



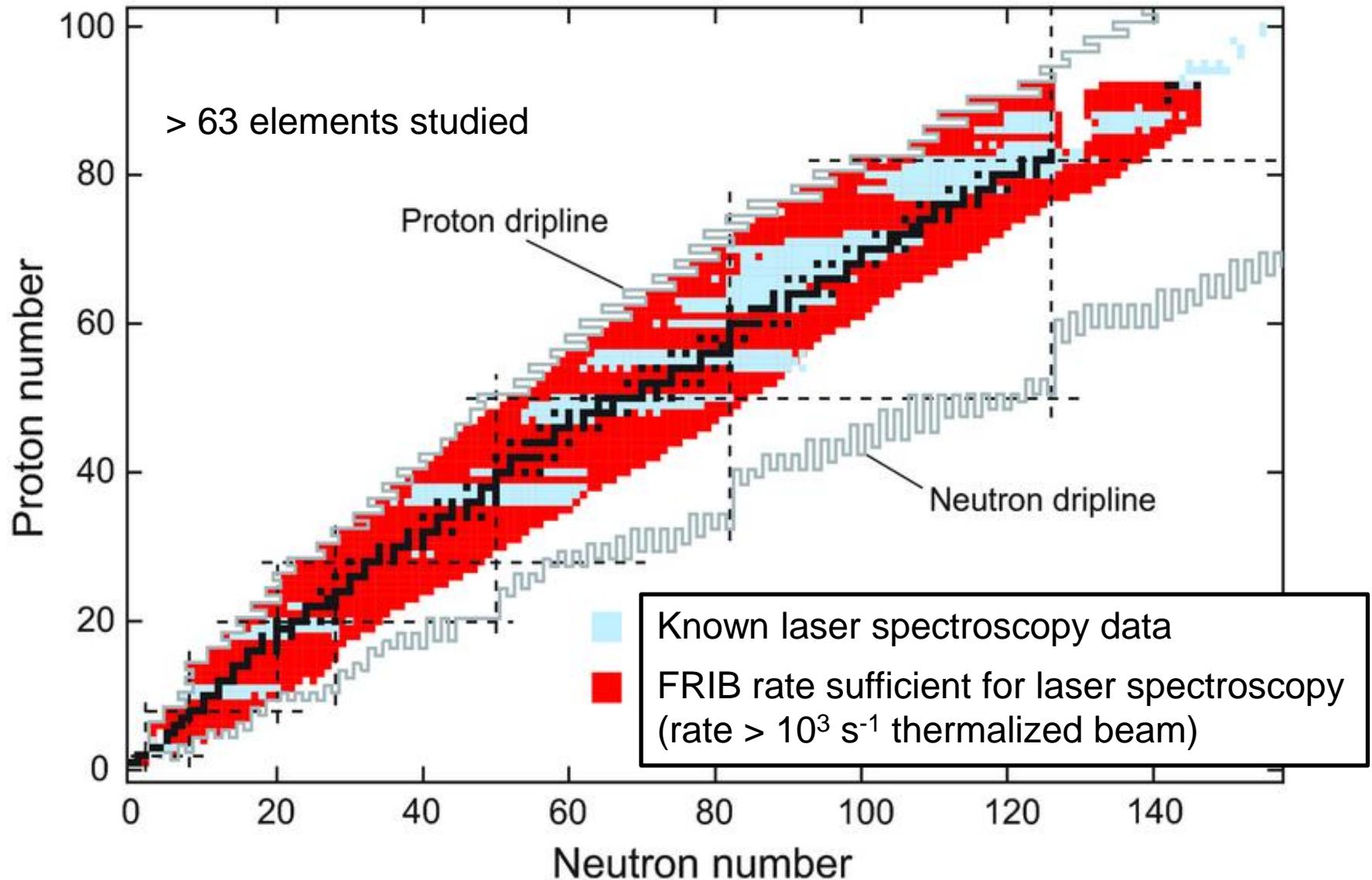
# Opportunities for the Laser Probing of Thermalized Beams of Rare Isotopes Produced via Projectile Fragmentation

Paul Mantica

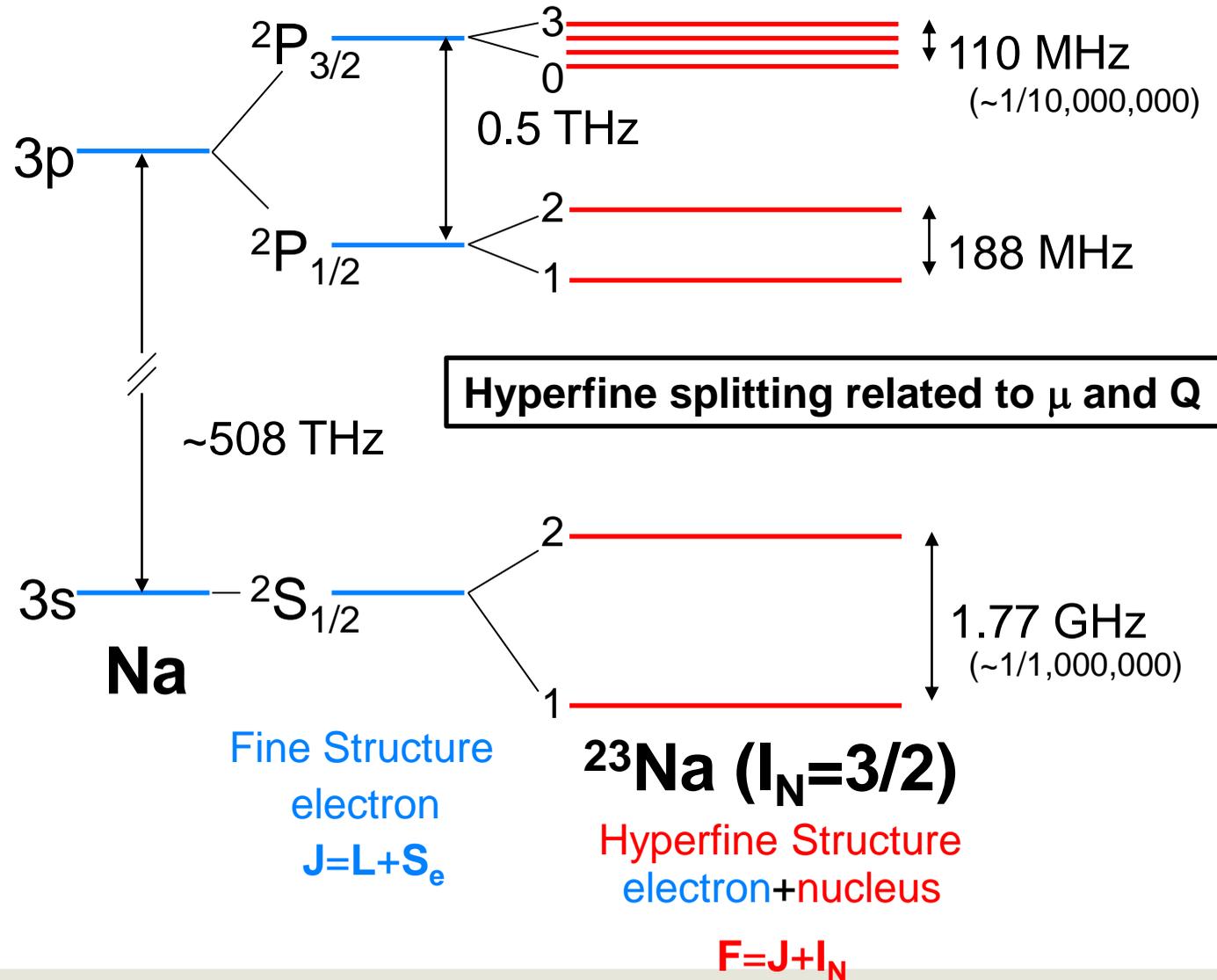
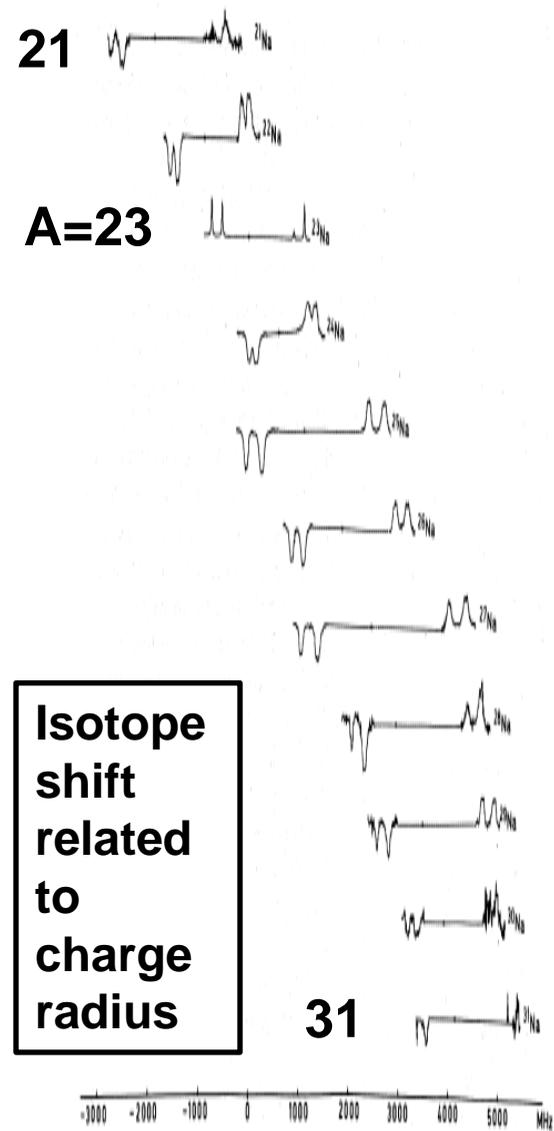


MICHIGAN STATE  
UNIVERSITY

# Elements Studied by Laser Spectroscopy



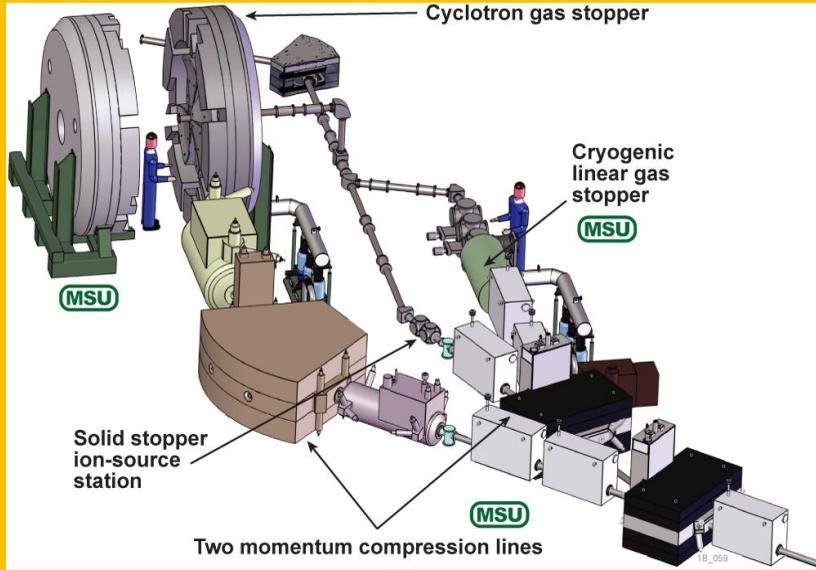
# Laser Spectroscopy as a Probe of Atomic Hyperfine Structure



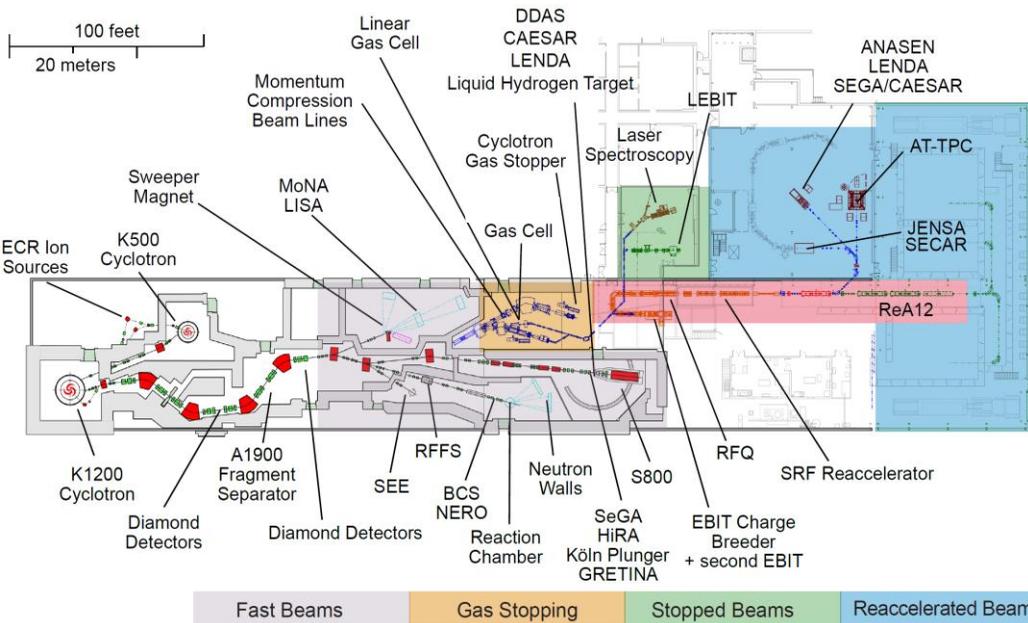
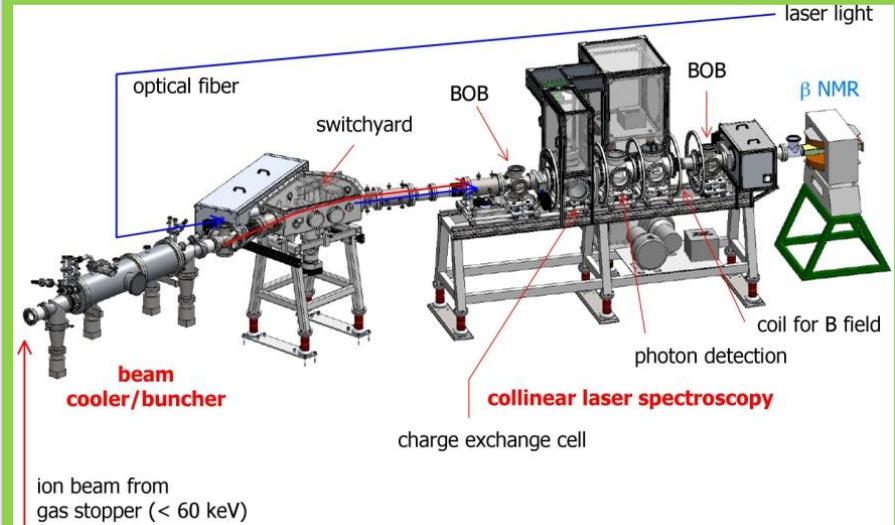
$$F = J + I_N, J + I_N - 1, \dots, |J - I_N|$$

# Low-Energy Beam Area LEBIT and BECOLA

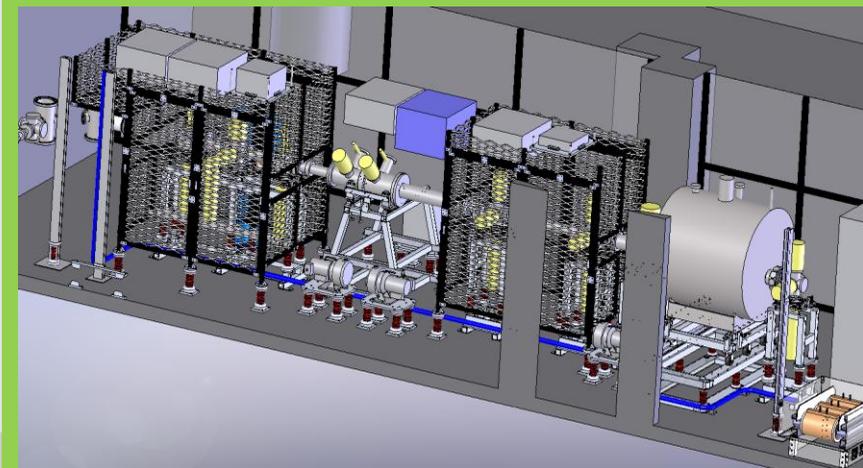
## Beam Thermalization in N4 vault



## BECOLA in Room 173



## LEBIT in Room 173

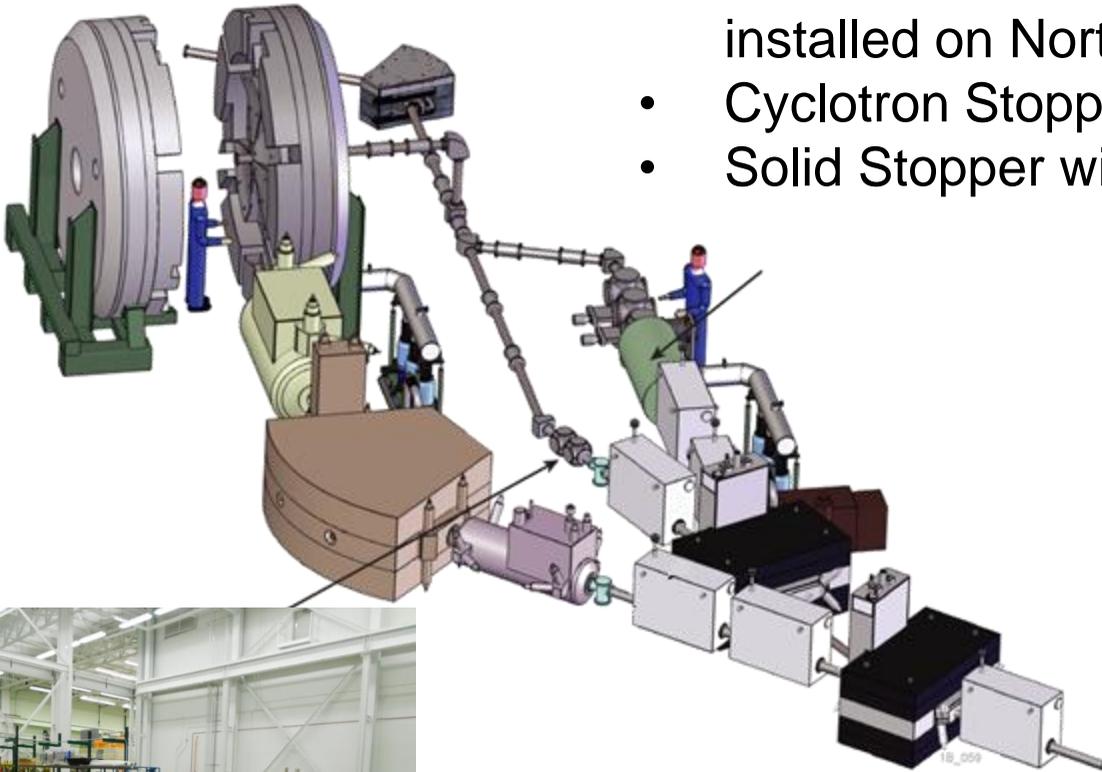


# N4 Vault Reconfiguration

## Enhanced Beam Thermalization Capabilities

Two momentum compression beam lines

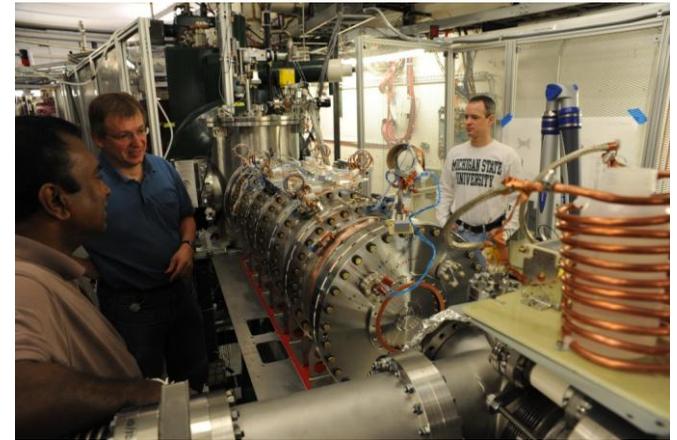
- ANL Linear Gas Cell (DOE-FRIB R&D) initially installed on North beam line
- Cyclotron Stopper (NSF-ARRA) under construction
- Solid Stopper will be a future development



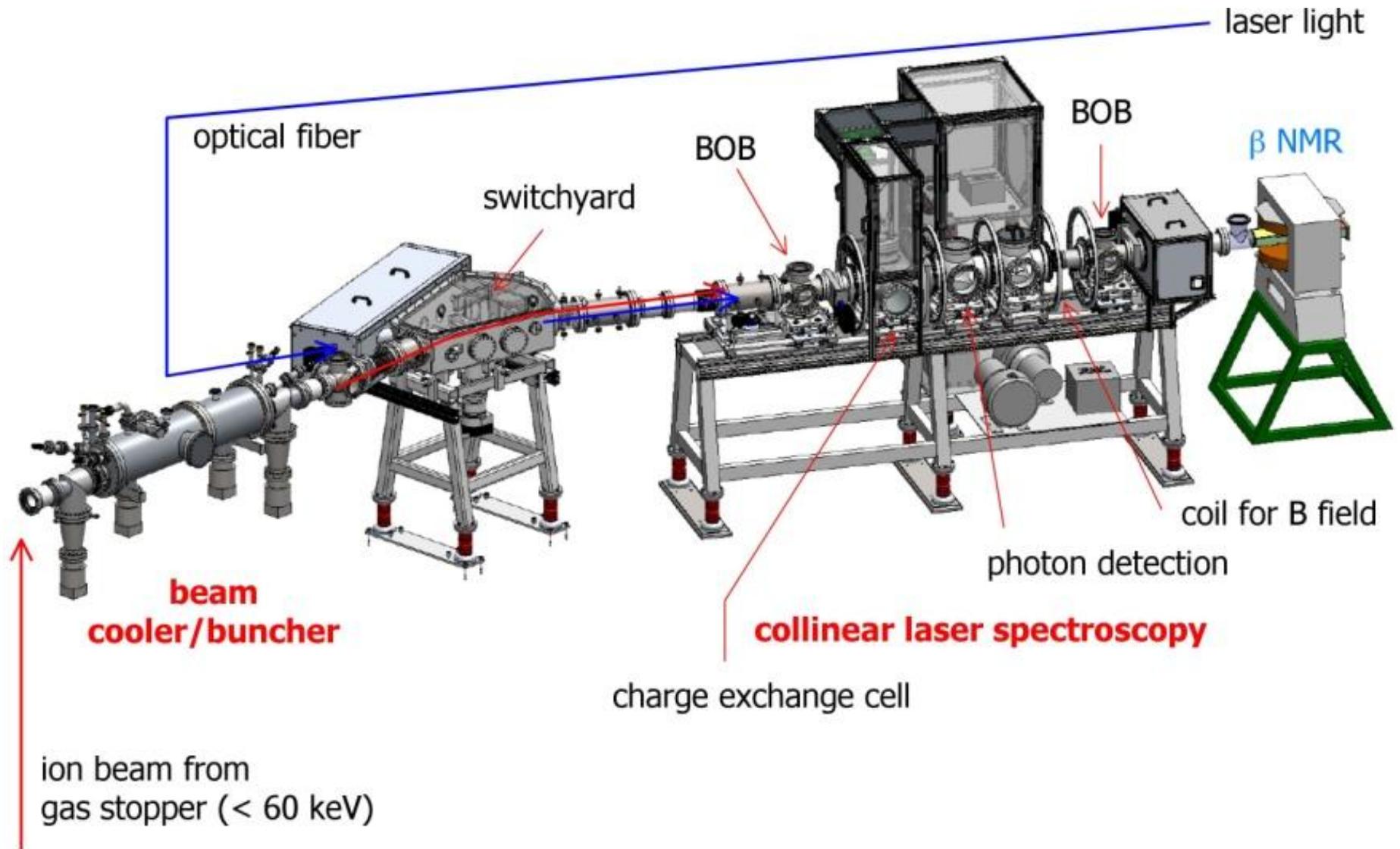
ANL Linear Gas Cell  
Delivered May 2012  
N4 Vault



Cyclotron Stopper  
Coil Winding  
ReA12 High Bay



# Beam Cooling and Laser Spectroscopy (BECOLA)



# Collinear Laser Spectroscopy with BECOLA

## Goals and Accomplishments

### • Goals

- Laser probing techniques to determine static properties of nuclear in their ground or isomeric states
  - » Nuclear spins ( $I$ ), nuclear moments ( $Q$ ,  $\mu$ ), mean square charge radii ( $\langle r^2 \rangle$ )
- Optical pumping via laser spectroscopy to produce highly polarized beams for testing fundamental symmetries
  - » Maximal parity violation in  $^{21}\text{Na}$ ,  $^{23}\text{Mg}$
  - »  $T$  violation from 5-fold coincidences following  $^{36}\text{K}$  beta decay

### • Accomplishments

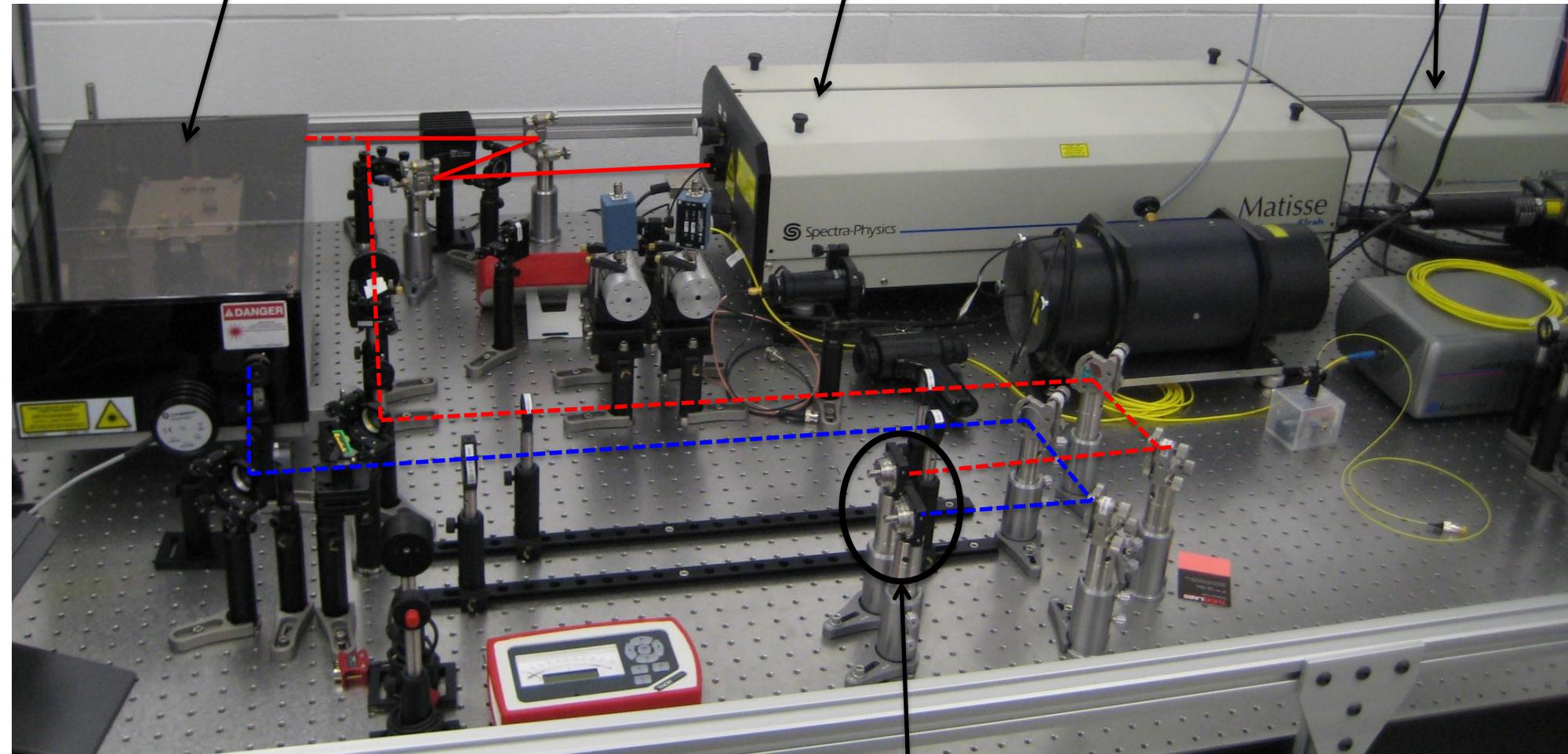
- Laser system operating since Summer 2009
- Vertical charge exchange cell commissioned in Summer 2011 at Mainz
- Collinear beam line completed in Fall 2011
- First resonance ( $4s S_{1/2} \rightarrow 4p P_{1/2}$  transition in Ca II) in Winter 2011
- Hyperfine structure of  $^{55}\text{Mn}$  (transition metal) obtained

# Solid State Laser System

Frequency Doubler  
350 - 500 nm

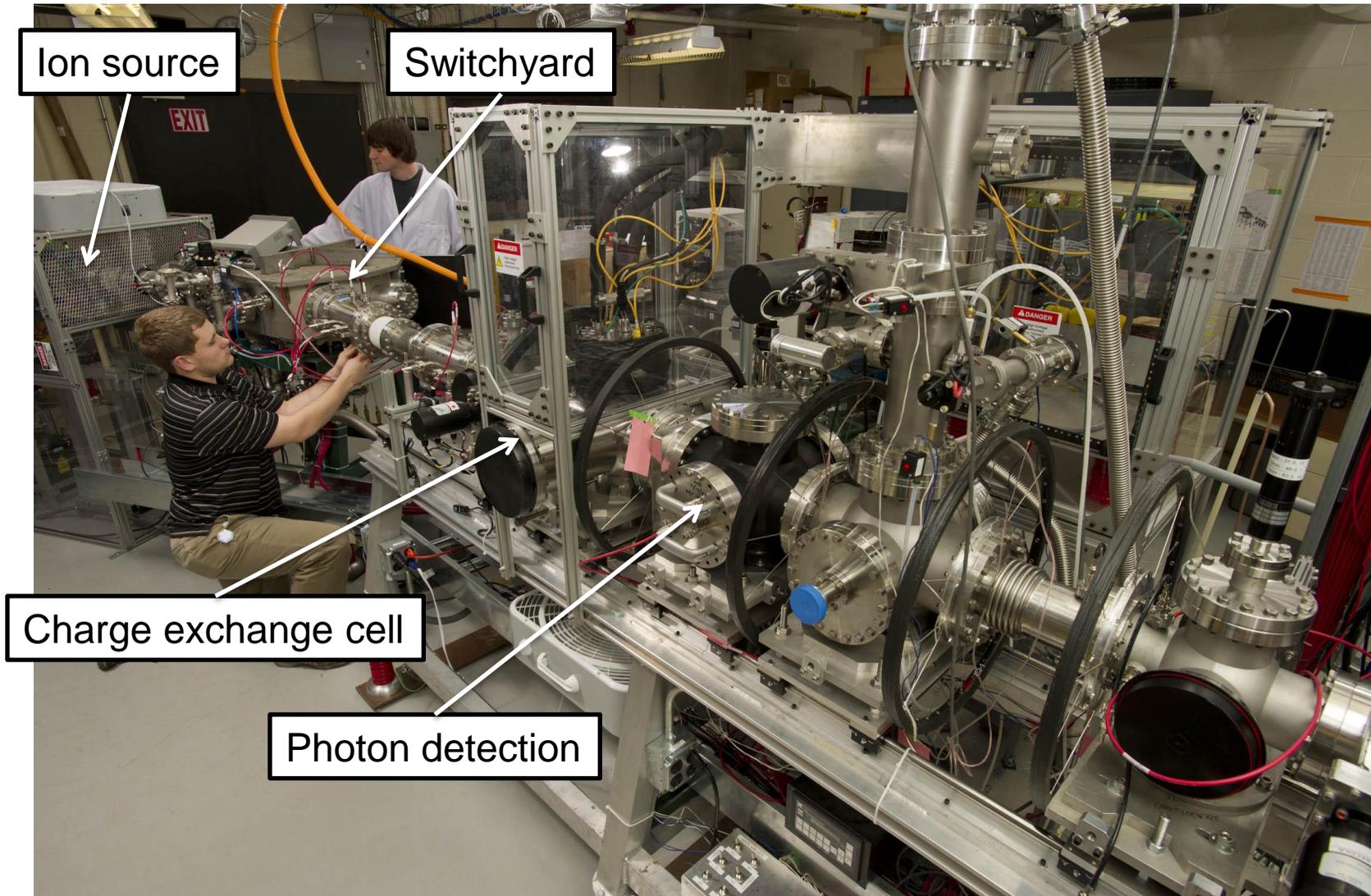
Ti:Sapphire  
700 - 1000 nm

Pump Laser  
532 nm

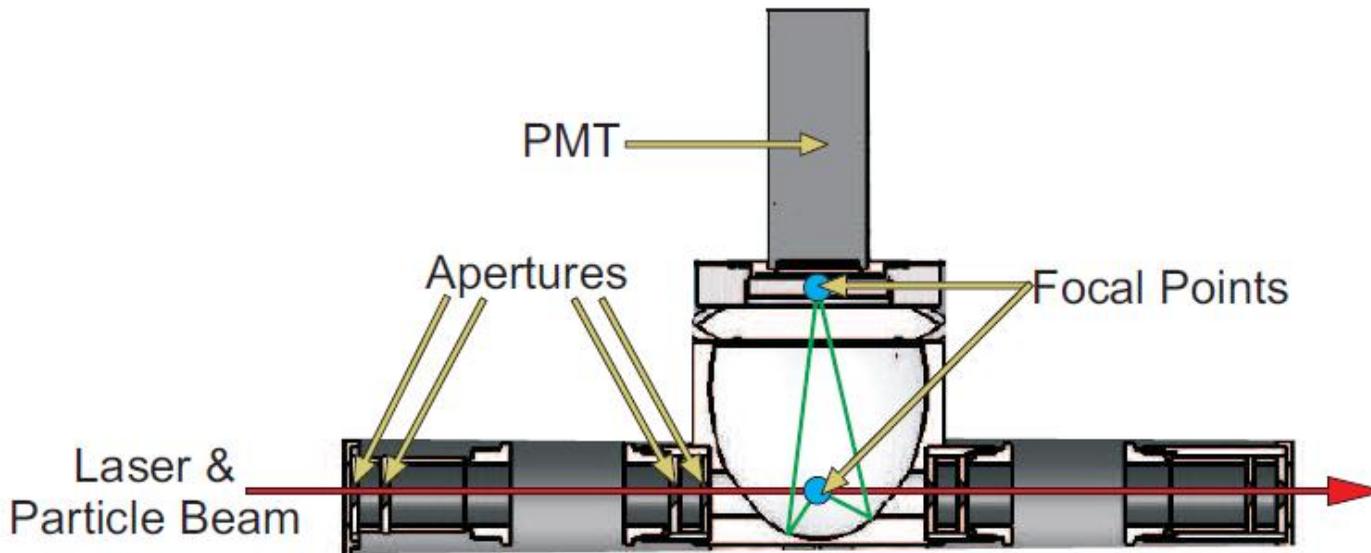


Optical Coupling

# Collinear Laser Spectroscopy Beam Line

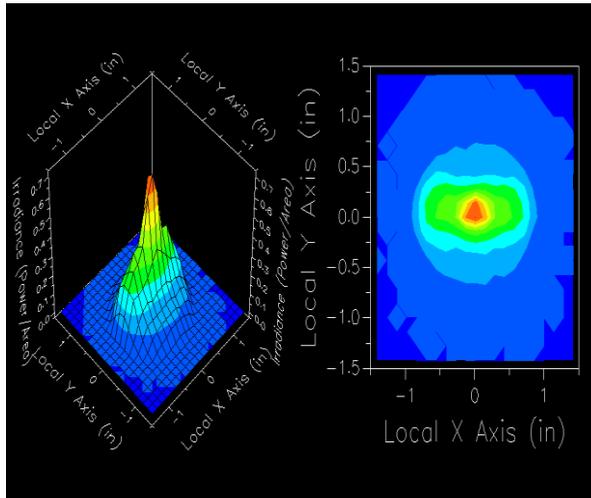


# Photon Detection System

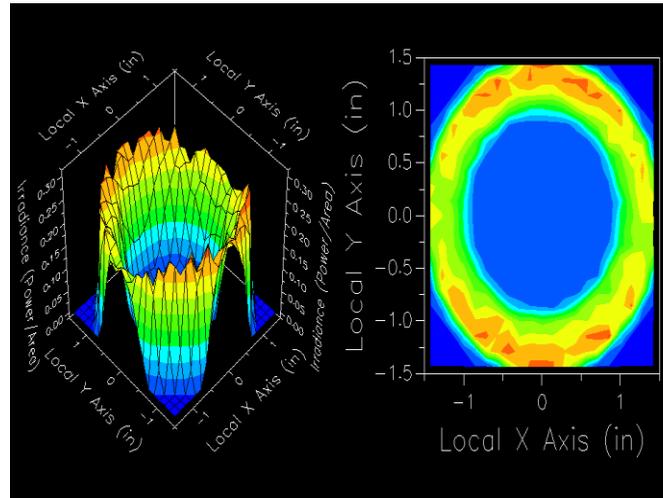


- Elliptical reflector to collect photons
- Apertures along light path to reduce scattered light
- Collimator at face of PMT to block stray light from reflector

Signal collection



Scattered light

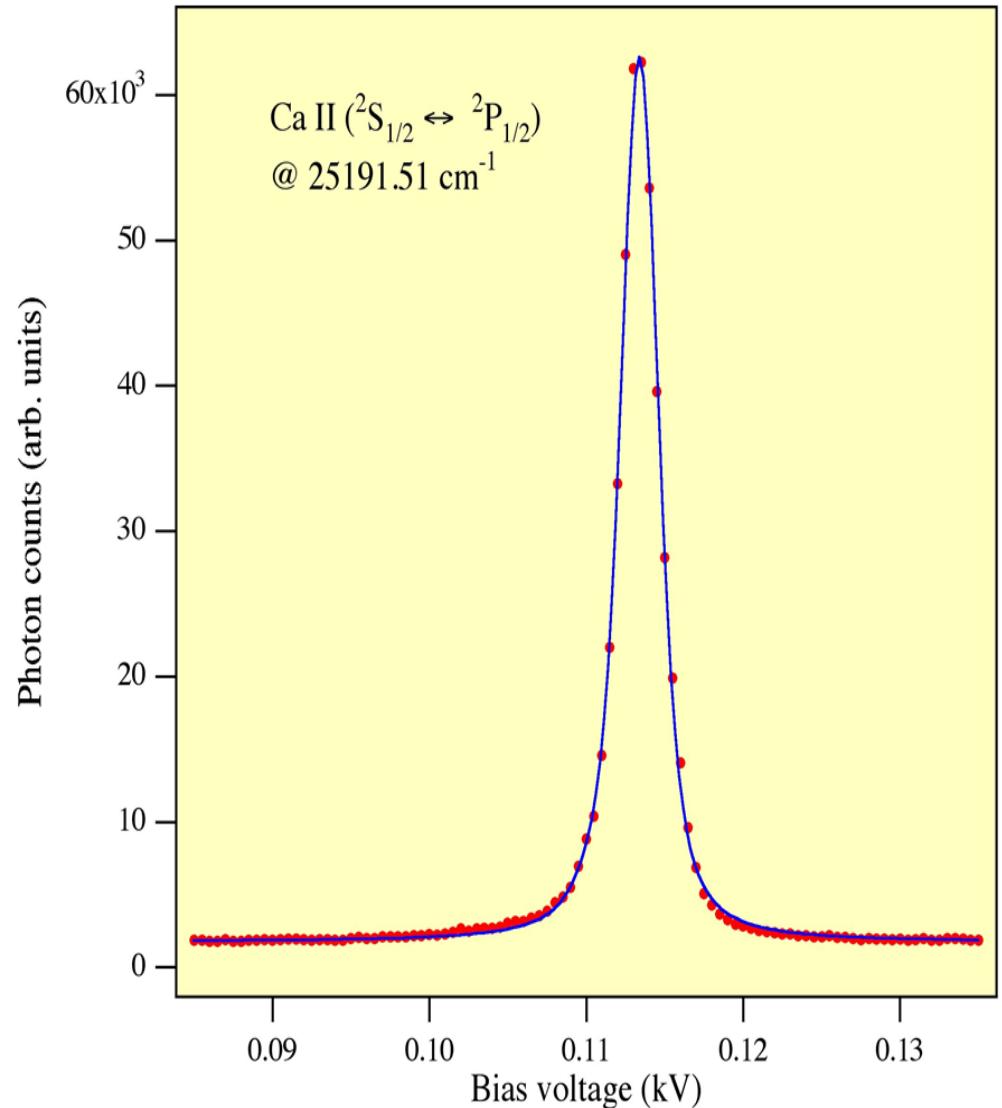
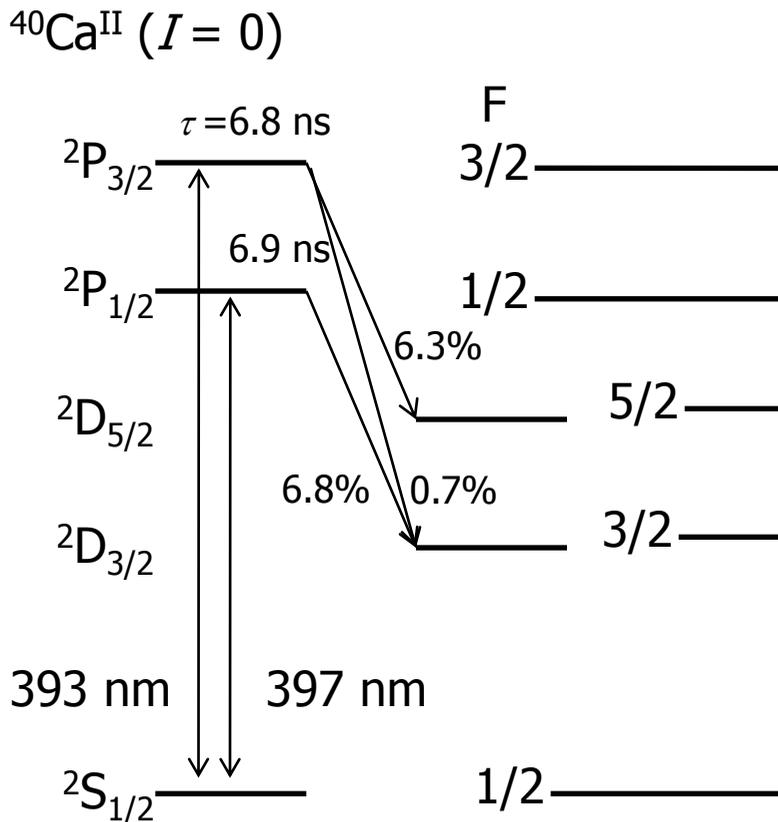


Simulations performed with FRED optical engineering software

# Off-line Commissioning Tests



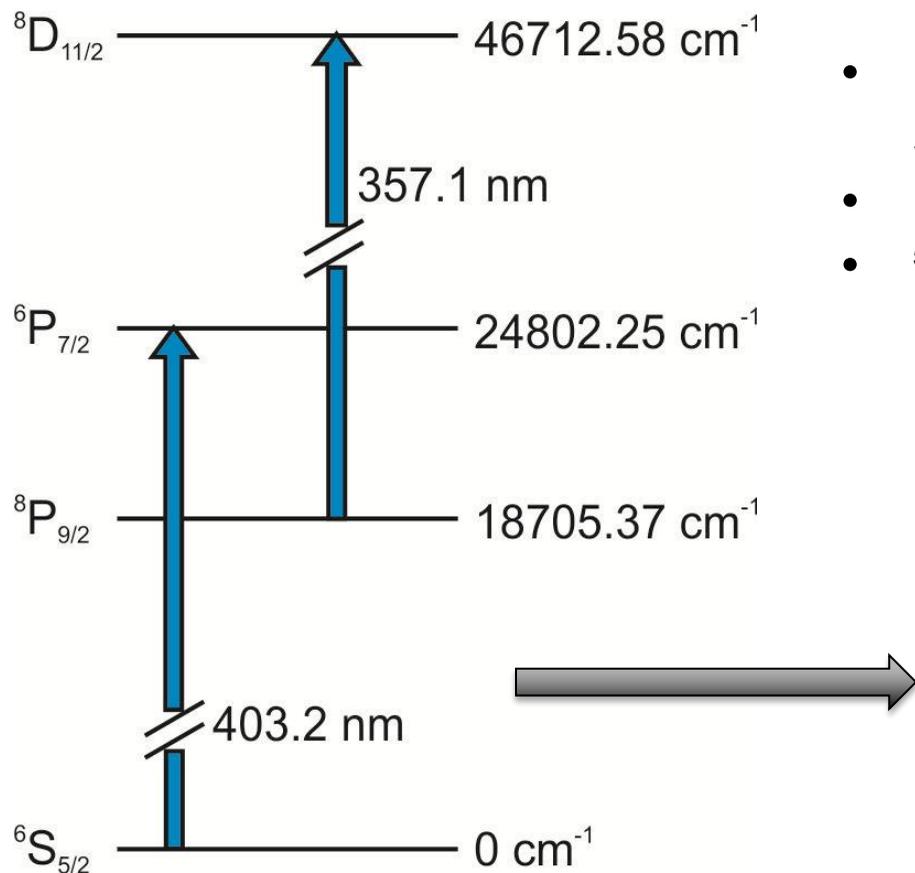
Laser spectroscopy beam line  
commissioned with off-line  
source of stable Ca ions



# Atomic Spectroscopy of Transition Metals

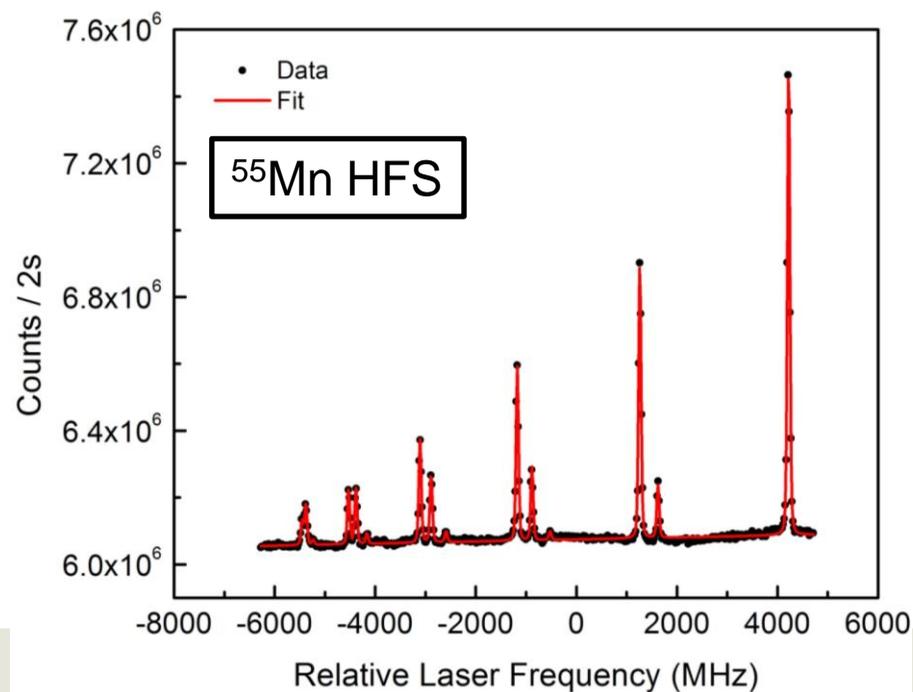
## HFS of stable $^{55}\text{Mn I}$

CLS of transition metals Ca  $\rightarrow$  Ni is a mid-term goal of the BECOLA science program



Mn I Laser-excitation schemes

- $\text{Mn}^+$  extracted from Colutron plasma ion source and neutralized in a Na vapor cell
- Ground-state HFS shown below
- $^{55}\text{Mn}$  has  $I_N=5/2$ , 15 transitions expected



# Collinear Laser Spectroscopy with BECOLA

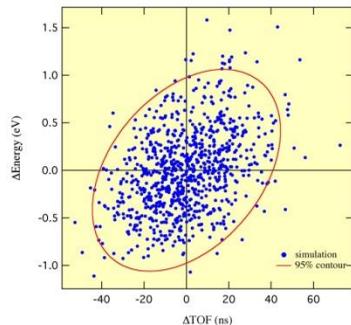
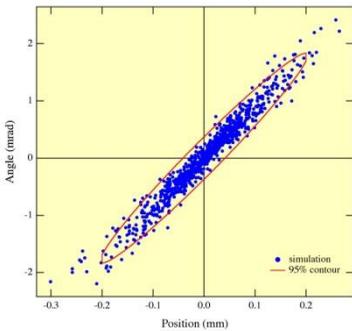
## Perspectives and Developments

- Perspectives
  - Continue studies of appropriate laser transitions for transition metals using commercial off-line ion sources
  - Install of high intensity cooler and buncher by end of CY2012
  - Upgrade photon detection system to improve fluorescence detection efficiency
  - On-line experiment to measure charge radii of radioactive  $^{35,36}\text{K}$  approved by NSCL PAC
- Equipment Development and Needs
  - Procure pump/dye laser to cover wavelength regions between 275 to 350 nm and 500 to 700 nm, complementing Ti:Sapphire system (NSF-MRI grant)
  - Implement new Penning ion source for off-line production of transition metal ions
  - Develop and implement high precision voltage divider for beam energy measurements
  - Identify funding source for procurement of frequency comb as an absolute frequency reference
  - Begin conceptual design work for new Collinear Resonance Ionization System

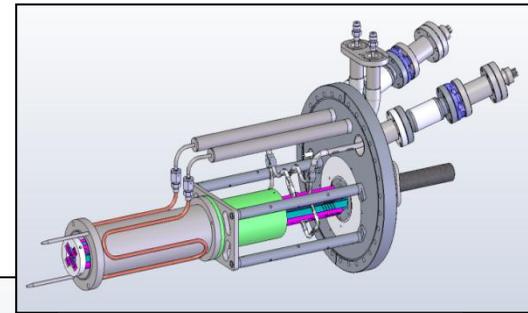
# High Intensity Cooler and Buncher

The reduced emittance and bunched beam will increase the signal to noise ratio in laser induced fluorescence measurements and allow ion rates as low as 100 Hz to be used for measurements.

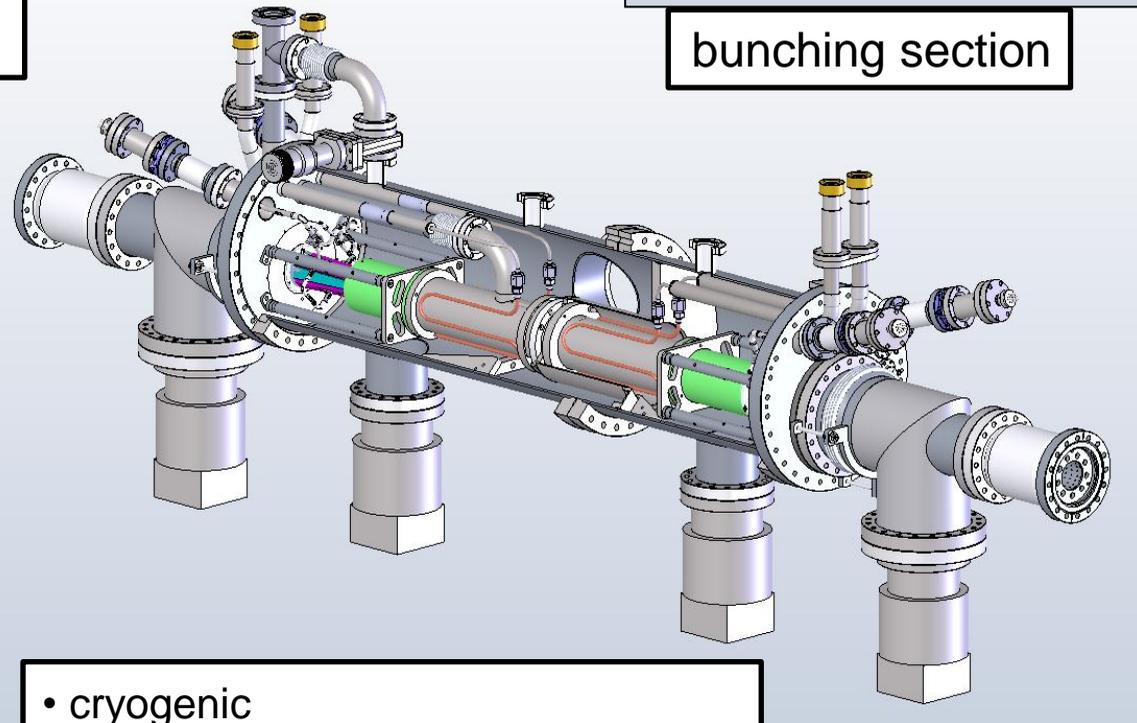
Simulations show that transverse and longitudinal emittances of  $1\pi$  mm-mrad at 60 keV and  $2$  eV- $\mu$ s achievable.



from gas  
stopping



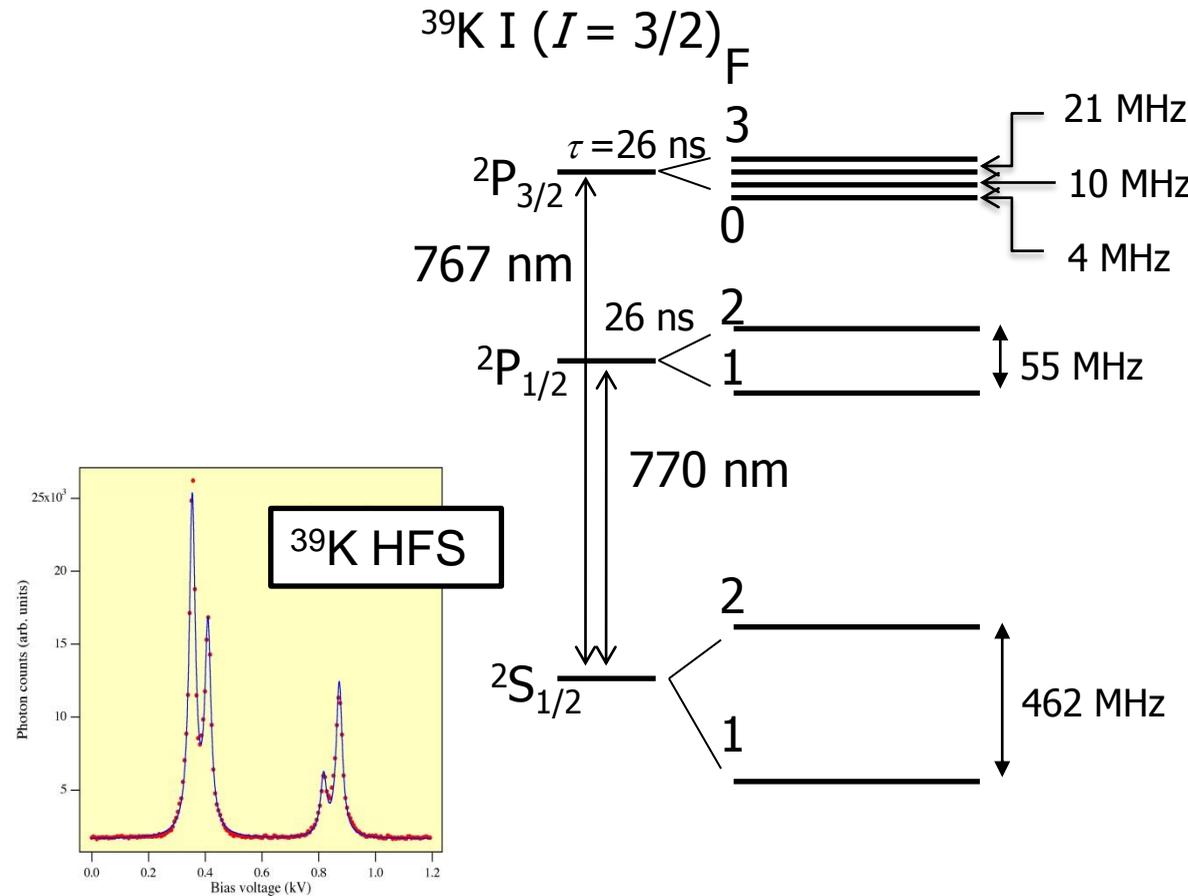
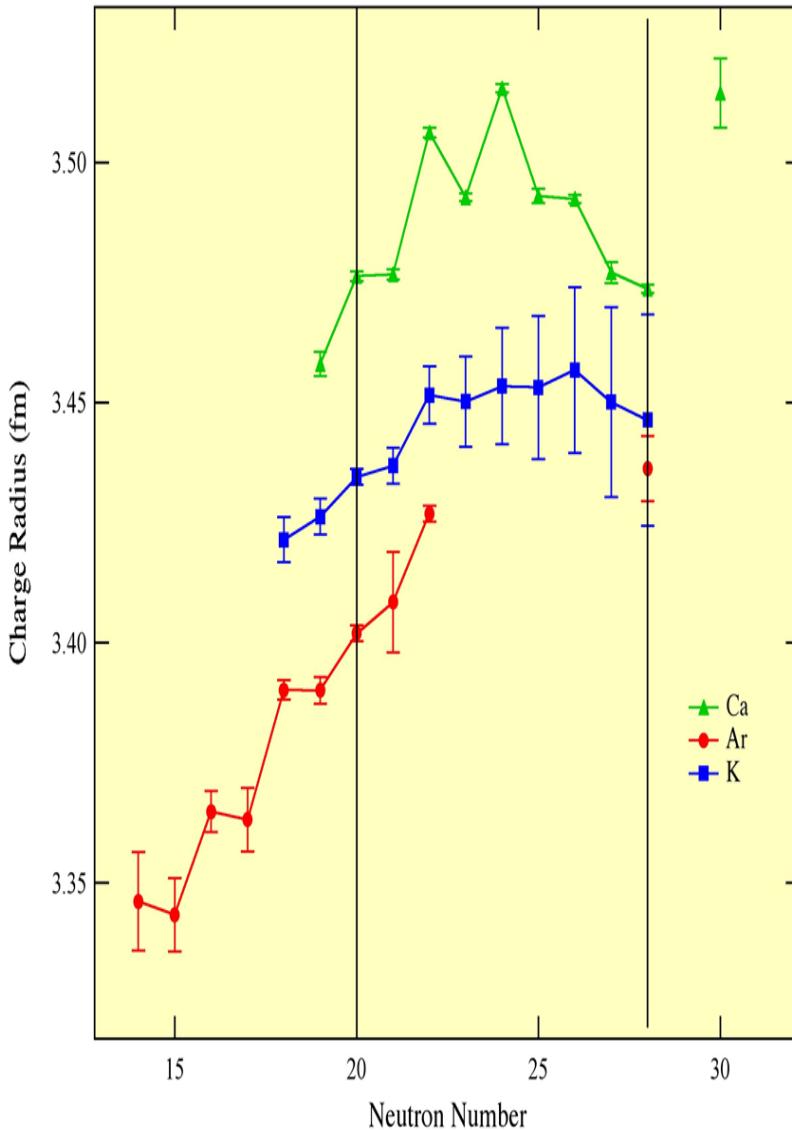
bunching section



- cryogenic
- separate cooling/bunching sections

# Approved NSCL Experiment 11011

## Laser Spectroscopy of $^{35,36}\text{K}$



Element	Mass	Lifetime (ms)	Nuclear spin	Rate (1/s/pnA)
<b>K</b>	35	190	3/2	$1.8 \times 10^1$
	36	342	2	$4.8 \times 10^2$
	37	1230	3/2	$6.2 \times 10^3$
	38	$458 \times 10^3$	3	$4.0 \times 10^4$

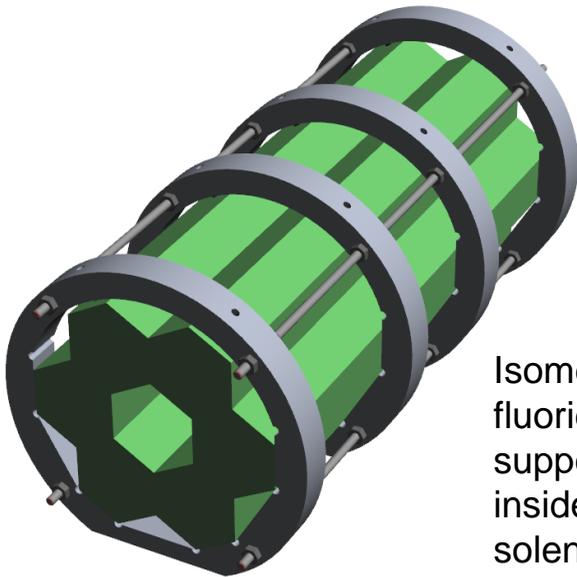
# Correlation Measurements in Beta Decay Perspective and New Developments

- Perspective

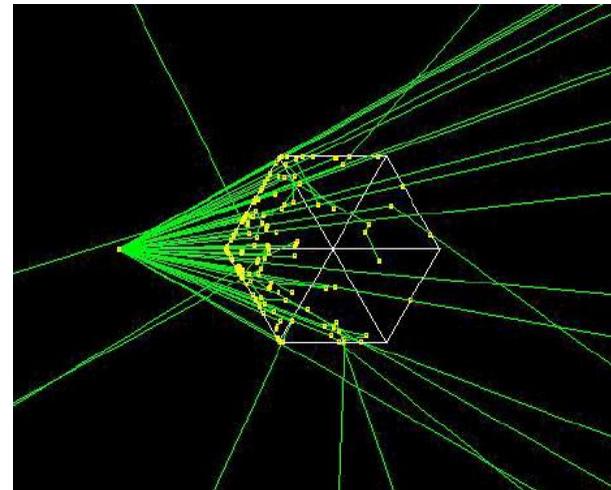
- Measure beta asymmetry in  $^{37}\text{K}$  decay (determination of GT/F mixing ratio)
- Commission positron polarimeter with (unpolarized)  $^{21}\text{Na}$
- Measure beta asymmetries in  $^{21}\text{Na}$  and  $^{23}\text{Mg}$  decays (requires upgrade of laser system)
- Measure beta longitudinal polarization in  $^{21}\text{Na}$  and  $^{23}\text{Mg}$  decays

- New Equipment Development

- Parts of a new positron polarimeter under design/construction/tests



Isometric view of barium fluoride detectors and support to be mounted inside a superconducting solenoid magnet



Geant4 simulation of barium fluoride detector response ( $^{137}\text{Cs}$  source)

# BECOLA Collaborators

- MSU/NSCL
  - CLS: K. Minamisono, A. Klose, A. Schneider, B. Johnson
  - Cooler/Buncher: B. Barquest, G. Bollen, R. Ringle
  - Polarimeter: G. Noid, O. Naviliat-Cuncic
- TRIUMF (M. Pearson, P. Levy, A. Voss)
- U. Mainz (W. Nörtershäuser, C. Geppert, et al.)
- Texas A&M U. (D. Melconian)
- U. Michigan (T. Chupp)
- North Carolina State U. (A. Young)
- K.U. Leuven (N. Severijns)