PLASMA4BEAM2: status

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

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

Sedi e responsabili.

Resp. Nazionale	M. Cavenago
LNL	R.L. M. Cavenago e A. Ruzzon
MI	R.L. M. Rome
MIB	R.L. G. Croci
Bari	R.L. V. Variale
LNS RL	R.L. G. Castro

Durata: Triennio 2024-2026

Layout

1) **Introduction**
2) **Workpackages**

WP1) manipolazioni di fasci e plasmi (in trappole elettromagnetiche), con applicazioni al raffreddamento di fasci tramite gas tampone

WP2) sorgenti di fasci intensi (H-, H+) per applicazioni alla fusione e NBI (Neutral Beam Injectors)

WP3) rivelatori di neutroni per applicazioni a NBI e rivelazione di breakdowns

WP4) simulazioni e modelli di interazione fascio/plasma o estrazione di fasci da plasma

3) **FTE e stime finanziarie**

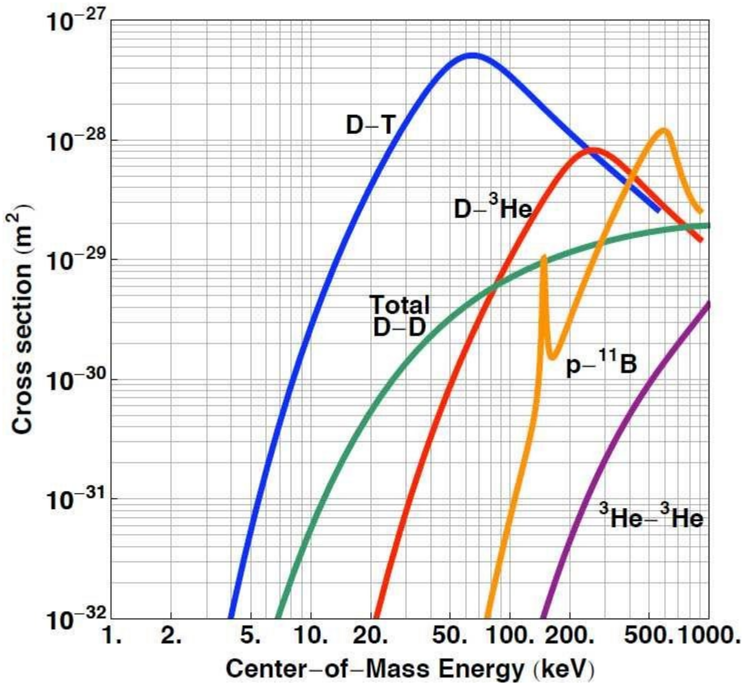
1. Introduction

Magnetically controlled thermonuclear fusion

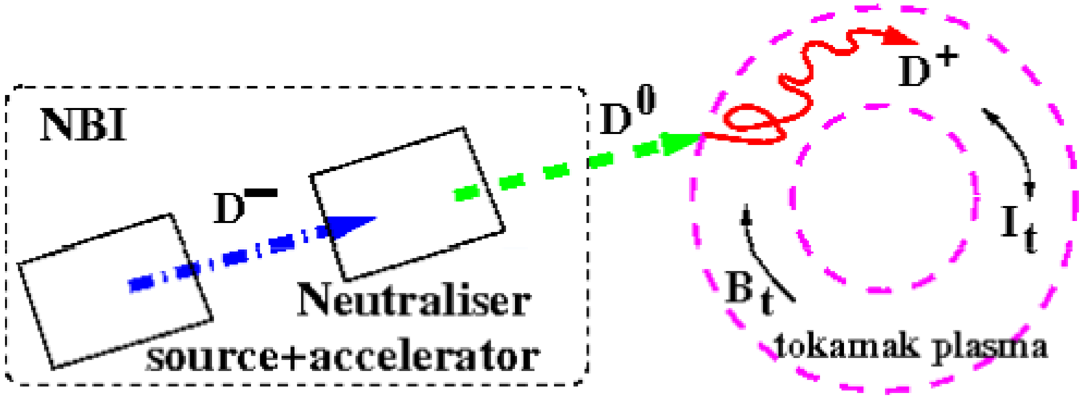
Plasma need to be confined and heated to ≈ 10 keV for long times; each pulse may be $10^{3.5}$ s long, but necessary aggregate operation time is > 5 10^8 s (sixteen years);

Energy flow on plasma container walls is large (10 MW/m^2);

Due to huge energies involved, theoretical and numerical modeling has to face a host of instabilities, nonlinearities, while engineering is utmost challenging



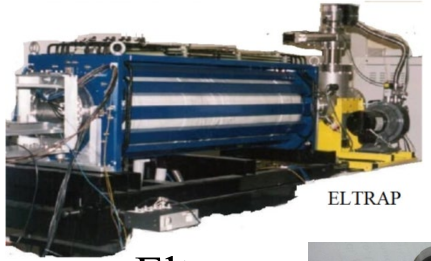
To mitigate these issues, ITER design is based on a relatively small field (6 T on toroidal axis) and large size/low density (n @10^{20} m^{-3}). Plasma stability requires to keep a toroidal current I_t into circulation (see figure), thanks also to external heating methods as the neutral beam injection



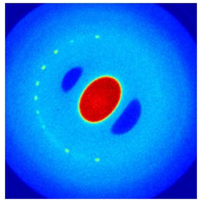
Concept of NBI:

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

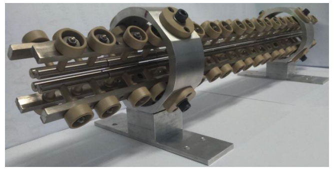
2. Workpackage highlights



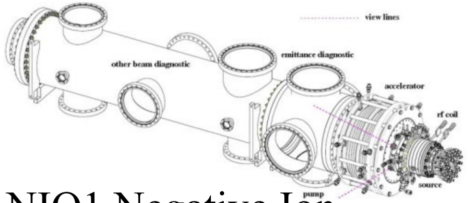
Eltrap

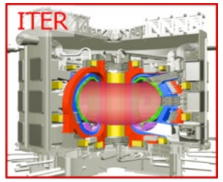

vortici

RFQ cooler



WP1: Linear traps of particles (K^+ to Cs^+) interacting with a plasma or a gas (He) as in a RFC cooler. Diagnostic from emittance meter will be integrated with accurate voltage scanning of collector voltages. Feasibility study of other Eltrap-like-machines.

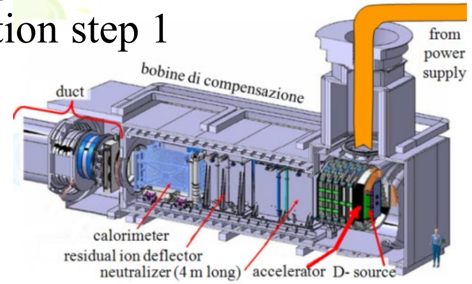

NIO1 Negative Ion Optimization step 1



1-3 dpa/lifetime

ITER

WP2: Production of H^- in reduced-size 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 equipment and diagnostics of interest also for H^- sources



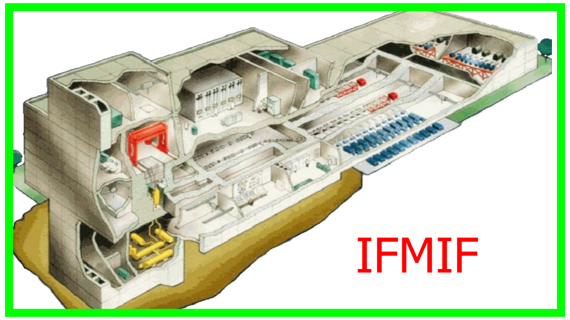
MITICA

WP3: a) development of diagnostics based on GEMs and scintillators to investigate the origin of vacuum discharges between two high voltage electrodes for the development of the compact accelerator for MITICA (NBI of ITER), using HV 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: Theoretical and computational aspects relevant to the previous subprojects. For example, calculation of trajectories of WP1 and WP2, shows for some WP3 electrode geometries the formation of fixed points of the impact positions. Statistical effects or collisions are included with Fokker-Planck or Langevin equations.



WP2 motivation and perspectives

Accelerator development is recognized as one of the leading activity of CSN5, and the Neutral Beam Injectors envisioned in the fusion reactor researches are accelerators, perhaps of exceptional size and complexity (many beamlets).

The experimental activity on NIO1 is still in pause due to overload of hosting institution RFX

WP2 and WP3 goals emphasizes physical understanding of underlying accelerator and plasma physics in particular:

- long term stability of apparatus [NIO1 has surpassed the 10^4 s continuous beam time per day, while most of installations dwells with order 10^2 s long operation and final aggregate goal is in the 10^8 s range]
- transport of negative particles in plasmas and uniformity of their extracted beams
- energy efficiency and recovery, high voltage holding

Bari activity on PIC simulation of large ion sources (SPIDER) is well progressing

LNL simulation (EM and hydrodynamical) of Faraday Shield were rapidly boosted to acceptable results in April 2024 in support of its construction.

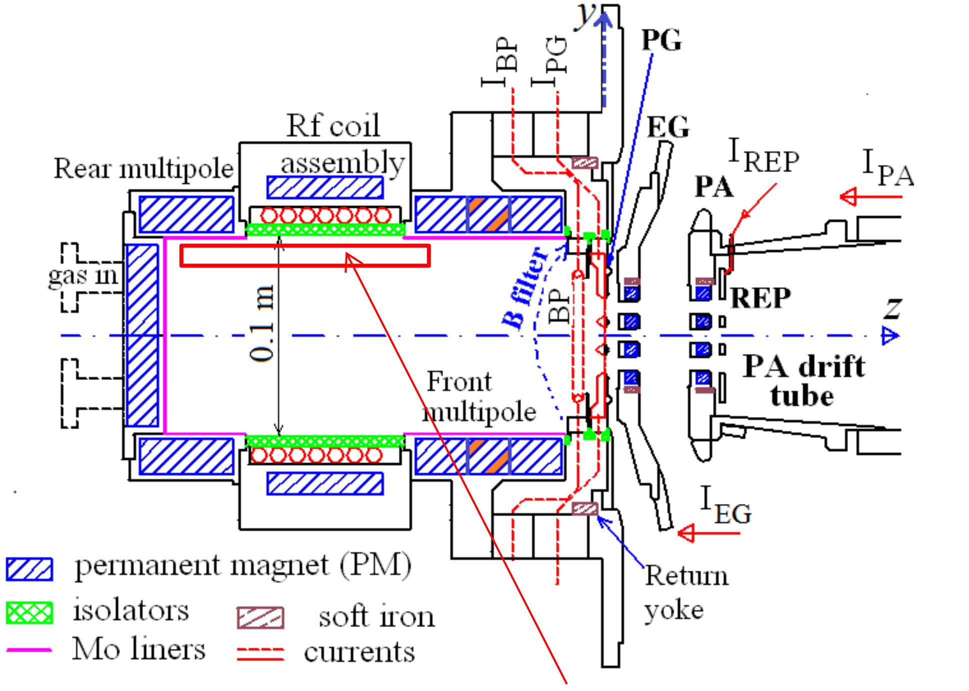
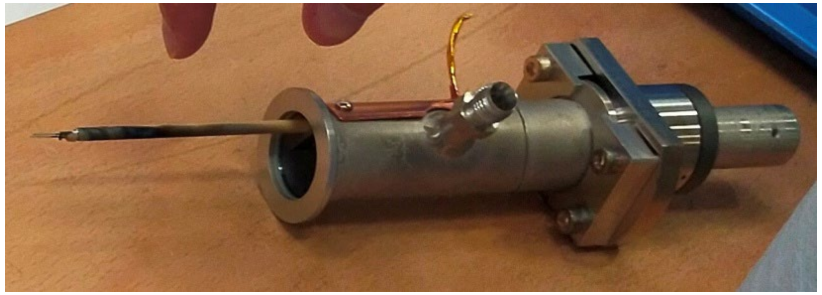


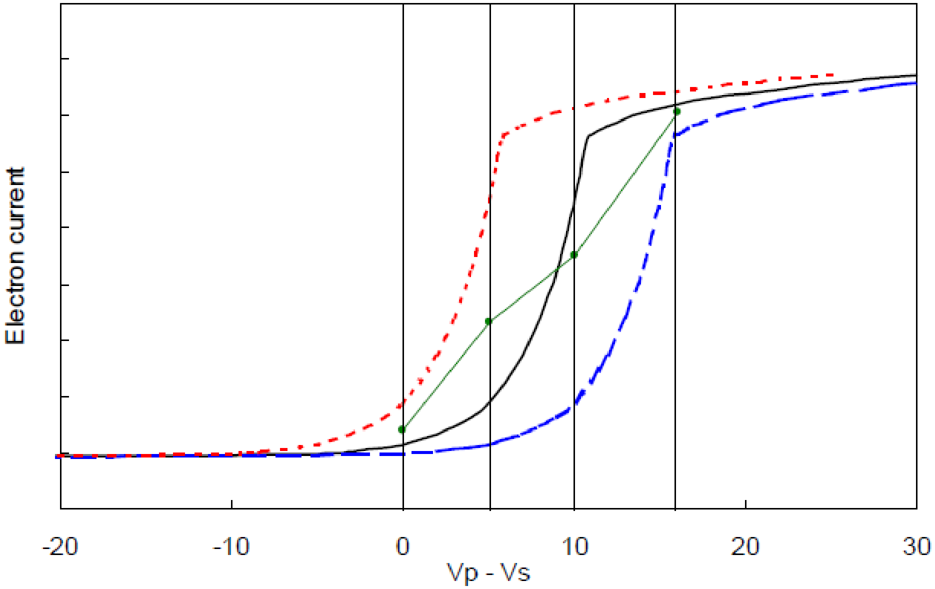
Figure: horizontal zy section of NIO1 source and electrodes; note filter position.

LNS contribution in WP2/WP4

LNS is contributing to the Langmuir Probe Diagnostics of a RF ion source on the MetAlice test-bench.
LP is an invasive diagnostics to measure plasma parameters: electron density, temperature and plasma potenzial

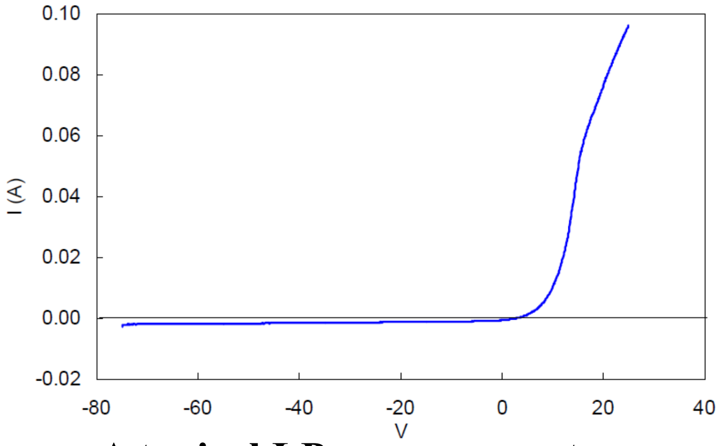


Langmuir Probe on the MetAlice test-bench LNL(LNS + RFX)

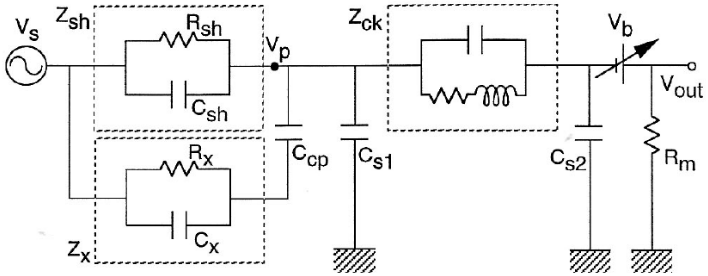


The center curve is the correct *I - V* curve. The dashed ones are displaced by ±5V, representing changes in *V*s. The green dotted line is the time-averaged *I - V* curve that would be observed, differing greatly from the correct curve.

MetAlice test-bench
Concept for multiple frequency matching box



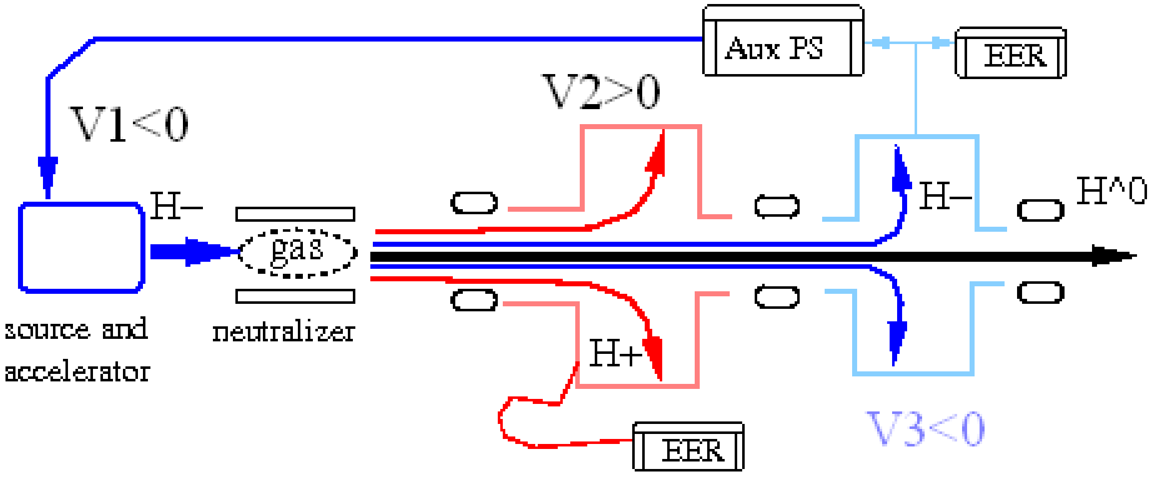
A typical LP measurement

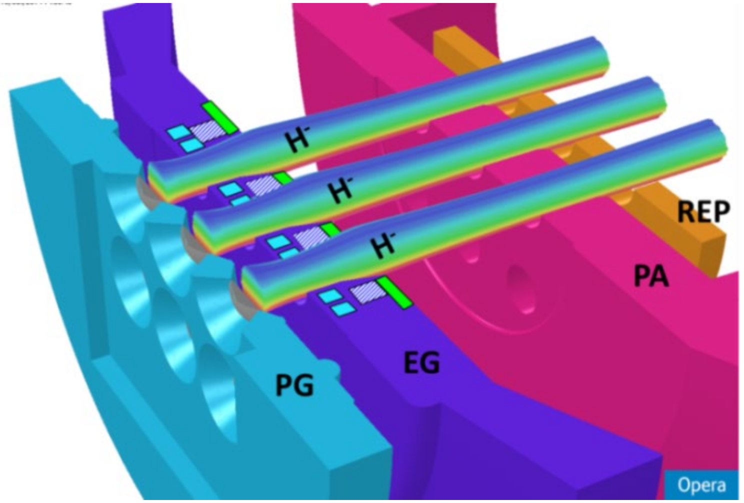


Circuit diagram of a probe-plasma system with rf compensation.

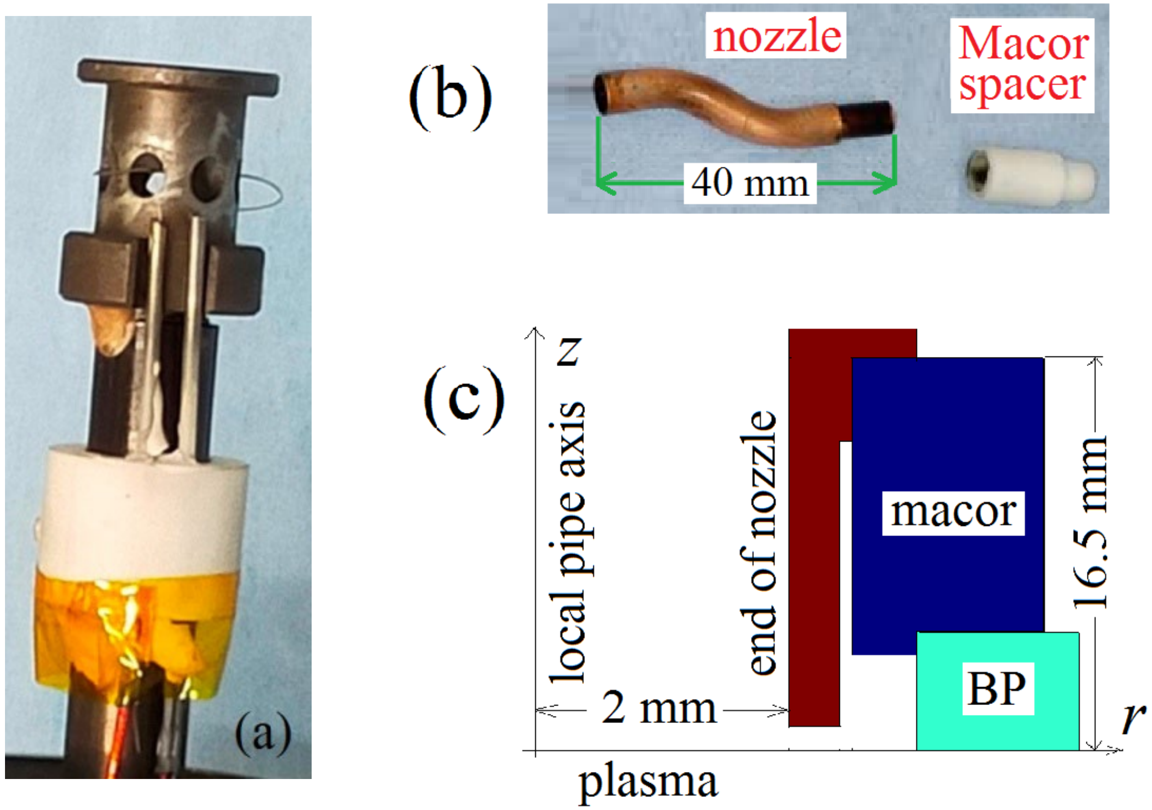
LNS contribution in WP2/WP4

WP2+WP4 Energy recovery scheme (LNL/S+BA)





Energy recovery concept design for energetic efficiency.



WP2+WP4 oven nozzle and dynamics (LNL/S+RFX)

3. FTE, Budget, Impatto e output potenziale

FTE

LNS	FTE
Giuseppe Castro	0.40
Leonardi Ornella	0.10
Celona Luigi	0.05
D'Agostino Grazia	0.20
Parisi Mattia	0.40
Totale	**1.15**

Impatto su divisioni e servizi LNS

Si richiede supporto Divisione Ricerca/Servizio Sviluppo Apparati Sperimentali (Antonio Caruso per Compensazione RF diagnostica LP).

BUDGET

- **Missioni: 2 k€+ 2 SJ** (Misure LP presso Test-bench LNL) – 2 settimane missione x 2 persone: 1 settimana per preparazione esperimento. – 1 settimana per esperimento
- **Consumo: 2 k€** (Metabolismo di consumo)
- **Contributo a Licenze Nazionali** (Comsol – opera, etc.): **4 k€** (da caricare su apposito sito per richieste calcolo).
- **Tot: 8 k€ + 2 SJ**

Potenziale output scientifico (LNS)

- **Pubblicazioni:** ~ 3 articoli su riviste internazionali previste nei prossimi 18 mesi (uno già sottomesso)
- **Talk/contributi a conferenza**: ~ 3 nei prossimi 18 mesi (un contributo già sottomesso ad ICIS)