Short-Range Correlations probed by electrons and protons

A.Corsi, CEA Saclay

ECT* workshop
"Probing exotic structure of short-lived nuclei by electron scattering"
July 16-20, 2018

Outline

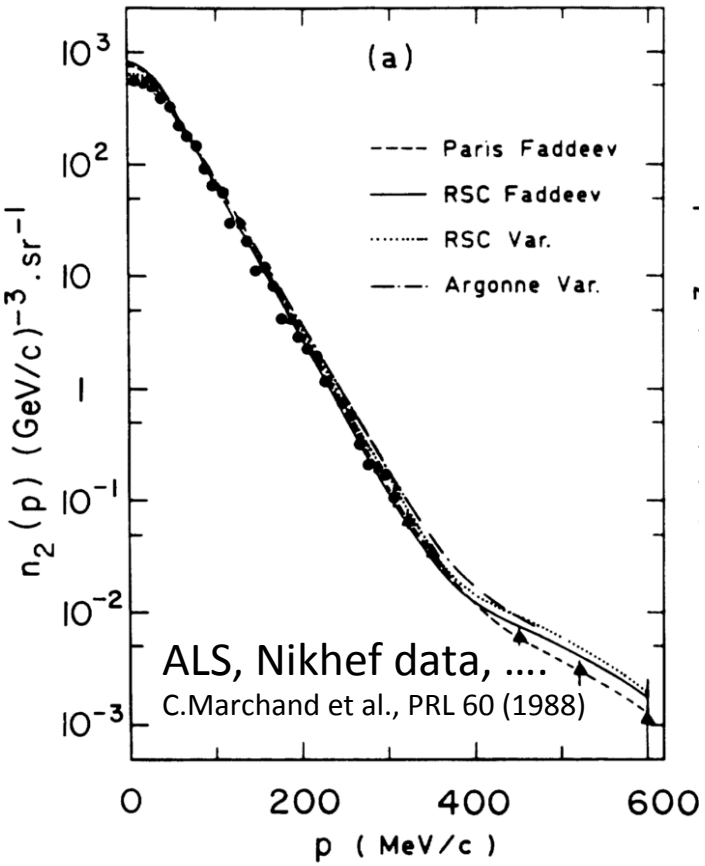
Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

- State of the art on Short-Range Correlations
- Study of Short-Range Correlations in exotic nuclei with proton probes
- Prospectives with electron probes

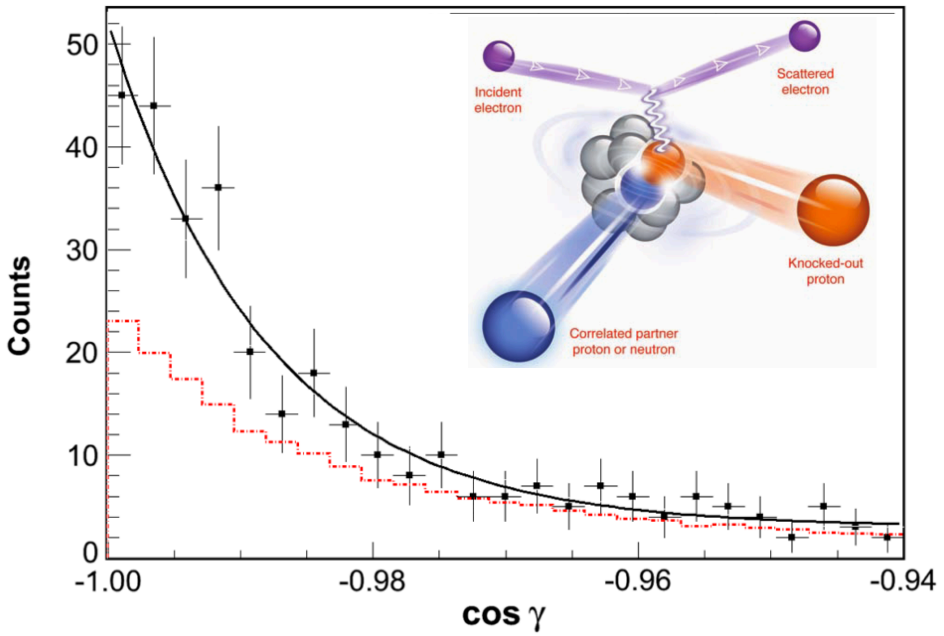
Thanks to: A.Chance (CEA), O. Hen (MIT), A.Obertelli (TUDa), J.Payet, V.Somà (CEA)

History of Short-Range Correlations (SRC) studies

High-momentum components in (e,e)



Back to back NN emission in (e,e'NN)



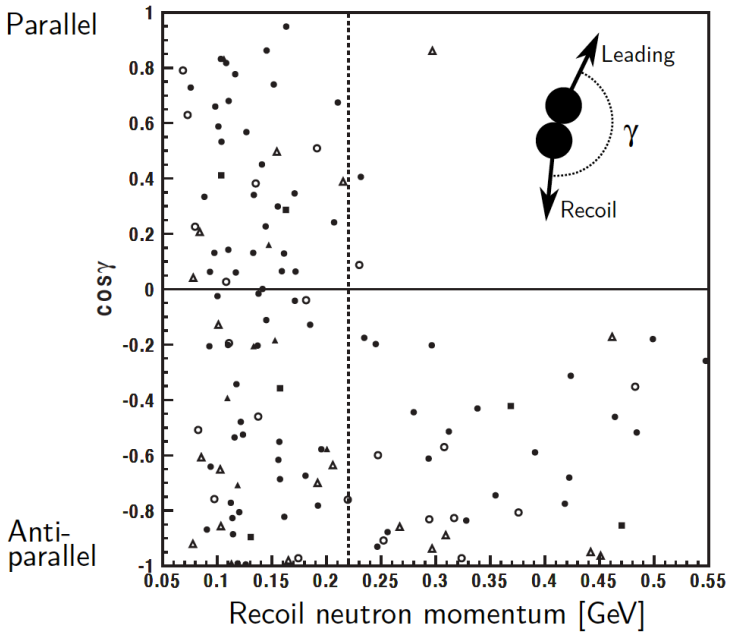
BNL and JLab data

E. Piasetzky *et al.,* PRL **97** (2006); R. Subedi *et al.*, Science **320** (2008); O. Hen *et al.,*, Science **346** (2014); I.Korover *et al.*, PRL **113** (2014)

Interpreted as due to the short interparticle part of the nuclear wave function (SRC)

History of Short-Range Correlations (SRC) studies

(p,p'NN)



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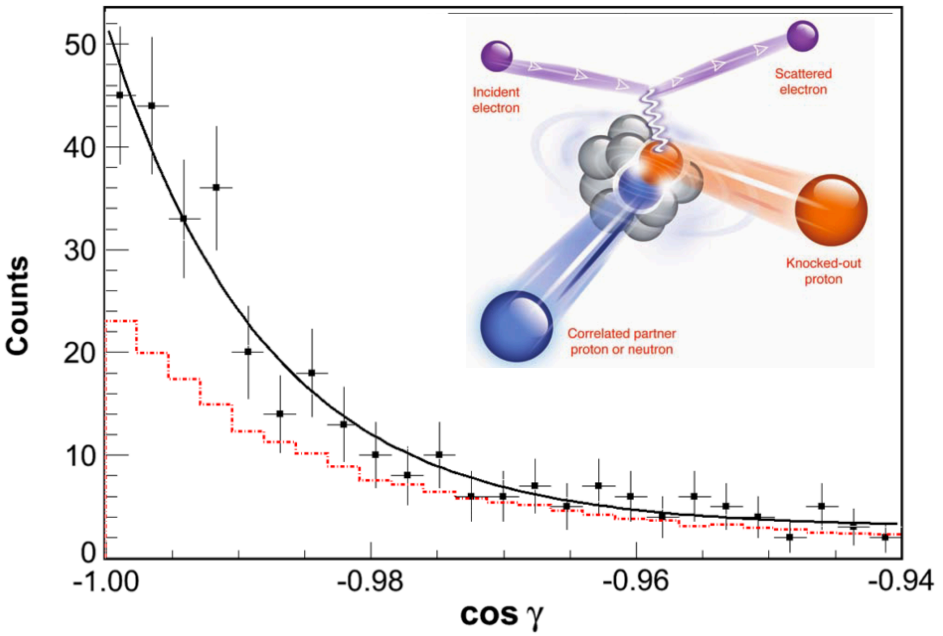
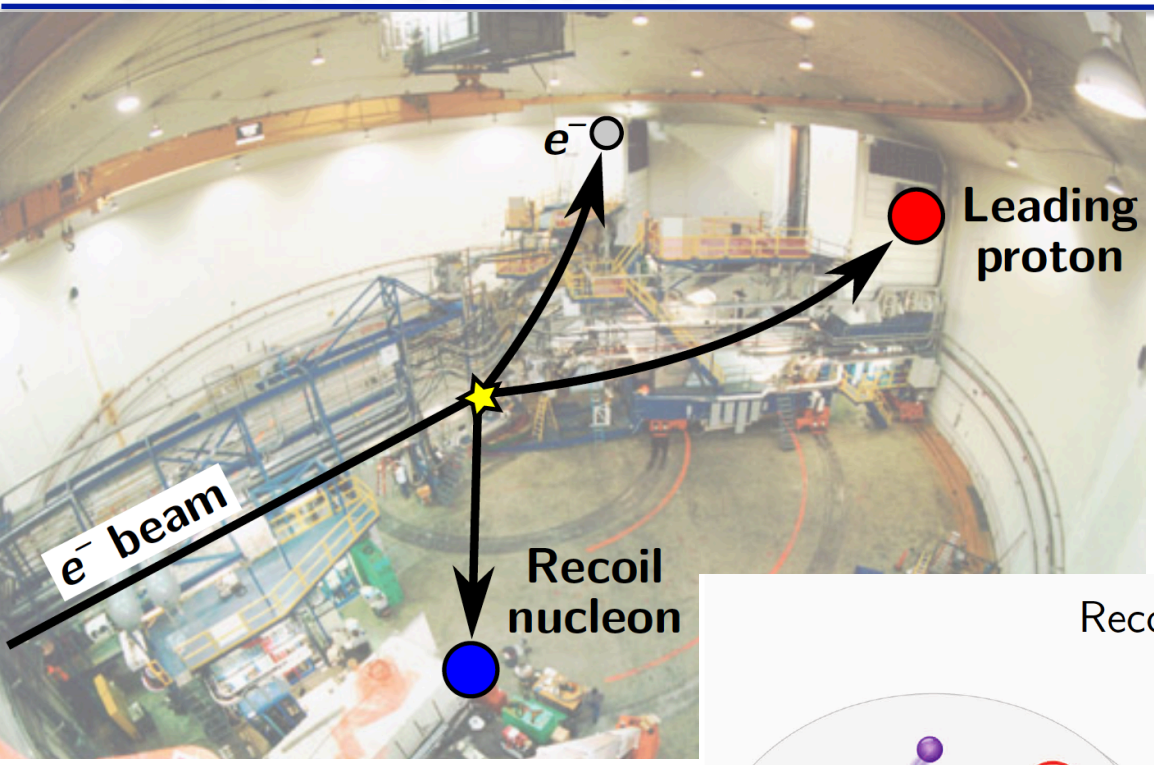


JLab data

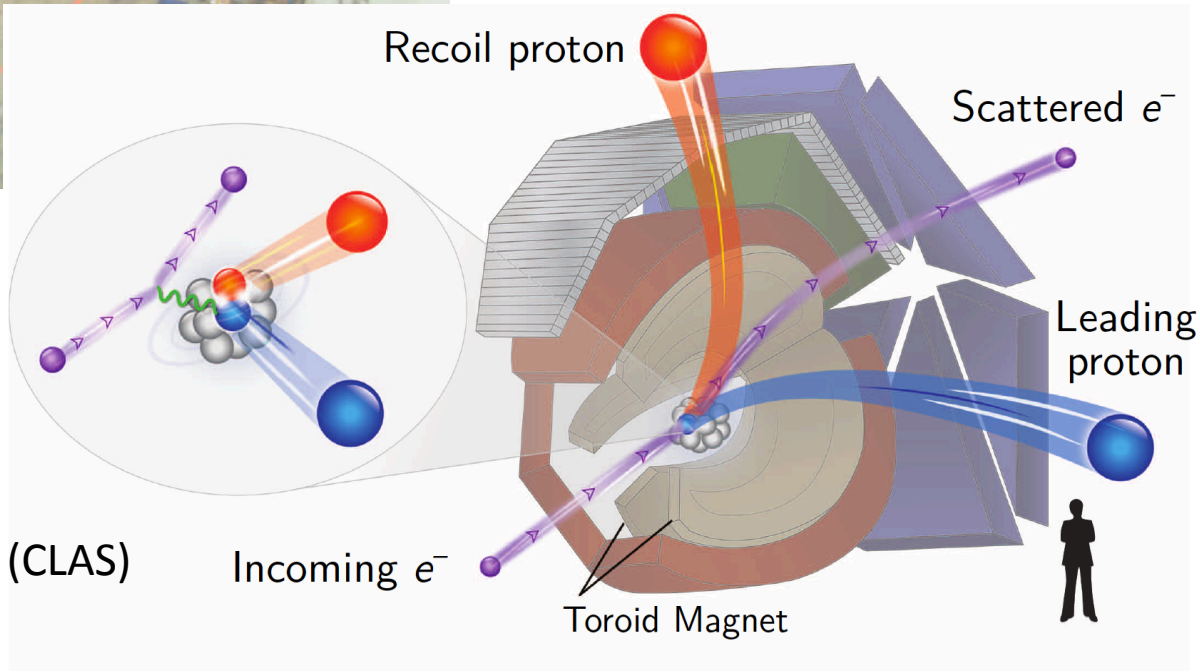
O. Hen *et al.,*, Science **346** (2014); I.Korover *et al.*, PRL **113** (2014)

Consistent results with protons and electrons

SRC studies at JLab



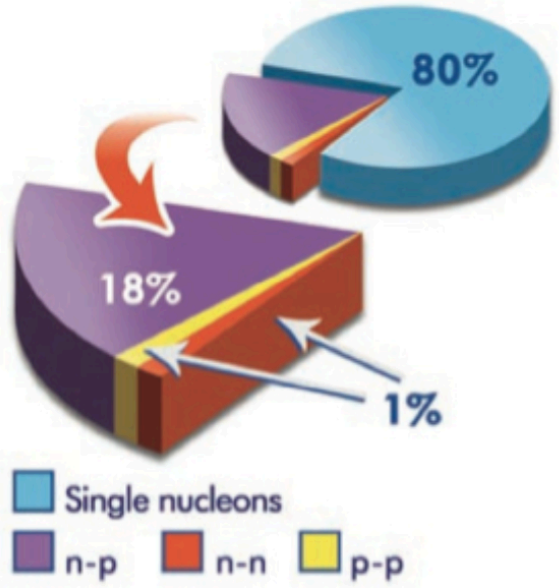
JLab Hall A
High resolution spectrometer

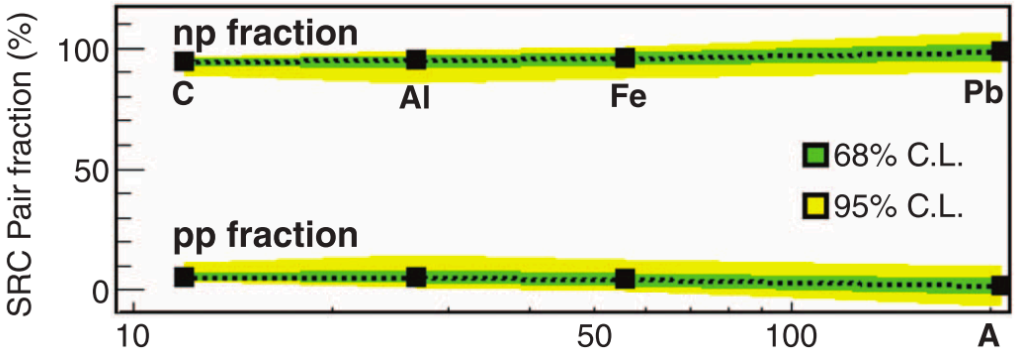


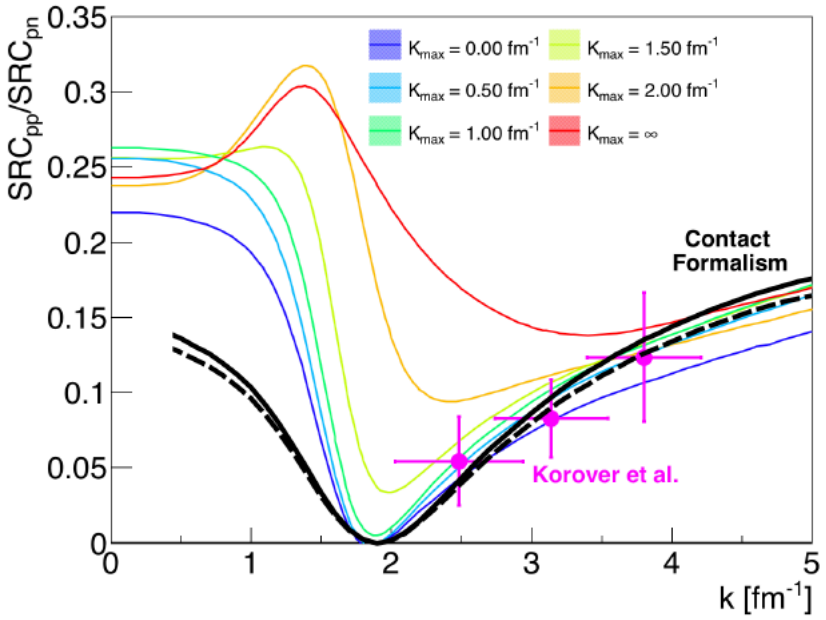
JLab Hall B
High acceptance spectrometer (CLAS)

What is known on Short-Range Correlations

- Concern 20% of nucleons
- Out of them, 18% are pn pairs
- The pn-pairs fraction
  - ✓ does not vary with A (<-> N/Z)
  - ✓ varies with missing momentum







R. Subedi *et al.*, Science **320** (2008)
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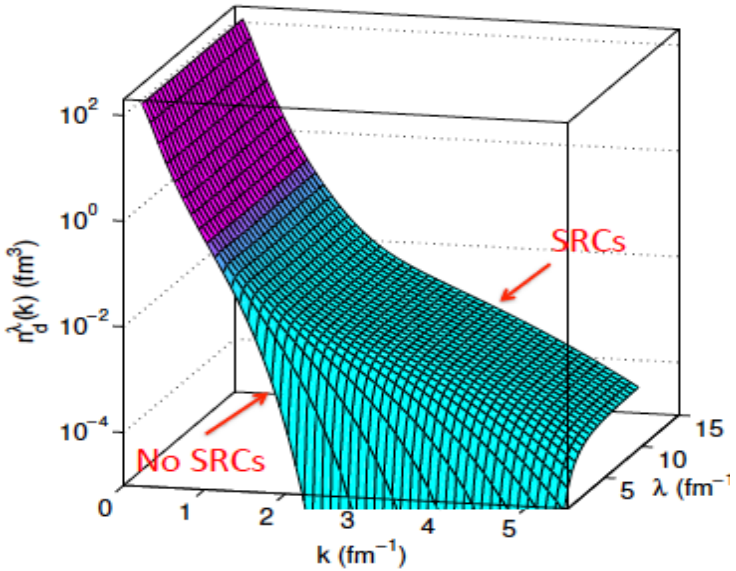
R. Weiss et al., PLB 780 (2018) 21

On the non observability of SRC

- Momentum distribution, two-body density, NN potentials are non-observable quantities



R.J. Furnstahl, arXiv:1309.5771v1(2013)

kinematics	before	after
high $\mathbf{q}^2$, low E' at $\lambda = \infty$	q, k_p, k_n	k_n, k_p
high $\mathbf{q}^2$, low E' at small λ	q, two-body, k_p, k_n	k_n, k_p

S. N. More et al., PRC 96, 054004 (2017);

- Different approaches to calculate many body wave function:
  - Green Functions — A.Rios et al., PRC 89 (2014)
  - Monte Carlo — R.Schiavilla et al., PRL 98 (2007); Chen et al., PRL 119, 262502 (2017)
  - Contact formalism — R. Weiss et al., PRL 114 (2015) 012501; PRC 92 (2015) 054311; PLB 780 (2018) 21; arXiv:1806.10217v1

- Cross sections are observable, but theoretical calculations available only for deuteron
  S. N. More et al., PRC 92 (2015) 064002 and PRC 96, 054004 (2017)

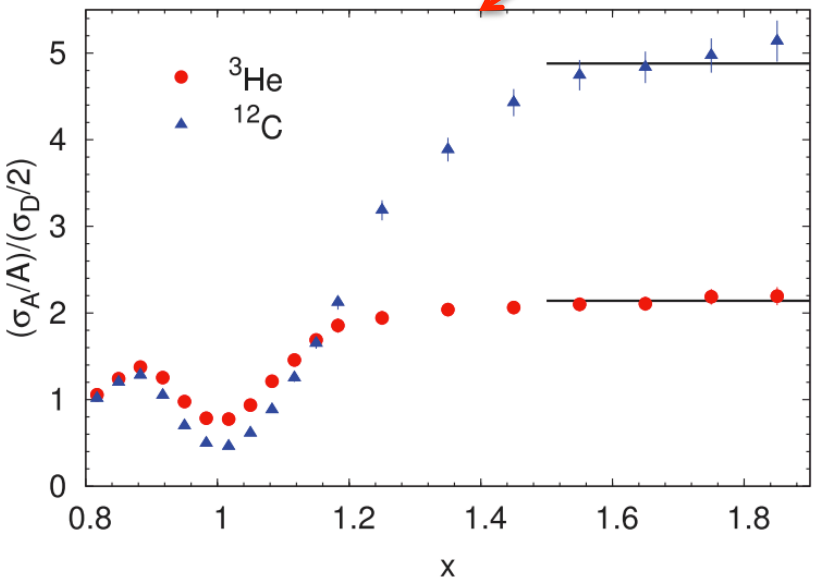
How to interpret observables

SCALE AND SCHEME INDEPENDENT

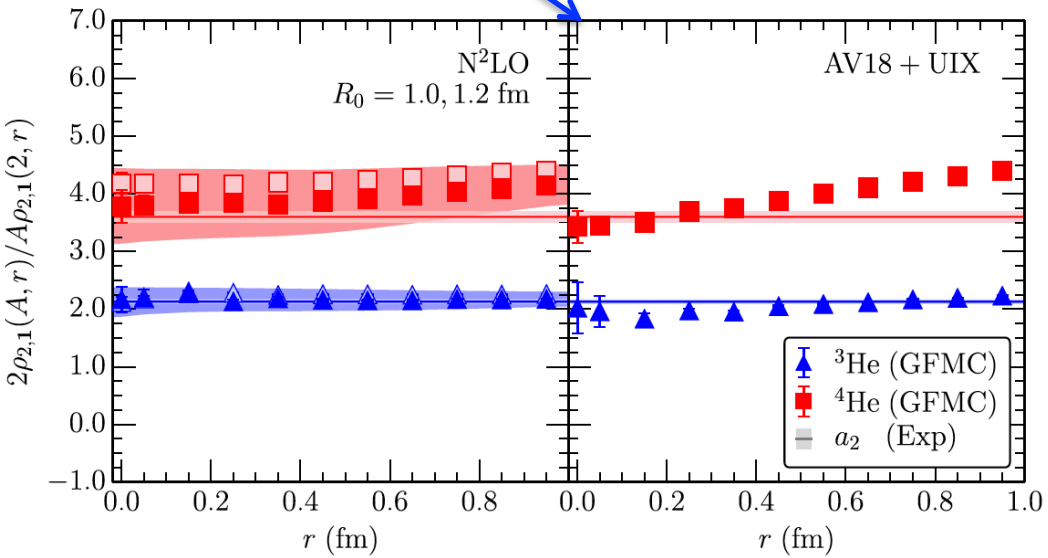
RATIO OF OBSERVABLES

RATIO OF NON-OBSERVABLES

$$a_2(A,x) \equiv \left.\frac{2\sigma_A}{A\sigma_d}\right|_{1.5<x<2} = \lim_{r\to 0}\frac{2\,\rho_{2,1}(A,r)}{A\,\rho_{2,1}(2,r)}$$



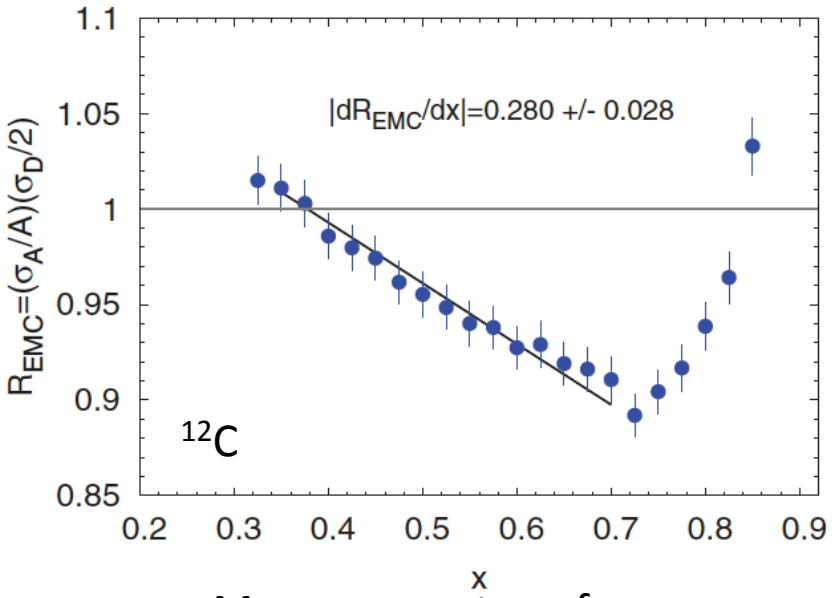
Arrington et al., PRC 86, 065204 (2012)



Chen et al., PRL 119, 262502 (2017)

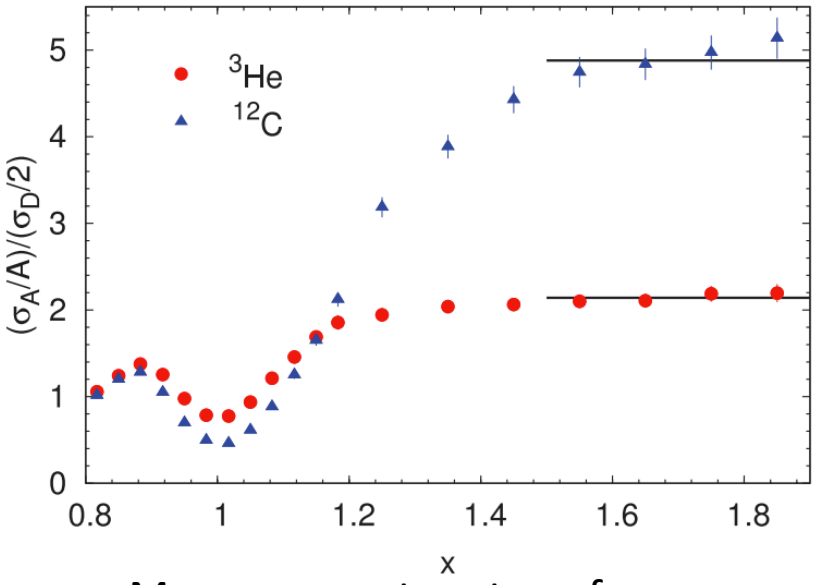
Probing the nuclei at different kinematics

Deep Inelastic Scattering



More energy transfer

Quasi Free Scattering



More momentum transfer

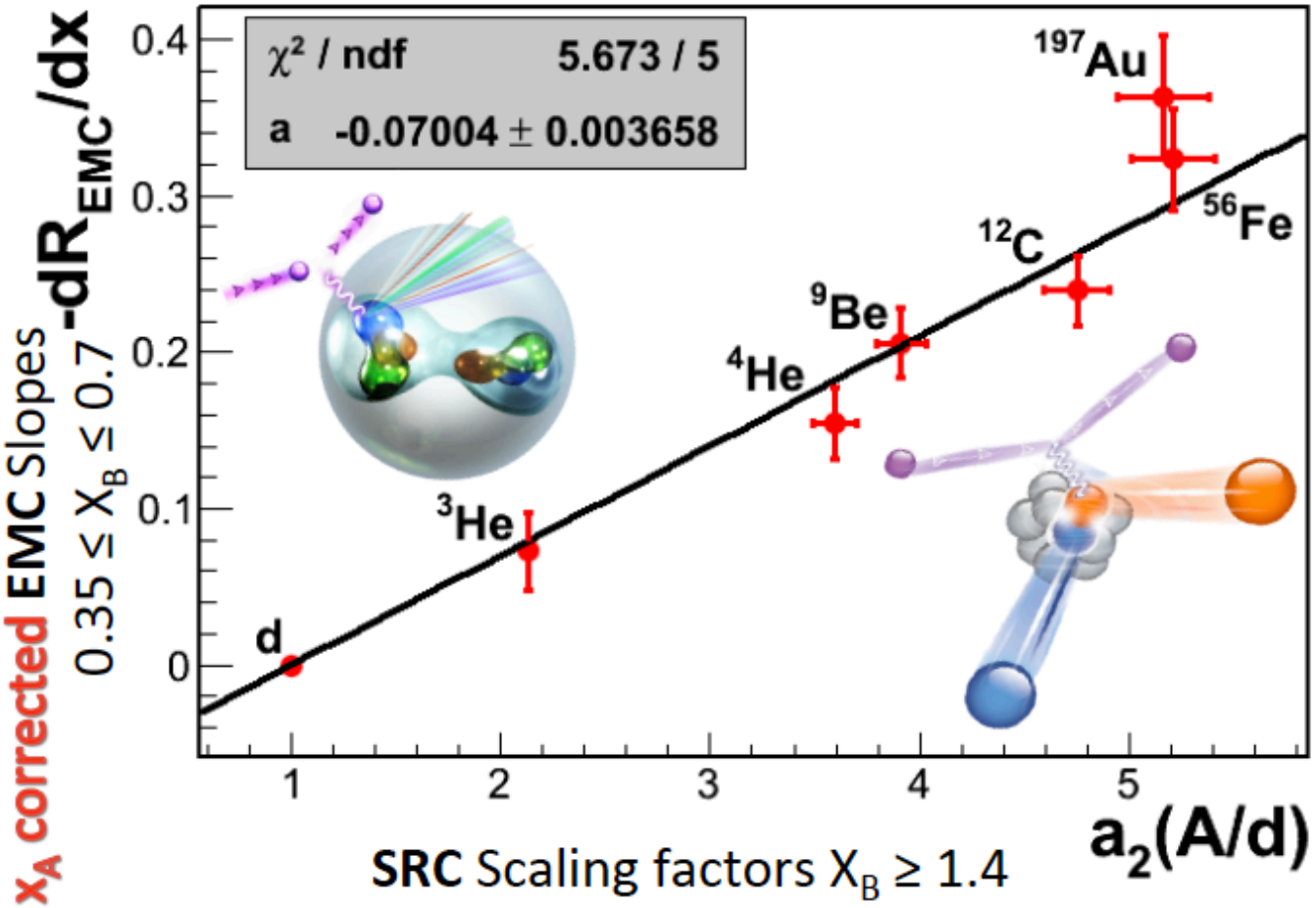
European Muon Collaboration (EMC) effect

- Reduction of DIS cross section on nucleus with A>2 wrt deuterium
- No agreement on the explanation (nuclear structure effect, modification of bound nucleons,…)

J. Aubert et al., Phys. Lett. B 123, 275 (1983)
Arrington et al., PRC 86, 065204 (2012)
Weinstein et al., PRL 106, 052301 (2011)

SRC and EMC effect

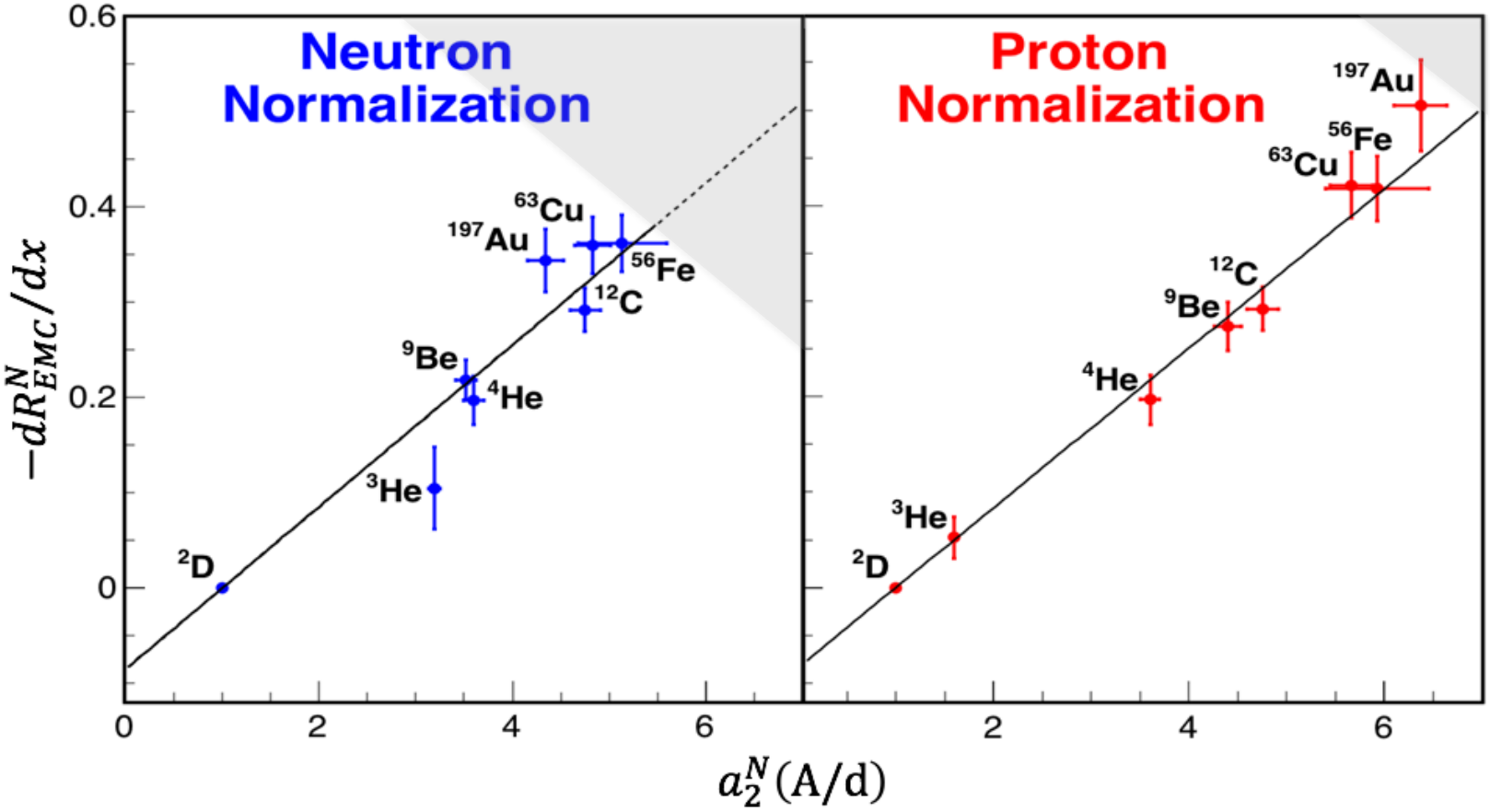
- Striking **linear correlation between EMC and SRC**
- Modifications of the quark distribution occuring in nucleons affected by SRC?



L.B. Weinstein *et al.*, PRL **106**, 052301 (2011)

SRC and EMC effect

- Striking linear correlation between EMC and SRC
- Modifications of the quark distribution occuring in nucleons affected by SRC?
- **Isospin dependence** of the EMC effect



Schmookler et al., arXiv:1711.00960v1 (2017)

SRC in exotic nuclei

First study of short- range correlations in **exotic nuclei (N/Z >> 1)**

Why?

- a_2(proton) ≠ a_2(neutron) => different behavior of protons and neutrons
- implications for nuclear structure&reactions, neutron matter

How? Proton target, inverse kinematics.

- higher detection efficiency, therefore statistics
- detection of A-2 recoil
- direct measurement of CM momentum of the pair
- no « hardware identification » of SRC events

Related programs:

✓ inverse kinematics with protons and ^{12}Ca beam at 4 GeV/u/c at Dubna (2018)
O.Hen, T.Aumann, M.Kapishin, E.Piasetzky

❑ direct kinematics with proton beam at 3-4.5 GeV at HADES/GSI (> 2018)
O.Hen et al.

❑ inverse kinematics with protons at R3B/GSI (> 2019)
A.Corsi et al.

❑ inverse kinematics at HESR
T.Aumann et al.

❑ with electron beams and exotic nuclei?

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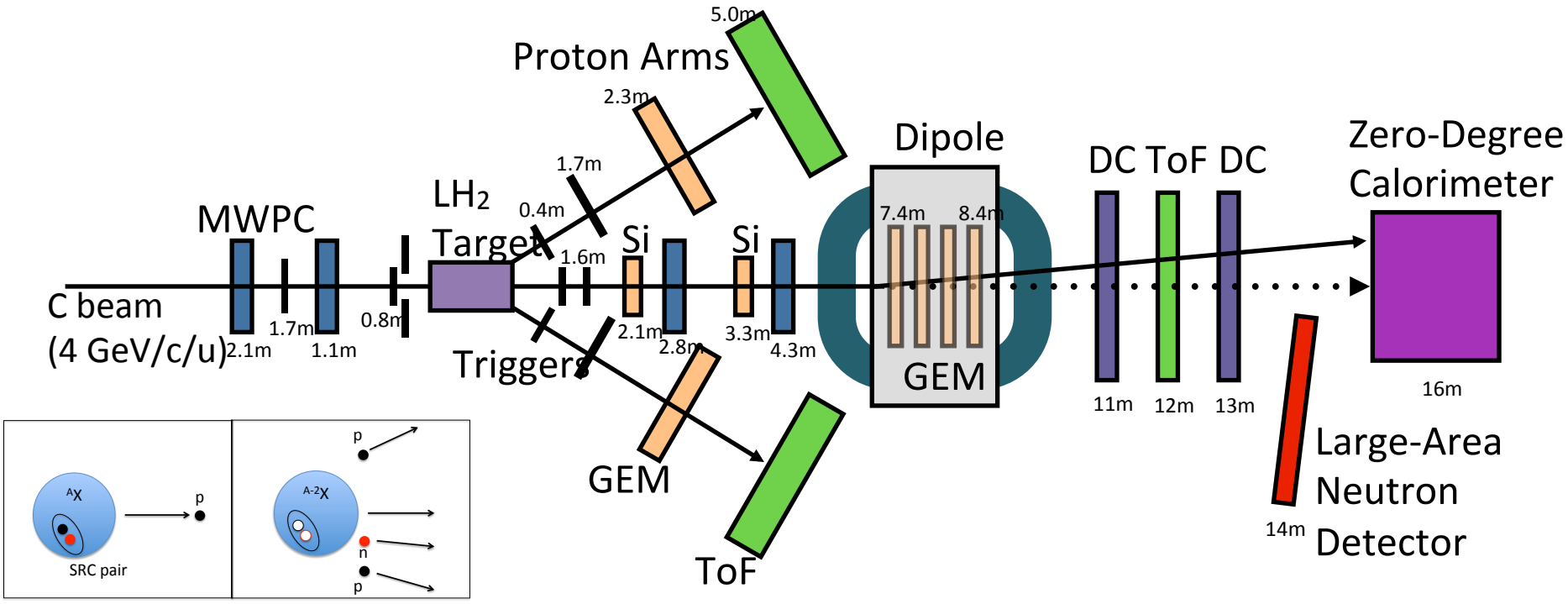
SRC in inverse kinematics at Nuclotron, Dubna



- MIT, Tel-Aviv, GSI, TUDa, Dubna, CEA collaboration
- ^{12}C+proton in inverse kinematics
- 1st data taking March 2018, more from 2020
- Data analysis ongoing….

❖ Proton vs electron as a probe?
❖ Impact of inverse kinematics on the measurement?
❖ First direct measurement of A-2

SRC in inverse kinematics at R3B, GSI

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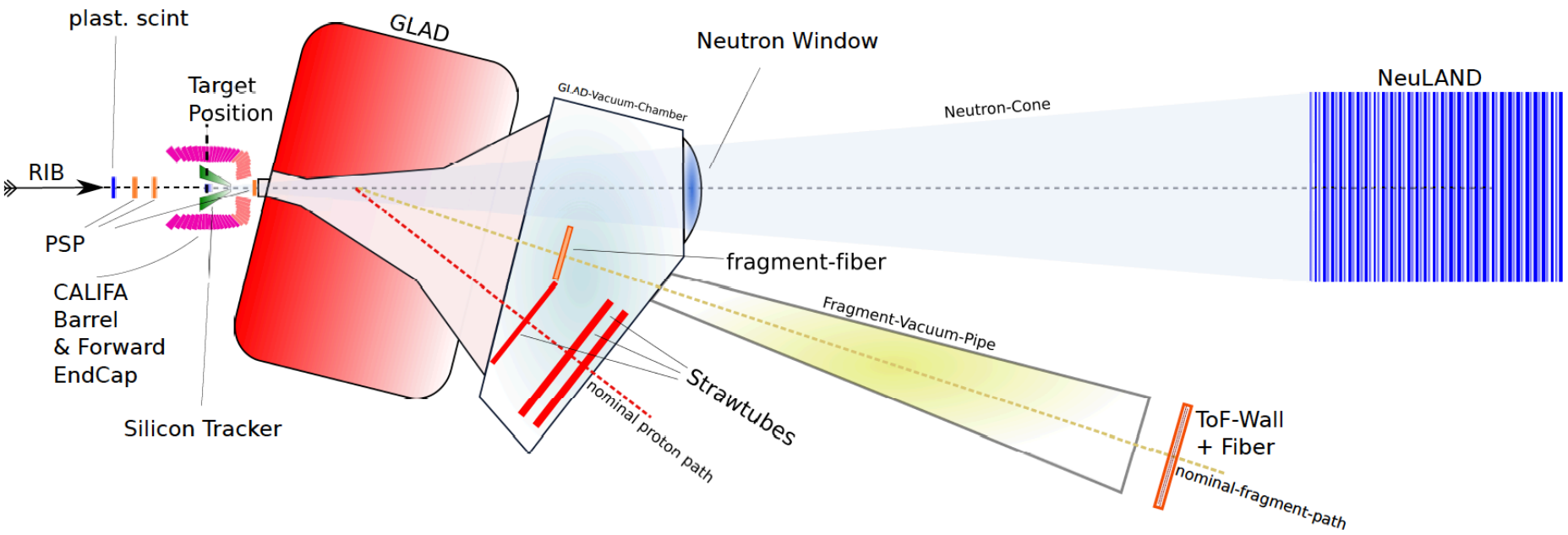
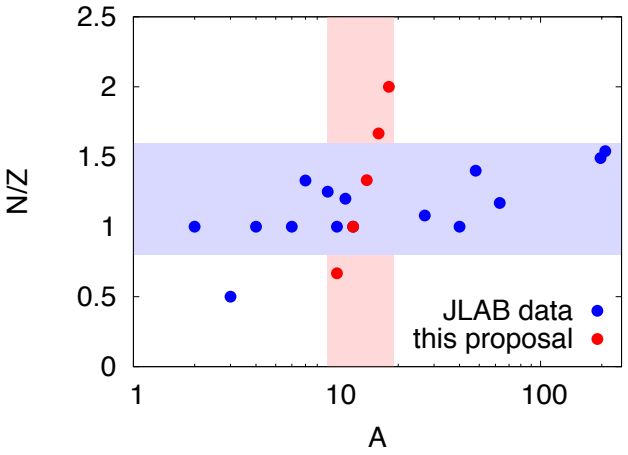
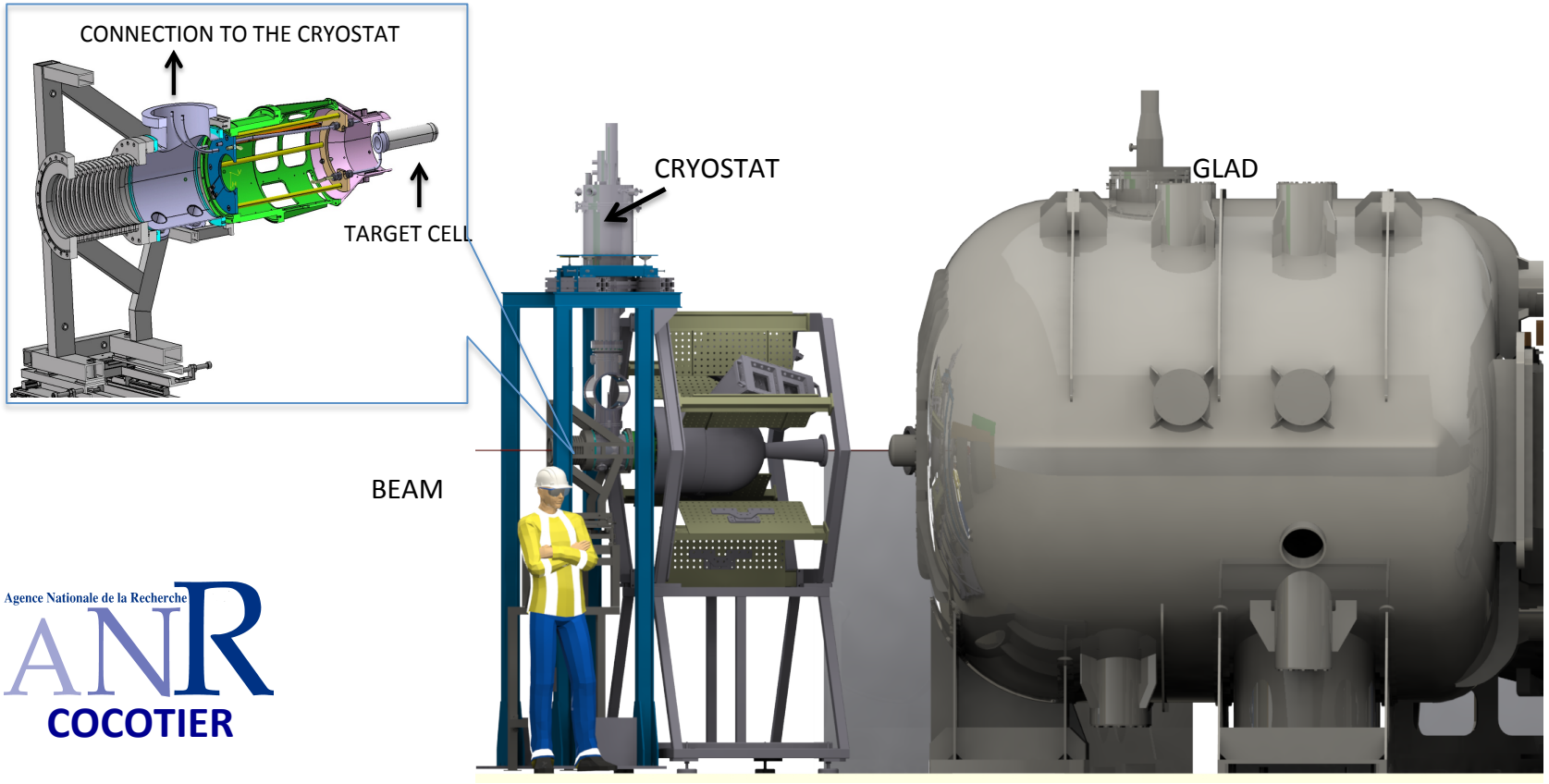


- CEA, GSI, TUDa (…) collaboration
- 1-1.5 GeV/u beams from GSI accelerator, 15 cm LH_2 target
- Kinematically complete measurement with R^3B+LH_2 target
- 1st experiment (to be proposed): $^{10\text{-}18}C$ (^{12}C benchmark)
- Next: light isotopes accessible by ab initio methods (^{x}He)?



LH_2 target for R3B

- LH_2 target under construction at CEA Saclay
- Different target cells size from 1.5 to 15 cm
- Available from June 2019 for QFS experiments at R^3B



Agence Nationale de la Recherche
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A european SCRIT?

2015 context

- Call for idea for the future of GANIL (GANIL 2015)
- Delay of ELISe@FAIR
- Kyoto prototype confirm the feasibility of the SCRIT concept

Working group on **ETIC** (Electron-Trapped Ion Collider) at CEA/IRFU (A.Chance, A.Corsi, A.Obertelli, J.Payet, V.Somà)
ETIC goal: gain a **factor > 100 in luminosity** w.r.t. SCRIT (**$10^{27\text{-}28}$ $cm^{-2}s^{-1}$)**

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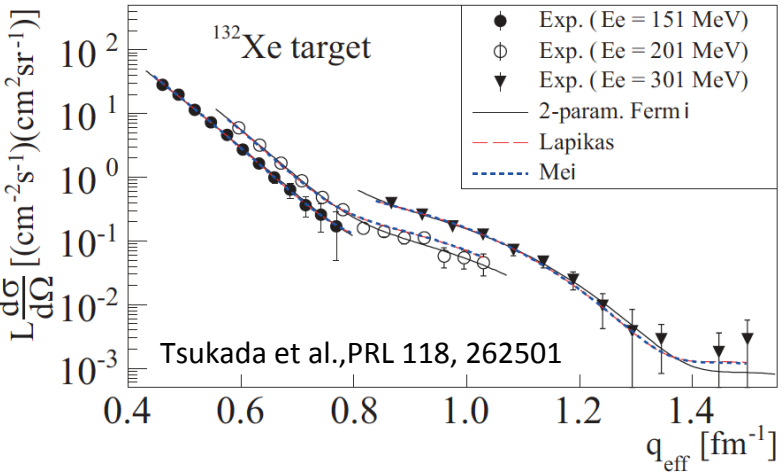
- SCRIT@RIKEN successfully commissioned
- Interest from CEA/CNRS on the ETIC project, but no support. Project frozen.



Facility	Luminosity($s^{-1}cm^{-2}$)	Beam (s^{-1})	Target (cm^{-2})
SCRIT	$10^{27\text{-}28}$	10^{18}	10^{9}
ETIC	10^{30}	10^{18}	10^{9}
ELISe	10^{28}	GAIN FROM KINEMATICS (x 10^{4})	

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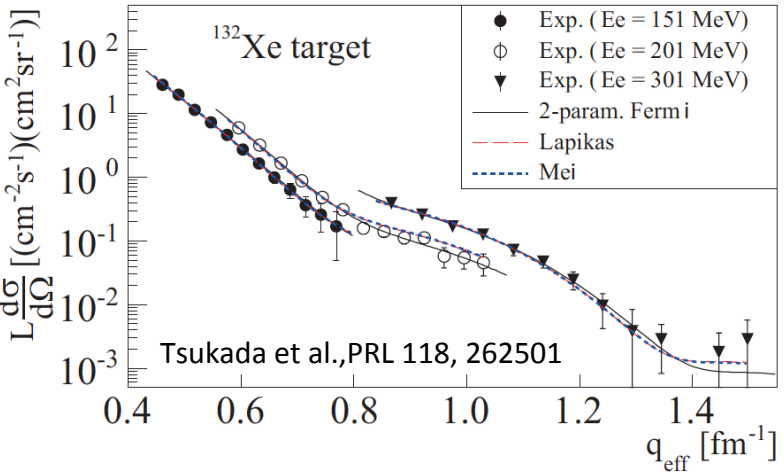

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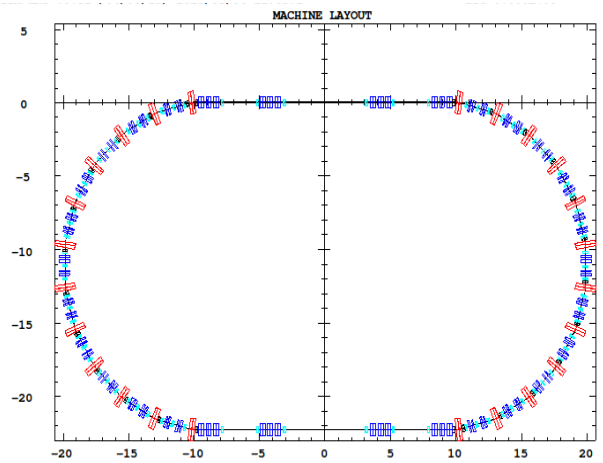
JLab	10^{36}	10^{15}	10^{21}

And more: DERICA, EIC, …

A european SCRIT?

Synchrotron

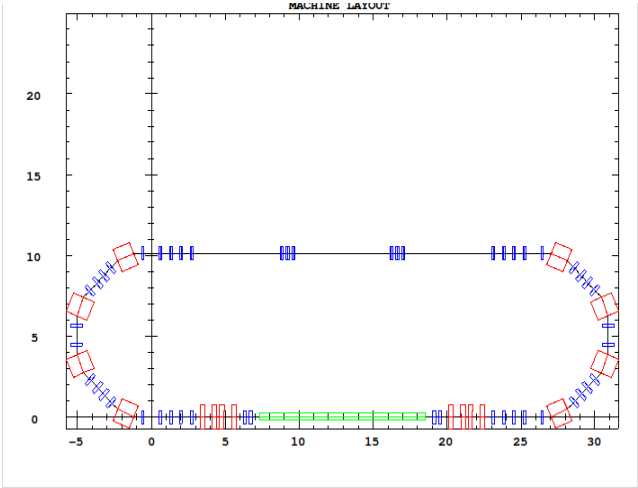


✔ "**Multiple Bend Achromat**" solution

✔ **Low emittance** + weak constraints on optical functions at IP

✔ Relatively well **known technology**

Energy Recover LINAC (ERL)



✔ Advantages of conventional LINACs
+ better ratio intensity / operational costs

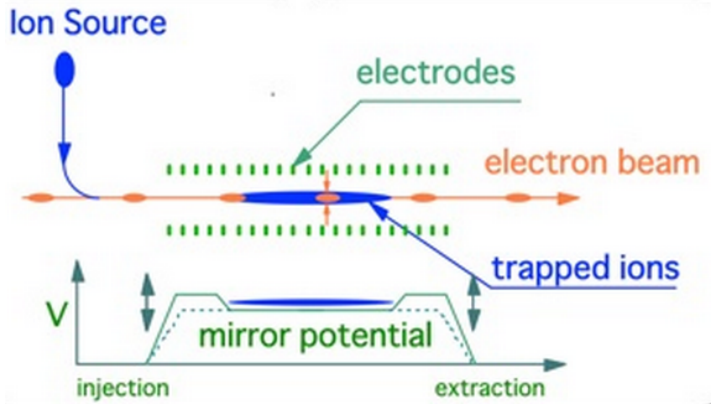
✔ Short bunch length (ps) might lead to attractive applications for a **wider physics community**

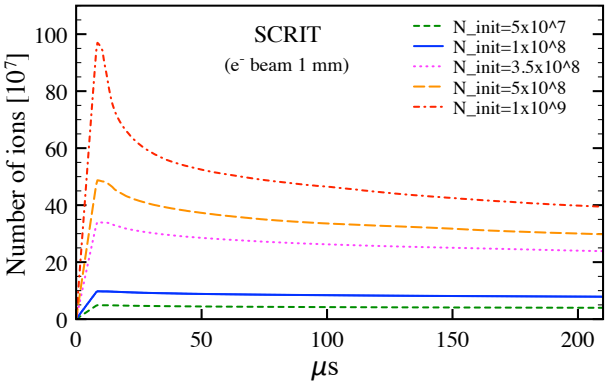
✔ Relatively recent technology

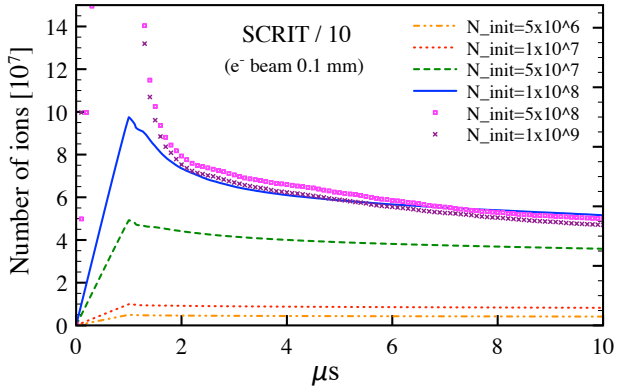
Both solutions **validated for a luminosity of 10^{30} cm^{-2} s^{-1}** for 10^7 trapped ions

A european SCRIT?

- Challenge: can we trap **as many ions as SCRIT in a smaller volume (0.1 mm rms)**?
- Simulations with WARP code [Livermore/Berkeley/MSU] designed for charged particle beams with high space-charge intensity







➔ ~10^7 ions trapped

➔ Gain of a **factor > 100 validated** for the test case of $^{132}Sn^{1+}$

➔ Ongoing simulations for a complete validation of the ETIC trapping system

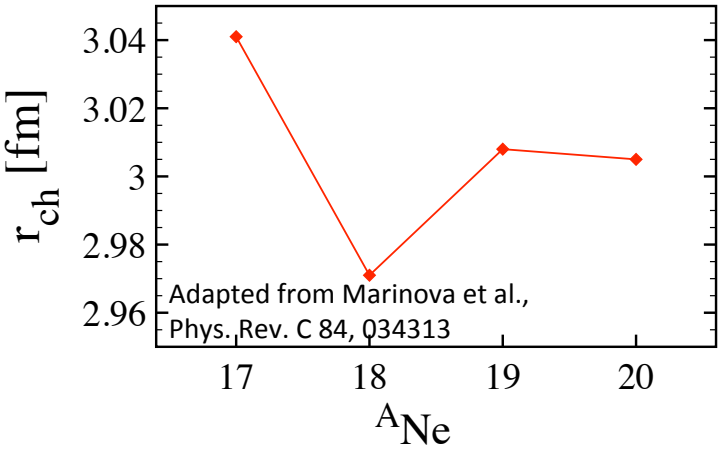
Possible physics program (a selection)

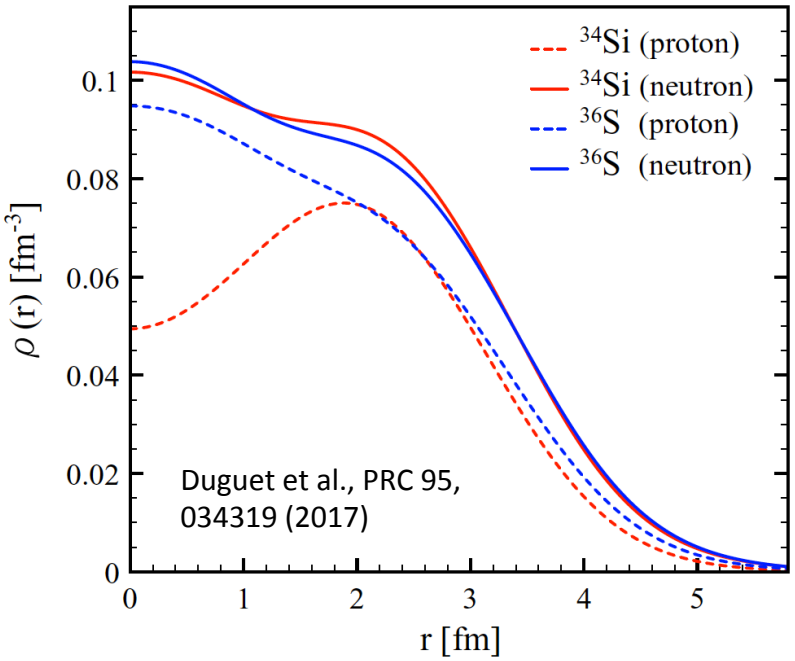
➢ (e,e) elastic scattering

Halo in light proton rich nuclei: ^{8}B, ^{14}O, ^{17}F, $^{17\text{-}18}$

Depletion in charge density distribution

Luminosity>10^{29}





➢ (e,e'p) quasi free scattering

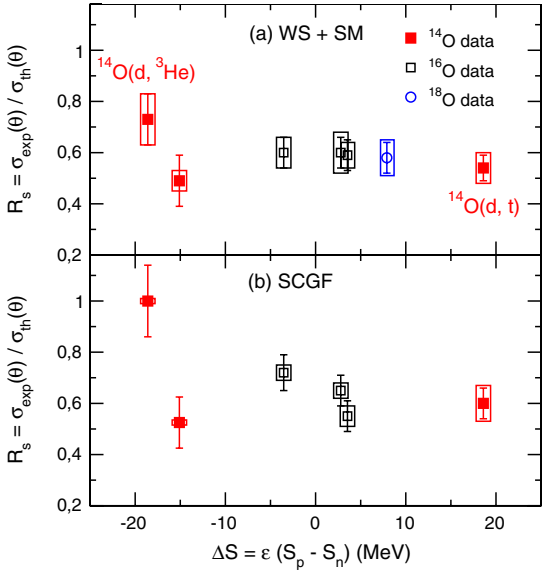
Spectroscopic strength

Luminosity>10^{30}

Short-Range Correlations

Luminosity>10^{31}

Luminosity in SCRIT-like scheme



F. Flavigny et al., Phys. Rev. Lett. 110 (2013)

Conclusions

- Short-Range Correlations program carried on mainly (but not only) with electrons
- Exotic nuclei demands the use of proton target in inverse kinematics
- Ongoing programs in the mid term with protons in inverse kinematics
- Long term: electron-exotic ion collisions