# The layout of the SPES Facility for RIB selection and acceleration

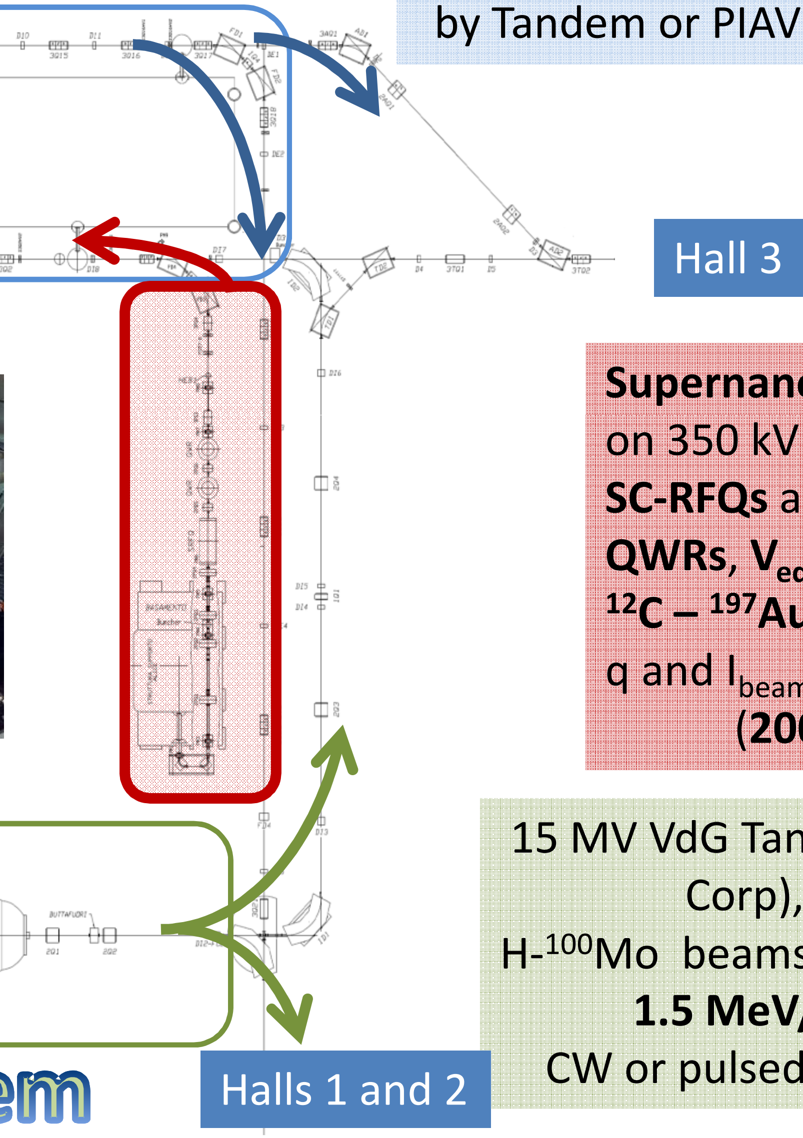
M. Comunian

# Outline

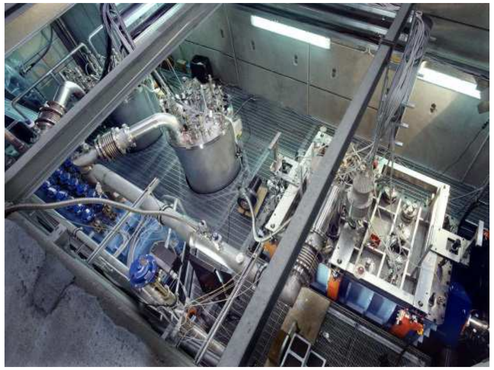
– Present day stable beam facility Overview.
– SPES Global Overview.
– From Target to RFQ Cooler.
– High Resolution Mass Spectrometer.
– Transport line from By pass to CB.
– Charge Breeder.
– Medium Resolution Mass Spectrometer.
– Transport Line to SPES RFQ.
– SPES RFQ as new injector for ALPI.
– NEW ALPI layout for SPES.

**SC Linac** with **QWRs** (Nb, Nb/Cu) at 4,5K in 19 cryostats **$V_{eq}$ ~ 48 MeV/q**, beams **from $^{12}$C to $^{197}$Au**, injected by Tandem or PIAVE (**1994**)

# SC Linac ALPI




# PIAVE

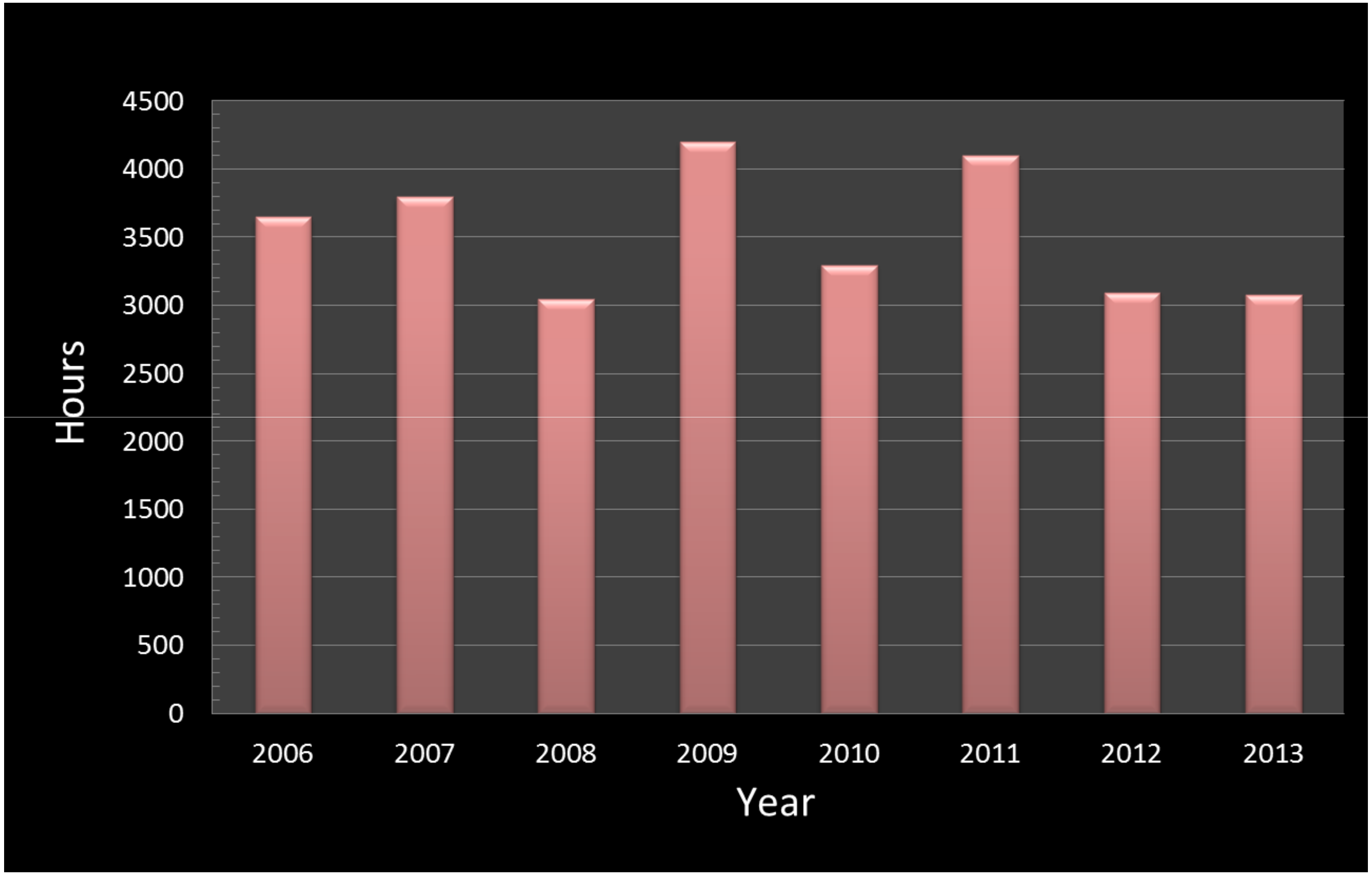


**Supernanogan ECR** on 350 kV platform **SC-RFQs** and **QWRs, $V_{eq}$ ~ 8 MV** **$^{12}$C – $^{197}$Au** (higher q and $I_{beam}$) (**2006**)

# XTU-Tandem

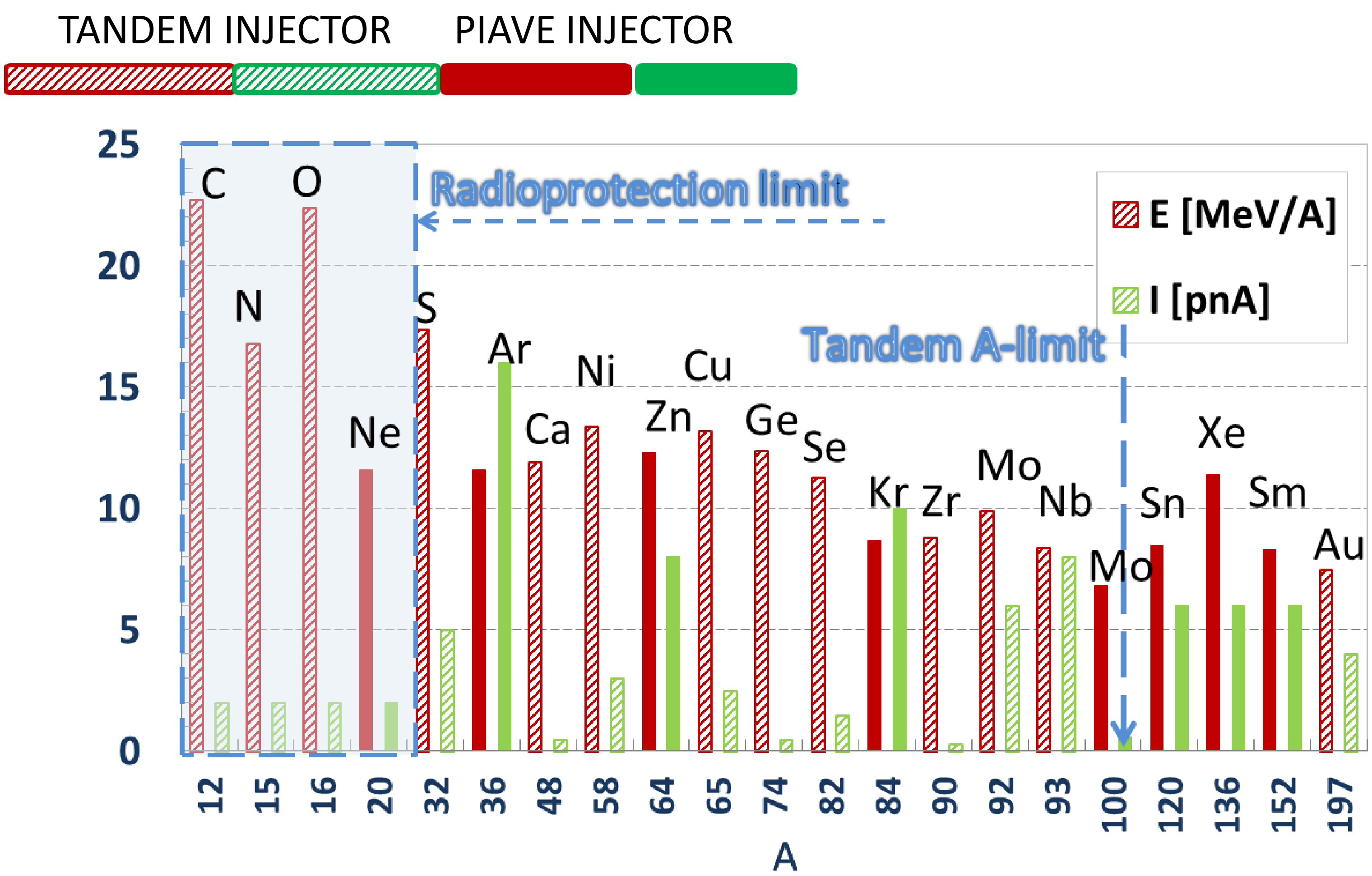
15 MV VdG Tandem (HV Corp), H-$^{100}$Mo beams, E = **30 ÷ 1.5 MeV/A**, CW or pulsed (**1984**)

# Operation with Stable Beams 2006-2013



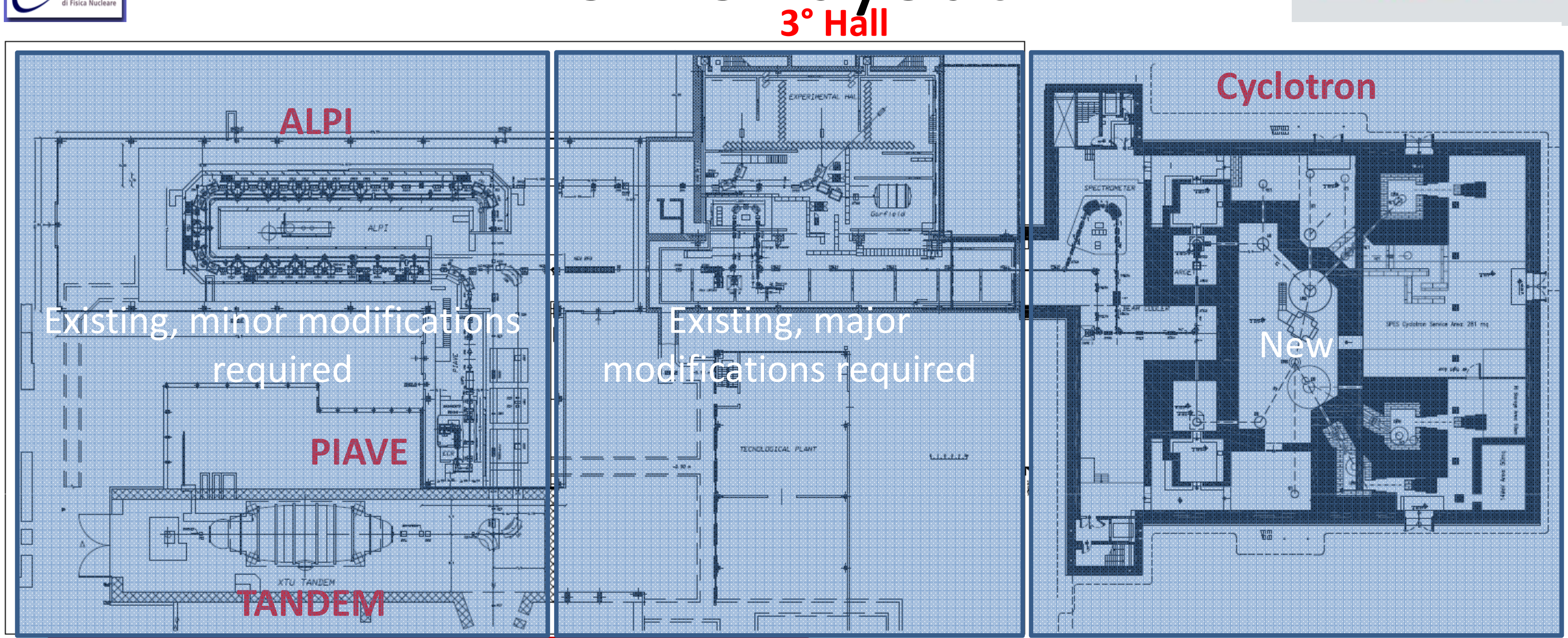

In **2013-2015** PIAVE and ALPI operation 50% of the time: contributes to **15% of the residual Budget** (spare on electricity bill) and concentrates **work force on the SPES project**.

# Representative Stable Beams Available




*Progressive development of new PIAVE beams: in 2013* ***Mo*** *and* ***Ca*** *(at least 10 pnA at the experiment;* $^{48}$***Ca*** *to be tested for min. consumption); Next:* ***Pb, Dy, Pd***

# SPES Layout



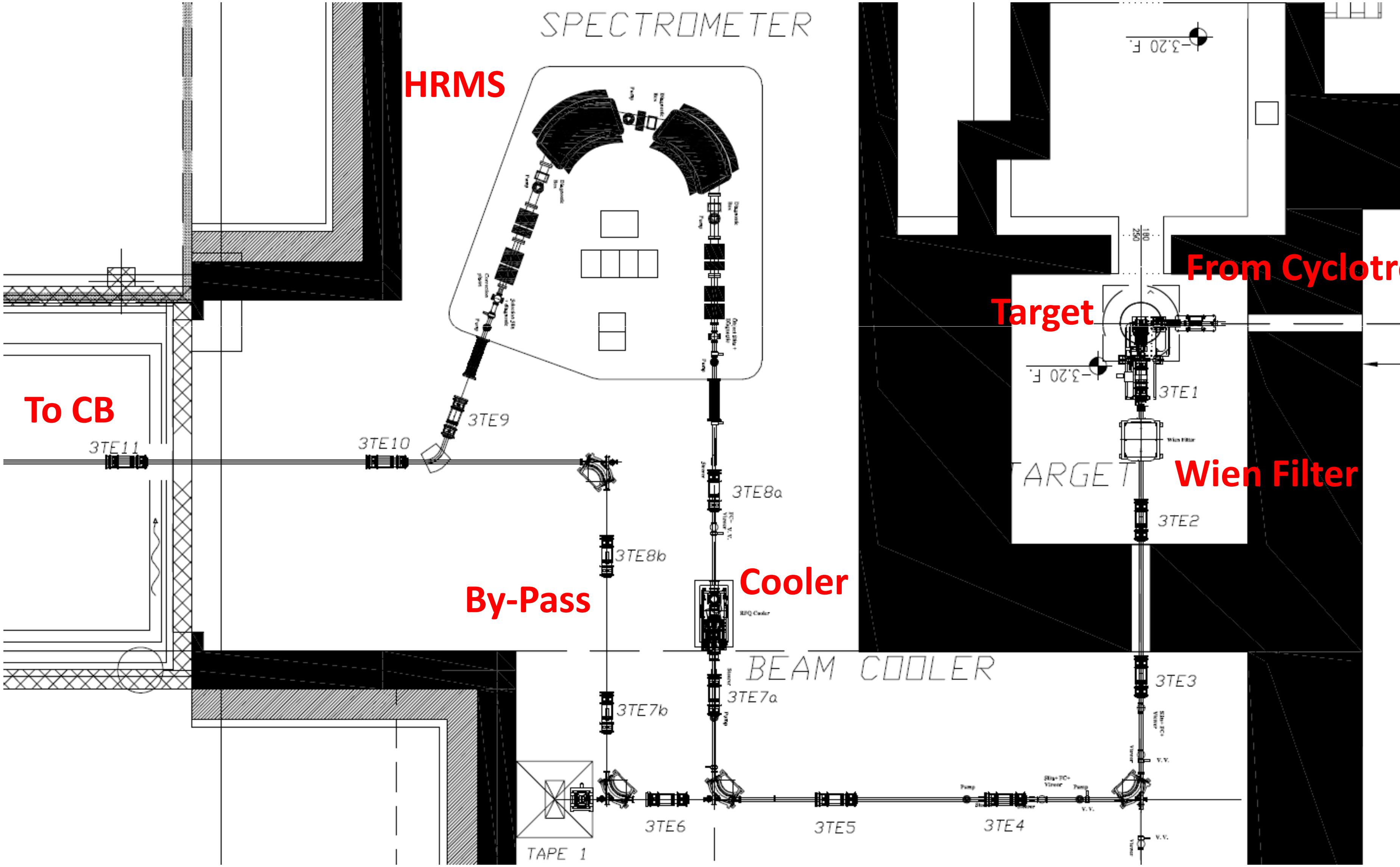

**ALPI UPGRADE**

- 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)

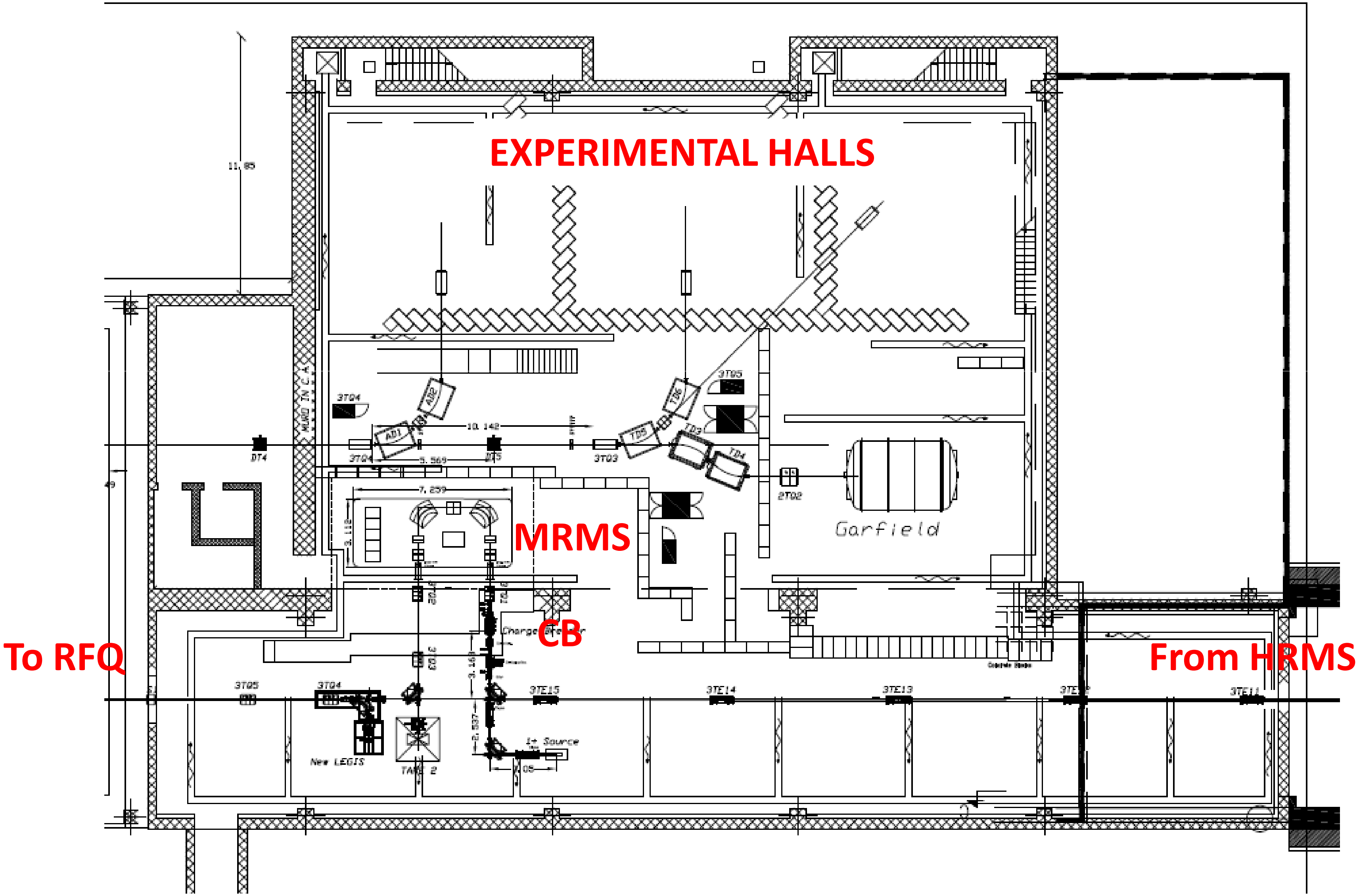
**NEW INJECTOR AND LINES**

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

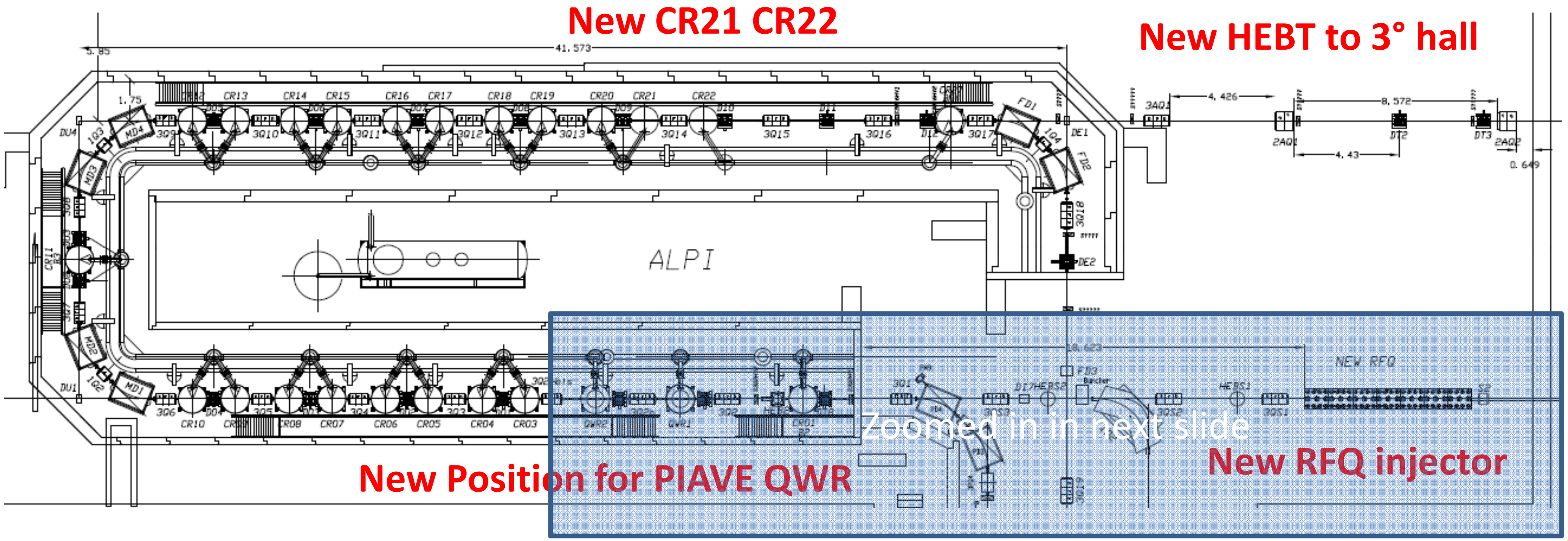
# SPES Layout: zoom on new building



# SPES Layout: zoom on 3° hall



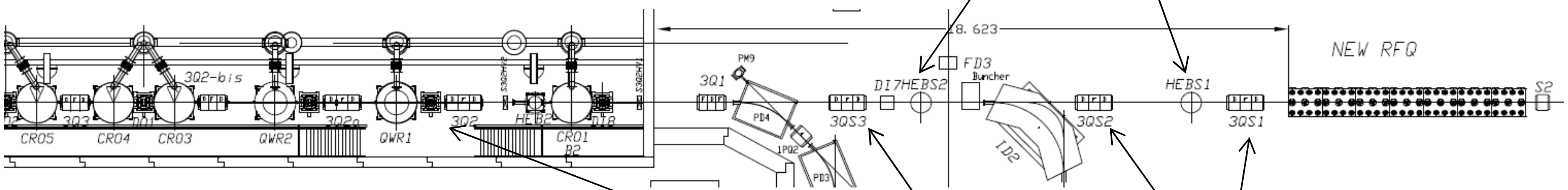
# SPES Layout: zoom on ALPI



# SPES Layout: zoom on ALPI low Beta

**PIAVE QWRs new position**

**2 new bunchers**



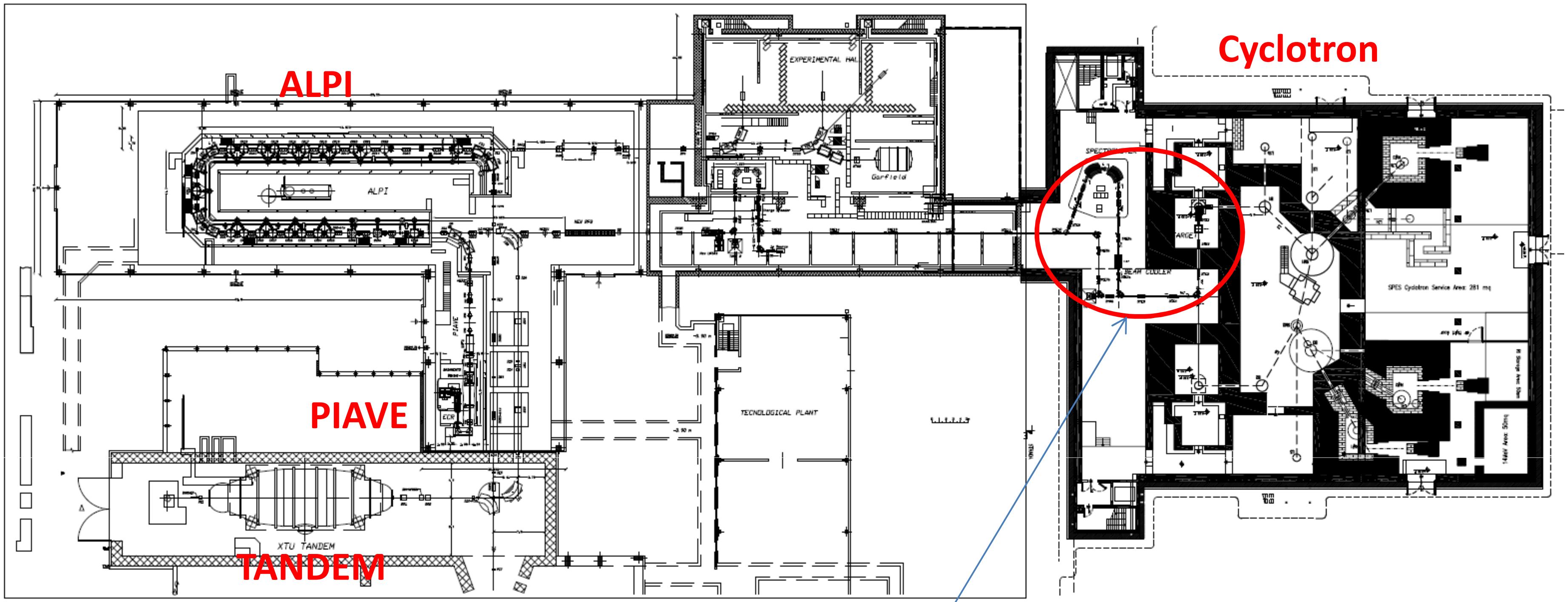

**4 m**

**3.5 m**

**4 new triplets**
**From 3° hall reshaping**

**A new buncher is also needed near the PIAVE SRFQ**

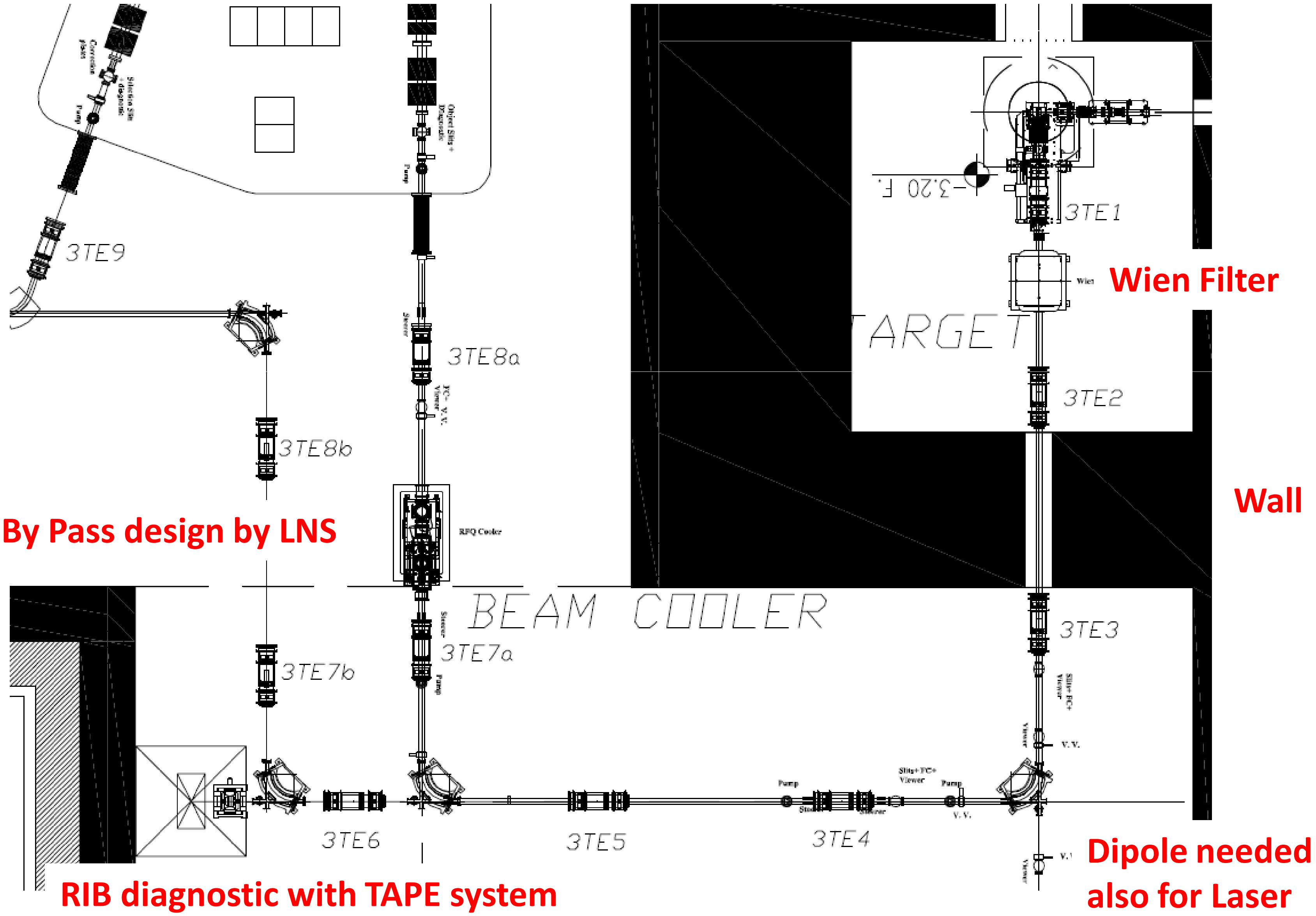
# SPES Layout



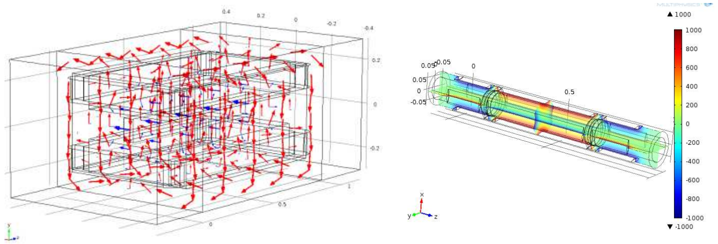

Input used for 1+ Beam from Target to RFQ Cooler:

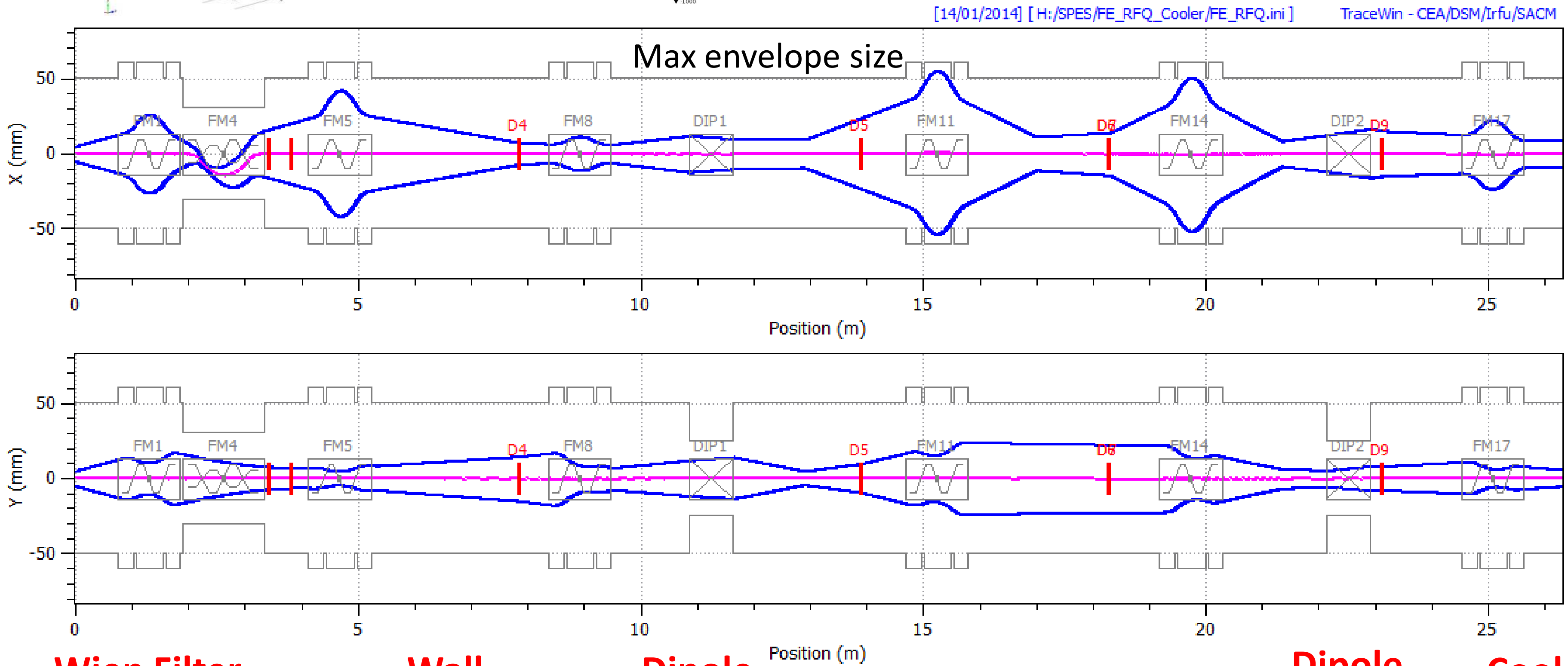
- Mass 132 A
- Voltage 40 kV
- RMS norm. Emittance 0.0033 mmmrad Geom=1.6 mmmrad, Tot Geom=14 mmmrad
- CEA TraceWin code
- Fields Maps for Electrostatic quads and Wien Filter

# Target -> RFQ Cooler.



# BD from Target to Cooler

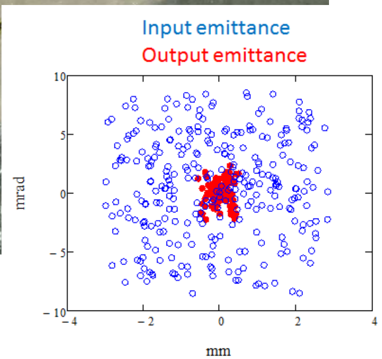


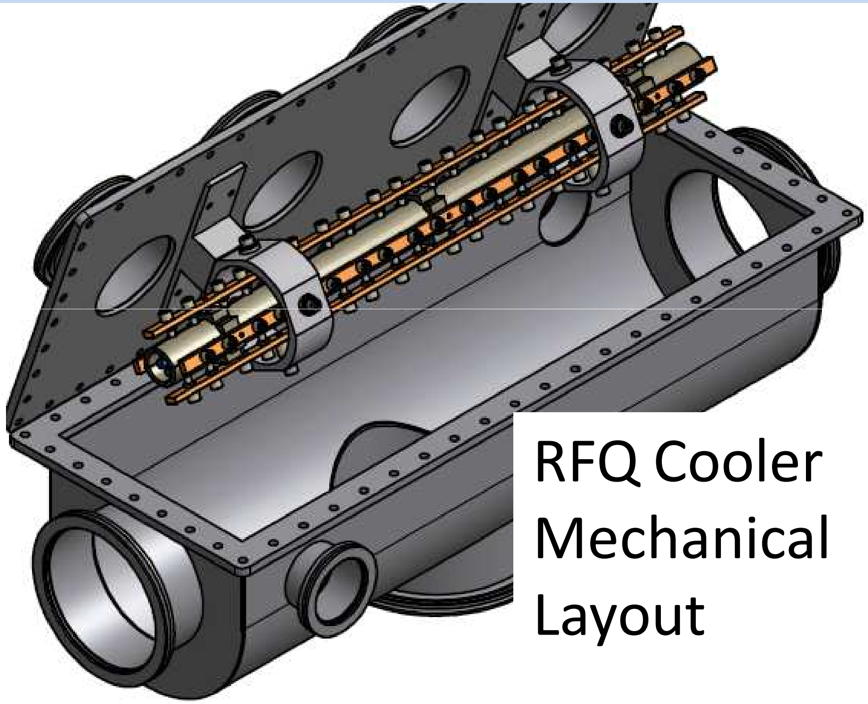



**Wien Filter** **Wall** **Dipole** **Dipole** **Cooler**

# RFQ BC: prototype studies

**Prototype Studies funded by INFN-CSN5 (COOLBEAM experiment, 2012→2015) – LNL, LNS, Mi-Bicocca Collaboration**



RFQ Cooler Mechanical Layout

**Status:** EM simulations of the whole structure completed; Beam Dynamics study in progress (Milano Bicocca develops a dedicated PIC code); RF system prototype being evaluated in collaboration with LNS. HV tests in high-P environment are starting at LNL.
Final mechanical design is in progress.

**M. Maggiore A. Porcellato S. Stark**

# HRMS physics design

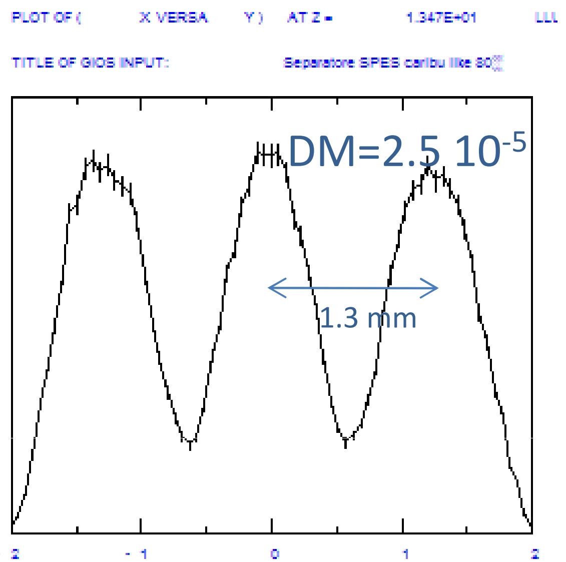
3° order effects analysis (LNS-LNL)

Input parameters:

- Energy= 260 KeV
- $\Delta\theta$=4 mrad
- **$\Delta$E= ± 1.3 eV**
- **Emittance=3$\pi$ mm mrad**

Linear Design Mass resolution: 1/40000

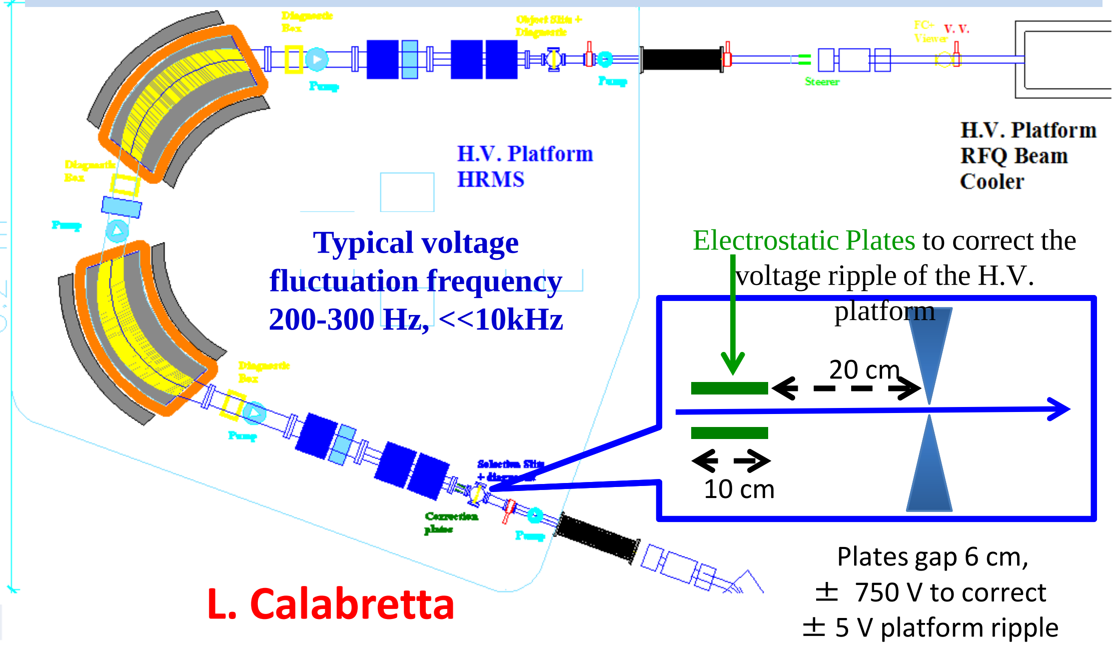
(eng. design: 1/25000)




## SPES RFQ Beam Cooler parameters

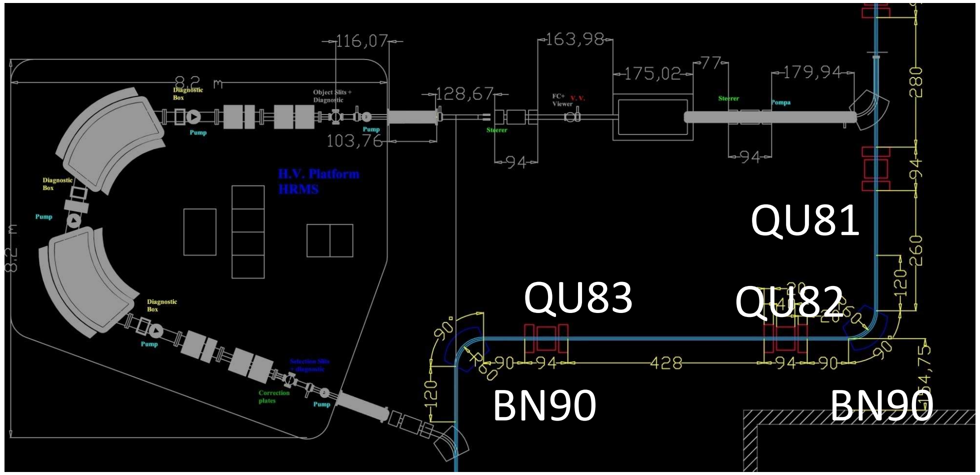
| | |
|---|---|
| Mass Range | 5-200 amu |
| Transverse Emittance Injected beam | 30 π mm mrad @ 40 keV |
| Emittance Reduction factor | 10 (max) |
| Buffer Gas | He @ 273 K |
| Beam Intensity | 50-100 nA → x10[11] pps |
| Energy spread | < 5 eV |
| RF Voltage range | 0.5 – 2.5 kV (1 kV at q=0.25) |
| 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 |

Scaled-up version of CARIBU-HRMS, ANL (USA)



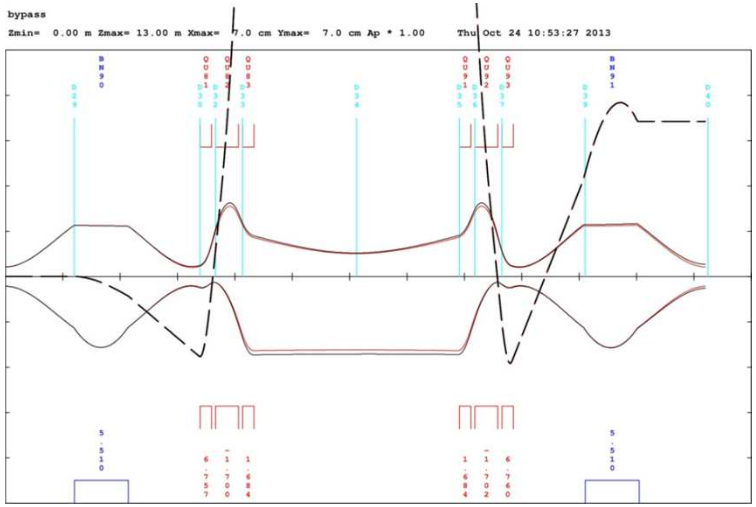

L. Calabretta

# By-pass line of Cooler and HRMS



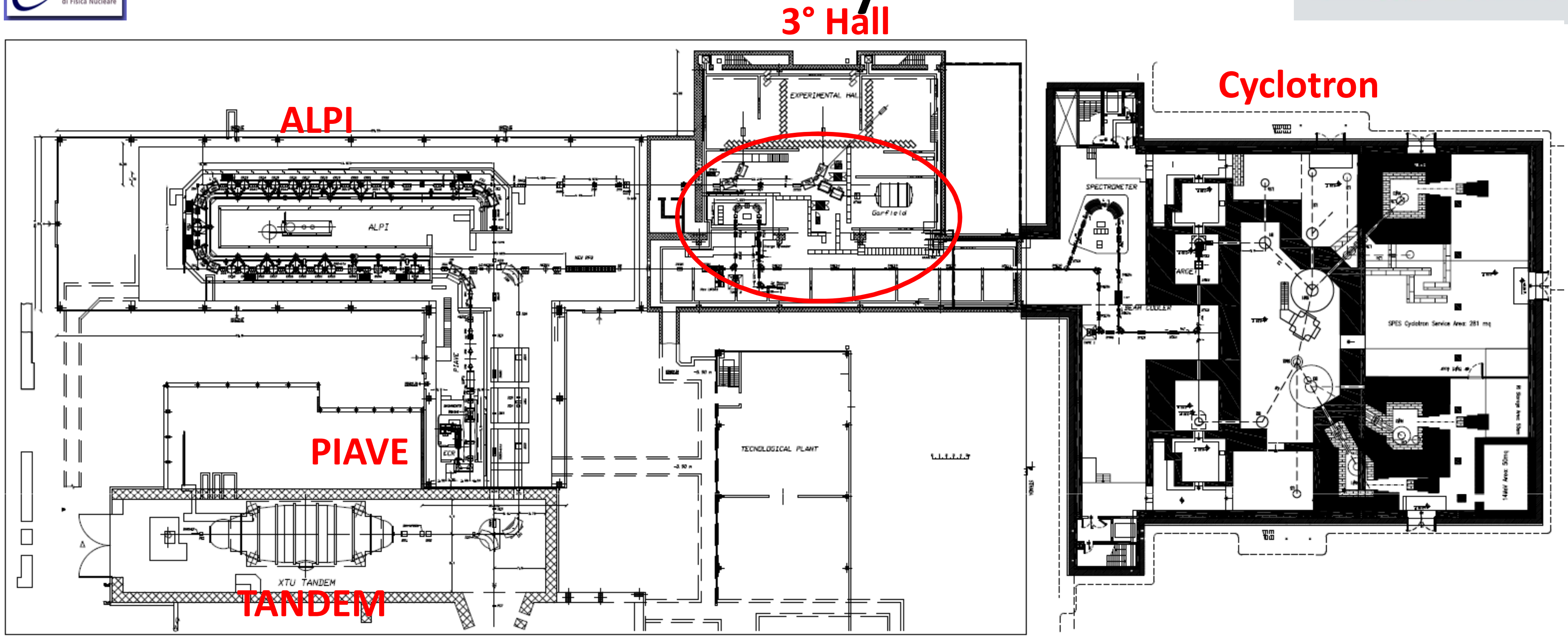

| Name | Lenght (m) | Width/Height or diameter(cm) | Magnetic field (kG) | Comments |
|---|---|---|---|---|
| D29 | 1.2 | | | |
| FI3 | 26.5° | | | Entrance edge |
| BN90 | 0.9425 | | 5.51 | R=0.6 m |
| F03 | 26.5° | | | Exit edge |
| D30 | 1.25 | | | |
| QU81 | 0.2 | ∅=8 | 6.76 | |
| D32 | 0.07 | | | |
| QU82 | 0.4 | ∅=8 | -1.7 | |
| D33 | 0.07 | | | |
| QU83 | 0.2 | ∅=8 | 1.68 | |
| D34 | 1.79 | | | |

- Polarity inversion on QU82 and QU83 contain the Y-size of the beam
- $\Delta M/M \approx 1/400$ (1° order)
- **$\Delta M/M \approx 1/250$ (2° order)**
- Analysis of tolerances on mechanical alignment on-going

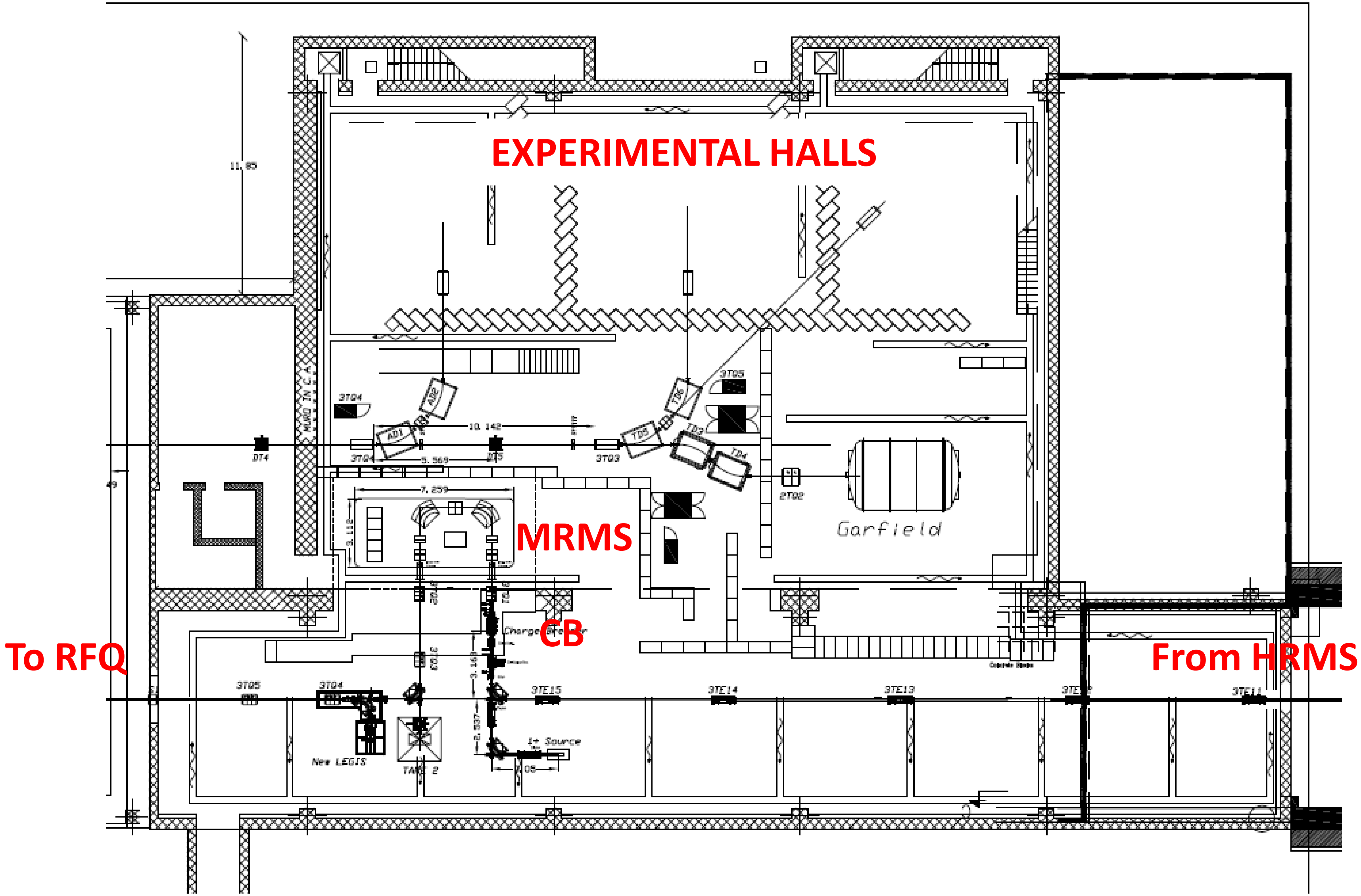



A. Russo

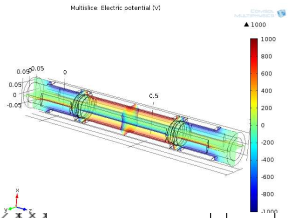
# SPES Layout


3° Hall
ALPI
Cyclotron
PIAVE
TANDEM
EXPERIMENTAL HALL
ALPI
Garfield
SPECTROMETER
TECNOLOGICAL PLANT
XTU TANDEM
ECR
PIAVE

# SPES Layout: zoom on 3° hall

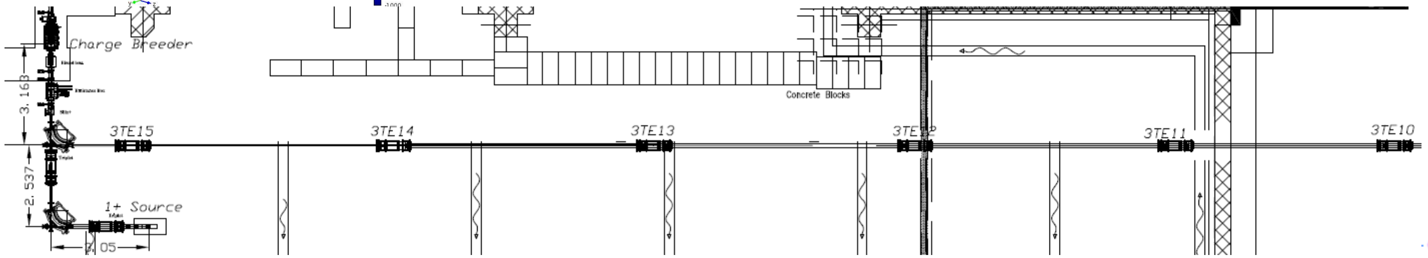


# Transport line from (By pass) to CB.

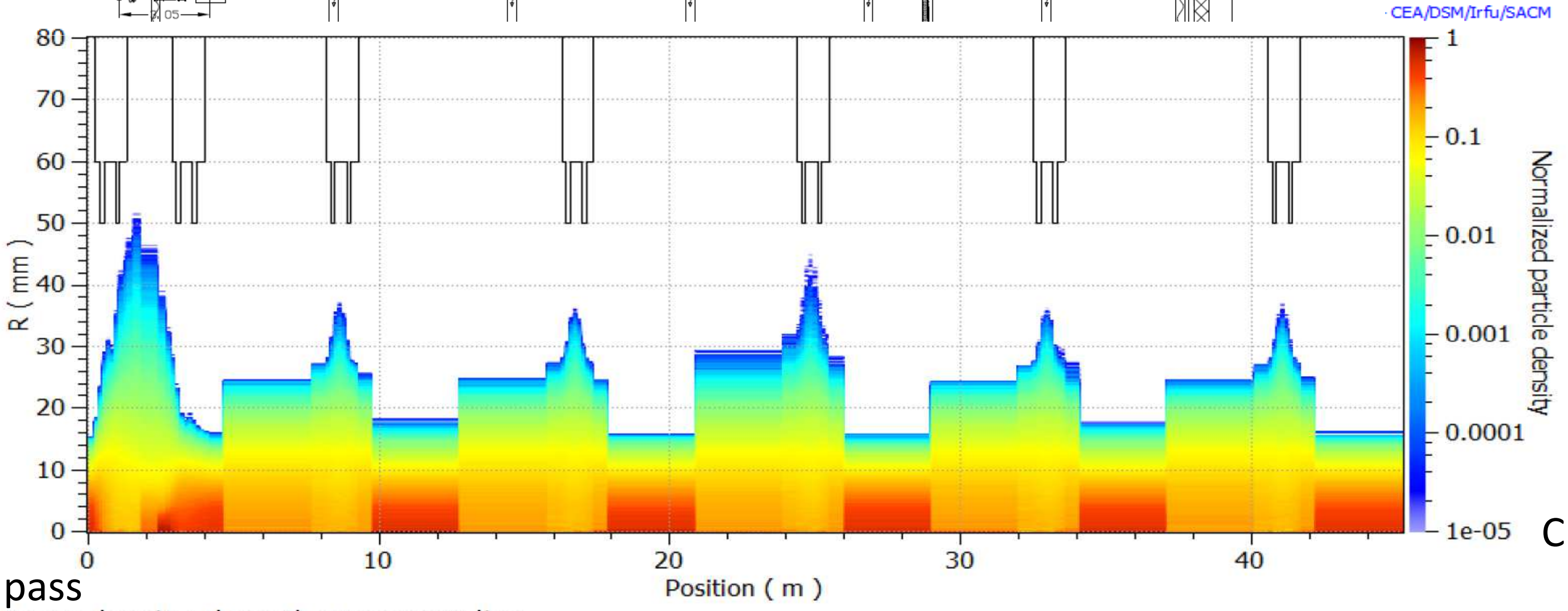


Full electric fields maps for Triplets

CB




By pass



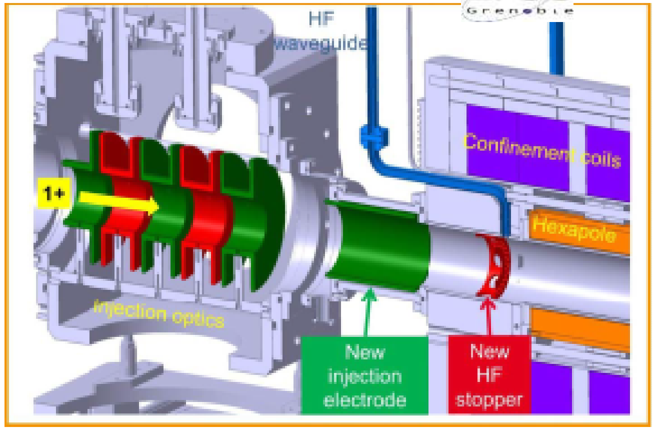

CB

By pass

Beam density along the transport line.

Similar solutions also with other mass and Voltage

# 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**

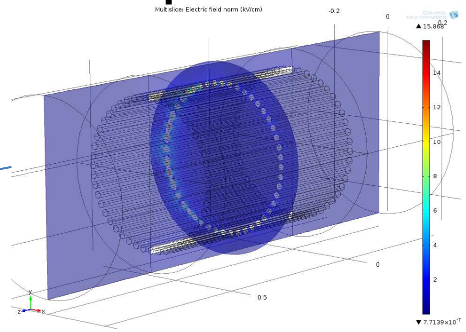
# Charge Breeder Contaminants

| isotope | element | Mass | abundance (%) | M/q | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1+ | 2+ | 3+ | 4+ | 5+ | 6+ | 7+ | 8+ | 10+ | 11+ | 12+ | 13+ | 14+ | 15+ | 16+ |
| 12 | C | 12.000 | 98.9 | 12.000 | 6.000 | 4.000 | 3.000 | 2.400 | 2.000 | | | | | | | | | |
| 13 | C | 13.003 | 1.1 | 13.003 | 6.502 | 4.334 | 3.251 | 2.601 | 2.167 | | | | | | | | | |
| 14 | N | 14.003 | 100 | 14.003 | 7.002 | 4.668 | 3.501 | 2.801 | 2.334 | 2.000 | | | | | | | | |
| 15 | N | 15.000 | 0.366 | 15.000 | 7.500 | 5.000 | 3.750 | 3.000 | 2.500 | 2.143 | | | | | | | | |
| 16 | O | 15.995 | 99'762 | 15.995 | 7.997 | 5.332 | 3.999 | 3.199 | 2.666 | 2.285 | 1.999 | | | | | | | |
| 17 | O | 16.999 | 0.038 | 16.999 | 8.500 | 5.666 | 4.250 | 3.400 | 2.833 | 2.428 | 2.125 | | | | | | | |
| 18 | O | 17.999 | 0.2 | 17.999 | 9.000 | 6.000 | 4.500 | 3.600 | 3.000 | 2.571 | 2.250 | | | | | | | |
| 36 | Ar | 36.968 | 0.337 | 36.968 | 18.484 | 12.323 | 9.242 | 7.394 | 6.161 | 5.281 | 4.621 | | | | | | | |
| 40 | Ar | 39.962 | 99.6 | 39.962 | 19.981 | 13.321 | 9.991 | 7.992 | 6.660 | 5.709 | 4.995 | | | | | | | |
| 78 | Kr | 77.920 | 0.35 | | | | | | | | | 7.792 | 7.084 | 6.493 | 5.994 | 5.566 | 5.195 | 4.870 |
| 80 | Kr | 79.916 | 2.25 | | | | | | | | | 7.992 | 7.265 | 6.660 | 6.147 | 5.708 | 5.328 | 4.995 |
| 82 | Kr | 81.913 | 11.6 | | | | | | | | | 8.191 | 7.447 | 6.826 | 6.301 | 5.851 | 5.461 | 5.120 |
| 83 | Kr | 82.914 | 11.5 | | | | | | | | | 8.291 | 7.538 | 6.910 | 6.378 | 5.922 | 5.528 | 5.182 |
| 84 | Kr | 83.912 | 57 | | | | | | | | | 8.391 | 7.628 | 6.993 | 6.455 | 5.994 | 5.594 | 5.244 |
| 86 | Kr | 85.911 | 17.3 | | | | | | | | | 8.591 | 7.810 | 7.159 | 6.609 | 6.136 | 5.727 | 5.369 |

The contaminants of the radioactive beam present in the beam delivered
by the charge breeder are due to gas like carbon, Nitrogen and Oxygen.
The mass separation needed to avoid contaminant peaks is in the order of 1/1000.

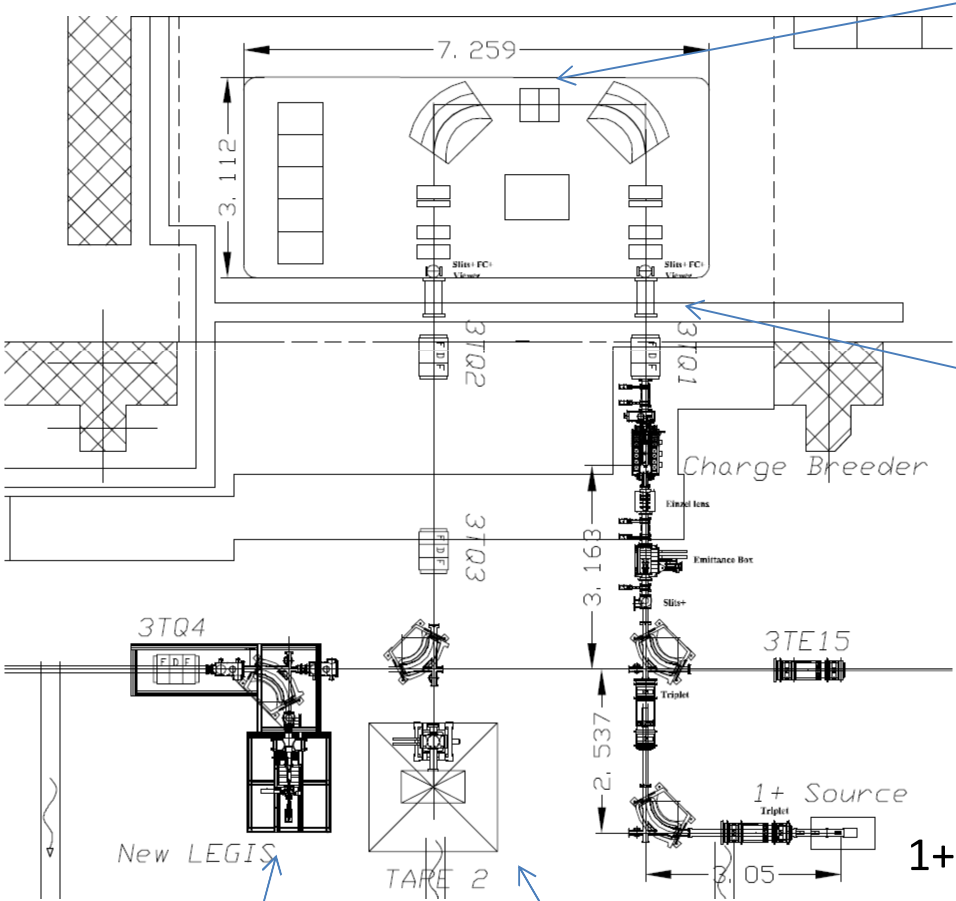
**A. Galata**

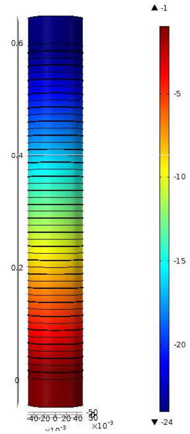
# CB and Medium Resolution Mass Spectrometer



Full Electrical fields maps for Multipoles

Platform +120 kV



Full Electrical fields maps
For Columns

RFQ

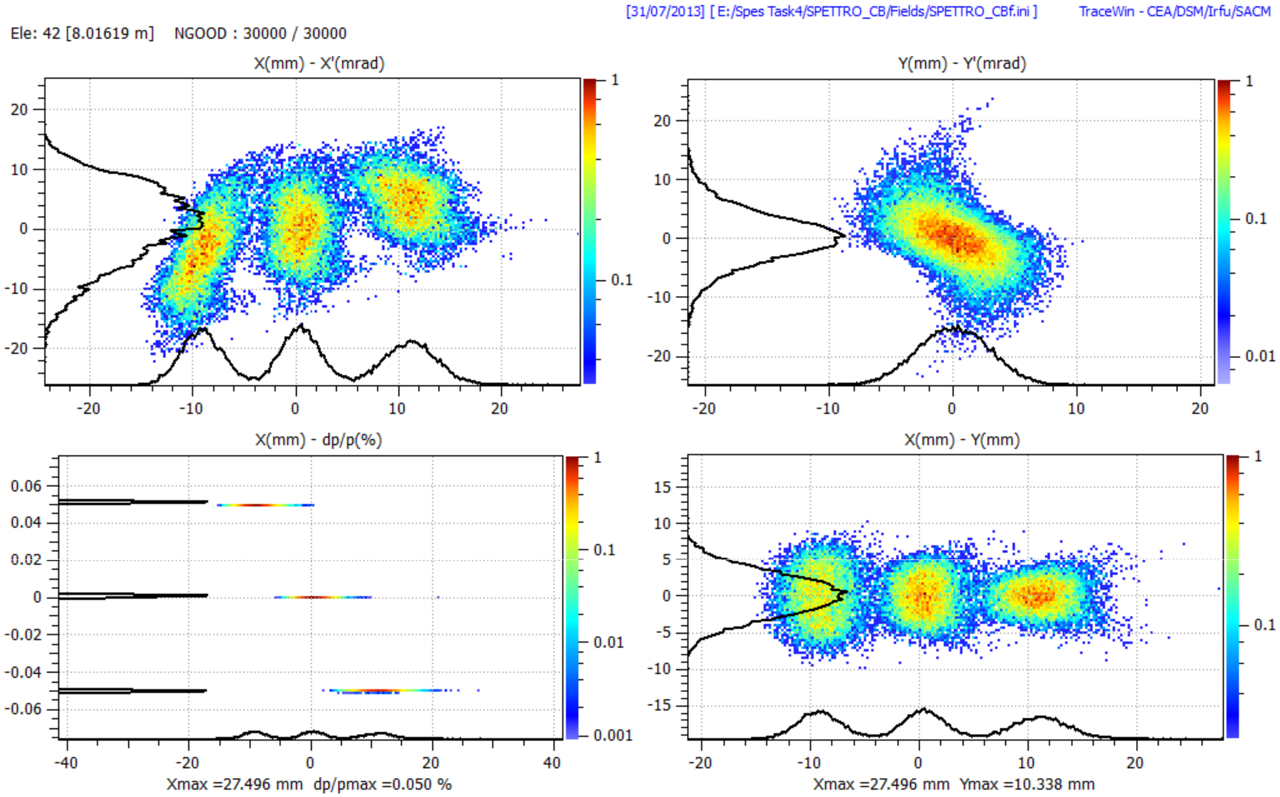
From transport line

1+ Source for CB tests

Future Stable Source for ALPI

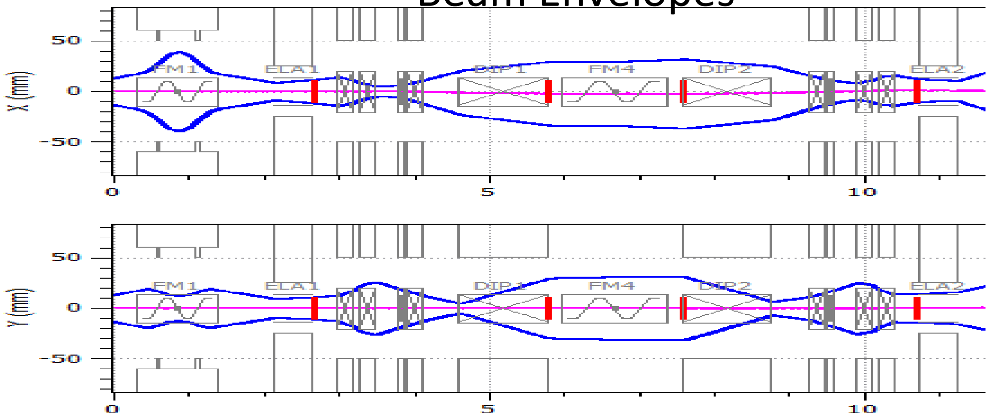
RIB Diagnostic with TAPE SYSTEM

# Beam optics of MRMS



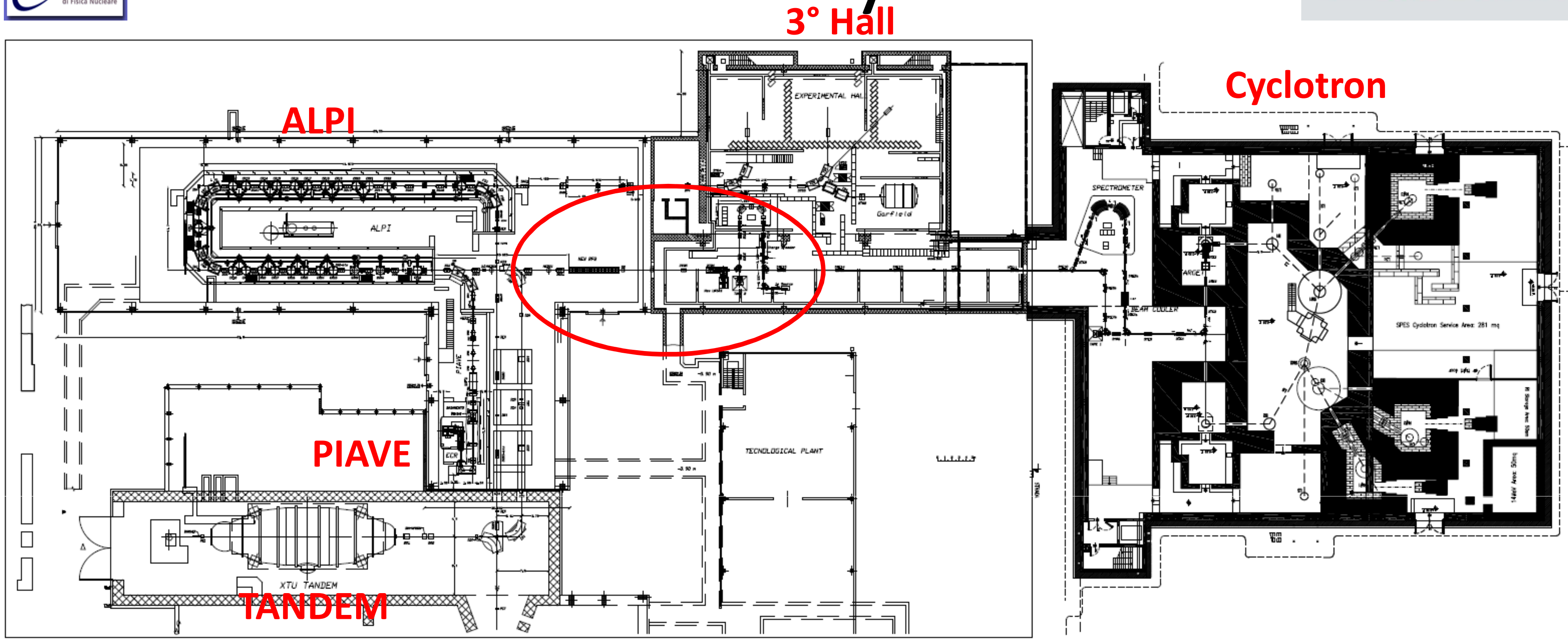

CARIBU multipoles elements

Beam Envelopes



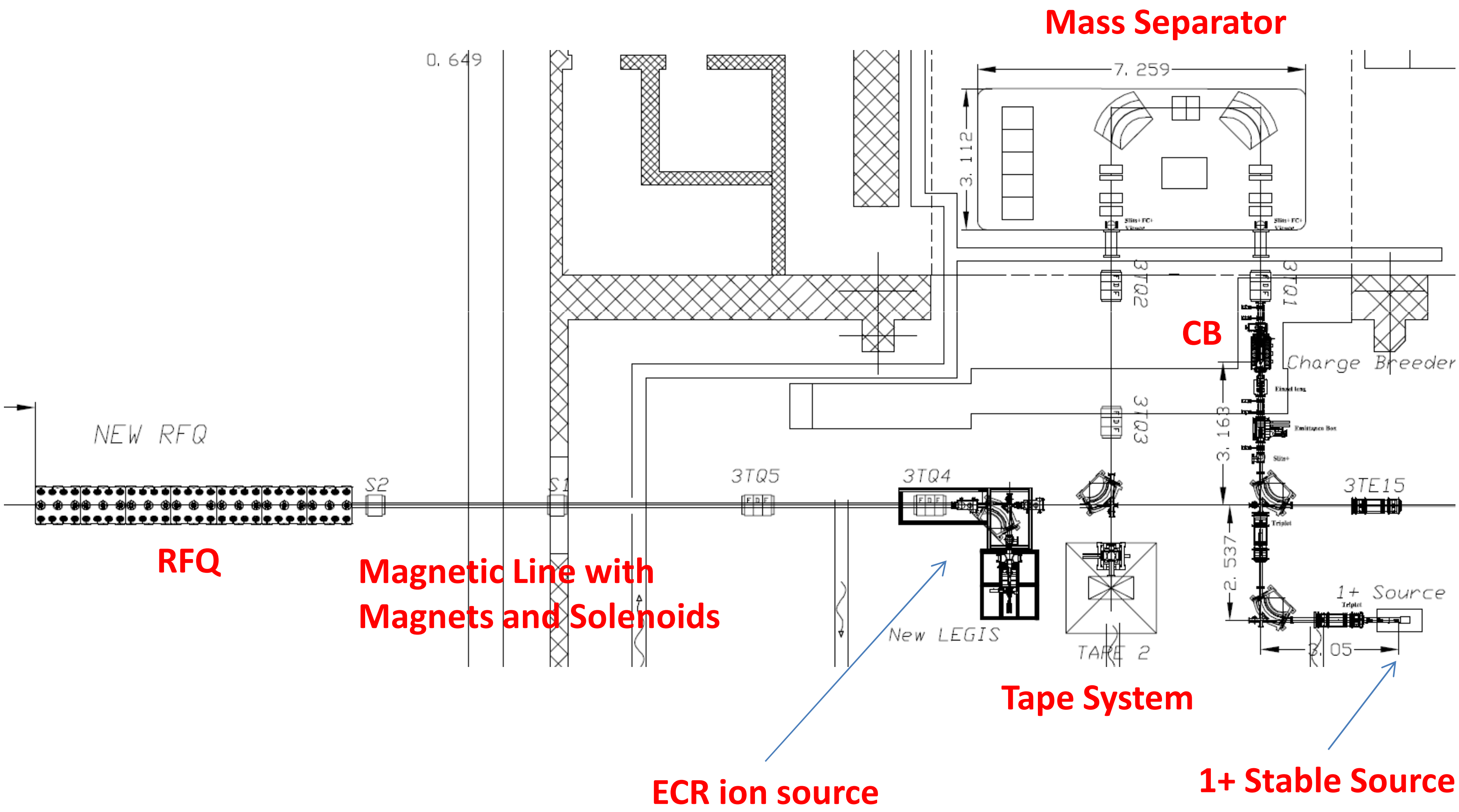

In figure are reported 3 beams, with the same emittance, injected separated by 1/1000 in mass.
After the MRMS the beams are fully separated in X.
RMS Tr. Norm. Input Emittance 0.06 mmmrad.
Gaussian Beam.

# SPES Layout

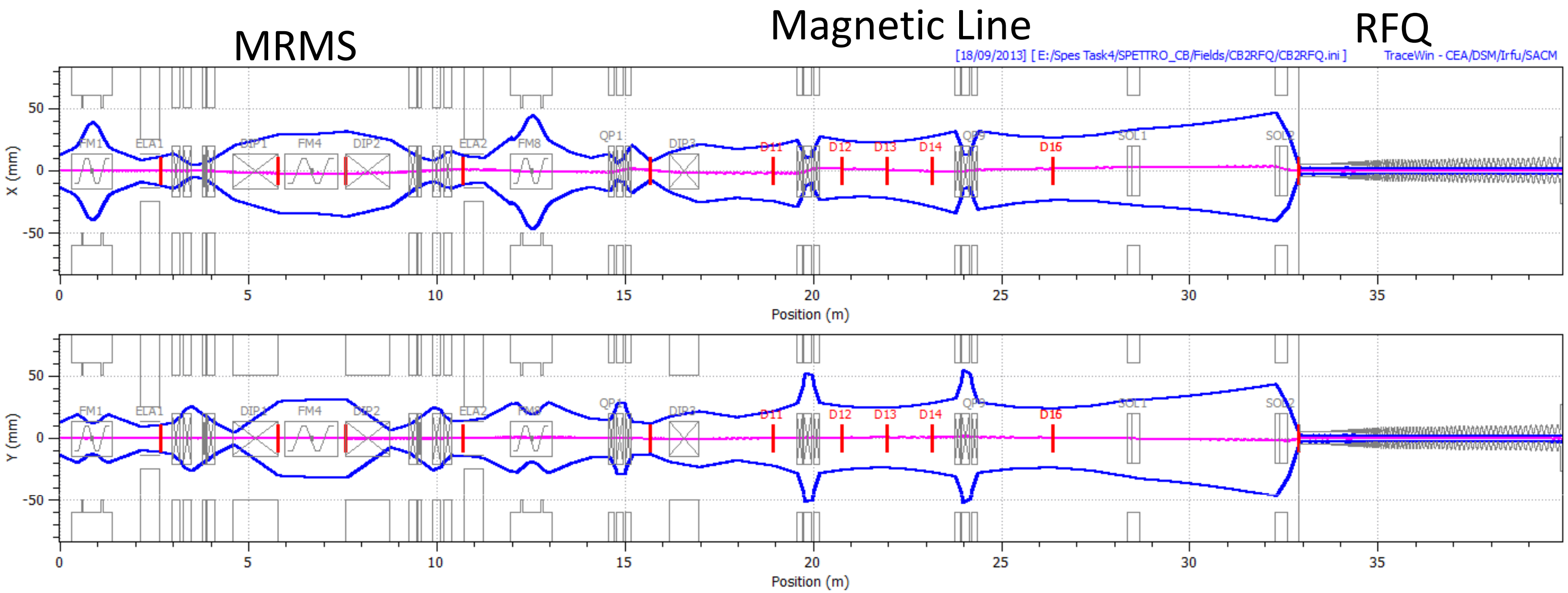


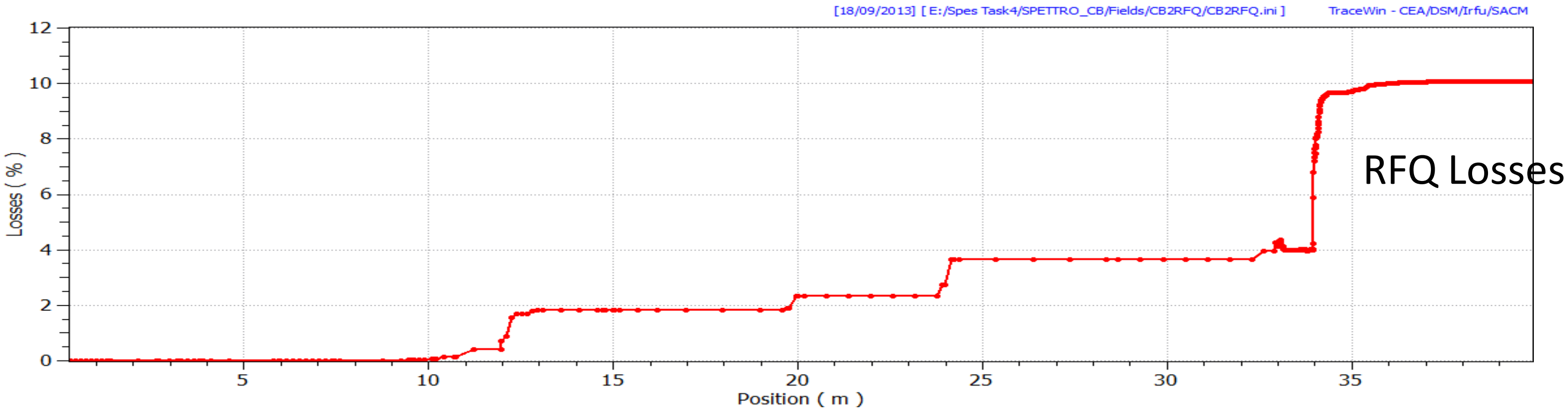
3° Hall
Cyclotron
ALPI
PIAVE
TANDEM
EXPERIMENTAL HALL
ALPI
SPECTROMETER
Garfield
BEAM COOLER
TECNOLOGICAL PLANT
XTU TANDEM
ECR

# Transport Line to SPES RFQ

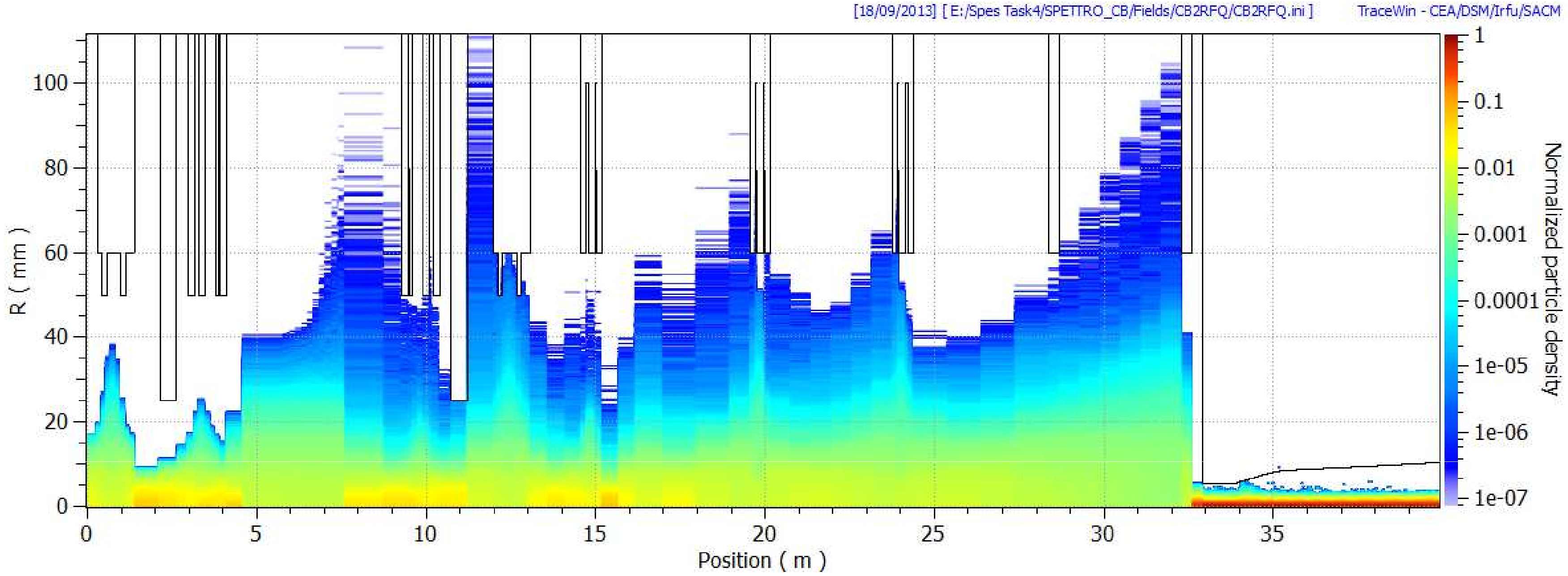


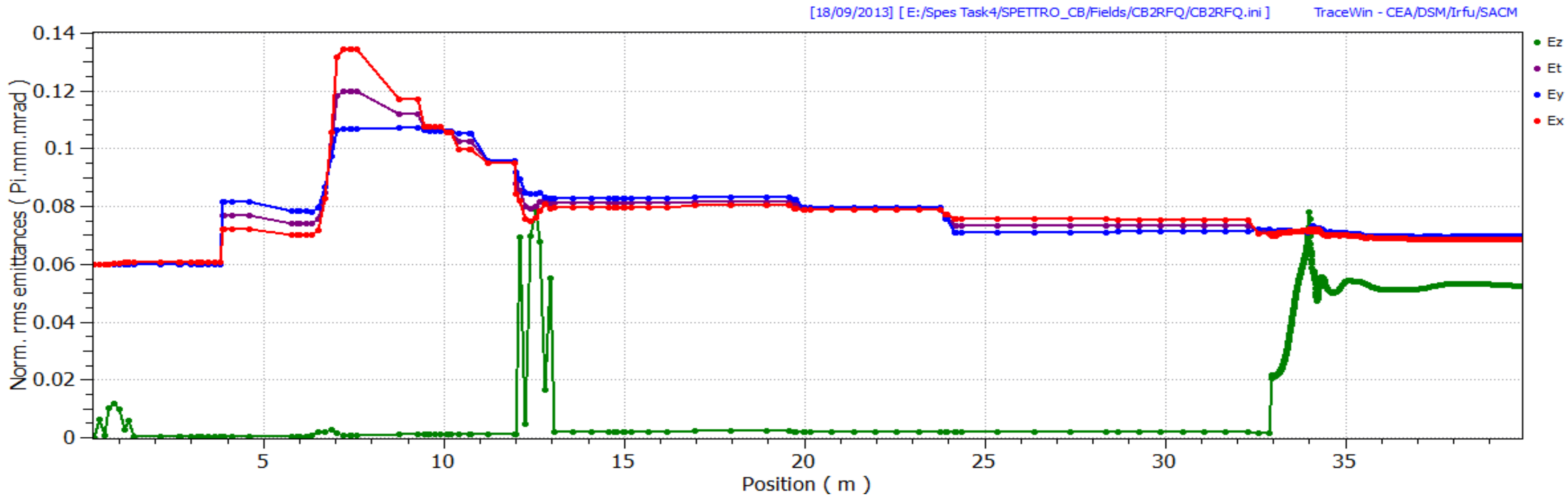
# Beam Optics of Transport line from CB to RFQ



# Beam Optics of Transport line from CB to RFQ

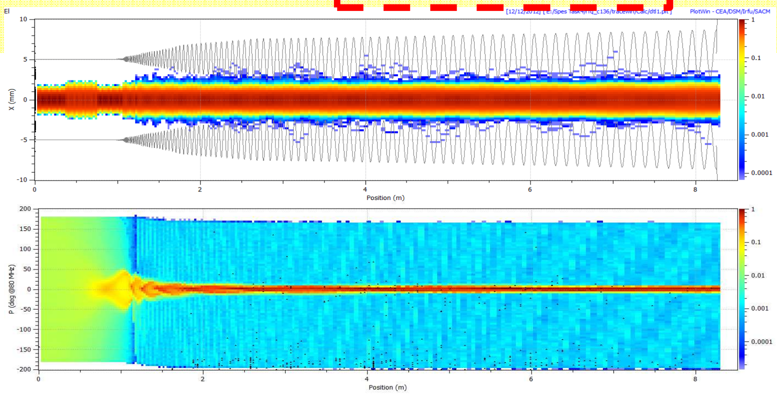


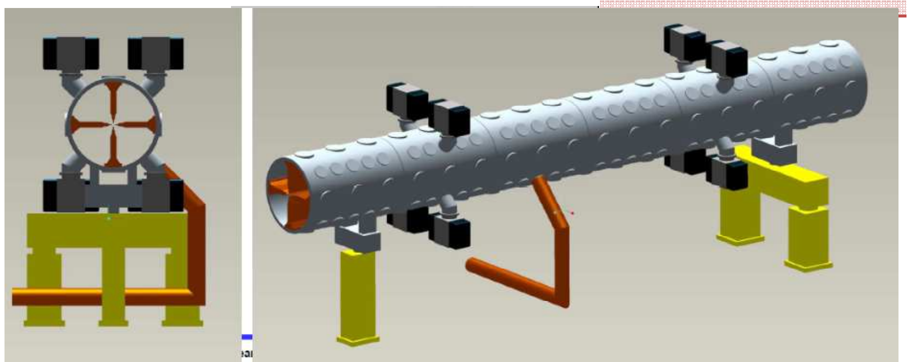
# New RFQ Injector for ALPI

- **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** (7 modules)
- Intervane voltage **63.8 – 85.8 kV**
- **RF power** (four vanes) **100 kW.**
- **Mechanical design** and realization, similar to the Spiral2 one, 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 |

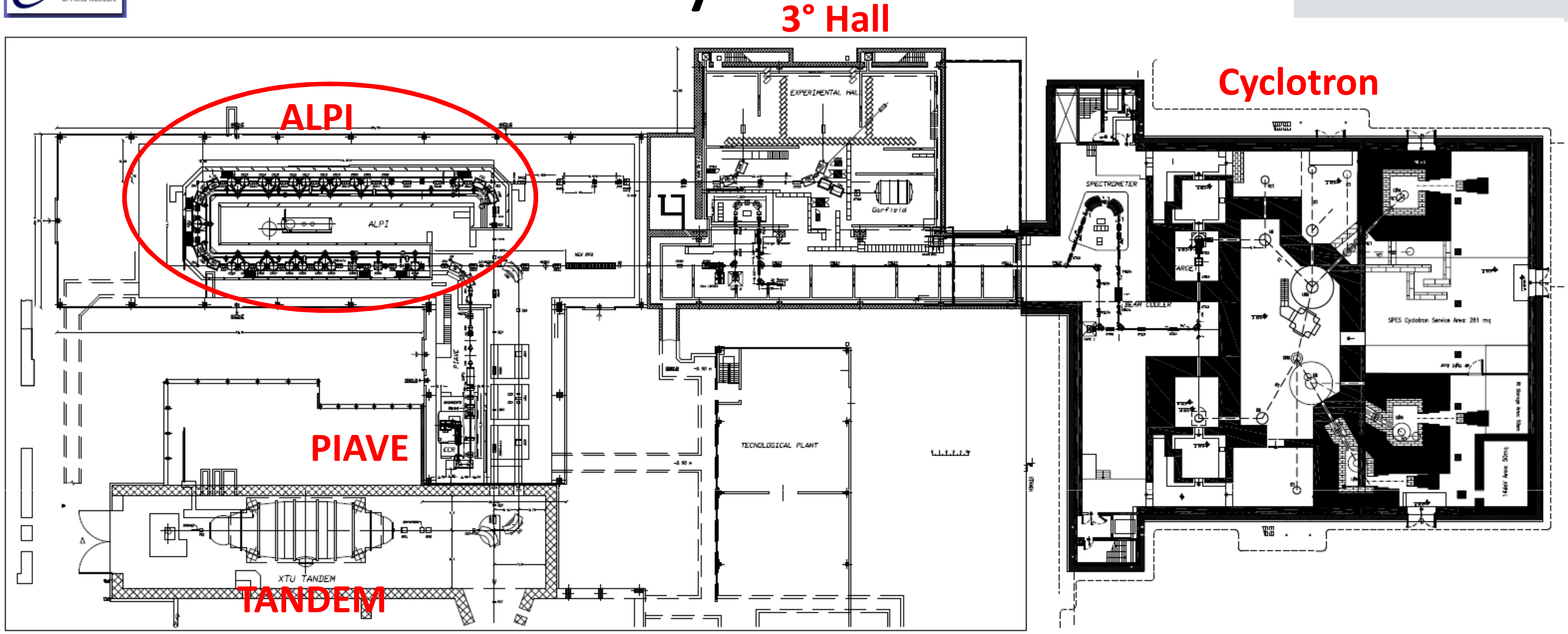


**A. Pisent**



Mechanical layout of the RFQ tank module (≈1 m)

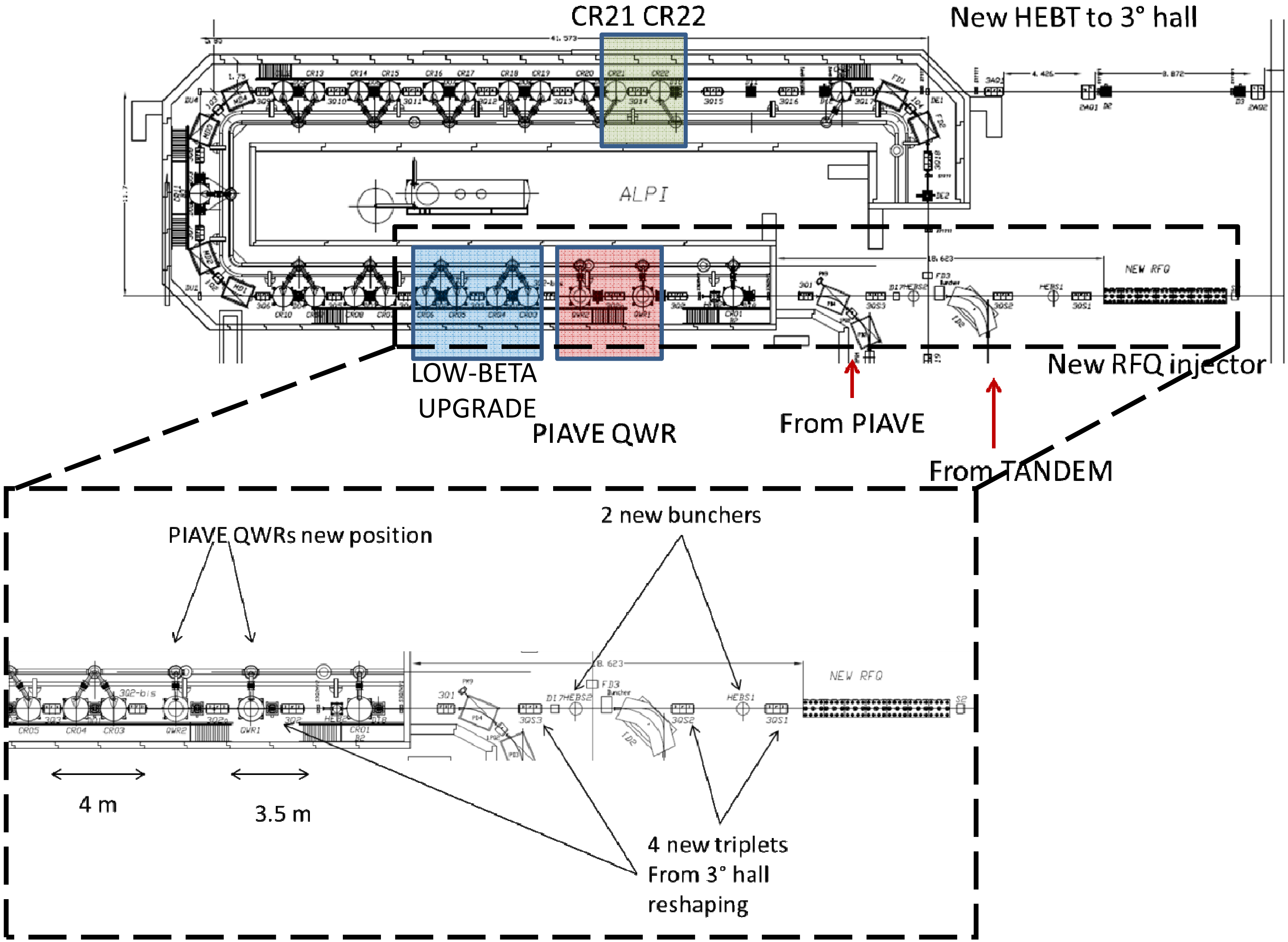
# ALPI Layout for SPES



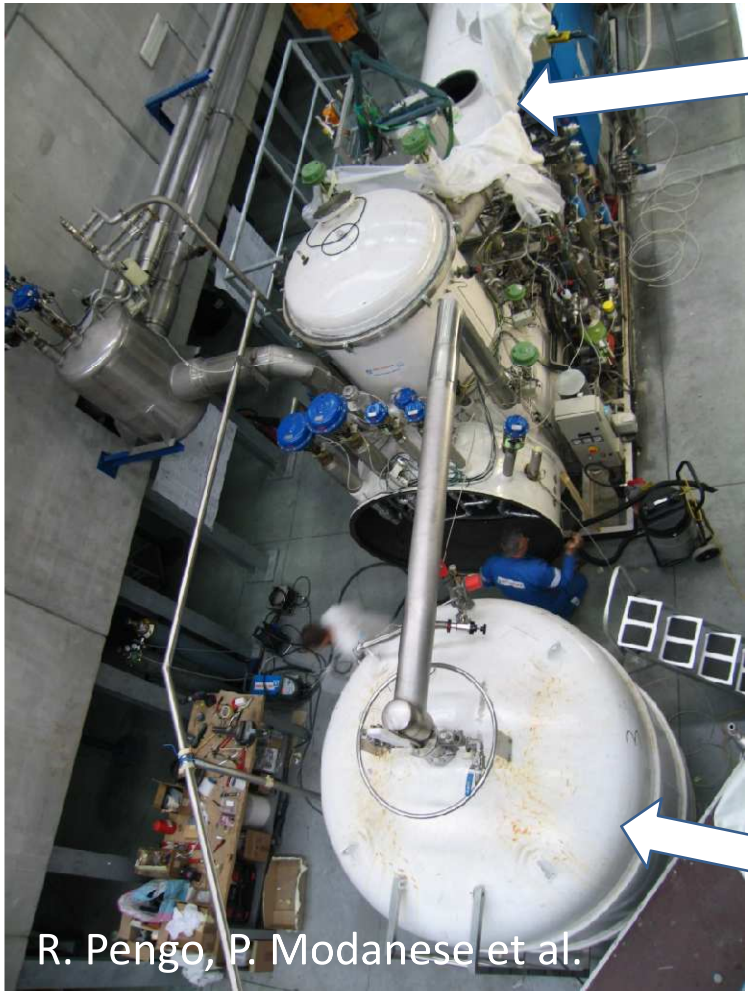
# ALPI Upgrade foreseen for SPES

- Upgrade on ALPI Layout.
- Cryogenics and energy upgrade.
- New HEBT to 3° Hall.
- Future Magnets upgrade, (20 -> 25 T/m)
- Diagnostics upgrade.
- Vacuum system and controls.

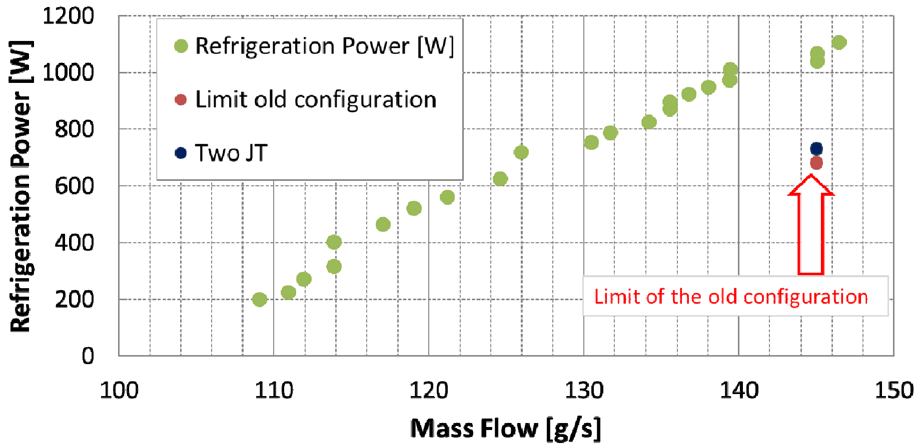
# SC Resonator Improvements on ALPI



# ALPI Cryogenic System Upgrade




1. Implemementation of a 3° turbine, in place of the «wet expander», increase of 30% of cryogenic power expected

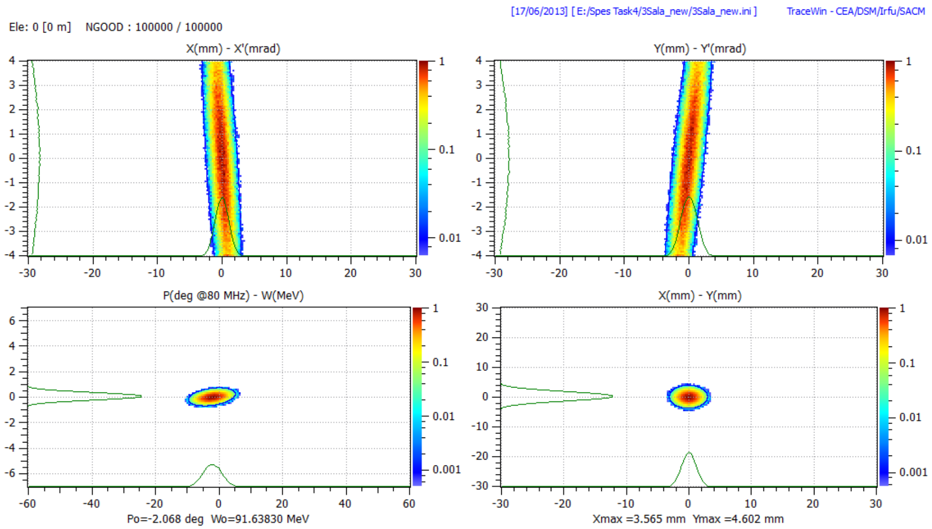



Measured **increase in the refrigeration capacity** 360 W (predicted 300W): **+ 51%**

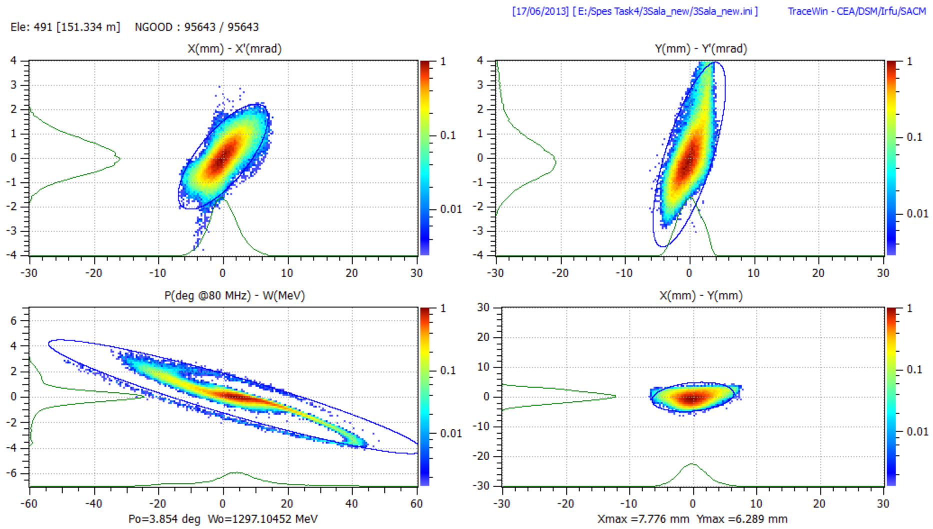
2. Replacement of the machine dewar (from 1600 to 3000 l storage capacity), helps system stability in operation

# SPES case for A/q=7

- Input energy from new RFQ: 91.6 MeV (β=0.0395) = 0.727 MeV/A.
- Output energy from CR22: 1297 MeV (β= 0.148) around 10 MeV/A.
- Input Transverse emittance of 0.1 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.

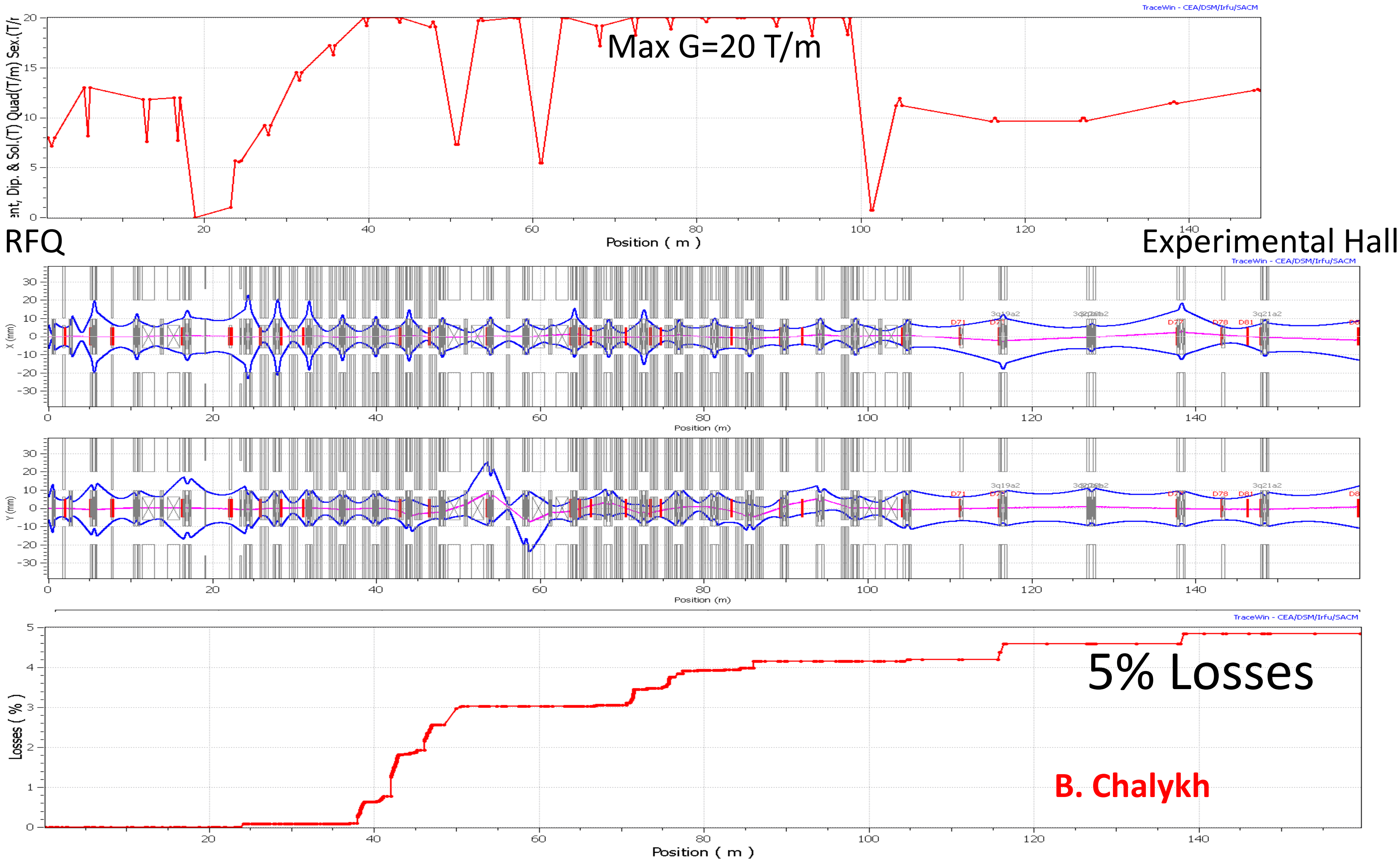



ALPI Input Phase Space

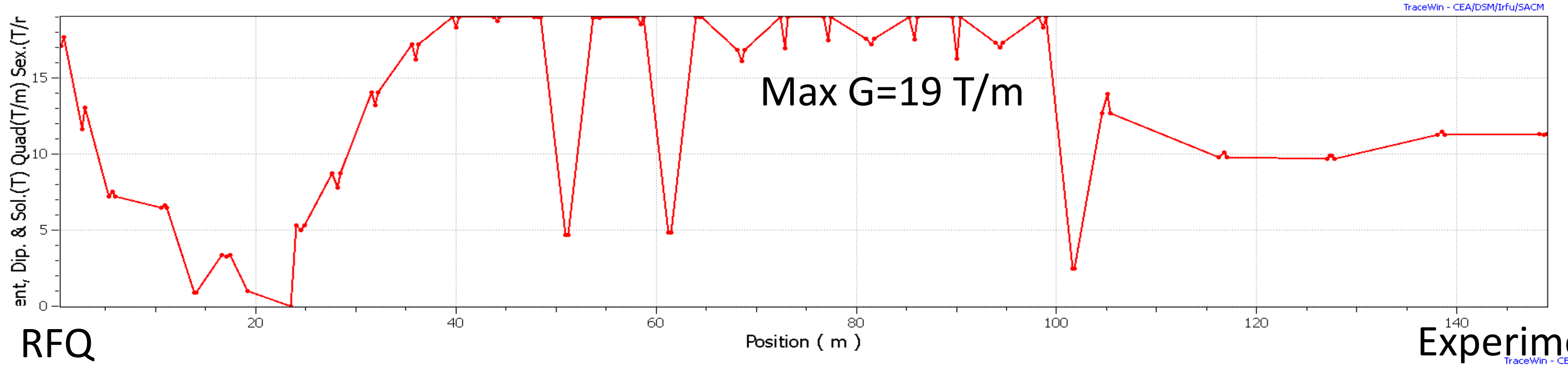


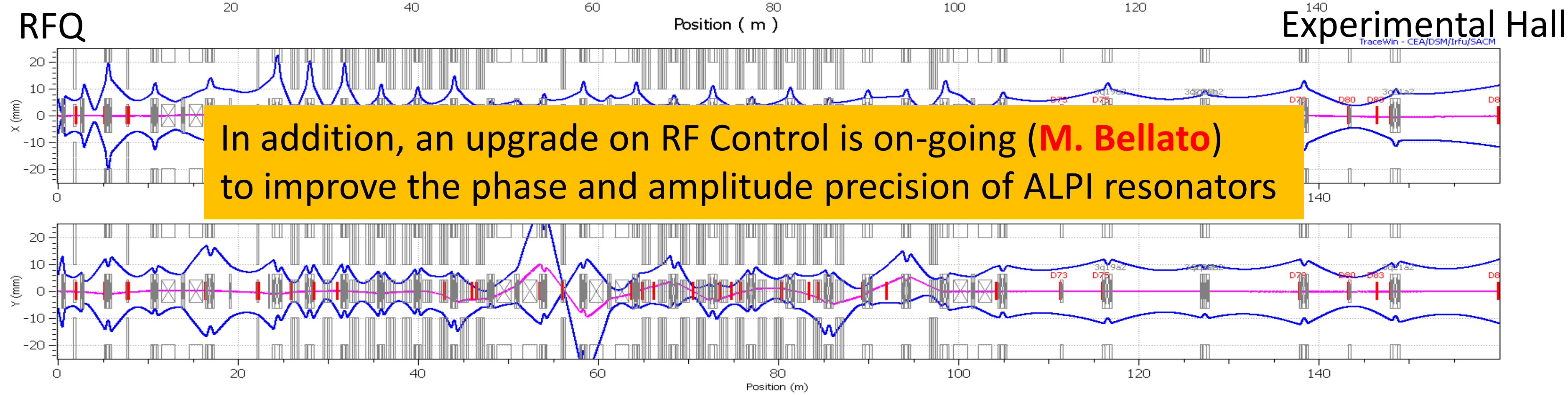

ALPI Output Phase Space

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

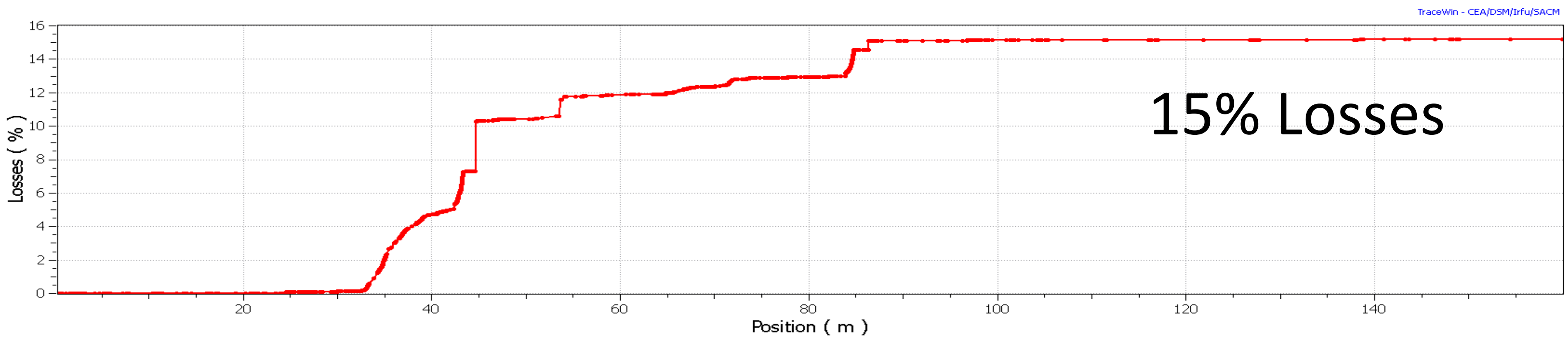


# Magnets Sensitivity analysis

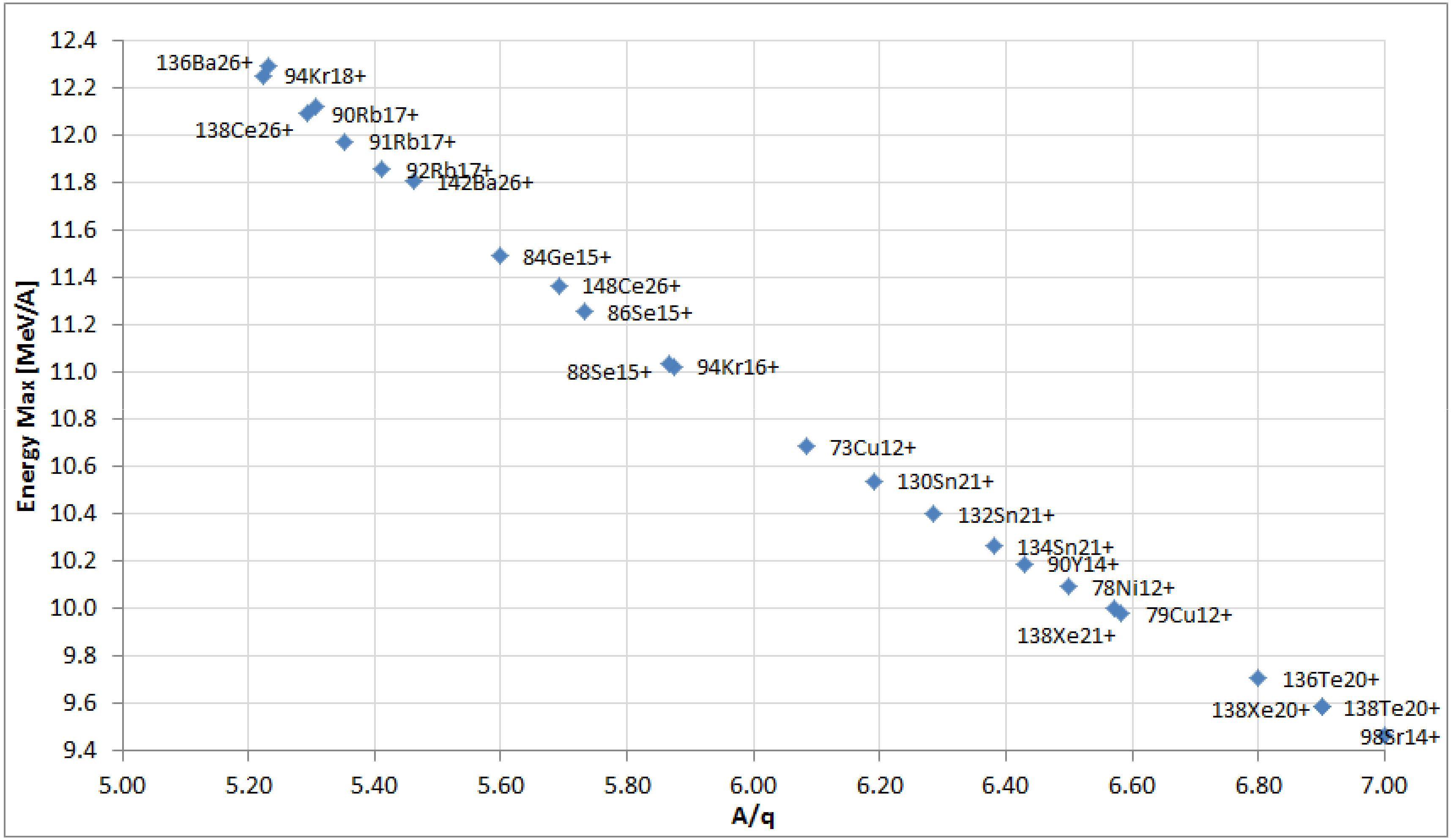



In addition, an upgrade on RF Control is on-going (**M. Bellato**)
to improve the phase and amplitude precision of ALPI resonators

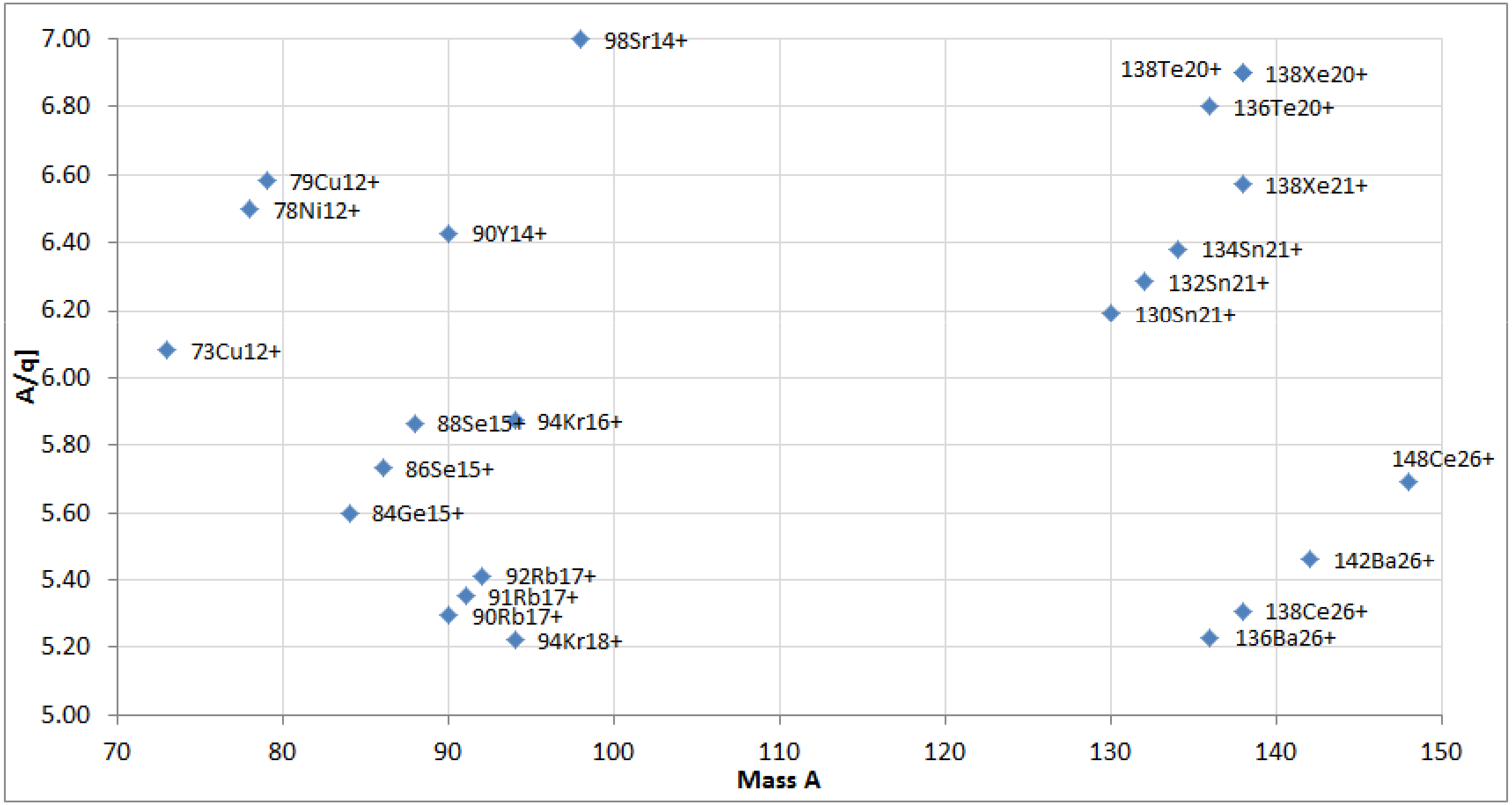


# Energy from SPES Post-Accelerator as function of A/q



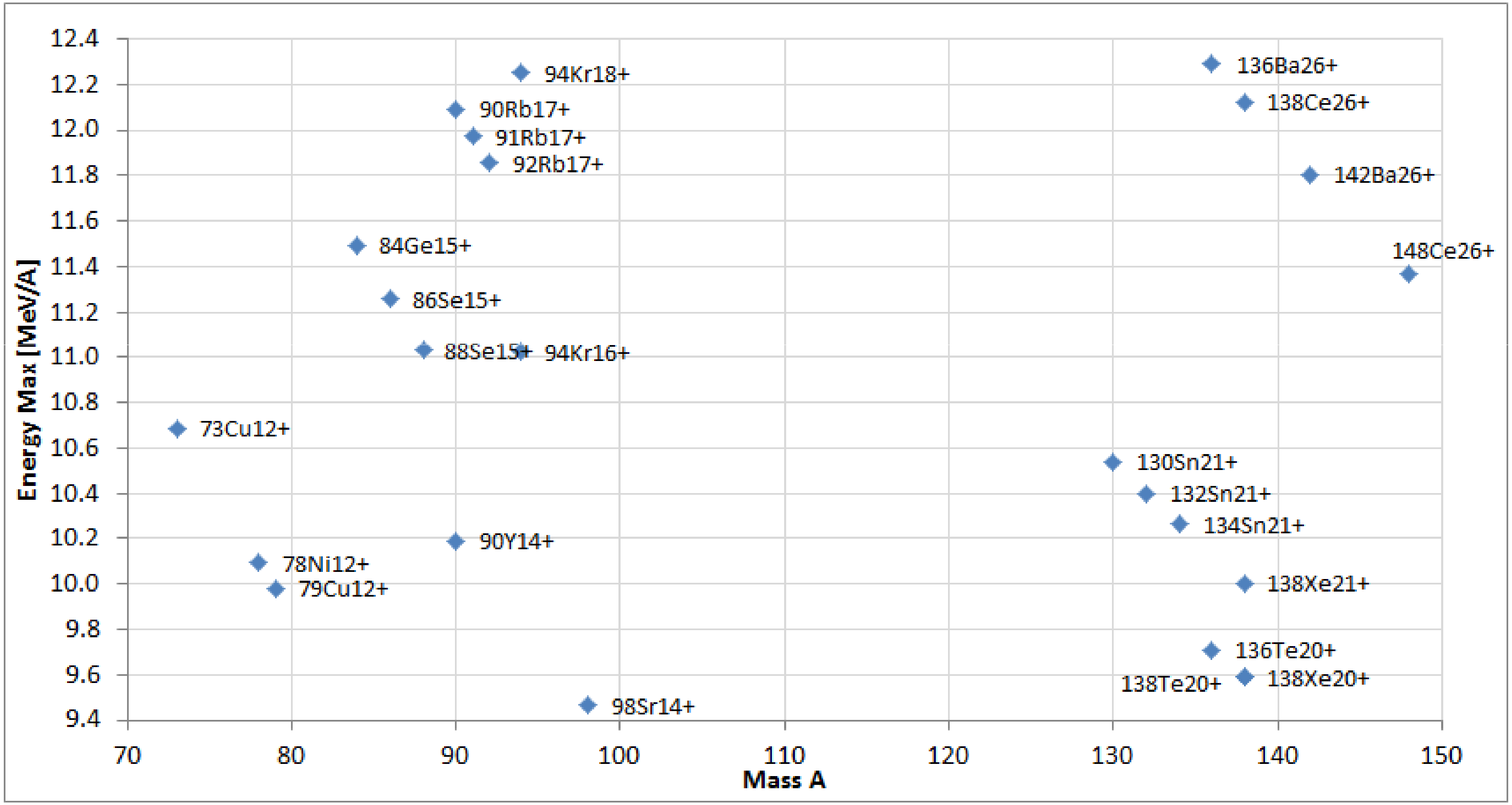

Preliminary results from alpi performances with 2 cavities off (margin), Low Beta=5 MV/m, Medium Beta=4.3 MV/m, High Beta=5.5 MV/m

# Possible A/q as function of Mass




PRELIMINARY RESULTS FROM CB PERFORMANCES

# RIB Energy as function of Mass



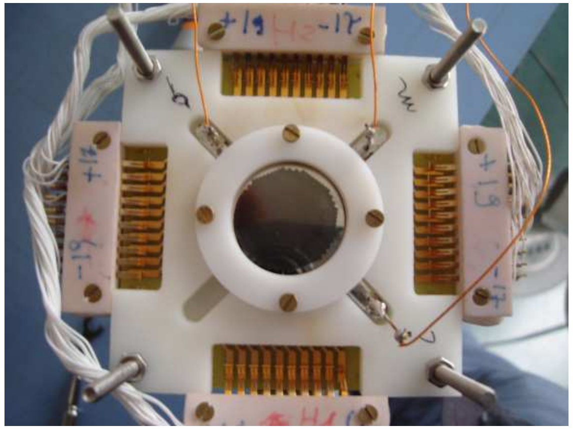

PRELIMINARY RESULTS FROM ALPI and CB PERFORMANCES

# Summary

- Dynamics and Physical design:  frozen
- Engineering design of beam line components and RFQ: starting (HRMS and Beam Cooler in R&D phase, pending their funding)
- Charge Breeder:  construction to be completed at the end of 2014
- ALPI upgrade (cryogenics, new cryomodules, RF systems, diagnostics, new beam line…): on going.

People involved on Beam Dynamics:
M. Comunian B. Chalykh L. Calabretta A. Russo A. Pisent

# Beam Diagnostics



**Beam position and profile monitors,** based essentially on microchannel plates (MCP) as beam intensifiers. MCP is put directly on the beam line. Electrons produced on it and collected, after multiplication, on a position sensitive anode give the beam impact position. Measured 0.75 mm position resolution was mesured for a 100 fA $^{12}C$ beam. **FC, E, $\phi$ detectors** are developed too.

**Tape station system**: under development for SPES; moving tape system (1 cm wide mylar tape ) and $\gamma$-ray counting chamber. Ge detectors, well shielded from potential background in the beam pipe, will be located at the counting chamber in a different position, a few cm far from the tape. The counting chamber will also accommodate plastic detectors for detecting positron decays.