The Short Baseline Near Detector
High Efficiency Light Collection System

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Three Liquid Argon Time Projection Chamber (LArTPC) detectors in the Booster Neutrino Beam

Due to its location near (110 m) the neutrino source and relatively large mass (112 ton active volume) SBND will have the world’s highest statistics in $\nu_\mu$-Ar and $\nu_e$-Ar interactions

- Testing the sterile neutrino interpretation of the anomalous excesses of electron (anti)neutrinos observed by LSND and MiniBooNE
- Play a major role in the on-going R&D efforts for the construction of DUNE, a multi-kiloton-scale LArTPC detector
Two primary physics goals:

1. Measure the unoscillated fluxes: $\nu_\mu$-CC, $\nu_e$-CC, and NC interactions to enable precise sterile neutrino oscillation searches in combination with the SBN far detectors, ICARUS and MicroBooNE

2. Study neutrino-nucleus interactions on argon with unprecedented precision and detail: inclusive and exclusive cross sections, and careful study of nuclear effects in neutrino-nucleus scattering
Two drift volumes separated by a central cathode plane

Each drift volume has a 2 m drift distance

Facing the cathode plane in each drift volume are Anode Plane Assemblies (APAs): 3 planes of sensing wires

Two sets of field cage modules surround the drift volumes to provide uniform drift field of 500 V/cm
SBND Light Detection System

- SBND is implementing a high light yield Light Detection System scheme
- PMTs + Light Guide Bars as detectors
- Possibility of adding WLS covered reflector foils under evaluation (generic R&D)
- Simulations show that foils can help in timing, calorimetry and position resolution

Adding WLS-covered reflector foils improves the overall performance of the system
Simulating the arrival time of photons

• In the optical simulations of SBND we have included the propagation time of the photons (typically ignored)
• We have parameterized the time distributions → resulted only from direct transport + Rayleigh scattering

Parametrization examples: the red lines are not fits

@ 43 cm
@ 122 cm
@ 201 cm
@ 230 cm

Fit example
Light Yield

Scintillation points generated randomly in the active volume at different fixed drift distances

• VUV-direct light

Light Yield with the LDS consisting (only) in the array of PMTs

\[ \text{PMT}_{\text{QE}} = 20\% \]

Uncertainties dominated by geometric (border) effects
Scintillation points generated randomly in the active volume at different fixed drift distances

- VUV-direct light
- Visible-reemitted
- Total component

- Uniform light collection
- More than a two-fold improvement of the collection efficiency: compared to existing liquid argon neutrino detectors at a fraction of the cost of adding new photon-detectors

Will lower the reconstruction threshold of liquid argon neutrino detectors (down to few MeV level)
Time structure of detected signals

Scintillation (emission):
\[ 0.3 \times \tau_{\text{fast}}(6 \text{ ns}) + 0.7 \times \tau_{\text{slow}}(1590 \text{ ns}) \]

Propagation:
Direct transportation + Rayleigh Scattering

\[ \tau_{\text{fast}} = 6 \text{ ns} \]
\[ \tau_{\text{slow}} = 1590 \text{ ns} \]

Average PMT signal at 100 cm

In “large” detectors transport effects will affect the effective time structure of the detected scintillation light.
Time structure of detected signals

- VUV-direct light
- Visible-reemitted
- Total component

Rayleigh scattering causes the “effective” fast component to change with distance from Photon-detectors.

That leads to the trigger efficiency differing with distance (in addition to effects caused by non-uniformity).

Adding foils mitigates this effect, because total (direct + reemitted) light is less prone to this effect.
Position Resolution

- Position resolution is extremely important for TPCs on the surface, as it is needed to reject cosmic tracks.
- Position resolution in SBND is quite good (thanks to large number of PMTs).

- Simulations show that good resolution is achievable with foils installed.
Drift position resolution

- When able to differentiate VUV from Visible (reemitted) possible to get position in x on the fly
- Useful for disentangling multiple events in the same frame
- Current PMT design foresees such a design
- Never done before in a LArTPC!
Conclusions

• SBND will play a crucial role in SBN program providing huge data sets of $\nu$-Ar interactions

• Further develop the LArTPC technology and help to build the expertise of the global neutrino physics community working toward DUNE

• Installation of foils in SBND can provide important input into the design of the DUNE light collection system ➔ Paper in preparation
Back-Up
This means \textbf{128000000000} photons to be tracked! (with Rayleigh scattering, reflections, absorptions, wavelength shifting) \textRightarrow a lot of CPU time and memory!
Visible light is faster (x 2.4) that VUV: improves resolution closer to cathode, where direct light does does worst.

Expected time resolution $\rightarrow$
In this LDS visible light preserves the ns time resolution of the scintillation light in LAr.
**Saturation studies**

- **LArSoft fast-mode output**
- **SER signal used**
- **500 MHz sampling: 2ns/bin**

Saturation condition \(\rightarrow 500 \text{ phe}\)

With a 14-bit Digitizer \(\rightarrow 2^{14} \approx 16K\)

Signal/bin > 16K adc

\(\rightarrow (16K \text{ phe} = 500\text{phe} \times 32 \text{ adc/phe})\)

visible light does not seem to contribute to the saturation probability
Efficiency used in the simulations

- The global quantum efficiency estimated for the light guide bars by the Indiana University group on DUNE is \(5 \times 10^{-2} \text{ ph-e/VUV photon}\) at 0 mm from the end of the bar where the SiPMs are.

- Fits to data predict **attenuation lengths of 2 meters** for the proposed light guide bars.

Finally:

Efficiency = \(5 \times 10^{-2} \exp(d / 2 \text{ m})\)
First results with the light-guide bars

TPB coated reflector foils on the cathode

Light guide bars configuration

All scintillation points generated in the center of the photocathode plane: \((y,z) = (0, 250 \text{ cm})\)
Arrival time distributions

- In the optical simulations of SBND we have included the propagation time of the photons (typically ignored)
- We have parameterized the time distributions → resulted only from direct transport + Rayleigh scattering

A Landau + Exponential function describes well the arrival time distributions of the VUV light at any distance from the photocathode

Parameterization ready in LArSoft:
- par0 = Landau normalization
- par1 = Landau MPV
- par2 = Landau width
- par3 = Expo constant
- par4 = Expo tau

And we have validated it (the direct component) also using the MicroBooNE geometry!
“Tracking” the events with light: some examples “cosmics”

1 GeV muons
VUV + Visible components
Contours = hottest PMTs with the 50% of the total detected light

Very simple assumption → Big room for improvements!