Status & first results of GPIB & PIPERADE beamline

Audric HUSSON, LP2i Bordeaux, GANIL Community Meeting 2022,
Connection to SPIRAL1
- Dedicated to beam purification and preparation
Context

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At LP2i Bordeaux

FEBIAD source
Produce alkaline
(surface ionization)
Main species – $^{39}$K
+ other alkalines

Acceleration : 30keV
At LP2i Bordeaux

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GPIB Cooler-Buncher
RFQ trap filled with He gas
- cooling via gas interaction
- bunching

29.9 kV
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L3keV line
90° electrostatic deflector
- new alkaline source
- new detectors
  (emittancemeter)

At LP2i Bordeaux

29.9 kV
27 kV /0V

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At LP2i Bordeaux

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PIPERADE double Penning trap
- 7T superconducting magnet
- beam purification
- mass measurement

At LP2i Bordeaux

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GPIB Cooler-Buncher

GPIB in the Hall de Montage before installation on the PIPERADE beamline
RadioFrequency Quadrupole trap
(linear Paul trap)

Ion confined:
- radially: RF oscillating potential
  (saddle shape potential)
- longitudinal: arbitrary potential slope
  potential well at the extraction

Objectives:
- Cool down the ion beam
  emittance reduction down to
  10\(\pi\) mm.mrad @ 3keV
  4.5\(\pi\) mm.mrad @ 30keV
- Make bunches/packets of ions with
  specific characteristics
  bunch length < 1\(\mu\)s
  energy spread < 1eV

M. Gerbaux et al., The General Purpose Ion Buncher: a radiofrequency quadrupole cooler-buncher for DESIR at SPIRAL2, 2022 (NIM), accepted
RadioFrequency Quadrupole trap
(linear Paul trap)

Two operation modes:
- continuous beam (CW)
  → transmission
  → (later) emittance – spot size / divergence
GPIB Cooler-Buncher

RadioFrequency Quadrupole trap (linear Paul trap)

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- bunch(ing) mode
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RadioFrequency Quadrupole trap (linear Paul trap)

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- continuous beam (CW)
  → transmission
  → (later) emittance – spot size / divergence
- bunch(ing) mode
  → bunch length
  → energy spread

Detectors:
- Faraday cup → beam current
- MCP (micro-channel plate) + retarding grid
  → detect bunch profile over time
  → scan the energy
  → longitudinal emittance
GPIB Cooler-Buncher - MCP + Retarding grid

Electroformed Ni/Nickel mesh, *Transmission 10 %*

- Cie : 10 %
- Image : 13.6 %
- Measure : 11.8 %

Micro-beam scan

*ALFIRA facility, LP2I Bordeaux*
GPIB Cooler-Buncher - MCP + Retarding grid

- Biased mesh
- Collection plate
- Grounded grid
- MCP plate

Ion beam

Graph showing count/s (x0.83), count/bunch, fit curve, 1st derivative - absolute values. Data points for μ: 3436.0 V and σ: 9.70 V.
GPIB Cooler-Buncher - MCP + Retarding grid

- Biased mesh
- Collection plate
- Grounded grid
- MCP plate

Energy

Time

f(E)

TOF
GPIB Cooler-Buncher - MCP + Retarding grid

energy

time

$T_{OF}$

$E$
GPIB Cooler-Buncher – First results

CW mode:
Intensity up to $10^{10}$ pps (~1nA)
Transmission with $K^+$ ions:
- **80% @ 30 keV**
- Routinely **70-75 % @ 3 keV**

Record transmission obtained after careful tuning - **92% @ 3 keV**

Bunch mode:
Rep. Rate: 1 – 100 Hz

Measured bunch length:
- Extraction 30keV: ~ **1-2 µs FWHM**
- Extraction 3keV: **0.7 µs FWHM**

→ Extraction potential to be optimized for bunch compression
**GPIB Cooler-Buncher – First results**

**CW mode:**
- Intensity up to $10^8$ pps (~20 pA)
- Transmission:
  - $80\% @ 30 \text{ keV}$
  - $92\% @ 3 \text{ keV}$

**Bunch mode:**
- Rep. Rate: 1 – 100 Hz
- Measured bunch length:
  - Extraction 30 keV: ~ 1-2 µs FWHM
  - Extraction 3 keV: 0.7 µs FWHM

→ Extraction potential to be optimized for bunch compression

Technical limitation in the energy spread measurement:
- $6 \text{ eV for 10 ms cooling}$

→ Cooling sequence/time to be optimized
→ Technical developments required
90° electrostatic deflector

L3-keV line
90° electrostatic deflector
- new alkaline source
- new detectors
  (emittancemeter)
90° electrostatic deflector

Test bench for the 90° electrostatic deflector

- Characterize the 90° deflector

- CW mode:
  - Energy measurement – Faraday cup
  - Transverse emittance measurement → optimization & characterization of an emittance-meter for GPIB

- Bunch mode:
  - Test the transmission measurement with a low number of ions,
  - Optimize the energy dispersion measurement,
  - Guarantee feasibility of TOF/energy measurement over all intensity range

High intensity (>10⁴ evts) → CF with trans-impedance FEMTO
Low intensity (<1000 evts) → MCP

Properties with medium intensity hard to evaluate ???
90° electrostatic deflector

Test bench for the 90° electrostatic deflector

Rubidium source
- source CC unders EPICS ✔️
  – upgrade to Phoebus made on the testbench
- beam properties measured, still problem with the energy
  * intensity ✔️
  * beam spot size ✔️
  * energy dispersion ✗
- bunch delivery implemented & tested: bunch down to 250ns ✔️
  – CC EPICS ✔️
- Pantechnik pepper-pot emittance-meter modified to be EPICS compatible ✔️

X position [pxl]

Y position [pxl]
## GPIB summary

### Extraction

<table>
<thead>
<tr>
<th>30 keV</th>
<th>CW beam</th>
<th>Bunched beam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transmission</td>
<td>Transverse emittance</td>
</tr>
<tr>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>&gt; 93%</td>
<td>estimation: ~3π mm.mrad</td>
<td>to be repeated</td>
</tr>
</tbody>
</table>

### 3 keV

<table>
<thead>
<tr>
<th>CW beam</th>
<th>Bunched beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>Transverse emittance</td>
</tr>
<tr>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>70 - 80%</td>
<td>coming soon</td>
</tr>
</tbody>
</table>

### TOF distribution

- Low = low intensity
- High = high intensity
- (10^8 ions/bunch or CW 100pA)

### Notes
- Need further developments
- HRS coupling?
- RF limit
PIPERADE

- double Penning trap
- 7T superconducting magnet
- beam purification
- mass measurement

29.9 kV
PIPERADE trap

Double Penning Trap
Magnetic field 7T, 2 homogeneous regions (<1ppm over 1cm³ volume)

Two traps in one:

1. **Purification trap**: large inner radius (>10⁴ ions/bunch)
2. **Measurement trap**: ion stacking/mass measurements

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*P. Ascher et al., PIPERADE: A double Penning trap for mass separation and mass spectrometry at DESIR/SPRAL2, published end of 2021 (NIM A)*
PIPERADE trap

Double Penning Trap

Magnetic field 7T, homogeneous (<1ppm over 1cm³ volume)

Ion confined:
- radially: magnetic field
- longitudinally: electrostatic quadrupolar field

Confinement leads to 3 cumulated eigen motions:

1. Axial motion
   - along the optical axis
   - ~100 kHz
   - \[ \omega_z = \sqrt{\frac{qU}{md^2}} \]

2. Reduced cyclotron motion
   - fast circular motion
   - ~ MHz
   - \[ \omega_p = \frac{\omega_c}{2} \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}} \]

3. Magnetron motion
   - slow circular motion around trap axis
   - ~ kHz
   - \[ \omega_m = \frac{\omega_c}{2} - \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}} \]
**PIPERADE trap - Principle**

First Penning Trap
- central « ring » electrode 8-fold segmented

Two types of excitation applied:

- Dipolar @ magnetron freq.: *change the magnetron radius ← almost mass independent*
- Quadrupolar @ cyclotron freq.: *conversion magnetron/cyclotron ← mass dependent*

Helium gas ← axial and modified cyclotron motion damped by collisions with gas
PIPERADE trap - Principle

First Penning Trap
- central « ring » electrode 8-fold segmented
- magnetron excitation ← mass independent
- cyclotron excitation ← mass dependent
- buffer gas cooling

→ now with multiple species
  (ion of interest + contaminants)

Ion of interest : centered
Contaminants : off-center

=> Ejection through the diaphragm to complete the selection

Helium gas ← axial and modified cyclotron motion damped by collisions with gas
Diaphragm
PIPERADE trap – First results

First Penning Trap
- first ion trapping ← September 2020
- first magnetron excitation seen – March 2021
  measured frequency ~660 Hz
  calculated frequency → 669 Hz

Ions out of the diaphragm - disappearance
PIPERADE trap – First results

First Penning Trap

- first ion trapping ← September 2020
- first magnetron excitation seen – March 2021 (660 Hz)
- first cyclotron excitation applied – April 2021
  buffer gas cooling recentering of $^{39}$K ions – 2.75283 MHz
PIPERADE trap – First results

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- first ion trapping ← September 2020

- first magnetron excitation seen – March 2021 (660 Hz)
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- 3 other species found during a ‘massive day’
  no more species found due to the GPIB selectivity
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- transfer and trapping in the second trap
  (Accumulation/Measurement Trap)

- apply excitations in the Accumulation/Measurement Trap + extraction
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  (Accumulation/Measurement Trap)
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- first ToF-ICR resonance
  → meas. Time-of-flight of the ions

MCP
GCM 2022, Caen
Currently preparing a 2D sensitive detector to perform PI-ICR technique (Phase Imaging) – also a very good debugging device.
THANK YOU

Permanent physicists
P. Ascher, B. Blank, M. Gerbaux, S. Grévy

Instrumentation
P. Alfaurt, L. Daudin, B. Lachacinski

Mechanics (‘BE’)
S. Perard

PhDs
M. Flayol, M. Hukkanen

Postdocs
D. Atanasov, A. Husson
1. Injection of ions in the trap (motions damped)
2. Extraction of ions

Measurement of the trap center projection on detector

End of step 1

Extraction

Courtesy: Mathias GERBAUX
1. Injection of ions in the trap (motions damped)
2. Dipole excitation $\omega_1$
3. Quadrupole excitation ($\pi$-pulse) at $\omega_Q$
4. Extraction of ions

Measurement of reference position

End of step 3

Extraction

Courtesy: Mathias GERBAUX
Measurement of magnetron frequency

1. Injection of ions in the trap (motions damped)
2. Dipole excitation \( \omega_+ \)
3. Quadrupole excitation (\( \pi \)-pulse) at \( \omega_Q \)
4. Extraction of ions

Phase accumulation time

Step 4

Total phase accumulation: \( 2\pi \times k_- + \phi_- \)

Courtesy: Mathias GERBAUX
Measurement of modified cyclotron frequency

1. Injection of ions in the trap (motions damped)
2. Dipole excitation $\omega_+$
3. Quadrupole excitation ($\pi$-pulse) at $\omega_c$
4. Extraction of ions

Phase accumulation time

Step 4

Total phase accumulation: $2\pi \times k_+ + \phi_+$

Courtesy: Mathias GERBAUX

GCM 2022, Caen
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