Neutron-Antineutron Annihilation Detector for the nnbar Experiment

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for the nnbar/HIBEAM Collaboration
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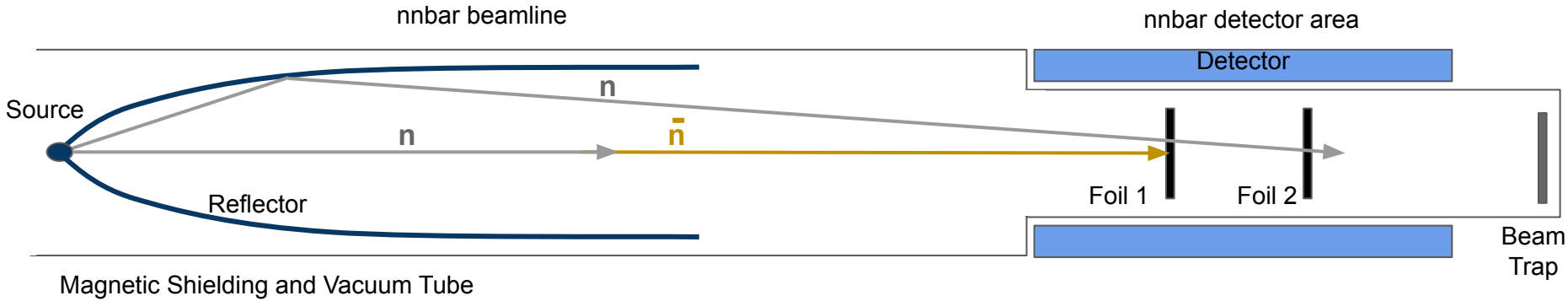
Stockholm University

Baryon Number Violation - motivation for nnbar searches

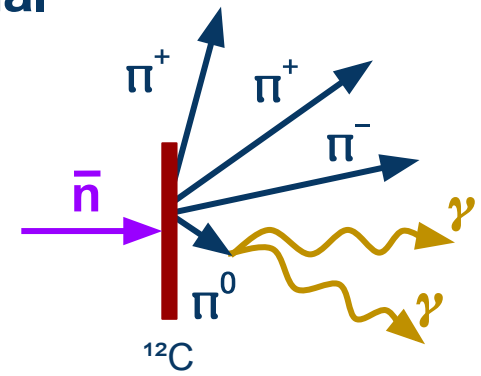
- BNV appears necessary to understand matter-antimatter asymmetry
  - Last unobserved Sakharov condition
- BNV is a hallmark of many BSM theories
- $\Delta B = 2$ (e.g. neutron-antineutron oscillation) probes complementary yet unique physics compared to proton decay and 0v2β (Super-K, DUNE, etc.)
- ESS is new opportunity to use high luminosity beam of thermal neutrons

nnbar@ESS

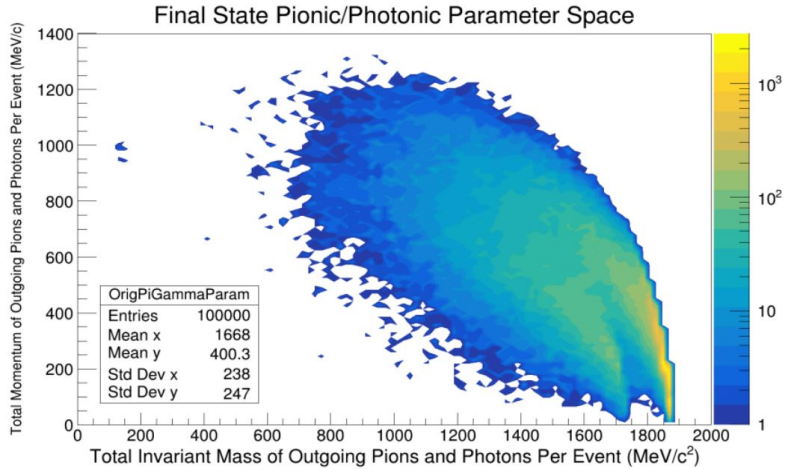


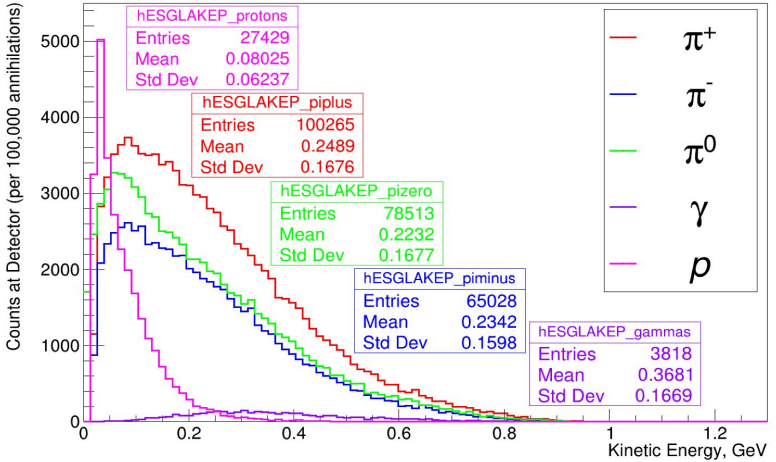
- Free neutron search for neutron-antineutron oscillations at the ESS (>2030)
- 2-stage experiment beginning with HIBEAM (mid 2020s)
  - HIBEAM: neutron-sterile neutron search, detector validation for nnbar
- Search for annihilation event between antineutron and neutron in Carbon foil target
- Expect ≥10^3 increase in sensitivity over previous experiment at ILL
  - Rare opportunity for discovery of testable mechanisms of baryogenesis
- Close collaboration with ESS through HighNESS project (see V. Santoro's talk)
  - Substantial investment by ESS in beamline infrastructure with nnbar in mind

Signal



- Annihilation event in C foil target
- Avg of ~4 pions, including π^0 which decays immediately to 2 gammas
- Ultimate Aim
  - Claim discovery with one event
  - Statistical corrections not possible
  - PID, Momentum and Energy of all annihilation and nuclear products





J. Barrow, E. Golubeva, C. Ladd [1], [2]

Single Event Confirmation

Topology

- Common vertex + two charged pions
  - No vertex in 2nd foil
- 3D tracking with TPC
- 2D track inside vacuum

Particle Identification

- Identify charged particles as π or p
- Identify pairs of gammas as π^0
- TPC for dE/dx combined with E or range from calorimeter

Energy and Momentum

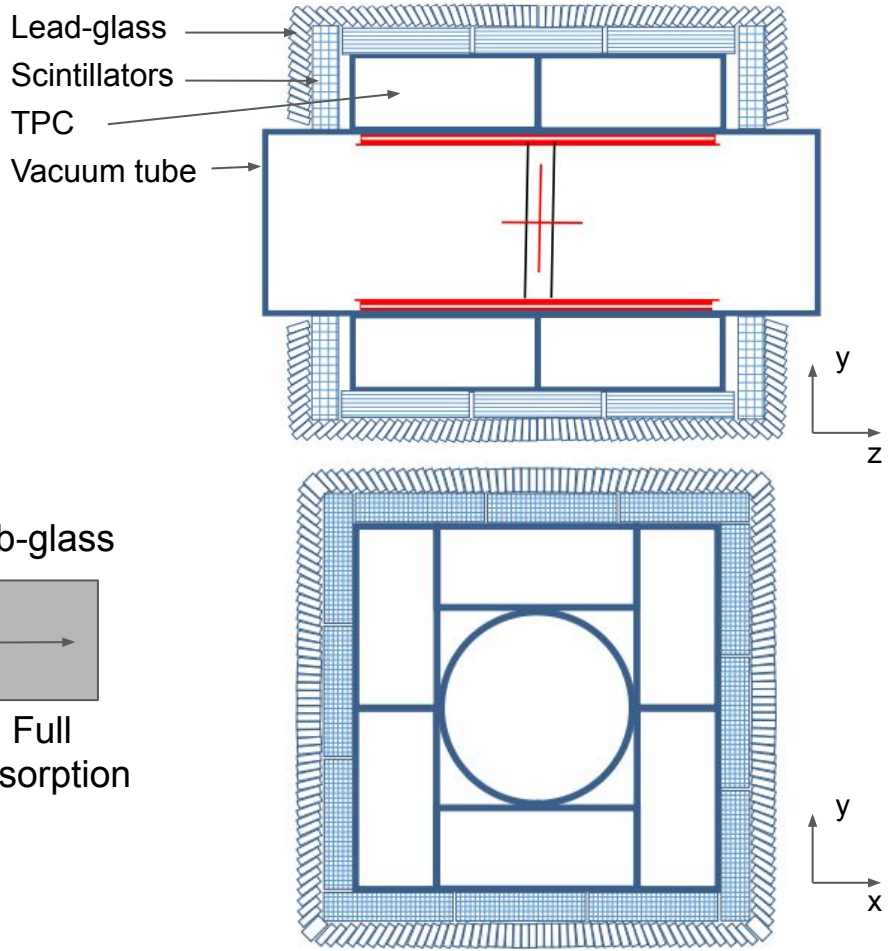
- Needs PID
- Large energy fraction carried by nuclear fragments
- Energy by neutrons lost

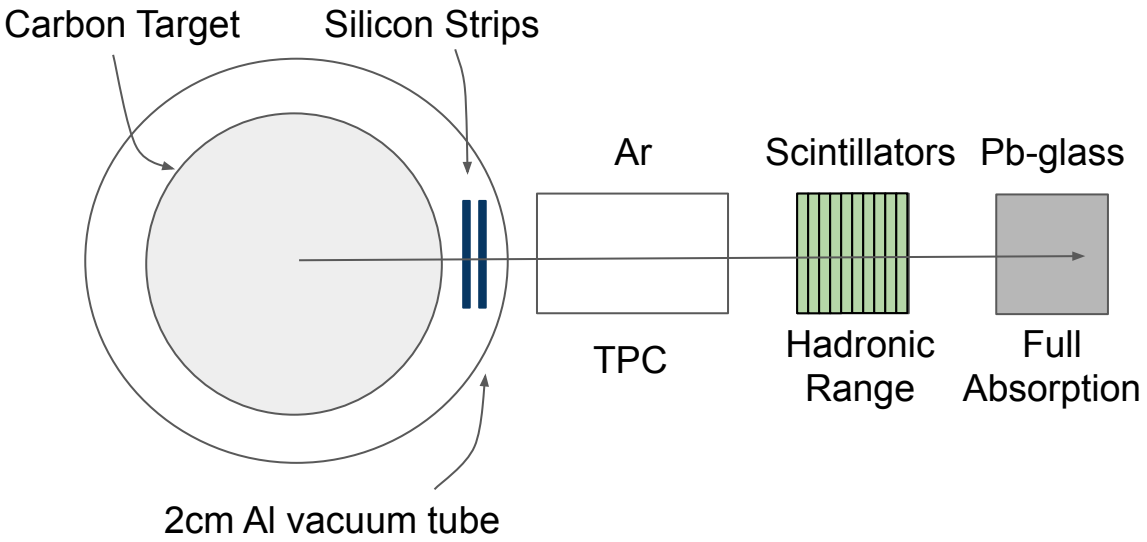
Direction

- All particles must move outwards
- Veto charged Cosmics

Schematic of Full Detector

- Silicon strips for vertex reconstruction
- TPC for tracking
- Hadronic range + full absorption





A. Oskarsson (LU)

Trigger and Data Acquisition in Calorimeter/TPC

Triggering

- Timing very useful
  - Coincidence windows for multi-pion events (ns resolution)
- Energy not as useful
  - Large uncertainties for low-energy particles

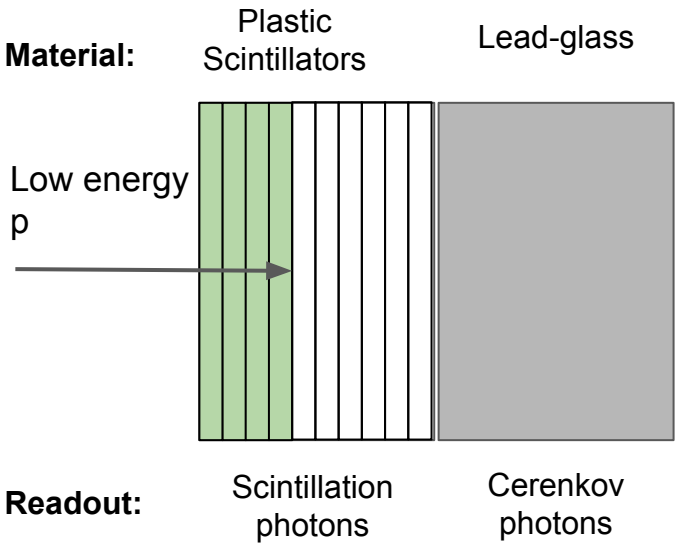
Background Rejection

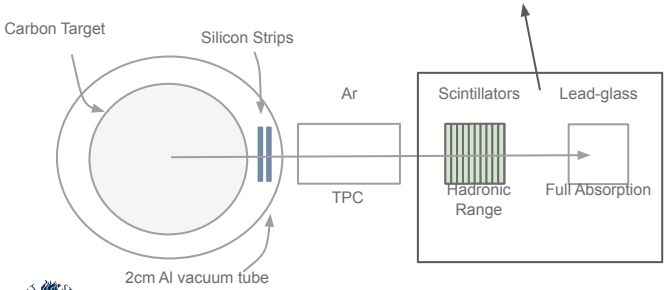
- Timing distinguish fake coincidences by cosmic hits
- Threshold to remove low energy photons, nuclear products

‘Triggerless’ DAQ

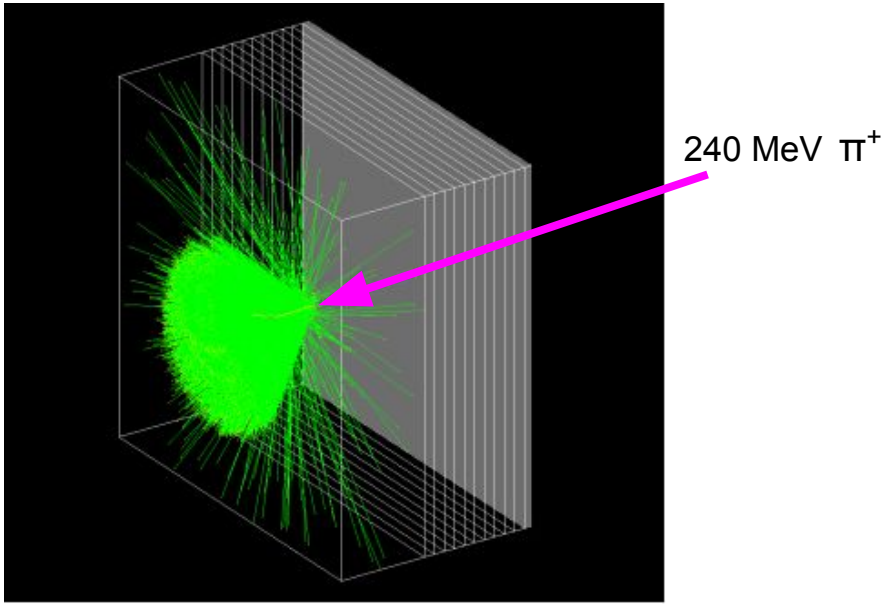
- Neutron beam essentially continuous
  - Event times unknown
- Calorimeter hit timing->TPC track data
- Self-triggered readout of calorimeter & veto channels

Calorimeter





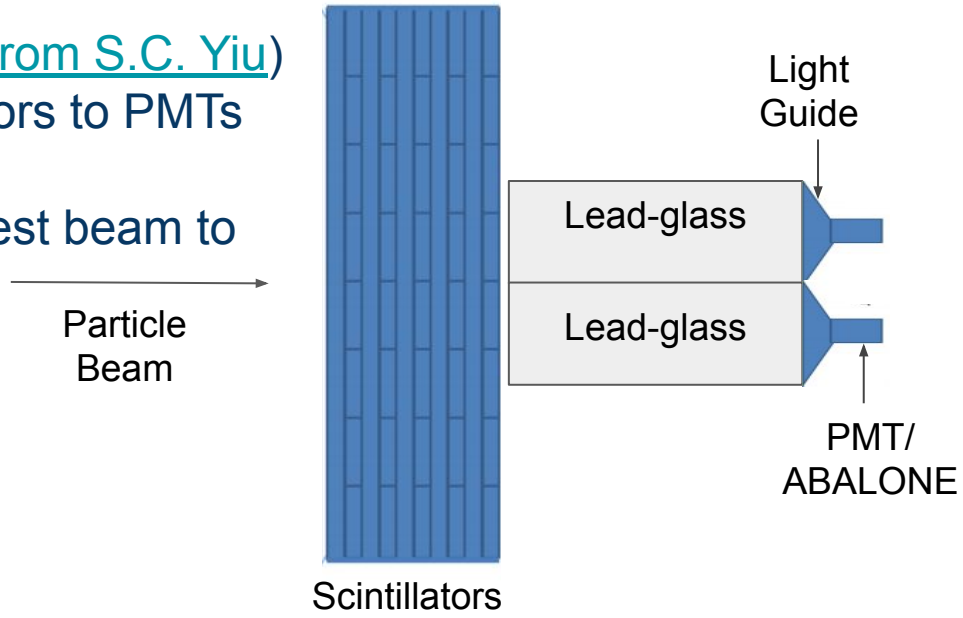
- Poor energy resolution for low energy π's
- Use binary readout (hit/no hit) of scintillators
- Direction of flight
  - Exploit fact that Cerenkov cone is directional



K. Dunne, in [3]

Calorimeter Prototype

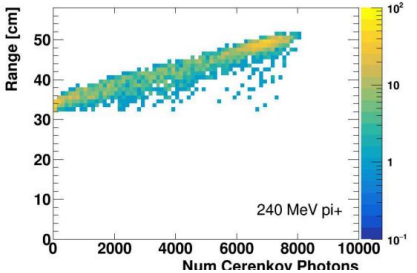
- Work ongoing at SU to build Calorimeter prototype
- Will validate at various test facilities
  - Energy reconstruction
  - Direction of flight with absorbing lead-glass inner face
  - Cosmic ray response (see talk from S.C. Yiu)
  - Comparison of ABALONE sensors to PMTs
  - Trigger and DAQ integration
- Ultimately deployed ~2023 at ESS test beam to validate background response

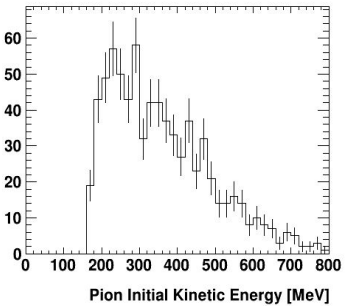


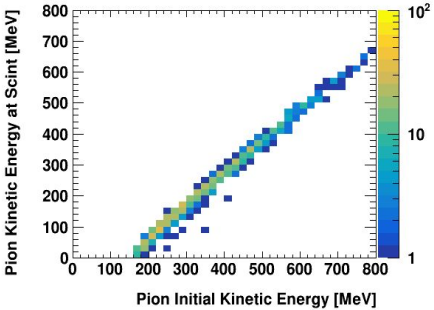
Detector Simulations

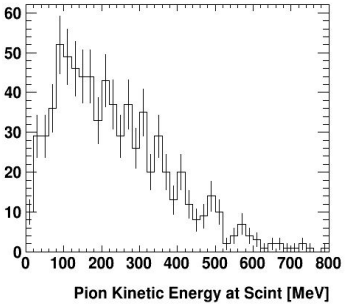
- Calorimeter prototype simulations
  - Energy reconstruction
  - Validate binary readout of scintillators
  - Lead-glass granularity for separation of gammas from π^0 decay
- Full detector simulations
  - Detector response to cosmic rays
  - Detector acceptance with various geometries

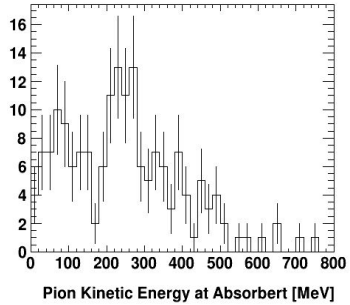
K. Dunne, in [3]

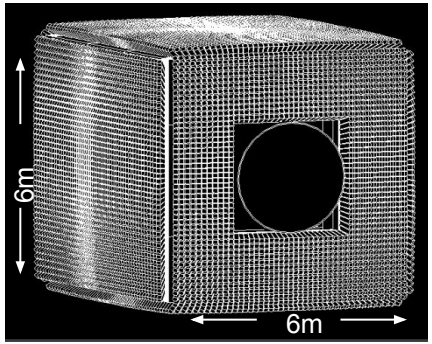












S. C. Yiu

The nnbar collaboration

New high-sensitivity searches for neutrons converting into antineutrons and/or sterile neutrons at the European Spallation Source

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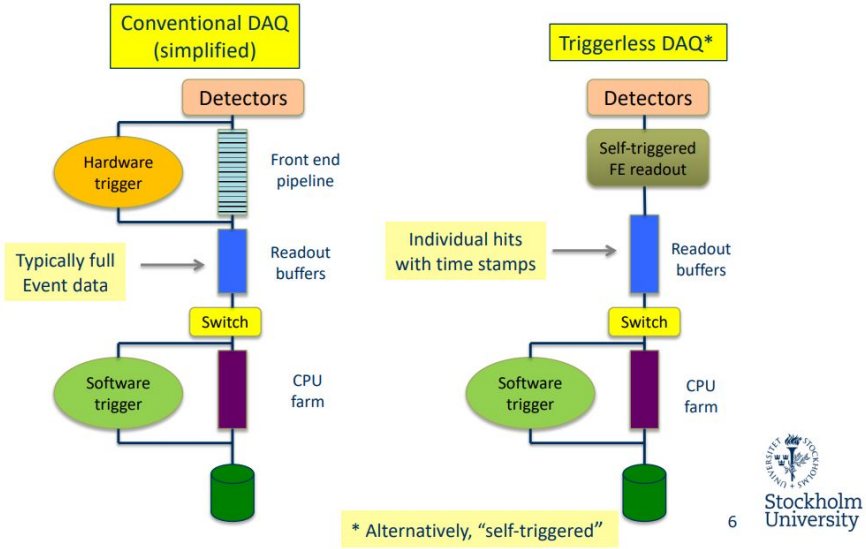
  - D. Milstead (SU)
- Lead Scientist
  - Y. Kamyshkov (UTK)
- Technical Coordinator
  - V. Santoro (ESS)
- Detector Simulation Coordinator
  - B. Meirose (SU)
- See our recent white paper

Extra Slides

What is a "triggerless" DAQ?



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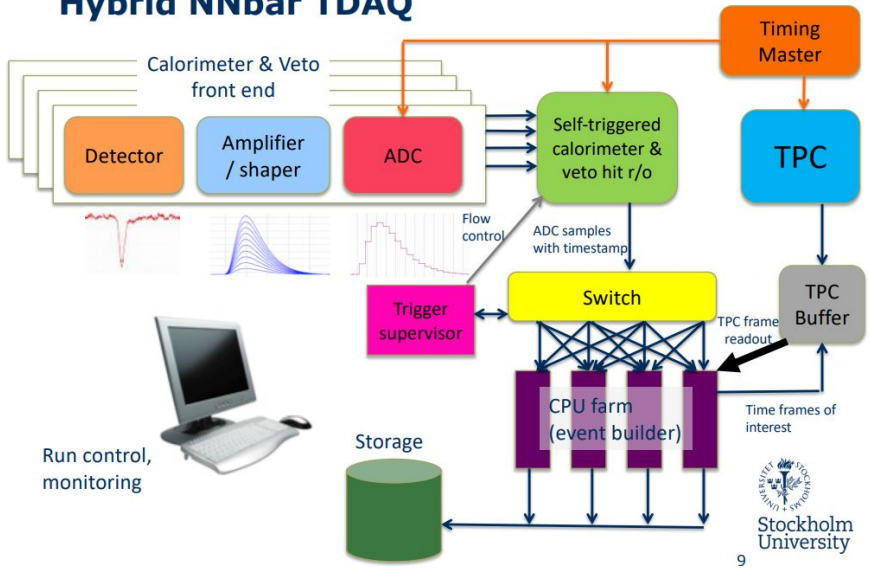
Hybrid NNbar TDAQ



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S. Silverstein

Trigger Algorithms

- Initial selection based on ”fast” calorimeter (& veto) data
  - Local algorithms (cell/tower)
    - Zero-suppression of low-energy hits
    - Multi-layer shower profile (particle ID, direction)
    - MIP
  - Topology algorithms (global)
    - Multi-pion event candidate
    - Cosmic track
    - Beam halo
- Physics-like algorithms (Calorimeter + Veto + TPC)
  - Matching pion candidates with TPC tracks
  - Multi-track vertex ID