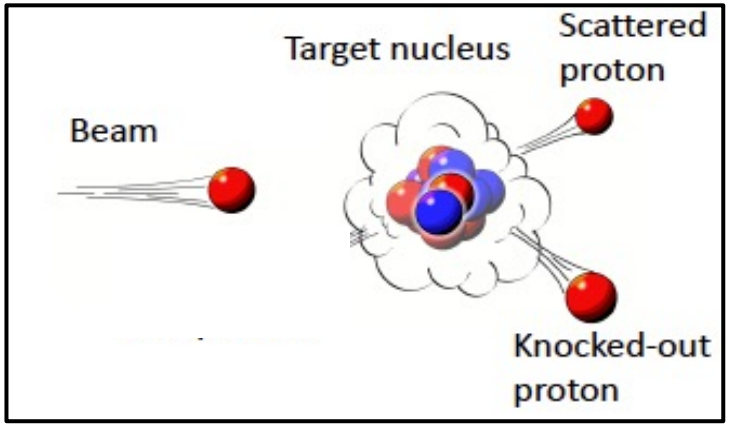
Probing the structure of exotic nuclei with protons targets

A.Corsi, CEA/IRFU/DPhN

IWM-EC2021, Nov. 23th-26th 2021, GANIL (Caen)

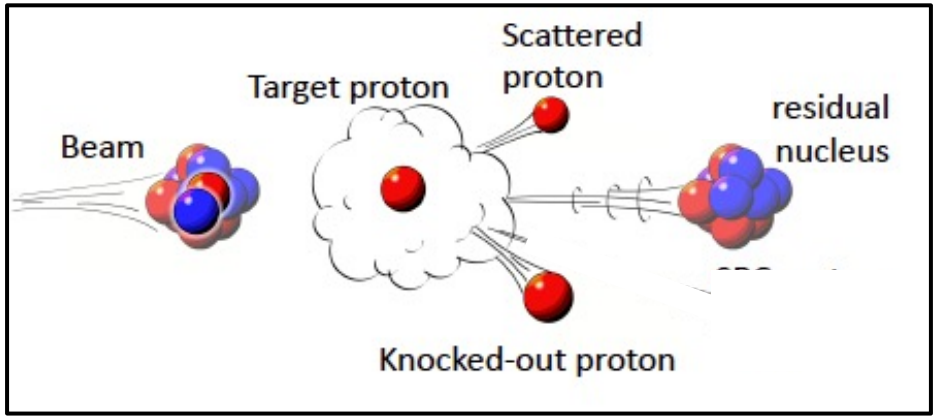
Quasi-free scattering reactions

PAST



G. Jacob, Th.A.J. Maris, Rev. Modern Phys. 38 (1966) 121–142.

PRESENT



T. Aumann, C.A. Bertulani, J. Ryckebusch, Phys. Rev. C 88 (2013) 064610.

Advantages of a proton target:

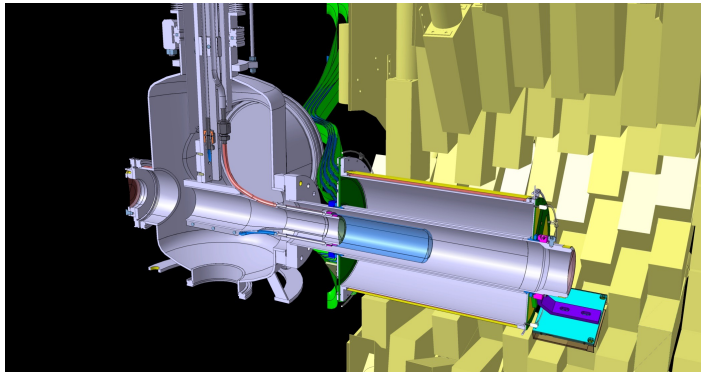
- Point-like probe
  - Analytic description of reaction mechanism (TC, IA)
  - Sensitive to the interior of nucleus

- Maximise n° scattering center with minimum energy loss
  - ^{100}Sn @ 200 MeV/u in 2 cm LH2 Eloss=35 MeV/u
  - ^{100}Sn @ 200 MeV/u in 7 mm C stopped!

Outline

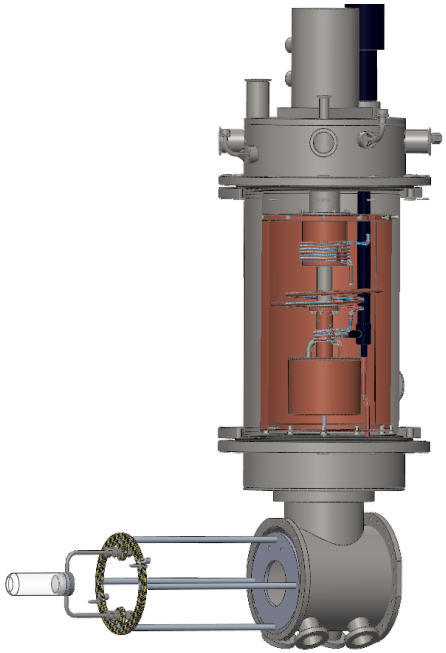
MINOS @ RIBF, RIKEN

- The setup
- Functioning of LH2 target
- SEASTAR
- Dineutron correlation

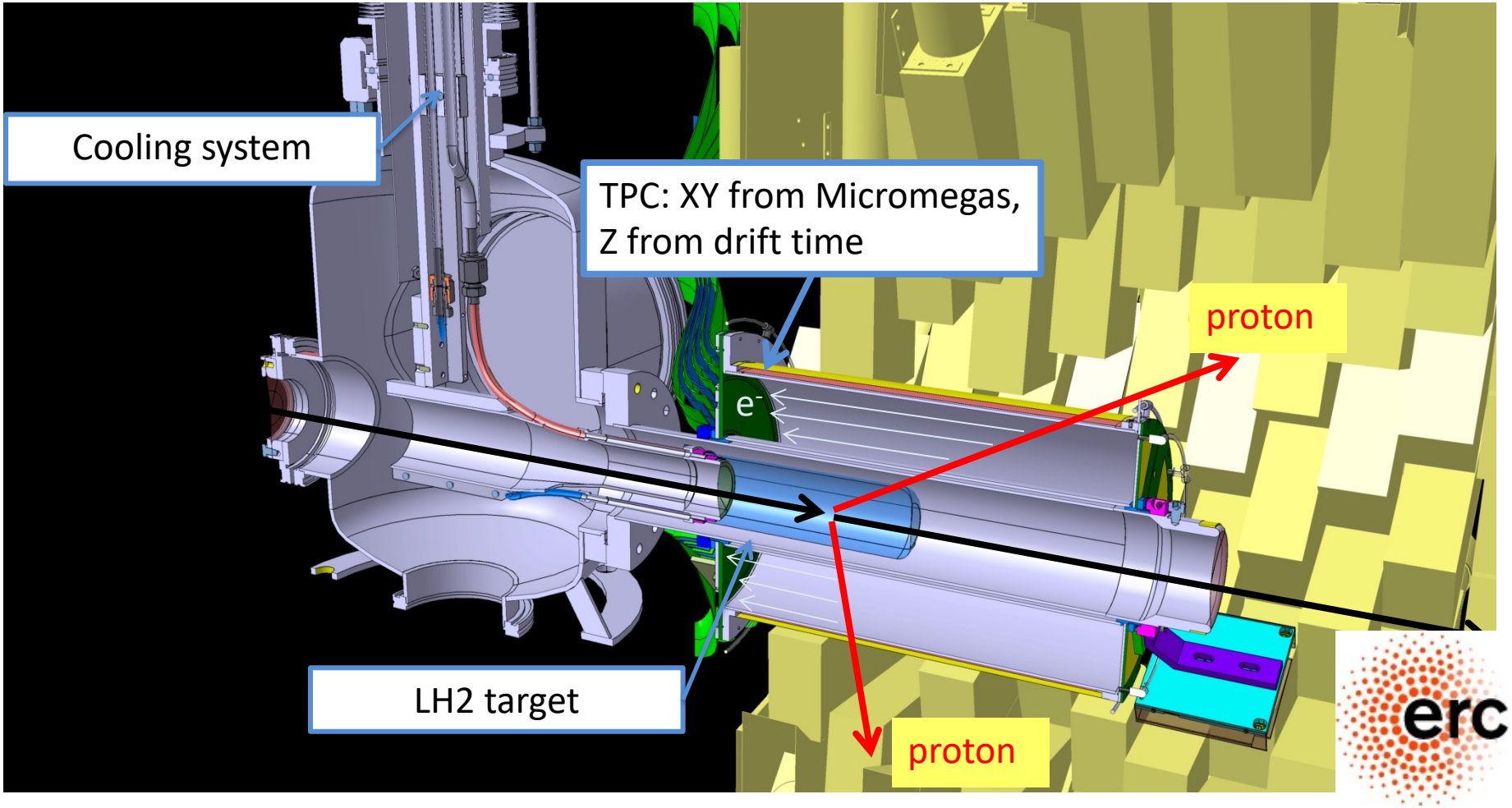


COCOTIER @ GSI

- The setup
- Short-Range Correlations at R3B



MINOS

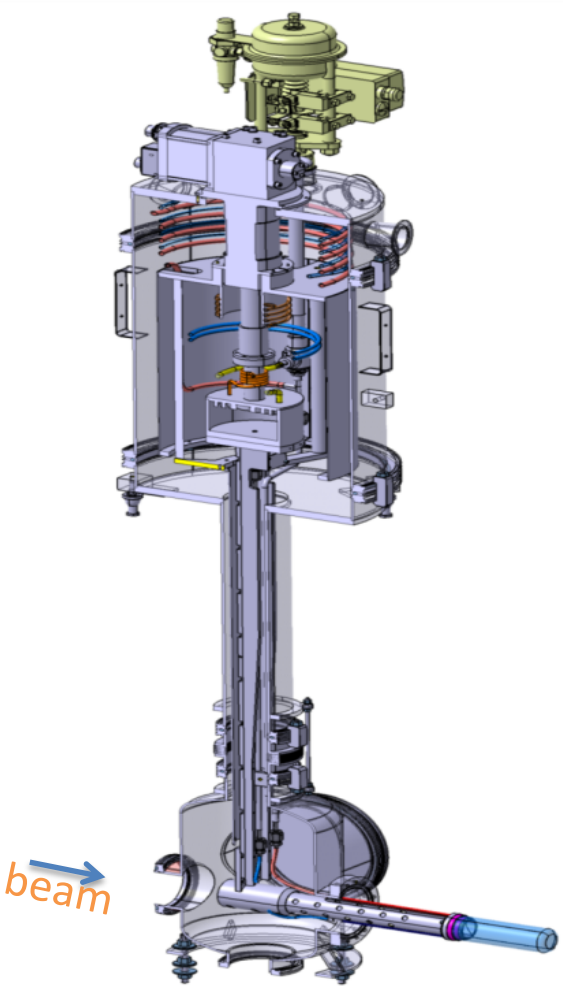


A. Obertelli *et al.*, Eur. Phys. Jour. A **50**, 8 (2014)

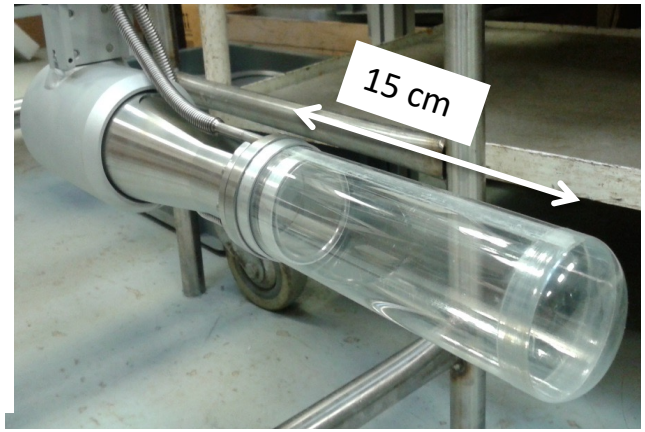
Vertex information (~3 mm sigma) for:

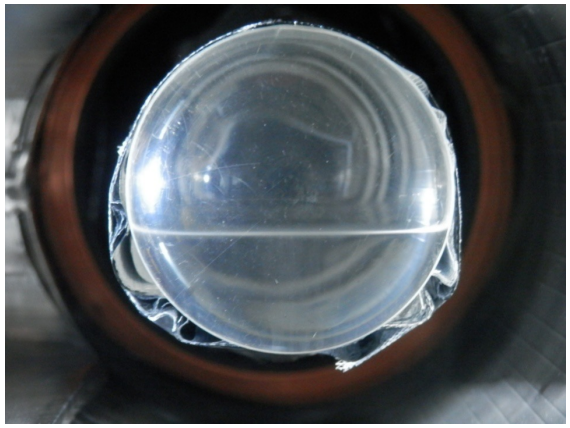
- Doppler correction in gamma spectroscopy
- Energy loss correction in invariant/missing mass spectroscopy

MINOS LH2 target

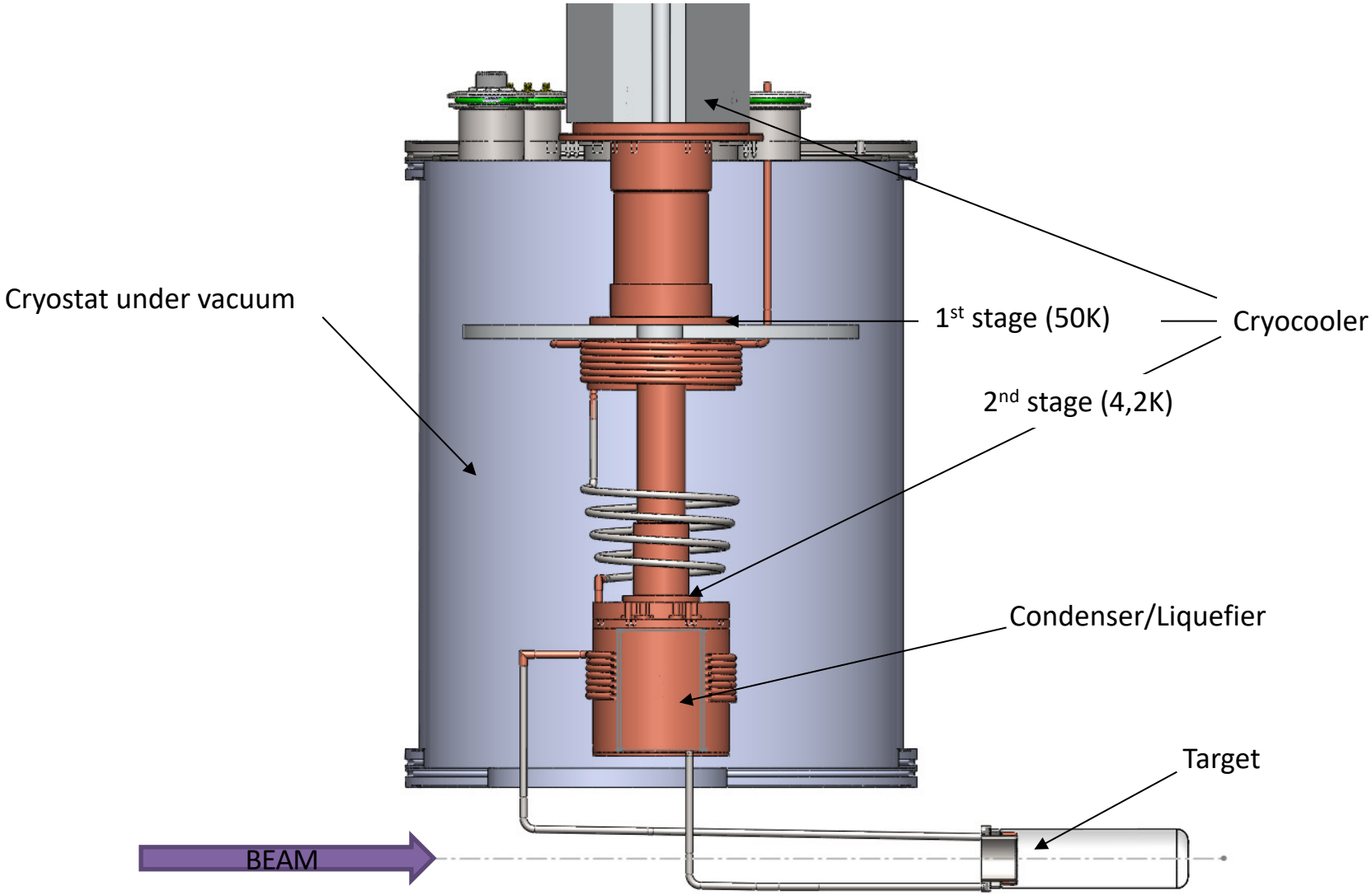


- Cryogenic target (20 K)
- Mylar cell: 200 microns, 38 mm entrance window
- 50-150 mm length, **≈ 1 g/cm^2 H**
- Surrounding space free for detection





LH2 target: how it works



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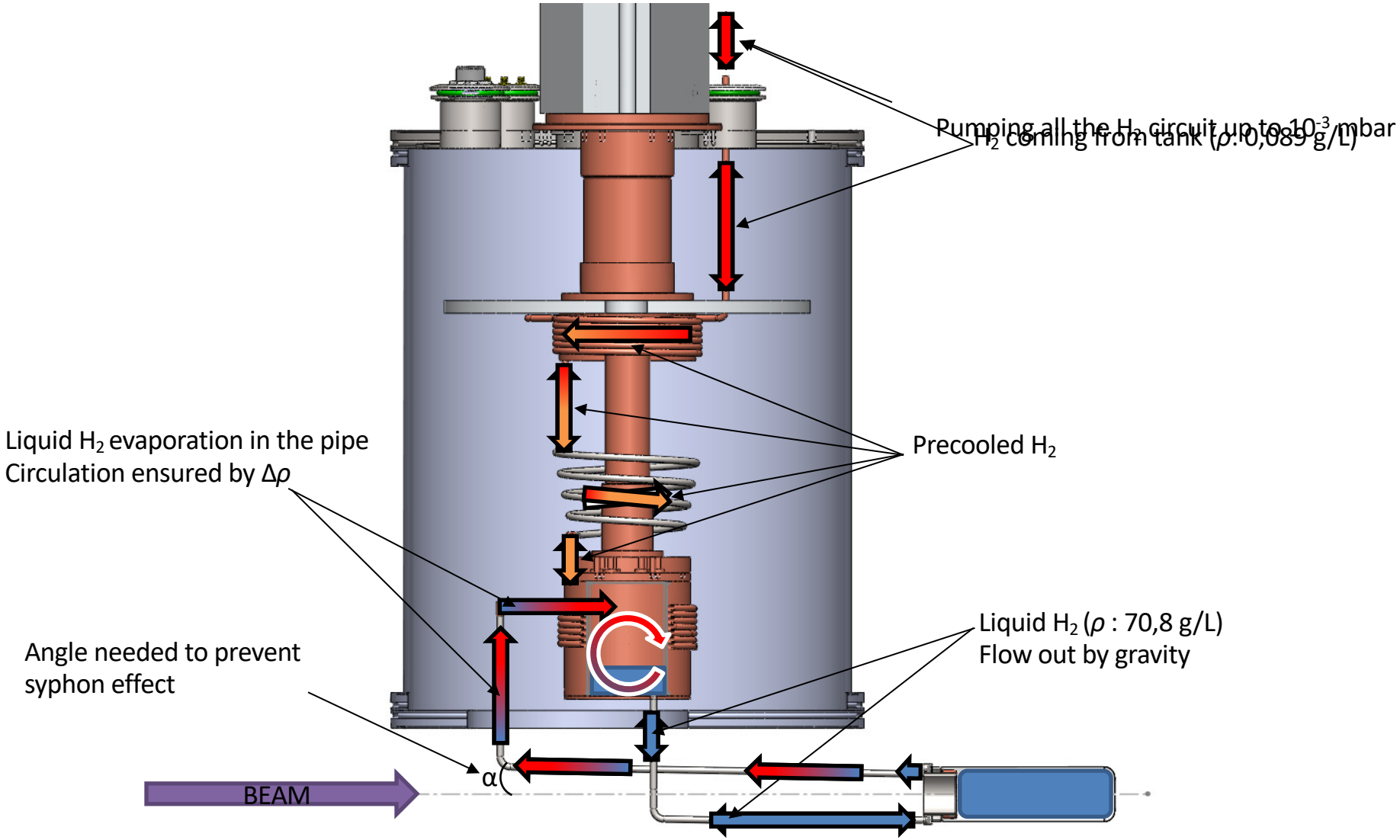
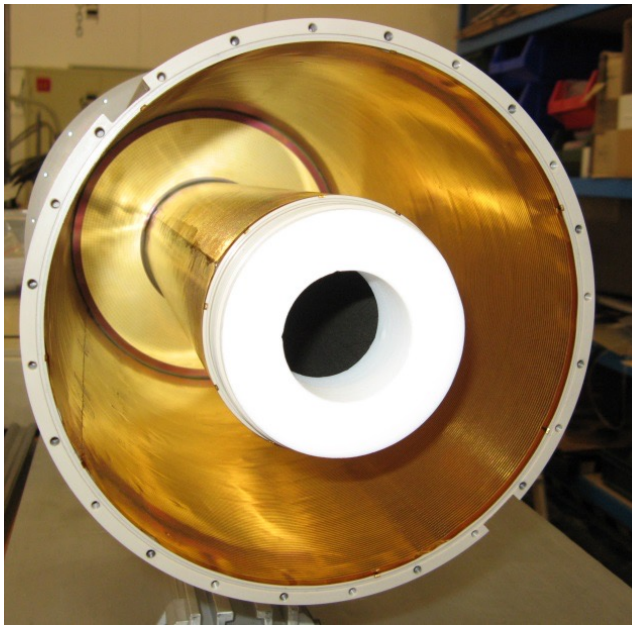
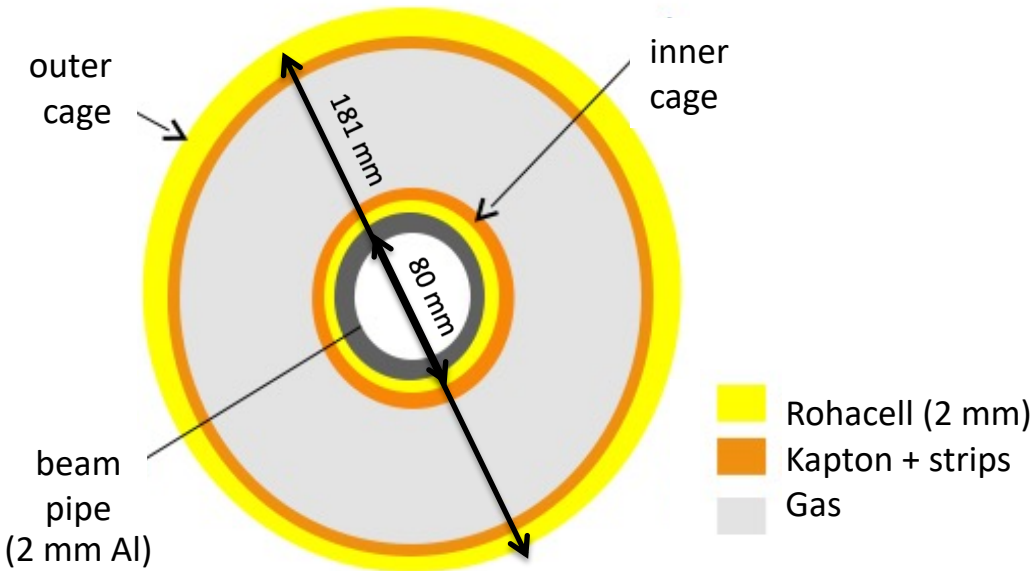
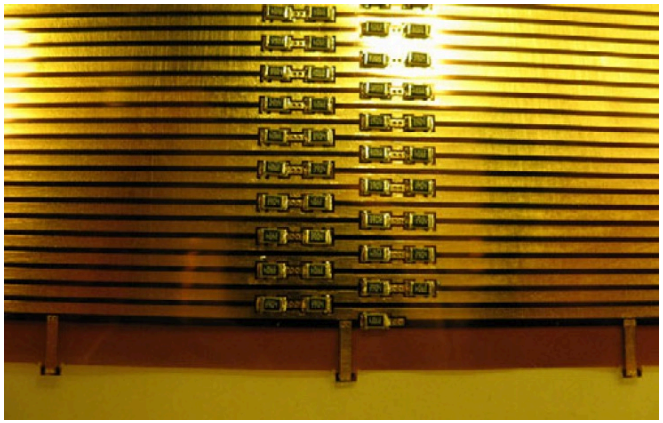


MINOS TPC – field cage







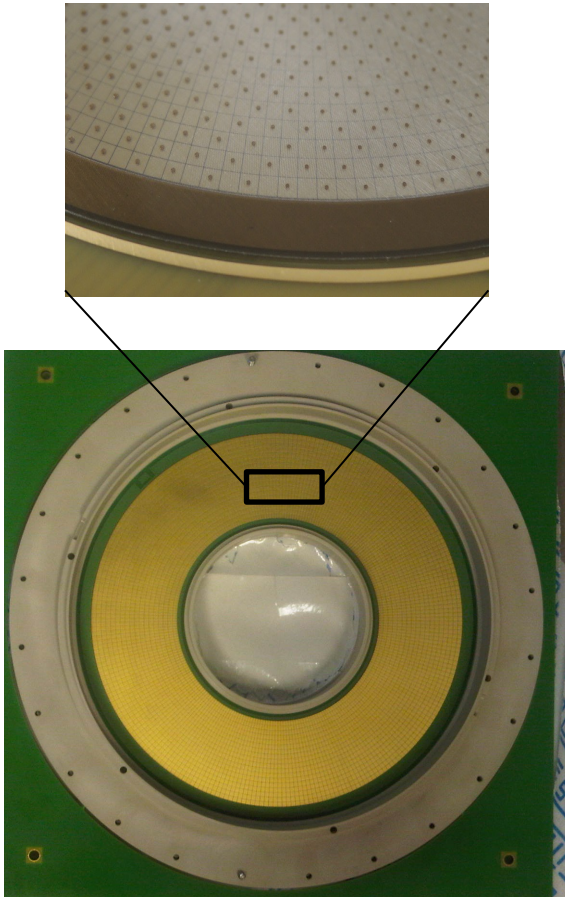
- 30-cm long drift space
- ~400 1-mm strips connected by 800 resistors
- Compact, low material budget field cage
- Ar (82%) + CF_4 (15%) + C_4H_{10} (3%) gas at 1 ATM
  Drift velocity ~4.5 cm/μs at 180 V/cm
  Transverse diffusion < 200 μm/√cm

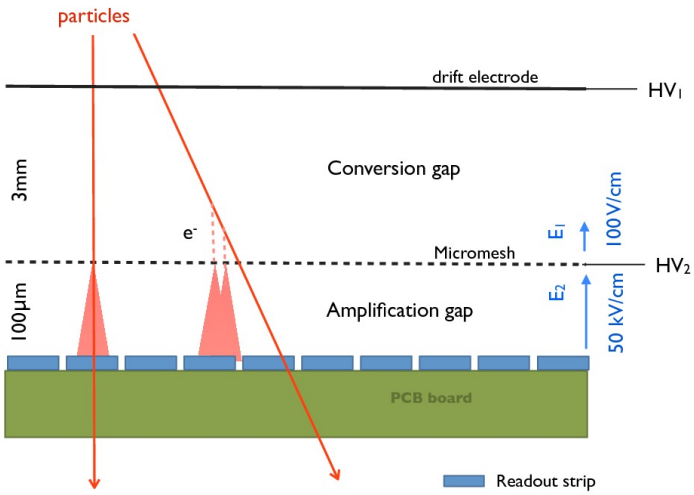
MINOS TPC - Micromegas

- Micromegas detector

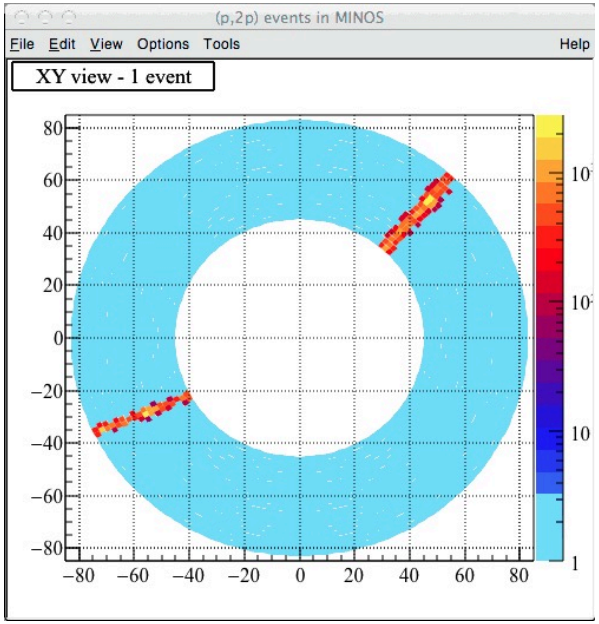
  G. Charpak, I. Giomataris, et al., NIMA 376, 29 (1996).

- 4000 pads of 2 x 2 mm^2





- Typical (p,2p) event



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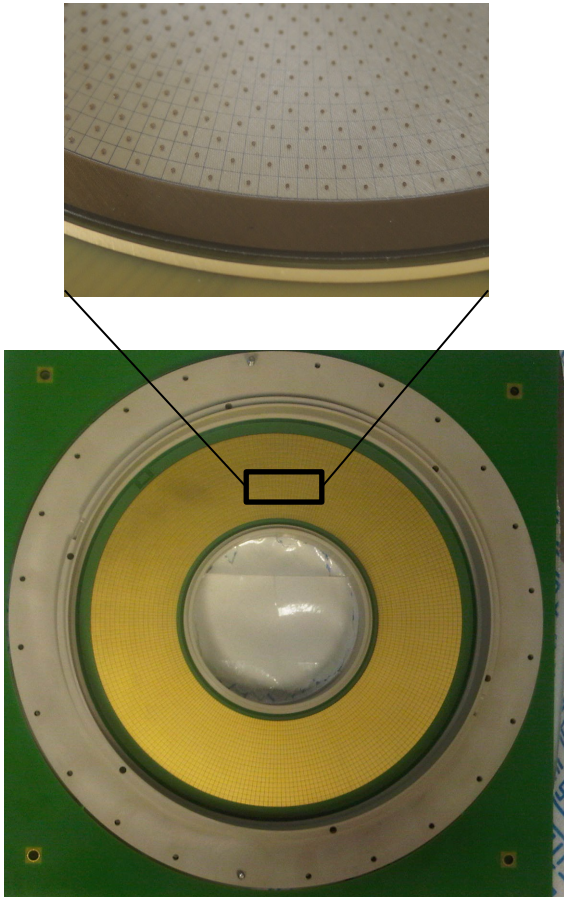
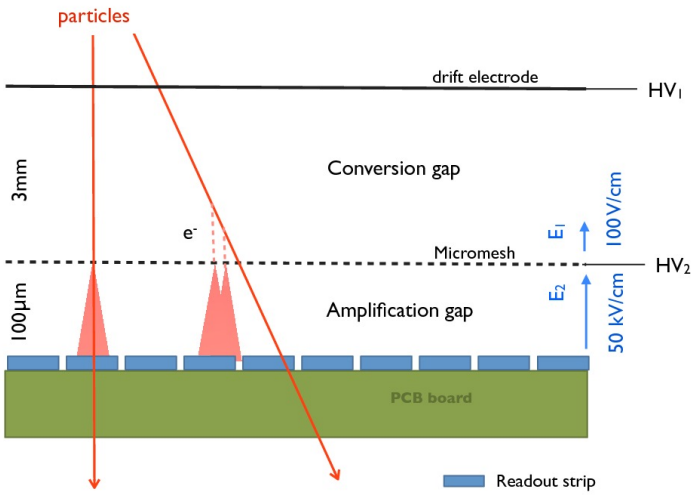
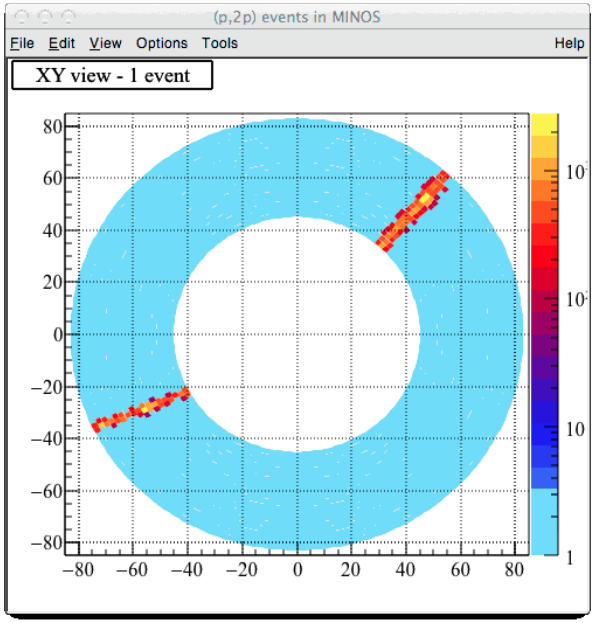




- Noise filtering+tracking algorithm (Hough transform)



GET: GENERIC ELECTRONICS for TPC

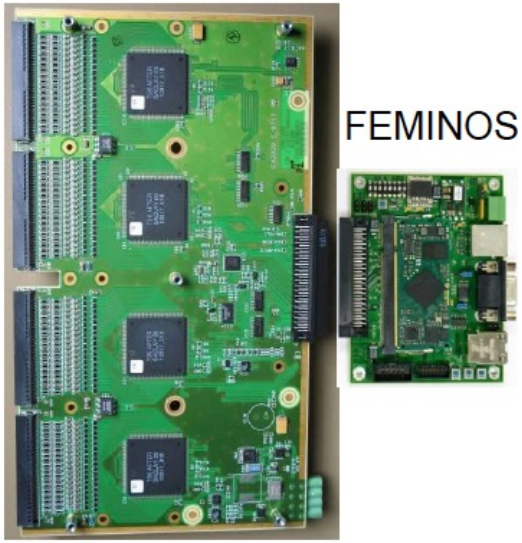
Spokesperson: E.C.Pollacco CEA/IRFU, CENBG, GANIL, NSCL-MSU, RIKEN collaboration

GET: GENERIC ELECTRONICS for TPC

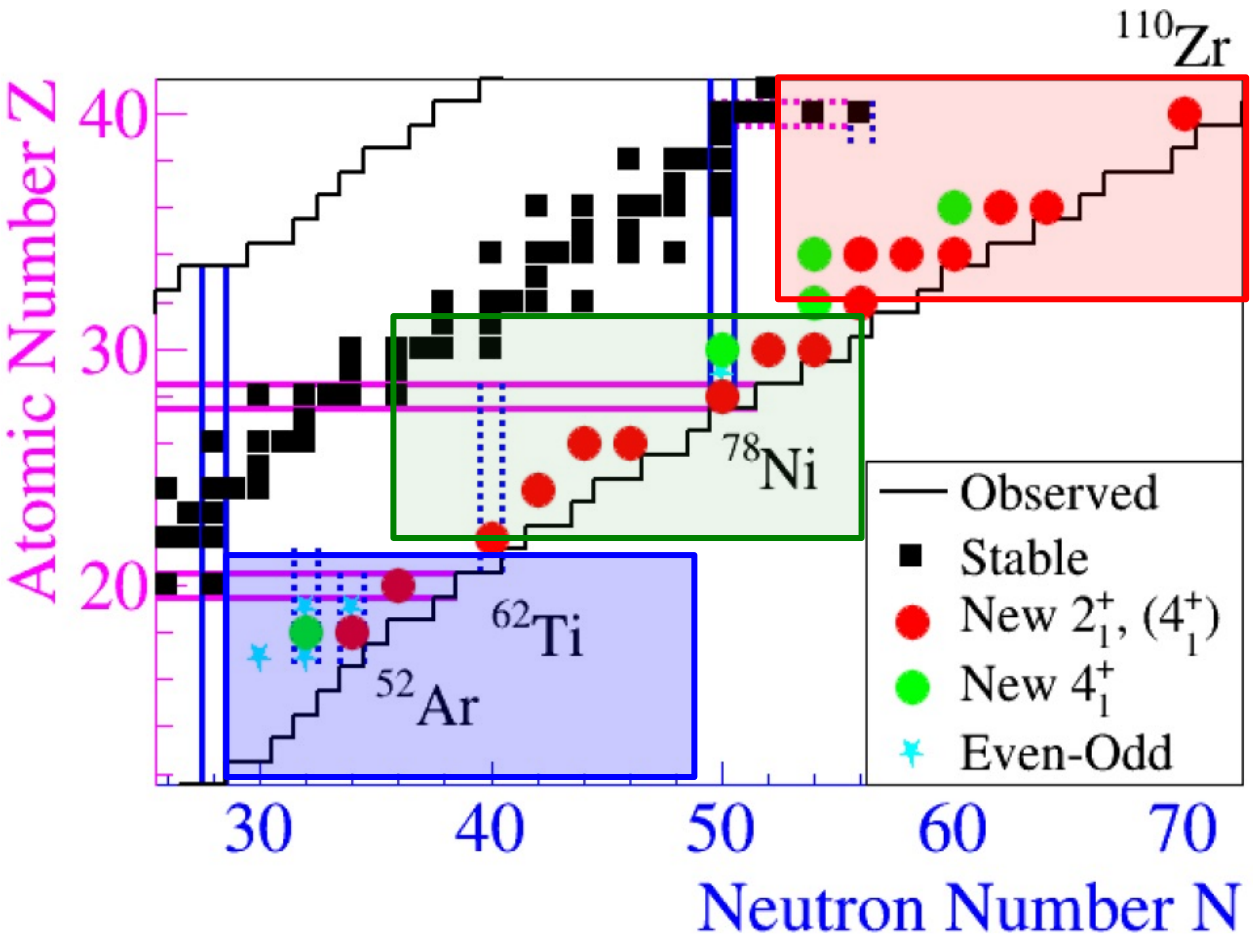
Within MINOS:

- Feminos readout card
  readout of AGET chip
  dead time ~80 µs at 1 kHz rate
- Dedicated DAQ software

Front End card
with 4 AGET chips



Shell Evolution and Search for Two-plus Energies At the RIBF (SEASTAR)

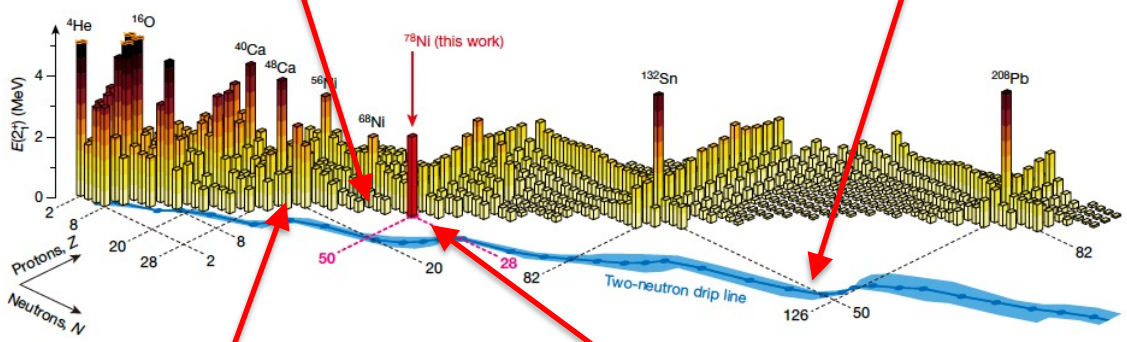


Spokespersons: P. Doornenbal (RIKEN), A. Obertelli (CEA)
30 days of beam time (2014, 2015, 2017)

Extension of the Island of Inversion towards N=50: Spectroscopy of 66Cr, 70,72Fe **PRL 2015**

Shape Evolution in Neutron-Rich Krypton Isotopes Beyond N=60: First Spectroscopy of 98,100Kr **PRL 2017**

Are There Signatures of Harmonic Oscillator Shells Far from Stability? First Spectroscopy of 110Zr **PRL 2017**



Restoration of the natural e($1/2_1^+$)-e($3/2_1^+$) energy splitting in odd-K isotopes towards N= 40 **PLB 2020**

Investigation of the ground-state spin inversion in the neutron-rich 47,49Cl isotopes **PRC 2021**

^{78}Ni revealed as a doubly magic stronghold against nuclear deformation **Nature (2019)**

SEASTAR – K and Cl isotopes

State of the art (<2017):

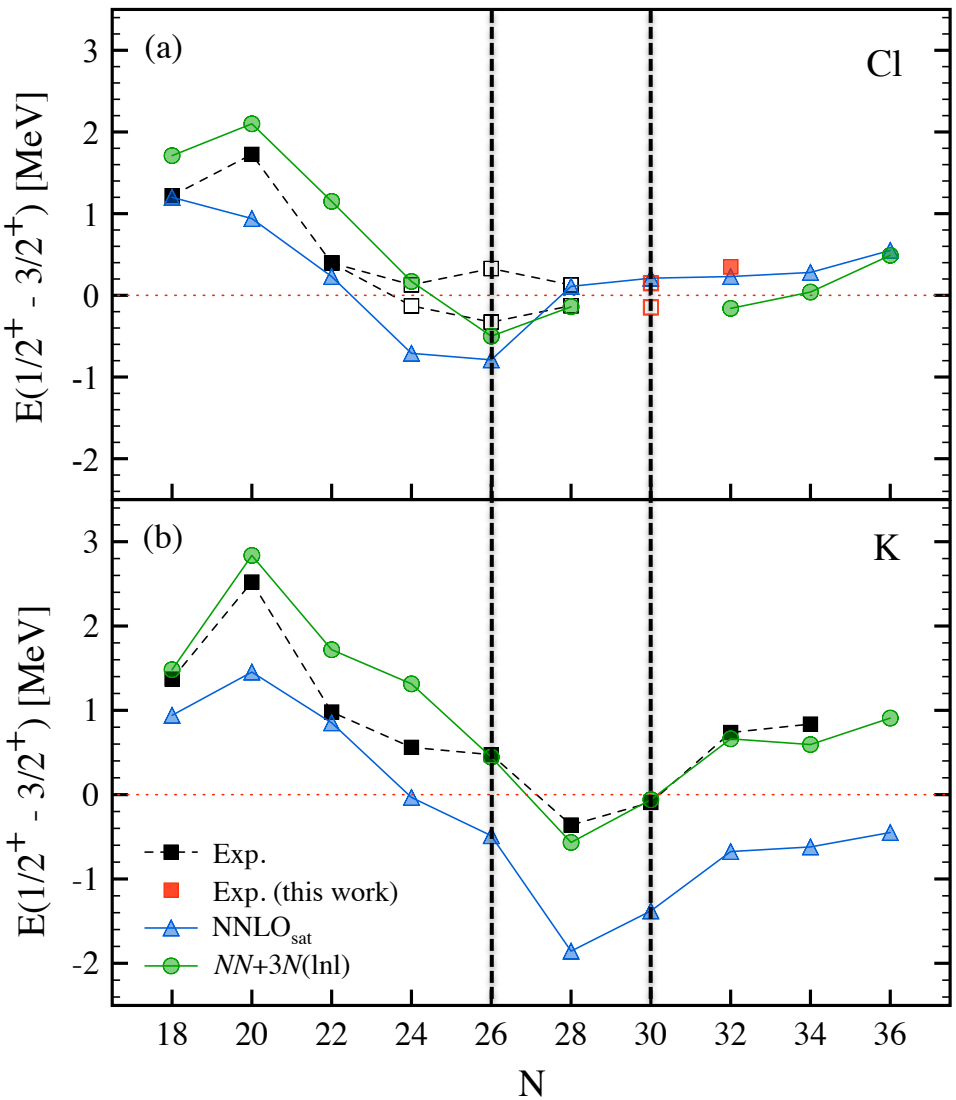
- Inversion at N=26->28 and 30->32 in K

SEASTAR (2017):

- Determine 1st level energy and spin at N=32, 34 in K, at N=30, 32 in Cl
- Restoration of the natural ordering of the $1/2_1^+$ and $3/2_1^+$ proton-hole state
- Restoration of Z=16 gap beyond N=30

Y. Sun, CEA and TUDa

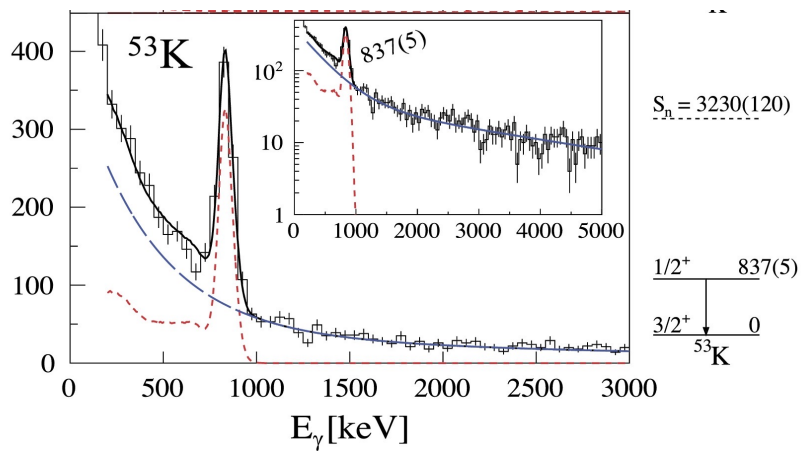
B.D.Linh, Vinatom

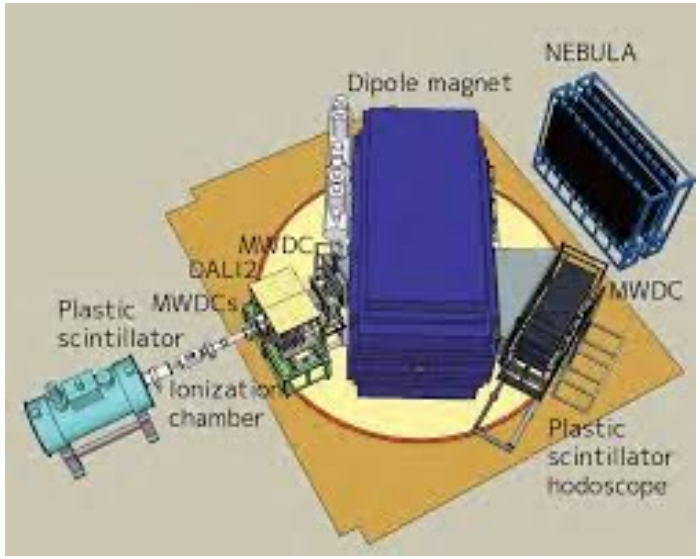


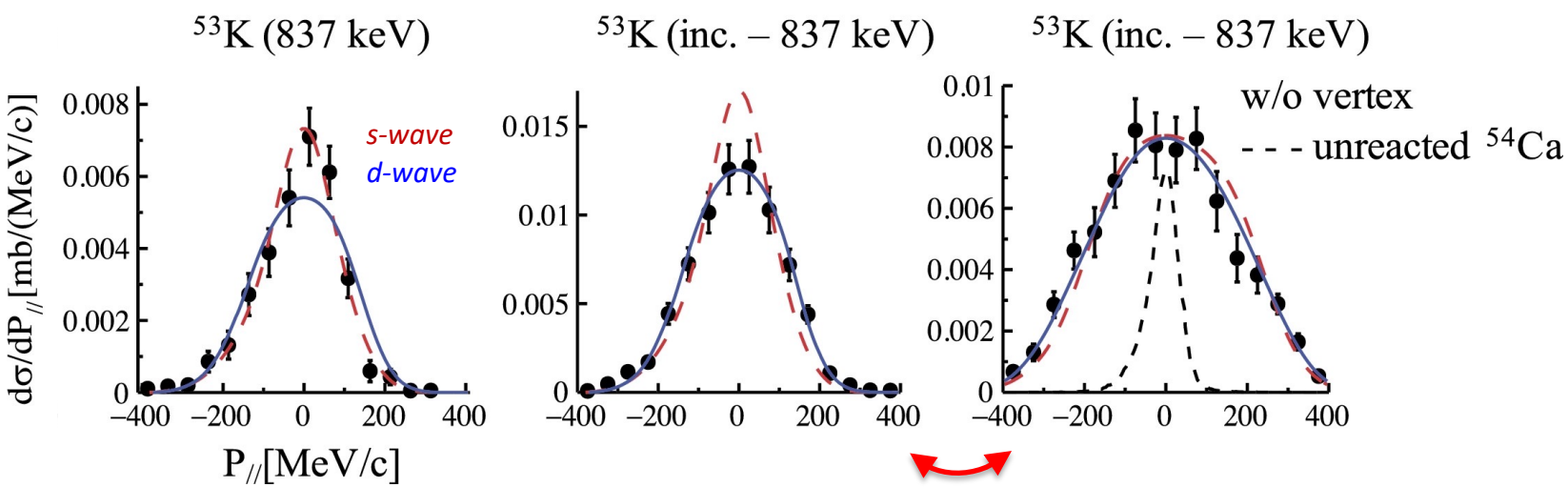
Y.Sun et al., PLB 802 (2020)
B.D.Linh et al., PRC 108 (2021)

SEASTAR – K and Cl isotopes

- MINOS+SAMURAI setup @ RIBF
- Gamma + parallel momentum distribution



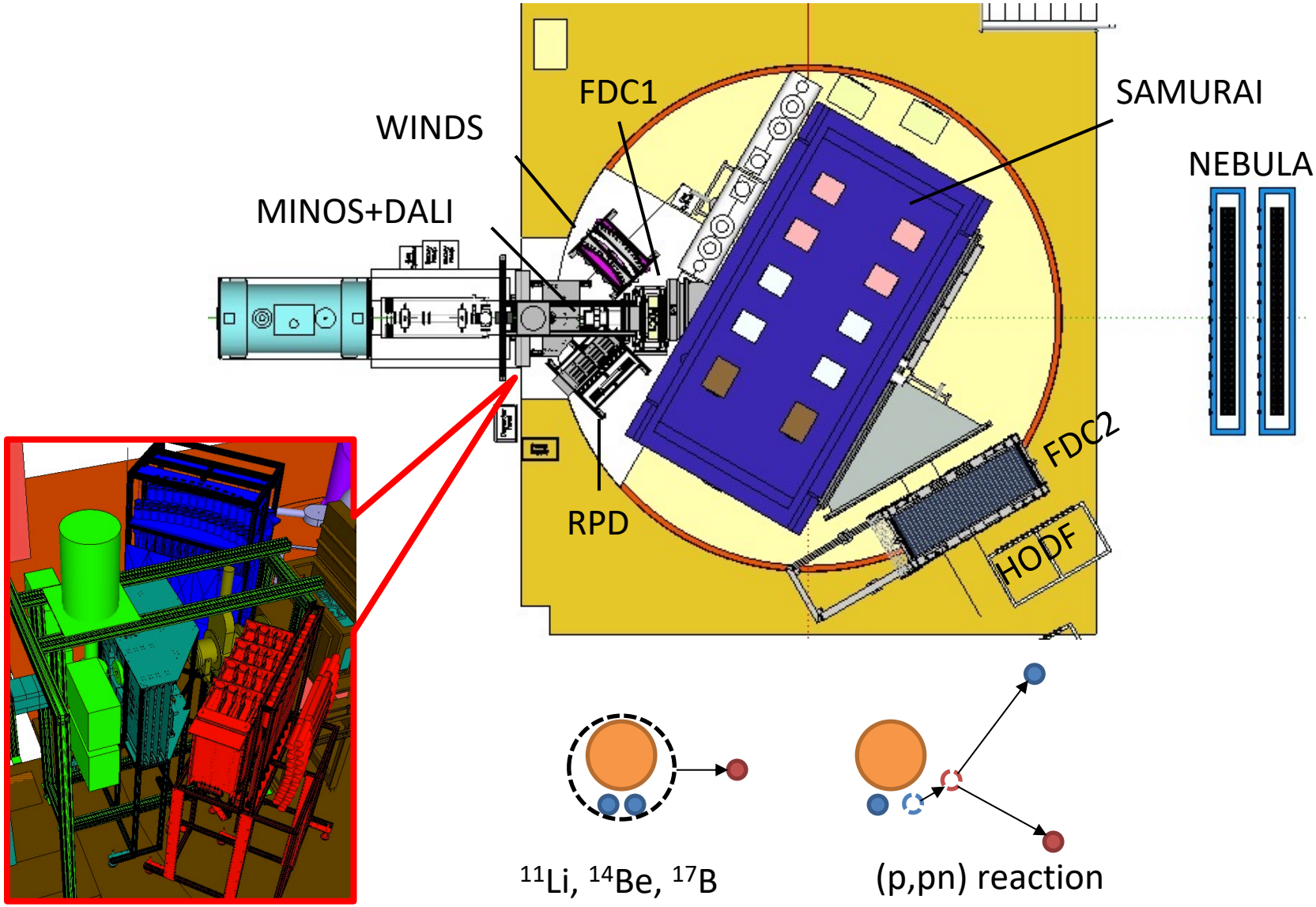




Y.Sun et al., PLB 802 (2020)

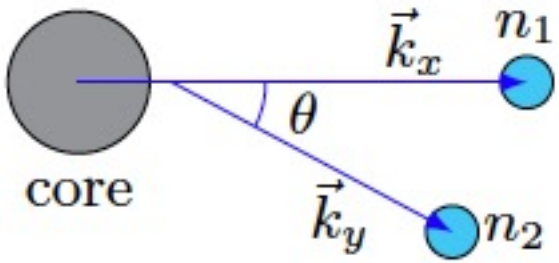
Dineutron correlation

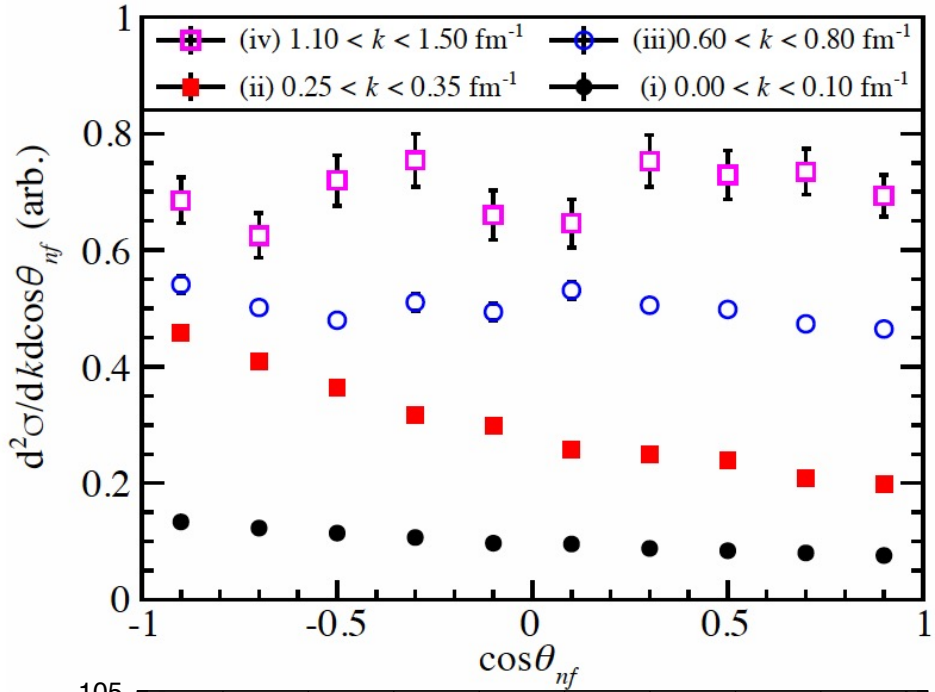
MINOS+SAMURAI+missing mass setup @ RIBF



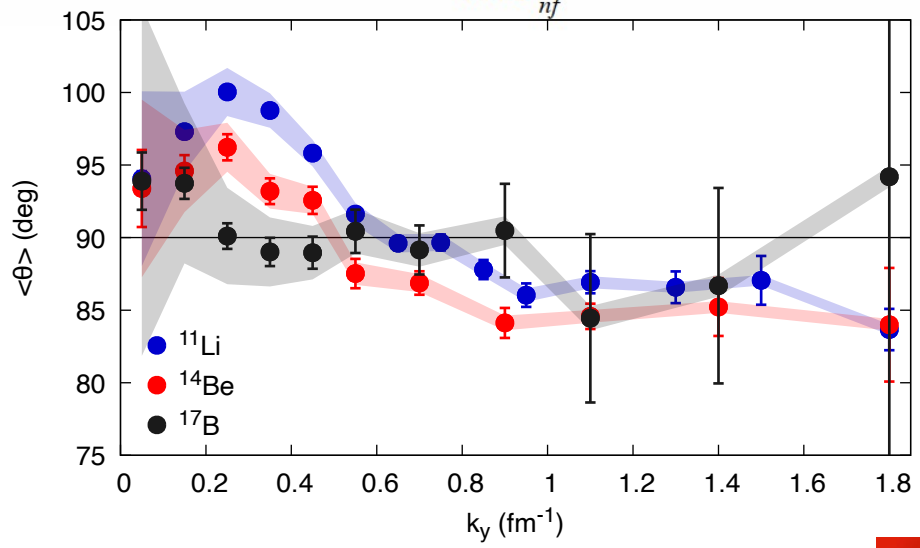
Dineutron correlation

- Correlation between <θ> and missing momentum k_y in (p,pn) sensitive to the localization of dineutron correlation





- <θ> > 90° ⇔ dineutron correlation, small k_y ⇔ nuclear periphery
- Dineutron correlation signal in ^{11}Li
- Progressive damping in ^{14}Be, ^{17}B



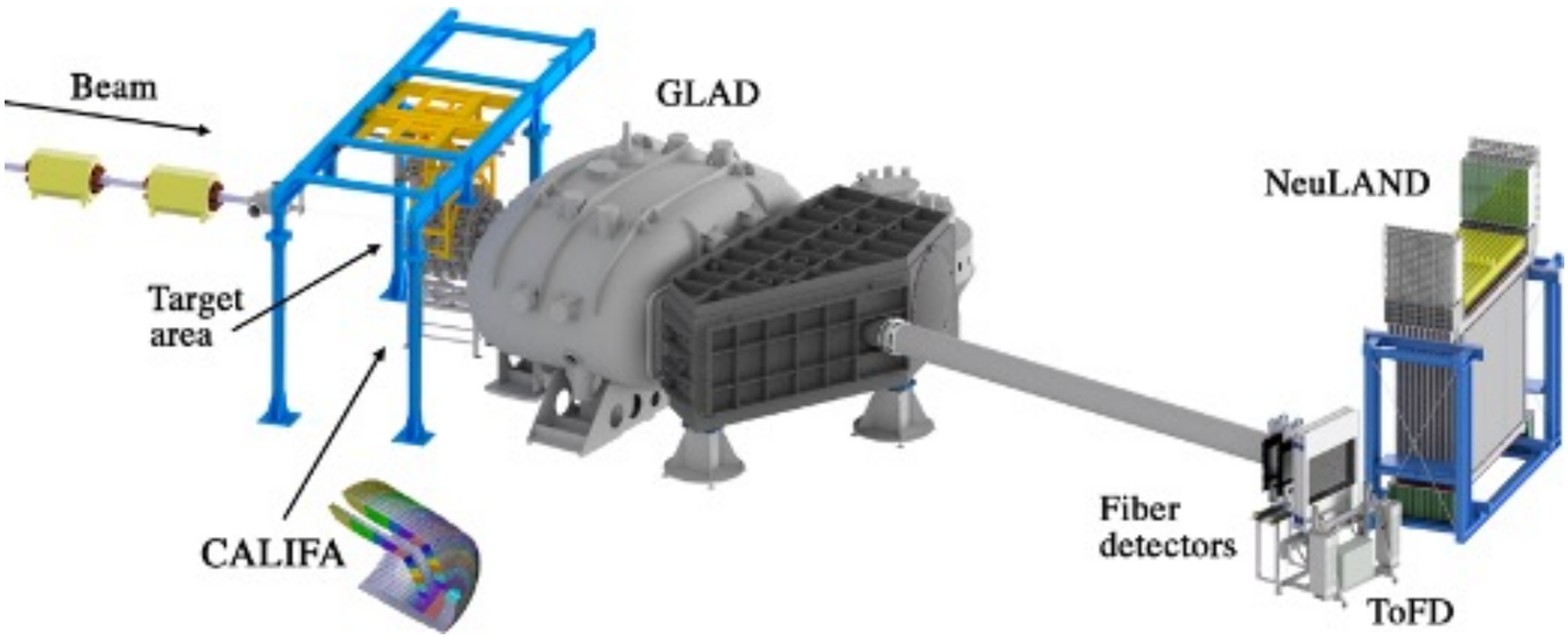
Y.Kubota t al., PRL 2020; A.Corsi, Y.Kubota, J.Casal, M.Gomez, in preparation (2021)

R³B Reactions with Relativistic Radioactive Ion Beams

Versatile setup to perform direct reactions in inverse kinematics

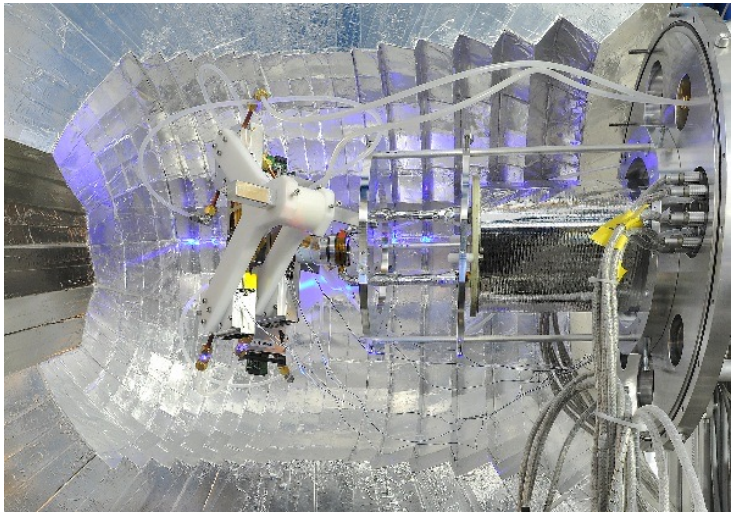
2019-2023 Fair phase-0 Radioactive beams from SIS + FRS

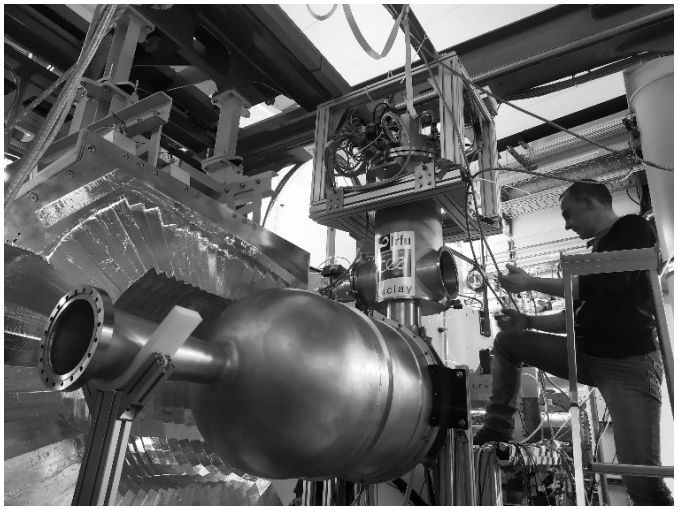
From 2025 Fair phase-1 Radioactive beams from SIS100 + Super FRS

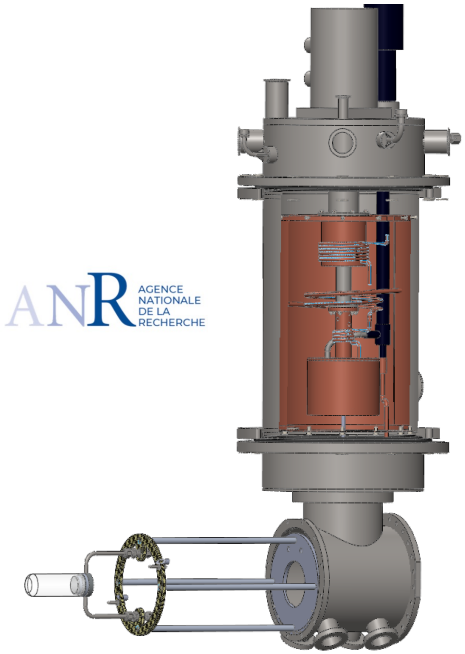


COCOTIER @ R3B

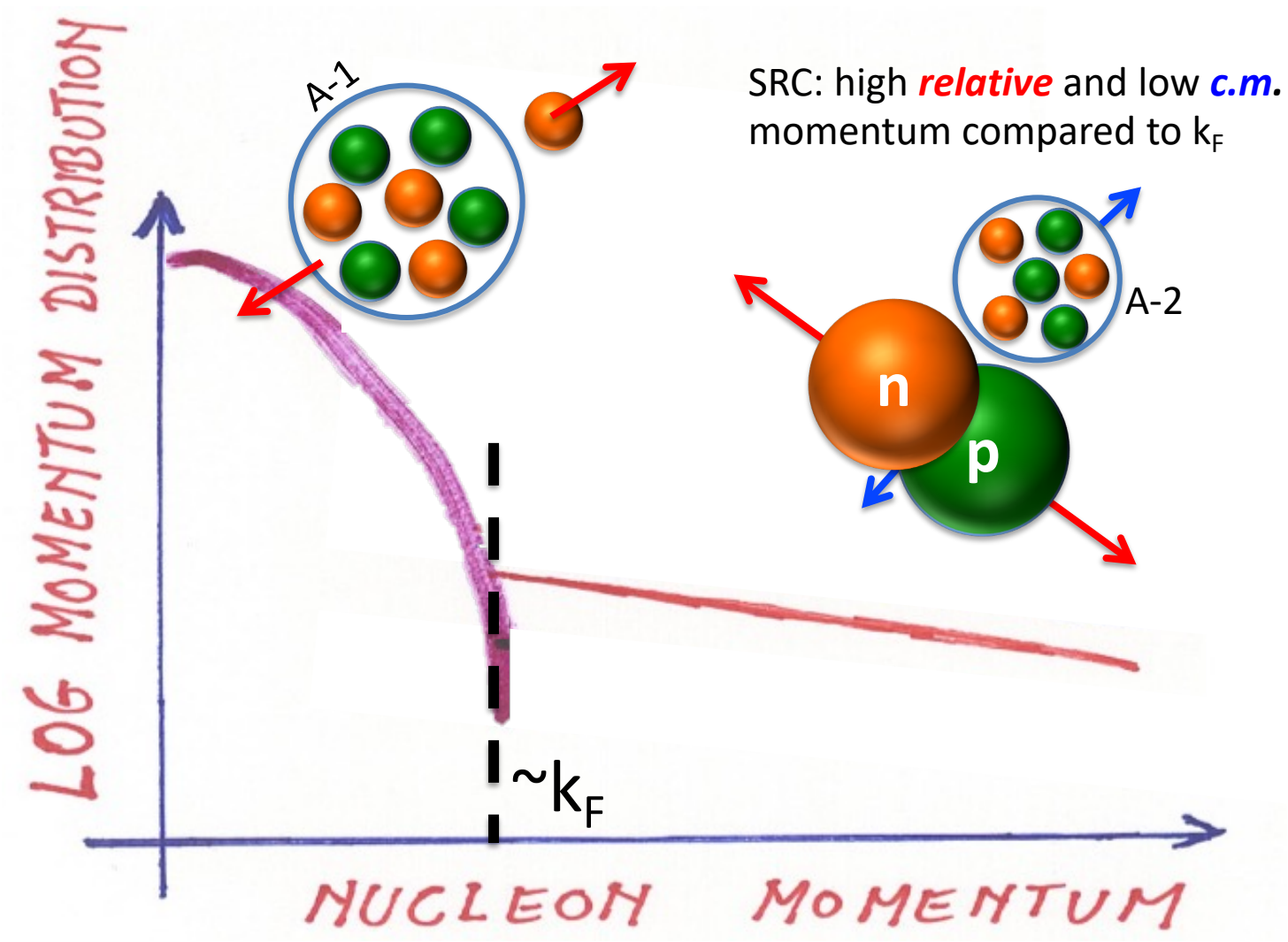
- Deported LH2 target (1.5, 5, 10 cm long)
- Developed in 2018-2019 at IRFU. Installed at GSI in 2019. Used since 2021.
- Project granted by the French Research Agency to carry on Short-Range Correlation studies with radioactive beams
- Tool of choice to perform Quasi-Free Scattering experiments







Short Range Correlations



Short Range Correlations

- SRC are mainly proton-neutron (pn) pairs
- Role of tensor force
- pp/pn does not change with A

I.Korver et al.,PLB 820 (2021)
Nature 578, 540 (2020)
Nature 566, 354 (2019)
Nature 560, 617 (2018)
Science 346 (6209):614 (2014)
Science 320(5882):1476 (2008)
PRL 124, 212501 (2020)
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PRL 122, 172502 (2019)
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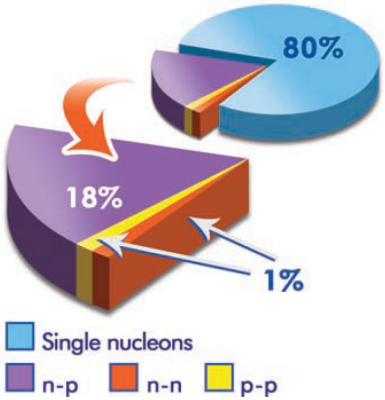
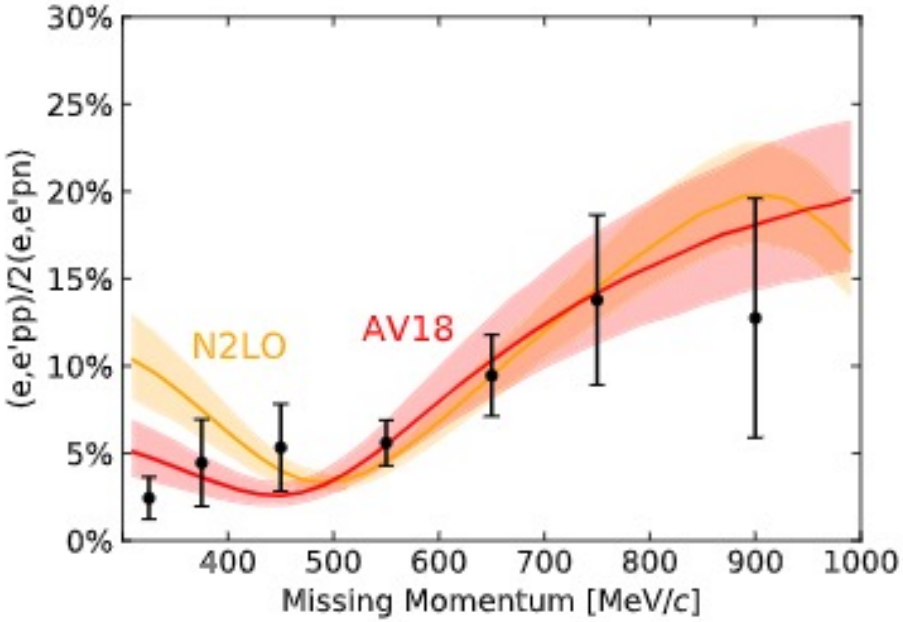
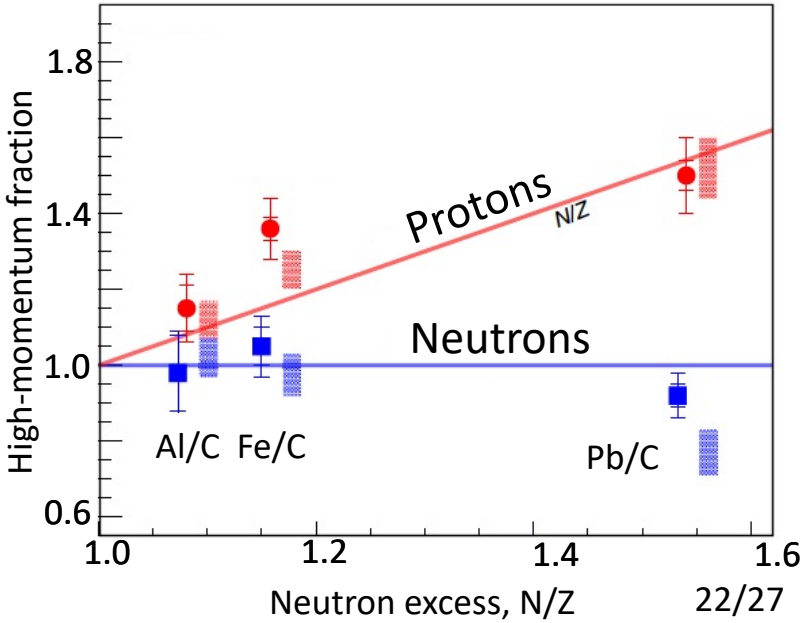
PRL 113, 022501 (2014)



Sensitive to details of NN interaction



The fraction of high momentum protons increases for nuclei with N>Z



... + R3B experiment

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I.Korver et al.,PLB 820 (2021)
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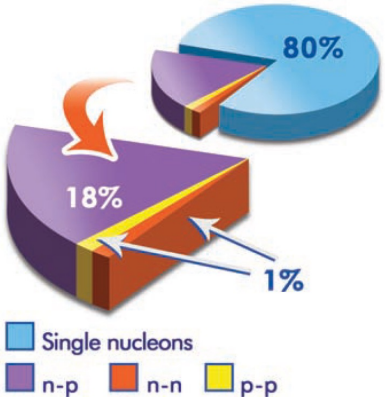

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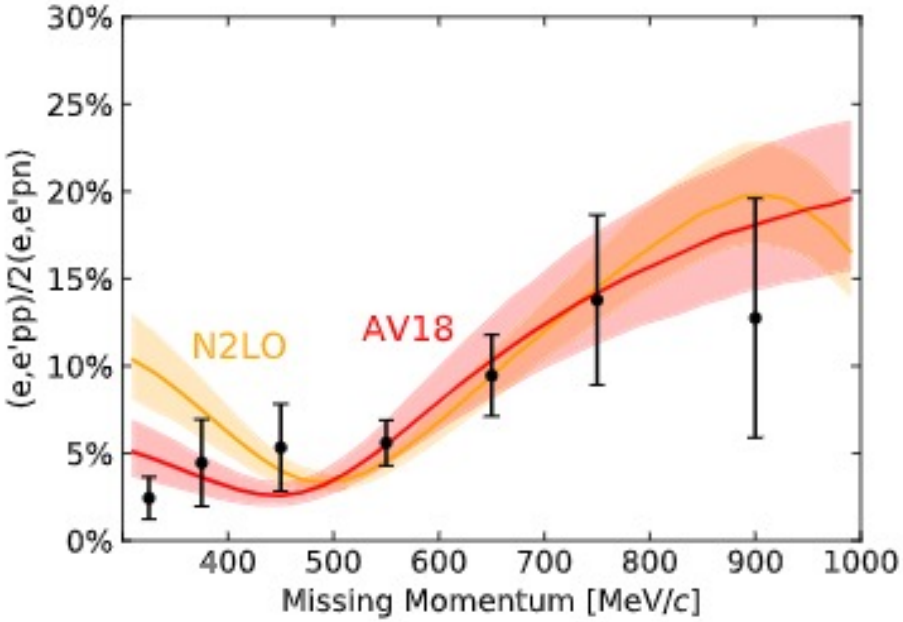

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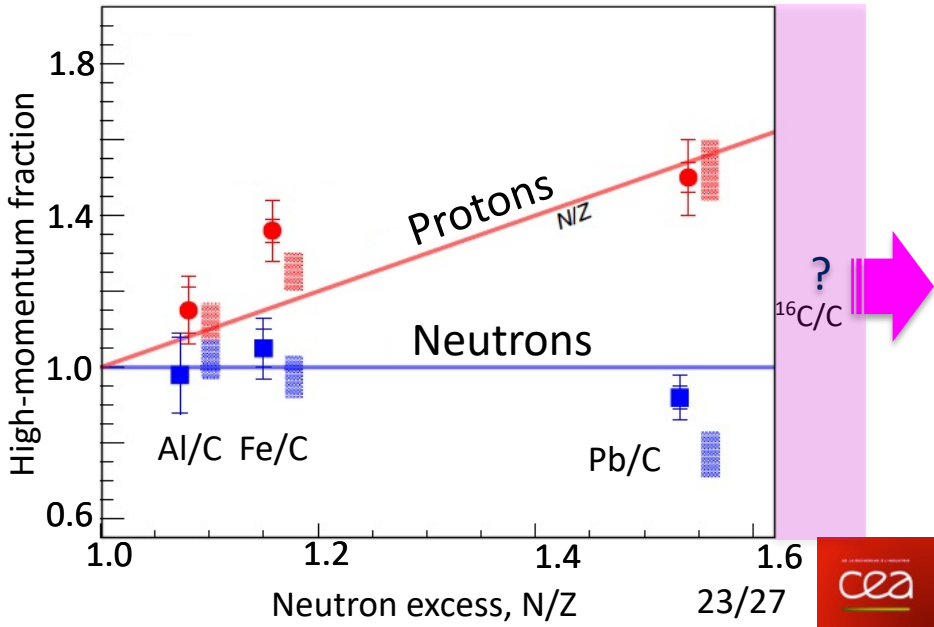
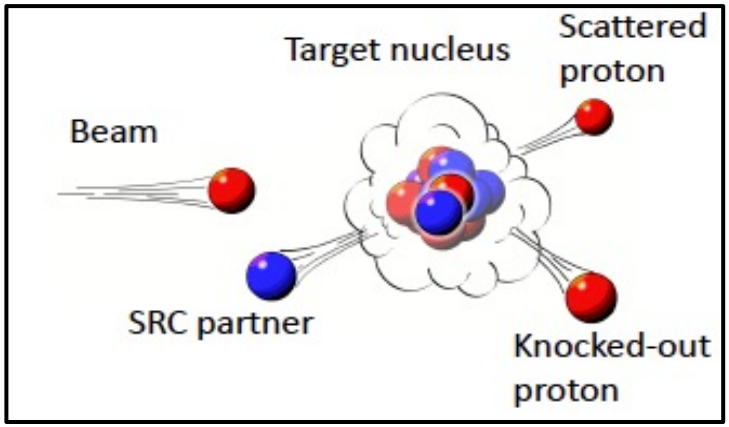
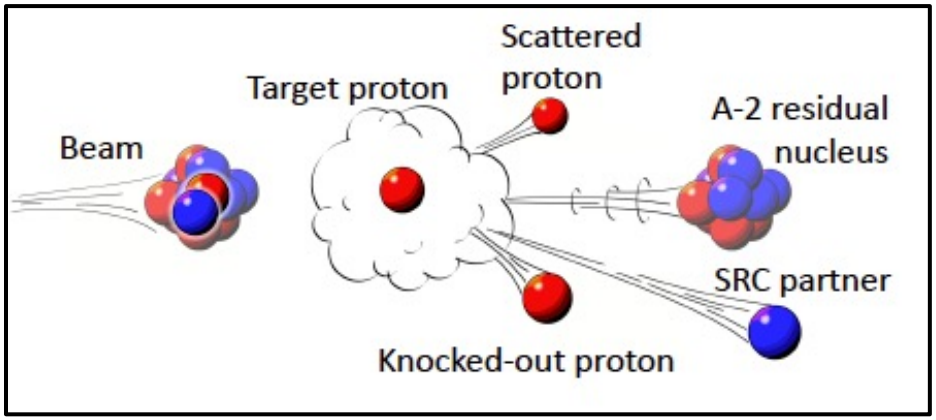


Probing SRC





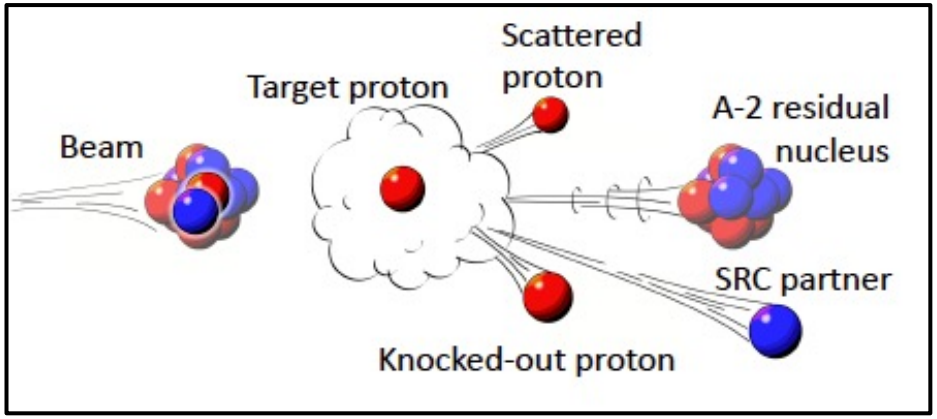
<u>Direct kinematics</u>

- ✓ p_{miss}, p_{recoil}
- ✓ p_{CM} (indirectly)
- ✗ Fragment ID

<u>Inverse kinematics</u>

- ✓ p_{miss}, p_{recoil}
- ✓ p_{CM} (directly)
- ✓ Fragment ID + p_{A-2}
- ✓ Exotic nuclei

SRC in inverse kinematics with protons

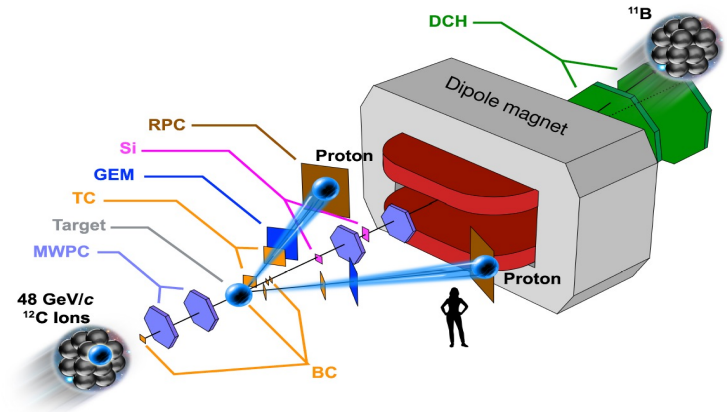


High cross-section compared to electrons (especially important for unstable beams)

Increased ISI/FSI challenges data interpretation

⇒ Proof of principle experiment with ^{12}C beam at Nuclotron, Dubna

M.Patsyuk et al., Nature Phys 17 (2021)

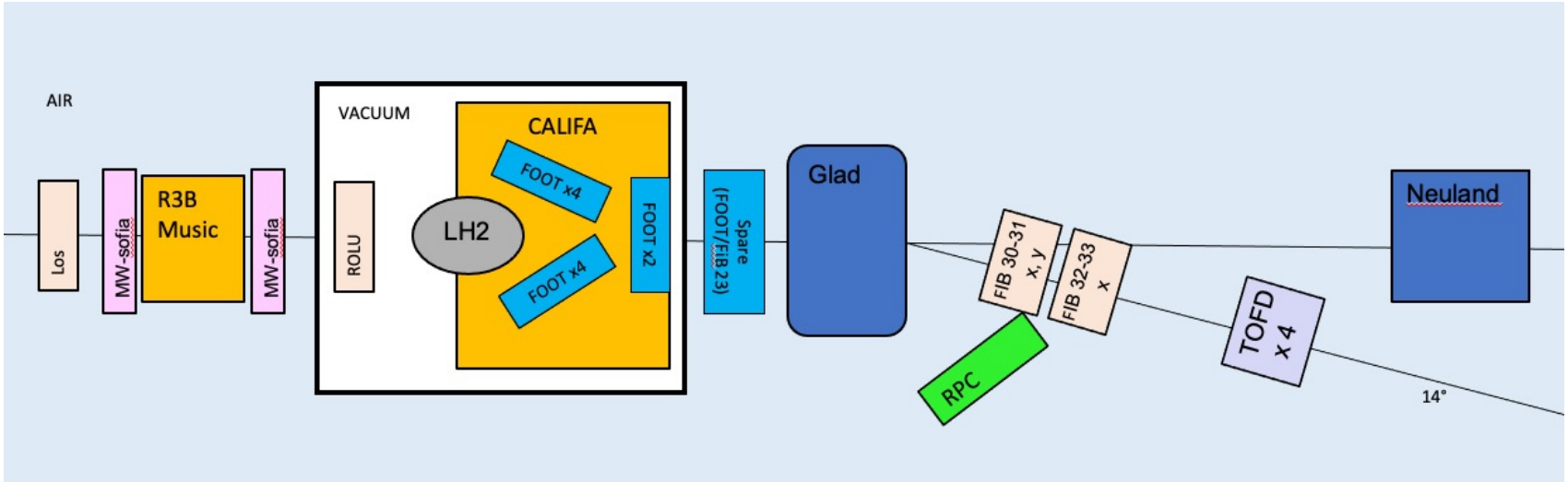


Short Range Correlations @ R3B

Goals

- 1st exotic nucleus ^{16}C @ 1.25 GeV/u
- direct comparison of isotopes $^{16}C/^{12}C$
- test lower limit in momentum transfer

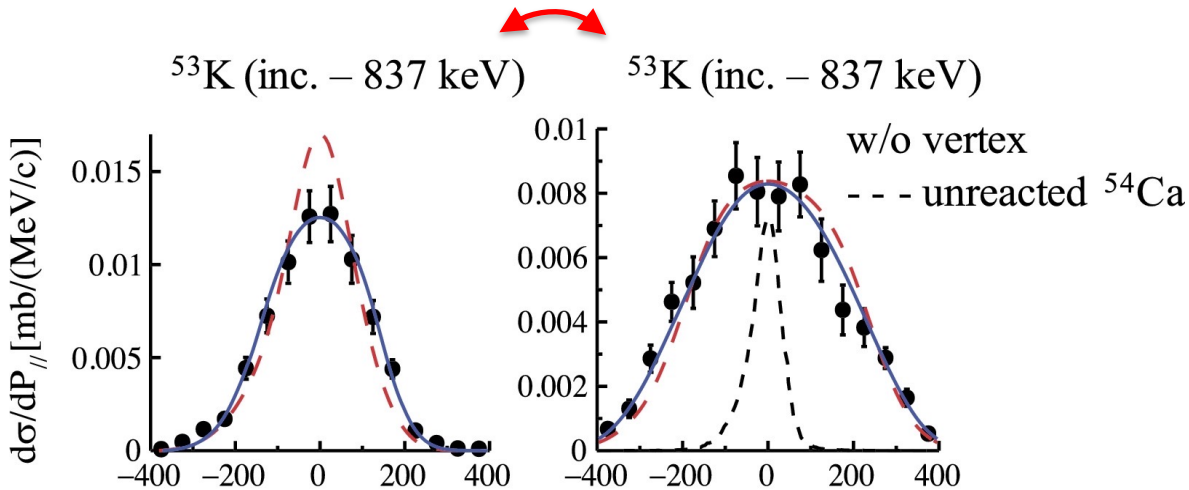
Scheduled in May 2022



Conclusions

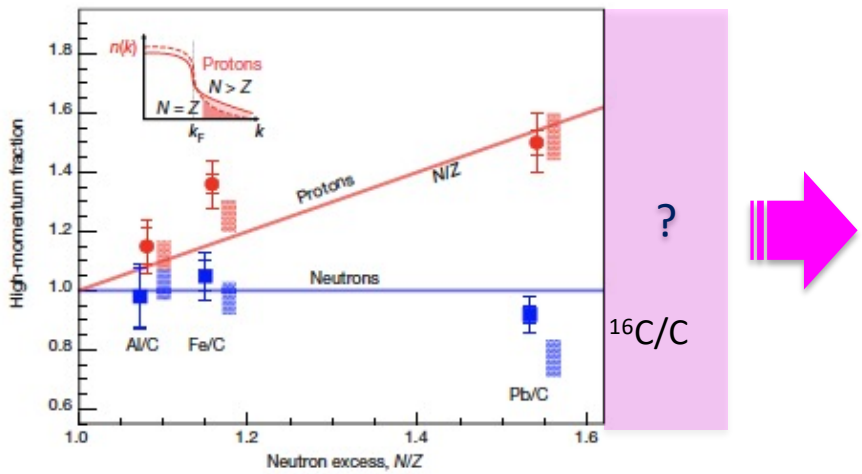
MINOS

- The setup
- Functioning of LH2 target
- SEASTAR
- Dineutron correlation
- Power of LH2 + vertex tracking



COCOTIER

- The setup
- Short-Range Correlations at R3B
- Experiment in 2022



Acknowledgements

- Y.Kubota (RIKEN, now TUDa), T. Uesaka (RIKEN), P.Doornenbal (RIKEN)
- T.Aumann (TUDa), O.Hen, J. Kahlbow (MIT), E.Piasetsky (TAU), V.Panin (GSI) and the R^3B collaboration
- A.Lagni, V.Lapoux, A.Gillibert, E.Pollacco, A.Revel (CEA/IRFU/DPhN)
- A.Obertelli (TUDa), G.Authelet (CEA) and all MINOS and COCOTIER teams