Expanding RIB Capabilities at the Cyclotron Institute: ^{3}He-LIG production with an Isobar Separator LSTAR

D. Melconian[1,2], G.P.A. Berg[3], P. D. Shidling[1], M. Couder[3], M. Brodeur[3], G. Chubarian[1], V. Kolhinen[1] and G. Tabacaru[1]

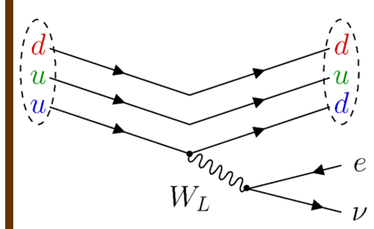
[1]*Cyclotron Institute* / [2]*Dept. of Physics & Astronomy, Texas A&M University, College Station, TX USA 77843-3366*
[3]*Department of Physics & Astronomy, University of Notre Dame, Notre Dame, IN USA 46556*

The Need: TAMUTRAP, the Penning-trap system at the Cyclotron Institute (Texas A&M University), has been built and commissioned using offline ion sources. Before TAMUTRAP's program of studying T=2 β-delayed proton decays to test the standard model can proceed, a radioactive ion beam (RIB) of short-live proton-rich species is needed.

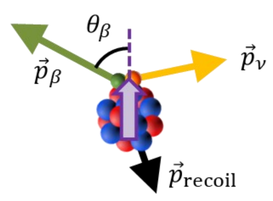
The Goal: To build an isotope separator to purify the proton-rich RIBs produced using a new ^{3}He-based light-ion guide (LIG) system using the K150 cyclotron, and efficiently transport the RIB to the TAMUTRAP facility. Long-term plans include adding an EBIT for charge-breeding and reacceleration through the K500 and creating a general-purpose end station pre- or post-trap.

Summary of current status: The ^{3}He-LIG system has been shown to produce RIBs of interest, though further development is required to reach the ≈3-5% efficiency needed. The design of LSTAR shown here will efficiently and effectively separate mass differences of $\Delta M/M \geq 1/3000$. Construction of the separator should begin at the start of 2023.

TAMUTRAP physics program

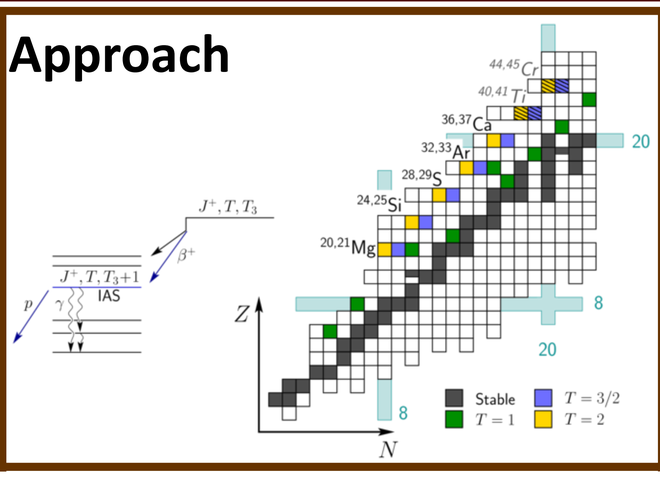


Right-handed W_R?
Leptoquarks? …?



Angular correlations of β decay are sensitive to BSM physics

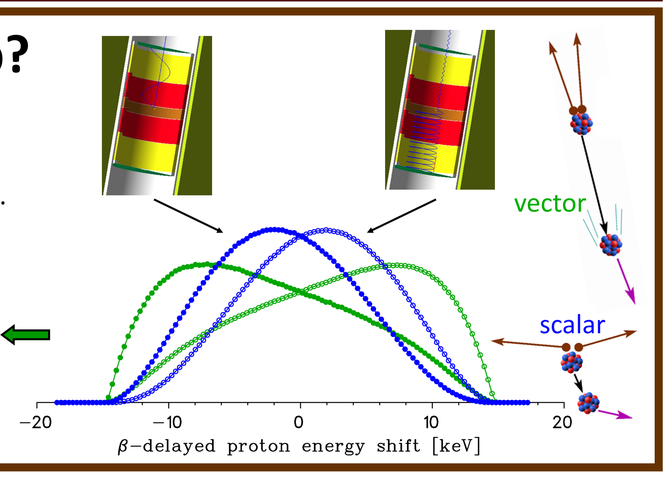
Approach



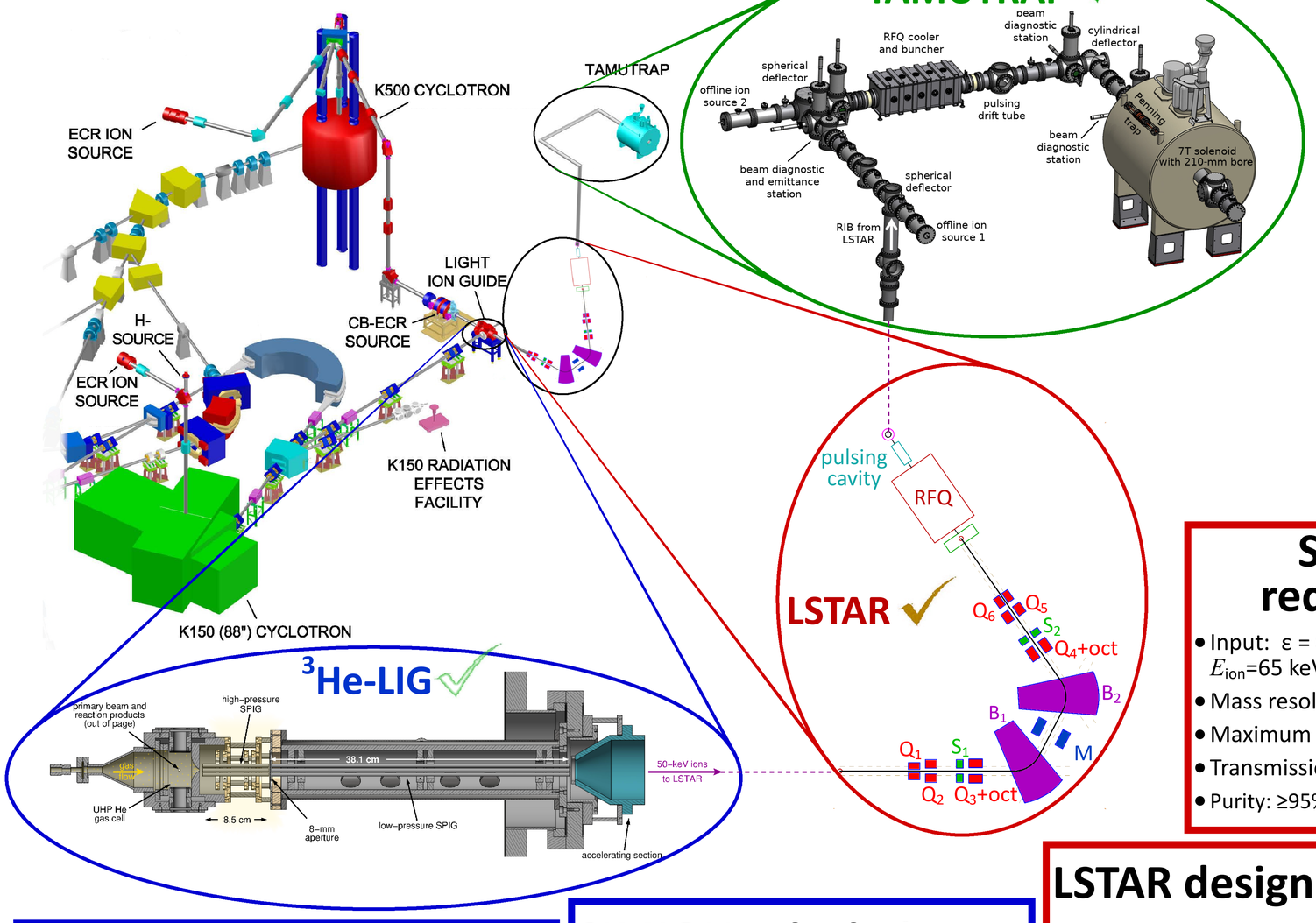
Why a Penning trap?

- The difference in means of same vs opposite would change in the presence of new physics, e.g. scalar currents. The precision needed is ≤0.1%.

→ Traps provide a **cold**, **clean**, **localized** source of **short-lived** ions with **4π collection** of the p and β^+ ←

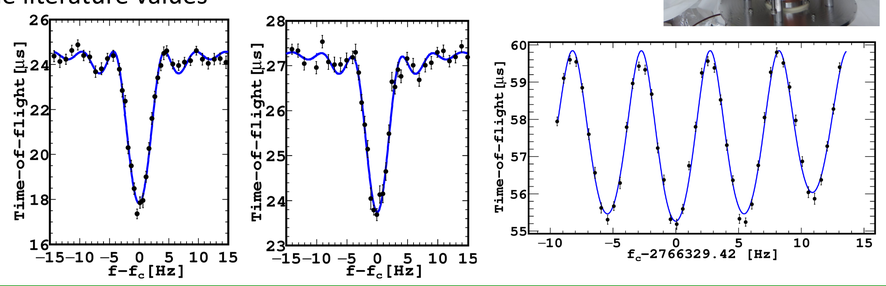


K500 → ^{3}He-LIG → LSTAR → TAMUTRAP



Unique 180-mm Penning trap commissioned

- Optimized TAMUTRAP beamline, RFQ and loading of the Penning trap using offline ions (^{23}Na, ^{85,87}Rb and ^{133}Cs)
- Demonstrated our novel design performs as well as typical cylindrical Penning traps via TOF-ICR and the Ramsey method
- Result: better than 0.1 ppm precision in agreement with the literature values

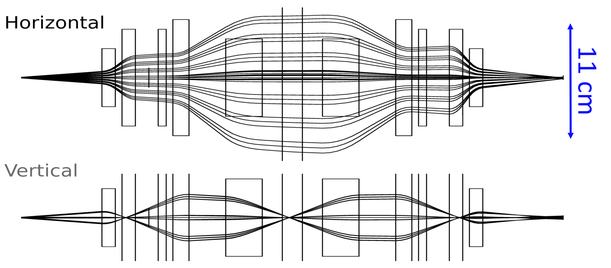


Separator requirements

- Input: ε = 0.7π mm mrad, $E_{\rm ion}$=65 keV, ΔE=±3.3 eV
- Mass resolution: ≥3,000
- Maximum mass: 50
- Transmission: >80%
- Purity: ≥95%

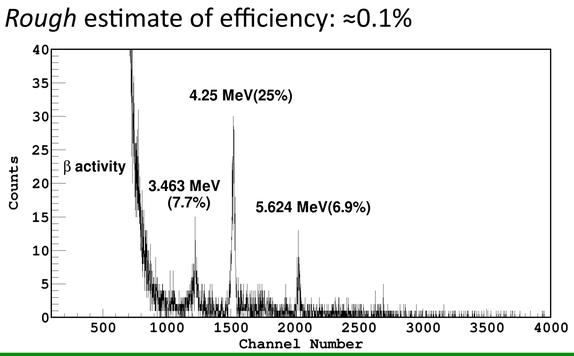
COSY INFINITY design

- Inspired by the 2×60° design of CARIBU at ANL
- Two 62½° dipole magnets ⇒ total bend of **125°**
- Electrostatic elements: 4 quadrupoles, 2 combined quadrupoles & octupoles, 2 hexapoles, and one 5$^{\rm th}$-order multipole
- Optimized up to 3$^{\rm rd}$ order



^{25}Si production test

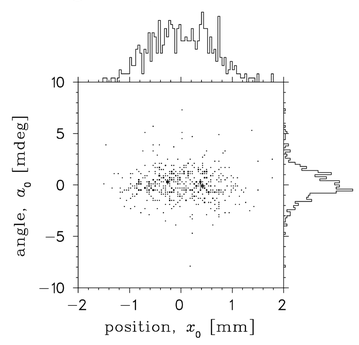
- Prototype gas-cell tested with $^{24(nat)}$Mg(^{3}He,3n)^{25}Si reaction (10 MeV/u ^{3}He, 2.75 pμA)
- Extracted with a SPIG, accelerated to 10 kV and implanted on a foil; a silicon detector observed β and p activity
- *Rough* estimate of efficiency: ≈0.1%



^{3}He-LIG gas cell working, but development over the next year is needed for higher efficiency

SIMION calculation of emittance

- With Einzel/steerers, can minimize either spatial or angular spreads

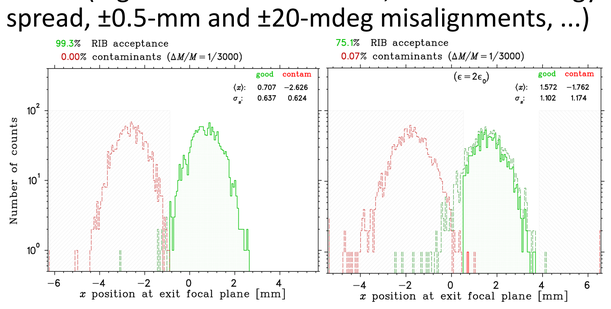


- Combined 0.65π mm mrad overall emittance is constant

This work is supported by the U.S. Department of Energy under Grant No. DEFG02-93ER40773 and by the State of Texas

LSTAR design study

- SIMION simulation of ^{3}He-LIG fed into COSY calculation of LSTAR, including simulated energy spreads and misalignments
- Benchmark toughest case: separation of mass differences ≥ 1 part in 3000 has >95% efficiency
- >75% acceptance, even if systematics are underestimated (e.g. 2x SimION emittance, 50% more energy spread, ±0.5-mm and ±20-mdeg misalignments, …)



- To do: investigate possible molecular contaminants, and optimize up to 7$^{\rm th}$ order

The current design exceeds specifications. Ready to proceed with production!

Looking forward

- Finalize technical specifications and submit bid requests for LSTAR
- Install a new dual-purpose chamber for both the ^{3}He- and p-LIG efforts
- Upgrade the current gas cell, and measure emittance from the ^{3}He-LIG system
- Prepare installation site for LSTAR: Remove shielding walls; upgrade HV isolation to 75 kV; drill holes for beamline through rough planks; ….
- Move RFQ to the focal plane of LSTAR, design pulsing cavities and electrostatic bends to transport cooled and bunched RIB for loading in TAMUTRAP
- Install, align and commission LSTAR in 2025