FEE for Nuclear Spectroscopy at FAIR

1st FAIR FEE Workshop
11th-13th Oct 2005

Ian Lazarus
NPG, CCLRC Daresbury

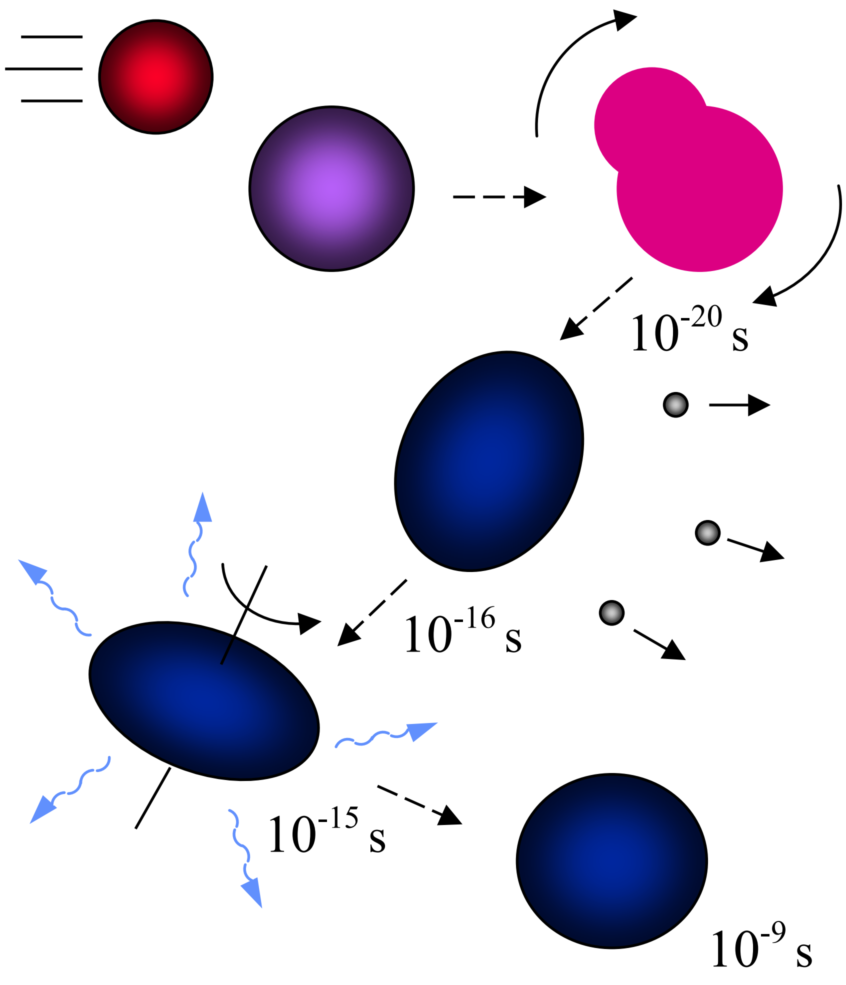
CCLRC Daresbury Laboratory

Overview

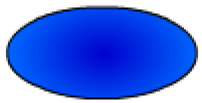
- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

Excite a nucleus. Then watch…



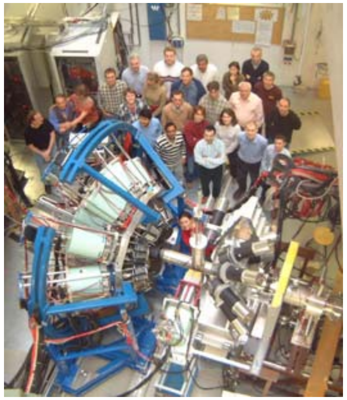
Level Schemes



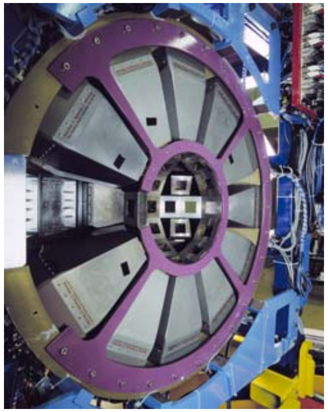
Heavy Ion Fusion Evaporation Reaction
>> Nucleus at High Spins <<

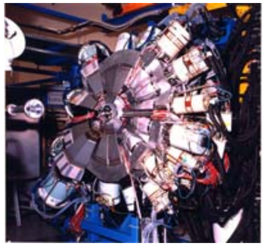
- Detector Requirements:
  - Good stopping power (density)
  - Good energy resolution (usually)
  - Good position resolution often needed too
- Detector materials:
  - Ge for best resolution
  - Scintillators (CsI, BGO, NaI) for price or timing
- FEE Requirements:
  - Energy resolving (0.1% over wide dynamic range)
  - As well as E, need T and often X,Y,Z position.
  - Low Noise
  - Good accuracy, low drift
  - High throughput rate (limited by filtering)

Nuclear Spectroscopy Instrumentation in Europe prior to FAIR



RISING, GSI





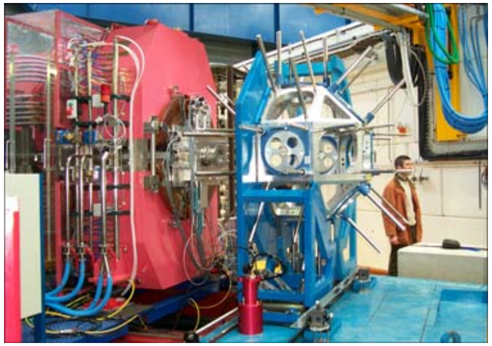
Euroball

CLARA, LNL

JUROGAM, GREAT, JYFL

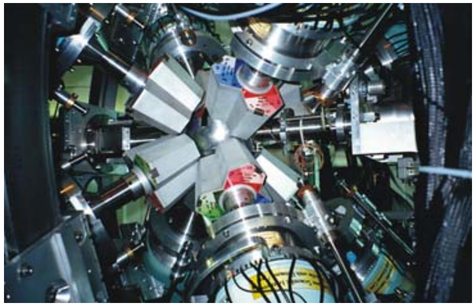
Radioactive beam spectroscopy

EXOGAM, SPIRAL, Ganil



- Segmentation
- Encapsulation
- Position determination from pulse shape analysis

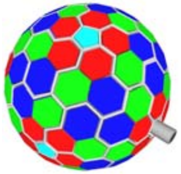
MINIBALL, RexIsolde, GSI



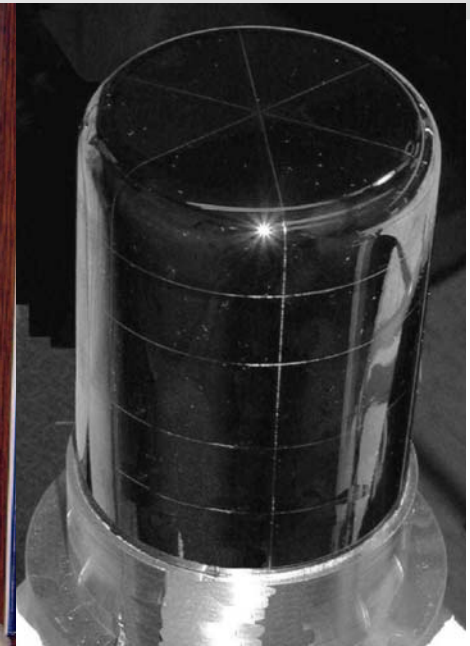
- Gamma-ray tracking

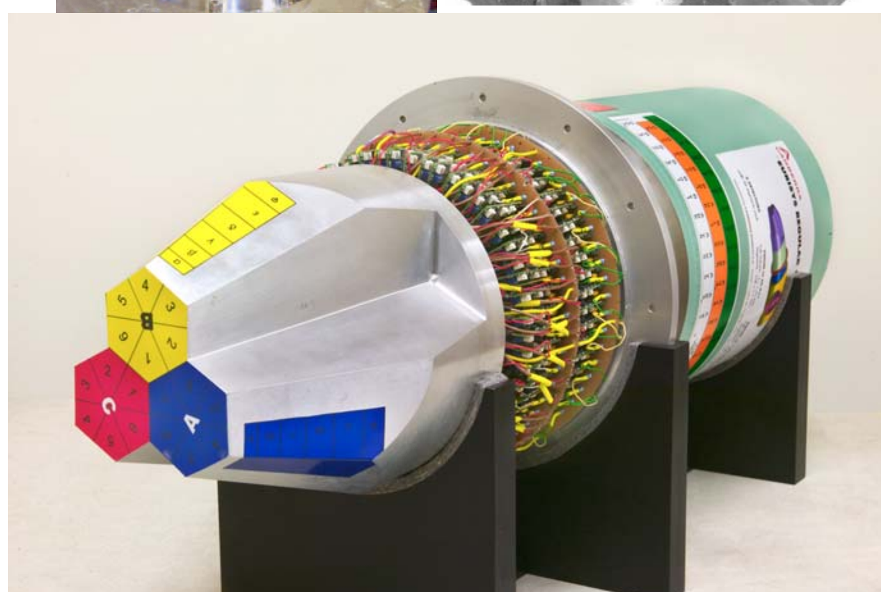
TMR EU collaboration

AGATA

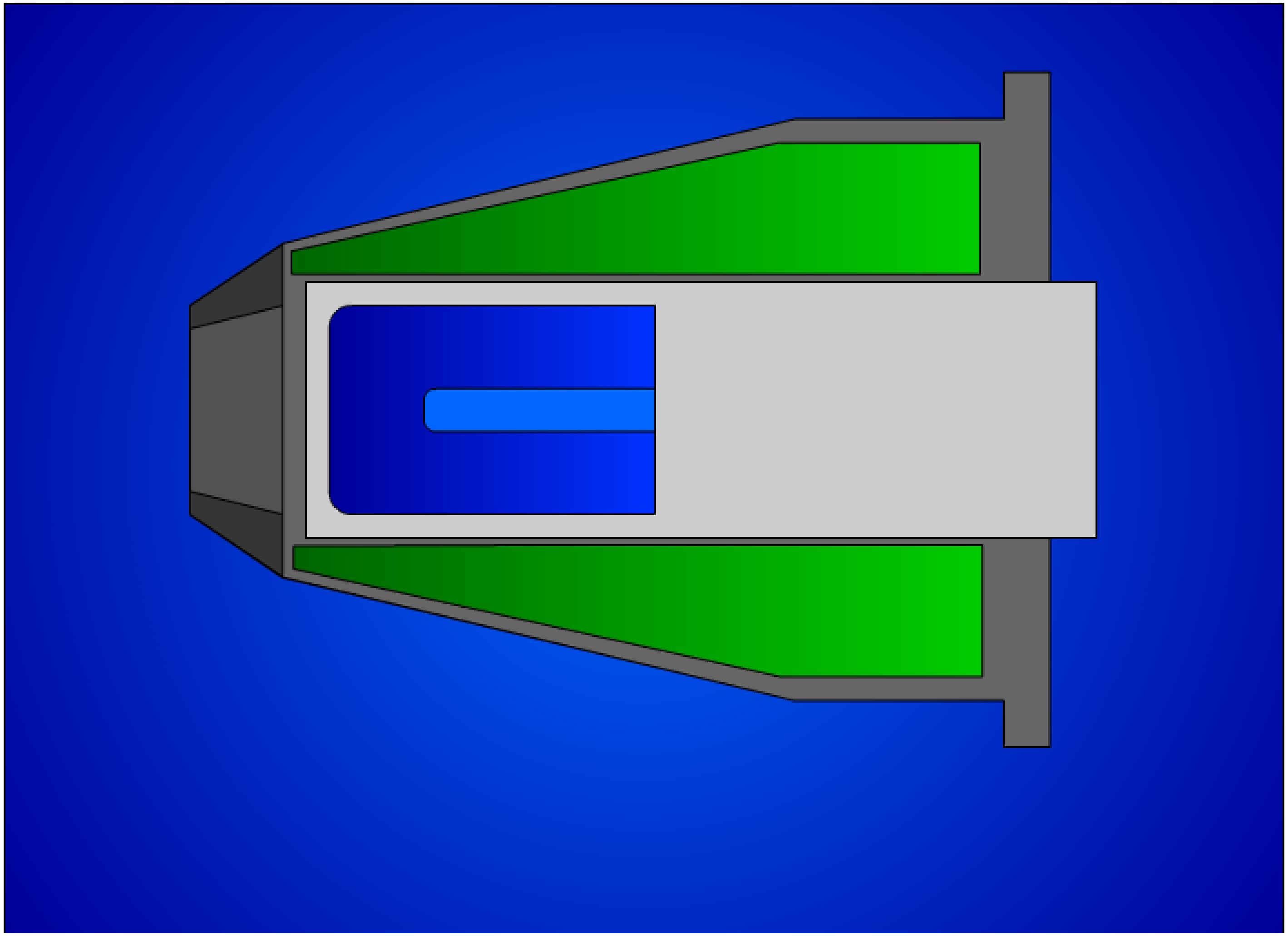


Typical Ge Detectors for observing gamma-rays





The scattering problem…



Idea of γ-ray tracking

Compton Shielded Ge

ε_{ph}	~ 10%
N_{det}	~ 100

Ω ~40%

$\theta \sim 8^o$

large opening angle means poor energy resolution at high recoil velocity.

Problems: wasting scattered gammas, solid angle

Solutions: track the scattered gammas in a Ge shell with no solid angle wasted with shields.

Ge Tracking Array

ε_{ph}	~ 50%
N_{det}	~ 100

Ω ~80%

$\theta \sim 1^o$

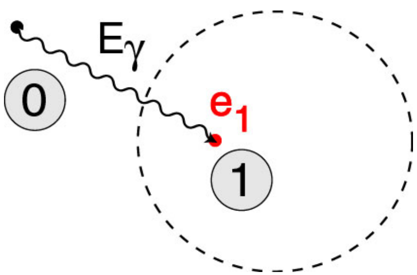
Combination of:

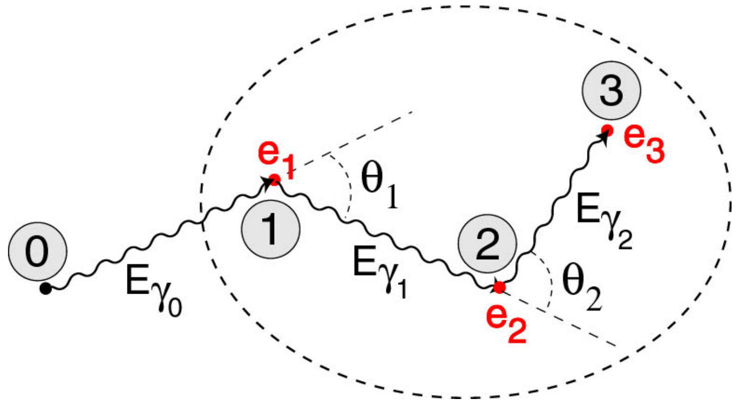
- segmented detectors
- digital electronics
- pulse processing
- tracking the γ-rays

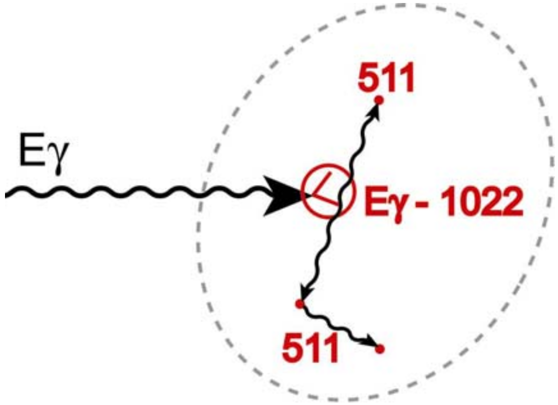
Interaction - Reconstruction Mechanisms

~ 100 keV | ~1 MeV | ~ 10 MeV | γ-ray energy

Photoelectric	Compton Scattering	Pair Production







Isolated hits	Angle/Energy	Pattern of hits

Probability of interaction depth

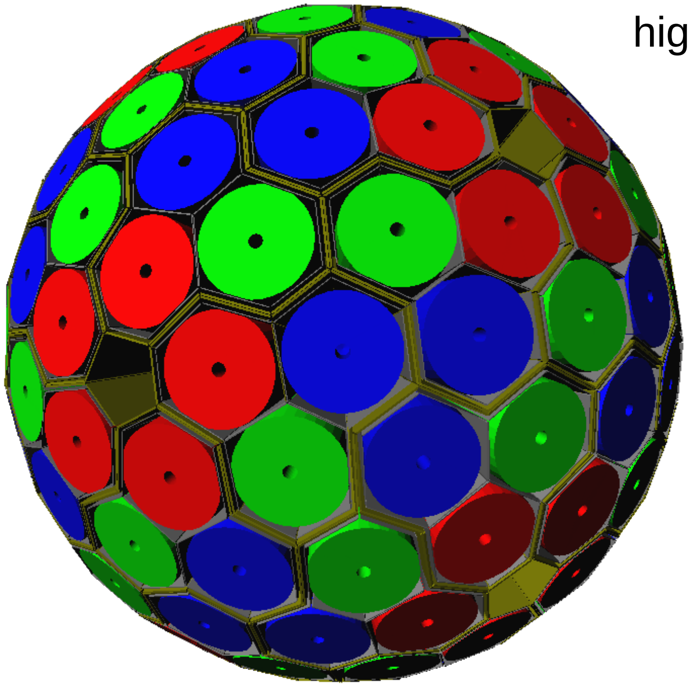
$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_0 c^2}\left(1 - \cos\theta\right)}$$

$$E_{1st} = E_\gamma - 2\ mc^2$$

Reconstruction efficiencies are limited by :
Position resolution; Short range scattering; Compton profile.

AGATA
(Advanced GAmma Tracking Array)

CCLRC Daresbury Laboratory



4π γ-array for Nuclear Physics Experiments at European accelerators providing radioactive and high-intensity stable beams

Main features of AGATA

Efficiency: 40% (M_γ =1) 25% (M_γ =30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

Peak/Total: 55% (M_γ=1) 45% (M_γ=30)
today ~55% 40%

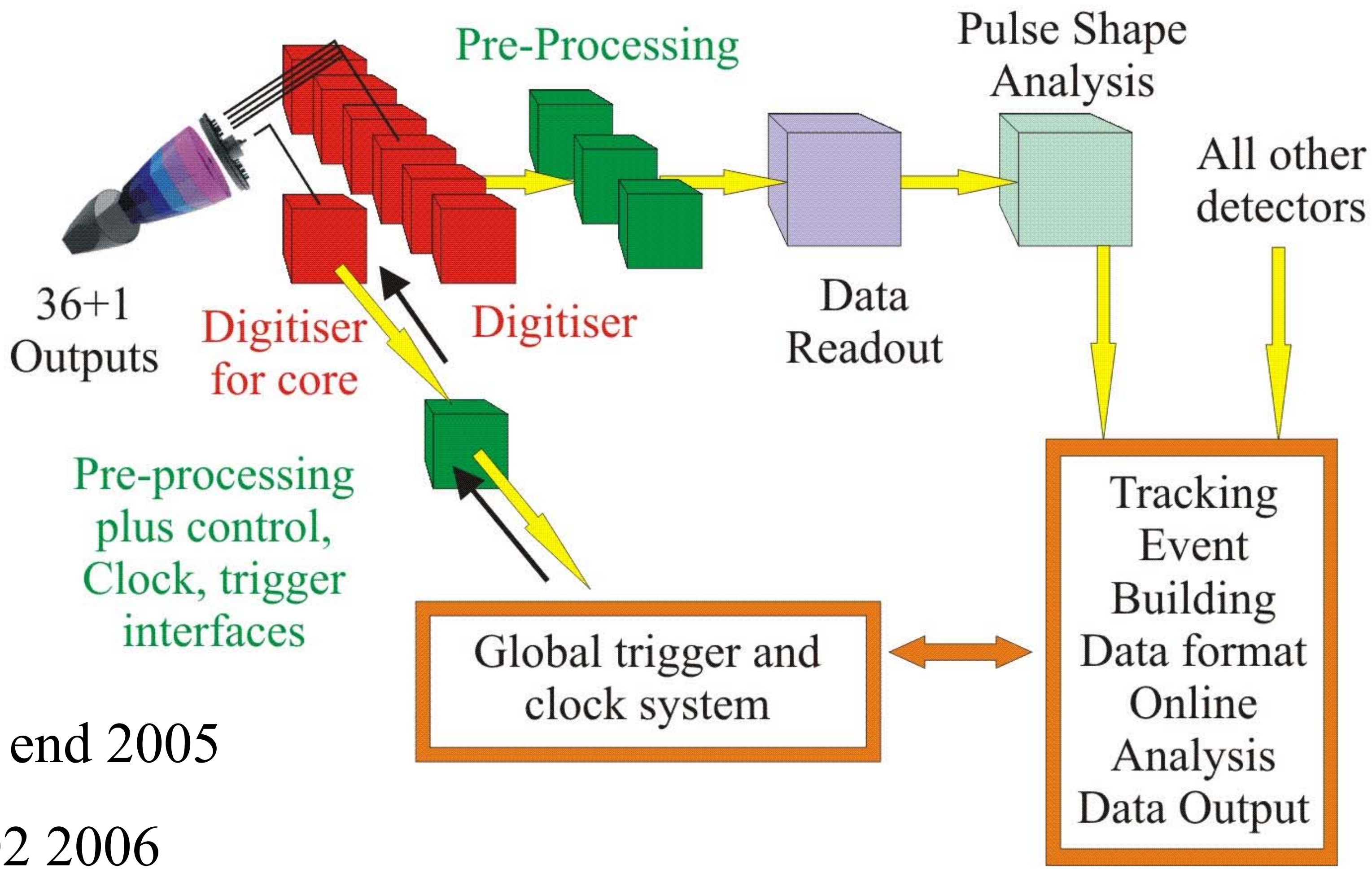
Angular Resolution: ~1º →
FWHM (1 MeV, v/c=50%) ~ 6 keV !!!
today ~40 keV

Rates: 3 MHz (M_γ=1) 300 kHz (M_γ =30)
today 1 MHz 20 kHz

- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

AGATA
(Advanced GAmma Tracking Array)

Schematic of the Digital Electronics and Data Acquisition System for AGATA



Prototypes end 2005

Test Q1, Q2 2006

15 Ge (555 channel) demonstrator 2007

- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

- Detector Requirements:
  - Energy measurement
    - Energy loss (delta-E)
    - Full energy (E)
  - Tracking
    - Beam
    - recoil fragments
    - Reaction products
  - Charge
  - Mass
  - Time of flight
- Detecting proton, alpha, LCP, or heavy ions

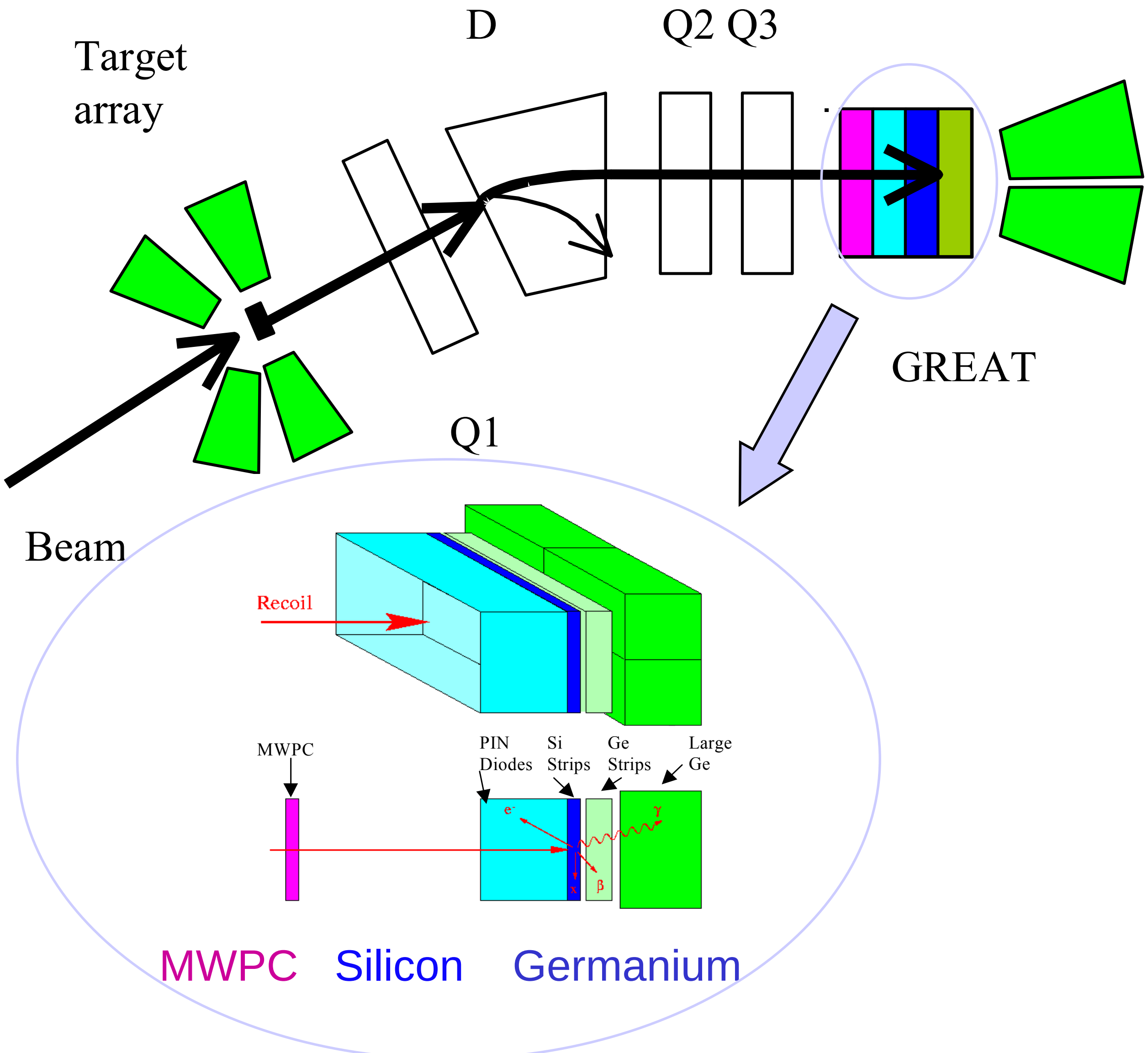
- Detector Types:
  - Si (DSSD, microstrip) SiLi
  - Scintillators (various from basic to exotic)
  - Gas
    - ionisation chambers,
    - PPAC,
    - MWPC
    - micropattern (GEM, micromegas, …)
    - Active Target/TPC
  - magnetic spectrometers for selection

- FEE Requirements:
  - Low Noise
  - Low threshold (e.g. tiny signals from thin Si)
  - Good accuracy, low drift, good timing
  - Very large dynamic range

Recoil Decay Tagging (GREAT): Schematic

Gamma
Recoil
Electron
Alpha
Tagging

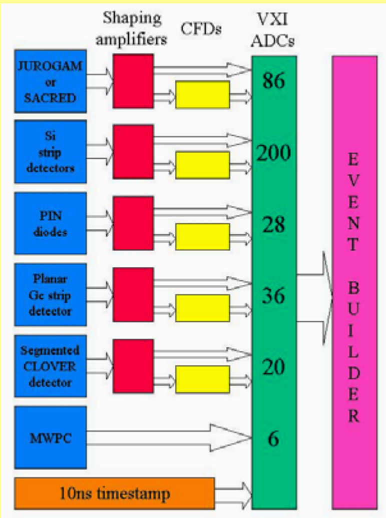
Spectrometer

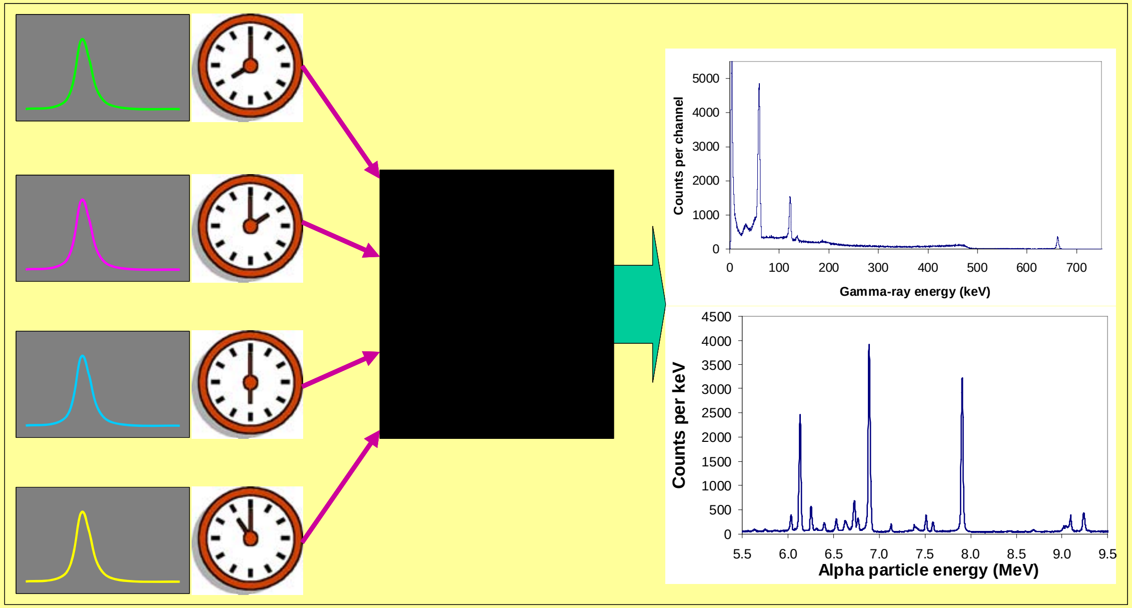


Recoil Decay Tagging (GREAT): Timestamping

Total Data Readout

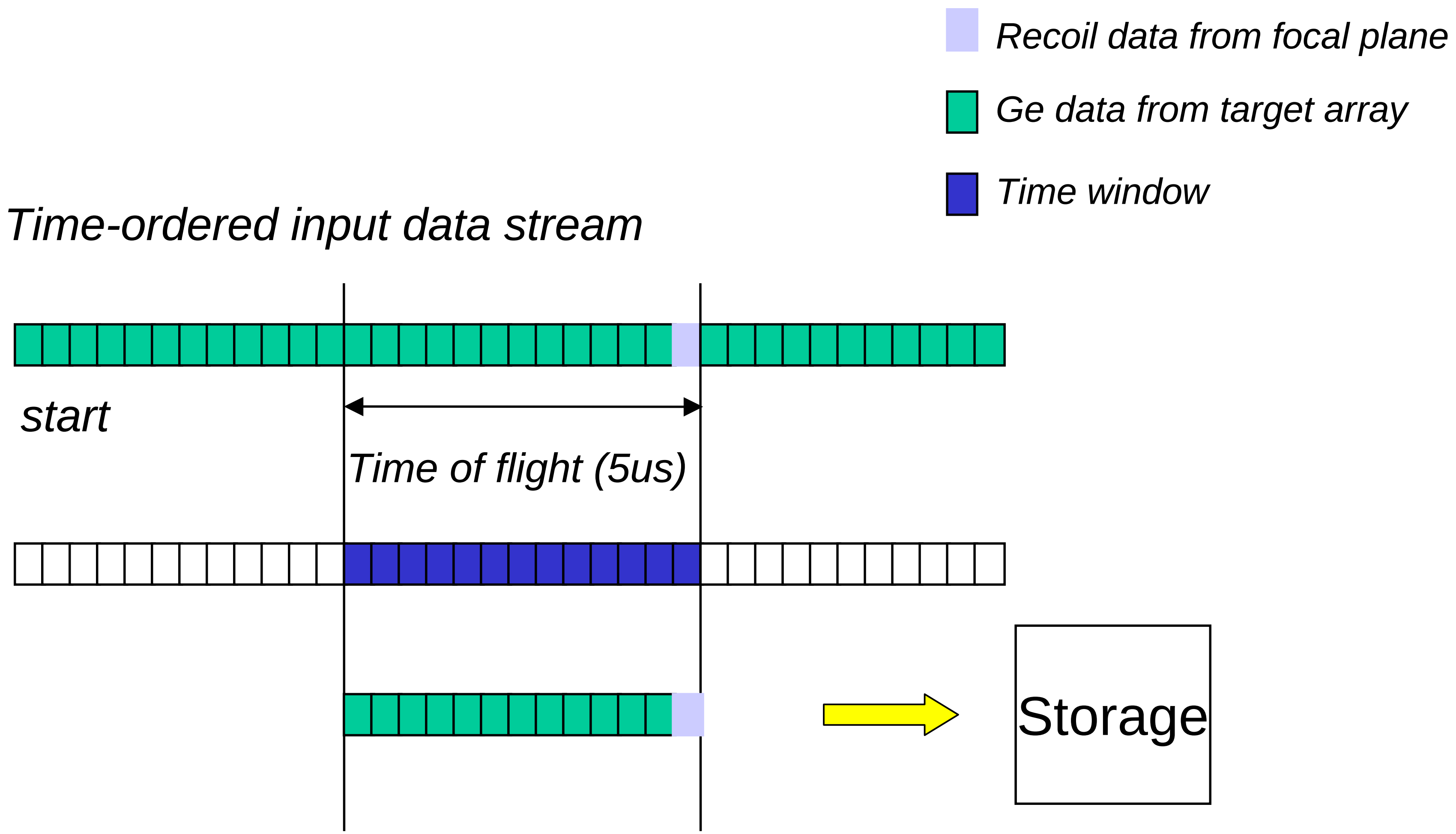
Novel triggerless data acquisition eliminates common dead time





I.H. Lazarus *et al*., IEEE TNS 48 (2001) 567

Recoil Decay Tagging (GREAT) Software Trigger

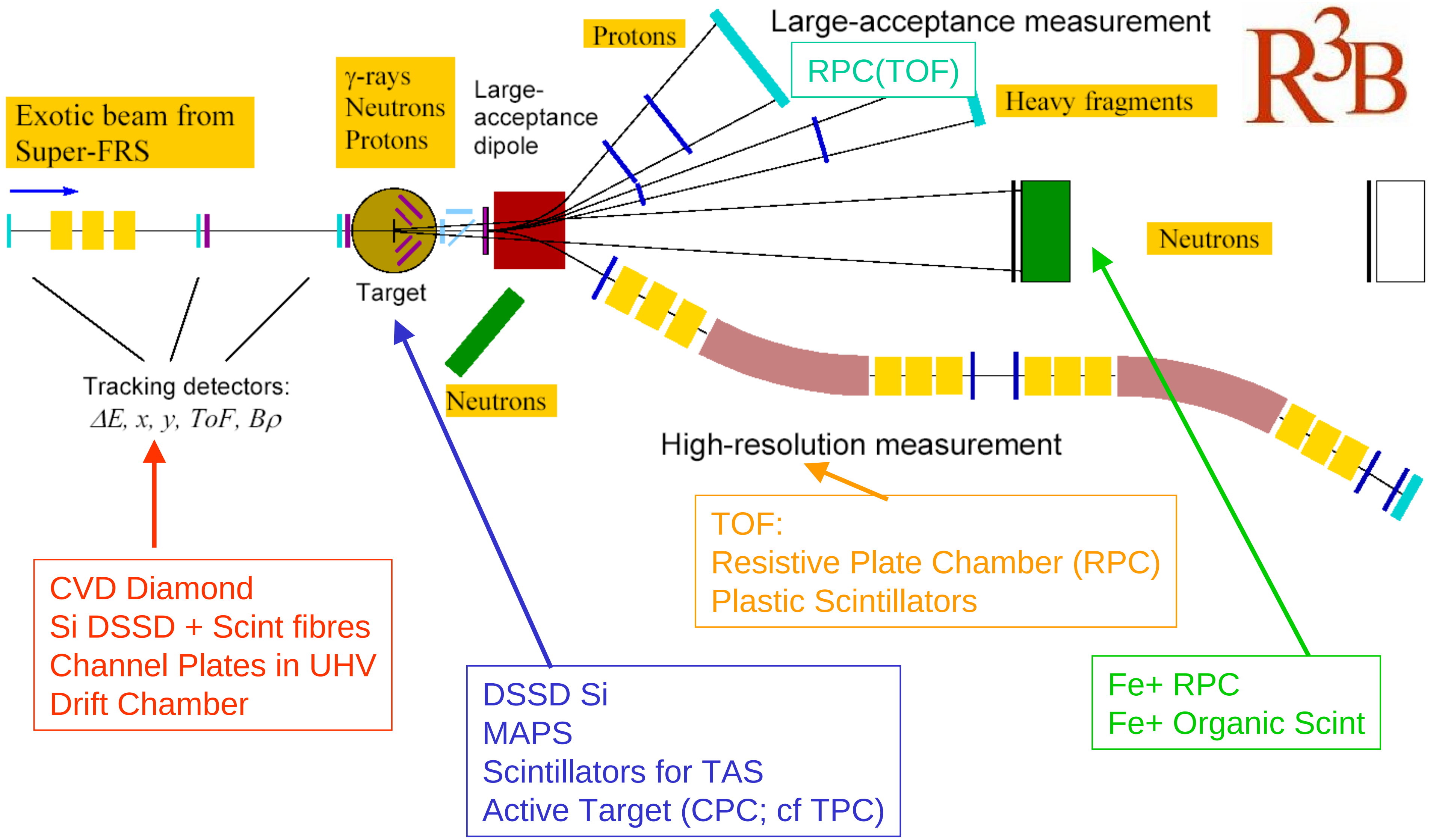


- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

The high-energy branch of the Super-FRS:

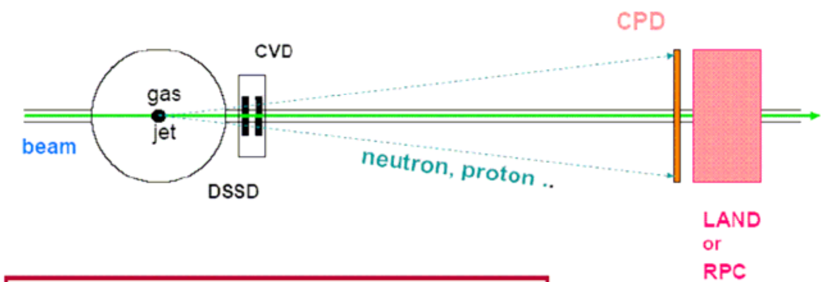
A universal setup for kinematical complete measurements of

Reactions with Relativistic Radioactive Beams



EXL

Kinematically complete measurements:
- detection of forward light particles emitted from the projectile (momenta measured)
- excitation energy of projectile residue, momentum (angular) correlations

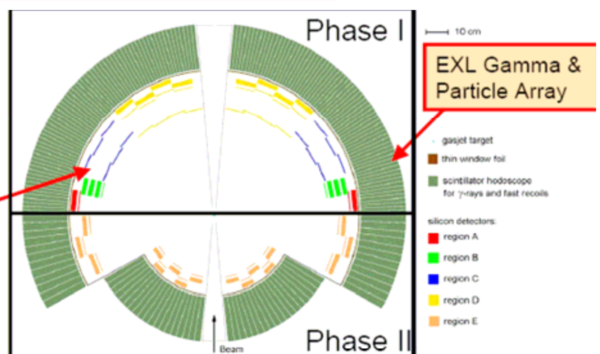


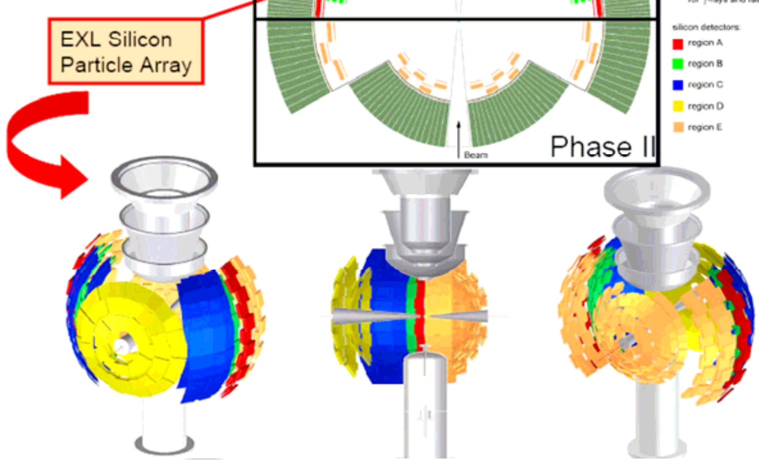
- High-resolution TOF and position measurements
- Full solid angle (forward focus)
- Phase I (LAND) and Phase II (RPC)

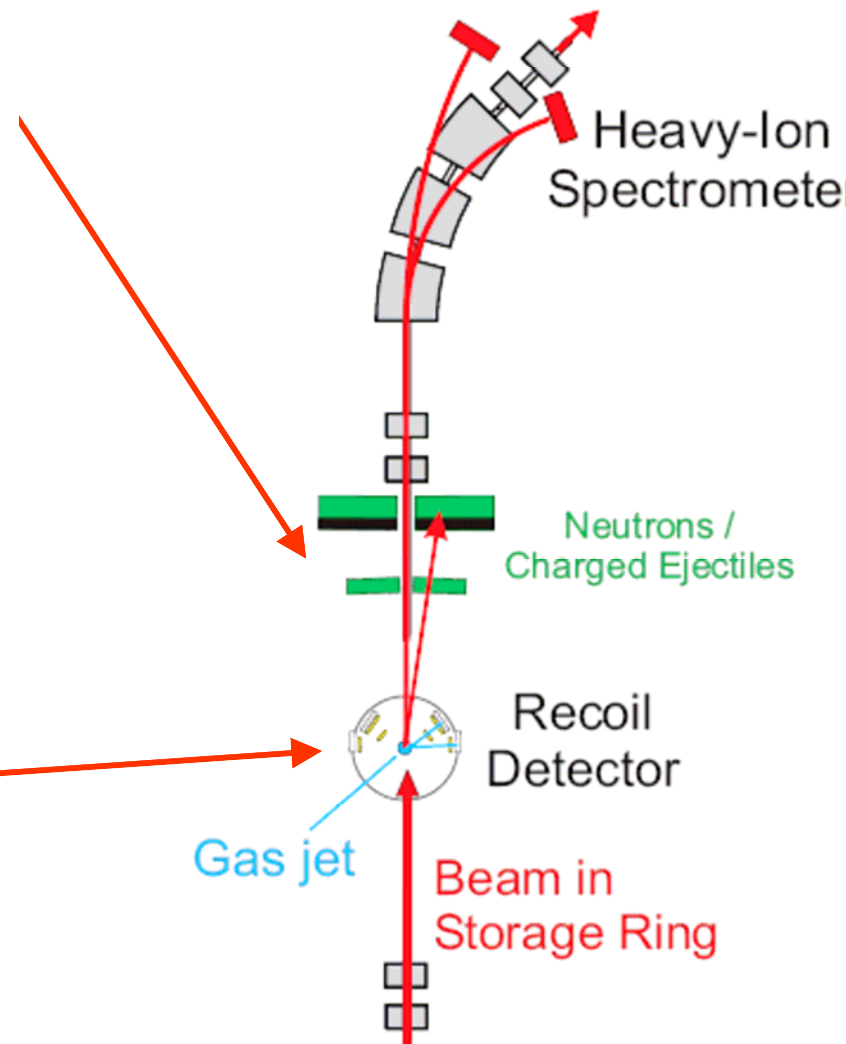
EXL

Recoil & Gamma

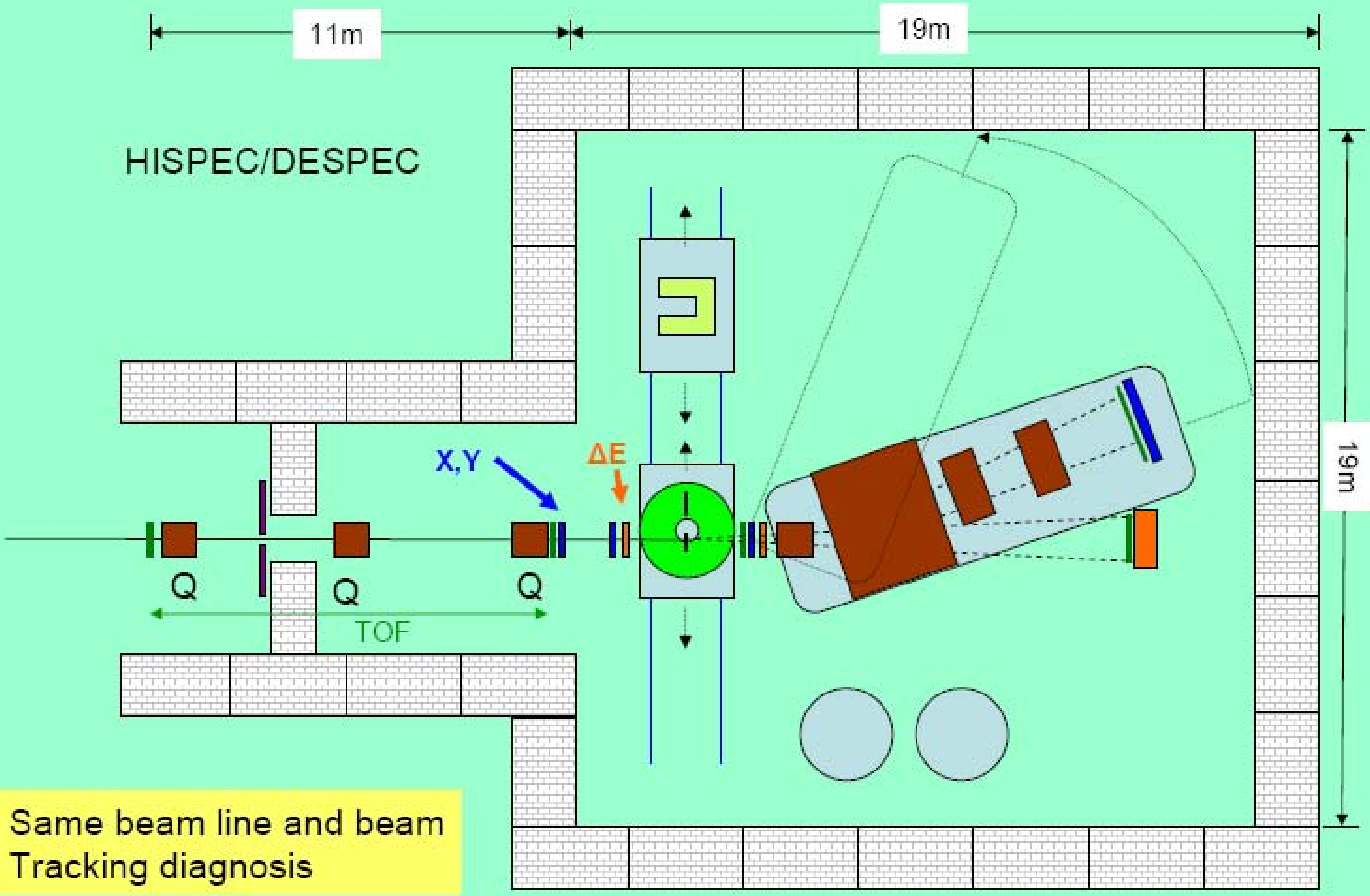
Array







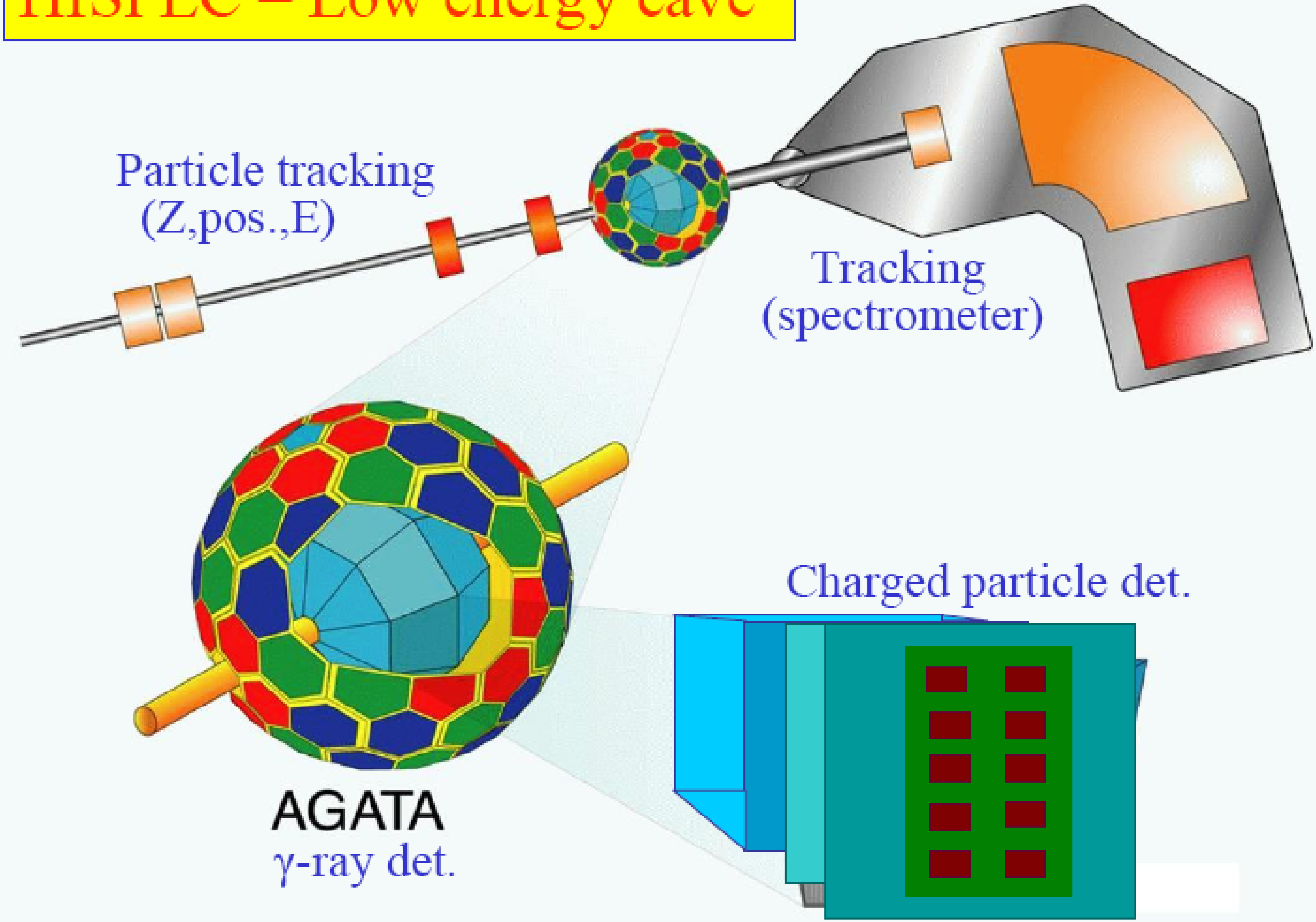
HISPEC DESPEC



Same beam line and beam
Tracking diagnosis

HISPEC

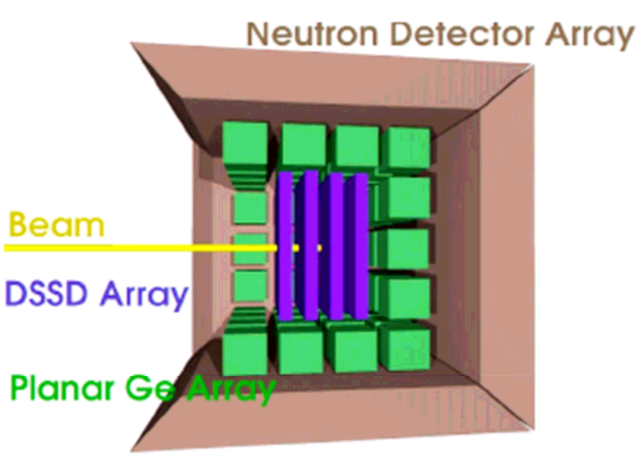
HISPEC – Low energy cave



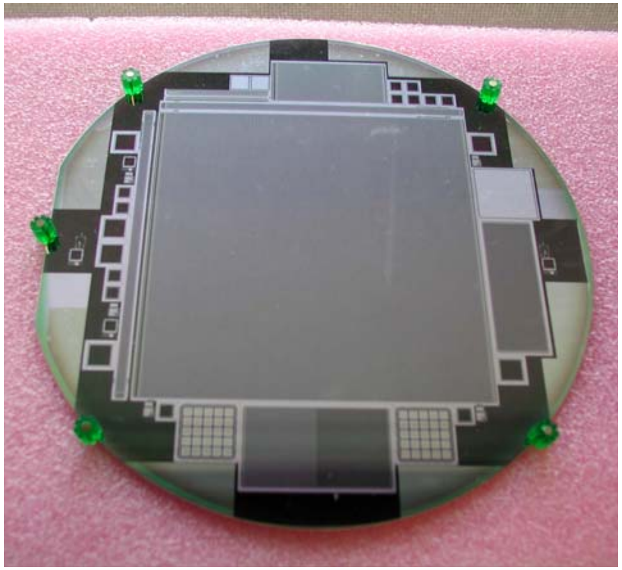
- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

AIDA for DESPEC- the concept

Concept and the detector



- Super FRS Low Energy Branch (LEB)
- Exotic nuclei – energies ~50-150MeV/u
- Implanted into multi-plane DSSD array
- Implant - decay correlations
- Multi-GeV DSSD implantation events
- Observe subsequent p, 2p, α, β, γ, βp, βn … decays
- Measure half lives, branching ratios, decay energies …



6" wafer-10cm x 10cm area
- 1mm wafer thickness
- Integrated components
  - a.c. coupling
  - polysilicon bias resistors

  … important for ASICs
- Series strip bonding (3 together)

AIDA for DESPEC- segmentation

CCLRC Daresbury Laboratory

DSSD Segmentation

We need to implant at high rates *and* to observe implant – decay correlations for decays with long half lives.

DSSD segmentation ensures average time between implants for given *x,y* quasi-pixel >> decay half life to be observed.

- Implantation profile
  - $\sigma_x \sim \sigma_y \sim$ 2cm
  - $\sigma_z \sim$ 1mm
- Implantation rate (8cm x 24cm) ~ 10kHz, ~kHz per isotope (say)
- Longest half life to be observed ~ seconds

Implies quasi-pixel dimensions ~ 0.5mm x 0.5mm

Segmentation also has instrumentation performance benefits

AIDA for DESPEC- Instrumentation

Instrumentation

Why use of Application Specific Integrated Circuit (ASIC) technology?

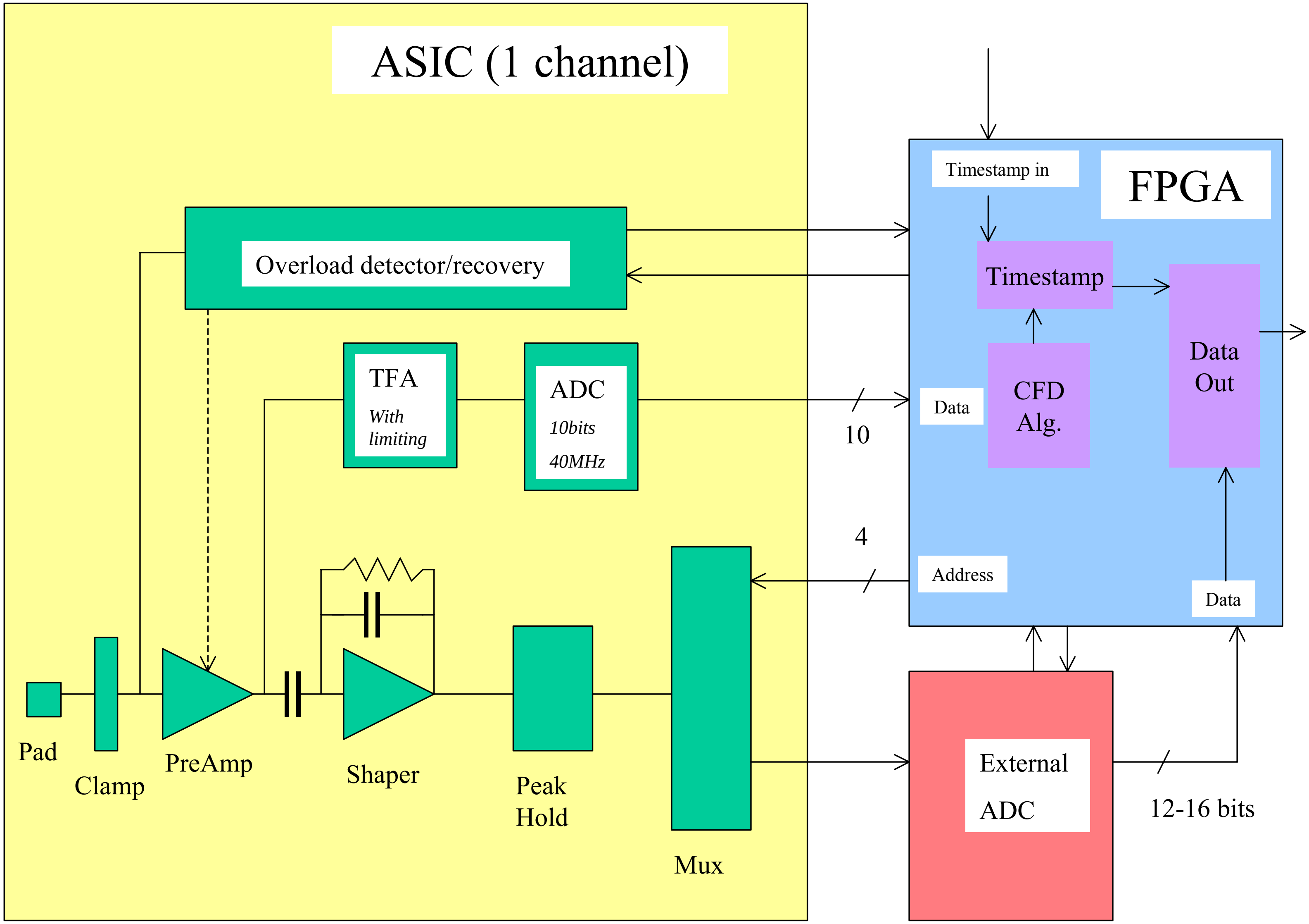
- Large number of channels required (8 x (128+(3x128))= 4096)
- Limited available space
- Cost

Outline ASIC Specification

- Selectable gain: low 20GeV FSR
  high 20MeV FSR
- Noise σ ~ 5keV rms.
- Selectable threshold: minimum ~ 25keV @ high gain (assume 5σ)
- Integral and differential non-linearity
- Autonomous overload recovery ~μs
- Signal processing time <10μs (decay-decay correlations)
- Receive timestamp data
- Timing trigger for coincidences with other detector systems

DSSD segmentation reduces input loading of preamplifier and enables excellent noise performance.

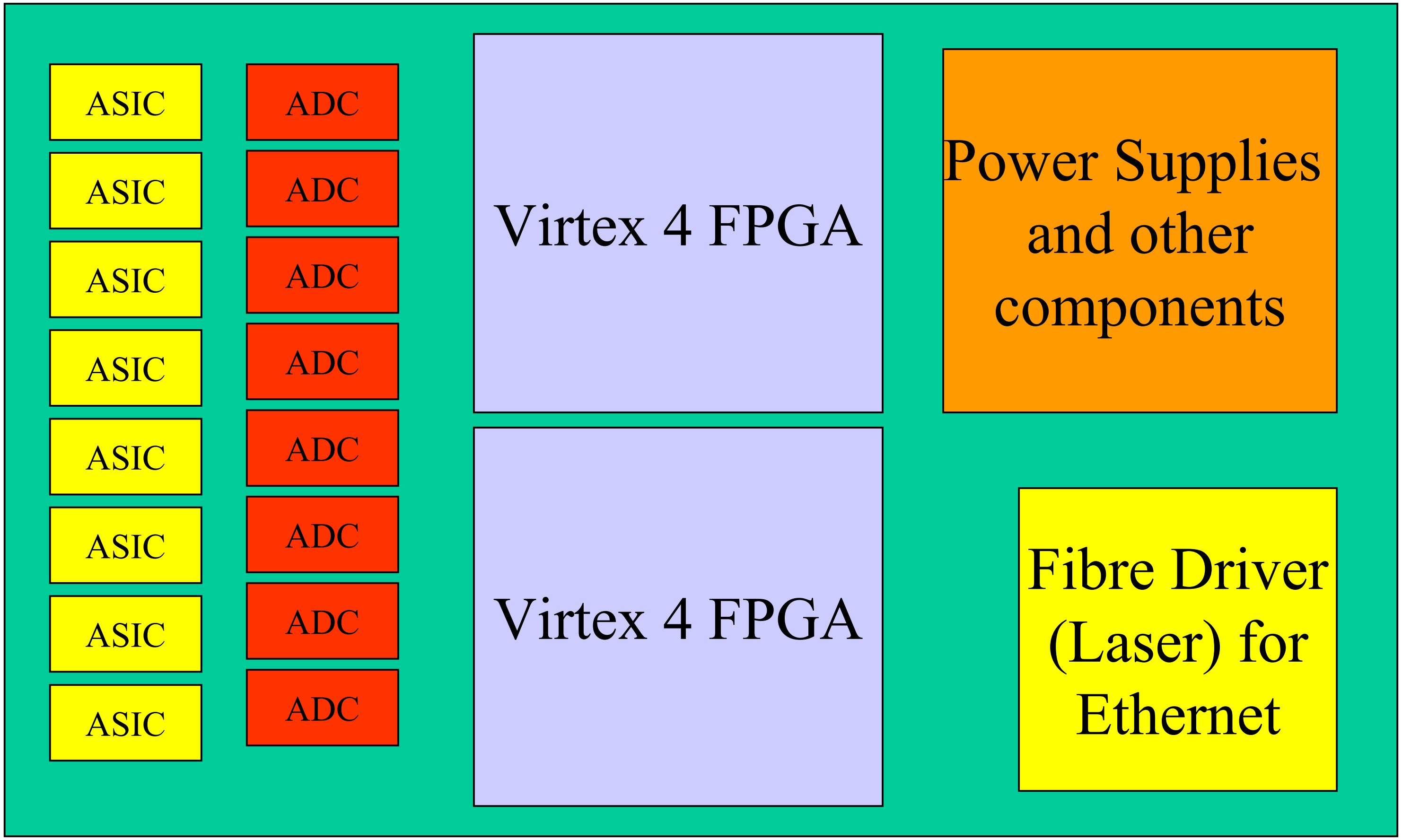
1 of the 16 channels in the DESPEC Implantation Detector ASIC (shown with external FPGA and ADC)



128 Channel FEE Card for DESPEC

16 ch ASIC *16 bit ADC*

128 detector signals in; 1 data fibre out



Estimated size: 80x220mm,

Estimated power 25W per 128ch (800W total)

CCLRC
Daresbury Laboratory

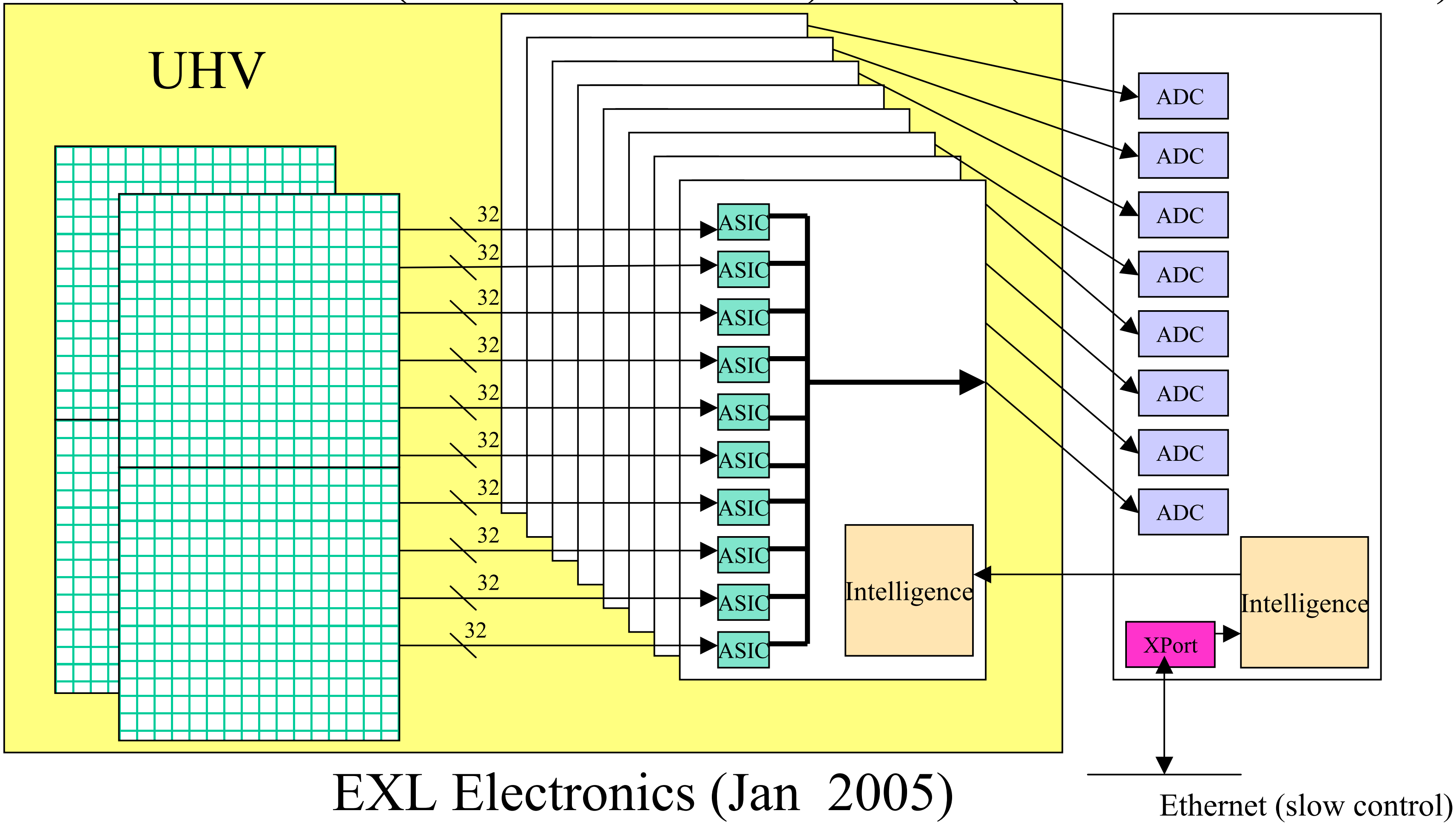
- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

NUSTAR EXL electronics.

Detectors- 560000 channels DSSD and SiLi

ASIC cards- approx 17500 ASICs on 1750 cards (32 channels/ASIC)

ADC cards- 1750 ADCs on 219 cards (320 channels/ADC)



EXL Electronics (Jan 2005)

- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

July 2005 FEE ASICs meeting

Small group (CCLRC & CEA Saclay) discussed EXL, R3B DESPEC, HISPEC and SPIRAL 2.

Found 3 FEE ASICs needed (so far) for NUSTAR:

1. Fast recovery after implantation of ion in DSSD Si to measure decay in the same pixel. (DESPEC)
2. EXL CsI calorimeters covering energy range 300keV to 500MeV. 13k channels needed.
3. EXL/R3B Si strip and SiLi detector ASIC. Normal Si processing chain of preamp, shaper, mux or ADC, timing. Add PSD too. Maybe 2 ASIC solution?

July 2005 FEE ASICs meeting

Why collaborate on ASICs and FEE?

- Limited ASIC manpower- don't waste it.
- Limited FEE and DAQ manpower too.
- Avoid duplication of design effort where 2 experiments need a similar ASIC
- Common software for slow control and DAQ (reduced software effort for experiments)
- Compatibility between experiments
- Independent design reviews (increase the probability of a working ASIC).

July 2005 FEE ASICs meeting

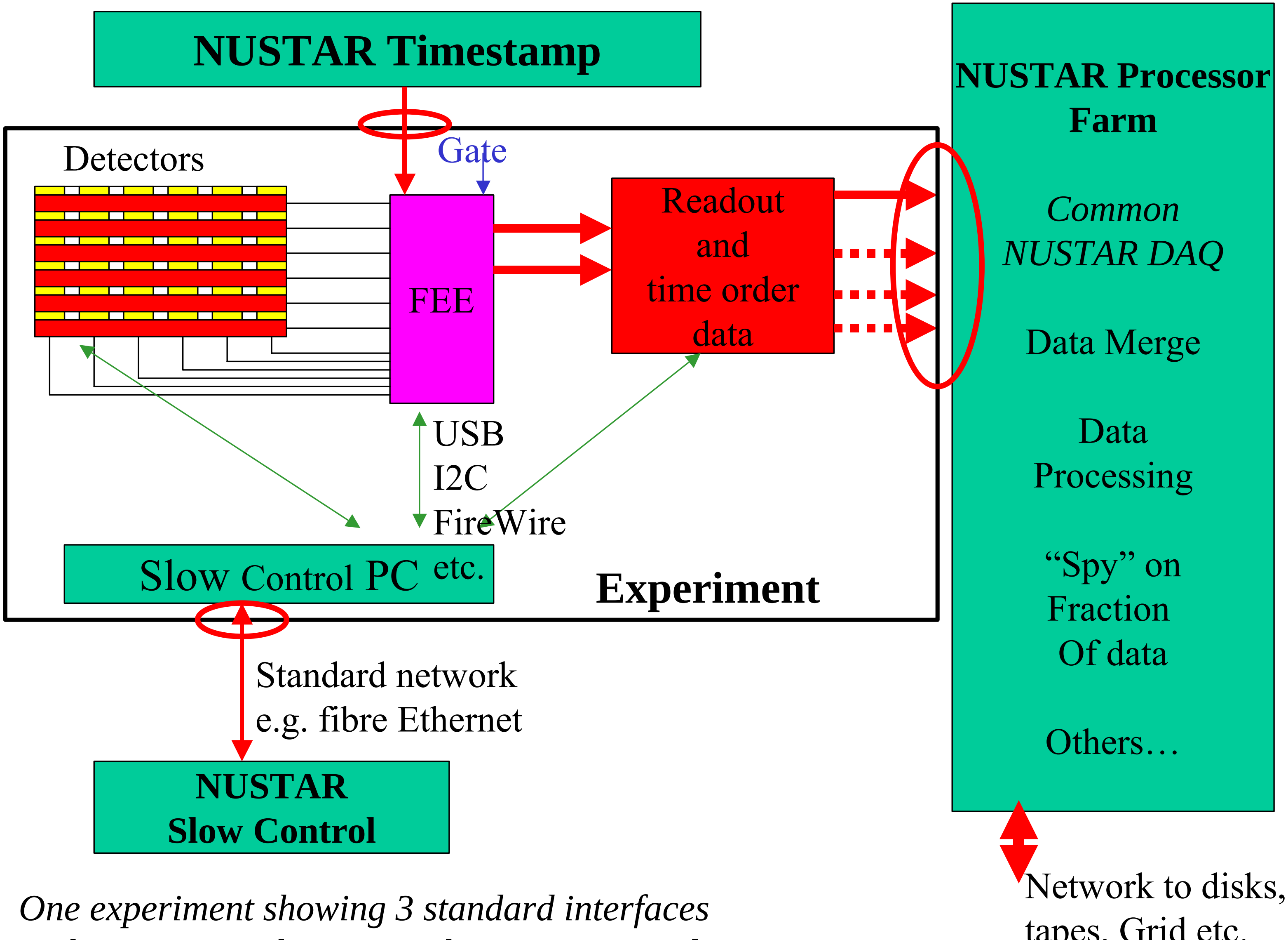
Actions/decisions:

1. Up to Jun 2006: Make physicists aware of these discussions about ASICs and collect the outline specs as they emerge from draft TDRs to look for synergy.
2. Find NUSTAR ASIC designers and talk to them!
3. ASIC Technology lifetimes- the NP (& HEP) market is so tiny as to have no influence on the lifetime if ASIC processes. Just use best guess. (CCLRC & CEA both use AMS 0.35um CMOS process for analogue.)
4. ASIC design cycle (3 iterations) takes 3-4 years. Start soon with 12 months of consultation and specification.
5. **Design a system, not just an ASIC (or FEE card).**

CCLRC
Daresbury Laboratory

- Detectors and FEE for Gamma-ray spectroscopy
- Detectors and FEE for Charged Particle spectroscopy
- Detectors in some of the larger NUSTAR experiments
- Examples of FEE- DESPEC Implantation Detector
- Examples of FEE- EXL recoil detector
- FEE ASIC meeting report
- Common FEE architecture

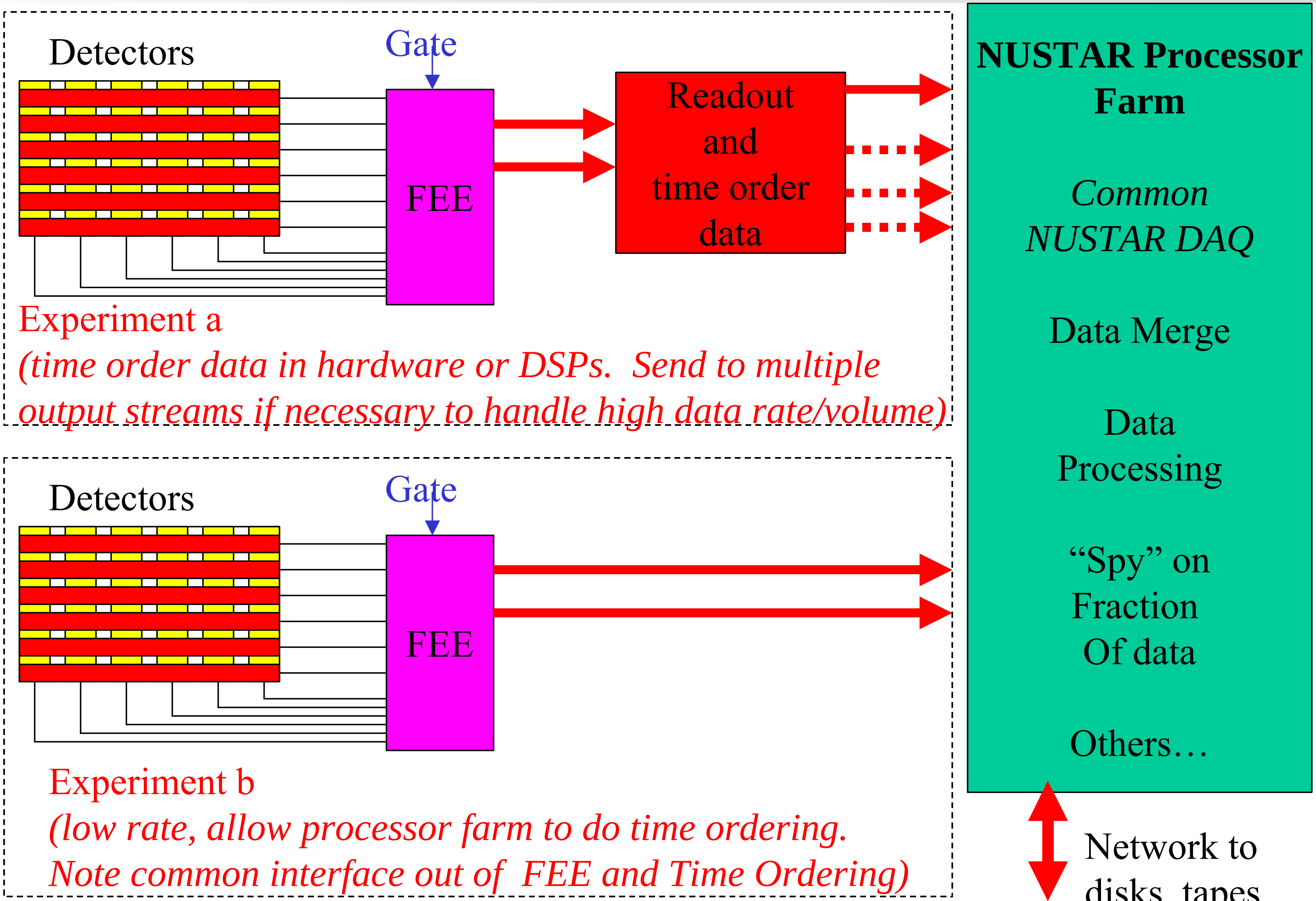
Schematic of a NUSTAR experiment



One experiment showing 3 standard interfaces to the NUSTAR Slow Control, Timestamp and DAQ

CCLRC Daresbury Laboratory

Flexibility from standard interfaces



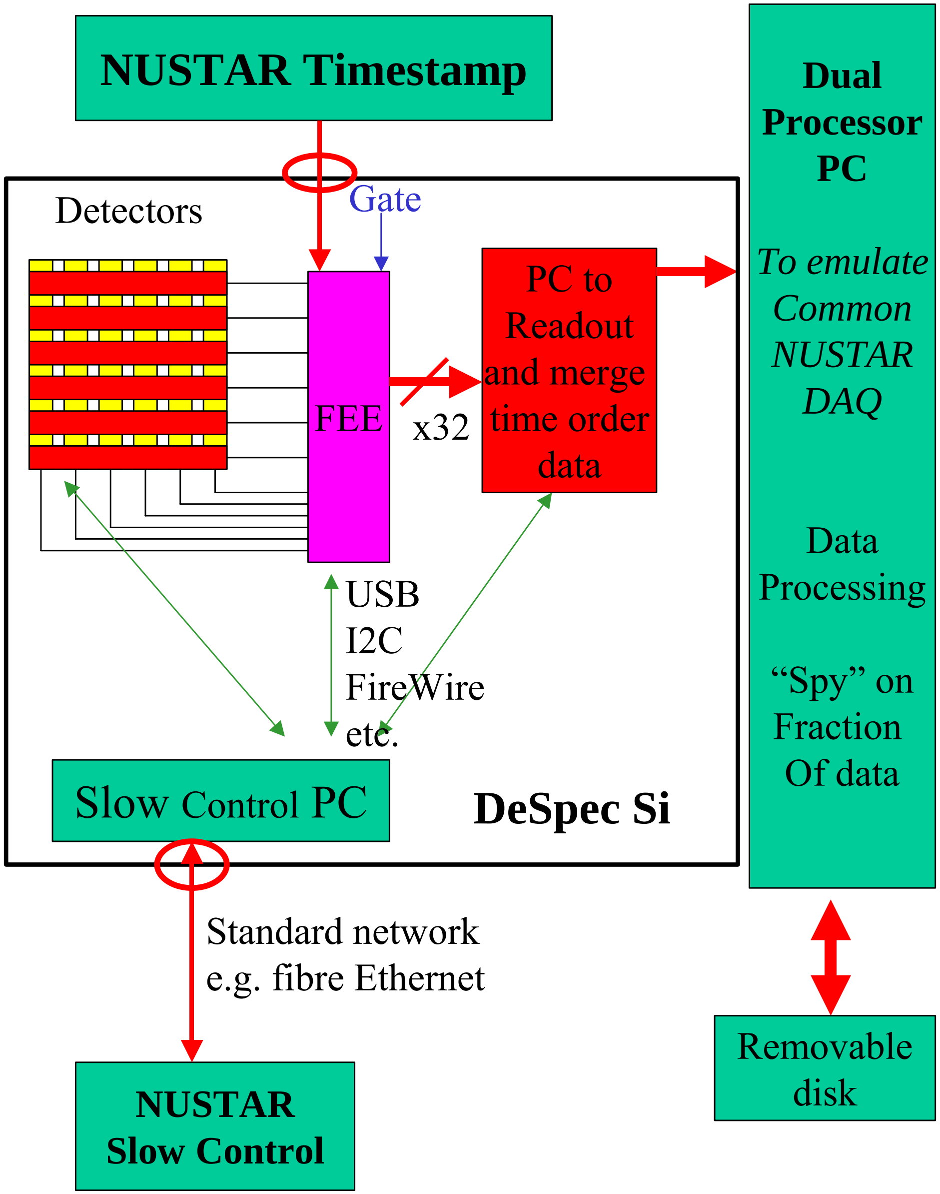
Network to
disks, tapes,
Grid etc

Optional bypassing of time ordering stage for low rate experiments.
The advantage of a common interface standard (e.g. (10)Gbit Fibre)

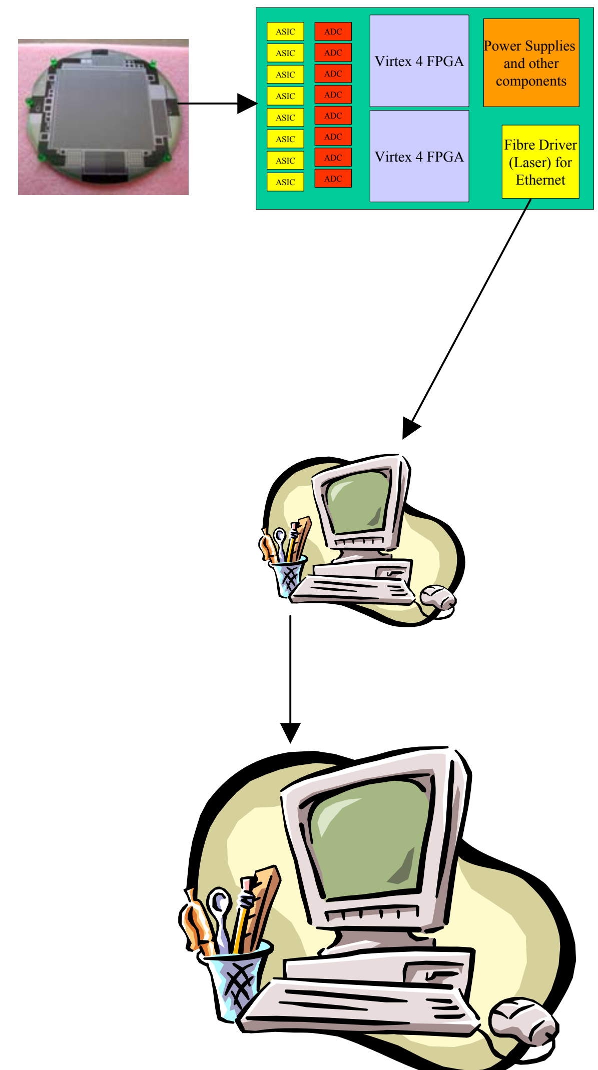
Some possible common FEE standards

- Common clock distribution and timestamp control method (synchronisation, heartbeats and resets)
- Data output format- 1st generation use fibre 10G Ethernet?
- Slow control- common interface (Ethernet/Soap???)
- On board processing- too early for device, maybe can now choose Type= FPGA and family=Xilinx?
- Power: 48V with local conversion
- Board size and format- doesn't matter (match to detector?)

DESPEC Si Implantation detector within common FEE and DAQ



DESPEC example



Conclusions

- Wide variety of requirements in NUSTAR.
  - Some (e.g. LASPEC) need just a crate of NIM or CAMAC and PC, no need for common FEE or DAQ.
  - Large systems e.g. EXL plans over 0.5M channels- should consider common DAQ and FEE.
- Large systems- forced to use ASICs by space constraints and cost (e.g. DESPEC, EXL).
- Limited resources so look for common ground in
  - FEE
  - ASICs
  - DAQ
- Design a **system;** don't work in isolation and hope!

Acknowledgements

Presentation includes pictures from other people.

Thanks to:

- John Simpson (CCLRC),
- Tom Davinson (University of Edinburgh)
- Robert Page (University of Liverpool)
- Roy Lemmon (CCLRC)
- Marielle Chartier (University of Liverpool)

NUSTAR FEE diagrams result from discussions with

- Haik Simon (GSI)
- Lolly Pollacco (CEA Saclay)
- Roy Lemmon (CCLRC)