The LISE spectrometer at GANIL present and near future

J.-C. Thomas, for the LISE collaboration

- **LISE operation 2011-2017**
  - Overview
  - Recent experiments (2016-2017)

- **LISE future**
  - Organization
  - Roadmap
The GANIL/LISE spectrometer

- Beams
  - Stable (CSS1+CSS2): \( \sim 5 \) to \( 95 \) MeV/u
    - \( \rightarrow \) Projectile fragmentation (\( 15 \) to \( 50 \) MeV/u); polarized
    - \( \rightarrow \) Fusion-evaporation reaction (FULIS mode)
  - (New) SPIRAL1 beam; purification

- Selection \( \mathbf{B}_\rho + \text{degrader} + \mathbf{B}_\rho + \text{Velocity filter} \)

- Identification \( \Delta E, \text{ToF} + \text{tracking} \)

- Experimental areas \( \text{D4, D6 + LISE2000} \)
LISE operation 2011-2017

- 576 UT (20 exp + 14 tests (14%))
  - Fragmentation: 66%
  - Fusion-evaporation: 26%
  - Stable beams: 8%

- Tests
  - LISE (detection)
  - Beam Prod S³ / Astrophysics
  - S³ (targets)

- Experimental technique

- Scientific cases
  - 68% = Nucl. Struc.
  - 21% = S³ related
LISE operation 2011-2017

- **Experimental setups**
  - Decay Station 33%
  - MUST2/ECLAN 32%
  - Château de cristal 16%
  - Maya 3%
  - β-NMR 9%
  - Others 7%

- **Publication record**
  - PRL/PLB/A&A: 13
  - PRC/EPJA: 18
  - Other peer reviewed: 13

  Average time: $\Delta t(\text{Pub.} - \text{Exp.})$
  - Letters = 3 years
  - PRC/EPJA = 5 years

- **EXOGAM** -> **EXOGAM2**
- **Château de cristal** -> **PARIS**
- **MUST2/TiaRa** -> **GASPARD**
- **MAYA** -> **ACTAR TPC**
- ** Decay (tape) station, β-N(Q)R, ...**
LISE experiments 2016-2017

- Nuclear structure and deformation at N=20
  -> $^{34}\text{Al}^m$ g-factor and quadrupole moment, $E650$ – G. Neyens et al., IKS Leuven
  
  Talk by H. Heylen

- Weak interaction
  -> 0+ -> 0+ super-allowed $\beta$ decay of $^{30}\text{S}$, $E691$, B. Blank et al., CENBG
  
  Talk by B. Blank

- Isospin mixing in the fp shell
  -> $\text{BR}_p/\text{BR}_\gamma$ in the decay of n-deficient nuclei, $E666$ – B. Blank et al., CENBG

- Nucleon-nucleon forces at the drip-line
  -> $^{10,12}\text{Be}(d,^3\text{He})^{10,12}\text{Li}$, $E748$ - A. Matta et al., LPC Caen

- Clusters
  -> $^{10,11,12}\text{Be} + ^4\text{He} -> ^{14,15,16}\text{C}^*$, $E692$ – C. Wheldon et al., Univ. Birmingham

  Run3 - 2017
E650 - G. Neyens, H. Heylen, Z. Xu et al.

Nuclear structure and deformation at N=20 (island of inversion)

-> g-factor and quadrupole moment of $^{32}\text{Al}$ and $^{34}\text{Al}^m$

$^{32}\text{Al} 1^+ \text{ g.s.} \quad \pi (d_{5/2})^{-1} \otimes \nu (d_{3/2})^{-1}$

$^{34}\text{Al} 1^+ \text{ iso.} \quad \pi (d_{5/2})^{-1} \otimes \nu (d_{3/2})^{-1}(f_{7/2})^2$

$E^* \sim 47 \text{ keV} - \text{R. Licà et al., PRC95, 021301(R) 2017}$

-> isomer configuration:

pure $1p-1h$ excitation?

associated deformation?

=> Answer this afternoon: H. Heylen
E650: Nuclear structure and deformation at N=20 (island of inversion)
-> g-factor and quadrupole moment of $^{32}$Al and $^{34}$Al$^m$

**Production**

$^{36}$S@77.5 MeV/u, 1.4 $10^{12}$ pps
frag./pick-up
+ spin polarization

**N=20**

Z=16  
$^{36}$S

Z=13  
$^{32}$Al  $^{33}$Al  $^{34}$Al

**Measurement:** $\beta$-NMR and $\beta$-NQR

$^{32}$Al
~15000 pps, 90 % purity

$^{34}$Al
~600 pps, 90 % purity

Isomeric ratio ~30 %
E691 – B. Blank, J. Giovinazzo, J.-C. Thomas et al.
Weak interaction study

- $0^+ \rightarrow 0^+$ super-allowed $\beta$ decay of the $T_z = -1$ nucleus $^{30}\text{S}$

**CVC hypothesis**

$$F_t = f_t \left(1 + \delta_R'\right) \left(1 - \delta_c + \delta_{NS}\right) = \frac{K}{g_V^2 \left(1 + \Delta_F\right) \langle M_F \rangle^2} = C_{st}$$

**Isospin symmetry breaking correction**

$$V_{ud} = \frac{g_V}{g_\mu} \rightarrow \text{CKM matrix unitarity test} \quad (V_{ud} = 0.97417 \pm 0.00021, \Sigma V_{uw} = 0.99978 \pm 0.00055)$$

G. F. Grinyer et al., NIM A 622, 236 (2010)

B. Blank et al., EPJA 51 (2015) 8: $^{18}\text{Ca} T_{1/2}$ & BR (0.5% precision)
LISE experiments 2016-2017

E691: 0+ -> 0+ super-allowed $\beta$ decay of The $T_z = -1$ nucleus $^{30}\text{S}$

Aim: $\Delta T_{1/2}/T_{1/2} \sim 0.1\%$ ($0.14\%$ today)
$\Delta BR/BR \sim 0.2\%$ ($1.3\%$ today)

Production
$^{32}\text{S}@50$ MeV/u, $10^{12}$ pps fragmentation

$^{30}\text{S}$
~few $10^4$ pps, typically 97% purity
NB: beam pipe cooling

Measurement: $\beta-\gamma$ coincidences, tape station
High precision HPGe

B. Blank et al., NIMA 776, 34 (2014)

Issue: remaining statistics after cleaning (Wien filter )?
LISE experiments 2016-2017


Isospin mixing in the fp shell ($T_z=-2$ case)
- $\text{BR}_p/\text{BR}_\gamma$ in the decay of IAS
tates

Theoretical framework: N.A. Smirnova et al., PRC 95, 054301
- $\beta \sim 1\%$ in the case of $^{44}\text{Cr}$, $^{48}\text{Fe}$ – Precise spectroscopic data needed
LISE experiments 2016-2017

**E666:** Isospin mixing from $\text{BR}_p/\text{BR}_\gamma$ in the decay of $T_z=-2$ nuclei

**Production**

$^{58}\text{Ni}@75 \text{ MeV/u, } 7 \times 10^{11} \text{ pps}$

$^{48}\text{Fe} \sim 3 \text{ pps}$

**Measurement**

Impl.-$\beta\gamma$ spatial and time correlations

- EXOGAM clovers
- $\Delta E-E$-Veto telescope
- DSSSD2*16*3 mm: XY
- ToF: CAVIAR-HF, D6-HF
LISE experiments 2016-2017

E666 Preliminary (J. Giovinazzo): $^{48}$Fe case

$^{48}$Fe $\beta$-p decay spectrum

5 ms < t < 2005 ms: good correlations
-2000 ms < t < 0 ms: wrong correlations
Difference: $^{48}$Fe decay

$^{48}$Fe $\beta(p)$-$\gamma$ decay spectrum

5 ms < t < 2005 ms: good correlations
-2000 ms < t < 0 ms: wrong correlations
Difference: $^{48}$Fe decay

$\Rightarrow$ Higher statistics than in all previous campaigns at LISE
Further cleaning work required (gating)

C. Dossat et al., NPA792 (2007) 18
LISE experiments 2016-2017

E748 – A. Matta, S. Koyama et al. – 1st exp. of the MUST2 campaign
Direct reaction modeling and nucleon-nucleon forces at the drip-line
- $^{10,12}\text{Be}(d,^3\text{He})^{9,11}\text{Li}$

✓ n-rich Be : halo structure

Geometrical w.f. mismatch
- very low cross section

n-rich Li: core excitations

✓ $^{10}\text{Be}(d,^3\text{He})$ vs. $^{12}\text{Be}(d,^3\text{He})$
- $\pi$ strength evolution in n-rich Be isotopes

✓ Other channels: (d,p), (d,d), (d,t), (d,α), (d,⁶Li)
- optical models, pn pairing, clustering, ...

✓ ToF & Tracking: CAVIAR, 2*CATS
✓ 0° detection: CHIO + NUMEXO2

Measurement
“Standard” MUST2 setup with 8 telescopes
LISE experiments 2016-2017

E748: $^{10,12}\text{Be}(d,^3\text{He})^{10,12}\text{Li}$

**Production**
$^{18}\text{O}@50\ \text{MeV/u, 2 to 6 }10^{12}\ \text{pps}$
fragmentation
$^{10}\text{Be} \sim 10^5\ \text{pps};\ ^{12}\text{Be} \sim 5 \times 10^4\ \text{pps}$
$\sim 95\%\ \text{purity}$

**Looks promising!**
LISE experiments 2016-2017

E692 – C. Whedlon et al., to be performed in November

Resonant elastic scattering to probe cluster structures in n-rich C isotopes

\[ \rightarrow ^{10,11,12}\text{Be}(\alpha,\alpha') \rightarrow ^{14,15,16}\text{C}(E^*, \Gamma, J^\pi) \]

Production

\(^{18}\text{O}@50\text{ MeV/u}, \text{few } 10^{12} \text{ pps} \)

Fragmentation \(\rightarrow ^{10,11,12}\text{Be}, \text{few } 10^4 \text{ pps} \)

Energy reduction down to 4-5 MeV/u

Exit channels to be investigated

\(^{10}\text{Be} + \text{4He} \rightarrow ^{14}\text{C}^* = ^{10}\text{Be} + \text{4He}; \quad ^{8}\text{Be} + \text{4He}; \quad ^{9}\text{Be} + \text{5He} ;\ldots \)

\(^{12}\text{Be} + \text{4He} \rightarrow ^{16}\text{C}^* = ^{12}\text{Be} + \text{4He}; \quad ^{10}\text{Be} + \text{6He};\ldots \)
LISE Future: organization

Organization based upon:

❖ Regular discussions with users: 3 LISE-ICC workshops in 2015-2016*

-> Physics program: 15 proposals
  ▪ nuclear structure and nuclear forces
  ▪ exotic decay modes
  ▪ nuclear astrophysics
  ▪ collective excitation modes

-> Definition of experimental campaigns:
  ▪ using existing (MUST2) and new detectors (ACTAR TPC, PARIS, MUGAST,...)
  ▪ using new beams (SPIRAL1-U)

-> Keeping the possibility to run standalone experiments

❖ Technical upgrade of the LISE spectrometer

-> Beam pipe cooling after the 1st dipole ✓ 2017
-> Improved detection capabilities: CAVIAR, CHIO+NUMEXO2 ✓ 2017
-> LISE QD6: optical/purity improvement for 2nd reactions 2017-2019

* Next LISE-ICC wks: GANIL, 6-8 December 2017
LISE roadmap: scientific program

2017 -> 2018

- 1st campaign: transfer with MUST 2
  - E748 performed – A. Matta et al.
  - Two remaining, dealing with exotic structures at the proton drip line
  - PAC 2017: 3 more proposals, nucl. struc./forces at the drip line; 1 astro.

-> Prog. in 2018: PAC res. & cryogenic target & SPIRAL1 beams

2019-2020

- 2nd campaign: 2p and ($\beta$)p decays + reactions with ACTAR TPC
  - Two accepted experiments: exotic decays
  - PAC 2017: 2 more proposals, 1 astrophysics, 1 nuclear structure

-> Prog. in 2019: to be defined in view of the other exp. In G3

- 3rd campaign: collective excitation modes
  - Proposal to the GANIL PAC: Ni isotopic chain
  - Part of the ACTAR TPC campaign if the LISE QD6 project is completed
LISE roadmap: technical developments

2017 -> 2018

- Removal of the D6 platform
- Removal of the last quadrupole (3Q -> 2Q)
- New diagnostic box (set closer to the Wien Filter)

2018->2019

Optics between the 1\textsuperscript{st} and 2\textsuperscript{nd} focalization points
- Technical solution to be defined (3Q, 4Q?)
  -> constraints = setup size, compatibility with slowed-down beams
- Implementation
Conclusion

- **2011-2017**
  - In average: ~1 month of beam time, 3 exp./year + tests
  - **2016-2017:**
    - Complementary investigation techniques/physics cases
    - Rather successful experiments
    - New MUST2 campaign initiated

- **2018 -> 2020**
  - MUST2 campaign completion with new proposals (?): requires a cryogenic target, SPIRAL1 beams -> organization
  - ACTAR TPC campaign (2 + x) -> scheduling vs G3 exp.

- **Risks/Opportunities**
  - Available/Required beam time
  - LISE QD6 scheduling -> timeline of the campaigns

Reminder: LISE-ICC Workshop, 6-8 December 2017 at GANIL
Thank you for your attention!

and to the contributors and reviewers

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