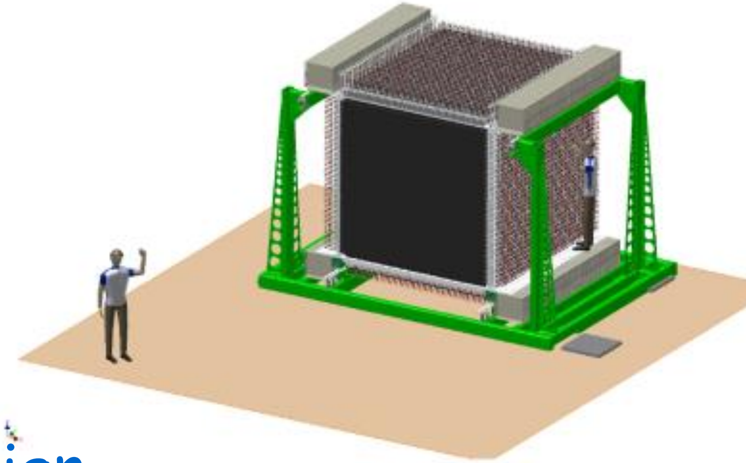
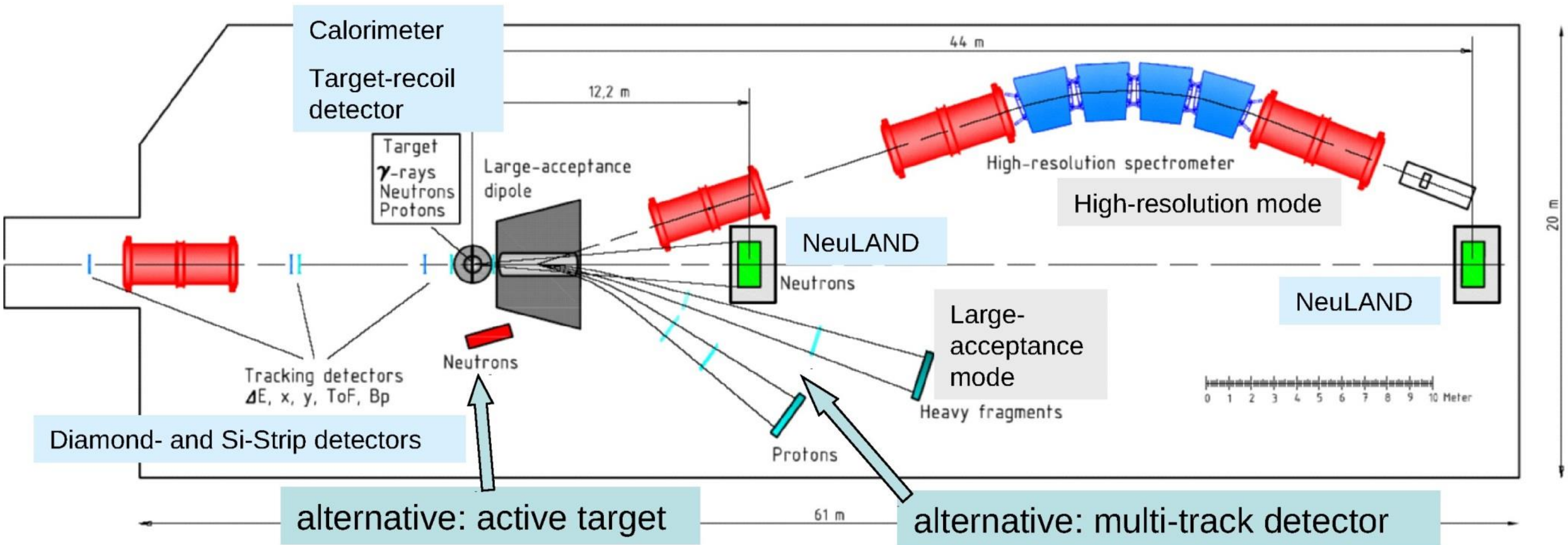
Experiments with NeuLAND@R^{3}B



- NeuLAND Design
- Experimental Programm at R^{3}B@FAIR
- Dipole Response of Exotic Nuclei
- NeuLAND Status 2016 towards 2018 beam at R^{3}B@GSI

R^{3}B
Reactions with Relativistic Radioactive Beams



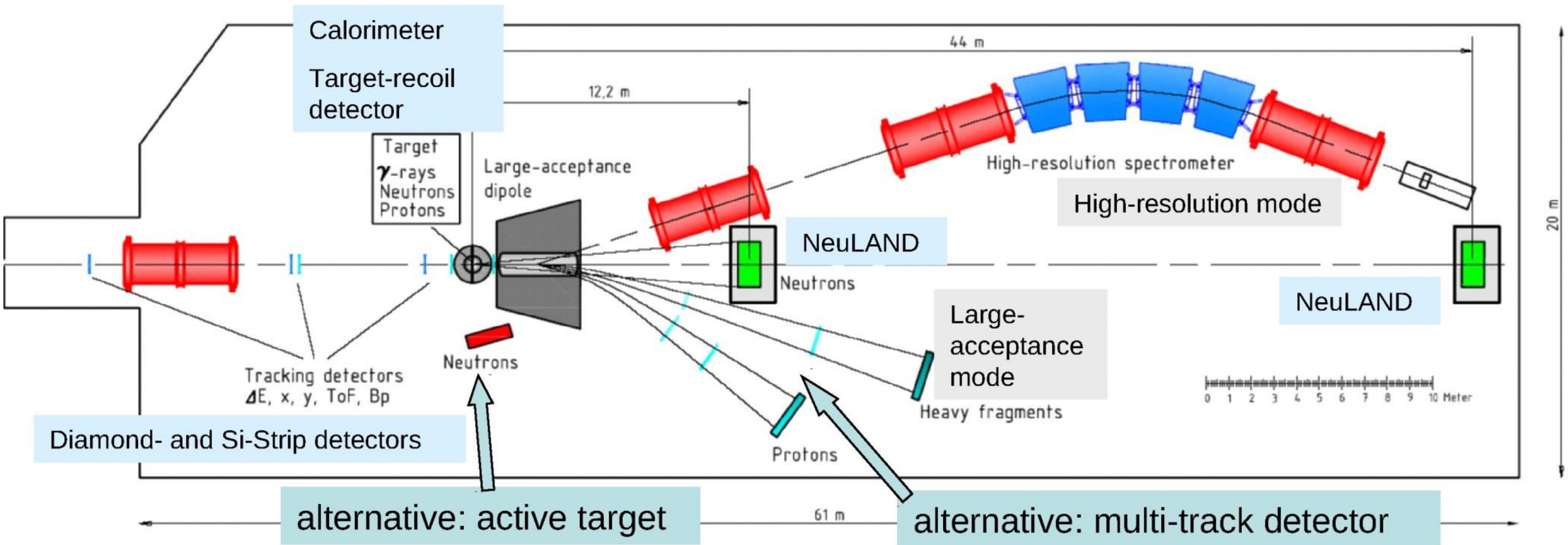
features:

- **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**

R^3B
Reactions with Relativistic Radioactive Beams



features:
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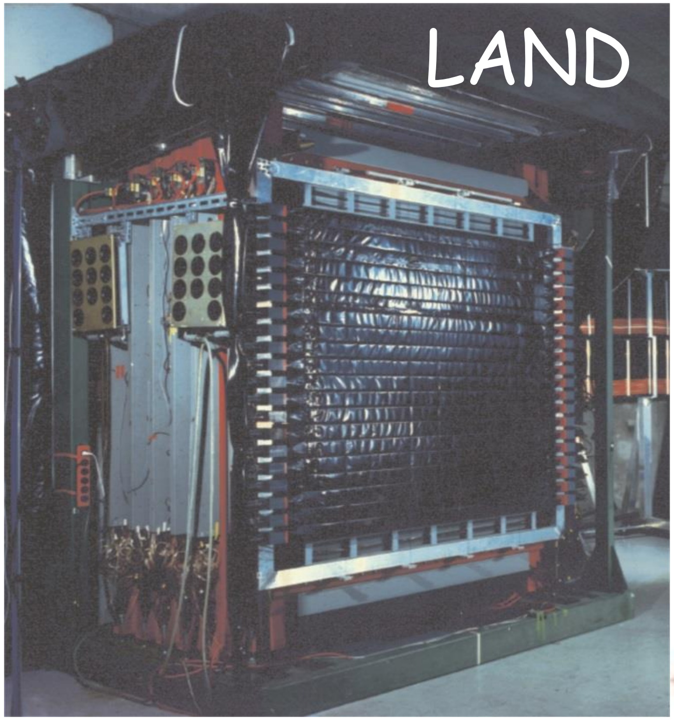
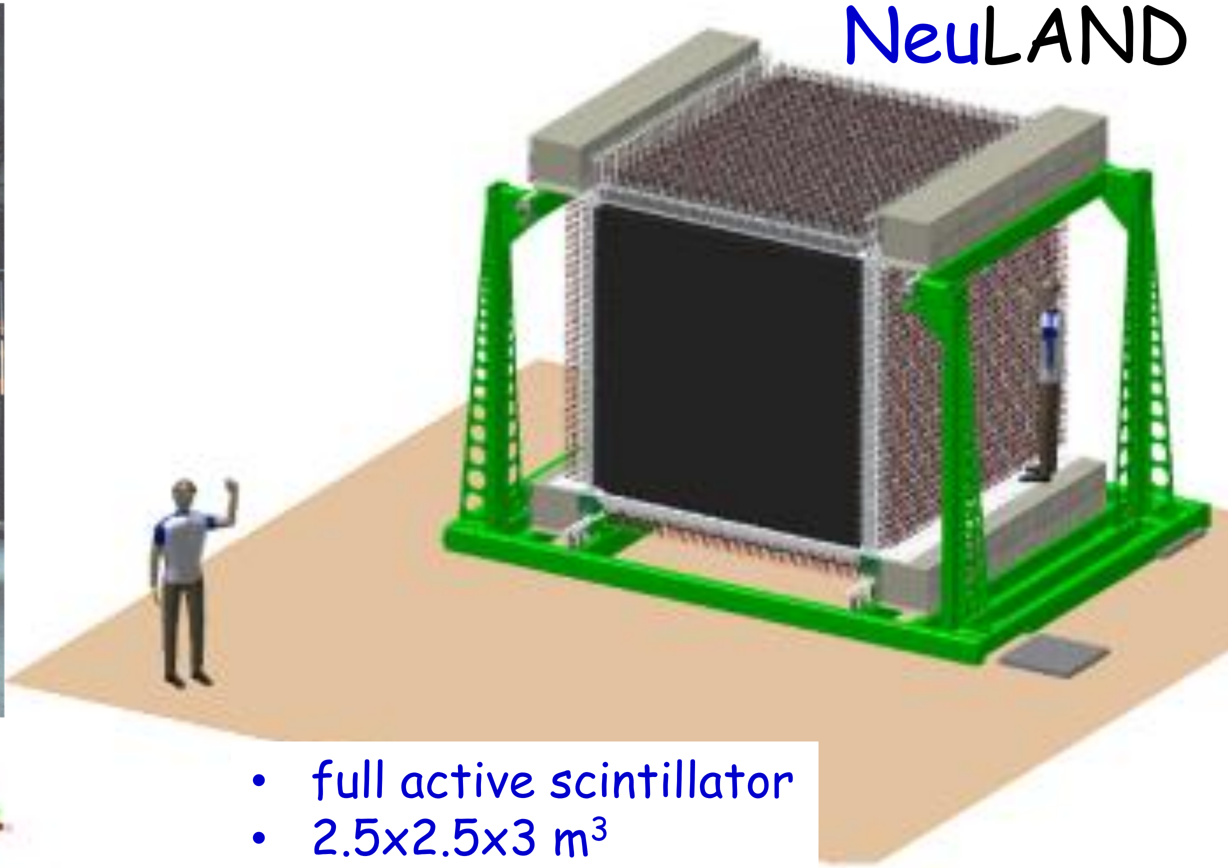
addresses:
- **nuclear reactions**
- nuclear astrophysics
- structure of (exotic) nuclei
- neutron-rich matter

→today: dipole response of exotic light and heavy nuclei

Detection of Fast Neutrons
LAND → NeuLAND





- iron-scintillator sandwich
- 2x2x1 m^3
- 400 modules

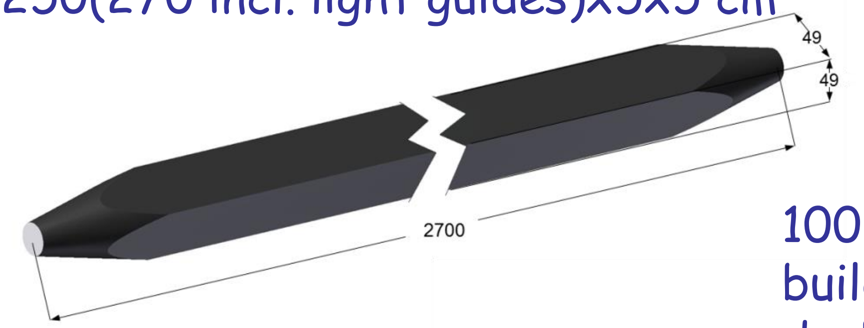
Nucl. Instr. Meth. A314 (1992) 136

- full active scintillator
- 2.5x2.5x3 m^3
- 3000 modules

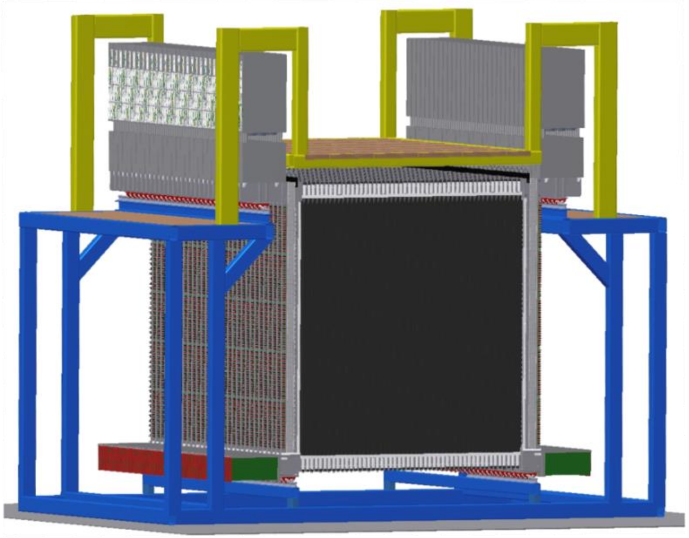
Technical Design Report, 2011,
http://www.fair-center.eu/fileadmin/fair/publications_exp/NeuLAND-TDR-Web.pdf

From Submodules to Complete NeuLAND

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



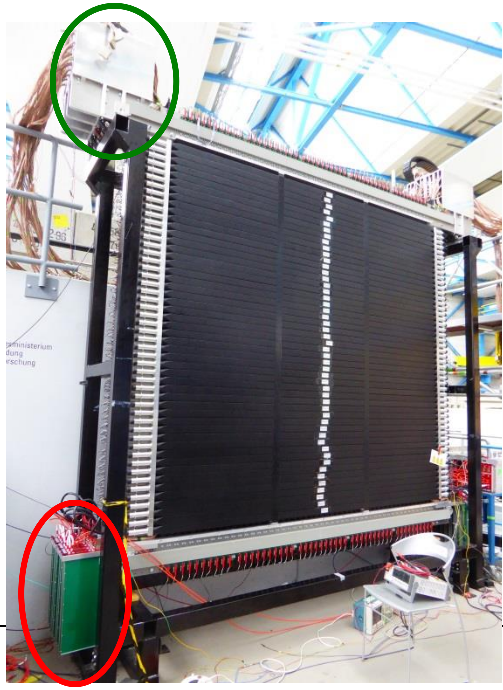
100 submodules
build one
double-plane

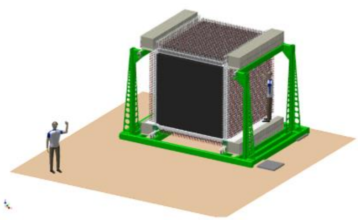


30 double-plane
build up NeuLAND
face sice
250x250 cm²
active depth 300
cm

Readout
Electronics

High Voltage
Distribution
System





NeuLAND: The High Resolution Neutron Time-of-Flight Spectrometer for R^3B

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**
  ΔE < 20 keV at 100 keV above the neutron threshold

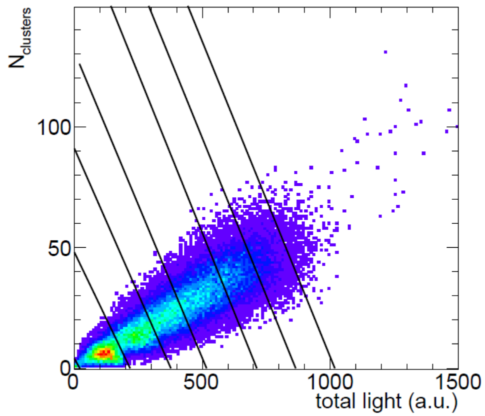
NeuLAND Demonstrator 2014

NeuLAND detector parameters:

- **full active** detector using RP/BC408
- face sice 250x250 cm^2
- active depth **300 cm**
- 3000 scintillator bars
- 6000 PM / readout channels
- $\sigma_{x,y,z} \approx 3$cm
- σ_t < 150 ps

calorimetric properties

	%	1000 MeV generated				
		1n	2n	3n	4n	5n
detected	1n	**89**	12	1	0	0
	2n	7	**78**	23	3	0
	3n	0	8	**63**	26	5
	4n	0	0	12	**63**	40
	5n	0	0	0	7	**46**
	6n	0	0	0	0	8



Physics List for NeuLAND

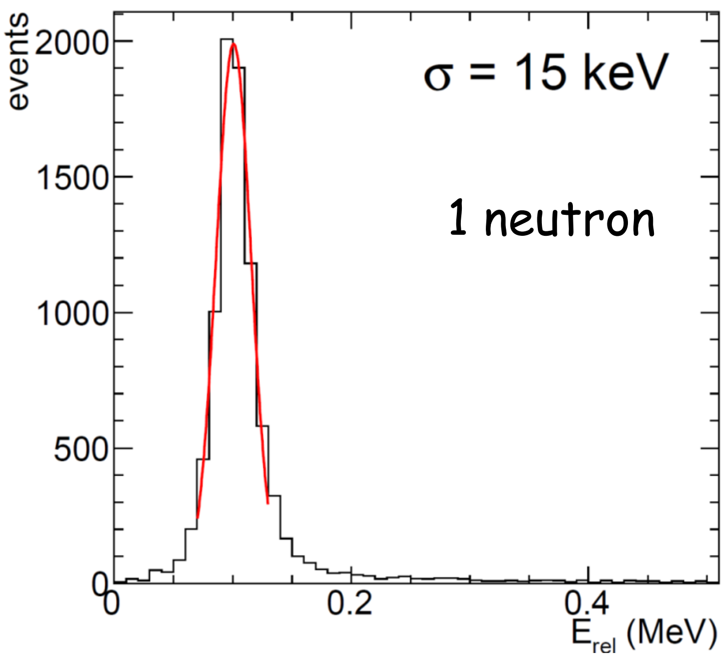
Excerpt from the TDR:

NeuLAND in „High-Resolution Mode"

NeuLAND-target distance 35 m, 600 MeV

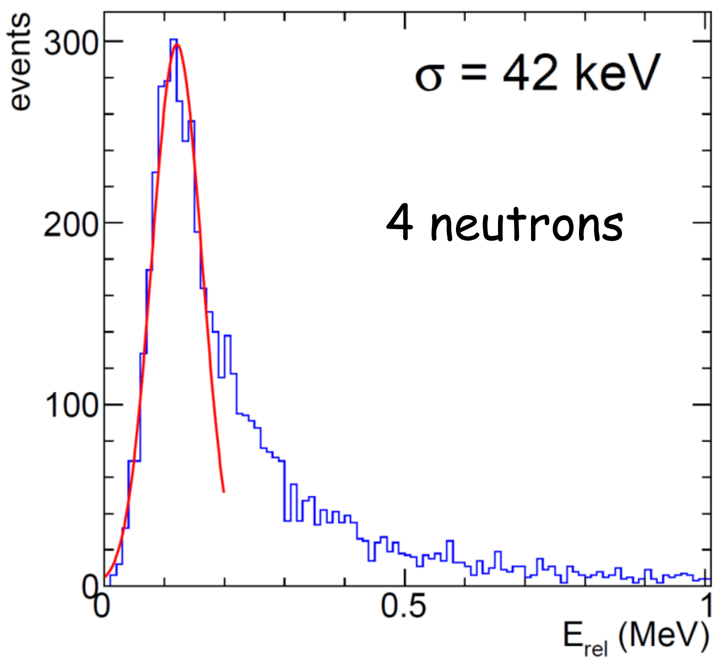
$\Delta E < 20$ keV at 100 keV

above the neutron threshold

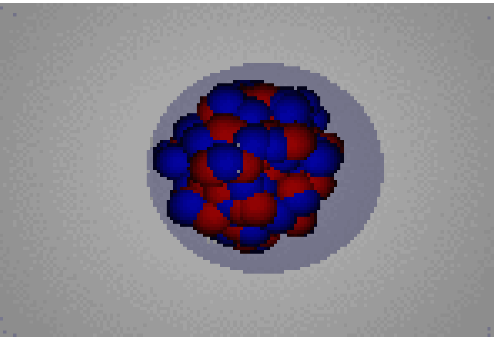


$\Delta E \approx 40$ keV at 100 keV

for 4 n's at 60% tot. efficiency



Equation of State



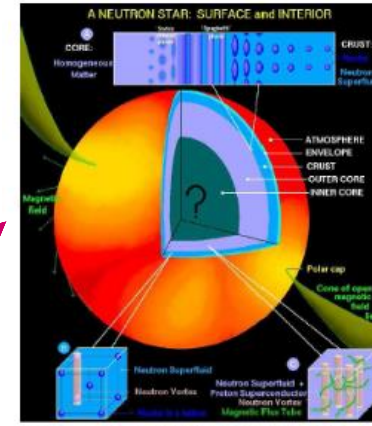


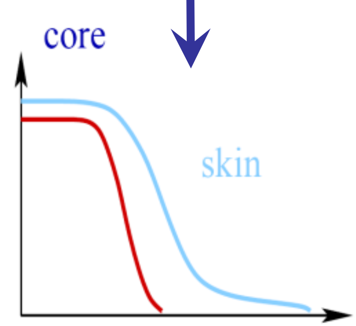
Fig. 3. State-of-the-art rendition of the structure of a neutron star (courtesy of Dany Page).

symmetry energy (ρ)

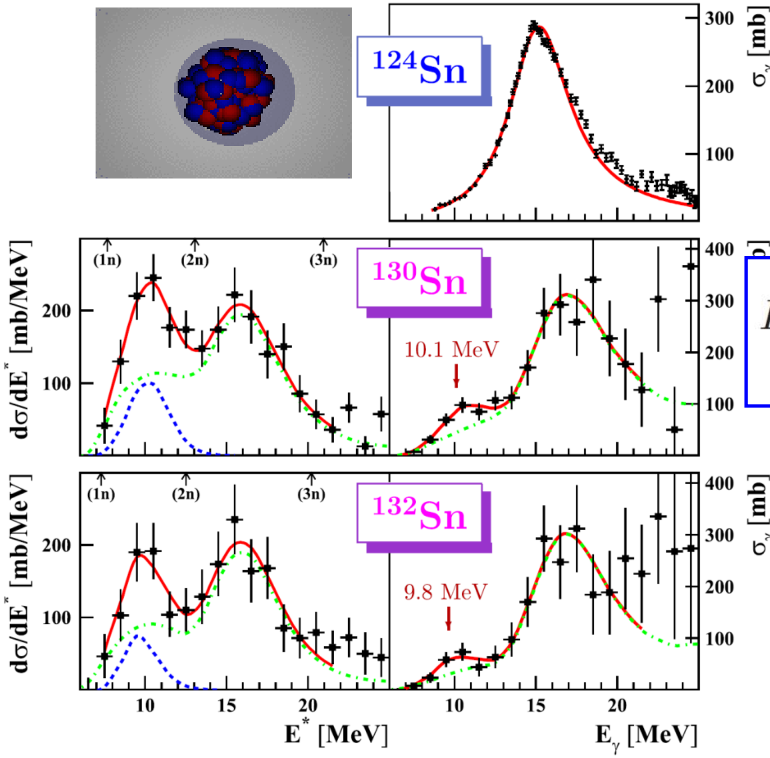
EQUATION OF STATE

symmetry energy (ρ)

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



Reminder: PDR/GDR and Neutron Skin in ^{132}Sn

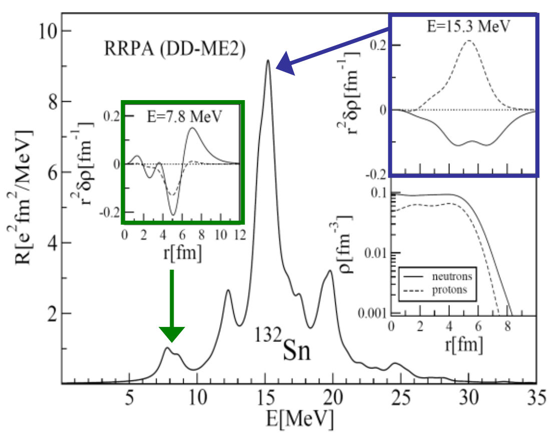


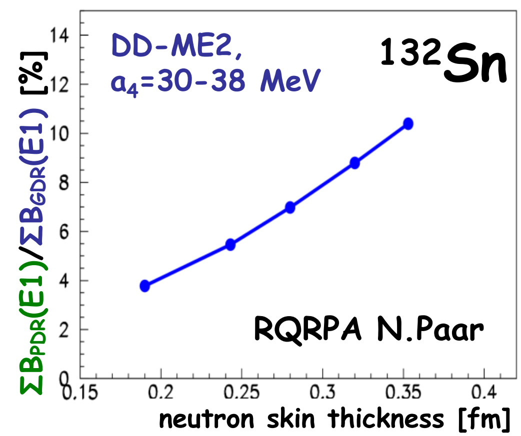
data taken at the LAND setup
Coulomb excitation in inverse kinematics
invariant mass method

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

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

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

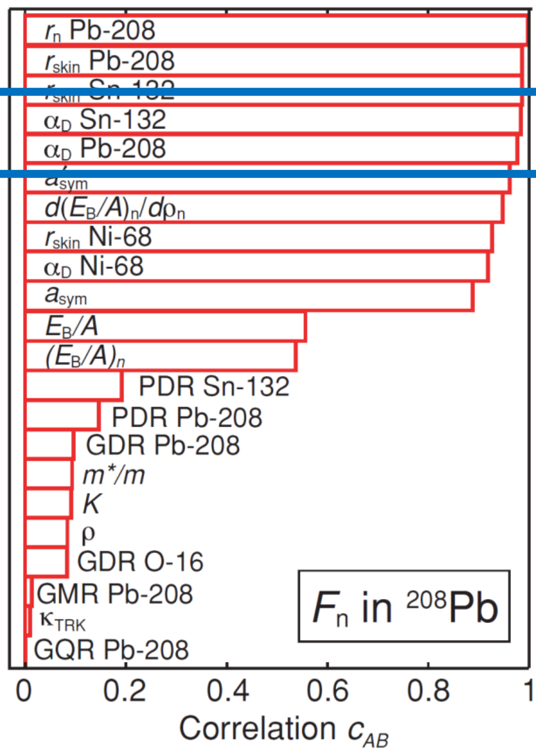




Dipole Polarizability and Neutron Skin

Covariance Analysis

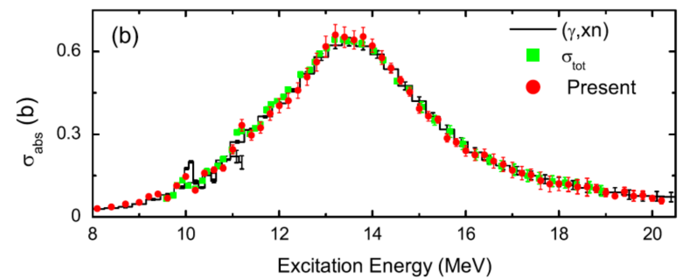
P-G. Reinhard and W. Nazarewicz, PRC **81** 051303(R) (2010)

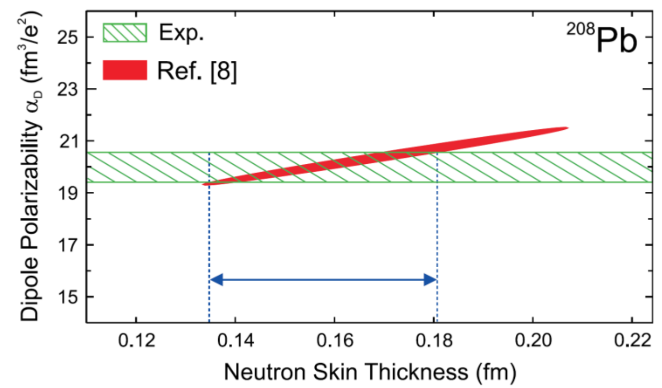


$$\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma(E)}{E^2} dE$$

Polarized Proton Scattering

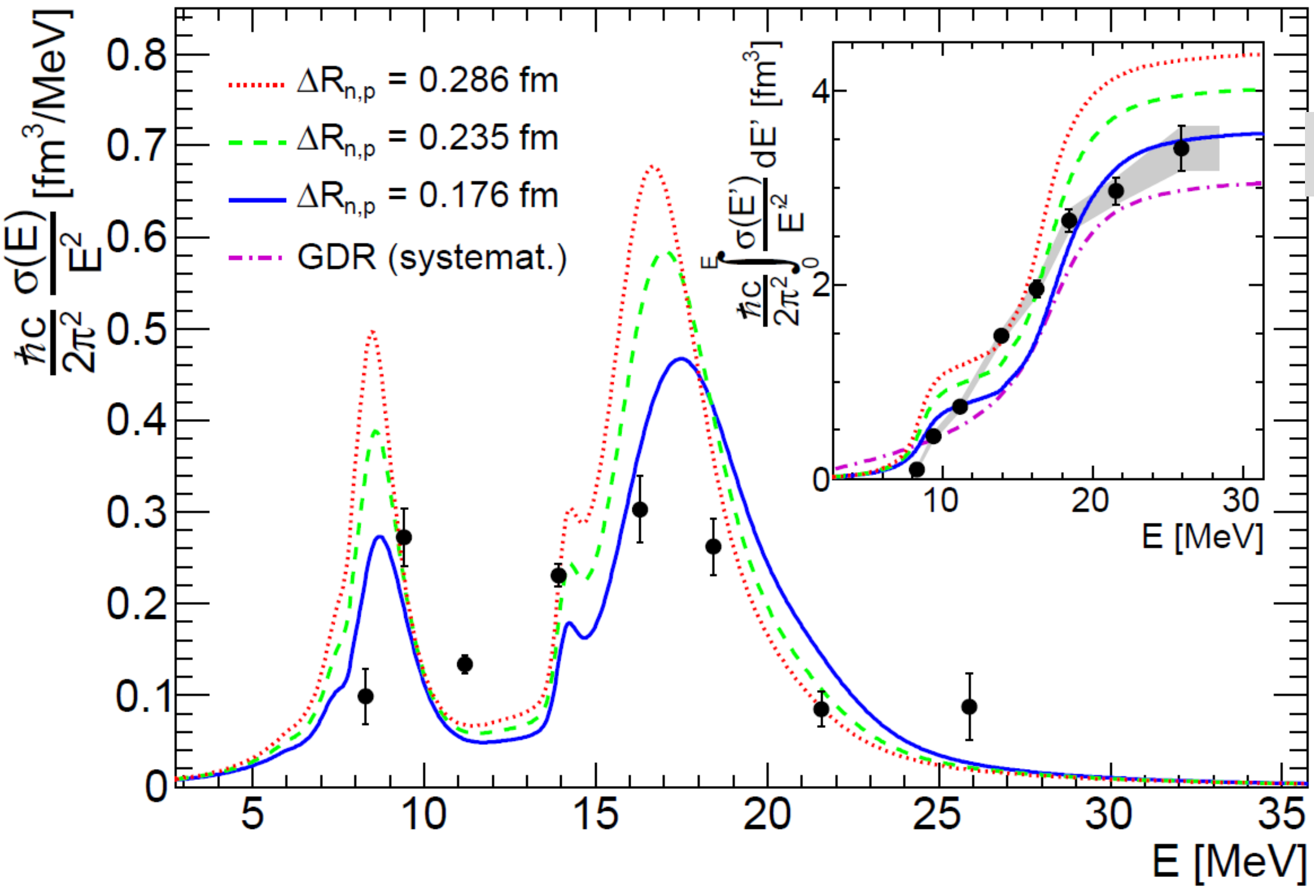
A. Tamii et al., PRL **107** 062502 (2011)





$$r_{\text{skin}} = 0.156^{+0.025}_{-0.021} \text{ fm}$$

Reminder: Dipole Polarizability in ^{68}Ni



α_D^{exp} = 3.40(23) fm^3

D. Rossi et al. , PRL 111, 242503 (2013)

→ neutron skin thickness

FSU Gold:
J. Piekarewicz, Phys. Rev. C 83, 034319 (2011)

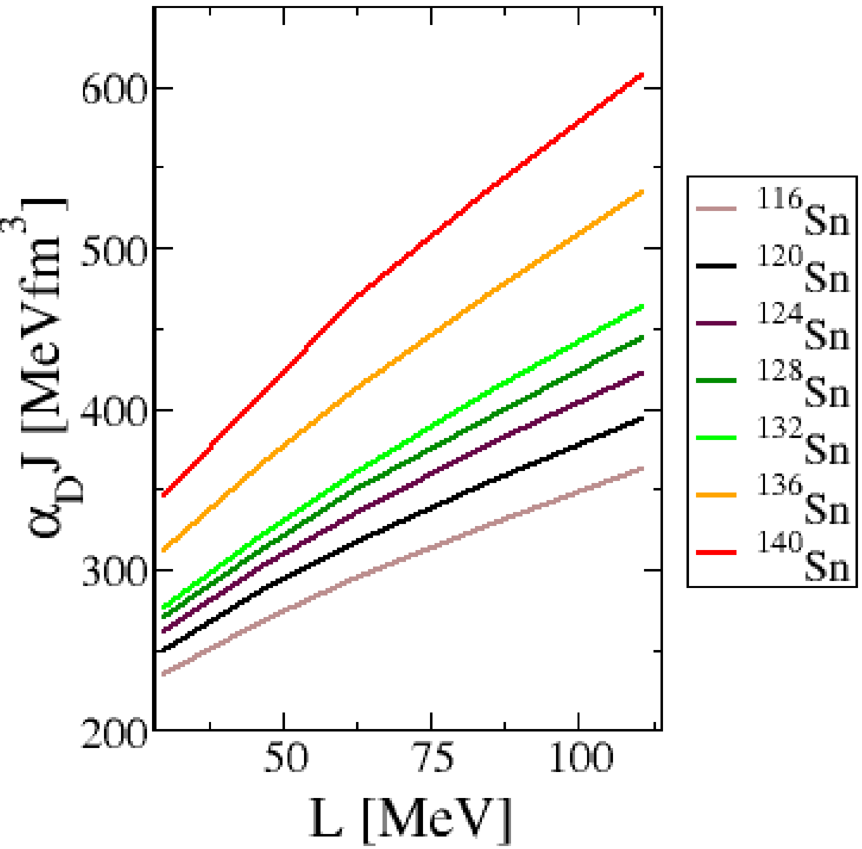
Agrees with

- (p,p') measurement on ^{208}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



R^{3}B@FAIR program includes

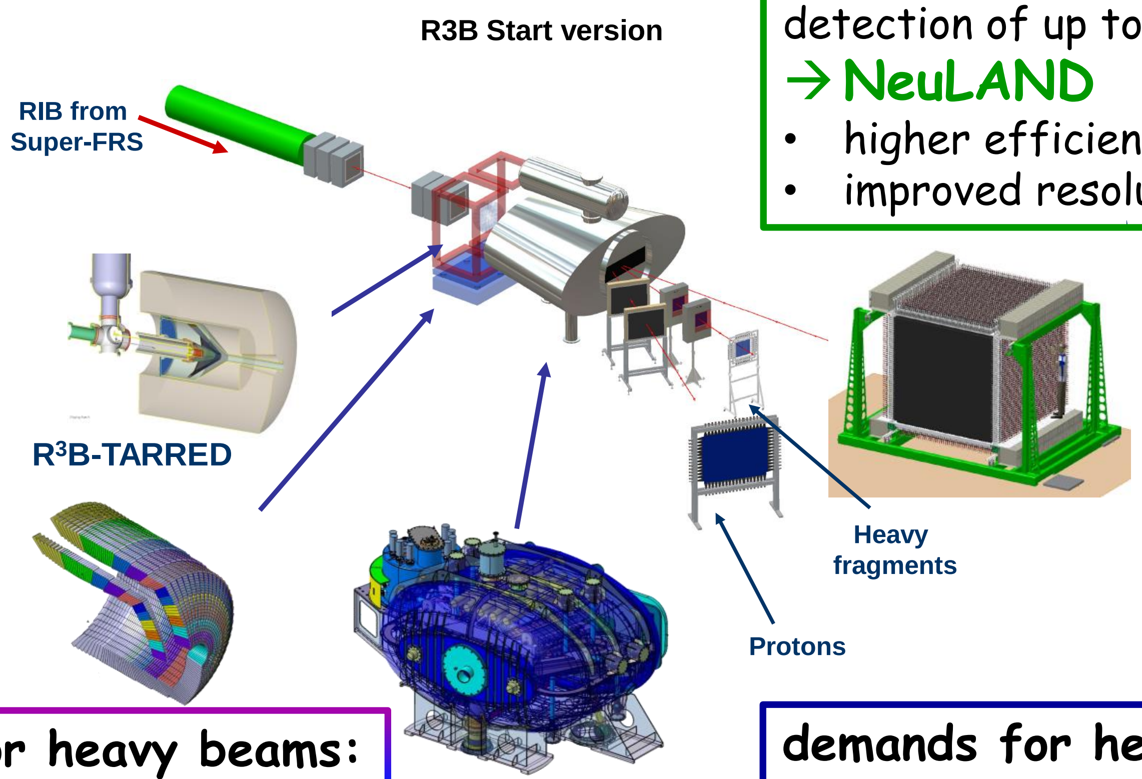
Dipole response including pygmy, GDR, polarizability of

- very neutron-rich Sn isotopes in the r-process path: **$^{134-140}$Sn** design intensity:
  200/spill ^{138}Sn, 2/spill ^{140}Sn
- heavy neutron-rich beams **$^{208-224}$Pb**, design intensity:
  100/spill ^{222}Pb, 5/spill ^{224}Pb)

with aimed for accuracy of 5% in α_D

„Dipole" Demands for R^3B

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



demands for heavy beams:
E_{beam} ≈ 1000 AMeV
→ CALIFA
- higher granularity
  (suppression of atomic bg)
- improved resolution

demands for heavy beams:
E_{beam} ≈ 1000 AMeV
→ GLAD + tracking det.
- $\sigma(B\rho)/B\rho \approx 10^{-3}$ → mass res.

NeuLAND in „Full Acceptance Mode“: Response for Coulomb Excitation of ^{136}Sn

PDR
E_m = 8 MeV
σ = 1 MeV
5% TRK SR

GDR
E_m = 15.5 MeV,
Γ = 4 MeV
100% TRK SR

	%	1n	2n	3n	4n	5n
		1000 MeV generated				
detected	1n	**89**	12	1	0	0
	2n	7	**78**	23	3	0
	3n	0	8	**63**	26	5
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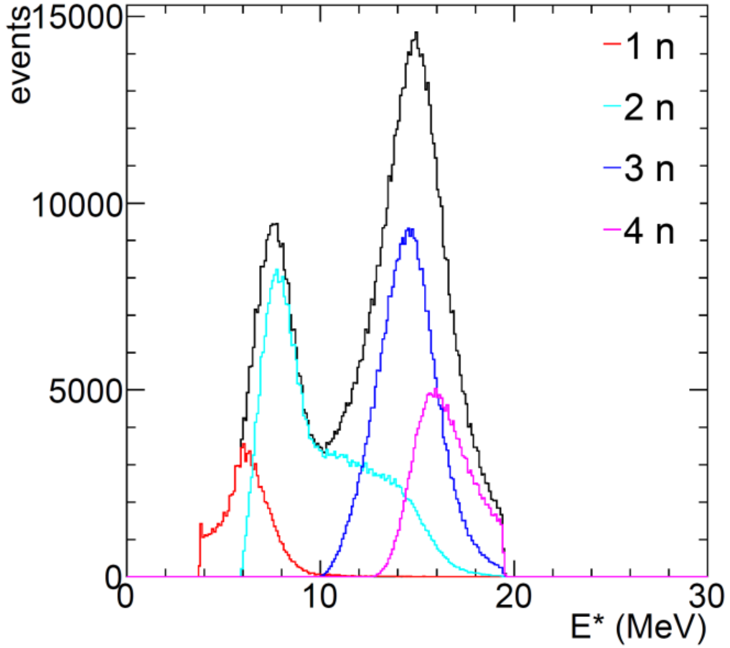
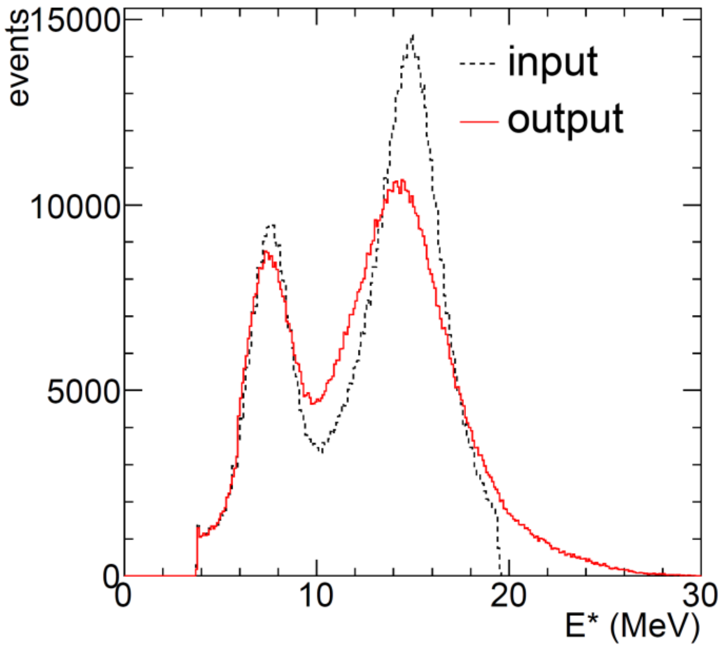




Status NeuLAND 2016 → 2018 at GSI

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

<u>Performed beam times:</u>

- IMPACT campaign - Oct. 15
- calibration beam time – Nov. 15

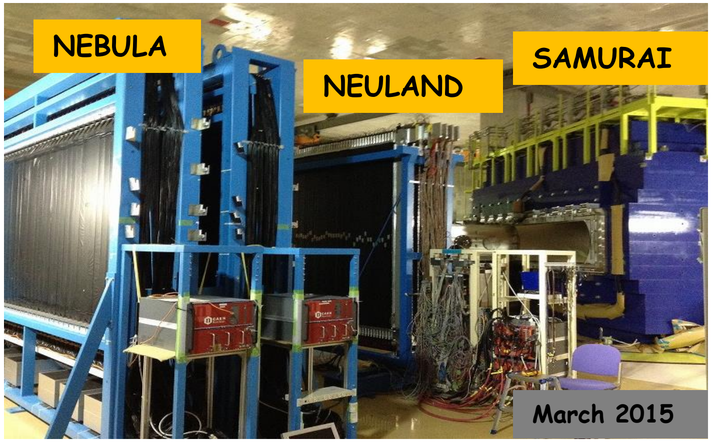
  1n efficiency at 110, 250 MeV, 7Li(p,n)
- ^{28}O experiment – Nov. 15
- Sπrit TPC – EOS experiment – Apr./May 16

  ^{108}Sn → ^{112}Sn target,

  ^{112}Sn → ^{124}Sn target,

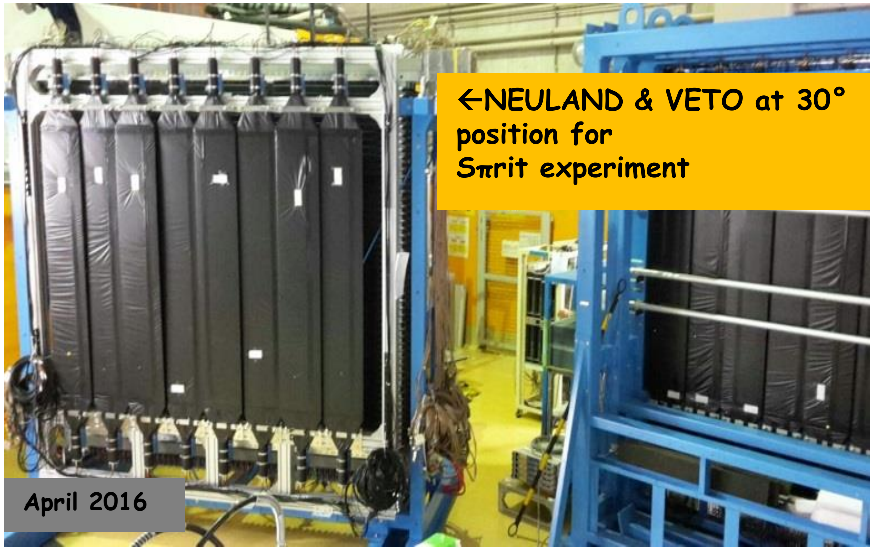
  ^{132}Sn → ^{124}Sn target

Some Pictures...2015



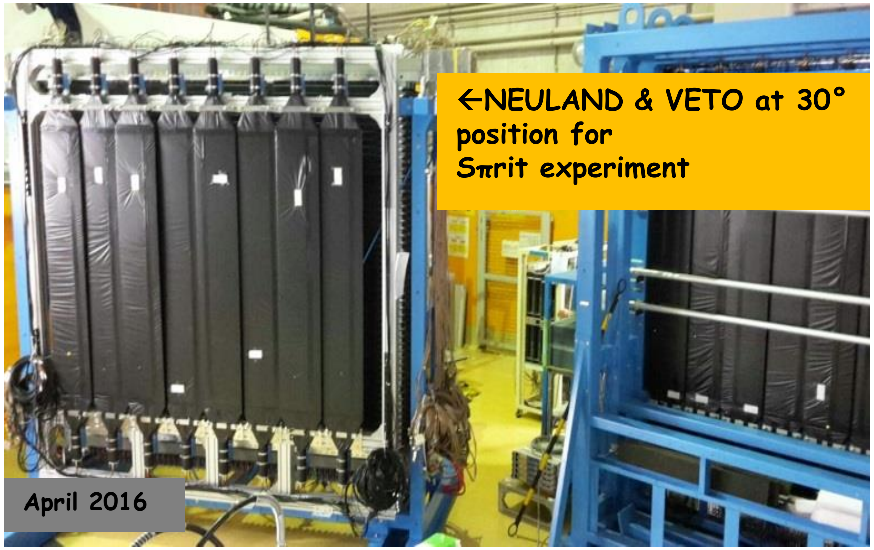
preliminary!

Some Pictures...2016



preliminary!

Some Pictures...2016



preliminary!

NeuLAND@RIKEN

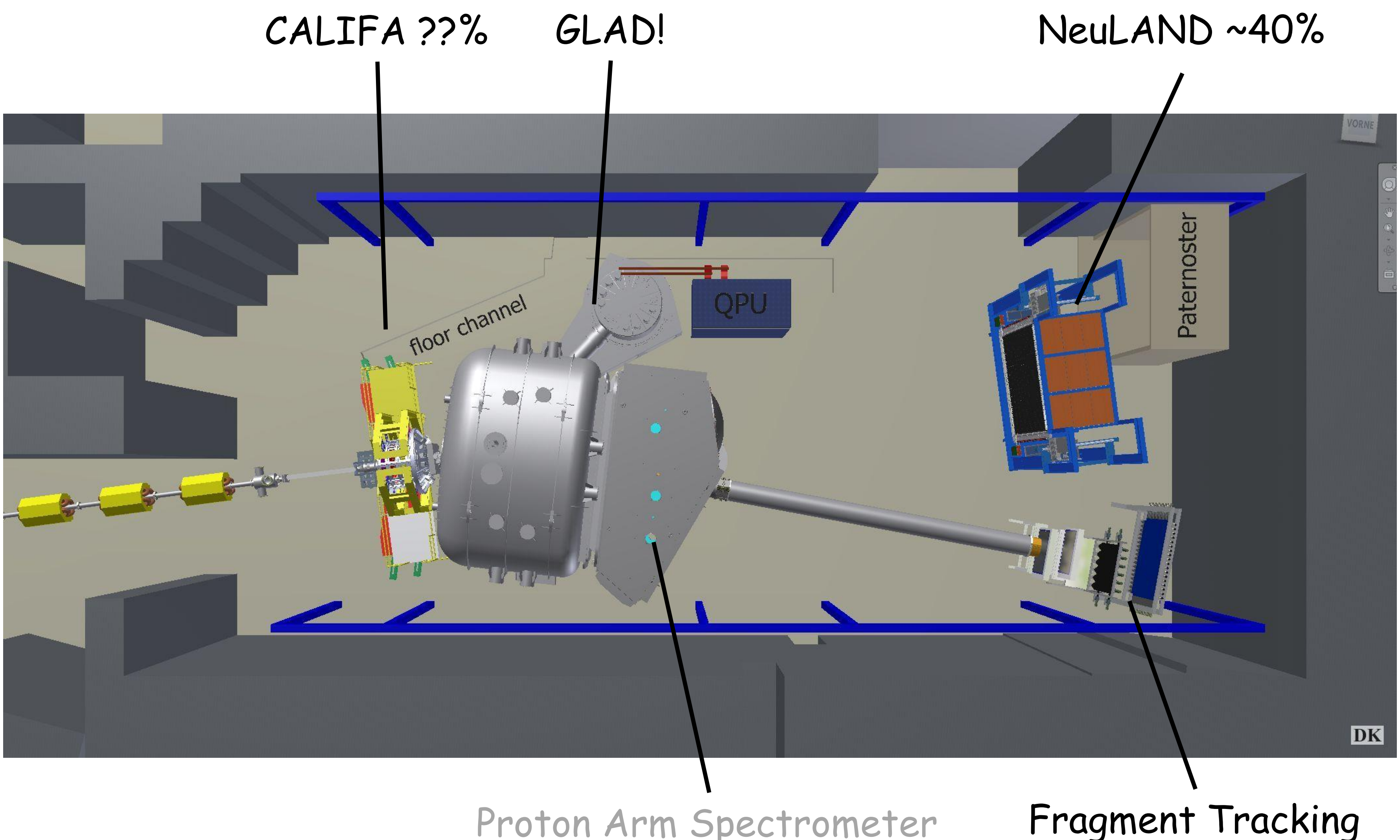
Scheduled Experiments (Nov/Dec 2016):

- Coulomb breakup and knockout reactions to investigate ^{31}Ne
- Removal reactions to investigate structure around N=16 shell closure
- Lifetime measurement of the ^{26}O ground-state (C. Caesar)

Approved Experiments:

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

2018 – R³B in Cave C



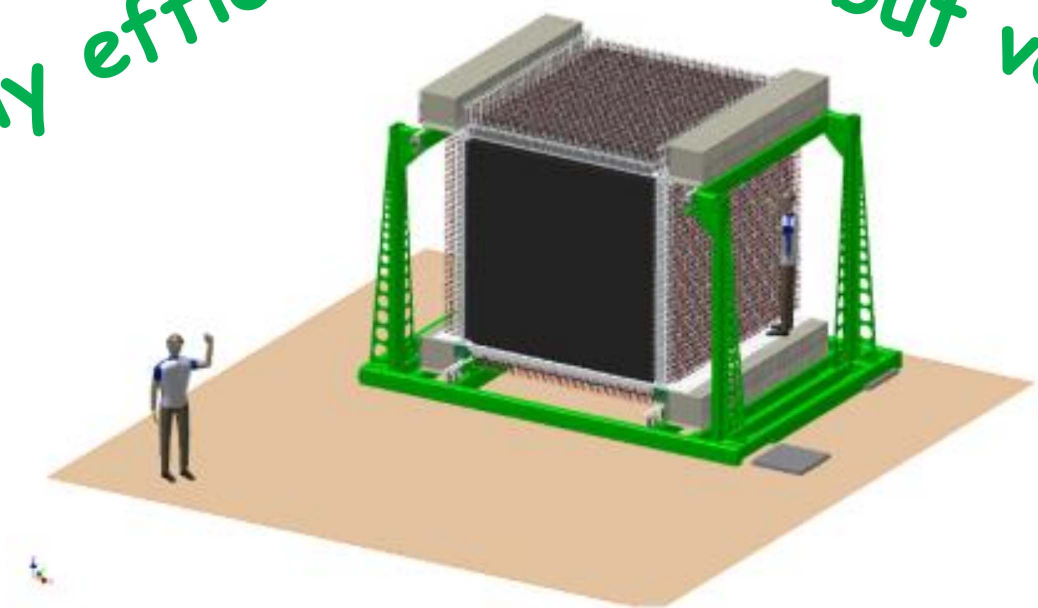
Physics Programm for R³B in Cave C 2018ff

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 ;-)