DF

Electron capture branching ratios for the odd-odd intermediate nuclei in ββ decay using TITAN

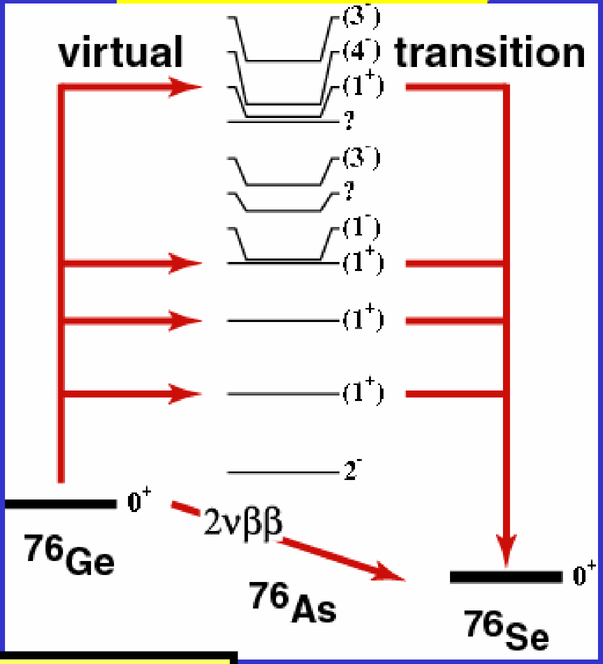
Prop.# 1066

- **Objectives:**
  - experimental determination of **nuclear matrix elements** for 2νββ decay and 0νββ decay
  - test theory and improve theoretical prediction
  - expose deficiencies in theory
  - allow more reliable extraction of **Majorana neutrino mass** from 0νββ decay by using mostly experimental information
- **Technique:**
  - measurement of K-shell EC X-rays using radioactive ions (i.e. intermediate nuclei) trapped in an ion trap (EBIT)
- **Advantages:**
  - no backing material, i.e. no absorption
  - high-purity sample
  - background-free situation, i.e. precision and sensitivity

ββ decay

2νββ decay

allowed in SM and observed in many cases



$$G^{2\nu}_{(\beta^-\beta^-)} = C\left(\frac{G_F}{\sqrt{2}}\cos(\Theta_C)\right)^4 F^2_{(-)}\left|M^{(2\nu)}_{\mathrm{DGT}}\right|^2 f(Q)$$

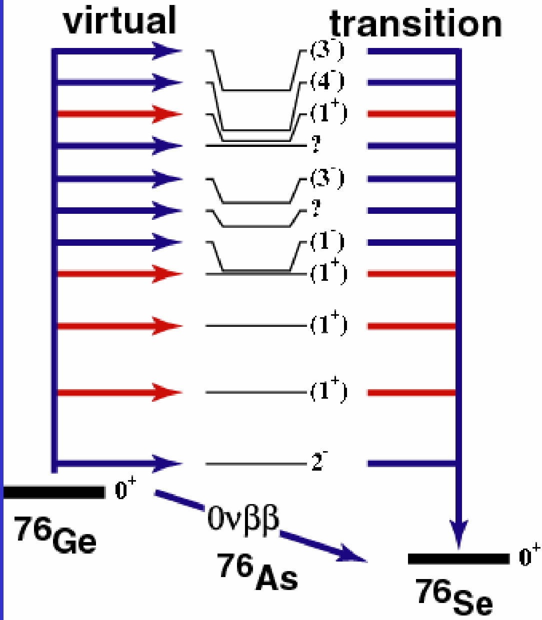
$$= G^{2\nu}(Q,Z)\left|M^{(2\nu)}_{\mathrm{DGT}}\right|^2$$

$$M^{(2\nu)}_{\mathrm{DGT}} = \sum_m \frac{\left\langle 0^{(f)}_{g.s.}\right|\sum_k \sigma_k \tau^-_k \left|1^+_m\right\rangle\left\langle 1^+_m\right|\sum_k \sigma_k \tau^-_k \left|0^{(i)}_{g.s.}\right\rangle}{\tfrac{1}{2}Q_{\beta\beta}(0^{(f)}_{g.s.}) + E(1^+_m) - E_0}$$

$$= \sum_m \frac{M_m\left(GT^+\right) M_m\left(GT^-\right)}{E_m}$$

accessible thru charge-exchange reactions in (n,p) and (p,n) direction (e.g. (d,^{2}He) or (^{3}He,t))

ββ decay



0νββ decay

forbidden in MSM
lepton number violated
neutrino enters as virtual
particle, → **$q \sim 0.5 fm^{-1}$**

mass of Majorana neutrino!!!

$$G^{0n}_{(b^- b^-)} = G^{0n}(Q,Z)\left| M^{(0n)}_{DGT} - \frac{g_V}{g_A} M^{(0n)}_{DF} \right|^2 \left\langle m_{n_e} \right\rangle^2$$

$$G^{0n}_{b^- b^-} = G^{0n} \left| \text{å}_m \frac{\langle 0^{(f)}_{g.s.} \| O_{st^-}(r,S,L) \| J^p_m \rangle \langle J^p_m \| O_{st^-}(r,S,L) \| 0^{(i)}_{g.s.} \rangle}{\tfrac{1}{2} Q_{bb}(0^{(f)}_{g.s.}) + E(J^p_m) - E_0} + \text{Fermi} \right|^2 \left\langle m_{n_e} \right\rangle^2$$

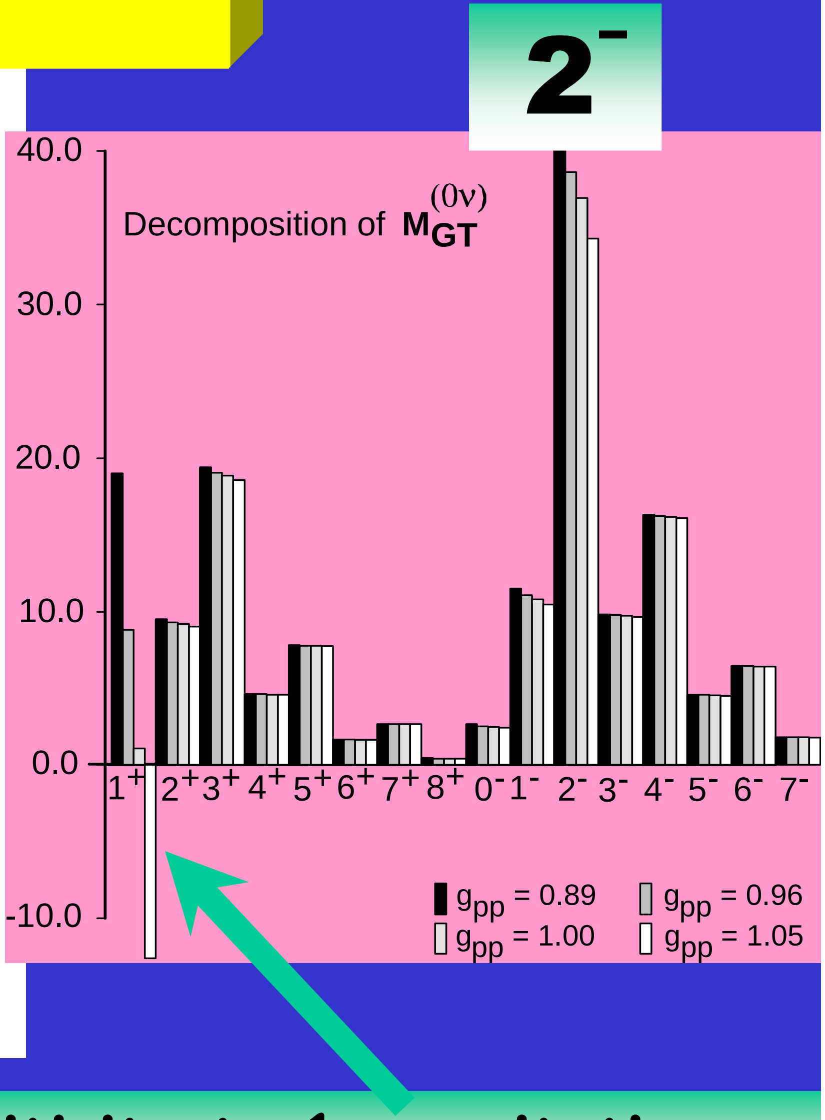
nucl. matrix element

NOT accessible thru
charge-exchange reactions

Theoretical situation

Theory claims:

1. both decay modes can be described with **ONE** parameter only, g_{pp}, which is the p-p part of the proton-neutron two-body interaction
2. g_{pp} is fixed to the experimental $2\nu\beta\beta$ decay half life (g_{pp} ~1)
3. there are no intermediate cross checks with experiment
4. $2\nu\beta\beta$ decay is **sensitive** to g_{pp}, $0\nu\beta\beta$ decay is **insensitive** to g_{pp}
5. nuclear structure remains hidden
6. Theory: **trust us!!**



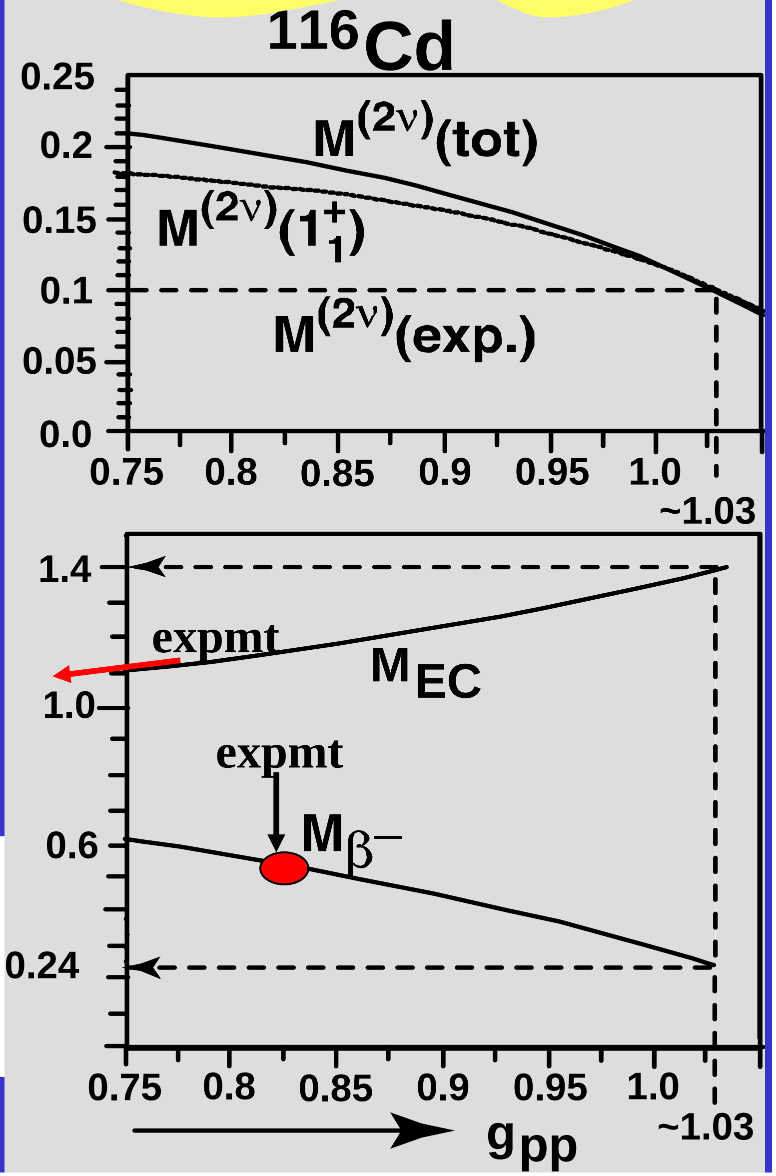
sensitivity to 1+ excitations

Recent critical assessment of the theoretical situation

1. gpp also enters into calculation of single β decay
2. this allows to make (in few cases) precise predictions about EC-rates
3. in confronting with experiment, theory fails **BADLY**

(if EC is known) !

example



In case of single state dominance

$$M^{(2n)}_{tot} \square \frac{M_{EC}\, M_{b-}}{\frac{1}{2} Q_{bb}(0^{(f)}_{g.s.}) + E_{g.s.}(1^+) - E_0}$$

$_{EC} = 1.4$ ε = 0.095% *log ft* = 3.77 theo

$_{EC} = 0.69$ ε = 0.023% *log ft* = 4.39 exp-1

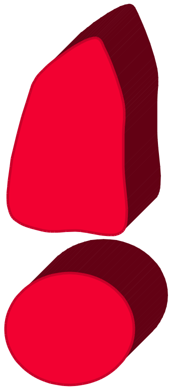
Summarizing the theory

The use of $g_{pp}(\beta\beta) \sim 1.0$ reproduces the $2\nu\beta\beta$ decay half-life via a conspiracy of two errors: a much too large EC matrix element (too fast EC decay) is compensated by a much too small β^- matrix element (too slow β^- decay).

Discrepancies of 1 – 2 orders of magnitude are possible

The loose end:

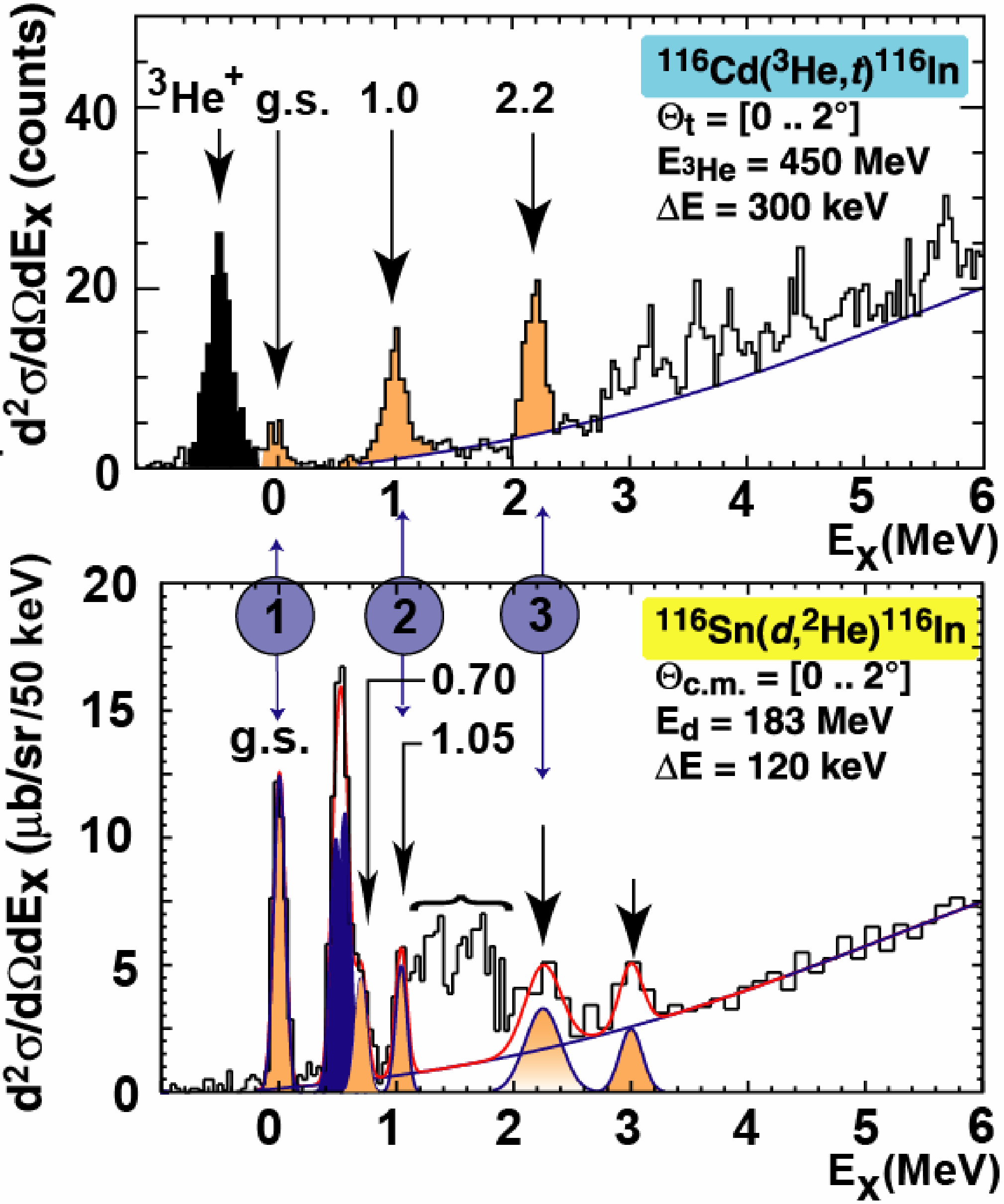
EC rats are badly known, or not known at all



^{116}Cd 2νββ decay

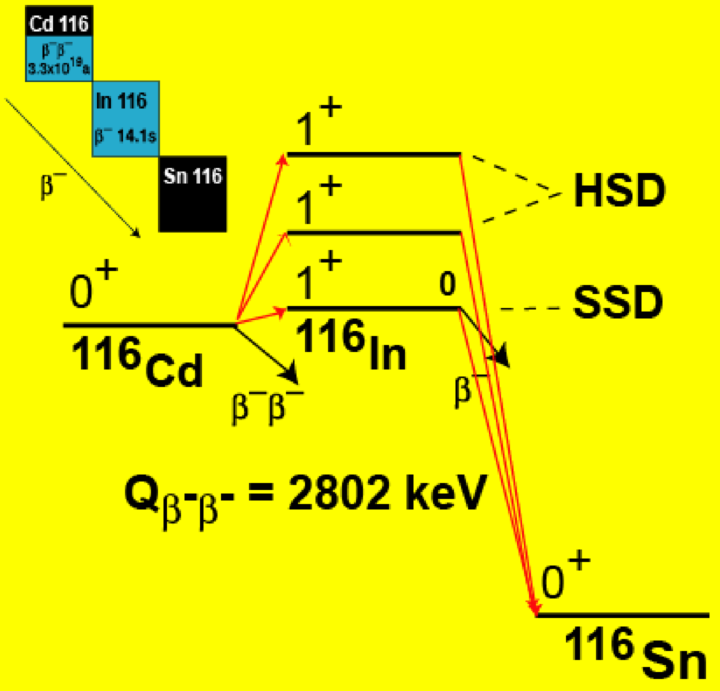
	$B(GT^-)$	$B(GT^+)$	M^m_{DGT}	running sum ΣM_{DGT}
①	0.032	0.256	0.025	0.025
②	0.12	0.11	0.020	0.045
③	0.17	0.07	0.013	0.058

Matrix element from counting experiment:
$\Sigma M_{DGT} = 0.064 \pm 0.007$



Single state dominance and its oddities

the conjecture

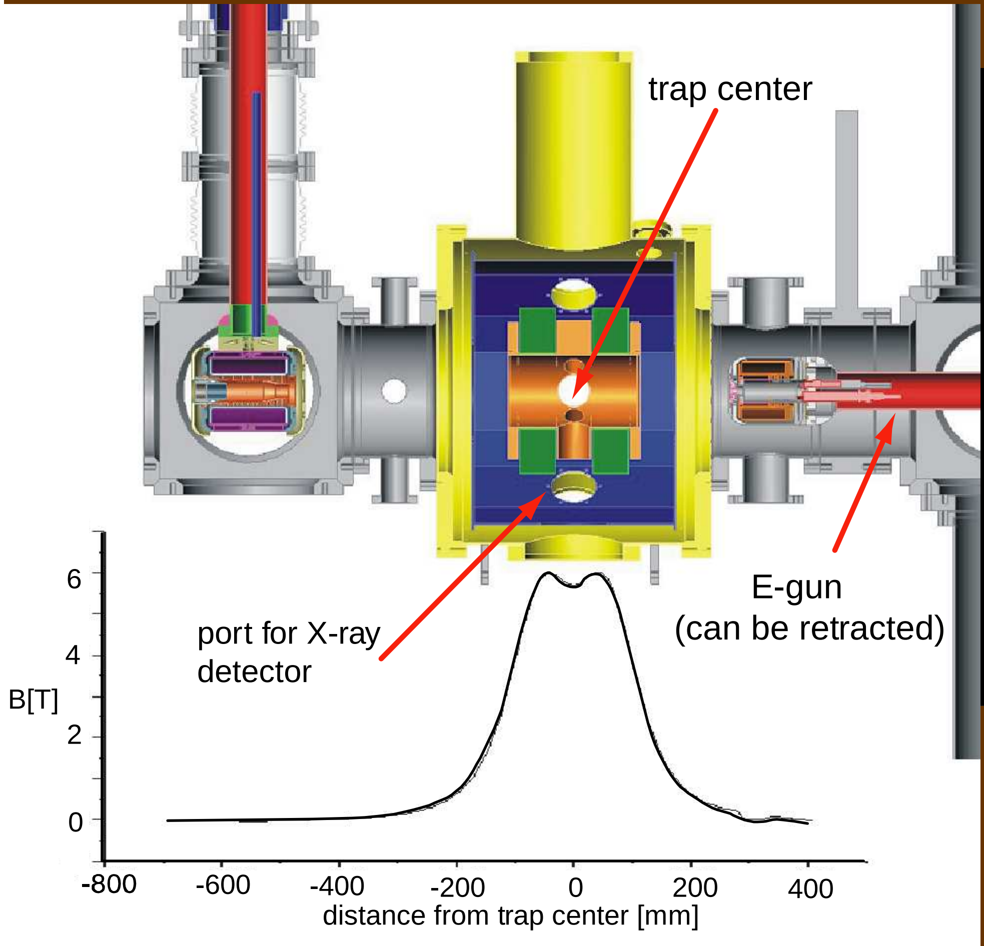


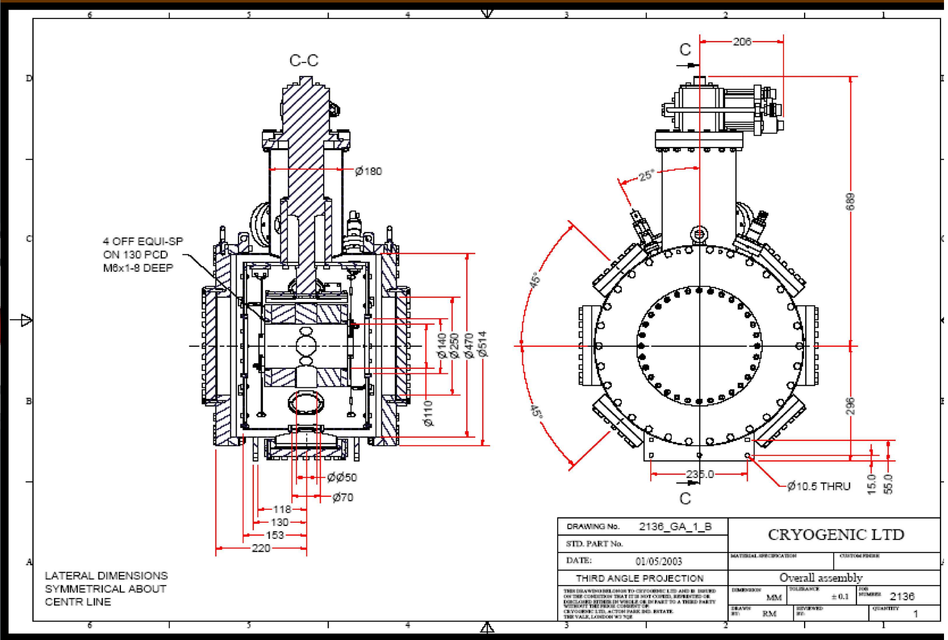
$$\begin{tikzcd} {}^{116}\mathrm{Cd} \arrow[r, shift right, "{(^{3}\mathrm{He},t)\ \mathrm{B(GT^-)}}"'] & {}^{116}\mathrm{In} \arrow[l, shift right, "\mathrm{EC}"'] \arrow[r, shift left, "\beta^-"] & {}^{116}\mathrm{Sn} \arrow[l, shift left, "{(d,^{2}\mathrm{He})\ \mathrm{B(GT^+)}}"] \end{tikzcd}$$

the oddity

Case	B(GT⁻)	B(GT⁺)	M(DGT)	$T_{1/2}^{(2\nu)}$ [10^{19} y]
direct	–	–	0.064	3.3
(^{3}He,t)/ β⁻	0.032	0.256	0.025	22
EC/ β⁻	0.47	0.256	0.09	1.5
theory	1.165	0.065	0.07	2.4
(^{3}He, t)/(d,^{2}He)	0.322*	0.436*	0.058	4.0

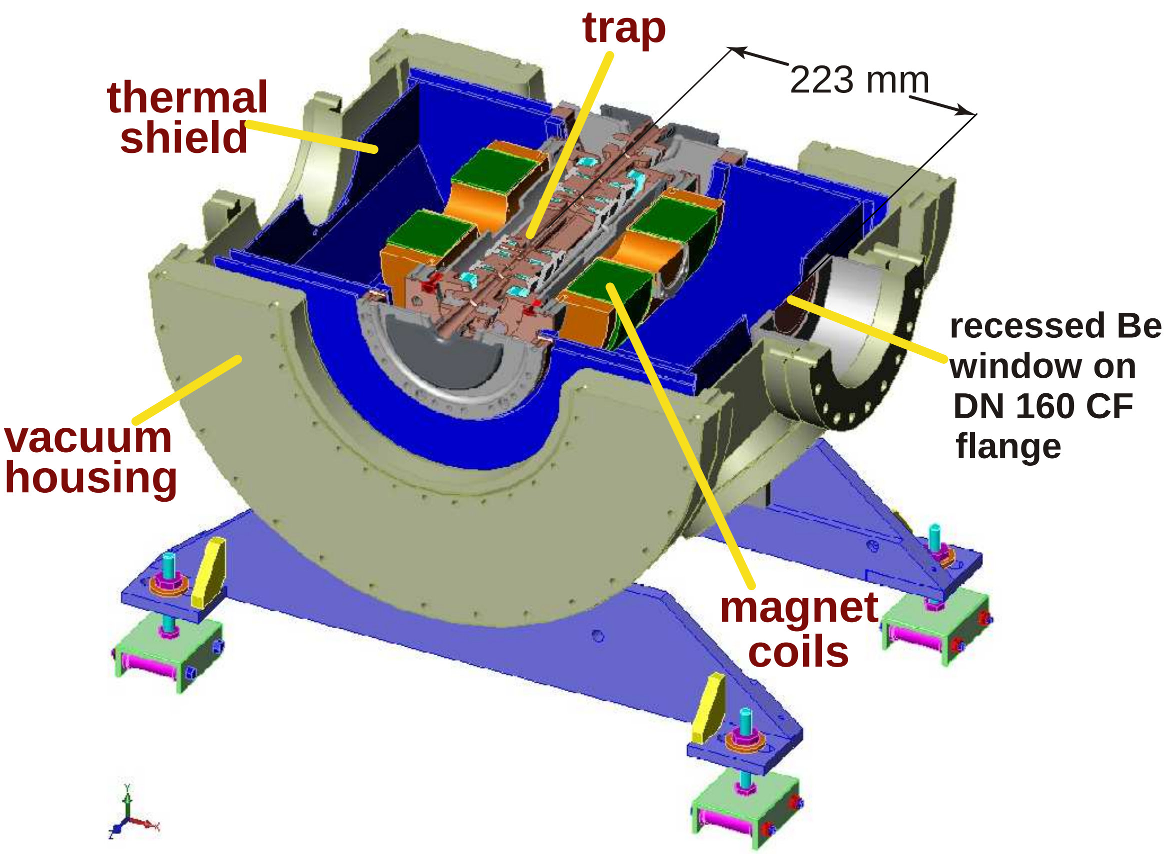
Experiment for EC using EBIT





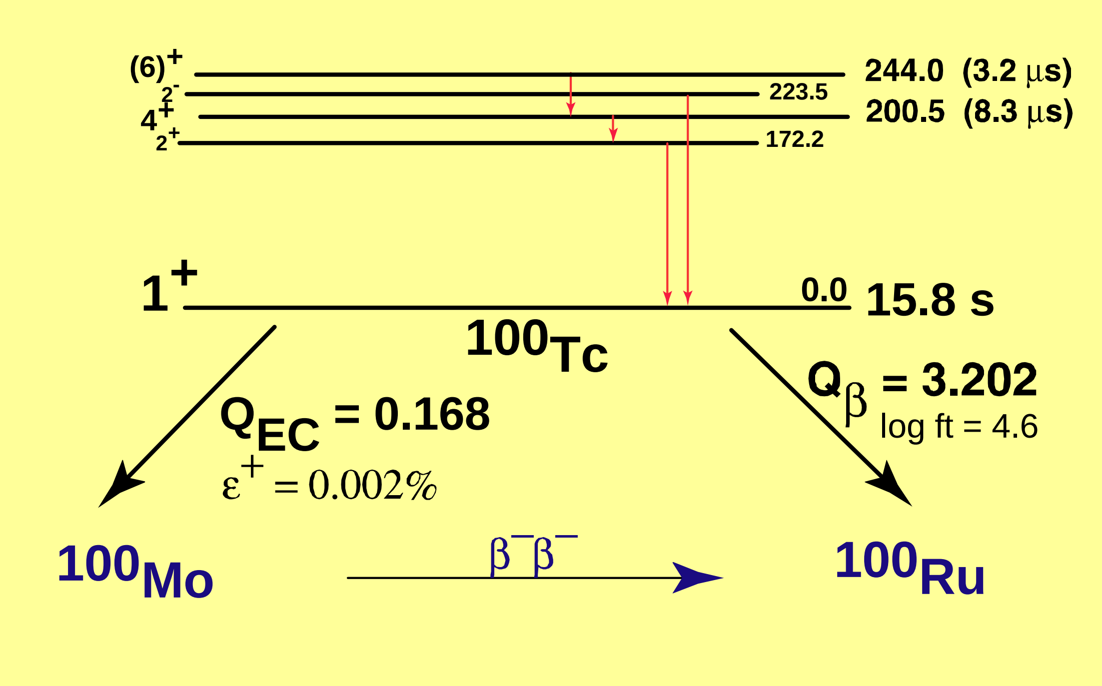
holding 7 ports for X-ray detectors

Experiment for EC using EBIT



- 7 X-ray detectors
- 2.1% solid angle (can be increased)
- 6T magnetic field
- carrierless suspension of ions in UH vacuum
- $10^5 – 10^6$ ions per load
- holding times: minutes or hours possible

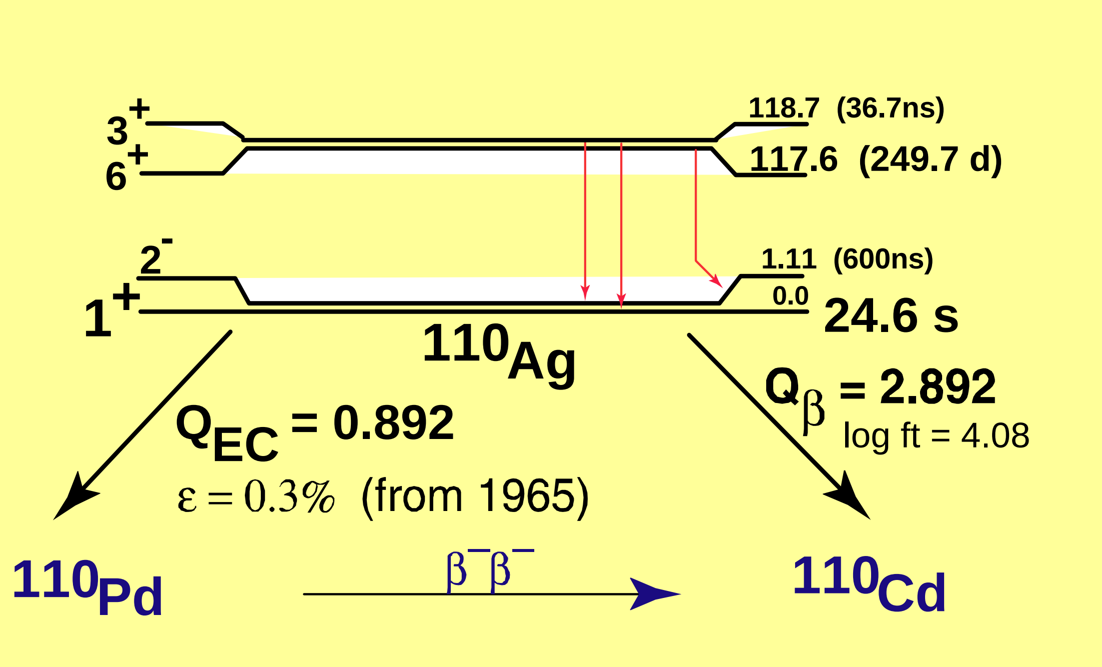
Electrons from β-decay (10^6 times more intense than EC) are giuded away to the exit of the trap and can be used for monitoring by a channeltron



presently investigated at Jyväskylä using „tape-station“ technique

Important to show how our technique can compete

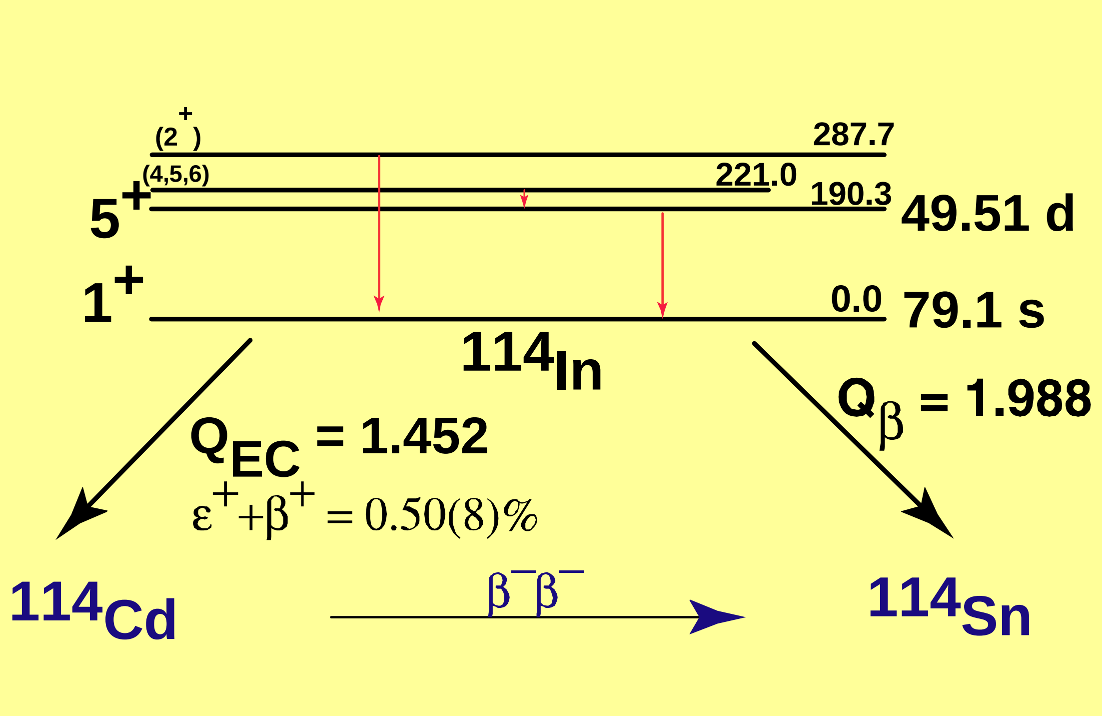
11 shifts /10% measurement
(*****)



easy measurement and used for proof of principle

will be used for initial tests

1 hour!! /10% measurement
(*****)

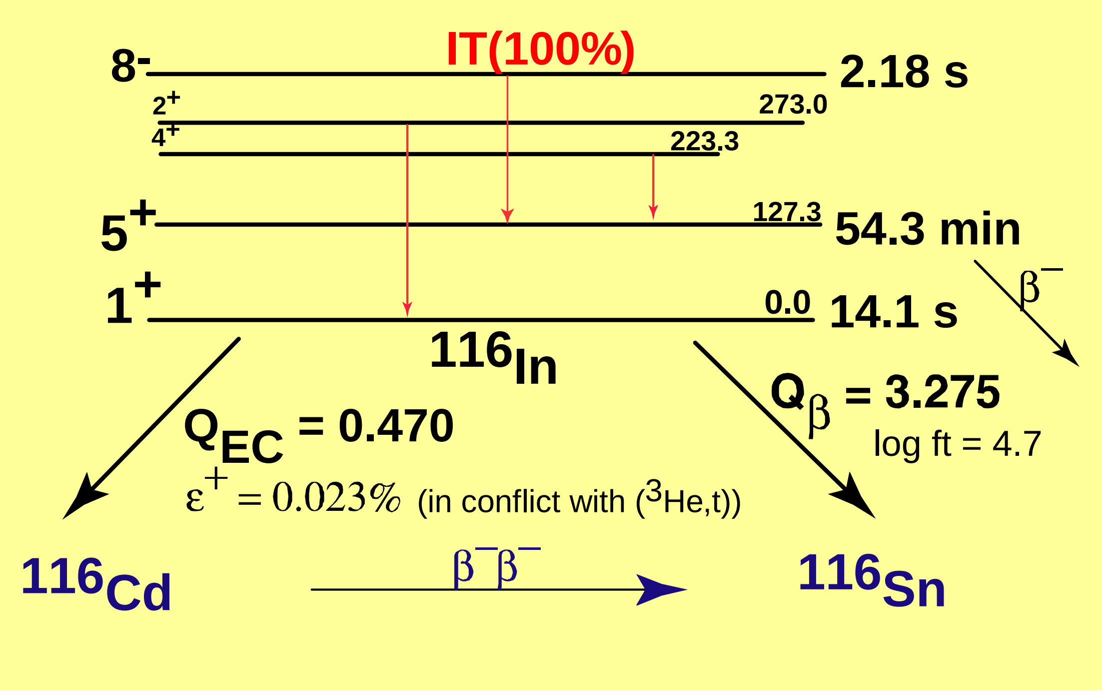


measurements of EC branch from 1956 (log ft= 4.85)

2^+ excited state at 558 keV can be reached

2 hour!! /10% measurement

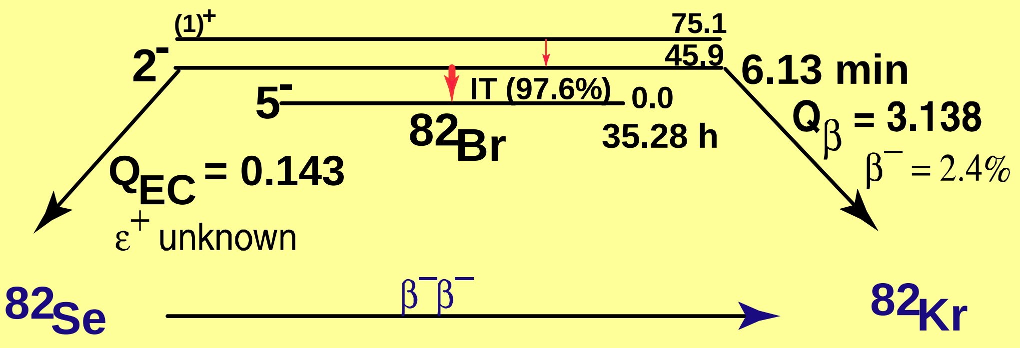
(***)



Important measurements also because of the present conflicting experimental values.

1 – 13 shifts depending on value of ε

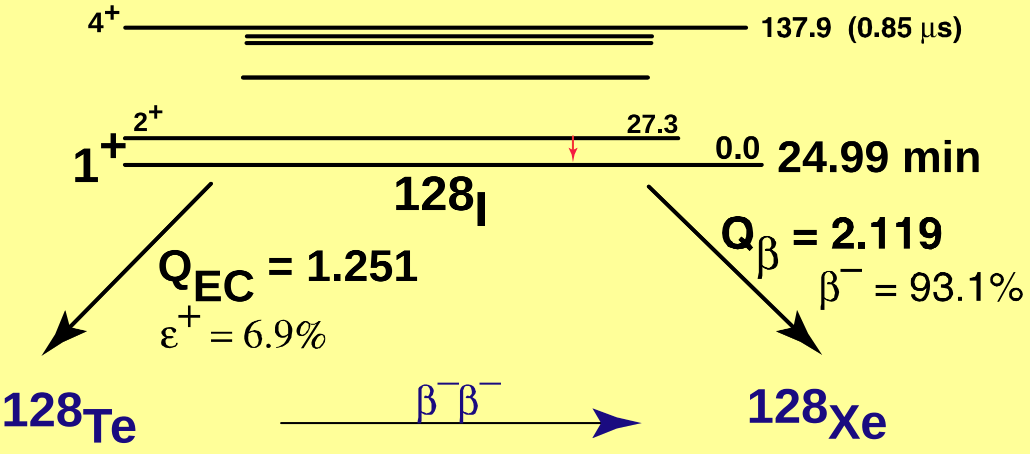
(*****)



Deferred!!

if log ft (EC) = log ft(β^-) ~8.4

$\varepsilon \sim 10^{-8} - 10^{-9}$

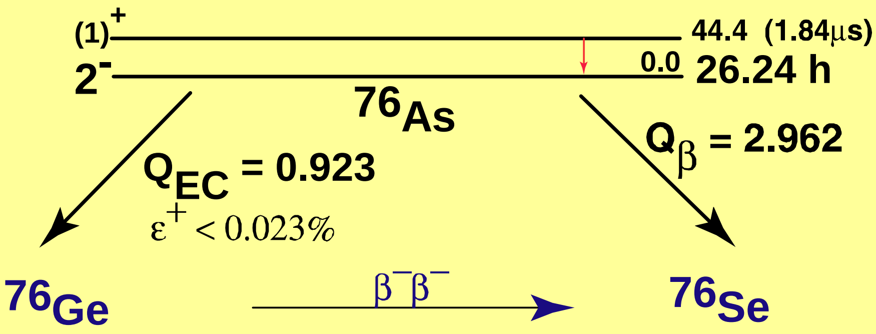


Can be used a standard

for calibration

branching has been measured with high precision (0.8%)

20 shifts for 5% measurement



The most important case!!!

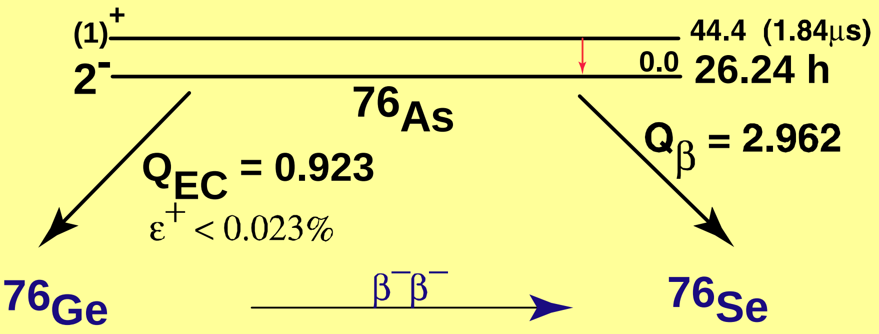
exp. log ft (β^-) = 9.7
exp. log ft (EC) ~ 9.1

theo. log ft (β^-) = 8.7
theo. log ft(EC) = 8.8

$\varepsilon = 0.01\%$

$\varepsilon = 0.02\%$

Estimated measuring time:
20,000 to 40,000 hours
(because of long half-life!)



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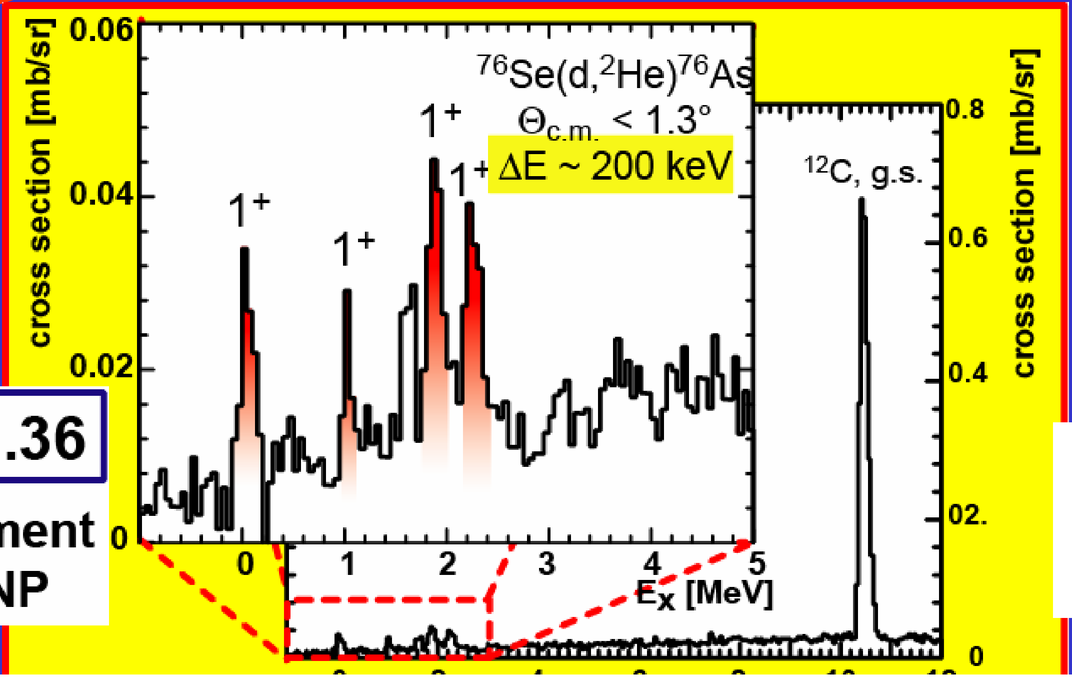

Σ B(GT$^+$) ~ 0.36

(^{3}He,t) measurement proposed at RCNP

M(β^-) = 0.38(exp)

M(β^-) =0.09(theo)

- **Improvements:**

- Increase solid angle by **factor 2.25**
- Increase load from 10^5 to $5\text{x}10^6$ **factor 50**

- **Beam time 200 – 400 hours (25 – 50 shifts at 10%)**

Presently requested beam time

- 2 x 6 shifts for tests and commissioning
  - storage capacitiy
  - storage times
  - isobar separation
  - capabilties of measuring absolute values
  - evaluating backgrounds

investments

- 7 high resolution X-ray detectors
  - to be applied for at German DFG