MINOS :
A NEW DEVICE FOR THE SPECTROSCOPY OF EXOTIC NUCLEI

A. Corsi
CEA Saclay

COMEX5, Krakow, September 14-18th 2015

Outline

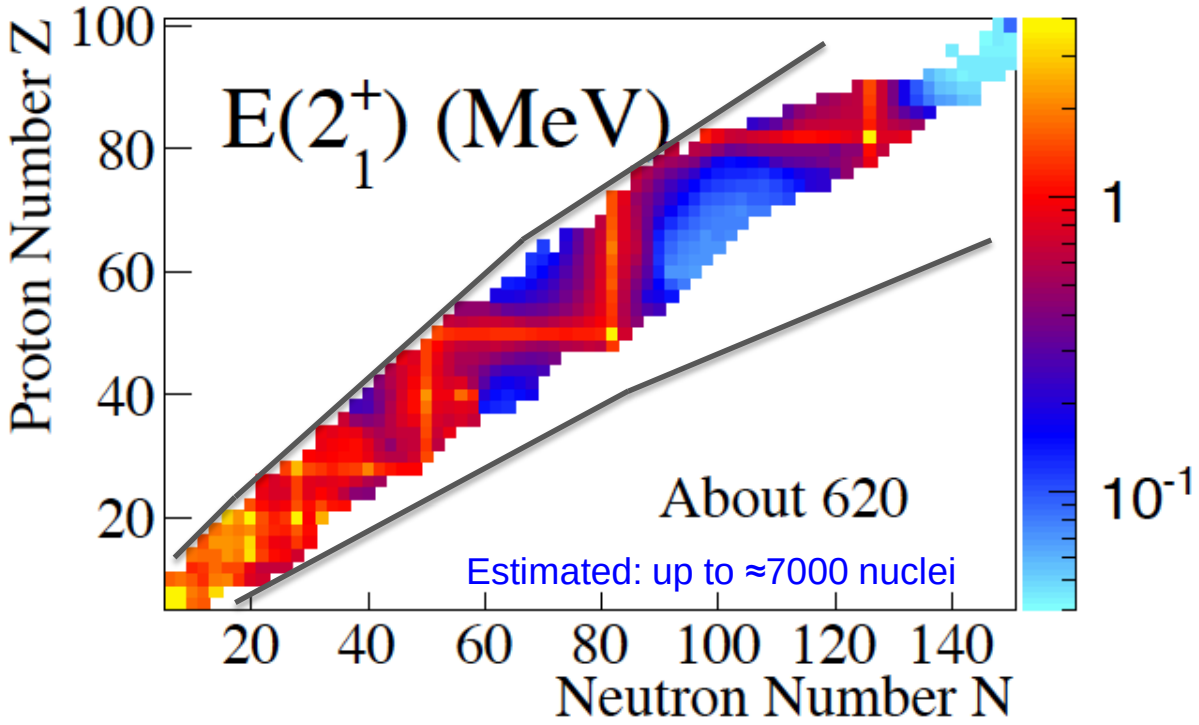
✧ Spectroscopy of exotic nuclei

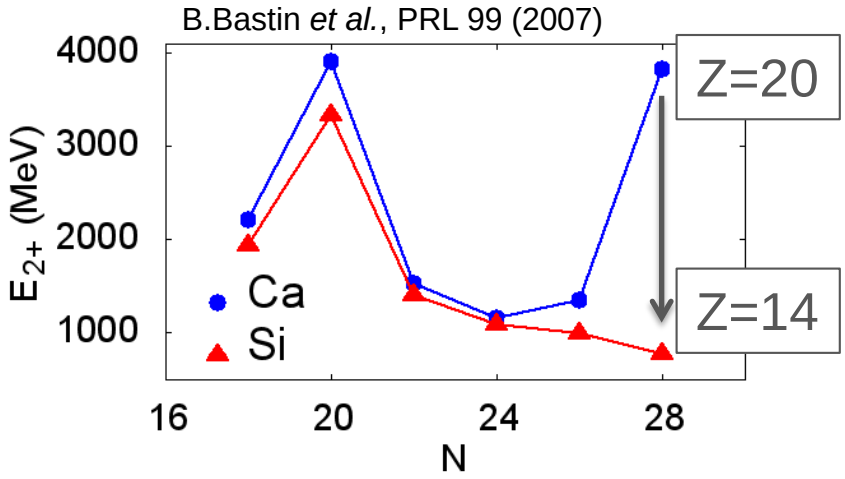
✧ The MINOS device

✧ Physics program at RIBF

- Shell Evolution and Search for Two-plus Energies At the RIBF (May 2014, May 2015)
- 2-neutron correlation in Borromean nuclei (Dec. 2014)
- ^{28}O invariant mass (Nov. 2015)

Spectroscopy of exotic nuclei



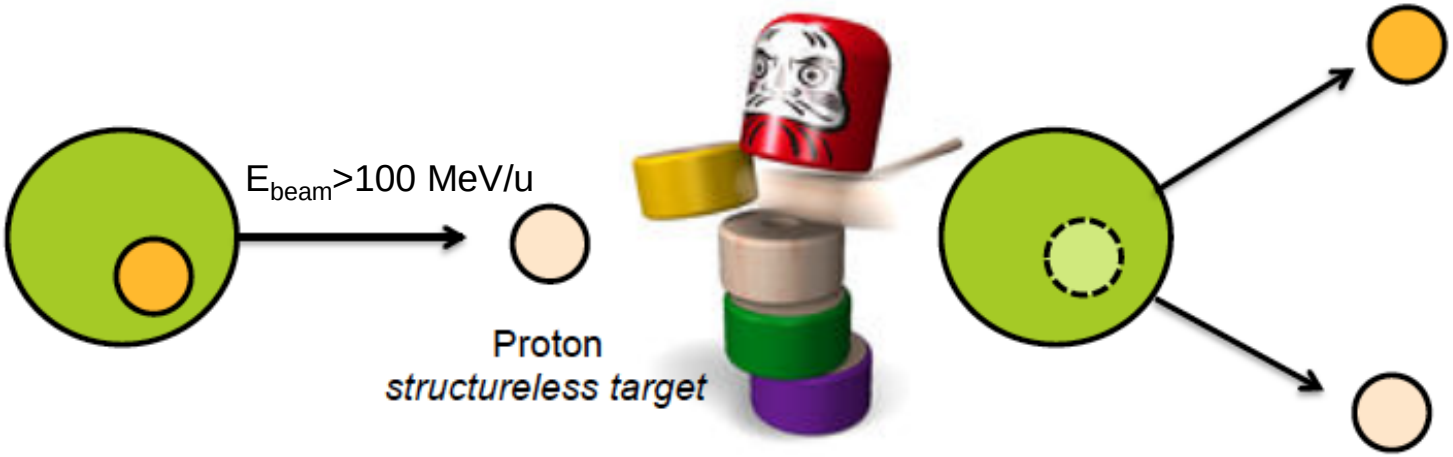


POSSIBLE DRIVING MECHANISMS:

- Central force T. Otsuka *et al.*, PRL 87 (2001)
- Tensor force T. Otsuka *et al.*, PRL 104 (2010)
- 3 body force G. Hagen *et al.*, PRC **80** (2009)

Quasi Free Scattering reactions

QFS is a powerful and clean probe for nuclear structure



Advantages for experiments:

	cleanliness	feasibility
(e,e'p)	++	--
QFS	+	+
knockout	-	+
transfer	+	-

Adapted from I.Sick, ECT*2008

Renewed interest from theory:

- C.Bertulani: Eikonal/PWIA

T. Aumann, C. Bertulani, J. Ryckebush, PRC 88 (2013)

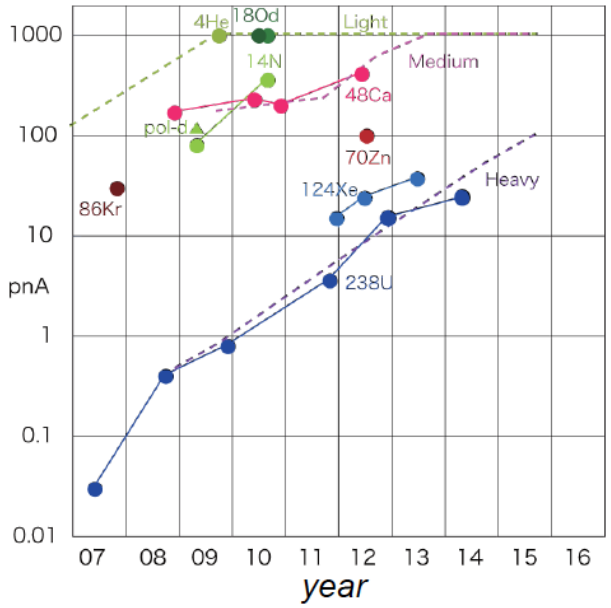
- K.Ogata: DWIA

K. Ogata, K. Yoshida, K. Minomo, arXiv:1505.06624v1 (2015)

- R.Crespo: Faddeev multipole scattering

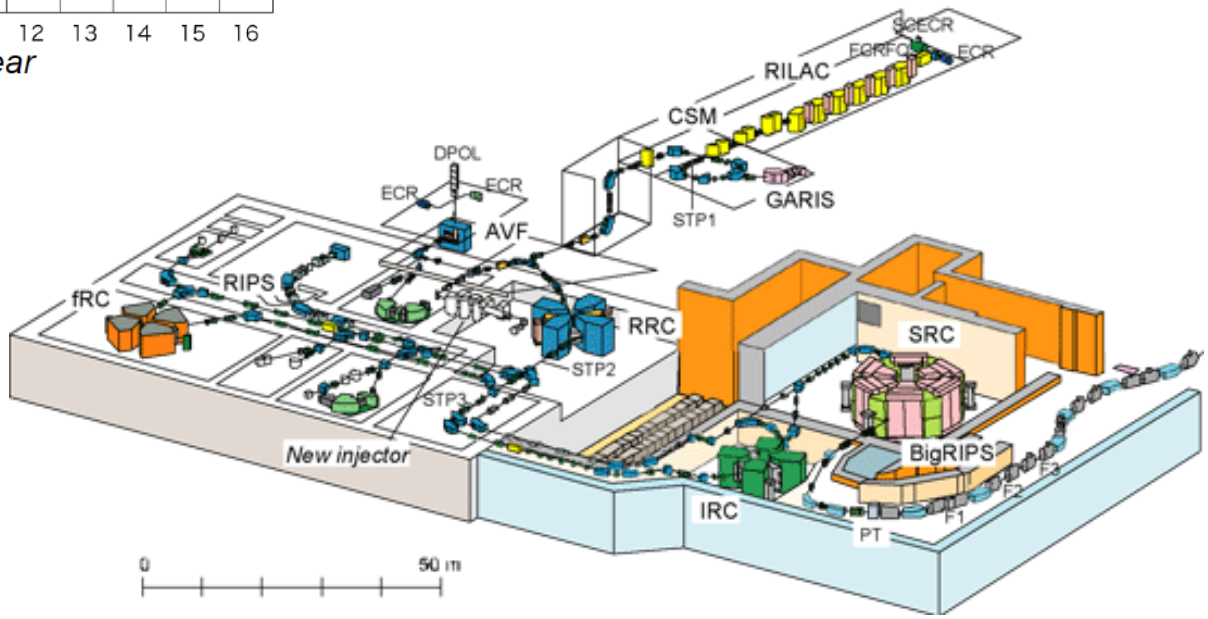
R. Crespo, A. Deltuva and E. Cravo, PRC 90 (2014)

RIBF facility at RIKEN



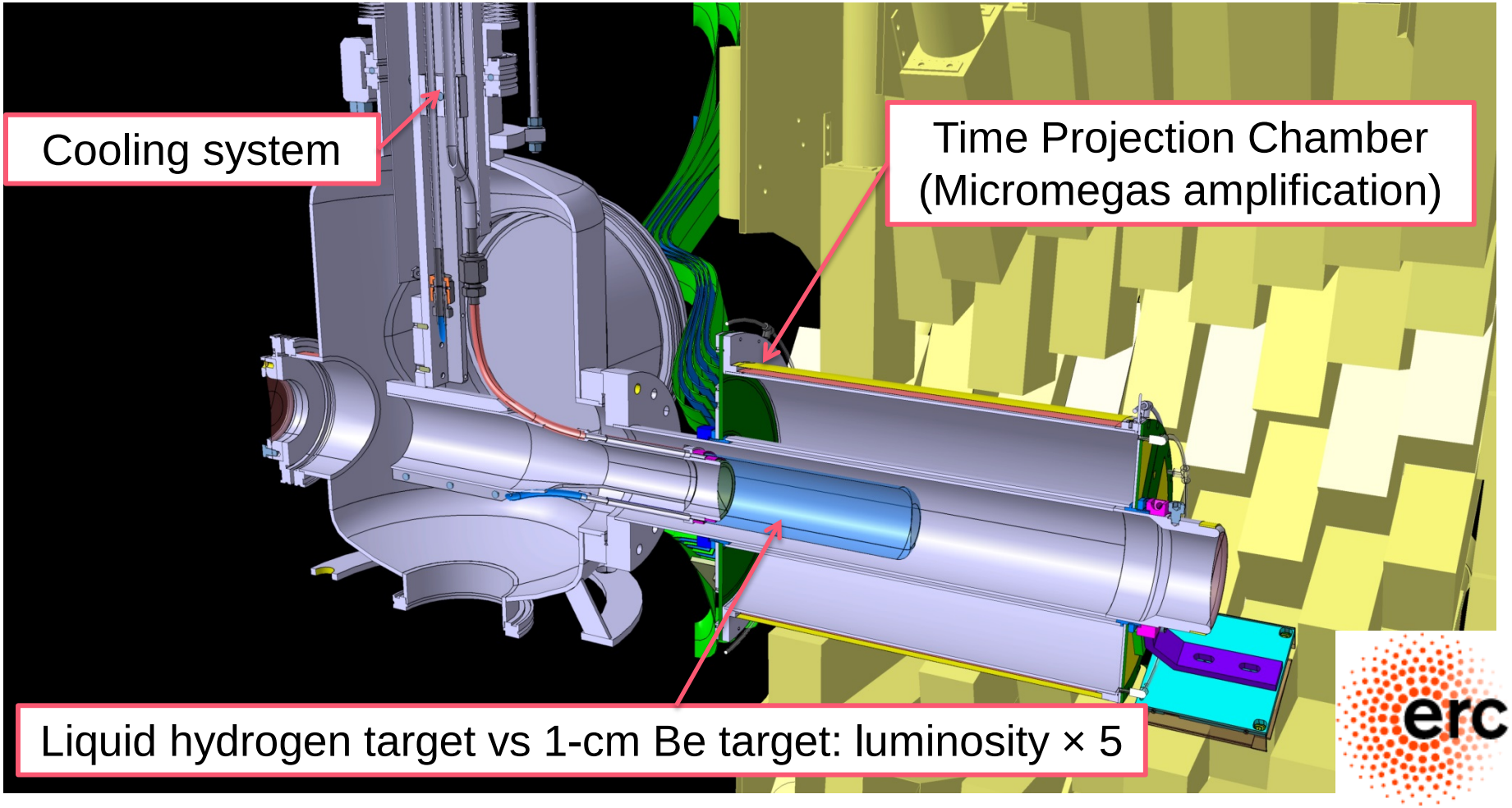
Primary beam	Energy (MeV/u)	Secondary beam (ΔN)	*i* (pps)
^{48}Ca	350	**^{41}Al (14)**	1 *(2014)*
^{70}Zn	350	**^{55}Sc (10)**	12 *(2012)*
^{238}U	350	**^{79}Cu (15)**	5 *(2014)*

ΔN: number of neutrons from the stability



experimental areas

MINOS : Magic Numbers Off Stability

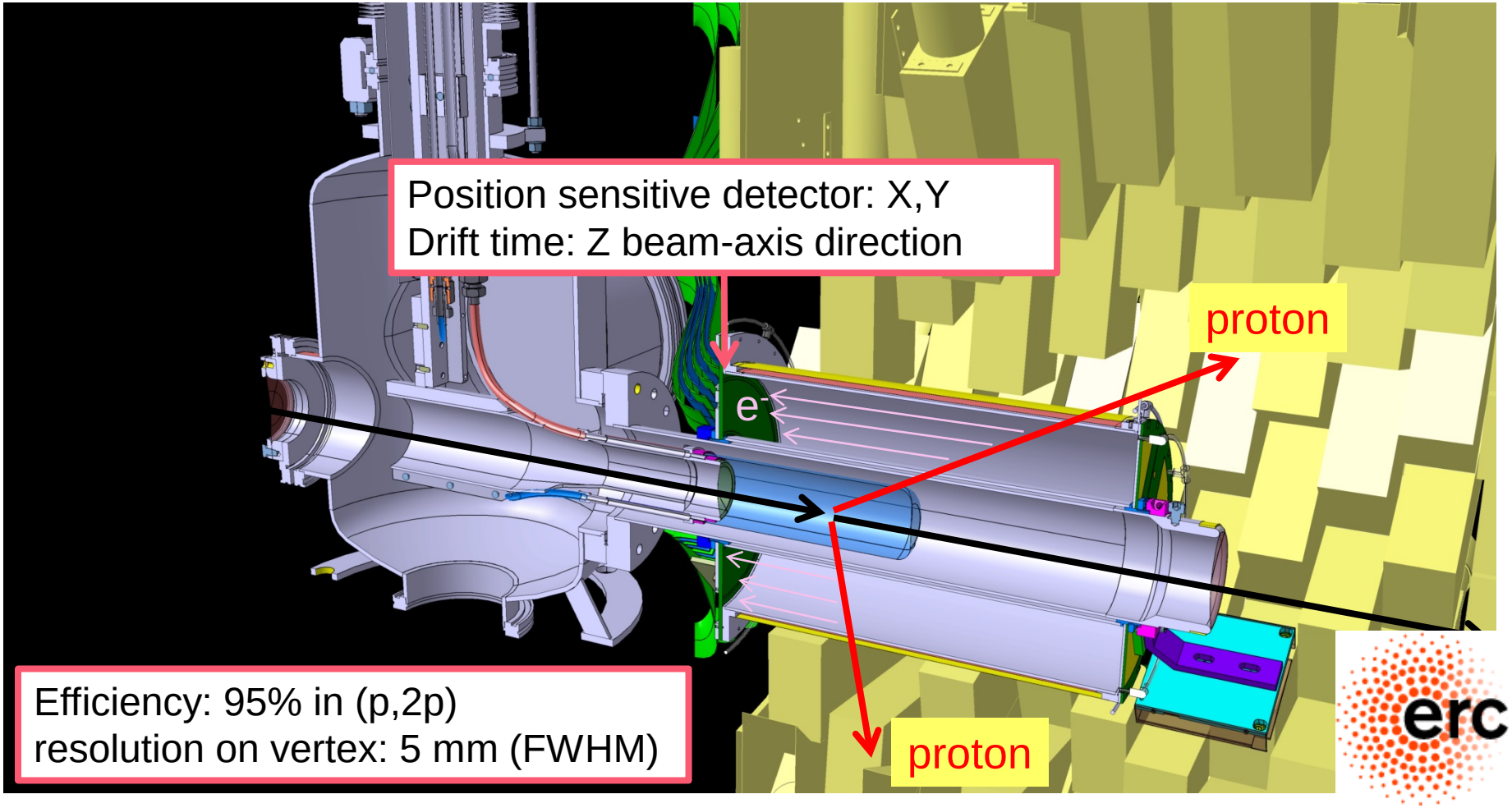


A. Obertelli *et al.,* Eur. Phys. Jour. A **50**, 8 (2014)

http://minos.cea.fr

Hosted by Spin-Isospin Laboratory of RIKEN Nishina Center

MINOS : Magic Numbers Off Stability

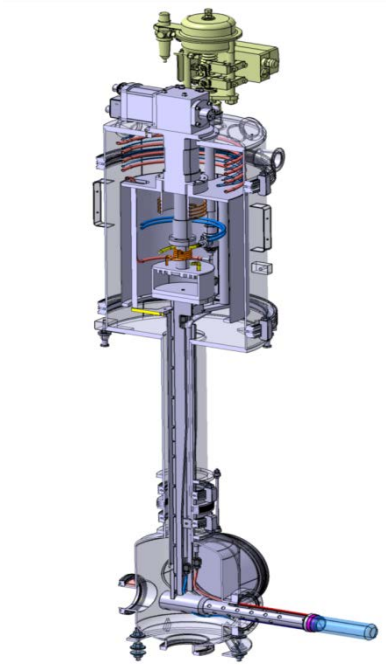


A. Obertelli *et al.,* Eur. Phys. Jour. A **50**, 8 (2014)

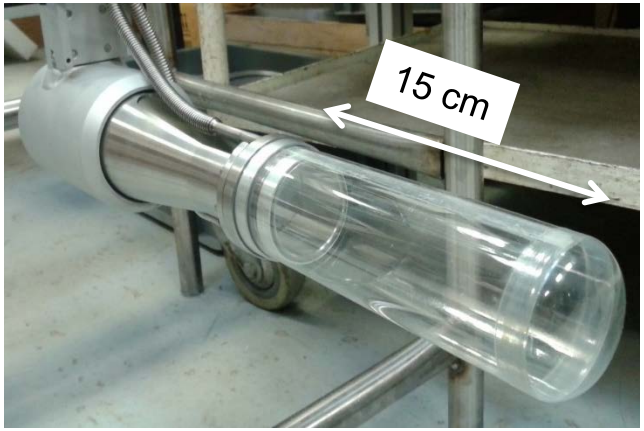
http://minos.cea.fr

Hosted by Spin-Isospin Laboratory of RIKEN Nishina Center

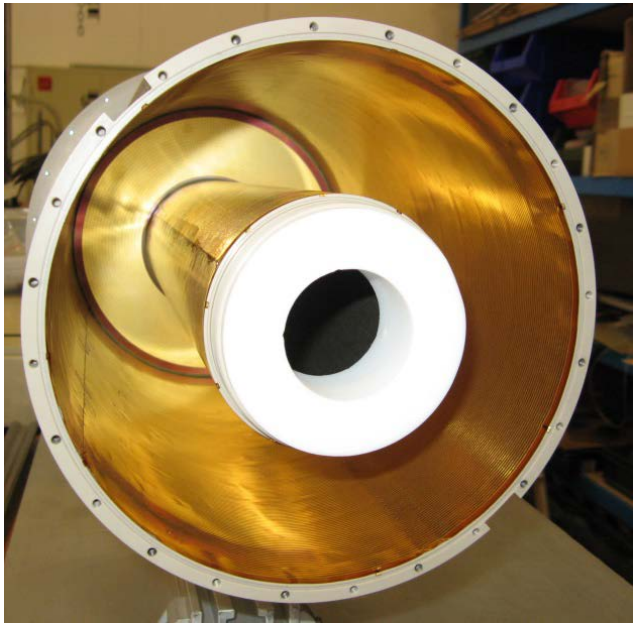
The MINOS device: LH_2 target

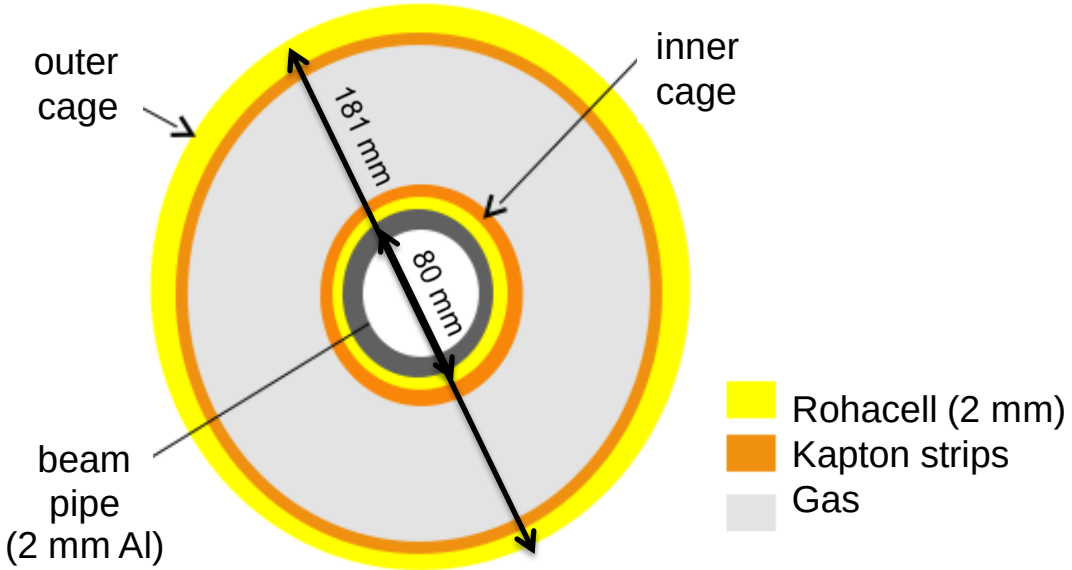


- Mylar cell: 200 microns
- 100-200 mm length **≈ 1 g/cm²**
- 100 mm ↔ E_{loss}=65 MeV/u for 250 MeV/u ^{78}Ni
- 38 mm entrance window



The MINOS device: TPC



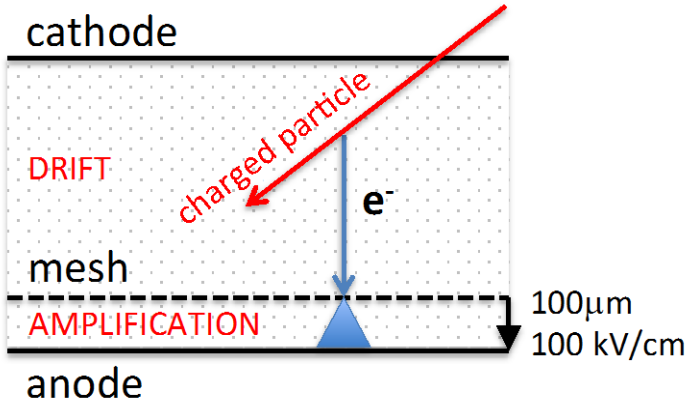


- Compact, low-budget material field cage (see also PANDA TPC, B. Voss et al.)
- Ar (82%) + CF_4 (15%) + C_4H_{10} (3%) gas
- Drift velocity of around 4.5 cm/μs at 180 V/cm
- Transverse diffusion below 200 μm/√cm

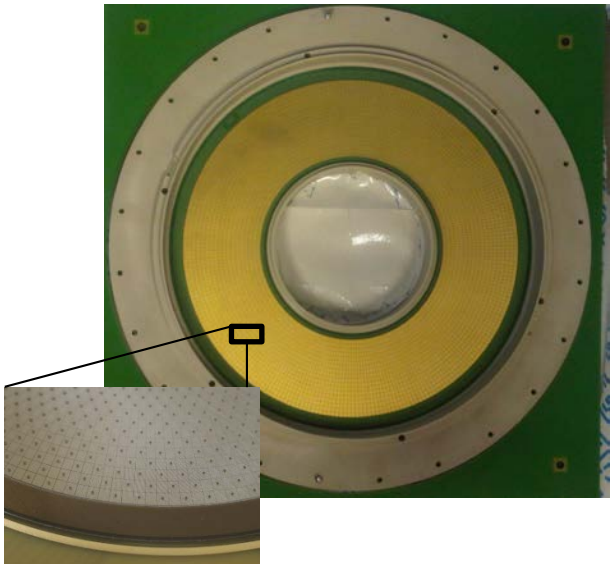
The MINOS device: TPC

Micromegas detector with ~4000 pads

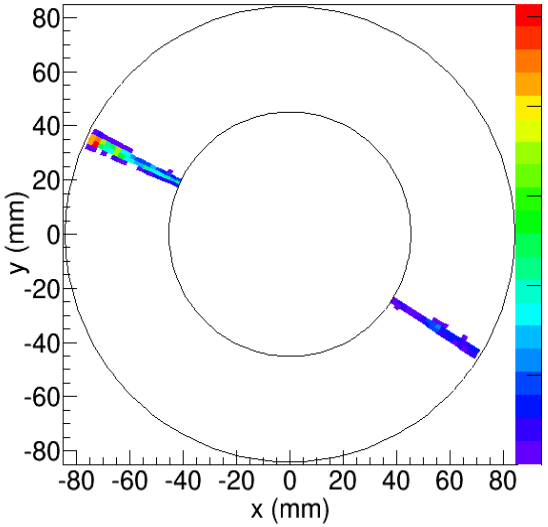
G. Charpak, I. Giomataris, *et al.*, NIMA 376, 29 (1996).

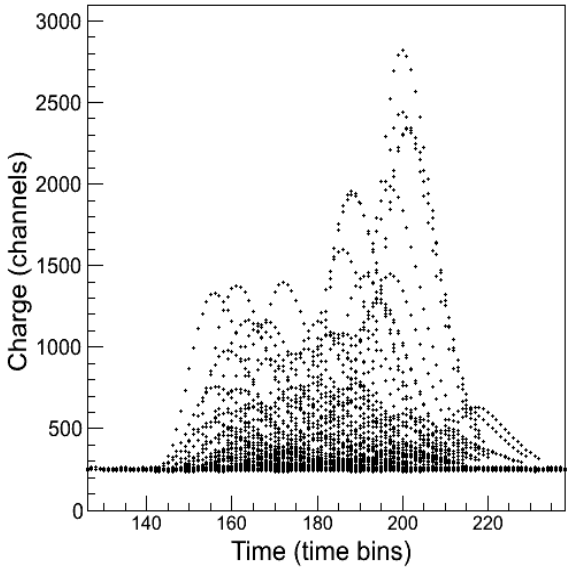


Micromegas detector



Typical track in (p,2p) event



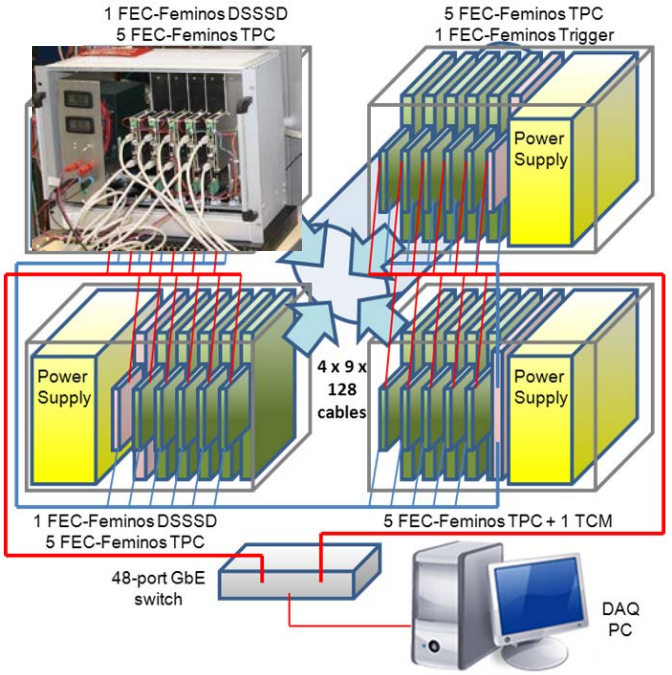


GET: Generic Electronics for TPC

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

The MINOS device: electronics

- Self of External **trigger**
- Rate up to **1 kHz**
- Average **dead time ~80 μs**
- Dedicated DAQ software

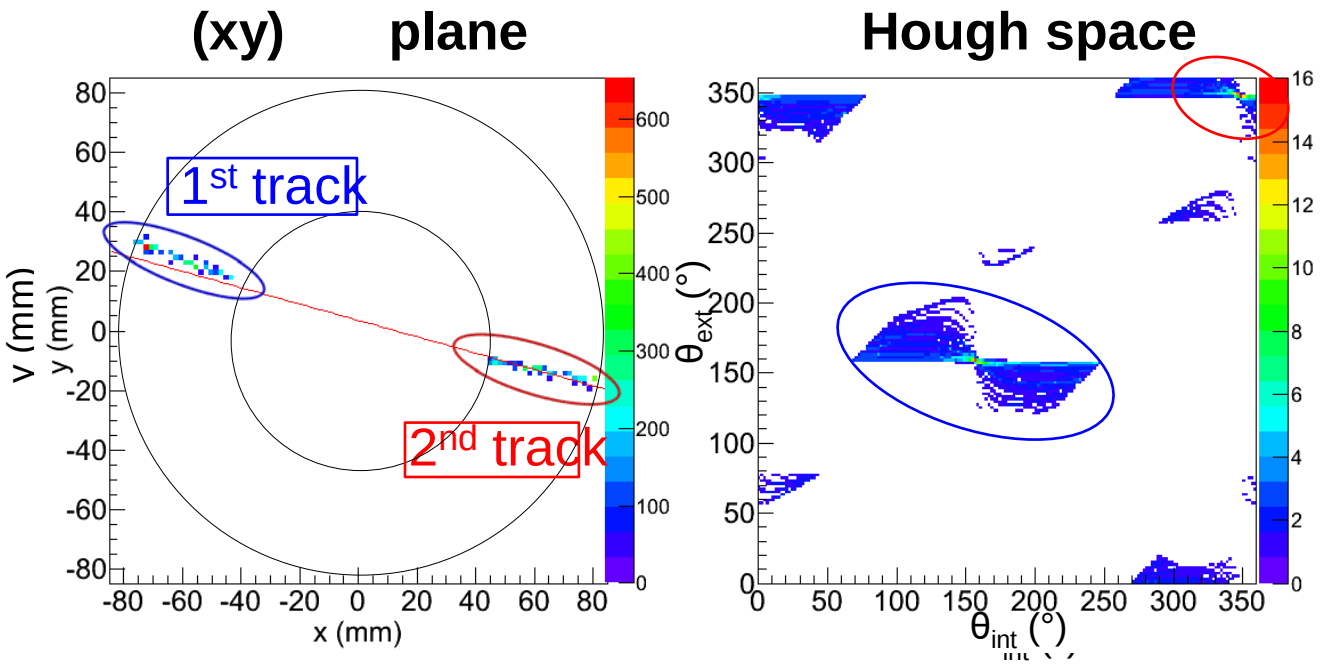


Tracking algorithm

Hough transform: pattern extraction technique

✓ Fast algorithm

✓ Pattern recognition & track fitting



In-beam test of the TPC at HIMAC

October 2013

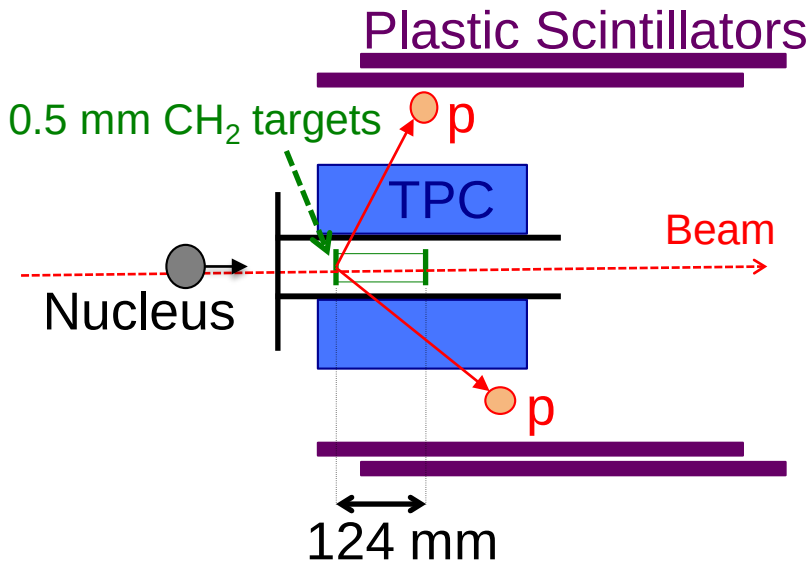
HIMAC accelerator @ Chiba, Japan

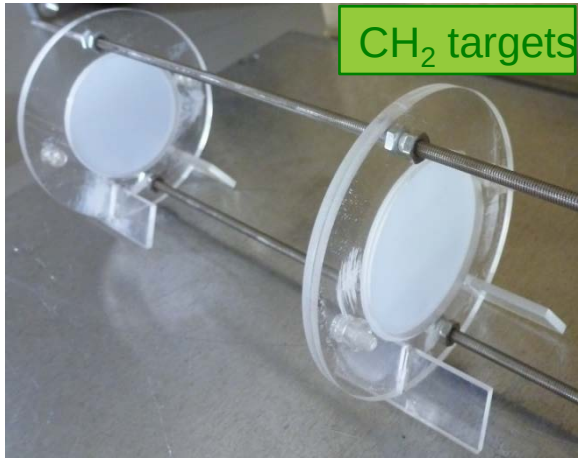
Beams :

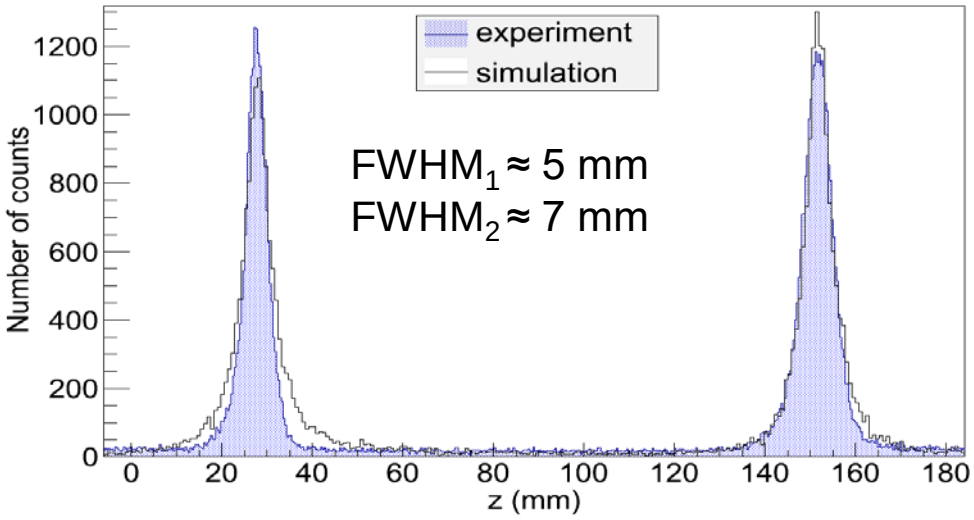
- ^{20}Ne @ 350 and 180 MeV/nucleon
- ^{4}He @ 200 MeV/nucleon

Target: 1 mm CH_2

C.Santamaria *et al.*, in preparation

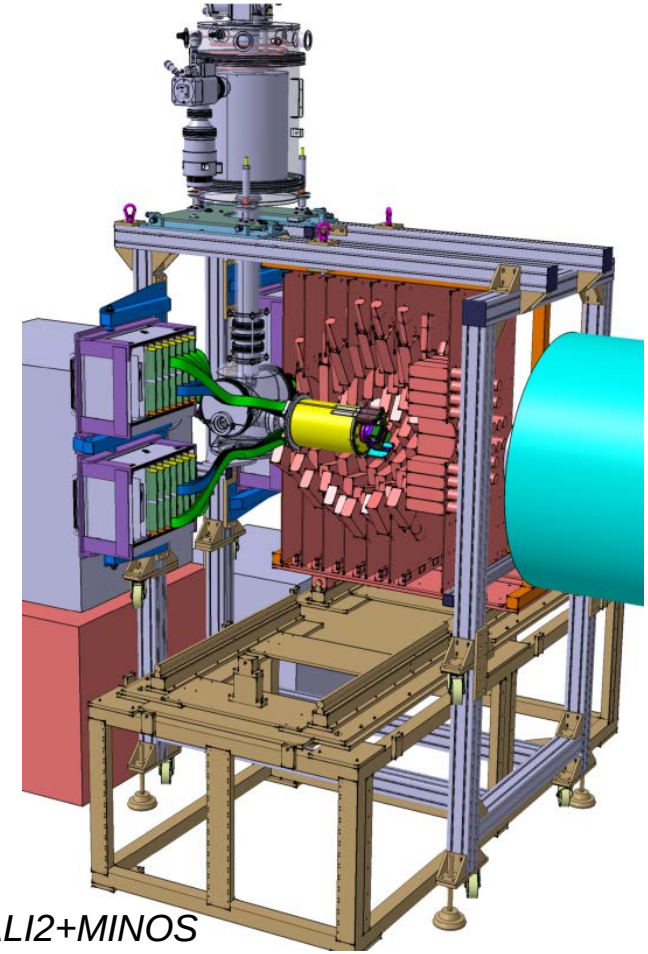






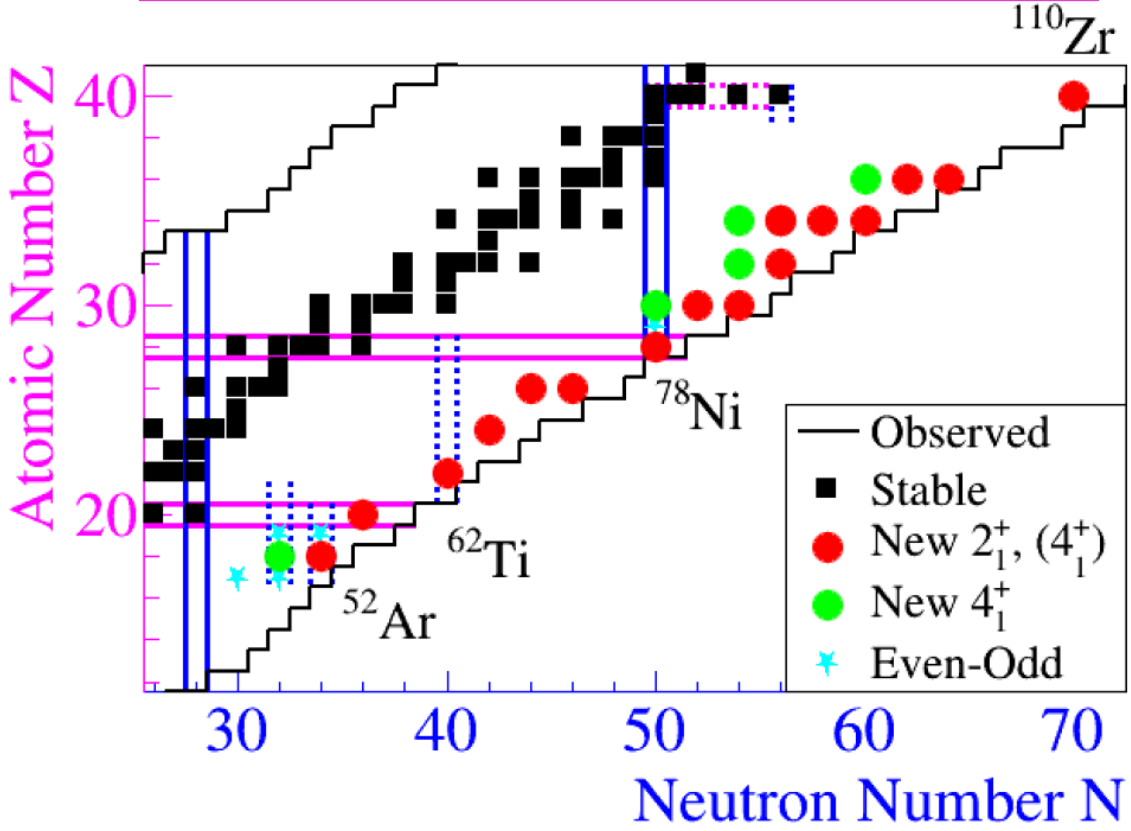
Shell Evolution and Search for Two-plus Energies At the RIBF (SEASTAR)

Spokespersons: P. Doornenbal (RIKEN), A. Obertelli (CEA)



DALI2+MINOS

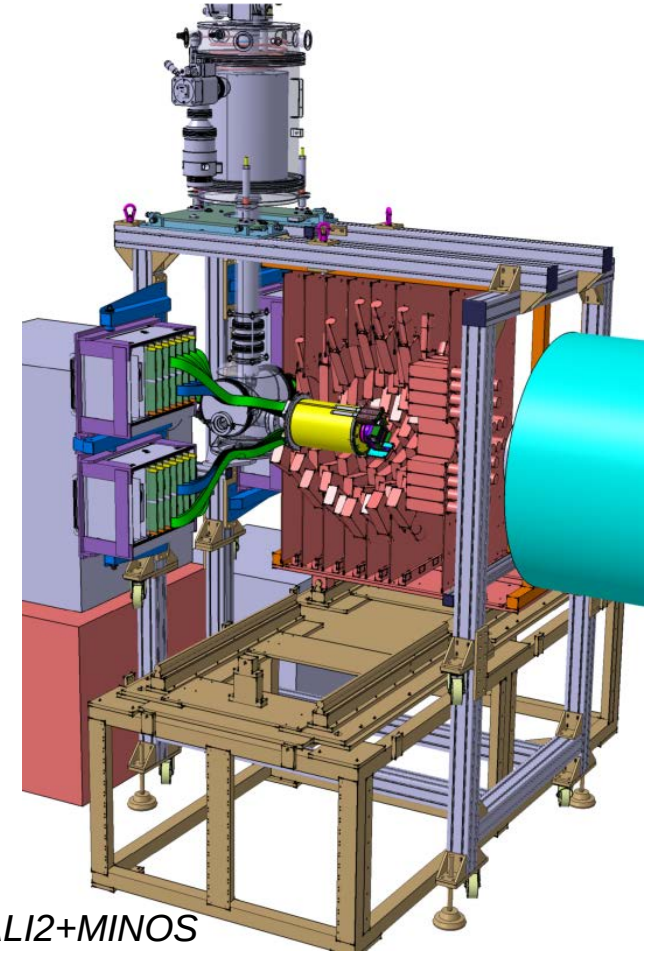
Full program: 30 days of beam time



Proposal for a Scientific Program promoted by H.Sakurai (RNC, Univ. of Tokyo) and T.Uesaka (RNC)

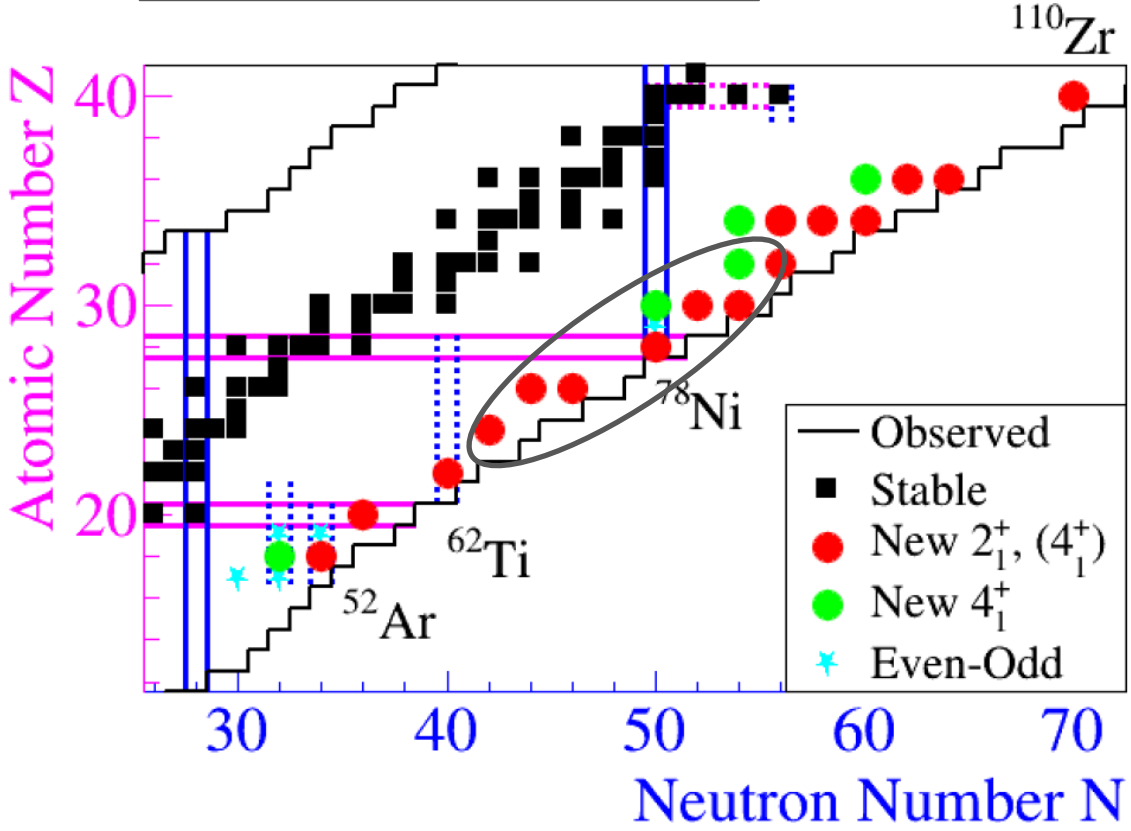
Shell Evolution and Search for Two-plus Energies At the RIBF (SEASTAR)

Spokespersons: P. Doornenbal (RIKEN), A. Obertelli (CEA)



DALI2+MINOS

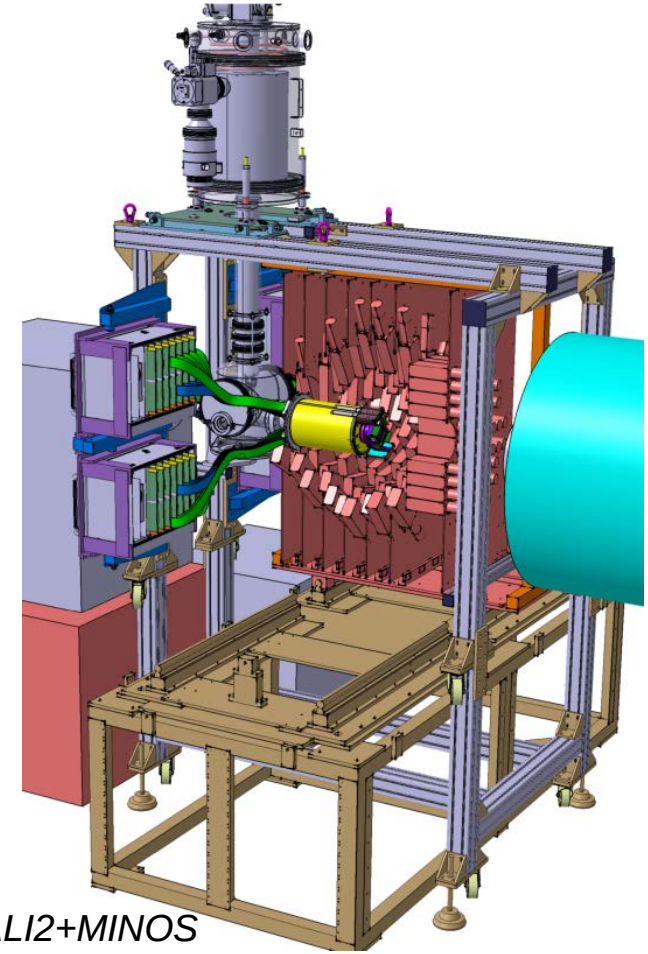
SEASTAR 1, May 2014



Proposal for a Scientific Program promoted by H.Sakurai (RNC, Univ. of Tokyo) and T.Uesaka (RNC)

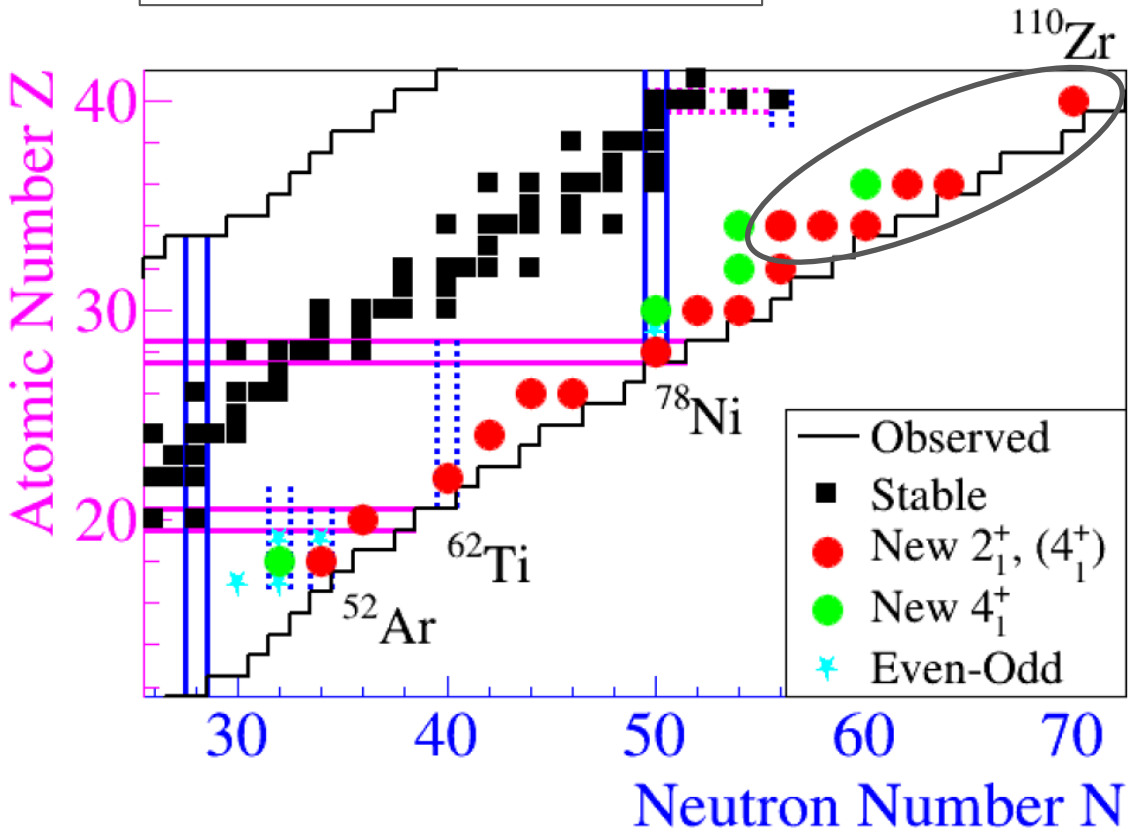
Shell Evolution and Search for Two-plus Energies At the RIBF (SEASTAR)

Spokespersons: P. Doornenbal (RIKEN), A. Obertelli (CEA)



DALI2+MINOS

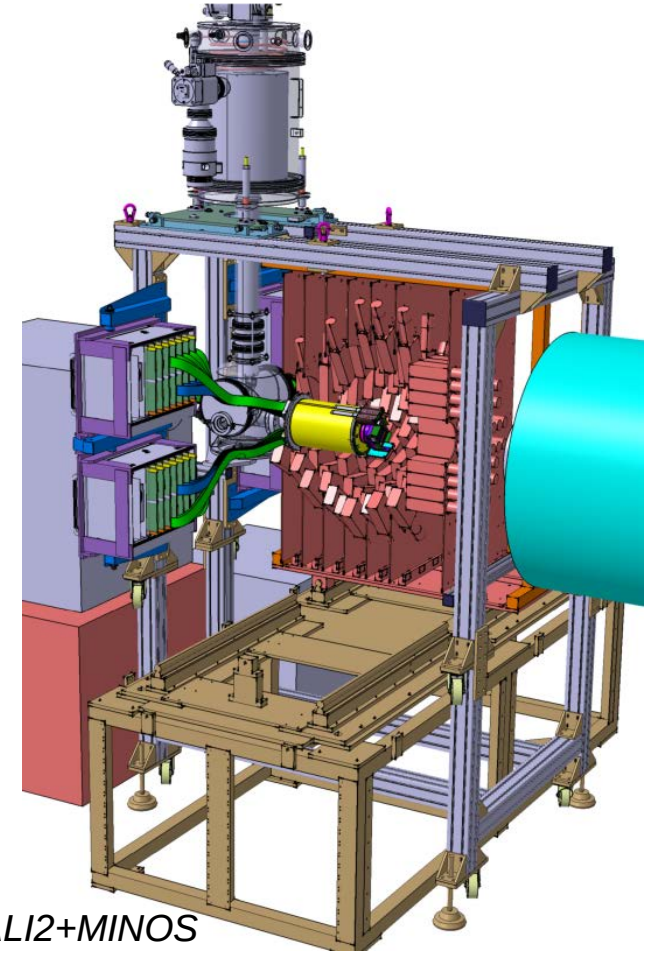
SEASTAR 2: May 2015



Proposal for a Scientific Program promoted by H.Sakurai (RNC, Univ. of Tokyo) and T.Uesaka (RNC)

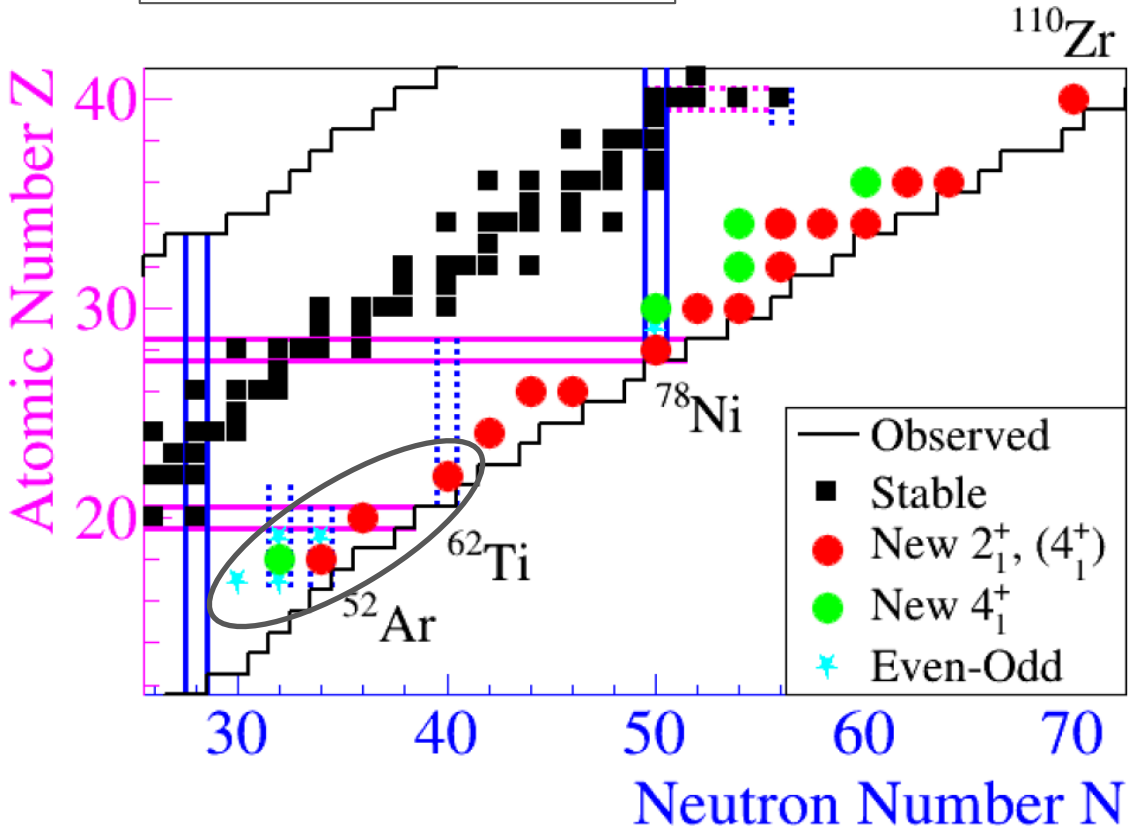
Shell Evolution and Search for Two-plus Energies At the RIBF (SEASTAR)

Spokespersons: P. Doornenbal (RIKEN), A. Obertelli (CEA)



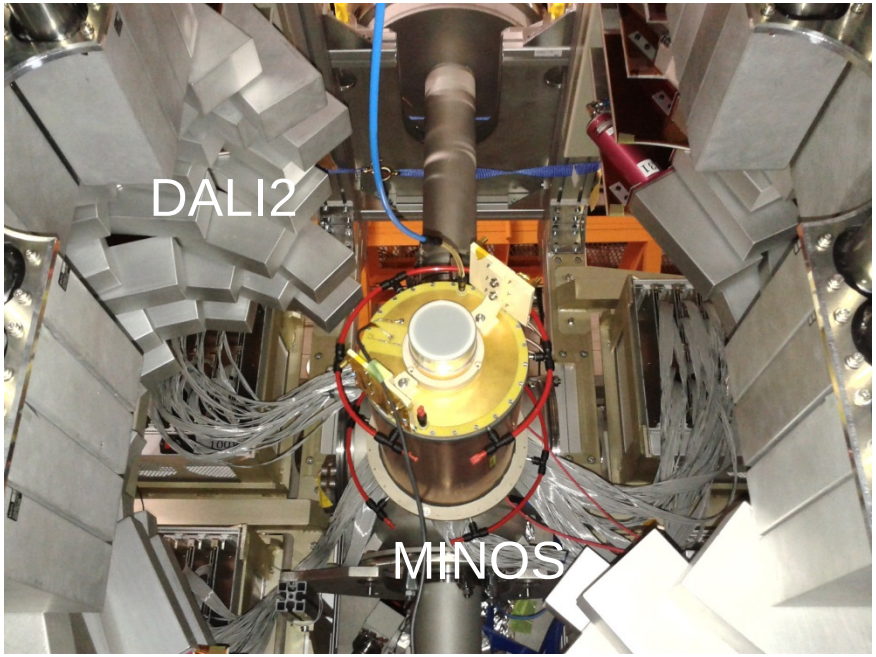
DALI2+MINOS

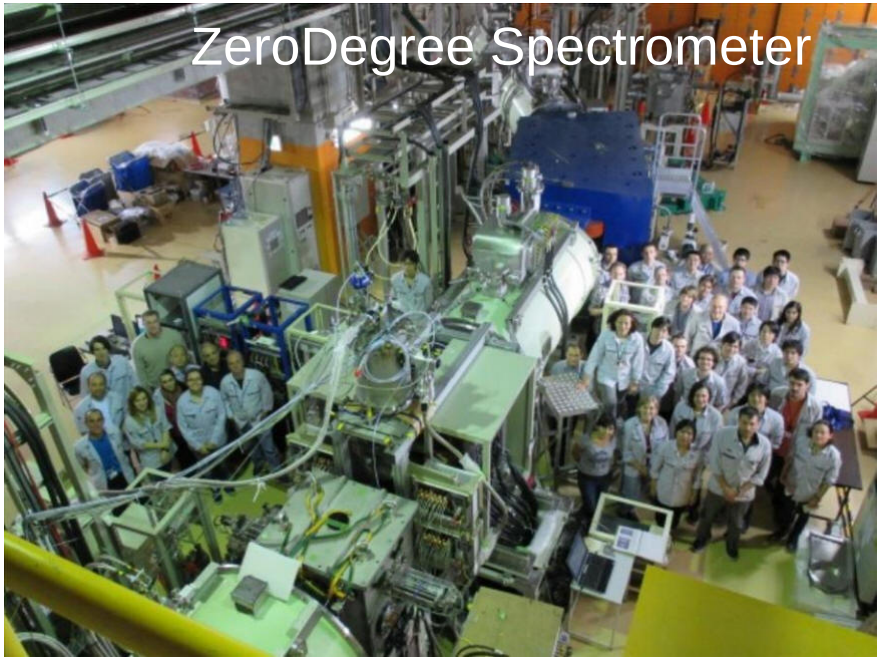
SEASTAR 3: 2016?

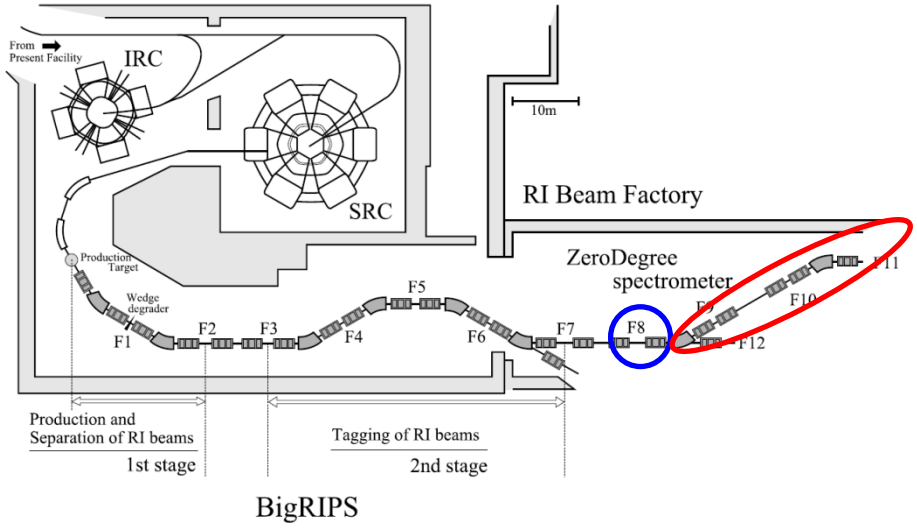


Proposal for a Scientific Program promoted by H.Sakurai (RNC, Univ. of Tokyo) and T.Uesaka (RNC)

DALI2-MINOS-ZeroDegree setup







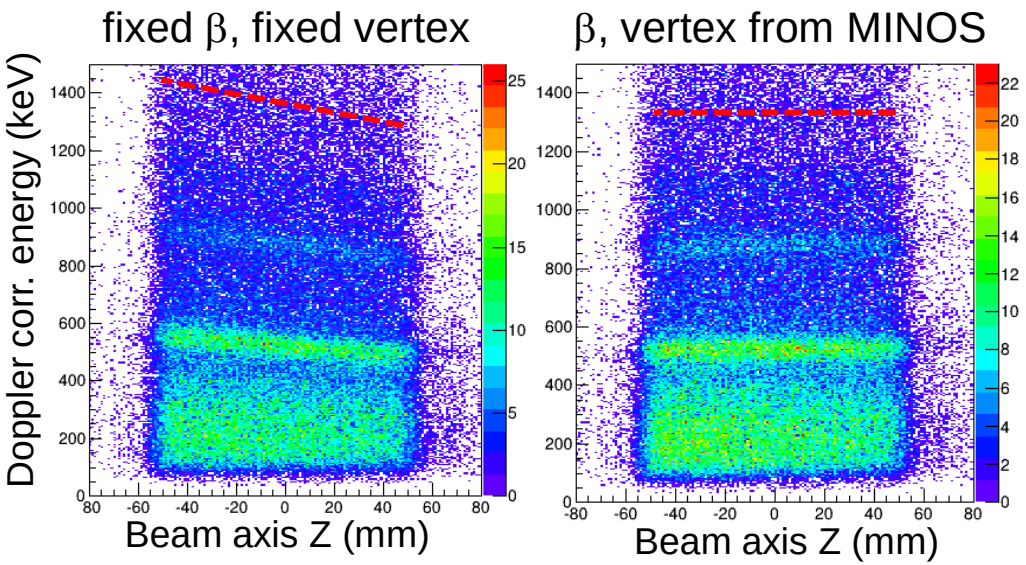
ZeroDegree Spectrometer

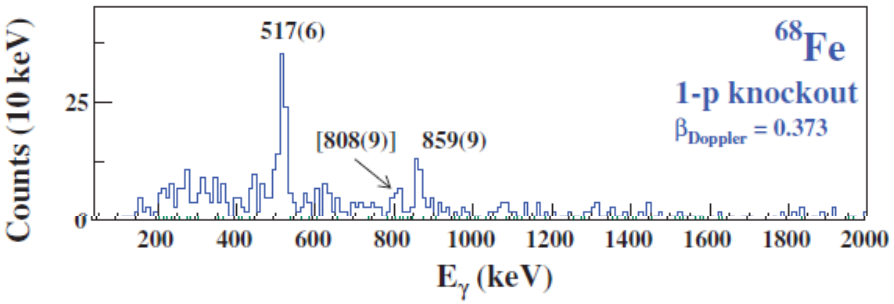
- Momentum acceptance: ±3%
- High resolution: P/DP≈6000

DALI2

- 186 NaI(Tl) crystals
- ε=20% and $\Delta E/E$=10% @ 1 MeV and β=0.6

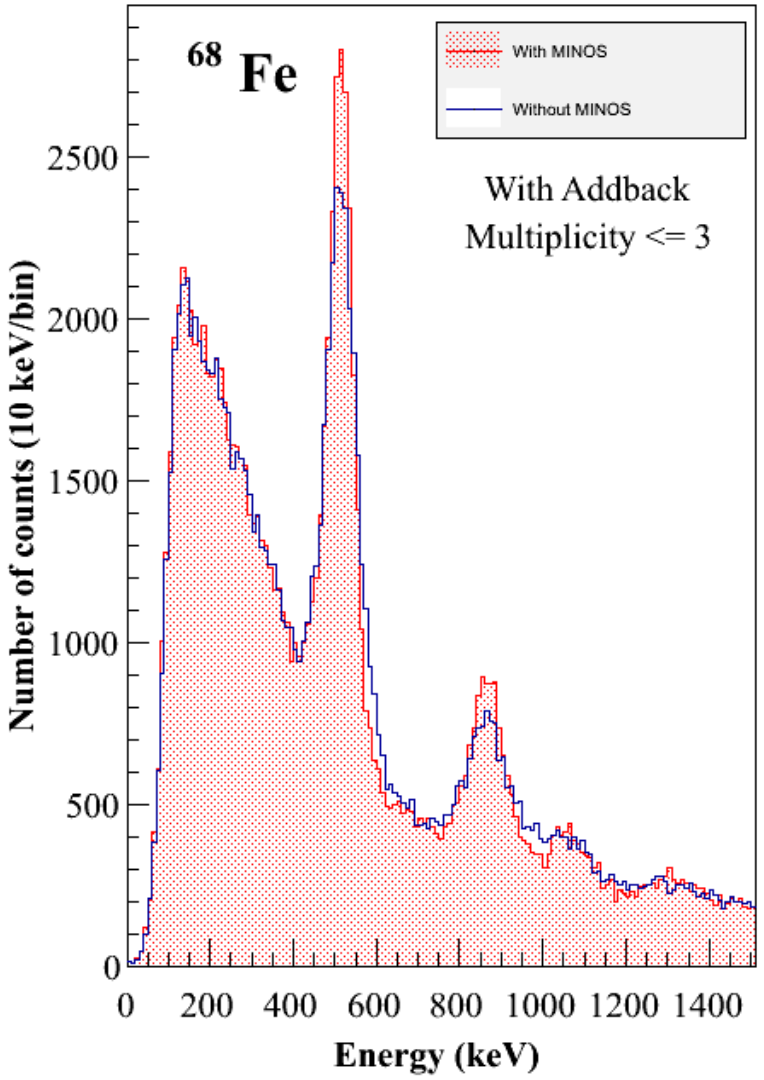
^{69}Co(p,2p)^{68}Fe @ 200 MeV/u: proof of principle





P. Adrich *et al.*, PRC **77**, 054306 (2007)

Cr setting: ^{69}Co (p,2p) ^{68}Fe



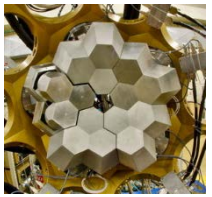
Resolution in in-beam gamma spectroscopy

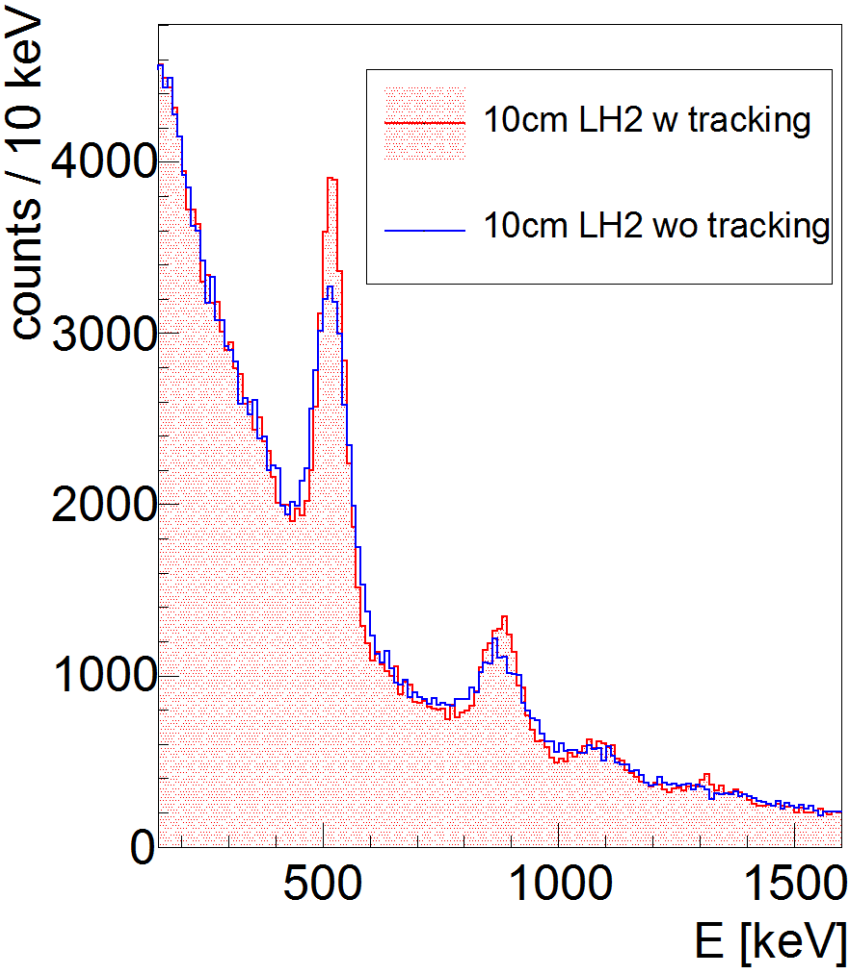
DALI2

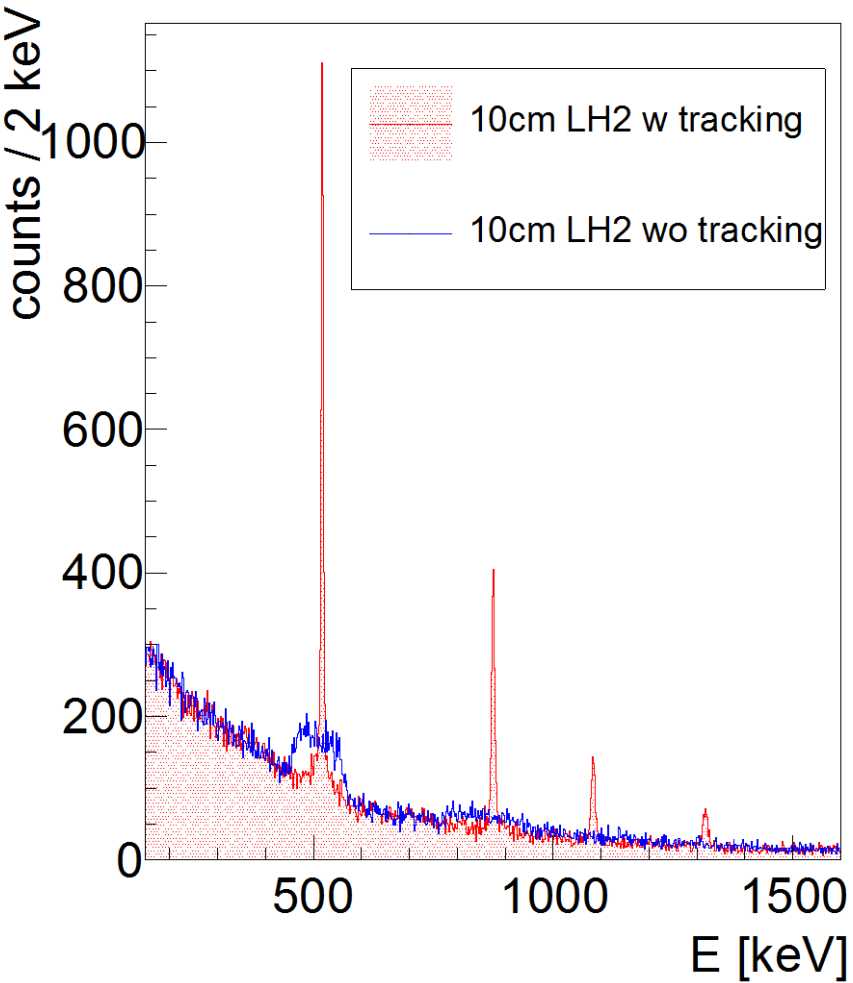
Simulation at 250 MeV/u

AGATA

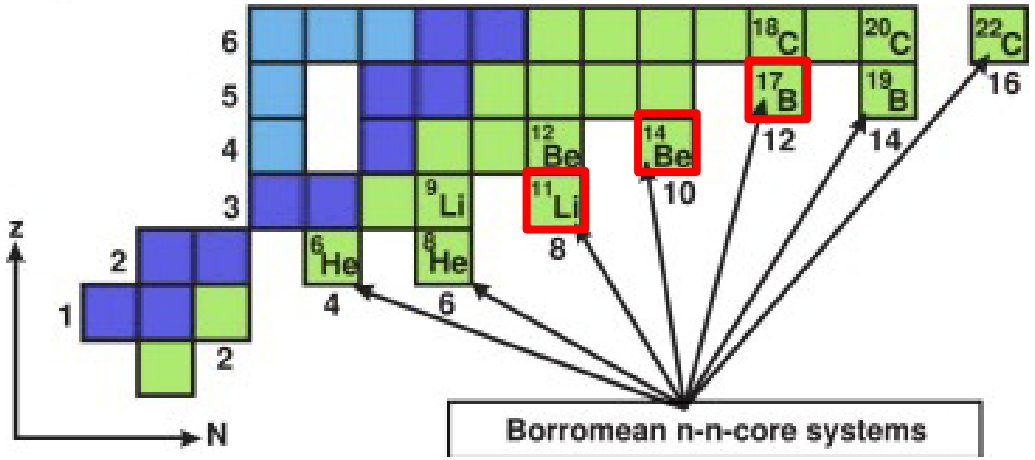
Simulation at 250 MeV/u
5T+5D AGATA clusters

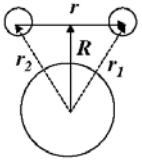




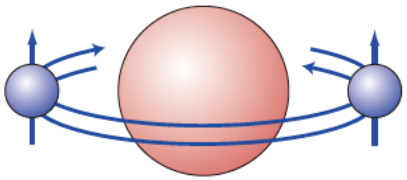


Study of dineutron correlation at SAMURAI

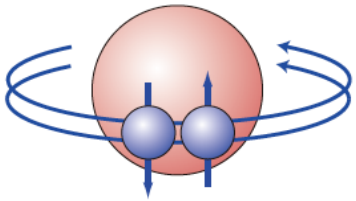


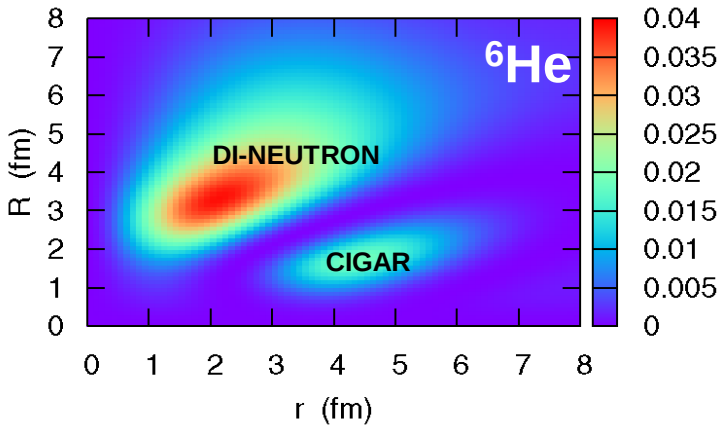


cigar (BCS like)



di-neutron (BEC like)

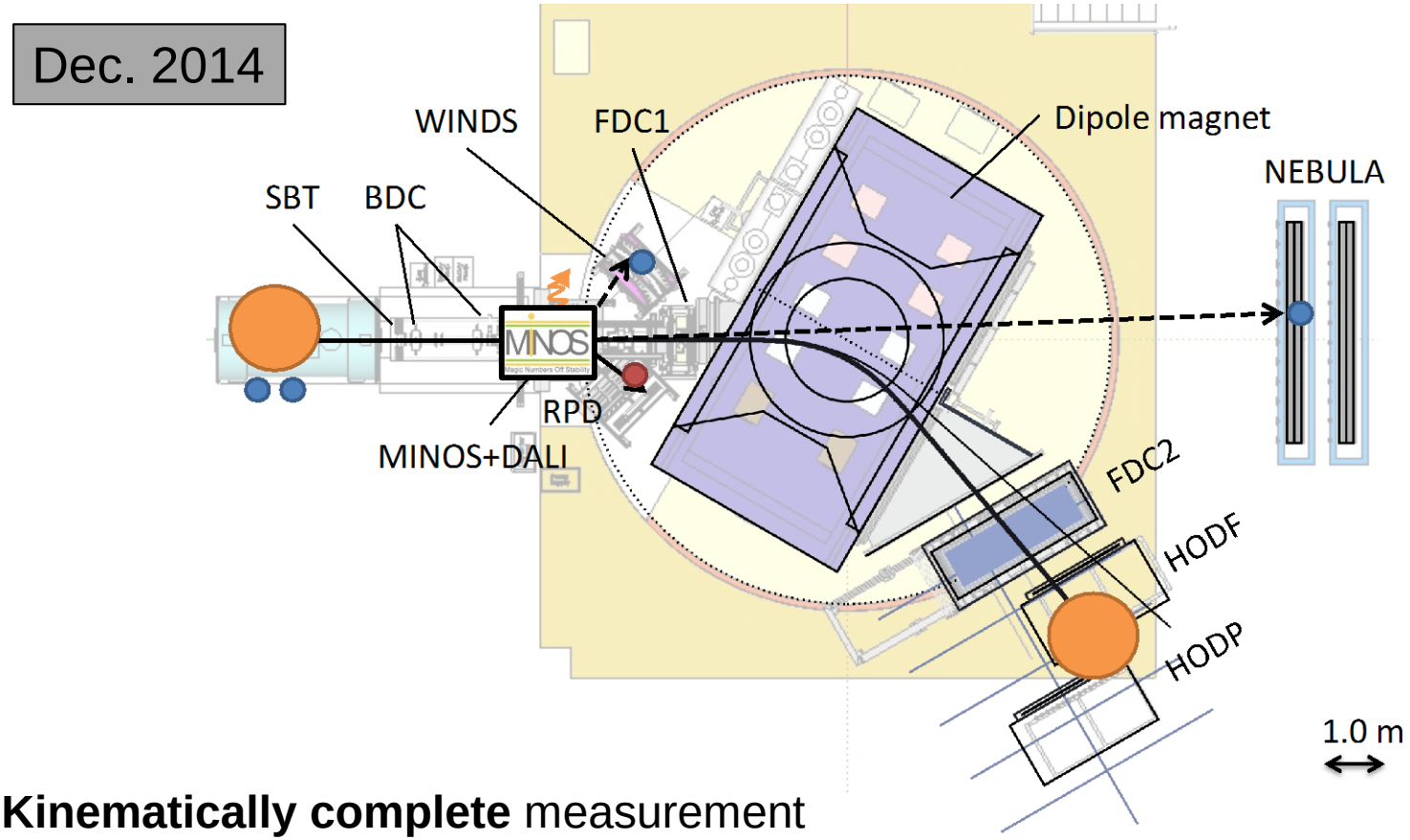




Hagino et al., PRL 99 (2007)

Study of dineutron correlations at SAMURAI

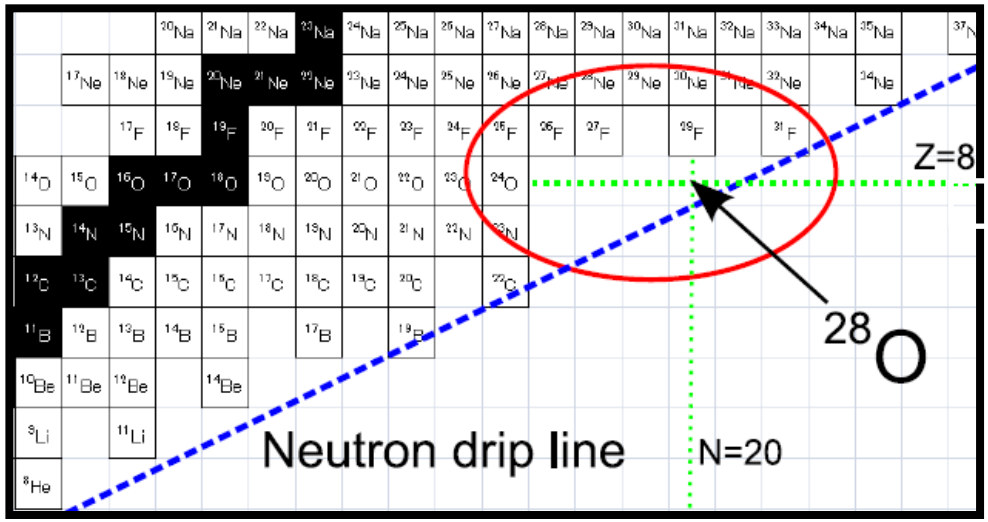
Spokespersons: Y.Kubota (CNS, RNC) and AC (CEA Saclay)

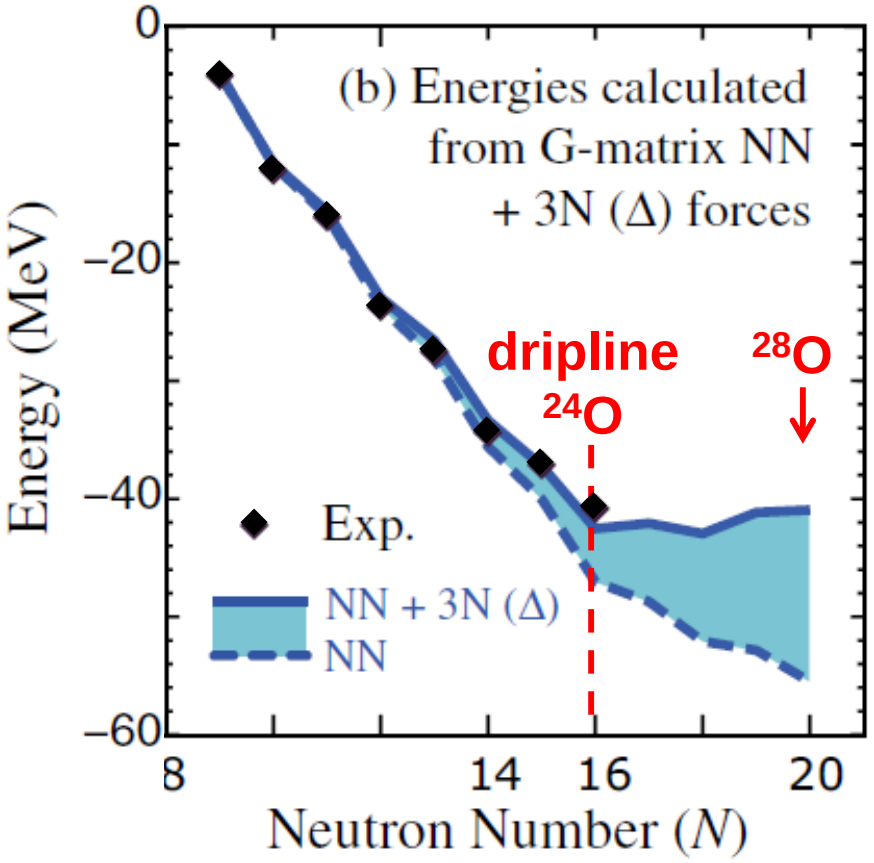


- **Kinematically complete** measurement
- Core excitation via γ detection
- High momentum transfer to **minimize final state interaction**

  ➔ Need high statistics : RIBF + MINOS thick target (15 cm)

Spectroscopy of ^{28}O at SAMURAI





Benchmark for 3N forces

T. Otsuka *et al.,* PRL **105**, 032501 (2010)
G. Hagen *et al.,* PRC **80**, 021306(R) (2009)
A. Cipollone *et al.,* PRL **111**, 062501 (2013)
H. Hergert *et al.,* PRL **110**, 242501 (2013)

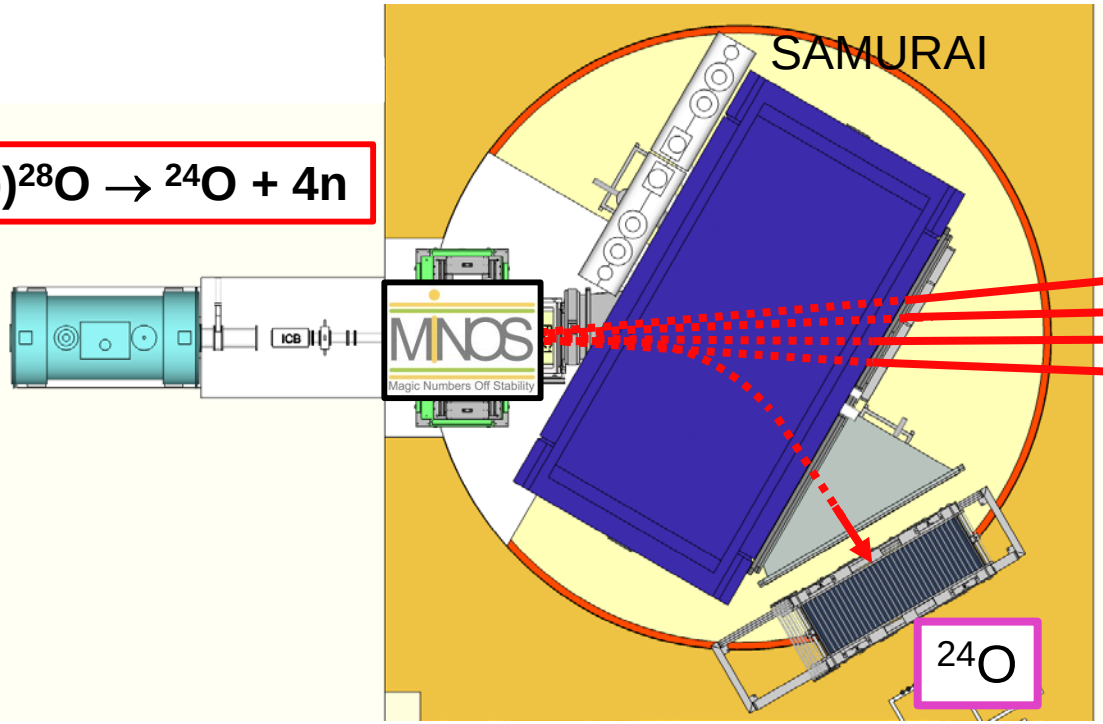
Spctroscopy of ^{28}O at SAMURAI

Spokesperson: Y. Kondo, Tokyo Institute of Technology

Nov. 2015

ε_{4n} = 0.8%
for E_{decay} = 4 MeV
with 3 detection layers

^{29}F(p,2p)^{28}O → ^{24}O + 4n



- Need high luminosity ➔ RIBF+MINOS thick target
- Vertex tracking: improve decay energy resolution

Summary and perspectives

MINOS developed in 2011-2012 at CEA Saclay

Current MINOS program @ RIBF:

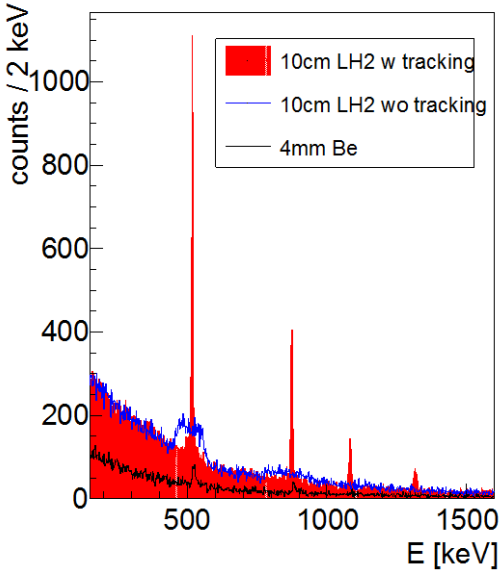
- New regions and methodologies explored in 2014-2015:

  N=20, N=34, N=50&Z=28, N=70, dineutron correlation

- Approved physics program up to 2016

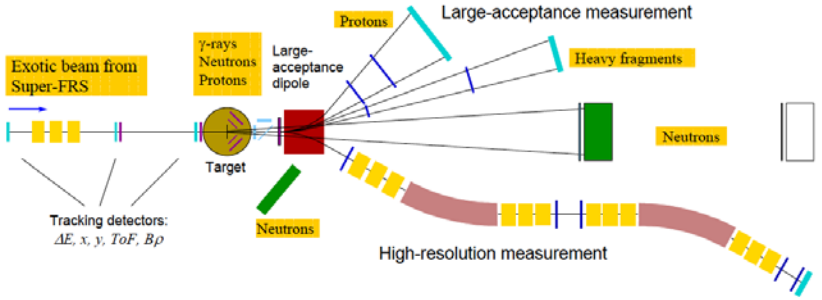
Beyond this program:

- High-resolution gamma spectroscopy with AGATA, GRETINA,..



- Missing+invariant mass measurement

R^{3}B @ FAIR



Collaborations

MINOS development and local teams

S. Anvar, L. Audirac, G. Authelet, H. Baba, B. Bruyneel, D. Calvet, F. Chateau, A. Corsi, A. Delbart, P. Doornenbal, J.-M. Gheller, A. Giganon, T. Isobe, Y. Kubota, C. Lahonde-Hamdoun, D. Leboeuf, D. Loiseau, M. Matsushita, A. Mohamed, J.-Ph. Mols, T. Motobayashi, M. Nishimura, A. Obertelli, S. Ota, H. Otsu, C. Péron, A. Peyaud, E.C. Pollacco, G. Prono, J.-Y. Rousse, H. Sakurai, C. Santamaria, M. Sasano, R. Taniuchi, S. Takeuchi, T. Uesaka, Y. Yanagisawa, K. Yoneda

Physics collaborations

Di-neutron correlations Uesaka, Sasano, Zenihiro, Yoneda, Sato, Otsu, Shimizu, Baba, Isobe, Sako, Stul, Panin (RNC), **Kubota**, Dozono, Ota, Kobayashi M., Kiyokawa (CNS), **Corsi**, Obertelli, Santamaria, Pollacco, Lapoux, Gillibert, Calvet, Delbart, Gheller, Authelet, Roussé (CEA), Kobayashi N., Koyama, Miyazaki (Tokyo Univ.), Kobayashi T., Hasegawa, Sumikama (Tohoku Univ.), Nakamura, Kondo, Togano, Shikata, Tsubota, Saito, Ozaki (Tokyo Tech), Yasuda, Sakaguchi, Shindo, Tabata, Ohkura, Nishio (Kyushu Univ.), Nakatsuka (Kyoto Univ.),Yukie, Kawakami, Kanaya (Miyazaki Univ.), Marques, Gibelin, Orr (LPC Caen), Flavigny (IPNO), Yang, Feng (Peking Univ.), Caesar, Paschalis (TUD), Reichert (TUM), Kim (Ehwa Womans University)

Oxygen isotopes Y. Kondo, T. Nakamura, Y. Togano, M. Shikata, J. Tsubota (Tokyo Tech), H. Baba, H. Sato, K. Yoneda, H. Otsu, T. Isobe, M. Sasano, Y. Shimizu, T. Uesaka (RIKEN Nishina Center), T. Kobayashi (Tohoku University), F. Château, D. Calvet, A. Gillibert, J.-M. Gheller, V. Lapoux, A. Peyaud, A. Obertelli, A. Corsi, E.C. Pollacco, C. Santamaria (CEA Saclay), T. Aumann, H. Scheit (TU Darmstadt), N. Orr, J. Gibelin, F.M. Marques, S. Leblond, N.L. Achouri, F. Delaunay (LPC Caen), Y. Satou, S. Kim, J. Hwang (Seoul National University), T. Murakami, N. Nakatsuka (Kyoto University), C.R. Hoffman (Argonne National Laboratory), A. Navin, M. Rejmund, A. Lemasson (GANIL), S. Stephenson (Gettysburg college), H. Simmon (GSI)

SEASTAR N. Alamanos, G. de Angelis, N. Aoi, H. Baba, C. Barbieri, C. Bertulani, A. Corsi, F. Delaunay, Z. Dombradi, **P. Doornenbal**, T. Duguet, S. Franchoo, J. Gibelin, A. Gillibert, S. Go, M. Gorska, A. Gottardo, S. Grévy, J.D. Holt, E. Ideguchi, T. Isobe, A. Jungclaus, N. Kobayashi, T. Kobayashi, Y. Kondo, W. Korten, Y. Kubota, I. Kuti, V. Lapoux, S. Leblond, J. Lee, S. Lenzi, H. Liu, G. Lorusso, C. Louchart, R. Lozeva, F.M. Marques, I. Matea, K. Matsui, Y. Matsuda, M. Matsushita, J. Menendez, D. Mengoni, S. Michimasa, T. Miyazaki, S. Momiyama, P. Morfouace, T. Motobayashi, T. nakamura, D. Napoli, F. Naqvi, M. Niikura, **A. Obertelli**, N. Orr, S. Ota, H. Otsu, T. Otsuka, N. Pietralla, Z. Podolyak, E.C. Pollacco, G. Potel, G. Randisi, F. Recchia, E. Sahin, H. Sakurai, C. Santamaria, M. Sasano, A. Schwenk, Y. Shiga, Y. Shimuzu, S. Shimoura, J. Simonis, P.A. Soderstrom, S. Sohler, V. Soma, I. Stefan, D. Steppenbeck, T. Sumikama, H. Suzuki, M. Tanaka, R. Taniuchi, K.N. Tuan, T. Uesaka, J. Valiente Dobon, Zs. Vajta, D. Verney, H. Wang, V. Werner, Zh. Xu, R. Yokoyama, K. Yoneda