VD PHOTON DETECTION SYSTEM -REQUIREMENTS

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VD-PD Prelimiary Design Review
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Basic Considerations

- We believe that the PDs of HD and VD modules of the far detector should have the same minimal physics requirements;
- This means that the VD module should be able to do at least the same physics as the HD one, but without limitations on possible scope expansions.

PD HD Physics and Detector Requirements

Label	Description	Specification (Goal)	Rationale	Validation
SP-FD-3	Light yield	$>$ 20 PE/MeV (avg), $>$ 0.5 PE/MeV (min)	Gives PDS energy resolution comparable to that of the TPC for 5-7 MeV SN νs, and allows tagging of $>$ 99 % of nucleon decay backgrounds with light at all points in detector.	Supernova and nucleon decay events in the FD with full simulation and reconstruction.
SP-FD-4	Time resolution	$<$ 1 µs ($<$ 100 ns)	Enables 1 mm position resolution for 10 MeV SNB candidate events for instantaneous rate $<$ 1 $m^{-3}ms^{-1}$.	

PD HD Physics Requirements

Label	Description	Specification (Goal)	Rationale	Validation
SP-FD-3	Light yield	> 20 PE/MeV (avg), > 0.5 PE/MeV (min)	Gives PDS energy resolution comparable to that of the TPC for 5-7 MeV SN νs, and allows tagging of > 99 % of nucleon decay backgrounds with light at all points in detector.	Supernova and nucleon decay events in the FD with full simulation and reconstruction.
SP-FD-4	Time resolution	< 1 µs (< 100 ns)	Enables 1 mm position resolution for 10 MeV SNB candidate events for instantaneous rate < 1 $m^{-3}ms^{-1}$.	

PD HD Detector Requirements

Label	Description	Specification (Goal)	Rationale	Validation
SP-FD-3	Light yield	> 20 PE/MeV (avg), > 0.5 PE/MeV (min)	Gives PDS energy resolution comparable to that of the TPC for 5-7 MeV SN νs, and allows tagging of > 99 % of nucleon decay backgrounds with light at all points in detector.	Supernova and nucleon decay events in the FD with full simulation and reconstruction.
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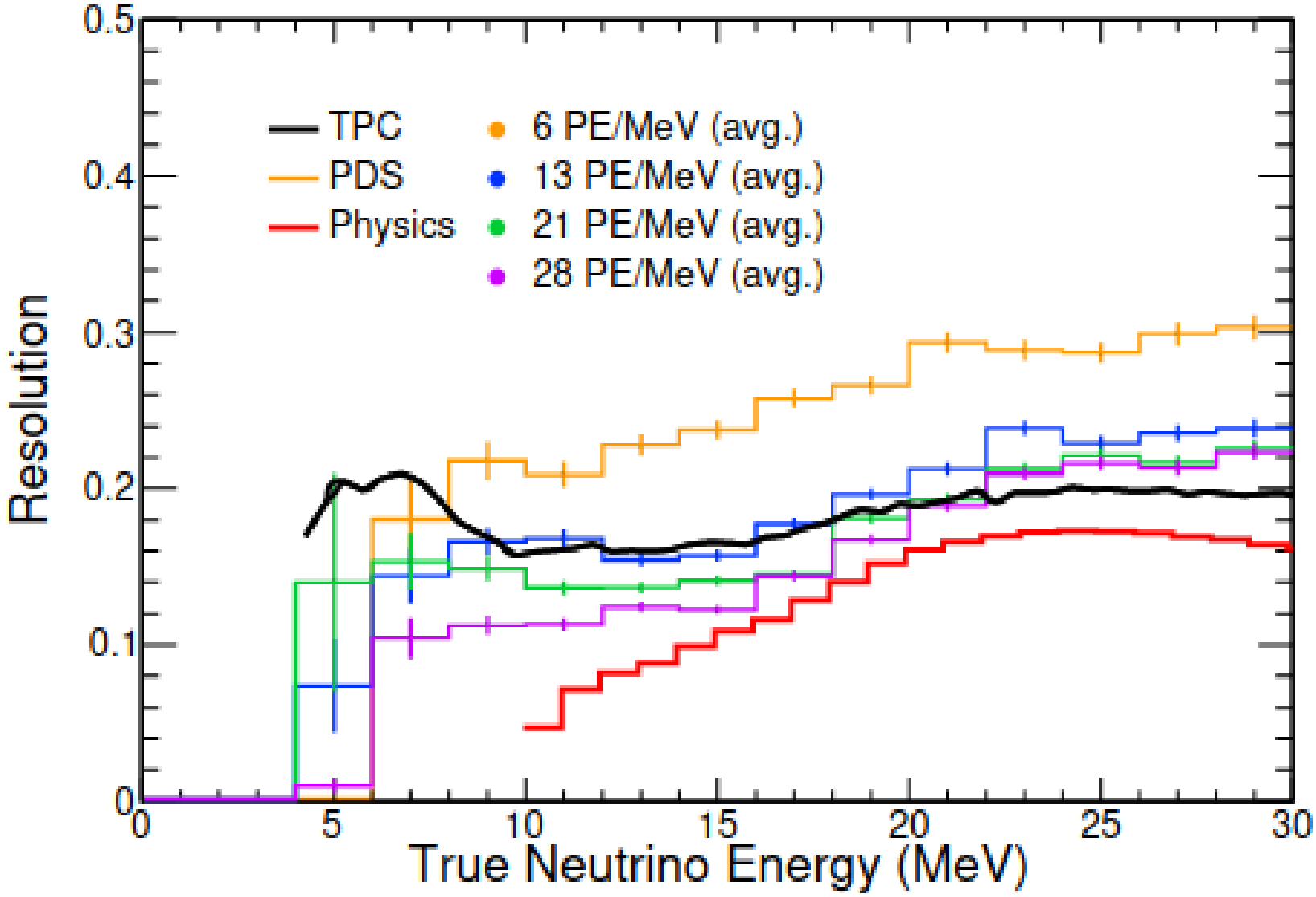
The Physics requirements have been translated into detector requirements through detailed (and very time consuming) full simulations of the SP HD far detector and of large samples of Supernova and nucleon decay events

Rationale of PD HD Detector Requirements

- The **detector requirements** of an **average LY of 20 phel/MeV** inside the TPC comes directly from the **physics requirement** of being able to reach, with the HD PD, **a similar energy resolution for Supernova neutrinos as that achievable with the detection of the charge with the TPC;**

- The **detector requirement** of a **minimum LY of 0.5 phel/MeV** comes from the **physics requirement** of being able to measure the **T_0 for nucleon decay background events everywhere inside the active volume**.


TPC
PDS
Physics
6 PE/MeV (avg.)
13 PE/MeV (avg.)
21 PE/MeV (avg.)
28 PE/MeV (avg.)
Resolution
True Neutrino Energy (MeV)
0
0.1
0.2
0.3
0.4
0.5
0
5
10
15
20
25
30

Path towards PD VD Detector Requirements

- The work done for the HD represents ***a solid starting poin***t and can allow us to make *some educated guesses fabout VD requirements*;
- It is reasonable to think that the requirement on the average LY, related to the ***average energy resolution*** of the PD, **will be similar to the HD one - around 20 phel/MeV. This requirement is assumed also for the VD;**
- The requirement ***on the minimum light yield could be slightly different***, because the TPCs have different geometrical configurations;
- Conservatively, **it looks appropriate** to assume the **minimum LY requirement of 0.5 phel/MeV everywhere in the TPC also for the VD**

Path towards PD VD Detector Requirements

- Assuming for the VD the same minimal physics requirements of the HD, the derivation of the detector requirements will follow the same process:
  - Simulation and reconstruction of large samples of Supernova neutrinos and nucleon decay events
- The Physics and Simulation WG of the PD Consortium has developed the Monte Carlo of the VD module. Production of large samples of SN neutrino and nucleon decay events will start in the next weeks. A refinement of the VD requirements is expected for mid-June

TB held Requirements

- TB held required of FD1 are assumed also for FD2, for the moment.

SP-FD-15	LAr nitrogen contamination	< 10 ppm	Maintain 0.5 PE/MeV PDS sensitivity required for triggering proton decay near cathode.	In situ measurment
SP-PDS-1	Clean assembly area	Class 100,000 clean assembly area	Demonstrated as satisfactory in ProtoDUNE-SP, and is the Deep Underground Neutrino Experiment (DUNE) assembly area standard.	ProtoDUNE-SP and in Fermilab materials test stand
SP-PDS-2	Spatial localization in y-z plane	< 2.5 m	Enables accurate matching of photon detector (PD) and TPC signals.	SNB neutrino and nucleon decay (NDK) simulation in the FD
SP-PDS-3	Environmental light exposure	No exposure to Sunlight. All other unfiltered sources: < 30 minutes integrated across all exposures	Shown to prevent damage to wavelength-shifting (WLS) coatings due to UV.	Studies in ProtoDUNE-SP, and at IU
SP-PDS-4	Environmental humidity limit	< 50 % RH at 70 °F	Demonstrated to prevent damage to WLS coatings due to humidity.	PD optical coating studies

TB held Requirements

SP-PDS-14	Signal-to-noise in SP-PD	> 4	Keep data rate within electronics bandwidth limits.
SP-PDS-15	Dark noise rate in SP-PD	$< 1\,\mathrm{kHz}$	Keep data rate within electronics bandwidth limits.
SP-PDS-16	Dynamic Range in SP-PD	$< 20\,\%$	Keep the rate of saturating channels low enough for effective mitigation.

Additional Considerations

- The VD design offers much more flexibility for the design of the PD than the HD and has much less mechanical constraints. It offers the possibility of expanding the Physics reach of the detector;
- An increased and more uniform Light Yield translates into:
  - Improved resolution for low energy events (SNB and solar neutrinos) → better identification of SNB spectral features, which can allow to discriminate different dynamical models;
  - Possibility of a light based and high efficiency SNB trigger;
  - Improved background rejection for low energy events by increasing the flash-track matching;
  - Improve the overall resolution for beam events (through the combination of charge and light signals).