ANNIE Phase I - Status and Perspectives

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The ANNIE experiment

- **ANNIE** is the Accelerator Neutrino-Neutron Interaction Experiment

- Water Cherenkov detector placed downstream of the Booster Neutrino Beam

- Aims at measuring the production rate of neutrons from neutrino interactions in water

- Significant impact in proton decay searches and neutrino-nucleon interactions understanding
ANNIE Phase 1 - Goals

- "Proof of concept" → Measurement of the neutron background rate

- Source of neutron background:
  - Skyshine neutrons → Neutrons from the beam dump entering the detector
  - Dirt neutrons → Neutrons originating from neutrino interactions downstream of the dump

- March-May 2016: Installation in the SciBooNE hall

- Taking data since June 2016 until the 2016 Summer shutdown (end of July)

- Different detector configuration than for the Physics run
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ANNIE Phase 1 - The detector

The tank

- 10x13’ tank covered with a white liner for light collection
- Filled with 26-ton of ultrapure water
- Equipped with 60 8-inch photomultipliers (from SuperK, lent by UC Irvine) at the bottom
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- First 2 layers in use (55 channels) instead of the 10 layers (362 channels) used in SciBooNE
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The Neutron Capture Volume (NCV)

- Neutron-sensitive subvolume within the tank
- 50x50 cm acrylic vessel (from UC Davis) filled with 100 liters of Gd-doped liquid scintillator
- Can be moved in the tank using a winch system
• Tank preparation and PMT installation done at the D0 Assembly Building

• Tank filled with **7000 gallons** of ultrapure water

• Water continuously flushed with nitrogen and filtered through a de-ionizing purification system

• Water quality requirement → Resistivity > 10 MΩ‧m⁻¹ (**0.05 ppm**)

• Water commissioning →
  - Observation of muon events
  - PMT characterization using LEDs
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• **100 liters** of EJ-335 liquid scintillator ordered from the Eljen company

\[ \rightarrow \text{Pseudocumene-based (high light yield), 0.25\% Gd-doping (high neutron capture cross-section)} \]

• Filling safely performed in collaboration with ES&H and the Fire Dept.

• Using the winch, the NCV can be moved in the vertical direction and along the beam direction

\[ \rightarrow \text{Allows a measurement of the neutron rate at different locations within the tank} \]
High voltage system

- Experts: University of Sheffield, UK
- 81 negative channels (veto, MRD) and 60 positive channels (tank PMTs)
- LabVIEW-based web interface for remote monitoring and control
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Data acquisition system

- Experts: Iowa State University and Queen Mary University, UK
- 16 VME-based FADC cards developed at the University of Chicago for the KOTO collaboration
- Veto and each MRD layer combined using a CAMAC DAQ and sent to the trigger board
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Trigger system

- Experts: Iowa State University
- Primary mode: Beam trigger
- Possibility to use an external trigger for cosmics searches or LED calibration
ANNIE Phase 1 - Light calibration

• **Goals:**
  - Monitor the PMT response to Cerenkov and scintillation light
  - Control the light attenuation in water
  - Monitor the PMT gain in-situ and continuously

• **4 LEDs** attached to the top of the tank
  - One blue and one green LED on each side, one equipped with a teflon diffuser
  - Can be plugged in directly to a pulse generator → Very easy to use
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- Neutron capture search: All waveforms after a beam trigger recorded for 80 $\mu$s

- **Event definition** → Coincidence of 5 or more PMT pulses above a certain threshold and within a given time window

- Background reduction: Comparison between cosmic muon, beam muon and neutron capture events

- Possibility to separate Cerenkov and scintillation light using pulse shape analysis
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- **First muon** observed during the water commissioning phase
  - Excess of events observed in coincidence with the RWM signal from the BNB
  - Neutron captures $\rightarrow$ Excess of events (exponential shape) after beam signal
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ANNIE Phase 1 - The future

- Data taking can continue even without beam → Cosmic data

- Design studies in progress to install small LAPPDs in the tank in a near future

- Possibility of adding Gadolinium to the water under investigation

- This ANNIE 'Phase 1b' will take place right after the Summer shutdown
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• **ANNIE Phase 1 is now complete and taking data!**

• First data looks very promising

• Huge effort undergoing on analysis

• Precise simulations of the beam (muons and neutrons generation) and the detector (response to neutron capture) are required

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**Thank you for your attention!**
Back-up
SciBooNE

- SciBar: Scintillator tracking detector (14’000 bars, 14 tons)
- Electron Catcher: 2 planes of calorimeter (lead and scintillating fibers)
- Muon Range Detector
- Measurement of CC-QE, CC-$\pi^\pm$, CC-$\pi^0$, NC-ES cross-sections
Booster Neutrino Beam

- 8 GeV protons from Booster beam
- Beryllium target, reversible horn polarity
- Mean neutrino energy of 700 MeV
- Composition: 93 % of $\nu_\mu$, 6.4 % of $\bar{\nu}_\mu$ and 0.6 % of $\bar{\nu}_e$ and $\nu_e$
**n-H capture**

- Capture time: $\sim 200 \mu s$
- 2.2 MeV emitted in one gamma
- Higher accidental background (natural radioactivity)

**n-Gd capture**

- Capture time: $\sim 20 \mu s$ (0.25% Gd-loading)
- $\sim 8$ MeV emitted in several gammas
- High background reduction
- Smaller diffusion path length
**Liquid scintillators**

- Scintillation: Process by which ionization produced by charged particles excites a material and light is emitted by fluorescence
- Liquid scintillators: Organic molecules diluted in an optically-inert liquid (mineral oil,..)
- Basically: Charged particle ionizes liquid $\rightarrow$ Excites molecules that de-excites emitting light
- This light is detected using photomultiplier tubes (PMT’s) that amplify it into a detectable current