# Electron capture branching ratio measurements for double decay experiments at TITAN-TRIUMF

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## Motivation - Neutrino physics

Neutrino oscillations indicate a small neutrino mass → neutrino flavour eigenstates *i* and mass eigenstates *j* are not equal: $|\ _i = U^L_{ij}\ |\ _j$

$U^L$: Weak Mixing Matrix

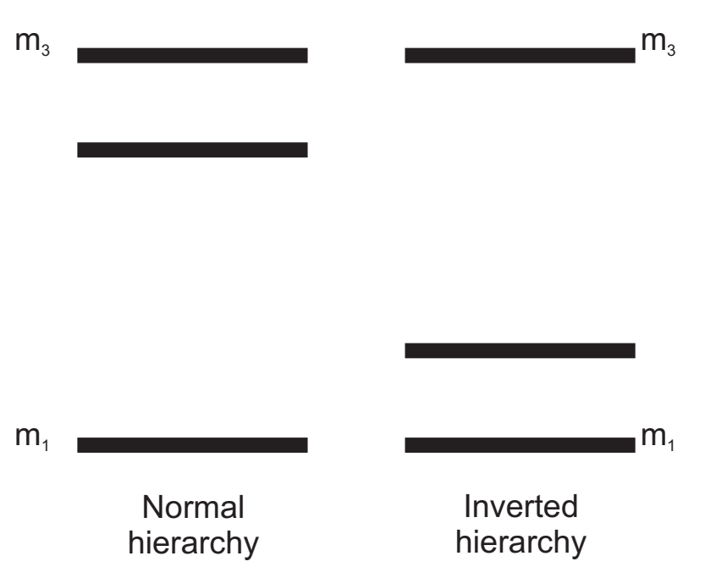
Neutrino character still unknown → is the neutrino a Dirac particle → $\bar{\ }$ or a Majorana particle = $\bar{\ }$

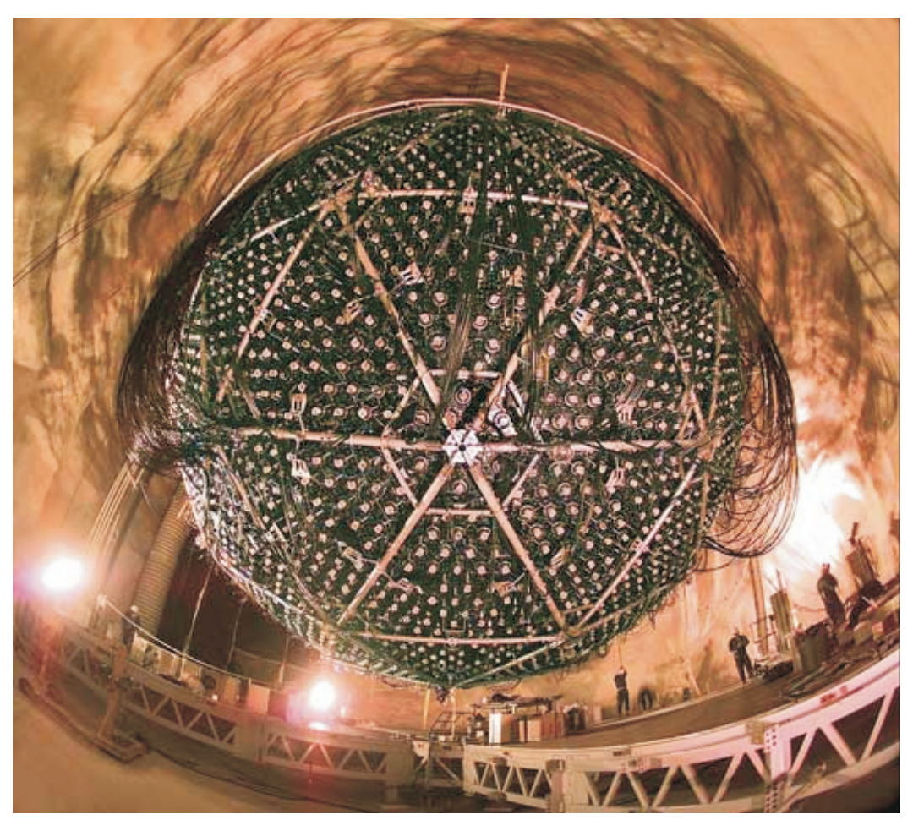
## Neutrino Experiments

### Neutrino oscillation

Relative mass scale, m², ij

- Indicates a neutrino mass [1]
- Determination of mixing angle
- Determination of m$^2$
- Experiments: SuperK, SNOlab





SNOlab detector

[1] T. Kajita and Y. Totsuka, *Rev. Mod. Phys.* 73(2001)85
Picture taken from http://www.oit.on.ca

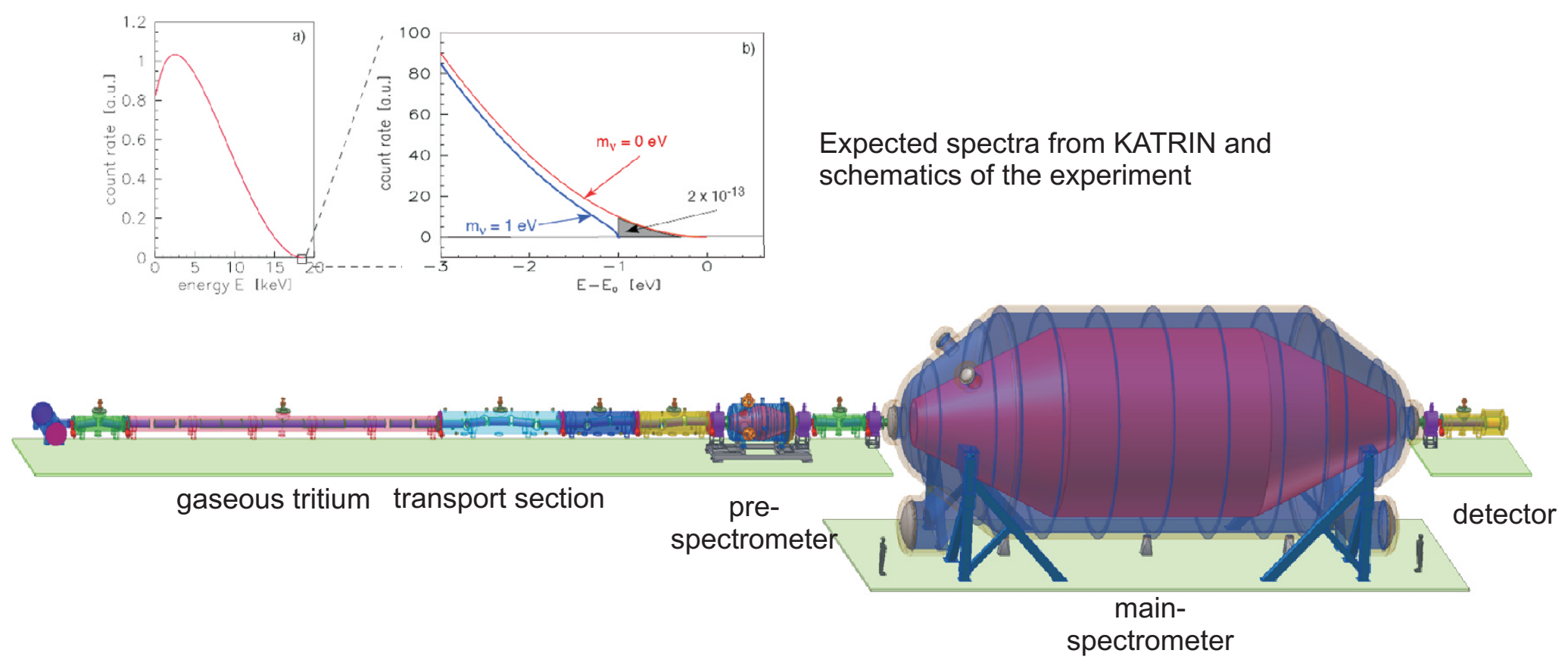
### Tritium decay

Absolute mass scale, m $_e$

- End point energy determination of $^3$H decay
- Effective mass for degenerated neutrinos [2]:

$$m_{\ e}^{\ 2} = \ _j |U_{ej}|^2\, m_j^2$$

- Experiment: KATRIN



Expected spectra from KATRIN and schematics of the experiment

[2] KATRIN design report 2004
Pictures taken from Background Simulations for the Karlsruhe Tritium Neutrino Experiment, M.L. Leber, 2006
http://students.washington.edu/mleber/researchProposal.pdf

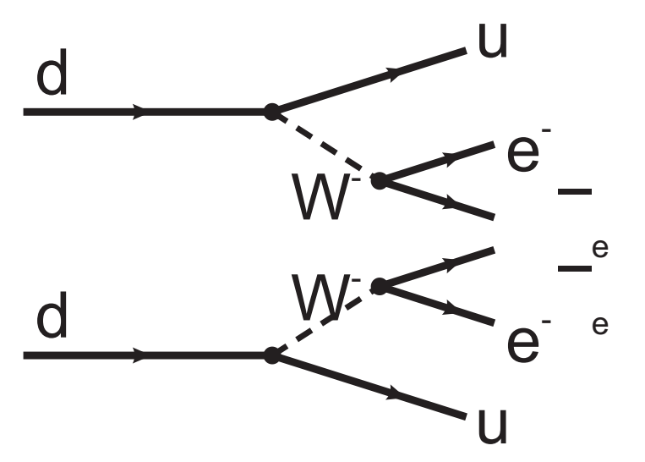
### Double decay

Absolute mass scale, Neutrino character

Believed to occur in at least two modes:

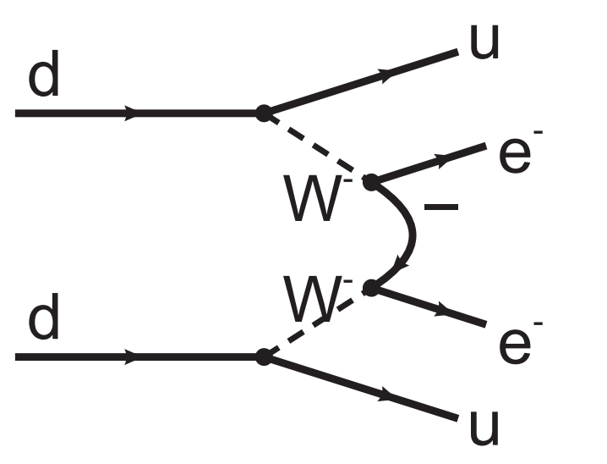
**2 decay**

- Allowed in Standard Model
- $T_{½} > 10^{17}$y



**0 decay**

- Physics beyond Standard Model
- $T_{½} > 1.5 \cdot 10^{25}$y [3]
- If observed:
  $| m\ | = (F_N\, T_{½}\ )^{-½}$ eV
  with nuclear matrix element $F_N$ [4]



[3] C.E. Aalseth et al., *Phys. Rev. D* 65(2002)092007
[4] S.R. Elliott and P. Vogl, *Annu. Rev. Nucl. Part. Sci.* 52(2002)115

## Nuclear matrix elements associated with double decay

### Theoretical description with $g_{pp}$

Theoretical description of these double decay nuclei with **nuclear shell-model** or **proton-neutron Quasiparticle Random Phase Approximation (pn-QRPA)**

Adjustable particle-particle parameter $g_{pp}$ in pn-QRPA for all **single** and **double** decay calculations [5]

The many-particle Hamiltonian is a function of $g_{pp}$

2 decay appears to be rather sensitive to $g_{pp}$ → tuning $g_{pp}$ by this decay [6 and ref. therein]

Fitting of calculated nuclear matrix elements to half life of
2 decay leads to $g_{pp}$
0 decay rather insensitive to $g_{pp}$

[5] M. Kortelainen and J. Suhonen, to be published in *Phys. Rev. C* 2007
[6] D. Frekers et al., *Can. J. Phys.* 85(2007)57

### Theoretical situation

2 used as a test case for pn-QRPA
Extrapolation of calculated matrix elements to 2 half life provides $g_{pp}$

This decay proceeds only via 1$^+$ intermediate states. The nuclear matrix element for this state coincides with total value of the matrix element near $g_{pp}$ = 1, the so called single-state-dominance (SSD)

In this case, the 2 matrix element simplifies to:

$$M_{tot} \quad M_{EC}\ M$$

This allows, in some cases, a theory cross check [6]
$g_{pp}$ is derived from 2 decay half life and tested in single and EC decays

The loose end:
EC rates poorly known or not known at all

### Experimental situation

Theory does not perfectly agree with experiments
Case $^{116}$Cd:
$M_{tot}$ leads to $g_{pp}$ = 1.03
The resulting EC matrix element $M_{EC}$ does not fit with experimental value (EC branching ratio ):

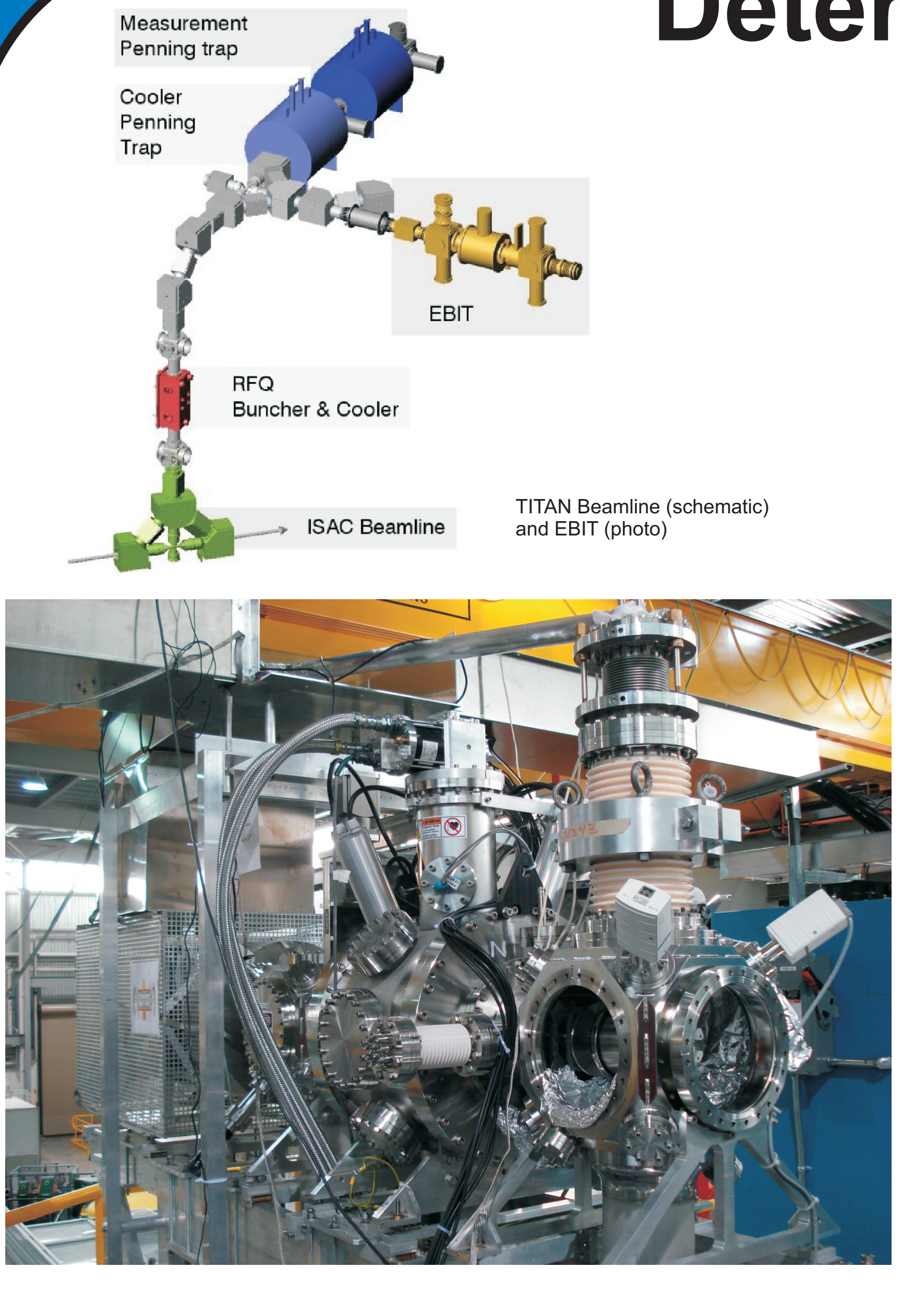
| | | | |
|---|---|---|---|
| $M_{EC}$=1.4 | = 0.095% | theory | [7] |
| $M_{EC}$=0.69 | = (0.023±0.006)% | experiment 1 | [8] |
| $M_{EC}$=0.18 | = (0.0019±0.0003)% | experiment 2 | [9] |

Conclusion: $g_{pp}$( )~1 reproduces 2 decay half life in QRPA by two compensating errors:
Theoretical EC matrix element too large
Theoretical matrix element too small

[7] J. Suhonen, *Phys. Lett. B* 607(2005)87
[8] M. Bhattacharya et al., *Phys. Rev. C* 58(1998)1247
[9] H. Akimune et al., *Phys. Lett. B* 394(1997)23

**Conclusion of present matrix element status:**
State-of-the-art theory (shell model, QRPA) is not in satisfactory agreement with experiments → **our goal:** provide a new and different approach to experimental BR determination using a clean and backing-free ion-trap system. Then compare the new results with theory to determine systematic theoretical shortcomings and to guide further developments towards a better theoretical understanding of 0 -decay.

## Determination of $M_{EC}$ with BR measurements at TITAN

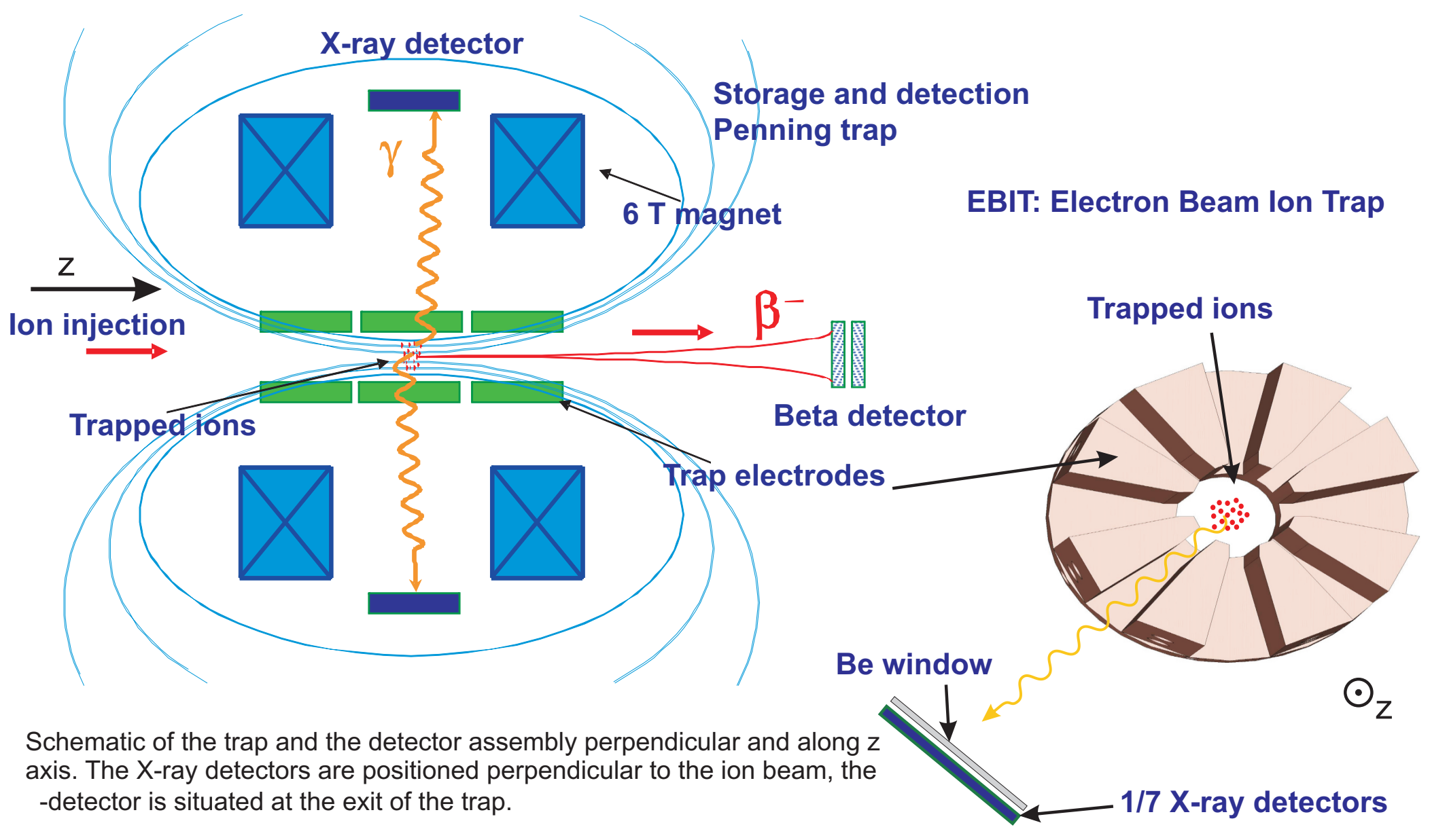


TITAN Beamline (schematic) and EBIT (photo)

### Novel approach to determine $M_{EC}$

- Conventional methods of implanting isotopes on a tape station reached a limit of sensitivity
- ISAC facility at TRIUMF for isotope production
- TITAN (http://titan.triumf.ca) trap system with the EBIT (without electron beam) as a central component of the measurement
- Carrierless suspension due to storage in the trap
- Segmented center electrode of the EBIT accommodates seven X-ray detectors radially positioned around the trap (2.1% solid angle of x-ray detectors)
- 6T magnetic field (superconducting coil) in the trap guides the decay electrons out of the trap onto a detector
- $10^5$ to $10^6$ ions in trap
- Holding times of minutes up to several hours (P $10^{-11}$ mbar)
- Monitoring of trapped ions via a PIPS (Passivated Implanted Planar Silicon) detector for detection
- No contamination due to isobar separation with trap techniques

**New method with trap and separation of $^-$ and X-ray provides contamination and bremsstrahlung-free measurements**



Schematic of the trap and the detector assembly perpendicular and along z axis. The X-ray detectors are positioned perpendicular to the ion beam, the -detector is situated at the exit of the trap.

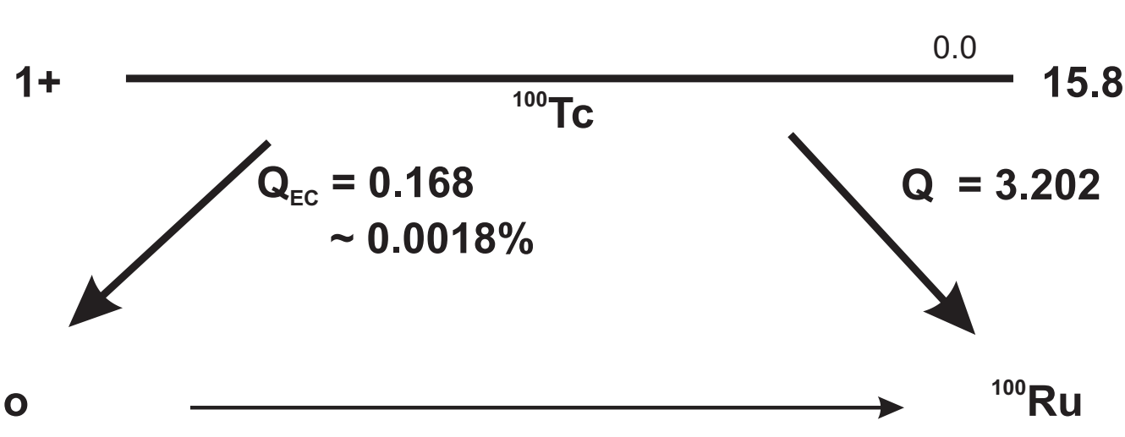
### Nuclides to be determined

decay candidates that are under investigation in experiments such as Majorana, EXO, COBRA, CUORE and others [6]:

| | | |
|---|---|---|
| $^{100}$Mo : $^{100}$Tc(EC) | [1$^+$ →0$^+$, $T_{½}$=15.8s] | K $_{½}$=17.5keV |
| $^{110}$Pd : $^{110}$Ag(EC) | [1$^+$ →0$^+$, $T_{½}$=24.6s] | K $_{½}$=21.2keV |
| $^{114}$Cd : $^{114}$In(EC) | [1$^+$ →0$^+$, $T_{½}$=71.9s] | K $_{½}$=25.3keV |
| $^{116}$Cd : $^{116}$In(EC) | [1$^+$ →0$^+$, $T_{½}$=14.1s] | K $_{½}$=25.3keV |
| $^{82}$Se : $^{82m}$Br(EC) | [2$^-$ →0$^+$, $T_{½}$=6.1min] | K $_{½}$=11.2keV |
| $^{128}$Te : $^{128}$I(EC) | [1$^+$ →0$^+$, $T_{½}$=25.0min] | K $_{½}$=27.5keV |
| $^{76}$Ge : $^{76}$As(EC) | [2$^-$ →0$^+$, $T_{½}$=26.2h] | K $_{½}$=9.9keV |

### Timeline

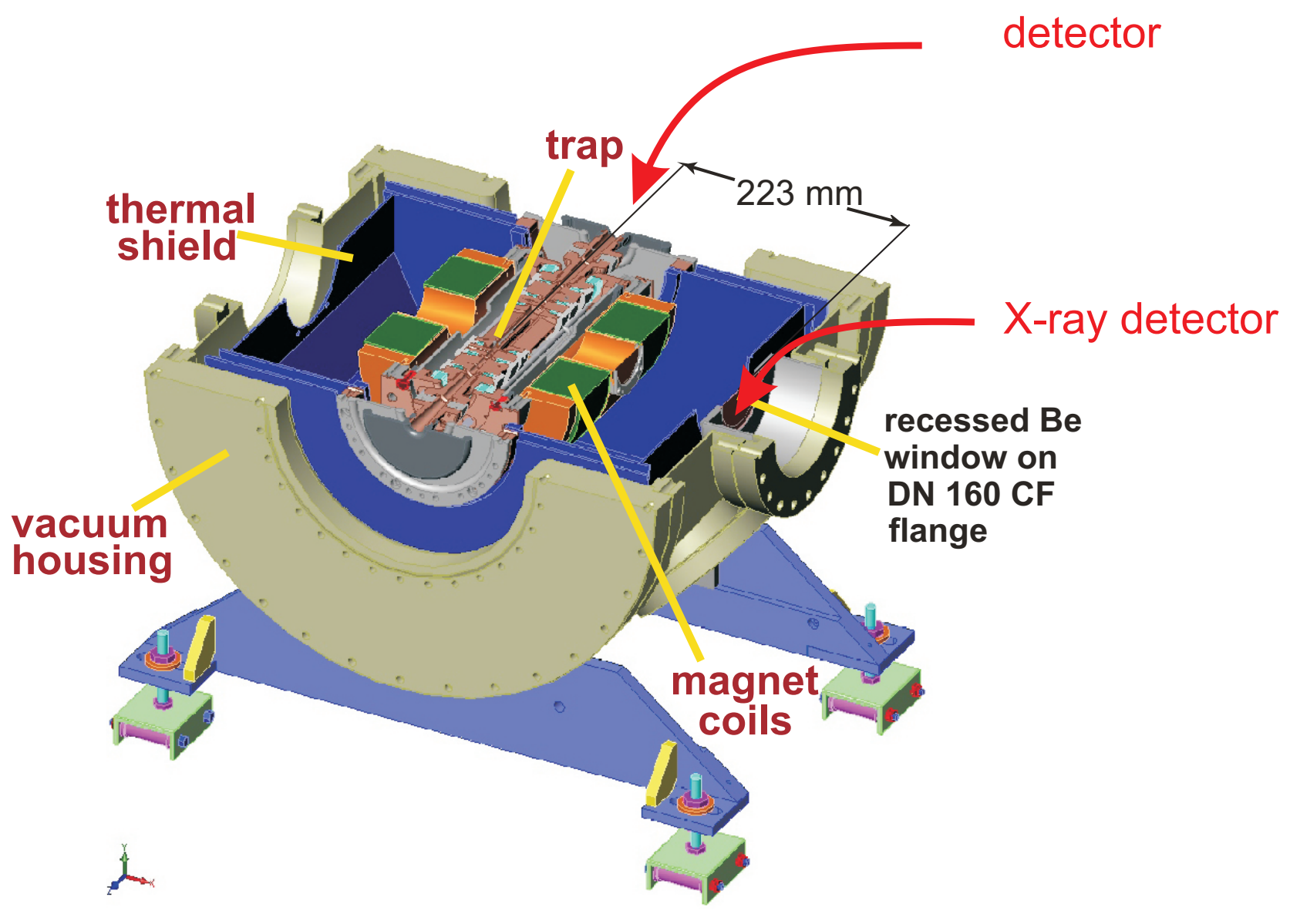
- Optimization of geometry by GEANT simulations
- Commissioning of the beam line in November
- First run with $^{100}$Tc to show how the technique can compete with other measurements



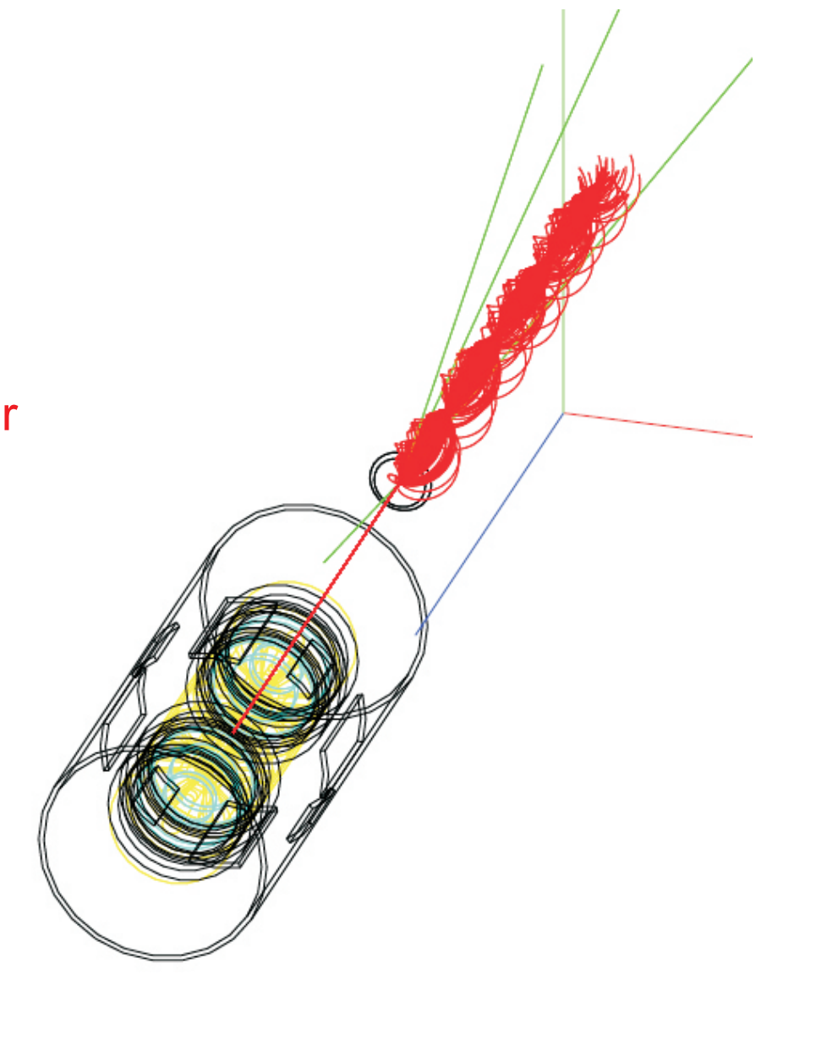
- $T_{½}$=(15.8±0.1)s
- EC branch
  ~ 0.0018%
- Solid angle EC 2.1%
- X-ray detection efficiency of 30%

- Accumulating 10 spills in EBIT
  100000 ions in trap
- Detection time of 15s calculates to [10]
  50000 $^-$ decays
  ~0.9 EC decays
  5.6*10$^{-3}$ detected EC in 15s
- A 10% accuracy needs 100 detected events:
  ~17.700 EBIT trap fills → 74h
  20% overhead → 14h
  Total estimated time → 88h

[10] TRIUMF Research Proposal E1066



Cut through the center of the EBIT



Geant4 Simulation of 3 MeV electrons leaving the trap and hitting the silicon detector in a magnetic field