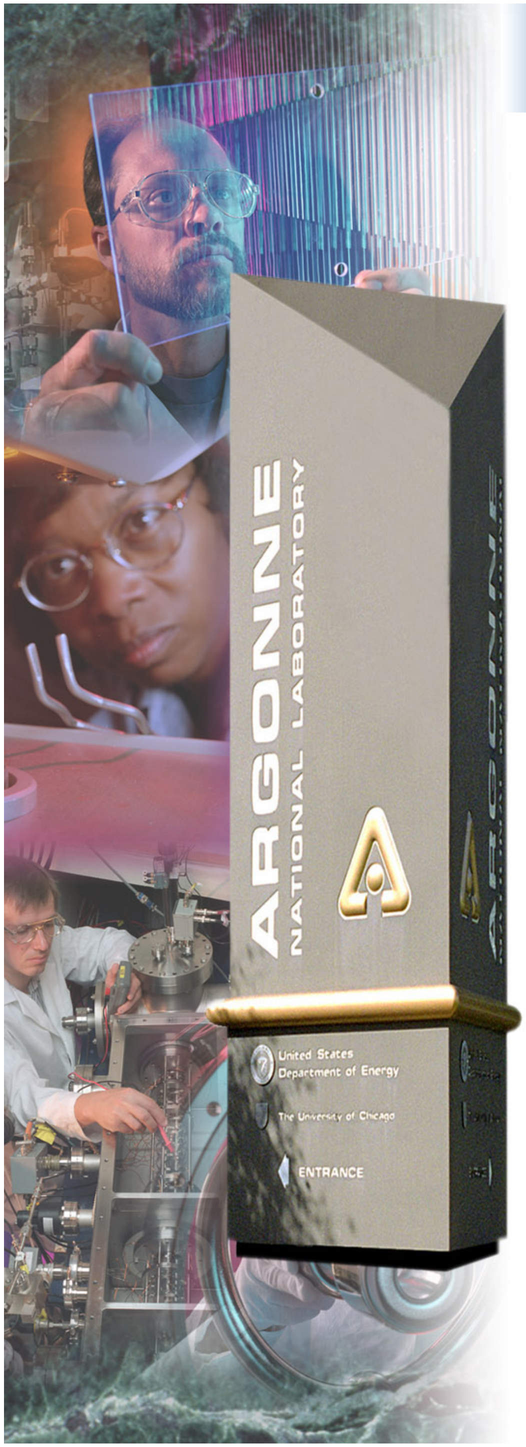


ARGONNE NATIONAL LABORATORY

Recent Highlights at ATLAS

Donald F. Geesaman

Physics Division

Argonne National Laboratory

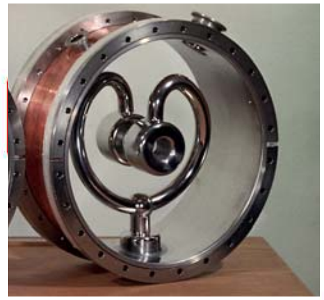
NSAC Meeting , 3/3/2006

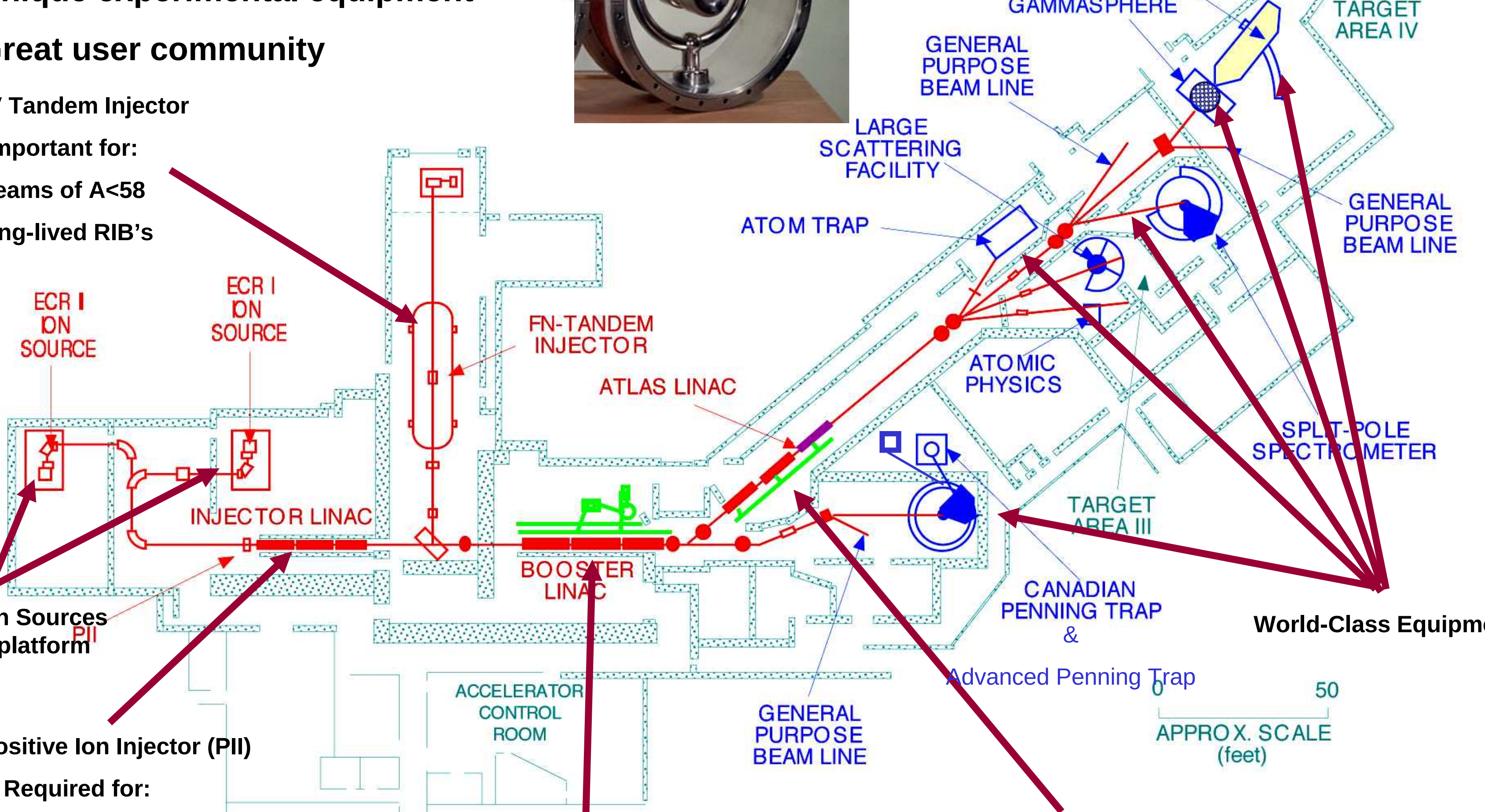
THE UNIVERSITY OF CHICAGO

Office of Science
U.S. DEPARTMENT OF ENERGY

The ATLAS Facility

- ✓ **Unique and powerful accelerator**
- ✓ **Unique experimental equipment**
- ✓ **Great user community**





8.5-MV Tandem Injector

Important for:

Beams of A<58

Long-lived RIB's

2 ECR Ion Sources on HV platform

12-MV Positive Ion Injector (PII)

Required for:

Beams with A>58

Noble gases

High current

18 Quarter-wave SC resonators

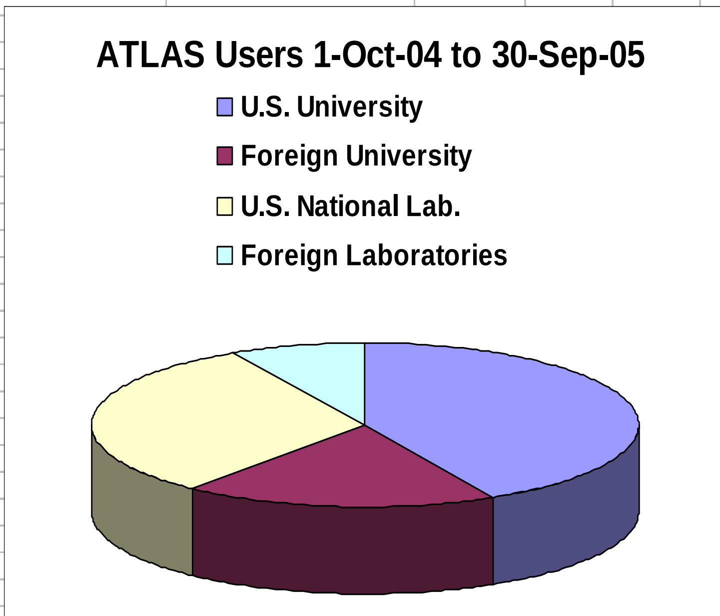
24-Resonator Booster

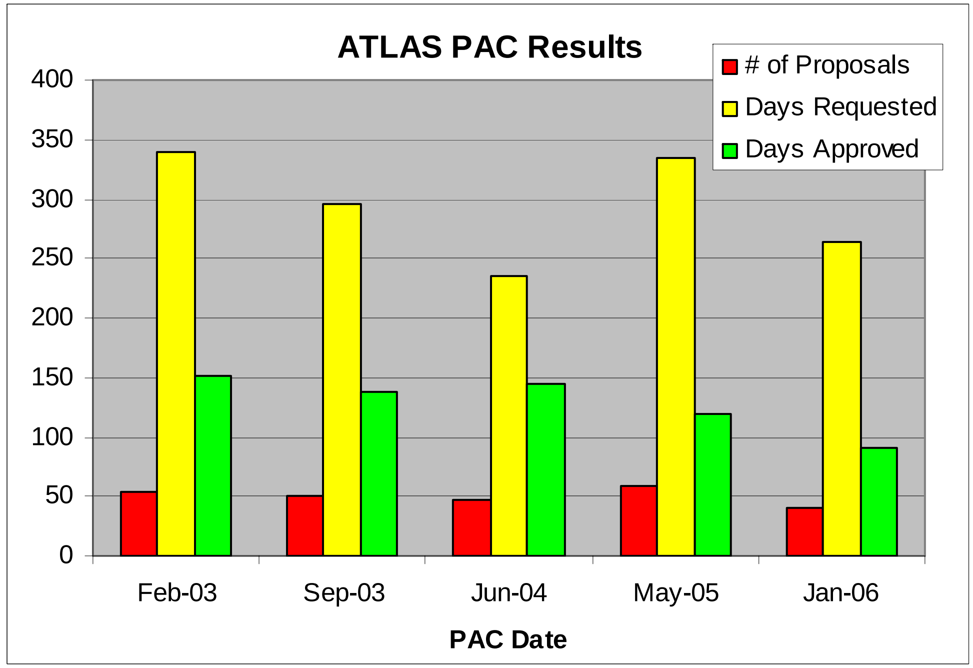
19-Resonator ATLAS

World-Class Equipment

The User Program at ATLAS

Institution	Number	
U.S. University	79	42%
Foreign University	35	19%
U.S. National Lab.	58	31%
Foreign Laboratories	15	8%
Total	187	



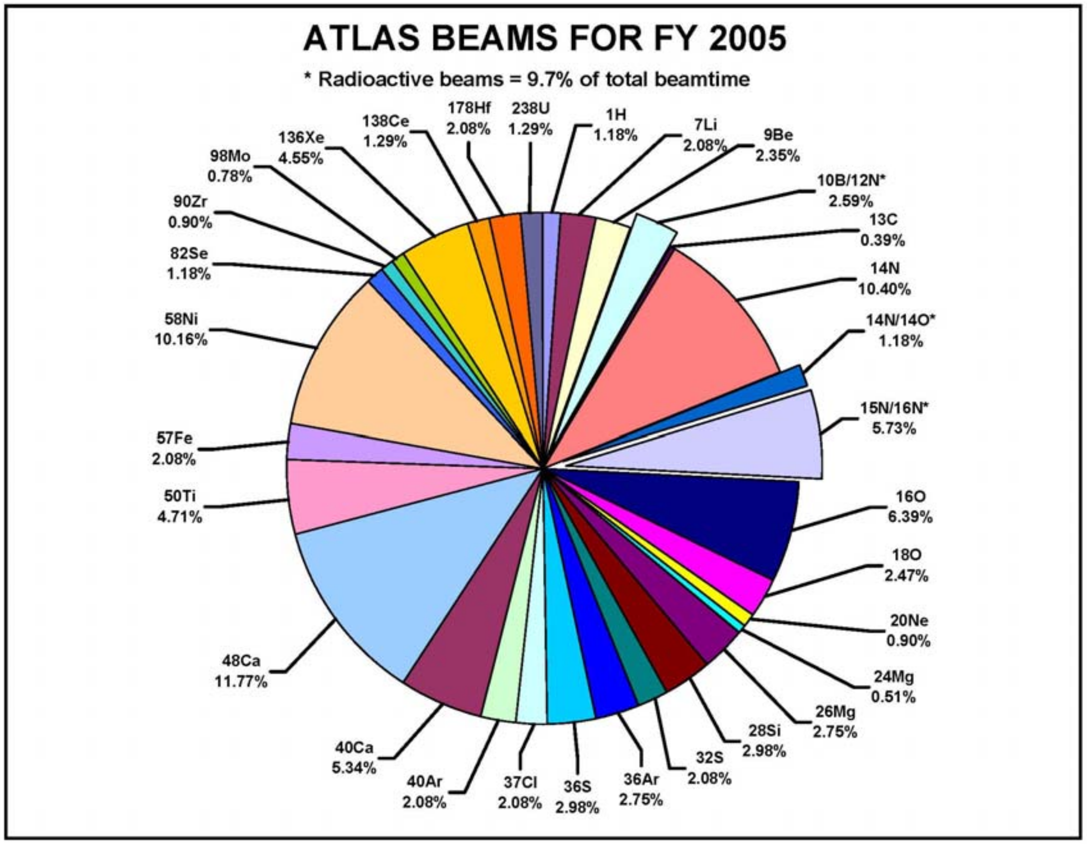


FY05 – 187 Users (53 Students / 13 Theses) 65 pubs in refereed journals (20 letters)

FY04 – 169 Users (52 Students / 11 Theses) 69 pubs in refereed journals (21 letters)

FY03 – 179 Users (58 Students / 9 Theses) 57 pubs in refereed journals (15 letters)

Beams at ATLAS



Total beam hours about 600 more – beam tuning

+ 1600 hours more for fission-fragments in CPT

+ few hundred hours source experiments in Gammasphere

FY2004

- 28 Beam Species
- 5559 Beam Hours (data taking & beam development)
  - 96.4% availability
- 1040 Hours of Rare (Radioactive) Beams

FY2005

- 30 Beam Species
- 4741 Beam Hours (data taking & beam development)
  - 95.2% availability
- 569 Hours of Rare (Radioactive) Beams

FY2006

- ~ 4000 Beam Hours (limited by funding)
- ~ 1000 Hours of Rare (Radioactive) Beams

ATLAS: Recent results

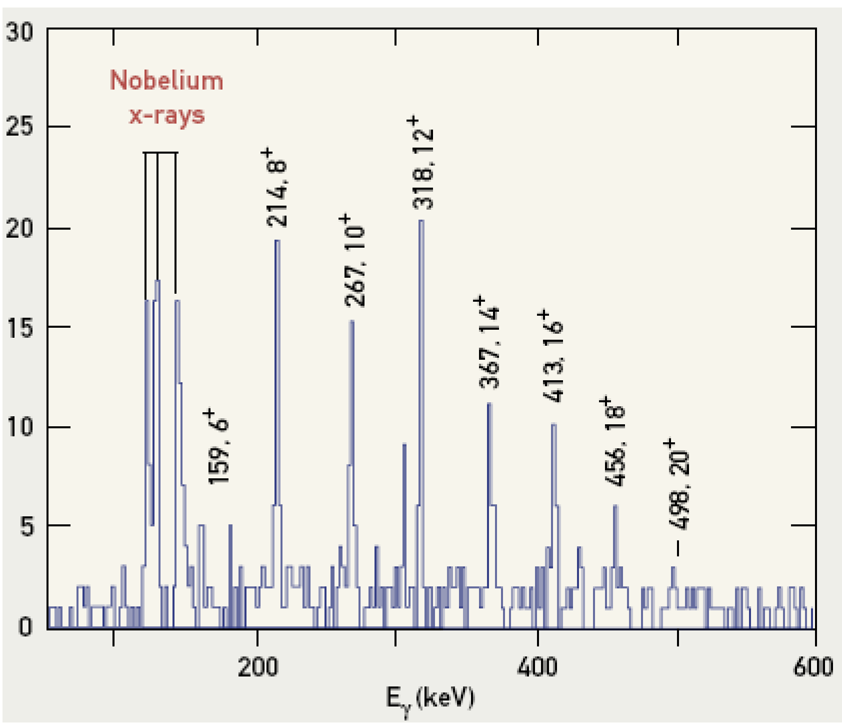
Structure & Stability of the heaviest nuclei:

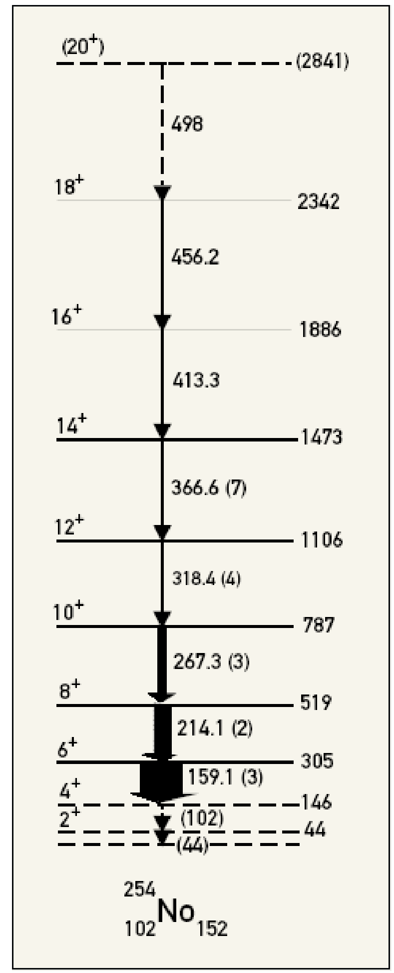
Physics of super-heavy nuclei: delicate balance between shell effects and Coulomb repulsion

Earlier work with Gammasphere and the FMA showed:

(1) shell stabilization via deformation as predicted by theory

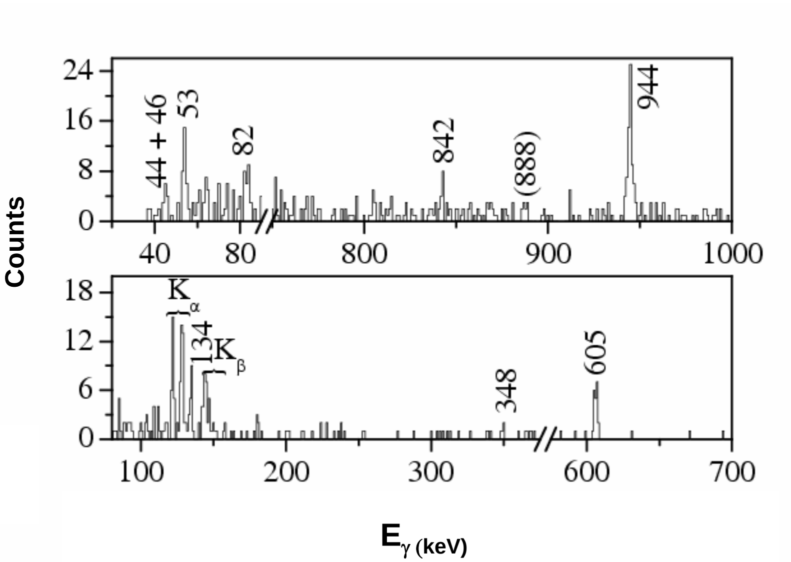
(2) ability to sustain angular momentum much larger than predicted



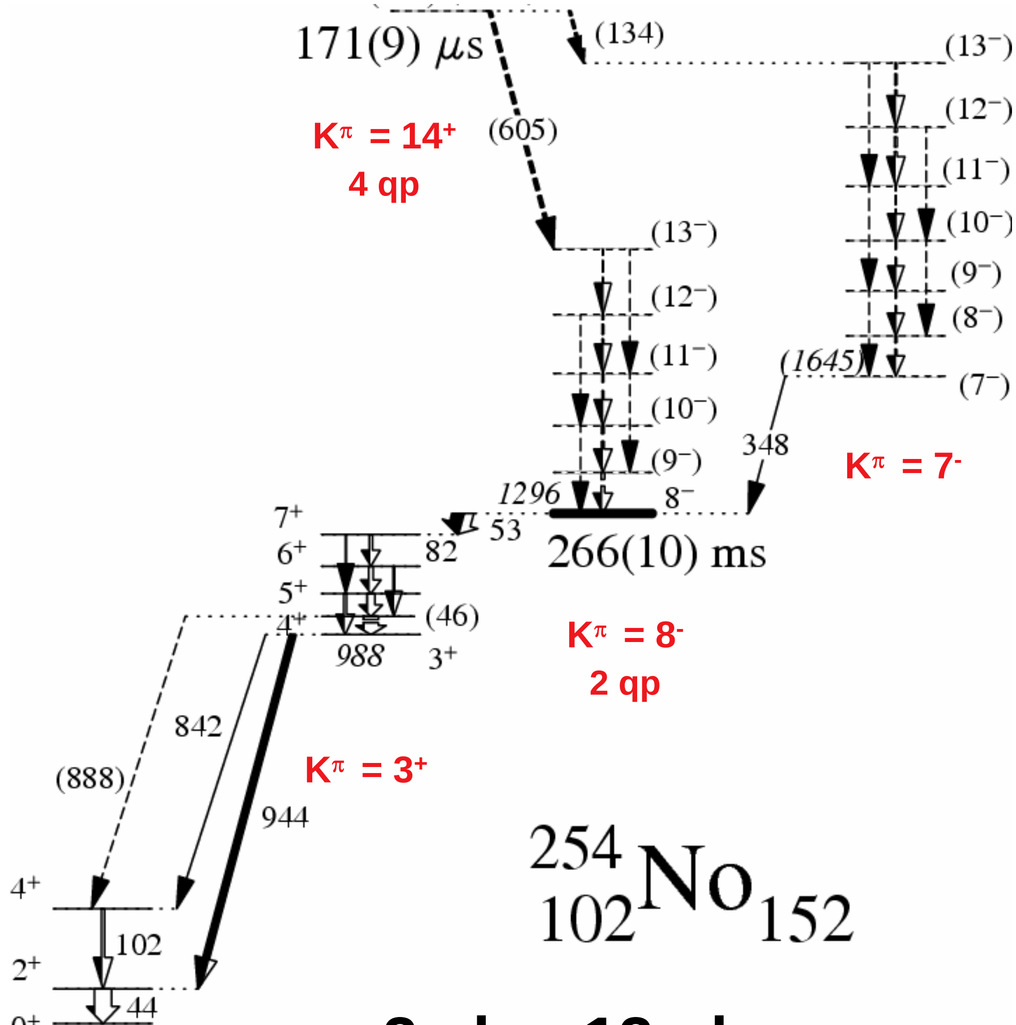


ATLAS: Recent results

Heaviest nuclei: Evidence for K-Isomers in ^{250,252,254}No



From electron & gamma-ray spectroscopy at the FMA focal plane :2 high-K isomers



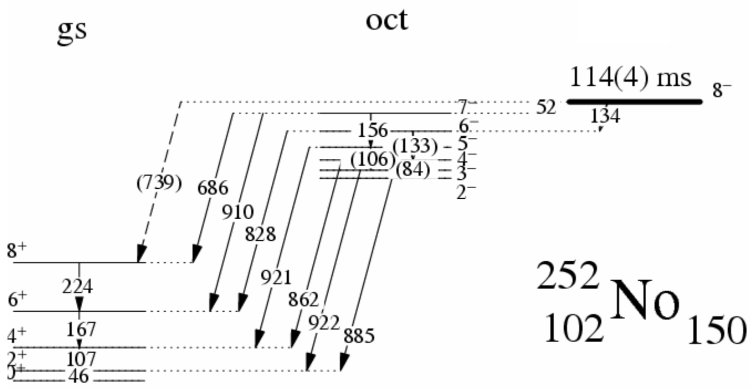
$\sigma \sim 2\ \mu b - 12\ nb$

ATLAS: Recent results

Heaviest nuclei: Evidence for K-Isomers in ^{250,252}No

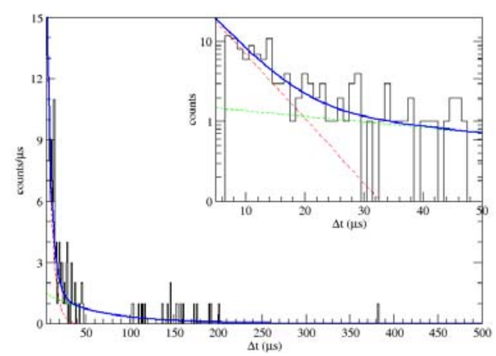
σ ~ 200 nb

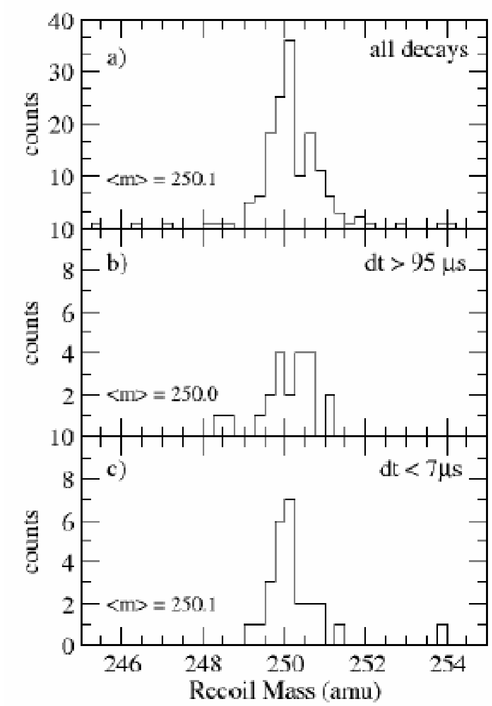
K^{π} = 8^{-}



^{250}No at FMA focal plane

σ ~ 12 nb





K^{π} = ? **43(15) μs**

$^{250}No_{148}$

0^{+} **3.7 (.9) μs**

SF

ATLAS: Recent results

Heaviest nuclei: K-Isomers in $^{250,252,254}No$– Lessons learned

- K is a good quantum number → shell-stabilized nobelium is axially symmetric

- 2 and 4 quasi-particle states seen

  → Axial symmetry is robust

  (and is conserved even for states with E* ~ 2.5 MeV, high spin and 2 broken pairs).

  → Information on E_{sp}

  gaps and spacings → shell stabilization → SHN

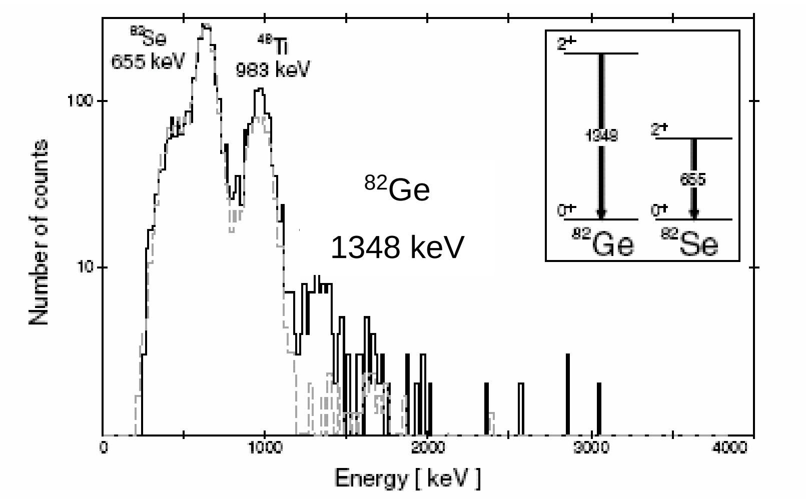
  → Data on pairing ($\Delta < E_{2qp}/2$)

- Calculations on-going

ATLAS: Recent results

Neutron-rich nuclei: Gammasphere at work in new ways

Technique: **Combine β-decay & Coulex of n-rich nuclei (NSCL, HRIBF) with Gammasphere data using deep inelastic reactions, fission and reactions on n-rich radioactive targets (^{14}C,..) with the FMA.**



HRIBF: Coulomb Excitation of ^{82}Ge

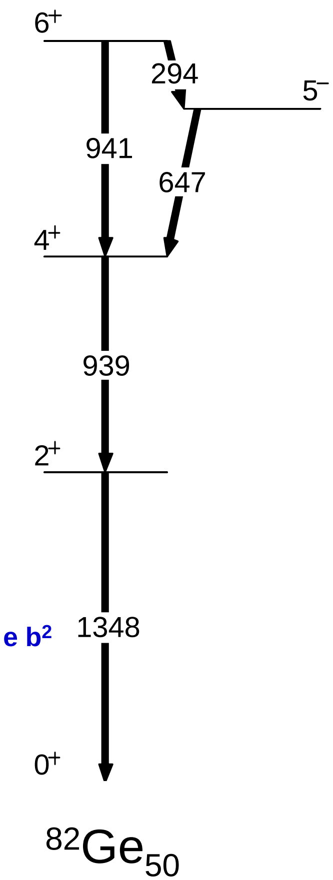
E. Padilla Rodal *et al.,* Phys. Rev. Lett. 94, 122051 (2005).

ATLAS and Gammasphere:

^{82}Se + ^{208}Pb & ^{238}U

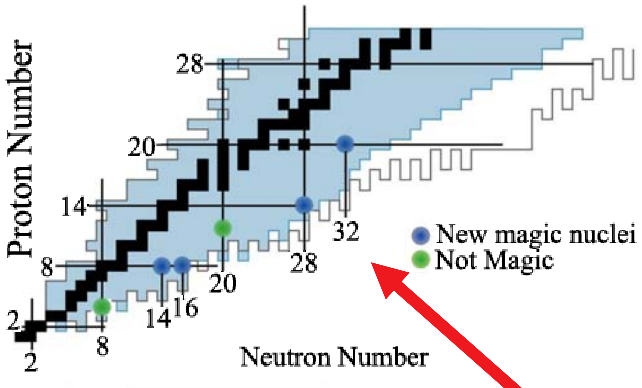
M.P. Carpenter *et al.*, to be published.

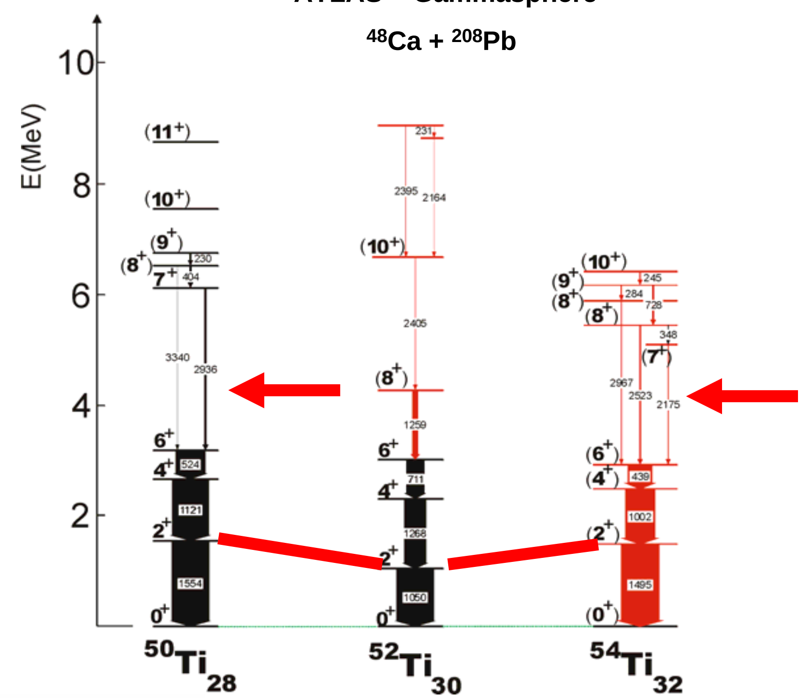
B(E2) **= 0.115(20) e b^2**

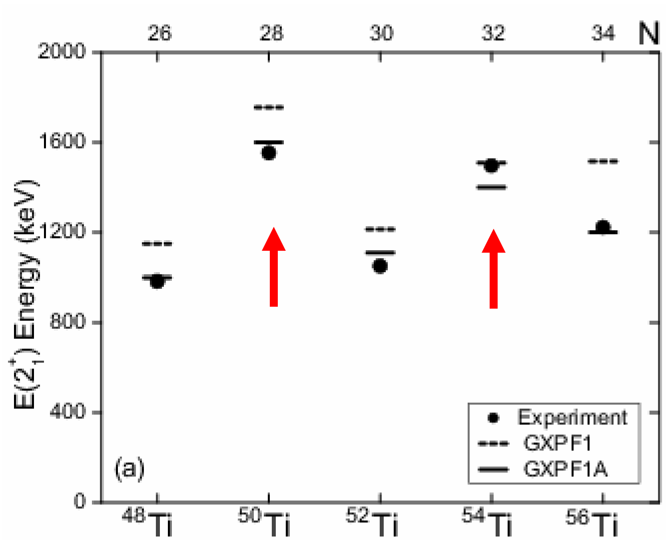


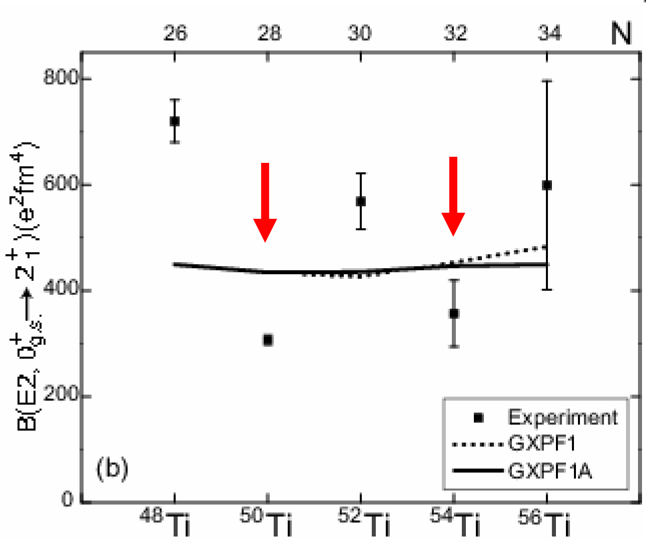
ATLAS: Recent results

Neutron-rich nuclei: New Magic Numbers









Change in π-ν Vστ interaction with *Z* & *N*

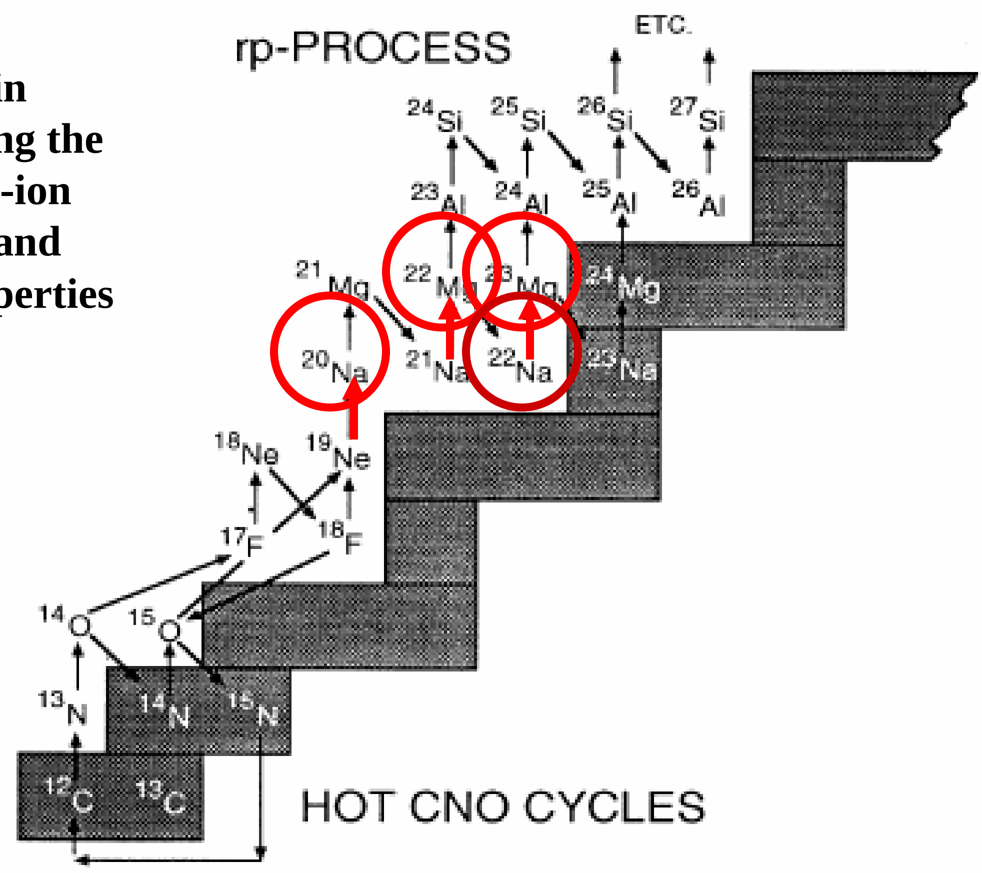
NSCL Coulex and β decay

ATLAS: Recent results

Gammasphere at work in new ways : nuclear astrophysics

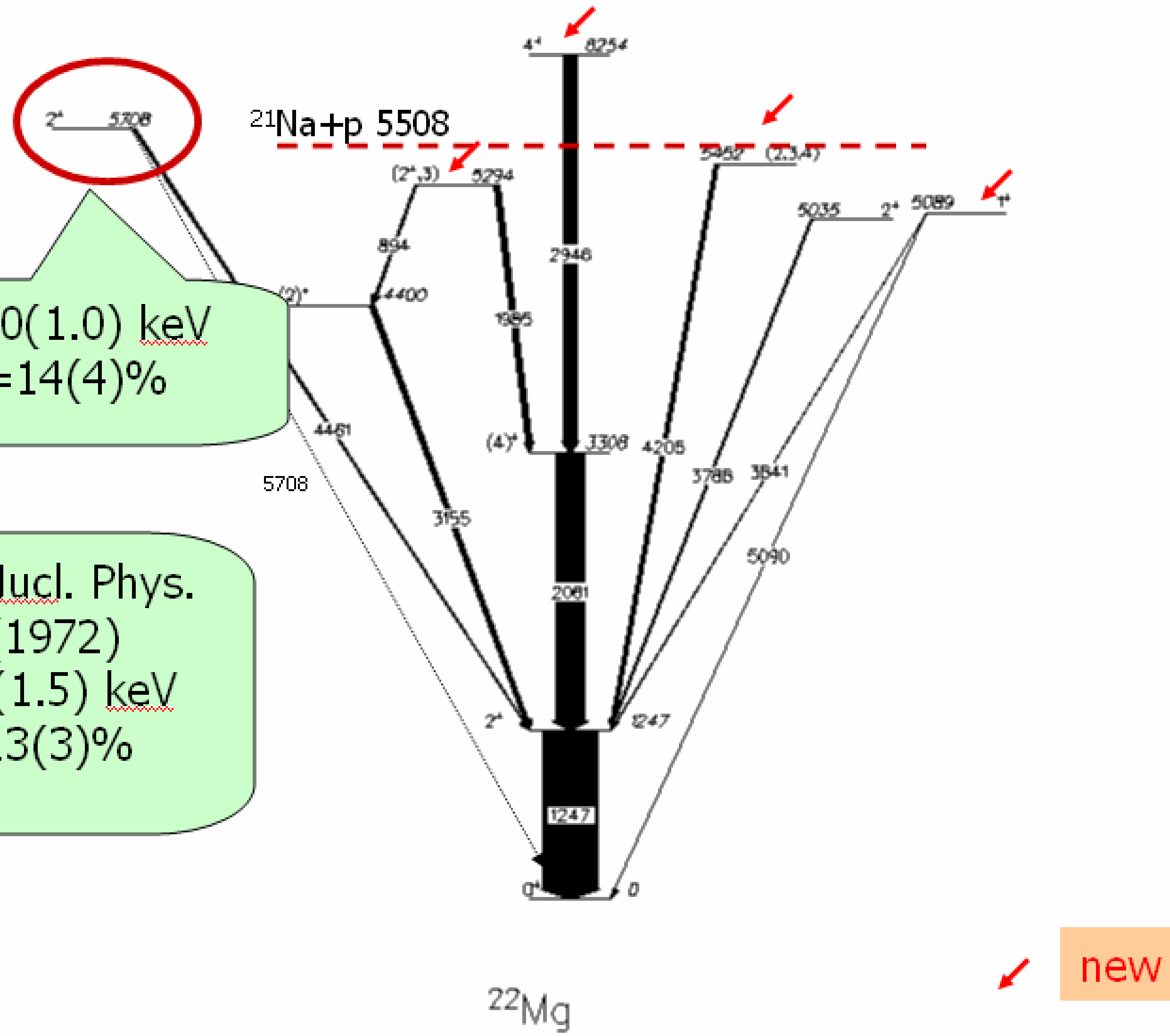
Breakout from the hot CNO cycle into the rp-process

Measure E*, I$^{\pi}$ of states within Gamow window by populating the states of interest using heavy-ion fusion-evaporation reaction and measuring their γ-decay properties



ATLAS: Recent results

(3) Solving the ^{22}Mg puzzle

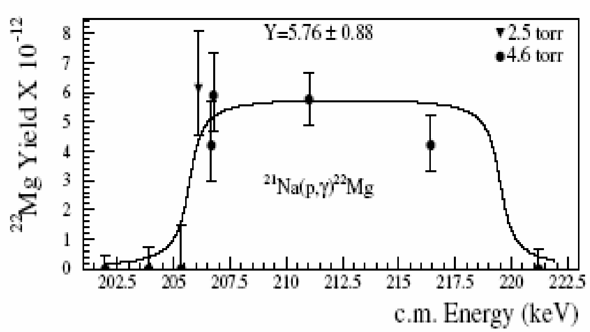


E(2$^+$)=5711.0(1.0) keV
b(2$^+$→0$^+$)=14(4)%

C. Rolfs et al. Nucl. Phys. A191, 209 (1972)
E(2$^+$)=5714.4(1.5) keV
b(2$^+$→0$^+$)=13(3)%

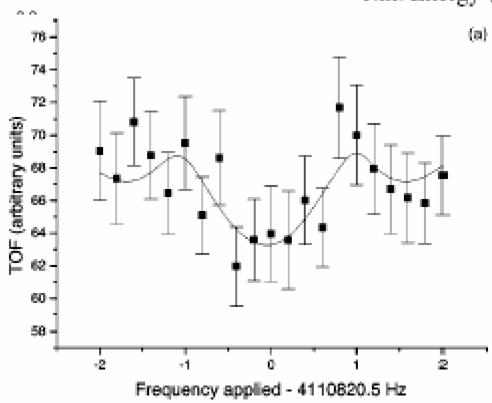
ATLAS: Recent results

The ^{22}Mg puzzle

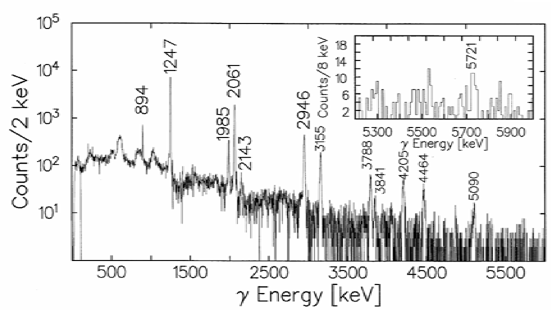


S. Bishop et al., PRL 90, 162501 (2003)
DRAGON at TRIUMF

E_R=205.7(5) keV
^{21}Na and ^{22}Mg masses and E*(2$^+$) give
E_R=212 keV???



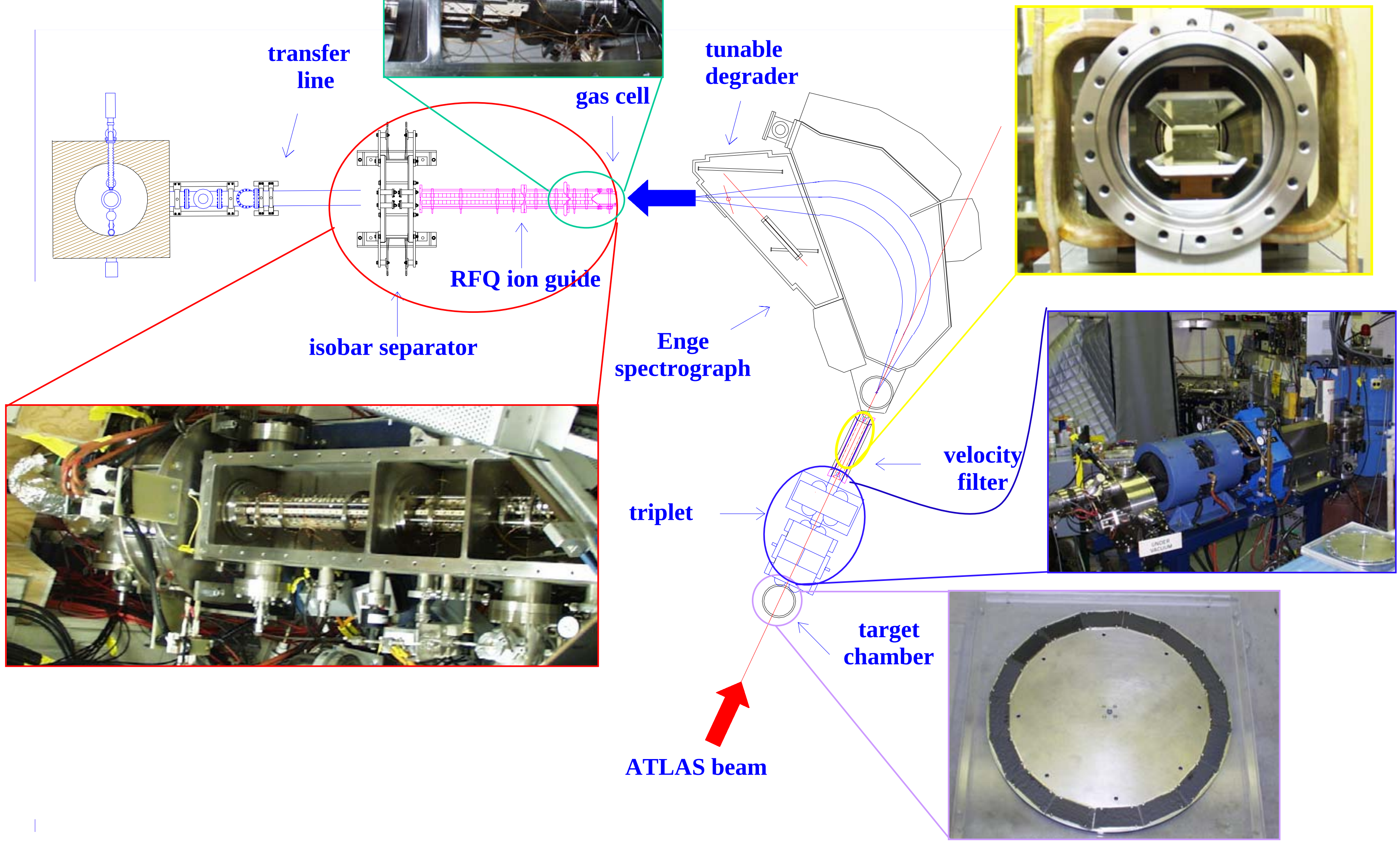
G. Savard et al., PR C (2004)
CPT at ANL
ΔM(^{22}Mg)=-399.64(63) keV



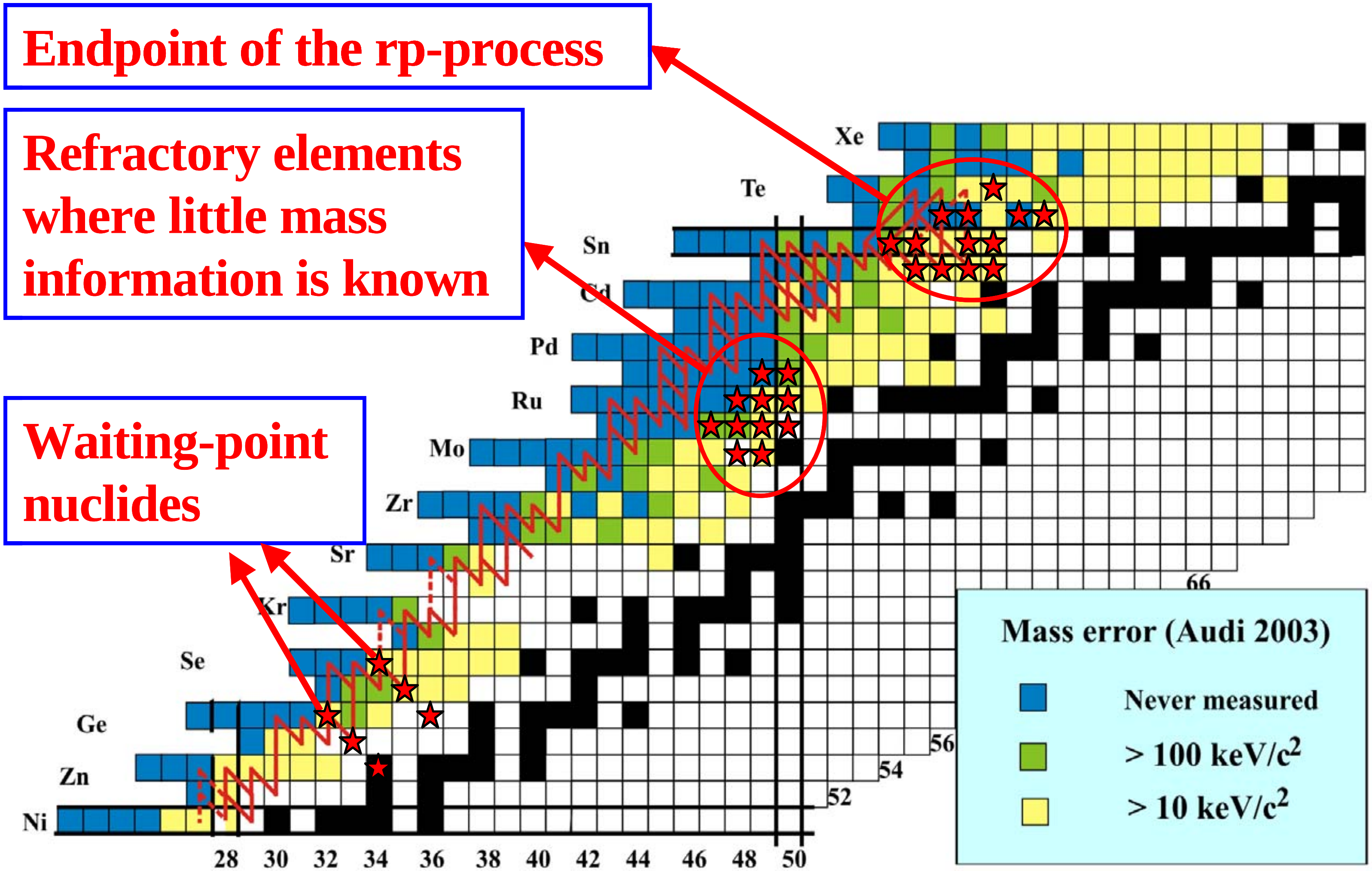
E_R=205.7(5) keV
^{21}Na mass
new E*(2$^+$)=5711.0(1.0) keV
ΔM(^{22}Mg)=-400.5(1.3) keV!!!

Overview of the CPT apparatus at ANL

- powerful and reliable apparatus to efficiently collect evaporation residues, purify and deliver to CPT
- working version of RIA-type gas stopper



Measurements on rp-process nuclides at CPT

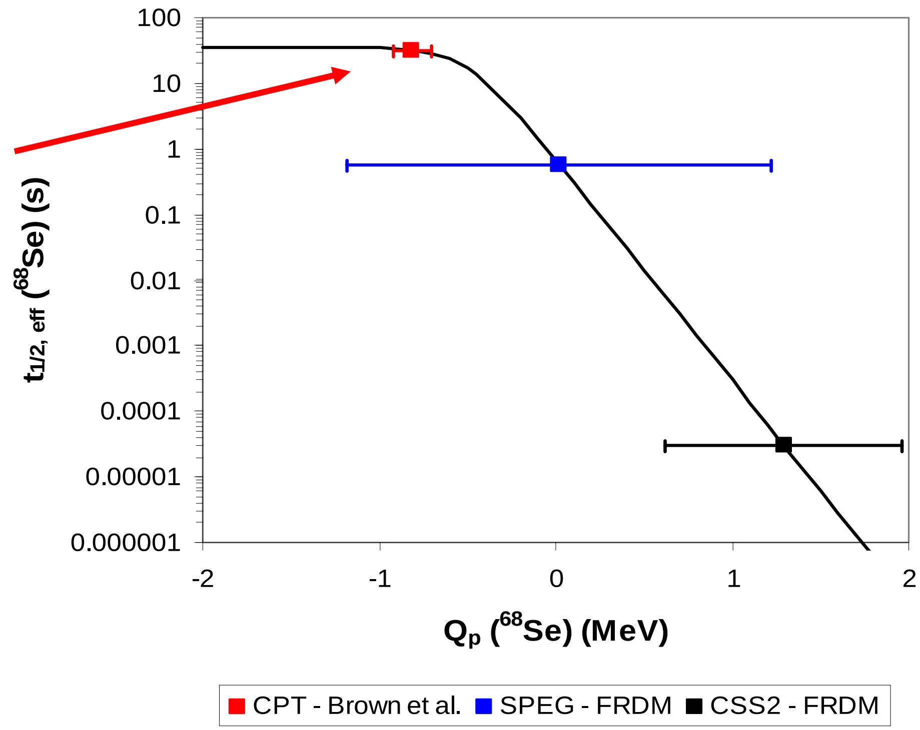


Effective lifetime of the waiting-point nuclide ^{68}Se

- **Effective lifetime is the beta decay lifetime, reduced by the proton capture rate**

- **A recent precision mass measurement at the CPT spectrometer at Argonne has determined the mass excess of ^{68}Se to be –54232 (19) keV**

- **With this value, the effective lifetime of ^{68}Se in astrophysical environments typical of X-ray bursts is found to be about 32 seconds … the waiting point at ^{68}Se is not bridged by two-proton capture and the rp-process must wait this full delay before proceeding further.**



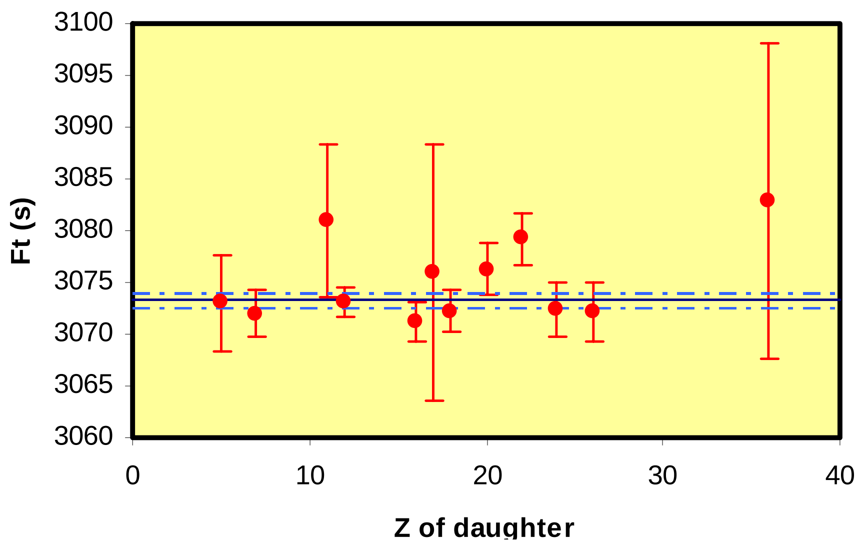
J. Clark et al, PRL 92 (2004) 192501.

ARGONNE NATIONAL LABORATORY

ATLAS: Recent results

0+ → 0+ decays & the unitarity of the CKM matrix

- **First measurement in Penning trap on the highest precision data cases**
  - ~8 x 10^{-9} accuracy achieved on a short-lived nucleus
  - For ^{46}V we obtain Q_{EC} = 7052.90(40) keV … previous average value 7050.71(89) keV
  - Adding new Q value and removing effect of discrepant measurement (or increasing its error bars until it is statistically acceptable) yields



PRL 95, 102501 (2005) PHYSICAL REVIEW LETTERS week ending 2 SEPTEMBER 2005

Q Value of the Superallowed Decay of ^{46}V and Its Influence on V_{ud} and the Unitarity of the Cabibbo-Kobayashi-Maskawa Matrix

G. Savard,[1,2] F. Buchinger,[3] J. A. Clark,[4,1] J. E. Crawford,[3] S. Gulick,[3] J. C. Hardy,[5] A. A. Hecht,[1,6] J. K. P. Lee,[3] A. F. Levand,[1] N. D. Scielzo,[1] H. Sharma,[4,1] K. S. Sharma,[4,1] I. Tanihata,[1] A. C. C. Villari,[1,7] and Y. Wang[4]
[1] *Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[2] *Department of Physics, University of Chicago, Chicago, Illinois 60637, USA*
[3] *Department of Physics, McGill University, Montreal, Quebec H3A 2T8, Canada*
[4] *Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada*
[5] *Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA*
[6] *Department of Chemistry, University of Maryland, College Park, Maryland 20742, USA*
[7] *GANIL, BP 55027, 14076 Caen Cedex 5, France*
(Received 15 April 2005; published 29 August 2005)

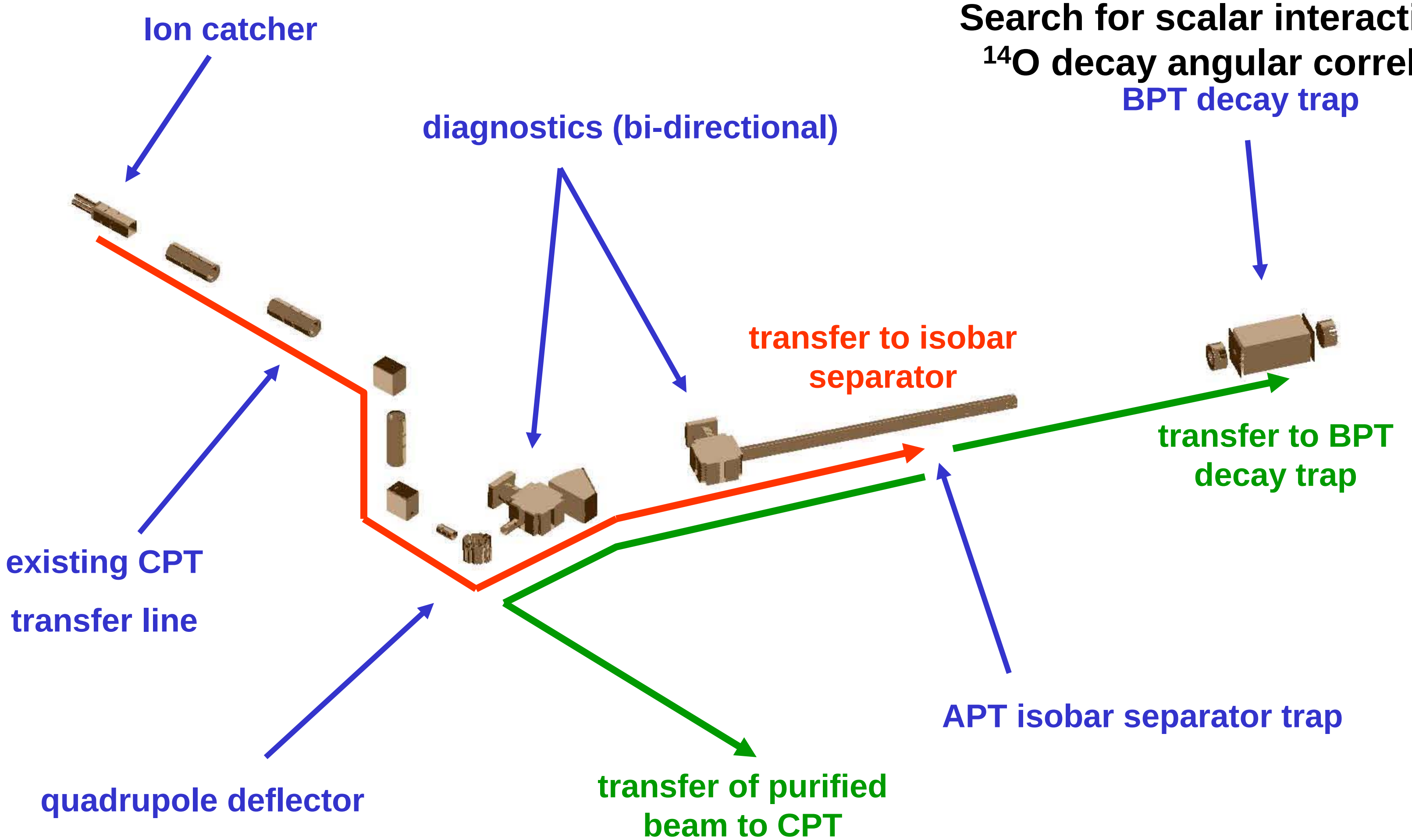
The masses of the radioactive nuclei ^{46}V and its decay daughter ^{46}Ti have been measured with the Canadian Penning Trap on-line Penning trap mass spectrometer to a precision of 1×10^{-8}. A Q_{EC} value of 7052.90(40) keV for the superallowed beta decay of ^{46}V is obtained from the difference of these two masses. With this precise Q value, the $\mathcal{F}t$ value for this decay is determined with improved precision. An investigation of an earlier Q-value measurement for ^{46}V uncovers a set of 7 measurements that cannot be reconciled with modern data and affects previous evaluations of V_{ud} from superallowed Fermi decays. A new evaluation, adding our new data and removing the discredited subset, yields new values for G_V and V_{ud}. When combined with recent results for V_{us}, this yields modified constraints for the unitarity of the Cabibbo-Kobayashi-Maskawa matrix and other extensions of the standard model.

- **CVC confirmed at the 3 x 10^{-4} level**
- **$\mathcal{F}t$ = 3073.66 ± 0.75 s** **χ^2/ν = 1.12**
- **V_{ud} = 0.9736 ± 0.0004** **ΣV_{ui} = 0.9981(10)**

ATLAS: Recent results

New capabilities with 2 Penning traps: Isobar Separation

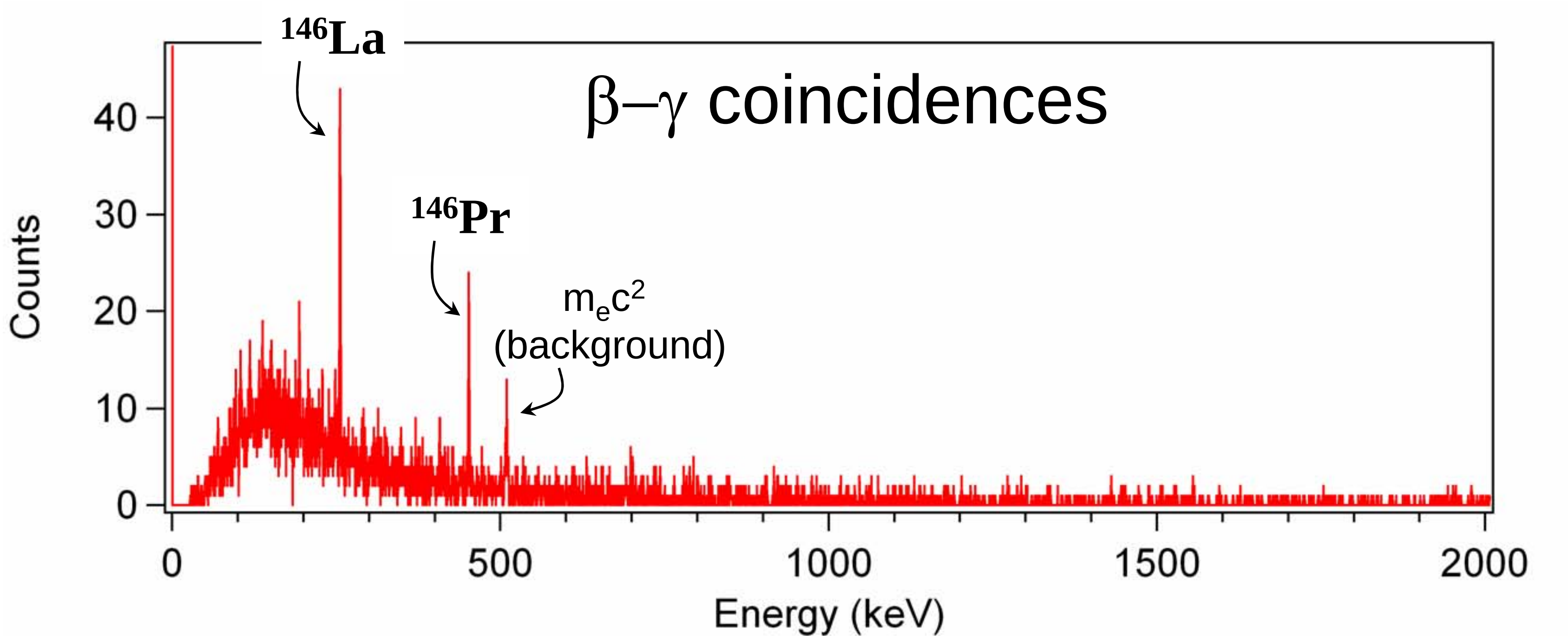
Search for scalar interactions in ^{14}O decay angular correlation



ATLAS: Recent results

New capabilities with 2 Penning traps: Isobar Separation & new decay trap

Fission fragments from ^{252}Cf source loaded into Decay Trap



ARGONNE NATIONAL LABORATORY

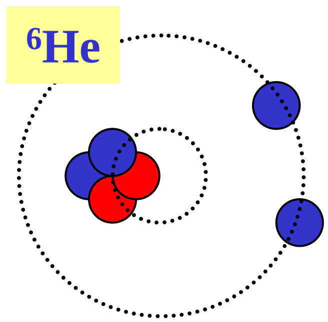
Atom Trapping: Charge radius of ^{6}He

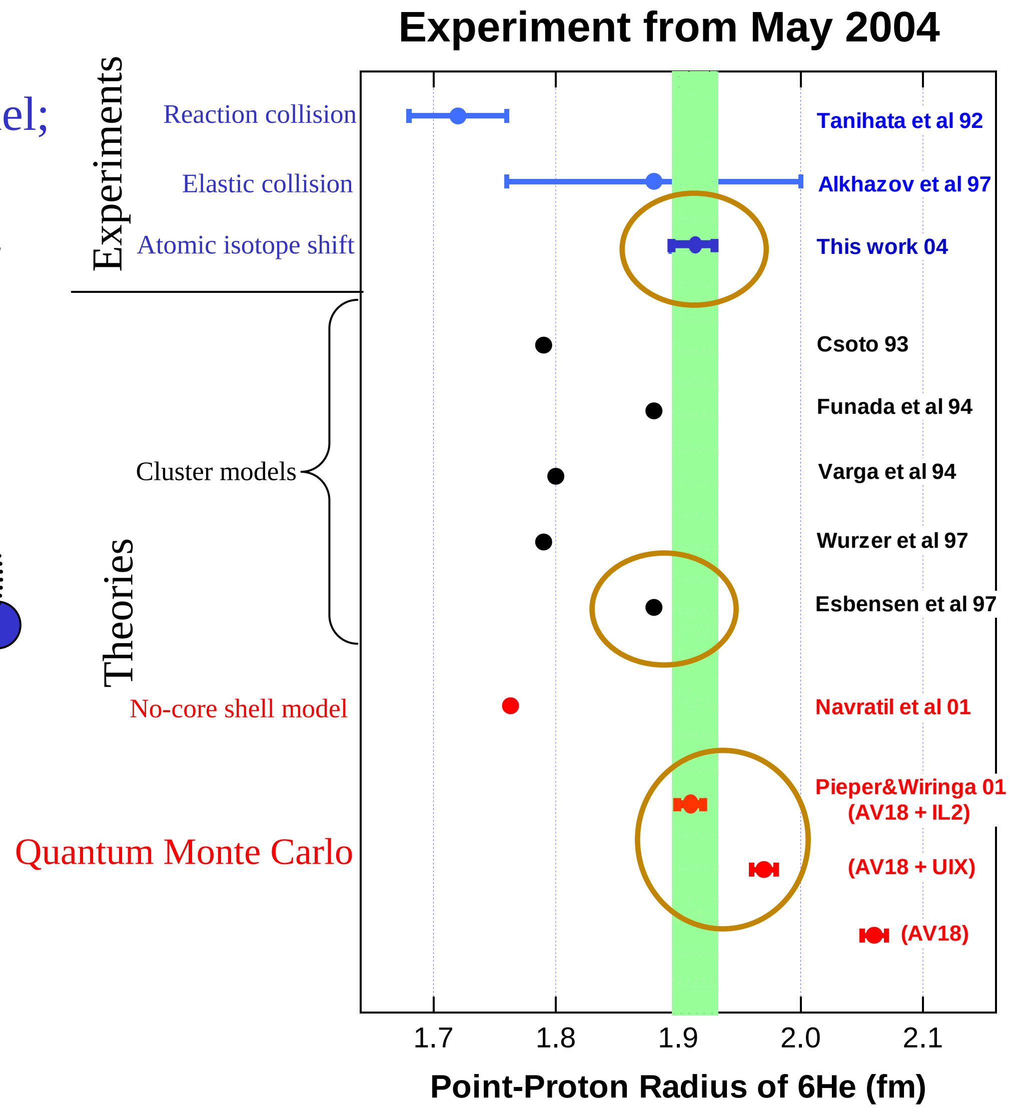
Motivation

- Test the Standard Nuclear Structure Model;

  Quantum Monte Carlo calculations of light nuclei. S.C. Pieper & R.B. Wiringa

- Study nucleon interactions in neutron-rich matter.



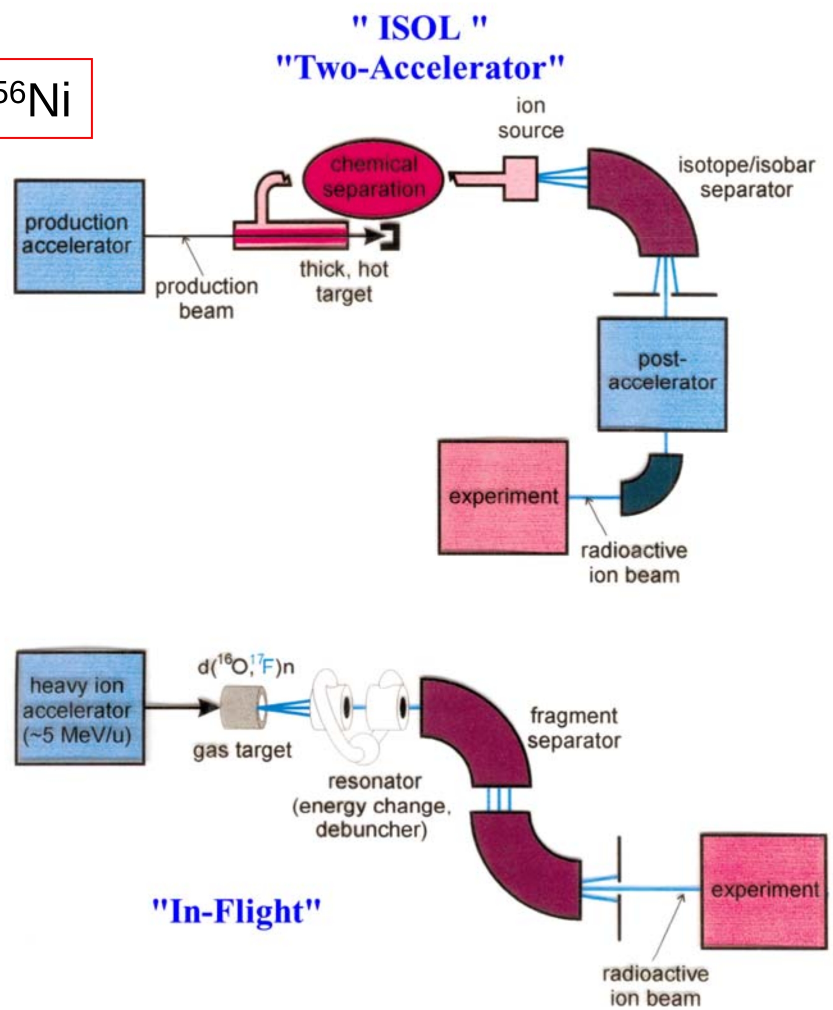


Beautiful integration of capabilities

- Theory
- ATLAS – production of ^{6}He
- Low Energy research
- MEP- Atom Trap Technology
- Ph.D. thesis of UIUC student – 2006 DNP Dissertation award

ATLAS: Exotic Beam Production - Techniques

Most recent beam: ^{44}Ti, ^{56}Ni

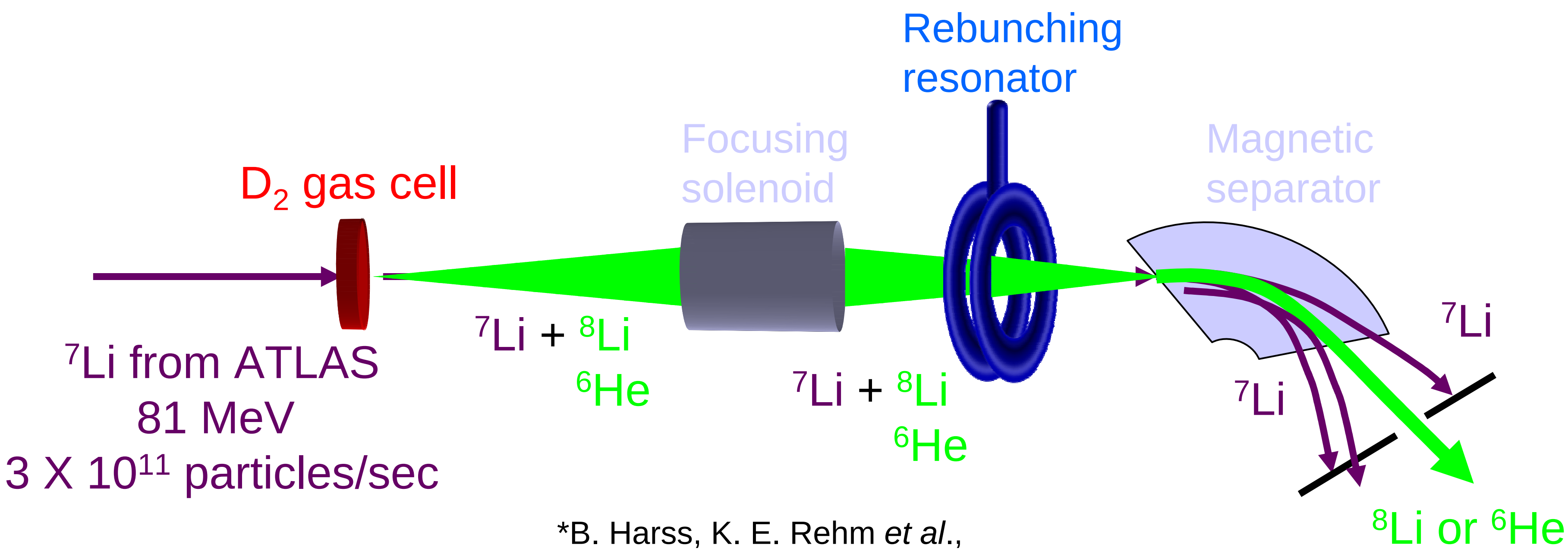


Most recent beams: ^{6}He, ^{8}Li, ^{16}N, ^{21}Na

15 different exotic beams thus far

ATLAS: Recent results

"In-flight" production of ^{8}Li and ^{6}He



*B. Harss, K. E. Rehm *et al.*,
Rev. Sci. Instrum. **71**, 380 (2000)

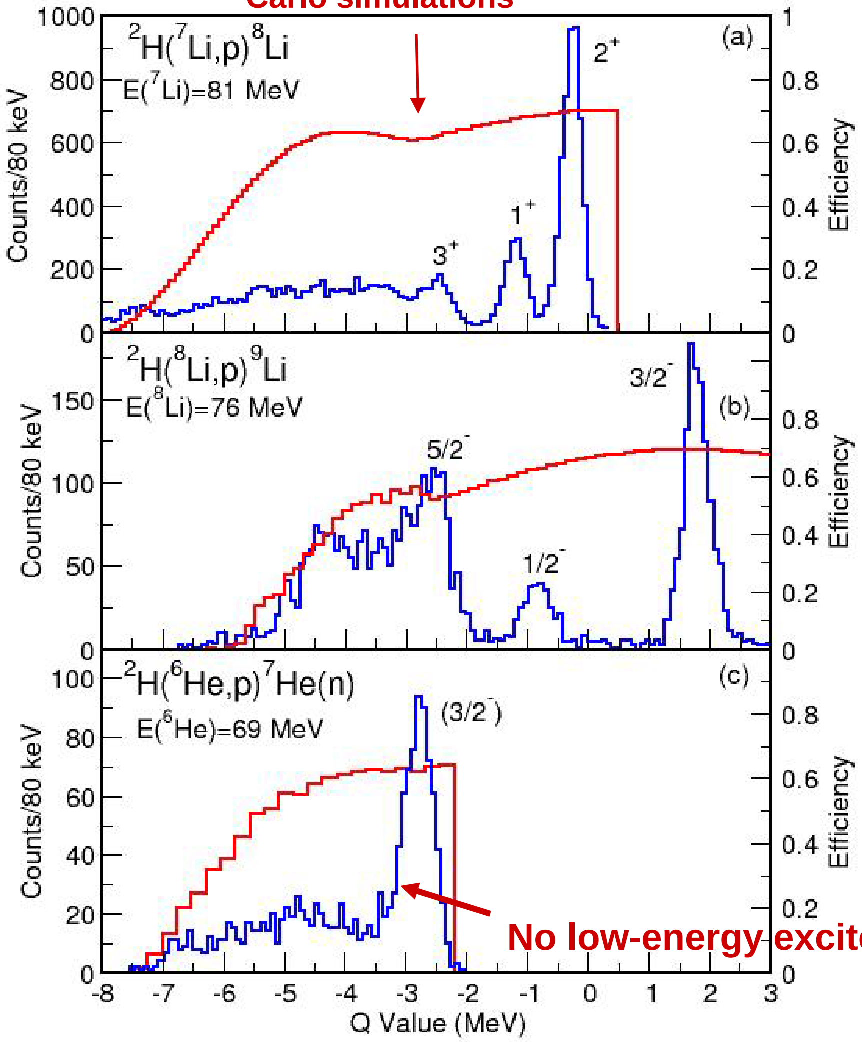
Beam	Production reaction	Energy	Intensity
^{8}Li	**^{2}H(^{7}Li,^{8}Li)p**	**76 MeV**	**50000 pps**
^{6}He	**^{2}H(^{7}Li,^{6}He)^{3}He**	**69 MeV**	**10000 pps**

![ARGONNE NATIONAL LABORATORY]

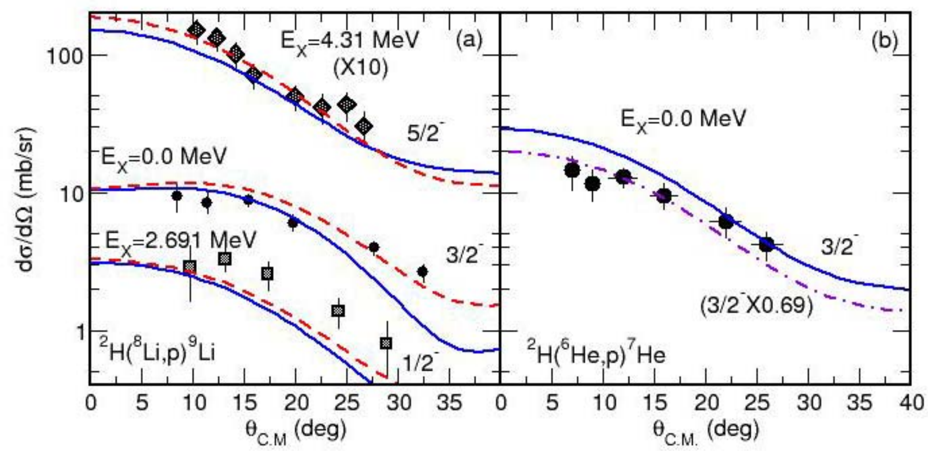
ATLAS: Recent results

(6) (d,p) reactions as tests of ab-initio calculations

Efficiency from Monte Carlo simulations



No low-energy excited state in ^{7}He



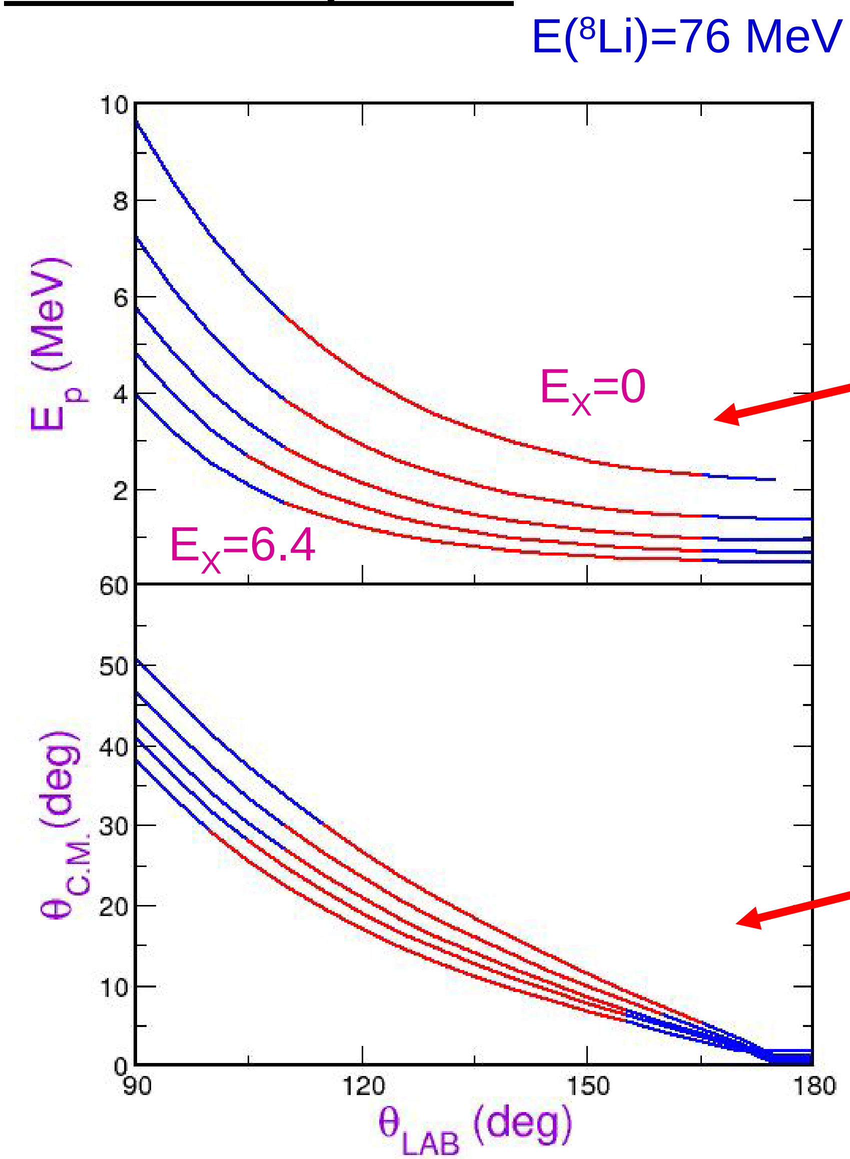
^{2}H(^{8}Li,*p*)^{9}Li
DWBA calculations
QMC predictions
no normalization

^{2}H(^{6}He,*p*)^{7}He$_{g.s.}$
DWBA calculations
QMC calculations

Optical-model parameters from Schiffer et al, PRC 164

A well-known problem

Kinematics for* d(*⁸Li*,p)*⁹Li



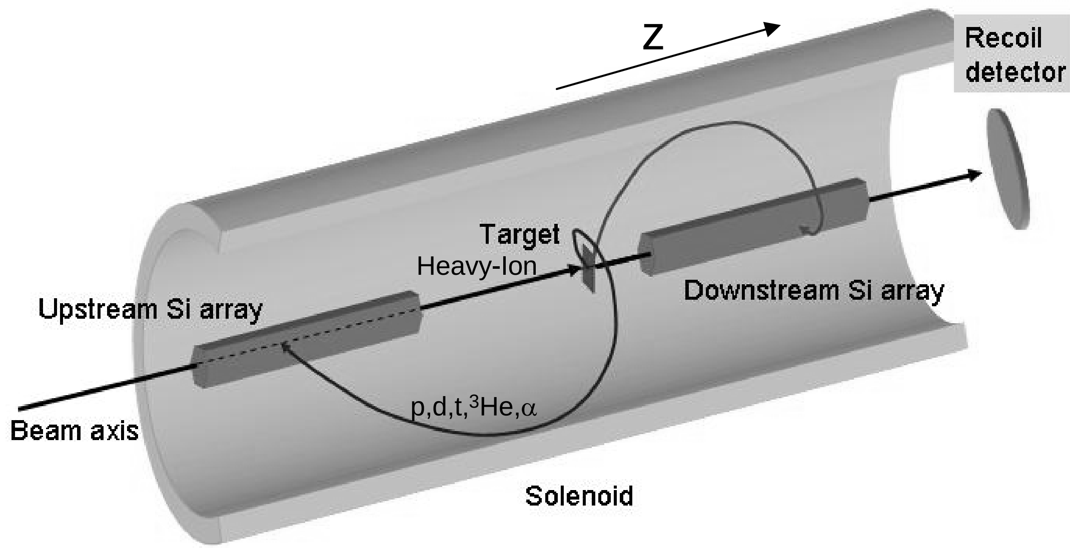
Forward proton angles in center-of-mass system – low proton energies

and small separation

Small proton angle range in center-of-mass system – large angle range in lab system

Proposed Superconducting Solenoid

- 4π solid angle
- Particle I.D. from TOF
- Simple detector and electronics - few channels
- Excellent center-of-mass energy and angle resolution
- Suppression of backgrounds



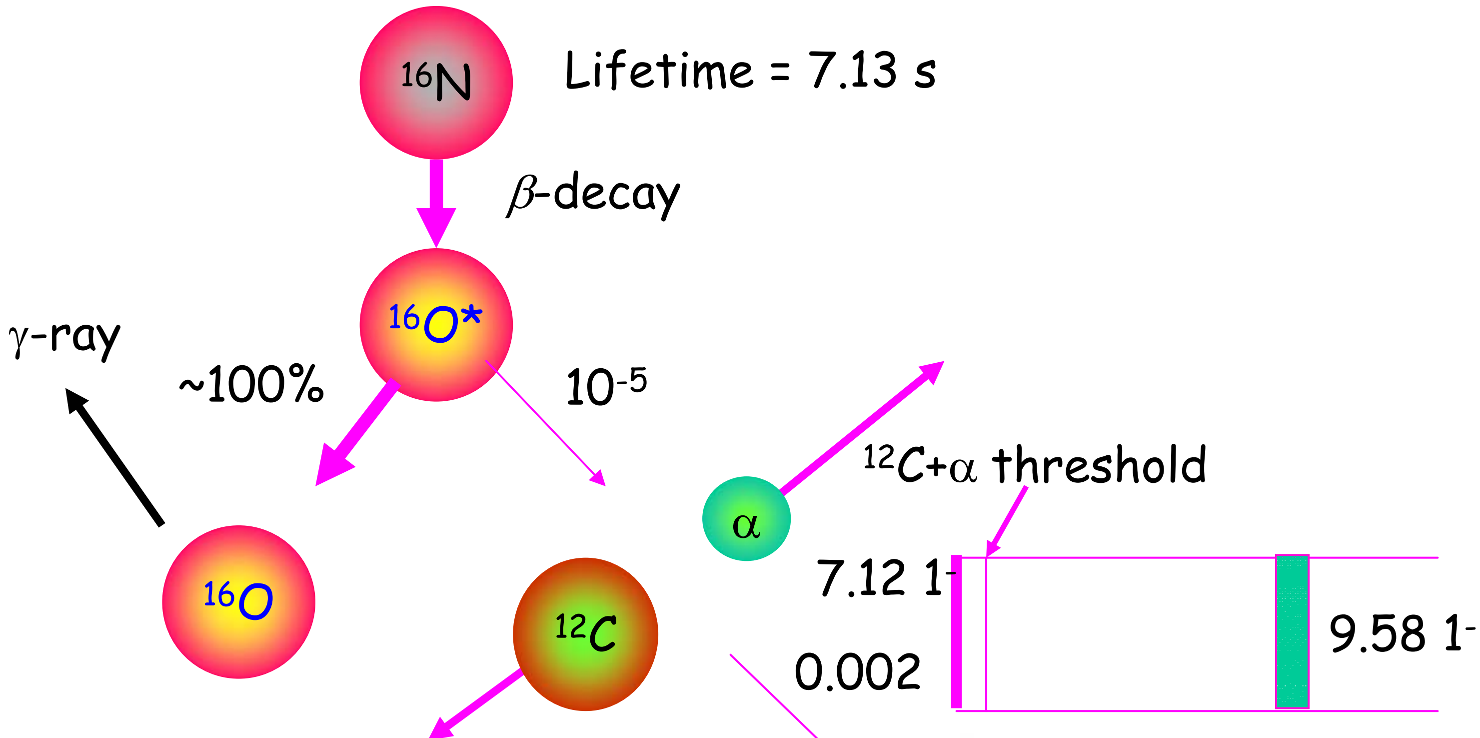
Ideal tool for reactions in inverse kinematics

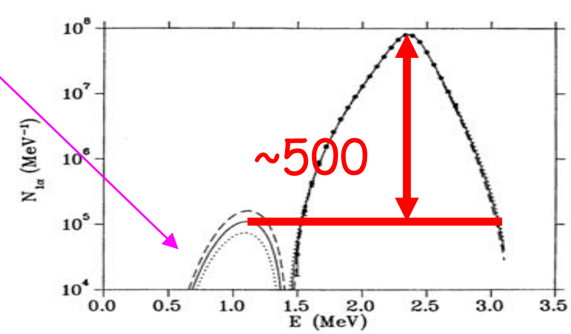
-Radioactive Ion Beams

Plan to build in FY07-FY08

ATLAS: Recent results

^{16}N β-*delayed α decay* and the S(E1) factor for the ^{12}C(α,γ) reaction

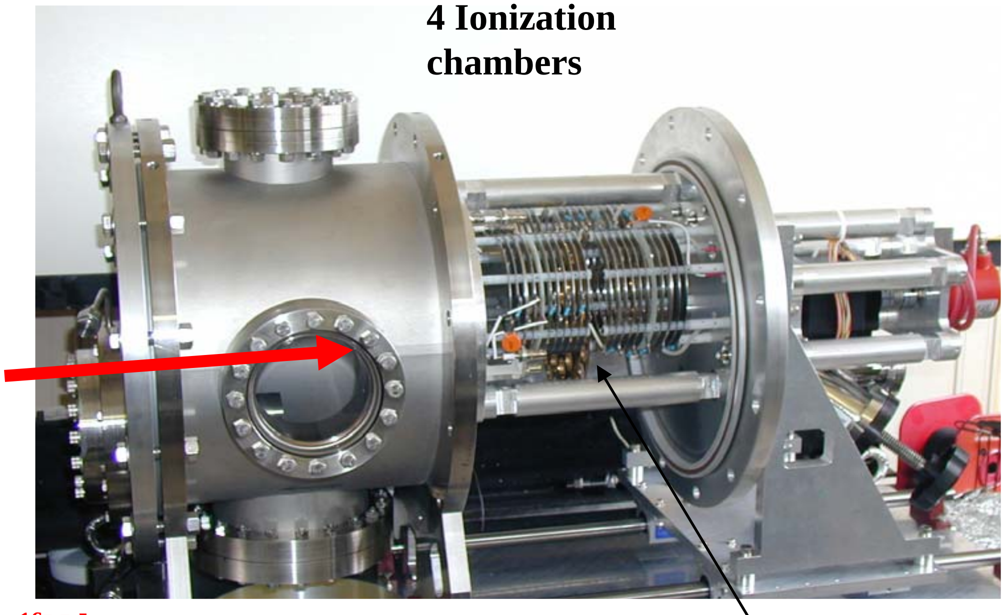




Calculation: Baye & Descouvemont NPA458(1988)445

4 measurements with Si detectors
With conflicting results
Limited by background of β rays

Experimental setup for the study of the β-delayed α decay of ^{16}N



^{16}N beam

$T_{½}$=7.1 s

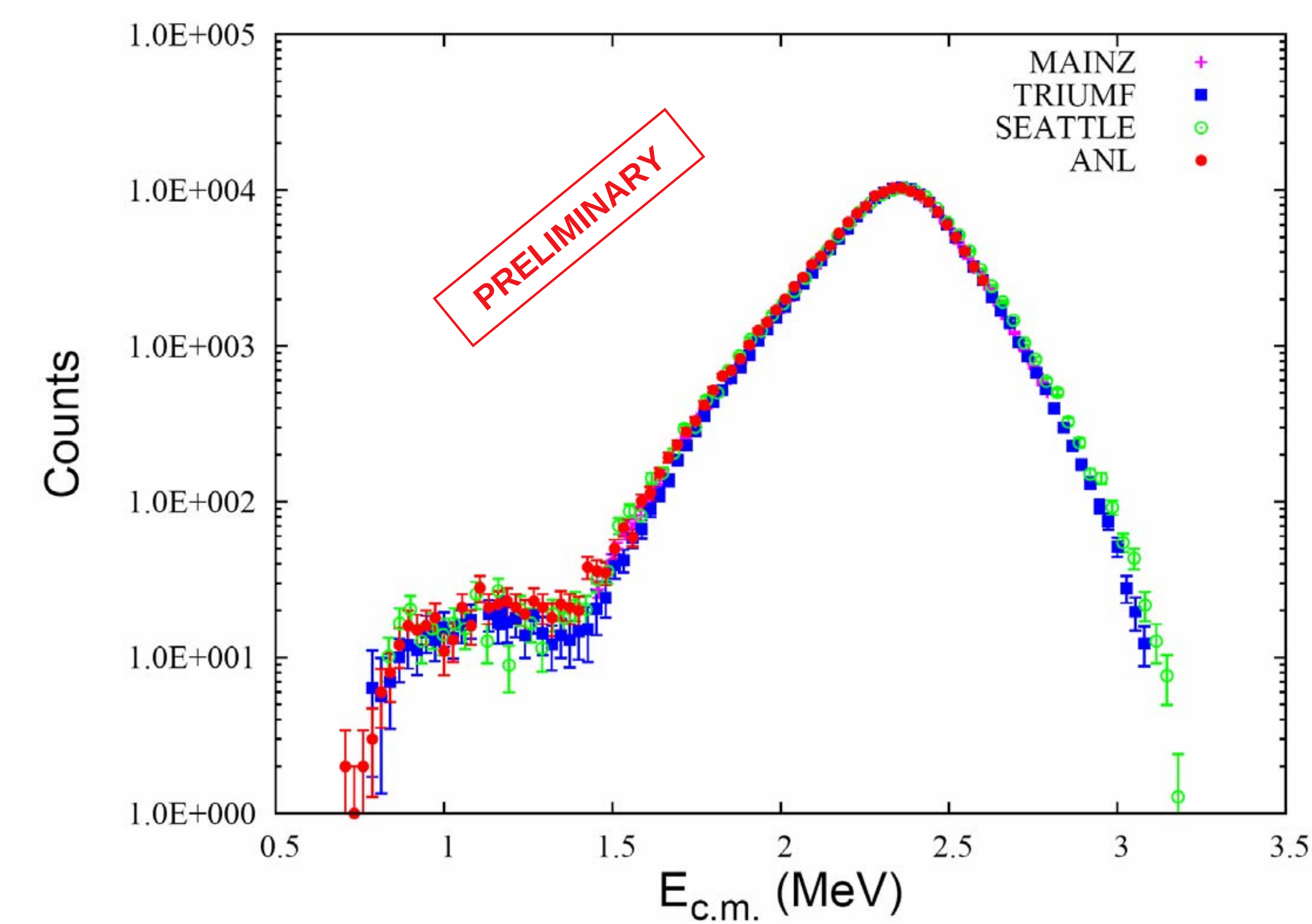
New Approach: Gas Counters

- Choose the thickness exactly as needed.
- Minimizes β sensitivity.
- No radiation damage
- Available with large areas
- Improved homogeneity
- No dead layers
- Smaller pulse height defects

Different technique, different systematic uncertainty

ATLAS: Recent results

(7) ^{16}N β-*delayed α decay* and the S(E1) factor for the ^{12}C(α,γ) reaction

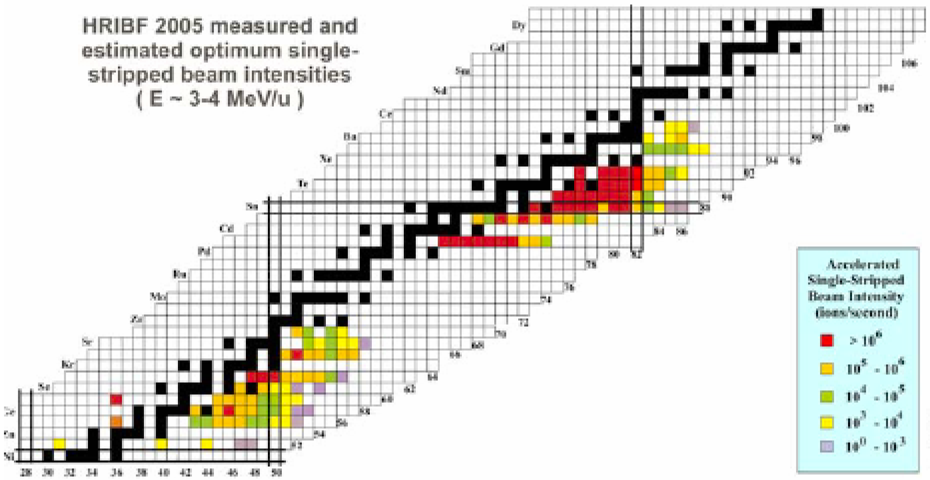


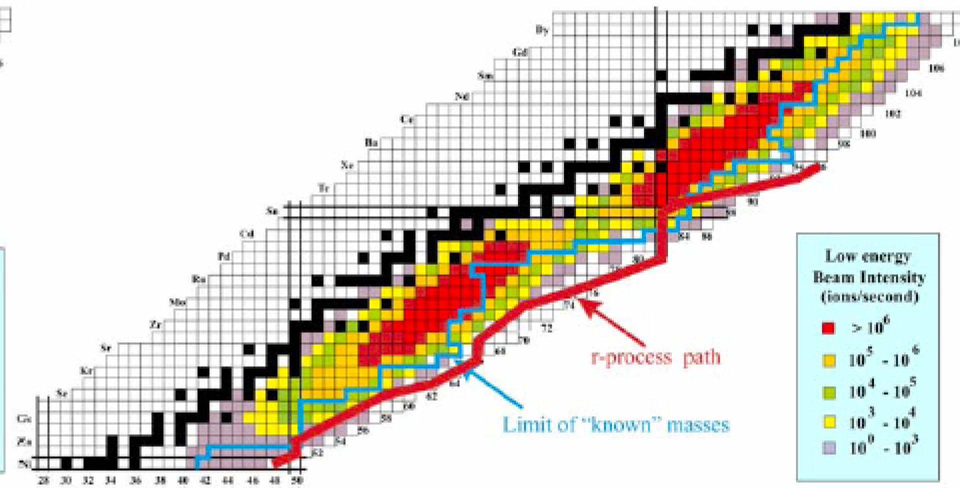
X. Tang et al., to be published

ATLAS Upgrades: Californium Rare Ion Beam Upgrade – CARIBU- and ATLAS Energy Upgrade

- Significant Upgrade to the technical capabilities of ATLAS to provide hundreds of neutron-rich reaccelerated rare isotope beams at energies well over the Coulomb barrier from a 1 Ci Californium source.
- Many of these beam species and energies will be uniquely available at ATLAS until RIA is built.
- Energy Upgrade is fully funded AIP project – $1.9M
- CARIBU is $3.4M AIP project to be completed in early in FY09
- Directed at DOE Nuclear Physics Performance Measures
  - "Measure changes in shell structure and collective modes as a function of neutron and proton number ... to moderately neutron-rich nuclei"
  - "Extend spectroscopic information in regions of critically doubly magic nuclei"
  - "Measure masses, lifetimes spectroscopic strengths and decay properties of selected neutron-rich nuclei in the supernova r-process."
- Capitalizes on unique ANL technical developments for RIA
  - Gas Stopping Technology
  - Charge Breeding
  - Superconducting Cavity and Cryostat Design
  - Weak beam diagnostics.
- Integrated into strategic plan developed with the user community for the near-term future of ATLAS
- Complements capabilities of other North American user facilities: HRIBF, NSCL and ISAC

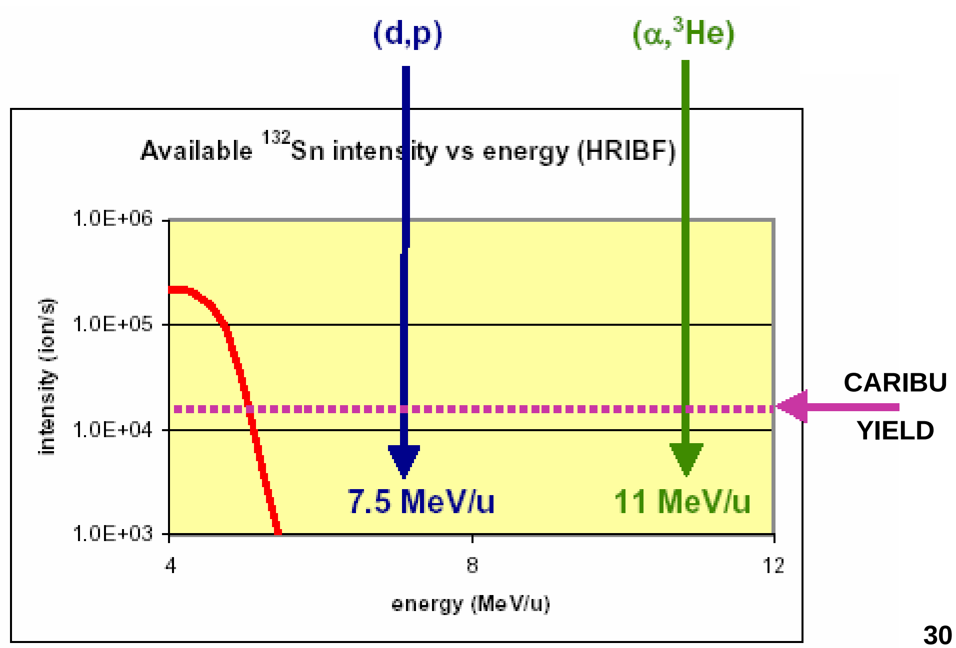
HRIBF yields from ^{238}U | ^{252}Cf spontaneous CARIBU yields





Energy Upgrade

	Current ATLAS		ATLAS Upgrade	
A	No Strip	Strip	No Strip	Strip
16	13.0	15.7	18.5	21.5
40	12.4	13.4	17.5	19.9
58	9.9	11.8	13.5	17.9
78	9.5	11.2	12.8	16.7
132	8.0	9.3	10.4	13.4
197	6.6	7.9	8.4	10.9
238	6.4	7.4	7.9	10.0

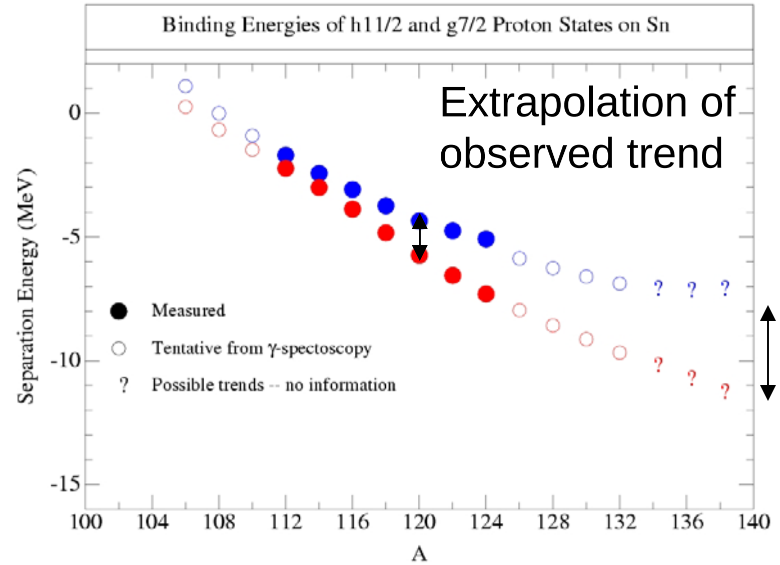


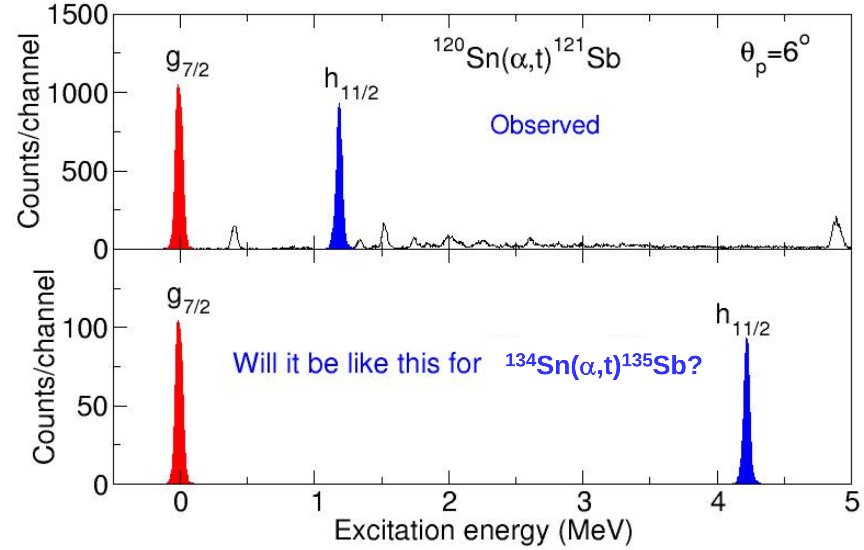
Change in shell structure?

QUESTION:
Are there major new shell gaps developing in the neutron-rich region, that could have major implications for structure and nucleosynthesis?

METHOD:
Proton-adding reactions on Sn isotopes studied with a new solenoid spectrometer

EXAMPLE:
$^{134}Sn(\alpha,t)^{135}Sb$
^{4}He target ~ 50μg/cm^{2}
10^{4} particles/s
12 MeV/u beam
5 mb/sr over at least 1 sr:
~300 cts/wk for each state



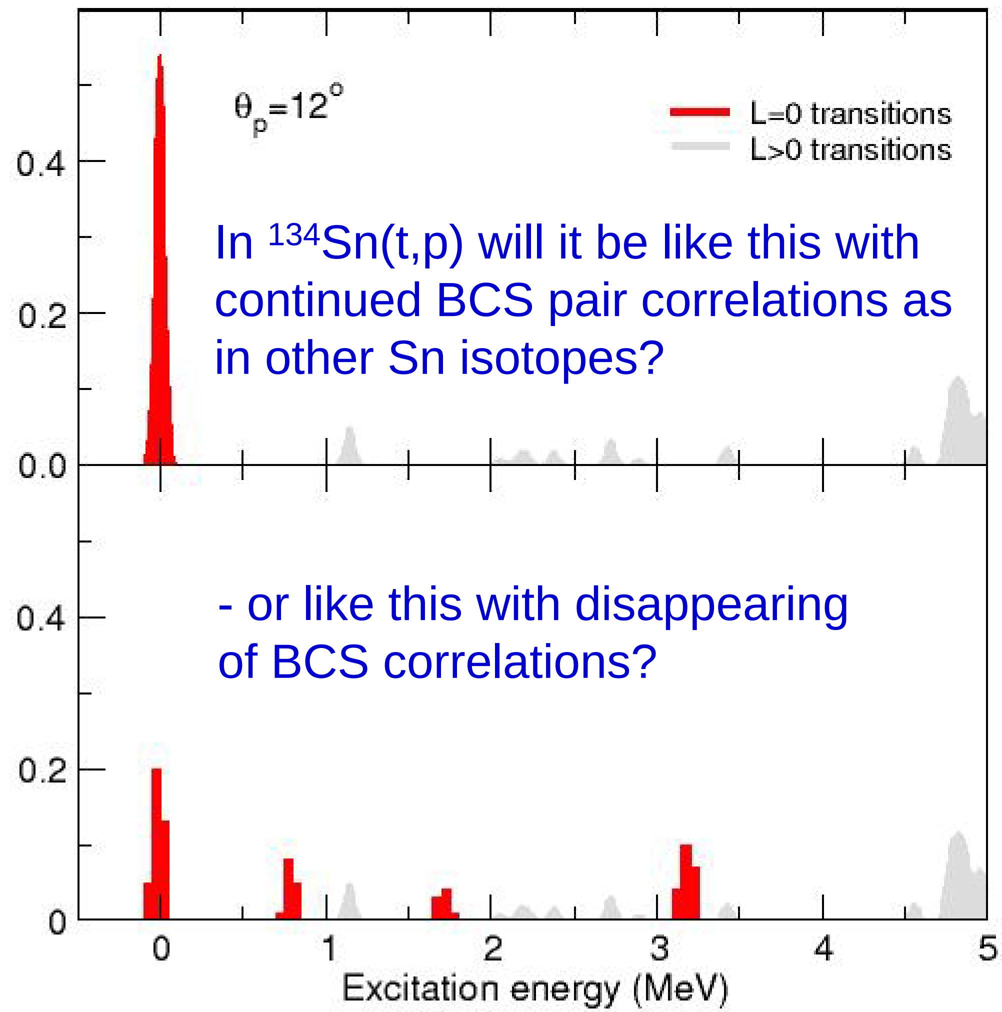


Breakdown of BCS pairing?

QUESTION:
Does BCS pairing that concentrates the L=0 strength in the ground state break down in neutron-rich nuclei?

METHOD:
Neutron-pair transfer on Sn isotopes studied with a new solenoid spectrometer

EXAMPLE:
$^{134}Sn(t,p)^{136}Sn$
Tritium target ~ 50μg/cm^2
10^4 particles/s
0.5 mb/sr over at least 1 sr:
~30 cts/wk for each state



Coulomb excitation

(with low intensity beams)

Take existing data set from beam Coulex of ^{138}Ce on 700 μg/cm^2 ^{12}C with Gammasphere.

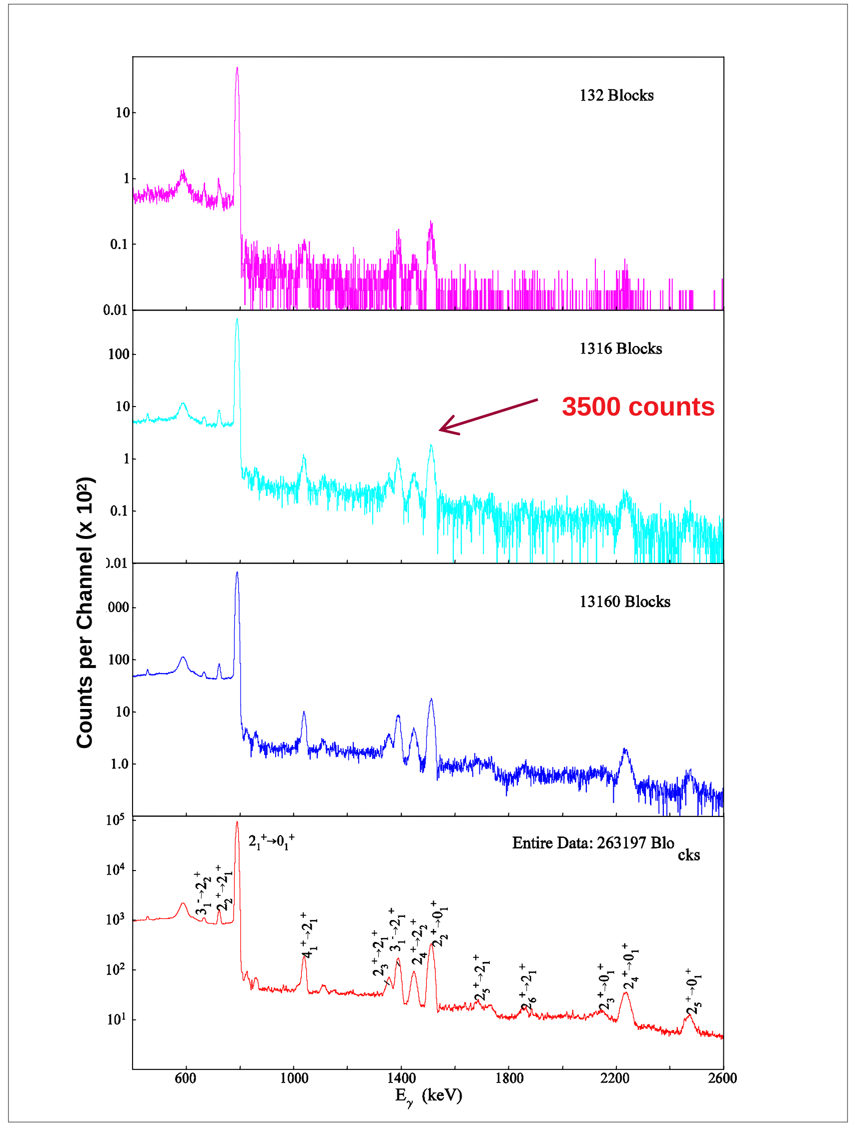
Rescale 1pna for 14hrs to various scenarios:

10^5 p.p.s for 5 days

10^4 p.ps for 5 days

10^3 p.p.s for 5 days

Even at 100 particles per second spectroscopy is possible at least for first excited state.



10^3

10^4

10^5

1pna

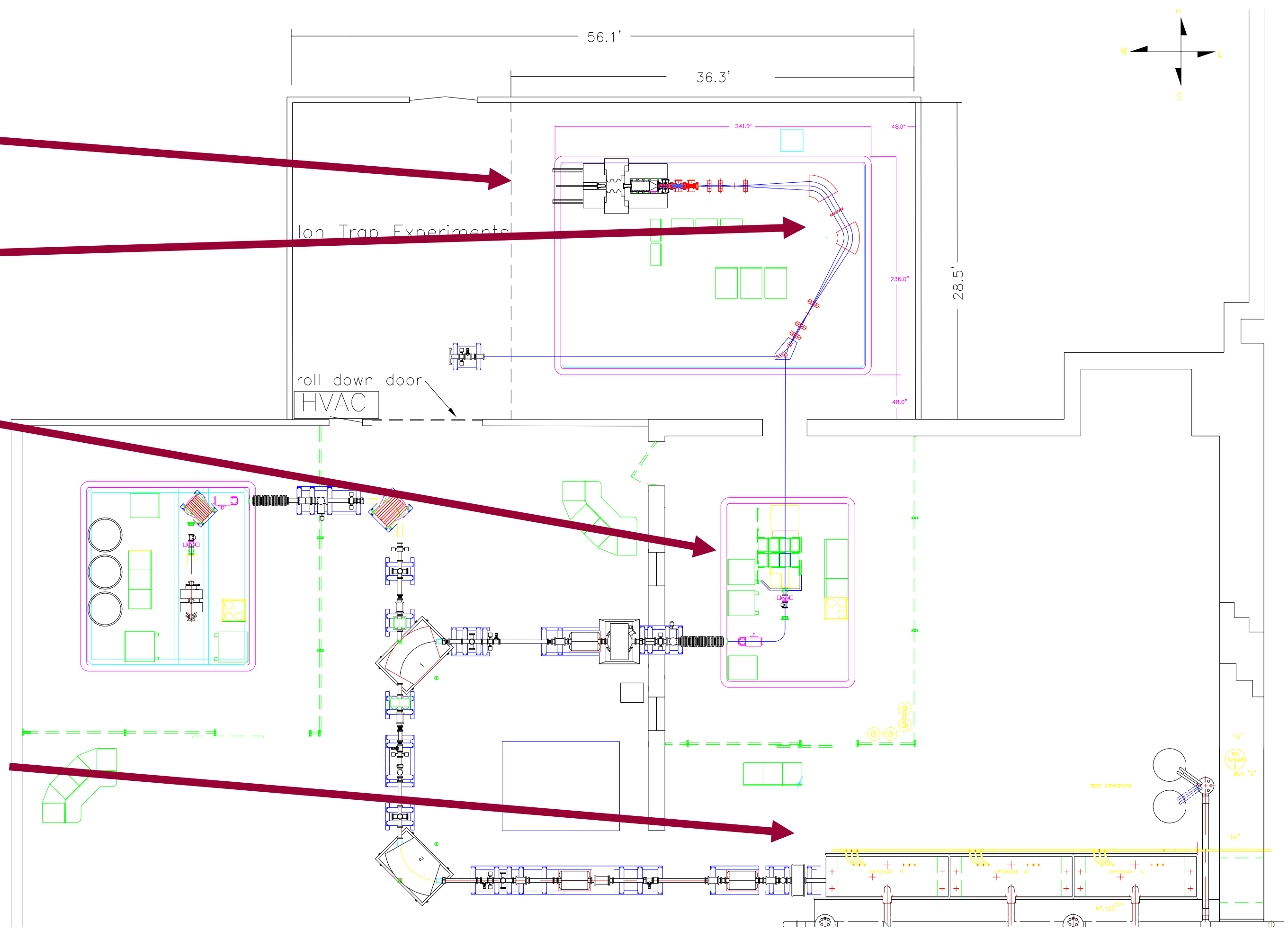
CARIBU: Integrating Concepts & Gaining Experience for RIA

Gas Catcher

High Resolution Isotope Separaror

Charge Breeding in ECR Source

Post-acceleration of weak beams



RIA R&D high priority topics: selected for potential to reduce risk & improve cost/performance

- Driver linac
  - Two-charge-state injector (demonstrate concept)
  - Multi-charge-state end-to-end beam dynamics (errors, halo and failure modes)
  - Superconducting resonator prototyping (triple-spoke resonators)
  - Low level RF controls and fast tuning
  - High power stripper concepts (thin liquid lithium & titanium foil)
  - Diagnostics for efficient tuning optimization (centroid, size, & phase)
- Production area
  - High power beam dumps (liquid tin)
  - Fragment separator area configuration (high acceptance optics)
  - High power ISOL target concepts (2-step target demonstration)
  - Target area concepts and remote handling (with ORNL, MSU, LLNL, ANL)
  - Gas catcher R&D (concepts for intensity increase)
- Secondary beam linac
  - Low q/m, high efficiency injector (RFQ concepts & helium stripper)

Conclusions:

ATLAS is an active facility producing exciting science. The superconducting linac at its core is an incredibly powerful and efficient device. We pioneered this technology for ion acceleration and have more experience with it than anyone else in the world.

The science carried out by the ATLAS Users increasingly requires the use of exotic beams.

CARIBU is a new capability that builds on RIA R&D developments and provides unique exotic beams suitable for pioneering experiments prior to RIA.

CARIBU enables a program with re-accelerated beams up to 10-15 MeV/u.

Major progress is being made to prepare for the next generation of rare isotope beam facility. Access to the type of stopped and precision re-accelerated beams for rare isotopes that ATLAS now provides for stable beams is essential for structure and astrophysics research.

New opportunity: ^{252}Cf source (1Ci) + large gas catcher as neutron-rich isotope source

- Shortened version of RIA gas catcher can efficiently stop fission products from a fission source
  - **~ 50% stopped in gas for backed source**
- About 45% of those can be extracted as charged ions
- Very efficient and fast source, provides cooled bunched beams for post-acceleration
- Production peaks in new regions and extraction is element independent … new isotopes available

Gas catcher technology developed, tested and now routinely used at ATLAS for CPT and RIA programs