ANALYSIS OF THE LIGHT PRODUCTION AND PROPAGATION IN THE 4 TON DUAL-PHASE LAR DEMONSTRATOR

LIDINE,

LIght Detection In Noble Elements Conference Series

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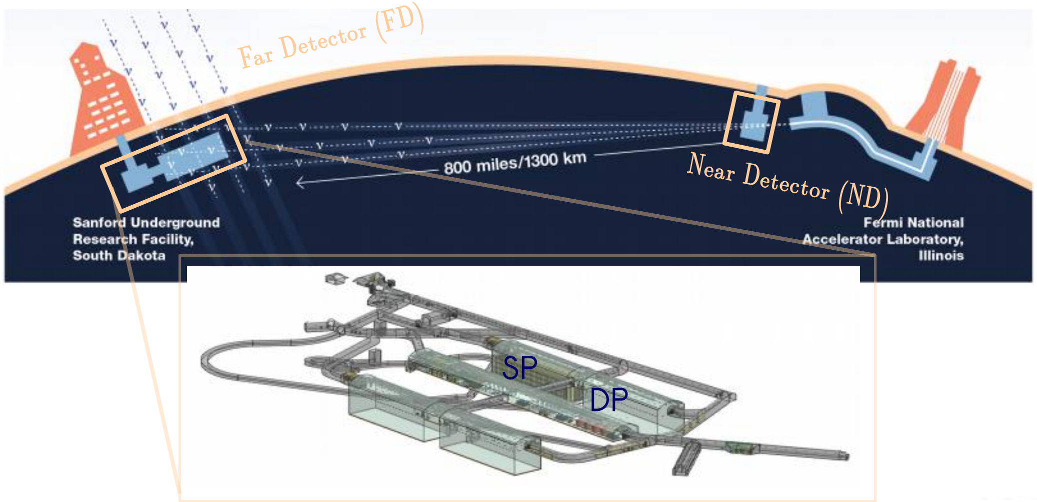
Motivation

- neutrino oscillation parameters, mass ordering, CP phase violation
- sensitivity to non beam searches (proton decay, supernovae events, etc..)



- 4x10kton LAr-TPC modules
- both SP and DP technologies are foreseen
- DP technology will allow
  - → 3D track reconstruction at high resolution
  - → sensitivity to low energetic events

Goal to demonstrate the feasibility of the technologies at such large scale is crucial!

Motivation

DP Approach

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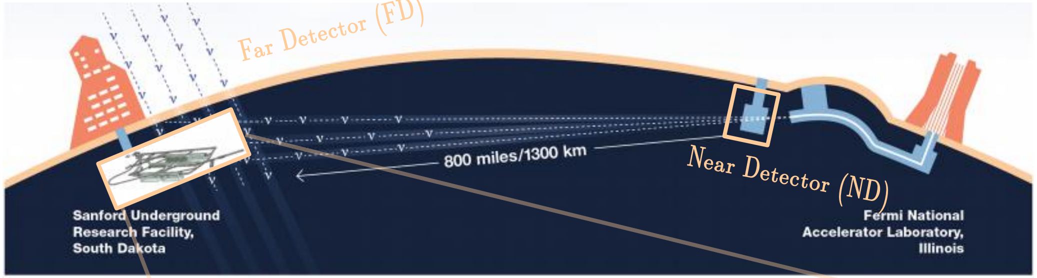
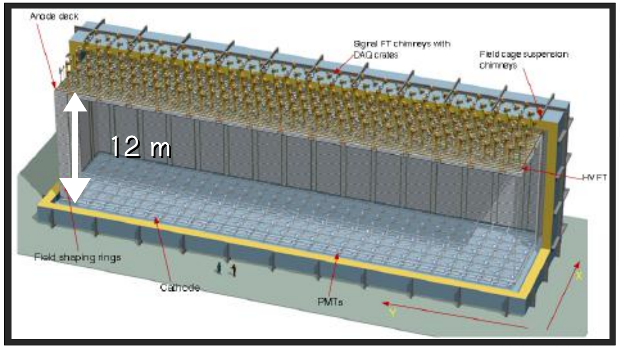
- sensitivity to non beam searches (proton decay, supernovae events, etc..)

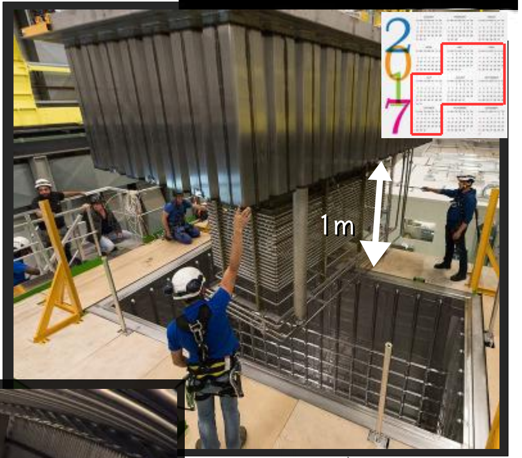


FD-DP module

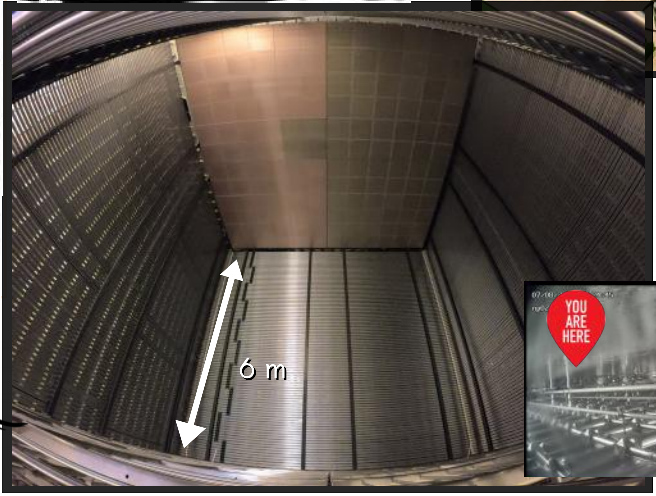


scale the technology using intermediate prototypes

4-ton demonstrator



ProtoDUNE-DP



See Laura Zambelli's talk on Thursday (15.15)

The 4 tonne demonstrator detector

- located at **CERN**
- exposed to **cosmic muons**
- data collection (stable conditions): **May-Nov. 2017**

Technological milestones

- extraction of ionization charge over $3m^2$ area
- amplification in pure Ar vapor by combining multiple 50×50 cm^2 LEMs units
- readout of the signal on two collection planes with strips (up to 3m length)

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Light detection system

five R5921-02Mod PMTs (8 inch) with different configurations:

- 2 TPB(*) coating (direct coating ○, TPB on PMMA plate ◎)
- 2 base configurations (positive ⊕ or negative ⊖ polarization)

Technological milestones

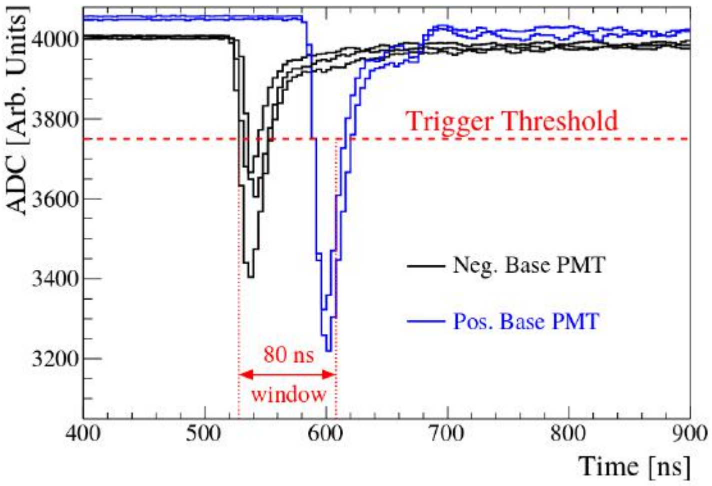
- extraction of ionization charge over $3m^2$ area
- amplification in pure Ar vapor by combining multiple 50×50 cm^2 LEMs units
- readout of the signal on two collection planes with strips (up to 3m length)
- detection of prompt and electro-luminescence light signals over 1m drift

(*)Tetraphenyl-butadiene

Trigger systems

PMT trigger (self trigger)

- 5 fold coincidence of prompt scintillation light signal over fixed threshold



Typical triggered event rate ~3 Hz (*~3*10⁶ of triggered ev.*)

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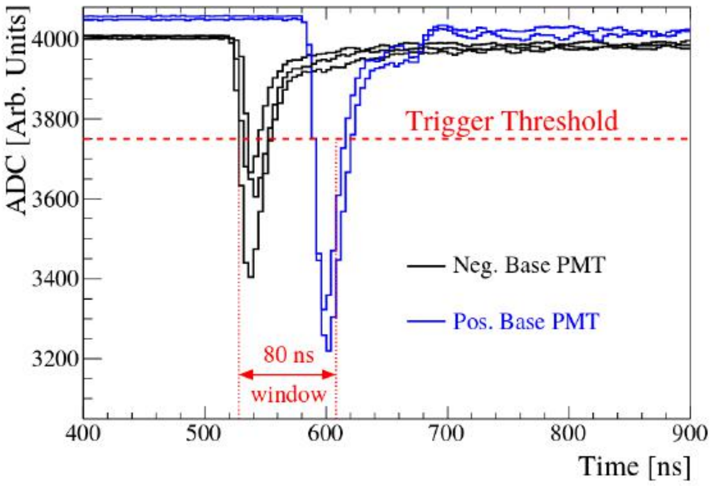

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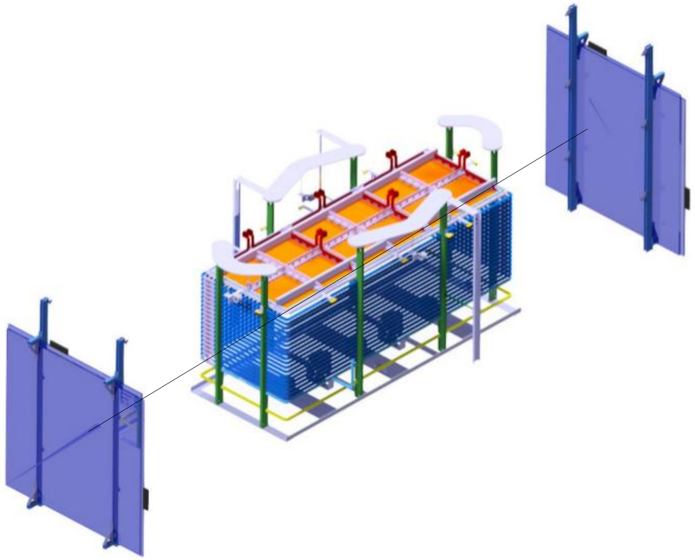
CRT trigger

- 4 modules of scintillators made by 16 strips each, 2 modules per side in such a way to create a matrix (1.8x1.8 m^2)
- **direct geometrical track reconstruction** for the triggered event, available also in absence of drift field

Typical triggered event rate ~ 0.3 Hz (*~7*10⁵ of triggered ev.*)



LAr response to energy lost by crossing particles

1. prompt **scintillation light** signal (S1)
   - t_0 time of the crossing particle
   - sensitive to detector conditions
     - → sensitive to drift field
     - → presence of impurities affects light signal (O_2, N_2)

2. **electro-luminescence light** signal (S2)
   - complementary information to 2D charge track trajectory
   - sensitive to detector conditions
     - → presence of impurities affecting e^- lifetime
     - → electron amplification in GAr
     - → space charge effect (SCE)

only μ-like events selected!

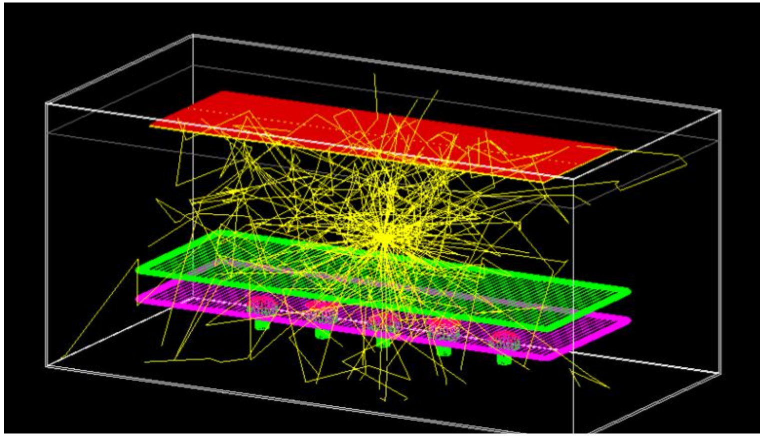
not available yet a complete understanding of light propagation in LAr

↓

combine data analysis with MC simulation is important

MC simulation

- data driven event generation
- light propagation using light maps in LAr and GAr
  - → different Rayleigh scattering length (20cm, 55cm , 163 cm)
  - → absorption length 30m
- PMT response simulation



MC simulation

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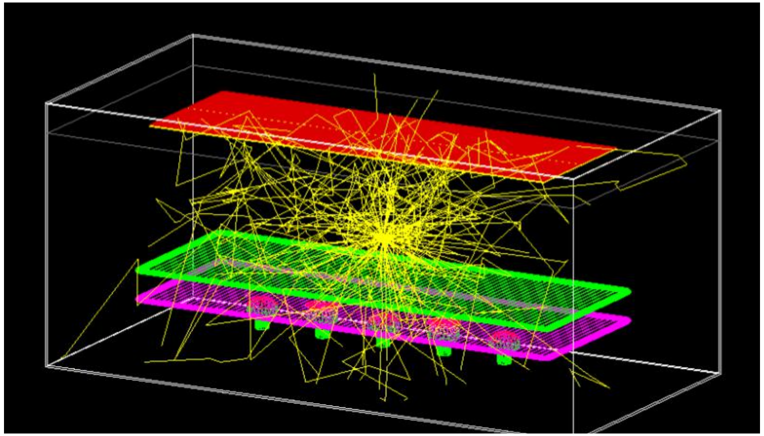
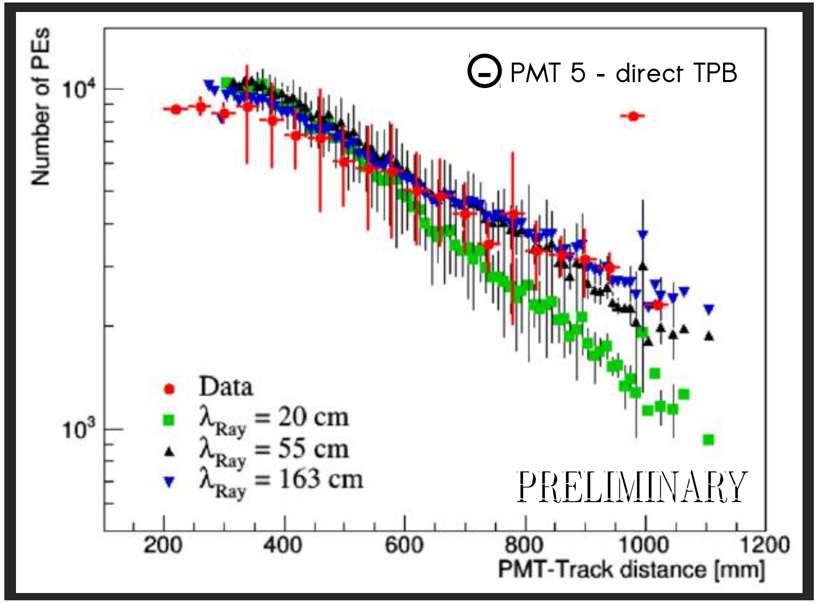


Rayleigh scattering length

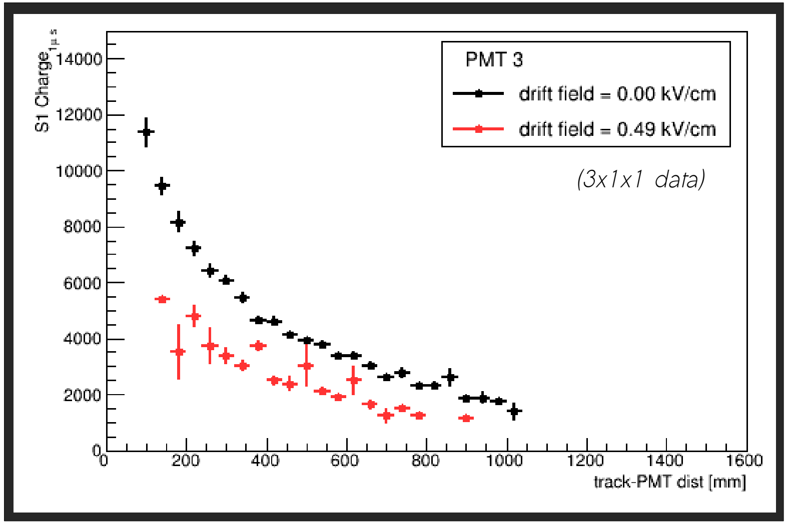
- data-MC comparison of **different Rayleigh scattering length** values 20cm, 55cm, 163cm (λ_{abs} = 30 m)

found **better agreement** for a Rayleigh scattering length **between λ_{Ray} = 55cm and λ_{Ray} = 163cm**



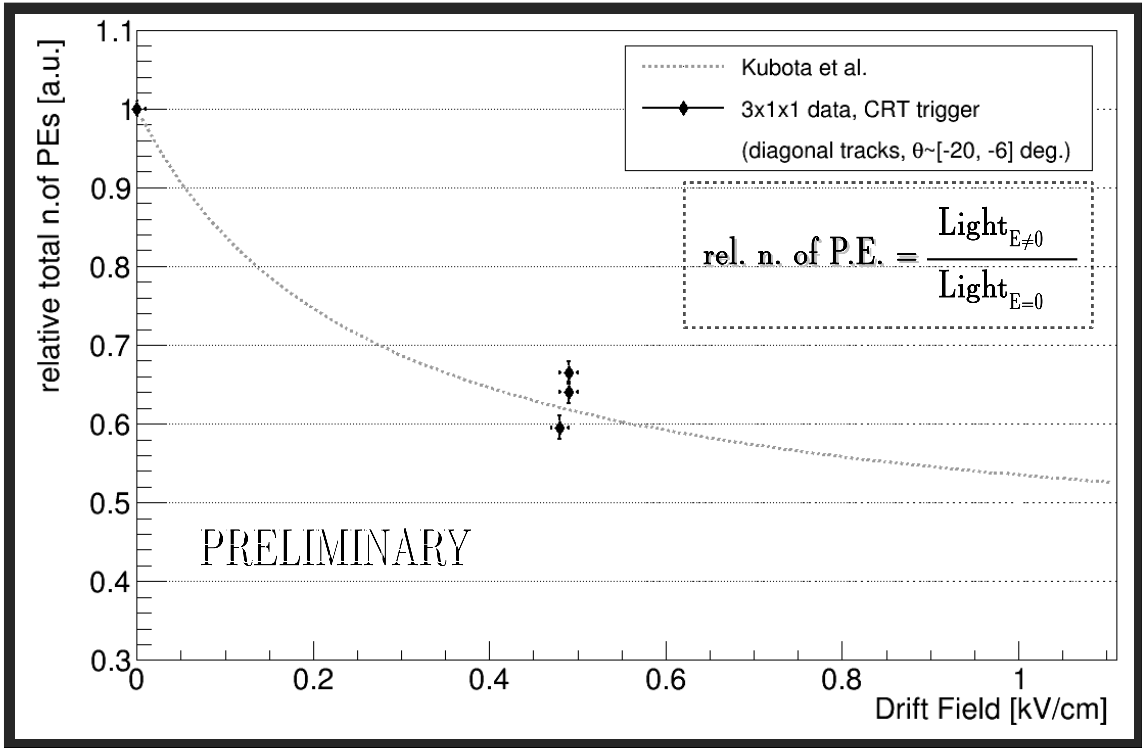
LAr recombination factor

- relative n. of P.E. has been calculated at different drift field values for each PMT



good agreement among the five PMTs

(agreement within 3%)

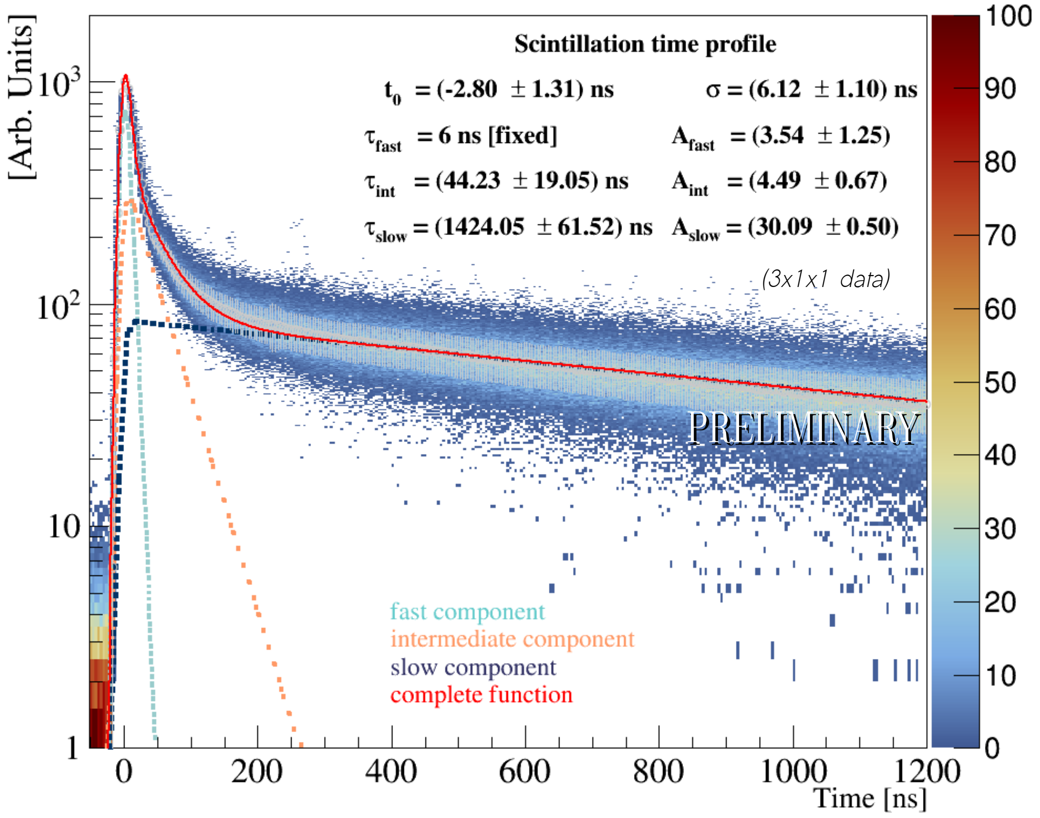


$$\text{rel. n. of P.E.} = \frac{\text{Light}_{E\neq 0}}{\text{Light}_{E=0}}$$

References: S. Kubota et al., Phys. Rev., vol. B20, pp. 3486-3496, 1979

at least ~40% of recombination contribution to the tot. scintillation light for drift field = 0.5 kV/cm

Scintillation light (S1 signal)



three exponentials contributions are needed

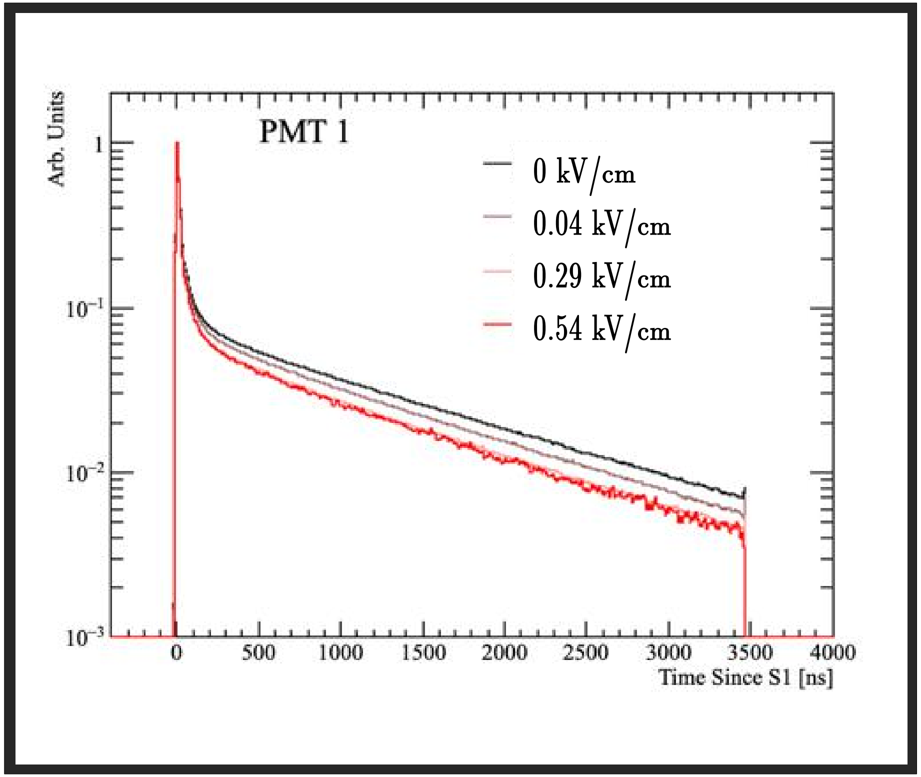
$$G(t-t_0, \sigma) \otimes \sum_i (A_i/\tau_i)^* \exp(-(t-t_0)/\tau_i)$$

- model the **detector response** to the triggered particles (**gaussian function**)
- **fast** and **slow** components fitted by two exponentials
- an **intermediate exponential** to improve the fit in the **fast/slow transition region**
- Ai, **relative amplitudes** → ΣiAi = integral of the average waveform

intermediate component is not expected from Ar atoms de-excitation theoretical description, but is measured by all LAr-TPC experiments (different hypothesis are proposed for its origin)

References:
E. Segreto, arXiv:1411.4524v2, R. Acciarri er al, JINST 5 P06003

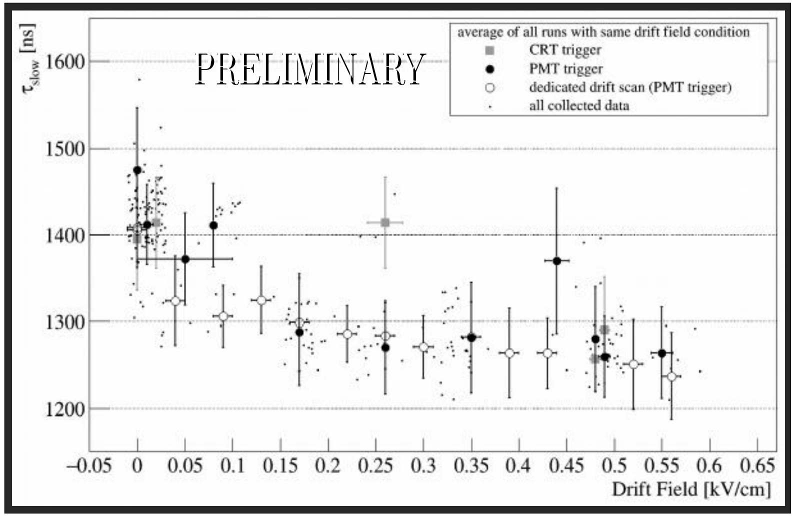
Effect of the drift field on the scintillation time profile



dedicated drift field scan and a lot of runs have been taken in different drift field conditions

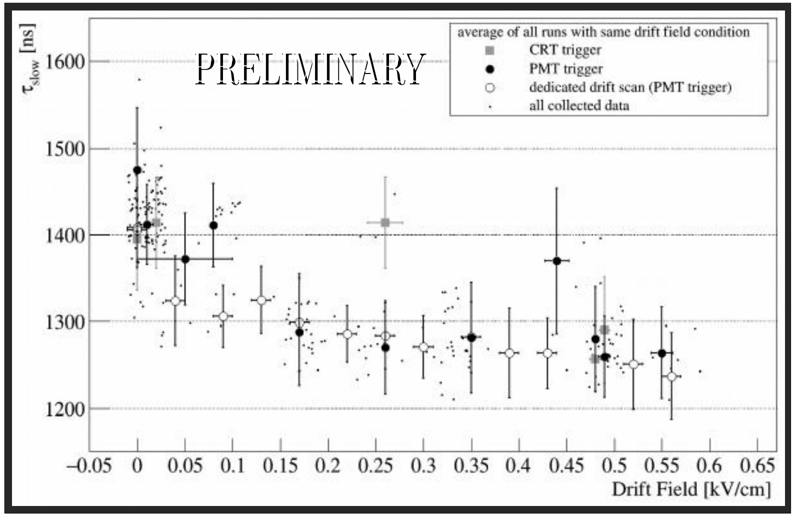
- evident difference in PMT waveform shape
- detailed analysis of the scintillation time profile signal

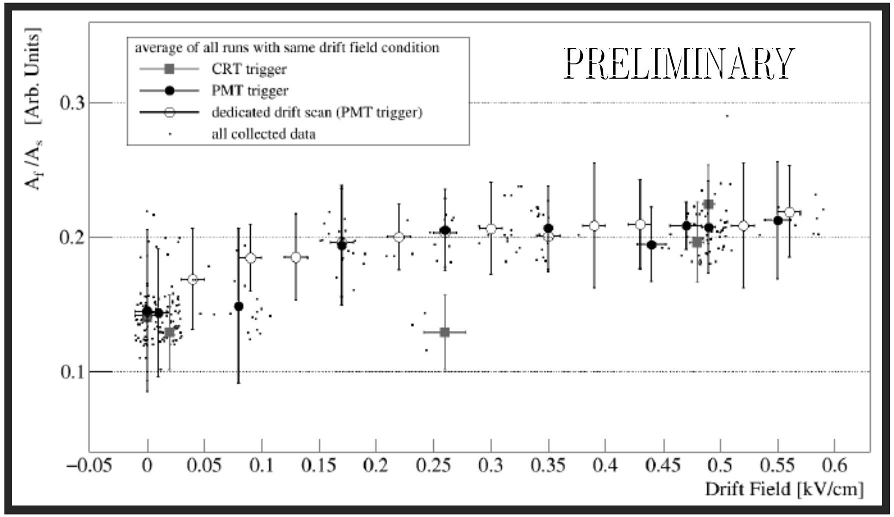
Effect of the drift field on the scintillation time profile



- decreasing of the τ_{slow} due to the increasing of the drift field

Effect of the drift field on the scintillation time profile





References:
S. Kubota et al., J. Phys. C : Solid State Phys., Vol. 11, 1978
R. Acciarri er al, JINST 5 P06003

- decreasing of the τ_{slow} due to the increasing of the drift field
- fast over the slow ratio (Af/As) increases with the drift field

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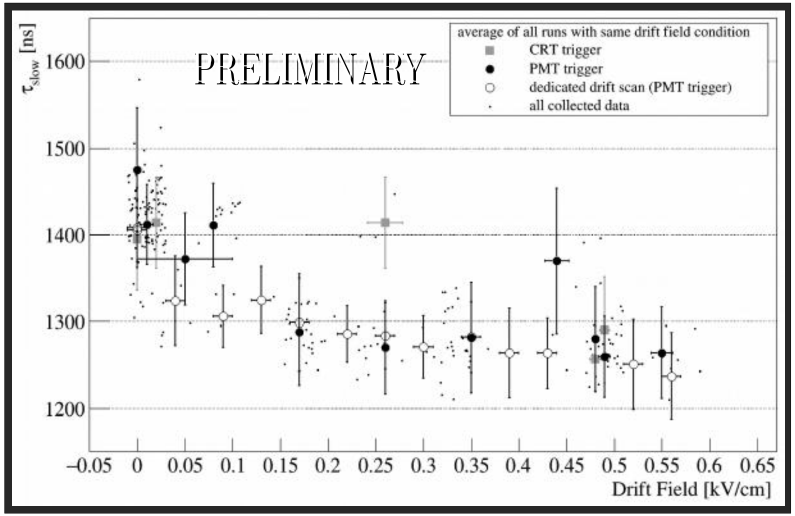

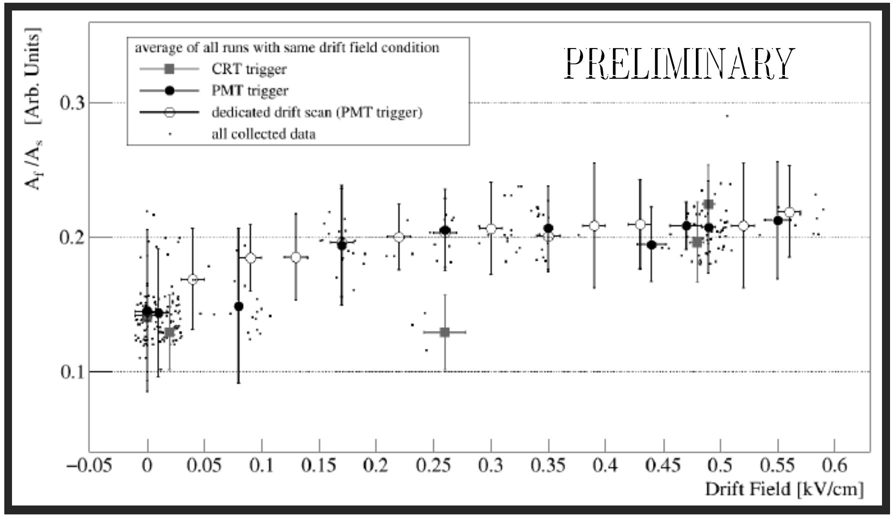

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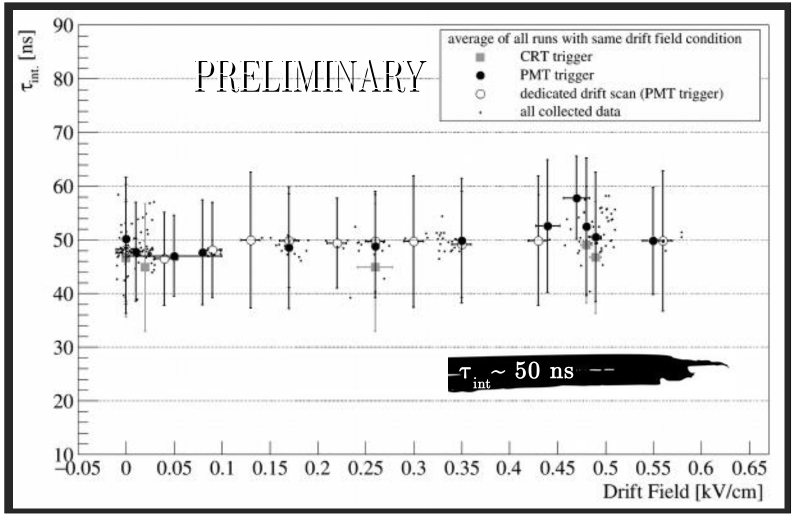
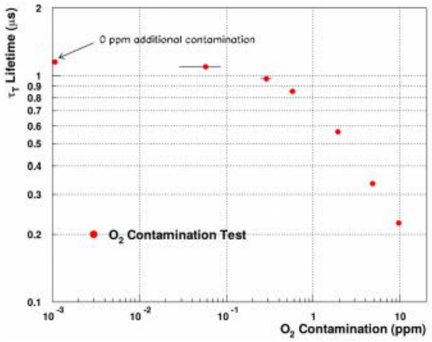


- decreasing of the τ_{slow} due to the increasing of the drift field
- increasing of Af/As with the drift field
- no clear dependence of τ_{int} with the drift field or the trigger system

Monitoring of LAr purity

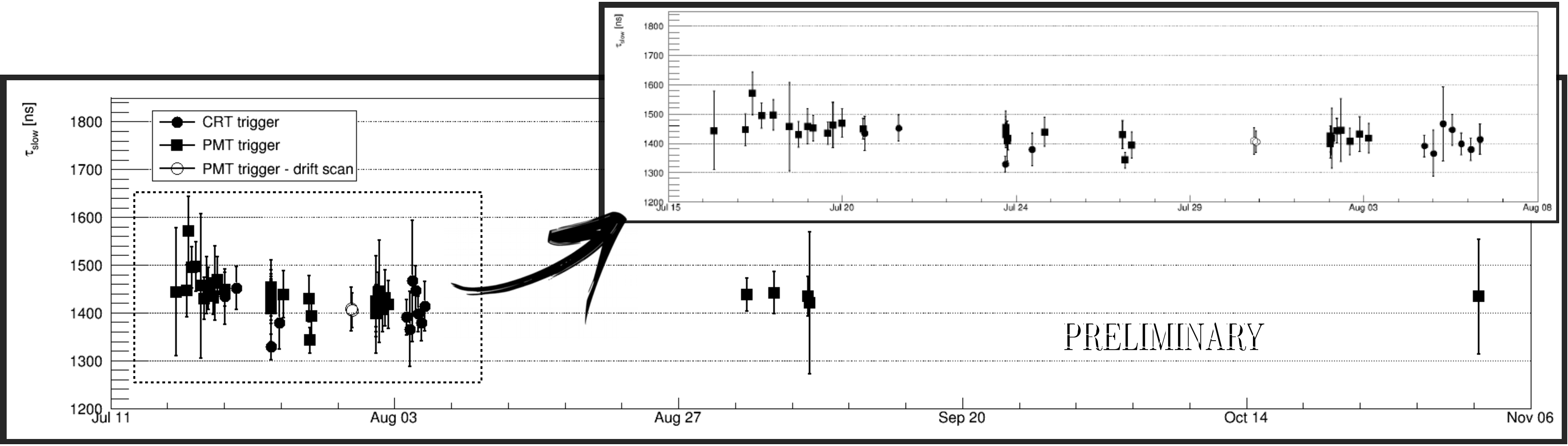
References:
R. Acciari et al., JINST 5 P05003
doi:https://doi.org/10.1016/j.nima.2009.03.142
B. Aimard et al., arXiv:1806.03317



decreasing of the LAr purity can be detected monitoring τ_{slow} (being the lifetime of triplet state sensitive to LAr purity)

- in the 4-ton demonstrator τ_{slow} almost constant during all the data taking

very small amount of O_2 and N_2 impurities from the beginning



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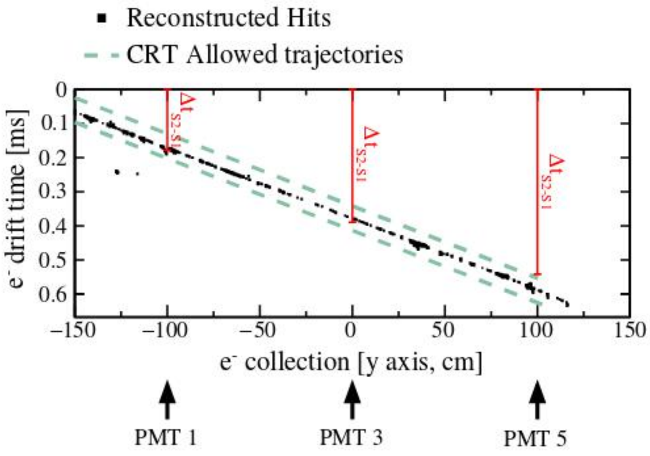
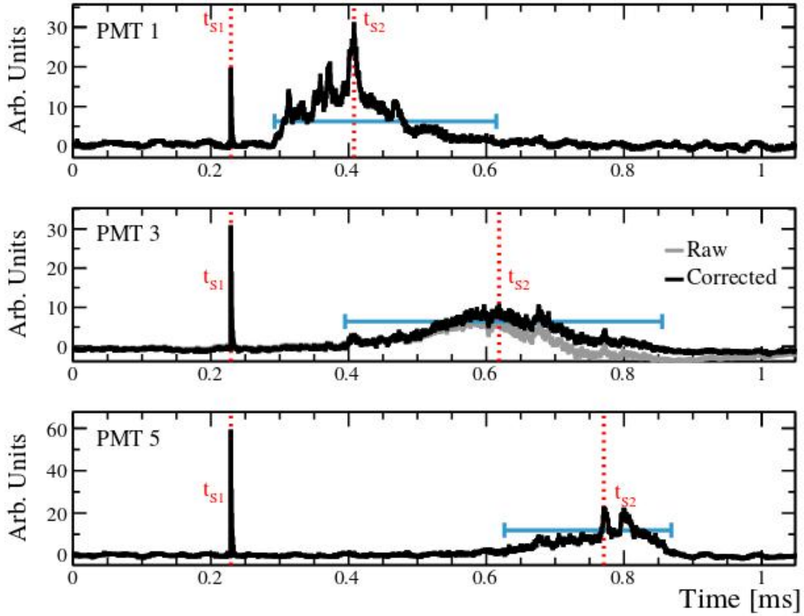


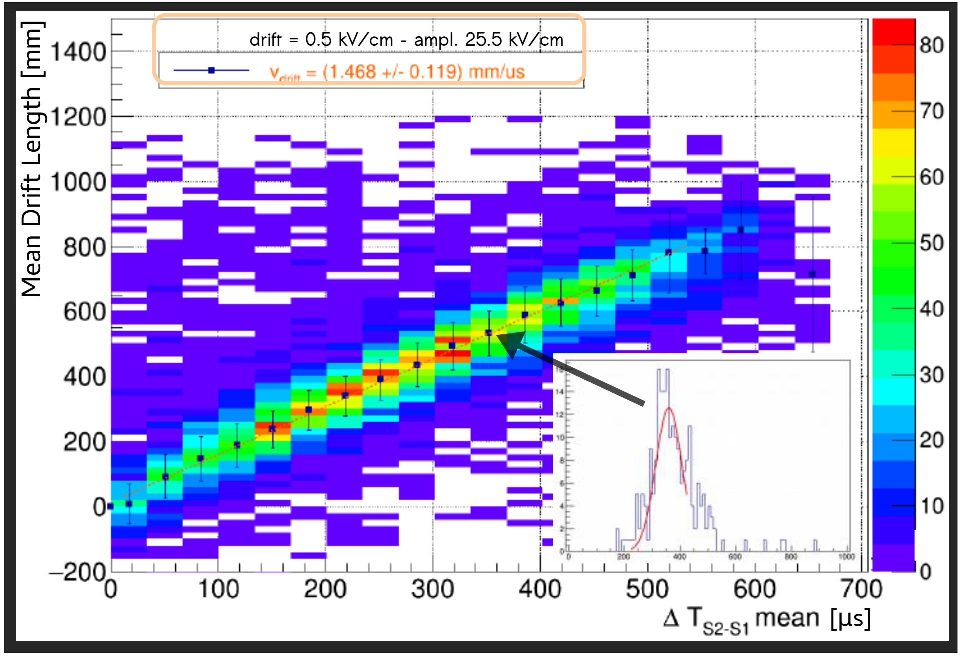


- **dedicated algorithm developed for S2 light signal reconstruction**
  - → S2 **time**, time distance ΔT_{S2-S1} between S2 and S1 peaks and S2 **duration** (related with track topology)
  - → integrated S2 **charge**

Electron drift velocity

- global measurement combining results of the 5 PMTs
  - → gaussian fit to the drift length distribution on each $\Delta T_{S2\text{-}S1}$ slice of 25µs (error bar from fit results)

$$v_{drift} = (1.468 +/- 0.119)\ mm/\mu s$$



- **data**/MC comparison is still **ongoing** but will improve the understanding of not well known parameters that describes light **production** and **propagation** through/from GAr phase:
  - → e.g.: sensitivity to the **electro-luminescence gain** (G_{el}, n. of γ produced per e^- extracted in GAr phase)

Conclusions and prospects

- 4-tonne demonstrator was the first DP LAr-TPC at that scale
- light analysis of these **data** provided the investigation the LAr response to crossing muons in different detector conditions
  - → monitor the **LAr purity**
  - → measure the **intermediate component**
  - → investigate the **effect of the drift field**
- combination of data analysis with **MC simulation** helped/will improve the study of light propagation in LAr and production in GAr
- a **paper** is in preparation and light data analysis of **ProtoDUNE-DP** will come soon ***...stay tuned!***

thanks for your attention!