Status of SPES Exotic Beam Facility

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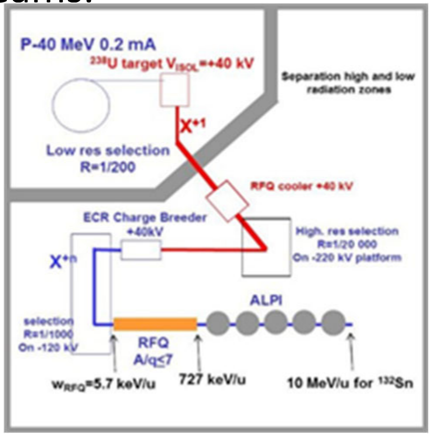
And all the SPES TEAM

M. Comunian

Index

- SPES main goals and Layout.
- The SPES cyclotron as primary driver.
- The target status.
- The high resolution stage: RFQ Cooler and the HRMS
- The transfer lines to the Low energy Experimental areas and to the Charge Breeder.
- The post acceleration stage: charge breeder and the MRMS with the purity issue.
- The matching line from CB to the SPES RFQ injector for ALPI LINAC
- ALPI LINAC performances as post-accelerator with Rare Beams.
- The Rare beams instrumentation
- The Time schedule and commissioning of the facility
- Conclusion

I will not cover: controls, safety and integration aspects.



SPES project goals

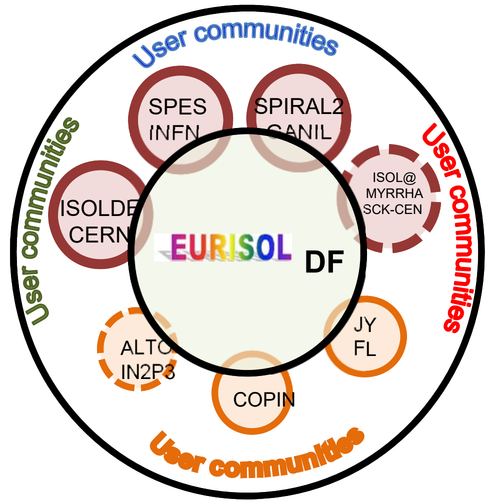
- **Second generation ISOL facility for nuclear physics as part of the EURISOL_DF initiative (ESFRI_2020):**

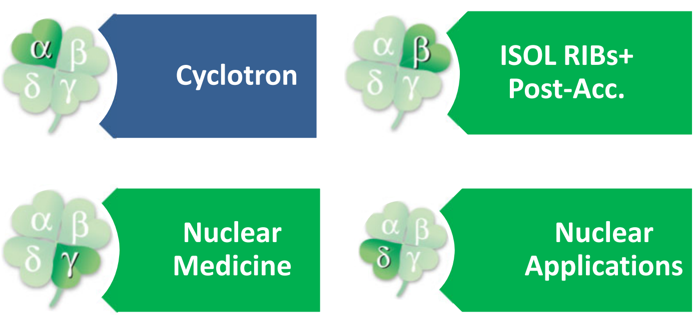
Production & re-acceleration of **exotic beams (neutron rich nuclei → 10^13 f/s)**

- Research and Production of **Radio-Isotopes for Nuclear Medicine**

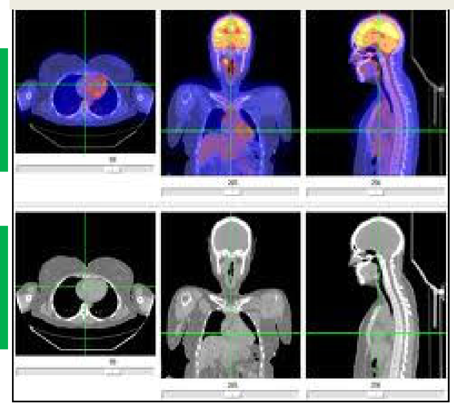
- Accelerator-based neutron source (**Proton and Neutron Facility for Applied Physics**)

Nuclear Physics with re-accelerated exotic beams

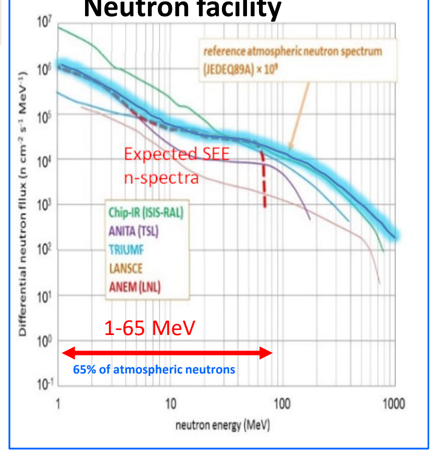




Radioisotopes for medicine



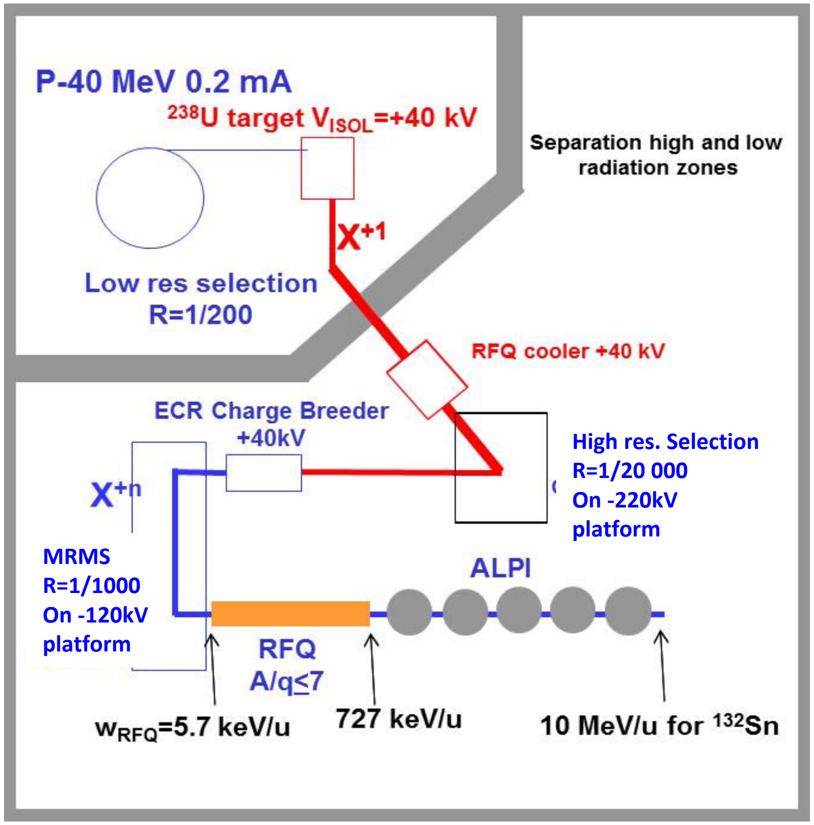
Neutron facility



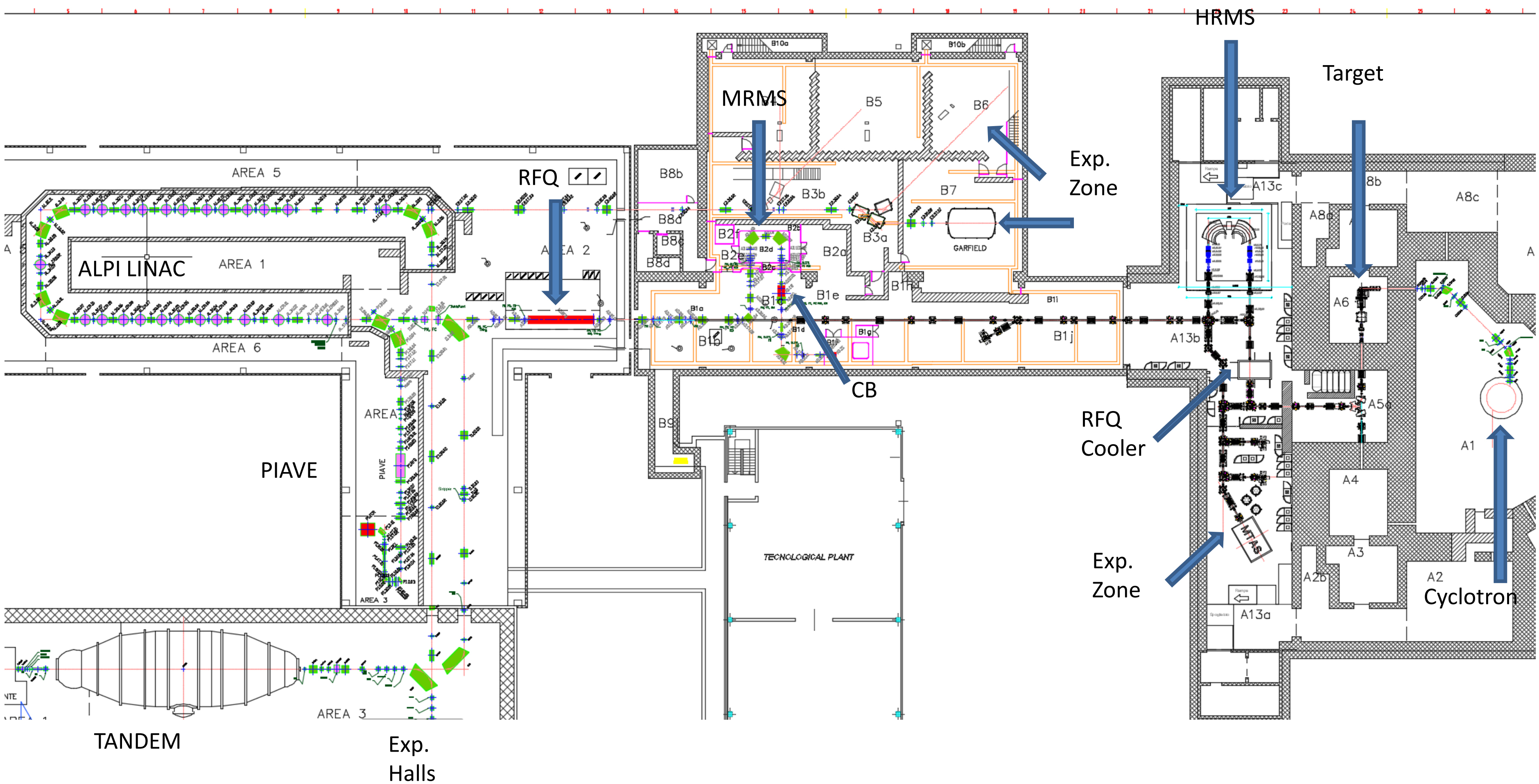
SPES Facility functional scheme

- The beam preparation scheme satisfies various requirements:

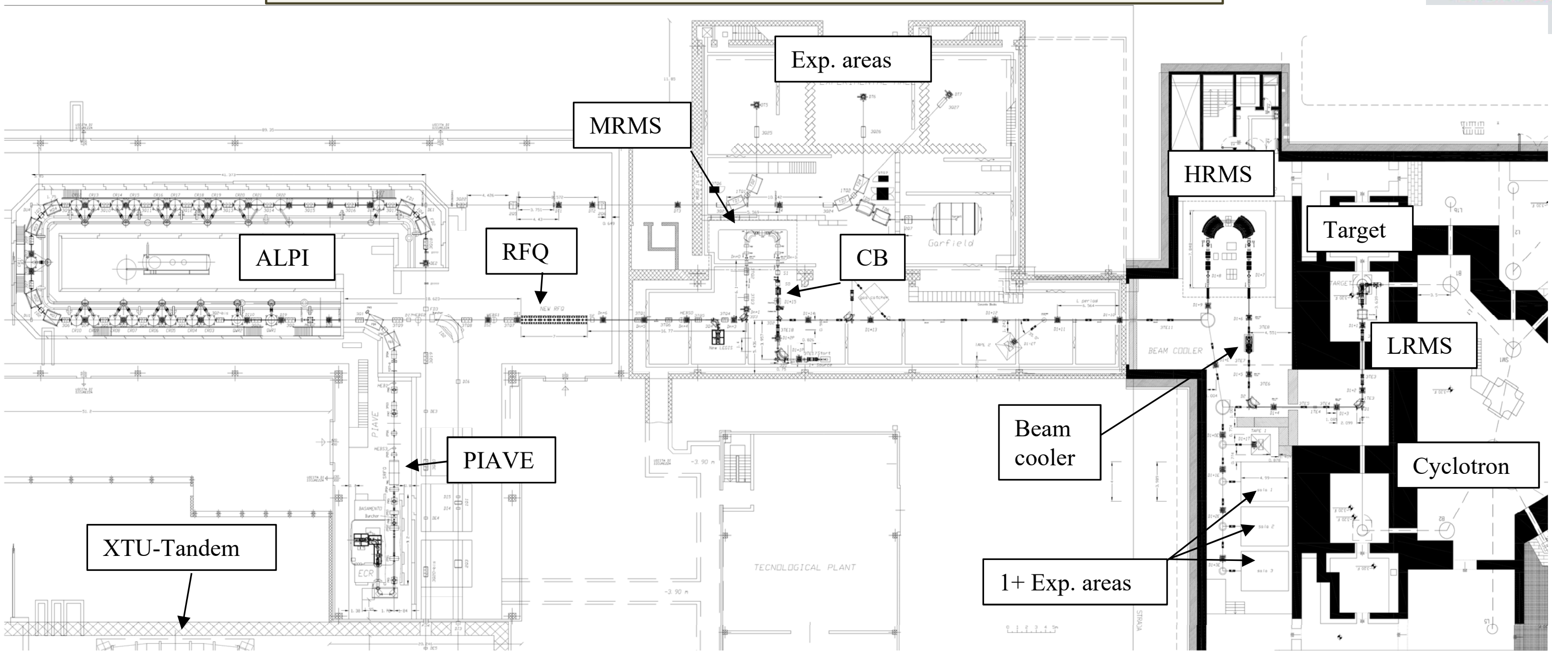
1. the zone with worst radiation protection issues is reduced by means of the first isobar selection (resolution R=1/200).
2. after that with an RFQ cooler the beam energy spread and transverse emittance are reduced both for further separation and to cope with the charge breeder acceptance (about 1 eV).
3. HRMS and MRMS (high and medium resolution mass spectrometers, R=1/20000 and R=1/1000 respectively) are used to select the RNB (with good transmission) and to suppress the contaminants from the charge breeder source.
4. Both the HRMS and the MRMS are installed on a negative voltage platform, to decrease the beam geometrical emittance, the relative energy spread and to keep the dipole field in a manageable range (>0.1 T).
5. The 7 m long RFQ has an internal bunching and relatively high output energy; this easies the setting and allows 90% transmission into ALPI longitudinal acceptance (constraint deriving from quite long ALPI period, 4 m).
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- ALPI Layout



The SPES Layout



General features

- The SPES facility may be divided in three stages: the RIB production, the magnetic isotope separation and the charge breeding with the post-accelartion.
- Low current beams (nA-fA) and transfer line with high dispersion require a careful manage of the beam optics.
- Several localised separation stages are needed for separate the nominal beam from the isotopes and fit the safety requirements.
- Very long transfer lines are needed in order to fit the new building with the existing linac ALPI.

Main stages

- The **cyclotron** accelerates 70 MeV proton beam of 750 μA onto a UCx **target**, heated at 2000 C°. The radioactive ions produced are extracted @ 20-40 keV, depending on the RFQ's β_s of the n+ beams.
- There are three separation stages: the **LRMS**, composed by a Wien filter and a 90° magnetic dipole 1/200 resolution in mass (isobar selection); the **HRMS**, with a capability of 1/20000 resolution (isotope separation) in mass and the **MRMS** of 1/1000, which removes the CB contaminants.
- The beam gains 1+ -> n+ charge and, after the removal of the **CB** contaminants is sent to an internal bunching **RFQ**, which accelerates the beam up to 727.3 keV/A (for A/q=7).
- The beam is longitudinally matched with the linac via a **MEBT** line (with two bunchers). The **ALPI linac** accelerates the beam up to 10 MeV/A .
- There are two experimental areas: the 1+ experimental areas down to the HRMS complex and the experimental areas down to ALPI for the post accelerated beams.

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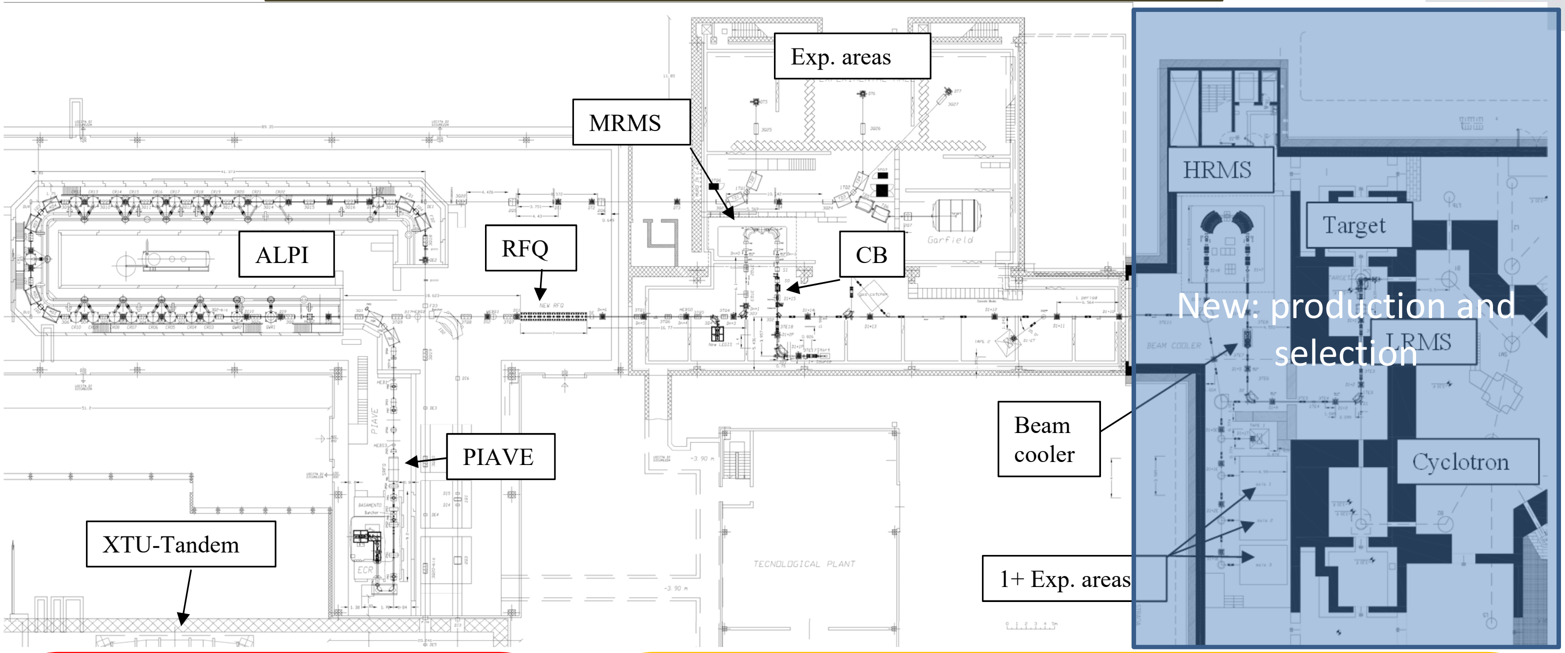

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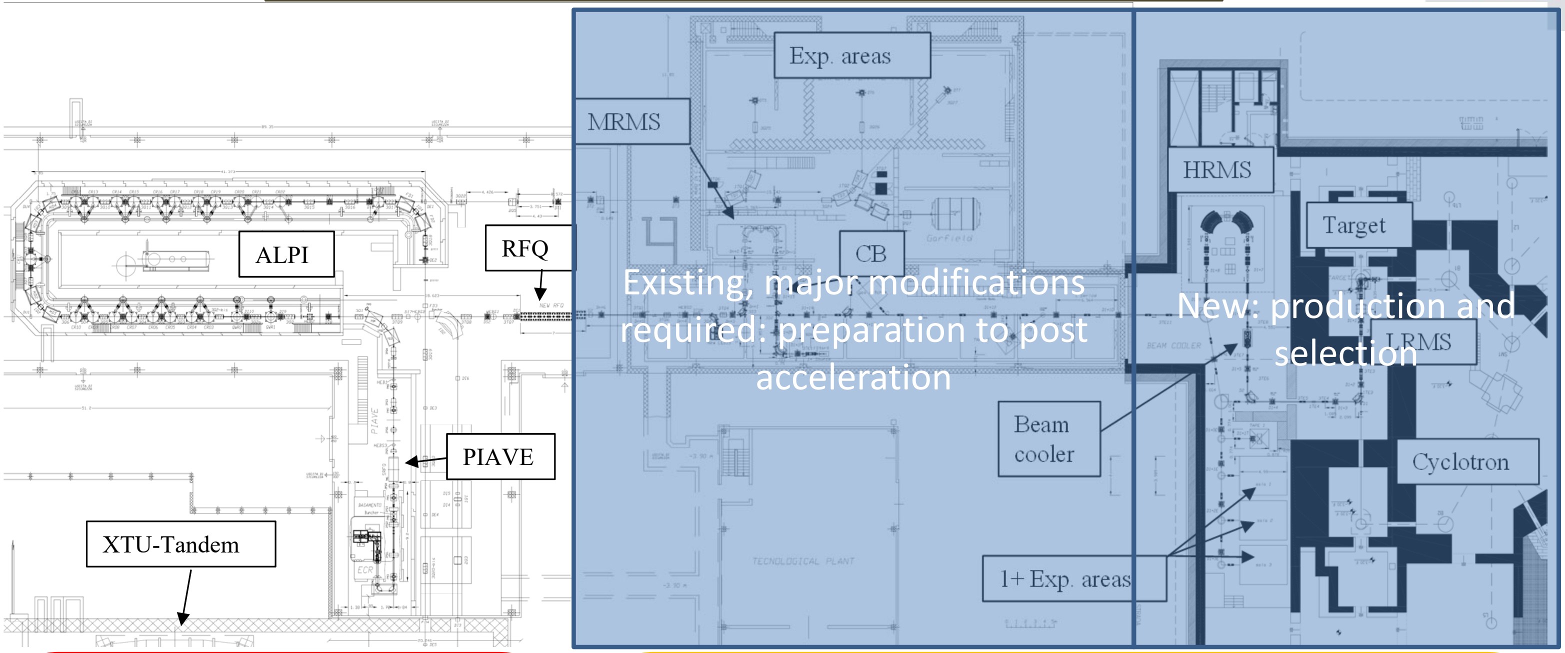

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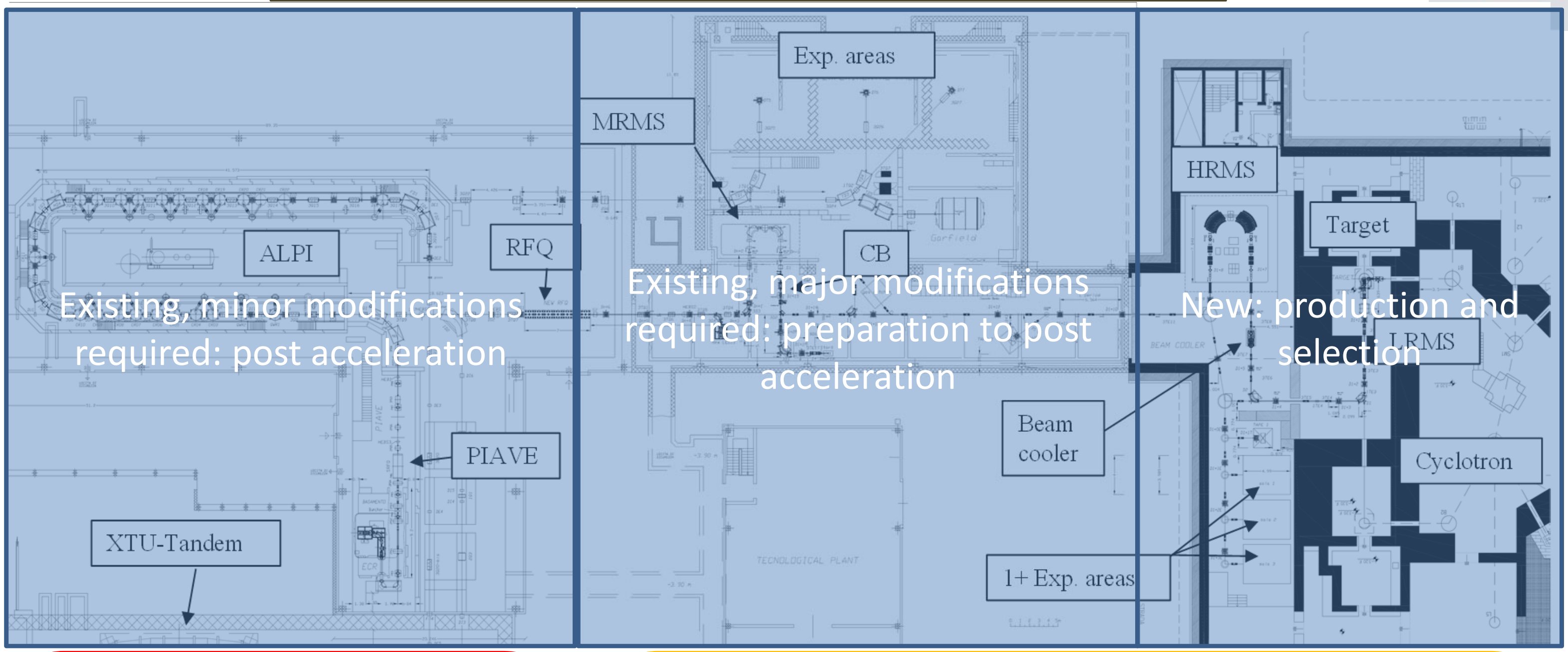

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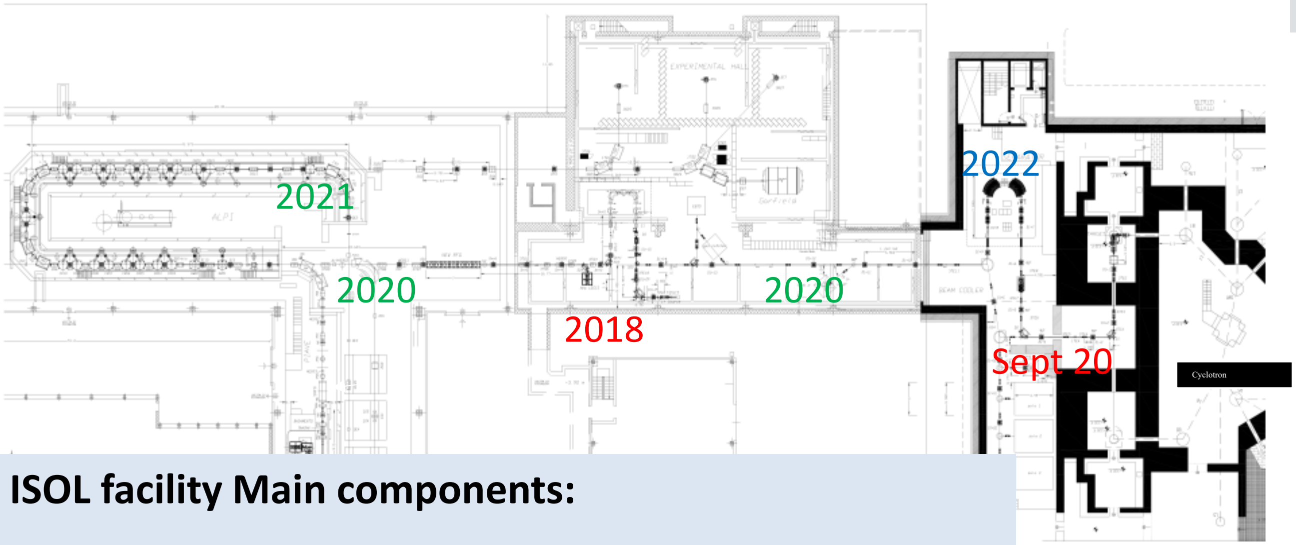
SPES infrastructure - layout

- New High power compact CYCLOTRON 70 MeV 750 microA (BEST company)
- New configuration of High power ISOL System (8 kW Target ion source)
- ALPI superconductive linac (up-graded) for RIB's reacceleration

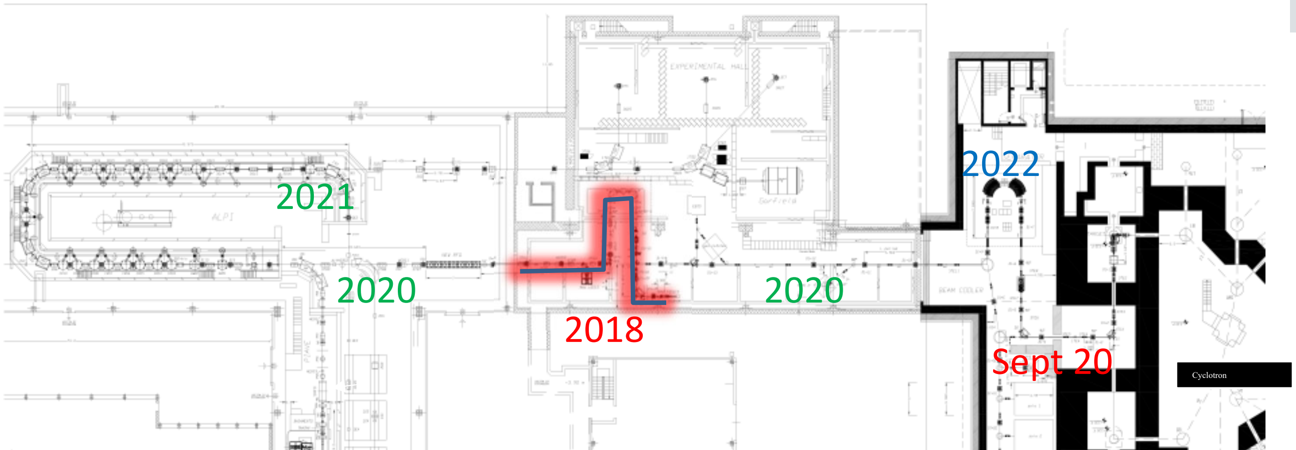
SPES layout and components 1/2



SPES ISOL facility Main components:

Cyclotron: Protons 35-70 MeV, 0,75 mA shared on two exits
ISOL System: UCx 8kW direct target, 10^13 fission/s
Low Resolution Mass Separator (Wien Filter & LRMS)
High Resolution Mass Separator (Beam Cooler & HRMS)
1+ beam transfer
Charge Breeder (ECR)
Medium Resolution Mass Separator (MRMS)
RFQ preaccelerator
ALPI superconductive linac

SPES layout and components 1/2



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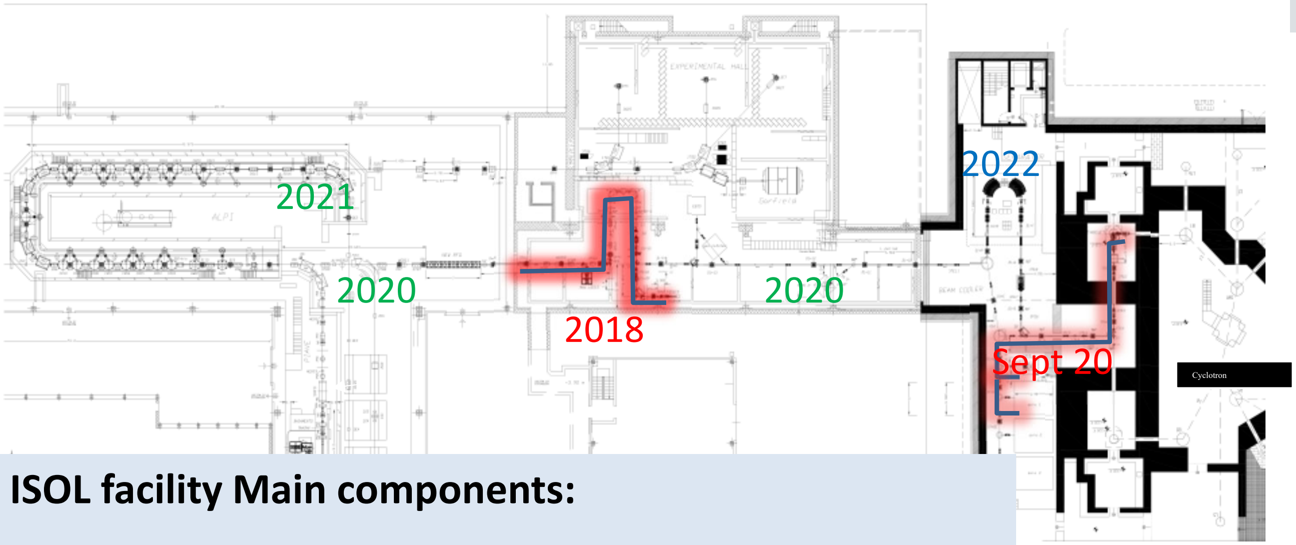

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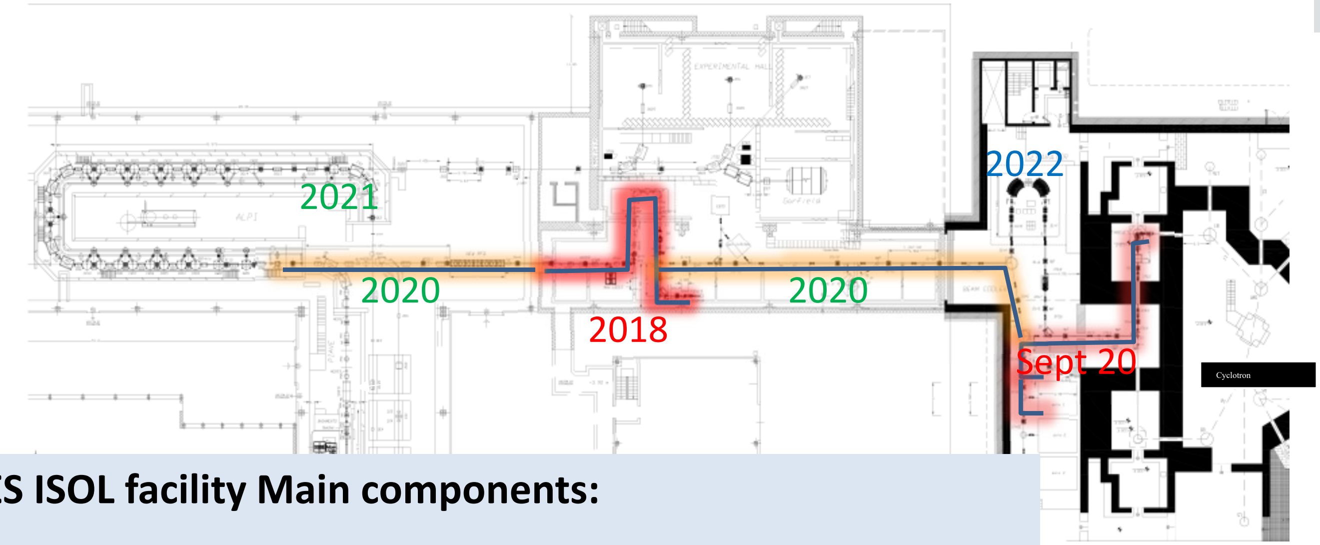

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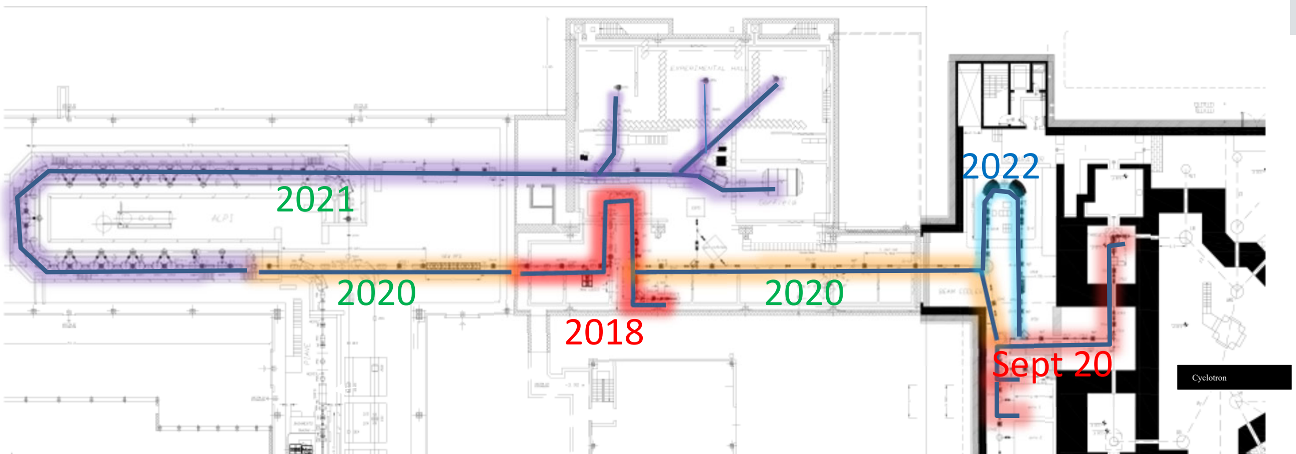

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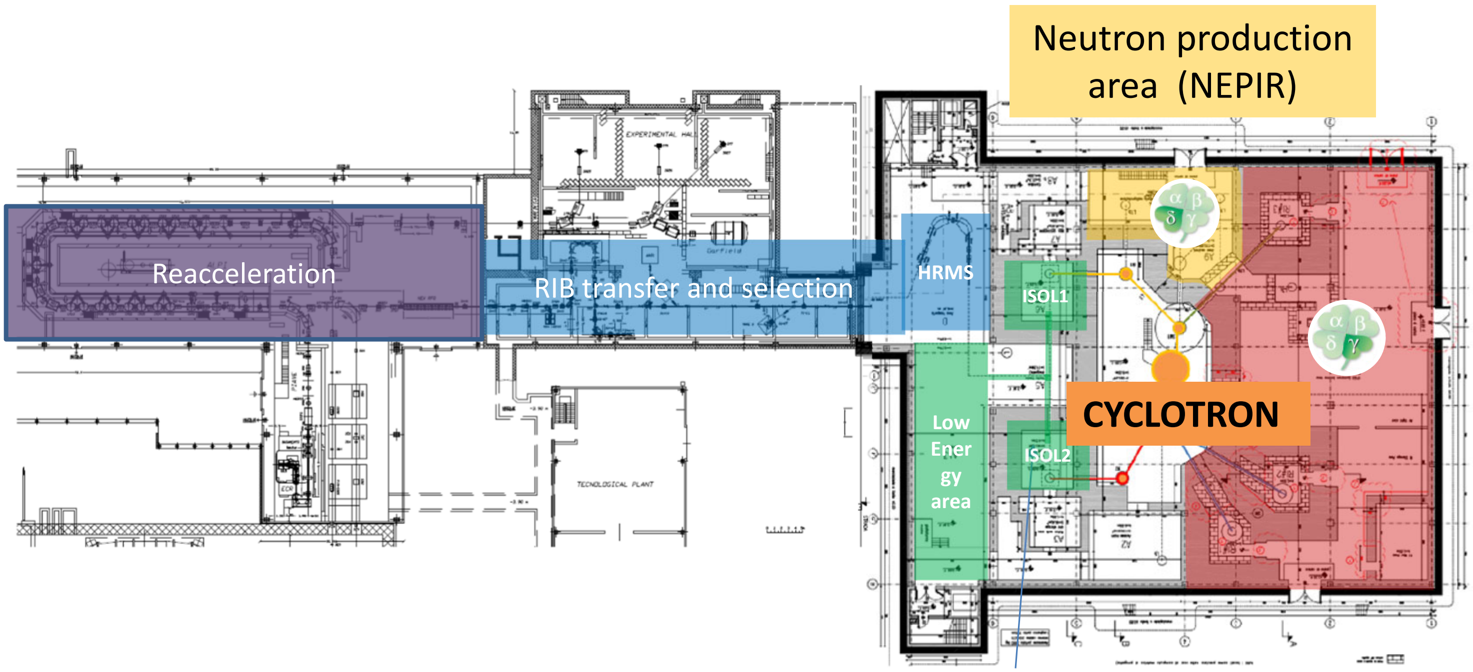
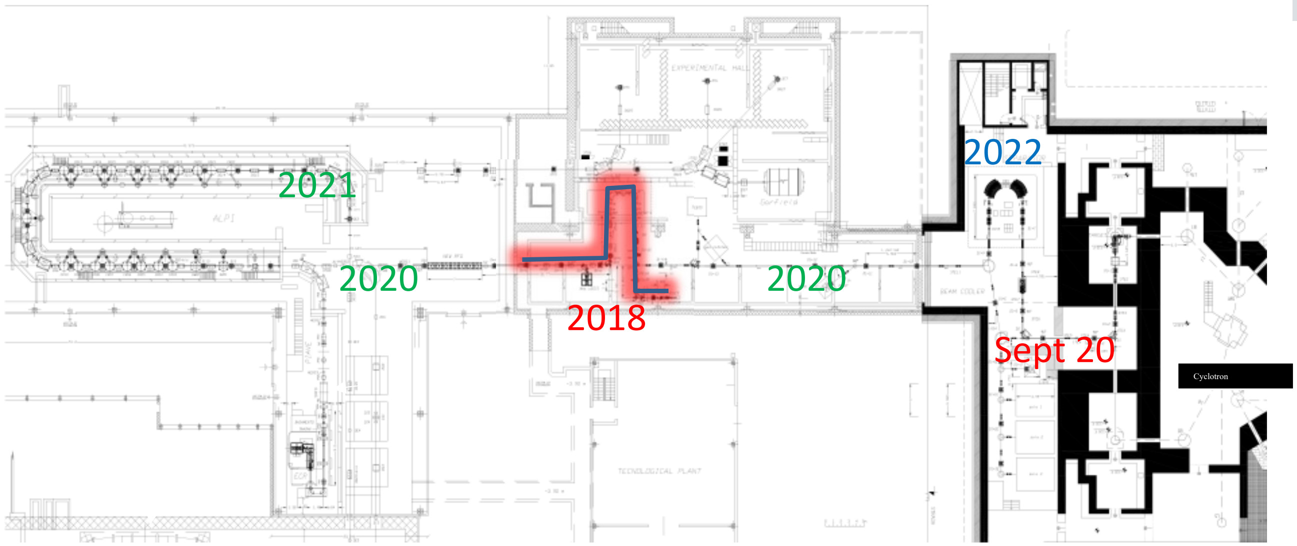


RIB reacceleration: • new RFQ • ALPI	1/20.000 Mass separator (Beam Cooler + HRMS) Elettrostatic beam transport Charge Breeder (n+) 1/1000 mass separator	ISOL bunkers 1/200 mass separator low energy experimental area	Radioisotopes production area (LARAMED)

SPES installation phases



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installation — Hardware commissioning — Beam commissioning

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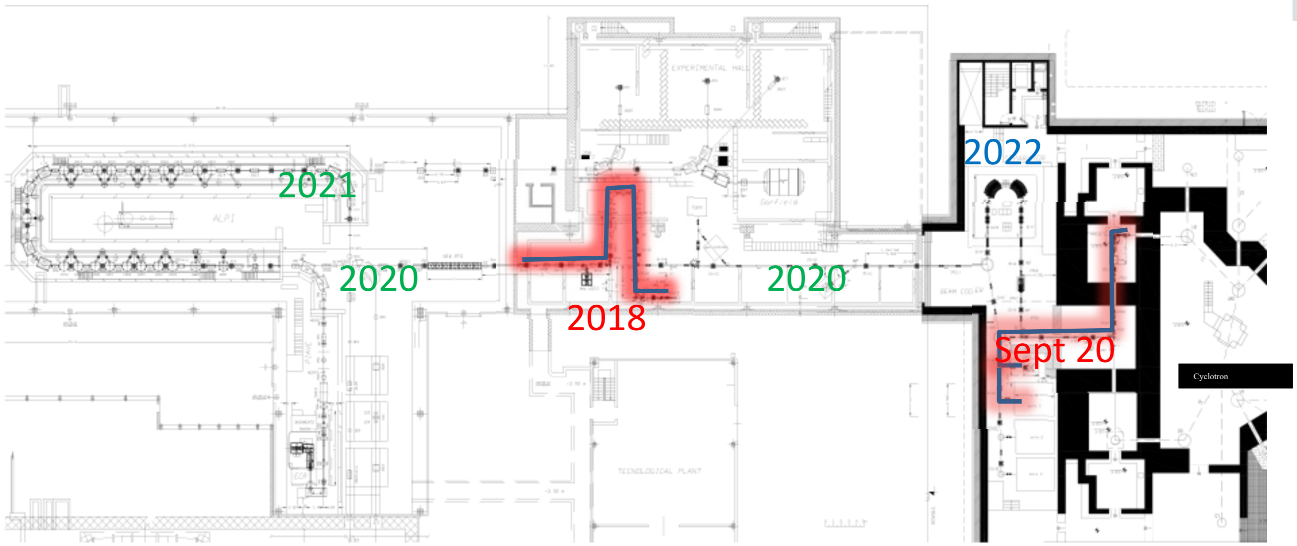

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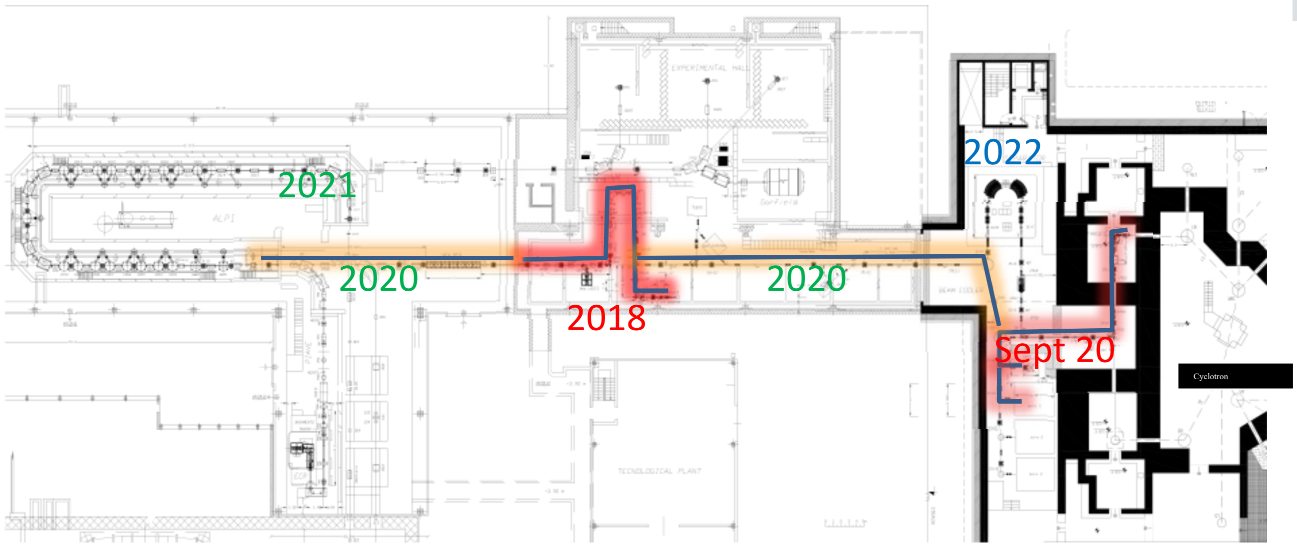
Experiments with non-reaccelerated beams 2020

installation **Hardware commissioning** **Beam commissioning**

SPES installation phases



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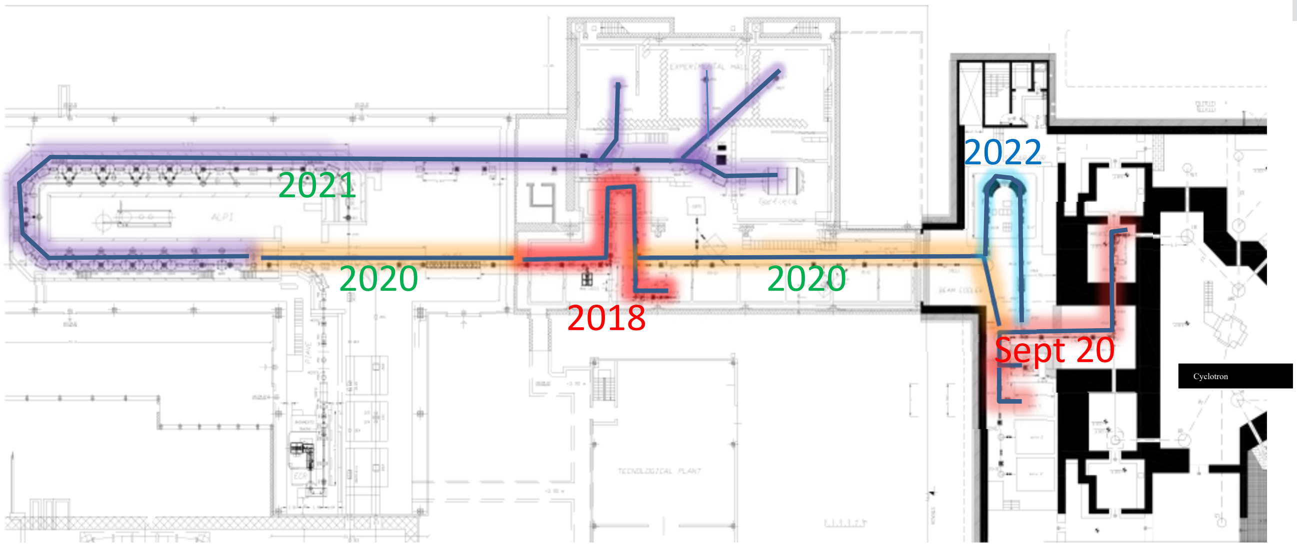

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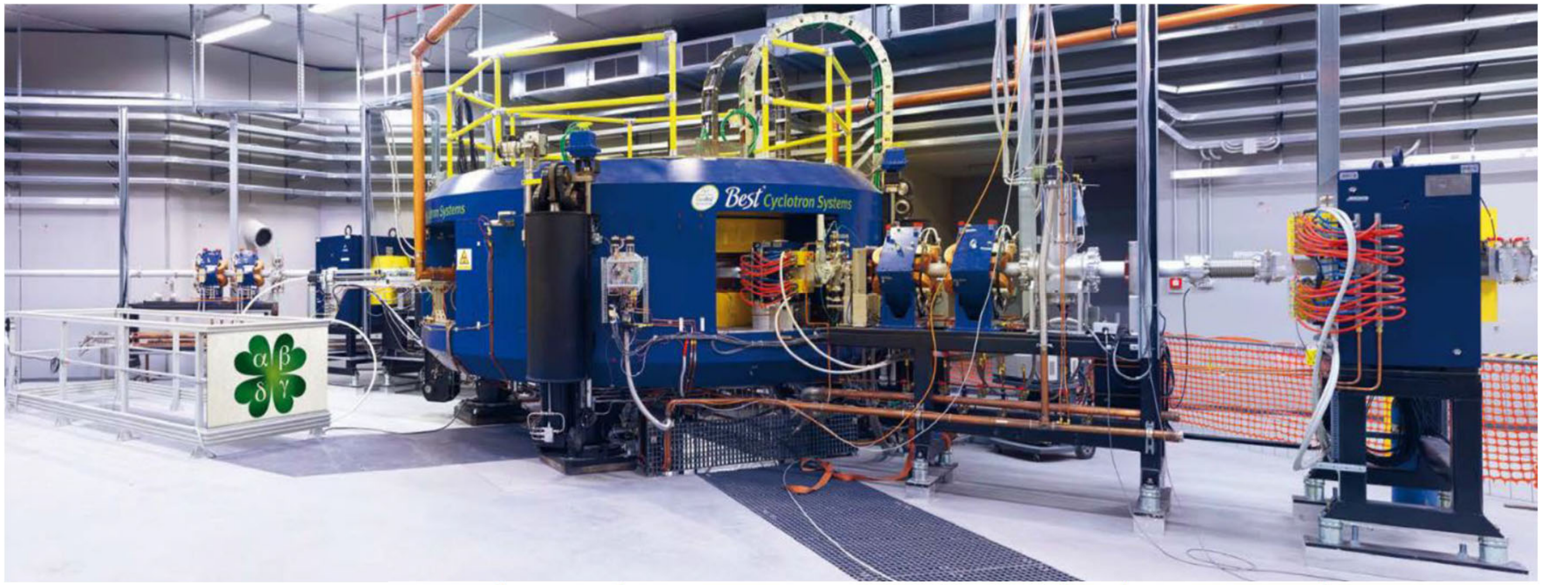
Experiments with non-reaccelerated beams 2020

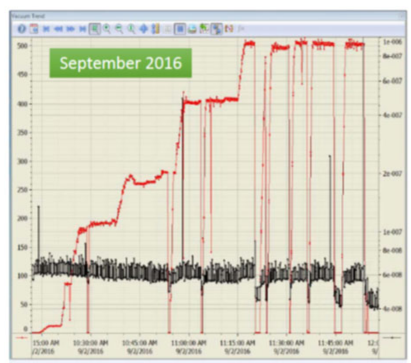
installation **Hardware commissioning** **Beam commissioning**

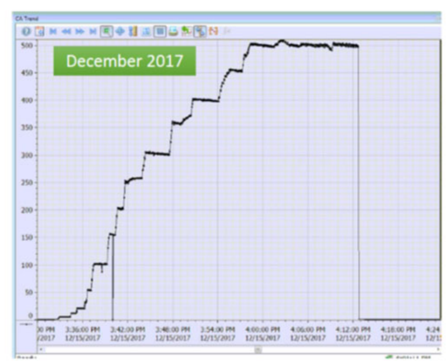
Cyclotron Status



35 kW beam power delivered to BD

1. Completed the cyclotron commissioning
2. Performed the personnel training for operation and maintenance
3. Started the cyclotron operation up to Beam Dump at 70 MeV 500 microA



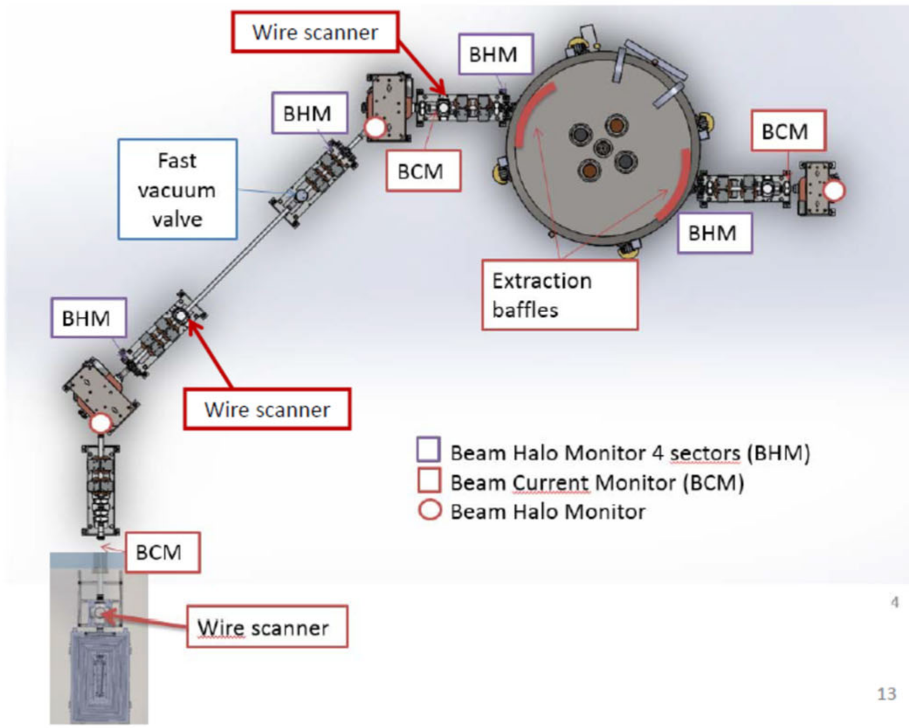


Courtesy of M. Maggiore

Beam transport at high current (35 kW beam power)

- To get **500 µA** on target
- Ion Source setting at **8.5mA**
- Injection acceptance ~11% (40 RF deg)
- optimize acceleration RF phase → ~40% current lost in CR
- Acceleration efficiency >95%
- Extraction efficiency >99%
- Transport efficiency >99%

$I_{target} / I_{IS} \sim 6\%$



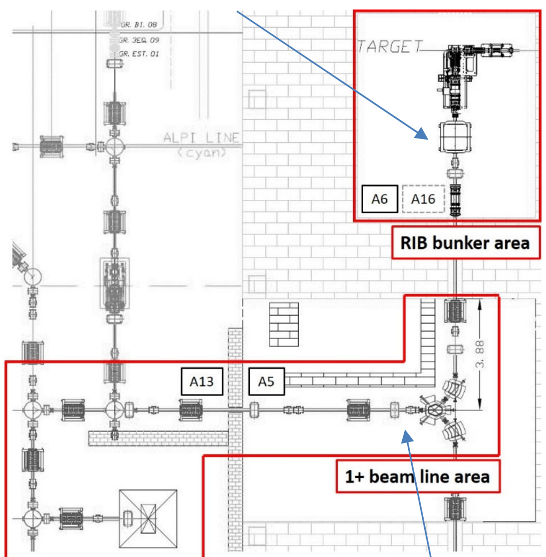
Courtesy of M. Maggiore

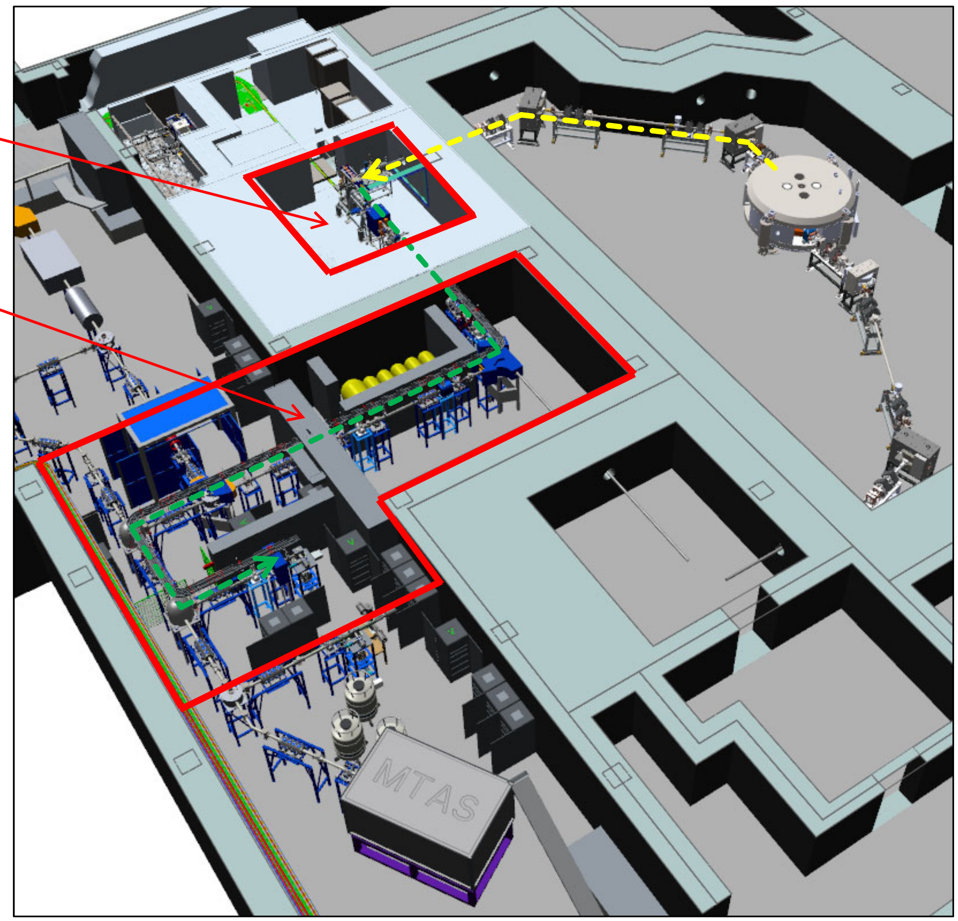
From Target to Tape System

RIB bunker

1+ beam line

Wien Filter





Courtesy of M. Manzolaro

Beam Selectivity of 1/200 (LRMS)

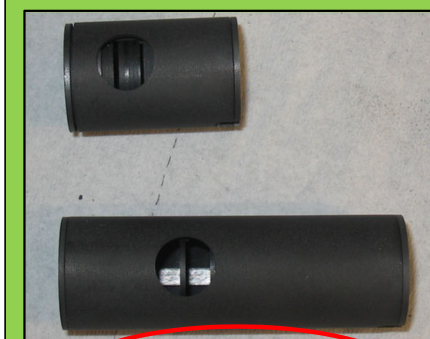
Toward the first SPES RIBs

the next two steps of the commissioning phase

40 MeV, 20 µA

SiC target

SAINT-GOBAIN

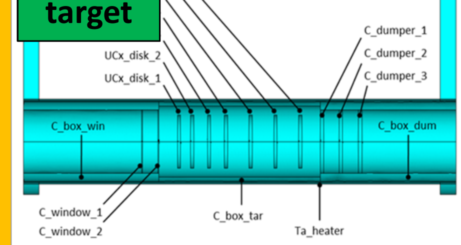


First SPES RIB (^{26}Al)

→ 40 MeV, 20 µA, 10^{12} f/s

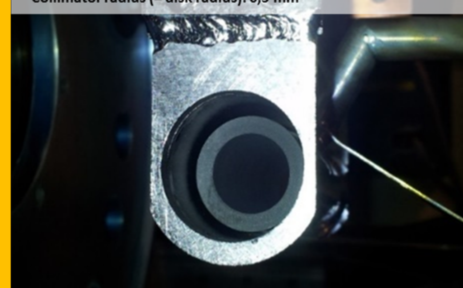
UCx target

the scaled SPES target for low intensity RIBs



Nominal parameters

- Target material: UCx (SiC as an alternative)
- Proton beam energy: 40 MeV
- Proton beam intensity: 20 µA
- Proton beam sigma: 5 mm
- Collimator radius (= disk radius): 6,5 mm

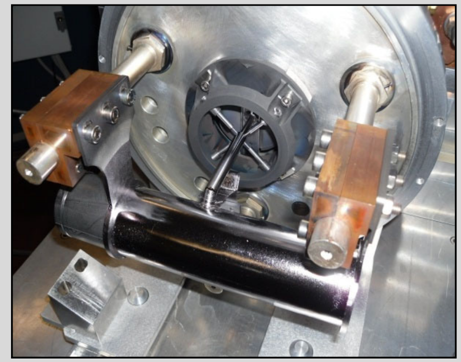


first n-rich fission isotopes

→ 40 MeV, 200 µA, 10^{13} f/s

UCx target

the full-scale SPES target for high intensity RIBs



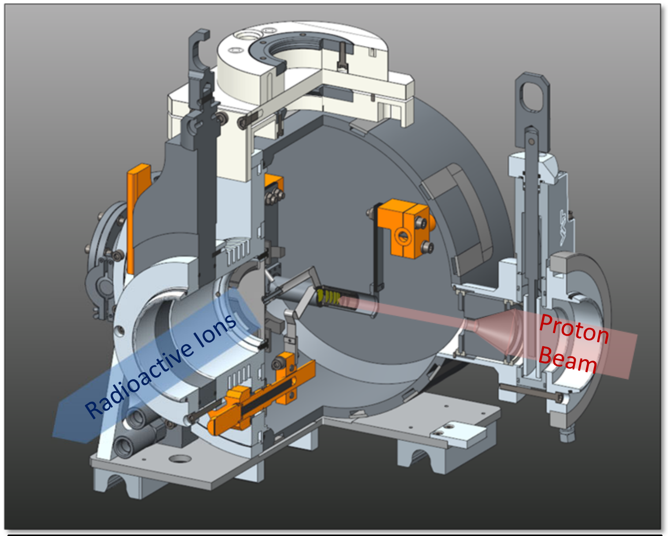
Nominal parameters

- Target material: UCx (SiC as an alternative)
- Proton beam energy: 40 MeV
- Proton beam intensity: 200 µA
- Proton beam sigma: 7 mm
- Wobbling radius : 11 mm

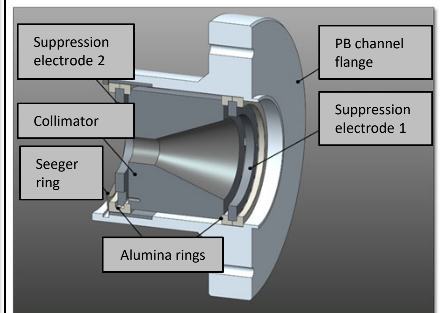
to high proton beam intensities (increase by a factor of 10)

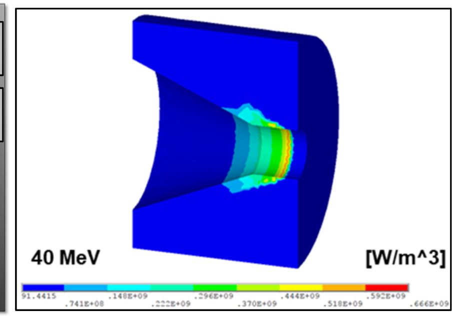
Courtesy of M. Manzolaro

WG 1: Development of the SiC Target - Ion Source Unit

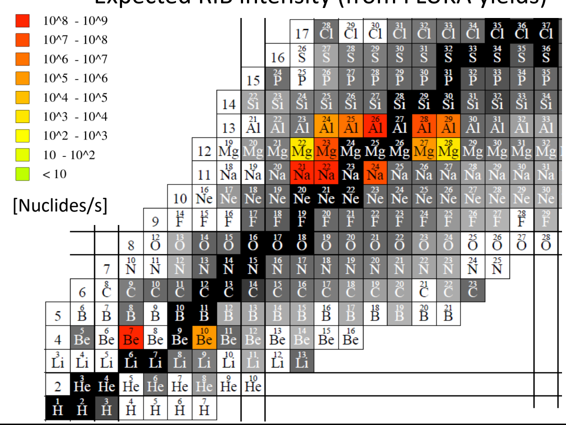


Collimator (required for the 13 mm target)

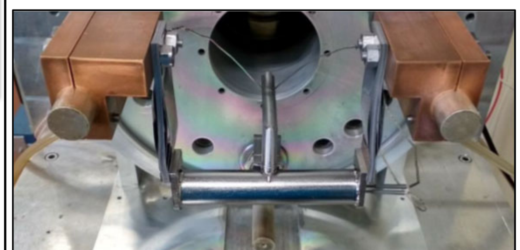


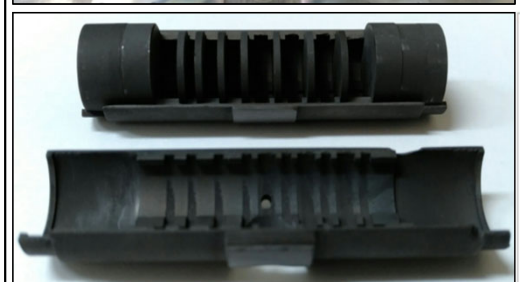


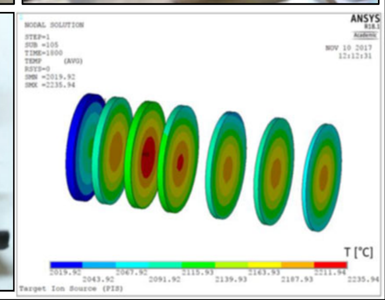
Expected RIB intensity (from FLUKA yields)



Silicon carbide 13 mm target

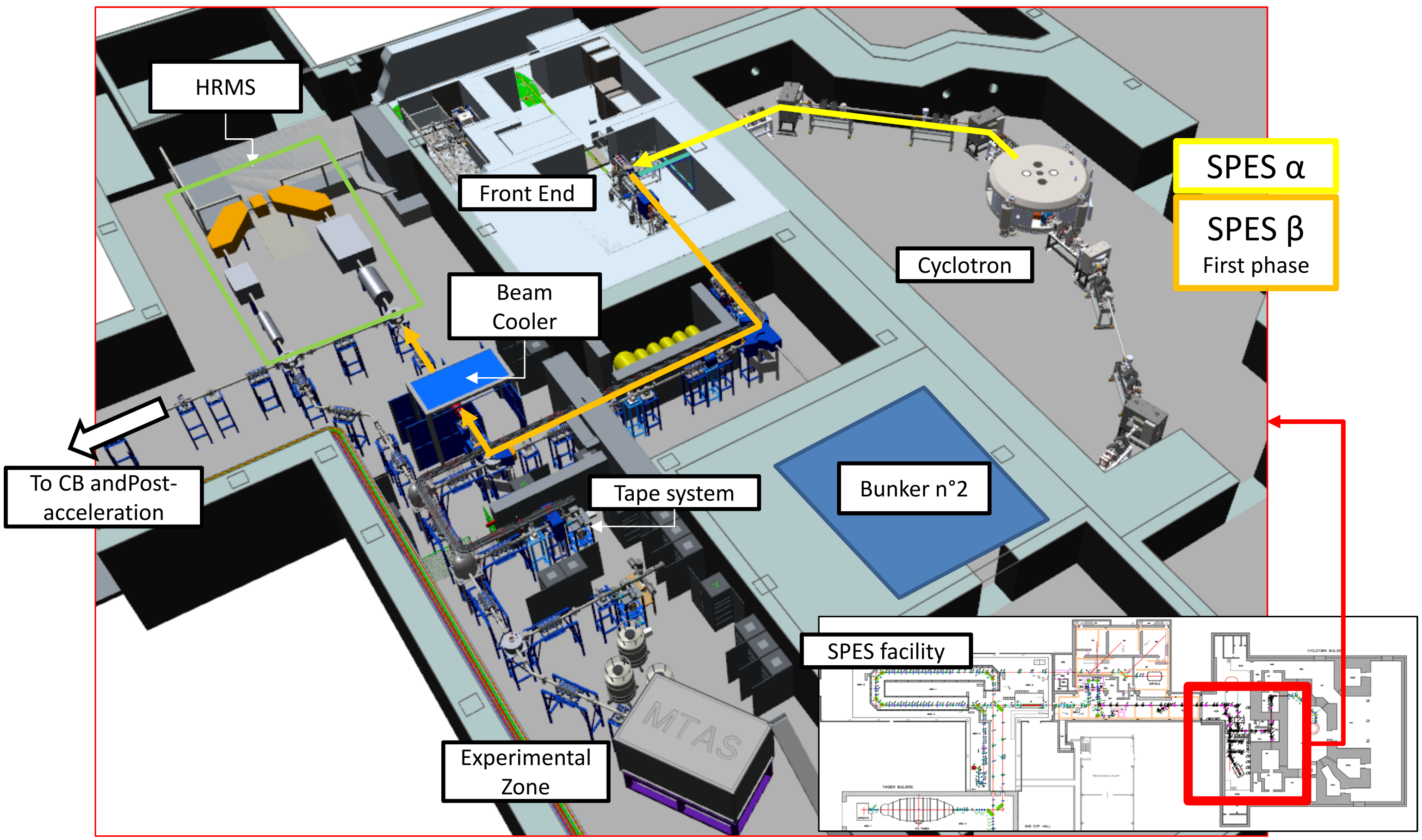




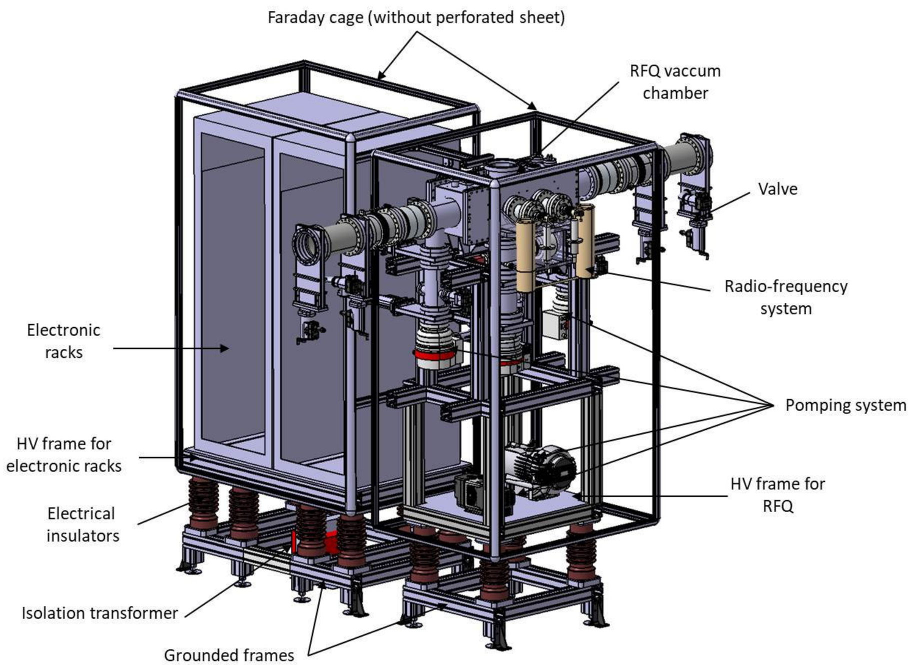


Courtesy of M. Manzolaro

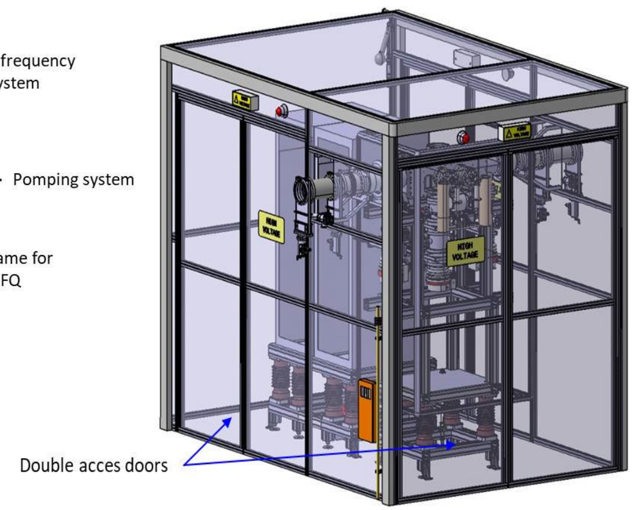
Beam Line From Cyclotron to HRMS



SPES RFQ cooler Layout



RFQ cooler without protective cage



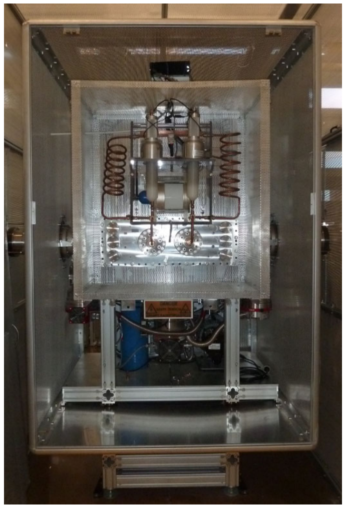
RFQ cooler with protective cage

Courtesy of G Ban- JF Cam

High intensity RFQ cooler origin

Demonstrator designed for SPIRAL2 / phase 2 :

RFQ cooler test bench at LPC



RFQ cooler

Electronic control devices

Initial requirements:

Incident beam to handle

- **Intensity: up to 1 µamp**
- **Energy: up to 60 keV**
- **Mass: 12 uma to 200 uma**
- **Emittance: 80 pi.mm.mrad**

SPES Cooler Delivery plan

Texte	Nom de la tâche	Milestone (2018–2021)
M0	Start of Project	17/09
M1	Final definition review (FDR)	16/11
M2	End of quadrupole qualification	16/03
M3	SPES BC mounted at LPC and functional tests done	08/07
M4	SPES BC has been characterised at LPC using beams on which LPC and INFN agreed	06/09
M5	SPES beam cooler packaged and transported to INFN-LNL	05/11
M6	SPES BC mounted at INFN-LNL and functional tests done	04/01
M7	SPES BC has been characterised using 4 beams of those used at LPC	04/04

Courtesy of G Ban- JF Cam

Expected performance from SPES RFQ Cooler

SPES preliminary values:

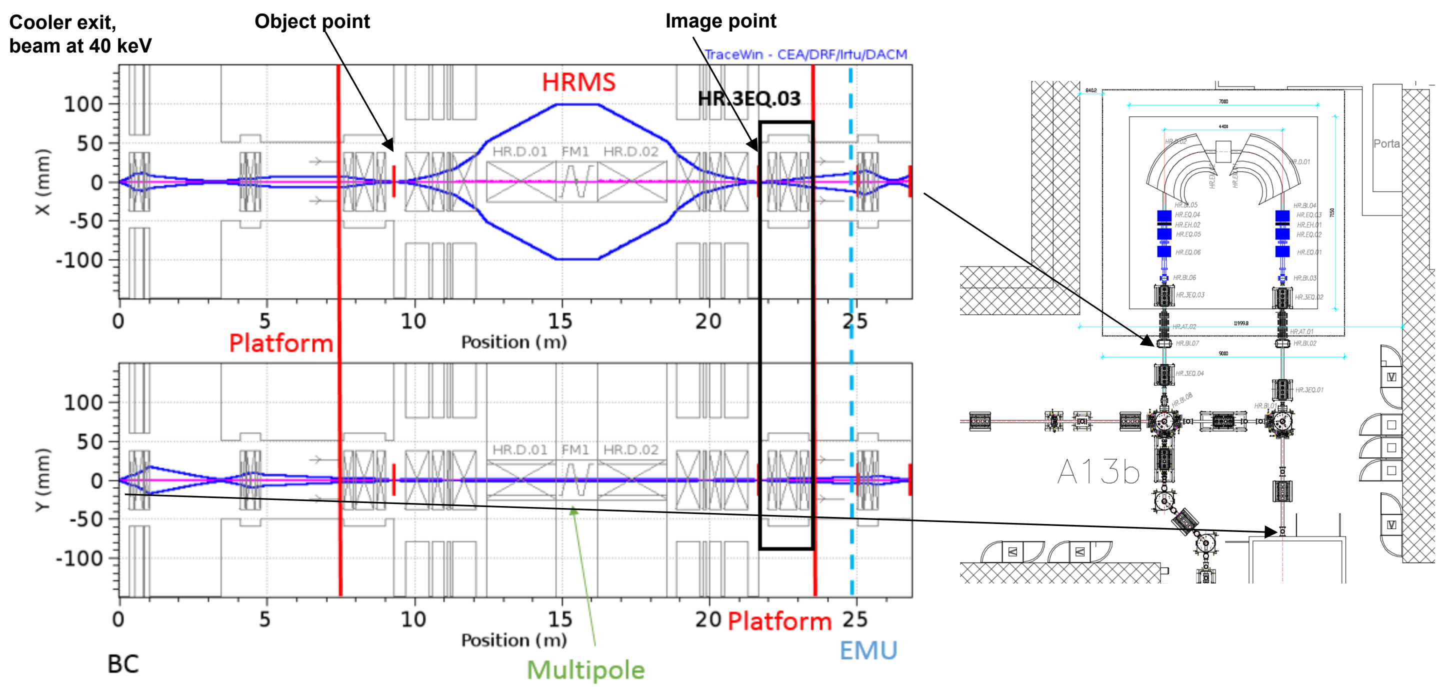
Parameters	Requested values
Transmission	>80%
Output beam Transverse Emittance (RMS norm)	< 1.5 E-3 pi.mm.mrad
Output Beam Energy Spread (FWHM)	< 0.7 eV
Input Beam maximum/nominal Current	100 nA / 50 nA
Energy of Beams at RFQC Output (*)	$V_{platform}$
Reduction factor of emittance $\varepsilon_{in}/\varepsilon_{out}$	>10

LPC RFQ cooler measurement results @ 5keV:

Element	Mass	Beam Current	RF frequency	RFQ pressure	Mathieu parameter q	Transmission	Energy spread FWHM	RMS Emittance @ 5keV	RMS normalised Emittance
Lithium	7 uma	**50 nA**	4,5 MHz	2,67 E^{-2} mBar	0,4	61%	0,82 eV	7,79 pi.mm.mrad	9,64 E-3 pi.mm.mrad
Potassium	39 uma	**50 nA**	3,5 MHz	2,15 E^{-2} mBar	0,34	70%	0,9 eV	5,37 pi.mm.mrad	2,82 E-3 pi.mm.mrad
Potassium	39 uma	**100 nA**	3,5 MHz	2,15 E^{-2} mBar	0,34	82%	1,05 eV	7,25 pi,mm.mrad	3,80 E-3 pi.mm.mrad
Cesium	133 uma	**50 nA**	2,5 MHz	2,08 E^{-2} mBar	0,11	63%	1,15 eV	7,25 pi.mm.mrad	2,06 E-3 pi.mm.mrad
Cesium	133 uma	**100 nA**	2,5 MHz	2,08 E^{-2} mBar	0,11	67%	1 eV	7,78 pi.mm.mrad	2,21 E-3 pi.mm.mrad

Courtesy of G Ban- JF Cam

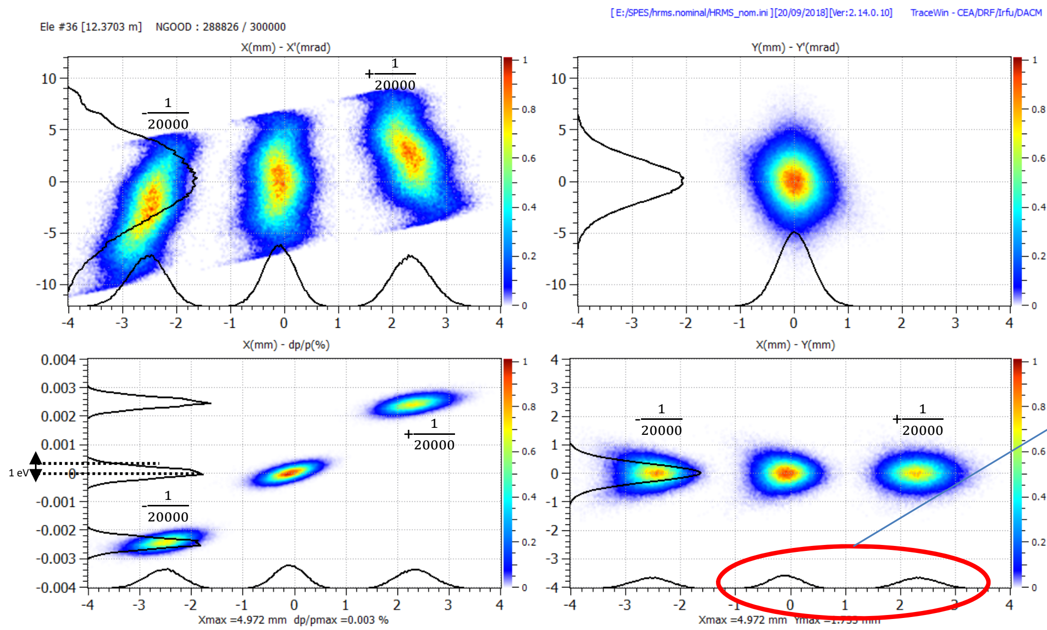
HRMS Multiparticle Beam envelope



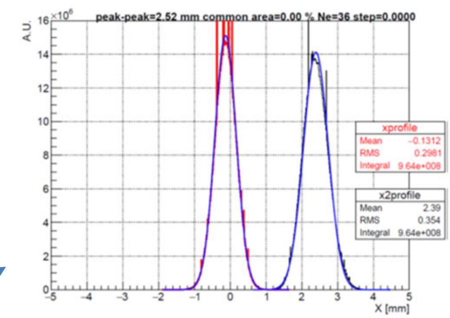
The beam dynamics from the RFQ Cooler through the HRMS to the EMU device is show.

Courtesy of L. Bellan

HRMS Beam Separation without slits at image point with a gaussian beam (cut at 4σ) and 1eV (rms) as energy spread

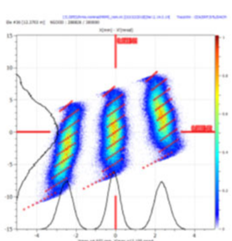


Total beam size=2 mm

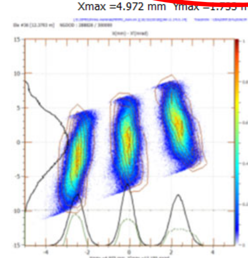


2.5 mm Beam separation

The output of TraceWin has been post-proceed with ROOT to calculate the beams separation and the common area



The output of TraceWin has been compared with COSY 5° order (red dots) and the results are the same.



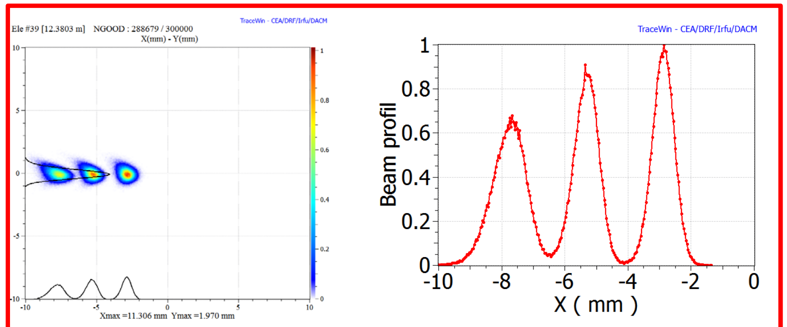
The output of TraceWin has been compared with GIOS 3° order (Brown lines) and the results are the same.

HRMS stability analysis

The input condition position and emittance, dipole position and quads position are changed all at the same time randomly taking +/- the maximum specified error. 50 runs have been made to accumulate statistics on 3 beams separated of 1/20000. Here it is presented the worst case.
The figure report the results with the followings errors:

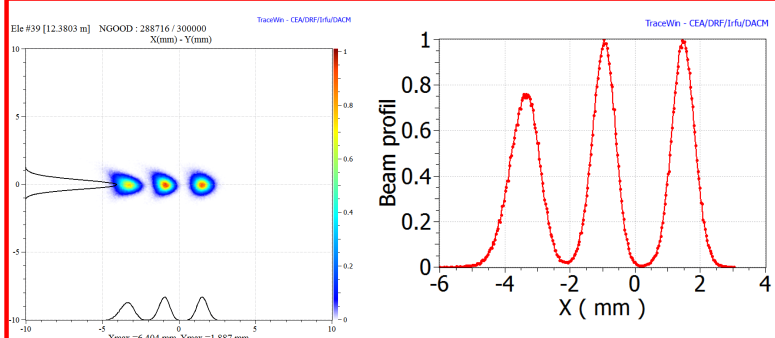
- Input beam position +/- 0.1 mm on X and +/- 0.1 mm on Y
- Input emittance increase of 10% on x and y and 10% on energy spread.
- Input mismatch of 10% on X and Y Twiss parameters.
- Dipole position error of +/- 0.1,0.05 mm on X and Y.
- Quadrupole position +/- 0.1,0.05 mm on X and Y.
- Multipole position +/- 0.1,0.05 mm on X and Y.
- No correction (like steerers or quad/dipole strength) has been used.

The 3 beams are still separated of more than 95%.



+/- 0.1 mm error on quadrupoles, multipole and dipoles alignment

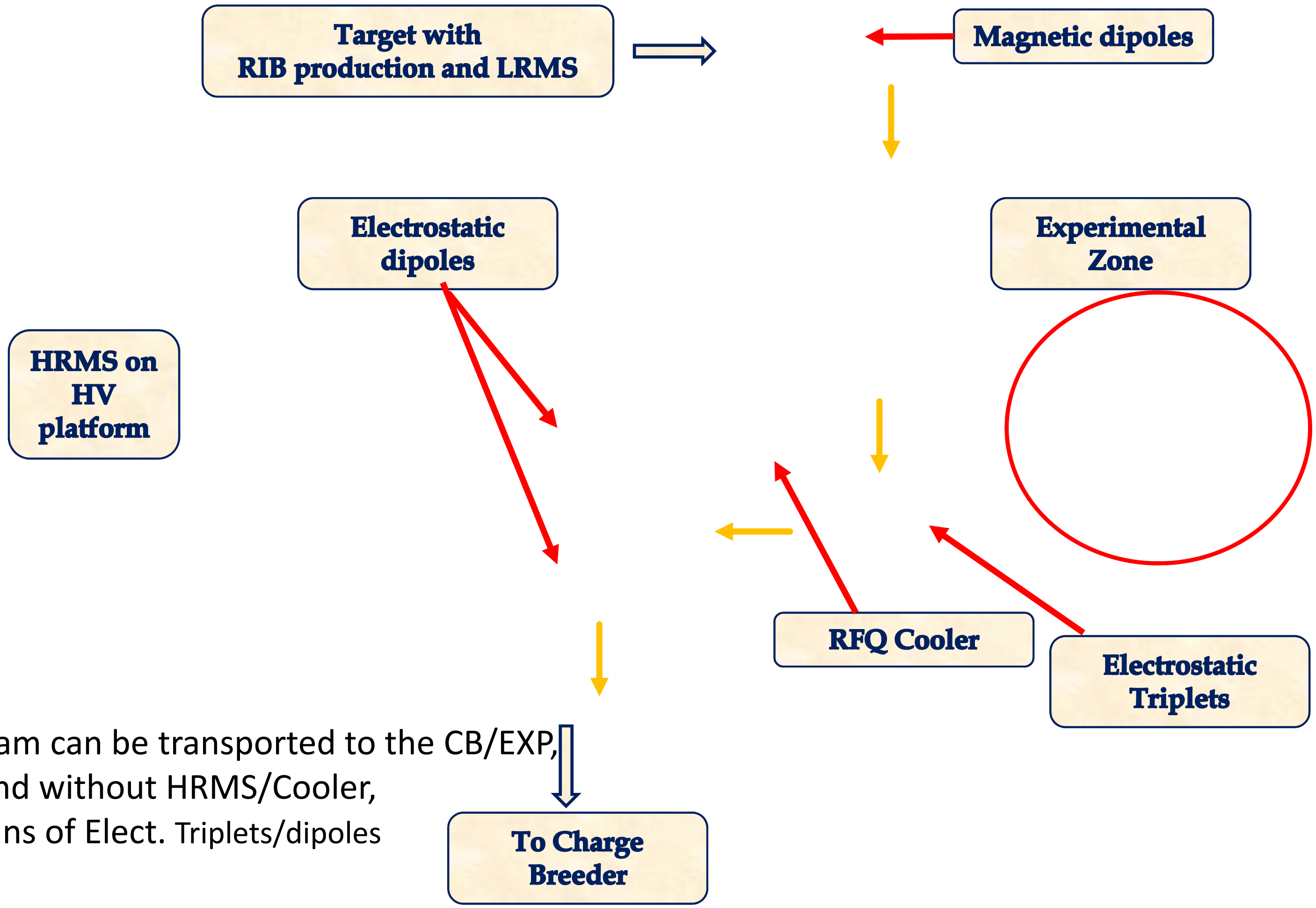
Requirement on Platform	Value	Units
Dipole Magnetic homogeneity	± 10^-5	
Dipole Power supply stability	± 10^-6	
Dipole homogeneity range	± 250	mm
Element alignment	± 0.05	mm
Energy spread RMS	± 1	eV
Platform voltage stability	± 10^-5	
Platform dynamic displacement	± 10	µm
Max geometric emittance (90%)	3	mmmrad



+/- 0.05 mm error on quadrupoles, multipole and dipoles alignment

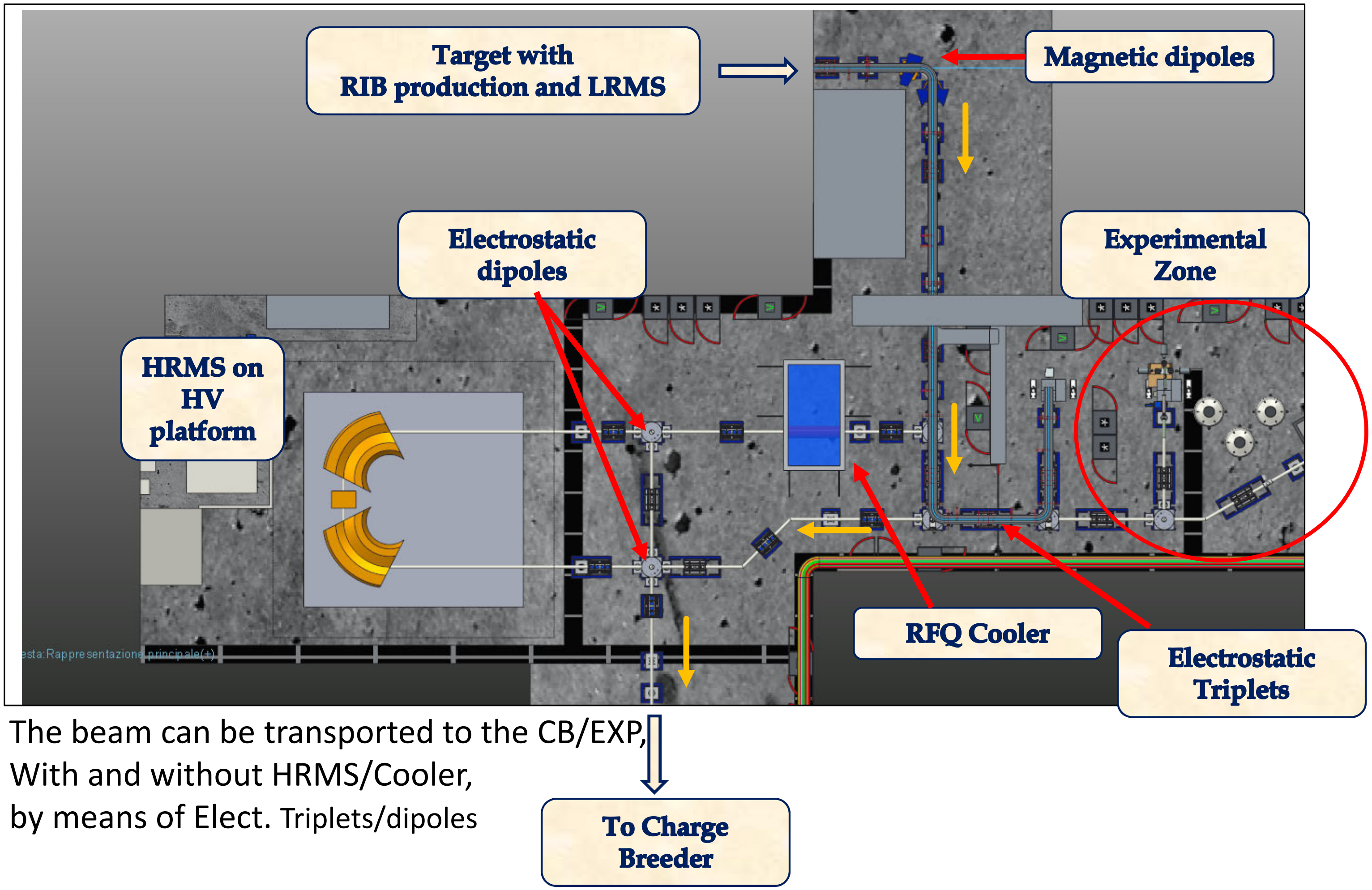
A downgraded version of the HRMS (120 kV platform) is under study

Beam Transport Line from Target to Charge Breeder



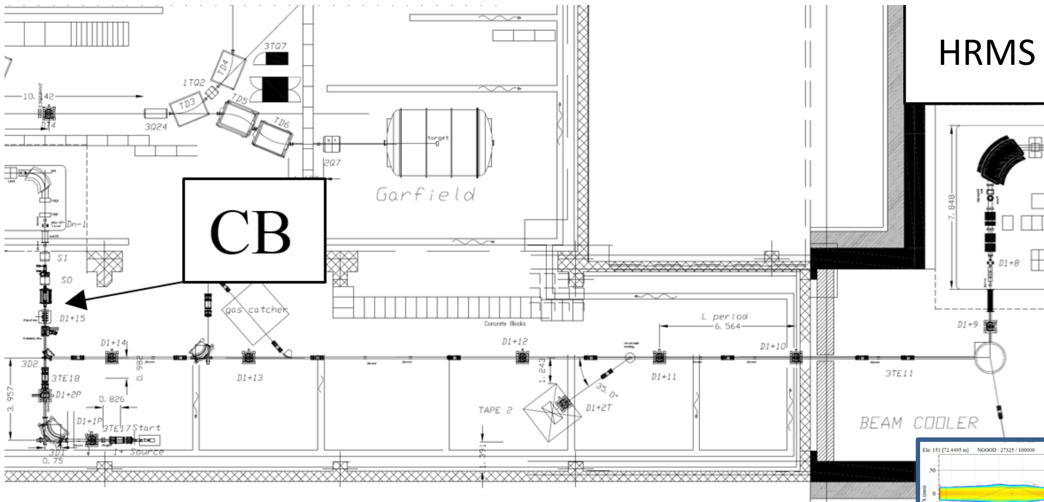
The beam can be transported to the CB/EXP,
With and without HRMS/Cooler,
by means of Elect. Triplets/dipoles

Beam Transport Line from Target to Charge Breeder

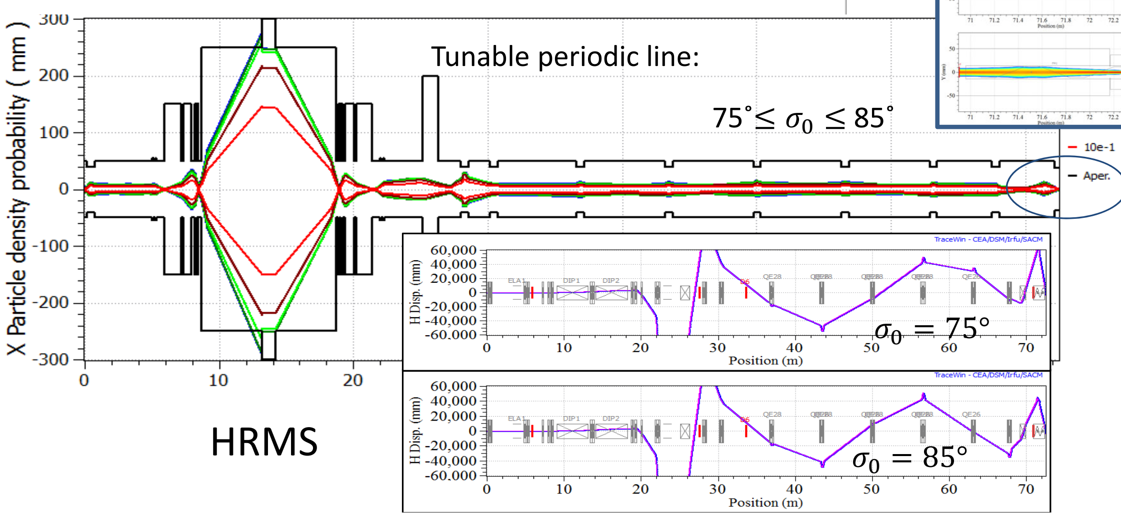


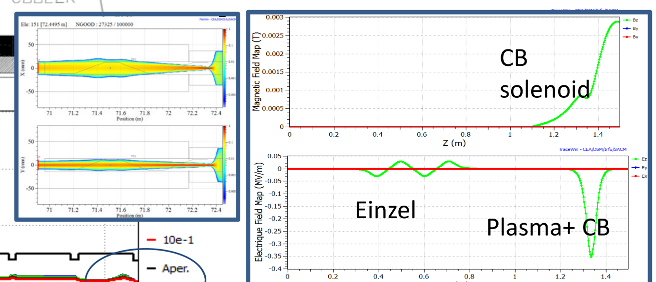
The beam can be transported to the CB/EXP,
With and without HRMS/Cooler,
by means of Elect. Triplets/dipoles

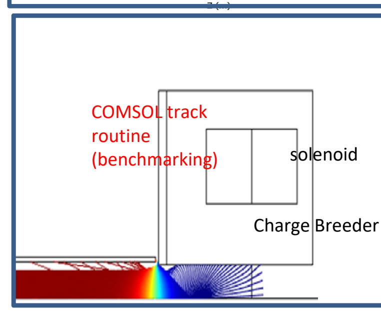
The periodic transfer line from HRMS to CB



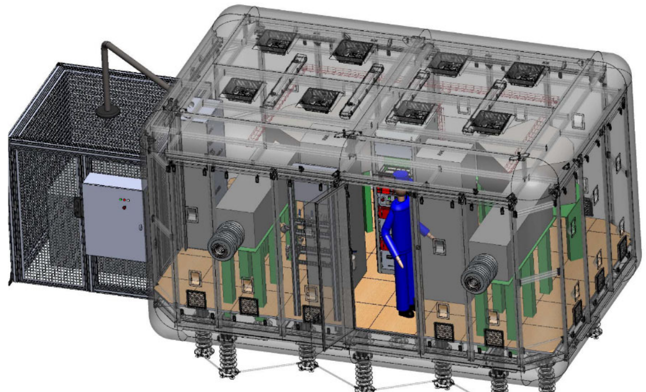
- The periodic transfer line is composed by electrostatic triplets.
- The phase advance of the periodic line can be tuned from $75^\circ \le \sigma_0 \le 85^\circ$ (drive by dispersion).
- Phase advance influences the maximum modulus of D_x along the periodic line
- Triplet after the image point on HV HRMS platform help to control dispersion at HRMS exit.

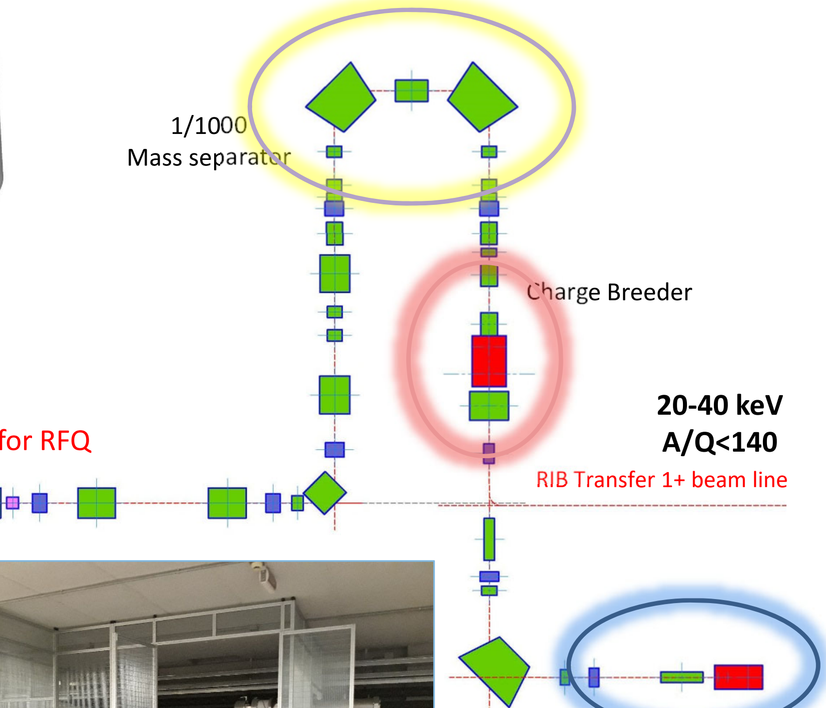




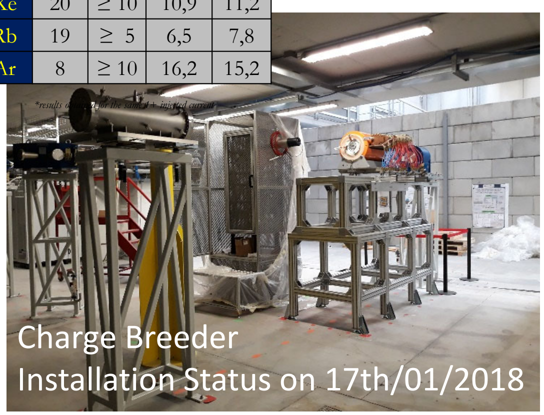


Charge Breeder and n+ beam line





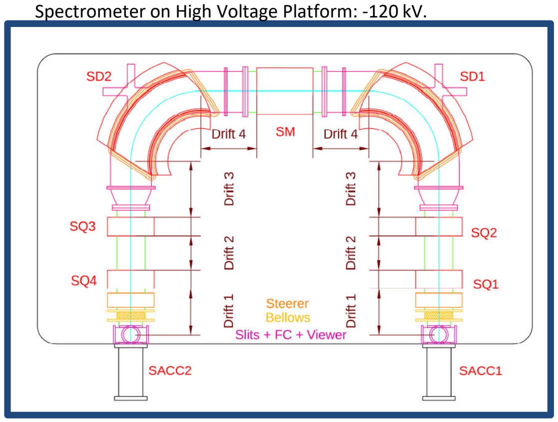
LPSC 2015		EFFICIENCY* [%]		
ION	Q	SPES req	Best LPSC	SPES-CB
Cs	26	≥ 5	8,6	11,7
Xe	20	≥ 10	10,9	11,2
Rb	19	≥ 5	6,5	7,8
Ar	8	≥ 10	16,2	15,2

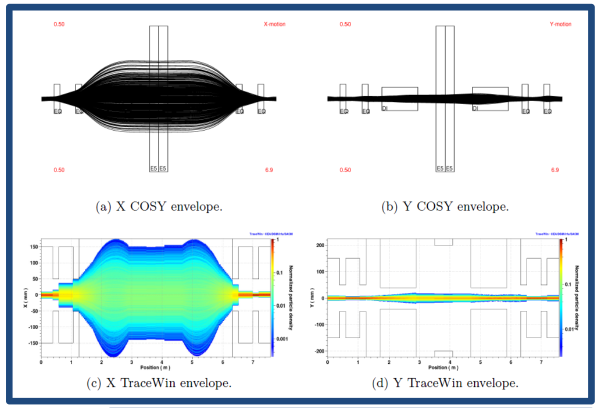


C.Roncolato

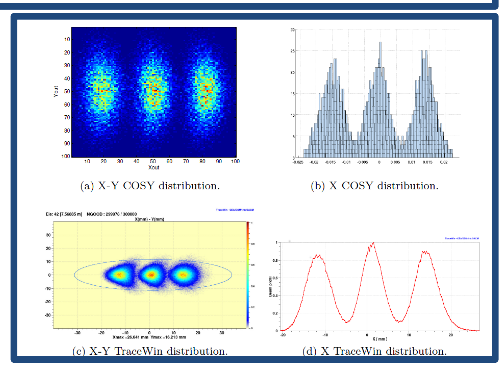
The MRMS: nominal separation 1/1000

Spectrometer on High Voltage Platform: -120 kV.

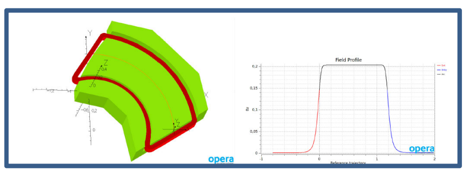


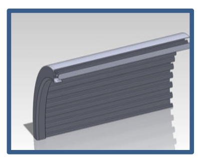


- The optics is composed by 4 electrostatic quadrupoles, 2 dipoles and a 12° order multipole.
- Dipole characteristics: 0.750 m bending radius, 90° bending angle. External edge curvature: 2.6 m. Edge angles β=33.35°. Horizontal aperture 0.4 m. Vertical aperture 0.08 m.
- Both the four quadrupoles are x defocusing.
- BD Benchmarking with COSYINFINITY.
- Required Platform stability of the order of 0.01% in voltage.

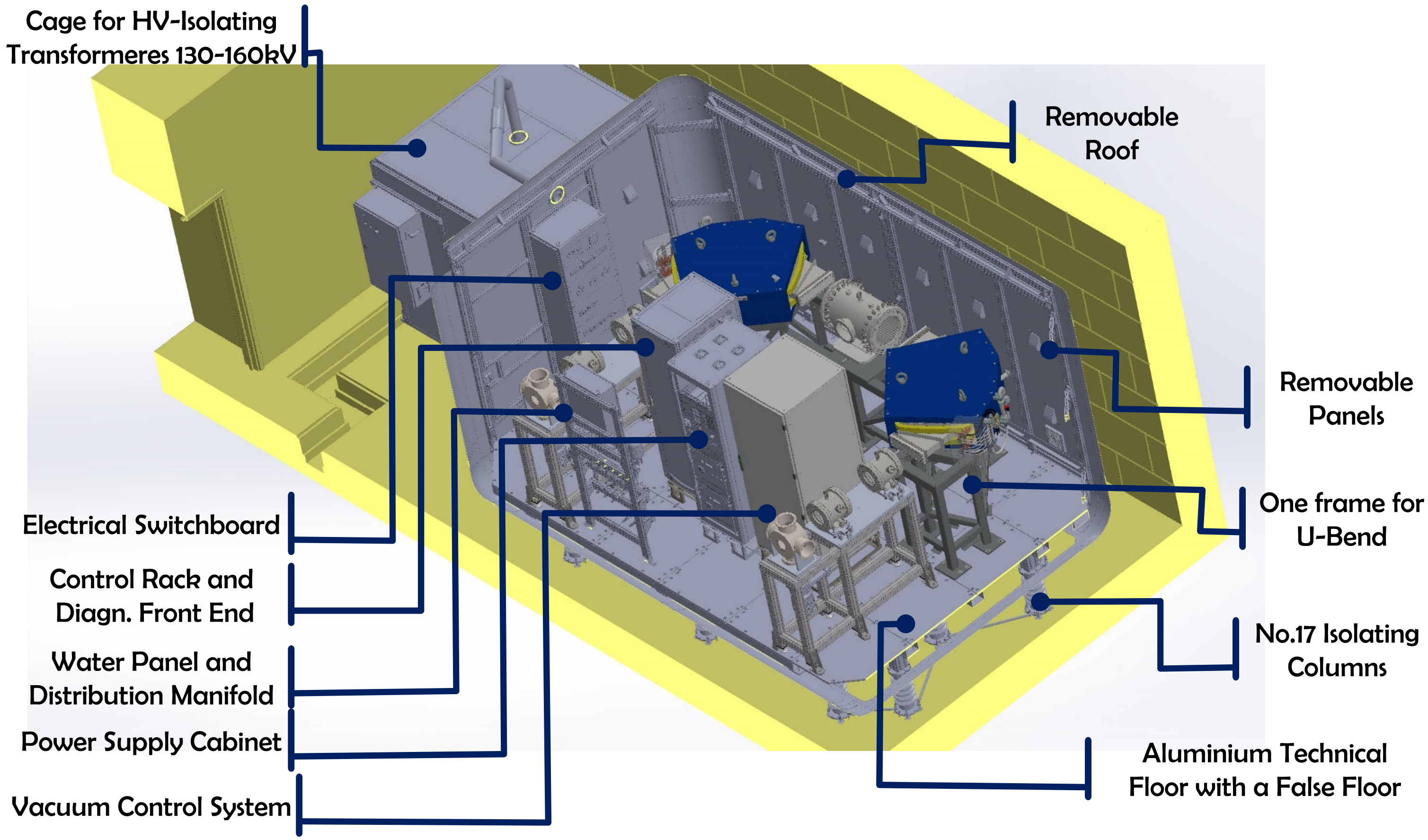


Beam separated on **A/q** of 1/1000



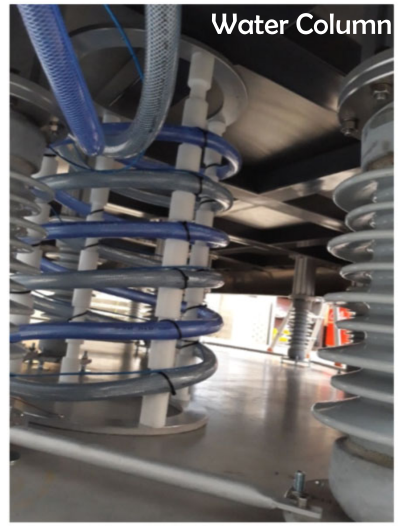


Layout of MRMS High Voltage Platform



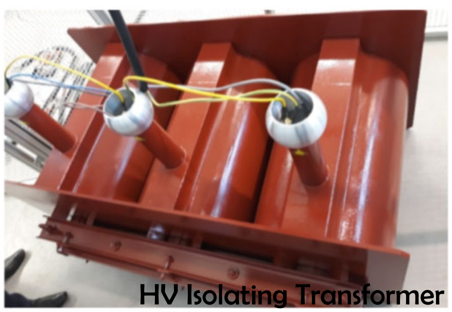
MRMS High Voltage Platform

HV Platform during the FAT



Water Column

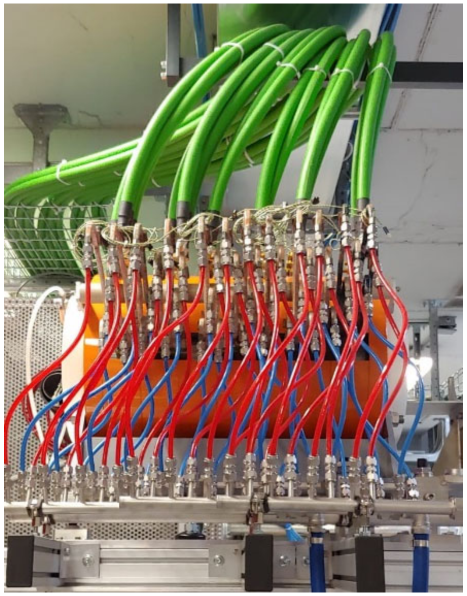
Water Panel



HV Isolating Transformer

SPES Charge Breeder

- Construction 2014-2015
- Acceptance tests on March-April 2015
- Delivery at LNL November 2015



- **Requirements fulfilled** without any problem.
- Very **low emittance** of the **n+** beam.
- **Good stability**.

		Efficiency* [%]		
Ion	M/Q	SPES req	Best LPSC	SPES-CB
Cs^{26+}	5.1	> 5	8.6	11.3
Xe^{20+}	6.6	> 10	10.5	11.2
Rb^{19+}	4.5	> 5	6.5	7.8
Ar^{8+}	5	> 10	16.2	15.2
*results obtained for the same 1+ injected current				

Courtesy of A. Galatà

$\varepsilon_{norm,rms} < 0.05$ *π*mm*mrad for both total and selected beam

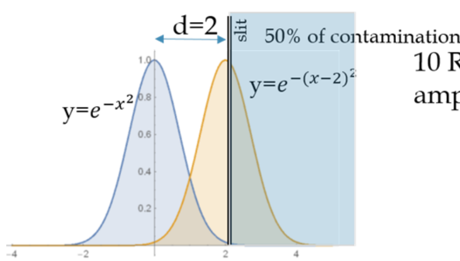
THE BEAM PURITY ISSUE:
Contaminants out of CB

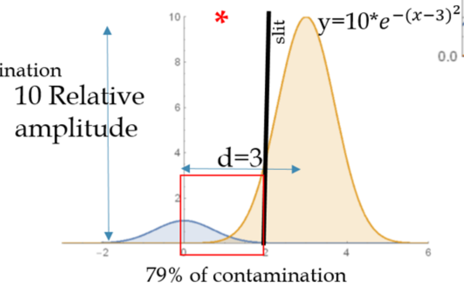
INFLUENCE OF RELATIVE AMPLITUDE

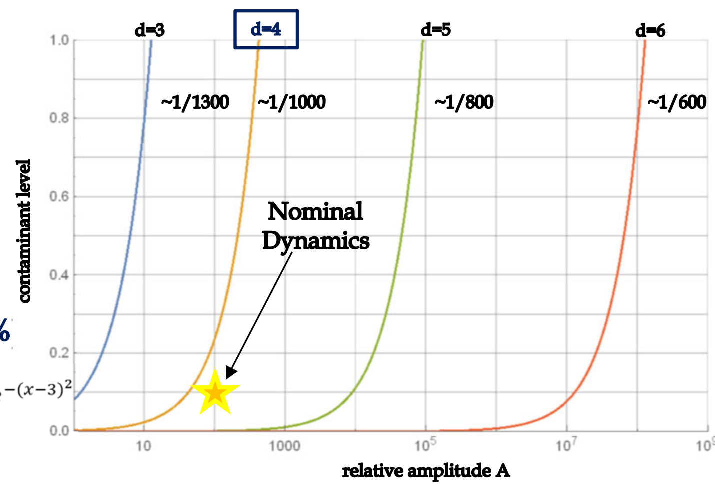
Important parameters

- Relative amplitude $A = I_{cont}/I_{RIB}$
- $\varepsilon_{rms} = 0.1\ \pi$ mm mrad
- Separation "d" between cont and RIB in units of σ
- For the MRMS d=D*(Δp/p)=8000*(1/2000)=4
- Slits position "s " in units of σ (2 in the present case, 95%

GAUSSIAN PEAKS







Given "D" and the slits aperture, A RIB CAN BE CLEAND BY A HIGH INTENSITY CONTAMINANT IF "d" HAS A SPECIFIC VALUE

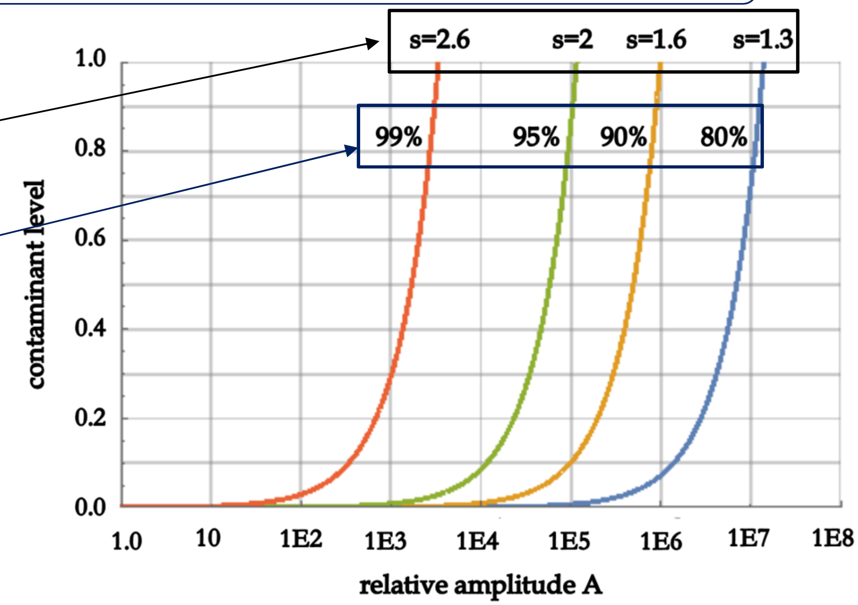
THE BEAM PURITY ISSUE

INFLUENCE OF SLITS APERTURE FOR d=5 ($\Delta m/m \sim 1/800$)

Contamination for different s

Slits aperture

% of the nominal beam



s=2 (95%)
- A contaminant with A=1E3 would be almost removed
- A contaminant with A=1E4 would be at 10%

s=1.6 (90%)
- A contaminant with A=1E4 would be almost removed
- A contaminant with A=1E5 would be at 10%

d=5 should limit the contamination from high intensity peaks

CONTAMINANT REDUCTION:
Source chamber materials

POSSIBLE PEAKS AVAILABLE BY EMPLOYING NEW MATERIALS

Conventional materials

POSSIBLE RIBs FOR POST-ACCELERATION	
^{26}Al	Contaminated by ^{13}C, ^{26}Mg, ^{52}Cr, ^{78}Kr: other materials
^{94}Rb	Contaminated by ^{94}Mo (SS)
^{130}Sn	Possible clean peaks at 19+,29+
^{132}Sn	Possible clean peaks at 19+,21+,23+
^{132}Sb	
^{132}Te	
^{134}Te	Possible clean peaks at 27+,31+
^{138}Cs	Possible clean peaks at 20+,22+,23+,26+,28+,30+,31+

Liners

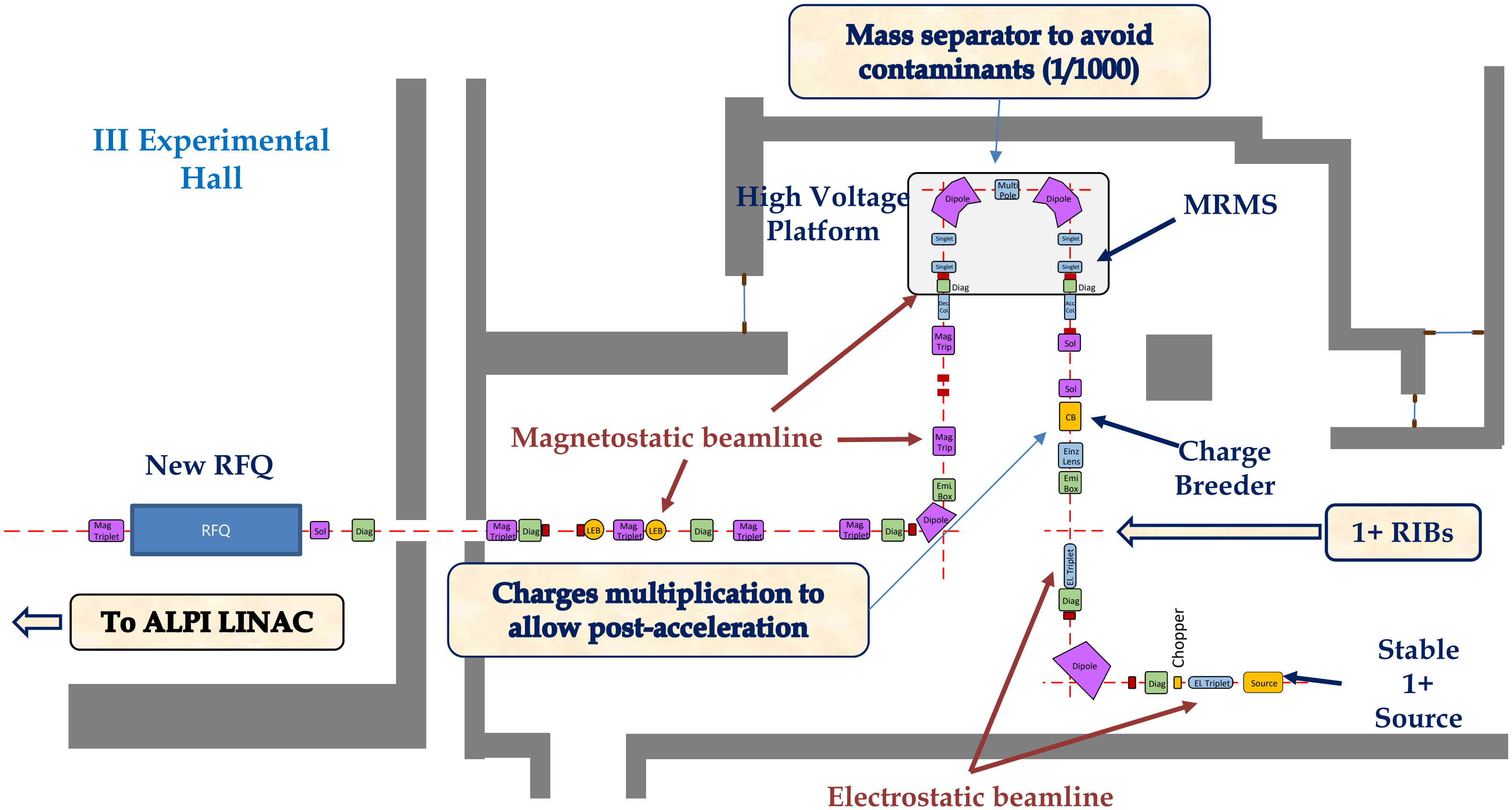
Nb

POSSIBLE RIBs FOR POST-ACCELERATION	
^{26}Al	Still problems due to ^{13}C, ^{78}Kr: two be verified after vacuum cleaning
^{94}Rb	Possible clean peaks at 15+,16+,21+
^{130}Sn	Possible clean peaks at 19+,22+,27+,29+,32+
^{132}Sn	Possible clean peaks at 19+-21+,23+-25+,30+-32+
^{132}Sb	
^{132}Te	
^{134}Te	Possible clean peaks at 22+,26+27+,28+,33+
^{138}Cs	Possible clean peaks at 20+,22+-26+,28+-32+

LINERS SHOULD INCREASE CHARGE STATES AVAILABILITY

Courtesy of A. Galatà

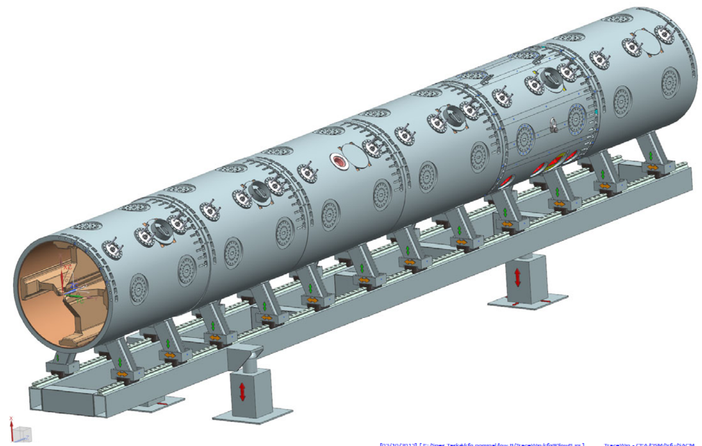
From the 1+ transport line to RFQ

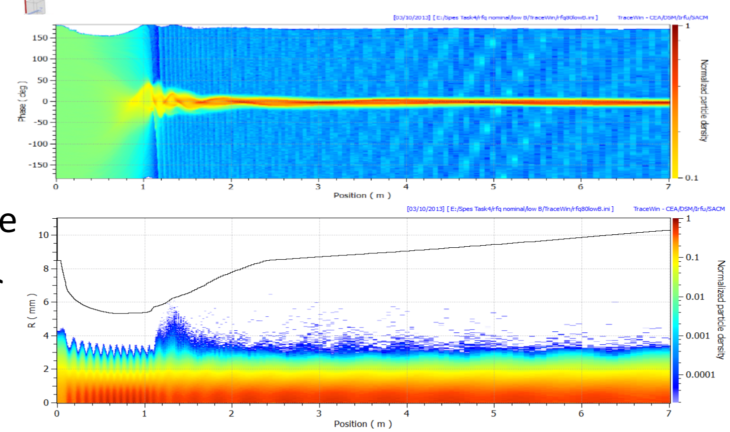


SPES RFQ: Main parameters

Paramater [units]	Design value
Frequency [MHz]	80
In/out. Energy [keV/u]	5.7-727 (β=0.0035-0.0359)
V_{iv}[kV]	63.76-85.85
Beam current [μA]	100
Vane Length [m]	6.95
R_0[mm]	5.29-7.58
ρ/R_0	0.76
Synchronous phase (deg.)	-90 ÷ -20
Focusing Strength B	4.7 ÷ 4
Shunt impedance [kΩ*m]	419-438 (30% margin)
Stored Energy [J]	2.87
RF Power [kW]	115 (with 30 %margin for 3D details and RF joint, and 20% margin for LLRF regulation)
Q_0 value (SF)	16100 (30% margin)
Max power density [W/cm²]	0.31 (2D), 13 (3D)
max $\delta V_{iv}/V_{iv}$ [%]	±3
Transmission [%]	94
Output Long RMS Emit [keV deg /u]	4.35

The SPES RFQ is designed in order to accelerate beams in CW with A/q ratios from 3 to 7. The RFQ is composed of 6 modules about 1.2 m long each.



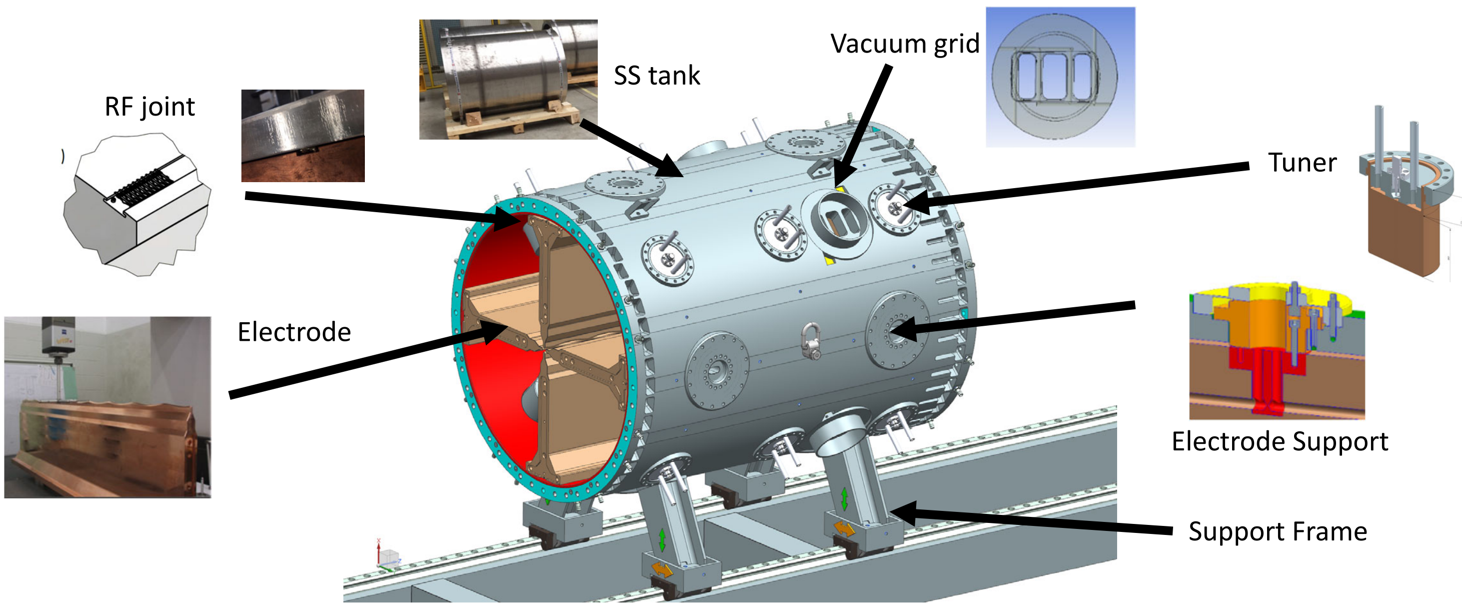


Phase and beam size inside the SPES RFQ

Courtesy of A. Palmieri

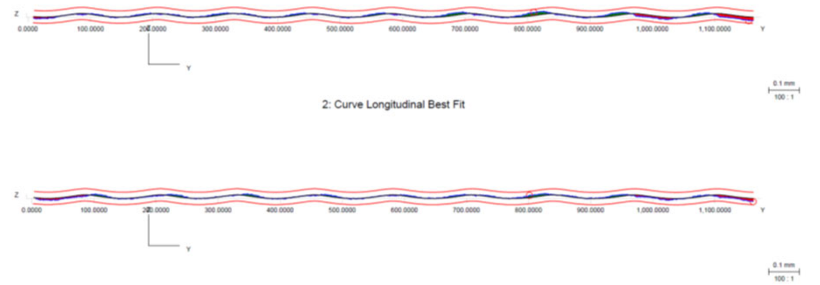
SPES RFQ: building blocks

Each module is basically composed of a Stainless Steel Tank (AISI LN 304) and four OFE Copper Electrodes. A copper layer thickness is plated on the tank inner surface and a spring joint between tank and electrode is used in order to seal the RF



Courtesy of A. Palmieri

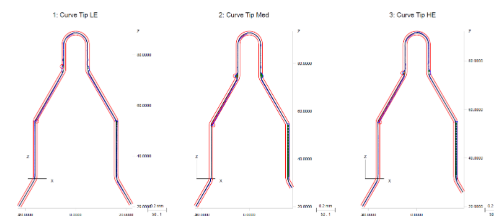
Construction Procedure and status: Electrode construction



No	Identifier	Sigma [mm]	Form [mm]	Number of Points	Lower Tol. [mm]	Upper Tol. [mm]	MinInd	Min Dev. [mm]	MaxInd	Max Dev. [mm]	Best Fit	X [mm]	Y [mm]	Z [mm]		X	Y	Z
1	Curve Longitudinal	0.0042	0.0244	1163	-0.0200	0.0200	1163	-0.0141	354	0.0102	Translation	0.0000	0.0000	0.0000	Rotation	0.0000	0.0000	0.0000
2	Curve Longitudinal Best Fit	0.0033	0.0172	1162	-0.0200	0.0200	1	-0.0101	363	0.0071	Translation	0.0000	-0.0255	0.0008	Rotation	-0.0001	-0.0000	-0.0010

Electrode construction awarded to Strumenti Scientifici CINEL, Vigonza (PD), Italy in September 2016
1st set of 4 electrodes (module 5) was successfuly delivered in April 2017
Electrode delivery completion May 2018

Almost all scanned profiles of each electrodes are in compliance with tolerance on best fitted curve profiles (0.04mm) except for some small spot (Outliers <1 % of measured points)

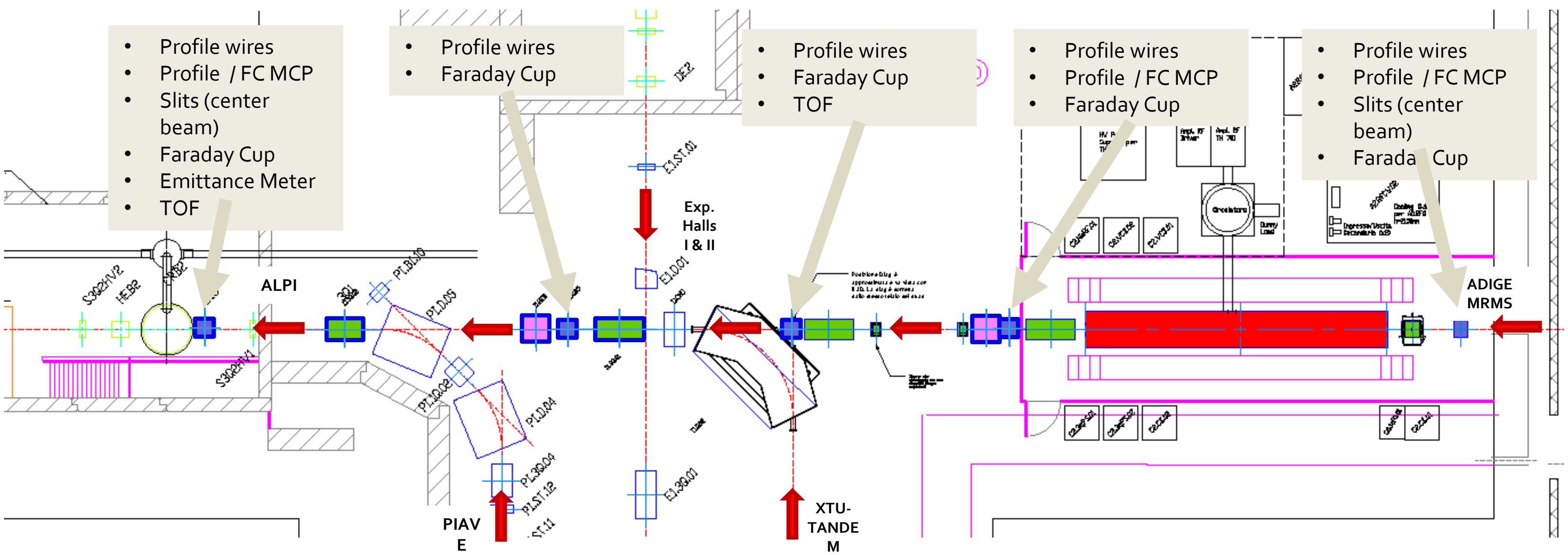


No	Identifier	Sigma [mm]	Form [mm]	Number of Points	Lower Tol. [mm]	Upper Tol. [mm]	MinInd	Min Dev. [mm]	MaxInd	Max Dev. [mm]
1	Curve Tip LE	0.0067	0.0384	498	-0.0200	0.0200	120	-0.0186	195	0.0198
2	Curve Tip Med	0.0101	0.0620	522	-0.0200	0.0200	121	-0.0245	522	0.0375
3	Curve Tip HE	0.0098	0.0465	523	-0.0200	0.0200	123	-0.0225	199	0.0239

Courtesy of A. Palmieri

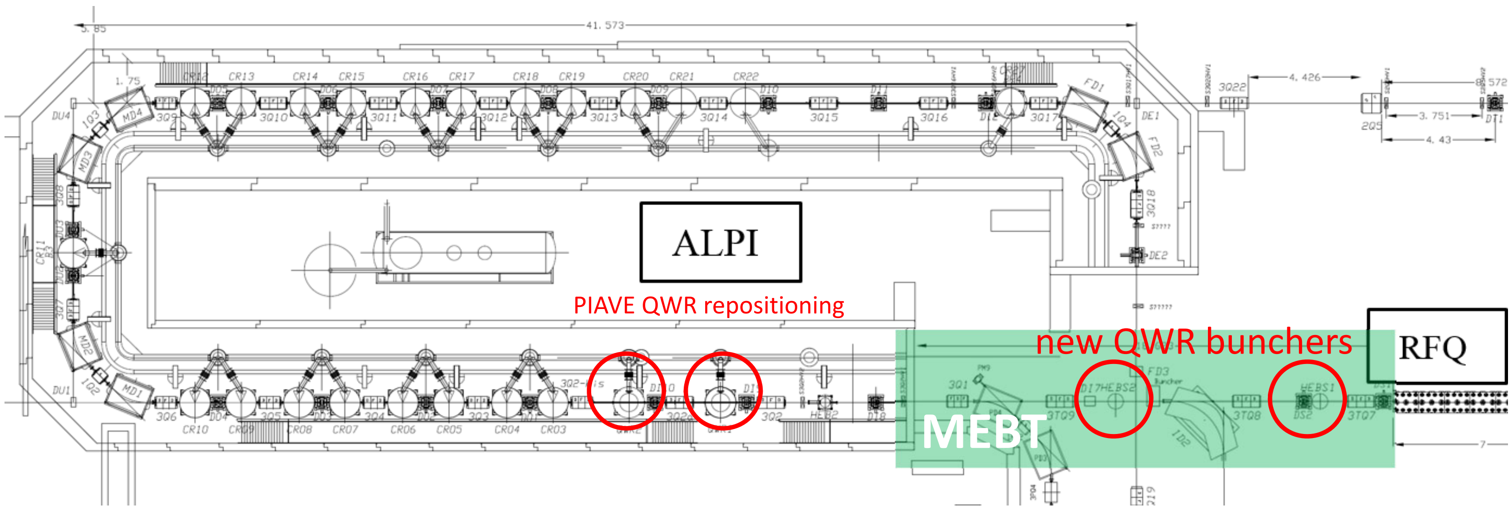
ADIGE – ALPI Matching Section

- ALPI input beam with β = 0.0393 (fixed value), $\varepsilon_{rms,n}$ = 0.1 mm-mrad , $\varepsilon_{L,rms}$ = 5 deg-keV/u
- Longitudinal Matching: two NC Buncher at 80 MHz (brand new);
- Transversal Matching: four magnetic triplets (from LNL spare);
- Four Diagnostic Boxes (first Diagnostic Box in ALPI *shall* acquire the experimental input beam parameters for ALPI beam dynamics simulation;

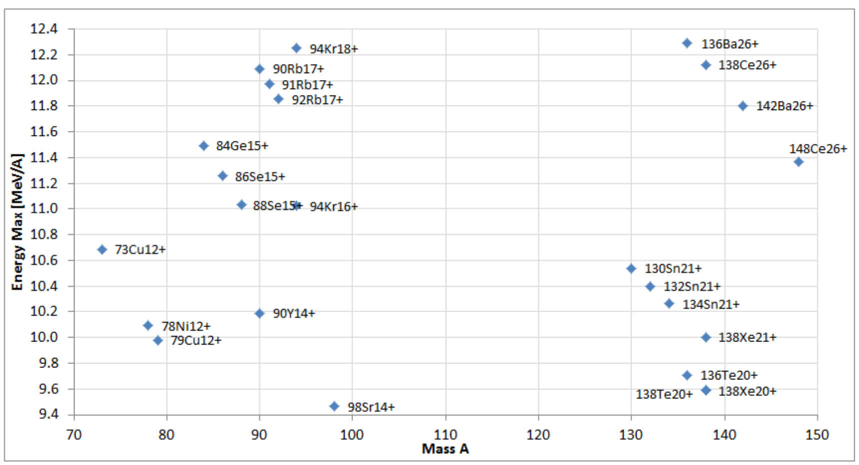


Courtesy of C. Roncolato

ALPI accelerator



RIB energy as a function of mass



- Independent cavity LINAC
- New quads with higher gradient (20→25 T/m) to optimize T
- MEBT will ensure longitudinal matching from the RFQ to ALPI
- Acceleration up to 10 MeV/u depending on the A/q ratio.

Courtesy of C. Roncolato

ALPI Upgrade Highlights

Our VISION (what shall ALPI be tomorrow?)

1. Obtaining an accelerator with increased reliability;
2. Limiting the losses with for heavy ion beams (A/Q=6÷7); (maintainability increases with a low contaminated machine);
3. Increasing the energy and the beam current of the RIBs at experiment.

Our STRATEGIES (how we will do it?)

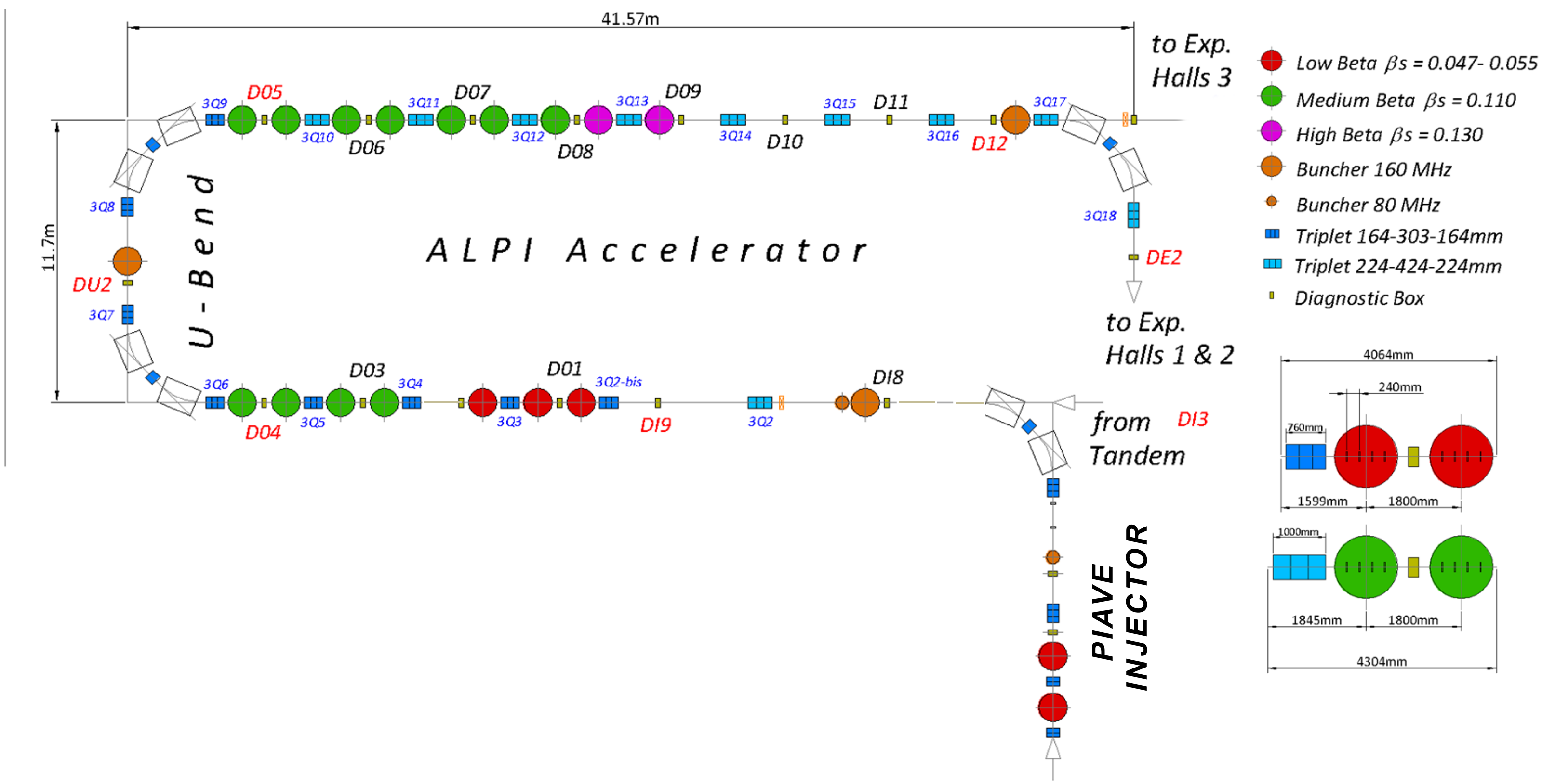
- Longer low energy branch section *shall* increase the injection energy in the medium beta accelerating section (higher transmission); (2)
- Higher focusing strength *shall* achieve a better transversal confinement for heavy ion beams A/Q=6÷7; (2)
- Better resolution for the SC cavity phase setting *shall* improve the coherence between the actual beam and the simulated beam dynamics; (2)
- An improved Beam Instrumentations *shall* permit a semi-automatic method for the beam steering; (it is a fold LINAC!) (2)
- Precise alignment of all the optical lens *shall* improve the beam transport quality; (2)

Our PLANS (what we need to do?)

- Displacement of two low beta cryostats (β = 0,052) from PIAVE to ALPI;
- Installation of ten brand new triplets w/ higher quadrupole gradient (from 20 to 30 T/m);
- New digital LLRF Controller;
- Production of new Diagnostic Boxes (the new boxes will be installed in a second phase '20-'21);
- Realignment campaign of the magnetic lenses, cryostats, diagnostic boxes;

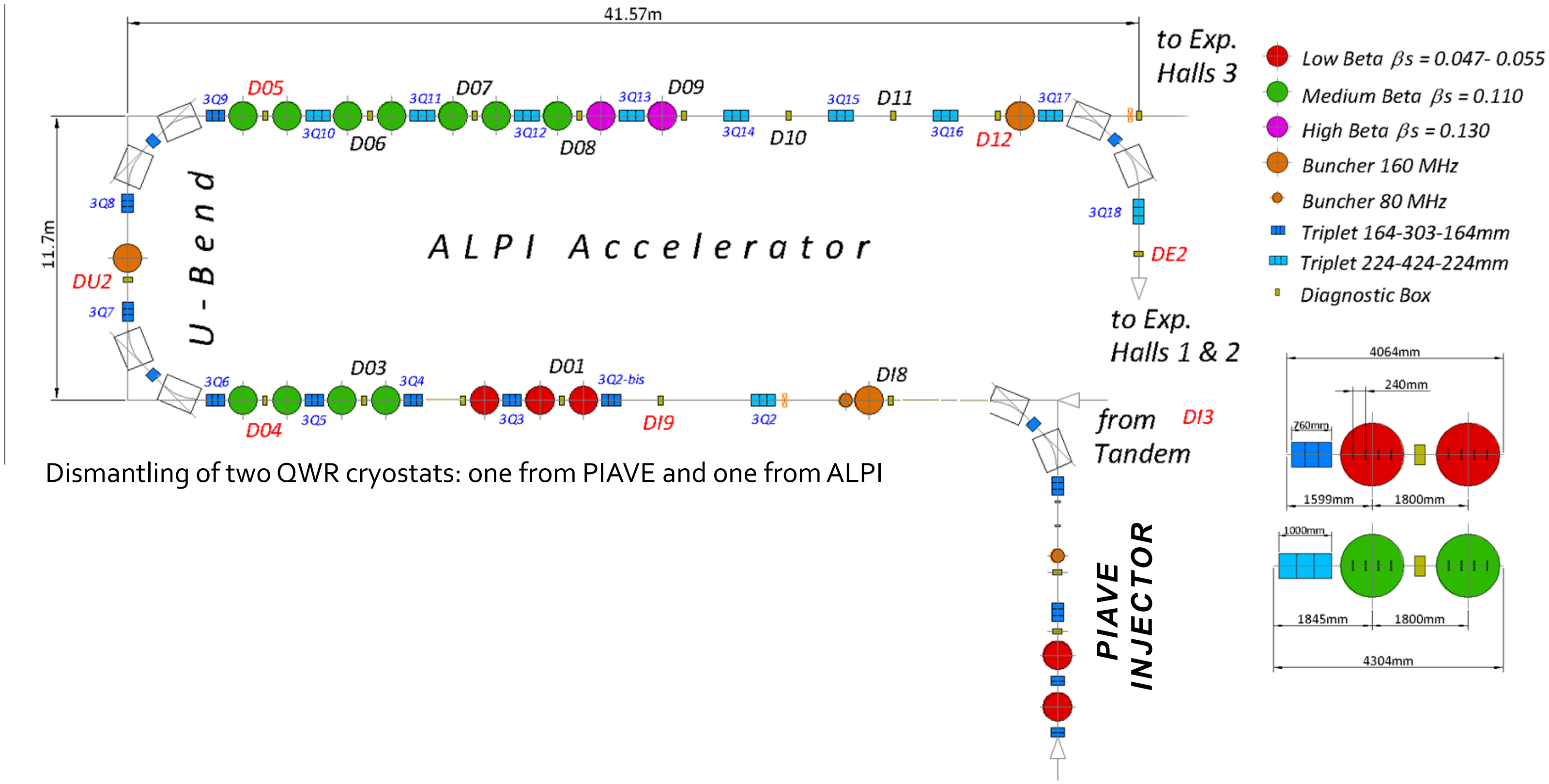
Courtesy of C. Roncolato

ALPI Upgrade Outline



Courtesy of C. Roncolato

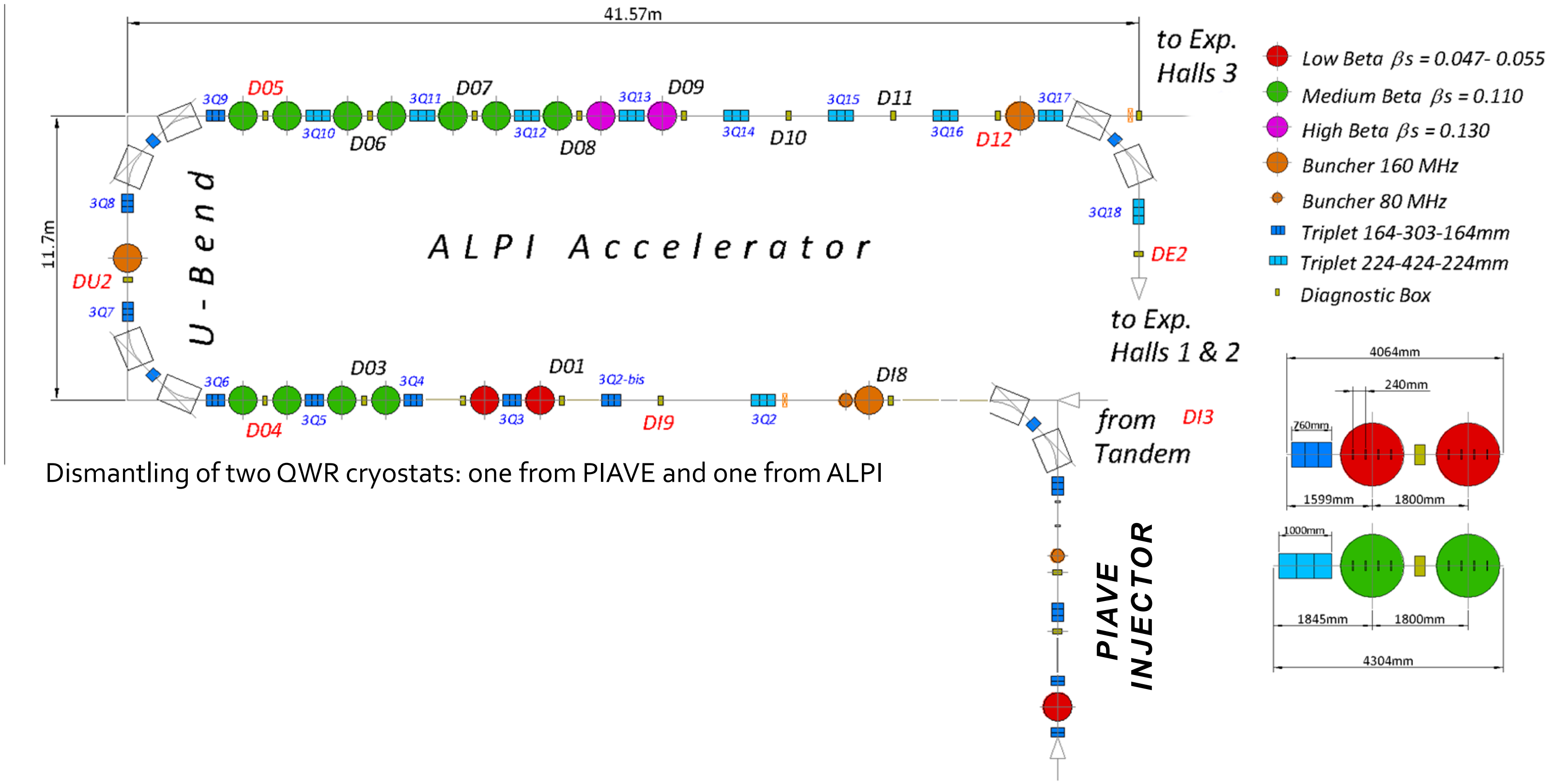
ALPI Upgrade Outline



Dismantling of two QWR cryostats: one from PIAVE and one from ALPI

Courtesy of C. Roncolato

ALPI Upgrade Outline



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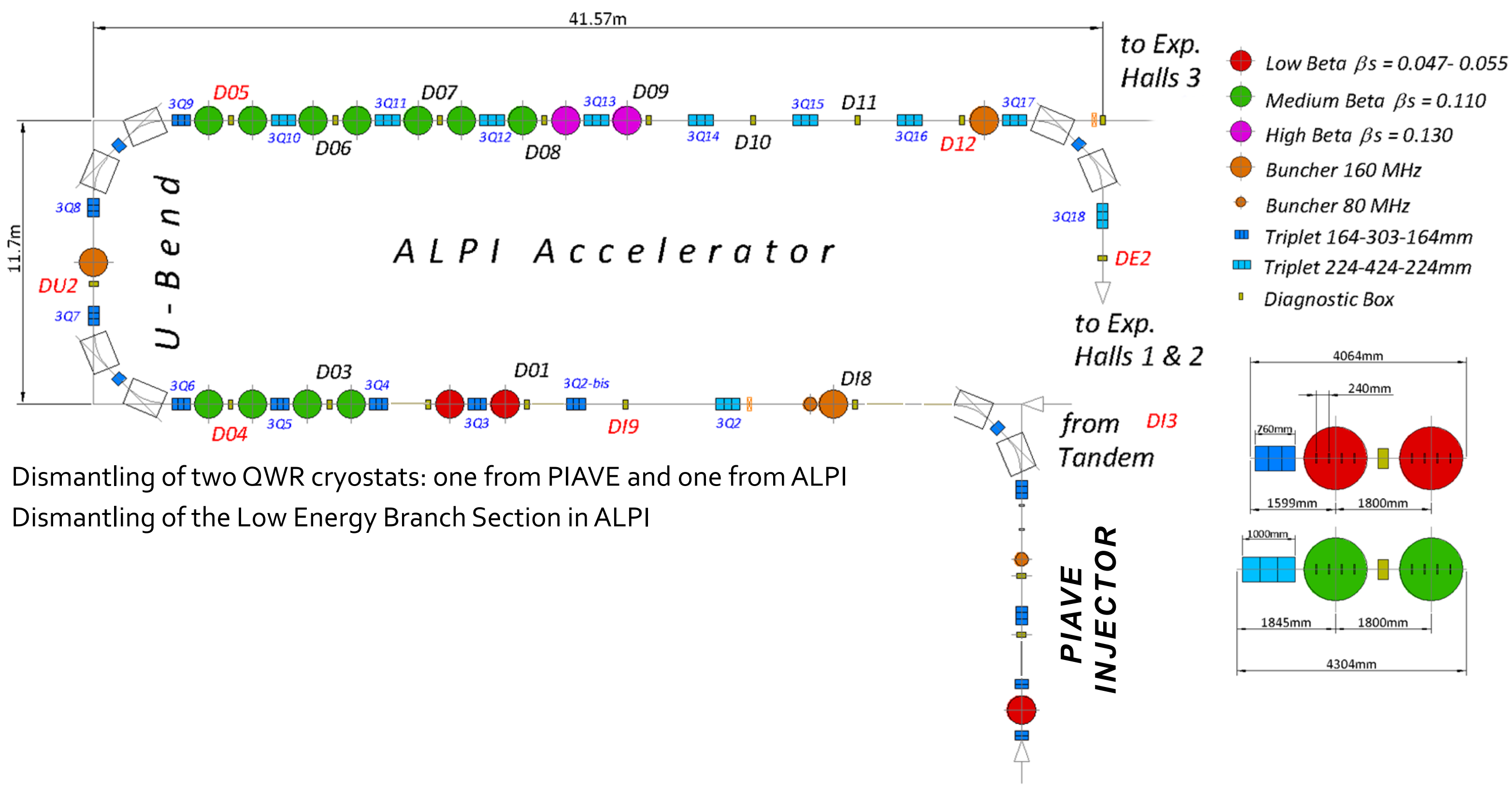
Courtesy of C. Roncolato

ALPI Upgrade Outline

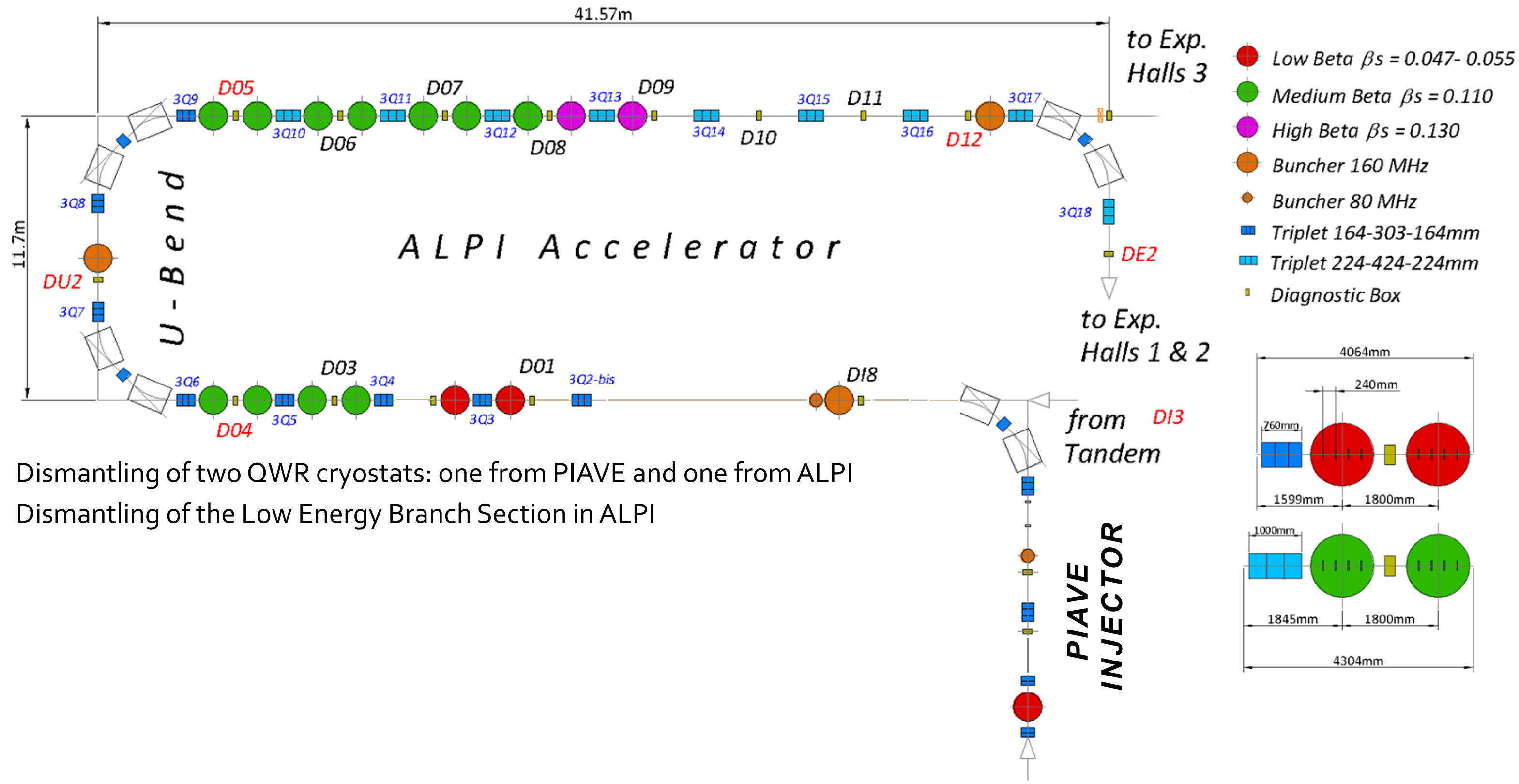


Dismantling of two QWR cryostats: one from PIAVE and one from ALPI

Dismantling of the Low Energy Branch Section in ALPI

Courtesy of C. Roncolato

ALPI Upgrade Outline



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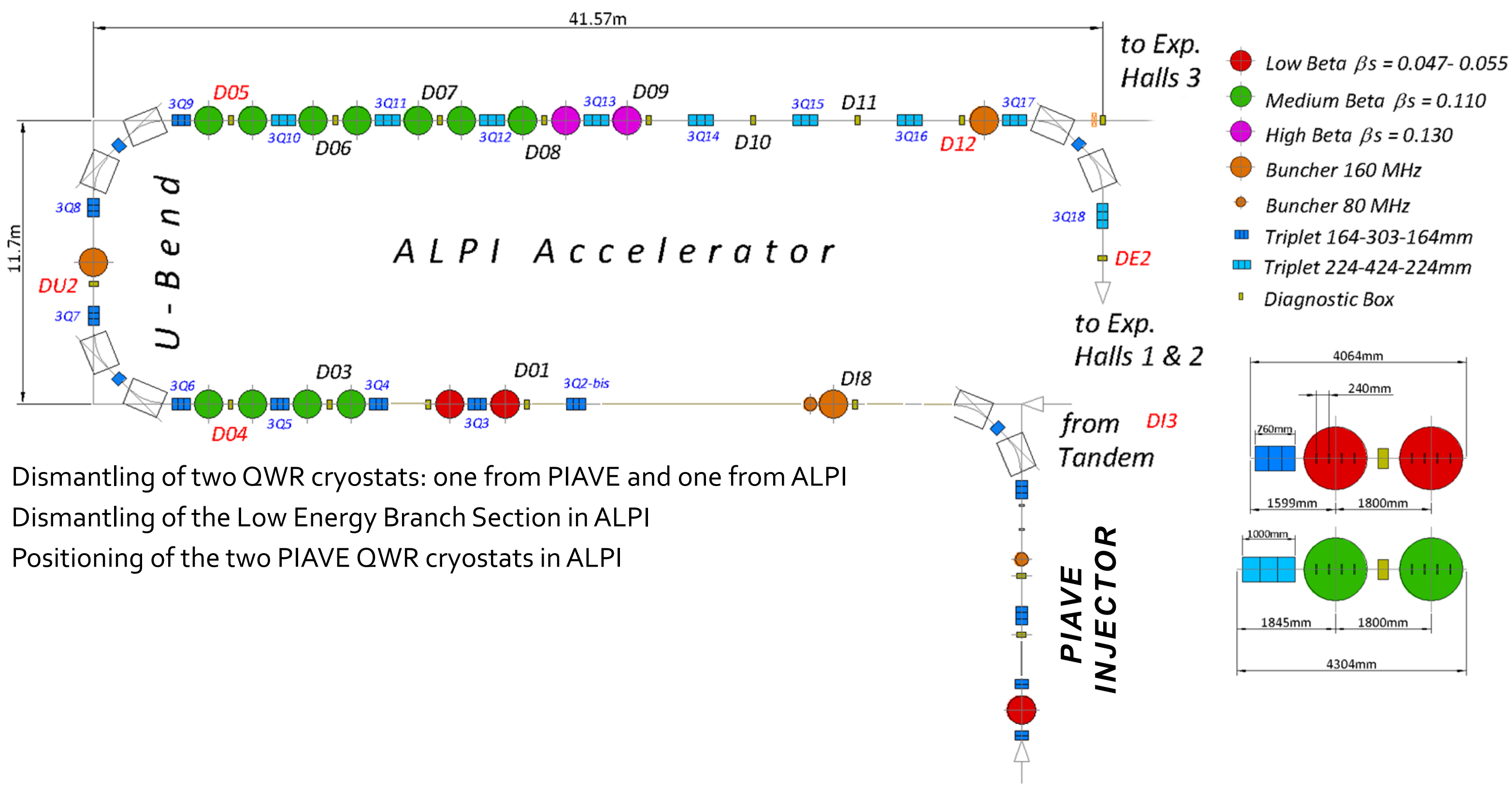
Dismantling of the Low Energy Branch Section in ALPI

Courtesy of C. Roncolato

ALPI Upgrade Outline



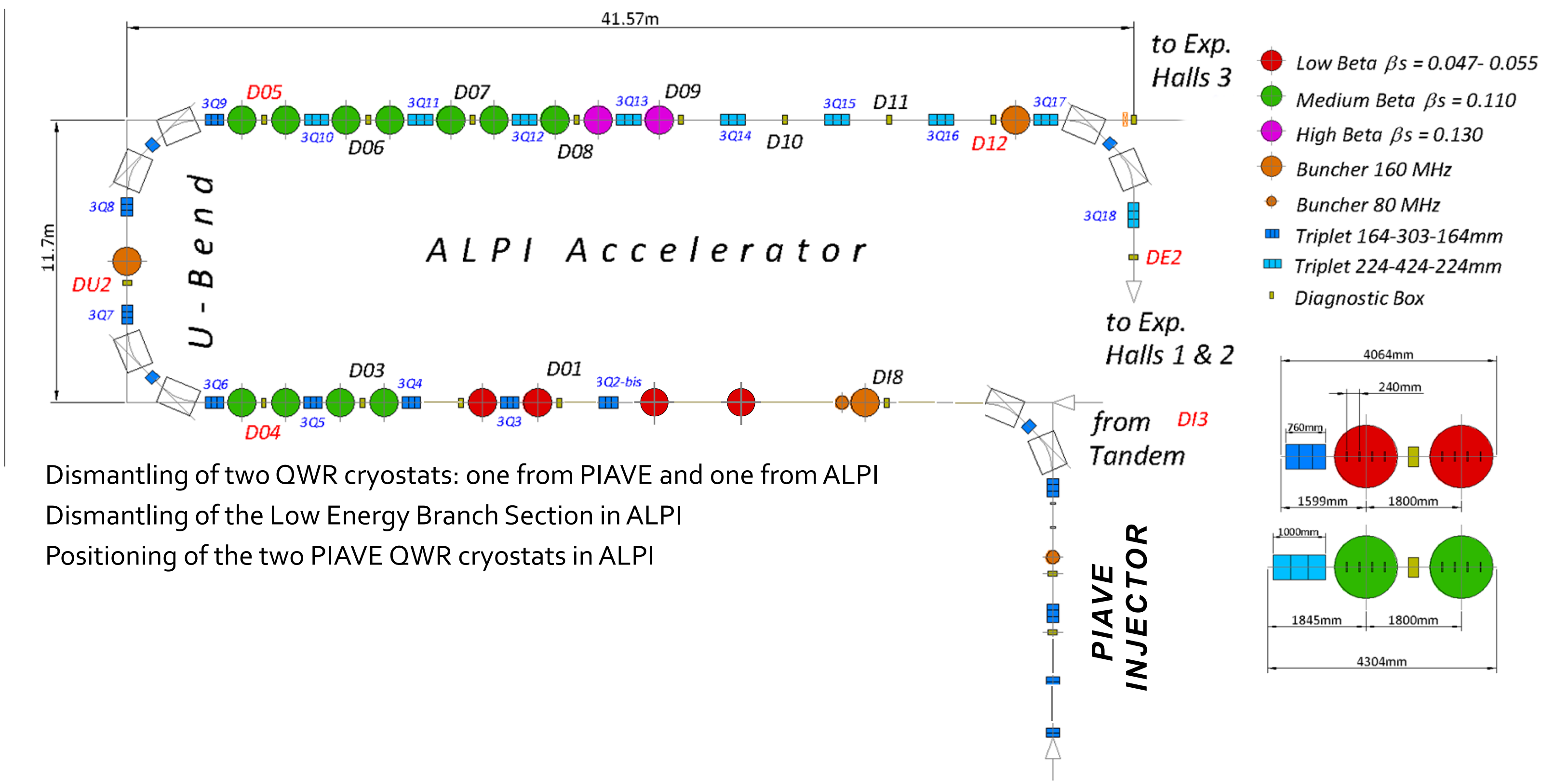
Dismantling of two QWR cryostats: one from PIAVE and one from ALPI

Dismantling of the Low Energy Branch Section in ALPI

Positioning of the two PIAVE QWR cryostats in ALPI

Courtesy of C. Roncolato

ALPI Upgrade Outline



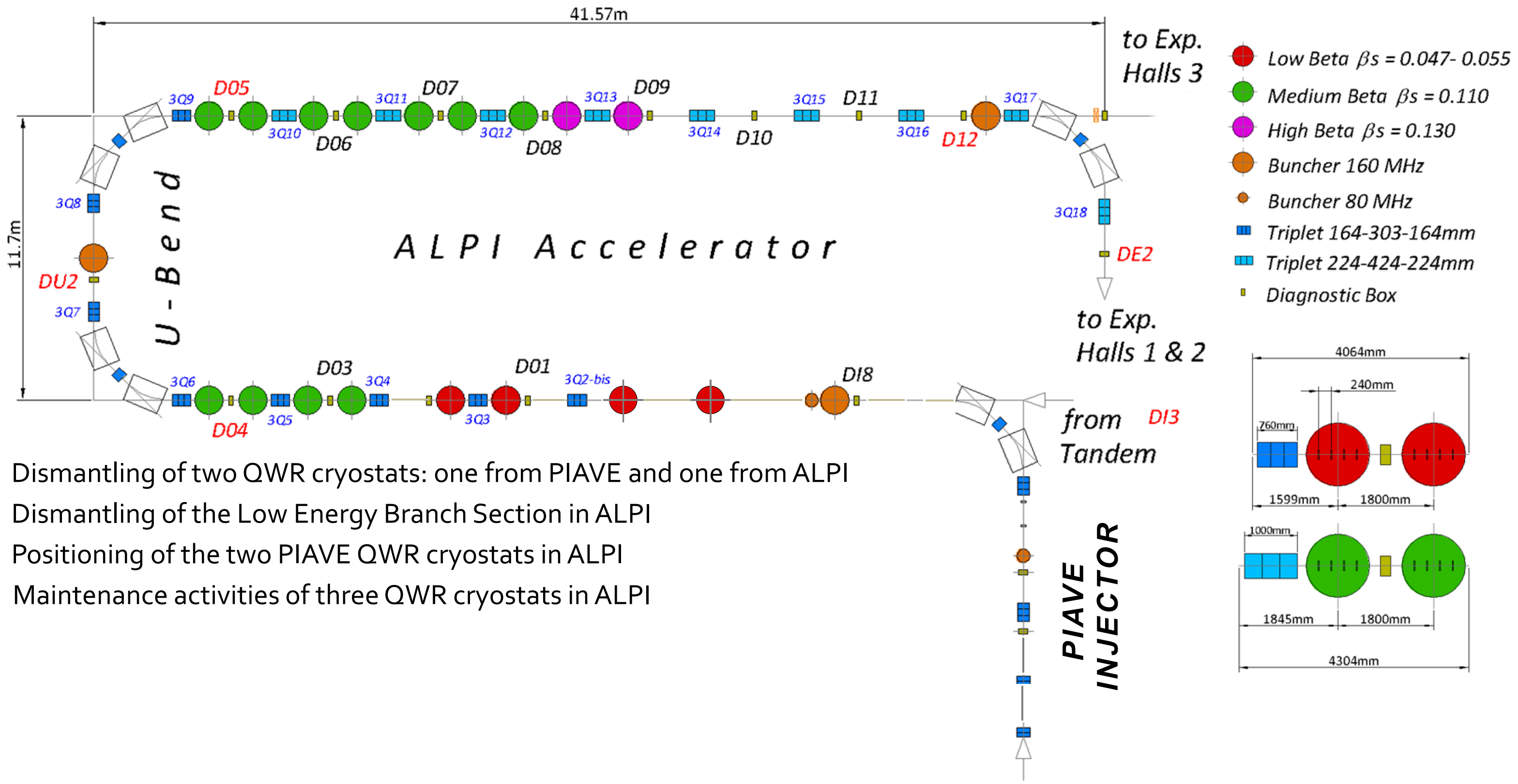
Dismantling of two QWR cryostats: one from PIAVE and one from ALPI

Dismantling of the Low Energy Branch Section in ALPI

Positioning of the two PIAVE QWR cryostats in ALPI

Courtesy of C. Roncolato

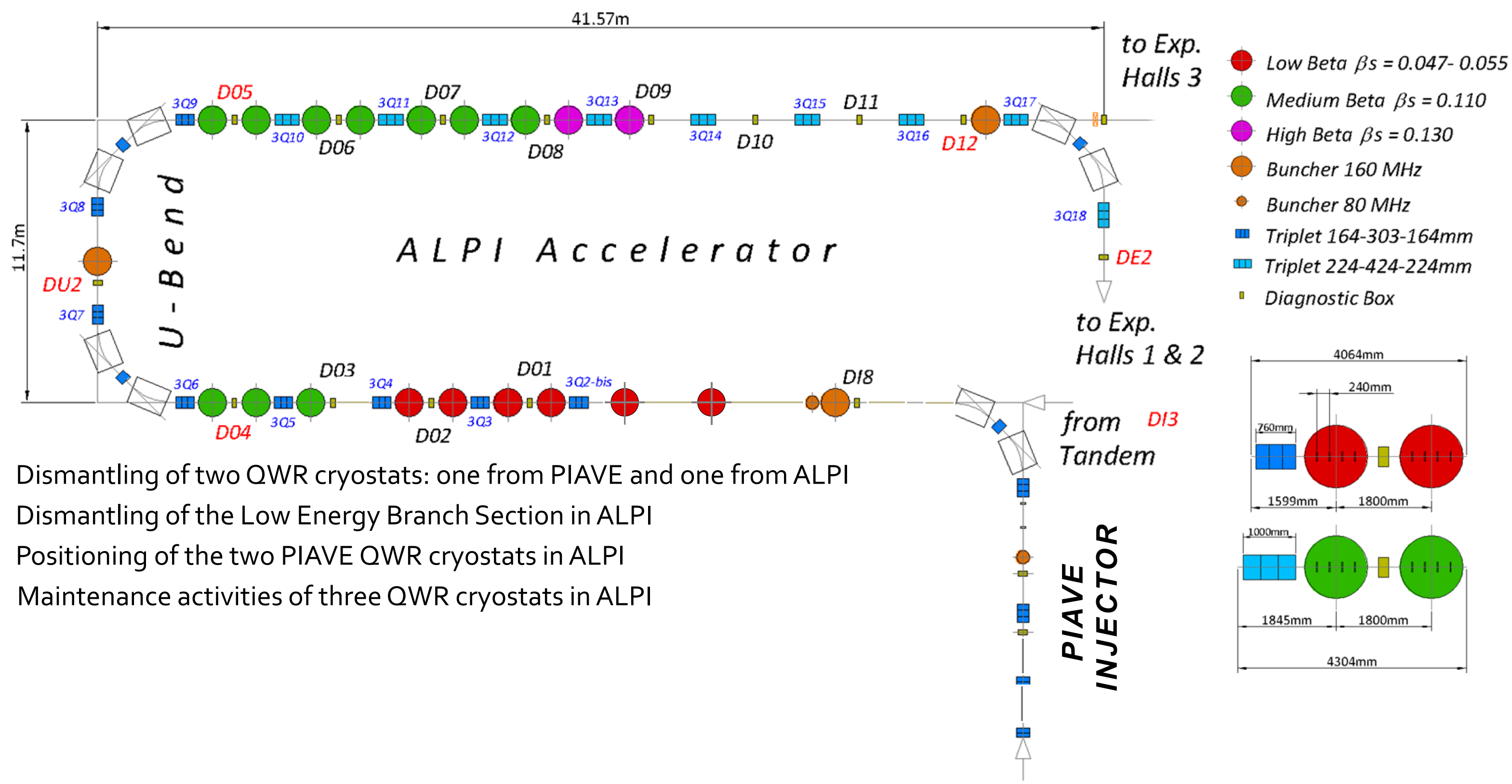
ALPI Upgrade Outline



Dismantling of two QWR cryostats: one from PIAVE and one from ALPI
Dismantling of the Low Energy Branch Section in ALPI
Positioning of the two PIAVE QWR cryostats in ALPI
Maintenance activities of three QWR cryostats in ALPI

Courtesy of C. Roncolato

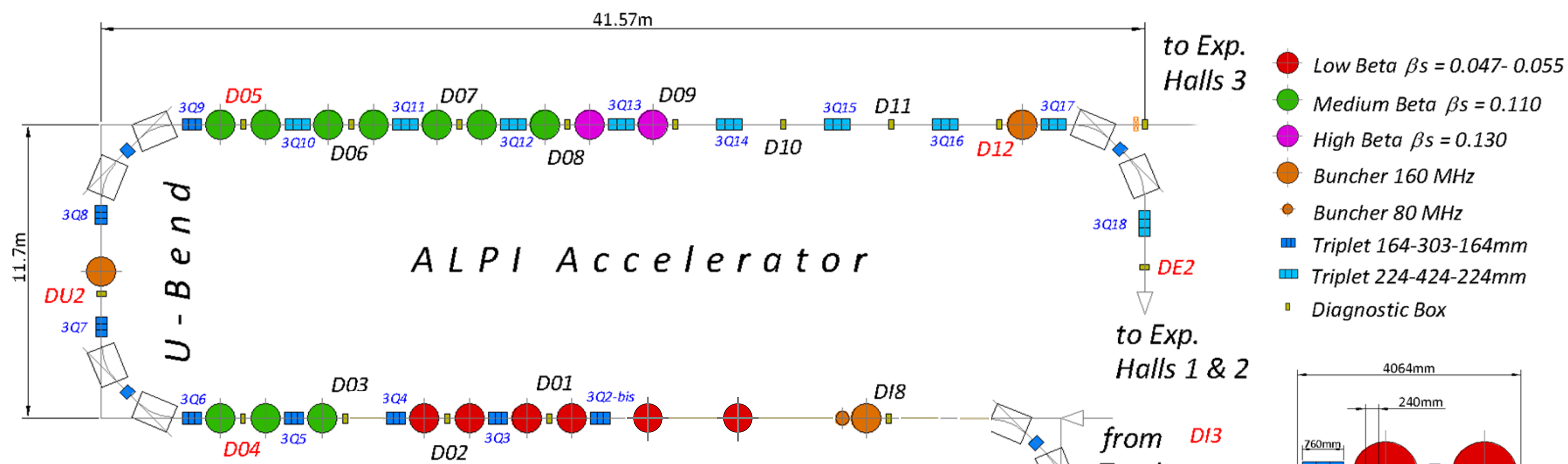
ALPI Upgrade Outline

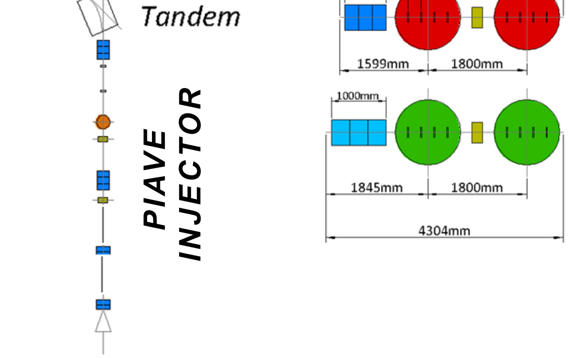


Dismantling of two QWR cryostats: one from PIAVE and one from ALPI
Dismantling of the Low Energy Branch Section in ALPI
Positioning of the two PIAVE QWR cryostats in ALPI
Maintenance activities of three QWR cryostats in ALPI

Courtesy of C. Roncolato

ALPI Upgrade Outline





Dismantling of two QWR cryostats: one from PIAVE and one from ALPI

Dismantling of the Low Energy Branch Section in ALPI

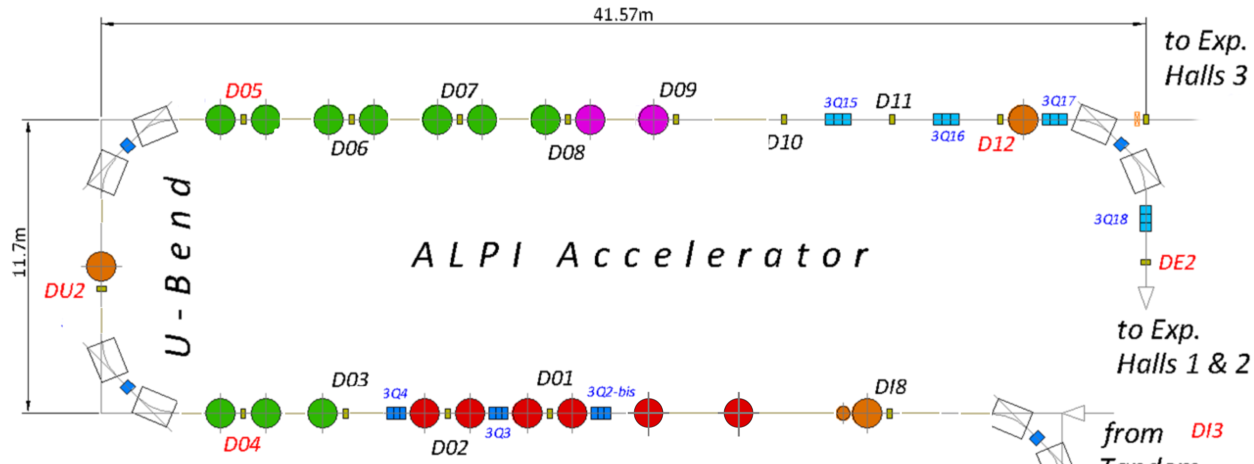
Positioning of the two PIAVE QWR cryostats in ALPI

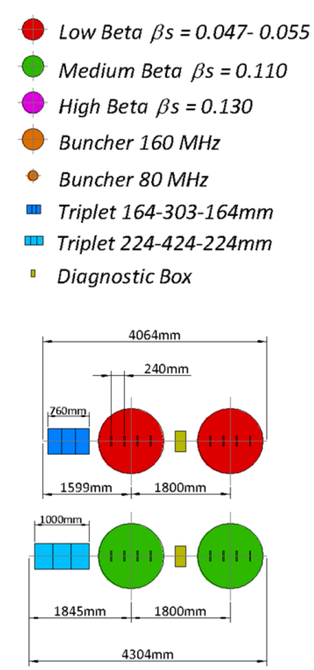
Maintenance activities of three QWR cryostats in ALPI

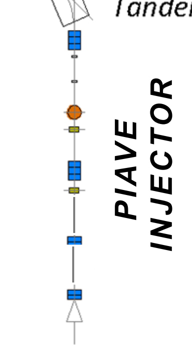
Dismantling of ten Quadrupole Triplets in ALPI

Courtesy of C. Roncolato

ALPI Upgrade Outline







Dismantling of two QWR cryostats: one from PIAVE and one from ALPI

Dismantling of the Low Energy Branch Section in ALPI

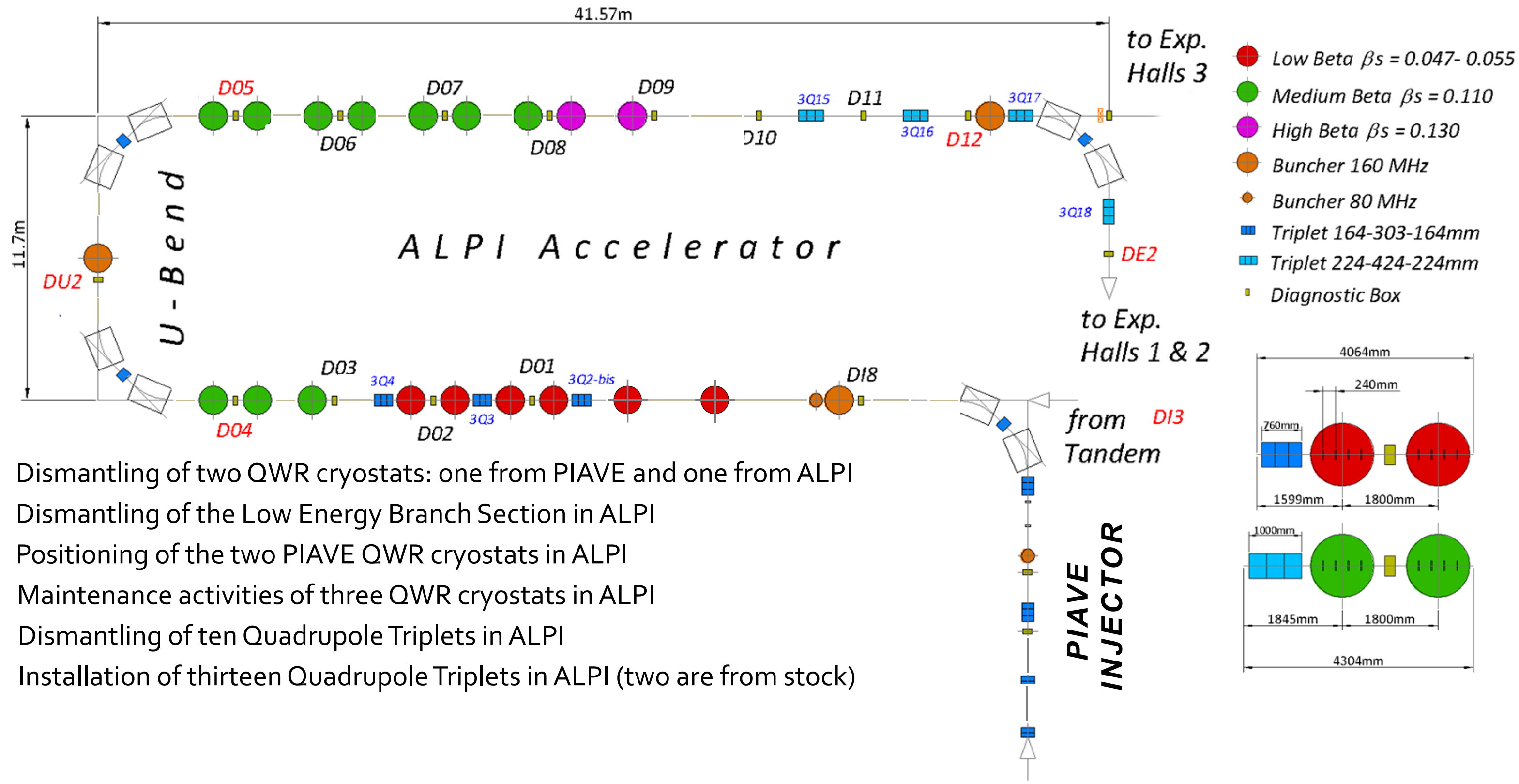
Positioning of the two PIAVE QWR cryostats in ALPI

Maintenance activities of three QWR cryostats in ALPI

Dismantling of ten Quadrupole Triplets in ALPI

Courtesy of C. Roncolato

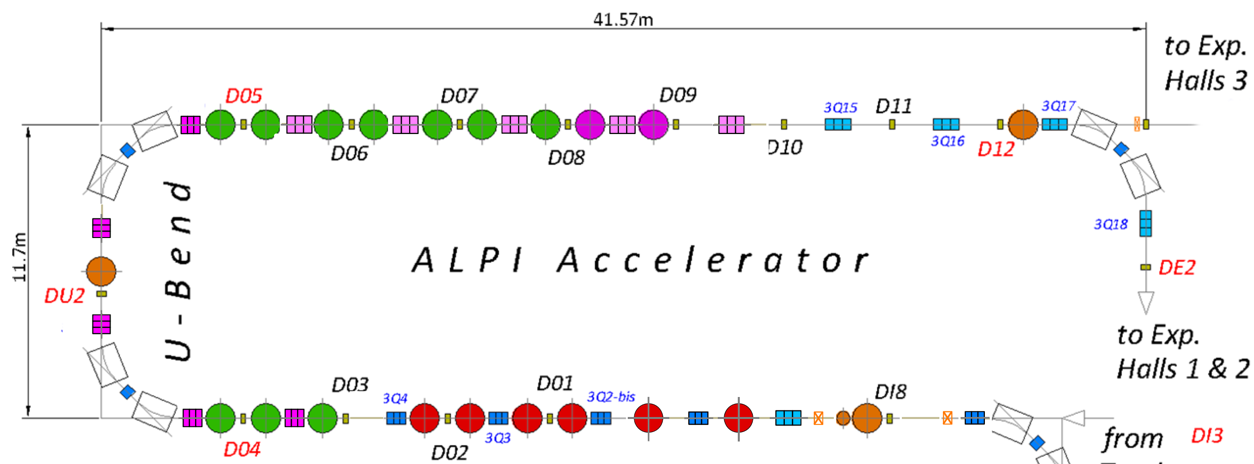
ALPI Upgrade Outline

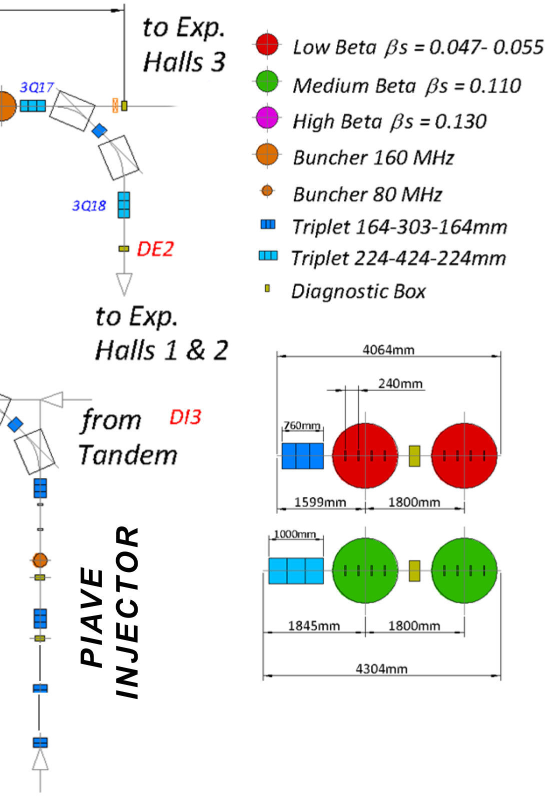


Dismantling of two QWR cryostats: one from PIAVE and one from ALPI
Dismantling of the Low Energy Branch Section in ALPI
Positioning of the two PIAVE QWR cryostats in ALPI
Maintenance activities of three QWR cryostats in ALPI
Dismantling of ten Quadrupole Triplets in ALPI
Installation of thirteen Quadrupole Triplets in ALPI (two are from stock)

Courtesy of C. Roncolato

ALPI Upgrade Outline





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Positioning of the two PIAVE QWR cryostats in ALPI
Maintenance activities of three QWR cryostats in ALPI
Dismantling of ten Quadrupole Triplets in ALPI
Installation of thirteen Quadrupole Triplets in ALPI (two are from stock)

Courtesy of C. Roncolato

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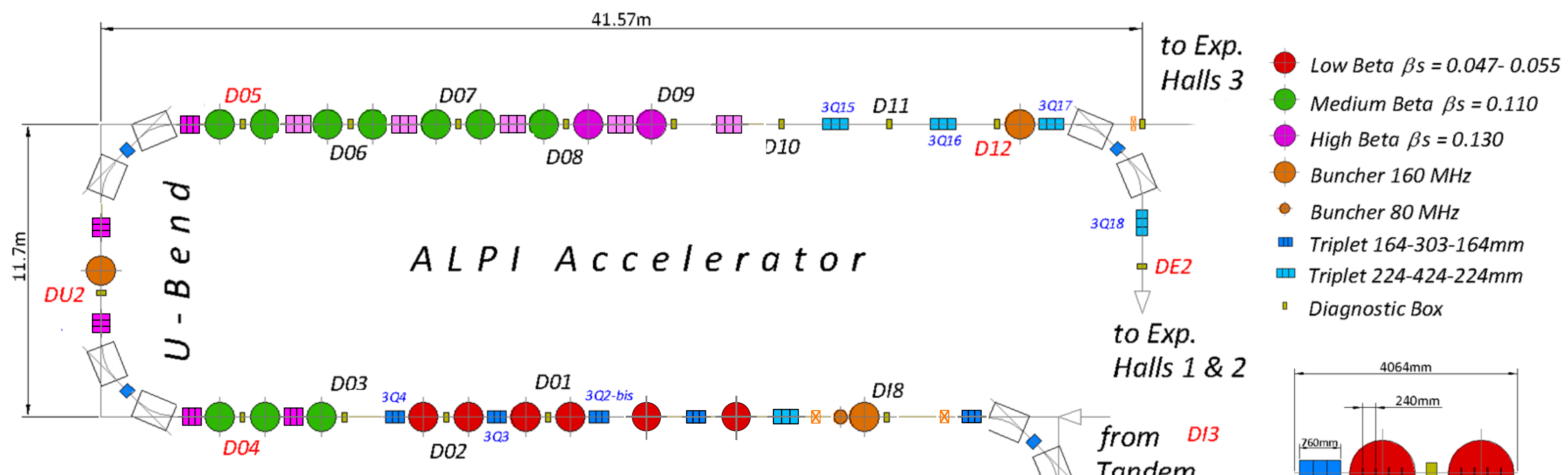

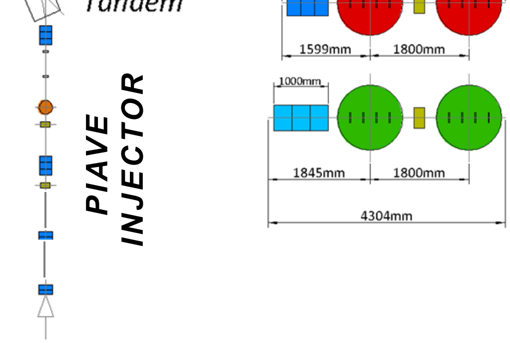

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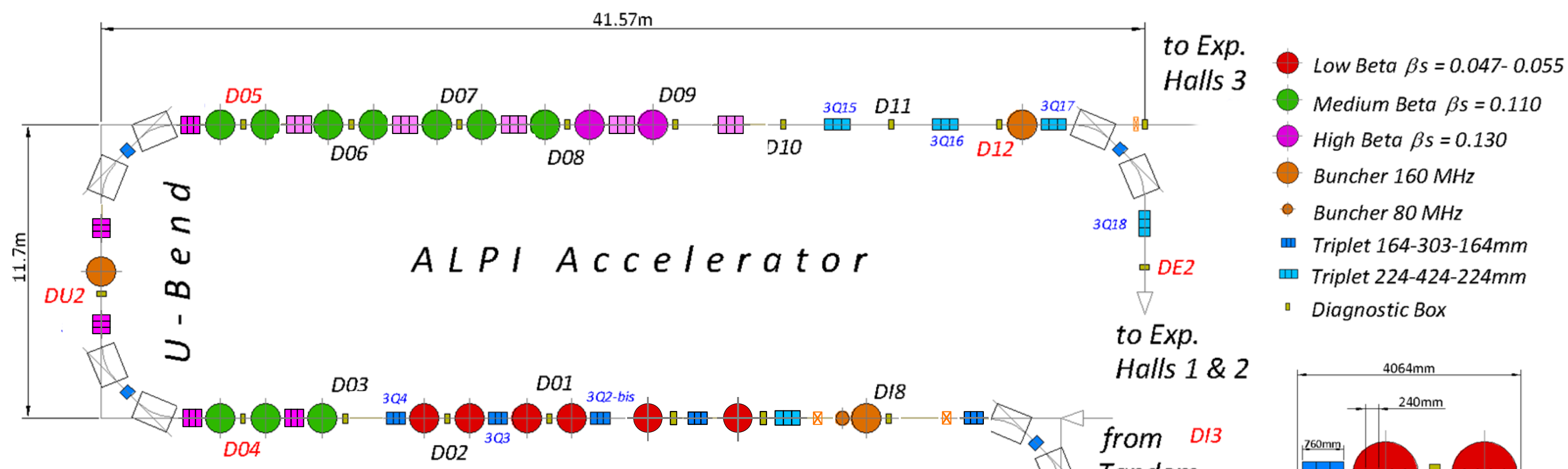
Dismantling of the Low Energy Branch Section in ALPI
Positioning of the two PIAVE QWR cryostats in ALPI
Maintenance activities of three QWR cryostats in ALPI
Dismantling of ten Quadrupole Triplets in ALPI
Installation of thirteen Quadrupole Triplets in ALPI (two are from stock)
Installation of two Diagnostic Box in ALPI (one is from stock)

Courtesy of C. Roncolato

ALPI Upgrade Outline



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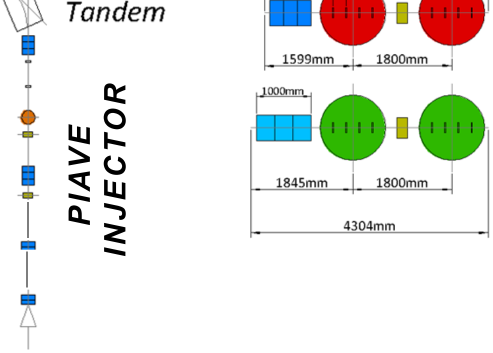
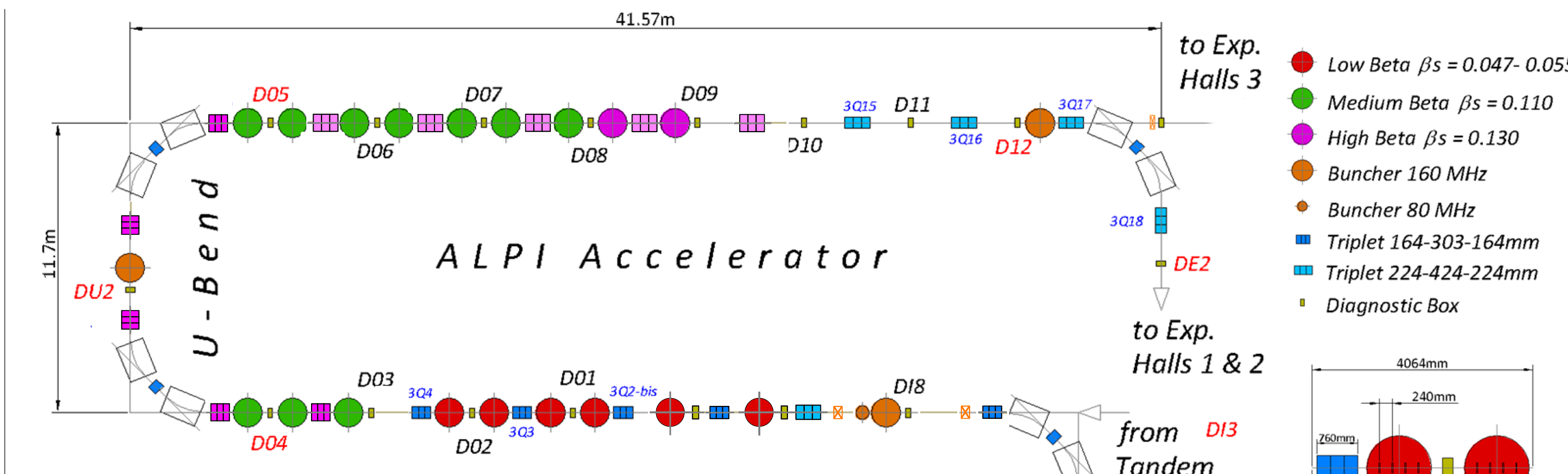
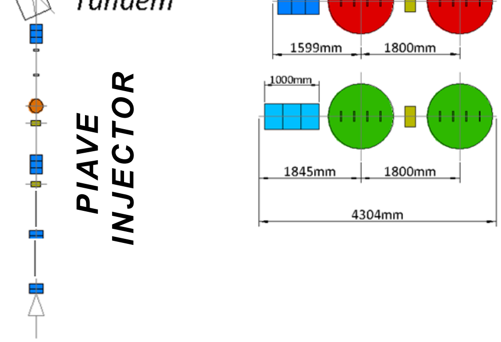


Courtesy of C. Roncolato

ALPI Upgrade Outline





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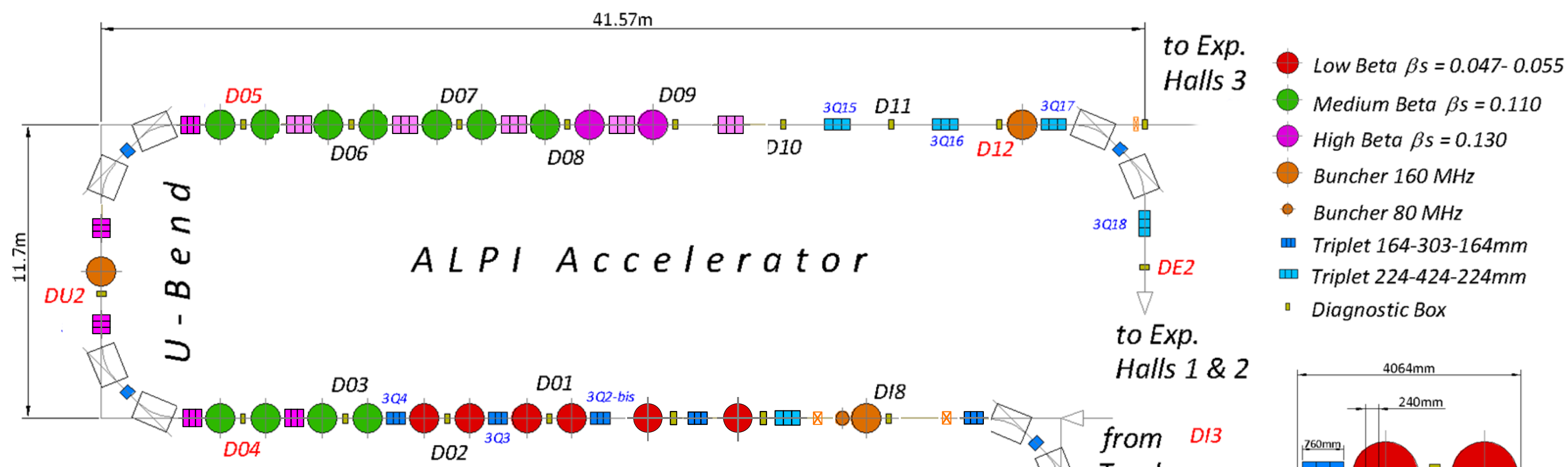
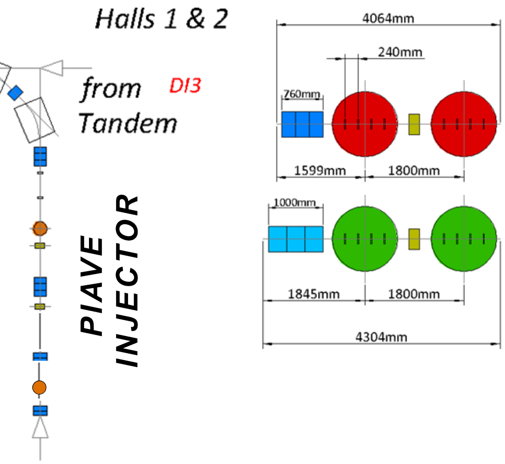
Dismantling of the Low Energy Branch Section in ALPI
Positioning of the two PIAVE QWR cryostats in ALPI
Maintenance activities of three QWR cryostats in ALPI
Dismantling of ten Quadrupole Triplets in ALPI
Installation of thirteen Quadrupole Triplets in ALPI (two are from stock)
Installation of two Diagnostic Box in ALPI (one is from stock)
Installation of the NC Buncher in PIAVE & CR07 in ALPI

Courtesy of C. Roncolato

ALPI Upgrade Outline





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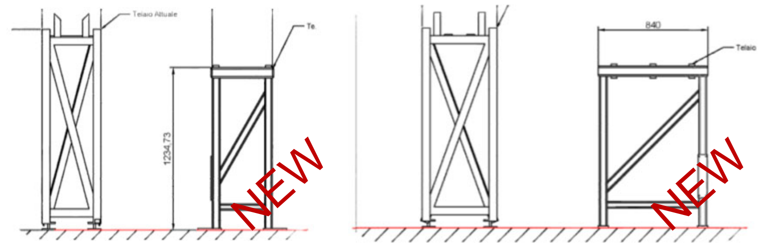
Installation of two Diagnostic Box in ALPI (one is from stock)
Installation of the NC Buncher in PIAVE & CR07 in ALPI

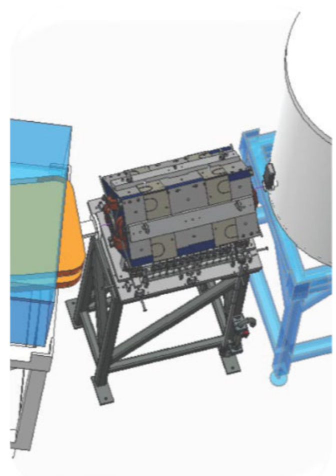
Courtesy of C. Roncolato

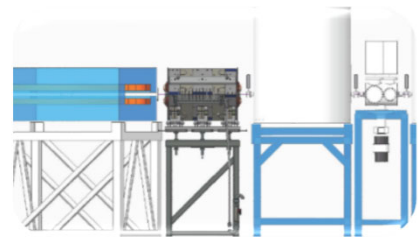
New Magnetic Triplets Highlights

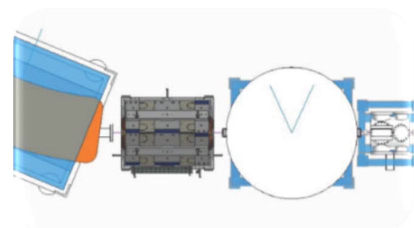
Main Specification	3Q5-3Q9	3Q10-3Q14	
Quantity	5	5	
Maximum Gradient Field	30.6	30.6	T/m
Effective Length	164/303/164	224/424/224	mm
Quadrupoles Separation	78	64	mm
Flange to Flange Length	850	1100	mm
Useful Diameter	40	40	mm
Nominal Current	175	154	A
Nominal Voltage	15.5 / 24.2 / 15.5	13.1 / 21.6 / 13.1	V
Weight (frame included)	750	1000	kg

- Increased Maximum Gradient
- Equal effective length
- Equal mechanical length
- Slightly larger useful diameter
- More powerful PS needed
- Two water connections
- Long water pipe can be use
- Lower support height
- Larger footprint
- Three separate cable connections
- One gross alignment regulation
- Three fine alignment regulations



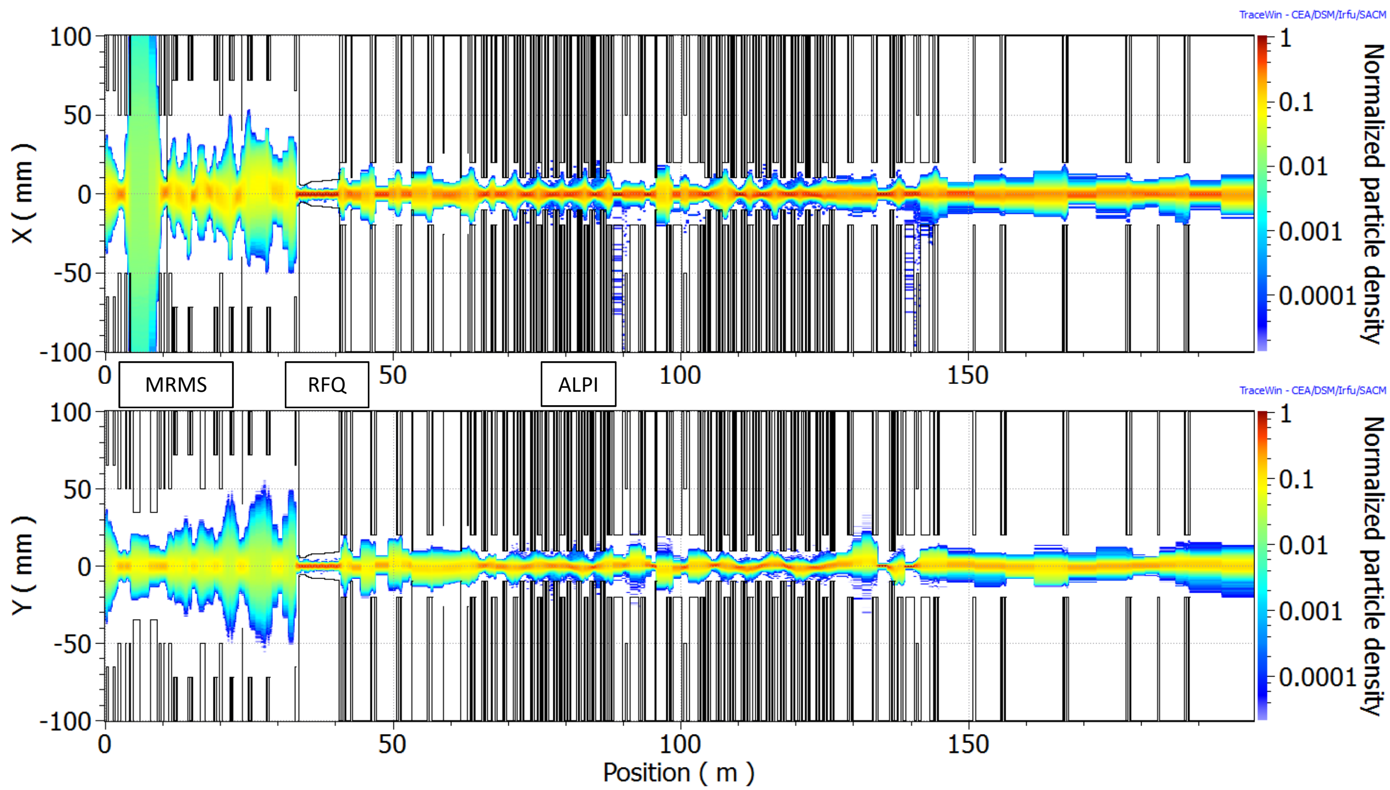






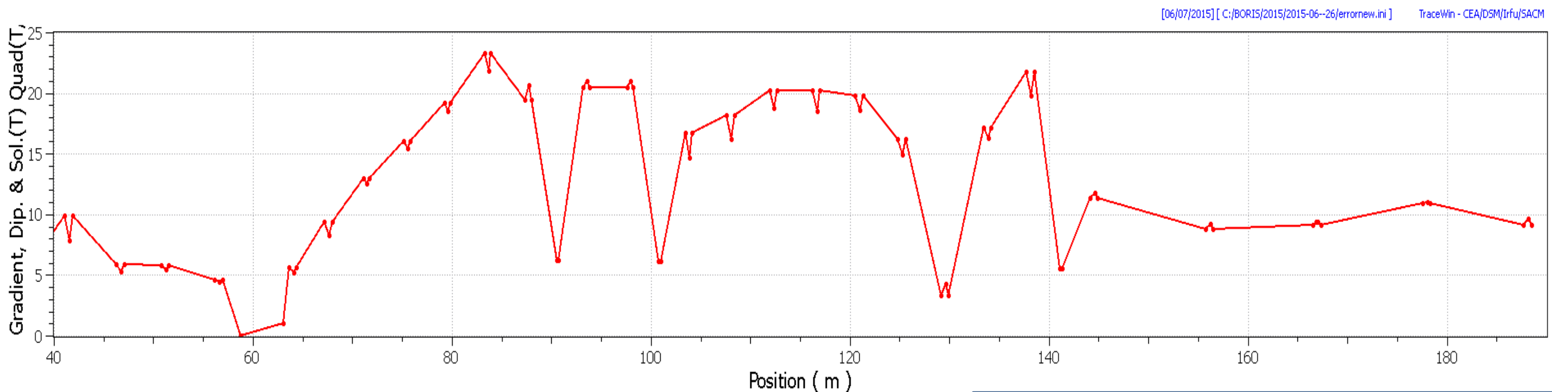
Courtesy of C. Roncolato

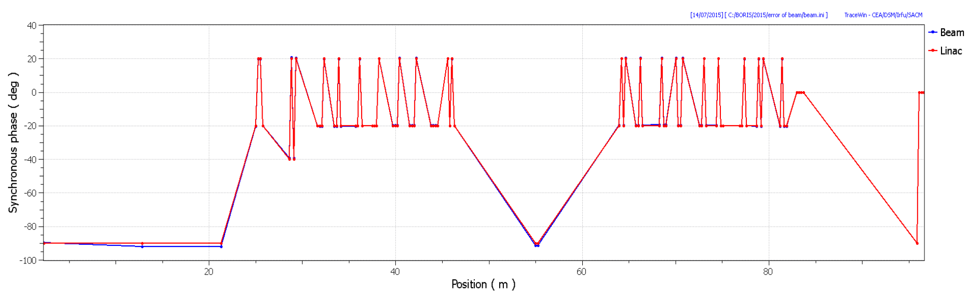
End to end simulation from the CB to end of ALPI

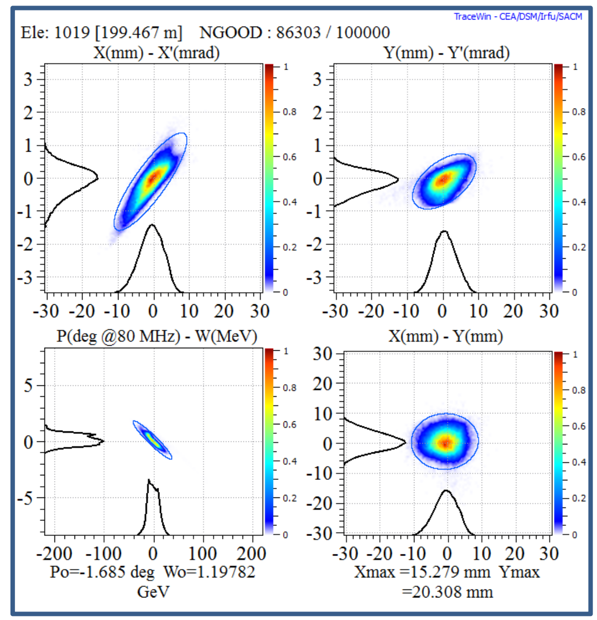


- Case of $^{132}Sn^{19+}$ @ 0.76 MeV with 0.1 mm mrad from the CB and +-15 eV of energy spread.
- The total losses in the nominal case are less than 14%, the final energy is 1200 MeV

End to end simulation from the CB to end of ALPI







- Gradient and synchronous phase along ALPI
- Phase space at Experimental Hall (FC7)

Highlight: Commissioning steps for HRMS

Basics checks and nominal separator beam dynamics

1. Beam Cooler output beam requirements check
2. low resolution transport trough the separator
3. Increase the resolution reaching the nominal beam BD.
4. Multipole fine tuning setting
5. Scaling test

"contaminant-free" beam

Step 1

Resolution validation

1. Beam Cooler output beam requirements check
2. Fine tuning of the HRMS

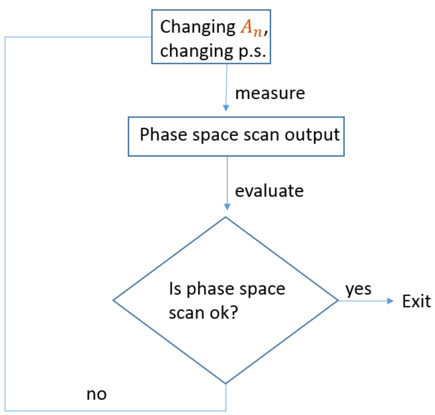
with isobar contaminant

Step 2

Courtesy of L. Bellan

Multipole tuning for MRMS and HRMS

- Tuning is performed onto $\varepsilon_{rms,n}$ and H_x[1] looking into diagnostics BI.07 at 40 keV for HRMS.
  - Very large variation of emittance ($\sim 10\varepsilon_{rms,n,optimum}$)
  - No needed to have specific beam phase space shape as soon as the Allison scanner can measure it.
  - Run time of hours.
  - Modification of A_n coefficients via Down Hill algorithm.
  - The procedure may stack in a relative minimum.
- Image point slits open.
- Tested in simulation with error of the multipole components of 30%-50%.

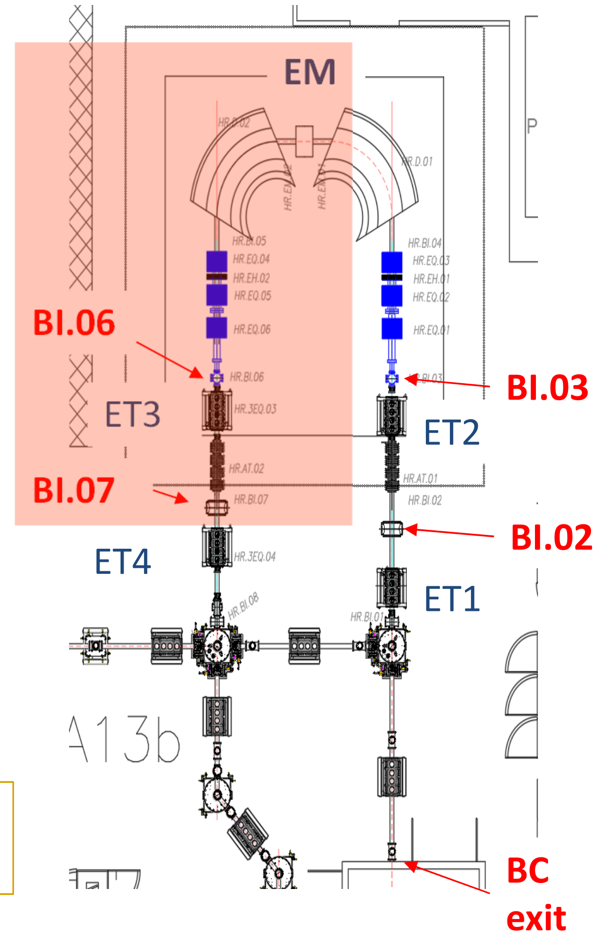


$$\phi(\rho,\theta)=\sum_n A_n\rho^n\cos(n\theta)$$

To be changed by the optimization algorithm

Fixed per each electrode position

Python script or TraceWin VA via EPICS variables

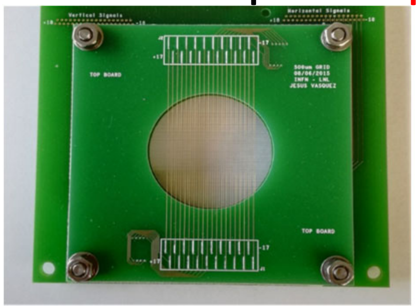


[1] C. K. Allen and T. P. Wangler, Phys. Rev. ST Accel. Beams, vol. 5, p. 124202, 2002.

Courtesy of L. Bellan

Beam Instrumentation

Grid for beam profiler – profile of stable ions



- Measured currents down to tens pA. Below this value, MCP detectors must be used for BP measurement. 40 wires.
- Resolution can be adjusted changing the wire spacing. For HRMS, the highest resolution required is 0.250 mm over 10x10 mm^2 monitor area (object and image point)

MCP (Micro Channel Plate) detectors, preliminary design – profile and current for RIB (Radioactive Ion Beams)