Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DEL SUD

Accelerator’s activities and perspectives at LNS

Luigi Celona

INFN-LNS Users Annual Meetinig

December 19th 2022

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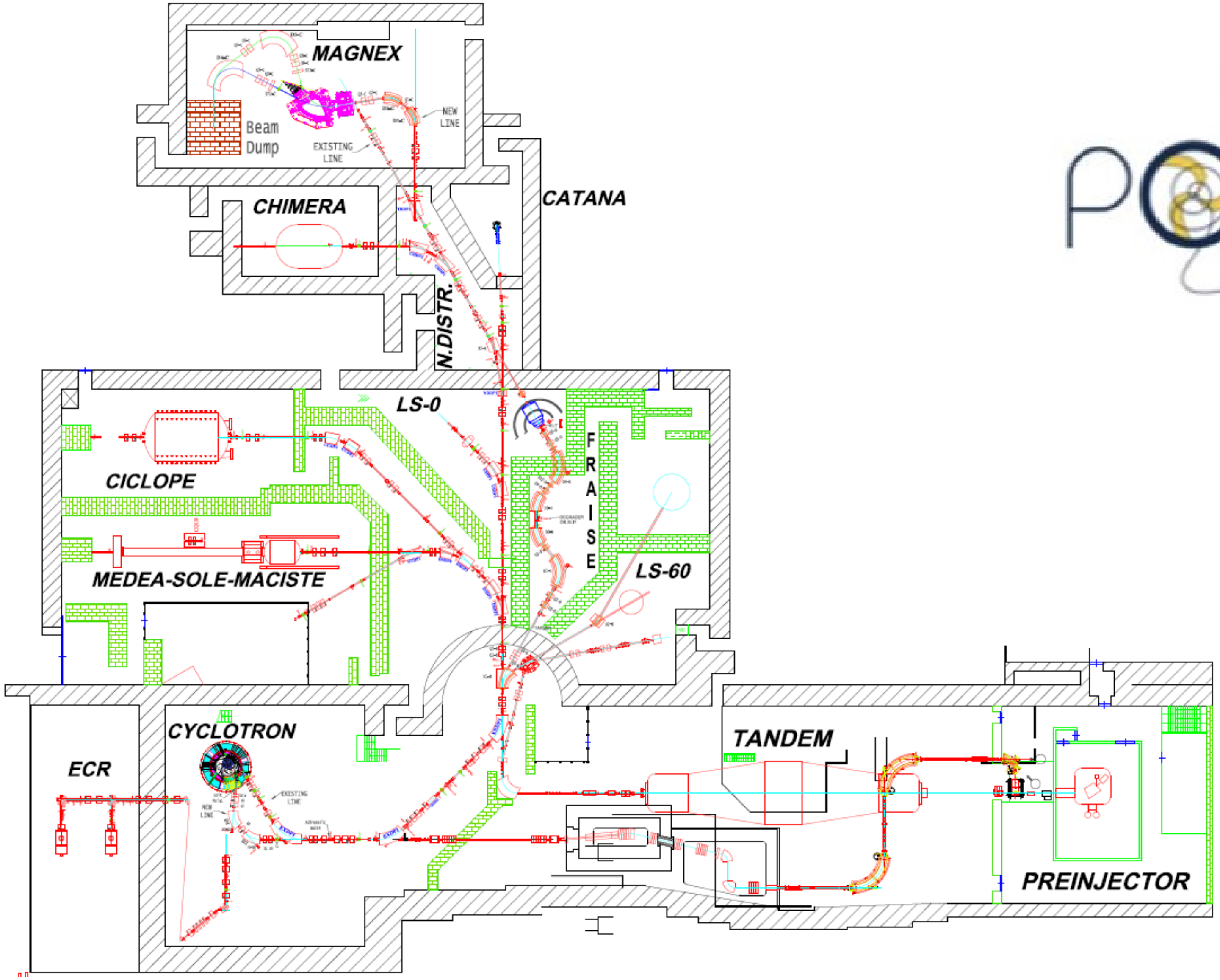
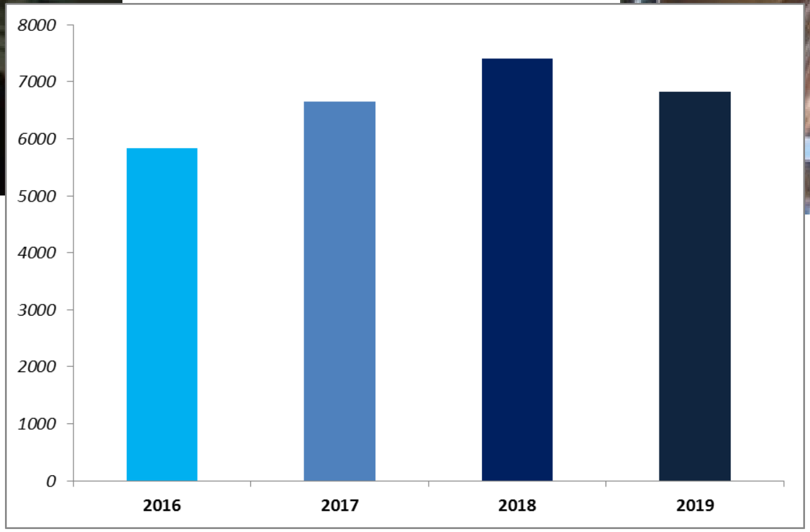


POTlns

Tandem + Cyclotron beam time



35 - 40 experiments per year, including the proton therapy sessions

Beam time lost for failures:

- ***Tandem: < 2%***
- ***Cyclotron: < 4%***

430 BTU circa per year delivered for each accelerator

(excluding beam time preparation)

TANDEM automation and instrumentation upgrading

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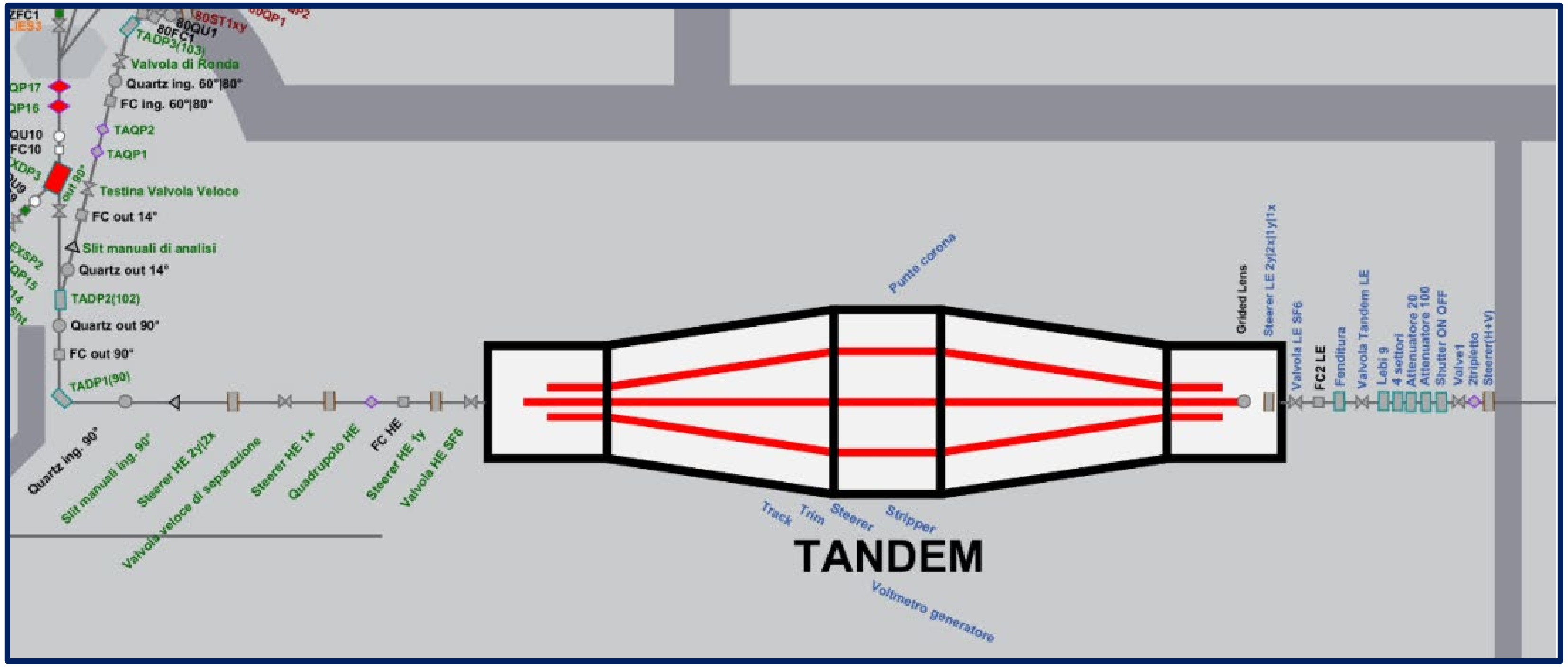

Implementation of a new software platform

Replacement of obsolete instrumentation

First Tandem operation expected for end of 2023

Tandem vacuum system February'23

Safety issues (RSPP prescriptions) March'23

Switching magnet installation May'23

Extra maintenance to electrical plant (compliance) June'23

Extra maintenance to SF6 plant (controls with redundancy of temperature and pressure gauges, alarm leak) July'23

Pelletron extra maintenance and relative tests (NEC discussion ongoing)

HV stabilization system

Alignment check

Power converters

Visual Diagnostics

Spectrometry of accelerated species

Tandem Beam Menu

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- ^{1}H, ^{2}H
- ^{6}Li, ^{7}Li
- ^{9}Be, ^{10}Be
- ^{10}B, ^{11}B
- ^{12}C, ^{13}C
- ^{14}N
- ^{16}O, ^{17}O, ^{18}O
- ^{19}F
- ^{23}Na
- ^{24}Mg, ^{25}Mg
- ^{27}Al
- ^{28}Si, ^{29}Si
- ^{32}S, ^{34}S
- ^{35}Cl, ^{37}Cl
- ^{40}Ca
- ^{58}Ni, ^{60}Ni
- ^{63}Cu, ^{65}Cu
- ^{70}Ge
- ^{79}Br
- ^{93}Nb
- ^{116}Sn, ^{120}Sn
- ^{127}I
- ^{197}Au

Maximum High Voltage ≈ 13.5MV

Pelletron charging system

HV stability ≈ 10^{-4}

Noble gases development in progress

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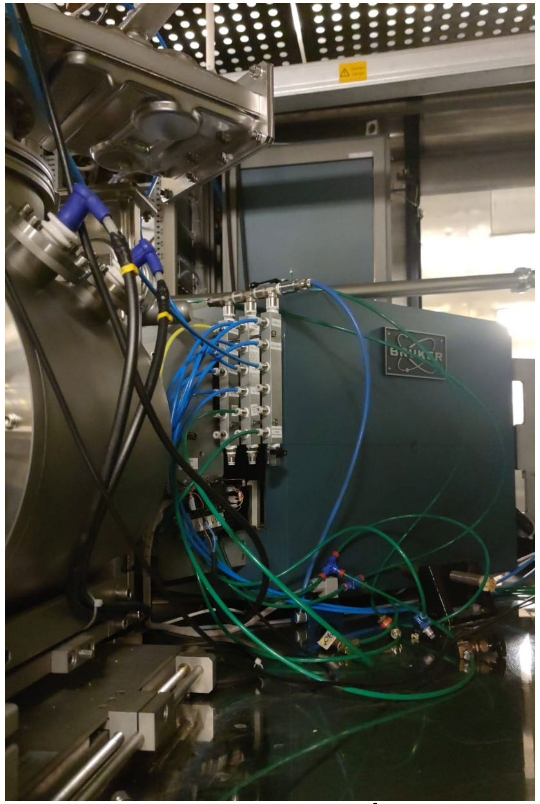
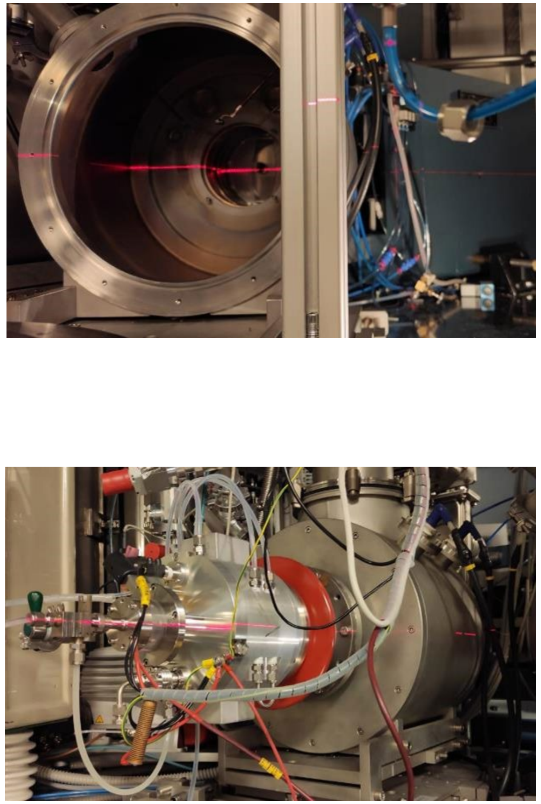
450kV PLATFORM

Extraordinary maintenance was carried out for all the subsystems

New Cooling Water Distribution System



New Compressed Air Distribution System



Aligment Check

TO DO:

- HV Distribution Rack: adaptation to current legislation

Planned for 2023

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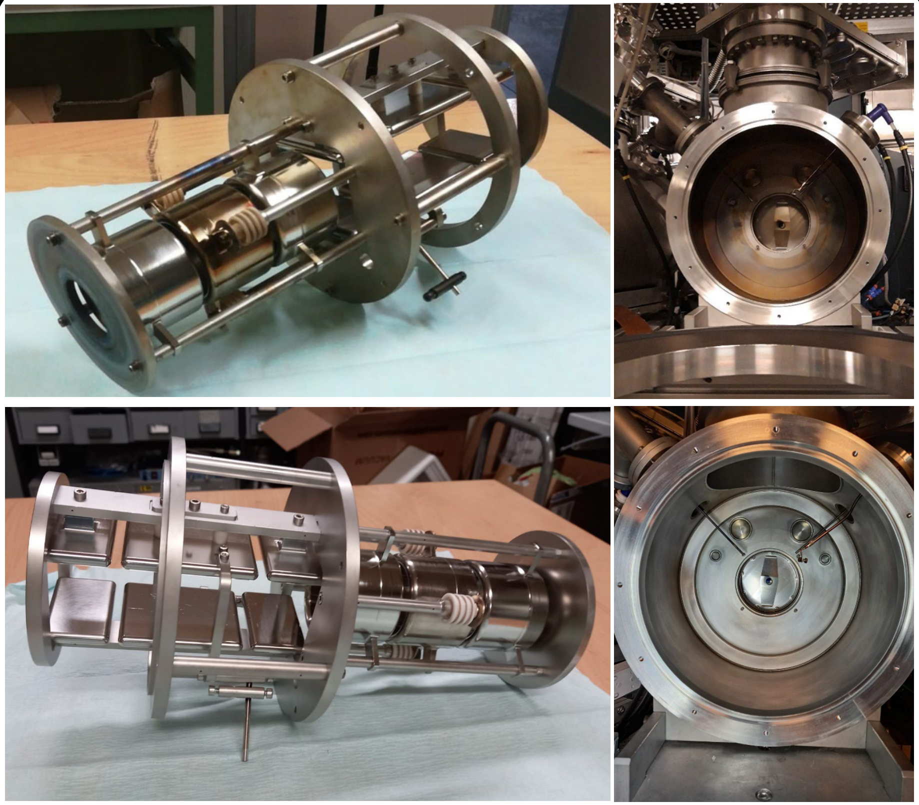
450kV PLATFORM

Extraordinary maintenance was carried out for all the subsystems



Vacuum cleaning

Vacuum Check

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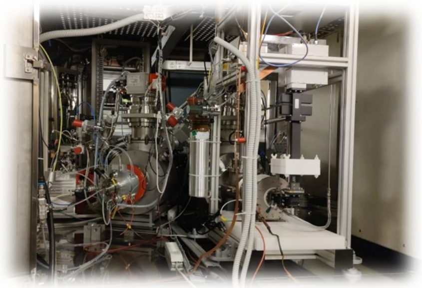
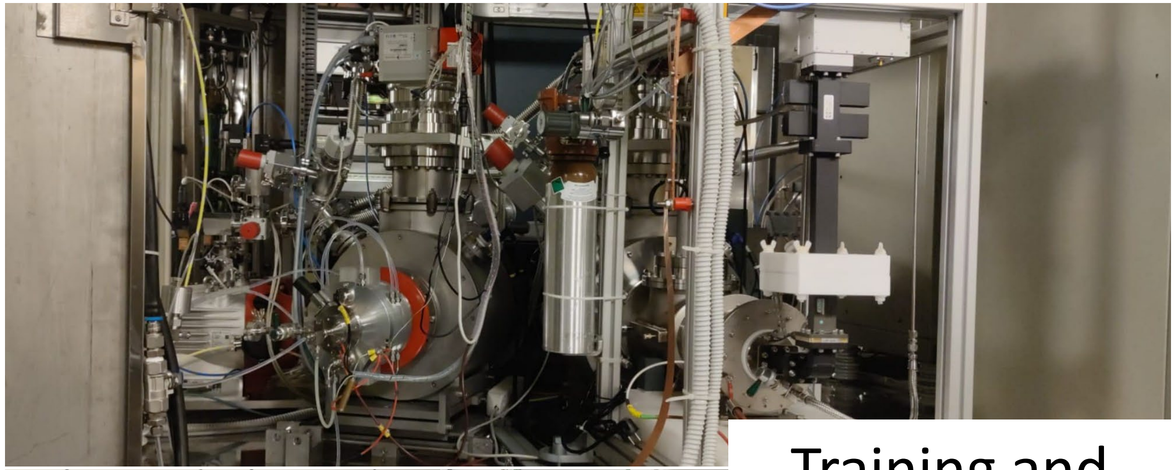
450kV PLATFORM-Sputter IS



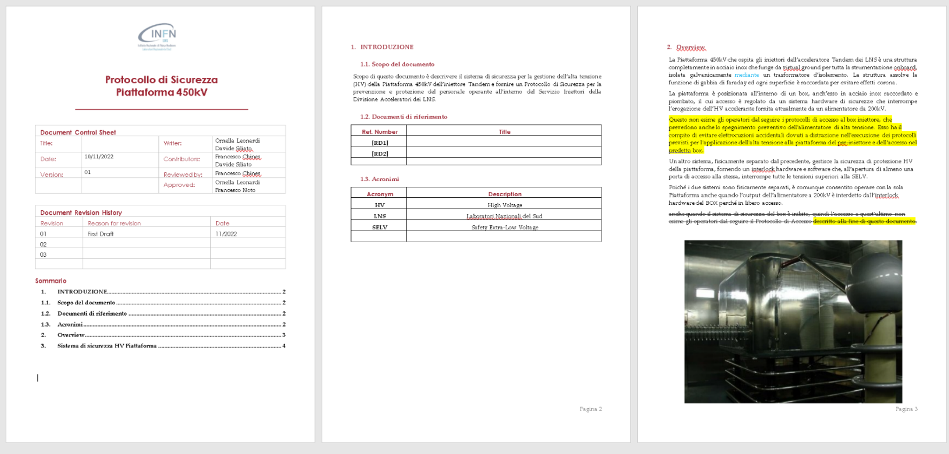
First sputtering beam planned for January 2023

1. **Gold -> reference beam**
2. **Aluminium**
3. **Lithium** } from Li_2O+Ag
4. **Oxygen** } from Li_2O+Ag
5. **Magnesium** from Mg +H_2 or Mg+NH_3
6. **Carbon** from BN+ graphite or B_4C



Training and Skills transfer

Approval of the HV Platform Safety Protocol by the RSPP



Protocollo di Sicurezza
Piattaforma 450kV

Document Control Sheet

Title:		Writer:	Ornella Leonardi Davide Siliato
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Document Revision History

Revision	Reason for revision	Date
01	First Draft	11/2022
02		
03		

Sommario

1. INTRODUZIONE

1.1. Scopo del documento

Scopo di questo documento è descrivere il sistema di sicurezza per la gestione dell'alta tensione (HV) della Piattaforma 450kV dell'iniettore Tandem e fornire un Protocollo di Sicurezza per la prevenzione e protezione del personale operante all'interno del Servizio Iniettori della Divisione Acceleratori dei LNS.

1.2. Documenti di riferimento

Ref. Number	Title
[RD1]	
[RD2]	

1.3. Acronimi

Acronym	Description
HV	High Voltage
LNS	Laboratori Nazionali del Sud
SELV	Safety Extra-Low Voltage

2. Overview

La Piattaforma 450kV che ospita gli iniettori dell'acceleratore Tandem dei LNS è una struttura completamente in acciaio inox che funge da virtual ground per tutta la strumentazione onboard, isolata galvanicamente mediante un trasformatore d'isolamento. La struttura assolve la funzione di gabbia di faraday ed ogni superficie è raccordata per evitare effetti corona.

La piattaforma è posizionata all'interno di un box, anch'esso in acciaio inox raccordato e piombato, il cui accesso è regolato da un sistema hardware di sicurezze che interrompe l'erogazione dell'HV accelerante fornita attualmente da un alimentatore da 200kV.

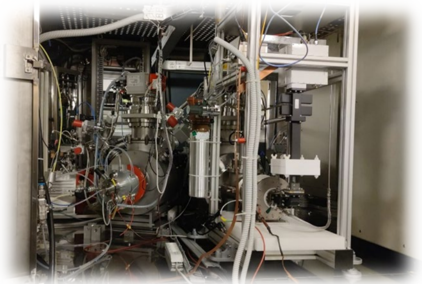
Questo non esime gli operatori dal seguire i protocolli di accesso al box iniettore, che prevedono anche lo spegnimento preventivo dell'alimentatore di alta tensione. Esso ha il compito di evitare elettrocuzioni accidentali dovuti a distrazione nell'esecuzione dei protocolli previsti per l'applicazione dell'alta tensione alla piattaforma del pre-iniettore e dell'accesso nel predetto box.

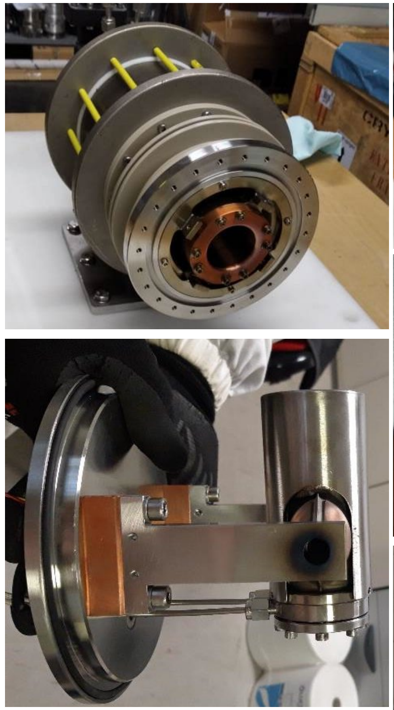
Un altro sistema, fisicamente separato dal precedente, gestisce la sicurezza di protezione HV della piattaforma, fornendo un interlock hardware e software che, all'apertura di almeno una porta di accesso alla stessa, interrompe tutte le tensioni superiori alla SELV.

Poiché i due sistemi sono fisicamente separati, è comunque consentito operare con la sola Piattaforma anche quando l'output dell'alimentatore a 200kV è interdetto dall'interlock hardware del BOX perché in libero accesso.

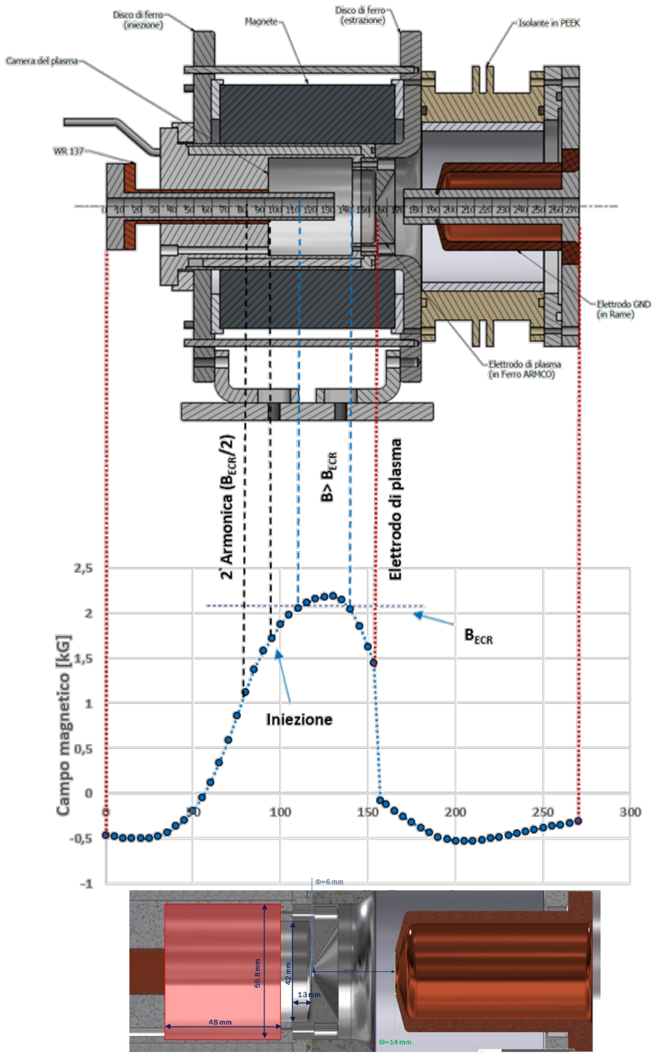
~~anche quando il sistema di sicurezza del box è inibito, quindi l'accesso a quest'ultimo non esime gli operatori dal seguire il Protocollo di Accesso descritto alla fine di questo documento.~~

450kV PLATFORM-NESTOR

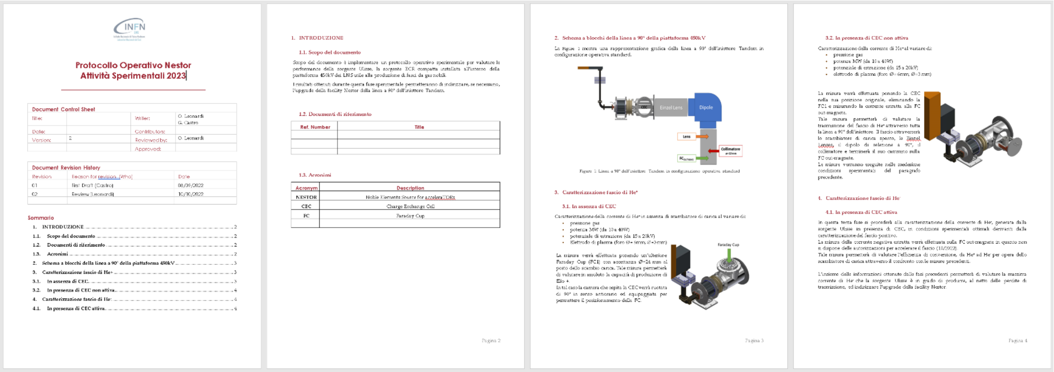




Totally disassembled and cleaned



New characterization is planned for January



Planned operations:

- Positive He production and relative transport along the beam line in different conditions and operations
- Charge-exchange cell installation and test of production of negative ion beams in different conditions and operations.
- Open issues resolution

L. Celona, INFN-LNS Users Annual Meeting, December 19th 2022

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Long half-life isotopes in batch-mode

^{10}Be (*$T_{1/2}$ = 1.39×10^{6} y*) *Tandem* beam has been produced in batch-mode, in collaboration with PSI (Zurich)

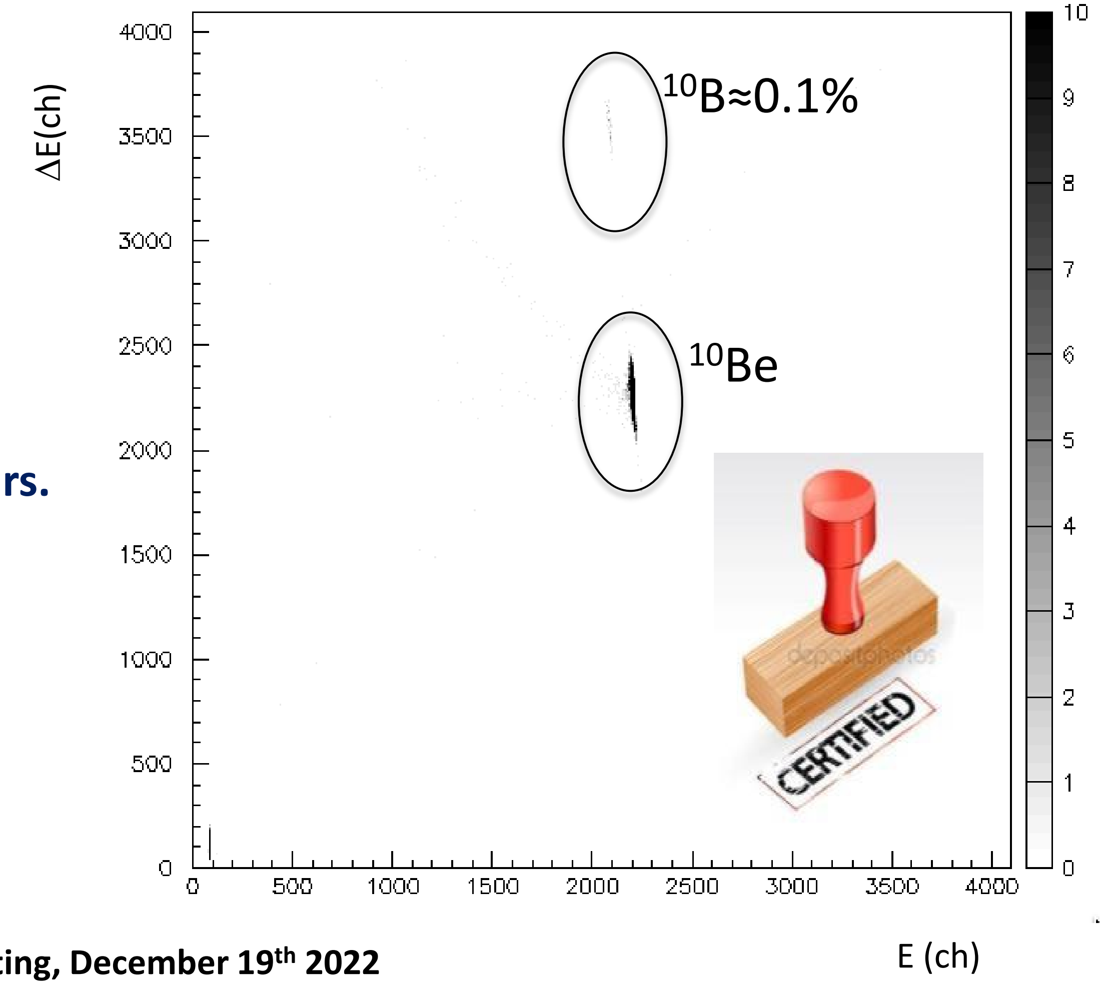
@ 47 MeV

I ≈10 nA for a few days

Contamination of ^{10}B≈ 0.1%

Batch-mode beam development is foreseen for the next years.

Next possible beam: ^{26}Al (*$T_{1/2}$=7.17×10^{5} y*)



Superconducting Cyclotron

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Operating 1994 - 2020

E_{MAX} ~ 80 AMeV for lighter ions

E_{MAX} ~ 25 AMeV for heavier ions (i.e. Au^{36+})

K_{bend} =800 - K_{foc}=200

Pole radius: 90 cm – Mag. field: 2.2 - 4.8 T

RF range: 15-48 MHz

Since 1999

Two ECR ion sources: CAESAR and SERSE

June 2020 last experiment, disassembly for the upgrading started in November.

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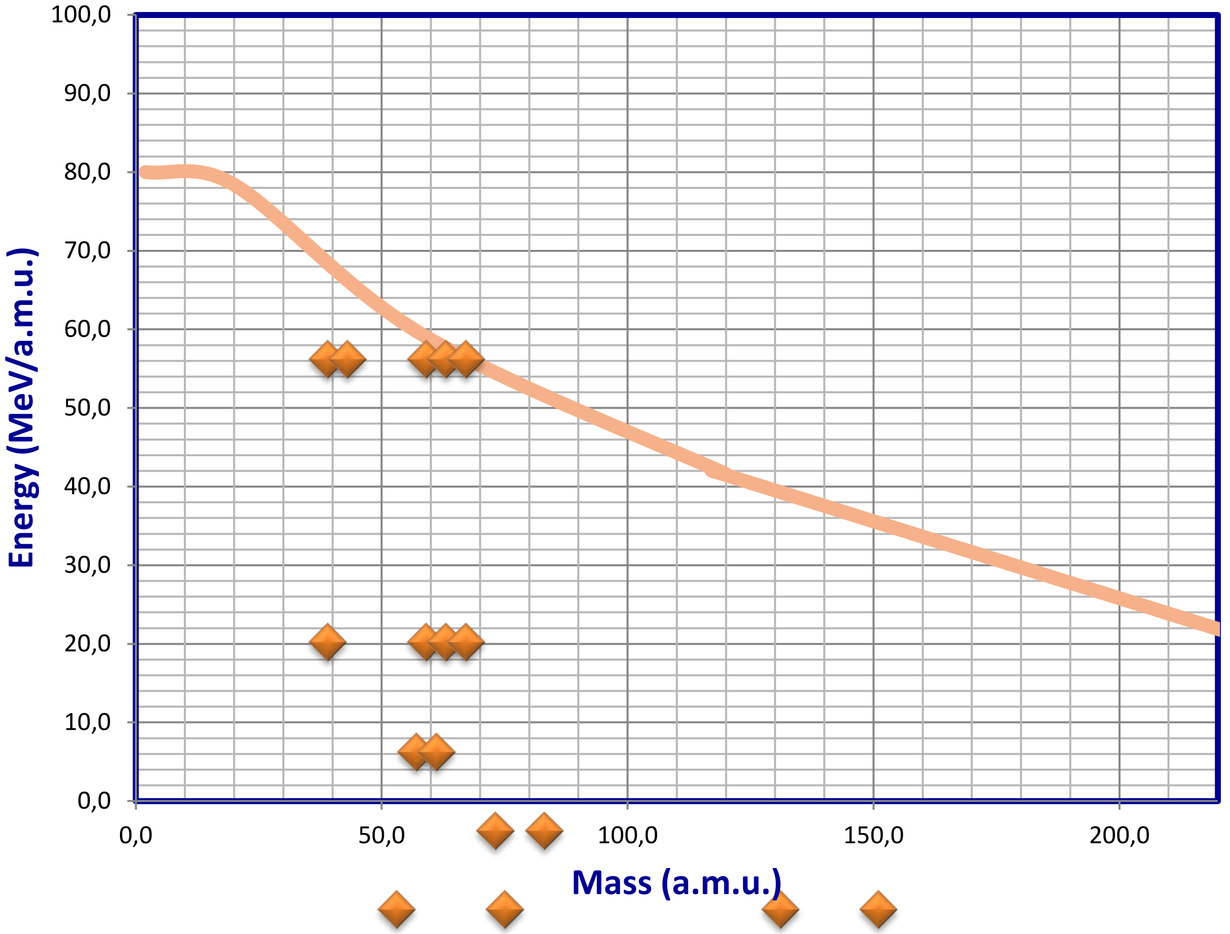
Cyclotron Beams Menu



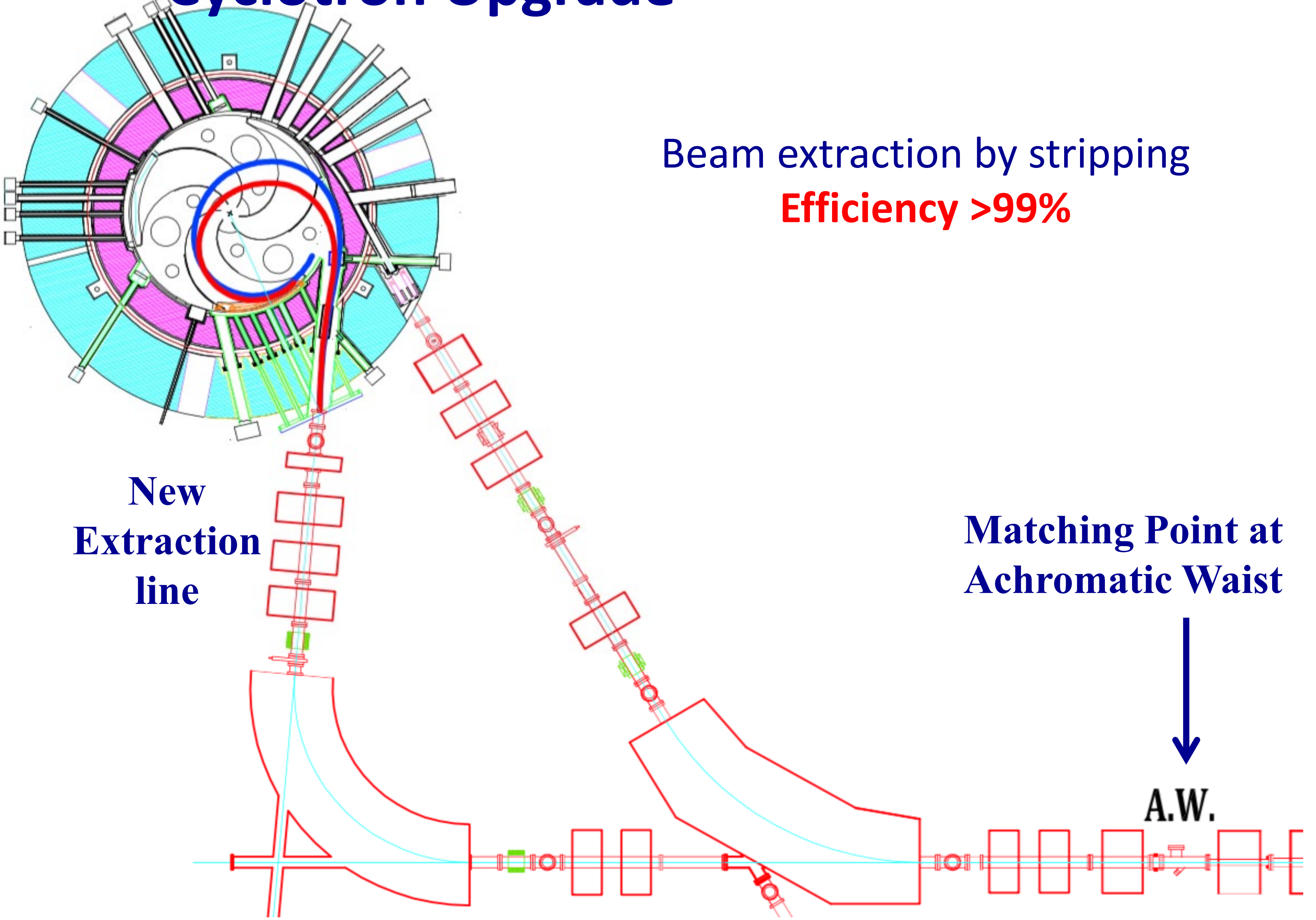
^{A}X	E (AMeV)
H_2^+	62,80
H_3^+	30,35,45
$^{2}D^+$	35,62,80
^{4}He	25,62,80
He-H	10, 21
^{9}Be	45
^{11}B	55
^{12}C	23,62,80
^{13}C	45,55
^{14}N	62,80
^{16}O	21,25,55,62,80
^{18}O	15,55
^{19}F	35,40,50
^{20}Ne	20,40,45,62
^{24}Mg	50
^{27}Al	40
^{36}Ar	16,38
^{40}Ar	15,20,40

^{A}X	E (AMeV)
^{40}Ca	10,25,40,45
^{42,48}Ca	10,45
^{58}Ni ,45	16,23,25,30,35,40
^{62,64}Ni	25,35
^{68,70}Zn	40
^{74}Ge	40
^{78,86}Kr	10
^{84}Kr	10,15,20,25
^{93}Nb	15,17,23,30,38
^{107}Ag	40
^{112}Sn	15.5,35,43.5
^{116}Sn	23,30,38
^{124}Sn	15,25,30,35
^{129}Xe	20,21,23,35
^{197}Au	10,15,20,21,23
^{208}Pb	10

Cyclotron Upgrade

Instantaneous change of the magnetic rigidity, when the charge state of the ion is suddenly increased crossing a thin carbon foil.

Beam extraction by stripping
Efficiency >99%



Cyclotron Upgrade: expected currents by stripping

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Ion	q	Energy	Isource	Iacc	I extract	rate
		MeV/u	eμA	eμA	eμA	pps
12C	4	18	400	60	90.0	9.5E+13
12C	4	30	200	30	45.0	4.7E+13
12C	4	45	400	60	90.0	9.5E+13
12C	4	60	400	60	90.0	9.5E+13
18O	6	20	400	60	80.0	6.3E+13
18O	6	29	400	60	80.0	6.3E+13
18O	6	45	400	60	80.0	6.3E+13
18O	6	60	400	60	80.0	6.3E+13
18O	7	70	200	30	34.3	2.7E+13
20Ne	4	15	600	90	225.0	1.4E+14
20Ne	7	28	400	60	85.7	5.4E+13
20Ne	7	60	400	60	85.7	5.4E+13
40Ar	13	60	300	45	20.8	1.0E+13

18O @ 20 MeV will be the beam used to commissioning of the machine:

- It is in a good area of operative diagram of the machine.
- The power is not to high and it could mitigate eventually activation issues during the commissioning phase.

During the commissioning of the machine the beam intensity will be increased step by step adjusting the duty cycle of the CHOPPER, monitoring the beam losses along the beam lines and optimizing the tuning to minimize them.

To increase the current accelerated the following parameters need to be checked during the operation:

1) **Beam currents at the beam dump** increased of the expected value set by chopper;
2) **Beam losses at** control slits installed on the stripping **exit channel** of cyclotron stay below the threshold of 200 W;
3) **Beam losses along the five beam transport rooms** monitored by Radioprotection service stay below the threshold corresponding to 100 W beam loss;
4) All the 8 **beam current monitors** (CWCT) along the beam lines measure the expected values;
5) All the **slits that intercept the beam halo** along the beam lines measure the expected values.

Coil performances vs Operative diagram

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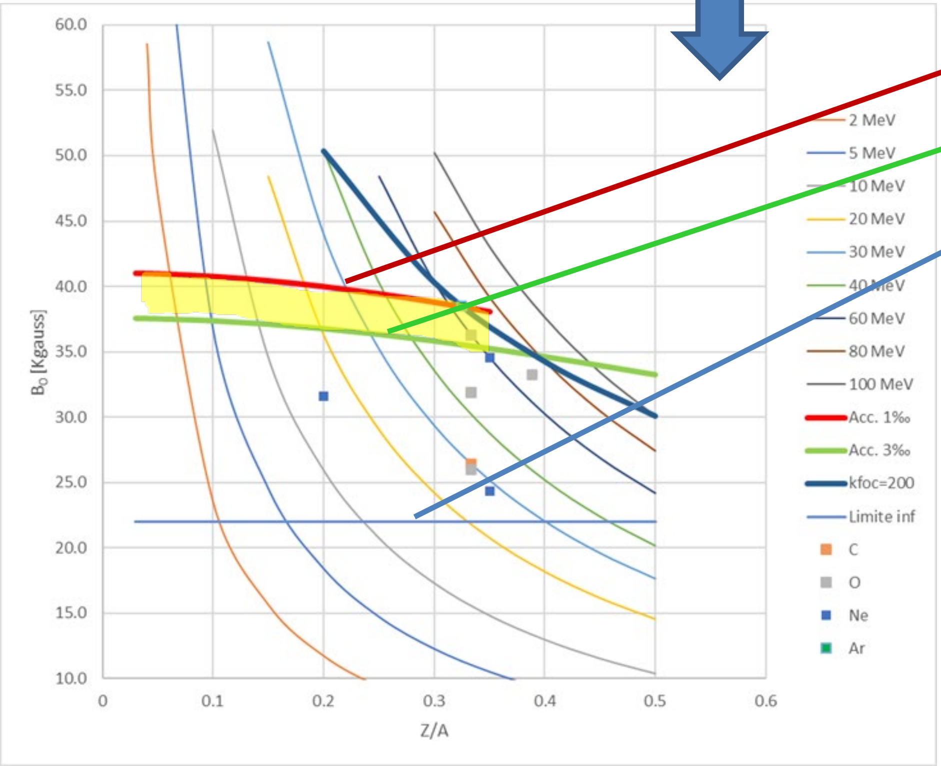
Deviation from the ideal form factor is expected.
Trim coils may help to contain this deviation, minimizing the performance reduction in terms of operative diagram.



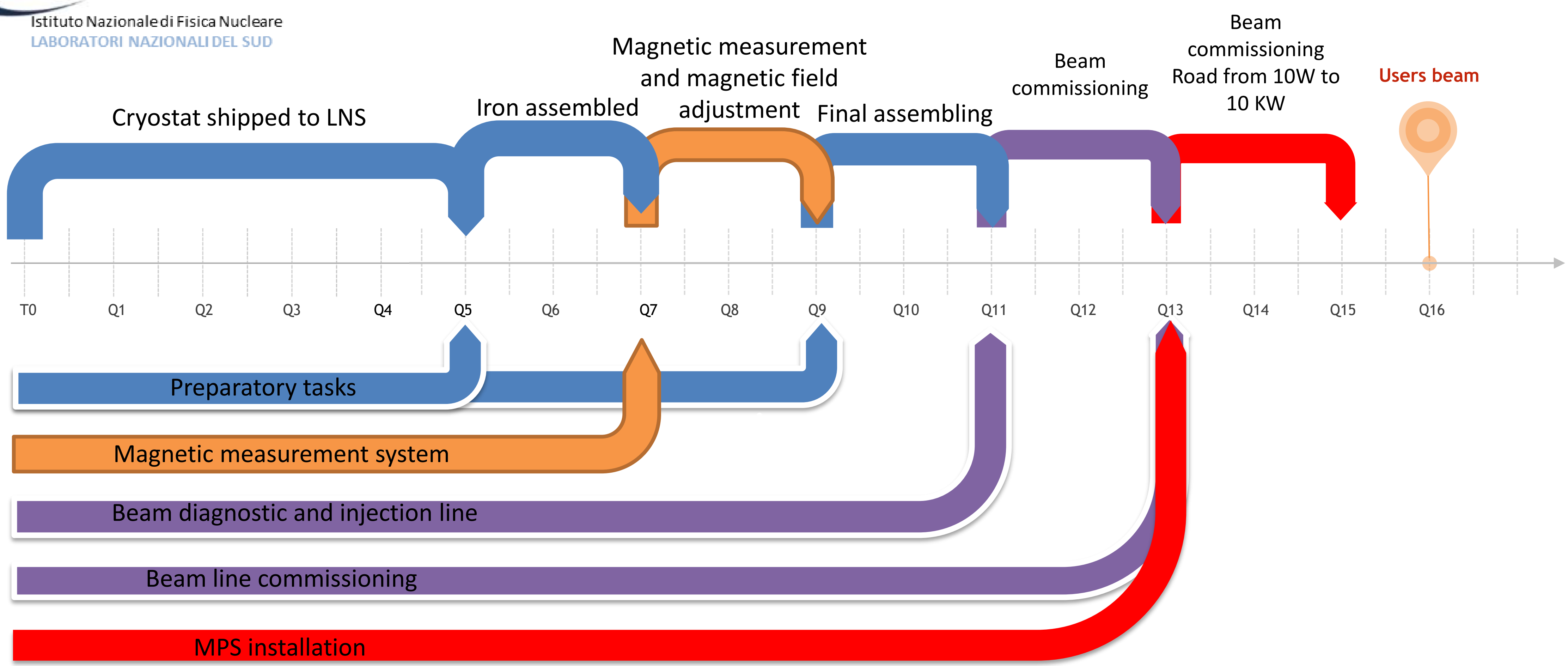
Upper limit of the magnetic field that should be correct whitin 0.1%

Case when the accuracy is 0,3%.

Lower limit

Beam dynamics simulation in progress.
Warm coil qualification will permit to refine the studies.

Masterplan



Cryostat shipped to LNS
Iron assembled
Magnetic measurement and magnetic field adjustment
Final assembling
Beam commissioning
Beam commissioning Road from 10W to 10 KW
Users beam
T0
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
Q13
Q14
Q15
Q16
Preparatory tasks
Magnetic measurement system
Beam diagnostic and injection line
Beam line commissioning
MPS installation

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Masterplan

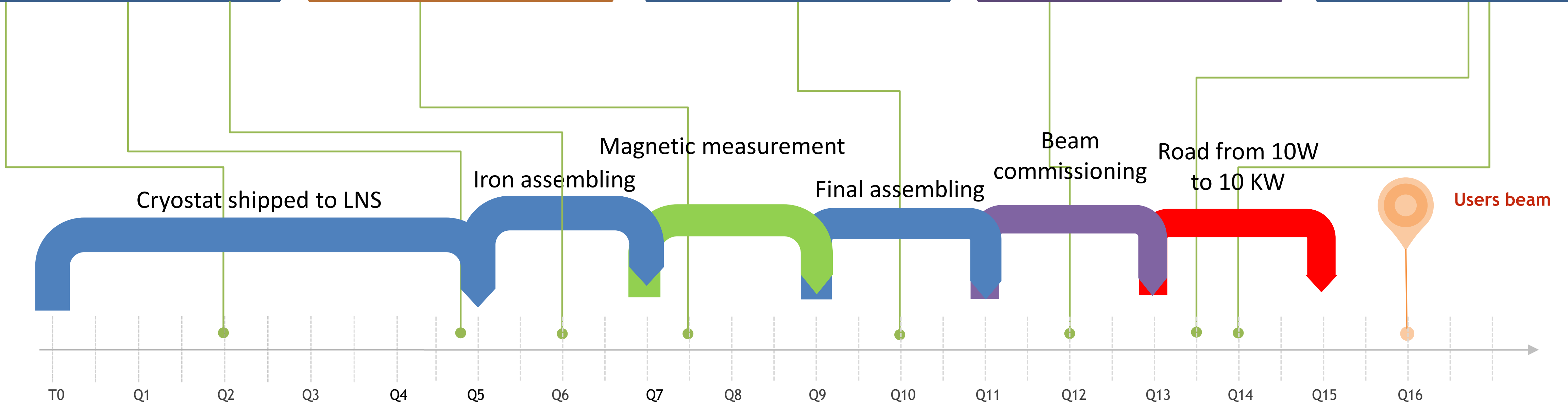
- Warm magnetic measurement
- Factory acceptance test
- Central ring
- Upper pole lifting system

- Mapping at different coils current
- Harmonic study
- Coils position adjustment

- RF System
- Stripping system
- Beam probe
- dismantled

- Deflecting method
- Stripping method
- Beam characterization

- Low power
- Medium power
- High power



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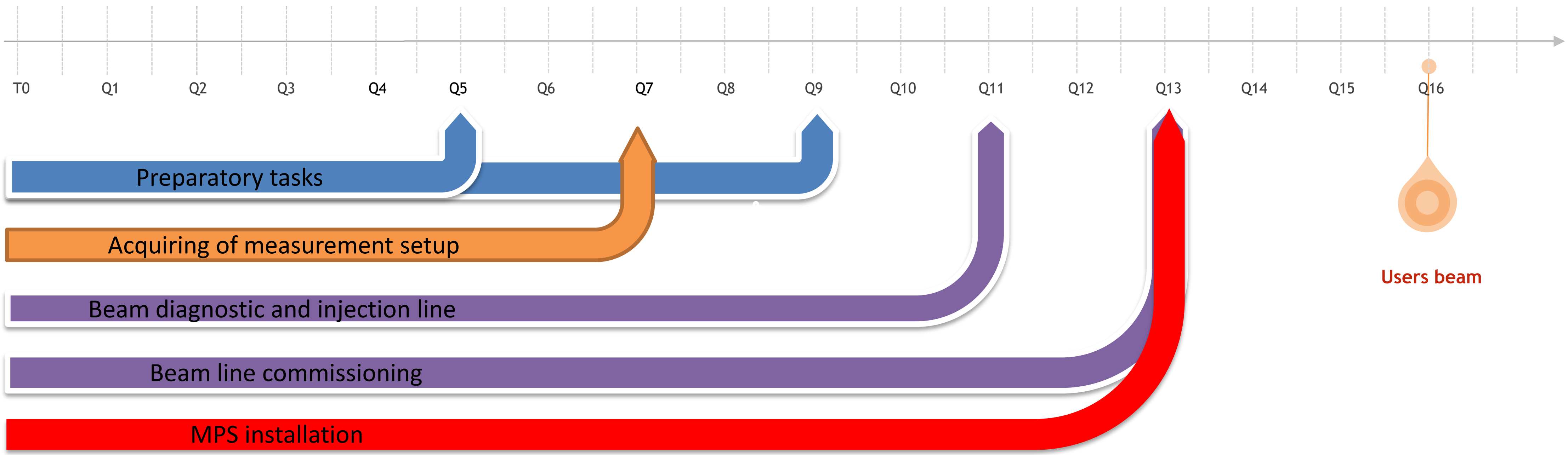
Masterplan



- Iron Cleaning
- Cavity Maintenance
- Liner installation
- Trim coils Maintenance
- Services restyling

- Probe positioning system
- Measurement probe

- Beam current probes on the machine
- Magnetic channel
- Injection line
- Chopper system

- New beam lines
- Diagnostic system
- New services
- Control system

- Control integration
- Cabling
- Testing

LNS

ml

ECR ion sources

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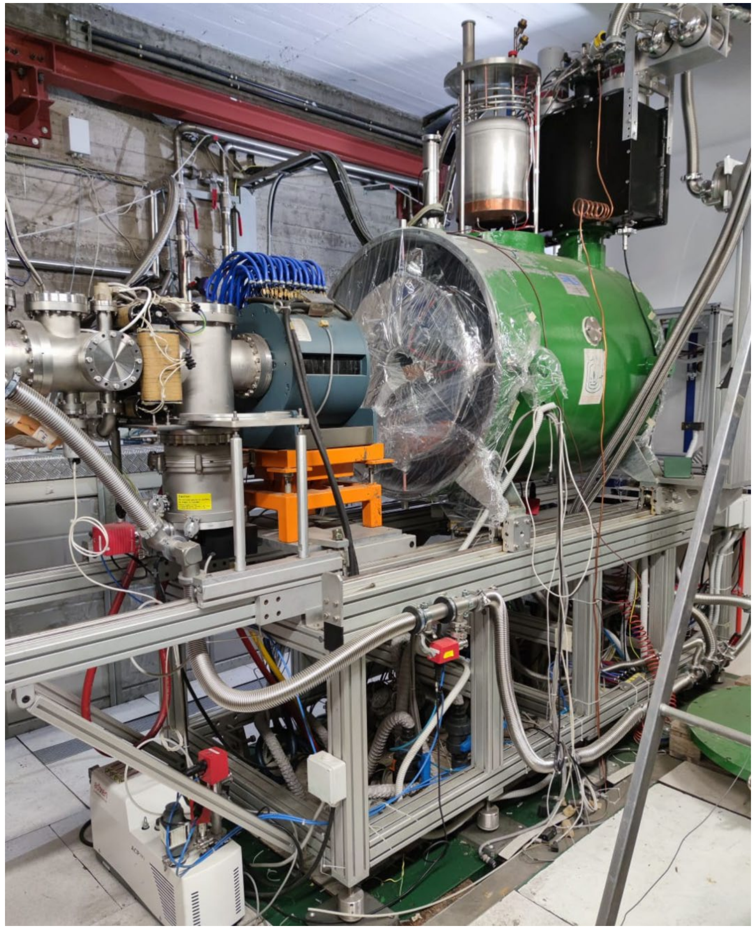
SERSE (1997)

Refurbishment of some subsystems carried out in previous years (controls, gas box, insulated rack), **but** serious cryogenic problem arose during last operations.



Activities carried out in summer 2022 to understand the possibility to revamp the cryogenic system, thanks to the addition of a third Single-Stage Pulse Tube to increase the refrigeration power of the nitrogen screen.

Unfortunately, the mechanics of the cryostat does not allow the creation of efficient thermal links.

HIGH INTENSITY operation and HCI production REQUIRE SERSE or a similar class ECR Ion Source

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CAESAR (1999)

The CAESAR ion source, although totally unsuitable to support the high intensities desired with the new CS, could continue to provide the less critical beams in the first operational years after a revamping of some subsystems (Obsolete Vacuum automation system, Vacuum and alignments check on the LEBT).

Other criticalities

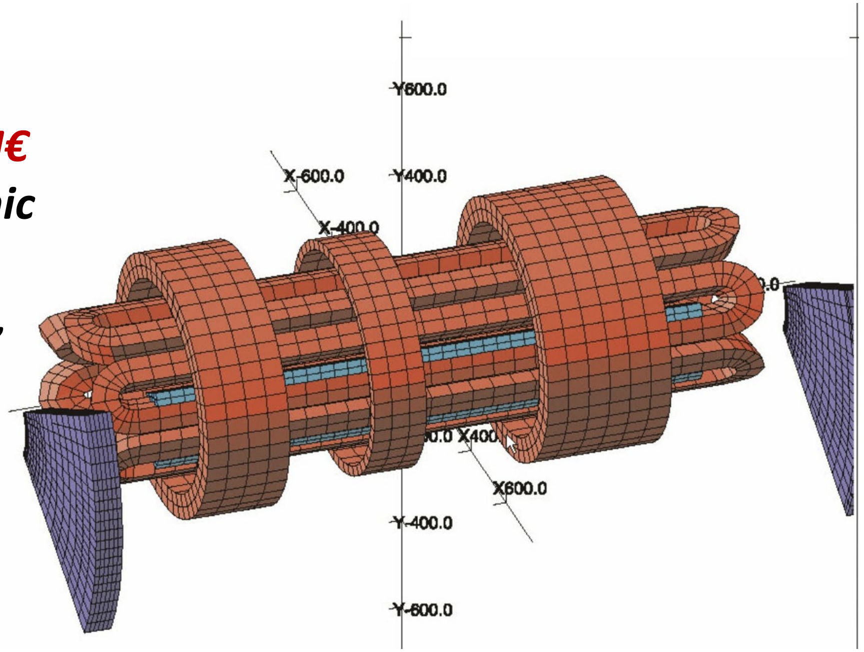
- ECR room shall be splitted to permit maintenance on one source while operating with the other.

SC-AISHa: a new ion source for INFN-LNS

- The AISHa ion source has been expressly conceived and realized for actual and future hadrontherapy facility (e.g.:HITRI+). It has a strong limitation on a radial field (1.28T instead of 1.55T of SERSE) affecting HCI production.
- A fully superconducting version has been conceived to overcome such limitation.

Radial field	1.9 T
Axial field	3.5 T - 0.5 T – 2.2 T
Operating frequencies	24 GHz – 18 GHz
Operating power	5 + 5 kW (max)
Extraction voltage	50 kV (max)
Chamber diameter / length	Ø 130 mm / 500 mm
LHe	Free
Warm bore diameter	140 mm
Source weight	2100 kg

Cost expected: 1.62 M€
(body source, cryogenic equipment for standalone operation, mechanics)



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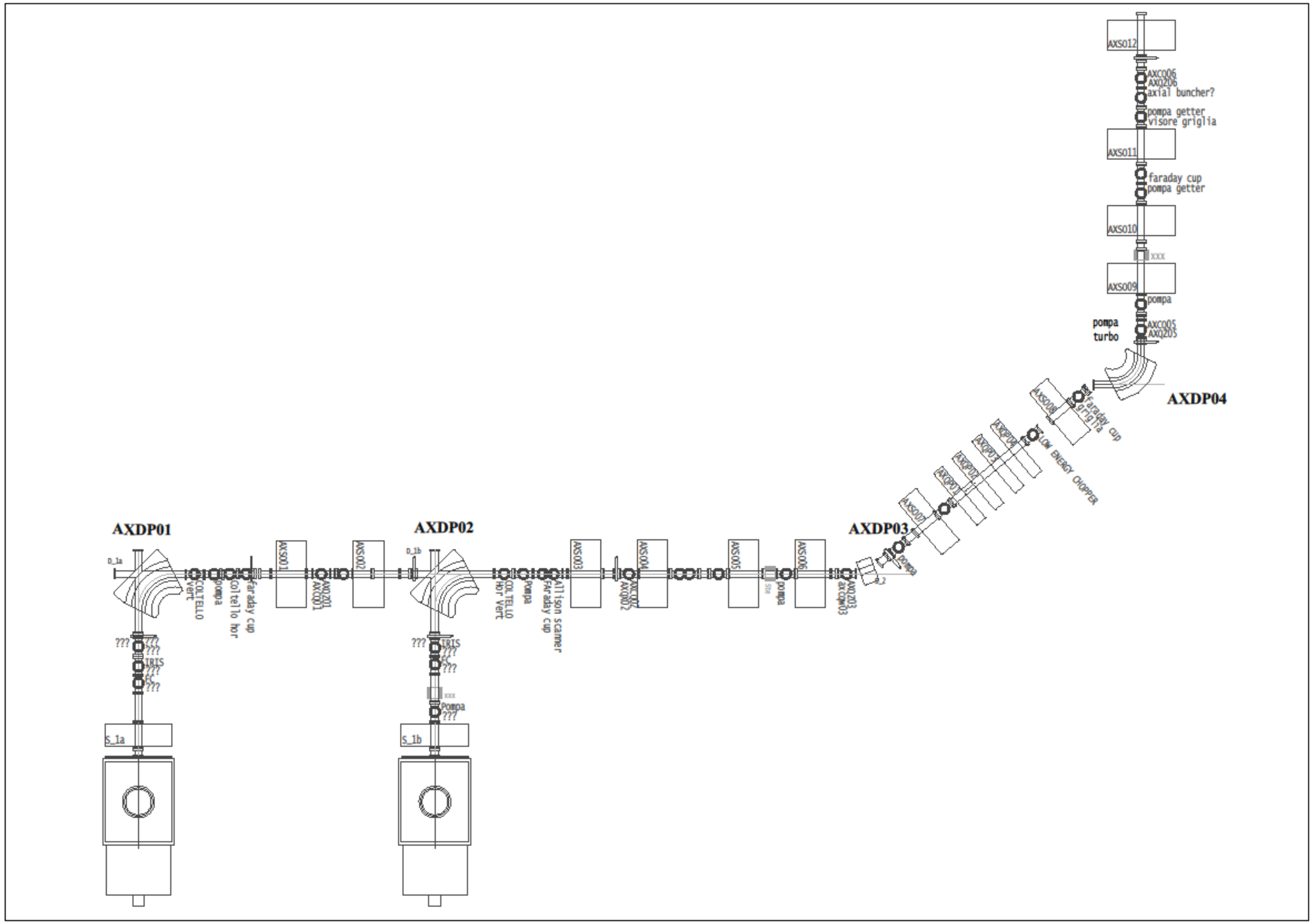
Axial injection beam line



Designed in late 90's to permit selection and transport of low currents of highly charged ions.

Review to adapt it for the transport with a good efficiency of high currents.

Insertion of a Low Energy Chopper as mitigation device for MPS.

Renewal of the two axial bunchers

Modification in beam diagnostics

Refurbishment vacuum sysytem and controls

Cost expected: 655k€

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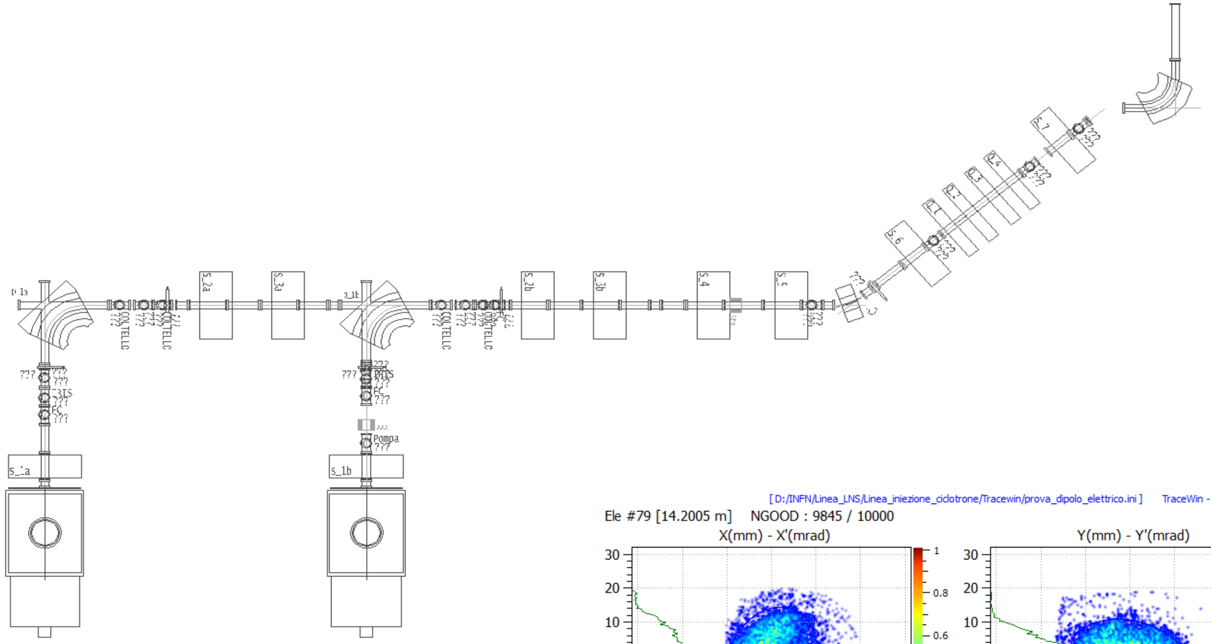
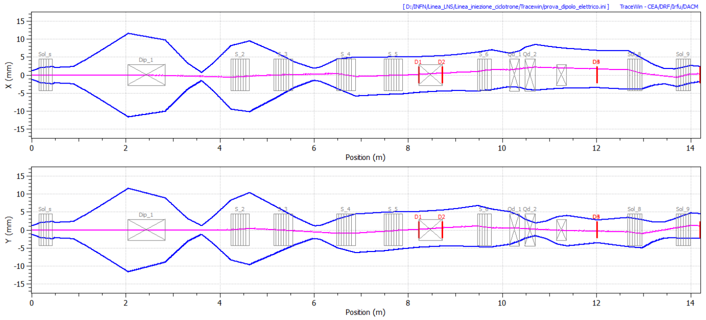
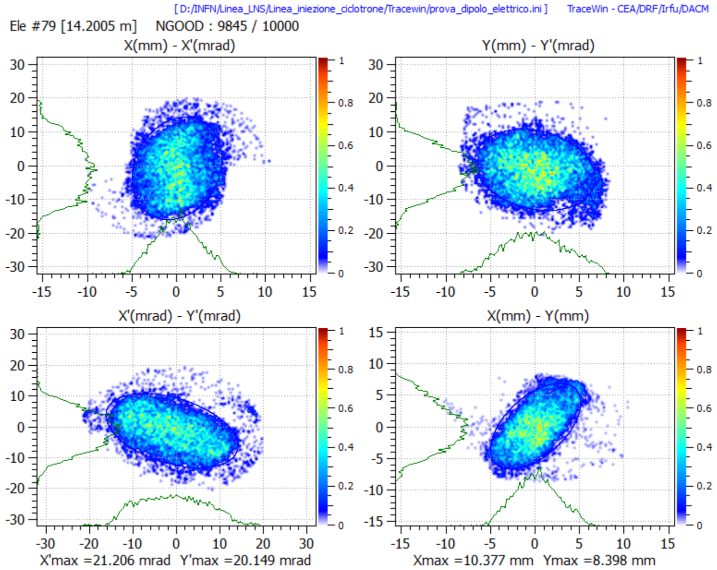
Axial injection beam line



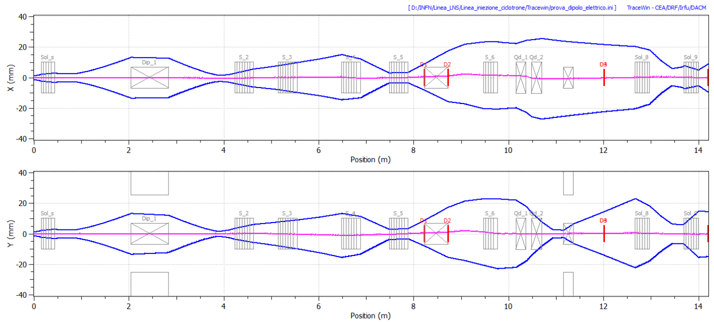
$12C^{4+}$ @ 10 AkeV

I=0 mA

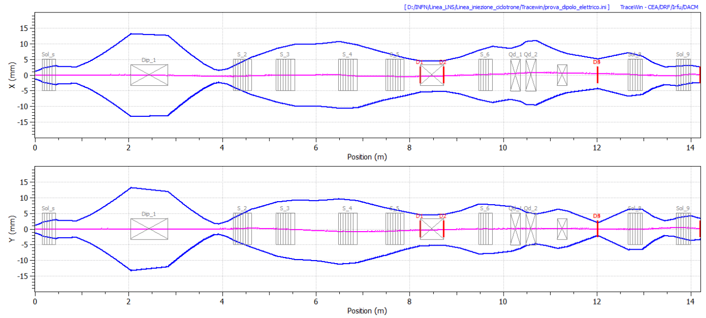




I=0.5emA-Not optimized



optimized



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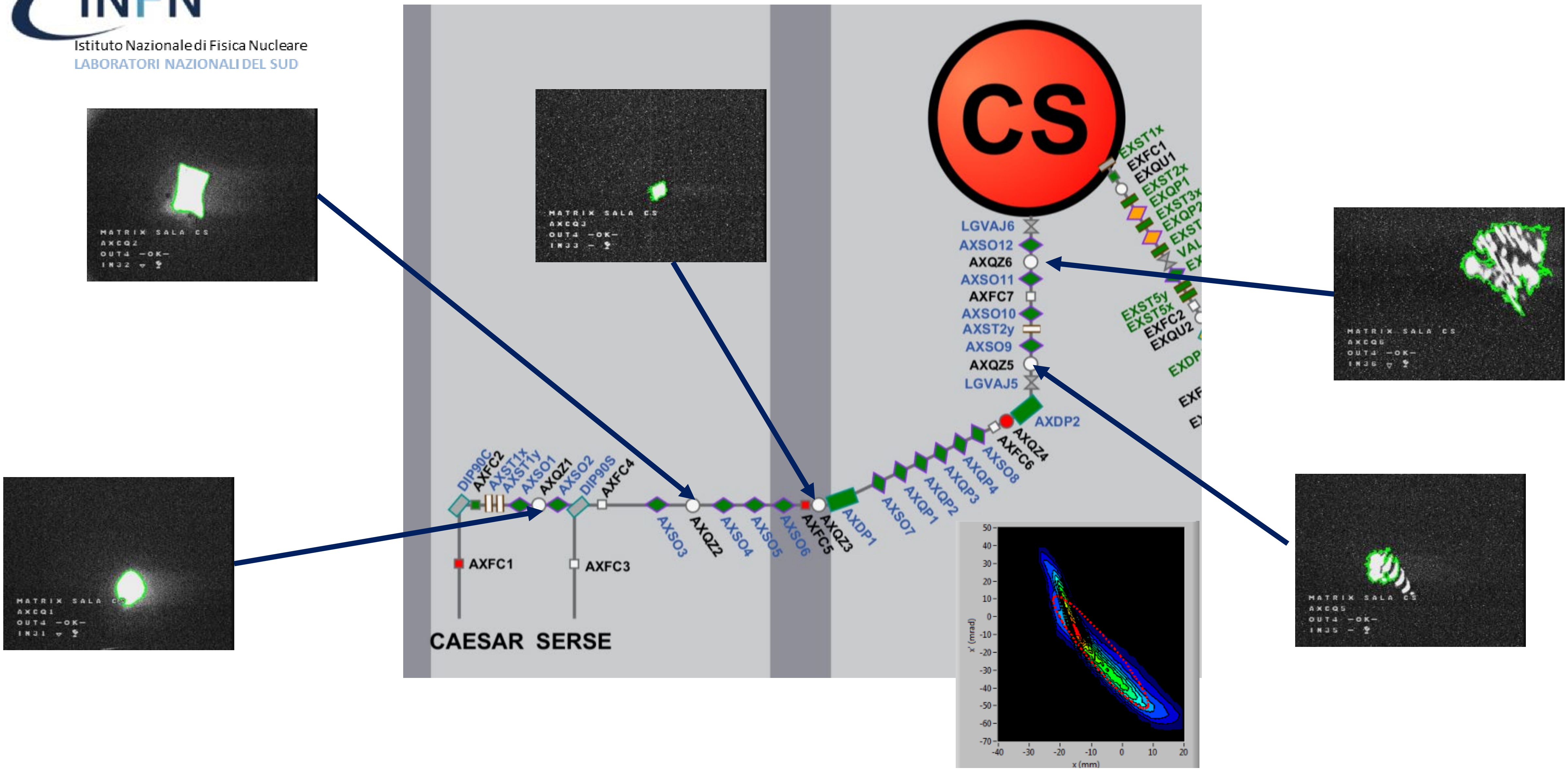
Ion Sources – Cyclotron matching optimization



AISHa: a testbench for INFN-LNS

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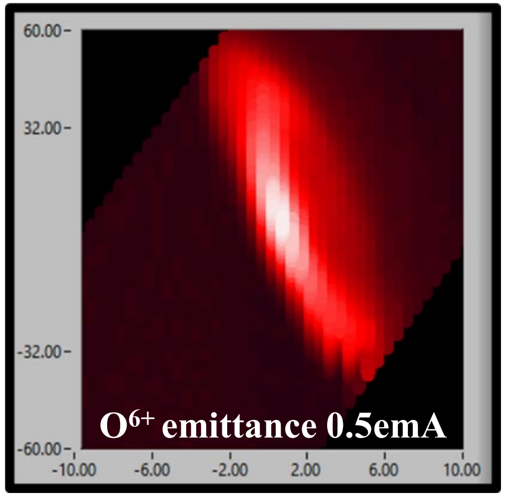
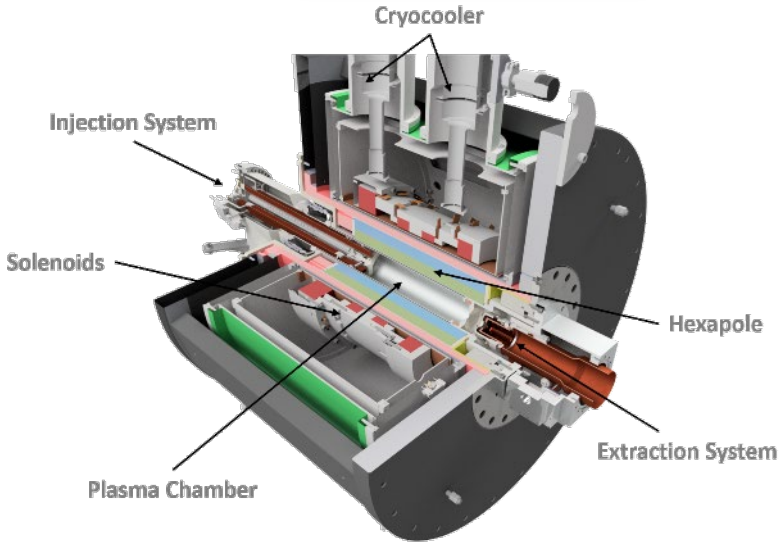
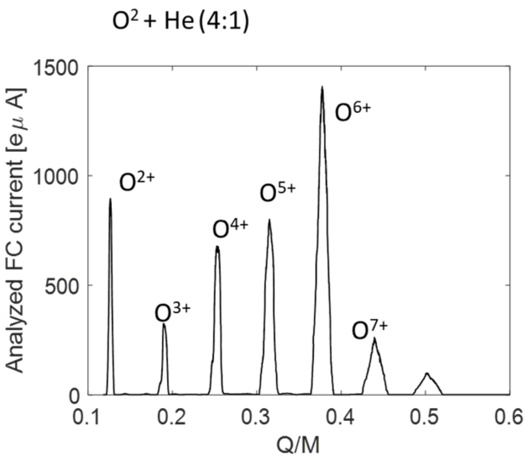
AISHa source has been moved to a new room to permit the civil works of CS upgrading.

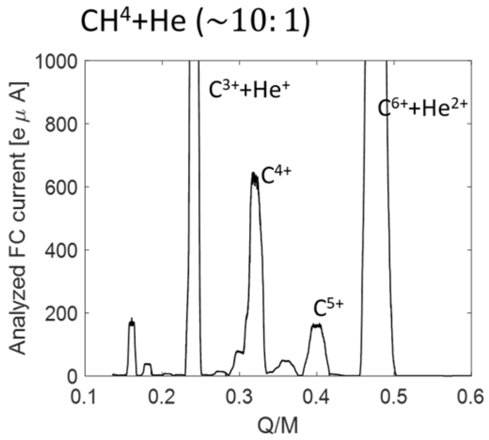
Installation of craine and services needed to operate is expected for June'23 and restart of operation is planned for October'23

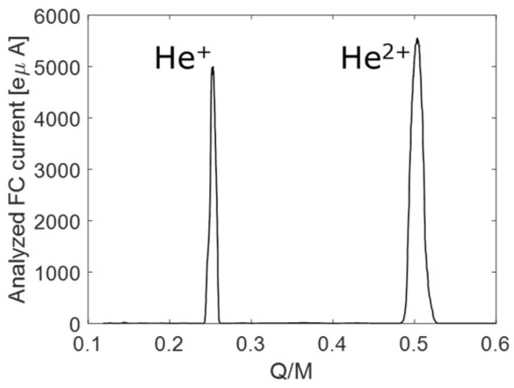




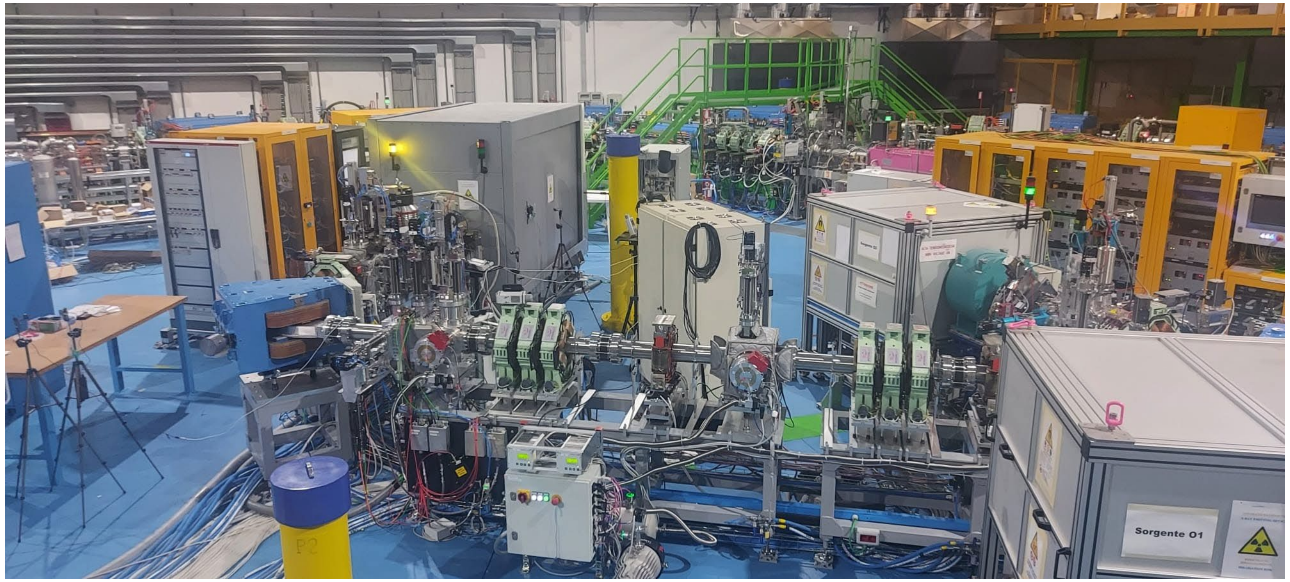
Charge state	Beam intensity [eμA]	$\varepsilon_{rms.norm}$ [$\pi \cdot mm \cdot mrad$]
$^{16}O^{6+}$	1400	0.2198
$^{16}O^{6+}$	225	0.115
$^{16}O^{7+}$	350	0.247
$^{12}C^{4+}$	650	0.272
$^{12}C^{4+}$	150	0.222
$^{12}C^{5+}$	165	---
$^{40}Ar^{11+}$	155	0.201
$^{40}Ar^{12+}$	140	0.201
He^{2+}	5400	0.418
He^{2+}	700	0.245

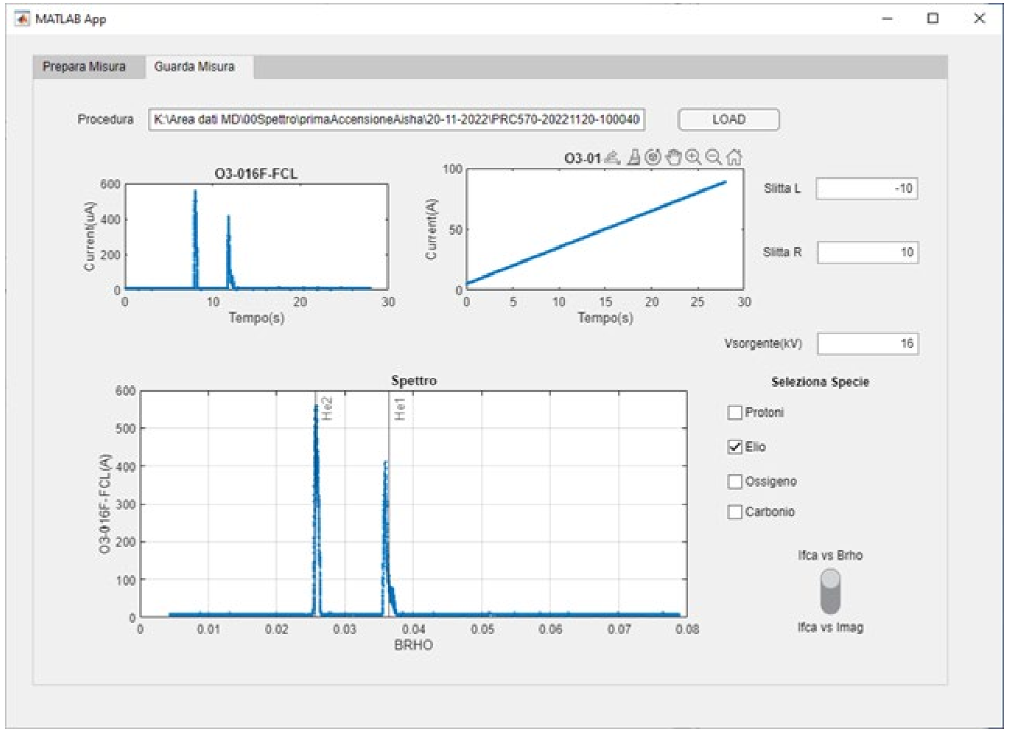






AISHa@CNAO (IRPT, INSPIRIT)





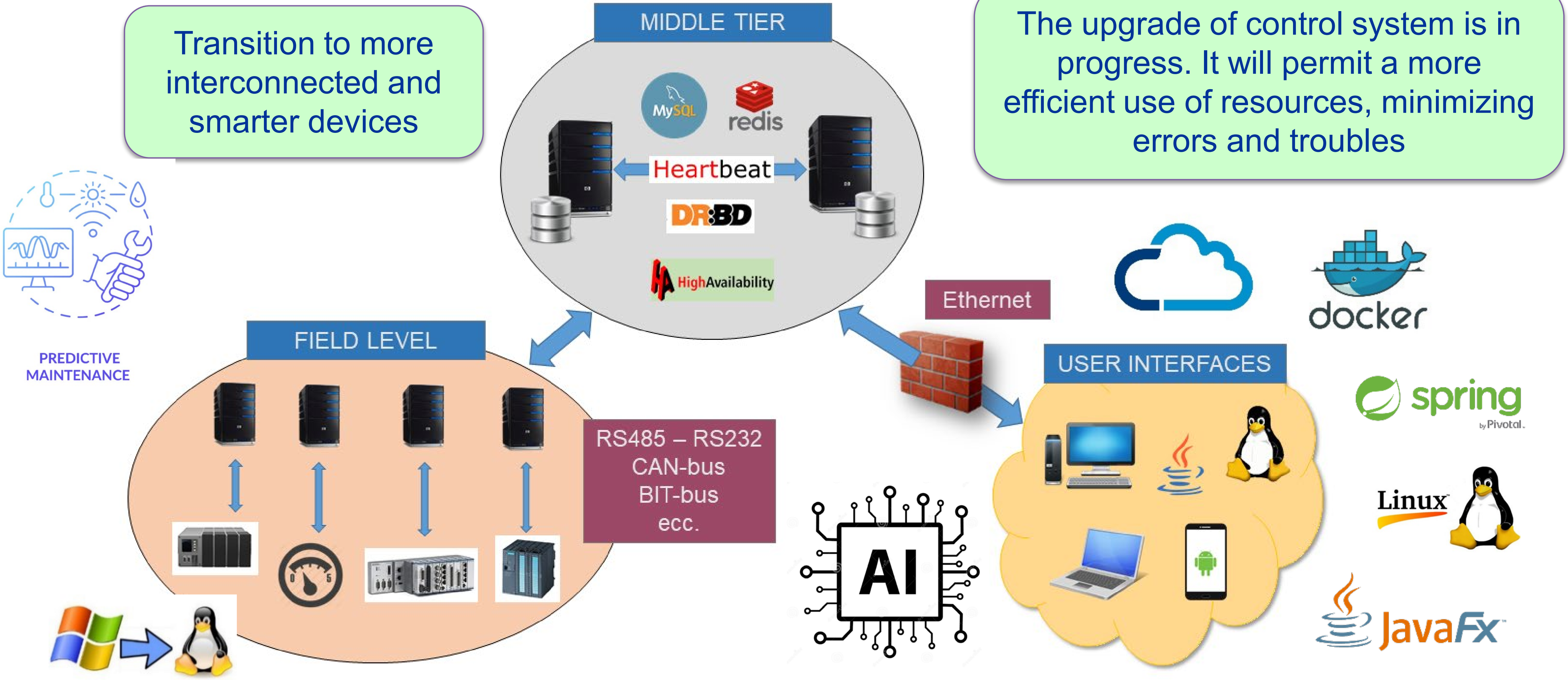
Ion	AISHa Performances [uA]	Requirement CNAO [uA]
C^{4+}	520	110
O^{6+}	1200	64
He^{2+}	5400	344
Li^{3+}	To be developed	230
Fe^{19+}	To be developed	175

First beam produced on 19/11/22 (He@16kV).

The new Control System Architecture

Transition to more interconnected and smarter devices

The upgrade of control system is in progress. It will permit a more efficient use of resources, minimizing errors and troubles



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Conclusion & Perspectives

- *Several infrastructures that have been for years the focus of the LNS Accelerator Division activities (CS, Tandem, Sources) are suffering from their years, a deep maintenance and development activity is in progress to ensure their use for a time frame comparable to that passed.*

- *Extraordinary maintenance activities are planned for the Tandem and a new control system will be realized, to be integrated in the accelerator management platform. The restart of Tandem operation is expected for end of 2023.*

- *The upgrade of the superconducting source SERSE is a key factor for the production of the beam intensities required by the Cyclotron. The CAESAR source is not able to produce these intensities and taking into account that both sources were conceived in the mid-90s it is important to start the study of a 3rd Generation source to replace them.*

- *The cyclotron upgrading works represents the core of the LNS Accelerator Division activities since most of the CS ancillary equipment will be upgraded (more details in M. Musumeci talk).*