# Nuclear Astrophysics Opportunities with the Modular Total Absorption Spectrometer (MTAS)

B.C. Rasco

Workshop on Nuclear Astrophysics Opportunities at ATLAS 2019

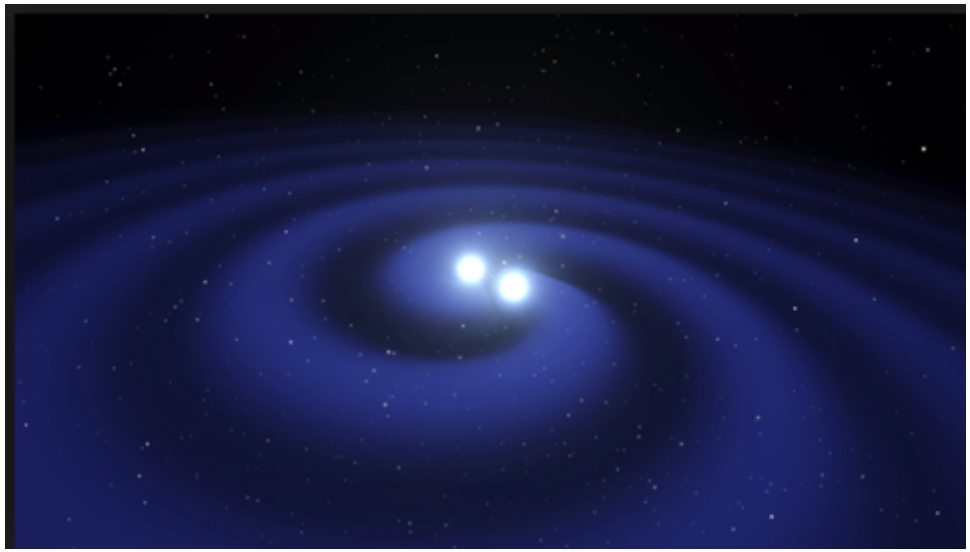
July XX, 2019

# Nuclear Astrophysics?

What qualifies as nuclear astrophysics?

What can the Modular Total Absorption Spectrometer (MTAS) measure?

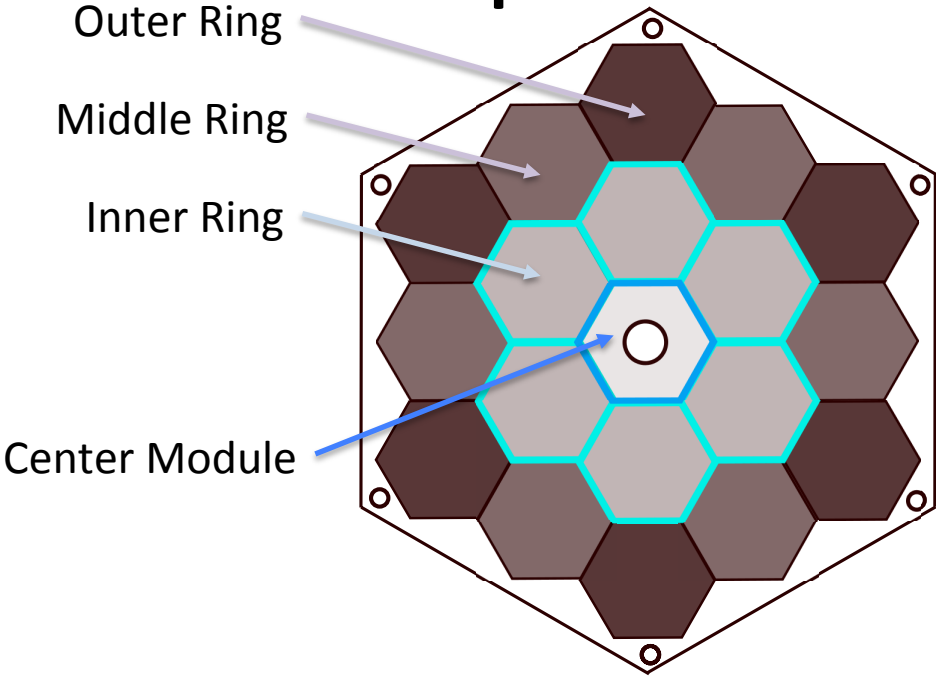
Dark Matter

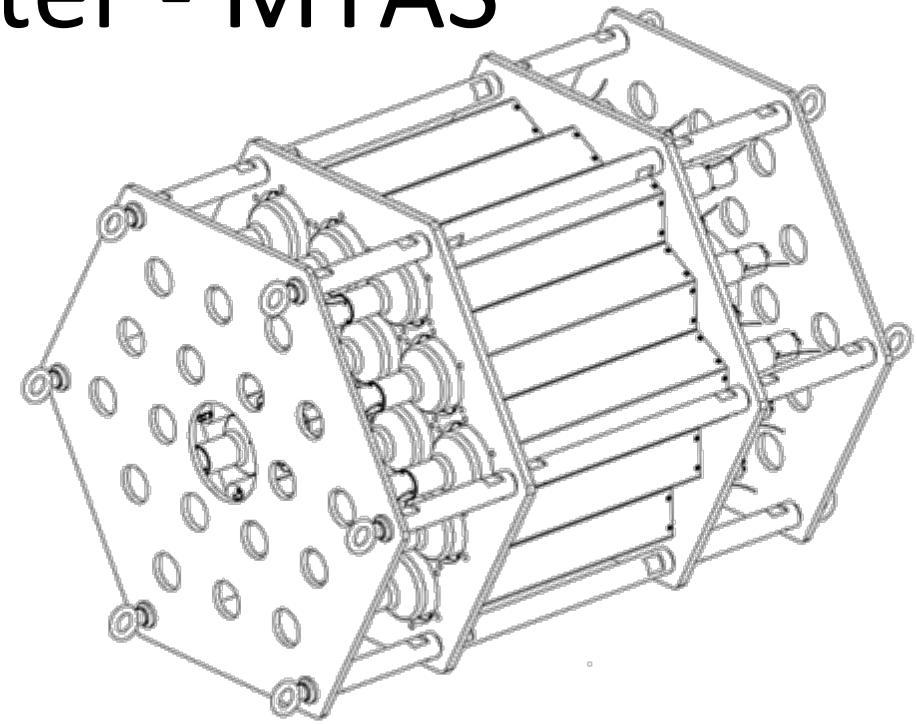


ESA

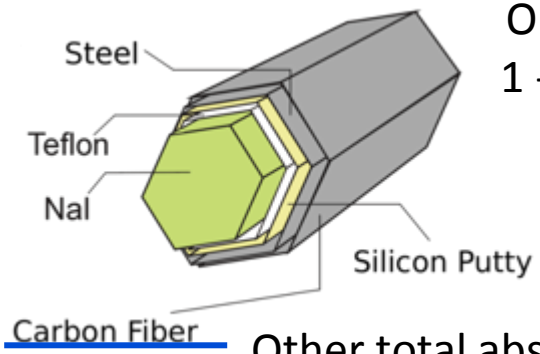
r Process - Explosion
r Process - Freeze Out

# The Modular Total Absorption Spectrometer - MTAS



MTAS: 18 - 8”x 7”x 21” (20cm x 17.8cm x 53.3cm) hexagon NaI(Tl) modules
Organized in 3 Rings of 6 modules each (Inner, Middle, and Outer)
1 - Center module, same dimensions but with a 2.5” diameter hole
Over 1 ton of NaI(Tl)!

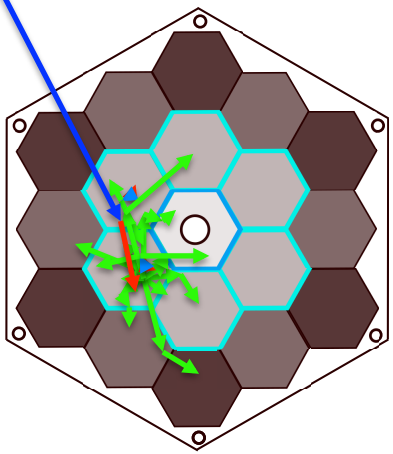



Over 5 tons of lead shielding + neutron shielding

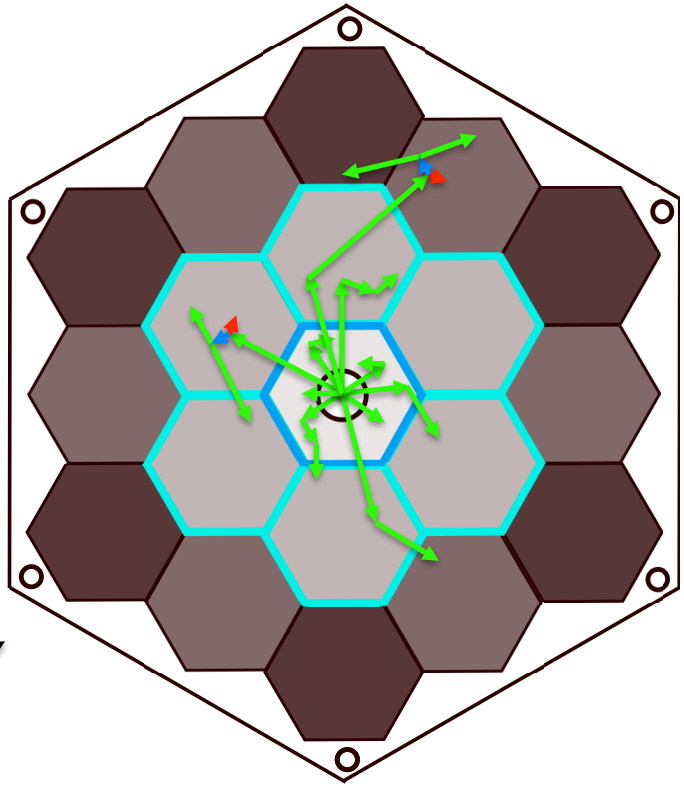
Other total absorption spectrometers include the TAS at ISOLDE, Lucrecia, TAS at GSI (now at UML), SuN (MSU), DTAS (Valencia, Jyvaskyla), HECTOR(ND).

# What MTAS Detects

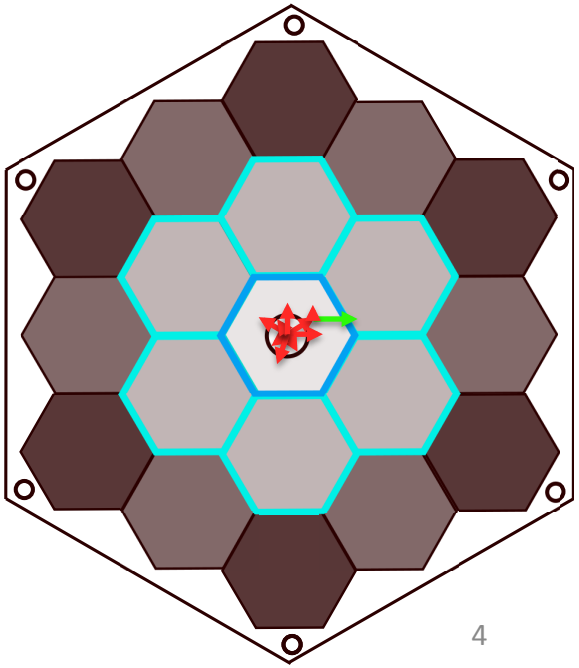
μs in MTAS



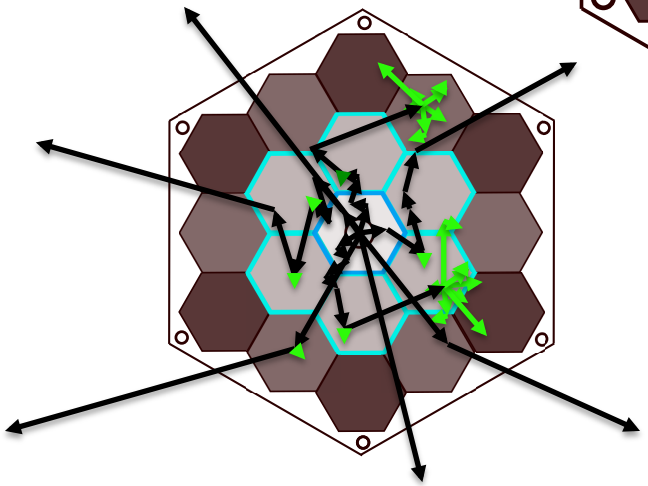
γs in MTAS



βs in MTAS



Neutrons in MTAS



# What MTAS Measures

For neutron rich nuclei, βs, γs, and neutrons will be present in almost every decay. MTAS can measure them all. By measuring all as a function of energy, we can measure the β-strength function in one experiment.

## MTAS γs

Detects single γs with a ~98% efficiency

Detects **level** feeding, which is directly relatable to Gamow-Teller strength

## MTAS βs

Detects βs with E > 2 MeV

## MTAS Neutrons

Detects neutrons with ~15% efficiency

Measures neutron energy ~250 keV FWHM

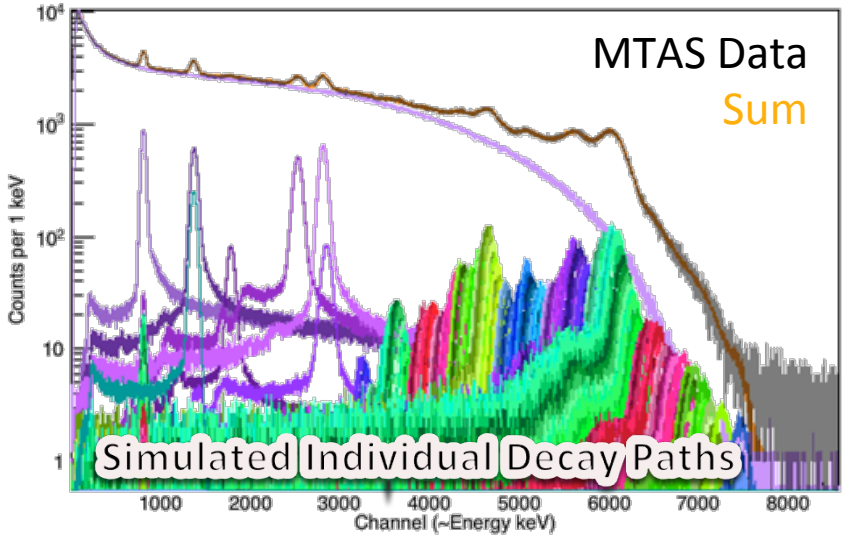
Detects very low energy neutrons

Detects neutron fine structure (γs following β-delayed neutron decay) feeding intensities

Measuring all three with one detector in one experiment is efficient. MTAS is a unique and powerful device.

# Measuring βs: $^{92}$Rb

$Q_\beta$= 8095 (6) keV  $T_{1/2}$= 4.48(3) s




B.C. Rasco, *et al.*, PRL **117**, 092501 (2016)

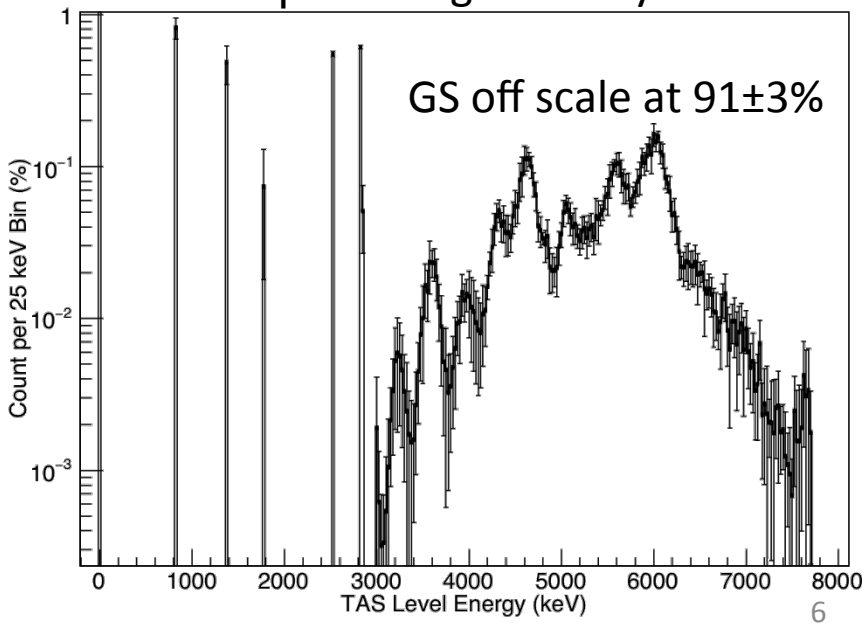
ENSDF Ground State Feeding: 95.2±.7%
(up from 50±18% in 2007)
and 87.5±2.5%*

*A.-A. Zakari-Issoufou *et al,* PRL **115**, 102503

MTAS Ground State Feeding: **91±3%**

Our uncertainty mainly from ground state β simulation.

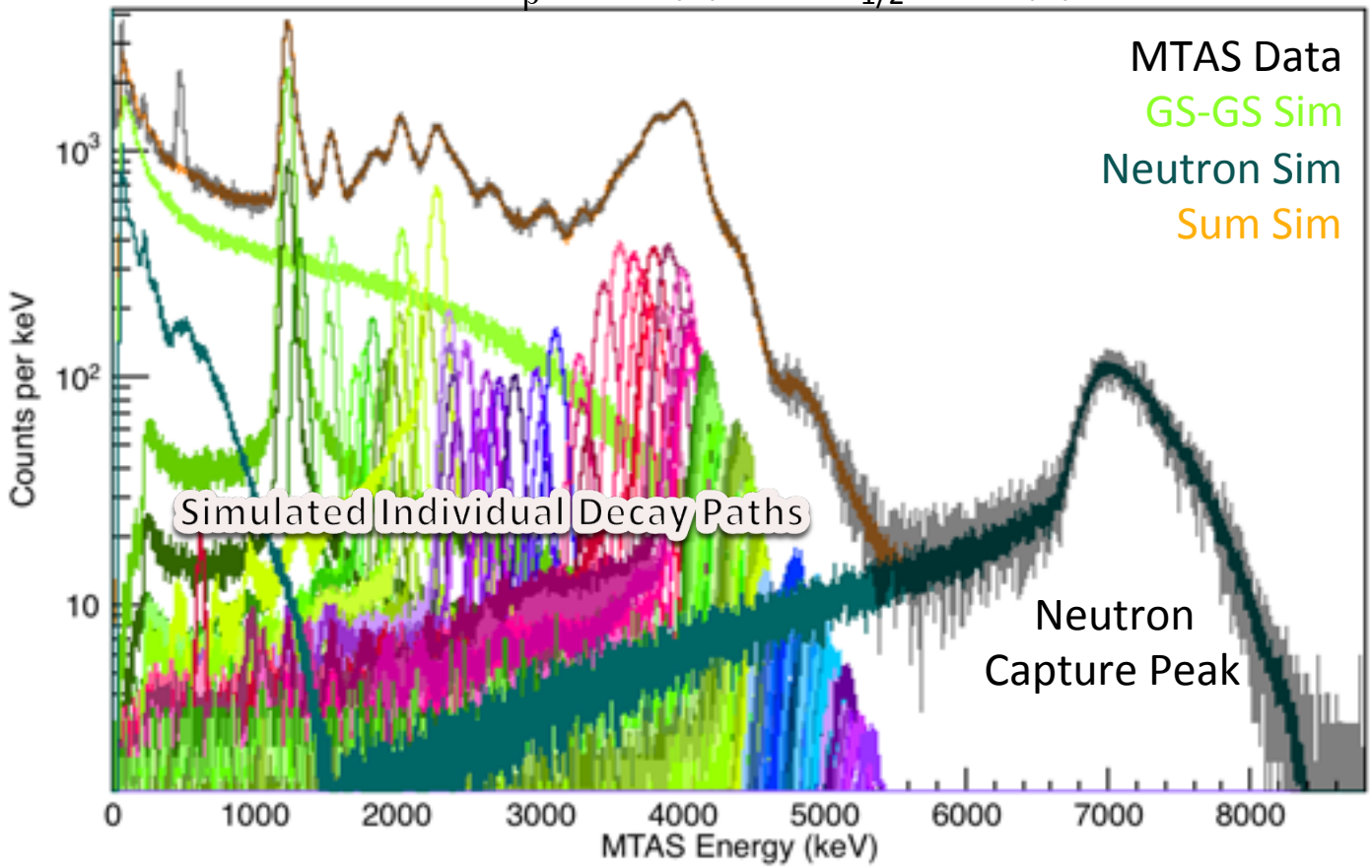
β-Feeding Intensity




Ground state feeding insensitive to exact decay pattern from higher states

# Measuring All Three at Once βs, γs, and Neutrons: $^{137}$I

$^{137}$I: $Q_\beta$= 6027(8) keV  $T_{1/2}$= 24.5(2) s



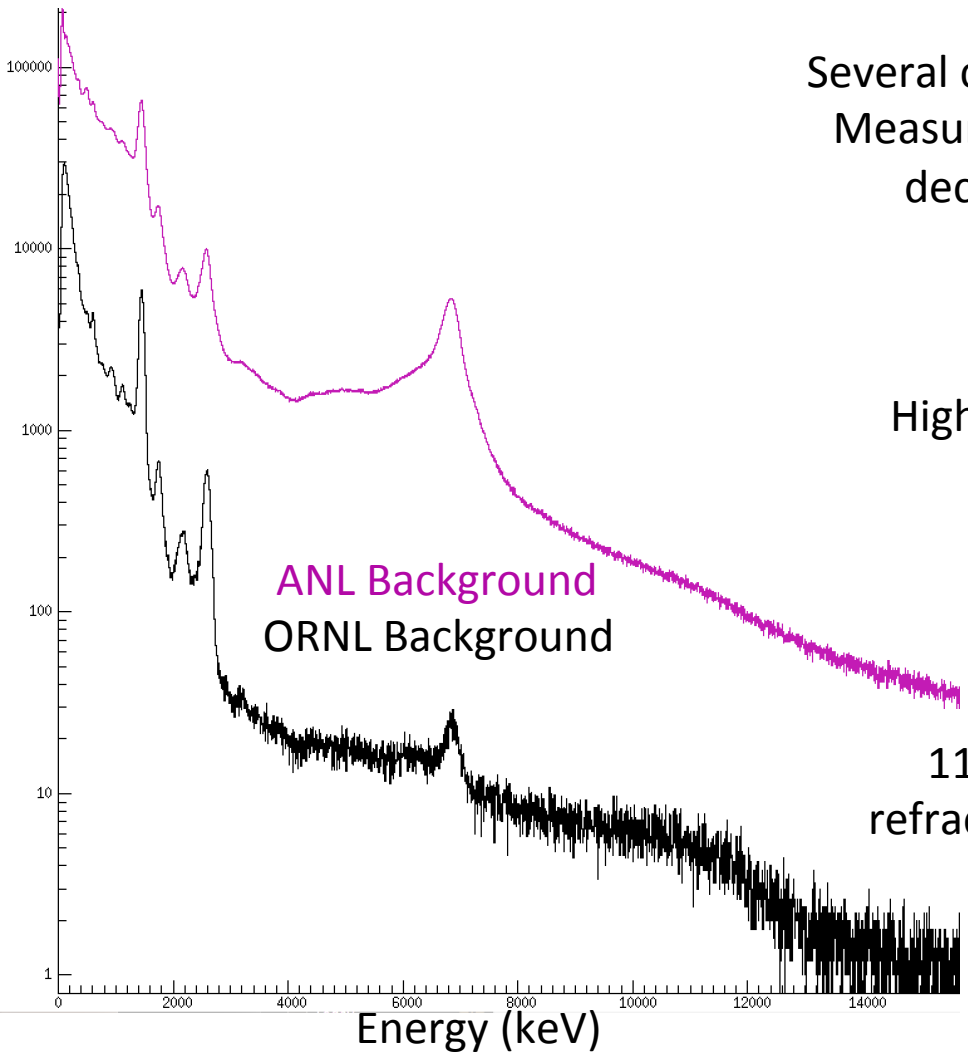

B.C. Rasco, *et al.*, PRC **95**, 054328 (2017)

Extracting all three components, β, γ, and neutrons from one decay

**This decay is important for r process decay to stability**

# MTAS

## Current and Previous Measurements




Not equal measurement time

Several campaigns in 2012-2016 at the HRIBF at ORNL:
Measured over 70 neutron rich nuclei important for decay heat and reactor antineutrino physics.
About a dozen have been evaluated.

2017-2018:
High precision source decay measurements of
$^{88}$Y, $^{54}$Mn, $^{65}$Zn, $^{40}$K

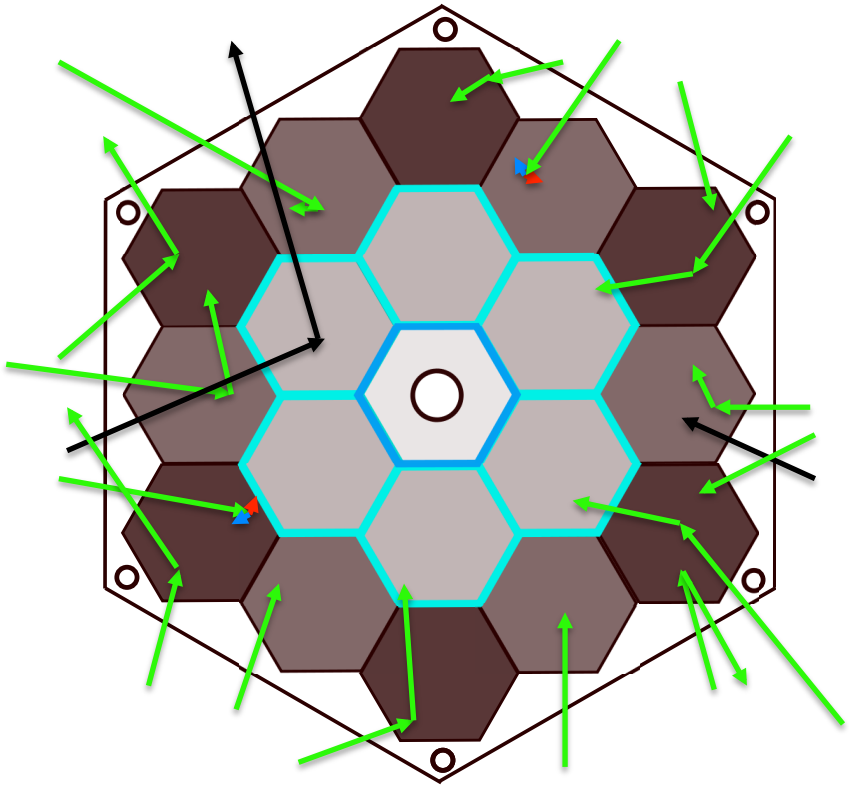
Up next:
At Argonne: Arrived in March 2019
11 days of beam time for measurement of refractory elements + some commissioning time

FRIB

# MTAS as an Active Veto

What are these measurements about?
2017-2018:
High precision source decay measurements of
$^{88}Y$, $^{54}Mn$, $^{65}Zn$, $^{40}K$

## MTAS Active Veto

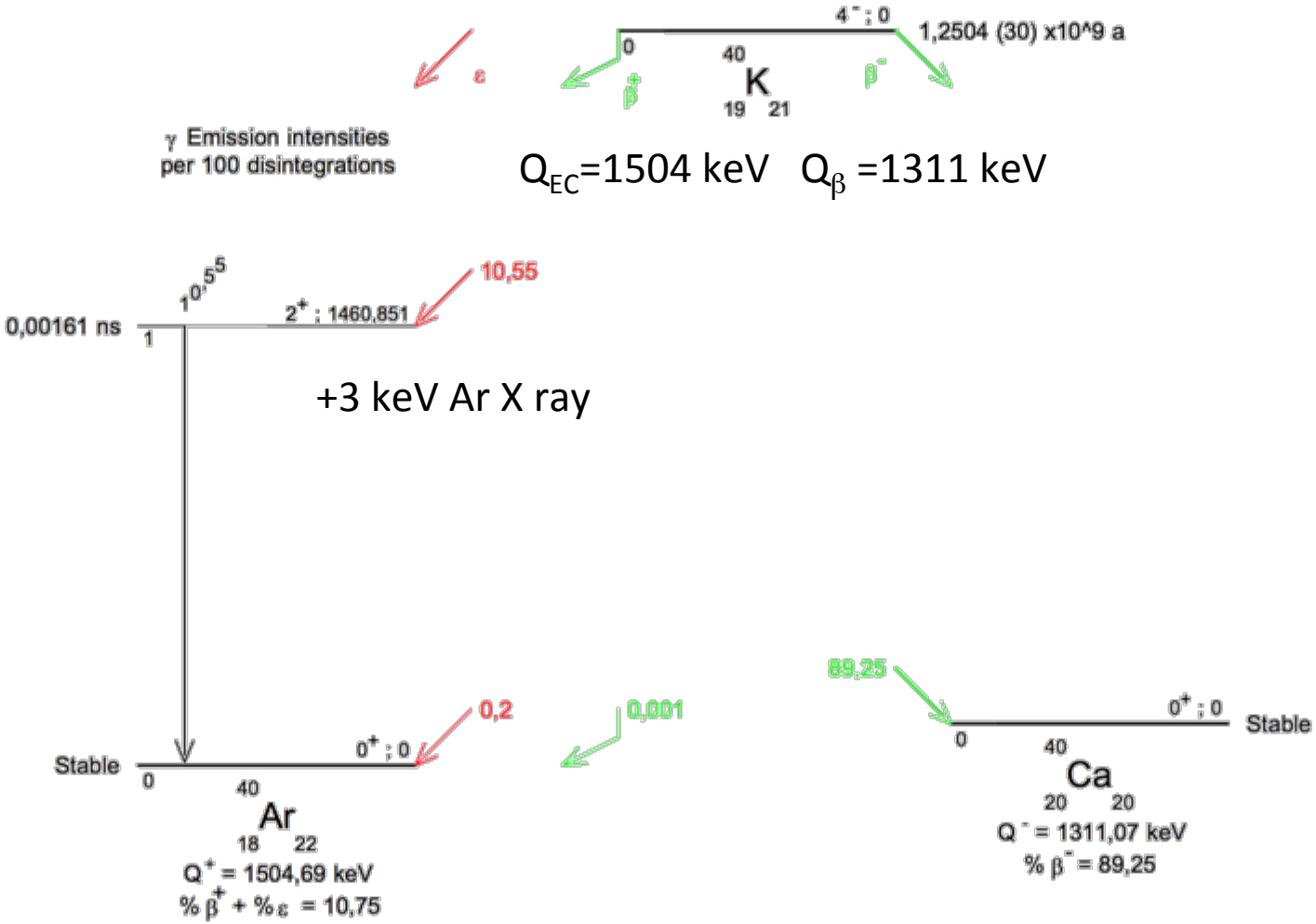


# MTAS

Why $^{40}K$ Measurements?

Background for signal (3-6 keV bump) at DAMA, SABRE, COSINE-100,... and other high precision beyond the standard model physics measurements

Improve precision of K-Ar Dating




$Q_{EC}$=1504 keV  $Q_{\beta}$ =1311 keV

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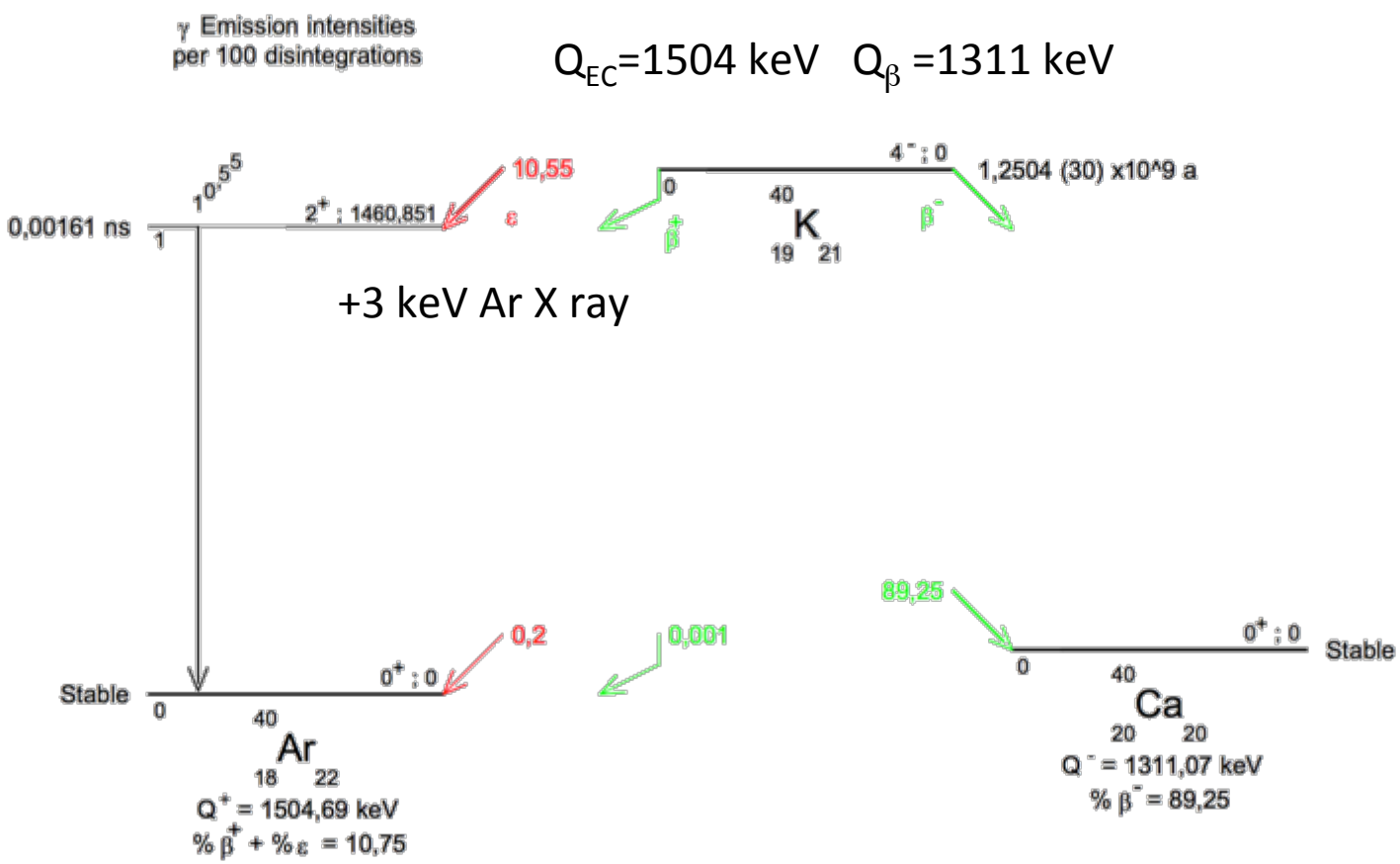

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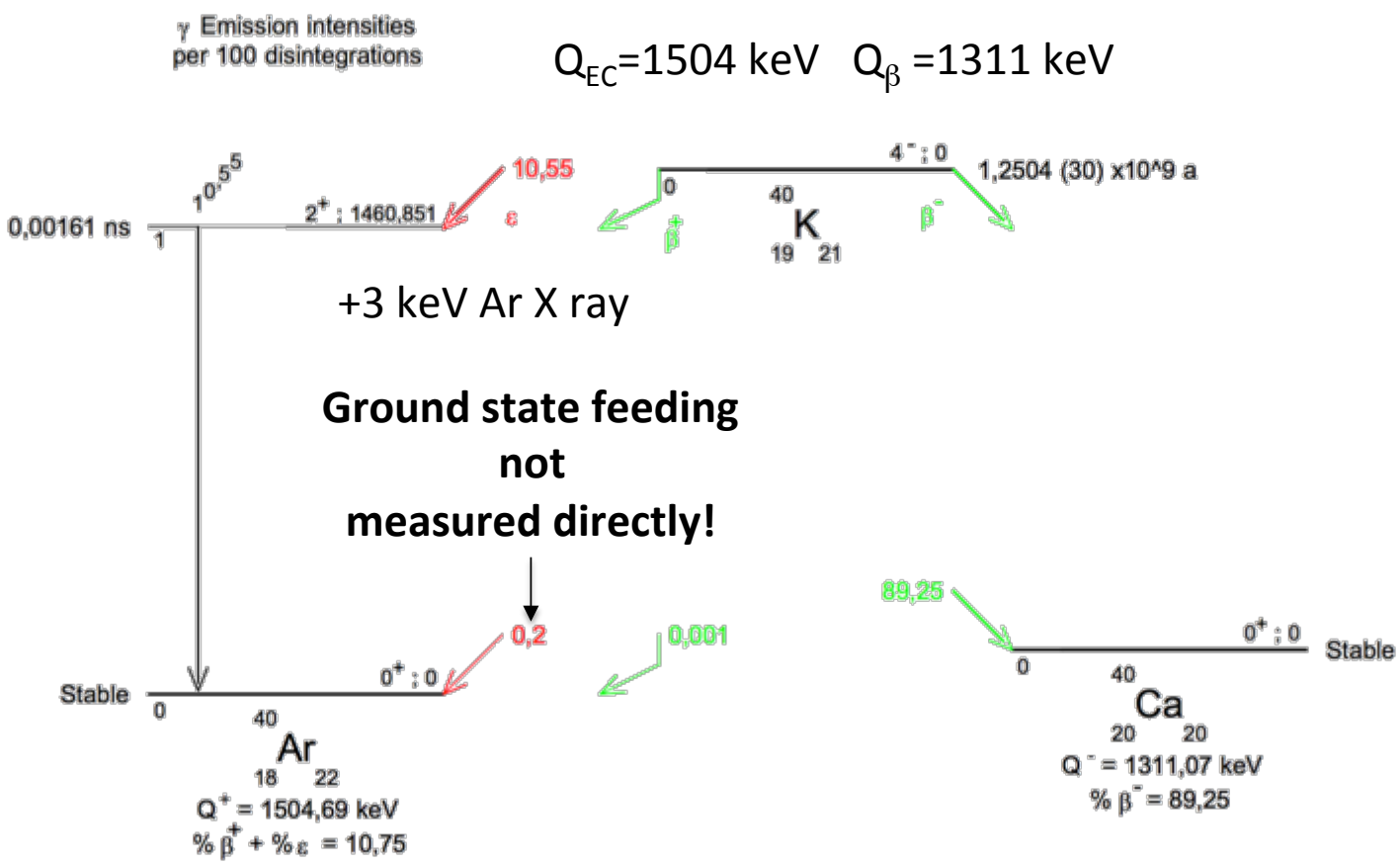


# $^{40}$K Decay to the Ground State

The different calculated branching ratios, $I_{(\beta^+ + \varepsilon)}$, of $^{40}$K (EC)

LNE-LNHB/CEA : Table of Radionuclides Vol 5, ISBN 978-92-822-2234-8 (2010)
$BR_{EC}$ =0.2(1)%

NNDC : Nuclear Data Sheets 140, 1 (2017)
$BR_{EC}$ =0.046(6)%

Indirect Experimental Half-Life Value
$BR_{EC}$ =0.8(8) %

KDK Collaborator Value (J. Kostensalo and J. Suhonen, Jyväskylä)
$BR_{EC}$ = 0.064(19)%

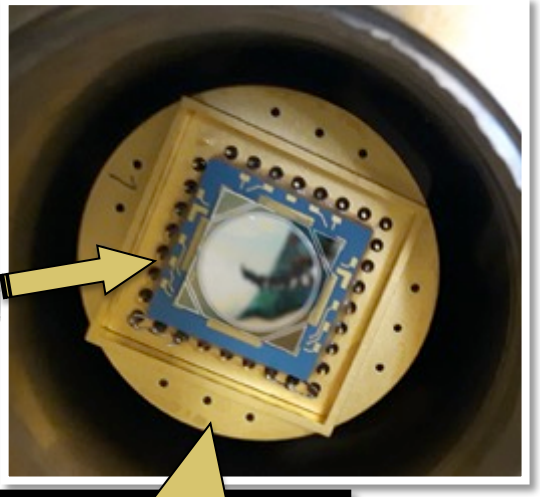
Calculated one $\sigma$ limits vary from 0.04% < $BR_{EC}$ < 0.3%
(~0-3% of electron capture measurement)

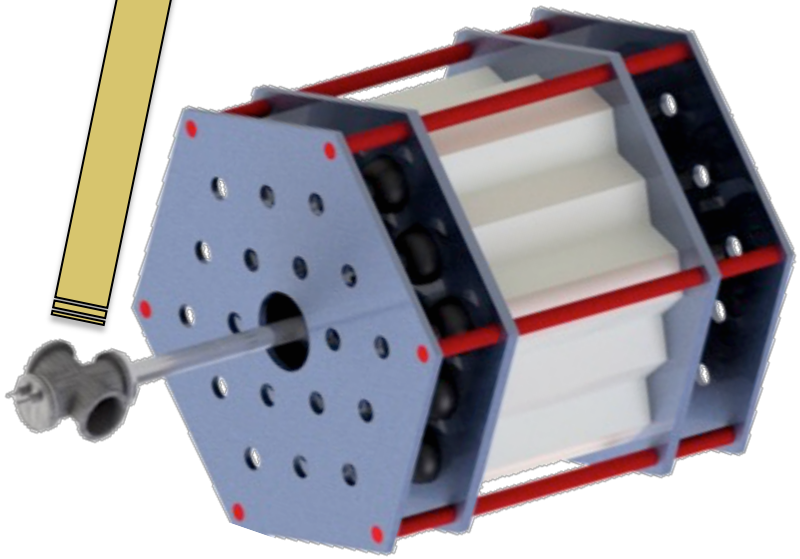
# $^{40}$K Decay Experiment (KDK)

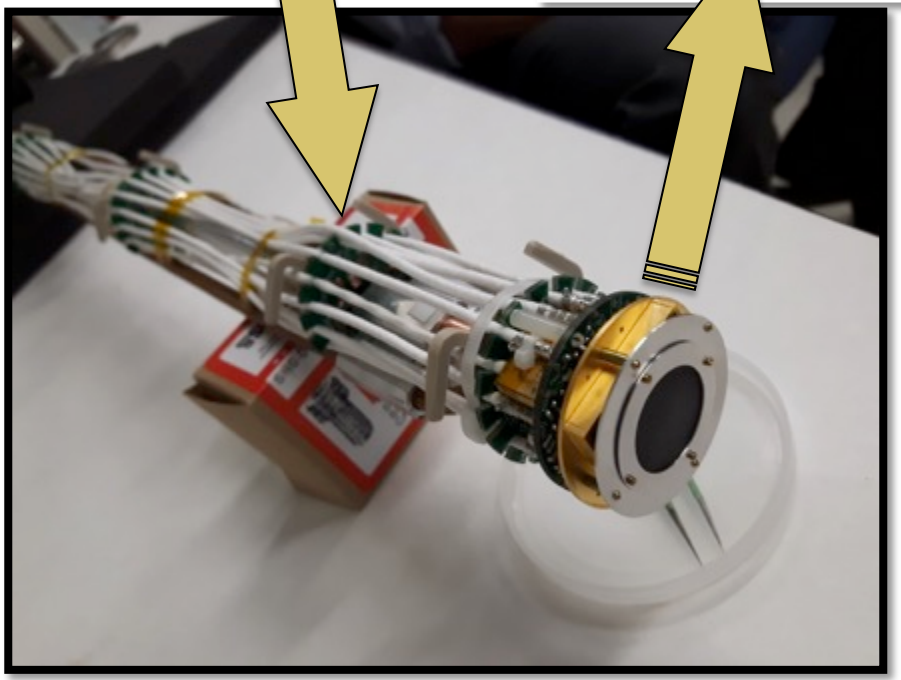
SDD X-Ray Detector

SDD Insert, Cooling, HV, and Readout

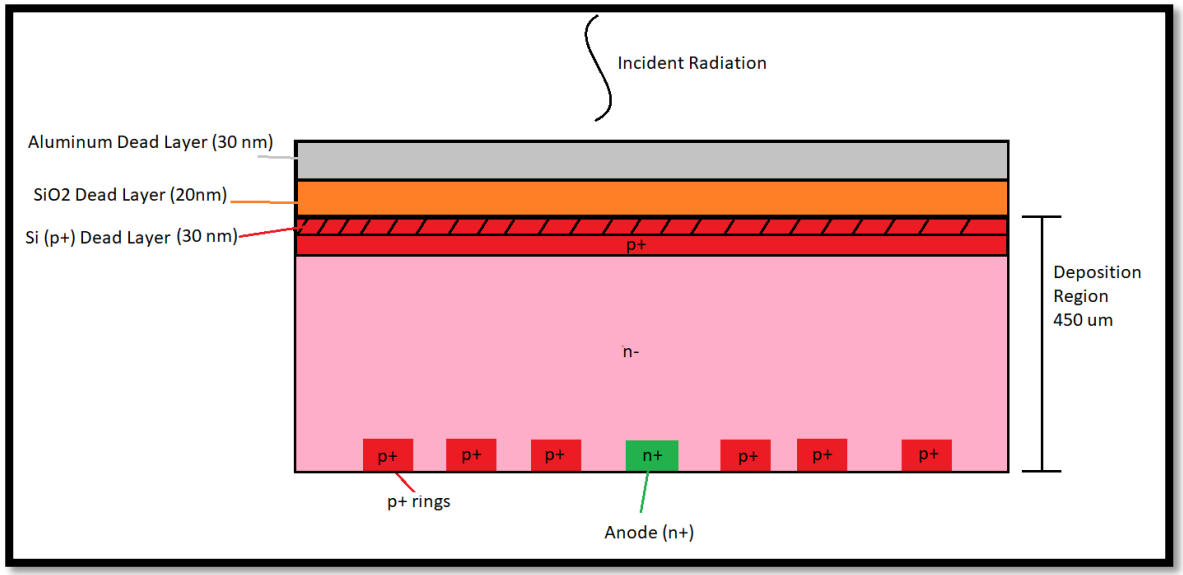
Inside Thin Aluminum Housing

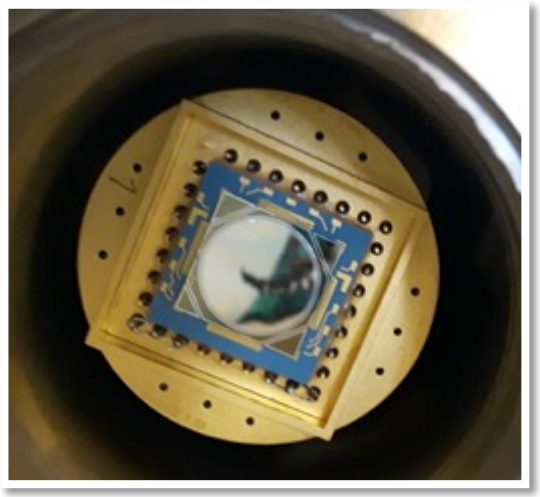




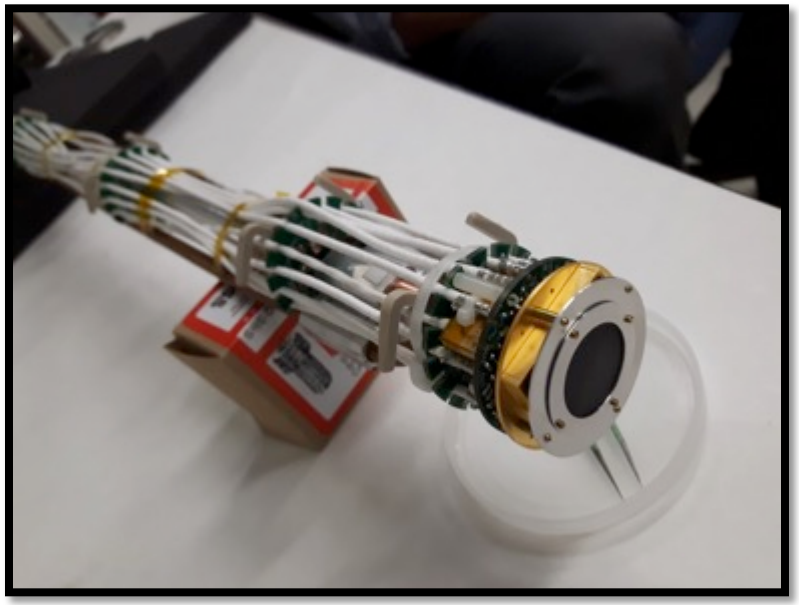


# Silicon Drift Detector (SDD)

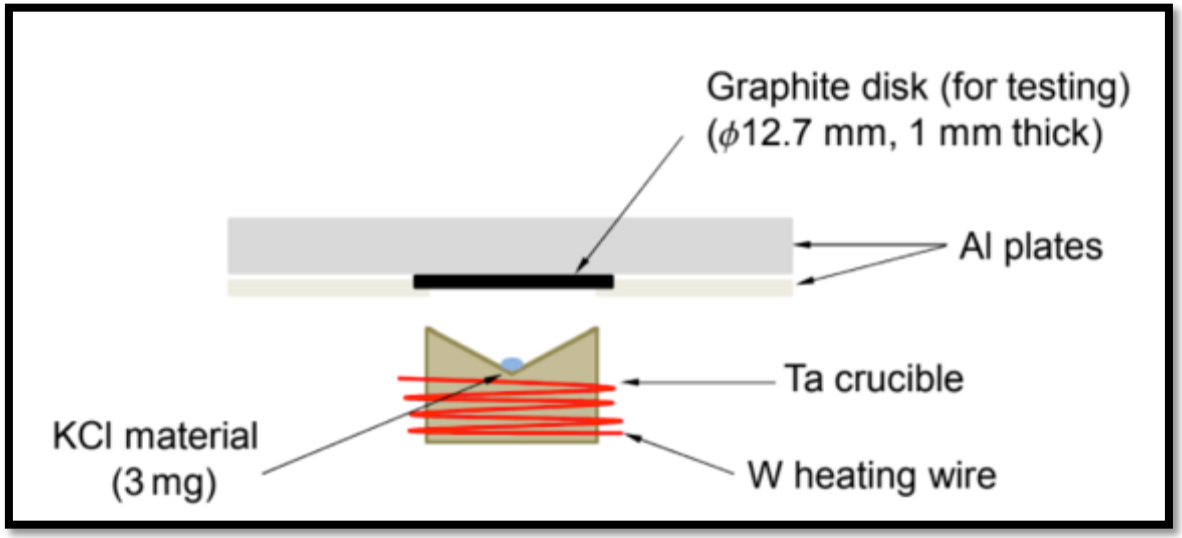


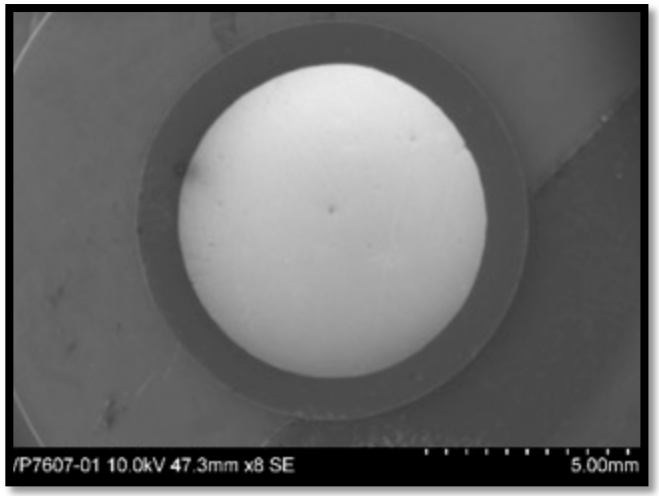



SDD Made at MPG, Munich
~15th iteration of design
They put SDDs on the Mars Rovers



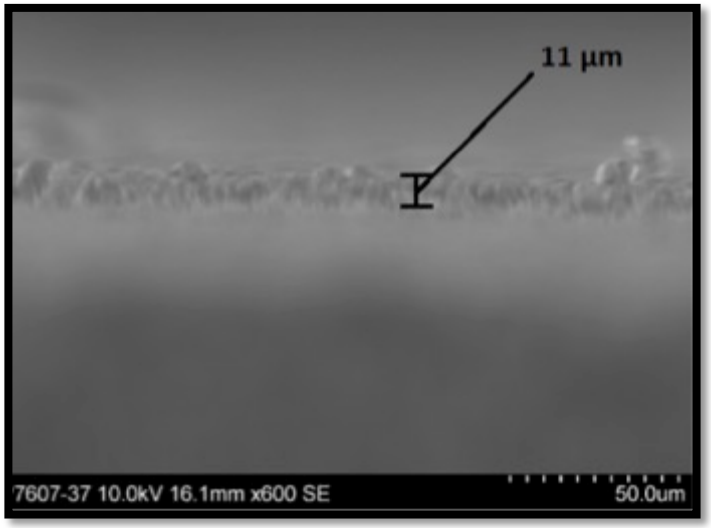
# Making Enriched $^{40}$K Source



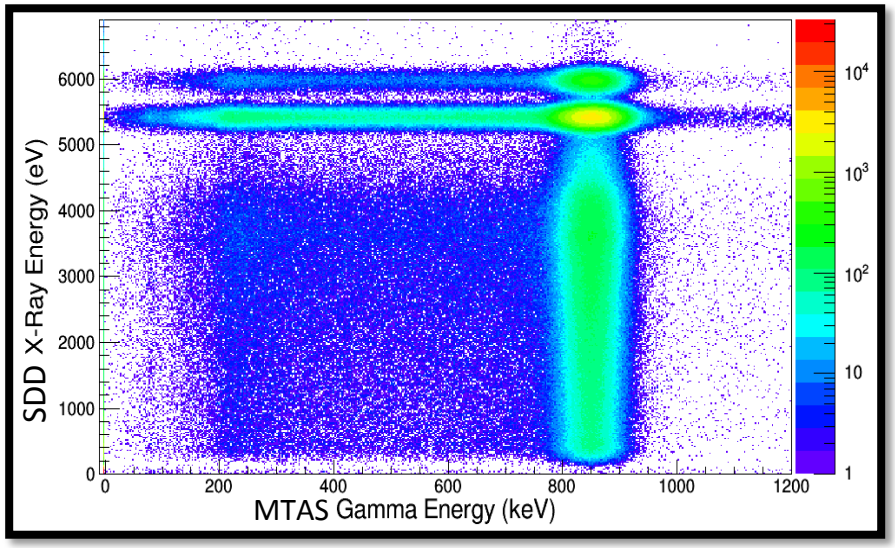




Enriched (16%) 3mg $^{40}$KCl source evaporated onto Carbon foil backing at ORNL (~3 bananas equivalent)

Needs to be thin so 2.9 keV X rays can escape from source



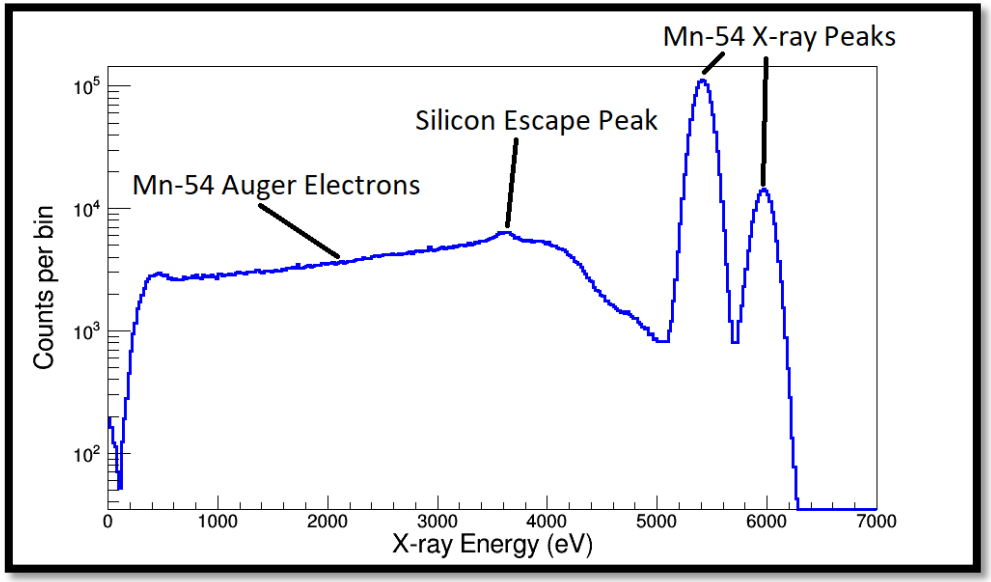
# $^{54}$Mn in KDK: SDD and MTAS



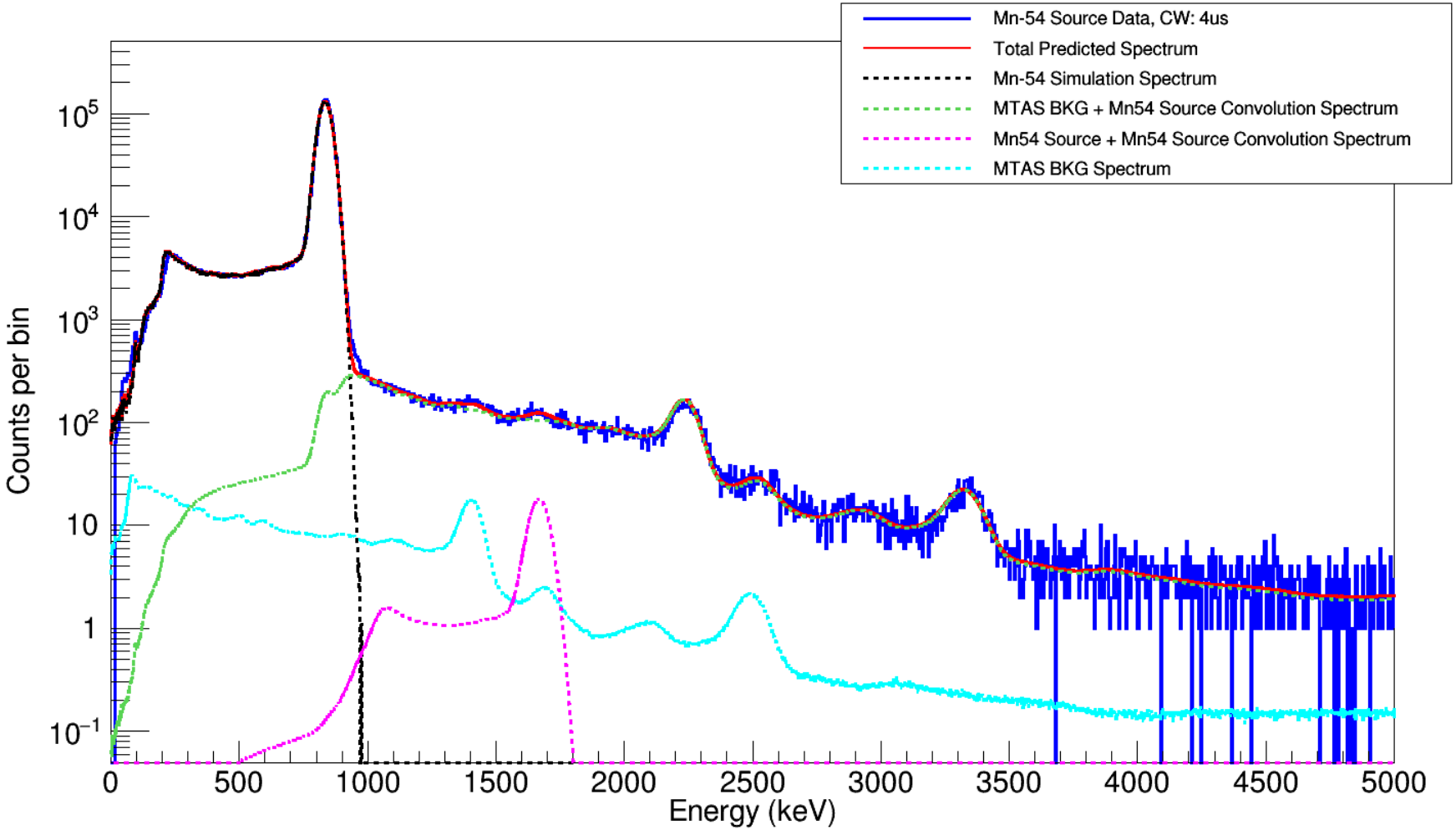

~50 nCi $^{54}$Mn source
200 cps triggered in SDD

Gating on each $^{54}$Mn X rays gives consistant MTAS single 834 keV $\gamma$ ray tagging efficiency to 4 significant digits!

Finalizing dead-time corrections before giving out efficiency



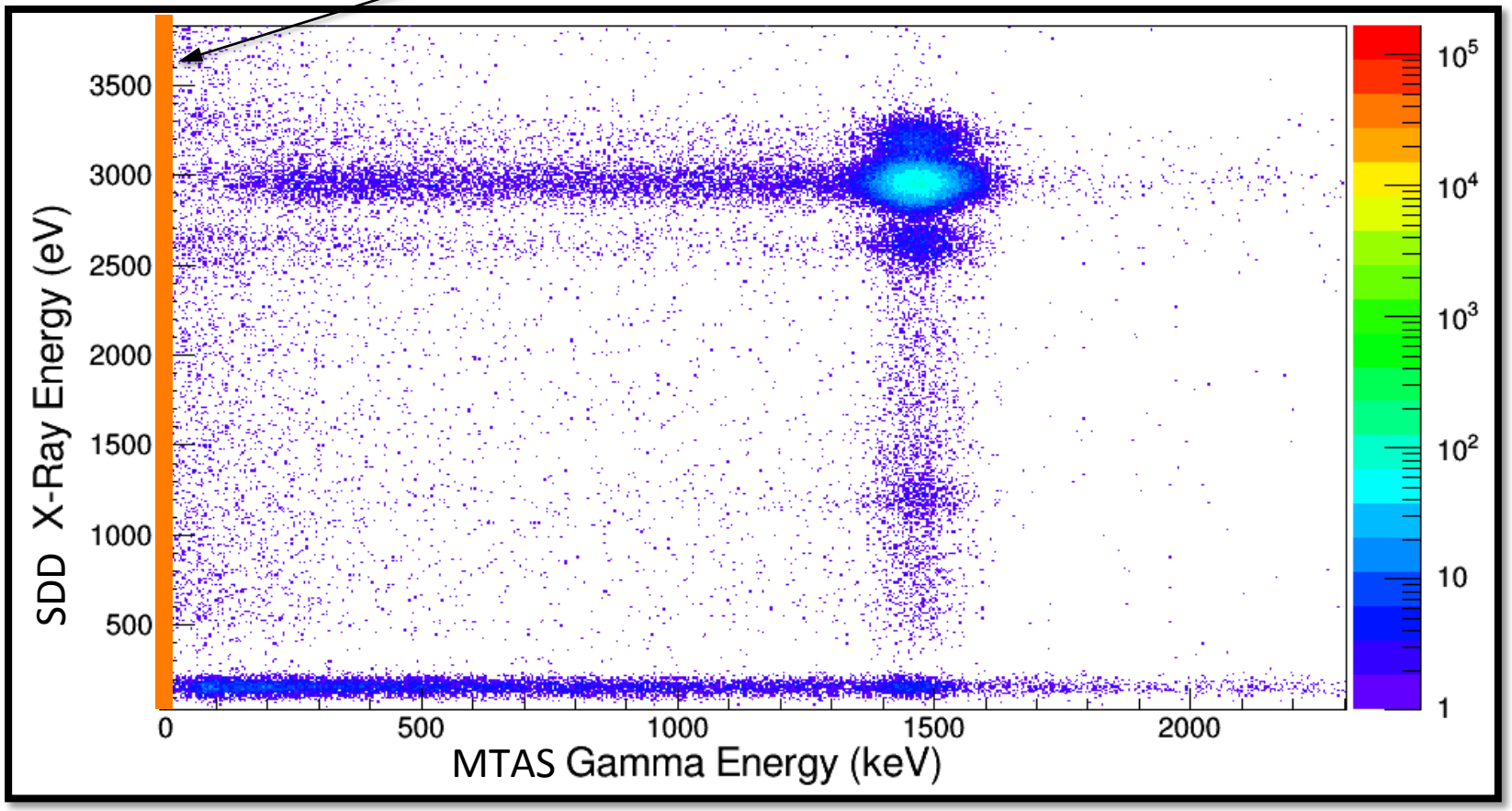
# $^{54}$Mn with SDD Trigger in MTAS




$^{54}$Mn spectrum in MTAS given a trigger in the SDD

# $^{40}$K Preliminary MTAS

**Blinded Data! Results soon!**




33 days of data with about 1 triggered counts per minute

# The KDK Collaboration

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

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[8] MPG Semiconductor Laboratory, Munich, Germany
[9] Max Planck Institute for Physics, Munich, Germany

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arXiv: 1711.04004

Thank You
for your
Attention