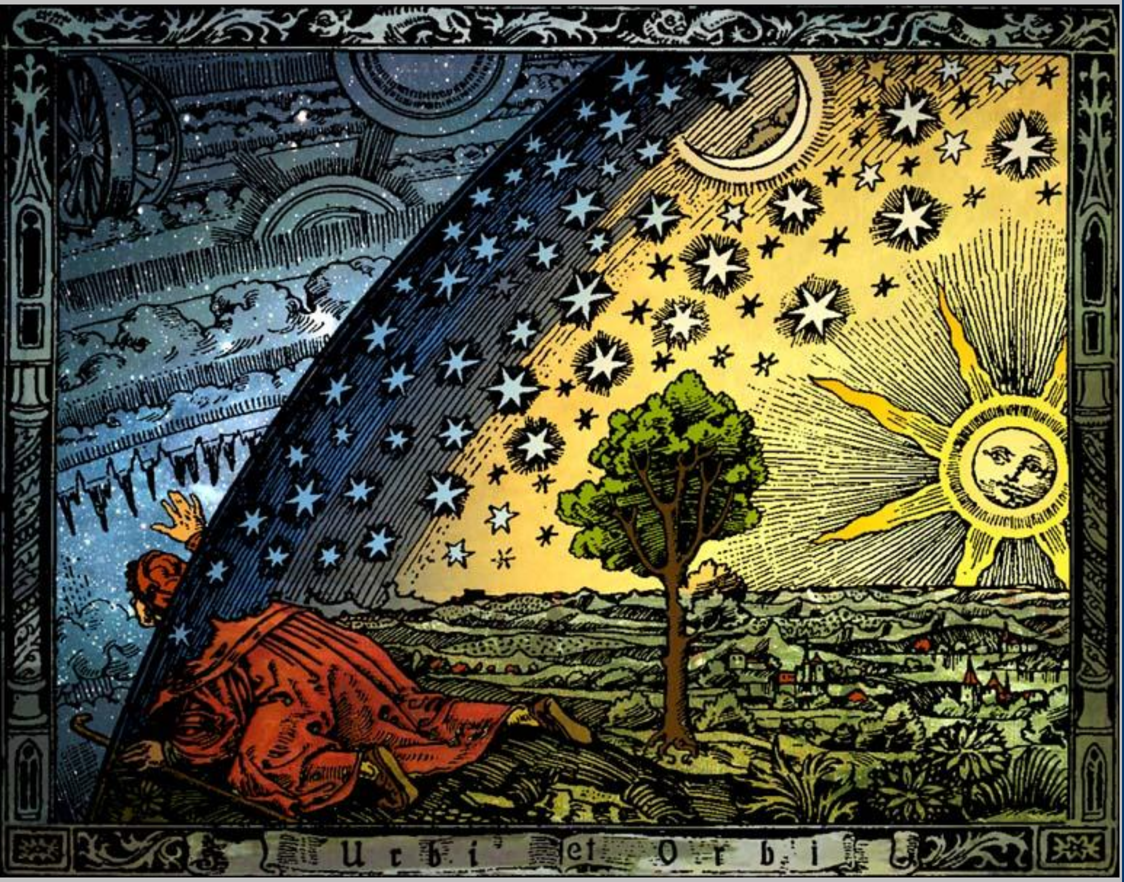
Crossing bounds: From exotic nuclear systems to FAIR

SAMURAI International Workshop
RIKEN, 2011-03-09

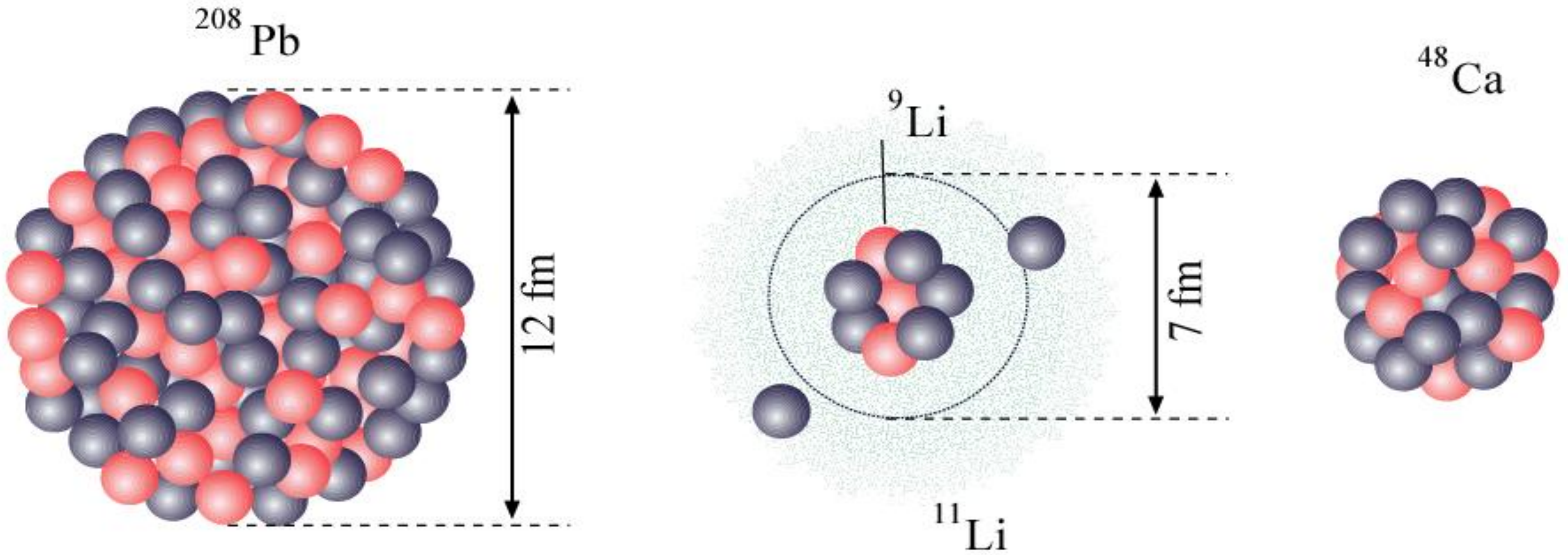


H. Simon GSI Darmstadt

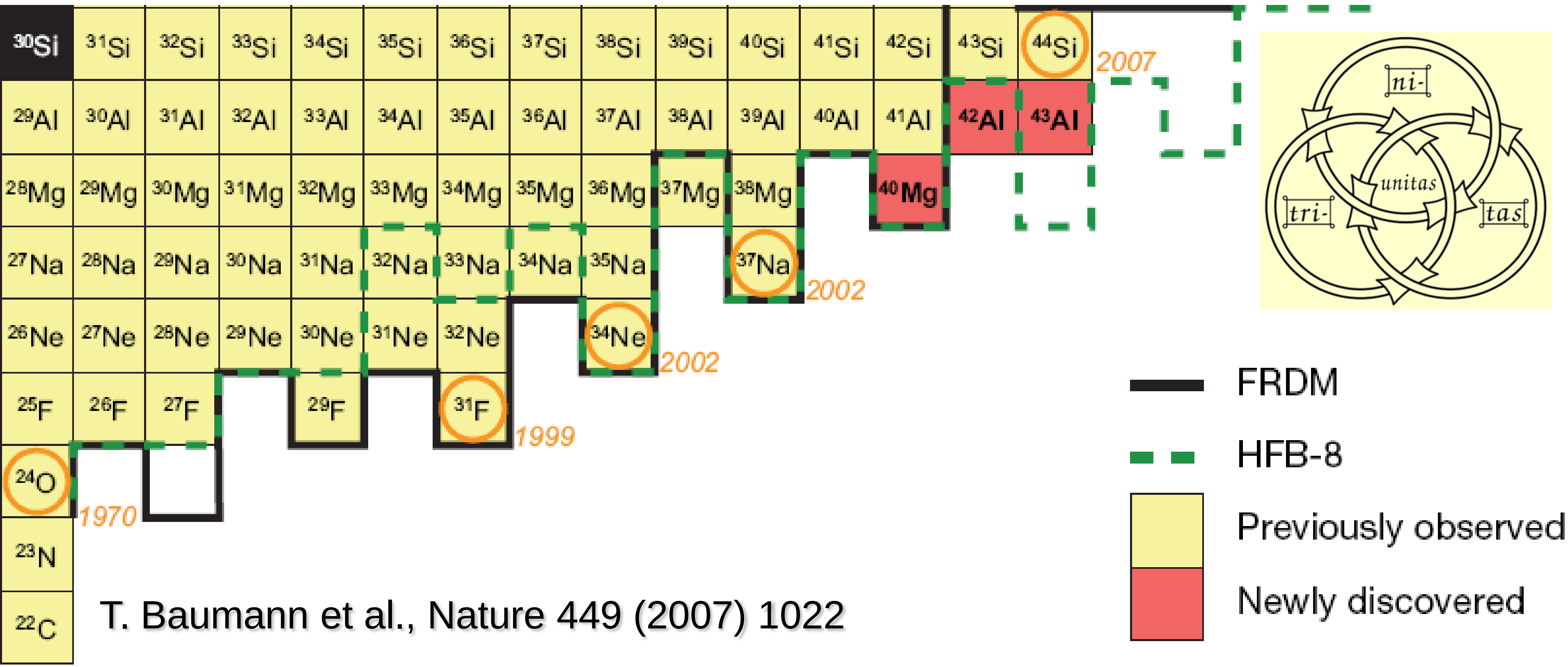
Menu

1. Motivation
2. 3-body continuum
3. Extremely neutron rich systems
   - remnants of halo nuclei
4. New experiments
5. Summary

Exotica: Haloes



Sheer Existence: Three body correlations

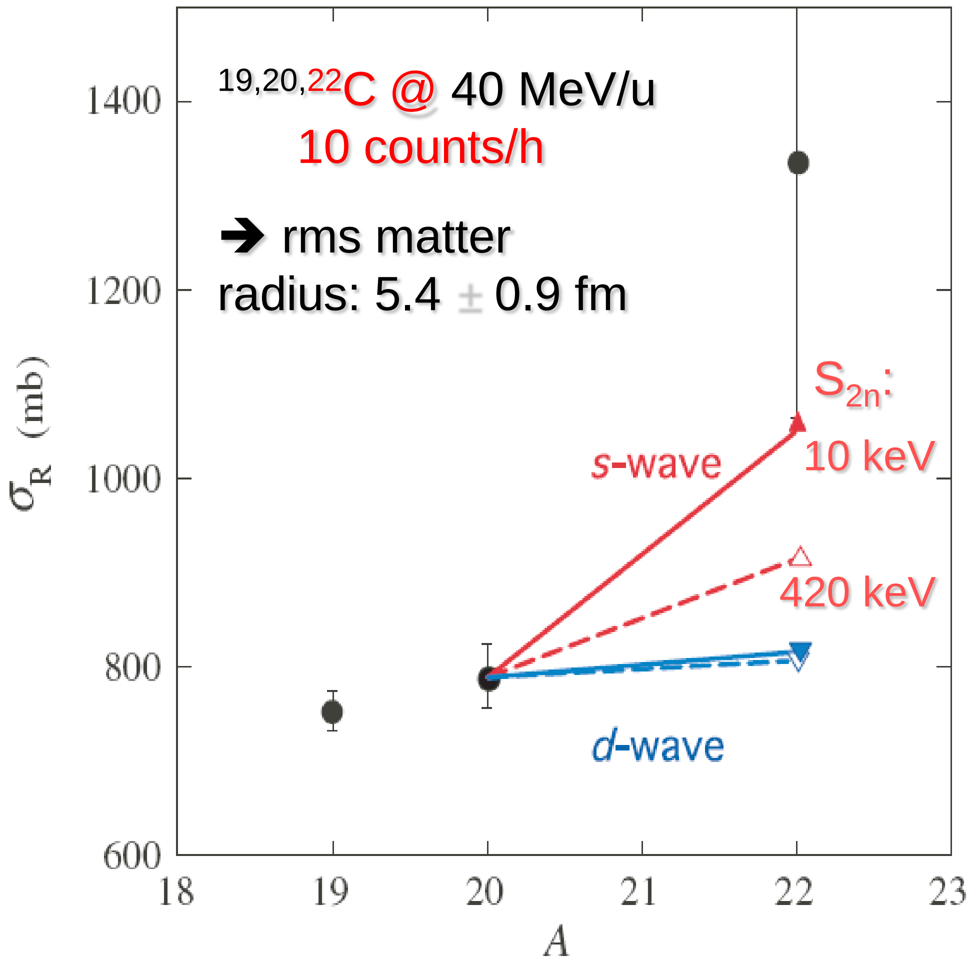


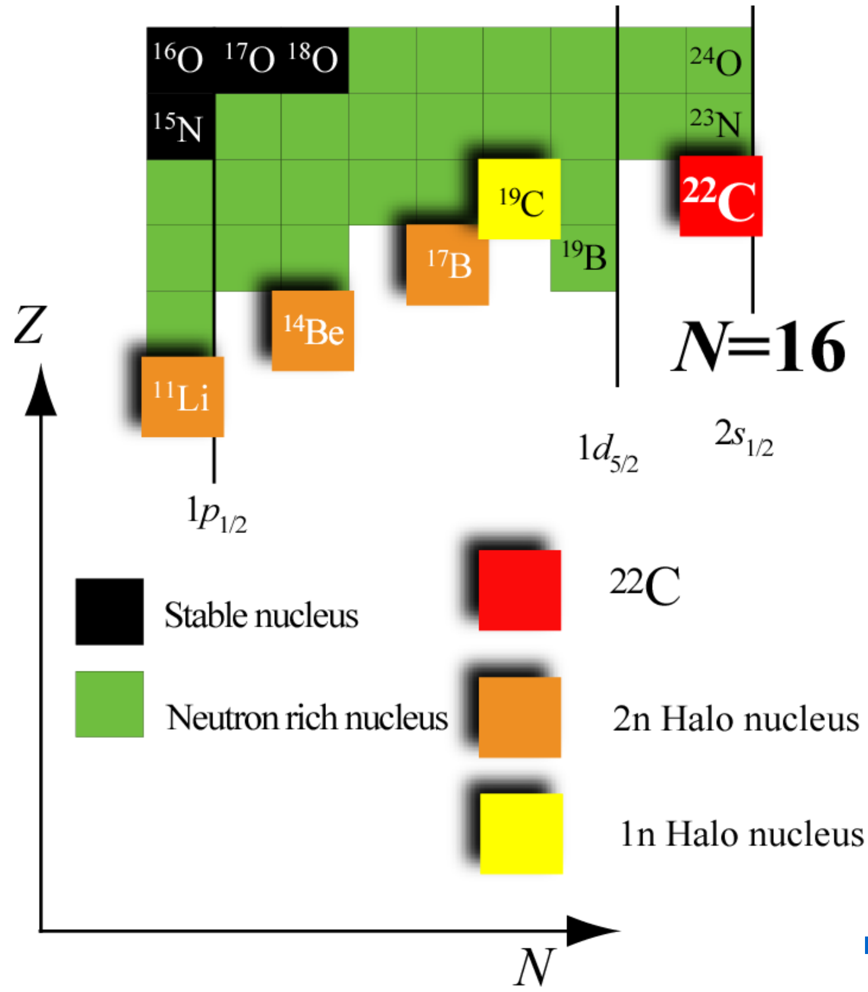
T. Baumann et al., Nature 449 (2007) 1022

Observation of a Large Reaction Cross Section in the Drip-Line Nucleus ^{22}C

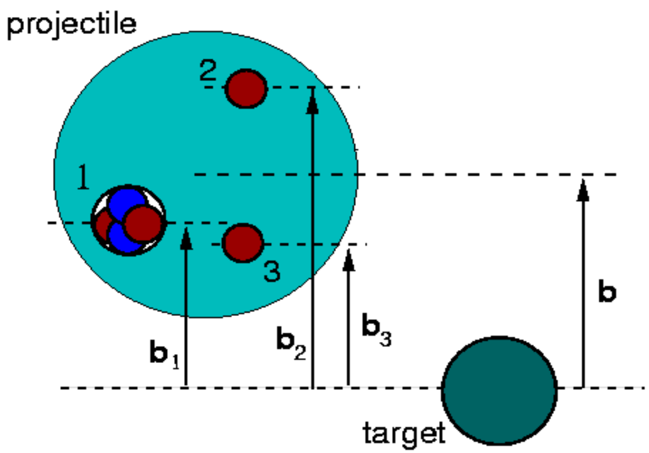
K. Tanaka,[1] T. Yamaguchi,[2] T. Suzuki,[2] T. Ohtsubo,[3] M. Fukuda,[4] D. Nishimura,[4] M. Takechi,[4,1] K. Ogata,[5] A. Ozawa,[6] T. Izumikawa,[7] T. Aiba,[3] N. Aoi,[1] H. Baba,[1] Y. Hashizume,[6] K. Inafuku,[8] N. Iwasa,[8] K. Kobayashi,[2] M. Komuro,[2] Y. Kondo,[9] T. Kubo,[1] M. Kurokawa,[1] T. Matsuyama,[3] S. Michimasa,[1,*] T. Motobayashi,[1] T. Nakabayashi,[9] S. Nakajima,[2] T. Nakamura,[9] H. Sakurai,[1] R. Shinoda,[2] M. Shinohara,[9] H. Suzuki,[10,6] E. Takeshita,[1,†] S. Takeuchi,[1] Y. Togano,[11] K. Yamada,[1] T. Yasuno,[6] and M. Yoshitake[2]

PRL 104 (2010) 062701





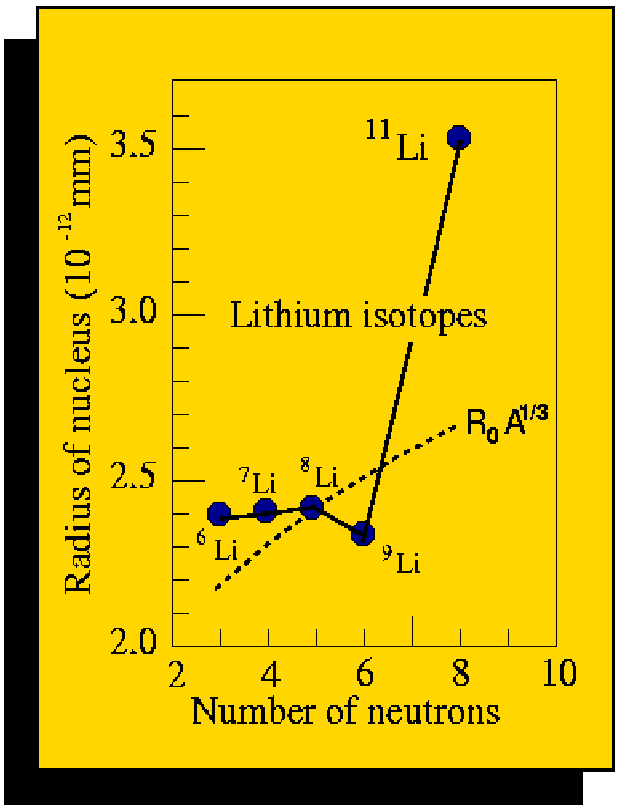
Caveat: Interaction cross sections



Al-Khalili& Tostevin, PRL76 (96) 3903

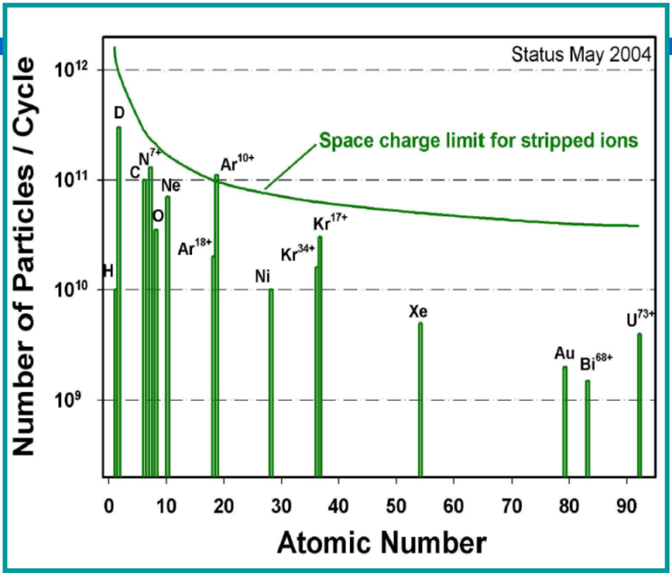
R(^{11}Li) = 3.53(10) fm

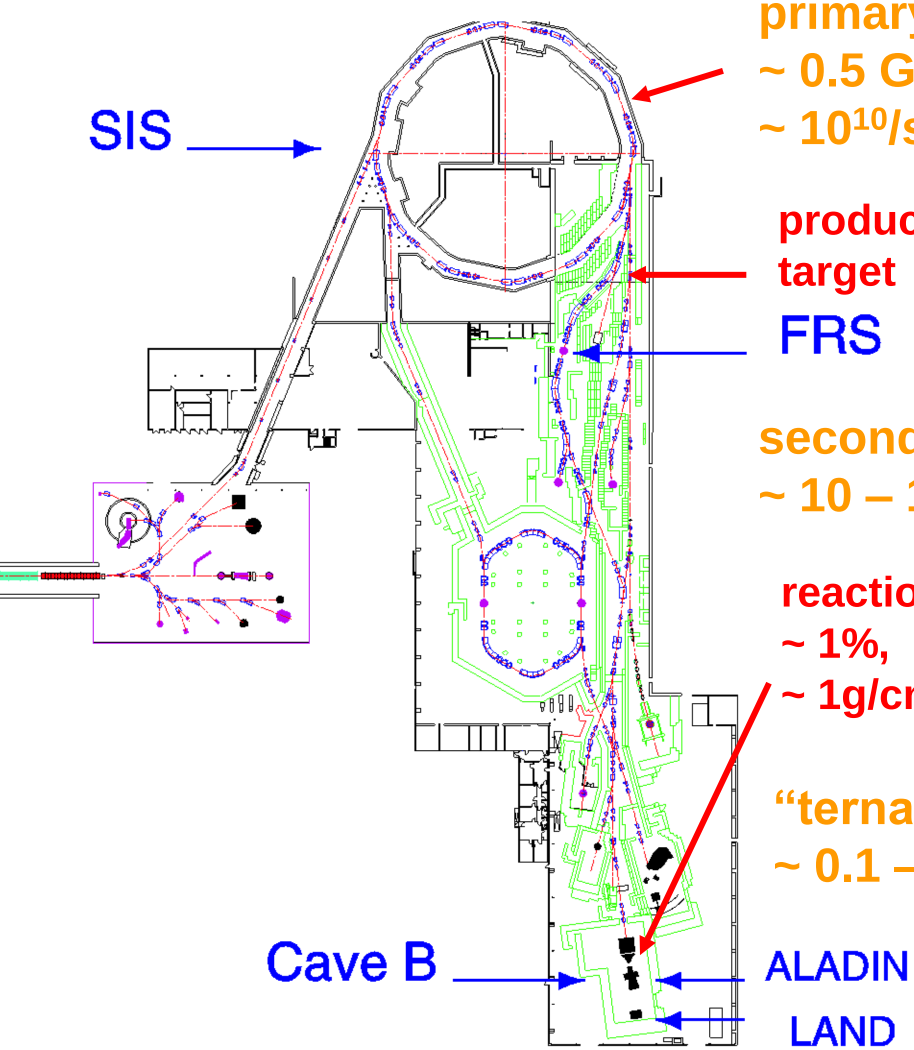
(Tanihata: 3.10(14) fm)



Correlations change interpretation
i.e. R extracted from σ_I

Beam conditions @ GSI





primary beam
~ 0.5 GeV/u
~ 10^{10}/s

production target

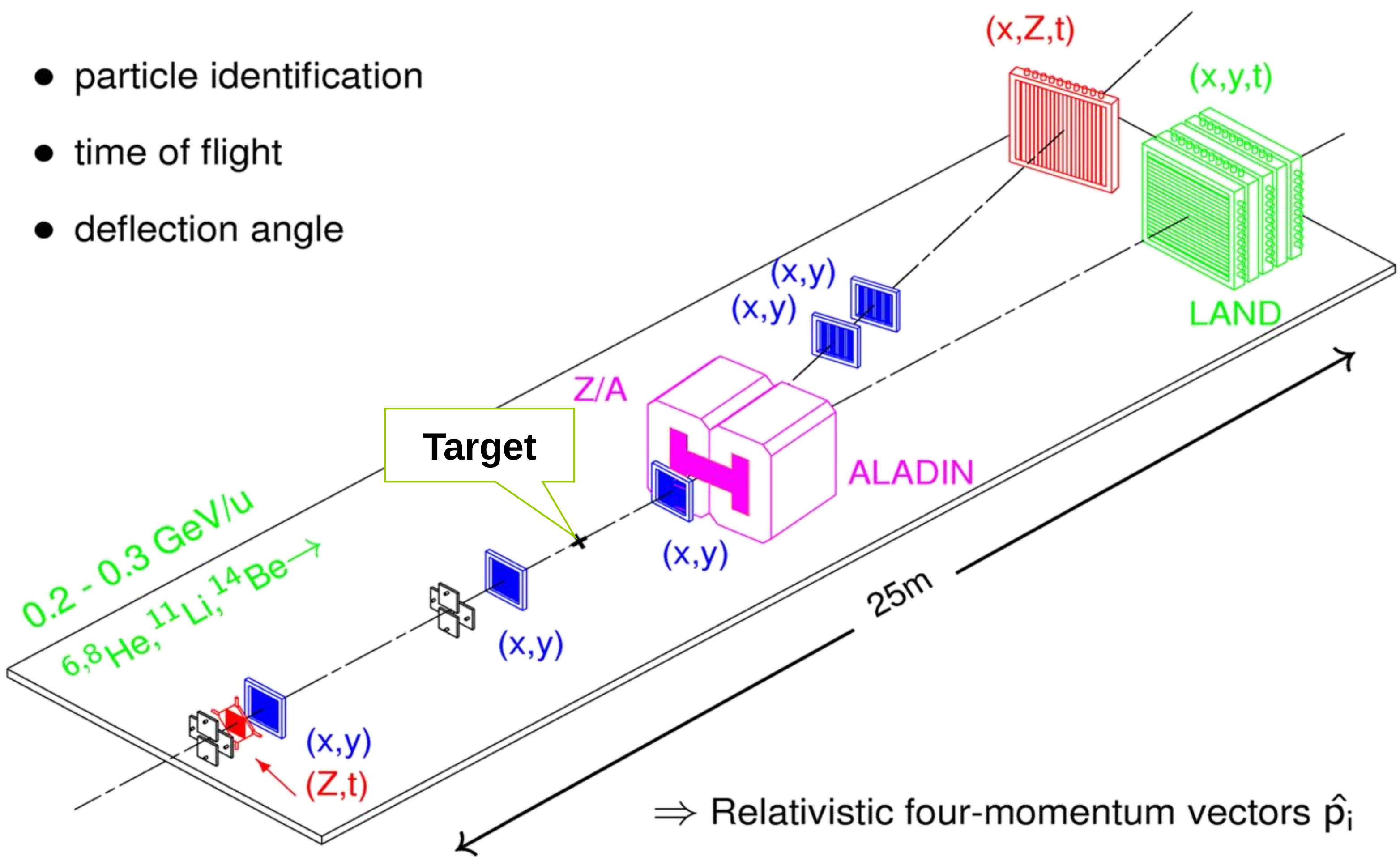
secondary beam
~ 10 – 1000 /s

reaction target
~ 1%,
~ 1g/cm² C

"ternary beam"
~ 0.1 – 10 /s

Experimental Setup (kinematically complete)

- particle identification
- time of flight
- deflection angle



⇒ Relativistic four-momentum vectors $\hat{p}_i$

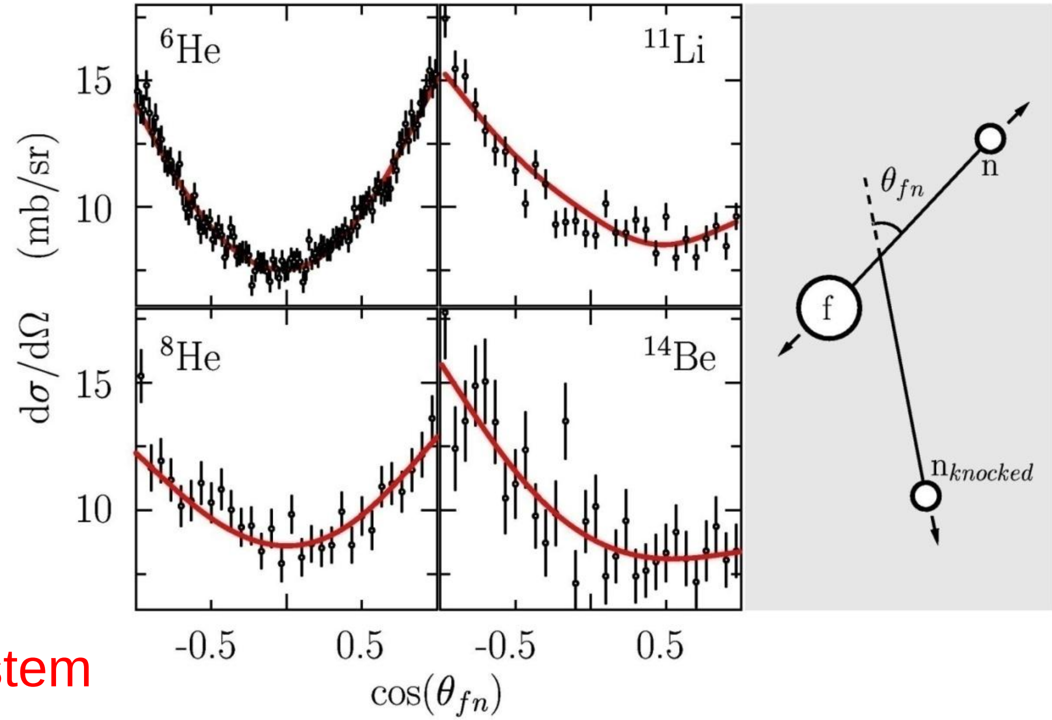
Two-body final state from 3-body system

Observables:

Momentum knocked out neutron

missing momentum

CMS: $\mathbf{p}_m = -\mathbf{p}_{n2} = \mathbf{p}_{n1} + \mathbf{p}_f$



Spectroscopy of intermediate system

relative energy

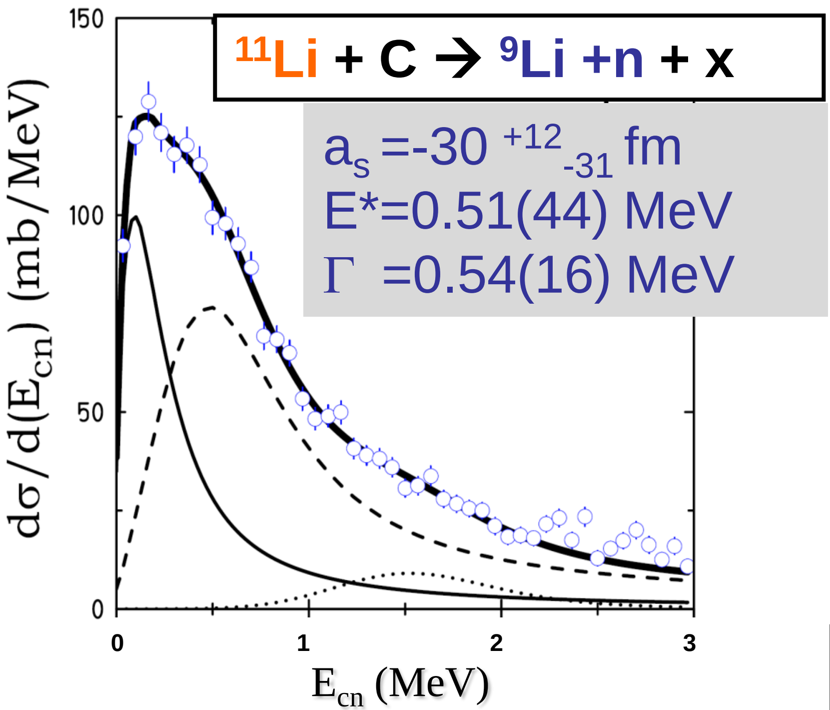
CMS: $\mathbf{p}_{fn} = \mu/m_n\, \mathbf{p}_n - \mu/m_f\, \mathbf{p}_f$

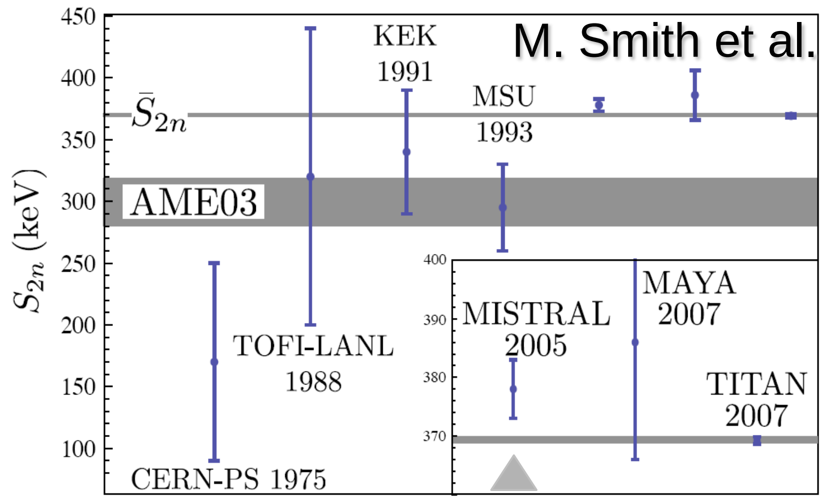
$E_{fn} = p_{fn}^2 / 2\mu$

Angular correlations (momenta)

$$\cos(\theta)_{fn} = \frac{\mathbf{p}_m\, \mathbf{p}_{fn}}{p_m\, p_{fn}}$$

^{11}Li: combining bits and pieces to get a Wave function !





PRL **101,** 202501 (2008) Nucl.Phys.**A826,** 1 (2009)

H.S. et al.
Phys. Rev. Lett. **83** (1999) 496
Nucl. Phys. **A 791** (2007) 267

→Confirmed eg @ GANIL
^{11}Be, ^{14,15}B → ^{9}Li+n
H. Al Falou et al. Niigata 2010

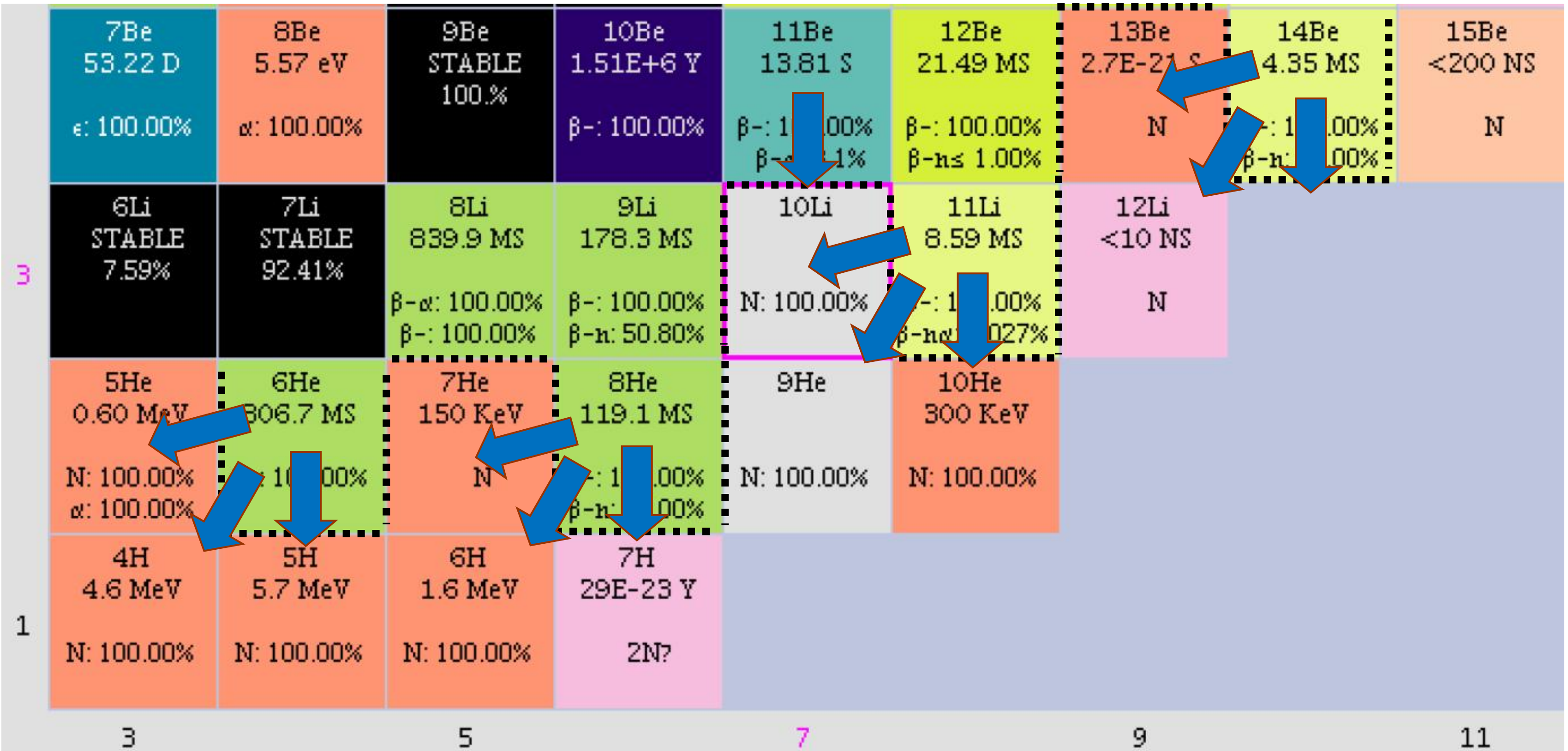
Correlation data, matter radii, B(E1), cross sections
binding energy 369.15(65) keV
charge radius 2.467(37) fm
R. Sanchez et al., PRL**96** (2006) 033002
quadrupole moment 33.3 (5) mb
R. Neugart et al., PRL**101**(2008)132502

Phenomenological wave function
N.B. Schulgina, B. Jonson, M.V.Zhukov
Nucl. Phys. **A825**(2009)175

$(s1/2)^2$: 37%
$(p1/2)^2$: 47%
$(p3/2)^2$: 9%

Exotic structure across the dripline:

P.G. Hansen, Nature 328 (1987) 476



➔ **most exotic systems**

➔ **nearly unbiased & clean production !**

Description of the three body continuum

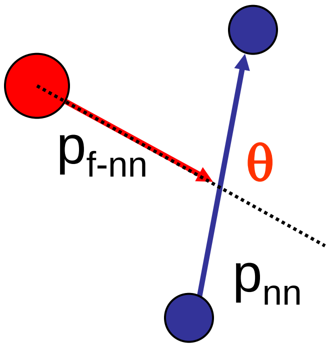
- Reduction (CMS, E*, rot. inv)

  9 variables $\rightarrow$ 2 variables **(ε, θ)**

ε is the fractional energy for a subsystem (e.g. $\varepsilon = E_{nn}/E_{nnf}$)
θ is the angle between the relative momenta (e.g. p_{nn}, $p_{f\text{-}nn}$)

- Three body correlation function (expansion in hyperspherical harm.):

$$W(\varepsilon,\theta) \propto \frac{d^2\sigma}{d\varepsilon d\theta} \propto \sum_{\alpha,\alpha'} C^{\dagger}_{\alpha'} C_{\alpha} \mathcal{Y}^{\dagger}_{\alpha'}(\varepsilon,\theta)\mathcal{Y}_{\alpha}(\varepsilon,\theta)$$



- Complex coefficients C depend on quantum numbers $\alpha=\{K,L,S,l_x,l_y\}$

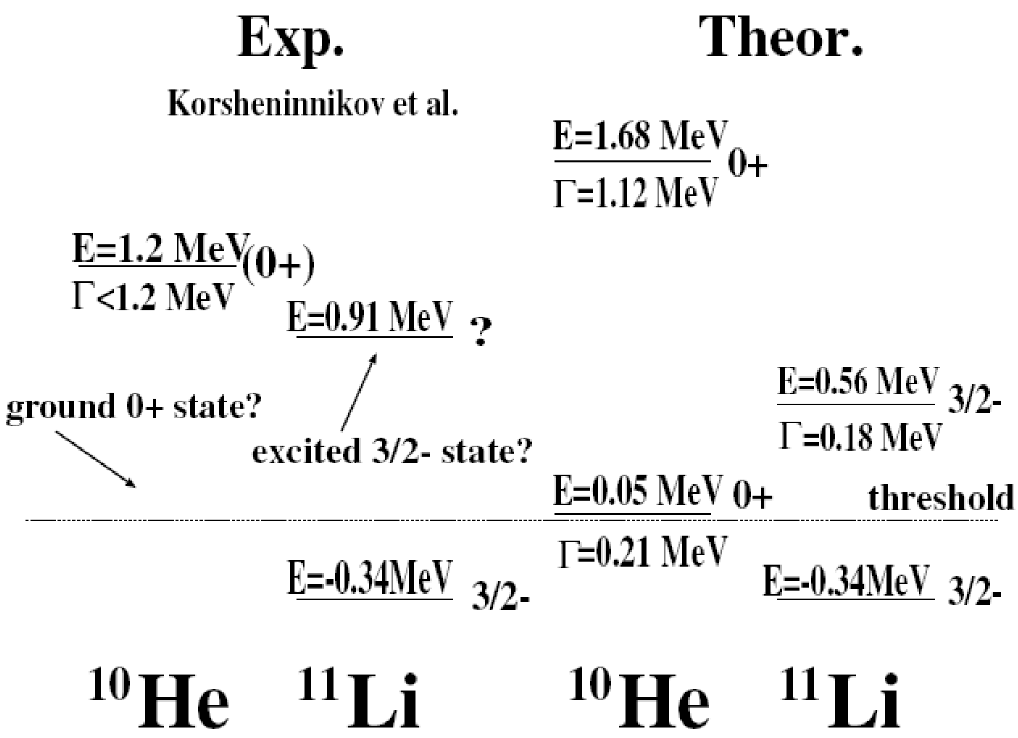
L.V. Chulkov, H.S., I.Thompson, et al., NPA759 (2005) 23
M.Meister, L.V. Chulkov, H.S., et al., PRL91 (2003) 16504

Getting neutron rich … ^{10}He

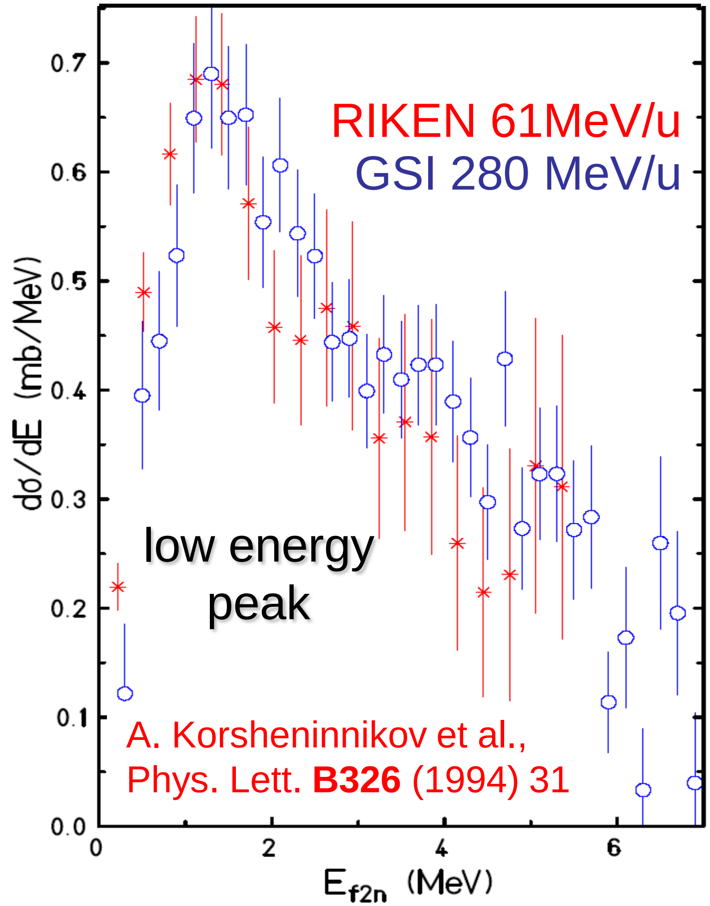
^{11}Li

^{10}He

Shigeyoshi Aoyama, PRL**89** (2002) 052501
possible similarity of ^{10}He and ^{11}Li g.s.

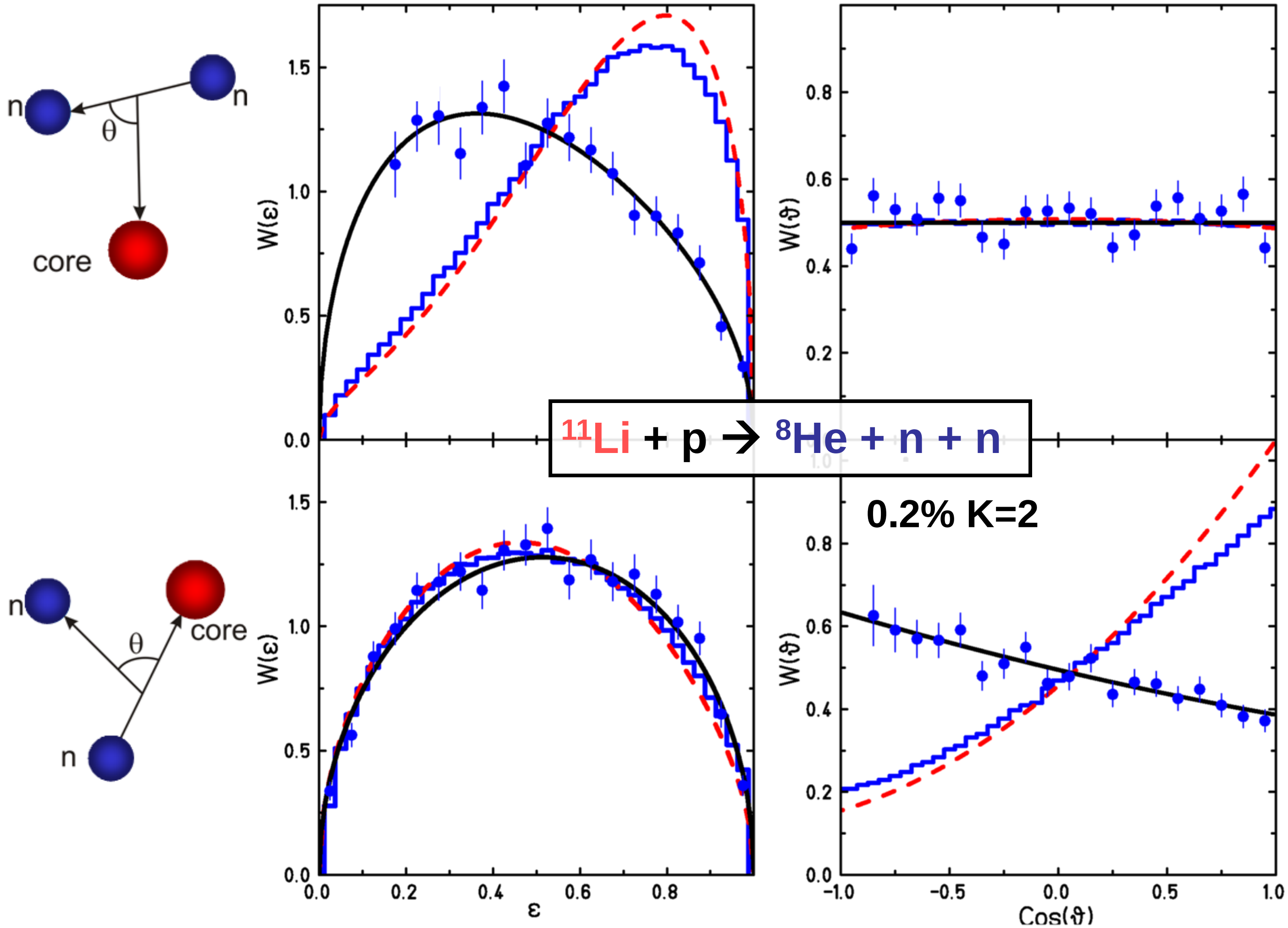


^{11}Li + p/CD_2,C → ^{8}He + n + n



^{11}Li vs. ^{10}He via angular correlations

^{11}Li
^{10}He



Excitation energy range 1-3 MeV (low energy peak)

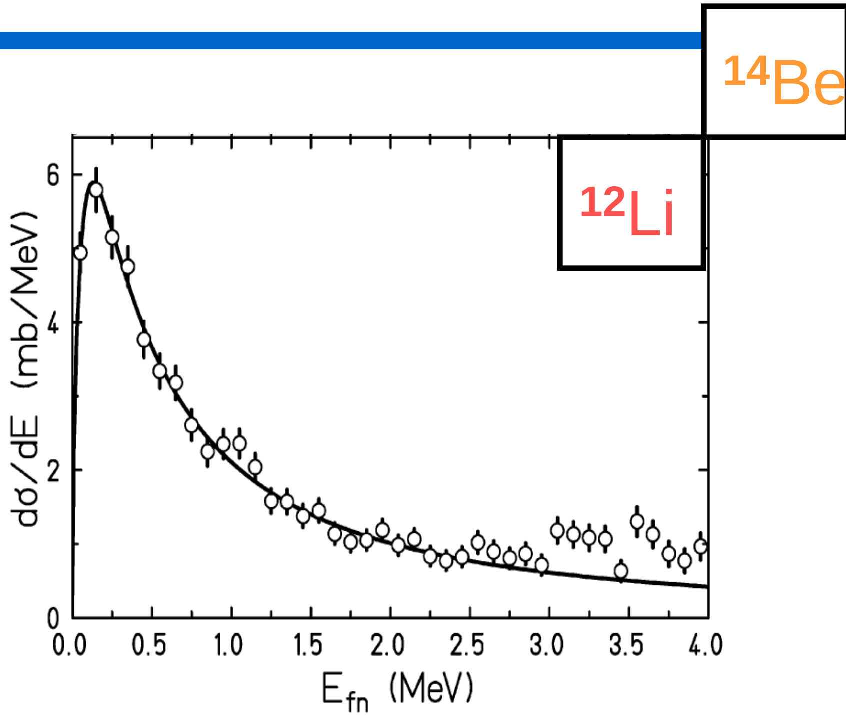
- no resemblance to ^{11}Li seed angular correlations

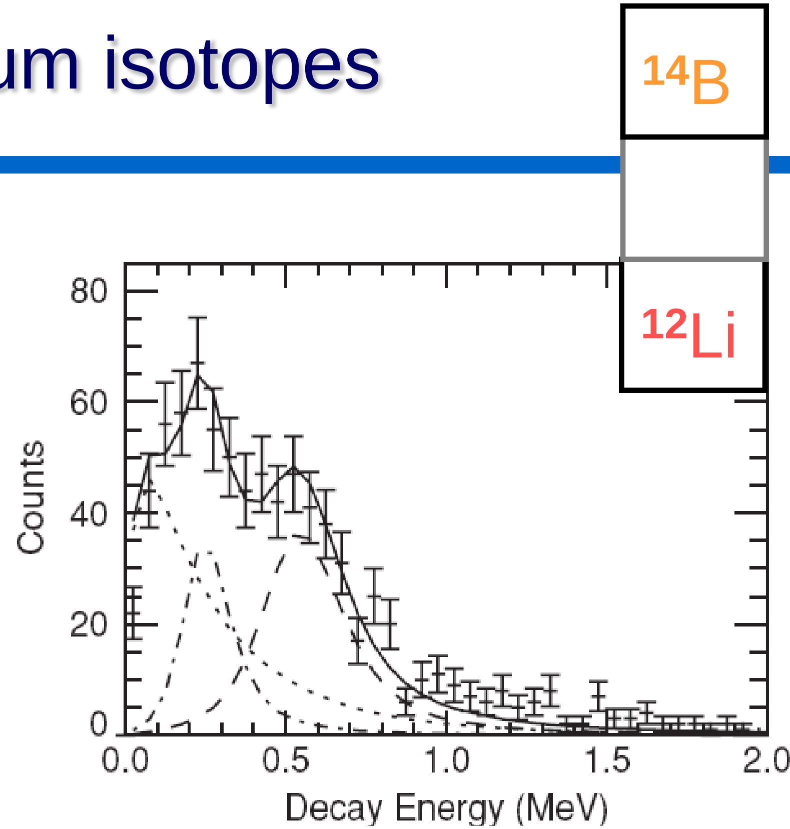
→ ^{10}He is structurally different

H.T. Johansson, Y. Aksyutina, Nucl. Phys. **A847** (2010) 66

^{11}Li wave function: N.B. Shulgina et al., Nucl. Phys. A825 (2009) 175

Exploring Unbound Lithium isotopes

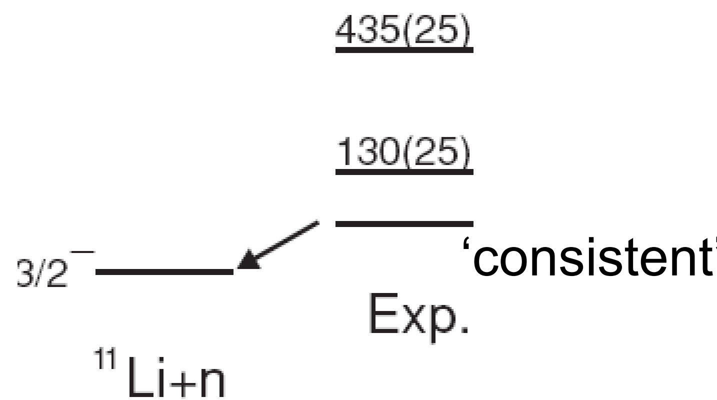




Bertsch, Hencken, Esbensen, PR**C57**(1998)1366

a_s (fm)	S_n(MeV)
-13.7(1.6)	1.47(0.19)

Close to S_{2n} ^{14}Be



Y. Aksyutina et al., PL**B666** (2008) 430

C. Hall et al., PR**C81** (2010) 021302

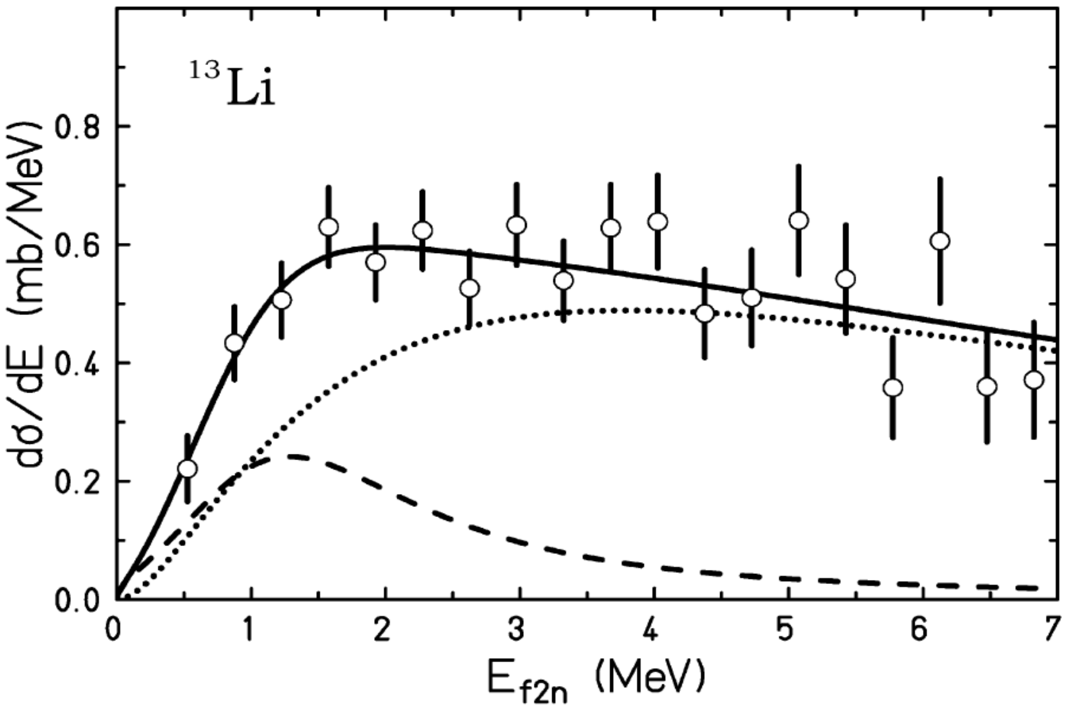
Exploring Unbound Lithium isotopes

^{14}Be
^{13}Li

^{13}Li: ^{14}Be + p → ^{11}Li + n + n

$d\sigma/dE_{noFSI} \propto E^2/(2.21\ S_{2n} + E)^{7/2}$ $K_0=0$

C. Forssén, B. Jonson, M.V. Zhukov NP**A673** (2008) 143



Momentum transfer small, ^{11}Li core survives collision !

➔ ^{11}Li + 2n resonance picture

Evidence for existence at 1.47(31) MeV.

Y. Aksyutina, H. Johansson et al., PL**B666** (2008) 430

^{13}Li: ^{14}Be + p → ^{11}Li + n + n

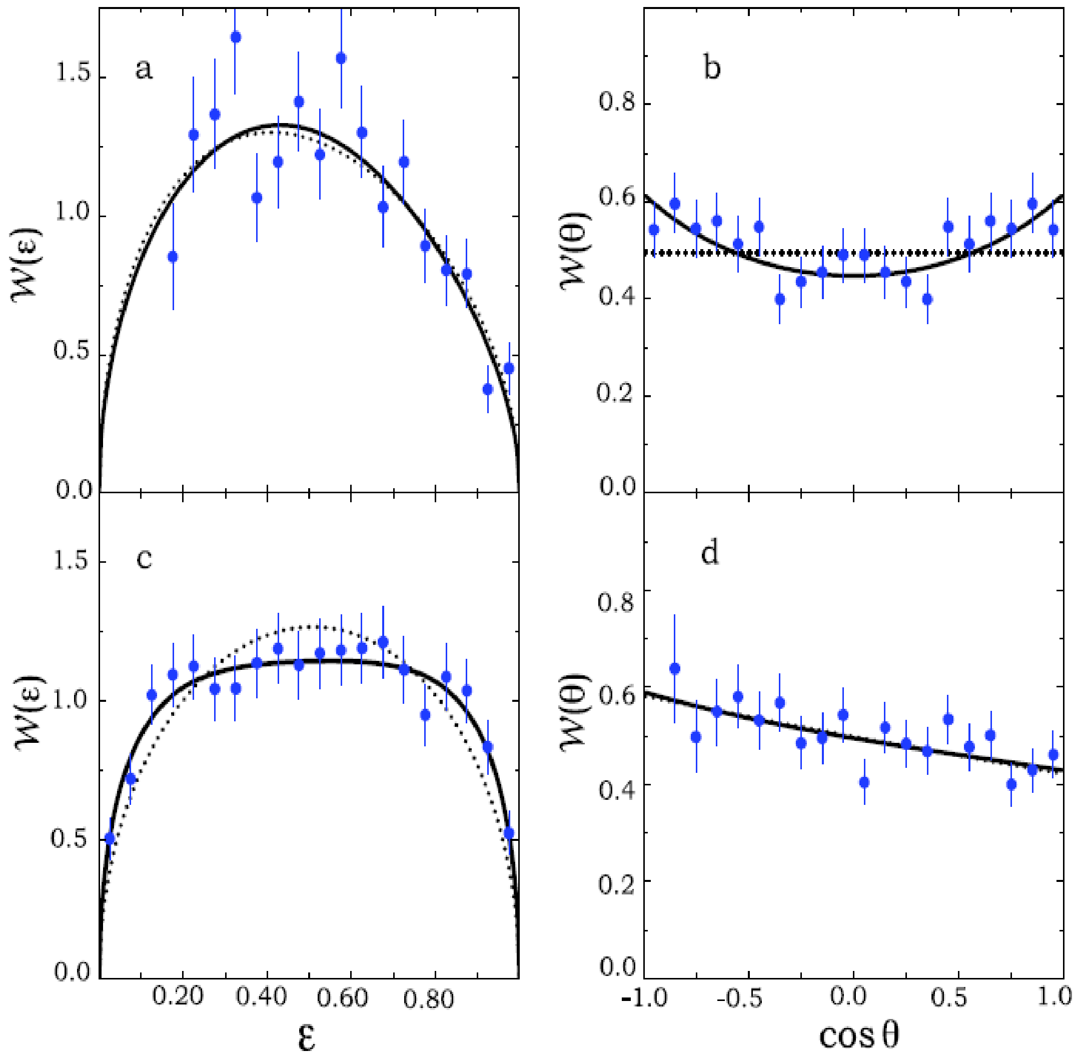
- Correlations ("T")

→ K <= 4

- Strong deviations from plain phase space.

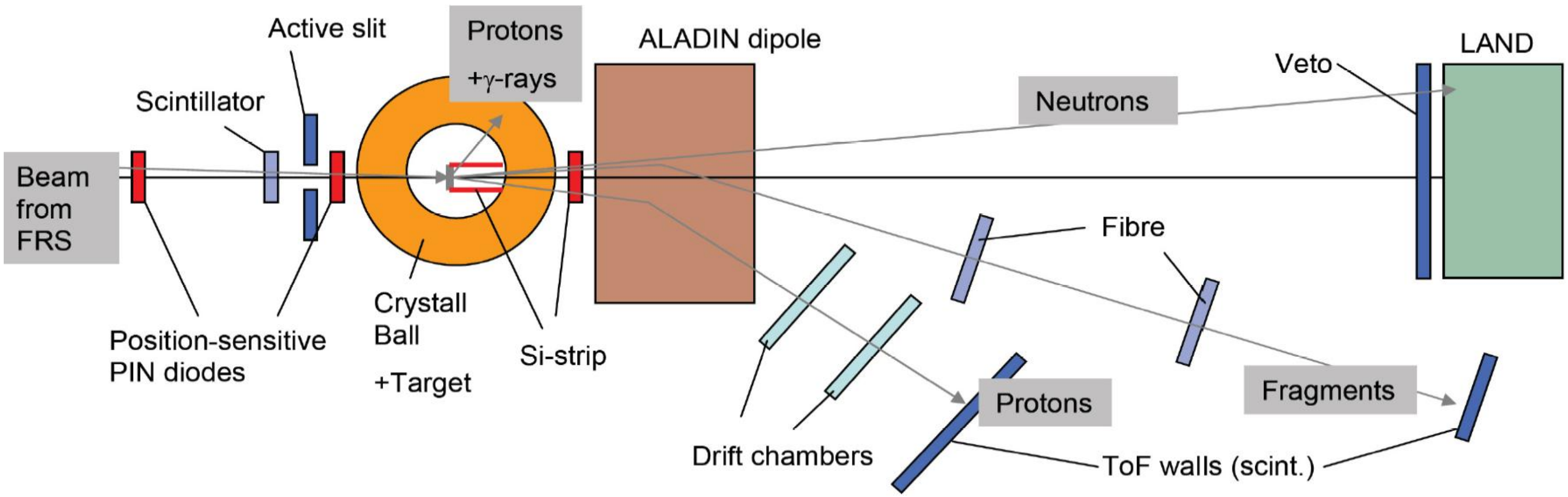
→ **^{13}Li existence confirmed**

H.T. Johansson, Y. Aksyutina, Nucl. Phys. **A847** (2010) 66



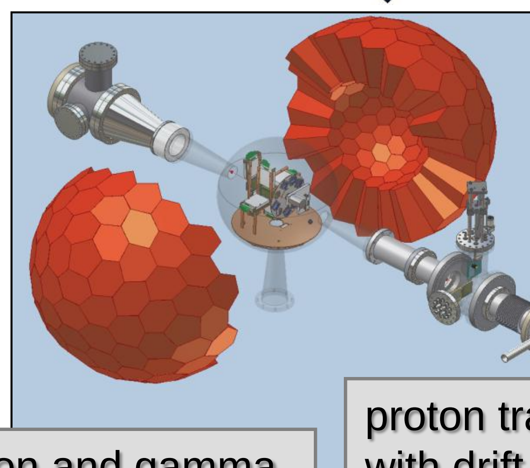
New Experiments (Aug/Sep 2010)

R³B/FAIR precursor: Setup at Cave C

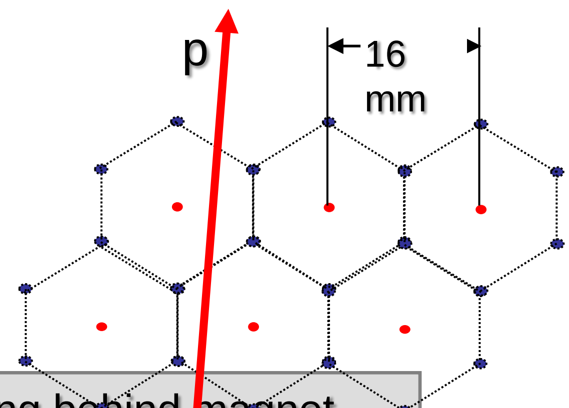


→ (p,2p) CH_2 target
Coulomb Diss. Pb

→ New Experiment: Neutron-rich nuclei at and beyond the dripline



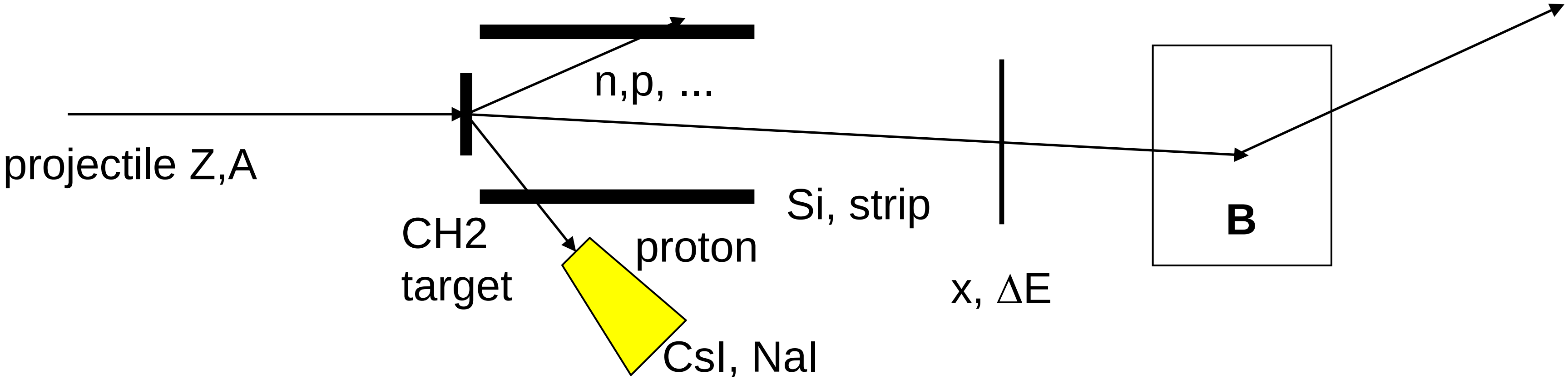
proton and gamma detection



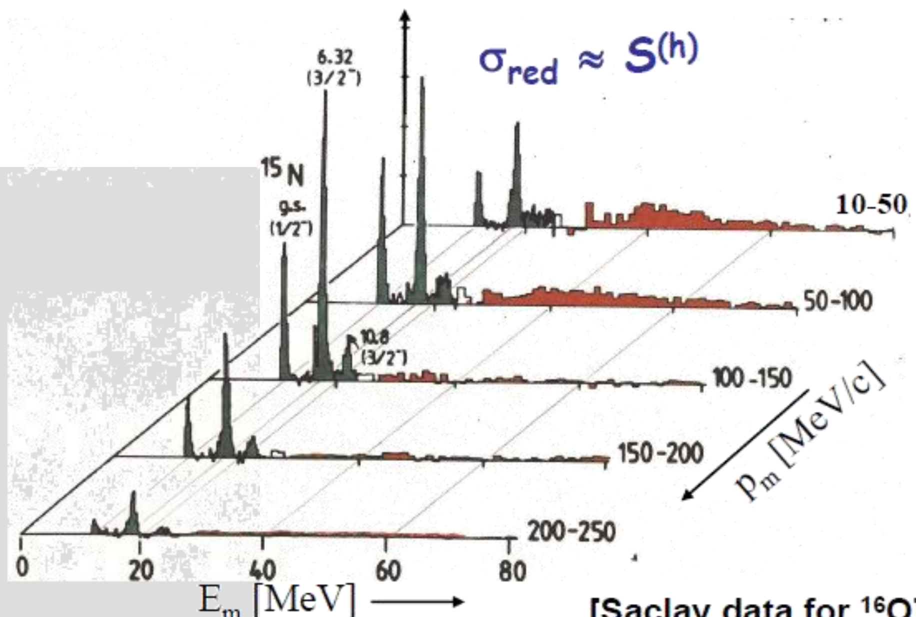
proton tracking behind magnet with drift chambers (100×80 cm^2)
resolution ~200 μm

Quasi-free scattering in inverse kinematics

Measurement of proton recoils after knockout reactions with a CH_2 target

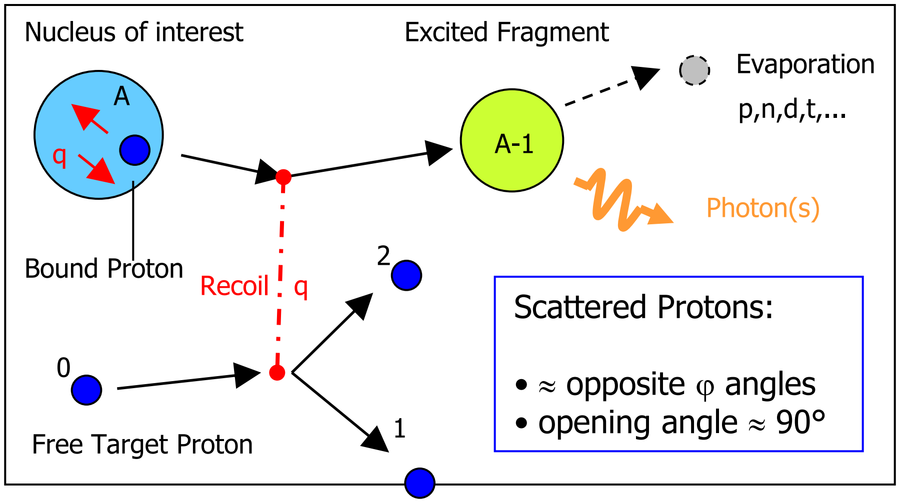


- kinematical complete measurement of
  - (p,pn), (p,2p), (p,pd), (p,a), ... reactions
- redundant experimental information:
  - kinematical reconstruction from proton momenta
  - plus gamma rays, recoil momentum, invariant mass
- sensitivity not limited to surface
  - → spectral functions
  - → knockout from deeply bound states
- cluster knockout reactions



[Saclay data for ^{16}O]

QFS with Exotic Nuclei: $^{17}Ne(p,2p)^{15}O+p$
The two-proton Halo (?) nucleus ^{17}Ne



Internal Momentum

$$q = -p_{A-1} = p_1 + p_2 - p_0$$

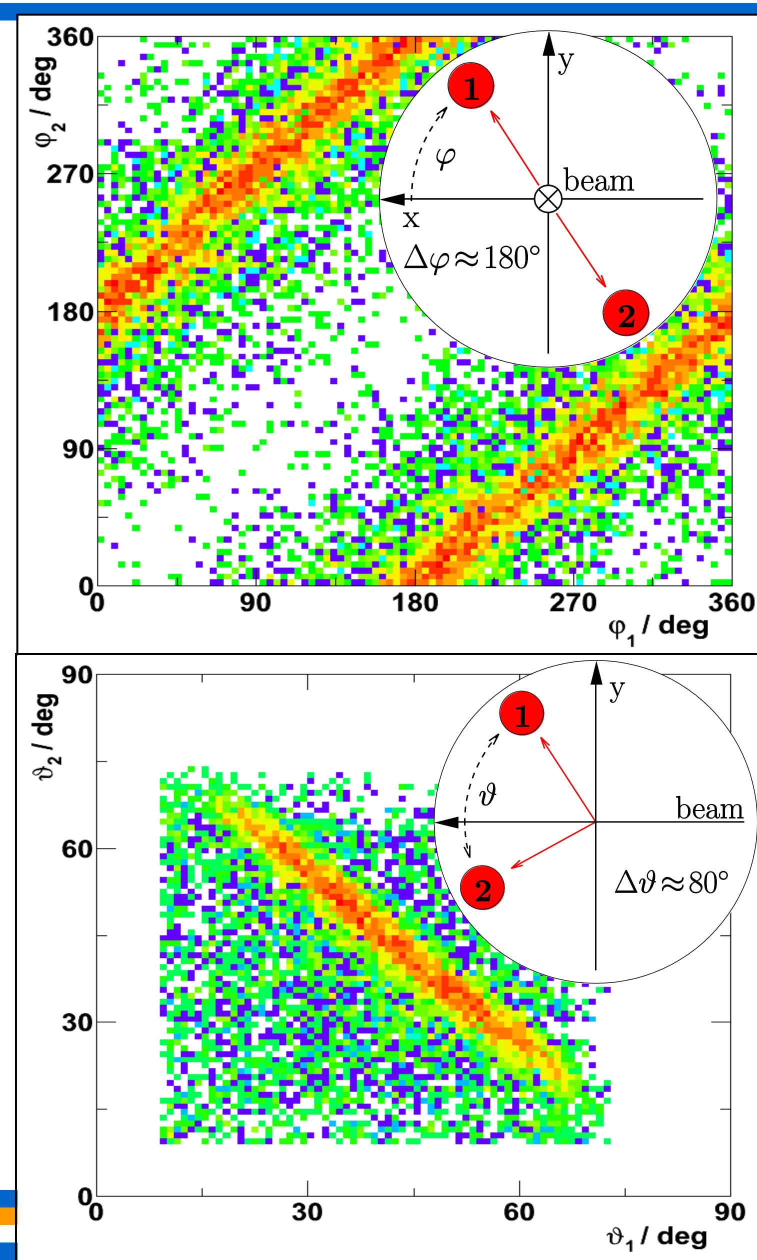
Separation Energy

$$E_S = T_1 + T_2 + T_{A-1} - T_0$$

Pilot experiments with ^{12}C, ^{17}Ne and Ni isotopes already performed at the LAND-R3B setup are under analysis …

Angular Correlations measured with Si-strip detectors for $^{17}Ne(p,2p)^{15}O+p$

Δθ~180°, Δϕ~83° (sim. as for free pp scattering)



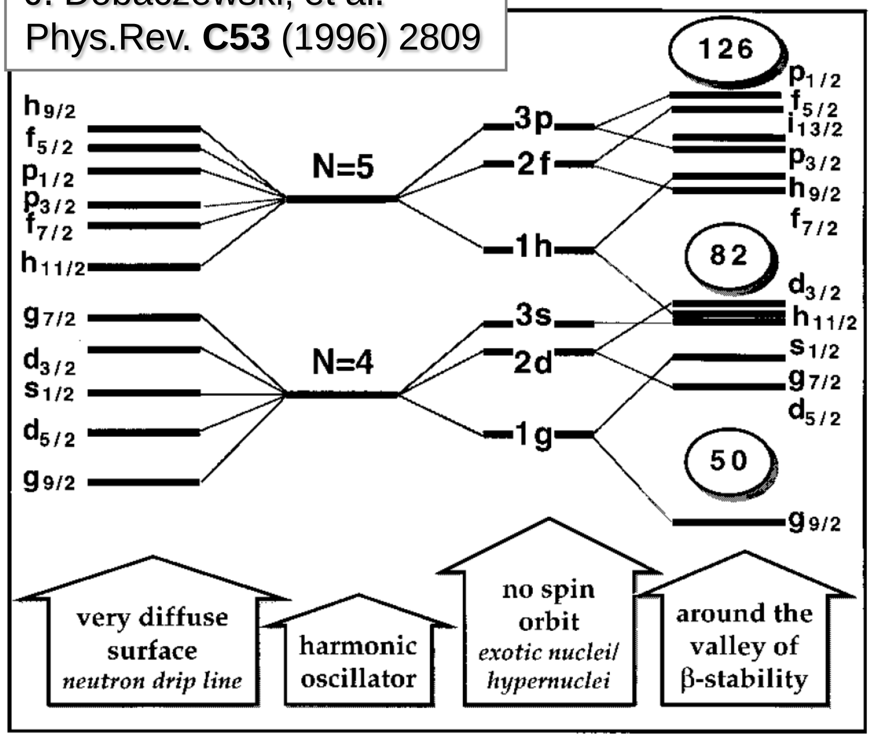
Shell reordering: Halo formation

Mean-field modifications

surface composed of diffuse neutron matter

derivative of mean field potential weaker and spin-orbit interaction reduced

J. Dobaczewski, et al. Phys.Rev. **C53** (1996) 2809



Nucleon-nucleon interaction

$\sigma\sigma\tau\tau$ interaction :

coupling of p-n spin-orbit partners in partly occupied orbits

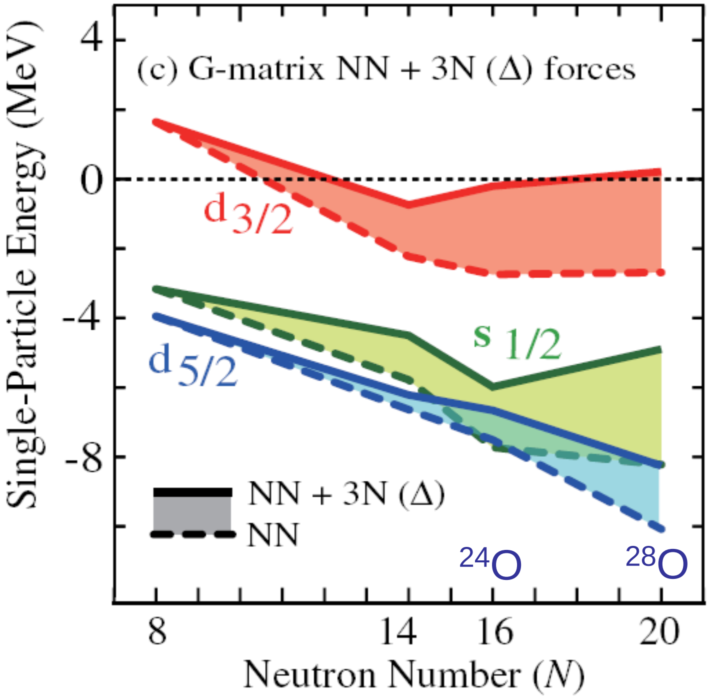
O: missing $\pi d_{5/2}$ do not bind $\nu d_{3/2}$ → N=16

T.Otsuka et al.,PRL**87** (2001) 082502

(tensor) PRL**95** (2005) 232502

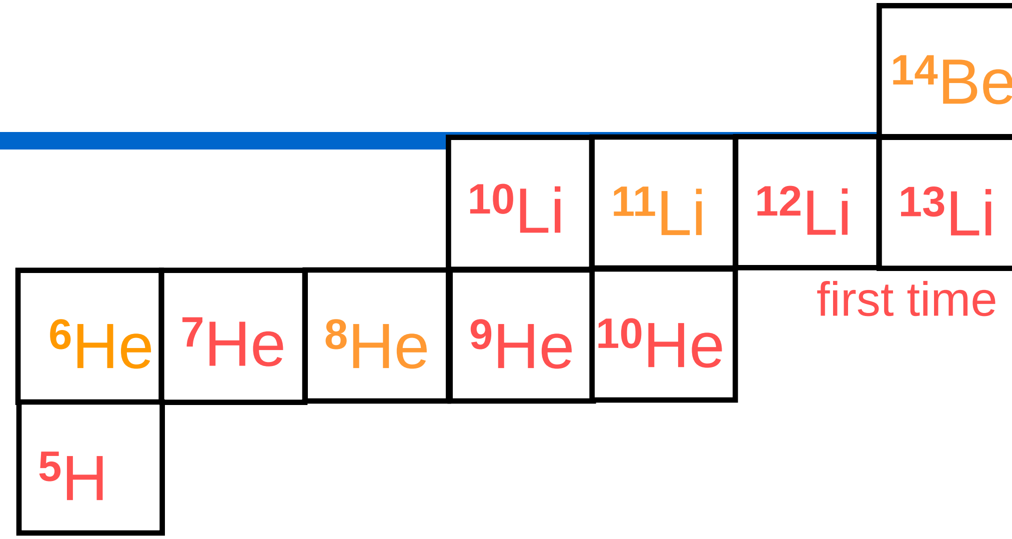
Repulsive 3N force

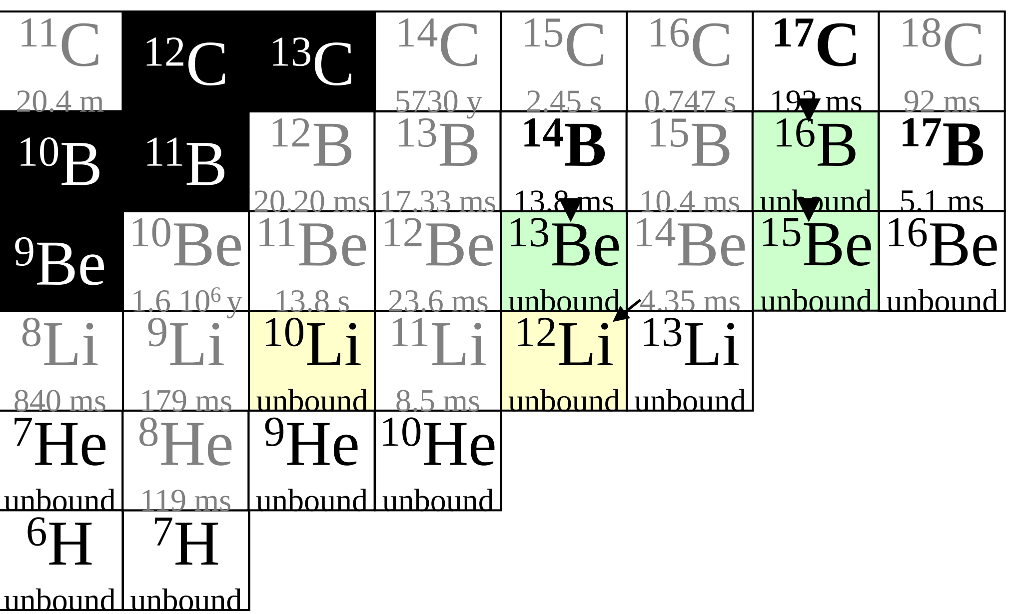
T.Otsuka et al., PRL**105** (2010) 032501



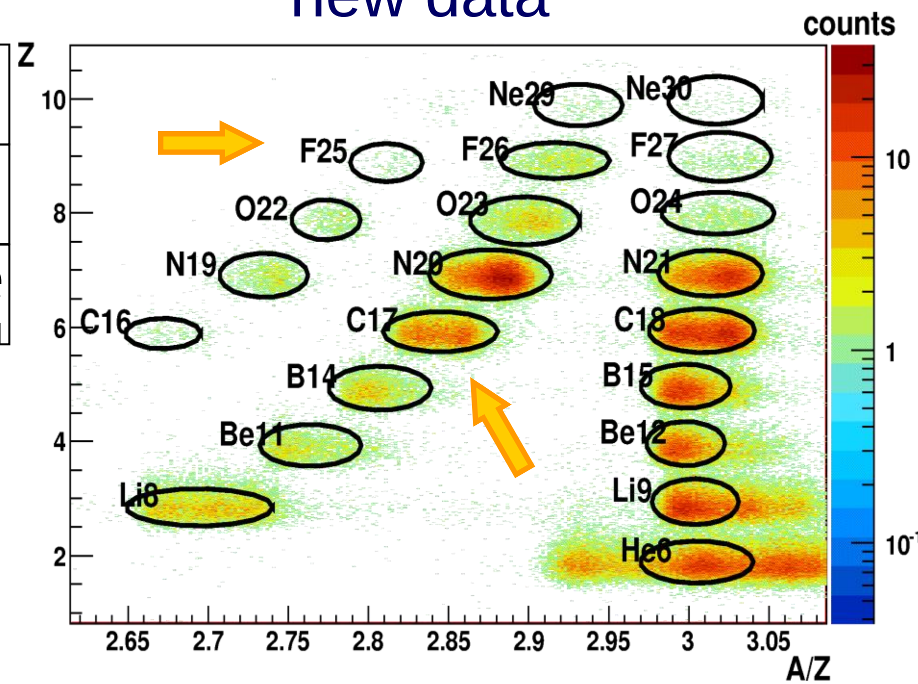
What do we have …

- Comprehensive study of exotic unbound systems with extreme A/Z
- Structure information unveiled

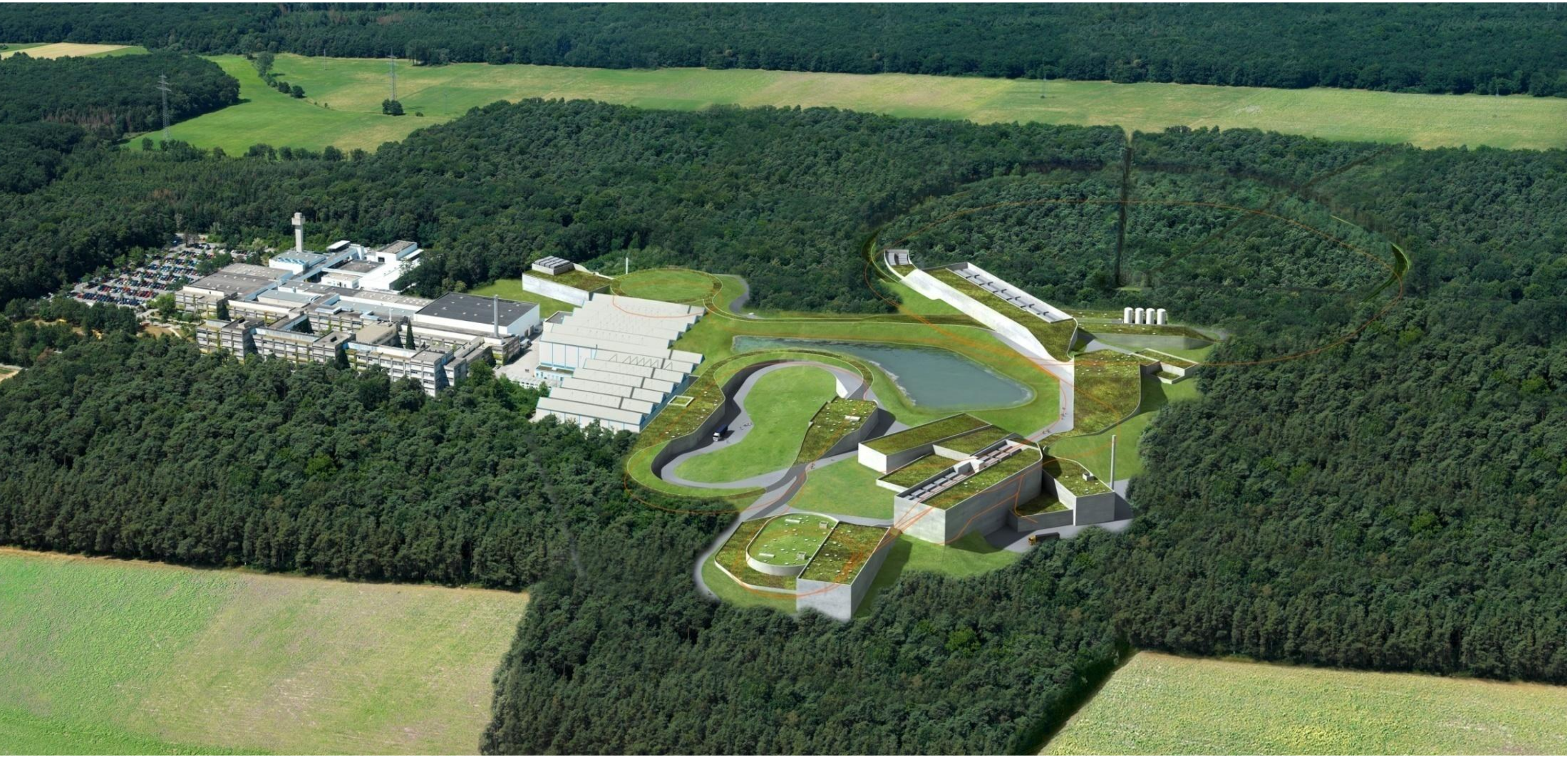




new data



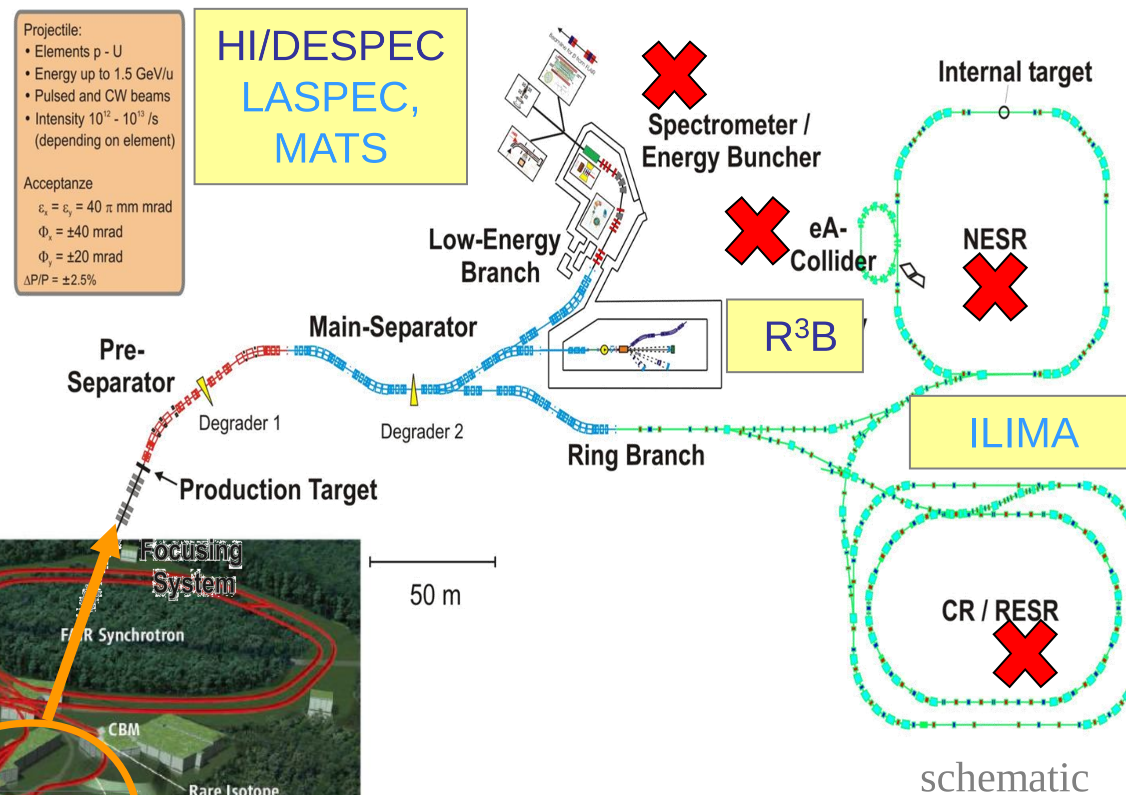
Preparing for FAIR ~2017/18

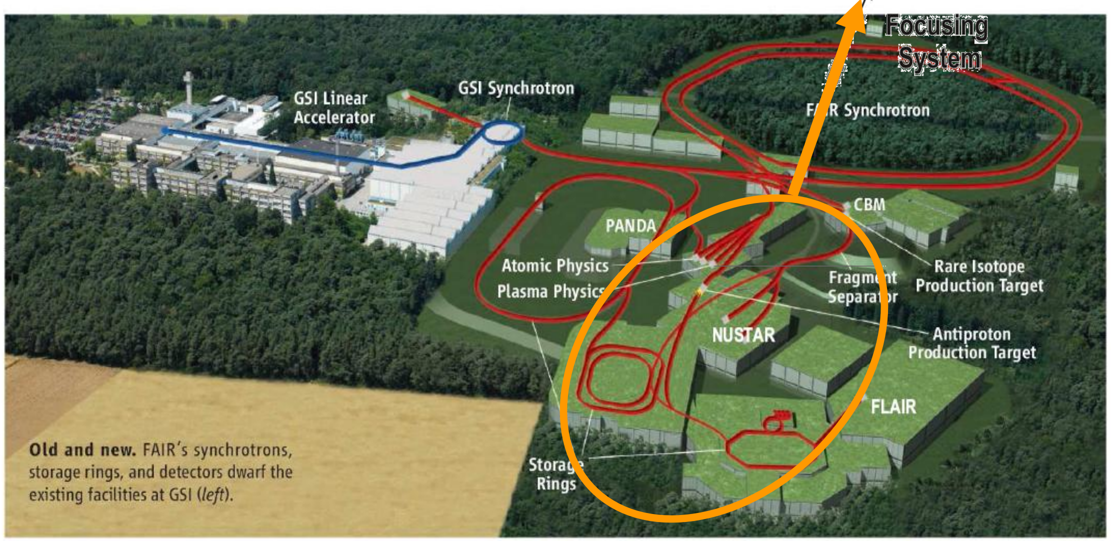


Intensity increase 3-4 orders of magnitude !

NUSTAR Experiments
(NUclear STructure Astrophysics and Reactions)

Exotic Nuclei
- Spectroscopy
- Reactions
- Mass/gs. prop.



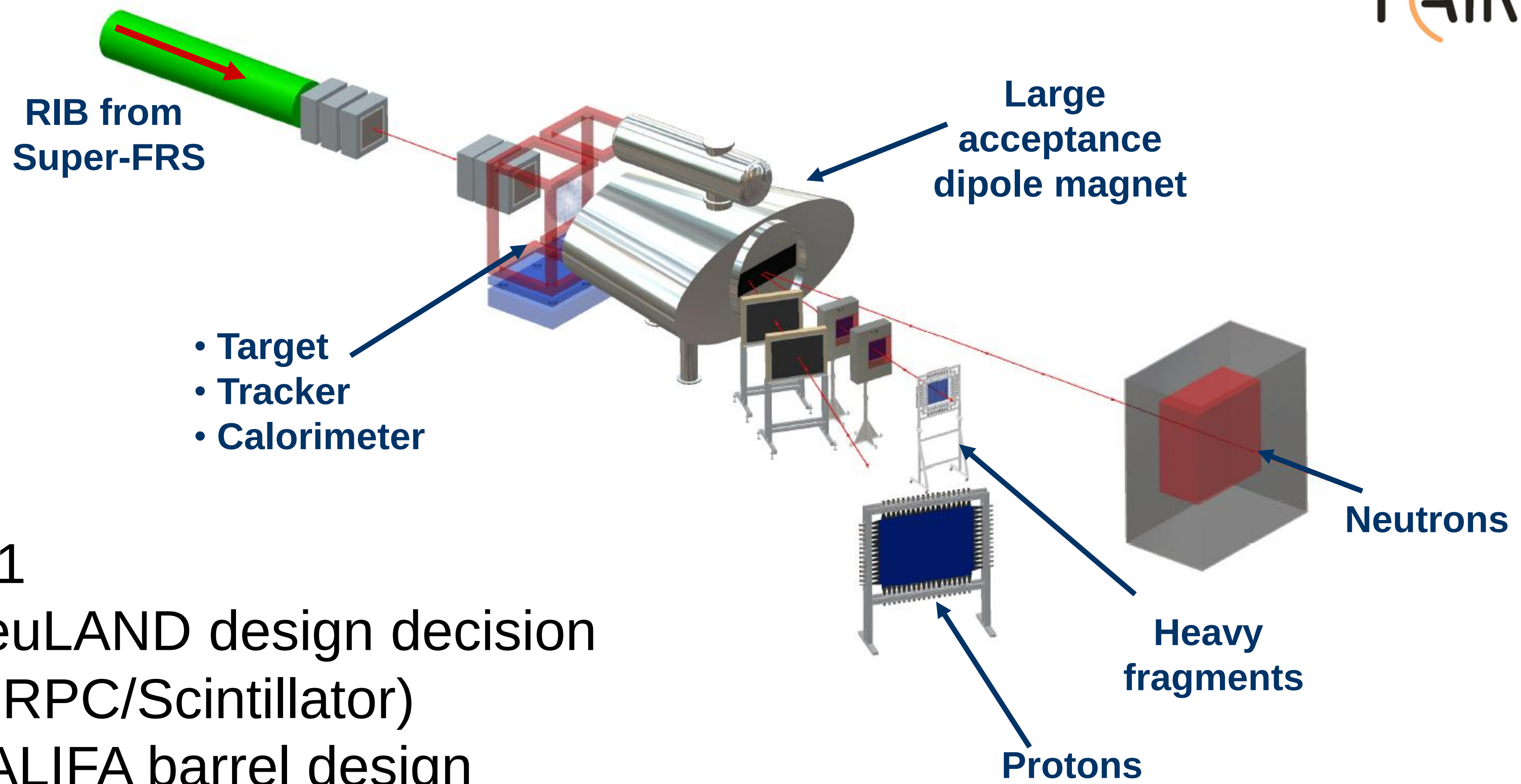


Old and new. FAIR's synchrotrons, storage rings, and detectors dwarf the existing facilities at GSI (*left*).

EXL : hadron scattering
ELISe : electron scattering
AIC : antiproton scattering

2 NOVEMBER 2007 VOL 318 SCIENCE www.sciencemag.org

Reactions with Relativistic Radioactive Beams (2017/18)



2011

- NeuLAND design decision (MRPC/Scintillator)
- CALIFA barrel design
  - R&D front-cap
- Si ASIC design ➔ TDRs

R3B – Cave C time schedule

2010 Integration of new CB readout electronics – New trigger electronics

Exp S393 Neutron-rich nuclei at and beyond the dripline

Wiescher 60Fe

Remaining shifts Datta Pramanik

Integration of LAND Taquila readout

2011 NeuLAND prototype production

d,t(p,2p)n,2n Exp – Critical Test/Calib NeuLAND / LAND

New heavy-ion tracking system

Exp: Pygmy dipole, GDR, GQR in Sn isotopes

New low-energy neutron detector

Exp: charge-exchange – GTR Astro; spin-dipole

2013 Dismount ALADIN, New superconducting dipole **ALADIN in Cave B?**

production of 20% NeuLAND

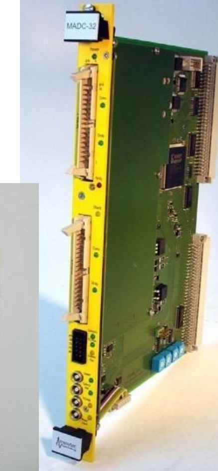
2014 R3B – phase 1 commissioning and first experiment

2014 – 2015 stepwise upgrade to final R3B plus experimental programme

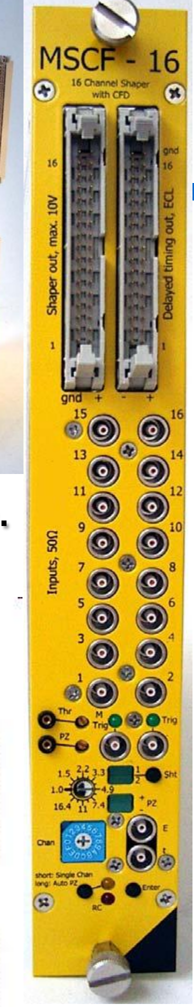
Planned experiments of other collaborations in Cave C

IKAR, HYPHI, Asy-EoS, FIRST/SPALADIN

FPGA logics



Shap. QDC



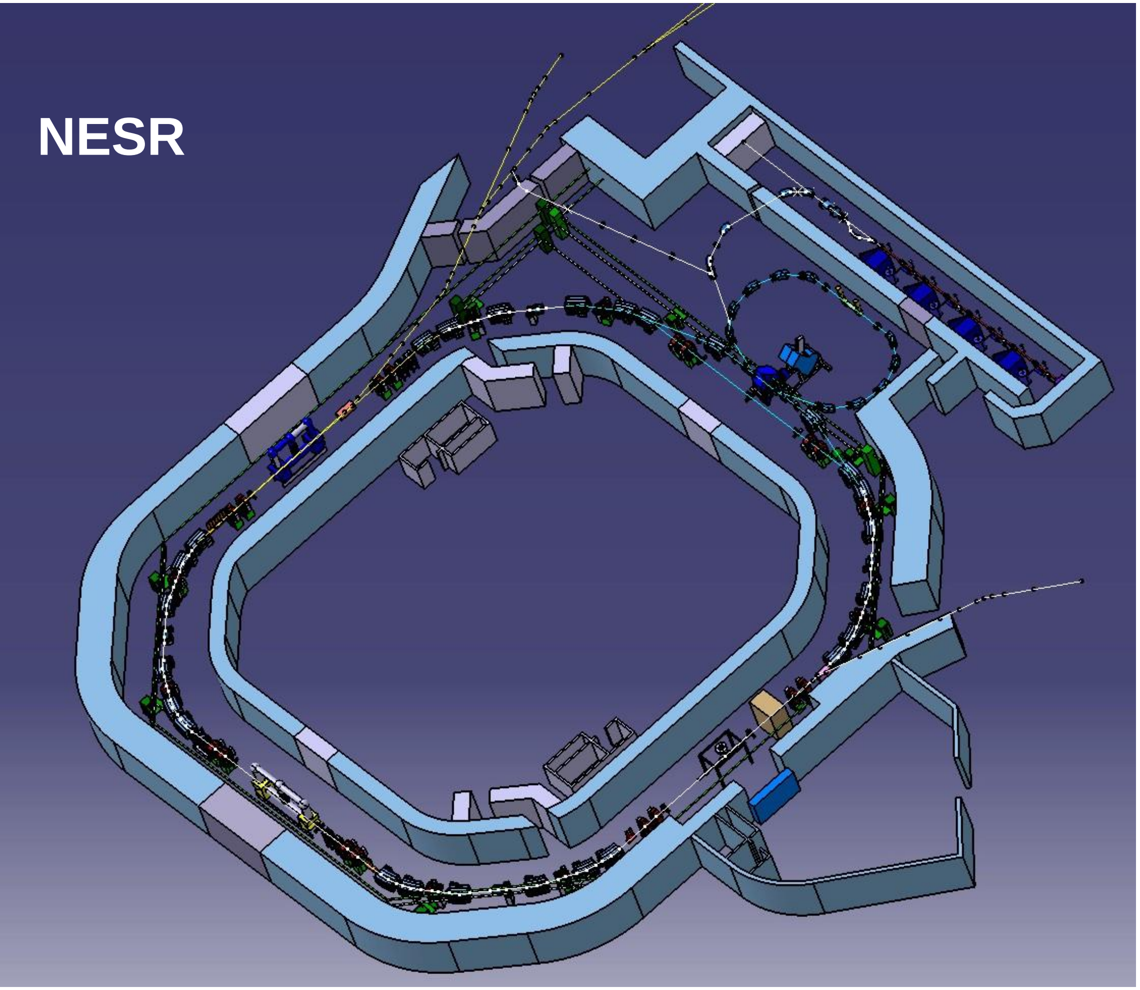
Online PSA

Open firmware

Realization of an RIB electron collider setup

The **ELISe** experiment

Haik Simon • GSI / Darmstadt



- 125-500 MeV electrons
- 200-740 MeV/u RIBs

➔ up to 1.5 GeV CM energy

- spectrometer setup at the interaction zone & detector system in ring arcs

- Part of the core facility

http://www.gsi.de/fair/reports/btr.html

AIC option:

- 30 MeV antiprotons

- detector system in ring arcs
- schottky probes

Why should one try to collide beams ?

- trying to get through the eye of the needle

• Target and scattered off particles can be detected

➔ excitation and de-excitation process is studied

• ‘no target absorption’

➔ unhampered detection

• kinematical focusing

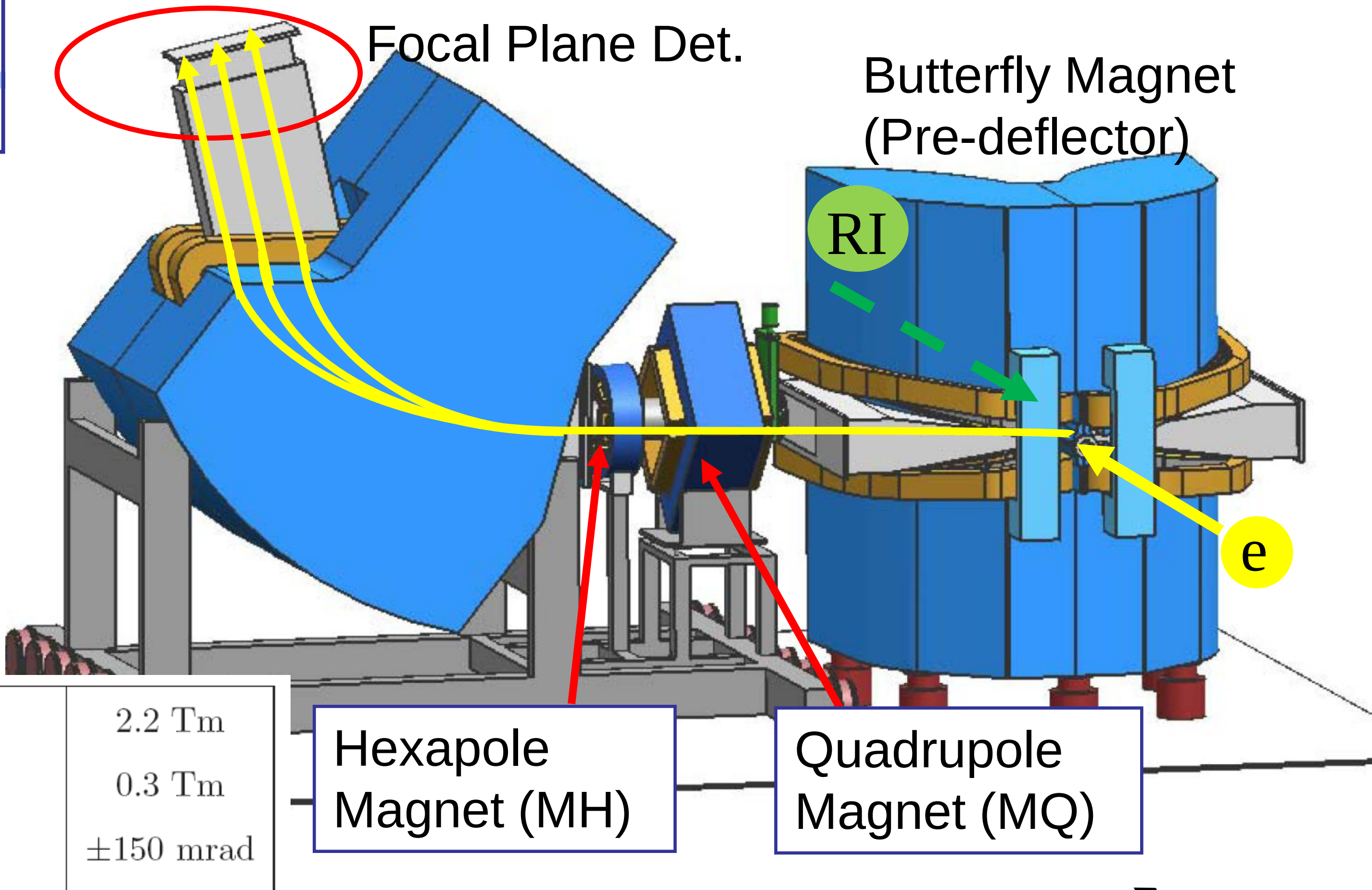
➔ solid angle

➔ Mott cross section enhanced (small angles)

• luminosity for unstable nuclei from a chemically non selective fragmentation facility

➔ 100µm x 100µm interaction area

High Resolution Large Acceptance Spectrometer



Maximum rigidity $B\rho$	2.2 Tm
Minimum rigidity $B\rho$	0.3 Tm
Angle acceptance, azimuthal	±150 mrad
Angle acceptance, polar at 11.4°	±24 mrad
Angle acceptance, polar at 22.7°	±70 mrad
Energy acceptance	± 5 %
Resolving Power $E/\Delta E$	$\approx 10^4$
Angle resolution	1 mrad
Kinematic compression factor	0.3 - 0.6

KVI/BINP/GSI NIM paper accepted

Integration

The Electron-Ion Scattering experiment ELISe at the International Facility for Antiproton and Ion Research (FAIR) - a conceptual design study

A.N. Antonov, M.K. Gaidarov, M.V. Ivanov, D.N. Kadrev

INRNE-BAS Sofia - Bulgaria

M. Aïche, G. Barreau, S. Czajkowski, B. Jurado

Centre d'Etudes Nucléaires Bordeaux-Gradingnan (CENBG) - France

G. Belier, A. Chatillon, T. Granier, J. Taieb

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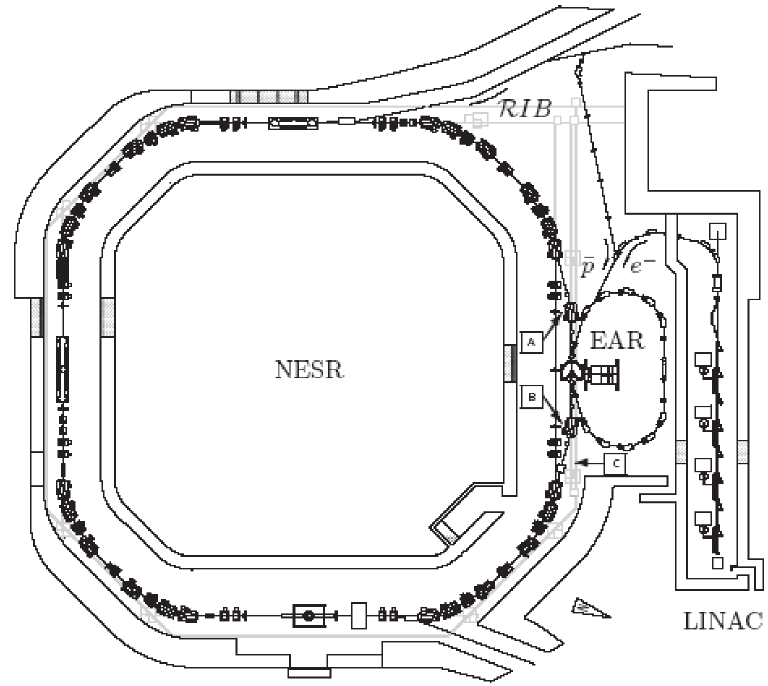
NIMA (2011) in press



➔ TDR 2011

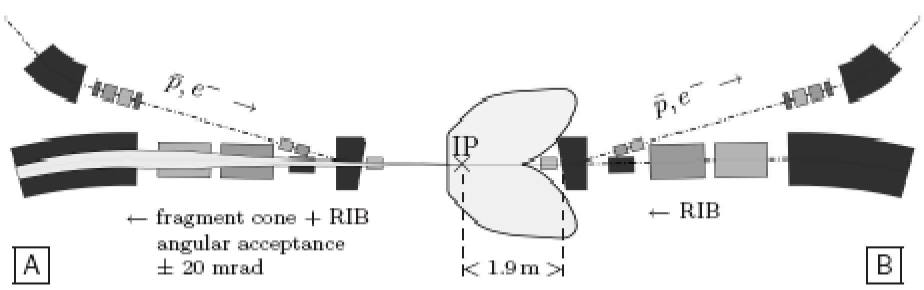


Figure 6: Interaction zone with the interaction point IP in the bypass section of the NESR.

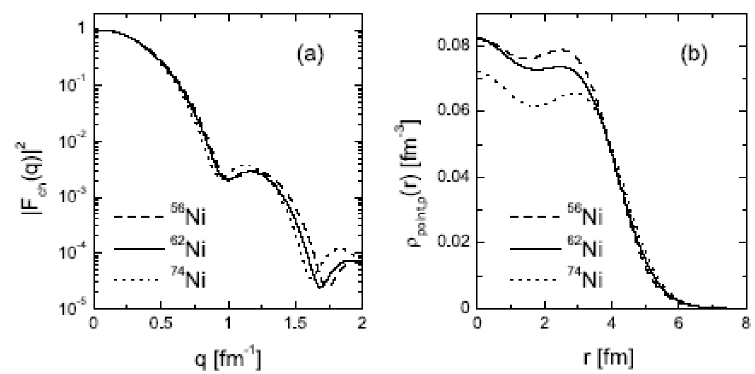


Figure 1: Charge form factors (panel (a)) calculated in DWBA and HF+BCS proton densities (panel (b)) for the unstable doubly-magic ^{56}Ni (dashed line), stable ^{62}Ni (full line) and unstable ^{74}Ni (dotted line) isotopes [7].

Final Remarks

- FAIR offers unique opportunities

- The process of building has now been started in a first reduced version offering already a viable program for all four communities

  APPA CBM panda NUSTAR

- Stay tuned! New website: http://www.fair-center.eu/

The Halo Collaboration

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