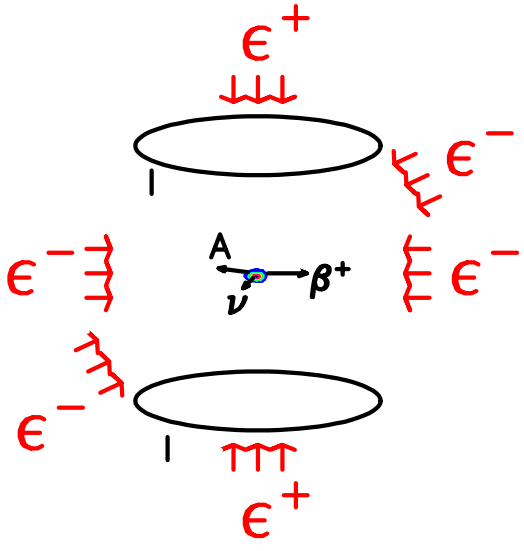
Kinetic energy of shakeoff atomic electrons from ^{37}K β^+ decay

Atomic electrons are 'shaken off' by β^+ decay.
We have measured their energies from 2-150 eV.



- **Motivations:**
  - **Precision measurement**
  - **Atomic energies in β decay**
  - **Radiation damage**
- **Experiment and results:**
  - **E_{e-} spectrum agrees with ψ_H**
  - **$\bar{E}_{e-}$ = 3 eV is less than estimated**
  - **$\Leftarrow$ K is like H**

TRIUMF Neutral Atom Trap collaboration

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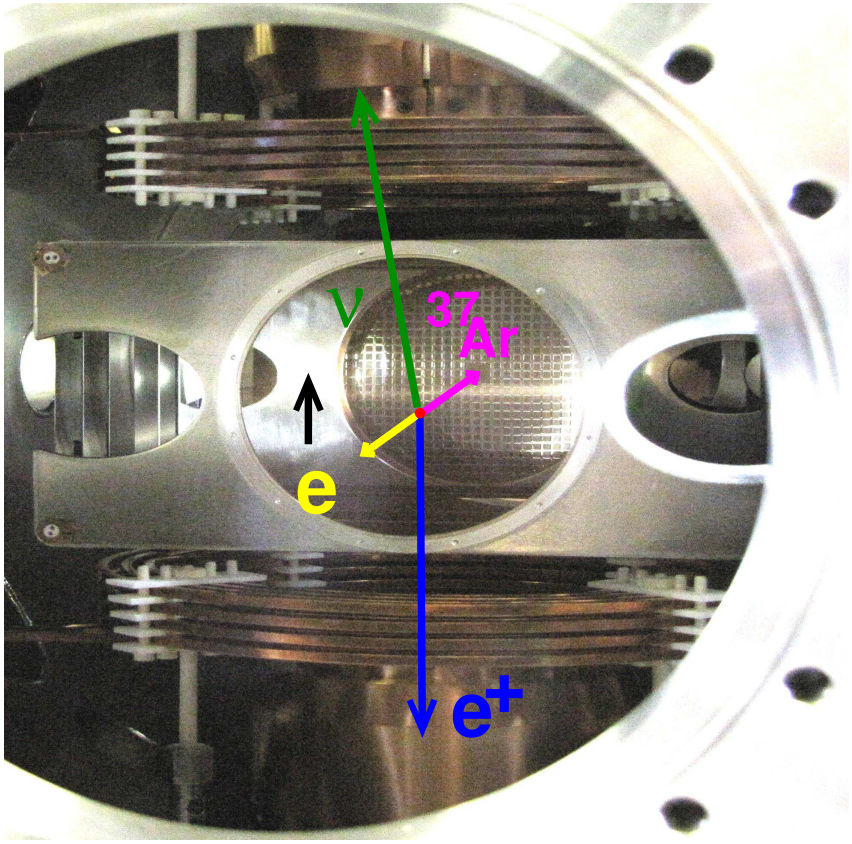
Main motivation: TRINAT precision exp



$^{37}K \rightarrow \beta^+ + \nu + {}^{37}Ar^-$

Gorelov H.I. 1999:
Ar^-, Ar^0 84%,
Ar^+ 11%, Ar^{+2} 3.1% ...

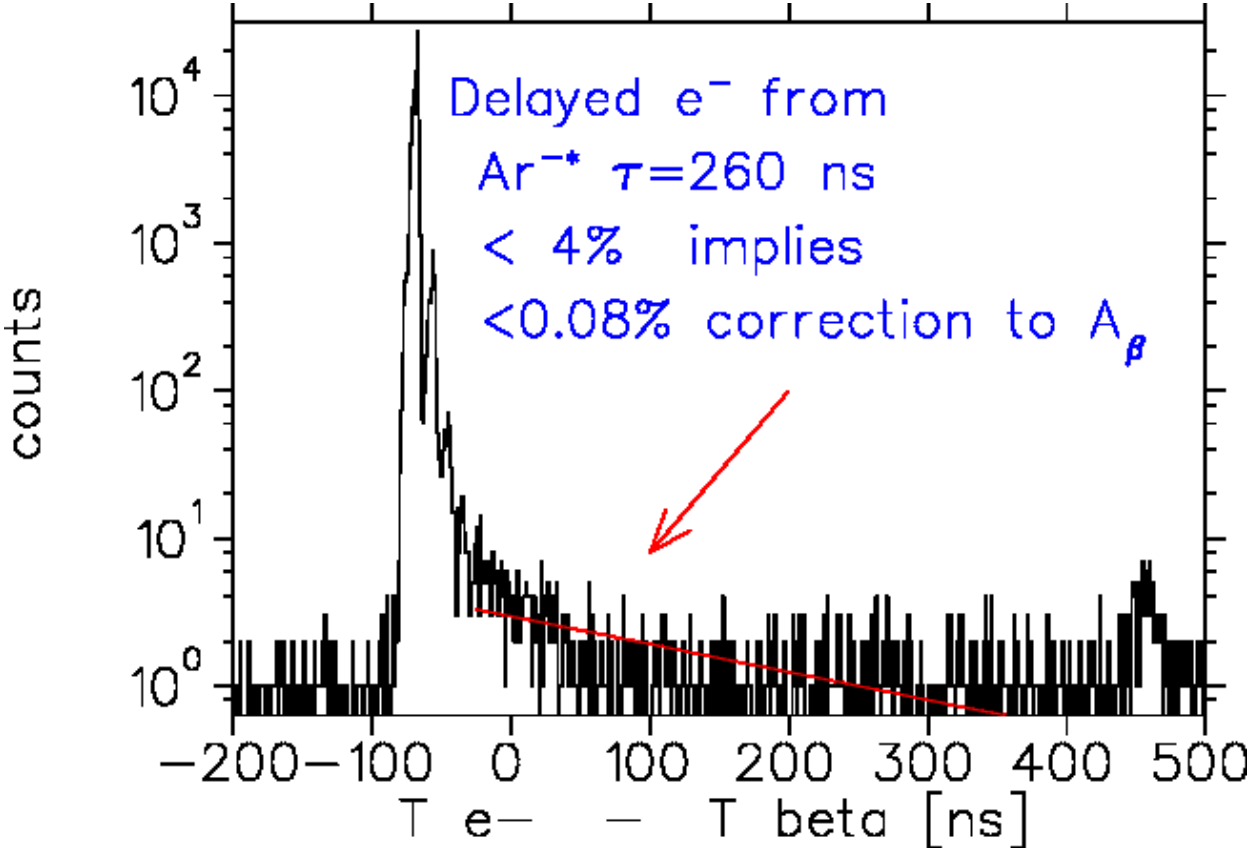
The shakeoff atomic e^- cleans up the β^+ asymmetry, and is the TOF trigger for recoil asymmetry.

We need to understand these atomic electrons well enough to ensure we don't introduce false asymmetries

- Test atomic ψ to calculate dependence of charge state on recoil momentum

Ar^- from ^{37}K β^+ decay

Ar^- has a metastable state $3s^2\ 3p^5\ 4p$, τ=260 ns
Unusual configuration: if populated in β^+ decay, Ar^- can move before releasing the electron.
Since ^{37}Ar has spin-correlated asymmetry, this generates a false β asymmetry
We constrain Ar^{-*} population from β^+-e^- timing:



Atomic energy change from β^+ decay

- Sudden approximation $\langle\psi_i|\psi_f\rangle$ predicts final ion charge states (Carlson PR169 1968; Couratin PRL108 2012).
- Levinger PR 90 1953 E_{e-} analytic calculation uses hydrogenic ψ_i and Coulomb ψ_f for K, L shells
- Serber Snyder 1952: Thomas-Fermi calculation for energy of atomic cloud change in $\beta^\pm$ decay (65 eV at Z=18)

Carlson used Levinger to estimate $\bar{E} = 1.8 \Sigma P_{nlj} E_{nlj}$ = 38 eV, accounting for 1/2 the atomic energy

- Superallowed $FT \propto Q^5 \rightarrow$ 100 eV makes a 0.0001 effect. The 65 eV calculated energy is worth testing.

Radiation damage from low-energy e^-

Radiation damage from β decay: creation of OH, H_2O_2 ions

Do shakeoff e^-'s add DNA breaking? Not much...

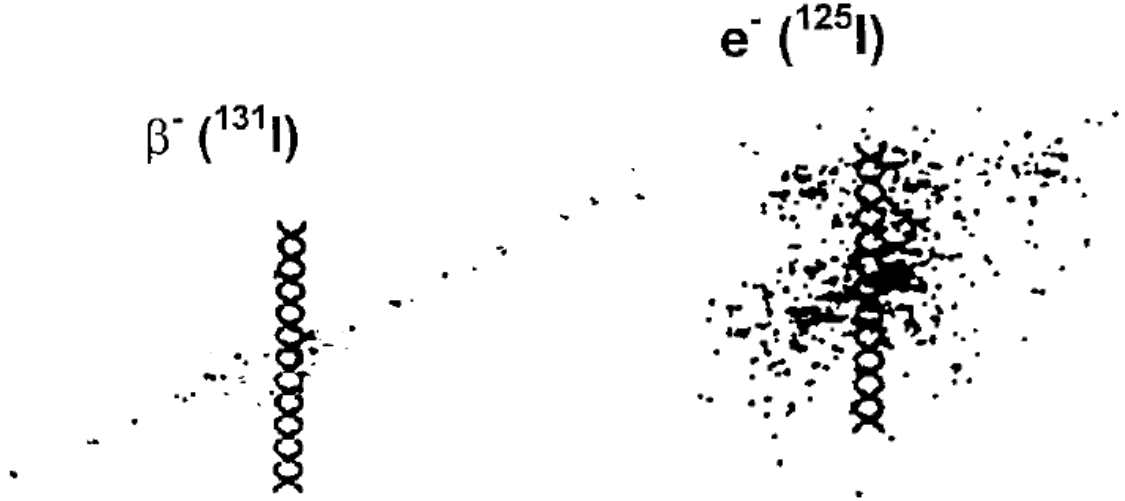
- **Double-strand DNA breaks:**

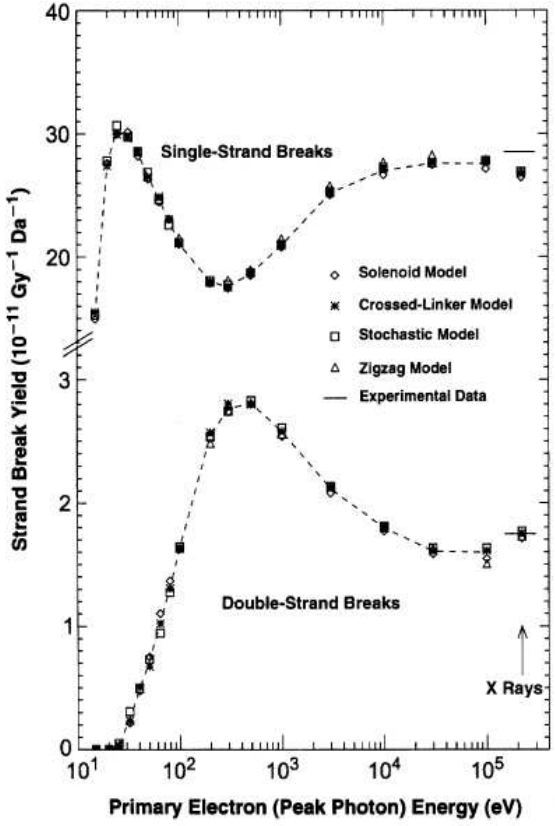
Threshold: $E_{e-} \approx 25$ eV

Peak: $E_{e-} \approx 400$ eV

[Friedland Rad Res 150 172 (1998)]

- **There is interest in EC decay for localized therapy: [T.Behr Eur J Nucl Med (2000) 27:753]**

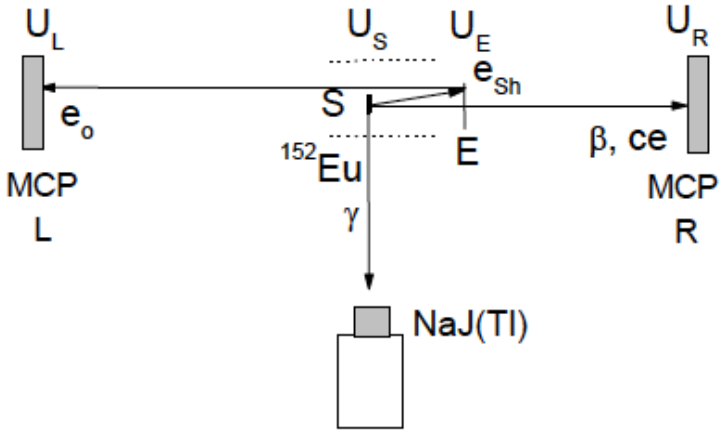




We could provide a benchmark for such MC [Lee Comp Math Meth Med 2012]

Other work: shakeoff E_{e-} at Kyiv

Mitrokhovich Nucl Phys Atom Energy 11 125 (2011)
Thin source, Integral spectrometer
^{152}Eu β^- decay for $E_{e-} > 150$ eV



Impressively low E_{e-} for a source with backing.

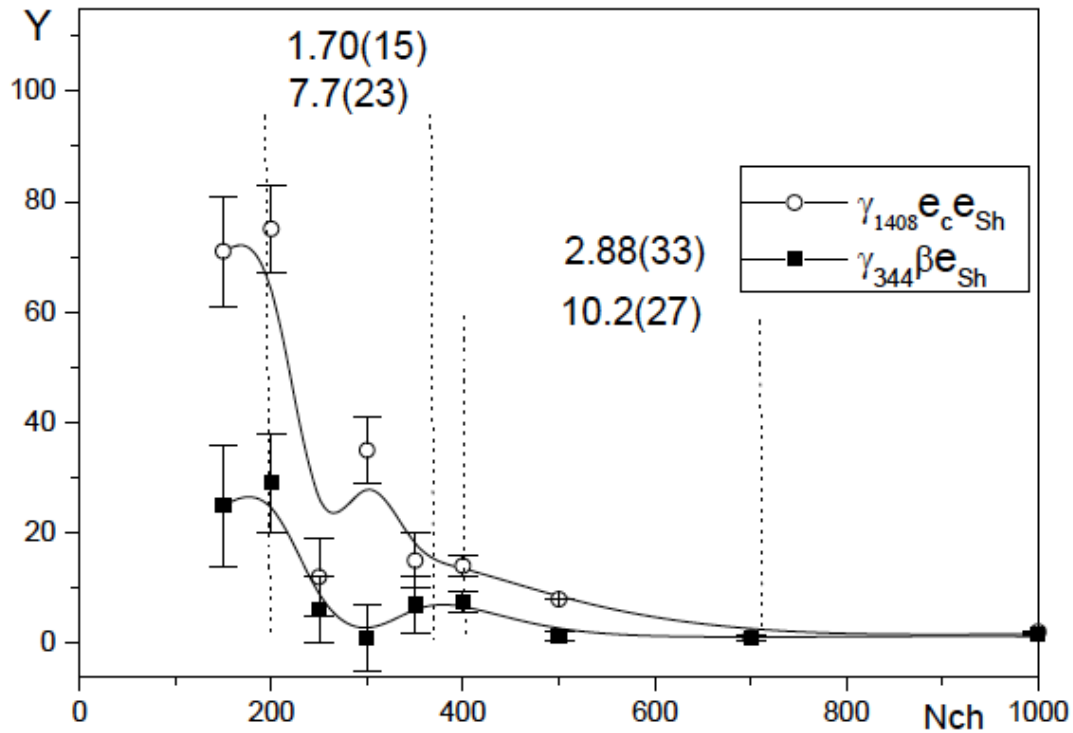


Fig. 5. The differential spectra of electrons of "shake-of
at β-decay (solid square dots) and internal conversio
(open circle) in ^{152}Eu, obtained from measurements
γee$_o$-coincidences. The values of a correlation ϒ f

Experimental method

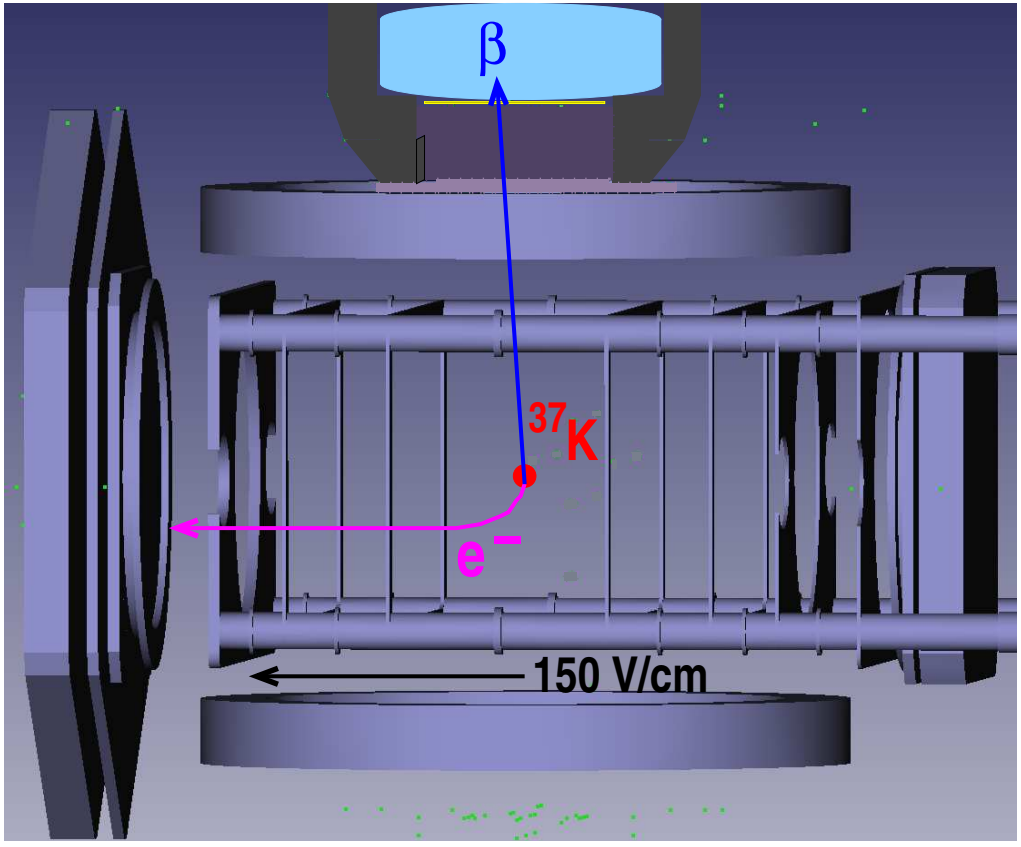
- β^+-e^- coincidence, uniform E field

AC MOT to turn B quad off quickly

Bz= 2.2 Gauss uniform

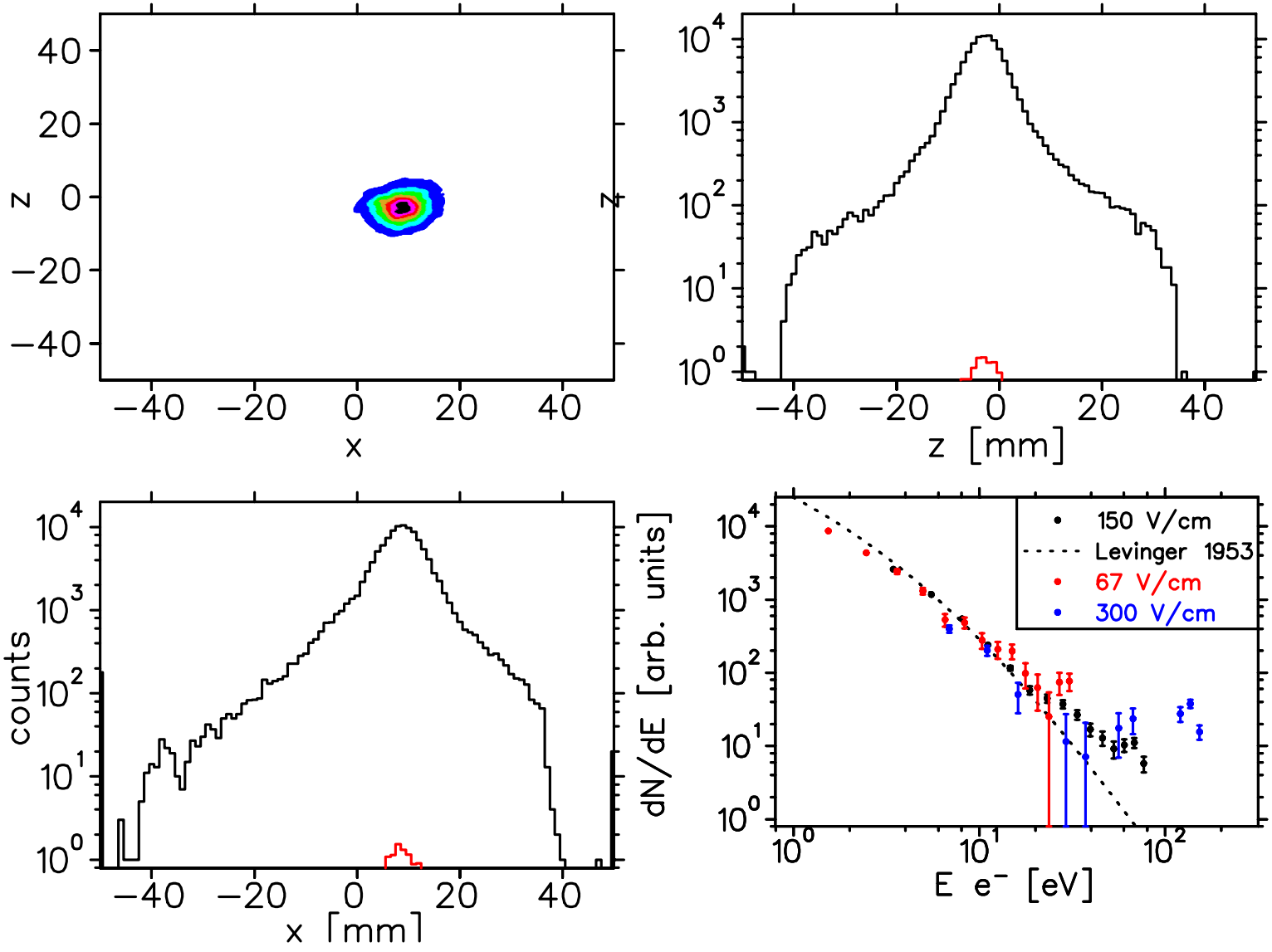
Position-sensitive 80 mm e^- MCP+delay-line anode (Roentdek HEX75)

- e^- distribution into 4π makes flat-topped position distributions with width given by E_e



^{37}K shakeoff e^- energy

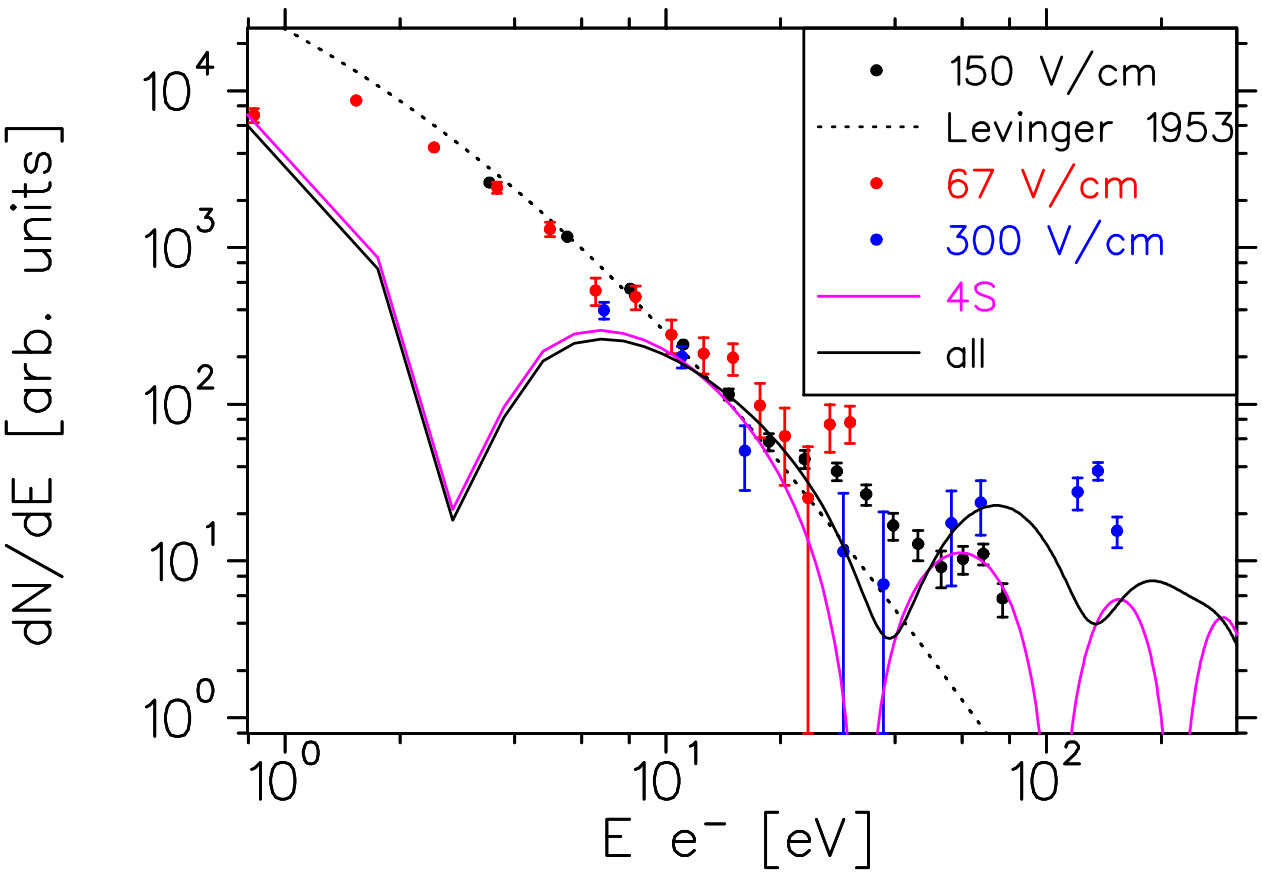
$|\vec{E}|$=150 V/cm, derivative of projection → dN/dE_e –



Improving ψ_i and ψ_f

- **Bound ψ_i Roothaan-H-F, Bunge et al. ADNDT 1993**
- **ψ_f: Coulomb wavefunctions, screened,**

Phase shift $r \rightarrow \infty$ from quantum defect [Burgess, Seaton MNRAS 120 122 (1960) photoionization accurate $\sim$ 20%]
Match ψ and $d\psi/dr$ as screened potential changes with r



- **Disagrees at low E_e—**
- **Predicts some high-E_e—**

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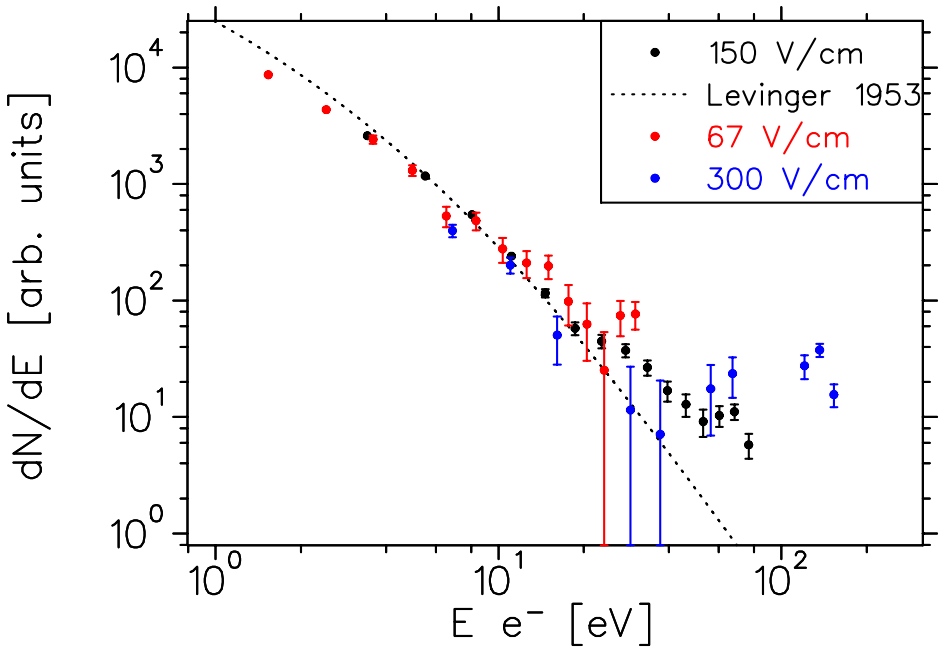

- **No bias for SM tests**

Little extra radiation damage

Rough agreement with 1953 Levinger

$\bar{E}$ = 3eV is less than estimated

(because K is hydrogen-like)

- **Some higher-E e^-**

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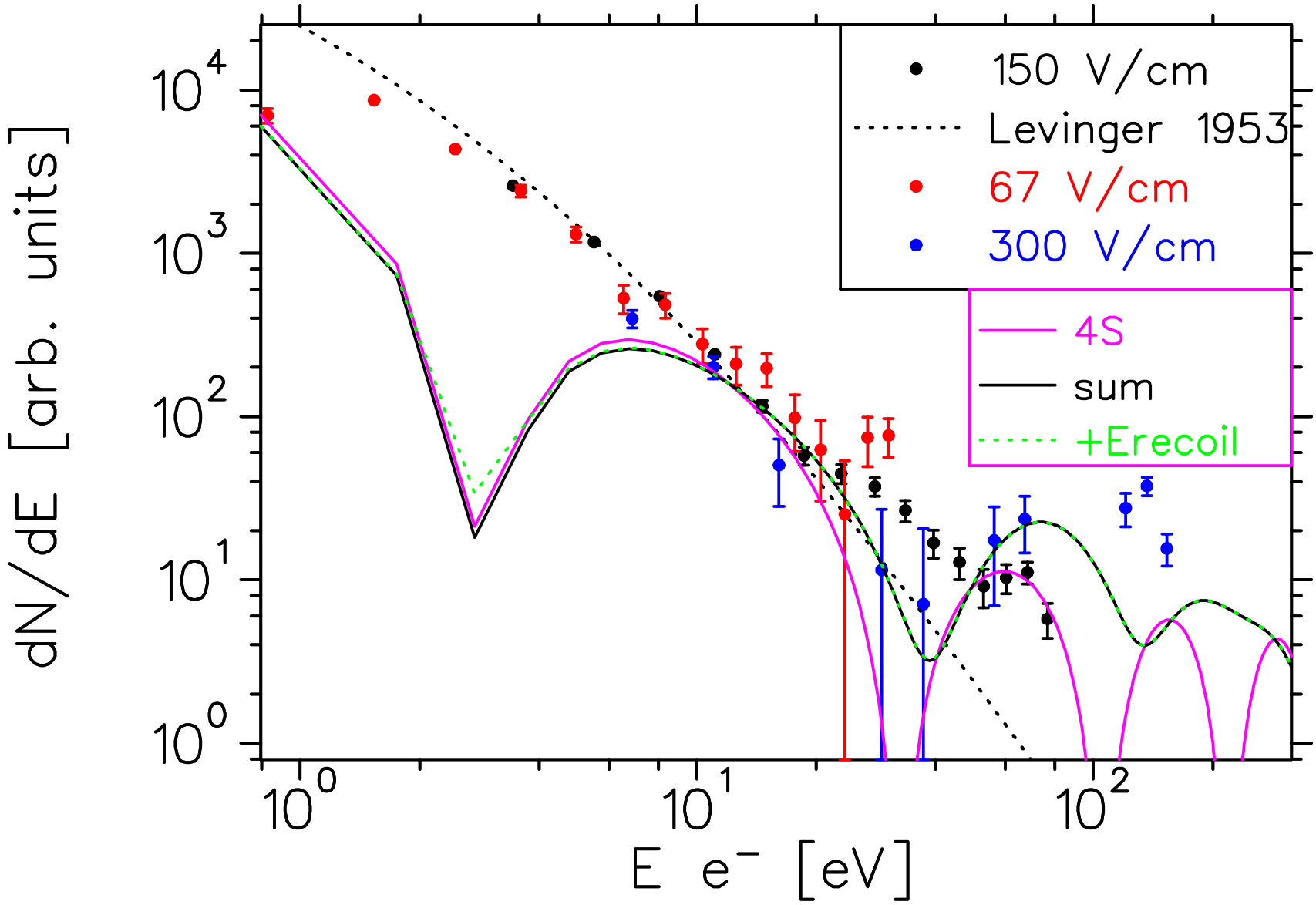
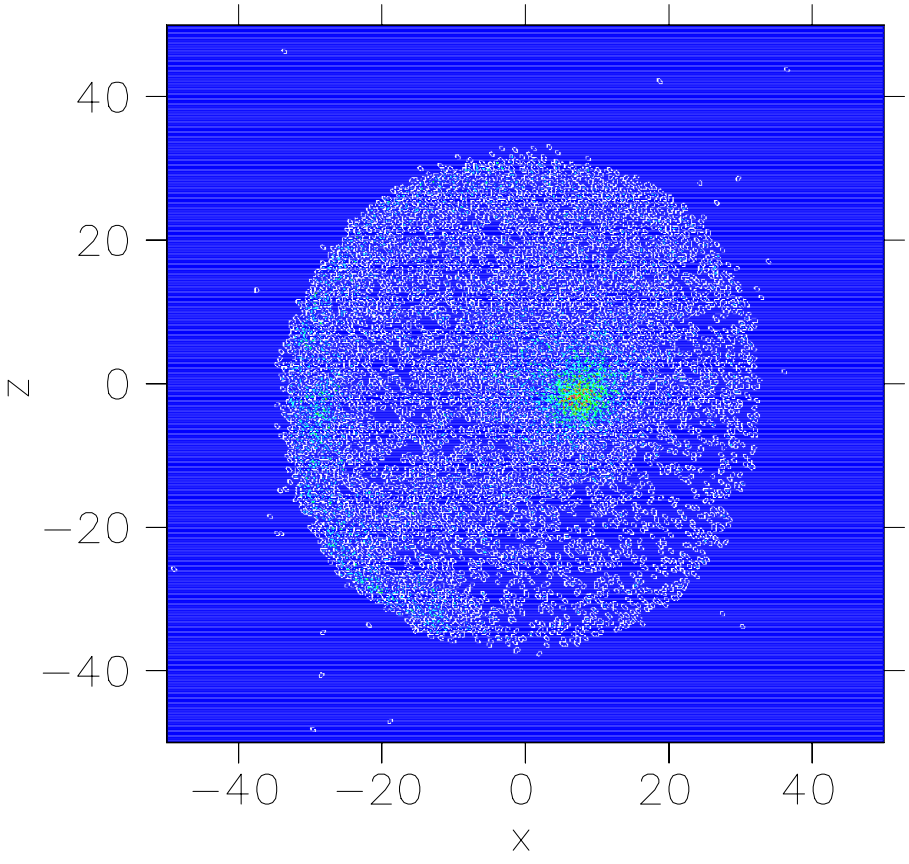
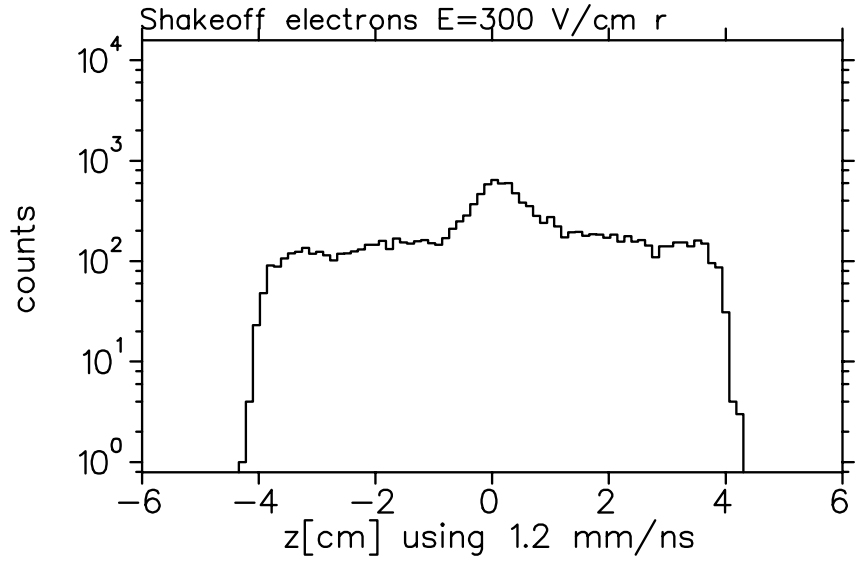
Prediction of E_{recoil}-dependence

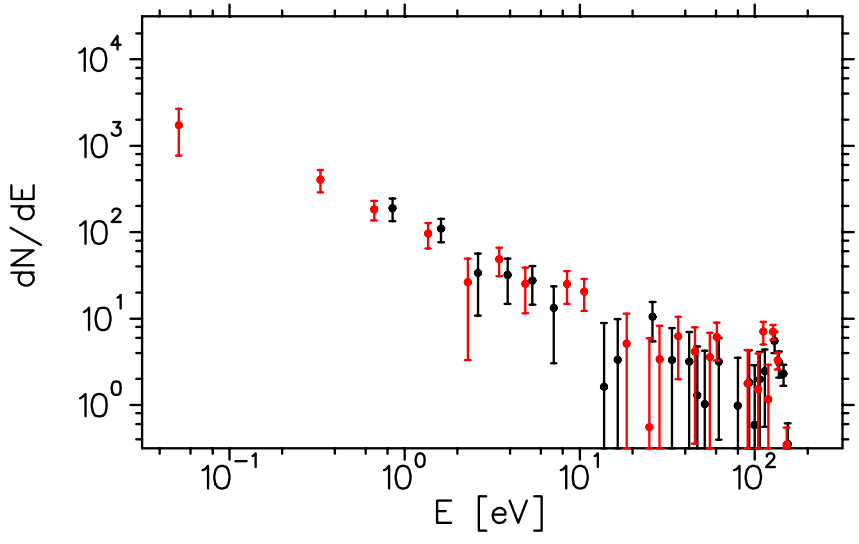
shakeoff



300 V/cm data


40
20
0
−20
−40
z
−40
−20
0
20
40
x


Shakeoff electrons E=300 V/cm r
counts
z[cm] using 1.2 mm/ns


dN/dE
E [eV]

^{37}Ar charge states

Gorelov Hyperfine Interactions **127** 373 (2000)

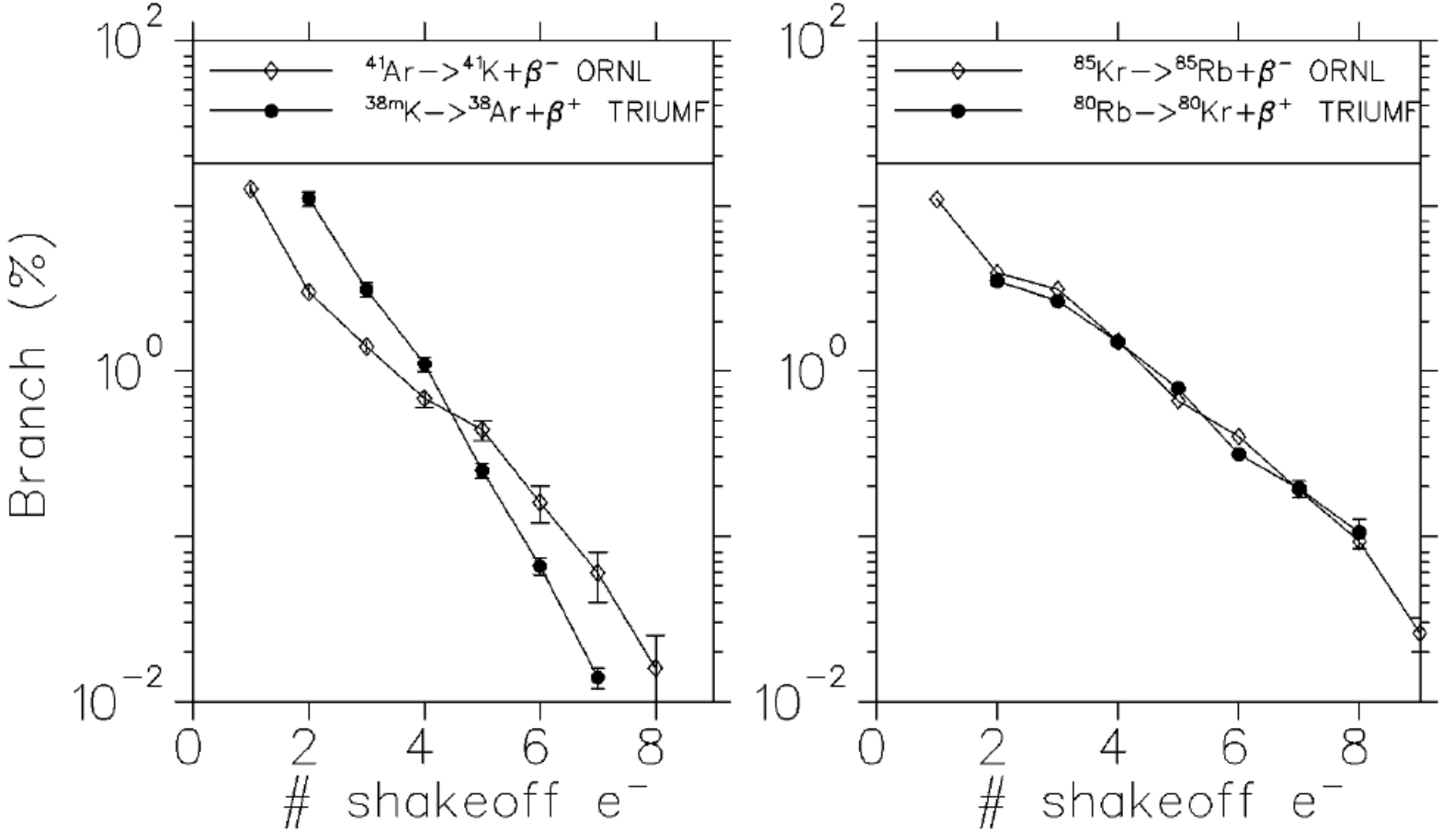


Figure 4. Daughter atom charge state distribution measured in ^{37}K, ^{80}Rb β^+-decay, compared to ORNL ^{41}Ar, ^{85}Kr β^--decay data. The normalization of ^{80}Rb is uncertain by 2×.

Charge state dependence on recoil momentum

- Behr and Gwinner JPG 2009
- Shakeoff depends on E_{recoil}
- So does $a_{\beta\nu}$
- But we measure much more than the E_{recoil} spectrum– we measure β-ν angle directly