Status of NBI for ITER and the related test facility

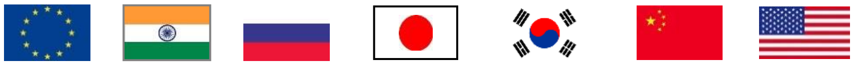
The NBTF team – presented by G. Serianni

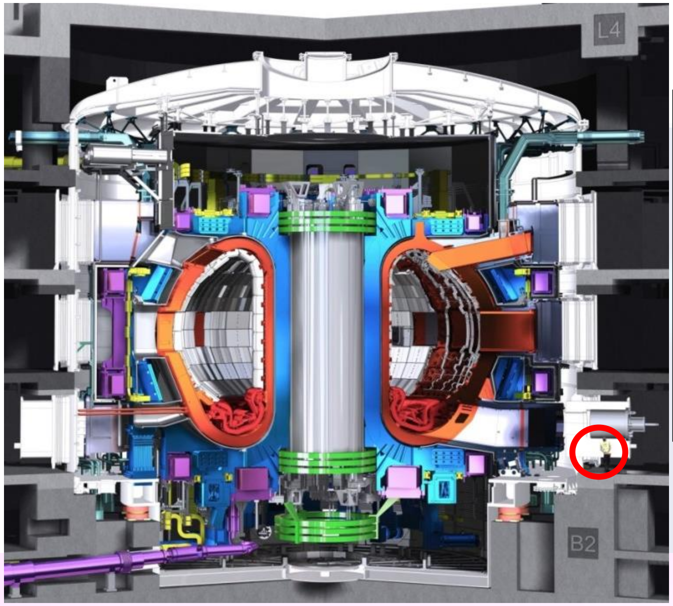
Consorzio RFX, Padova, Italy

LNL, Legnaro (PD), Italy

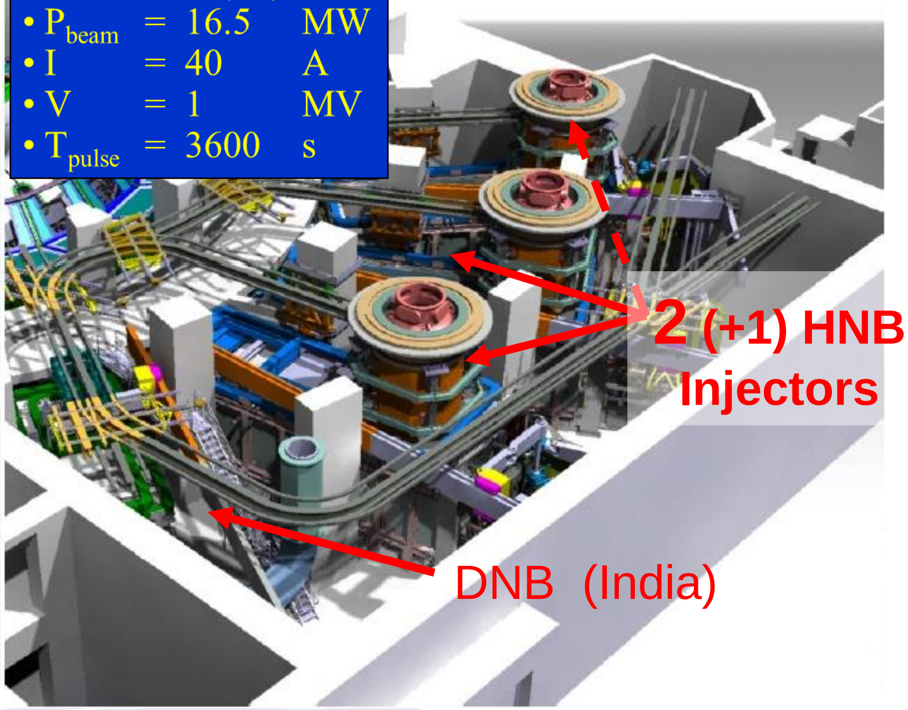
Neutral Beam Injectors (NBI) for ITER H-CD

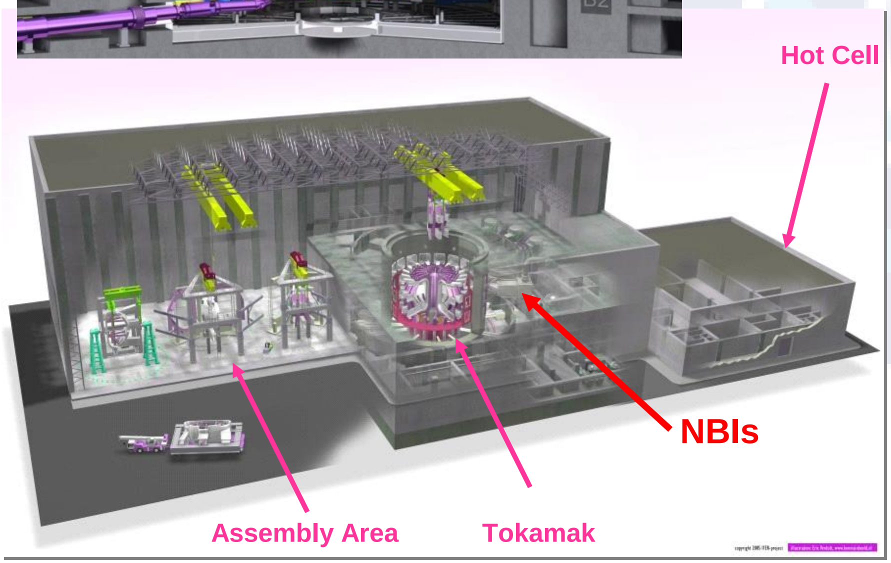
CONSORZIO RFX
Ricerca Formazione Innovazione





- 2 N-HNBs (+1)
- P_{beam} = 16.5 MW
- I = 40 A
- V = 1 MV
- T_{pulse} = 3600 s





Large scientific/technological step from existing NBIs ➔ a full scale Neutral Beam Test Facility (PRIMA)

Agreements between IO and F4E (with endorsement of Japan and India) and between F4E and Consorzio RFX

R. S. Hemsworth et al., Rev. Sci. Instrum. **79** (2008) 02C109
L. Grisham et al., Fusion Eng. Des. **87** (2012) 1805

Summary

- Physics of ITER Neutral Beam Injectors (NBI)
  - SPIDER

	Unit	H	D
Beam energy	keV	100	100
Maximum Beam Source pressure	Pa	<0.3	<0.3
Uniformity	%	±10	±10
Extracted current density	A/m^2	>355	>285
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

  - MITICA

	Unit	H	D
Beam energy	keV	870	1000
Acceleration current	A	49	40
Maximum Beam Source pressure	Pa	0.3	0.3
Beamlet divergence	mrad	≤7	≤7
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

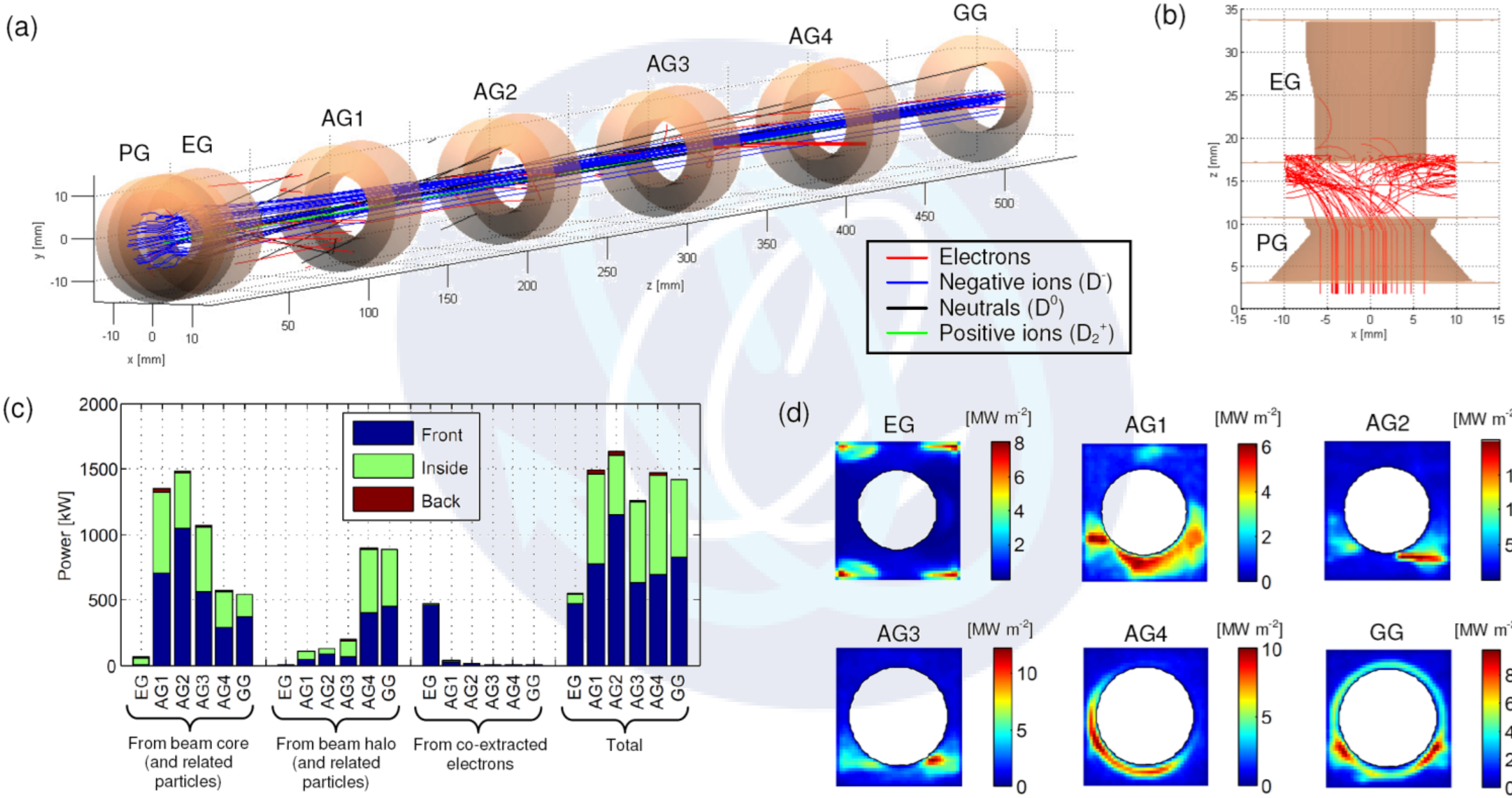
- Status of PRIMA, the ITER NBI test facility

L. Svensson et al., SRD-53-PR, -MI, -MP, -SI, -SP (NEUTRAL BEAM TEST FACILITY), Version 1.2, ITER Organization internal document ITER_D_2WCCSG, October 2009

- The accelerators of ITER Neutral Beam Injectors

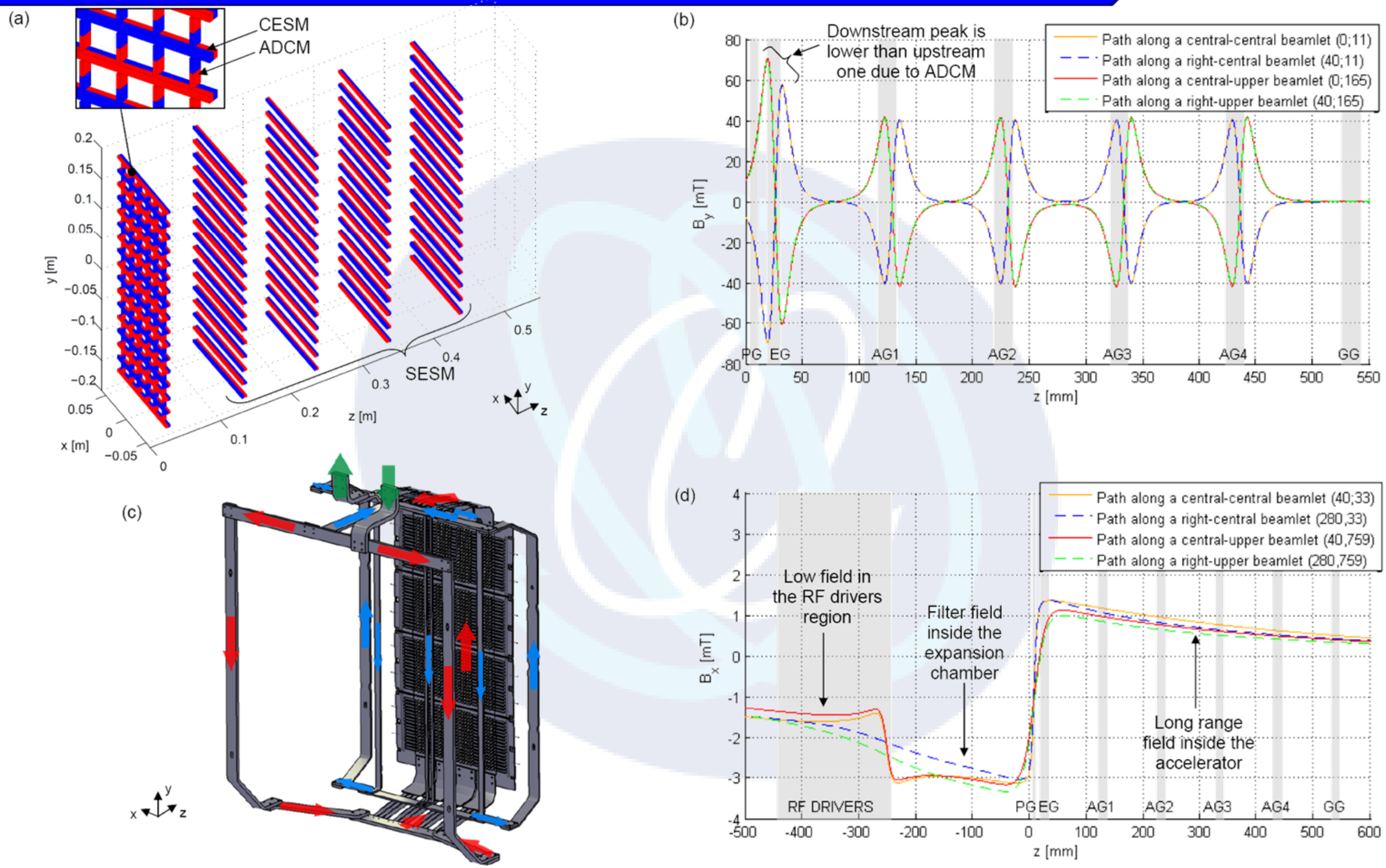
Physics design: particle trajectories & heat loads

- Based on designs by IPP (RF source) and JAEA (5-stages accelerator)



P. Agostinetti et al., Nucl. Fusion **56** (2016) 016015

MITICA: Magnetic configuration

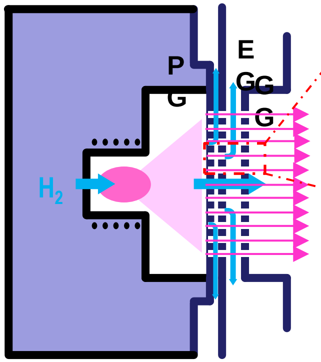


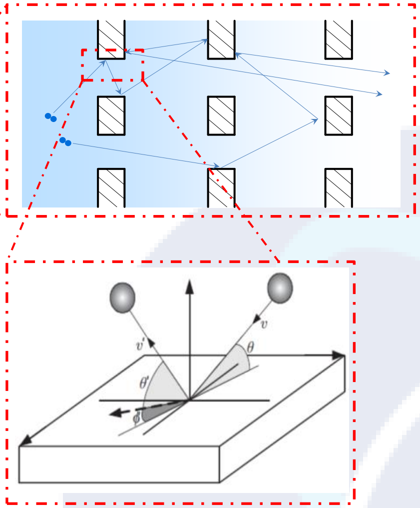
G. Chitarin et al., Rev. Sci. Instrum. **85** (2014) 02B317

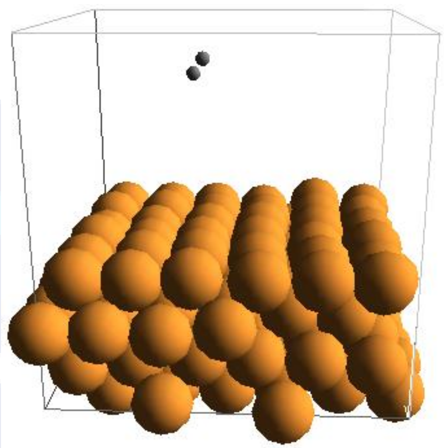
V. Antoni et al., Rev. Sci. Instrum. **85** (2015) 02B128

G. Chitarin et al., patent WO2014191890), MAGNET GRID

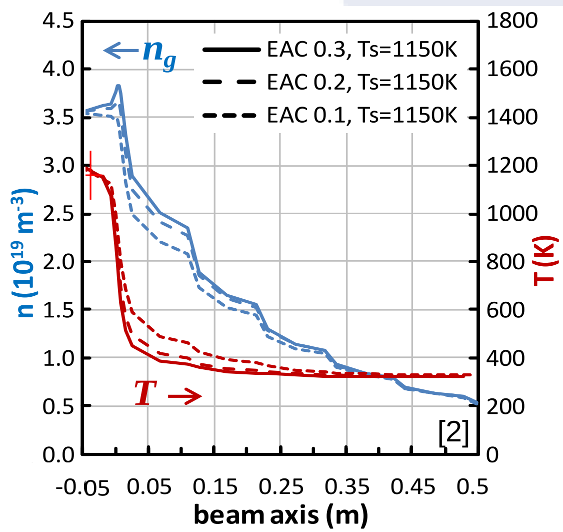
Background gas density

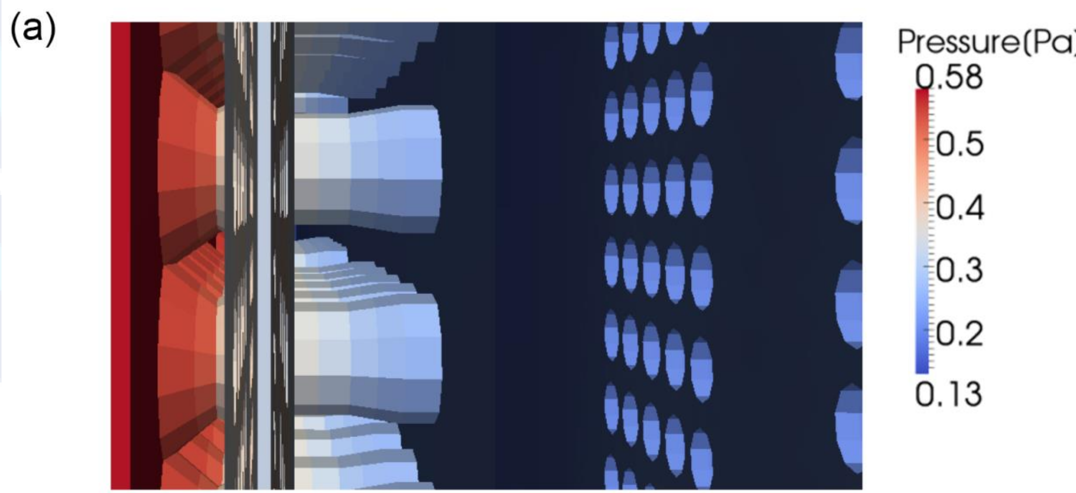






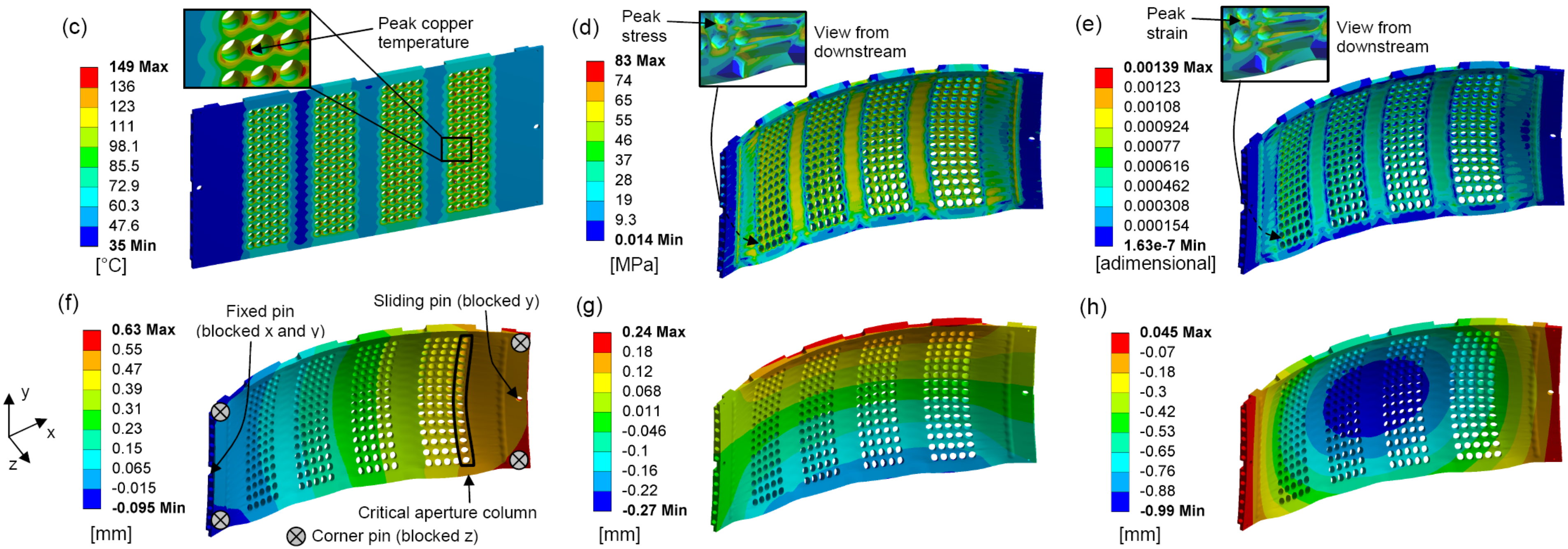
- single impact on nanoscale
- H_2, D_2 on Cu
- different gas temperatures
- sampling gas velocity distrib. (1000 simulations per point)
- C++, parallel implementation





E. Sartori et al., Rev. Sci. Instrum. **87** (2016) 02A502

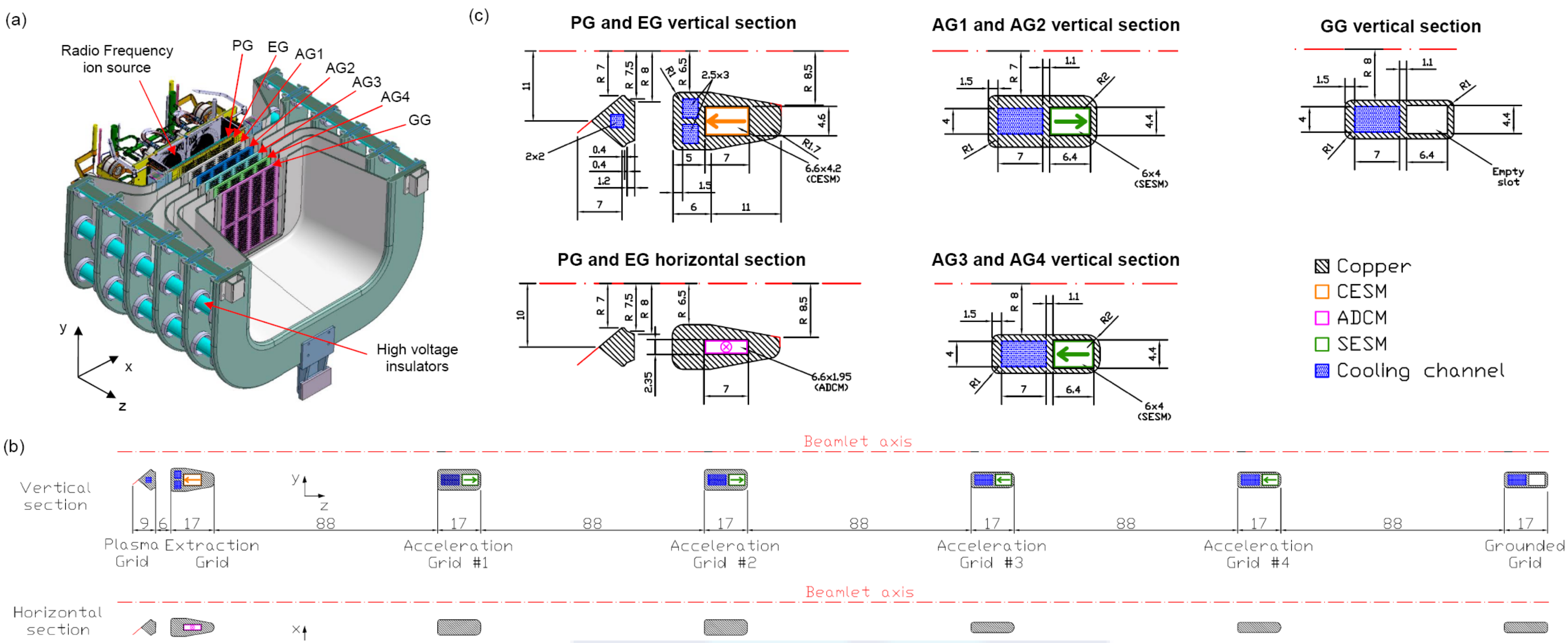
Heat loads and optics: feedback



P. Agostinetti et al., Nucl. Fusion **56** (2016) 016015

MITICA grid system

CONSORZIO RFX
Ricerca Formazione Innovazione



P. Agostinetti et al., Nucl. Fusion **56** (2016) 016015

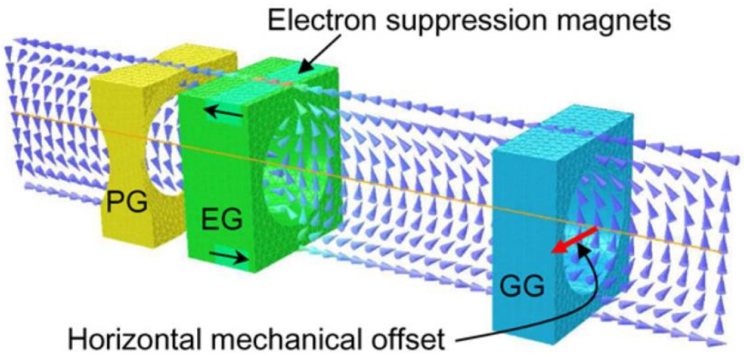
SPIDER: magnetic system

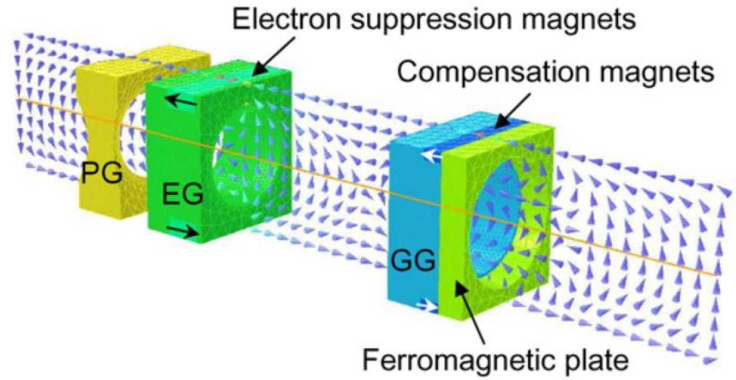
CONSORZIO RFX
Ricerca Formazione Innovazione

1. Mechanical offset of the GG apertures

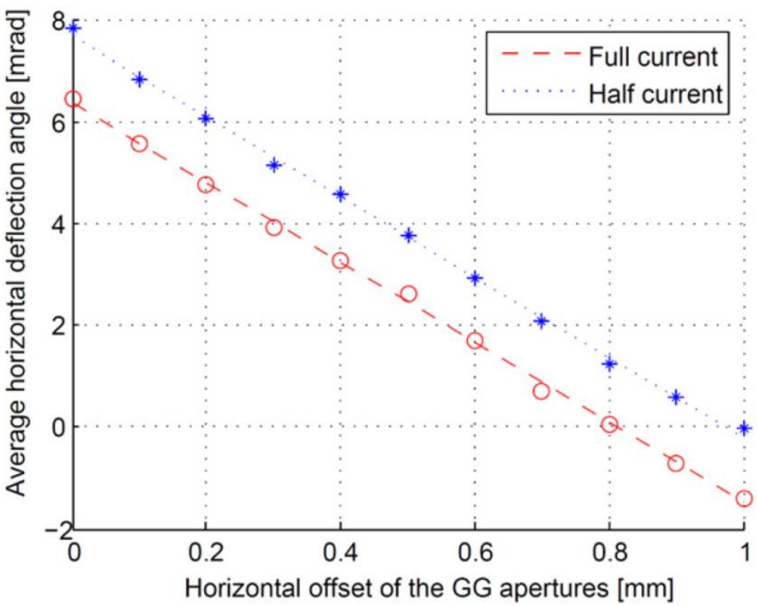
2. Deflection magnets and ferromagnetic material added to the GG

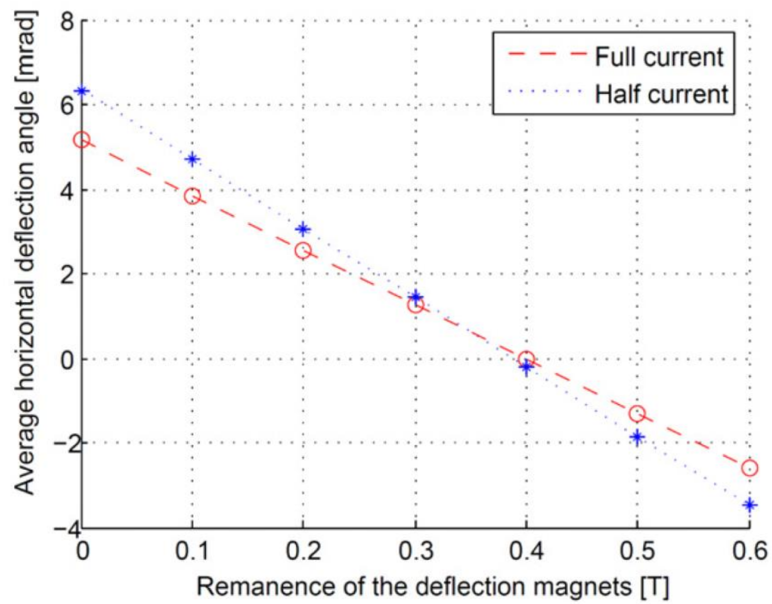
OPERA-3D model





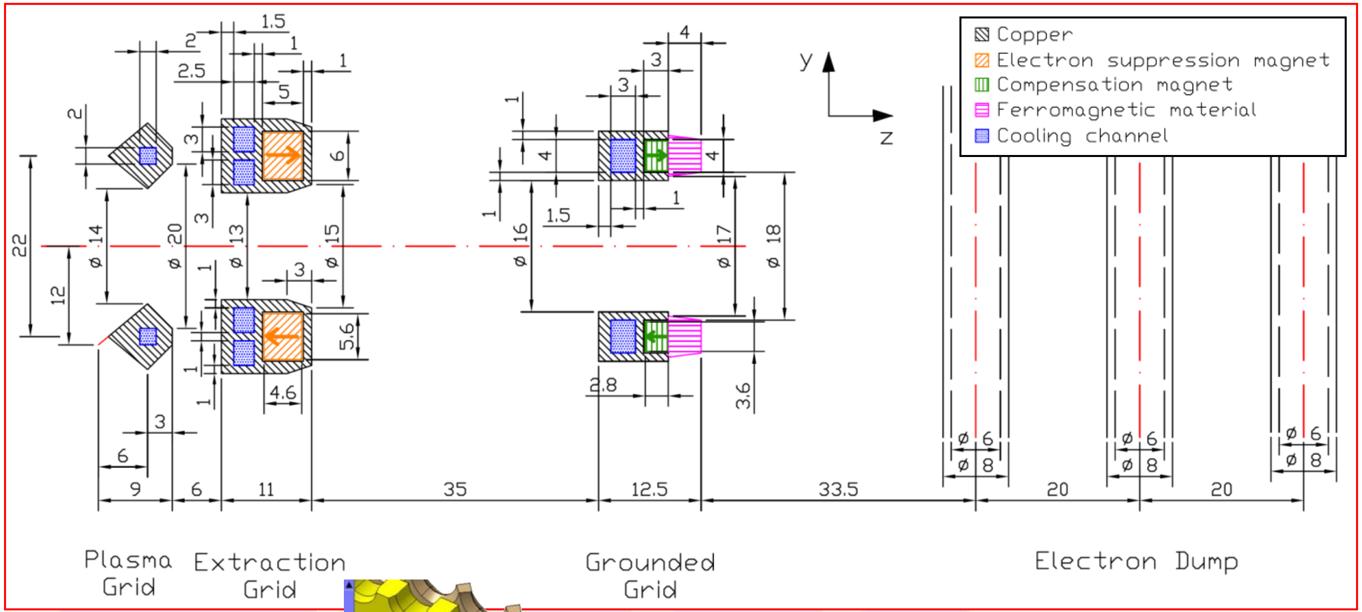
Deflection compensation



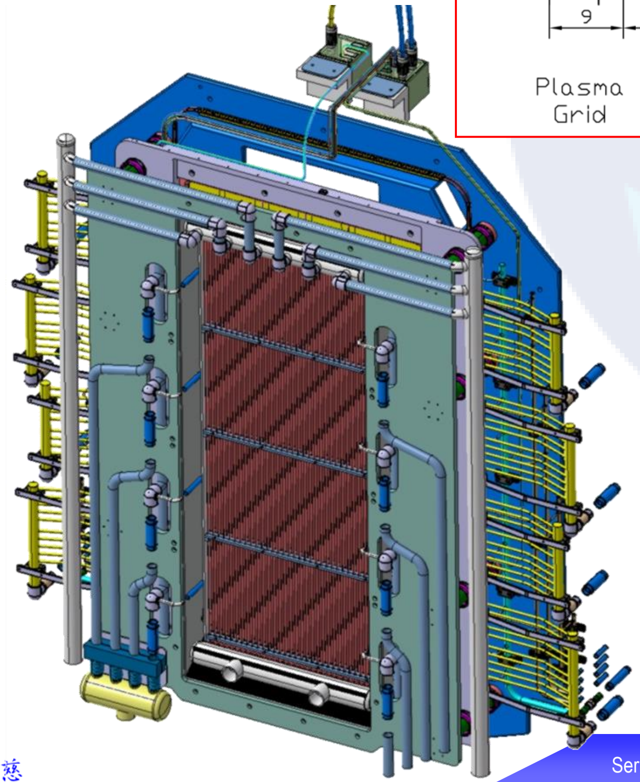


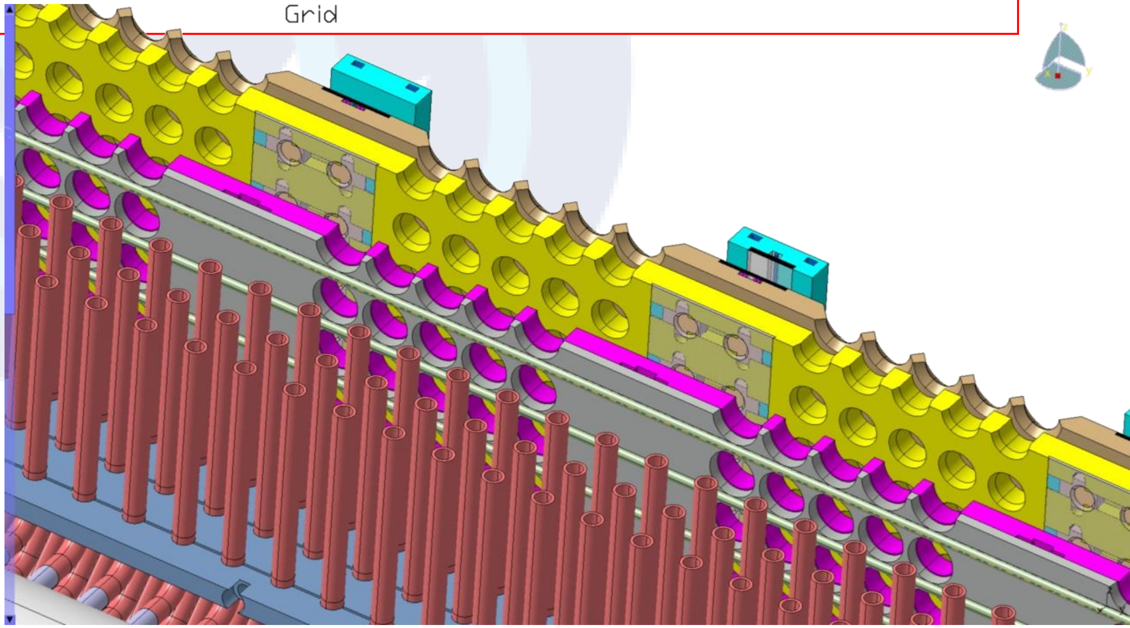
P. Agostinetti et al., Nucl. Fusion **51** (2011) 063004

SPIDER grid system



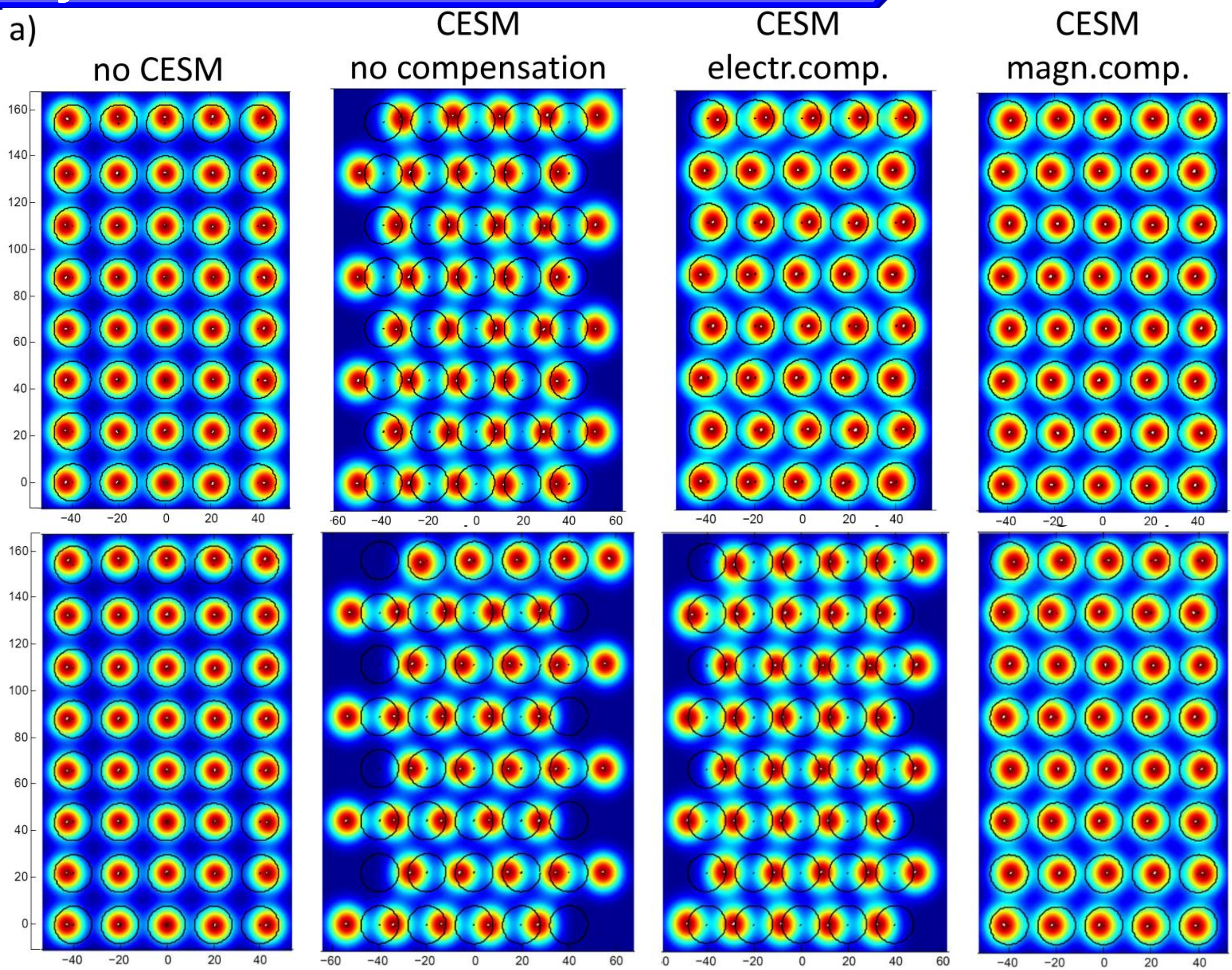
P. Agostinetti et al., Nucl. Fusion **51** (2011) 063004





Simulations of SPIDER magnetic deflection compensation systems

Jextr=100%
V_{GG}/V_{EG}=
100kV/9.4kV

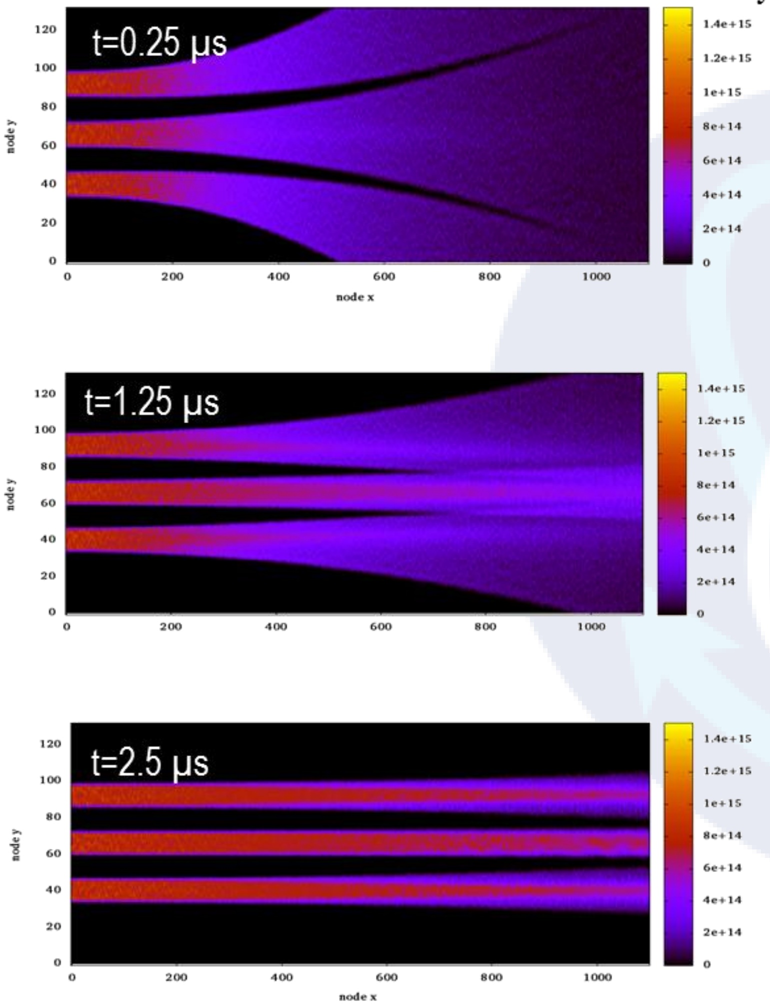


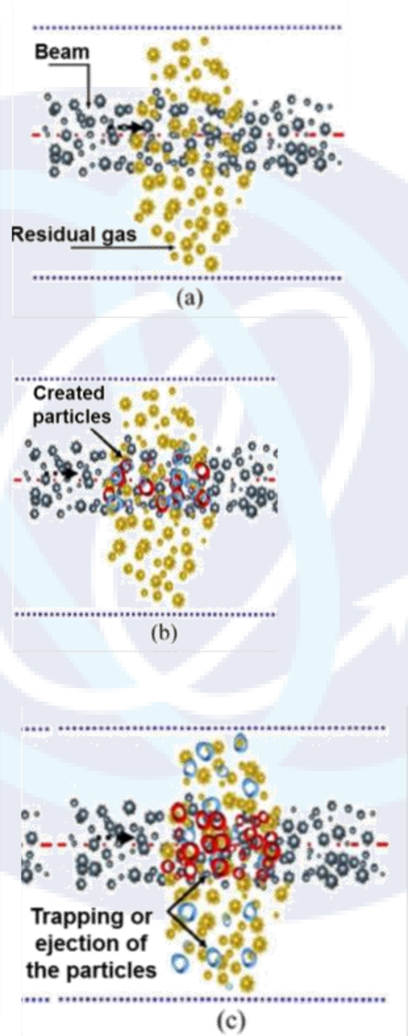
Jextr=10%
V_{GG}/V_{EG}=
22.4kV/2.14kV

C. Baltador et al., Rev. Sci. Instrum. **87** (2016) 02B141
G. Serianni et al., Rev. Sci. Instrum. **87** (2016) 02B927

Drift region: space charge compensation

H- density





At t=0 the beamlets expand under the influence of their own space charge

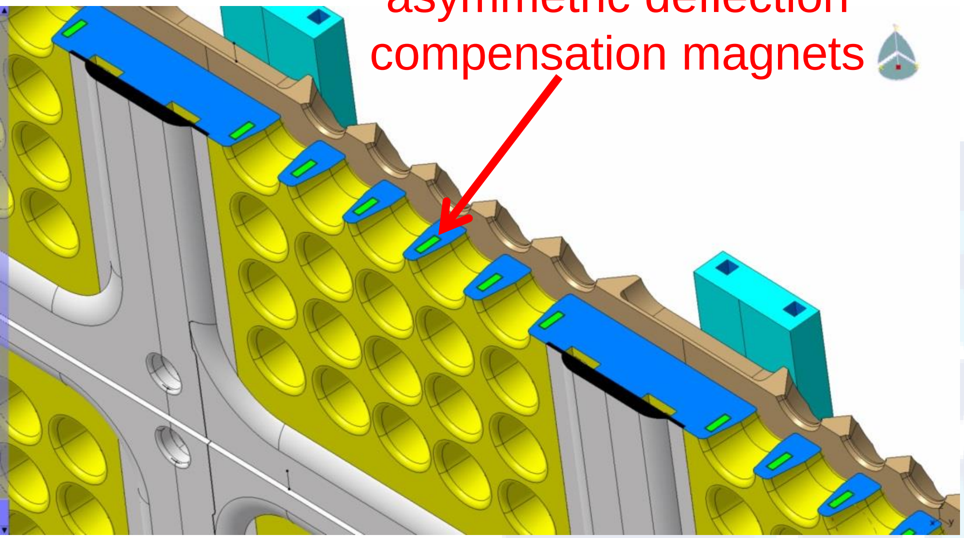
By interactions with background gas the secondary particles are created: main reactions: ionization of H_2 by H- and stripped electrons

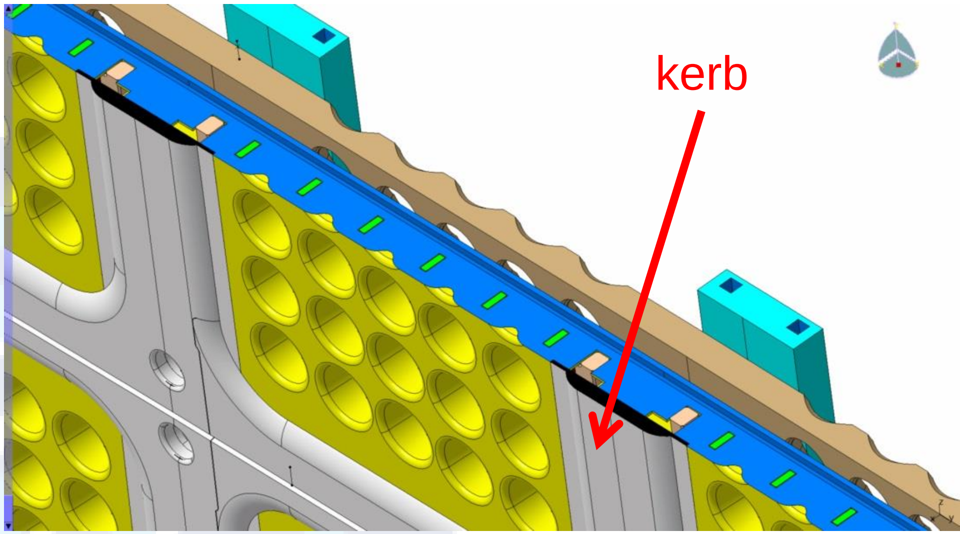
A balance between trapped and ejected particles establishes

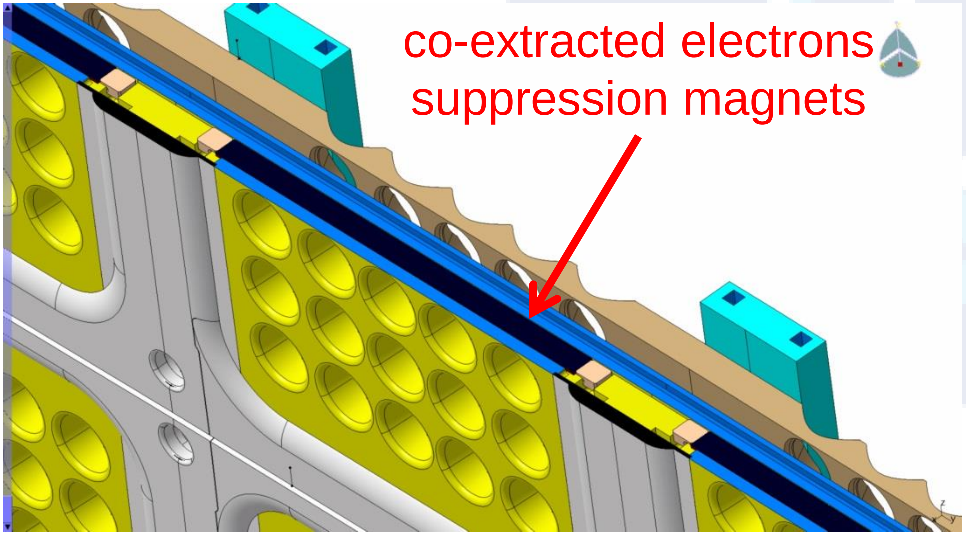
System reaches the equilibrium in a time: $t=1/(n_{gas}\sigma_{ion}*v_b) \approx 3\ \mu s$. ($n_{gas}$, σ_{ion}, v_b are gas density, ioniz. Cross section and beam speed respectively.)

E. Sartori et al., Rev. Sci. Instrum. **87** (2016) 02B917

MITICA Extractor and Accelerator







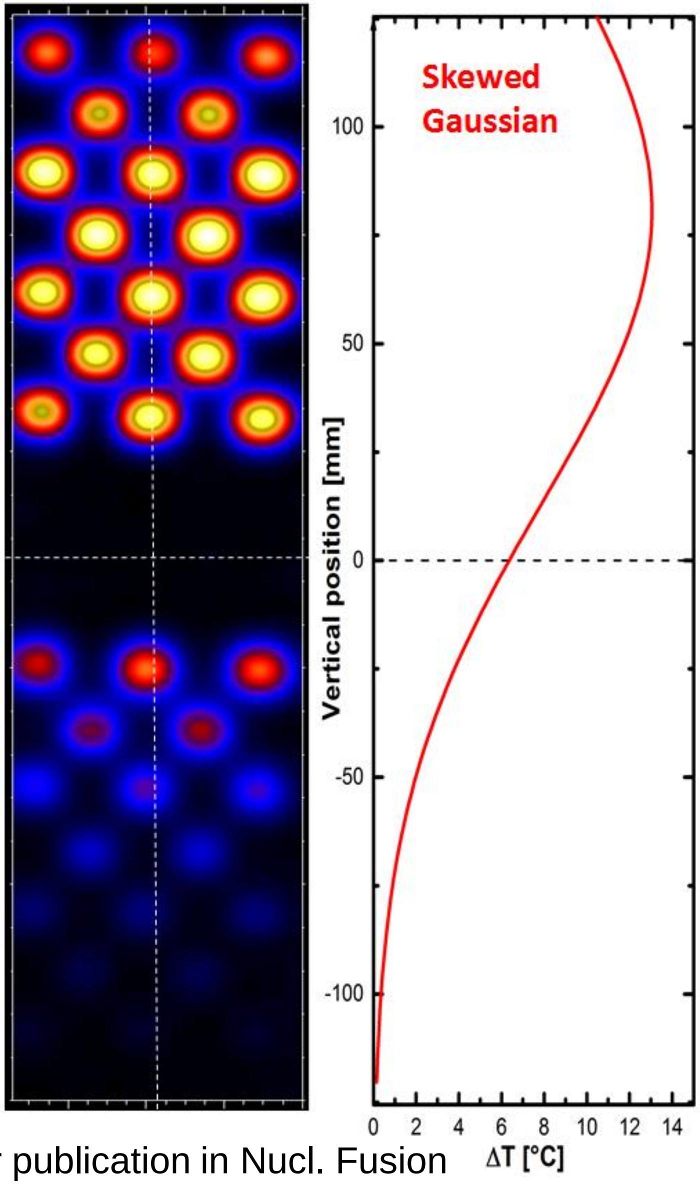
- Aiming:
  - Horizontal & vertical beamlet aiming
  - Vertical beamlet group aiming
- Compensation of repulsion:
  - Aperture displacement
  - Kerbs

Test of diagnostic systems: collaboration IPP-Consorzio RFX

Max-Planck-Institut für Plasmaphysik
EURATOM Association

CONSORZIO RFX
Ricerca Formazione Innovazione

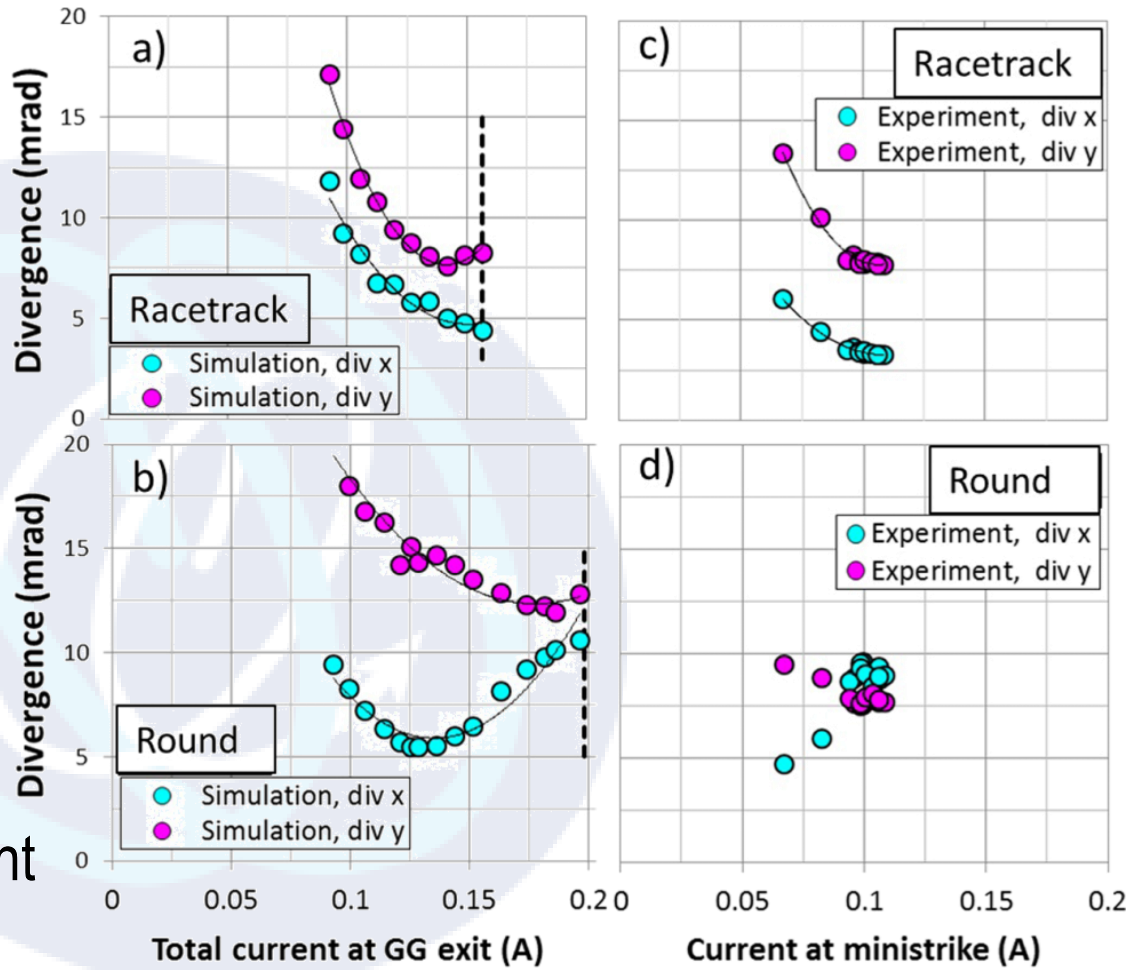
- Test of SPIDER diagnostic calorimeter (STRIKE)
- Test of diagnostic tools (CCD)
- Collaboration on diagnostic exploitation (spectroscopy)
- Direct experience on RF sources and beams



R. Maurizio et al., under review for publication in Nucl. Fusion

Benchmark of numerical codes: collaboration NIFS-Consorzio RFX

- Measurements with mini-STRIKE in NIFS-RNIS
- Comparison with numerical simulations
- Test of current measurement



- Recently, analogous comparison activity started with NIO1 (see Veltri)

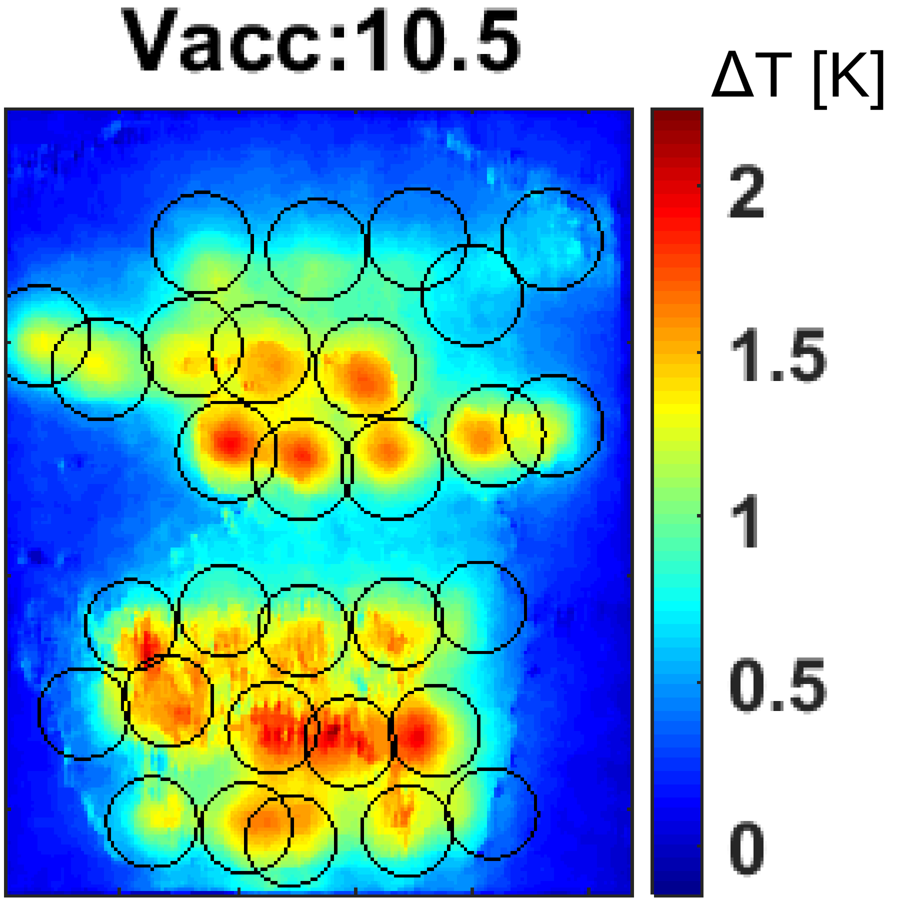
P. Veltri et al., Rev. Sci. Instrum. **87** (2016) 02B908

Test of Asymmetric Deflection Compensation: collaboration JAEA-Consorzio RFX

- Magnetic Grid for Asymmetric Deflection Compensation under validation in Negative Ion Test Stand at JAEA

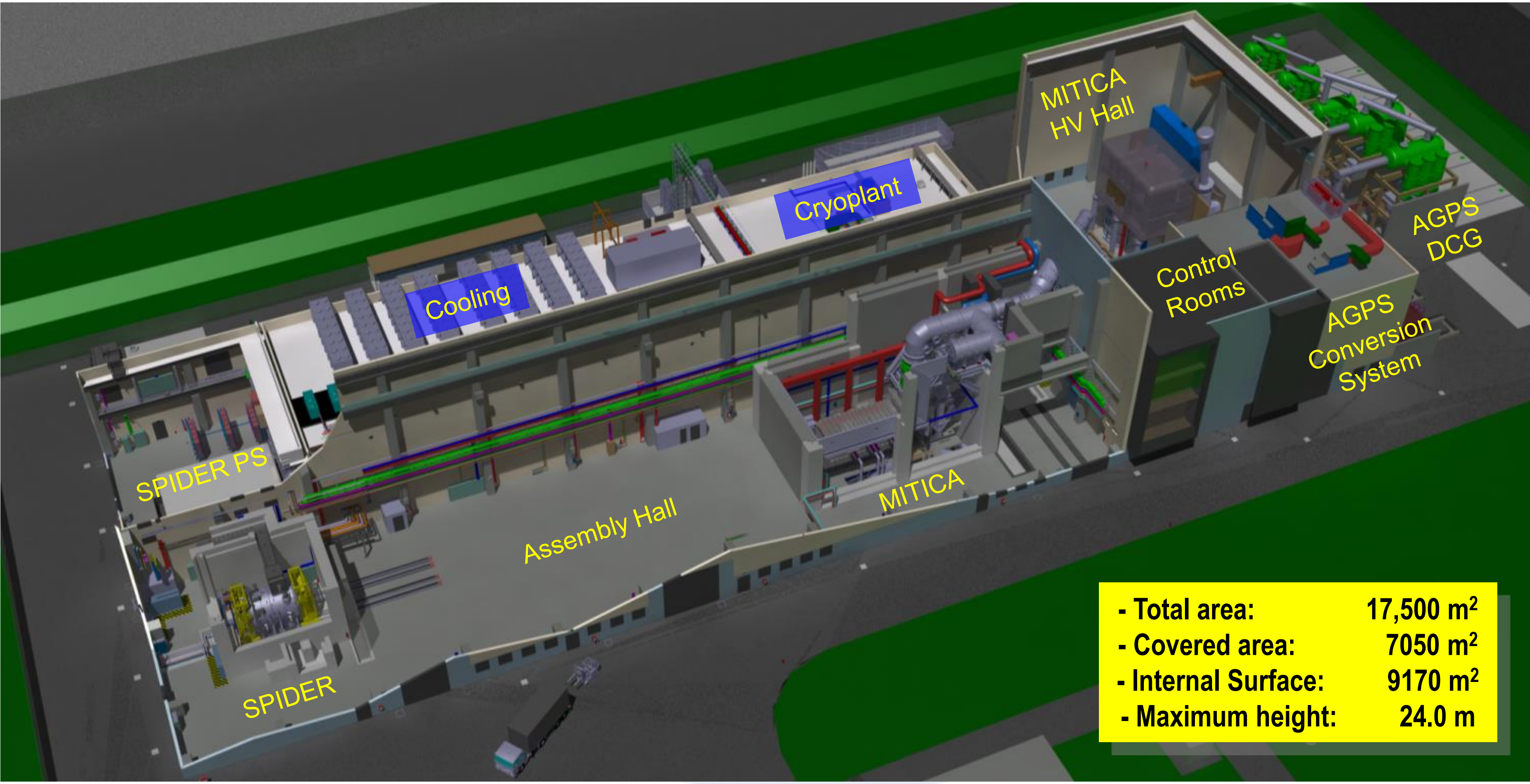
Half-grid featuring uncompensated magnetic deflection

Half-grid provided with Asymmetric Deflection Compensation Magnets



- Status of ITER NBI test facility, PRIMA

PRIMA: Neutral Beam Test Facility



- Total area:	17,500 m^2
- Covered area:	7050 m^2
- Internal Surface:	9170 m^2
- Maximum height:	24.0 m

Prima hosts the two experiments: the negative ion source **SPIDER** and the 1:1 prototype of the ITER injector **MITICA**

Each experiment is inside a concrete biological shield against X-rays and neutrons produced by the injectors

Thanks to this shielding the assembly/maintenance area will be fully accessible also during experiments

PRIMA - Buildings and Auxiliaries

Main building hosting experiments

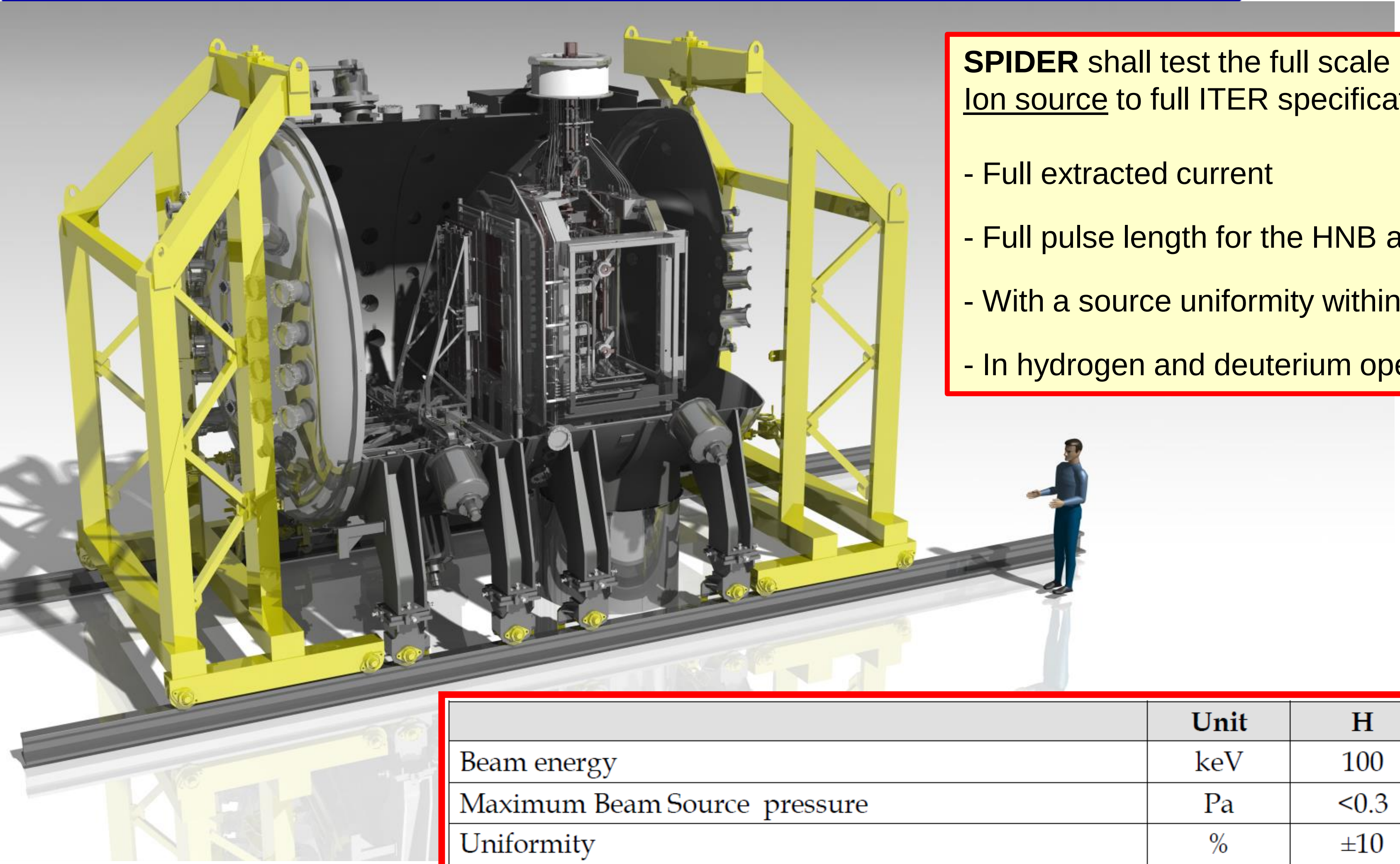

SPIDER PS hall

PRIMA buildings and auxiliaries available for plant installations since October 2014


Control rooms Buildings


HV Hall & Control Rooms

SPIDER

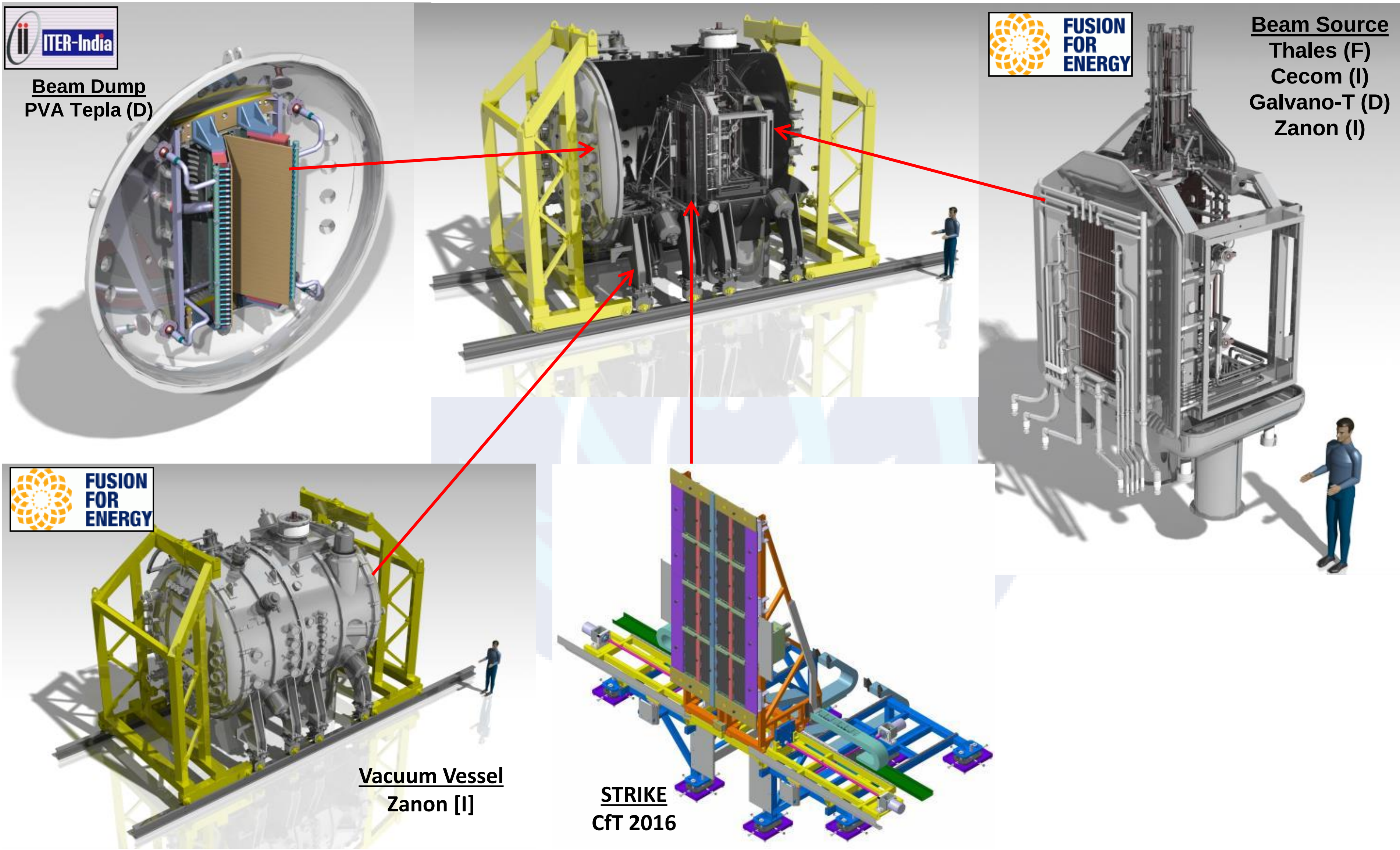


SPIDER shall test the full scale ITER HNB Ion source to full ITER specification:

- Full extracted current
- Full pulse length for the HNB and DNB
- With a source uniformity within ±10%
- In hydrogen and deuterium operation

	Unit	H	D
Beam energy	keV	100	100
Maximum Beam Source pressure	Pa	<0.3	<0.3
Uniformity	%	±10	±10
Extracted current density	A/m^2	>355	>285
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

SPIDER Source Components



SPIDER - Vacuum Vessel & Beam Source

The procurement contract includes Vacuum Vessel, Beam Source and Handling Tool

Contract signature in Oct 2012 with a Consortium (Thales, Zanon, Galvano-T, Cecom)

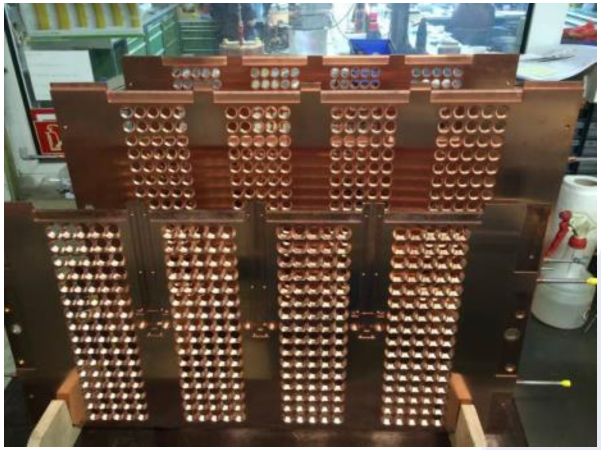
Vessel, realized by Zanon, delivered on Site in March 2015, Site Acceptance Tests passed, now electric and hydraulic flanges under installation

SPIDER VV during vacuum tests on-site

SPIDER VV during baking on-site

SPIDER VV inside the bio-shield

SPIDER - Beam Source

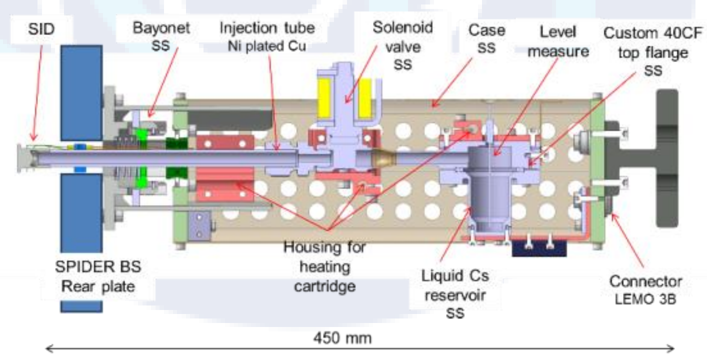


Plasma Grid segments machined

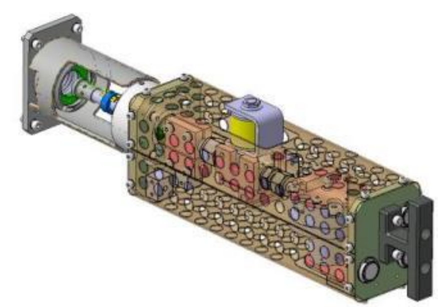
In vacuum He pressure and leak tests of the cooling circuit of a Plasma Grid segment

SPIDER Faraday Shields Lateral Walls manufactured and tested by Galvano-T

Views of: 112kV BS ceramic supports (a), 12kV PG-EG post insulators (b), 100kV EG-GG post insulators



Section view of the updated Cs Oven for SPIDER with main components



View of the updated CAD model of SPIDER Cs Oven

SPIDER - Beam Dump

- SPIDER Beam Dump (BD) procured by INDIA Domestic Agency
- BD delivered to Site on December 2014; Site Acceptance Tests performed in July 2015
- In 2016 Beam Dump to be completed with TC’s and then installed on a SPIDER Vessel Lid

SPIDER Beam Dump: Rear side

SPIDER Beam Dump: Front side

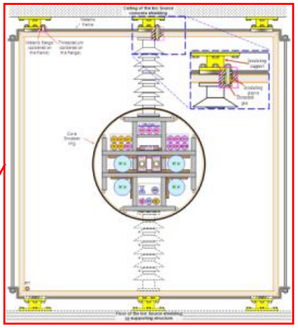
SPIDER PS - HV Deck & Transmission Line

Supplier: Coelme srl (I)

HVD during installation

HVD completed,
tested and accepted, during
Installation of ISEPS inside

Insulating
Cooling pipes



Cross-section

Factory tests of SPIDER Transmission Line

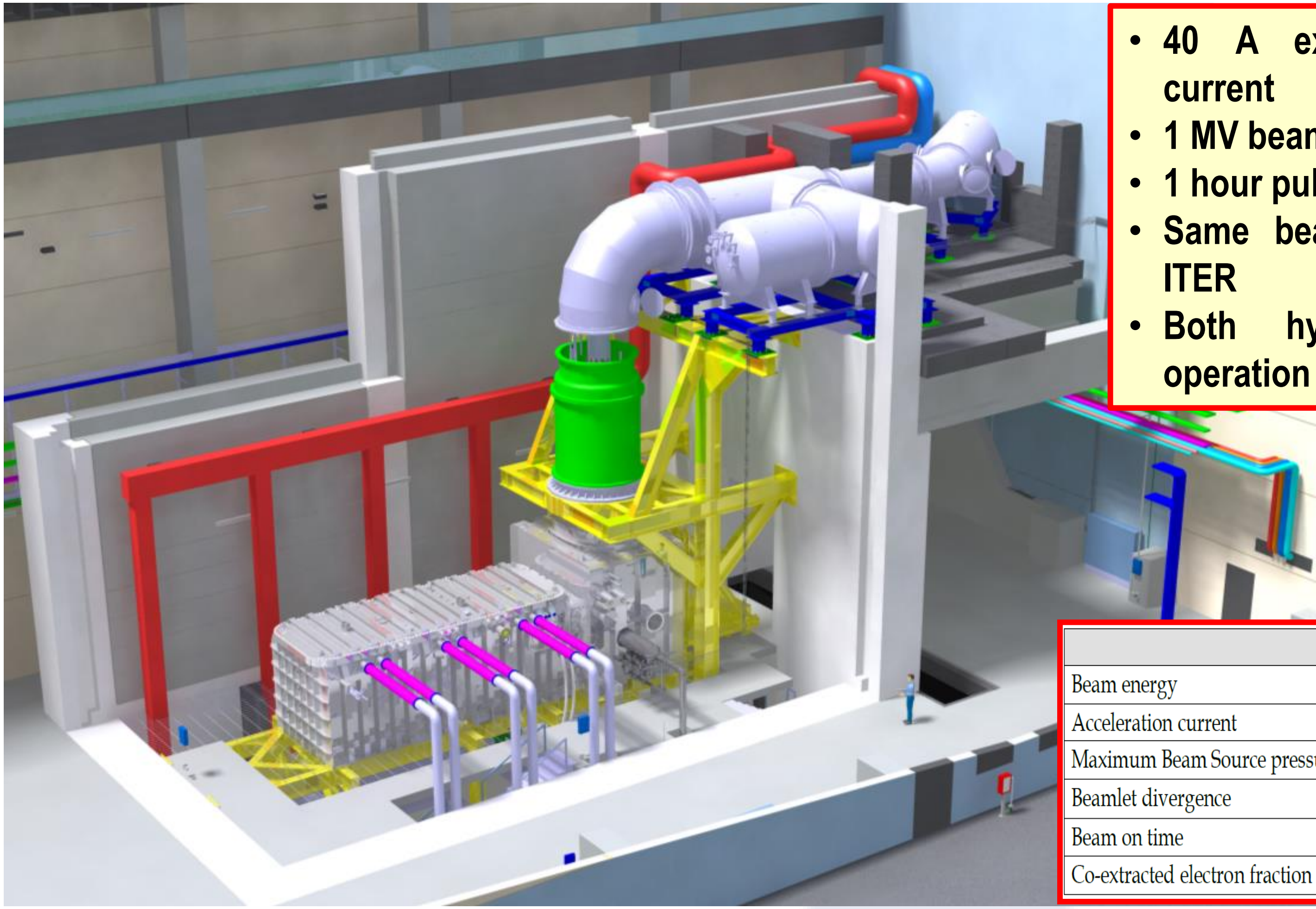
HV Deck is a Faraday cage, air insulated to ground at -100kV and hosting Ion Source Power Supply
External size: 13m x 11m x 5m
Insulating distance from ground and walls: 1m

Transmission Line connects HVD to SPIDER Vessel. Outer conductor grounded. Internal conductor, at -100kV, contains all ISEPS conductors. Insulation between inner and outer conductors by natural air

SPIDER – Summary of status

- procurement of SPIDER components shared between F4E and INDA
- design of all components concluded; all procurement contracts launched between 2010 and 2013
- Factory activities, including manufacturing of components and factory acceptance tests, well advanced for almost all components; many components and plant systems delivered on site and now under installation
  - AGPS: shipping started 8/3/2016; start of work on site expected end April 2016
- All components to be installed by middle 2016 apart SPIDER Beam Source, to be be delivered to site in Q4 2016 and installed right afterwards
- During 2016 integrated commissioning including power supply integrated tests to be performed
- Experimental phase to start at beginning of 2017

MITICA: 1:1 scale prototype of the ITER HNB injector

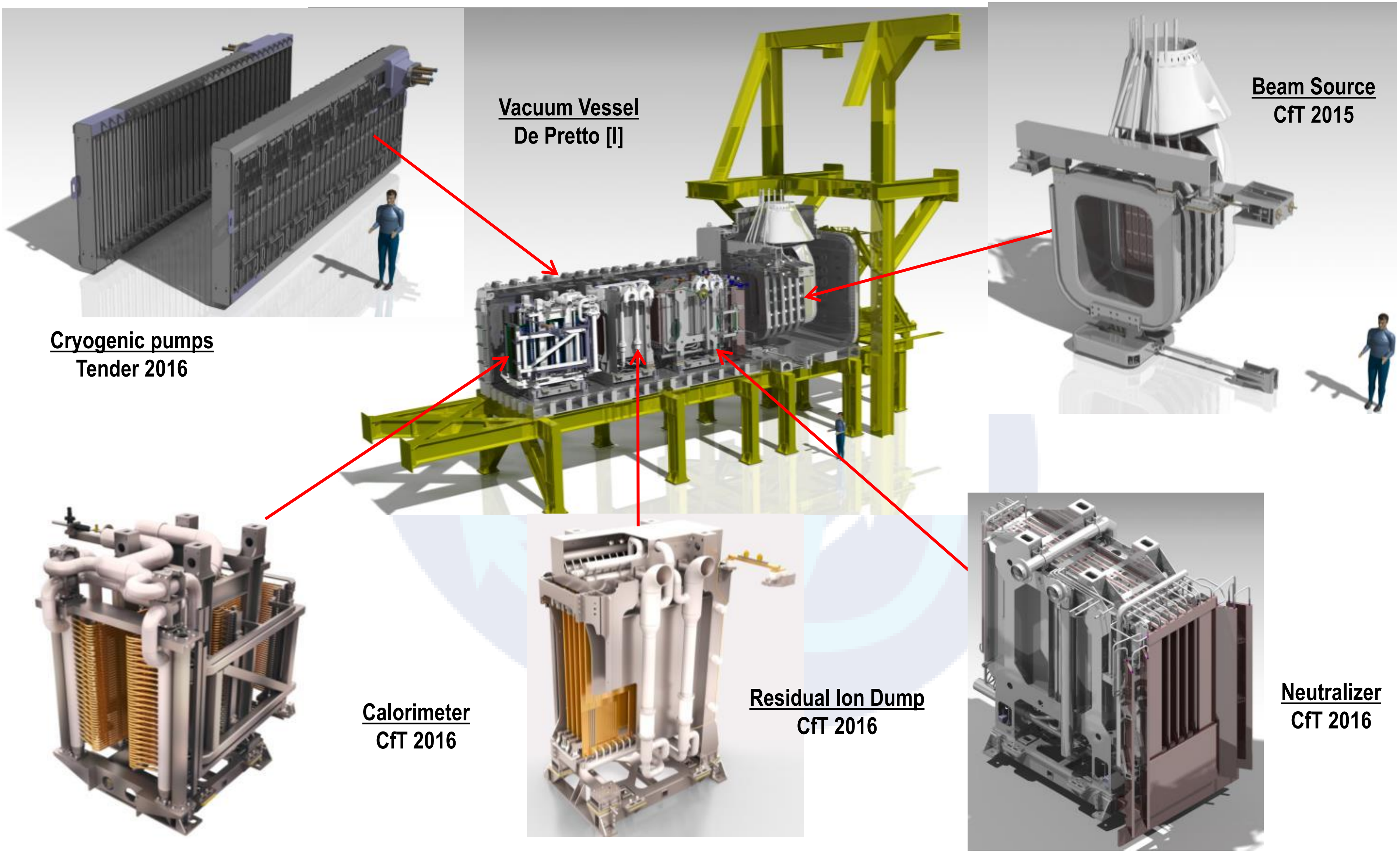


- 40 A extracted and accelerated current
- 1 MV beam energy
- 1 hour pulse length
- Same beam optics as needed for ITER
- Both hydrogen and deuterium operation

	Unit	H	D
Beam energy	keV	870	1000
Acceleration current	A	49	40
Maximum Beam Source pressure	Pa	0.3	0.3
Beamlet divergence	mrad	≤7	≤7
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

MITICA bio-shield and injector.
Transmission line (Japan Domestic Agency procurement) connected to vacuum vessel via High Voltage Bushing (in green), also procured by JADA

MITICA: Neutral Beam Injector Components

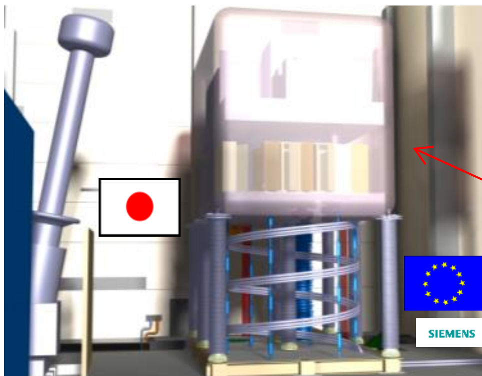


MITICA Power Supply

Aim: to feed Acceleration Grids (AGPS), Ion Source (ISEPS), and Residual Ion Dump (RID-PS) of MITICA injector

Main Systems:

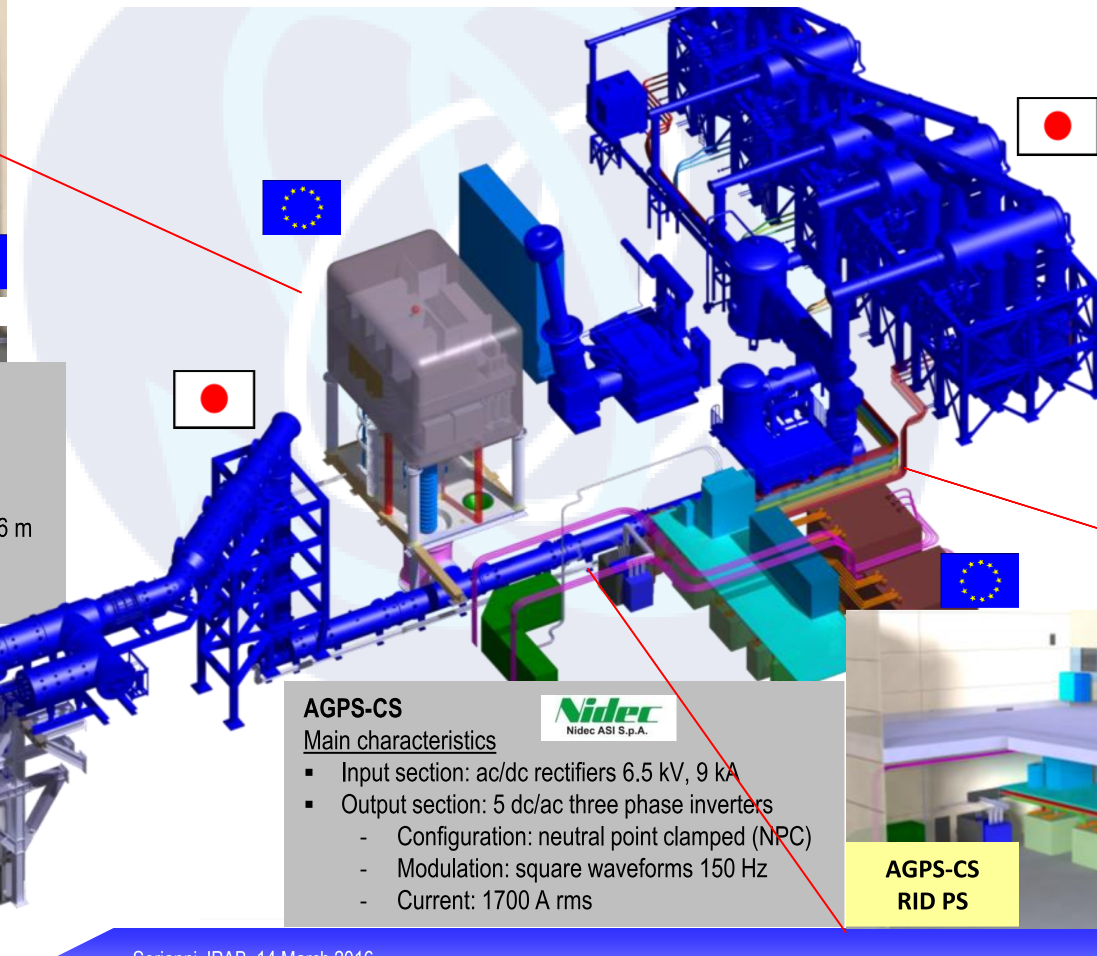
- AGPS composed of conversion system (AGPS-CS) feeding step-up transformers and diode rectifiers (AGPS-DCG)
- HV Transmission Line (TL) connecting power supplies to injector
- HV Deck (HVD1) Faraday cage air insulated, hosting ISEPS and connected to TL through air-gas High Voltage Bushing
- Residual Ion Dump Power Supply (RID-PS) applying electric field between plates of Residual Ion Dump



HVD1 1MV Faraday Cage hosting ISEPS

Main characteristics

- Insulation: 1 MV dc
- Size: 8,4 m x 12,5 m x 9,6 m
- Insulating supports: 8 fiberglass insulators > 6 m
- Total weight (including PS): about 100 ton
- Total height: 15 m



RID-PS

Dc generator
Ratings: 30 kV, 60 A

AGPS-CS

Main characteristics

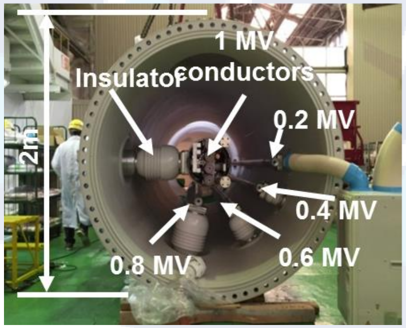
- Input section: ac/dc rectifiers 6.5 kV, 9 kA
- Output section: 5 dc/ac three phase inverters
  - Configuration: neutral point clamped (NPC)
  - Modulation: square waveforms 150 Hz
  - Current: 1700 A rms

AGPS-CS
RID PS

MITICA PS - JADA Components

- Almost all of components realized
- First batch of them tested in factory and delivered to Site
- Ship arrived at Marghera port, closest port to Padova, in December 2015; first components delivered to Site
- Installation of JADA components started in December 2015 and due to be completed at beginning of 2017
- Afterwards insulating tests and power integrated tests to be performed

Step-up transformer



Internal view

HV Transmission Line

MITICA PS - JADA Components

Firsts JADA components stored in RFX

MITICA PS - JADA Components

Installation of 200kV step-up transformer

Installation of transmission line

MITICA – Status of the project

- Procurement of MITICA components shared between F4E and JADA
- Design of all components concluded (tech spec documentation of Beam Line Components under finalization)
- Procurement contracts signed since 2012 (JADA power supply components), in 2014 (F4E components Vessel, HVD1 and Bushing), and in 2015 (AGPS-CS, GRPS). Further procurement contracts to be signed in 2016–2017
- JADA components at well advanced manufacturing phase
- Installation of first JADA components started in December 2015
- By end 2016 also installation of F4E components to begin starting from Vacuum Vessel

International collaborations

CONSORZIO RFX
Ricerca Formazione Innovazione

CONSORZIO RFX
Ricerca Formazione Innovazione

ENEA

INFN

iter
china eu india japan korea russia usa

FUSION FOR ENERGY

ITER JADA

ITER-India

प्लाज़्मा अनुसंधान संस्थान
Institute for Plasma Research

IPP
Max-Planck-Institut für Plasmaphysik
EURATOM Association

JAEA

KIT
Karlsruhe Institute of Technology

CCFE
CULHAM CENTRE FOR FUSION ENERGY

cea

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

IFP
Istituto di Fisica del Plasma "Piero Caldirola"
Consiglio Nazionale delle Ricerche

NIFS

IENI
Istituto per l'Energetica e le Interfasi