Experiments with NeuLAND@R³B

- NeuLAND Design
- Experimental Programm at R³B@FAIR
- Dipole Response of Exotic Nuclei
- NeuLAND Status 2016 towards 2018 beam at R³B@GSI
features:
- **kinematically complete** measurements of nuclear reactions in inverse kinematics
- → invariant mass
- high beam energies: 100-1000 MeV/u
- high energy branch of SuperFRS

addresses:
- nuclear reactions
- nuclear astrophysics
- structure of (exotic) nuclei
- neutron-rich matter
Reactions with Relativistic Radioactive Beams

features:
- **kinematically complete** measurements of nuclear reactions in inverse kinematics
- high beam energies: 100-1000 MeV/u
- high energy branch of SuperFRS

addresses:
- nuclear reactions
- nuclear astrophysics
- neutron-rich matter
- today: dipole response of exotic light and heavy nuclei

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Detection of Fast Neutrons
LAND \rightarrow NeuLAND

- iron-scintillator sandwich
- 2x2x1 m³
- 400 modules


- full active scintillator
- 2.5x2.5x3 m³
- 3000 modules

Technical Design Report, 2011,

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From Submodules to Complete NeuLAND

NeuLAND submodule
250(270 incl. light guides)x5x5 cm³

100 submodules build one double-plane

30 double-plane build up NeuLAND face size 250x250 cm² active depth 300 cm

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NeuLAND design goals:
- >90% efficiency for 0.2-1.0 GeV neutrons
- Multi-hit capability for up to 5 neutrons
- invariant-mass resolution: NeuLAND-target distance 35 m
  \[ \Delta E < 20 \text{ keV} \text{ at } 100 \text{ keV above the neutron threshold} \]

NeuLAND detector parameters:
- full active detector using RP/BC408
- face size 250x250 cm\(^2\)
- active depth 300 cm
- 3000 scintillator bars
- 6000 PM / readout channels
- \(\sigma_{x,y,z} \approx 3\text{cm}\)
- \(\sigma_t < 150\text{ ps}\)
Physics List for NeuLAND

Excerpt from the TDR:

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NeuLAND in „High-Resolution Mode“

NeuLAND-target distance 35 m, 600 MeV

$\Delta E < 20$ keV at 100 keV
above the neutron threshold

$s = 15$ keV
1 neutron

$\Delta E \approx 40$ keV at 100 keV
for 4 n's at 60% tot. efficiency

$s = 42$ keV
4 neutrons
Equation of State

\[ \alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma(E)}{E^2} \, dE \]

symmetry energy (\(\rho\))

EQUATION OF STATE

Fig. 3. State-of-the-art condition of the structure of a neutron star (courtesy of Dusay Page).
Reminder:
PDR/GDR and Neutron Skin in $^{132}\text{Sn}$

data taken at the LAND setup
Coulomb excitation in inverse kinematics
invariant mass method

\[
E^* = \sqrt{\sum_i m_i^2 + \sum_{i \neq j} \gamma_i \gamma_j m_i m_j (1 - \beta_i \beta_j \cos \theta_{ij}) + E_\gamma - m_{proj}}
\]

$^{124}\text{Sn}$

$^{130}\text{Sn}$

$^{132}\text{Sn}$

P. Adrich et al., PRL 95, 132501 (2005)

$\rightarrow$ neutron skin thickness and symmetry energy parameters in
A. Klimkiewicz, N. Paar et al., PRC 76 (2007) 051603(R)

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Dipole Polarizibility and Neutron Skin

Covariance Analysis
P-G. Reinhard and W. Nazarewicz,
PRC 81 051303(R) (2010)

\[
\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma(E)}{E^2} dE
\]

Polarized Proton Scattering
A. Tamii et al., PRL 107 062502 (2011)

\[
r_{\text{skin}} = 0.156^{+0.025}_{-0.021} \text{ fm}
\]
Reminder:
Dipole Polarizability in $^{68}\text{Ni}$

$\alpha_D^{\text{exp}} = 3.40(23) \text{ fm}^3$

D. Rossi et al.,
PRL 111, 242503 (2013)
→ neutron skin thickness

Agrees with
- $(p,p')$ measurement on $^{208}\text{Pb}$ (Tamii et al. PRL 107 062502 (2011))
- coherent pion production measurement (Tarbert et al. PRL 112, 242502 (2014))
Dipole Response: Experimental Future

Relativistic Mean Field Calculation by Andrea Horvat

→ Higher sensitivity for n-rich nuclei

R³B@FAIR program includes

Dipole response including pygmy, GDR, polarizability of

• very neutron-rich Sn isotopes in the r-process path: $^{134-140}\text{Sn}$ design intensity:
  200/spill $^{138}\text{Sn}$, 2/spill $^{140}\text{Sn}$

• heavy neutron-rich beams $^{208-224}\text{Pb}$, design intensity:
  100/spill $^{222}\text{Pb}$, 5/spill $^{224}\text{Pb}$)

with aimed for accuracy of 5% in $\alpha_D$
„Dipole“ Demands for R³B

demands for very exotic beams:
detection of up to 5 neutrons
→ NeuLAND
  • higher efficiency (≈ 60% for 4n)
  • improved resolution

demands for heavy beams:
$E_{\text{beam}} \approx 1000$ AMeV
→ CALIFA
  • higher granularity
    (suppression of atomic bg)
  • improved resolution

$E_{\text{beam}} \approx 1000$ AMeV
→ GLAD + tracking det.
  • $\sigma(Bp)/Bp \approx 10^{-3} \rightarrow$ mass res.
NeuLAND in „Full Acceptance Mode“: Response for Coulomb Excitation of $^{136}$Sn

- **PDR**
  - $E_m = 8$ MeV
  - $\sigma = 1$ MeV
  - 5% TRK SR

- **GDR**
  - $E_m = 15.5$ MeV
  - $\Gamma = 4$ MeV
  - 100% TRK SR

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- $E^* (\text{MeV})$
- $\text{input}$
- $\text{output}$

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Status NeuLAND 2016 → 2018 at GSI

NeuLAND@RIKEN (2015-2017):
Demonstrator (4dp) fully functional - Tacquila electronics, CAEN HV

NeuLAND@GSI:
7 dp fully equipped - 1 with new Tamex3 electronics, HVDS system
additional 2 dp close to finished
funding in 2017 allows to build one more!

→ 12 dp (40% of full detector) ready for beam in 2018 at GSI
NeuLAND@RIKEN

Performed beam times:
• IMPACT campaign - Oct. 15
• calibration beam time - Nov. 15
  1n efficiency at 110, 250 MeV, 7Li(p,n)
• 28O experiment - Nov. 15
• Spirt TPC - EOS experiment - Apr./May 16
  108Sn → 112Sn target,
  112Sn → 124Sn target,
  132Sn → 124Sn target

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Some Pictures...2015

preliminary!
Some Pictures...2016

NEULAND & VETO at 30° position for $S\pi$rit experiment

preliminary!
Some Pictures...2016

NEULAND & VETO at 30° position for Sπrit experiment

April 2016
Scheduled Experiments (Nov/Dec 2016):
• Coulomb breakup and knockout reactions to investigate $^{31}\text{Ne}$
• Removal reactions to investigate structure around N=16 shell closure
• Lifetime measurement of the $^{26}\text{O}$ ground-state (C. Caesar)

Approved Experiments:
• Dipole response of dripline nuclei (T. Aumann & T. Nakamura): $^6,^8\text{He}$, $^{24}\text{O}$, $^{29}\text{F}$
• Tetra-neutron system:
  - $^8\text{He}(p,pa)4n$ (S. Paschalis, D. Rossi & S. Shimoura)
  - $^8\text{He}(p,2p)^7\text{H}$ (K. Kisamori & F. M. Marqués)
• Electric dipole response of neutron-rich Ca isotopes (T. Kobayashi & Y. Togano)
• + ...
2018 - R³B in Cave C

CALIFA ??%  GLAD!  NeuLAND ~40%

Proton Arm Spectrometer  Fragment Tracking

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Physics Programm for R³B in Cave C 2018ff

was discussed actively in R³B Meeting last week at PNPI
NeuLAND is...

bulky
but highly efficient
boring
but very versatile
active
fully - in many respects ;-(