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# Proof of concept for a scintillator powder calorimeter

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# Outline

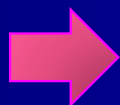
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- ★ The LiquidO detection technique
- ★ Powder calorimeter
- ★ The proof of concept
  - Simulation results
  - Experimental results
- ★ Future work

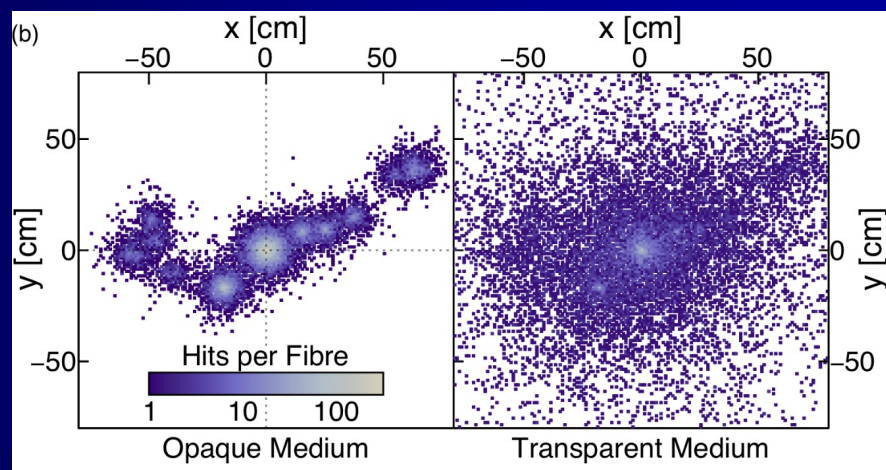
# The LiquidO technology

LiquidO is a new detection technique making use of opaque liquid scintillator read-out by means of WLS fibers

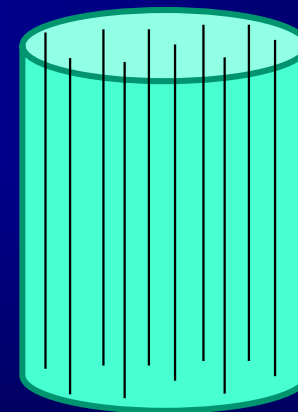
Opaque detection medium



Stochastic light confinement



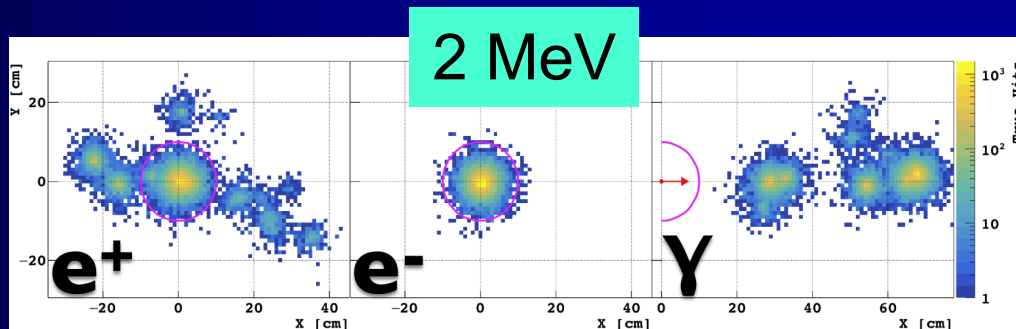
LiquidO concept:  
TPC-like detector with  
« light drifting »



# The LiquidO technology

LiquidO is a new detection technique making use of opaque liquid scintillator read-out by means of WLS fibers

Excellent PID is expected



Possible application for:

- Neutrino physics
- Medical imaging
- High energy physics
- ...

A. Cabrera et al. LiquidO First Publication [arXiv1908.02859]  
C. Buck et al. LiquidO First Opaque Scintillator [arXiv:1908.03334]  
S. Wagner et al. Micro-Crystal Opaque Scintillators [arXiv:1807.00628]

# Detectors for e+e- colliders

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For future e+e- colliders: EM calorimeters based on sampling technique  
(CALICE, Dual Read-out Calorimeter)

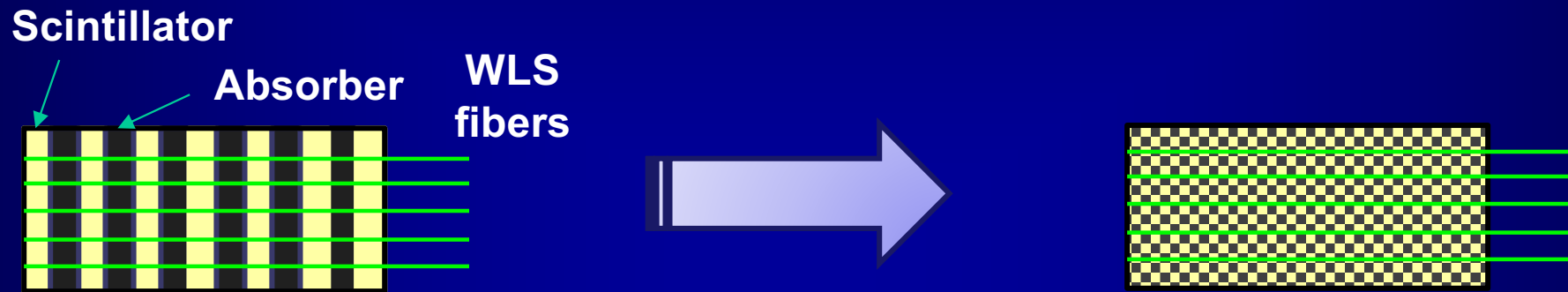
- Good granularity at limited cost 😊
- Rather poor photon energy resolution 😞
  - ↳ at small energies:  $R \sim 10\%/\sqrt{E}$

**Proof of concept for a next-generation  
calorimeter with extremely fine sampling:  
PowderO**

→ For improved photon energy resolution while  
maintaining a good jet energy resolution

# The PowderO concept

## Scintillator powder calorimeter



**Shashlyk Calorimeter: alternate layers of scintillators and absorbers**

- High granularity
- Modest energy resolution

**PowderO: mix of scintillator and absorber grains in the same volume**

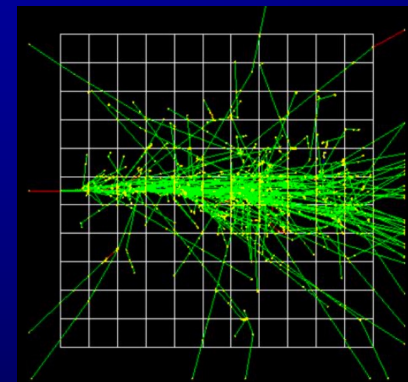
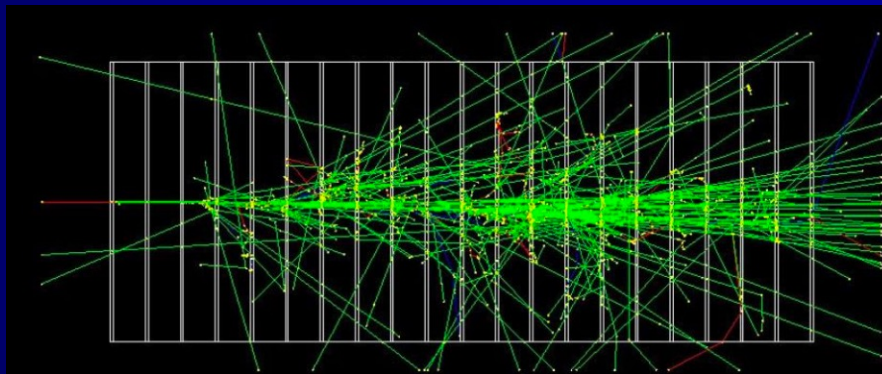
- High granularity
- Good energy resolution

**Proof of concept: simulation and experiment**

# Simulation for 1 GeV photons

Geant4 MC simulation: shower produced by a 1 GeV photon in a conventional Shashlyk and in a PowderO calorimeter

- **Shashlyk:** alternate plates of Pb and CH  
Same geometry as LHCb:  $150 \times 150 \times 2$  mm<sup>3</sup> plates
  - **PowderO:** ZnWO<sub>4</sub> grains + CH<sub>2</sub>I<sub>2</sub> distributed with two different geometries
    - Alternating cubes
    - Randomly distributed cubes
- } 2 and 3 mm-side cubes  
150×150 mm<sup>2</sup> lateral dimension

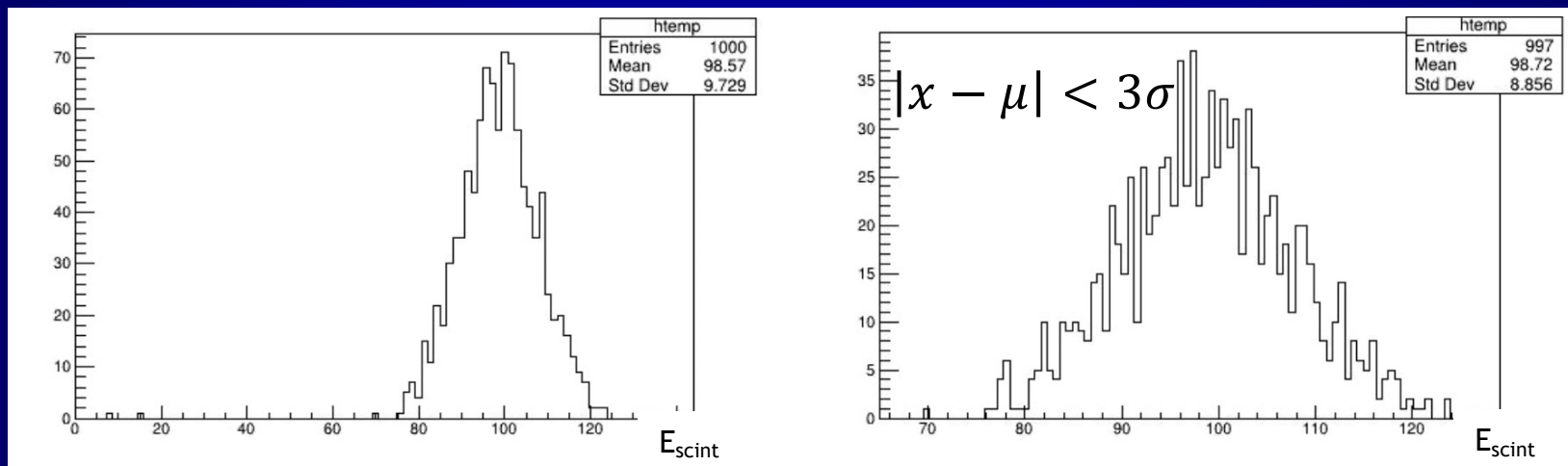


Total length: 25 X<sub>0</sub> in the absorber material (127 in Pb and 201 in CH<sub>2</sub>I<sub>2</sub>)

# Simulation results

- Total energy deposit in the absorber:  $E_{abs}$
- Total energy deposit in the scintillator:  $E_{scint}$

Energy deposit in the scintillator



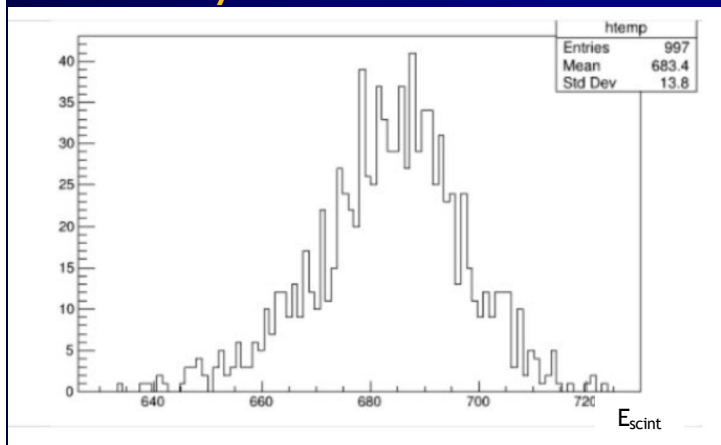
Shashlik calorimeter:  $\frac{\Delta E}{E} \approx 8.9\%$



# Simulation results

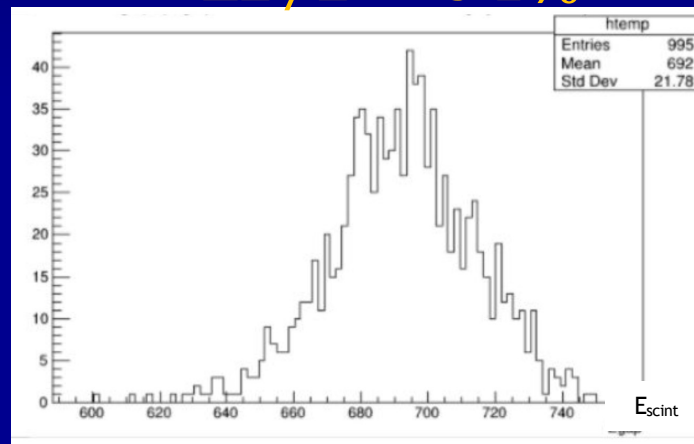
Alternating cubes, 2mm:

$$\Delta E/E \approx 2.0\%$$



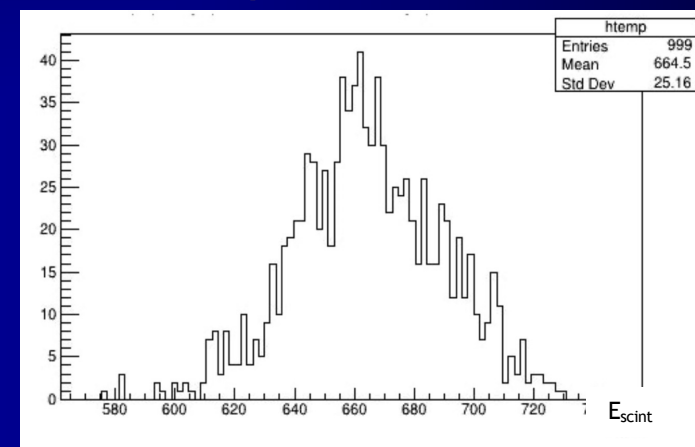
Random cubes, 2mm:

$$\Delta E/E \approx 3.1\%$$



Random cubes, 3mm:

$$\Delta E/E \approx 3.7\%$$

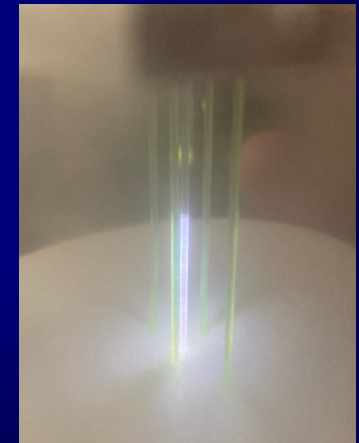
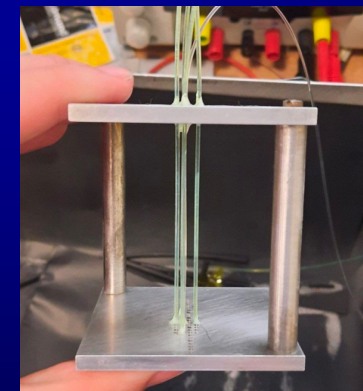
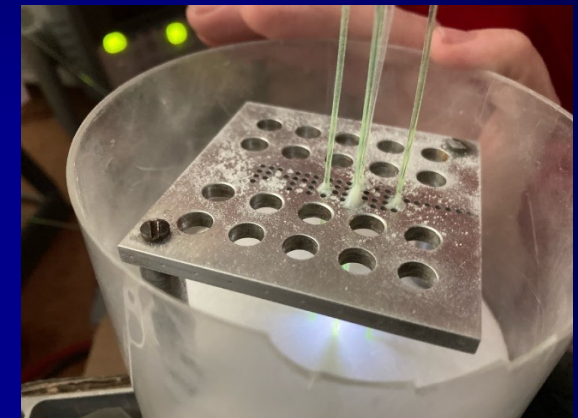
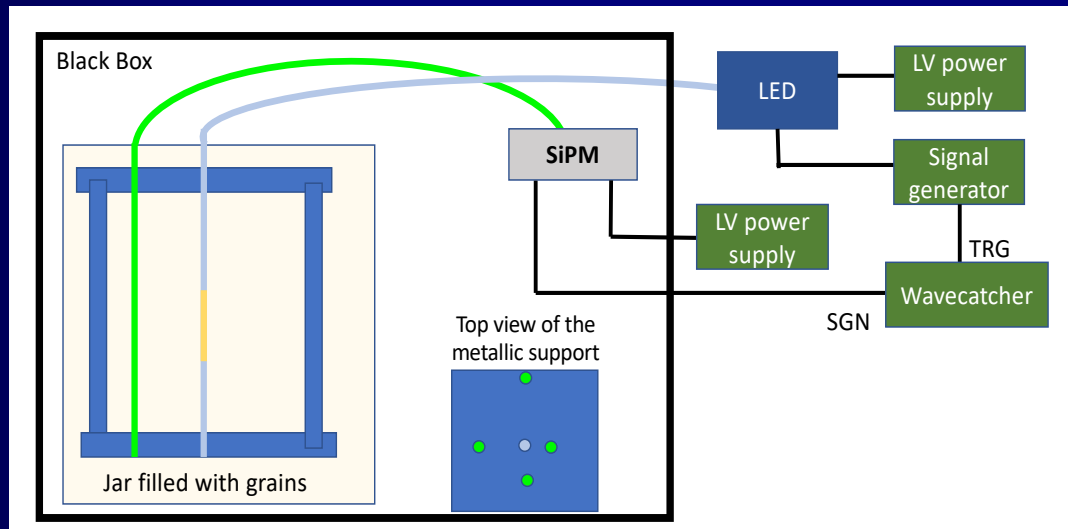


$\Delta E/E$  scales as the sqrt of the cubes linear dimension:

$$\frac{3.7\%}{3.1\%} = 1.2 \sim \sqrt{\frac{3}{2}}$$

→ expected 1.5% energy resolution for 0.5 mm cubes

# The experimental set-up



- WaveCatcher digitizer @ 3.2GS/s
- 60-cm long Saint Gobain BCF9929A WLS fiber
- Blue LED
- Clear fiber unpolished on 2 cm

# The experimental set-up

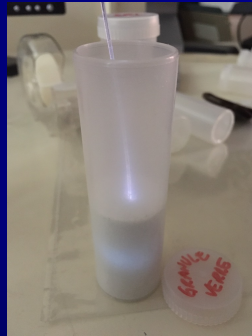
For the proof of principle we used kitchen salt

Injection of the light with a clear fiber and comparison of the signals acquired by the WFS fibers located and increasing distance from the light injection, in three different conditions:

- In air
- In salt (grain size  $\sim 0.5$  mm)
- In salt + isopropanol



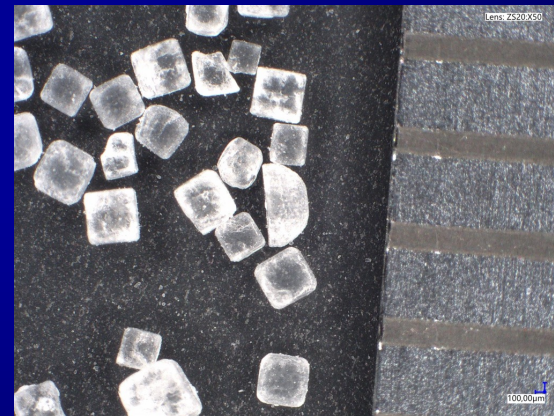
Salt



Glass grains

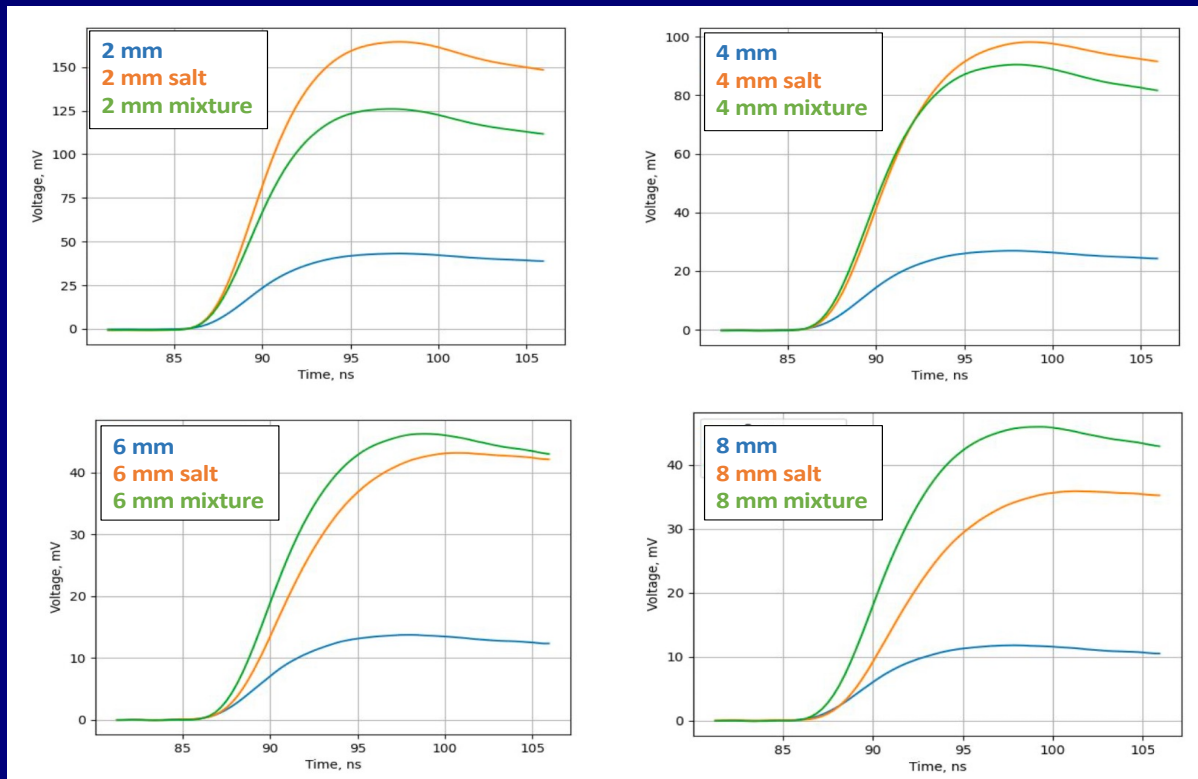


Glass spheres



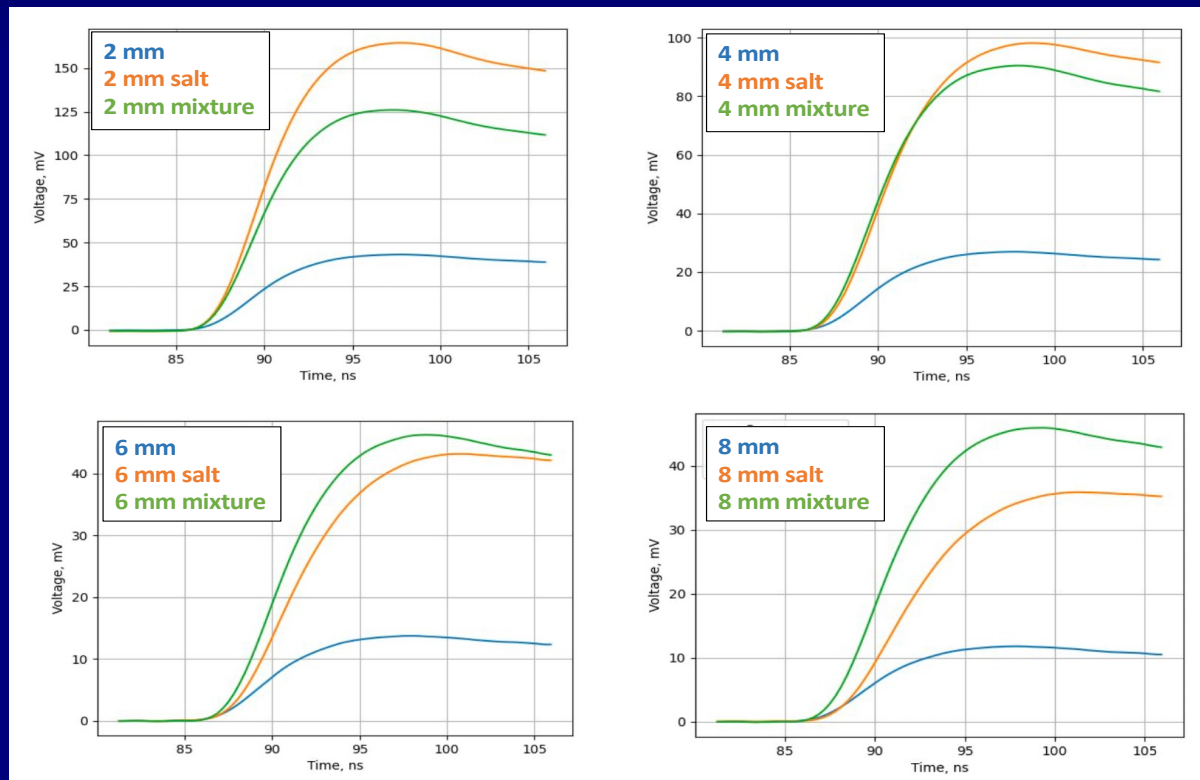
For each configuration we acquired 10k signals and we estimated the mean WF

# Results



1. With salt we collect more light than in air

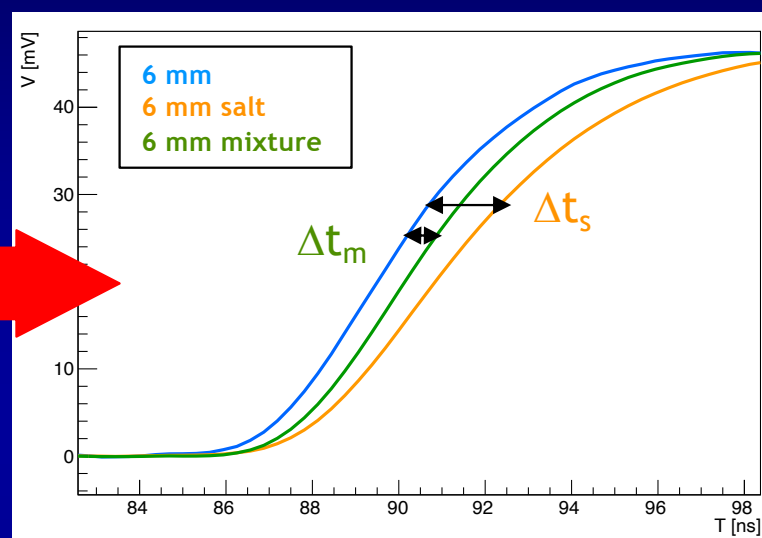
# Results



2. If we add isopropanol to salt, the signal amplitude decreases next to the light injection but increases at 6 and 8 mm from it

# Results

Linear fit on the rising edge  
and estimate of  $t$  @ peak/2



3. The time difference between the signals acquired in air and salt is always bigger than the time difference in air and salt+isopropanol  
→ with isopropanol there is less light scattering  
→ the light has to travel less to be collected on the WLS fiber

At 6 mm:  $\Delta t_s \sim 1.4 \text{ ns} \rightarrow \Delta l_s \sim 28 \text{ cm}$   
 $\Delta t_m \sim 0.6 \text{ ns} \rightarrow \Delta l_m \sim 12 \text{ cm}$

# Conclusion and future work

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## We demonstrated the feasibility of PowderO

- Geant4 shower simulation predicts an energy resolution of about  $1.5\%/\sqrt{E}$  for 0.5 mm size  $\text{ZnWO}_4$  grains +  $\text{CH}_2\text{I}_2$
- Powder (kitchen salt) = Light confinement
- Mix = Powder + liquid (isopropanol) = higher total density and better optical coupling
- From salt to inorganic crystal grains: possible collaboration with ISMA (Ukraine) to produce 1 kg of  $\text{ZnWO}_4$
- Test of a 16-fibers device to study of the uniformity response of the detector
- Characterization of a full length and fully equipped 16-fibers prototype
- Development of a 14 cm x 14 cm demonstrator

**Thank you!**