Status of the KDK Experiment: A Measurement of ^{40}K Relevant for Rare-Event Searches

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On behalf of the KDK Collaboration

February 18, 2022

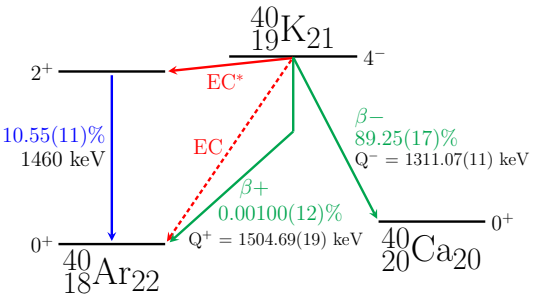
WNPPC 2022, Virtual

Potassium-40

- Naturally-occuring radioactive isotope ($0.0117(1)\%$[2] ^{40}K in $^{\text{nat}}$K)
- **E.C. $\rightarrow$ g.s. ($I_{\mathbf{EC}}$) is ill-known. Predictions: $\sim (\mathbf{0.0 - 0.3})\%$**

1. Rare-event searches

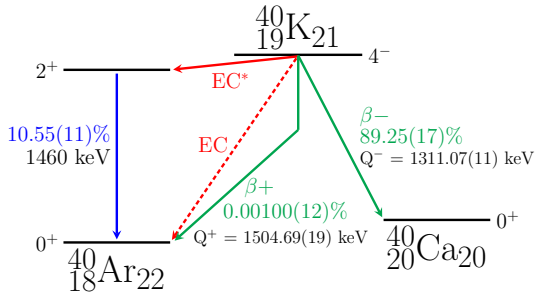
- Contaminant in NaI volumes (e.g. DAMA/LIBRA, SABRE, COSINUS)
- Irreducible background at $\sim 3\,\text{keV}$ [3]



- Naturally-occuring radioactive isotope
- **E.C. → g.s. (I_{EC}) is ill-known. Predictions: $\sim (0.0 - 0.3)\%$**

2. Geochronology

- Lifetime $\sim 10^9$ y
- K-Ar (& Ar-Ar) dating dependent on ^{40}K decay scheme [4]
- Ill-known I_{EC} becoming an important systematic



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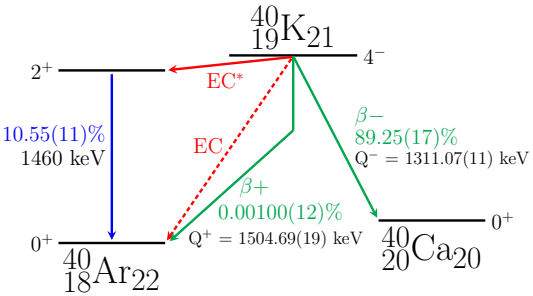
3. Nuclear Theory

- I_{EC} is an extremely rare *unique third-forbidden* decay
- Theoretical predictions vary widely



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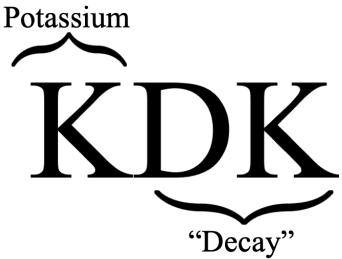
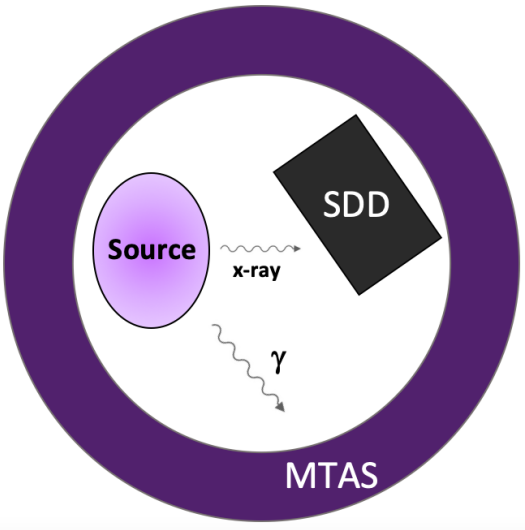
The KDK Collaboration

International collaboration making the **first measurement of Potassium-40's rare $I_{\mathbf{EC}}$ decay**

Instrumentation paper (NIM A, Stukel et al., 2021) available **here**



KDK Setup I



- EC event: X-ray/Auger
- EC* event: X-ray/Auger & gamma

Inner **Silicon Drift Detector (SDD)**[†] *(MPP/HLL Munich)*; ~ 10 g

Outer **Modular Total Absorption Spectrometer (MTAS)** *(Oak Ridge National Laboratory)*; $\sim 1,000$ kg

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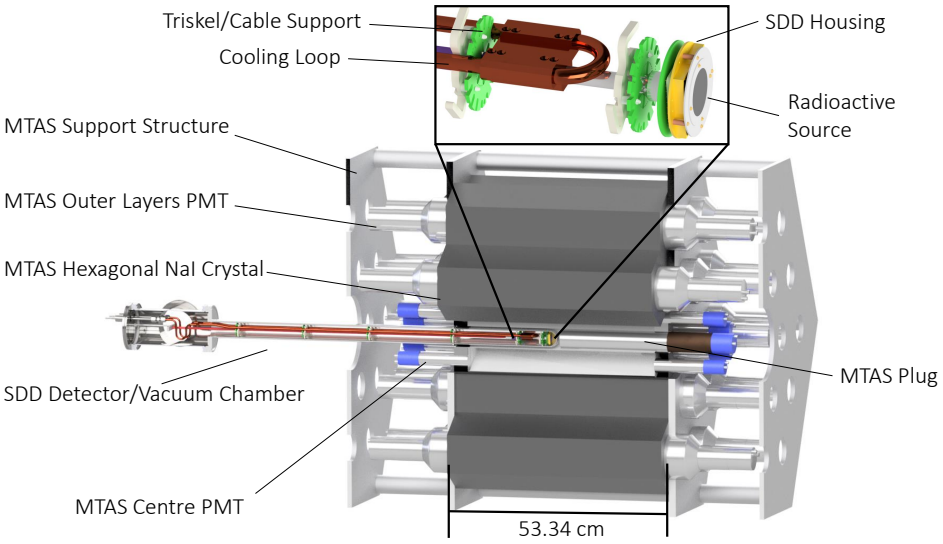
KDK measures $\rho = I_{\mathbf{EC}} / I_{\mathbf{EC*}}$

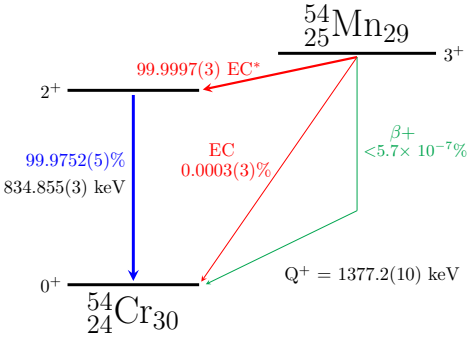
[†]or KSI

KDK Setup II (https://doi.org/10.1016/j.nima.2021.16559)



Leading Systematic - MTAS Gamma-Tagging Efficiency, ^{54}Mn

To discriminate I_{EC} from I_{EC^*} **γ-tagging efficiency must be very well-known.**



Measurement of ^{54}Mn γ efficiency is combined with ratio of Geant4-simulated values

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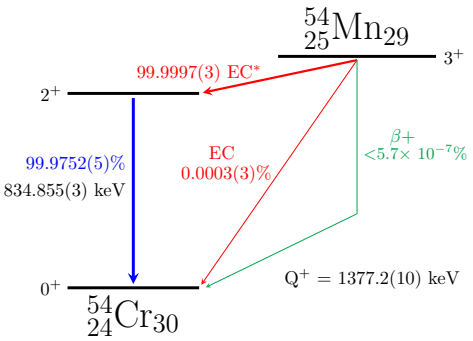

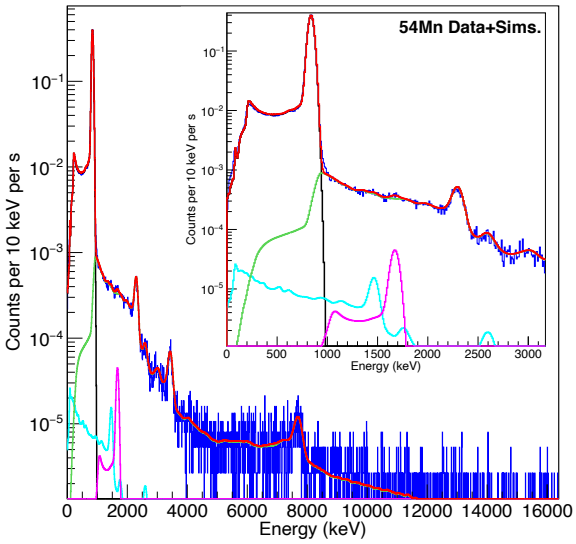

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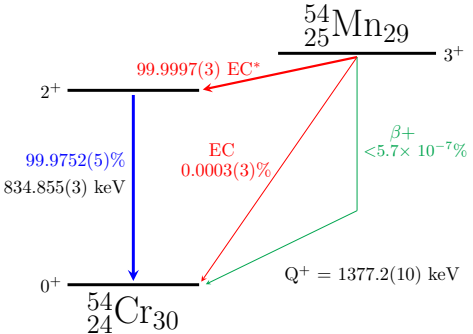


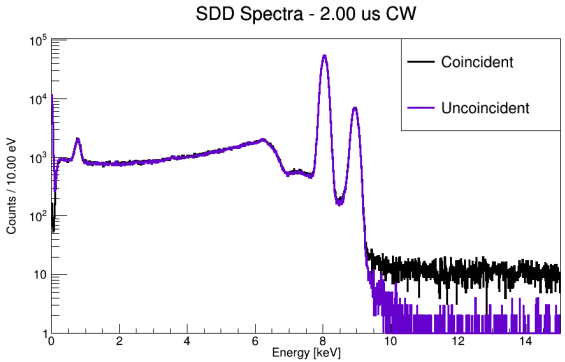
Measurement of ^{54}Mn γ efficiency is combined with Geant4-simulated values.

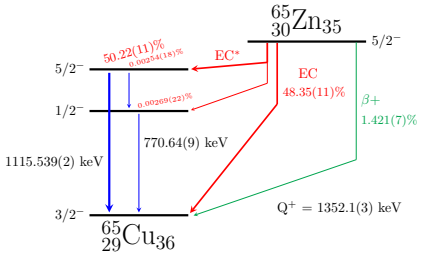
Scale 835 keV gamma to 1460 keV (^{40}K), correct for dead time:

(1 µs CW): Measured ^{54}Mn 97.75(1)% $\longrightarrow$ ^{40}K **97.89(6)%**

Testing Methods - ^{65}Zn

Test methodology for obtaining $\rho = I_{\mathrm{EC}} / I_{\mathrm{EC}^*}$ via ^{65}Zn, similar decay

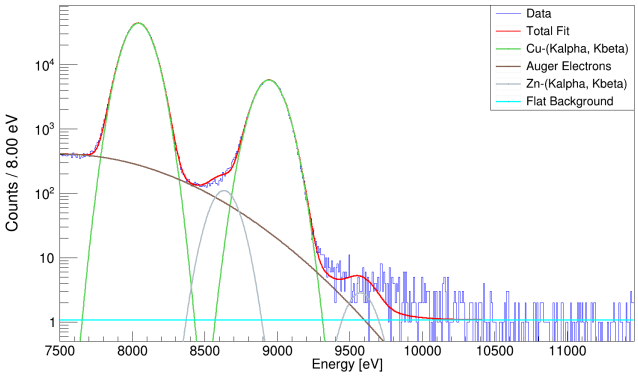


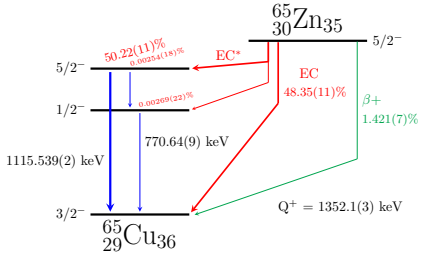


Resolution 198 eV FWHM at 8 keV

Testing Methods - ^{65}Zn

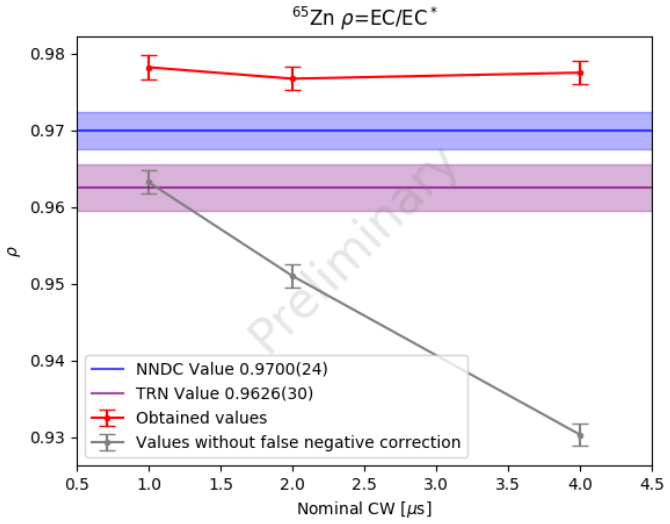
Fit coincident & uncoincident (below) spectra simultaneously





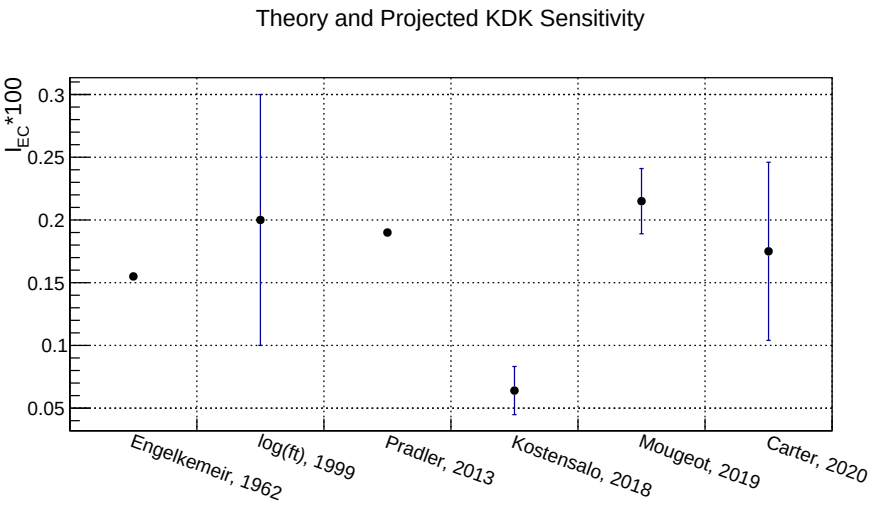
Fit accounts for false positives and negatives
Notably: $< 100\%$ MTAS efficiency, EC coincidence with MTAS background

Testing Methods - ^{65}Zn

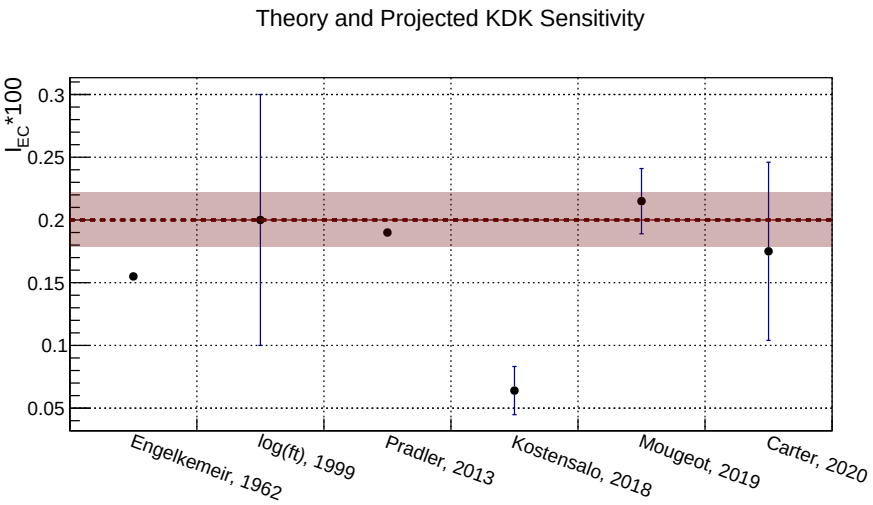


- False negative correction removes unphysical CW-dependency
- Finalizing systematics

^{40}K: Blinding, Sensitivity



^{40}K: Blinding, Sensitivity



Takeaway

- ^{40}K measurement applicable to many fields: rare-event searches, geochronology, nuclear theory
- KDK is making a measurement of ^{40}K, along with other isotopes
- ^{40}K data unblinded (internally), systematics checks ongoing
- Stay tuned for the final value in the coming weeks

Thank you to the KDK Collaboration

N. Brewer[1], H. Davis[2], P.C.F. Di Stefano[3], A. Fijałkowska[1,4,5], Z. Gai[1], K.C. Goetz[1], R. Grzywacz[4], J. Kostensalo[6], P. Lechner[7], Y. Liu[1], E. Lukosi[2], M. Mancuso[8], D. McKinnon[2], C.L. Melcher[2], J. Ninkovic[7], F. Petricca[8], B.C. Rasco[1], K.P. Rykaczewski[1], D. Stracener[1], M. Stukel[3], J. Suhonen[9], M. Wolińska-Cichocka[1,4,10], I. Yavin

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[7]MPG Semiconductor Laboratory, Munich, Germany
[8]Max Planck Institute for Physics, Munich, Germany
[9]University of Jyvaskyla, Jyvaskyla, Finland
[10]Heavy Ion Laboratory UW, Warsaw, Poland

Technical & Electronic Support: M. Constable, F. Retiere (TRIUMF), K. Dering[4], P. Davis, University of Alberta.

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[1] M. Stukel, B. C. Rasco, N. T. Brewer, P. C. F. Di Stefano, K. P. Rykaczewski, H. Davis, E. D. Lukosi, L. Hariasz, M. Constable, P. Davis, K. Dering, A. Fijałkowska, Z. Gai, K. C. Goetz, R. K. Grzywacz, J. Kostensalo, J. Ninkovic, P. Lechner, Y. Liu, M. Mancuso, C. L. Melcher, F. Petricca, C. Rouleau, P. Squillari, L. Stand, D. W. Stracener, J. Suhonen, M. Wolińska-Cichocka, and I. Yavin.

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[3] Josef Pradler, Balraj Singh, and Itay Yavin.

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