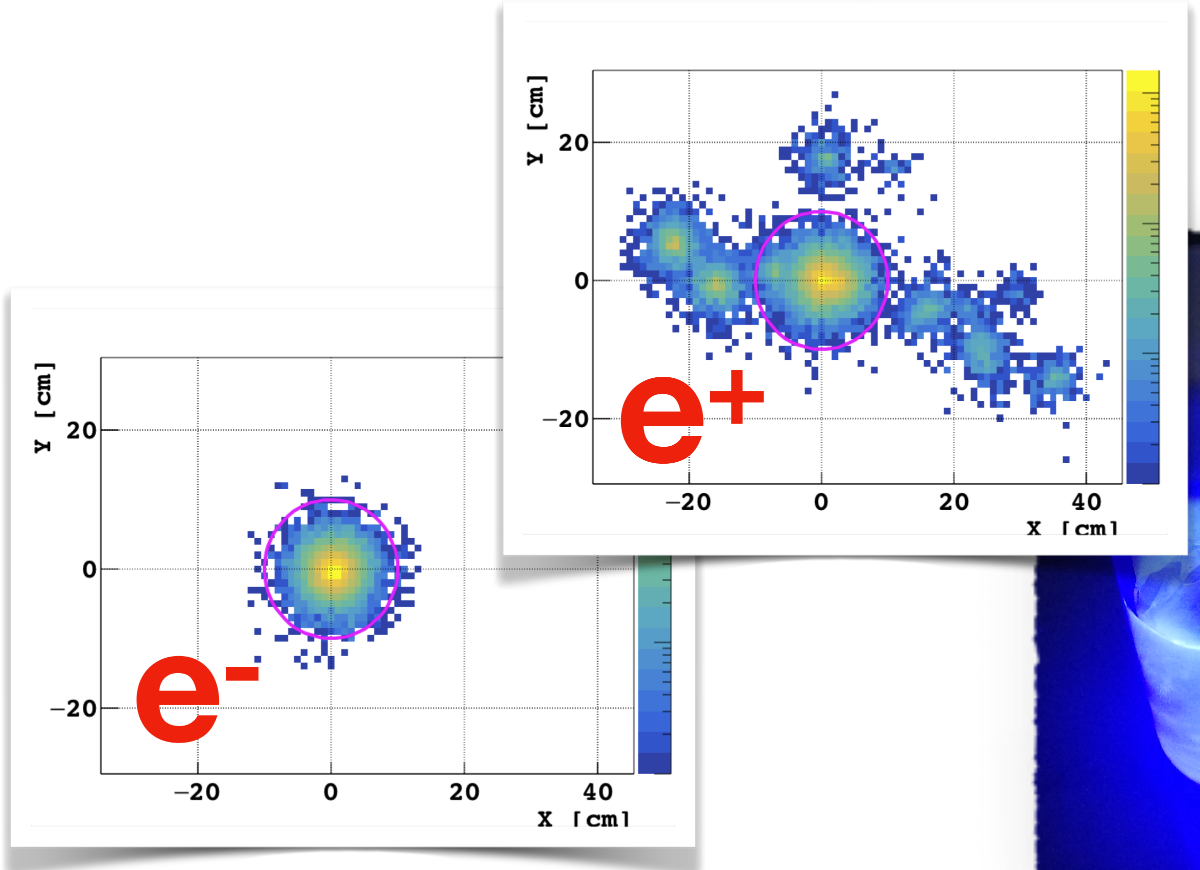
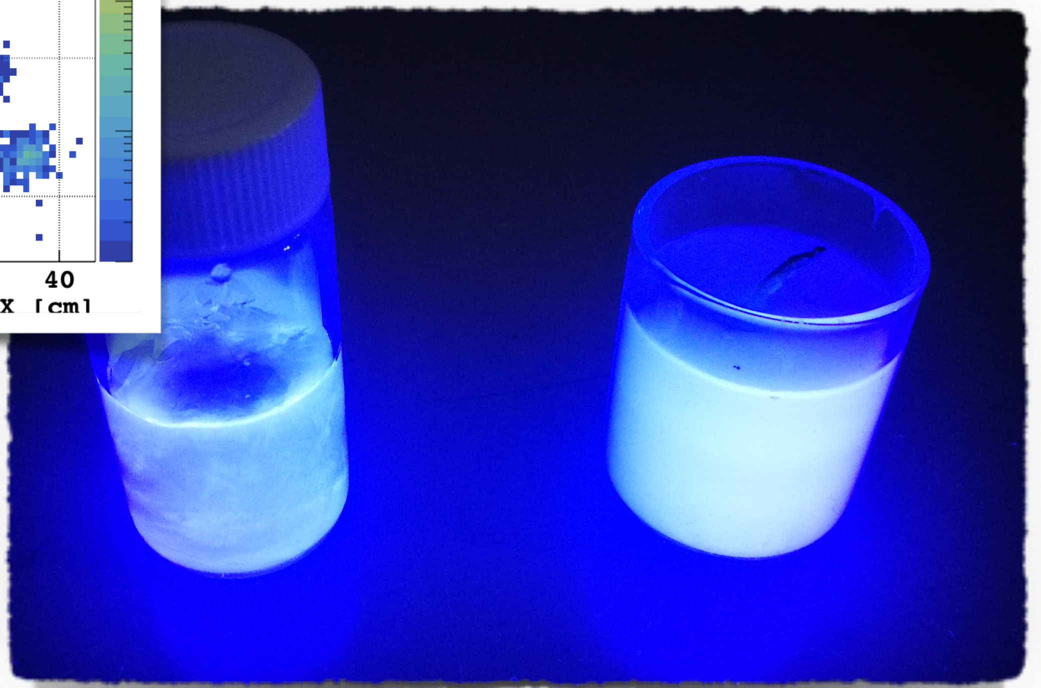
LiquidO: a Novel Neutrino Detection Concept

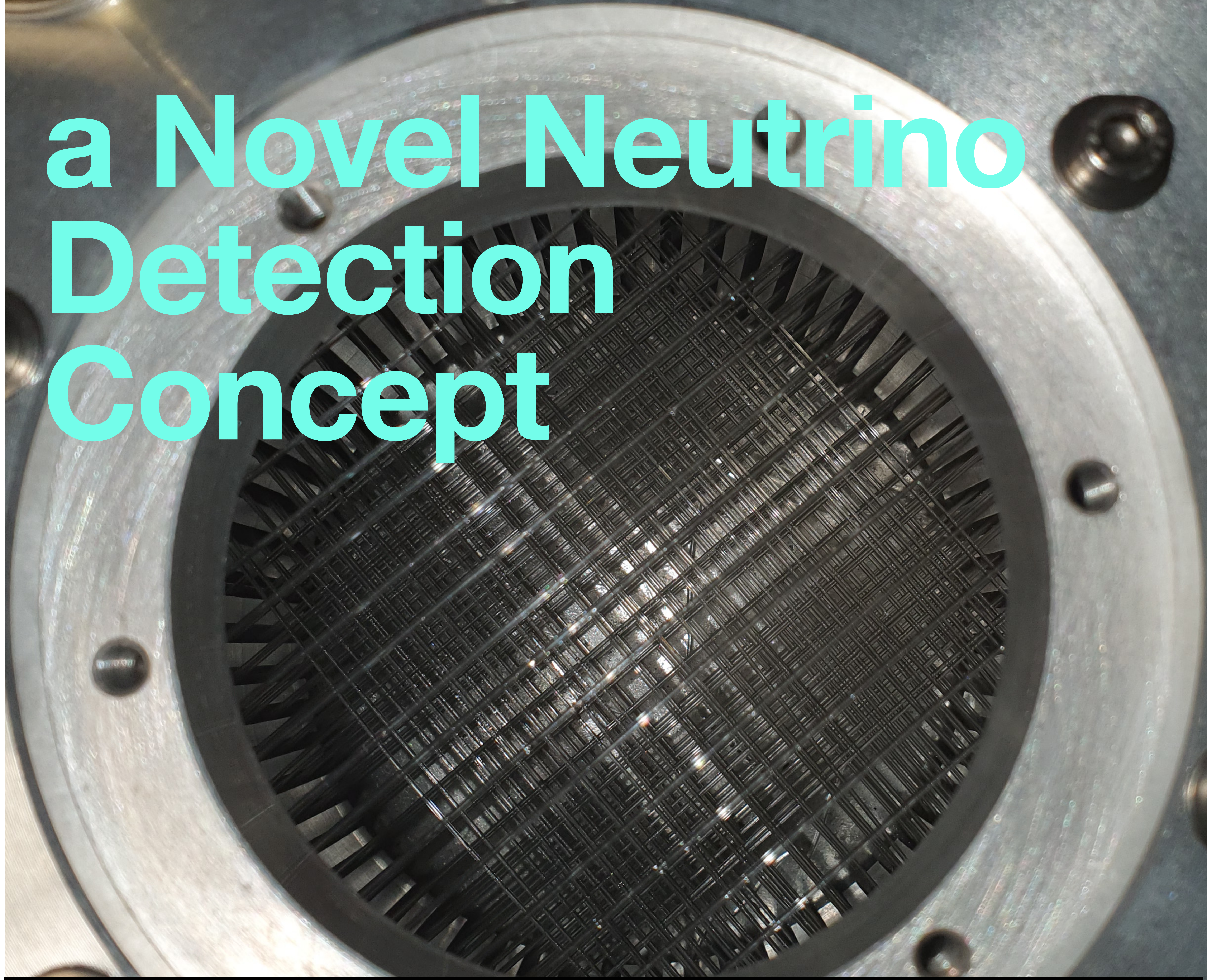
Stefano Dusini
(INFN Padova)
on behalf of
LiquidO consortium

European Innovation Council

AGENCE NATIONALE DE LA RECHERCHE ANR







INFN
Istituto Nazionale di Fisica Nucleare

Liquid
LiquidO neutrino detection project

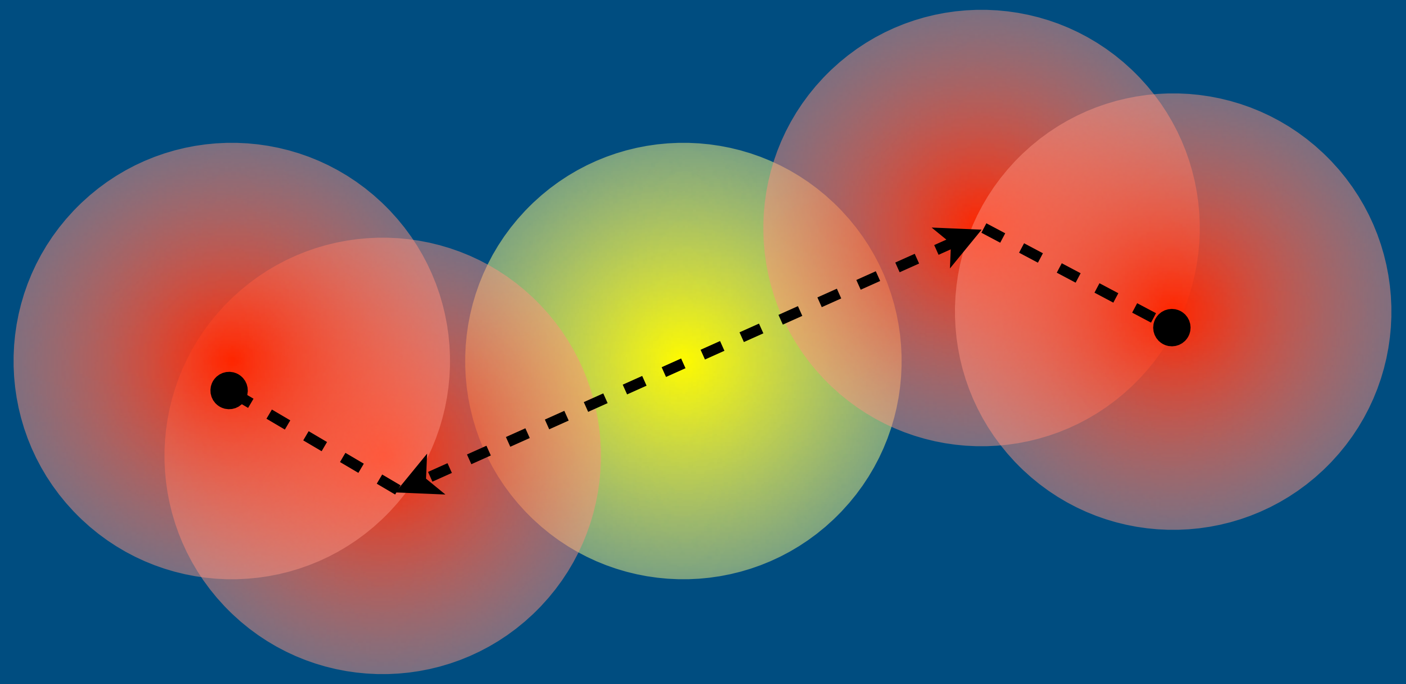
ICHEP 2022 BOLOGNA

ICHEP 2022
XLI
International Conference
on High Energy Physics
Bologna (Italy)

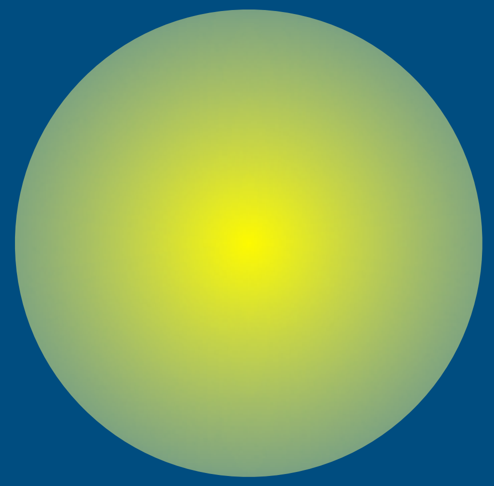
6
13 07 2022

Particle Identification (PID) in homogeneous (target = detector) and non-segmented detector is a major challenge in MeV neutrino detection.

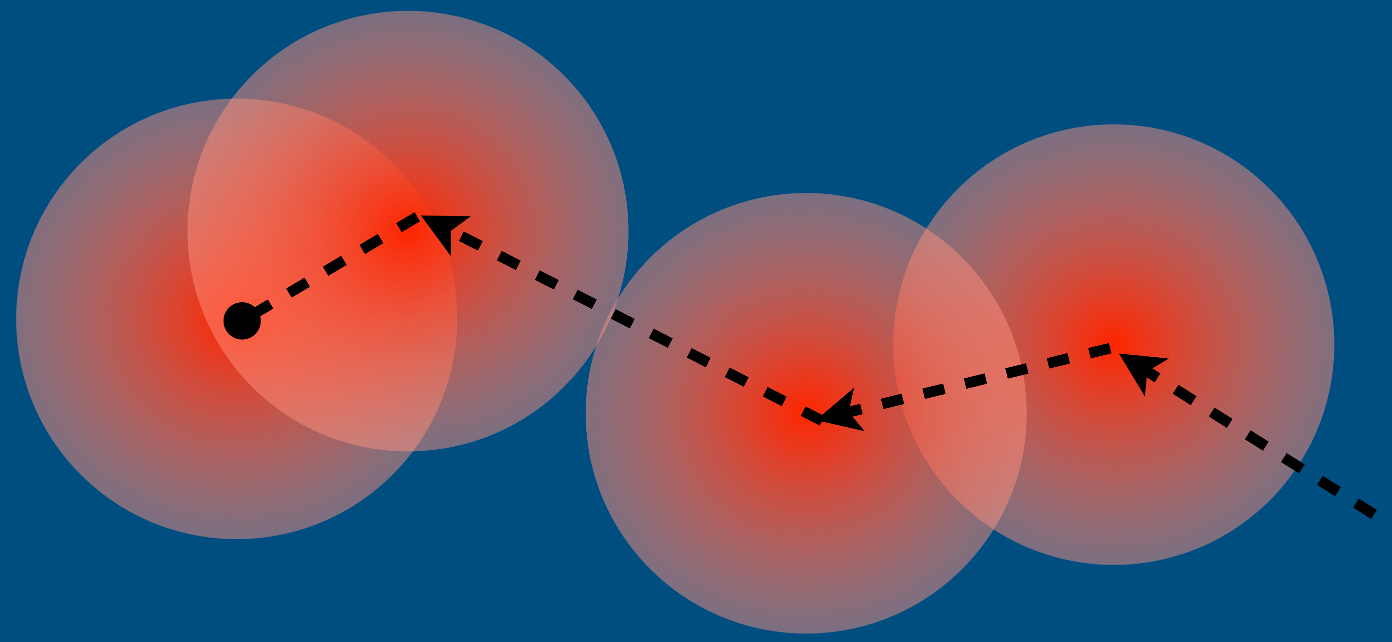
e^+ annihilation



MeV electron or alpha/p dE/dx Bragg peak



Compton scattering
(ended by photon-electric effect)



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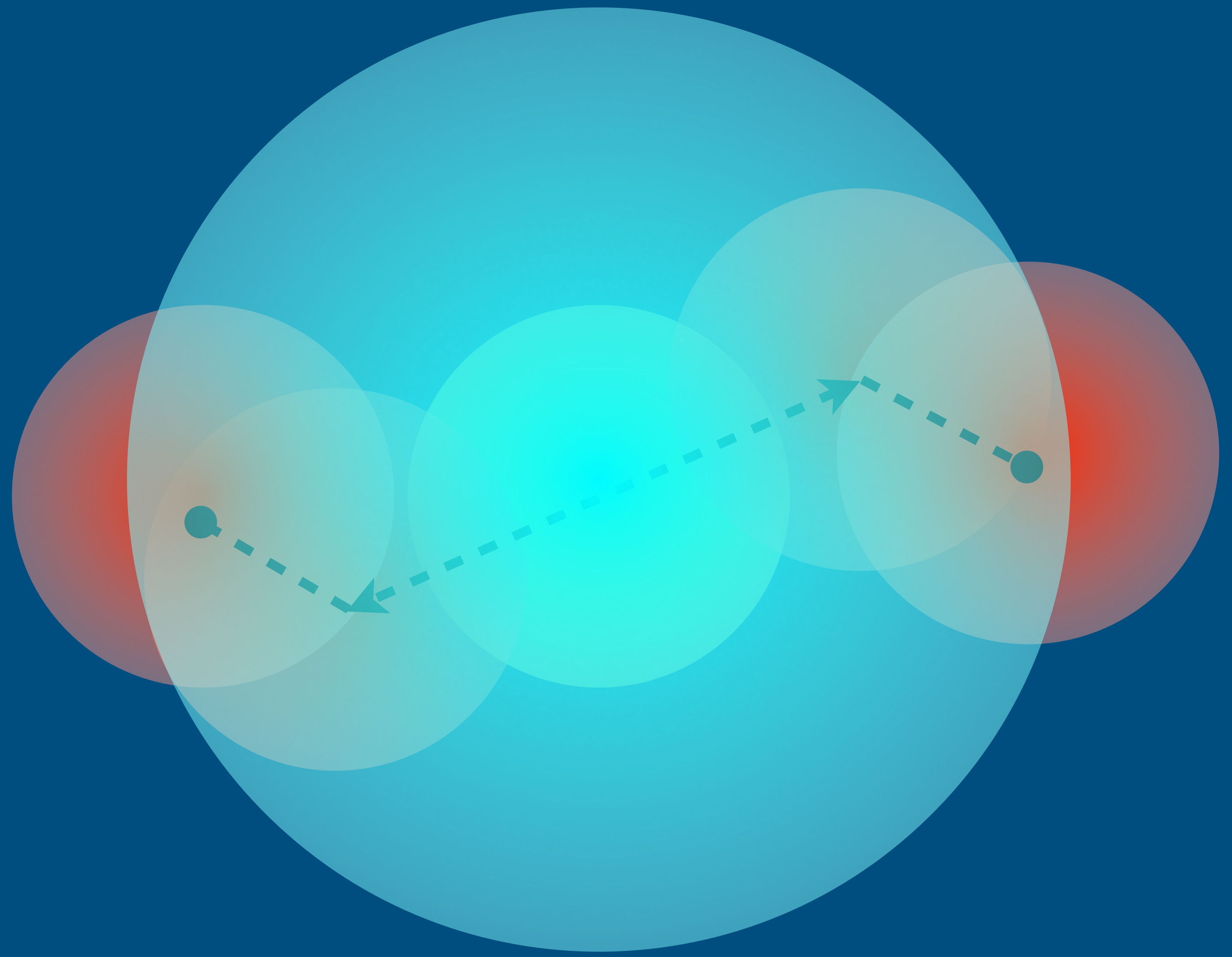

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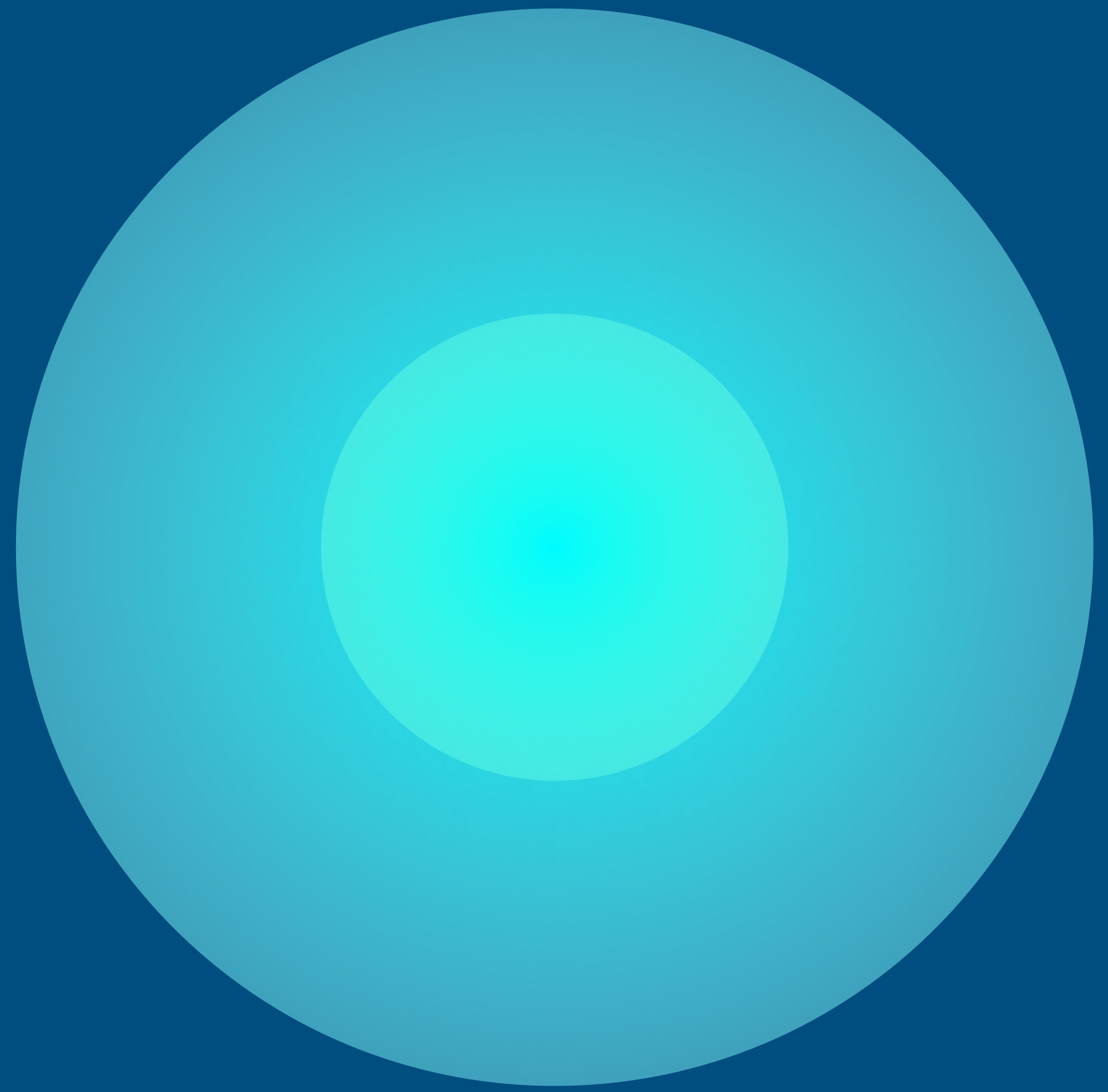

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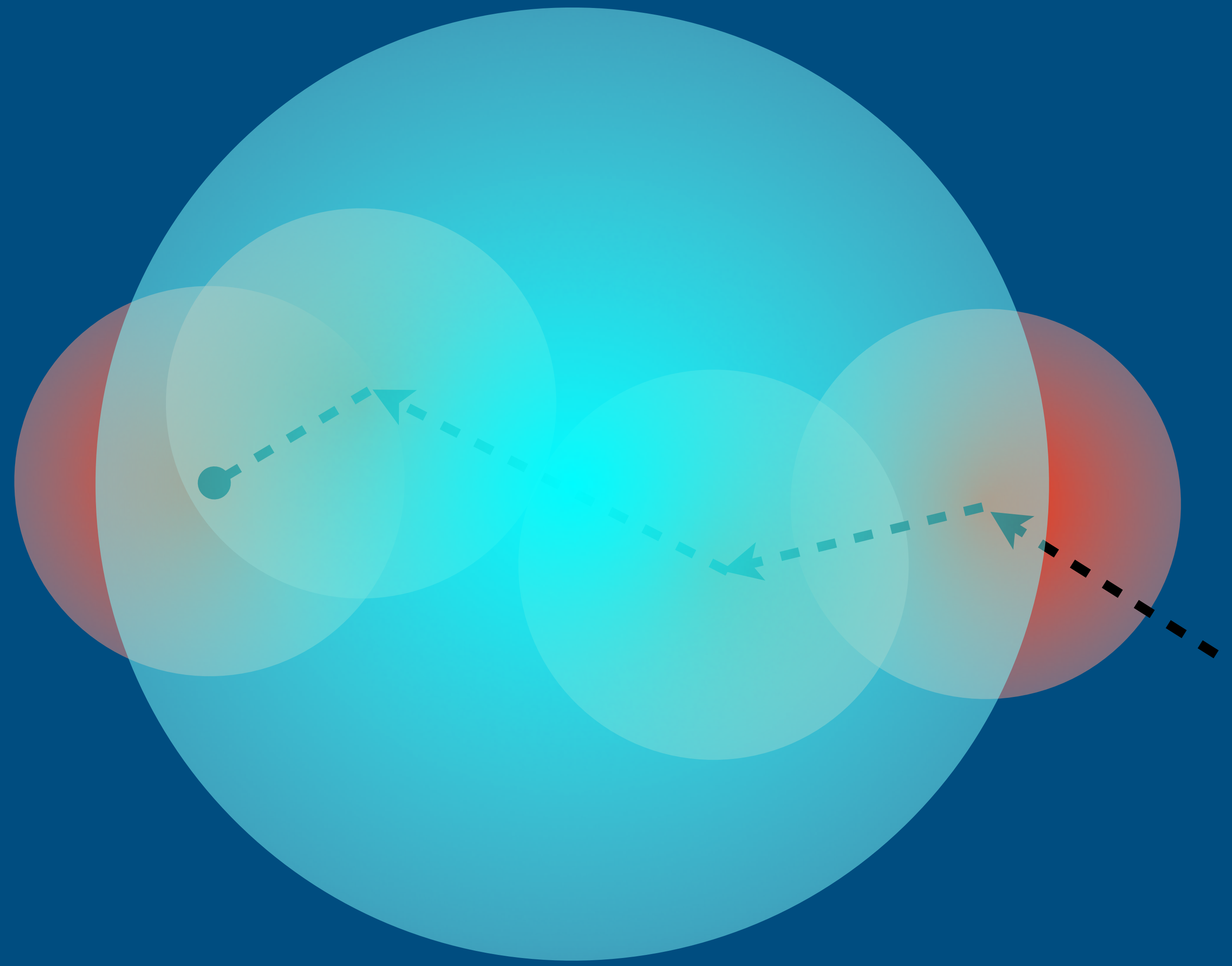
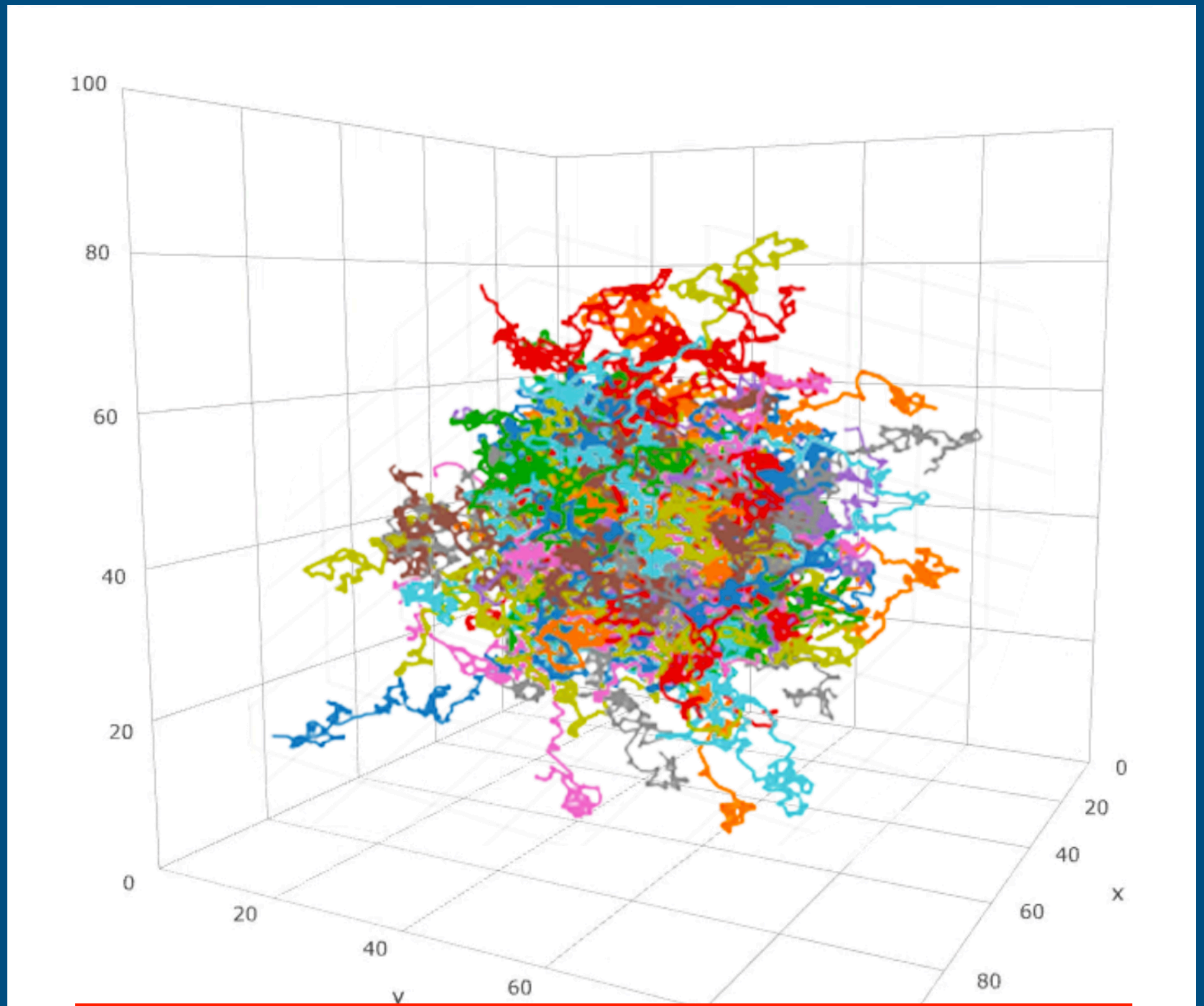


In a typically Liquid Scintillator Detector @ MeV scale with PMT readout

Stochastic light confinement



LiqudiO→ photon's "random walk" (self-confinement)

Confine the light to the production point
- ✓ **interaction pattern can be reconstructed**
- ✓ **Particle ID, tracking, fine calorimetry, dE/dx….**

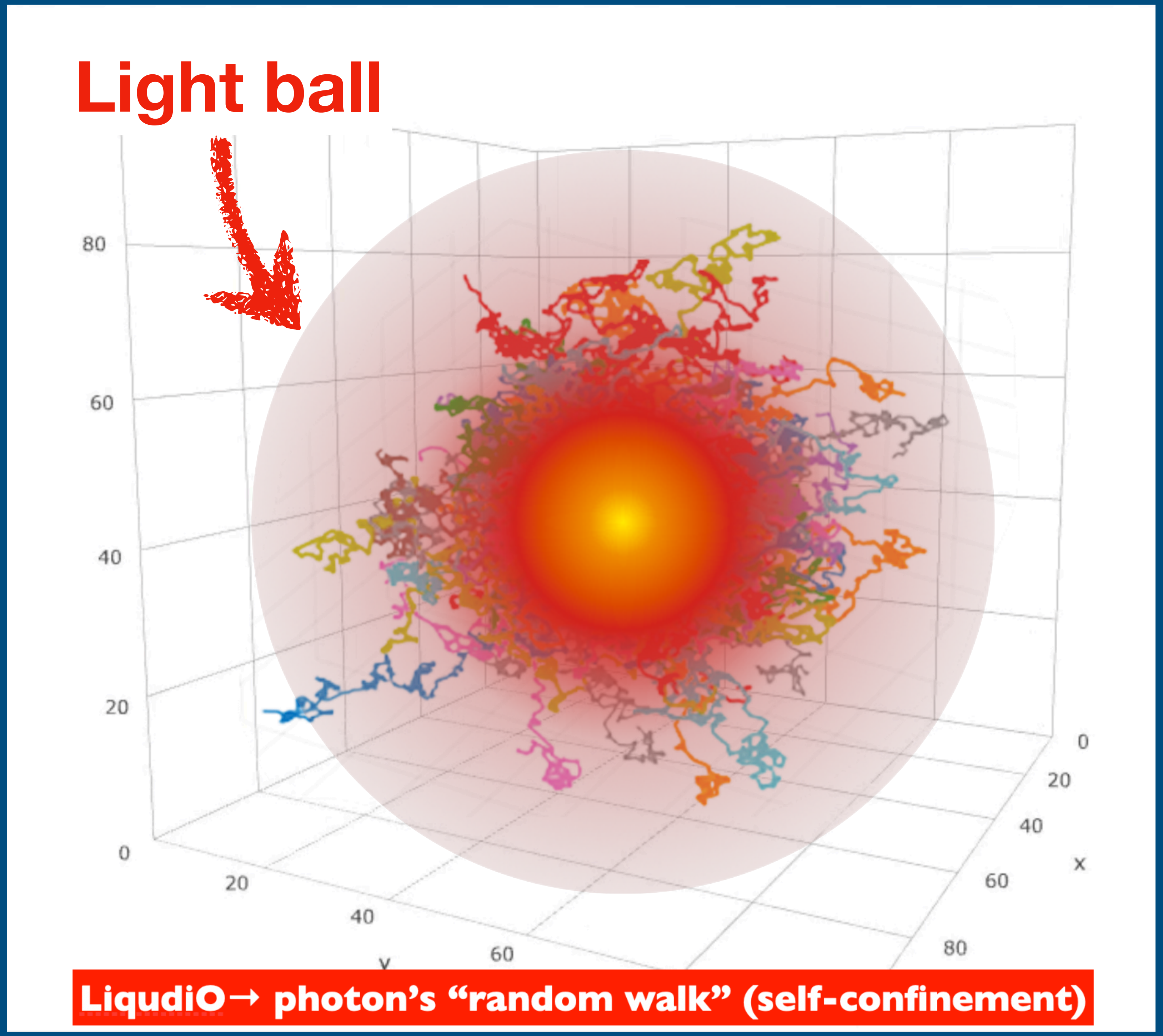
Scattering —> "random walk" —> light ball (order 1cm)

Increase lossless scattering:
- ✓ Mie scattering: achromatic and tiny losses, "cloudy" touch
- ✓ Rayleigh scattering: chromatic and lossless

Transparency
λ(scattering)≥**10m**

Rayleigh & Mie Scattering
λ(scattering)≥**10m**

Stochastic light confinement



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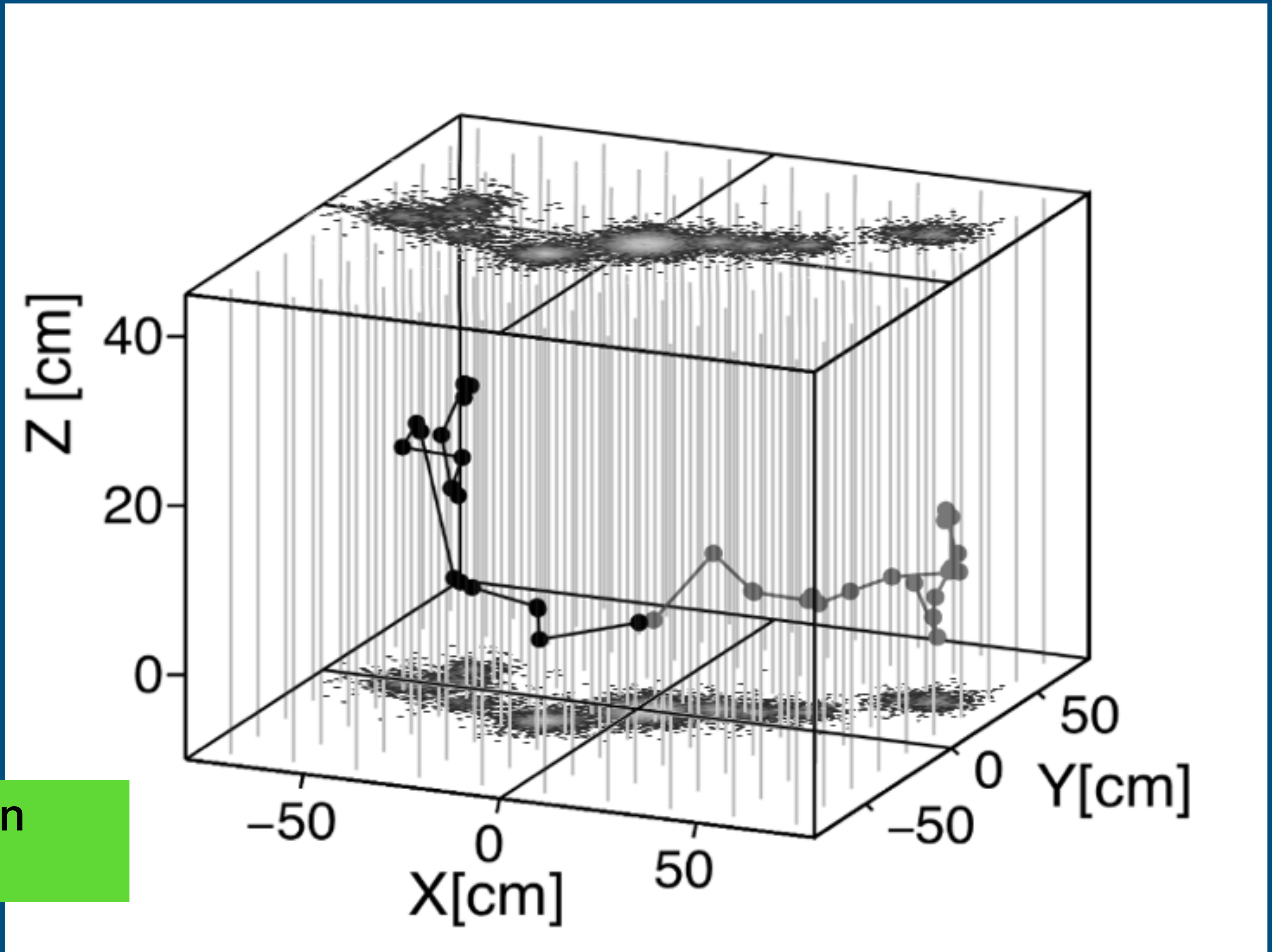
Rayleigh & Mie Scattering
λ(scattering)**≥10m**

The produced light have to be read by an array of fibres to produce 1 or more projection like in gas TPC chambers.

Top view: (x,y) projection



1 MeV positron interaction

Bottom view: (x,y) projection

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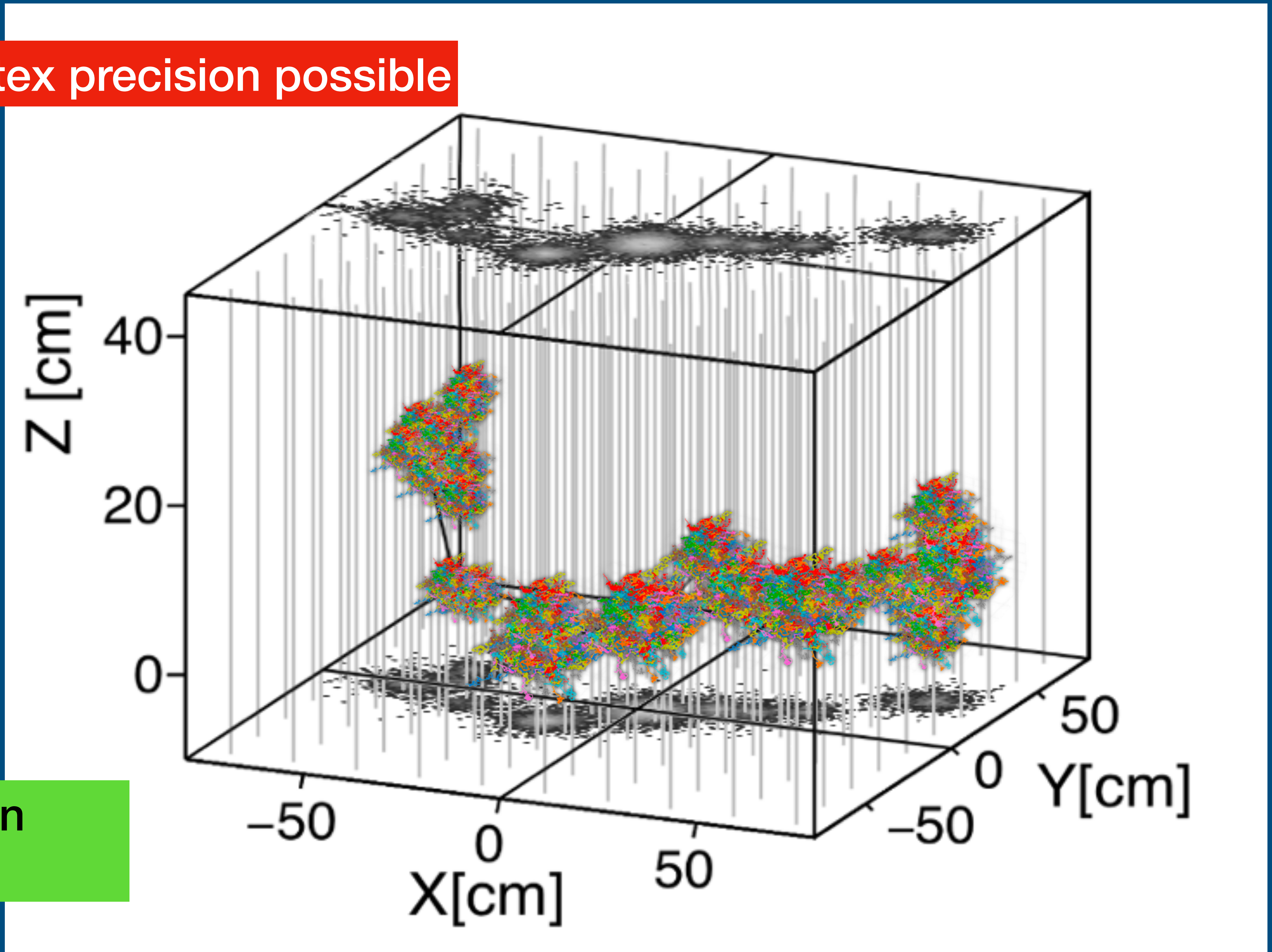
Top view: (x,y) projection

sub-mm vertex precision possible



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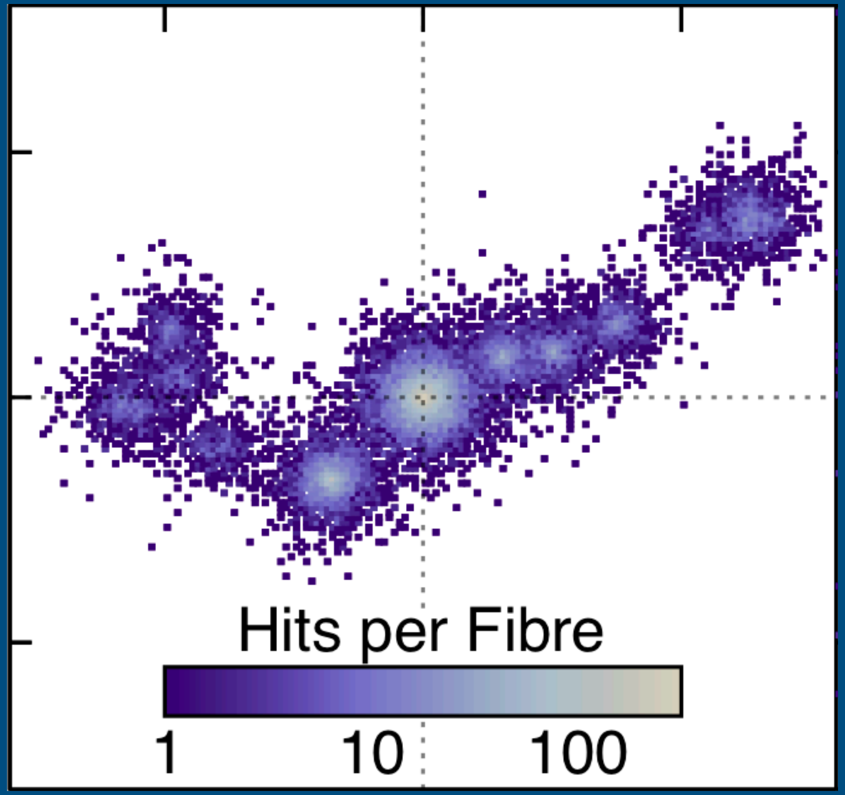

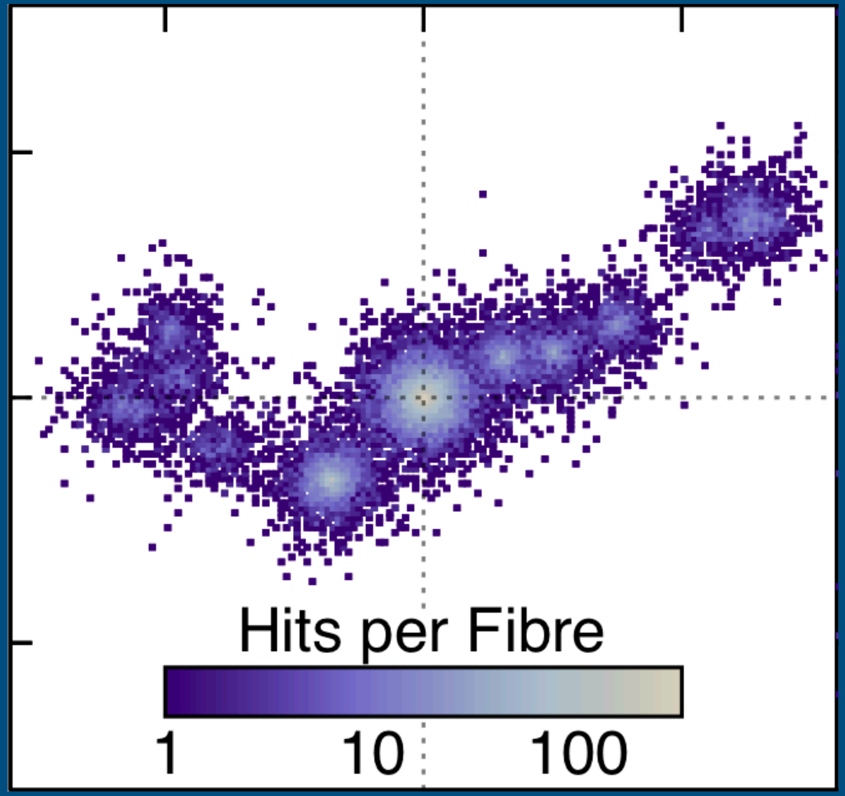

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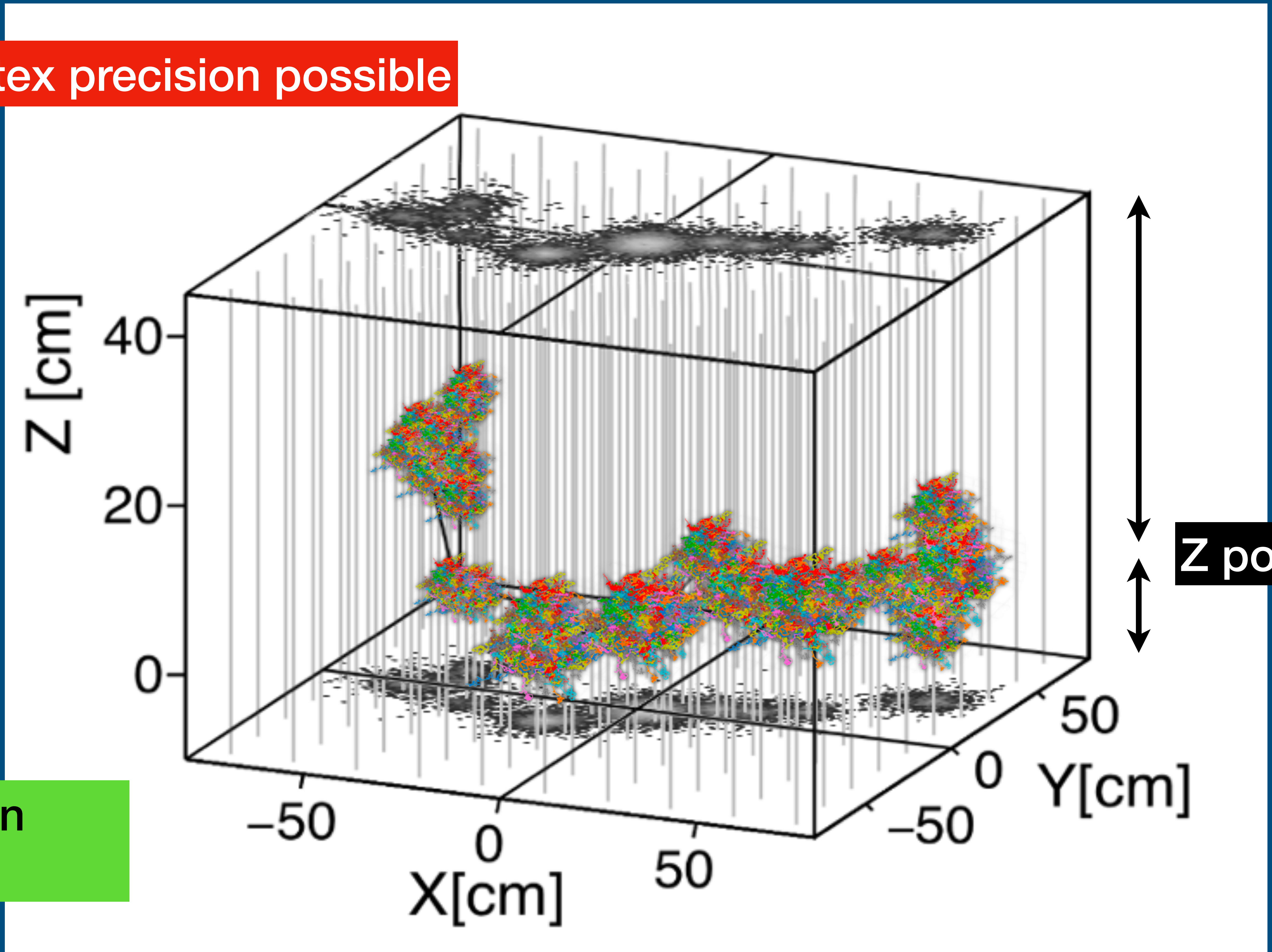
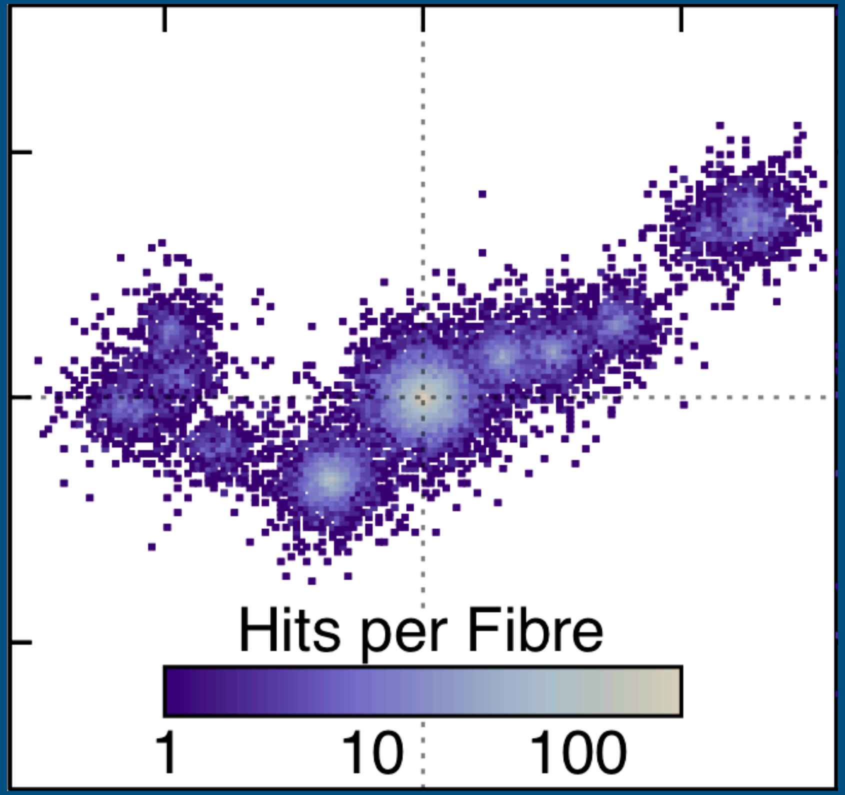
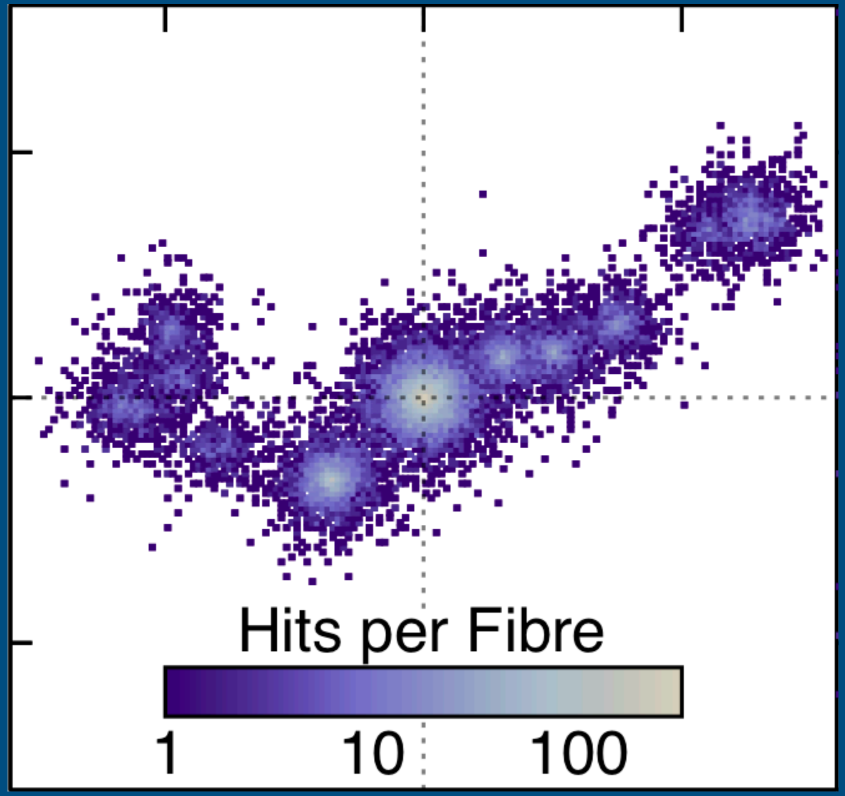




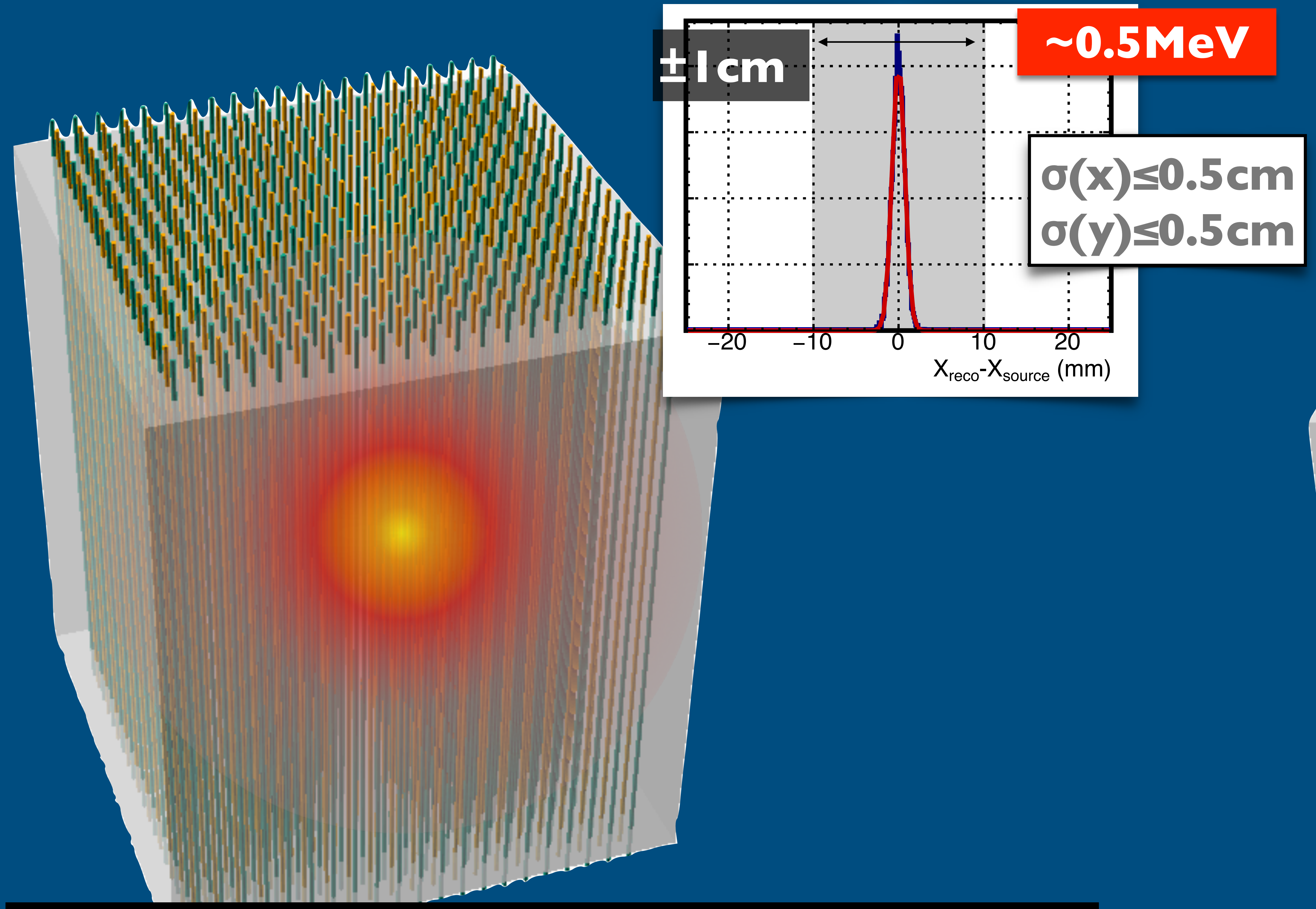
Z position using: Δt (time difference)

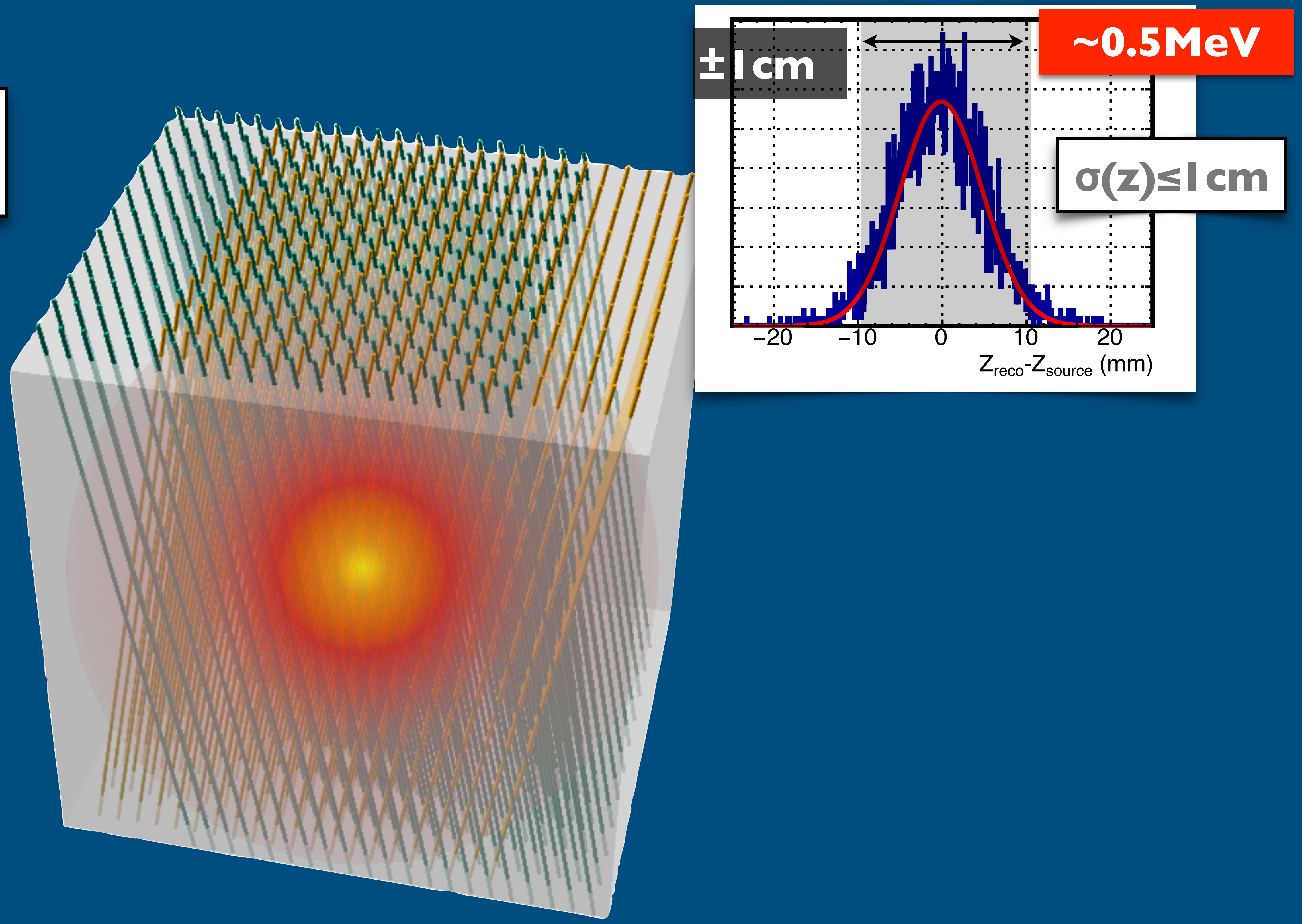


1 MeV positron interaction

Bottom view: (x,y) projection

LiquidO novel engineering solutions…





1x Axis(Z) — minimal configuration
- (X,Y): topology→ **mm resolution** (robust)
- Z: timing→ **few cm resolution**

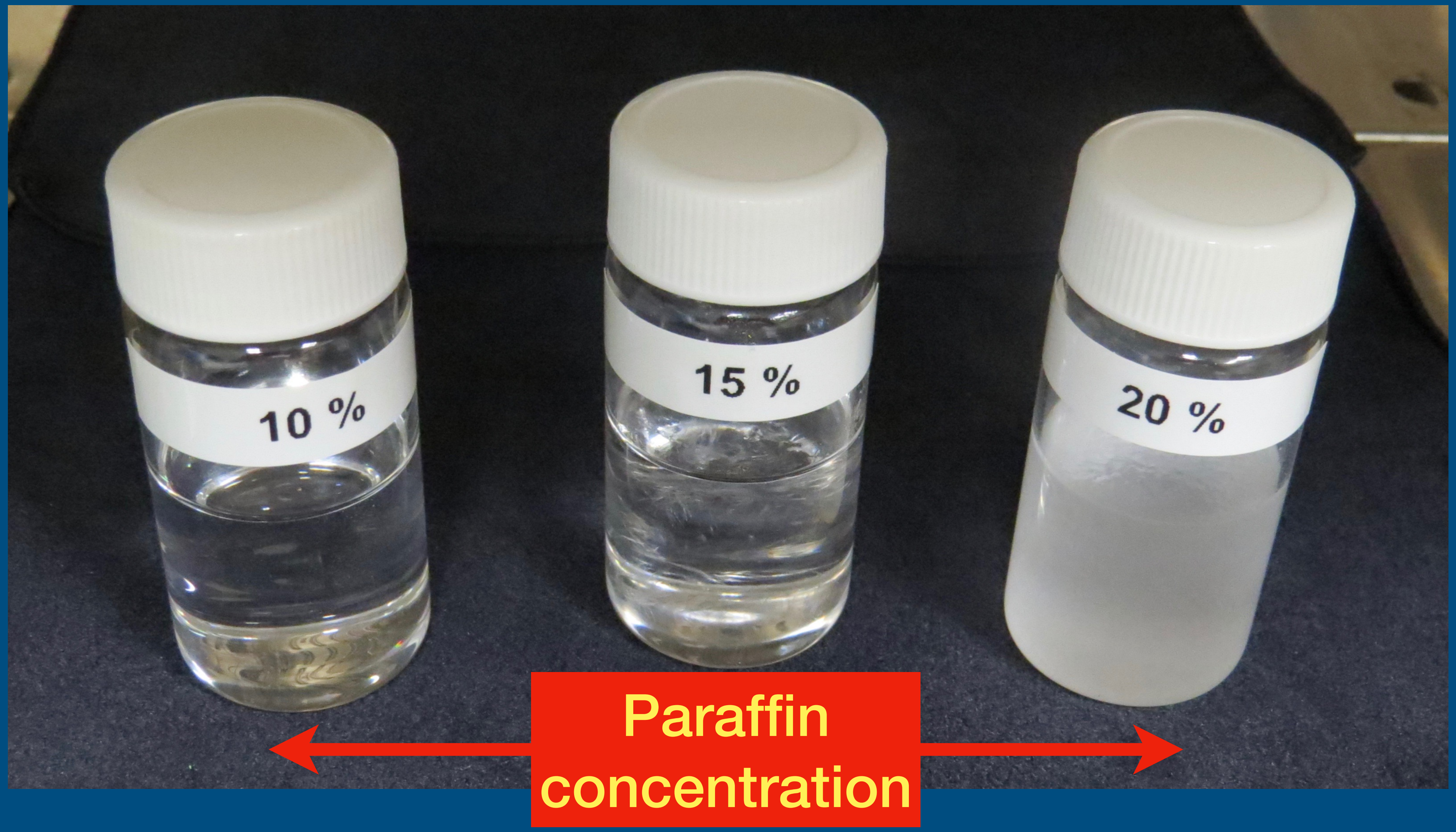
2x Axes — complexity & cost…
- (X,Y,Z): topology→ **mm resolution** (robust)
- (X,Y,Z): timing→ cheap-readout / over-constrained

"Tilted fibres" along one axis
- **engineering under development**
- (X,Y) from fibre position, **mm resolution** (robust)
- Z from topology, **cm resolution** (robust)

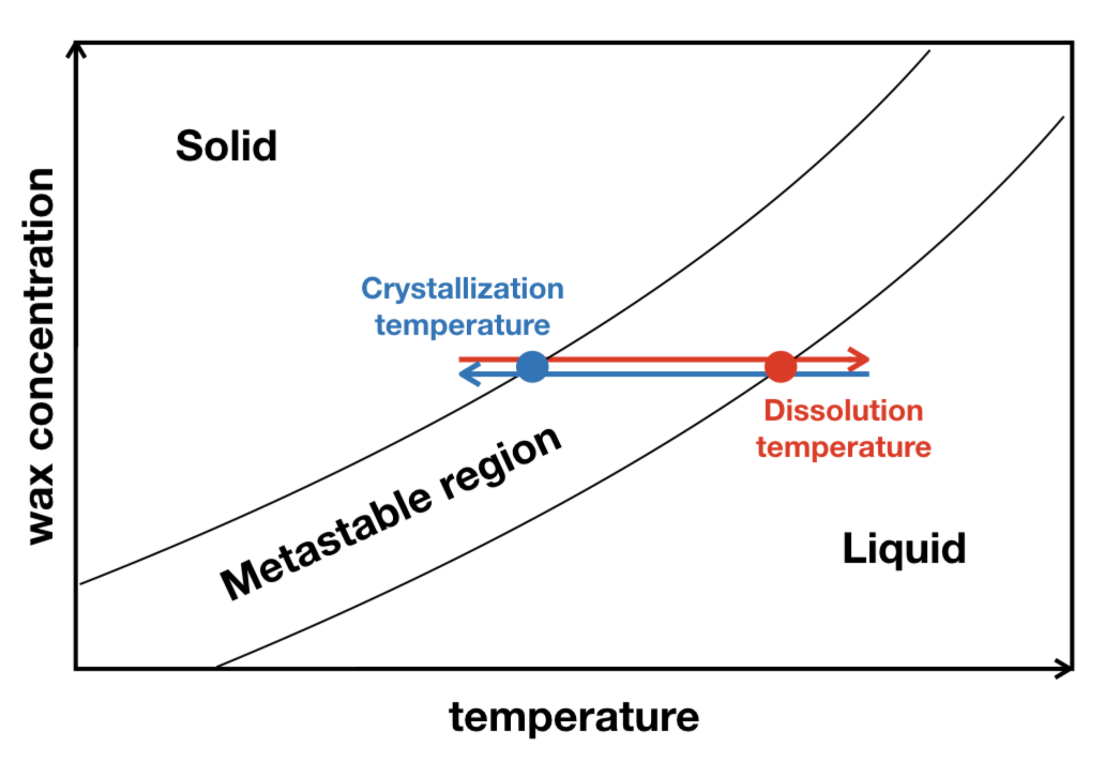
Opaque Scintillator : NoWaSH

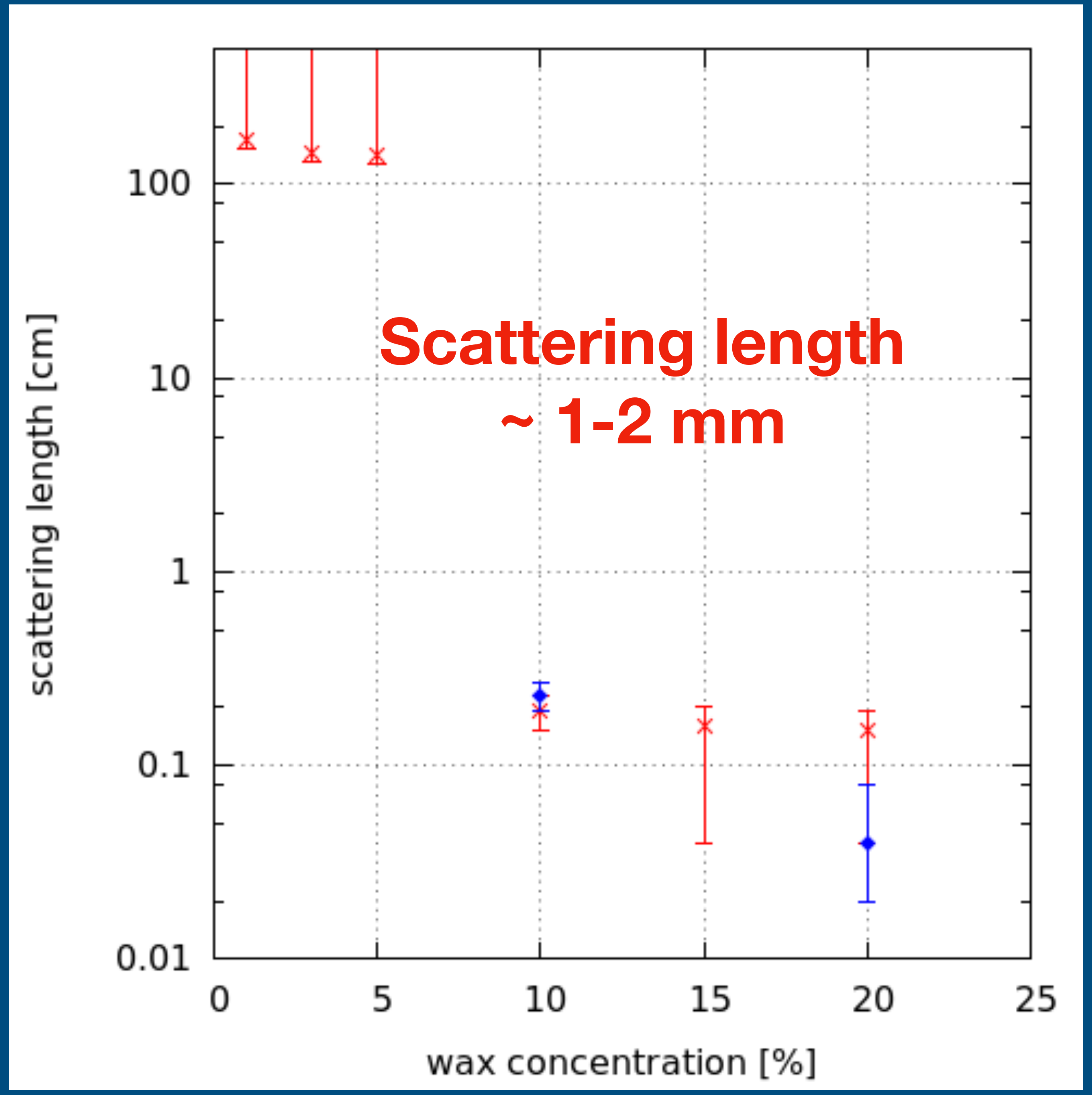
“NoWaSH” scintillator = Linear Alkyl Benzene + PPO (0.3%) Paraffin

Opacity depends on
- ✓paraffin concentration
- ✓temperature which control the crystallisation



C. Buck, B. Gramlich, S.Schoppmann, JINST 14 (2019) P11007





unprecedented PID @ MeV

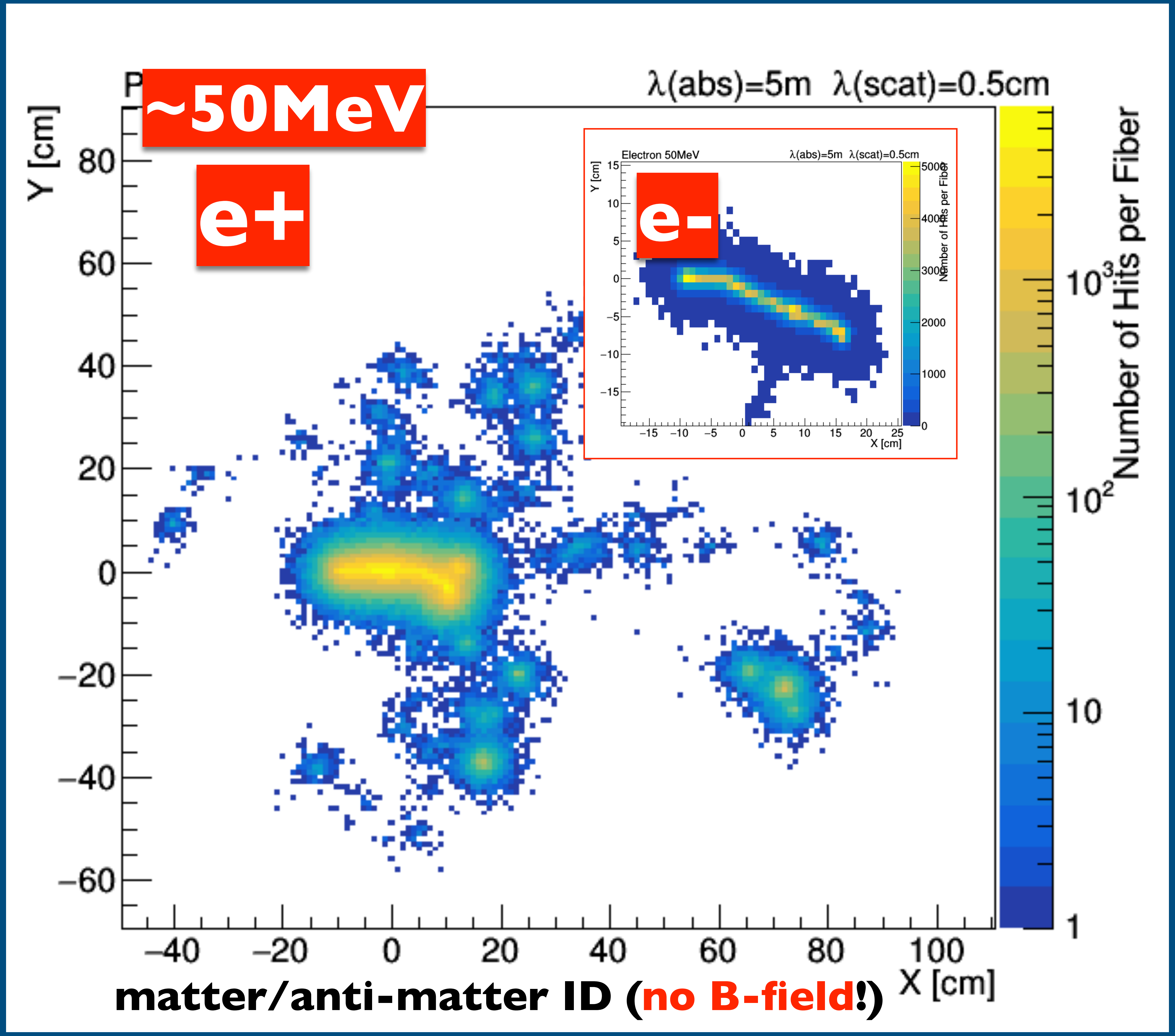
~2MeV

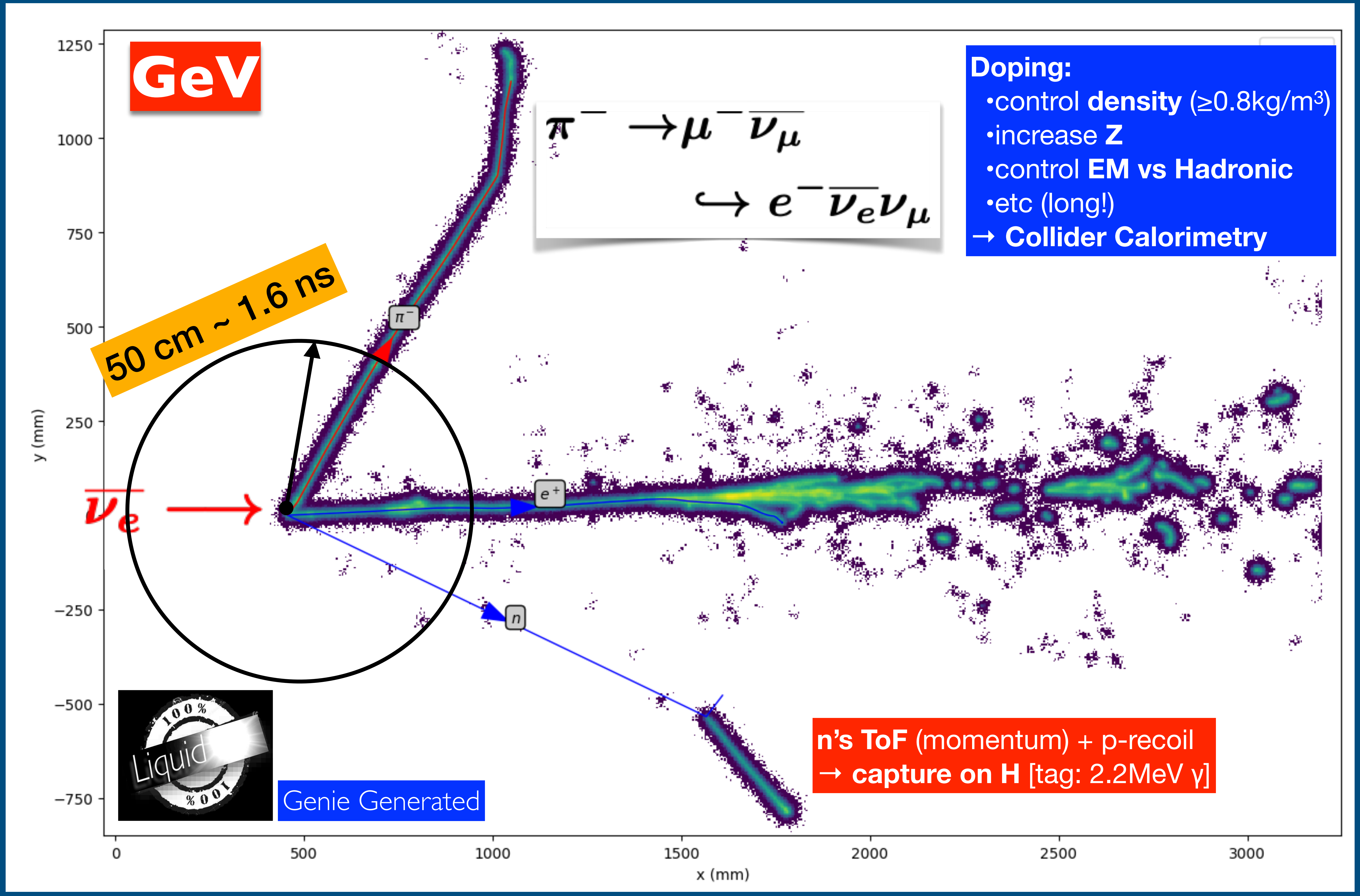
✓ $\nu_e/\overline{\nu}_e$ separation

✓ background (cosmogenic) identification

✓ no segmentation (less background for MeV physics)

From multi MeV to GeV

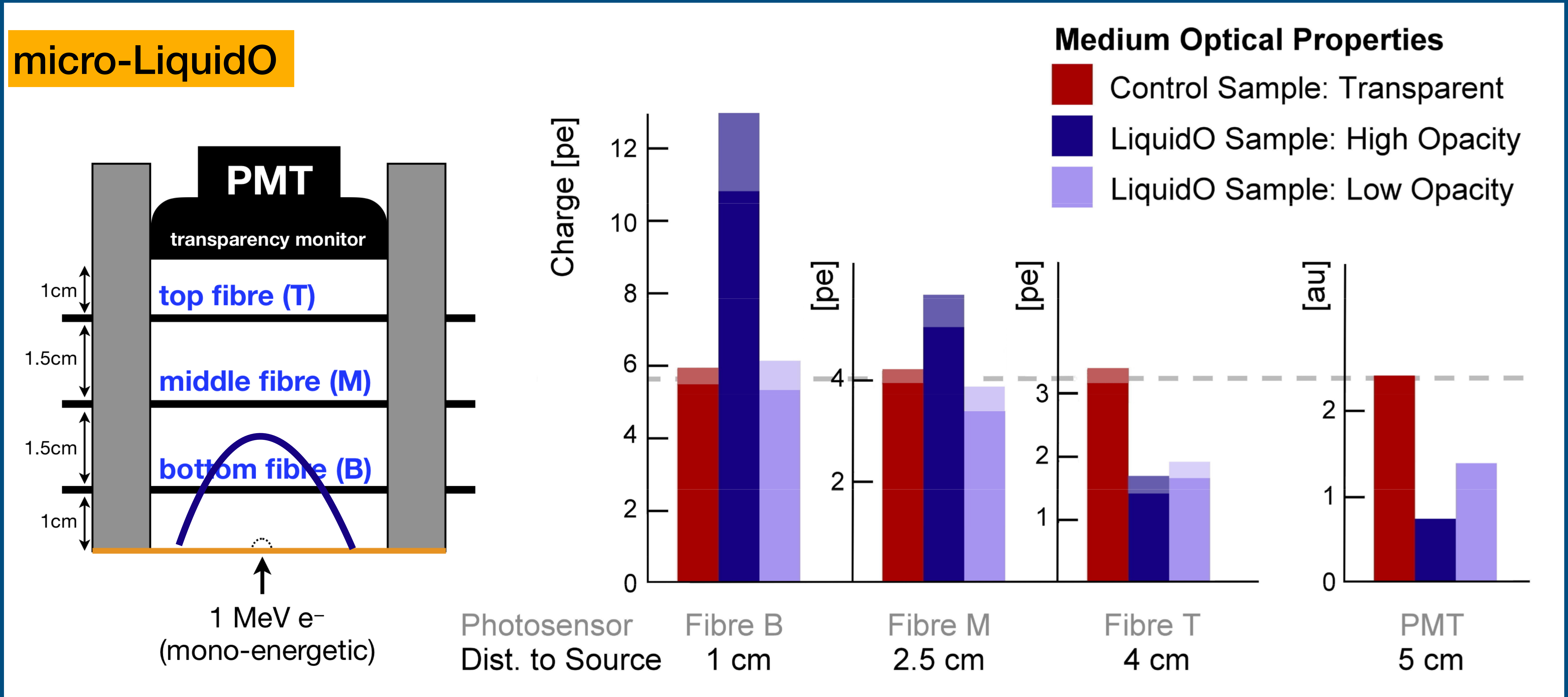




- ✓ DAR neutrinos
- ✓ Supernova neutrinos (directionality !!)
- ✓ Antmospheric neutrinos

- ✓ Superb GeV calorimetry, stochastic error 0.1% [~10^5 PE/GeV]
- ✓ Tracking
- ✓ Timing, time-of-flight

First experimental proof of principle



Increasing the opacity light is confined close to the production point

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Neutrino physics with an opaque detector

LiquidO Consortium

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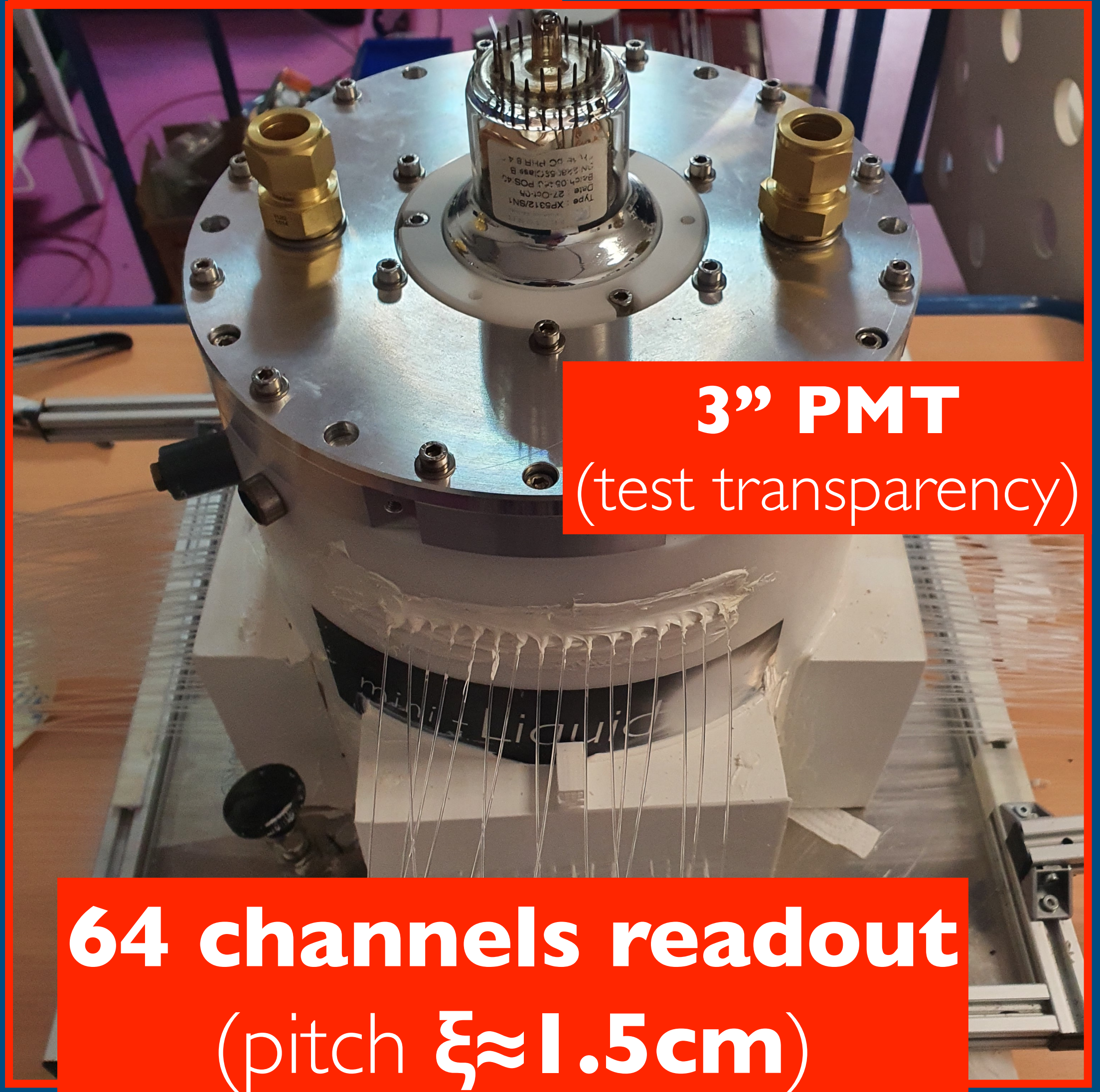
LiquidO's prototype MINI-II (upgrade)

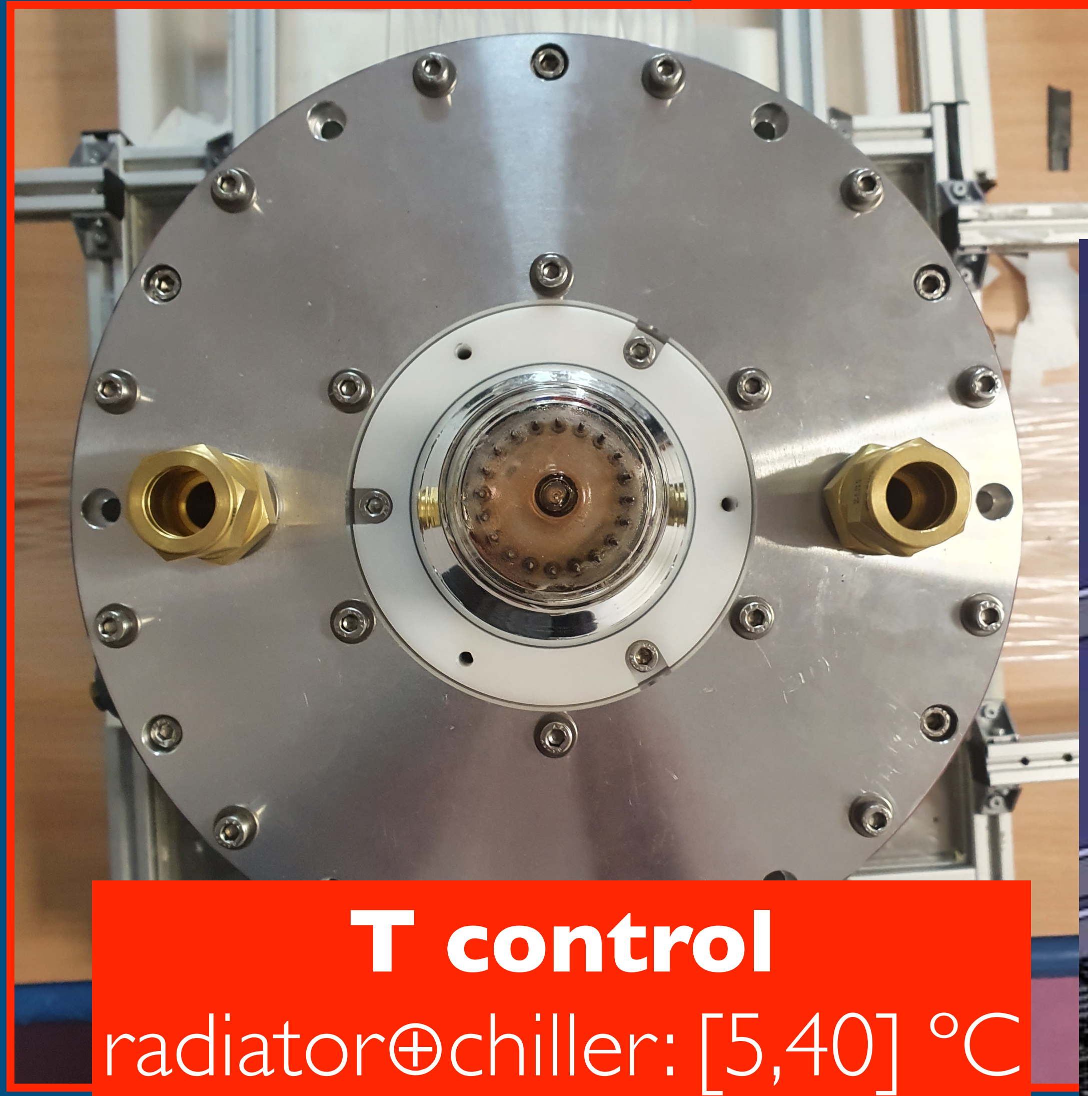
- 10 L prototype
- we can test several different media
  - ✓ water (transparent)
  - ✓ transparent scintillator
  - ✓ opaque scintillator (opacity controlled with temperature)

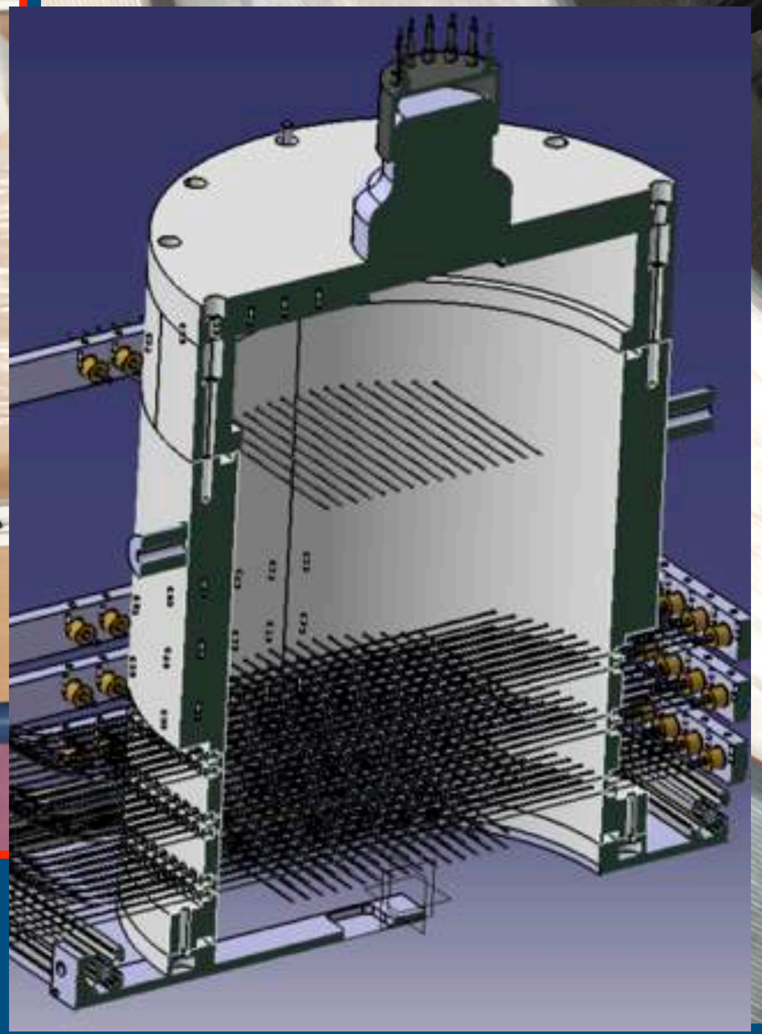
data taking since 2021

overall view



top view





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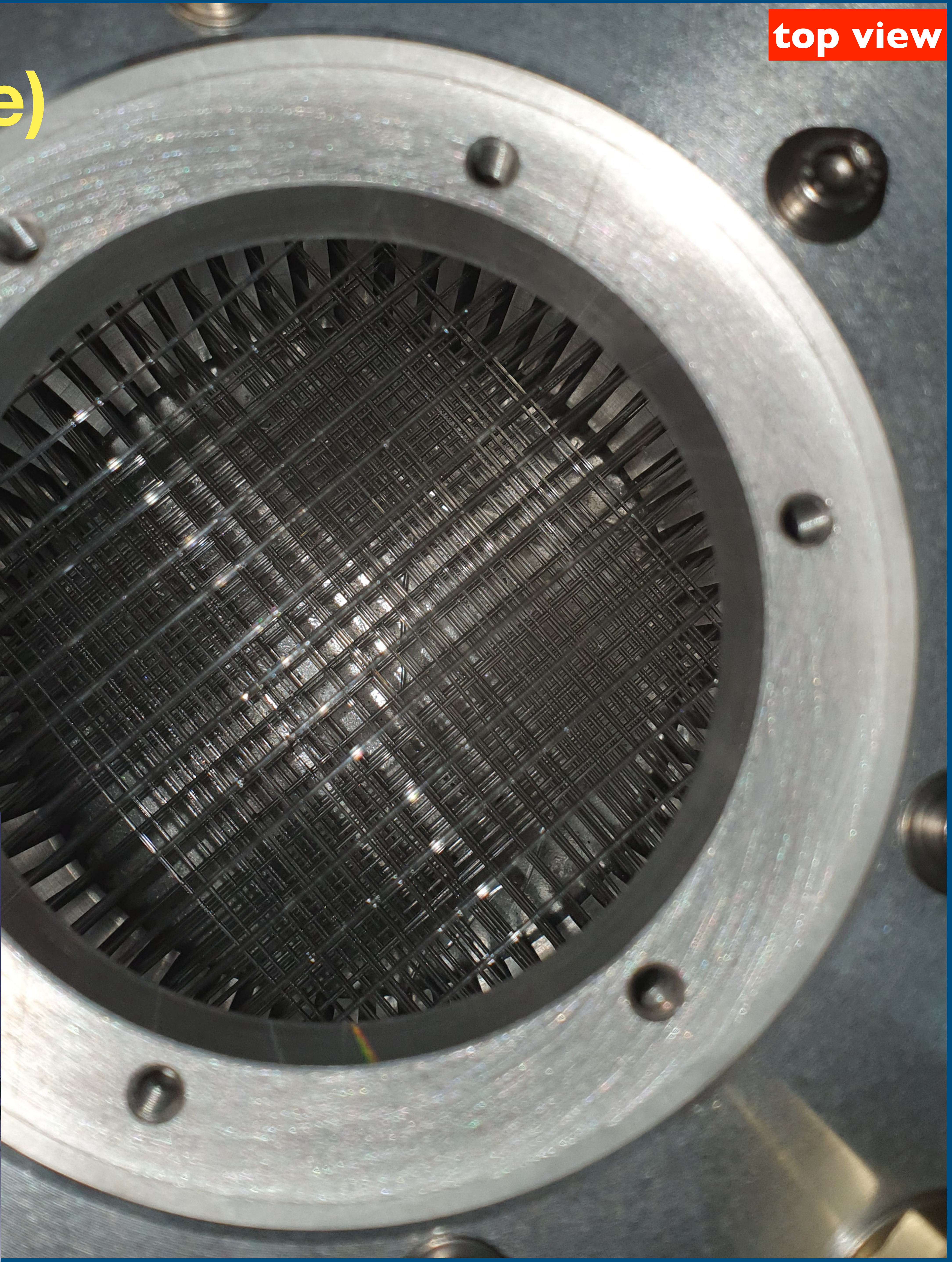
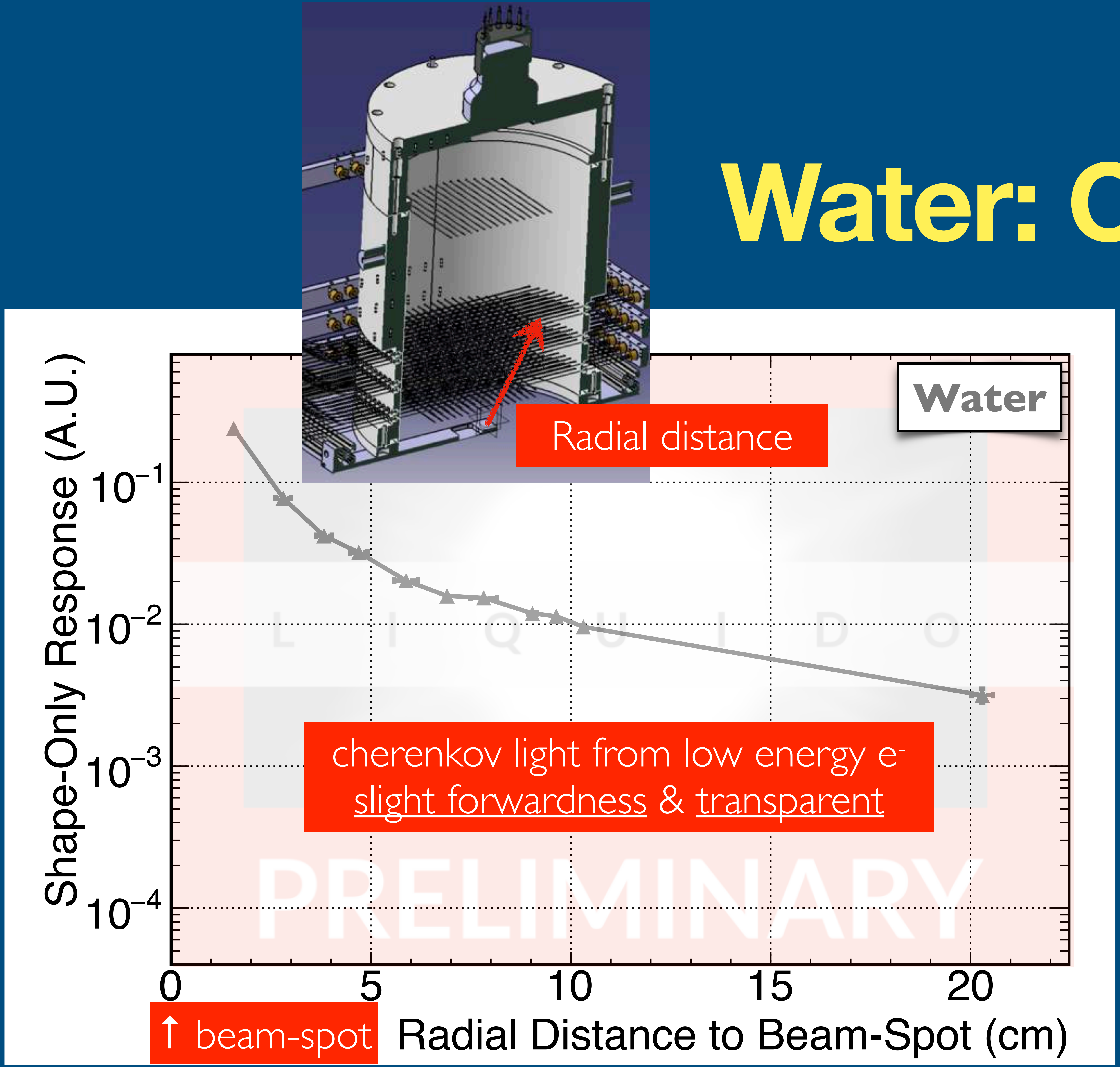
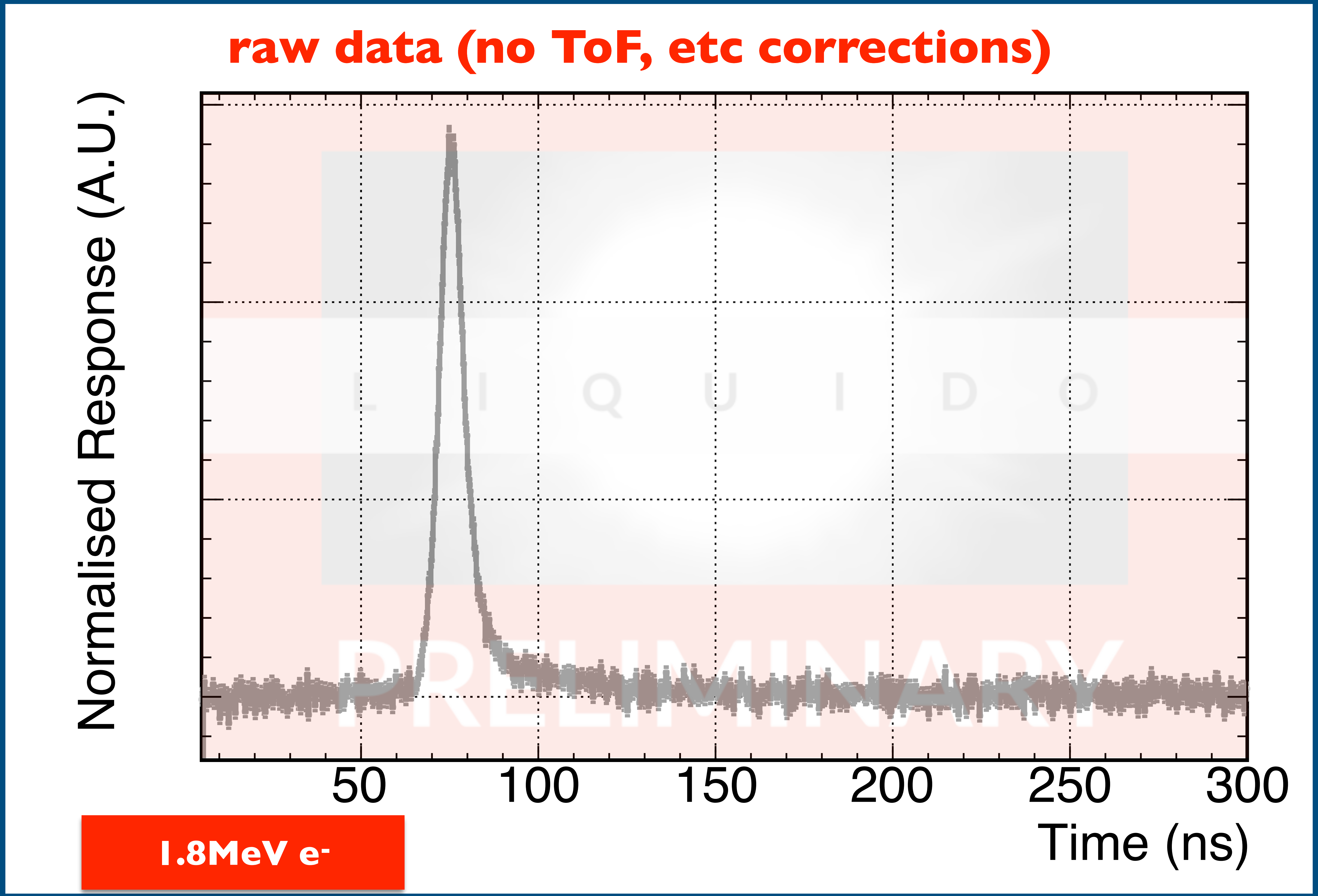


Water: Cherenkov light only…

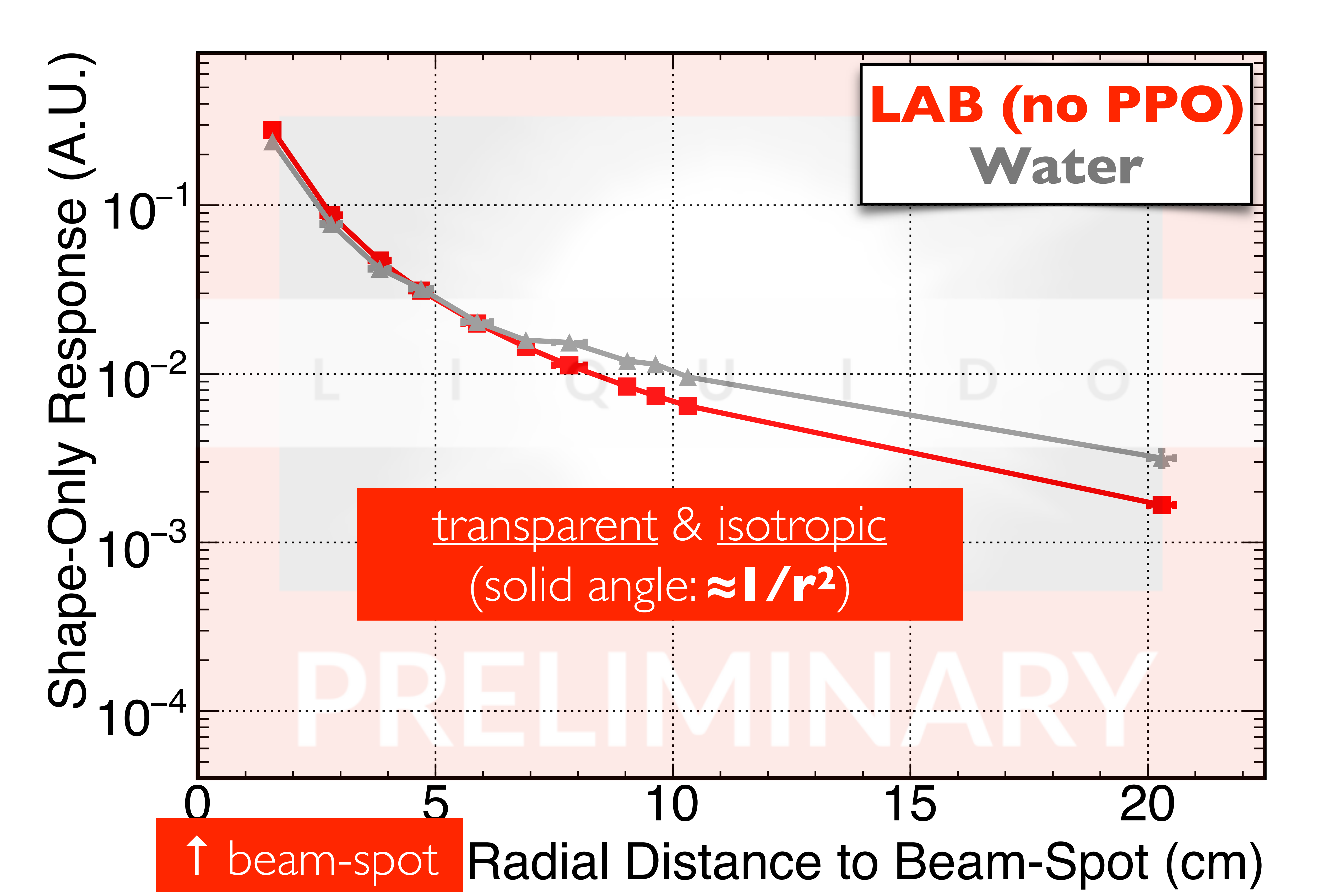


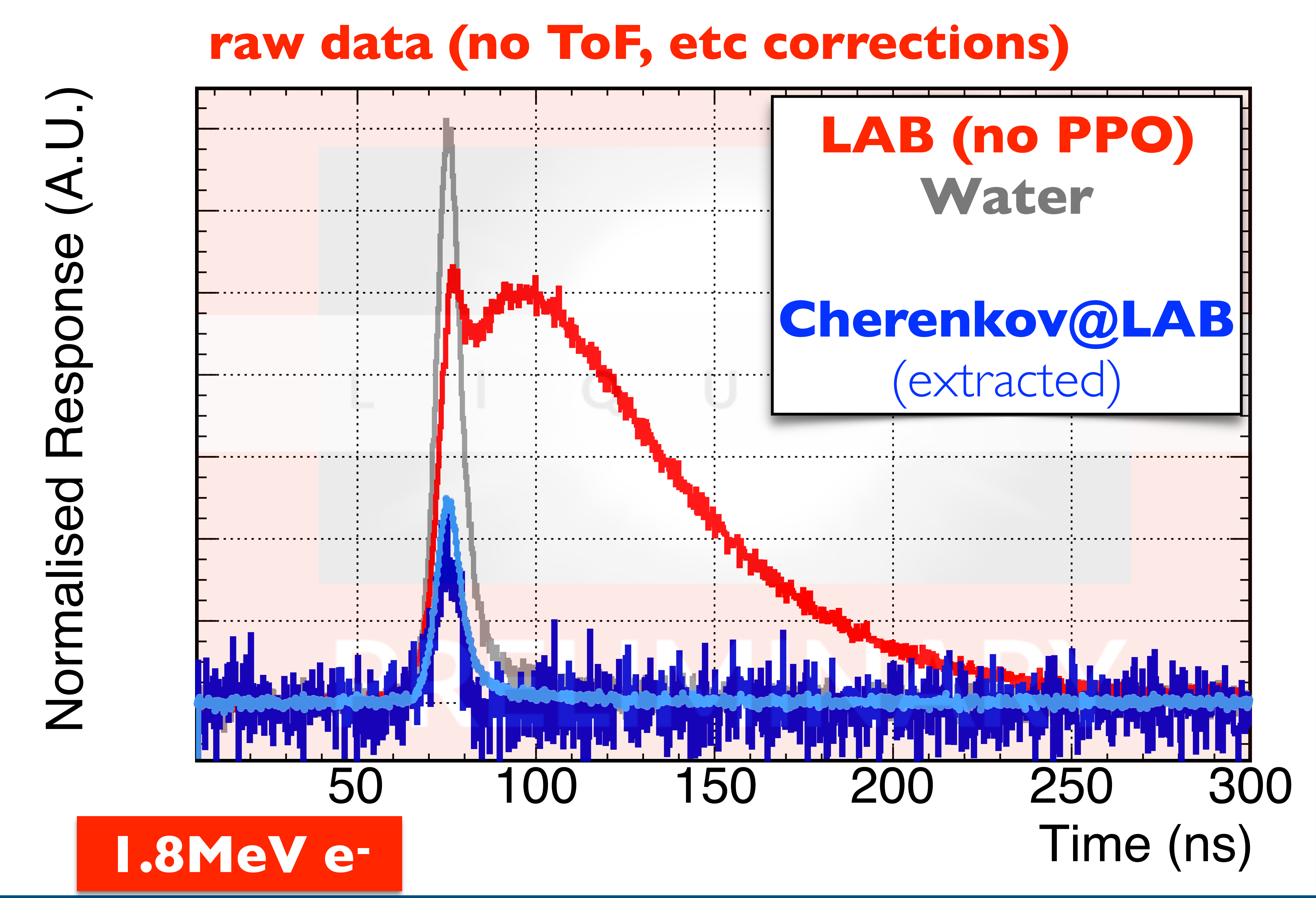


Validate detector timing with known signal

Timing dominated by fibre excitation?

LAB (no ppo): scintillation + Cherenkov





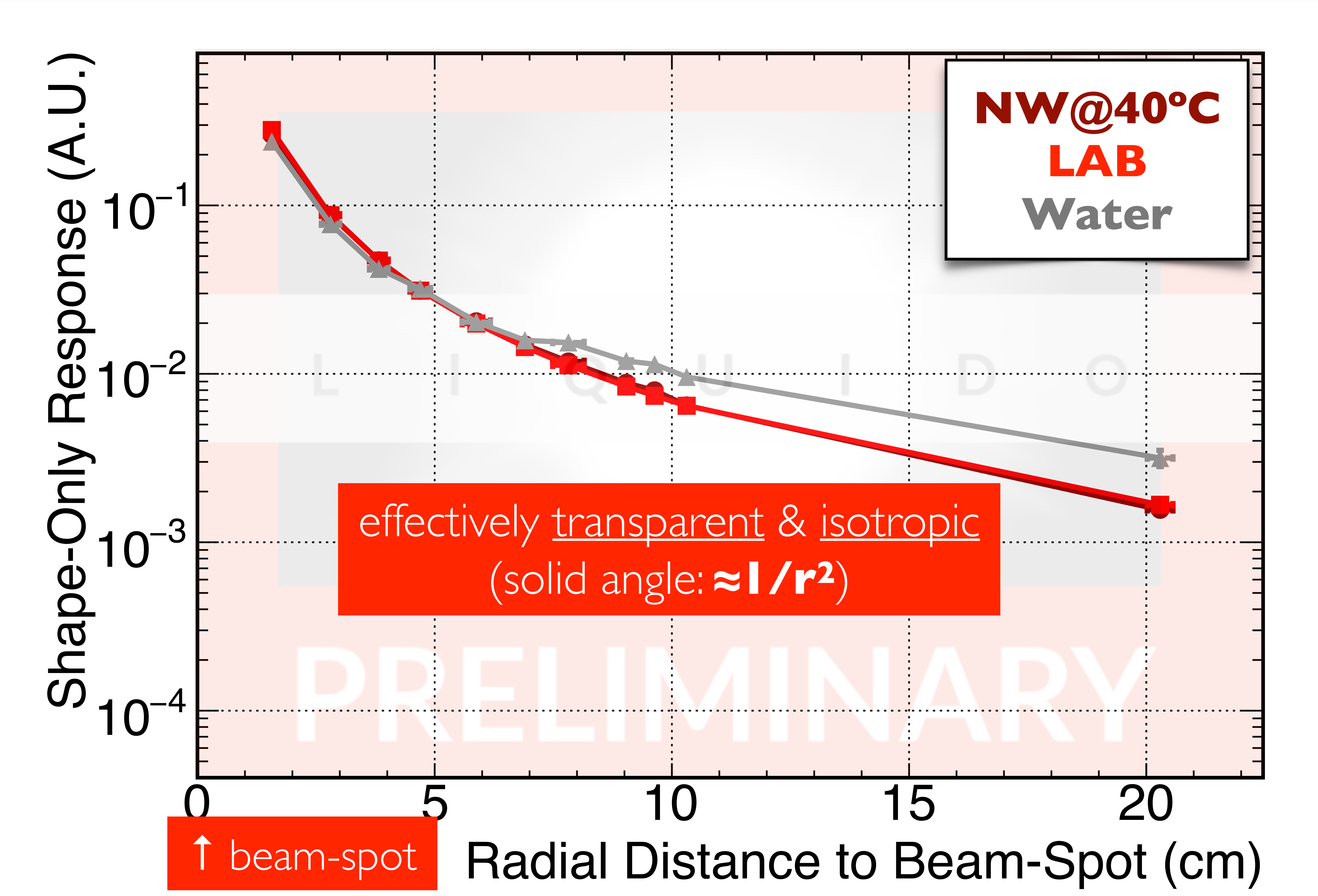
Strong increase of the light due to the LAB:

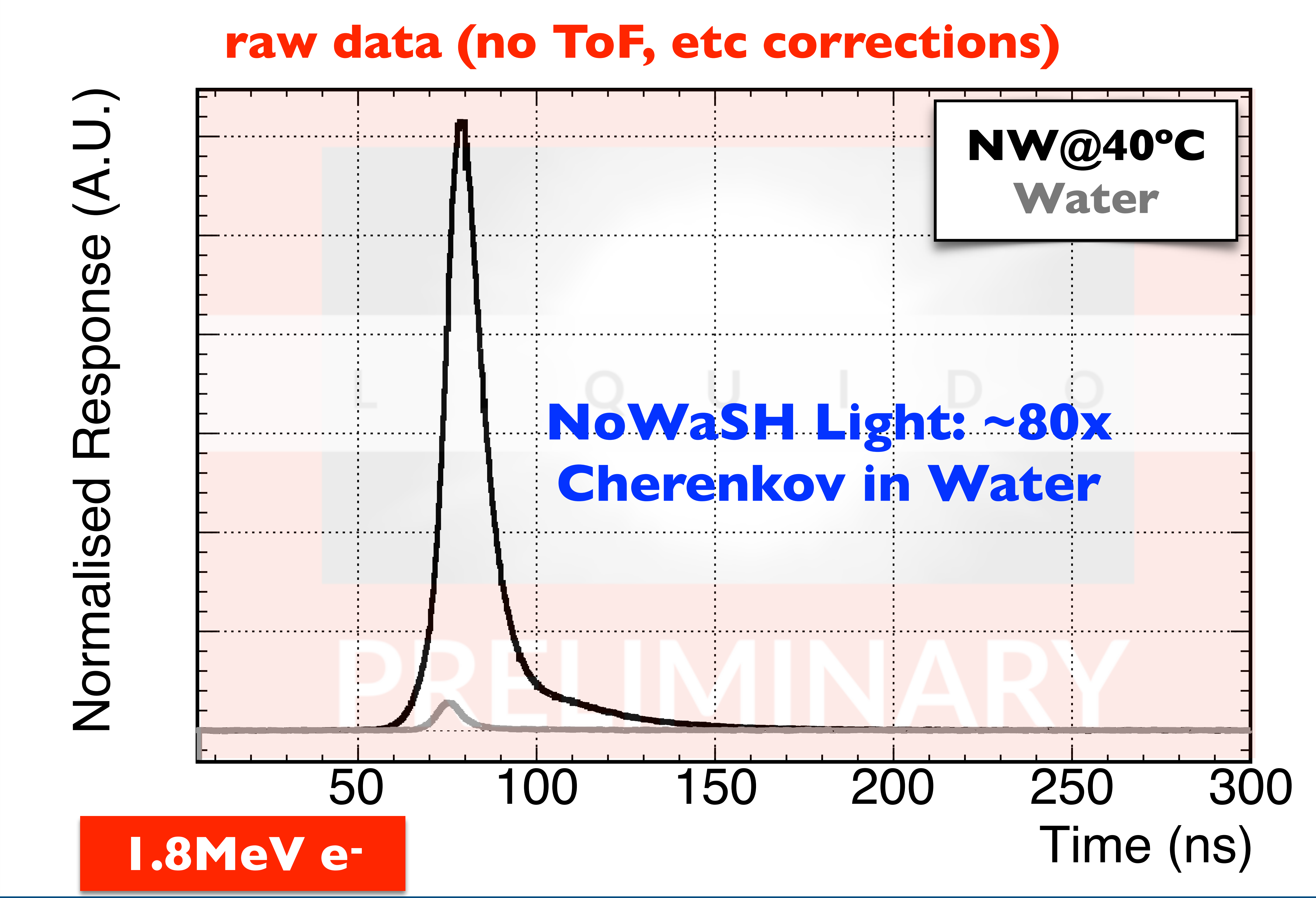
✓~8.7x more light wrt water

✓with PPO (< 3 g/L) we expect an additional 4x increase

Using water-data we can extract the fraction of Cherenkov light that excite the scintillator

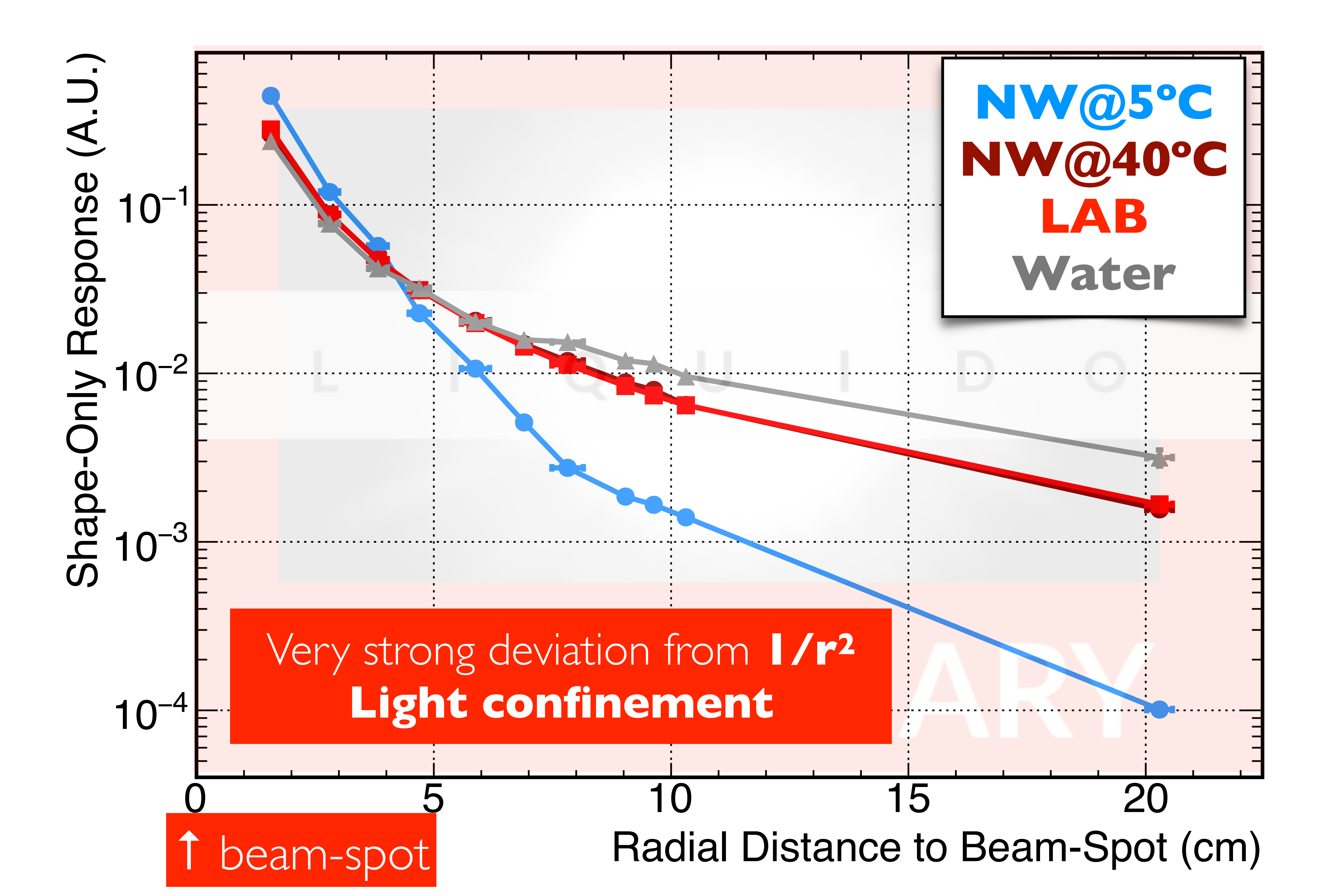
NoWaSH @40º : Scintillation, no Cherenkon

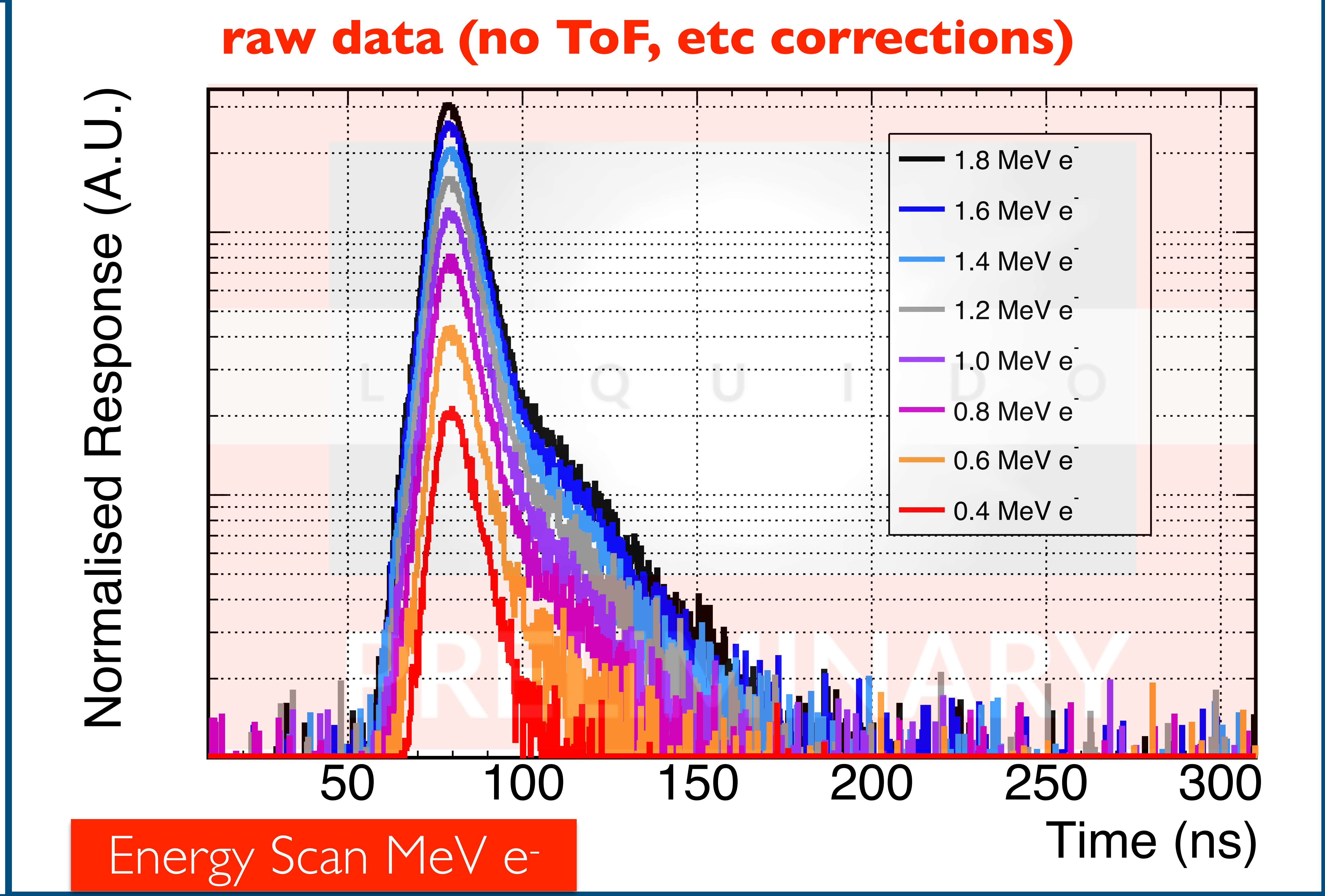




- At 40º NoWaSH is almost transparent (on the scale of MINI detector)
- Cherenkov light reduced by the paraffin (under investigation)

NW@5º : LiquidO (scintillation)



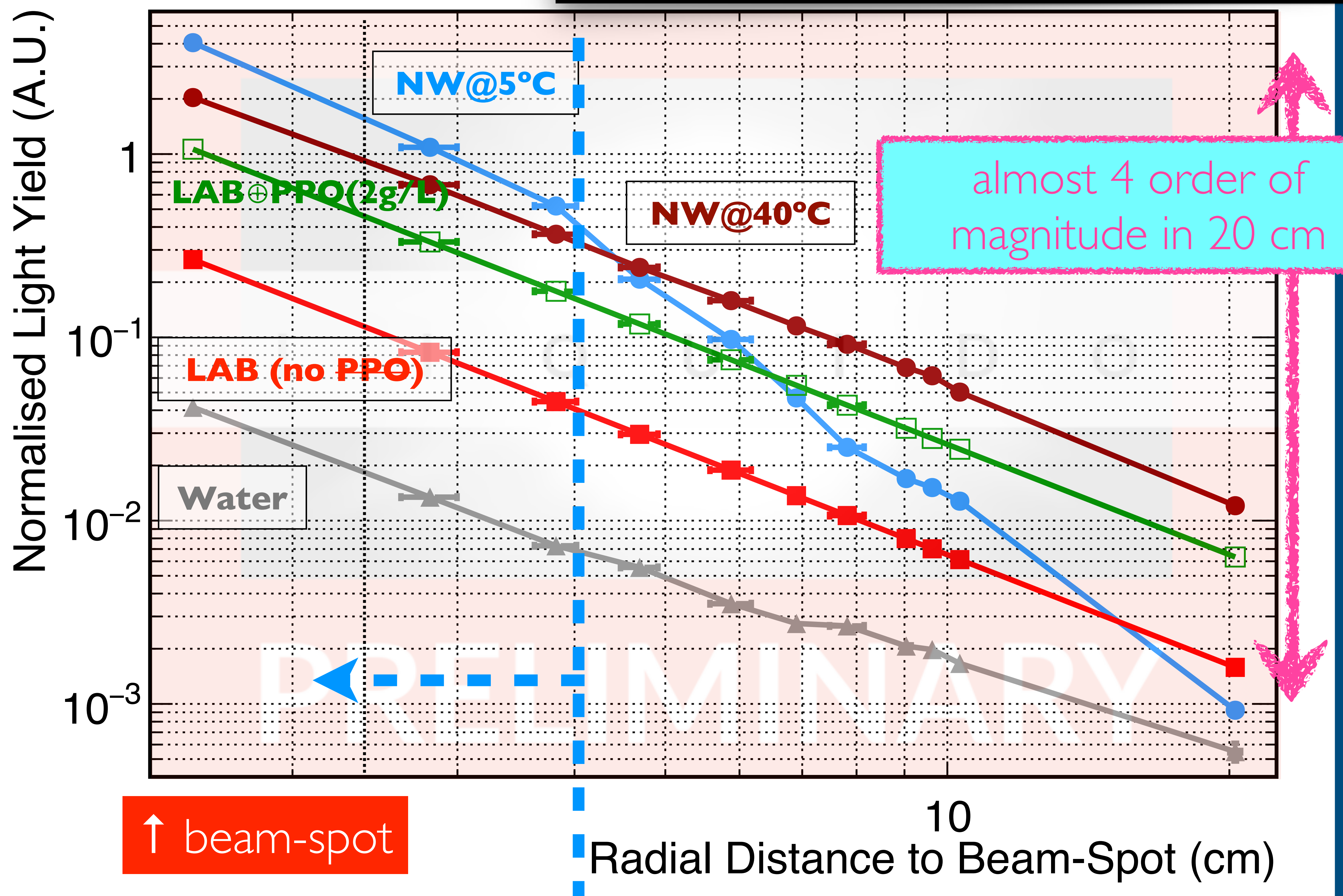


Strong deviation of the light profile due to the trapping of the light close to the production point = LiquidO

Transparent to opaque transition

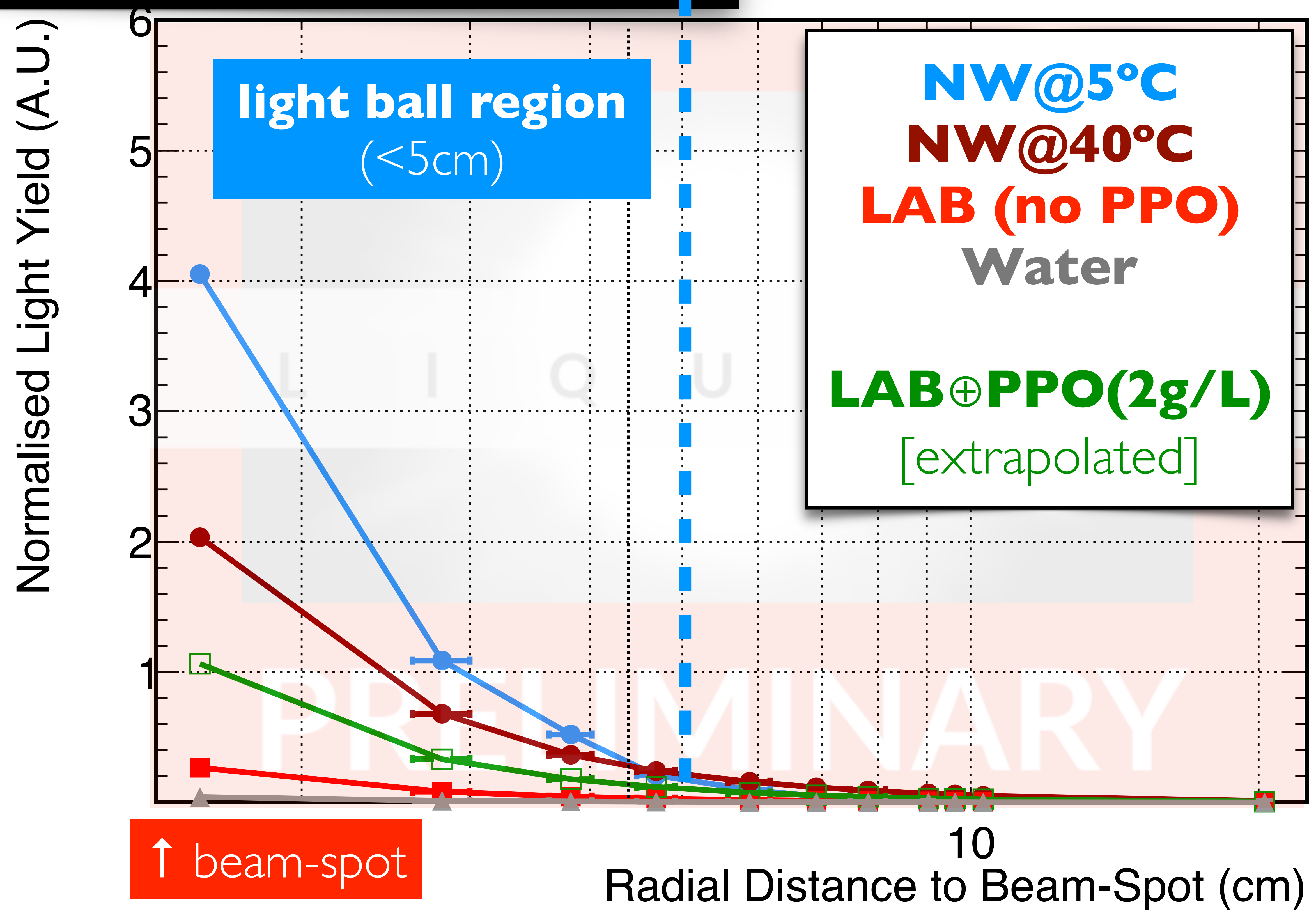
Light yield

LiquidO: ~80% light collected within 5 cm's



↑ beam-spot

Linear scale



↑ beam-spot

light ball region (<5cm)

- ✓ effective detected light yield >120PE/MeV [@ SiPM]
- ✓ ≥250PE/MeV — optimisation (ongoing engineering)

Topology PID (no timing)

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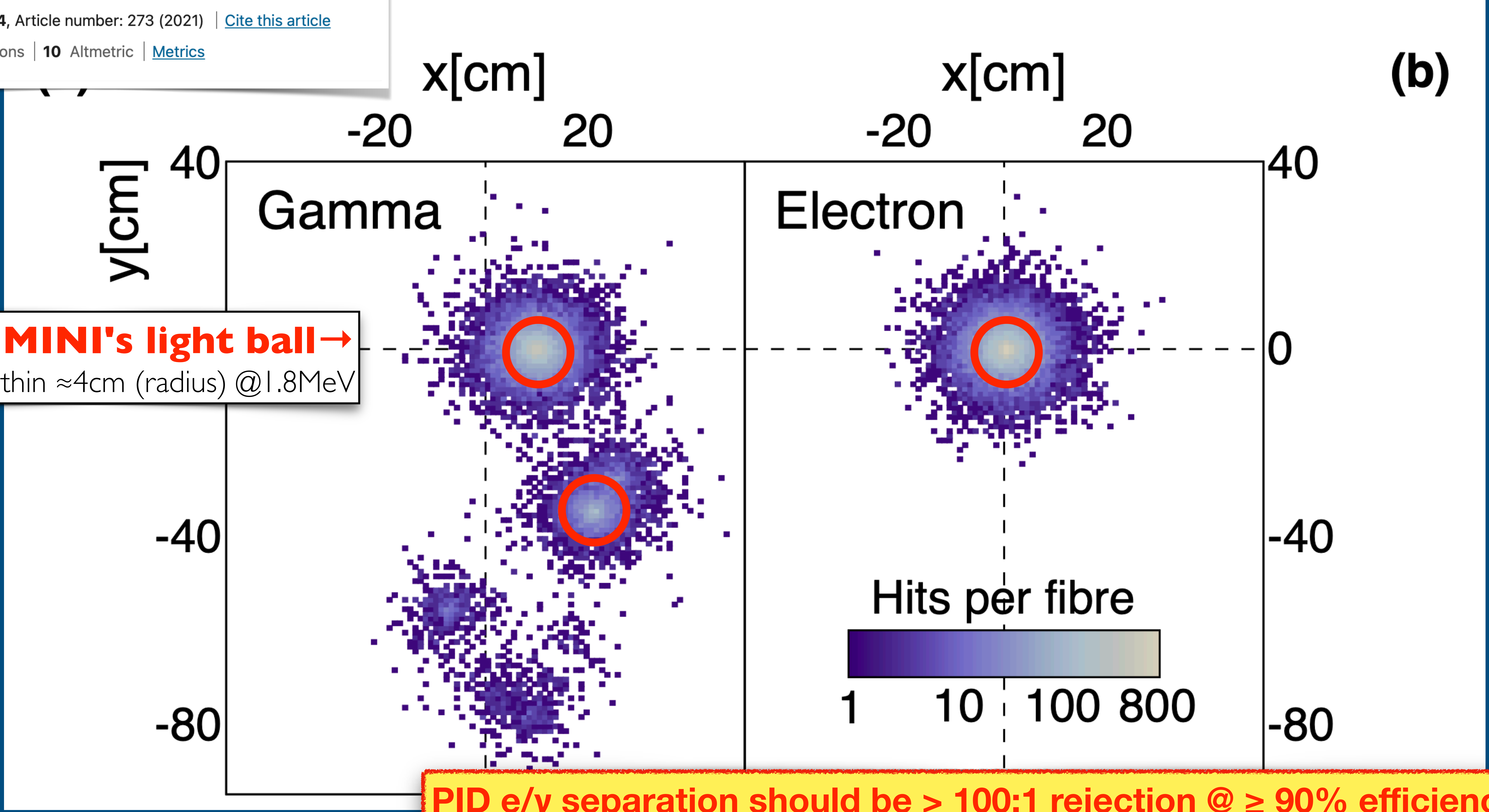


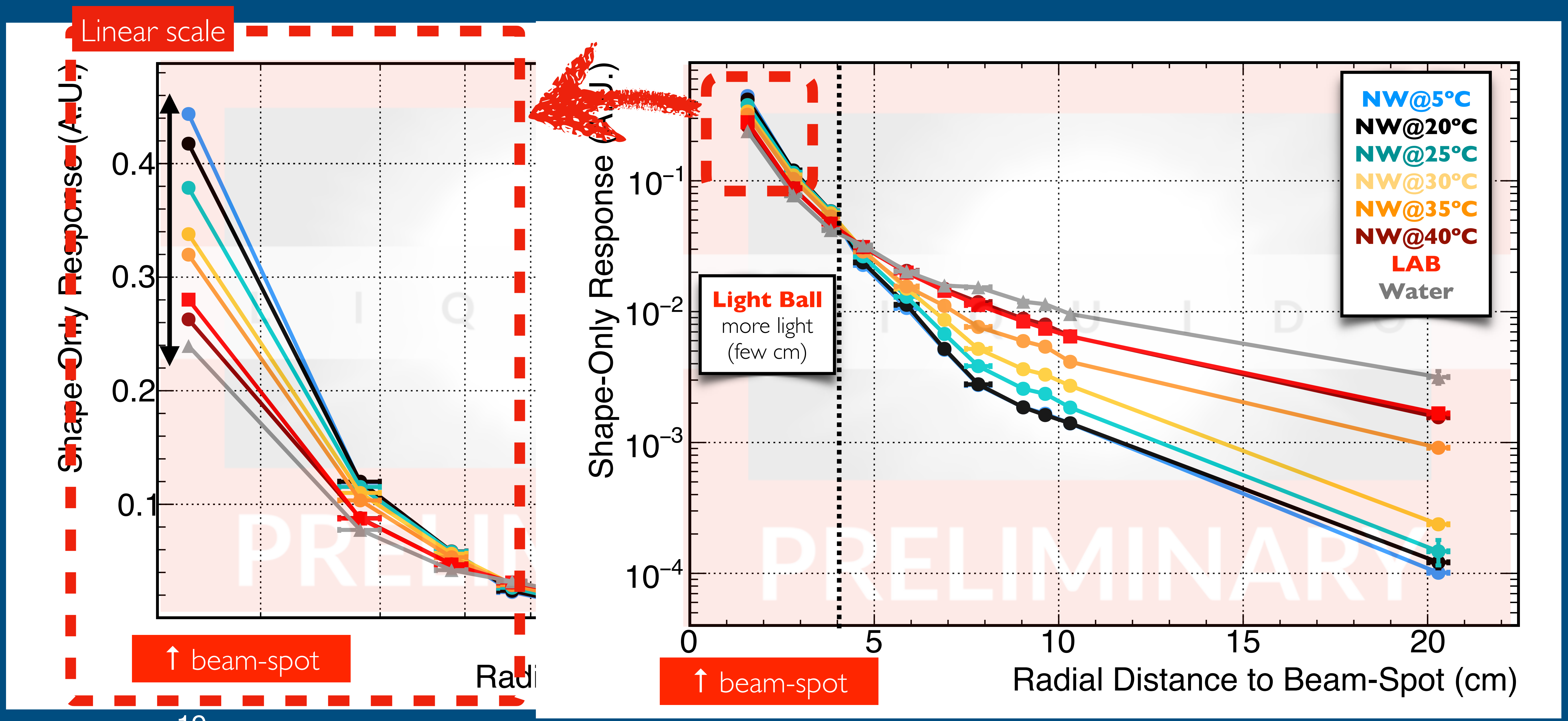
MINI's light ball→
~80% light within ≈4cm (radius) @1.8MeV

PID e/γ separation should be > 100:1 rejection @ ≥ 90% efficiency

Conclusions

With Micro & Mini LiquidO we have demonstrate

- ✓ Opaque medium → Stochastic light confinement
- ✓ In opaque medium light ball can be read using an array of optical fibres
- ✓ LiquidO principle works with any type of
  - light, not only scintillator
  - media (liquid, solid, …)



Summary

LiquidO = **light detector** with **opaque** medium

stochastic light confinement —> imaging & PID

light base "TPC" (highest duty cycle)

imaging (PID, tracking, energy flow…)

uniform calorimeter (with scintillator medium)

Time-of-Flight (4π acceptance)

doping (new physics)

first experiment…

Check out also today talks at 17:00 in Neutrino Physics session (Room 2) "The SuperChooz Pathfinder Exploration" A.Cabrera

European Innovation Council

UK Research and Innovation

C L O U D

Innovation Programme (confidential for now) — "Antimatter-OTech"
Fundamental Science Programme (soon)

- **EDF** (France) — **first time in neutrinos!**
- **CIEMAT** (Spain)
- **IJCLab**/Université Paris-Saclay (France)
- **J-G Universität Mainz** (Germany)
- **Subatech**/Nantes Université (France)
- **Sussex University** (UK)

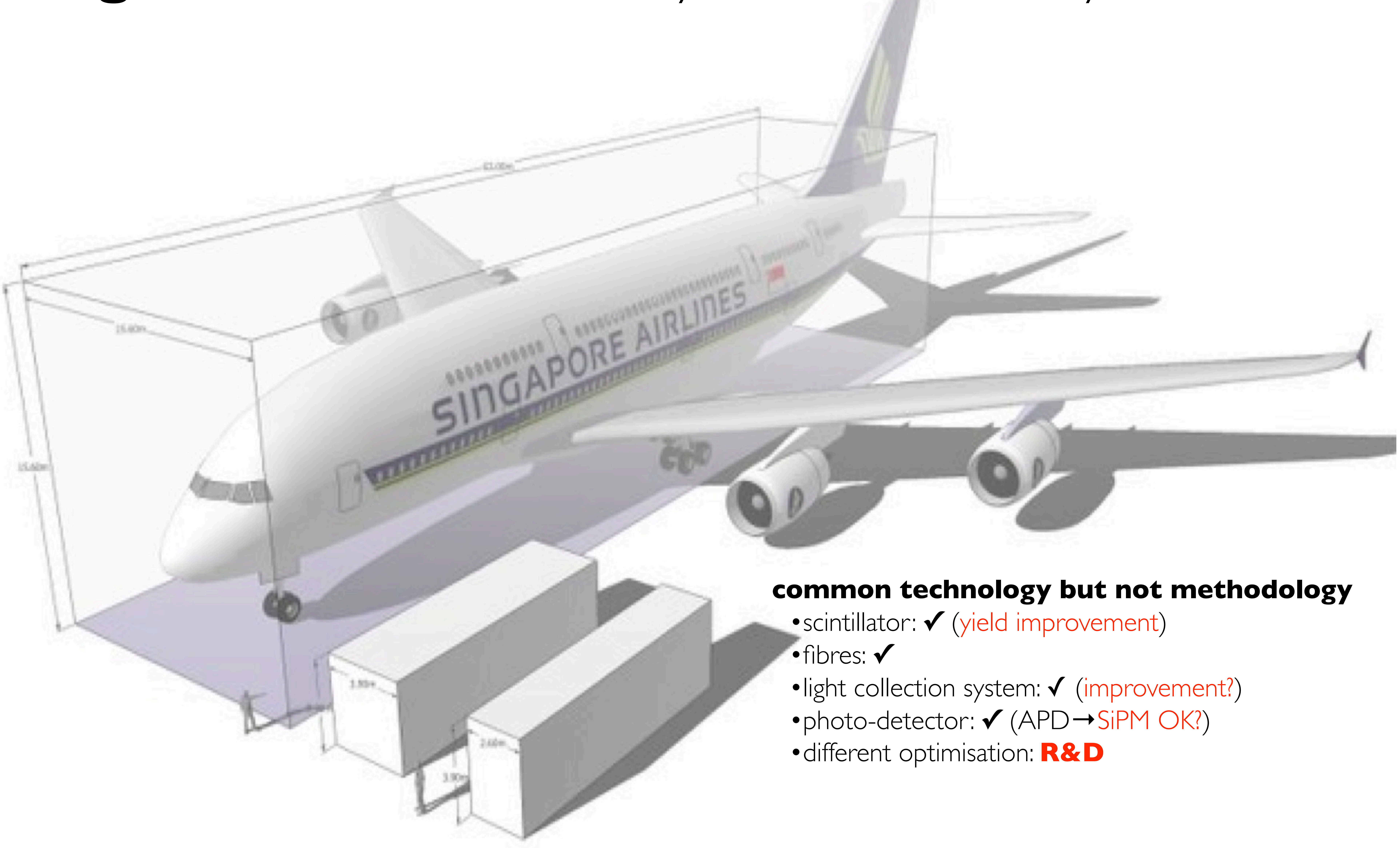
—

- **Charles University** (Czech Republic)
- **INFN-Padova** (Italy)
- **UC-Irvine** (US)
- **Universidade Estadual de Londrina** (Brasil)
- **PUC-Rio** de Janeiro (Brasil)
- **Queen's University** (Canada)
- **University of Zaragoza** (Spain)
- **Tohoku University** / **RCNS** (Japan)

CLOUD collaboration (EDF⊕13 institutions over 10 countries)

Thank you…

scaling to tons? much already demonstrated by **NOvA**…



common technology but not methodology

- scintillator: ✓ (yield improvement)
- fibres: ✓
- light collection system: ✓ (improvement?)
- photo-detector: ✓ (APD→SiPM OK?)
- different optimisation: **R&D**

PID(e⁻:γ) @ 2MeV

e/γ separation only with pattern, no timing

100:1 rejection @ ≥ 90% efficiency

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