EXPAND

“EXPLORATIONS ACROSS THE NEUTRON DRIPLINE”

LPC-CAEN, IRFU/CEA-SACLAY, IPN-ORSAY
TOKYO INSTITUTE OF TECHNOLOGY, RIKEN NISHINA CENTER

AND THE “SAMURAI COLLABORATION”
EXPAND - PHYSICS: STRUCTURE & CORRELATIONS AT AND BEYOND THE NEUTRON DRIPLINE

(A<50)

LOI NPAC12 RIBF
Orr, Kondo, Obertelli, Nakamura et al.
... NUCLEON “KNOCKOUT”, BREAKUP ($\beta \approx 0.6$) + IN-FLIGHT DECAY

$\Rightarrow$ FRAGMENT – n FSI

$$E_d(\Lambda^+X) = \sqrt{(E_f + E_n)^2 + (p_f + p_n)^2 - (M_f + M_n)c^2}$$

**NOTE:** VERY THICK TARGET ($\sim 1 \text{ g/cm}^2$) AND VERY FORWARD FOCUSING OF REACTION PRODUCTS.
SAMURAI + NEBULA @ RIBF-RIKEN

BigRIPS + $^{48}$Ca @ 345 MeV/nucleon (~800* pnA) \(\Rightarrow\) "INTENSE" LIGHT NEUTRON DRIPLINE BEAMS

$^{22}$C @ ~60 pps, $^{31}$Ne @ ~1500 pps

* "DayOne" 2012 ~80 pnA ... 2016/17 ~600 pnA
SAMURAI+NEBULA Commissioning - 2012
NEBULA ...

120 MODULES
2 x 2 LAYER WALLS

MODULE

VETO PADDLE

EXPAND – Explorations Across the Neutron Dripline
NEBULA DETECTION EFFICIENCY @ 200 MeV/nucleon ...
“NEBULA-PLUS” …

UPGRADE NEBULA WITH ADDITION OF 90 NEW MODULES + ELECTRONICS + HV

⇒ 4 WALLS EACH OF 44 / 46 / 60 / 60 MODULES

EXPAND – Explorations Across the Neutron Dripline
NEBULA-PLUS vs NEBULA vs NEULAND-NEBULA DETECTION EFFICIENCY

@200 MeV/N

\( d(\text{target, NEB}) = 13 \, \text{m} \)

\( d(\text{Neu, NEB}) = 1.7 \, \text{m} \)

\( \Delta d(\text{NEB}) = 85 \, \text{cm} \)

EXPAND – Explorations Across the Neutron Dripline
NEBULA-PLUS RESOLUTION @ 200 MeV/nucleon ...

→ NEBULA-PLUS RESOLUTION SLIGHTLY DEGRADED COMPARED TO NEBULA Owing to shorter distance to new walls.

→ NEULAND+NEBULA – CONTRIBUTION OF SUPERIOR NEULAND GRANULARITY.
NEBULA-PLUS ...

• Original goal to double number of Nebula modules / walls ...
  ... deemed too costly by ANR.

• Resubmission accepted for 90 modules ...
  
  However ... grant awarded 100 k€ less than requested + $ vs € exchange rate drop + at 
  tendering price scint.

  Modules (St. Gobain) x1.5

• Neuland-type wall(s) investigated: too costly + electronics-DAQ issue
  ... demonstrator used (2015-2017) for part of physics 
  programme.

• Strategy: acquire 90 scintillator modules (Nebula design, including light guides + PMTs) & equip as 
  many as possible (60)
  with readout electronics & HV.

• After installation & commissioning upgrade to equip remaining 30 scint. modules –
  supplementary financing

* Essentially owing to increased cost of scintillator modules.

EXPAND – Explorations Across the Neutron Drifline
NEBULA-PLUS ...

STATUS & CALENDAR:

- **SCINTILLATOR BARS (90) + LIGHT GUIDES: ELJEN (USA) — FINAL BATCH DELIVERED MID-MAY**

- **PMTS: H22184 HAMAMATSU — 80 DELIVERED (40 TESTED), REMAINING 100 BY EARLY-SEPT**

- **ACCEPTANCE TESTING OF SCINT. MODULES COSMIC RAYS + SOURCES (90 TESTED) — APRIL-JUNE 2019**

- **FASTER READOUT ELECTRONICS & 180 CHANNEL HV SYSTEM — OCT-NOV 2019**

- **SHIP NEBULA-PLUS TO JAPAN — NOV-DEC 2019 (VAT~50-60k€)**

- **INSTALLATION & SOURCE + COSMIC RAY TESTS — JAN-APRIL 2020**

- **COMMISSIONING (BEAM) — MAY-JULY 2020 ... TO BE CONFIRMED**

- **FIRST EXPERIMENT — OCT-NOV 2020 ... TO BE CONFIRMED**

- **COMPLETE READOUT ELECTRONICS INSTRUMENTATION (30 SCINT. MODULES) — 2020-21**
SELECTED HIGHLIGHTS PHYSICS PROGRAMME (2012-18) *

- **Spectroscopic study of the unbound systems (Z=5 & 6) in the region of N=14-16**
- **Determination of the total interaction cross section of $^{22}\text{C}$**
- **First observation of $^{20,21}\text{B}$ (N=15,16)**
- **First observation of $^{24,25}\text{N}$ (N=17, 18) and the spectroscopy of $^{23}\text{N}$ (N=16)**
- **Investigation of two-neutron unbound system $^{26}\text{O}$**
- **Search for $^{27,28}\text{O}$ and the investigation of the very neutron rich F isotopes near N=20 [analyses in final stages]**
- **An investigation of the two-neutron unbound system $^{16}\text{Be}$ [analyses being finalised]**
- **A search for the $^4\text{n}$ system and the investigation of $^7\text{H}$ [analyses in progress]**
- **Investigation of clustering in the neutron-rich Be isotopes: $^{10,12,14}\text{Be}(p,p\alpha)$ quasi-free knockout [analyses in progress]**

*IN2P3 SPOKESPERSONS/GROUPS PLAYED MAJOR/KEY ROLE*
$Z=6$: STRUCTURE IN THE REGION OF $N\sim 14 - 16$ \((\nu 2s_{1/2} - \nu 1d_{5/2})\) ...
FIRST OBSERVATION & SPECTROSCOPY OF $^{21}$C:
$C(^{22}N/^{22}C, ^{20}C+n)$ @ ~250 MeV/nucleon

$E_r = 0.90 \pm 0.10$ MeV
$E_r = 1.50 \pm 0.10$ MeV

$l = 0$
$l = 2$

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<th>$E_x$ (MeV)</th>
<th>$J^\pi$</th>
<th>$\ell$</th>
<th>$\sigma_{sp}$ (mb)</th>
<th>$C^2 S$</th>
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Eikonal + shell model C$^2$S
JA Tostevin

S Leblond et al., NP1106-SAMURAI04
SPECTROSCOPY & NEUTRON-NEUTRON CORRELATIONS IN $^{16}\text{Be}$:

$$H(^{17}\text{B}, ^{14}\text{Be}+n+n)2p @ 250 \text{MeV/nucleon}$$

J Casal et al., PRC (2019)
**Physics Programme with Nebula-Plus: Near Future (2020-23) ...**

- **Search for Excited (Continuum) States of $^{22}$C $-$ $2^+$ ($N=16$ Sub-Shell Closure)**

- **Investigate Two-Neutron Decay of $^{21}$B & Search for $^{21}$B* ($N=16$) & 3-Neutron Decay of $^{20}$B**

- **Search for $^{23}$C ($N=17$) – Possible Application of ($^{12}$C,$^{12}$N)**

- **Spectroscopy of $^{39}$Mg ($N=28$)**

**Projet Strasse * (~2020-22) ...**

- **Improved Vertex Detection for Minos-Type Thick Liquid H$_2$ Target – (p,xp), ...**

- **Si Microtip Dets for Tracking Protons**

- **LPC $\sim$150k€ via Normandy Region [Chaire d’Excellence - F Flavigny]**

* Led by TU-Darmstadt with GSI + Tokyo Tech
FINANCIAL RESOURCES (IN2P3) ...

- 2012-2018: AP IN2P3 ~20k€/YEAR + LIA ~3-6 k€/YEAR - ESSENTIALLY TRAVEL (JAPAN)
  
  INCREASED COMMITMENT TO SAMURAI [NEBULA-PLUS & STRASSE] & FTE + ~1.5

- REQUEST (TRAVEL) 2020-2023: AP IN2P3 ~30k€/YEAR + LIA ~5 k€/YEAR

- REQUEST (EQUIPMENT-ELECTRONICS NEBULA-PLUS) 2020-2021: AP IN2P3 15k€/YEAR
  
  MATCHING FUNDS – LPC (UNDER DISCUSSION)

MANPOWER (IN2P3) ...

- 2012-2018: ~5-6 FTE† [PHYSICISTS]

- LPC - MARIAN PARLOG - RETIRED (JAN 2018), FRANCK DELAUNAY - SABBATICAL (2018-19)

- IN2P3/CNRS FUNDED POSTDOC - OCT 2019 (LPC)

- "CHAIRE D’EXCELLENCE’’ NORMANDY REGION – FREDDY FLAVIGNY* (OCT 2019)

- 2020-23: ~6-7 FTE† [PHYSICISTS] + ~0.2 - 0.5 FTE [IR/IT] IN2P3

* Research project: RIBF (Strabe - EXPAND) & GRIT
† Including graduate students
**SWOT Analysis**

**Strengths**

- RIBF’s unequalled secondary beam intensities for light (A<50) neutron-rich beams.
- State of the art setup and instrumentation.
- Collaboration very experienced in the simulation and analysis of complex experiments, including multi-neutron detection and cross talk analyses.
- French collaborators play key role in collaboration – reinforced with NEBULA-Plus.

**Weaknesses**

- Shortfall in ANR funding.
- SAMURAI electronics and DAQ not state of the art.
- Limited beam time at RIBF (maximum of 4 months/year).
- Recent difficulties in procuring $^{48}$Ca source material (Nishina Centre/RIBF).
- Very limited theory support (France).
- Travel funds.

**Opportunities**

- With successful commissioning of NEBULA-Plus the SAMURAI collaboration will be ideally positioned to play a leading role in neutron dripline physics for the next decade.
- Improvements possible with the Stra/e active target.

**Threats**

- FRIB (>2022) and to a lesser extent FAIR (>2025) – but long lead times in ramping up primary beam power.
I heard the Prime Minister speaking to the Queen...

... “It’s hot enough to boil a monkey’s bum, your Majesty”
he said and she smiled quietly to herself.

- She’s a good Sheila, Bruce, and not at all stuck up.