Doppler shift lifetime measurements in ^{94}Sr using the TIGRESS Integrated Plunger

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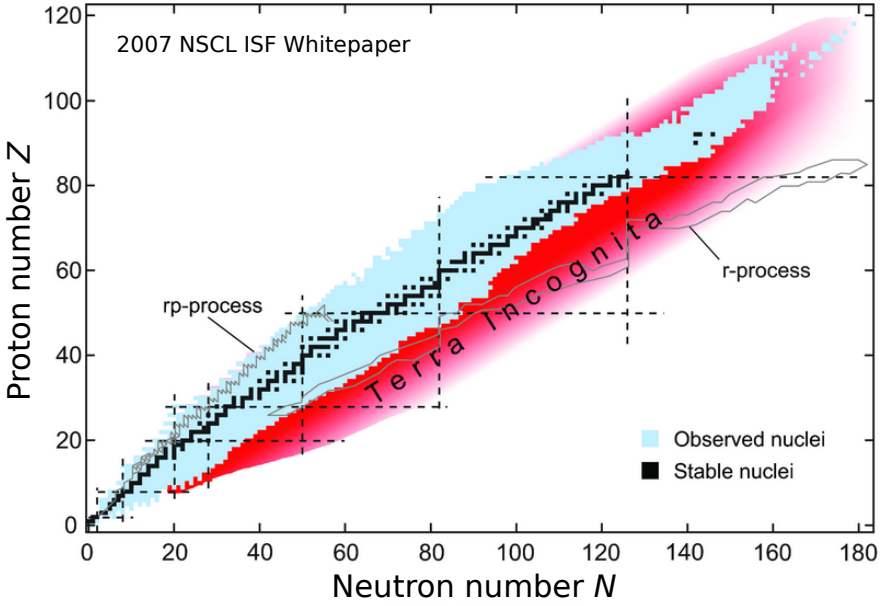
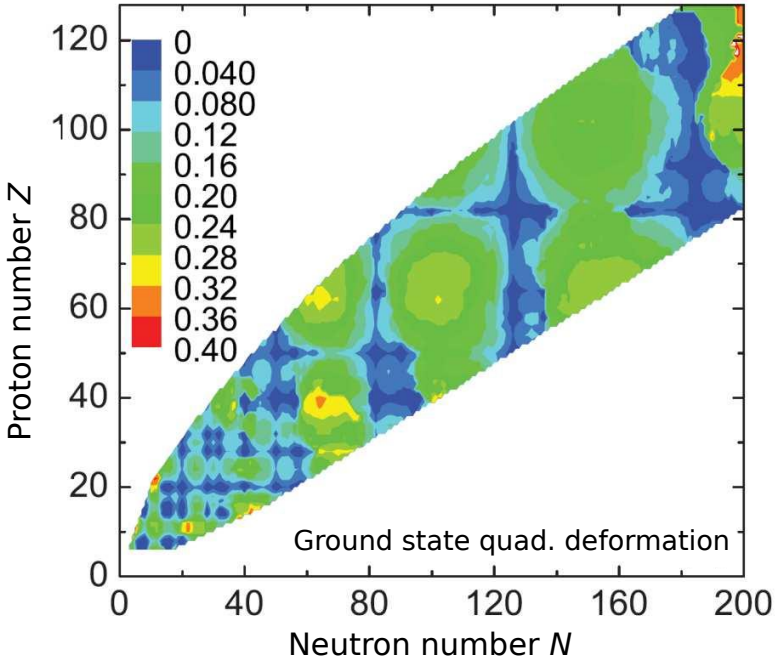
Selected goals of nuclear science research



N. Wang et al. Phys. Rev. C 82 (2010)

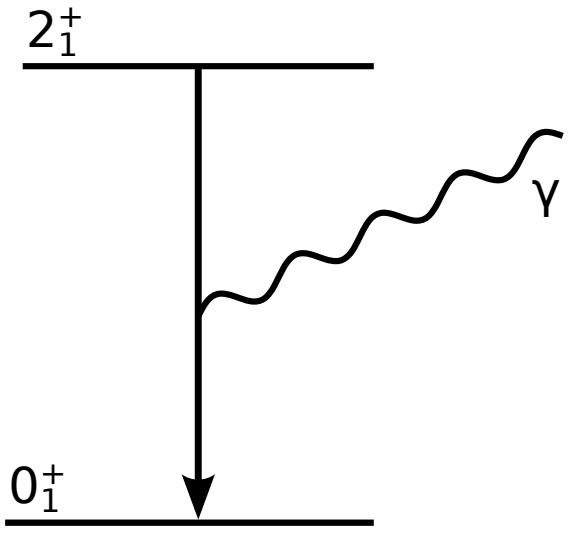


- Understand the mechanisms of shell evolution in medium-mass and heavy nuclei as a function of isospin.
- Develop a theoretical framework that is able to make accurate predictions of nuclear properties.

TRIUMF 5 Year Plan 2015–2020.

Studying nuclear structure using the electromagnetic force

- The electromagnetic force provides a convenient non-intrusive probe of nuclear systems bound by the strong force.
- Lifetime measurements using gamma-ray spectroscopy provide:
  1. An observable sensitive to nuclear structure.
  2. A sensitive benchmark for nuclear model calculations.



$$\tau(E2; 2_1^+ \rightarrow 0_1^+) = \lambda(E2; 2_1^+ \rightarrow 0_1^+)^{-1}$$

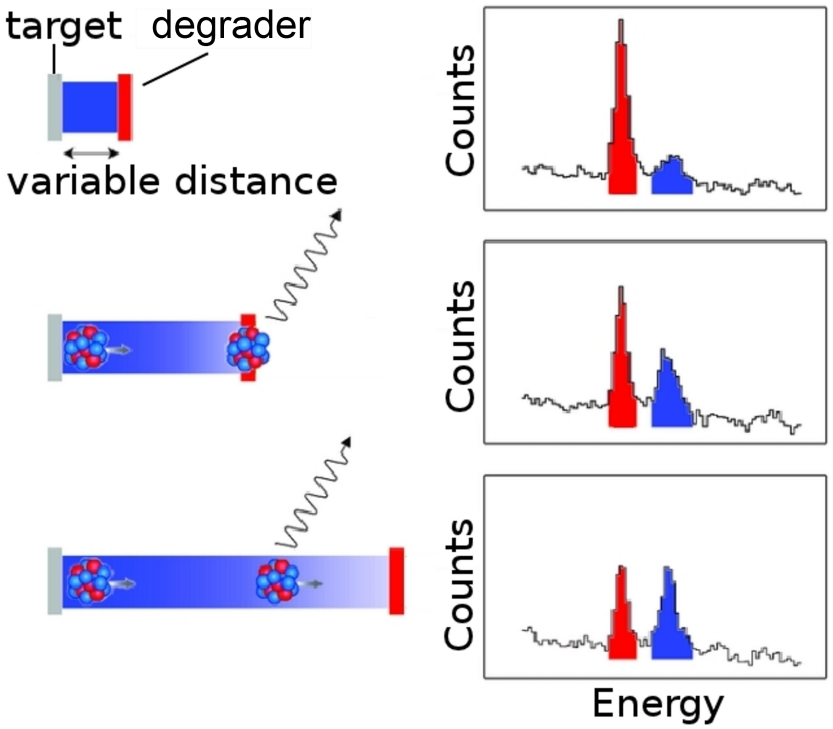
$$\lambda(E2; 2_1^+ \rightarrow 0_1^+) \propto E(2_1^+)^5 \times B(E2; 2_1^+ \rightarrow 0_1^+)$$

$$B(E2; 2_1^+ \rightarrow 0_1^+) = \frac{1}{5} \langle 2_1^+ || E2 || 0_1^+ \rangle^2 \propto \beta^2$$

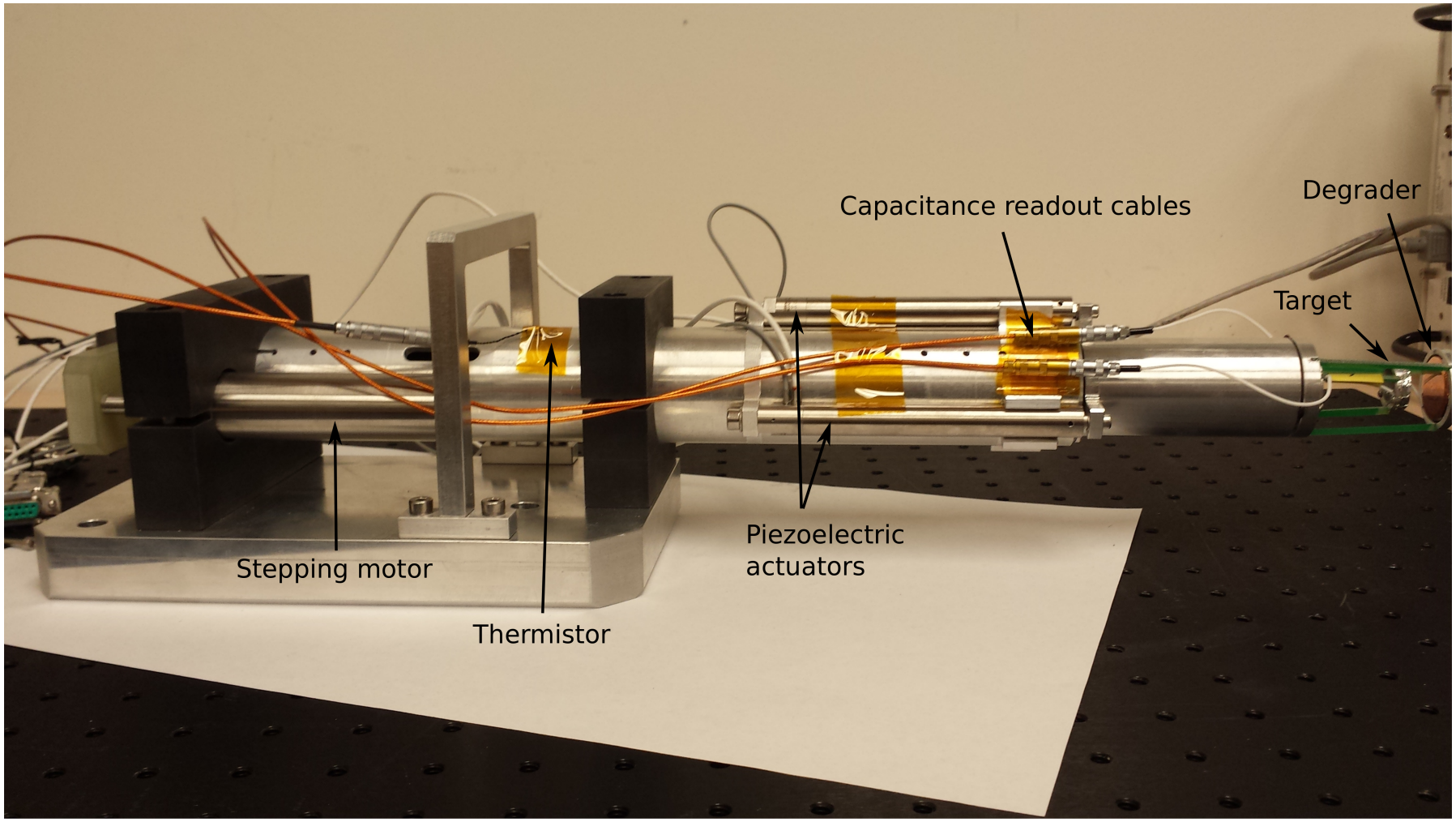
The Recoil Distance Method (RDM)

$c = 300\ \mu\text{m/ps}$ $\beta = \frac{v}{c} \sim 0.05$ $1\ \text{ps} \sim 15\ \mu\text{m}$

- Doppler shift of emitted gamma rays depends on the decay position.
- The lifetime can be inferred from the ratio of peak intensities if the recoil velocity is known.
- The velocity is measured from the Doppler shift.

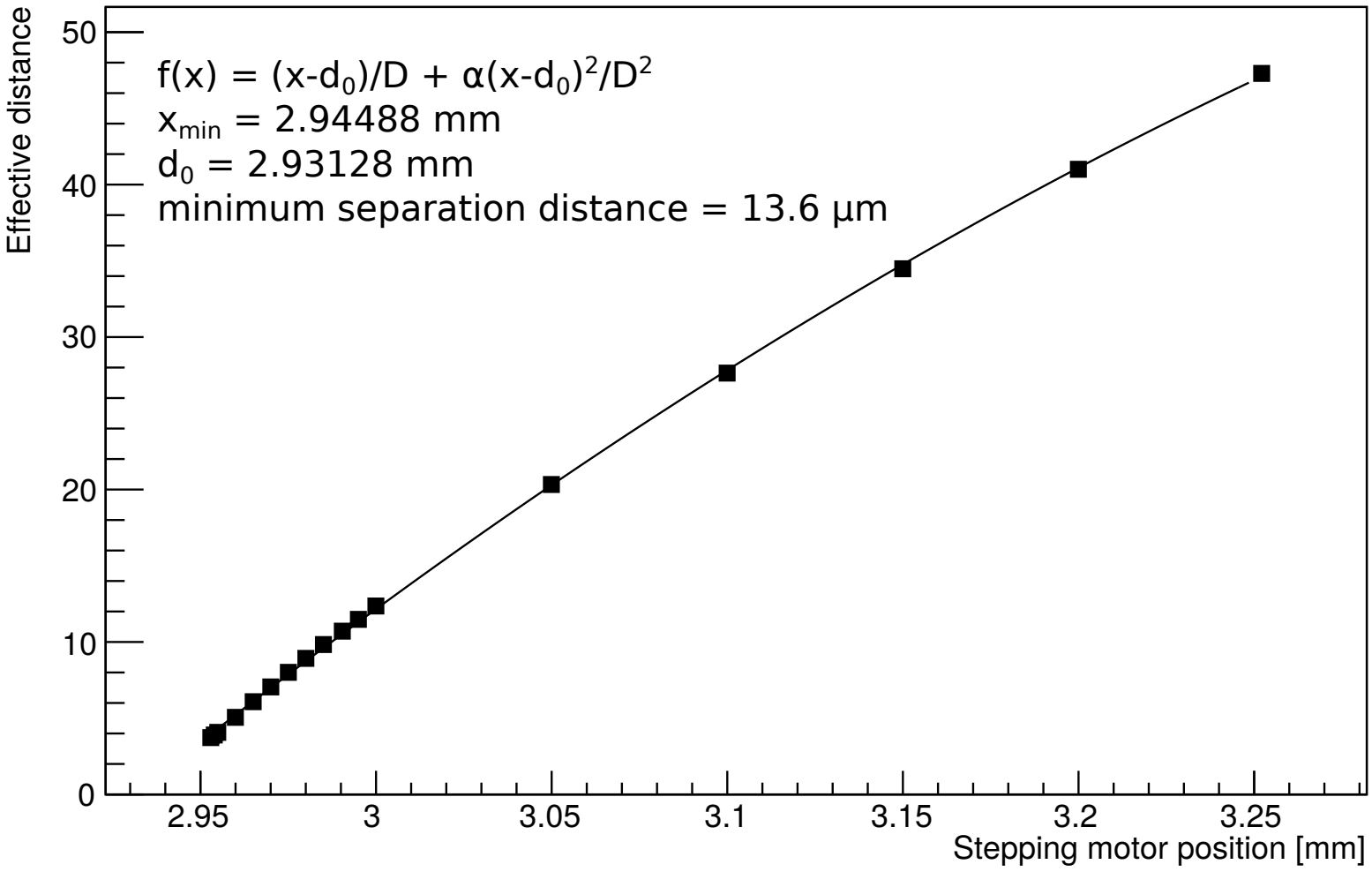


The TIGRESS Integrated Plunger (TIP) device

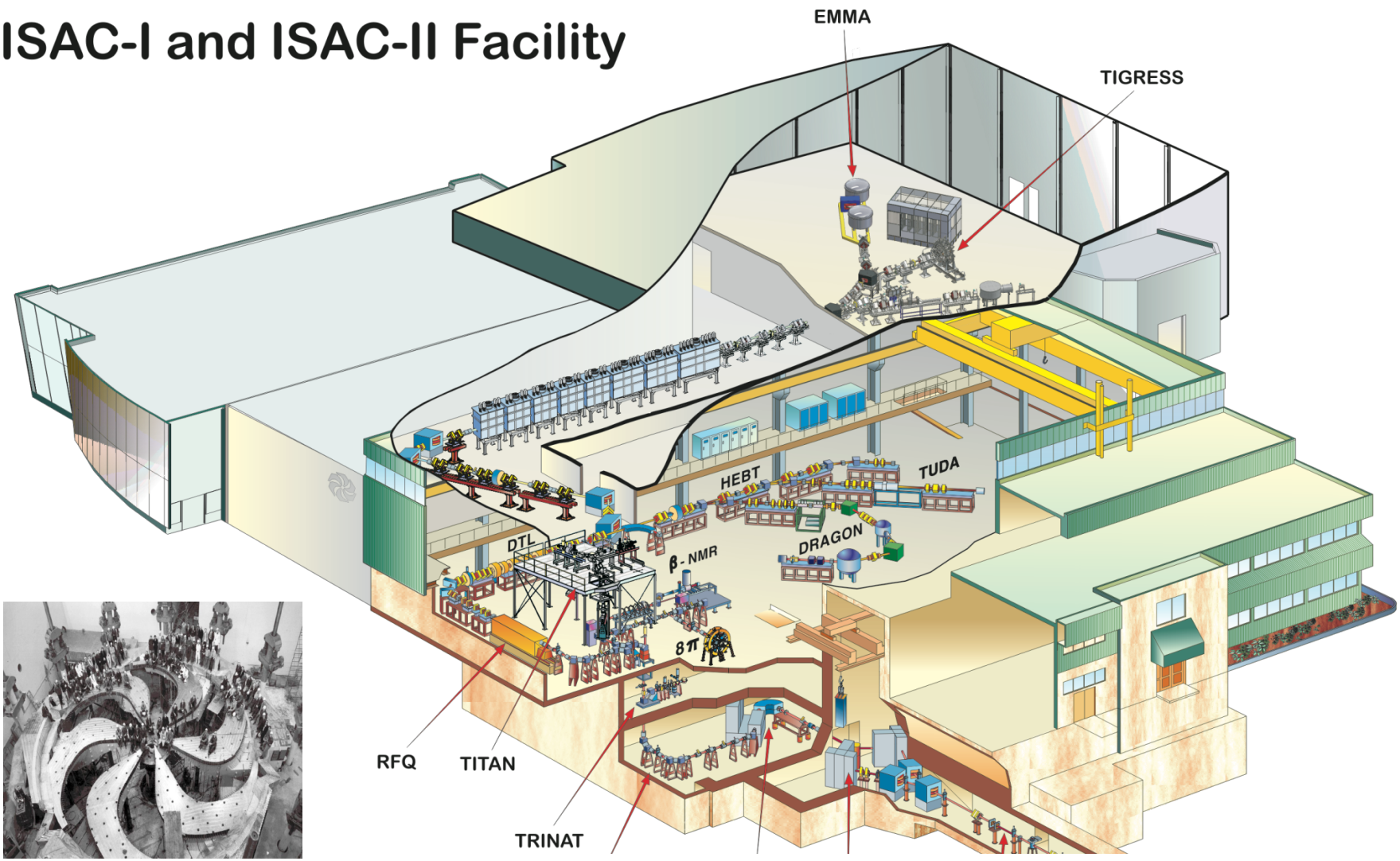


P. Voss et al. Nucl. Inst. and Meth. A 746 (2014) 87.

TIP: calibrating target/degrader separation

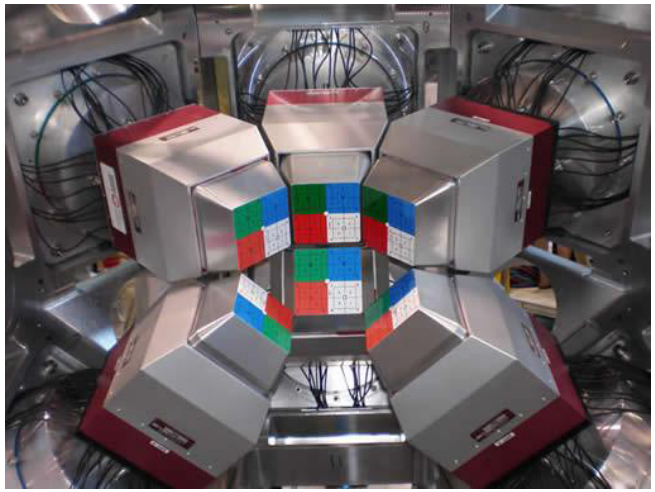


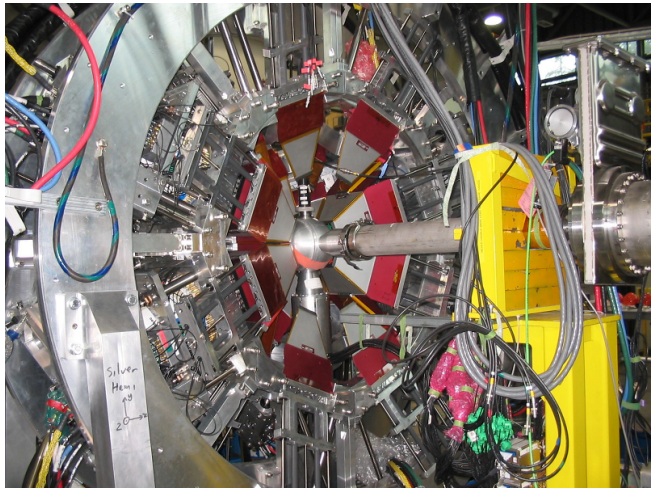
RIB production at TRIUMF



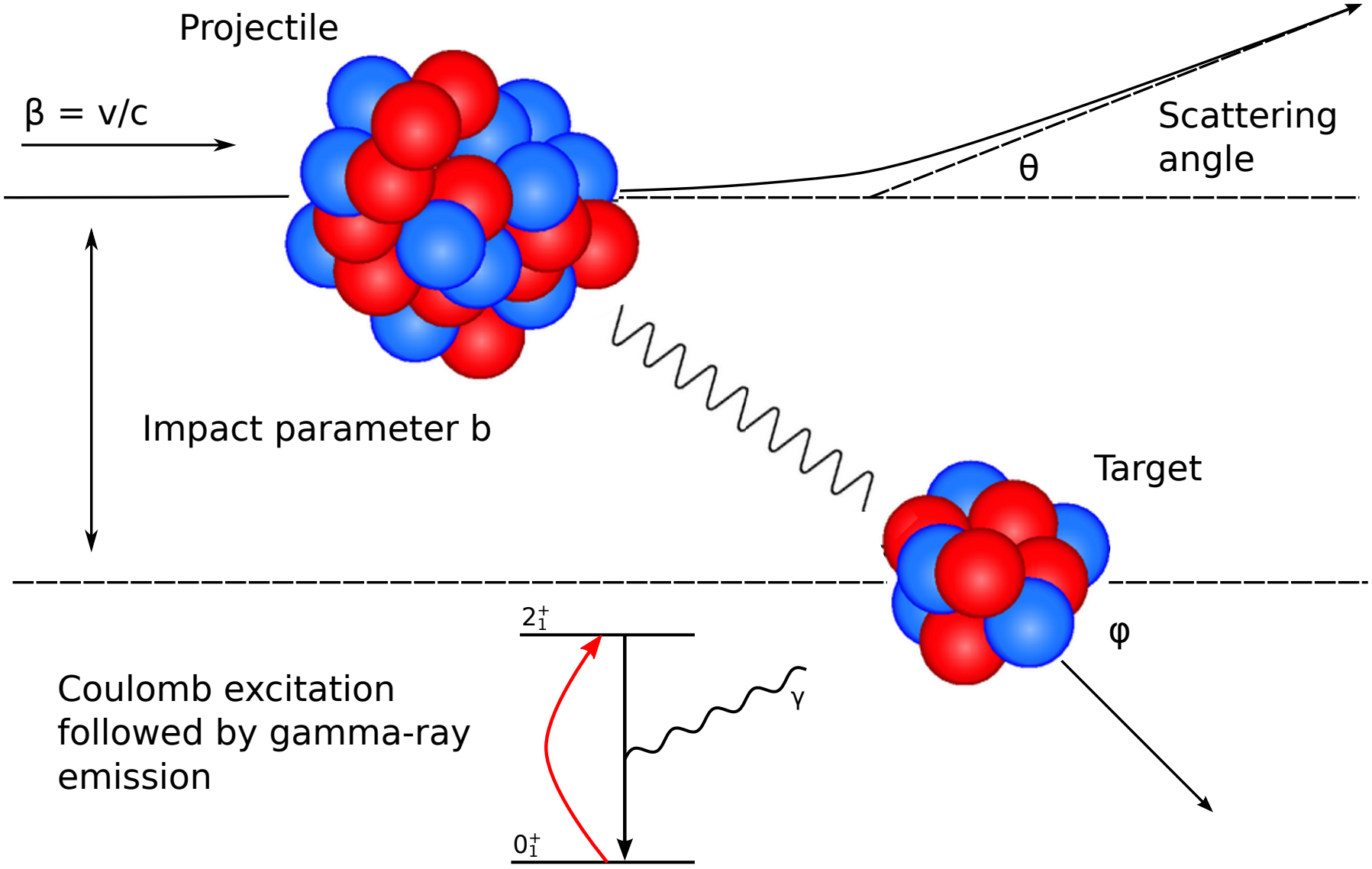
TIGRESS at TRIUMF

- TRIUMF-ISAC Gamma-Ray Escape Suppressed Spectrometer (TIGRESS) is an array of up to 16 segmented HPGe detectors.
- Each detector consists of 4 crystals with 8 segments/crystal with sub-segment position sensitivity.
- TIGRESS can be run in multiple configurations utilizing BGO shielding and optional X-ray absorbers.





Coulomb excitation (inverse kinematics)



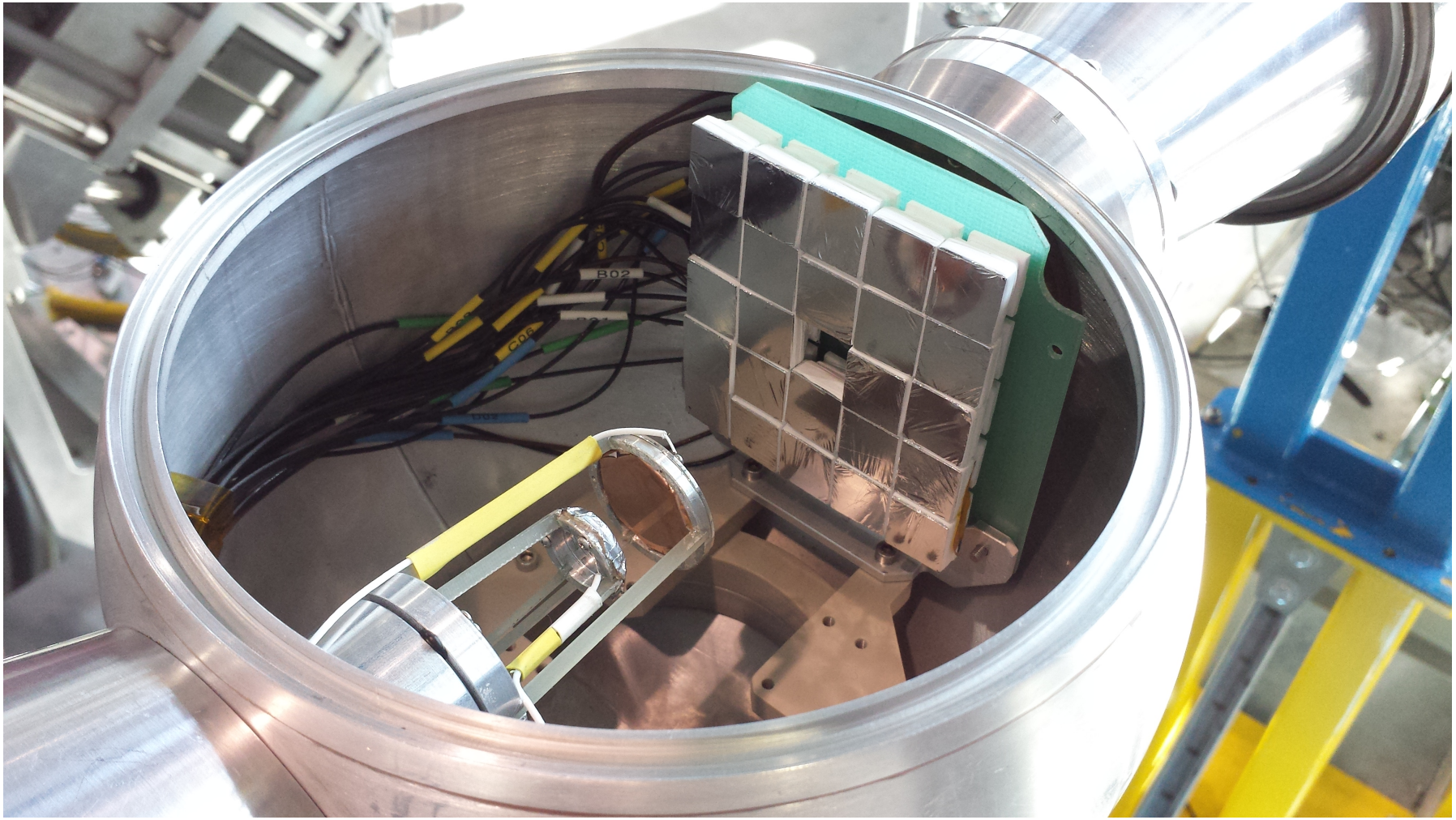
Coulomb excitation followed by gamma-ray emission

TIP commissioning experiment

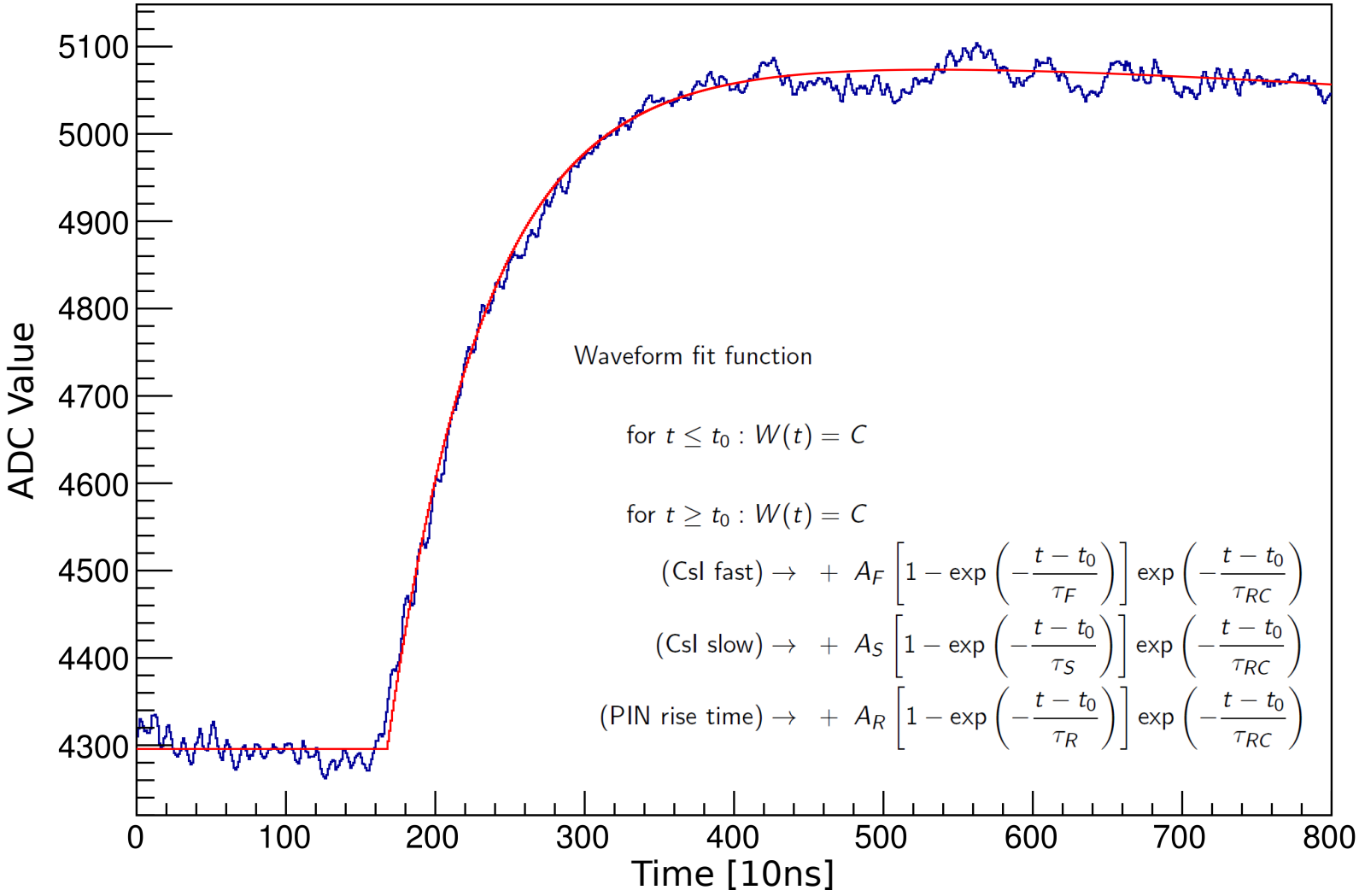
- Goal: measurement of the $2_1^+ \rightarrow 0_1^+$ lifetime in ^{84}Kr.
- Previous measurement: 5.84(18) ps.
- TIP and 11 TIGRESS detectors in a 3/5/3 configuration with 24-element CsI(Tl) wall.
- Excited state populated via partially unsafe Coulex reaction.
- Data acquired using a TIGRESS/CsI(Tl) coincidence trigger.

T. J. Mertzimekis et al. Phys. Rev. C 64 (2001) 024314.

TIP with the CsI(Tl) wall

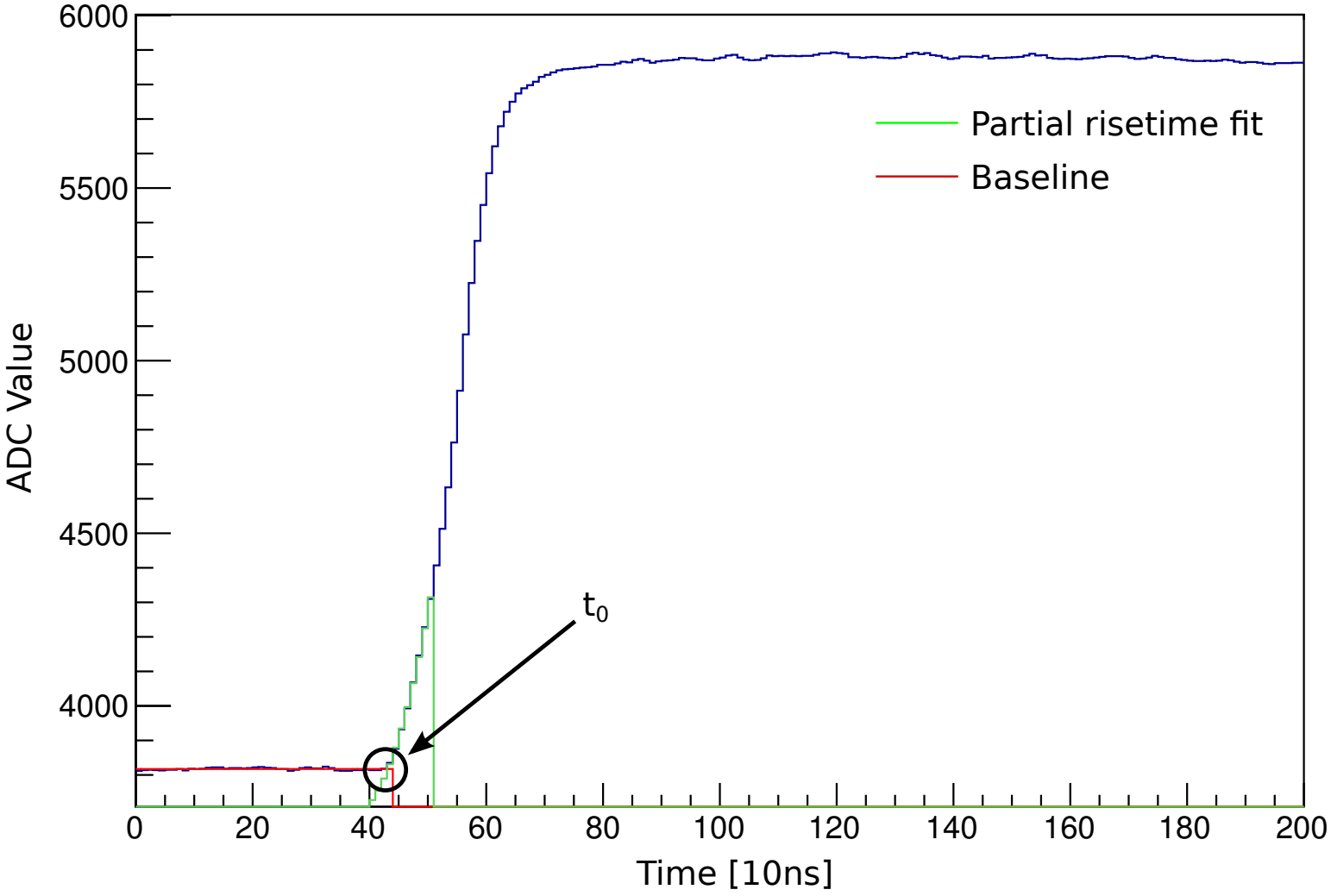


CsI(Tl) detector waveform fits

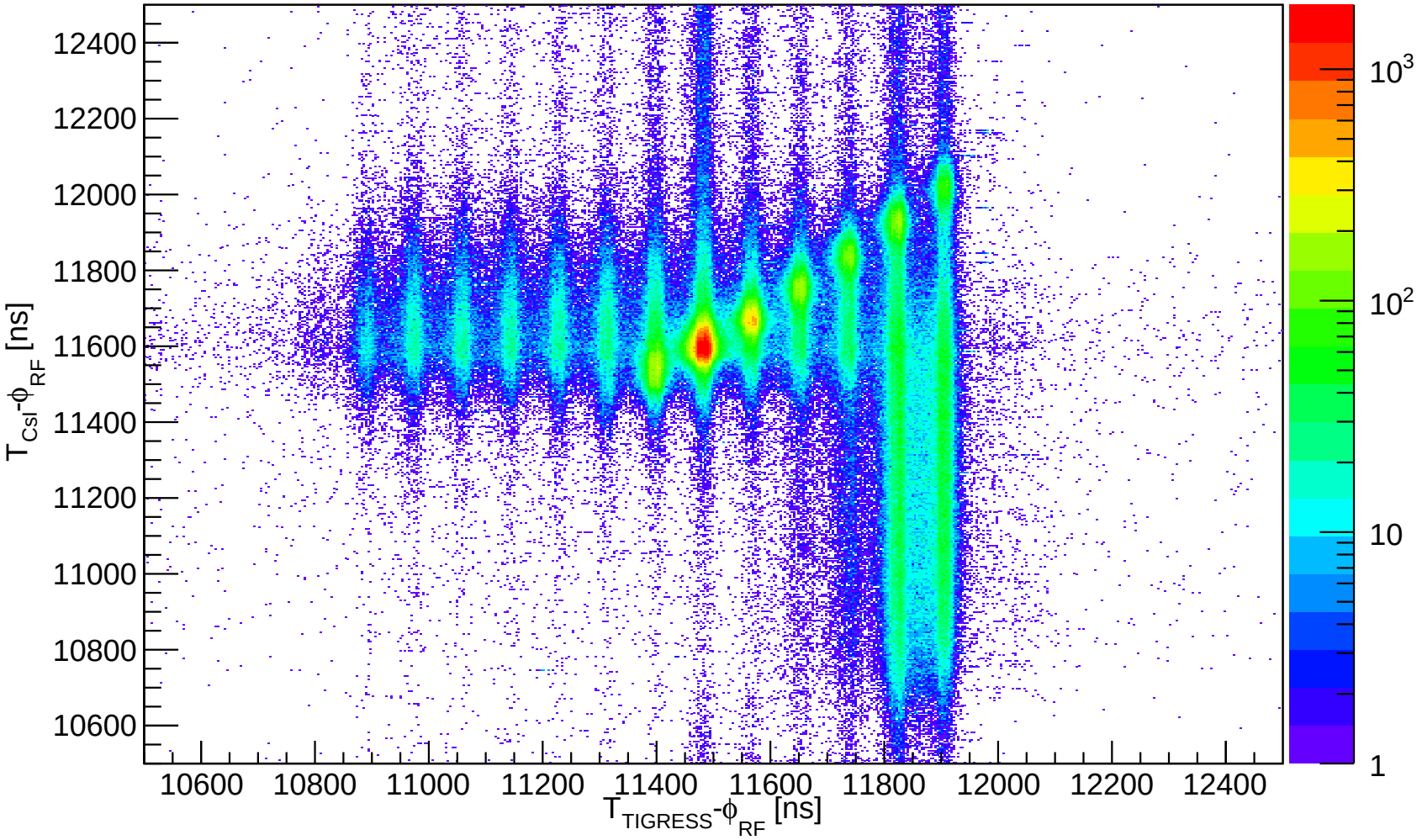


M. Bendel et. al. Eur. Phys. J. A 49 (2013) 69.

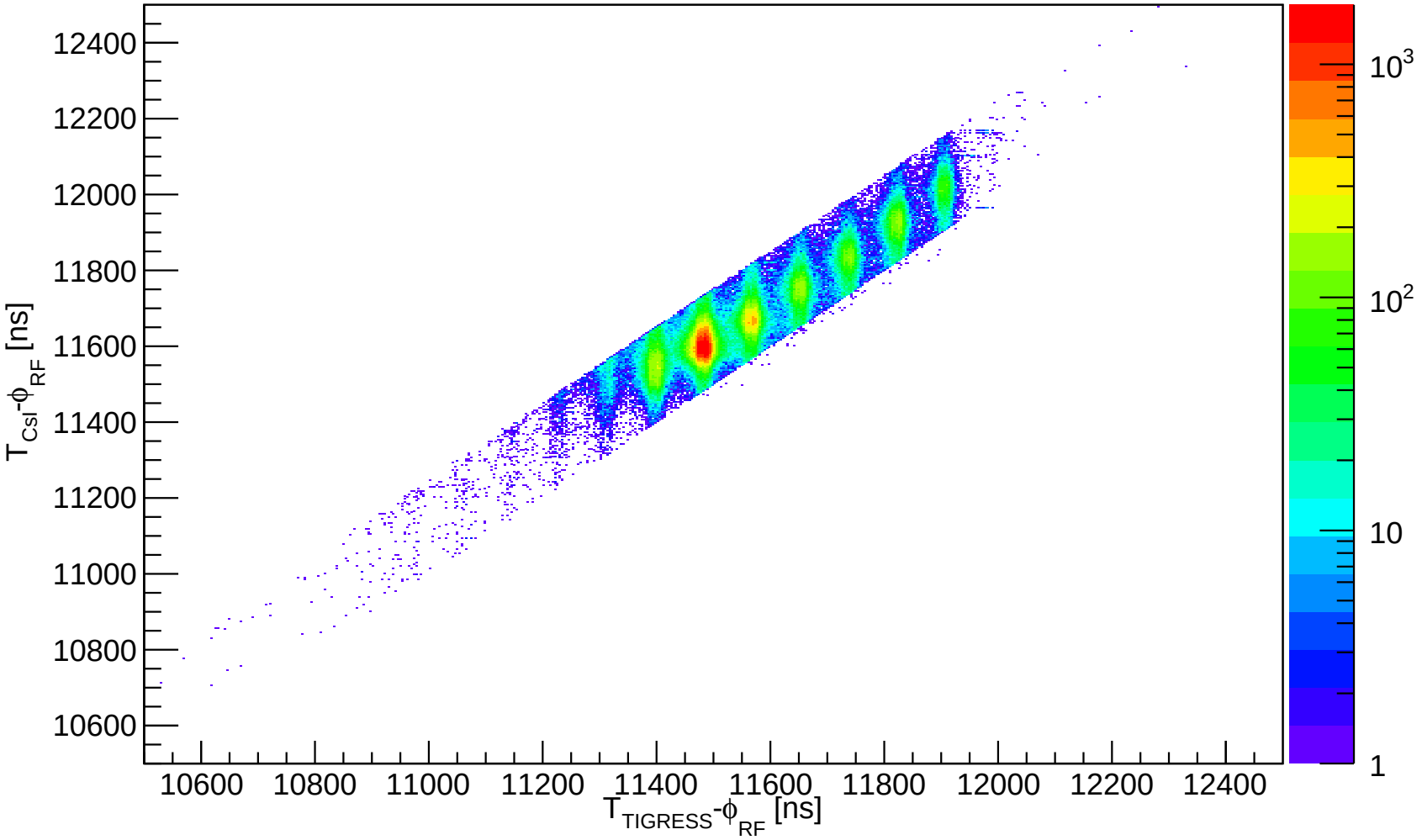
TIGRESS detector waveform fits



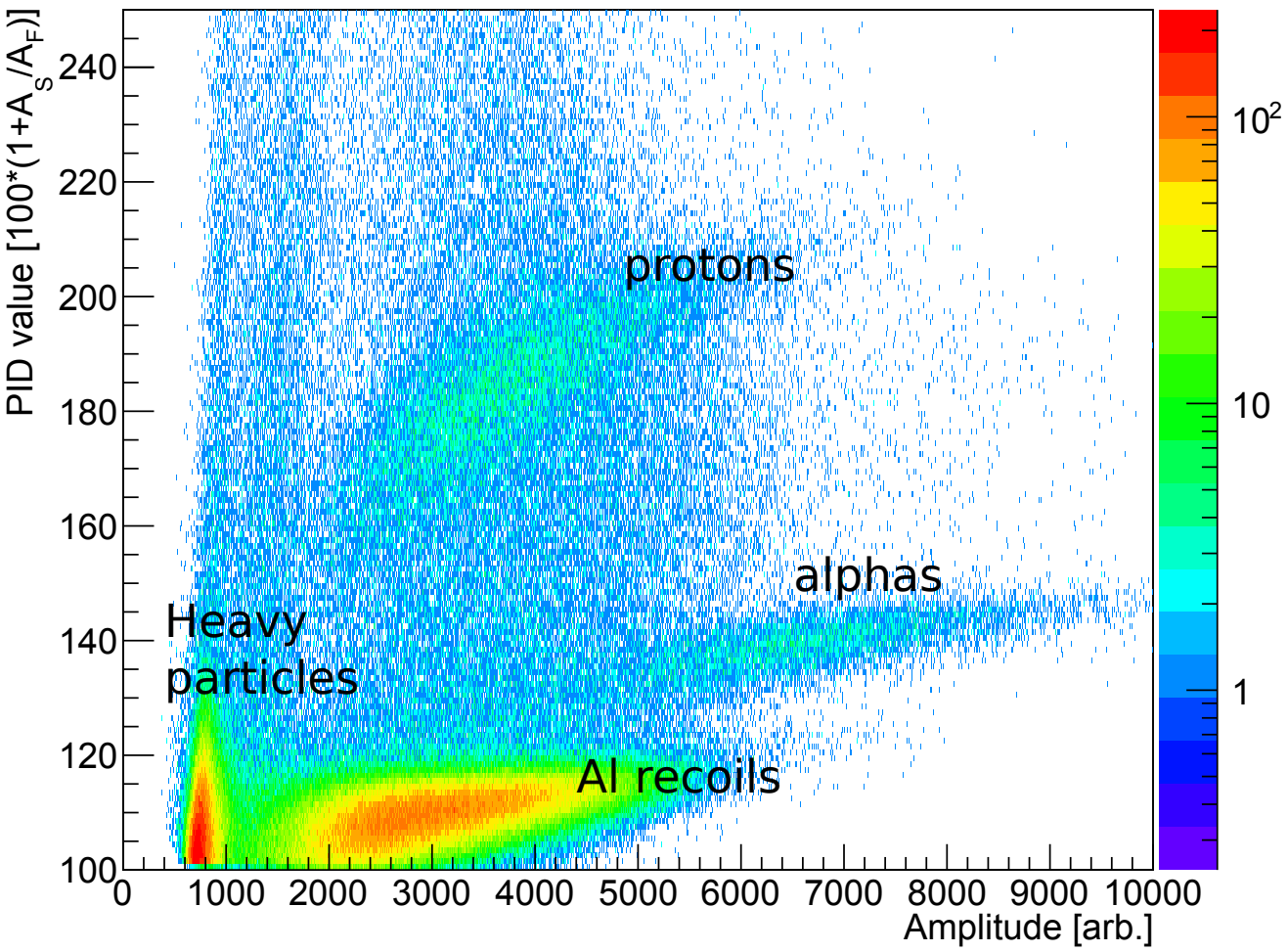
TIGRESS/CsI(Tl) array timing plot



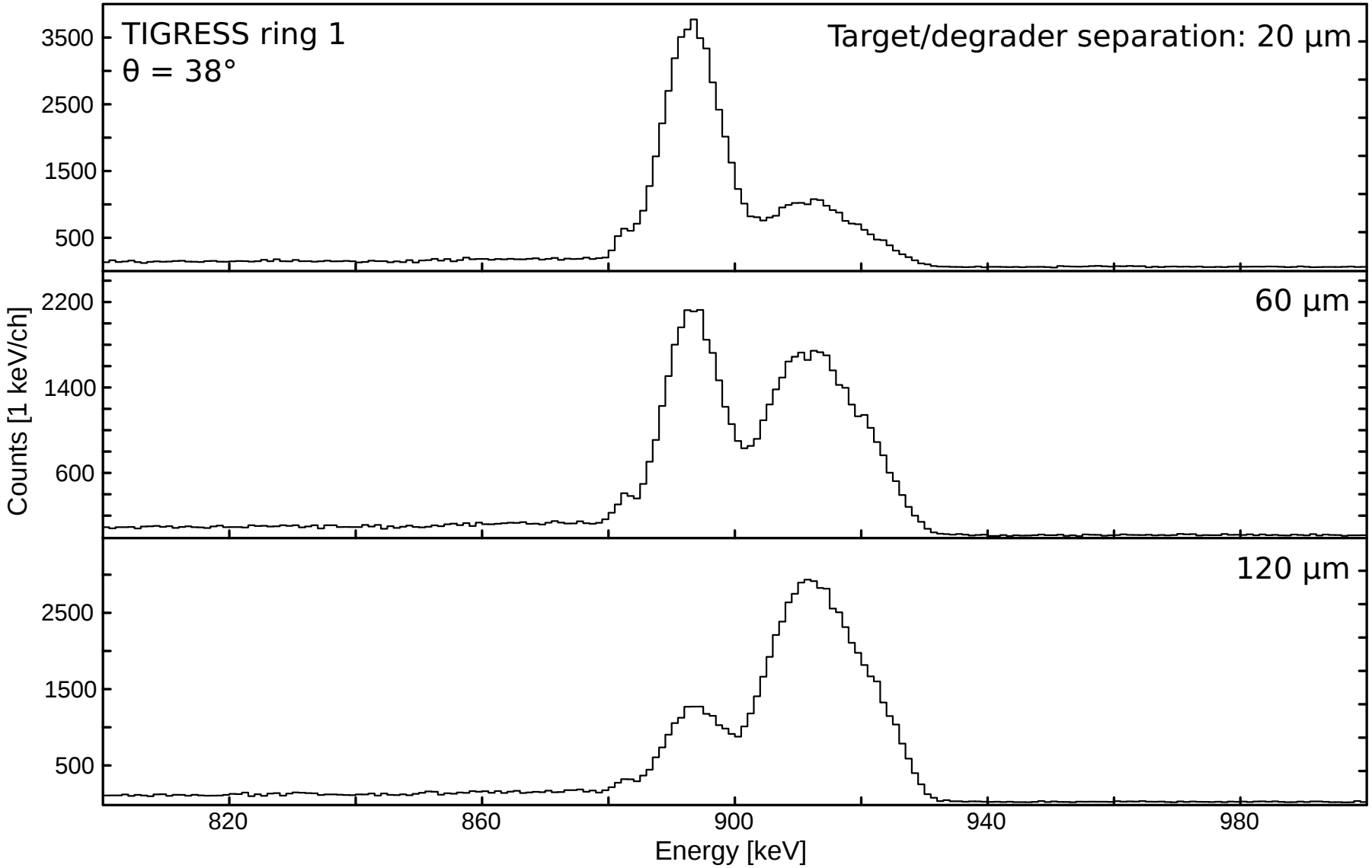
TIGRESS/CsI(Tl) array: time correlated events only



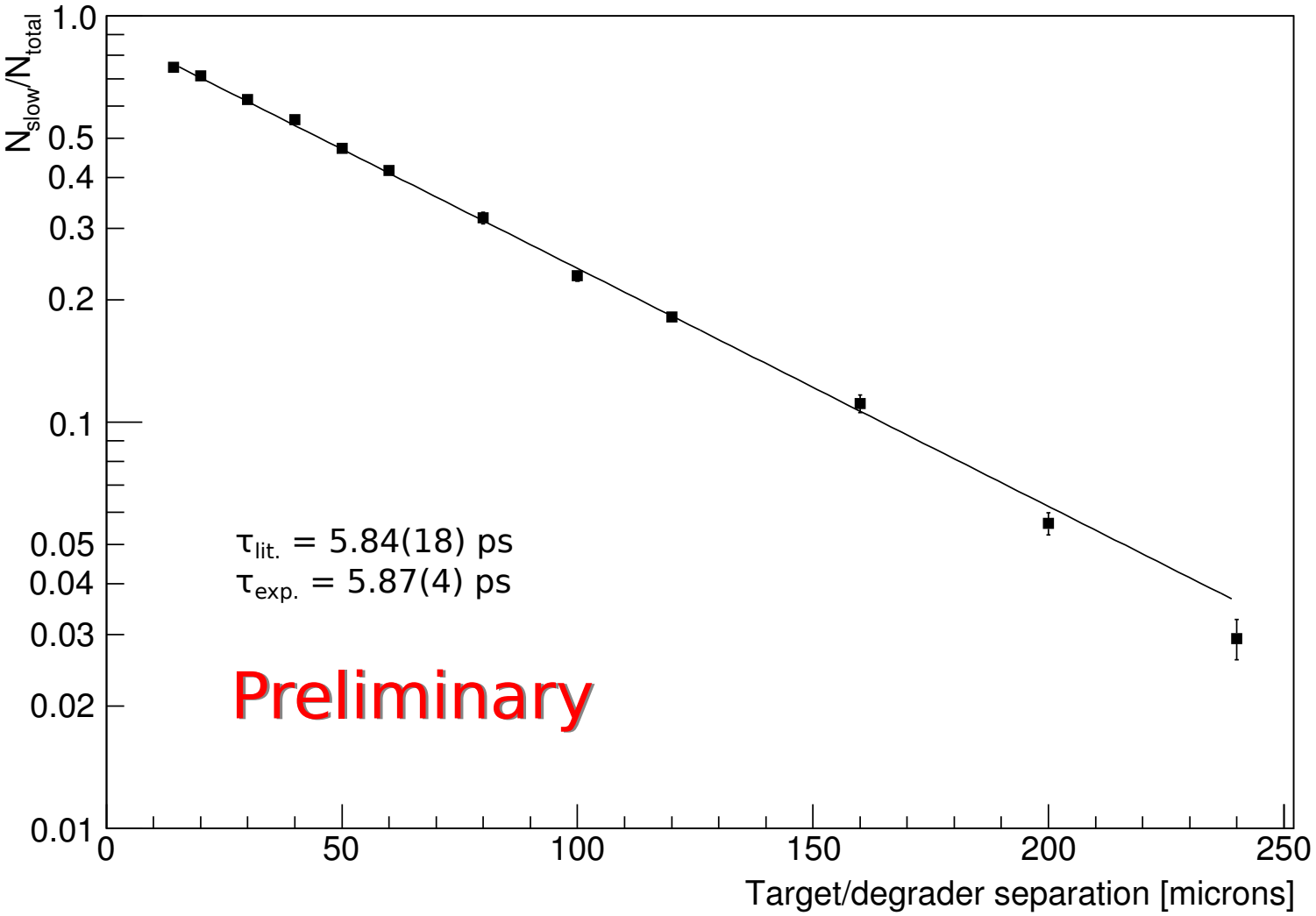
Identifying ^{84}Kr Coulex recoils



Effect of target/degrader separation

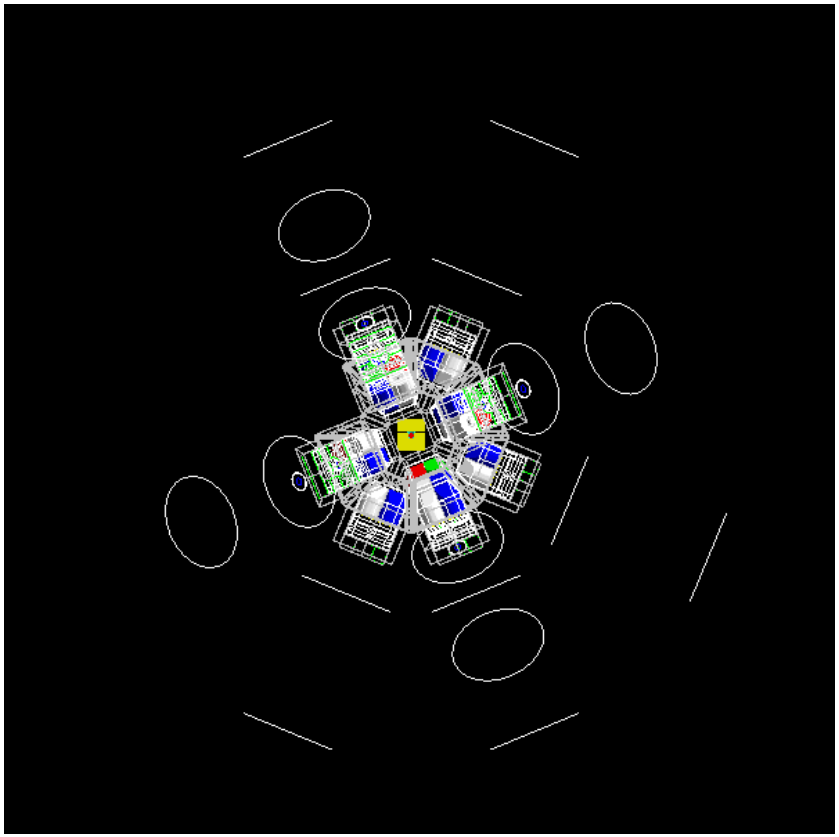


^{84}Kr decay curve



TIP Geant4 simulations

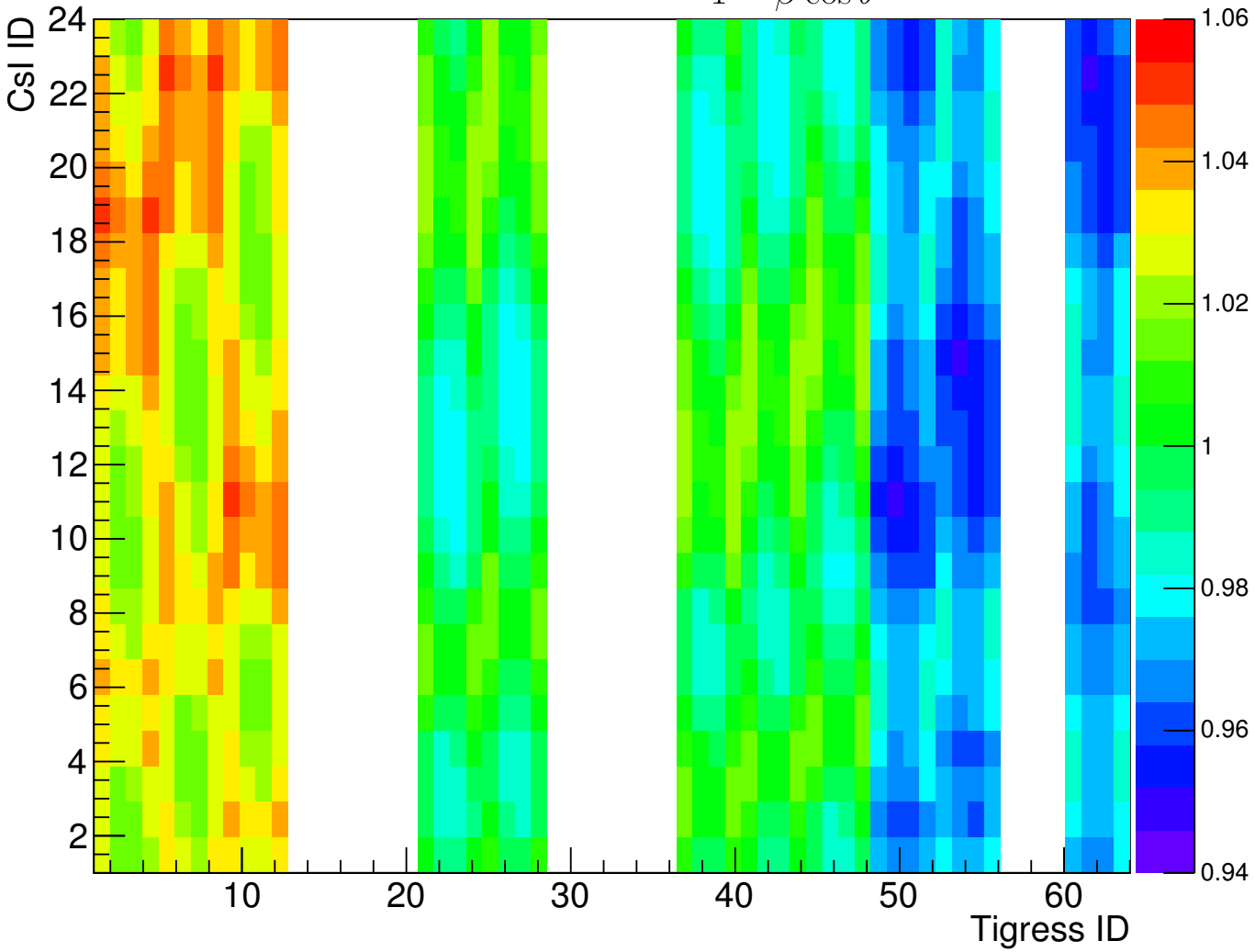
- User-defined reaction mechanism (Coulex) followed by gamma-ray decay.
- Analytic solutions for single step $E2$ process (Coulex kinematics, cross sections, angular distributions).
- Gamma-ray sensitive detectors ported from GRIFFIN/TIGRESS code originating from Guelph.
- Simulate lineshapes $\rightarrow$ extract lifetimes.



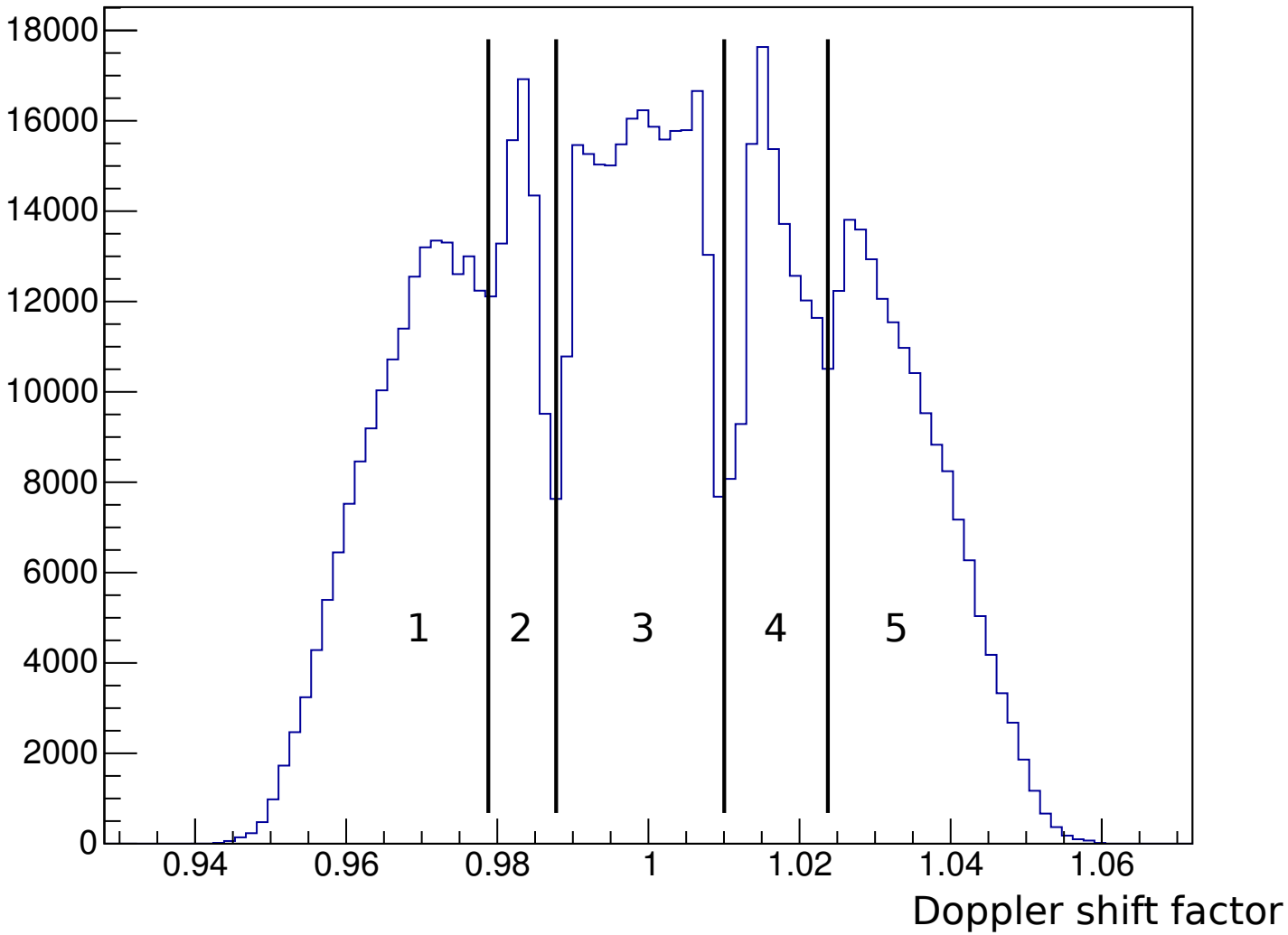
Adrich et al. Nucl. Inst. and Meth. A 598 (2009) 454, Alder et al. Rev. Mod. Phys. 28 (1956) 432.

Simulated Doppler shift map for ^{84}Kr

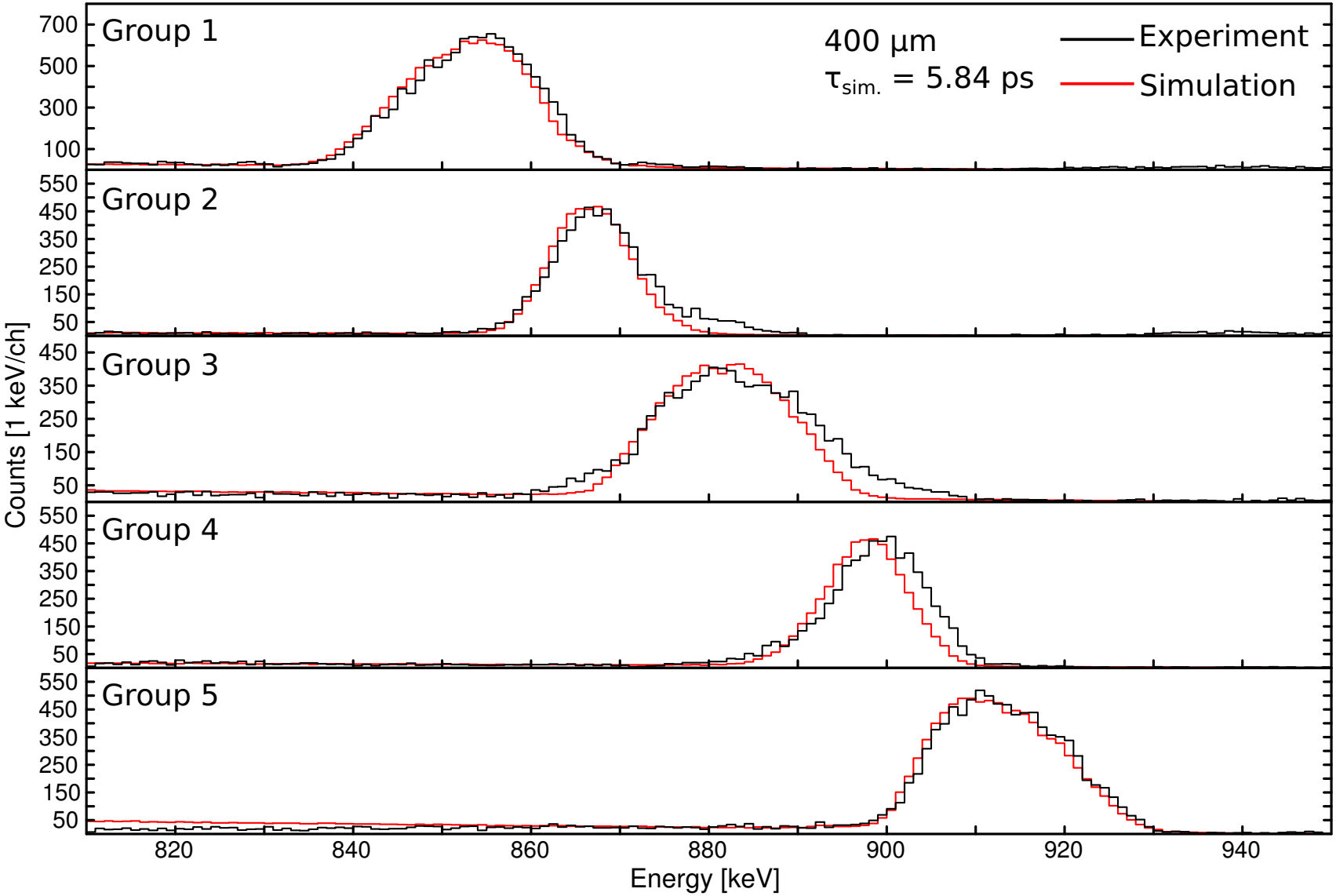
$$\text{Doppler shift factor} = \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$



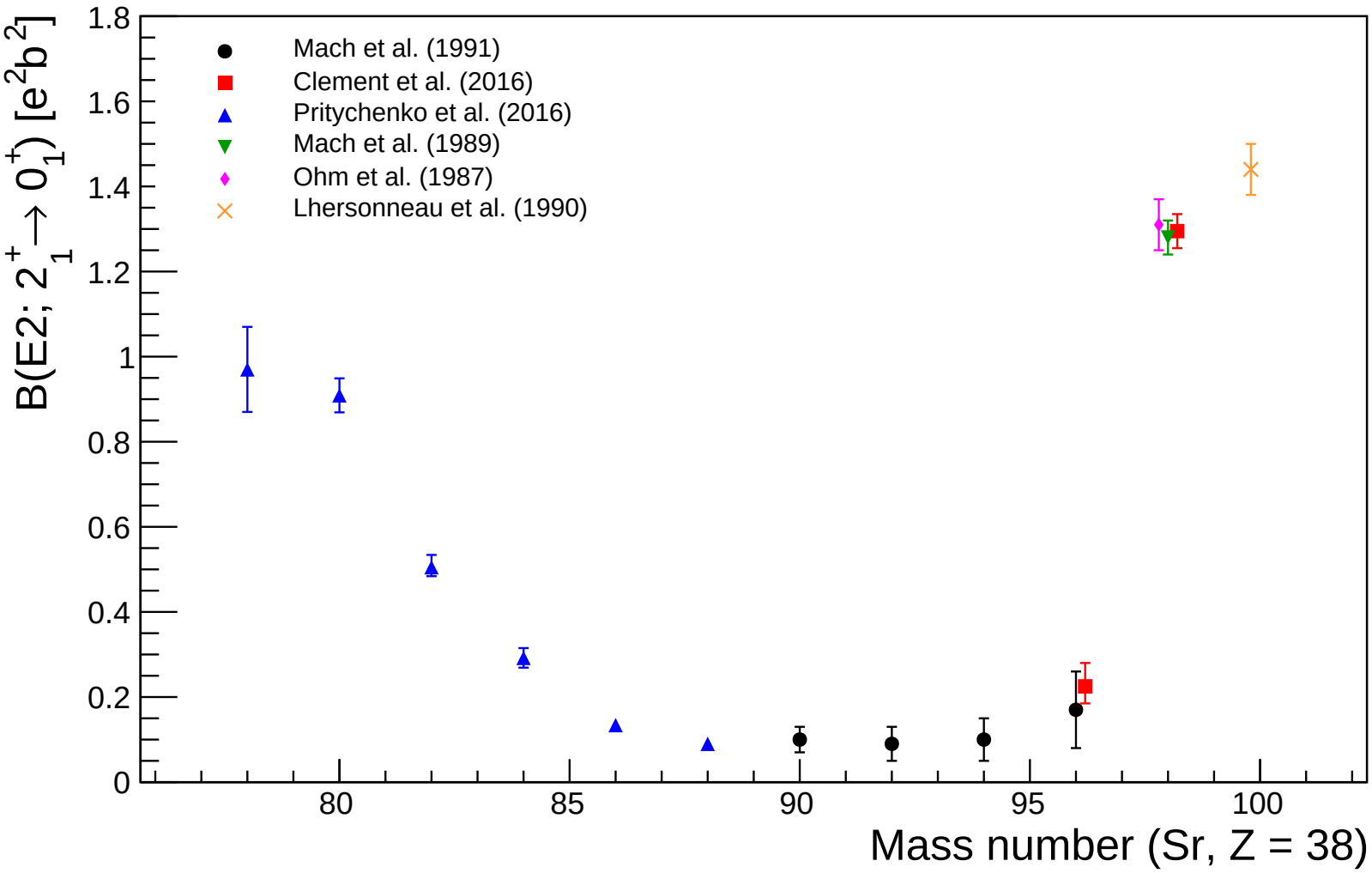
Doppler shift groups for lineshape analysis



RDM lineshape fits for ^{84}Kr



Coulex/RDM at TRIUMF: the case for ^{94}Sr

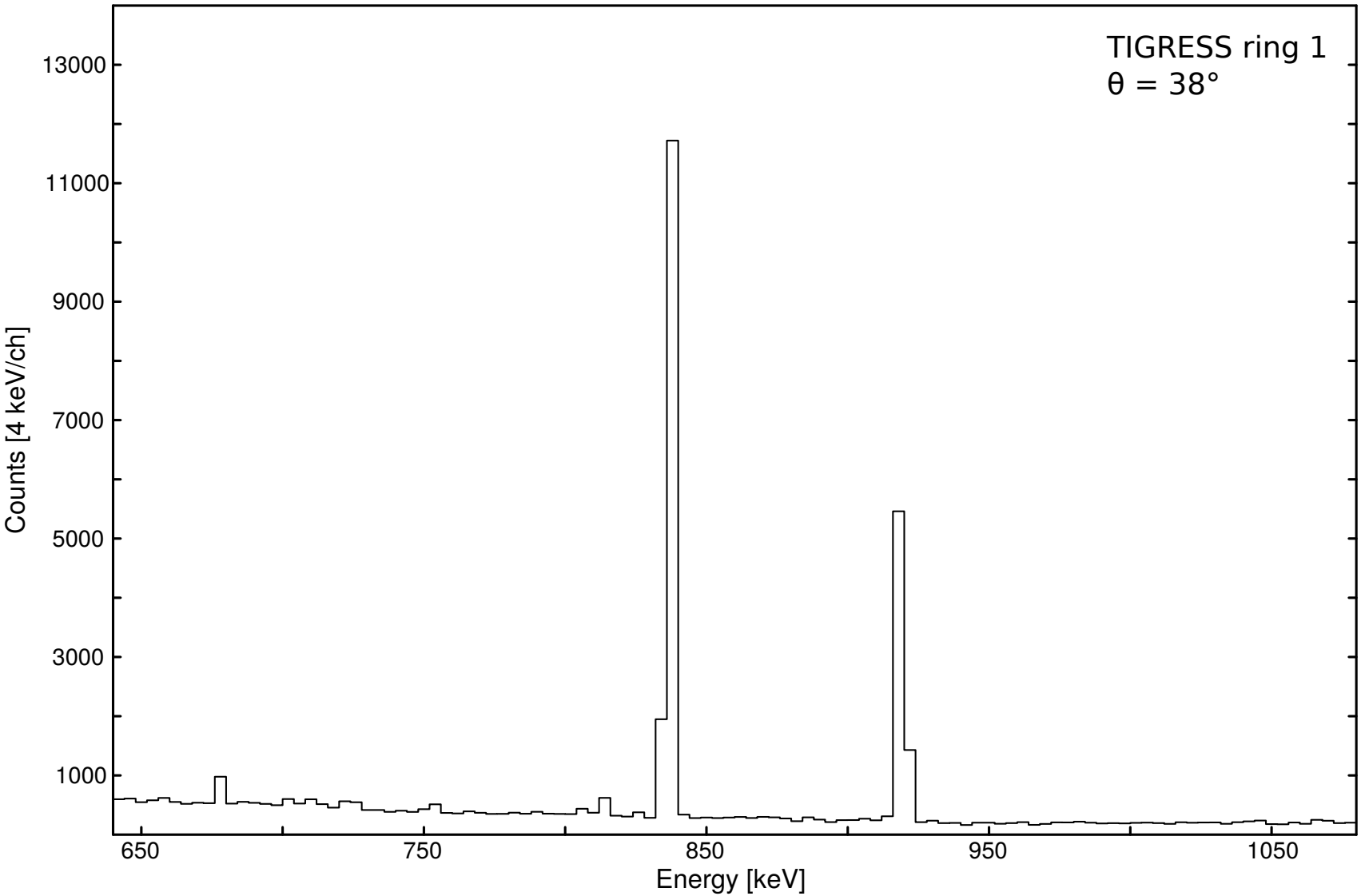


^{94}Sr proposal

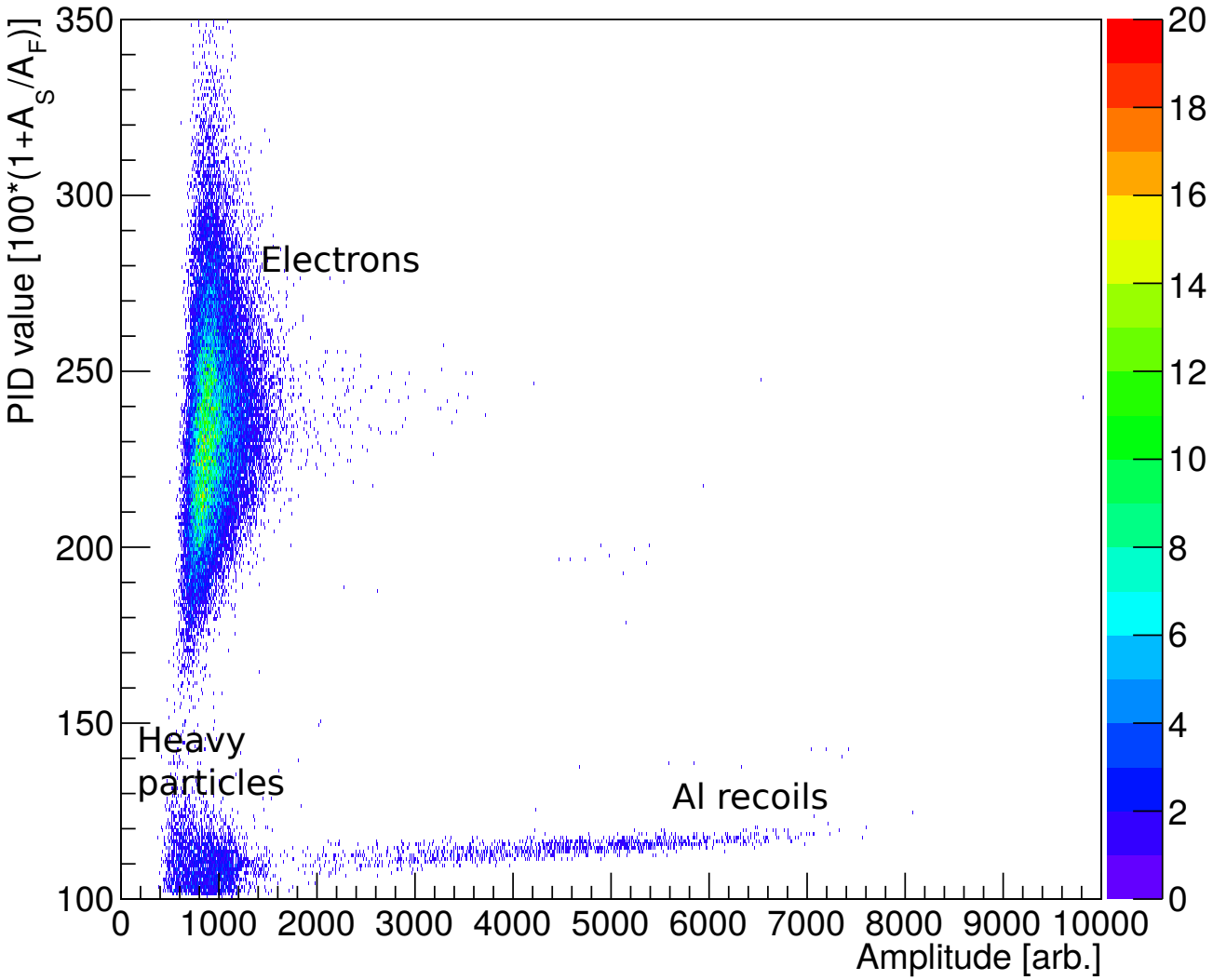
- Based on the success of the commissioning run, a ^{94}Sr lifetime measurement experiment was performed from December 9–14 at TRIUMF.
- Goal: measurement of the $2_1^+ \rightarrow 0_1^+$ lifetime in ^{94}Sr.
- Previous measurement: 10(4) ps.
- TIP and 16 TIGRESS detectors in a 4/8/4 configuration with 24-element CsI(Tl) wall.
- Reaction mechanism, trigger settings and analysis techniques established during commissioning run.

Mach et al. Nuc. Phys. A 523 (1991) 197.

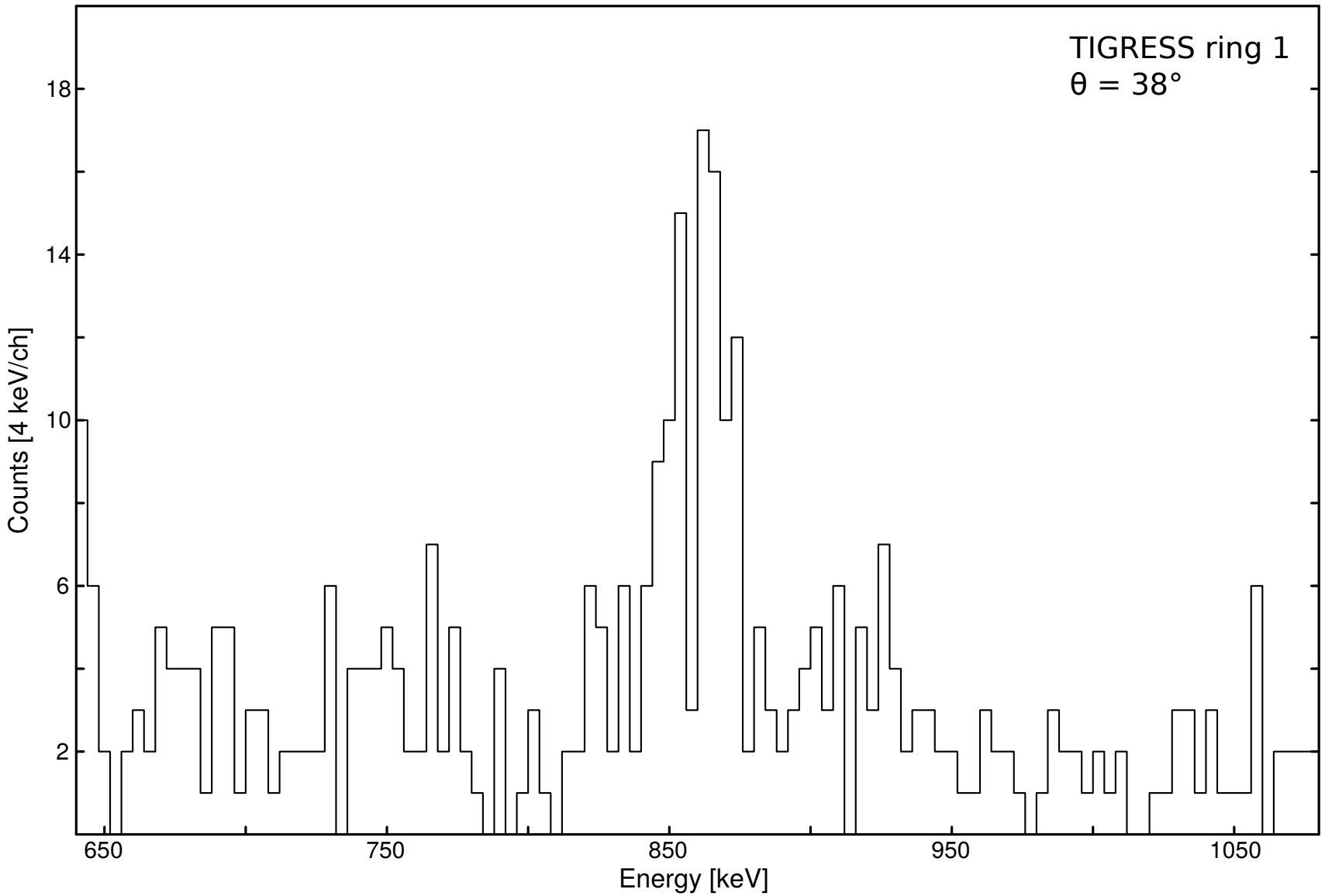
^{94}Sr RDM spectrum: 100 μm



Identifying ^{94}Sr Coulex recoils



PID gated ^{94}Sr RDM spectrum: 100 μm



Simulated Doppler shift map for ^{94}Sr

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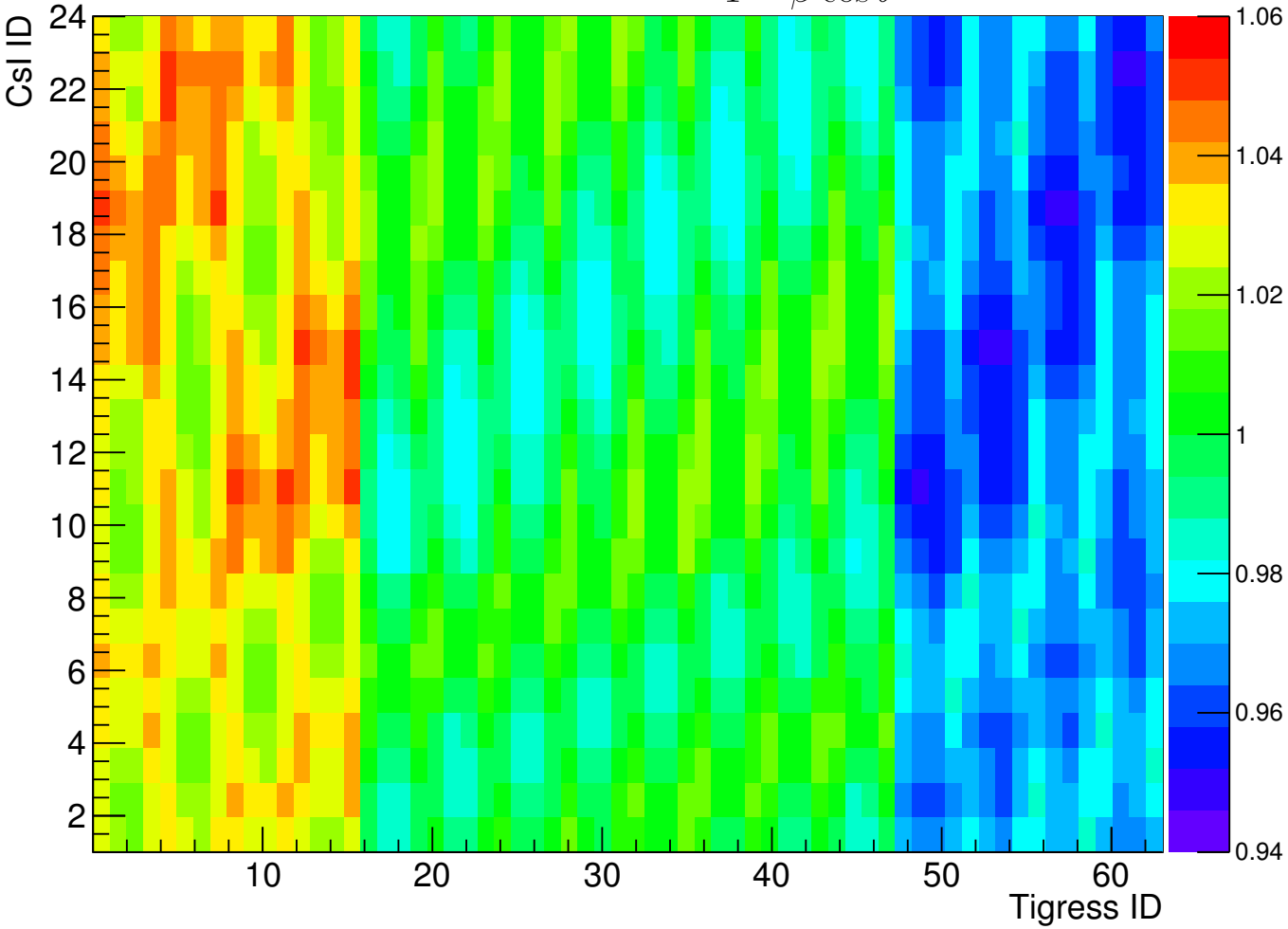
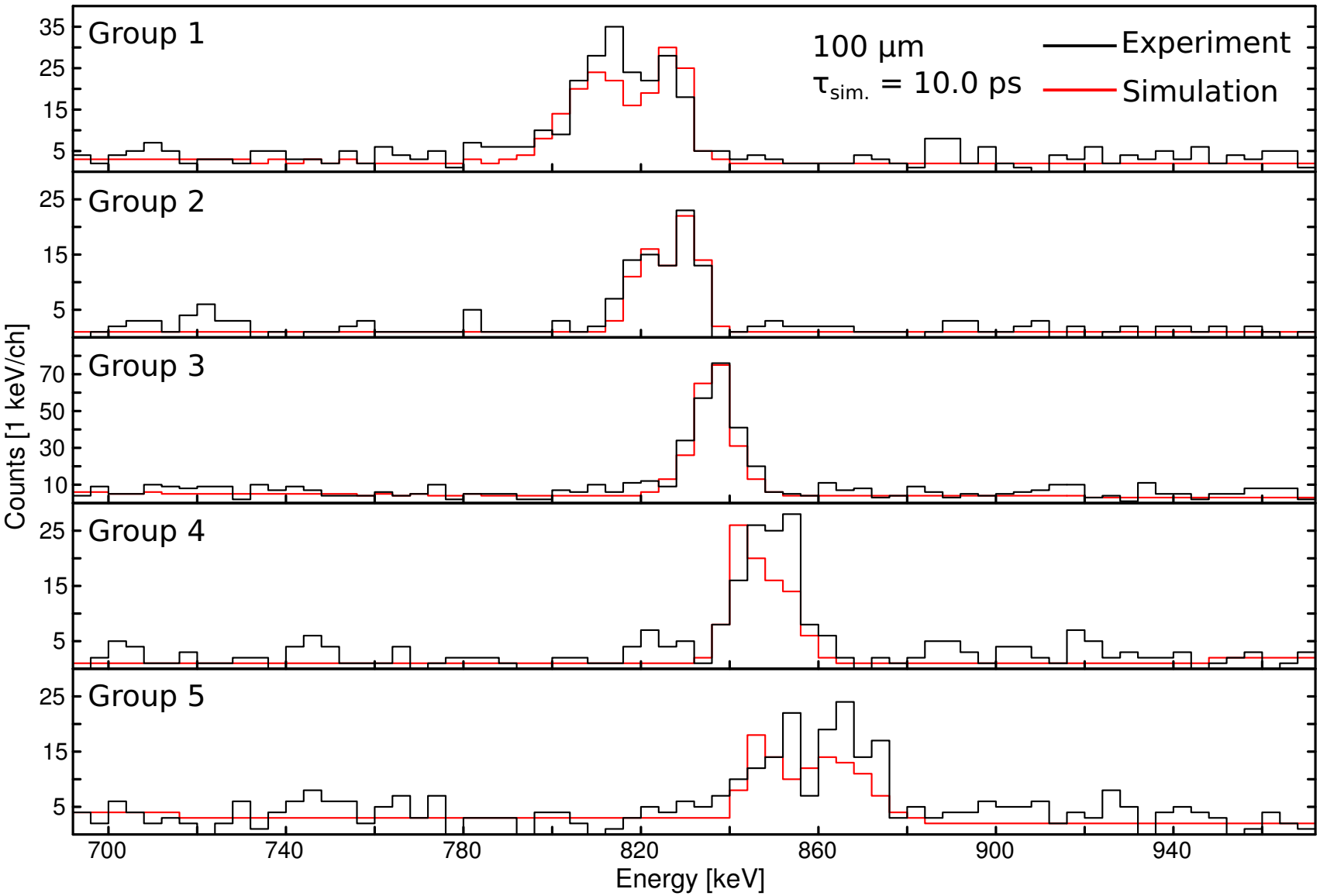


RDM lineshape fits for ^{94}Sr



Acknowledgments

TIP Design
R. Henderson, TRIUMF

Simon Fraser University
C. Andreoiu, D. Cross, T. Domingo, J. Pore, U. Rizwan, K. Starosta, P. Voss, J. Williams

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R. Holland, P. Kowalski, J. Shoults, K. Van Wieren

TRIUMF
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E. T. Rand, C. Svensson

University of Toronto
T. E. Drake

University of Surrey
L. Evitts, S. Hallam

St. Mary's University
R. A. E. Austin

CINP ICPN Canadian Institute of Nuclear Physics Institut canadien de physique nucléaire

SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD

TRIUMF

NSERC CRSNG

TIP commissioning experiment

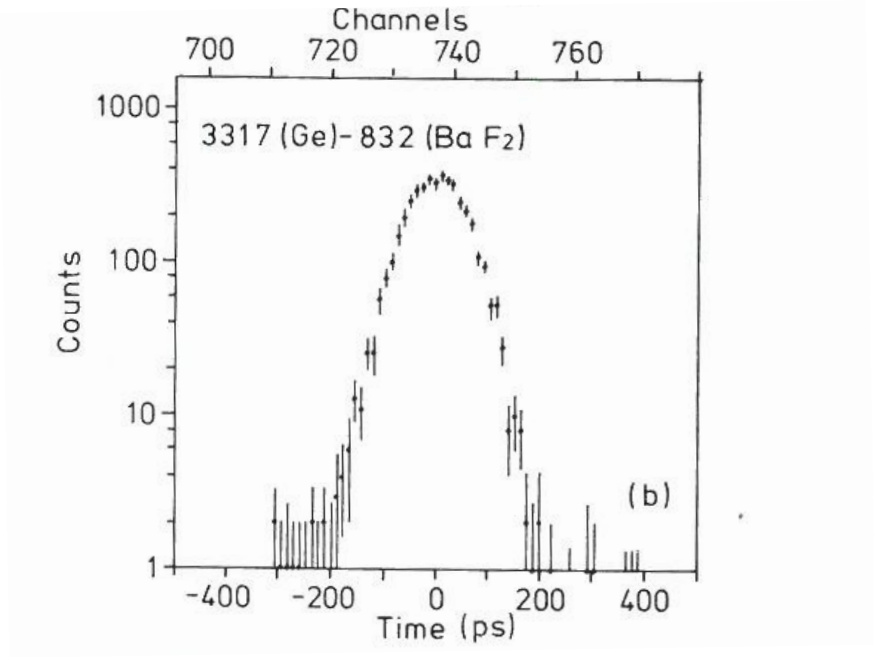
^{84}Kr properties	
E_γ	881.615 keV
$\tau_{lit.}$	5.84(18) ps

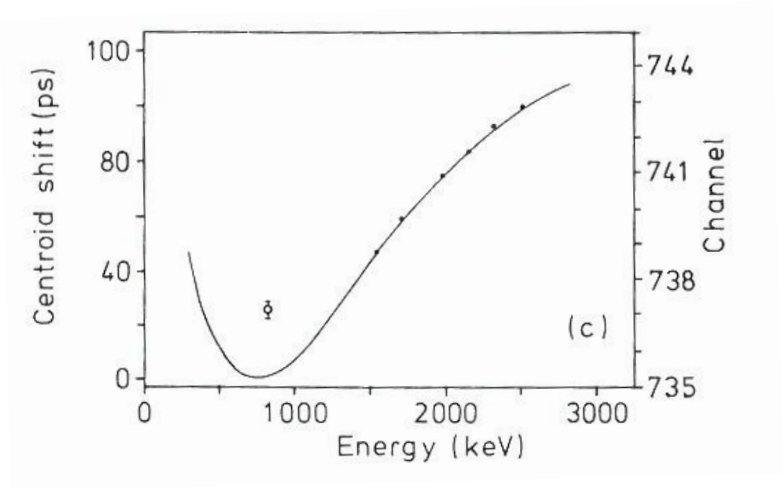
Plunger setup

	Material	Thickness [mg/cm^2]	Thickness [μm]
Target	Al	1.07(4)	3.96(16)
Degrader	Cu	3.90(16)	4.35(18)

^{84}Kr beam properties	
	Energy [MeV]
Coulomb barrier	313
Safe Coulex	200
Beam energy	250

^{94}Sr: Previous results





Timing spectrum and observed centroid shift for ^{90}Sr.

Mach et al. Nuc. Phys. A 523 (1991) 197.

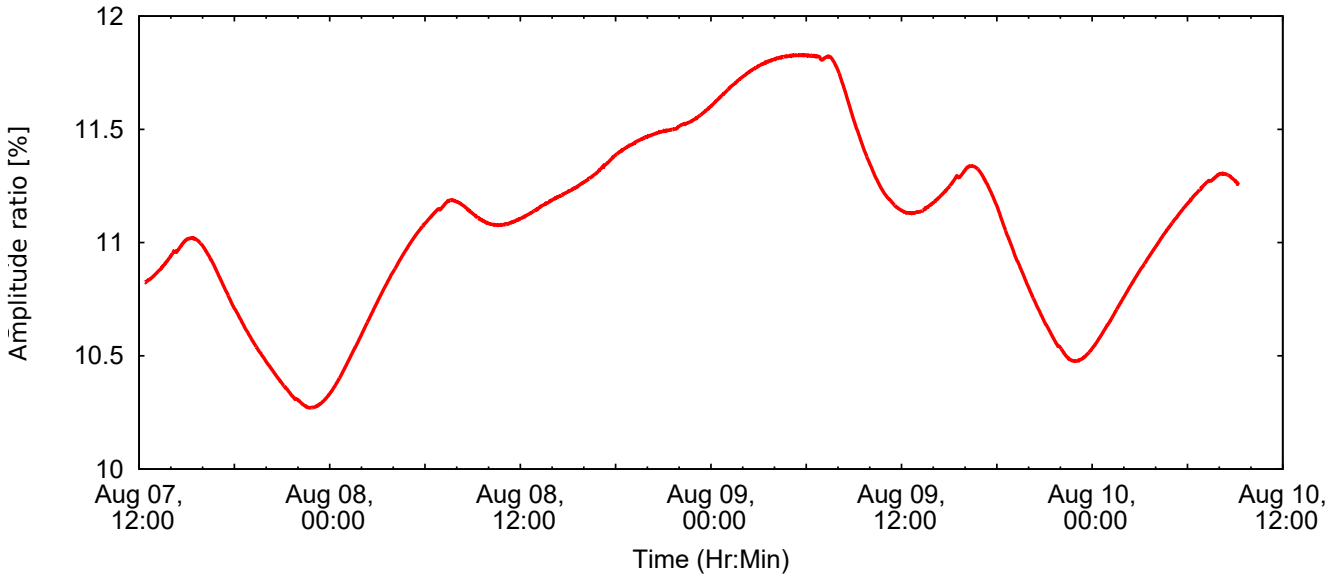
^{94}Sr: Previous results

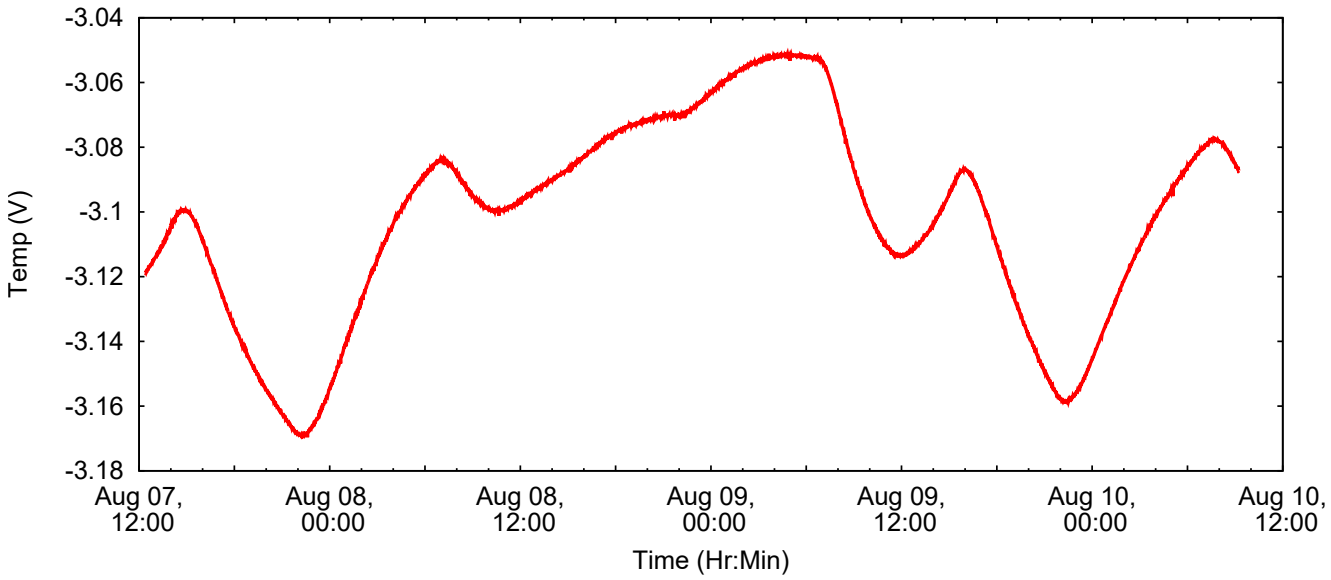
	Time [ps]
Centroid shift	20.1(3.0)
RD correction	10.4(2.6)
Compton correction	-0.6(2.0)
$\tau_{2_1^+ \rightarrow 0_1^+}$	10(4)

- Timing spectrum FWHM is 96 ps.
- These measurements are at the limit of the applicability of the fast timing technique.
- Is the onset of deformation in the Sr isotopes truly as sudden as it appears?

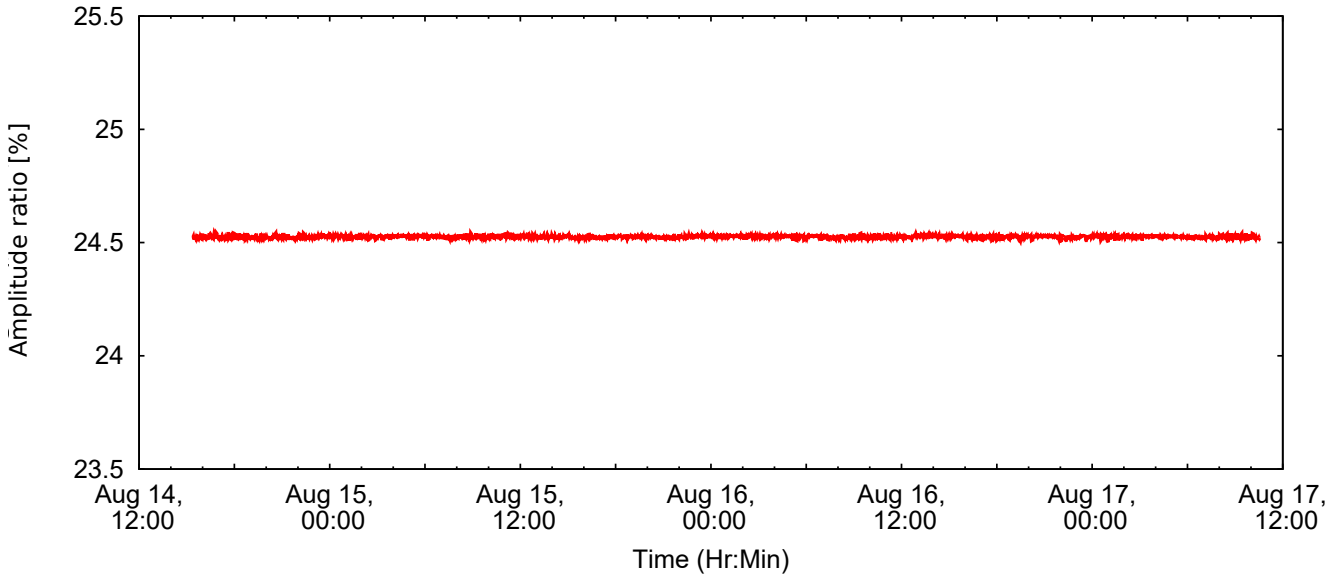
Mach et al. Nuc. Phys. A 523 (1991) 197–227.

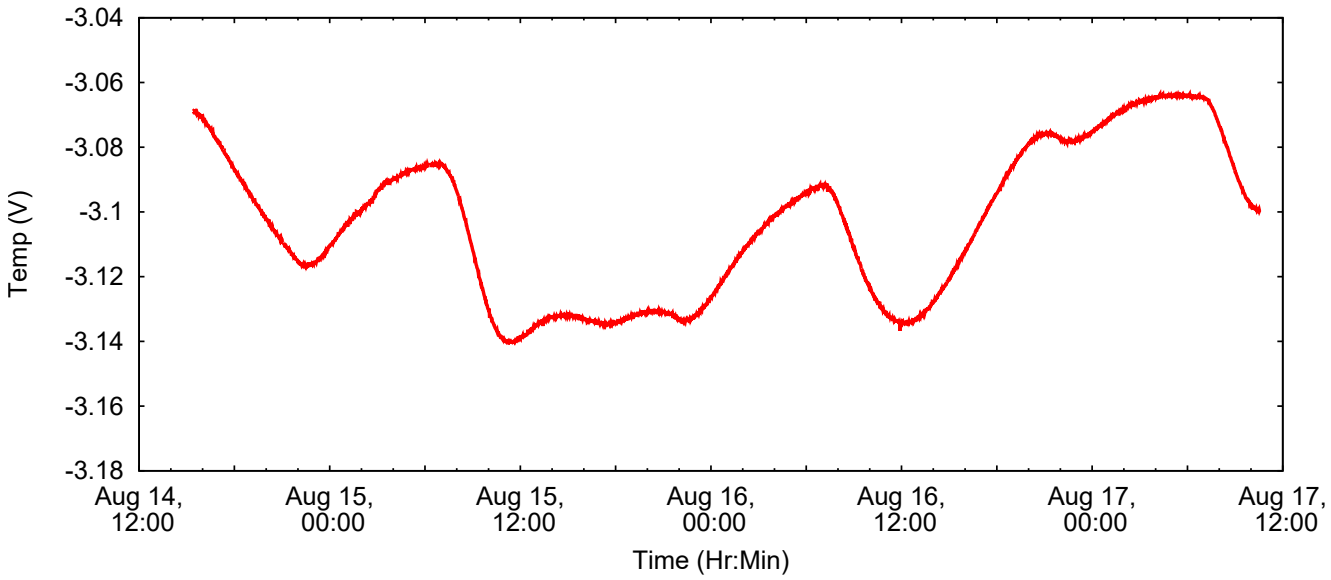
TIP: capacitance stabilization



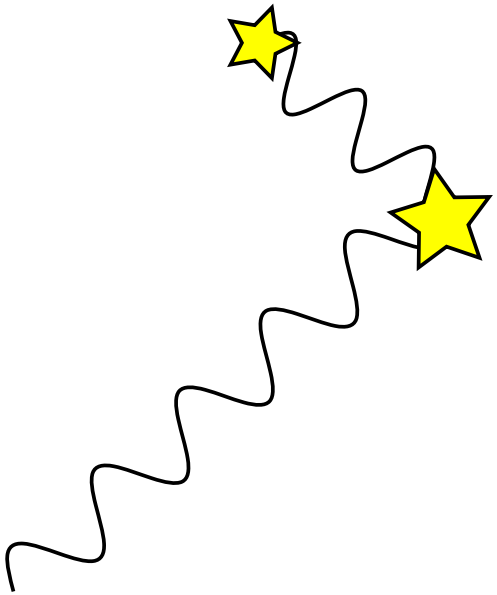


TIP: capacitance stabilization

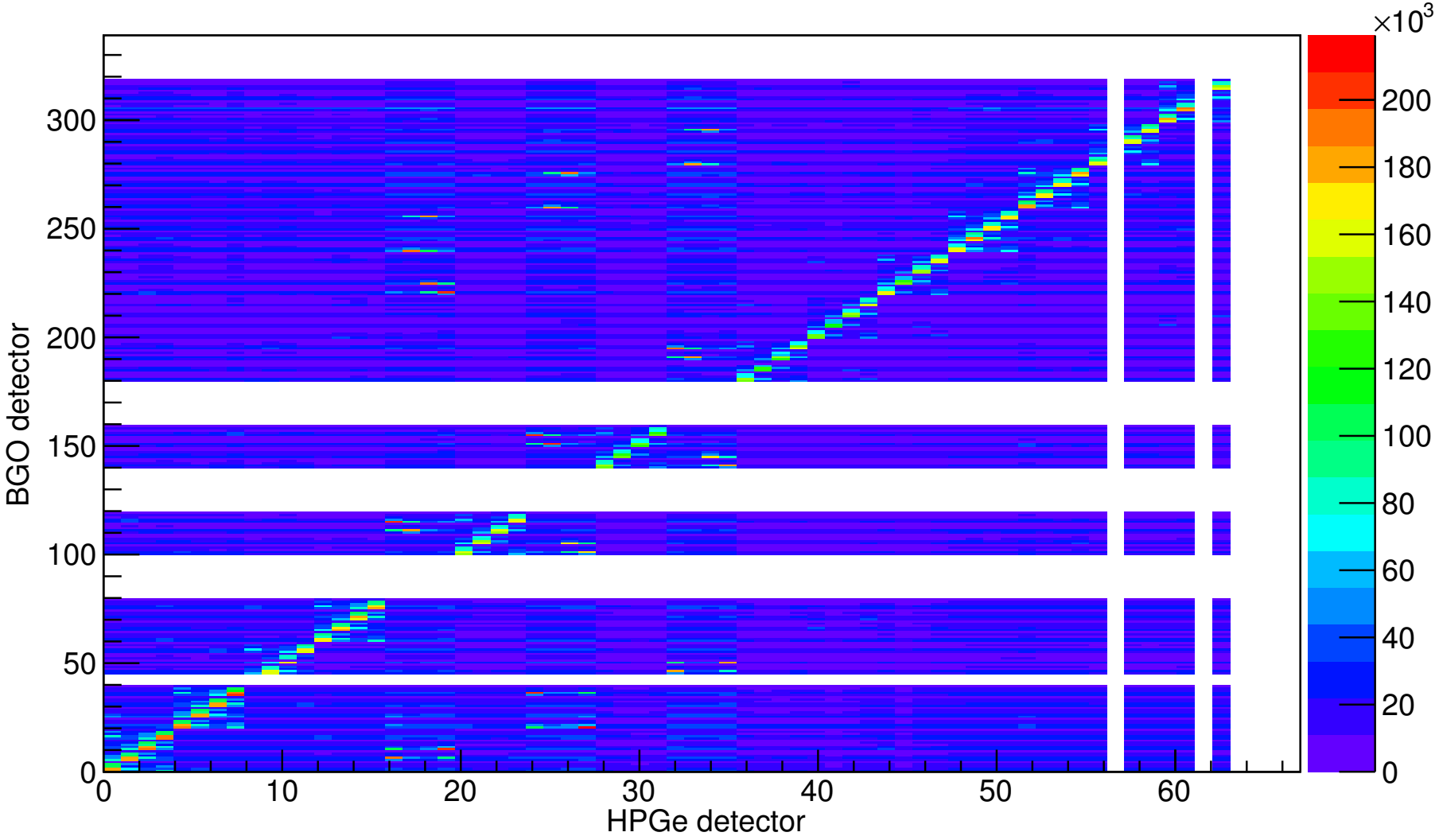




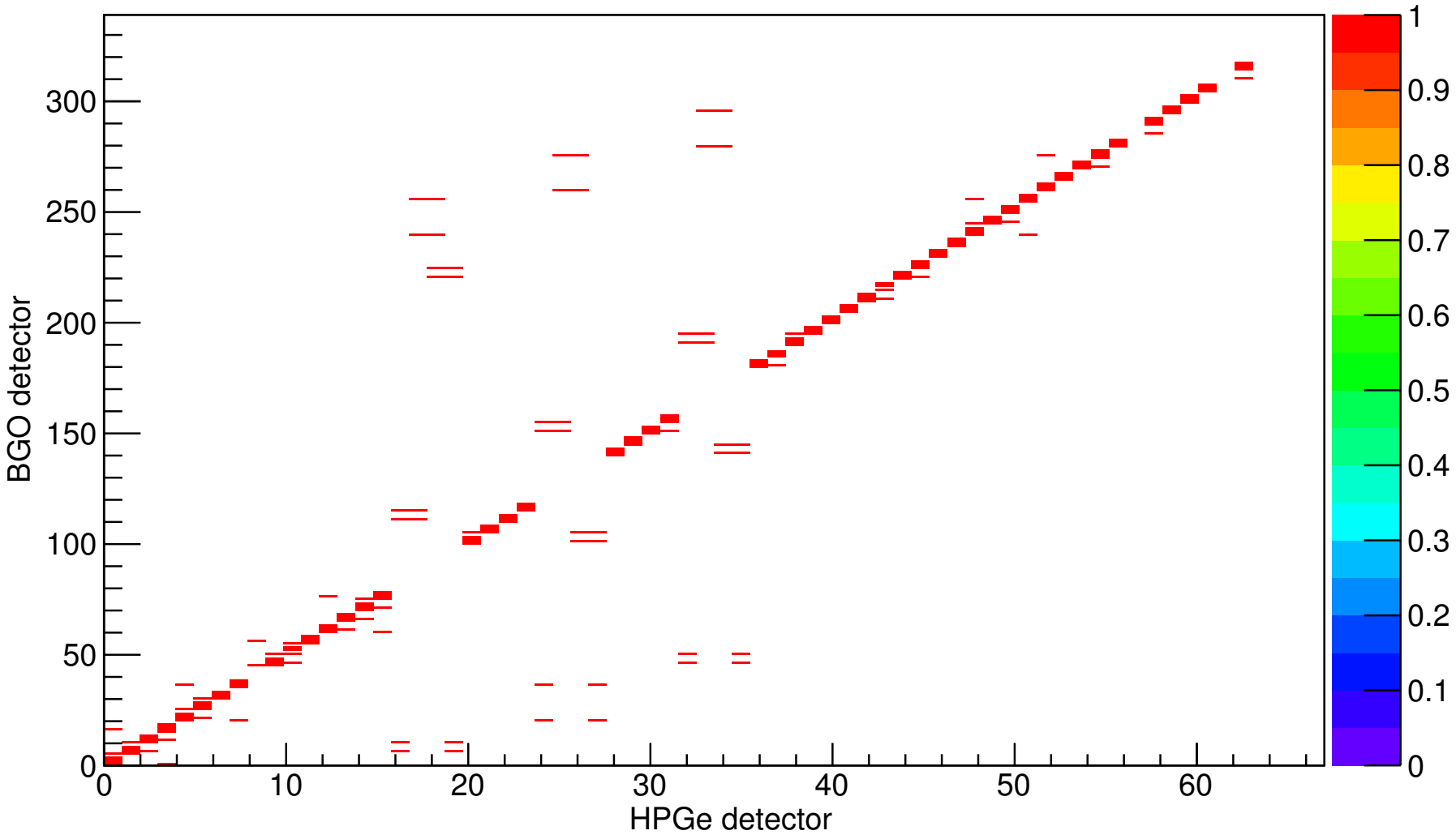
Compton suppression with TIGRESS



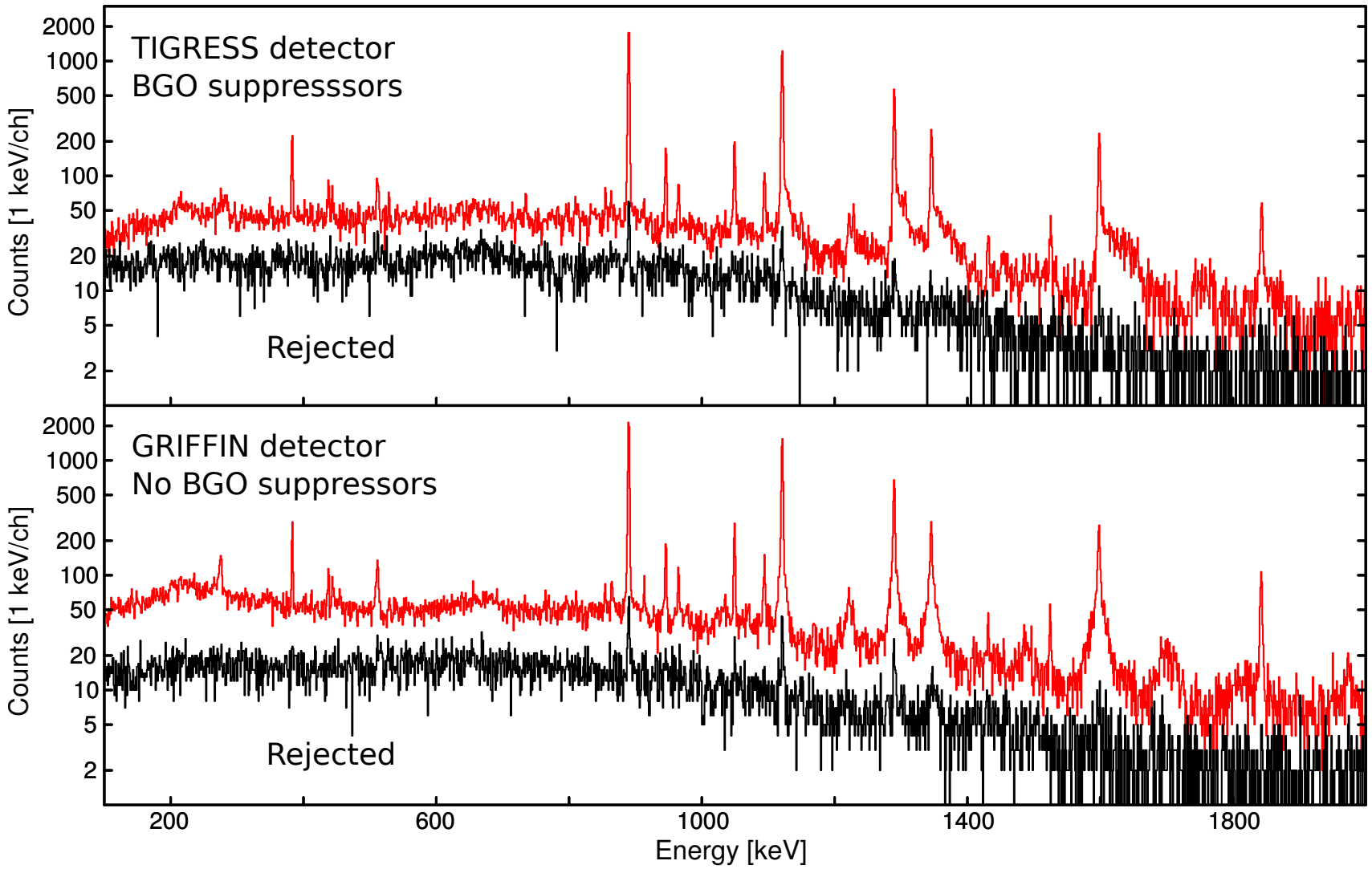
HPGe/BGO hit map



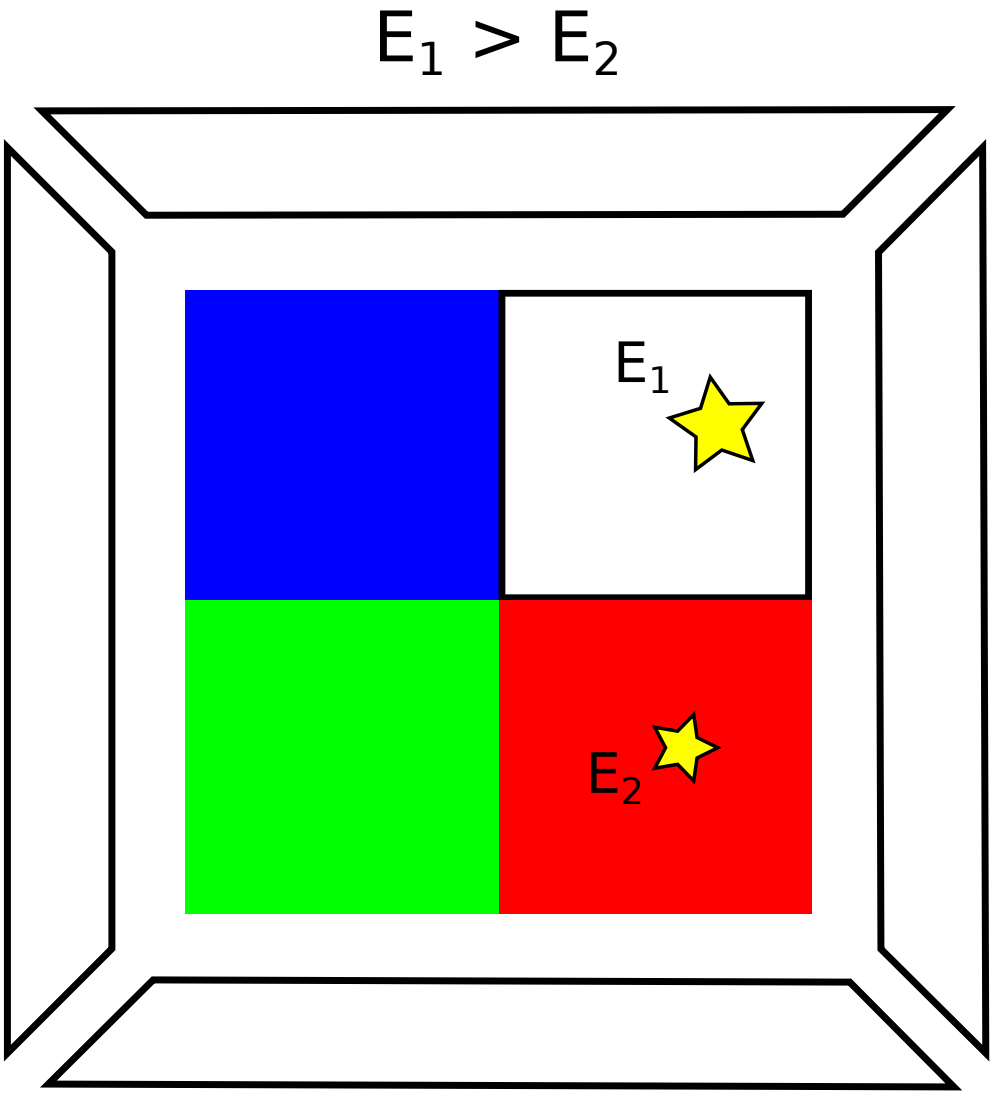
HPGe/BGO suppression map



Compton suppression results

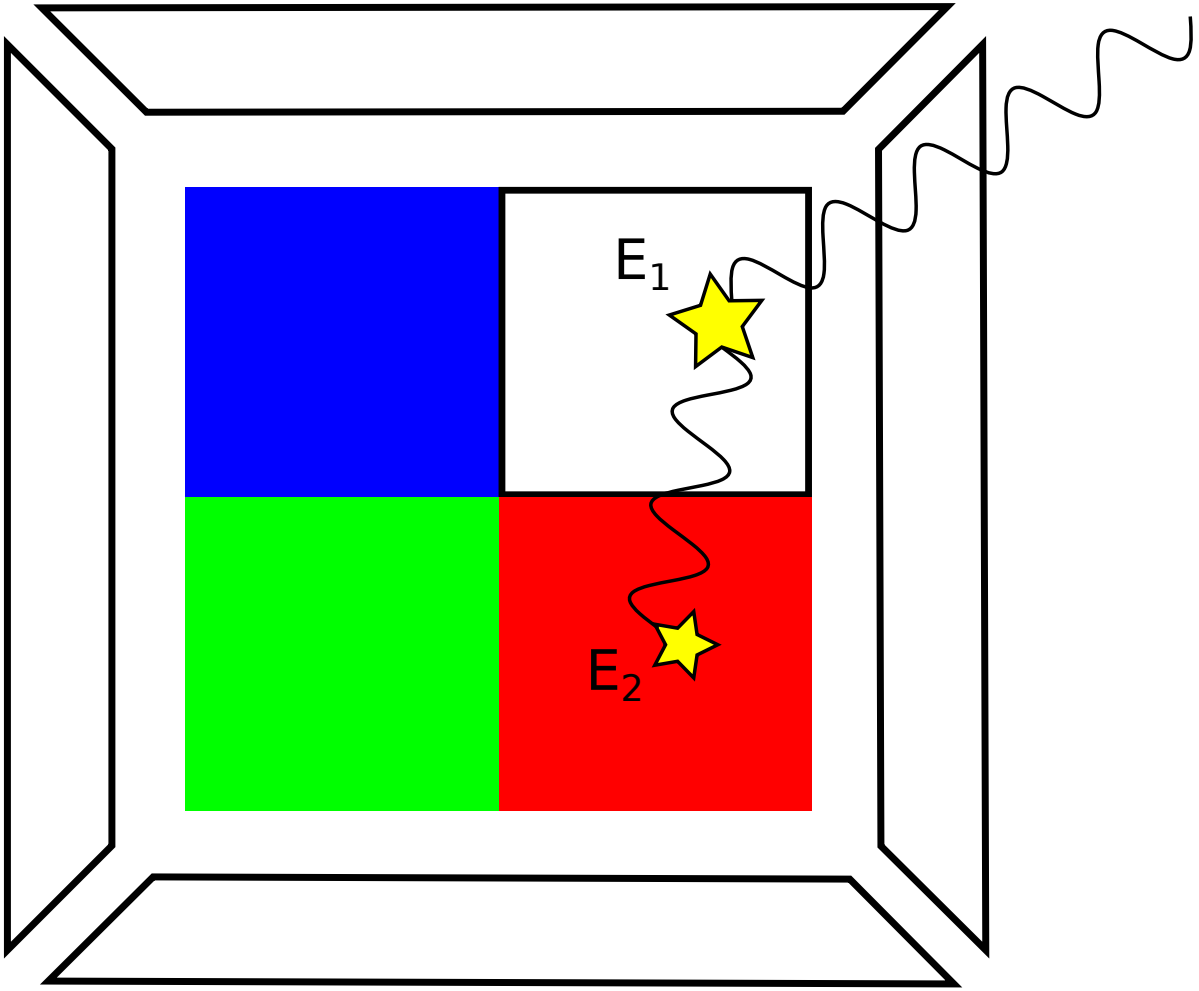


Add-back procedure



Add-back procedure

$E = E_1 + E_2$ assigned to white



Add-back results

Add-back factor = 1.37 (37% more counts in add-back) at 889 keV.