Weak Interaction Physics at *TwinSol*

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P.I. : Ion-Trap Project

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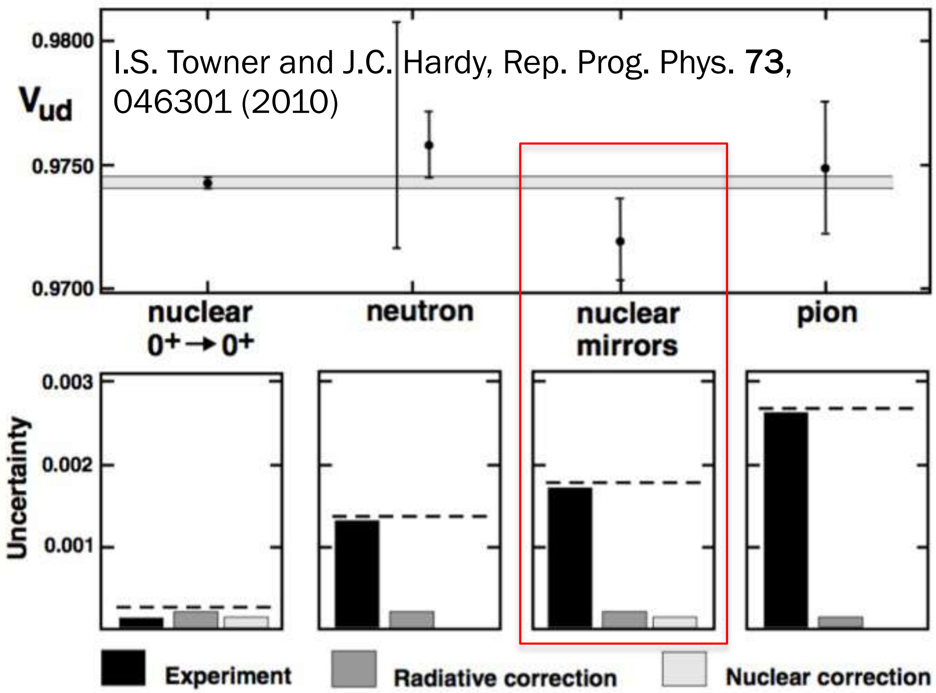
Precision Tests of the Standard Model

Via the CKM matrix unitarity test.

$$\sum_i |V_{ui}|^2 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 \qquad \begin{pmatrix} |d_w\rangle \\ |s_w\rangle \\ |b_w\rangle \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} |d_s\rangle \\ |s_s\rangle \\ |b_s\rangle \end{pmatrix}$$

largest element; *involves nuclear physics*

- Non-unitarity: **new physics** (or uncover erroneous data/theoretical corrections)



- For a reliable CKM matrix unitarity test, V_{ud} needs to be both precise and accurate.
- Accuracy can be tested by a determination of V_{ud} using multiple systems.
- Pure Fermi β-decay: most precise at this moment.

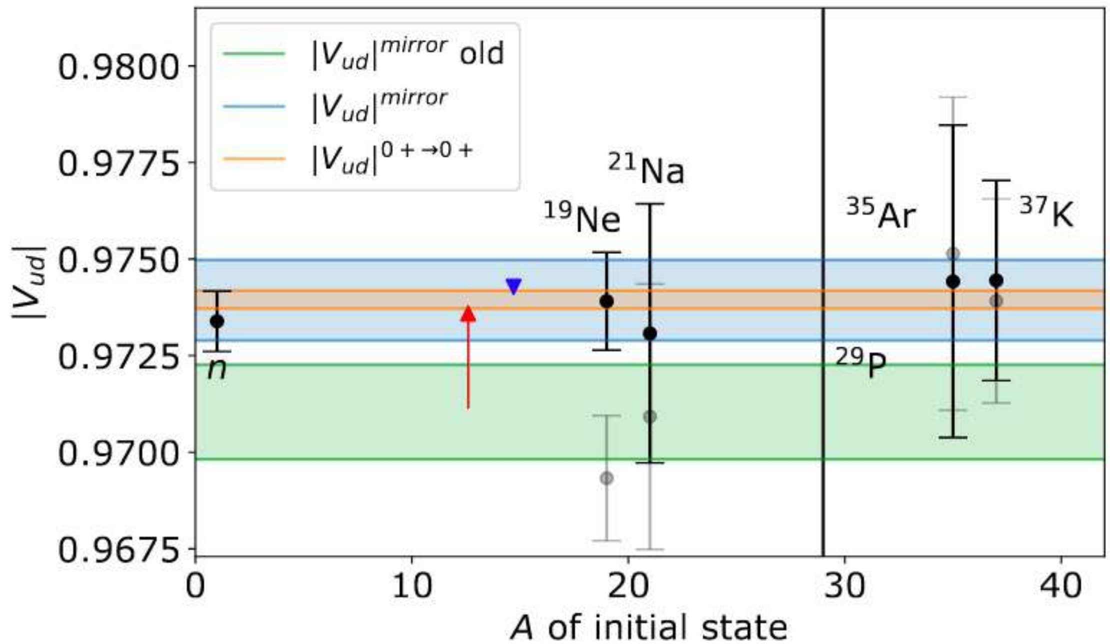
V_{ud} from mixed-mirror transitions

- Another avenue to extract V_{ud}, test CVC, and test δ_c.

- Only 5 nuclei so far.
- Parameters needed:
  - ✓ Half-life
  - ✓ Branching ratios
  - ✓ Q-values
  - ✓ Fermi-to-Gamow Teller mixing ratio ρ

ρ determined by measuring either:

- β asymmetry parameter A_β
- ν asymmetry parameter B_ν
- **β-ν angular correlation $a_{\beta\nu}$**



V_{ud} from mirror transitions is currently*:

- ~3.5 times less precise than pure Fermi.
- In agreement with pure Fermi, after re-evaluation using new theoretical corrections.

*** https://arxiv.org/pdf/2102.03458.pdf**

Experimental Considerations

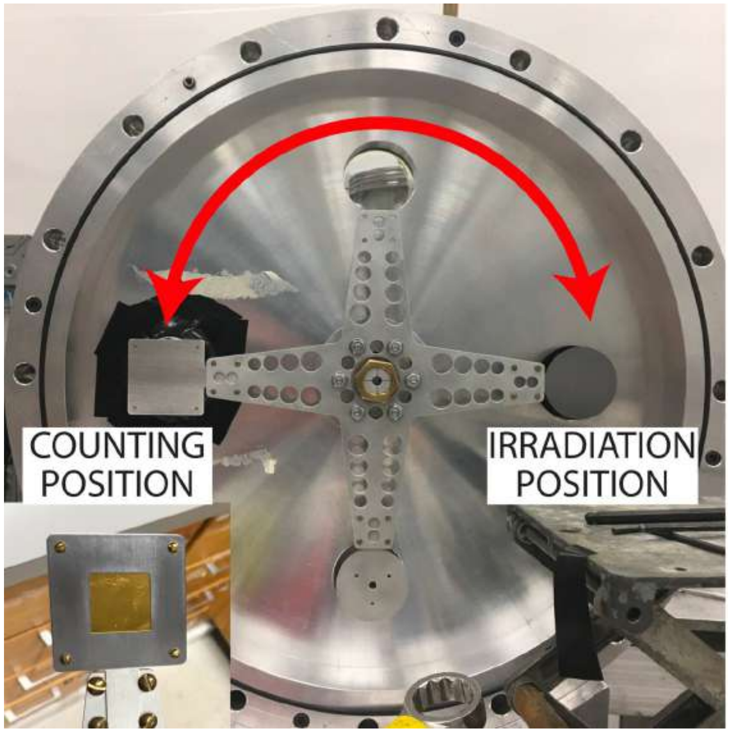
(1) Device to **rotate** the stopper away from the beam location.

(2) Gold stopper: reduces contaminants formed by the beam incident on Ta impurities.

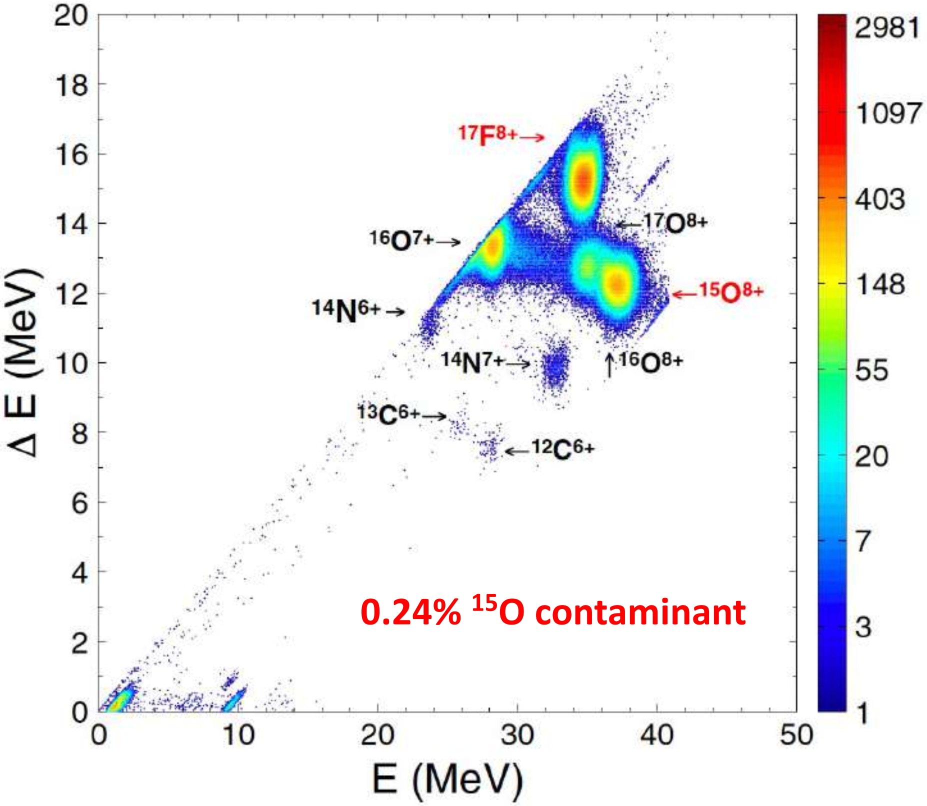
(3) Detector: 1 mm plastic scintillator on a light guide: reduces interference from γ-radiation.

(4**) Quartz-window PMT**: reduces background from the window by about a **factor of 10**.

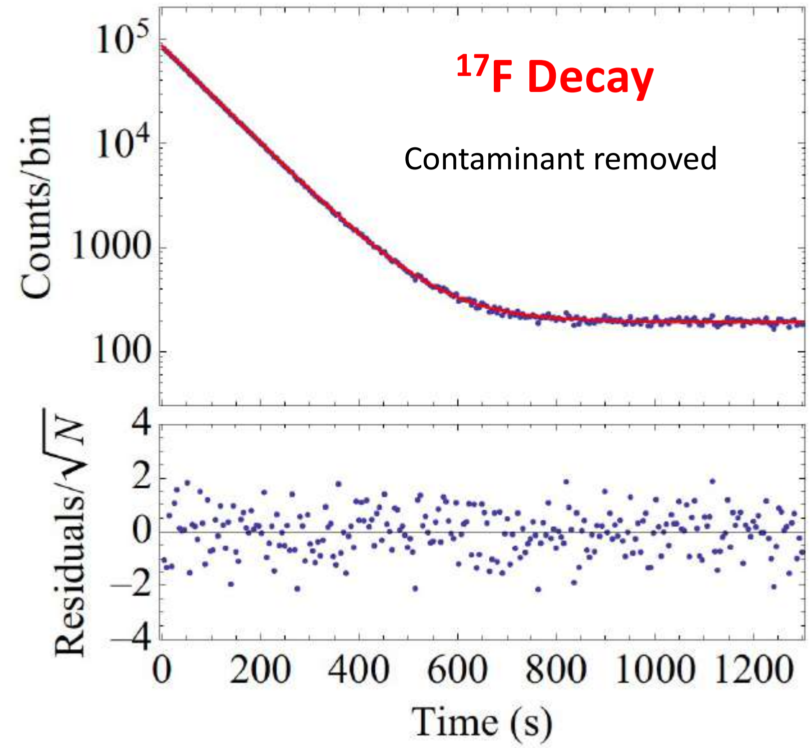
(5) Beam removed during counting period using a **pre-tandem electrostatic deflector**.



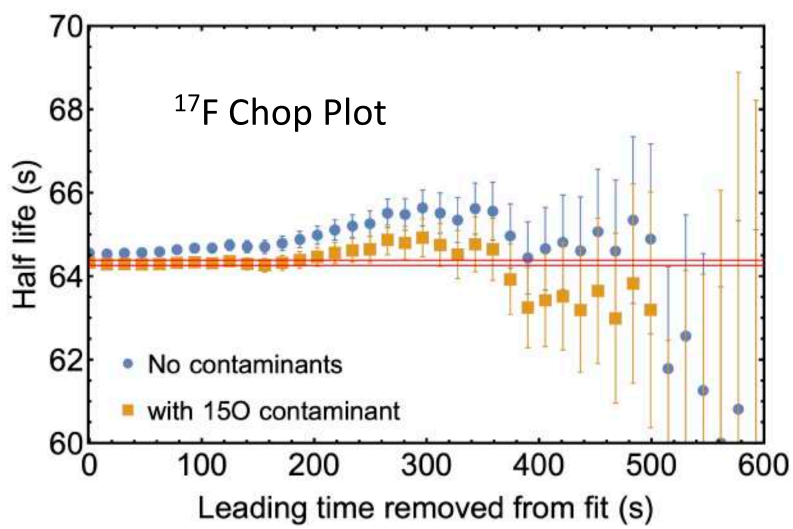
Beam-direction view of the apparatus.
The cross structure (meant for simultaneous irradiation while counting) was not used in these experiments. Note the gold stopper.



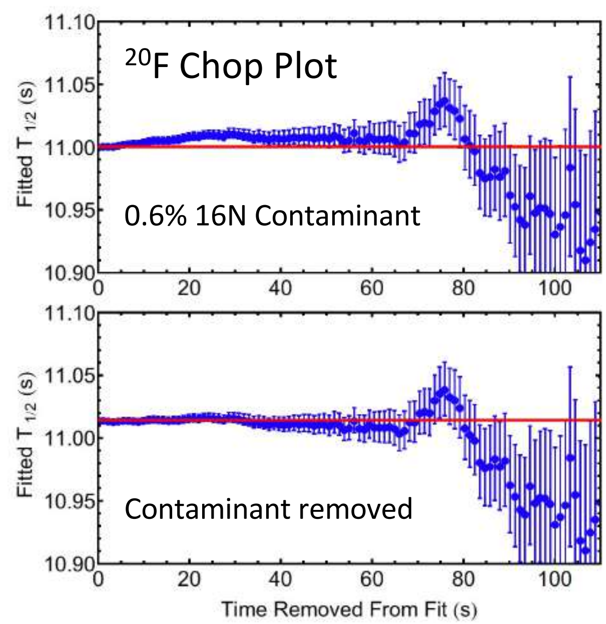
Δ E (MeV)
E (MeV)
17F8+
16O7+
17O8+
15O8+
14N6+
14N7+
16O8+
13C6+
12C6+
2981
1097
403
148
55
20
7
3
1
0.24% 15O contaminant



17F Decay
Contaminant removed
Counts/bin
Residuals/√N
Time (s)

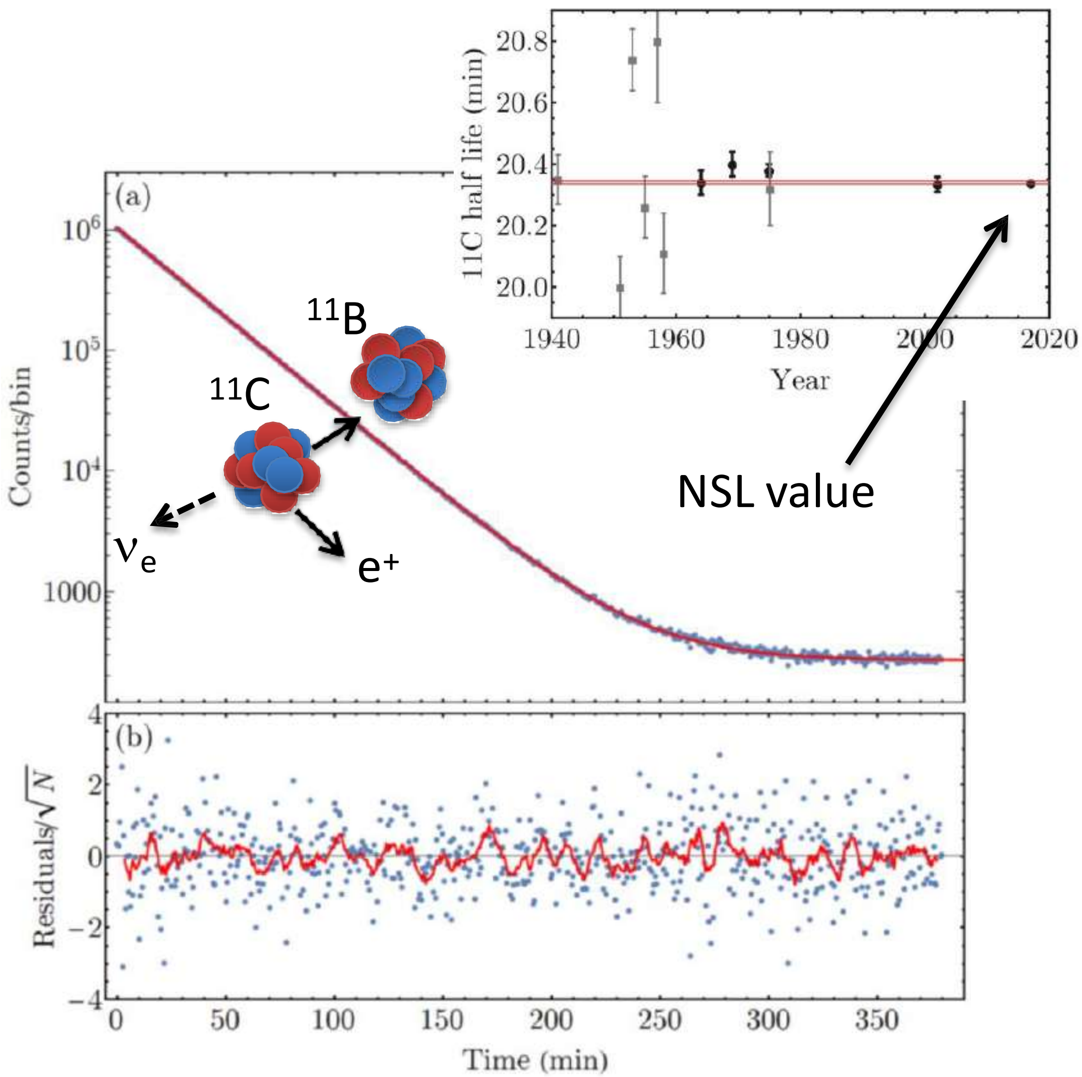


17F Chop Plot
Half life (s)
No contaminants
with 15O contaminant
Leading time removed from fit (s)



20F Chop Plot
0.6% 16N Contaminant
Contaminant removed
Fitted T 1/2 (s)
Time Removed From Fit (s)

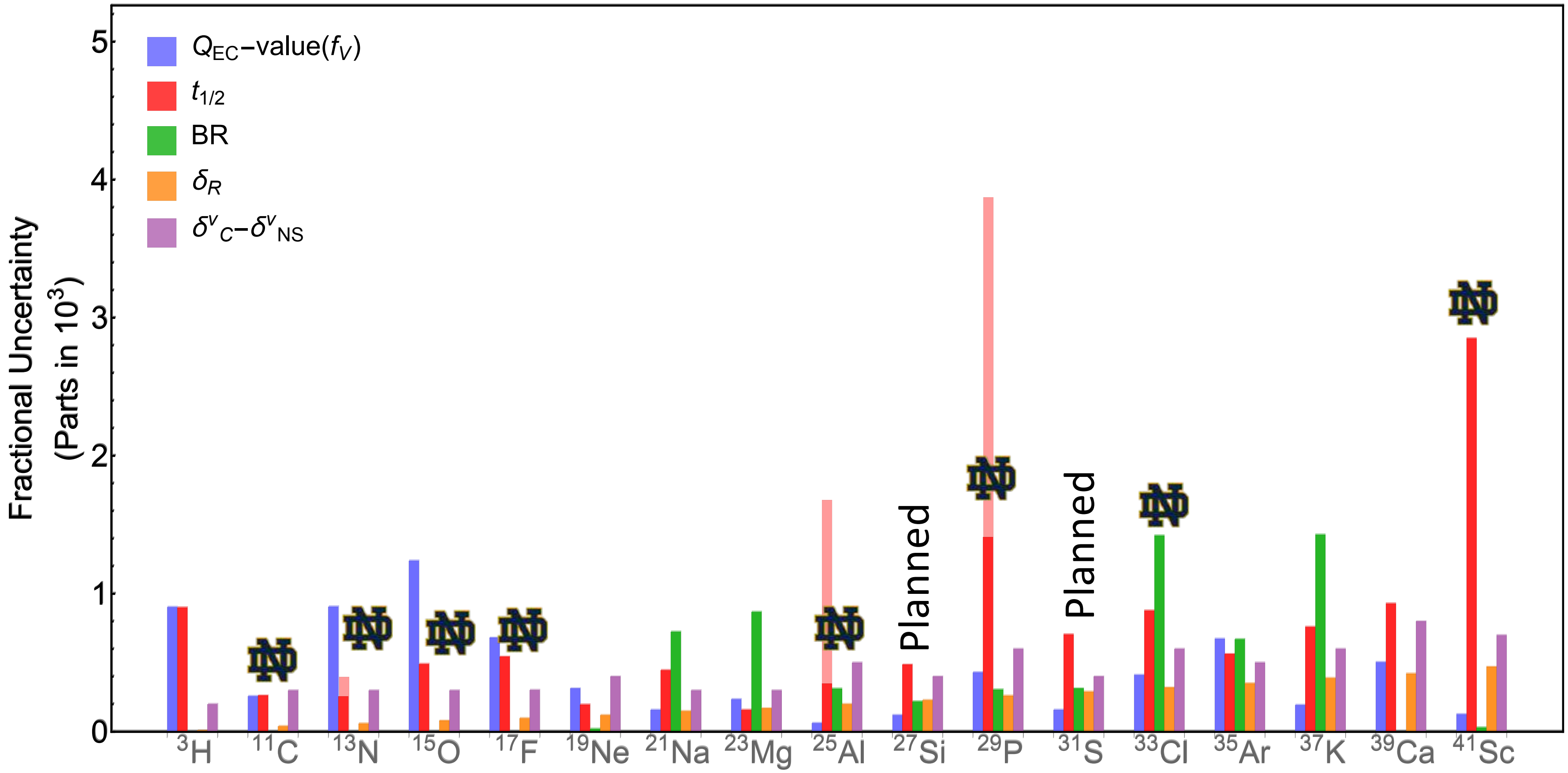
^{11}C half-life measurement at the NSL



- Superallowed mixed mirror decays → precision tests of SM through V_{ud}
- Measurement of ^{11}C $t_{1/2}$ @ UND → **most precise** of all SA mixed decays
- **Lightest** of all mirror transitions: to test CVC
- Measurement of mixing ratio using the future ion trap is planned to extract V_{ud}.

A. A. Valverde *et al.*, PRC **97** 035503 (2018)
PHY-1713857, PHY-1401343, PHY-1401242

Ft-values of Mirror Transitions



^{11}C: A. Valverde *et al.*, PRC **97**, 035503 (2018)

^{15}O: D. Burdette *et al.*, PRC **101**, 055504 (2020)

^{17}F: M. Brodeur *et al.*, PRC **93**, 025503 (2016)

^{25}Al: J. Long *et al.*, PRC **96**, 015502 (2017)

^{29}P: J. Long *et al.*, PRC **101**, 015501 (2020)

^{13}N: J. Long *et al.*, in preparation

^{33}Cl: P. O'Malley *et al.*, in preparation

^{41}Sc: B. Liu *et al.*, in preparation

Others: ^{20}F: D. Burdette *et al.*, PRC **99**, 015501 (2019)

^{28}Al: B. Liu *et al.*, in preparation

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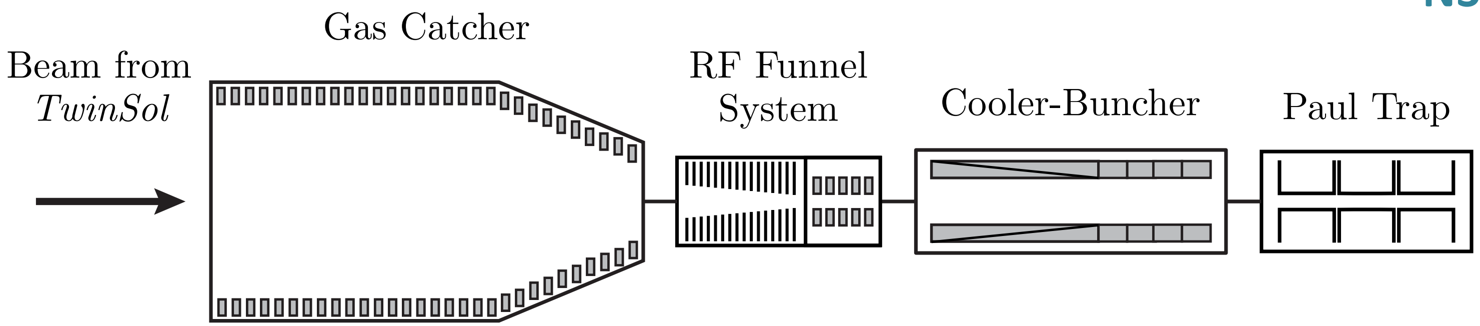
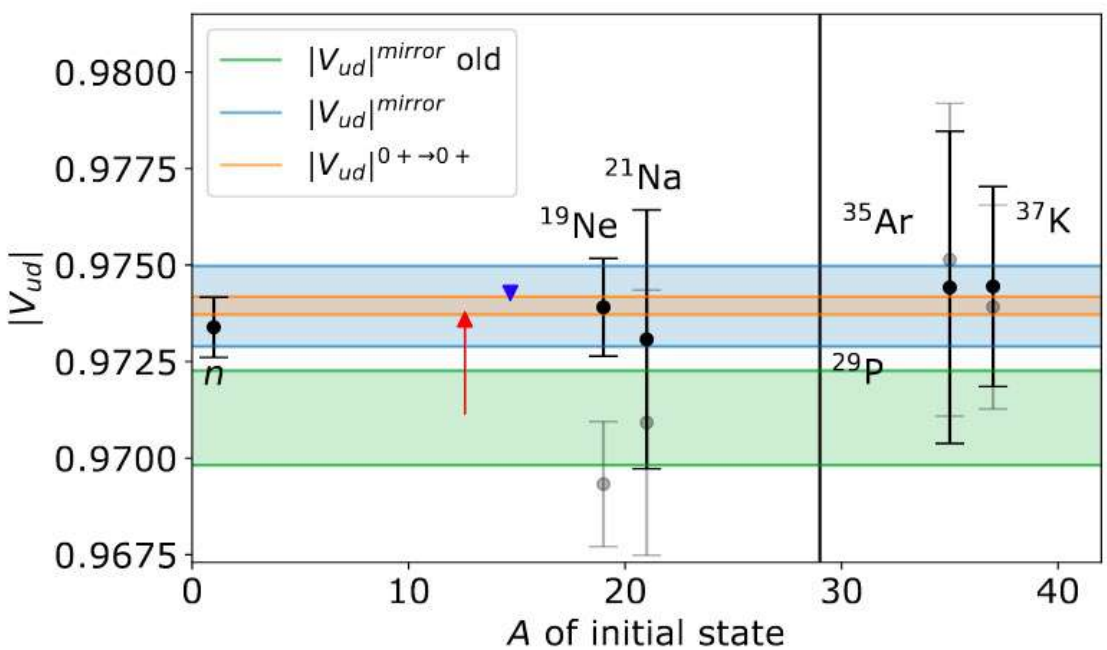
“St. Benedict” to measure ρ

NSF: MRI PHY-1725711



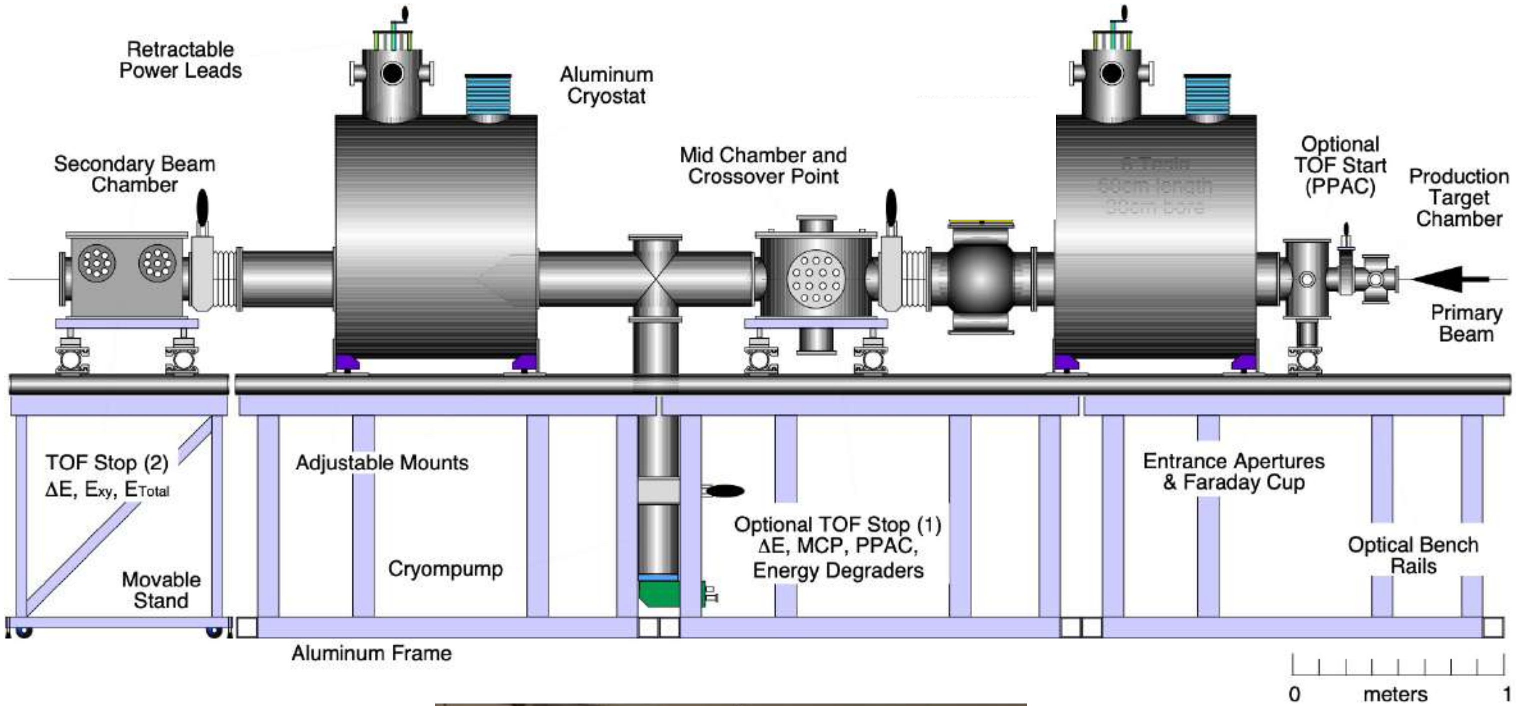
Gas catcher and cooler-buncher are completed.
RF carpet commissioning is presently underway.



N. Severjins *et al*., PRL **63**, 1050 (1989)*

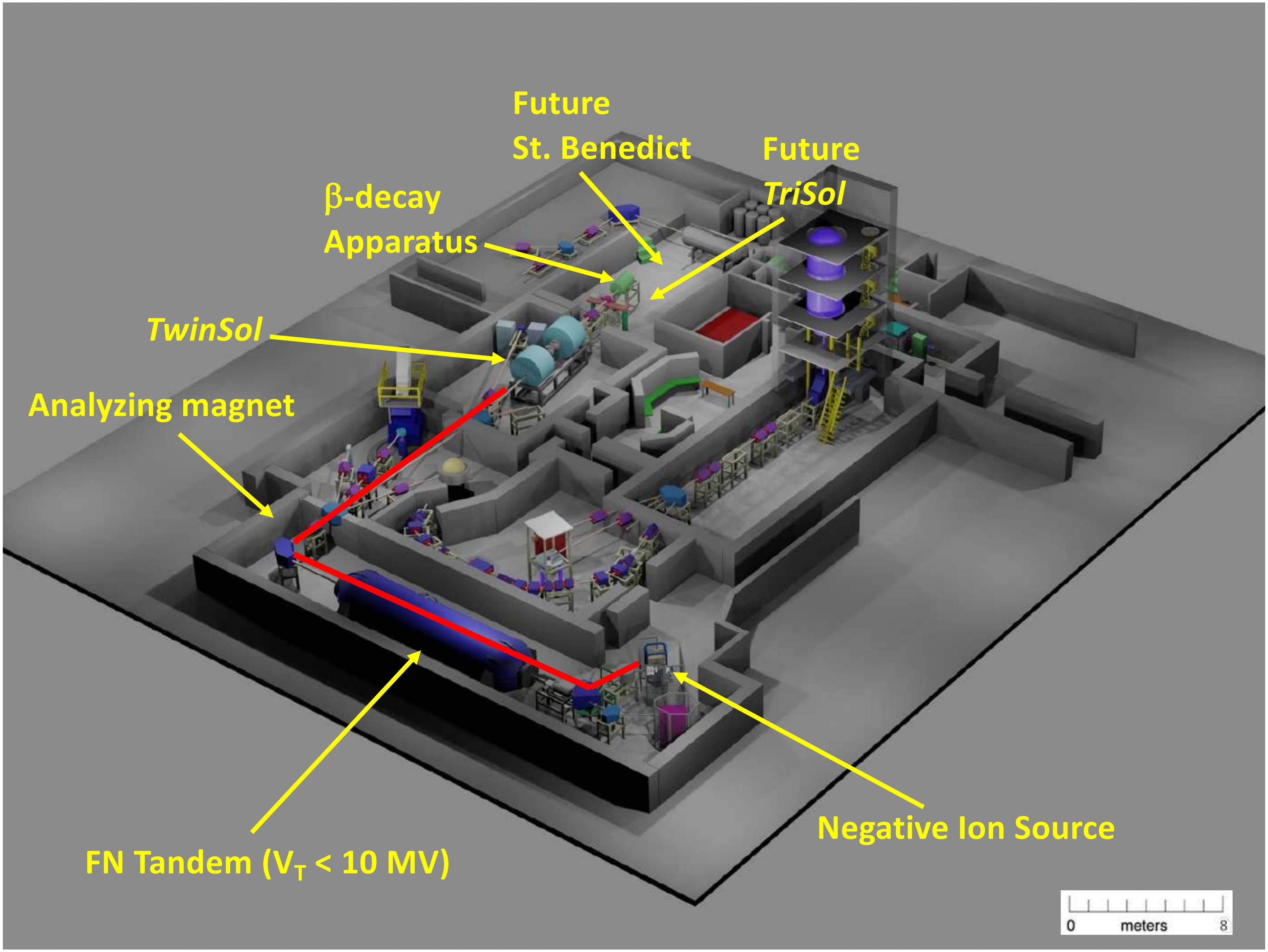
- *Also ^{17}F {but low precision)
- ^{17}F is one of the most plentiful *TwinSol* beams (~2x10^{6} pps)
- This will likely be the first trap experiment.
- Next: measure lighter nuclei (^{11}C to ^{15}O) since they can also probe for scalar/tensor currents.

TwinSol (original and mods)



Modified Target Chamber

Gas Cells


Future
St. Benedict
Future
TriSol
β-decay
Apparatus
TwinSol
Analyzing magnet
FN Tandem (V_T < 10 MV)
Negative Ion Source
0 meters 8

LISE++ to Calculate Settings

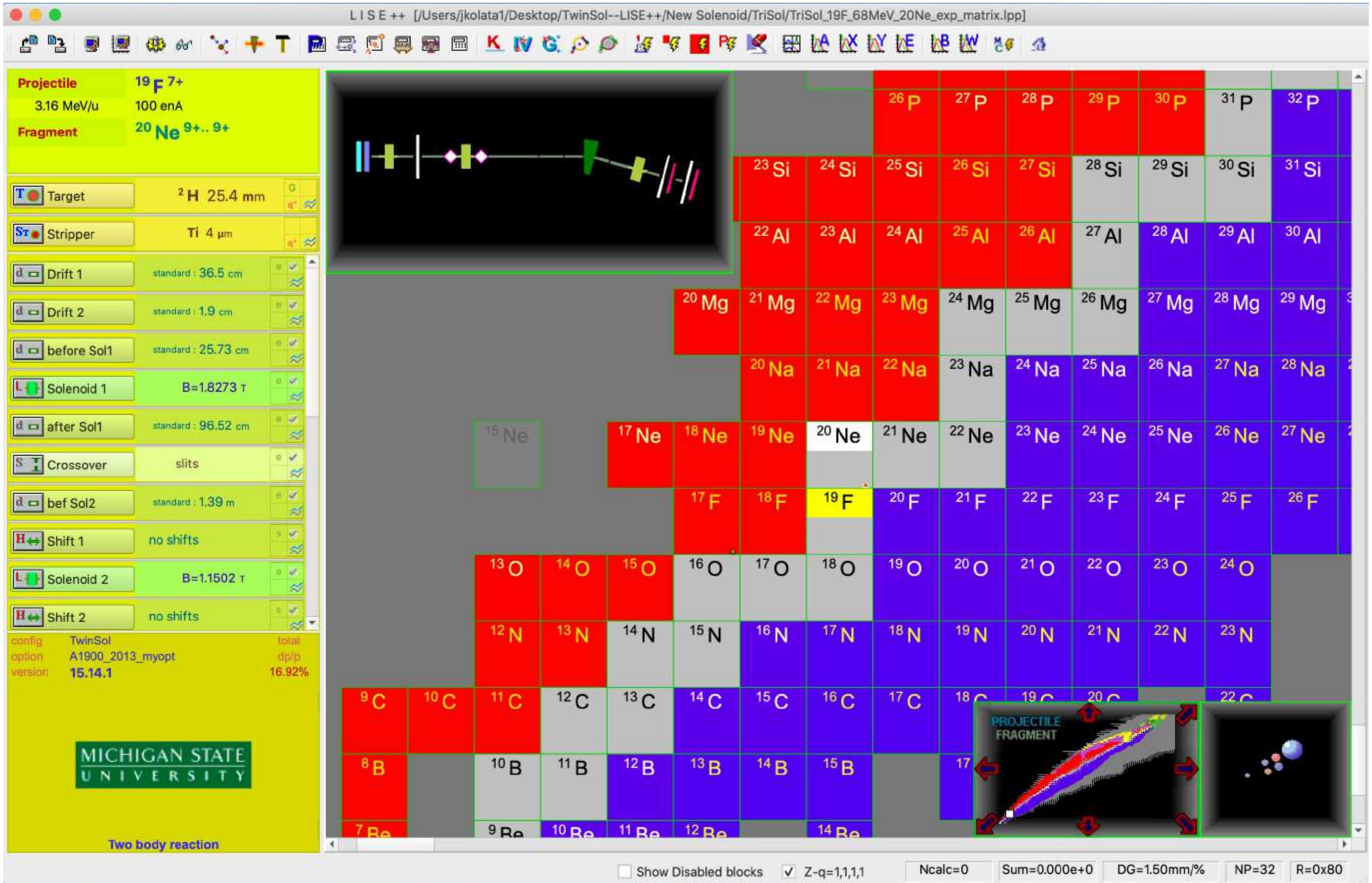
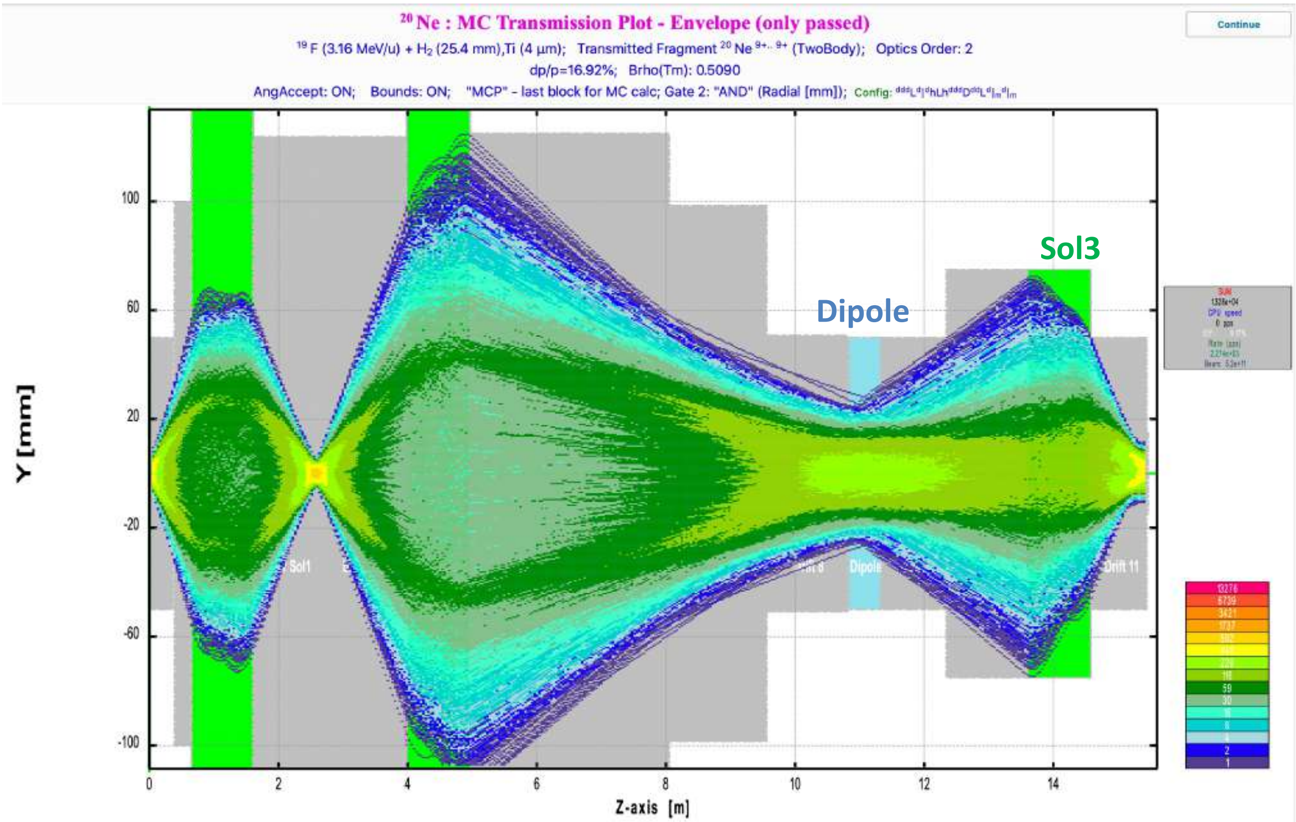


Illustration: ^{20}Ne production

Calculated Beam Envelope



Using the ^{19}F(d,n) reaction at 68 MeV:

8.5 MV on the FN terminal will produce 50 MeV ^{20}Ne. Energies up to 60 MeV might be possible if we're willing to push the terminal voltage.

Calculated beam properties:

2.3×10^{3}/s for 100 enA ^{19}F (7^{+})
10 mm FWHM
ΔE = 1.65 MeV FWHM
±1.75° angle

Purity should be high since the (d,n) Q-value is > +10 MeV. Only ^{17}O has a similar Q-value.

Why ^{20}Ne?

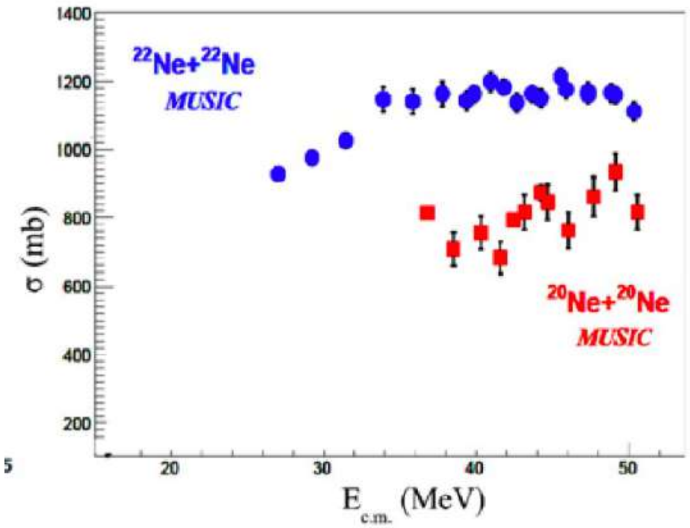
Submission to FRIB PAC-1:

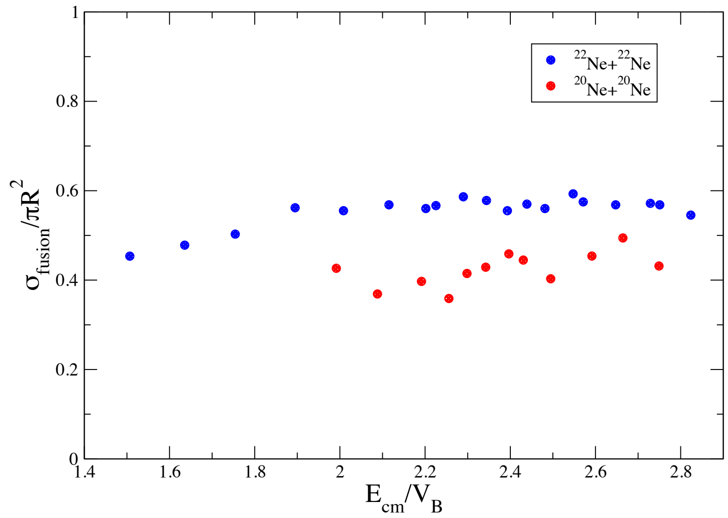
Measurement of ^{26}Ne+^{20}Ne fusion cross sections with the AT-TPC to constrain pycnonuclear burning in accreting neutron stars.

Jaspreet S. Randhawa, Rahul Jain
February 12, 2021

As part of this proposal, it was suggested that a comparison with the fusion of lighter systems, such as ^{20}Ne+^{20}Ne, would be necessary.

Recent Ne+Ne Fusion Data





Avila, et al. ; MUSIC chamber
Argonne National Lab. [2016]
(Preliminary analysis.)

"Reduced" data: corrected for nuclear radius. The big cross section difference remains.

(Note oscillations in ^{20}Ne data)

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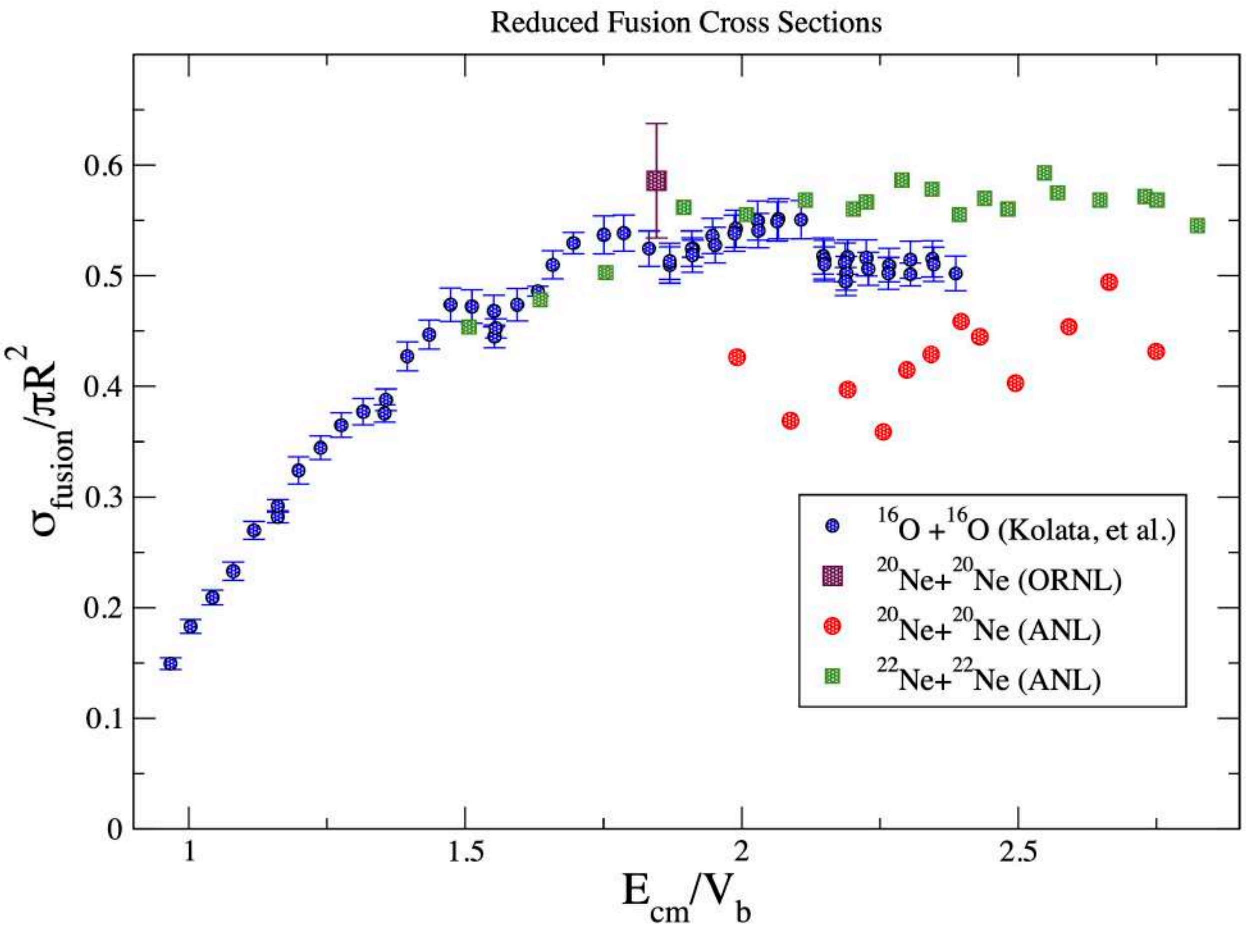
Additional Fusion Data (Reduced)

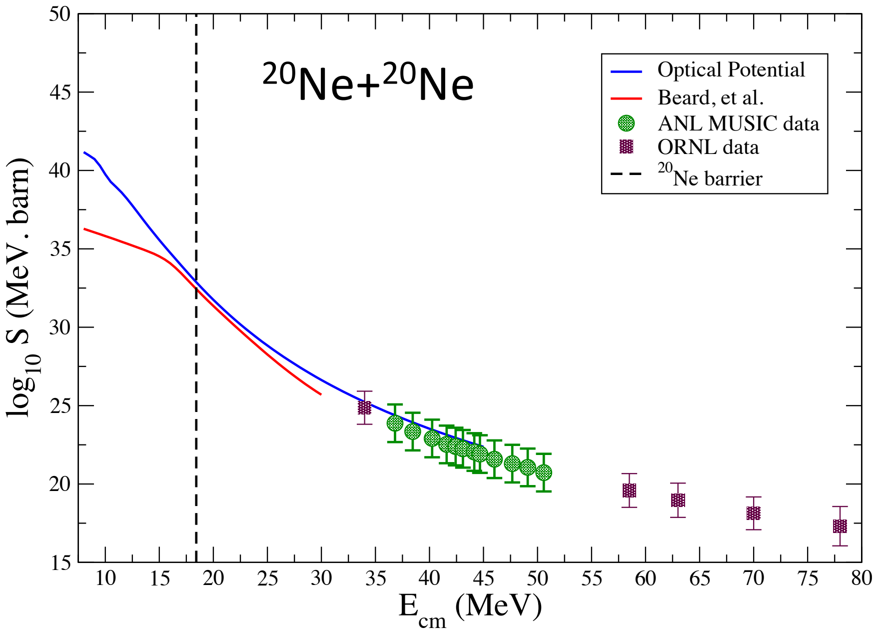


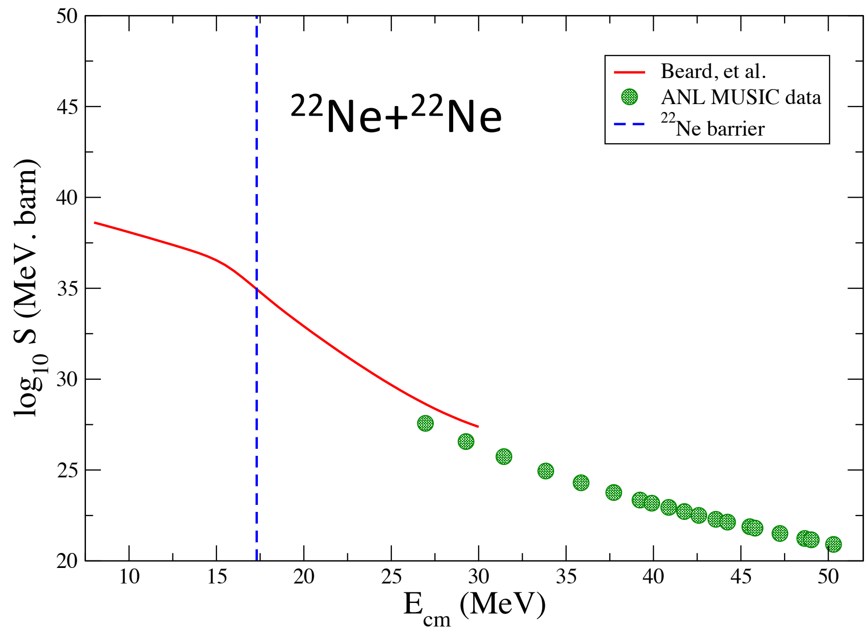
ORNL: PRC 28, 1148 [1983].
Kolata, *et al*.: PRC 16, 891 (1977).

Oscillations in $^{16}O+^{16}O$ occur due to anti-symmetrization in this identical-particle system, which eliminates the odd partial waves. Does $^{20}Ne+^{20}Ne$ show this effect?

The observed absolute magnitude of the ANL $^{20}Ne+^{20}Ne$ data disagrees substantially with the additional data. The big effect of neutron excess disappears. Which is correct?

Astrophysical S-factor





S-factor predictions from M. Beard, *et al.,* At. Data Nucl. Data Tables 96, 541 (2010) using the Sao Paulo potential. (These predictions, based on a polynomial approximation, become increasingly unrealistic above E_{cm} = 30 MeV).

Note that these predictions actually suggest that the ^{20}Ne+^{20}Ne experimental cross sections are too high while the ^{22}Ne+^{22}Ne cross sections are too low, I.e., the observed neutron-excess effect may even have been under-estimated.

An experiment starting at E_{cm} = 25 MeV should easily reach the region below 16 MeV where there is increasing disagreement between Beard, et al. and optical-model predictions.

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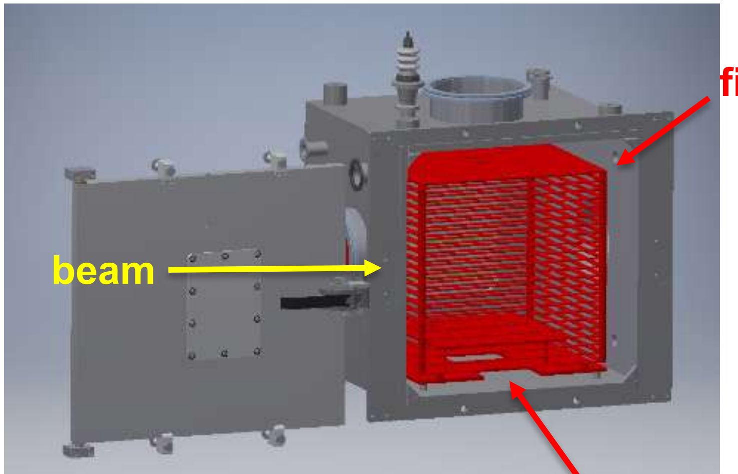
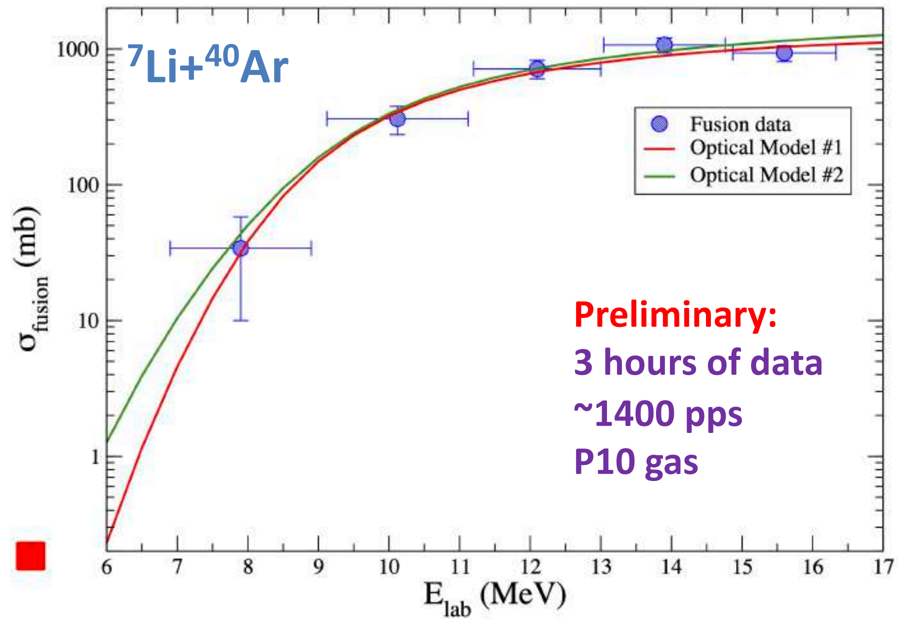
ND-CUBE





- Rectangular geometry ; perpendicular drift
- 40 cm x 40 cm x 40 cm chamber, up to 1 atm
- Micropattern gas detector (MPGD)
- 20 cm x 30 cm, active area ; **1000 anode pads**
- Micromegas with thick GEM amplification

Optical Models:

#1: K.W. Potthast, et al., NPA614, 95 (1997)

#2: J. Cook, et al., NPA388, 153 (1982)

Collaborators

Weak Interaction Physics

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Fred Becchetti
James J. Kolata
Patrick O'Malley

Dan Burdette
BiYing Liu
Jacob Long
Adrian Valverde

TriSol Project

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Patrick O'Malley
Jaspreet Randhawa

Sydney Coll (undergrad)

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