The Short Baseline Near Detector High Efficiency Light Collection System

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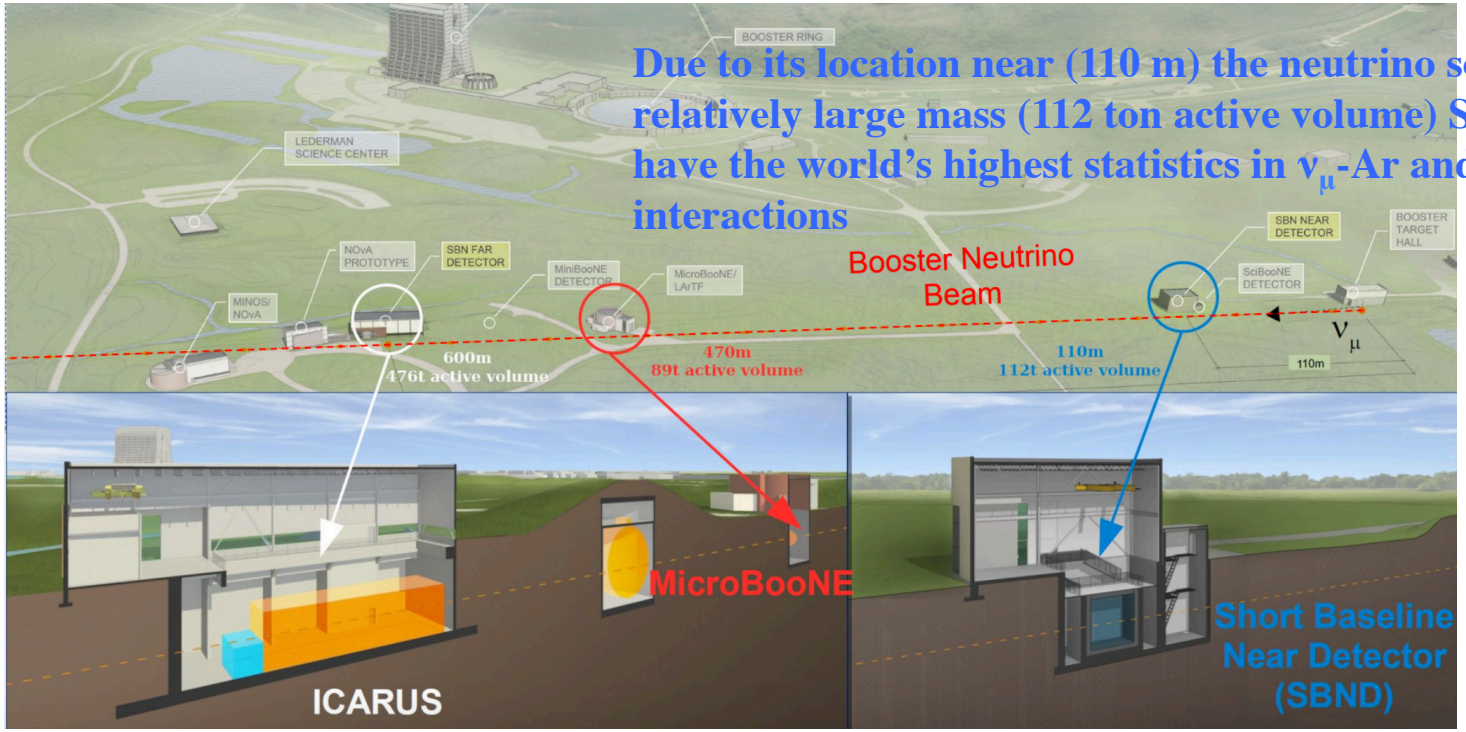
The University of Manchester

Short Baseline Neutrino (SBN) program @ Fermilab

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



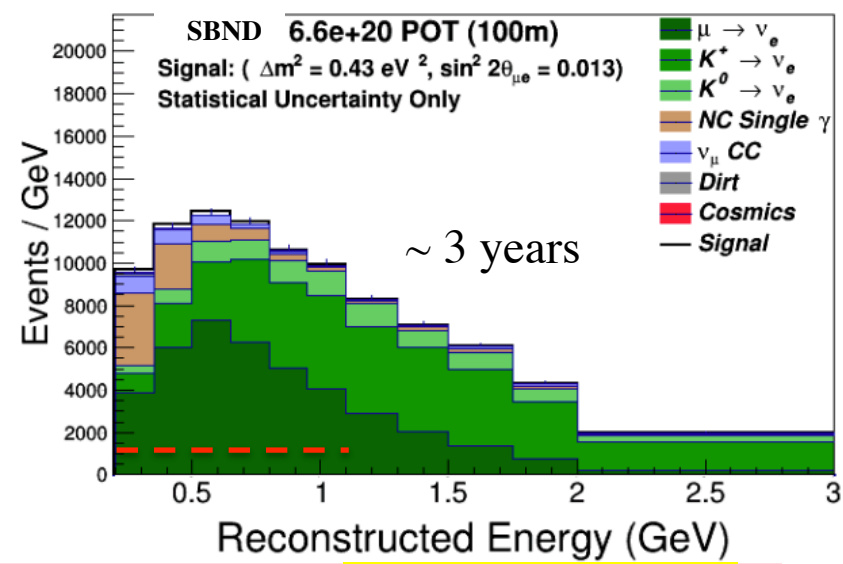
Due to its location near (110 m) the neutrino source and relatively large mass (112 ton active volume) SBND will have the world's highest statistics in ν_μ-Ar and ν_e-Ar interactions

- 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

SBND Physics Goals

Two primary physics goals:

1. **Measure the unoscillated fluxes:** ν_μ-CC, ν_e-CC, and NC interactions to enable precise sterile neutrino oscillation searches in combination with the SBN far detectors, ICARUS and MicroBooNE

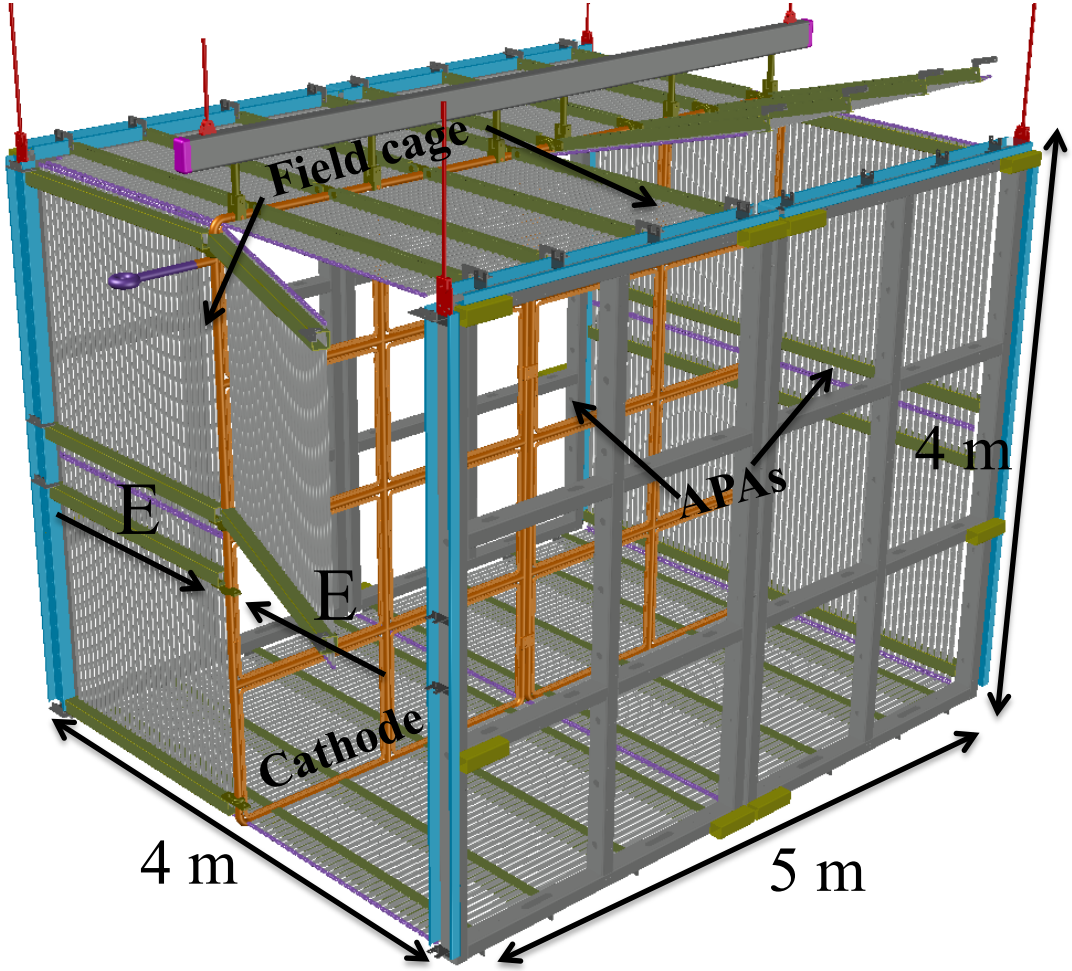


$\nu_\mu - Ar \rightarrow 7x10^6$

$\nu_e - Ar \rightarrow 5x10^4$

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

SBND TPC Layout

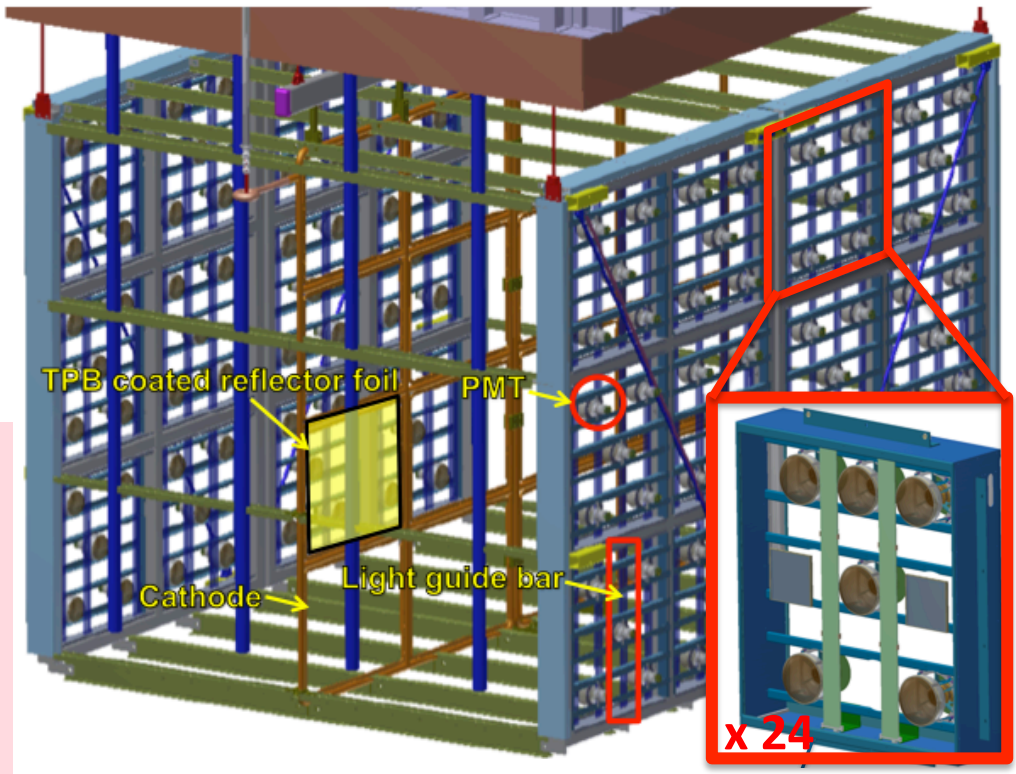


- ✓ Two drift volumes separated by a central cathode plane
- ✓ Each drift volume has a 2 m drift distance
- ✓ Facing the cathode plane in each drift volume are Anode Plane Assemblies (APAs): 3 planes of sensing wires

- ✓ Two sets of field cage modules surround the drift volumes to provide uniform drift field of 500 V/cm

SBND Light Detection System

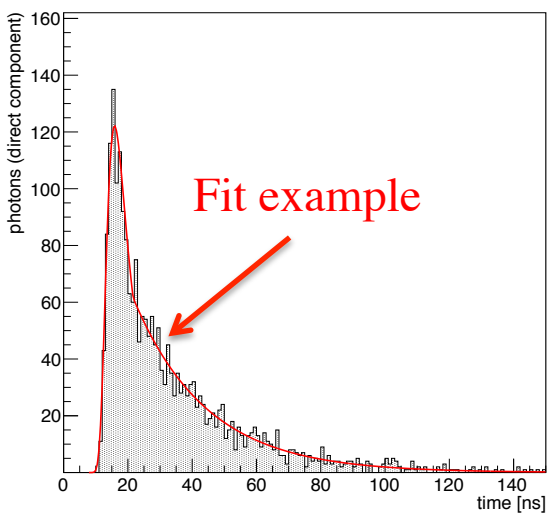
- ✓ SBND is implementing a high light yield Light Detection System scheme
- ✓ PMTs + Light Guide Bars as detectors
- ✓ Possibility of adding WLS covered reflector foils under evaluation (generic R&D)
- ✓ Simulations show that foils can help in timing, calorimetry and position resolution →

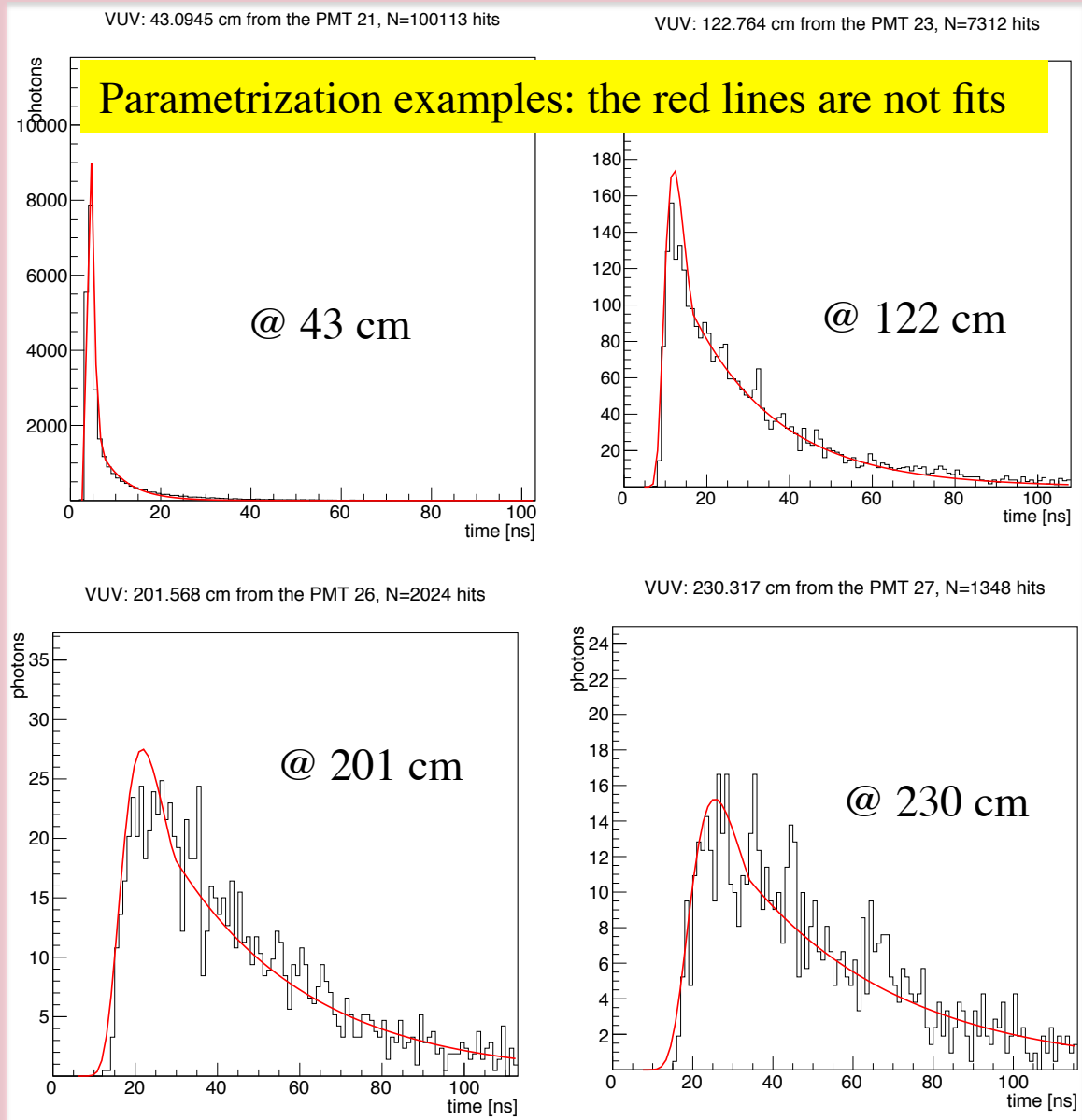


Adding WLS-covered reflector foils improves the overall performance of the system

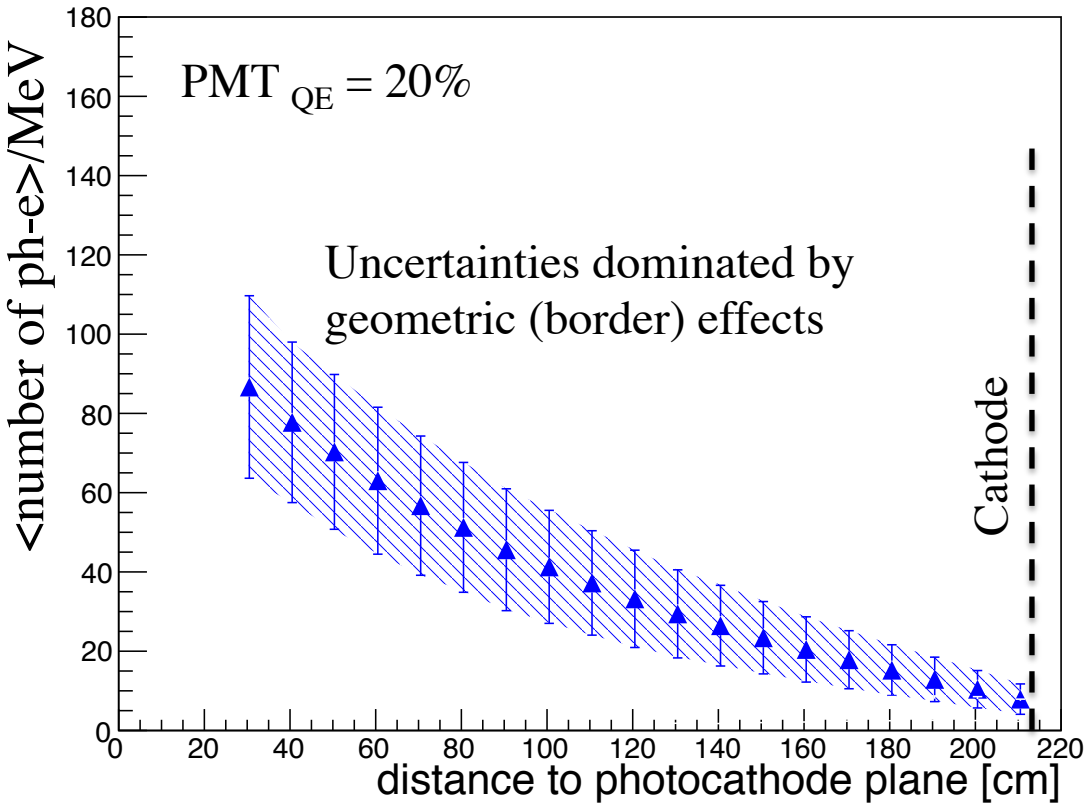
Simulating the arrival time of photons

- 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





Light Yield

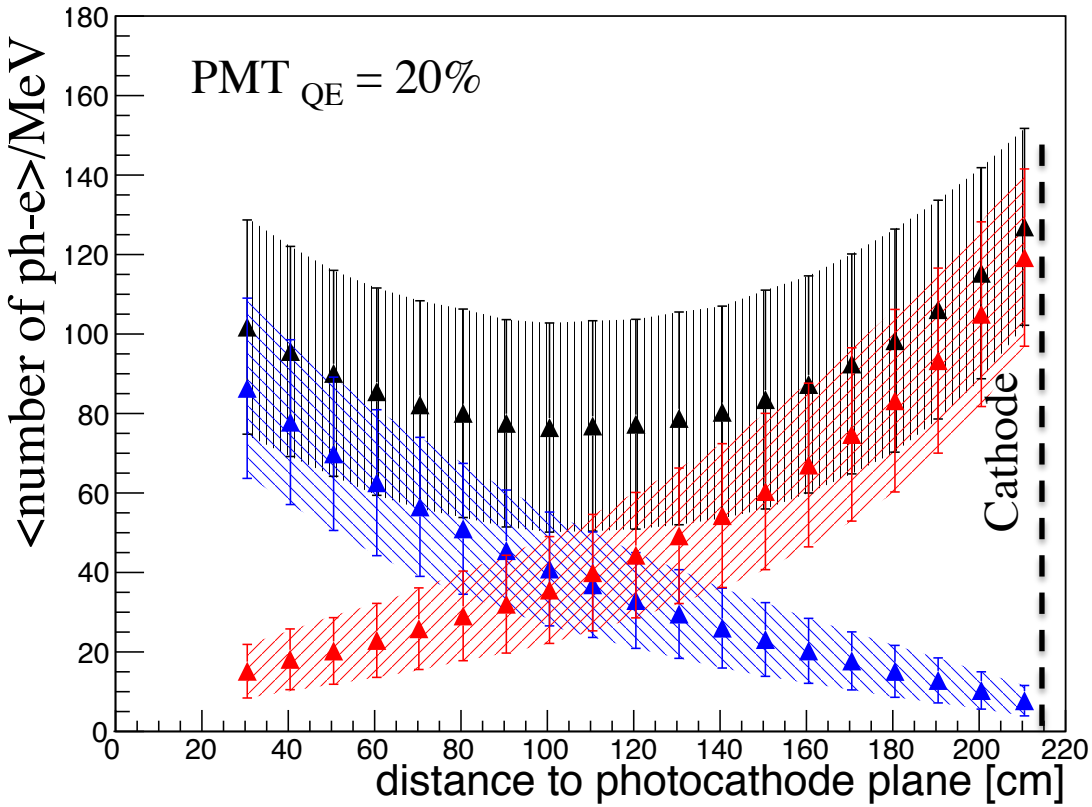


Scintillation points generated randomly in the active volume at different fixed drift distances

- VUV-direct light

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

Light Yield



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

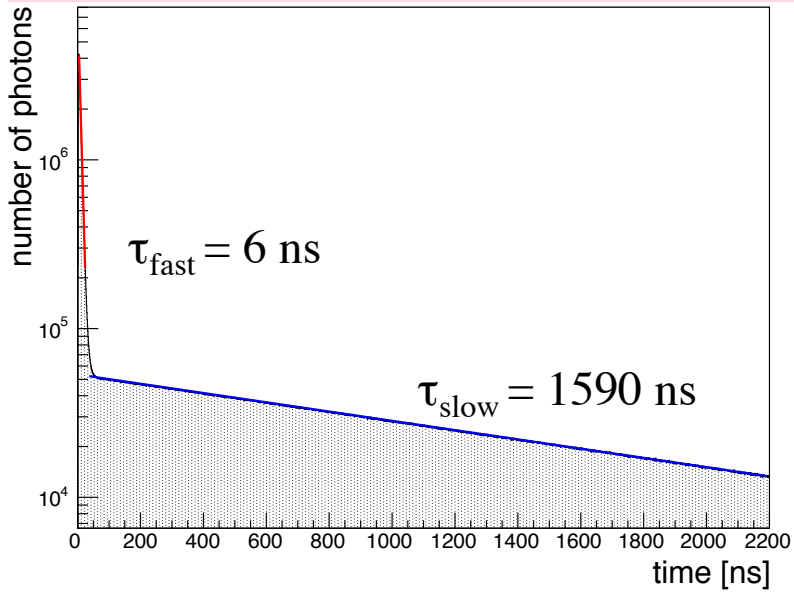
Will lower the reconstruction threshold of liquid argon neutrino detectors (down to few MeV level)

Time structure of detected signals

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

+

Propagation: Direct transportation + Rayleigh Scattering



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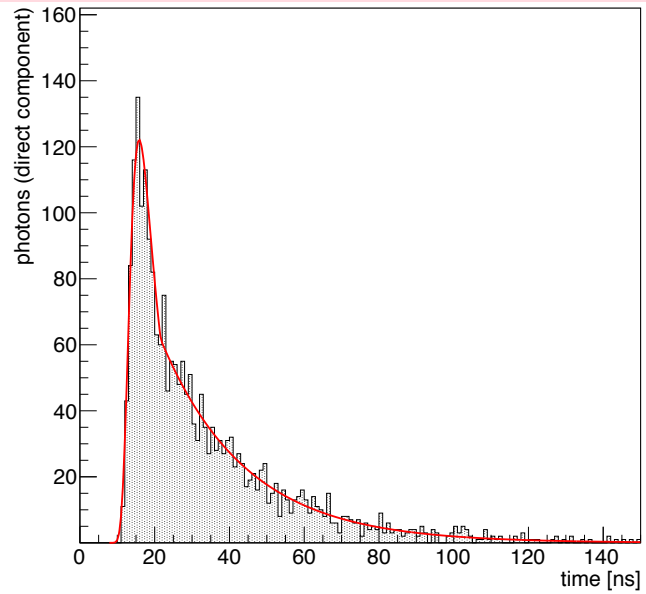

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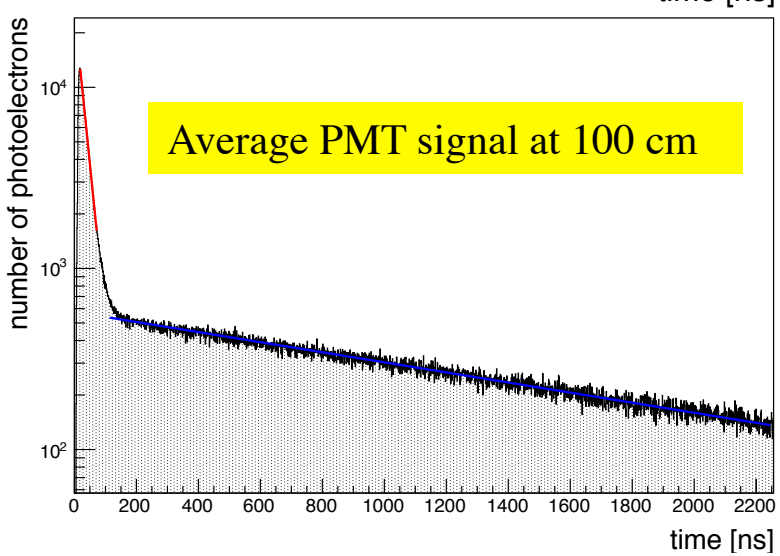
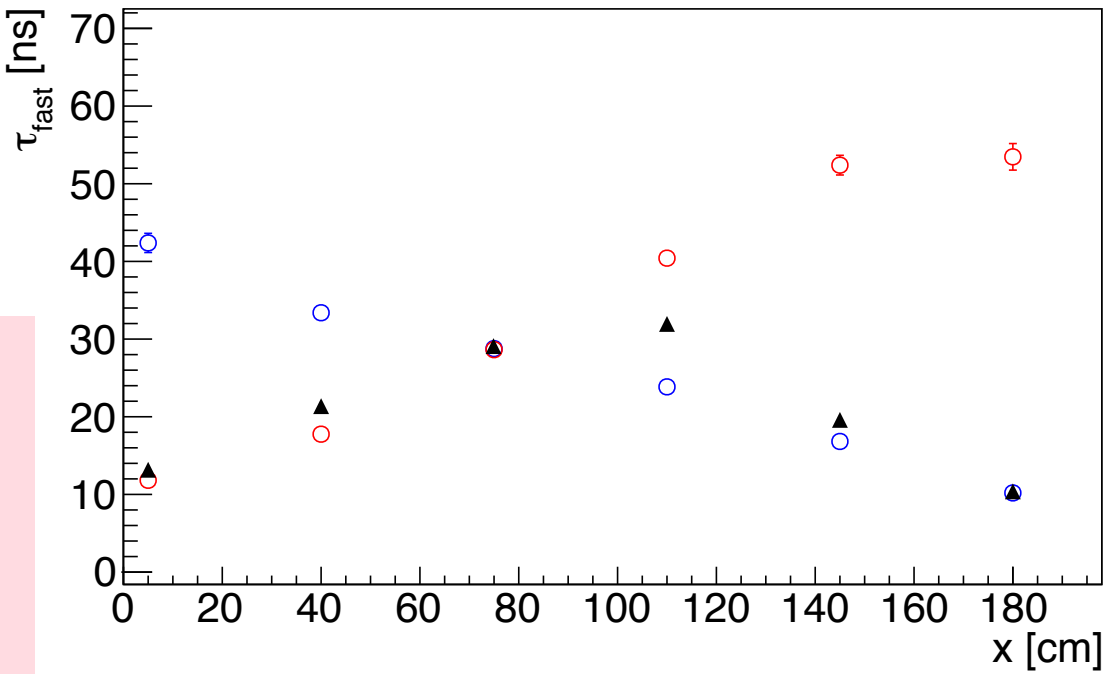


In "large" detectors transport effects will affect the effective time structure of the detected scintillation light

Time structure of detected signals

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

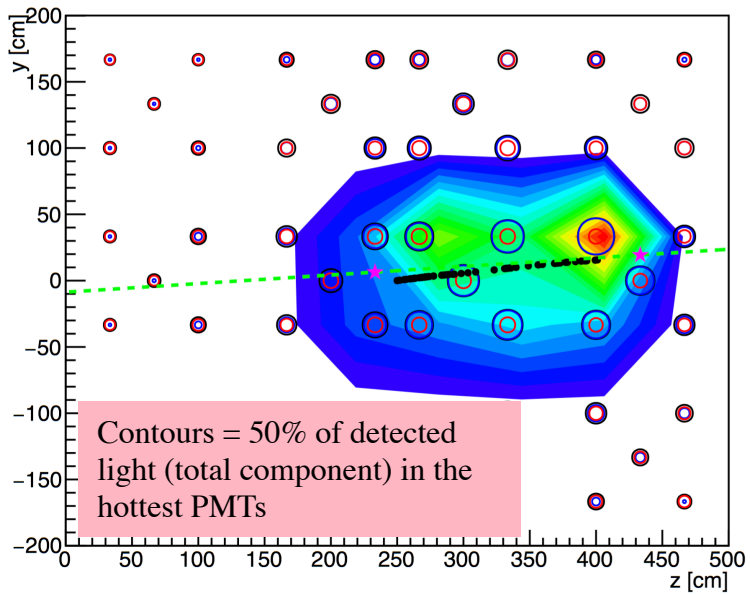


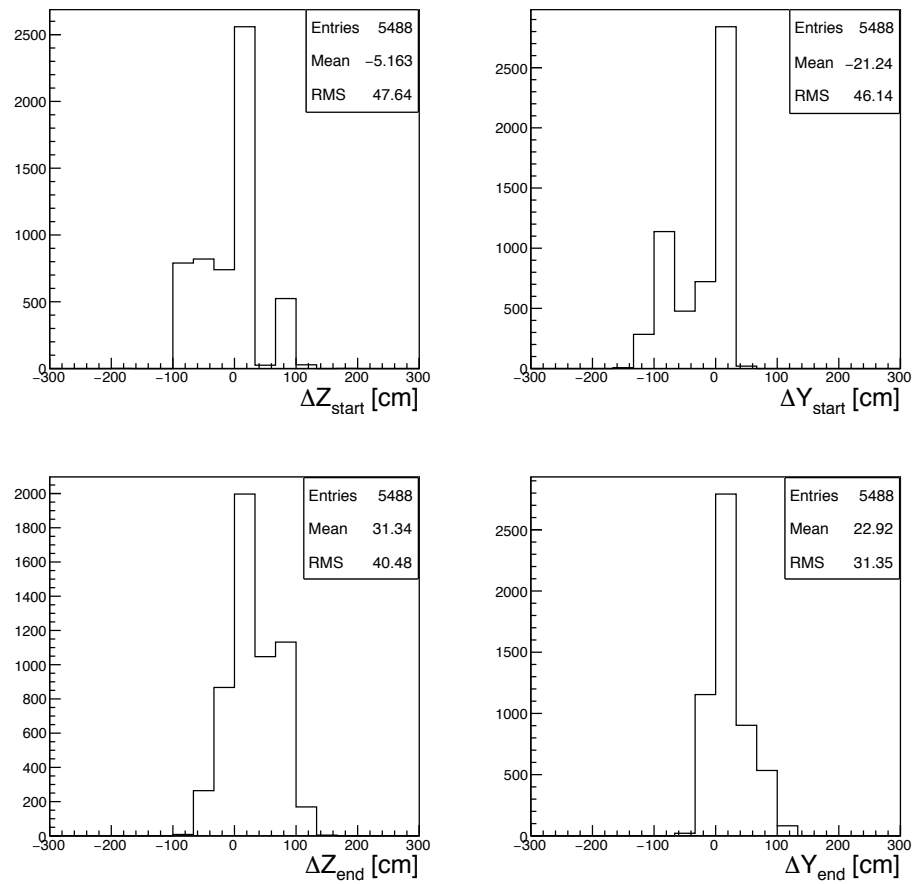
- Rayleigh scattering causes the "effective" fast component to change with distance from Photon-detectors

- 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

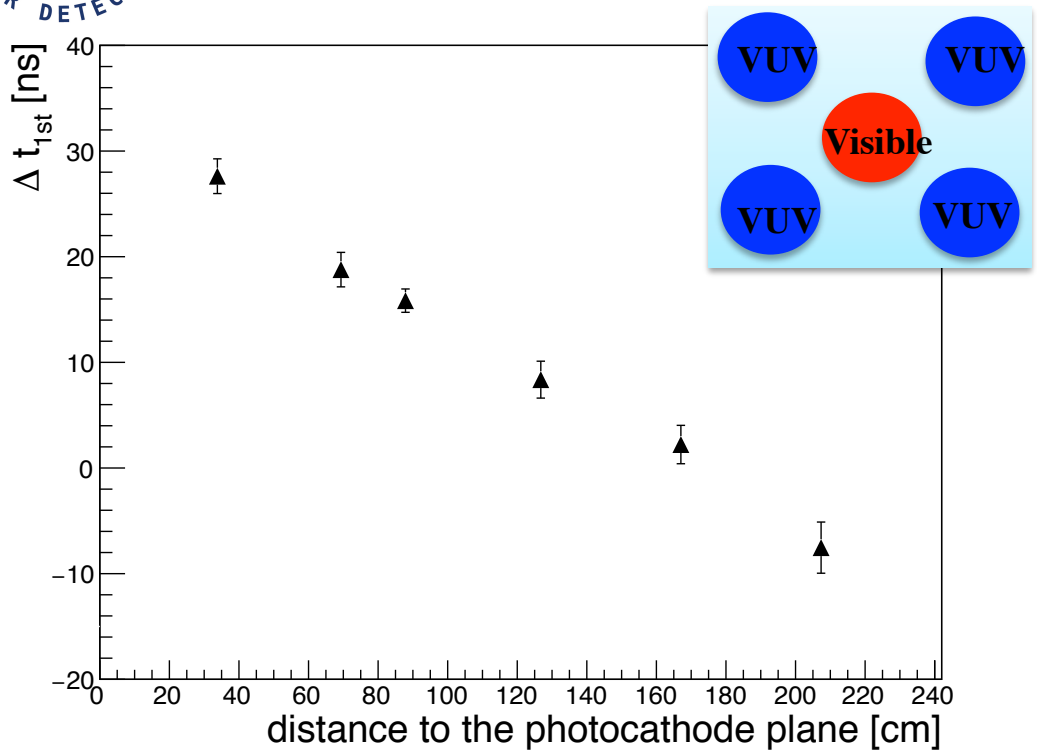


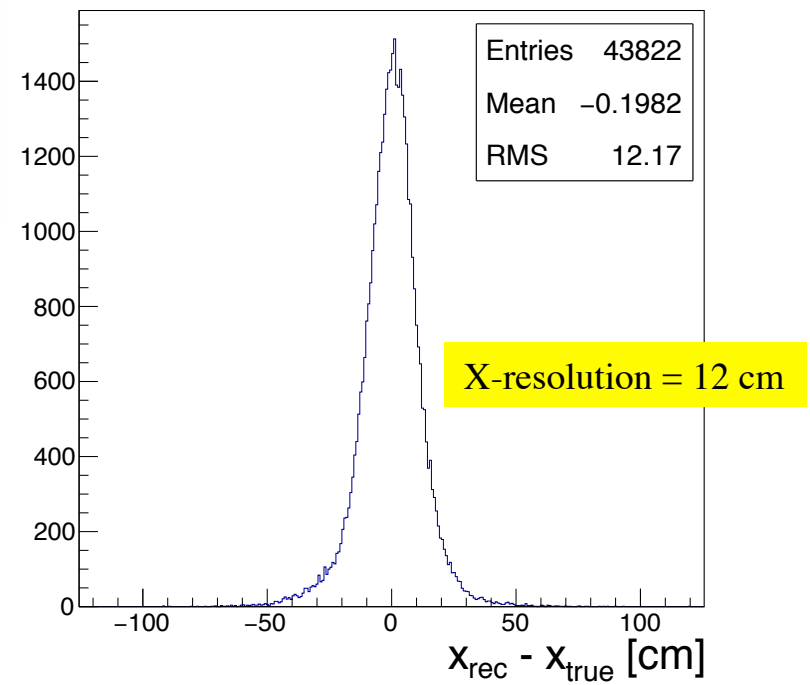


- Position resolution is extremely important for TPCs on the surface, as it is needed to reject cosmic tracks
- Position resolution in SBND is quite good (thanks to large number of PMTs)

- 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

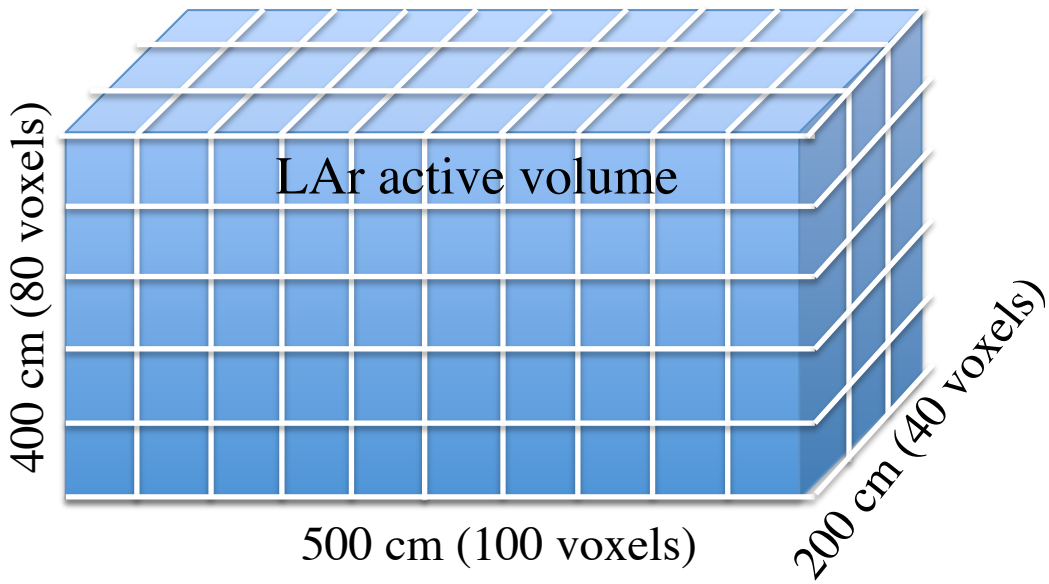
- SBND will play a crucial role in SBN program providing huge data sets of ν-Ar interactions

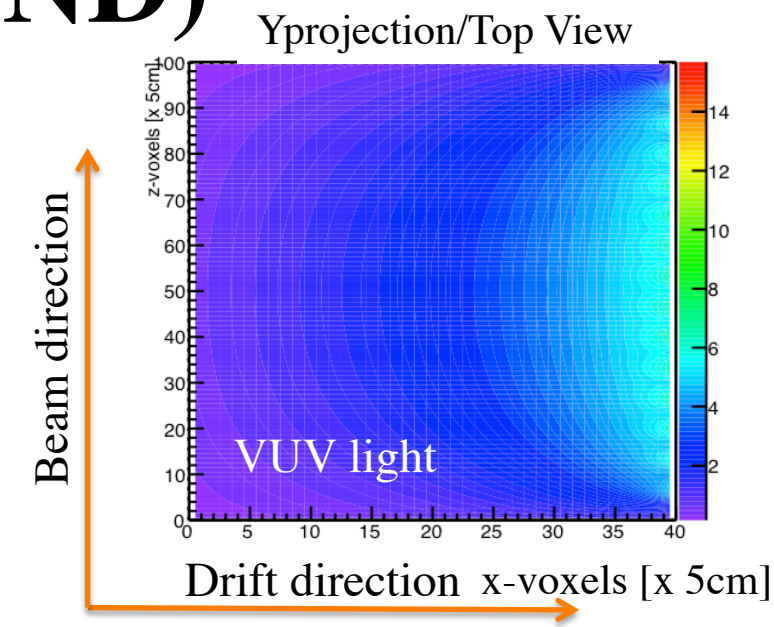
- Further develop the LArTPC technology and help to build the expertise of the global neutrino physics community working toward DUNE

- Installation of foils in SBND can provide important input into the design of the DUNE light collection system → Paper in preparation

Back-Up

Fast Lookup Library (for SBND)

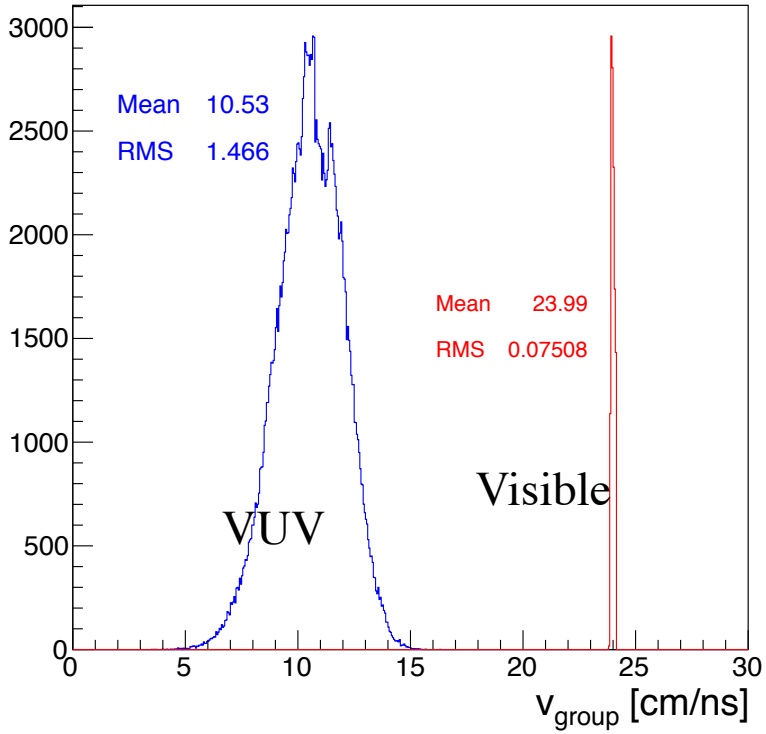




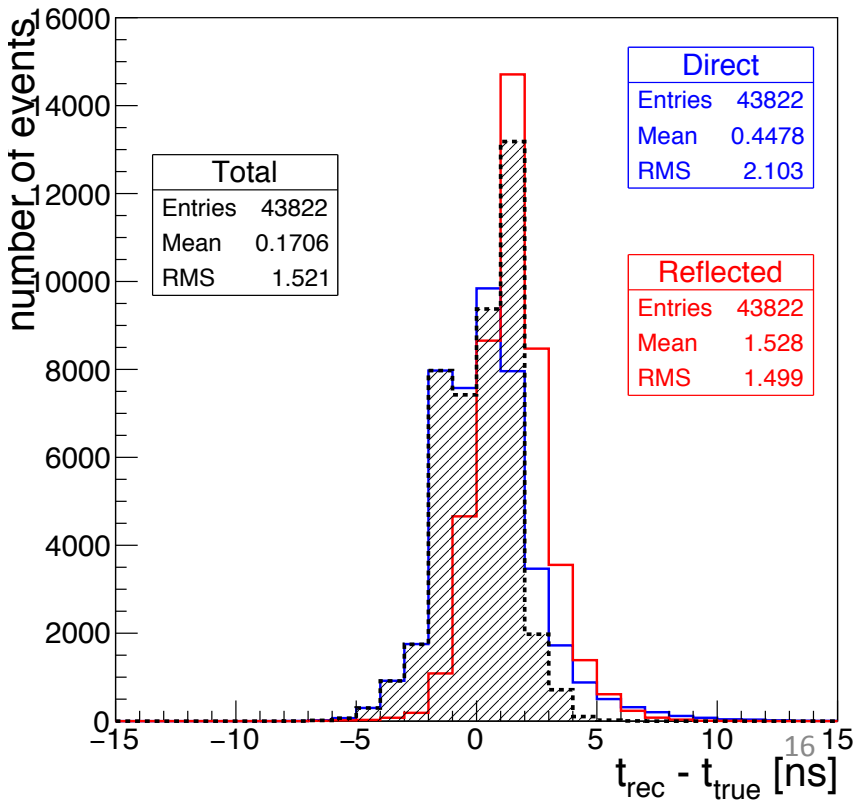
40 x 80 x 100 = 320000 voxels → 1 voxel = 5x5x5 cm^3
400000 photons/voxel

This means **128000000000 photons to be tracked**! (with Rayleigh scattering, reflections, absorptions, wavelength shifting) → a lot of CPU time and memory!

Timing

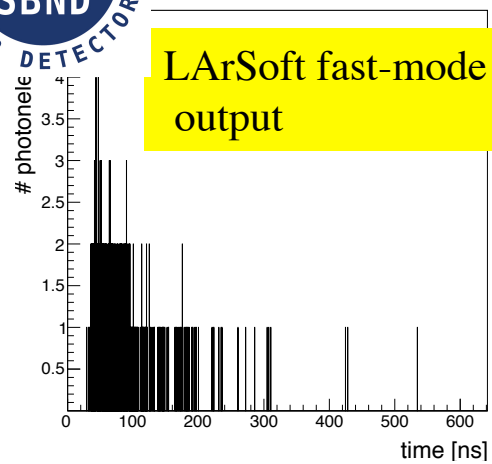


Visible light is faster (x 2.4) that VUV: improves resolution closer to cathode, where direct light does worst



Expected time resolution →
In this LDS visible light preserves the ns time resolution of the scintillation light in LAr

Saturation studies



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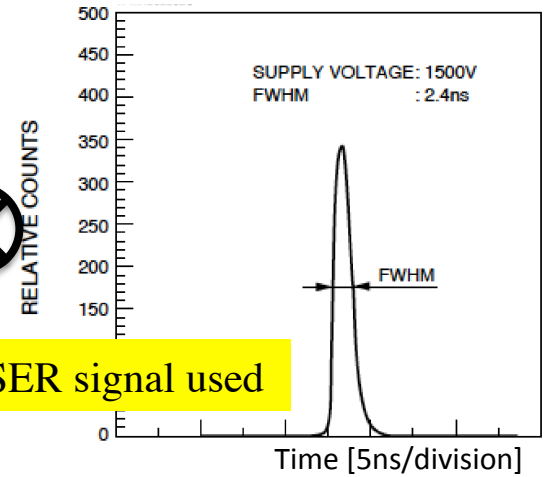

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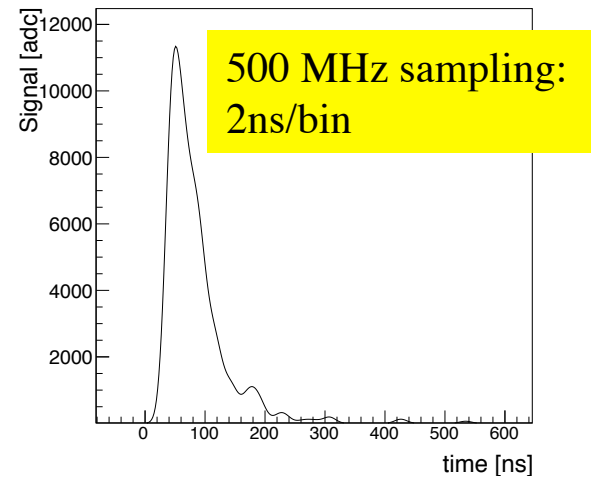
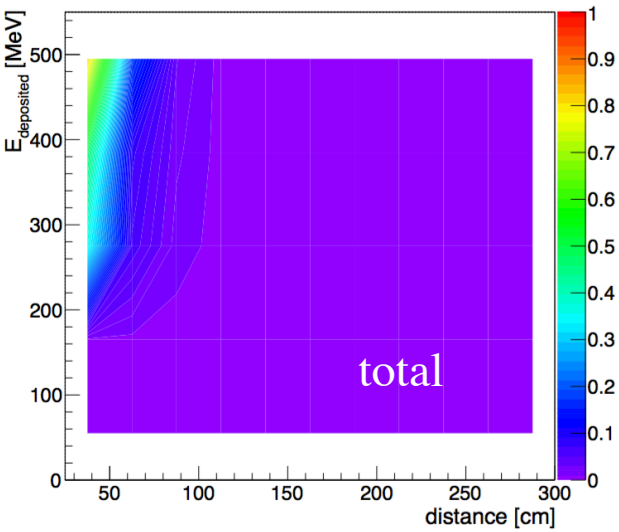
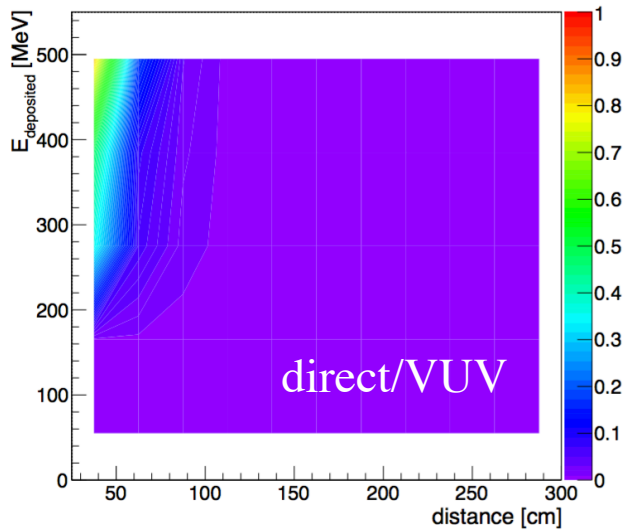
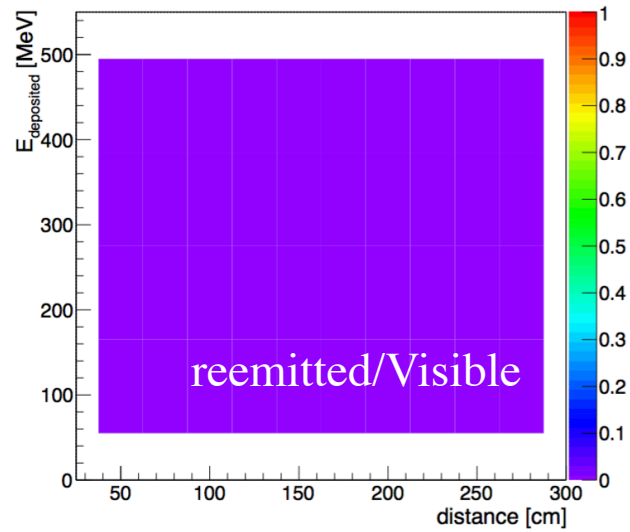








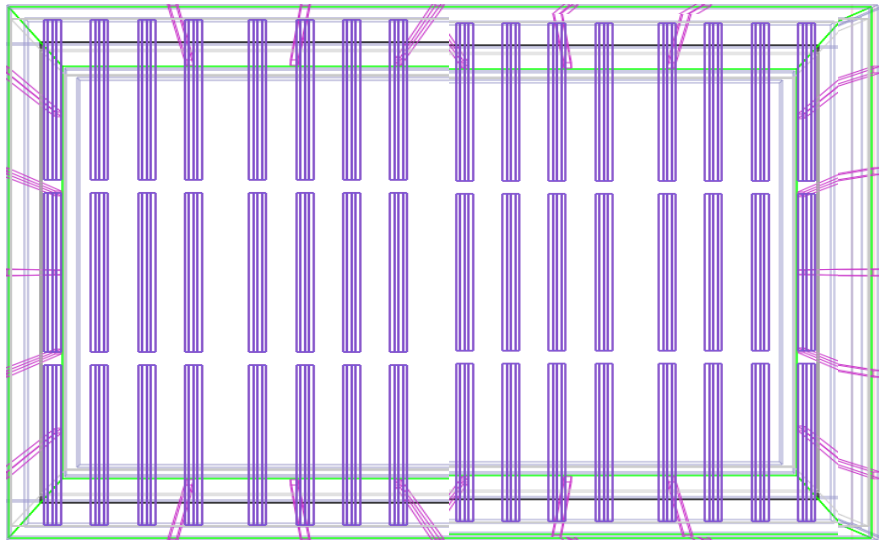
Saturation condition → 500 phe
With a 14-bit Digitizer → $2^{14} \approx 16K$
Signal/bin > 16K adc
→ (16K phe = 500phe x 32 adc/phe)

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 **5e-2 ph-e/VUV photon** at 0 mm from the end of the bar where the SiPMs are

photocathode configuration with the LGB



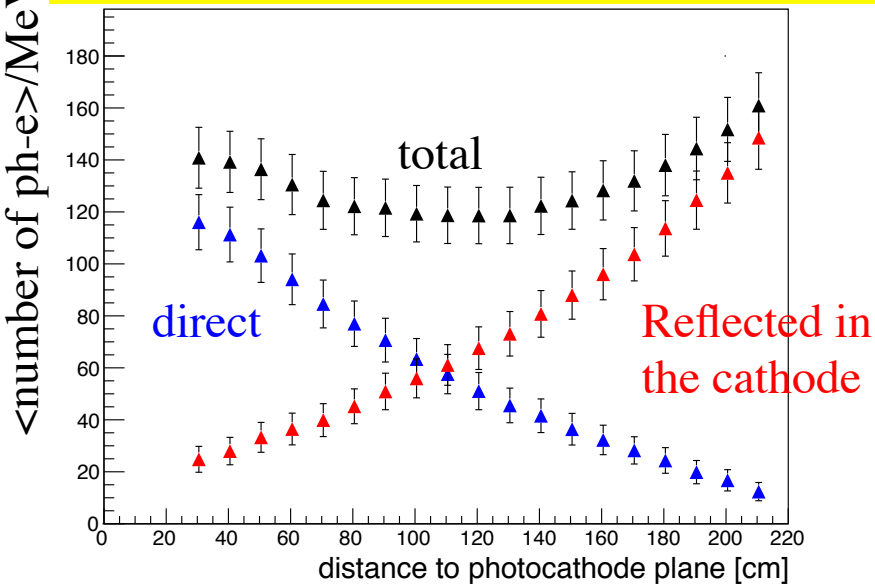
- Fits to data predict **attenuation lengths of 2 meters** for the proposed light guide bars
  arXiv:1604.03103 [physics.ins-det]

Finally:
Efficiency = 5e-2*exp(d / 2 m))

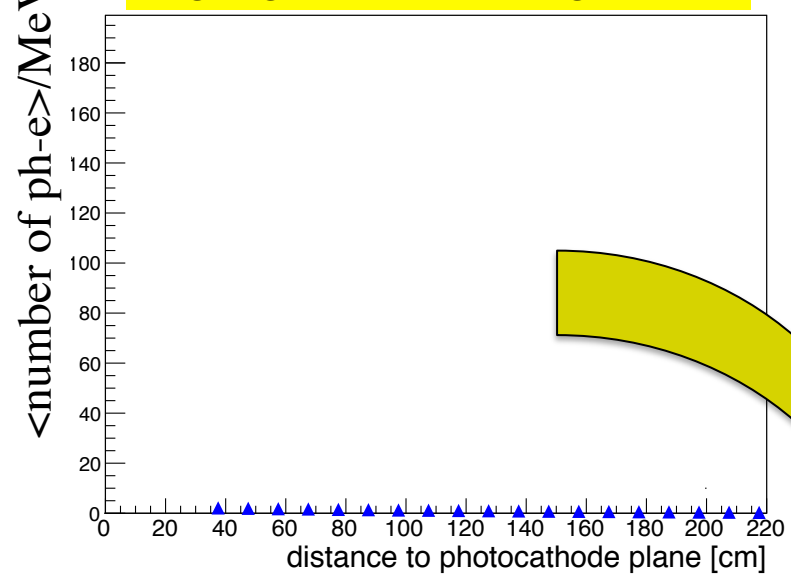
192 x 2 bars →
16 x APA window

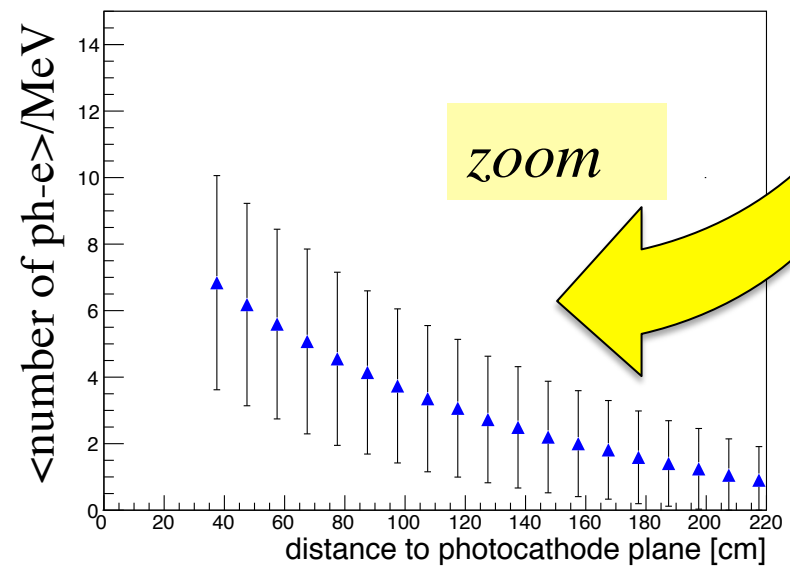
First results with the light-guide bars

TPB coated reflector foils on the cathode



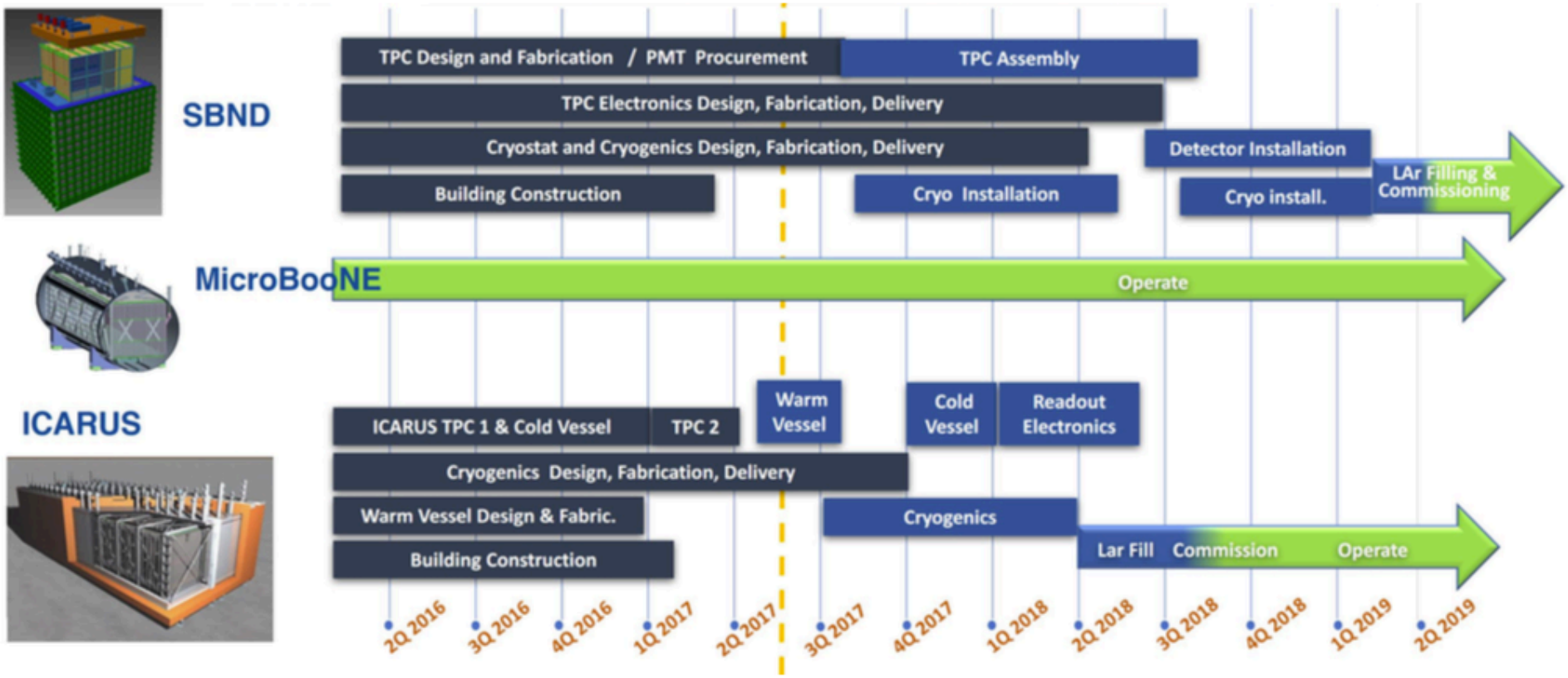
Light guide bars configuration





All scintillation points generated in the center of the photocathode plane: (y,z) = (0, 250 cm)

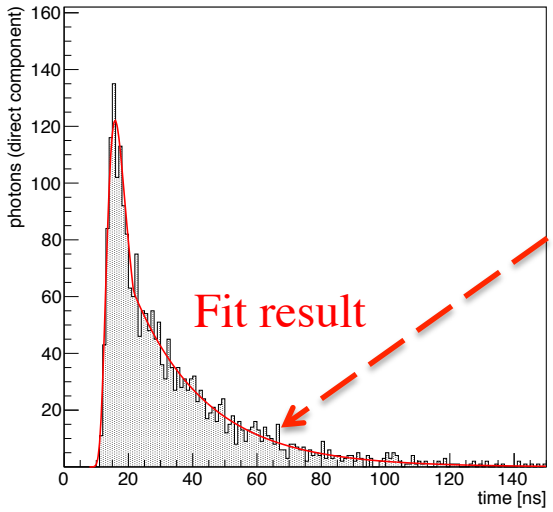
SBN schedule



Anne Schukraft (FNAL)
@ Fermilab Users Meeting 2017

Arrival time distributions

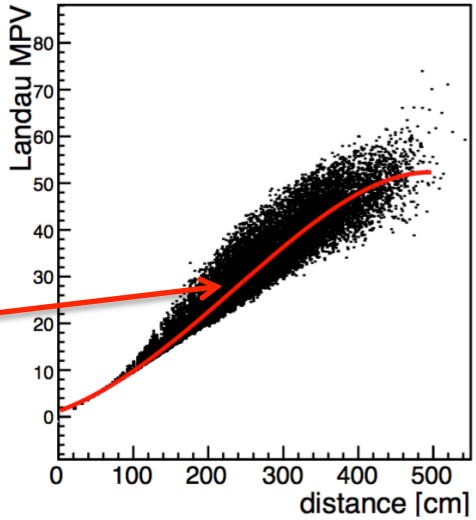
- In the optical simulations of SBND we have included the propagation time of the photons (typically ignored)
- We have parameterized the time distributions → resulted only from direct transport + Rayleigh scattering



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

Parameterization ready in LArSoft:

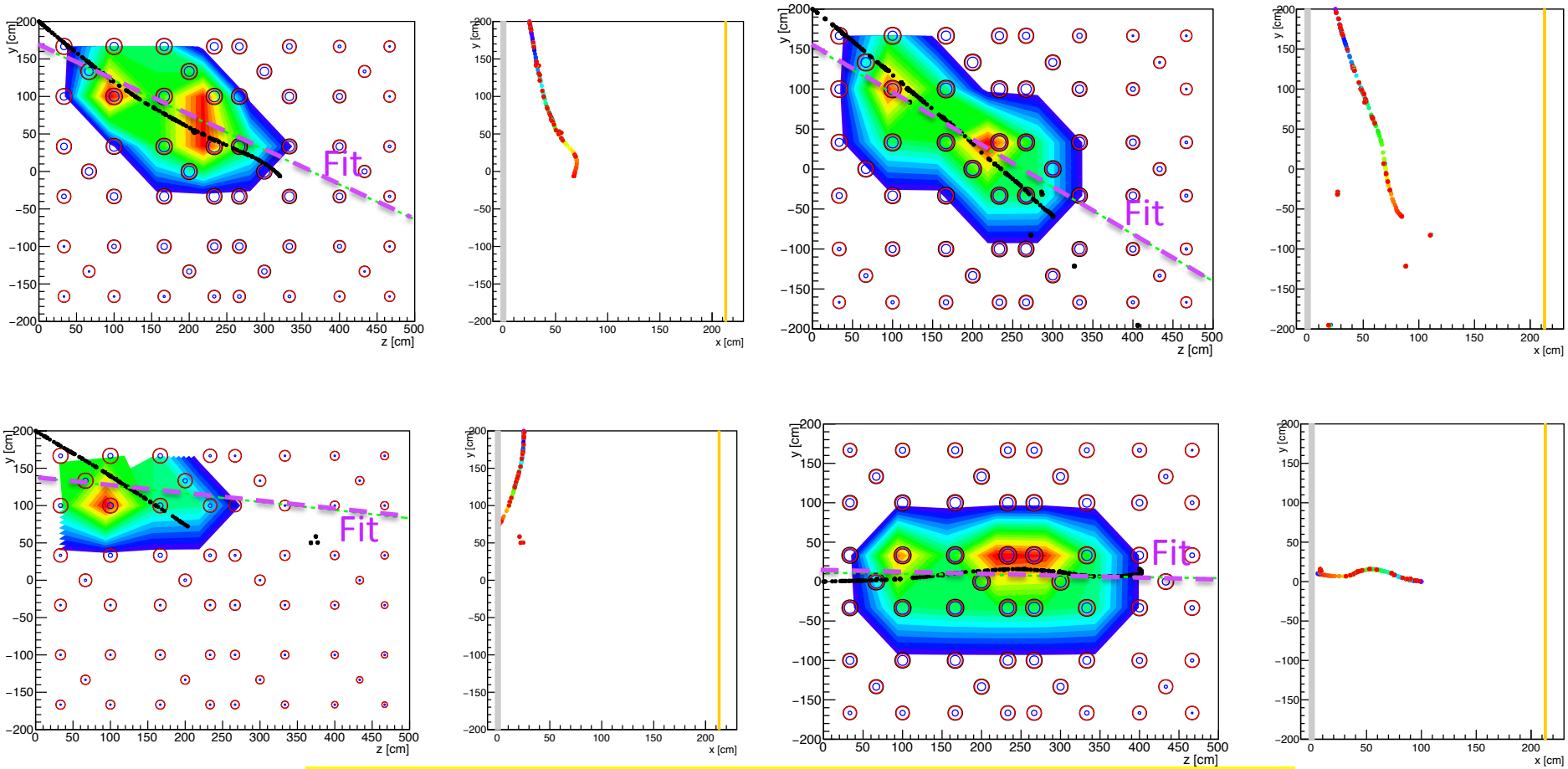
par0 = Landau normalization
par1 = Landau MPV
par2 = Landau width
par3 = Expo constant
par4 = Expo tau



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!