Status and timing of MIRACLS installation at LA2 (and RCX10)

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CERN research physicist
Outlook

• Recall: MIRACLS
• Summary of MIRACLS’ proof-of-principle experiment
• Planning for a compact MIRACLS at LA2
• Planning for full MIRACLS at RCX10 (=NICOLE site)
Collinear Laser Spectroscopy (CLS)

beams of $\geq 30$ keV
minimises Doppler-broadening
$\Rightarrow$ high resolution

$\delta \nu \propto \frac{\delta E}{\sqrt{E}}$

P. Campbell et al., Prog. Part. and Nucl. Phys. 86, 127-180 (2016)
the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy

- **ion trap** ⇒ long observation time ⇒ higher sensitivity ⇒ more exotic nuclides accessible

- **MR-ToF devices**
  - first RIB mass measurements

**novel approach for collinear laser spectroscopy:**
- ion trap ⇒ long observation time
- 30 keV beam ⇒ high resolution

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**proof-of-principle experiment**

- modified existing MR-ToF (low beam energy)
- adapted for purpose of CLS
- demonstrate potential of the technique
- validate simulations for the 30 keV device

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S. Lechner et al., *Hyperfine Interact* 240, 95 (2019)
V. Lagaki et al., *in preparation*
First CLS signals in an MR-ToF

**extracOon from Paul trap**

**extracOon from MR-ToF**

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First CLS signals in an MR-ToF

extraction from Paul trap

extraction from MR-ToF

Photon counts

0 200 400 600 800 1000

0 20 40 60 80

TOF (µs)

conventional CLS

shown here for 7 revolutions

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First CLS signals in an MR-ToF

Extraction from Paul trap

Extraction from MR-ToF

Achieved milestones
- CLS over 5000 revolutions
- Simultaneous anti/collinear laser spectroscopy
- Optical re-pumping

Photon counts

TOF (μs)

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MIRACLS sensitivity in $^{24}$Mg$^+$

**SN in PoP experiment**
(for 1500 ion shots per frequency step)

**ion number per shot sent into MR-ToF device**

**Fund. Frequency [GHz]**

1500 revolutions = 10.7 ms

**extrapolated S/N in 30-keV setup**
(for 1 ion shot per frequency step)

online measurements with O(10) ions/sec possible
MIRACLS 30-keV setup

unique linear Paul trap
- beam cooling to cryogenic temperature for optimal (longitudinal) emittance
  → good time focus and energy spread

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unique linear Paul trap
• beam cooling to cryogenic temperature for optimal (longitudinal) emittance
  ➔ good time focus and energy spread

new opportunities
• fast & selective mass separation (fundamental physics & applications)
• spectroscopy of negative ions
• excellent emittance (PUMA, emission channeling,...)
• fundamental physics with radioactive molecules (e.g. EDM searches)
Integration plan at ISOLDE

MIRACLS at RCX10
- laser lab?
- ion-beam emittance?
- no crane access
- NICOLE still there
Integration plan at ISOLDE

MIRACLs at RCX10
- laser lab?
- ion-beam emittance?
- no crane access
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- COVID lockdown:
  - lost already 4 months
  - many developments still on hold

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Integration plan at ISOLDE

**MIRACLs at RCX10**
- laser lab?
- ion-beam emittance?
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- **COVID lockdown:**
  - lost already 4 months
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**Compact MIRACLs at LA2**
- COLLAPS laser lab
- measured emittance at LA1 in 2019
- crane access
- currently free location
- **COVID lockdown:**
  - start with room-temperature Paul trap
  - reutilise components of PoP experiment
  - ‘best possible’ MR-ToF

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MIRACLS at LA2

discussions about integrations ongoing
(K. Johnston, E. Siesling, Di Giulio, J. Devine, J. Troska, COLLAPS, etc.)
Paul trap
(almost) identical trap design but at room temperature

Design Status
- 43 grid to enhance gas outflow and reduce pressure on photon detection with MPPC
- Cryogenic Paul trap
- 30° bend (new)
- Acceleration to 50 keV (new)
- Electrostatic mirror of 30-keV MR-ToF

2 keV beamline (on HV platform)
(existing, minor modifications)

offline ion source
existing and operational
Paul trap (almost) identical design but room temperature

bunched and cooled beam

offline beam
- commissioning
- references during beamtime

offline ion source existing and operational

grid to enhance gas outflow and reduce photon detection with MPPC
Simulations of ion beam optics (Mg)

1. Ion cooling in Paul trap
2. Ion-beam transfer
3. Trapping in MR-ToF

Results:
- Trapping efficiency >90%
- Laser ion-overlapping
- CLS resonance

3-step simulation approach
Benchmarked for PoP setup in

F. Maier et al., Hyperfine Interact. 240, 54 (2019)

Setup not optimal, but addresses first physics

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Laser Setup

Compact MIRACLS@LA2 laser setup
- ISOLDE Hall
- COLLAPS laser lab (Bat. 508)
- frequency doubler (Wavetrain)
- cw Dye laser (MATISSE DS)
- pump laser (Millennia 20 eV)

Collaps lasers connected to interlock system of lab

<10 mW
280 nm up to 100 mW
532 nm up to 20 W
560 nm up to 1 W

Beam dump

Mode cleaner, lenses, etc.

Deflection box

Shutter

Integration requirements
- new laser-transport tubes
- hole ISOLDE-laser lab
- tube installation
- ‘deflection box’ with (temporary) access
- interlock system

Discussions with CERN safety ongoing (L. Di Giulio, J. Troska, K. Johnston)
Required Resources

**Infrastructure at LA2**
- laser-beam transport (see previous slide)
- removal of block 5
- displacement of block 4 (including distribution of power, pressurised air; radiation detector, etc.)
- removal and relocation of cable trays
- passage through LA1 or LA2?
- electrical power: 80 kW (peak), ideally low noise
- pressurised air, cooling water

**Required information**
- access to ISOLDE 3D model
  - for minimal interference with COLLAPS and LA1
  - safety (laser, access, etc.)
- ion-beam optics along ISOLDE beamline
- emittance measurement at LA2 (TRIUMF emittance meter?)

**additional lab space:**
- air conditioning at all times in COLLAPS laser lab (including early 2021)
- lab space for clean assembly of apparatus
- DAQ room/section (?)
ISOLDE beam requirements

- ISOLDE operation at 50 keV
- if possible, stable ISOLDE beam for emittance measurement (fall 2020)
- stable ISODLE beam (end of 2020 and early 2021) to establish ion-beam transfer
  ➡ initially e.g. $^{39}$K ok, later $^{24-26}$Mg and something heavier e.g. $^{133}$Cs
  ➡ continuous beam for GPS (2020)
  ➡ HRS+ISCOOL for bunched ions (2021)
  ➡ 3x 4 days
## Timeline: compact MIRACLS

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<thead>
<tr>
<th>Activity</th>
<th>2020</th>
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<td>Ion optical simulation</td>
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Preferred periods for ISOLDE beam:
**Main upgrade: cryogenic Paul trap**
- better MIRACLS performance
- essential for MR-ToF mass separation with high ion capacity
- cooling of molecules ↔
- high quality RIB to downstream users

**Proposal for integration**
- **2021**: independent commissioning of cryogenic Paul trap at RCX10
- **2022**: experiments with (ionic) radioactive molecules
- **End of 2022**: end of compact MIRACLS and move 30-keV MR-ToF to RX10
- **2023**: beam deliver to PUMA and others

S. Malbrunot: ISCC June 2020
Summary and Conclusions

- Successful proof-of-principle experiment
  - demonstration of novel technique
  - benchmark of simulation approach for 30-keV MR-ToF
  - experimental sensitivity estimate

- compact MIRACLS@LA2
  - response to COVID-19 lockdown
  - initial setup with reduced complexity (and capabilities)
  - addresses ERC science goals within funding period
  - commissioning of 30-keV MR-ToF device

- MIRACLS@RCX10
  - MIRACLS in its full potential
    - incl. downstream users and mass separation
  - initial & independent commissioning of cryogenic Paul trap
    - first physics with radioactive molecules

MIRACLS Alumni:

CERN based people:
PhD students
MSc students
BSc students
Fellows

funding:

CERN Applications Funds

https://miracls.web.cern.ch