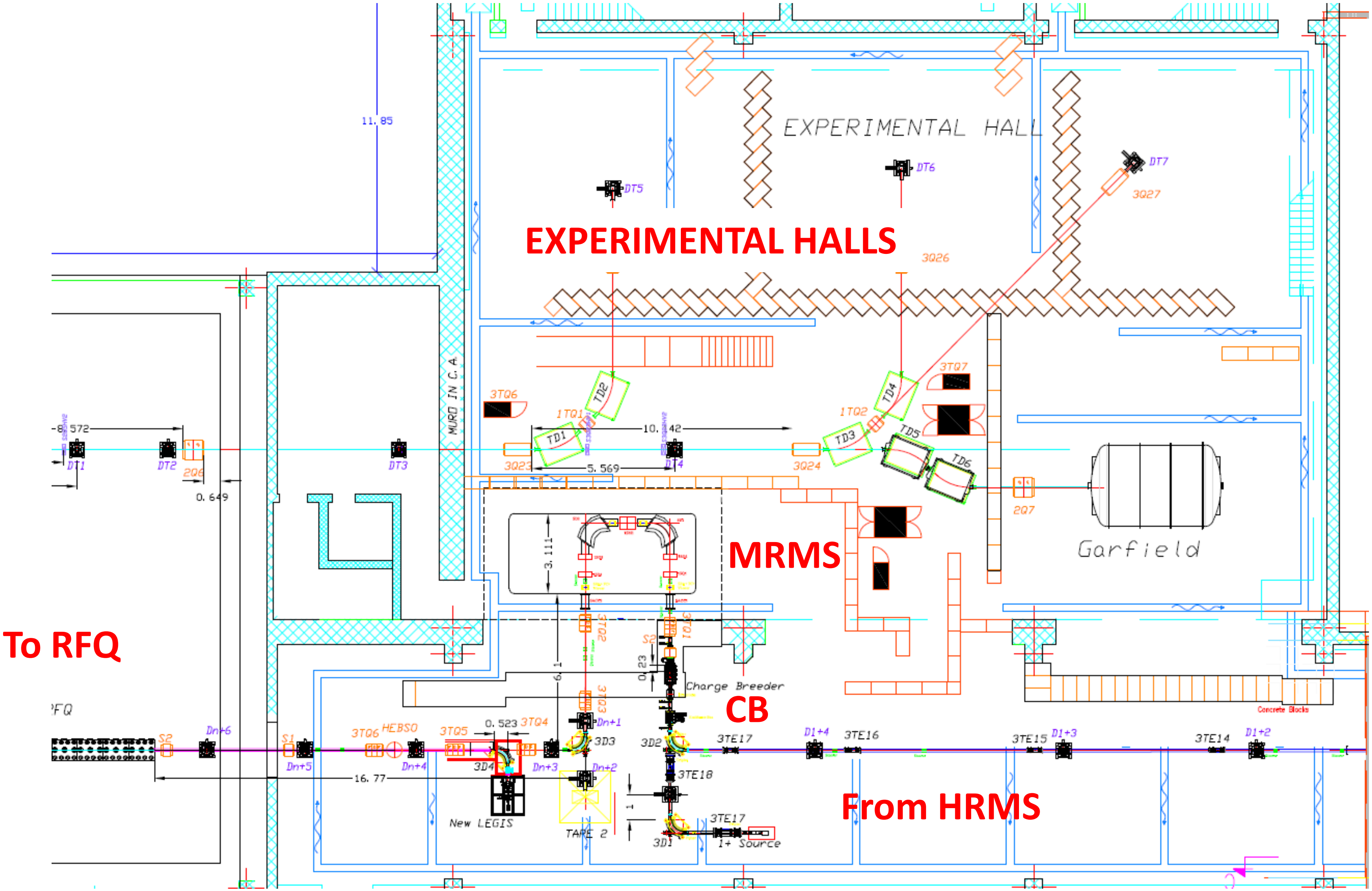
COOLBEAM experiment financed by INFN-CSN5, 2012→2015
Collaboration: LNL-LNS, Mi Bicocca



M.Maggiore

SPES Layout: zoom on 3° hall



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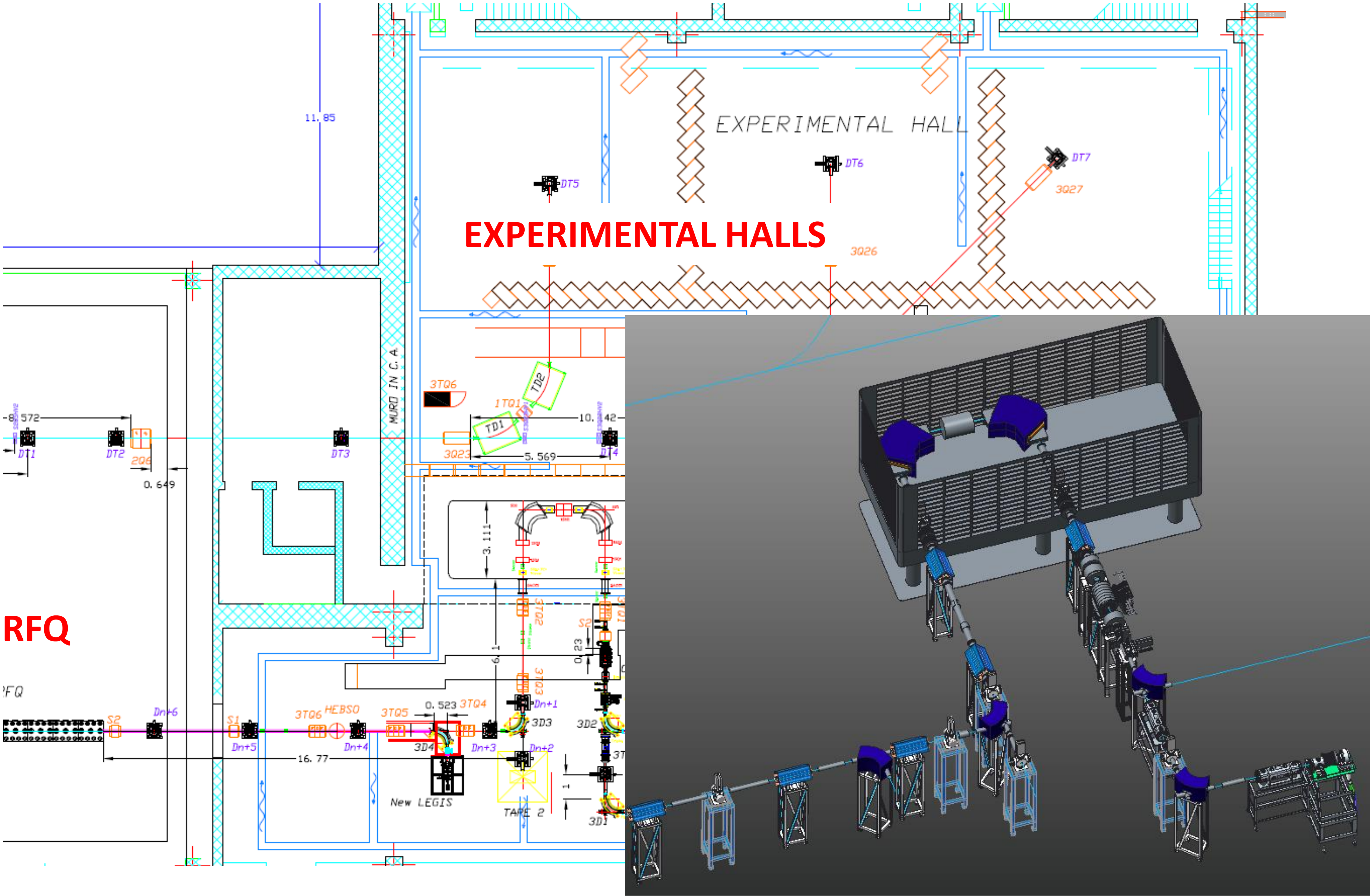
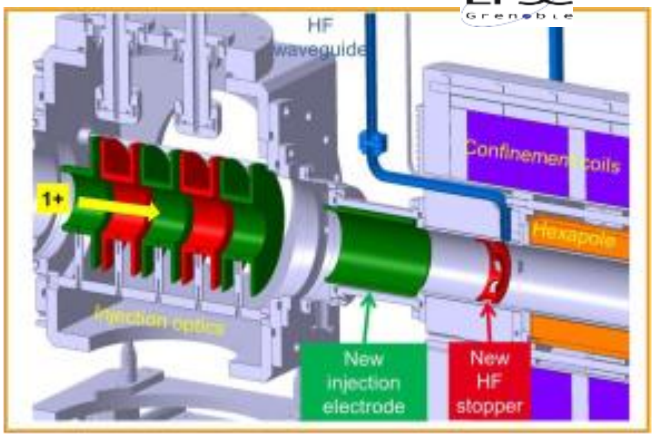


To RFQ

ECR-type Charge Breeder



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

<u>Features</u>: 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 ~<u>14.5 GHz</u> and a maximum power of <u>600 W</u>; operation at <u>18 GHz</u> also possible.

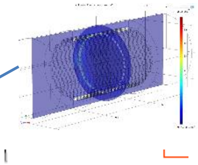
Mass Range			ION	Q	Efficiency [%]	Year Data Source	(M/q)_min	(M/q)_max
		138	Xe	20+ (21+)	10,9 (6,2)	2012 (2005)	6.57	6.90
130	132	134	Sn	21+	6	2005	6.19	6.38
		98	Sr	14+	3.5	2005	7	7
		94	Kr	16+(18+)	12(8,5)	2013	5.22	5.88
90	………..	99	Y	14+	3.3	2002	6.43	7.07
74	………..	80	Zn	10+	2.8	2002	7.40	8.00
	81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

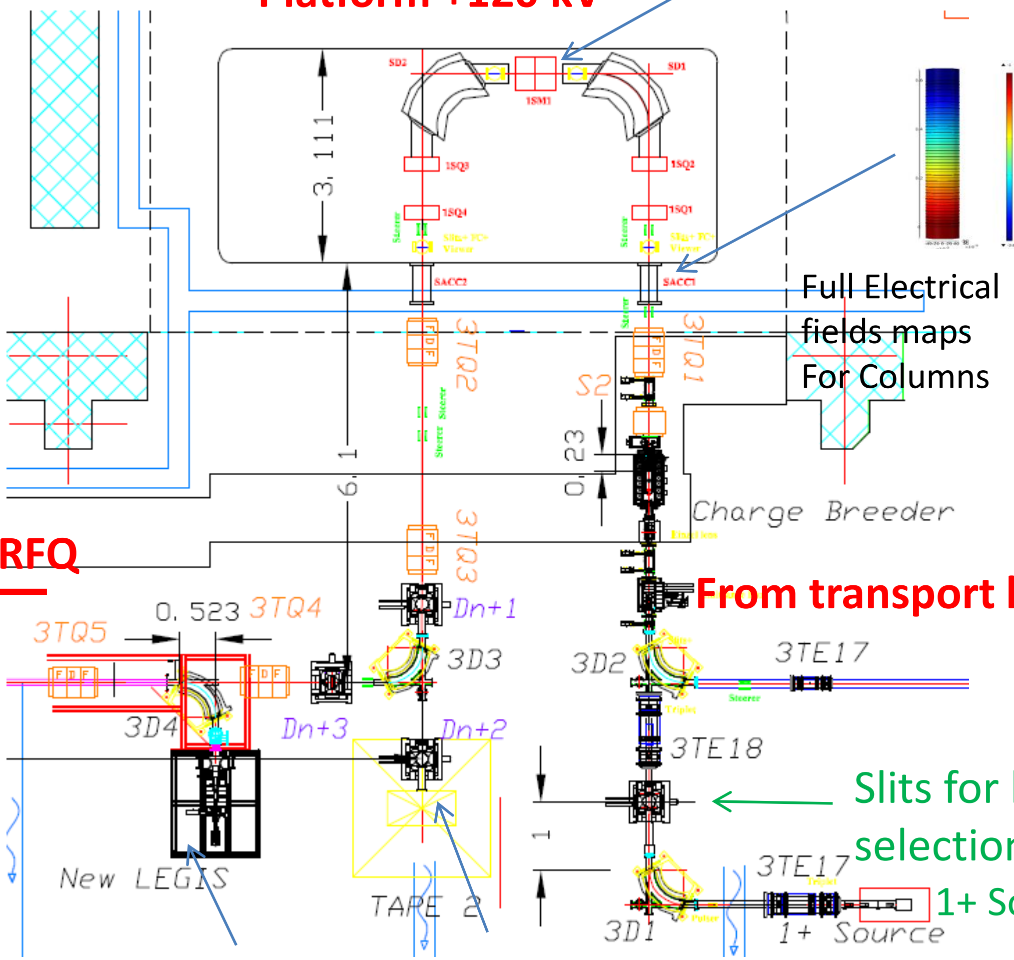
CB and Medium Resolution Mass Spectrometer

Error study performed

Full Electrical fields maps for Multipoles



Platform +120 kV



Full Electrical fields maps For Columns

RFQ

From transport line

Slits for beam selection, 1/166 sep

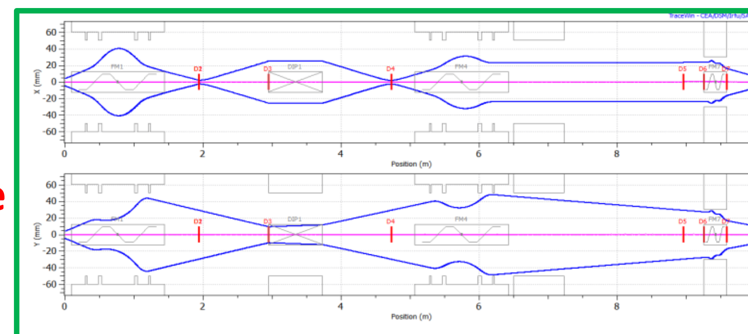
1+ Source for CB tests

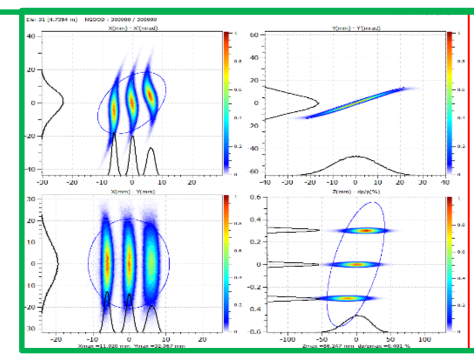
Future Stable Source for ALPI

RIB Diagnostic with TAPE SYSTEM

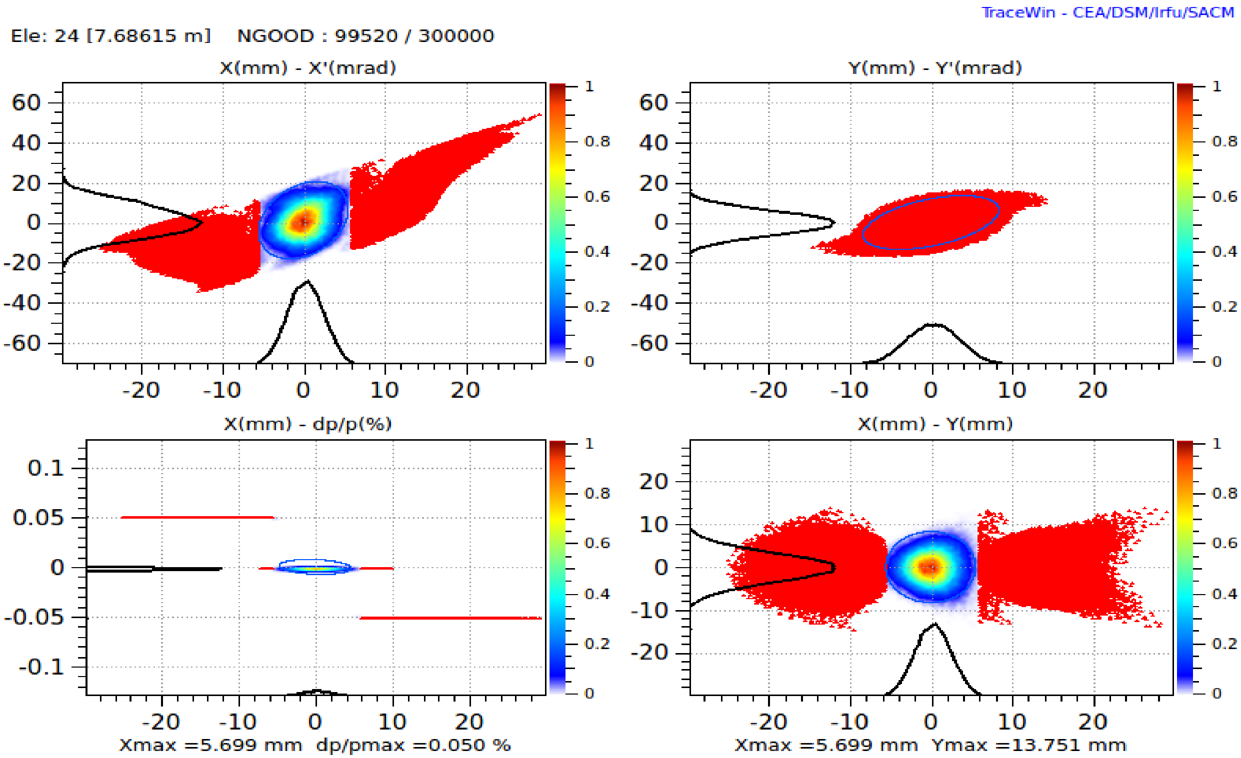
Input: 0.1 rms transverse norm., 28.44 rms geo. Tot geo emittance 222.7 pi mm mrad.

Input Twiss parameters from simulation of CB. Spread of 5 eV.. Brho = 0.076 Tm





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)

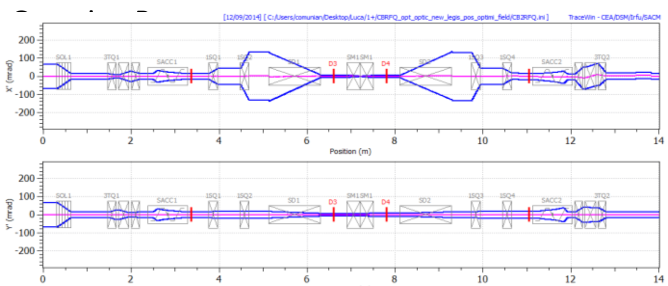
Electrostatic multipoles elements

In the center (bore beam diameter=300 mm

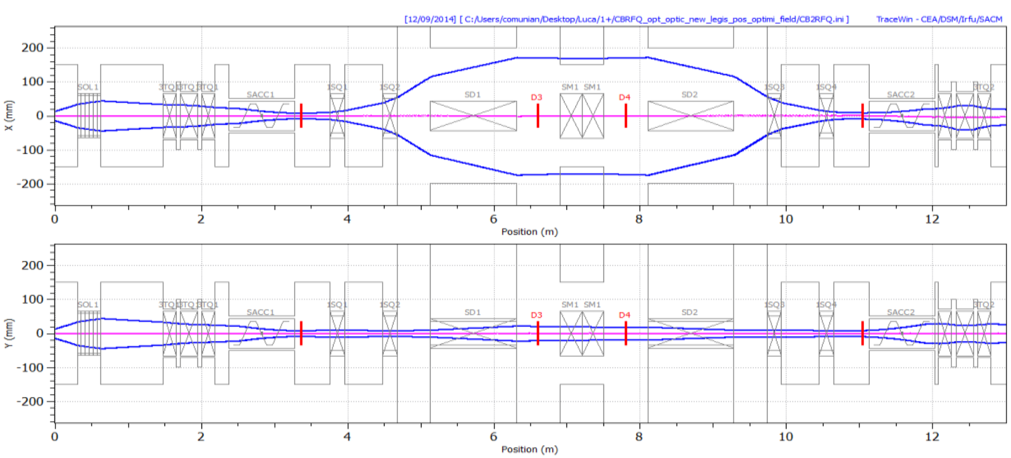
In figure are reported 3 beams, with the same emittance, injected separated by **1/1000** in mass.

After the MRMS the beams are fully separated in X.

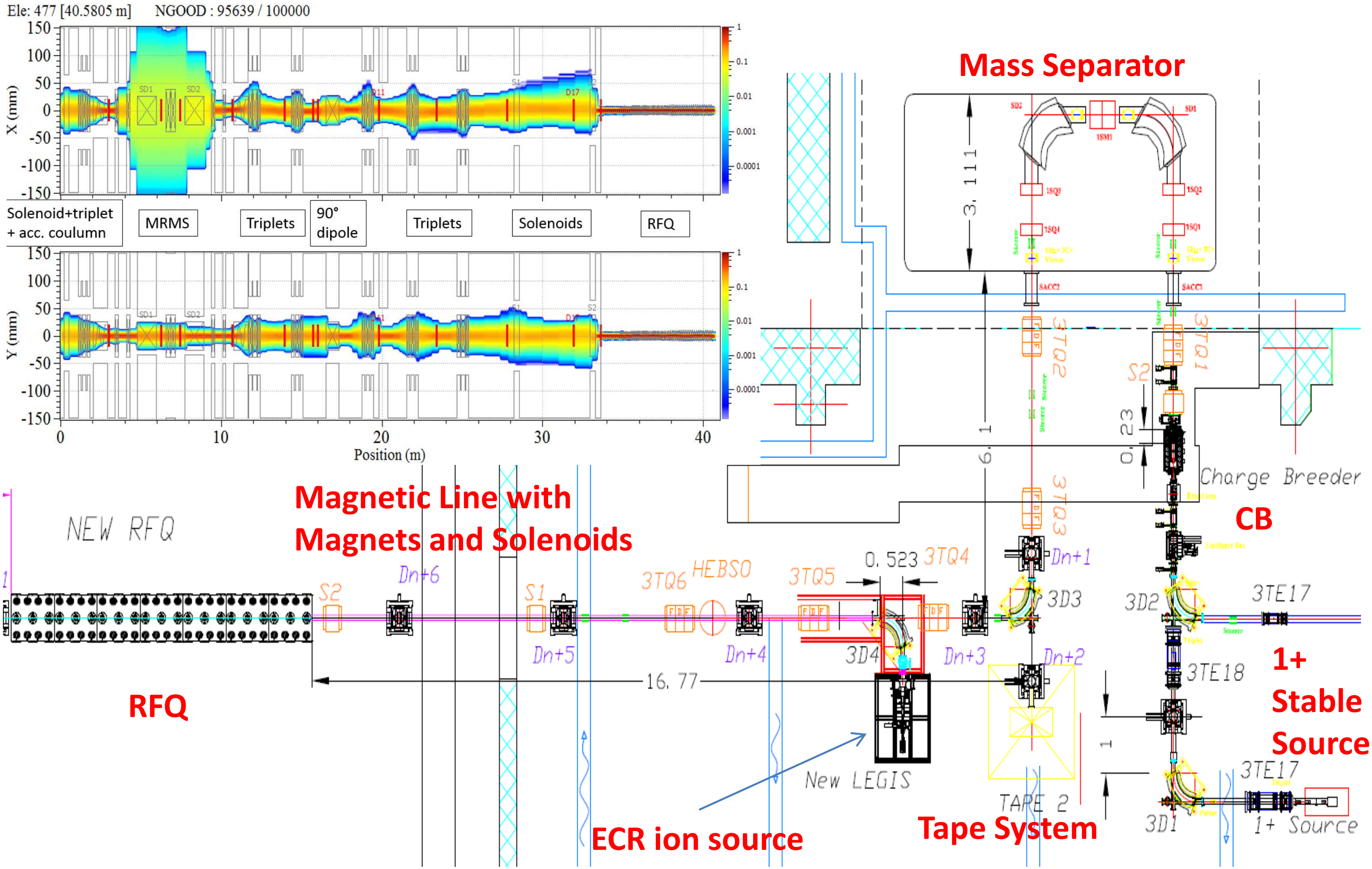
RMS Tr. Norm. Input Emittance 0.1 mmmrad.



Beam Envelopes



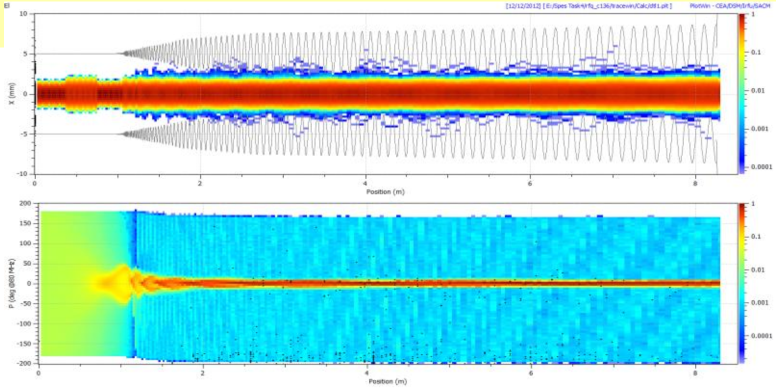
Transport Line to SPES RFQ



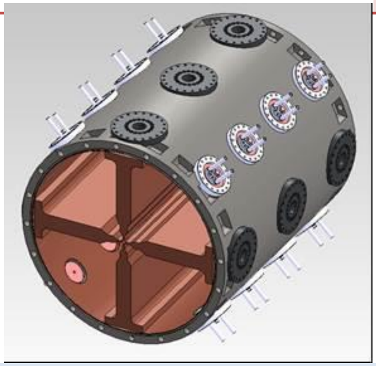
New RFQ Injector for ALPI

- **Energy 5.7 –> 727.3 keV/A** [β=0.0395] (A/q=7)
- **Beam transmission** >95%
- $\varepsilon_{long,RMS,out}$ = 0.15 ns*keV/u.
- **L=695 cm** (6 modules)
- Intervane voltage **63.8 – 85.8 kV**
- **RF power** (four vanes) **100 kW.**
- **Mechanical design** takes advantage of IFMIF experience (LNL, INFN_Pd, Bo, To) **for up to 1 mA**

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)
Accelerated beam current (μA)	100
Charge states of accelerated ions (Q/A)	7 – 3
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
Synchronous phase (deg.)	-90 – -20
Focusing strength B	4.7 – 4
Peak field (Kilpatrick units)	1.74
Transmission (%)	95
Output Long. RMS emittance (mmmrad) / (keVns/u)/(keVdeg/u)	0.055 / 0.15 / 4.35



See Talk of A. Palmieri



Mechanical layout of the RFQ (tank module ≈1.2 m)

New RFQ Injector for ALPI

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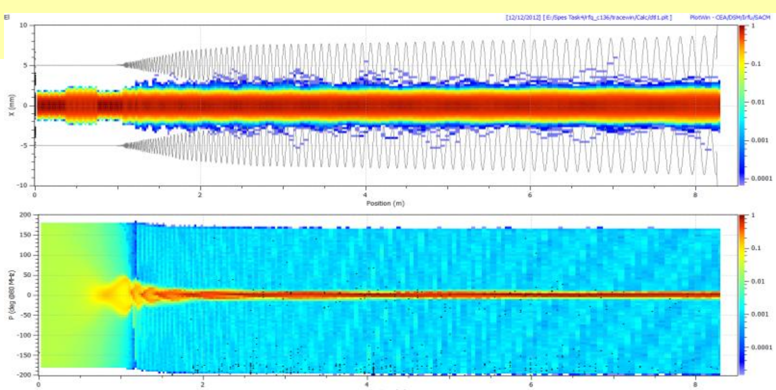
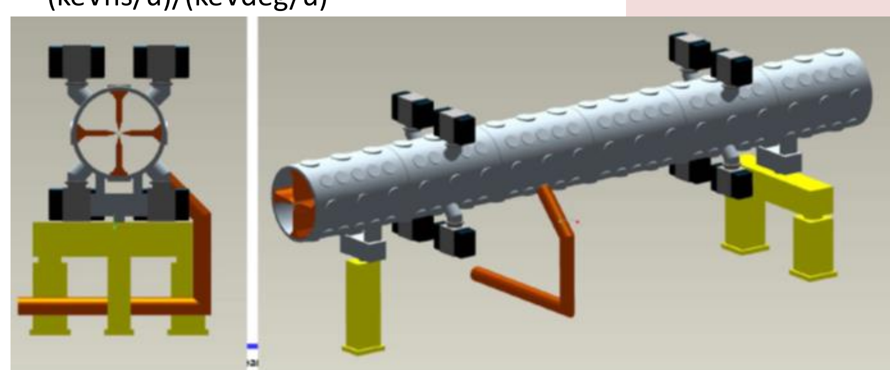
Transmission (%)	95
Output Long. RMS emittance (mmmrad) / (keVns/u)/(keVdeg/u)	0.055 / 0.15 / 4.35



See Talk of A. Palmieri



Mechanical layout of the RFQ (tank module ≈1.2 m)

SPES RFQ

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

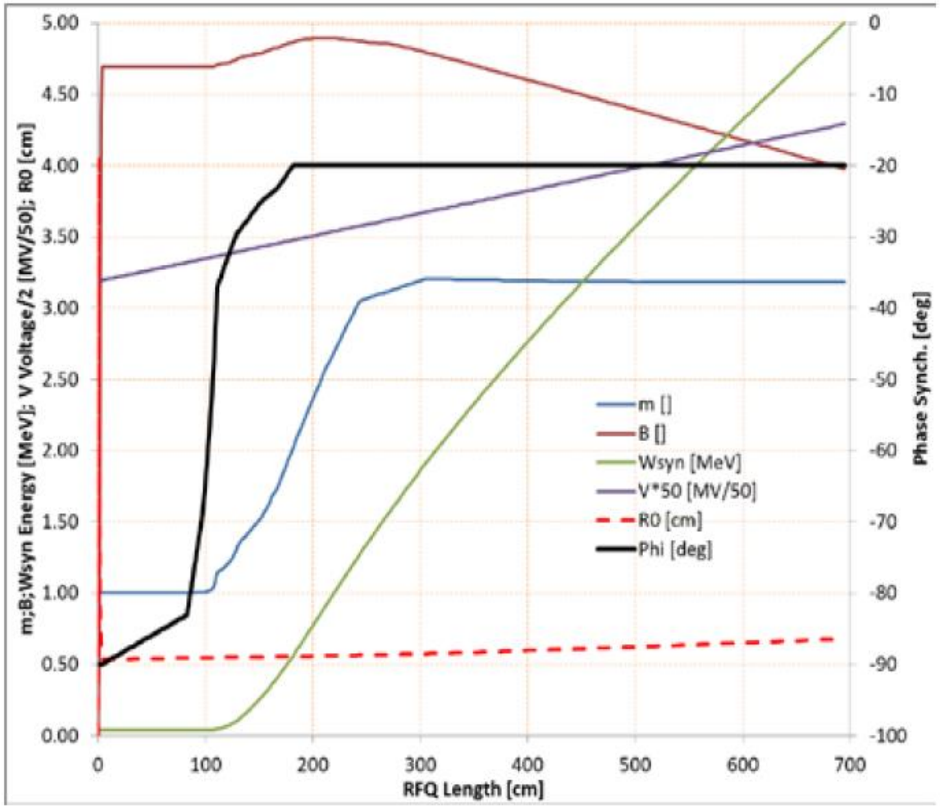
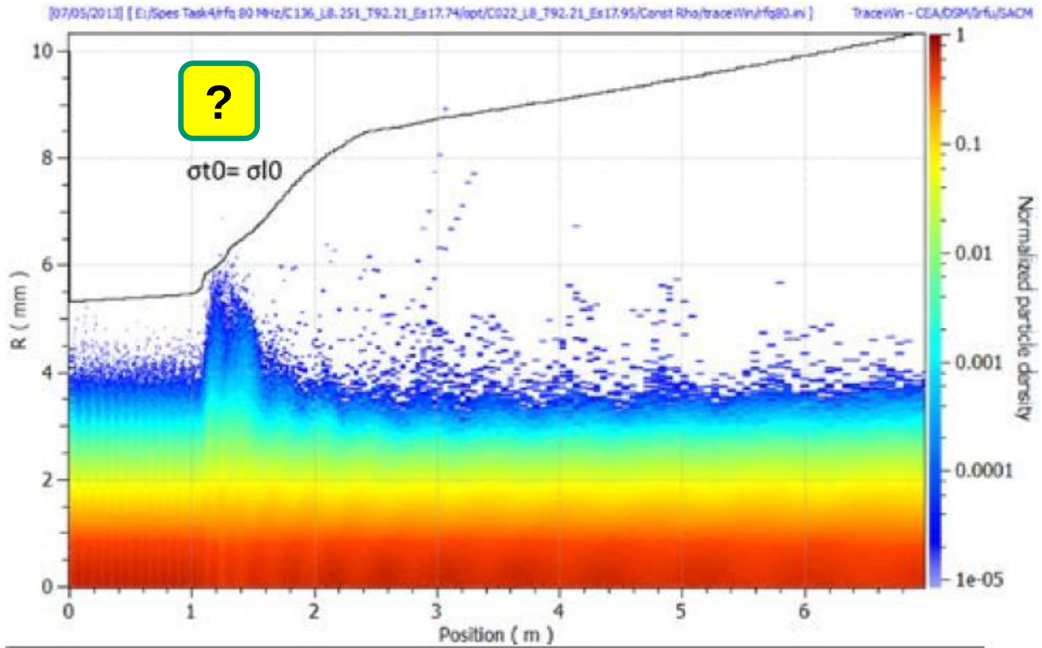
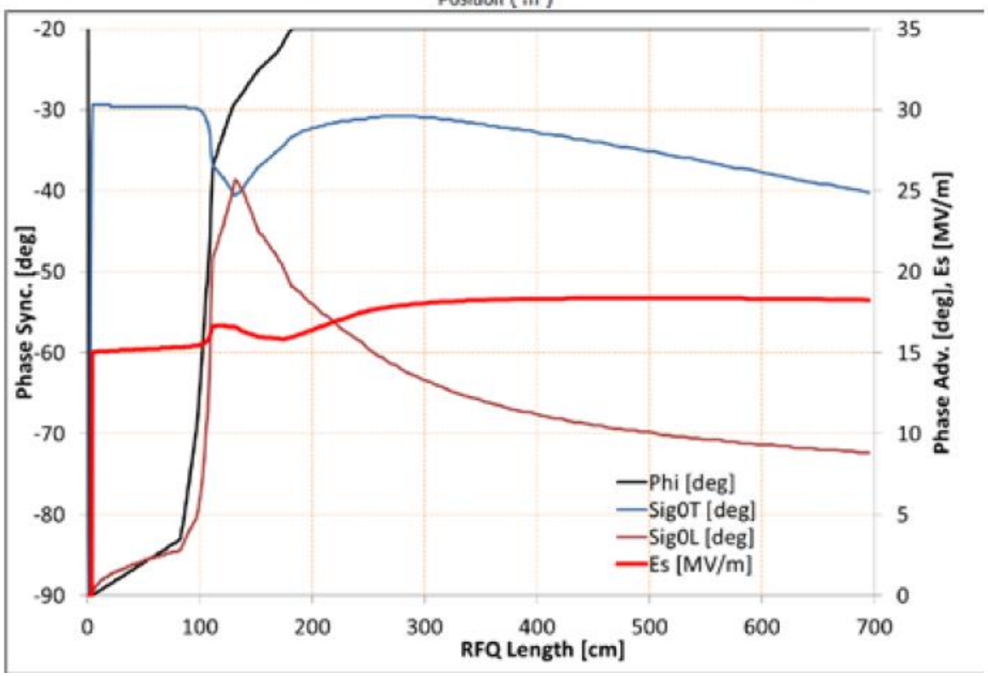


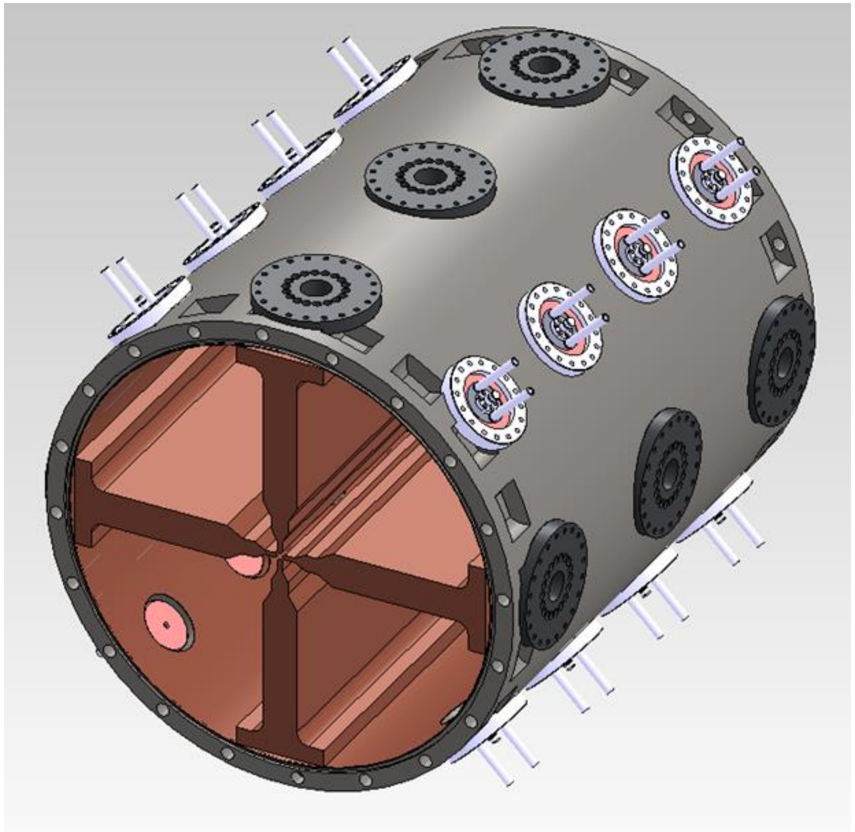
Figure 1: The main RFQ parameters vs. length.

Design parameters





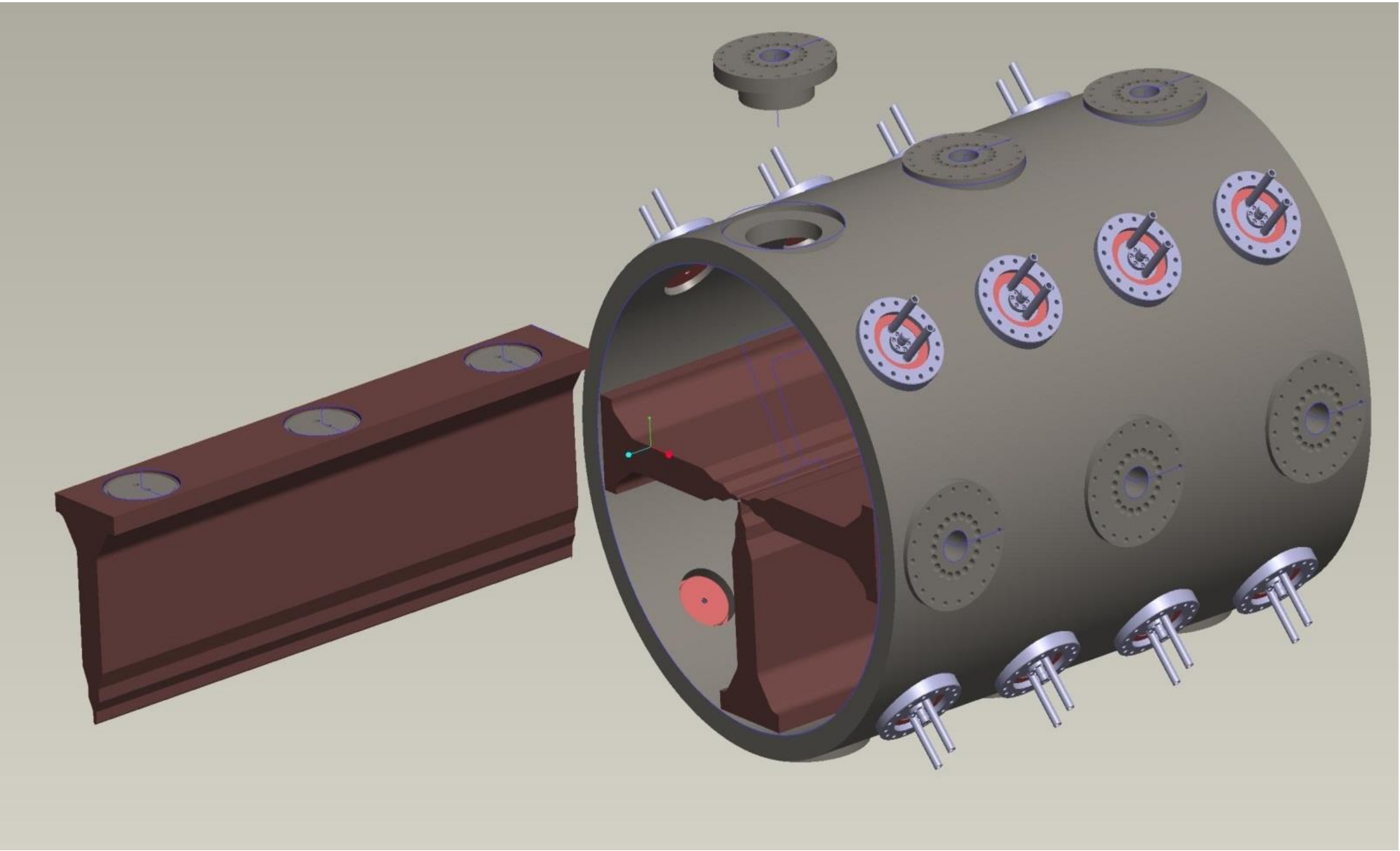
RFQ Mechanical concept



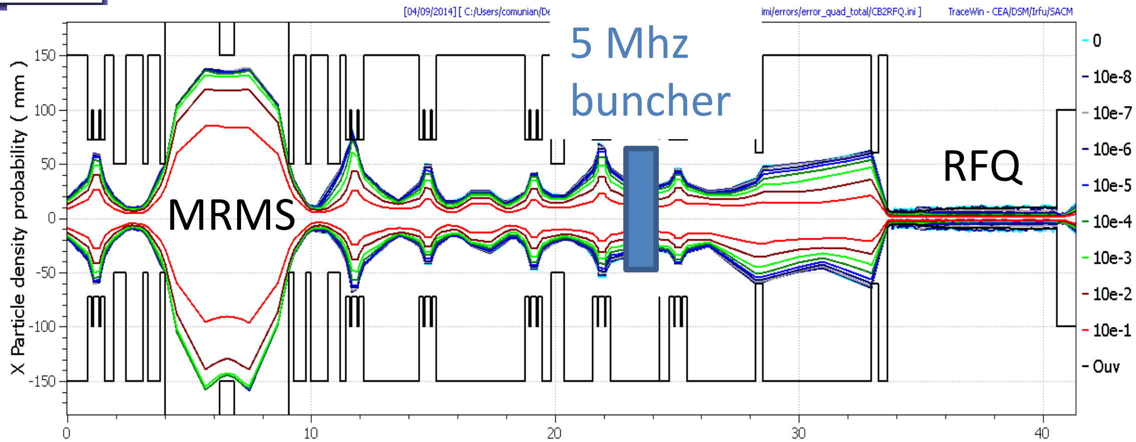
Bolted electrodes, copper plated 304L tank, metallic circular joints, brazing of electrodes and other components before assembly

Tank inner radius 375 mm, 40 mm thickness

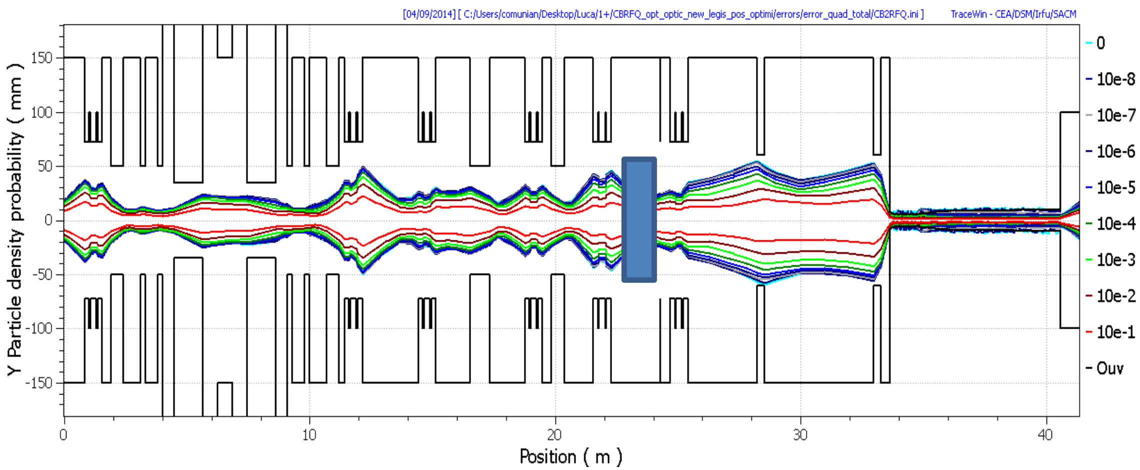
Electrode assembly concept



BD from CB to end of RFQ

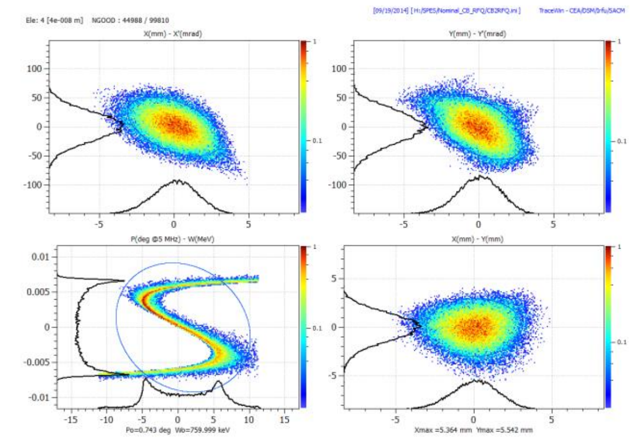


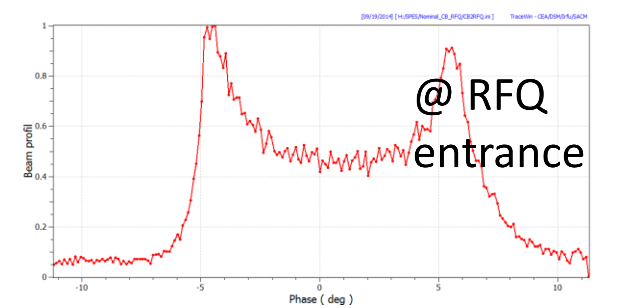
Total amount of space occupied by the beam due to quad errors



To be compared with the case without buncher: total losses 93-94 % after the RFQ, output longitudinal emittance 0.067 .

IF 5 MHz buncher on:

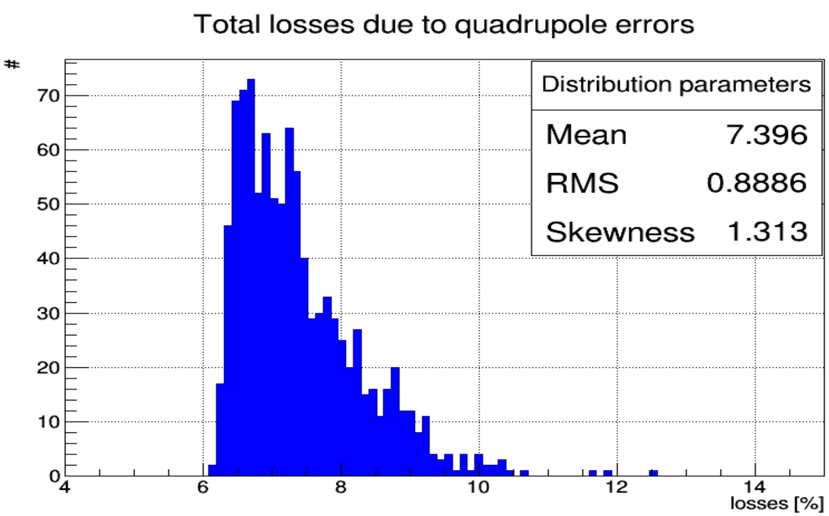


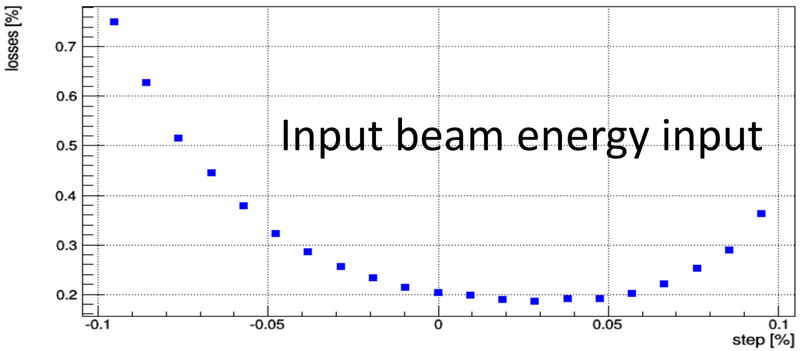


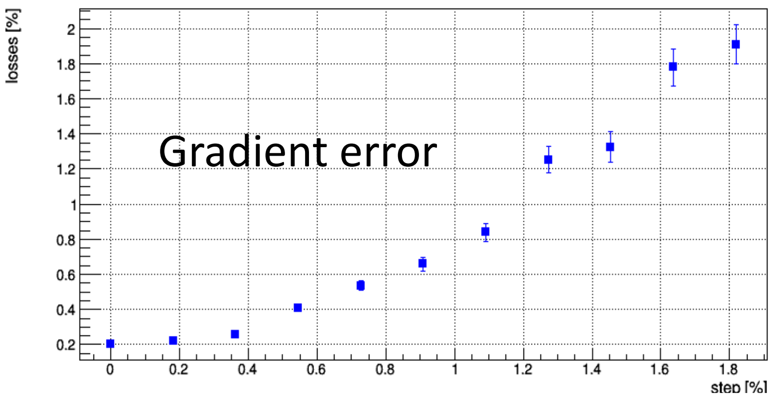
Transmission 45 % chopper,
Transmission RFQ output 43%
emittance long rms 0.0371
π *mmmrad*

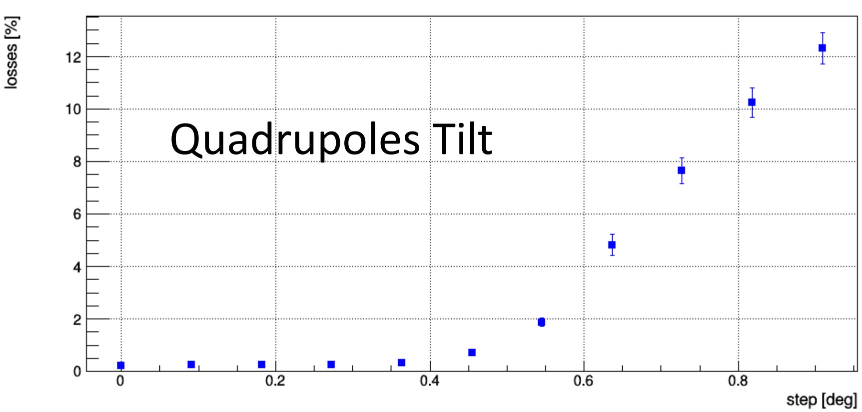
Beam Optics of Transport line from CB via RFQ with static errors study

Quad error type	Values
Misalignement	
Tilt	0.15
Gradient error	0.3%
Multipolar components	0.3%



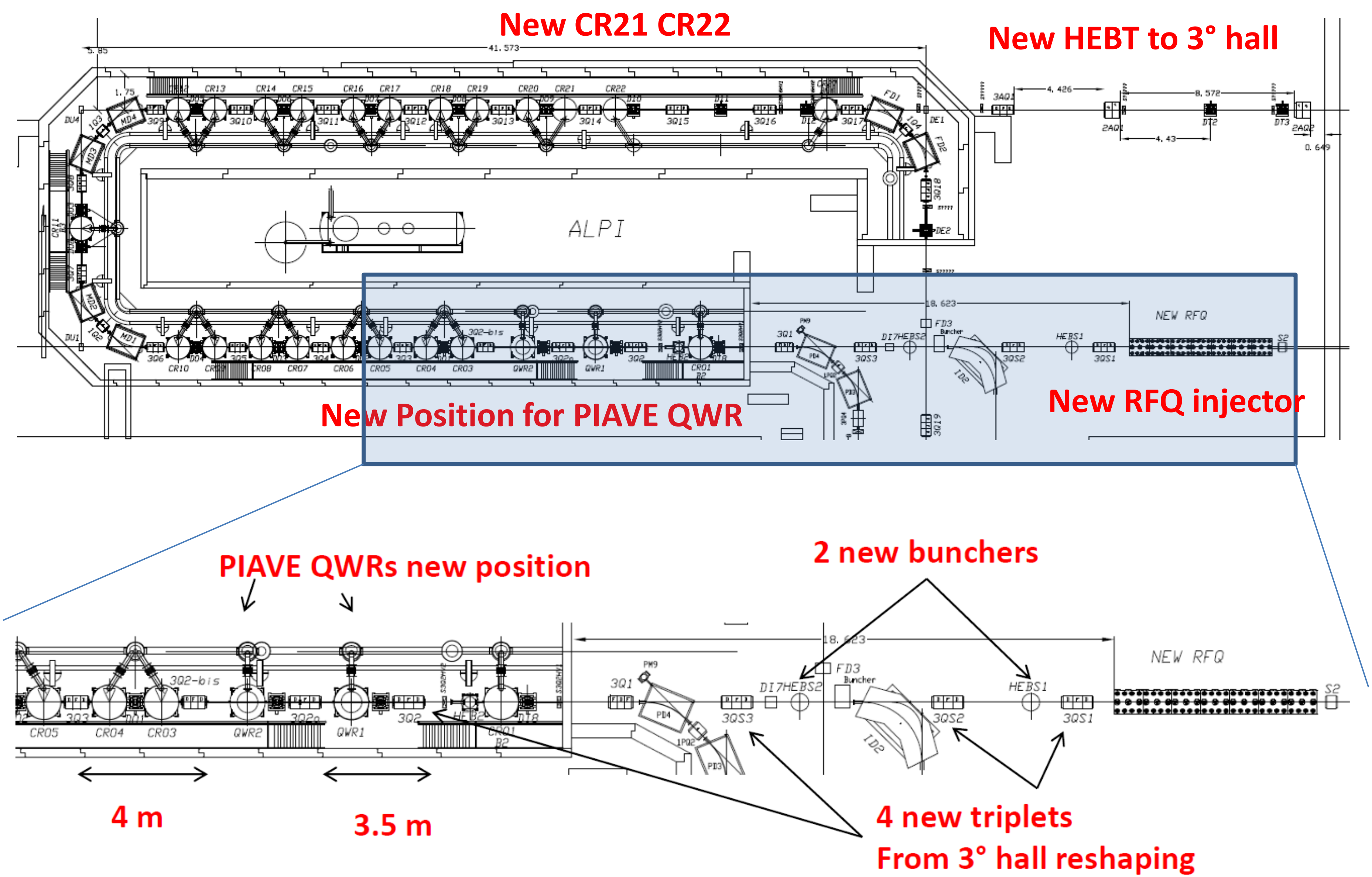






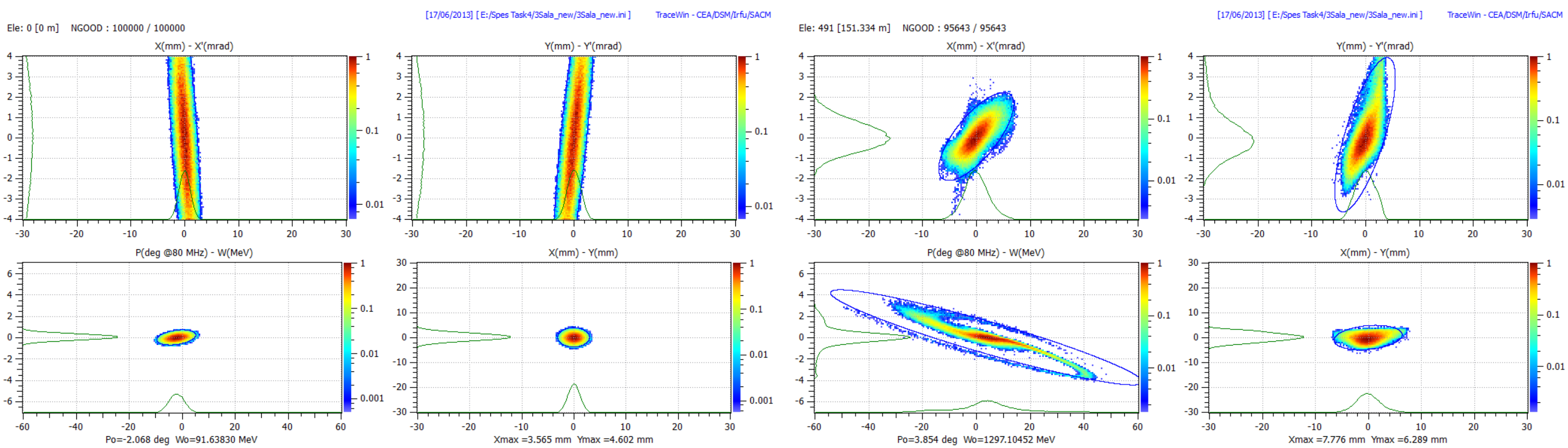
With this set of Errors we get an average of 7.4% of losses out of RFQ

SPES Layout: zoom on ALPI LINAC



ALPI LINAC for SPES case A/q=7

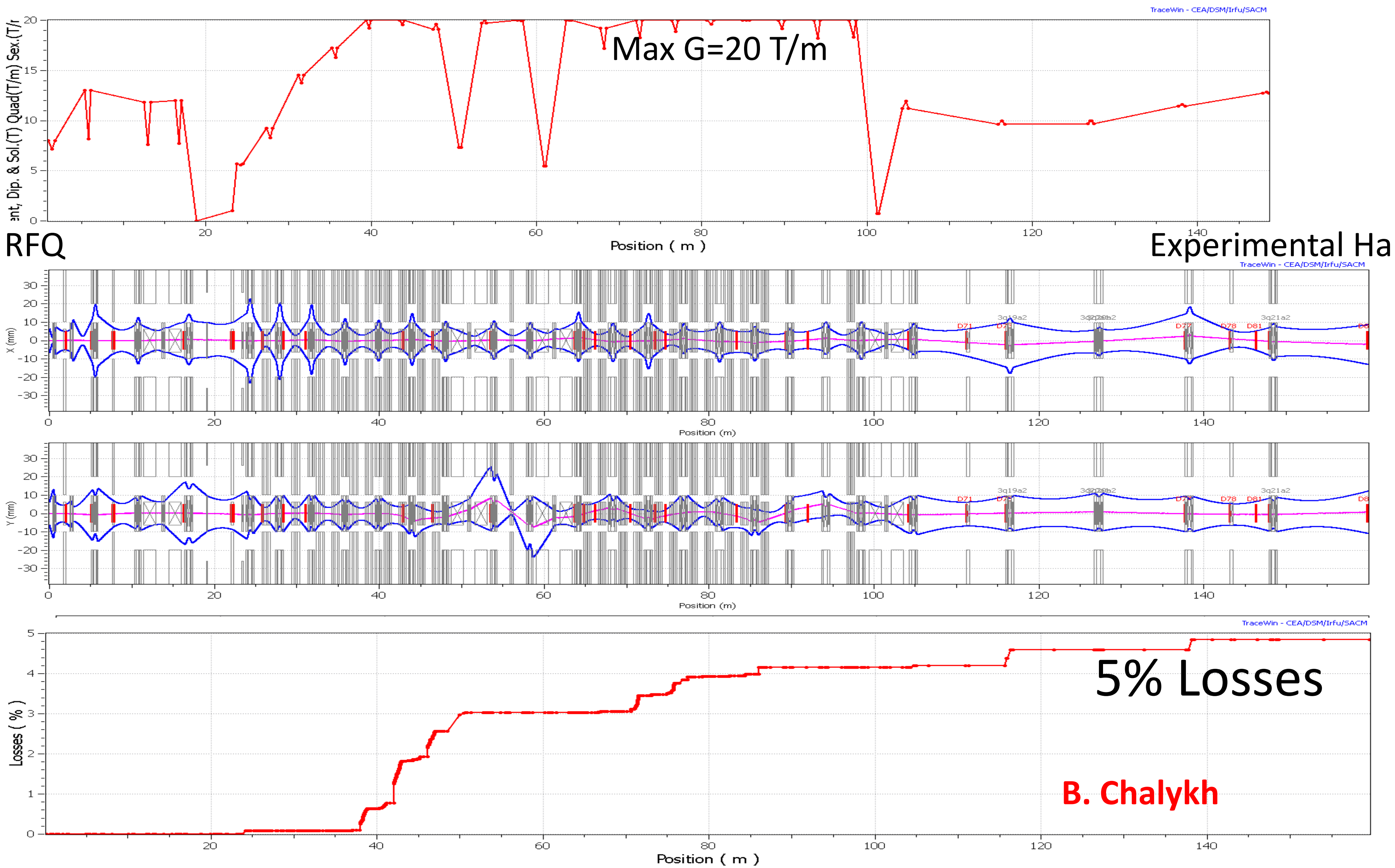
- Input energy from new RFQ: 93.9 MeV (β=0.0395) = 0.711 MeV/A.
- Output energy from CR21: 1285 MeV (β= 0.143) around 9.7 MeV/A.
- Input Transverse emittance of 0.12 mmmrad RMS norm.
- Global transmission from CB to Experimental Hall: 0.95 (RFQ)*0.95(ALPI)=0.9=90%.
- Simulation software: Tracewin with full RF fields Maps for cavities.



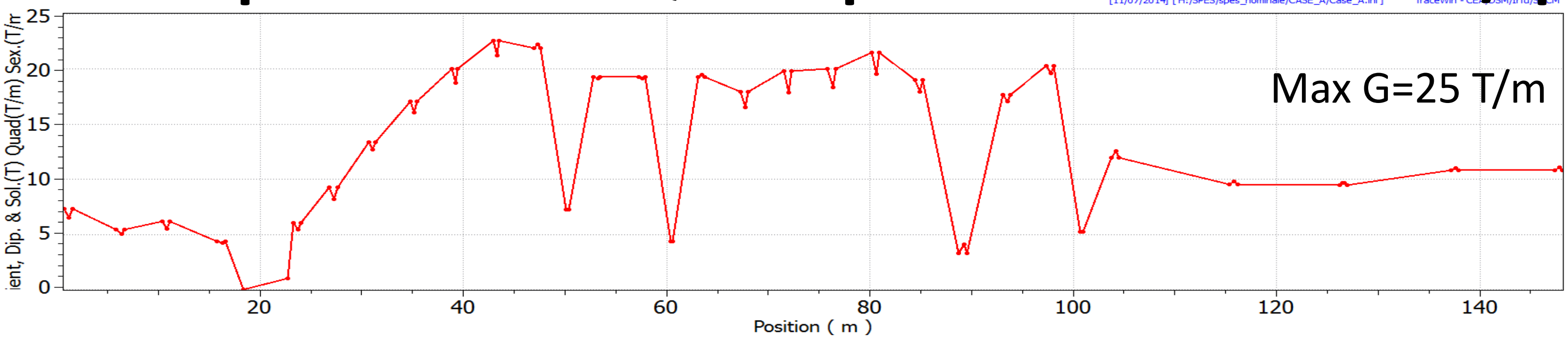
ALPI Input Phase Space

ALPI Output Phase Space

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

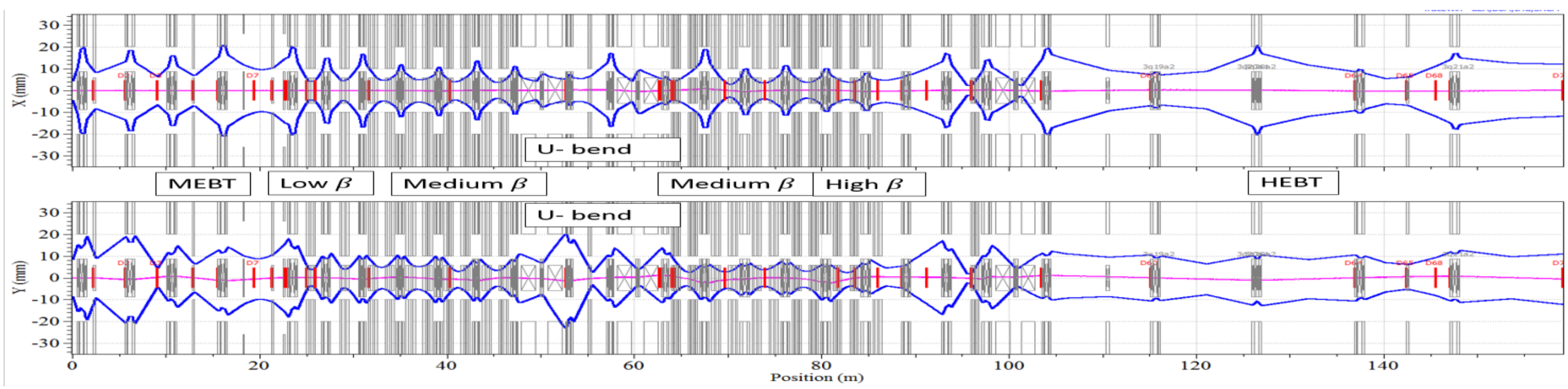


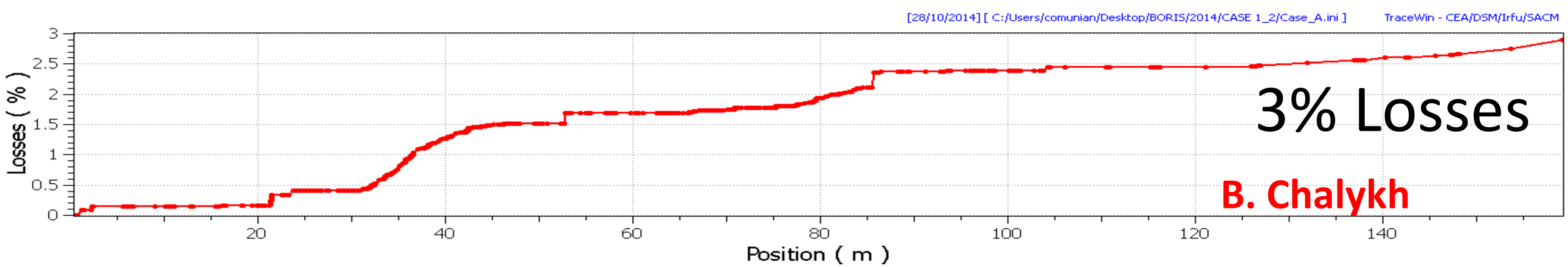
Beam Optics from RFQ to Experimental Hall for A/q=7



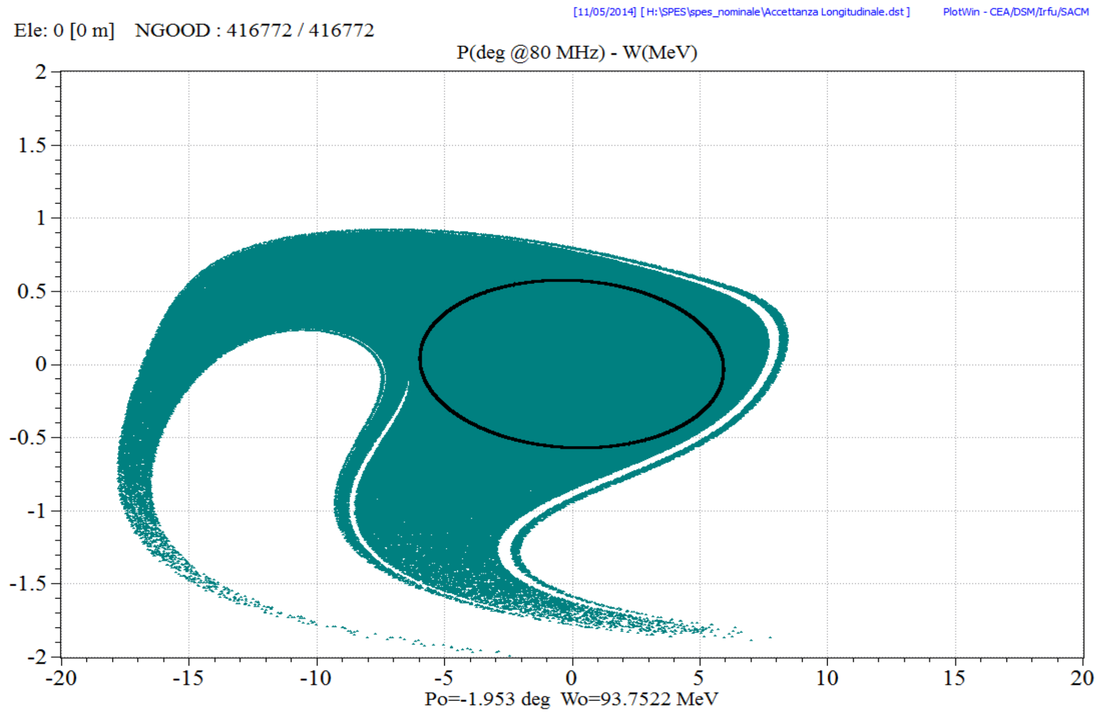
RFQ

Experimental Hall

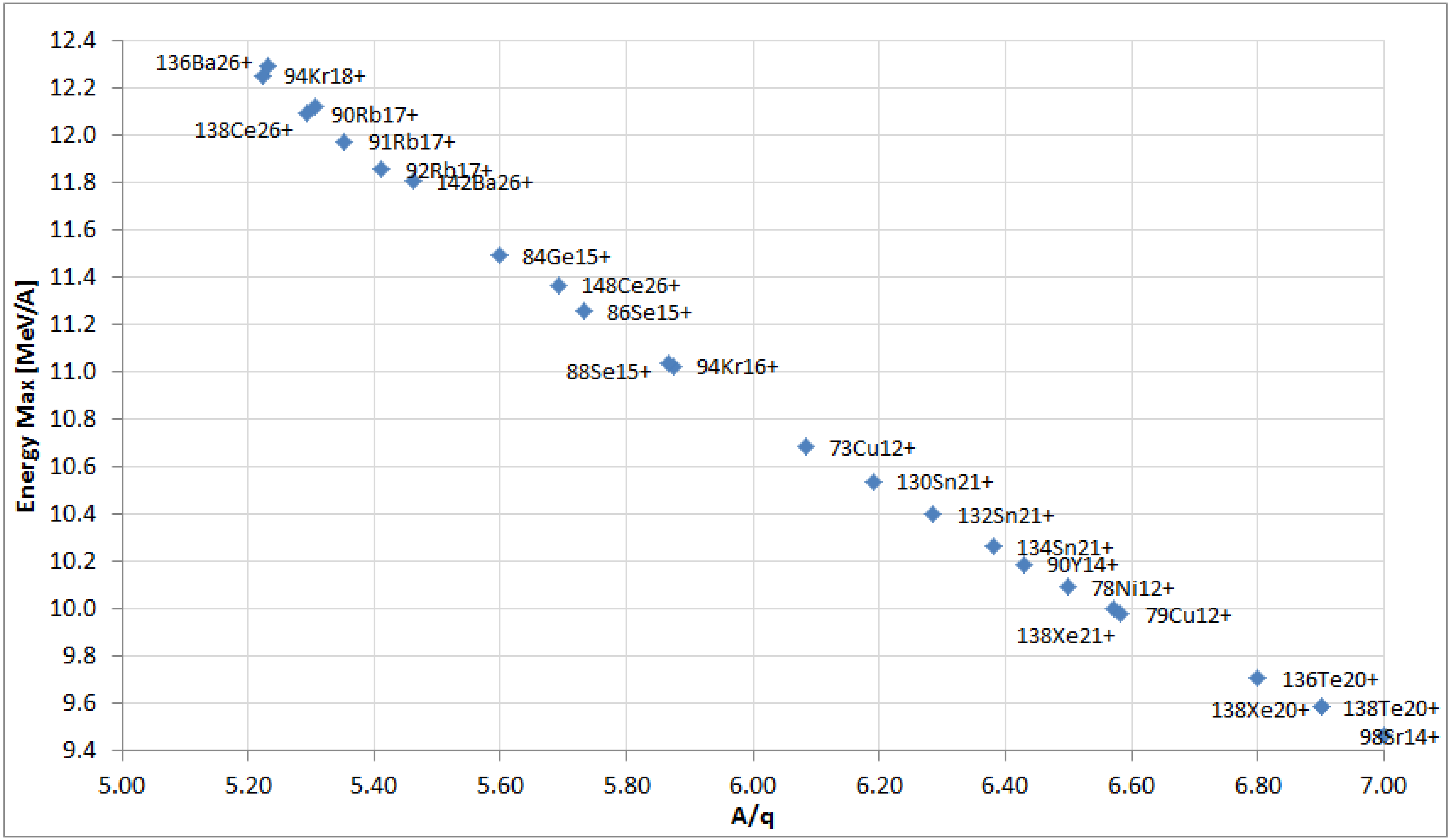




ALPI long acceptance plot



Energy from SPES Post-Accelerator as function of A/q



Preliminary results from alpi performances with 2 cavities off (margin), Low Beta=5 MV/m, Medium Beta=4.3 MV/m, High Beta=5.5 MV/m

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.
- SPES cyclotron and building will be delivered March 2015
- The mechanical design of RFQ and HRMS will be completed during 2015; procurement procedure will follow within 2015.

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

The background

INFN Laboratori Nazionali di Legnaro

ALPI PIAVE accelerates ions up to Gold, energies up 10 MeV/u, is the largest superconducting linac for ions in Europe


ALPI tunnel


Inside the cryostat


Superconducting RFQ

Legnaro

INFN organization

INFN Organization for the accelerator constructio

Three projects are active in this moment for the development of high intensity linear accelerators in INFN

IFMIF EVEDA (International Fusion Material Facility)

MUNES (Multidisciplinar Neutron Source)

ESS (European Spallation sources) design

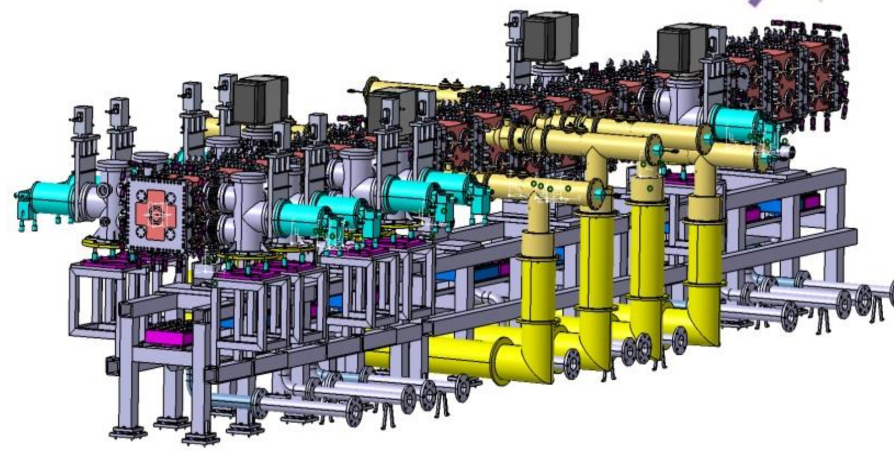
About 30 persons involved, 20 FTE, 10 dedicated contracts, dedicated funds from MIUR of about 30M€

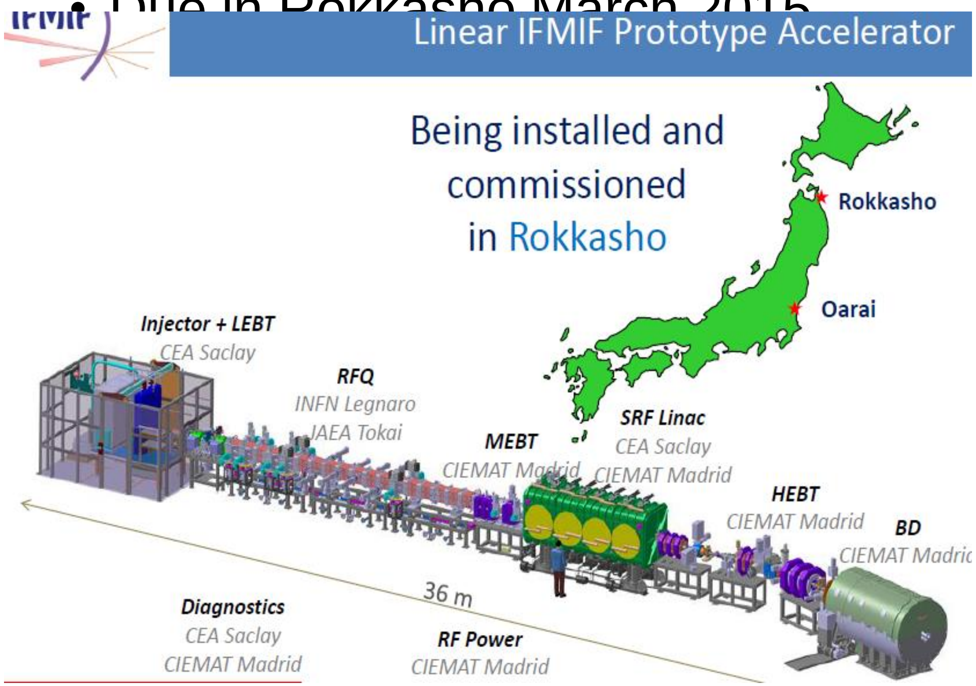
The sections indicated in the map are involved

INFN organization

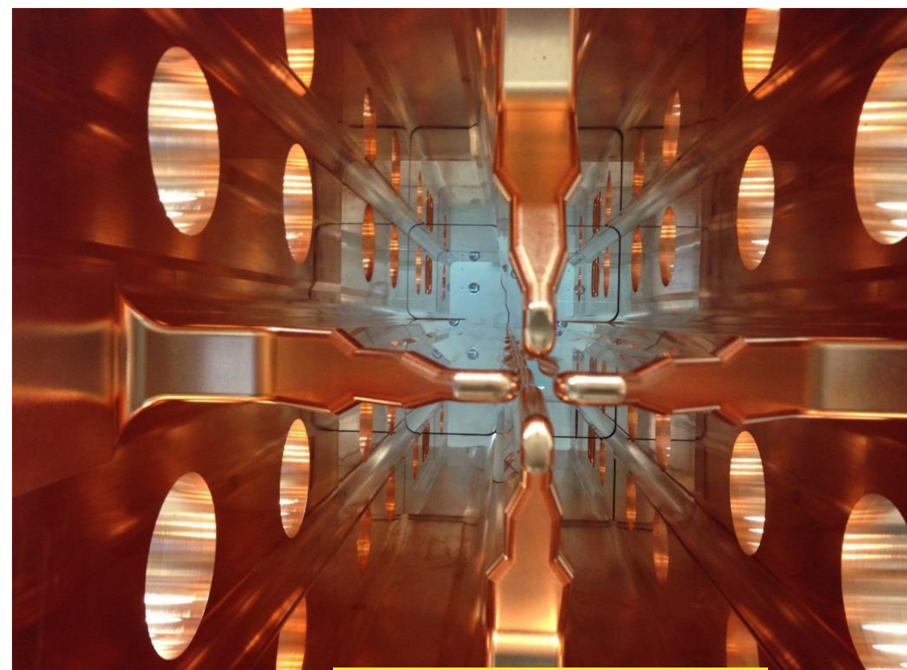
IFMIF-EVEDA RFQ (built by INFN)

- The most powerful RFQ beam (650kW)
- 130 mA deuterons accelerated
- 5 MeV final energy
- 9.8 m length, 18 brazed modules
- Due in Rokkasho March 2015



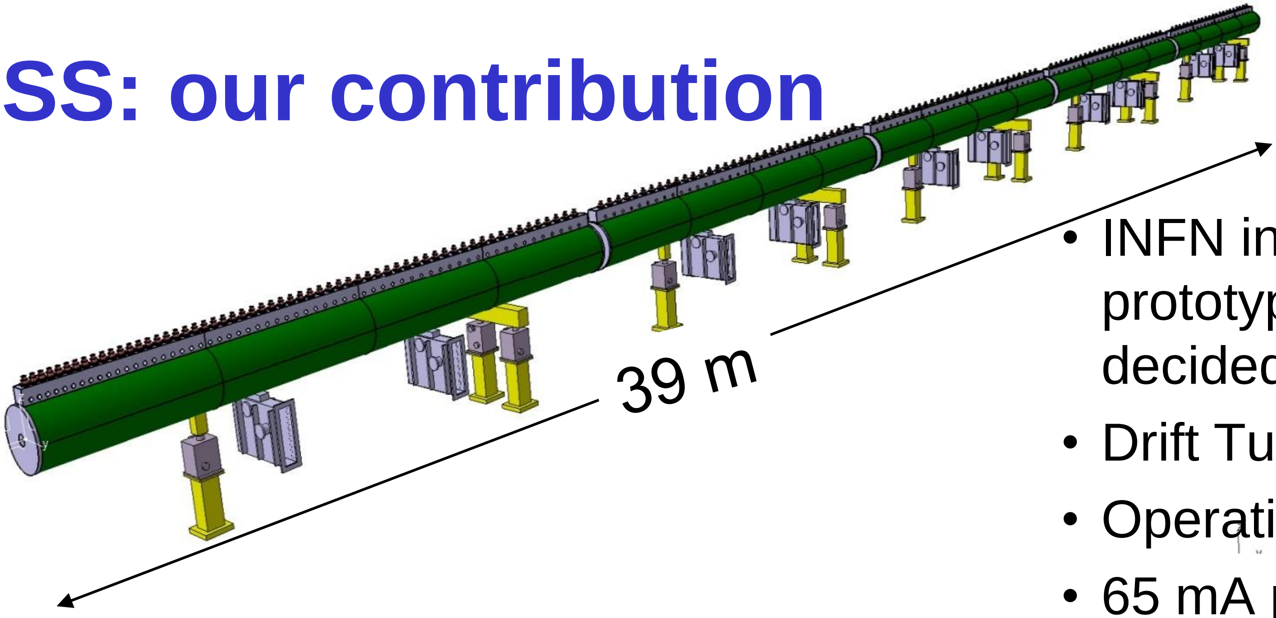


The 130 mA 9 MeV prototype built in EU and commissioned in JA



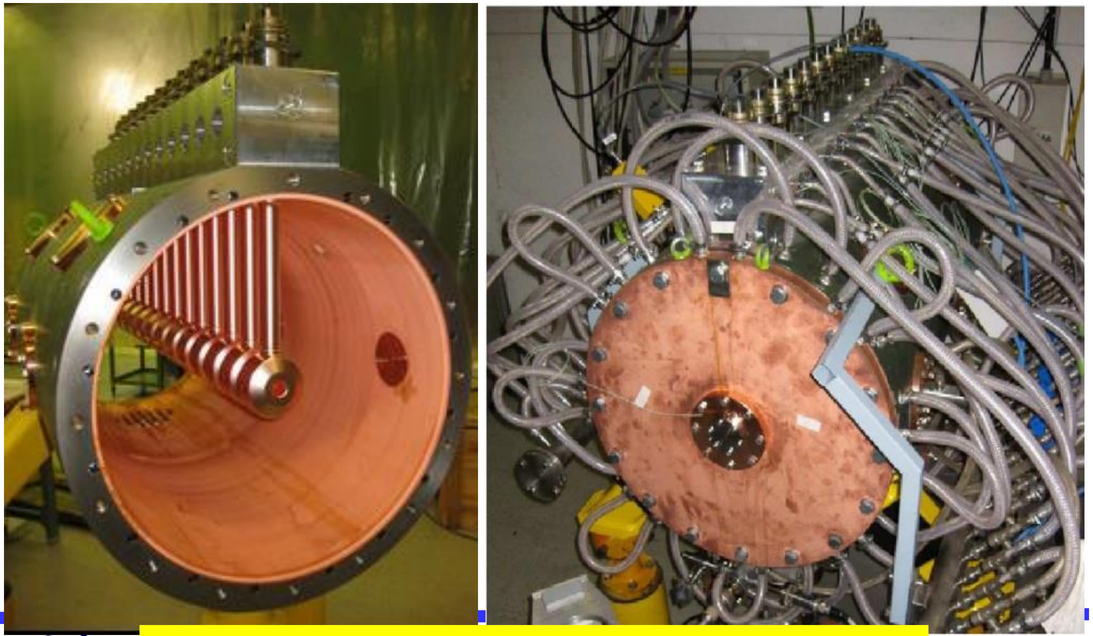
RFQ inside view

ESS: our contribution

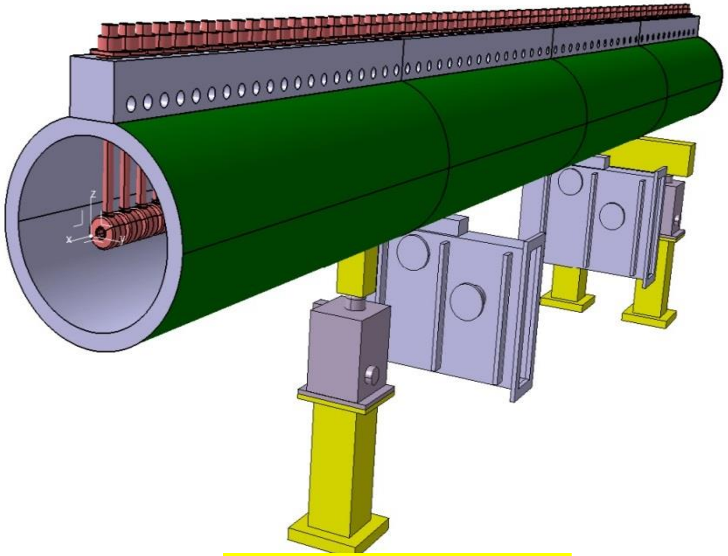


EUROPEAN SPALLATION SOURCE

- INFN in charge of design and prototypes, in kind contribution to decided in the next months
- Drift Tube Linac (3.6-90 MeV)
- Operating frequency 352.2 MHz
- 65 mA protons
- Duty cycle up to 7%

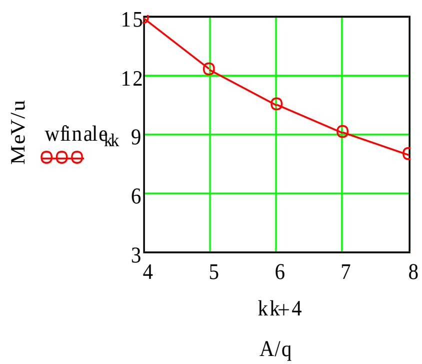


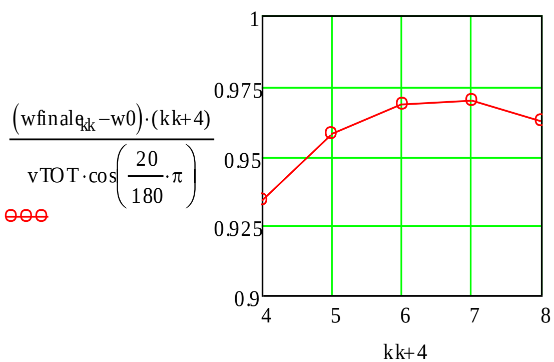
CERN-INFN prototype



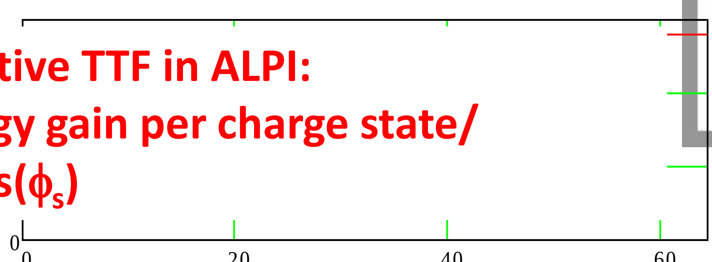
First tank

Choice of A/q





A/q



Effective TTF in ALPI:
Energy gain per charge state/
VTcos(ϕ_s)