Masses of $T = 2$ nuclides

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TITAN collaboration meeting
TRIUMF
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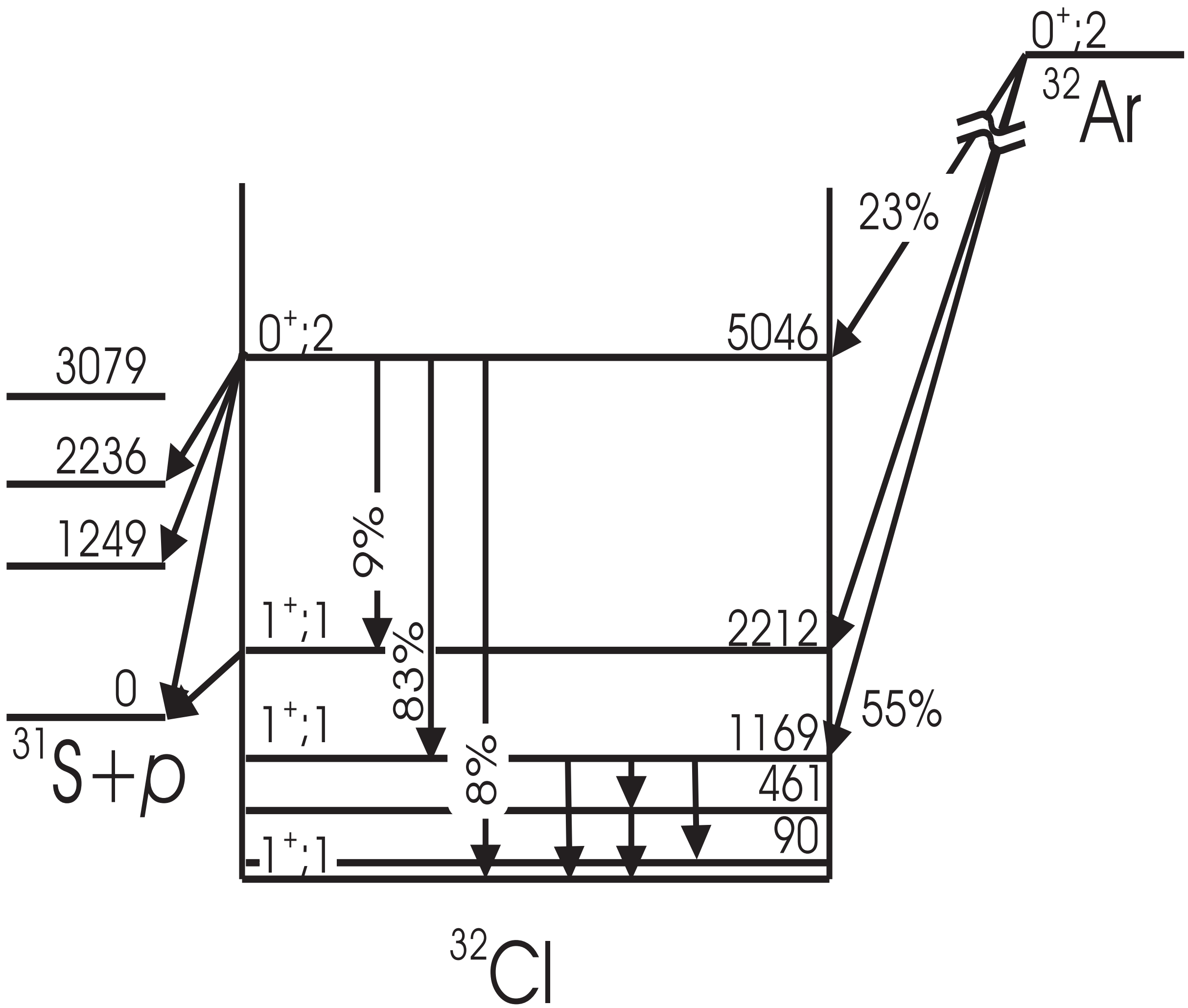
Outline

- Superallowed $0^+ \rightarrow 0^+$ $T = 2$ β decays
- Searching for scalar currents: the β–ν correlation coefficient $\tilde{a}$
- Testing CKM matrix unitarity: the isospin symmetry breaking correction δ_c
- Dependencies on Q_{EC} and calibration data
- Recent experiments on masses of superallowed $T = 2$ β decay daughter levels
- TITAN: masses of $T = 2$ parents (and daughters)

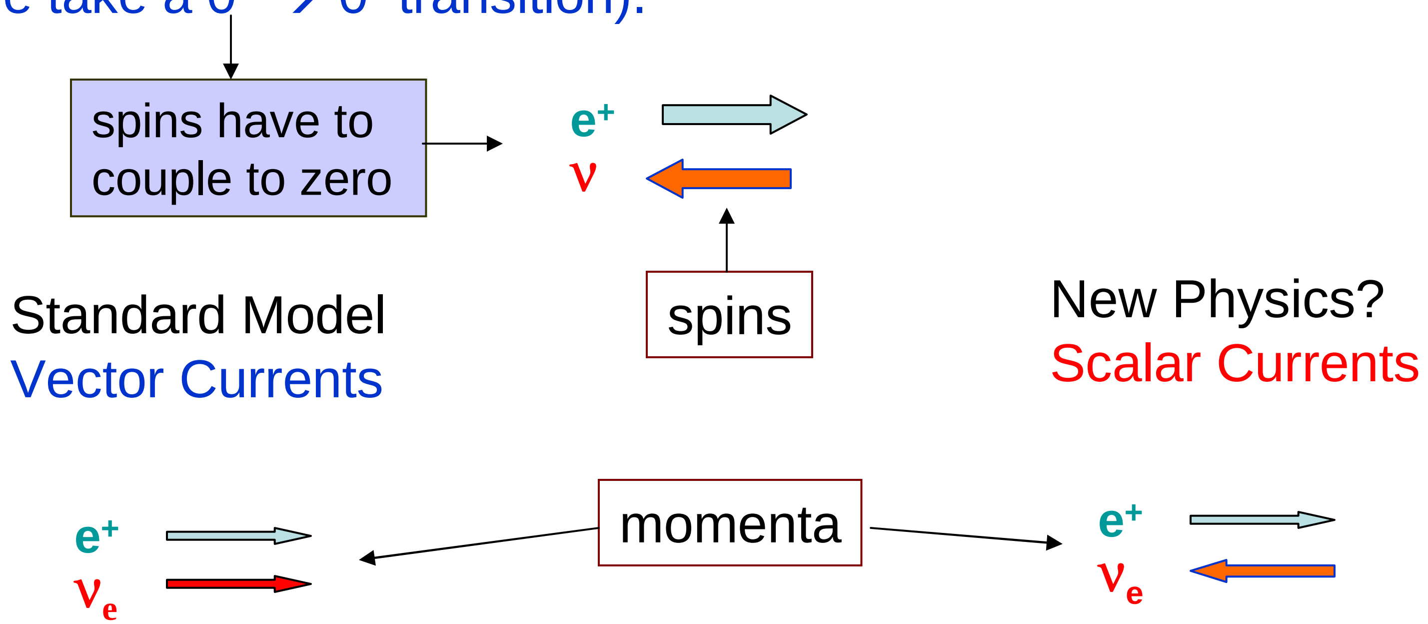
Superallowed T = 2 β decays:
eg. ^{32}Ar(β^{+}ν)^{32}Cl*



Bhattacharya *et al*., PRC **77**, 065503 (2008)

Detecting scalar currents in weak decays

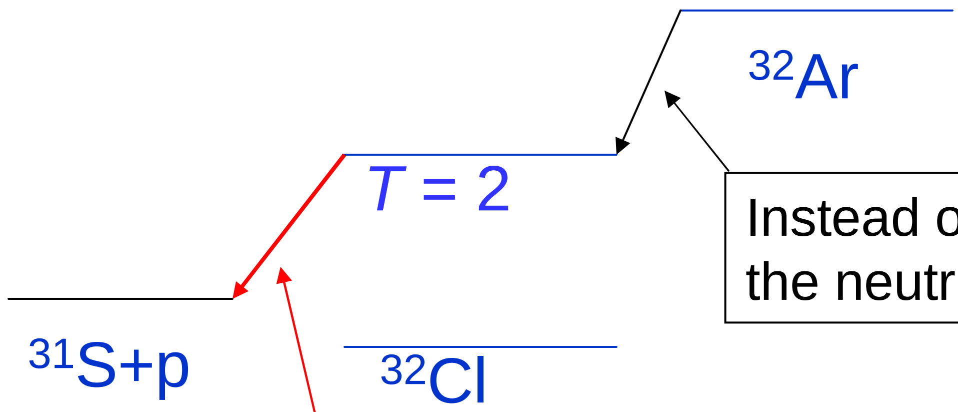
The e-ν correlation depends strongly on the nature of the carrier (we take a $0^+ \rightarrow 0^+$ transition).



$dW/d\Omega = 1 + \mathbf{p}_e \mathbf{p}_\nu / E_e E_\nu$

$dW/d\Omega = 1 - \mathbf{p}_e \mathbf{p}_\nu / E_e E_\nu$

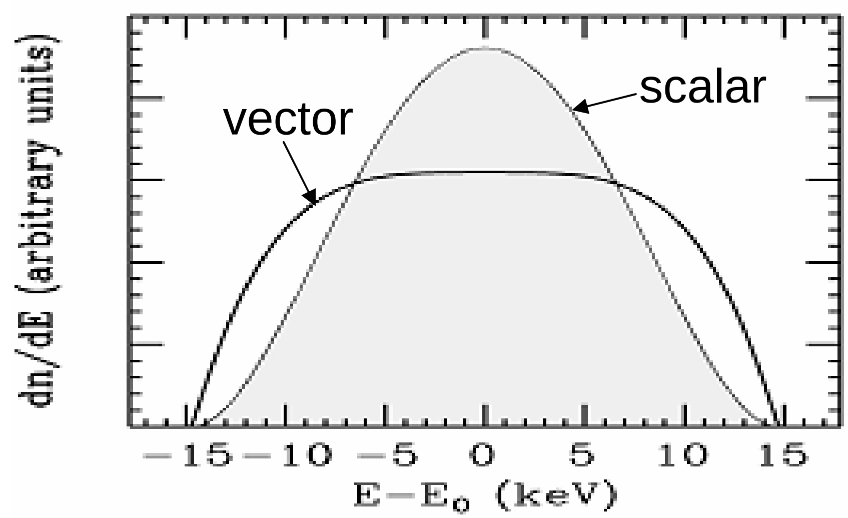
A trick to avoid detecting the neutrino



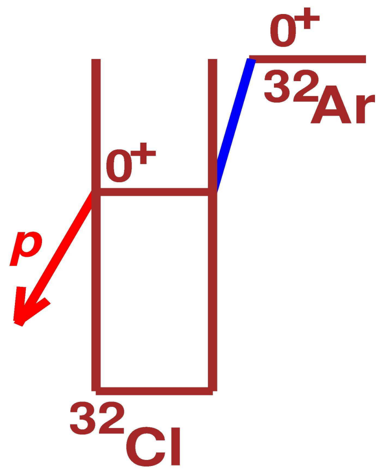
Instead of detecting the neutrino

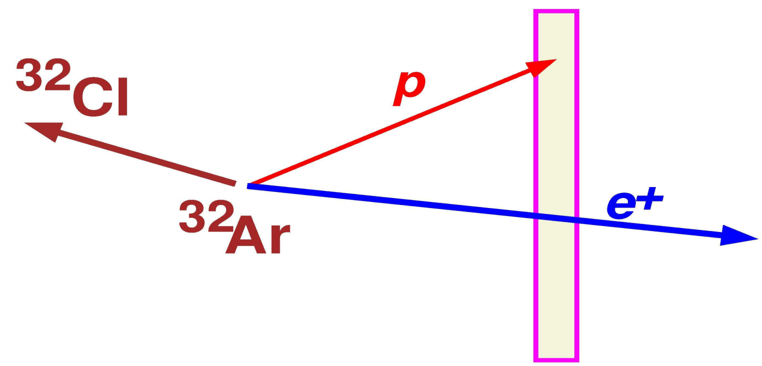
Detect the proton that contains the info about the ^{32}Cl recoil (Doppler)

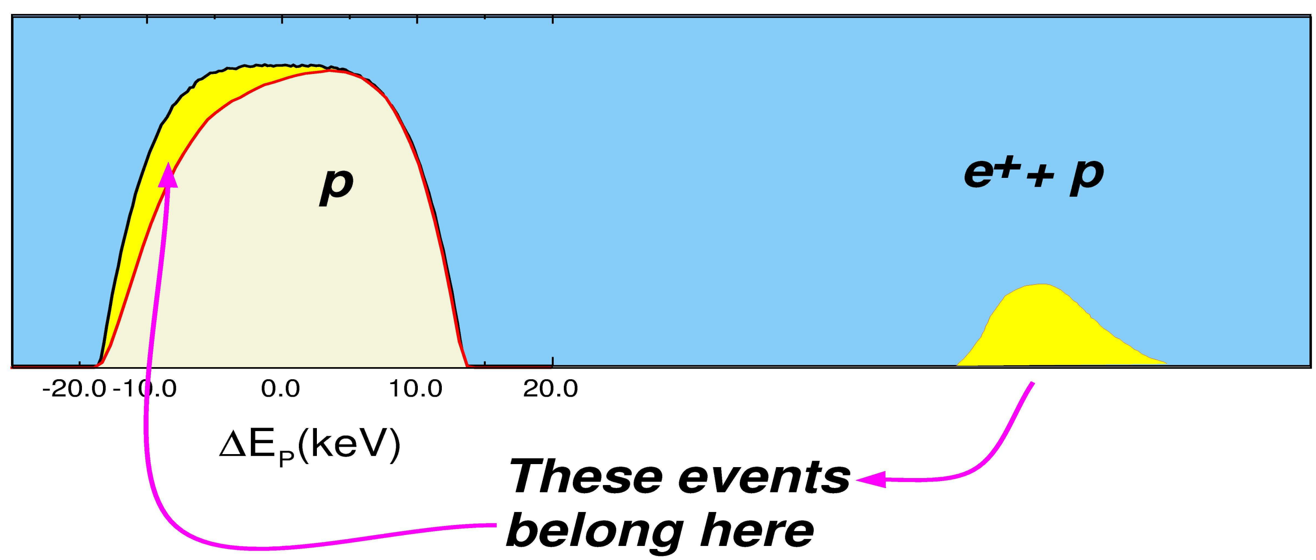
Monte-Carlo calculation of proton energy



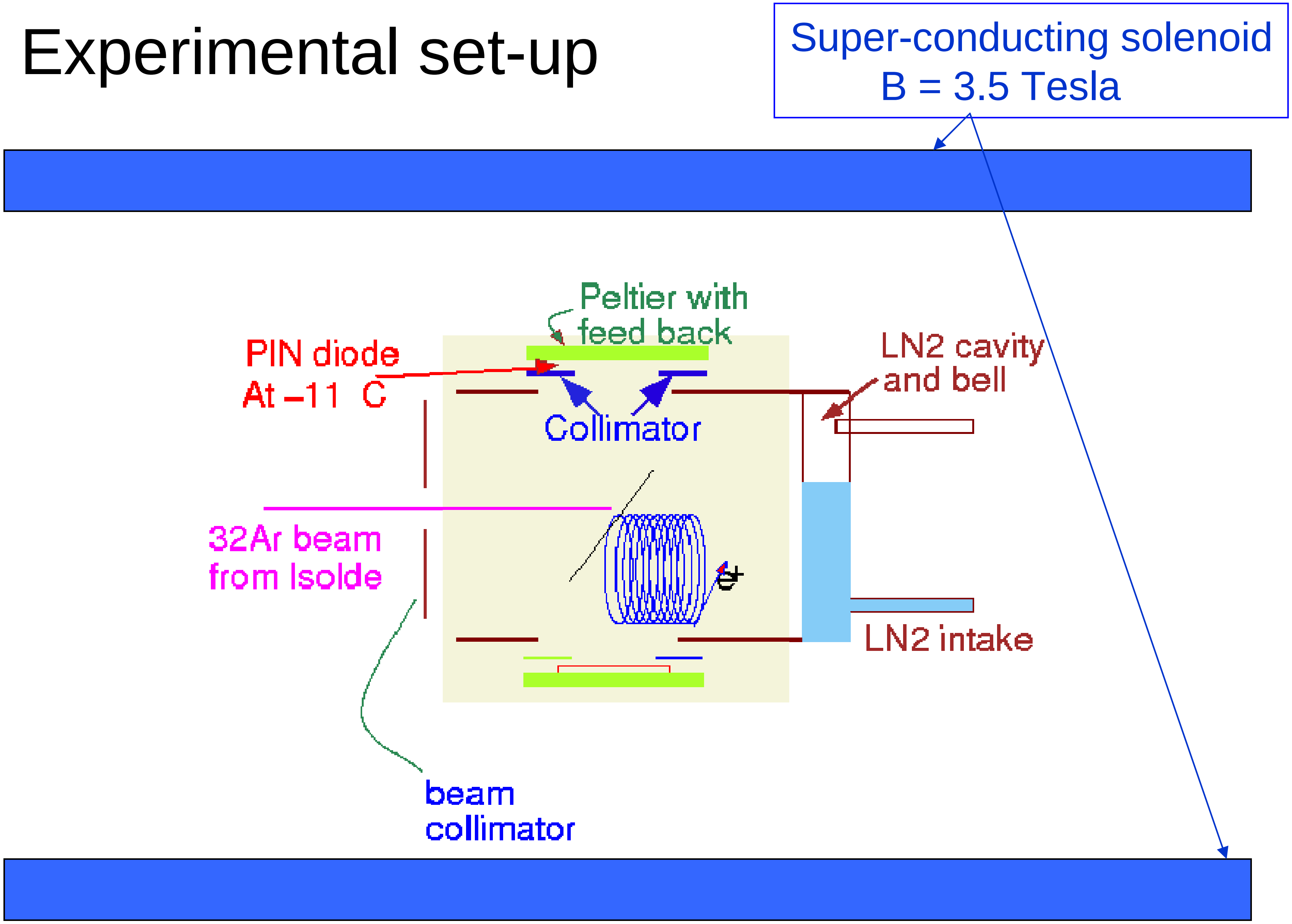
Problem: Summing with positrons distorts the shape of the proton peak





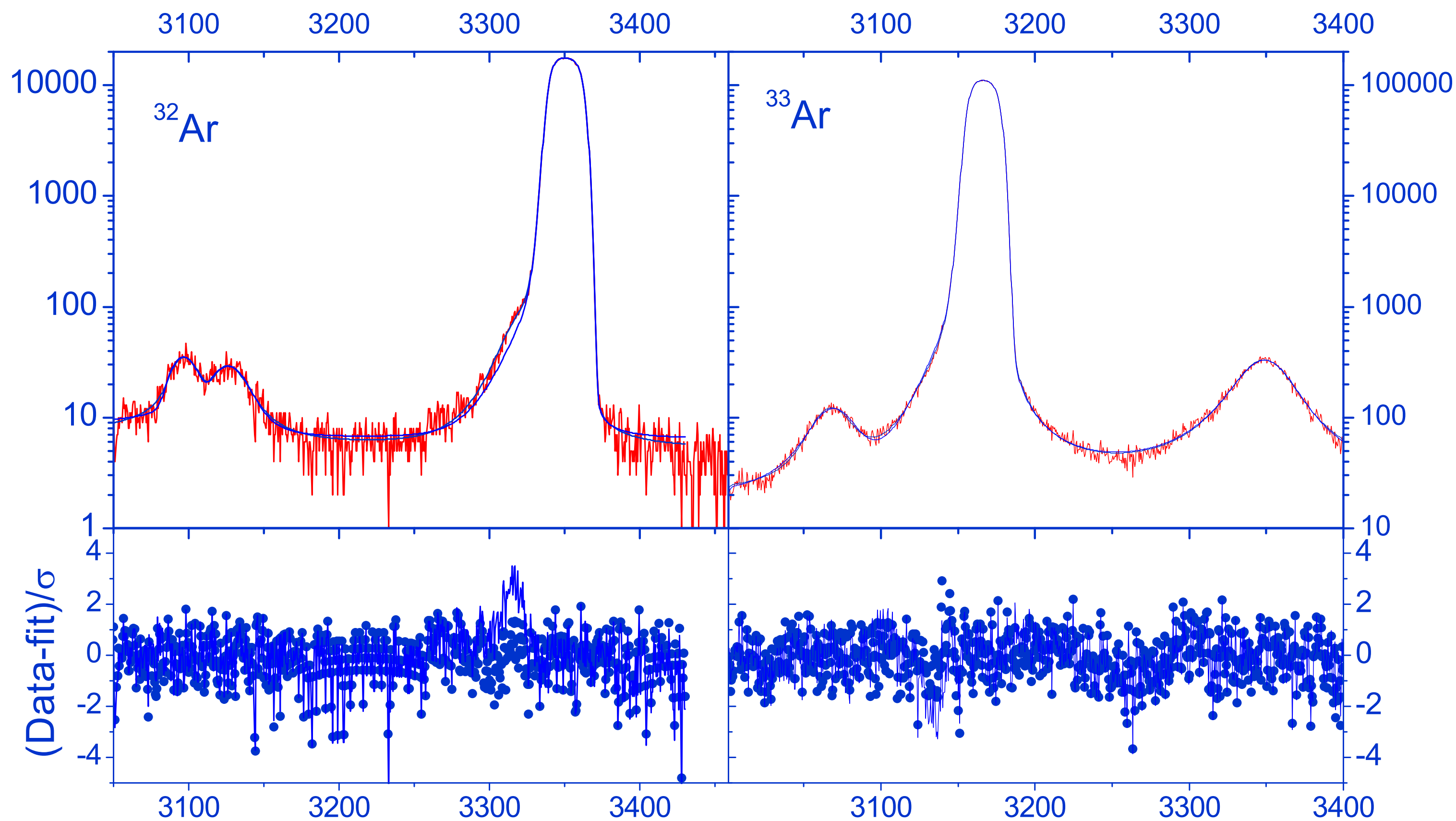


Experimental set-up



Adelberger *et al*., PRL **83**, 1299 (1999)

Simultaneous fit of ^{32}Ar and ^{33}Ar data



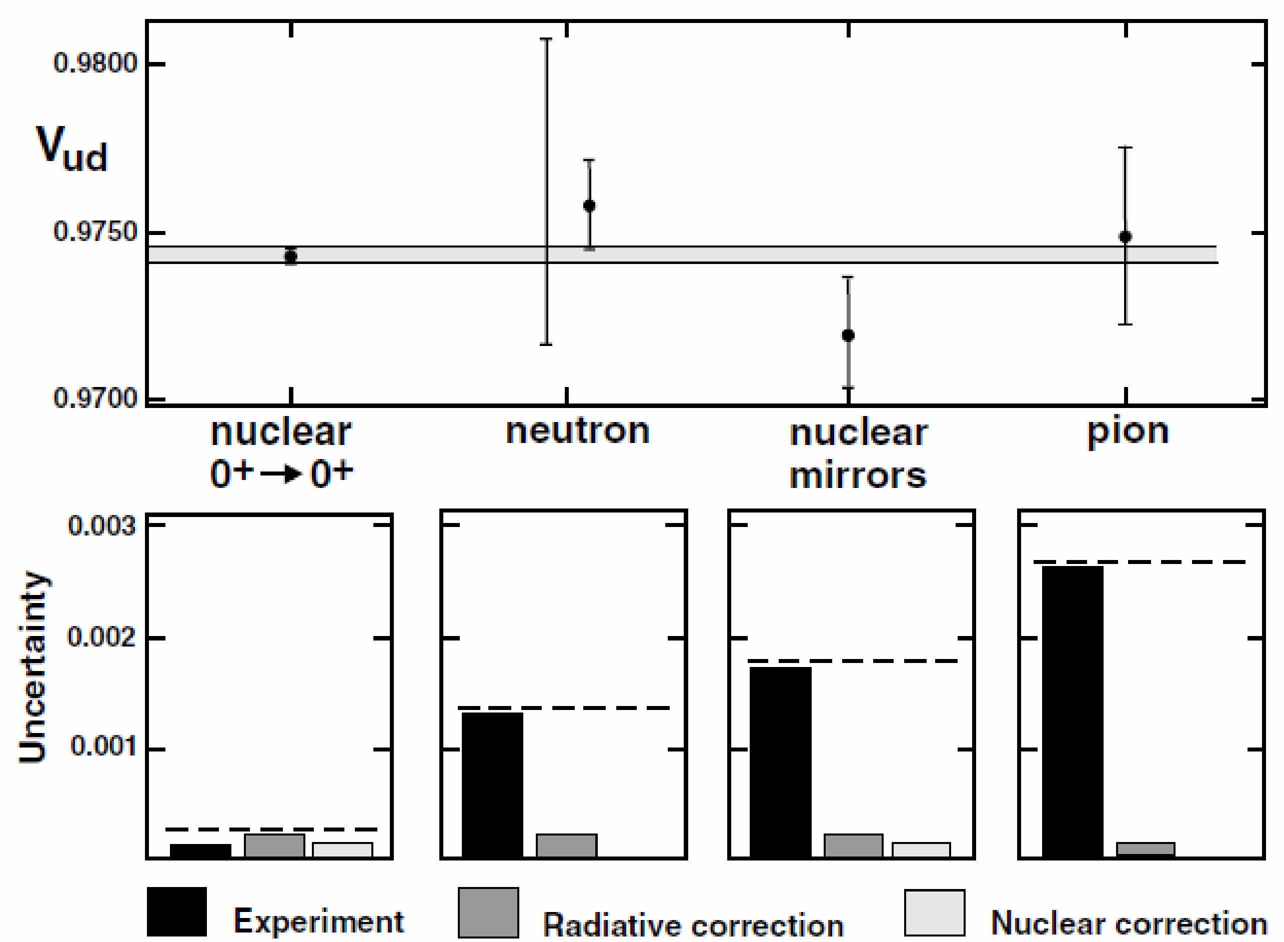
1999 result: $\tilde{a} = 0.9980(52)_{stat}(39)_{syst}$

[Adelberger *et al*., PRL **83**, 1299 (1999)]

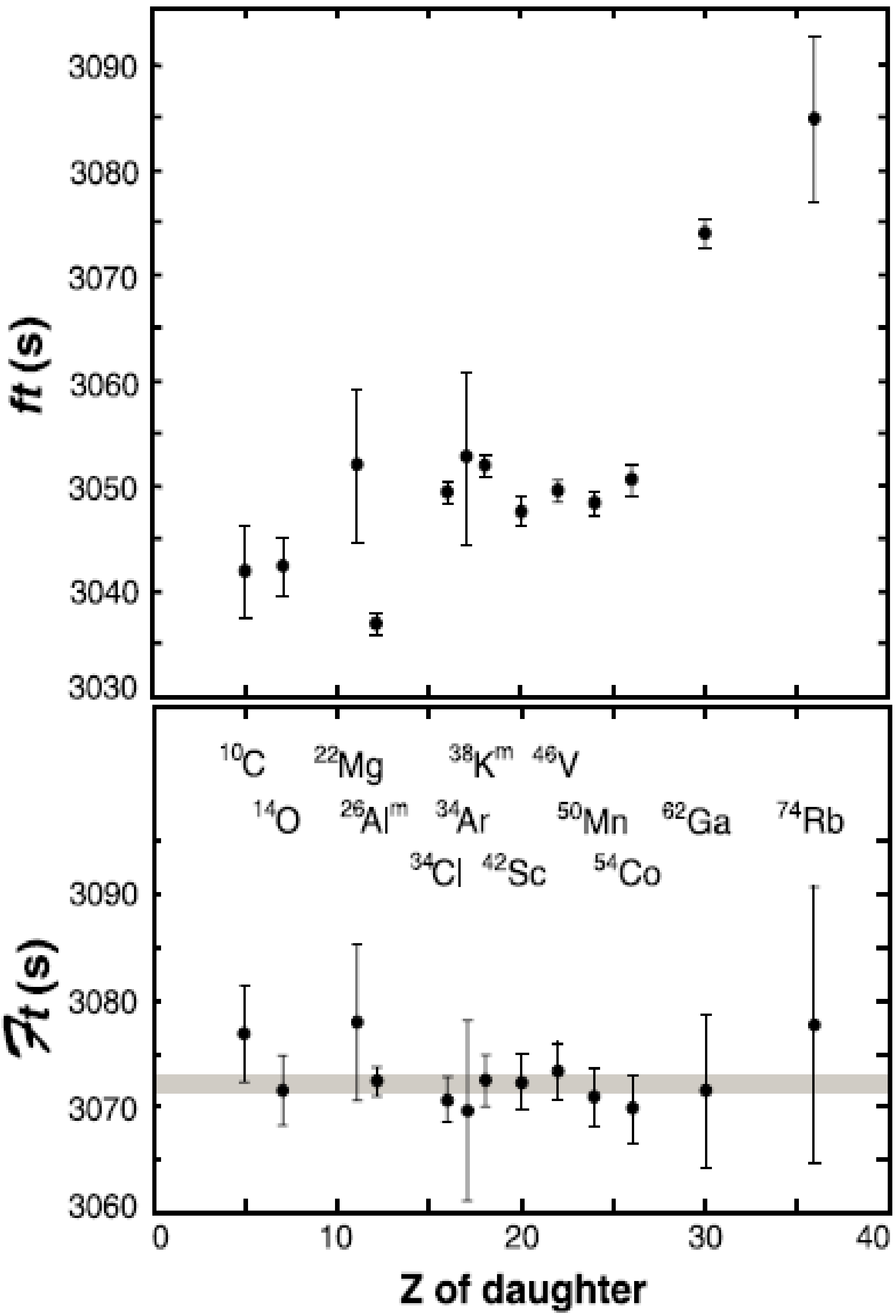
But, since then…

- Precision measurement of $^{32}S(p,p)^{32}S$ 3374.7-keV resonance energy [Pyle *et al*. PRL **88**, 122501 (2002)]
- Precision measurement of ^{32}Ar mass [Blaum *et al*., PRL **91**, 260801 (2003)]
- Precision determinations of the mass of the lowest $T = 2$ level in ^{32}Cl via precision measurements of ^{32}Cl mass [Wrede *et al*., PRC **81**, 055503 (2010)] and ^{31}S mass [CPT collaboration (in preparation)]
- All of these change ã substantially!

Current status of V_{ud}



Towner and Hardy, Rep. Prog. Phys. **73**, 046301 (2010)



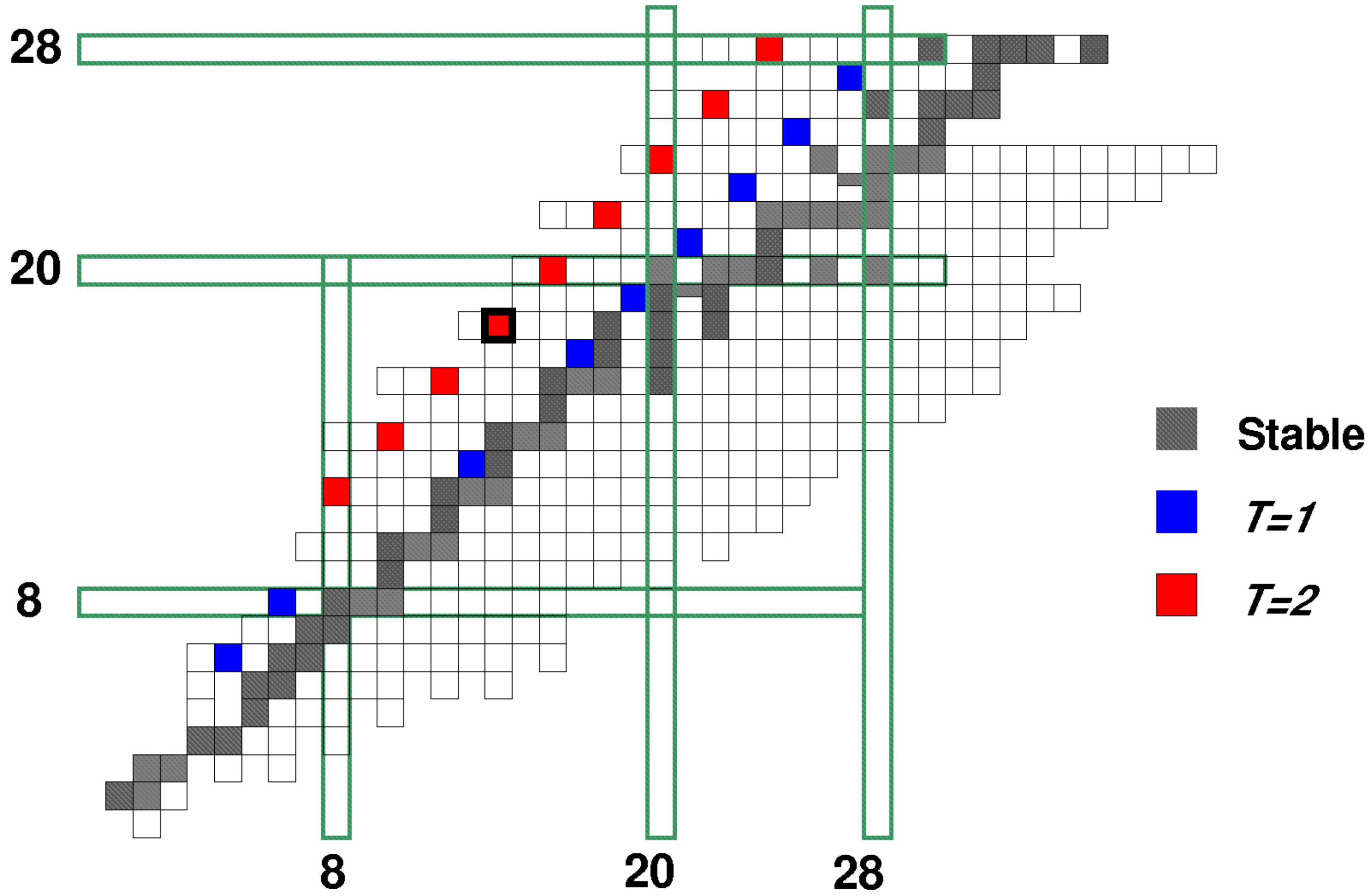
V_{ud} from superallowed (T = 1) $0^+ \rightarrow 0^+$ β decay

$$\mathcal{F}t = ft(1 - \delta_c)(1 + \delta_R)$$

Towner and Hardy, Rep. Prog. Phys. **73**, 046301 (2010)

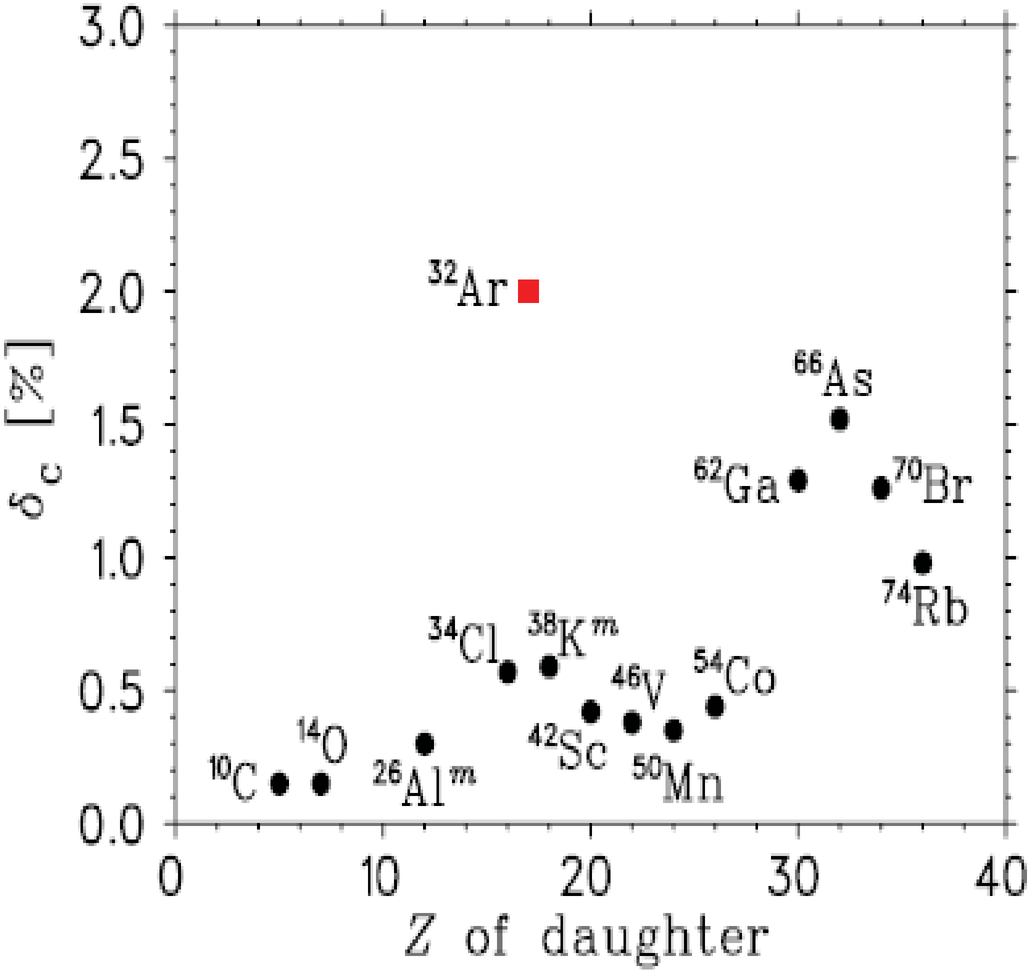
T = 2 nuclei present an alternative way to check

Isospin breaking corrections



Bhattacharya *et al*., PRC **77**, 065503 (2008)

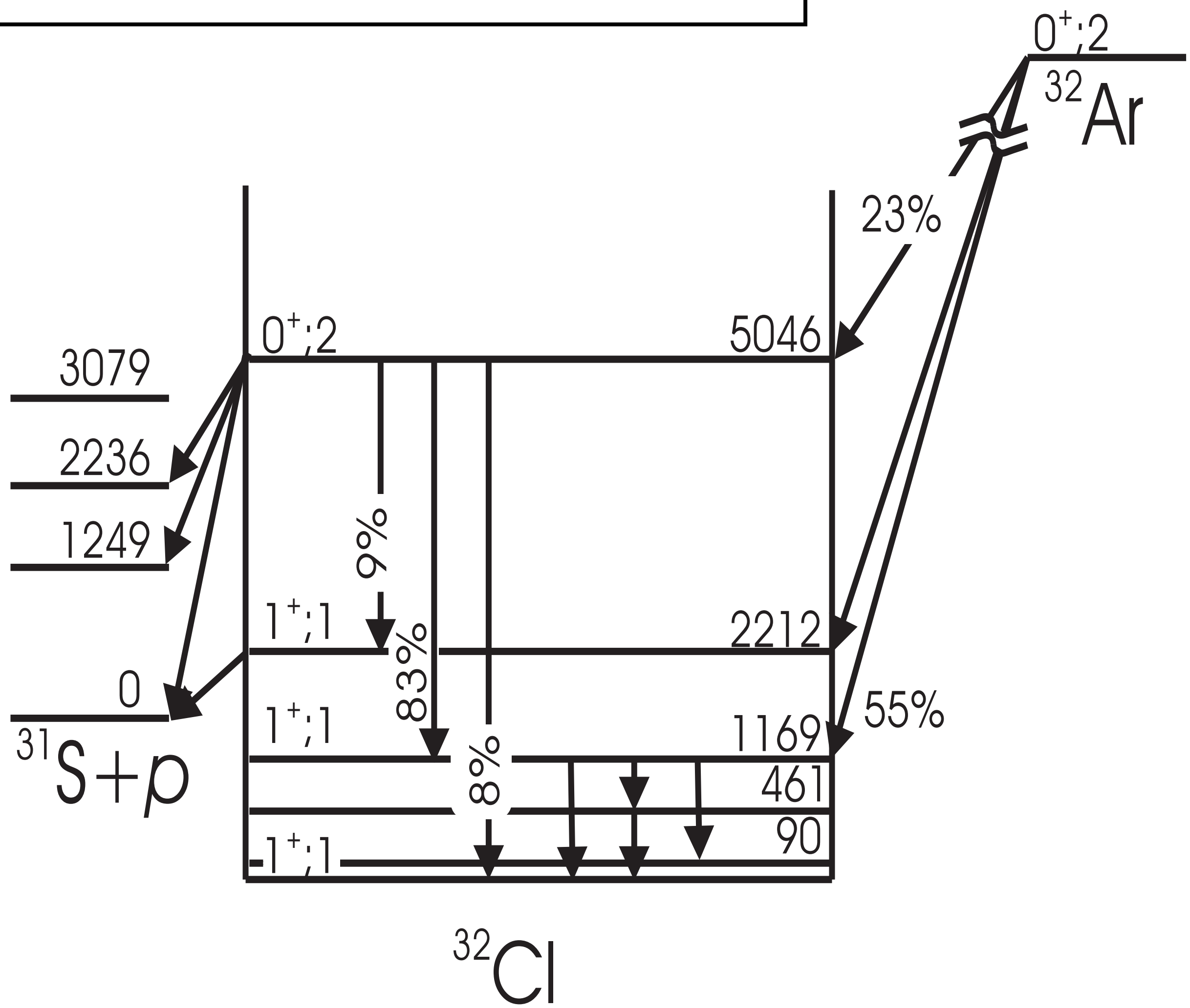
δ_C from superallowed $T = 2$ $0^+ \rightarrow 0^+$ β decay



$$\delta_C^{\exp} = 1 - \frac{\overline{\mathcal{F}t}(T=1)}{2(1+\delta_R)\,ft(^{32}\mathrm{Ar})}$$

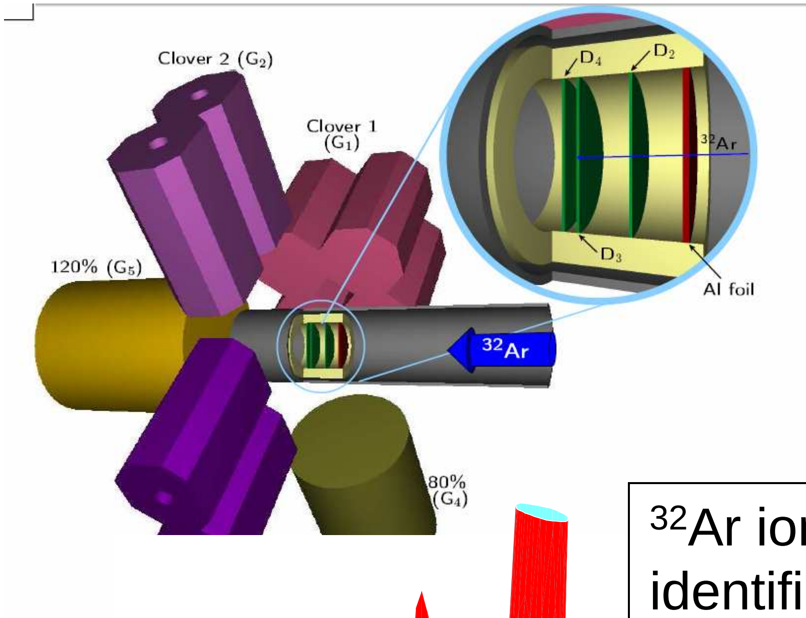
Bhattacharya *et al*., PRC **77**, 065503 (2008)

proton and γ-ray emission from T = 2 state in ^{32}Cl

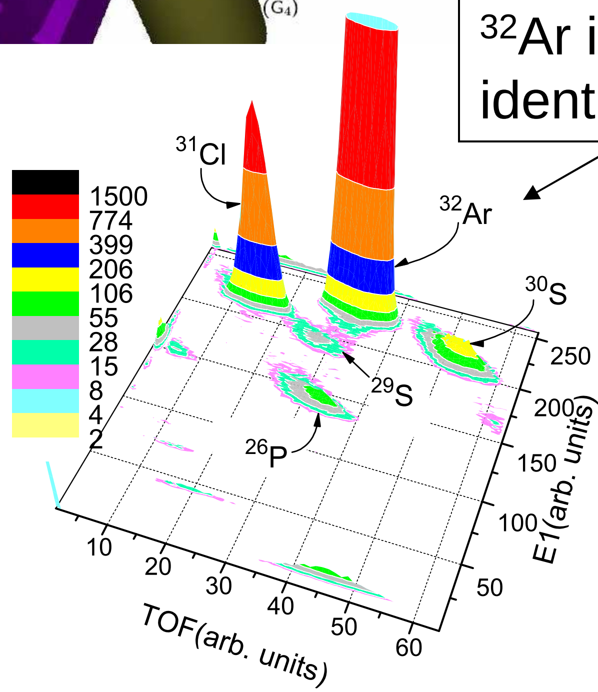


Experiment to determine branch of ^{32}Ar superallowed transition (MSU)

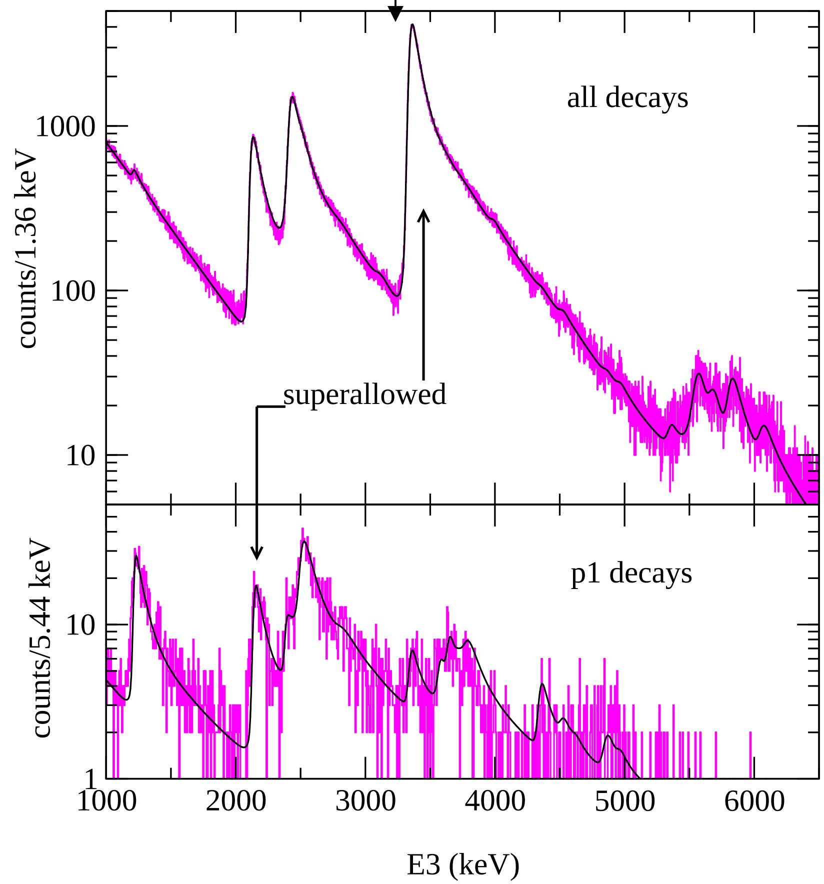
Bhattacharya *et al*., PRC **77**, 065503 (2008)



^{32}Ar ion identification



β-delayed proton spectrum



Summary of super-allowed ^{32}Ar branches:

$$\frac{N_p}{N_{Ar}} = \underbrace{\frac{N_{p0}}{N_{Ar}}}_{\approx 20.4\%}\left(1+\frac{N_{p1}}{N_{p0}}+\frac{N_{p2}}{N_{p0}}\right) = 20.9(1)\%$$

$$\frac{N_\gamma}{N_{Ar}} = \frac{\overbrace{\sum_i N_\gamma(i)}^{from\ spectrum}}{\underbrace{N_{Ar}\sum_i \varepsilon_\gamma(i)\varepsilon_\beta}_{from\ ^{32}Cl}} = 2.03(10)\%$$

Systematic uncertainties

Component	*b*(%)
implt. ^{32}Ar's	0.2
p0 branch	0.5
p1 branch	0.04
p2 branch	0.04
p3 branch	0.07
gamma branch	0.4
other	0.01

Isospin-breaking correction:

Measurement: $\delta_c^{\exp} = 2.1(8)\%$

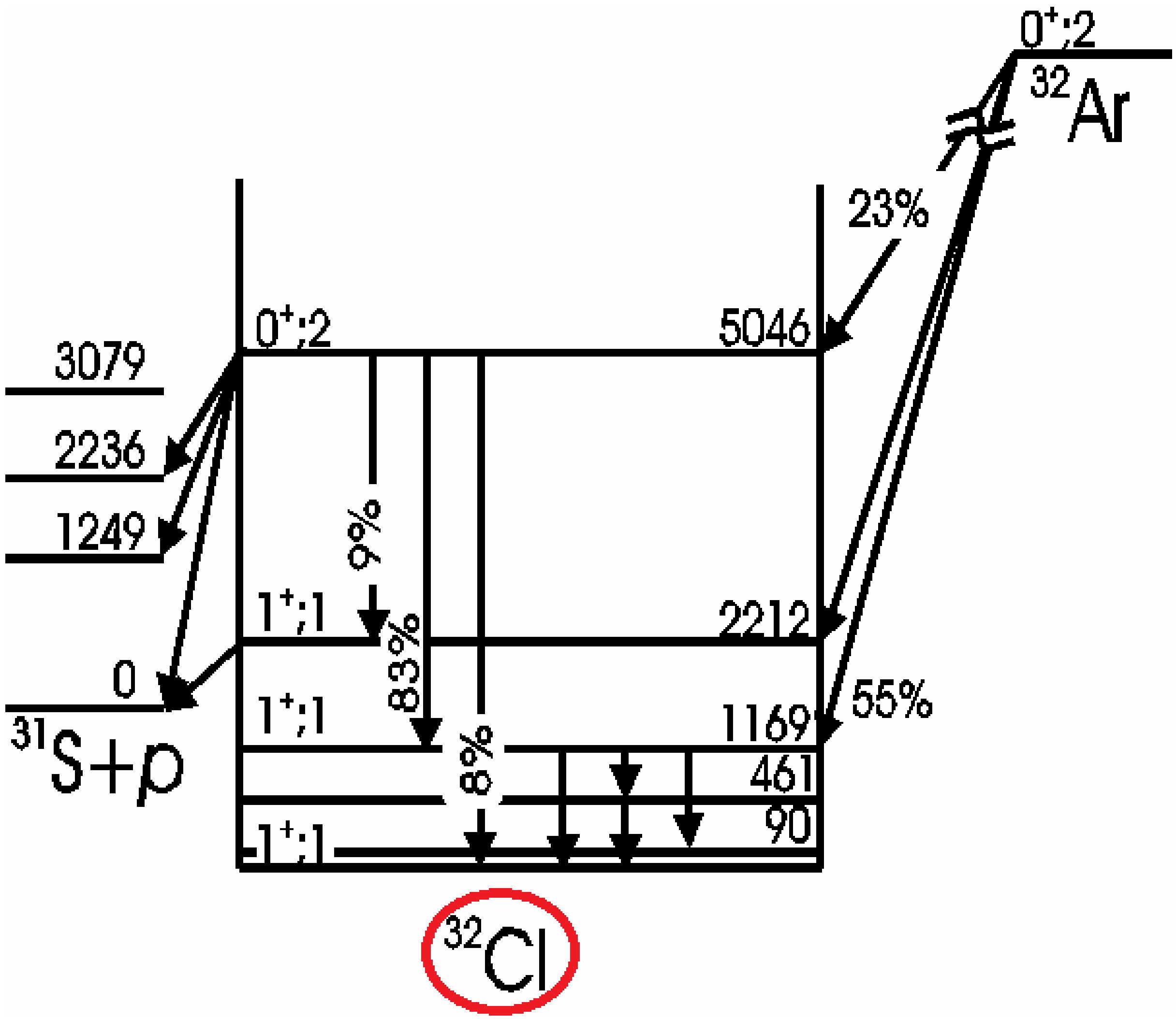
Theory: $\delta_c^{th} = 2.0(4)\%$

Bhattacharya *et al*., PRC **77**, 065503 (2008)

But, results are dependent on…

- Absolute gamma-ray branching from $^{32}Cl(\beta^{+}\gamma)^{32}S$: measured separately [Melconian *et al*., in preparation]
- Results of the lepton-correlation experiment described previously [Adelberger *et al*. PRL **83**, 1299 (1999) ; Garcia *et al*. (in preparation)]
- Nuclear masses: ^{31}S [AME03] and ^{32}Ar [Blaum *et al*., PRL **91**, 260801 (2003)]

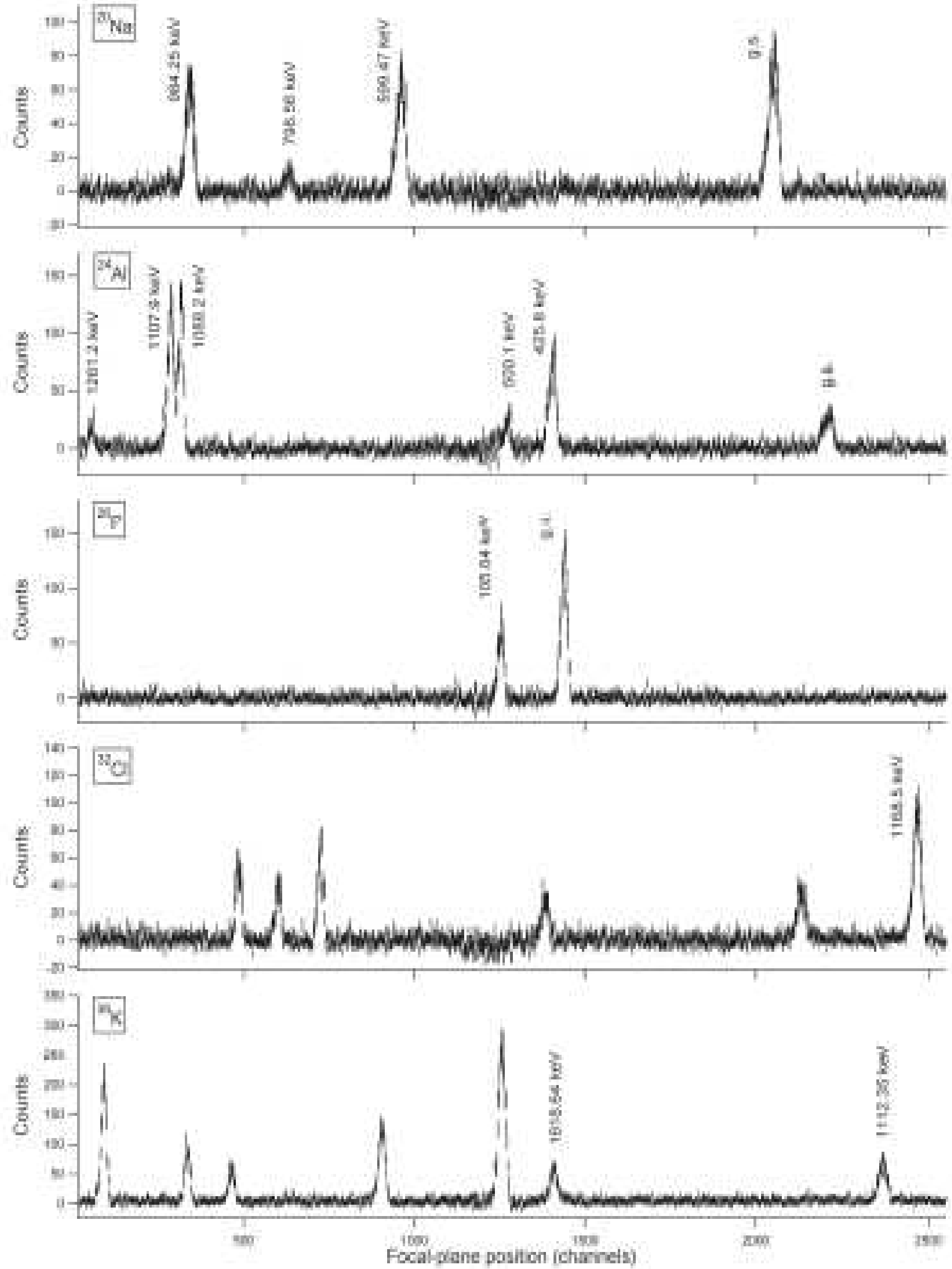
T = 2 daughter masses



Bhattacharya *et al*., PRC **77**, 065503 (2008)

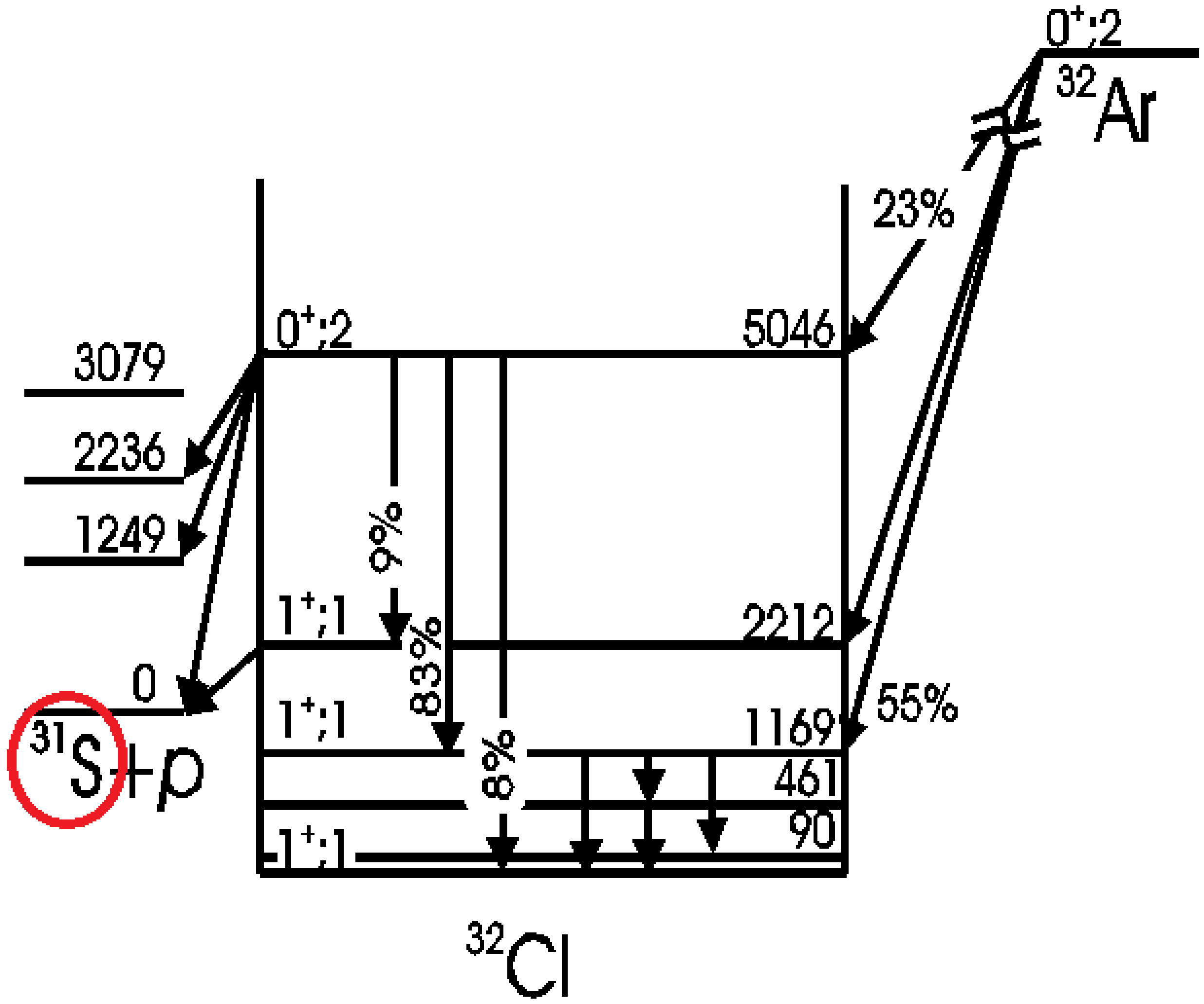
T = 2 daughter masses

- Ground-state masses of ^{20}Na, ^{24}Al, ^{28}P, ^{32}Cl via (^{3}He,*t*) reaction *Q* values
- Ion-implanted carbon foil targets made at University of Washington
- Measurements with Q3D spectrograph at Maier Leibnitz Laboratory (Munich)
- Precision of ~1 keV
- Large improvements on (and discrepancies with) AME03
- Change in δ_C from 2.1% to 1.8%
- Substantial impact on *ã* for *A* = 32 case
- Published on Friday!



Wrede *et al*. PRC **81**, 055503 (2010)

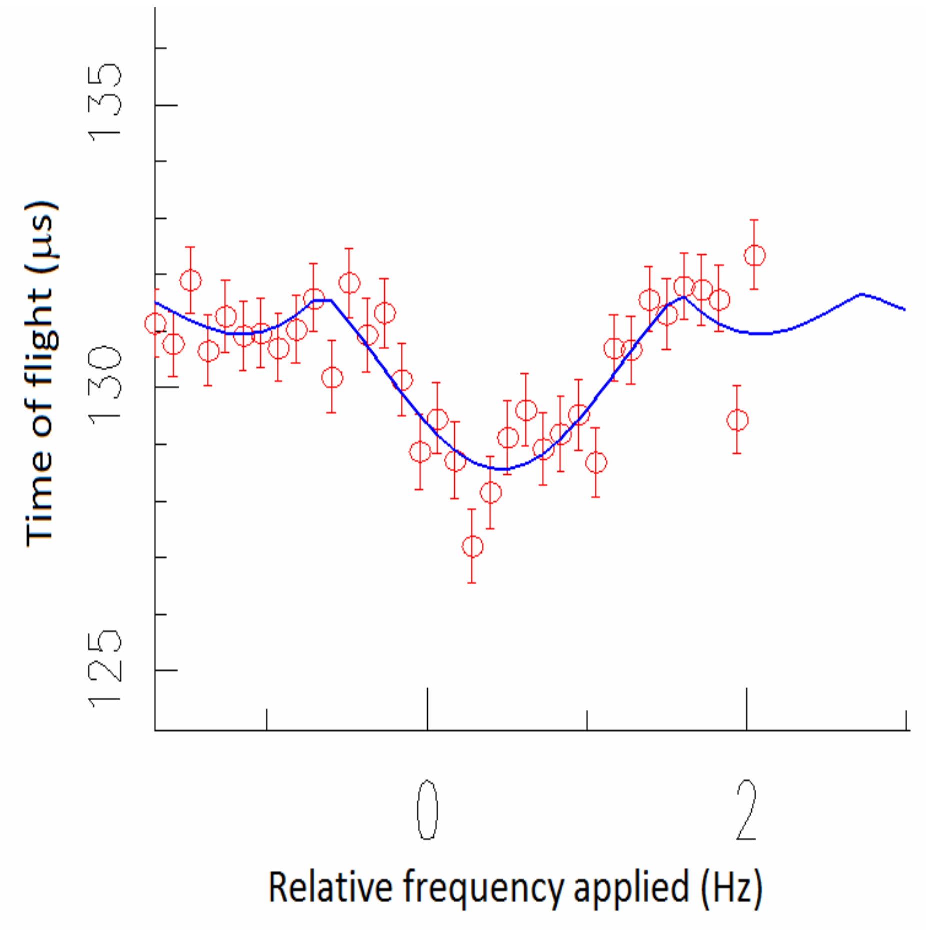
T = 2 daughter masses



Bhattacharya *et al*., PRC **77**, 065503 (2008)

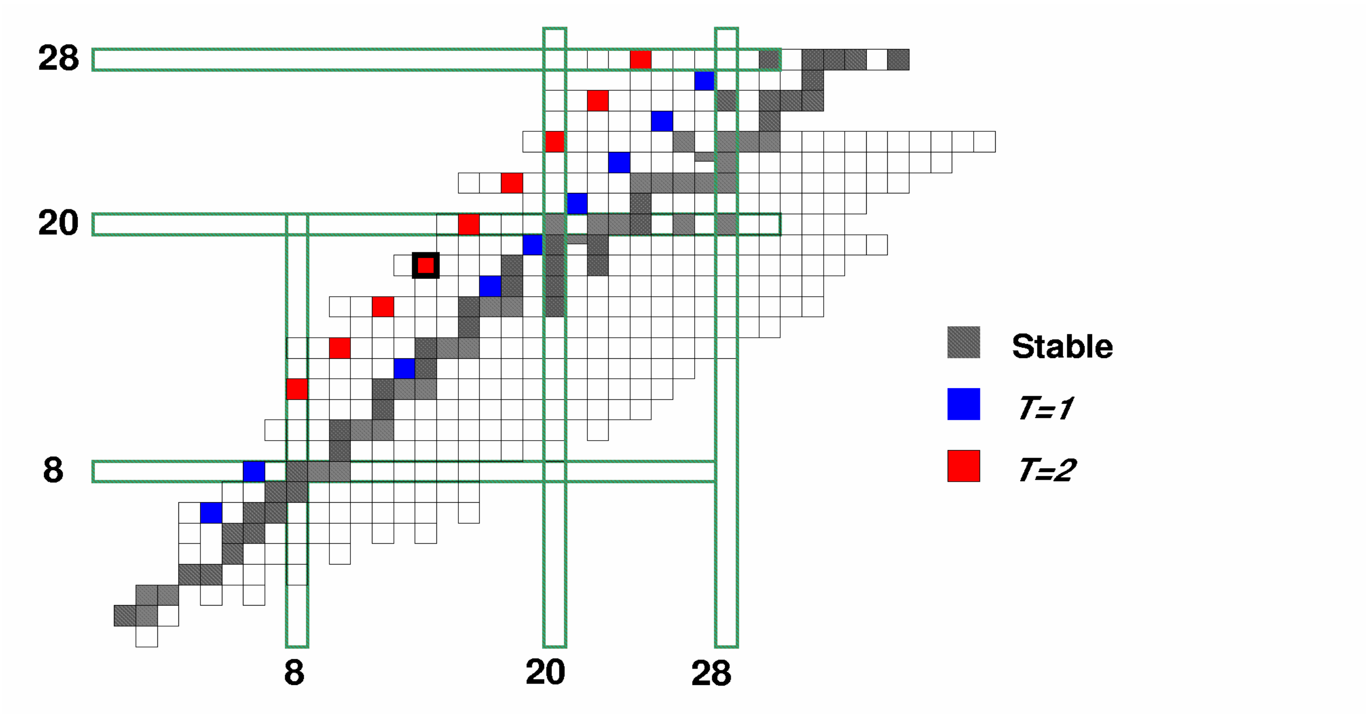
T = 2 daughter masses

- Ground-state mass of ^{31}S via Penning trap mass spectrometry
- CPT at Argonne-ATLAS
- Precision of ~0.5 keV
- Disagreement with AME03 at ~2σ level
- Good agreement with Munich ^{32}Cl mass & proton threshold
- Higher precision on mass of lowest T = 2 level in ^{32}Cl
- Best test of IMME
- Publication in preparation



•Argonne-ATLAS Experiment 1289 (C. Wrede, C.M. Deibel, co-spokespersons)

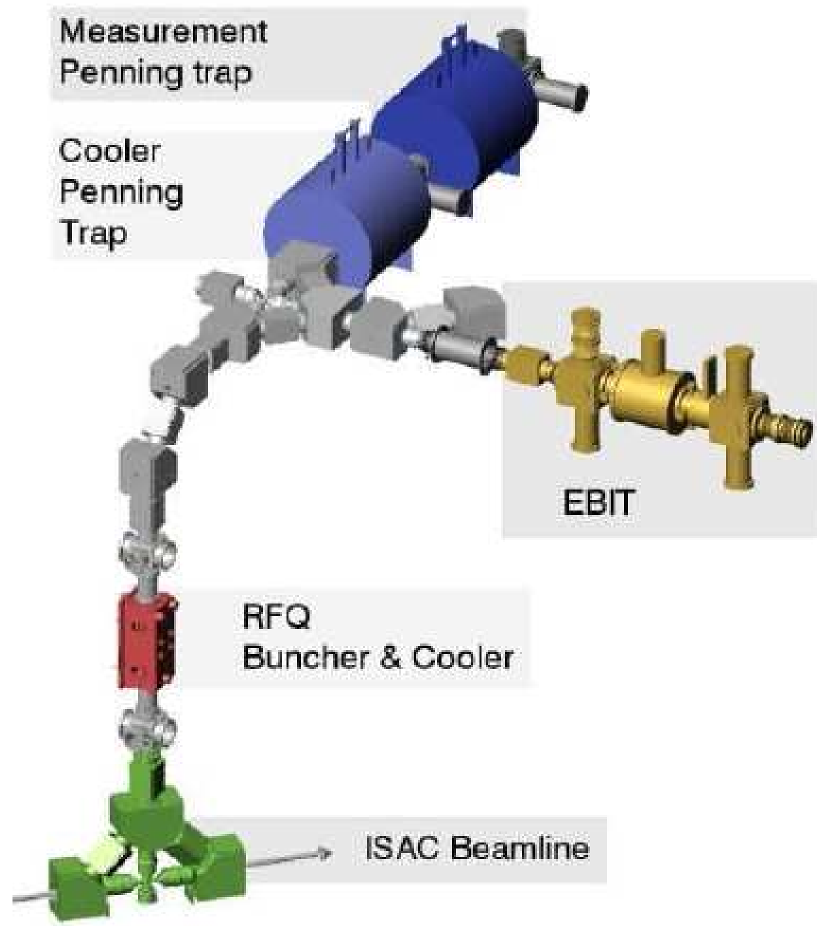
TITAN: TRIUMF Experiment S1242
(S. Ettenauer, J. Dilling, spokespersons)



- Measure masses of *T* = 2 parents ^{20}Mg, ^{24}Si, ^{28}S, ^{32}Ar, ^{36}Ca, ^{40}Ti, ^{44}Cr, ^{48}Fe, and ^{52}Ni (& also daughters)

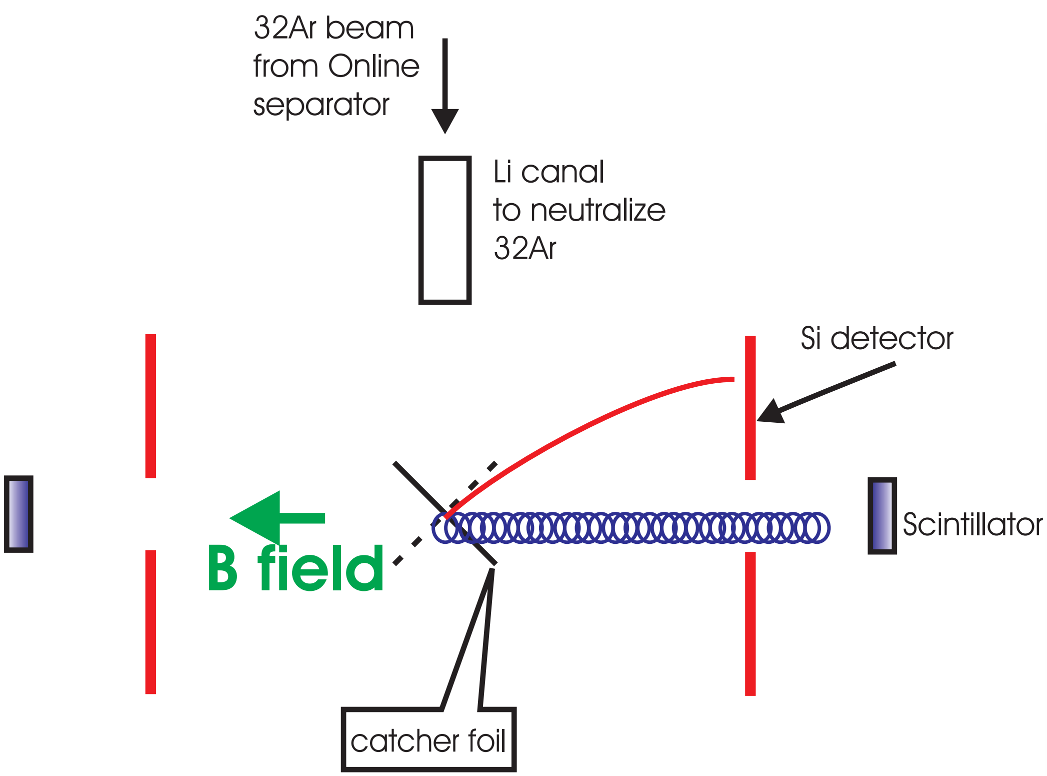
TRIUMF Experiment S1242 w/ TITAN

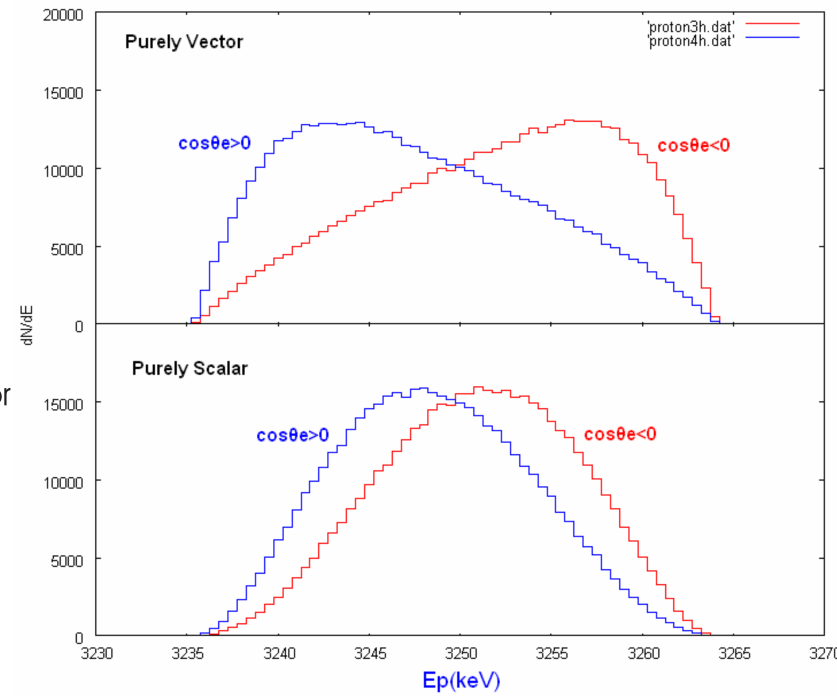
- Mass precision proportional to charge state
- Charge breeding can improve precision by an order of magnitude, or more
- Goal: precision of a few hundred eV
- A = 20 case in 2010
- A = 36 case probably next
- A = 32 case interesting!
- Potential challenge: ISAC beam development for elements with chemistry issues?



An idea to determine lepton correlations and particle branches with high precision

In the short term we can improve determination of *a* in ^{32}Ar by a factor of 5!





In the longer range this device can be used to produce useful standards for calibration of particle branches and as a spectroscopic tool.

Summary

- superallowed $0^+ \rightarrow 0^+$ β decays of $T = 2$ nuclides can contribute to tests of the standard model of particle physics
- Q_{EC} values need to be determined independently to ~1 keV or better
- TITAN is in a good position to measure the relevant ground state masses to the required precision

Thank you!