# AB-NCT projects worldwide and in particular in Argentina

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*Workshop on AB-NCT, Oct 15-16, Grenoble, France.*

# Outline

- **AB-NCT Accelerator Programs Worldwide.**

- **Program in Argentina: Development of an Electro-Static-Quadrupole (ESQ) accelerator-based facility and other accelerator types.**

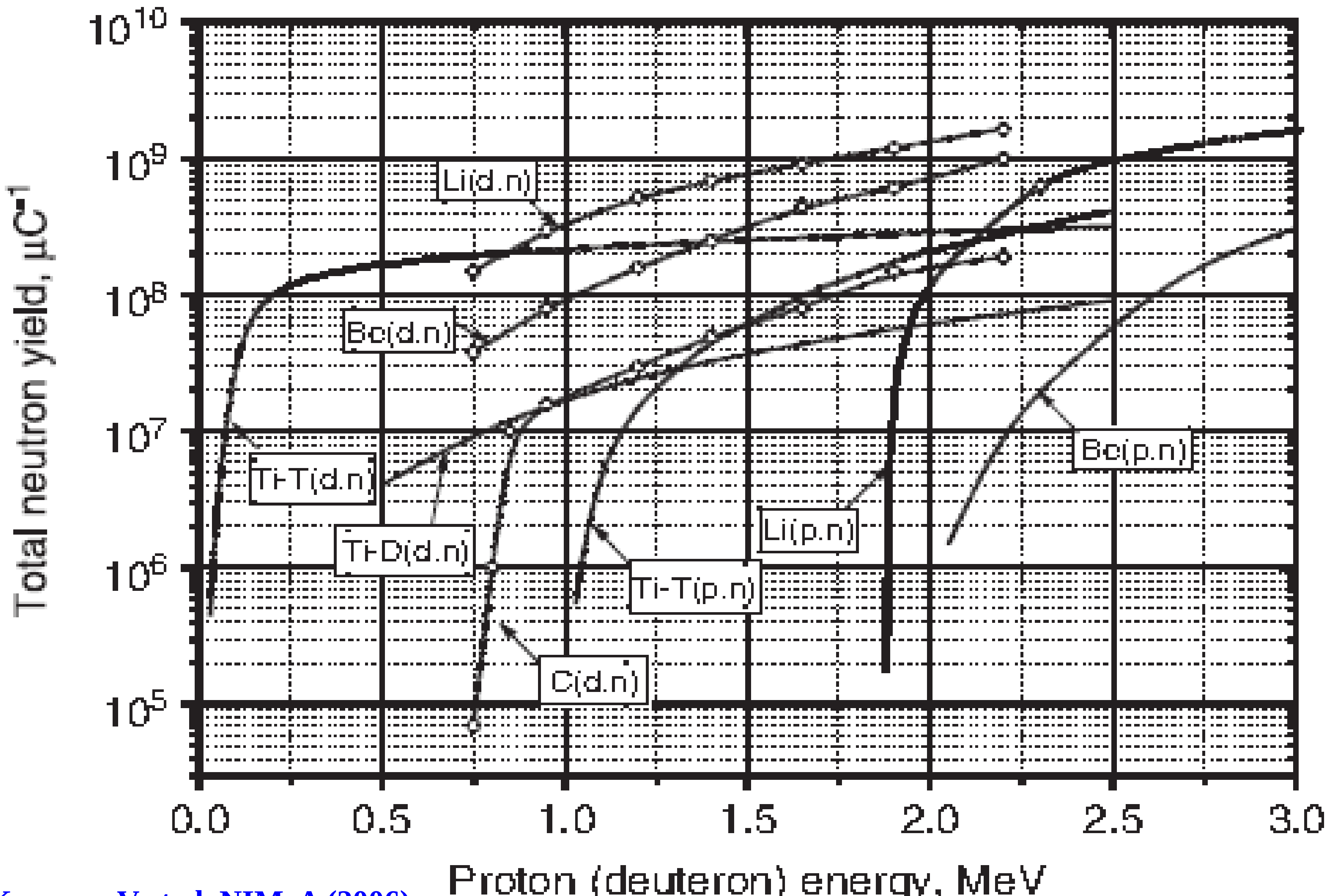
- **Conclusions/remarks.**

# In-hospital AB-BNCT

**Quest for "best" solutions. Criteria for widest possible dissemination:**

- **Safety**
- **Simplicity**
- **Lowest possible cost**

# Neutron producing reactions




Kononov V et al. NIM. A (2006)

# Active AB-BNCT Programs worldwide

- **1. Russia: BINP, Novosibirsk .**
- **2. UK: Birmingham.**
- **3. Italy: LNL & Padova & Pavia, INFN.**
- **4. Japan (x7 ?): Kyoto; Tsukuba; National Cancer Center-Tokyo; Osaka/Tohoku;..**
- **5. Israel: Soreq-SARAF.**
- **6. Argentina: CNEA.** **7. France?**

# Accelerators for BNCTworldwide

| Location | Machine (Status) | Target & reaction | Beam energy<br>Neutron energy<br>(MeV) | Beam current<br>(mA) |
|---|---|---|---|---|
| Budker Institute Russia | Vacuum insulated Tandem (Under dev.) | Solid $^{7}Li(p,n)$ | 2.0<br>< 1 MeV | 2 |
| Birmingham University UK | Dynamitron (Ready, but to be upgraded) | Solid $^{7}Li(p,n)$ | 2.8<br>< 1 MeV | 1-2 |
| KURRI Japan | Cyclotron (Completed, clinical trials started) | Be(p,n) | 30<br>up to 28 MeV | 1 |
| SARAF Israel | RFQ-DTL (Ready) | Liq. $^{7}Li(p,n)$ | up to 4 | 1-2 |
| Legnaro INFN Italy | RFQ (Under construc-tion, well advanced) | Be(p,n) | 4-5<br>up to 2-3 MeV | 30 |
| Tsukuba Japan | RFQ-DTL (Under construction, adv.) | Be(p,n) | 8<br>up to 6.1 MeV | 10 |
| CNEA Buenos Aires Argentina | Single ended ESQ Tandem Electrostatic Quadrupole (TESQ) (Under construction) | Be(d,n)<br><br>Solid $^{7}Li(p,n)$ | 1.45<br>69% ($0^{o}$)< 1MeV (5.7)<br>1.9-2.3<br>< 1 MeV | 30<br><br>30 |
| NCCenter, CICS, Japan | RFQ (Under development) | Solid $^{7}Li(p,n)$ | 2.5<br>< 1 MeV | 20 |

# Nuclear reactions & material properties

| Reaction | $E_{thres}$ (MeV) | Radioactive products | Melting T ($^oC$) | Therm cond (W/m-K) |
|---|---|---|---|---|
| $^7Li(p,n)^7Be$ | 1.88 | Yes | 180 | 84.7 |
| $^9Be(p,n)^9B$ | 2.06 | No[a] | 1287 | 190 |
| $^9Be(d,n)^{10}B$ | 0 (exoergic) | No | 1287 | 190 |
| $^9Be(d,n)^{10}B^*$ | ≈1.0[b] | No | 1287 | 190 |

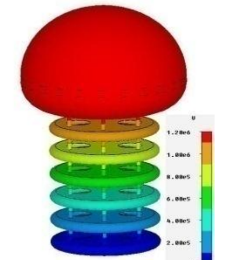
[a]Very short lived activity with no gamma emission.

[b]Population of excited states at ≈ 5.1 MeV in $^{10}B$. The reaction for population of these states has an effective threshold of ≈1 MeV.

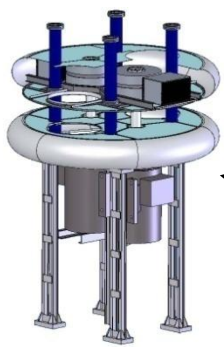
**Reminder: Coulomb barriers of protons on common structural materials, Fe and Cu ≈ 5 MeV. Activation threshold for neutrons ≈ 6 MeV.**

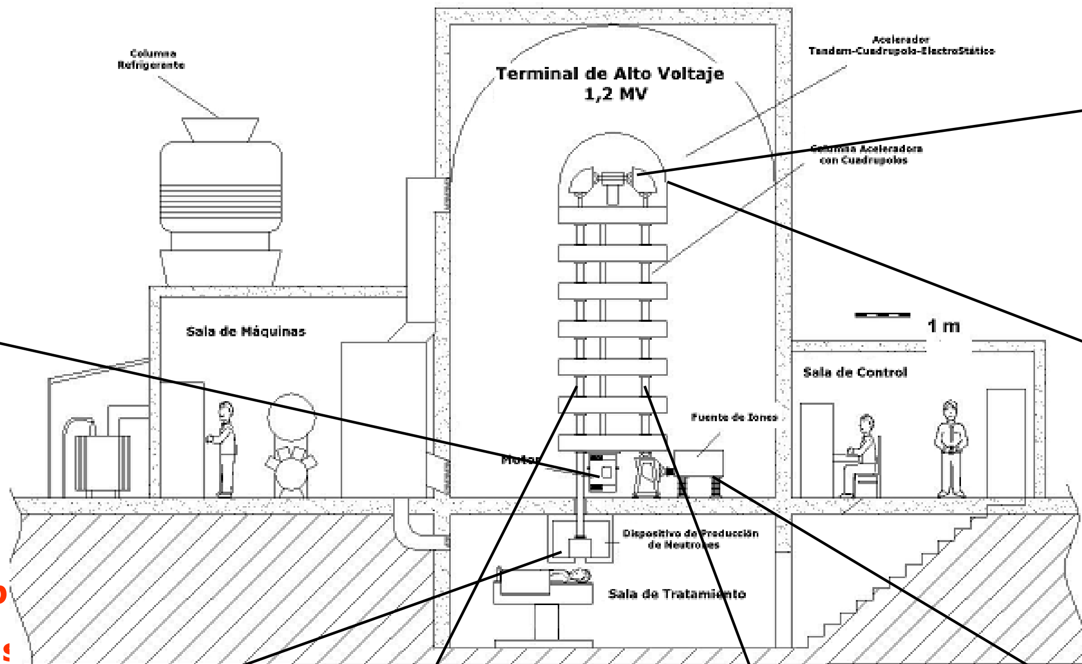
# Working Areas

Electric Potential Distribution

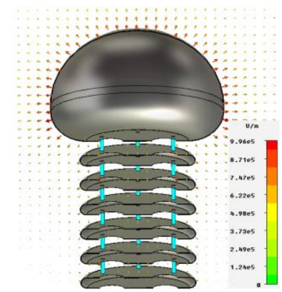


Mechanical Structure and Components of Module






Electric Field Distribution



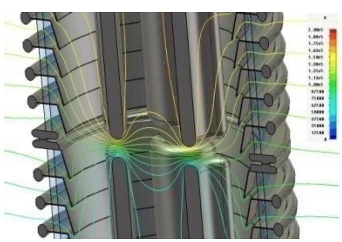
Generators

High voltage supp

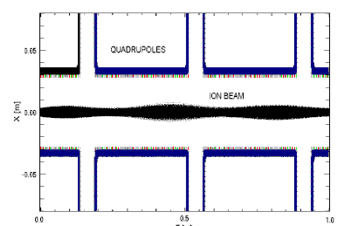
Insulating Rotating s

Insulating posts

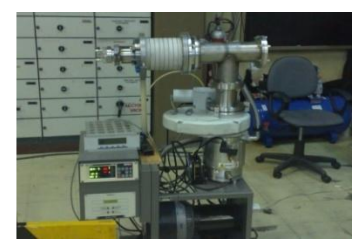
Neutron Production target and Beam Shaping Assembly



Accelerator tubes with Quadrupoles




Beam Transport Simulations



Ion Sources

# Working areas

1. **Mechanical design and construction.**
   **J.C. Suárez Sandín, M. Igarzábal, J.Erhardt, G. Conti,** et al.

2. **Electronic/electromechanical design: High voltage supplies, transformers, ..: M. Baldo, D. Mercuri, N. Real, M. Gun** et al.

3. **Electrostatics, column, tubes y ion optics (transport of high intensity beams): D. Cartelli, N. Cánepa** et al.

4. **Cooling systems: J.C. Suárez S., M. Igarzábal**,et al.

5. **Vacuum systems: M.E.Debray, J.C. Suarez Sandín, M. Igarzábal,** et al.

6. **Ion sources: J. Bergueiro, H.Somacal, J.C.Suárez Sandín, M. Igarzábal** et al.

# Working areas (Cont.)

- **7. Neutron production targets (neutronics), epithermalization Beam Shaping Assembly, patient treatment room: M.E. Capoulat, D.Minsky, A.A. Valda,** et al.

- **8. High power neutron production targets (thermomechanical aspects and materials science and technology issues): L. Gagetti, M. Suarez Anzorena, M. del Grosso, A. Bertolo, J.C. Suarez Sandin** et al.

- **9. Control sysytems: J. Padulo, M. Baldo** et al.

# Working areas (Cont.)

- **10. Licensing of facility: M.E. Capoulat, A. A.Valda, et al.**

- **11. Treatment planning: M. Herrera, S. J. Gonzalez, M.E.Capoulat, D.M. Minsky, et al.**

- **12. Development of a SPECT (Single Photon Emission Computed Tomography) : D.M. Minsky, A.A.Valda et al.**

# A comprehensive study on $^{9}Be(d,n)^{10}B$-based neutron sources for deep tumor treatment.

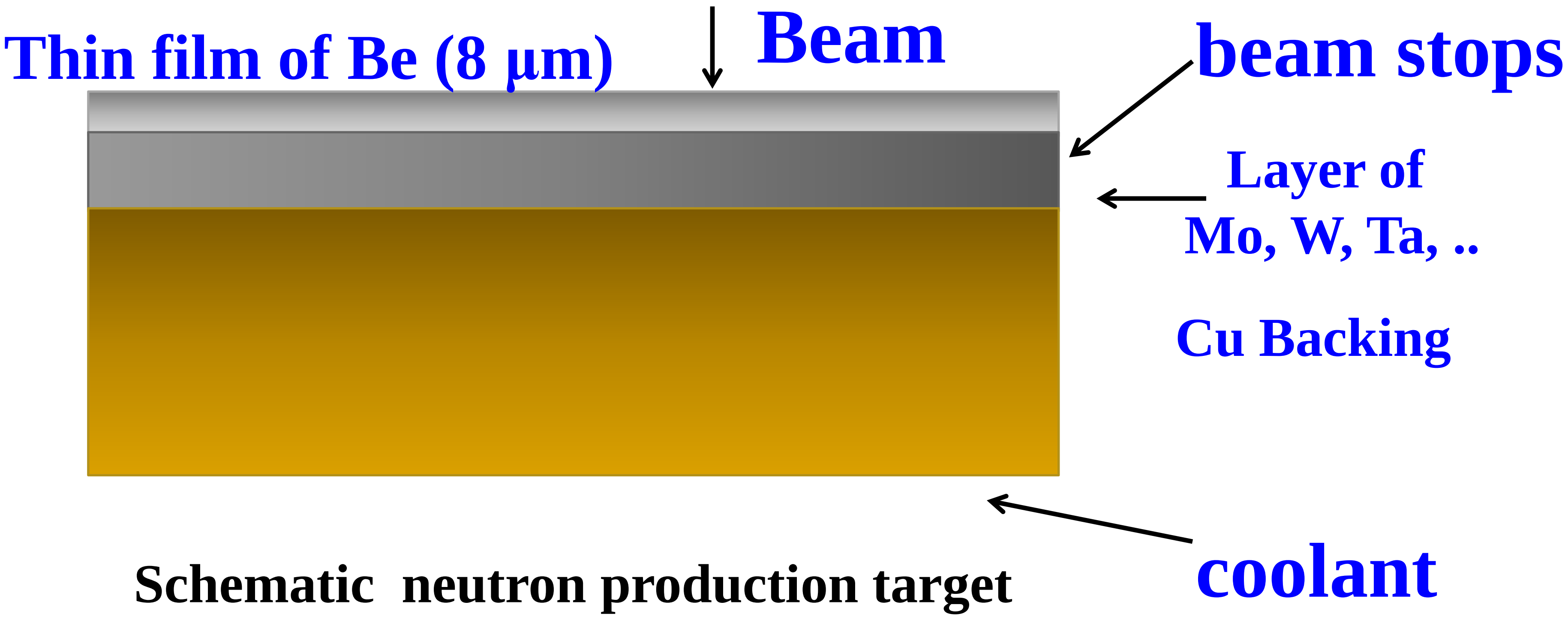
# (Next talk)

***Computational assessment of deep-seated tumor treatment capability of the $^{9}Be(d,n)^{10}B$ reaction for AB-BNCT*, Physica Medica (Europ. Journal Med. Phys.), 30 (2014) 133-146.**

**M.E. Capoulat, D.M. Minsky, and A.J.Kreiner**

**PhD Thesis M. E. Capoulat, March 2014.**

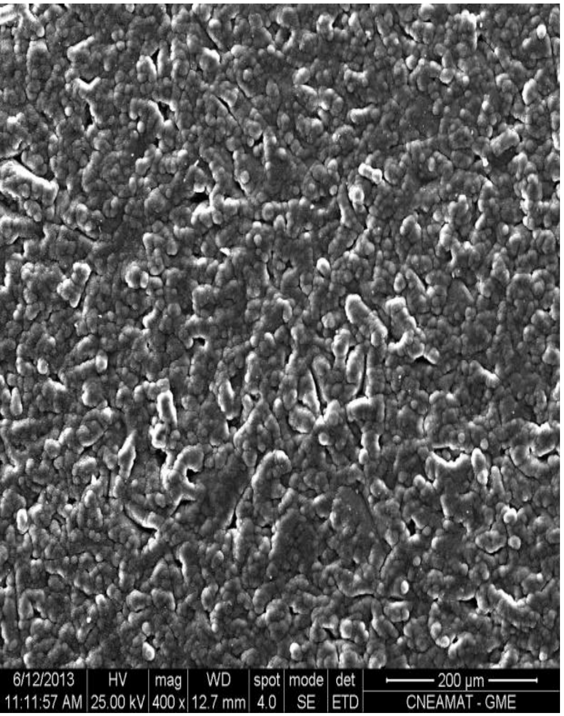
**Progress in the design and development of a neutron production target for Accelerator-Based Boron Neutron Capture Therapy.** **L. Gagetti , M. Suarez Anzorena, M.F. del Grosso, A. Bertolo & A.J.K., Int. Cong. of Sc. &Tech. of Metallurgy & Materials,SAM-CONAMET,Argentina (Proc. Mater.Sci. 2015(8), 471/77).**



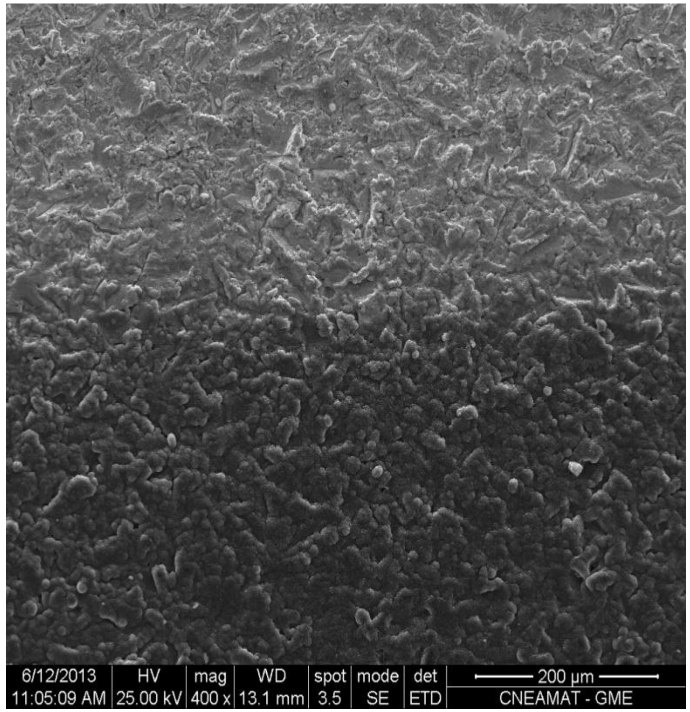

**Schematic neutron production target**

# Target

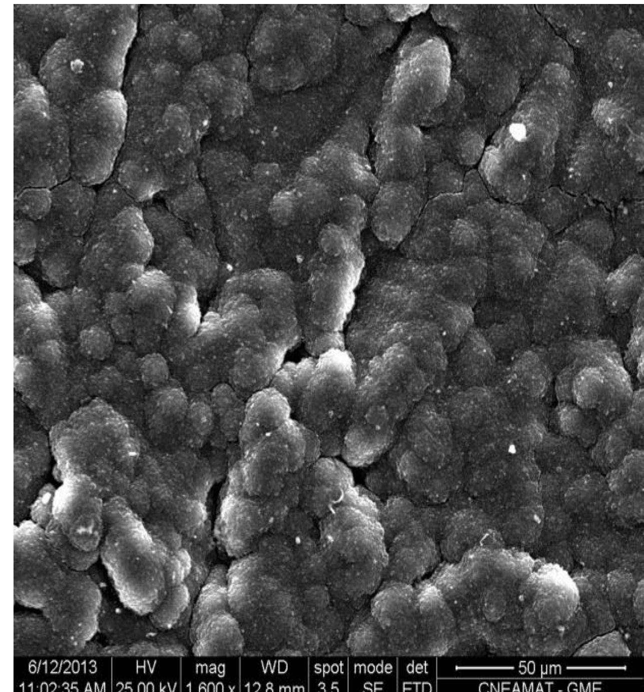
## SEM images of Be deposits on different substrates.




**Substrate: Tungsten**
**Thickness: 10 µm**

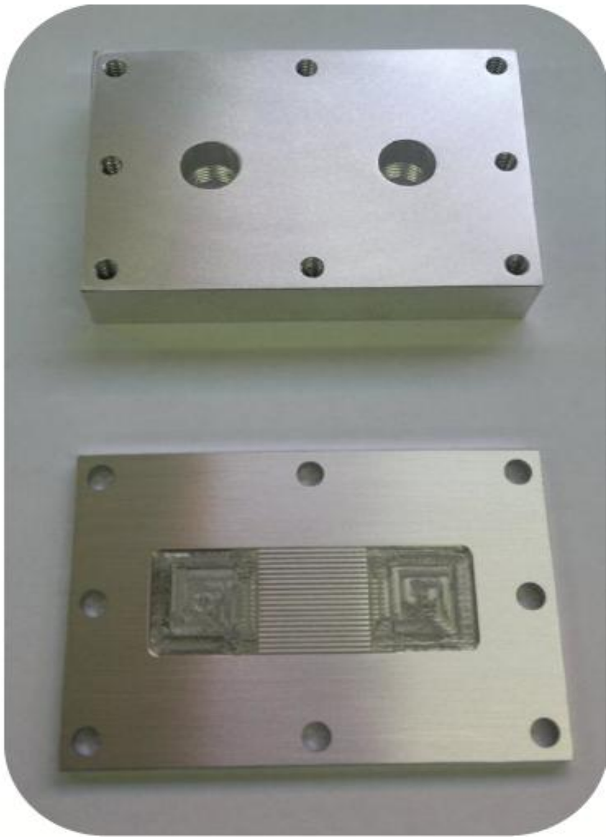


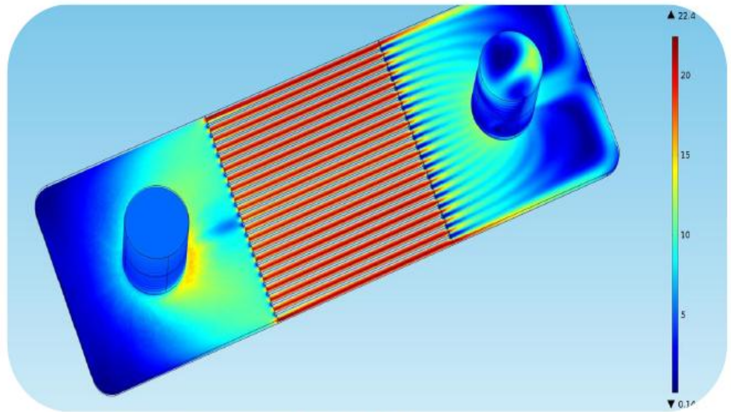

**Substrate: Molibdenum**
**Midlayer: 0.5 µm Ag**
**Thickness: 10 µm**




**Substrate: Molibdenum**
**Midlayer: 0.5 µm Ag**
**Thickness: 10 µm**

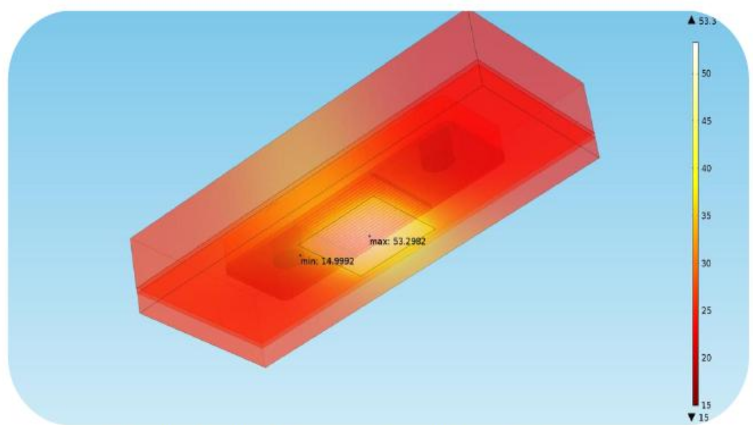
# Neutron production targets: microchannel prototype





Simulación de la velocidad del fluido en el prototipo.

**Fluid dynamics simulations**



Simulación de la temperatura del prototipo.

**Temperature simulations**

**Experimental validation of simulations**

# Analyzing the performance of accelerators in BNCT: evaluation of the therapeutic potential of the proposed facility and its comparison with global benchmark clinical beams

**M.S. Herrera, S.J. González, W.S. Kiger III, H. Kumada, A.J. K.**

- **$^{7}Li(p,n)$: GBM, Head & Neck, Nodular Melanoma in extremities ( Herrera et al., Physica Medica, EJMP, 272 (2013) )**
- **$^{9}Be(d,n)$: GBM (Capoulat et al., Proceedings of 15-ICNCT, ARI).**
- **Conclusions: Equal quality treatment to best existing reactor.**

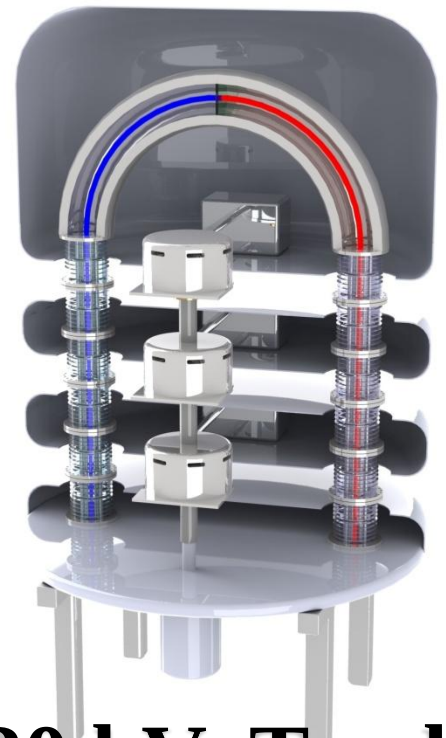
# Development of an Electrostatic -Quadrupole Accelerator (ESQ) Facility for BNCT

**"A Tandem-ESQ for Accelerator-Based Boron Neutron Capture Therapy", Kreiner, A. J. et al, NIM B261 (2007) 751-754.**

**Appl. Rad. & Isotopes: 67 (2009)S266-S269 ; 69(12) (2011) 1672–1675; 88(2014)185.**

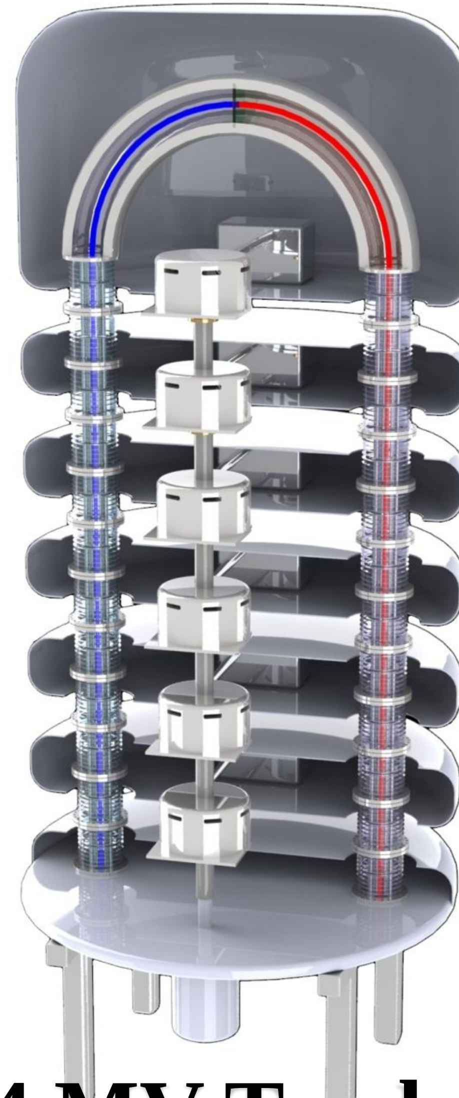
# Different accelerators under development

**200 kV Accelerator**



**720 kV Tandem Accelerator**

**Also single-ended**



**1.4 MV Tandem Accelerator**

# 200 kV accel mounted with Faraday cage

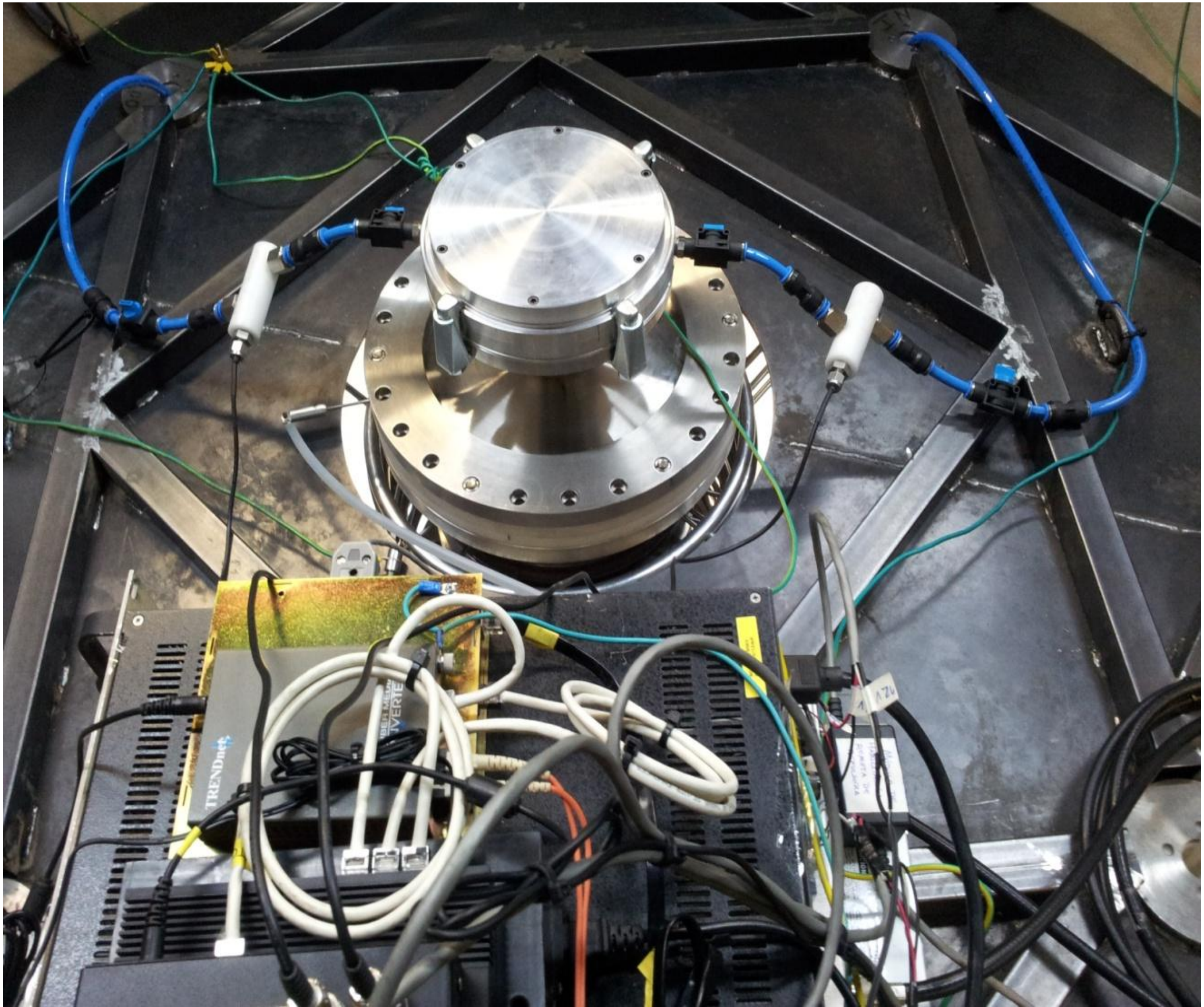
# D. Cartelli & N. Canepa: Mounting the tubes

# Accelerator tubes in place and tested

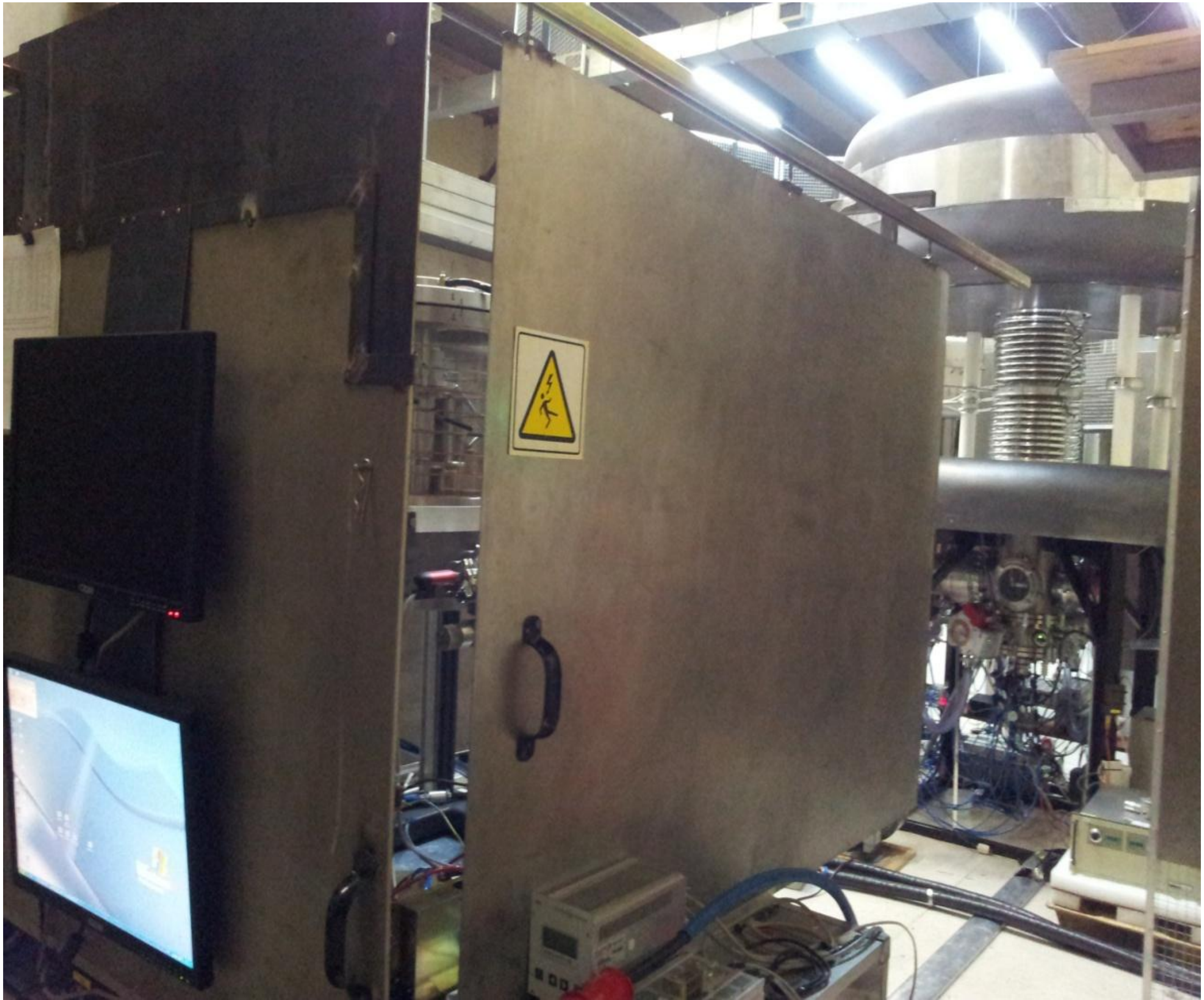
# Accelerator with all systems mounted (HV, cooling, vacuum, control)

# Accelerator column with tubes under vacuum

# Neutron production target (cooled)



# Control system, test stand and accelerator



# Control interface: Javier Padulo et al

# Control and monitoring system

# Accelerator tubes with quadrupoles

# 100 kV tubes, assembled and tested:

## M. Igarzabal, J.M.Kesque, D.Cartelli

# Before assembling the quads

# Quads assembled

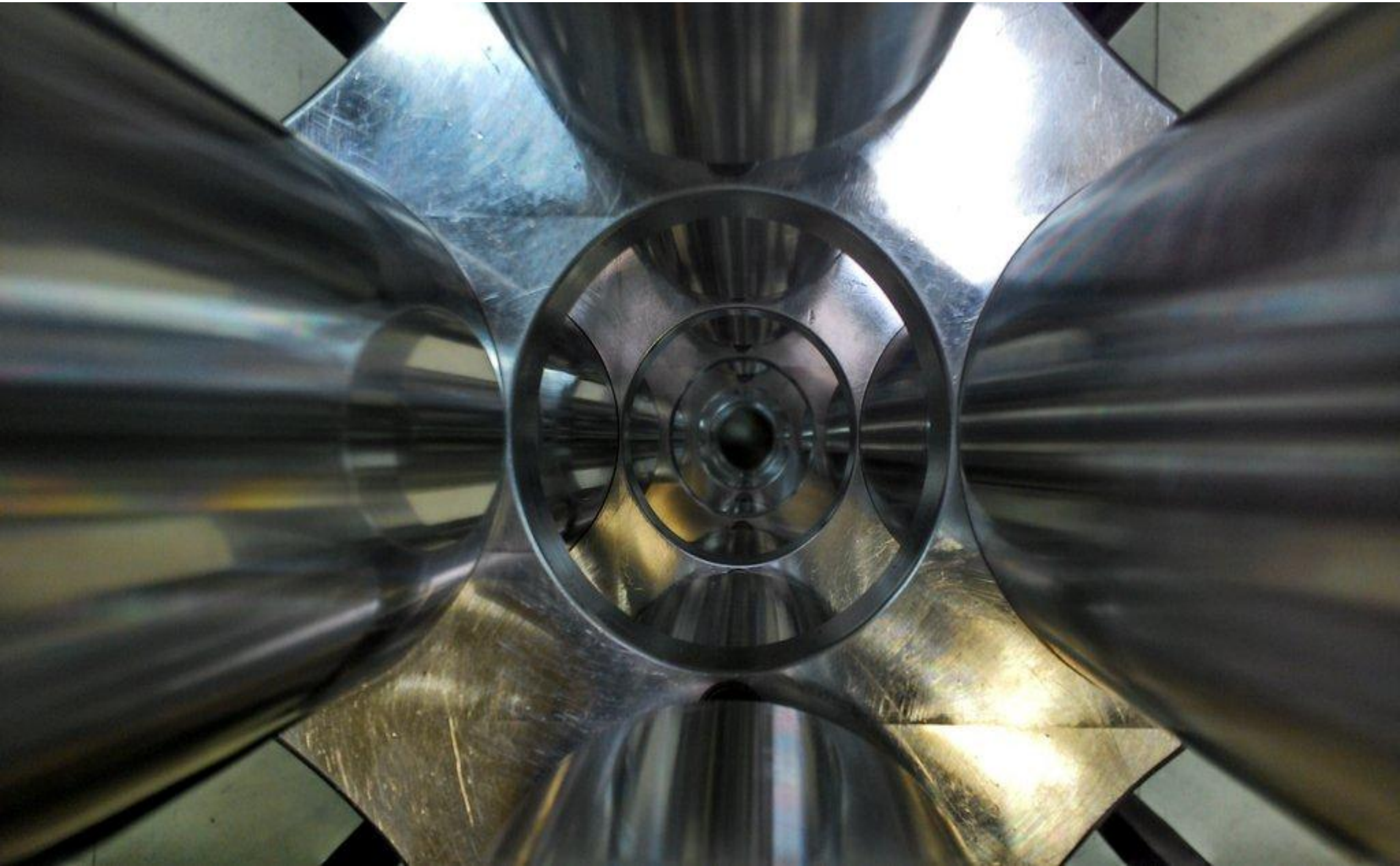
# Centering the quads inside tube

# Matching section being assembled

# Tube with MS next to accelerator

# Watching into accel tube with quads

# Watching along the matching axis

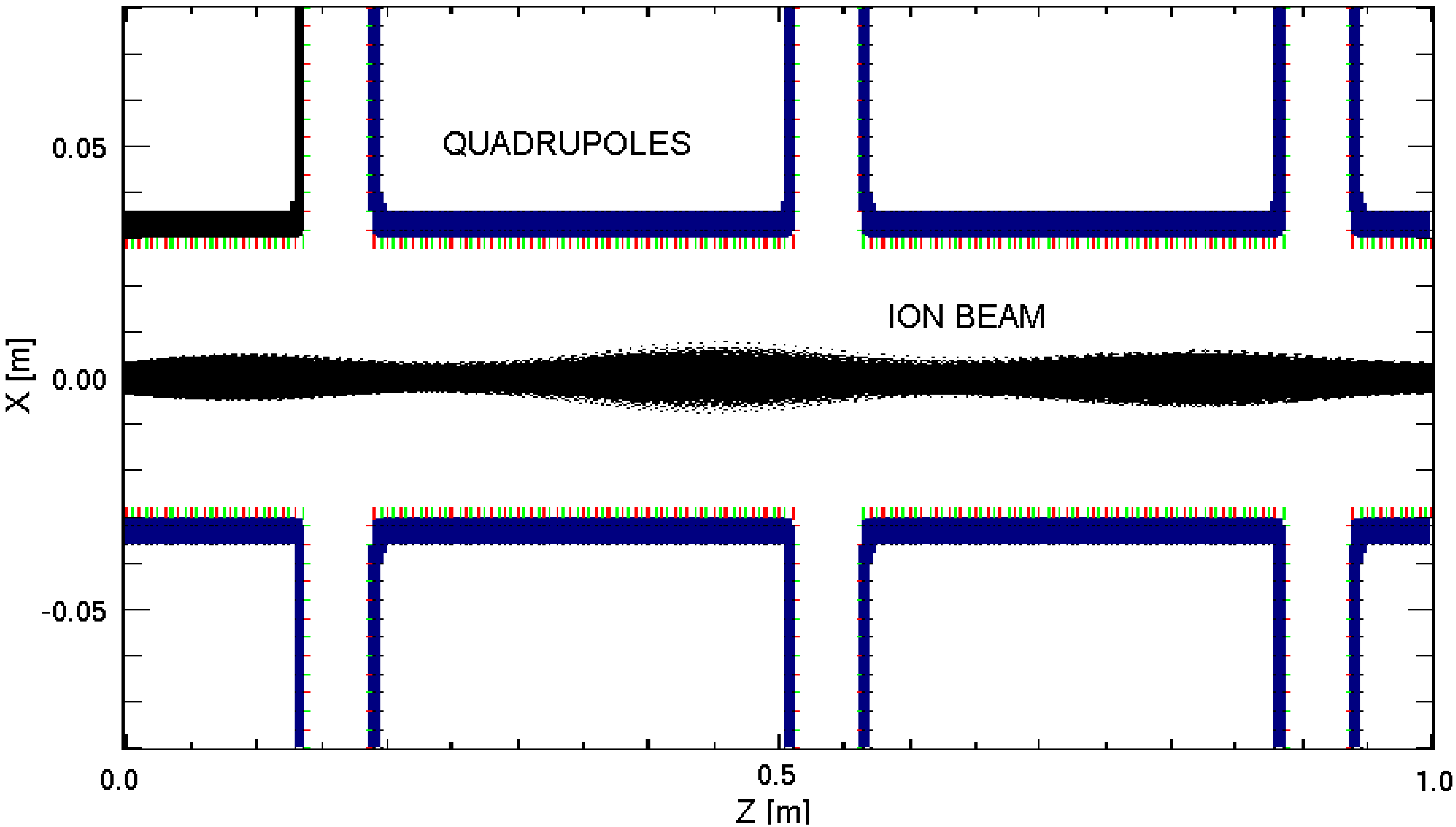


# Lifting MS and tube into accelerator

**Ion Optics (high intensity selfconsistent beam transport, space charge effects):**

**Daniel Cartelli, N. Cánepa et al.**

# Proton beam transport (30 mA)

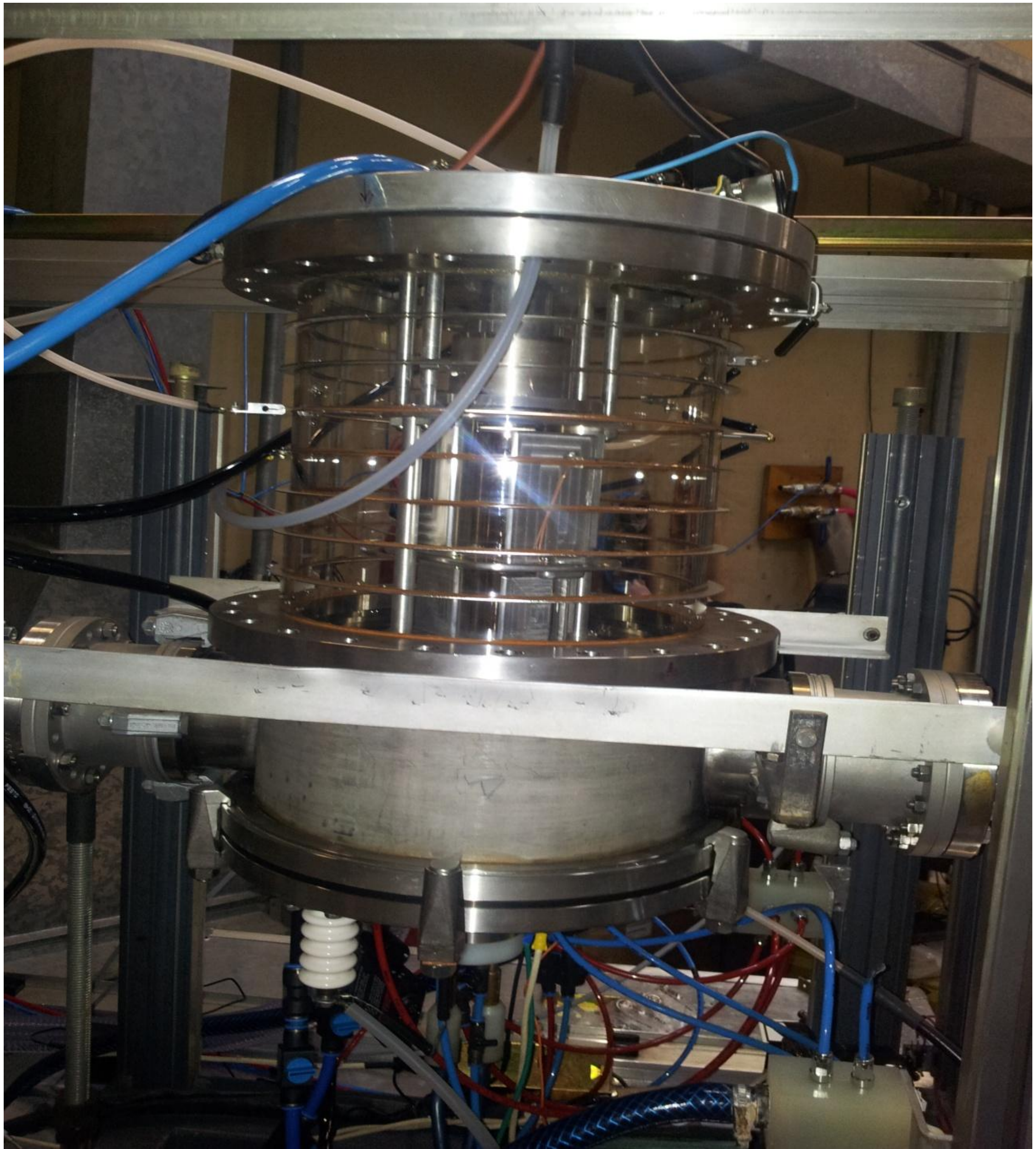


# Ion sources, injector, test stand and accelerator

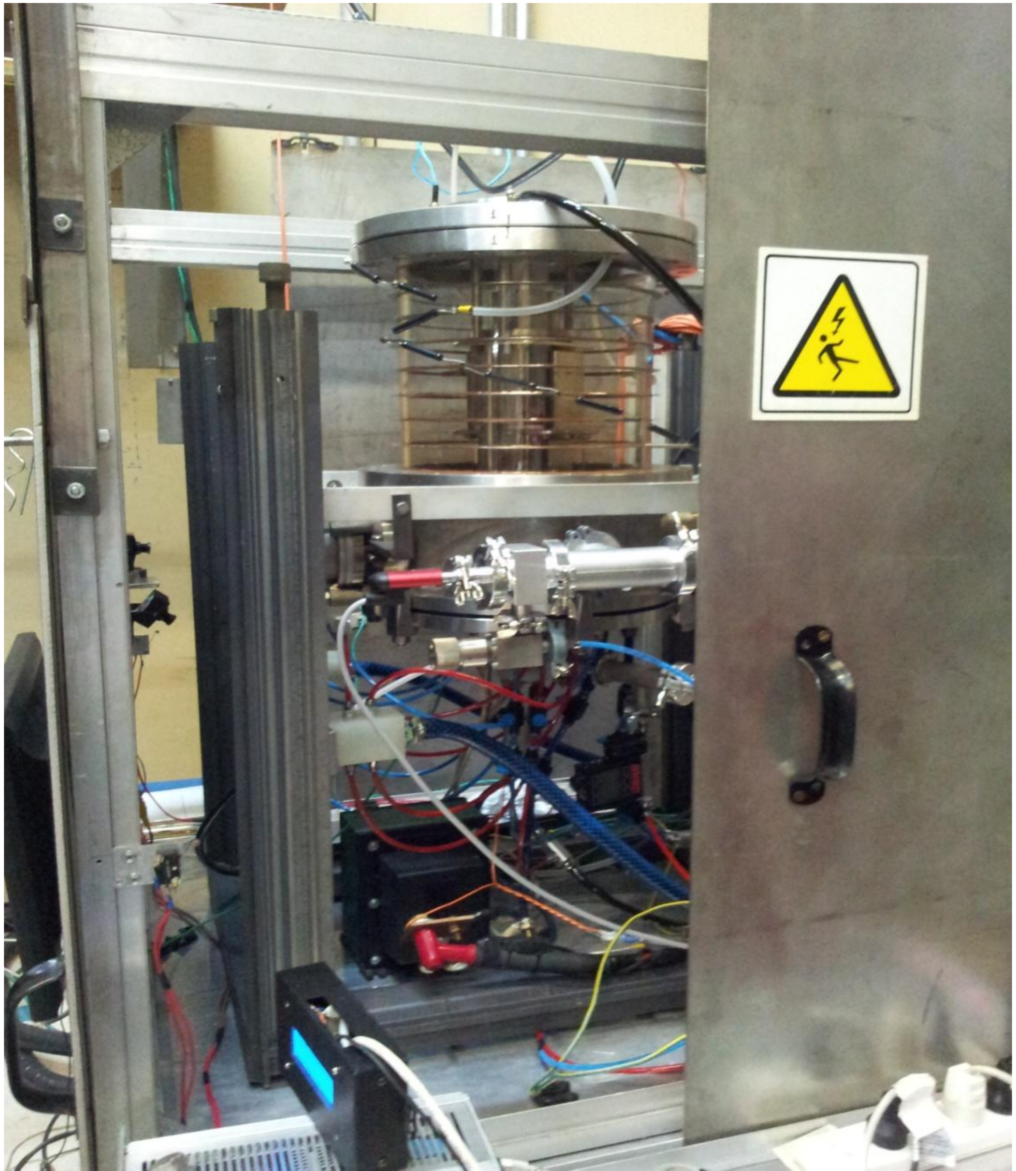
**J. Bergueiro, H.Somacal, M.Igarzabal, J.C.Suarez Sandin, et al.**

# New high power ion source: ready

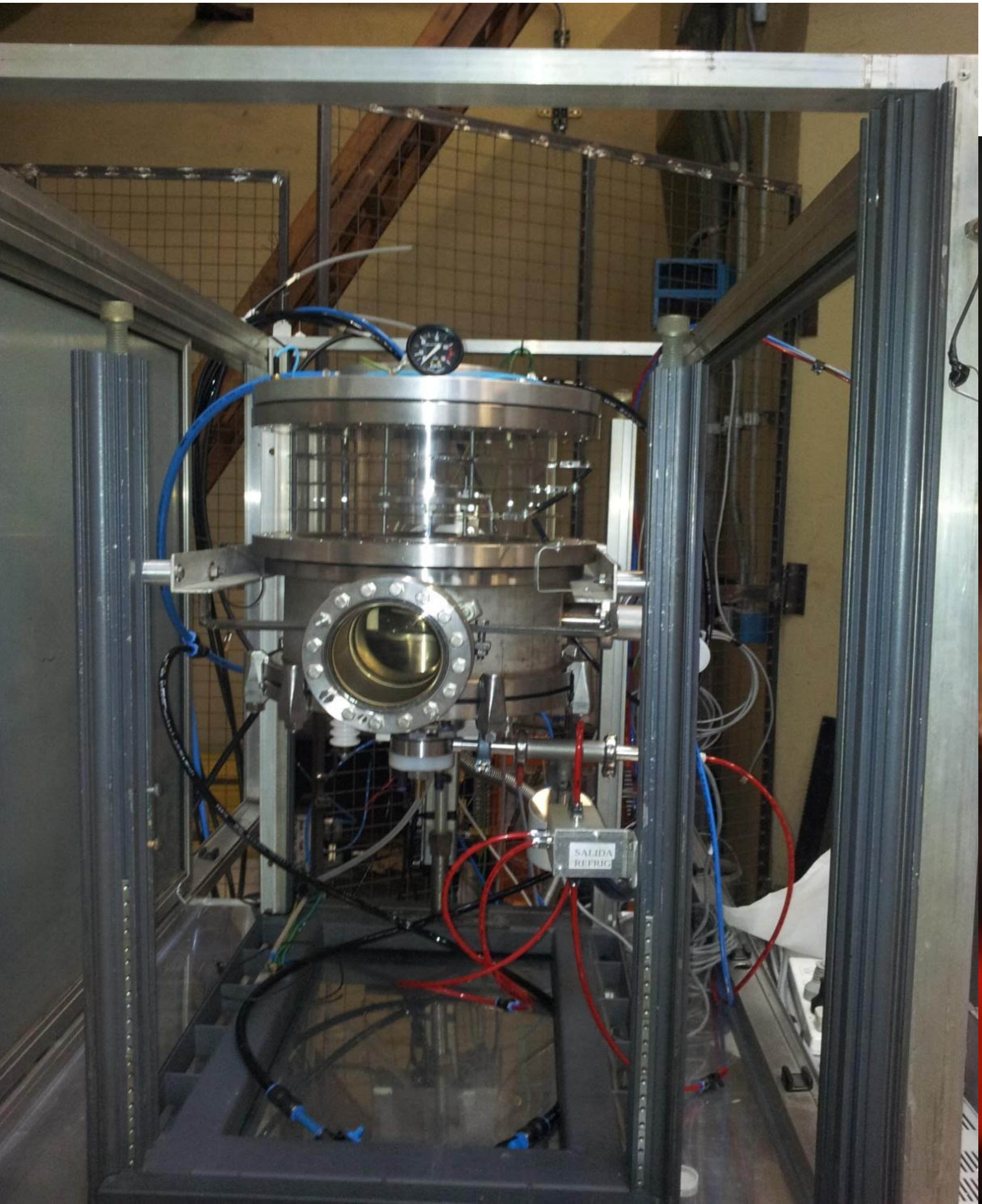
# Ion source test stand (40 kV)

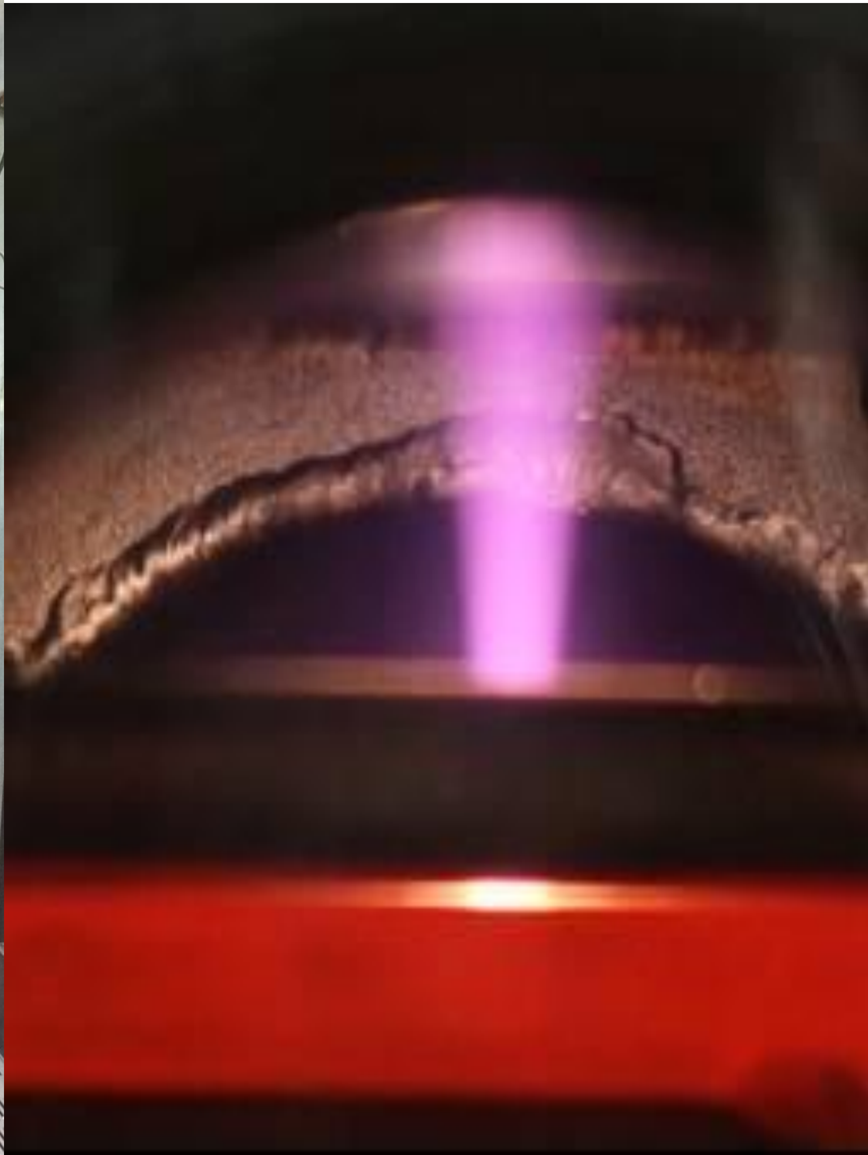


# Ion source test stand with quadrupole doublet- 40 kV

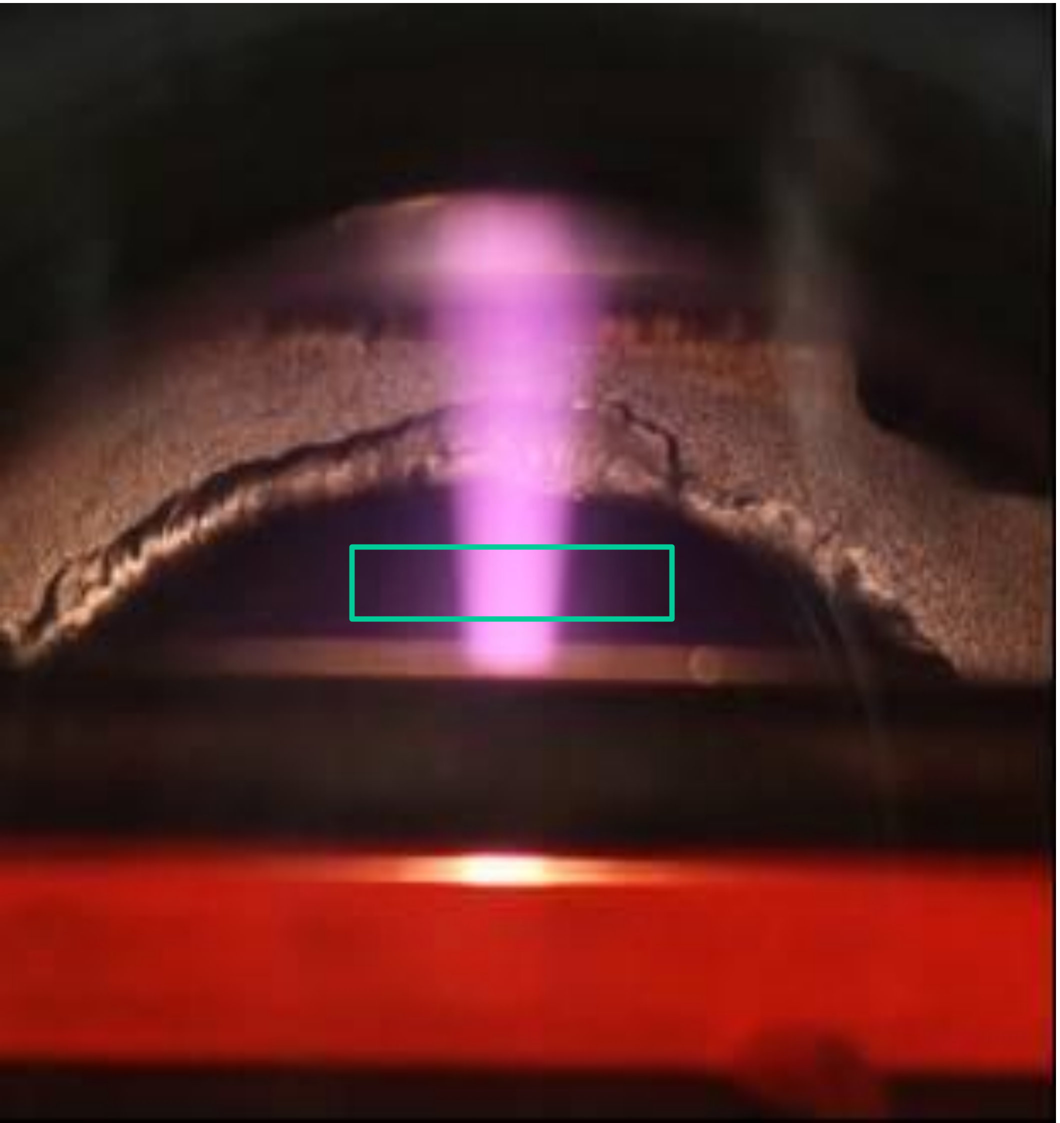


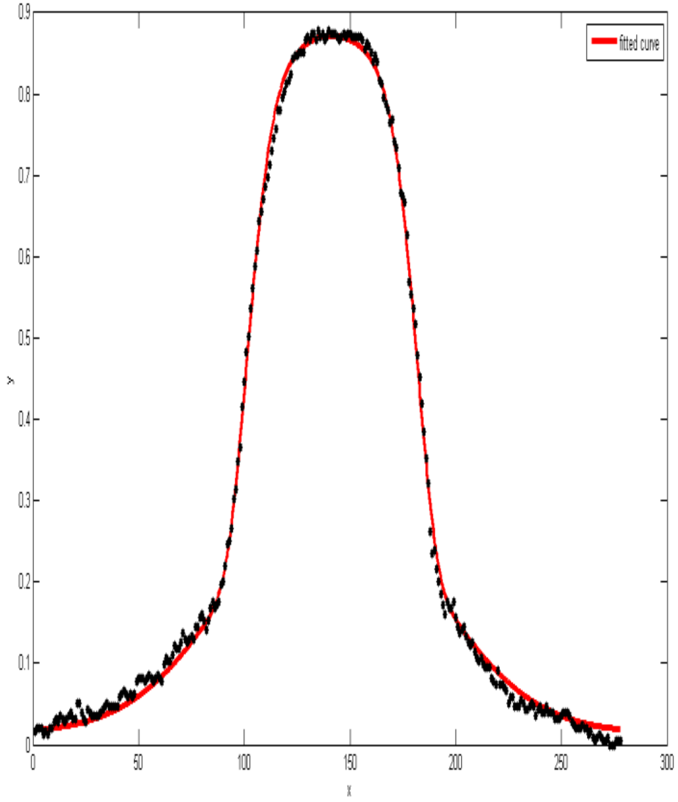
# 30 mA proton beam



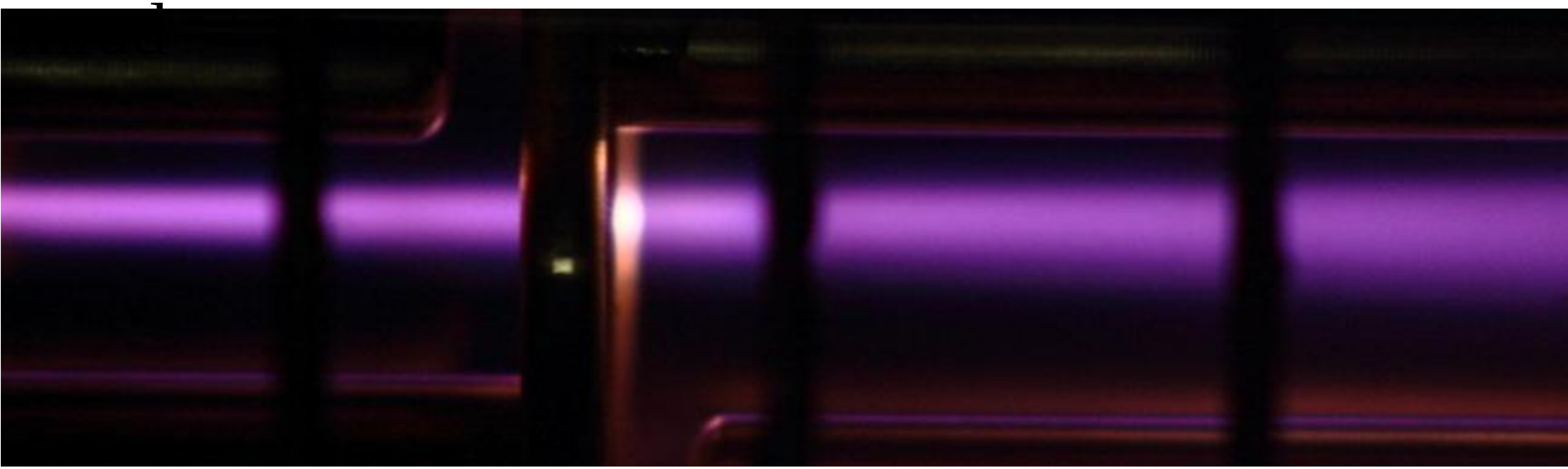



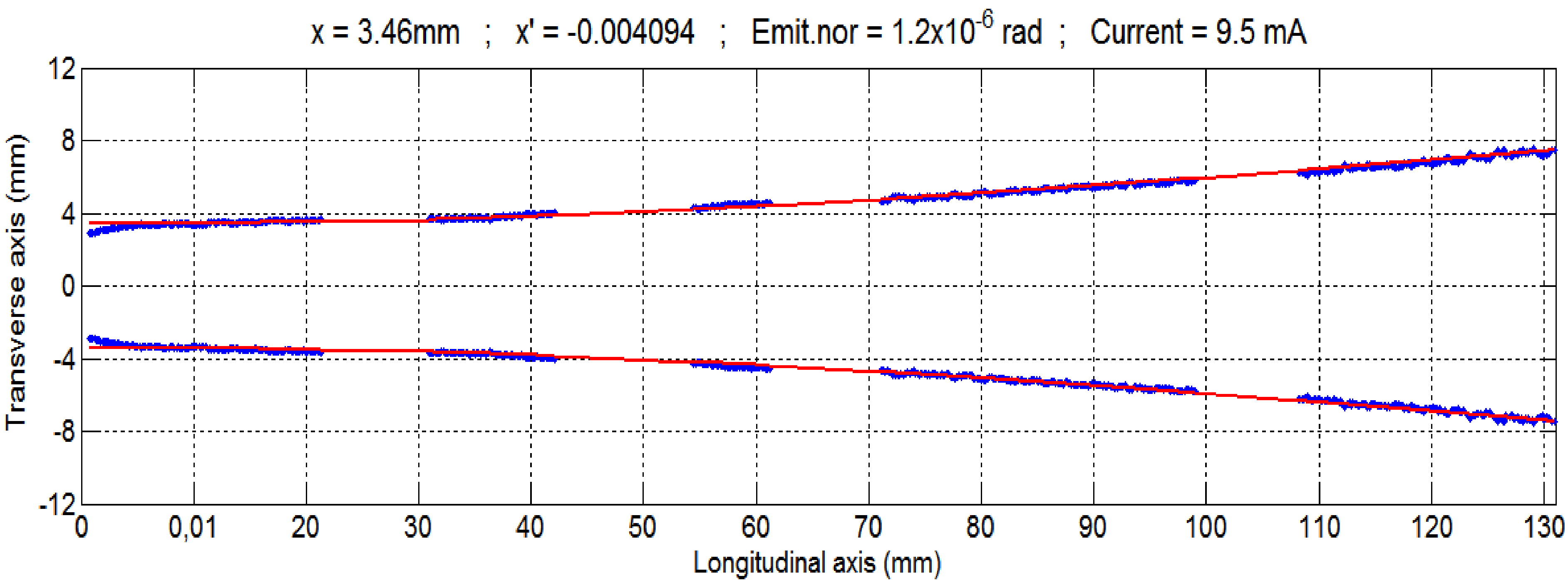
# Beam shape analysis through induced fluorescence in residual gas



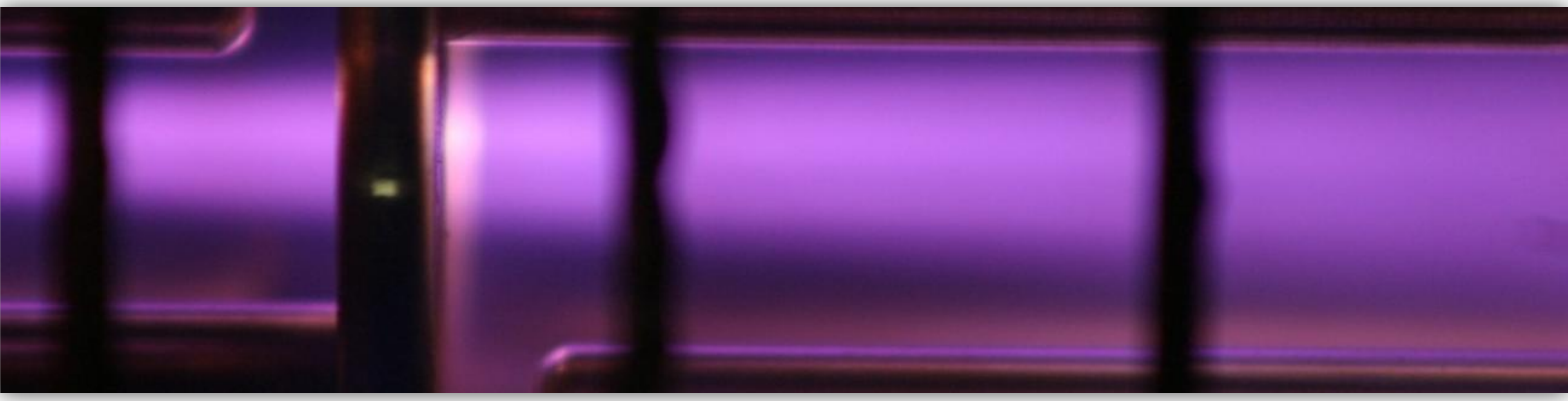


# 9.5 mA, Radius=3.5 mm; Emittance$_N$=0.38 π mm mrad

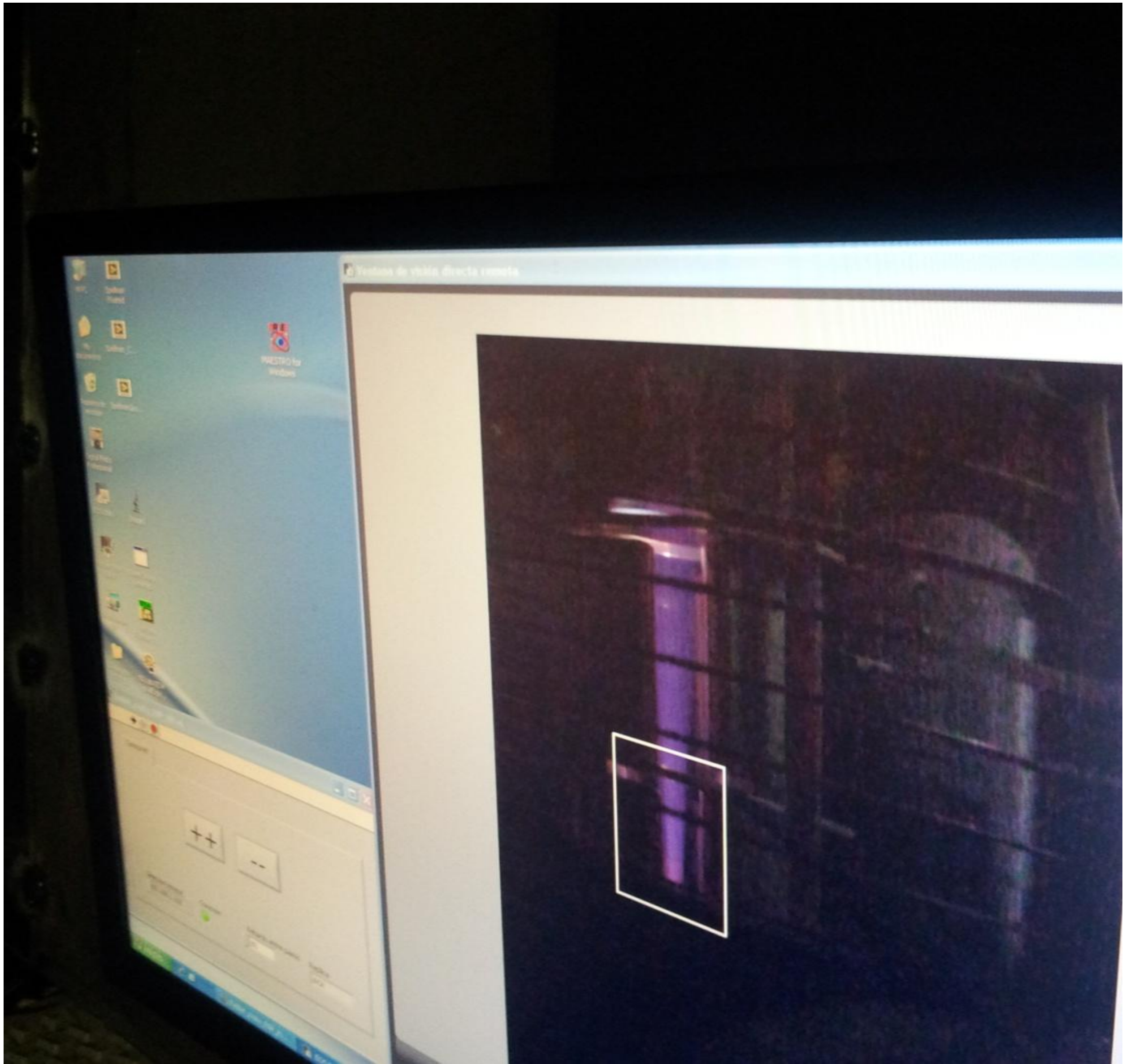




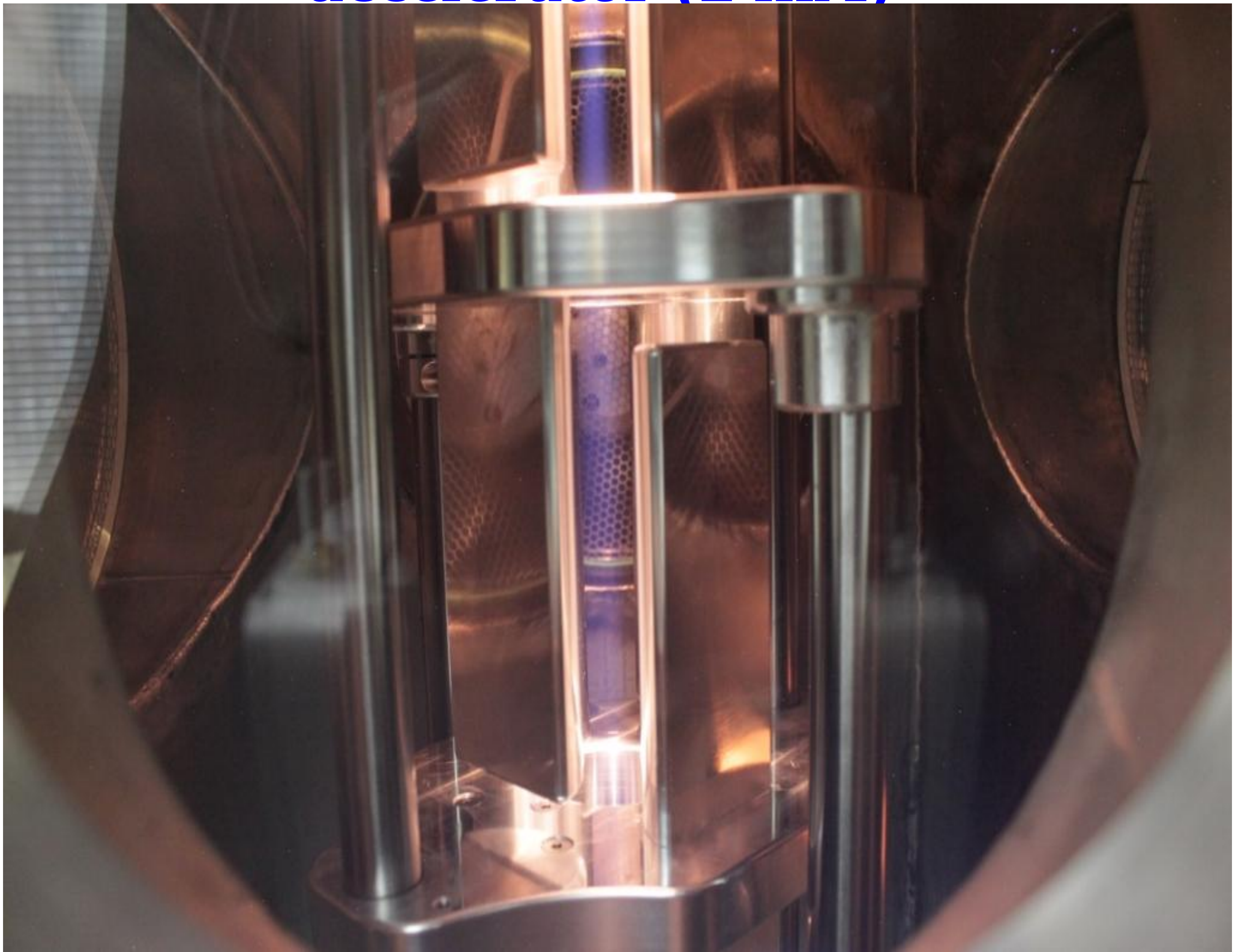
**20.3 mA, Radius=6.3 mm; $Emittan_N$= 1.36 $\pi$ mm mrad**



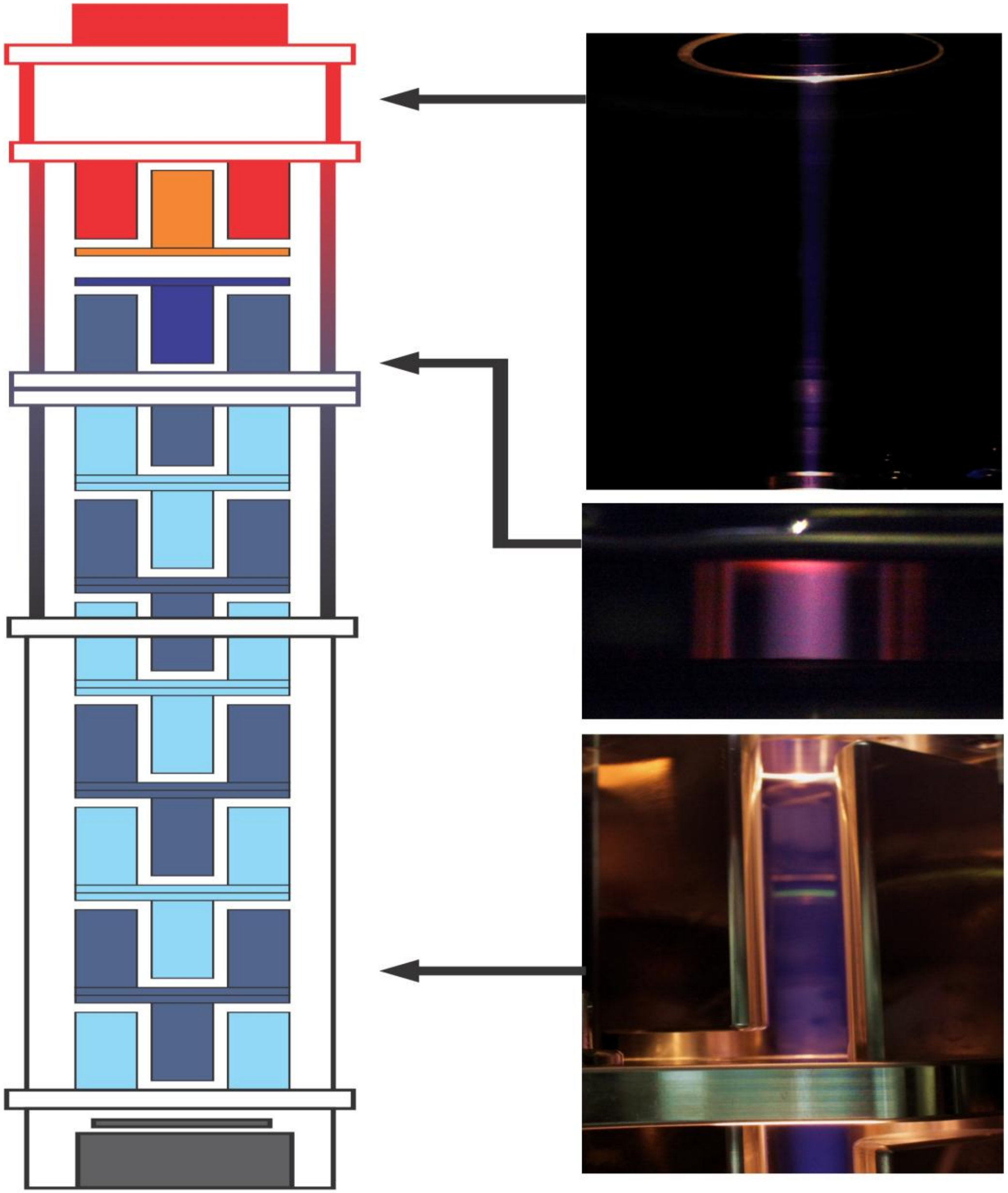
# 30 mA beam propagating thru a quadrupole doublet in test stand (40 kV) into a FC



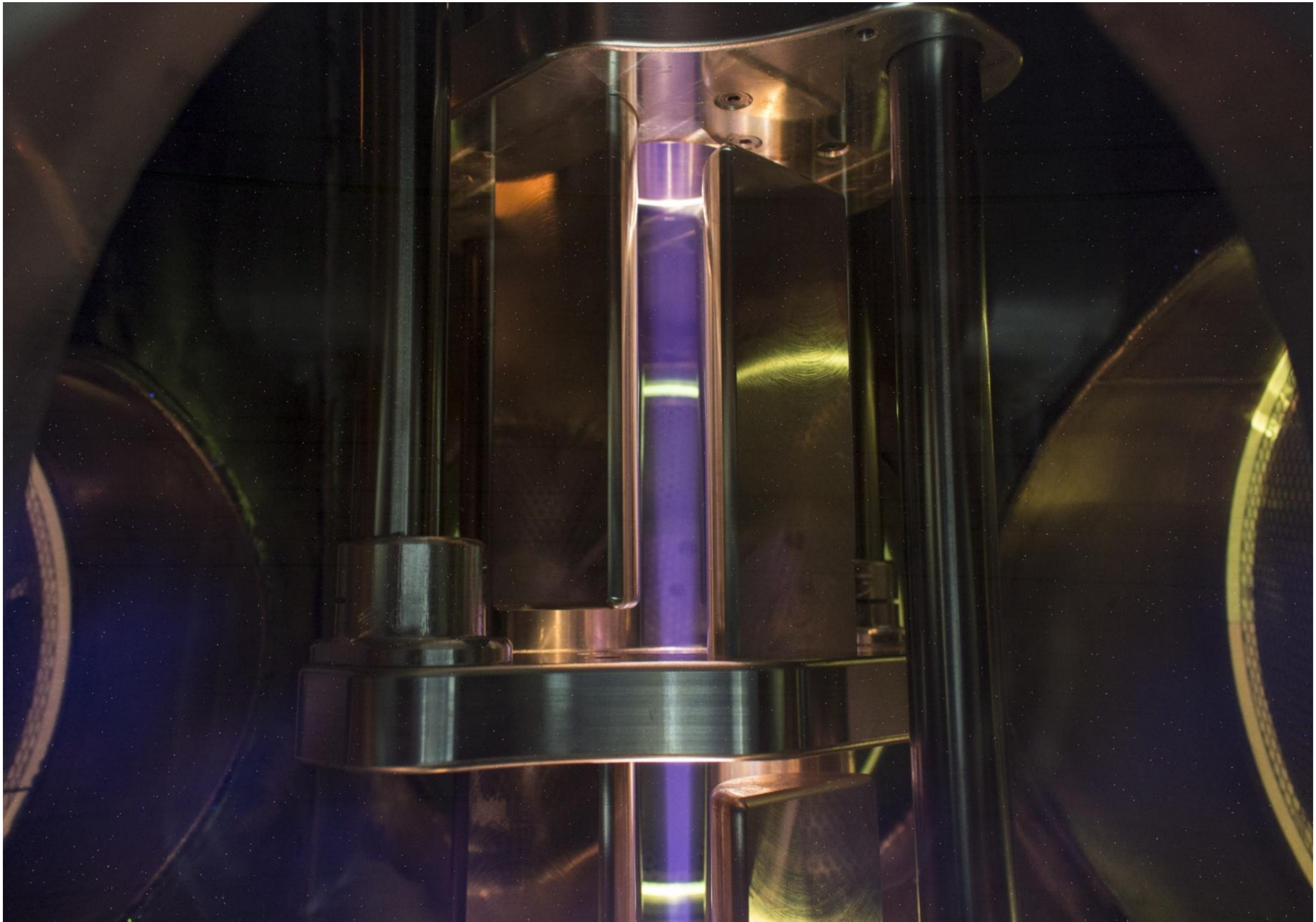
# First beam propagating through the 200 kV accelerator (2 mA)



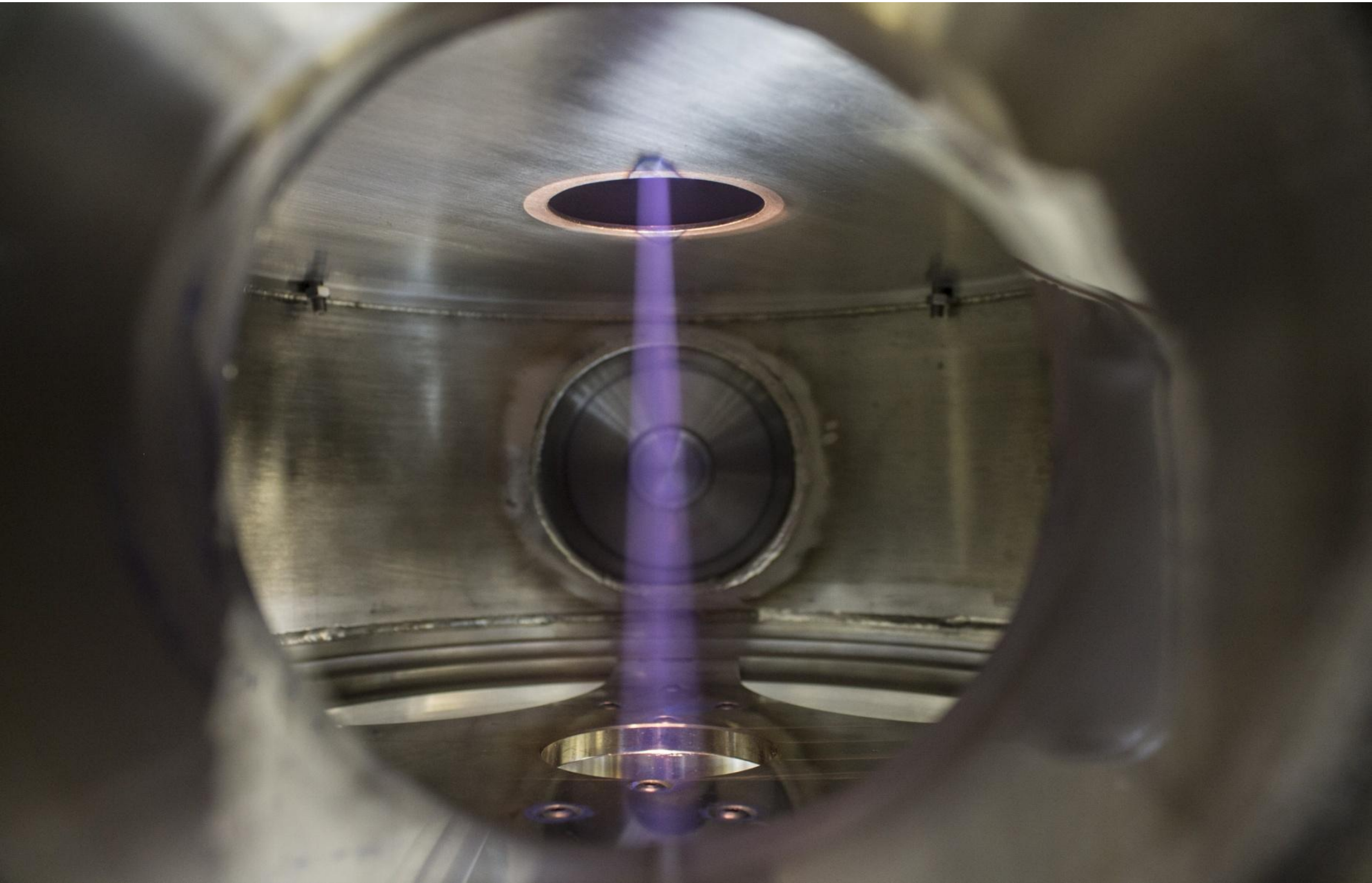
# Beam images along the tube

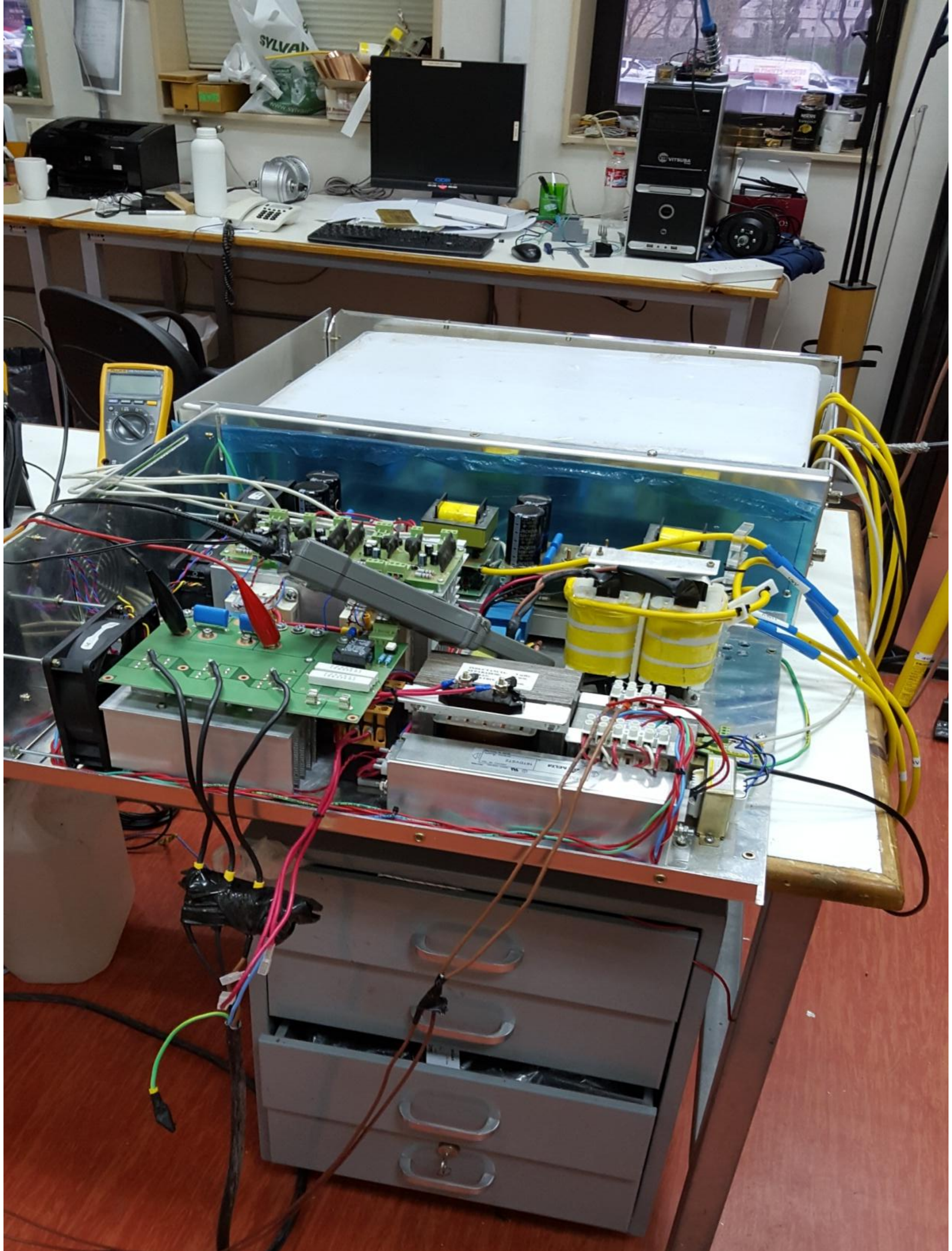


# 5-10 mA, View of lower chamber (05-09)



# 5-10 mA, view of upper chamber (05-09)



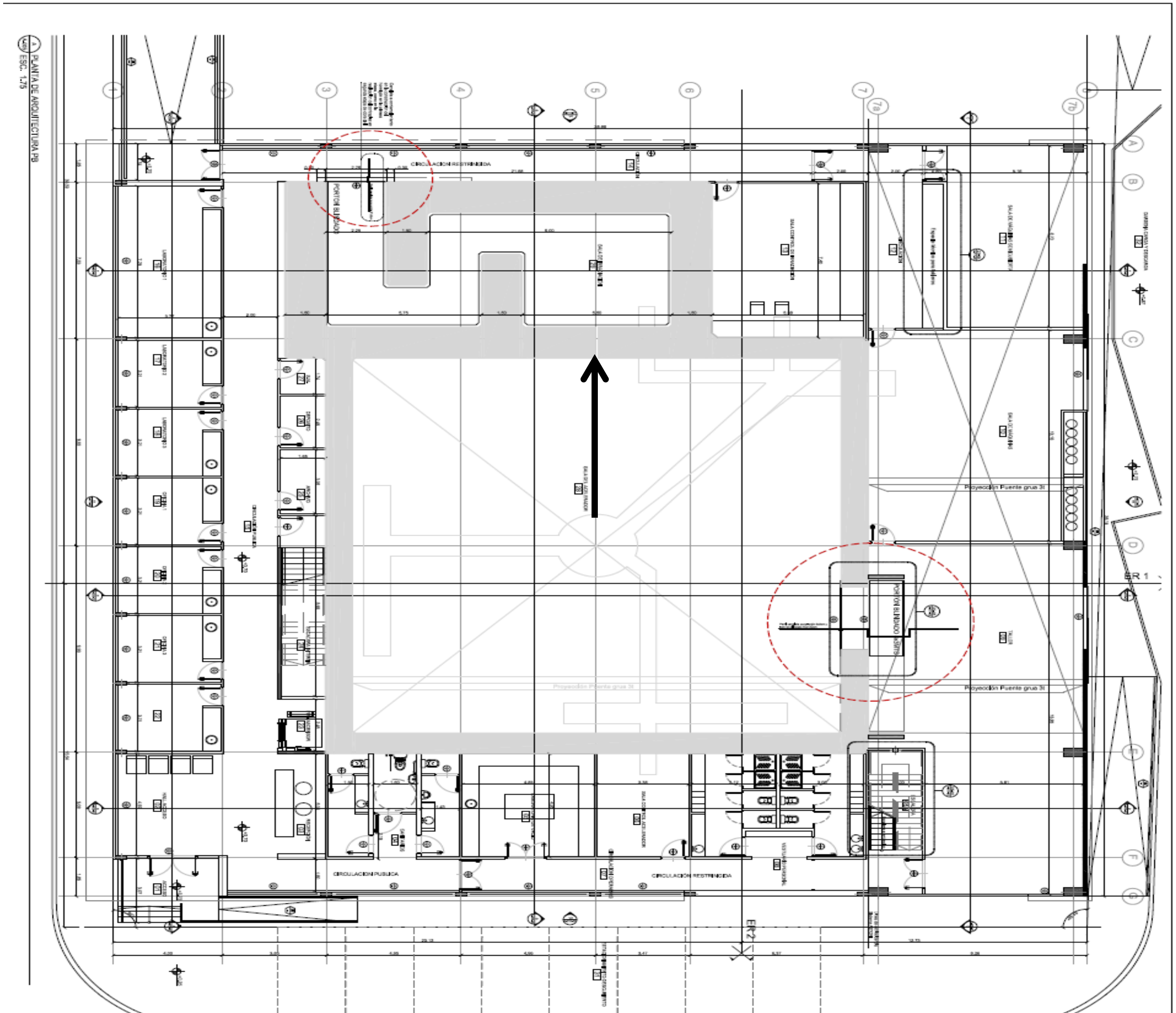


# High voltage supplies: M. Baldo, D. Mercuri, N. Real.

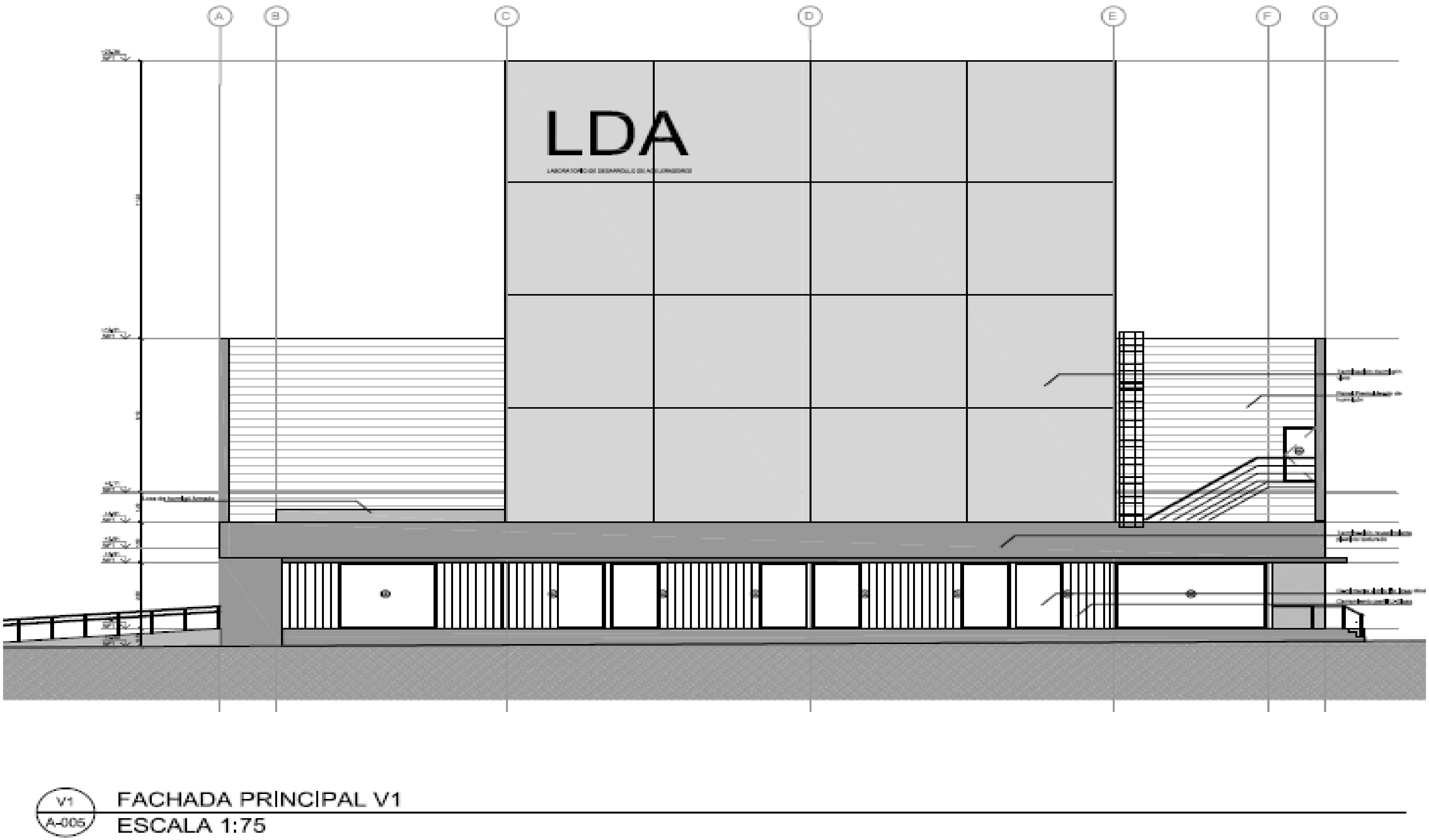
# 720 kV machine being assembled:

Juan Carlos Suarez Sandin, M. Igarzabal, J. Erhardt, G. Conti

# New Lab & BCNT Centre (CNEA)



# Front view of new Centre



# Breaking the ground…

# Digging..

# CONCLUSIONS/REMARKS

- **The era of in-hospital neutron sources has started. Worldwide effort: a variety of different accelerators and nuclear reactions are being evaluated. So relative merits and costs may be compared. As good as best reactor.**

- **The suitability of $^{9}Be(d,n)^{10}B$ @ 1.45 MeV as an epithermal/thermal neutron source has been demonstrated. The technology is well advanced.**

- **0.2 MV ESQ accelerator ready. In-air folded 0.72 MV Tandem ESQ (TESQ) is being built. Other options (single ended 1.4 MV and 1.4 MV Tandem) are also being pursued.**