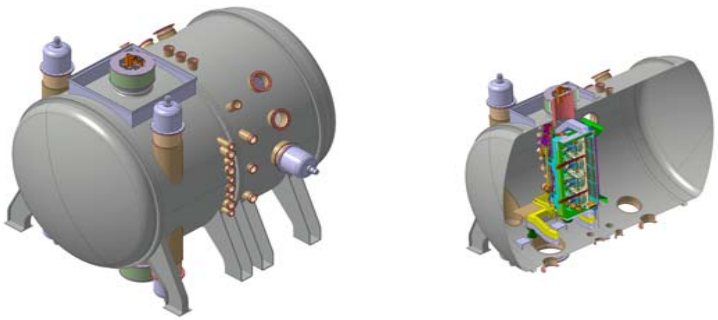
MITICA: il prototipo dell'iniettore di neutri da 1 MeV-22 MW per ITER

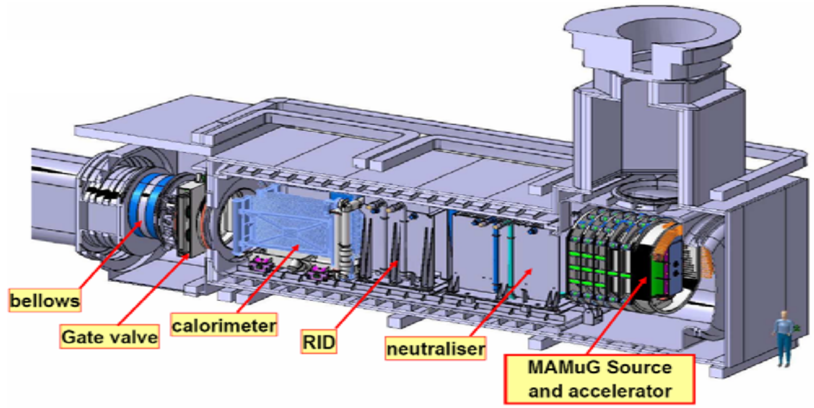
P.Sonato

Acronimi & partners

PRIMA
Padova **R**esearch on **I**njector **M**egavolt **A**ccelerated

Saranno ospitati due esperimenti

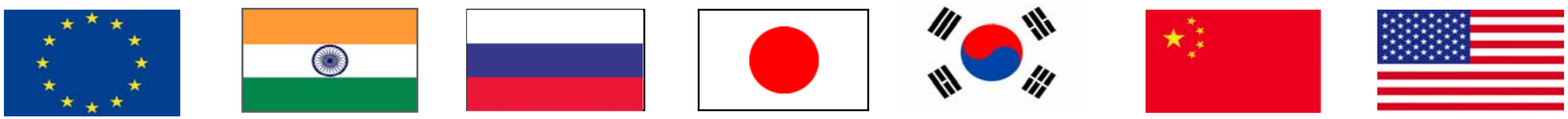




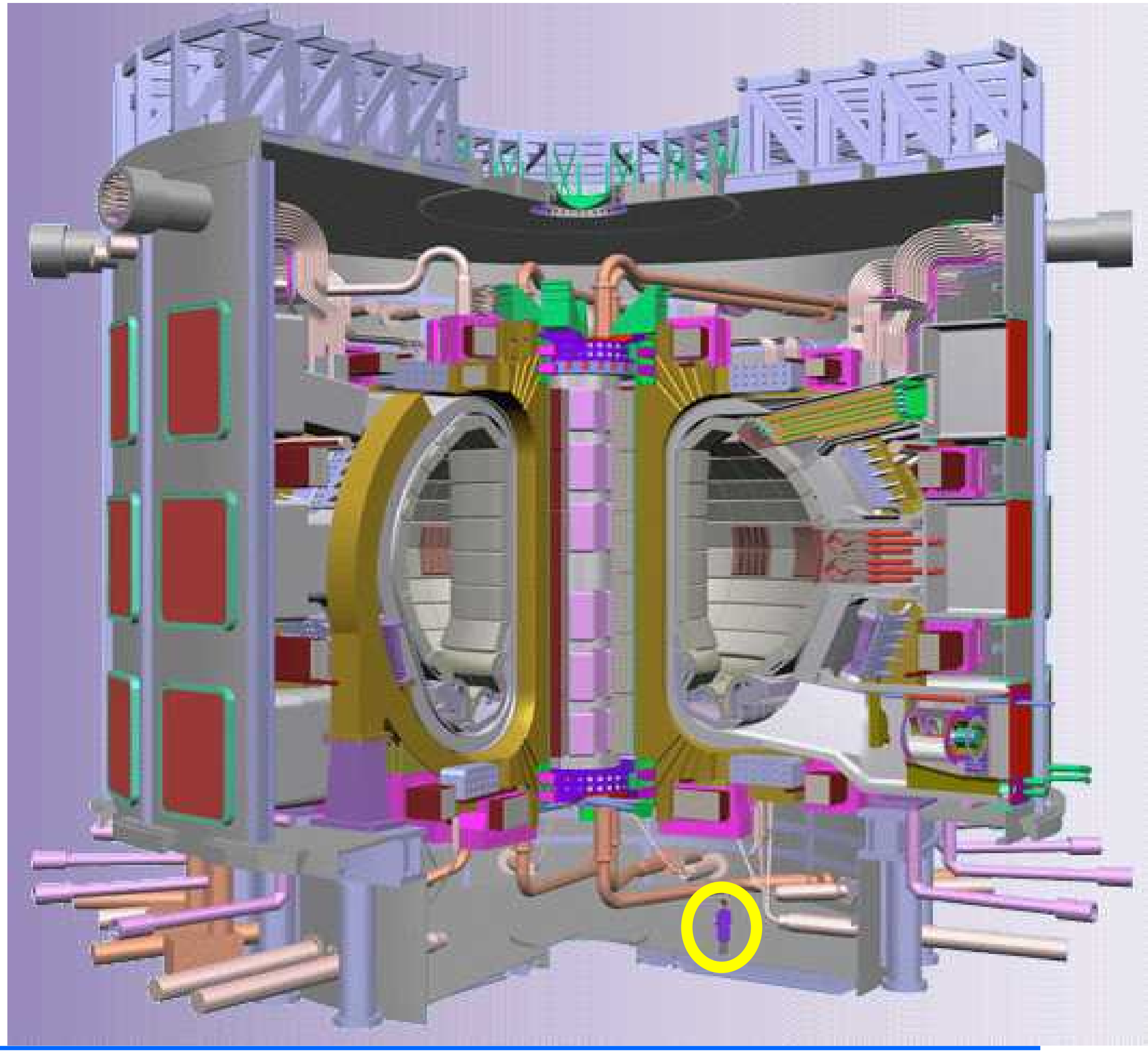
SPIDER
Source for **P**roduction of **I**on of **D**euterium **E**xtracted from **R**f plasma

MITICA
Megavolt **IT**ER **I**njector & **C**oncept **A**dvancement

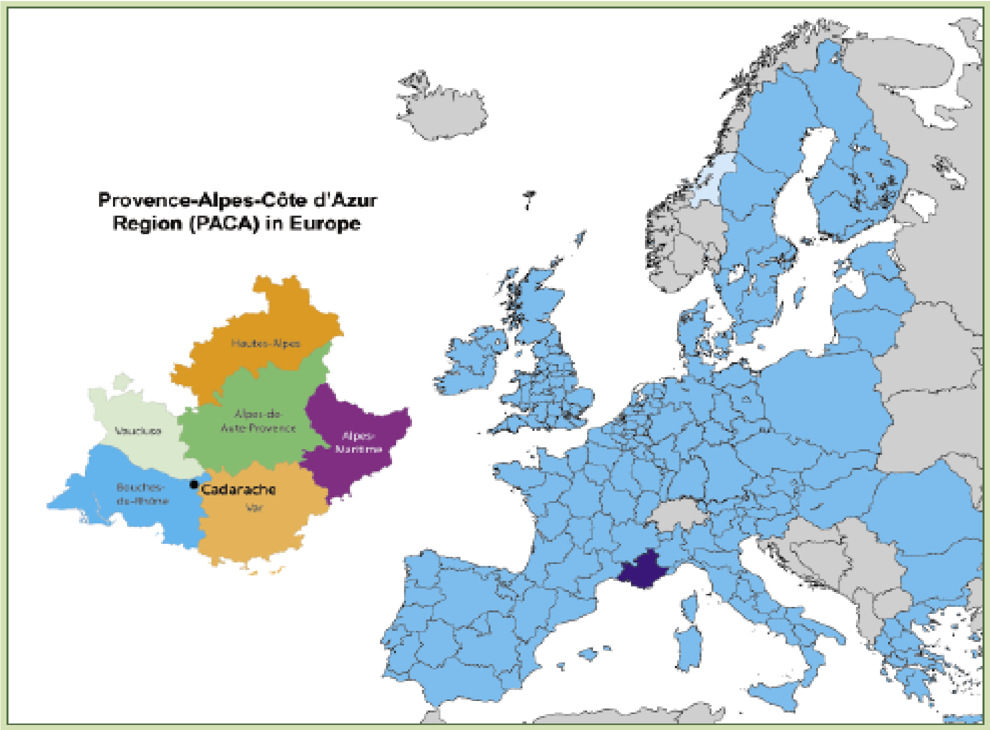
ITER: International cooperation



Total fusion power	500 MW
Q = Pot. Out/Pot. In	10
Pulse duration	300 s
Plasma major radius	6,2 m
Plasma minor radius	2 m
Plasma current	15 MA
Toroidal field B_T	5,3 T
Plasma volume	837 m^3
Plasma surface	678 m^2
Tipical plasma temperature	20 keV

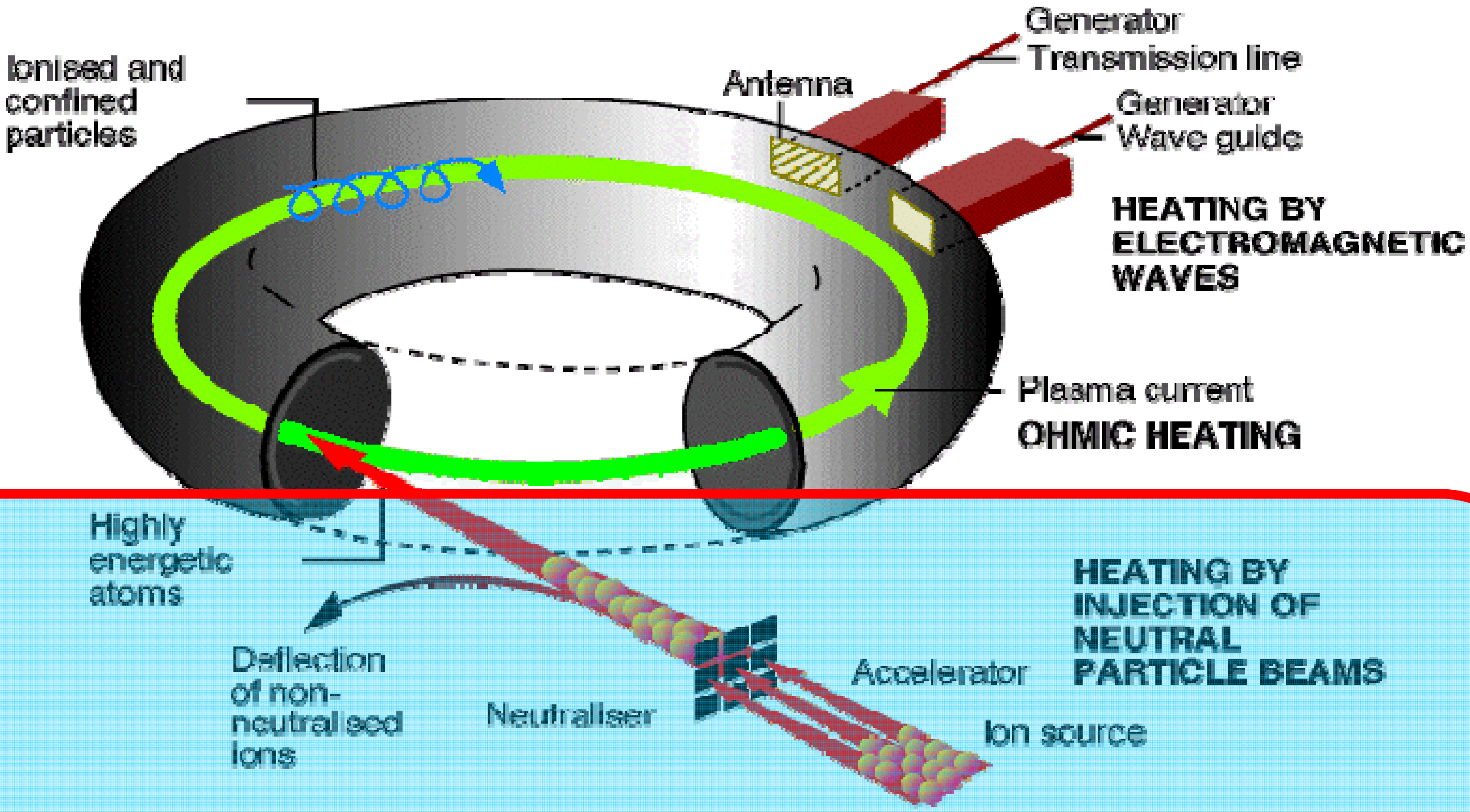


ITER: sito



- Will cover an area of about 60 ha
- Large buildings up to 170 m long
- Large number of systems

Heating and Current Drive Systems in ITER

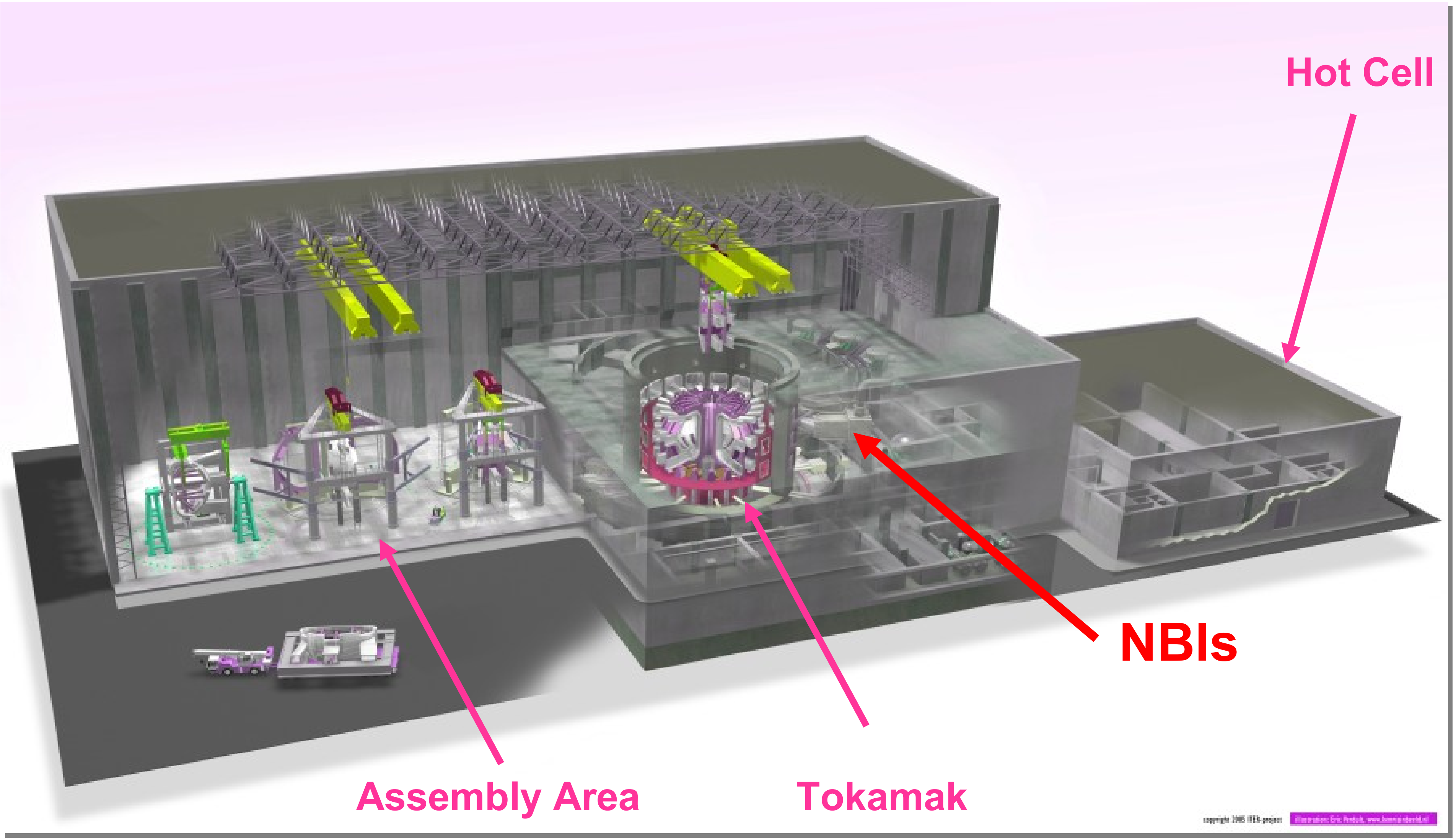


R&D di 1 iniettore prototipo

R&D di sorgente di 1 sorgente di ioni negativi

Sviluppo del progetto di 2(3) iniettori di ITER

ITER: edifici principali



ITER: additional heating – Neutral Beam Heating

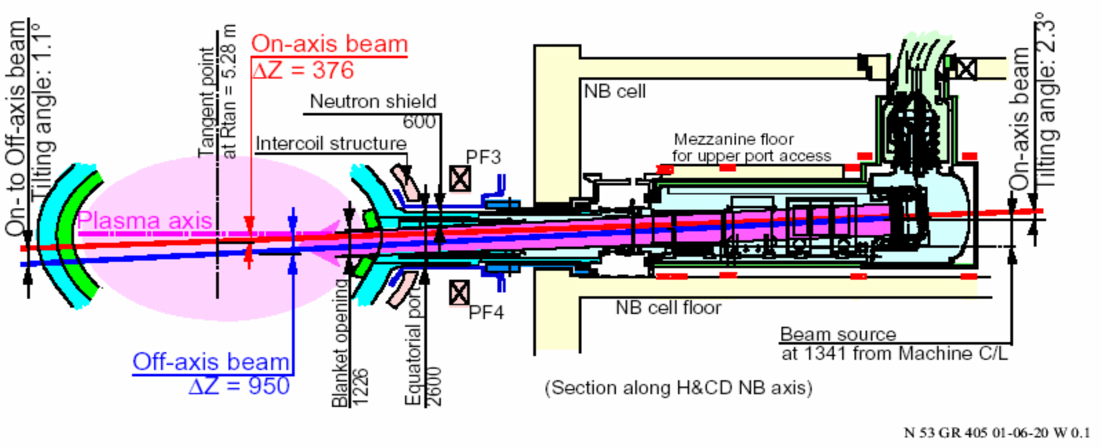
2 NBIs (+1)

P_{beam} = 16.5 MW

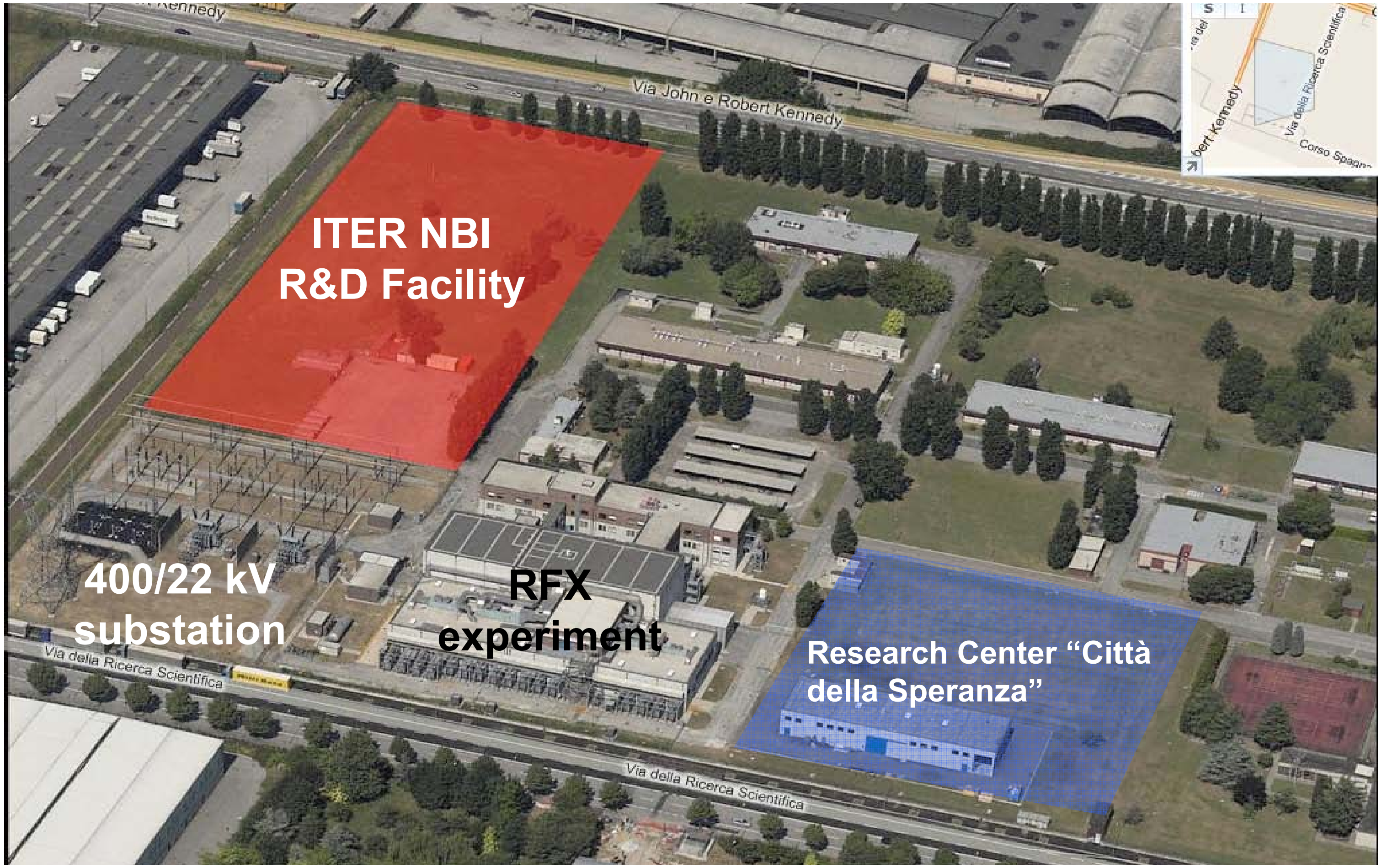
I = 40 A

V = 1 MV

T_{pulse} = 3600 s



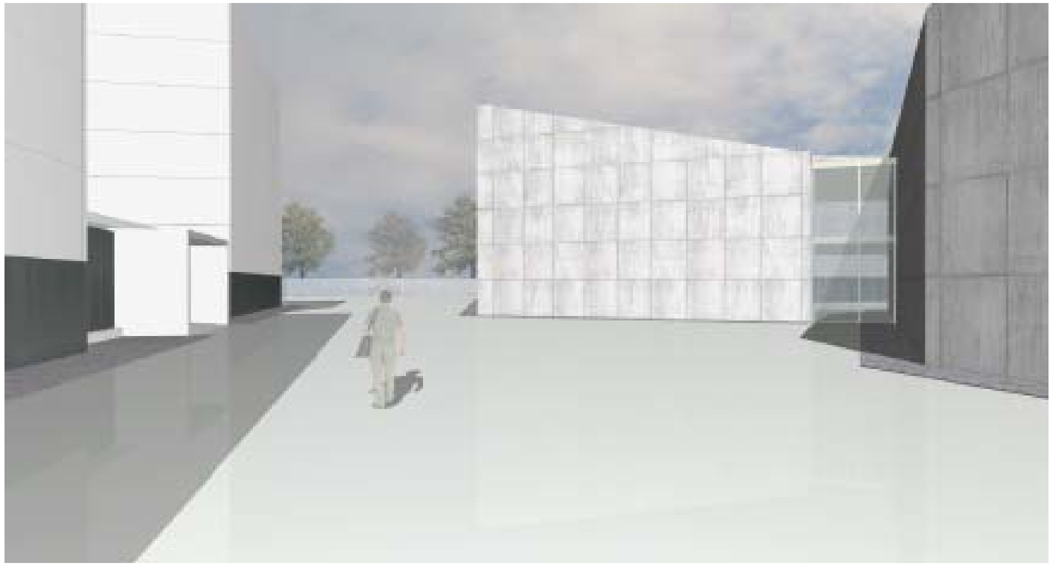
Area di ricerca del C.N.R.

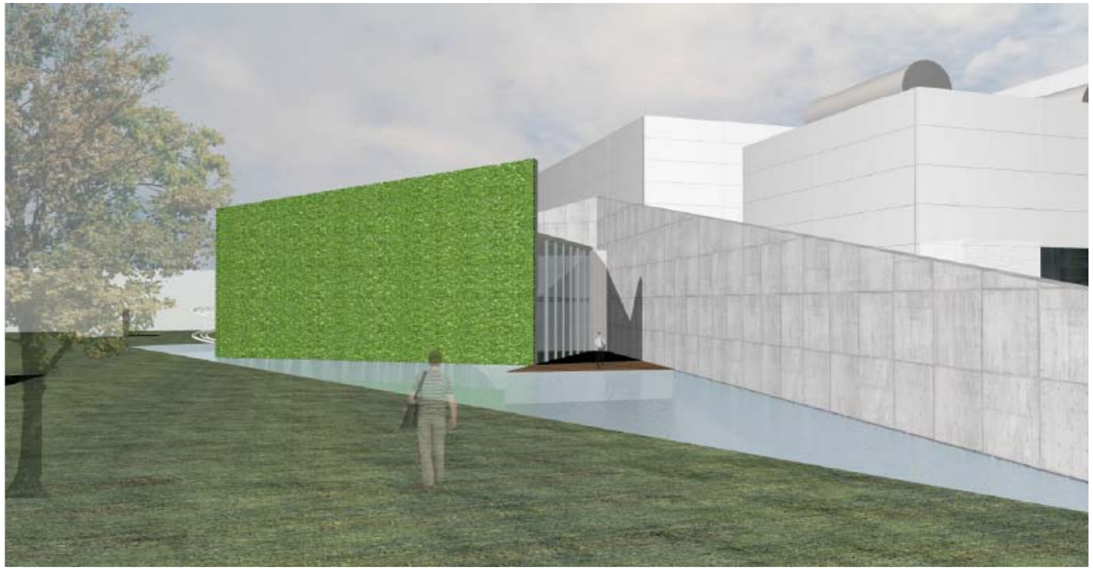


RFX substation: 400/21.6 kV – 2 x 50 MVA transformers
The power to feed the NBI facility (80 MVA) is available at the site

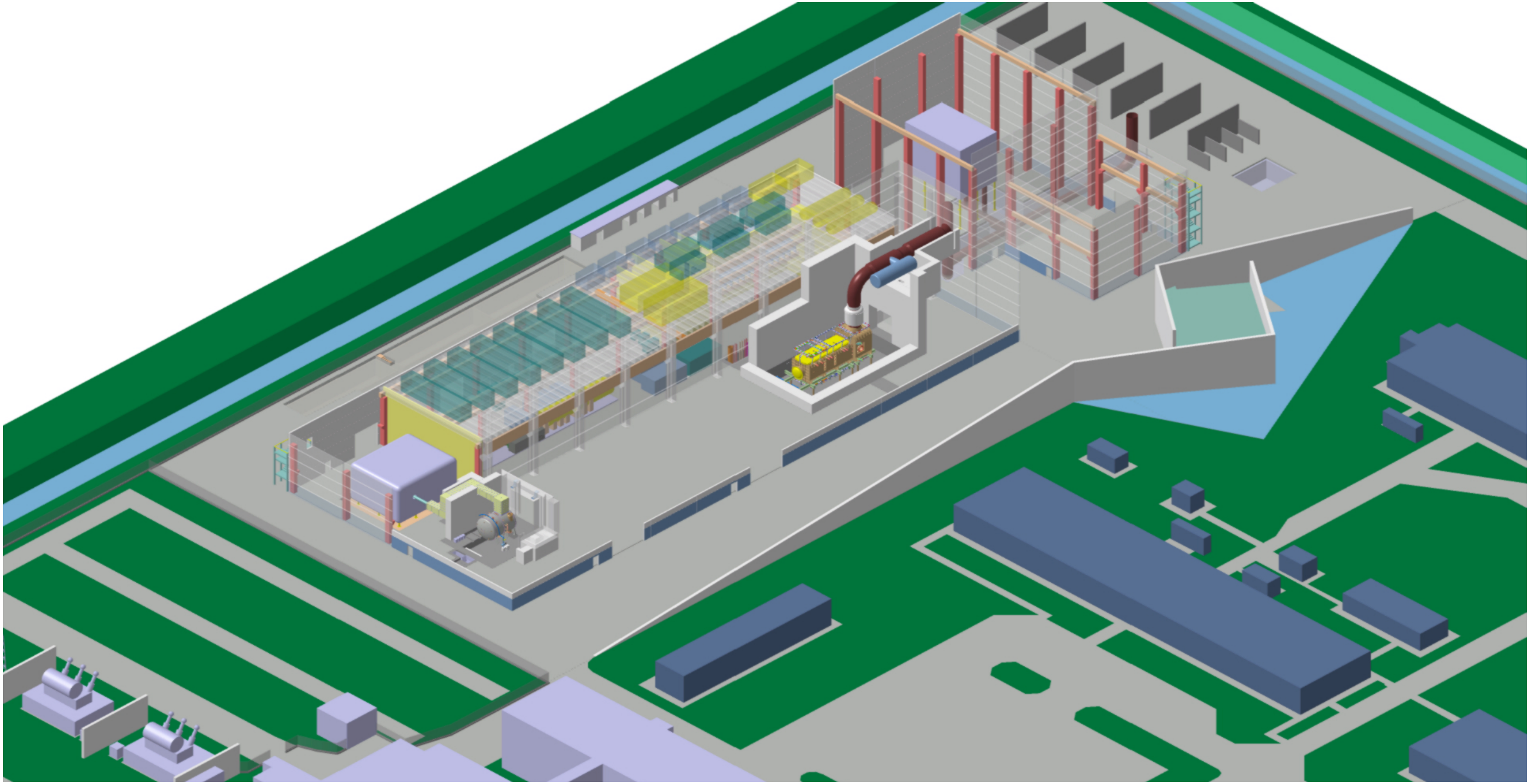
CONSORZIO RFX
Ricerca Formazione Innovazione

PRIMA → Buildings: Architectural view





PRIMA edifici



SPIDER ➔ requirements

- **Current density**

	Ion	Energy (keV)	Extracted Ion J (A/m²)	Extr. Ion I (A)	1 MV Accelerated I (A)
HNB	**D-**	1000	**290**	**48**	**40**
HNB	**H-**	870	**330 - 350**	**56 - 60**	**46**

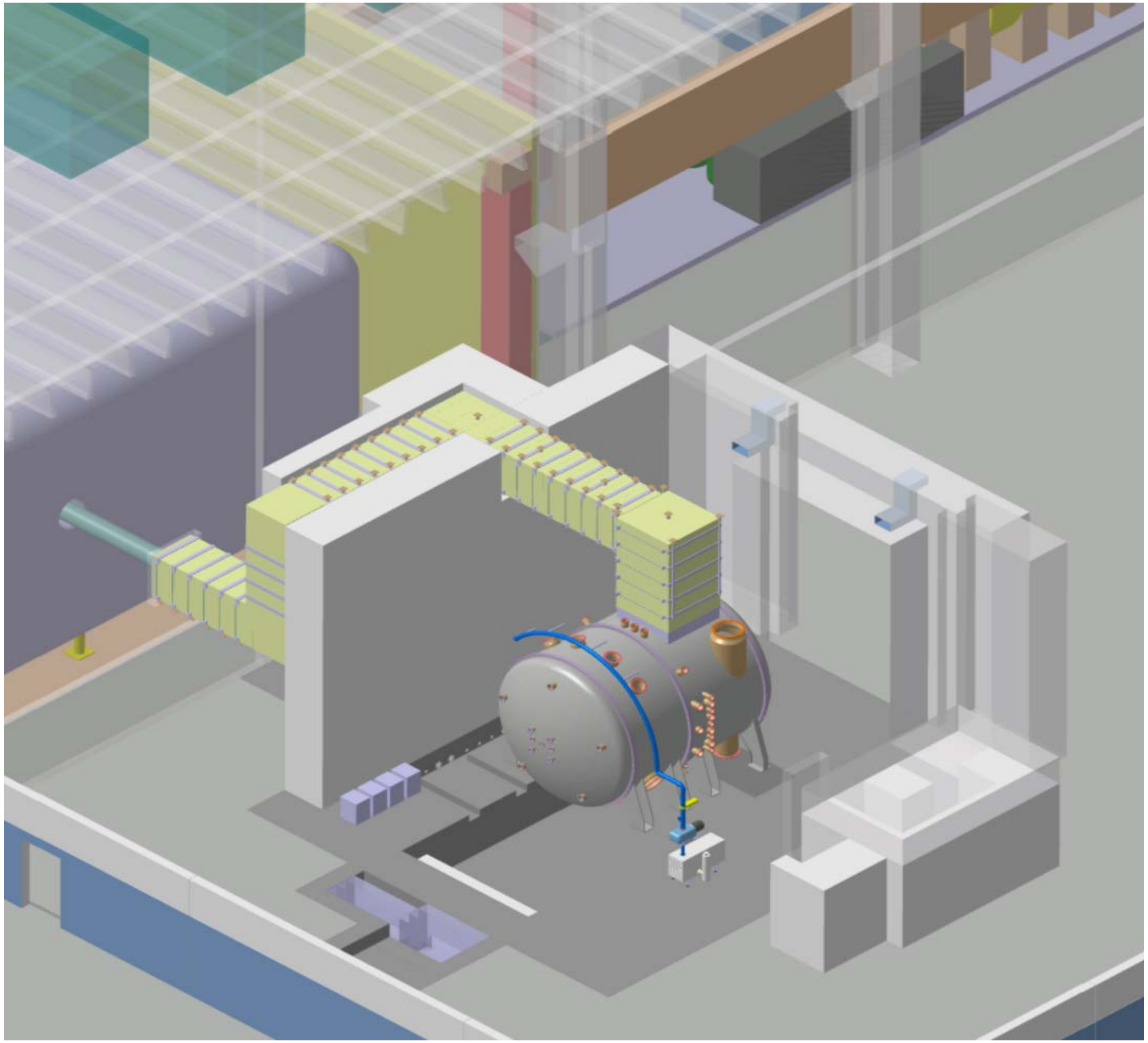
$J_{D^-} \approx 300\ \text{A/m}^2$ $J_{H^-} \approx 350\ \text{A/m}^2$

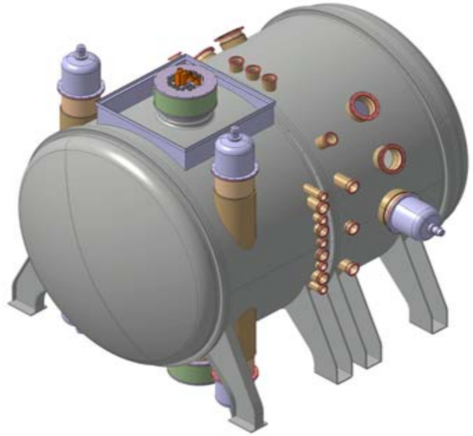
- **Extracted electron to ion ratio from PG, to be stopped in the EG** $\frac{e}{D^-} < 1$ for HNB

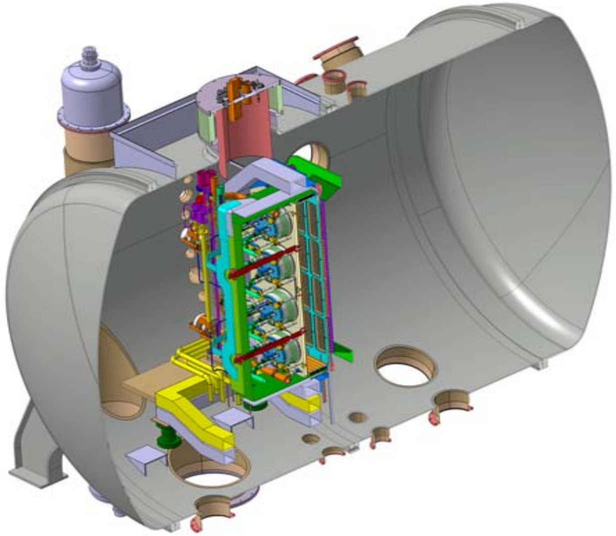
- **Uniformity** **ΔJ= ±10%**

- **Source operation**
  - **Long pulse operation** **400 s for H^-,D^- 3600 s for D^-**
  - **Source modulation** **HNB ≤ 7 Hz T_{on}≈50 ms T_{rise}≈ 80 ms**
- **Cs consumption and control**
- **Impurity tolerance: He, Ne, N_2, Mo,…**

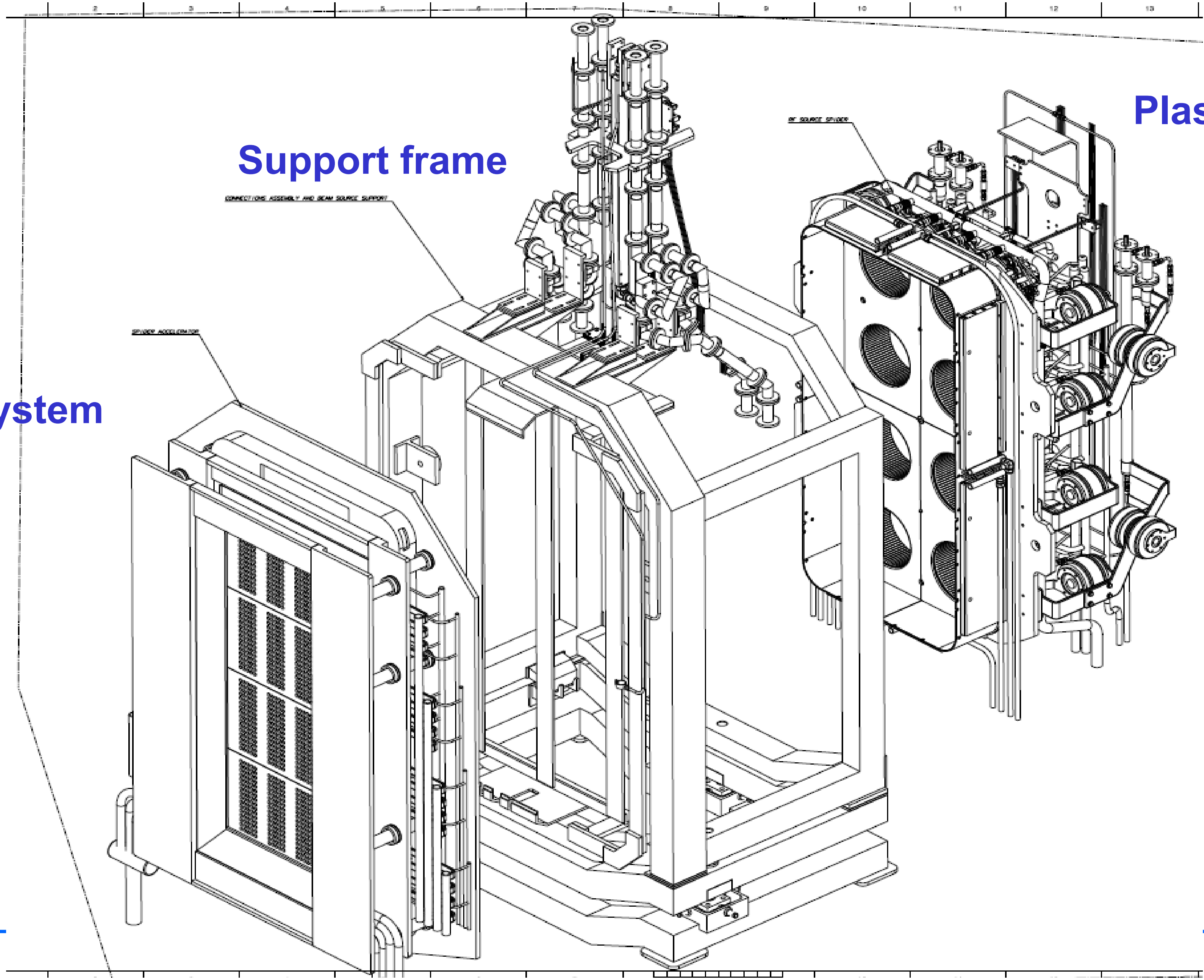
SPIDER → Layout and schermi



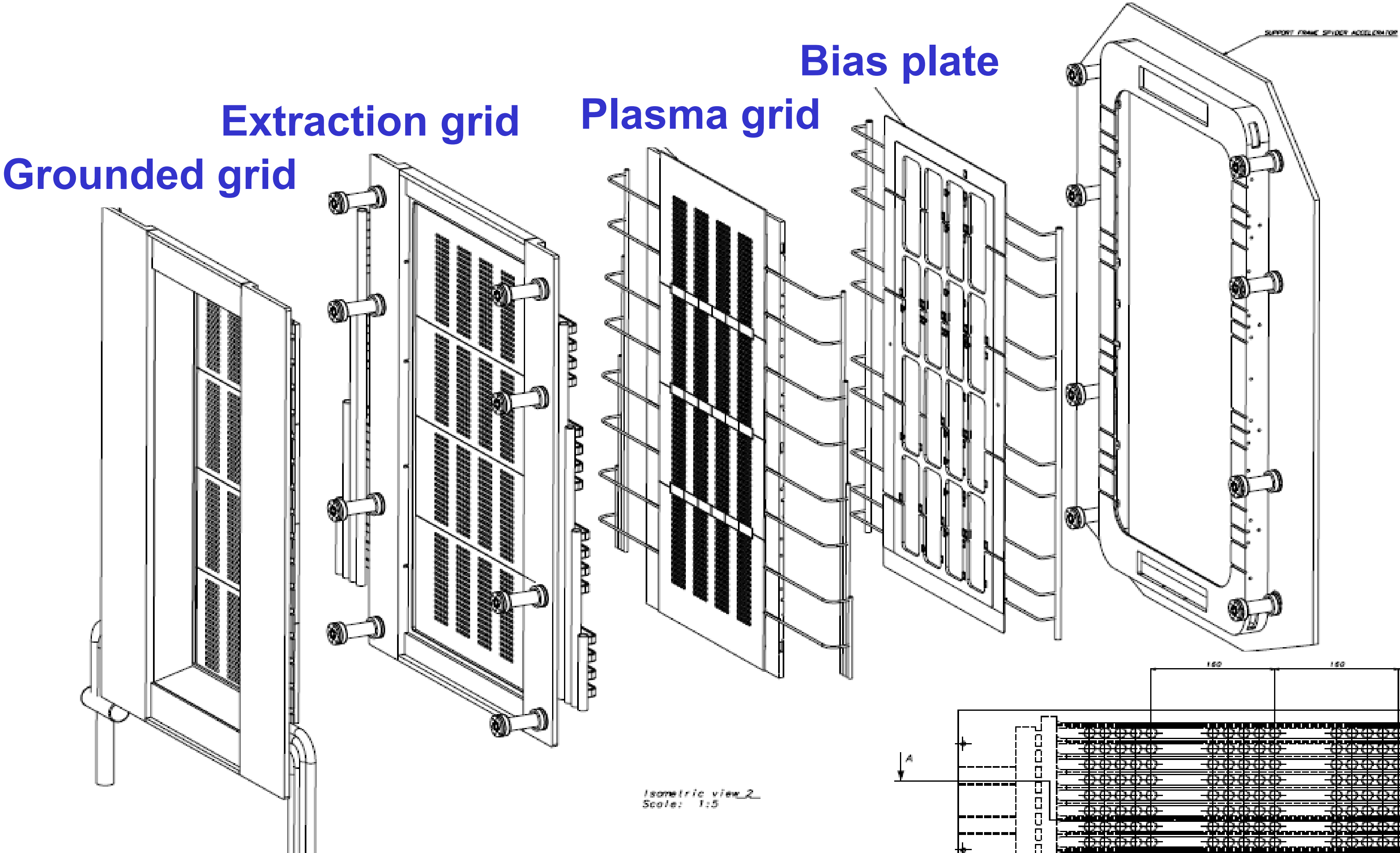




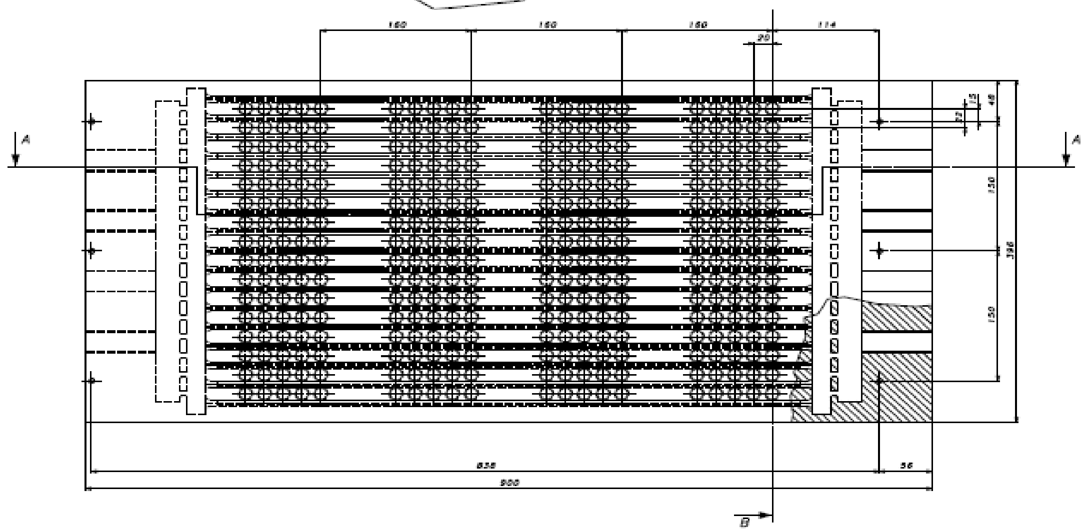
SPIDER ➔ The beam system



SPIDER ➔ The grids system

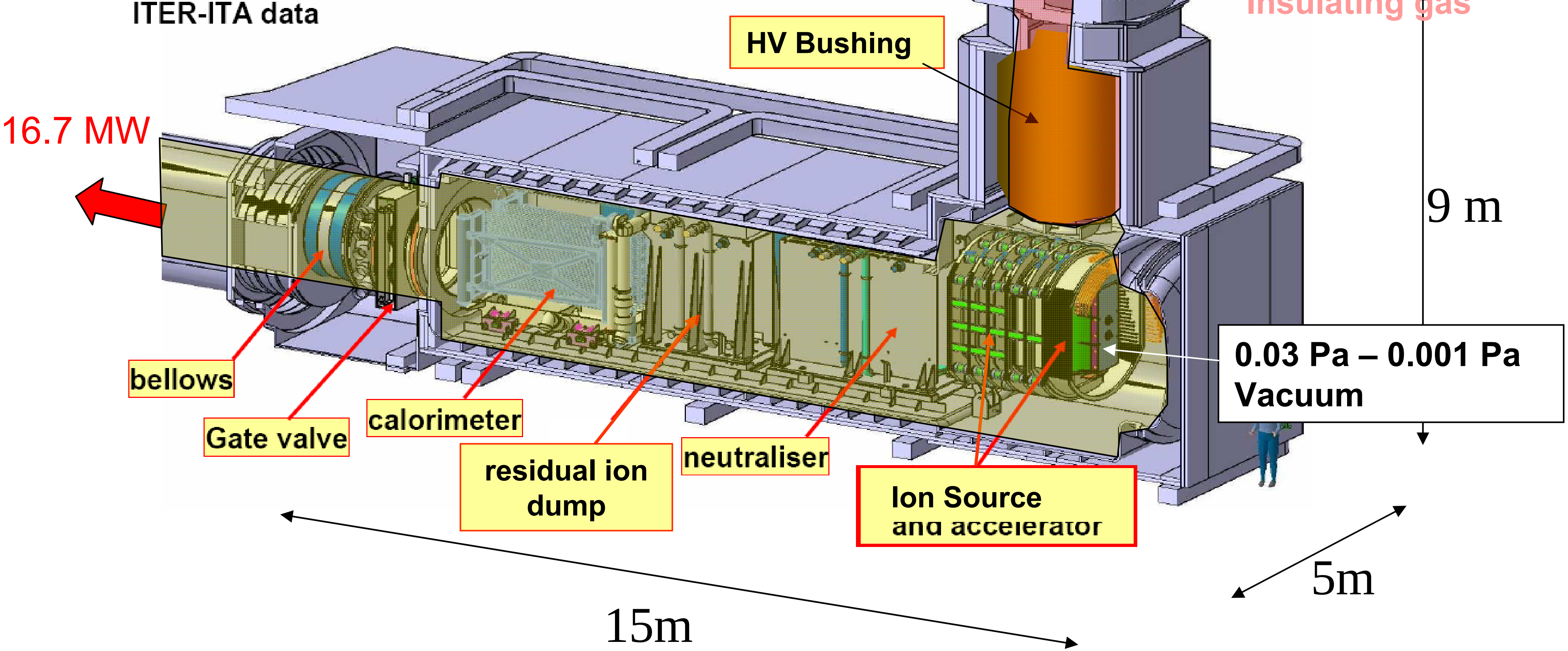


- 1280(16x5x16) beamlets
- 4 segments

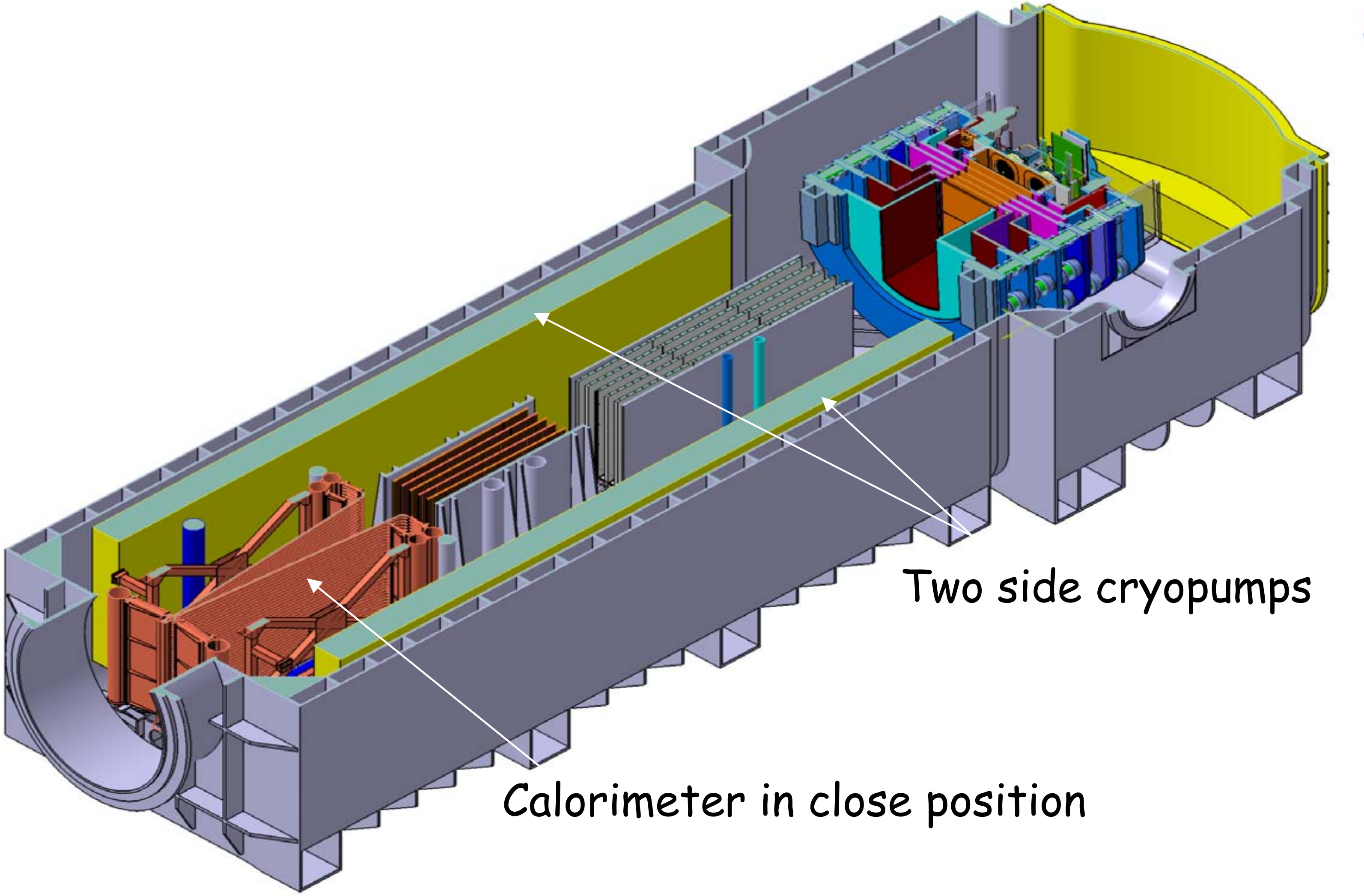


Iniettore HNB di ITER e il prototipo MITICA a Padova

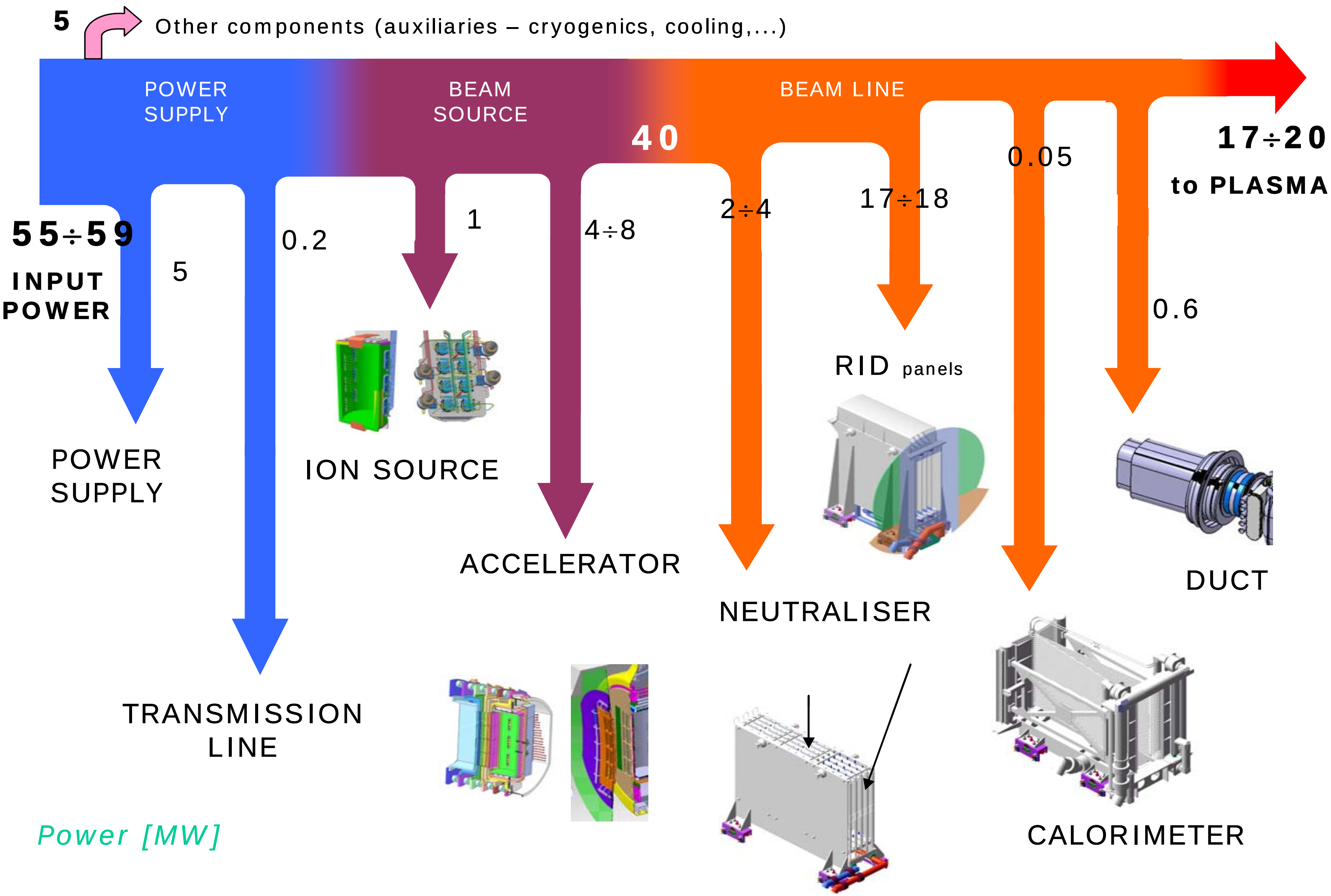
2 NBIs (+1)		
P_{beam}	= 16.7	MW
I	= 40	A
V	= 1	MV
T_{pulse}	= 3600	s



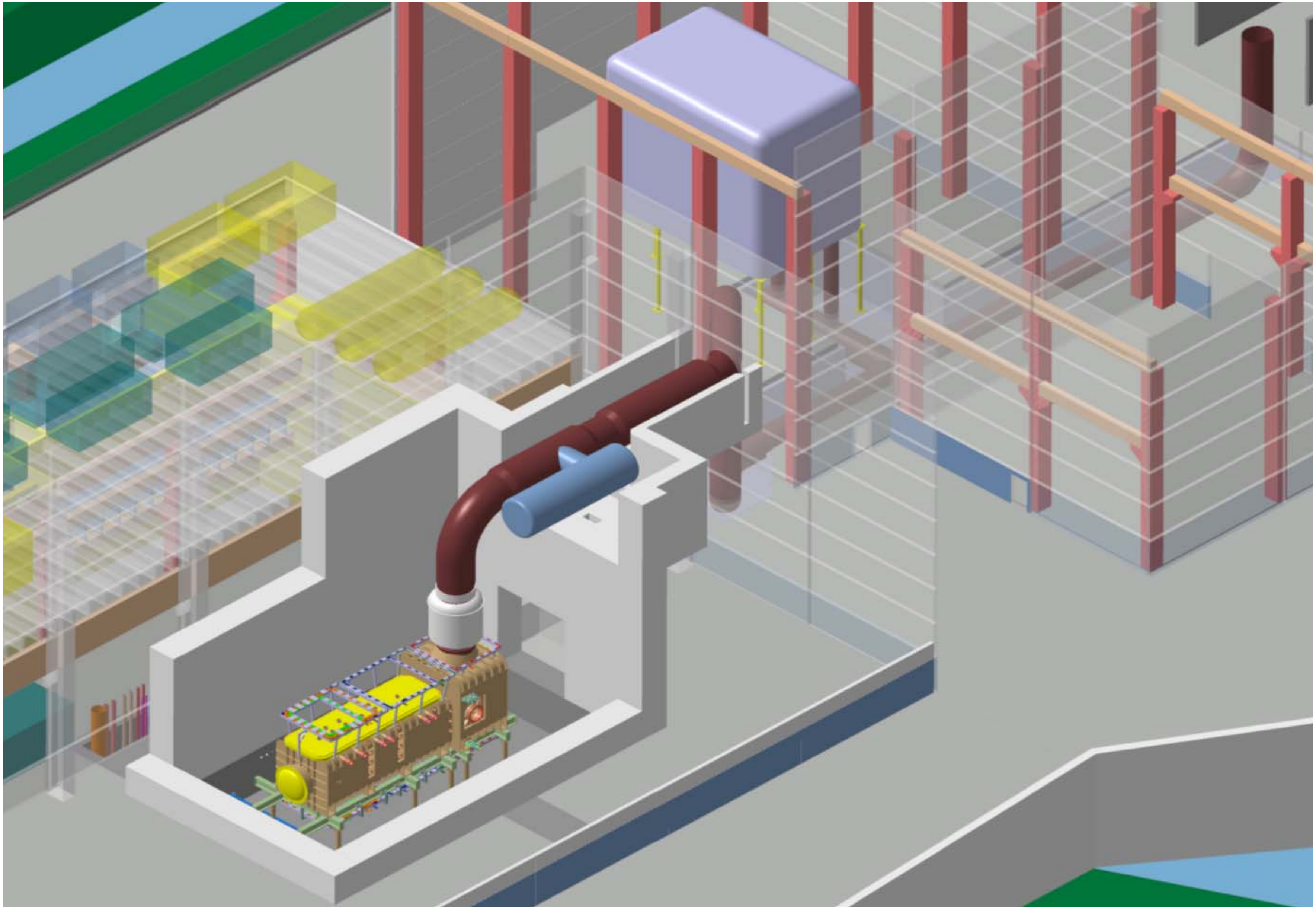
MITICA → The Injector internal components



MITICA ➔ Power flow

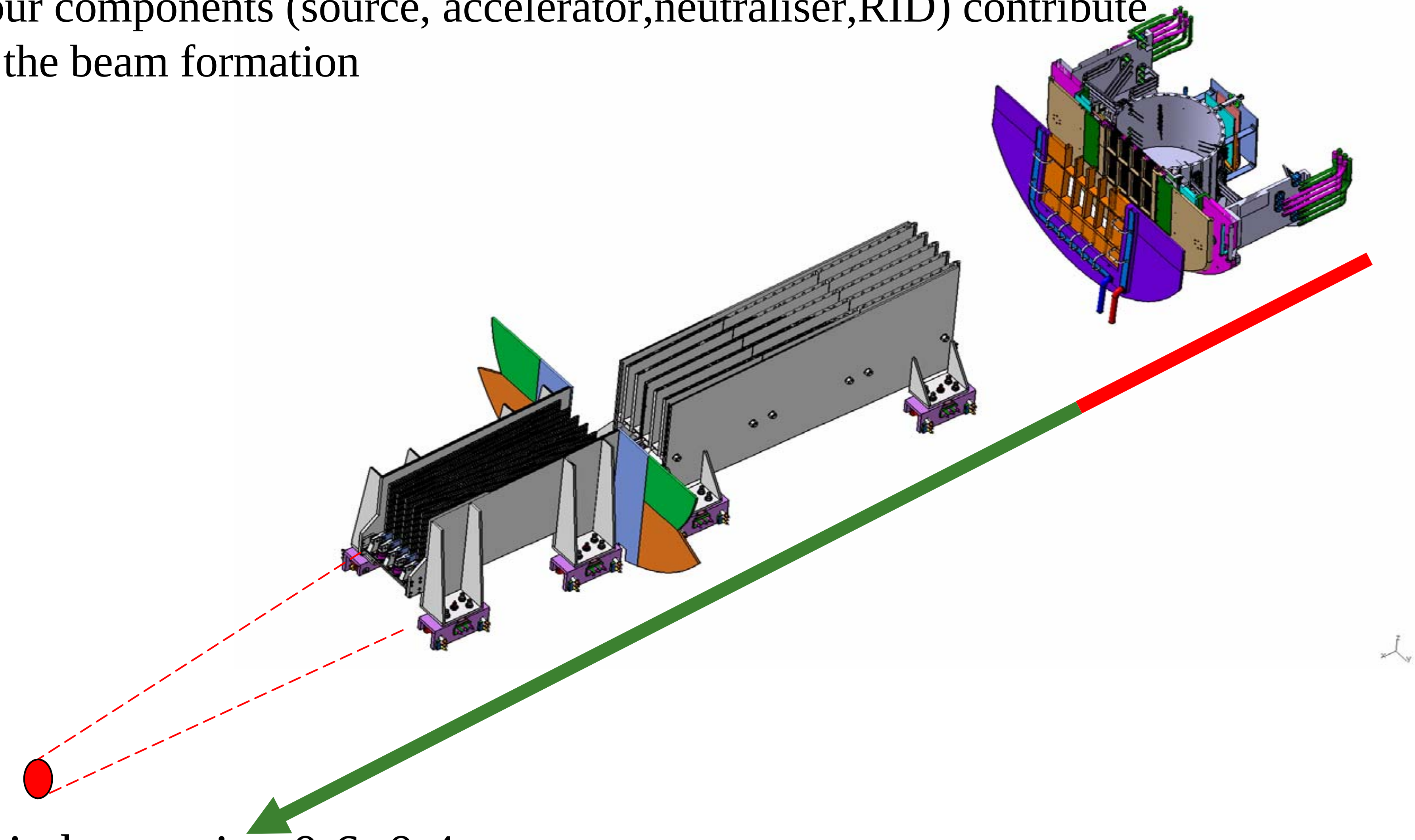


MITICA → layout



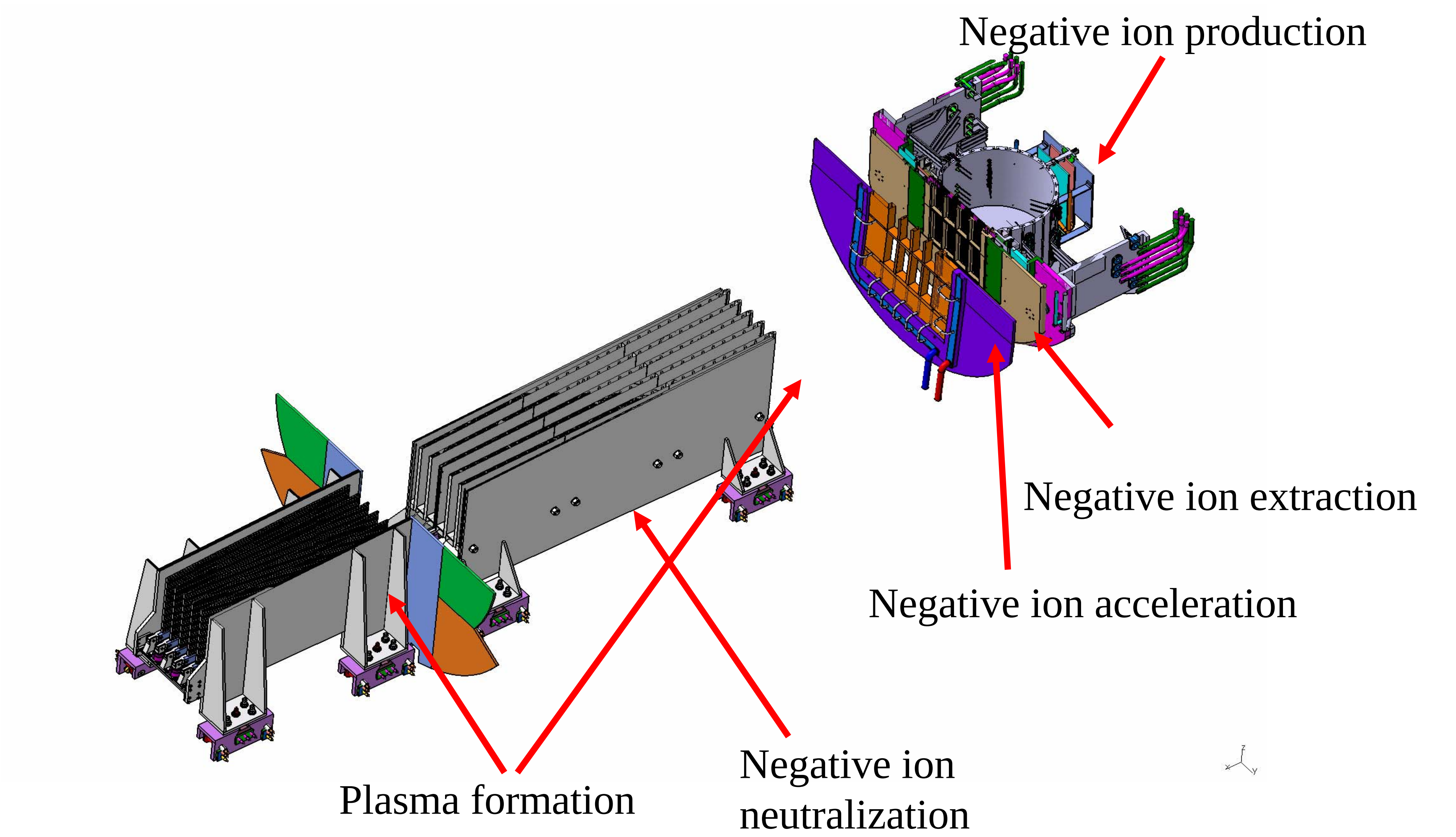
Beam formation

Four components (source, accelerator,neutraliser,RID) contribute to the beam formation



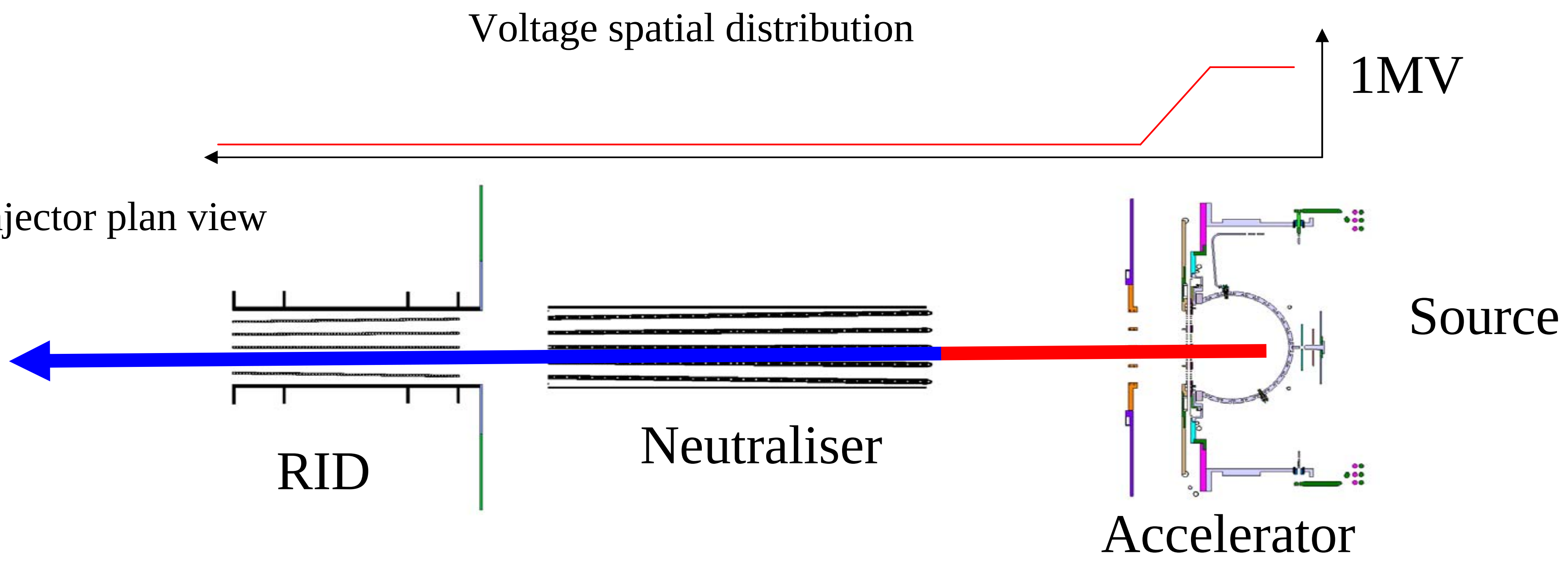
Elliptic beam size 0.6x0.4m

Physics



Negative ion production
Negative ion extraction
Negative ion acceleration
Plasma formation
Negative ion
neutralization

Beam formation (acceleration and neutralisation)



neutralisation of D^- ions by charge exchange collisions with D_2 molecules:

neutralisation

$$D^- + D_2 \Rightarrow D^0 + D_2 + e$$

re-ionisation (competing reaction)

$$D^0 + D_2 \Rightarrow D^+ + D_2 + e$$

Additional electrons from
a) co-extraction,
b) Stripping losses (low p: p_{source}<0.3Pa)
c) Secondary electrons

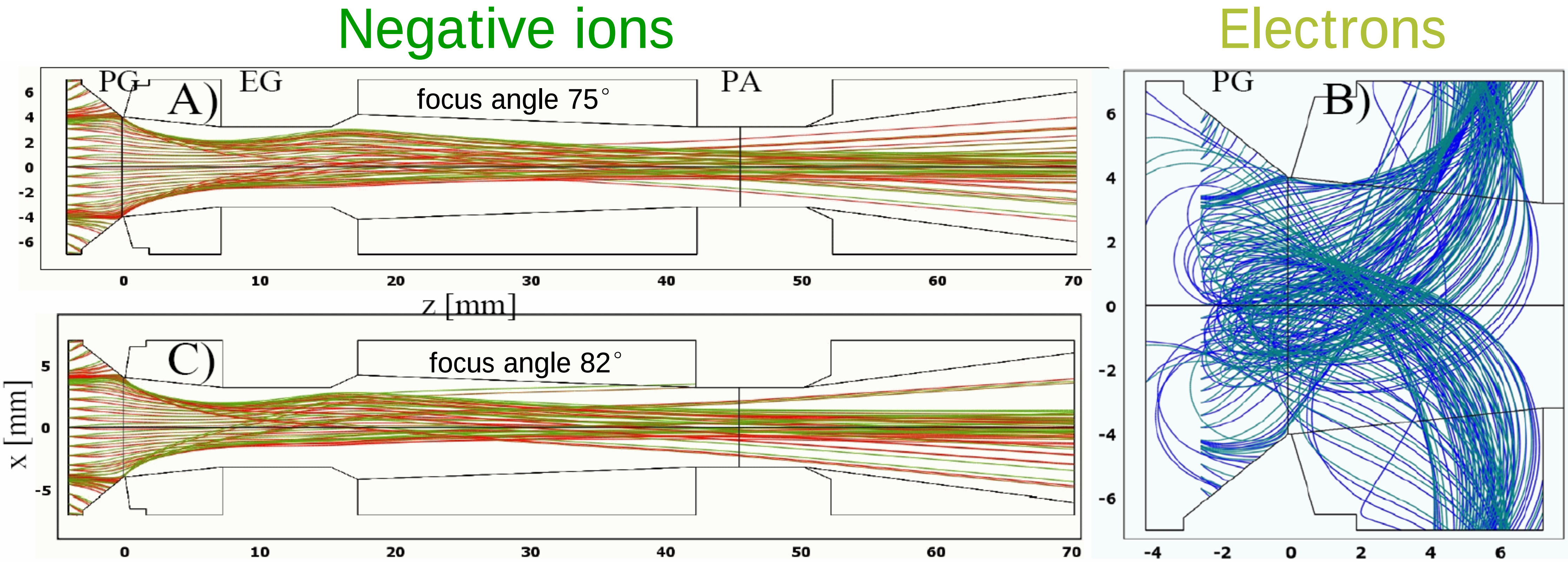
Main atomic reactions

- secondary electrons due to ion and electron impact
- back-scattering of ions and electrons

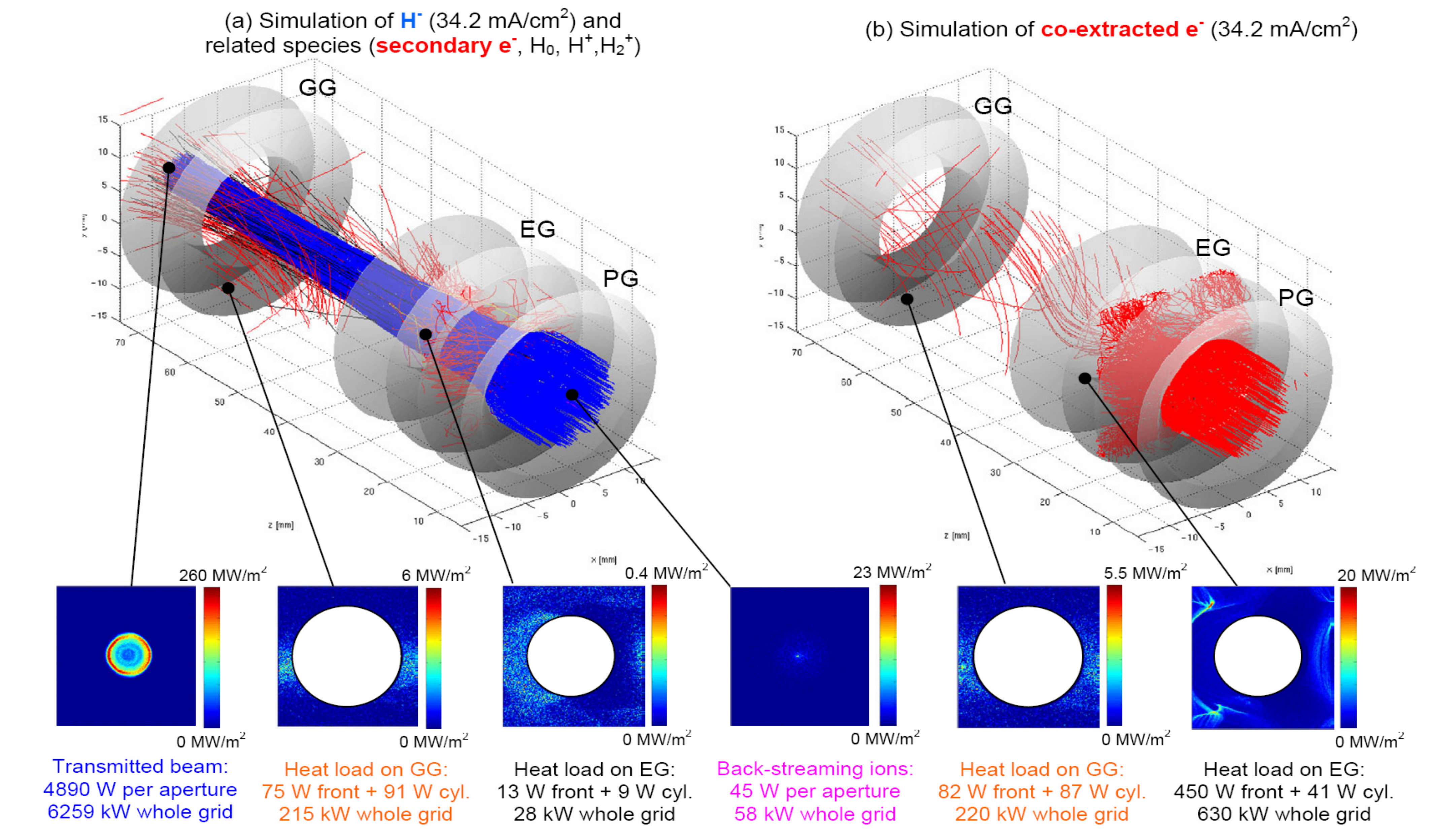
- interaction of ions and residual gas:

Reaction #	Process	Label
1	$H^- + H_2 \rightarrow H^0 + H_2 + e^-$	Single stripping
2	$H^- + H_2 \rightarrow H^+ + H_2 + 2e^-$	Double stripping
3	$H^- + H_2 \rightarrow H^- + H_2^+ + e^-$	Ionization
4	$H^0 + H_2 \rightarrow H^0 + H_2^+ + e^-$	Ionization

Simulazioni numeriche estrazione



Simulazioni numeriche accelerazione



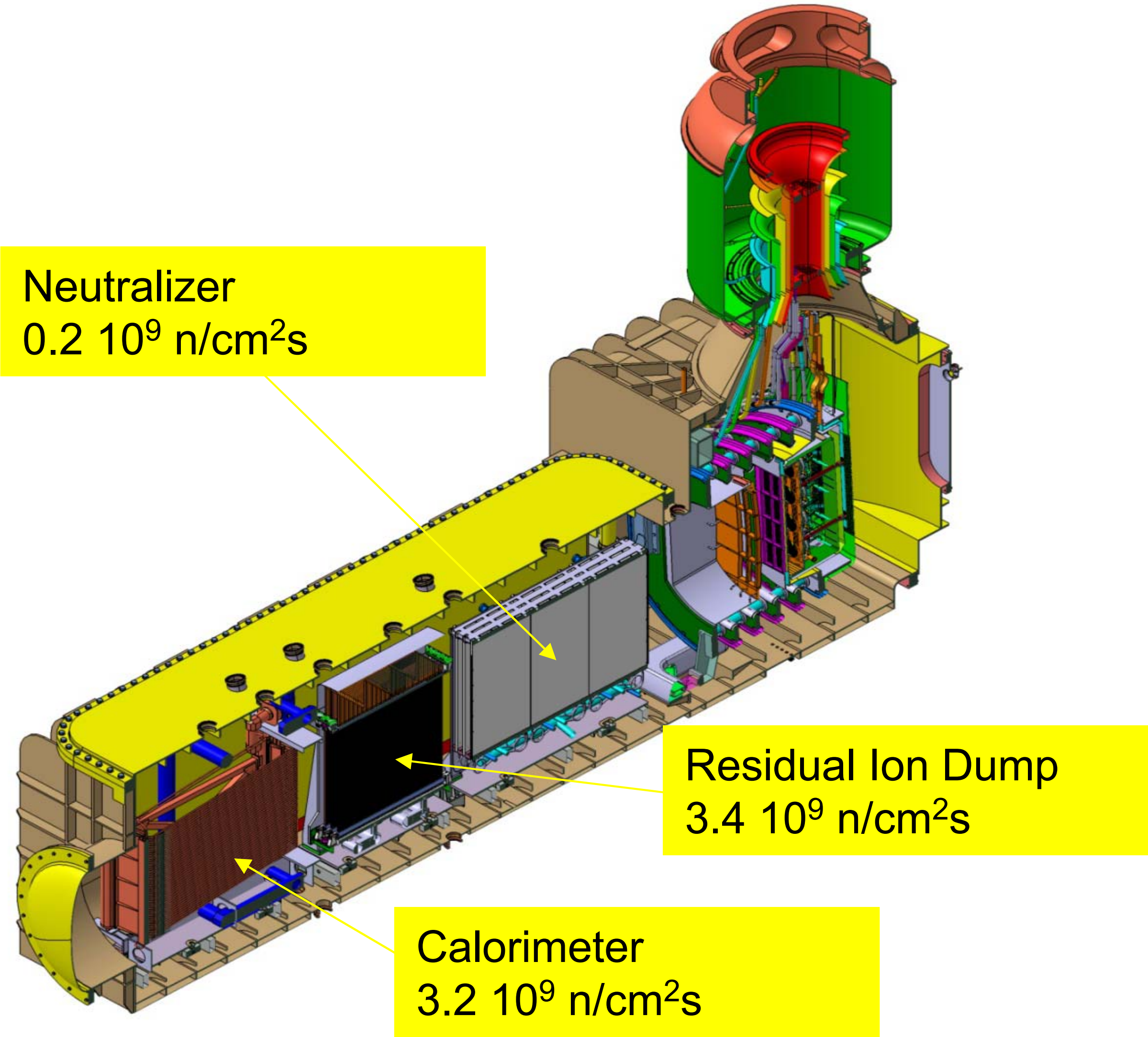
RADiaton COMpatibility Issue for NBI Injectors

- RADCOM has never been faced in the existing NBI systems up to now
  - Moderate beam energy (<0.3 MeV)
  - Moderate power (<1.5 MW)
  - Absence of thermonuclear plasma

- In ITER, the injectors will be immersed in the radiation field produced by D-T reaction in the plasma and self-produced by the beam interaction with the beam-line components (grids, neutralizer, RID, calorimeter)
  - Radiation induced by the fusion reaction $^{2}_{1}D + ^{3}_{1}T \rightarrow ^{4}_{2}He(3.5MeV) + n(14.1MeV)$
  - Expected fusion power 500 MW
  - Beam energy up to 1 MeV
  - Beam power up to 40 MW

- MITICA/SPIDER experiments will face the effects caused by the self-produced radiation field

n flux distribution in MITICA



Estimated value of integral neutron flux for 1A of deuterons

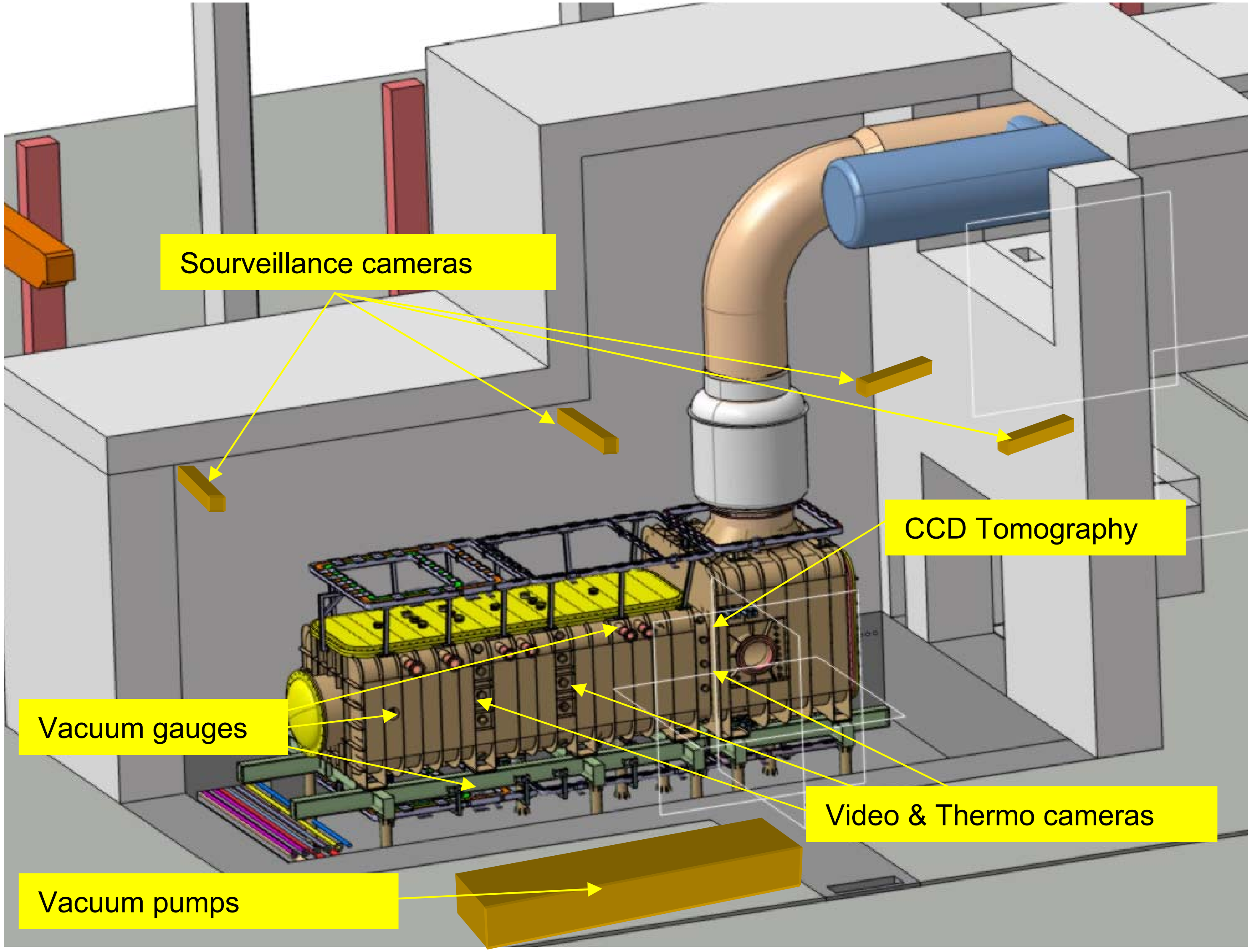
Neutron flux generated by interaction between deuteron beam with deuterons implanted:
D + D → T (1.01 MeV) + p (3.02 MeV)
D + D → 3He (0.82 MeV) + n (2.45 MeV)
D + T → 4He (3.5 MeV) + n (14.1 MeV)

D-T neutrons produce remarkable secondary γ emission

Xrays bremmstrahlung emission is also present

NEIGHBORING ELECTRONICS WILL BE VERY LIKELY AFFECTED

Electronic device locations



Example (not exhaustive) of the devices potentially equipped with electronics, which have to be installed inside the biological screen

Many other passive components will be here installed (cables, Optical Fibers, windows, thermocouples…) and shall be Radiation compatible

The design of the diagnostic, vacuum and ancillary systems has to be carried out taking into account RADCOM, to guarantee an adequate experiment availability.

Same considerations apply to the SPIDER experiment, even if the radiation environment is less severe

Actions

- Accurate mapping of the radiation field
  - n integrated flux in energy slots (< 0.4eV, 1÷10MeV, 10÷20MeV) to evaluate Single Event Effect risk
  - Photons (X&γ) accurate rates and total doses and energetic spectra, to evaluate Total Ionizing Dose risk
- Creation of component database
  - Electronic device category
  - Material
  - Location / Shielding
- Compatibility assessment
  - Failure risk evaluation
  - Design change request
  - Mitigation prescriptions

An activity is going to be launched between
the Dept. of Information Engineering (DEI) – Padova University
Radio Protection Service – ENEA Research Center Frascati
Consorzio RFX - Padova

Tempi

- Progetto di SPIDER in fase di conclusione della preparazione delle Spec. Tecn. per la fase di gara
  - Gare per l’assegnazione dei componenti principali nel 2009
  - Operativo nel 2013

- MITICA
  - Progetto in corso
  - Gare principali nel 2010-2011
  - Operativo nel 2015

- Garanzia a ITER di operare sino al 2030