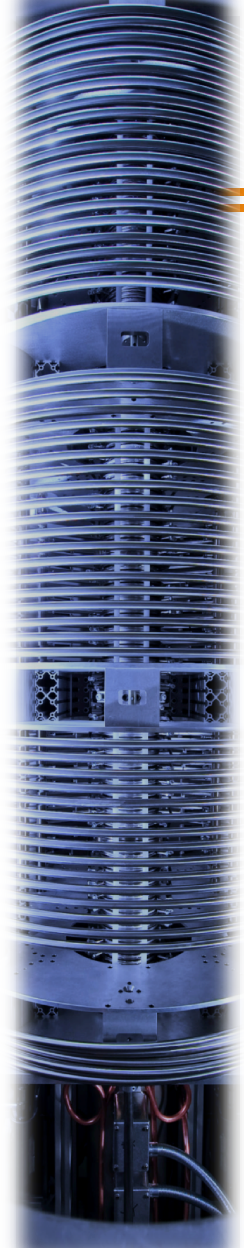


Status of St. Benedict at the Nuclear Science Laboratory

Daniel Burdette
University of Notre Dame

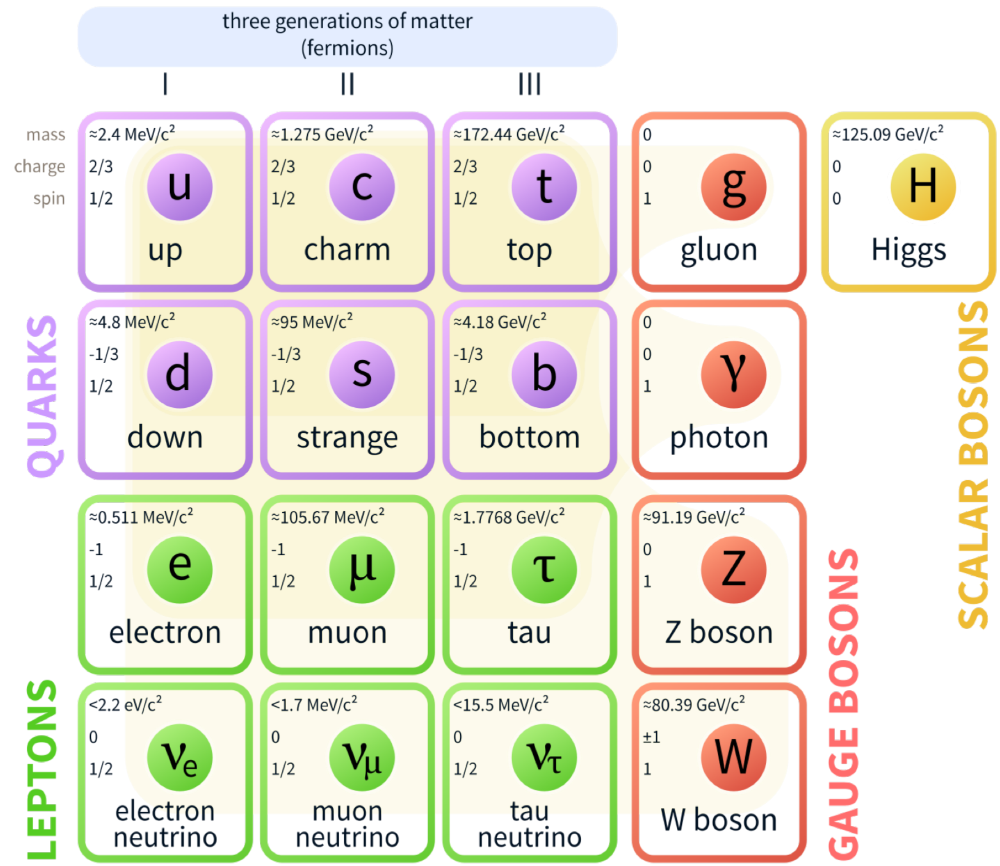
SMI 2019
July 17, 2019
Montreal, Québec

The Standard Model of Elementary Particles

- Provides a description of matter in the universe

- There are still a couple shortcomings:
  - matter vs. antimatter asymmetry
  - dark matter/energy
  - why 3 generations?
  - neutrino hierarchy

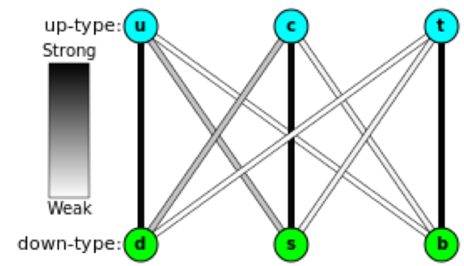
- Want to find some sort of experimental evidence that there is something beyond this



The CKM Matrix

- The CKM matrix describes mixing between quark's strong eigenstates through weak interactions

$$\begin{pmatrix} |d_w\rangle \\ |s_w\rangle \\ |b_w\rangle \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} |d_s\rangle \\ |s_s\rangle \\ |b_s\rangle \end{pmatrix}$$



- The standard model requires the CKM matrix to be unitary, with most precise test given by top row

$$\sum_i |V_{ui}|^2 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

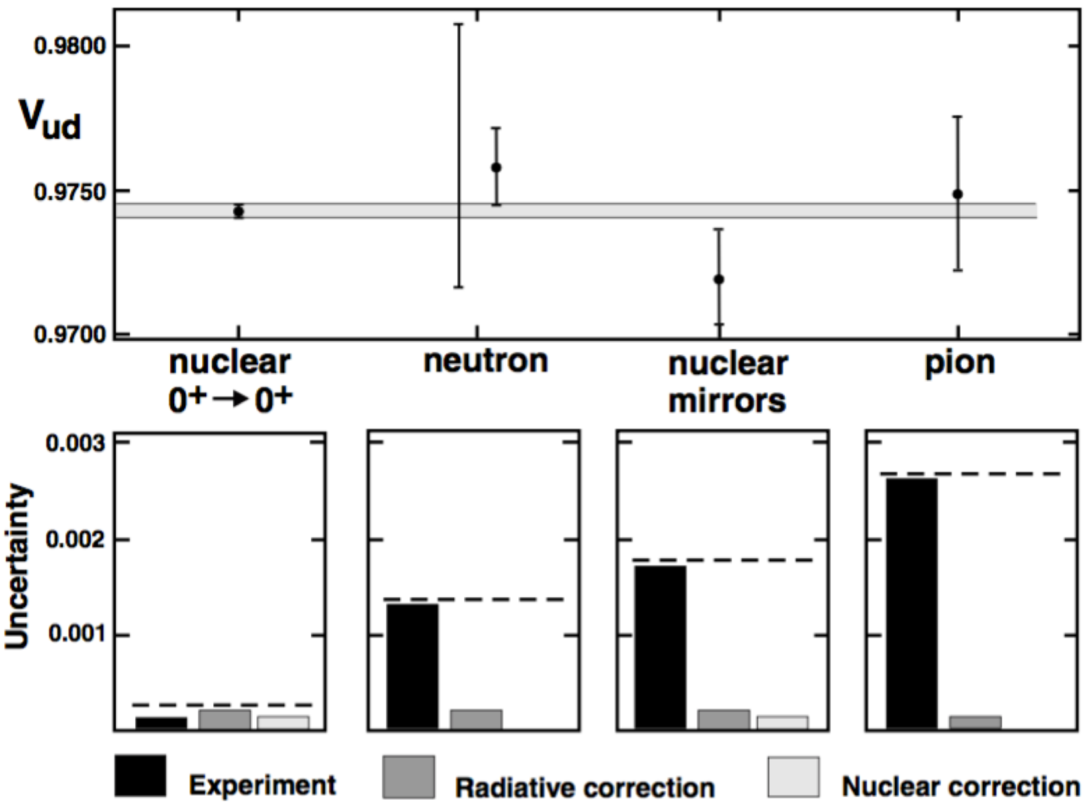
- Imperfections could lead to new physics:
  - Another quark generation
  - Extra Z boson
  - Supersymmetry

...or be from bad experimental data..

V_{ud} can be obtained via nuclear beta decay

Obtaining the V_{ud} element

- For a reliable CKM matrix unitarity test, V_{ud} need to be precise and accurate.
- Accuracy tested by a determination of V_{ud} using multiple systems.



I.S. Towner and J.C. Hardy, Rep. Prog. Phys. **73**, 046301 (2010)

- Neutron decay
  - ➢ No nuclear corrections
  - ➢ Lifetime issues
  - ➢ Need Fermi-GT mixing ratio
- Pion decay
  - ➢ No nuclear corrections
  - ➢ Very low branching ratio
- Pure Fermi transitions
  - ➢ Most precise determination
  - ➢ Need nuclear corrections
- Nuclear Mirrors
  - ➢ Need nuclear corrections
  - ➢ Need Fermi-GT mixing ratio

Probe V_{ud} with $\mathcal{F}t$ value

Study strength of transition with corrected $\mathcal{F}t$ value,

$$\mathcal{F}t^{0^+ \to 0^+} = ft(1+\delta_R')\left(1+\delta_{NS}^V-\delta_C^V\right) = \frac{K}{2{G_V}^2(1+\Delta_R^V)}$$

$$G_V = G_F V_{ud}$$

Need both experimental measurements and theoretical calculations:

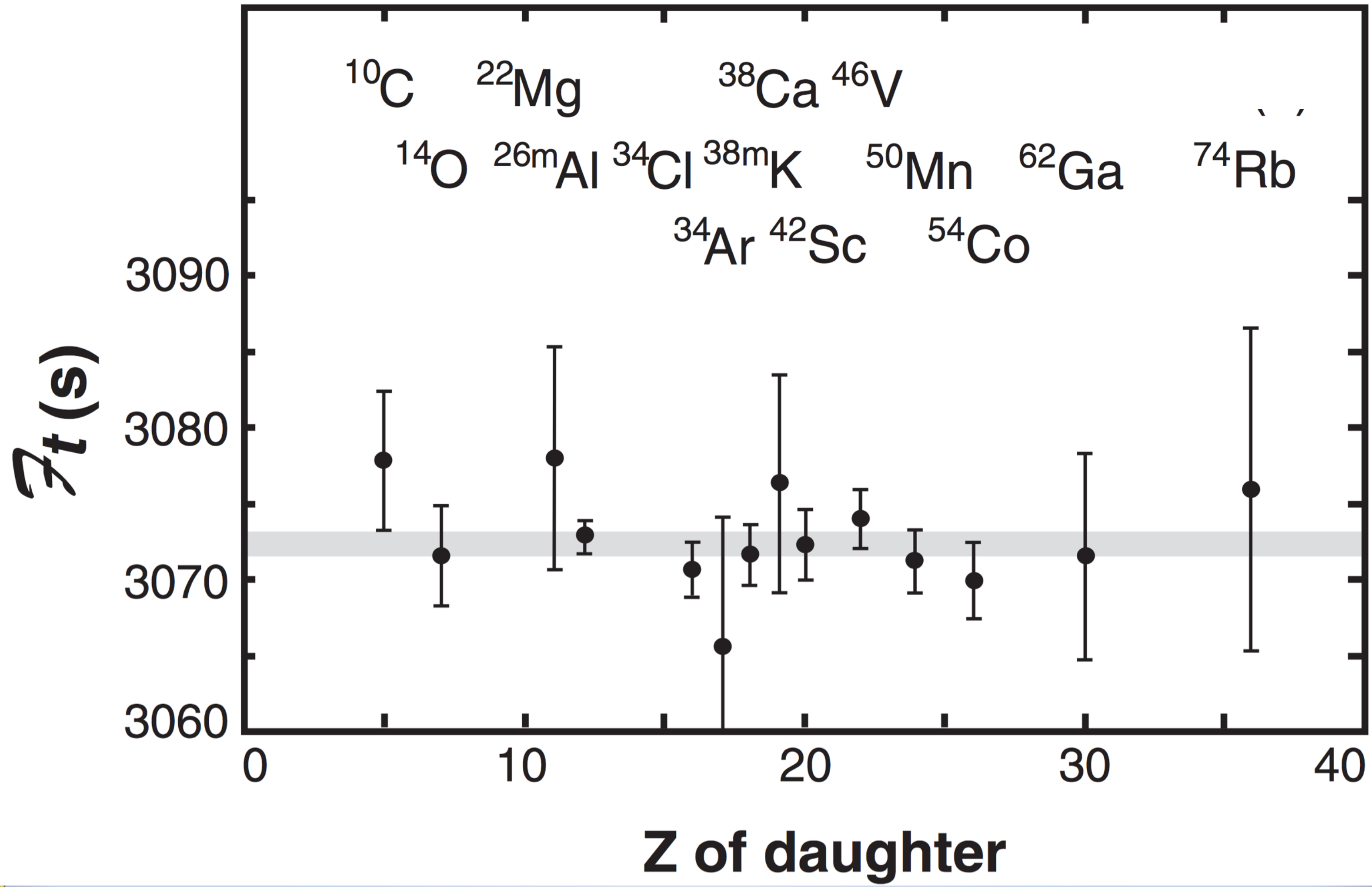
- Experimental
  - Q value (f)
  - half-life ($t_{1/2}$)
  - branching ratio (BR)

$$t = t_{1/2}\left(\frac{1+P_{EC}}{BR}\right)$$

- Theoretical
  - Nucleus dependent radiative terms (δ_R' and δ_{NS}^V)
  - Isospin symmetry breaking correction term (δ_C^V)

Superallowed $0^+ \rightarrow 0^+$ Pure Fermi Decays

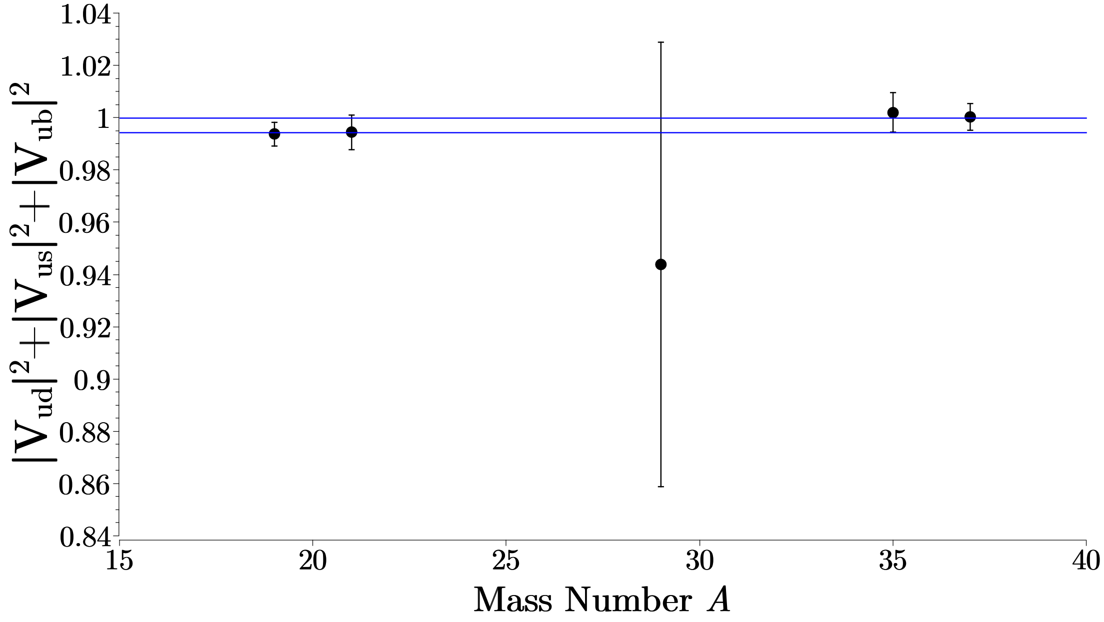
J.C. Hardy and I.S. Towner, PRC **91**,025501 (2015).



V_{ud} from mirror transitions

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

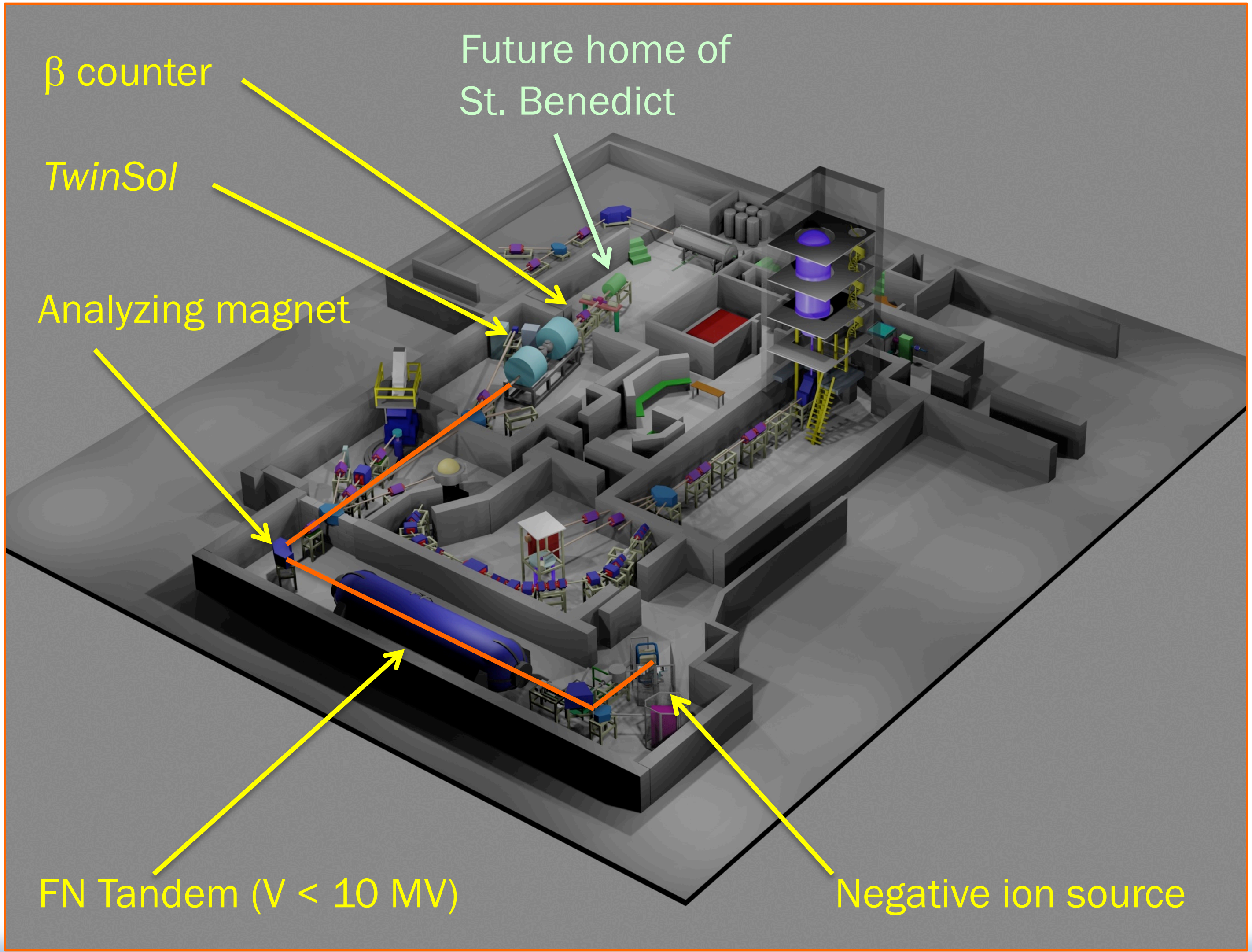
- Only 5 nuclei
- One more parameter needed:
  - ✓ Half-life
  - ✓ Branching ratios
  - ✓ Q-values
  - ✓ Fermi-to-Gamow Teller mixing ratio ρ



ρ determined by measuring either:

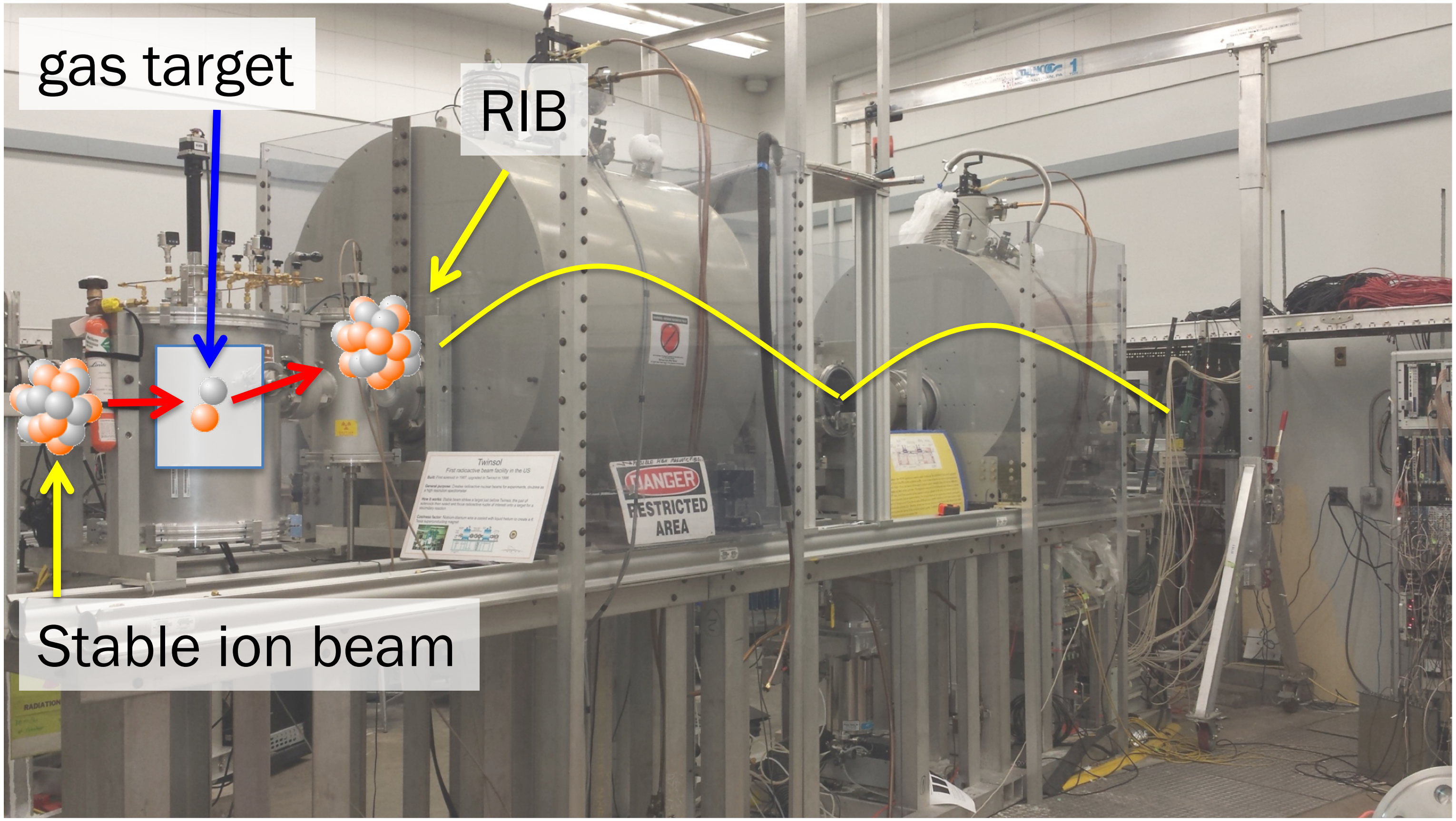
- β asymmetry parameter A_β
- ν asymmetry parameter B_ν
- β-ν angular correlation $a_{\beta\nu}$

Nuclear Science Laboratory



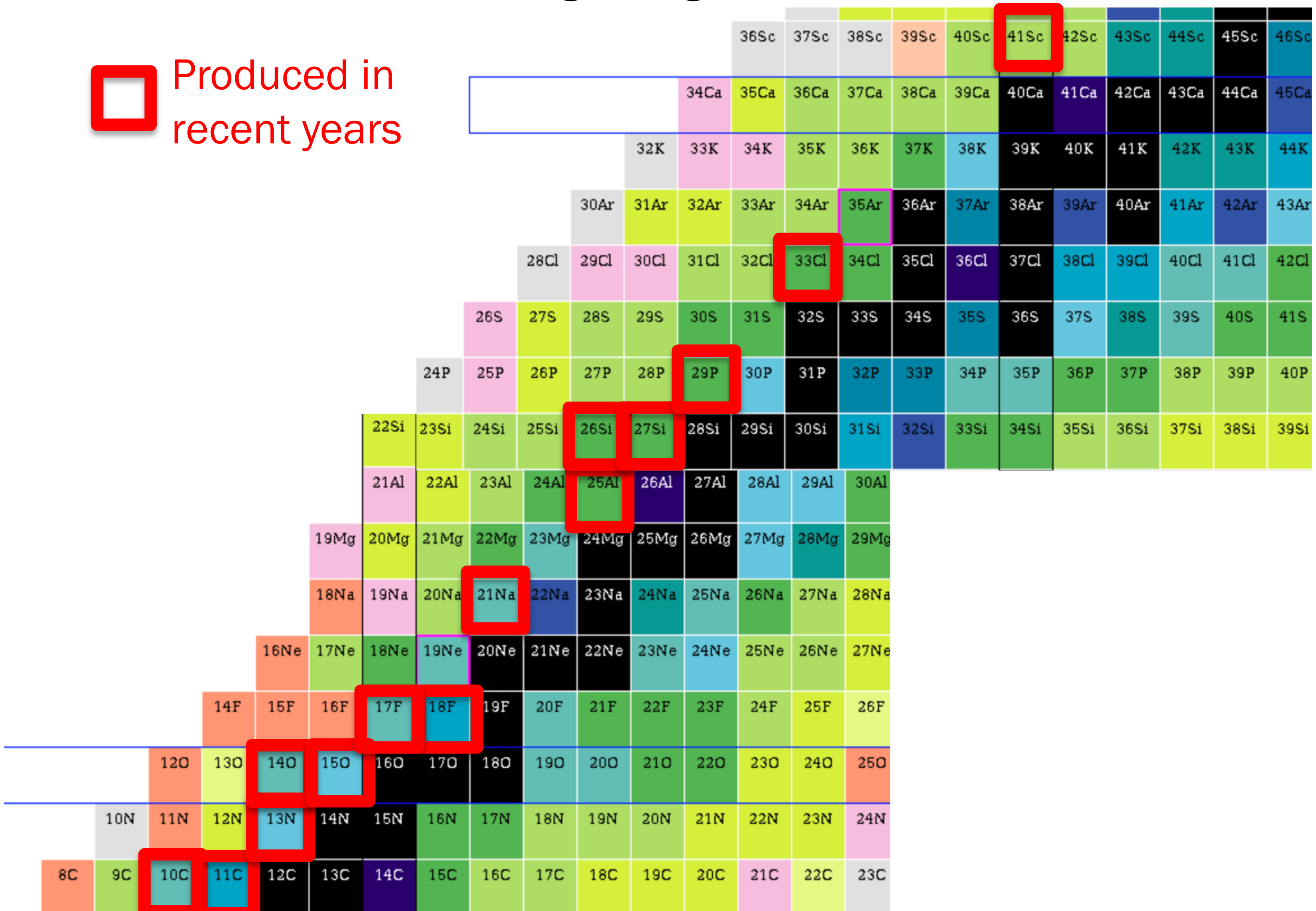
TwinSol facility

F.D. Becchetti *et al.*, NIM A **505**, 377 (2003)

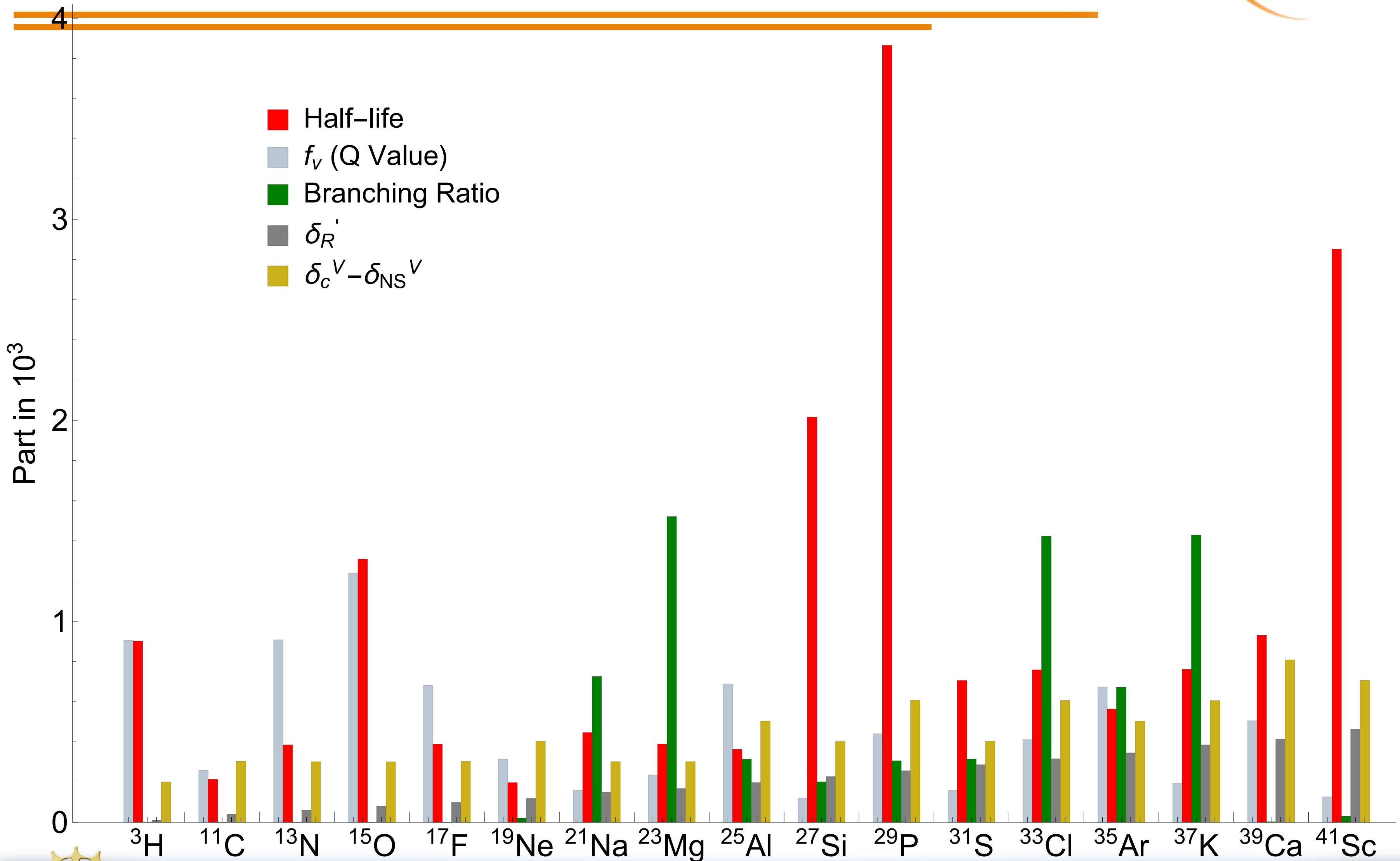


RIB produced at *TwinSol*

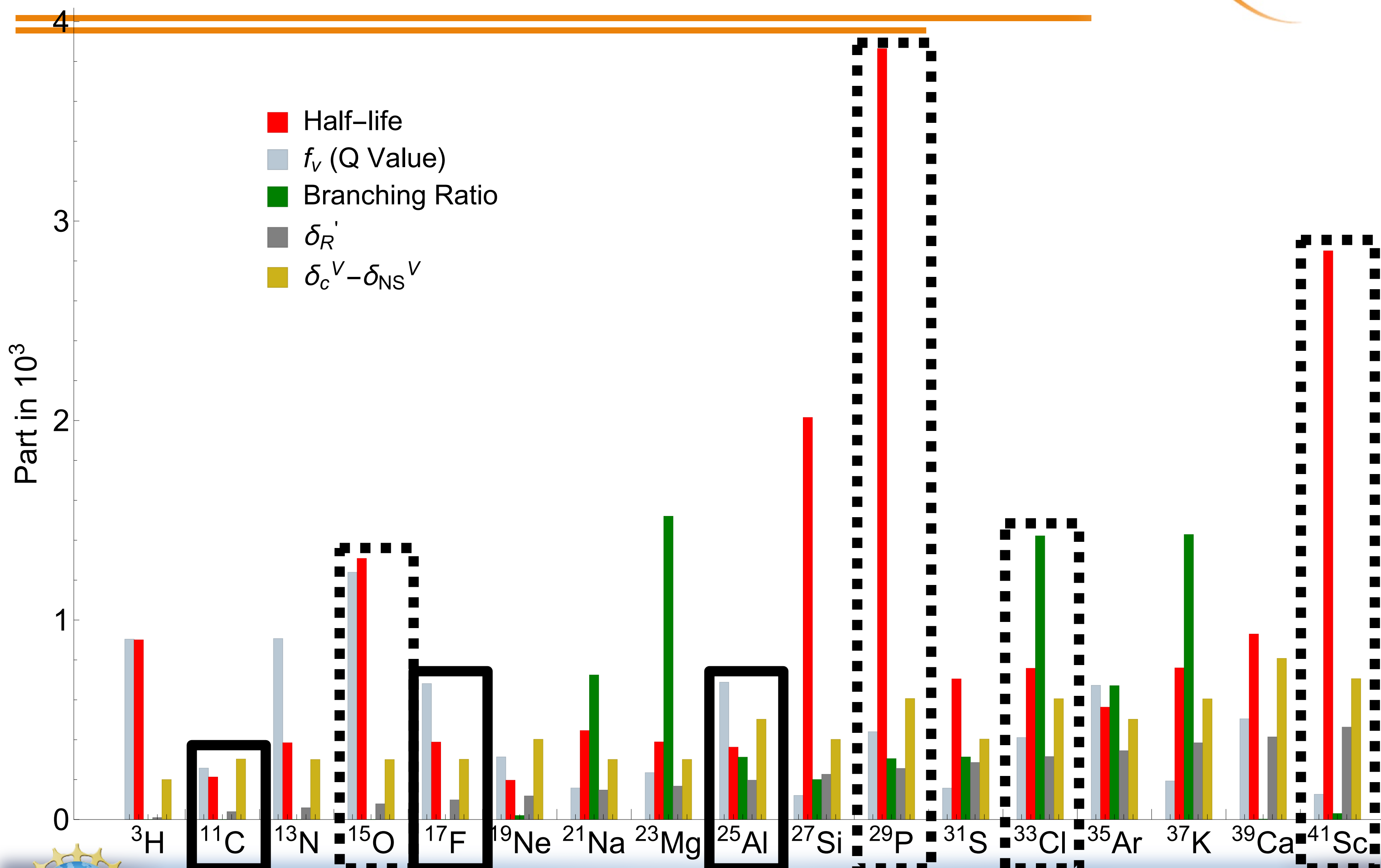
Expended list of delivered RIB due to growing research activities



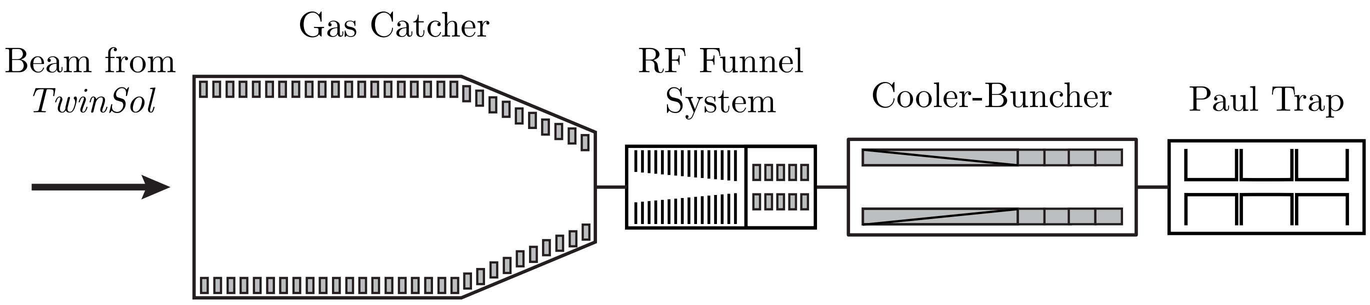
Recent Work with the β–Counting Station



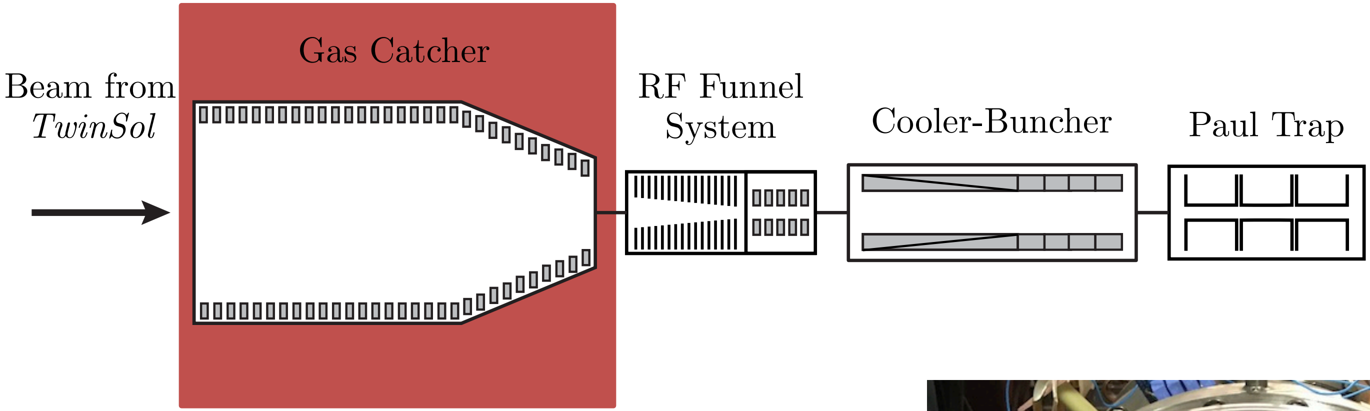
Recent Work with the β–Counting Station

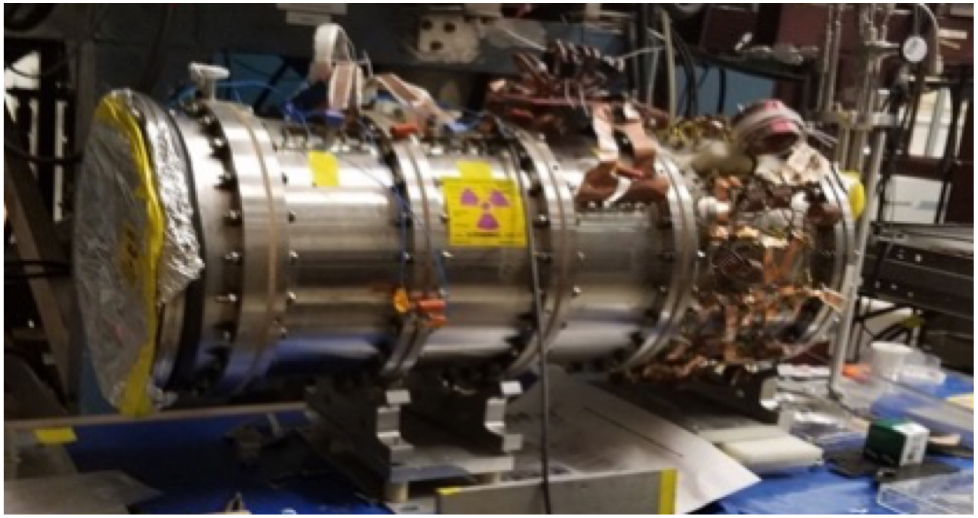


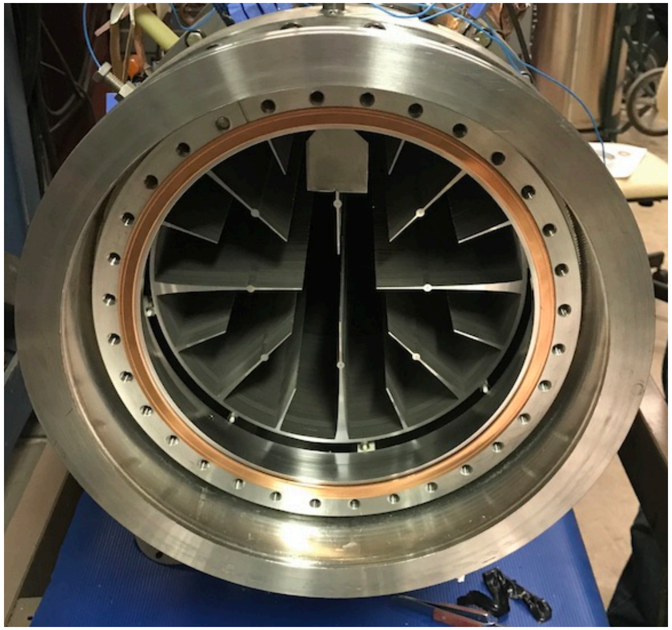
Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap



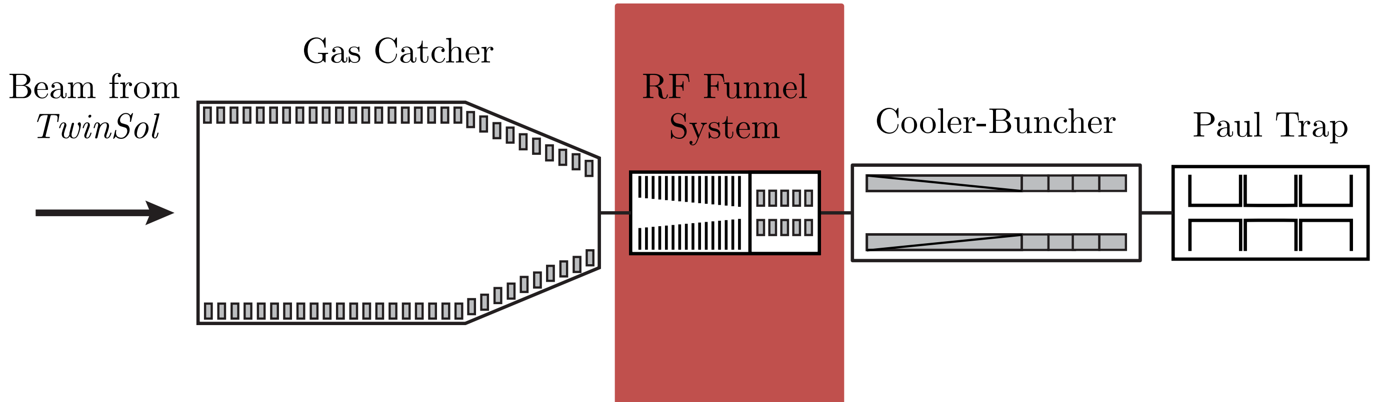
Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap

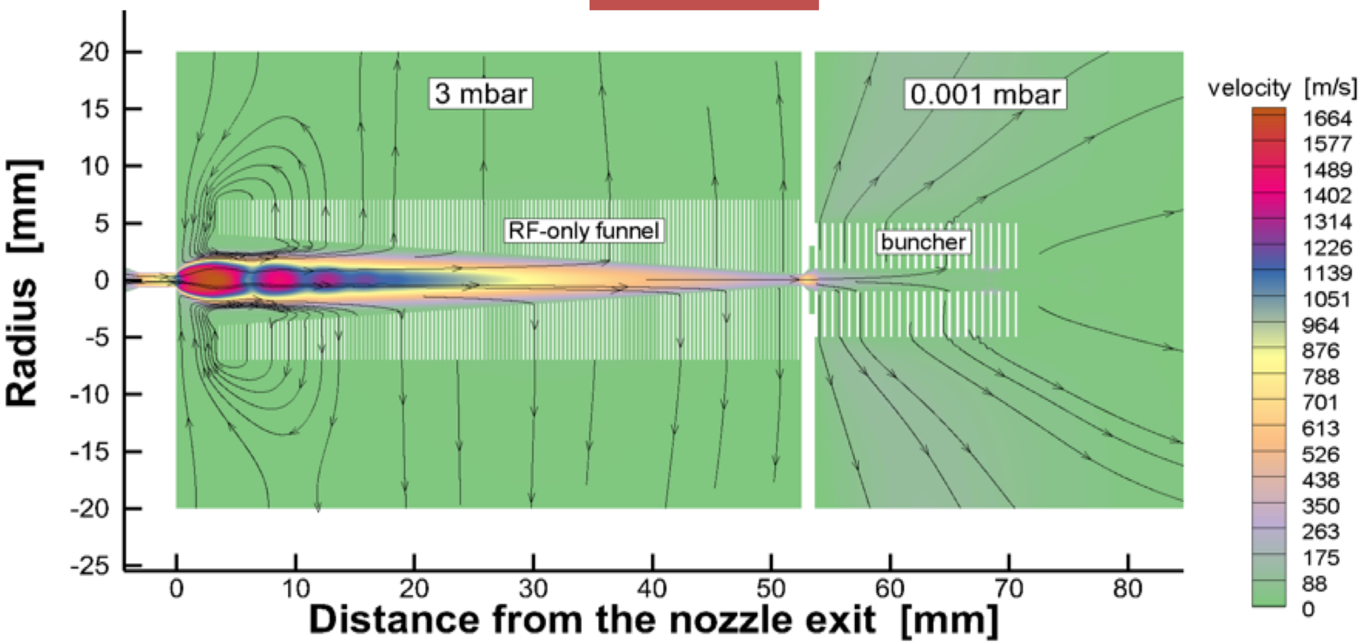




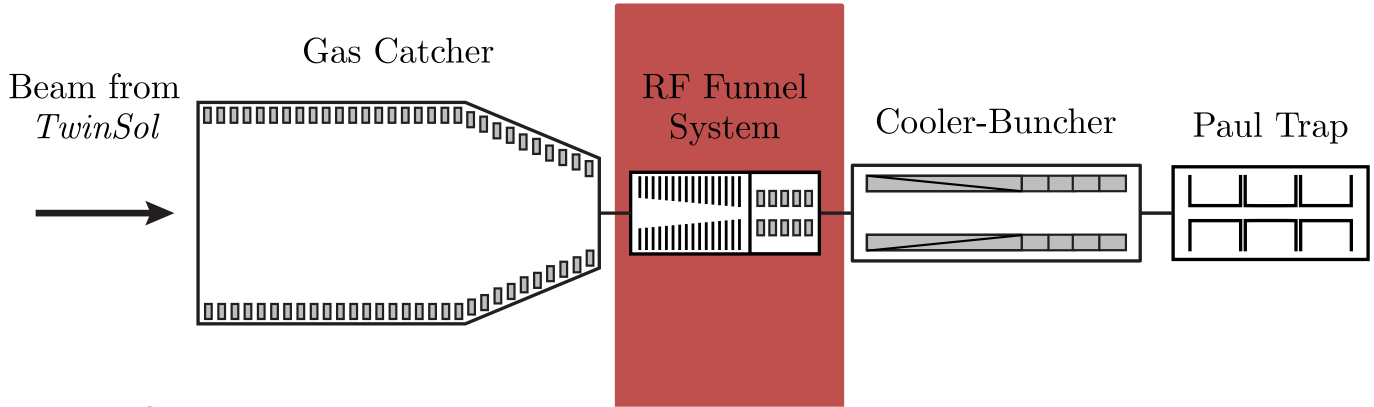


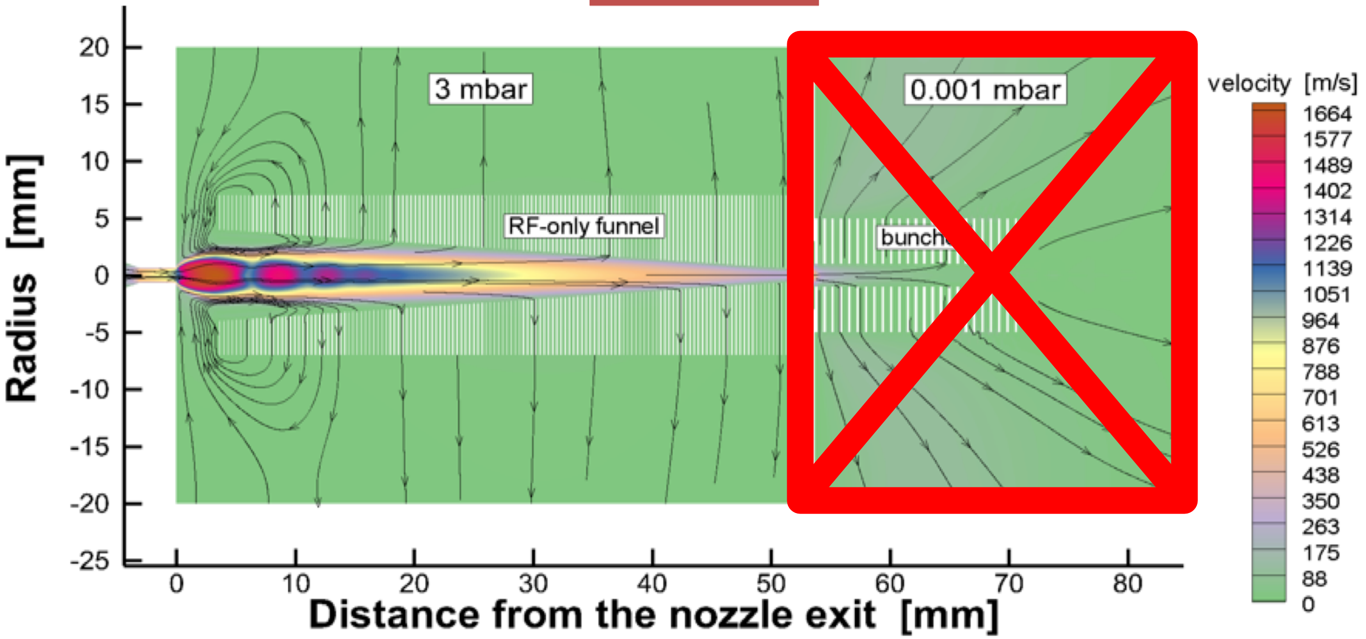
Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap



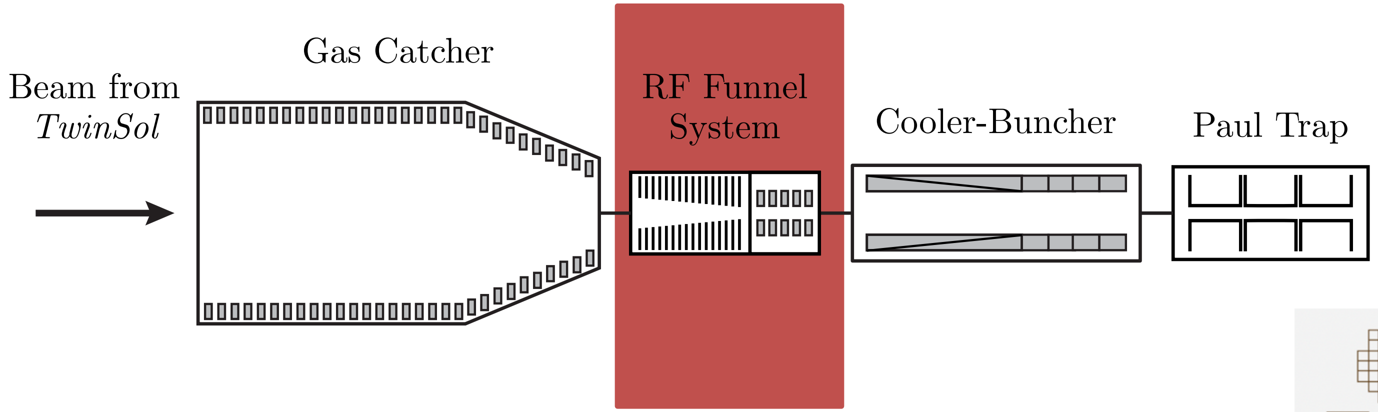


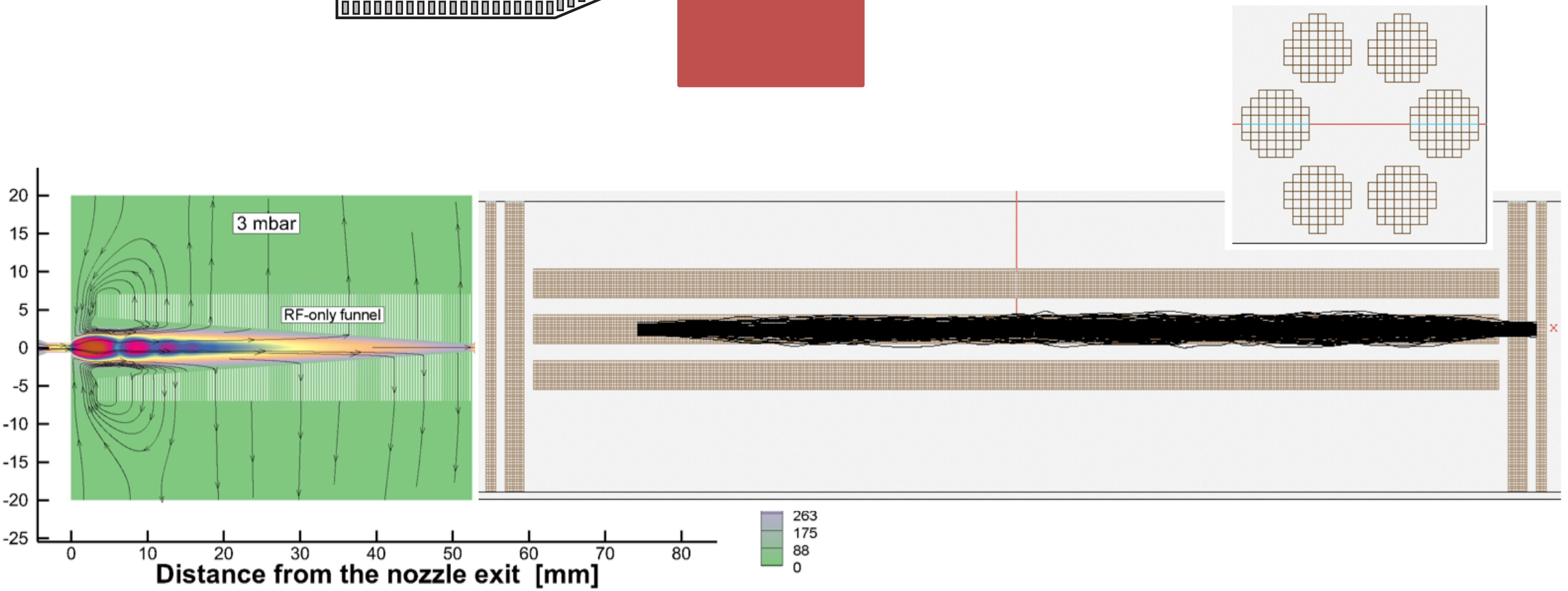
Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap



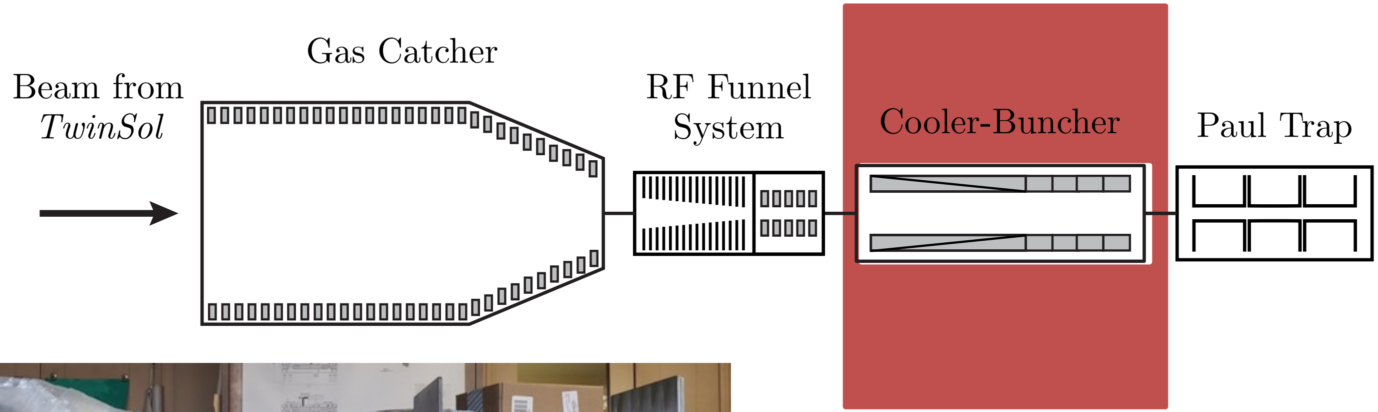


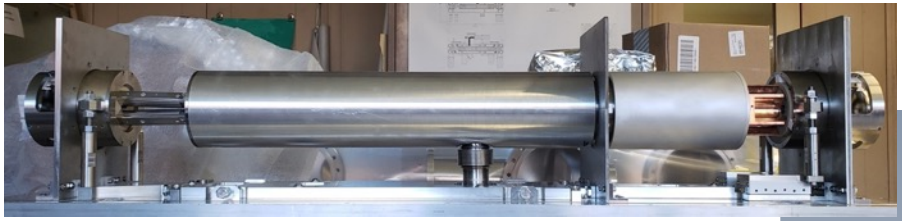
Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap

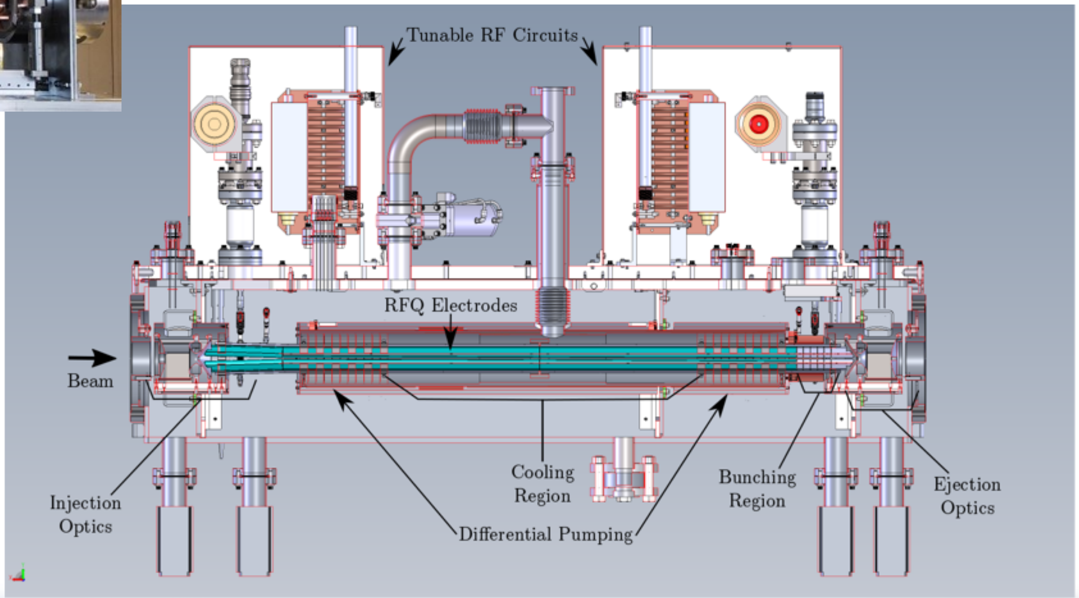




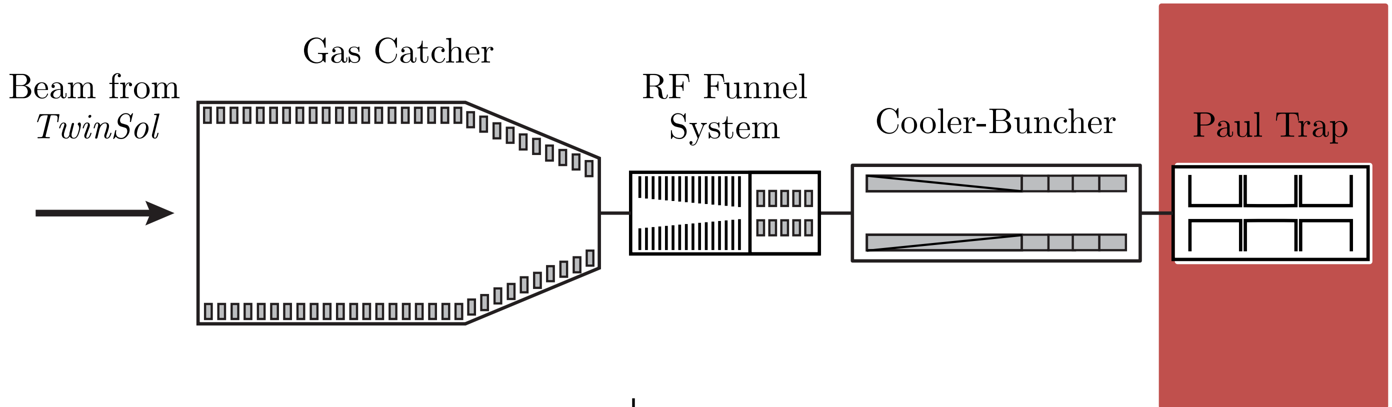
Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap

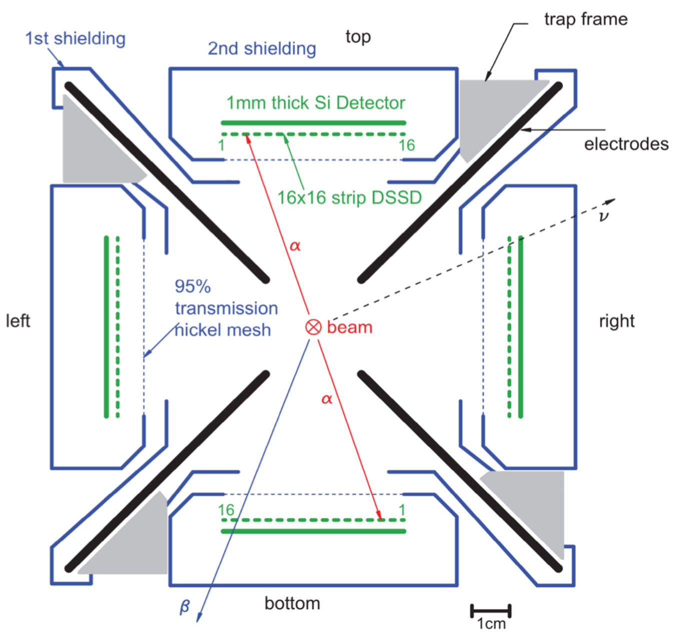


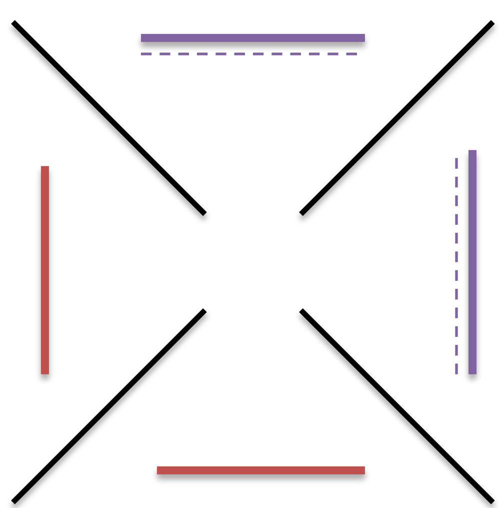




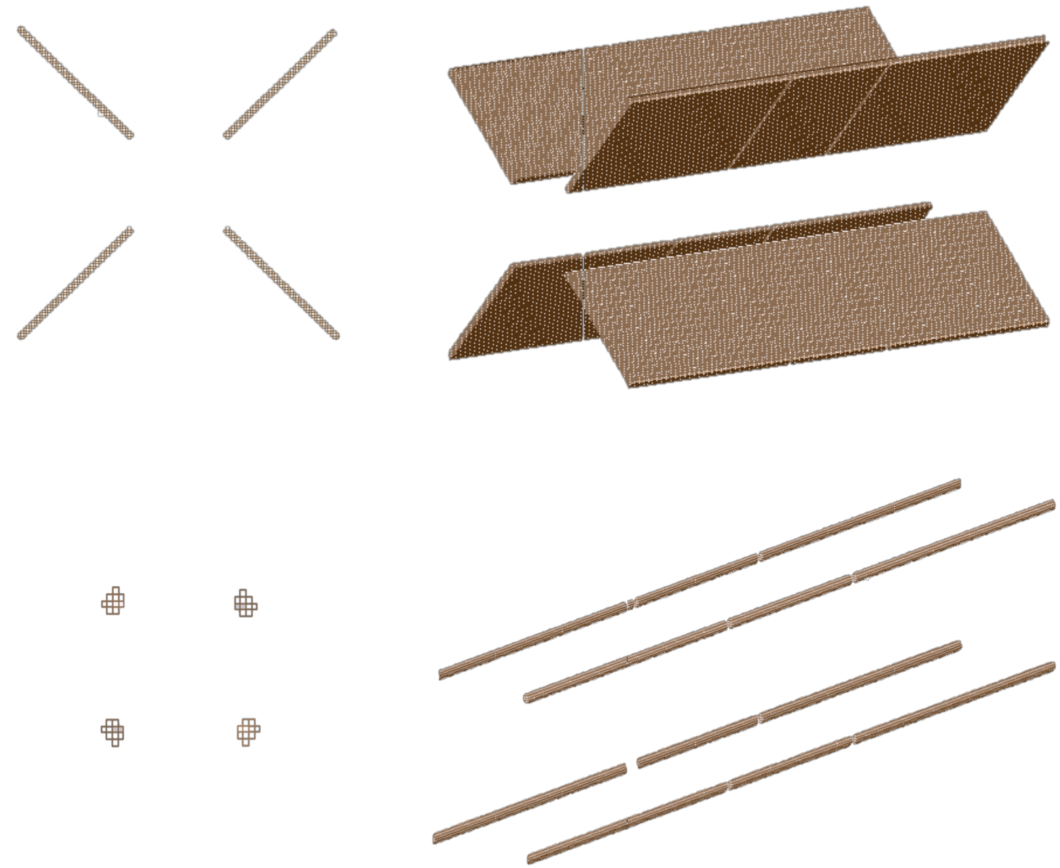
Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap

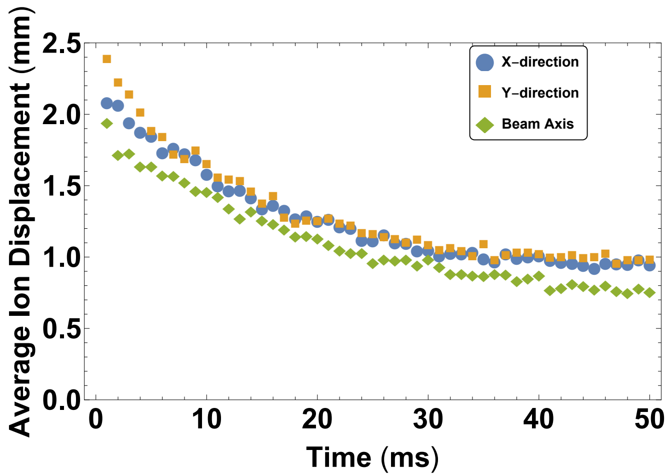


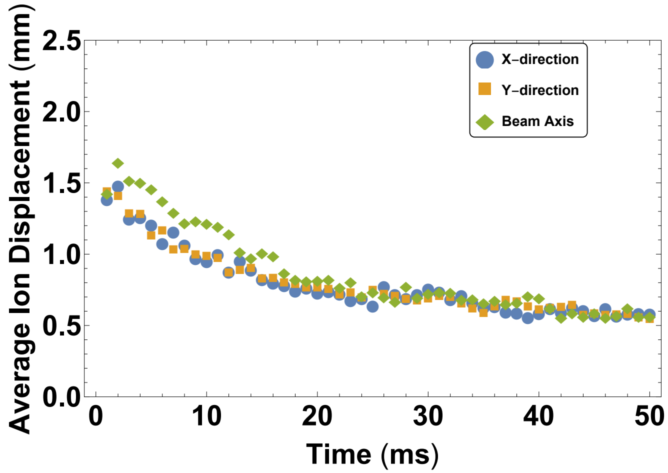




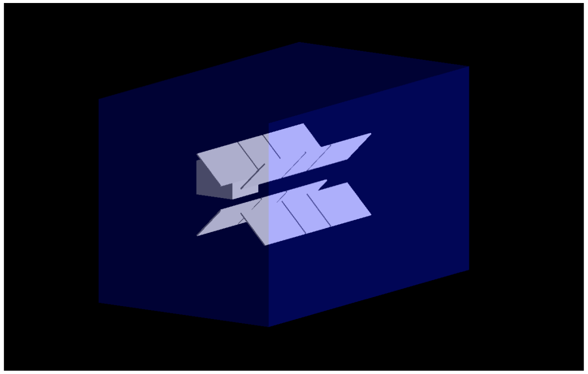
Paul Trap Simulations

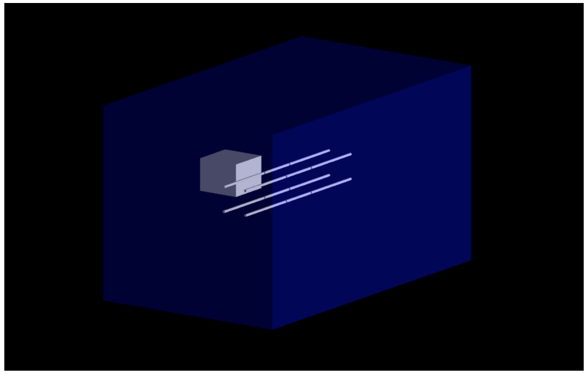


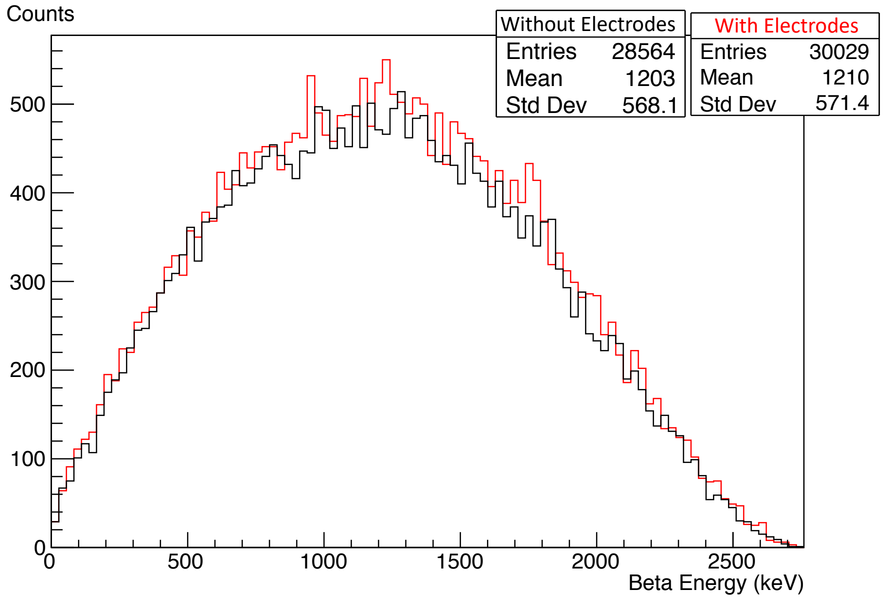


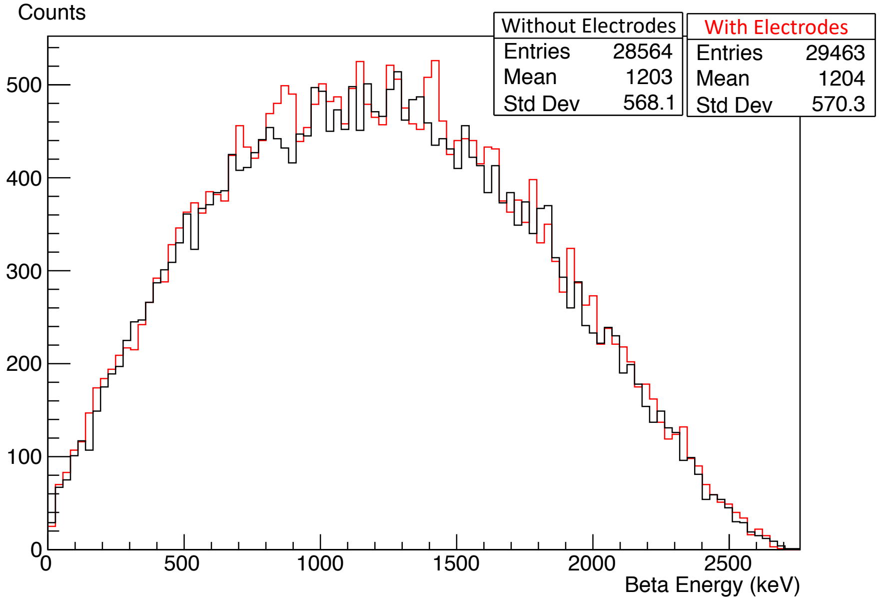


Paul Trap Simulations









Conclusion

- Although the most precise determination for V_{ud} comes from superallowed pure Fermi decays, mixed mirrors provide another test for accuracy
- With the half-life program winding down and production of mirror nuclei developed, the compilation of St. Benedict can begin
- Fast beams from *TwinSol* will be decelerated, thermalized and formed into bunches for injection into the Paul trap using a combination of a gas catcher, RF funnel, SPIG, and cooler-buncher
- Simulations of the Paul Trap are underway to determine the ideal electrode geometry to perform the angular correlation measurement

Acknowledgements

Maxime Brodeur
Jason Clark
James Kelly
Jeffrey Klimes
Andreas Pardo
Biying Liu
Jacob Long
Patrick O'Malley
Ryan Ringle
Guy Savard
Adrian Valverde
Victor Varentsov

Thank you!