PLASMA4BEAM2 at LNL and in CSN5

INFN sez. BA, LNL, MI, MIB; collaboration RFX, CNR-ISTP, Univ. Padova

M.Cavenago for the INFN/Plasma4beam2 group

Goal: study of ion, plasma and gas collision physics for transport of beams into collisional media (RFQC cooler), negative ion beams (NIO1) relevant to fusion and photon detectors (GEM) for High Voltage breakdown survey

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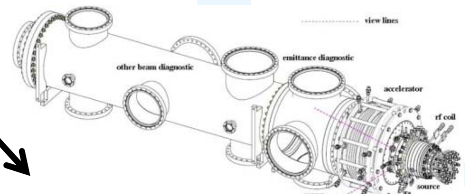
3 years 2024-6; in 2024 about 90 kE (40 kE at LNL) and 8 FTE (2 at LNL)

1) Workpackage highlights in brief

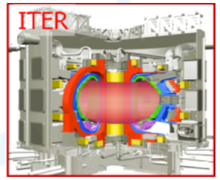
RFQ cooler, 1st LNL prototype

WP1: Linear traps of particles (K^+ to Cs^+) interacting with a plasma or a gas (He) as in a RFC cooler. For the RFQCs, the triode/tetrode ion extraction tests aims to verify the theoretical prediction in favour of the latter; also iris shaped electrodes as in the SPES RFQC will be studied. Diagnostic based on emittance meter will be integrated with accurate voltage scanning of collector voltages. Feasibility study of other Eltrap-like-machines.

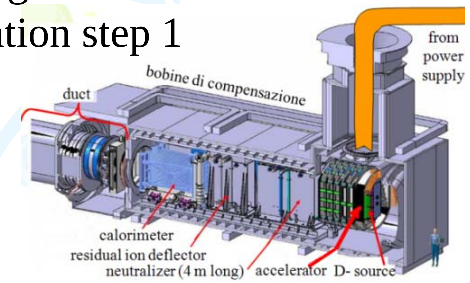
WP2: Production of negative ions H^- in reduced-size or full-scale models of multi-aperture ion sources relevant to fusion (from NIO1 to MITICA and other ion sources). Cesium dynamics and other H^- catalyst . Collaboration to development of proton sources, to easily test equipments , including fast emittance scanners and high beam power Faraday cups, of interest also for H^- sources.



NIO1 Negative Ion Optimization step 1

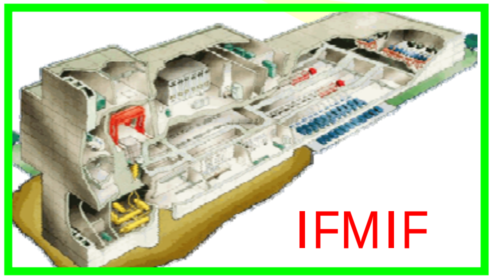


1-3 dpa/lifetime **ITER**



MITICA

WP3: a) development of diagnostics based on GEMs (gas electron multipliers) and scintillators to investigate the origin of vacuum discharges between two high voltage electrodes for the development of the accelerators for MITICA (or ITER), using HV (high voltage) facilities at Padua University and Consorzio RFX; b) Development of fast neutron GEM detectors for SPIDER and MITICA; c) support to the study of regenerative cascades of secondary particles (ping-pong) , especially in cesiated electrode conditions.



WP4 deals with theoretical and computational aspects of previous subprojects. E.g. +calculation of trajectories, with cooling (WP1), and space charge (WP2), and the formation of fixed points of the 'ping-pong' impact positions for some electrode geometries (WP3). Statistical effects or collisions are included with Fokker-Planck (WP3) or Langevin (WP1) equations.

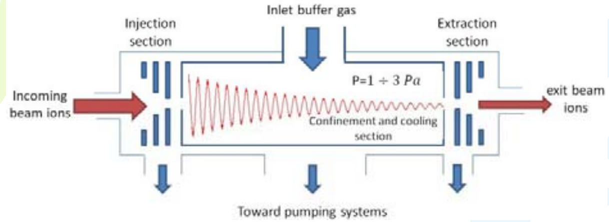
The experimental group and equipment is based on previous activities from CoolBeam to Ion2neutral [in aggregate, over 100 ISI-indexed publications in 2013-2022]. Some doi of further recent (2023-2024) publications given here. Abbr. RSI=Rev. Sci. Instrum., JPCS= J. Phys. Conference Series, TPS =IEEE Transactions on Plasma Science

WP1: linear beam traps for plasma and gas interactions (MI+LNL)

Main plan and goals

RFQC (MI+LNL) Systematic first test 2023. Upgraded electrode structure 2024-2025; energy spread analysis (ESA) 2024-2026

Eltrap (MI) Support to RFQC and to teaching



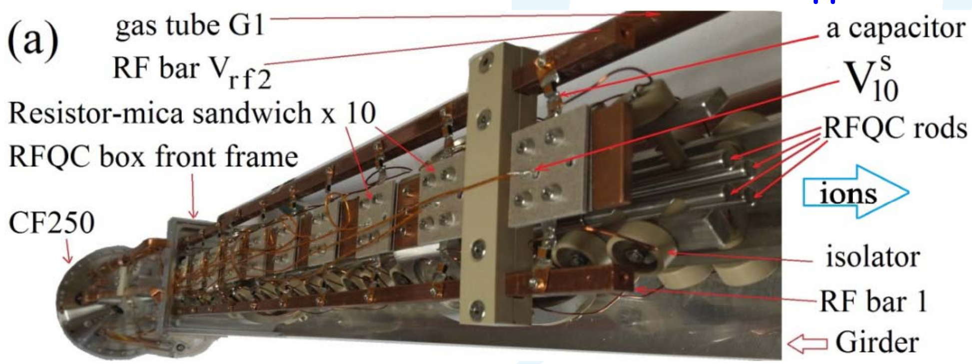
RFQ cooler scheme

Duel/Eltrappino e- source

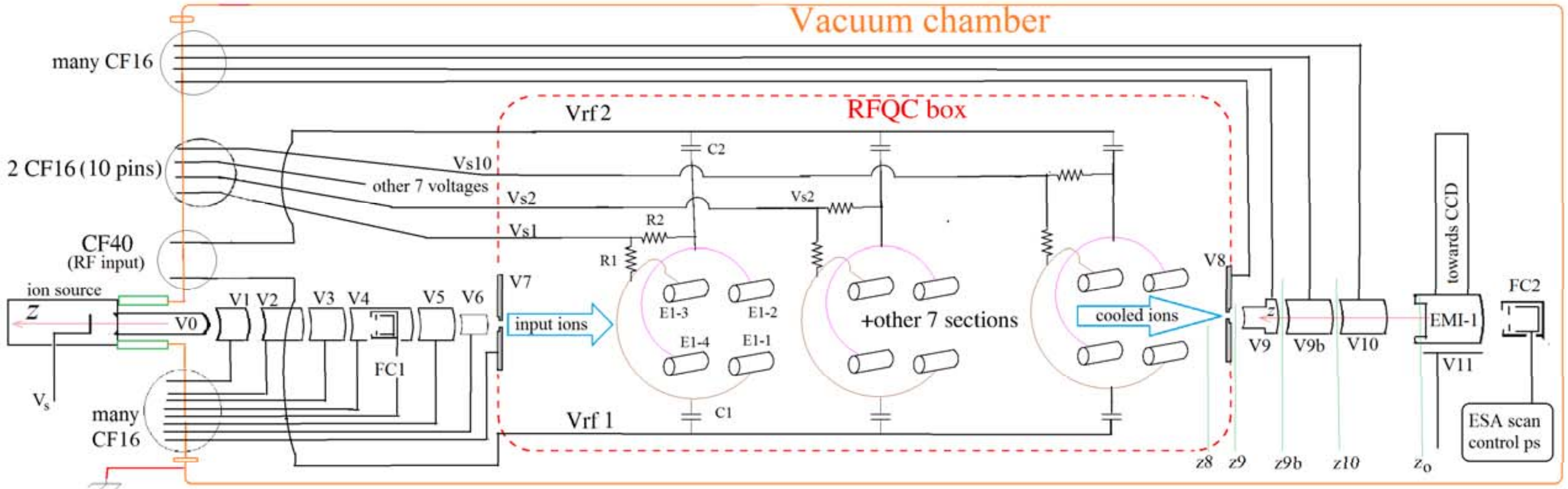
WP1 planned activities highlights:

1) Test di trasmissione (2024-2025) di un fascio di Cs raffreddato via RFQ e buffer gas in condizioni di interesse per progetto SPES con analisi influenza campo magnetico assiale (fino a 0.2 T). New extraction line (tetrode).

2) Completion of Langevin-equation-based formalism of collisional heating and cooling mechanism and experimental comparisons (see also WP4)



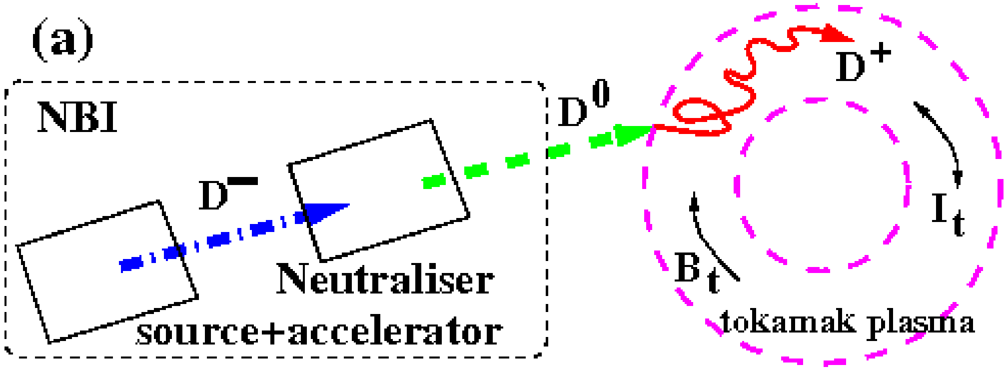
RFQ Cooler design and setup, see fig 1a in JPCS 2024, accepted 06/2/24 (see also MC et al, RSI 2019, JPCS 2022 for more drawings)

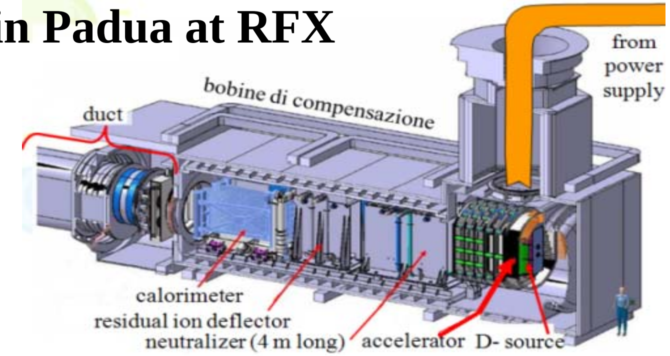


The RFQC conceptual reference scheme, see Fig 3 in J. Plasma Phys. (2024), doi:10.1017/S0022377823001484

WP2: high current ion sources for NBI neutral beam injector and fusion LNL+BA

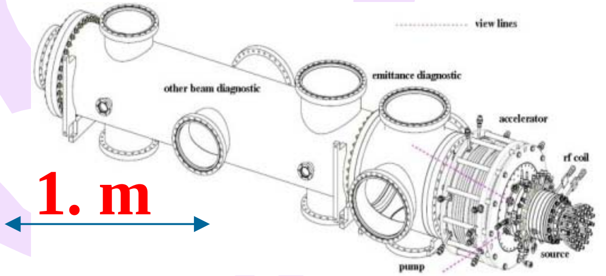
In fusion reactors like ITER or DEMO, many (3) neutral beam injectors are needed for: i) heating; ii) current drive. A test facility is being built in Padua at RFX





MITICA **$10^{1.}$ m**

(a) Concept of NBI: D^- are more easily converted to D^0 than D^+ would be; then D^0 ions may enter a magnetically confined plasma and are ionized to D+ which heat the plasma and drive toroidal current I_t (from Fig 1a in Cavenago, Il Nuovo Cimento 39 C (2016) 291 doi 10.1393/ncc/i2016-16291-0)

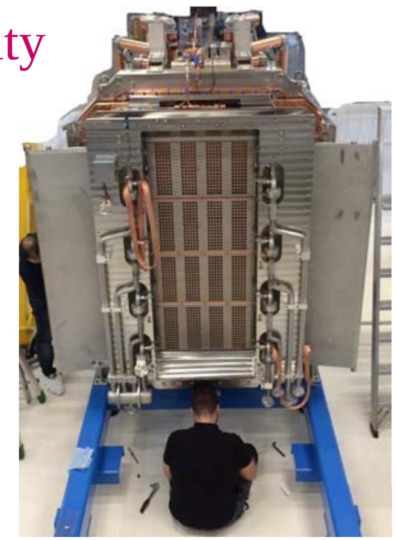


NIO1 Negative Ion Optimization step 1

NBTF= Neutral Beam Test Facility

SPIDER = 100 kV/55 A system

MITICA = 1 MV/40 A beam [see D. Aprile et al., TPS 48 (2020) 1555]



Front view of SPIDER

<u>NIO1 programme aims at investigating these physical issues</u> in a drastically reduced scale, still preserving/including:

- **+multi beamlets (9);** **+continuous operation (surface evolution);**
- **+multipole magnets also behind RF coil [**see M.C et al. Rev. Sci. Instrum. 81, 02A713 (2010) doi: 10.1063/1.3271247**].**

Accelerator physics before plasma engineering: proposed NIO1 upgrades

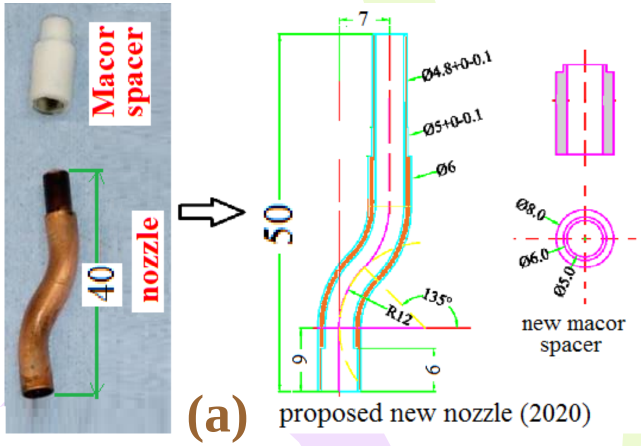
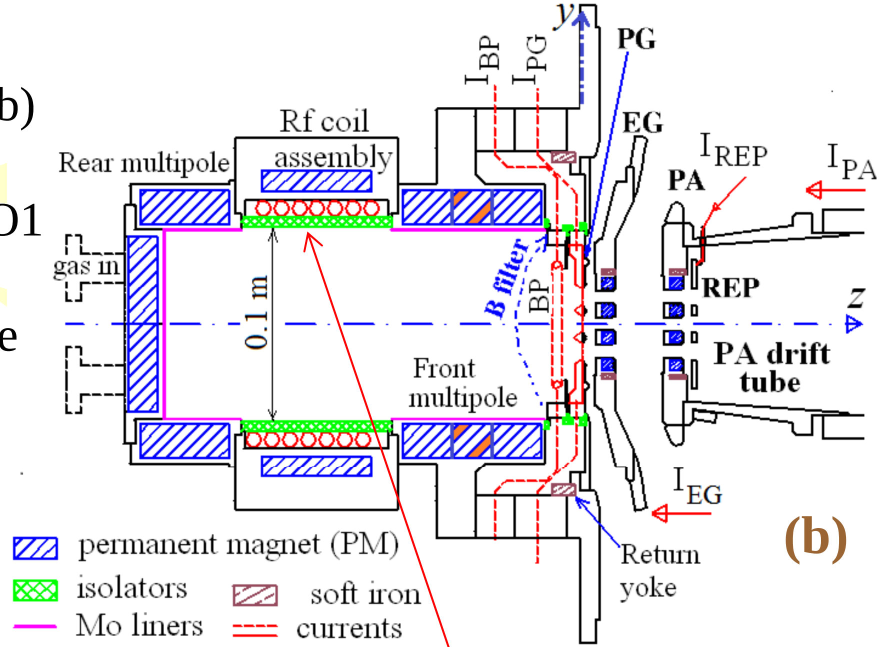
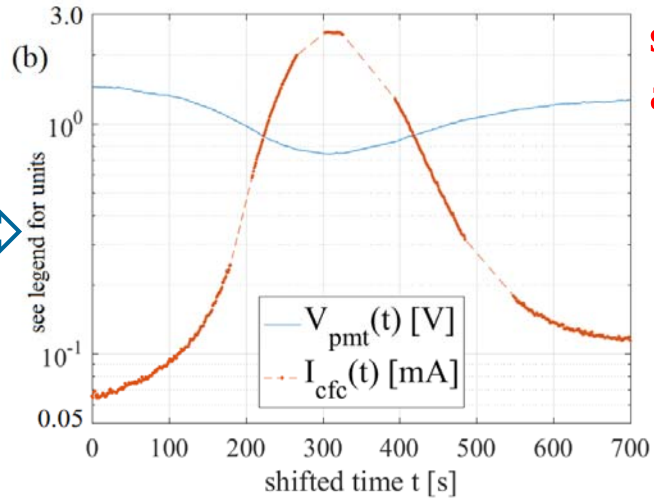


Figure: (a) Cs pipe nozzle; (b) horizontal zy section of NIO1 source and electrode; note filter magnet position.

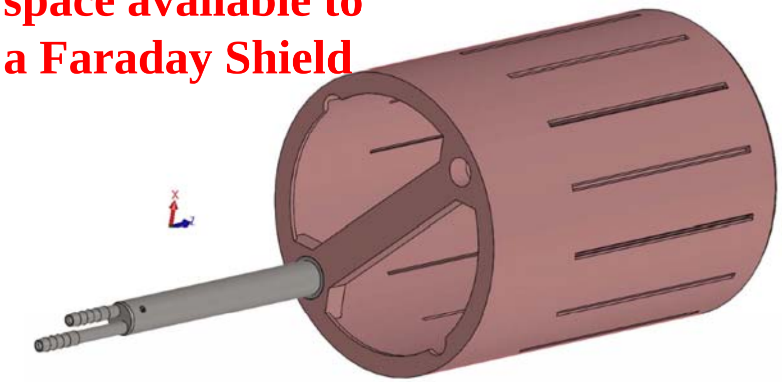


Cesium performance of NIO1 will require: (1) the new nozzle designed in 2020, a simple S-bend tube; (2) gas conditioning (for in-vacuum in-situ final cleaning)

The so-called transients (anti-correlated changes of plasma luminosity and ion current) show when you look for them (i.e. CW NIO1 operation) and are typical of Nonlinear Partial Differential Equations, doi: 10.1088/1748-0221/19/01/C01017, 10.1088/1748-0221/18/09/C09009



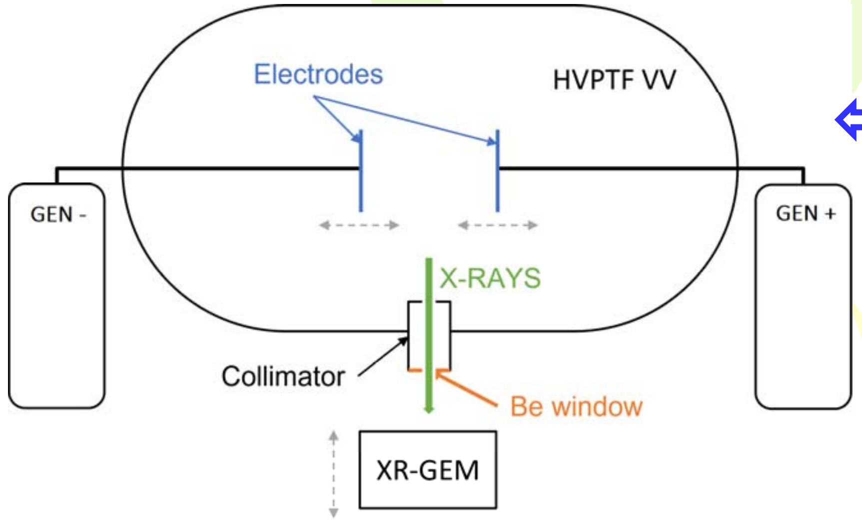
space available to a Faraday Shield



The Faraday Shield: Both inox and copper parts by Addictive Manufacture, including water hose connections (under construction at Addtoshape, www.addtoshape.com, Italy)

Last but not least: +Energy recovery of NBI residual ions; + Synergies with IFMIF and TRIPS

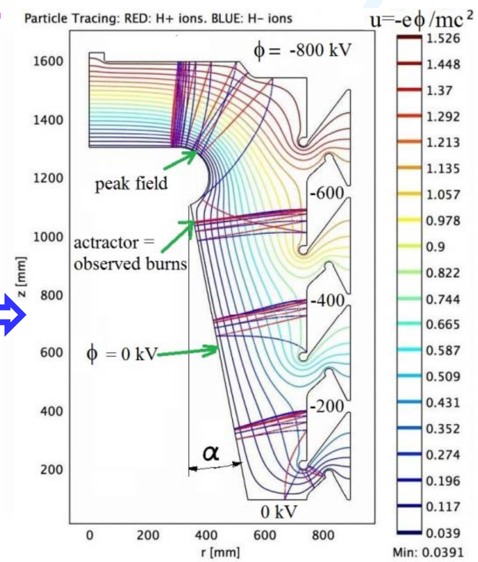
WP3: GEM for surveying fusion plasmas and HV vacuum discharges (MIB)



(a) Scheme of the HVPTF facility: tests include several electrode shapes and distances; GEN +/- rated 400 kV (b) 2022 view of X-ray GEM detector

The GEM detector (financing for upgrade to 0.4 mm resolution pending in CSN5) is mounted on a radial sightline. Pinhole collimator with Be window, 12 μm thick to allow transmission of low energy (< 3 keV) X-Rays.

WP3+WP4: high voltage (HV) vacuum discharges have a rich physics: they may not happen at higher field surfaces, but at accumulation points of regenerative cascades of secondary particles (a.k.a. ping-pong). Discussed (with trajectory iterations and/or Fokker Planck eq., ...) in Cavenago et al 2010, N. Pilan et al 2011, 2018, 2022, J. Appl. Phys. (2022)10.1063/5.0087343



The 750 kV SINGAP

GEM: SPIDER calorimeter

Thank you for attention!