HOW IDIOSYNCRATIC IS THE WEAK FORCE?

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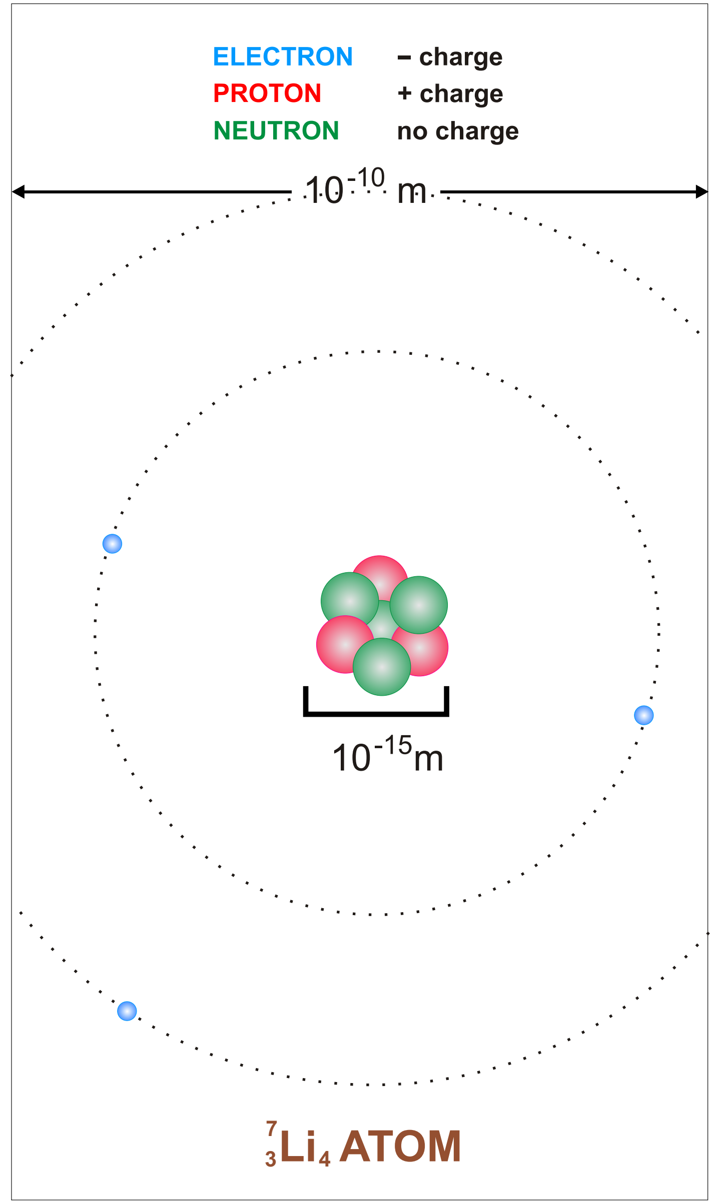
1. What is the weak force?
2. Is it universal?
3. The nucleus as laboratory
4. Current status of data
5. Measurements in progress
6. Summary and outlook

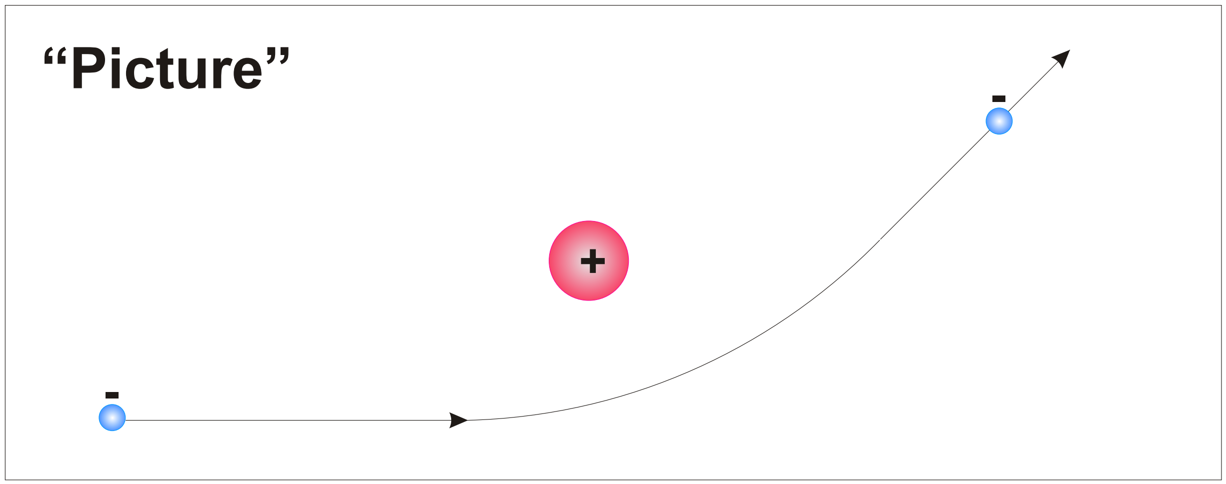
THE FORCES IN NATURE

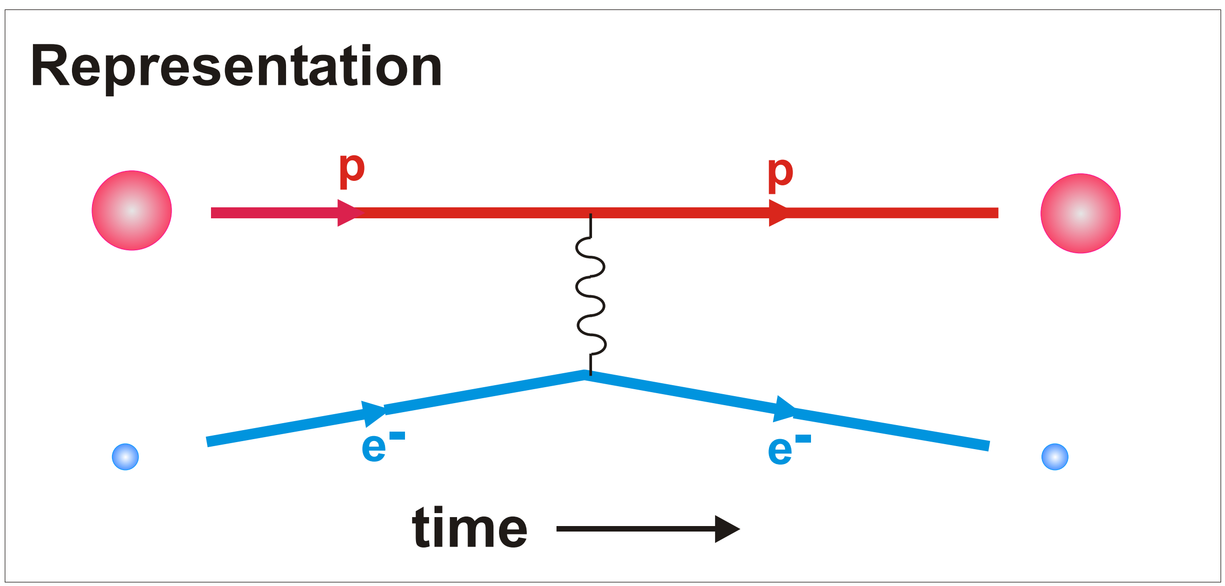
Name	Relative Strength	Range	Acts on
Strong	1	10^{-15}m	neutrons protons ...
Electromagnetic	10^{-2}	long ($1/r^2$)	charged particles
Weak	10^{-5}	10^{-18}m	all
Gravity	10^{-41}	long ($1/r^2$)	masses



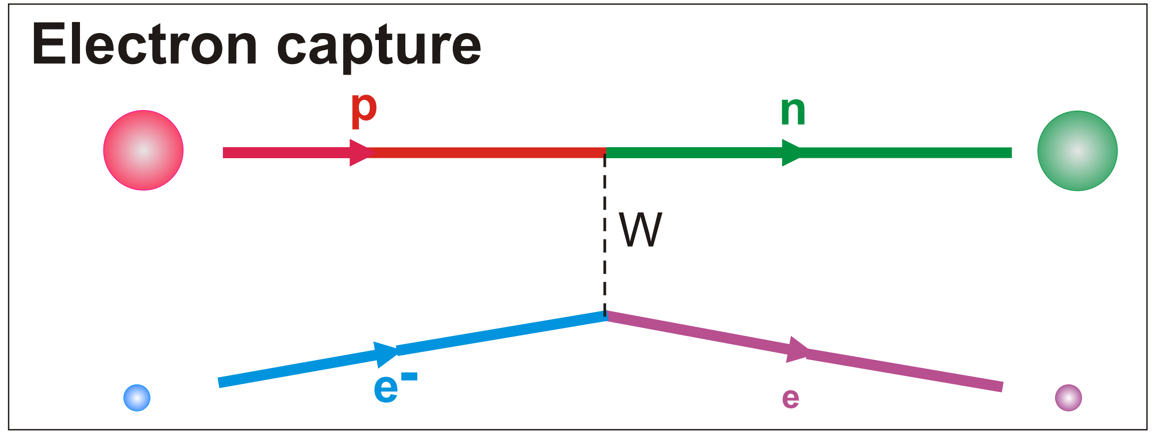
ELECTROMAGNET FORCE

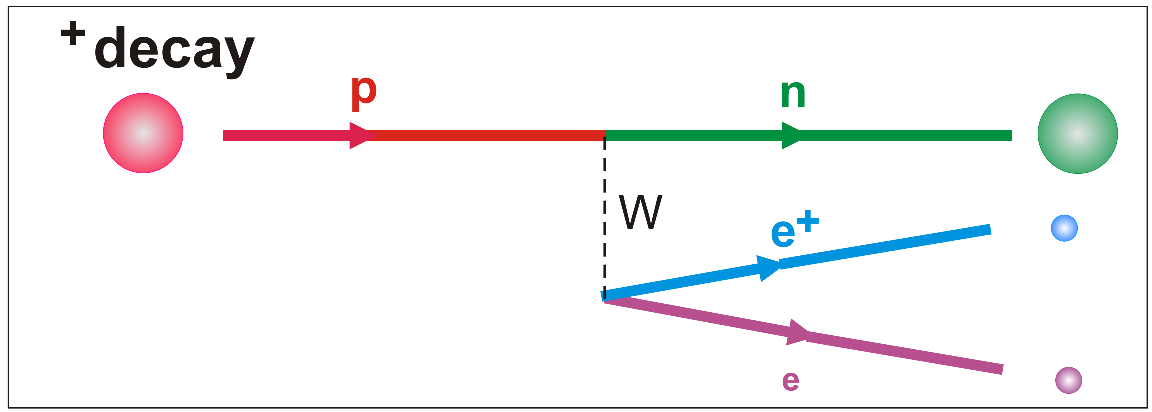
Electron scattering:

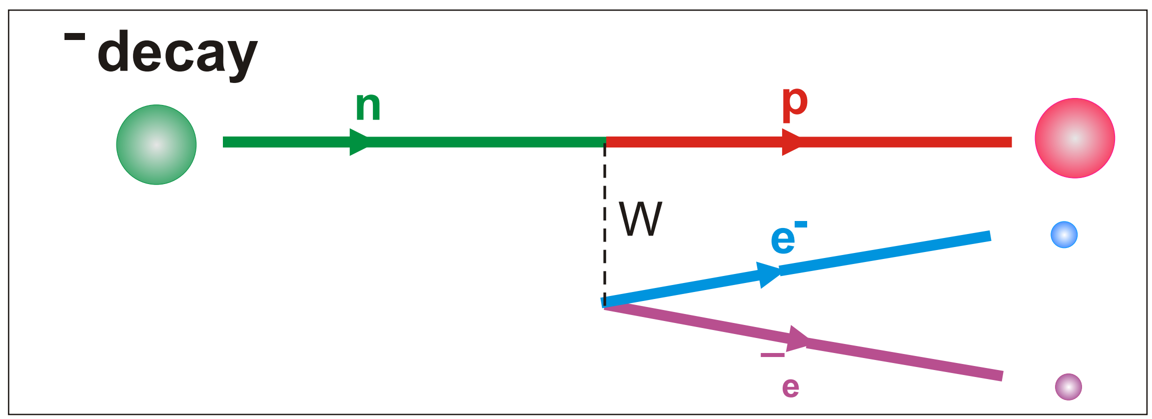


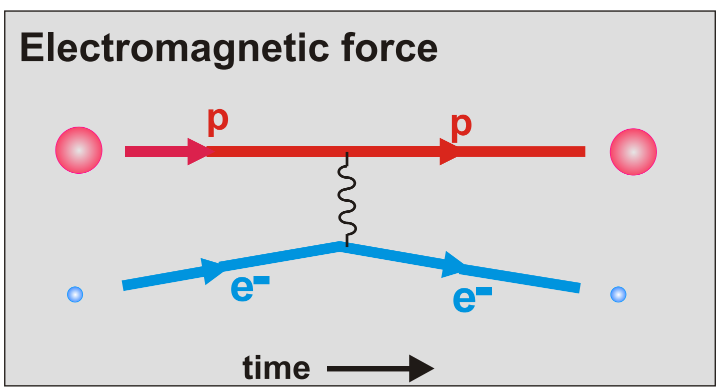


WEAK FORCE


Electron capture
p
n
W
e-
e

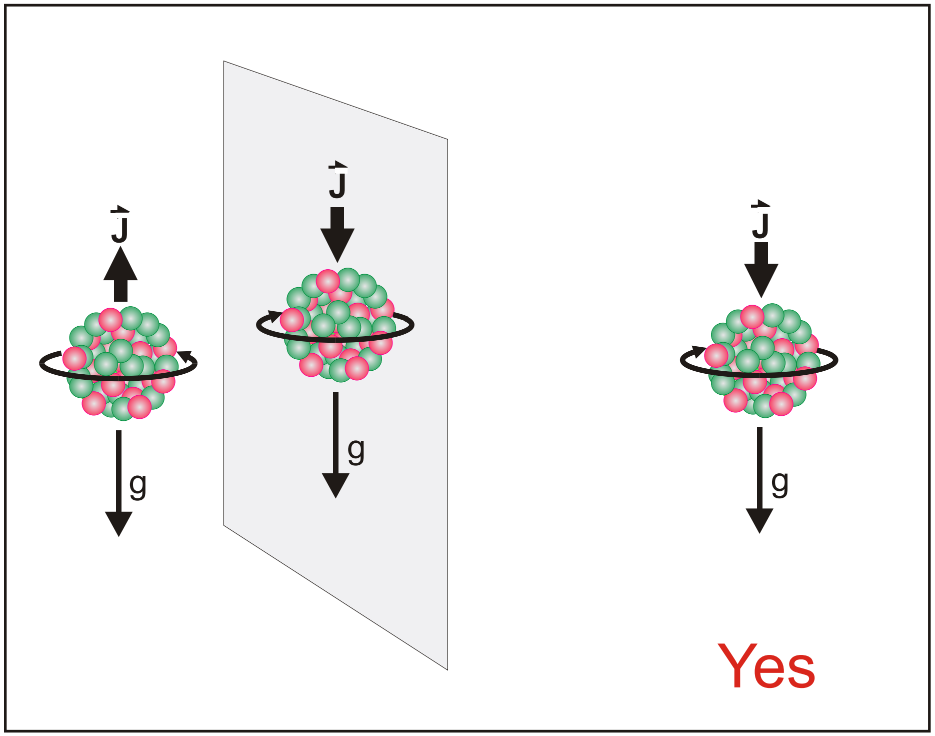

+ decay
p
n
W
e+
e


- decay
n
p
W
e-
e


Electromagnetic force
p
p
e-
e-
time

IS PARITY CONSERVED?

Gravity



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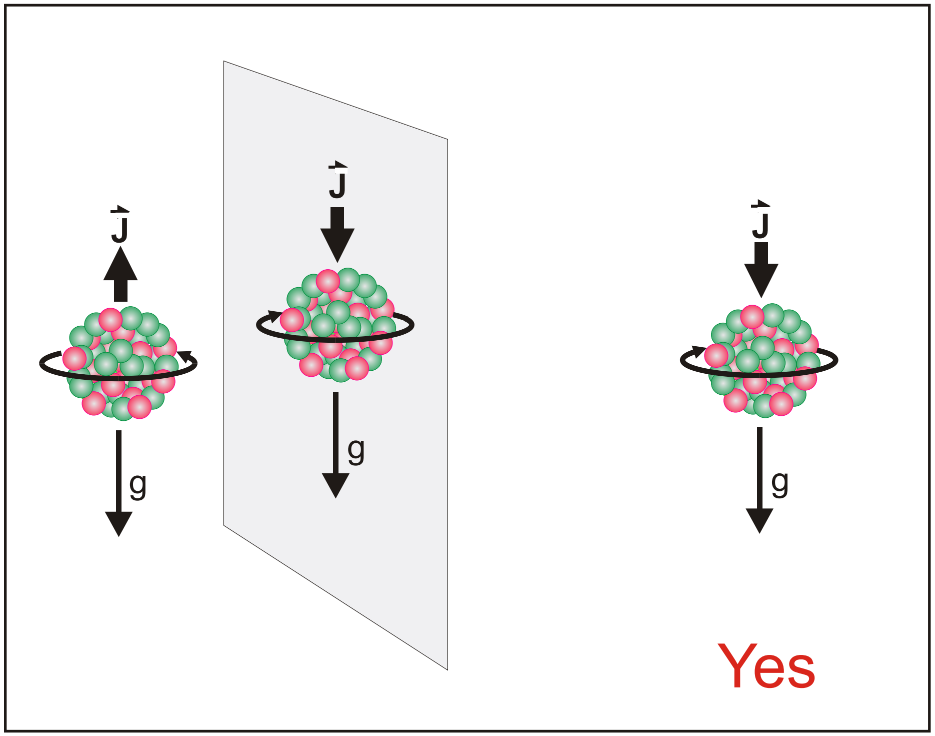
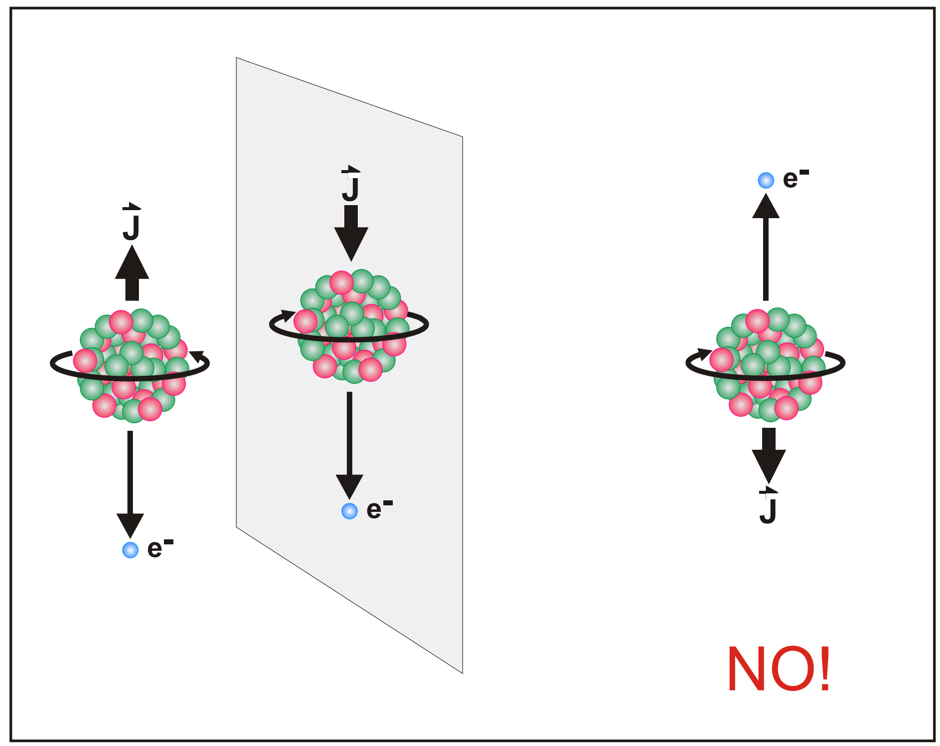
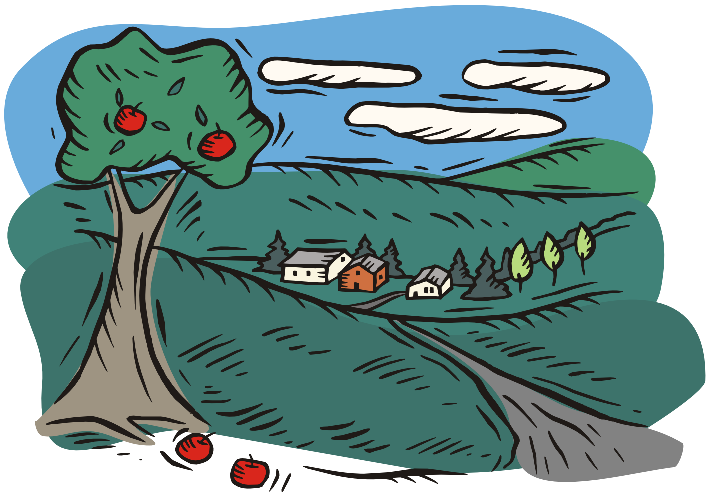


Weak interaction



WHAT ABOUT UNIVERSALITY?



Newton's Insight
~1700

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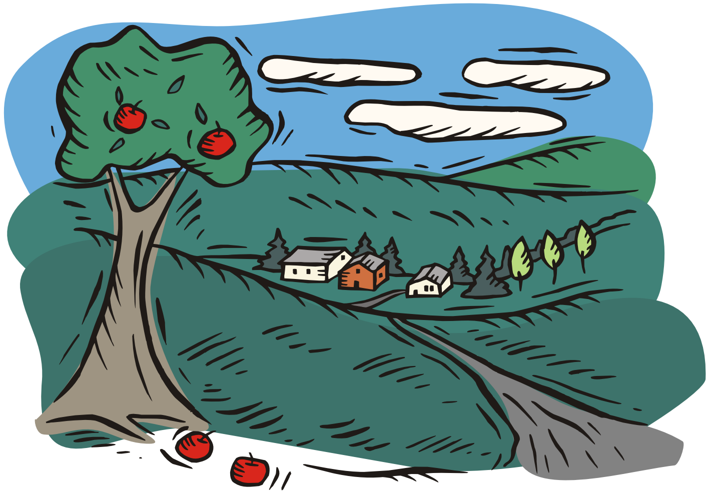

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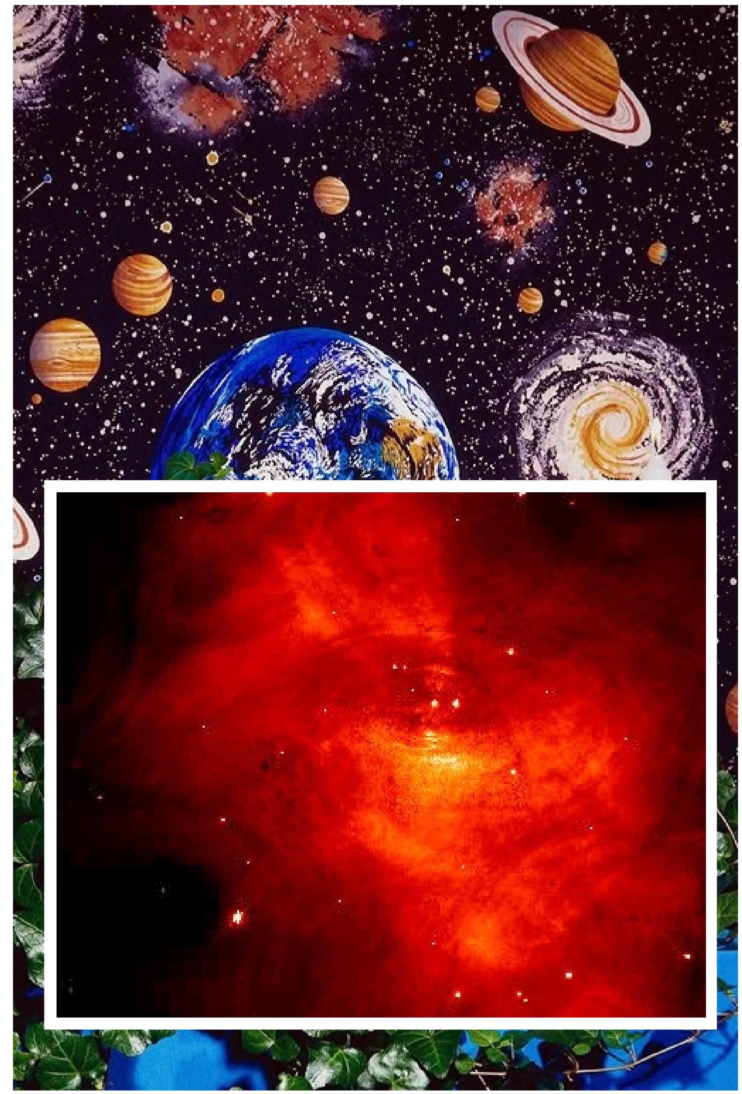
Universality
of
Gravitational force



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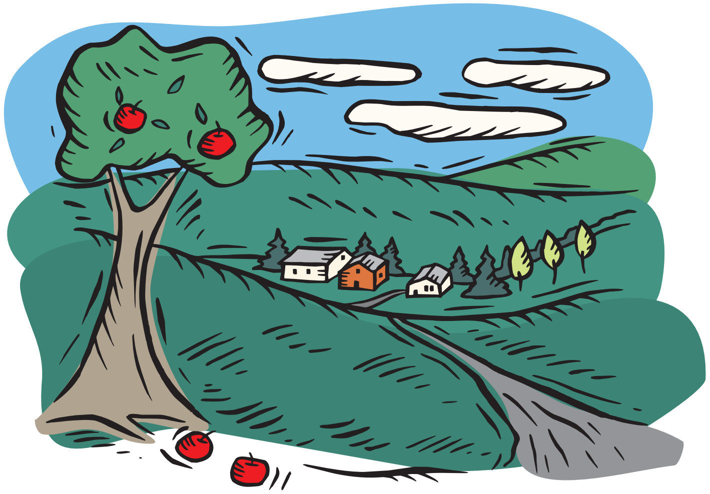

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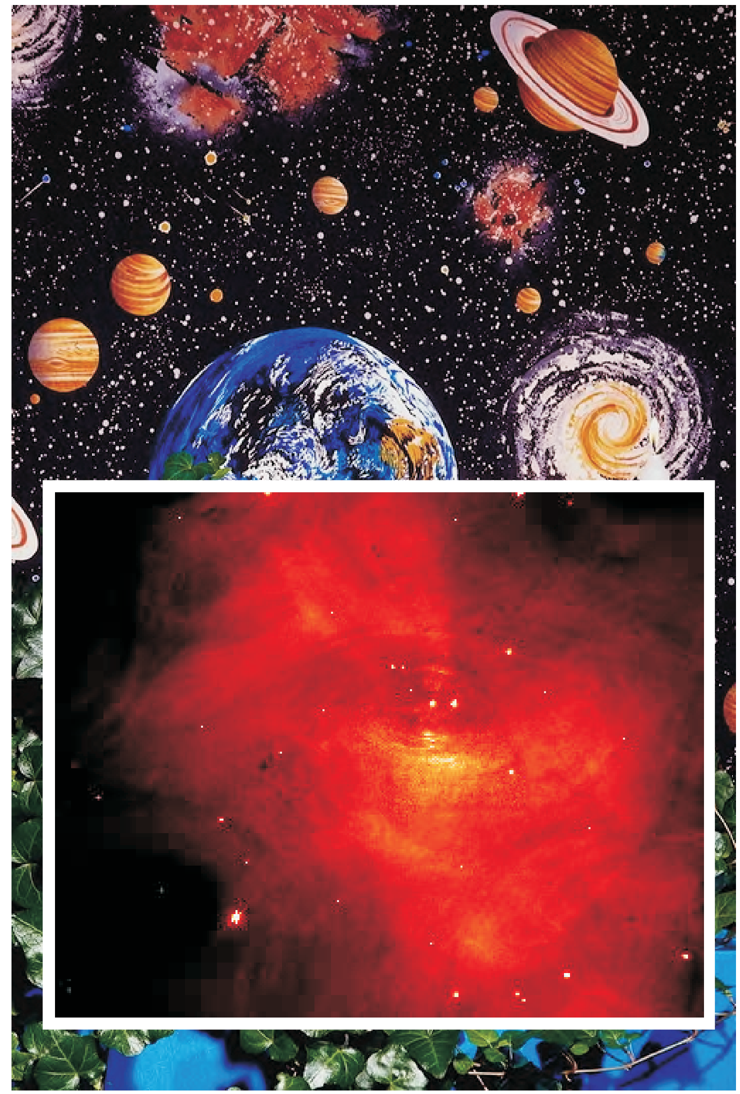
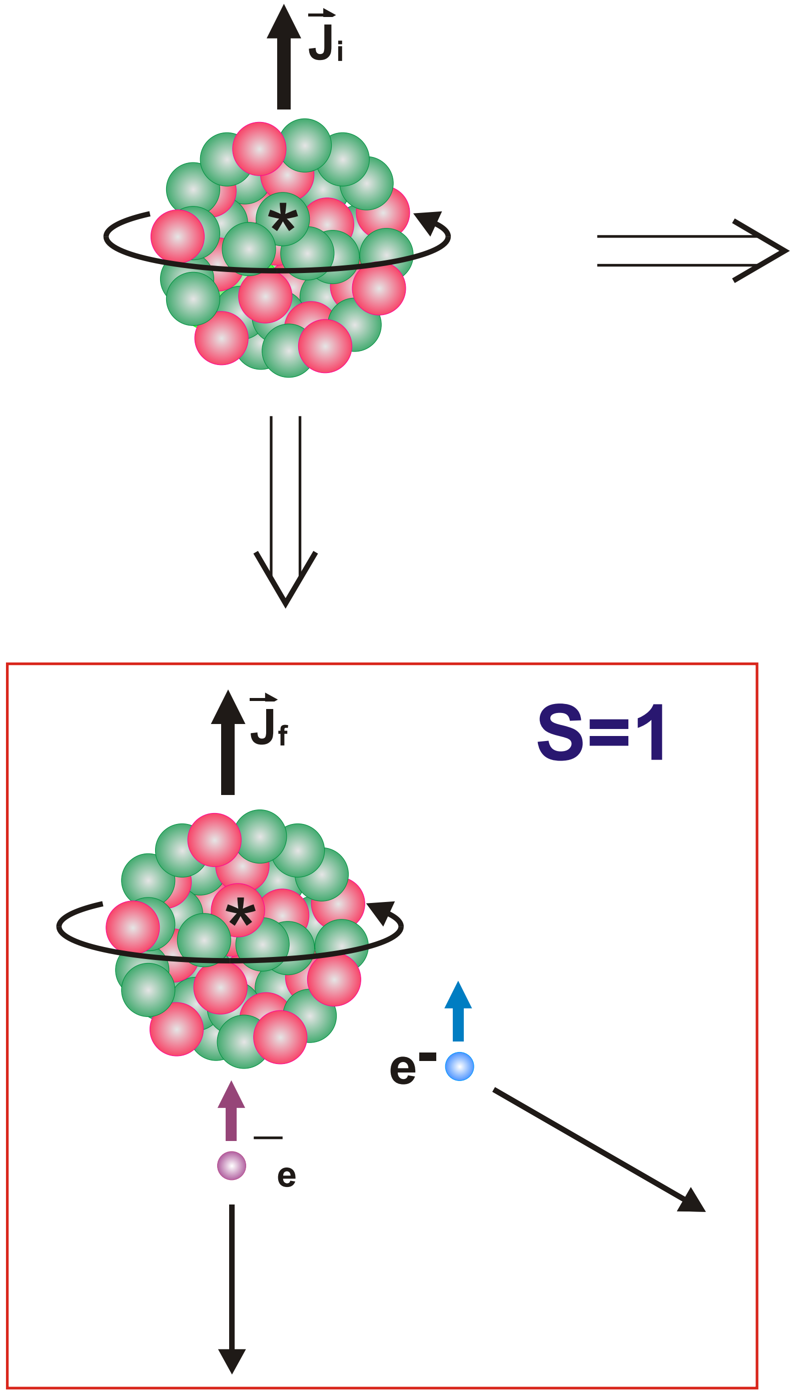
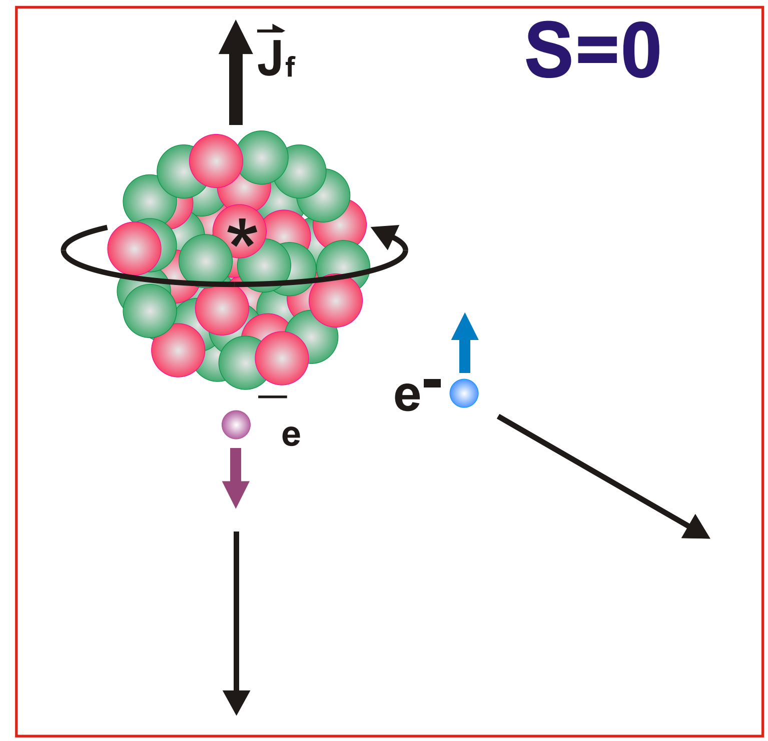


Now 300 years later ...
We can ask if this idiosyncratic weak force is universal too?

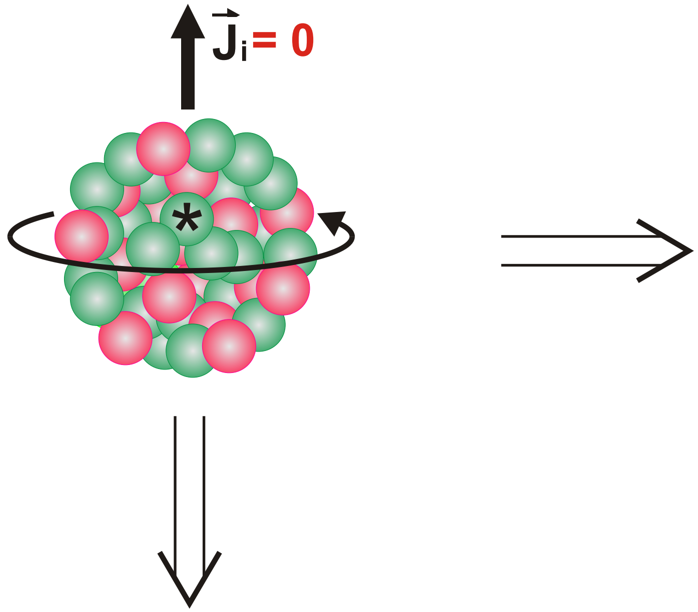
NUCLEAR BETA DECAY

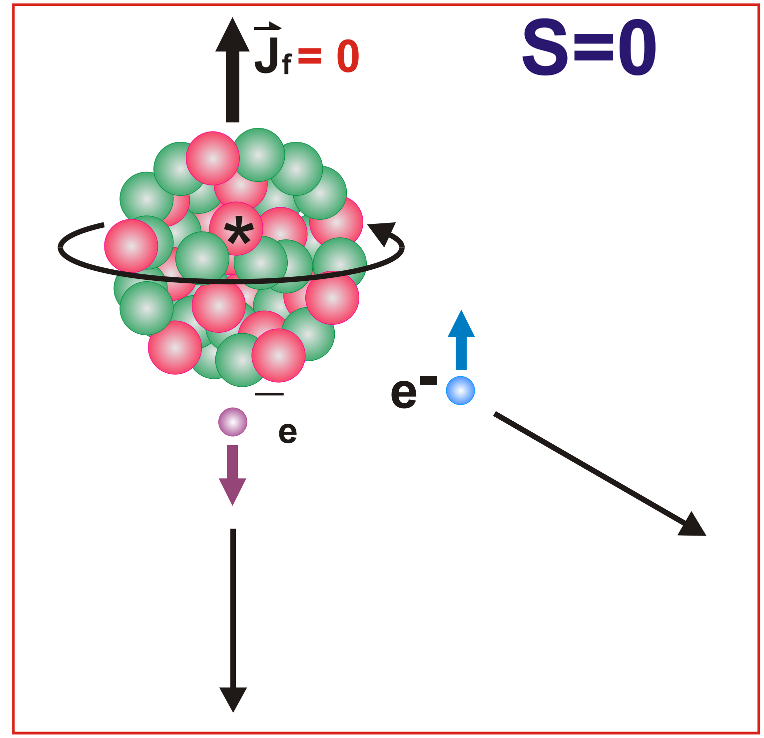


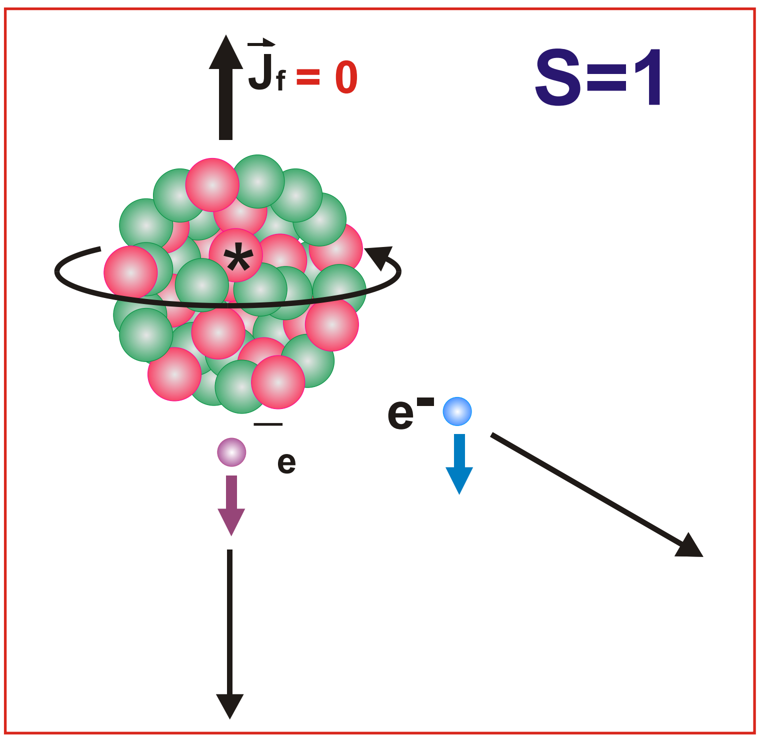


Both S=0 and S=1 transfers are allowed in general.

"SUPERALLOWED" $0^+ \rightarrow 0^+$ BETA DECAY







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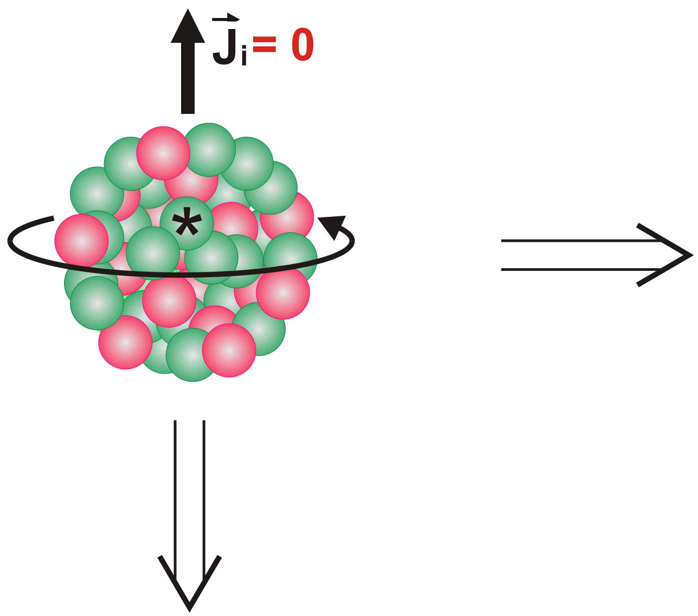

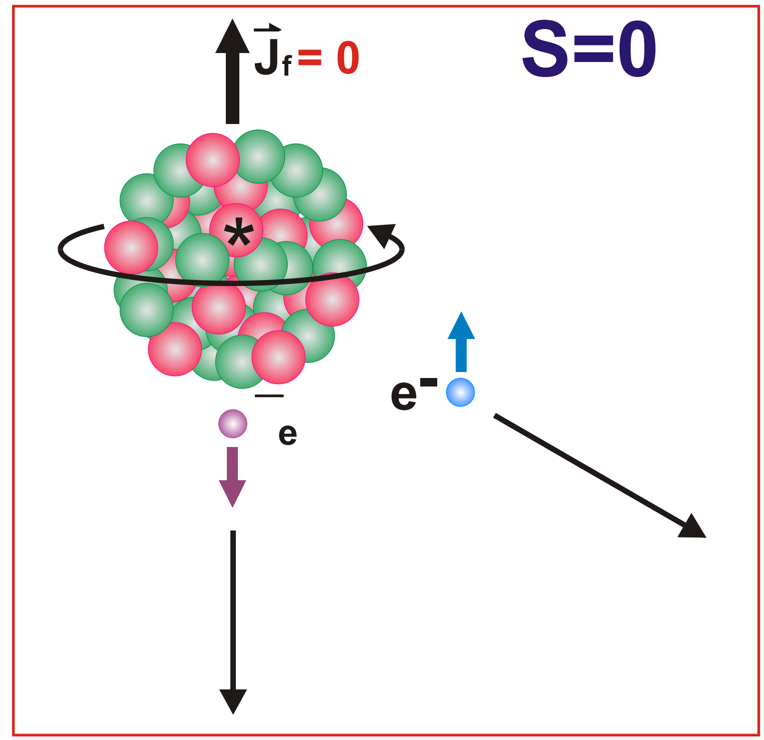

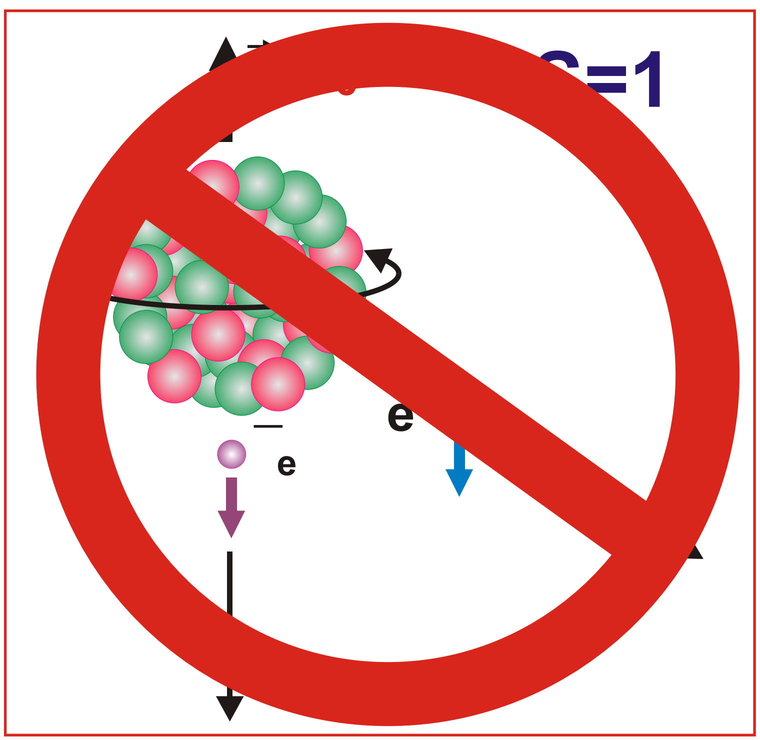

Only S=0 transfer allowed between J=0 states.

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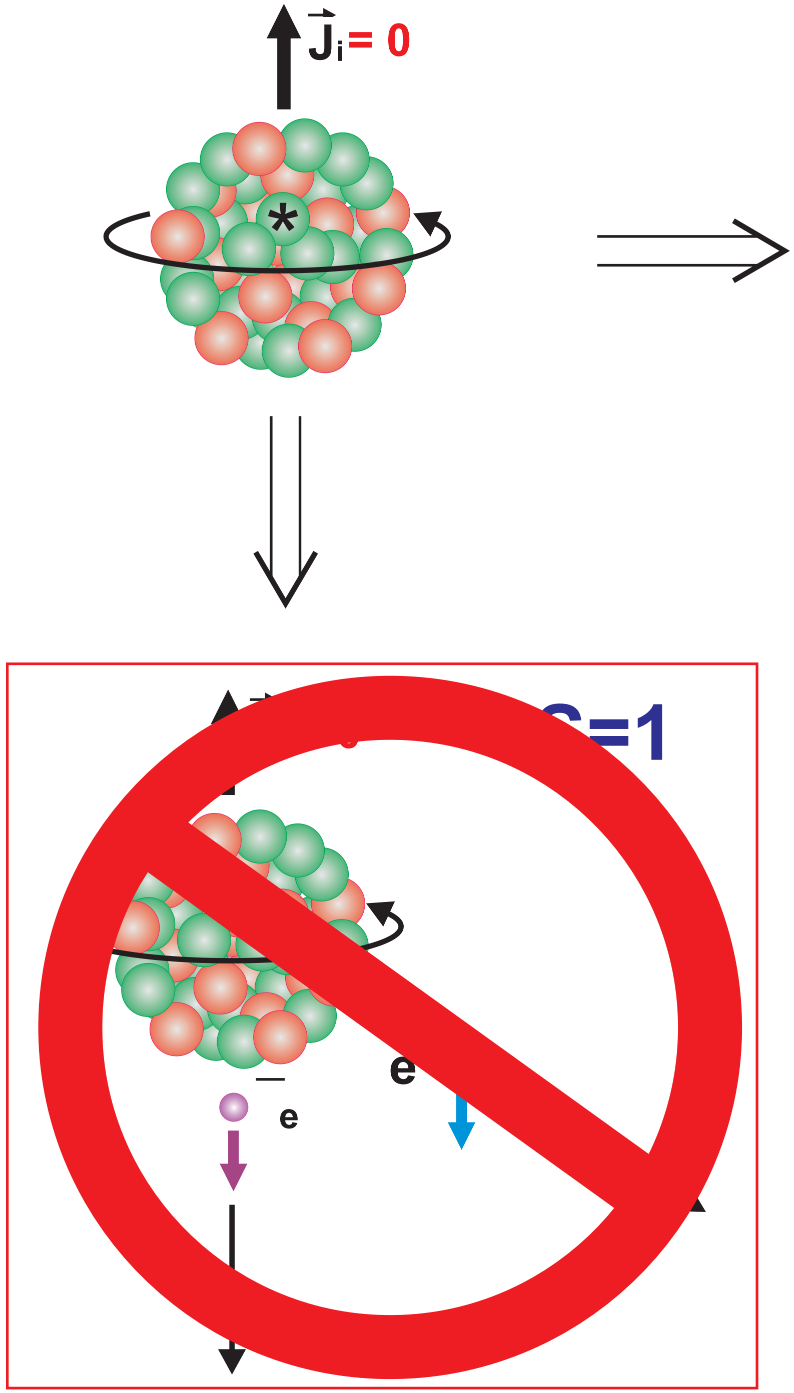
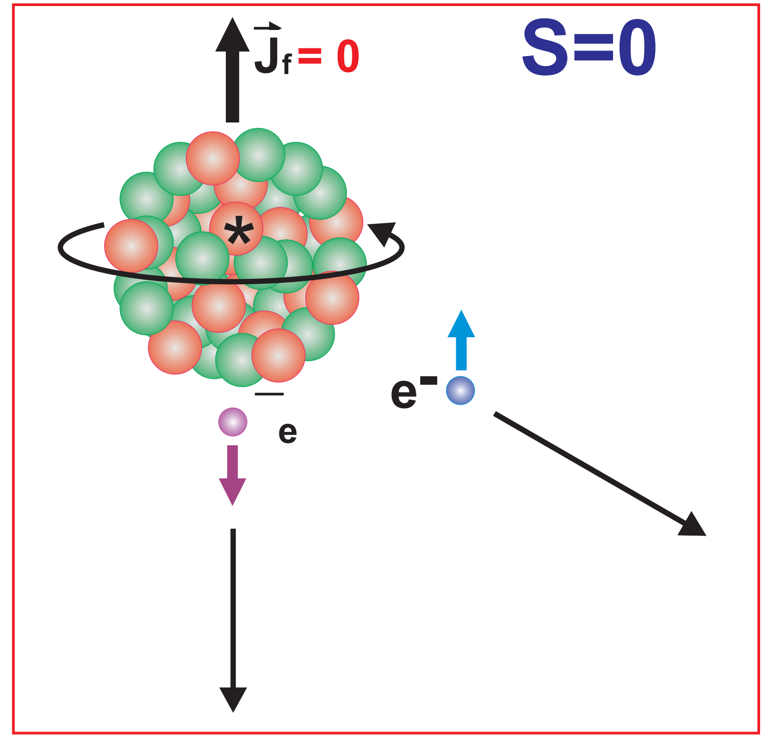
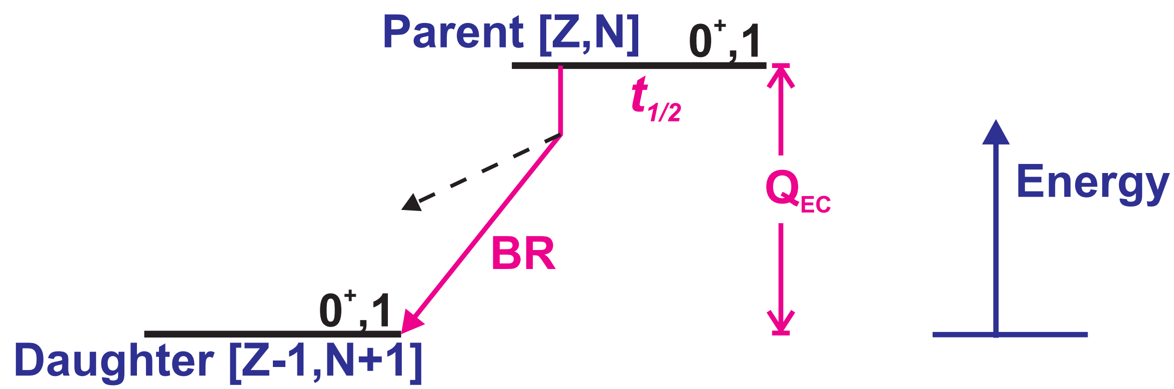




Test universality by measuring this decay in a wide variety of nuclei.

SUPERALLOWED $0^+ \rightarrow 0^+$ BETA DECAY

EXPERIMENT



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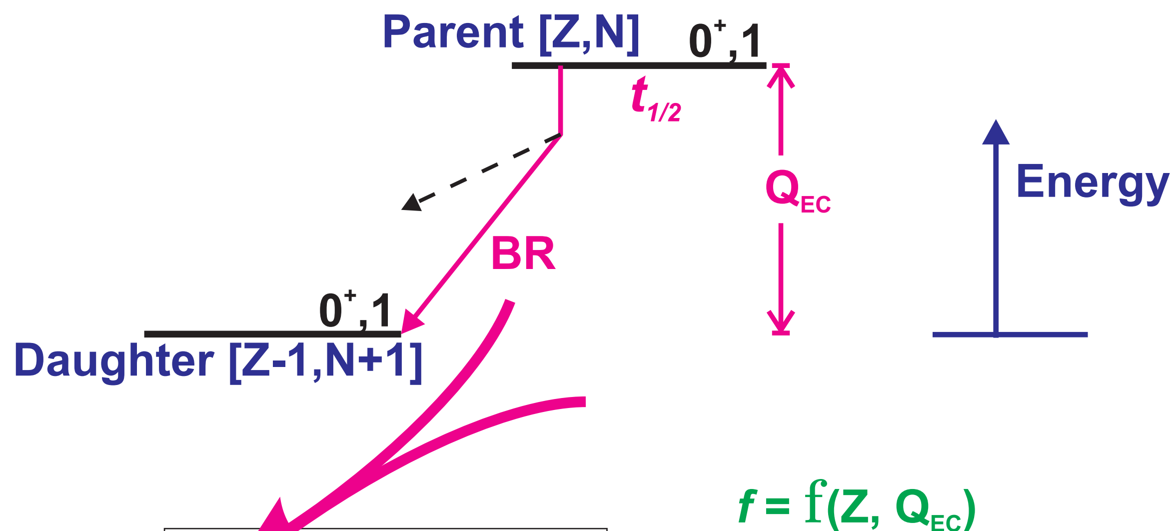

WEAK DECAY EQUATION

$$ft = \frac{K}{G_V^2 \langle 1 \rangle^2}$$

$f = \mathrm{f}(Z, Q_{EC})$

$t = \mathrm{f}(t_{1/2}, BR)$

$\langle 1 \rangle$ = structure overlap

G_V = weak force strength

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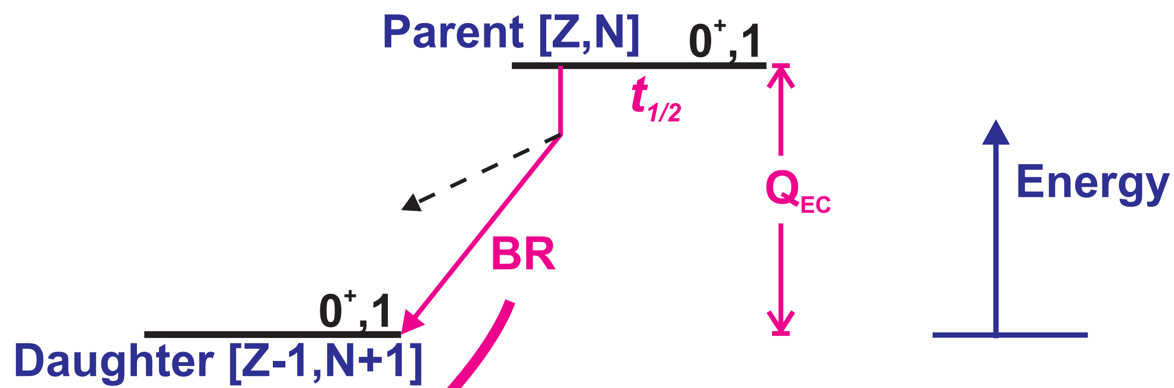

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RADIATIVE CORRECTIONS

$_R$, $_R$, $_{NS}$, $_C$

all ~ 1%

$_R = f(Z, Q_{EC})$

$_R = f(\text{interaction})$

$_{NS}$, $_C = f(\text{nuclear structure})$

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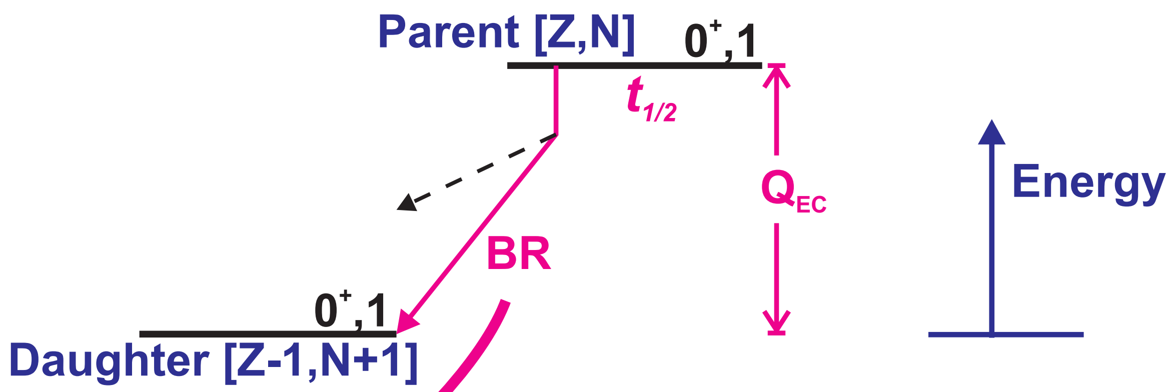
EXPERIMENT



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$$\mathcal{F}t = ft\,(1 + \;_R)[1 - (\;_C - \;_{NS})] = \frac{K}{2G_V^2\,(1 + \;_R)}$$

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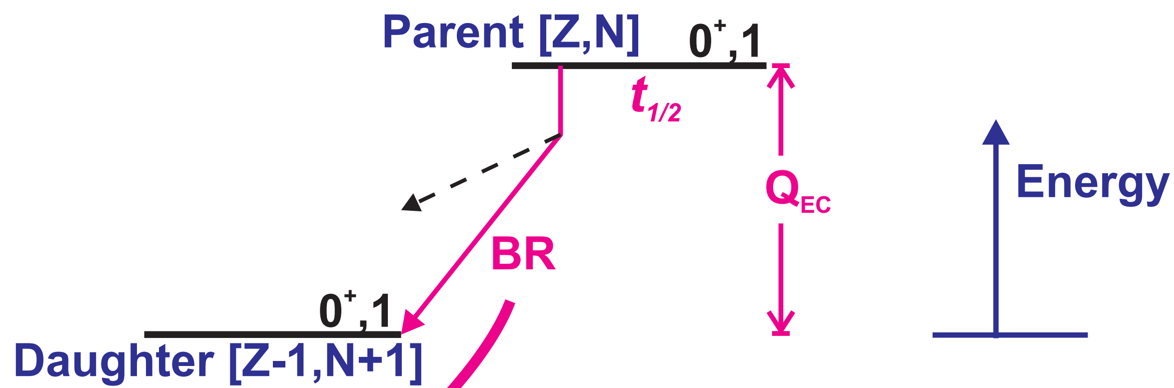

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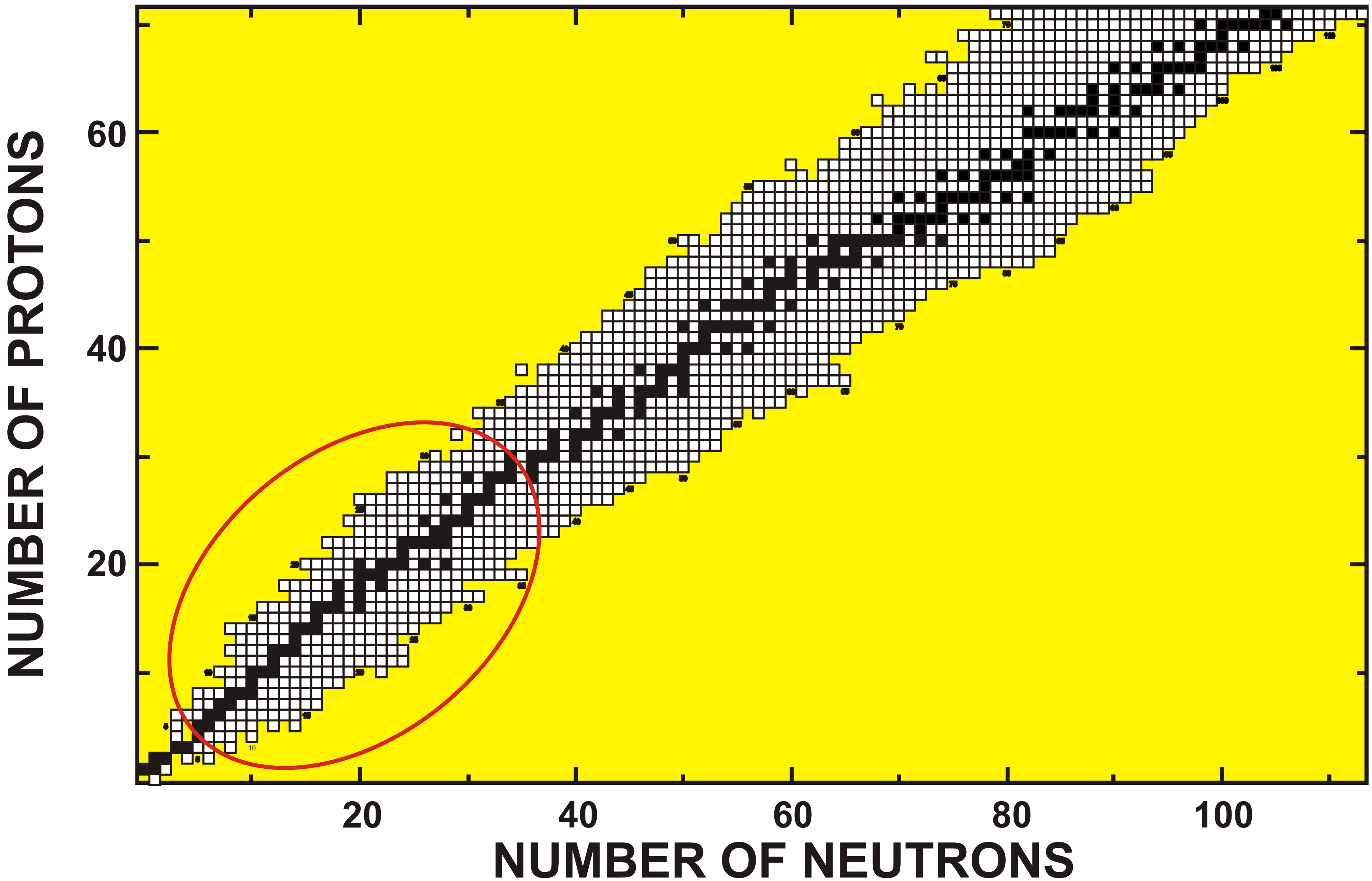
Do measured $\mathcal{F}t$ values yield a constant G_V?

NUCLEAR CHART



WORLD DATA FOR $0^+ \rightarrow 0^+$ DECAYS

- 10 cases with *ft*-values measured to ~0.1% precision; 3 more cases with <0.3% precision.
- ~150 individual measurements with compatible precision

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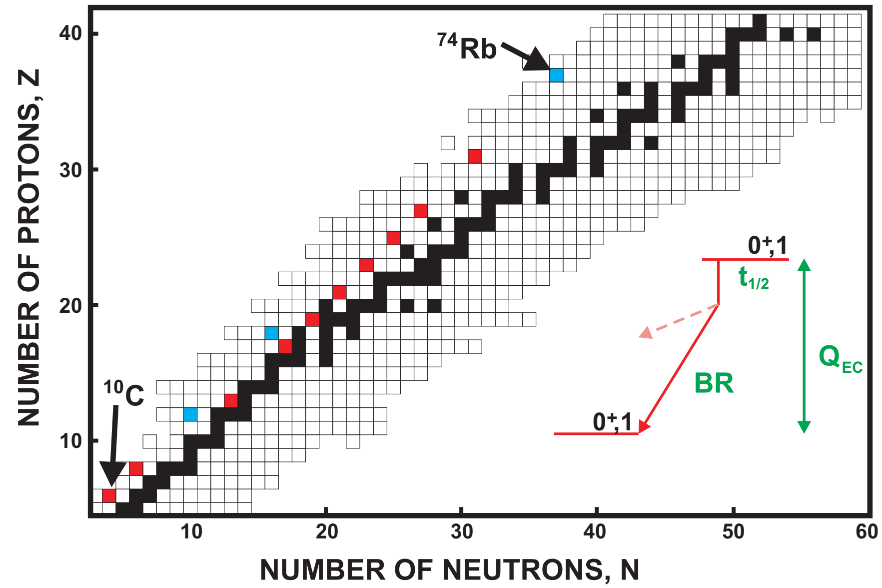

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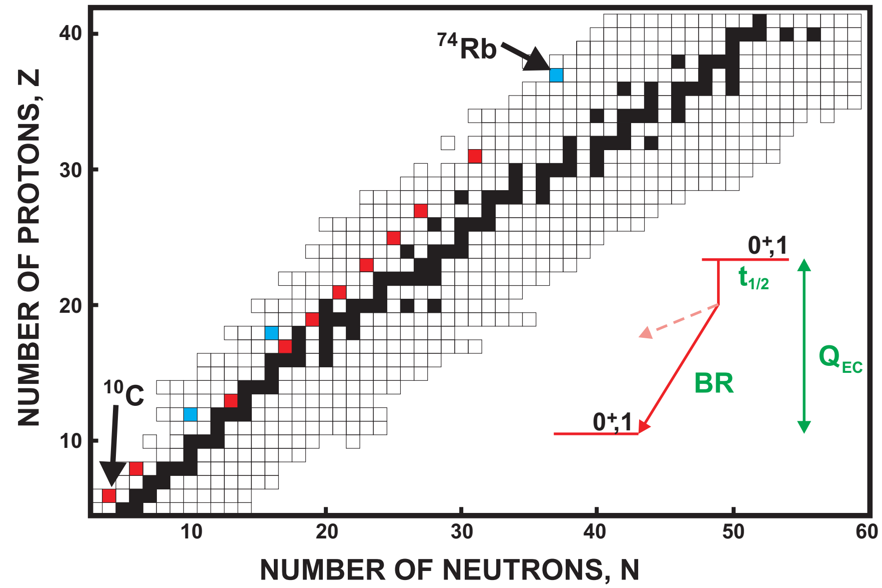
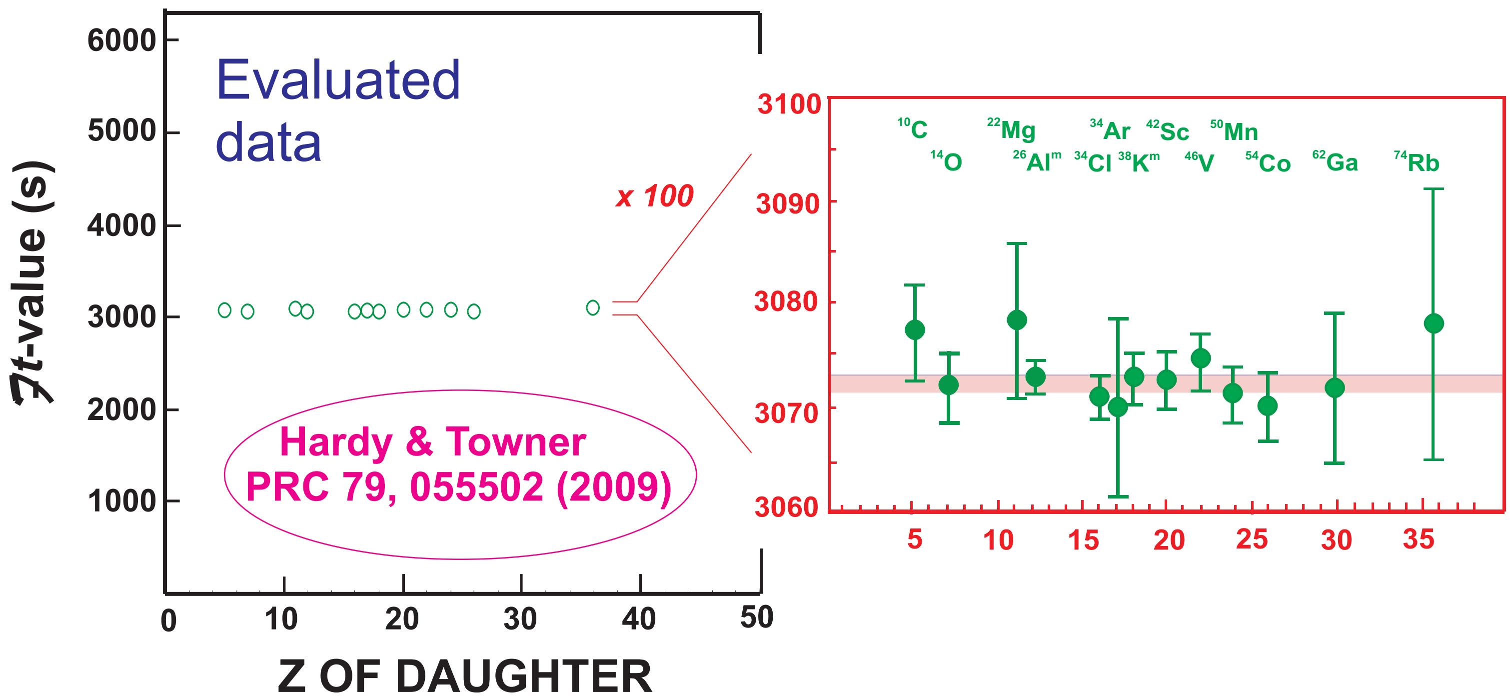


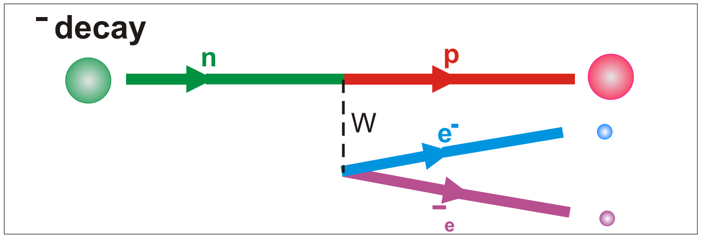


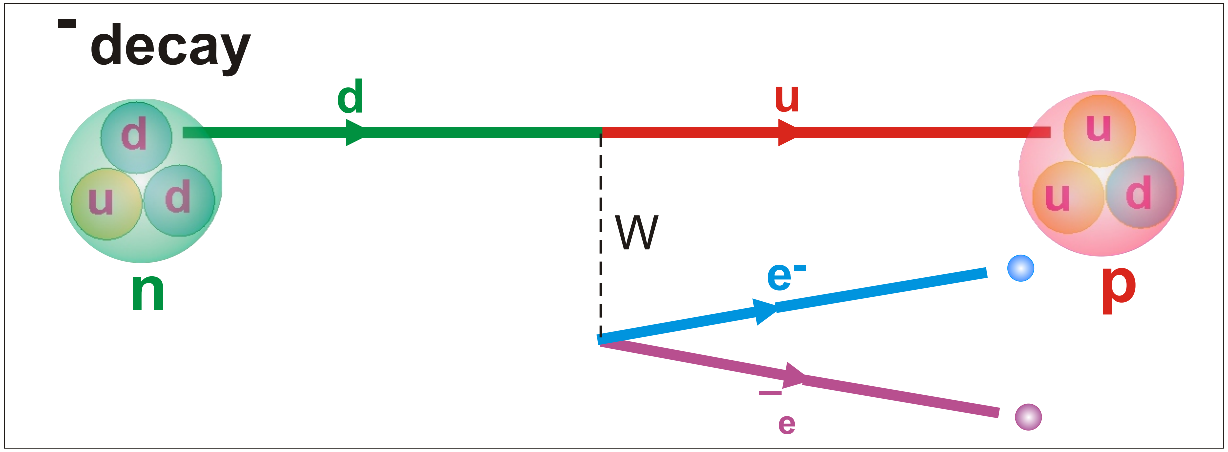
$\overline{\mathcal{F}t}$ = 3072.2(8)

$G_V(1+\ {}_R)^{1/2}/(\hbar c)^3$
= 1.14961(15) $\times 10^{-5}$ GeV^{-2}

A WIDER VIEW

When a neutron (or proton) decays, it is really one of its constituent quarks that is decaying.





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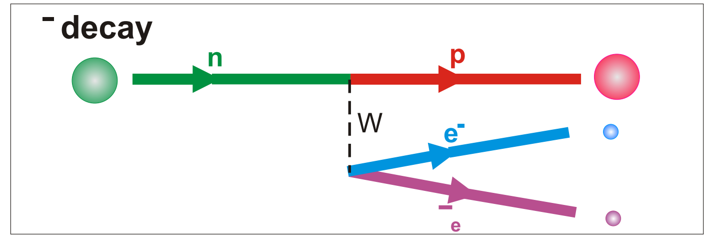
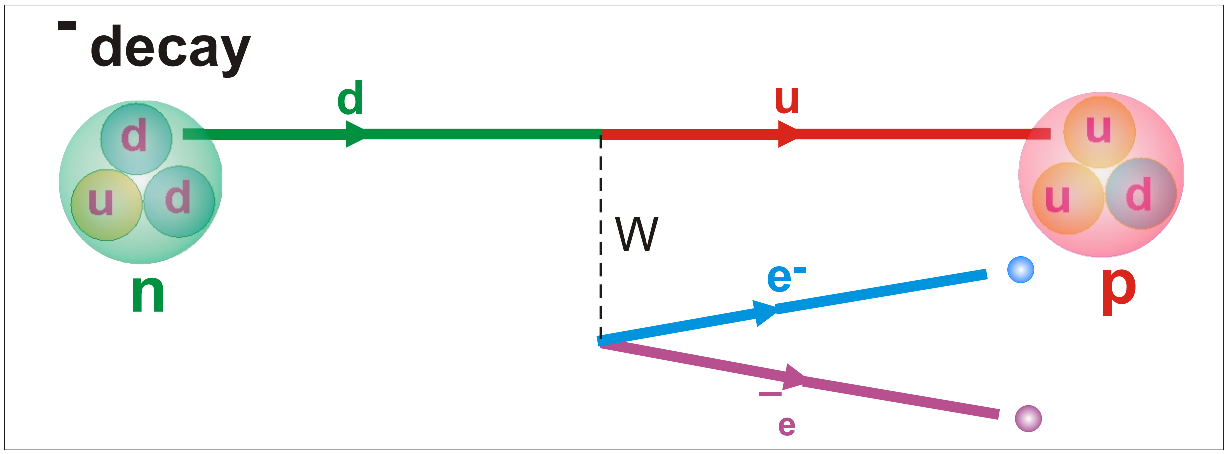
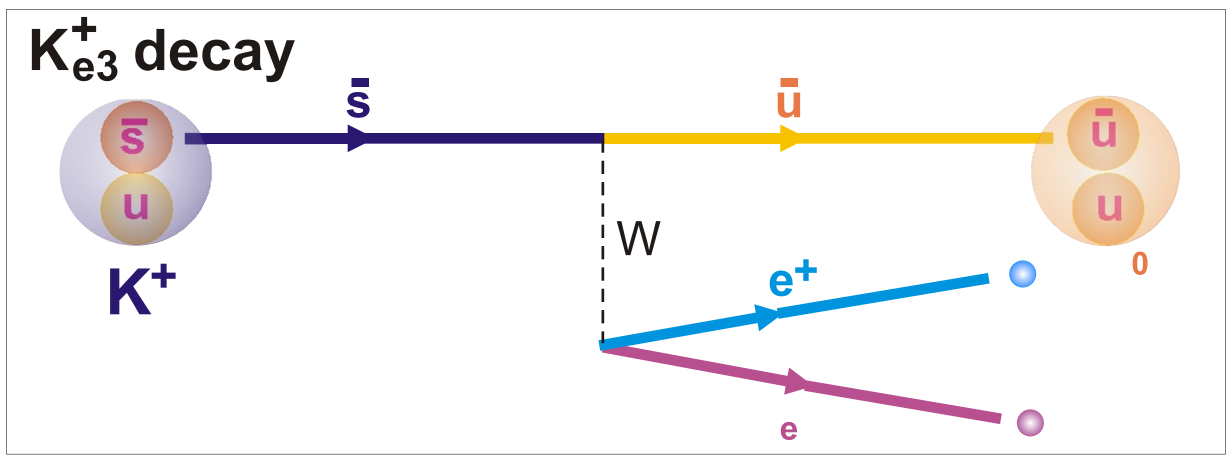




The weak decays of mesons involve different quark decays:



CKM MATRIX AND UNITARITY, 2010

CABIBBO-KOBAYASHI-MASKAWA QUARK-MIXING MATRIX

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

weak eigenstates (d', s', b')

mass eigenstates (d, s, b)

This is the most demanding test available!

THREE-GENERATION UNITARITY

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

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$|V_{ud}| = G_V / G$

nuclear decays
muon decay

0.9743 ± 0.0002
± 0.0001 exp't

$|V_{us}|$

$K^+ \longrightarrow {}^0 e^+ {}_e$

$K_L^0 \longrightarrow {}^{\pm} e^{\mp} {}_e$

0.2246 ± 0.0012

$|V_{ub}|$

B decays

0.0039 ± 0.0004

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WORLD DATA, 2010

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.99990 \pm 0.00060$$

Where to from here?

Status today:

- Nuclei present a consistent picture: G_V constant
- Nuclear and kaon decays consistent: limits “new physics”
- Uncertainties dominated by theory

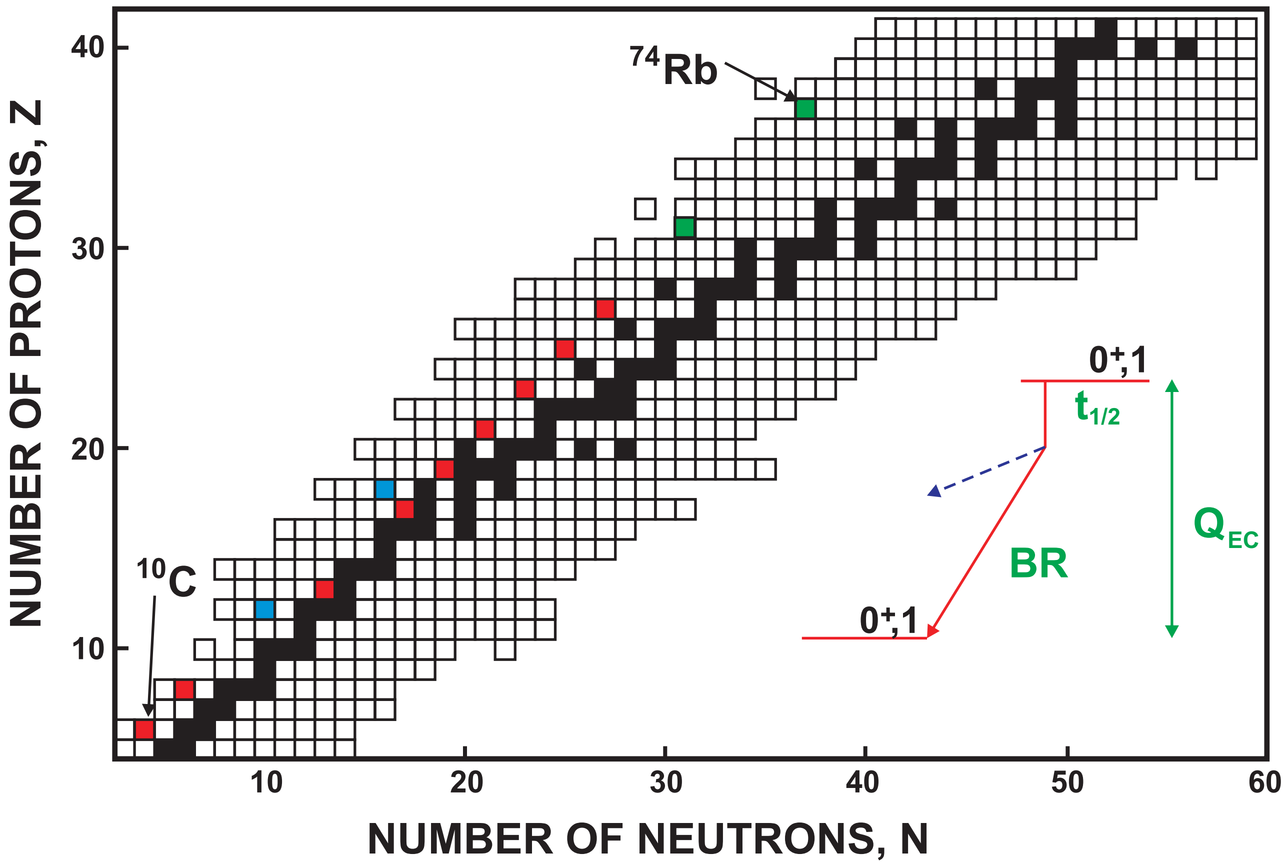
Active programs:

- Refine theoretical correction terms
- Measure new nuclear cases with larger calculated correction terms: independent test of corrections

WHAT WE MEASURE

We must measure three quantities (all to a precision of ±0.1% or better):

- Energy released in the decay, Q_{EC}
- Half-life, $t_{1/2}$
- Fraction of decays in path of interest, BR



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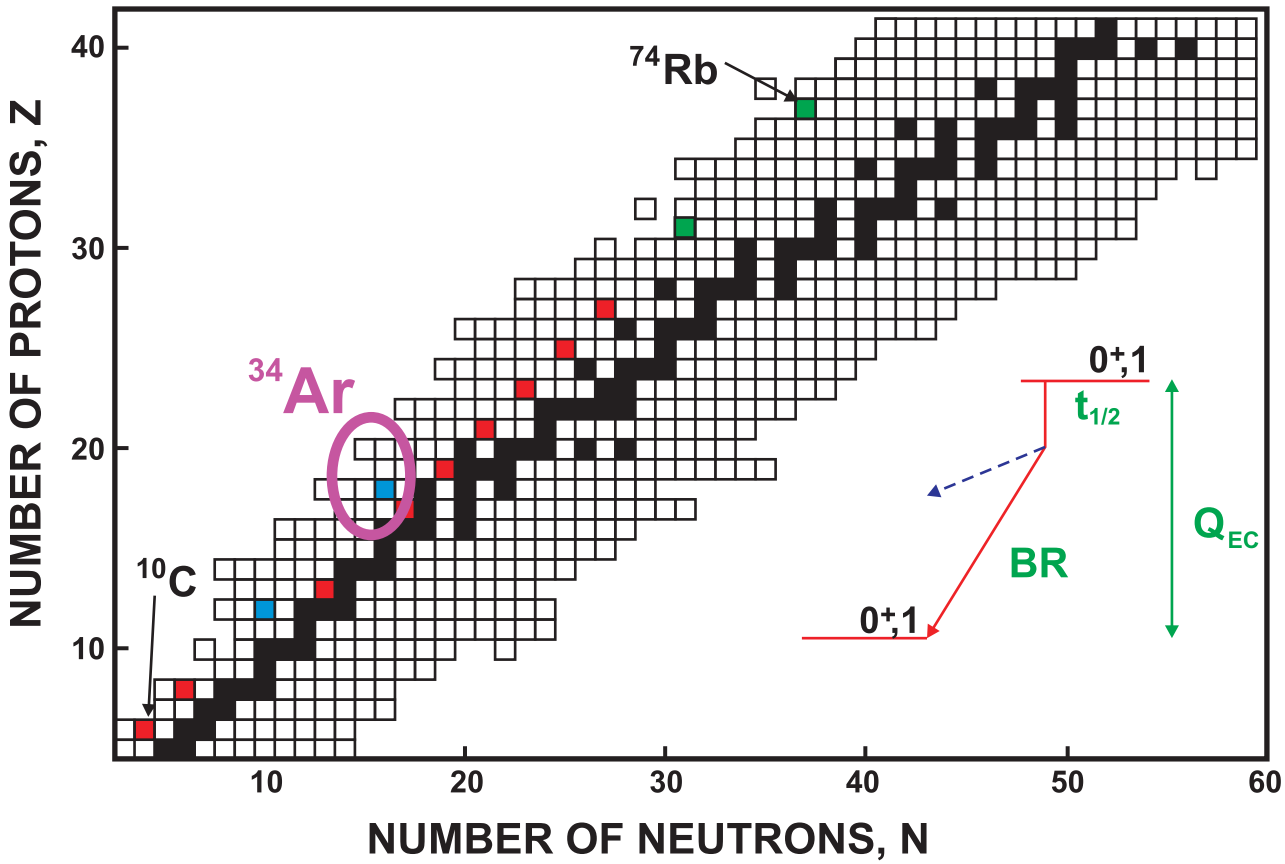
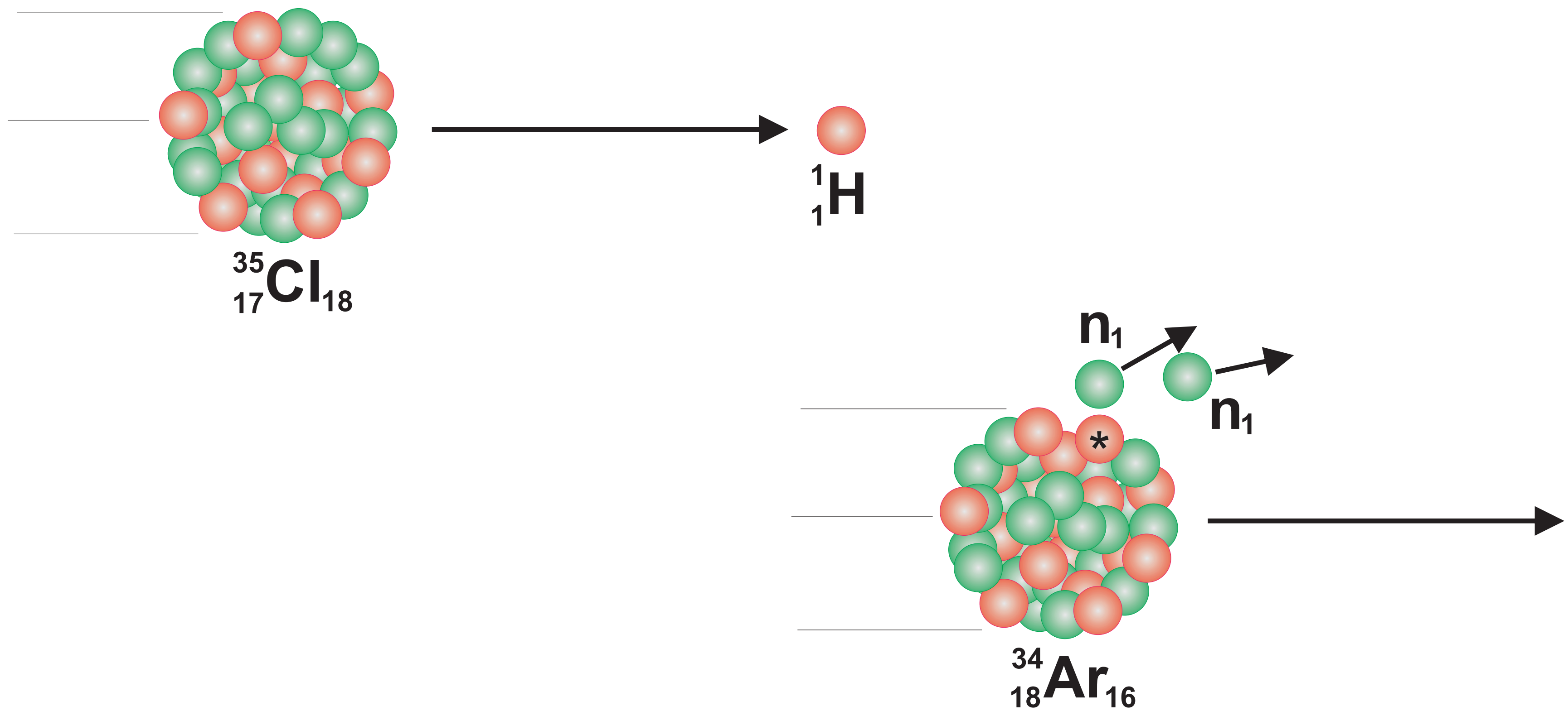


An example of one experiment done here: ^{34}Ar decay ($t_{1/2}$=0.85 s)

HOW WE PRODUCE ^{34}Ar



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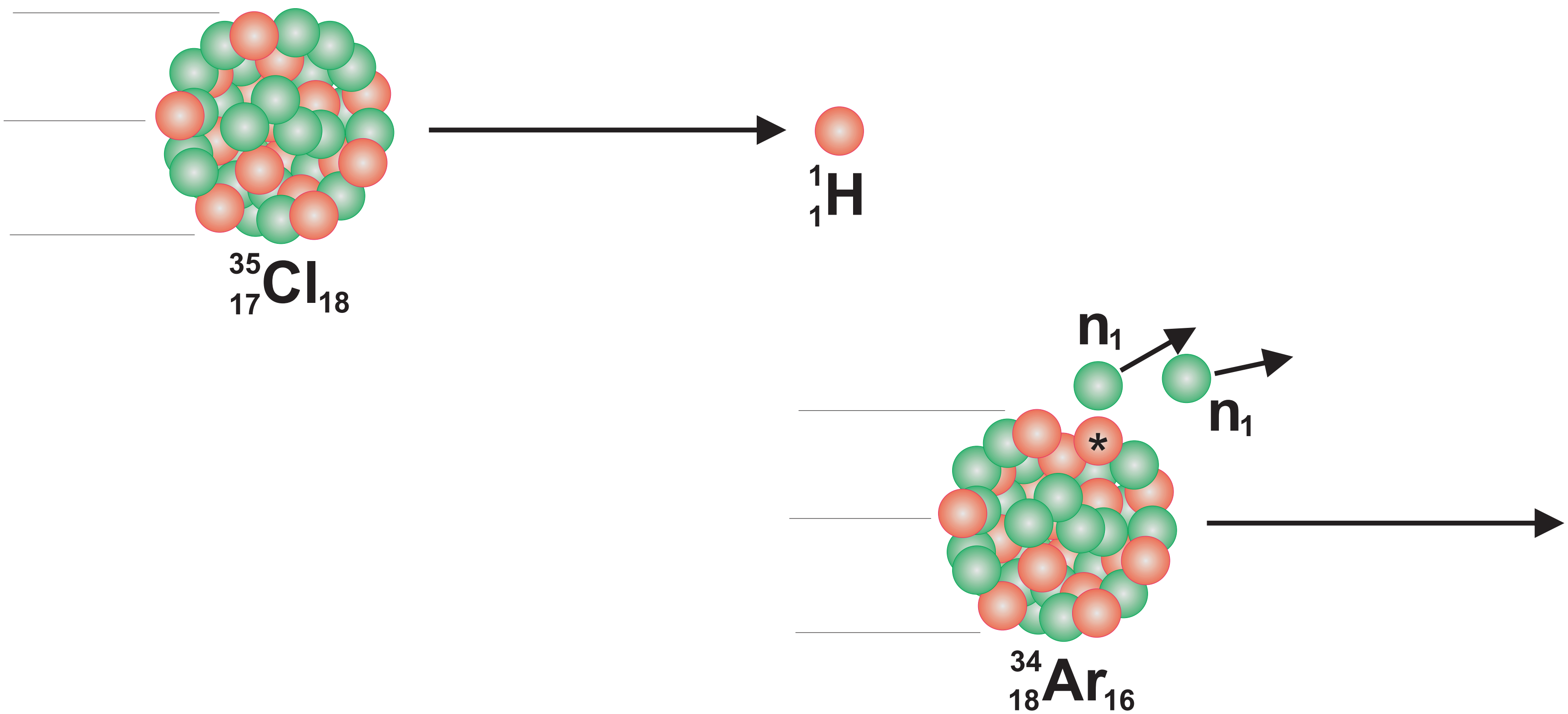
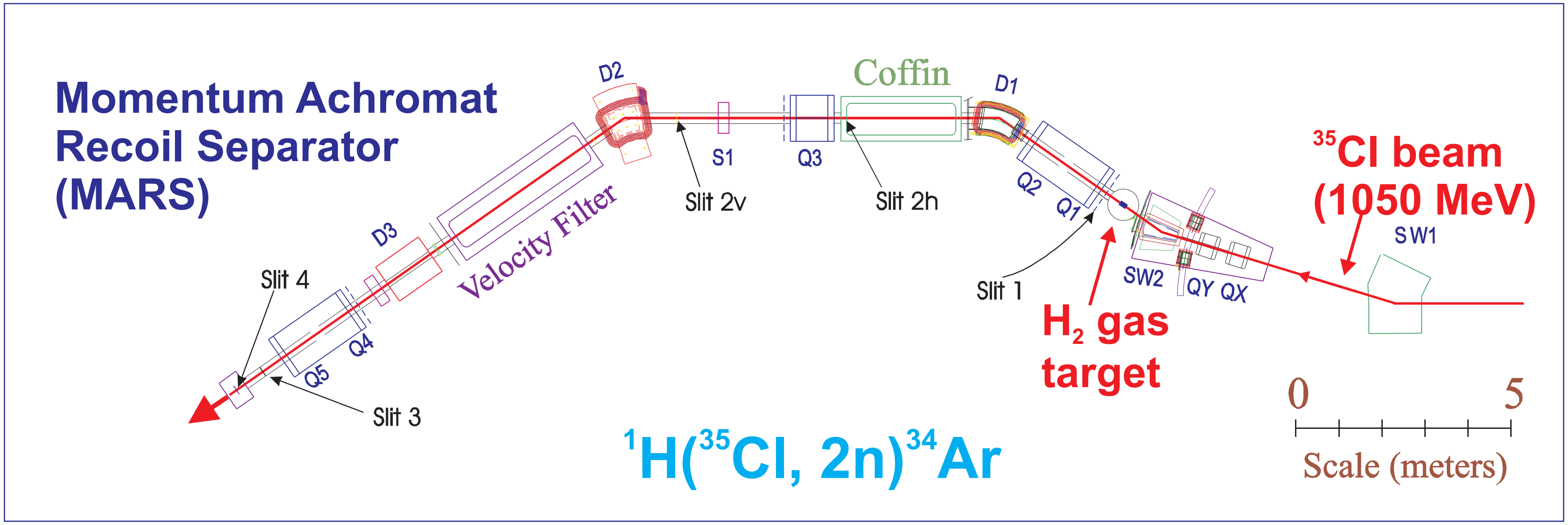


But other nuclei can be produced too, so we need to apply a “filter” that lets ^{34}Ar through but nothing else.

PRECISION DECAY MEASUREMENTS AT TAMU



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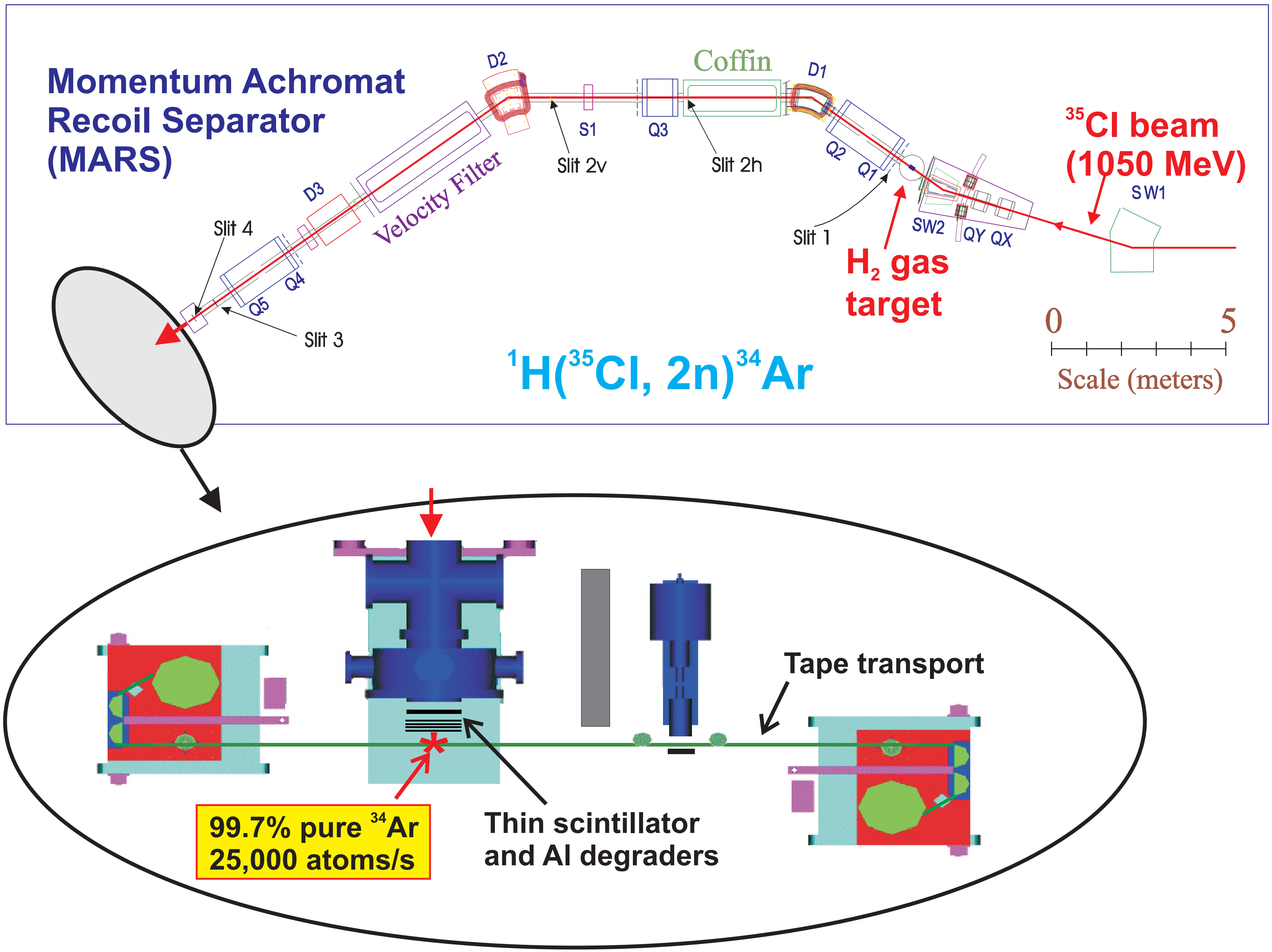

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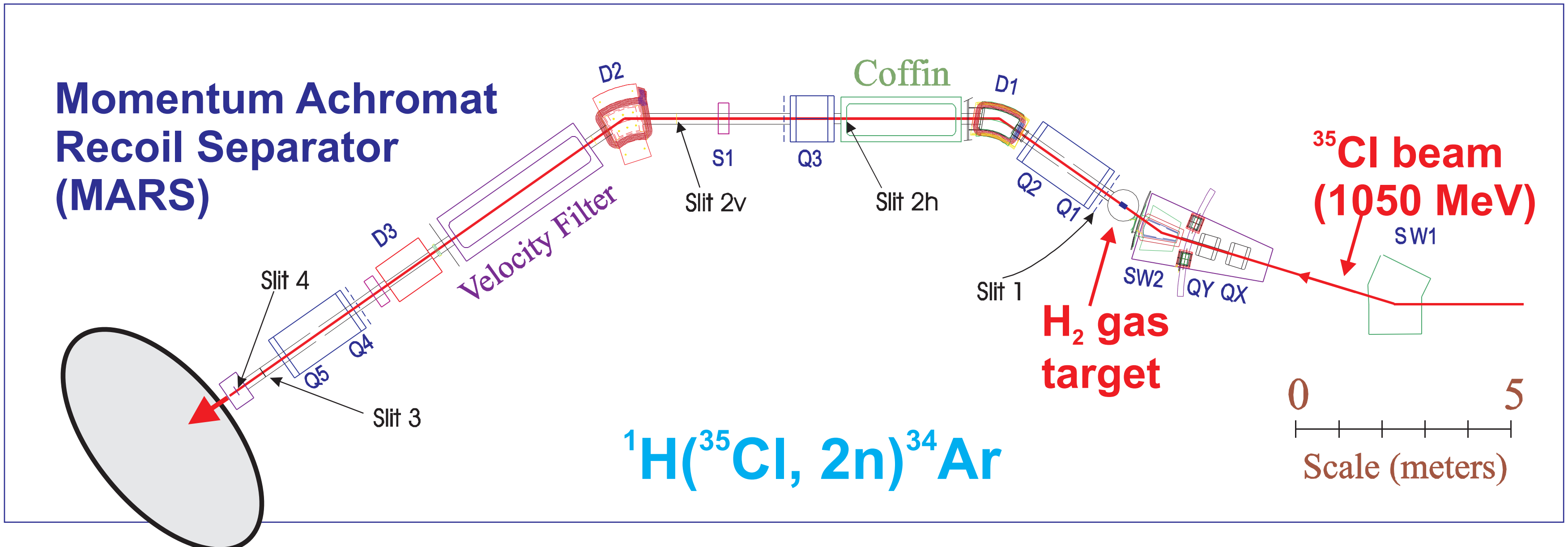

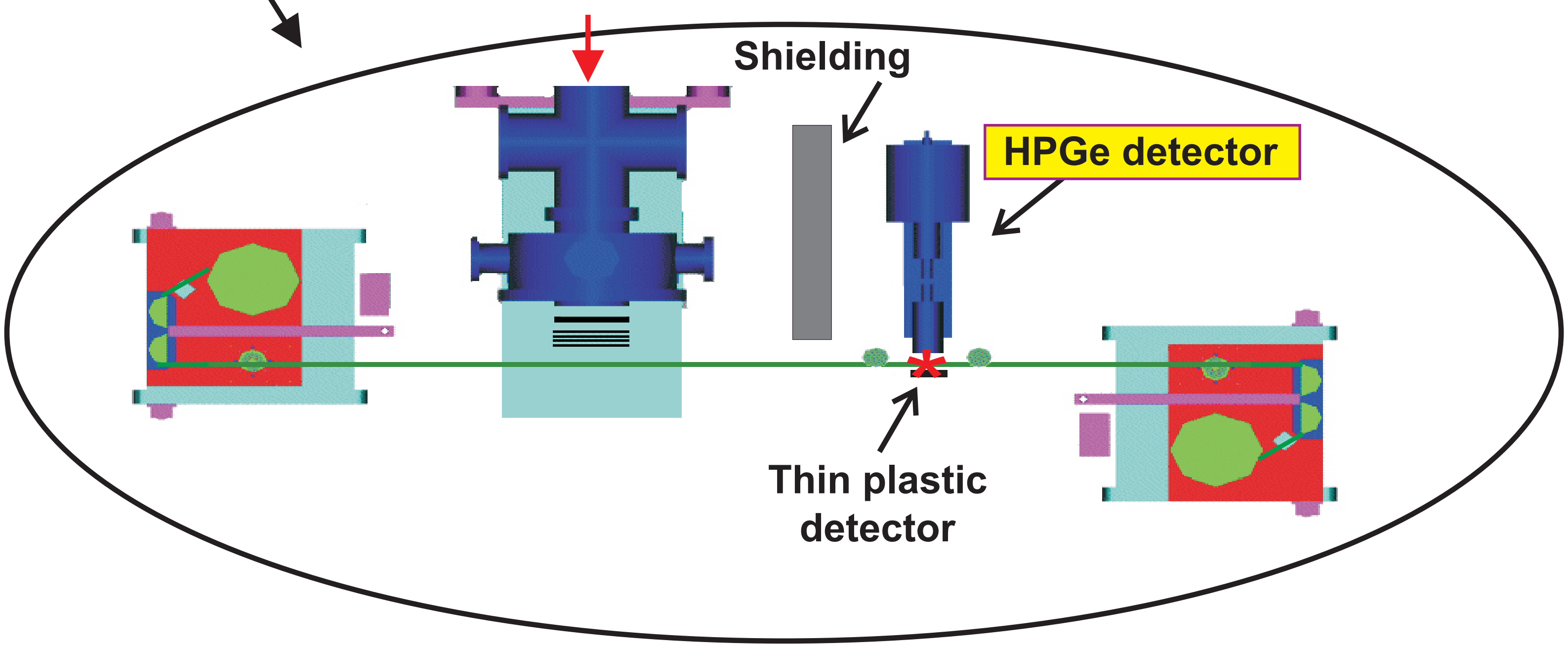

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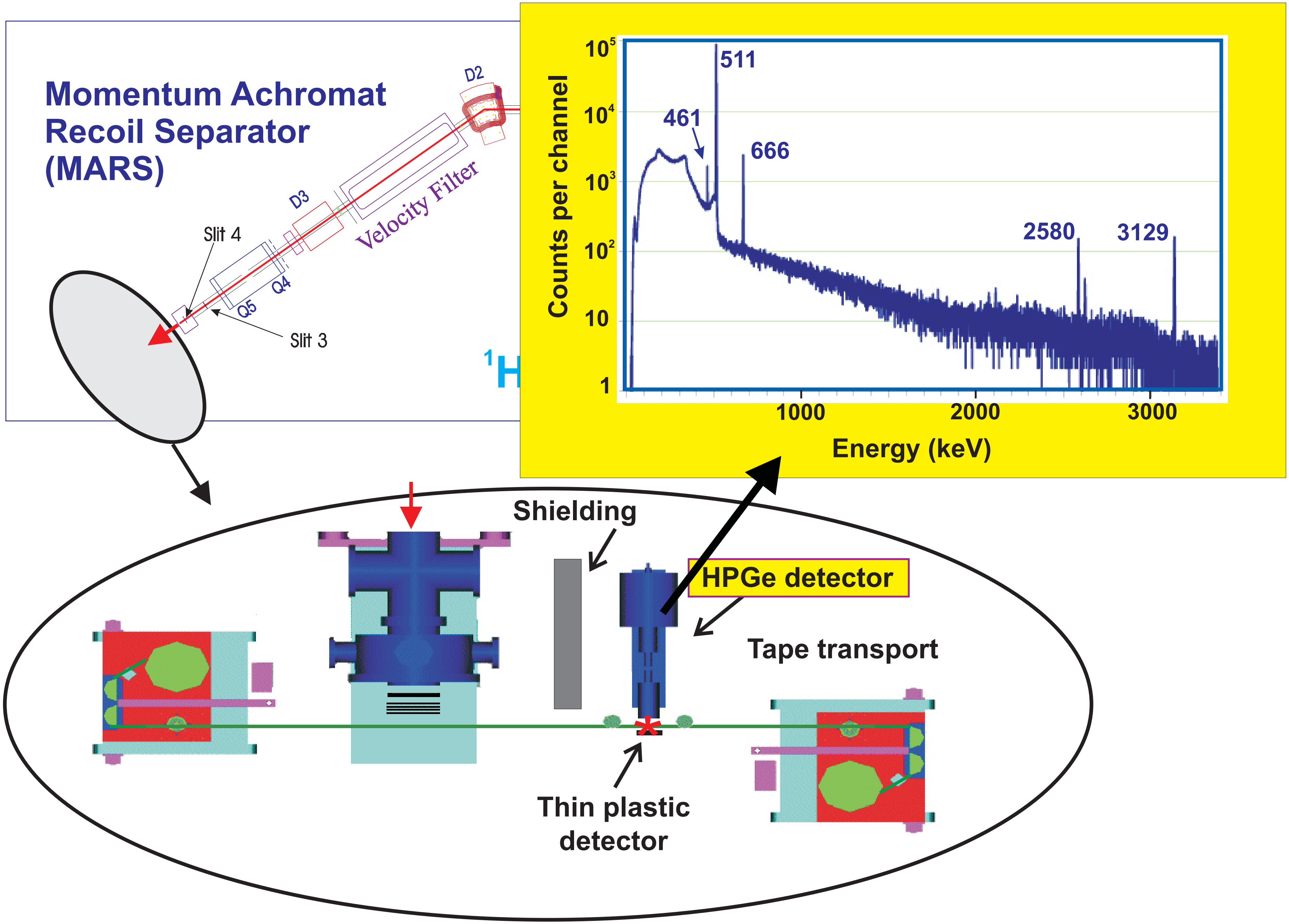

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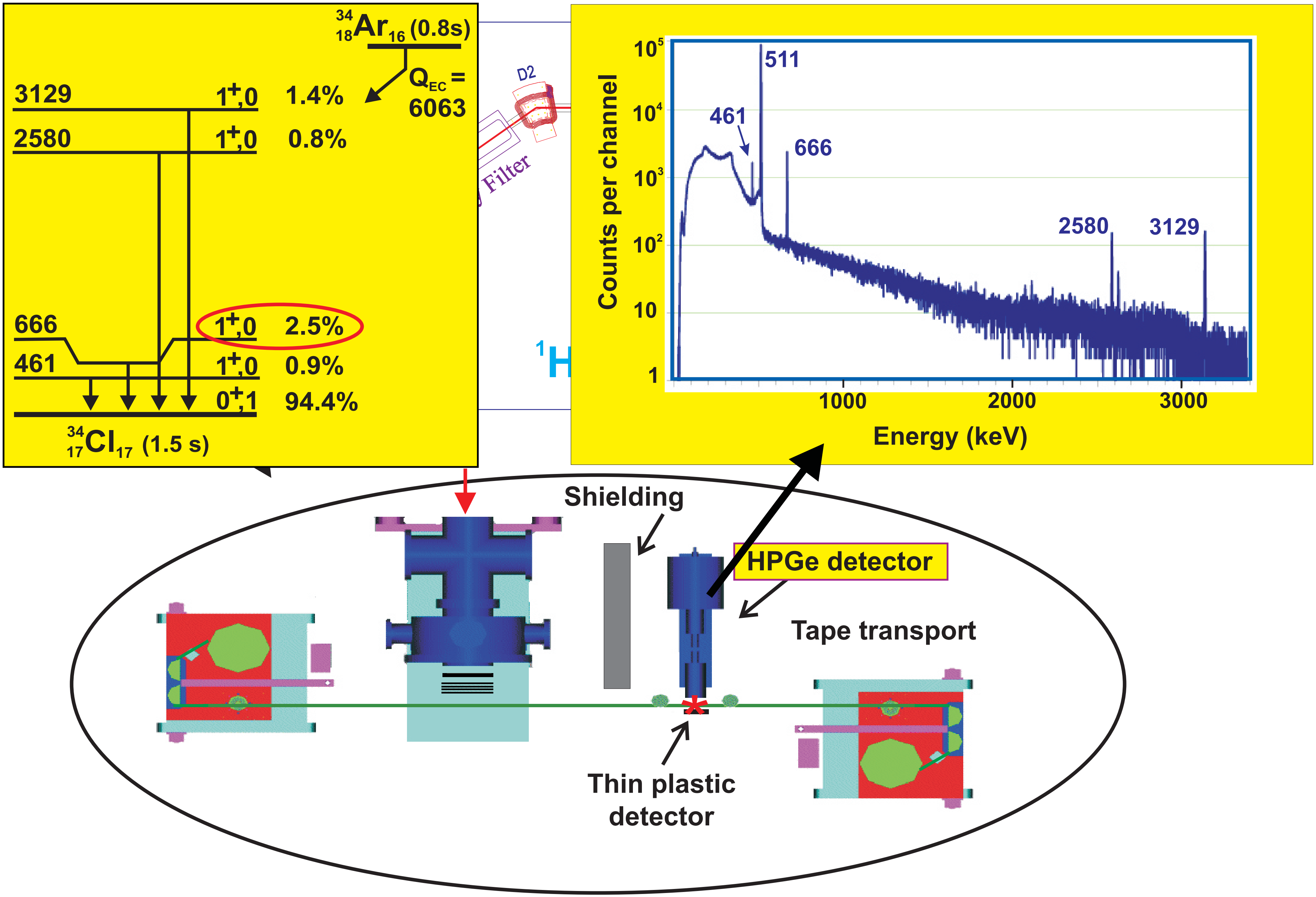

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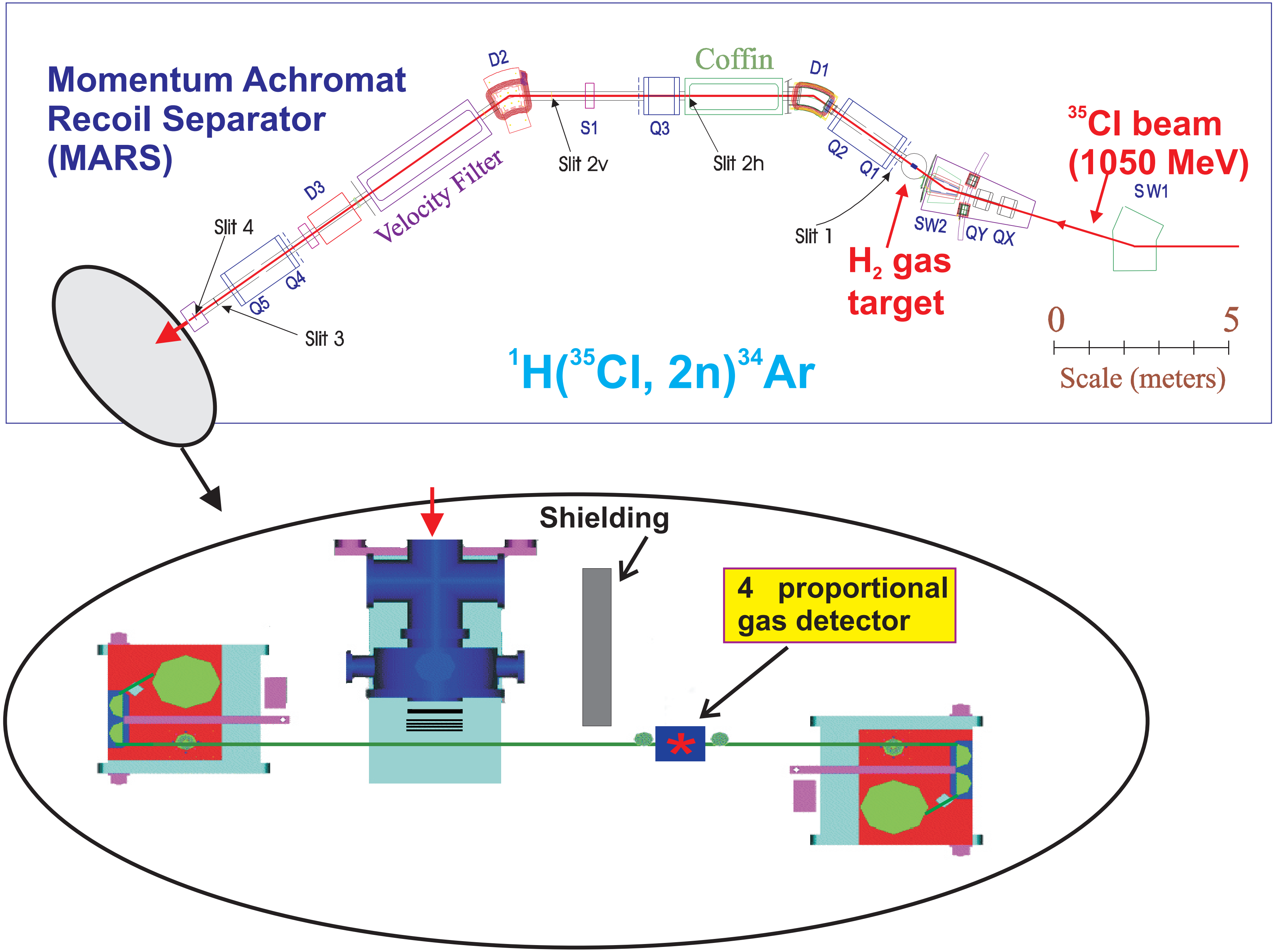
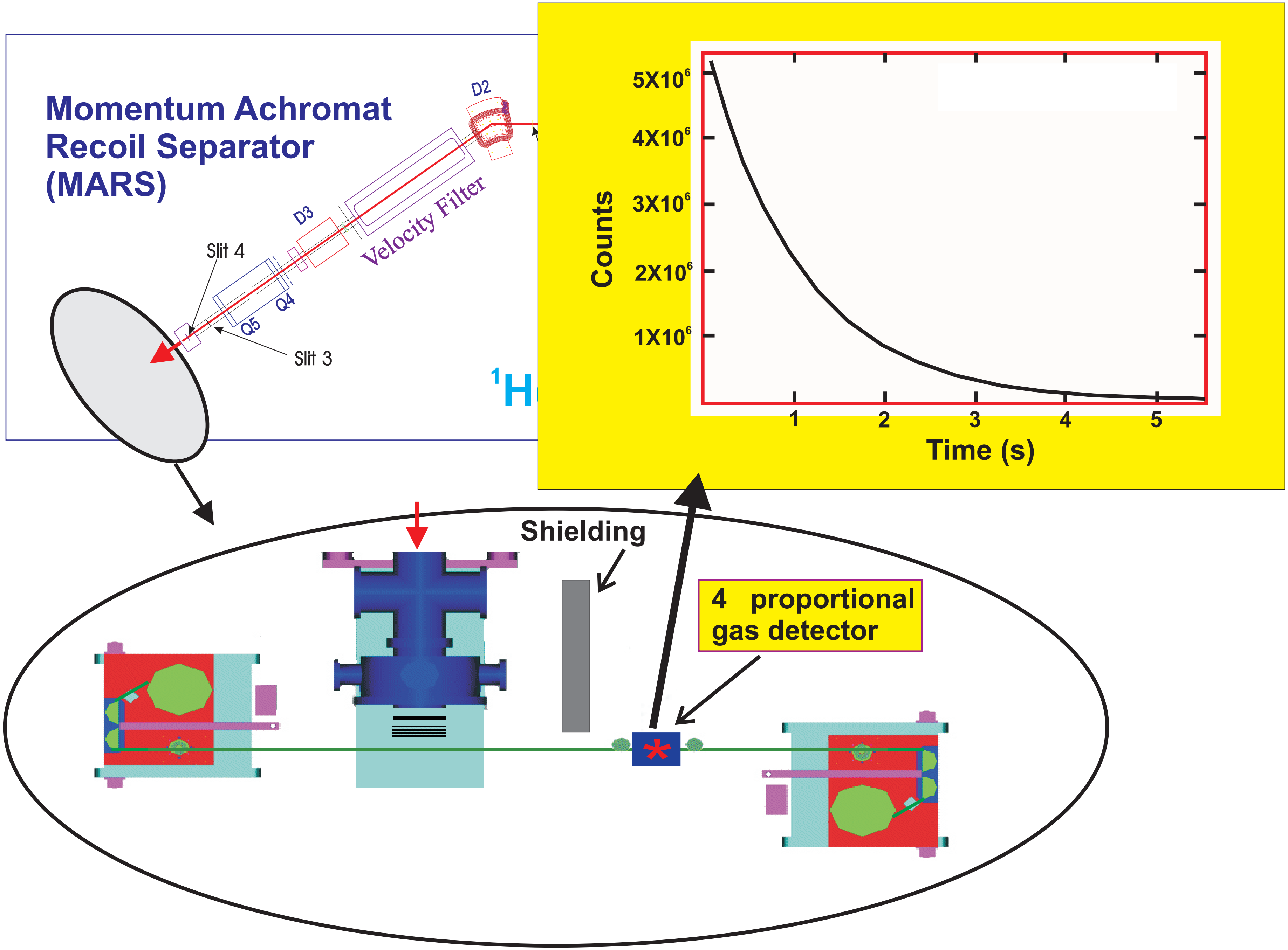
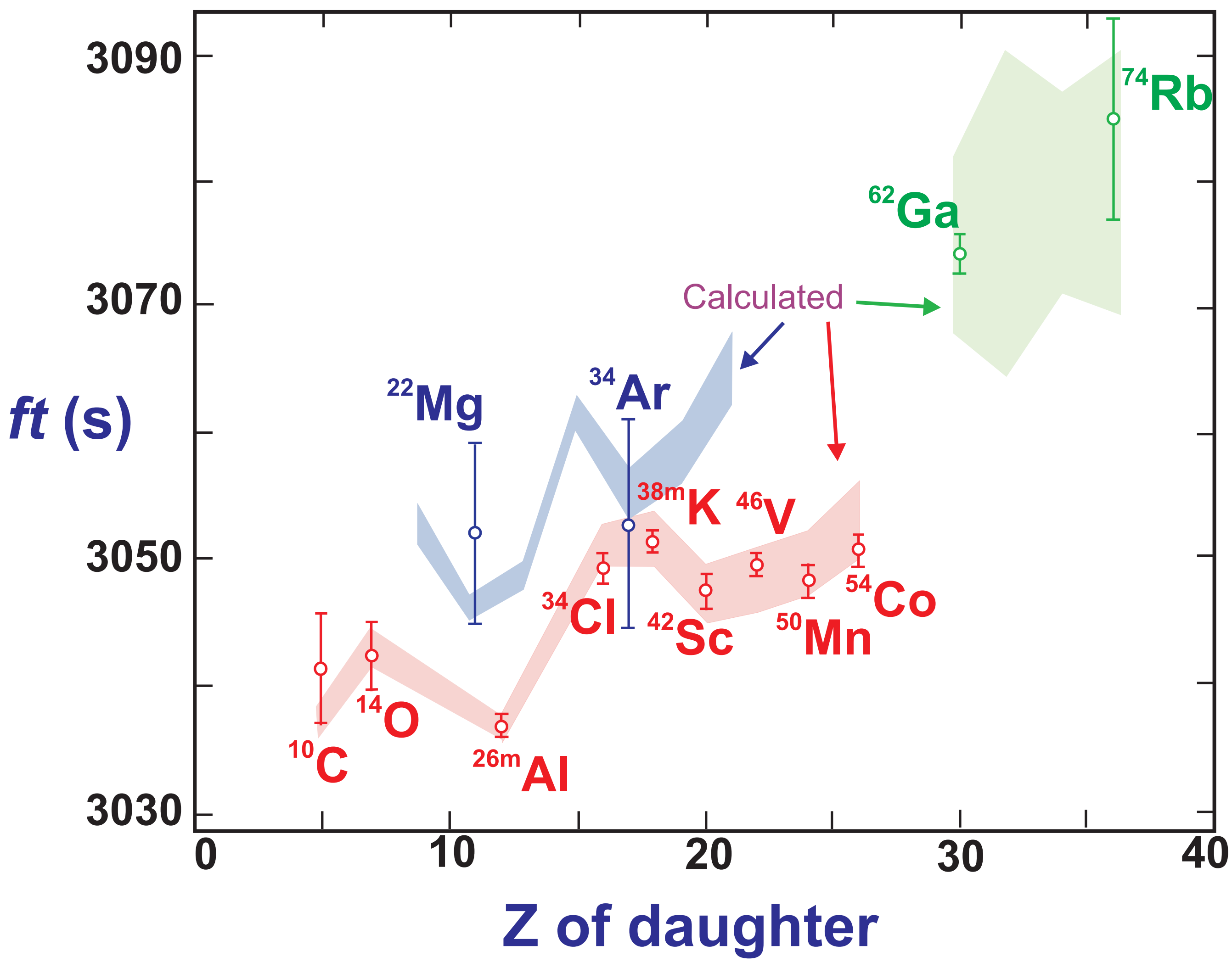


PRECISION DECAY MEASUREMENTS AT TAMU



STATUS OF CORRECTION TEST

$$\text{Calculated } ft\text{-value} = \frac{\overline{\mathcal{F}t}}{(1 + \ _{R})[1 - (\ _{C} - \ _{NS})]}$$



SUMMARY AND OUTLOOK

We know now that ...

1. The weak force (vector component) is constant in nuclei to 0.026%.
2. We can also test full universality of the weak force -- including the decay of other particles like the kaon -- and this also agrees within 0.1%!
3. Nuclear physics is the source of key data for these tests, the most precise ones available.

Within 5 years, expect ...

1. Nuclear measurements will reduce uncertainty still further.
2. Full universality of the weak force will be tested to a precision of $\lesssim 0.1\%$.