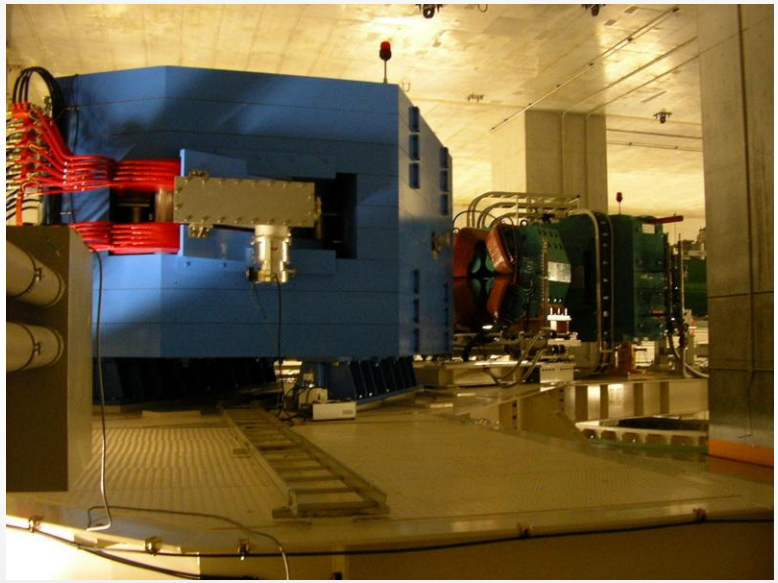
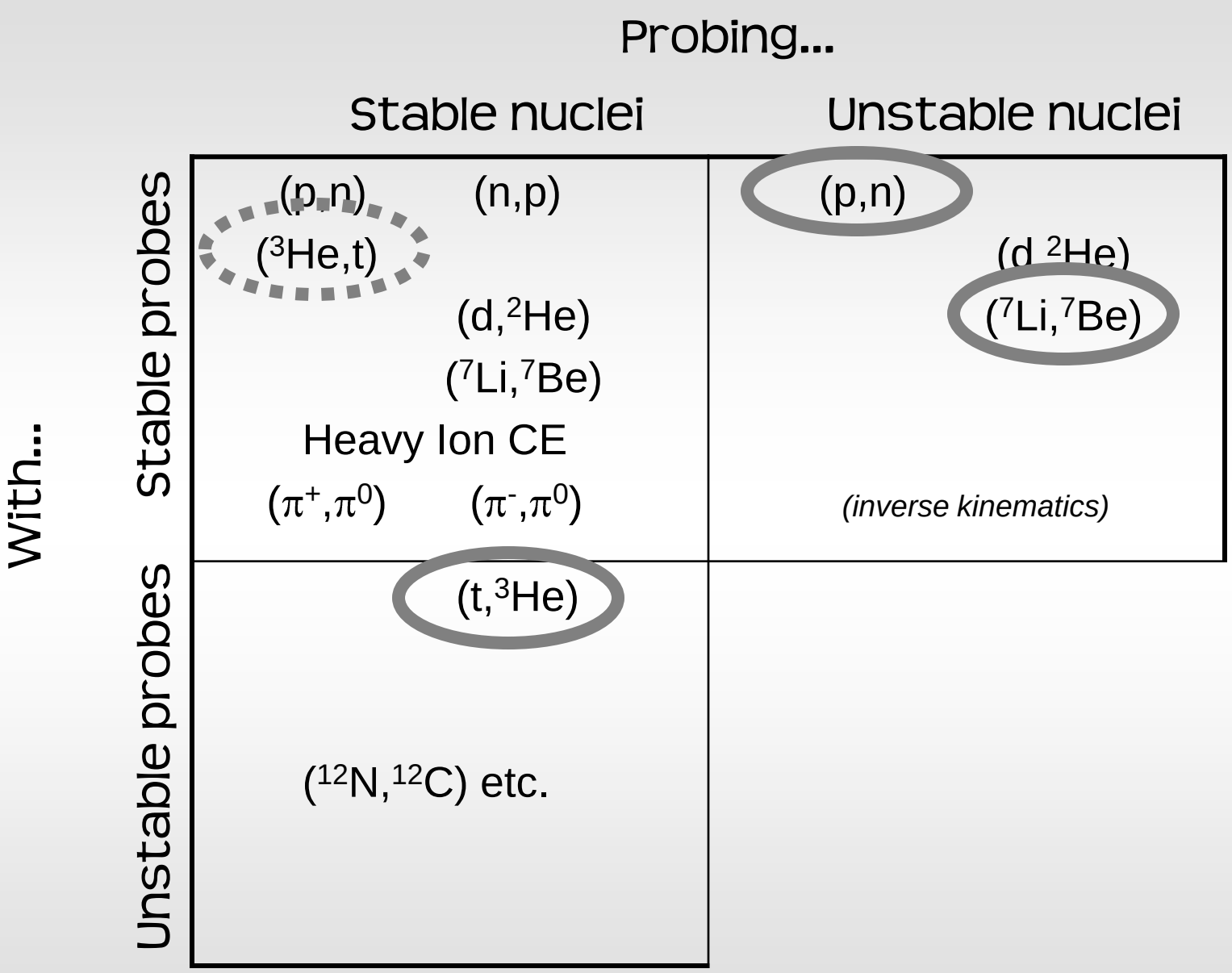
Charge-exchange experiments at intermediate energies using high-resolution spectrometers

Remco Zegers

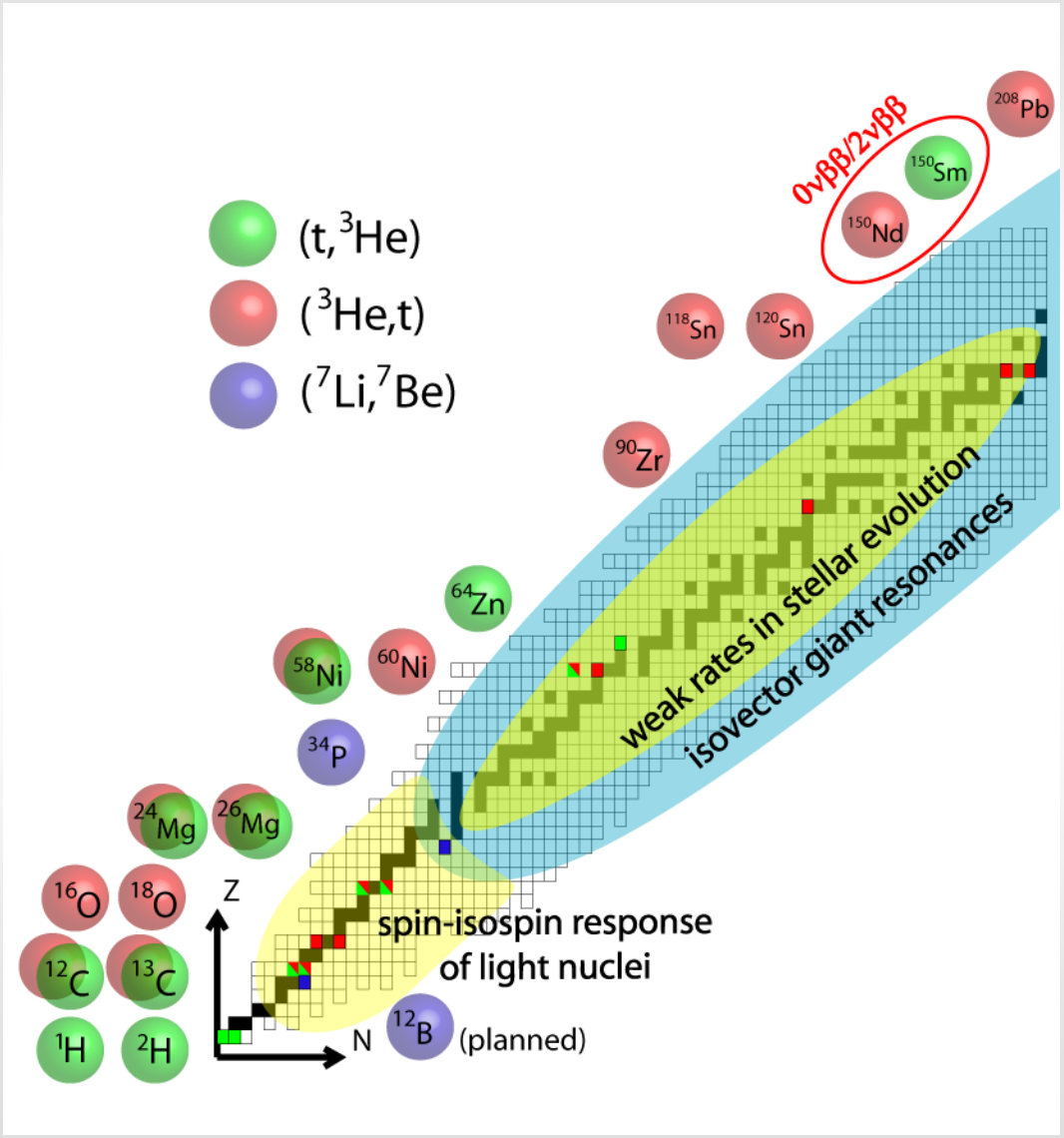
S800 @ NSCL



SHARAQ @ RIBF


Probing...
Stable nuclei
Unstable nuclei
With...
Stable probes
Unstable probes
(p,n)
(n,p)
(3He,t)
(d,2He)
(7Li,7Be)
Heavy Ion CE
(π+,π0)
(π-,π0)
(p,n)
(d,2He)
(7Li,7Be)
(inverse kinematics)
(t,3He)
(12N,12C) etc.

NSCL Charge-Exchange group program



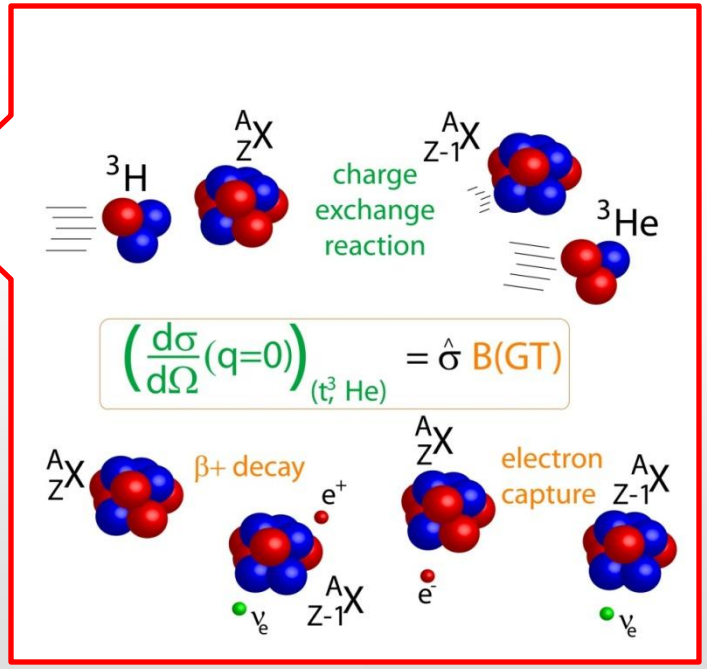
- CE reactions on stable nuclei:
  - (t,³He)
  - (³He,t) – RCNP
- CE reaction on unstable nuclei (inverse kinematics)
  - (⁷Li,⁷Be)
  - (p,n)

Isovector transitions

- isospin transfer: $\Delta T=1$
- Angular momentum transfer: $\Delta L=0,1,2,3...$
  - Near $\theta_{cm}=0$ and E~100 MeV/u low ΔL is preferred
- spin-transfer: $\Delta S=0$ or $\Delta S=1$

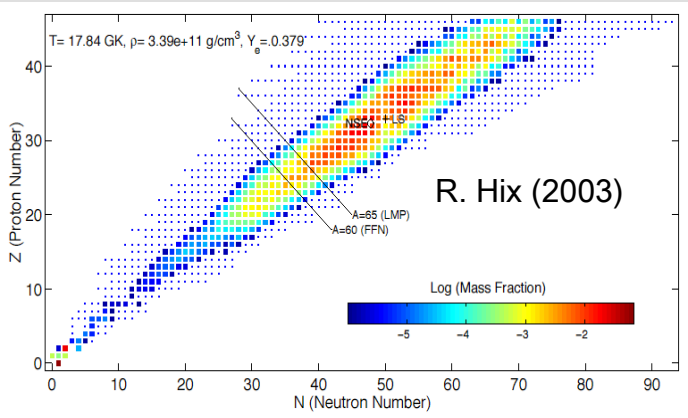
$$\Delta J = \Delta L + \Delta S$$

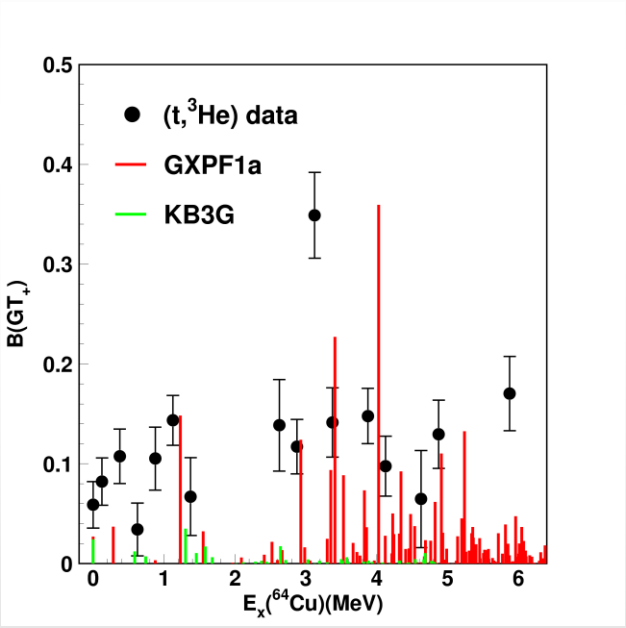
ΔT	ΔL	ΔS	$0^+ \rightarrow J^\pi$
1	0	0	0^+ Fermi transitions
1	0	1	1^+ Gamow-Teller
1	1	0	1^- dipole
1	1	1	$0^- 1^- 2^-$ spin-dipole
1	2	0	2^+ quadrupole
1	2	1	$1^+,2^+,3^+$ spin-quadrupole

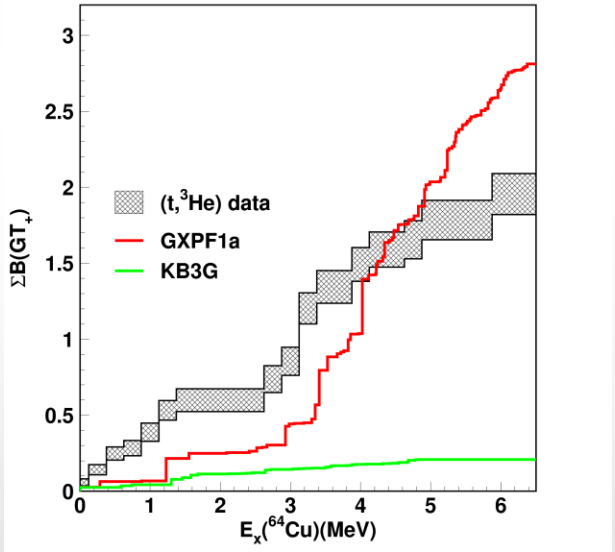


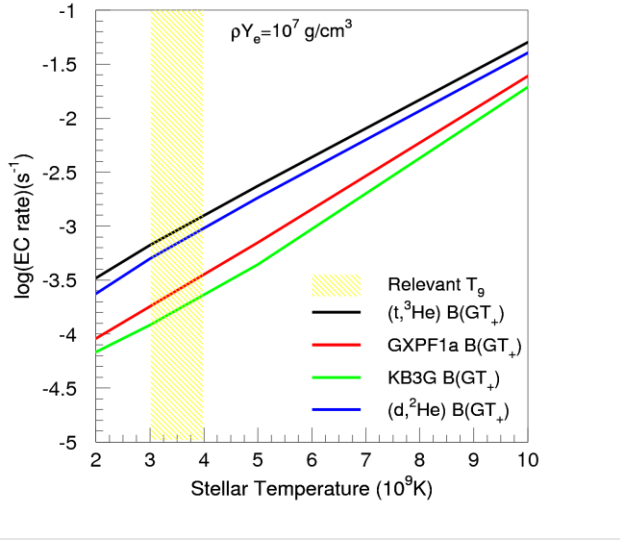
Motivations

- Astrophysics: weak reaction rates
  - ec-captures in type Ia & II Supernovae
  - Neutron-star crust
  - S-process
  - Neutrino interactions





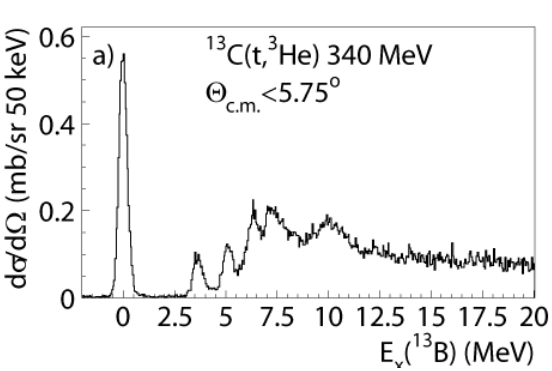




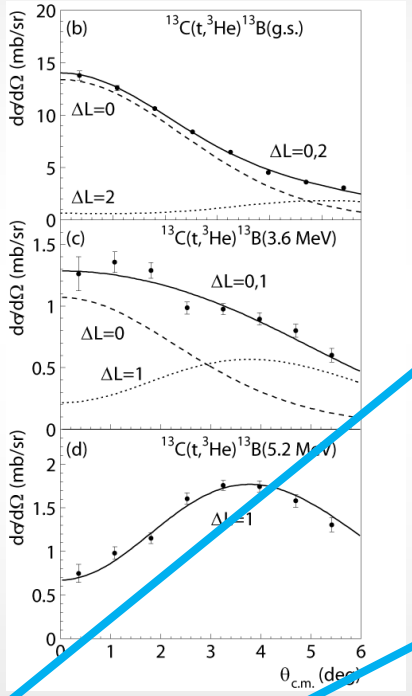
^{64}Zn(t,^{3}He) **Hitt et al.**
Phys.Rev. C 80, 014313 (2009)

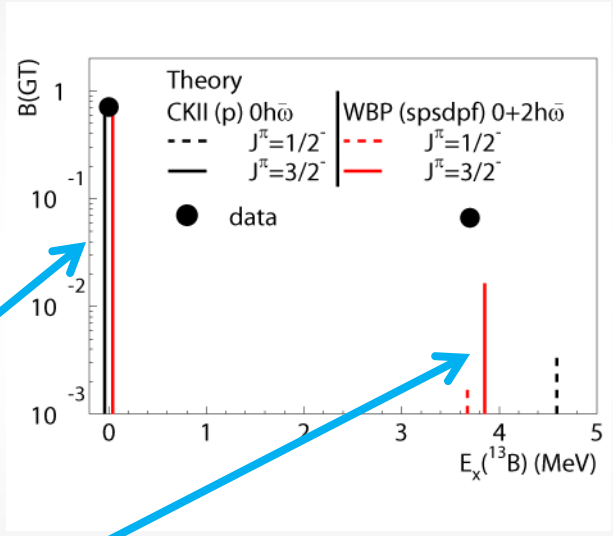
Nuclear structure

- GT transitions are a good tool to investigate the nature of wave-functions near shell crossings in a model-independent manner



^{13}C(t,^{3}He) 10^{7} pps 2008





Mostly 0ħω

$$|\,^{13}\mathrm{C}> = 0.918\,|\,^{13}\mathrm{C}, 0\hbar\omega> + 0.397\,|\,^{13}\mathrm{C}, 2\hbar\omega>$$

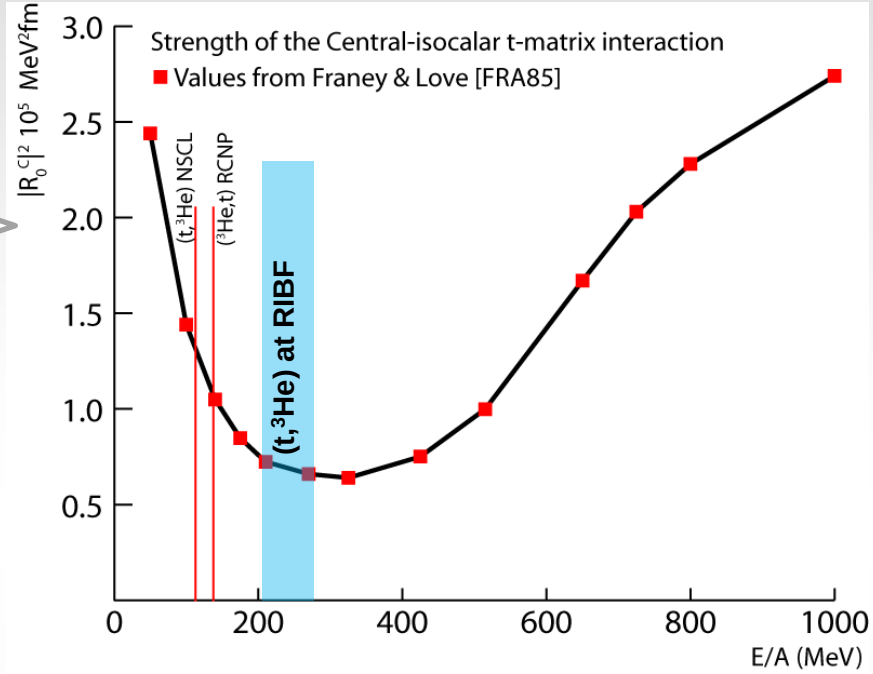
$$|\,^{13}\mathrm{B}>_1 = 0.871\,|\,^{13}\mathrm{B}, 0\hbar\omega> + 0.491\,|\,^{13}\mathrm{B}, 2\hbar\omega>_1$$

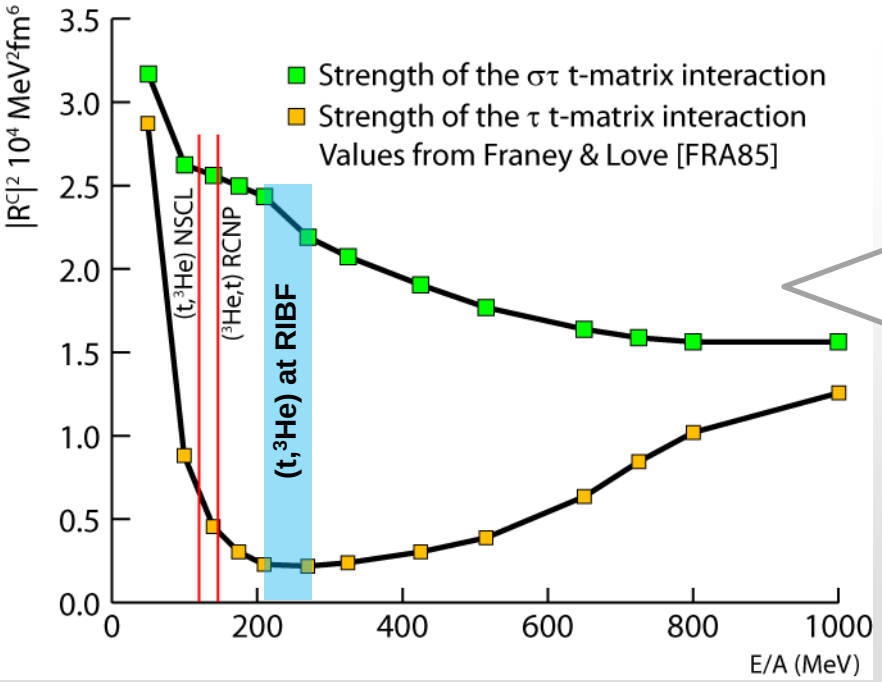
$$|\,^{13}\mathrm{B}>_2 = -0.237\,|\,^{13}\mathrm{B}, 0\hbar\omega> + 0.972\,|\,^{13}\mathrm{B}, 2\hbar\omega>_2$$

Interference 0ħω an 2ħω

(t,^{3}He) reactions

Distortions & rescattering small enough to ensure predominant single-step mechanism





Spin-flip Isospin-flip transitions are near maximal.

Non-spin-flip isospin-flip transitions are strongly suppressed

Franey & Love, PRC 31, 488, 1985

S800-SHARAQ in high-resolution (dispersion-matched) mode

	S800	SHARAQ (high resolution)
configuration	QQDD	QQDQD
Maximum Rigitidy (Tm)	4	6.8
Dispersion (cm/%)	10	5.86
Momentum Resolution (object size of 0.5 mm)	1/20000	1/147000 (1/8100 achieved)
Energy Resolution* (RI Beam)	1800-3400	?
angular resolution (prim. beam) (dispersive/nondispersive)	0.5/1.7 mrad	~ 1/1 mrad
angular resolution (RI beam)** (dispersive/nondispersive)	1/7 mrad Beam & tune dep.	?
Momentum acceptance	6%	2%
Angular acceptance (dispersive/nondispersive)	7°/10°	2°/6°

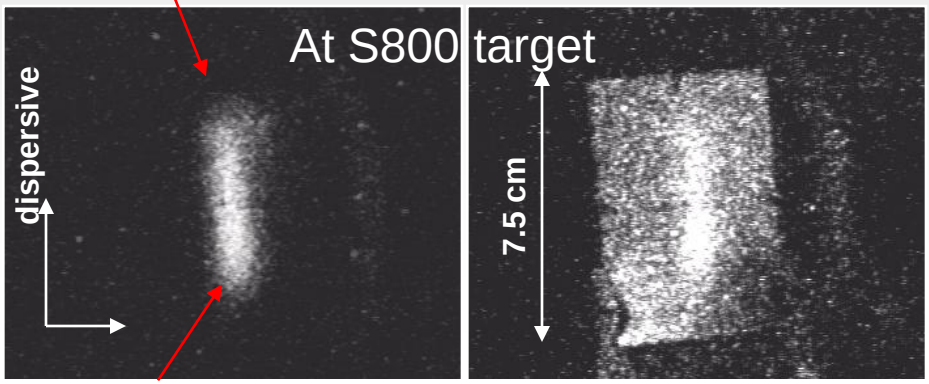
* tune optimized for rate

** Assuming no beam tracking

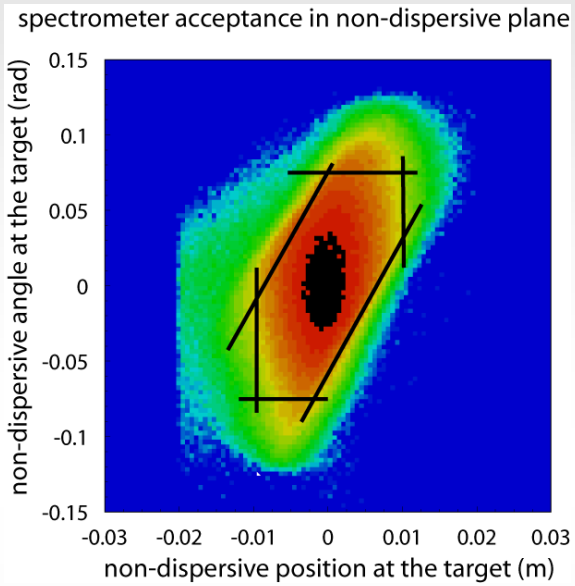
(t,^{3}He) at the S800 spectrometer

- dispersion matching: ~3 MeV $\Delta E_{triton} \Rightarrow \sigma_E(t,^3He)$ ~ 250 keV
- raytracing with 5th order map ~1^o angular resolution

Low momentum



High momentum

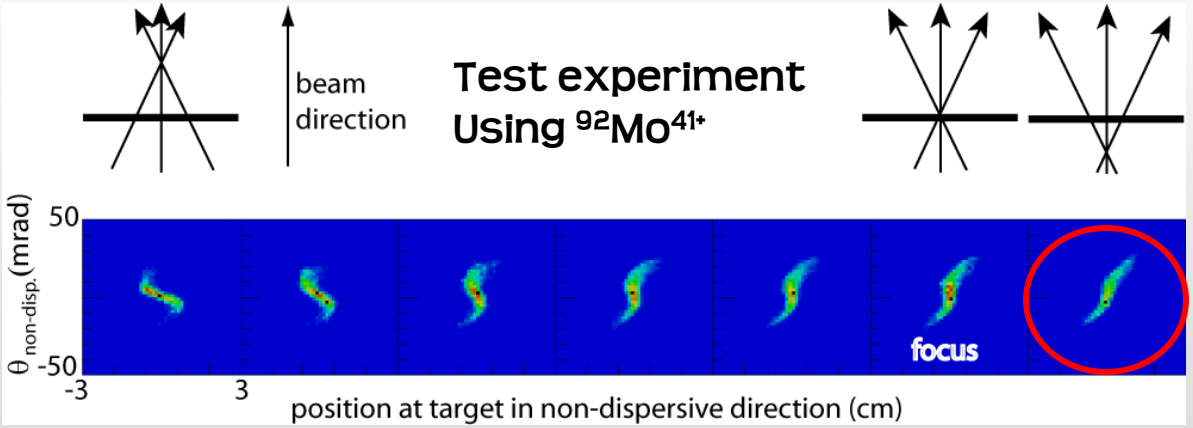


Acceptance is a complex function of:

- $X_{non\text{-}dispersive}$
- $\theta_{non\text{-}dispersive}$
- $X_{focal\ plane}$
- $\theta_{dispersive}$

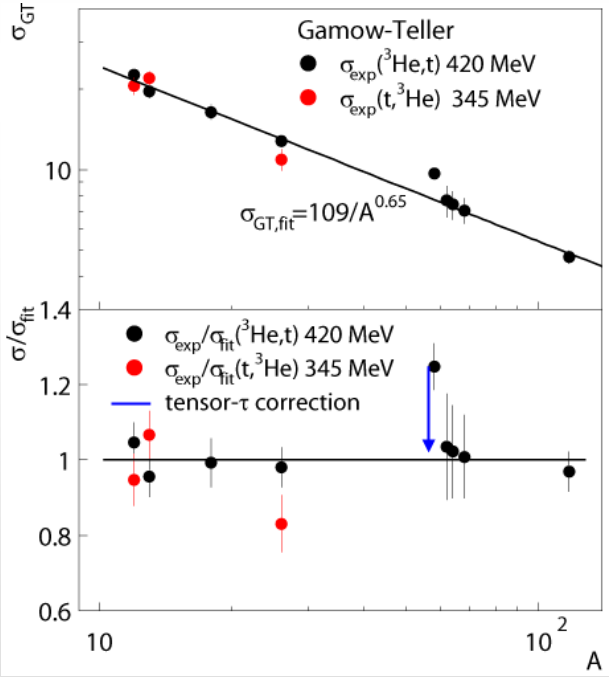
Monte-Carlo Simulations needed

Non-dispersive defocusing of the beam to increase angular resolution improves angular resolution to ~0.5^o.



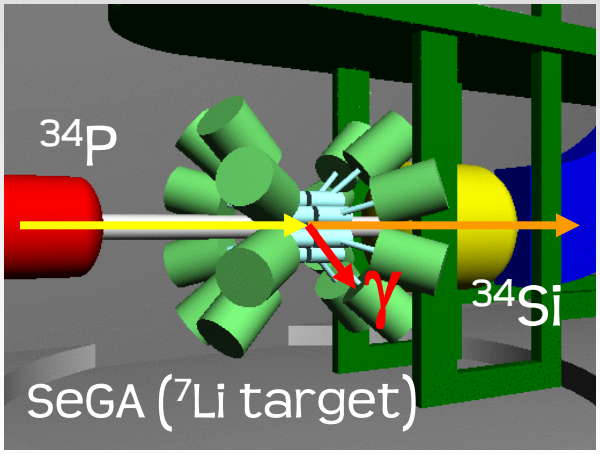
High-resolution (t,^{3}He) @ SHARAQ

- Some things to consider
  - High energy (300 AMeV) -> reduced absolute resolution
  - Leverage yield against quality?
  - High energy: simpler reaction mechanism but less experience
    - Optical potentials
    - Unit cross sections (no comparable (3He,t) probe)
  - Tracking? Rate limited to ~10^6

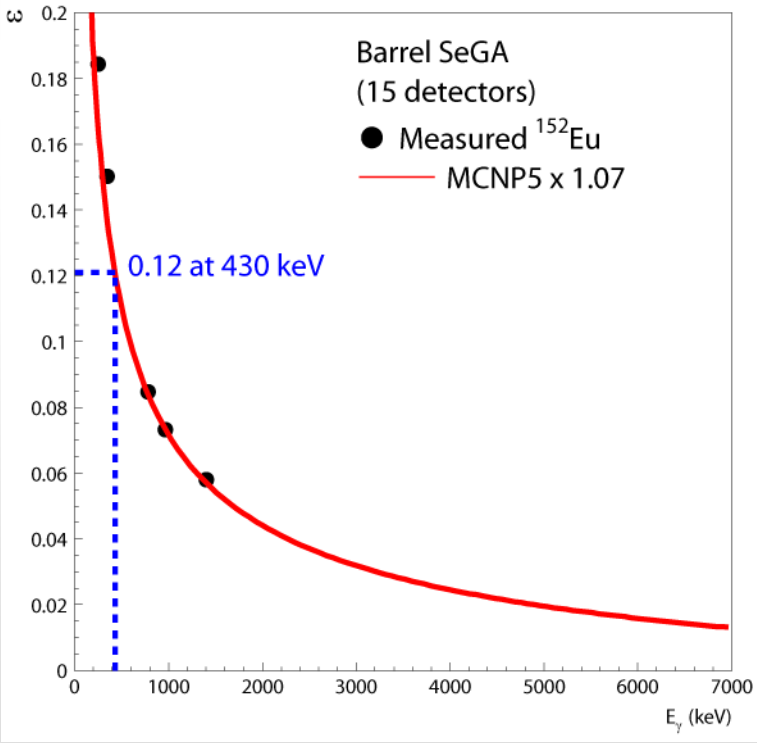


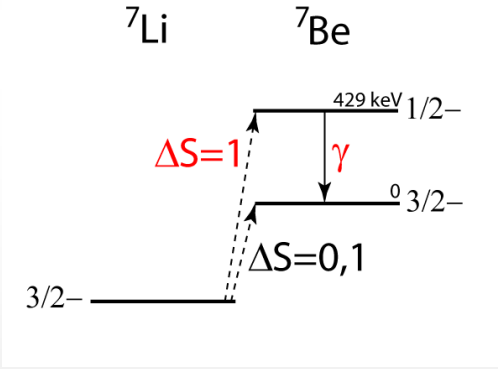
Zegers et al. PRL 99, 202501 (2007)

(^{7}Li,^{7}Be+γ) in inverse kinematics



- Measure heavy residual in S800
- dispersion matching resolution ~ 1 MeV
  - Affected by decay-flight
  - Affected by energy loss in target
- thin target 2.5-5 mg/cm^2
- tag with 0.43 MeV γ in SeGA



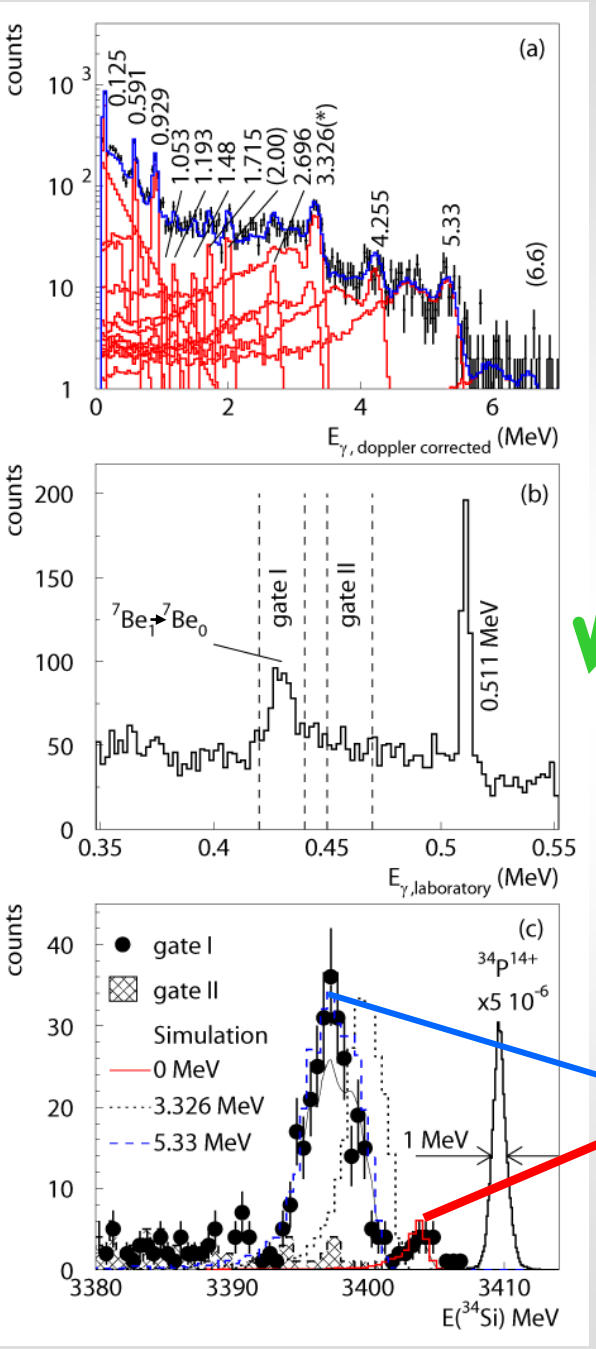


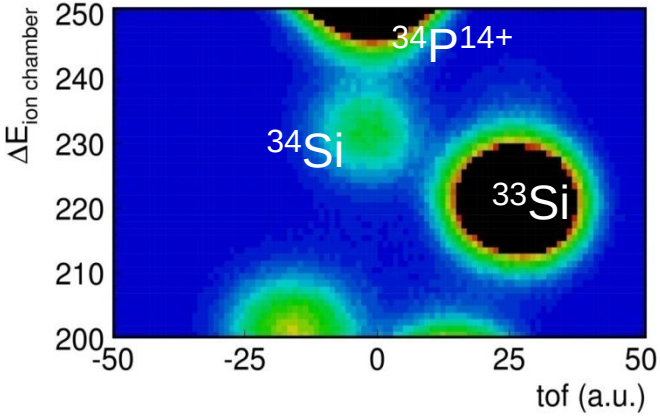
close-packed configuration (ε~12%)

Experiments:

- ^{34}P(^{7}Li,^{7}Be+γ) analysis finished
- ^{12}B(^{7}Li,^{7}Be+γ) Oct. 2009

$^{34}P(^{7}Li,^{7}Be+\gamma)$ SeGA/S800





~2x10^{6} pps

Preliminary results omitted

(^{7}Li,^{7}Be+γ) @ SHARAQ (using GRAPE?)

advantages

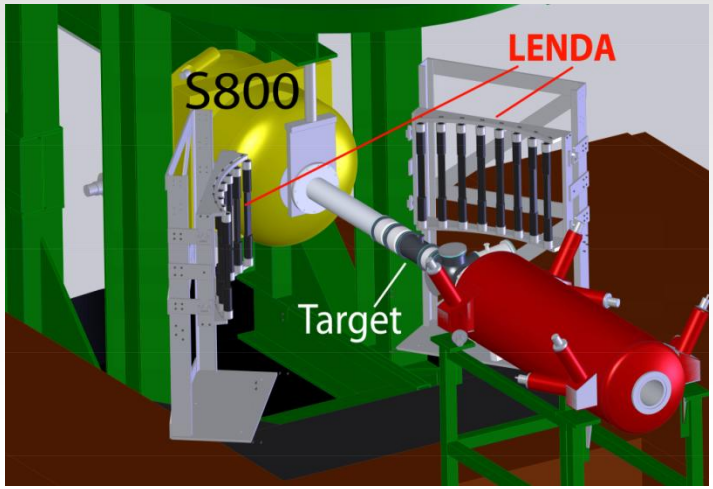
- High energy -> thicker targets
- High energy -> less charge-state events
- High energy -> tracking detectors affect beam less
- High energy -> reaction mechanism simpler

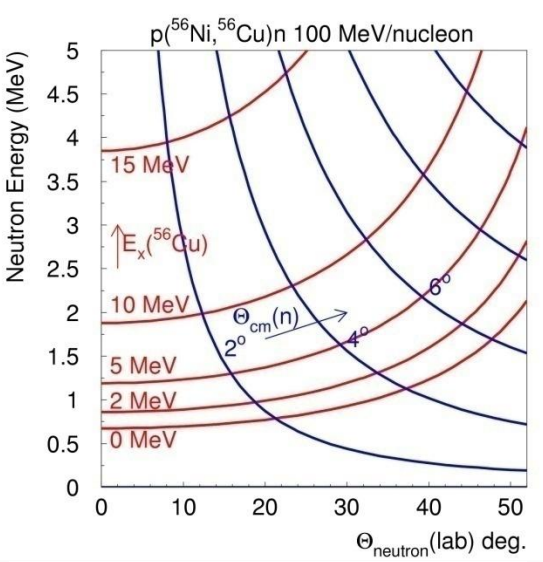
disadvantages

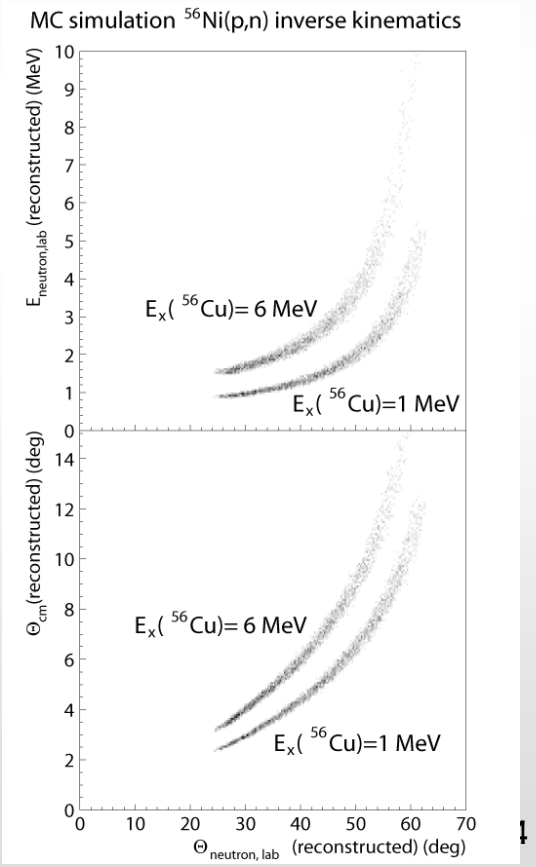
- High energy -> reduced absolute energy resolution
- High energy -> stronger forward boosting -> reduced c.m. angular resolution
- High energy -> less efficiency for Doppler-boosted photons
- High energy ->no experience in forward kinematics

For high A,E high rate tracking is needed (diamond detectors?) at both S800/SHARAQ

(p,n) inverse kinematics – LENDA Low-Energy Neutron Detector Array







- 24 plastic scintillators (2.5x4.5x30cm)
- Neutrons > 130 keV
  - $\Delta E \approx 20$ keV for $E_n = 200$ keV
  - $\Delta\theta_{lab} < 2^o$
  - Efficiency >30% for $E_n < 4$ MeV
- Construction finished Summer 2009

Working group for the high-resolution spectrometer (S800) at FRIB

- Explore, develop and design the necessary infrastructure for experiments at FRIB that utilize the high-resolution spectrometer (S800)
- Advocate the needs for the science program with the high-resolution spectrometer at FRIB to the community
- Initial Contacts: Daniel Bazin, Alexandra Gade, Remco Zegers

Website available soon.
Please join!