Status of Nuclear β-decay Measurements

Dan Melconian

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Pure Fermi $0^+ \rightarrow 0^+$ decays

The comparative half-life of β decay is:

$$\boxed{ft = \left(\begin{array}{c}\text{phase}\\ \text{space}\end{array}\right)\left(\begin{array}{c}\text{partial}\\ \text{half-life}\end{array}\right) = \frac{K}{G_V^2\,|M_F|^2 + G_A^2\,|M_{GT}|^2}}$$

$K/(\hbar c)^6 = 2\pi^3\hbar \ln 2/(m_e c^2)^5$ and by CVC, $G_V = G_F\,V_{ud}$

For pure Fermi

$T=1$ decays

$\left(T_3 \equiv \frac{1}{2}(N-Z) = \textbf{isospin}\right)$

$$M_F = \sqrt{2}$$

$$M_{GT} = 0$$

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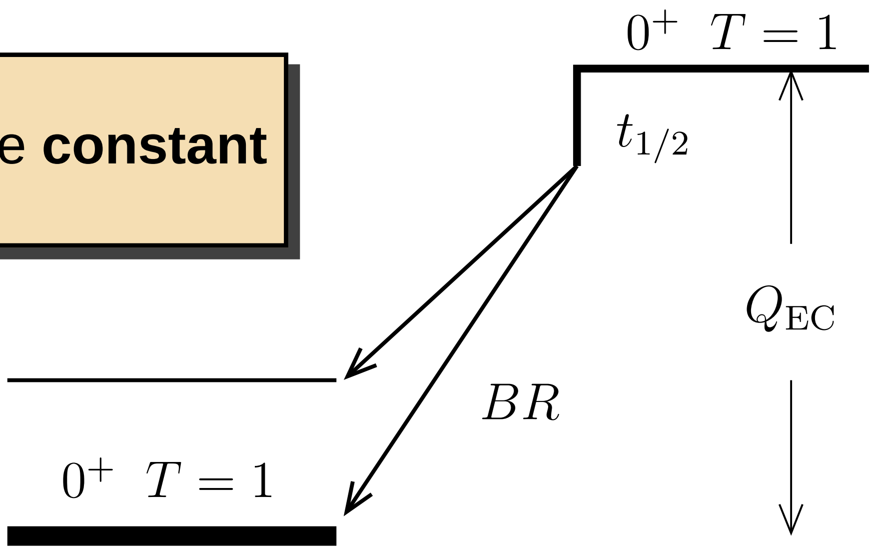
$$M_F = \sqrt{2}$$
$$M_{GT} = 0$$

$$\boxed{ft = \frac{K}{2G_F^2|V_{ud}|^2} \text{ should be \textbf{constant}}}$$

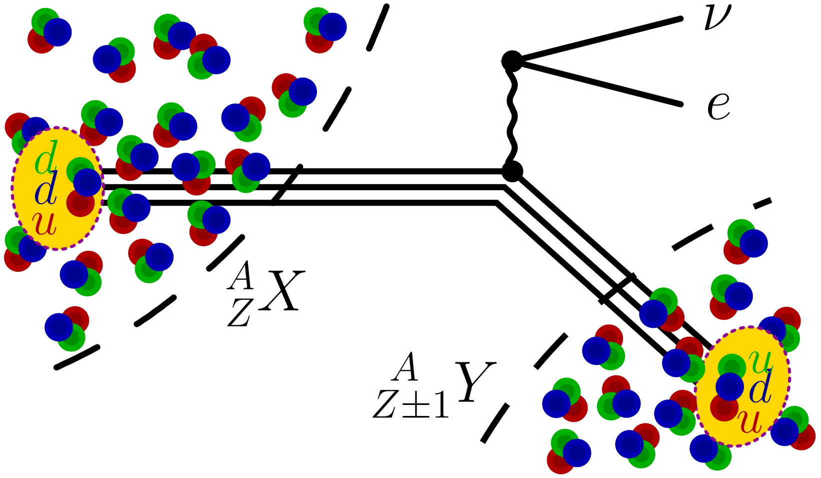
$$Q_{EC} \Rightarrow f$$

$$\left.\begin{array}{l} t_{1/2} \\ BR \end{array}\right\} \Rightarrow t$$



Corrected $\mathcal{F}t$ value

We must account for the fact that **the decay occurs within the nuclear medium**



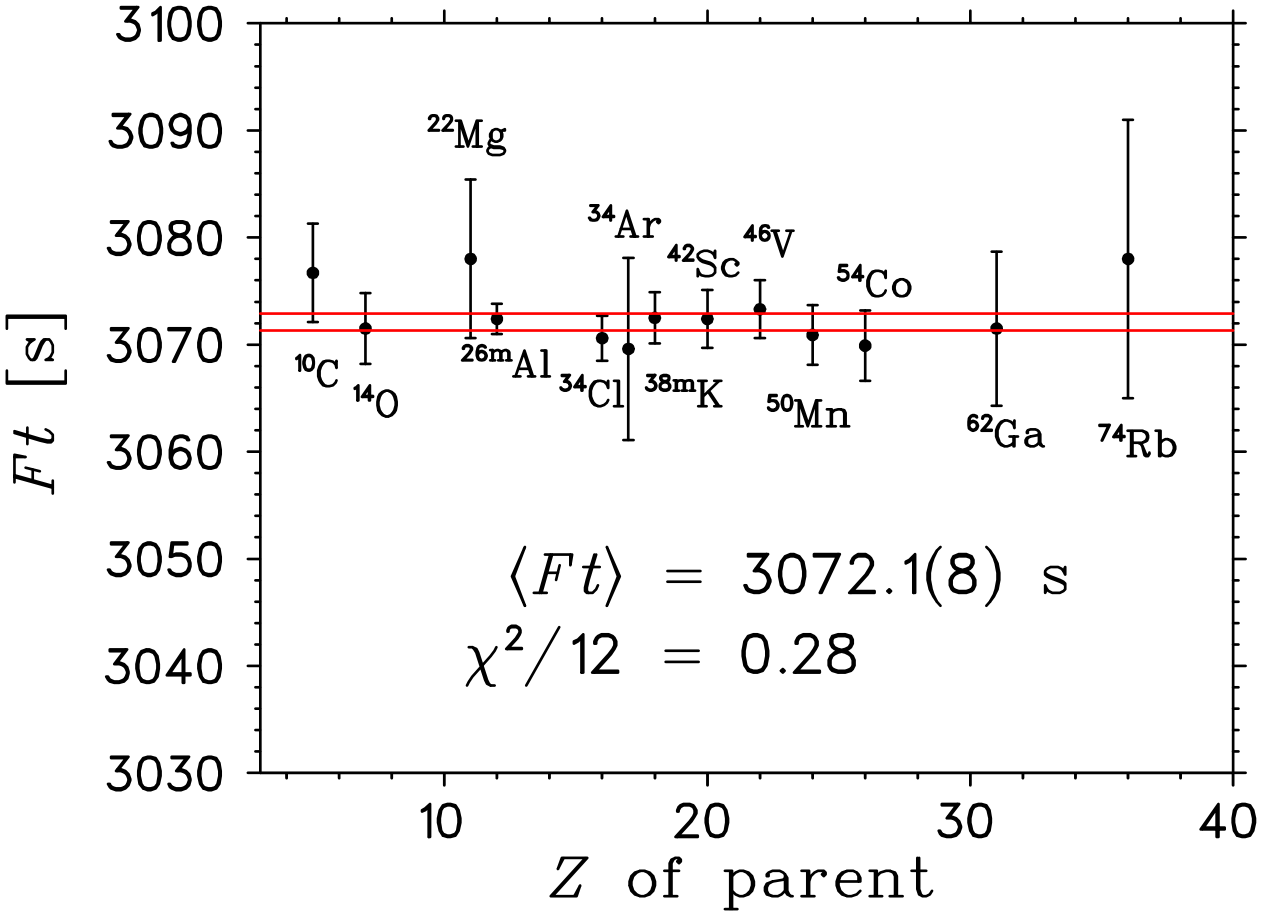
$$\mathcal{F}t \equiv ft\left(1+\delta'_R\right)\left(1+\left(\delta_{NS}-\delta_C\right)\right) = \frac{K}{G_F^2|V_{ud}|^2|M_F|^2\left(1+\Delta_R^V\right)}$$

(*really* should be constant)

- δ'_R = $E_e^{\max}$ and Z dependent radiative correction
- δ_{NS} = nuclear structure depenedent radiative correction
- δ_C = isospin symmetry-breaking correction
- Δ_R^V = transition independent radiative correction

$\mathcal{F}t$ values of $0^+ \rightarrow 0^+$ decays

Towner and Hardy, PRC **79** 055502 (2009)



corrected $\mathcal{F}t$ values constant to better than 3 parts in 10^4!

hooray for the conserved vector current hypothesis!

The name of the game nowadays

- over 200 measurements have gone into superallowed ft values

  . . . hard for one new one to have a high impact ($\langle \mathcal{F}t \rangle$ is robust!)

- some measurements are **old**; worth going back and checking some of the results (e.g. masses)

- biggest question is often in the isospin-mixing corrections

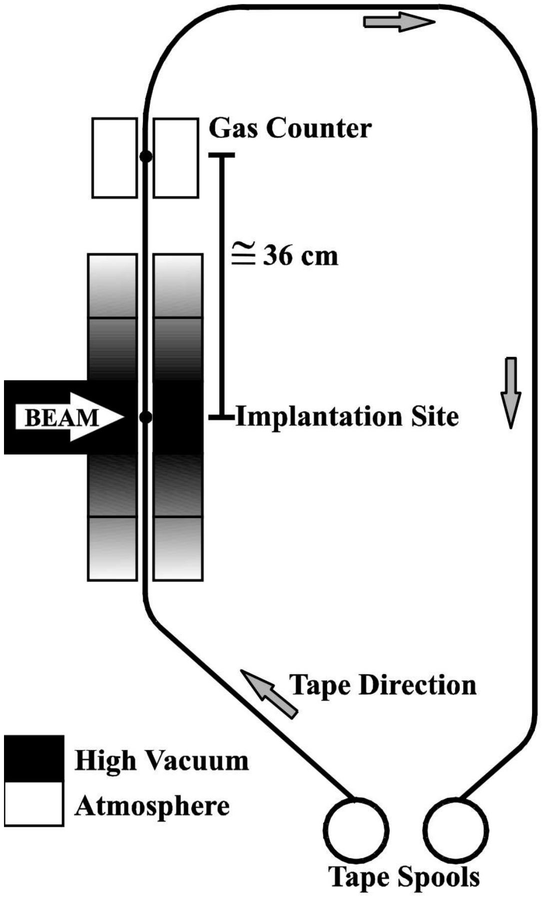
  . . . *measure* them!

- pursue other avenues, notably the neutron; maybe $T = 1/2$ decays?

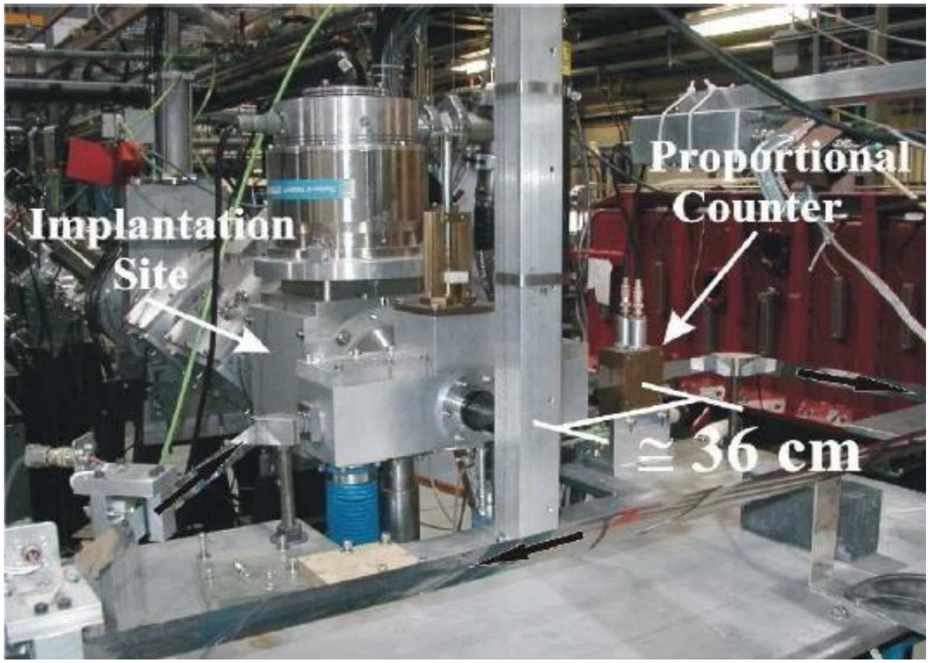
- use the average $\mathcal{F}t$ value to fix SM predictions and search for new physics via angular correlation parameters

Half-lives continue to be improved

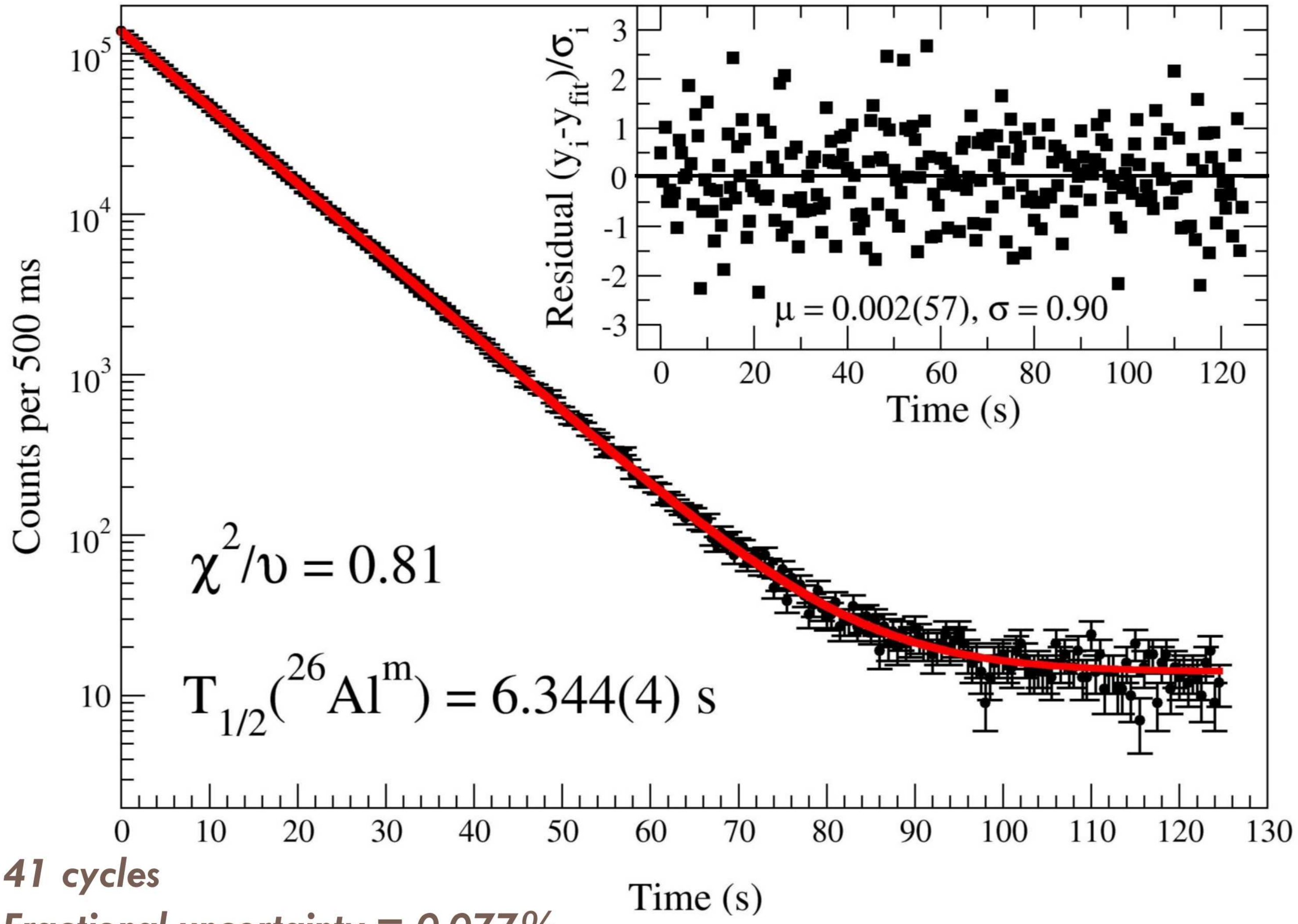
Example: GPS at TRIUMF



4π continuous-flow gas-proportional counter and fast tape transport system



Typical half-life spectrum



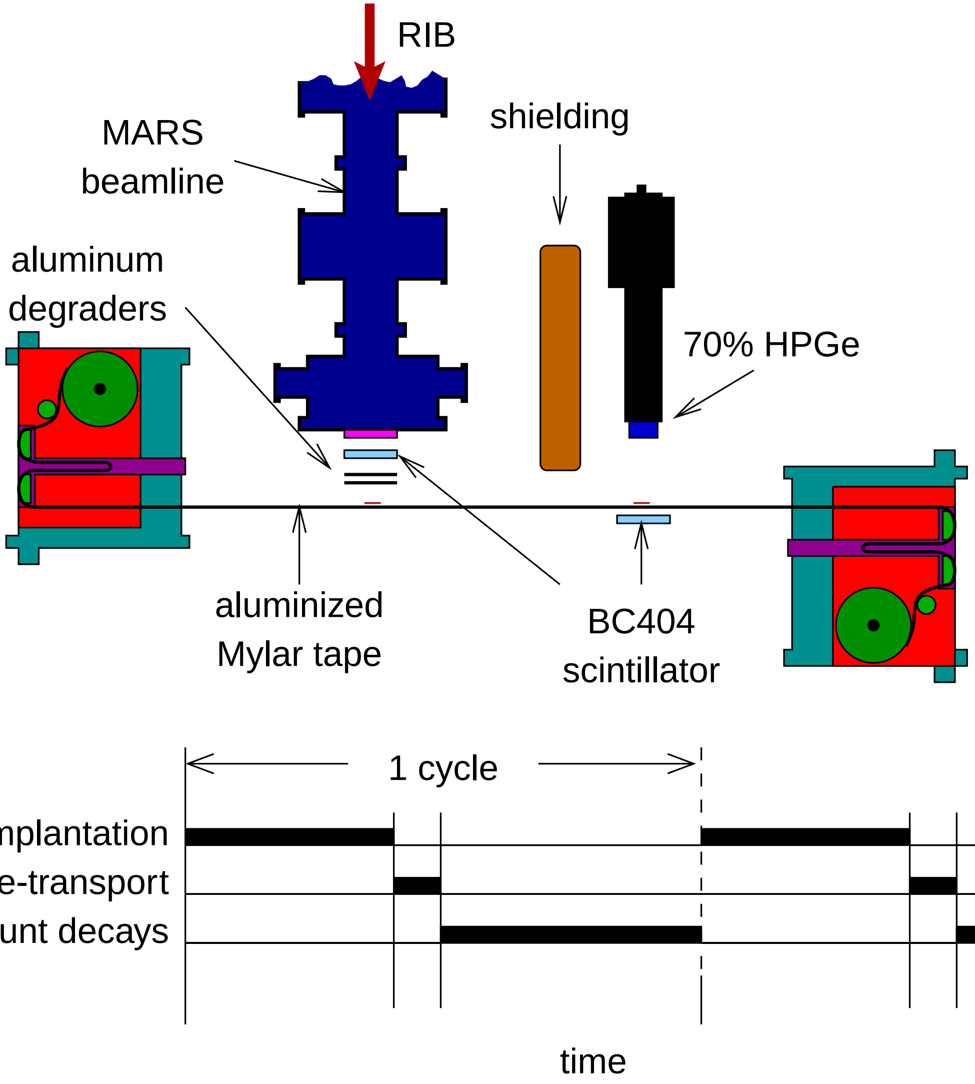
41 cycles

Fractional uncertainty = 0.077%

(courtesy of P. Finlay)

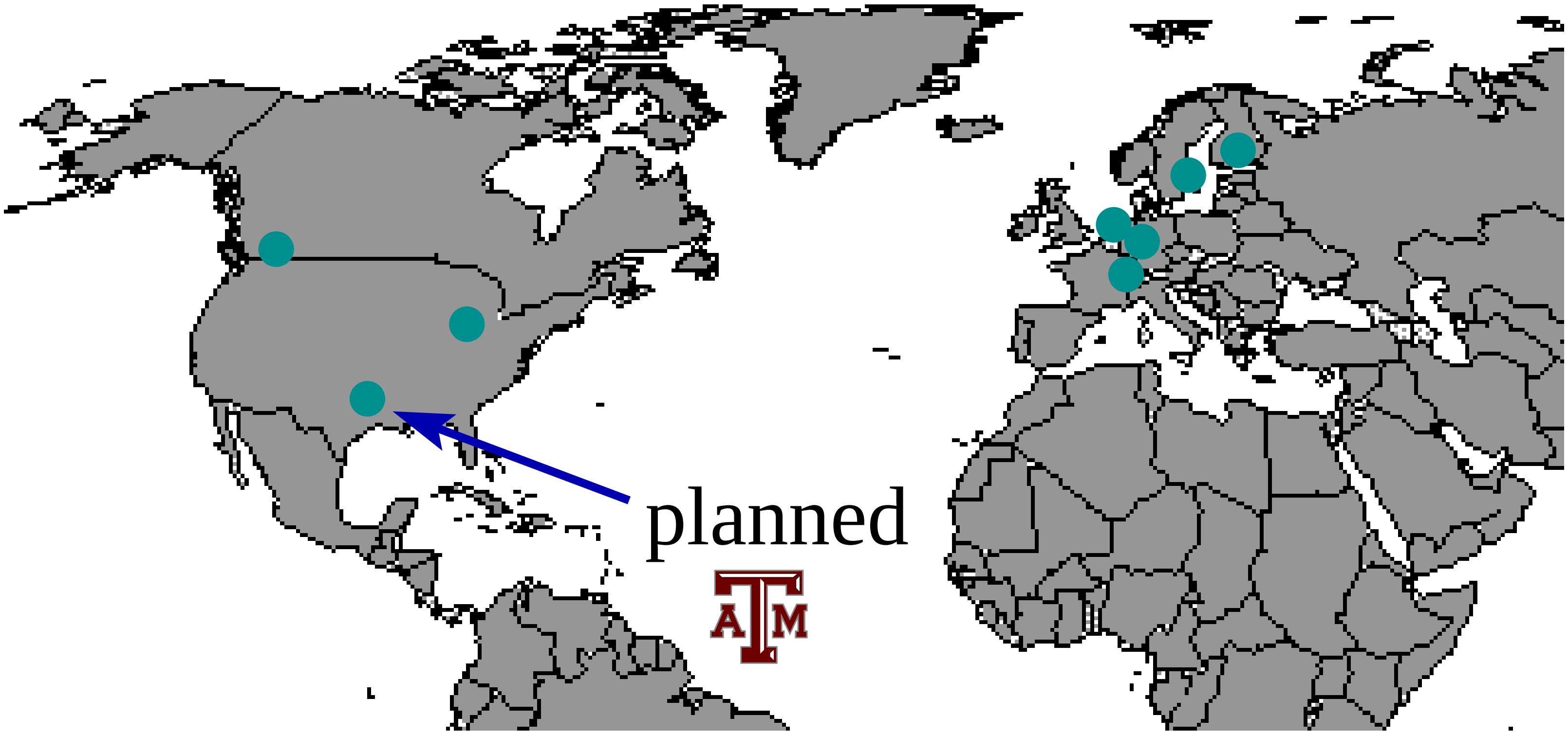
Branching ratios continue to be improved

Example: Fast tape-transport at CI/TAMU



Penning traps at RIB facililties

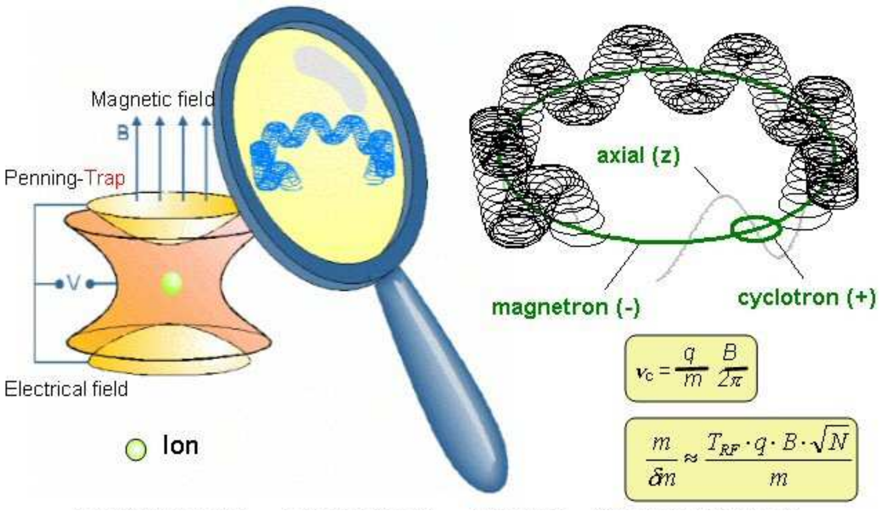
mass measurements, correlation studies, EC branches, . . .

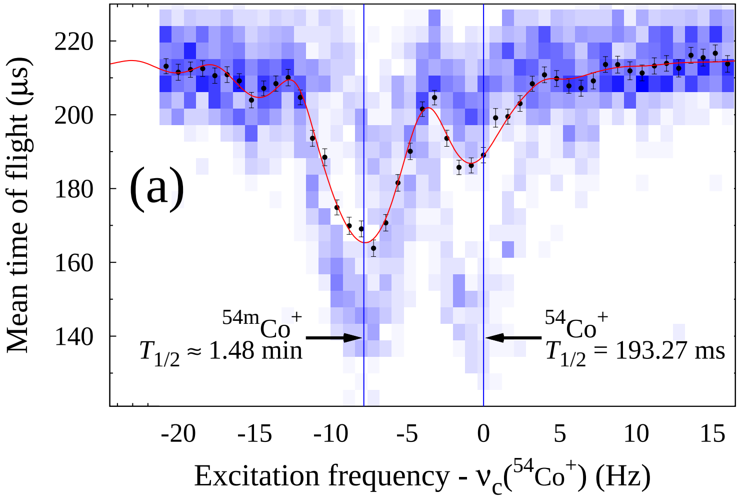


ISOLDE, ANL, JYFL, NSCL, GSI, TRIUMF, KVI, Stockholm, Ganil

Q_{EC} Values

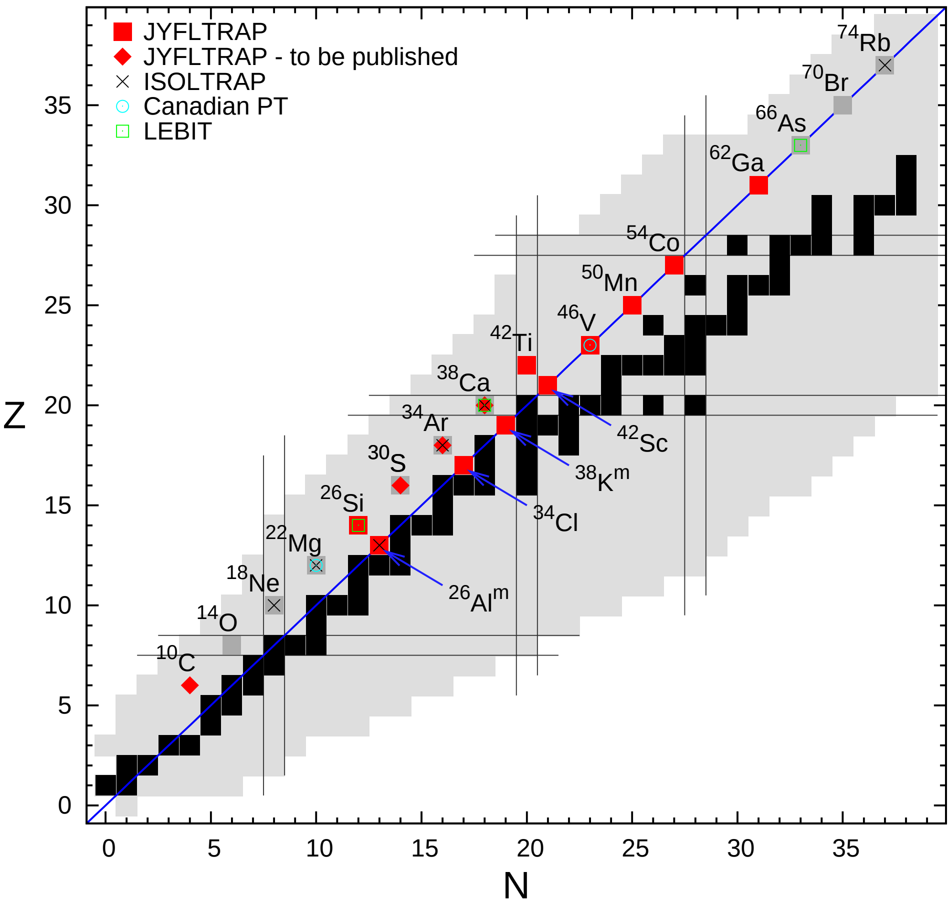
- Penning traps at RIB facilities now producing results at a steady, impressive rate
- Mass resolution ≈ 100 eV (!)
- Check/improve previous mass determinations, e.g. $(^3\mathrm{He}, t)$ rxns





difference of 197 keV

(Re-)Measured superallowed masses



(courtesy of T. Eronen)

Hardy & Towner,
PRC **79**, 055502 (2009)

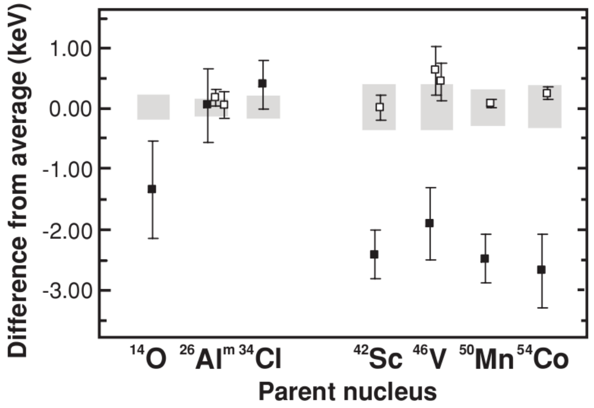
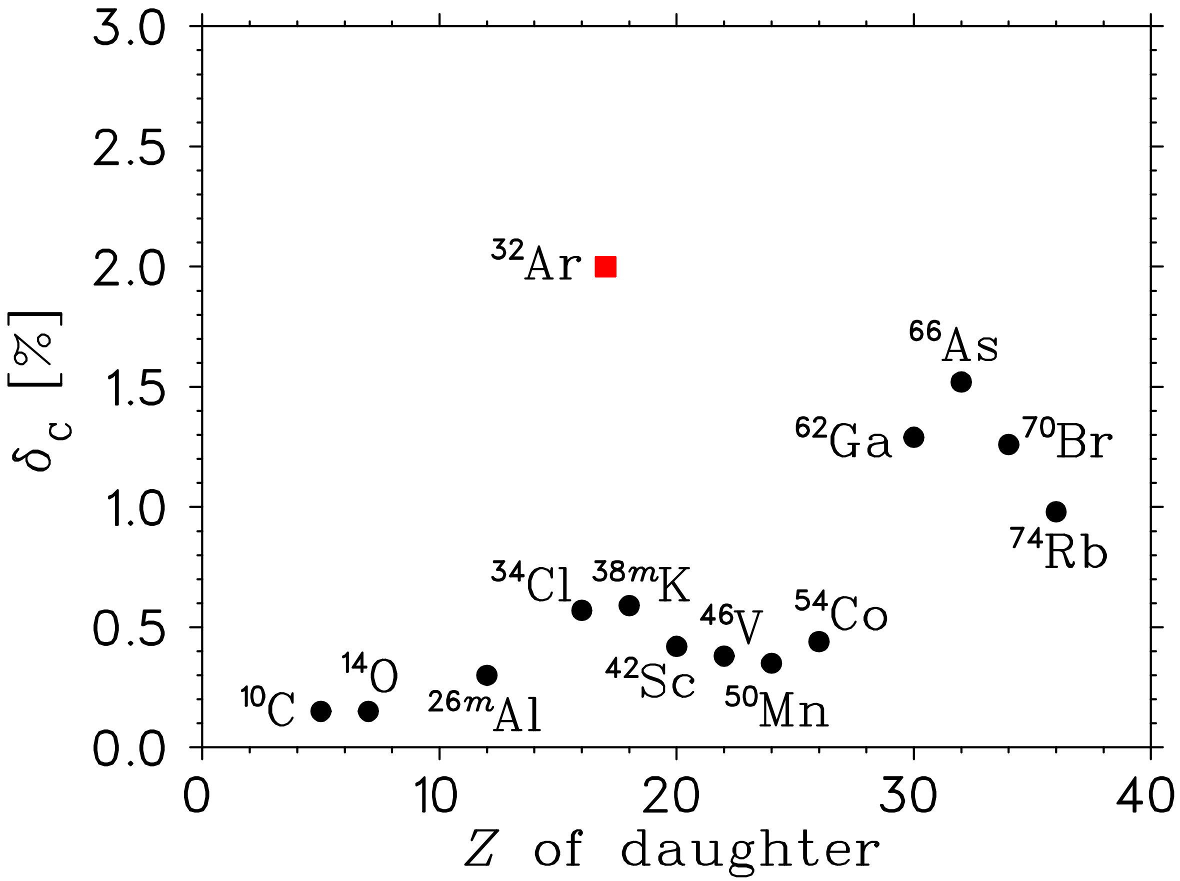


FIG. 1. Differences between individual measurements and the averages of all measurements for the seven parent nuclei studied by Vonach *et al.* [162]. The filled squares are the results of the (^{3}He, *t*) measurements of Vonach *et al.*; the open squares are recent Penning-trap results [61,62,73,149]. For each parent nucleus, the gray band about the zero line represents the uncertainty of the average for that case. Note that all the averages include the results of Vonach *et al.*, the Penning-trap results, and any other relevant measurements appearing in Table I.

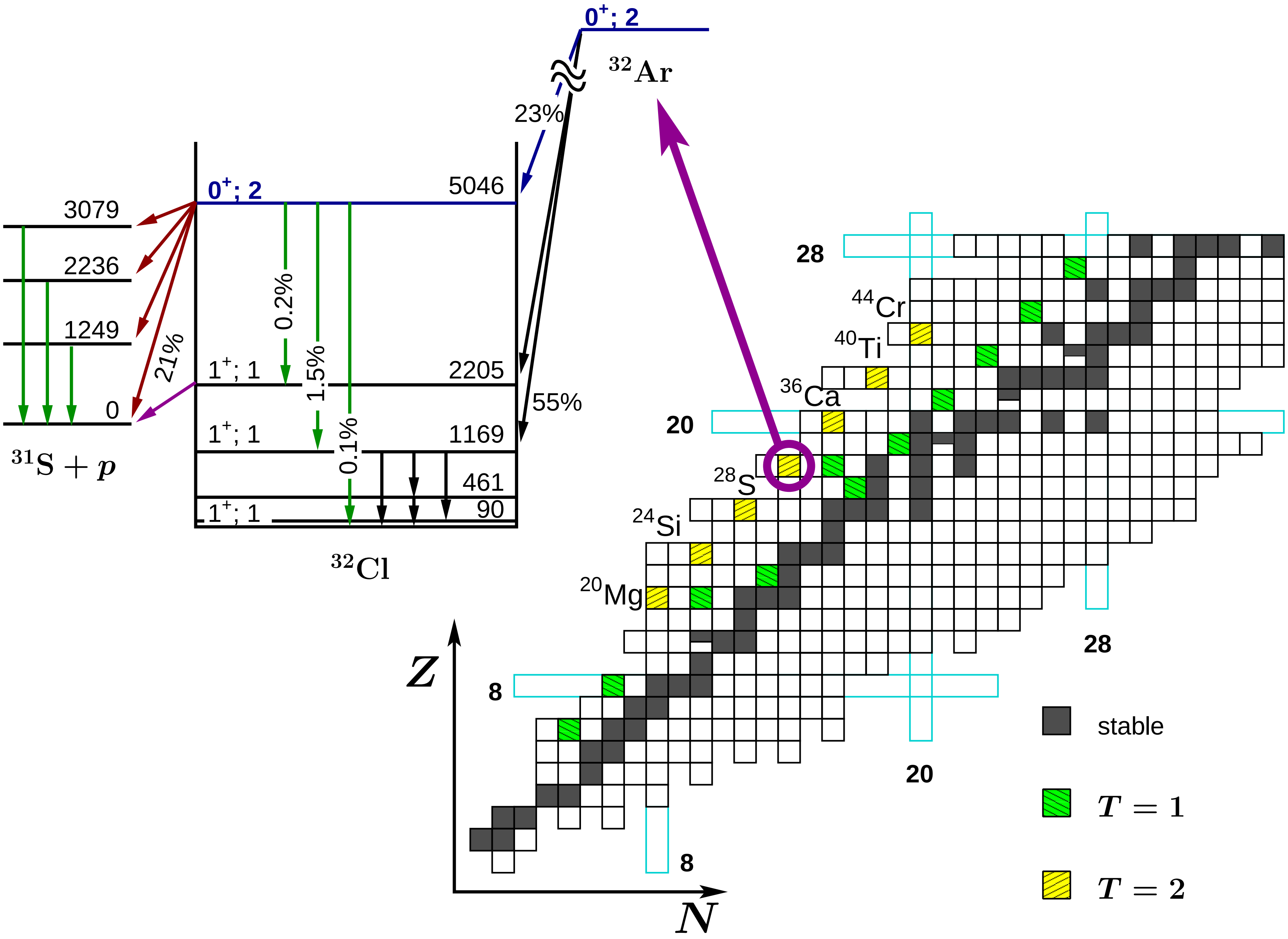
Isospin breaking corrections

How can we **test** these theoretical corrections?

⇒ **measure** it in a case where it is **large**



$T = 2$ superallowed decays



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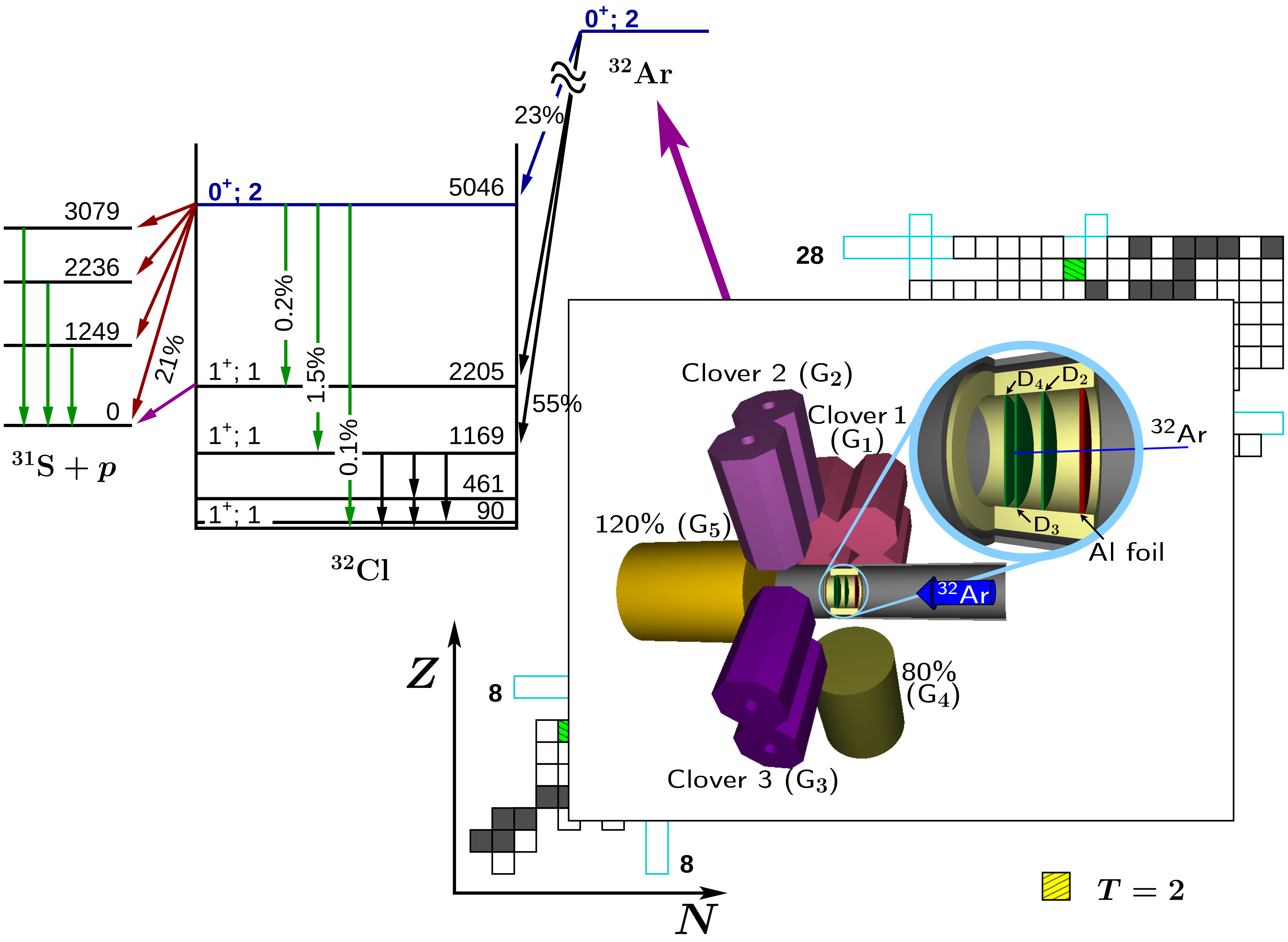

Result from ^{32}Ar

Branching ratios

protons:

$$N_p/N_{\mathrm{Ar}} = 20.79(14)\%$$

Summary of systematic uncertainties on the absolute superallowed branch in ^{32}Ar decay.

Component	$\Delta b^{\beta}_{\mathrm{SA}}/b^{\beta}_{\mathrm{SA}}$ [%]
Implanted ^{32}Ar's	**±0.23**
p_0 branch	**±0.52**
p_1 branch	±0.04
p_2 branch	±0.04
p_3 branch	±0.07
γ statistics	**±0.43**
^{32}Cl branching ratios	±0.11
HPGe detector efficiency	±0.09
Total	±0.70

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$$N_\gamma/N_{\mathrm{Ar}} = \ 1.92(\ 9)\%$$

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$f = 3505(8)$ and

$t_{1/2} = 100.5(3)$ ms

$\Rightarrow ft = 1538(14)$ s $\Rightarrow$

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experimental value: $\delta_C^{\mathrm{exp}} = 2.1(8)\%$

versus predicted: $\delta_C^{\mathrm{theory}} = 2.0(4)\%$

1st sub-% measurement of a $T = 2$ pure Fermi $0^+ \longrightarrow 0^+$ decay

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

ft of neutron decay

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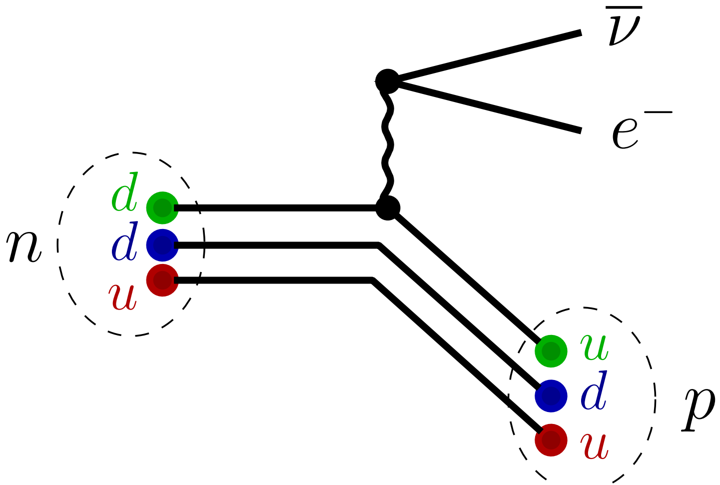
$K/(\hbar c)^6 = 2\pi^3\hbar\ln 2/(m_e c^2)^5$ and $G_V = G_F\,V_{ud}$ (CVC)

$G_A \approx -1.27\,G_F\,V_{ud}$ (PCAC)



theoretically simpler 3-quark system:

- no isospin corrections
- smaller radiative corrections

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For neutron decay: $\boldsymbol{M_F} = 1$ and $\boldsymbol{M_{GT}} = \sqrt{3}$

Gamow-Teller component ⇒ have to measure $\boldsymbol{\lambda \equiv G_A/G_V}$

$$ft = \frac{K}{G_F^2|V_{ud}|^2(1+3\boldsymbol{\lambda}^2)} \quad\Leftrightarrow\quad |V_{ud}|^2 = \frac{4903.7\pm3.8\,\mathrm{s}}{\boldsymbol{\tau_n}(1+3\boldsymbol{\lambda}^2)}$$

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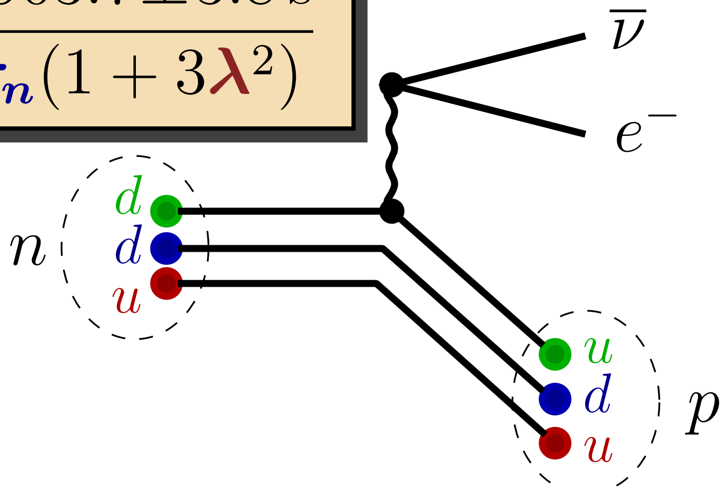


How to get the Gamow-Teller part?

$\beta-\nu$ correlation

Fierz interference

$$\frac{d^5W}{dE_\beta d\Omega_\beta d\Omega_\nu} = \overbrace{\frac{G_F^2}{(2\pi)^5}|V_{ud}|^2\, p_e E_e (E_\circ - E_e)^2}^{\text{unpolarized decay rate}}\, \xi \left[1 + a_{\beta\nu}\frac{\boldsymbol{p}_\beta\cdot\boldsymbol{p}_\nu}{E_\beta E_\nu} + b\frac{m_e}{E_\beta} \right.$$

$$\left. + \boldsymbol{\sigma}_n \cdot \left(\boldsymbol{A_\beta} \frac{\boldsymbol{p}_\beta}{E_\beta} + \boldsymbol{B_\nu}\frac{\boldsymbol{p}_\nu}{E_\nu} + \boldsymbol{D}\frac{\boldsymbol{p}_\beta\times\boldsymbol{p}_\nu}{E_\beta E_\nu}\right)\right]$$

neutron spin

β asymmetry

ν asymmetry

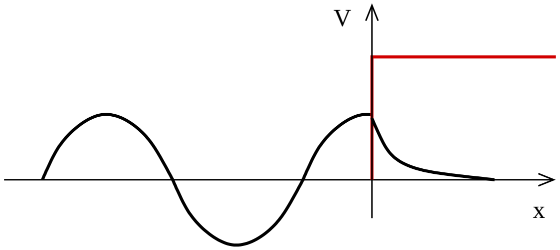
time-reversal violating

Within the Standard Model and in terms of $\boldsymbol{\lambda} \equiv G_A/G_V$:

$$\boldsymbol{A_\beta} = -2\frac{|\boldsymbol{\lambda}|^2 + \Re e(\boldsymbol{\lambda})}{1+3|\boldsymbol{\lambda}|^2}$$

$$\left.\begin{aligned} &= -0.1173(13) \\ \Leftrightarrow \boldsymbol{\lambda} &= -1.2695(27) \end{aligned}\right\} \text{PDG 2006}$$

Advantage of UCNs



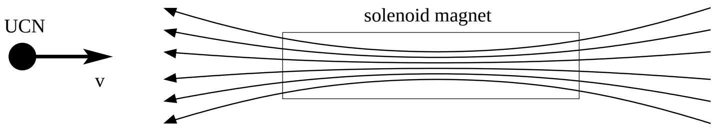
Reduced backgrounds:

- higher ratio of decays/neutrons
- no production source bkgds

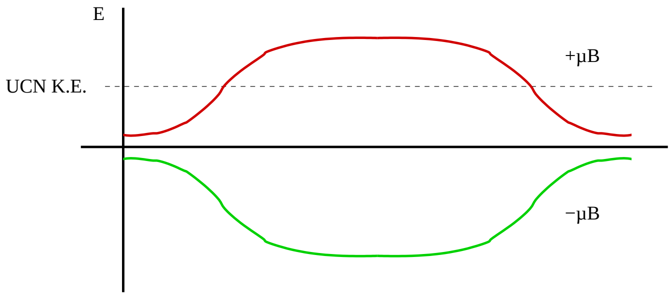
$$V_{^{58}\mathrm{Ni}} = 335\,\mathrm{neV}(\Rightarrow\ 8\,\mathrm{m/s})$$

$$V_{\mathrm{grav}} = mgh = 102\,\mathrm{neV/m}$$

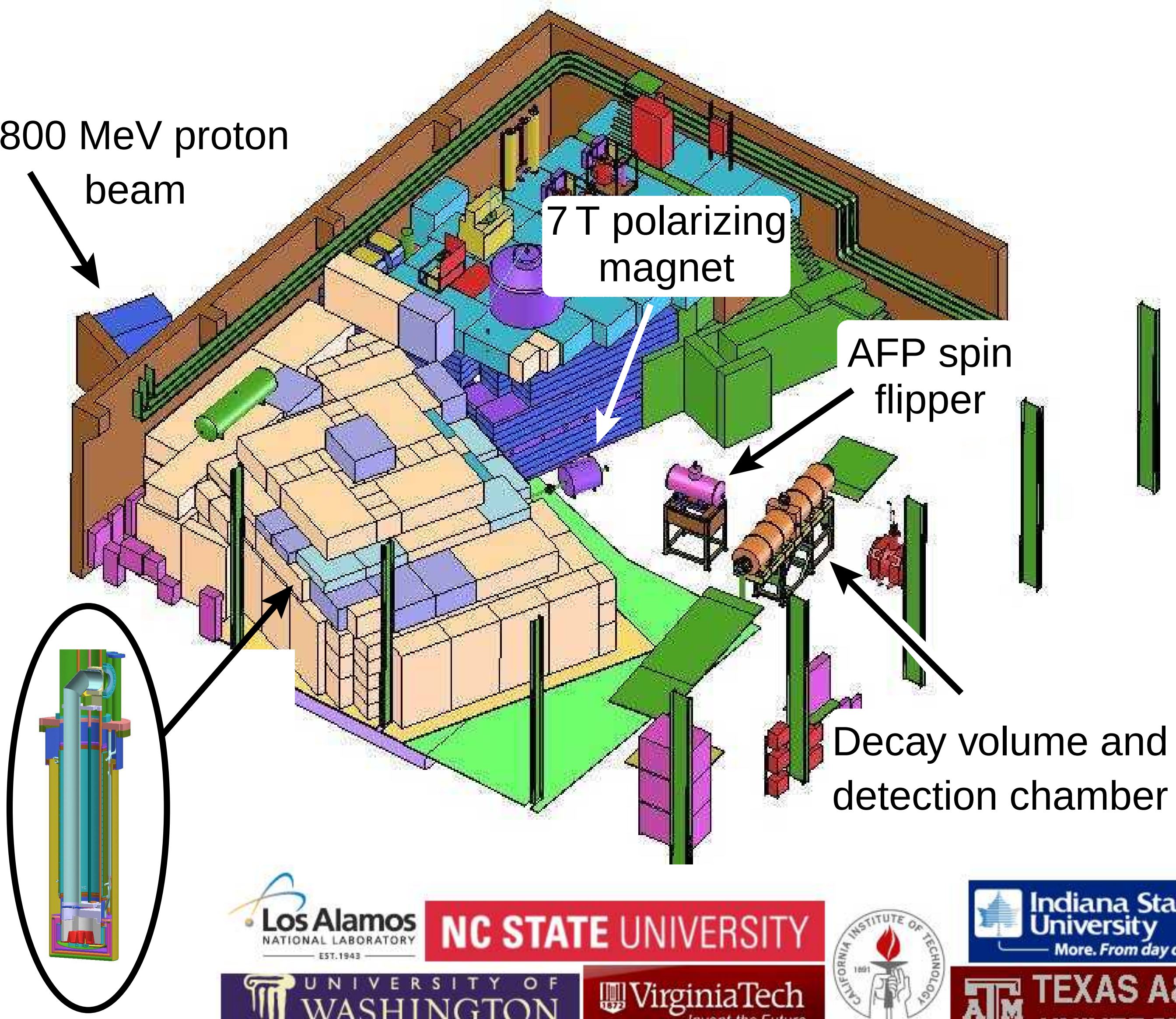
$$V_{\mathrm{mag}} = \boldsymbol{\mu}\cdot\boldsymbol{B} = 60\,\mathrm{neV/T}$$



100% polarization using magnetic fields



Area B at LANSCE



800 MeV proton beam

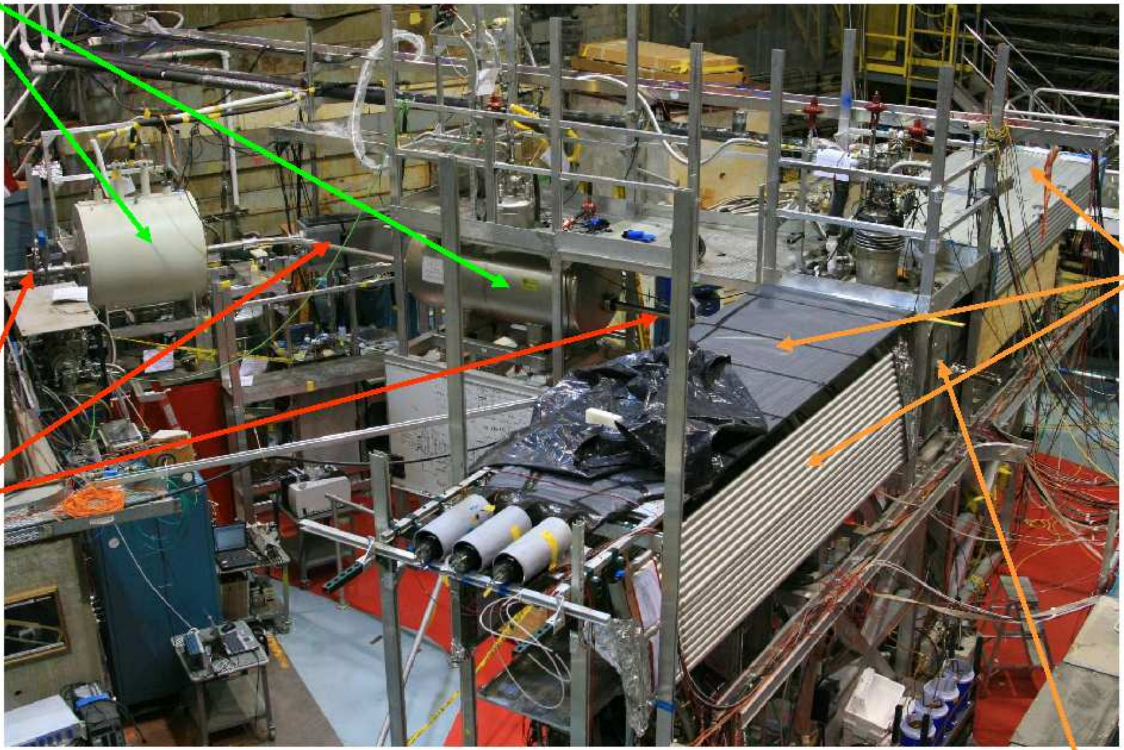
7 T polarizing magnet

AFP spin flipper

Decay volume and detection chamber

SD_2 UCN source

Area B at LANSCE



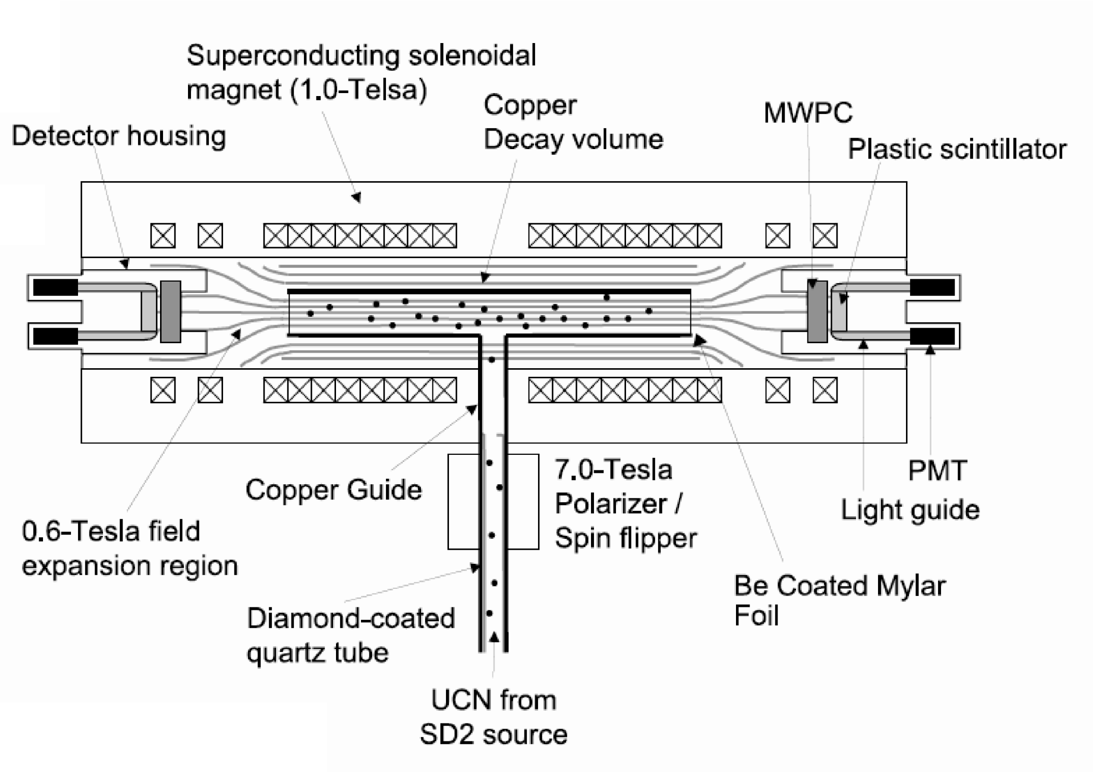
polarizing magnets

UCN beamline

muon vetoes

1 Tesla spectrometer

β spectrometer data collection



Asymmetry extracted from super-ratio:

$$S(E) = \frac{R(E)_1^{\uparrow} R(E)_2^{\downarrow}}{R(E)_1^{\downarrow} R(E)_2^{\uparrow}}$$

$$A_{\rm exp}(E) = \frac{1 - \sqrt{S(E)}}{1 + \sqrt{S(E)}}$$

$$A_{\circ} = \frac{A_{\rm exp}(E)}{\langle \beta \cos\theta \rangle}$$

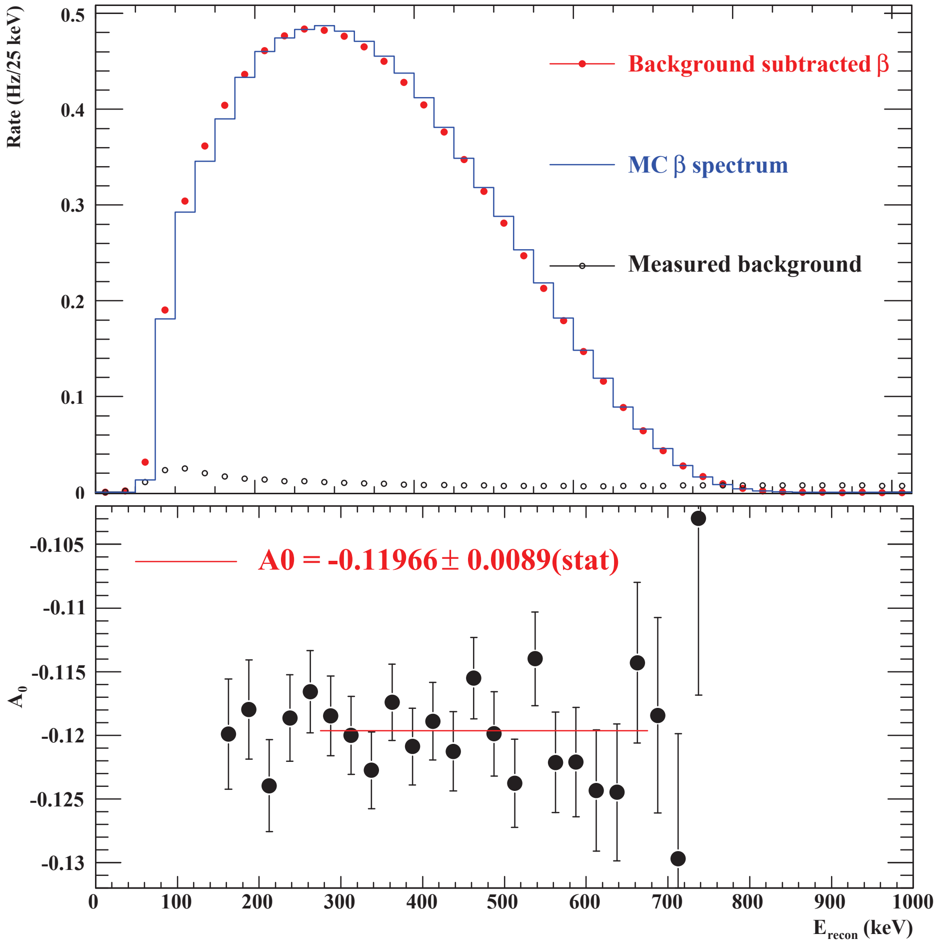
- solenoidal magnet with 1 T central field
- field expands to 0.6 T (supress backscatter)
- MWPC + scintillator detection

Data taken in “pulse pair” cycles:

- 720 s bkgd
- 3600 s asymmetry
- 720 s depolarization

UCN β spectrum and asymmetry

- S/N over ROI (275–625 keV) $\approx$ 40
- lower limit for initial UCN polarization: $P > 99.48\%$



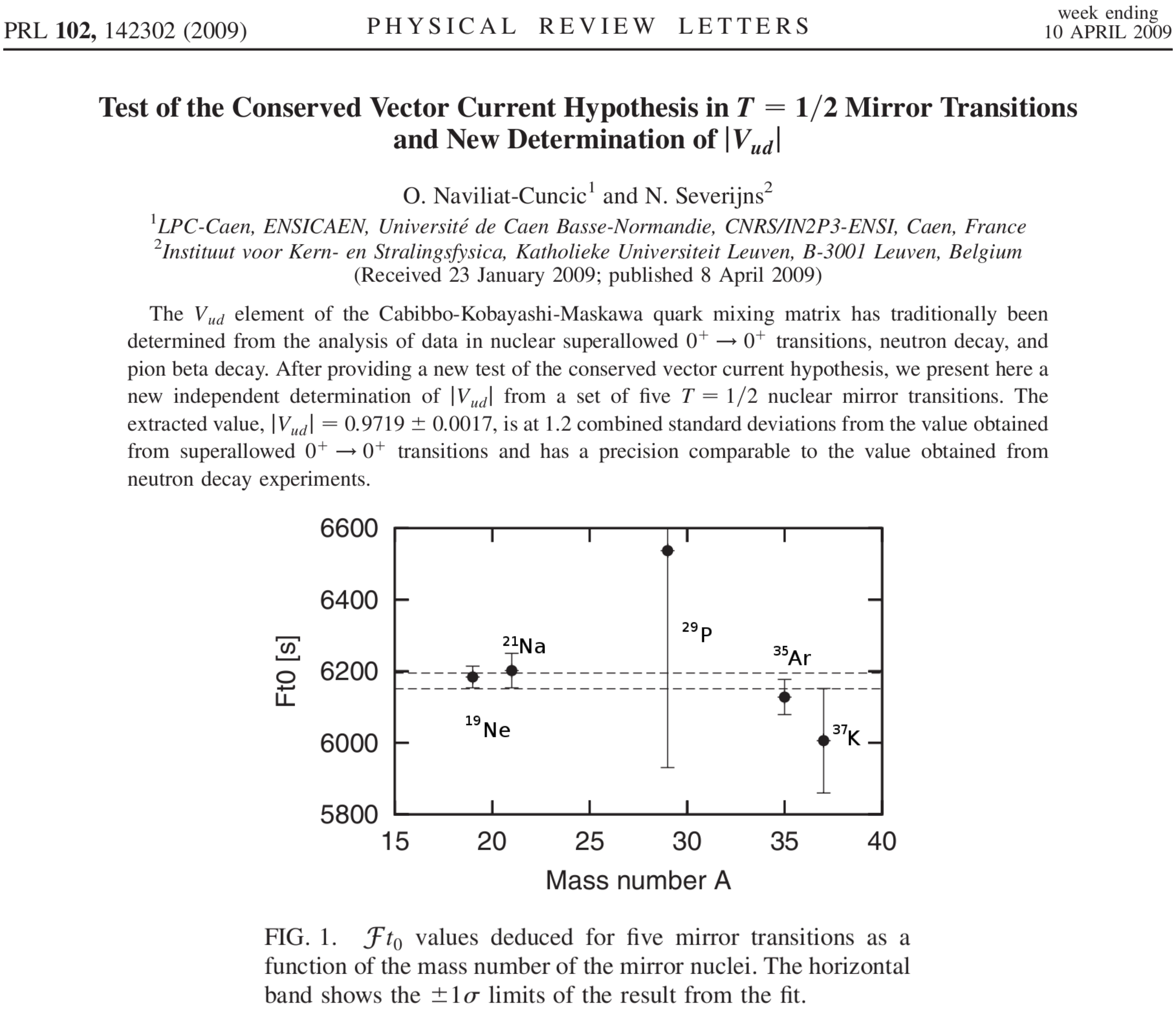
Preliminary error budget

Systematic	Correction	$\Delta A/A[\%]$
Polarization	—	${}^{+0.52}_{-0}$
Field non-uniform	—	${}^{+0.2}_{-0}$
Gain fluctuation	—	0.2
Energy response linearity	—	0.47
μ veto efficiency	—	0.3
live time	—	0.24
fiducial cut	—	0.24
recoil-order corr	-1.79	0.03
radiative corr	0.1	0.05
Angle effects	few $\%$	~ 0.1
Backscattering	$\sim 1\%$	~ 0.3

$$\boxed{A_\circ = -0.11966 \pm 0.00089^{+0.00123}_{-0.00140}}$$

arXiv:1007.3790 [nucl-ex]

$T = 1/2$ mirror nuclei: A new avenue!



PRL **102,** 142302 (2009) PHYSICAL REVIEW LETTERS week ending 10 APRIL 2009

Test of the Conserved Vector Current Hypothesis in $T = 1/2$ Mirror Transitions and New Determination of $|V_{ud}|$

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[1]*LPC-Caen, ENSICAEN, Université de Caen Basse-Normandie, CNRS/IN2P3-ENSI, Caen, France*
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(Received 23 January 2009; published 8 April 2009)

The V_{ud} element of the Cabibbo-Kobayashi-Maskawa quark mixing matrix has traditionally been determined from the analysis of data in nuclear superallowed $0^+ \to 0^+$ transitions, neutron decay, and pion beta decay. After providing a new test of the conserved vector current hypothesis, we present here a new independent determination of $|V_{ud}|$ from a set of five $T = 1/2$ nuclear mirror transitions. The extracted value, $|V_{ud}| = 0.9719 \pm 0.0017$, is at 1.2 combined standard deviations from the value obtained from superallowed $0^+ \to 0^+$ transitions and has a precision comparable to the value obtained from neutron decay experiments.

FIG. 1. $\mathcal{F}t_0$ values deduced for five mirror transitions as a function of the mass number of the mirror nuclei. The horizontal band shows the $\pm 1\sigma$ limits of the result from the fit.

$T = 1/2$ mirror nuclei: A new avenue!

N. SEVERIJNS, M. TANDECKI, T. PHALET, AND I. S. TOWNER

PHYSICAL REVIEW C **78**, 055501 (2008)

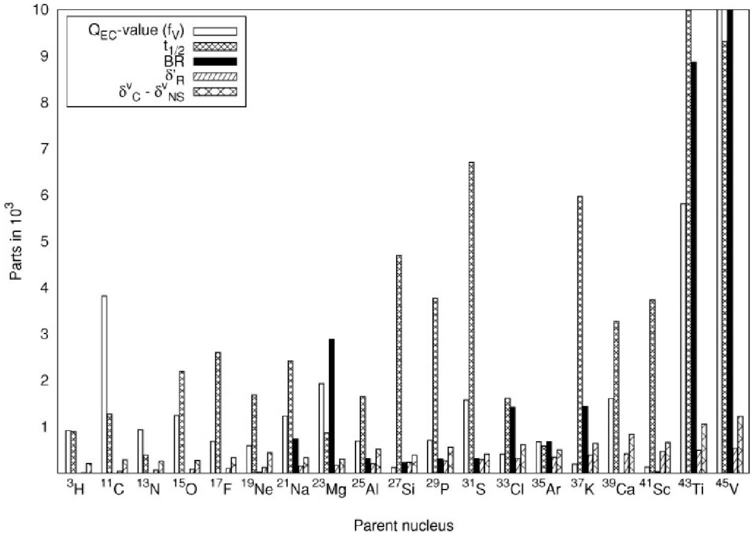


FIG. 1. Histogram of the fractional uncertainties attributed to each experimental and theoretical input factor that contributes to the final $\mathcal{F}t^{\text{mirror}}$ values.

TABLE X. Calculated standard model values for the a, A, B, N, and R correlation coefficients for the $T = 1/2$ mirror β transitions up to ^{45}V, using the mixing ratios listed in Table IX. The D triple correlation is zero in the standard model. The β particle longitudinal polarization, G, is -1 for β^- decay and $+1$ for β^+ decay. The N and R correlations are nonzero due to final-state interactions (FSI). Note that the about 10% accuracy to which the Eqs. (32) and (33) used to calculate N^{FSI} and R^{FSI} are valid [41] is not included in the error bars.

Parent nucleus	spin J	a_{SM}	δa (%)	A_{SM}	δA (%)	B_{SM}	δB (%)	R^{FSI}	N^{FSI}
^{3}H	1/2	-0.08593 ± 0.00038	0.44	-0.09408 ± 0.00046	0.49	0.991849 ± 0.000076	0.01	0.005045 ± 0.000025	0.09077 ± 0.00044
^{11}C	3/2	0.5236 ± 0.0035	0.67	-0.59946 ± 0.00016	0.03	-0.8853 ± 0.0023	0.26	-0.008100 ± 0.000006	-0.20804 ± 0.00012
^{13}N	1/2	0.6840 ± 0.0011	0.16	-0.333028 ± 0.000040	0.01	-0.6490 ± 0.0012	0.18	-0.004568 ± 0.000001	-0.099454 ± 0.000022
^{15}O	1/2	0.6228 ± 0.0024	0.39	0.7087 ± 0.0022	0.31	0.33148 ± 0.00020	0.06	0.008470 ± 0.000027	0.16124 ± 0.00051
^{17}F	5/2	0.1713 ± 0.0017	0.99	0.99739 ± 0.00018	0.02	0.64222 ± 0.00092	0.14	0.013582 ± 0.000003	0.226180 ± 0.000049
^{19}Ne	1/2	0.0435 ± 0.0010	2.30	-0.04166 ± 0.00095	2.28	-0.998186 ± 0.000085	0.01	-0.000522 ± 0.000012	-0.00779 ± 0.00018
^{21}Na	3/2	0.5587 ± 0.0027	0.48	0.8614 ± 0.0019	0.22	0.59661 ± 0.00032	0.05	0.010731 ± 0.000024	0.14457 ± 0.00033
^{23}Mg	3/2	0.6967 ± 0.0044	0.63	-0.5584 ± 0.0017	0.30	-0.7404 ± 0.0040	0.54	-0.006529 ± 0.000020	-0.08023 ± 0.00025
^{25}Al	5/2	0.4818 ± 0.0021	0.44	0.9350 ± 0.0011	0.12	0.71289 ± 0.00016	0.02	0.011214 ± 0.000013	0.12639 ± 0.00014
^{27}Si	5/2	0.5774 ± 0.0053	0.92	-0.6959 ± 0.0013	0.19	-0.8771 ± 0.0032	0.36	-0.007899 ± 0.000015	-0.08230 ± 0.00015
^{29}P	1/2	0.7154 ± 0.0048	0.67	0.6154 ± 0.0046	0.75	0.33083 ± 0.00044	0.13	0.007298 ± 0.000054	0.07059 ± 0.00053
^{31}S	1/2	0.7190 ± 0.0084	1.17	-0.33043 ± 0.00083	0.25	-0.6114 ± 0.0080	1.31	-0.003804 ± 0.000010	-0.034356 ± 0.000087
^{33}Cl	3/2	0.8848 ± 0.0029	0.33	-0.4007 ± 0.0040	1.00	-0.4699 ± 0.0057	1.21	-0.004739 ± 0.000048	-0.04010 ± 0.00040
^{35}Ar	3/2	0.9004 ± 0.0016	0.18	0.4371 ± 0.0036	0.82	0.3773 ± 0.0026	0.69	0.005102 ± 0.000041	0.04063 ± 0.00033
^{37}K	3/2	0.6580 ± 0.0061	0.93	-0.5739 ± 0.0021	0.37	-0.7791 ± 0.0058	0.74	-0.006863 ± 0.000025	-0.05158 ± 0.00019
^{39}Ca	3/2	0.6036 ± 0.0041	0.68	0.8270 ± 0.0029	0.35	0.58916 ± 0.00076	0.13	0.009766 ± 0.000034	0.06950 ± 0.00024
^{41}Sc	7/2	0.2970 ± 0.0033	1.11	0.99777 ± 0.00032	0.03	0.76344 ± 0.00080	0.10	0.012480 ± 0.000004	0.084287 ± 0.000027
^{43}Ti	7/2	0.480 ± 0.016	3.33	-0.7737 ± 0.0016	0.21	-0.9470 ± 0.0057	0.60	-0.009563 ± 0.000023	-0.06147 ± 0.00014
^{45}V	7/2	0.629 ± 0.021	3.34	0.852 ± 0.017	2.00	0.729 ± 0.010	1.37	0.01060 ± 0.00022	0.0650 ± 0.0013

TABLE IX. The $\mathcal{F}t^{\text{mirror}}$ values and Gamow-Teller/Fermi mixing ratios, ρ (assuming $C_A = -1.27\ C_V$), with their relative uncertainties.

Parent nucleus	$\mathcal{F}t$ (s)	$\delta\mathcal{F}t$ (%)	ρ	$\delta\rho$ (%)
^{3}H	1135.3 ± 1.5	0.13	-2.0951 ± 0.0020	0.10
^{11}C	3933 ± 16	0.41	0.7456 ± 0.0043	0.58
^{13}N	4682.0 ± 4.9	0.10	0.5573 ± 0.0013	0.23
^{15}O	4402 ± 11	0.25	-0.6281 ± 0.0028	0.45
^{17}F	2300.4 ± 6.2	0.27	-1.2815 ± 0.0035	0.27
^{19}Ne	1718.4 ± 3.2	0.19	1.5933 ± 0.0030	0.19
^{21}Na	4085 ± 12	0.29	-0.7034 ± 0.0032	0.45
^{23}Mg	4725 ± 17	0.36	0.5426 ± 0.0044	0.81
^{25}Al	3721.1 ± 7.0	0.19	-0.7973 ± 0.0027	0.34
^{27}Si	4160 ± 20	0.48	0.6812 ± 0.0053	0.78
^{29}P	4809 ± 19	0.40	-0.5209 ± 0.0048	0.92
^{31}S	4828 ± 33	0.68	0.5167 ± 0.0084	1.63
^{33}Cl	5618 ± 13	0.23	0.3076 ± 0.0042	1.37
^{35}Ar	5688.6 ± 7.2	0.13	-0.2841 ± 0.0025	0.88
^{37}K	4562 ± 28	0.61	0.5874 ± 0.0071	1.21
^{39}Ca	4315 ± 16	0.37	-0.6504 ± 0.0041	0.63
^{41}Sc	2849 ± 11	0.39	-1.0561 ± 0.0053	0.50
^{43}Ti	3701 ± 56	1.51	0.800 ± 0.016	2.00
^{45}V	4382 ± 99	2.26	-0.621 ± 0.025	4.03

β-decay observables of ^{37}K

$$ft = \begin{pmatrix}\text{phase}\\ \text{space}\end{pmatrix}\begin{pmatrix}\text{partial}\\ \text{half-life}\end{pmatrix} = \frac{K}{G_V^2|\boldsymbol{M_F}|^2 + G_A^2|\boldsymbol{M_{GT}}|^2}$$

For isobaric analogue decay: $\boldsymbol{M_F} = 1$ and $\boldsymbol{M_{GT}} = ???$

GT component ⇒ have to measure $\boldsymbol{\rho} \equiv \boldsymbol{G_A M_{GT}/G_V M_F}$

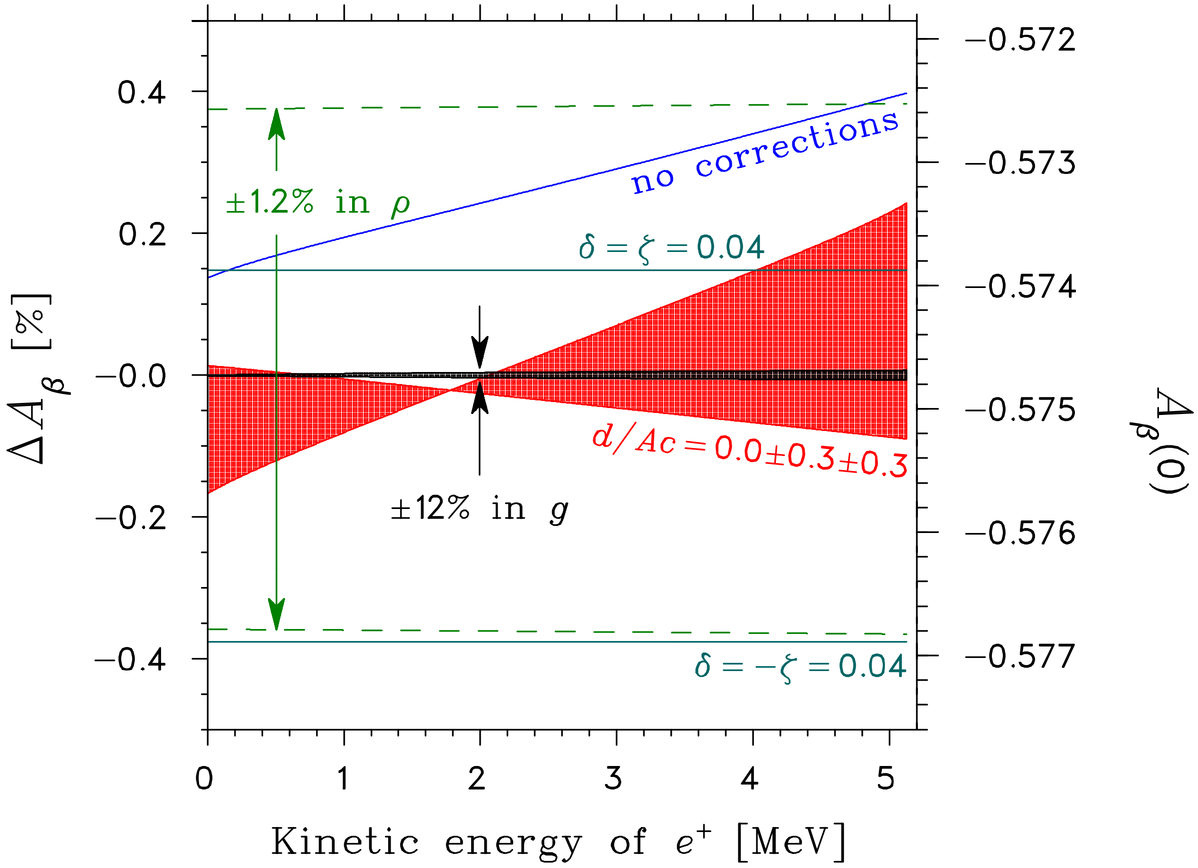
$$\boxed{ft = \frac{K}{G_F^2|V_{ud}|^2(1+\boldsymbol{\rho}^2)}}$$

Angular distribution of the $\frac{\mathbf{3}}{\mathbf{2}}^+ \rightarrow \frac{\mathbf{3}}{\mathbf{2}}^+$ decay:

$$dW \sim 1 + a\frac{\boldsymbol{p}_e\cdot\boldsymbol{p}_\nu}{E_eE_\nu} + b\Gamma\frac{m}{E_e} + \frac{\boldsymbol{I}}{I}\cdot\left[\boldsymbol{A_\beta}\frac{\boldsymbol{p}_e}{E_e} + \boldsymbol{B_\nu}\frac{\boldsymbol{p}_\nu}{E_\nu} + \boldsymbol{D}\frac{\boldsymbol{p}_e\times\boldsymbol{p}_\nu}{E_eE_\nu}\right]$$

$$+ c_{\text{align}}\left[\frac{\boldsymbol{p}_e\cdot\boldsymbol{p}_\nu}{3E_eE_\nu} - \frac{(\boldsymbol{p}_e\cdot\hat{\imath})(\boldsymbol{p}_\nu\cdot\hat{\imath})}{E_eE_\nu}\right]\left[\frac{I(I+1) - 3\langle(\boldsymbol{I}\cdot\hat{\imath})^2\rangle}{I(2I-1)}\right]$$

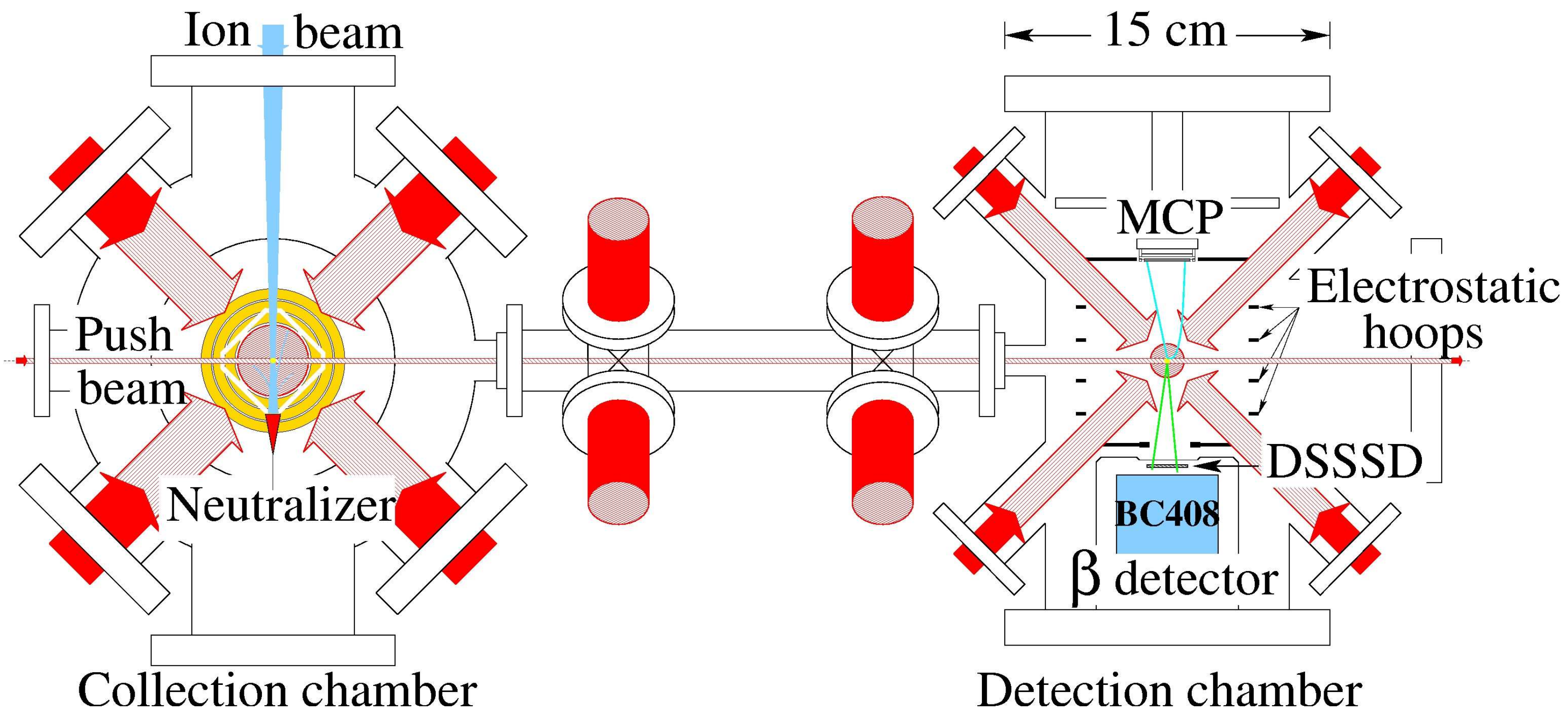
The β asymmetry



$$A_\beta = \frac{-2\rho\left(\sqrt{3/5} - \rho/5\right)}{1+\rho^2}$$

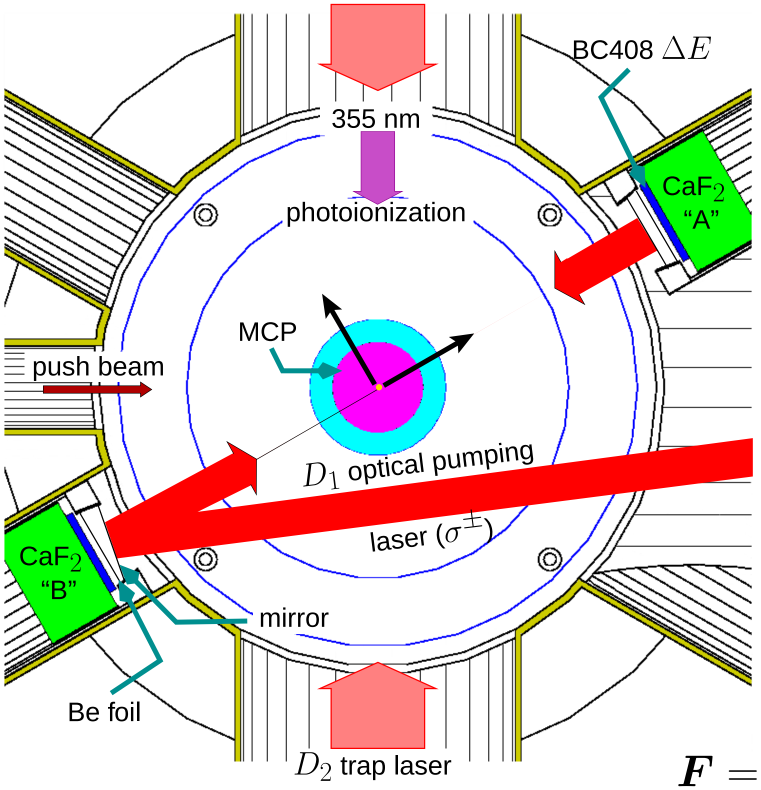
- recoil order corrections under control
- also sensitive to RHCs and SCCs

TRIUMF’s Neutral Atom Trap



- Isomerically selective
- $\lesssim 1$ mm^3 cloud size
- $\approx 10^{-3}$ K cloud temperature
- recoils escape unperturbed

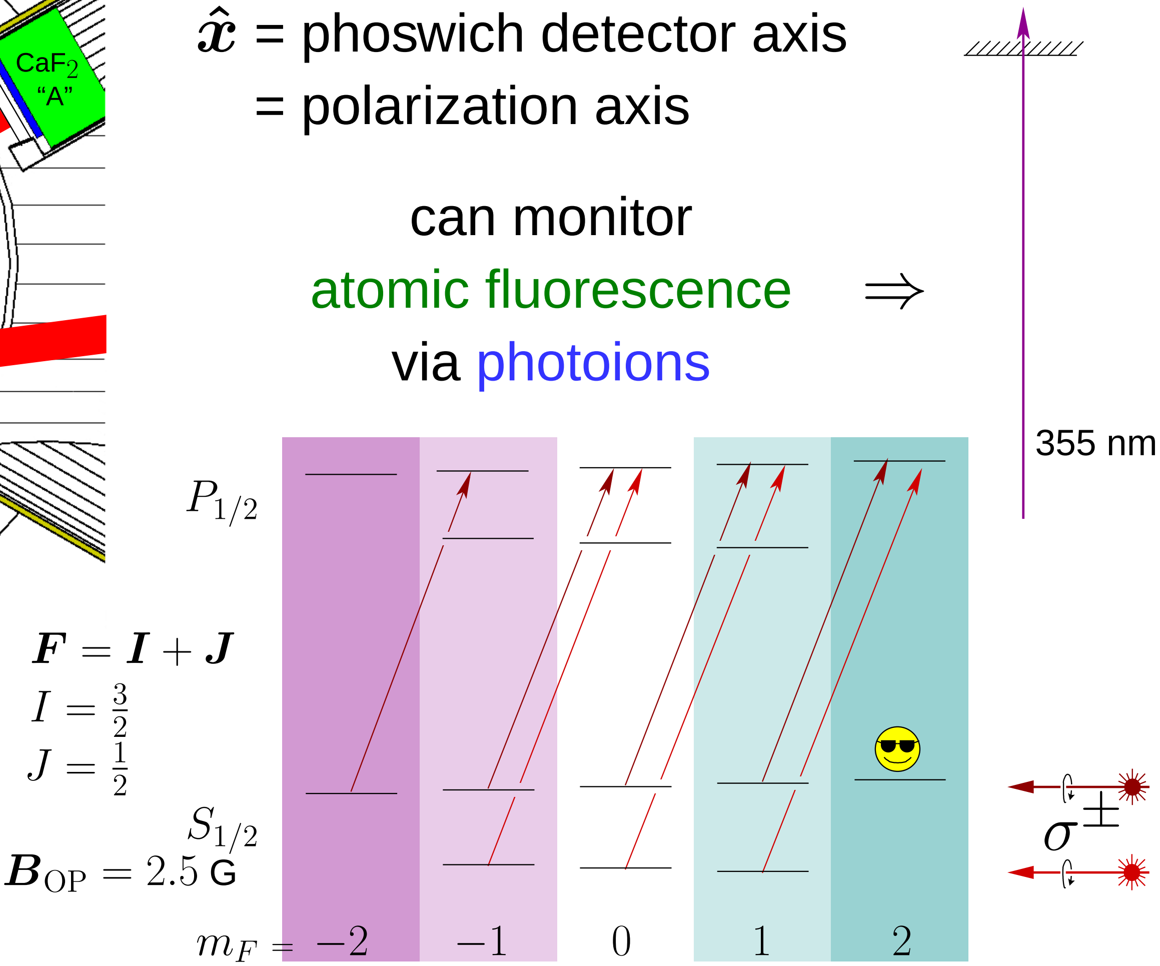
Side view of 2nd trap



$\hat{\boldsymbol{z}}$ = MCP–$\boldsymbol{\beta}$-telescope axis

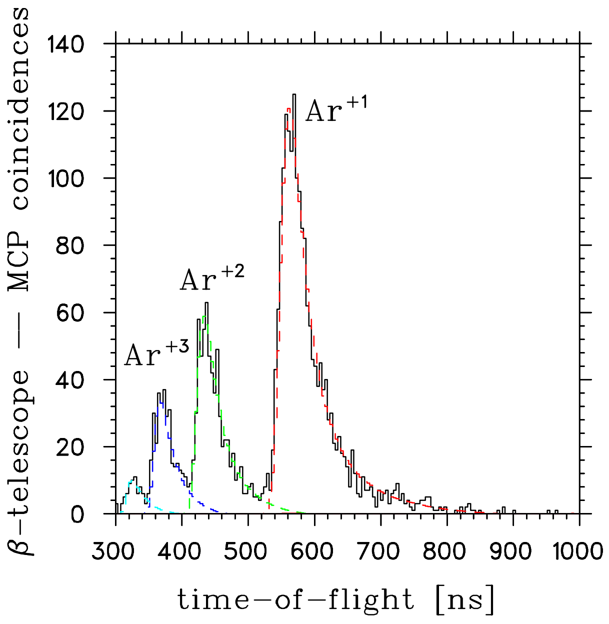
$\hat{\boldsymbol{x}}$ = phoswich detector axis
= polarization axis

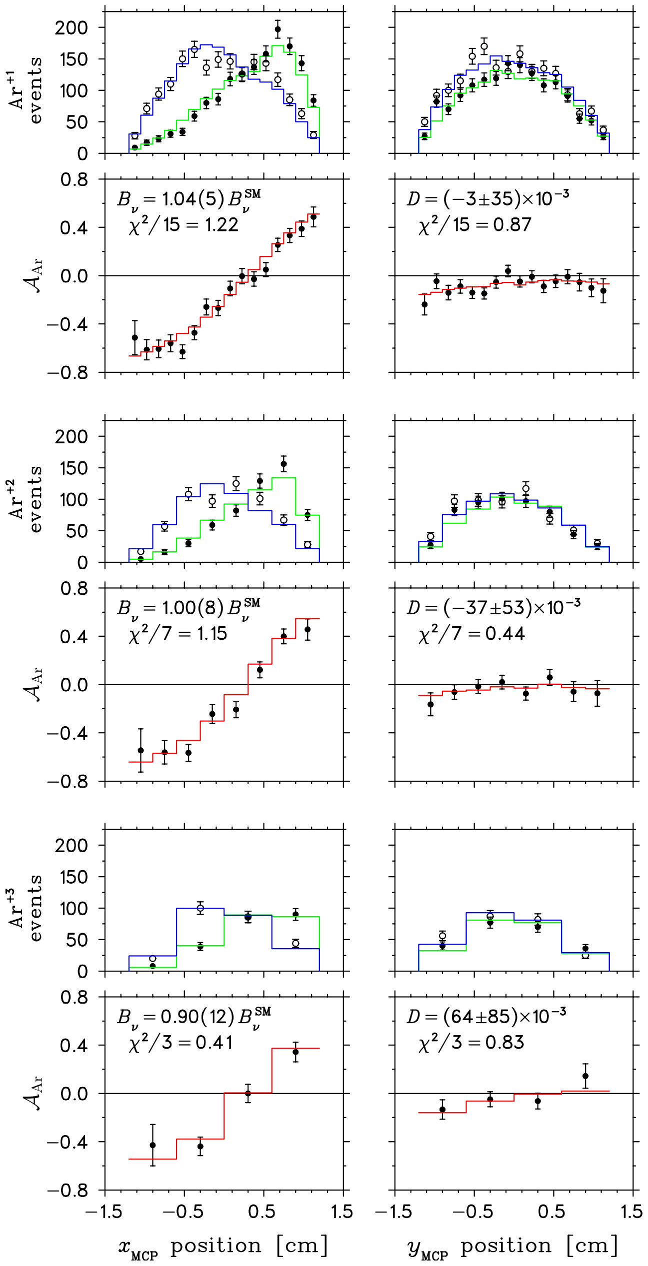
can monitor
atomic fluorescence ⇒
via photoions



$$\boxed{\Rightarrow\ P_{\text{nucl}} = 96.74 \pm 0.53^{+0.19}_{-0.73}}$$

The neutrino asymmetry measurement





$$1^{\rm st}:\quad \langle B_\nu\rangle = (0.995 \pm 0.040)_{\rm (stat)} B_\nu^{\rm SM}$$

$$2^{\rm nd}:\quad \langle B_\nu\rangle = (0.975 \pm 0.031)_{\rm (stat)} B_\nu^{\rm SM}$$

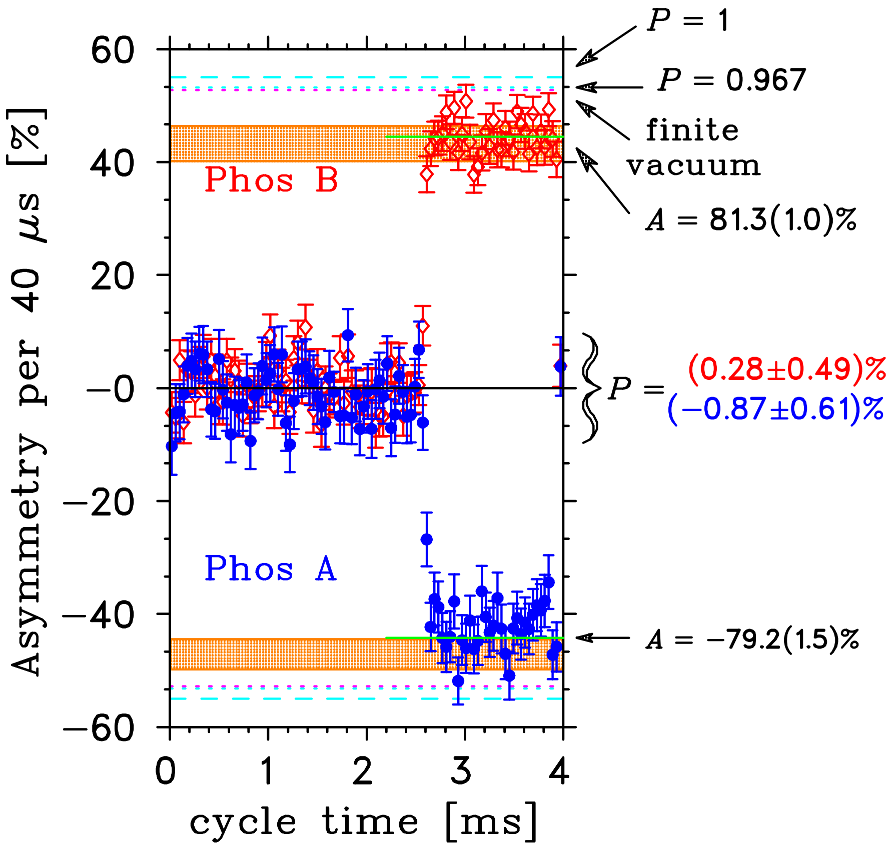
$$\Rightarrow \boxed{\boldsymbol{B_\nu = 0.981(26)(17)B_\nu^{\rm SM}}}$$

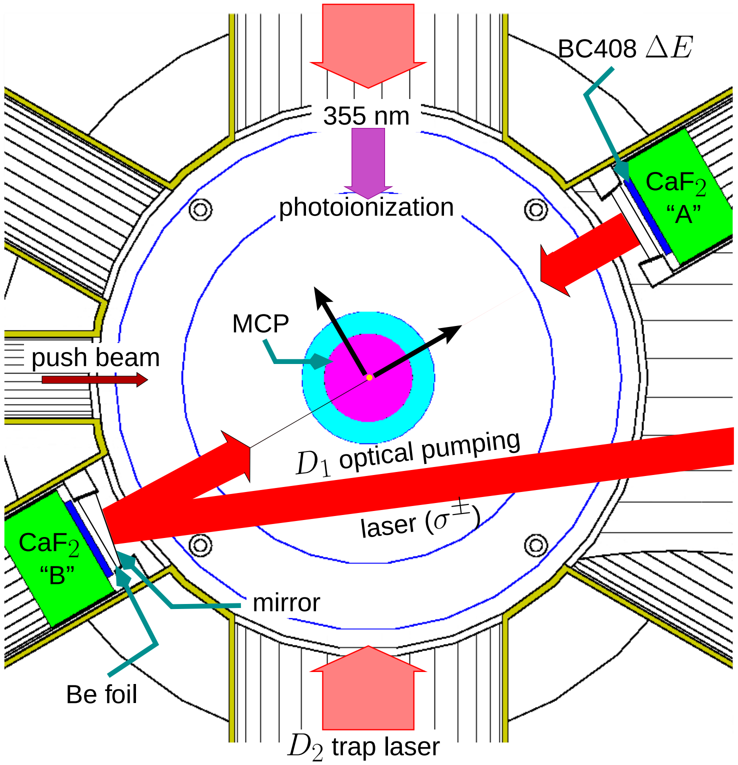
(Melconian, PLB 649 (2007) 370)

A_β – Phoswich asymmetries

$$\text{Asymmetry} = \frac{N(\sigma^+) - N(\sigma^-)}{N(\sigma^+) + N(\sigma^-)}$$

$$\sim P A_\beta \left\langle \frac{p_e}{E_e} \right\rangle$$





A_β – Phoswich asymmetries

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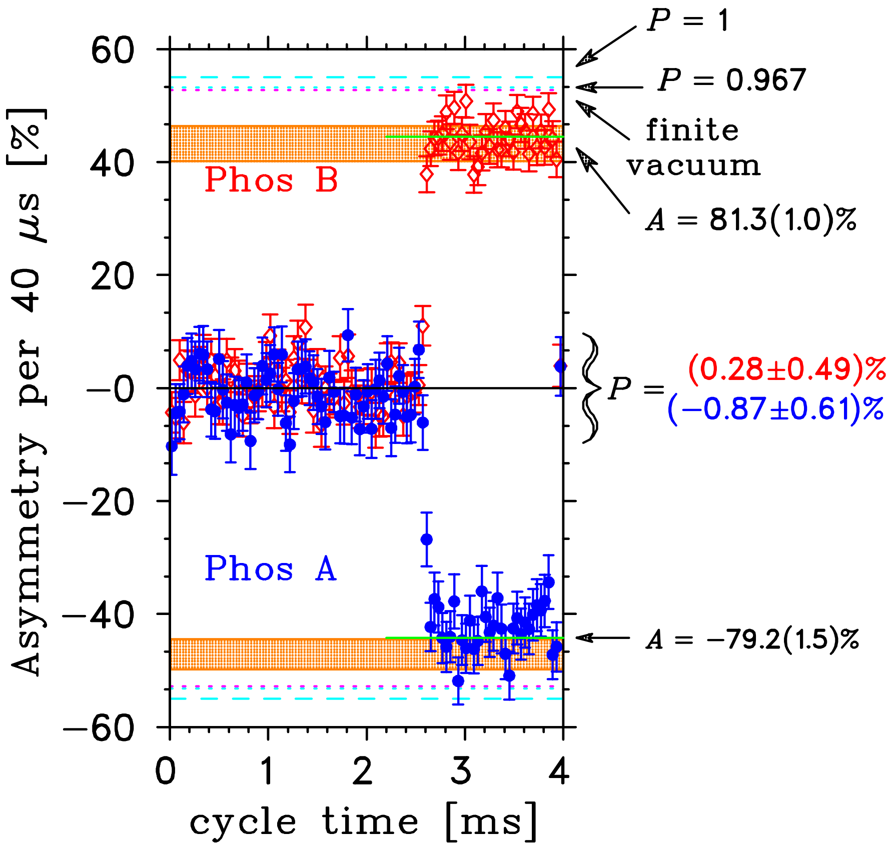
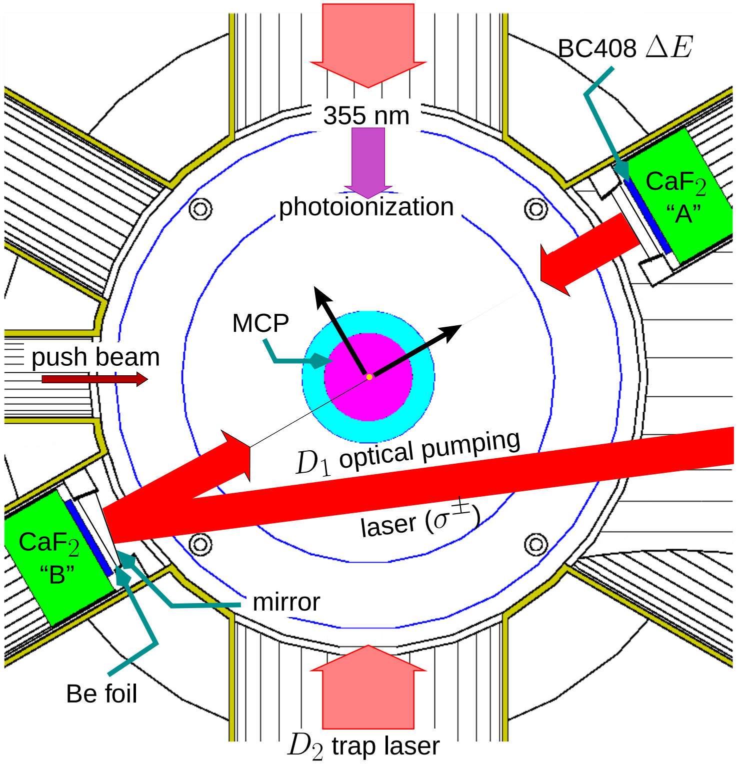




Lots of improvements being made . . . but no time to go through them. Expect new results by the next CKM workshop!

(Some) Planned or recently completed projects

- many Penning traps: many Q_{EC} values
- Bordeaux/JYFL: ^{39}Ca, ^{29}P half-lives; ^{31}S half-life and branch
- TUNL/KVI: ^{19}Ne, ^{21}Na, ^{37}K half-lives
- TRIUMF: ^{19}Ne, ^{26m}Al half-lives
- TAMU/TRIUMF: ^{37}K half-life, branch, A_β, B_ν, $(\ldots)$
- LPC-Caen: ^{35}Ar $\beta - \nu$ correlation
- TAMU: $T = 2$ super-allowed ft and $\beta - \nu$ correlation:

  ^{20}Mg, ^{24}Si, ^{28}S, ^{32}Ar, ^{36}Ca, ^{40}Ti
- TAMU: ^{10}C, ^{26}Si half-lives

Conclusions

- value of V_{ud} within quoted uncertainty after many years/expts
- hard to dramatically affect $\langle\mathcal{F}t\rangle$ with one measurement
- there are still many strong programs in $0^+ \rightarrow 0^+$ decays:
  - check/improve old measurements
  - test/develop theoretical corrections
  - limits on scalar and RH currents
  - $T=2$ β-delayed proton decays
- other avenues: neutron, $T=1/2$ mirror decays

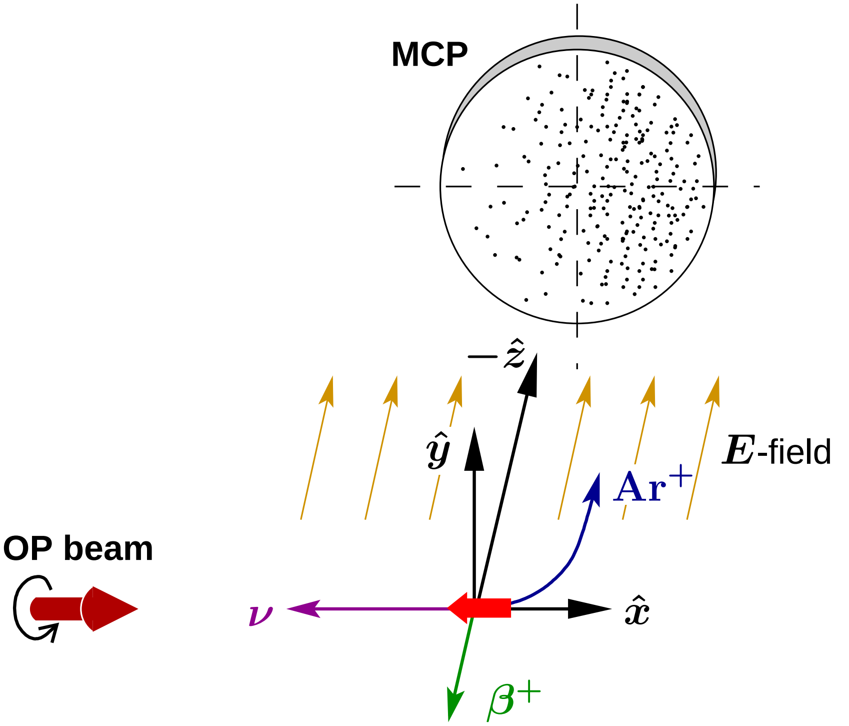
Thanks to G. Ball (TRIUMF), T. Eronen (JYFL), J. Äystö (JYFL), P. Finlay (UGuelph), O. Naviliat-Cuncic (NSCL), G. Bollen (NSCL), J.C. Hardy (TAMU), the UCNA collaboration, the TRINAT collaboration

S. Behling, M. Mehlman, P. Shidling and the staff at the CI

and to you for your attention!

Measuring B_ν (and D)

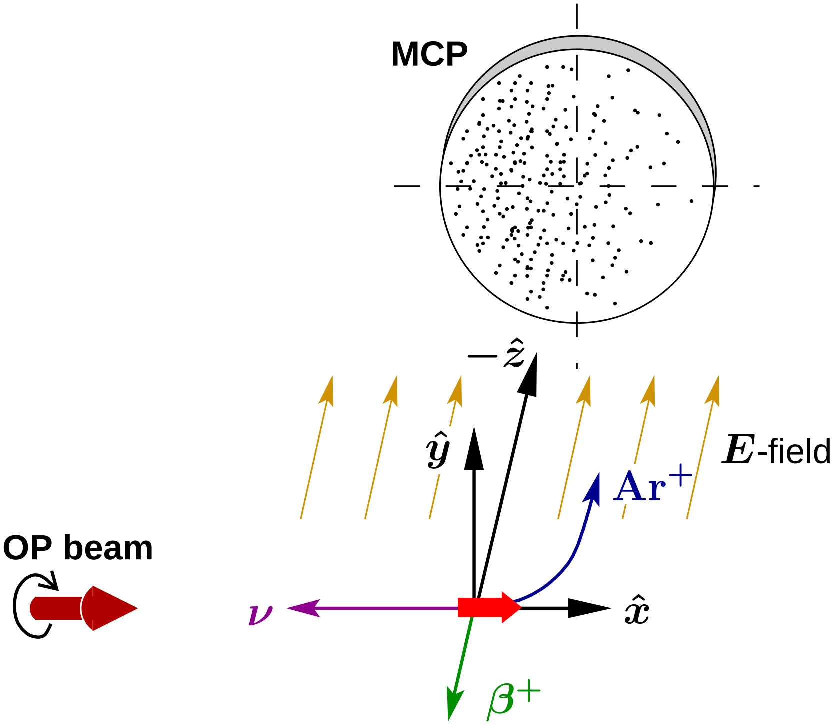
$$d\Gamma \sim \boldsymbol{P}\boldsymbol{B_\nu}\hat{p}_\nu \cdot \hat{i} + \boldsymbol{P}\boldsymbol{D}\frac{\hat{i}\cdot(\boldsymbol{p}_\beta \times \hat{p}_\nu)}{E_\beta}$$



$$\hat{p}_\beta \approx \hat{z} \quad \Rightarrow \boldsymbol{p}_\nu \approx -\boldsymbol{p}_{\mathrm{Ar}}$$

Measuring B_ν (and D)

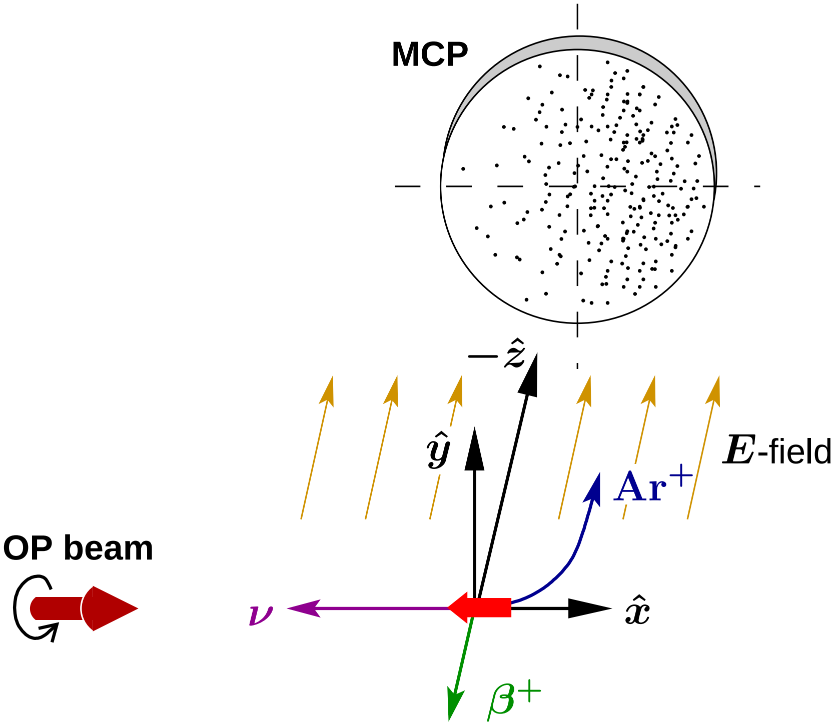
$$d\Gamma \sim \boldsymbol{P}\boldsymbol{B_\nu}\hat{p}_\nu\cdot\hat{i} + \boldsymbol{P}\boldsymbol{D}\frac{\hat{i}\cdot(\boldsymbol{p}_\beta\times\hat{p}_\nu)}{E_\beta}$$



$$\hat{p}_\beta \approx \hat{z} \quad\Rightarrow\quad \boldsymbol{p}_\nu \approx -\boldsymbol{p}_{\mathrm{Ar}}$$

Measuring B_ν (and D)

$$d\Gamma \sim PB_\nu \hat{p}_\nu \cdot \hat{i} + PD \frac{\hat{i} \cdot (\boldsymbol{p}_\beta \times \hat{p}_\nu)}{E_\beta}$$

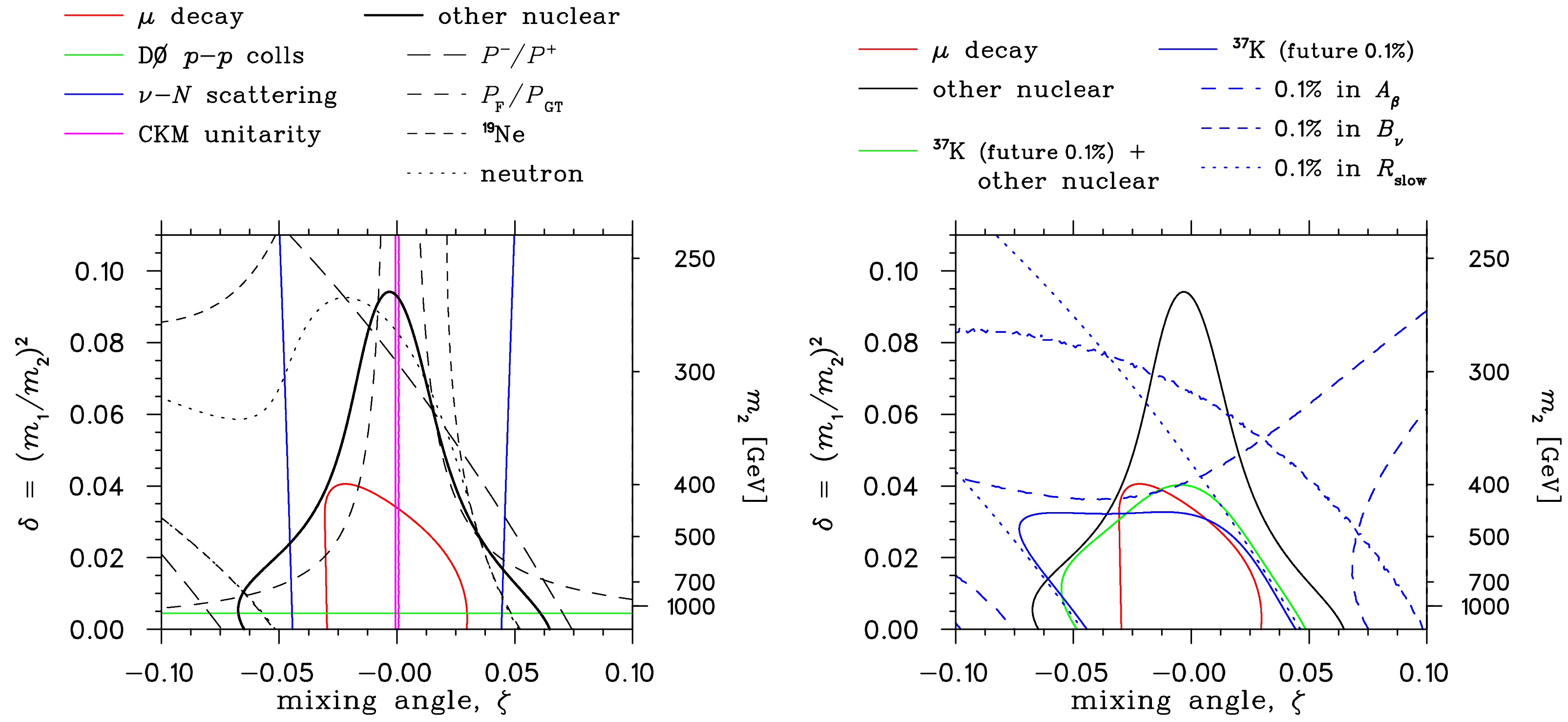


$$\hat{p}_\beta \approx \hat{z} \quad \Rightarrow \boldsymbol{p}_\nu \approx -\boldsymbol{p}_{\mathrm{Ar}}$$

$\hat{x}$ asymmetry $\sim PB_\nu$

$\hat{y}$ asymmetry $\sim PD$

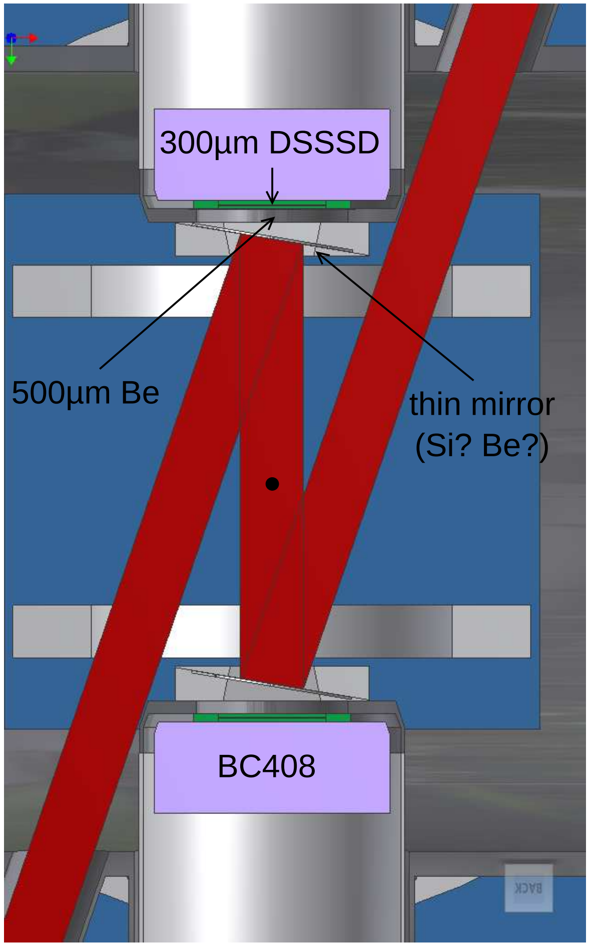
B_ν measurement and current limits

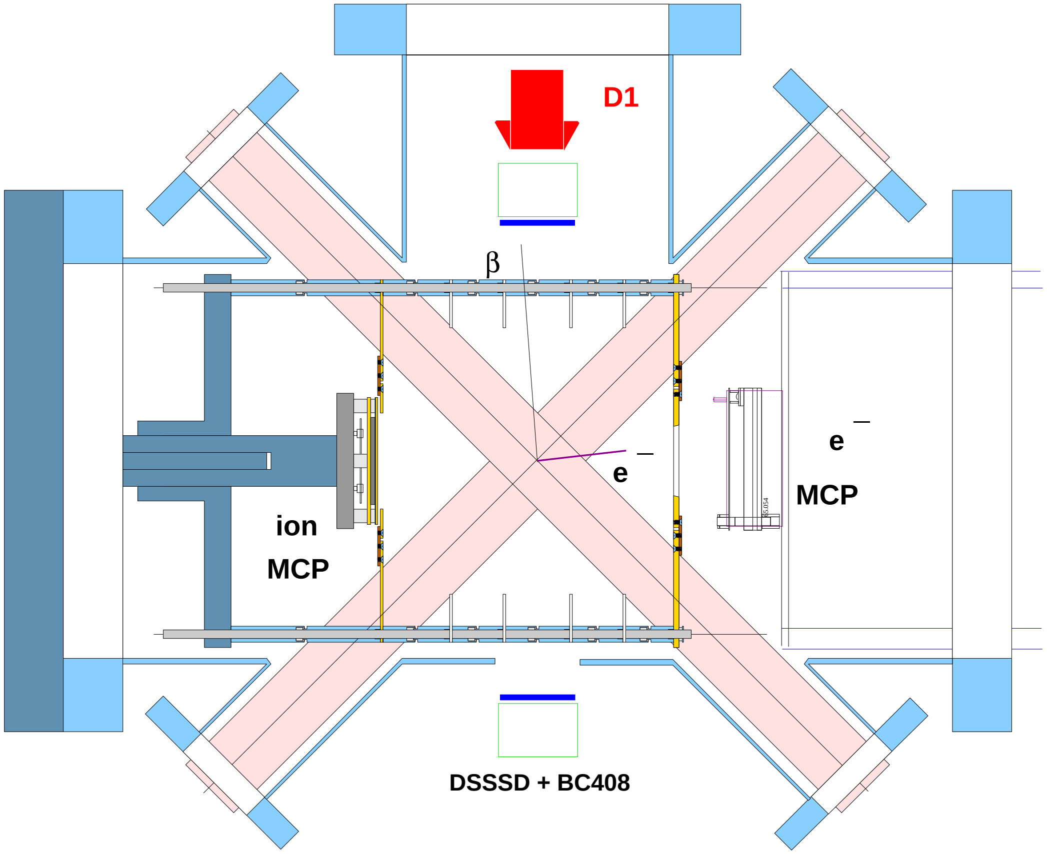


Expected limits if A_β, B_ν and R_{slow} all measured to 0.1%

see Profumo, Ramsey-Musolf and Tulin, PRD **75** (2007) 075017

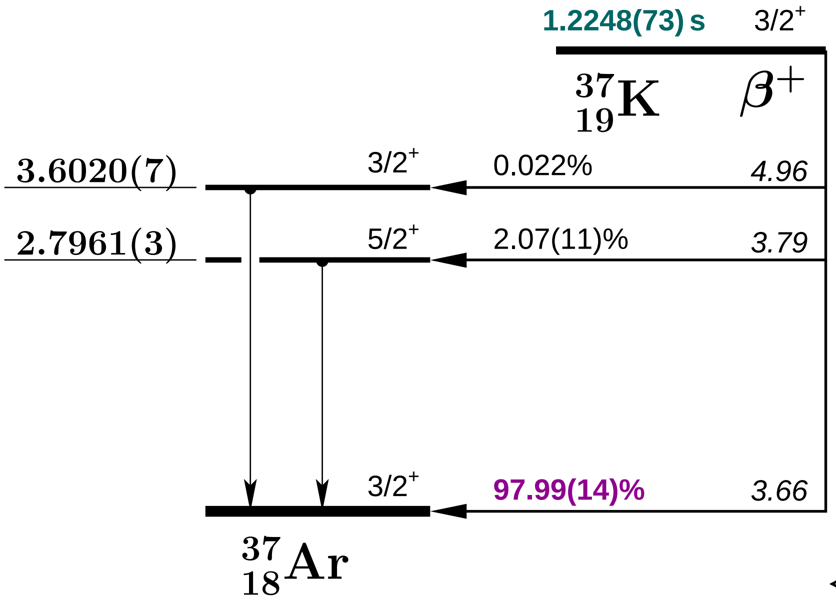
Geometry with shakeoff e^- detector





- high-statistics!
- *know* decay occured from trap!
- S1188 approved with high priority
- goal is 0.1% in A_β (and B_ν and R_{slow})

β^+ decay of polarized $^{37}\mathrm{K}$



Q(^{37}K) = 5.1265(15) MeV

$\boldsymbol{B.R.}$ = 0.9789(11)

and $\boldsymbol{t_{1/2}}$ = 1.2533(10) s

$\Rightarrow \boldsymbol{\mathcal{F}t/ft}$ = 0.6655(9)

$\Leftrightarrow |\boldsymbol{G_A M_{GT}/G_V M_F}|$ = 0.5754(16)

$$\frac{d^5W}{dE_\beta\, d\Omega_\beta\, d\Omega_\nu} \sim \cdots + \frac{\langle \boldsymbol{I} \rangle}{I} \cdot \left[\boldsymbol{A_\beta} \frac{\boldsymbol{p}_\beta}{E_\beta} + \boldsymbol{B_\nu} \frac{\boldsymbol{p}_\nu}{E_\nu} + \boldsymbol{D} \frac{\boldsymbol{p}_\beta \times \boldsymbol{p}_\nu}{E_\beta E_\nu} \right] + \cdots$$

$\mathcal{F}t/ft$ + SM

$$\Rightarrow \begin{cases} \boldsymbol{A_\beta} = -0.5702(6) \\ \boldsymbol{B_\nu} = -0.7692(15) \end{cases}$$

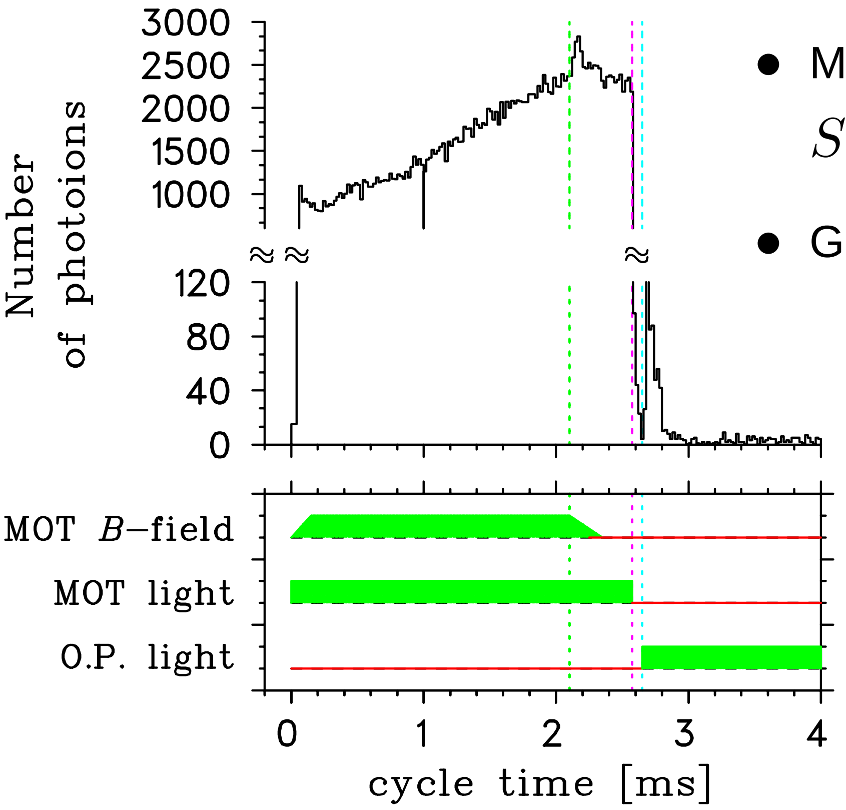
cold neutrons

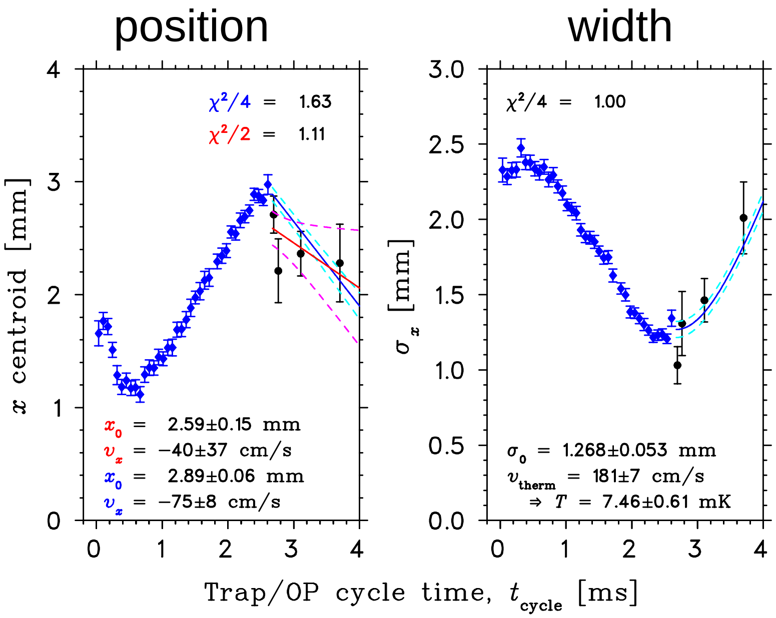
$$\Rightarrow \boldsymbol{D} = (-4 \pm 6) \times 10^{-4}$$

Soldner et al.,
PhysLett **B581** (2004)

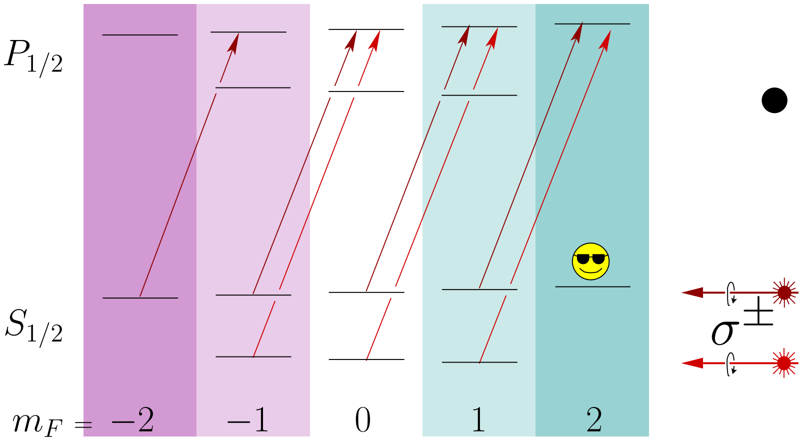
Trap/optical pumping cycle

- re-trap atoms before they expand too far
- MCP–laser coinc. and position cuts ⇒ high S/N
- Gaussian fits ⇒ $\hat{x}, \hat{y}, \hat{z}$ characterization

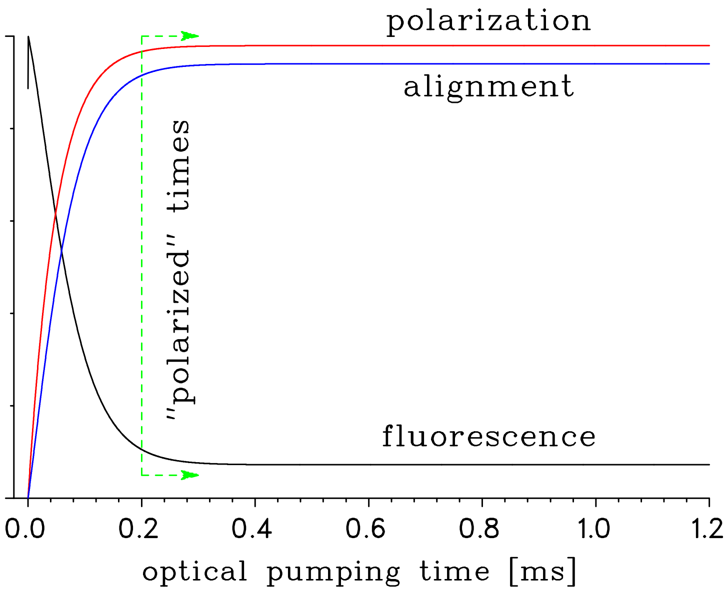


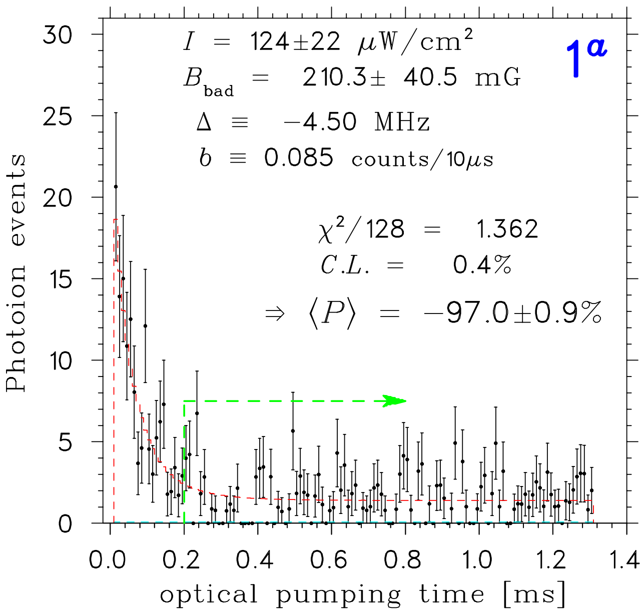


Atomic measurement of P



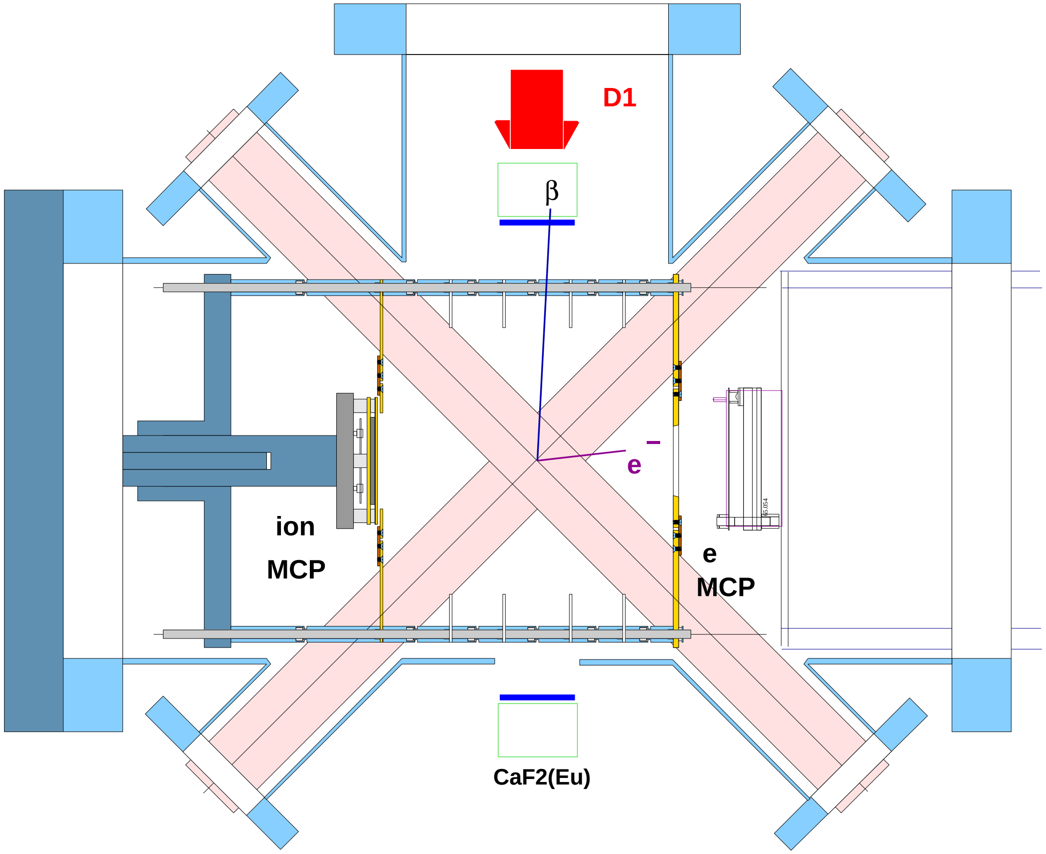
- deduce P based on a model of the excited state populations:





$$\Rightarrow P_{\rm nucl} = 96.74 \pm 0.53^{+0.19}_{-0.73}$$

Geometry with shakeoff e^{-} detector



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