COVER PAGE

DOE AWARD NUMBER: DE-SC0005089

Name of Grantee: Washington University

PI Name: Lee Sobotka

Project Title: Intermediate Energies for Nuclear Astrophysics and the Development of a Position Sensitive Microstrip Detector System

Final Close-out Report/Product #: DOE-WASHU-0005089-1

OVERALL PROJECT DIRECTOR: R. Tribble (TAMU),
Additional PIs: L.G. Sobotka (Wash. Univ.), J. Blackmon (LSU), C. Bertulani (TAMU-Com.).

A closeout report of the overall project can be found with DE-SC0004972, from TAMU. This report only details the Wash. Univ. contributions.

1. **Final close-out Report/Product #DOE-WASHU-0005089-1 (Award DE-SC0005089)**

RECIPIENT: Lee G. Sobotka
NAME OF PROJECT: Intermediate Energies for Nuclear Astrophysics and the Development of a Position Sensitive Microstrip Detector System
OVERALL PROJECT DIRECTOR: R. Tribble (TAMU),
Additional PIs: L.G. Sobotka (Wash. Univ.), J. Blackmon (LSU), C. Bertulani (TAMU-Com.).

A closeout report of the overall project can be found with DE-SC0004972, from TAMU. This report only details the Wash. Univ. contributions.

2. **There are no distribution limitations on this report.**

3. **Executive Summary**

The chemical elements are made at astrophysical sites through a sequence of nuclear reactions often involving unstable nuclei. The overarching aim of this project is to construct a system that allows for the inverse process of nucleosynthesis (i.e. breakup of heavier nuclei into lighter ones) to be studied in high efficiency. The specific problem to be overcome with this grant is inadequate dynamic range and (triggering) threshold to detect the products of the breakup which include both heavy ions (with large energy and large deposited energy in a detector system) and protons (with little energy and deposited energy.) Early on in the grant we provided both TAMU and RIKEN (the site of the eventual experiments) with working systems based on the existing technology. This technology could be used with either an external preamplifier that was to be designed and fabricated by our RIKEN collaborators or upgraded by replacing the existing chip with one we designed. The RIKEN external preamplifier project never can to completion but our revised chip was designed, fabricated, used in a test experiment and performs as required.

4. **Actual accomplishments**

A. Fabrication and use of two 512-channel systems based on our HINPc chip [1].

One of these systems went to TAMU and the other to RIKEN. Each of these systems consisted of:

a) 16 + 2 spare Chip Boards (CB). Each CB services 32 detector channels.
b) One mother board (MB) which services 16 CB's.
c) One power supply
d) One break-out board for linear and NIM logical signals.
e) One XLM-XXV VME module for data acquisition (ACQ).
f) All necessary cables
g) Software for control and ACQ.

The system delivered to TAMU was tested locally and used in an experiment at TAMU that lead to two publications [2,3].
The system delivered to RIKEN was employed in two test runs at HIMAC (in Japan).

B. Design, fabrication and testing of new Si-strip pulse processing ASIC

The preexisting chip [1] had neither the dynamic range nor the ability to trigger low enough for the desired science objectives. We therefore designed fabricated and deployed a new chip with the required functionality. The simplified (block diagram) schematics of the new Silicon-Strip processing chip, HINP-d (d for dual) produced by this grant is shown below. By this technology we sought to both extend the linear range and reduce the triggering threshold over existing technologies. Both of these principal objectives were met.

The range of the linear side was extended by using dual active shapers with a gain difference of a factor of 4, Fig. 1, top. Lower thresholds are achieved by the addition of a x10 amplifier before the leading-edge comparator, Fig. 1 bottom. We had 160 of these chips (each 16 ch) fabricated. We have tested about 60 chips in a test rig, made a prototype system of 192 channels and used this system in a test experiment at TAMU [4]. An itemized list of the results of the testing and initial employment follows.

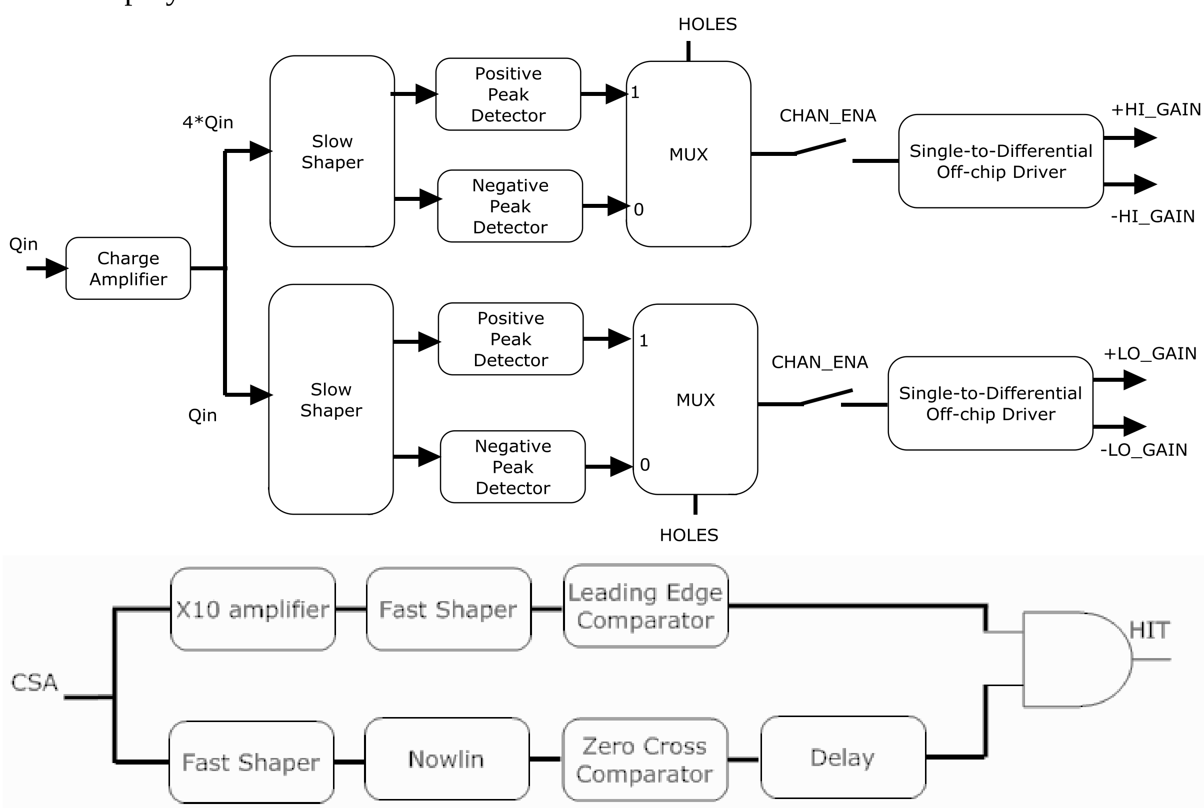

***Figure 1**: Schematics of the dual-gain Si-strip signal processing chip. The nominal full ranges of the two active ranges are 100 and 400 MeV. The significant changes relative to our prior chip are a different design of the charge amp, the dual active shapers, and a 10x amp in the logic branch. This chip cannot process external charge amps (CSA's)*

a. There is a logical error on the chip that requires a slower than planner download procedure to circumnavigate. The procedure took us a month to develop but there are no serious repercussions from this error.
b. About 75 % of the chips passed all tests in the test rig. At present we have not figured out the nature what the failures are due do. We suspect some of the failures are due to operator error, likely chip misplacement in the rig. From past experience, we expect that about 15% of produced ASIC's are unsuitable for ultimate use.
c. There is a pulser cross coupling from the pulser input to channel 7. This only affects pulser data as the pulser input is normally open when taking data.
d. The fully differential (chip to ADC) linear signals have a negative offset of about 500 keV (on the high-gain branch, i.e. out of 100 MeV) on negative polarity. This required a change in the chip board (CB) to bleed in a small charge. This change was made after the TAMU test, has been tested and is now in the production CB's.
e. The dual-gain operation works almost exactly as simulated as simulated. A pulser ramp is shown for a high-gain channel in Fig. 2. The one exception is that *some* channels have a slight non-linearity starting about ½ scale. At present we do not understand this channel-to-channel variation. However it is easily calibrated.
f. The chip (when attached to Si) can trigger down to between 200 and 250 keV on both polarities. (The linear range on negative polarity only recently recovered, down to the trigger point, with the redesigned CB mentioned above.)

A 512-channel system is now in production.
One experiment and the associated published paper resulted from work early in the project with the initial chip (HINP-c) and the system delivered to TAMU [1]. An experiment was done with HINP-d from which a science paper can be expected in 2016 [4]. In 2016, the technical paper describing the HINP-d chip will be submitted [5].

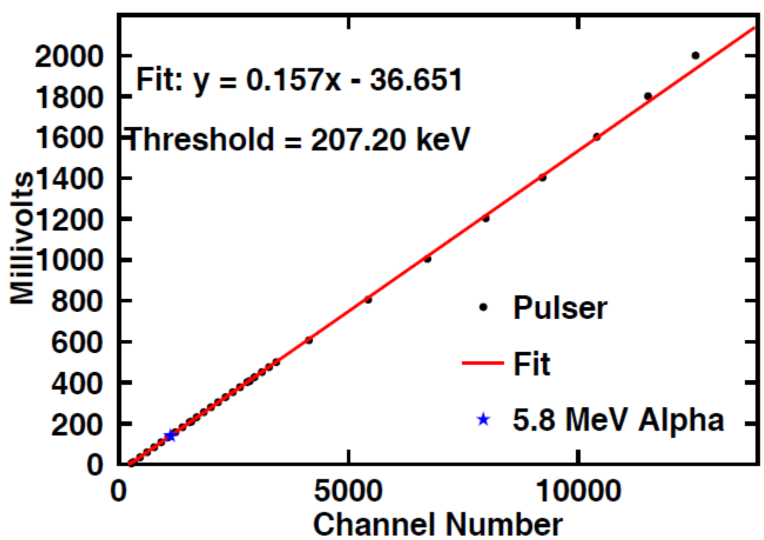

Figure 2*: Pulser and α linearity test of the high-gain channel of the dual-range chip. Not all channels are this linear. The linear fit is on the dense data at low pulse height.*

[1] "A Multi-Channel Integrated Circuit for Use in Low and Intermediate Energy Nuclear Physics - HINP16C," G. L.Engel, M. Sadasivama, M. Nethia, J. M. Elson, L. G. Sobotka, and R. J. Charity, Nucl. Instru. Meth. A **573**, 418 (2007),
http://dx.doi.org/10.1016/j.nima.2007.08.248.

[2] M. Jager, R. J. Charity, J. M. Elson, J. Manfredi, M. H. Mahzoon, L. G. Sobotka, M. McCleskey, R. G. Pizzone, B. T. Roeder, A. Spiridon, E. Simmons, L. Trache, and M. Kurokawa, "*Two-proton decay of ^{12}O and its isobaric analog in ^{12}N*," Phys. Rev. C **86**, 011304 **(R)** (2012),
http://dx.doi.org/10.1103/PhysRevC.86.011304.

[3] L. G. Sobotka, W. W. Buhro, R. J. Charity, J. M. Elson, M. F. Jager, J. Manfredi, M. H. Mahzoon, A. M. Mukhamedzhanov, V. Eremenko, M. McCleskey, R. G. Pizzone, B. T. Roeder, A. Spiridon, E. Simmons, L. Trache, M. Kurokawa, and P. Navrátil, *"Proton decay of excited states in ^{12}N and ^{13}O and the astrophysical $^{11}C(p,\gamma)^{12}N$ reaction rate"*, Phys. Rev. C **87**, 054329 (2013),
http://dx.doi.org/10.1103/PhysRevC.87.054329.

[4] "Spin alignment of excited ^{7}Li projectiles facilitated by spin-flipping the molecular structure of ^{9}Be targets," D. Hoff et al., work in progress.

[5] "HINP16Dual; A pulse processing Circuit with dual active shapers for use with Si-strip detectors," G. L.Engel, S.Thota, R. Singamaneneni, J. M. Elson, L. G. Sobotka, K. Brown, and R. J. Charity, manuscript in preparation (2016).

5. Summary

Signal processing systems based on the previous ASIC (HINP-c) were delivered as proposed to both TAMU and RIKEN. One science experiment (at TAMU) and two test runs (in Japan) were done with these systems. Two science papers not discussed in the proposal resulted from the experiment at TAMU. One of these publications did pertain to the main thrust of this proposal – nuclear astrophysics.

A new ASIC (HINP-d) was designed, fabricated and employed in a test experiment at TAMU. A publication (on a topic not included in the original proposal) will result from this experiment. While the design specifications were as proposed, the implementation (via-dual gain shapers) was different than proposed. This new chip will be used in all RIKEN projects (employing Si tracking) as the RIKEN solution using HINP-c has not materialized. All experiments at RIKEN have been delayed due to local (i.e. Japanese) problems. (For details see TAMU report **DE-SC0004972.**

6. Products

a) Publications

1. M. Jager, R. J. Charity, J. M. Elson, J. Manfredi, M. H. Mahzoon, L. G. Sobotka, M. McCleskey, R. G. Pizzone, B. T. Roeder, A. Spiridon, E. Simmons, L. Trache, and M.

Kurokawa, "*Two-proton decay of ^{12}O and its isobaric analog in ^{12}N*," Phys. Rev. C **86**, 011304 **(R)** (2012),
http://dx.doi.org/10.1103/PhysRevC.86.011304.

2. L. G. Sobotka, W. W. Buhro, R. J. Charity, J. M. Elson, M. F. Jager, J. Manfredi, M. H. Mahzoon, A. M. Mukhamedzhanov, V. Eremenko, M. McCleskey, R. G. Pizzone, B. T. Roeder, A. Spiridon, E. Simmons, L. Trache, M. Kurokawa, and P. Navrátil, *"Proton decay of excited states in ^{12}N and ^{13}O and the astrophysical $^{11}C(p,\gamma)^{12}N$ reaction rate"*, Phys. Rev. C **87**, 054329 (2013),
http://dx.doi.org/10.1103/PhysRevC.87.054329.

b) No web sites are maintained (by the WU group) with special information on this project.

c) Collaborations fostered
ASIC development: WU (Chemistry/Physics) and SIUE (Engineering)
Science : TAMU – WU - LSU

d) Technologies

The dual gain ASIC (with dual shapers for range enhancement and improved CFD for lowering triggering thresholds will be fully presented in a paper we are presently preparing for submission:"HINP16Dual: A pulse processing Circuit with dual active shapers for use with Si-strip detectors," G. L.Engel, S.Thota, R. Singamaneneni, J. M. Elson, L. G. Sobotka, K. Brown, and R. J. Charity, manuscript in preparation (2016).