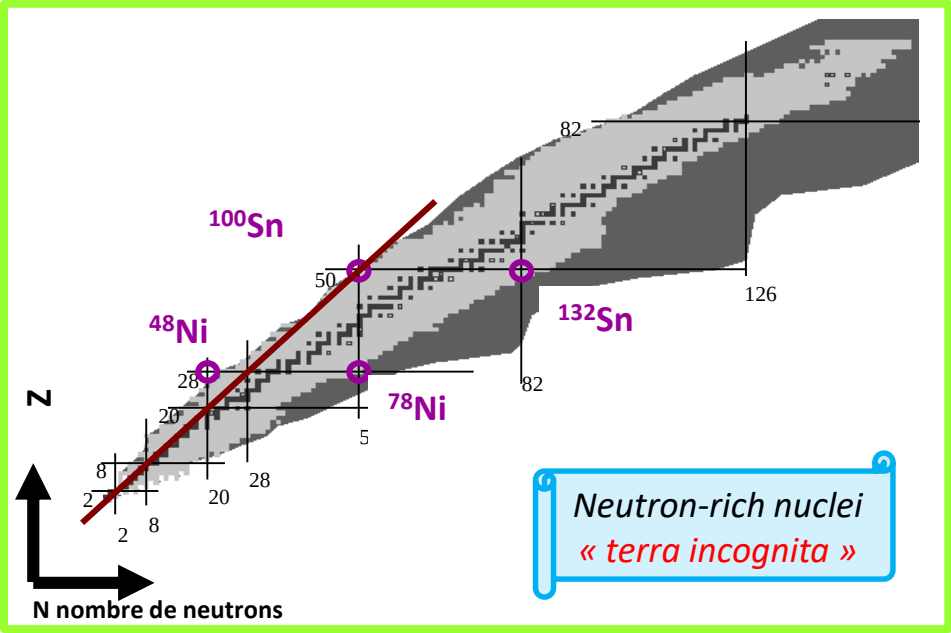
Direct Structure observables from electron –radioactive ion collisions at GANIL

Main long-standing questions of the nuclear physics – cf NuPECC 2017 Long Range Plans

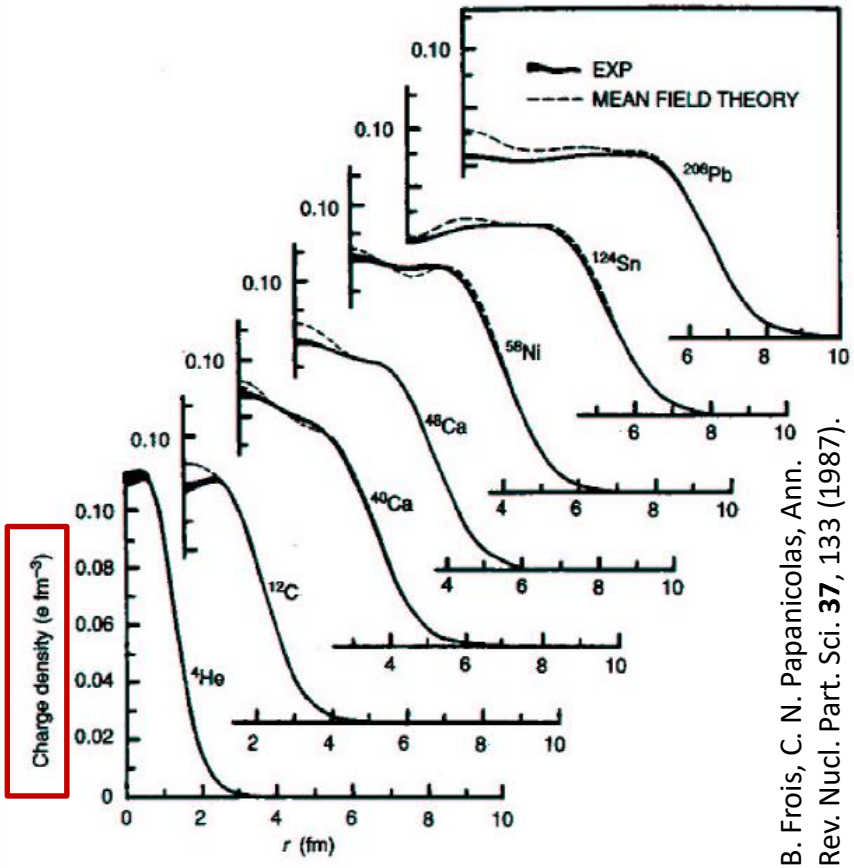
How can we improve our knowledge on nuclear interactions ?

How to understand and to model the structure of the nucleus?
Shell structure evolution? Nuclear sizes and densities?
What are the (effective) interactions between nucleons inside the nucleus?

Building blocks of our knowledge on nuclei → charge distributions



Neutron-rich nuclei « terra incognita »



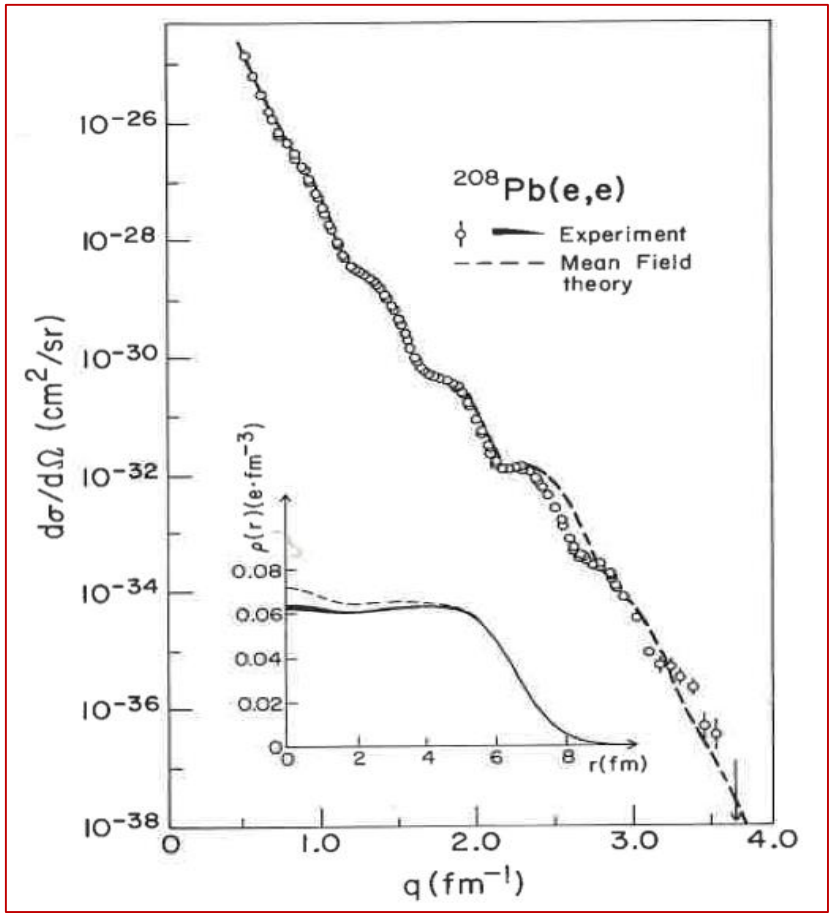
B. Frois, C. N. Papanicolas, Ann. Rev. Nucl. Part. Sci. **37**, 133 (1987).

*Direct comparison between experiment and theory on **observables** : nuclear densities → e- RIB measurements in the 2030s*

GOAL: Proton densities for RIB via (e,e) measurements

From (e,e) form factors →ρ_{ch}, ρ_p

Goals for Nuclear matter densities: charge density profiles for RI as done for stable nuclei



B. Frois, C. N. Papanicolas,
Ann. Rev. Nucl. Part. Sci. **37**, 133 (1987).

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{Mott}} |F(q)|^2$$

$$F(\vec{q}) = \int d^3r \rho_{ch}(\vec{r}) e^{i\vec{q}\vec{r}}$$

Extraction of densities
(e,e) scattering observables←→ nuclear density fit
I. Assuming various density shapes,
with parameters fitted on (e,e) data
II. Parameterization from theory
III. Model-independent (FB expansion,…)
functions for the nuclear densities

Tables encoding the knowledge on nuclear densities since the 50^{ies} -Observables

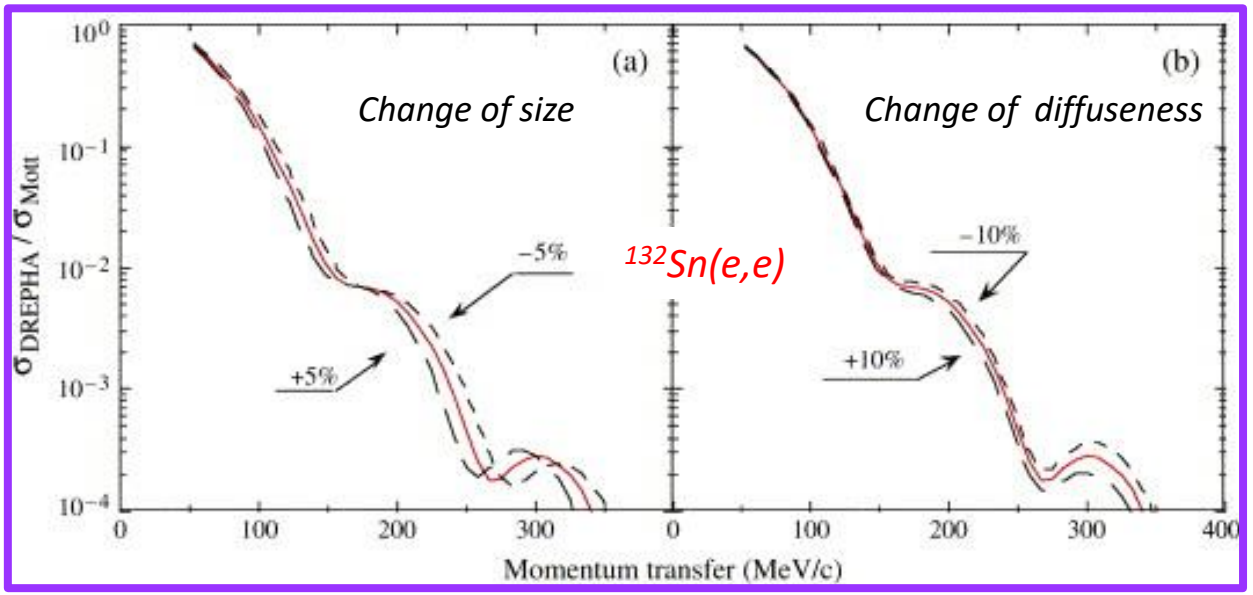
H.De Vries, C. W.De Jager, and C.De Vries,
At. Data Nucl. Data Tables 36 (1987) 495-536
Nuclear charge density distribution parameters from electron elastic scattering

(e,e) scattering measurements ; sensitivity to the shape of the density

NuPECC
www.nupecc.org
Long Range Plan 2017
"*Perspectives in Nuclear Physics*" ; *2016 Subgroup Nuclear Structure Question 4*

Observables-Deduced quantity	**Reactions**	**I [s^{-1}] L [$cm^{-2}s^{-1}$]**
r.m.s. matter radii	(p,p) *at small q*	I =10^4 (light)
Matter density with 3 parameters ρ_m	(p,p) *2nd min.*	I = 10^{5-6} (medium-heavy)
r.m.s. charge radii	(e,e) *at small q*	L: 10^{24} (light)
Charge density with 2 parameters ρ_{ch}	(e,e) *First min.*	10^{24-28} (light-heavy)
Charge density with 3 parameters ρ_{ch}	(e,e) *2nd min.*	10^{26-29} (medium-heavy)
Neutron skin density from ρ_m and ρ_{ch}	**(p,p) and (e,e)**	**(p,p) : 10^6/s e: 10^{28} 10^{29}**

Works by Hofstadter et al. (1950s)
Ee ~150 MeV
N_{beam} ~ 1nA (~10^9 /s)
~10^{28} /cm^2/s



T. Suda and M. Wakasugi, PPNP. 55, 417 ('05)

http://esnt.cea.fr/Phocea/Page/index.php?id=58
Electron-radioactive ion collisions: theoretical and experimental challenges 25-27 April 2016

Observables deduced quantities	**Reactions** *(q: momentum transfer)*	**Type of nucleus**	**Intensity I or Luminosity L**
r.m.s. matter radii	**(p,p)** *elastic at small q*	Light to heavy	I : 10^4 10^6 s^{-1}
r.m.s. charge radii	**(e,e)** *elastic at small q*	Light	L: 10^{24} $cm^{-2}s^{-1}$
Charge density distribution with 2 parameters ρ_{ch}	**(e,e)** *First min. in elastic form factor*	Light Medium Heavy	L: 10^{28} 10^{26} $cm^{-2}s^{-1}$ 10^{24}
Charge density distribution with 3 parameters ρ_{ch}	**(e,e)** *2nd min. in elastic form factor*	Medium Heavy	L: 10^{29} $cm^{-2}s^{-1}$ 10^{26}
Energy spectra, width, strength, decays	**(e,e')**	Medium-Heavy	L: $10^{28\text{-}29}$ $cm^{-2}s^{-1}$
Neutron-skin density from ρ_m and ρ_{ch}	**(p,p) and (e,e)** Combined (p,p') and (e,e')		(p,p) I: 10^6 s^{-1}; **(e,e) L : $10^{29\text{-}30}$** (p,p') I:$10^{6\text{-}8}$ s^{-1} ; **(e,e') L ~10^{30}**
Spectral functions, correlations Magnetic form factor → Proton and neutron transition densities *Direct access to neutron-skin*	**(e,e'p)**		$10^{30\text{-}31}$ **(e,e'p) L ~$10^{30\text{-}31}$** $cm^{-2}s^{-1}$

International context of the projects of (e,e) scattering off RI beams

Electron-RI beam facilities

In progress → SCRIT Self-Contained Radioactive Ion Target a RIKEN

L limited to 10^{28} cm^{-2} s^{-1} for 10^7 trapped ions

-> but limited to the range of RI with long lifetime (~1ms)

Feasibility of the SCRIT concept demonstrated in 2018. SCRIT e beam 10^{18} /s ; target-like 10^9 cm^{-2}

Foreseen projects

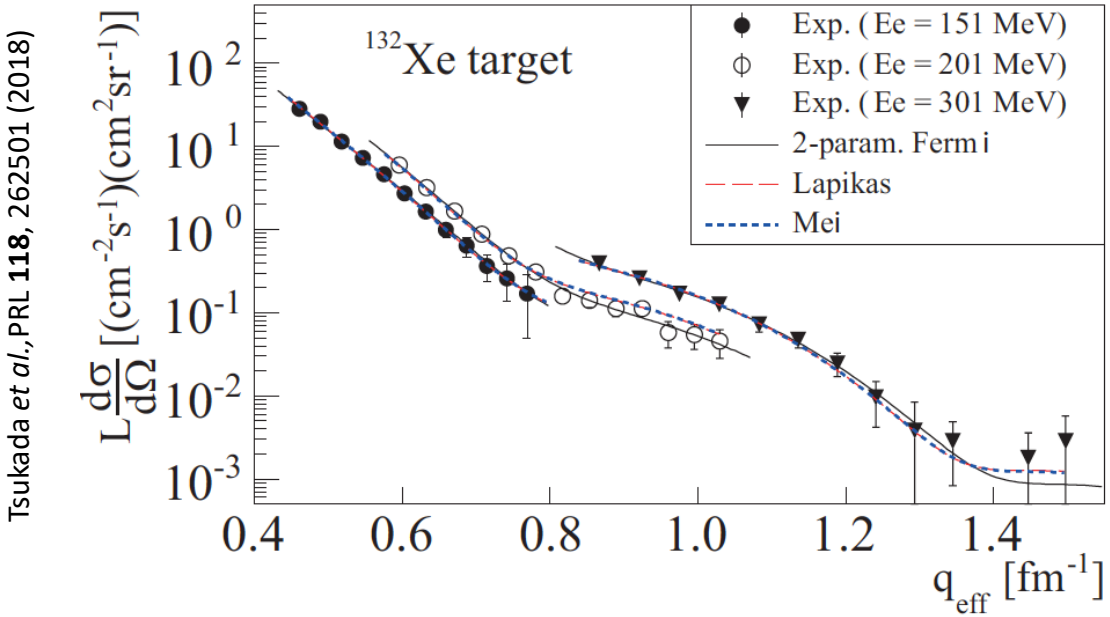
→ ELISe FAIR **10^{28} cm^{-2} s^{-1} ;** e beam 10^{18} /s; *E 125 to 500 MeV e- linac stored in the EAR.* ion ring NESR E~ 0.2 -0.74 GeV/ n. *Postponed*

→ DERICA Dubna **10^{28} cm^{-2} s^{-1}** ; *Ee 500 MeV e- linac ; Erib 300 A.MeV*

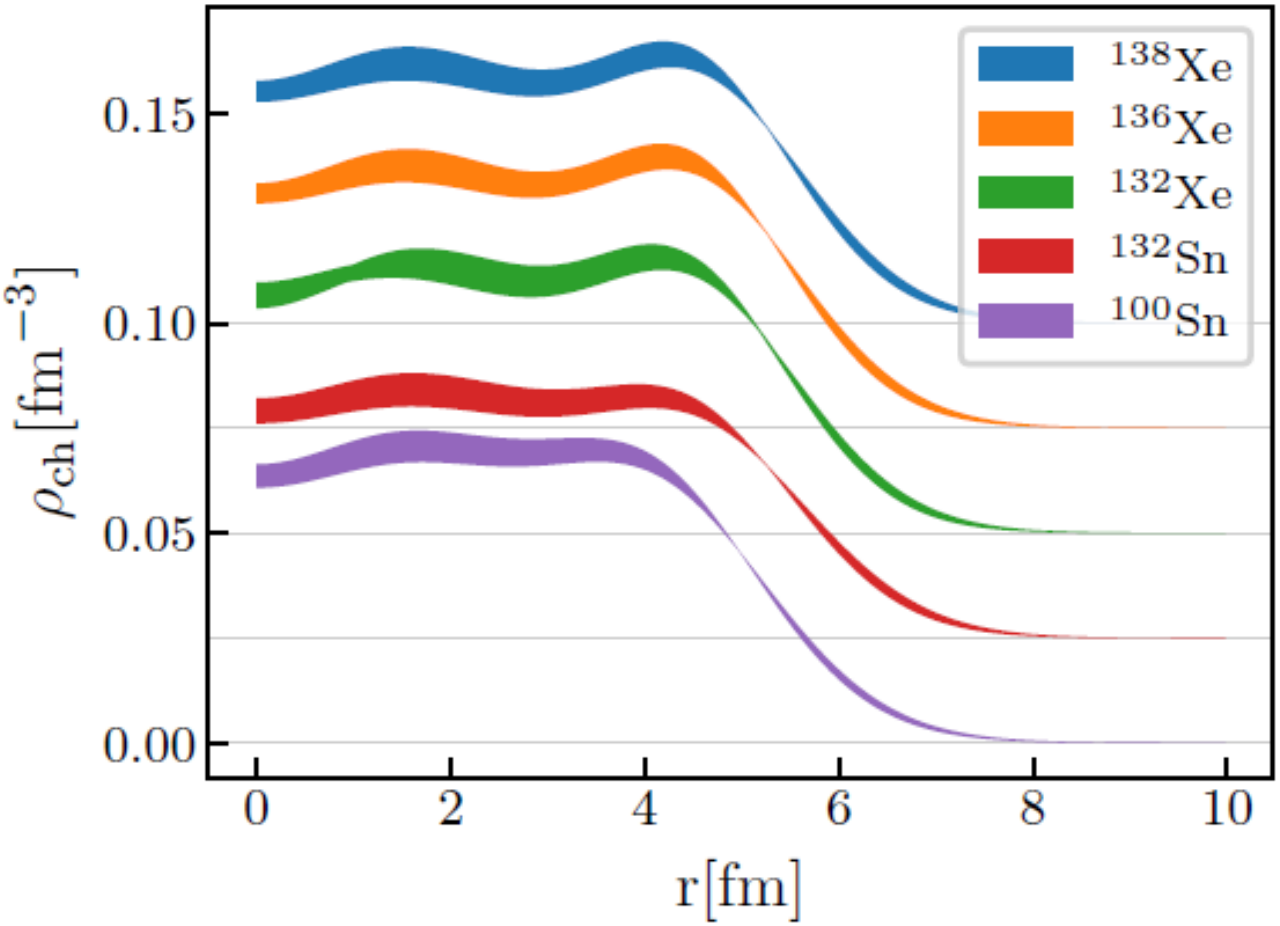
→ *Not considered in the first stage of the Dubna project*

EIC etc…JLAB (L 10^{36} ; e beam 10^{15} /s ; target-like 10^{21} cm^{-2})

→ *ERL*



Ab initio computation of charge densities for Sn and Xe isotopes
P. Arthuis, C. Barbieri, M. Vorabbi, P. Finelli
https://arxiv.org/pdf/2002.02214v2.pdf

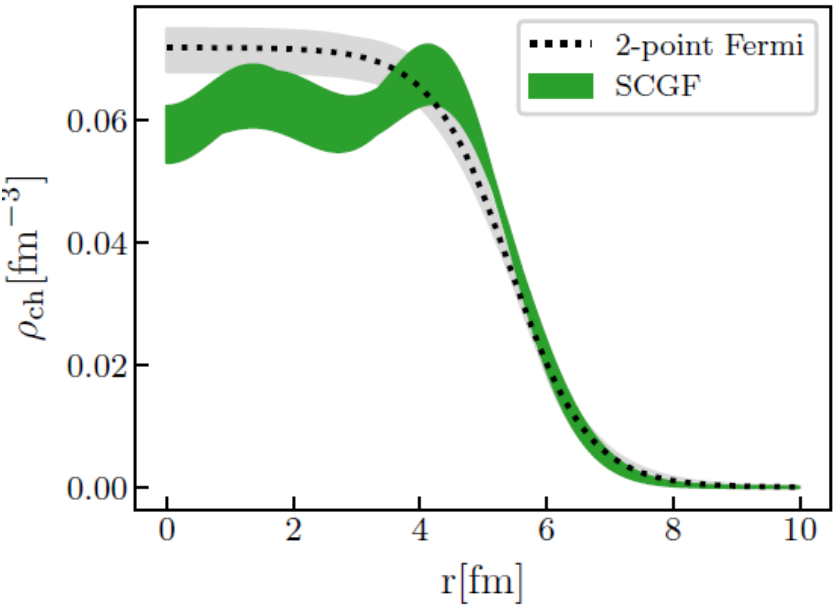


("coloured bands for the theoretical error associated with model space convergence")

Charge densities from (e,e) –experiment and ab initio calculations

Ab initio computation of charge densities for Sn and Xe isotopes
P. Arthuis, C. Barbieri, M. Vorabbi, P. Finelli
https://arxiv.org/pdf/2002.02214v2.pdf

SCRIT data in K. Tsukada et al.,
PRL 118, 262501 (2017)



Arxiv Calc Gorkov SCGF calculations at ADC(2).
2pF with parameters in PRL 118 (2017)