Pulsed Neutron Source (PNS) for Photon Detector System (PDS) calibration

Ajib Paudel (On behalf of the PNS for PDS calibration group)

ProtoDUNE Module 1/0 VD PDS meeting

March 22, 2024

DD Generator: (Hardware status)

The neutrons will be generated from a commercial Thermo Fisher MP-320 Deuterium-Deuterium Generator (DDG), which produces monoenergetic 2.45 MeV neutrons with a flux of up to 10^6 neutrons/second.

Currently at CERN

Shielding Details for DDG: **Have not arrived at CERN yet**

→15cm of Borated polyethylene on all sides of the neutron source (except the window) - 5% boron by weight

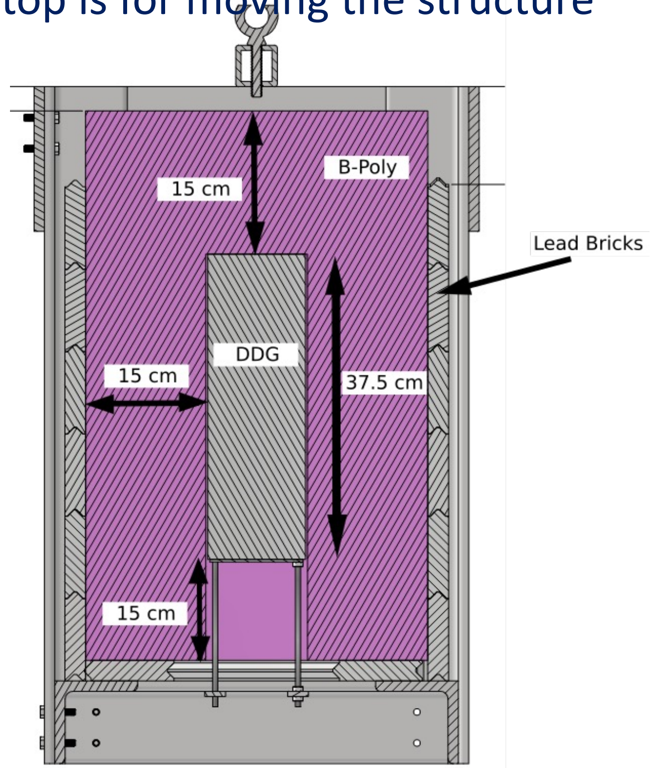
→1" of lead (the chevron shaped interlocking pieces near the outside edge in the drawing)

→12cm square 'window' for collimating outgoing neutrons

→The supporting structure is primarily made from angle-aluminum, eye-bolt at the top is for moving the structure

Delay in shipping of shielding due to technical issues (Jingbo mentioned they haven't sent items directly from SDSMT in the past so facing some technical problems).

In the worst-case scenario, we might have to use the old shielding that was used for ProtoDUNE-SP run (also known as ProtoDUNE-I these days)

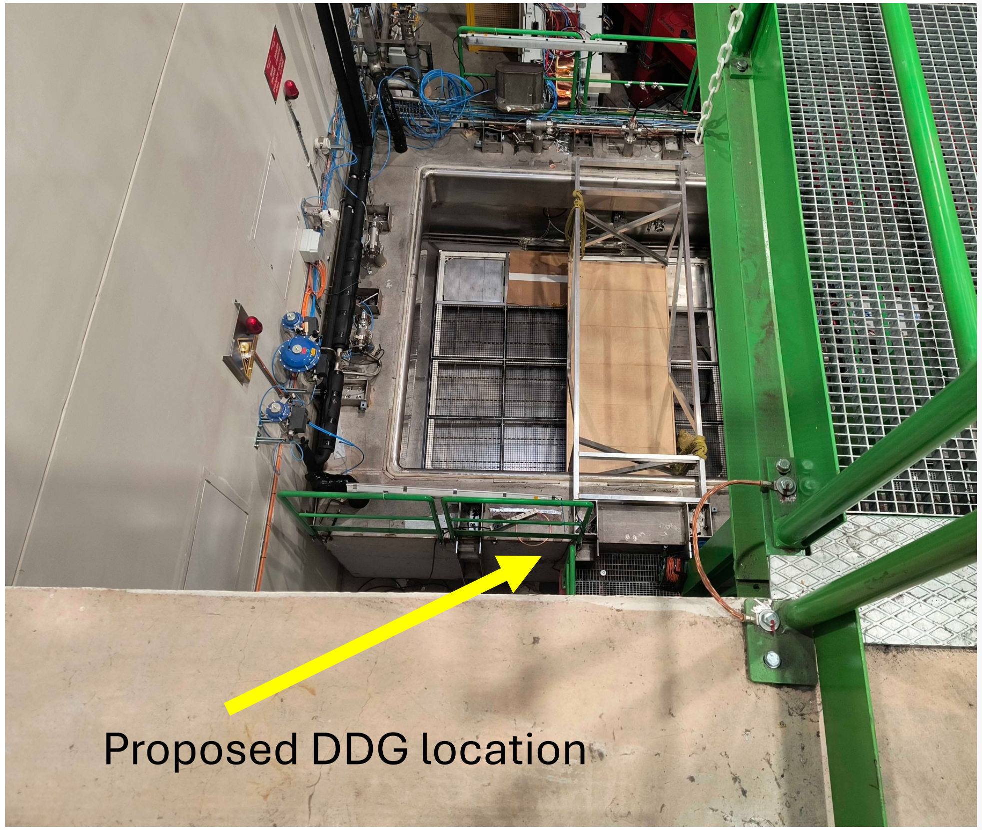


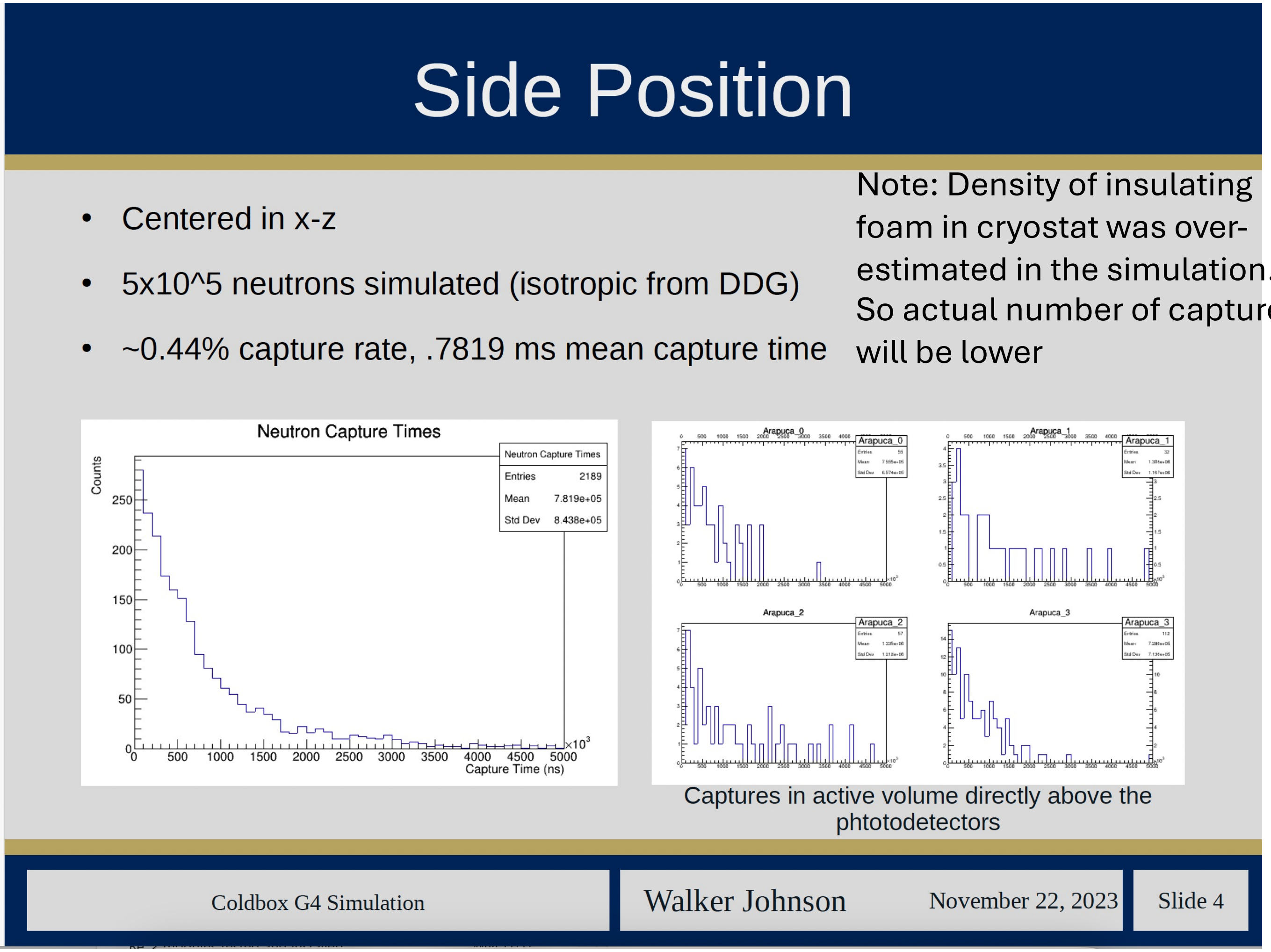
Walker Johnson from the source team gets to CERN on March 26th Tuesday for installation; he will coordinate with Filippo once there.

Desired Position of DDG:

Geant4 (by Walker Johnson) and FLUKA (Paola Sala) simulations carried out for neutron capture with VD ColdBox geometry resulted in similar number of captures for top and side position.

Slightly preferred position is the side position.





Data-taking:

- Have been in touch with DAQ group
- Hardware Trigger details:
  - Type: BNC
  - Description: This is a 5V TTL signal capable of driving into 50 Ohms. This signal is reserved for use by the customer for triggering equipment synchronized with the neutron pulse.”

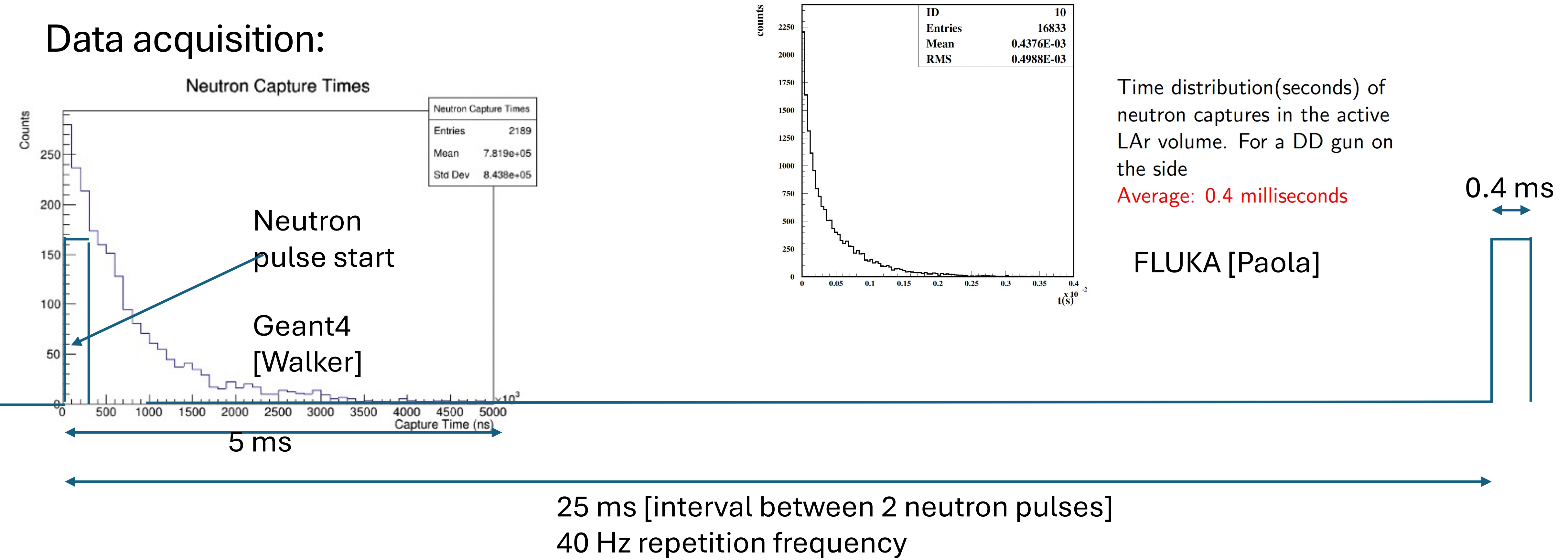
- Preferred set of data (TPC+PDS); TPC information needed for precise location of neutron capture
- PDS data used for Light Yield map reconstruction and absolute energy scale calibration.

→Minimum frequency at which DDG can be operated is 40 Hz (which is the frequency we want to use).

→DAQ (TPC+PDS) can take data at 4 Hz rate for a data window of 1 ms [which is the configuration we think is optimal]

→PDS only data planned to be acquired at higher acquisition rate (desired 40 Hz)

Data acquisition:



- Neutron pulse minimum width is 0.4 ms
- Minimum repetition rate that can be used is 40 Hz
- Neutron capture average time is <1 ms [there is some difference between FLUKA and geant4 simulation; we are trying to resolve the difference]. The two simulations will be useful to understand the systematics of the analysis.

- Most of the neutron capture occurs within the first milli-second of neutron pulse. The proposed DAQ window is 1 ms long. Also, the DAQ rate is limited by the window size; for 1 ms data window a maximum of 4 Hz DAQ sampling frequency possible for TPC+PDS data.

DAQ [Looking at data]:

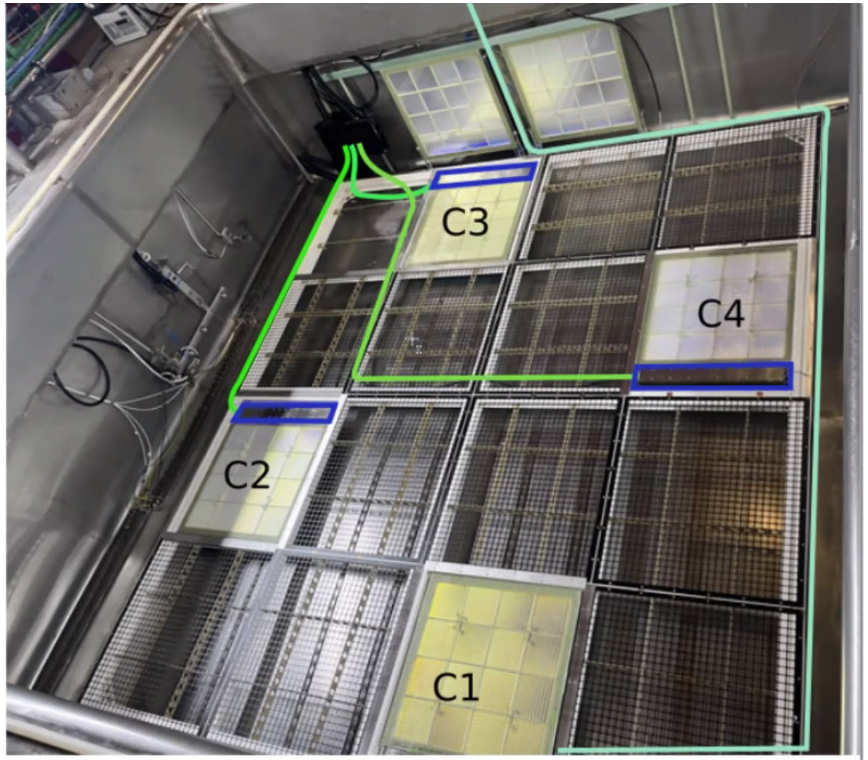
- For DAPHNE readout we have a LArSoft based decoder which works but there is some tuning needed.

- In addition, Vitaliy Popov and Laura Zambelli have python-based scripts to check TPC and PDS signals

- I will work on the LArSoft/ROOT based tools but for the time being we are in good shape due to availability of alternatives.

Some simulation studies [from Wei Shi→ LArSoft using particle gun and VD ColdBox geometry]

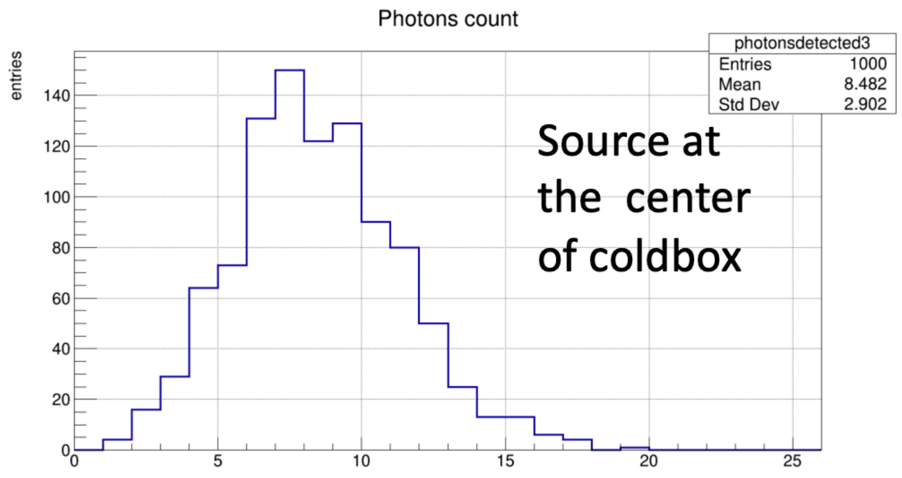
- I will briefly show some ongoing simulation studies before going into the goals of the run



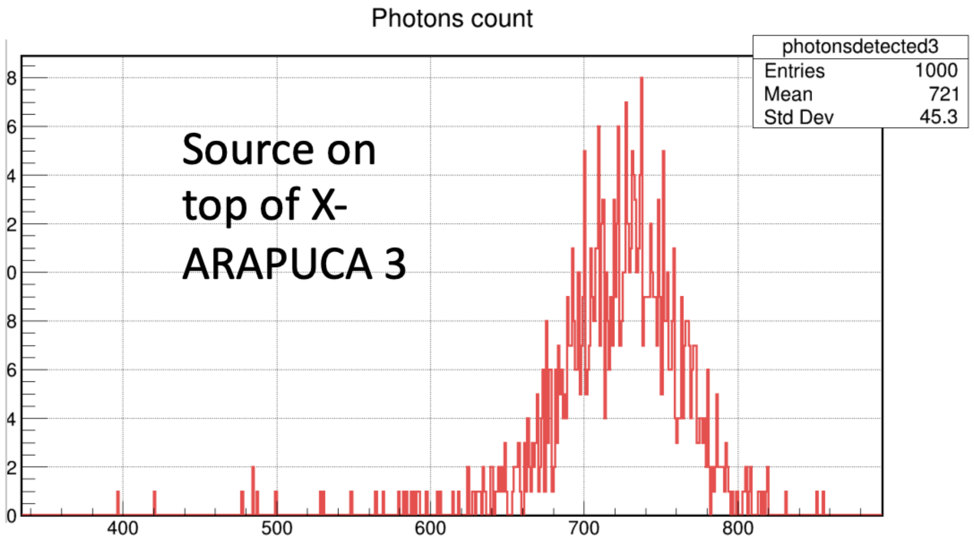
Single neutrons generated by particle gun in LArSoft (Coldbox geometry)

Slide from Wei Shi

4.7 MeV electron generated at the center (left plot) and on top of an X-ARAPUCA



No of photons detected by X-ARAPUCA 3



No of photons detected by X-ARAPUCA 3

As the drift volume is small; a small change in position of the detector makes a significant difference in solid angle suspended at the detector (and hence LY).

Focus on n-capture right on top of any of the 4 XAs on cathode

Neutron capture on 39Ar produces gamma cascade of known energy (total 6.1 MeV)

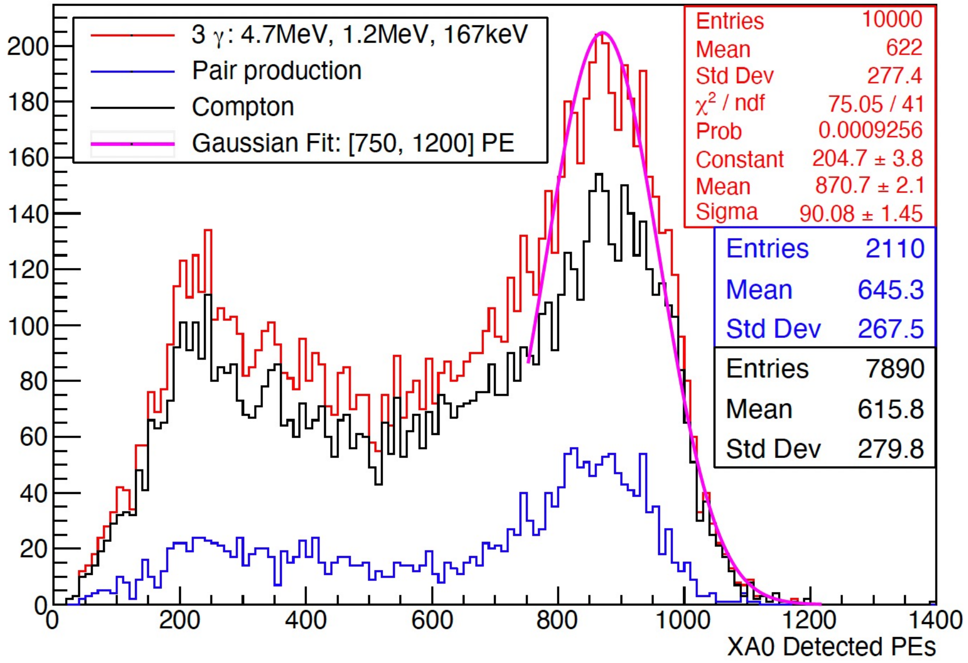
Slide from Wei Shi

Particle gun - Altogether: 4.7MeV + 1.2MeV + 167keV γs

875-PE@5.37MeV Gaussian fit: sigma/mean ~ 10%

This is the simulated calibration uncertainty (i.e., broadening due to γ interaction)

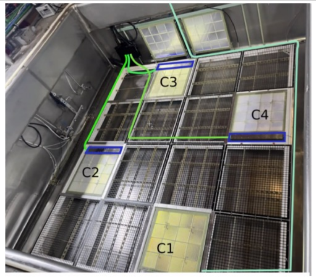
Statistical resolution @875PE is 1/$\sqrt{875}$ ~ 3.4%



If we don't know the position of capture [We don't see a peak; from initial simulation results absolute energy calibration is not possible]: [Hence having CRP together for the runs is very important]

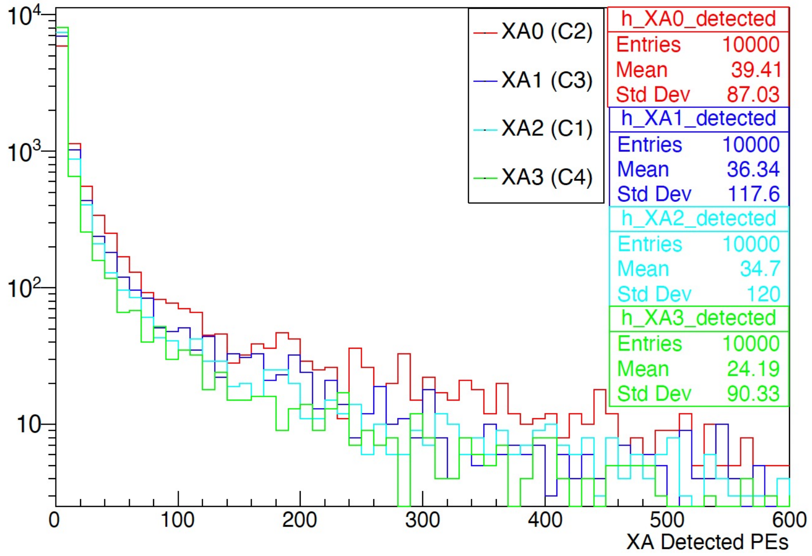
Slide from Wei Shi

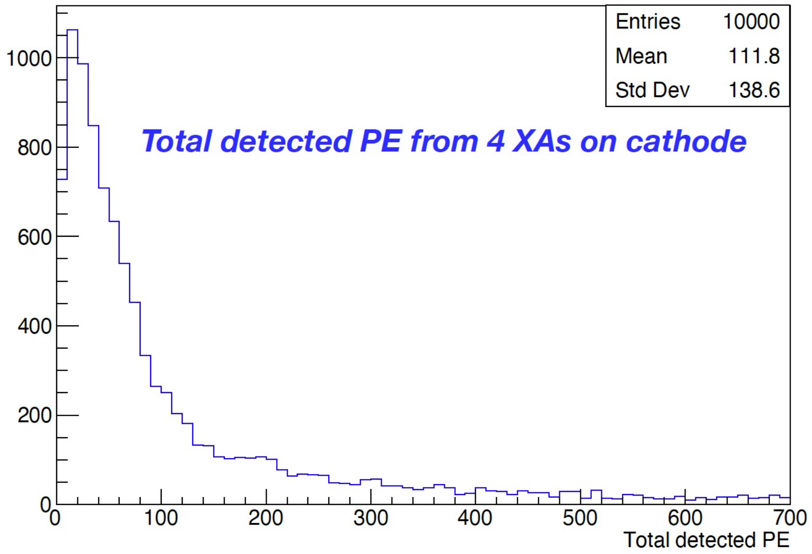
PNS from the side:
Expected signal distributions



XA0 (C2) is the farthest XA from the PNS (see more captures in G4 sim)
XA3 (C4) is the closest XA to PNS

Peak at small PE: because most captures are far from XA 60cm x 60cm acceptance window → small solid angle (next slide)





For simulation/physics updates please join the Wednesday 9:00 am CST meeting.
Recent meeting indico page: https://indico.fnal.gov/event/63902/

How much data do we need [Working on these slides]:

Goal of the analysis (this slide is in preparation and any comments or suggestions are welcome; I am giving a presentation next Wednesday in the VD demonstrator meeting):

→Identify neutron capture signals using PDS system [for this we don't need much data]. If we can do this quickly, we may test software-based triggers in the later part of the run]. Wei has some simulation studies to implement for software-based trigger, but we think first set of data should be collected on full streaming mode based on hardware trigger.

→Reconstruct neutron capture energy peaks; compare data and simulations

→Match the PDS t0 with corresponding CRP signal and reconstruct precise (x, y and z position of n-capture events).

→1 hour = 3600sec X4Hz =14400 events (1 day = ~10 hours; if we can take data for 4 days (TPC+PDS) we get >500k events.

Tentatively, I would say (4 days of TPC+PDS; 1 day of PDS only; 1 day in software trigger mode with TPC+PDS). But we are doing some calculations; which will be based on how much events we can get in a small voxel above PDS modules. [I will try to update this part within next few days]

(suggestions and feedback are welcome)

PNS-PDS Team at CERN:

- PNS source expert: Walker Johnson arriving on March 26, 2024 (will be at CERN for 4 weeks)

- Tel-Aviv group already at CERN for PDS+PNS activities

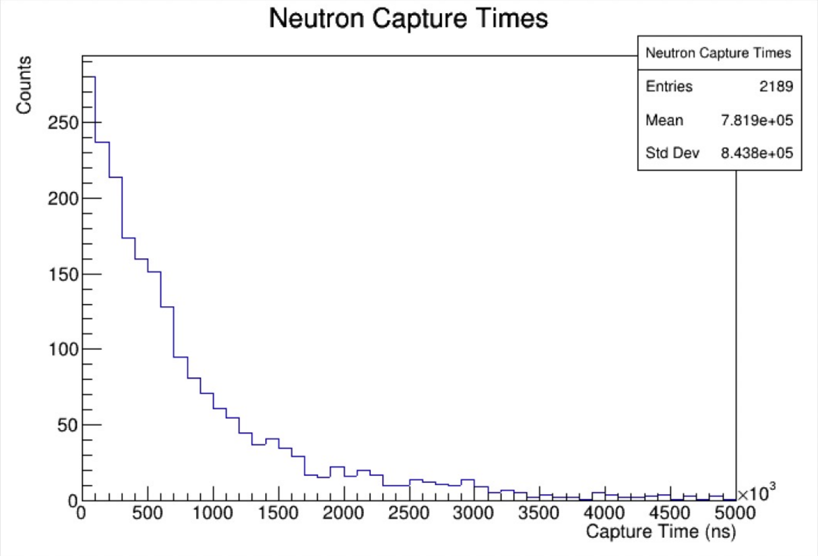
- I (Ajib) will be arriving on March 31^{st} for PNS+PDS data-collection; leaving on April 19^{th}

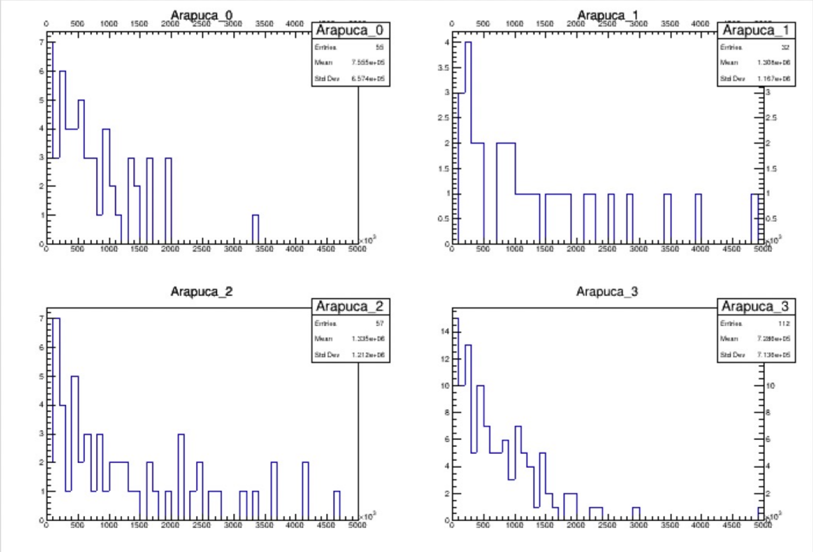
- Besides, PDS consortium members will be working together (Henrique, Vitaliy, Sam Fogarty, and others)

Backup:

Side Position

- Centered in x-z
- 5x10^5 neutrons simulated (isotropic from DDG)
- ~0.44% capture rate, .7819 ms mean capture time

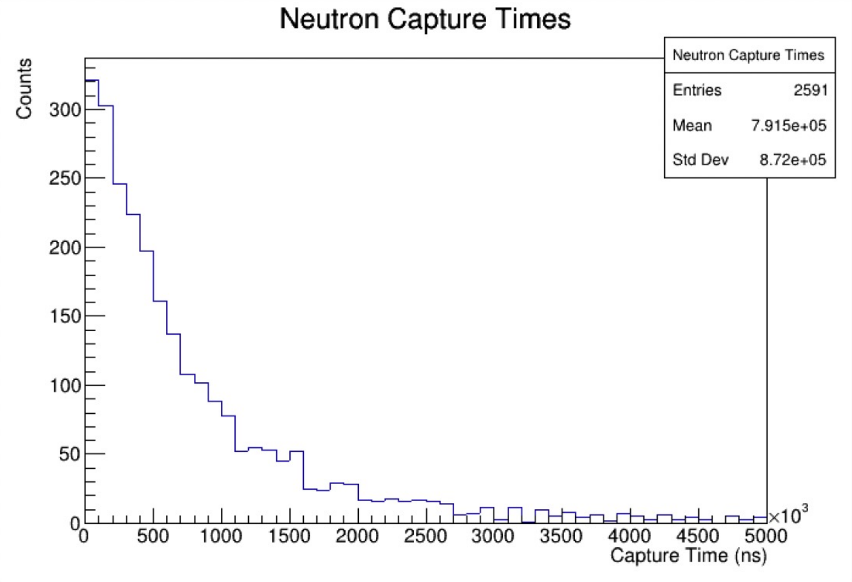


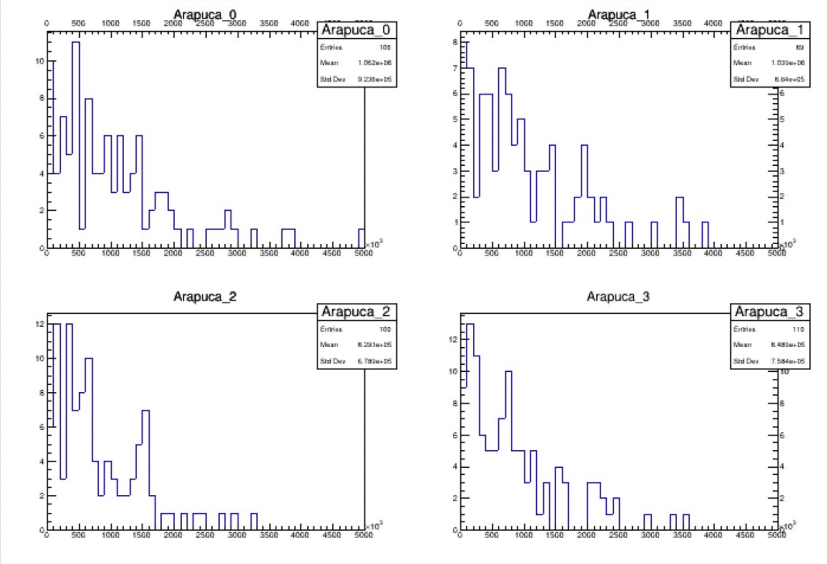


Captures in active volume directly above the phtotodetectors

Top Position

- Centered in y-z
- 5x10^5 neutrons simulated (isotropic from DDG)
- ~0.52% capture rate, .7915 ms mean capture time





ThermoFisher VS Starfire

- Preferred condition (<100 µs pulse; <20 Hz rate) is not possible with the ThermoFisher **MP320** generator, but can be achieved with the Starfire **n-Gen310** generator.
- DUNE project and SD Mines purchased n-Gen310 and received it during this csollaboration meeting week

Data sheet of the DDG to be used

Thermo Scientific MP 320 Neutron Generator

Technical Specifications	
Neutron Yield	1.0E+08 n/s for DT, 1.0E+6 n/s for DD
Neutron Energy	14 MeV
Typical Lifetime	1,200 hours @ 1×10^8 n/s
Pulse Rate	250 Hz to 20 kHz, continuous
Duty Factor	5% to 100%
Minimum Pulse Width	5 µsec tested to be 400 µsec
Pulse Rise Time	Less than 1.5 µsec
Pulse Fall Time	Less than 1.5 µsec
Maximum Accelerator Voltage	95 kV
Beam Current	60 µamps
Power Supply	Integral
Neutron Module	12.07 cm x 57.15 cm (4.75 in x 22.5 in)
Control Module	Integral, digital
Safety Features	Keylock: on/off Emergency: on/off Normal-open and normal-closed interlocks Pressure switch
Total Weight	12 kg (26.46 lb)
Remote Control	RS-232/RS-485

Starfire n-Gen310 Neutron Generator

Neutron Output	
Time-averaged Yield	10^7 DD n/s max; 5×10^8 DT n/s max
DD Neutron Energy	~2.5MeV (DT 14MeV option by special request)
Ion Source Type	Electrodeless RF
Pulse Options	Continuous, >50% duty factor optional
Max Neutron Flux	~1×10^6 n/cm^2•s
Pulse Rate	0-1 kHz standard
Pulse Width	2-1000µs
Pulse Rise/Fall Time	< 5µs
Nominal Duty Factor	5-10%
Power and Operation	
Operating Voltage	up to 140kV
Power Requirements	Up to 100W
System Information	
Neutron Source Dimensions	3" OD x 18" L (7.6 cm OD x 46 cm L)
Neutron Source Weight	10 lbs (4.5 kg)
Supporting Hardware Dimensions	4" W x 6" H x 9" L (10 cm W x 15 cm H x 22 cm L)
Supporting Hardware Weight	4.0 lbs (1.8 kg)
Integrated cooling w/ Cowling Dimensions	3.5" OD, 22.5" length with fan
Warranty	500 operating hours, or 12 months