Post-acceleration of high intensity RIB through the CIME cyclotron in the frame of the SPIRAL2 project at GANIL

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on behalf of SPIRAL2 and GANIL teams
GANIL-SPIRAL1-SPIRAL2 facility layout

- **Existing Exp. Areas**
  - Stable beams and RIBs

- **DESIR**
  - Low Energy RIBS

- **CIME cyclotron**
  - Radioactive beams (SPIRAL1) 1999
  - + Radioactive beams (SPIRAL2) 2013

- **RIB Production**

- **S3**

- **LINAC**

- **RFQ**

- **C01,C02,CSS1,CSS2 (since 1982)**
  - Stable beams: C…Uranium < 96 Mev/A

- **A/q=3**
  - HI ECR

- **A/q=2**
  - LI ECR

- **A/q=6 option**
### SPIRAL2 Driver Beam Characteristics

<table>
<thead>
<tr>
<th>Q/A</th>
<th>I (mA)</th>
<th>Energy (Mev/u)</th>
<th>CW max beam Power (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>1/1</td>
<td>5</td>
<td>2 - 33</td>
</tr>
<tr>
<td>Deuterons</td>
<td>1/2</td>
<td>5</td>
<td>2 - 20</td>
</tr>
<tr>
<td>Ions</td>
<td>1/3</td>
<td>1</td>
<td>2 - 14.5</td>
</tr>
<tr>
<td>Ions (option)</td>
<td>1/6</td>
<td>1</td>
<td>2 - 8</td>
</tr>
</tbody>
</table>

Machine underground (beam axis = -8m)
Spiral2 Accelerator Building Integration

- Public inquiry started (conclusion in Oct.)
- Construction permit expected by December
- Effective Construction in 2011
- Safety authorization in 2012

- Accelerator construction done in parallel
- Technical and beam tests distributed in various laboratories
Technical & beam Commissioning 2010:
- Automats, C/C (Epics), Vacuum...
- Faraday cups, profilers
- Emittance-meters, slits
- PHOENIX V2 @ 18 GHz
  - Extraction at 47 kV
  - Ar, O, Xe, Ca...
- Feedback with TRACEWIN transport code

Next steps: increase voltage 47 → 60 kV

Beam profiles and emittance
(O16 6+, March 2010)

Xe132 25+ O16 3+ Separation using slits

Up to 98% transmission !!!

LCO oven (metallics)
Deuteron/proton source + LEBT2 +LEBTC (CEA/IRFU Saclay)

Deuteron 2.45 Ghz ECR source tested successfully in March 2010

LEBT2 ready for beam tests
LEBC installation in progress

First proton beam observed last week on beam stop after first bending magnet!!
Automated test bank for RF tests is operational (was used on prototype...)

4-vane 88 MHz RFQ (CEA/SACLAY)

Construction of RFQ: first segment finished in a few days!

Safe segment rotation (storage and transport)

System for RFQ assembly

Implantation study into tunnel...
Some objects of the MEBT...

- Rebuncher under test at Ganil
- Slits (elimination of Halo…)
- Quadrupole measurements
- Fast Chopper (for NFS experiments)
SC-LINAC collaboration

- Cavities and cryomodules A
  - IRFU/Saclay

- Amplifiers
  - GANIL/Caen

- Cavities and cryomodules B
  - IPNO/Orsay

- Couplers
  - LPSC/Grenoble
Some objects of the LINAC warm Sections

LINAC Support structure

Magnetic Measurements of Linac warm Quadrupoles

BPM prototype (Orsay)
Cryogenic Transfer Lines (IPN Orsay)

- 2 prototype valve boxes connected to Cryomodules A and B at Orsay and Saclay
- 6 valve boxes already delivered and OK
- 16 valves boxes in fabrication
HEBT Lines… (modularity…)

Towards production

Activation of various materials
(Romania)

Studies of the Main Beam Dump
And first segments (IPN-Lyon + Spain)
RIB Production

LINAC beam
Production hall
Identification Station
Charge booster
Maintenance area
High Resolution Separator

$^{132}\text{Sn}$
$5 \times 10^9$ pps

CIME
Production area (hot cell)
Production Module (inside)

Extracto

Deuteron

Converter 1750° C

Einzel lens

Steerer

Insulator HV

Target + oven 2000° C

Deuteron beam diagnostic

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Beam transport systems

High Resolution Separator (CENBG) (1/20 000 with RFQ-cooler)

1+ beam line (IPHC)

n+ source: Phoenix booster (from LPSC)
CIME Cyclotron

Compact cyclotron with Axial injection
100-300 turns  2 RF (9.6-14.4 Mhz) cavities
Ejection with 2 Electrostatic deflectors and 2 Magnetic channels

Energy range:
1.2 MeV.A - 24 MeV.A  
(q/A)<1/8  (q/A) >1/3
CIME cyclotron : improvement of the mass separation
(P. Bertrand et al., Cyclo’04, ECPM 09)

<table>
<thead>
<tr>
<th>beam</th>
<th>Possible pollutant</th>
<th>d(q/m)/(q/m)</th>
<th>Phase shift at ejection (φ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{15}\text{O}^4+$</td>
<td>$^{15}\text{N}^4+$</td>
<td>$1.9 \times 10^{-4}$</td>
<td>48°</td>
</tr>
<tr>
<td>$^{132}\text{Sn}^{20+}$</td>
<td>$^{132}\text{Xe}^{20+}$</td>
<td>$1.0 \times 10^{-4}$</td>
<td>35°</td>
</tr>
<tr>
<td>$^{140}\text{Cs}^{21+}$</td>
<td>$^{140}\text{Ba}^{21+}$</td>
<td>$4.8 \times 10^{-5}$</td>
<td>16°</td>
</tr>
</tbody>
</table>

$V(t) = V_{\text{max}} \sin\left(\frac{\nu}{\hbar} \omega_{hf} t\right) \sin(2 \omega_{hf} t)$
Vertical Mass Separator: results

Pollutant/beam of interest (%) 800 V

- dB/B*10^-4

- without VMS
- with VMS
Radiological aspects: Measurements

- **Spiral1 TISS**
- **78Kr 70 MeV.A**
- **76Kr or 77Kr beams 10^7 pps**
  - 76Kr(14.8h) → 76Br(16.2h) → 76Se
  - 77Kr(1.23h) → 77Br(57.0h) → 77Se

- Measurement of radioactivity in beam lines and inside the cyclotron
- Measurement of contamination of cryogenic pumps
Results

400 μSv/h

1 mSv/h at contact
Superficial contamination
9 000 Bq $^{76}$Br / 900 Bq $^{76}$Kr

- Plate : 1 mSv/h (contact)
- No contamination
Contamination of cryogenic pumps

- Before acceleration:
  10-20% gases are released and pumped

- After acceleration:
  <1% released

Spectroscopy  Cryogenic trap
Estimated annual collective dose: 10 man.mSv. Operation is possible with some optimisations, including use of spares for inflectors, deflectors, and improvement of mechanics in order to reduce the operation time.
Safety

• MODIFICATIONS OF THE CIME HALL
  Taking into account an accidental contamination during operation maintenance, static (walls) and dynamic (nuclear ventilation) confinement will be necessary
  The modifications are quite important (preliminary cost ~2 M€).

• VACUUM SYSTEM
  Up to the CIME cyclotron, the contamination of the pumps justifies the storage of gases.
  After CIME ejection, contamination of the “vacuum” gases is reduced. Storage is not necessary but gases must be analyzed before release.
Experimental areas

- Challenge: high activity (up to $10^{10}$ Bq) close to a gamma detector.
- The incident beam has to be stopped away from the detector with a shielding.
- Interactions of the incident beam with residual gas resulting to halo and other causes of losses.
- Rutherford scattering on target.
CONCLUSION

- SPIRAL2 accelerator components are in technical tests and/or construction. Accelerator building is completely defined.

- The detailed design solution of the RIB process equipments and the production building, compatible with the safety constraints, is underway.

- The necessary modifications of the existing GANIL facility have been identified, but are still to be fully validated.

At the beginning of SPIRAL2 operation with the cyclotron CIME, the beam intensity will probably be reduced to check the hypothesis in terms of radioprotections, safety, and detection.
THANK YOU !
SPIRAL2 is a collaboration between many laboratories:

CEA/IRFU/SACM,SIS
CEA/DPTA
CNRS/IN2P3/IPNO, IPHC, LPC Caen, LPSC, CENBG, CSNSM
GANIL-CEA/CNRS,
Gatchina, Legnaro, Bucarest

international MoU:
Bucarest (Romania)
Spain
Argonne lab. USA
Triumf (Canada)
Soreq/Saraf (Israel)

And many physics collaborations (detectors...)
The new vertical separator device
RF circuit

Cimp : Condensateur variable pour adapter le circuit à 50 Ohm
Lp : Self fixe du circuit RLC
Cp : Condensateur variable du circuit RLC
Rsh : Résistance d’environ 200Ohm d’une puissance de 1500 Watts
Câble de 50 Ohm sa longueur varie suivant la fréquence de travail
Le tube H.F mesure 1970mm pour un diamètre de 80mm.
Ct : C’est la capacité équivalente du Trieur Vertical, environ 33pF
Le signal entrant sur l’amplificateur provient de la cavité de cime, la fréquence de ce signal est multipliée par 2, avant d’être mixée par un signal BF. Pour produire la modulation d’amplitude (AM)
88 MHz SC-LINAC

- Deuterons 5 mA, 40 MeV
- q/A=1/3, 1 mA, 14.5 MeV/A
- q/A=1/3 1 mA, 2 MeV/A
- q/A=1/6 1 mA, 2 MeV/A

Track code (P. Ostroumov)
End-to-end for 0.5 mA
q/A=1/6 1 mA, 8.5 MeV/A

MEBT
1/6 MEBT
ECR
End Linac
RFQ...
LME
LME