Current nuclear-reaction research at ATLAS

Workshop on “Nuclear Reactions: A Symbiosis between Experiment, Theory and Applications”

Institute of Nuclear Theory,

Seattle, March 13-16, 2017

Birger B. Back

Overview

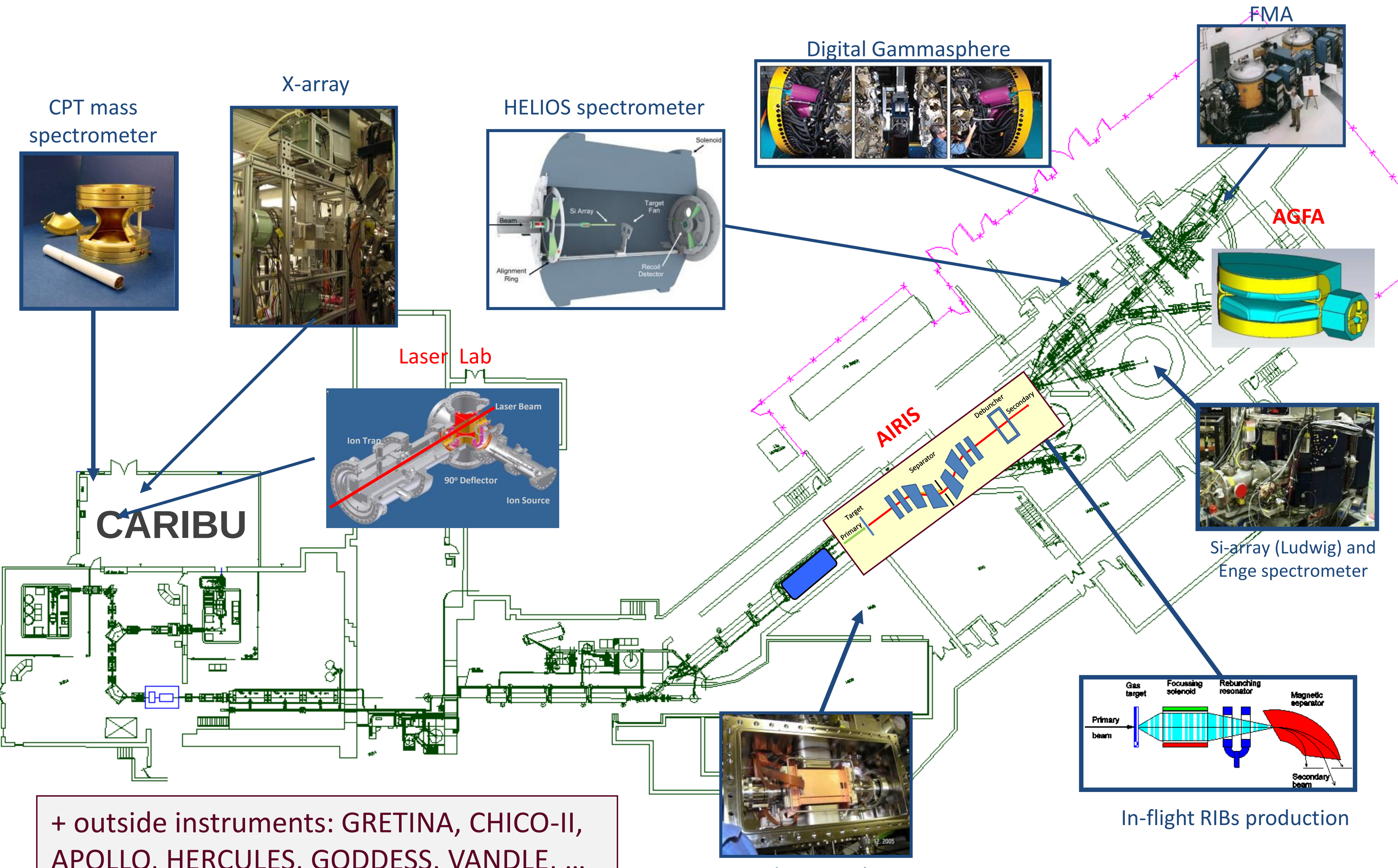
- **ATLAS facility overview**
  - Re-accelerated CARIBU beams (new EBIS source)
  - In-flight radioactive beams
- **Nuclear reaction studies**
  - Sub-barrier fusion
  - Astrophysical reactions
  - Coulomb excitation
  - Transfer reactions (HELIOS)
- **New Instrument developments**
  - Argonne Gas-Filled Separator
  - Argonne In-flight Radioactive Ion Separator
- **Summary**

ATLAS

ATLAS Accelerator Complex

- Ion sources
  - ECR II for stable beams
  - CARIBU ^{252}Cf fission fragments
    - low energy beamlines
    - New Electron Beam Ion source
- ATLAS – Argonne Tandem Linac Accelerator System (now without Tandem)
  - Room temp RFQ + 51 individually phased superconducting accelerating resonators
- Experimental areas
  - Area II
    - Gas stopper and RFQ cooler to prepare slow beams
    - Beta Paul trap
  - Area III & IV
    - ATSCAT – large 36” diam scattering chamber
    - Spectrograph, MUSIC II – Astrophysics studies
    - HELIOS – HELIcal Orbit Spectrometer – Inverse kinematics transfer reactions
    - Gammasphere / GRETINA – gamma-ray studies of nuclear structure
    - FMA – fusion evaporation product identification – m/q resolution small solid angle
    - AGFA – fusion evaporation products – large solid angle

ATLAS suite of experimental equipment

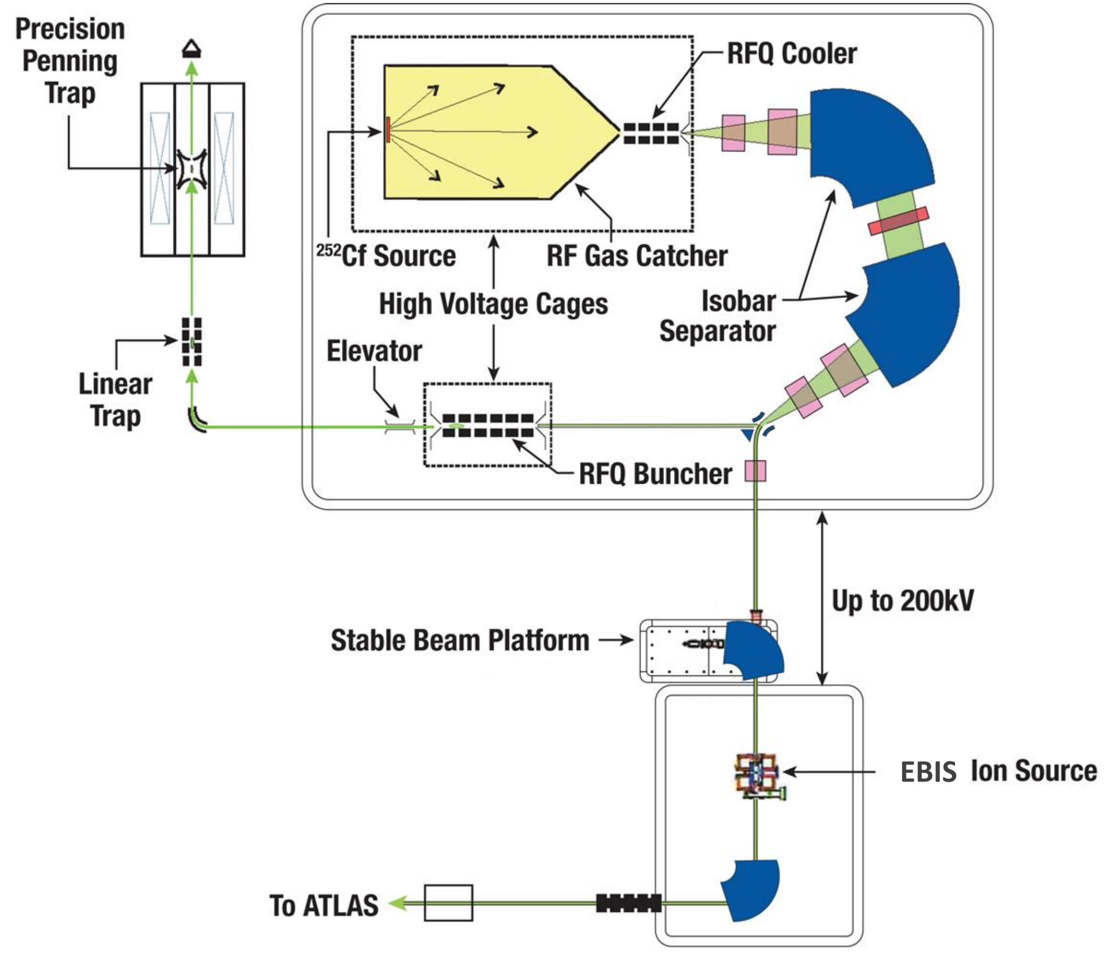


+ outside instruments: GRETINA, CHICO-II, APOLLO, HERCULES, GODDESS, VANDLE, …

Neutron-rich beams for ATLAS: CARIBU “front end” layout

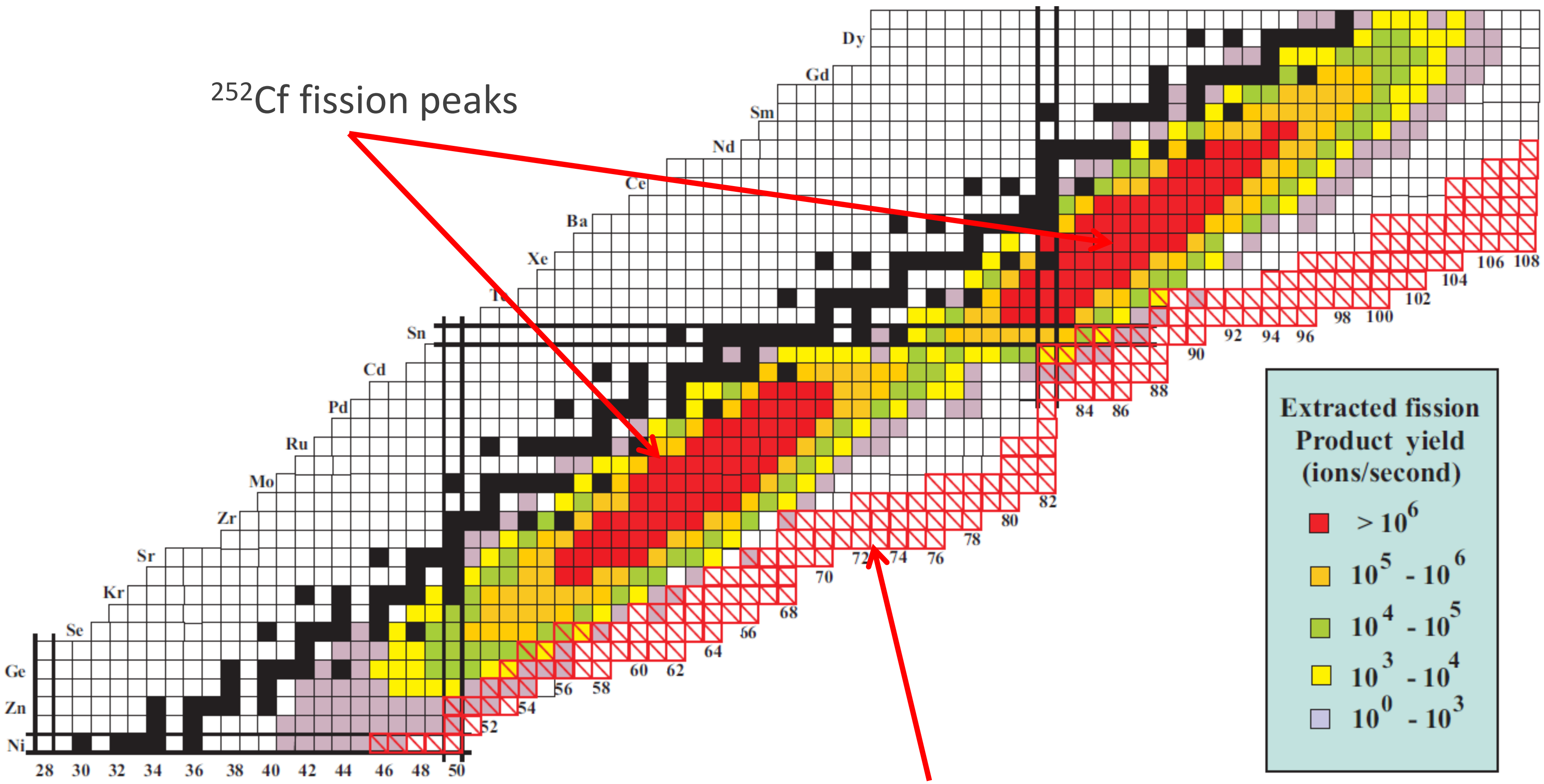
Main components of CARIBU

- **PRODUCTION**: “ion source” is ^{252}Cf source inside gas catcher
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam
- **SELECTION**: Isobar separator
  - Purifies beam
- **DELIVERY**: beamlines and preparation
  - Switchyard
  - Low-energy buncher and beamlines
  - Charge breeder to Increase charge state for post-acceleration
  - Post-accelerator ATLAS and weak-beam diagnostics



CARIBU Beams

^{252}Cf fission peaks



r-process path

EBIS charge breeder upgrade

- Removing stable beam contamination of reaccelerated beams from ECR charge breeder
  - Concept developed and demonstrated by accelerator R&D group
  - Provides two important gains versus ECR charge breeding at CARIBU
    - Higher charge breeding efficiency demonstrated for pulse injection operation (ANL tests at BNL EBIS … and now operating off-line at ANL)
    - UHV system leads to stable beam background suppression

- Main goal: suppression of stable beam contaminants
- As a bonus, gain in intensity for reaccelerated CARIBU beams
  - Light fission peak

    17-21% (25-30%) for EBIS+buncher vs. 4-6% for ECR
  - Heavy fission peak

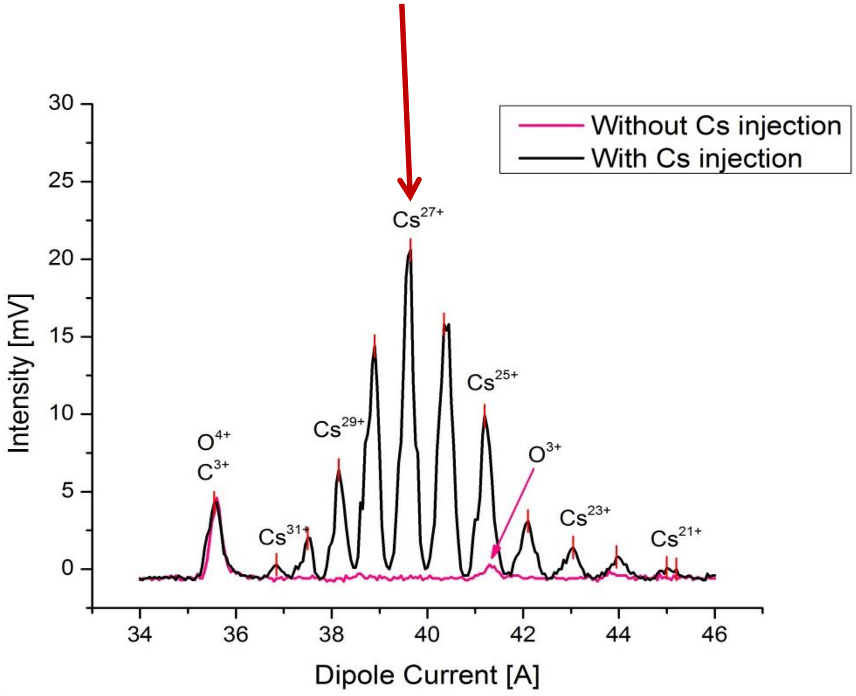
    16-20% (20-25%x0.8) for EBIS+buncher vs. 8-12% for ECR

EBIS charge breeder operating

- Charge distribution narrower than with ECR CB → higher efficiency in one M/Q
- Beam dominated by charge-bred injected beam, not background from the source

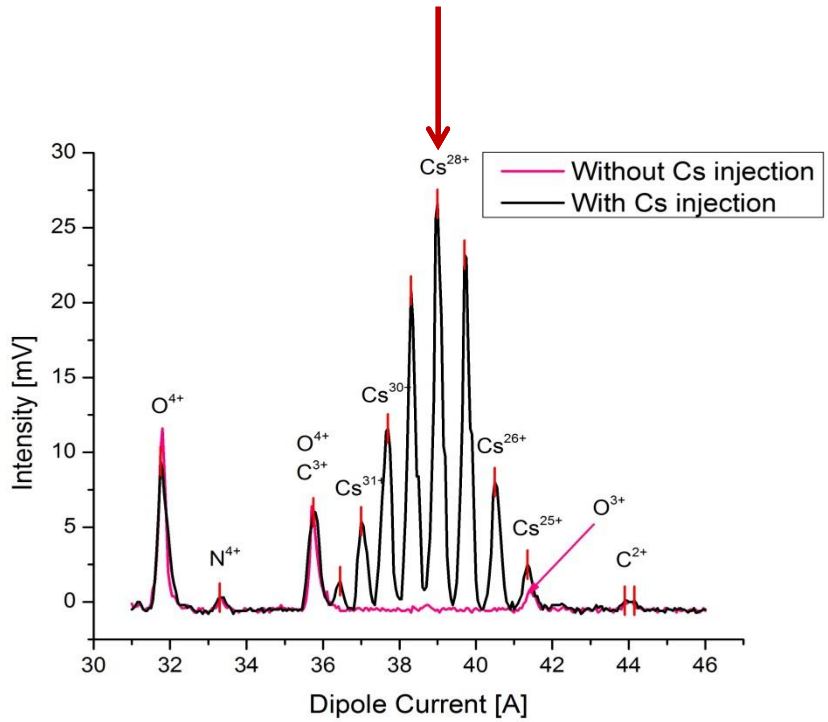
20 msec

Cs^{27+}, M/Q=4.925



30 msec

Cs^{28+}, M/Q=4.75



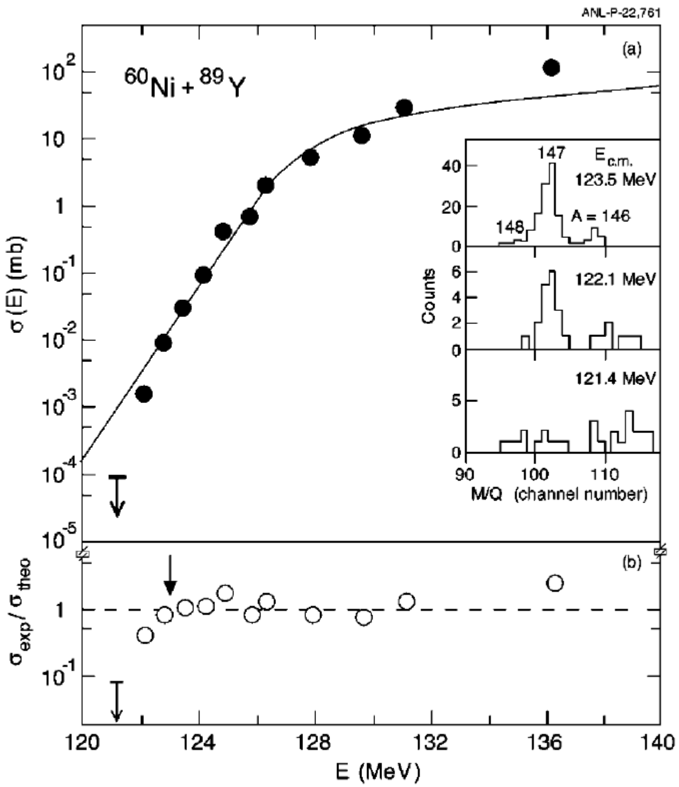
Nuclear Reaction studies

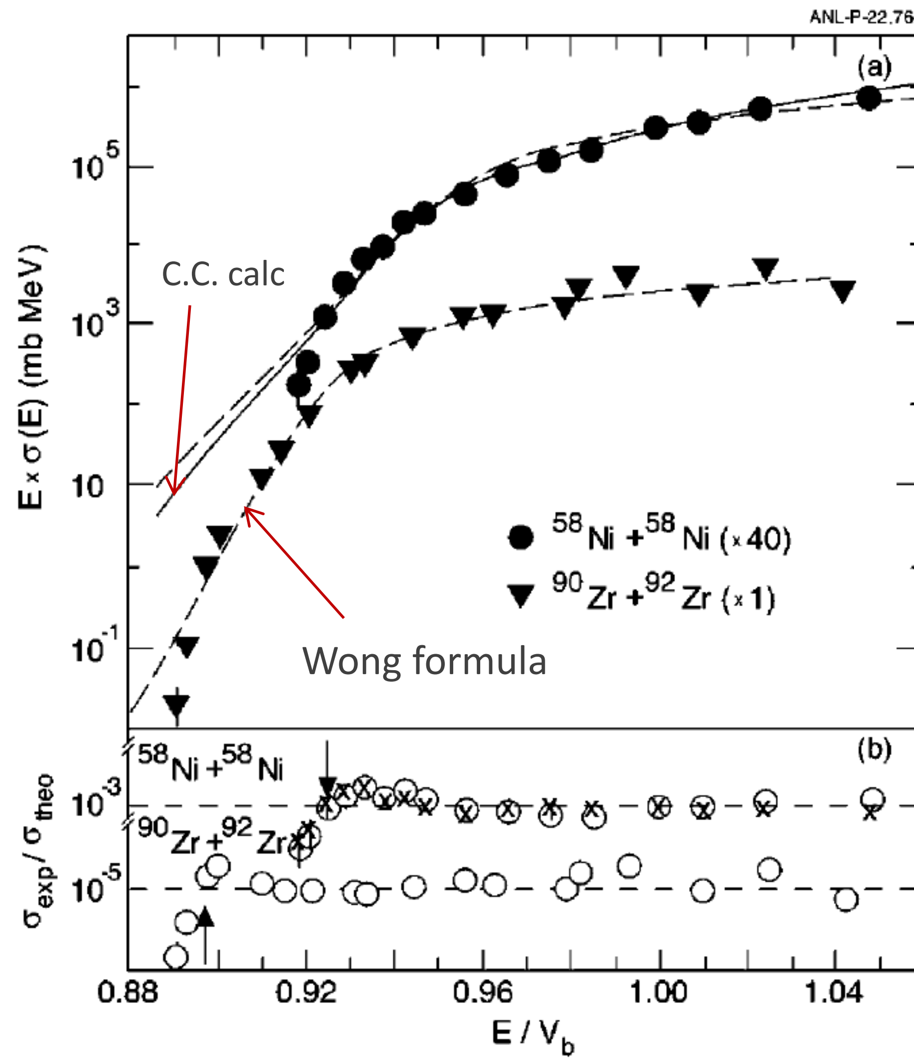
Sub-barrier fusion

Sub-barrier fusion hindrance - discovery

- New measurement of $^{60}Ni+^{89}Y$

Jiang et al., Phys. Rev. Lett. 89, 052701 (2002)

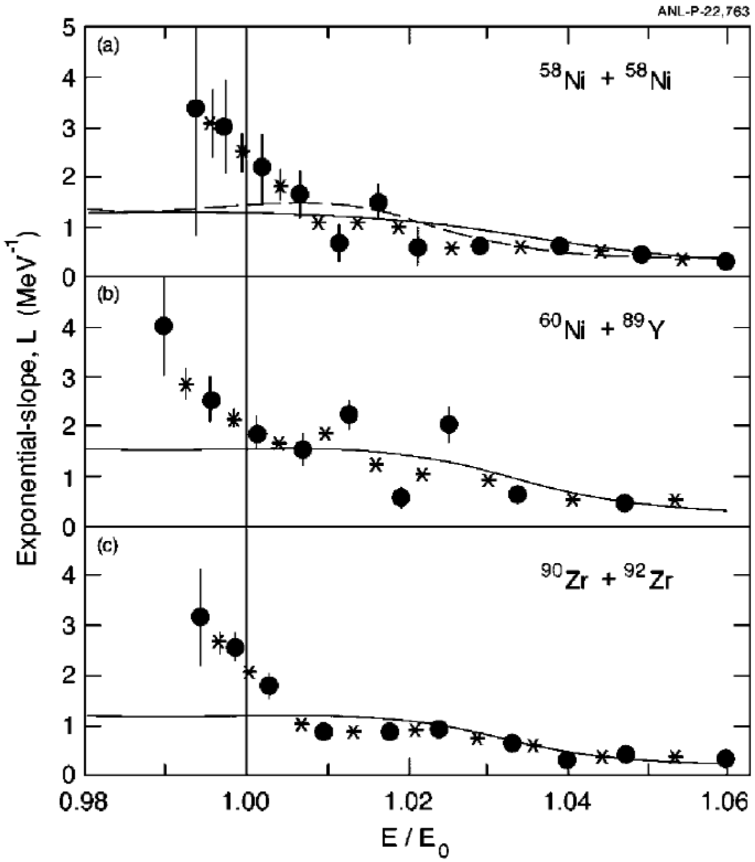




Observation: Low energy fall-off steeper than expected based on conventional potentials

Barrier distribution, logarithmic derivative, S-factor

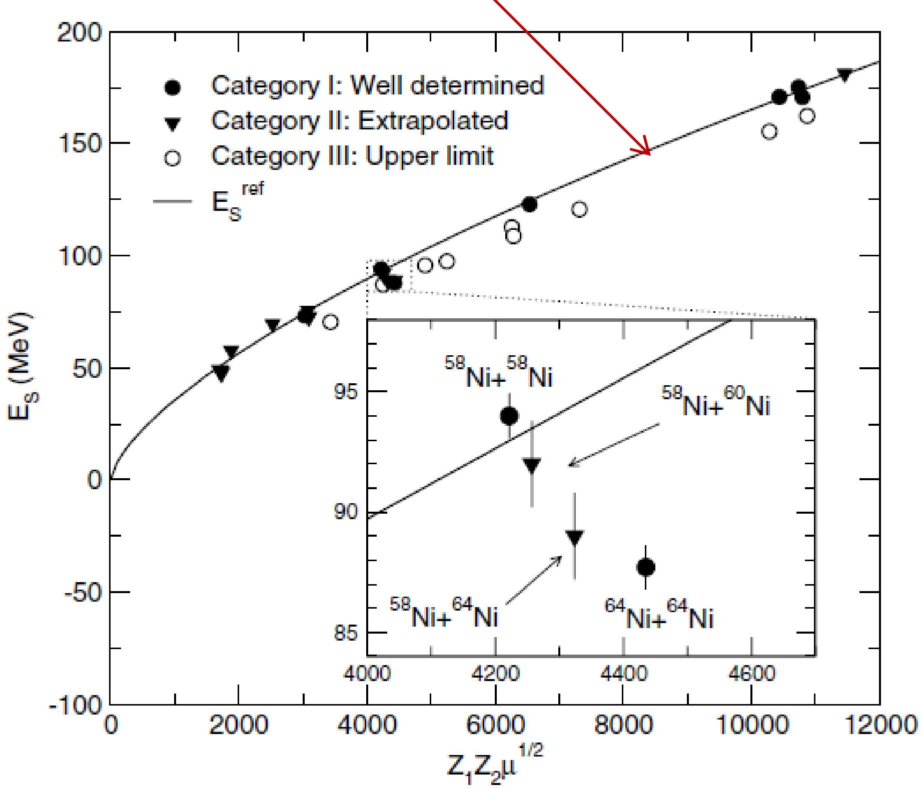
- Barrier distribution: $B(E) = d^2(\sigma E)/dE^2$ — Rowley et al. Phys. Lett. B 254, 25 (1991)
- Logarithmic derivative: $L(E) = \frac{d(ln\sigma E)}{dE}$ — Jiang et al., Phys. Rev. Lett. 89, 052701 (2002)
- Relationship : $B(E) = \sigma E\left[\frac{dL(E)}{dE} + \ (L(E))^2\right]$
- Advantages:
  - $L(E)$uses only first derivatives of x-section
  - Sudden rise → fusion hindrance
  - Model independent
- S-factor (astrophysical)
  - $S(E) = \ \sigma E e^{(2\pi\eta)}$, where
  - η= Sommerfeld parameter: $\eta = Z_1 Z_2 e^2/(\hbar v)$
- Relationship : $\frac{dS}{dE} = S(E)\left[L(E) - \frac{\pi\eta}{E}\right]$
- S-factor maximum: $L(E) = \frac{\pi\eta}{E}$, OR
- $L_{cs}(E) = \frac{0.495 Z_1 Z_2 \sqrt{\mu}}{E^{\frac{3}{2}}}(MeV^{-1})$

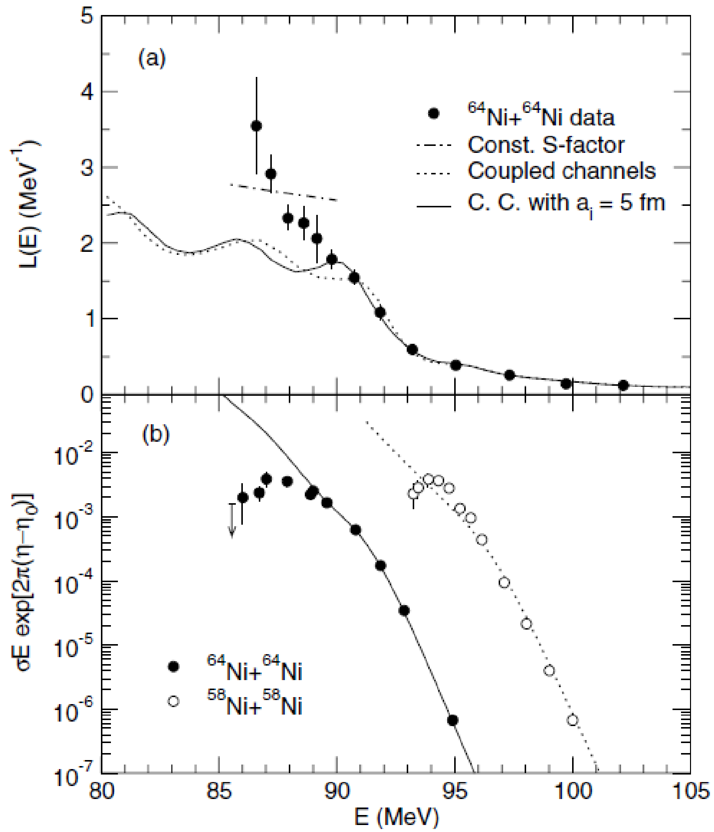


Nuclear structure effects and systematics

$$E_s^{\ ref} = 0.356(Z_1 Z_2\sqrt{\mu})^{\frac{2}{3}}(MeV)$$

Jiang *et al.* Phys. Rev. Lett. 93, 012701 (2004)

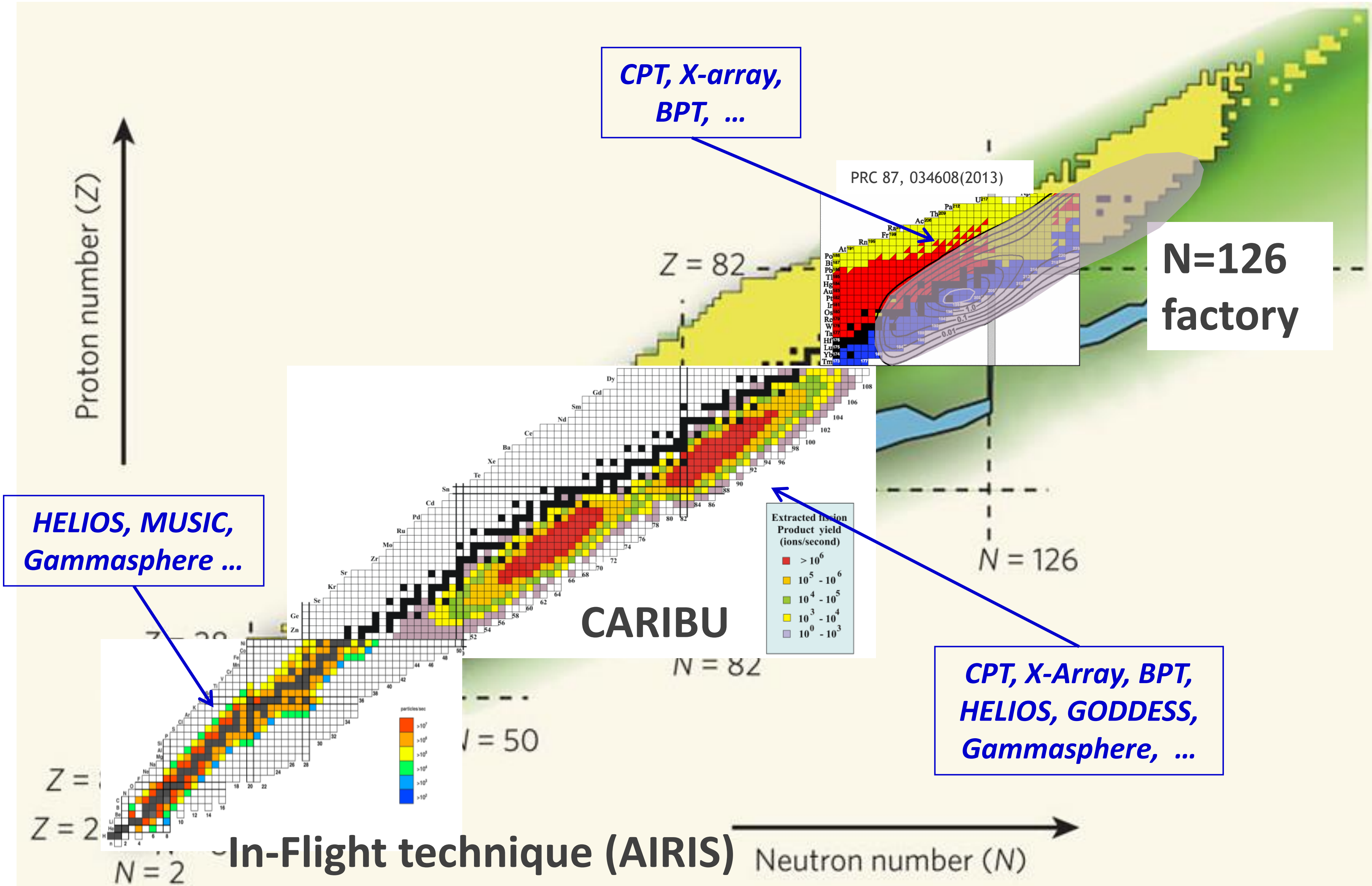




Observation: S-factor maximum follows
Simple empirical systematics

Astrophysics

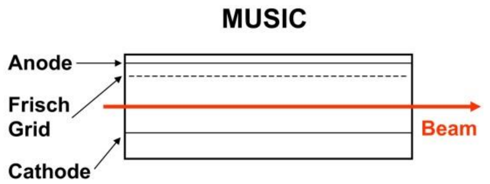
r-process and rp-process measurements

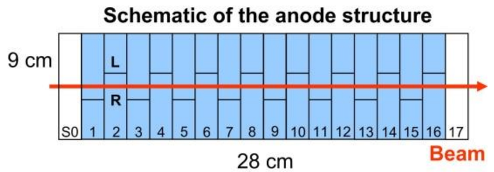


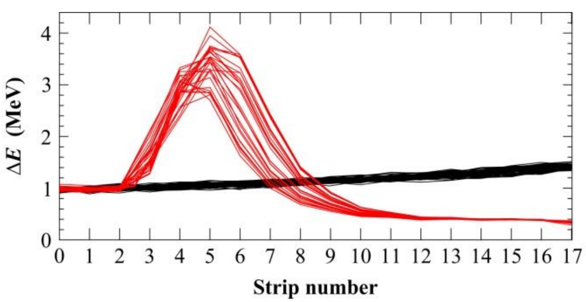
MUlti Sampling Ionization Chamber (MUSIC)

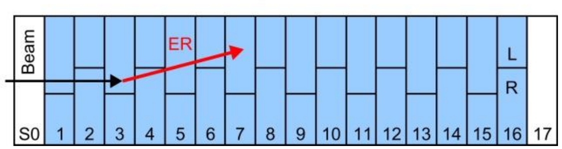
<u>Active target: *e.g.* 4He gas</u>

Principle/simulation



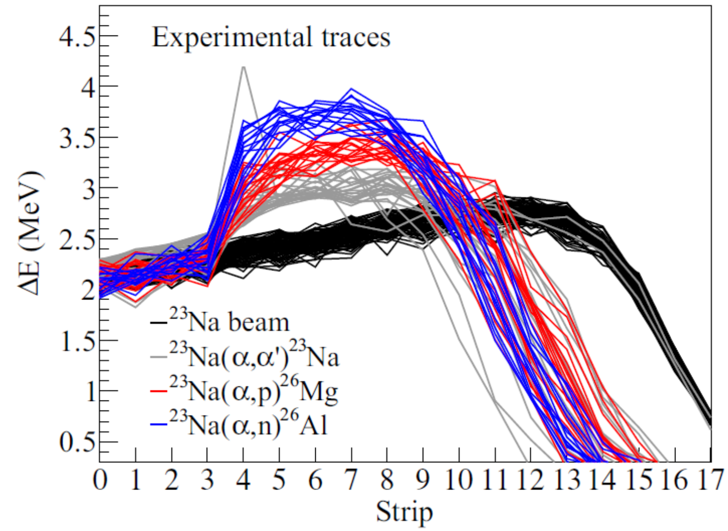


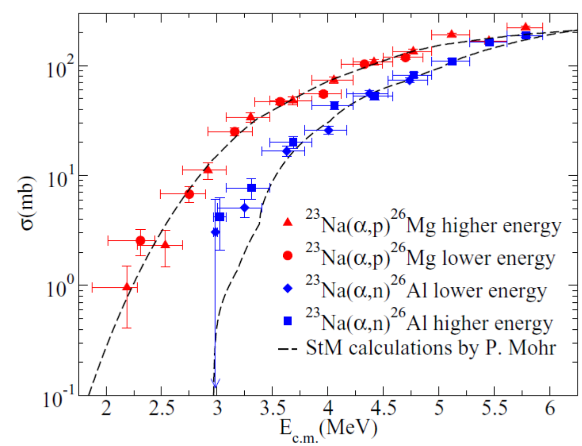




Carnelli et al, Nucl. Instr. Meth. 799, 197 (2015)

Experimental results



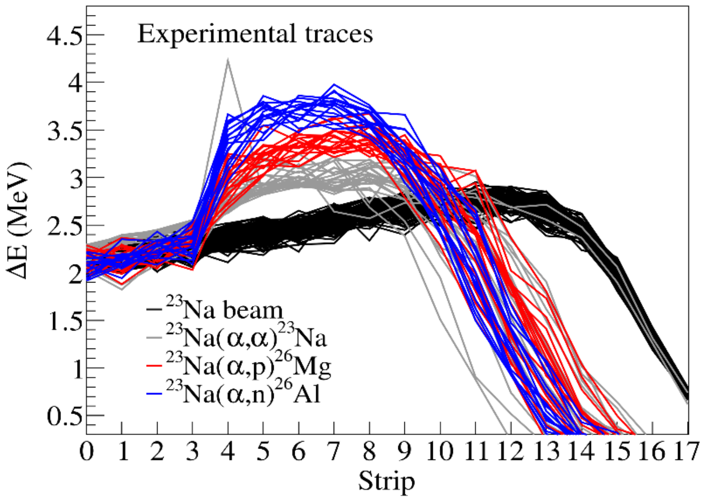


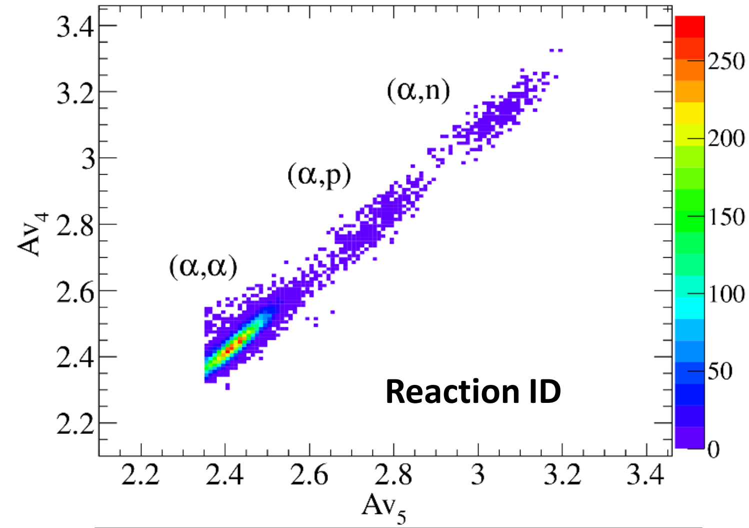
Avila et al., Phys. Rev. C 94, 065804 (2016)

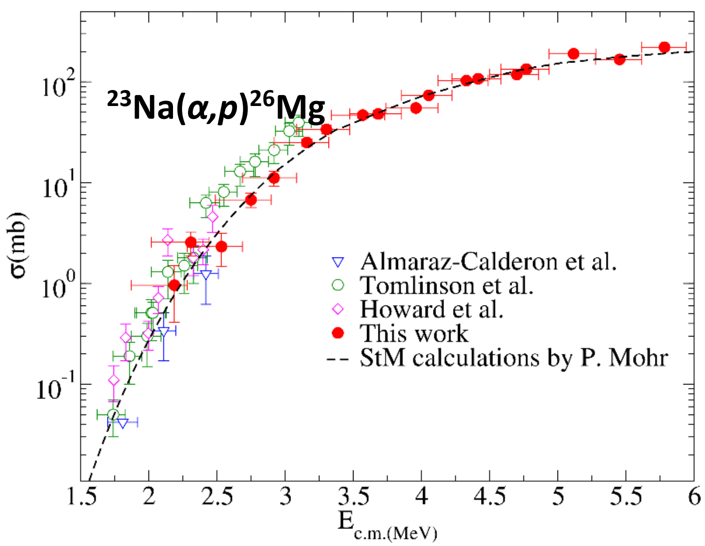
Simultaneous measurement of (α,p) and (α,n) reactions

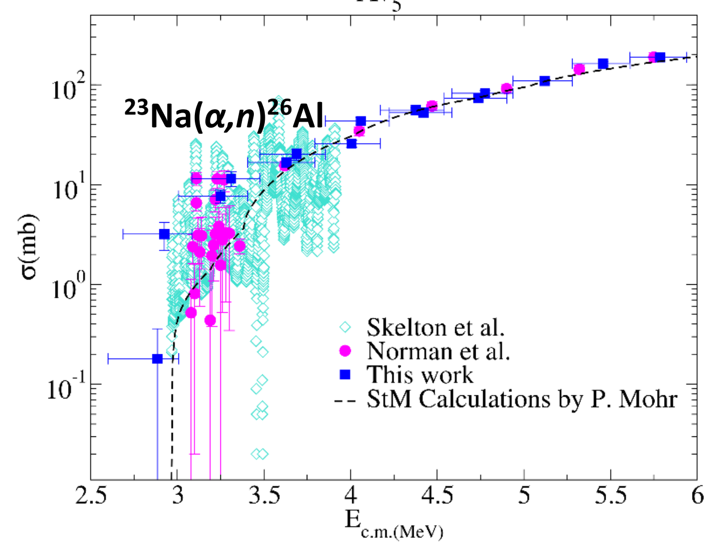
Avila et al., Phys. Rev. C 94, 065804 (2016)

The ^{23}Na(α,p)^{26}Mg reaction directly influences the production of ^{26}Al in massive stars









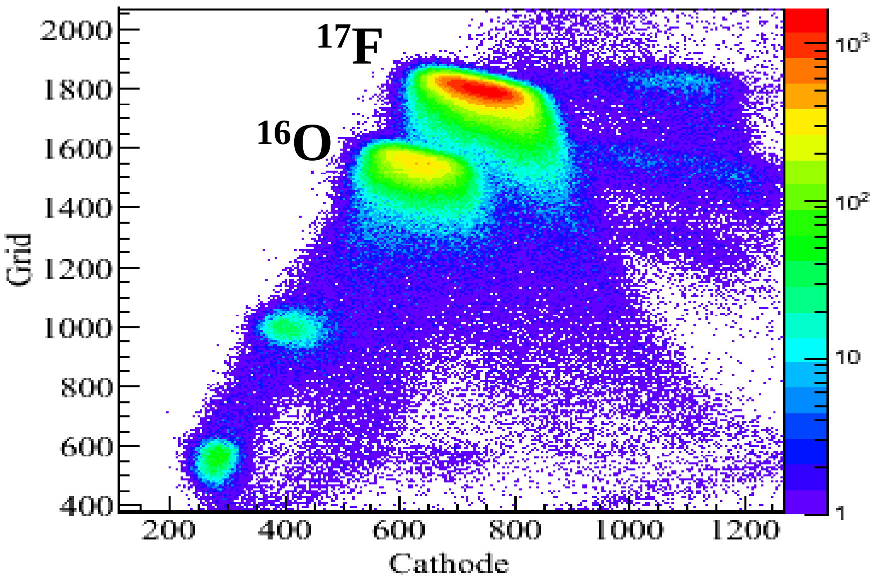
The $^{17}F(\alpha,p)^{20}Ne$ reaction

Avila (ANL), Rehm (ANL), Santiago-Gonzalez (LSU), Talwar (ANL)

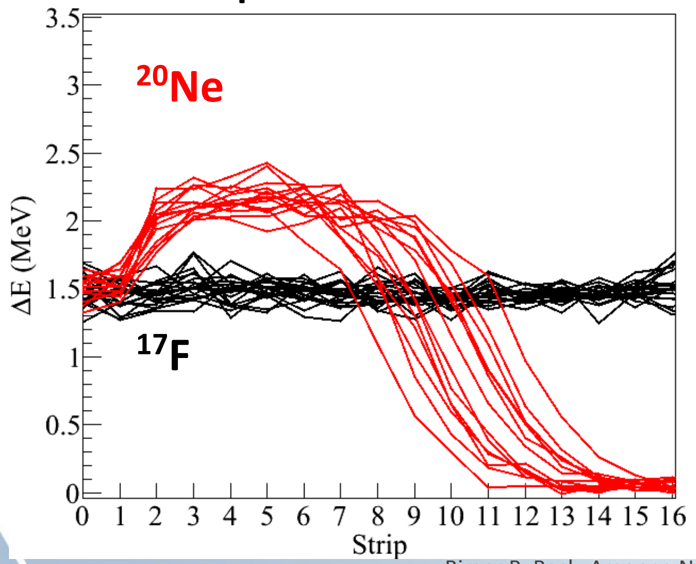
The $^{17}F(\alpha,p)^{20}Ne$ is one of the primary reactions that affect the ^{44}Ti production in core collapse supernovae

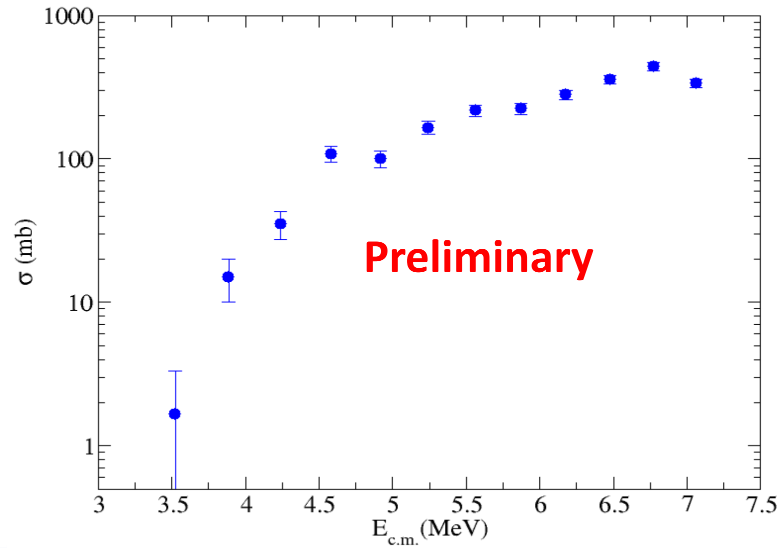
G. Magkotsios *et al.*, Astrophys. J. Suppl. Ser. **191**, 66 (2010).

Particle ID



Experimental traces





$^{12}C+^{10,14,15}C$ fusion: Implications for X-ray bursts

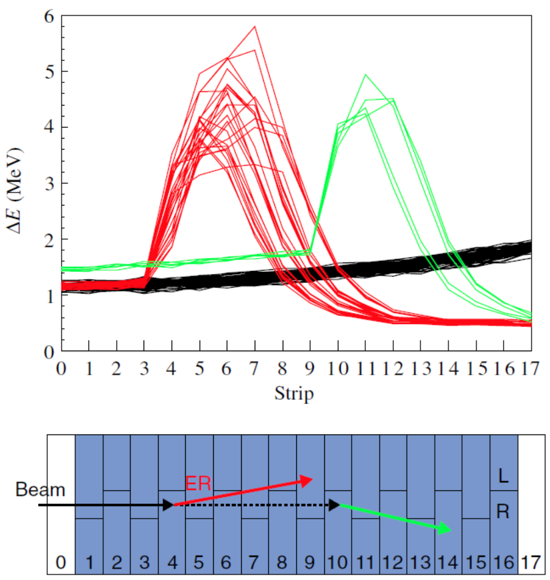


***Fig. 1:** Top: ΔE signals for reactions induced by ^{15}C and ^{15}N particles. Black: ΔE signals in the 18 strips for ^{15}C beam particles. Red: ΔE values measured for evaporation residues produced by ^{15}C particles in anode strip 4. Green: ΔE values measured for evaporation residues produced by ^{15}N particles in anode strip 10. Bottom: Schematic of the anode structure.*

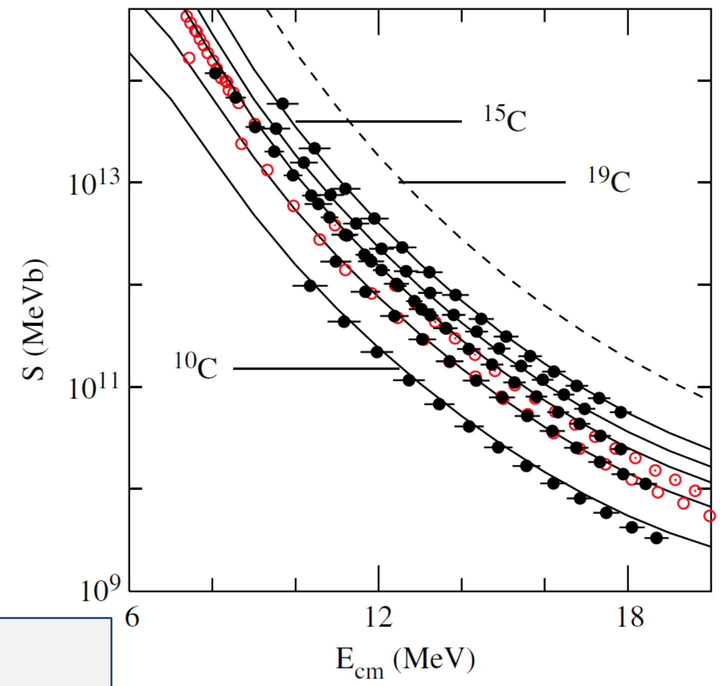


***Fig. 2:** Solid points: Experimental data for the S factors in the fusion reactions $^{10,12,13,14,15}C + ^{12}C$. Open circles: Experimental data for $^{12,13}C+^{12}C$ from literature. Solid lines: Theoretical S factors for the systems $^{10,12,13,14,15}C+^{12}C$ taken from the calculations of Yakovlev et al.. Dashed line: Theoretical S factor for the system $^{19}C+^{12}C$.*

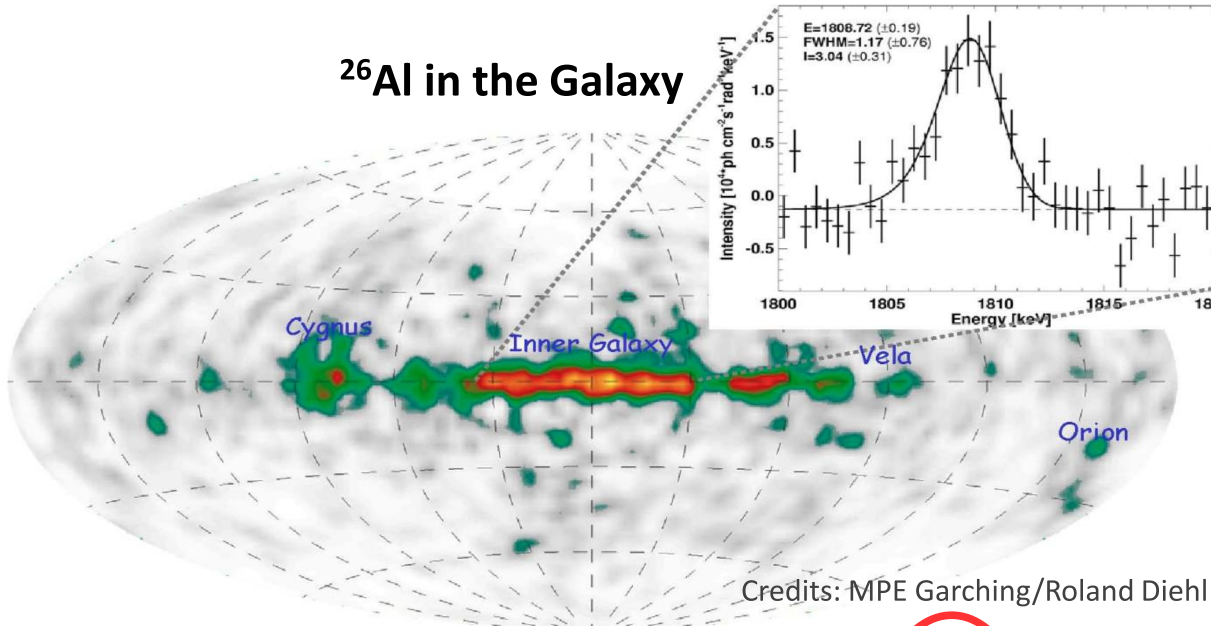
- Fusion between neutron-rich nuclei is important for understanding the energy production through pycnonuclear reactions in the crust of neutron stars.
- We have performed the first measurements of the total fusion cross sections in the systems $^{10,14,15}C+^{12}C$ using a new active target-detector system, MUSIC.
- In the energy region accessible with existing radioactive beams, a good agreement between the experimental and theoretical cross sections is observed. This gives confidence in our ability to calculate fusion cross sections for systems which are outside the range of today's radioactive beam facilities.

Carnelli *et al.*
Phys. Rev. Lett. **112**, 192701 (2014)

The $^{26}Al^{m}(d,p)^{27}Al$ reaction

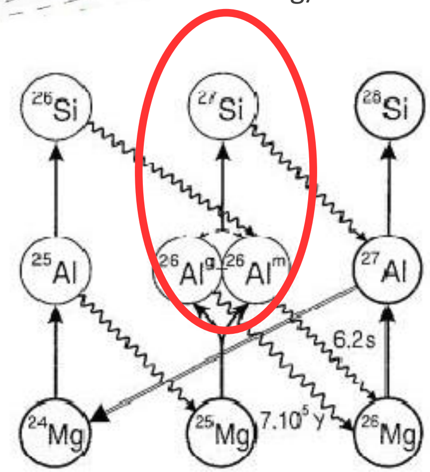
Almaraz-Calderon (FSU), Rehm (ANL), Avila (ANL), Santiago-Gonzalez (LSU), Talwar (ANL)

- $^{26}Al^{g}$ (5^{+}, $t_{1/2} = 7.4 \times 10^{5}$ y) is observed in the Galaxy via the 1.8-MeV γ-ray line.
- ^{26}Al in the Galaxy is mainly destroyed via $^{26}Al(p,\gamma)^{27}Si$ reactions.



Credits: MPE Garching/Roland Diehl

- Low-lying proton captures on $^{26}Al^{m}$ (0^{+}, E_{ex}=0.228 MeV, $t_{1/2}$ = 6.3 s) could influence the destruction of ^{26}Al in the Galaxy.
- We are studying the $^{26}Al^{m}(d,p)^{27}Al$ reaction to obtain spectroscopic information of the relevant resonances in ^{27}Si via its mirror nucleus (^{27}Al).



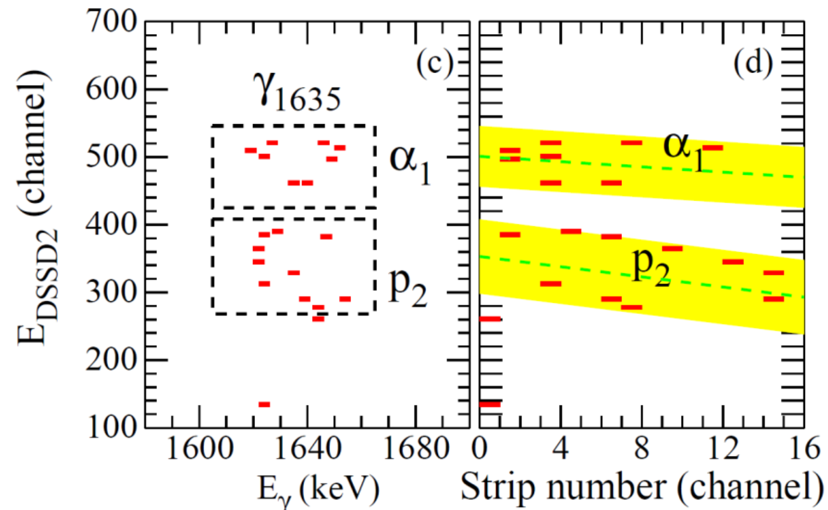
C. Iliadis *et al.* Astrophys. J. Suppl. Ser. **142**, 105 (2002).

Reaction rate for carbon burning in massive stars

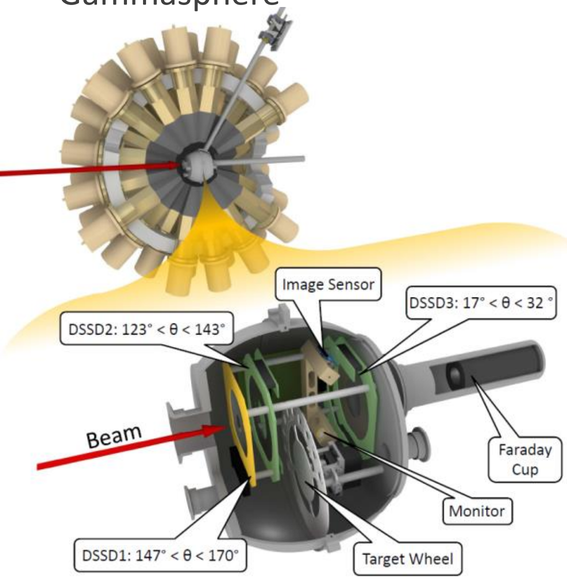
Topic: Carbon burning, *i.e.*, $^{12}C + ^{12}C$ fusion is an important route for the production of elements with mass A>20 in the final phases of massive stars >20$M_{\odot}$ or type Ia supernovae.

Data: Particle-γ coincidence measurements allow for clean measurements of the fusion cross section at low bombarding energies.

Clean events @ E_{cm}=2.84 MeV

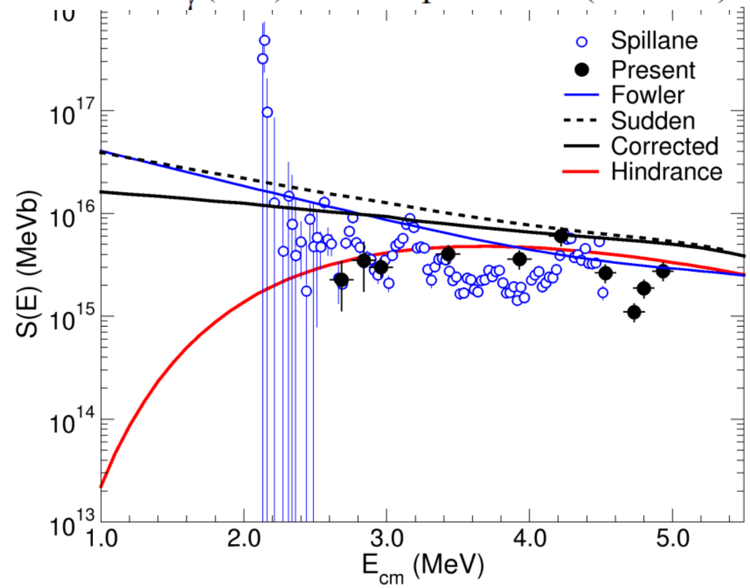


Gammasphere



Si detectors

Results: Clean measurements obtained over the range E_{cm}=2.68-4.93 MeV allows for more reliable extrapolation to lower energies of relevance for stellar carbon burning..



Outlook: A dedicated, long-term measurement using this technique could yield reliable measurements in the Gamow window for carbon burning.

C. L. Jiang *et al*., Phys. Rev. Lett. – submitted, Jan 2017

Coulomb excitation
of
re-accelerated beams

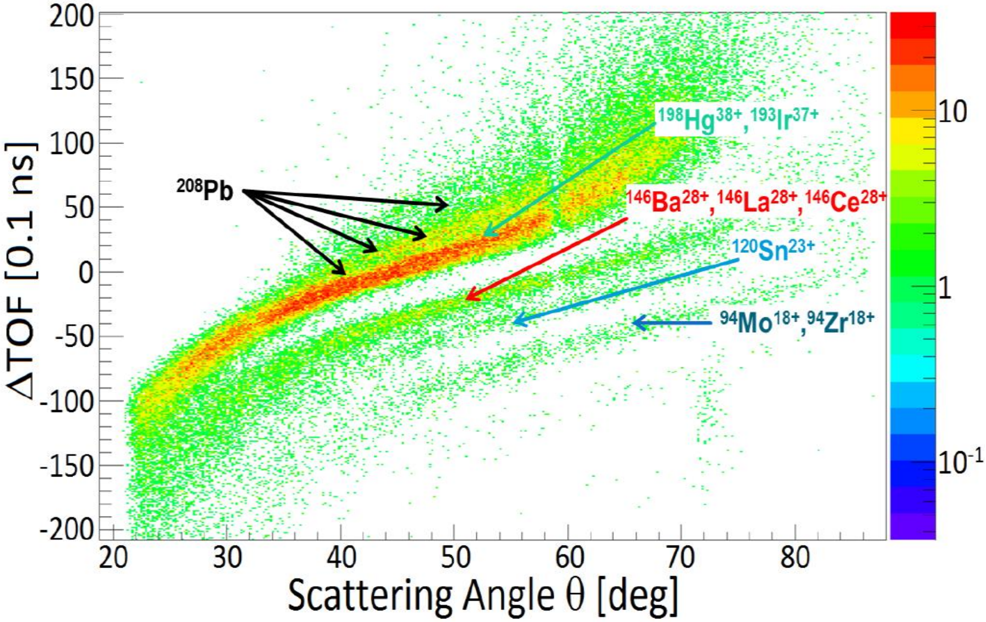
Confirmation of Octupole Deformation in heavy Ba

Experiment:

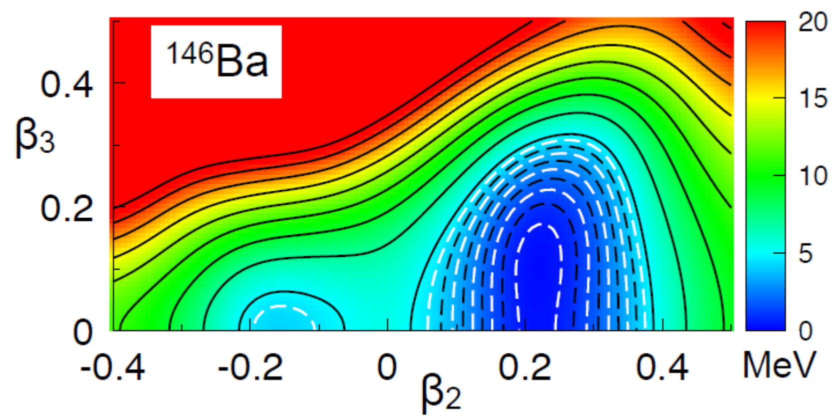
- ^{146}Ba CARIBU re-accelerated beam
- CHICO-2 and GRETINA
- Coulomb excitation using 3000 ions/sec
- Separation of ^{144,146}Ba from contaminants other than isobars made by the measured two-body kinematics: Time-of-flight difference vs. scattering angle;

Results

- ^{146}Ba: B(E3;3-→0+) = 48^{+21}_{-29} W.u.
- ^{144}Ba: B(E3;3-→0+) = 48^{+25}_{-34} W.u.
- Dipole strength: ^{144}Ba, B(E1) strength is two orders of magnitude larger than it is in ^{146}Ba;
- The measured E3 strengths are the same in ^{144}Ba and ^{146}Ba, despite the two orders of magnitude difference in B(E1) strengths in these two nuclei.
- The results demonstrate, for the first time, the significant impacts of the shell effects on the nuclear intrinsic dipole moments.



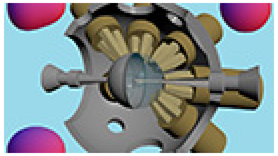
HFB potential energy surface



B. Bucher, S. Zhu *et al.*, Phys. Rev. Lett. in press

Strength of octupole correlations in neutron-rich Ba

B. Bucher *et al.*, Phys. Rev. Lett. **116**, 112503 (2016).

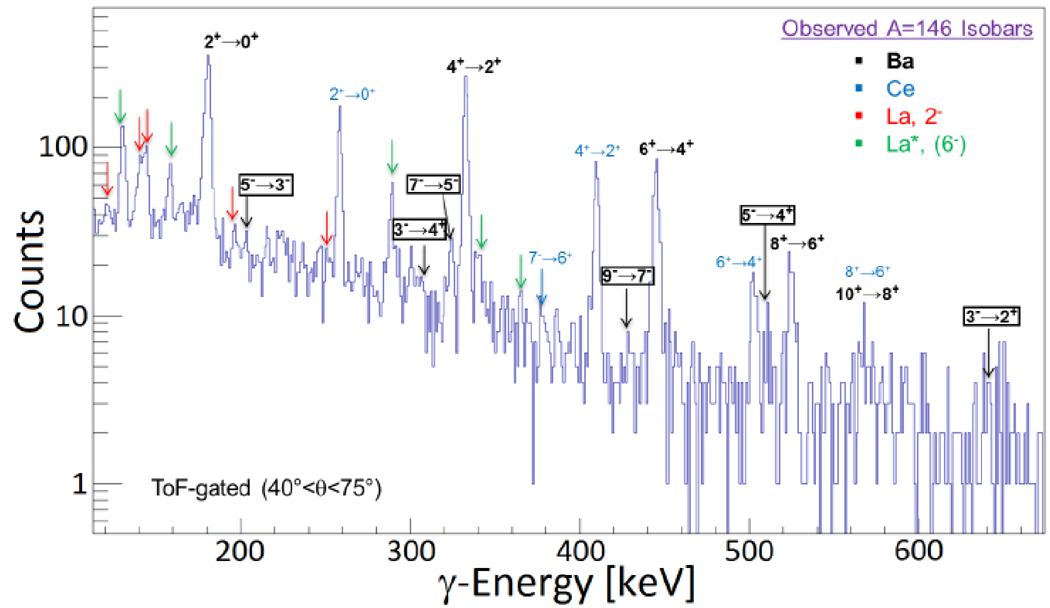


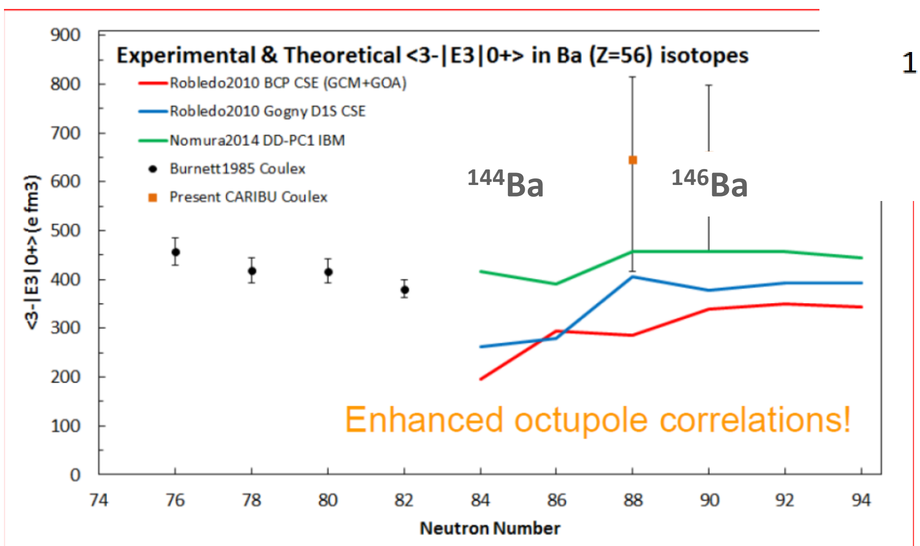
06.06.16 | SCIENCE HIGHLIGHT

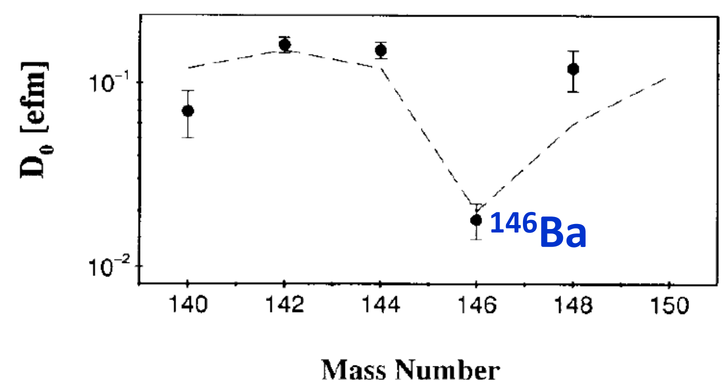
Confirmed: Heavy Barium Nuclei Prefer a Pear Shape

Cutting-edge experiment with a beam of radioactive barium ions provides direct evidence of nuclear pear-shape deformation. Read More »

- Octupole collectivity experimentally demonstrated for both Ba nuclei
  - ➢ region, not just one case
- Nature of variations in B(E1) strength under discussion
  - ➢ shell effect?



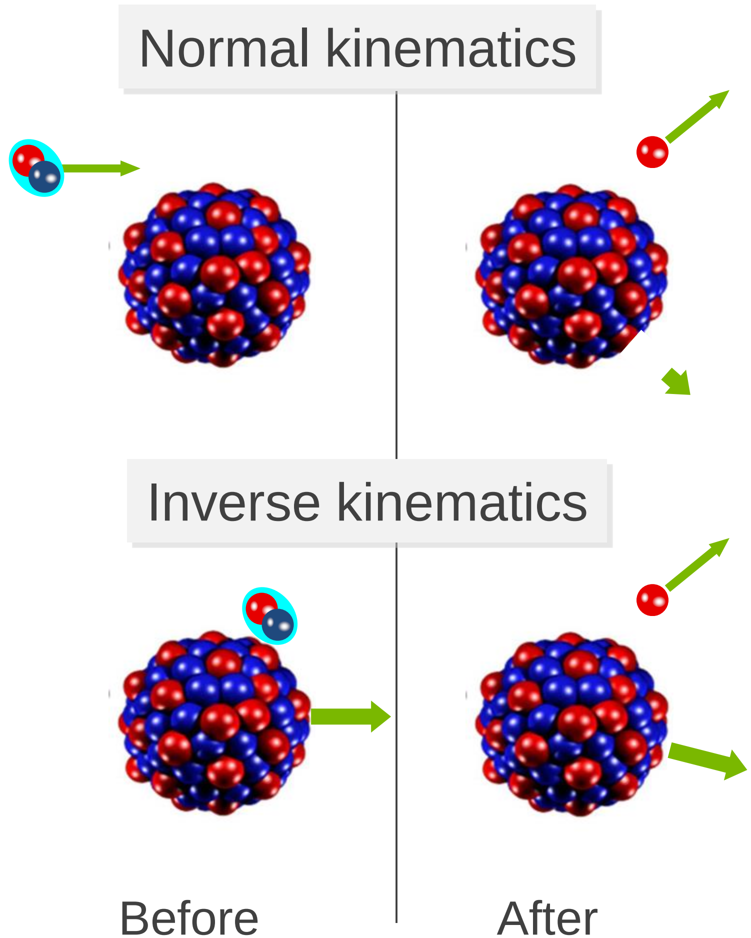


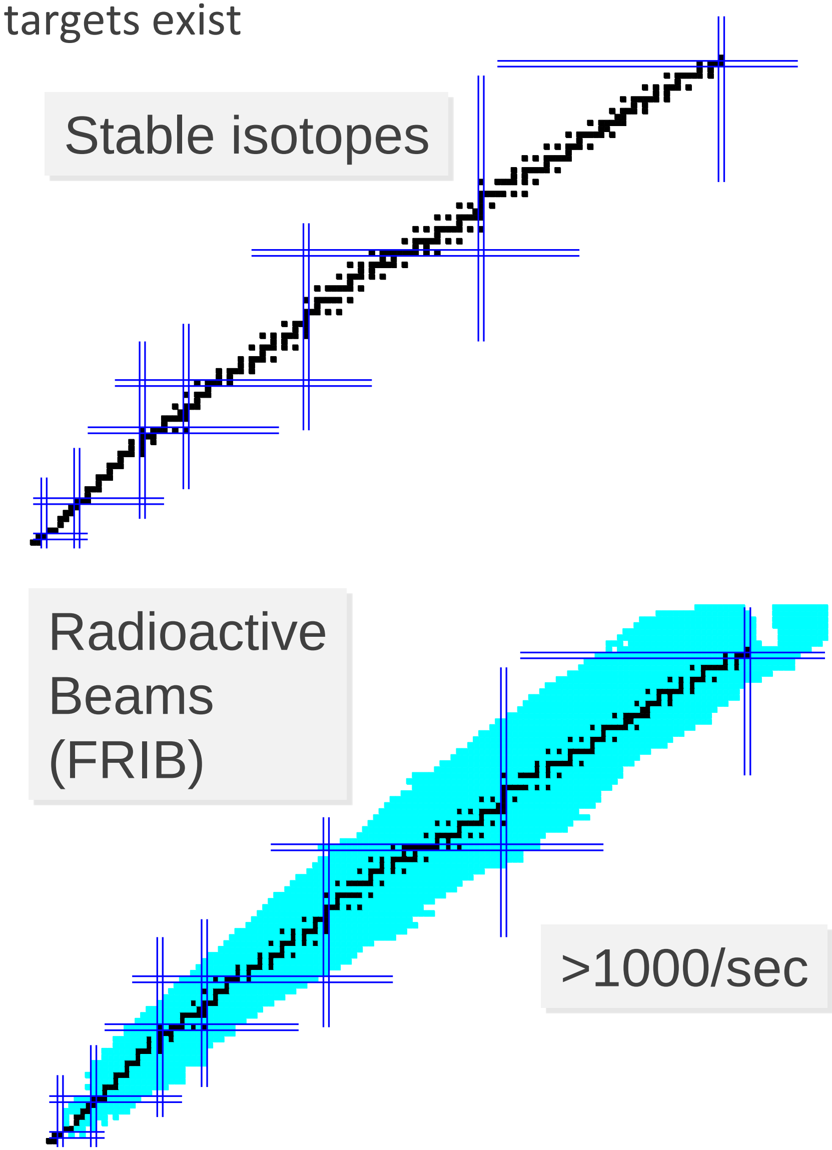


Transfer reactions
in
inverse kinematics

Inverse kinematics - wide applications

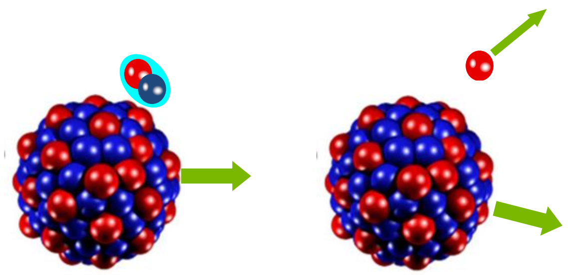
Precision studies of nuclei in regions where no targets exist

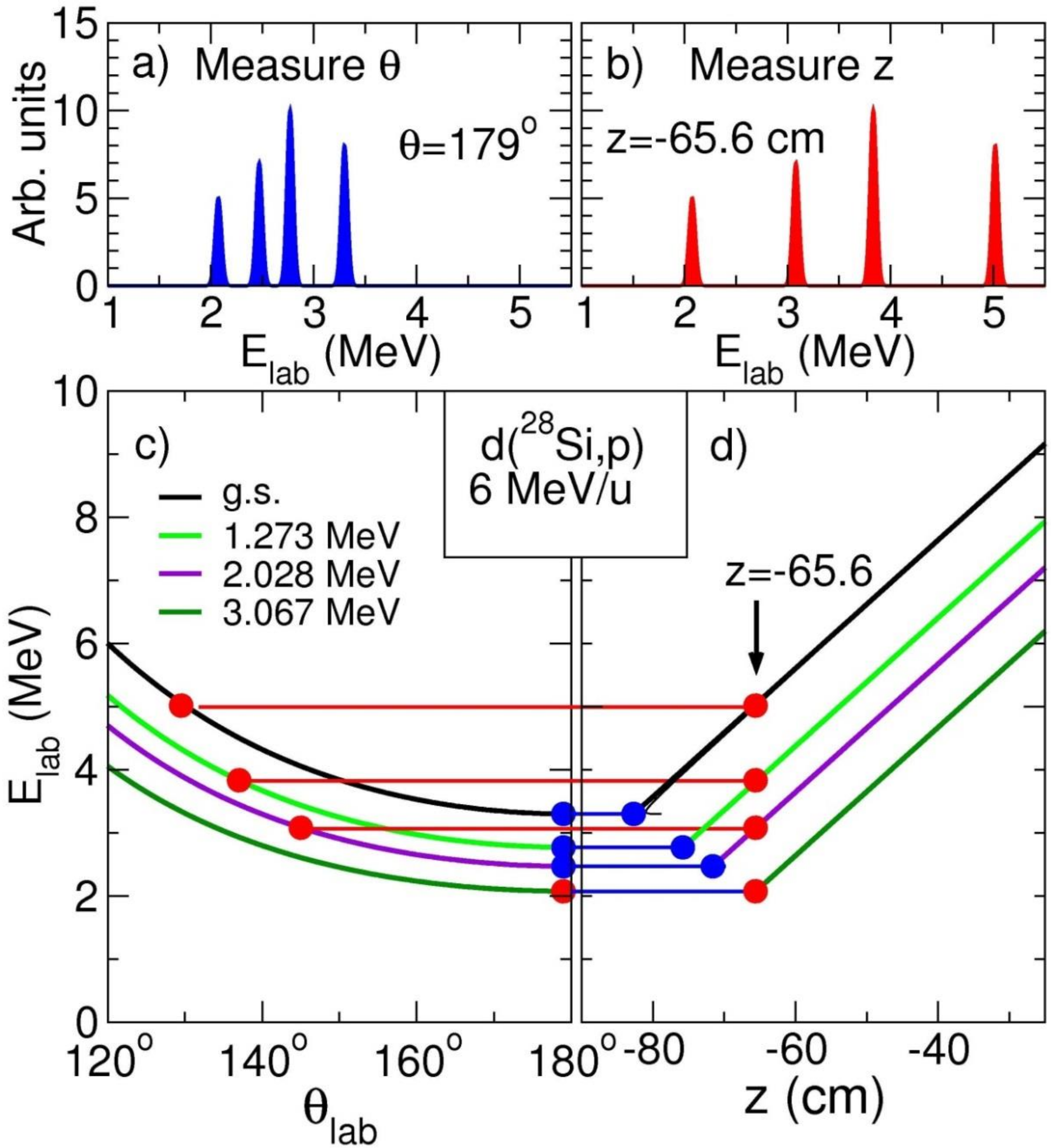




Measure θ or z (in magnetic field)?

Inverse kinematics





Q-value resolution:

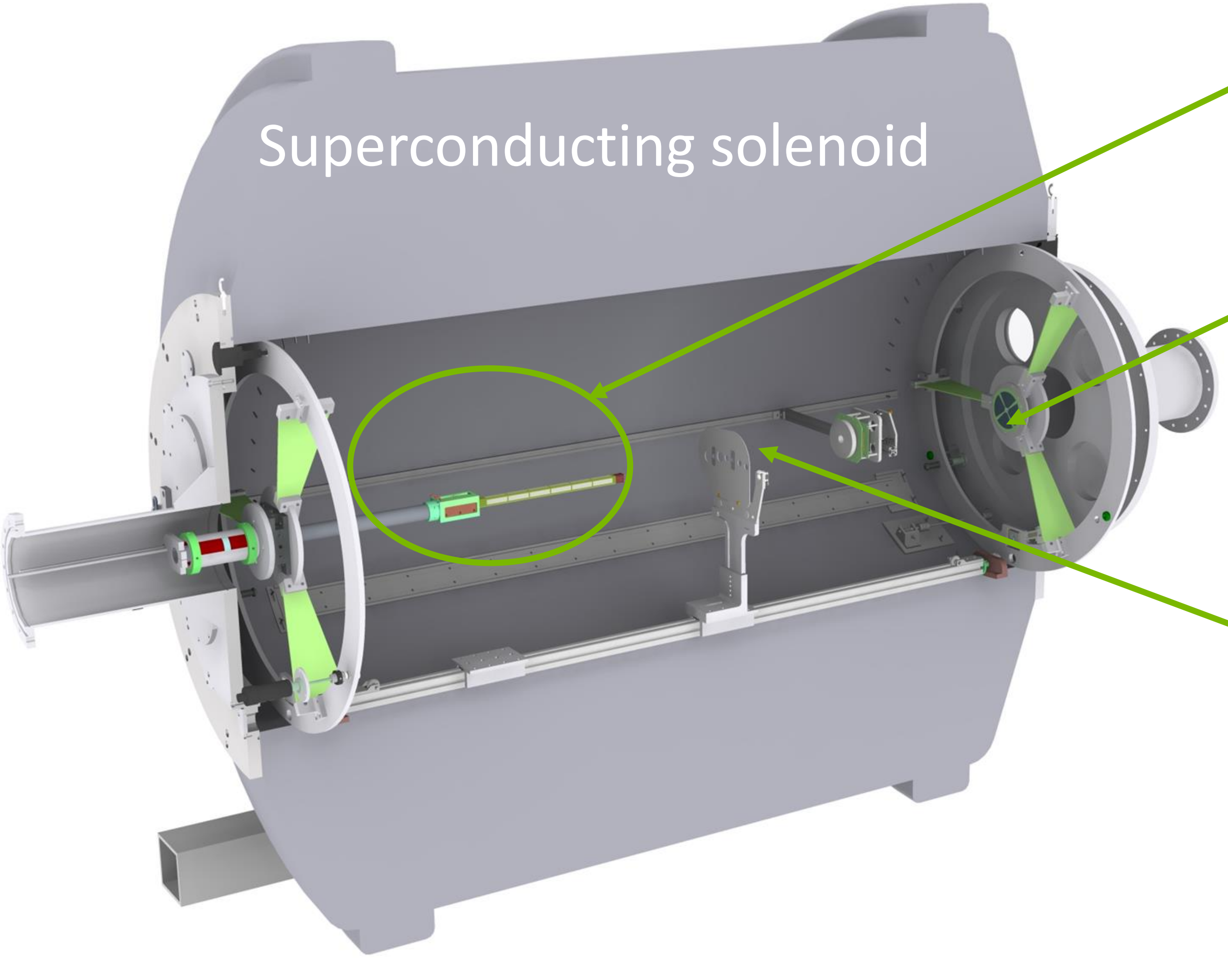
Improvement: 2–4 at backward angles

Other contributions:

1. Detector resolution
2. Target thickness
3. Beam quality

HELIOS – HElical Orbit Spectrometer

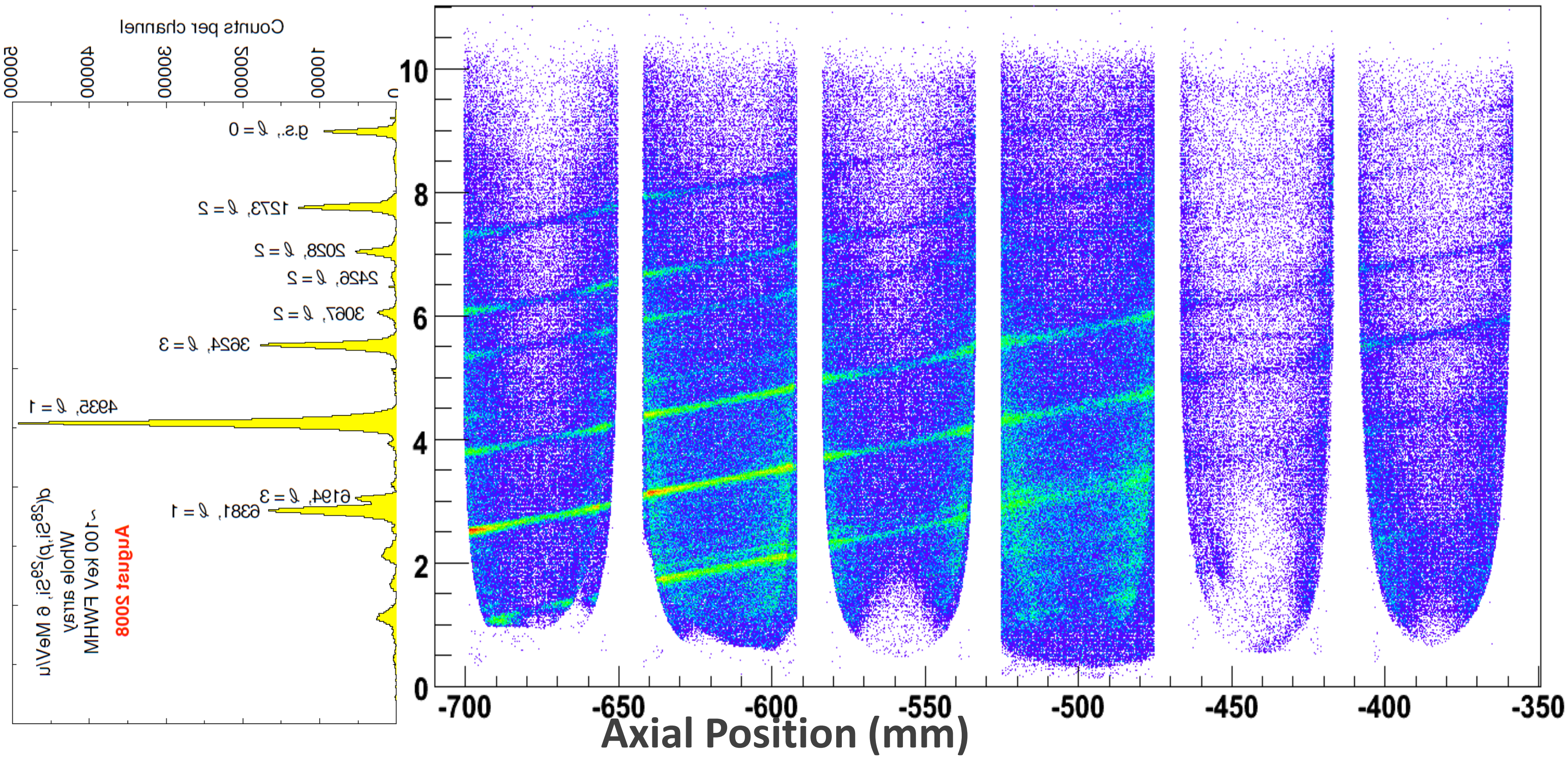
HELIOS



Commissioning: Energy vs. position

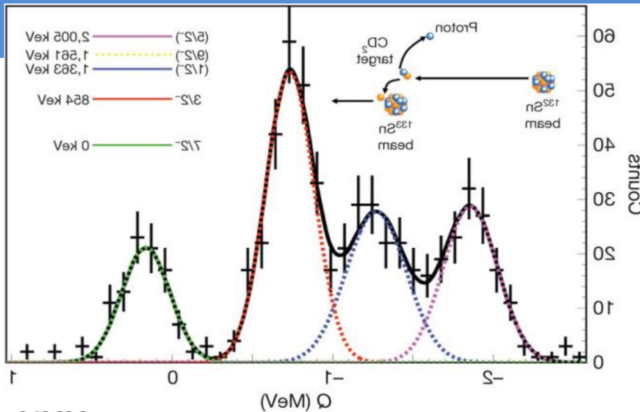
d(^{28}Si,p)^{29}Si , 6 MeV/A ^{28}Si on 84 μg/cm^2 CD_2 target, B= 1.915 T

Lighthall *et al.*, Nucl. Instr. Meth. A622, 97 (2010)



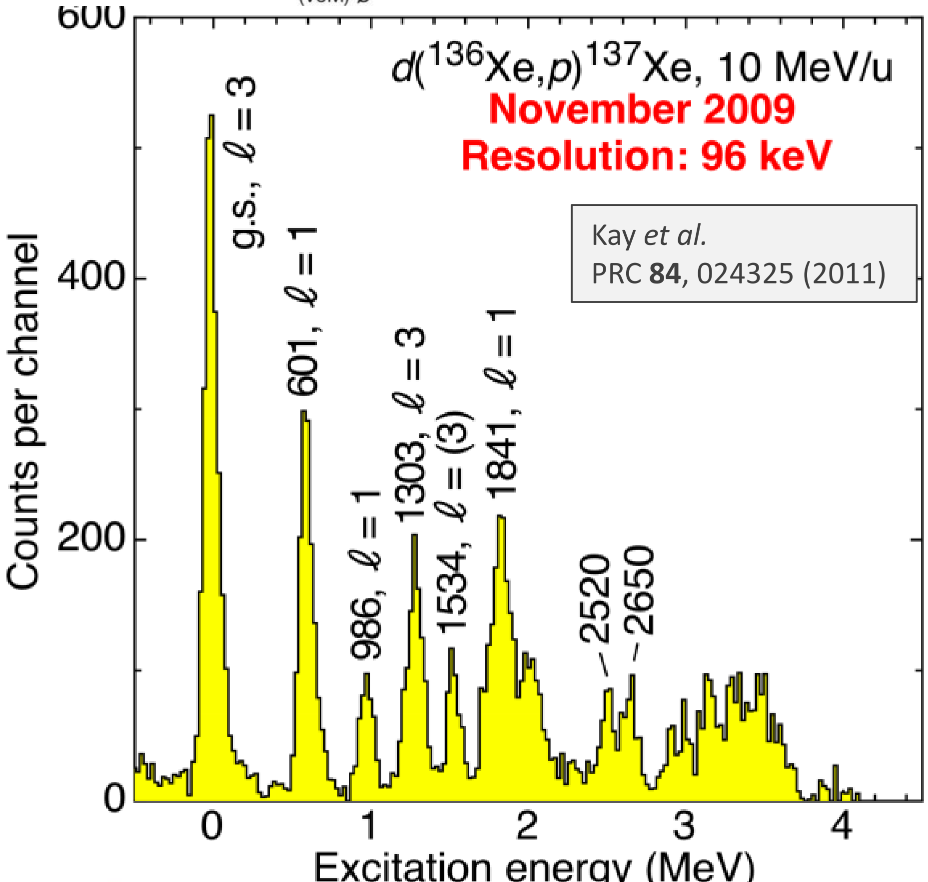
HELIOS vs. Si-detector arrays

HELIOS

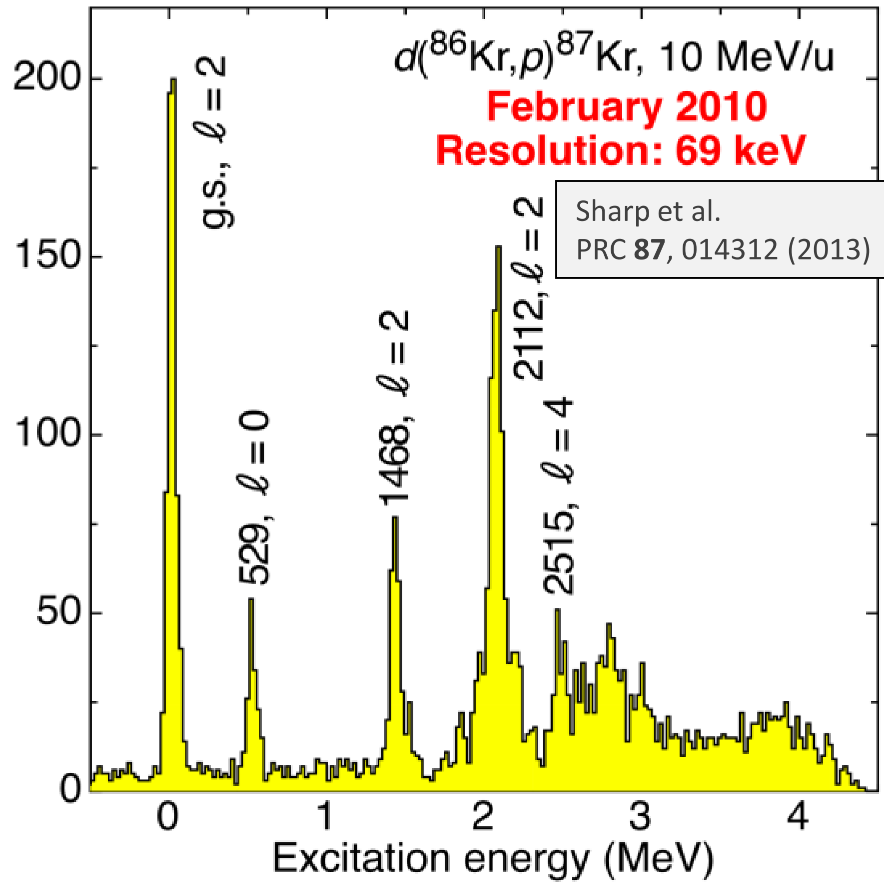


K. L. Jones *et al.*,
Nature **465**, 454 (2010).

J. Cizewski, tomorrow, 2:15PM



Kay *et al.*
PRC **84**, 024325 (2011)



Sharp et al.
PRC **87**, 014312 (2013)

$^{12}B(d,p)$ - First published HELIOS result

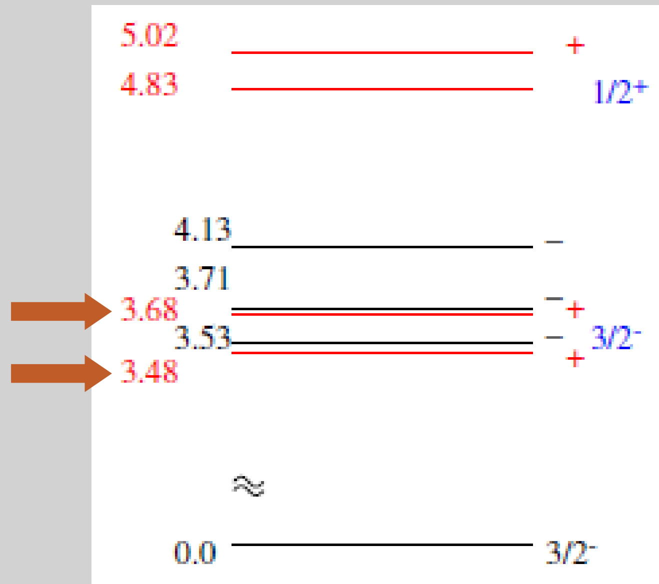
Back *et al.*, PRL **104**, 132501 (2010)

Wuosmaa, WMU
Schiffer, ANL

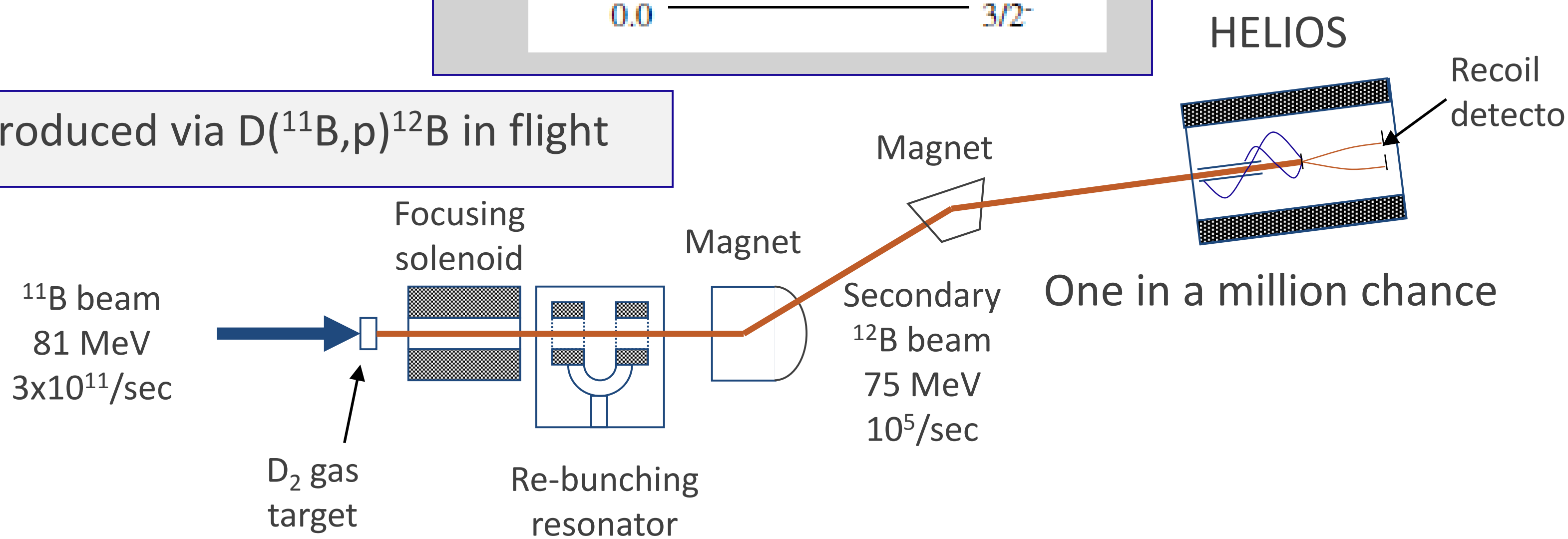
Purpose:

- Separate two closely spaced positive parity states
- Determine L-transfer

^{13}B level scheme



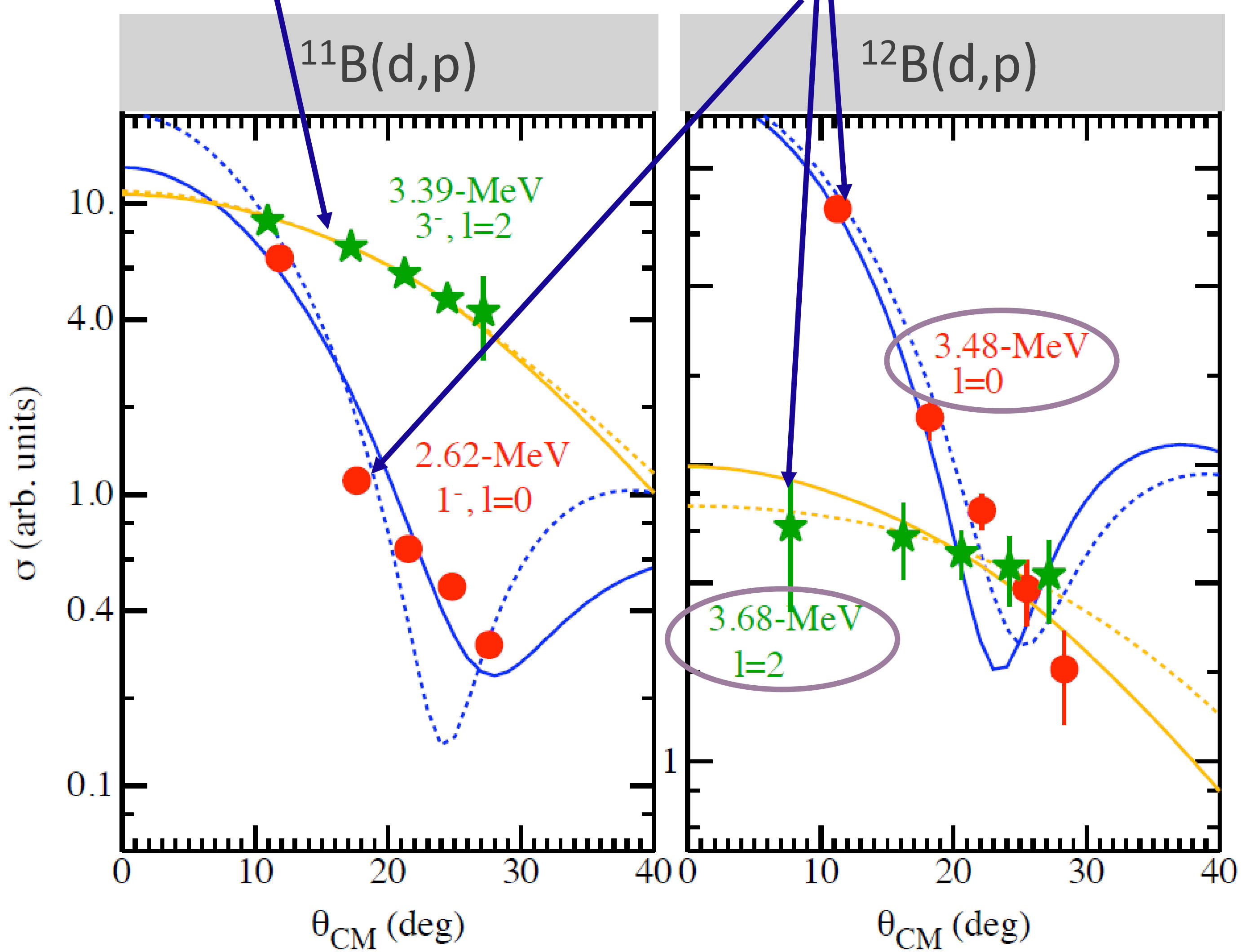
^{12}B beam produced via $D(^{11}B,p)^{12}B$ in flight



One in a million chance

Angular distributions for $^{11,12}B(d,p)$

Normalize angle-dependent efficiency, ε(z)   Use ε(z) to obtain dσ/dΩ and relative strengths



Back *et al.*,
PRL **104**, 132501 (2010)

Got some good press

IOP A website from the Institute of Physics

physicsworld.com

Home | News | Blog | Multimedia | In depth | Jobs | Events

News archive

News: April 2010

New element 117 discovered

Apr 10, 2010 7 comments

Progress on route to the superheavy island of stability

Black hole twins spew gravitational waves

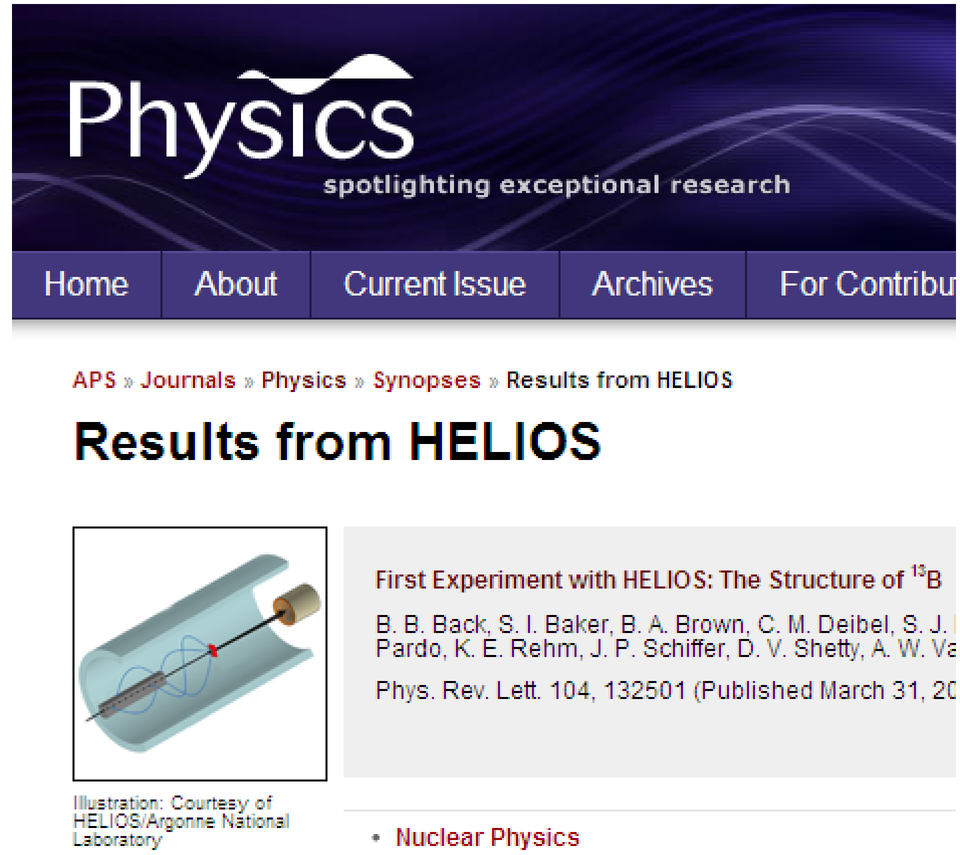
Apr 11, 2010 13 comments

Stars less metallic than we thought

Argonne lab tackles exotic nuclei

Apr 9, 2010

First results obtained from new Helical Orbit Spectrometer



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APS » Journals » Physics » Synopses » Results from HELIOS

Results from HELIOS

First Experiment with HELIOS: The Structure of ^{13}B

B. B. Back, S. I. Baker, B. A. Brown, C. M. Deibel, S. J.
Pardo, K. E. Rehm, J. P. Schiffer, D. V. Shetty, A. W. Va

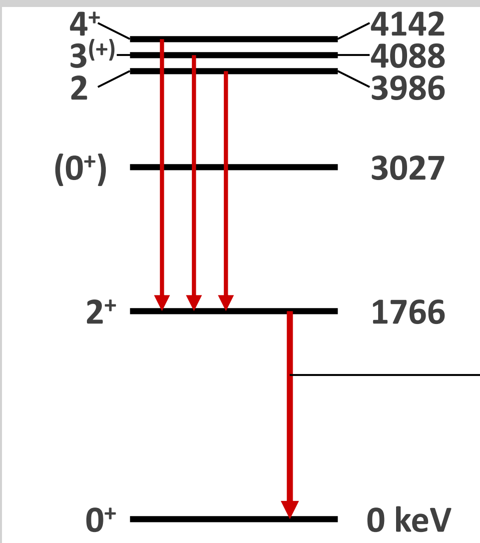
Phys. Rev. Lett. 104, 132501 (Published March 31, 20

Illustration: Courtesy of HELIOS/Argonne National Laboratory

- Nuclear Physics

^{15}C(d,p) - spect. factors for 0$^+$, 2$^+$,3$^+$ states in ^{16}C

^{16}C level scheme



Wuosmaa *et al.*, PRL, **105**, 132501 (2010)

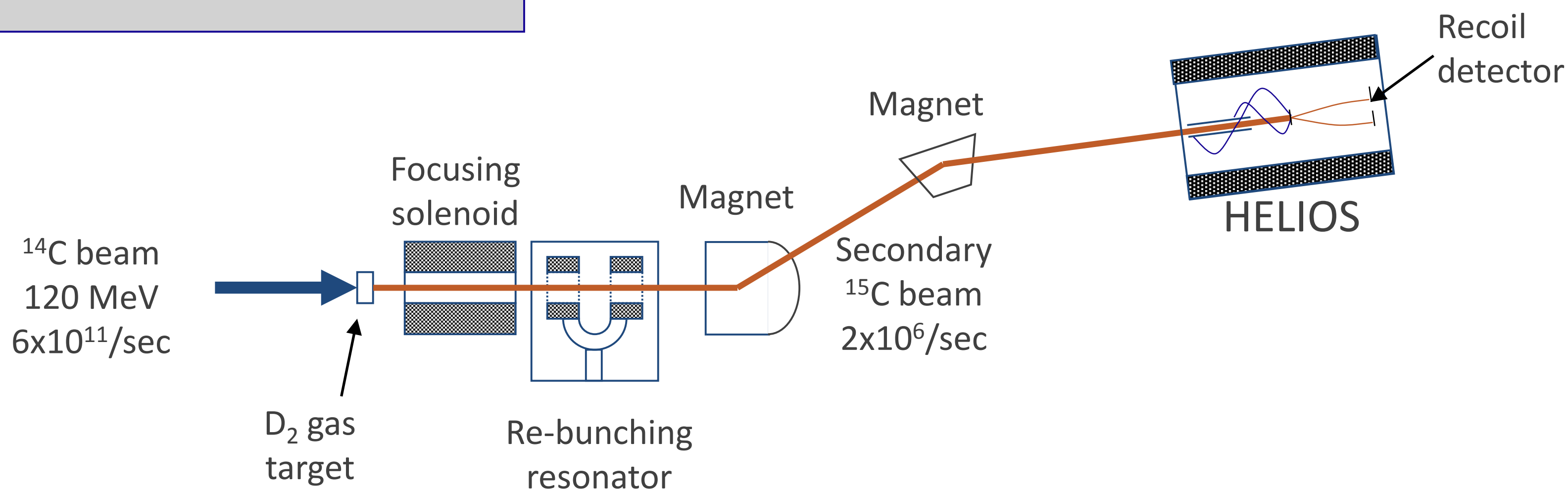
Question: Are the motions of the protons and neutrons decoupled in ^{16}C?

<u>B(E2) W.U.</u>

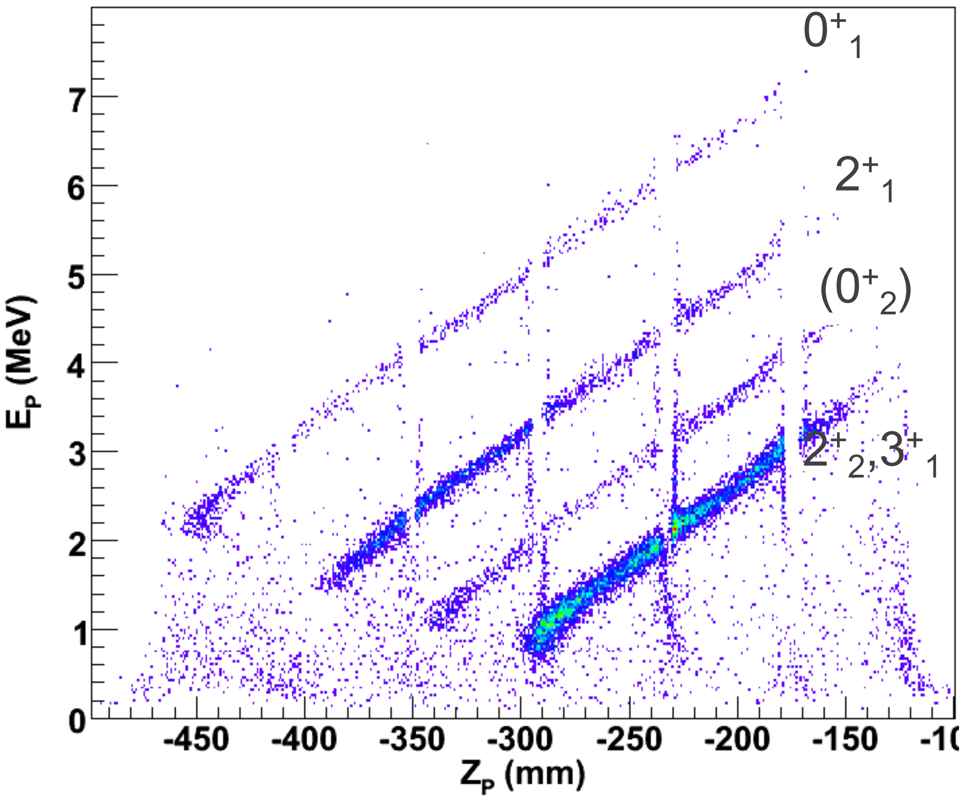
0.26 Imai *et al*. PRL 92, 62501 (2004) ^{16}C scattering

0.28 Elekes et al., PLB 586, 34 (2004) ^{16}C scattering

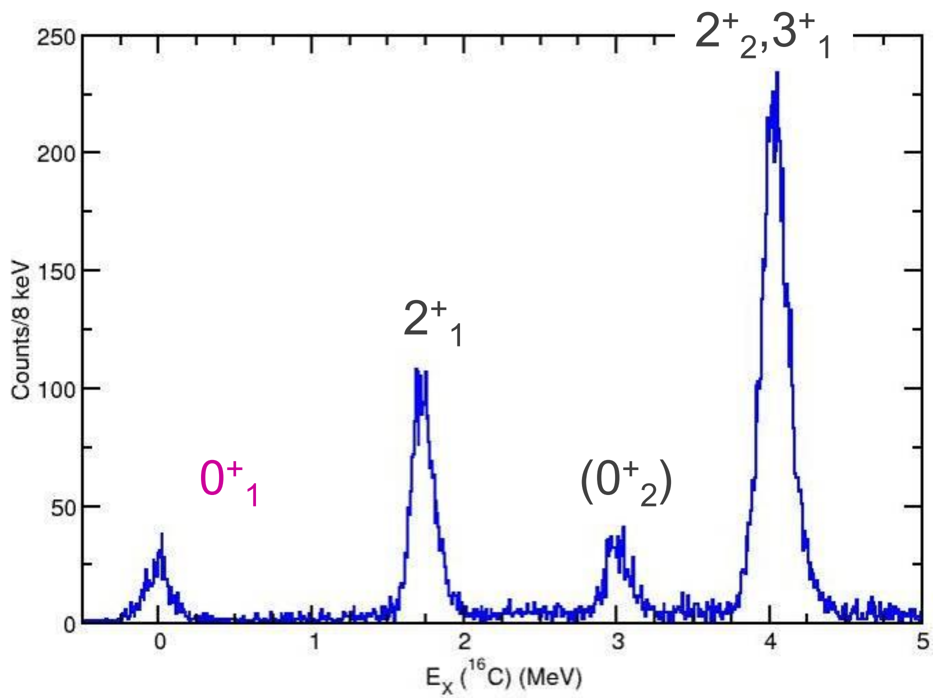
1.73 Wiedeking *et al*, PRL 100, 152501 (2008) Fusion-evap



HELIOS data for $^{15}C(d,p)^{16}C$

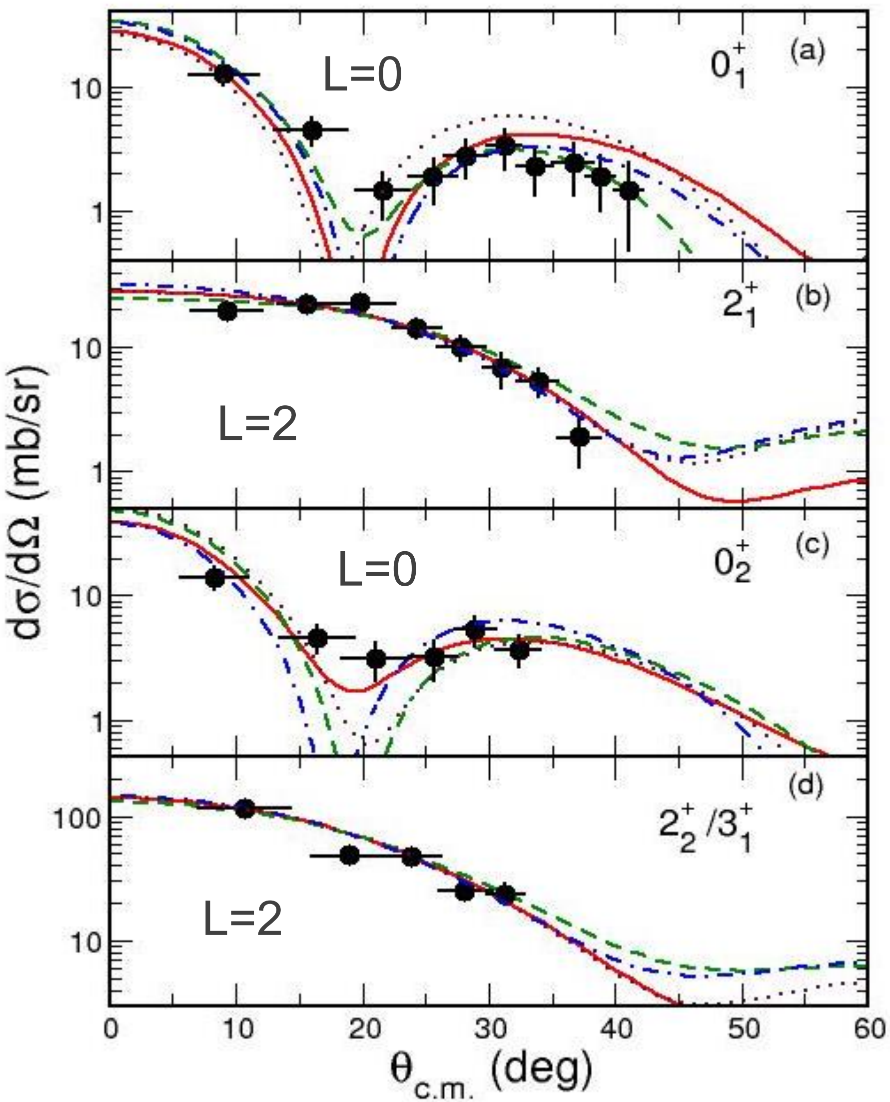


Wuosmaa *et al.*, PRL, **105**, 132501 (2010)



^{15}C beam from $^{14}C(d,p)^{15}C$
8.2 MeV/u 1.5X10^6 pps

$^{15}C(d,p)$ angular distributions



Wuosmaa *et al.*, PRL, **105**, 132501 (2010)

Curves are DWBA calculations with various optical-model potentials.

Spectroscopic factors obtained from the average over four sets of OMP.

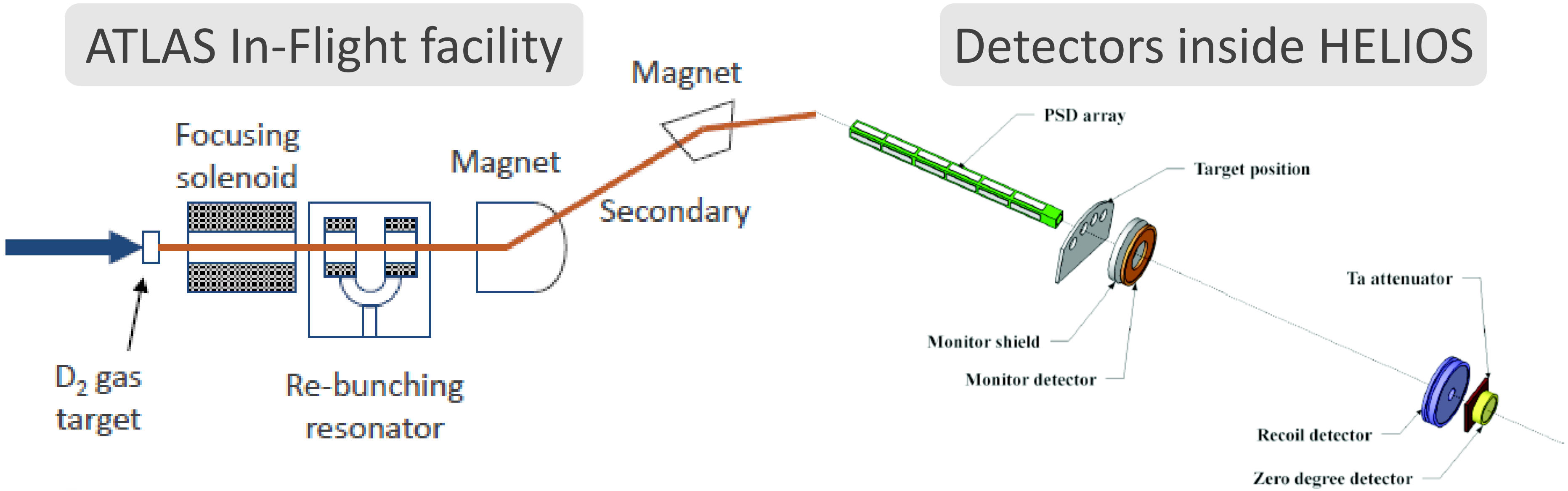
Relative uncertainties in SF dominated by OMP variations
Absolute uncertainty (~30%) from beam-integration uncertainty

Conclusion

- Relative spectroscopic factors agree with SM calculations – strongly mixed 0^+ and 2^+ states
- The B(E2) measured by the LBL group is also consistent with SM calculations

Neutron single-particle strength in ^{20}O

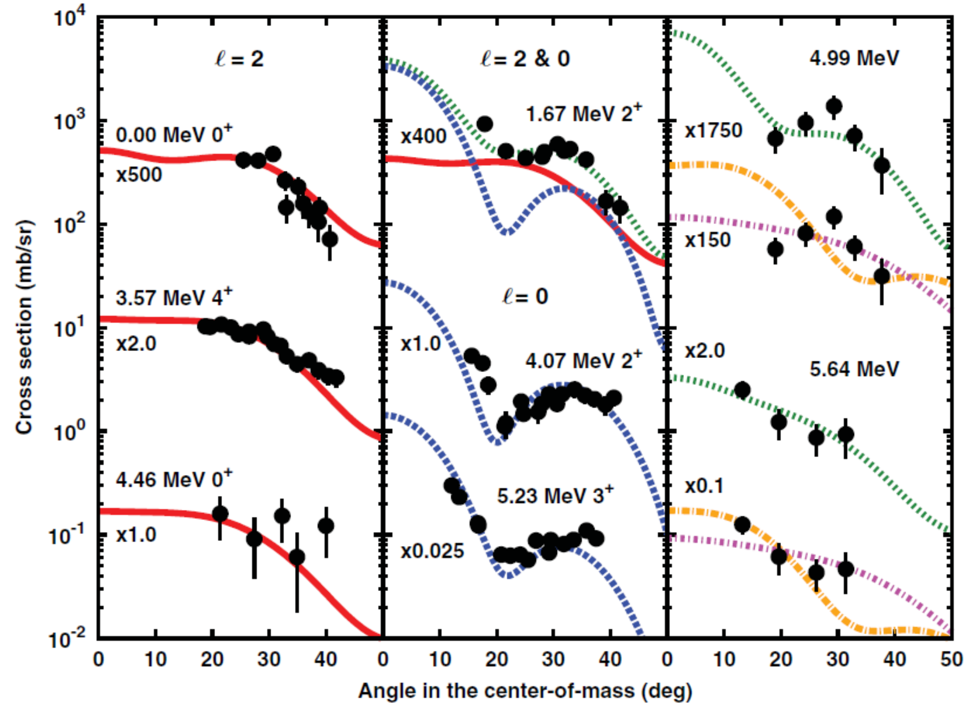
- $^{19}O(d,p)^{20}O$ @ 6.9 MeV/u
- In-flight secondary beams
  - ^{18}O @ 8.1 MeV/u on cryo cooled D_2 gas target (1400 mbar)
  - ~10^5 pps
- CD_2 solid target: 260μg/cm^2



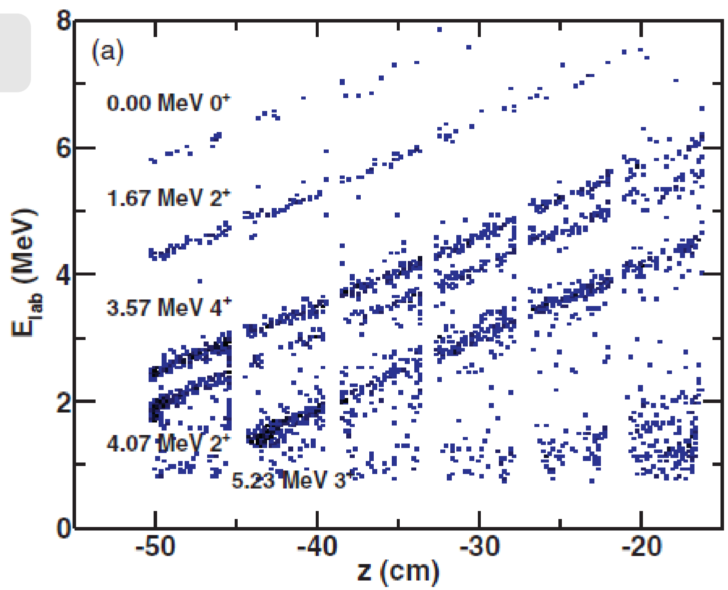
B. Harss et al., Rev. Sci. Instrum. 71, 380 (2000)

$^{19}O(d,p)$

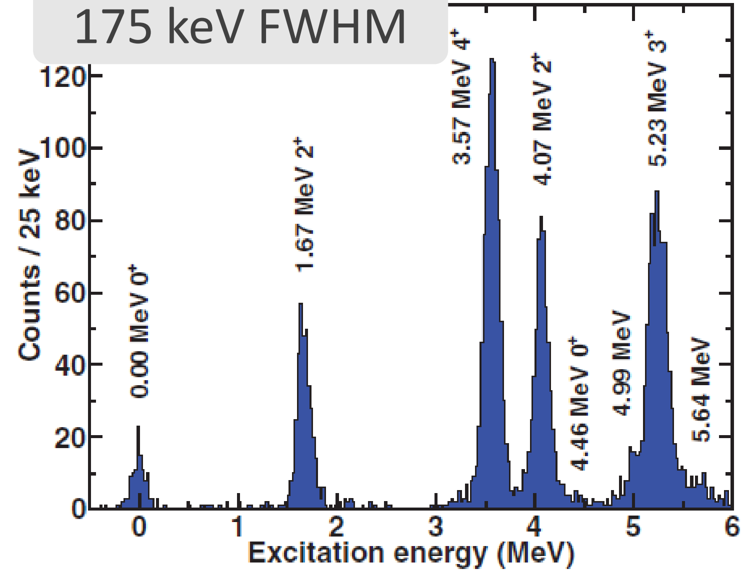
- 8 states identified up to 7 MeV
  - Absolute σ from deuteron scattering (20%)
    - Angular distributions
      - Distorted wave Born approximation
    - Identified $l = 0$ 3^+ level at 5.23 MeV



B = 2T

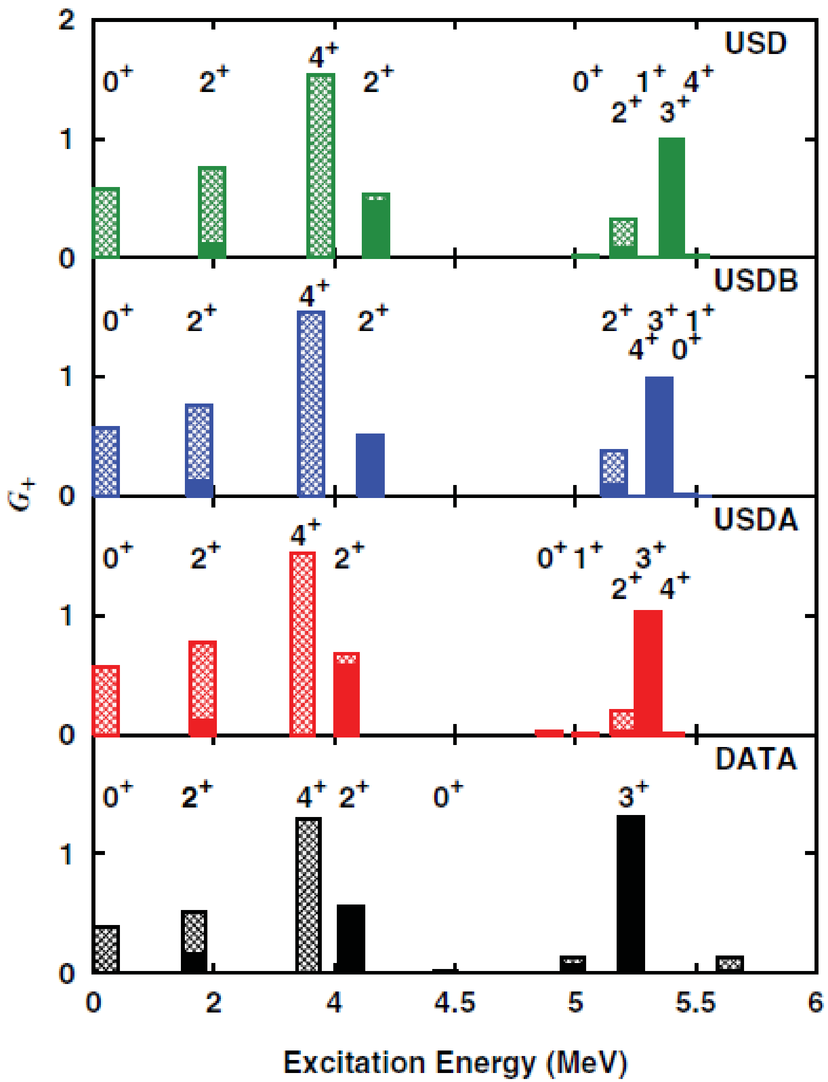


175 keV FWHM



C. M. Perey and F. G. Perey, PR 132, 755 (1963); J. P. Schiffer et al., PR 164, 1274 (1967)

$^{19}O(d,p)^{20}O$ results



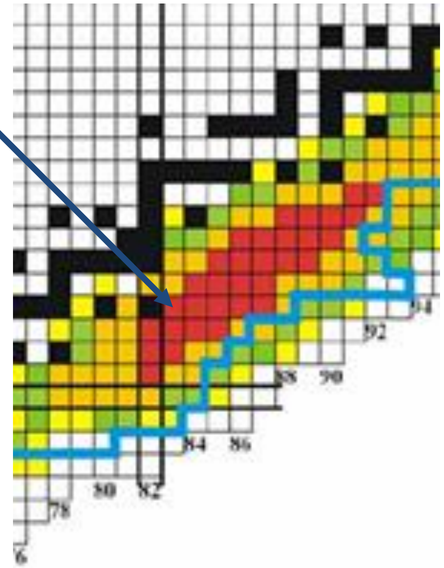
C. R. Hoffman et al., PRC 85, 054318 (2012)

- Distorted wave analysis to extract spectroscopic factors
  - Normalized to $^{16}O(d,p)^{17}O$ data
  - 30% uncertainty in total
  - 12% relative to one-another
- Checks w/ sum rules & $^{18}O(d,p)^{19}O$ data
- Superb reproduction of strength by sd shell interactions
- Some strength to 2p-2h (1p-1h) dominated states
  - 0^+ @ 4.46 MeV
  - 4.99 or 5.64 MeV states
- SOLID → $l = 0$ HATCHED → $l = 2$

$$G_+ = \frac{2J_f + 1}{2J_i + 1} C^2 S,$$

^{136}Xe(d,p) - single neutron strength near N=82

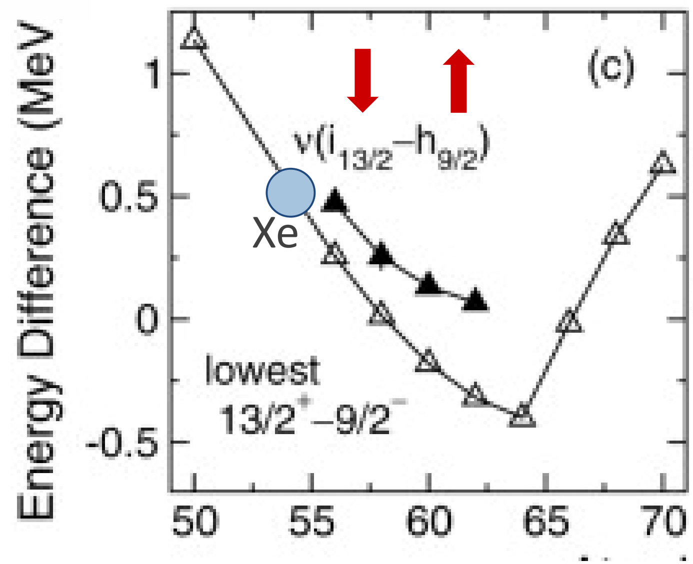
^{137}Xe



Kay et al., Phys. Rev. C **84**, 024325 (2011)

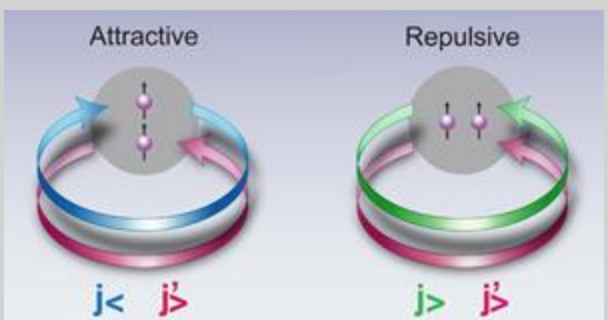
Effect of filling $g_{7/2}^{<}$ orbit on $i_{13/2}^{>} - h_{9/2}^{<}$ spacing

Kay et al. PLB 658, 216 (2008)



Tensor force:

Otsuka *et al.* PRL 95, 232502 (2005)
"Opposites attract"



Physics 3, 2 (2010) DOI: 10.1103/Physics.3.2, Viewpoint
Implications of old physics simplify the understanding of nuclei
John P. Schiffer
Published January 4, 2010

The $h_{9/2-}$ and $i_{13/2+}$ neutron strength in ^{137}Xe

Absolute cross sections have an estimated uncertainty of ±15%

Relative spectroscopic factors extracted using the Ptolemy code and appear to be self-consistent.

Kay et *al.*, Phys. Rev. C **84**, 024325 (2011)

ℓ=5 (1218–1590 keV)

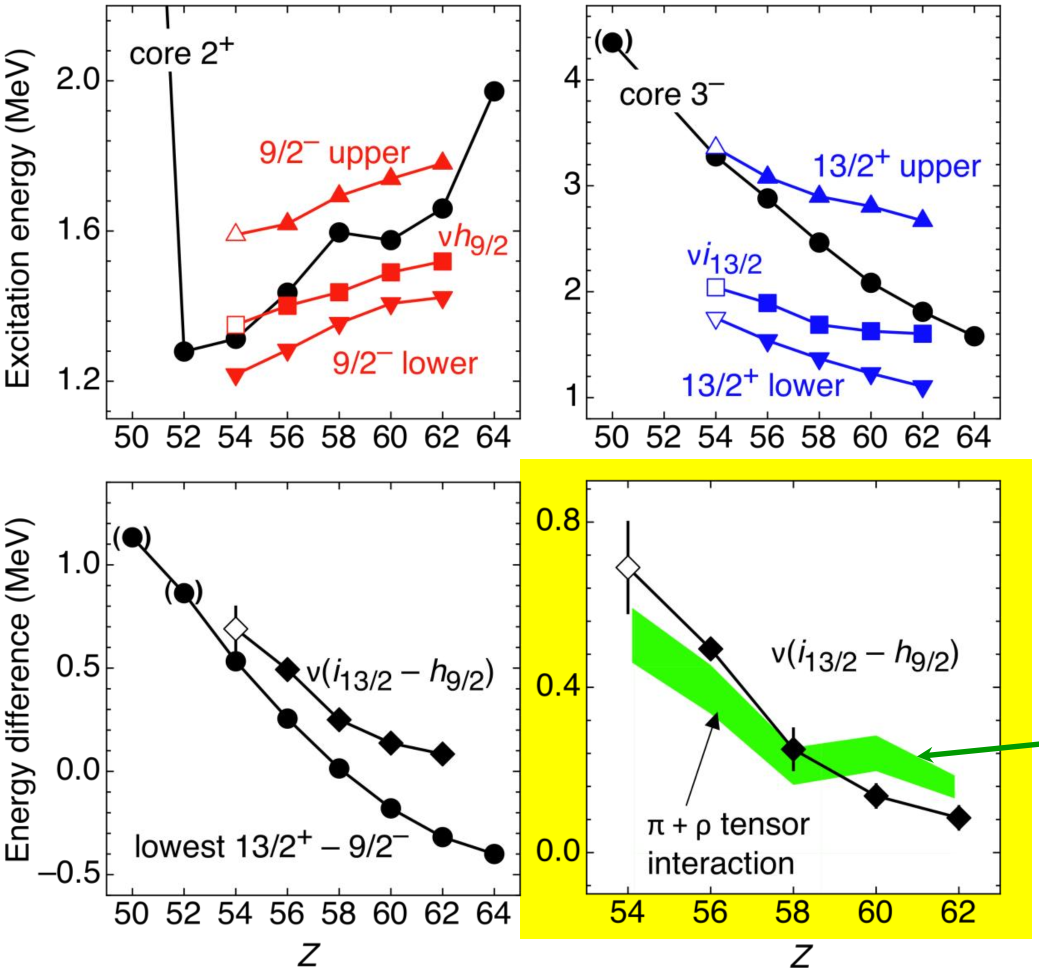
ℓ=6 (1751–~3610 keV)

E (keV)	ℓ	J^π	σ(θ) (mb/sr)	C^2S
0.0	3	$7/2^-$	18.8, 15.2°	1.00
601	1	$3/2^-$	10.6 (11.8°)	0.55
986	1	$1/2^-,3/2^-$	2.2 (16.5°)	0.37
1218	5	$9/2^-$	1.1 (33.3°)	0.46
1303	3	$5/2^-$	4.4 (14.9°)	0.23
1534	3	$5/2^-,7/2^-$	2.2 (19.2°)	0.13
1590*	(5)	$9/2^-$	0.7 (32.5°)	0.25
1751	(6)	$13/2^+$	2.2 (37.9°)	0.89
1841	(1)	$3/2^-$	3.9 (24.9°)	0.31
1930*	(3)	$5/2^-,7/2^-$	2.8 (17.8°)	0.11
2025*	(1,3)?	–	2.1 (19.7°)	0.22 / 0.16
2120*	(1,3)?	–	0.9 (19.4°)	0.10 / 0.06
2510*	(1)	$1/2^-,3/2^-$	2.0 (22.6°)	0.20
2650*	(1)	$1/2^-,3/2^-$	2.1 (22.1°)	0.17
~2900*	(1,3)?	–	0.8 (15.6°)	0.08 / 0.05
~2990*	(1,3)?	–	1.4 (21.1°)	0.17 / 0.05
~3150*	–	–	0.3 (35.1°)	0.12**
~3310*	–	–	0.3 (34.7°)	0.12**
~3470*	–	–	0.5 (34.4°)	0.18**
~3610*	–	–	0.4 (34.1°)	0.14**

*Determined in this work

**If assumed $13/2^+$

N = 82 so far … results fall nicely into systematics



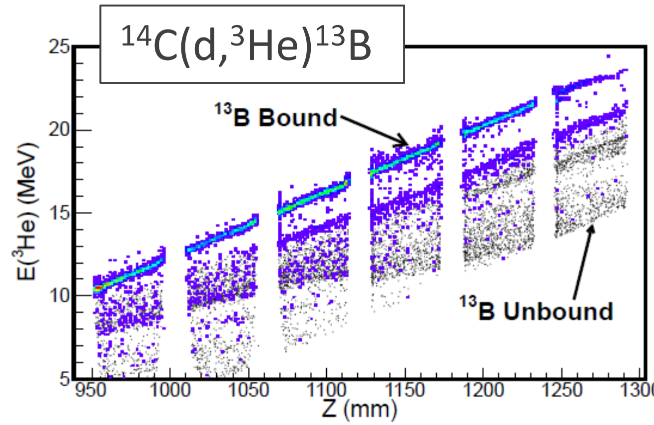
Kay et *al*., Phys. Rev. C **84**, 024325 (2011)

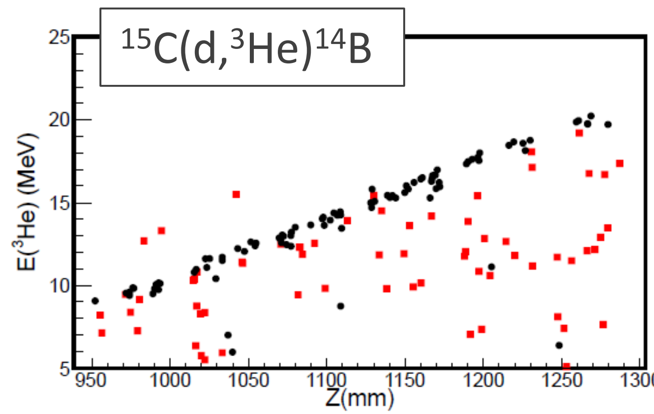
T. Otsuka et al.
PRL **104**, 012501 (2010).

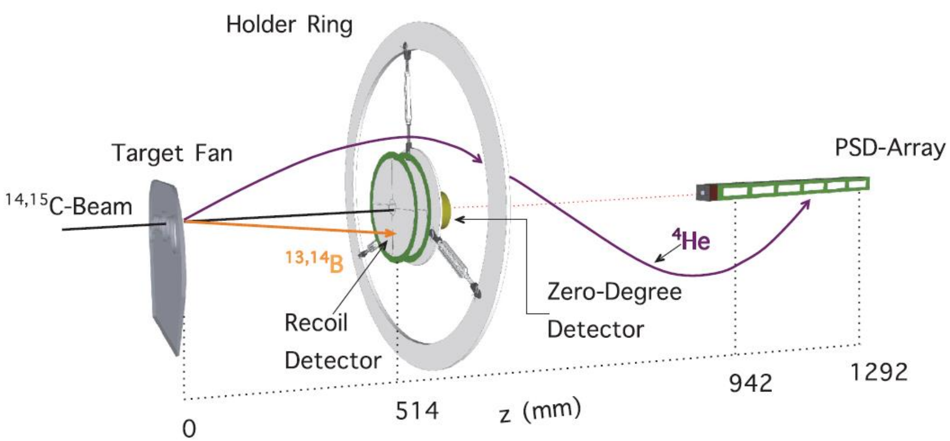
π + ρ tensor interaction courtesy of T. Otsuka (priv. comm., 2007)

Study of Proton-Hole States in Light Nuclei

- Investigated through single-proton removal reactions
- Provides complementary information to the neutron data
- Additional experimental challenges
- $^{14,15}C(d,^3He)^{13,14}B$ – Track proton-hole strength around N = 8 shell gap



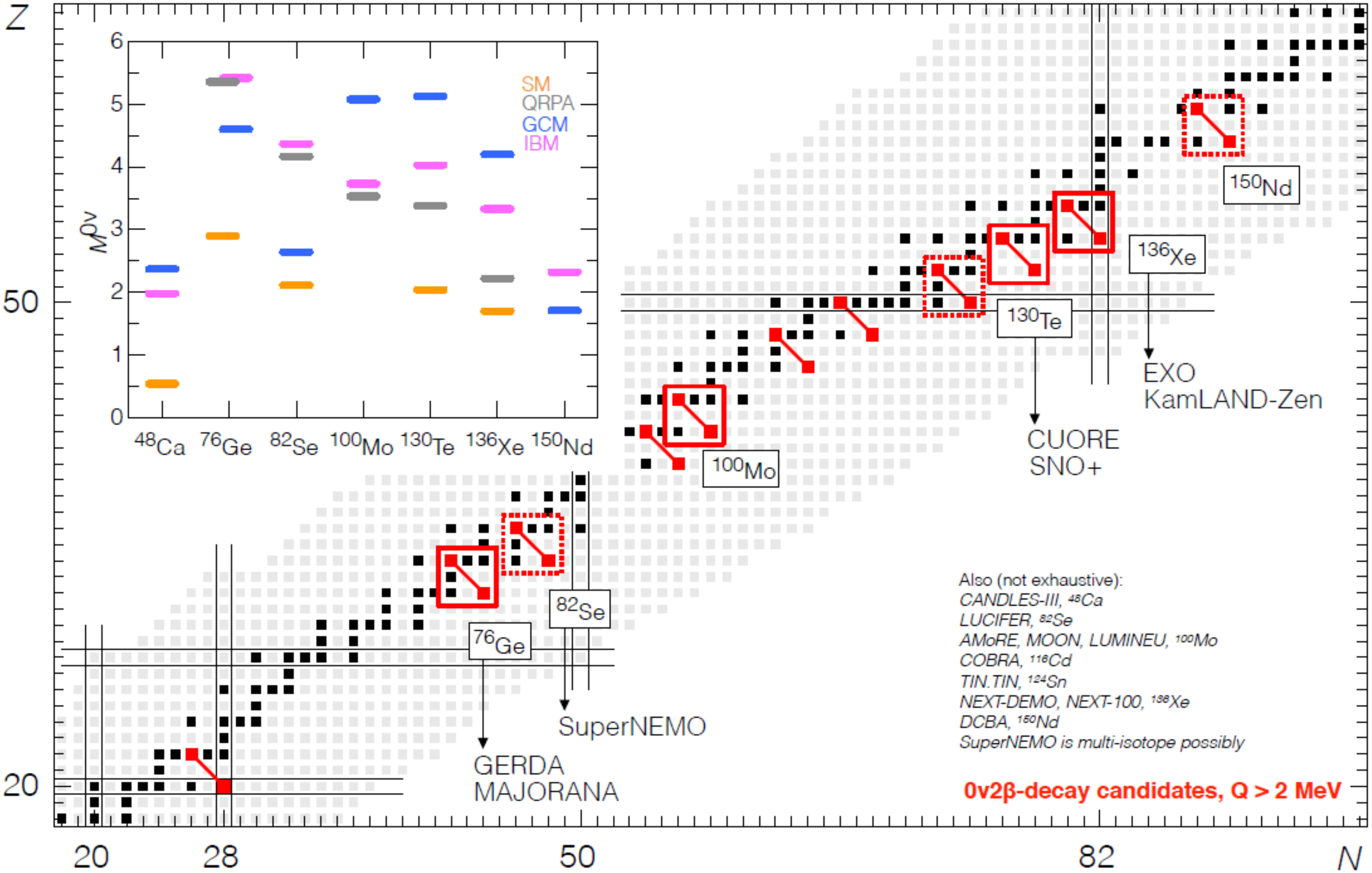




S. Bedoor *et al.*, Phys. Rev. C 93, 044323

The 0ν2β Decay Landscape

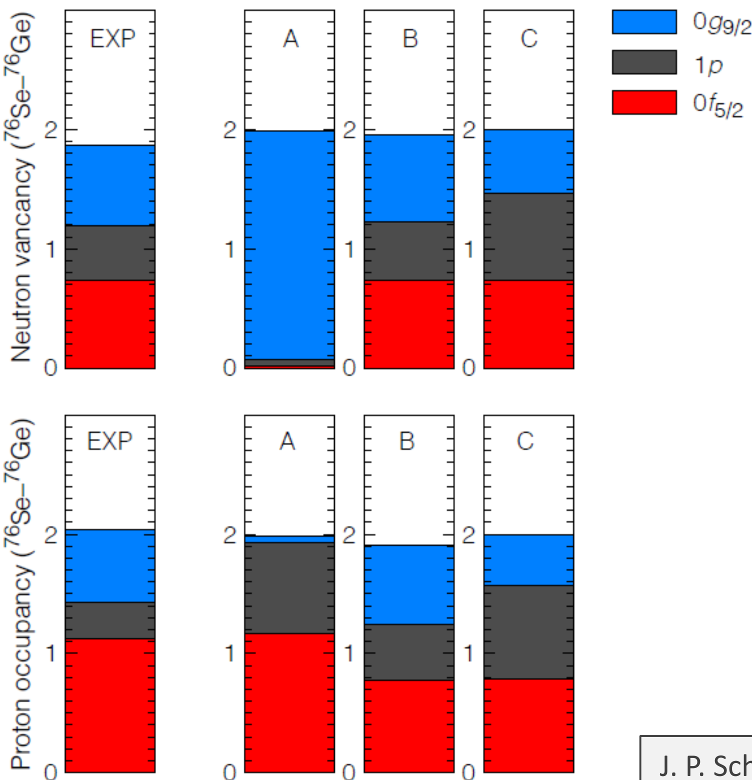
$$[T^{0\nu}_{1/2}]^{-1} = (\text{Phase Space Factor}) \times |\text{Nuclear Matrix Element}|^2 \times |\langle m_{\beta\beta}\rangle|^2$$



What is changing in the anatomy of initial and final states by precision studies of transfer reactions, e.g., **valence nucleon compositions** and **correlations**

Impact of Past Results: ^{76}Ge - ^{76}Se

$$[T^{0\nu}_{1/2}]^{-1} = (\text{Phase Space Factor}) \times |\text{Nuclear Matrix Element}|^2 \times |\langle m_{\beta\beta}\rangle|^2$$



- QRPA calculation before measurement
  Rodin et al., Nucl .Phys. A (2006)
- B — QRPA calculation after measurement
  Suhonen et al., Phys. Lett. B (2008)
- C — Shell model calculation after measurement
  Caurier et al., Phys. Rev. Lett. (2008)

IMPACT: Factor of ~2 in the calculated matrix element

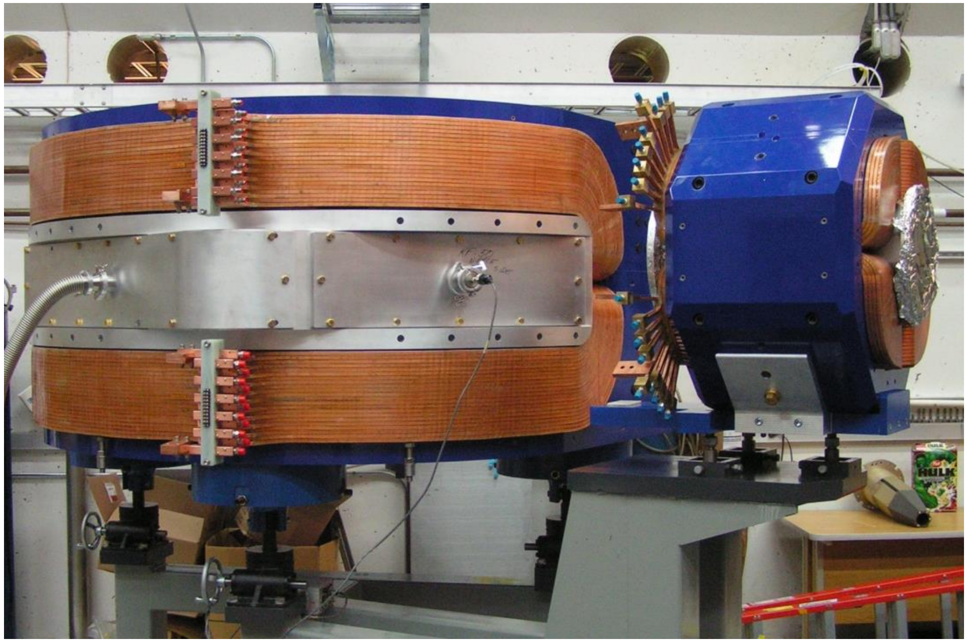
J. P. Schiffer et al., Phys. Rev. Lett. (2008); BPK et al., Phys. Rev. C (R) (2009)

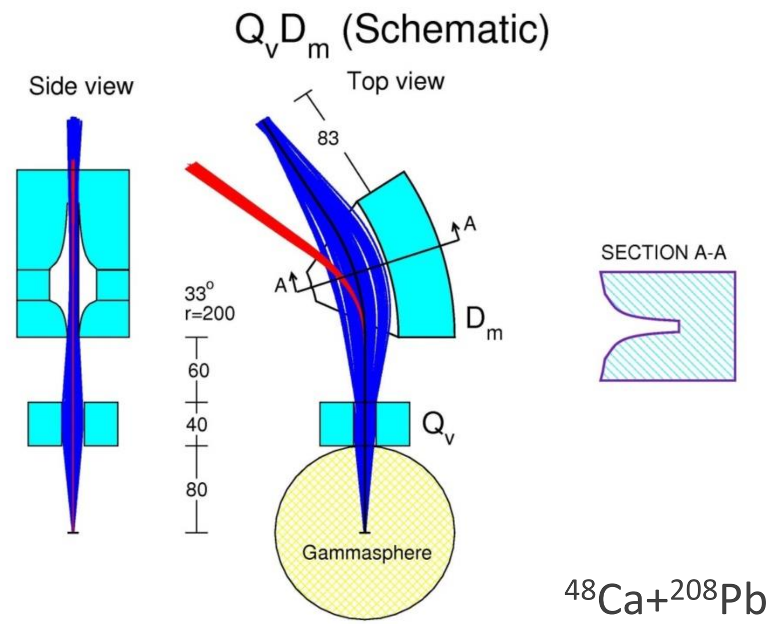
- DETERMINE what is changing in the anatomy of initial and final states by precision studies of transfer reactions, e.g., **valence nucleon compositions** and **correlations**

Instrumentation developments

Argonne Gas-Filled Analyzer
AGFA

AGFA: Unique design by David Potterveld





FEATURES:

Compact design – two magnets, length 3.7- 4.3 m
Quad: vertical focusing - Dipole: 38° bend and horizontal focusing
Gammasphere at target position – solid angle 22.5 msr
Small focal plane – one DSSD implantation detector
Bρ-max: 2.5 Tm

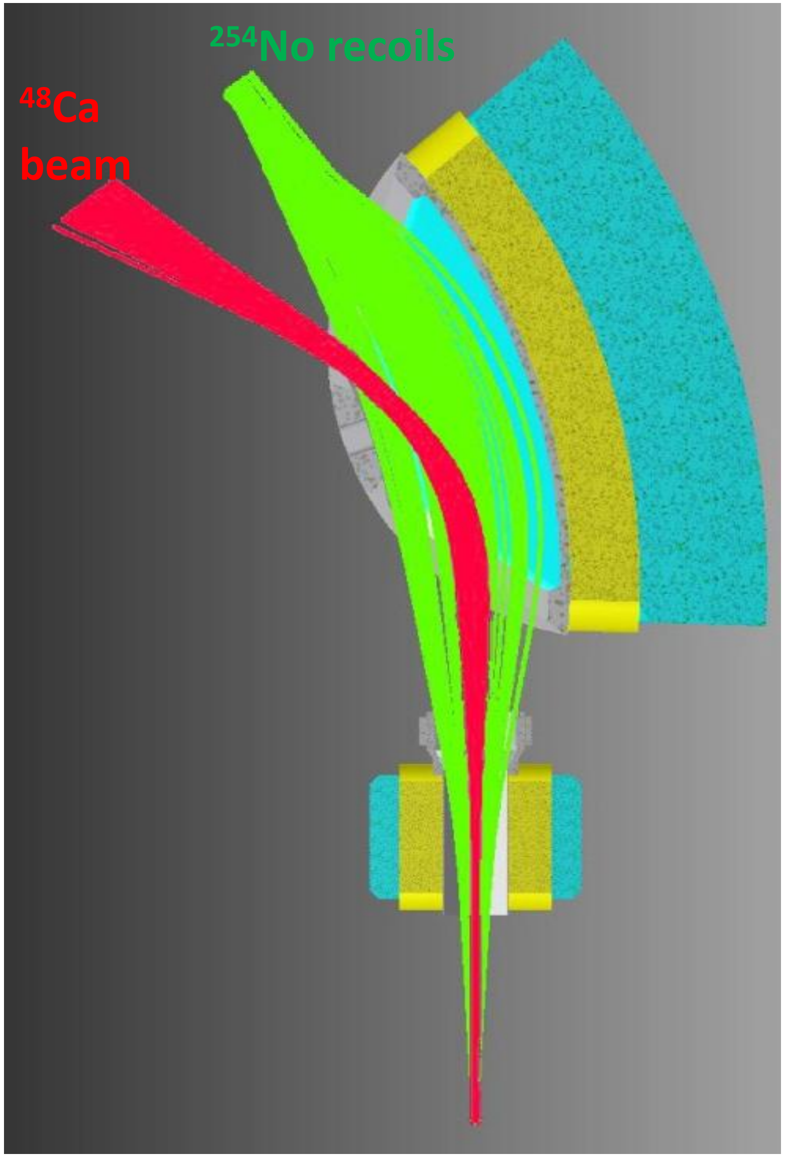
Simulations: ^{254}No test case (David Potterveld)

$^{48}Ca + ^{208}Pb \rightarrow ^{254}No + 2n$

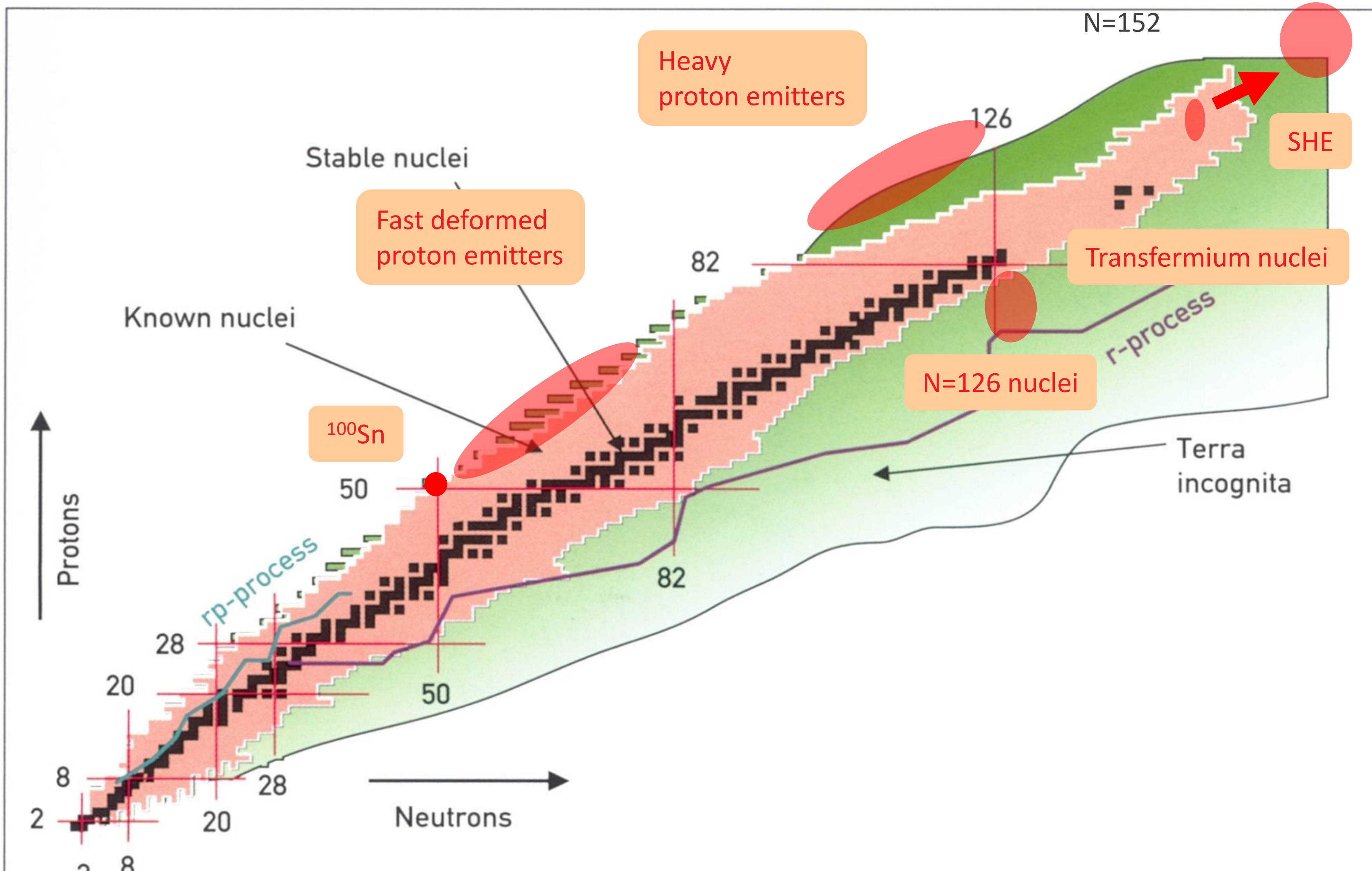
$E_{beam} = 220$ MeV

- 1 Torr He, 5 x 2 mm beam spot
- ^{254}No angular distr: Gaussian, σ = 51 mr
- ^{48}Ca stripped, (C foil) $q_{bar} = 17.1$

- 89% of ^{254}No transported to focal plane
- 71% fall within a 64 x 64 mm^2 DSSD
- Solid angle to DSSD is 22.5 msr.
- Beam is well separated.



AGFA: Physics reach



Birger B. Back, Argonne National Laboratory

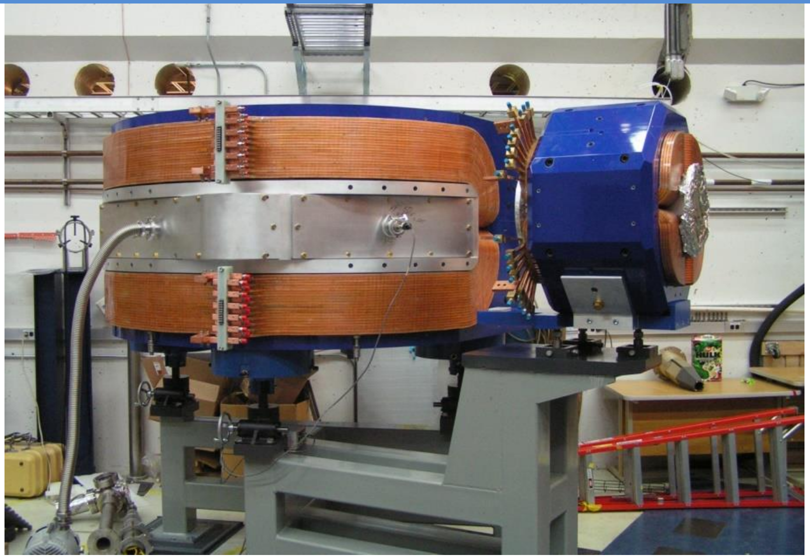
Gammasphere move and refurbishment

- New Gammasphere support frame
- New Gammasphere cable support
- Gammasphere moved to AGFA November 2016
- All Gammasphere detectors being refurbished
- Replacement of LN2 valves

AGFA status

STATUS Feb 2017

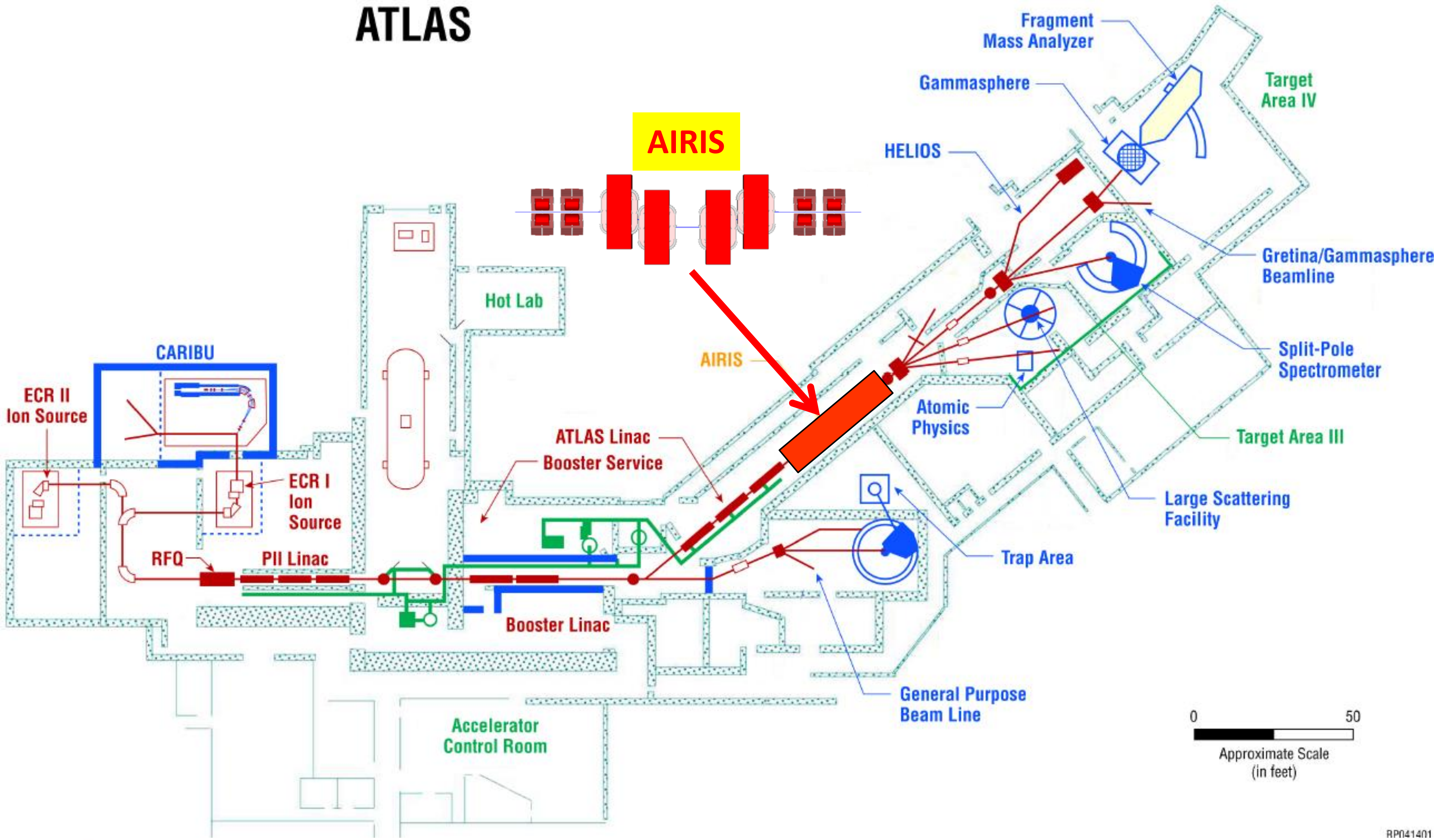
- Magnets, vacuum chambers, power supplies installed.
- Gammasphere moved to AGFA
- Commissioning: June-July 2017



- Sept. 2016 PAC:
  - 9 AGFA proposals submitted
  - Approved:
    - AGFA Commissioning (Seweryniak, ANL)
    - ^{255}Lr spectroscopy (Clark, LBNL)
    - ^{254} No high spin spectroscopy (Korichi, Orsay)
    - ^{32}S + ^{89}Y fusion hindrance (Jiang, ANL)

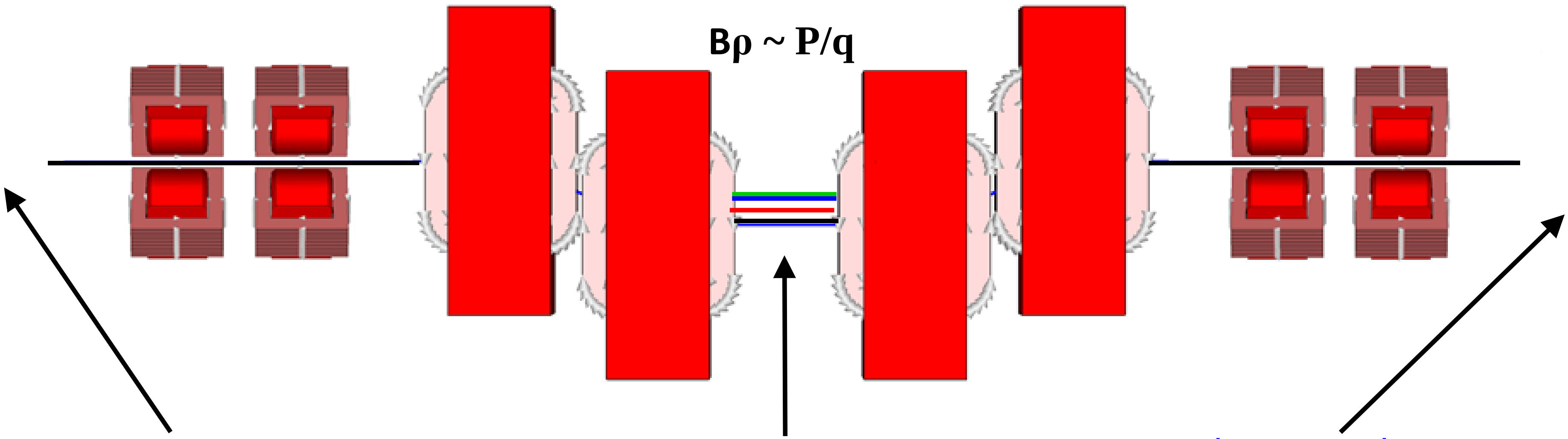
AIRIS

AIRIS Location within ATLAS



Principle of operation: Magnetic Separation

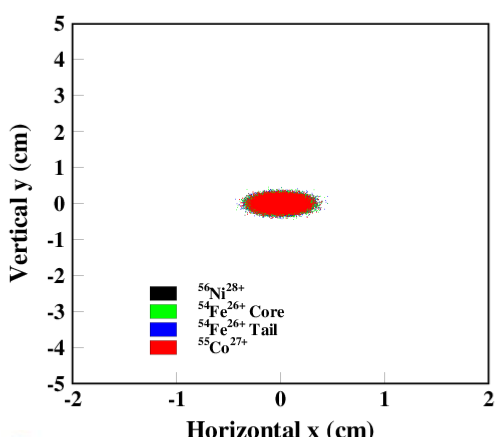
$^{56}Ni^{28+}$ produced from ^{54}Fe (^{12}C, ^{10}Be) ^{56}Ni at 10 MeV/u

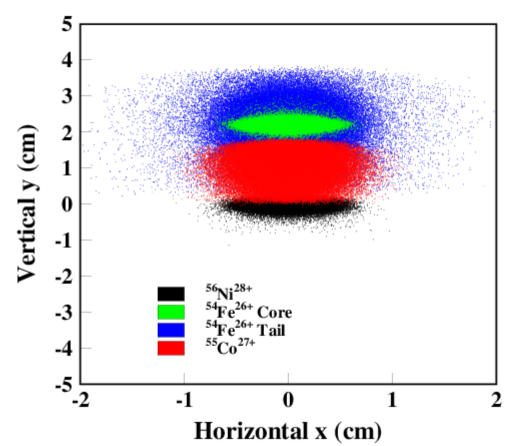


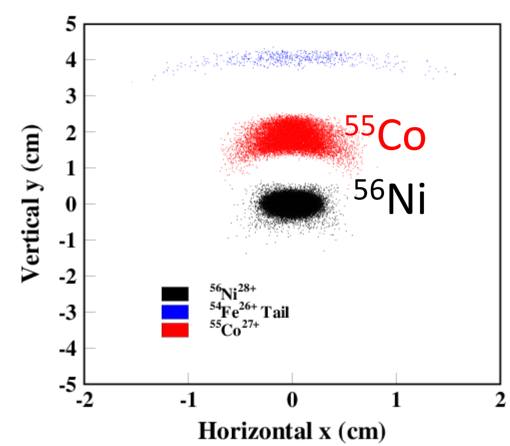
Target: All beams, no separation

Middle: Clear separation from primary beam

Exit: Separation from other beams

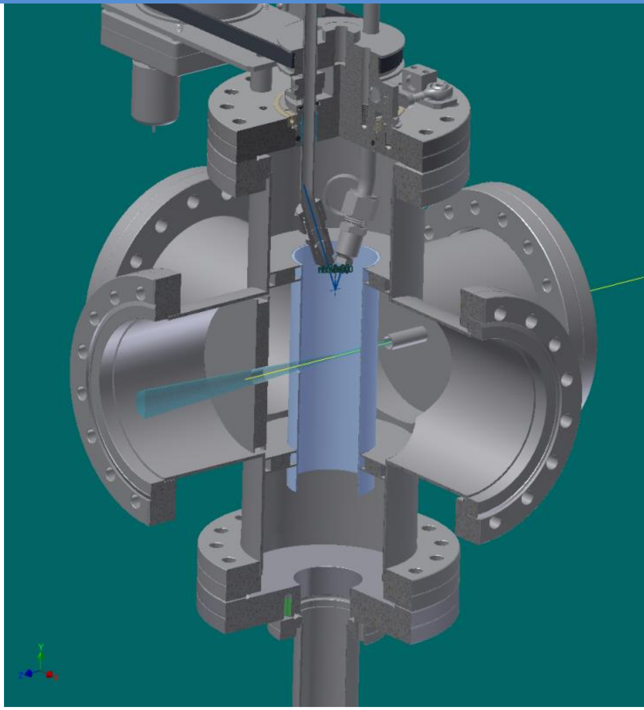






Test setup with intercepting oil jets

Guy Savard, Tony Levand



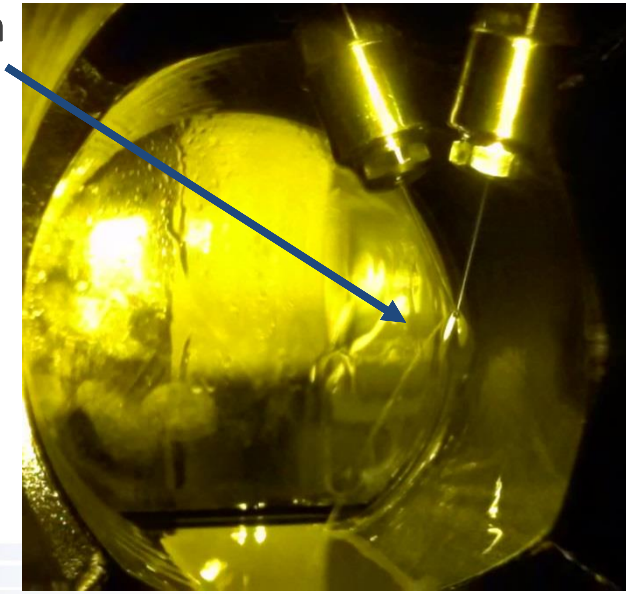
Concept:

- Two oil jets of .020” diameter impinging in vacuum.
- Rotate the film by offsetting the jets from outside the chamber.
- Pressure is ~ 250 psi.

High intensity test:

- ^{40}Ar at 10-15 μA
- 4 days stable operation
- no deterioration
- I_{beam}> 20 times gas target tolerance
- no degradation of beamline vacuum

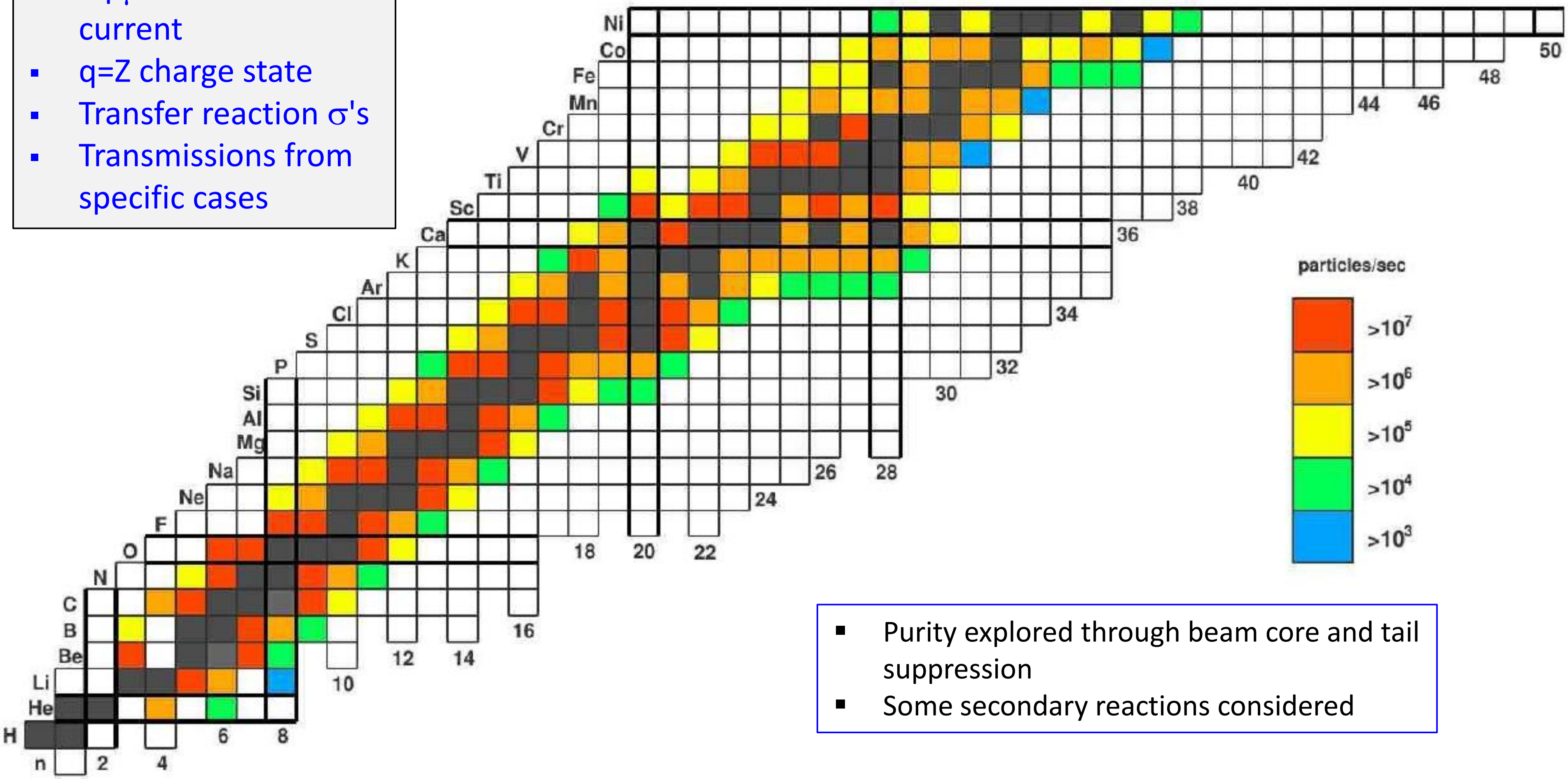
Oil film area



Summary of Expected In-Flight Beams

- 2 mg/cm^2 targets
- 1 pμA of beam current
- q=Z charge state
- Transfer reaction σ's
- Transmissions from specific cases

Rate uncertainties up to one order of magnitude



- Purity explored through beam core and tail suppression
- Some secondary reactions considered

See AIRIS web site for more details: www.phy.anl.gov/airis

Summary

Summary

- **ATLAS capable to provide a wide range of beams**
  - Intense stable beams from protons to uranium
  - Radioactive beams produced by the in-flight method
  - Re-accelerated, neutron-rich beams from ^{252}Cf fission
- **Nuclear reactions studies in:**
  - Astrophysics reactions w. radioactive beams – MUSIC and other instruments
  - Heavy-ion fusion reactions at sub-barrier energies: Fusion hindrance
  - Coulomb excitation of re-accelerated CARIBU beams
  - Transfer reactions in inverse kinematics – HELIOS:
- **New capabilities:**
  - EBIS ion source – clean reaccelerated CARIBU beams
  - AGFA – studies of heavy elements, proton emitters, ^{100}Sn region etc.
  - AIRIS – enhanced in-flight beam production to all target stations

Credits

AGFA Team

B.B. Back *, ANL*
R.V.F. Janssens *, ANL*
W.F. Henning *, ANL*
T.L. Khoo*, ANL*
J.A. Nolen *, ANL*
D.H. Potterveld *, ANL*
G. Savard, *ANL*
D. Seweryniak*, ANL*
M. Paul*, Hebrew University, Jerusalem*
P. Chowdhury, *U-Mass Lowell*
C.J. Lister, *U-Mass Lowell*
W.B. Walters, *University of Maryland*
P.J. Woods, *University of Edinburgh*
K. Gregorich, *LBNL*
W. Loveland, *Oregon State University*

AIRIS team

M. Alcorta *(now at Triumf, Canada)*
B. B. Back
C. Dickerson
C. R. Hoffman
B. P. Kay
A. Levand
S. Manikonda *(now at AML, Florida)*
B. Micklich
B. Mustapha
J. Nolen
P. Ostroumov
R. C. Pardo
K. E. Rehm
G. Savard
J. P. Schiffer
D. Seweryniak