Optimized (organic) scintillators for future neutrino experiments

Neutrino 2022, Seoul (virtual)

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

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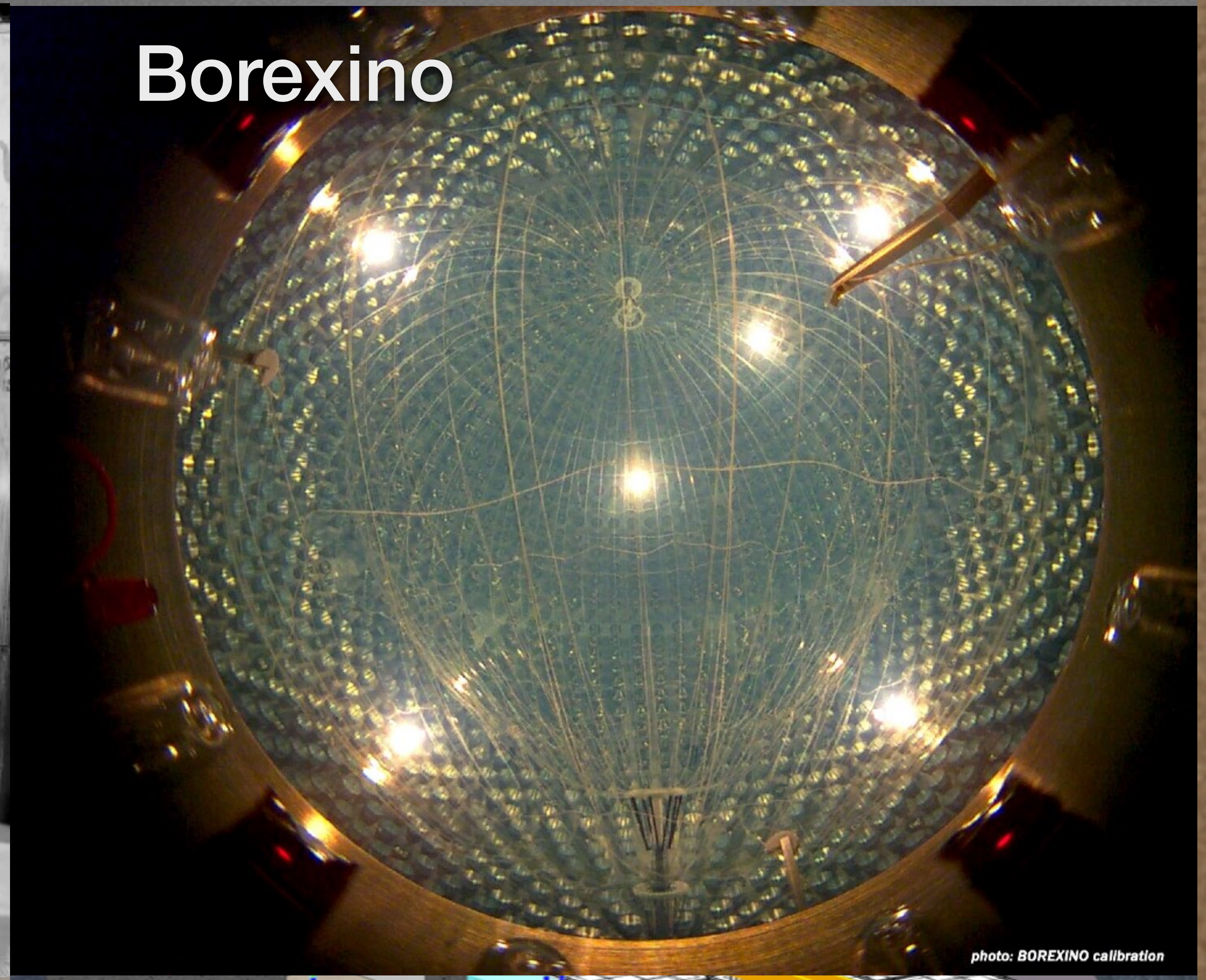
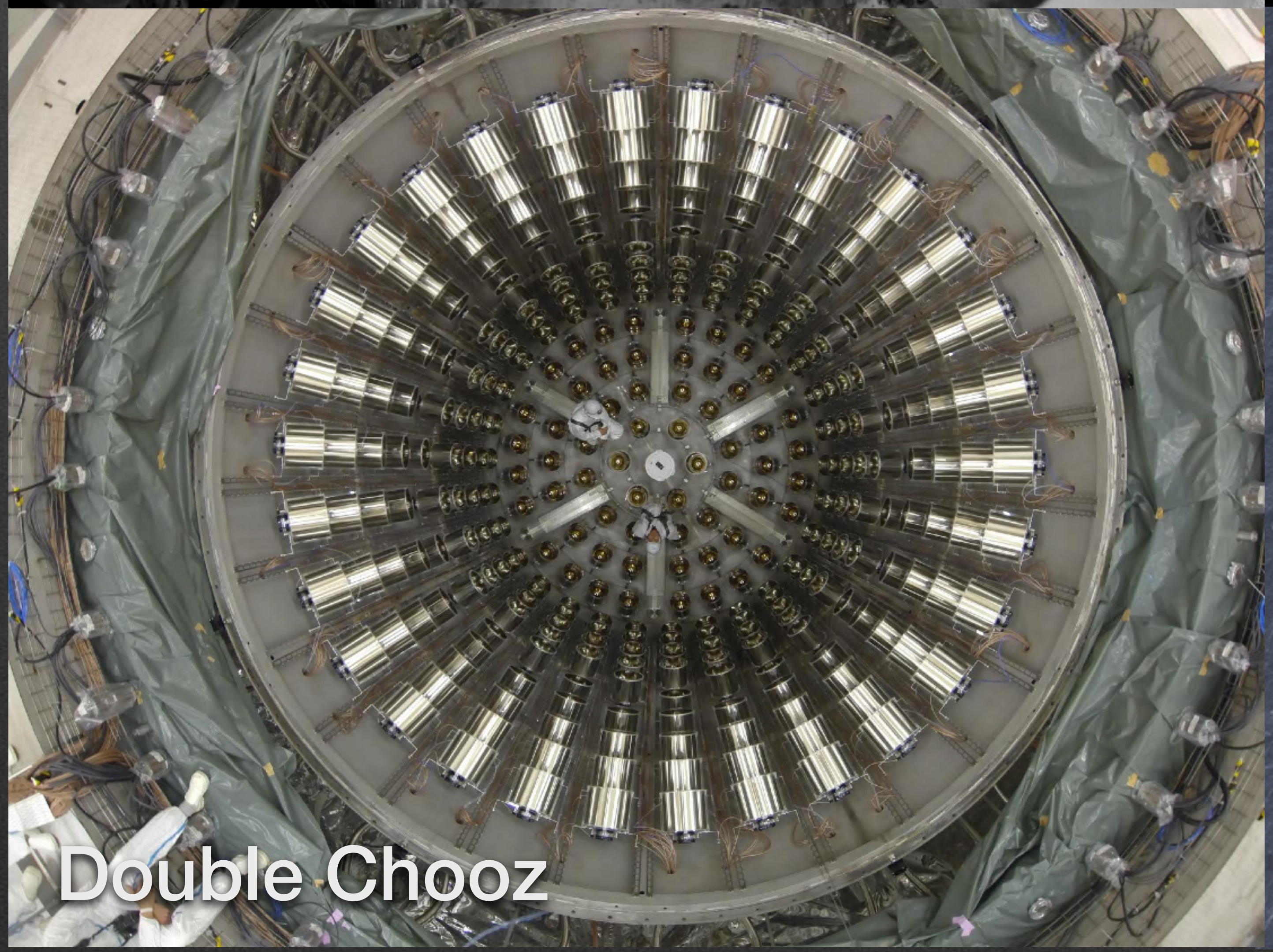
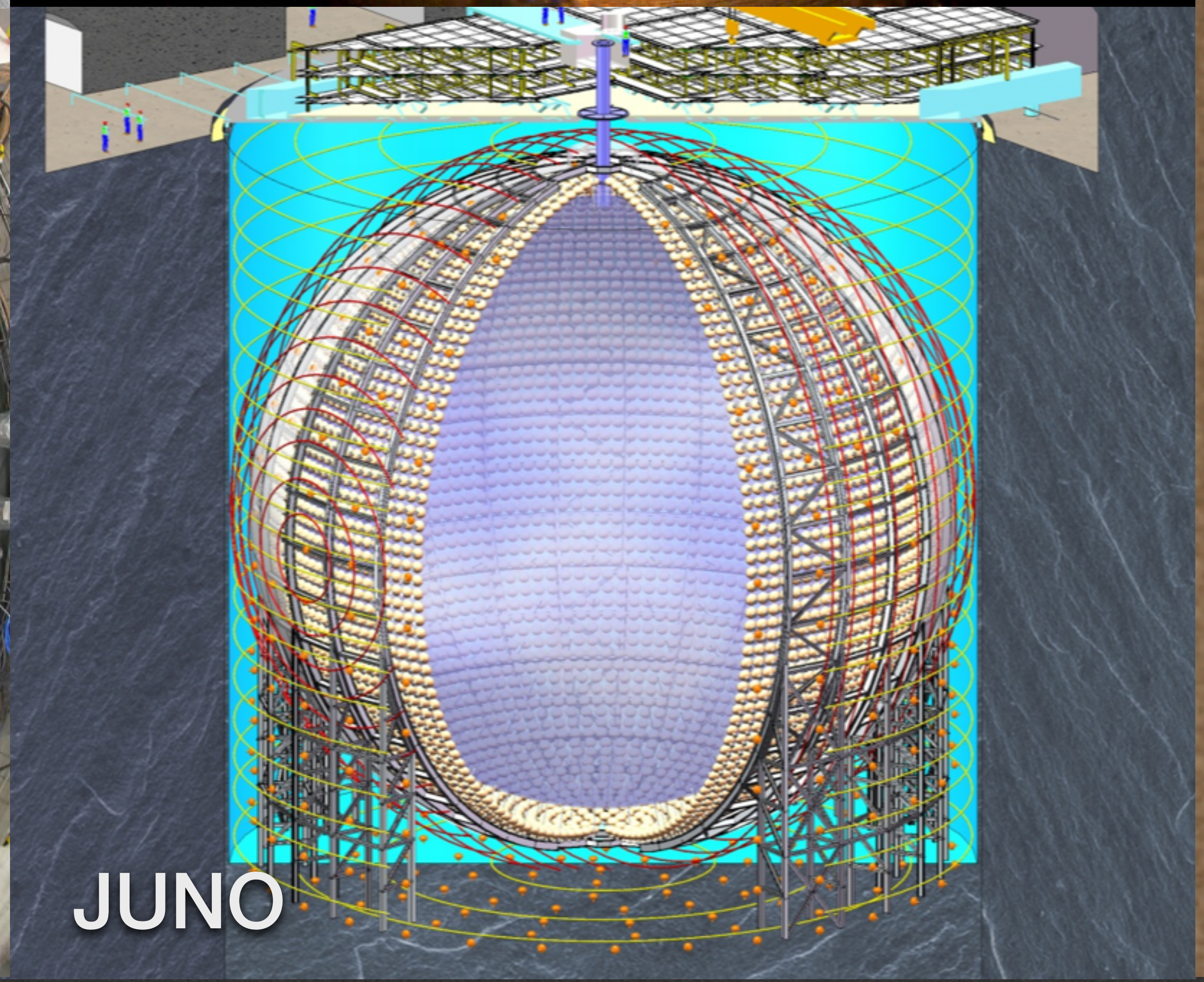
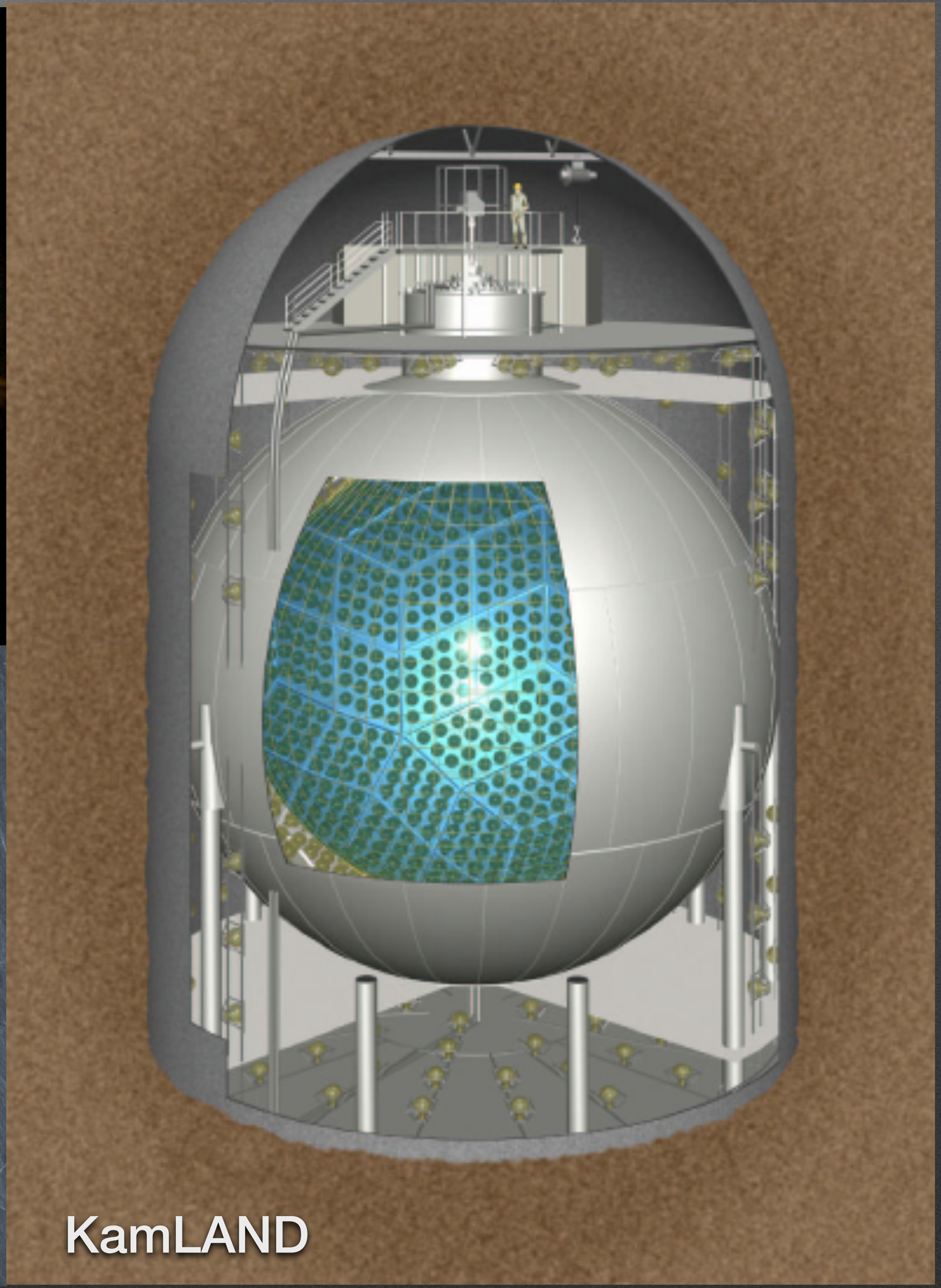
Liquid scintillator detectors

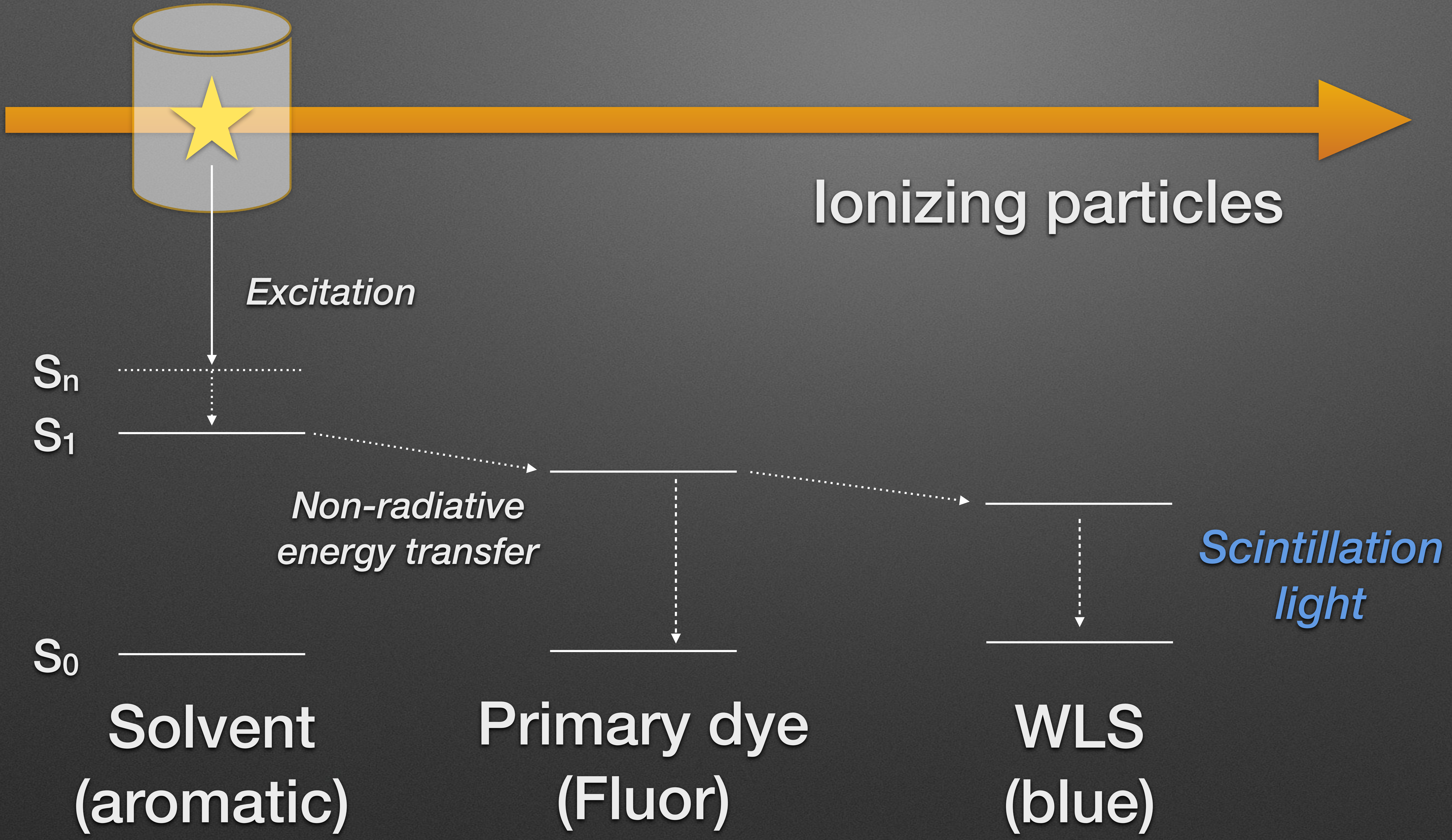


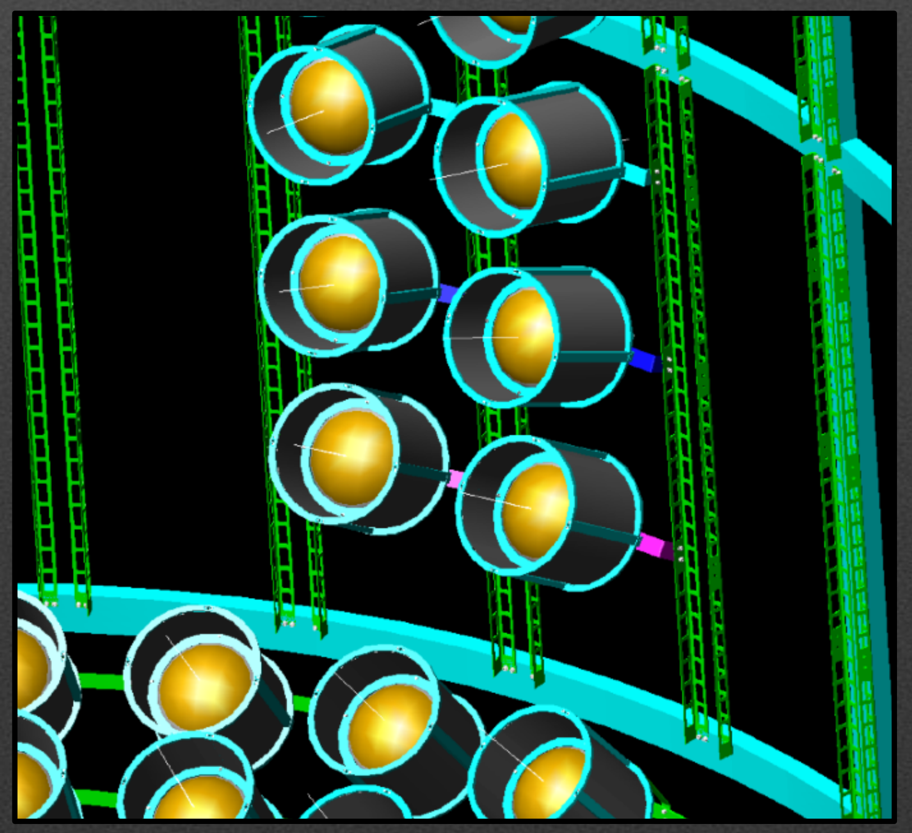






Composition





Photosensors

Safe scintillators - definition?

Most classical LS
not classified toxic

Most common
criterium: flash point
(< 93°C flammable)

Many LS called „safe“
harmful or hazardous

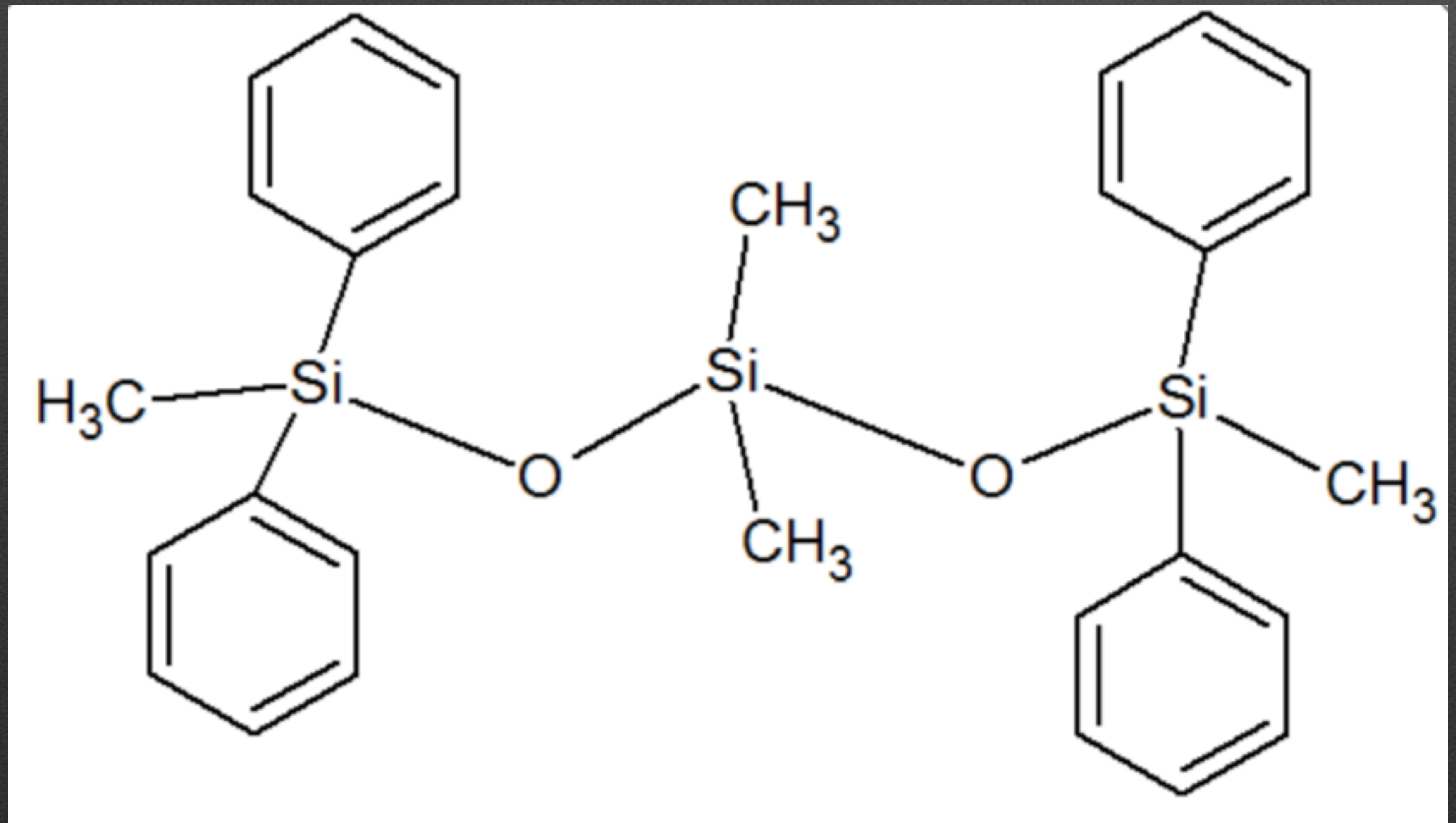
Very important in
case of spill

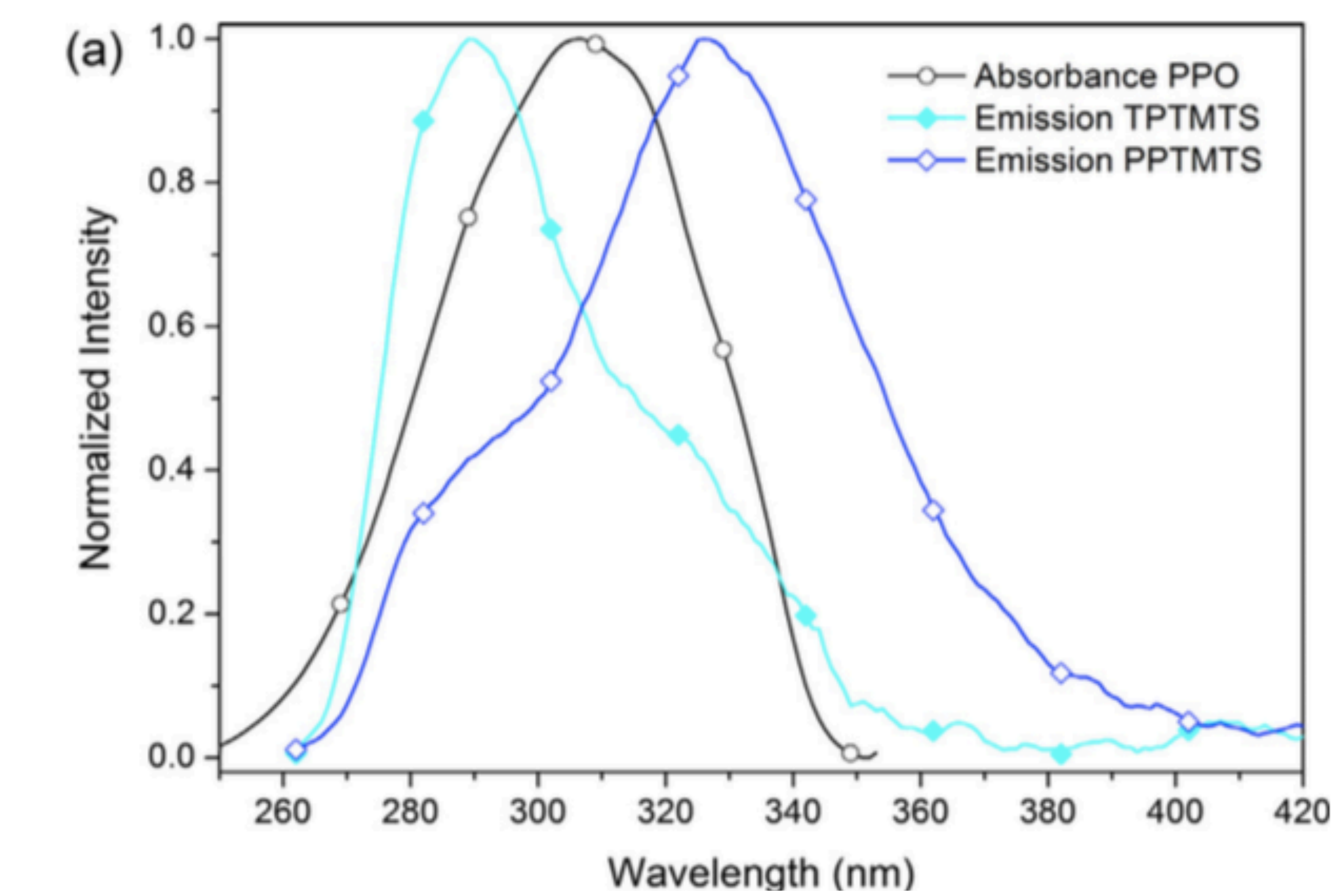
Other relevant property: Should be odorless

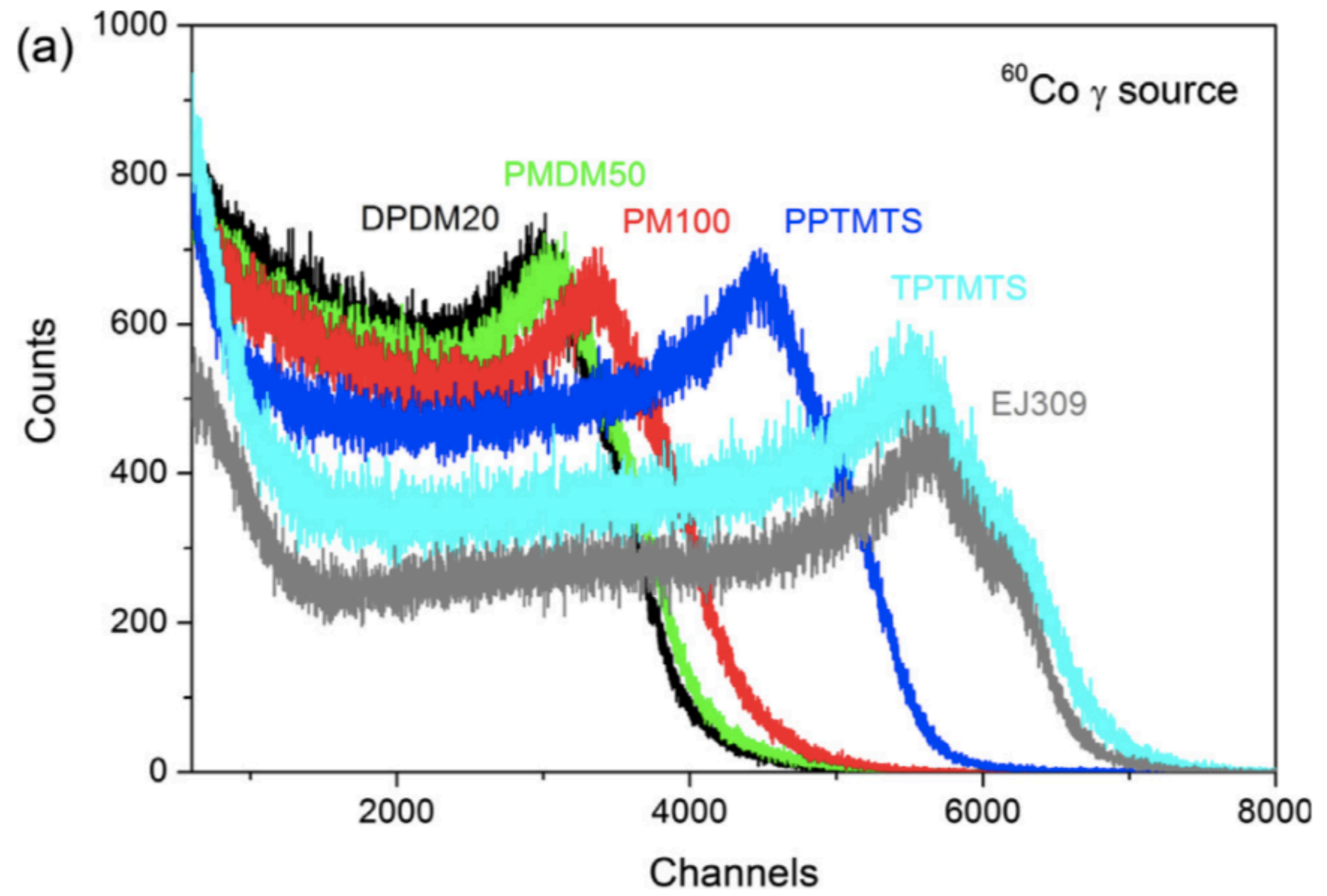
Typical „safe“ solvents: LAB, DIN, PXE, mineral oil,… (flash points > 100°C)

Polysiloxane based detectors

- Non hazardous (safer than the other safe)
- Strong Si-O instead of C-C bonds (robust!)
- Less radical formation (more stable!)
- Viscosities: 33 cSt - 10000 cSt
- Low vapor pressure (used in diffusion pumps)
- Density > 1 kg/l and higher Z

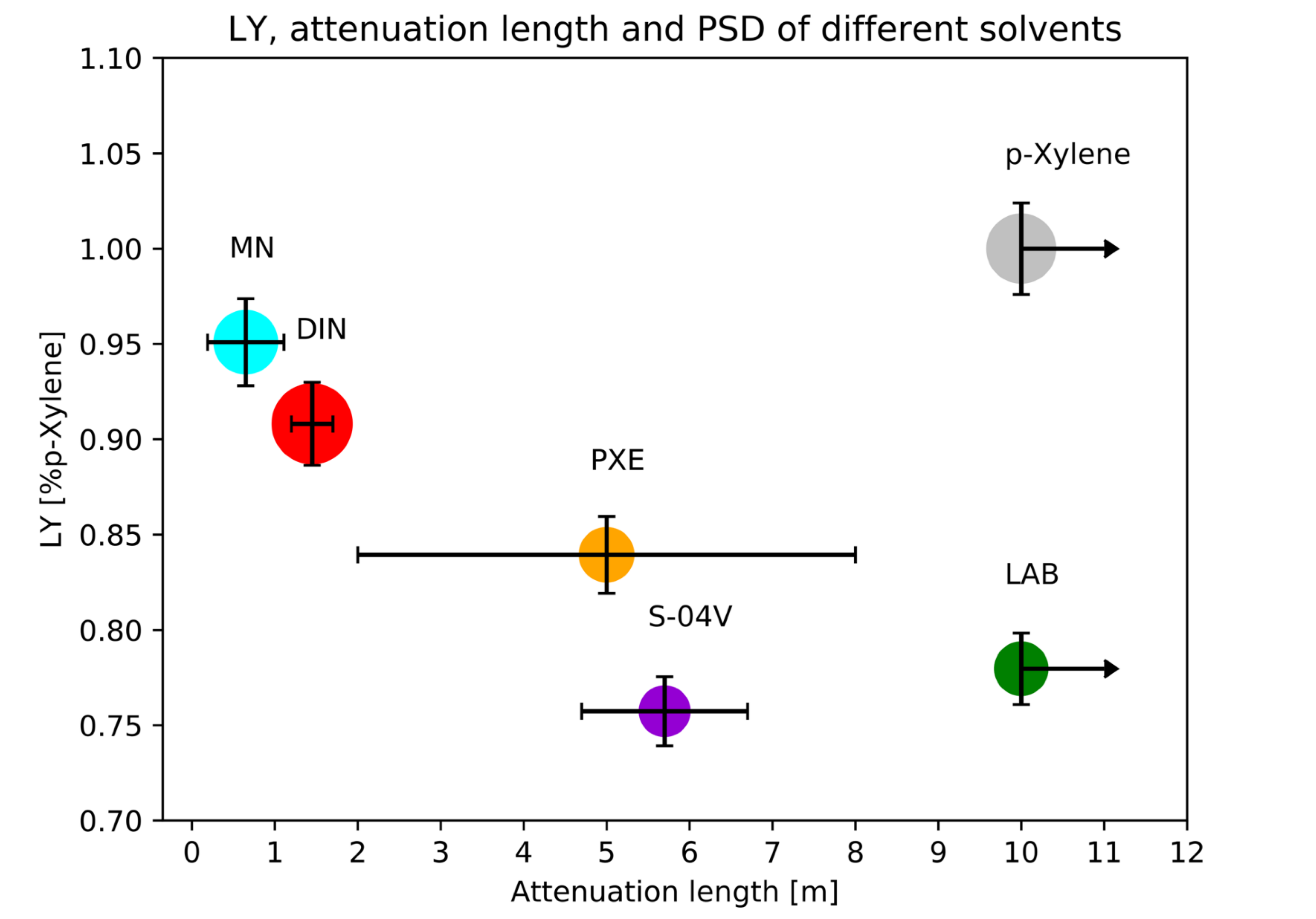






M. Dalla Palma et al., Optical Materials 42 (2015) 111

Comparison of performance



A.Bonhomme et al., arXiv:2205.15046

	DENSITY	FLASH POINT	VAPOR PRESSURE
XYLENE	0.86 kg/l	27°C	900 Pa
METHYL-NAPHTALENE (MN)	1.02 kg/l	82°C	200 Pa
LAB	0.86 kg/l	140°C	1.3 Pa
DIN	0.96 kg/l	140°C	0.5 Pa
PXE	0.99 kg/l	167°C	0.1 Pa
POLYSILOXANE (S-04V)	1.07 kg/l	230°C	~10^{-5} Pa

- Results vary with purity, storage conditions, sample preparation, setup, supplier,…
- Parameters can be tuned by mixture of solvents

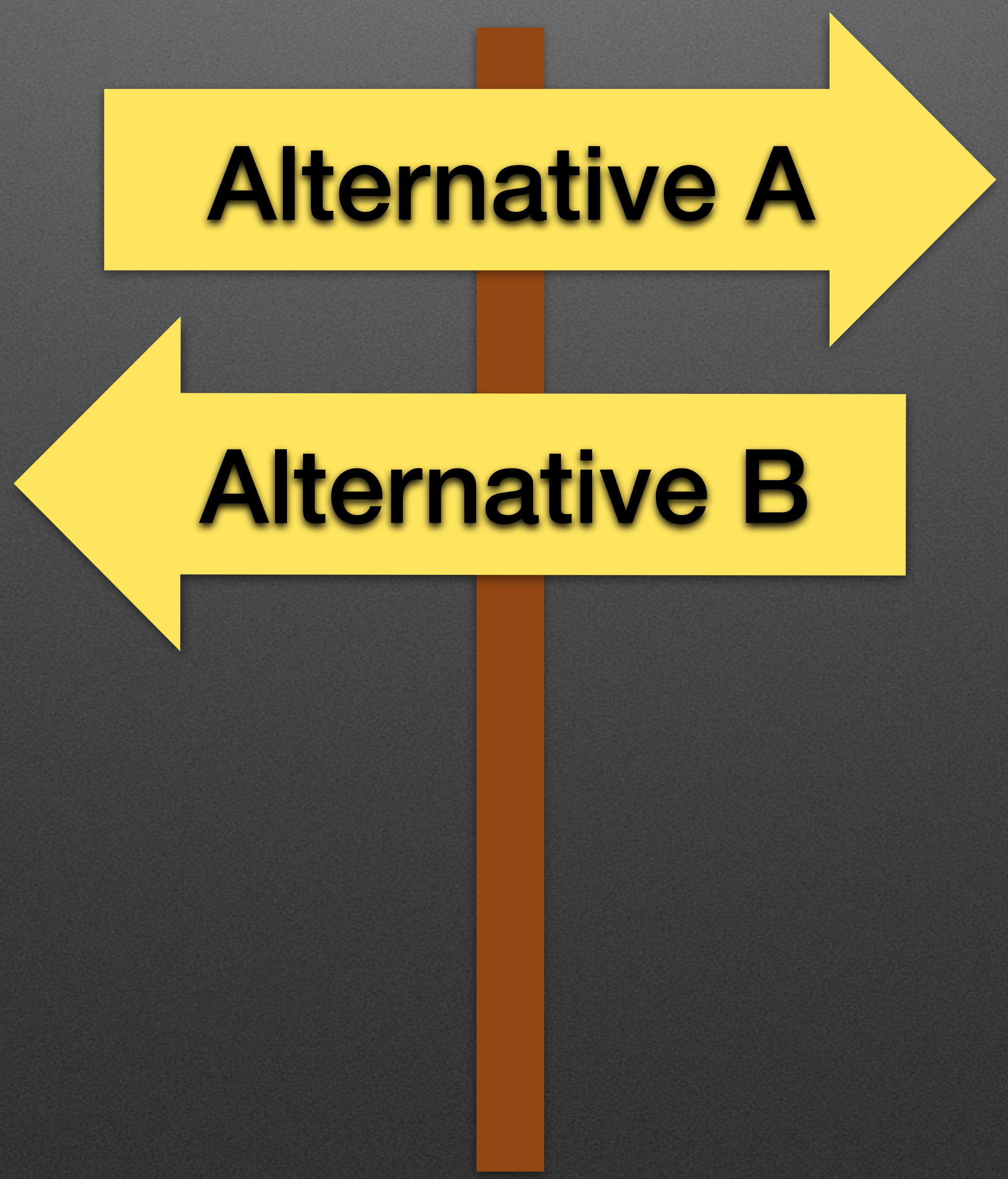
Best solution?

First define your primary goals, main requirements

Transparency: LAB	High LY, PSD: DIN	Safety: Polysiloxane
Large detector (e.g. JUNO)	Neutron detector (particle identification)	Special environment (reactor, underground)

Other factors: costs, availability, density, material compatibility, H fraction…

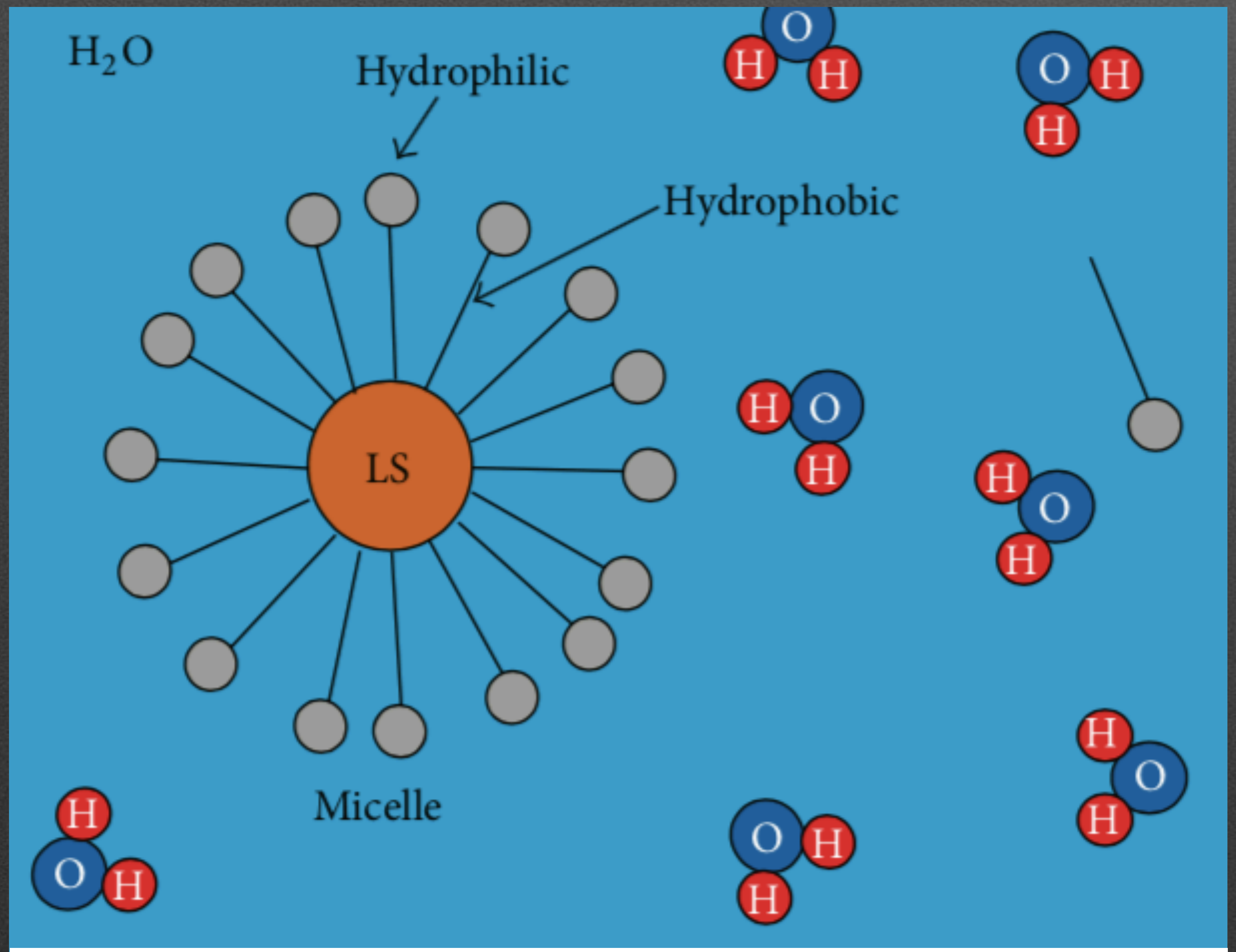
Current ideas on non-standard approaches



Water based liquid scintillators

Transparent ~~organic~~ liquid scintillators

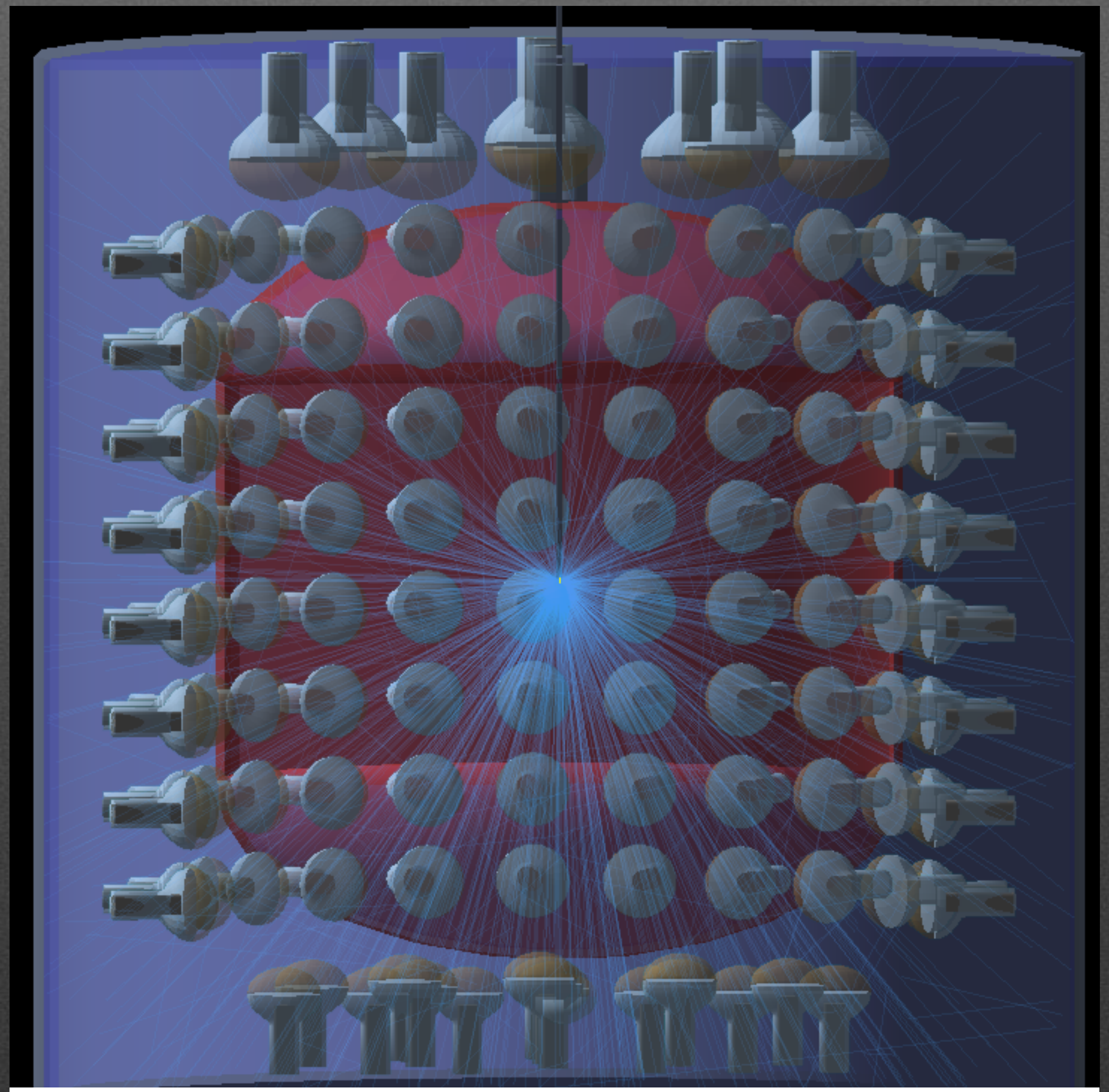
Concept



S.H. So et al., Adv.High Energy Phys. 2014 (2014) 327184

Organic (1-10%), surfactant, H_20

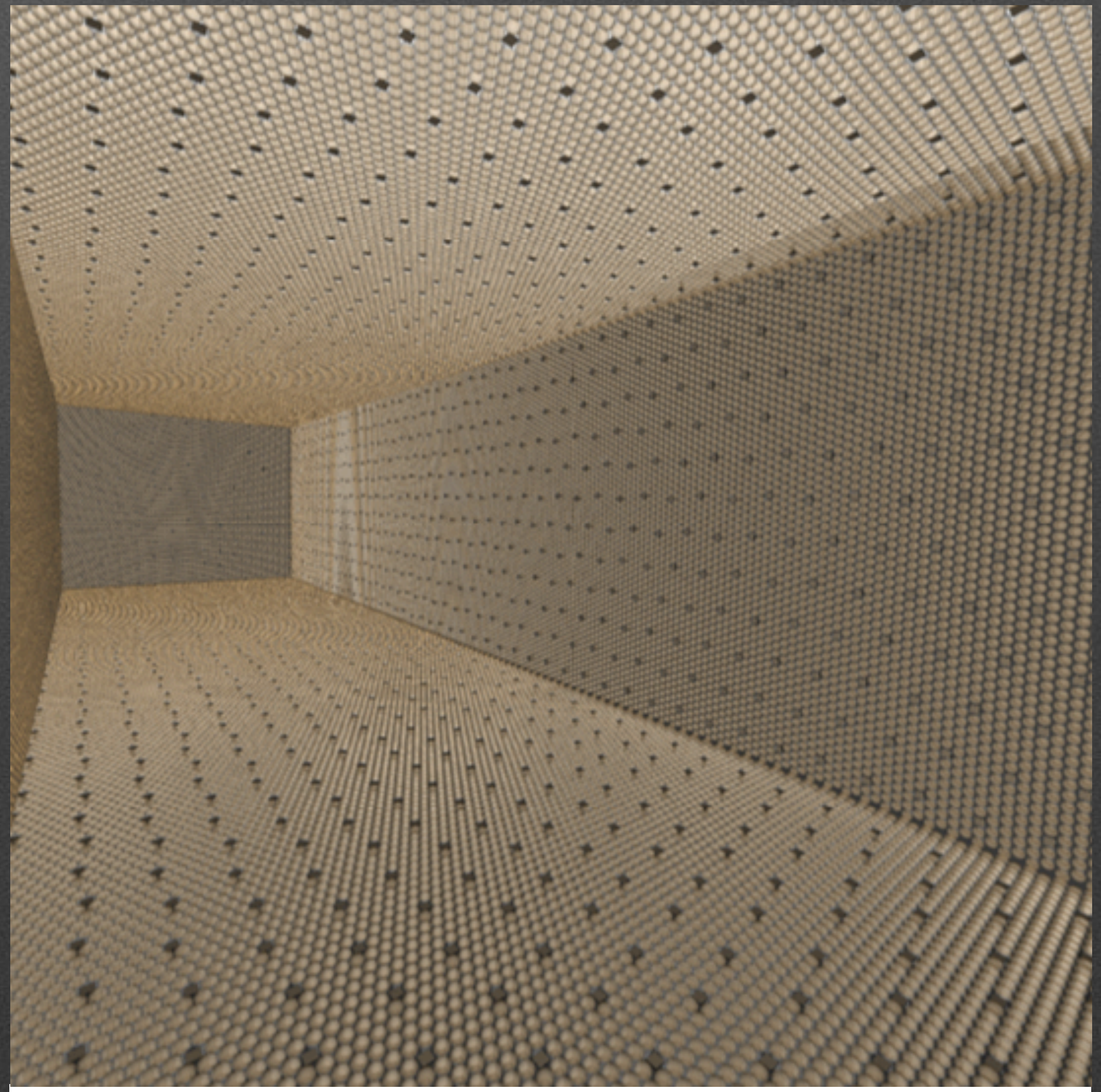
R&D (ton scale)



https://nino.lbl.gov/eos/home.html

EOS, Annie

Large scale plans



Klein et al..,arXiv:2203.07479

Theia, Watchman

Gel forming scintillators

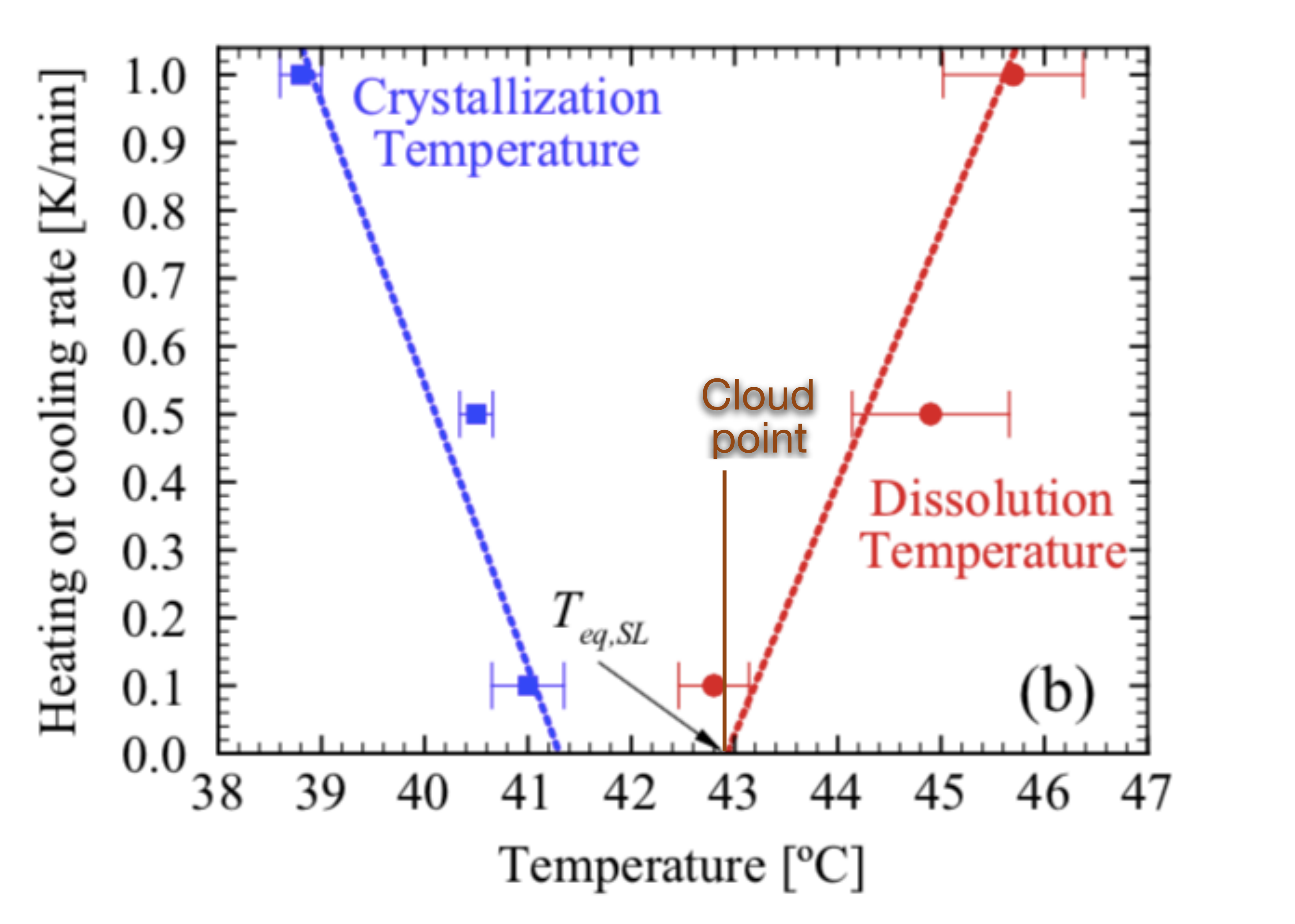
Transparent organic ~~liquid~~ scintillators

- Best of plastic and liquid
  - Liquids: safety issues, spills, convection
  - Solid: dead volumes, more complicated production, fragile (transport, vibrations,…)
- Examples:
  - Gel scintillation counting (T.K. Bell, J.Clin.Path., 20 (1967) 629)
  - CaF_2 scintillator for DM searches (N.J.C. Spooner et al., Astr.Phys. 8 (1997) 13)
  - Tin-LS for γ/neutron detection (X.Wen et al., NIM A 897 (2018) 47)
- Grains of insoluble materials can be suspended in gel —> metal loading!

Viscosity 10000 cSt

Wax based scintillators

- Paraffins: radiopure, low absorbance, non-hazardous
- Production: paraffin pellets are added to LAB + PPO mixture
- Heat to 60°C and slowly cool down —> crystallization
- Wax/oil mixtures studied in crude oil production (cold pipes)
- Metastable region between crystallization and dissolution T



Andrade et al., Fuel 206 (2017) 516–523

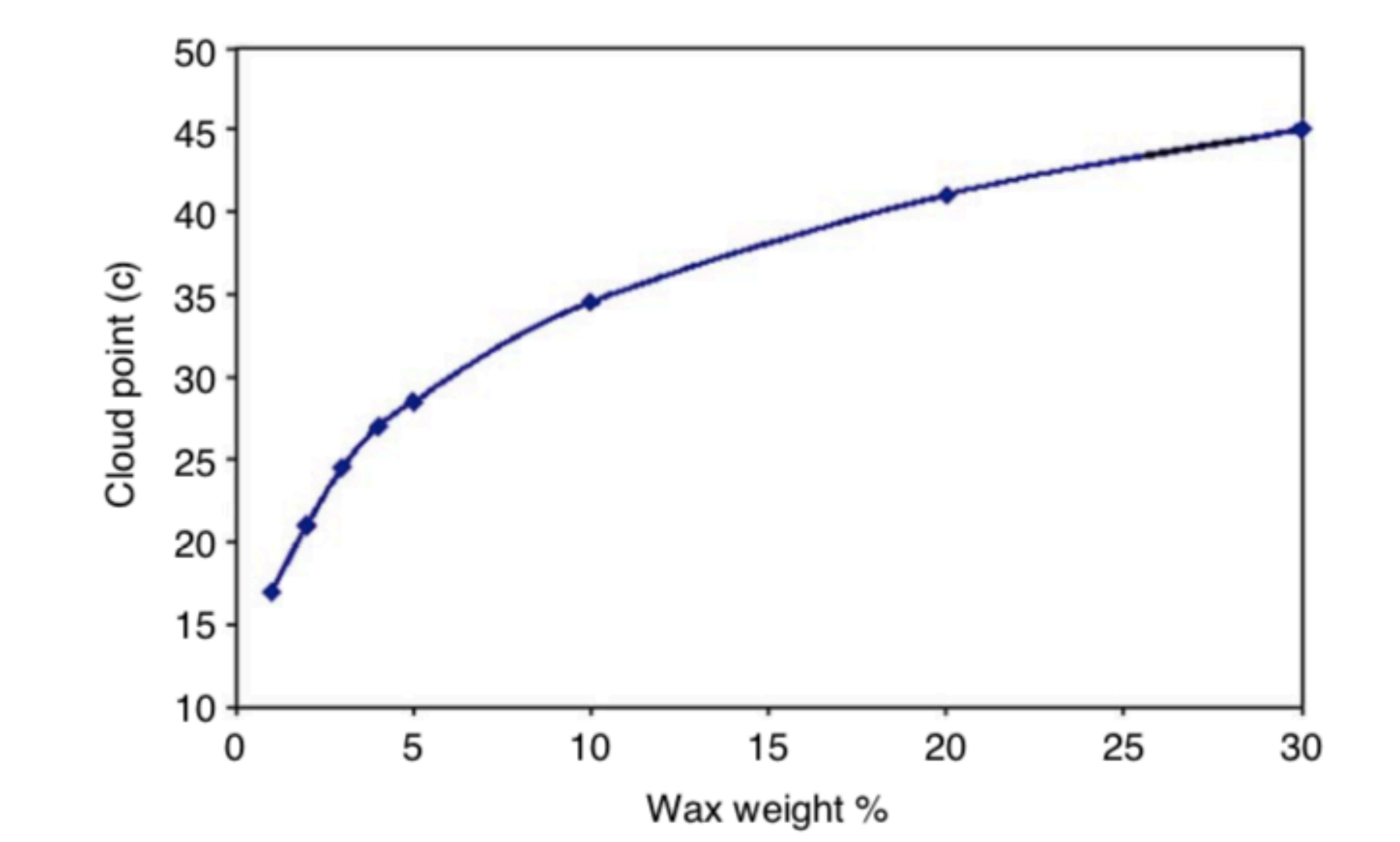


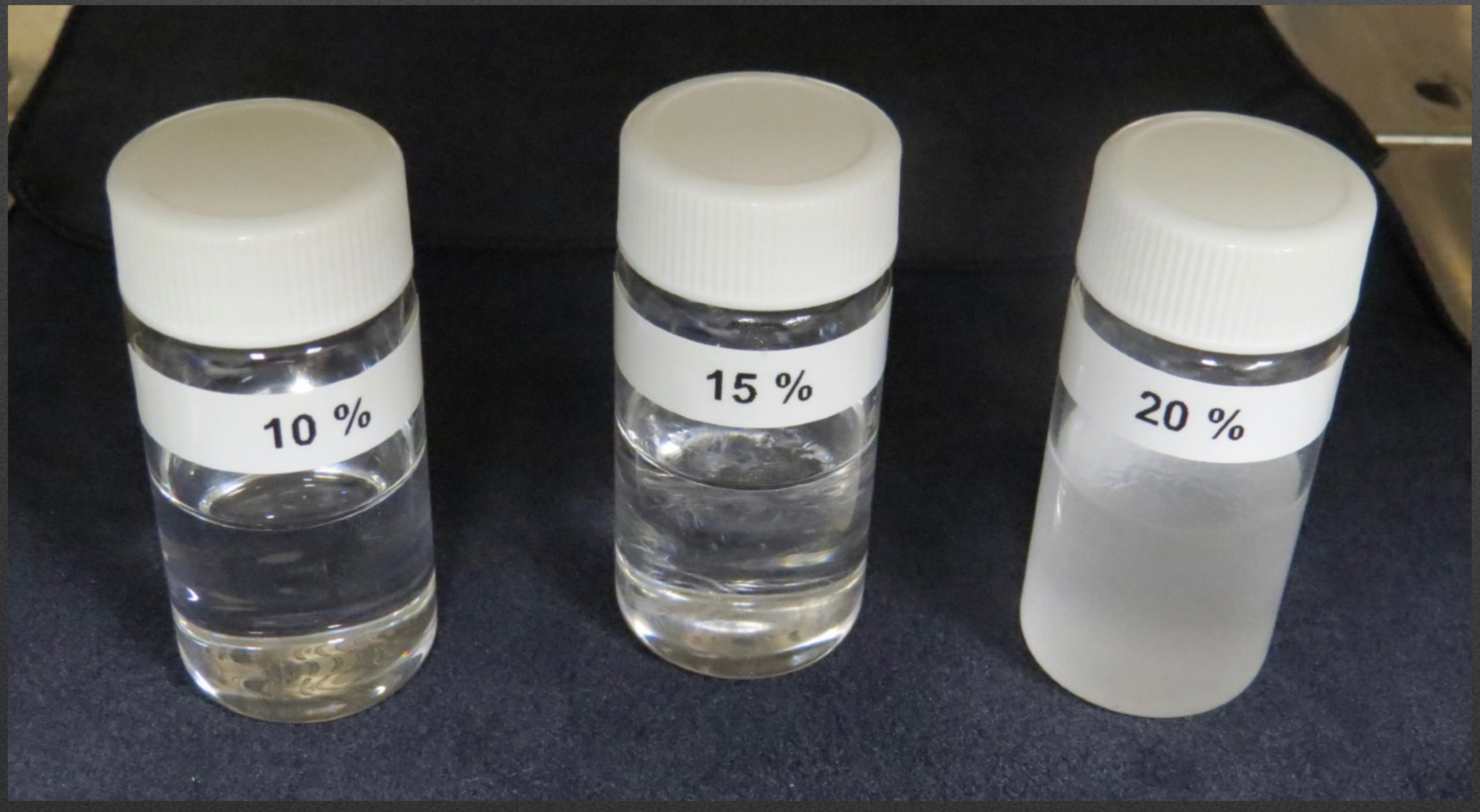
Fig. 5. Cloud point curve for paraffin wax in Coray-15.

R.Venkatesan et al., Chem. Eng. Science 60 (2005) 3587–3598

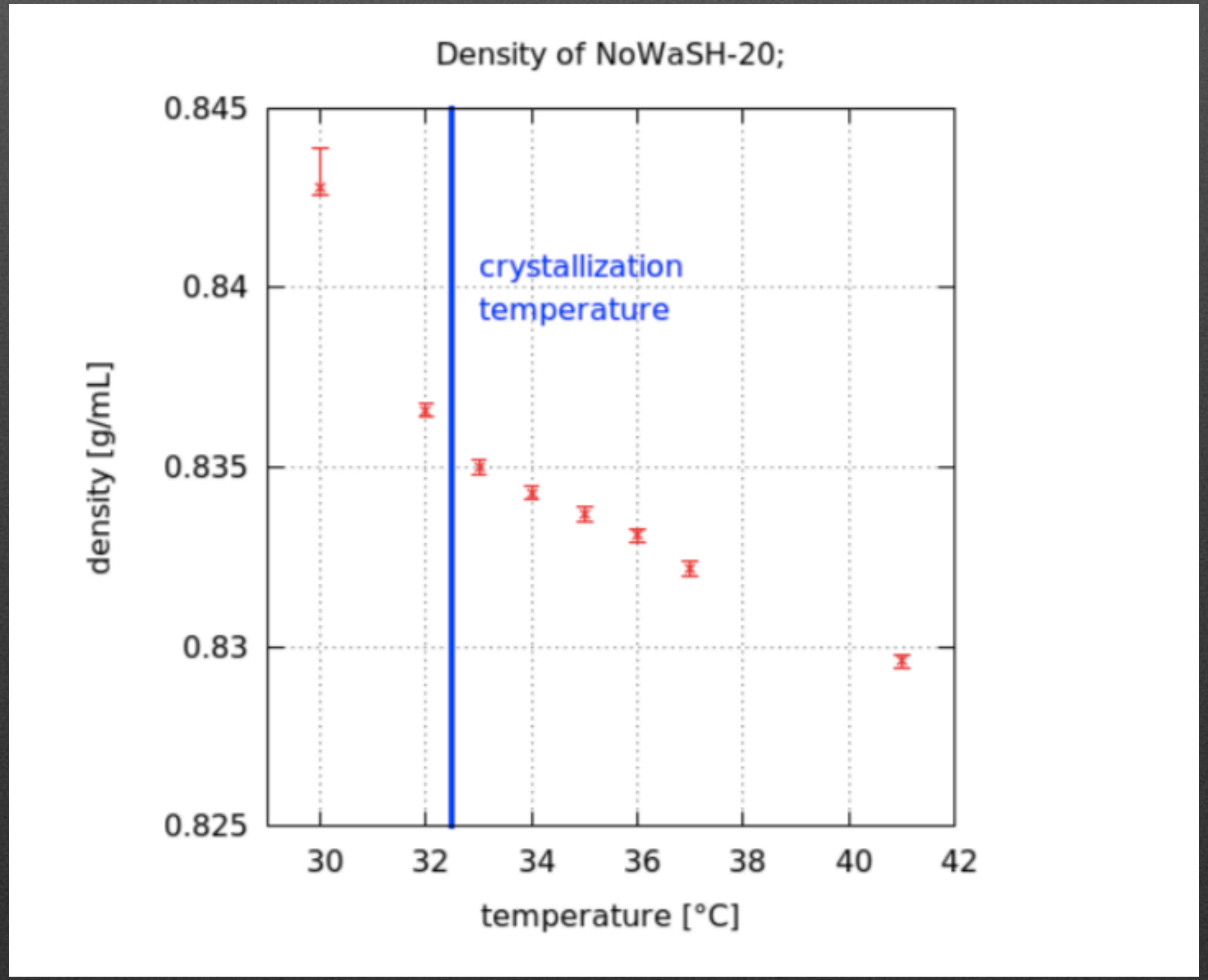
NoWaSH

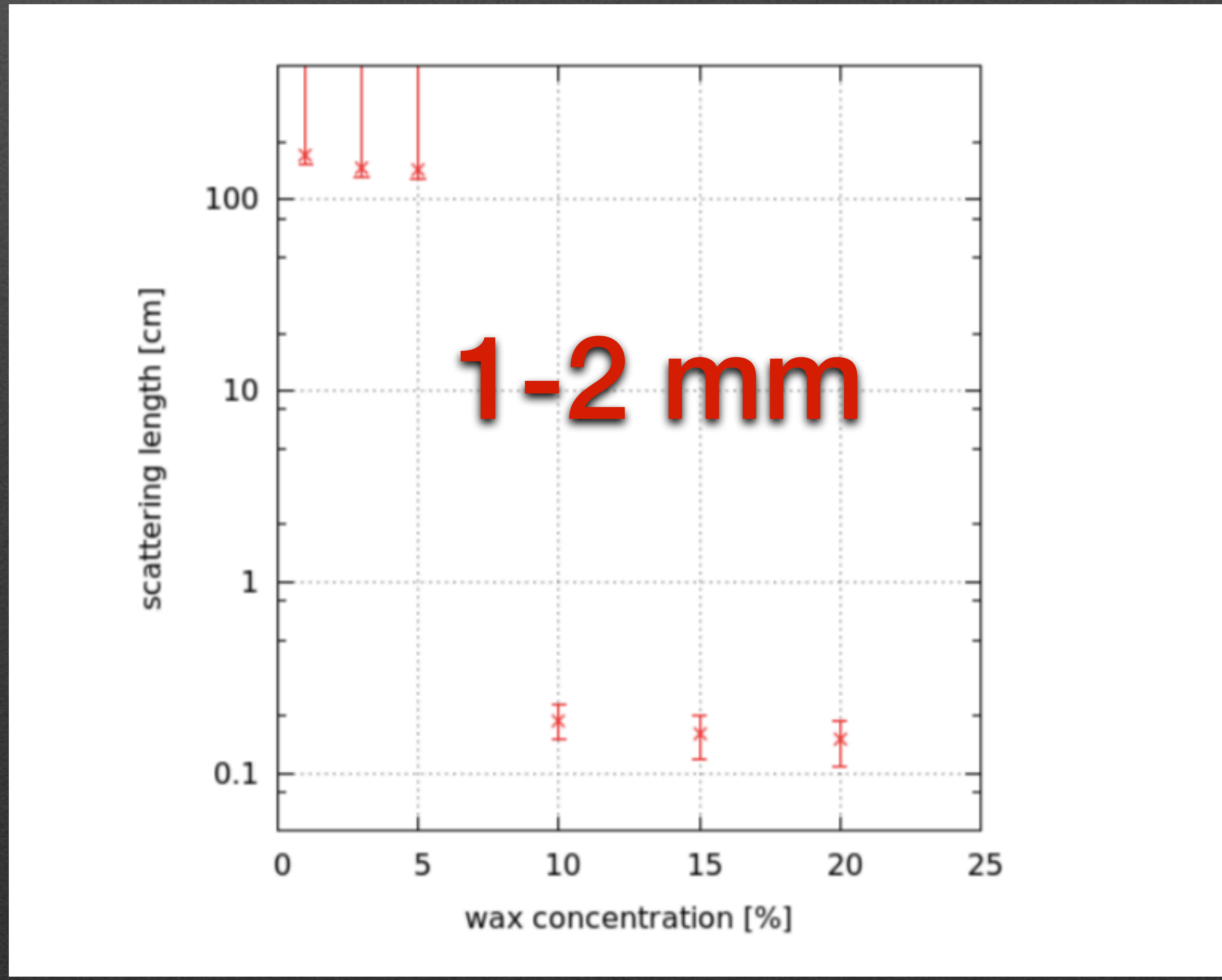
- New opaque Wax Scintillator Heidelberg
  - Linear alkyl benzene (~80 wt.%)
  - Paraffin wax (~20 wt.%)
  - PPO (0.3%)
- Cloud point: 35°C (crystallization T 32°C)
- Metal loading: first tests with 2.8% B (active neutron shield)

~~Transparent~~ organic liquid scintillators



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





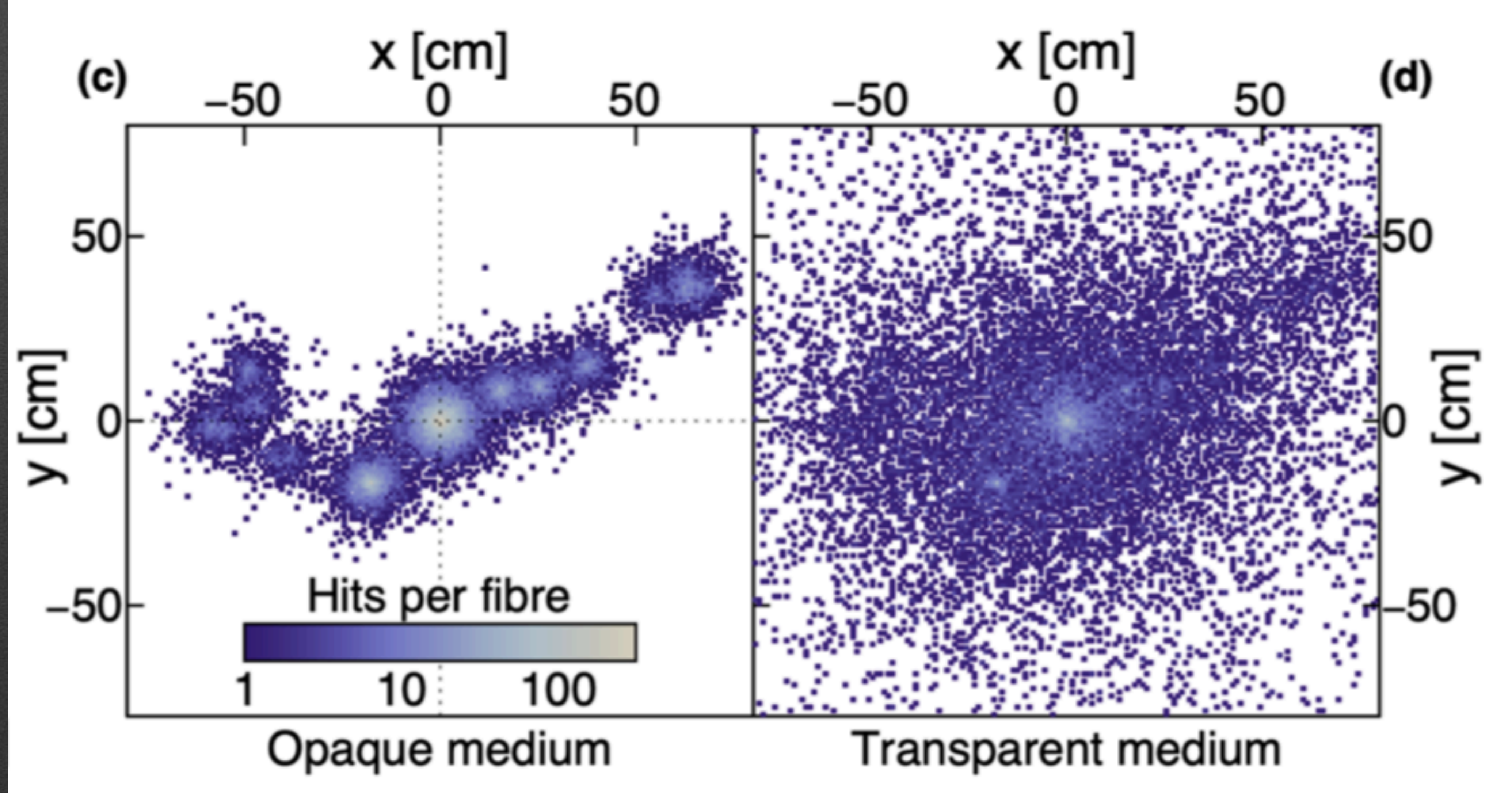
Opaque scintillator detector

- Light collection at origin using fibers
- Fast readout and electronics

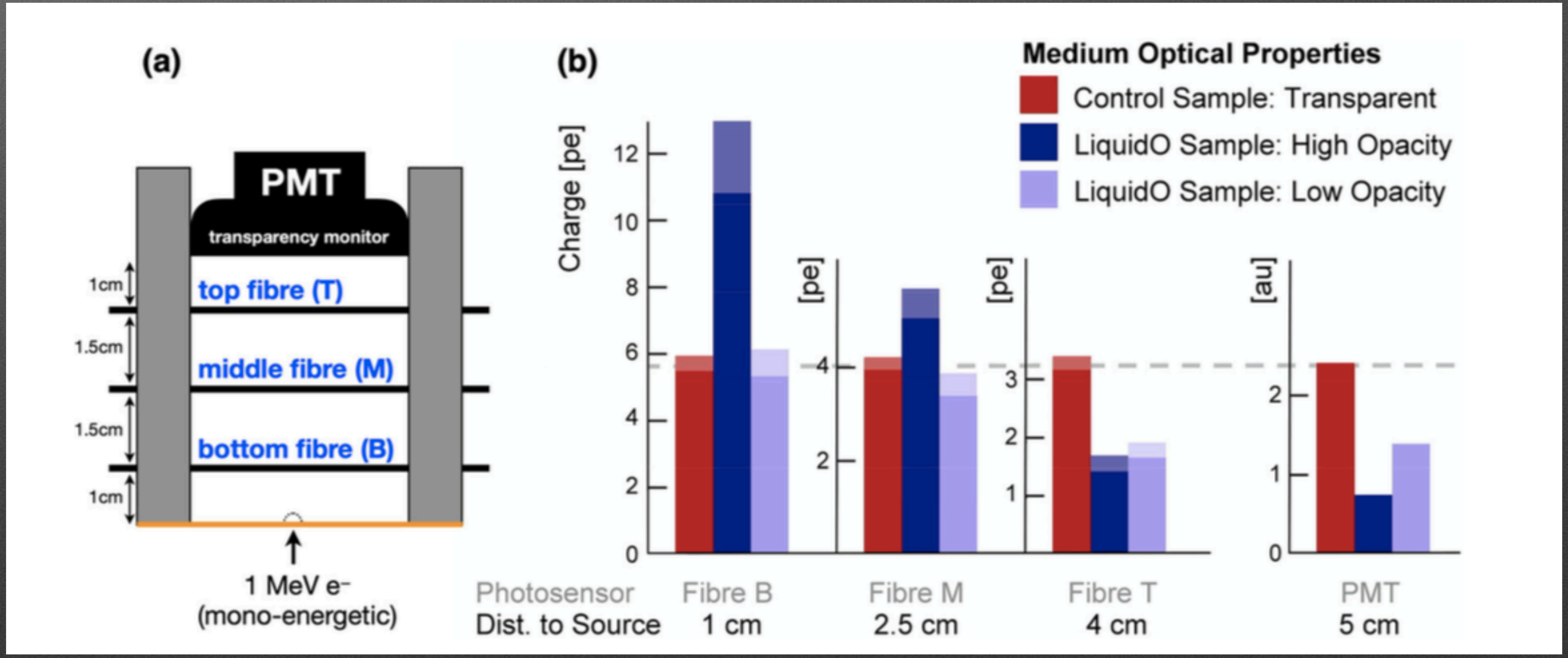
==> Improved vertex reconstruction!

Micro-LiquidO setup filled with NoWaSH:

- Proof of principle in 0.25 liter prototype
- Point-like electron source (1 MeV)



A. Cabrera et al., Commun.Phys. 4 (2021) 273



Reduced transparency constraints
==> large scale detector

More details and results on upscaled prototype: see LiquidO talk (next!)

Metal loading

- Prepare and dissolve organometallic complex
- Carboxylate systems: favorable optics, high loading
- Beta-diketone systems: radiopurity, stability
- Quantum dots: tunable optical properties (e.g. NuDot)
- SNO+ approach (simple, high loading)
- More options and better stability expected in gel/wax scintillator

Gd-LS production at Daya Bay (carboxylate)

L.Winslow, Presentation at Aspen Winter Workshop (2013)

$In(BDK)_3$ crystals

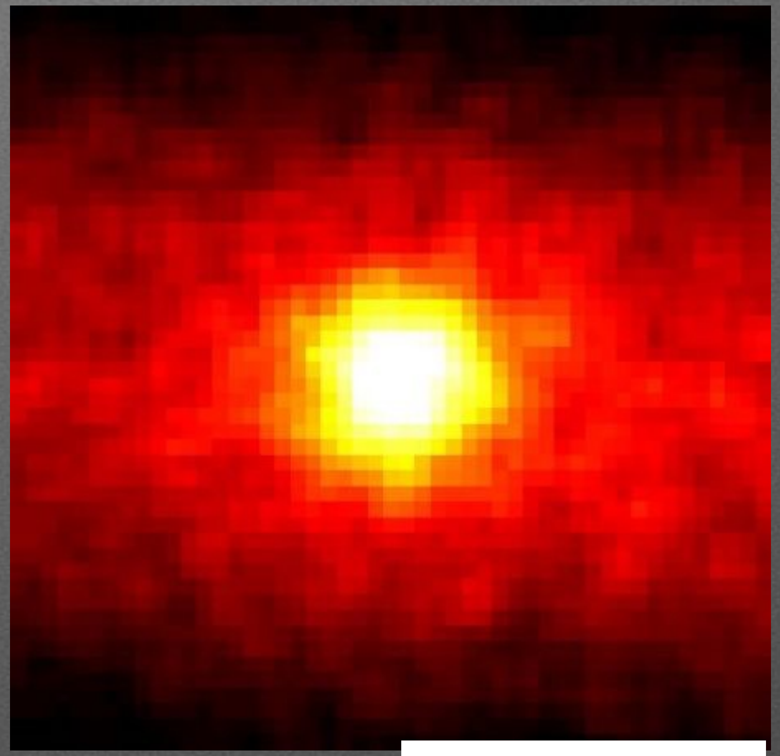
Loading requirements

Stability crucial!

Antineutrinos (IBD)

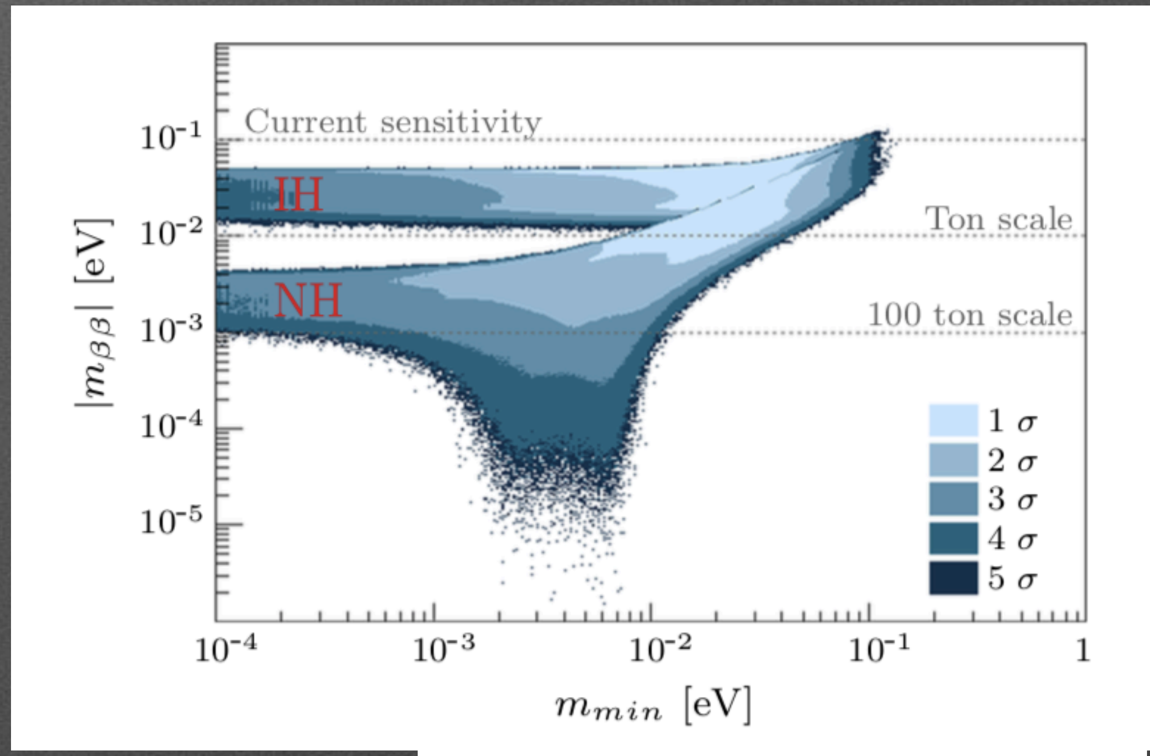
Brokdorf

Solar



Superkamiokande

0νββ



G.Benato, Eur. Phys. J. C (2015) 75:563

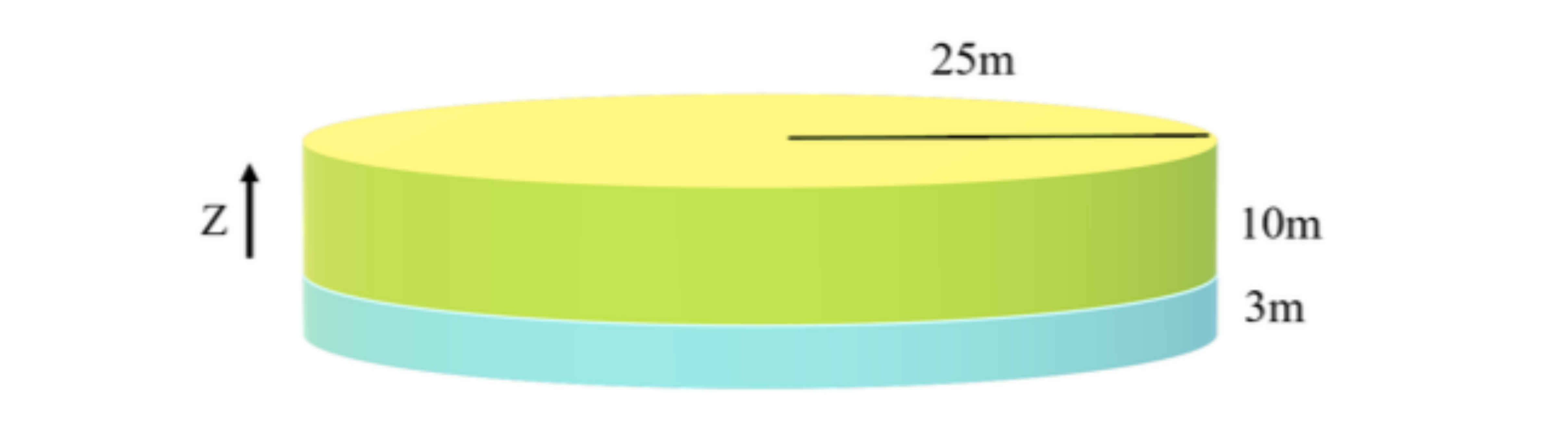
Loading	Gd, Li or Cd	In, Yb	Te, Ca, Nd, Zr, Mo, ,…
Purpose	Neutron detection	Target	Target
Concentration	Few g/l	High	High

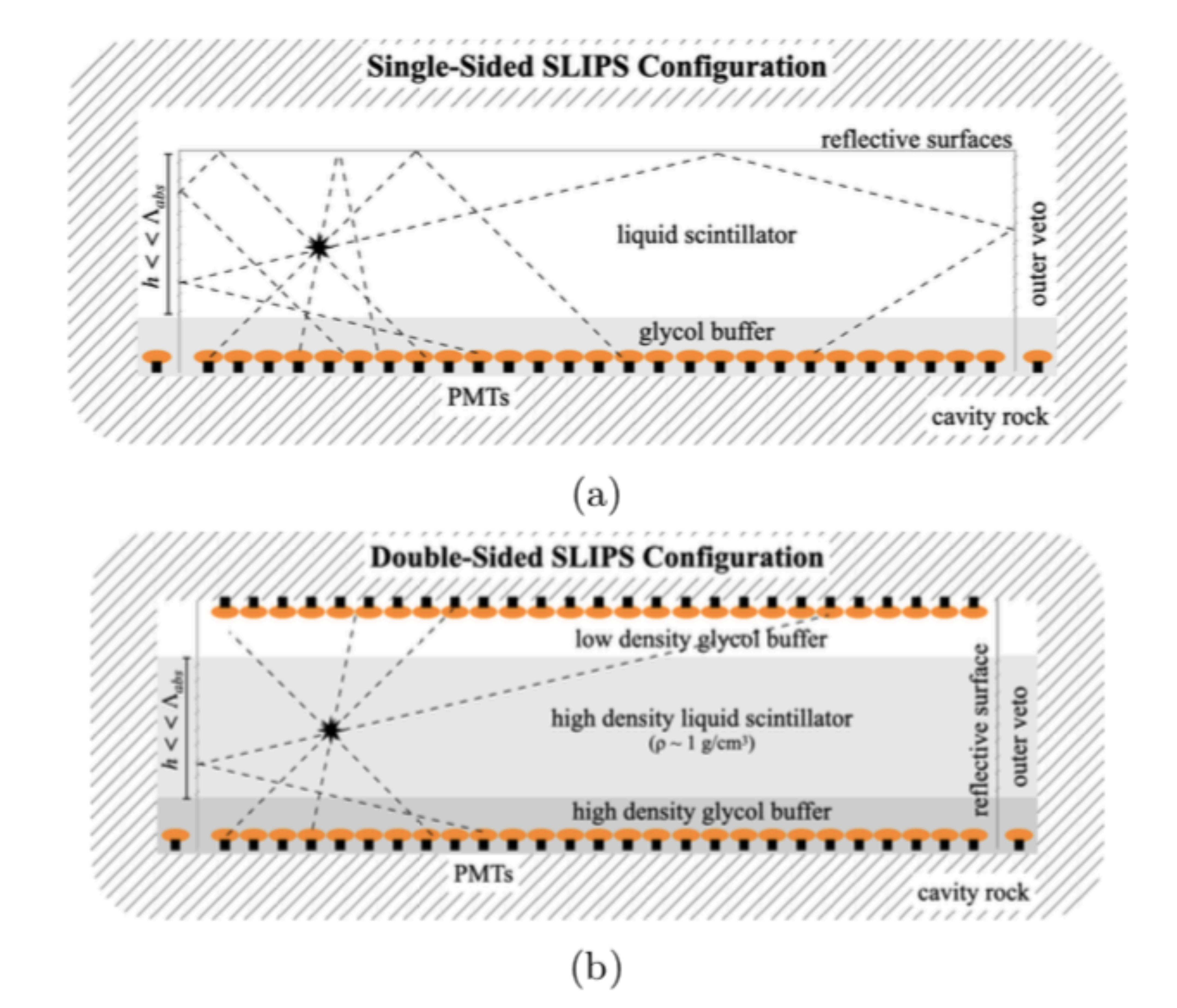
Achieved/realistic metal loadings:

- Tin 32%
- Carbox. ~10%
- BDK ~5%
- QD <1%

SLiPS

- Novel approach to separate liquid scintillator from PMTs
- Concept: „Stratified Liquid Plane Scintillator“ (liquid layers)
- Proposed for large scale neutrino detectors
- No need for acrylic vessels or nylon balloons
- Matching of refractive indices ==> glycol better than water
- Improve light collection with reflective sheets





I.Morton Blake, S.D.Biller, arXiv:2201.06498

Summary

- Most running and upcoming neutrino experiments use transparent, „safe“ organic LS (LAB, PXE and DIN)
- Polysiloxane based scintillators: competitive optical and outstanding safety characteristics (e.g. for veto systems)
- Gel and wax-like scintillators combine some of the advantages of liquid and plastic scintillators, good stability expected
- New technology of opaque scintillators capable of improving vertex reconstruction and reducing transparency constraints —> high loadings!
- Many proposed experiments will need (high) metal loading: new approaches (WbLS, gel, wax) offer additional possibilities