A PROPOSAL TO STUDY RADIATION HARDNESS OF CRITICAL MATERIALS IN THE SPES FRONT-END TARGET ION SOURCE (TIS) AT LNL

EXTENSION OF THE ACTIVITIES OF SPES_PV – INFN PV IN COLLABORATION WITH L.E.N.A. - UNIPV AND LABORATORIO DI SCIENZA E TECNOLOGIA DEI MATERIALI - UNIBS

Aldo Zenoni – CdS INFN PV 15-07-2014

SPES: the 'hope' of the laboratory

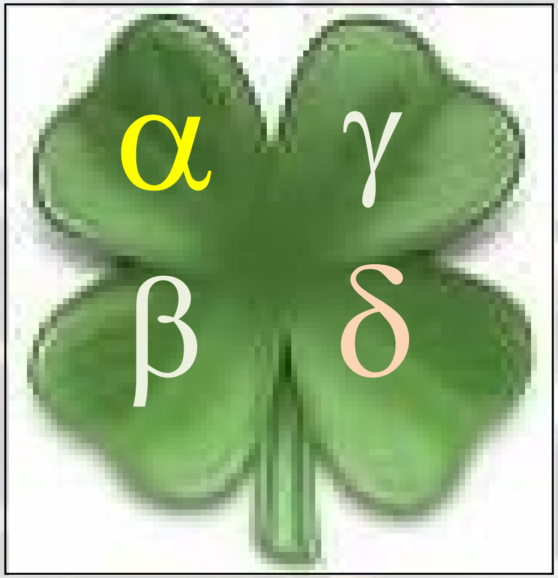
exotic beams for science

Goal: to expand into the future the nuclear physics at LNL

SPES is: 1) A second generation ISOL facility (for neutron-rich ion beams)
2) An interdisciplinary research center (for p,n applications)

Building + Cyclotron & ISOL target

The SPES staging



Radionuclides production

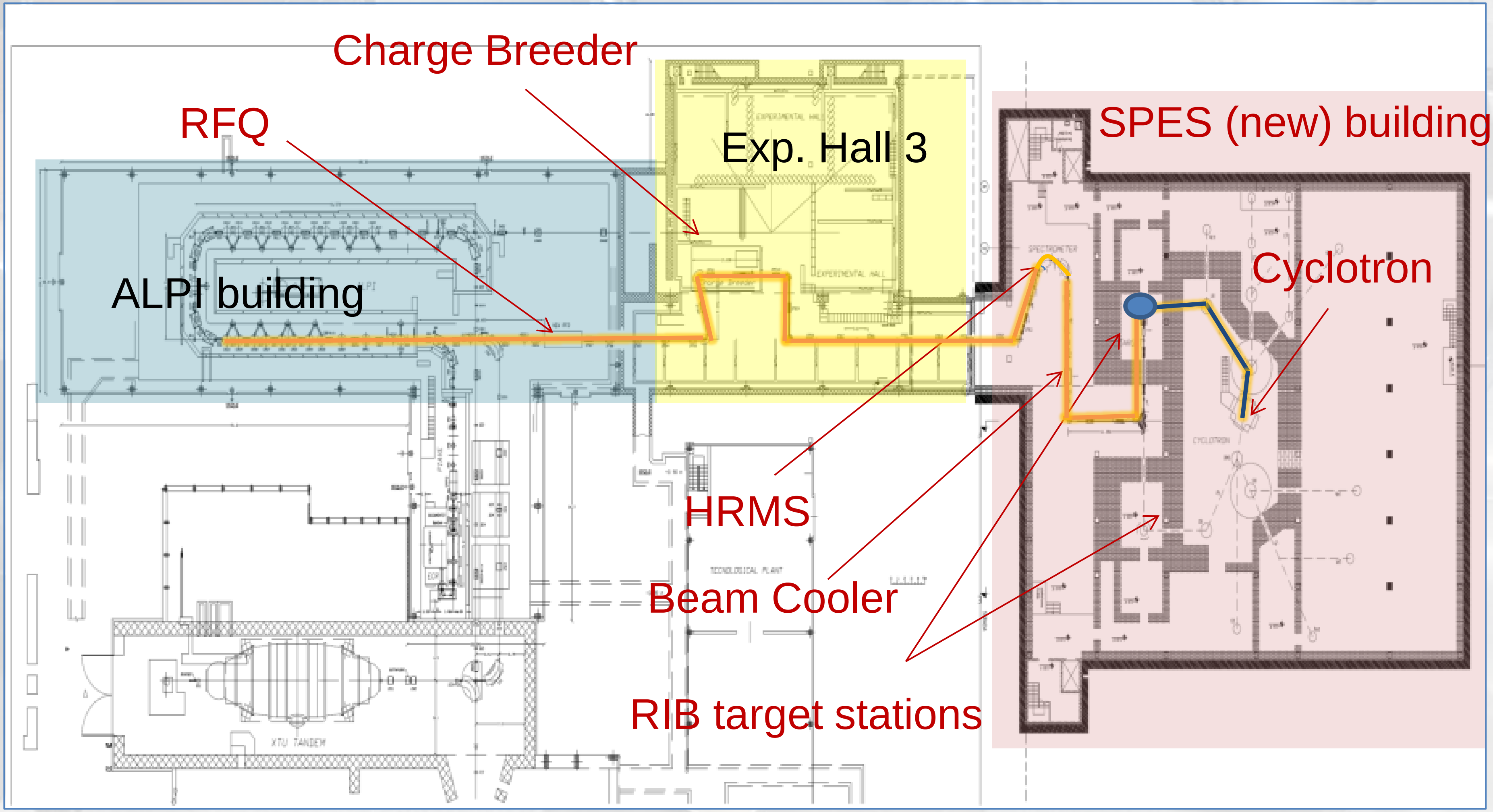
N rich RIBs production & reacceleration

PCyclo & Ncyclo

Protons & neutrons from cyclotron

SPES project status:

Building design & study of beam transport to ALPI are completed

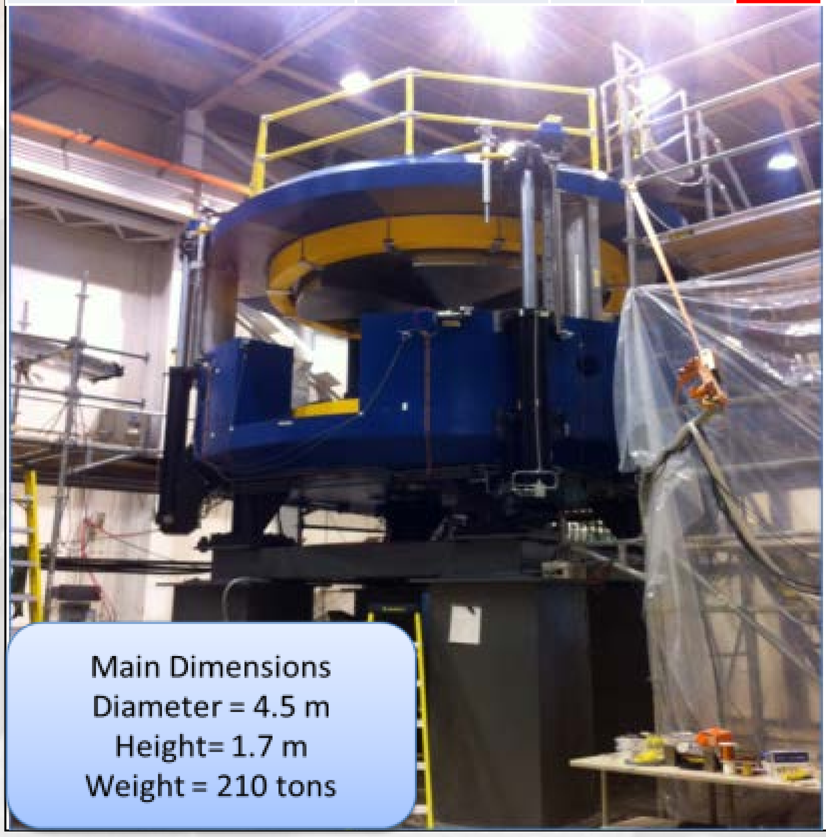



INFN
SPES
09/07/2014
13:00

SPES Cyclotron

SPES exotic beams for science

	2013		2014		
	II	III	I	II	III
Final Assembly and Testing	■				
Factory Commissioning		■			
Disassembly and Shipping			■		
Installation at LNL				■	
Commissioning at LNL					■

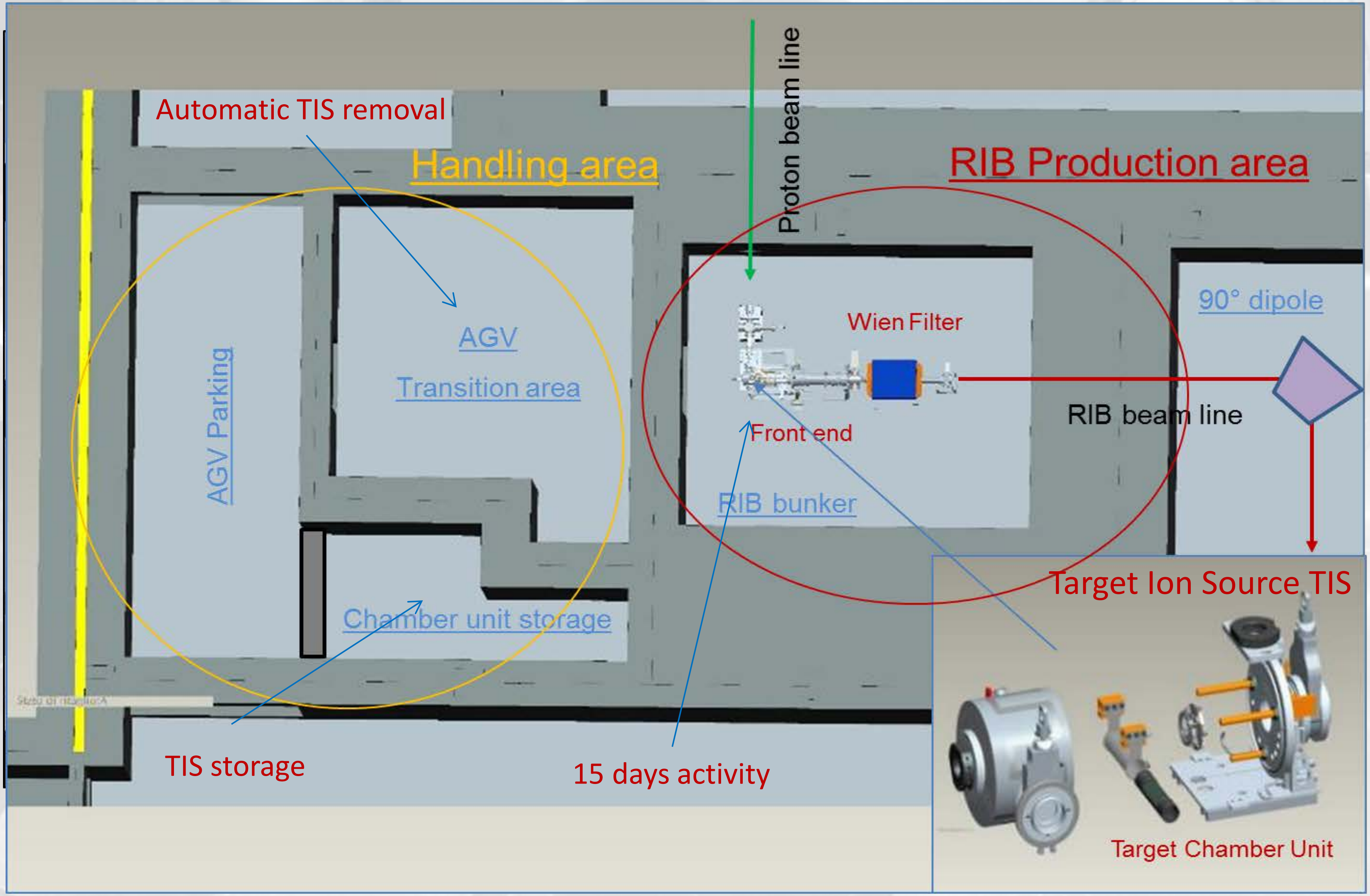


Main Dimensions
Diameter = 4.5 m
Height= 1.7 m
Weight = 210 tons

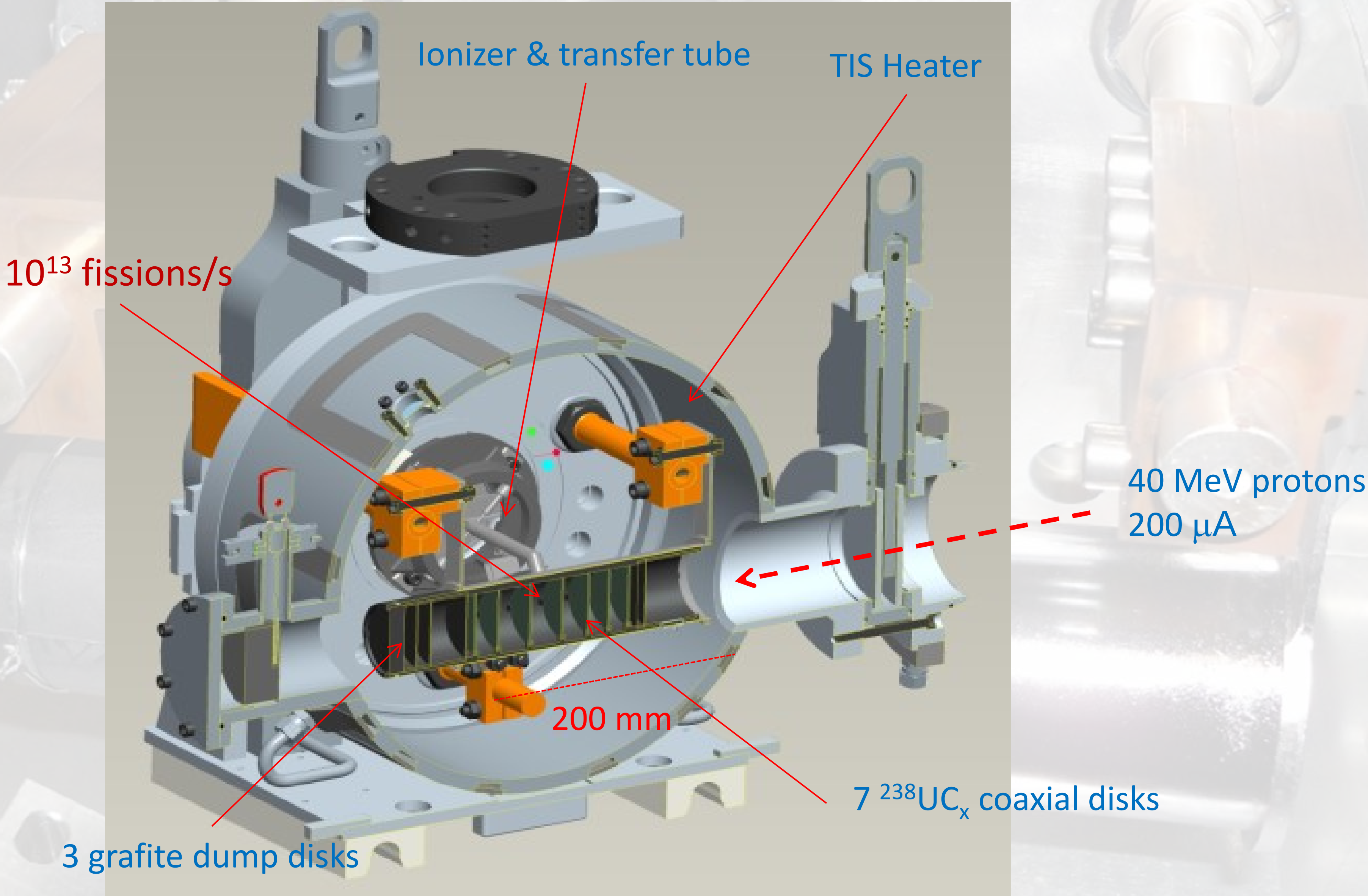
Best Theratronics

Accelerated Particle	H-
Extracted Particle	Protons
Energy	35-70 MeV (variable)
Current	> 700 uA (variable)
Extraction System	By stripping → simultaneous dual beam extraction
Injection System	Axial Injection → External Multicusp Ion Source 15-20mA DC
Main Magnet	B_{max} = 1,6 T Coil current = 127 kAt Power supply = 30 kW 4 sectors, deep valley
RF System	2 resonators Frequency= 58 MHz Harmonic mode=4 Dissipated Power=15 kW per cavity DEE voltage=60-80 kV
Operational Vacuum	2 e -7 mbar

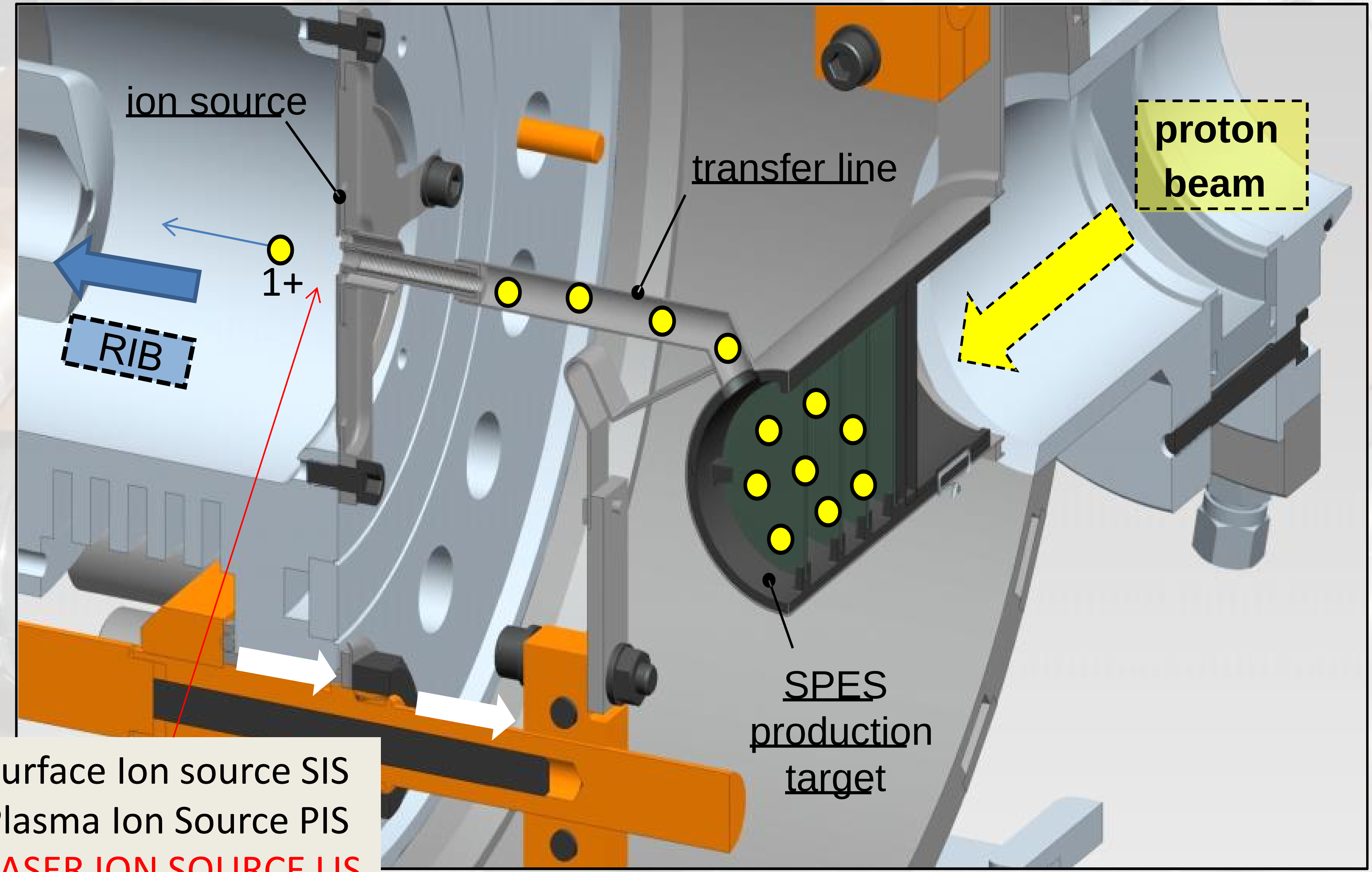
The RIB production area



Target & Ion Source complex (TIS)

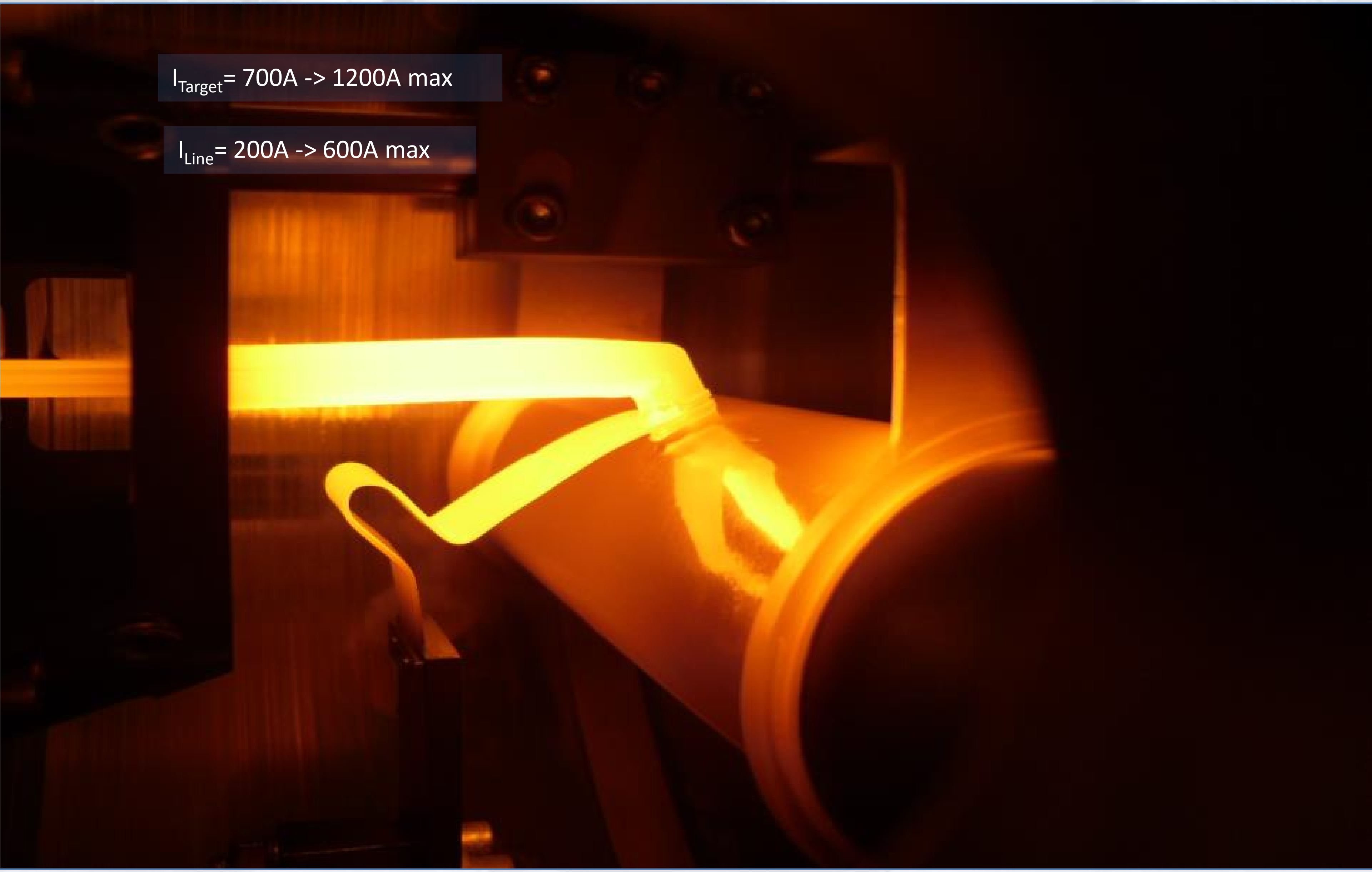


Target & Ion Source complex (TIS)



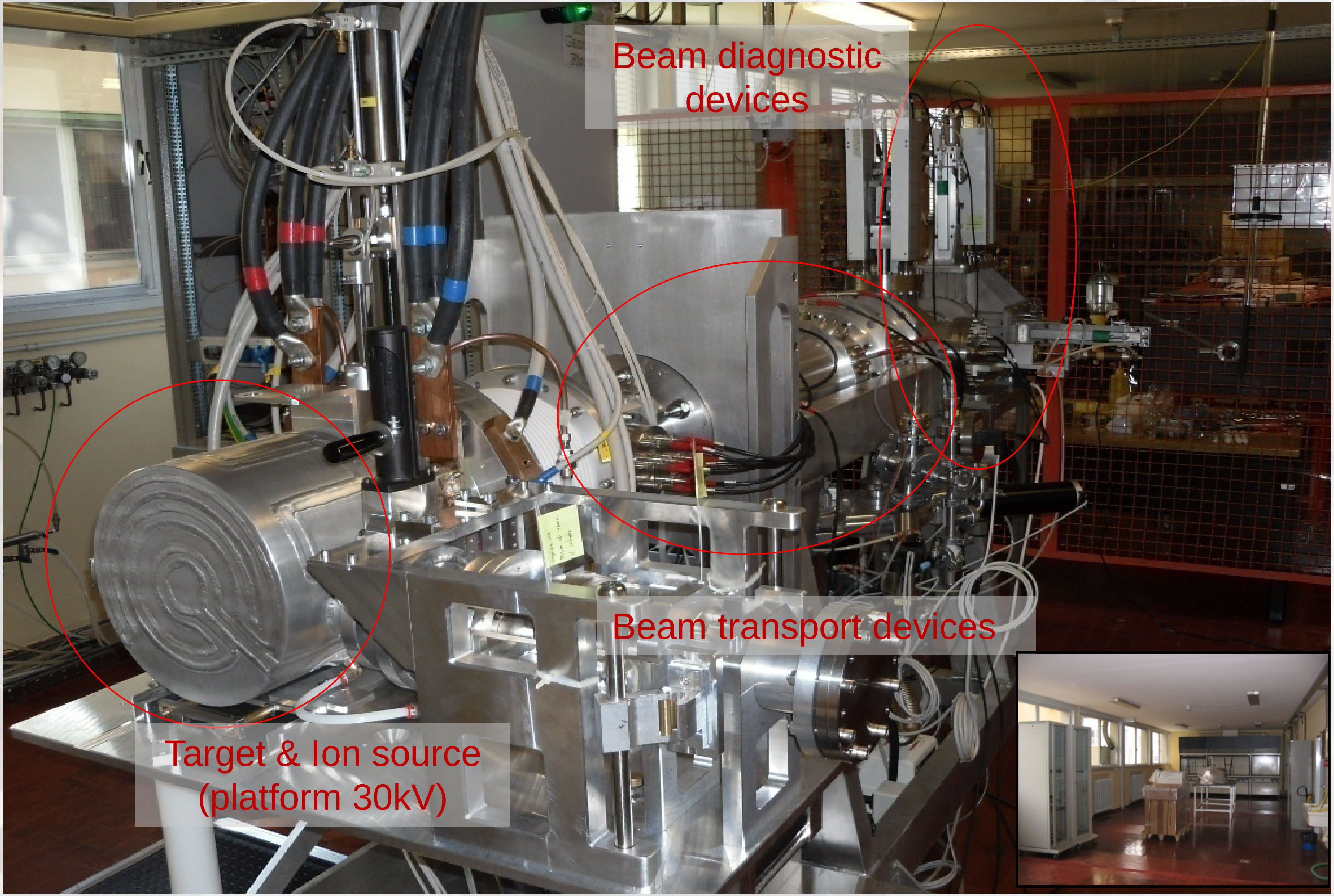
Surface Ion source SIS
Plasma Ion Source PIS
LASER ION SOURCE LIS

Target & Ion Source complex (TIS)

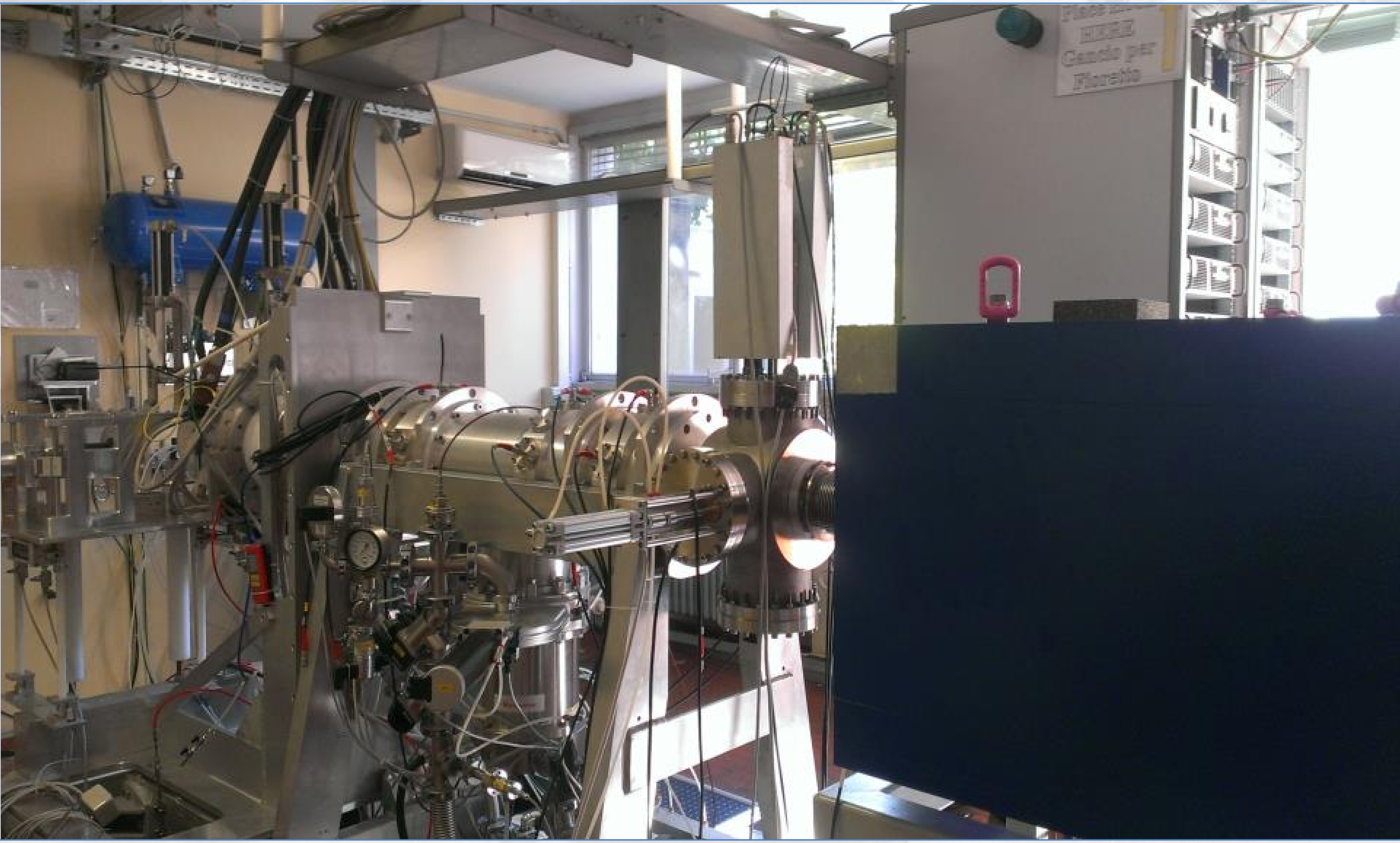


The SPES off-line Front end

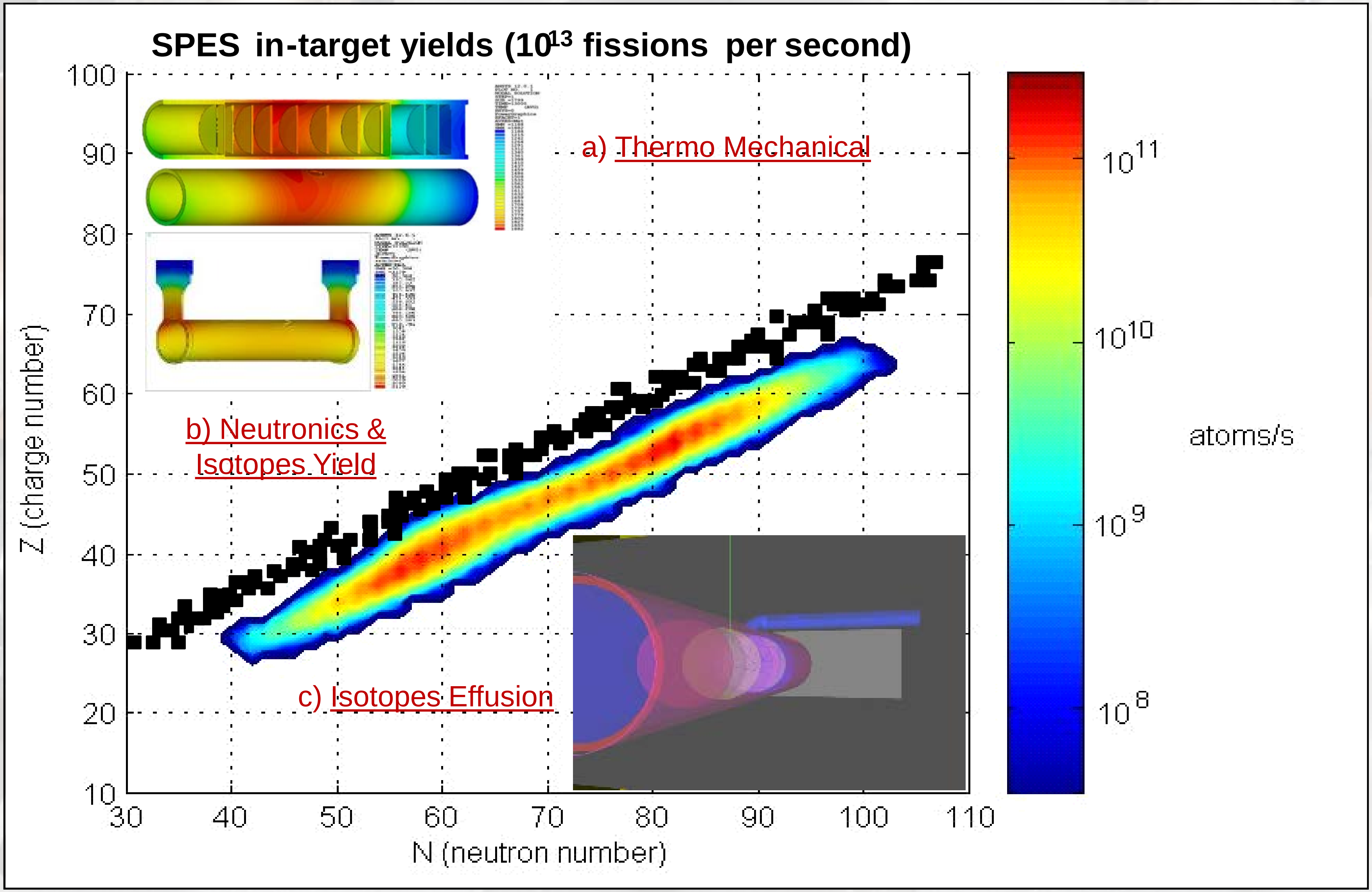
(working since 2010 - evolution of ISOLDE FE6)



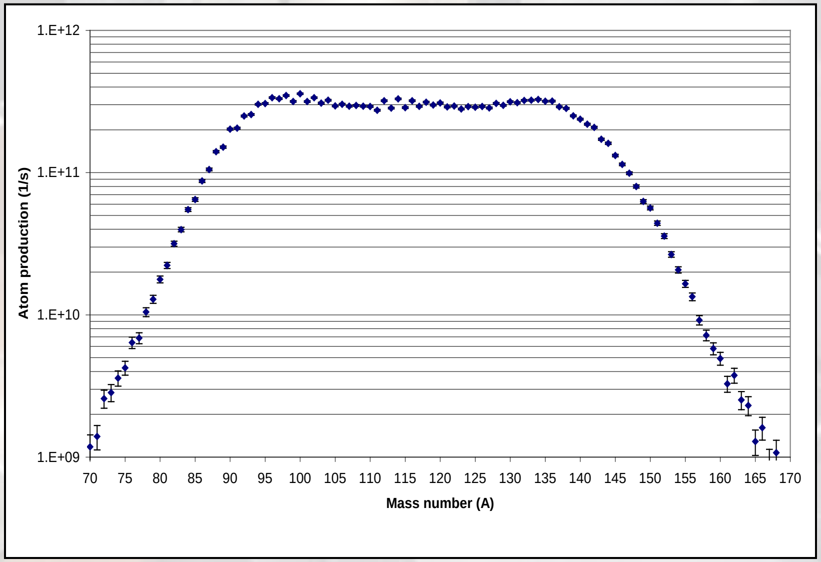
Ionization & transport measurements

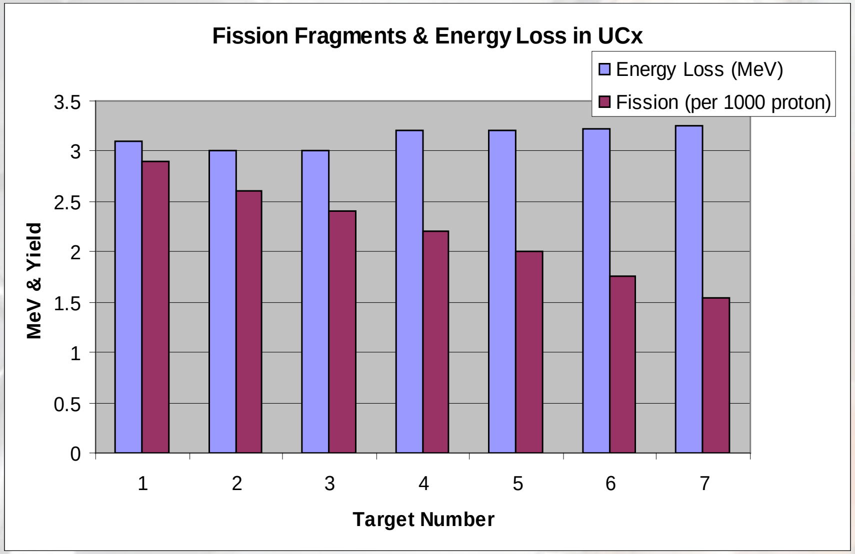


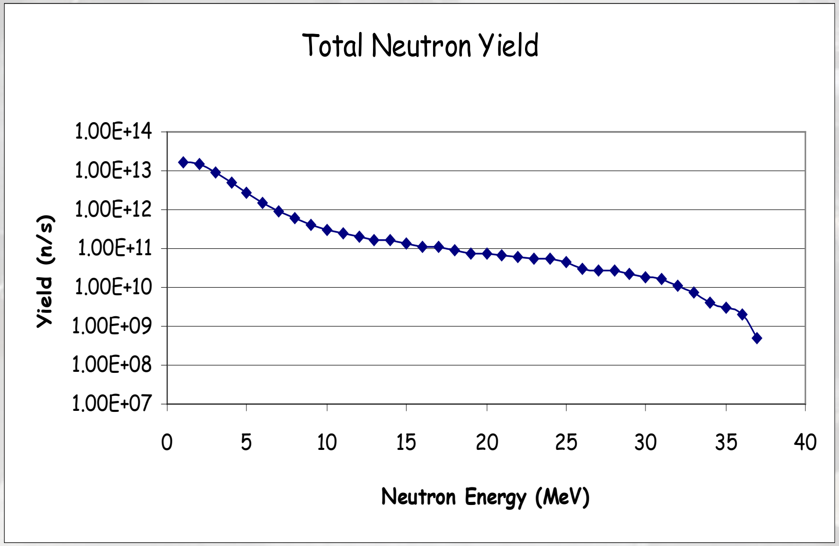
The TIS simulations

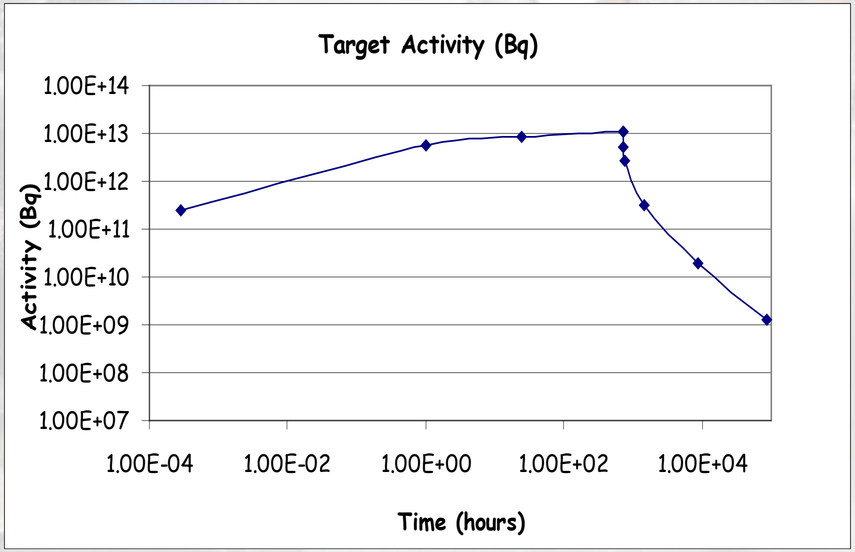


The TIS simulations (MCNPX)

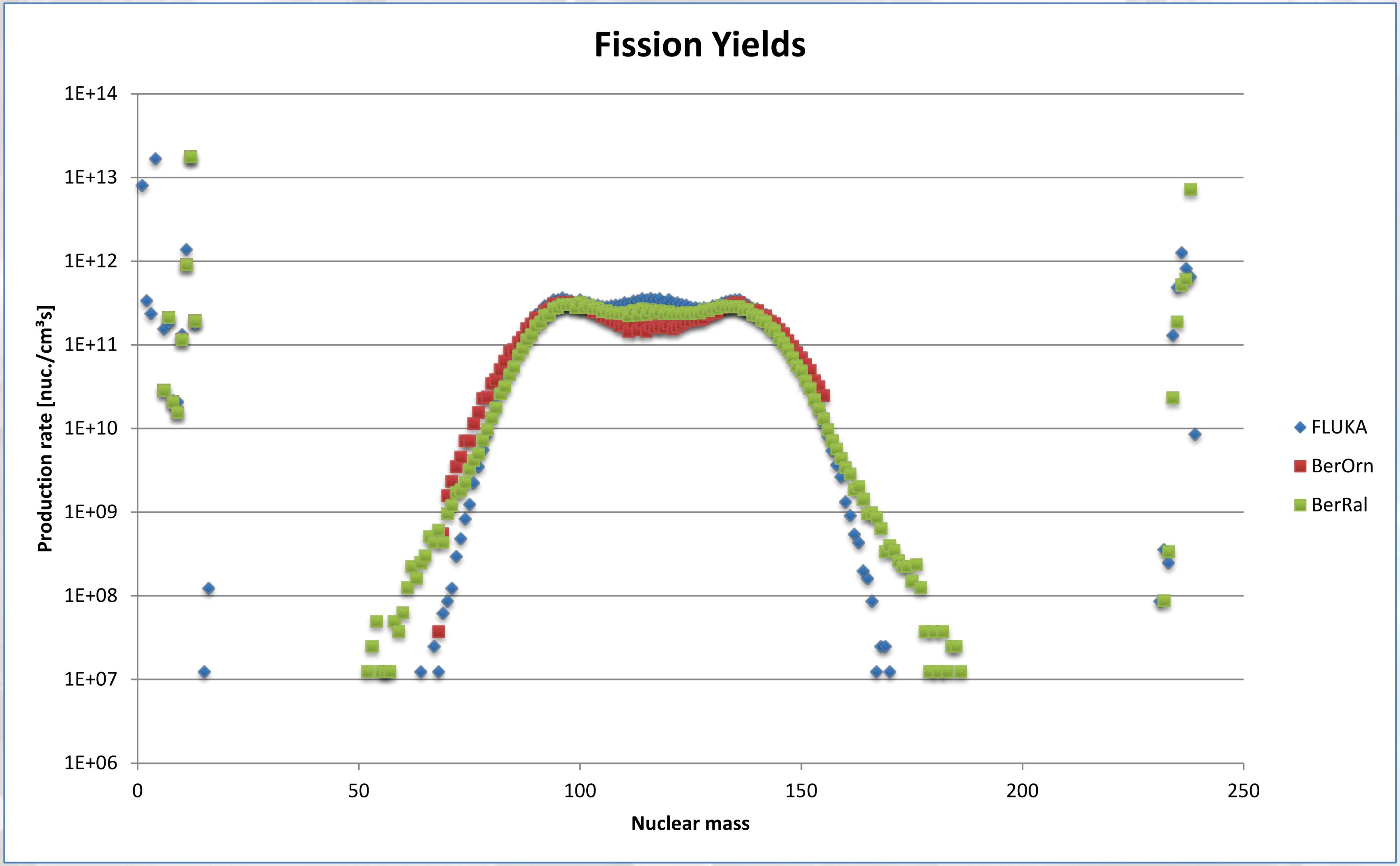








FLUKA versus MCNPX



A recent Rad-hard study in the SPES bunker

SPES Front-End: Technical Report
Neutron and gamma damage study of critical SPES Front-End components

Raúl Vivanco*

May 8, 2014

DRAFT

Author	Reviewed	Approved
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ESS bilbao

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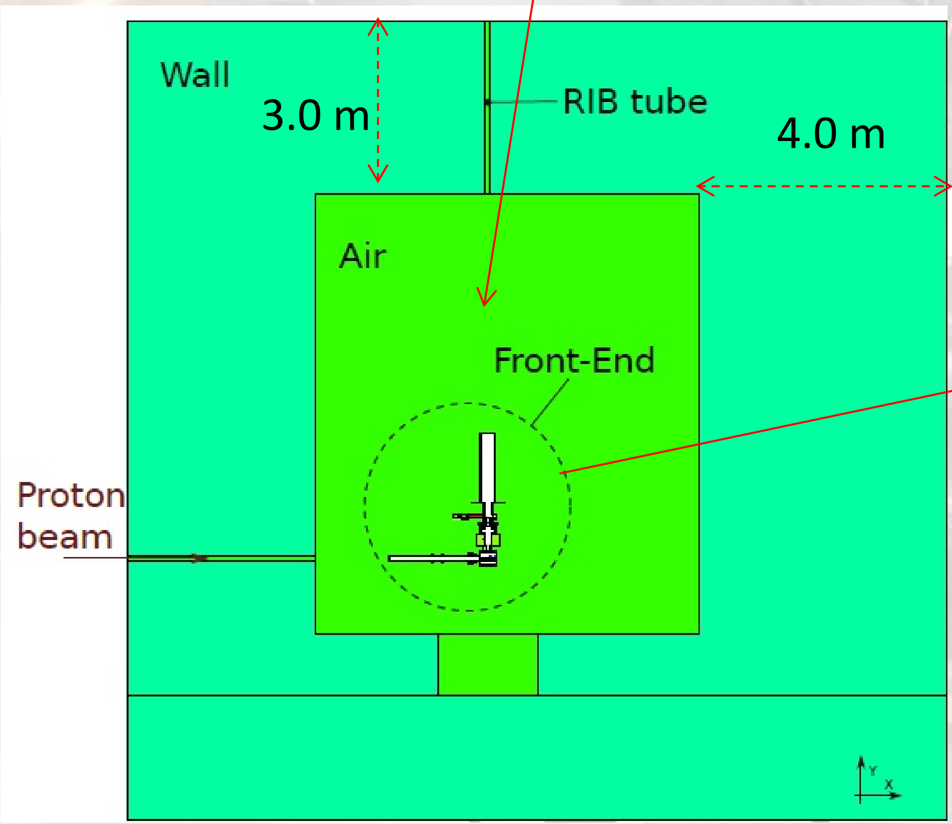
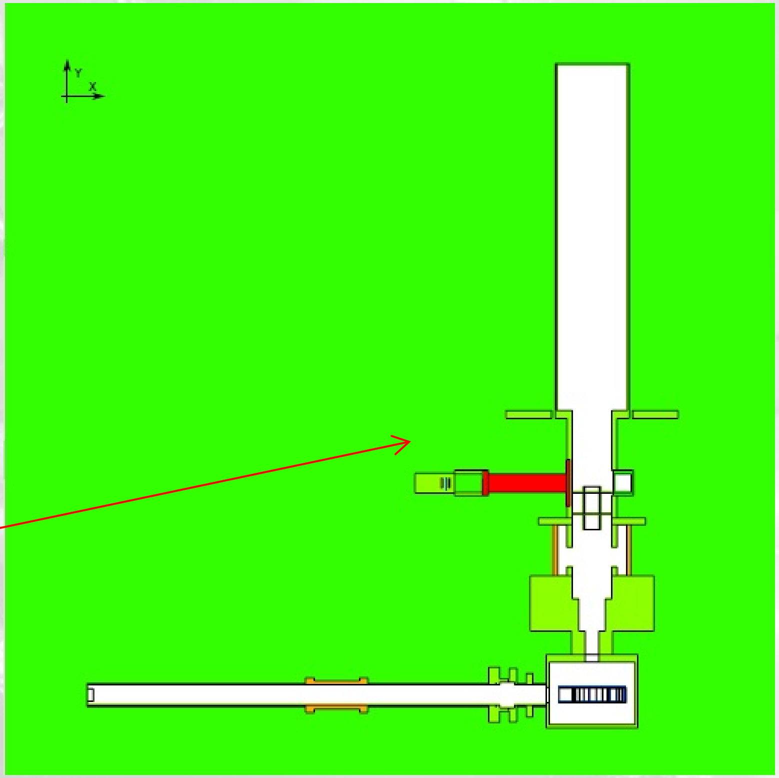
Pro/E CAD model of the SPES Front-End in MCNPX

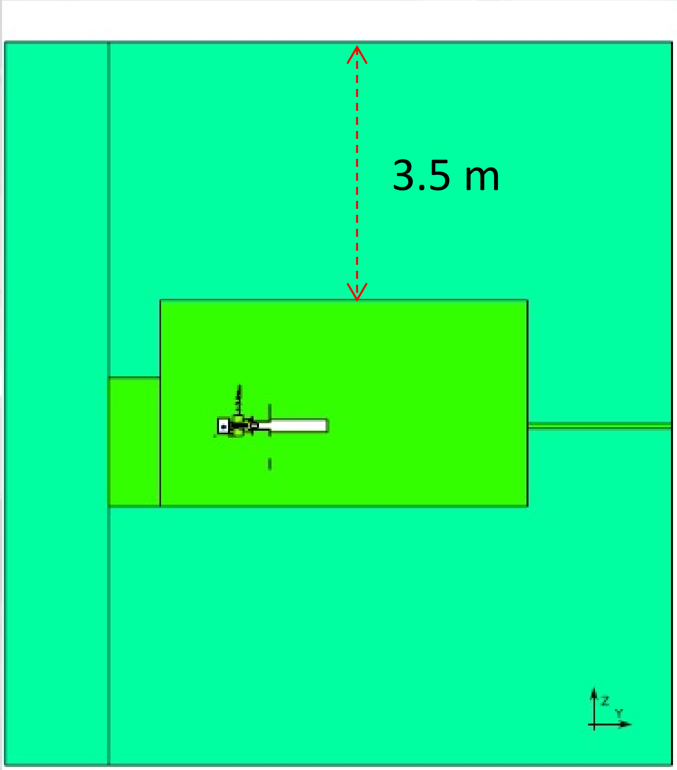
Front-End room

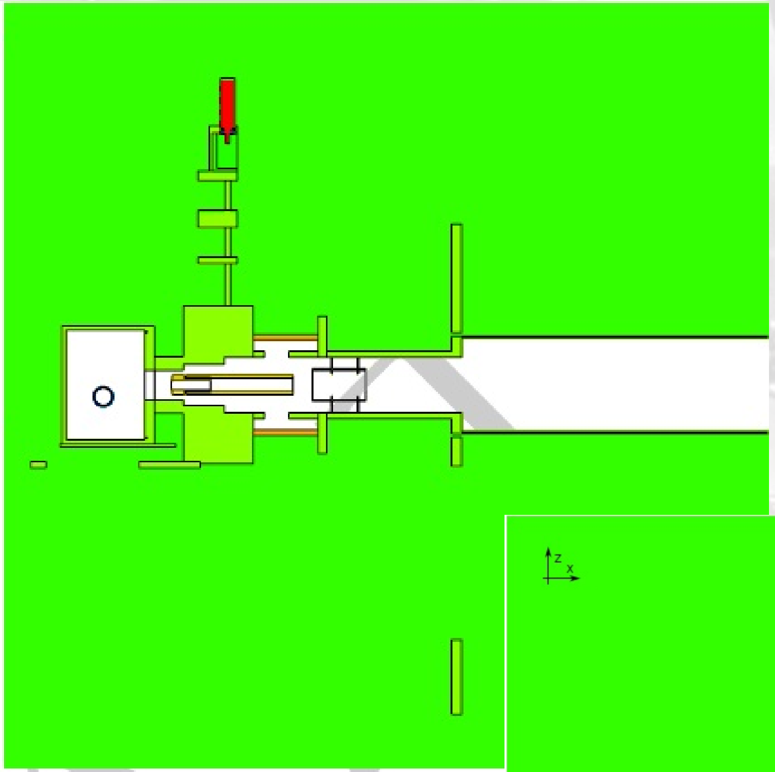


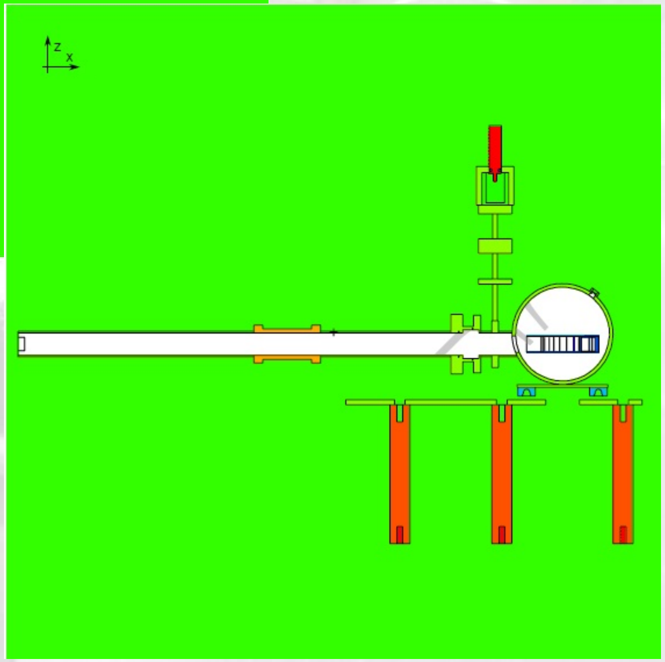


Top cross section view

Front-End room

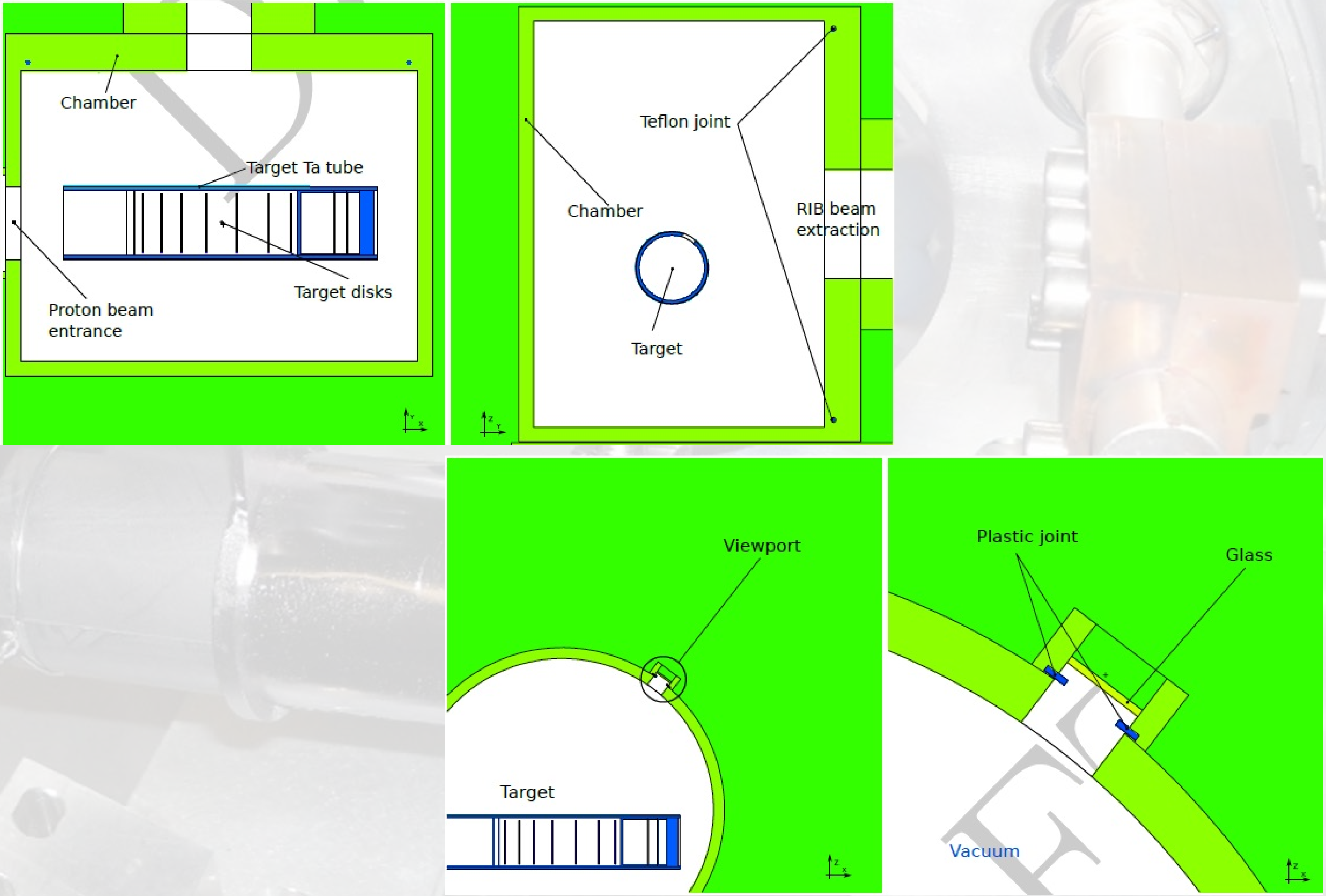




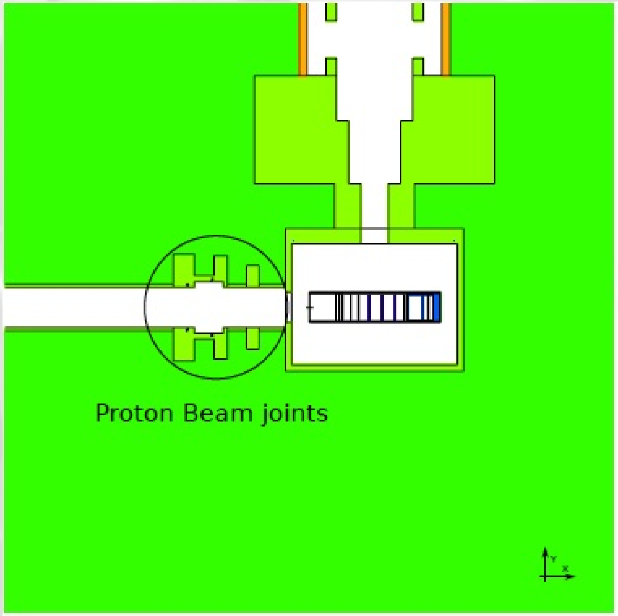


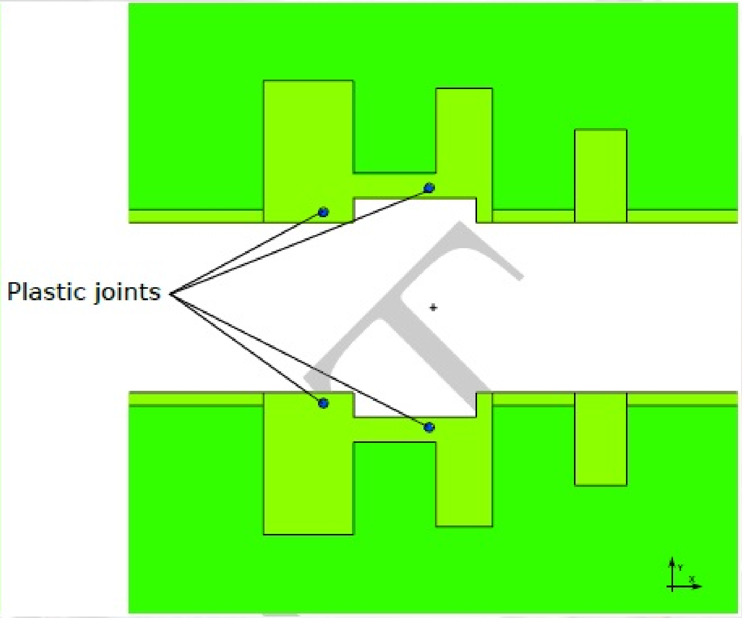
Side cross section view

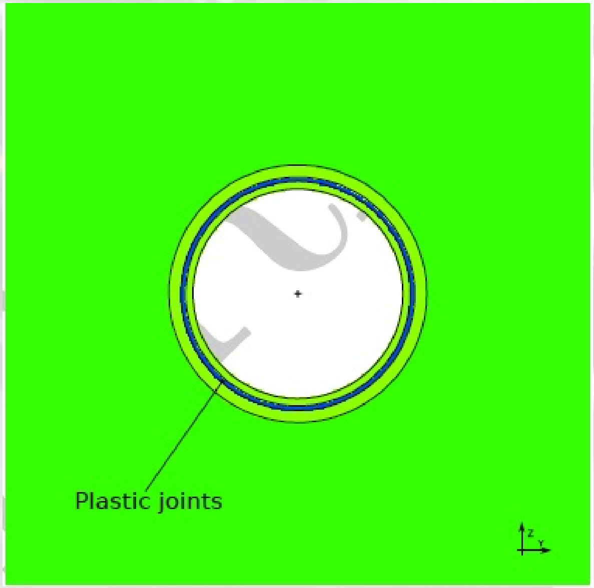
Target and Chamber



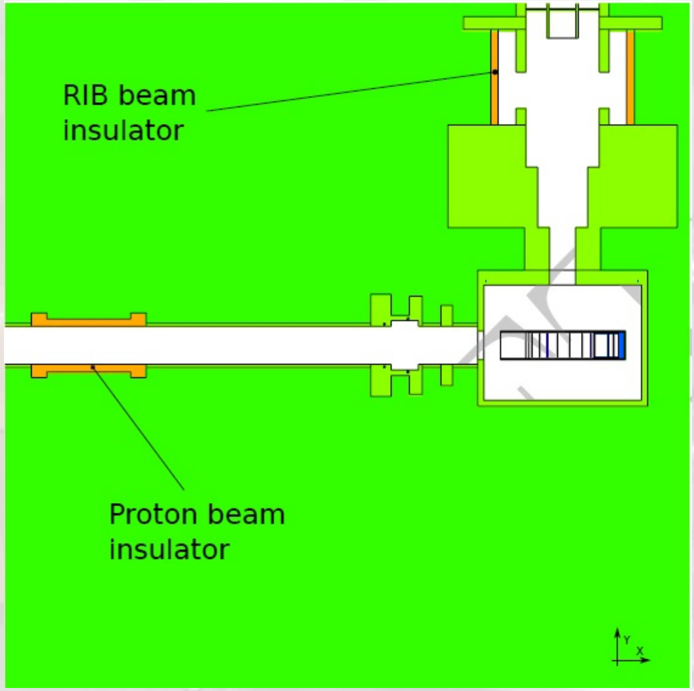
Plastic joints

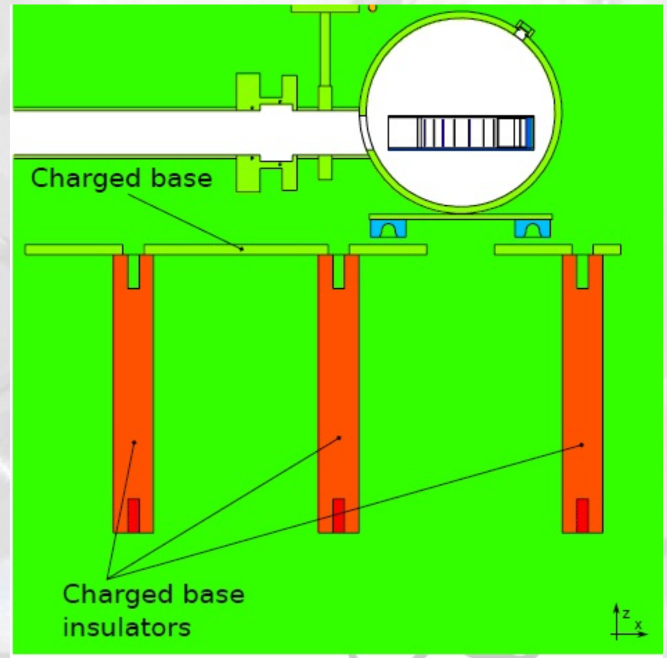


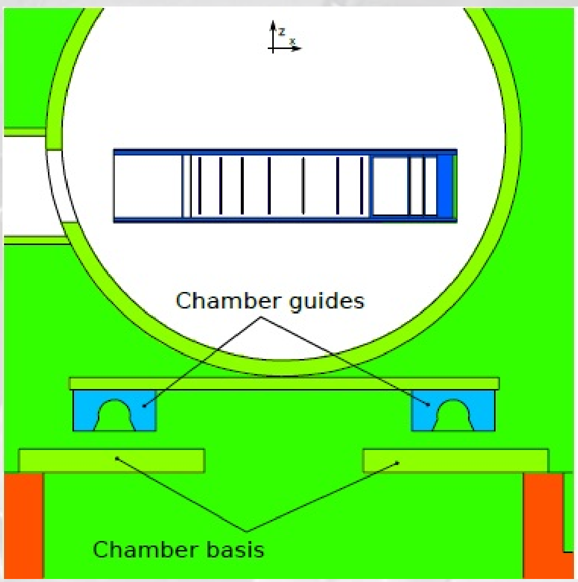


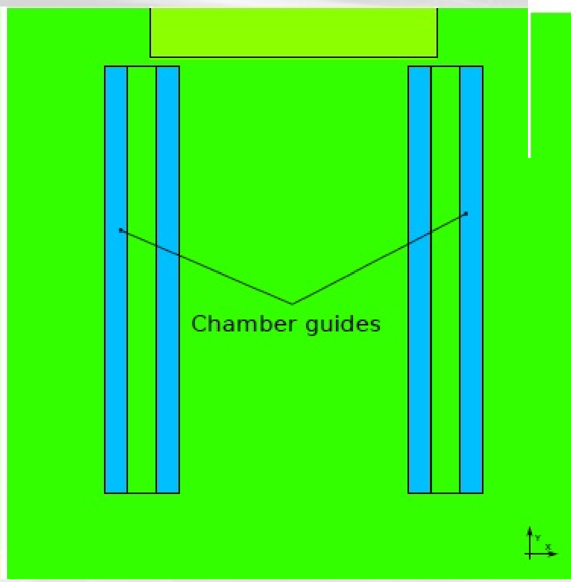


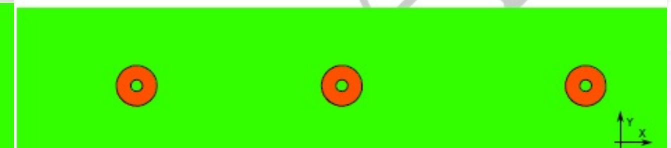
Insulators and chamber guides











TIS critical components modeled

Component	materials
Chamber structure	Aluminum AL6082T6
Chamber joints	TEFLON, EPDM
Viewport glass and joints	Silicon oxide based glass, VITON, EPDM
Insulators	Ceramic Alumina Al_2O_3
Proton beam joints	EPOXY, VITON, EPDM
Chamber handling guides	TEFLON, TPE-SBR
Charged base insulators	PEEK
Pneumatic motors	(lack of information) virtual O-ring in EPDM
Electrical motors	(lack of information) joints in EPDM, insulators EPON-862, Lubrificant BiEster $C_6O_1H_{12}$
AC power wire jackets	Thermoplastic TPE-SBR
RIB wires	Thermoplastic TPE-SBR
Wire collector	Thermoplastic TPE-SBR
Optical fiber core	PMMA, Glass Epoxy 1 A2 and 1 B2
Optical fiber cladding	FEP (Fluorinate Ethylene Propylene)

Results of the Rad-hard TIS simulation - I

TEFLON and VITON cannot be used

15 days operation are foreseen

Component	Material	Dose absorbed [Gy/s]	Error [%]	Dose Limit [Gy]	Maximum op. days [d]
Viewport glass	Glass (SiO_2)	4.57E+00	7.91	1.00E+07	25.3
Viewport joint	TEFLON	3.53E+00	9.08	1.00E+05	0.33
Chamber O-Ring	Viton	2.12E-01	0.9	1.00E+04	0.55
Chamber Guide (left)	TEFLON	8.73E-02	0.28	1.00E+05	13.3
Chamber Guide (right)	TEFLON	8.89E-02	0.31	1.00E+05	13.0
RIB tube Insulator	ALUMINA	4.33E-03	0.61	1.00E+07	26738.3
Proton tube Insulator	ALUMINA	2.46E-03	1.91	1.00E+07	47083.3
1st Proton tube O-Ring	VITON	7.30E-02	2.68	1.00E+04	1.59
2nd Proton tube O-Ring	EPOXY	2.12E-01	2.68	$<$ 1.00E+07	$<$ 546.3
1st Chamber base insulator	PEEK	4.76E-02	0.57	2.00E+07	4866.5
2nd Chamber base insulator	PEEK	4.28E-02	0.54	2.00E+07	5409.3
3rd Chamber base insulator	PEEK	2.06E-02	0.69	2.00E+07	11263.4

Radiation damage rate
From MCNPX

Rad.resistance dose limit
From existing literature

Max operating days
before failure

Results of the Rad-hard TIS simulation - II

Component	Material	Dose absorbed [Gy/s]	Error [%]	Dose Limit [Gy]	Maximum op. days [d]
Viewport joint	EPDM	2.49E+00	9.08	3.00E+07	139.7
Chamber O-Ring	EPDM	1.03E+00	1.02	3.00E+07	335.8
Chamber Guide (left)	TPE-SBR	2.44E-01	0.38	3.00E+06	142.4
Chamber Guide (right)	TPE-SBR	2.48E-01	0.41	3.00E+06	139.9
1st Proton tube O-Ring	EPDM	3.47E-01	3.01	3.00E+07	1001.3
2nd Proton tube O-Ring	EPDM	3.10E-01	2.79	3.00E+07	1120.6
1st Chamber base insulator	PEEK	4.68E-02	0.64	2.00E+07	4945.6
2nd Chamber base insulator	PEEK	4.19E-02	0.60	2.00E+07	5520.1
3rd Chamber base insulator	PEEK	2.04E-02	0.77	2.00E+07	11319.5
Electric Motor O-Ring	EPDM	1.67E-02	6.94	3.00E+07	20757.4
Electric Motor Insulator	DGEBF + CE	9.81E-03	5.77	2.00E+06	2360.3
Electric Motor Lubricant	BiEster	1.70E-02	4.41	2.00E+06	1363.0
Pneumatic Motor (1) O-Ring	EPDM	1.92E-02	9.68	3.00E+07	18050.7
Pneumatic Motor (2) O-Ring	EPDM	2.92E-02	7.68	3.00E+07	11875.2
Optical Fibber Jacket	FEP	7.59E-02	8.17	?	-
Optical Fibber Core (1st Option)	PMMA	3.50E-01	1.51	?	-
Optical Fibber Core (2nd Option)	Epoxy 1A2	1.54E-01	0.88	1.00E+08	7531.2
Optical Fibber Core (3rd Option)	Epoxy 1B2	1.54E-01	0.91	1.00E+08	7529.3
Wire Jacket AC Power [3]	TPE-SBR	4.27E-01	1.64	3.00E+06	81.3
Wire Jacket RIB [4]	TPE-SBR	1.24E-02	15.93	3.00E+06	2804.0
Wire collector	TPE-SBR	-	-	3.00E+06	-

PEEK, EPDM, KAPTON, TPE-SBR
are used instead of weaker materials

Mechanical requirements
are still accomplished?

To what extent are data
from literature reliable?

CERN report (1982)

CERN 82-10
Health and Safety
Department
4 November 1982

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

COMPILATION OF RADIATION DAMAGE TEST DATA

PART III: Materials used around high-energy accelerators

INDEX DES RÉSULTATS D'ESSAIS DE RADIORÉSISTANCE

IIIe PARTIE: Matériaux utilisés autour des accélérateurs de haute énergie

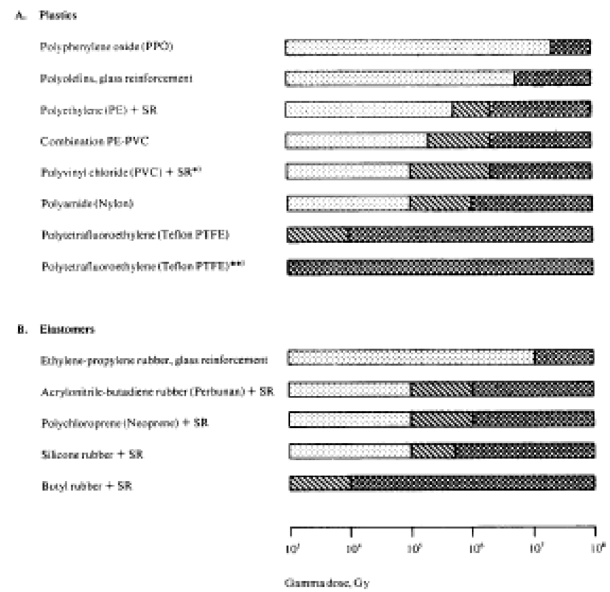
P. Beynel, P. Maier and H. Schönbacher

GENEVA
1982

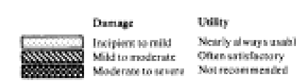
APPENDIX 5.4

General relative radiation effects: Hoses

These appreciations are taken from the references cited and can only serve as a general guideline. Atmospheric and other environmental conditions such as temperature and dose rate are not taken into consideration. See also Sections 2 and 3.



SR = synthetic reinforcement. All results for 1 bar, except *) for 1 and for 15 bar and **) for 20 bar water bursting pressure.



REFERENCES: 36

CERN report (1982)

Table 1

Characteristics of various radiation sources used for this data compilation

Radiation source	Irradiation position[a]	Characteristics of radiation field	Irradiation medium	Irradiation temperature (°C)	Dose rate (Gy/h)	Dosimetry method	Items irradiated
7 MW ASTRA research pool reactor	Pos. 11	$5 \times 10^{16}\ n_{th}/m^2 s$ $3 \times 10^{16}\ n_f(E > 1\ MeV)/m^2 s$	Water	40–50	2×10^4	Calorimeter[1] Activation detector[7]	Thermosetting resins[1]
	Ebene 1 (E1)	$4 \times 10^{15}\ n_{th}/m^2 s$ $3 \times 10^{14}\ n_f(E > 1\ MeV)/m^2 s$	Air	32–45	2×10^3	Ionization chamber[7]	Cable-insulating materials[1]; other organic materials
	SNIF	$2 \times 10^{13}\ n_{th}/m^2 s$ $5 \times 10^{13}\ n_f(E > 1\ MeV)/m^2 s$	Air	35–45	n: 2×10^3 γ: 2×10^2	Activation detector Ionization chamber	Electronics components[8], optical glasses[9]
	Core	$1 \times 10^{18}\ n_{th}/m^2 s$ $8 \times 10^{17}\ n_f(E > 1\ MeV)/m^2 s$	Water or N_2 or He	50–100	3×10^4	Activation detectors Calorimeter	Magnetic materials, copper wires[10]
Fuel elements ASTRA	Pos. 35	Gamma radiation field characteristic for reactor fuel elements (0.5–3 MeV)	Air	25–35	1×10^4 1×10^3	Ionization chamber[7]	Insulating materials containing metal; boxes with metal connectors
^{60}Co source	Various	Gamma rays 1.2 MeV	Air	≈ 25	1×10^4	Fricke dosimeter	Insulating materials containing metal; motors
CERN accelerators	ISR beam dump	Hadron cascade and secondary gamma rays. Primary proton energy ≈ 30 GeV	Air	≈ 22	4	RPL and PDG glass dosimeters[12]	Electronics components and items containing metal, up to 10^7 Gy
	SPS neutrino target area	Hadron cascade and secondary gamma rays. Primary proton energy ≈ 400 GeV	Air	≈ 23	3×10^2	RPL and glass dosimeters[13]	Cable and magnet insulations; items containing metal, up to 5×10^8 Gy
	PS or SPS ring	Primaries (losses) and secondaries up to 30 GeV (PS) or 250 GeV and 400 GeV (SPS)	Air	≈ 22	1–10	RPL and glass dosimeter, ionization chambers[14]	Cable and magnet insulation; paints; operational life-tests

a) Specified on each entry in the data compilation section.

REASONS TO PROPOSE A PROGRAM FOR RAD-HARD TESTS FOR SPES

- Radiation hardness of materials and components is a critical item for ISOL sources (SPES, REX-ISOLDE, SPIRAL2, EURISOL….)
- Data in the literature are somewhat abundant but often not recent
- New materials, products and suppliers should be tested
- Specific materials and products utilized in the assembly should be tested in spite of generic materials
- Existing data mainly refer to gamma ray damage
- Reliable tests should reproduce as close as possible real operating conditions
- Specific mechanical, electrical, optical requirements of materials and products should be tested against radiation damage
- Complex components ad electrical motors or electronic circuits should be tested.
- Interest for a systematic campaign of Rad-hard tests for ISOL sources and other applications has been expressed by ISOLDE (Cern), iThemba (South Africa), CNR (RFX – ITER).

INTERNATIONAL EXTENSION OF THE PROJECT

UNIVERSITÀ DEGLI STUDI DI BRESCIA - FACOLTÀ DI INGEGNERIA
DIPARTIMENTO DI INGEGNERIA MECCANICA E INDUSTRIALE
Via Branze, 38 - 25123 BRESCIA
Codice Fiscale 98007650173 - Partita IVA 01773710171

Brescia University, July 15th, 2014

Dear Colleague,

we would like to inform you that, in the framework of the SPES project at INFN LNL, we have the intention to start a working group devoted to the systematic experimental study of the radiation damage of critical materials to be utilized for the construction of the SPES production target and front end.

The radiation damage of materials has always been an important item for accelerator science and space science, as well as for nuclear engineering, and, for this reason, it has been intensively studied in the past. We consider, however, that it could be of scientific and technical interest to perform a new radiation damage study specifically devoted to ISOL application, for several reasons:

- Radiation hardness of materials and components is a critical item for all ISOL sources;
- Data in the literature are somewhat abundant but often non recent;
- New materials, products and suppliers should be tested;
- Specific materials and products utilized in the assembly should be tested in spite of generic materials;
- Existing data largely used for accelerator projects mainly refer to gamma ray damage;
- Reliable tests should reproduce as close as possible real operating conditions;
- Specific and not generic mechanical, electrical, optical requirements of materials and products should be tested against radiation damage effects;
- Complex components as electrical or pneumatic motors or electronic circuits should be tested.

This project is going to start in fall 2014, will be supported by INFN, in the context of the SPES initiative, and will be located at Sezione INFN at Pavia University. Partners of the project, until now, are the Laboratorio Energia Nucleare Applicata LENA of Pavia University, where a TRIGA Mark II nuclear reactor is available and will be used for the irradiation tests of materials and components and the Laboratory of Materials Science and Technology of the Brescia University, where the tests on the property modifications of irradiated materials and components will be performed.

We would like to ask you whether you consider interesting this project and worth to be pursued and, if it is the case, we will be grateful if you will contact the responsible, Prof. Aldo Zenoni Brescia University, for an exchange of ideas and for providing him with suggestions and very welcome contributions. This would be of invaluable importance in order to allow us to aim our research program and efforts at the best possible results.

Looking forward to hearing you soon.

Aldo Zenoni, Brescia University and INFN Pavia
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Richard Catherall:
(ISOLDE tecnical coordinator)
Yacine Kadi:
(HIE- ISOLDE project coordinator)
Thierry Stora :
(CERN Medicins project coordinator)
Lowry Conradie:
(Ithemba Head Accelerator division)
Abdelhakim SAÏD
(Alto Coordinator)
Samuel *DAMOY*
(Spiral2 technical coordinator)
Mats Lindroos
(ESS Head of Accelerator Division)
Vanni Antoni:
(RFX Project Director: CNR - Padova)
Giuseppe Gorini:
(Gruppo Milano Bicocca)

PROPOSED PROGRAM OF COLLABORATION

INSTITUTIONS

- INFN SPES @ LNL
- Sezione INFN PV – SPES_PV
- L.E.N.A. @ UniPv
- Fundamental and applied physics group @ UniBs
- Materials Science and Technology Laboratory @ UniBs

RESEARCH PROGRAM

- Compilation of materials and products to be rad-hard tested with definitions of the actual mechanical, electrical, optical, operational requirements to be granted
- Simulation of the radiation fields and cumulated dose expected on the critical TIS components in foreseen operational conditions
- Irradiation campaigns at L.E.N.A. on sample materials and products. Radiation fields as close as possible to the expected ones (neutrons vs gammas). Systematics on adsorbed dose levels.
- Test of physical and operational properties of materials for different levels of irradiated dose
- Analysis of the relation between physical properties changes and structural modifications due to radiation damage in materials (polymers)
- One or two year research program

PERSONALE E FINANZIAMENTO DELLE ATTIVITA' PER IL 2014-2015

W.P. RDS_SPES (Radiation Damage Study for SPES) NELLA SIGLA SPES_PV

PERSONALE PARTECIPANTE E FTE

Gruppo di Brescia Sezione di Pavia

Aldo Zenoni PO	60%	
Antonietta Donzella TD	50%	
Fabio Bignotti PA	30%	Laboratorio Scienza e Tecnologia dei Materiali UniBS

L.E.N.A UniPV

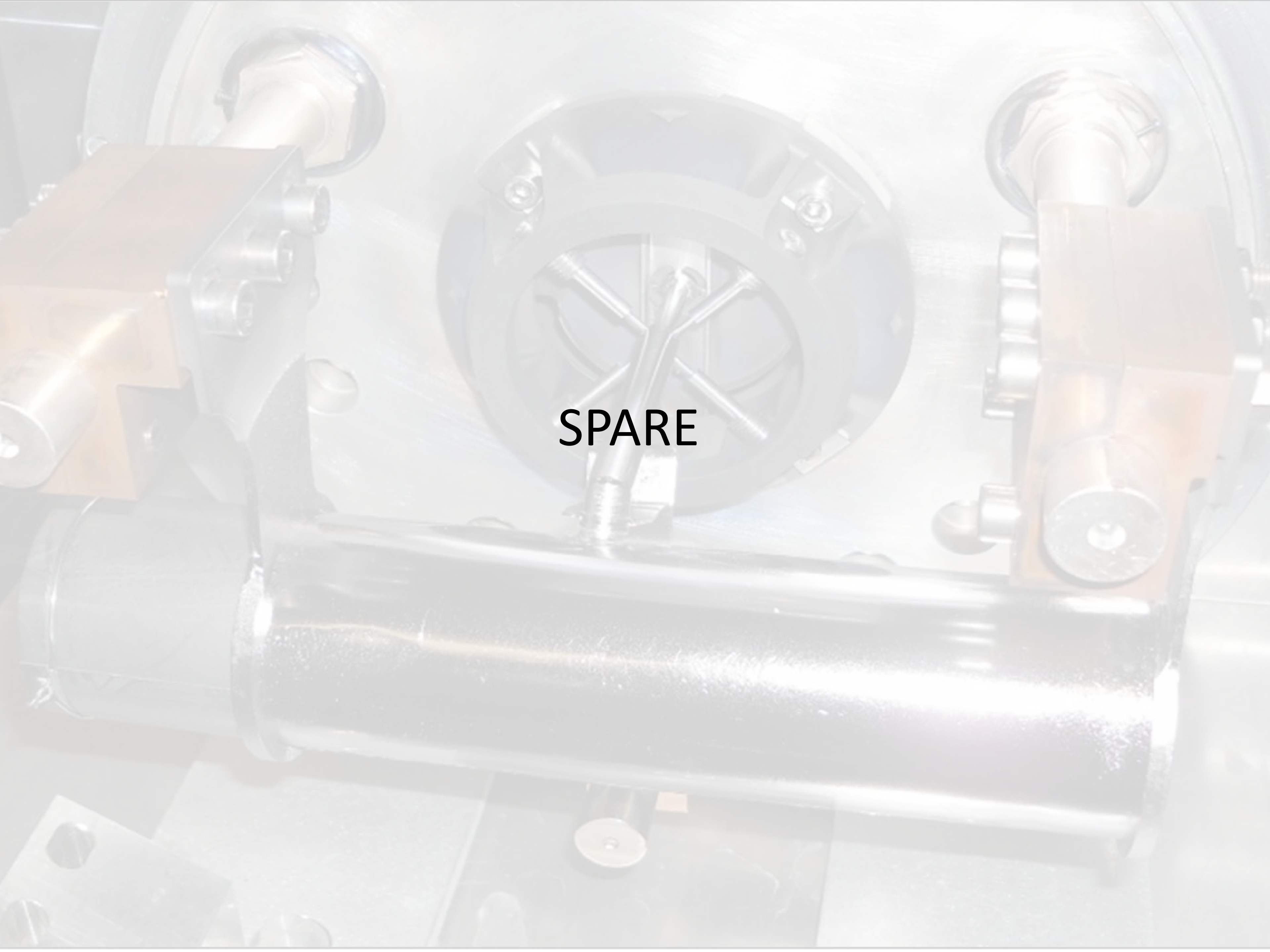
Daniele Alloni	30%	
Michele Prata	30%	
Andrea Salvini	20%	
Giovanni Magrotti	20%	totale 2,4 FTE

SPES LNL

Una borsa di studio biennale INFN per neolaureati

FINANZIAMENTI RISERVATI SU PROGETTO SPECIALE SPES LNL

Borsa di studio	36 k€
Missioni interne e estero	15 k€
Materiale consumo laboratorio	5 k€ (su fondi PV)
Materiale inventariabile	2 k€
Acquisto servizi	da stabilire con LNL SPES



SPARE

Target & Heater

SPES Target :

Optimized for 8 kW power dissipation

(E= 40 MeV, I= 200 μA)

7 UCx coaxial disks:

thickness: 1.3 mm

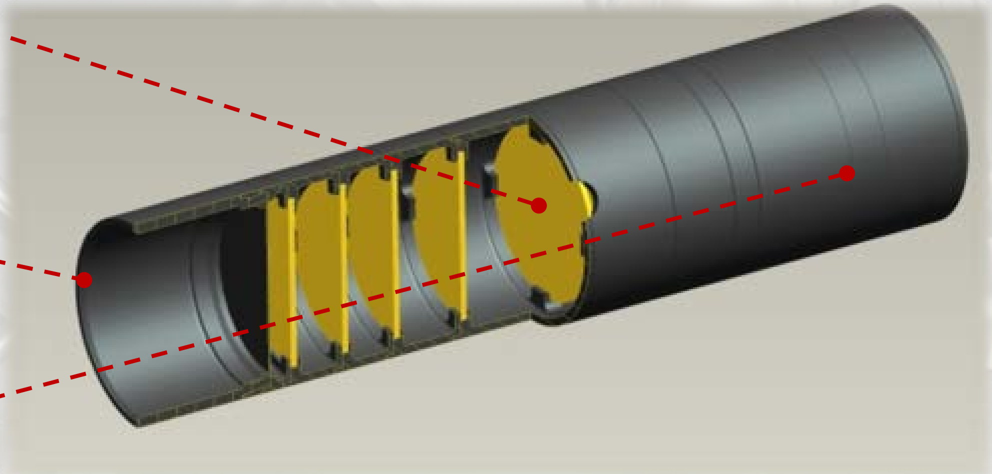
diameter: 40 mm

Graphite box:

external diameter: 49 mm

average length: 200 mm

3 graphite dump disks



SPES Heater, Ionizer & Chamber

Tantalum tube:

external diameter: 50 mm

thickness: 0.35 mm

length: 200 mm

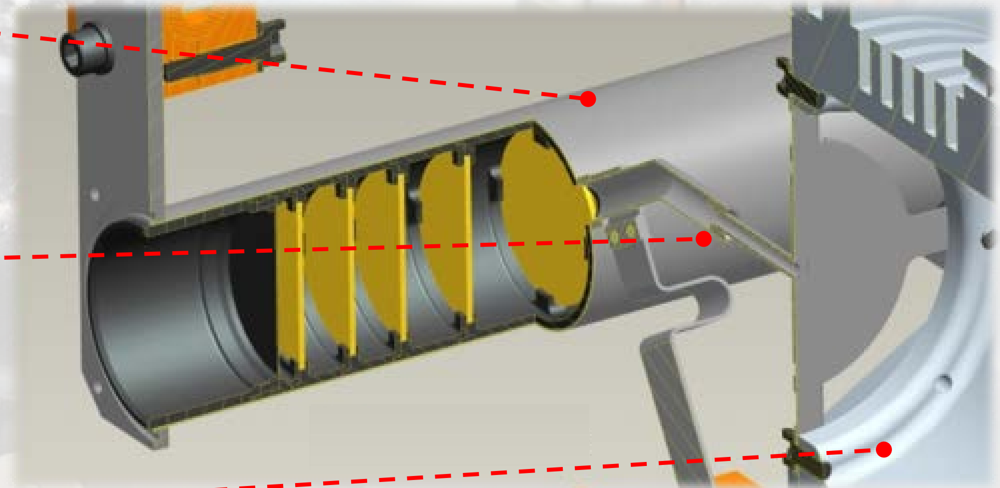
Ionizer & transfer tube:

thickness: 1 mm

height: 34 mm

Inner diameter: 3 mm

Aluminum target unit



name	composition	
EPDM	Etylene-Propylene Diene Monomer	rubber
PEEK	Polyether ether ketone	organic thermoplastic polymer
PMMA	polymethilacrilate	Plexiglass, lucite
SBR	Styrene-butadiene	rubber
TPE	Thermoplastic elastomer	rubber
VITON	Fluoropolymer elastomer	rubber
TEFLON	Politetrafluoretene	
KAPTON	poly-oxydiphenylene-pyromellitimide	

Materials employed for the simulations

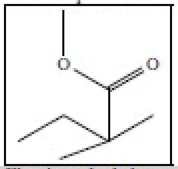
Commercial name	Composition	Notes	References	Density $\left[\frac{g}{cm^3}\right]$
VITON A-410C	VF2 (34%wt) HFP (66%wt)	-	[7]	1.810
TEFLON	C_2F_4	-	-	2.200
AL-6082 T6	Mn (0.700%wt) Fe (0.250%wt) Mg (0.900%wt) Si (1.000%wt) Cu (0.050%wt) Zn (0.100%wt) Ti (0.050%wt) Cr (0.125%wt) Al (96.825%wt).	-	[8] [9]	2.698
Ti-TA6V	Al (6.00%wt) V (4.00%wt) C (0.08%wt) Fe (0.30%wt) O (0.20%wt) N (0.07%wt) Ti (89.35%wt).	-	[10]	4.430
PEEK	O (6 mol) C (19 mol) H (12 mol).	PEEK-1000	[11] [12]	1.310
SS316L	Fe (66.037%wt) Cr (17.250%wt) Ni (12.000%wt) Mo (2.500%wt) N (0.100%wt) C (0.030%wt) Mn (1.410%wt) Si (0.630%wt) P (0.031%wt) S (0.012%wt).	-	[13] [14]	8.000
EPOXY	Epoxy Resin (71,94%mol) and Amine (28.06%mol)	Epoxy Resin: $C_{21}H_{24}O_4$ Amine: $C_{11}H_{18}N_4$	Epoxy Resin: [15]. Amine: [16]	1.159
EPDM	C (21 mol) H (34 mol)	-	[17]	0.868
TPE - SBS	C_8H_8 (2 mol) C_4H_6 (1 mol)	SBS	-	0.819
TPE - SBR	C_8H_8 (23 %wt) C_4H_6 (77 %wt)	SBR	-	0.956
SS304L	Fe (68.045 %wt) C (0.030 %wt) Si (0.750 %wt) Mn (2.000 %wt) P (0.045 %wt) S (0.030 %wt) Cr (19.000 %wt) Ni (10.000 %wt) N (0.100 %wt)	-	[18]	7.857
Bakelite	C (95 mol) H (88 mol) O (12 mol)		[19]	1.360
DGEBF+CE	C (72.972 %wt) H (5.851 %wt) O (17.995 %wt) N (3.182 %wt)	DGEBF: 70%wt CE: 30%wt	[20]	1.220 Same as EPON 862 [21]
LUBRICANT	C (24 mol) H (48 mol) O (4 mol)	Bi-Ester	[22]	1.209
PMMA	$(C_5H_8O_2)_n$	Polymethyl Methacrylate - Plastic Optical Fiber core 	[23] [24] [25]	1.180
FPE	C_2F_4 (95 %mol) C_3F_6 (5 %mol)	Fluorinated ethylene propylene - Optical Fibber Jacket	[22]	2.150
EPOXY	C (71.301 %wt) H (13.542 %wt) O (7.530 %wt) N (7.627 %wt)	Optical Fibber matrix	[26]	1.159
1A - GlassFibber	Al_2O_3 (62.5 %mol) Y_2O_3 (37.5 %mol)	YAG Glass Fibber	[27]	4.492
1B - GlassFibber	Al_2O_3 (60.0 %mol) SiO_2 (40.0 %mol)	YAG Glass Fibber	[27]	3.470
Fibber Core 1A2	EPOXY (34 %wt) Fibber 1A (66 %wt)	Optical Fibber core mixture 1A2	[27]	2.272
Fibber Core 1B2	EPOXY (34 %wt) Fibber 1B (66 %wt)	Optical Fibber core mixture 1B2	[27]	2.069

Table 4: Summary of materials employed in the simulations.