C Y C L O T R O N 2010

Lanzhou, China
September 2010

CYCLONE® 70 ARRONAX Cyclotron Progress Report

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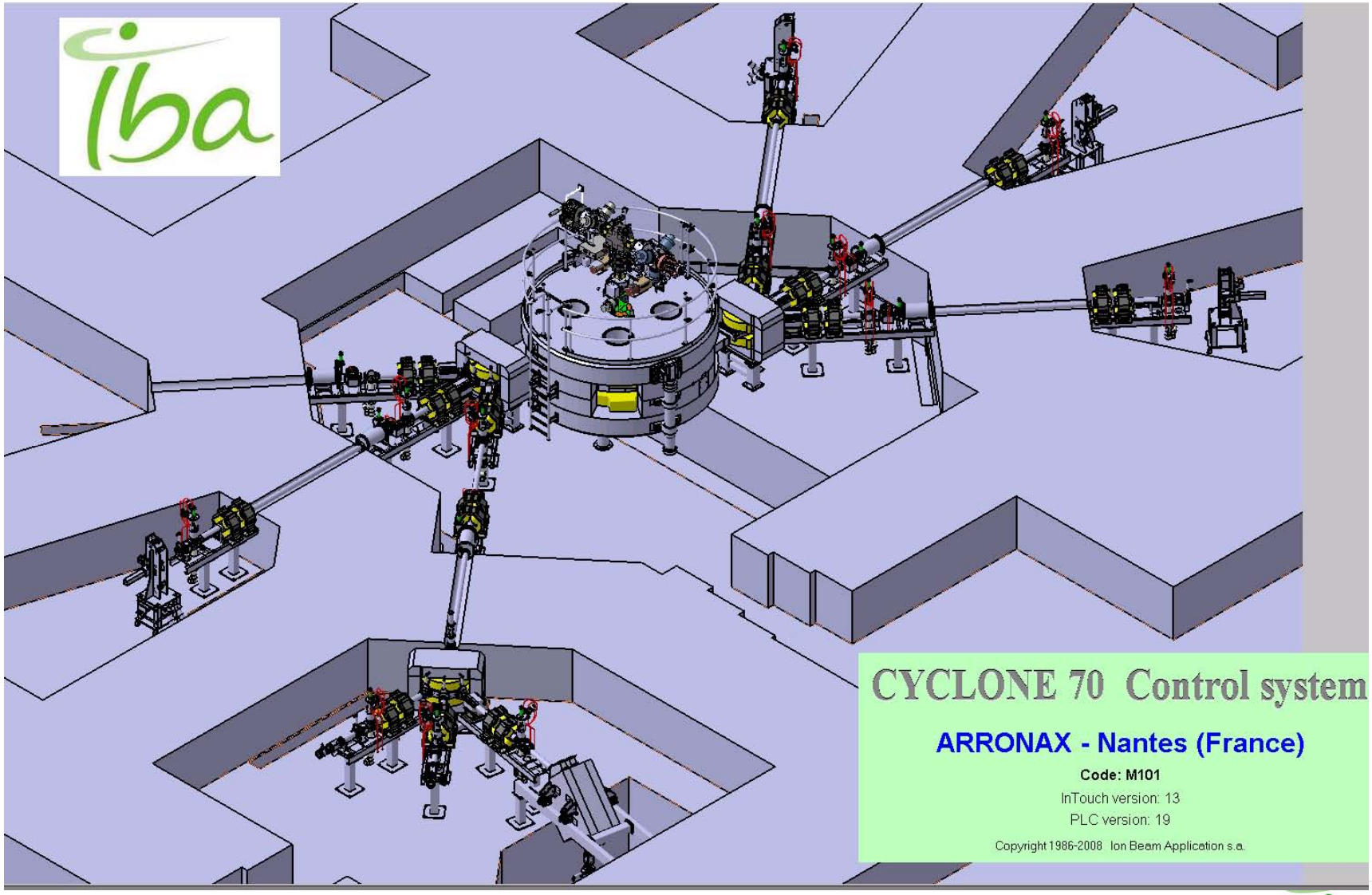
Project Manager
On behalf of the IBA team…

We protect, enhance and save lives

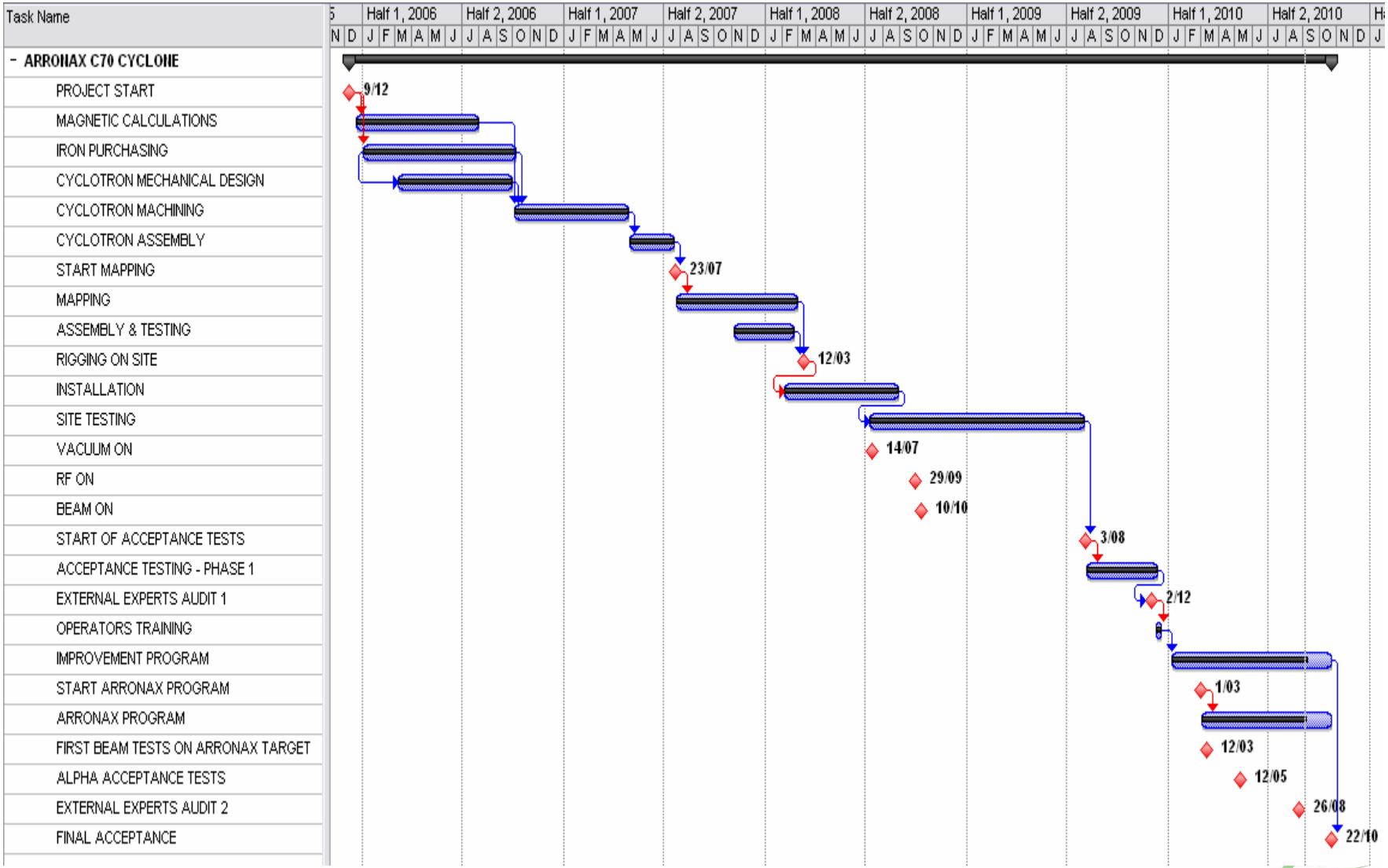
The Goals

Accelerated Beam	Extracted Energy (MeV)	On target Beam Intensity (eμA)	Extraction mode
H^-	30 – 70	750	Stripper (dual)
D^-	15 – 35	50	Stripper (dual)
$^4He^{2+}$	70	70	Deflector (single)
HH^+	35	50	Deflector (single)

The Goals



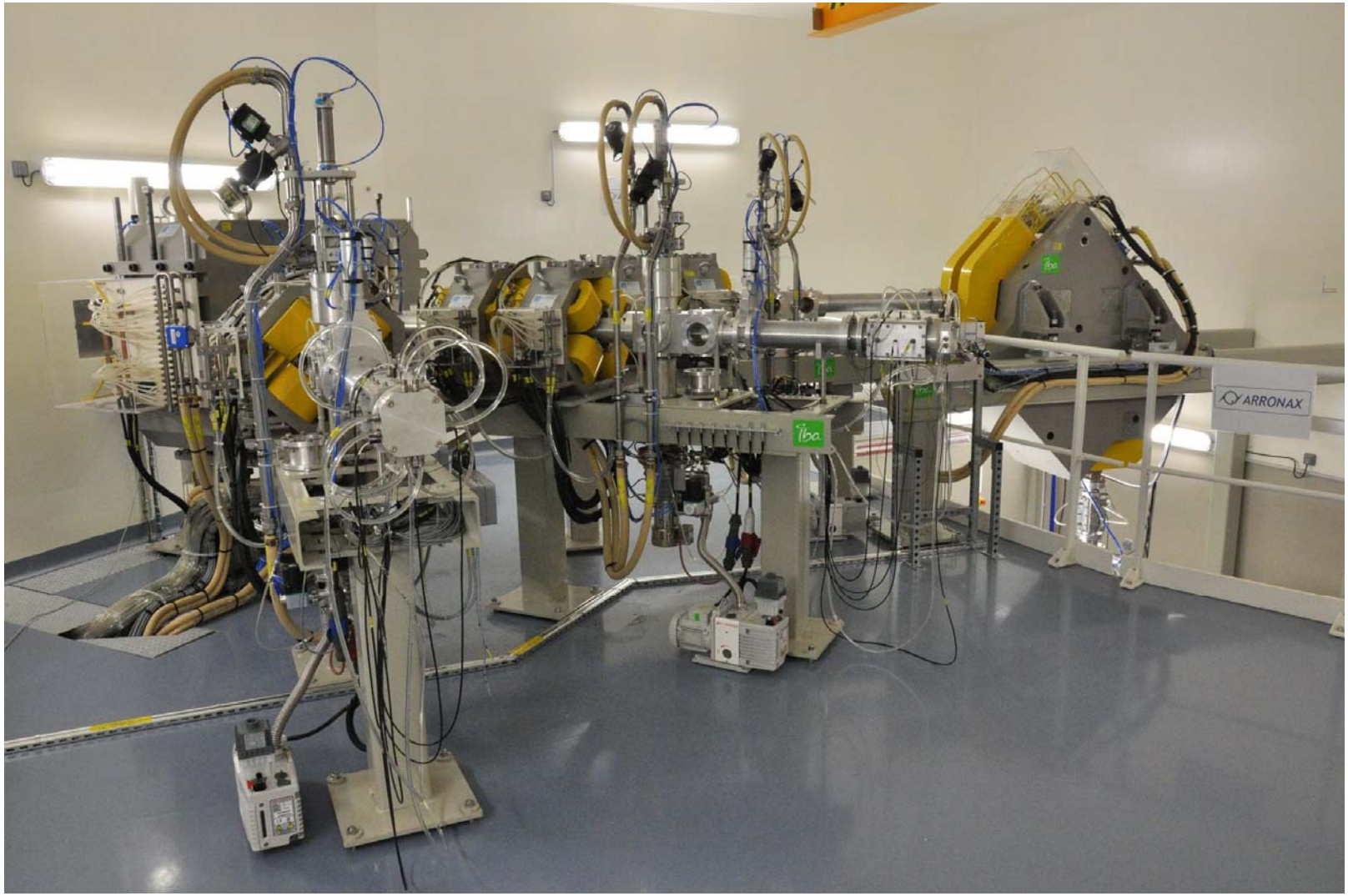
The Time Line



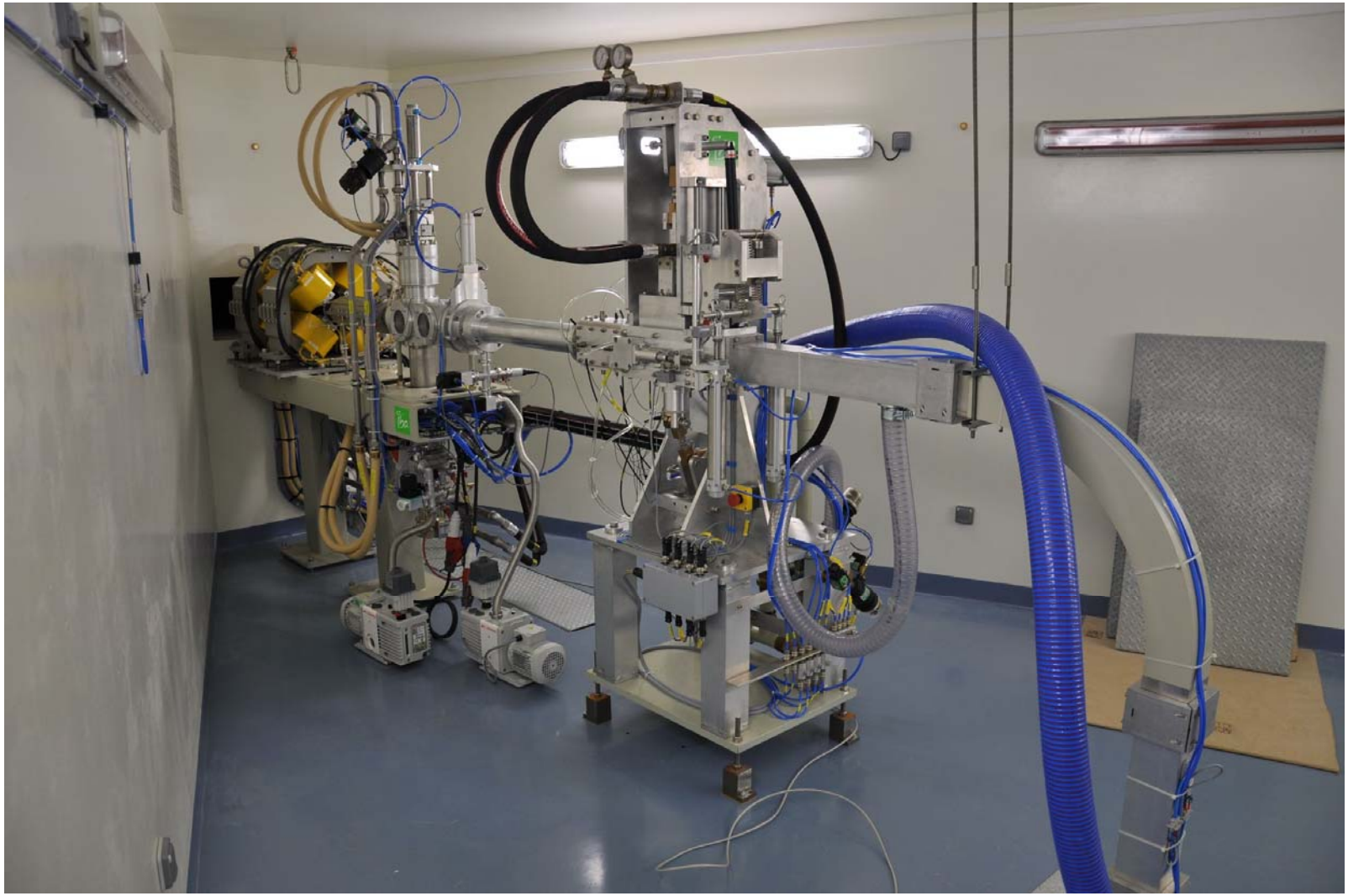
Birthday…30/04/2006

Today…07/09/2010

Today…07/09/2010



Today…07/09/2010



Today…07/09/2010

Status Report

- **Overtaken Hurdles:**
  - ✓ **Compensation coils**
  - ✓ **Harmonic 1**
  - ✓ **Electrostatic deflector**

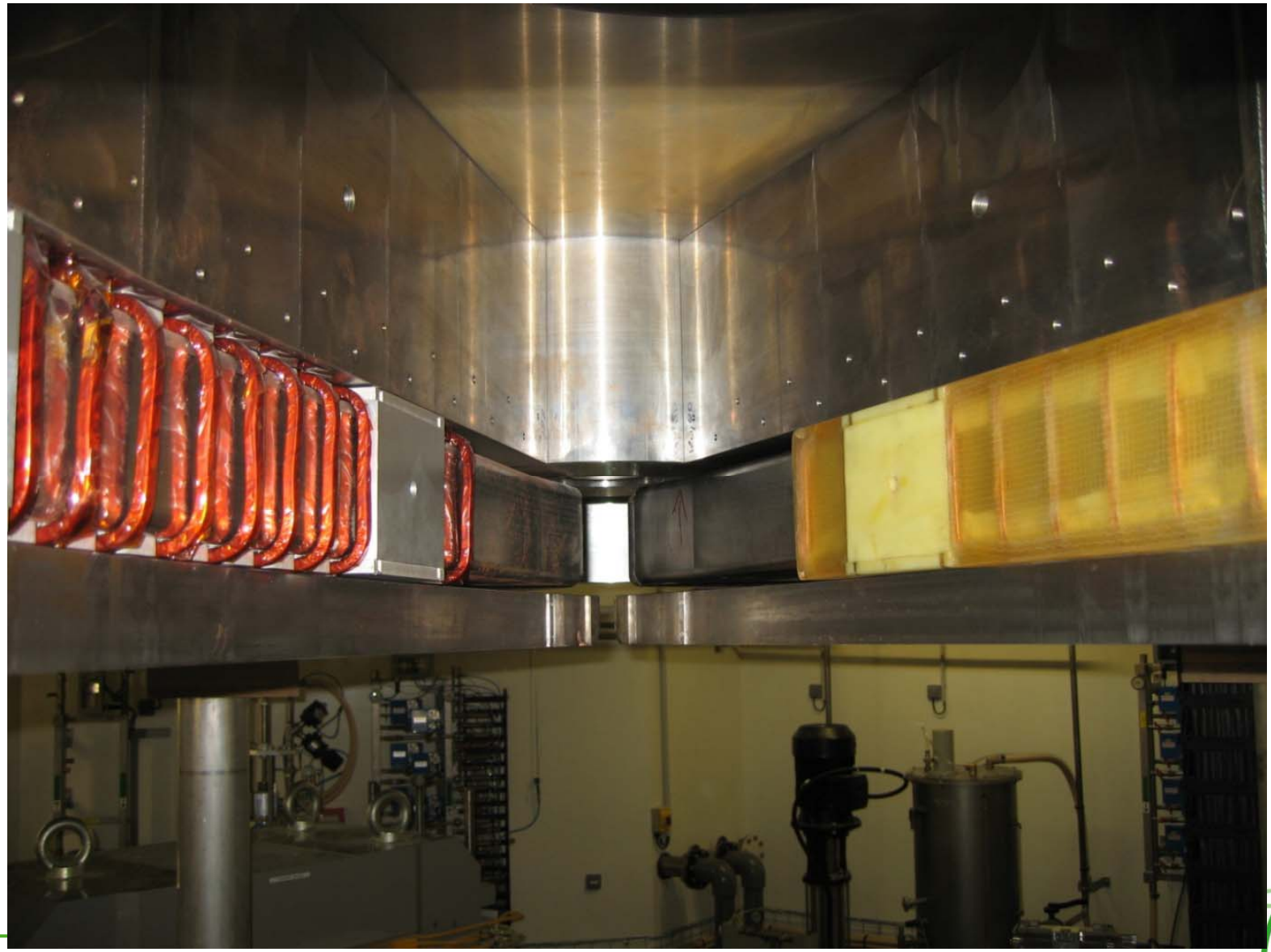
- **Final challenges to success:**
  - ❖ **Vacuum improvement**
  - ❖ **High intensity 70MeV proton beam**

- **Substantial steps to full operation:**
  - ❖ **90% of acceptance tests passed with success**
  - ❖ **Several months of beam tests successfully carried out for ARRONAX**

Compensation Coils

- **Issue:**
  - **Important electromagnetic forces during current ramp-up**
- **Consequences:**
  - **Displacement of the conductors:**
    - **Wear out of the kapton isolation**
    - **short-circuits → iron**
- **Solution:**
  - **Epoxy isolated coils**

Compensation Coils



Harmonic 1

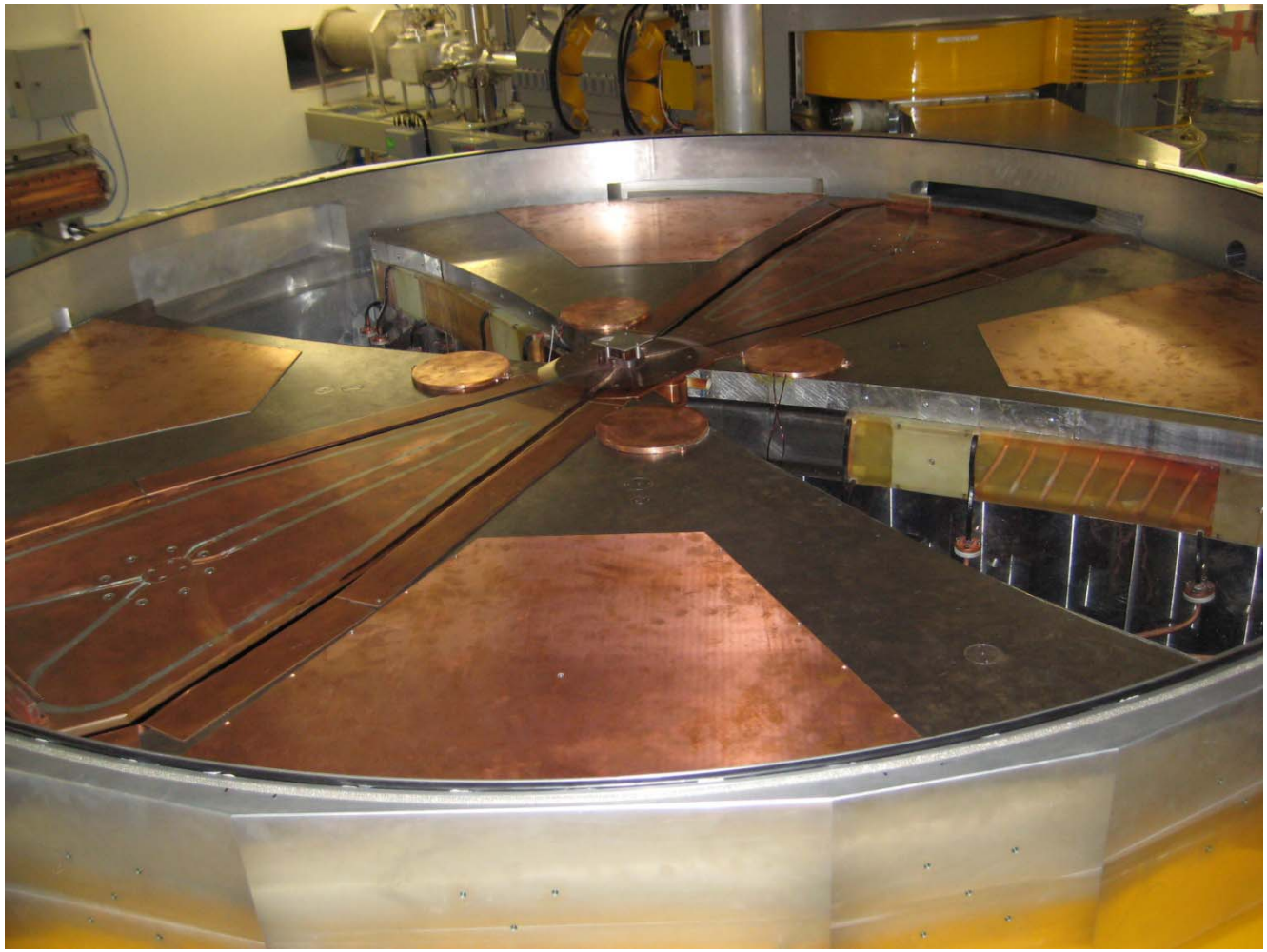
- **Issue:**
  - **H1 magnetic component ~ 10G (B ~ 1,6T)**
- **Consequences:**
  - **Beam decentering**
  - **Dangerous crossing of $\nu_z = 0.5$ & $\nu_r = 2\ \nu_z$**
    - **Negative impact on the He^{2+}, D^- and HH^+ beam optics**
- **Solution:**
  - **Harmonic coils → center & outer radii**

Harmonic 1 – Center Coils

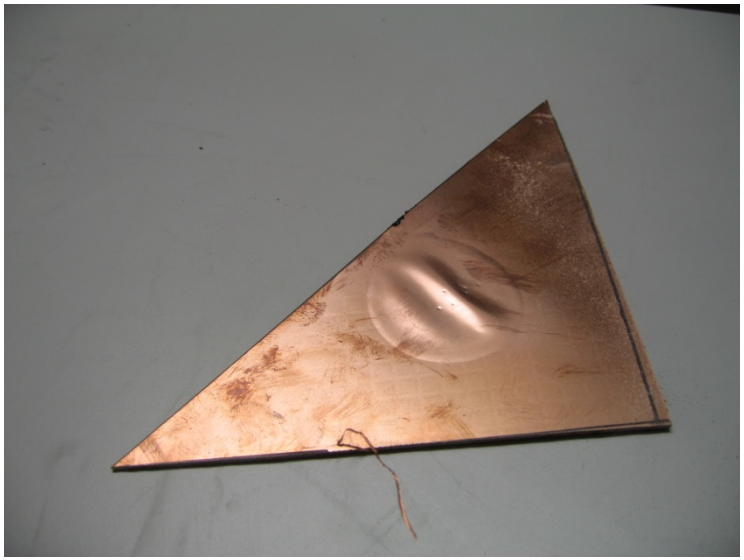
- Center radii → 300At
- Magnetic gap decreased from 30mm → 16mm

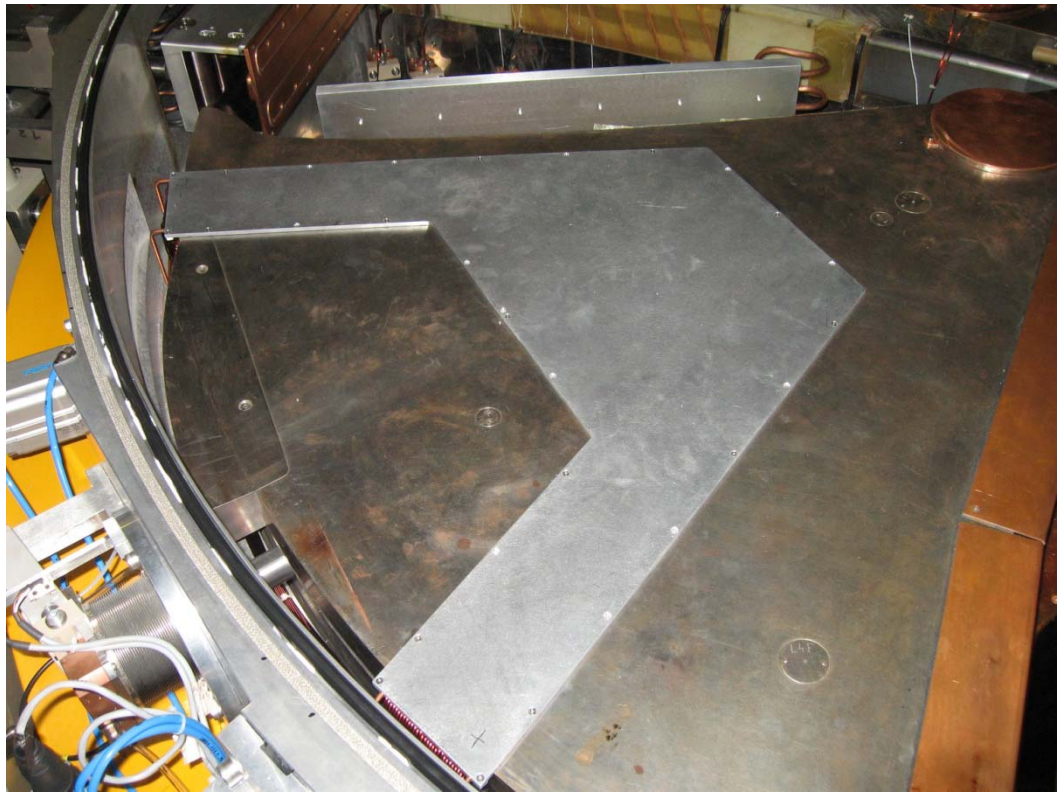
Harmonic 1 – Outer Coils

- Outer radii → 90At
- Magnetic gap decreased from 30mm → 20mm



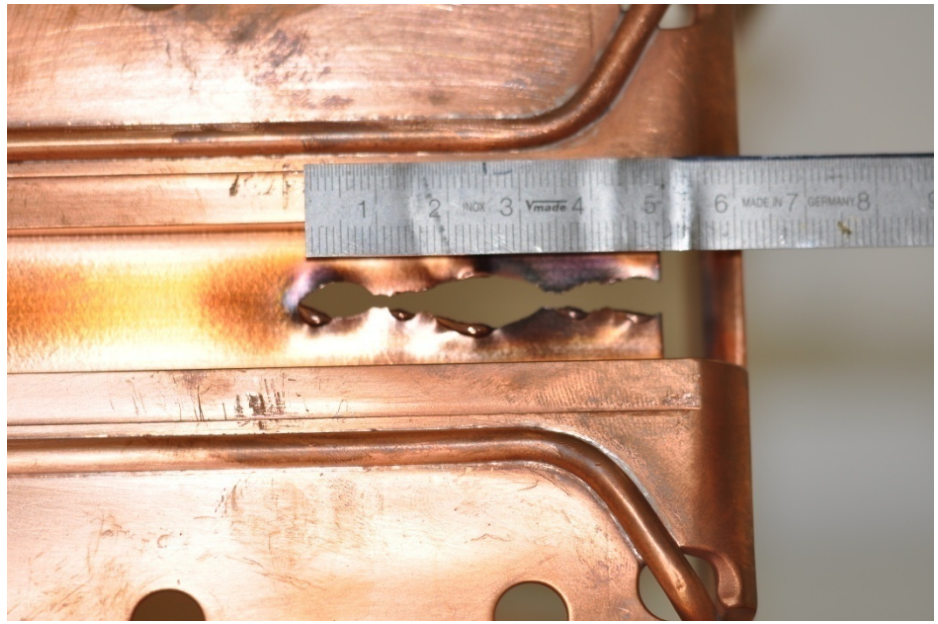
Harmonic 1 – Outer Coils





Electrostatic deflector

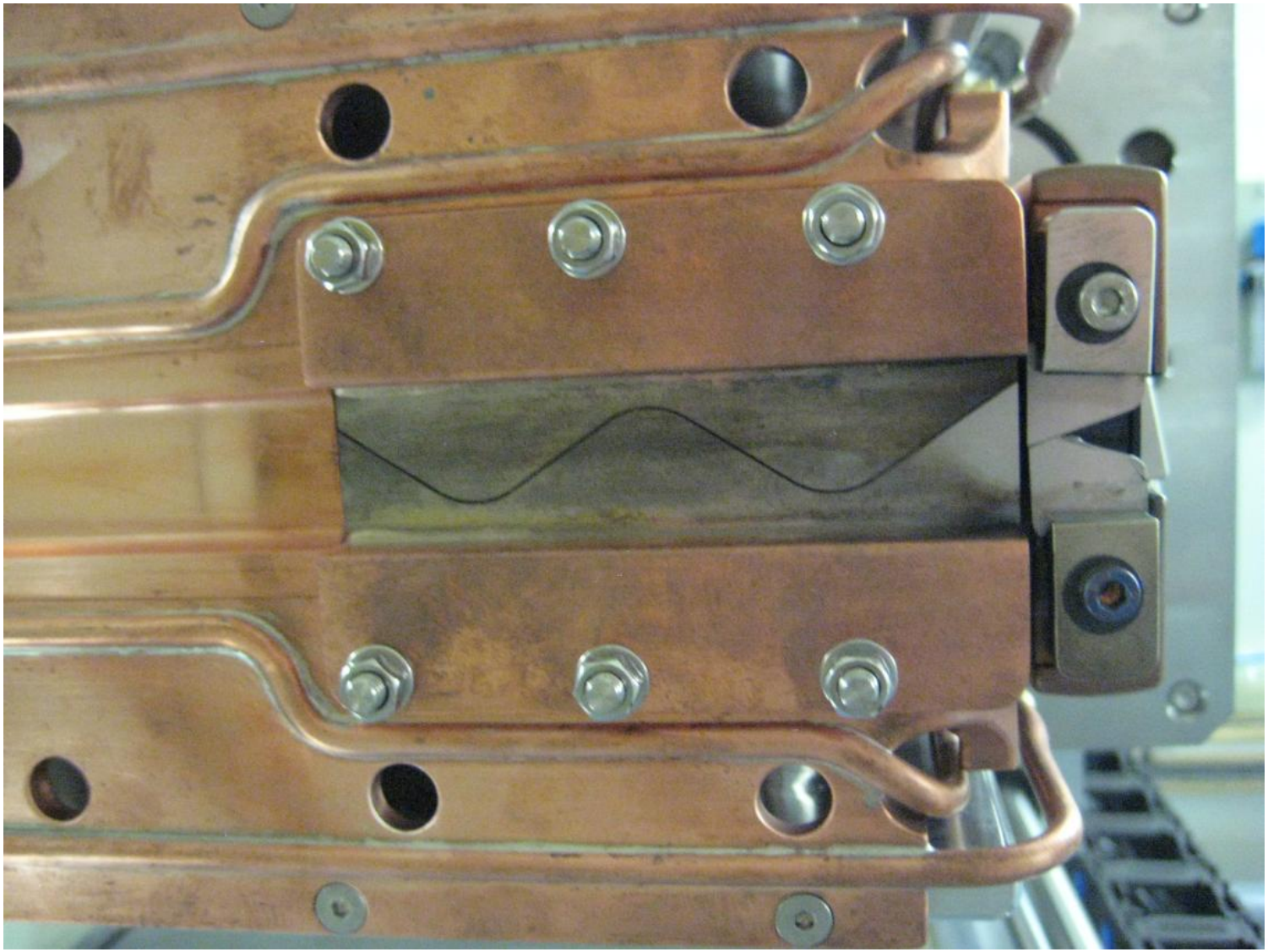
- **Issues:**
  - Septum's power dissipation capacities
  - Pre-septum's position
- **Consequences:**
  - Limited beam intensity extraction (25eμA – 70MeV)



Electrostatic deflector

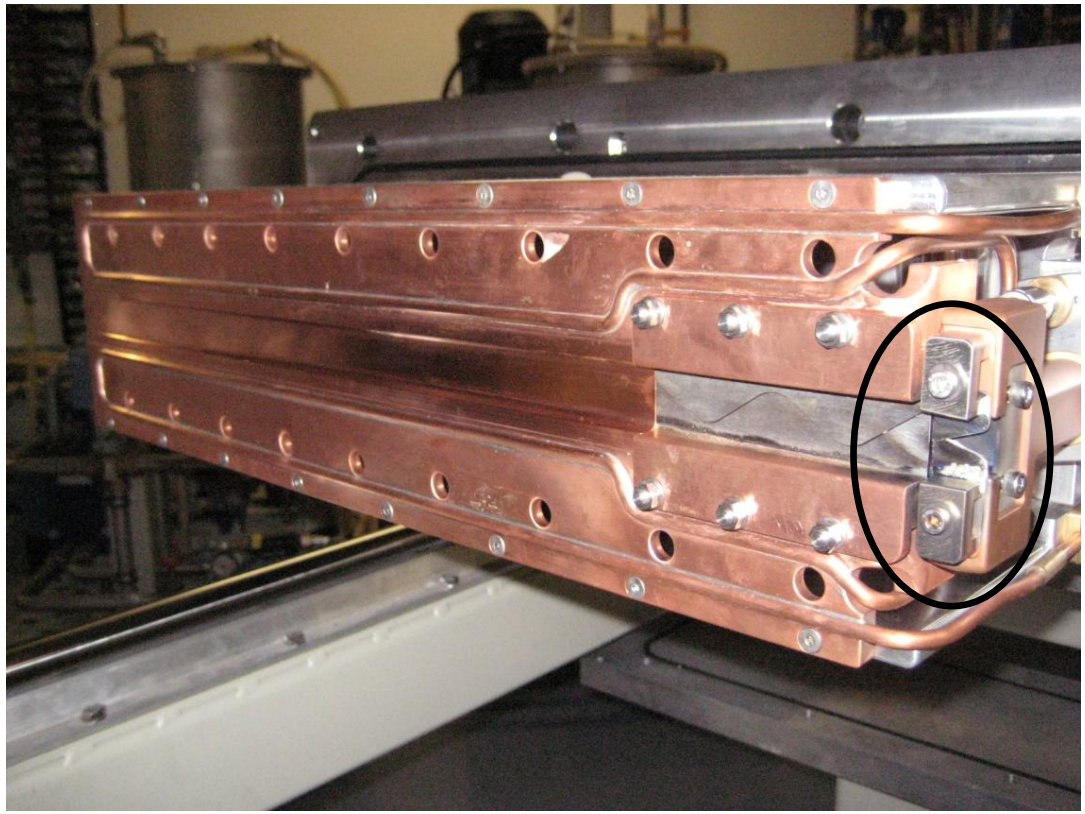
- **Solutions:**
  - **Redesigned septum & pre-septum:**
    - **W insert:**
      - Increase power dissipation
    - **Optimized profile:**
      - Recalculated thickness variation → increase power dissipation
      - Gap variation: 4 – 8mm
      - Vext = 65 – 70kV
    - **Optimized pre-septum thickness → 0.6mm**
  - **Reduced septum to pre-septum distance: 10mm → 1mm**
    - Improved septum protection

Electrostatic deflector – W insert



Electrostatic deflector – Pre-septum

- **Issue:**
  - Thermal contact of the pre-septum blades
- **Proposed solution:**
  - Braze the W blades (same technique used for the septum)



High Intensity 70MeV Proton Beam

- **Issues:**
  - **Fast o-ring deterioration:**
    - **Stripper probes**
    - **Stripper air locks**
    - **Extraction vacuum chamber**
  - **Outgassing:**
    - **Stripper probes**
    - **Vacuum chamber**
  - **Vacuum level in the non pumped valleys (RF cavity valleys)**

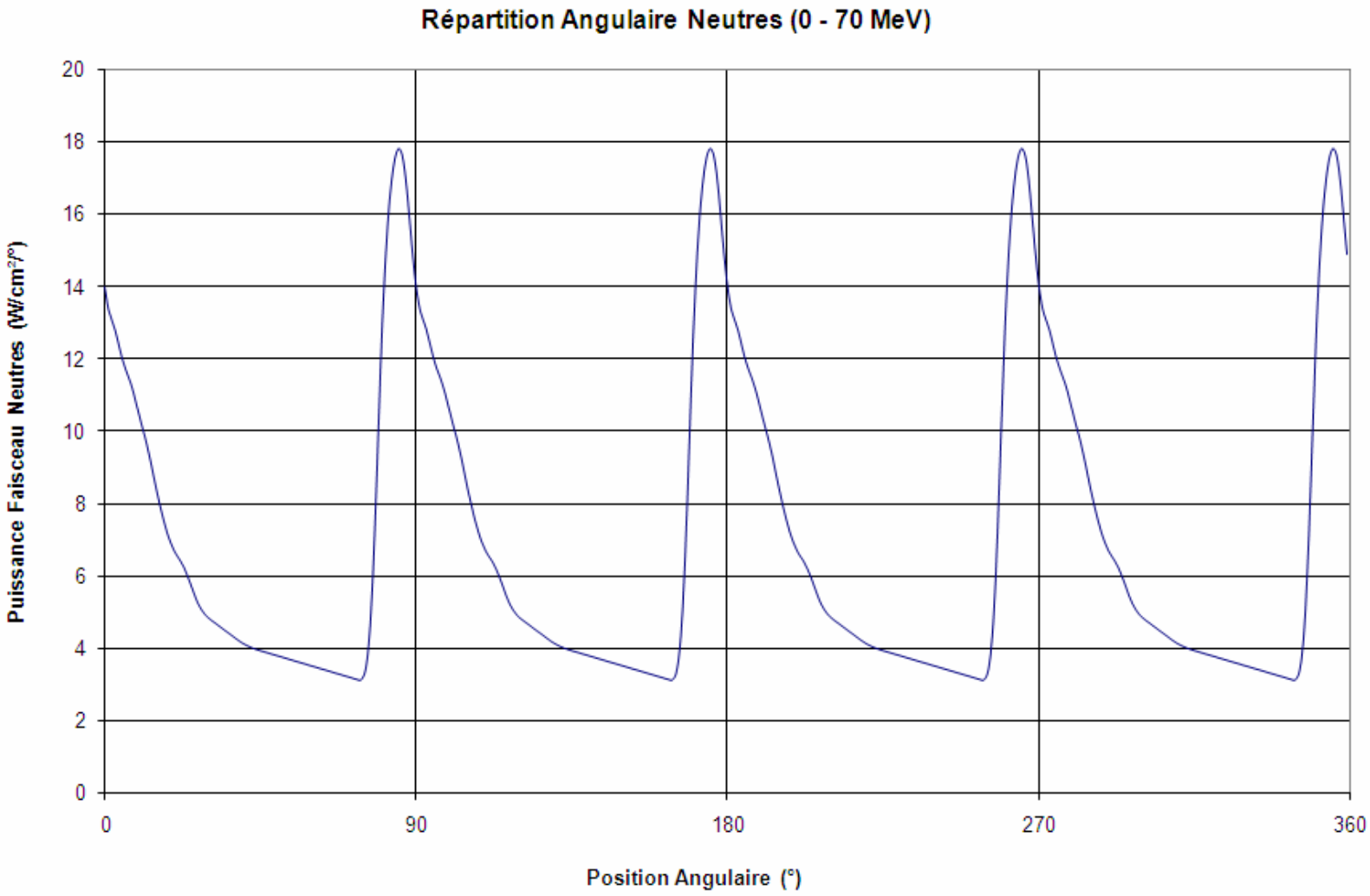
- **Consequences:**
  - **Rapid deterioration of the base vacuum impacting the transmission yield and limiting accelerators H- performances**
  - **H- limited performances (~ 450eμA) due to outgassing induced by neutral beam essentially heating up the vacuum chamber**

High Intensity 70MeV Proton Beam

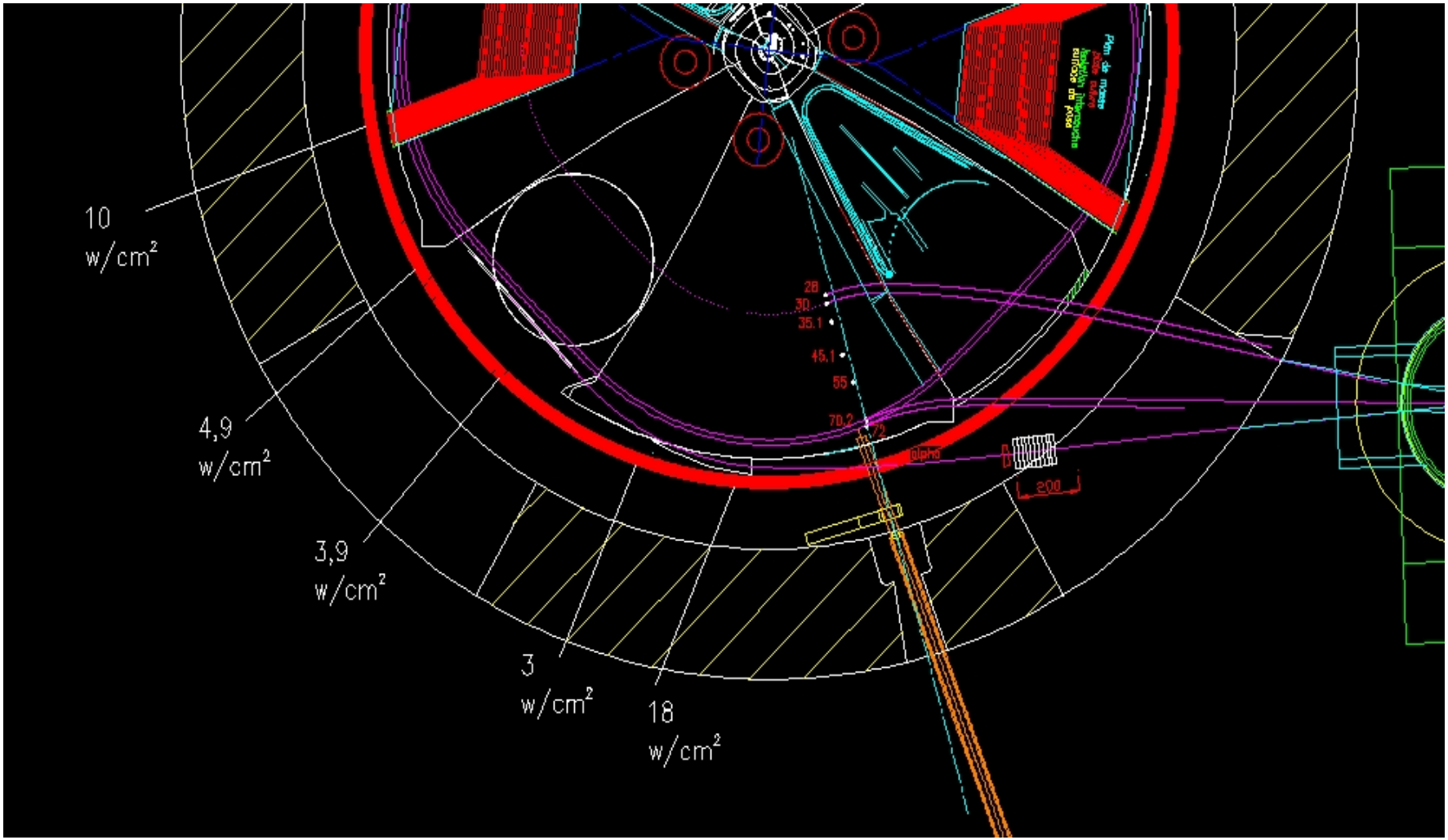
- **Specific studies:**
  - ✓ Vacuum chamber neutral beam distribution and temperature analysis
  - ✓ Residual Gas Analysis
  - ✓ Detailed model of the vacuum system
    - ➢ See poster presented by Vincent Nuttens
  - ✓ Long term activation

- **Solutions:**
  - ✓ New stripper probes → double cooling circuit
  - ✓ Local o-ring shielding
  - ✓ External Cooling → vacuum chamber
  - ✓ Internal vacuum chamber cooling
  - ✓ Pumping speed improvement

Vacuum Chamber Neutral Beam Distribution

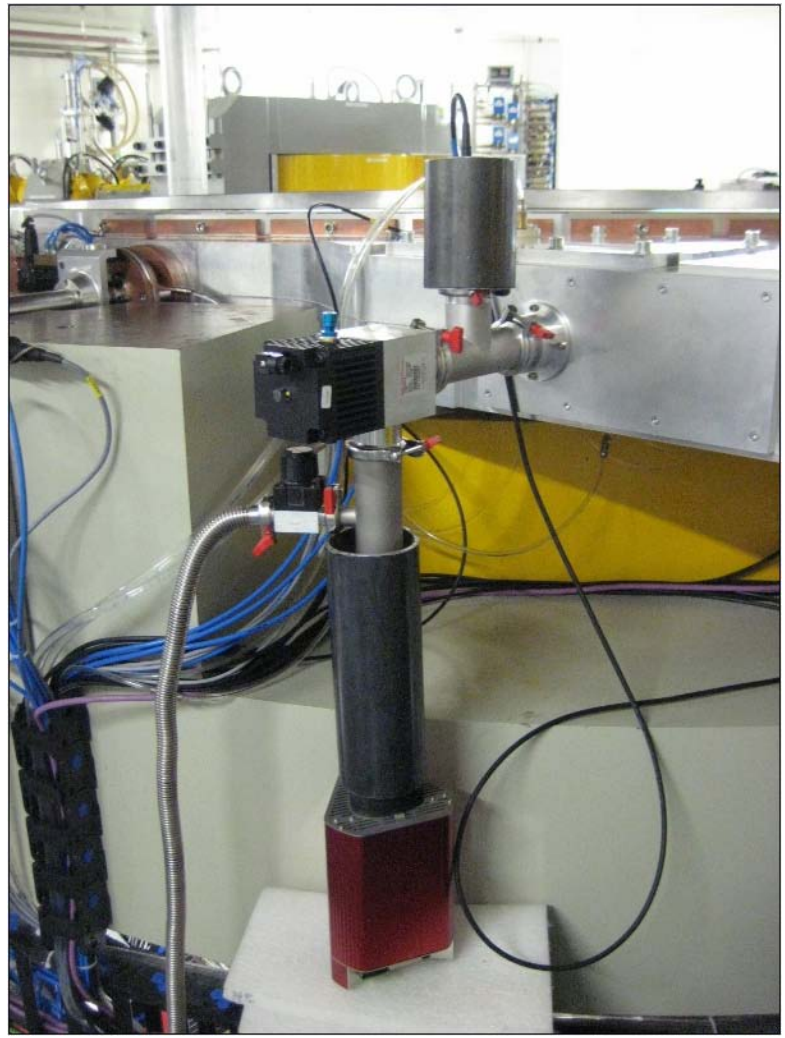


Vacuum Chamber Temperature Analysis



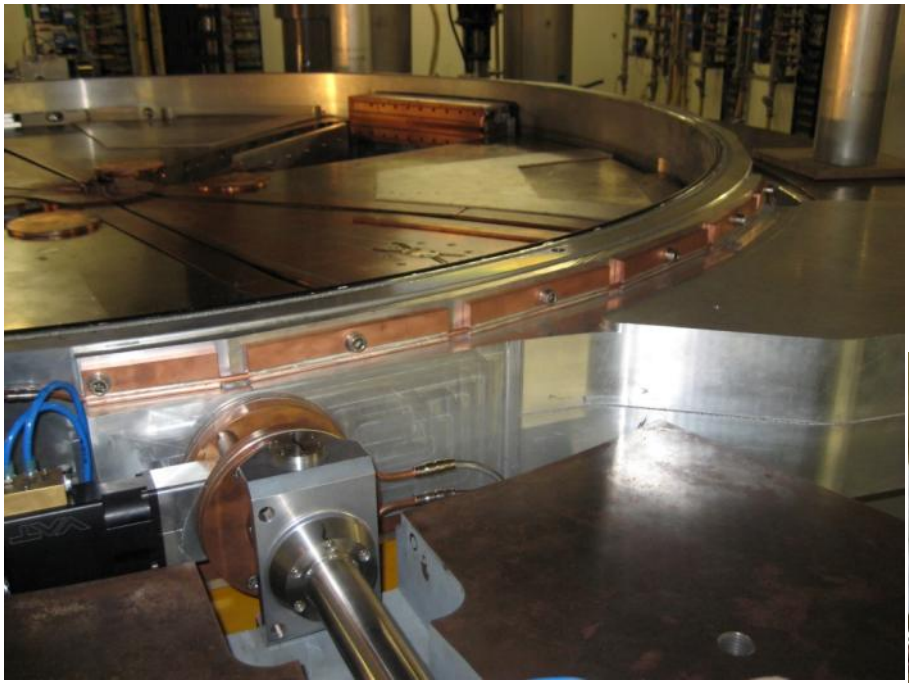
Residual Gas Analysis

- **Difficult set-up:**
  - Magnetic field
  - Distance from the cyclotron → sensibility of the measurement
  - Neutron flux
- **Limited operation level → 125µA / 70MeV**
- **Conclusions → proper vacuum up to 125µA**
  - Major detected compound: water



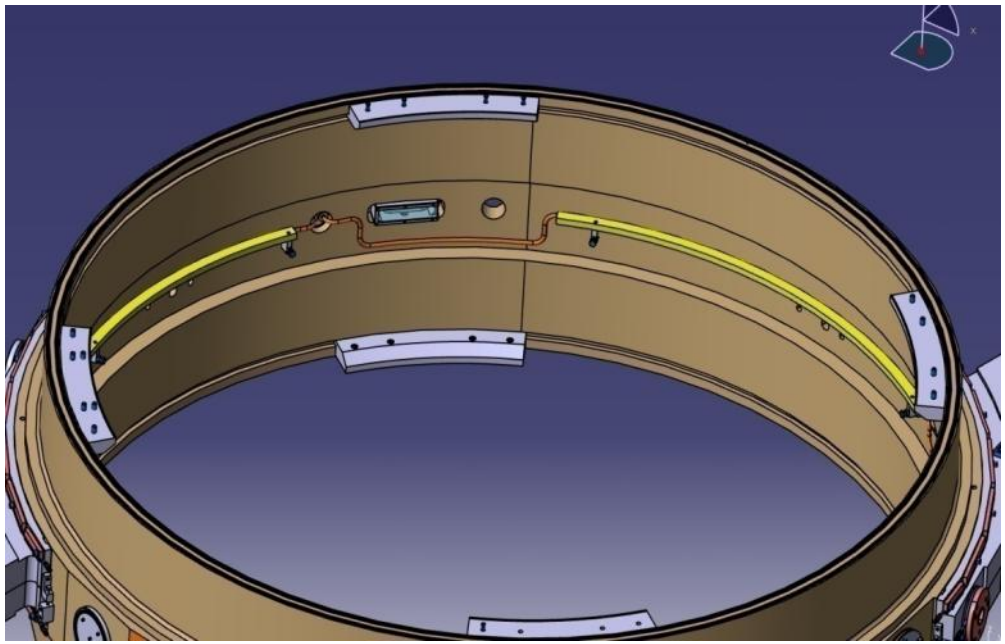
Local o-ring shielding

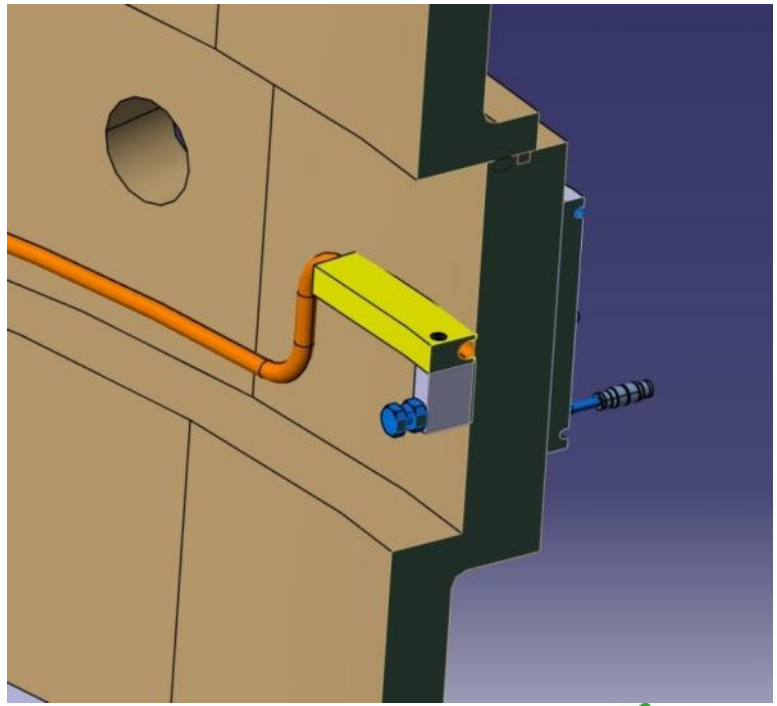
External cooling – vacuum chamber



Internal cooling – vacuum chamber

- **Decrease outgassing:**
  - Resulted from the external cooling experience that was not sufficient
- **20mm Al water cooled neutral “beam stop” → acceleration plane**

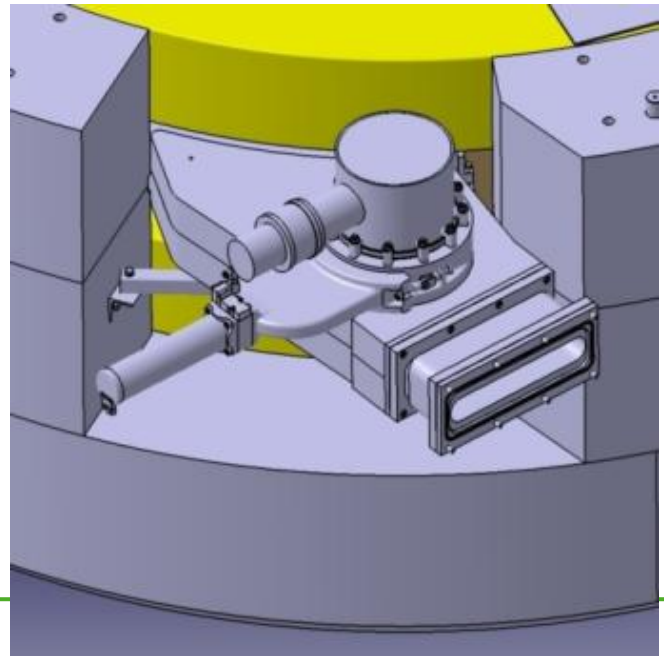


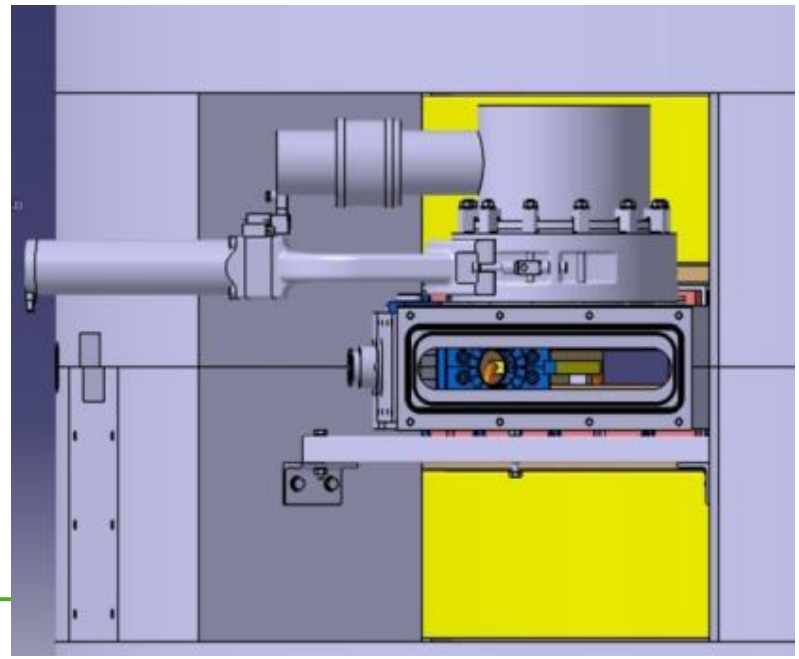


Internal cooling – vacuum chamber

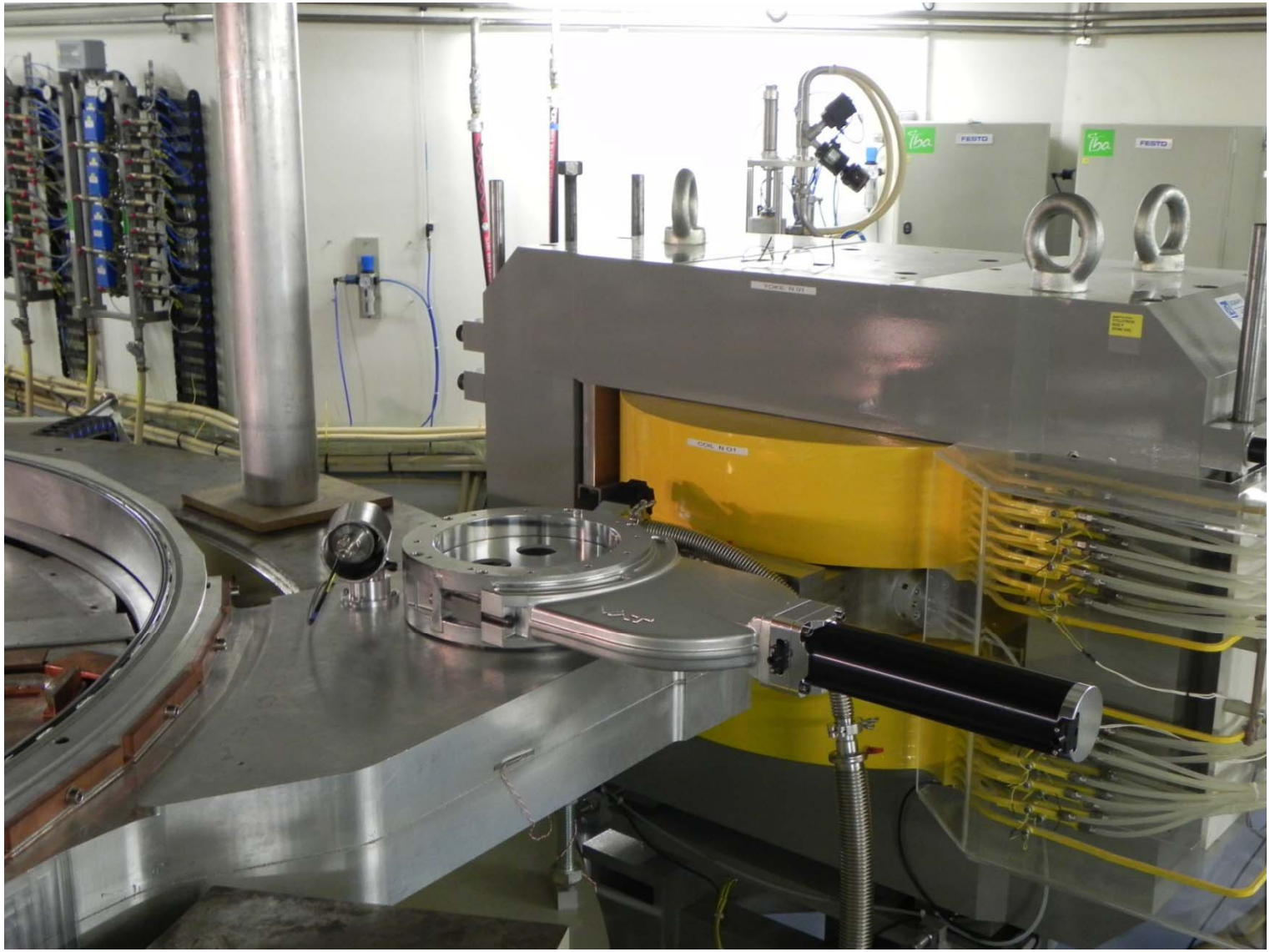
Pumping improvement upgrade

- **Solution:**
  - 2 additional cryo pumps → extraction chambers
    - Pumping speed: 6300l/s H_2O
- **Objective:**
  - 90% transmission yield at 750µA / 70MeV
  - Full proton beam performance





Pumping improvement upgrade



Long term activation analysis

- **Main assumptions:**
  - **ARRONAX operational plan (very ambitious):**

Proton Beam 70 MeV		
Year	Intensity (µA)	Time (h)
2010	40	300
2011	100	2000
2012	250	2200
2013	400	2300
2014	600	2500
2015	750	2700

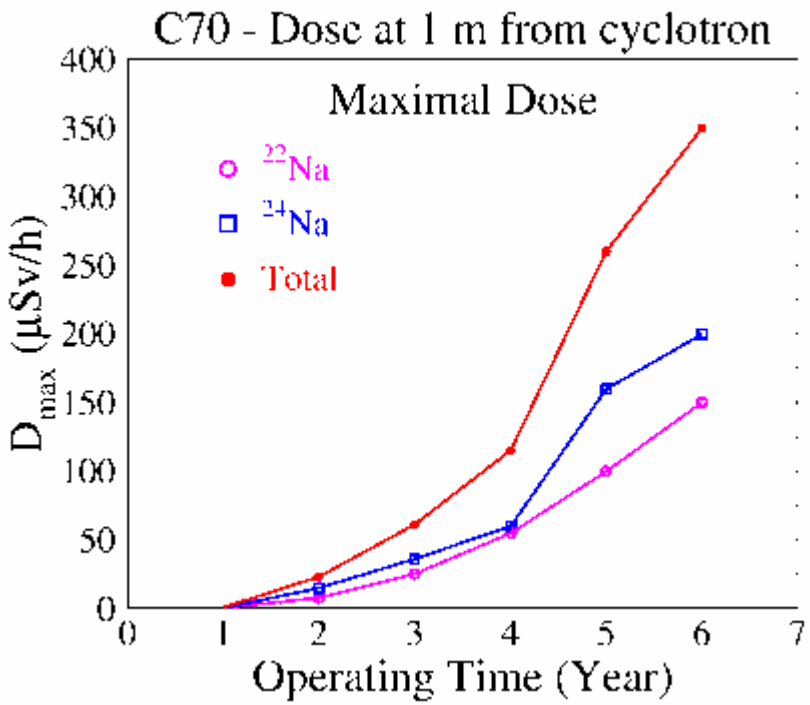
  - **Transmission yield at high current:**
    - **90% (vacuum calculations with cryo pump upgrade)**
  - **Neutral beam distribution on vacuum chamber**
    - **measured on site**

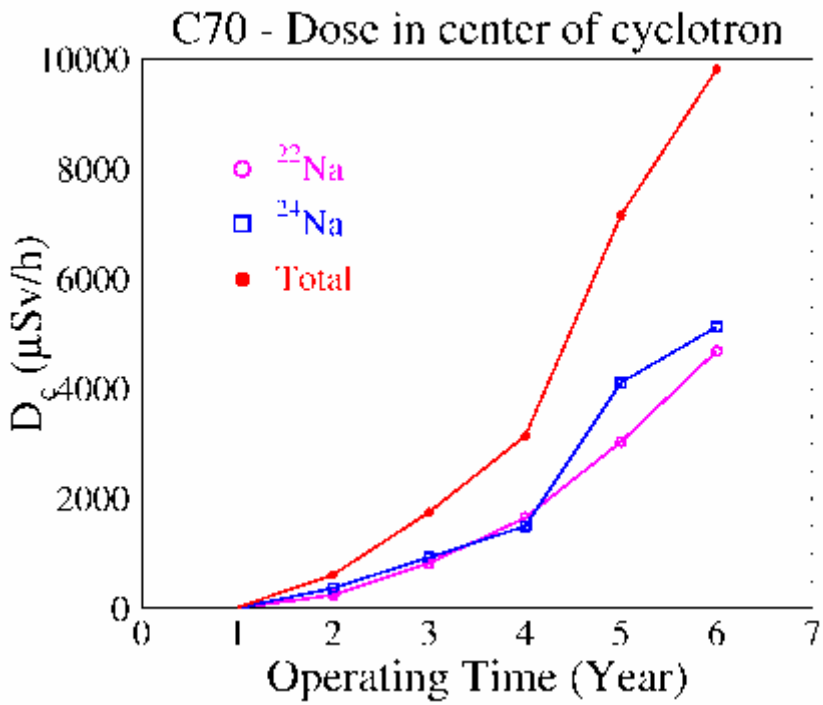
Long term activation analysis

- **Conclusions:**
  - Calculations based on PHITS and measured cross sections:
    - Principle radioisotopes contributing (for E > 30MeV on Al):
      - ^{22}Na: $T_{1/2}$ = 2.6 yrs
      - ^{24}Na: $T_{1/2}$ = 14.96 hrs
  - Cumulated activities after 6 years:
    - ^{22}Na: 7.35 10^{10} Bq
    - ^{24}Na: 2.98 10^{10} Bq

Long term activation analysis

- Dose rates:





Long term activation analysis

- **Solution:**
  - **Add an aluminum 20mm thick belt that can be replaced at a given frequency:**
    - **Neutral beam beam stop**
    - **Reduce to acceptable levels the dose rates**
      - **Maintenance !**
  - **Internal cooling circuit → perfect match !**

- **In progress:**
  - **Determine the frequency of replacement**

Achievements – Acceptance Tests

- **Injection yields:**
  - ✓ **H^-: > 35% (with buncher)**
  - ✓ **He^{2+} / HH^+ / D^- : > 10% (with buncher)**

- **Transmission yields:**
  - ❖ **H-: 85% (at 450µA)**
  - ✓ **D^-: 75% (taking into account magnetic gap variation)**
  - ✓ **He^{2+} : 85% (taking into account magnetic gap variation)**
  - ✓ **HH^+: 85% (taking into account magnetic gap variation)**

- **Extraction yields:**
  - ✓ **He^{2+} : 83%**
  - ✓ **HH^+: 80%**
  - ✓ **H^- / D^- : > 99%**

Achievements – Acceptance Tests

- **Simultaneous beam extraction:**
  - ✓ **H^- 70 MeV: > 200µA**
  - ✓ **H^- 30 MeV: > 200µA**

- **Beam transport on all beam lines and all particles:**
  - ✓ **Transport yields: > 96%**
  - ✓ **Target yields: 92%**
    - 😐 **Exception: 90° magnet beam line → 68%**

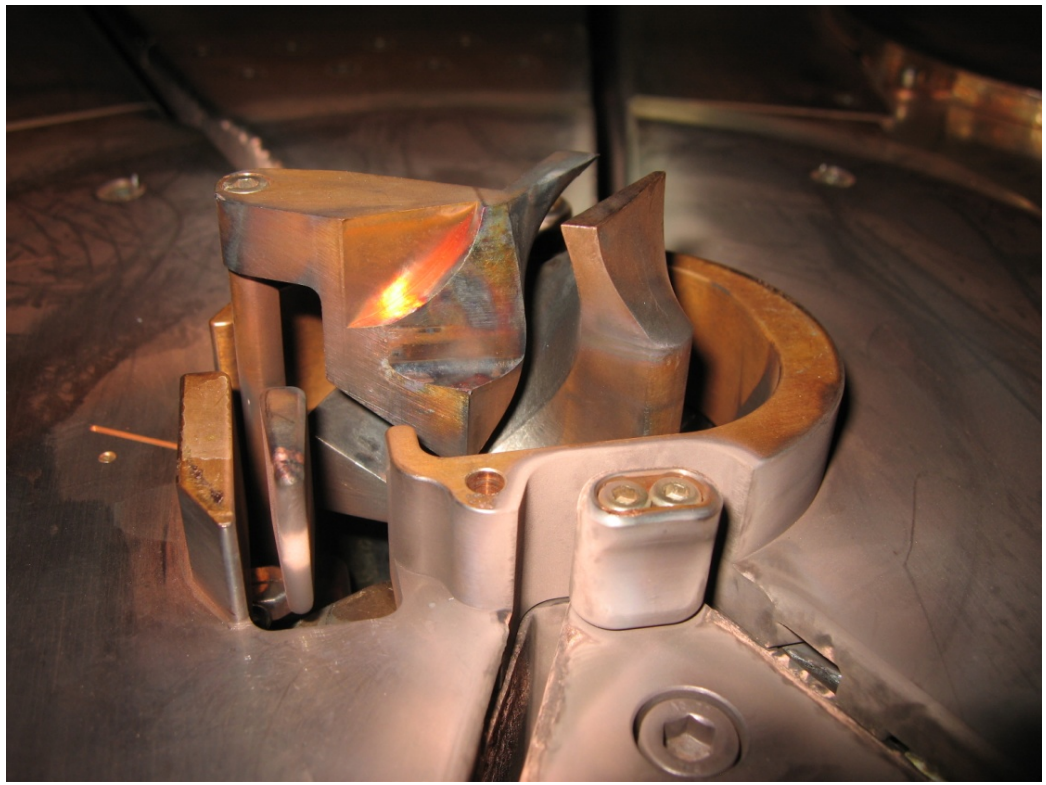
- ✓ **Validated solid target system**

- ✓ **Validated control system**

- ✓ **Validated interlock system**

Achievements – Present Performances

- H^- :
  - 1mA at 150mm (1MeV)
  - High current BTL validated at 375µA 70MeV
  - 2 x 200µA 70MeV



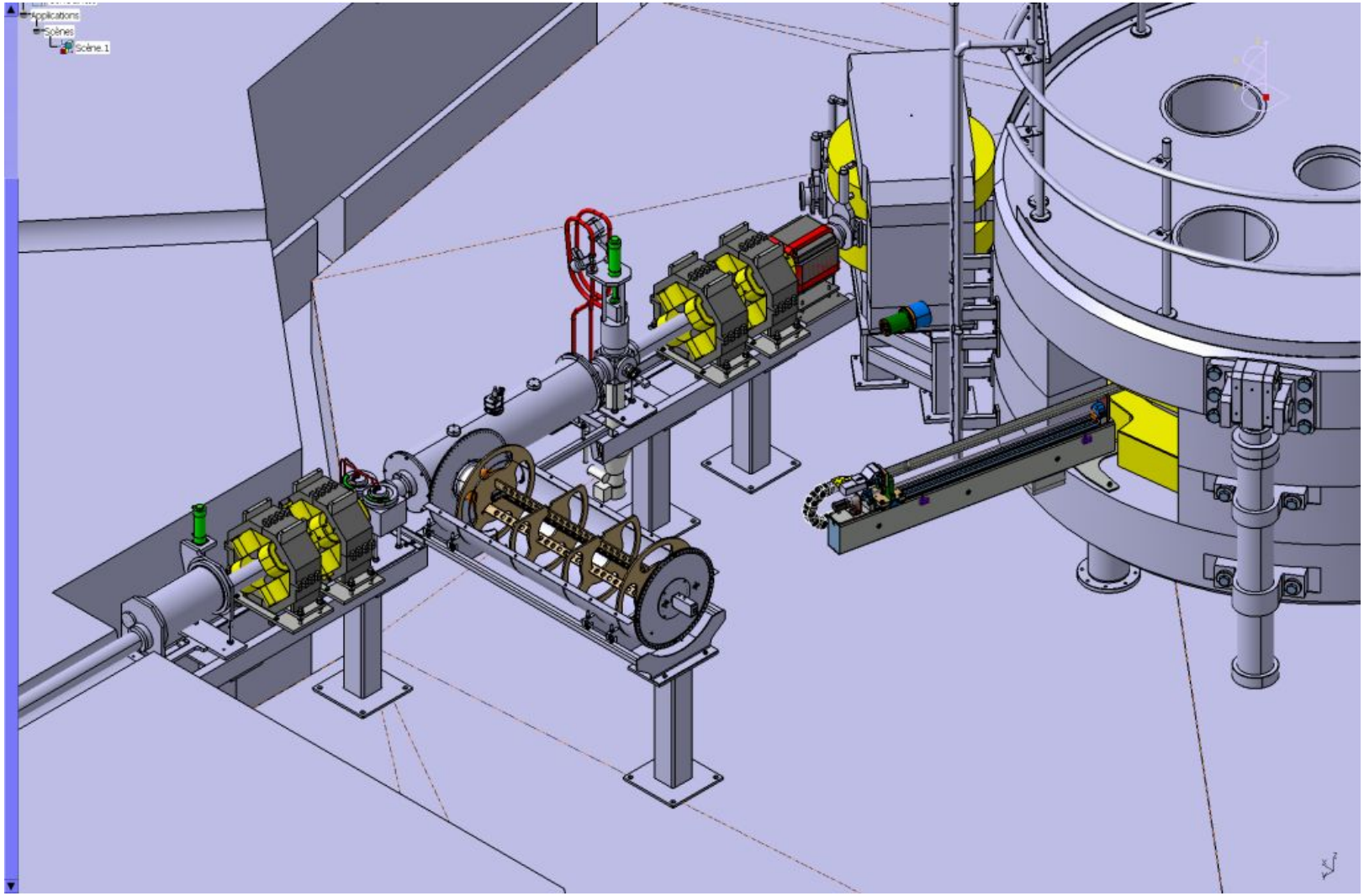
- D^- :
  - ✓ 50µA 35MeV
- He^{2+} :
  - ✓ 70µAe 70MeV
- HH^+ :
  - ✓ 50µAe 35MeV
- Base vacuum: 4 10^{-7}mbar (without cryo pump upgrade)

Major Final Steps...

- **H- :**
  - **2 x 375µA 70MeV**
  - **55kW proton beam**
  - **Goal: 24 hour test**

- **Alpha pulsing**

Alpha Pulsing



Alpha Pulsing

Thank-you…

Team…

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- QC:
  - Pascal Pelerin
- Supply Chain:
  - Louis-Guy Servotte
  - Pascal Robert
- Partners:
  - Sigmaphi
  - Pantechnik
  - Cegelec