Highly Segmented Detector Arrays for Studying Resonant Decay of Unstable Nuclei

*MASE: Multiplexed Analog Shaper Electronics*

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Outline

1. Resonant Decay
2. Detectors
3. Electronics
   - ASIC electronics
   - MASE
When a hot nucleus decays … Resonance Spectroscopy

- Tool to measure the existence and properties of short-lived intermediates

\[ 1 + R(q) = \frac{1}{C_{12}} \sum Y_{12}(p_1, p_2) \sum Y_{1}(p_1)Y_{2}(p_2) \]

\( \Gamma = 3.5 \text{ MeV} \)
\( 11.35 \text{ MeV} \)
\( 11.44 \text{ MeV} \)

\( \Gamma = 1.51 \text{ MeV} \)
\( 3.03 \text{ MeV} \)
\( 3.12 \text{ MeV} \)

\( \Gamma = 6.8 \text{ eV} \)
\( \text{gr. st.} \)
\( 8 \text{Be} \)
\( 93 \text{ keV} \)
\( \alpha + \alpha \)

Relative Energy Determined by Quantum State

\[ \Delta t = \frac{\hbar}{\Gamma} \]
\( \Gamma = 1.51 \text{MeV} \Rightarrow \Delta t = 4.35 \times 10^{-23} \text{ s} = 130 \text{ fm / c} \)

J. Pochodzalla et al., PRC 35, 1695 (1987)

Inclusive analysis!
Proximity decay: Tidal effects in nuclear decay

Coulomb interaction

• Decay into two identical particles
  ➥ Same acceleration after decay
• Change of the relative velocity
  □ Transverse decays have higher relative energy
  □ Longitudinal decays have lower relative energy
• Decay angle dependence of the probability
  \[
  P(E) \propto e^{-\frac{V}{T}} \quad \text{and} \quad V = f(\beta) \Rightarrow P(E, \beta)
  \]
  □ Higher probability to decay transverse to the emission direction
Tidal effect: angle dependence

- Longitudinal decay ➔ Lower $<E_{\text{rel}}>$
- Transverse decay ➔ Higher $<E_{\text{rel}}>$
- Additional velocity restriction yields semi-quantitatively comparable result

Consistent with tidal model

~20% effect
Highly segmented arrays

To study such decays requires the ability to resolve multi-particle decays with:

- good particle identification (Z and A)
- good angular resolution (high segmentation)
- good energy resolution.

Examples of such arrays are FIRST, LASSA, HiRA, MUST and MUST II. Such arrays typically consist of several hundred to a few thousand independent segments. Despite the high segmentation, the number of particles in a given event is small suggesting signals from the independent segments can be multiplexed to a single ADC. As a result the readout of the detector array is both considerably faster and simpler.

Considerations -

1. Si Thicknesses from 65 μm-1.5 mm (Thresholds, punch-thru)
2. Dynamic range 10 MeV - 8 GeV
3. Capacitance
**High Resolution Array**

Transfer reactions, inelastic excitation, resonance spectroscopy, etc.

- 64 mm x 64 mm (each telescope)
- 65 µm ΔE detector (32 strips)
- 1.5 mm det. (32 x 32 strips)
- 4 cm CsI(Tl)/PD

HiRA 20 telescopes (1920 strips) are highly configurable for different experiments.
Limitations of the conventional approach

- Not multiplexed \(\Rightarrow\) requires 1 ADC/channel
- Triggering on small signals is limited by the short integration time of the TFA
- CAMAC (a dying standard)
- Scalability is poor (both in complexity and cost)
  - Typical cost of 16-channel shaper (e.g. Picosystems > $3k)
  - Typical cost of 16-channel disc. (> $3k)
  - Typical cost of 16-channel ADC (> $4k)
One solution: HINP16C (HiRA ASIC)

16 channel chip includes:
- Multiple Preamps (100 MeV, 250 MeV, external)
- Slow Shaper and Timing Filter Amplifier
- Discriminator (5 bit)
- Time to amplitude converters

Gain of shapers and discriminators controlled with low resolution!

**Table 2 Source tests (FWHM)**

<table>
<thead>
<tr>
<th>test</th>
<th>$E_{\text{res}}$(keV)</th>
<th>$T_{\text{res}}$(ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^-$, external</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>$\alpha$’s, external</td>
<td>27</td>
<td>1.0</td>
</tr>
<tr>
<td>$\alpha$’s, internal</td>
<td>52</td>
<td>1.5</td>
</tr>
</tbody>
</table>

ASIC works significantly better with external preamp!
**MASE - An alternate approach to ASICs**

**Goal**
Design and build a high resolution, low-cost, scalable system for processing the energy signals of an array that is < 1024 channels.

**The MASE concept**

![Function block diagram of a single analog channel](image)

**Advantages**
- lower development costs, greater adaptability that ASIC
- lower triggering threshold
- larger dynamic range
- dynamically selectable input polarity
- seamless scalability from 16 to 4096 channels
Design Specifications

- 16 channels/module with dual H/L gain on each channel
- Gain matching of channels to <1% independent of gain
- Time-to-voltage converter (TVC) on each channel to provide random rejection
- 32 independent discriminators on slow signal
- Ability to mask off discriminators
- Easy control of disc. and amplifier gains (independent of DAQ)
- Standalone operation of a single module
- Compact crate configuration for a set of 16 modules
- Multi-crate functionality
- Identical DAQ software for single module/crate operation (seamlessly scalable)
- Module addresses are configurable
- Shaping time: 1 μs (Si); 3 μs (CsI(Tl))
- Dynamic range
  - 10 MeV full scale (with 40 mV/MeV CSA)
  - 7.5 GeV full scale (with 0.9 mV/MeV CSA)
Analog Inputs:
16 channels from CSA to 34 pin connector on front panel

Analog outputs:
Differential Energy and Time streams multiplexed via 2pin LEMO on front panel

Logical outputs
Addresses: via LVDS at back of module
Inspect, sum out, fast Trigger, etc via front panel LEMO

Booting FPGAs: JTAG interface
Slow control: USB

A module is 0.8 in. thick
A Channel board measures 16 in. x 9 in.

Logical decisions are made by a Xilinx Spartan 3 400 and 200 that operate in a master-slave relationship.
The crate configuration consists of:

- Upto 16 MASE channelboards
- One MASE controller
- A MASE crate/backplane
Function Block diagram of CB
Shaper produces good bipolar pulse with a shaping time of 1.1 \( \mu \text{s} \)

Output of multiplexer following peak find/hold circuit shows a settling time of \(~400\) \( \text{ns} \) after the multiplexer switches.
Output analog data stream

**Graph a)**
- Voltage (Volts) vs. Time (µs)

**Graph b)**
- Voltage (Volts) vs. Time (µs)
Features of MASE

- Inspect any channel (either bipolar or held analog levels) in the system (w/o unplugging cables)
- Sum out (50 mV/hit) provides multiplicity information
- Controller board has memory to preserve all settings
- PROMS on each channelboard preserve discriminator thresholds and amplifier gains
Readout with XLMXVV (or SIS 3301)

**XLMXVV (JTech)**

- 40 or 65 MHz sampling VME ADC
- 2 dual ADCs per module
- ADC is either 12 or 14 bit
- ADC is +/- 1V full scale
- Logical inputs via LVDS and ECL

**SIS 3301 + XLM80 (JTech)**

VME ADC, 8 channels (4 pairs), **14-bit** differential, pipeline, from SIS/Struck, [http://www.struck.de](http://www.struck.de).

VME address and control module, XLM72/80 designed by Jan Toke, Univ. of Rochester, [www.JTEC-Instruments.com](http://www.JTEC-Instruments.com).
XLMXVV (or SIS 3301+XLM80)
USB control (+ isolation)

Slow control of gains, thresholds, triggering masks

BoardSelection

Options

- Alternate Labels
- coarse gain range 255
- fine gain range 255
- display messages

File Selection Dialog

- File: E:\MASE\testfile.mase
- Selection: E:\MASE\changelog.txt

Open File:

- E:\MASE\testfile.mase

Uploaded all settings
Pulser fence/linearity

Low gain shaper has non-linearity of <0.02% over the entire dynamic range.

Slight discontinuity between last two gain ranges!
• Test setup: LASSA 500 µm detector; $^{241}$Am source
• MASE exhibits resolution of 30 keV for a 5.4 MeV $\alpha$, comparable to the conventional PICOSYSTEMS + peak sensing ADC.
Goal of TVC is to allow separation of beam bursts for random coincidence rejection.

- TVC is started by peak-find logical pulse relative to a common pulse.
- can be run in either common stop of common start mode.
For a fixed amplitude signal the MASE TVC exhibits an intrinsic resolution of ~ 2.5 ns.

- Individual fixed amplitude from pulse provides start signal
- COMMON STOP provided is varied in time
Timewalk: TVC variation with signal amplitude

- Amplitude of an individual input from pulser is varied, providing the start signal.
- COMMON STOP provided is held constant.
- For $V_{in} > 0.05\ \text{V}$, the timewalk is linear and the resolution is $\sim 3\ \text{ns}$ (intrinsic).
- For $0.02\ \text{V} < V_{in} < 0.05\ \text{V}$, the time resolution is still reasonable.
- For $V_{in} < 0.02$, the time resolution rapidly deteriorates with decreasing input signal amplitude.

Timewalk in MASE can be as large as 18 ns. For much of the dynamic range however, the resolution is good allowing one to correct for the timewalk.
TVC variation with gain

- TVC exhibits a dependence on the DAC gain setting (expected from design).
- Two channels with different fine gains will for the same signal exhibit a relative time difference (160 ns difference)
- Fine gain in MASE intended to be used only in the range of the vertical dotted lines (80-160) – max. difference of 30 ns
- Calibration of this dependence when gains are changed allows the TVC to be used for its intended purpose (random rejection).
Summary/Outlook

- We have developed a multiplexed analog system for convenient and low-cost readout of detector arrays (e.g. Si) of < 1024 channels.
- Resolution of <30 keV for a 5 MeV alpha particle has been achieved.
- Linearity, Cross-talk, etc. are well within acceptable limits.
- Intrinsic time resolution of ~2.5 ns
- Timewalk and dependence of gain on time can be corrected
- The channelboard is now in production stage
- The controller and backplane are presently in the construction stage.
- We estimate completion of the project by Dec. 2006.