In-trap decay spectroscopy for 2νββ decay experiments – Status of TITAN-EC

T. Brunner

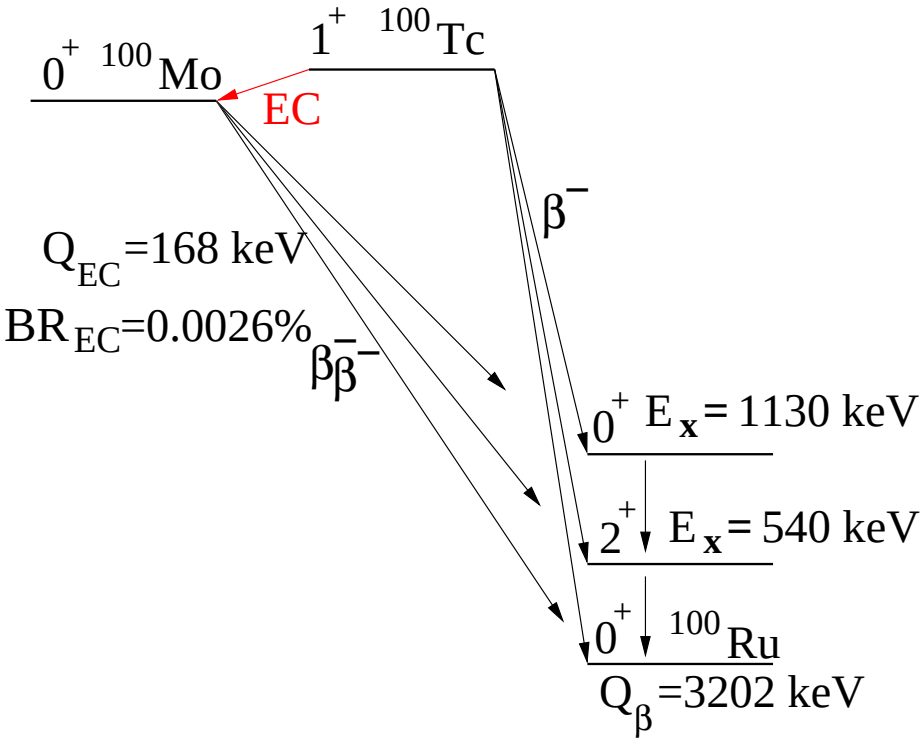
Outline:

- EC-BR setup at TITAN
- Status and first experimental results

TRIUMF ISAC

TITAN
ISAC-TRIUMF

Theoretical benchmark



S.K.L. Sjue et al., Phys. Rev. C 78(2008)064317

$$M^{2\nu} \propto \sum_m \frac{\left\langle 0^f_{g.s.} \left| \hat{O} \right| 1^+_m \right\rangle \left\langle 1^+_m \left| \hat{O} \right| 0^i_{g.s.} \right\rangle}{E_m - E_i + Q_{\beta\beta}/2}$$

Single-State Dominance hypothesis

Transition via lowest 1^+ state in intermediate nucleus accounts for entire $M_{2\nu}$

D. Fang et al., Rhys. Rev. C 81(2010)037303

Knowledge of EC and β^- BR can be used to benchmark the theoretical framework of $\beta\beta$ decays

But:

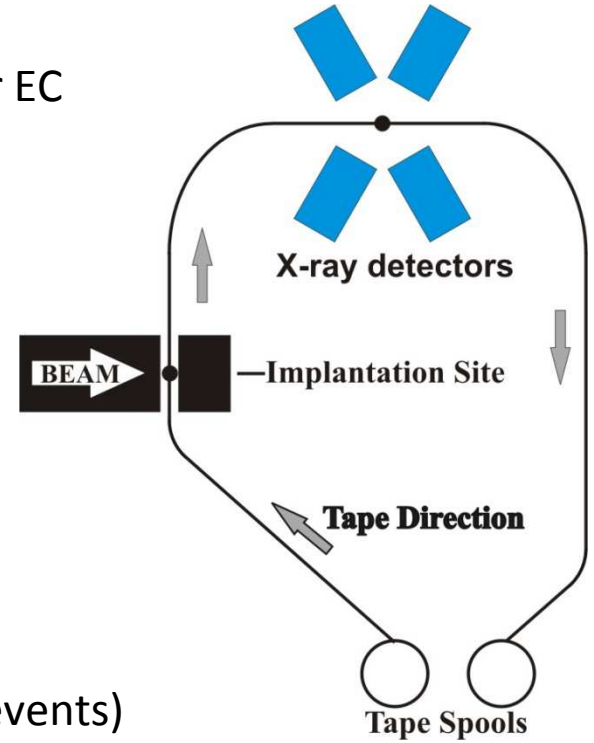
- Difficult measurement due to a small EC branch and difficult X-ray signatures
- High background due to dominating beta decay and possible bremsstrahlung
- Isobaric contamination

EC-BR measurements

Traditional method: tape station & observe X-rays after EC

Drawbacks:

- Contaminations
- Intense β background
- X-ray absorption in the backing material



Recent development:

S. K. L. Sjue et al., Phys. Rev. C 78, 064317 (2008)

- Contamination free due to ion trap
- Implantation into hole in scintillator (veto 90% of β events)

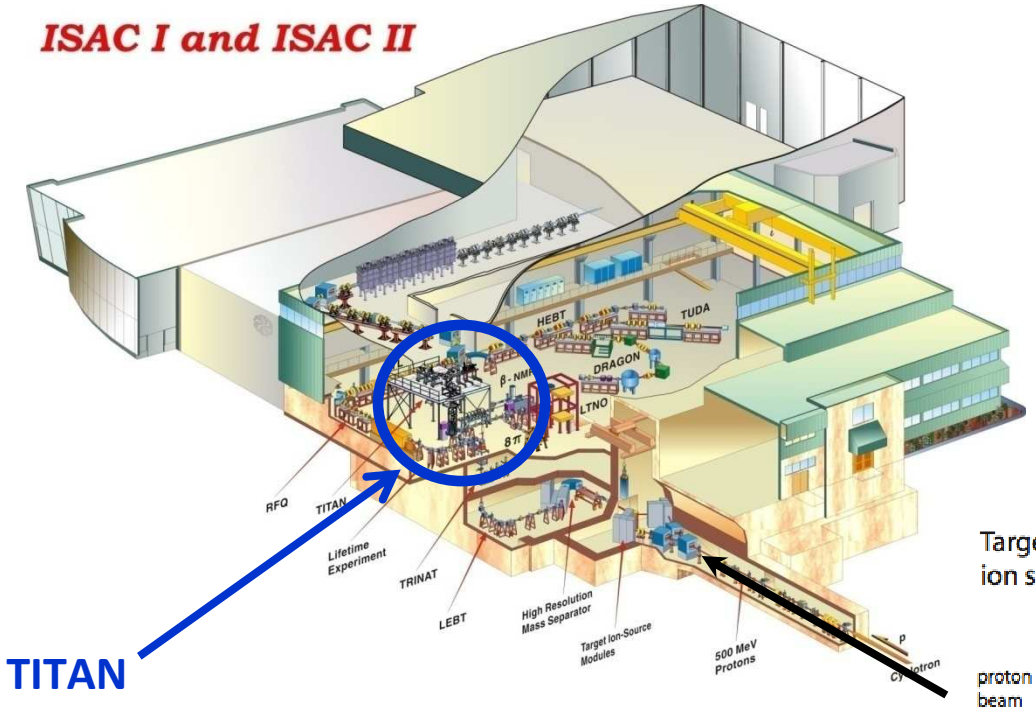
Novel approach proposed:

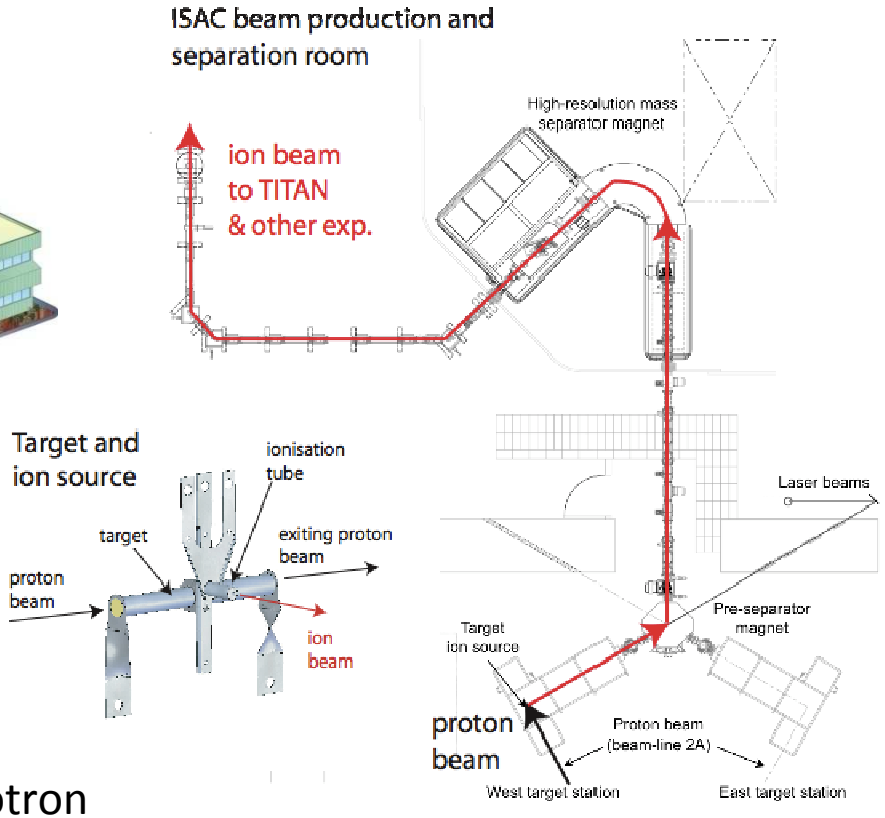
EC-BR measurement of ions stored in a Penning trap at TITAN

J. Dilling et al., Can. J. Phys. 85, 57 (2007)

remedy to all drawbacks in TITAN setup at TRIUMF

ISAC



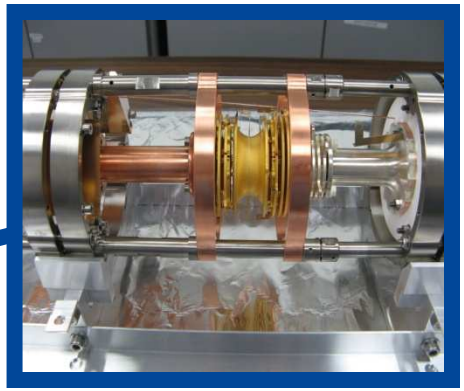


- DC protons with 100 μA @ 500 MeV from cyclotron
- Protons hit thick target, unstable nuclei produced, diffuse, get ionized, extracted – ISOL type target
- Contamination removed using mass separator (resolution: m/Δm = 3000)

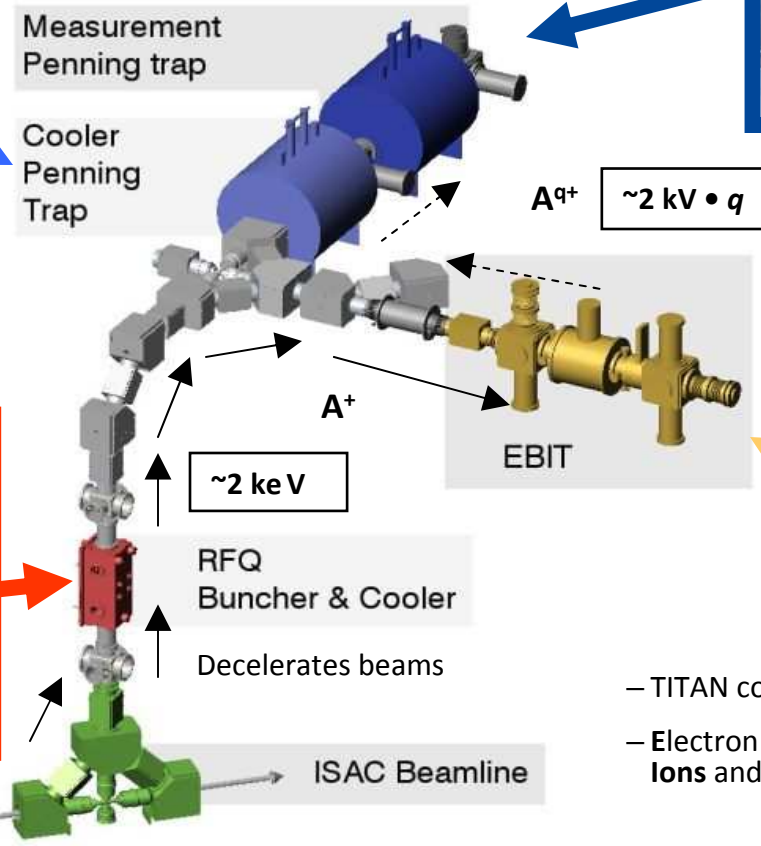
Yields: ^{11}Li 5x10^4/s, ^{74}Rb 2x10^4/s, ^{62}Ga 2x10

What is TITAN ?

TRIUMF's **I**on **T**rap for **A**tomic & **N**uclear Science



Under construction:
Installation planned
for Dec. 2010



– TITAN composed of **3 ion traps** *(presently)*

– **E**lectron **B**eam **I**on **T**rap (**EBIT**): Produces **Highly Charged Ions** and is used for in-trap **decay spectroscopy**

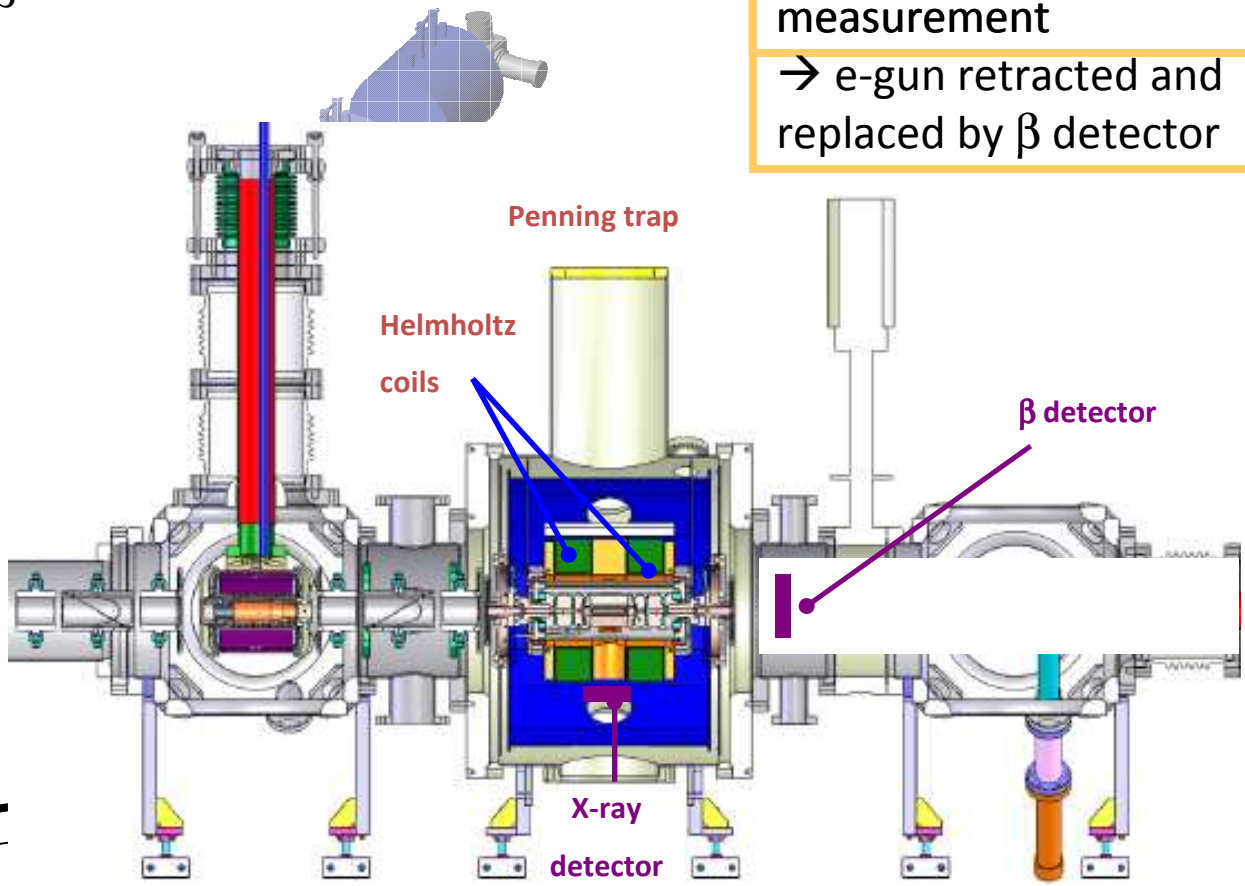
Radioactive isotopes from an **ISOL** facility (TRIUMF ISAC).

TITAN-EC technique

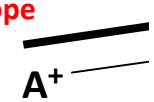
- Use TITAN facility at ISAC
- make use of the open access Penning trap EBIT (no e-beam)
- Spatially separate X-ray and β detection

Electron Beam Ion Trap (EBIT) in Penning trap mode for EC-BR measurement

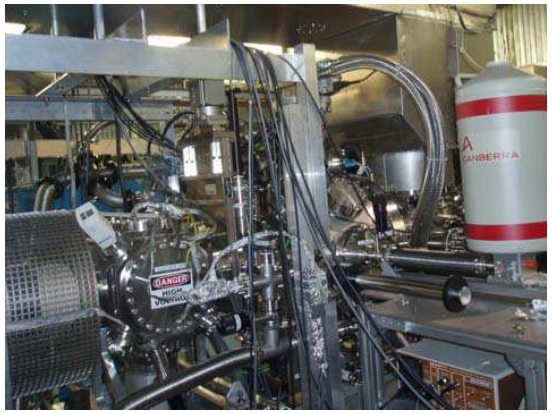
→ e-gun retracted and replaced by β detector



Short-lived isotopes from an Isotope Separator and Accelerator (ISAC)

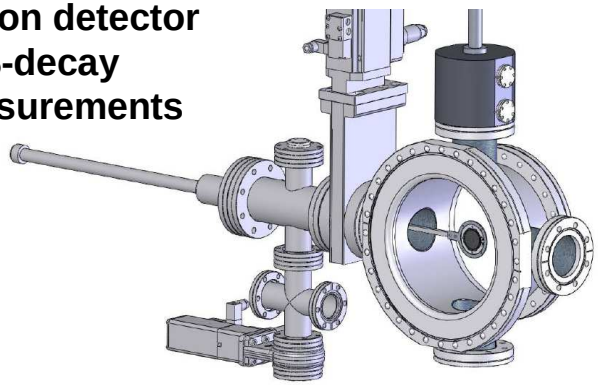


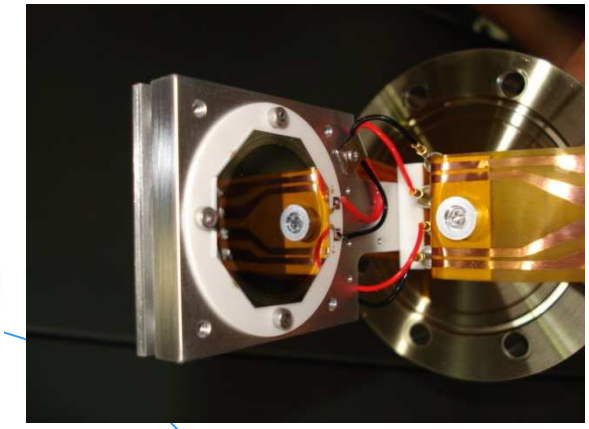
TITAN-EC technique

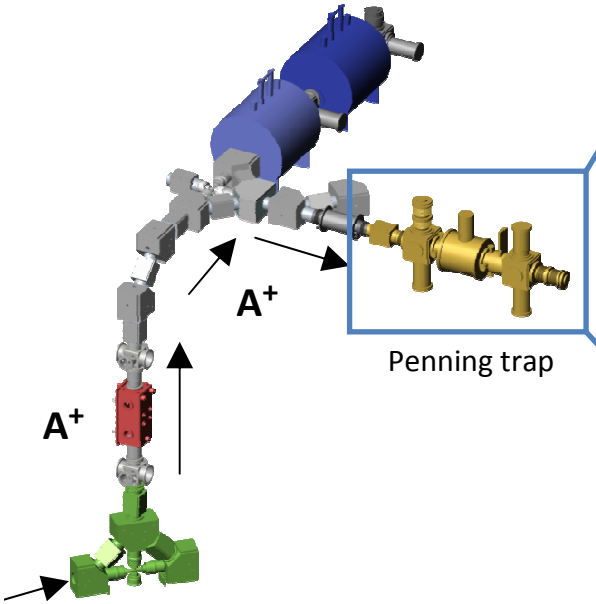


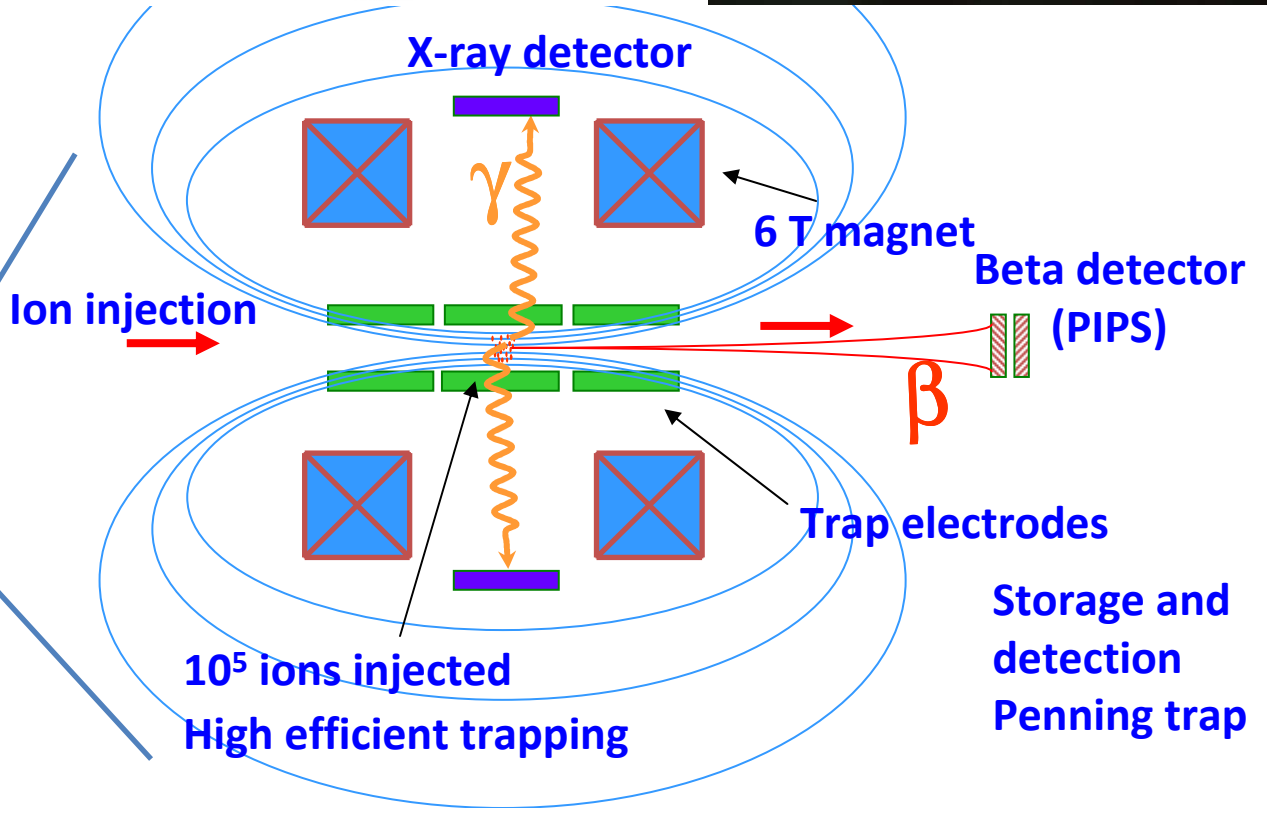
X-ray detector

Silicon detector for β-decay measurements

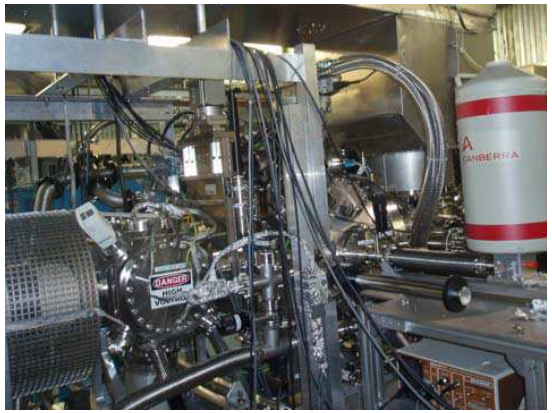








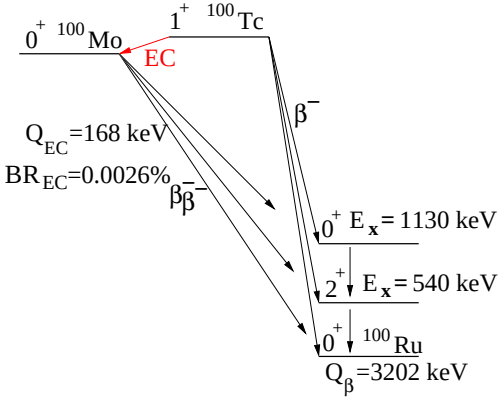
TITAN-EC technique



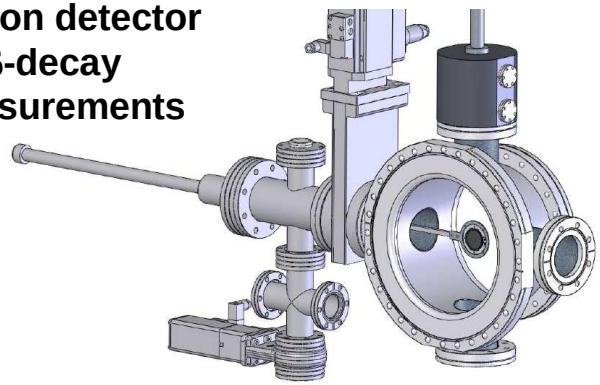
X-ray detector

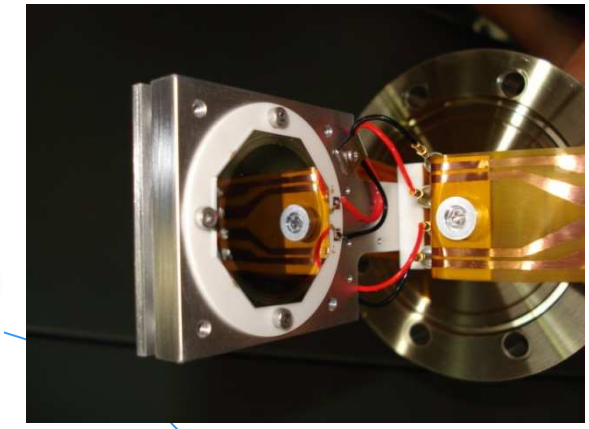
Novel method:

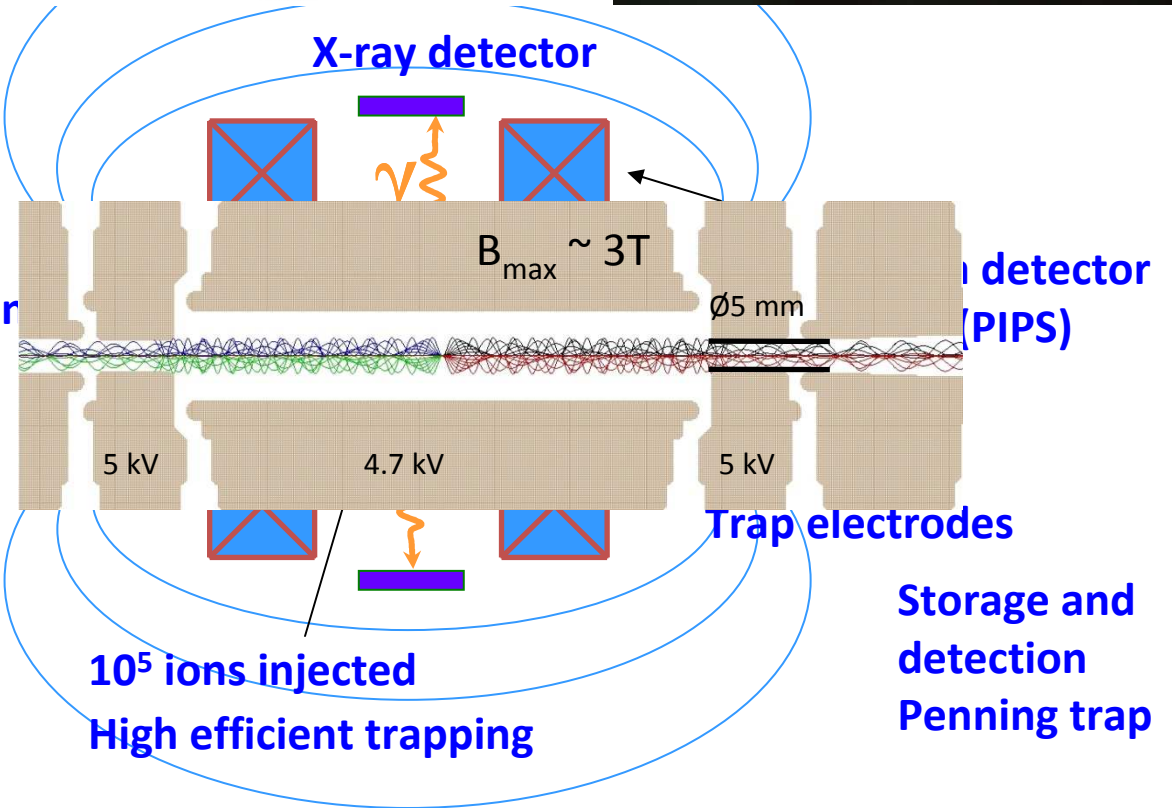
- Backing free
- Isobaric sample
- Spatial separation of β^- and X-ray detection



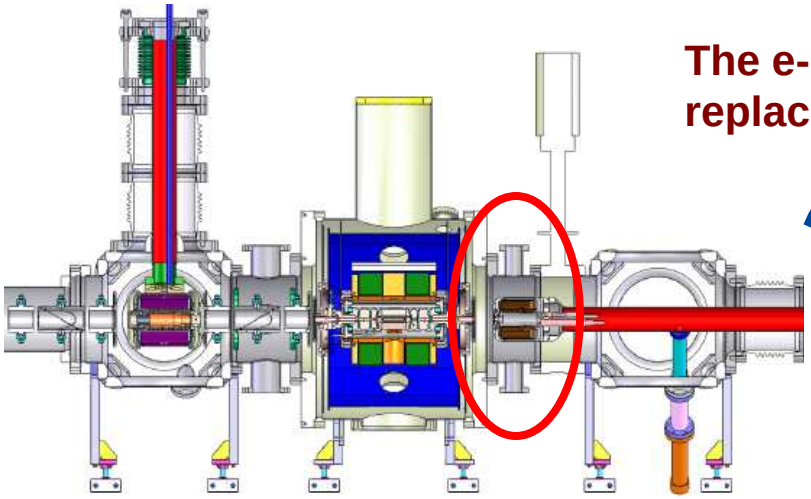
Silicon detector for β-decay measurements



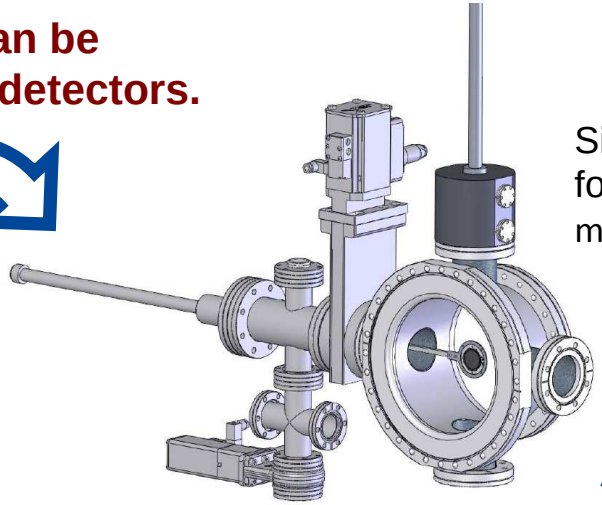




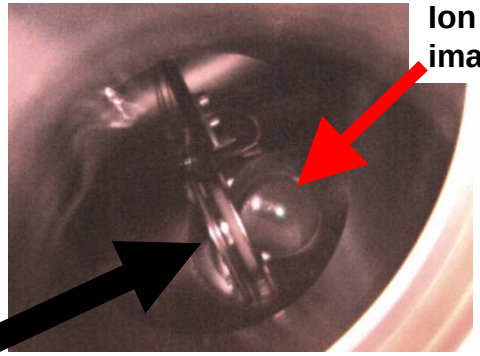
Retractable Electron Gun



The e-gun can be replaced by detectors.



Silicon detector for β or α-decay measurements



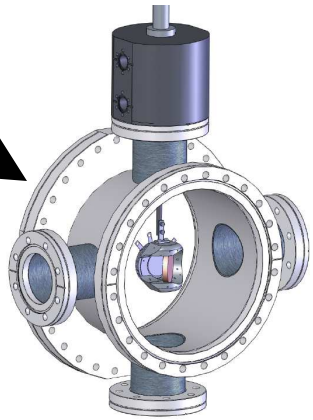
Ion beam image

Li-ion beam **Radius: ~1.5mm**

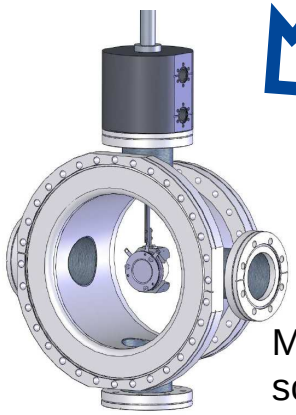
MCP w/ phosphor screen placed between the trap & electron gun for alignment of singly charged ion beams (injection).

Ion beam

Ion beam image from a mirror



Back view

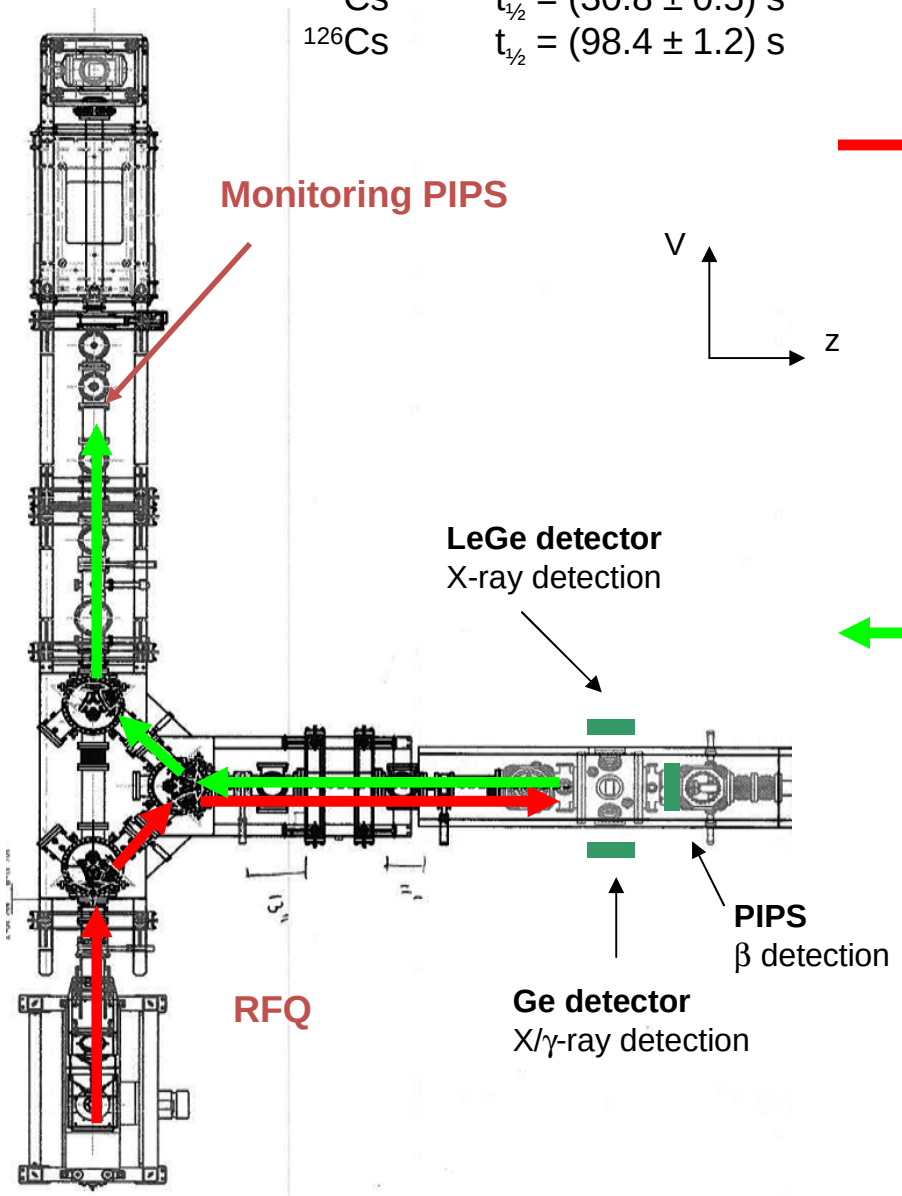


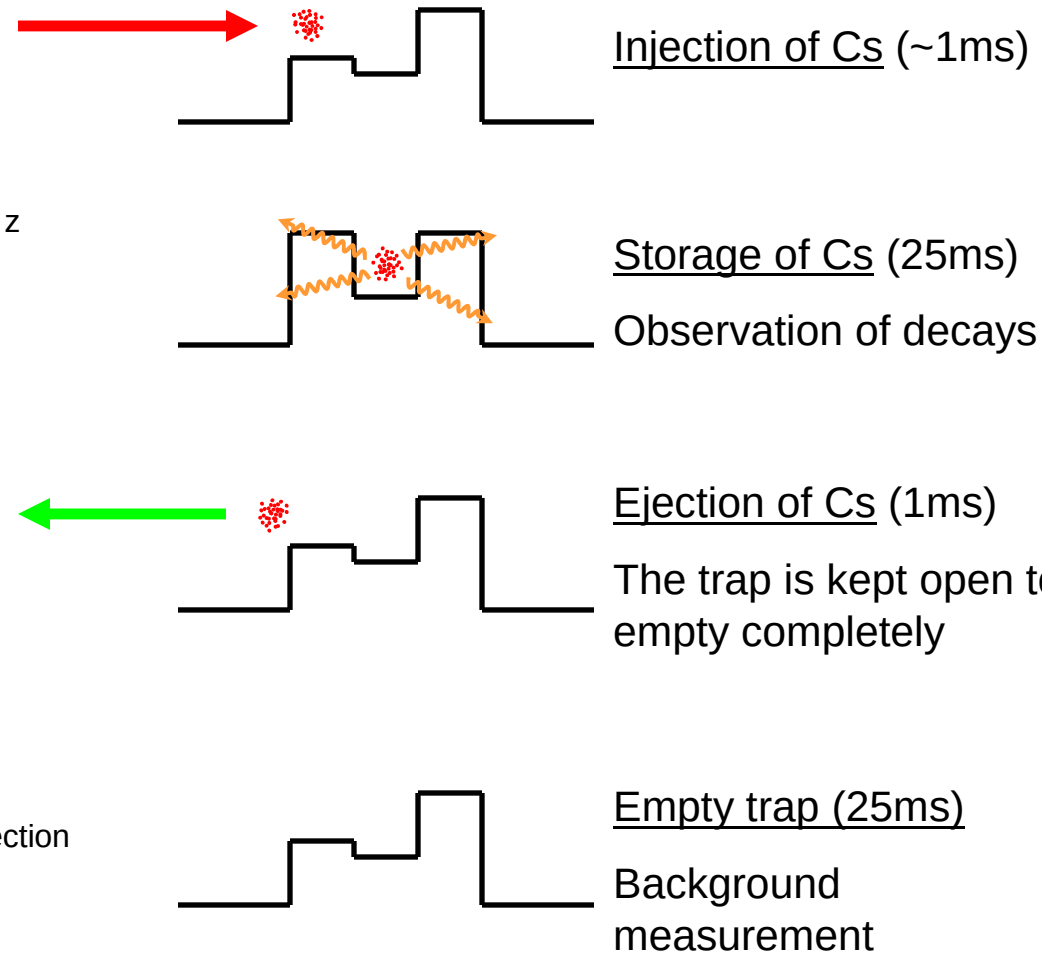
Front view

MCP w/ phosphor screen to have an image injected beams with a CCD camera.

TRIUMF Systematic studies with $^{124, 126}$Cs

^{124}Cs $t_{1/2}$ = (30.8 ± 0.5) s
^{126}Cs $t_{1/2}$ = (98.4 ± 1.2) s





Injection of Cs (~1ms)

Storage of Cs (25ms)

Observation of decays

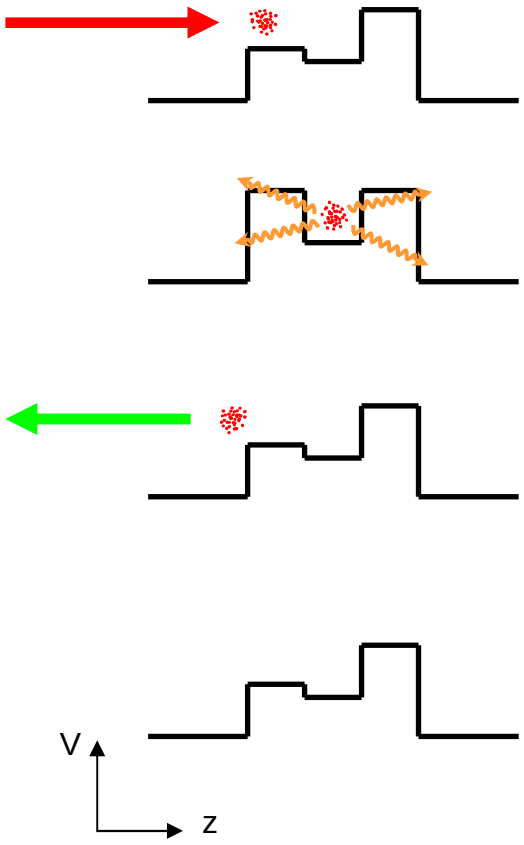
Ejection of Cs (1ms)

The trap is kept open to empty completely

Empty trap (25ms)

Background measurement

TRIUMF Systematic studies with $^{124, 126}$Cs



Injection of Cs (~1ms)

Storage of Cs (25ms)

Observation of decays

Ejection of Cs (1ms)

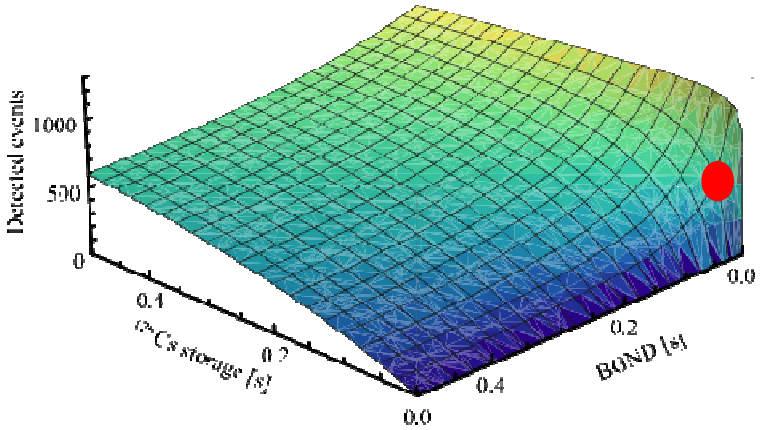
The trap is kept open to empty completely

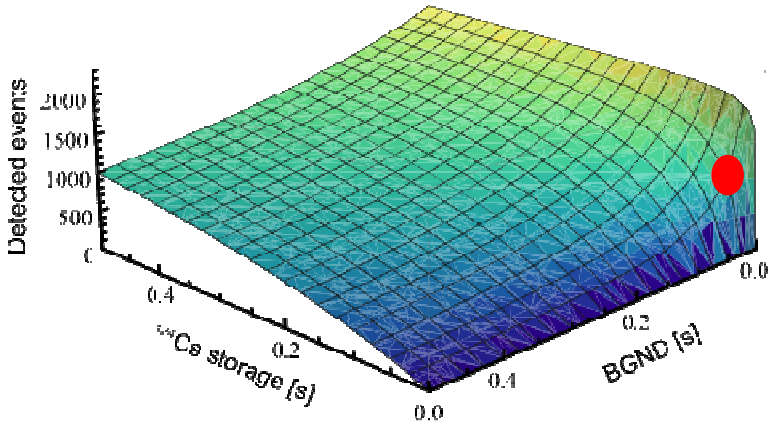
Empty trap (25ms)

Background measurement

Three times:

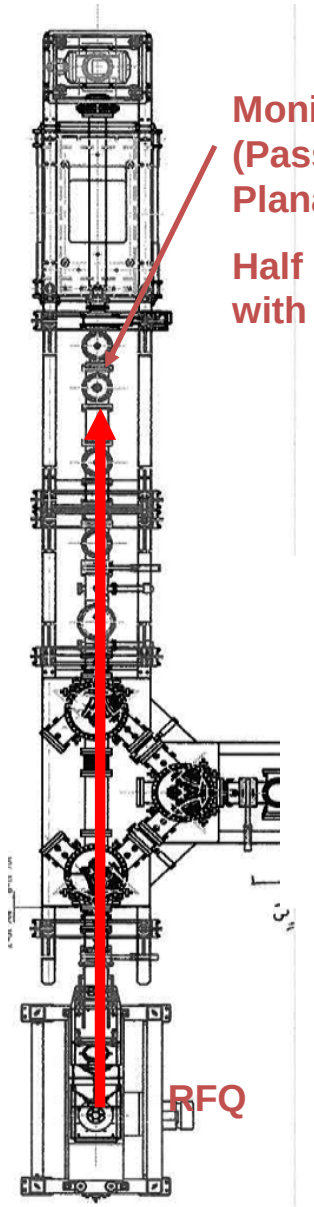
- Transfer times
- Storage time
- BGND measurement time





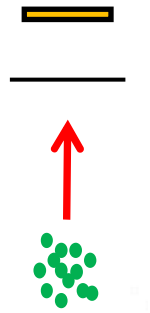
1 hour
10^5 ions
0.25% ε_{detect}

ions/shot & half life of ^{126}Cs

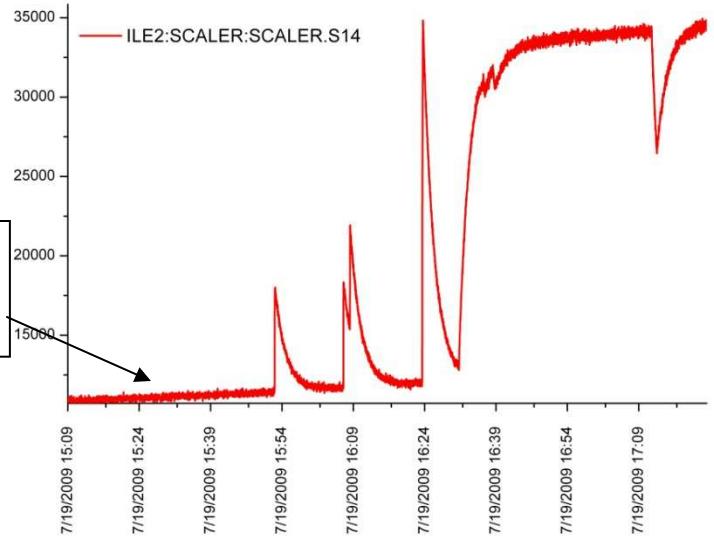


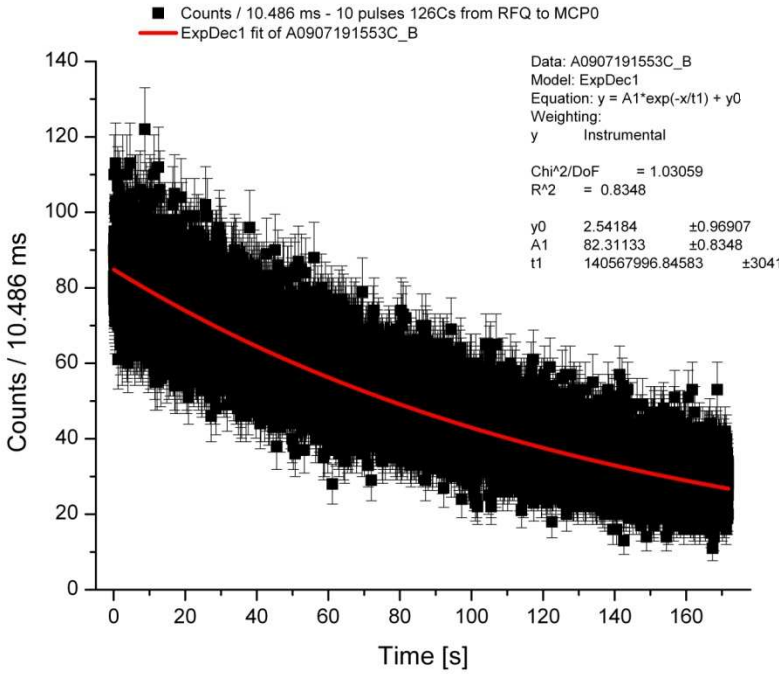
Monitoring PIPS (Passivated Implanted Planar Silicon)

Half life data obtained with a MCS



6 hrs beam off before first 10 pulses ^{126}Cs





$t_{½}$ = 97.4 ± 2.1 s (fit) (lit: 98.4 ± 1.2s) for first 10 shots (1st spike)

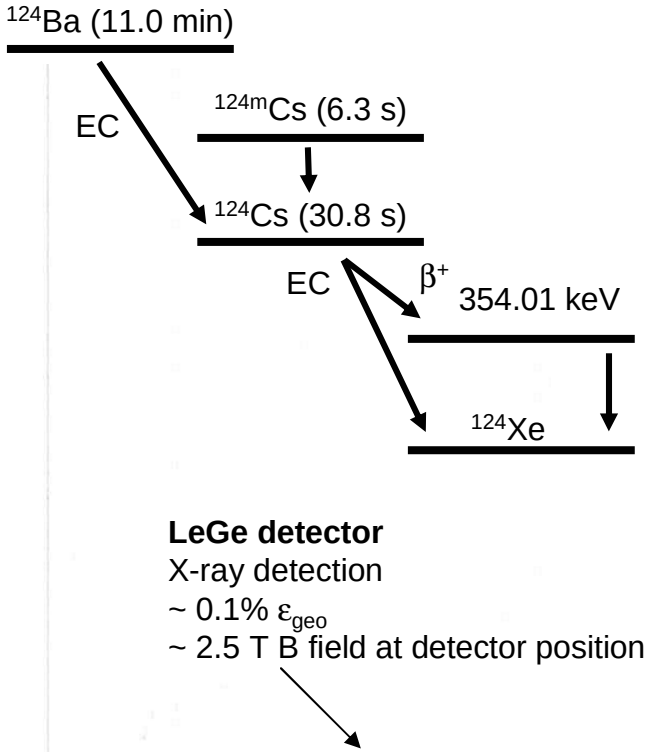
Beam intensity ≈ **3 * 10^5** ions/RFQ extraction pulse @ 10 Hz

BUT:

Half life increases for the following $t_{½}$ measurements

→ Contamination built up on PIPS detector (~30% ^{126}Ba contamination)

Observation of ^{124}Cs EC X-rays

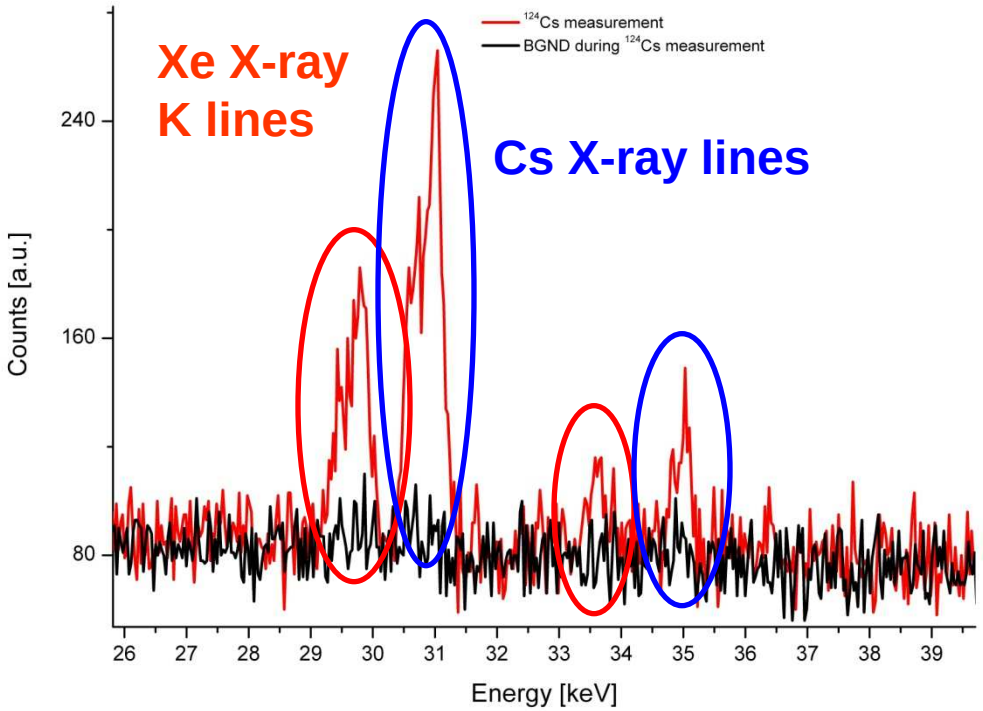


LeGe detector
X-ray detection
~ 0.1% ε_{geo}
~ 2.5 T B field at detector position

RFQ

Ge detector
X/γ-ray detection

PIPS
Passivated Implanted Planar Silicon
β detection



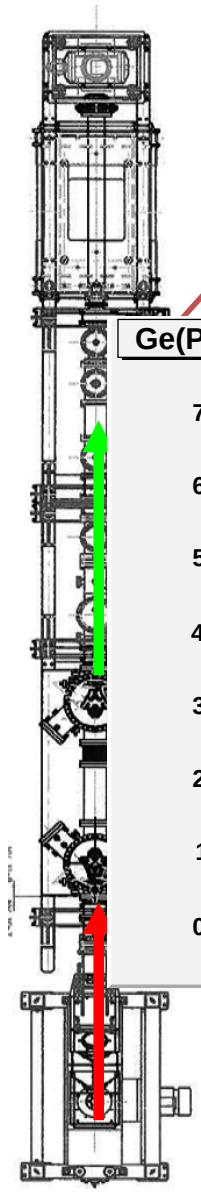
Xe X-ray lines: due to ^{124}Cs EC

Cs X-ray lines: probably dominant due to ^{124}Ba contamination and decay of ^{124m}Cs

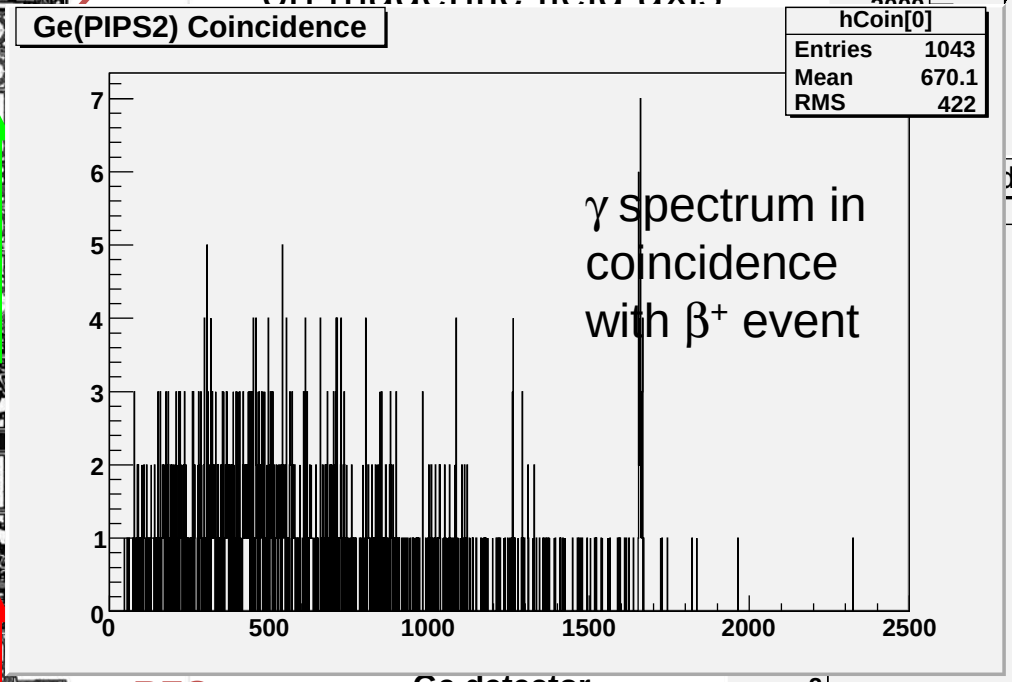
$\gamma - \beta^+$ time correlation

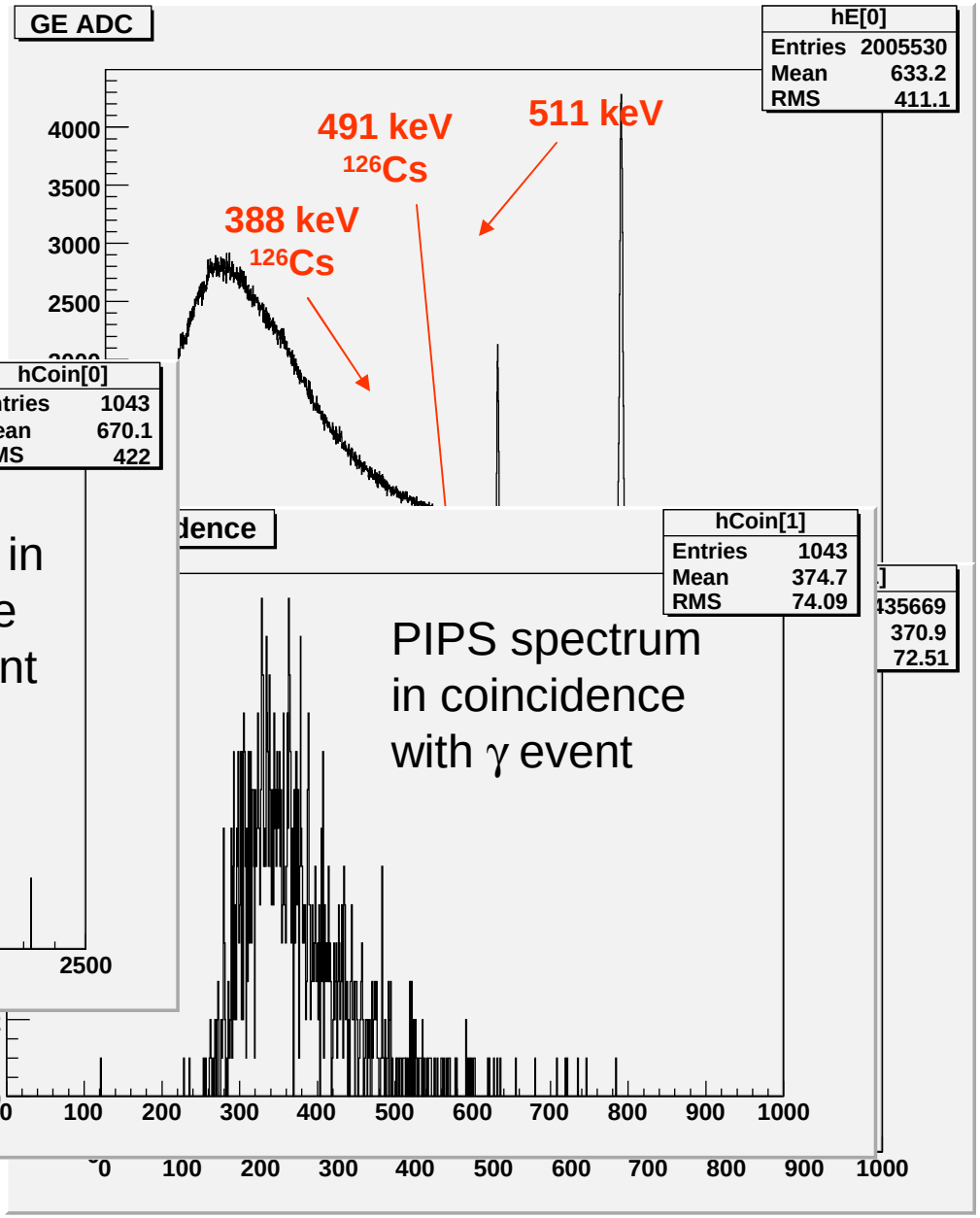
Ge detector
~ 0.15% ε_{geo}
Outside vacuum vessel

PIPS detector
Si detector (500μm)
on magentic field axis



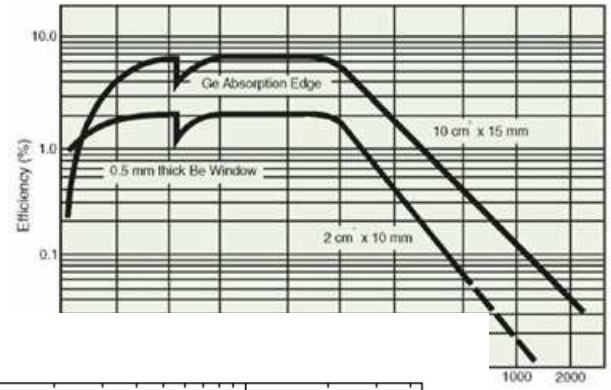
Ge detector
X/γ-ray detection

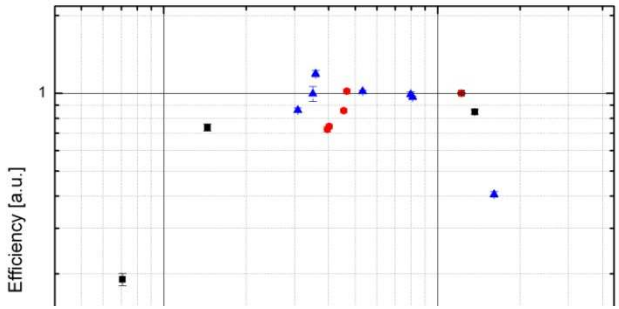




Data analysis

- LeGe Calibration spectra
- Fit ^{124}Cs run: peaks for ions stored and BGND
- Fit ^{126}Cs run: peaks for ions stored and BGND
- Determine BGND contribution to spectra of ions stored
- Determine ECBR of $^{124, 126}$Cs

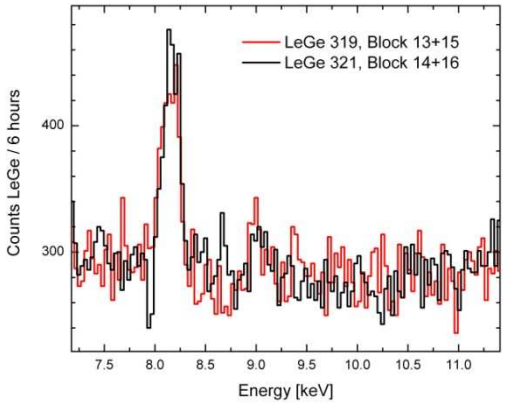


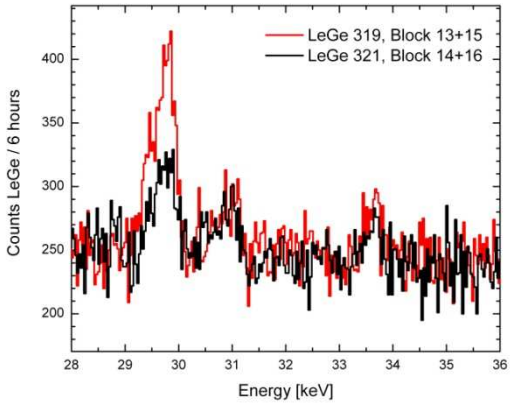


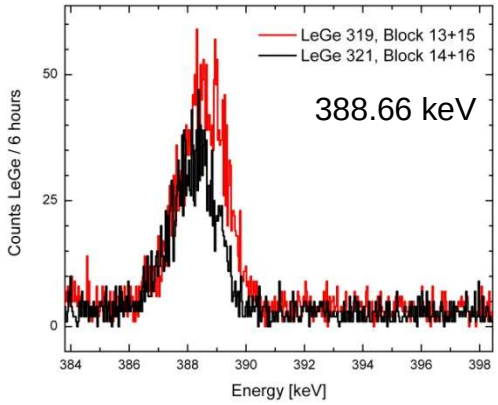
EC ^{126}Ba

EC ^{126}Cs

EC ^{126}Cs







Summary

- EC-BR measurement as benchmark experiment for theoretical description
- TITAN EBIT offers a novel approach for EC-BR measurements
  - Backing free method
  - Low background at X-ray detector – spatial separation of β and X-ray detection
  - Isobaric sample
- Successful storage of radioactive ions (long storage times: $P < 10^{-11}$ mbar)
- First observation of an Electron Capture decay in a Penning trap