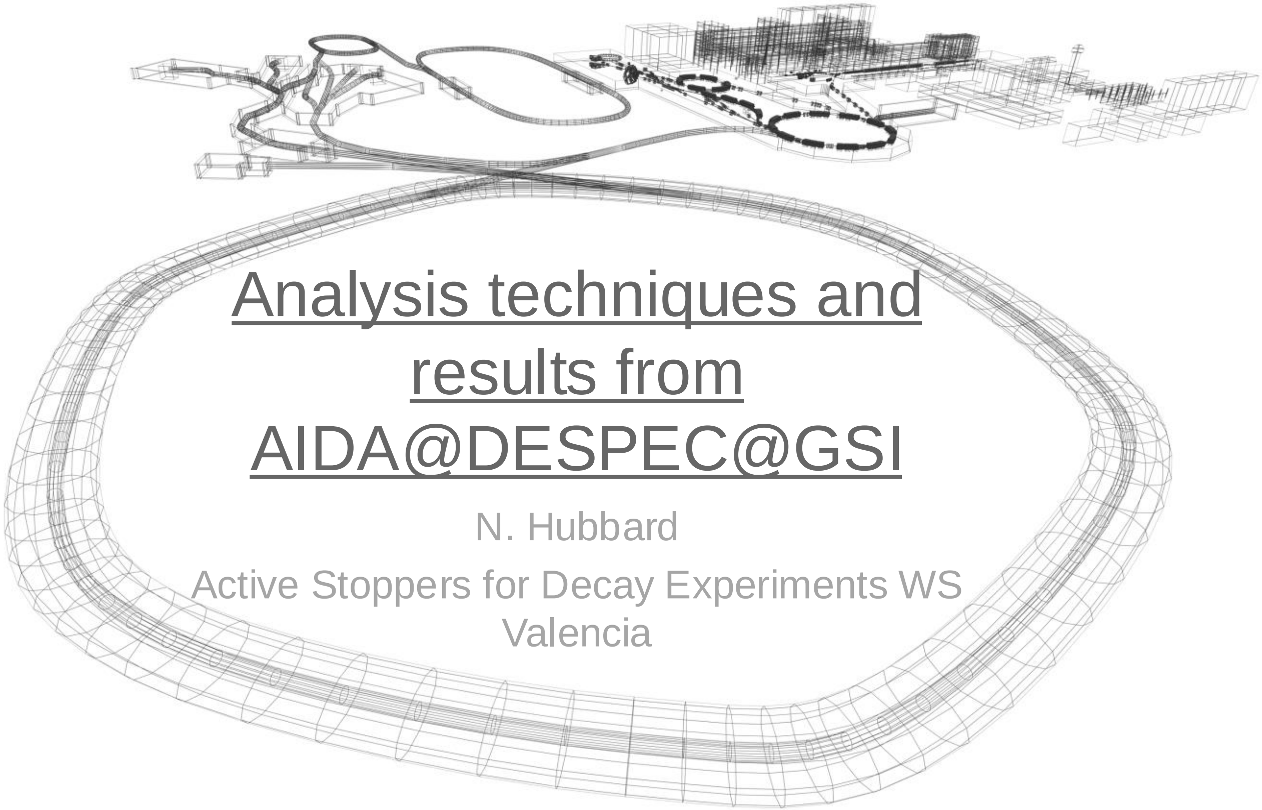


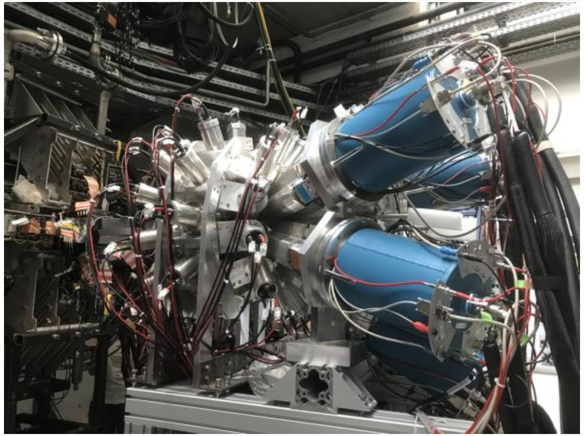
Analysis techniques and results from AIDA@DESPEC@GSI

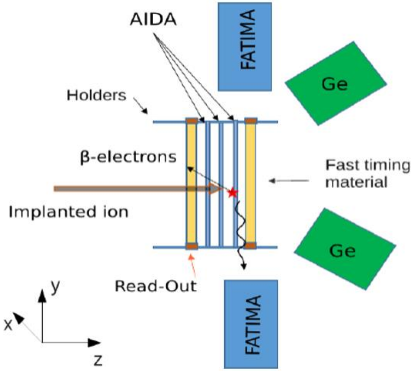
N. Hubbard

Active Stoppers for Decay Experiments WS Valencia

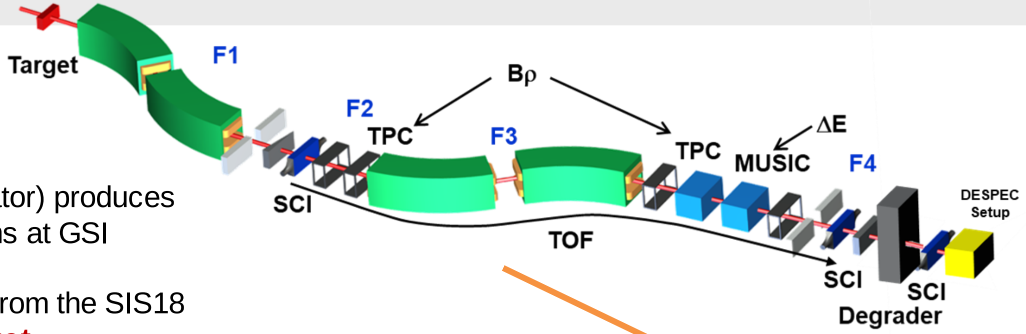
DESPEC Overview

- **DE**cay **SPEC**troscopy at GSI/FAIR
- Study of nuclear structure via nuclear decay studies
  - Isomeric Lifetimes
  - Beta-delayed half-lives
  - Charged particle decay
- Situated in S4 at the end of the FRS
- Exotic nuclei produced in fission/fragmentation are implanted in the active stopper (AIDA) and decays are measured via a flexible array of ancillary detectors (beta, gamma, neutron)





FRS



The **FRS** (Fragment Seperator) produces radioactive secondary beams at GSI

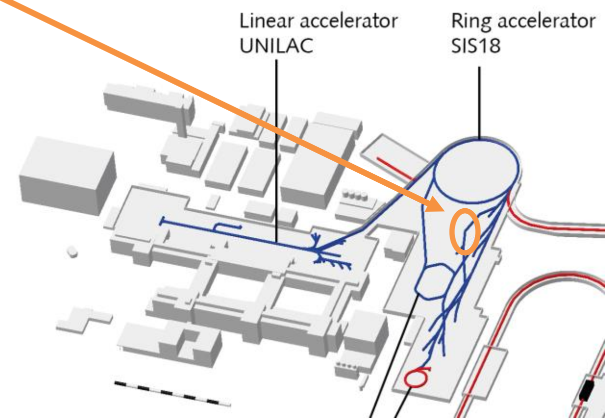
High energy primary beam from the SIS18 impinges a **production target**

Seperation of fragments via the Bρ-dE-Bρ method

Event-by-event **identification** of fragments via the Bρ-dE-ToF method

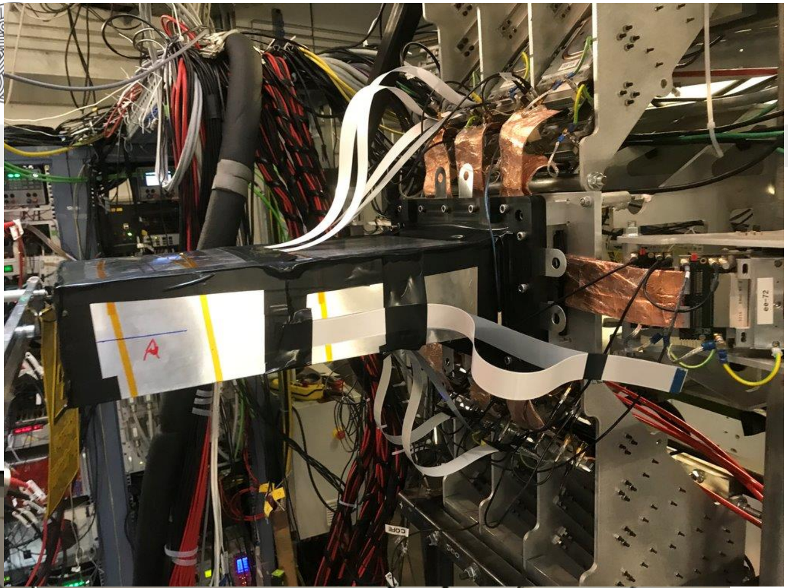
Standard FRS Detectors
SEETRAM: Beam Intensity
Pair of TPCs (F2, F4): Position (x, y)
Scintillators (F2, F4): Time of flight
MUSIC (F4): Energy loss
Additional Detectors:
Scintillator (F1), MUSIC (F2), TPC (F3)

Synchotron beam
Typical structure
1s off (acceleration)
1-3s on (extraction)
"Spill"



Review of AIDA

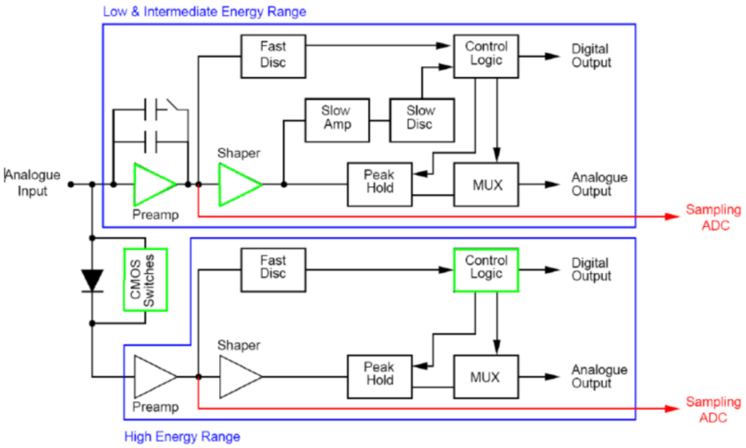
- AIDA is a DESPEC detector system for the measurement of decay properties at fragmentation/fission facilities
- A 'stack' of DSSSDs that can detect both the implanted ions (~10 GeV) and the subsequent decays (~200 keV)
- High segmentation (0.5mm) supports implantation rates ~kHz
- DESPEC: 8x8cm "narrow" or 24x8cm "wide"
(wide covers entire FRS focal plane)

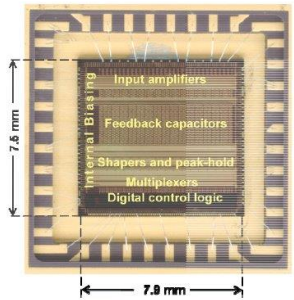


T. Davinson's Talk for Full Details!

Review of AIDA

- High dynamic range: two different gains
  - Low gain for ion implantation: 0-20 GeV
    High gain for decay measurement: 0-20 MeV
  - Custom ASIC circuit which automatically switches gains
    - No external "beam" signal required!
- Fast recovery: ~10 µs after beam
- Fully linear in both gains – excellent energy reconstruction
- ‘Triggerless’ DAQ readout – rates of up to 400 kHz per 64-channels possible
- Total 768 channels





AIDA Data Acquisition

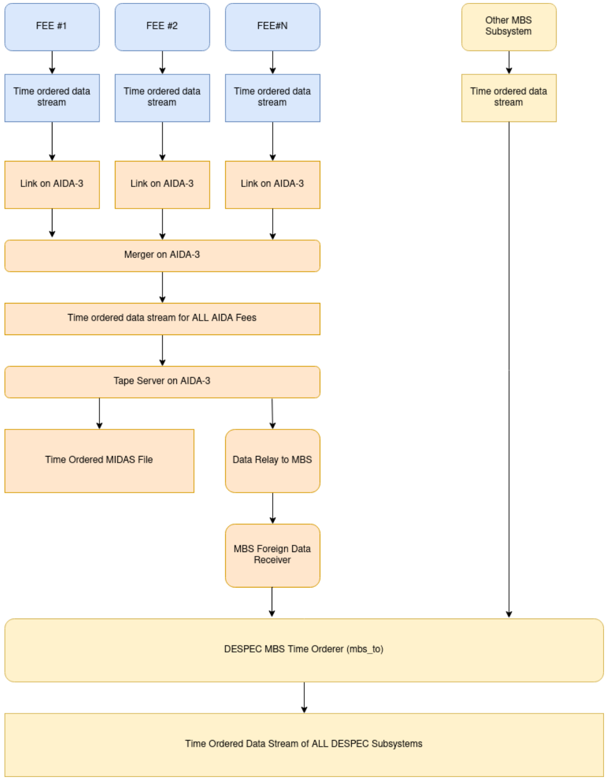
- AIDA uses "TDR" triggerless concept: Each ADC channel triggers itself asynchronously and is read-out independently: no global trigger!
- DSSD connected to 64-channel FEEs which are complete DAQ
  - 4xFEEs per 8x8 DSSD
  - 8xFEEs per 24x8 DSSD
- No events: They must be built in analysis
- AIDA FEE is fast: Dead time <1% for <200k data items per second
- Data output from a FEE is a **time-ordered data stream** of individual hits and miscellaneous data

- Challenges for DESPEC@GSI:
  - Integration into GSI MBS DAQ
  - Correlations with other subsystems

http://npg.dl.ac.uk/documents/edoc504/edoc504.html

AIDA Data Flow

- Each FEE generates its own time ordered data
- It is sent to a workstation (AIDA-3) via Ethernet
- A merger task merges all FEEs into a single time ordered AIDA data stream
- This is written to "tape" (hard disk) in 64 kiB blocks
- These "tape blocks" are forwarded to an MBS Foreign Data Receiver (FDR). One tape block is one "MBS Event" with an MBS WR timestamp of the first data item timestamp
- The MBS FDR sends data to the DESPEC Time Sorter (mbs_to) and is merged with other data streams
- **Raw MBS events for AIDA are physically meaningless**
- **Correlations cannot be done at this stage!**

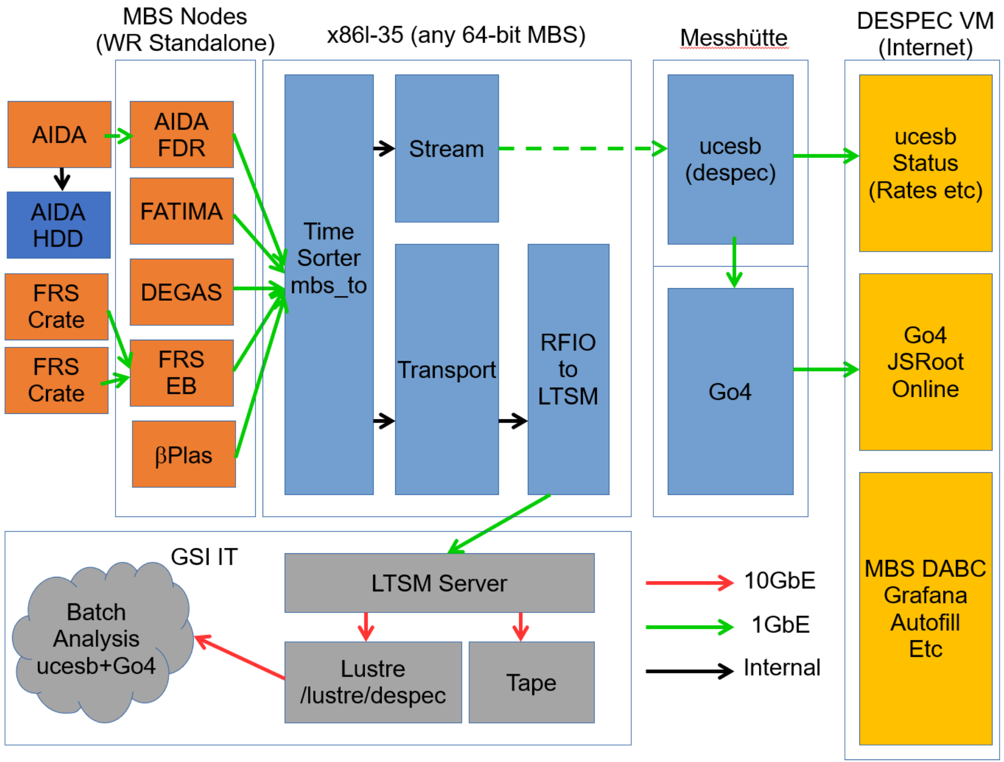


DESPEC Data Flow

DESPEC DAQ is many independent subsystems linked via White Rabbit (Common Clock)

Time order **orders** “events” (see caveat for AIDA) in time

Each event contains only one subsystem! No correlations



First Stage Analysis: ucesb

- Two “complexities” to DESPEC Analysis:
  - AIDA Event Building
  - Subsystem Correlation
- Solved by a customised copy of ‘ucesb’ (Chalmers)
  - Does AIDA Event Building
  - Does “Time-Stitching”
- **Fast** : > 200 MB/s
- **Dumb**
- Simplifies the work of the full analysis code by emulating a classical DAQ
- Ideal for online (quick), but for offline alternatives can be more specific

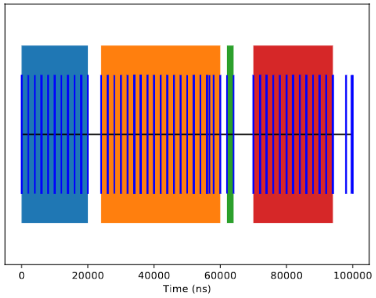
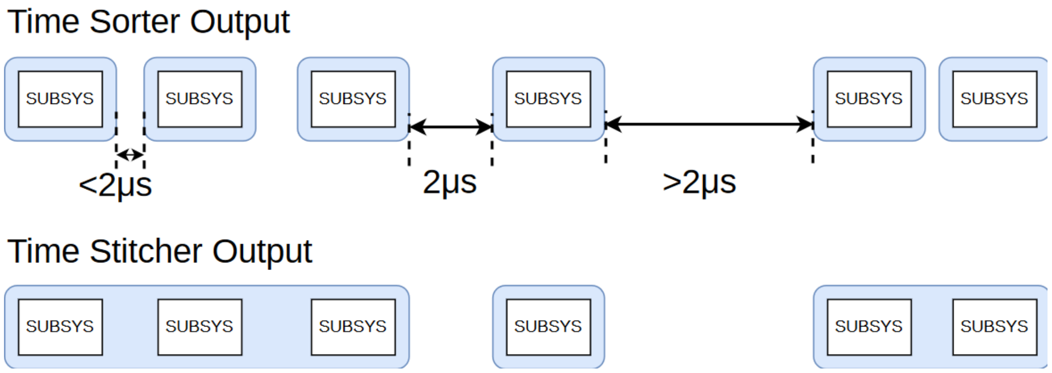


Figure 1: Figure of event building from S460f004. The blue lines correspond to timestamps of individual data items. The shaded areas are the events built from the data items - collecting all events until a gap of > 2 us is observed.

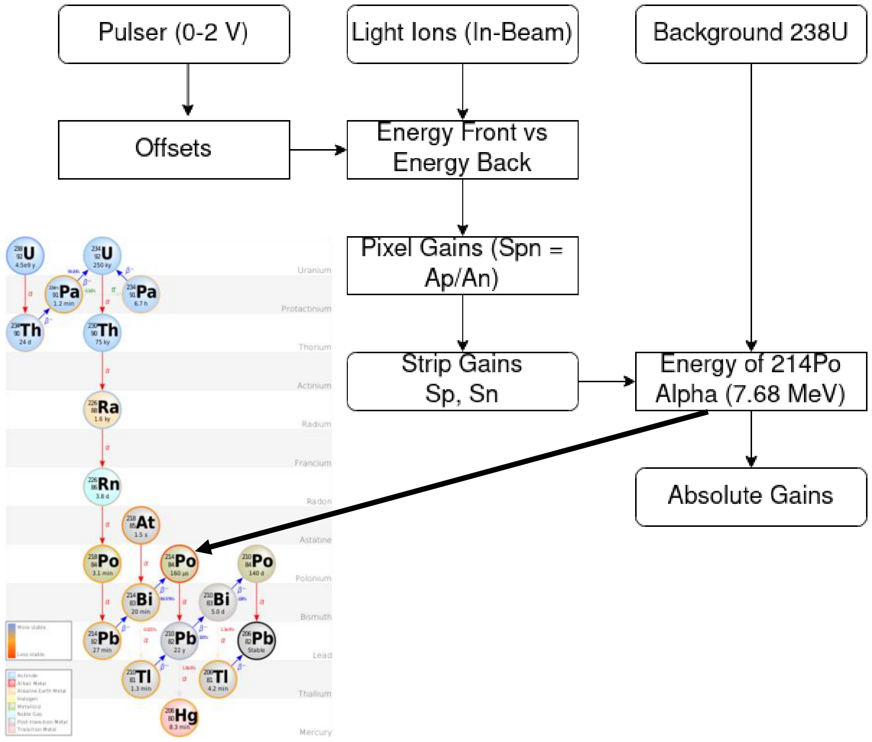
DESPEC Time Stitching (ucesb)

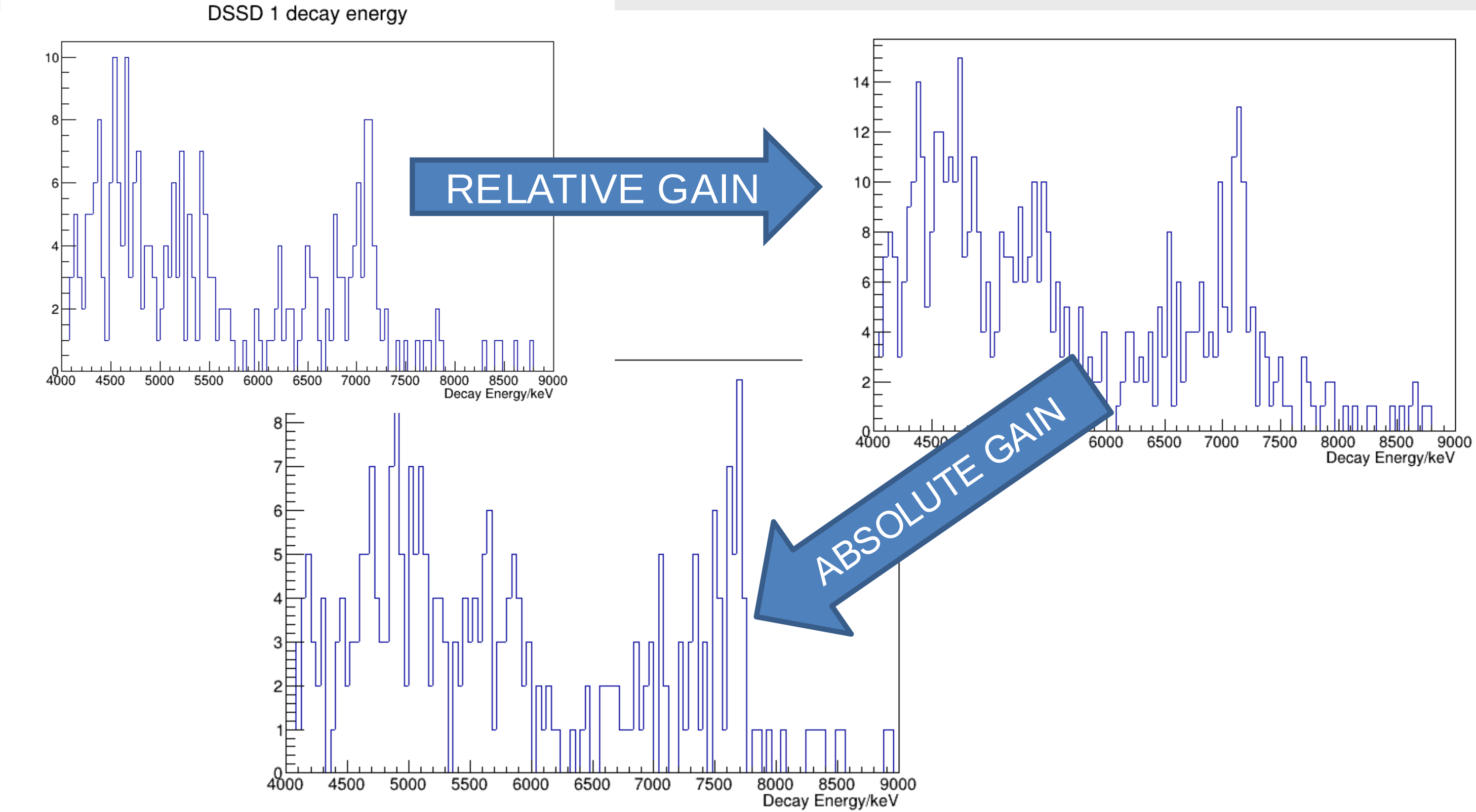
- Correlates data from different subsystems that occur "close" in time: Defined as 2 µs (same as AIDA tick)
- 2 µs is less than the other DAQs dead time! Events only ever contain 1 of each subsystem type (except in theory AIDA)
- Time Stitching is fast and crude: It only looks at the White Rabbit timestamp (no data inside the event is modified)
- First guess only of correlation
- Actual physically correlated events must be confirmed later in analysis (e.g. dT gates)
- Simplifies later analysis (like a triggered system)
- Repeatedly confirmed to be robust!
  - Also used at R3B and FRS



AIDA Calibration

- Improve energy resolution by calibration
- Highly segmented silicon detector: 768 channels to calibrate
  - Infeasible time with calibration sources
- Technique by M. Reese et al; Automatic intrinsic calibration of double-sided silicon strip detectors
- Relative gain matching from in-beam data
  - Now entire DSSD effectively single-pixel
- *Absolute* gain matching from background 238U decay series




DSSD 1 decay energy
Decay Energy/keV
RELATIVE GAIN
Decay Energy/keV
ABSOLUTE GAIN
Decay Energy/keV

Implant-Decay Correlations

- Nothing above does implant-decay correlations!
- Complexities:
  - Implants and Decays are temporally separated (seconds/thousands of events)
  - Beta decays are difficult to identify (dE ~ 300 keV, Scattering)
  - High rates:
    - 1 kHz Implantation
    - Light particles
    - Neutrons
    - Non-beta Electrons
  - Nearby degrader
  - Spill structure

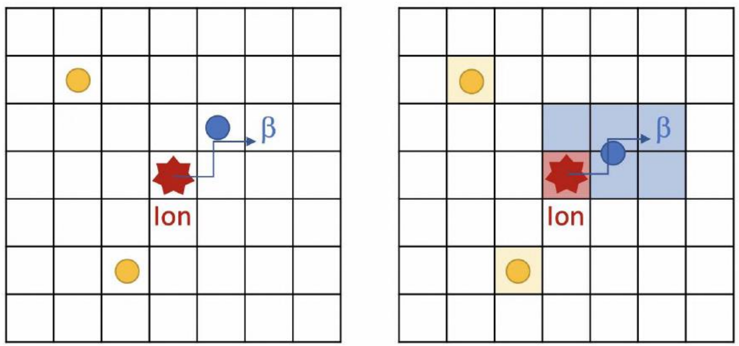
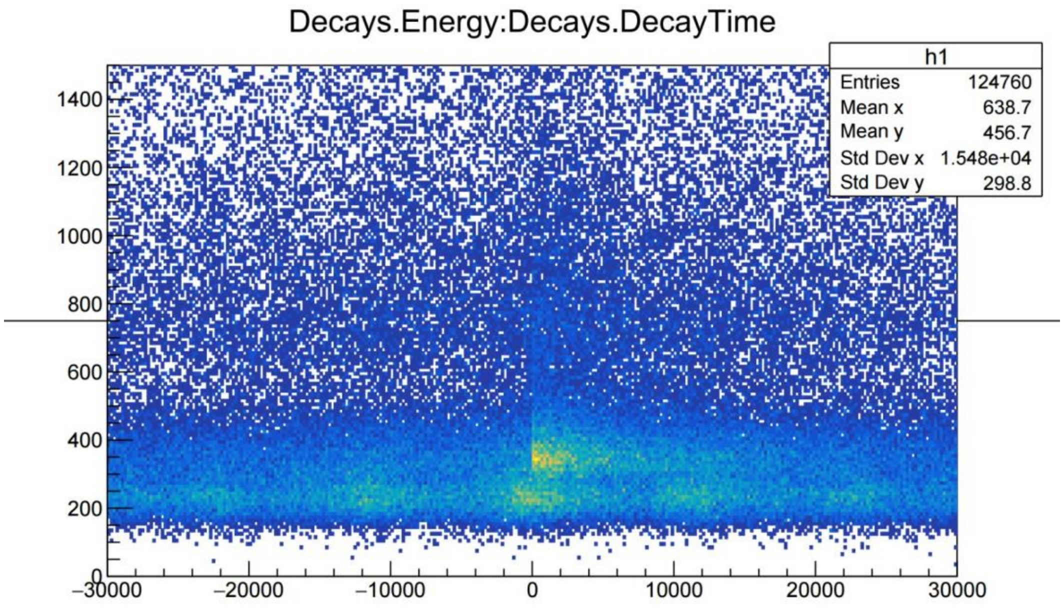


Figure 4.25: Ion and β position correlation as usually implemented (left panel) and the implementation in the case of higly-segmented detectors such as AIDA (right panel).

First Correlations in 2019

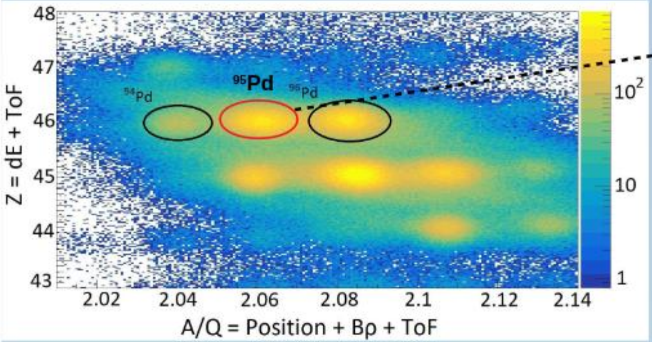
- Commissioning of AIDA with ^{34}Si secondary beam

- Forward and backwards correlation using trees
- Clear decay seen



S480

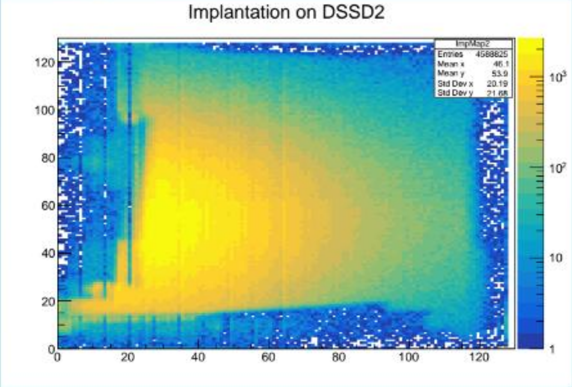
Implanted Ions : ^{95}Pd



^{95}Pd Ions from FRS are implanted on the Active Stopper, AIDA

- 3 DSSSD in Narrow Conf.
- 128x128 pixels
- 0.6 mm strip pitch
- Implant Energy > 500 MeV

Low Gain Preamplifier



Implant Timing is stored as a function of position $T_{implant}(x,y)$

Slides: B. Das

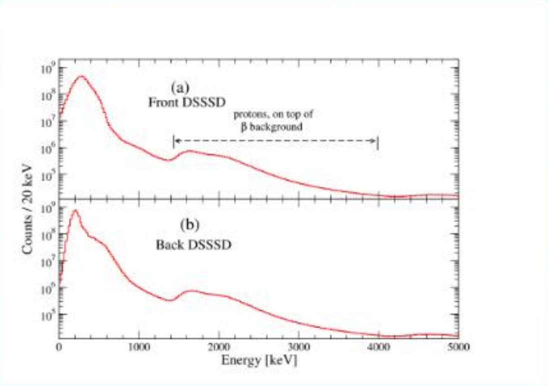
S480

S480

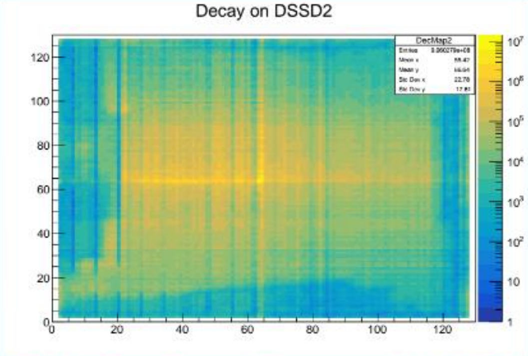
β Decay at the AIDA : ^{95}Pd

$$\left\{ \begin{matrix} T_{implant}(x, y) \\ T_{implant}(x, y\pm 1) \\ T_{implant}(x\pm 1, y) \\ T_{implant}(x\pm 1, y\pm 1) \end{matrix} \right\} < T_{decay}(x,y) < \left\{ \begin{matrix} T_{implant}(x, y) \\ T_{implant}(x, y\pm 1) \\ T_{implant}(x\pm 1, y) \\ T_{implant}(x\pm 1, y\pm 1) \end{matrix} \right\} + 3\tau_{1/2}$$

Decay Energy

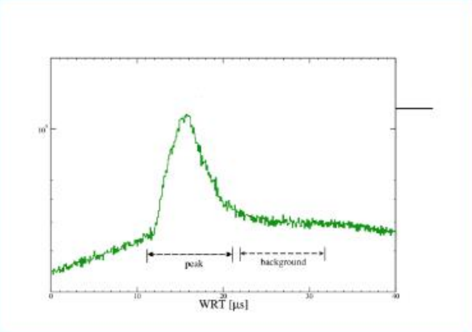


Decay Mapping



150 keV < Decay Energy < 1300 KeV

The FATIMA – AIDA WR time window

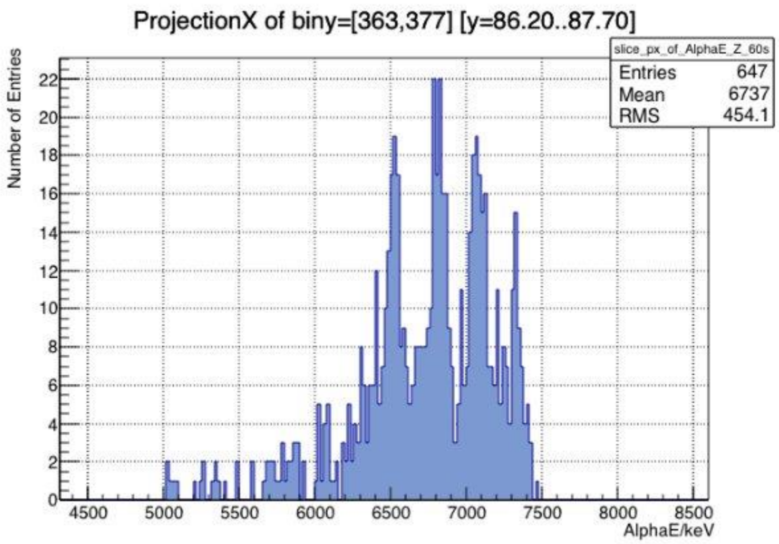


- β's registered in DSSSD & γ's registered in FATIMA detectors are correlated using the White Rabbit clock.

Slides: B. Das

S460

Alpha Energy spectrum of ions with Z=86-87

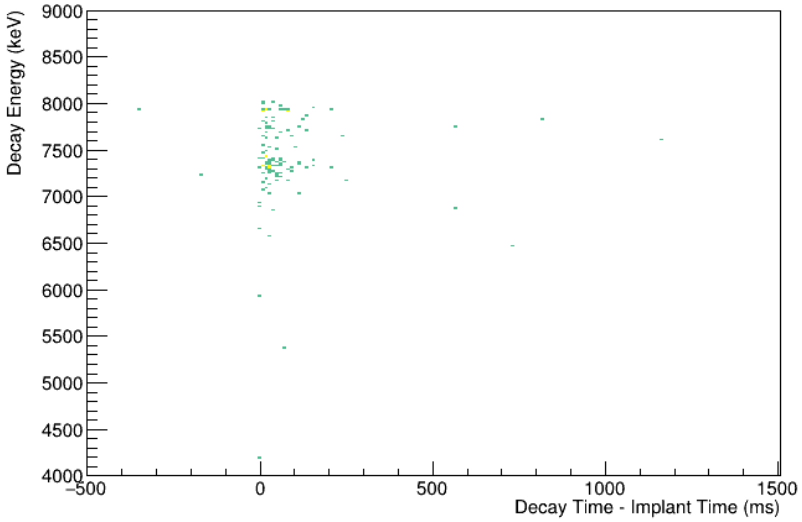


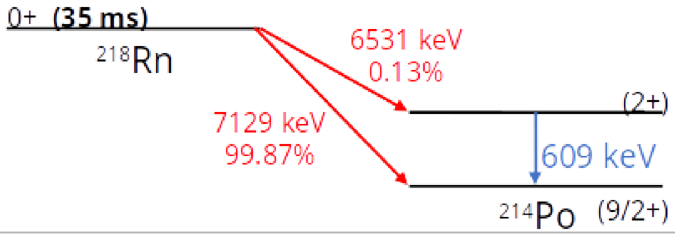
Alphas much easier to observe in Si than betas

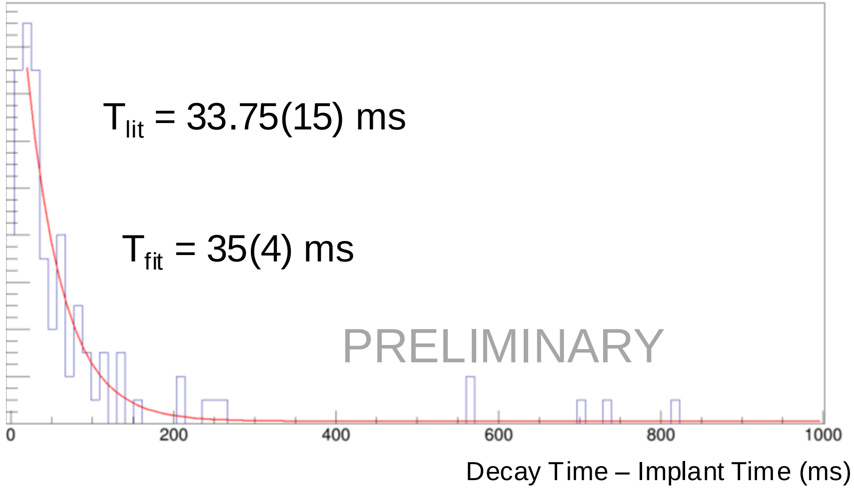
Idea: Test correlation procedures

Problem: Degrader meant most alphas not stopped in AIDA!

Alpha decay of 218Rn

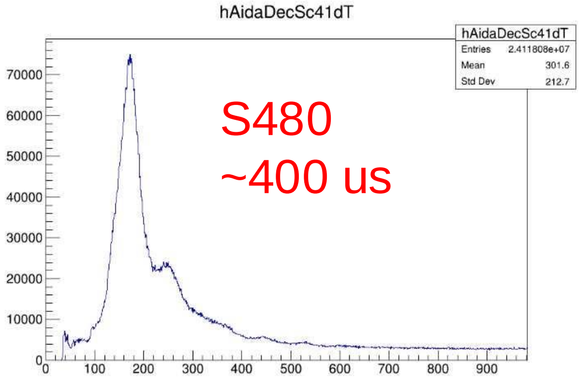


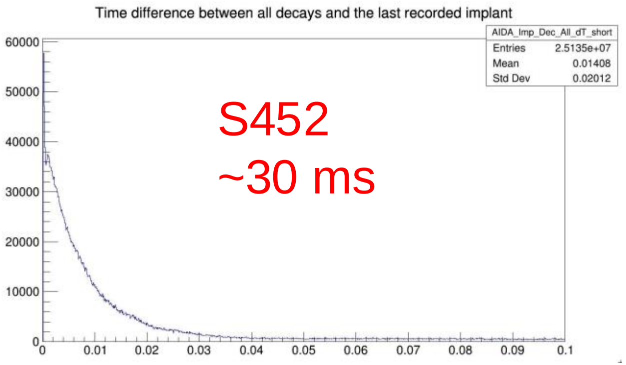




Rate and Noise

- For the large majority of experiments AIDA has struggled with higher than anticipated rates due to various factors
- Especially the Wide AIDA campaign highlighted serious rate issues with the n+n ohmic strip (length 22.5 cm)
- Success in d002 (^{34}Si) and S480
- Further experiments have shown significant difficulties in seeing decays, high rates and significant rate after an implant





S505

Narrow + DTAS

Heavy ground improvements

Much quieter than previous runs

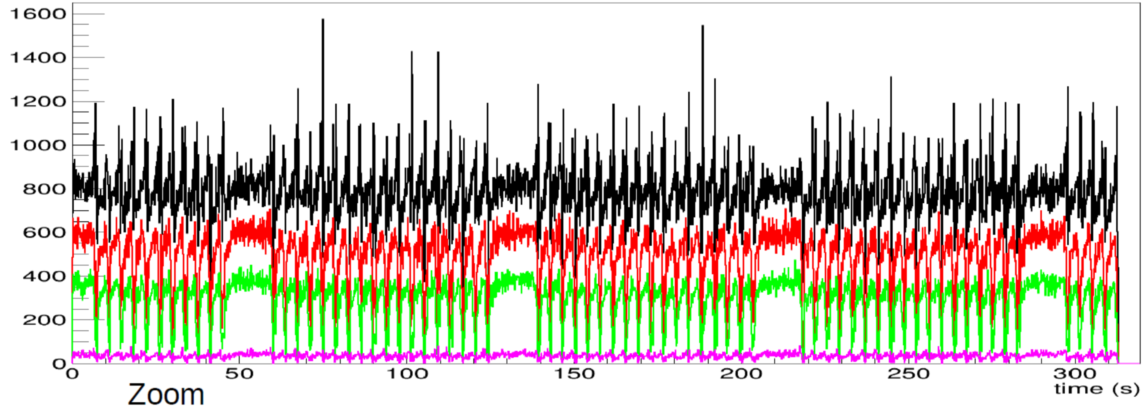
Still see high implant-induced rates

Analysis ongoing

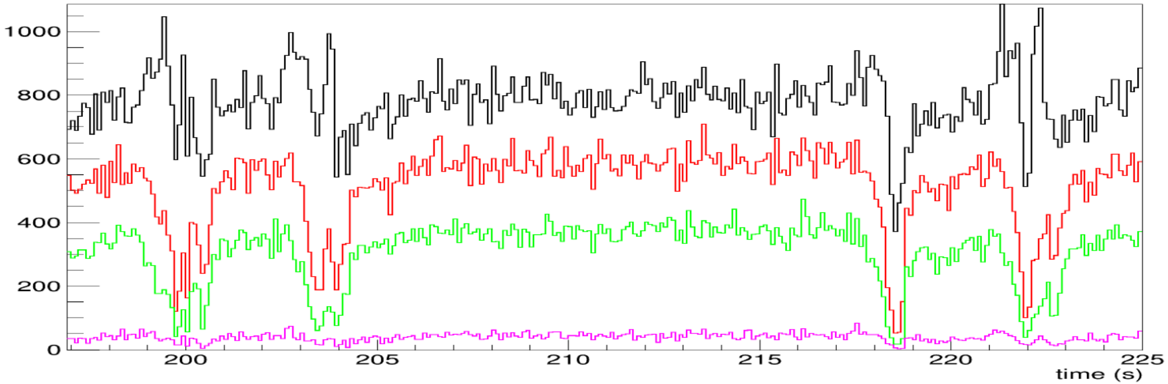
Beta Rates in DSSD1:

Hardware strip threshold
Ex,Ey>250keV
|Ex-Ey|<150keV

Black: No condition, Red: nx,ny<11, Green: nx,ny<6, Pink: nx,ny<6 & no noisy strips



Zoom



D. Rodriguez

Noise Improvements Oct 2023

- All tests using a 24cm x 8cm 'triple/Wide' DSSD

- Old situation (S450 May 2022)
  - p+n junction Strips   90 keV FWHM
  - n+n ohmic strips   300 keV FWHM

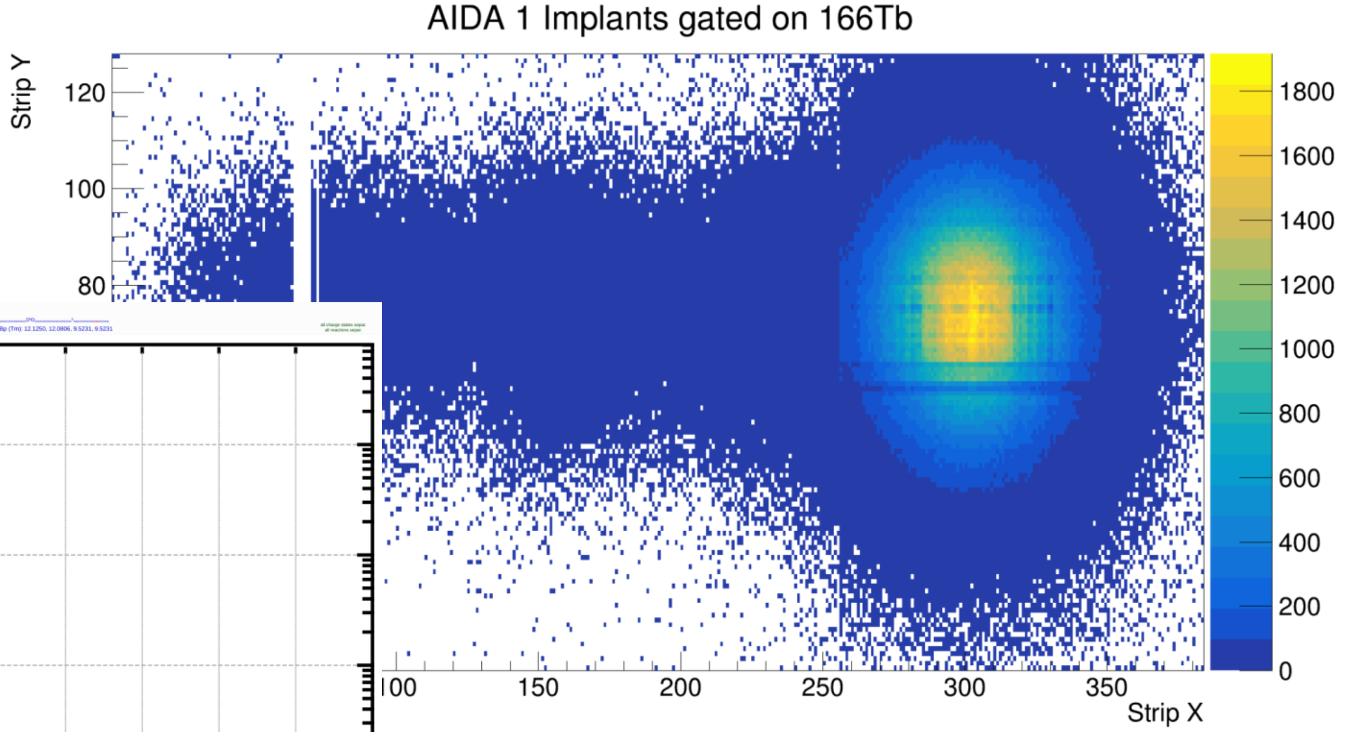
- New situation
  - p+n junction strips   45 keV FWHM
  - n+n ohmic strips   75 keV FWHM

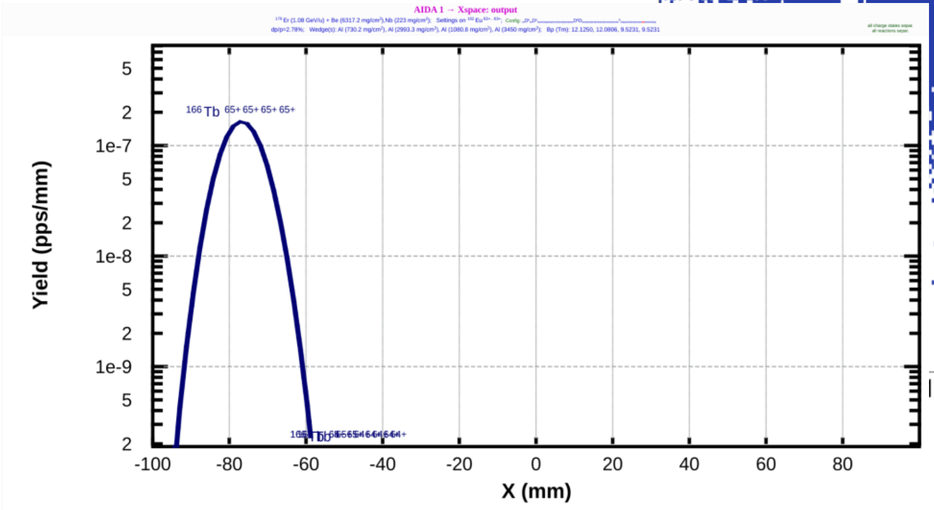
- These values agree with expected noise for triple DSSSD capacitance and leakage currents

G-22-00100

AIDA(I)+FRS Correlation

Ion location confirmed





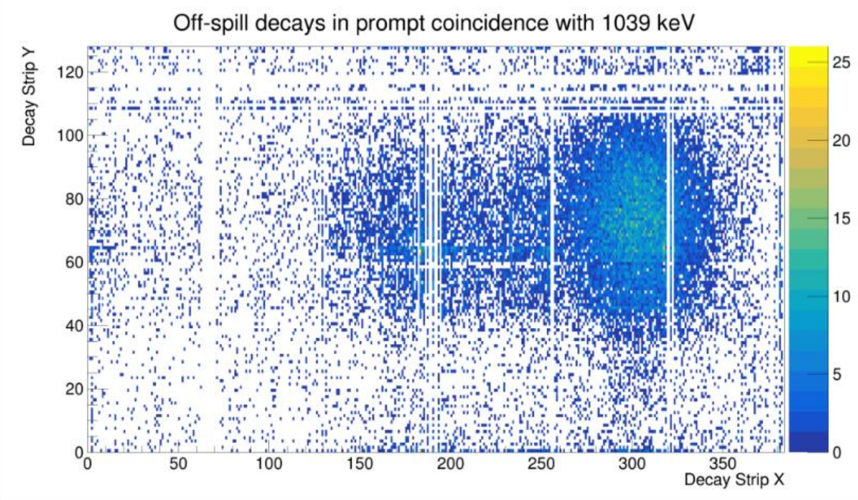
J. Bormans

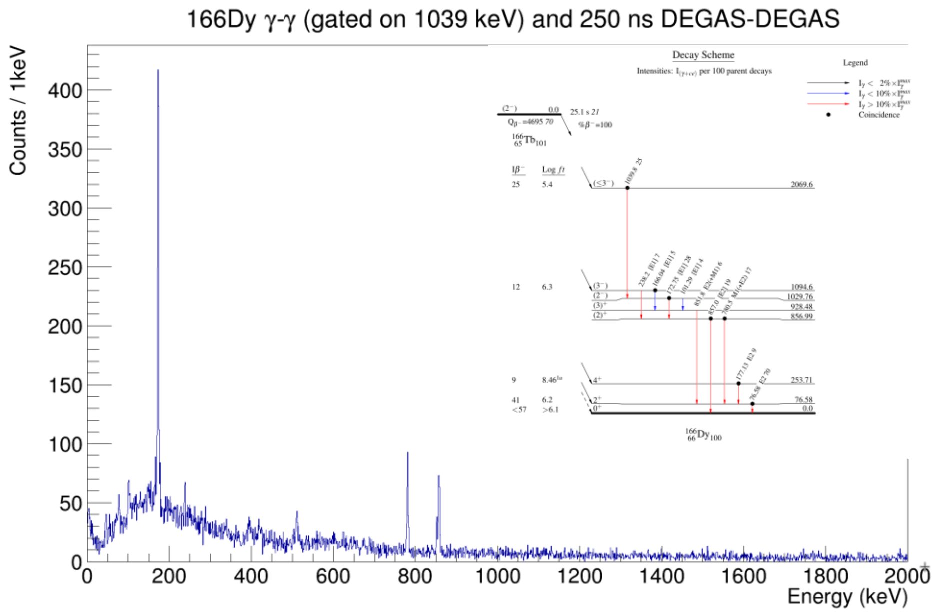
G-22-00100

166Tb (β-) → 166Dy γ-γ gated on 1039 keV
- Decays in AIDA DSSSD 1

Background sources unknown

Preliminary

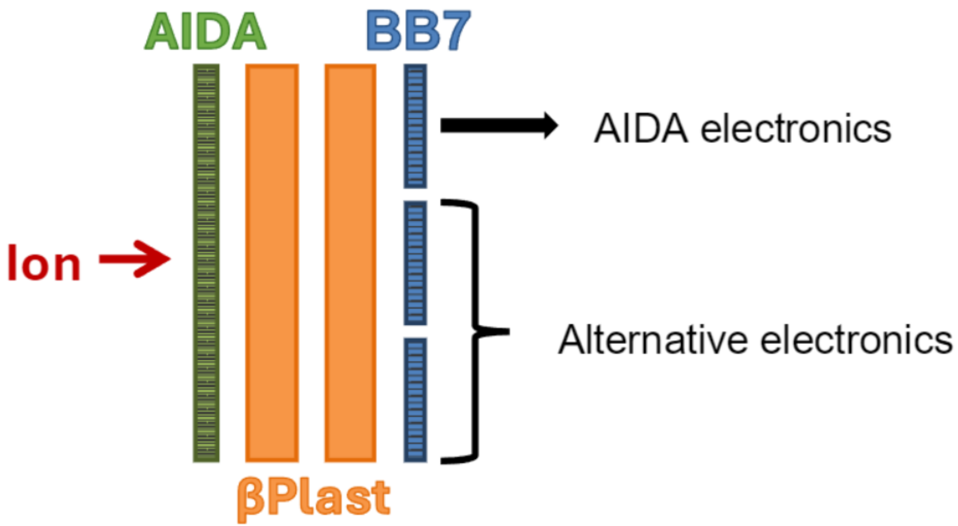




J. Bormans

G-24-00302

- Test of DESPEC Implantation Stack
  - BB7: Talk by M. Polletini
  - bPlast: Talk by C. Chatel
- 8h 82Nb implanted in AIDA
  - Rate: ~0.1KHz
  - T1/2: ~100ms
  - “Easy” case for Correlations
  - Confirm principle



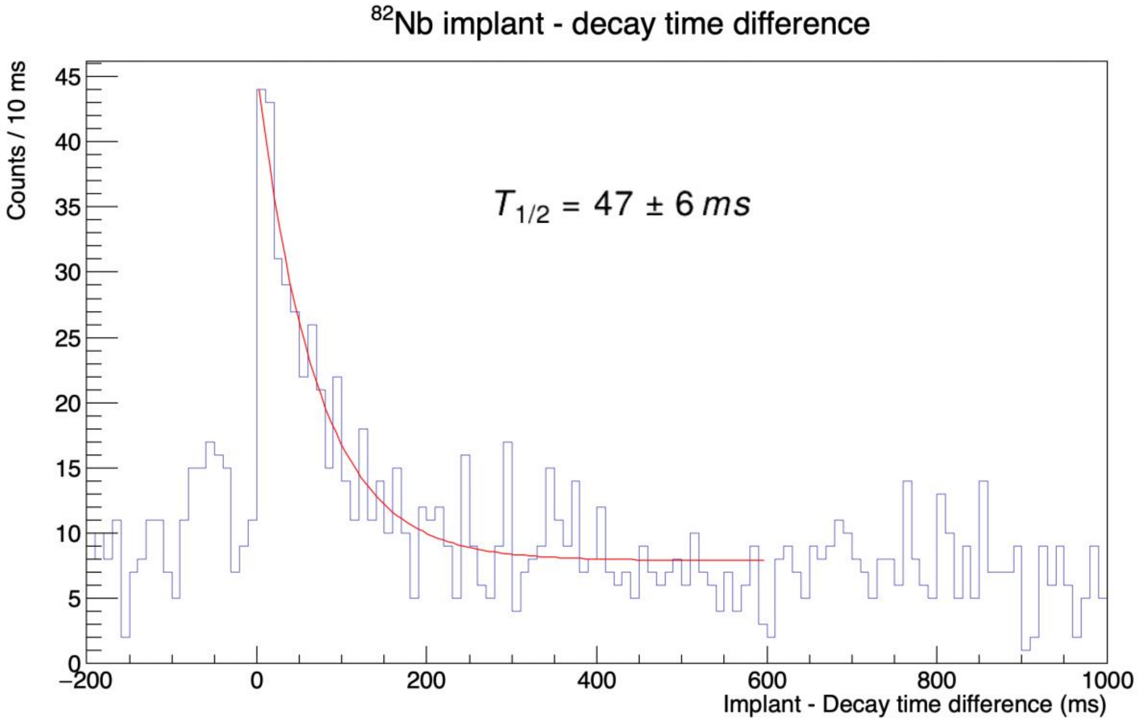
G-24-00302

Successful extraction of curve (within a day!)

Proof that correlations work in principle

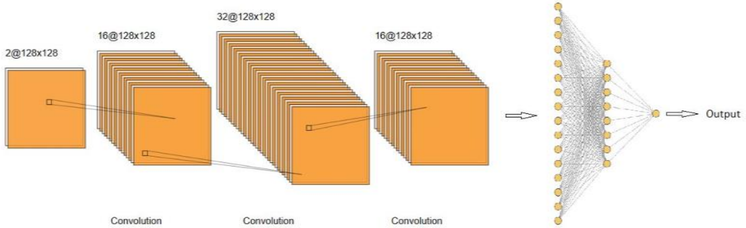
Further investigation:
What changed this time?

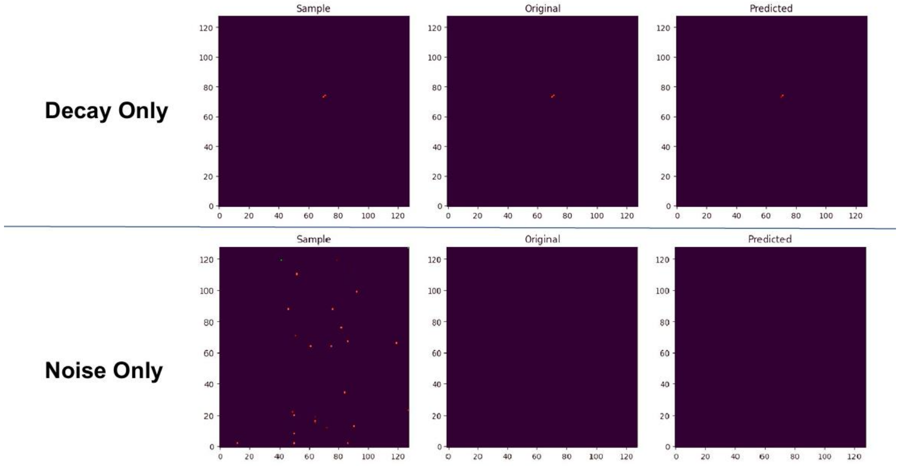
What rates/decay times can we achieve?



Machine Learning for AIDA

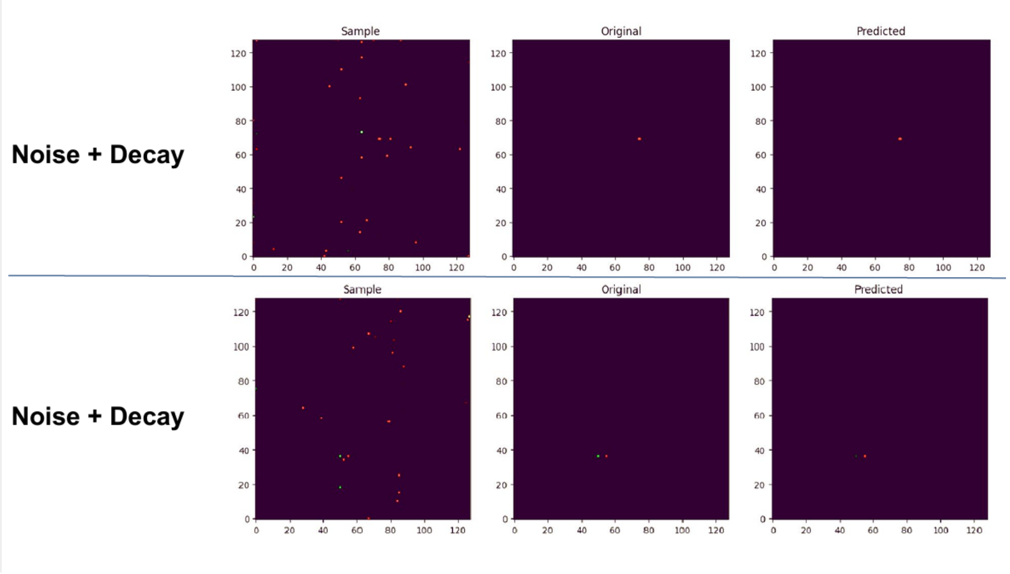
- Discriminating betas and noise is a perpetual issue
  - Can AI help us?
  - Project by A. Calo (GET_Involved@GSI) Using Simulated Data





Machine Learning for AIDA

- Discriminated betas and noise is a perpetual issue
  - Can AI help us?
  - Project by A. Calo (GET_Involved@GSI) Using Simulated Data



Simulated data (Geant4 decay + Realistic noise)
Model can predict the real decay against the noise

Proof of principle only!

Conclusion

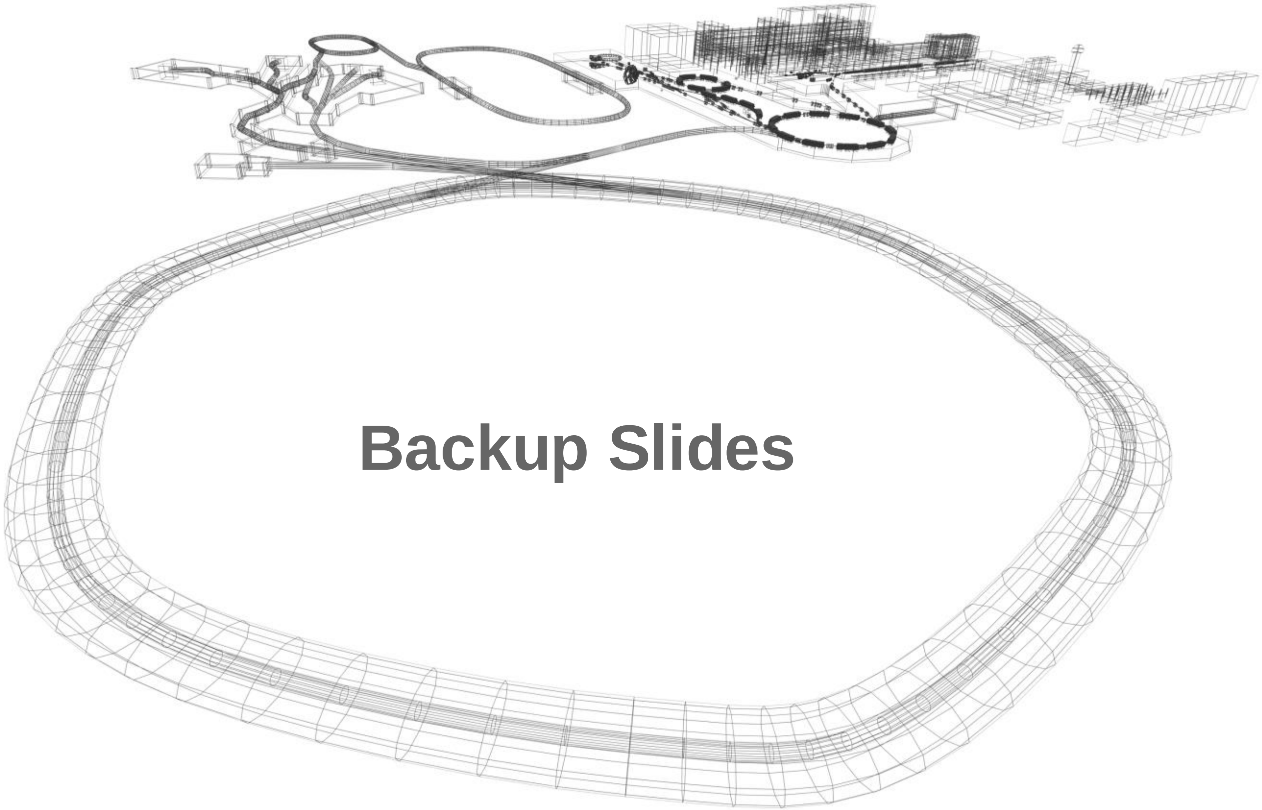
- AIDA@DESPEC has been used for 6 years
- Lots of experiments, lots of work on analysis
- … But it’s a complicated task!
- Principle of correlation repeatedly confirmed
- Correlation with other DESPEC Subsystems and FRS very simple
  - Frequently tested: FRS-AIDA, AIDA-GAMMA, FRS-GAMMA
- Distinguishing betas difficult!
  - Minimal ionisation of beta electrons in Silicon
  - Environmental situation at GSI
- Careful experiment design is necessary!
  - Implant Rates and Background
- Techniques applicable not just to GSI

Acknowledgements

- T. Davinson, O. Hall, P. Woods, R. Taylor, P. J. Coleman-Smith, V. Pucknell, C. Unsworth, C. Chatel, J. Bormans, H. Albers
- B. Das, M. Polettini, A. I. Morales, M. Kundu, D. Rodriguez, G. Bruni, A. Calo

- **AIDA Collaboration**
- **HISPEC/DESPEC Collaboration**
- **NUSTAR Beam Team**
- **FRS/S-FRS Experiment Collaboration**

Backup Slides

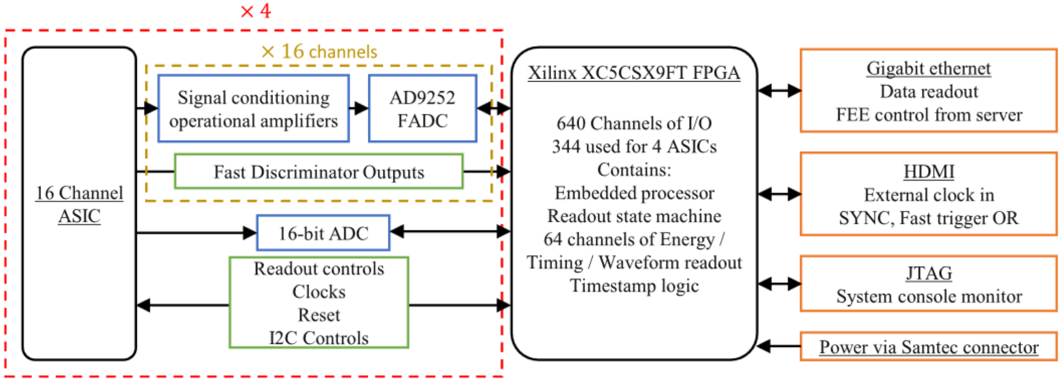


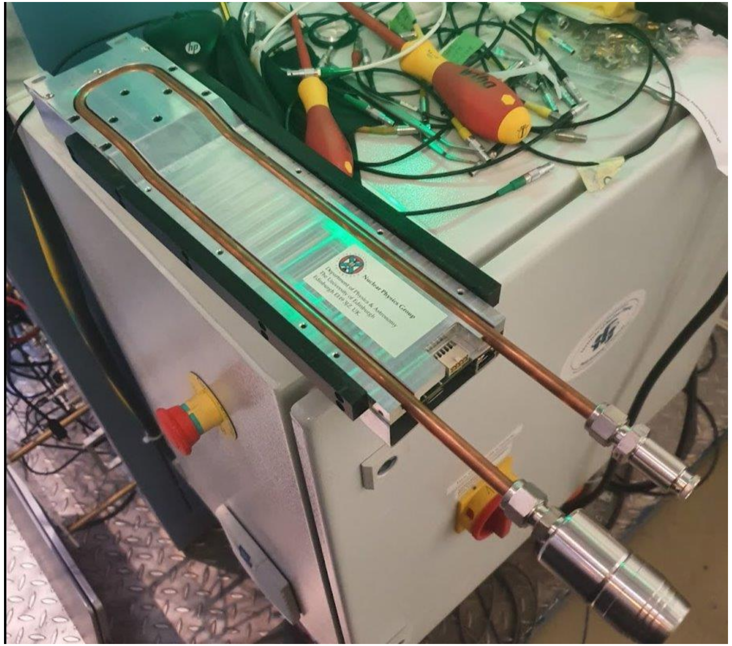
AIDA Electronics

AIDA connected to custom AIDA front end electronics card "FEE[64]"

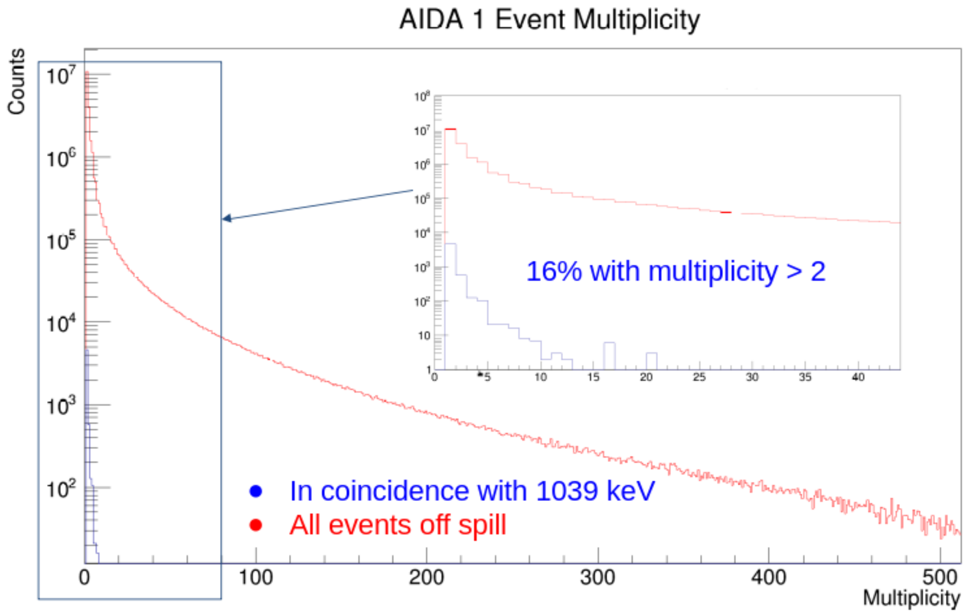
FEE is a whole DAQ! Handles entire processing chain from raw detector signals, sends digitised data out via **ethernet**.

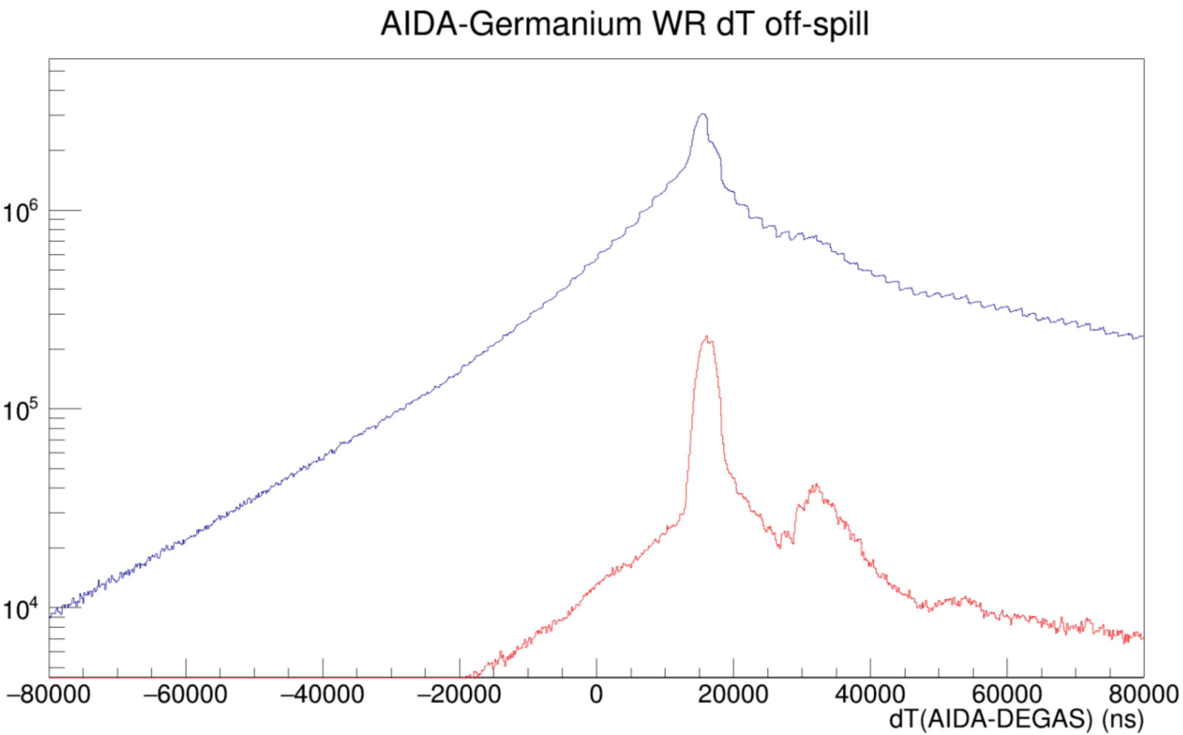
One FEE64 is 64-channels: need 4 (narrow) or 8 (wide) FEE64s per DSSD: Synchronised via **White Rabbit** over HDMI





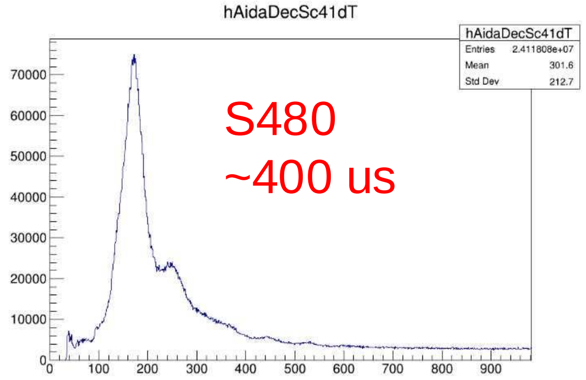
AIDA decay event Multiplicity off-spill

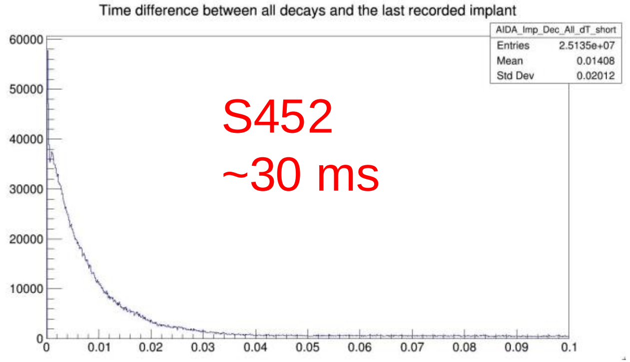



AIDA-Germanium WR dT off-spill
10^6
10^5
10^4
−80000
−60000
−40000
−20000
0
20000
40000
60000
80000
dT(AIDA-DEGAS) (ns)

Rate and Noise

- For the large majority of experiments AIDA has struggled with higher than anticipated rates due to various factors
- Especially the Wide AIDA campaign highlighted serious rate issues with the n+n ohmic strip (length 22.5 cm)
- Success in d002 (^{34}Si) and S480
- Further experiments have shown significant difficulties in seeing decays, high rates and significant rate after an implant

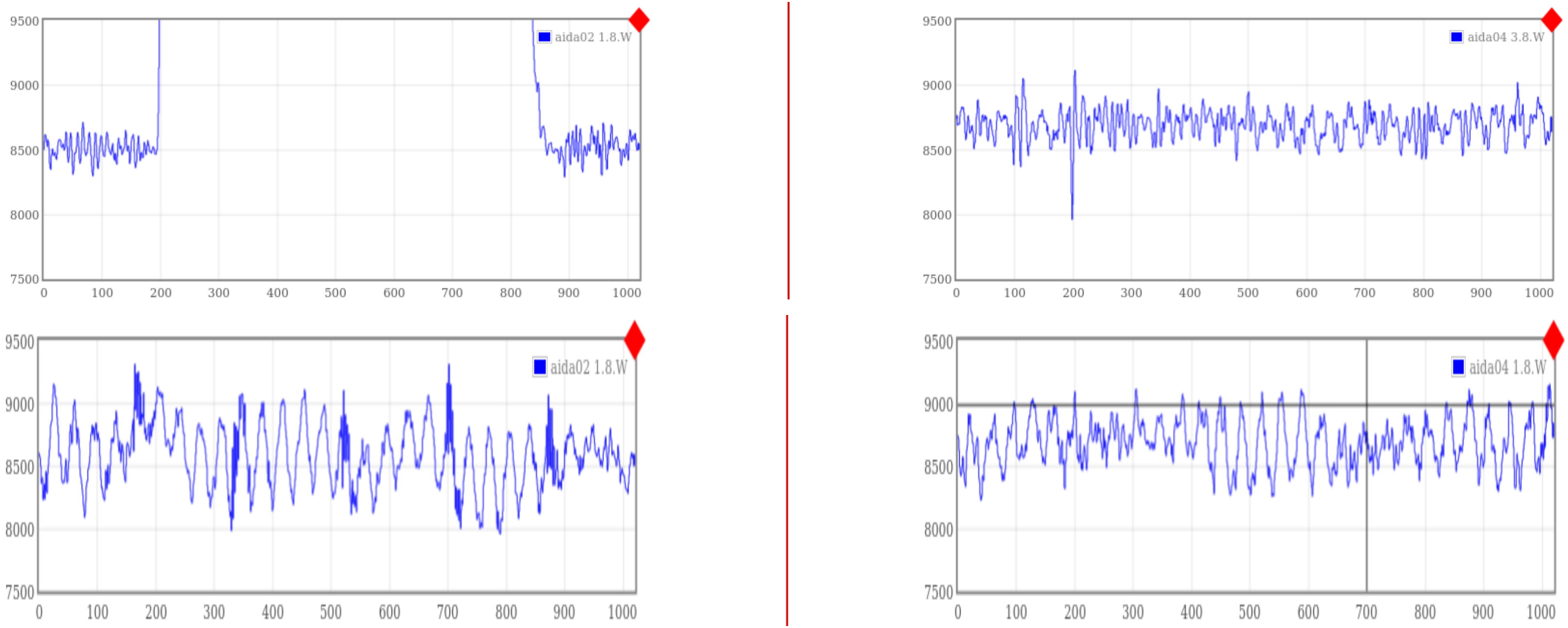




n+n Ohmic Strips

NEW
Oct 2023

OLD
May 2022

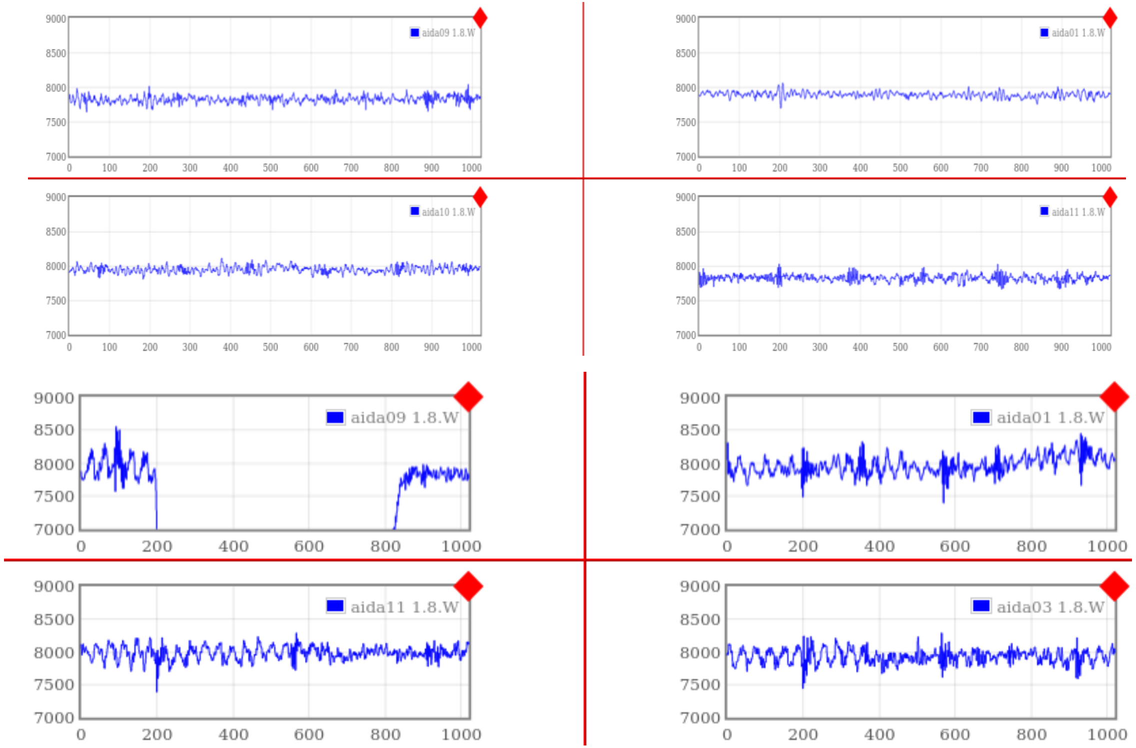


Per strip preamplifier outputs – y-axis range = 244mV, x-axis range = 20μs

p+n Junction Strips

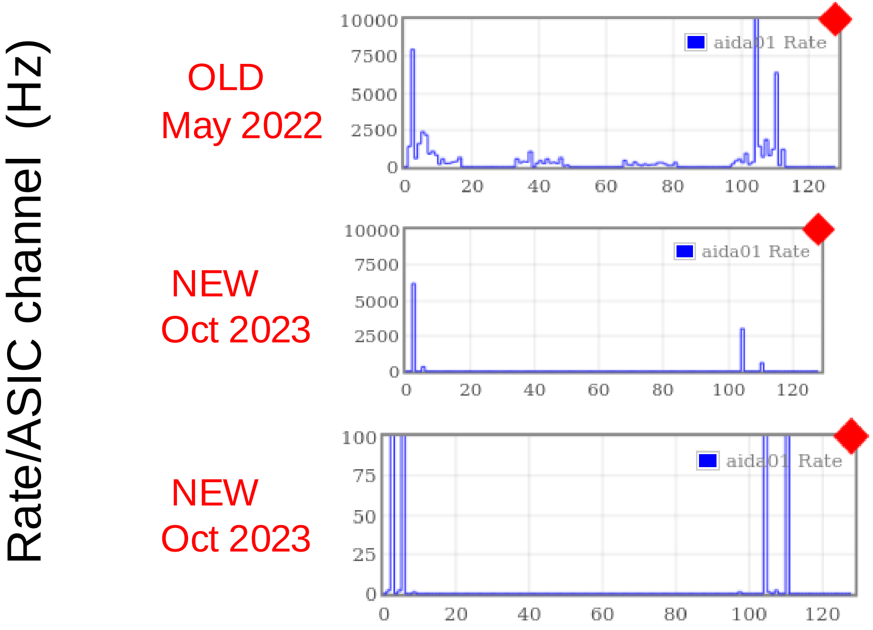
NEW
Oct 2023

OLD
May 2022



Per strip preamplifier outputs – y-axis range = 244mV, x-axis range = 20μs

p+n Junction Strips - Rate



FEE64 aida01 rate/channel (Hz) – 100keV threshold

x100 change in y-scale

Further tests with thresholds 50-90keV confirm 5σ threshold *c.* 90-100keV
Most channels (~ 60-62 of 64) < 1Hz
2-4 'hot' channels per FEE64 at physical boundaries of FEE64
– 'hot' channels less hot