Pushing the precision and sensitivity frontier: β-decay studies at TRIUMF-ISAC

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γ-ray spectroscopy studies with β-decay at TRIUMF-ISAC

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- Three general themes
  - Studies related to *fundamental symmetries*, e.g. superallowed Fermi β decay, characterized by *high-precision* measurements
    - ^{10}C, ^{14}O, ^{18}Ne, ^{19}Ne, ^{26}Al^{m}, ^{38}K^{m}, ^{62}Ga, ^{74}Rb
    - Requires DAQ that has a high degree of diagnostics, records pileup, deadtime, etc.
  - Studies related to nuclei *far from stability*, characterized by *weak beams* and *low rates*
    - e.g. ^{32}Na, ^{50,52}Ca, ^{102}Rb
    - Requires high-efficiency detectors
  - Studies related to nuclei *on or near stability*, characterized by *intense beams* and *high rates*
    - e.g. ^{94}Y, ^{110,112}In/Ag, ^{122,124,126}Cs, ^{156}Ho, ^{158}Tm

Nuclear structure studies with β-decay at TRIUMF-ISAC

- 8π spectrometer was the workhorse for γ-ray spectroscopy following β-decay from 2002 – 2013
  - Arguably the best of the second-generation arrays constructed in the 1980's
  - Still producing world-leading results – despite HPGe obsolesce, array was ***dedicated and optimized*** for β-decay studies and combined with beams from TRIUMF-ISAC, achieved world-leading sensitivity

- New era: GRIFFIN at ISAC
  - Combining the best of high efficiency and high data throughput to provide detailed spectroscopy for both near-to and far-from stability studies

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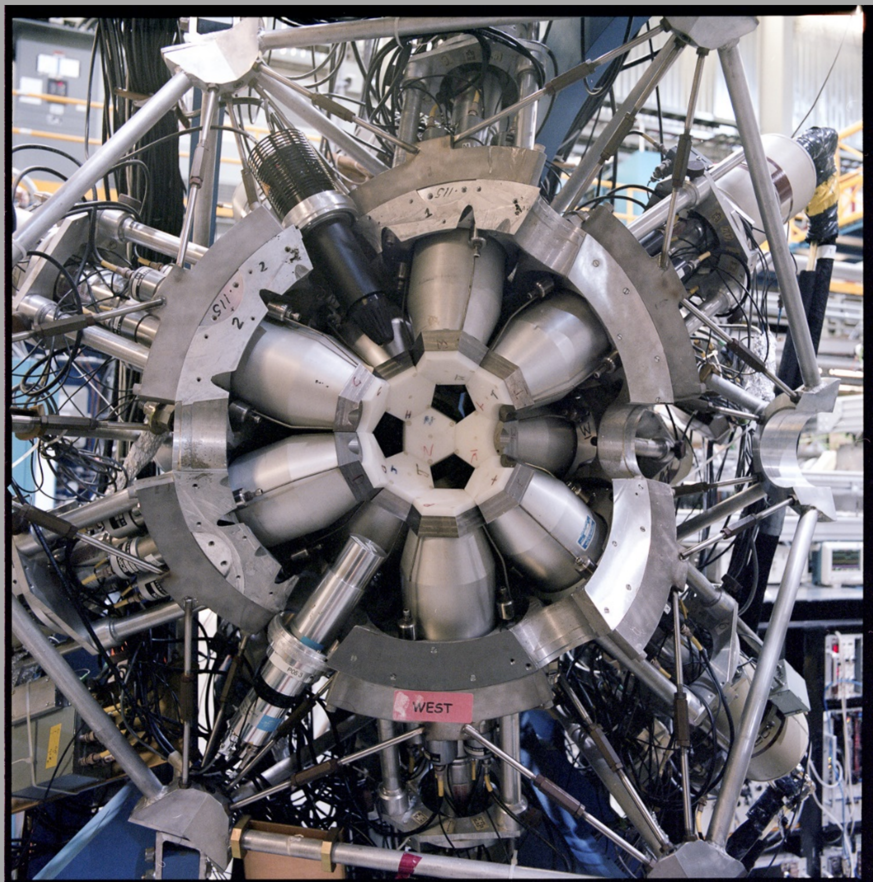
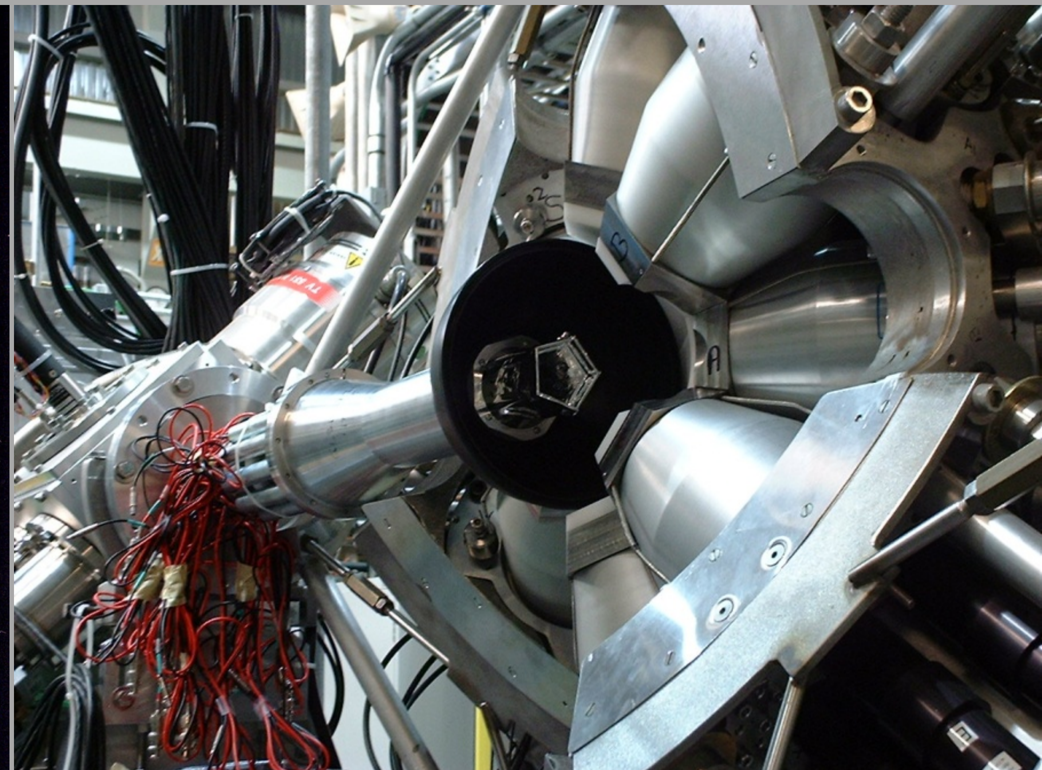
The 8π (now decommissioned) spectrometer





The 8π spectrometer was a world unique device for β-decay studies. Simultaneous collection of γ-singles, γγ coincidences, β tagging, conversion electrons, and lifetime measurements

High-statistics ^{124}Cs β-decay
Beam: 9.8×10^{7} ions/s ^{124}Cs ($J^{\pi}=1^{+}$, $t_{1/2}$=30.8s) and 2.6×10^{6} ions/s ^{124}Cs^{m} ($J^{\pi}=(7)^{+}$, $t_{1/2}$=6.3s)

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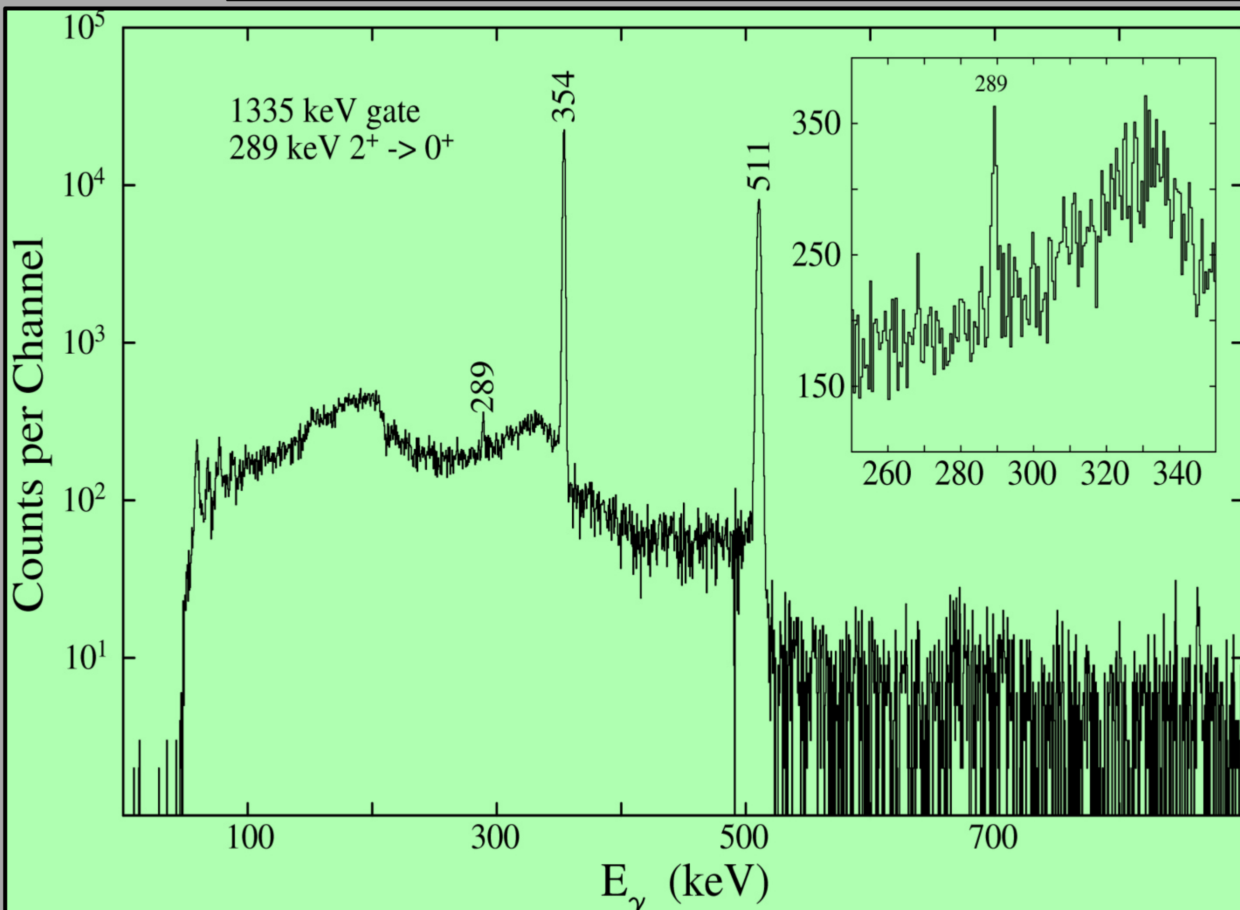
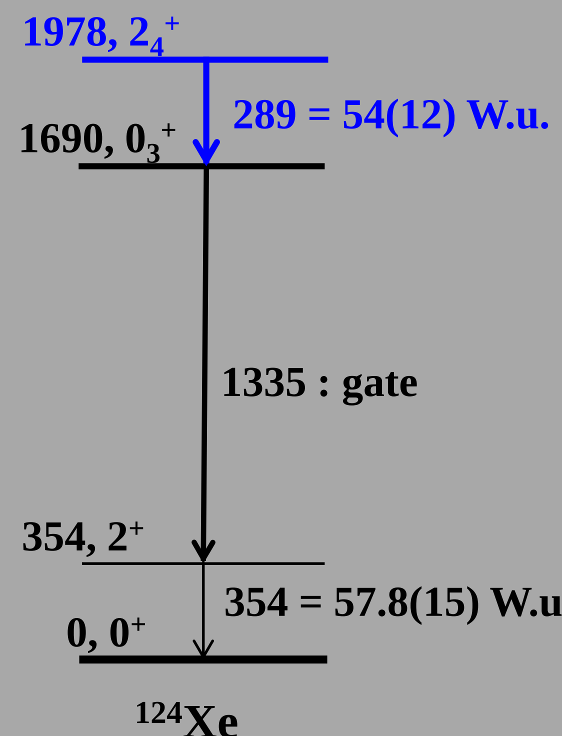
Time-random background subtracted γγ matrix 4.5×10^{8} events



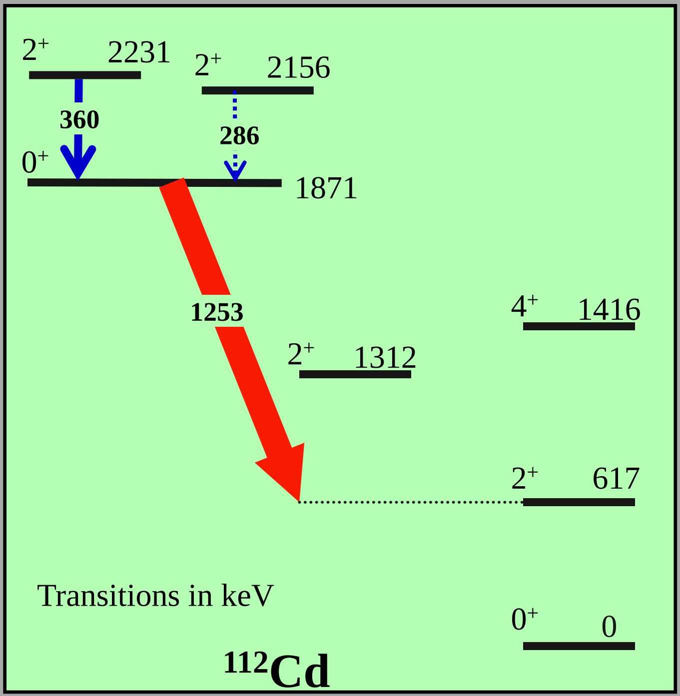
0.79(9)% branch → 54(12) W.u.

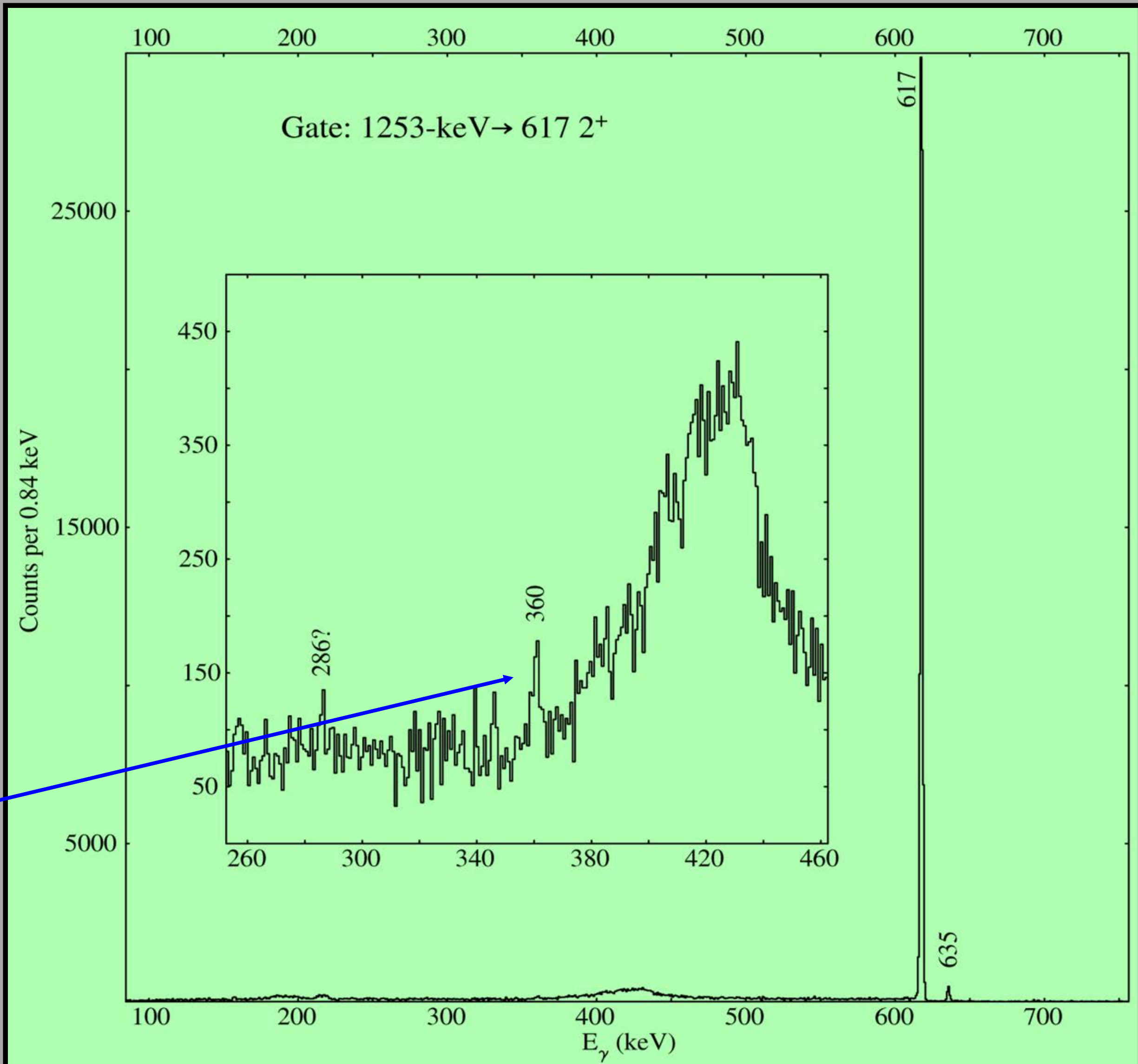


Intensity of 289-keV line is 10^{-5} of the $2^{+}\rightarrow0^{+}$

Studies on or near stability can take advantage of complementary information

Exploration of nature of highly-excited non-yrast states requires extreme sensitivity





5×10^{-4} γ branch from 2231-keV level

$I_\gamma(360) \approx 10^{-6}$ of $I_\gamma(617\text{-keV}, 2^+\rightarrow0^+)$

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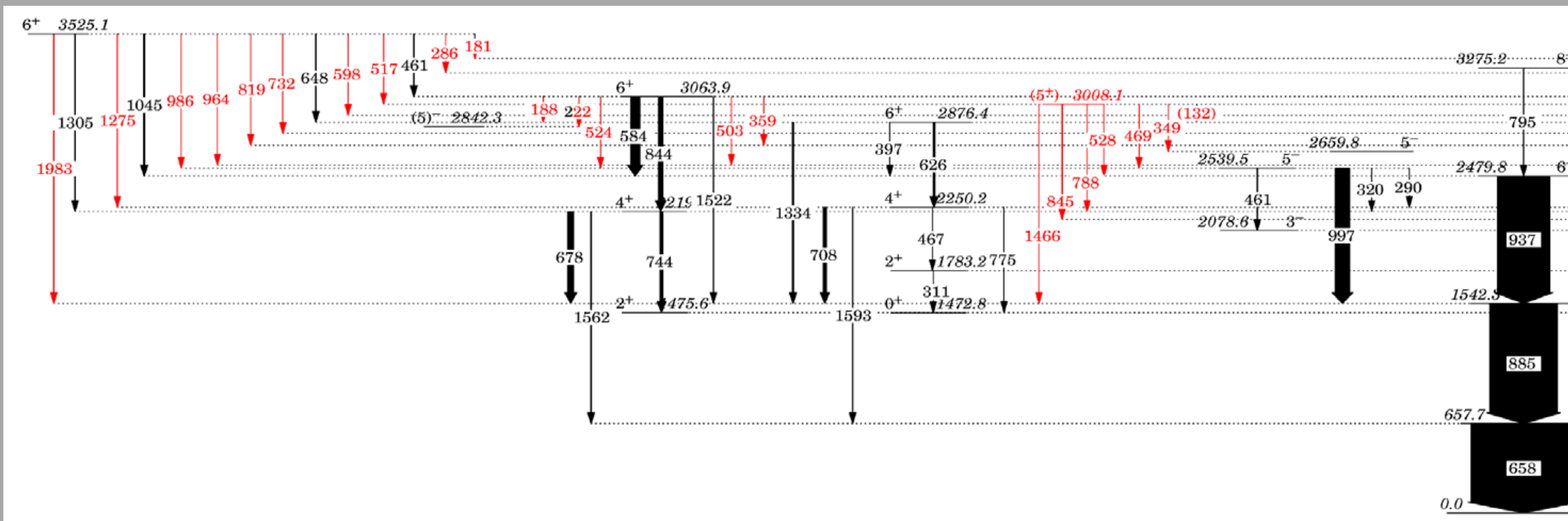
With high statistics, detailed spectroscopy follows…

- Partial level scheme from ^{110}In β^{+}/EC decay to ^{110}Cd

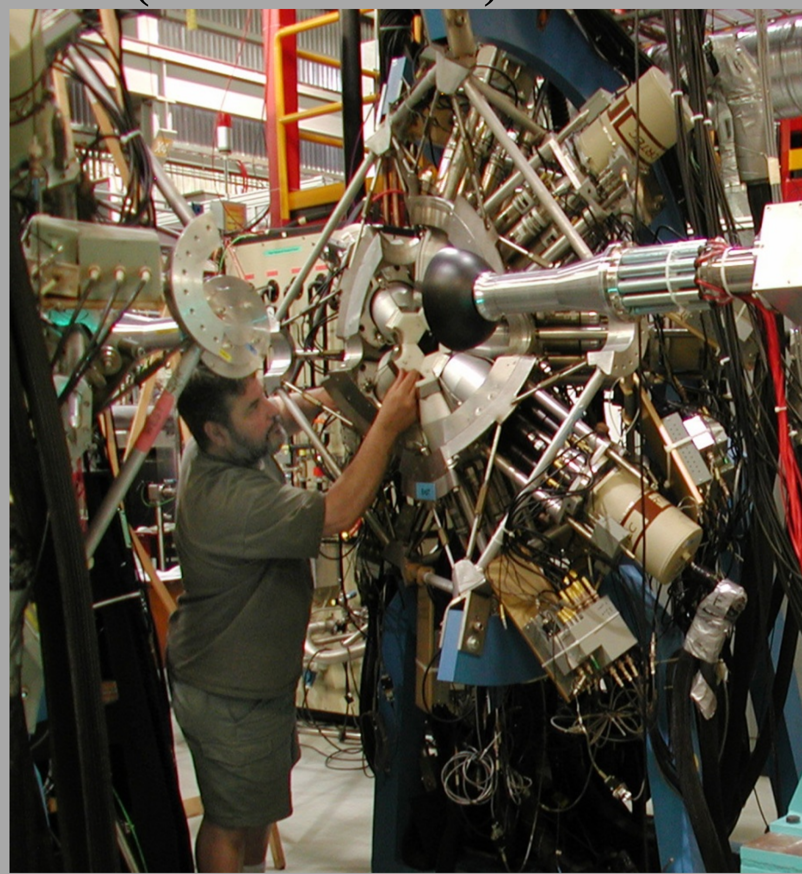


- In some cases, observe or place stringent limits on ***all*** possible decays from excited states allowing details tests of models

Moving tape collector for transport of activity

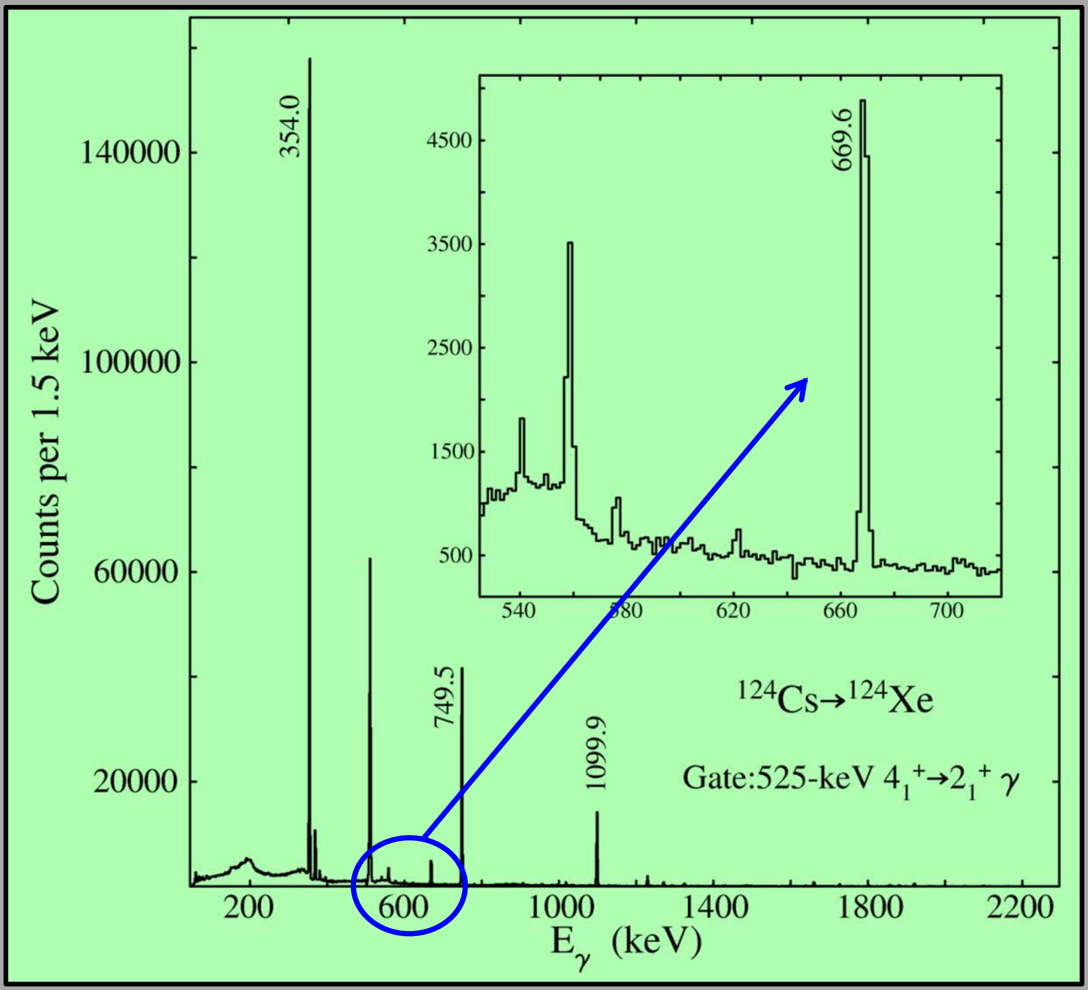
- Beam implanted onto a moving tape at center of array
  - Allows for movement of long-lived activity out of focus of spectrometer
- Tape speeds, dwell times, etc., variable
- Control of beam kicker tightly coupled – beam collection time variable (down to ~ 100ms)

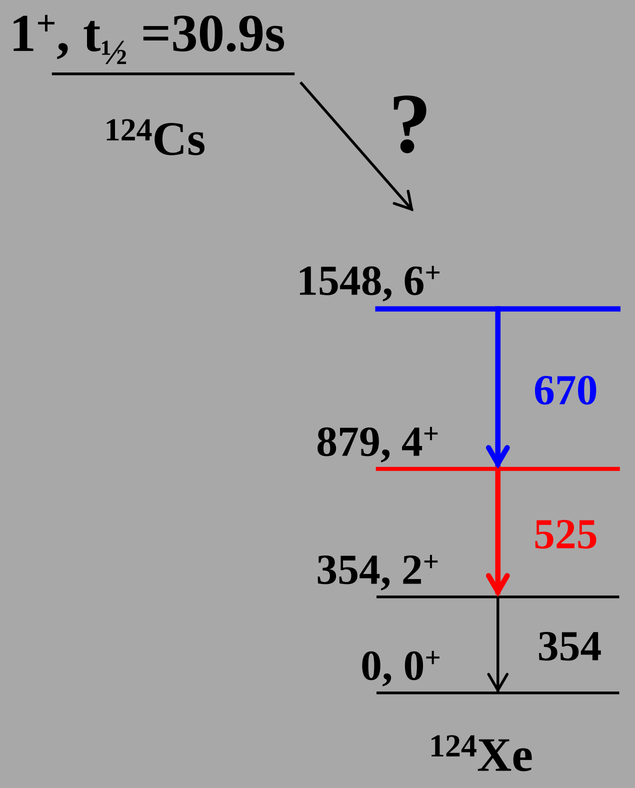
- Tape transport very flexible: can be motionless, or operated in continuous motion
- Disadvantage: study of long-lived activity in presence of intense, short-lived isobar



Built by E. Zganjar, LSU

High spin states fed in ^{124}Cs decay



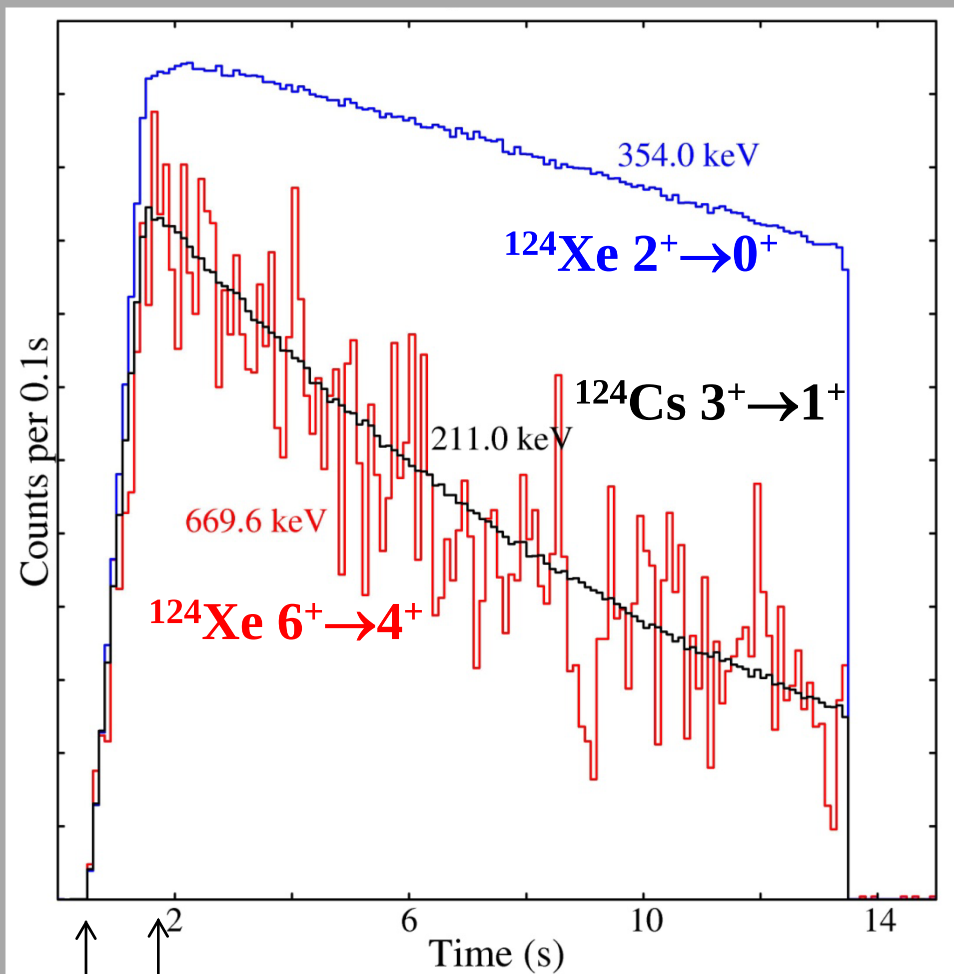


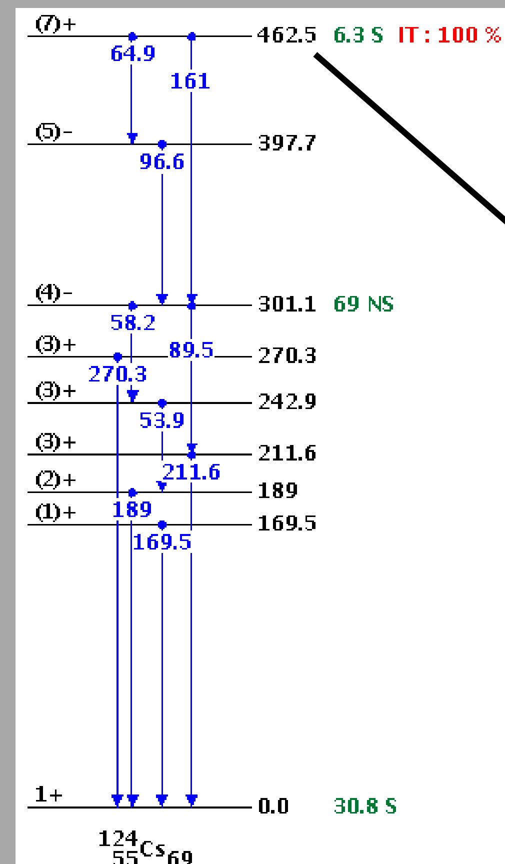
How does the 1$^+$ parent populate the 6$^+$ member of the daughter gsb?

It doesn't!

$^{124}Cs^{m}$ decay – unknown β branch identified via half life

Counts observed in photopeak C(*t*)





β^{+}/EC 0.11(2)% branch

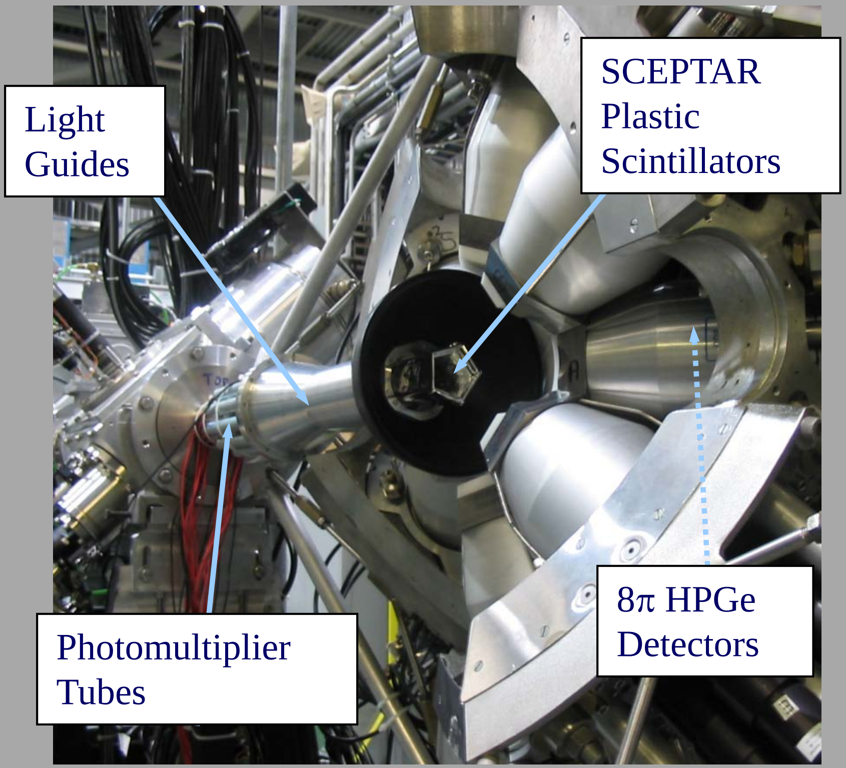
^{124}Xe 6^{+},7^{+},8^{+} levels

Beam on

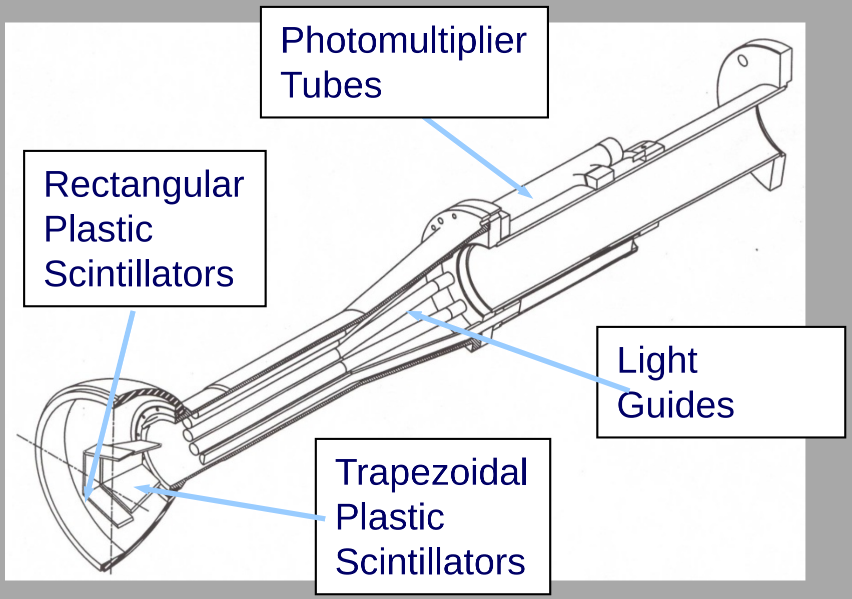
Beam off

Usefulness of beam pulsing and tape cycling to determine half lives

SCEPTAR – plastic scintillator array for tagging on β particles



- SCEPTAR divided into two hemispheres.
- Each half contains 10 thin (~1.6 mm) plastic scintillator panels.
- 10 panels arranged in two pentagonal rings.



- 1-to-1 correspondence between the SCEPTAR detectors and the Ge detectors allows to veto event that arises from high-energy β particles that reach Ge detector

8π experiment to examine ^{32}Na decay

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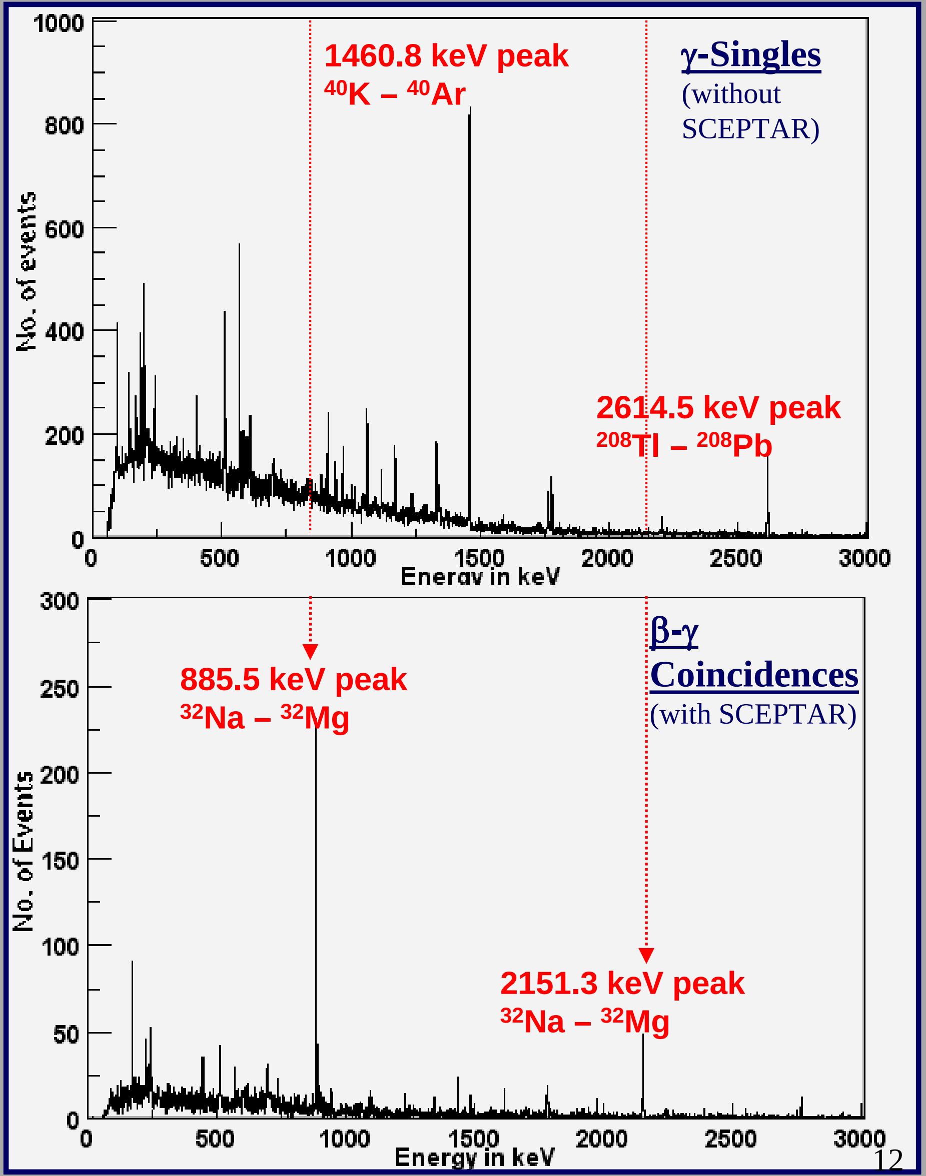
- ^{32}Na decay investigated as a means to study the excited nuclear states of ^{32}Mg (Z=12, N=20).
- Investigate the breakdown of shell closures far from stability.
- β-γ coincidences measured with 8π and SCEPTAR.
- Reduce background and allow weak ^{32}Na decay spectrum to be measured. (^{32}Na beam rate at ~2 ions/s).



PACES – 5 Si(Li) detectors inside target chamber for conversion electron detection

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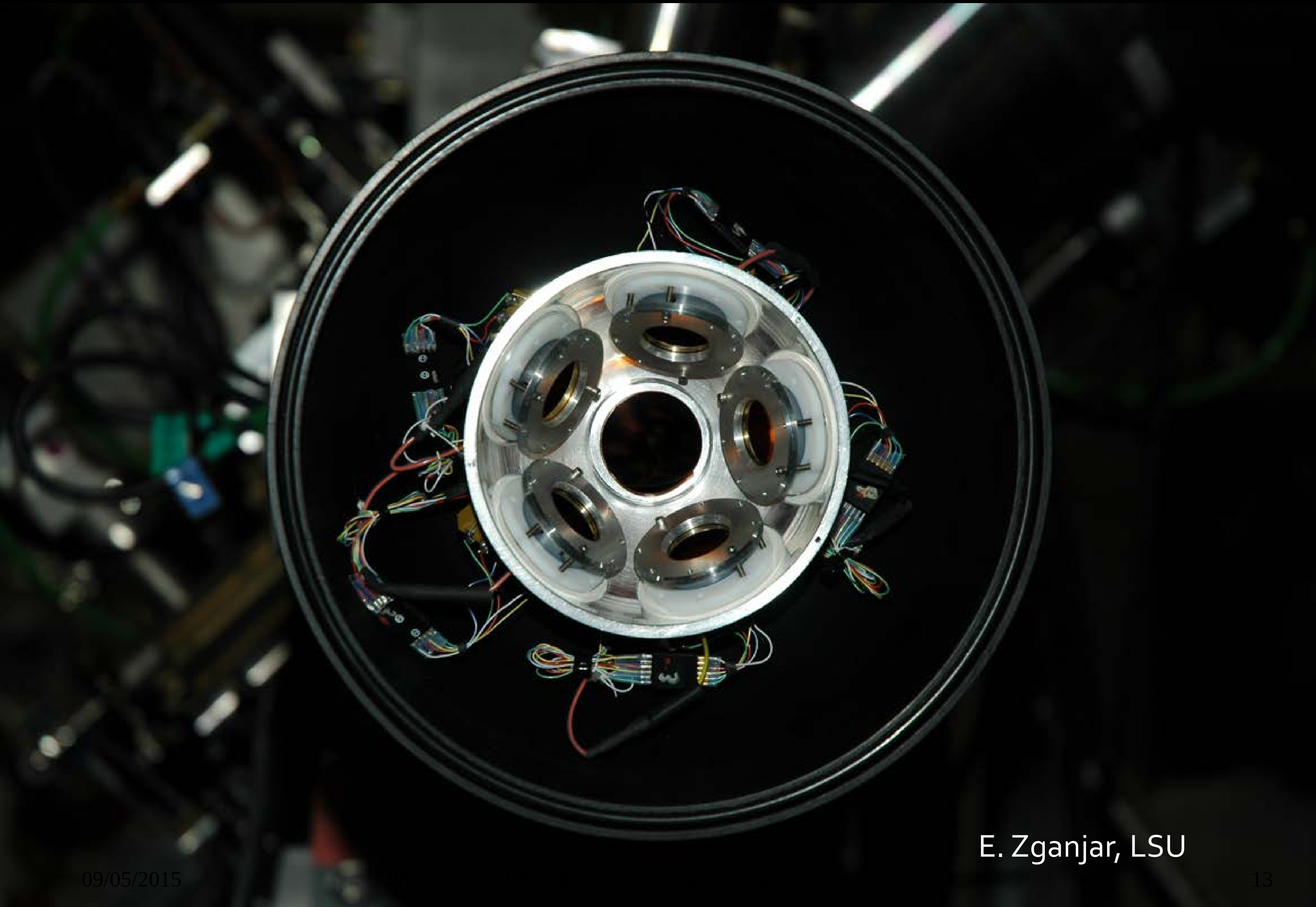
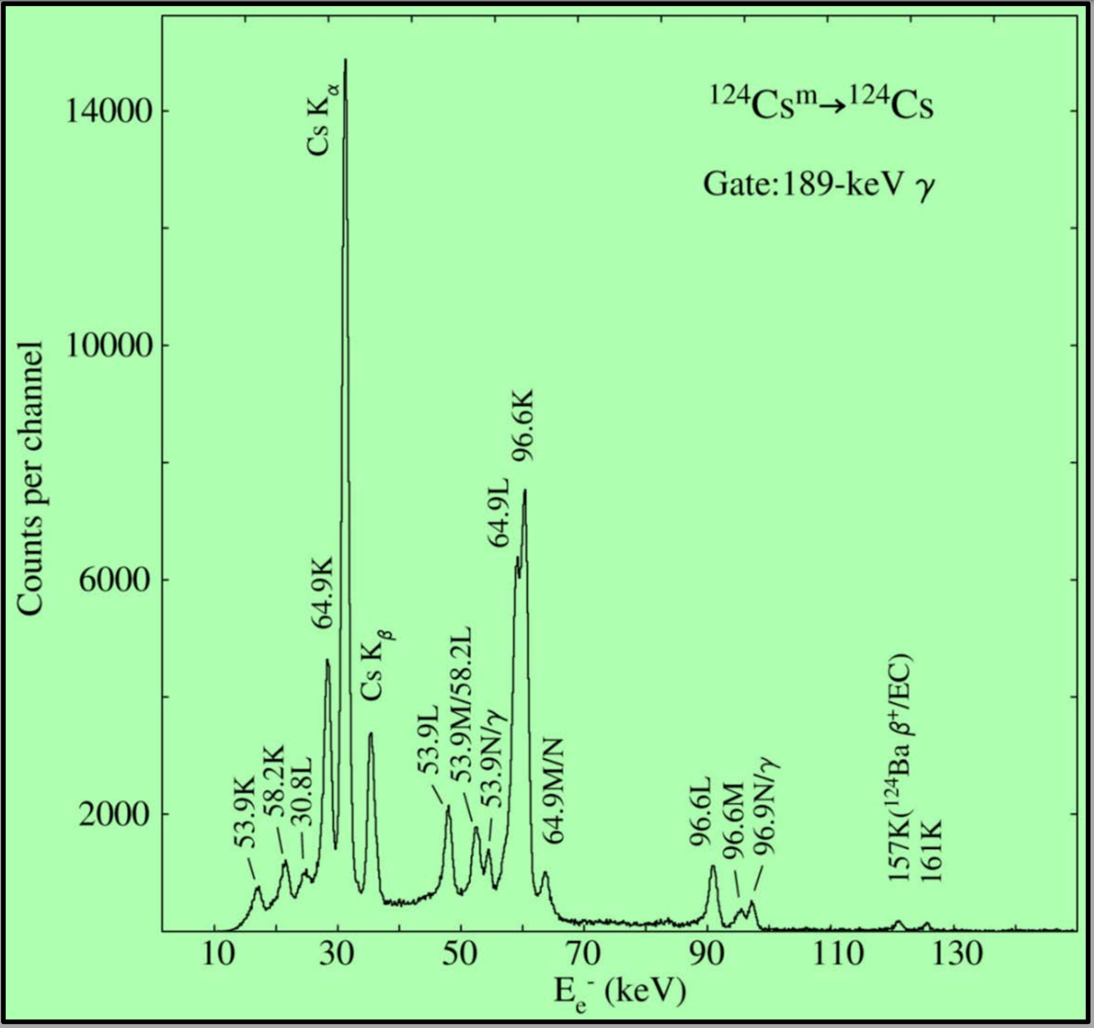
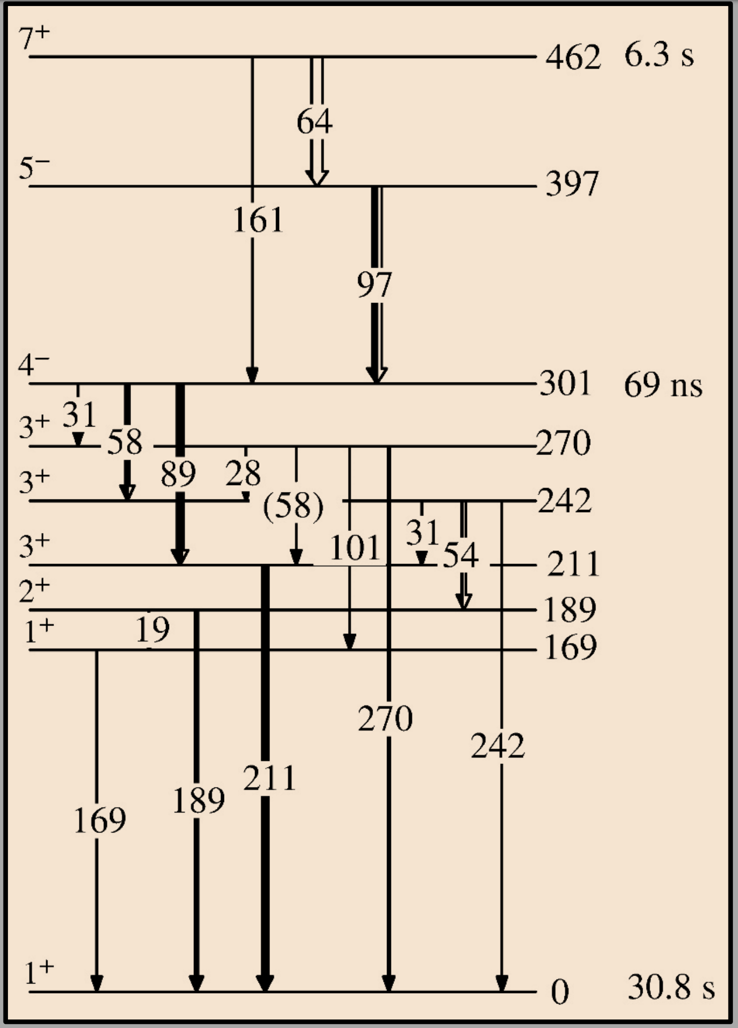


E. Zganjar, LSU

Importance of conversion electron spectroscopy – $^{124}Cs^m$ isomer decay





Routinely observe electrons down to 10 – 15 keV →
important for spectroscopy of odd-odd nuclei and actinides

Disadvantage of Si geometry inside focal volume of Ge array

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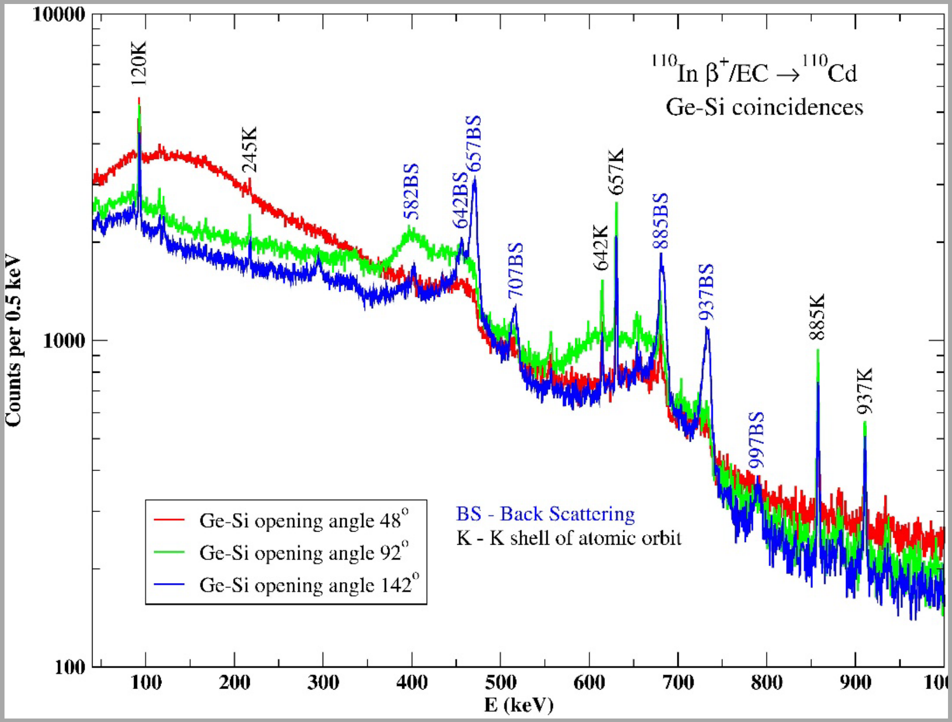
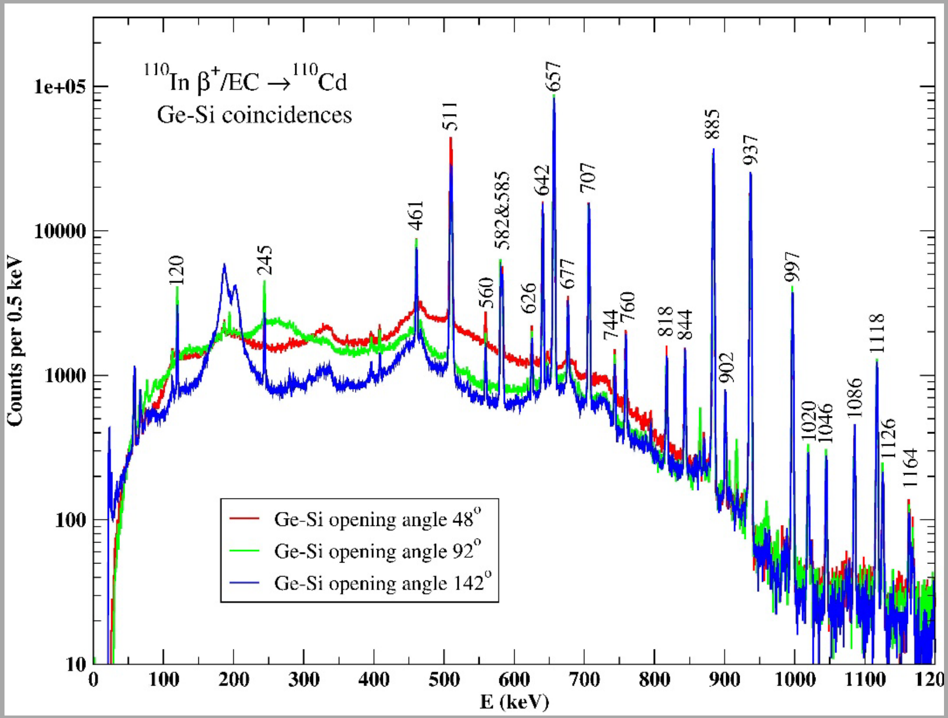
Coincident events in Si detectors



Coincident events in Ge detectors



New *E0* in ^{110}Cd transitions through γ-gated e^- spectroscopy

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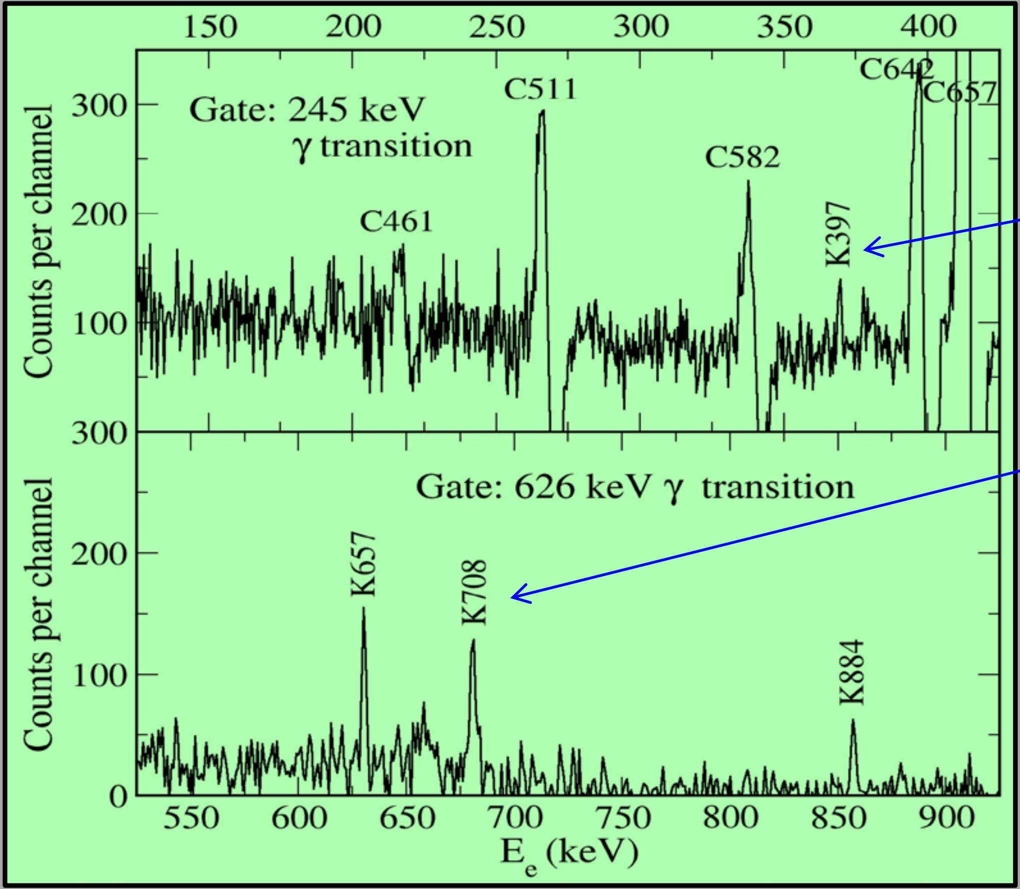

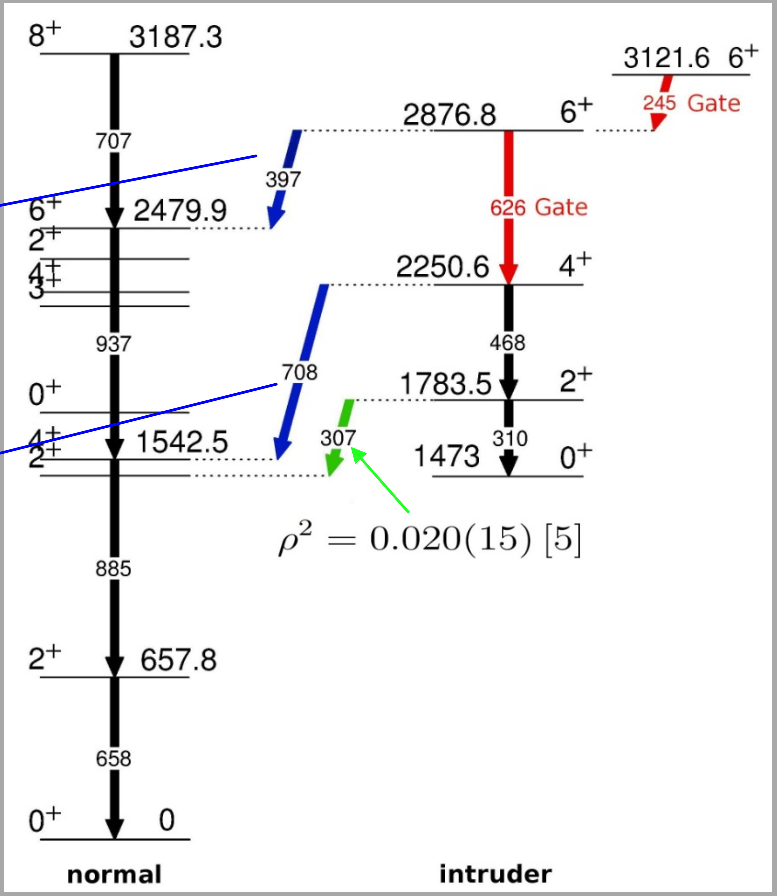

708-keV 4$^+$(intruder) → 4$^+$(gsb) $\rho^2(E0) = 0.101^{+86}_{-79}$

ρ^2(E0) dependent on deformation differences and mixing

β-decay at TRIUMF with GRIFFIN

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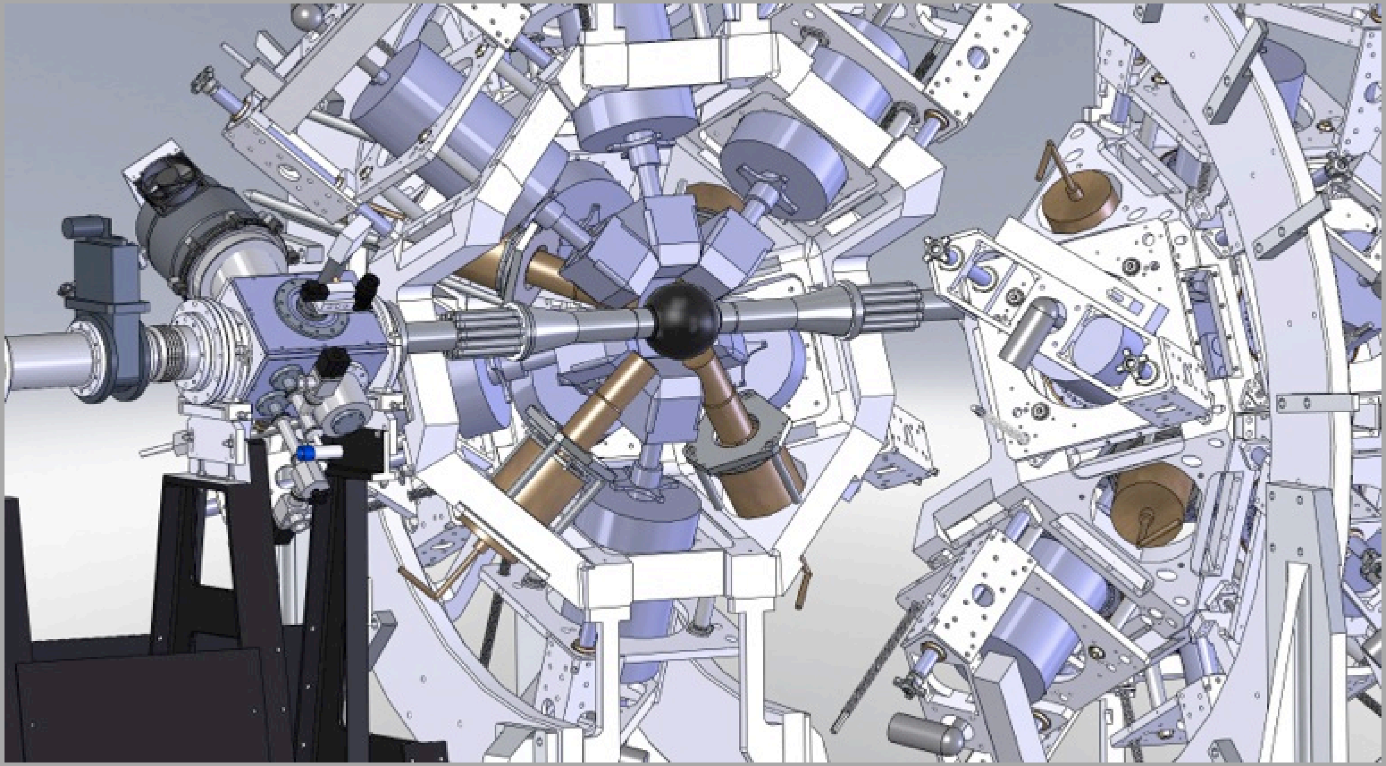
***G**amma-**R**ay **I**nfrastructure **F**or **F**undamental **I**nvestigations of **N**uclei*



- Phase I ($8.9M) complete
  - 16 large-volume unsegmented clover detectors (40% crystals – 220% with addback)
  - Support structure, new beam line, etc.
  - Digital DAQ – triggerless with aim to write 300 MB/s (~1 MHz event rate)
- Commissioned fall 2014

GRIFFIN Efficiency – extending the spectroscopy reach to 1 ion/min

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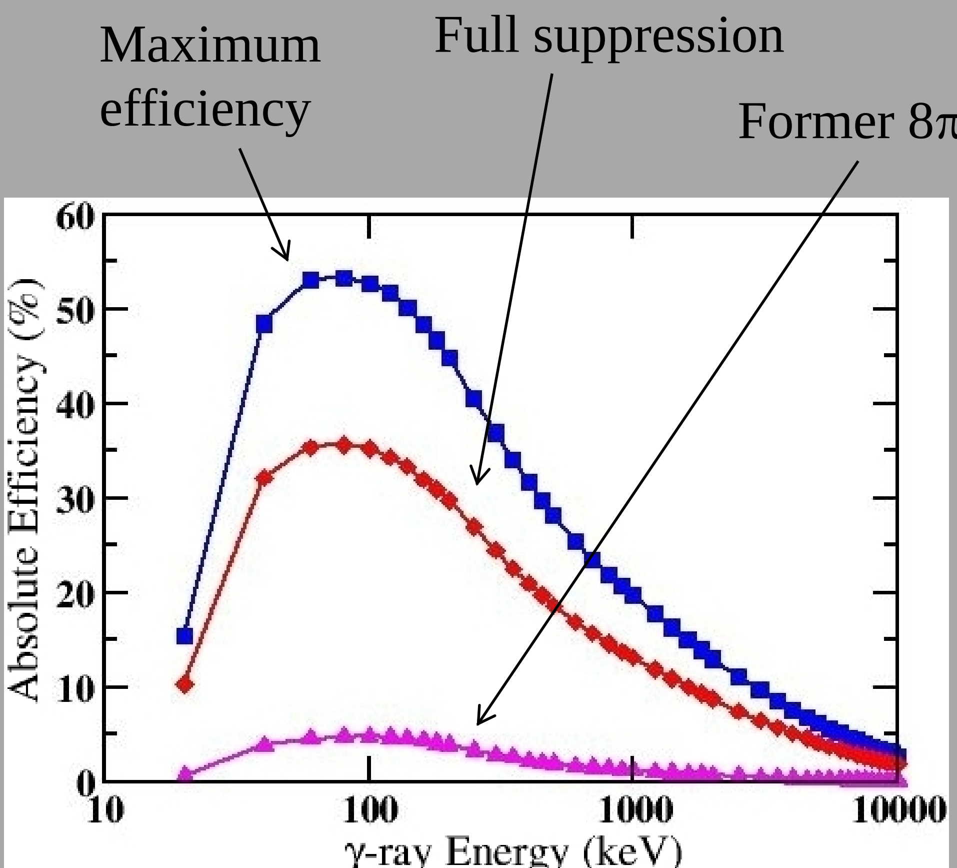
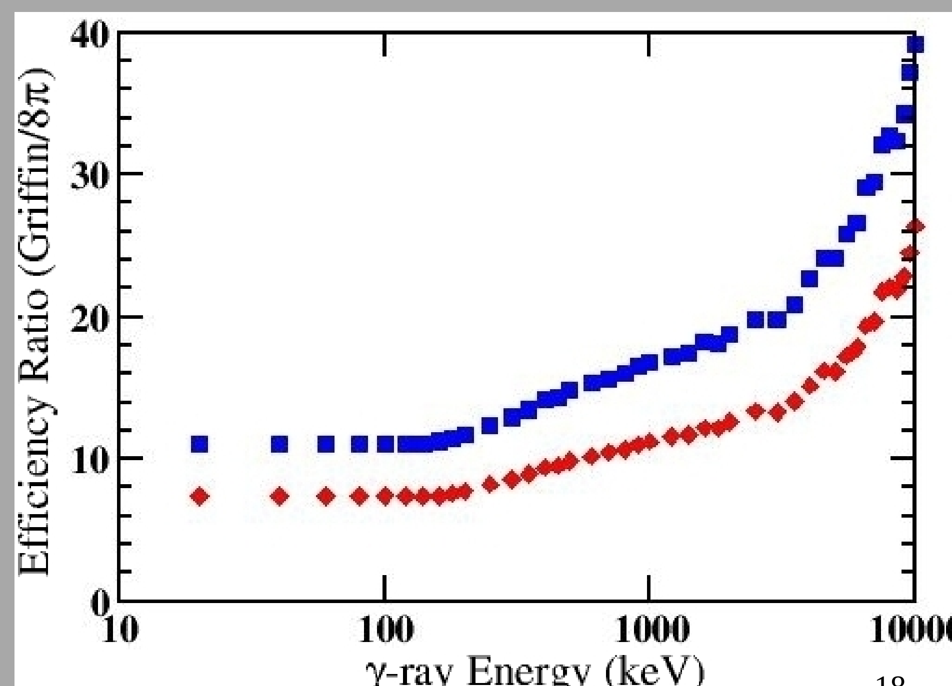
- **Operate in 2 modes**
  - **maximum efficiency mode (detectors fully forward, source-to-detector distance 11 cm)**
  - **full-suppression mode (allow for future BGO shields)**





GRIFFIN Phase I – operational

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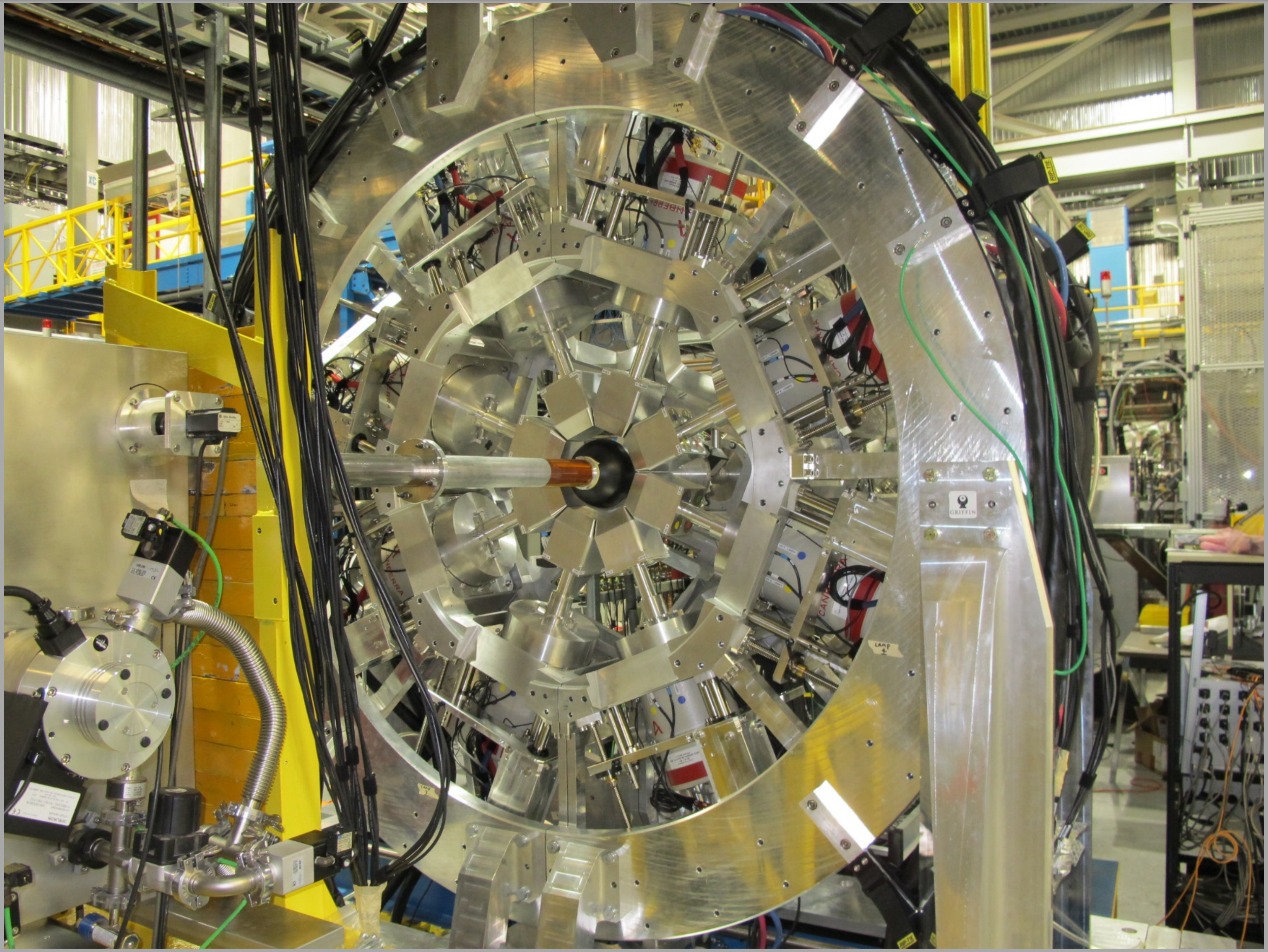
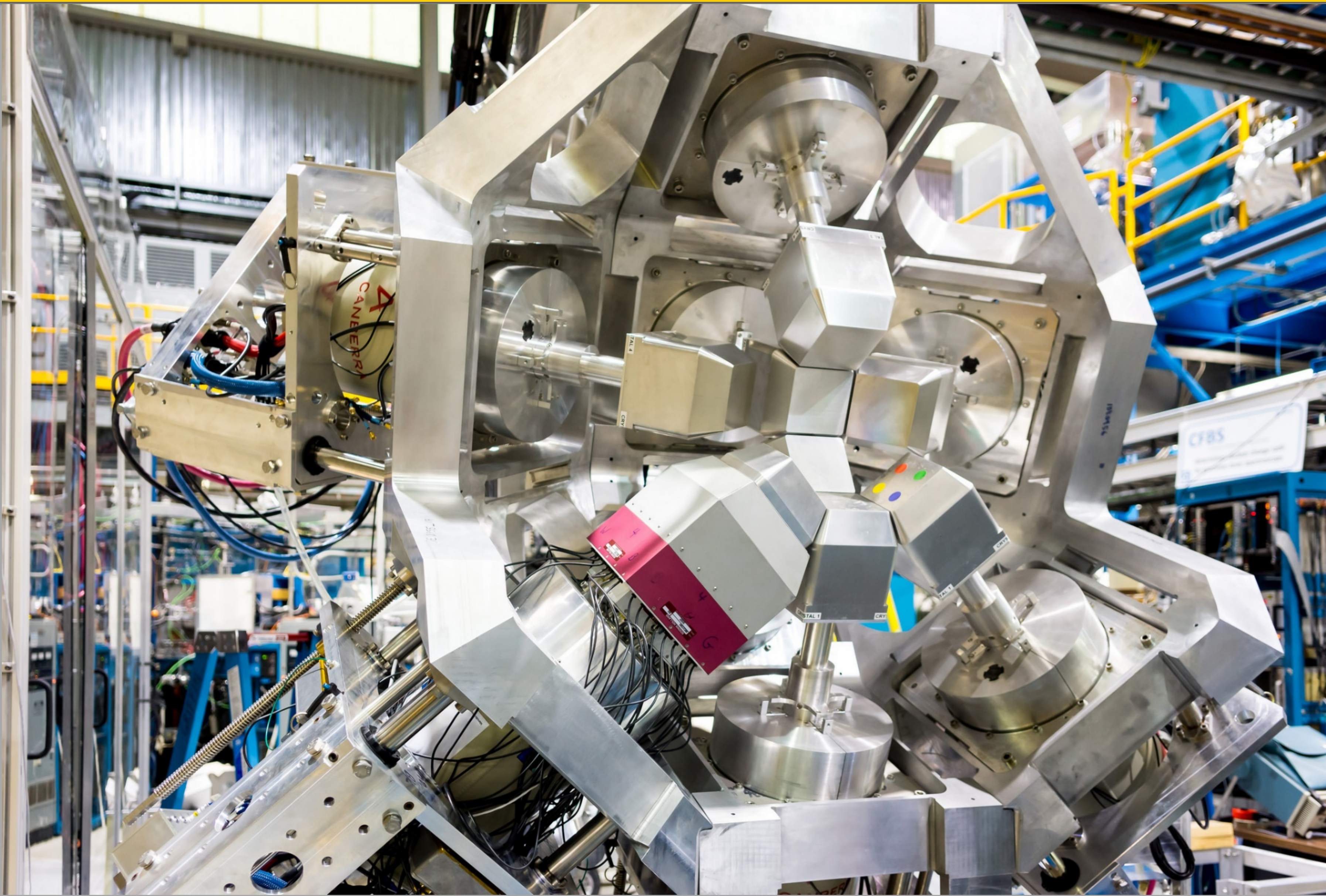


GRIFFIN Phase I – operational



Commissioning experiment to study ^{115}Ag decay to ^{115}Cd – motivated by abundance of ^{116}Cd

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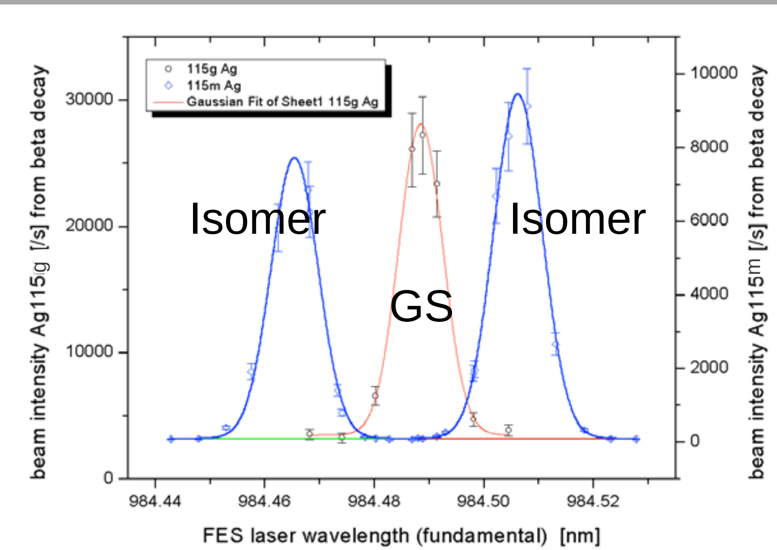
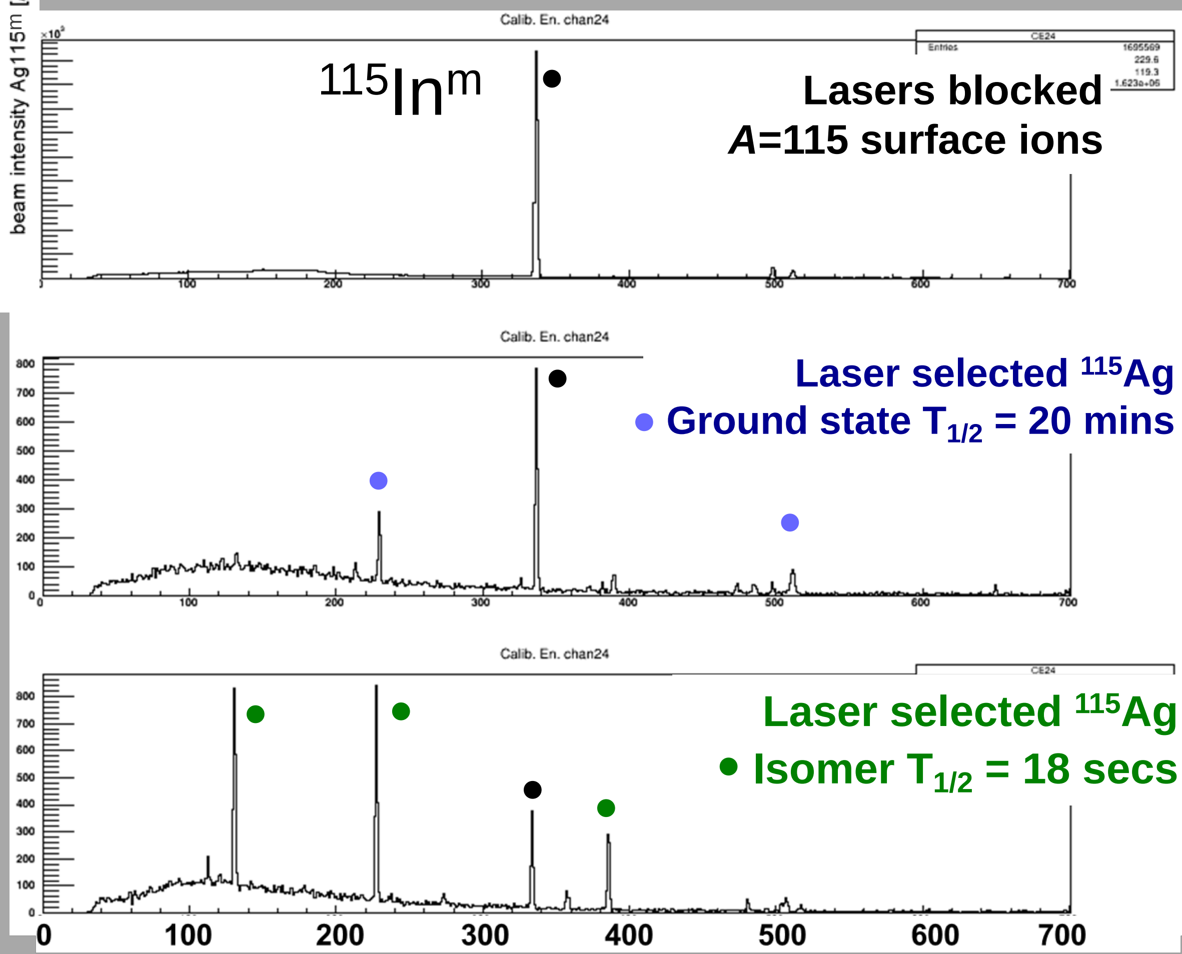


Jens Lassen and TRILIS team

Search for gateway states connecting gs and isomer in ^{115}Cd



Clean separation of the Isomer and ground state using the TRILIS lasers

10,000pps ^{115}Ag Isomer 7/2^{+}

30,000pps ^{115}Ag GS 1/2^{-} (with 80pps isomer)

Configuration of GRIFFIN for ^{32}Na decay: plastic scintillators, Si(Li), DESCANT neutron detectors

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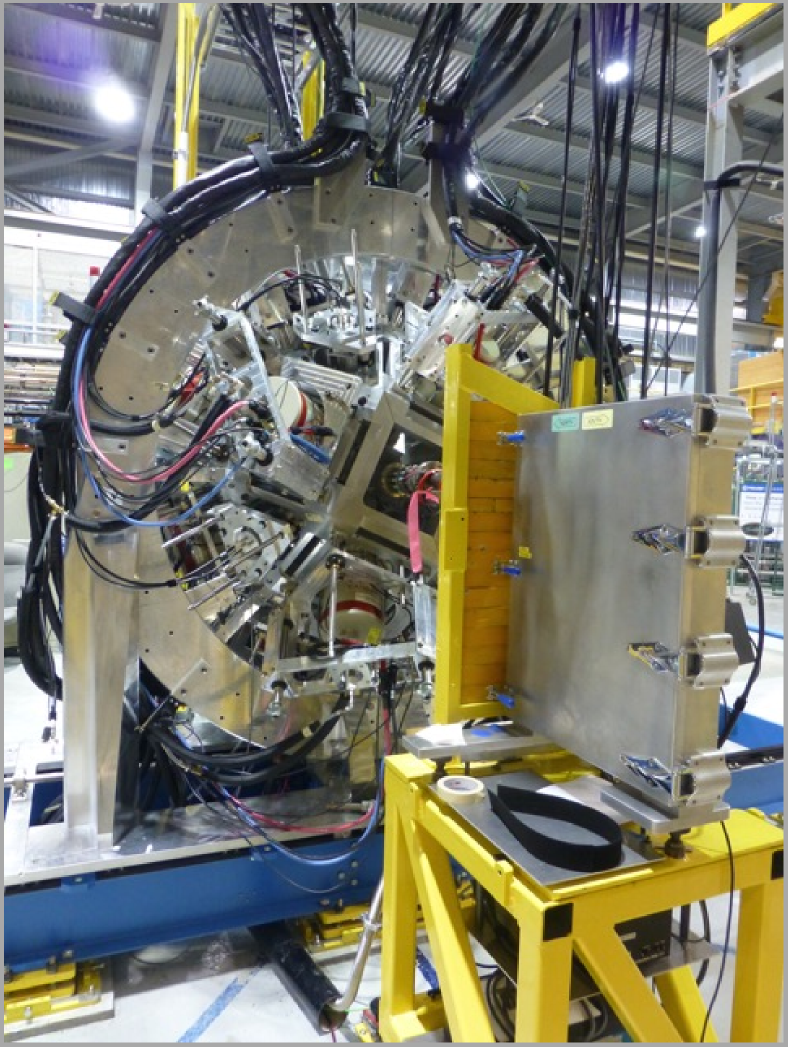
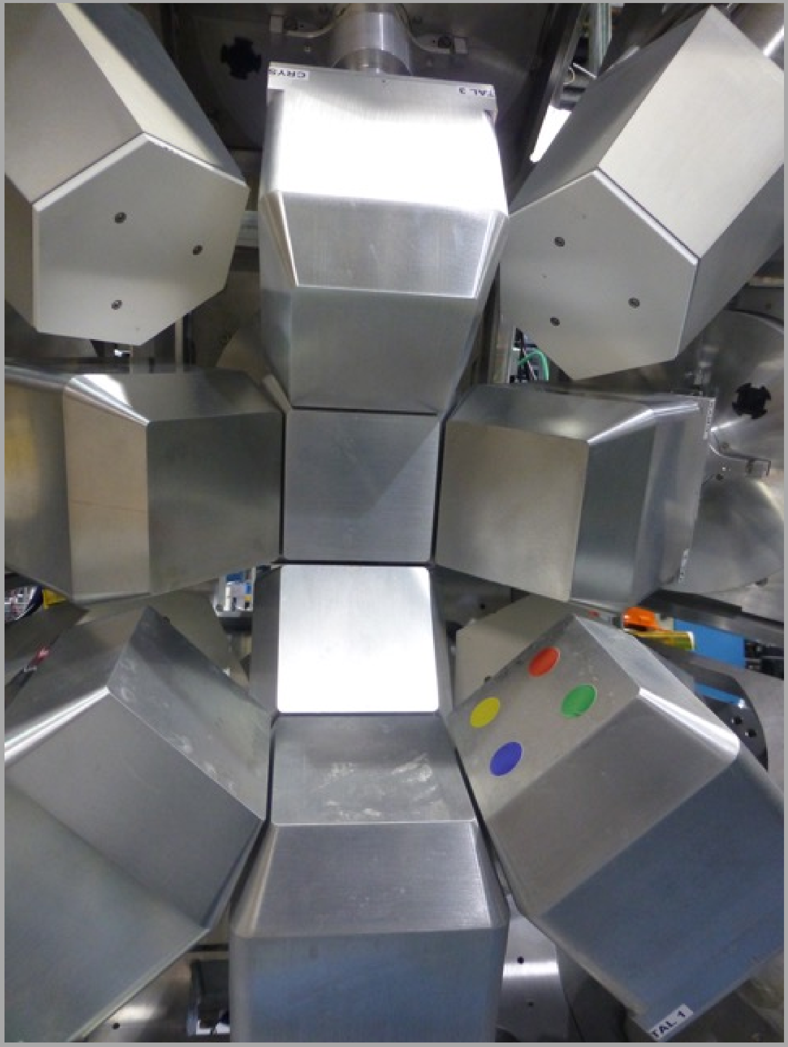
What we see



What the decay radiation sees



Comparison of 8π and GRIFFIN

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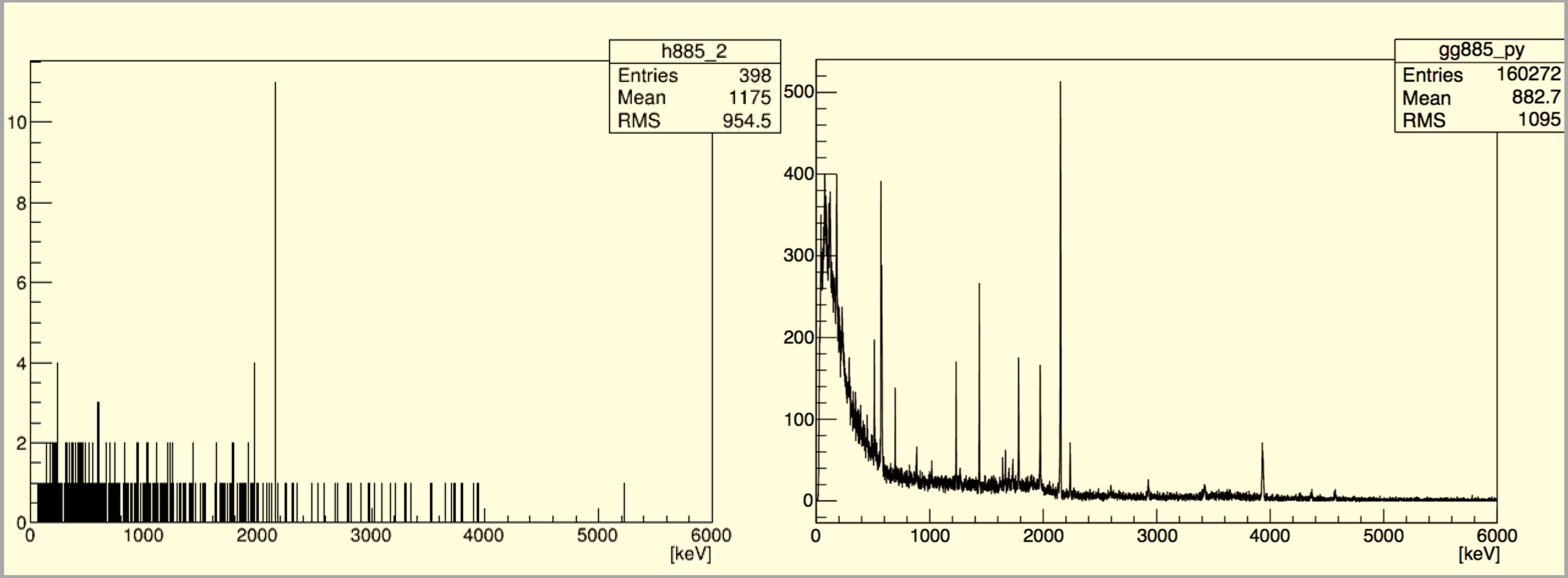
- γ coincidences with 885-keV $2^+ \rightarrow 0^+$ in ^{32}Mg

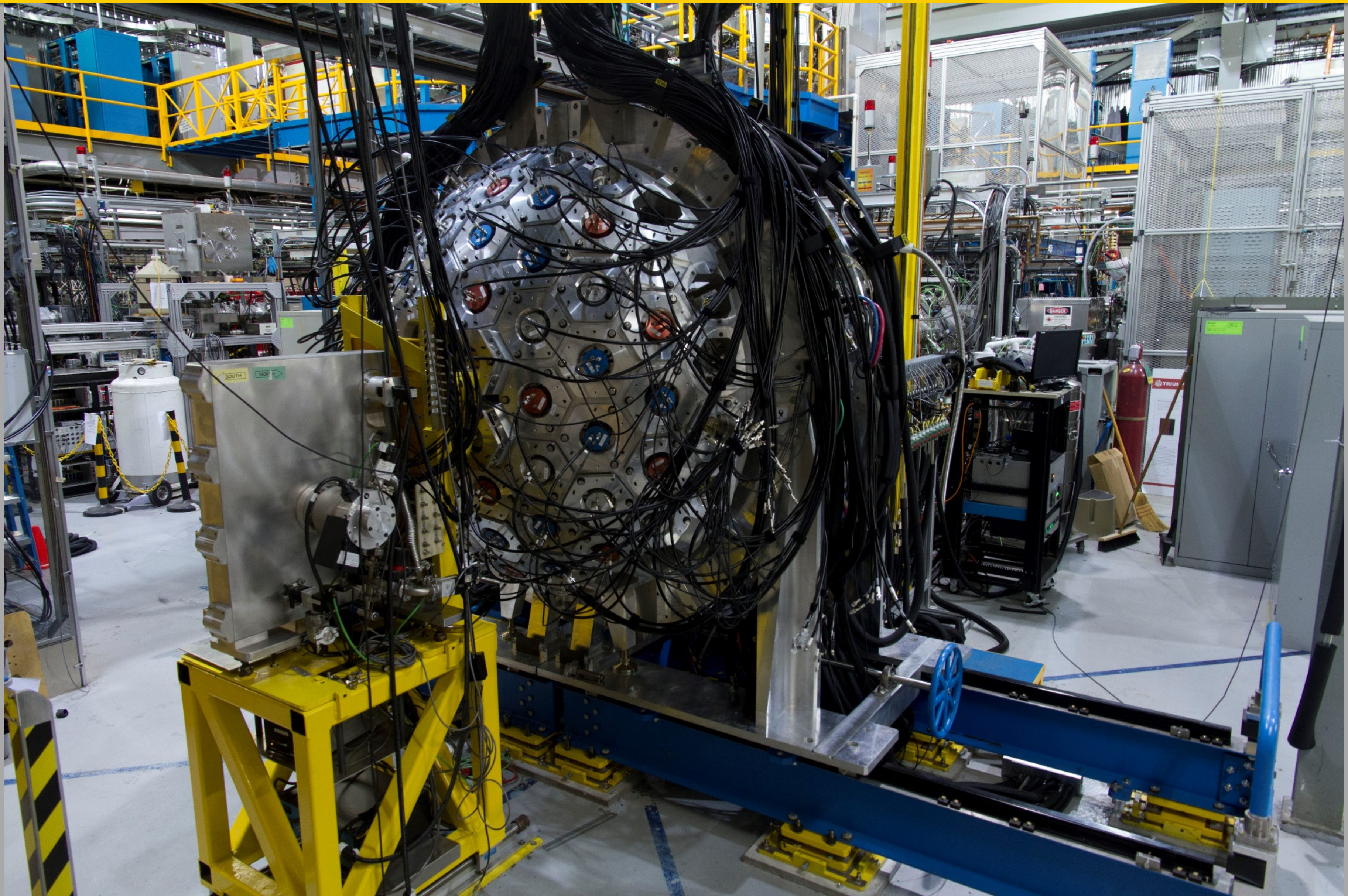


8π: 2-3 pps, 5 days **GRIFFIN: ~9 pps, ~2 days**

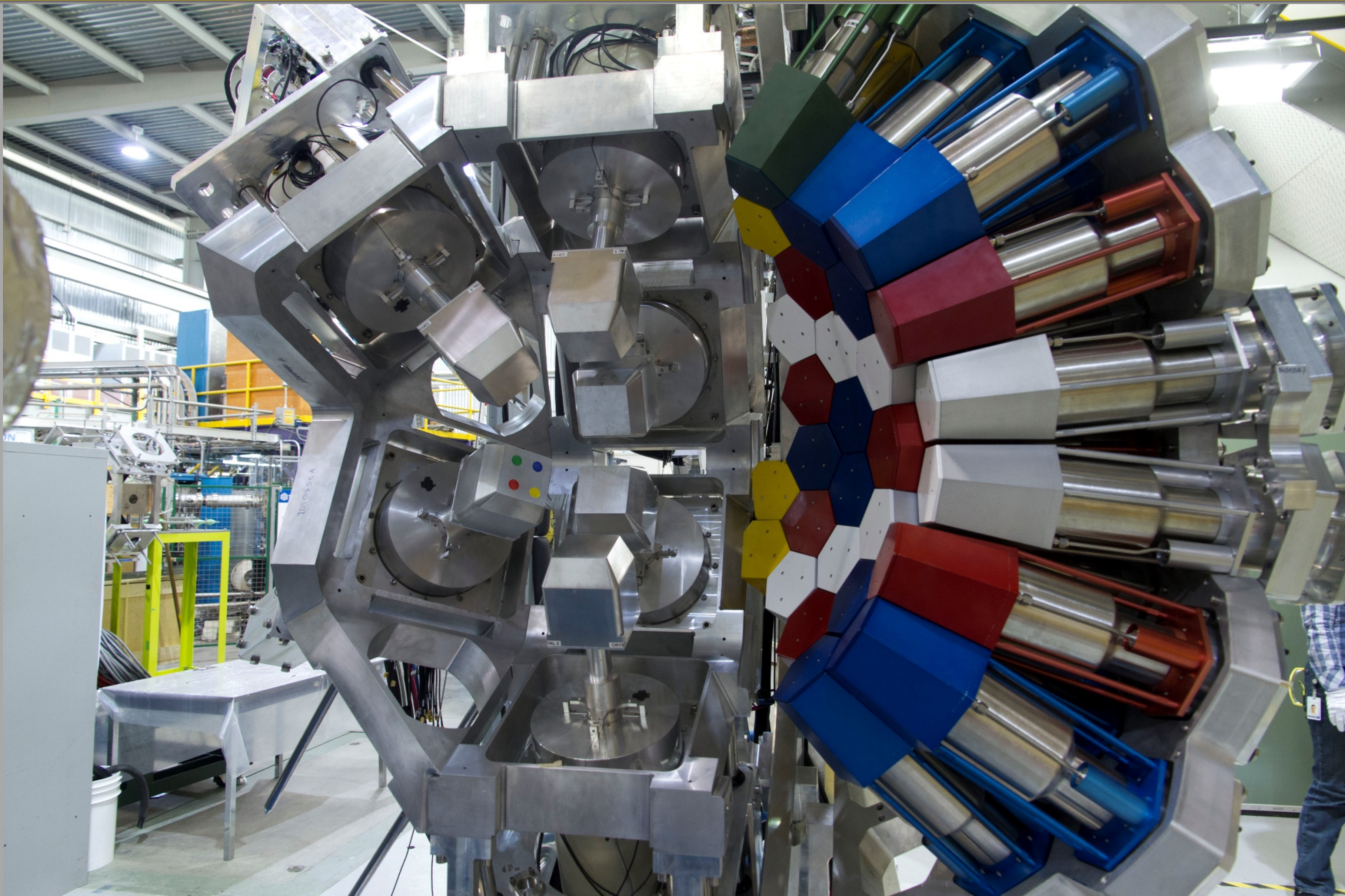
C. Mattoon et al., PRC**75**, 017302 (2007)

Note scale!

Current configuration of GRIFFIN with DESCANT – measurement of β-delayed *n* emitters



GRIFFIN with DESCANT



Issues to consider for β-decay spectroscopy

- **Balanced programme of *near* and *far* from stability**
  - Still much to be learned from studies near stability – requirement to firmly establish benchmarks near stability and proper systematics
- **Clean beams nearly as important for β decay as in-beam studies**
- **Statistics, statistics, statistics,…**
  - With the 8π at TRIUMF, we aimed for $10^8 – 10^9$ events in our γγ matrices for near-stability experiments
  - GRIFFIN will move us into the realm of 10^{10} events for γγ, and γγγ cubes
- **Tape collector with variable beam-spill control is vital**
  - Flexibility with deposit either internal or external of array is highly desirable
- **High-throughput DAQ**
- **Measurement of angular correlations**
  - Complements e^- for multipolarities, spin sequences
  - Many (perhaps *most?*) previous γ branching ratios wrong
    - Singles problematic, coincidences affected by angular correlations

Issues to consider for β-decay spectroscopy

- **Auxiliary detectors to increase range of physics**
  - Si for conversion e^- for multipolarities, *E0* transitions
    - Need LN2 cooling – restrictive geometry
    - Si count rates quickly become limiting factor – segmentation
    - Place Si outside focal volume of Ge to minimize scattering – e.g. BESCA with CARDS at ORNL
  - Introduction of fast-timing detectors like $LaBr_3$
  - Neutron detectors for β-delayed *n* emission

- **β-delayed neutron measurements**
  - Scattering is a serious issue – desirable to have open geometry
  - Compromise between coincidence efficiency and scattering

- **Design of a collection station**
  - For long-lived implanted sources
    - Spares target chamber from contamination
    - Enables e^- measurements on long-lived activities

Decay spectroscopy programme at TRIUMF is one of its most successful

Collaborators

- **University of Guelph**
  - **J. Bangay, L. Bianco, V. Bildstein, H. Dawkins, G.A. Demand, A. Diaz Varela, A. Finlay, K.L. Green, G.F. Grinyer, D. Jamieson, B. Jigmeddorj, K.G. Leach, A.A. Phillips, A. Raddich, E.T. Rand, M.A. Schumaker, C. Sumithrarachchi, C.E. Svensson, J. Wong**
- **TRIUMF**
  - **G.C. Ball, D.S. Bandyopadhyay, P.C. Bender, A. Garnsworthy, G. Hackman, S. Ketelhut, A.C. Morton, J.N. Orce, C.J. Pearson, E. R. Tardiff, S. Triambak, Z.-M. Wang, S. Williams**
- **Georgia Institute of Technology**
  - **J.L. Wood**
- **Oak Ridge National Laboratory**
  - **M. Allmond**
- **University of Kentucky**
  - **A. Chakraborty, E.E. Peters, B.P. Crider, M.T. McEllistrem, F.M. Prados-Estevez, S.W. Yates**
- **Simon Fraser University**
  - **C. Andreoiu, D.C. Cross, J. Pore, K. Starosta**
- **Colorado School of Mines (^{32}Na decay)**
  - **R. Braid, S. Ilyushkin, W. Moore, K. Kuhn, F. Sarazin**