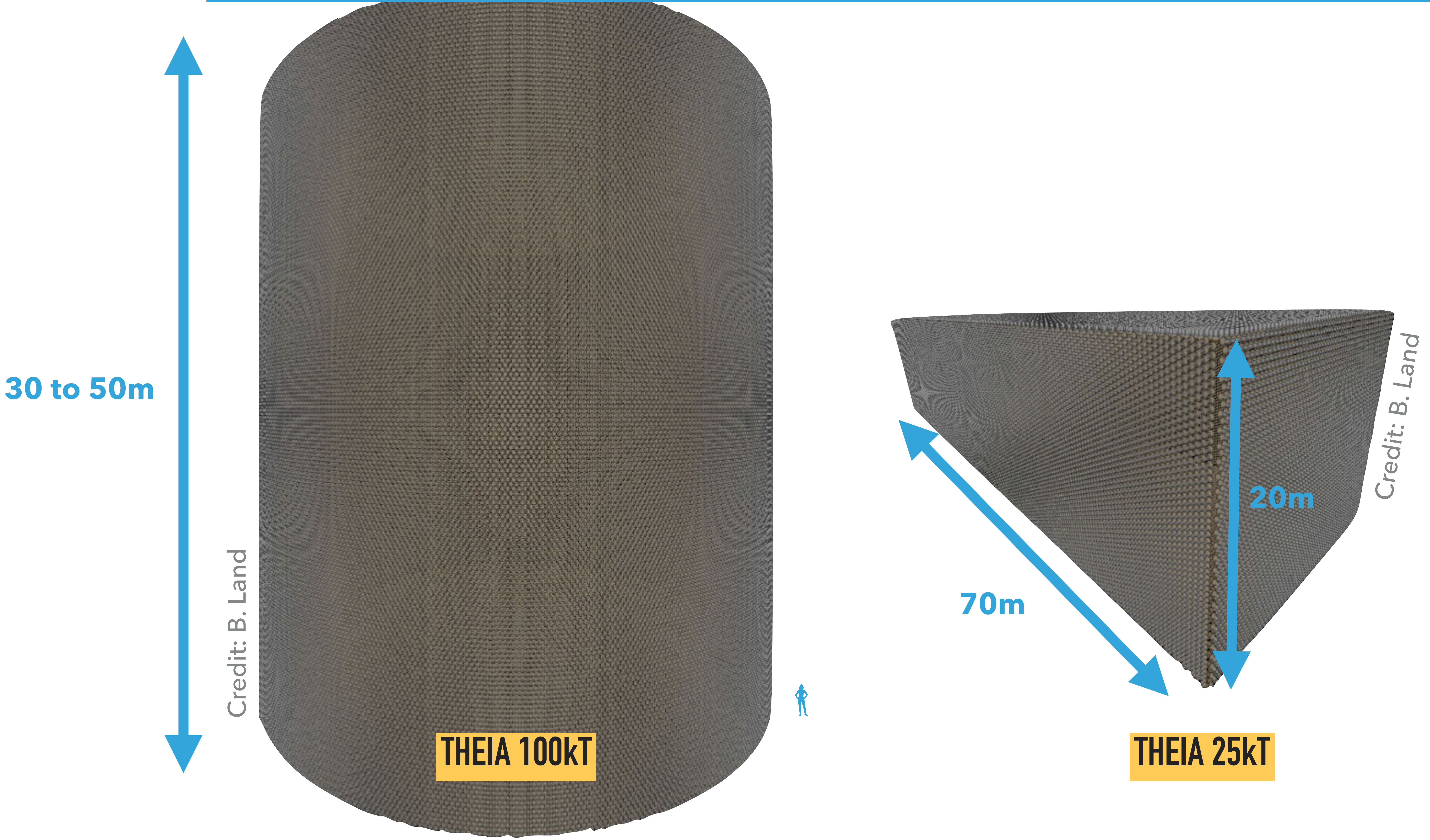
JAVIER CARAVACA FOR THE THEIA COLLABORATION

WATER-BASED LIQUID SCINTILLATOR AND CHERENKOV/SCINTILLATION SEPARATION FOR THEIA

THE THEIA CONCEPT

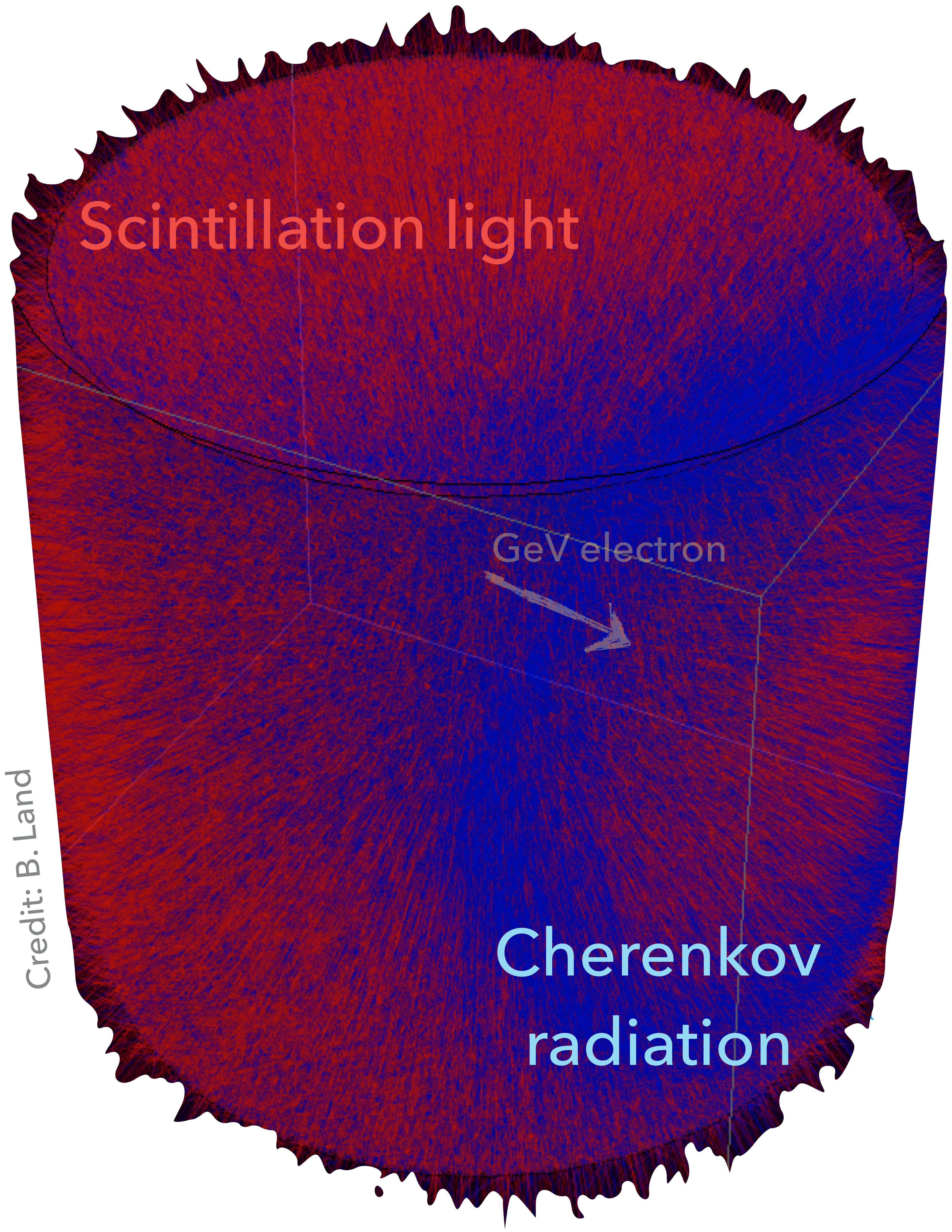
TENS-OF-KILOTONS SCALE HYBRID CHERENKOV/SCINTILLATION DETECTOR



THE THEIA CONCEPT

TENS-OF-KILOTONS SCALE HYBRID CHERENKOV/SCINTILLATION DETECTOR

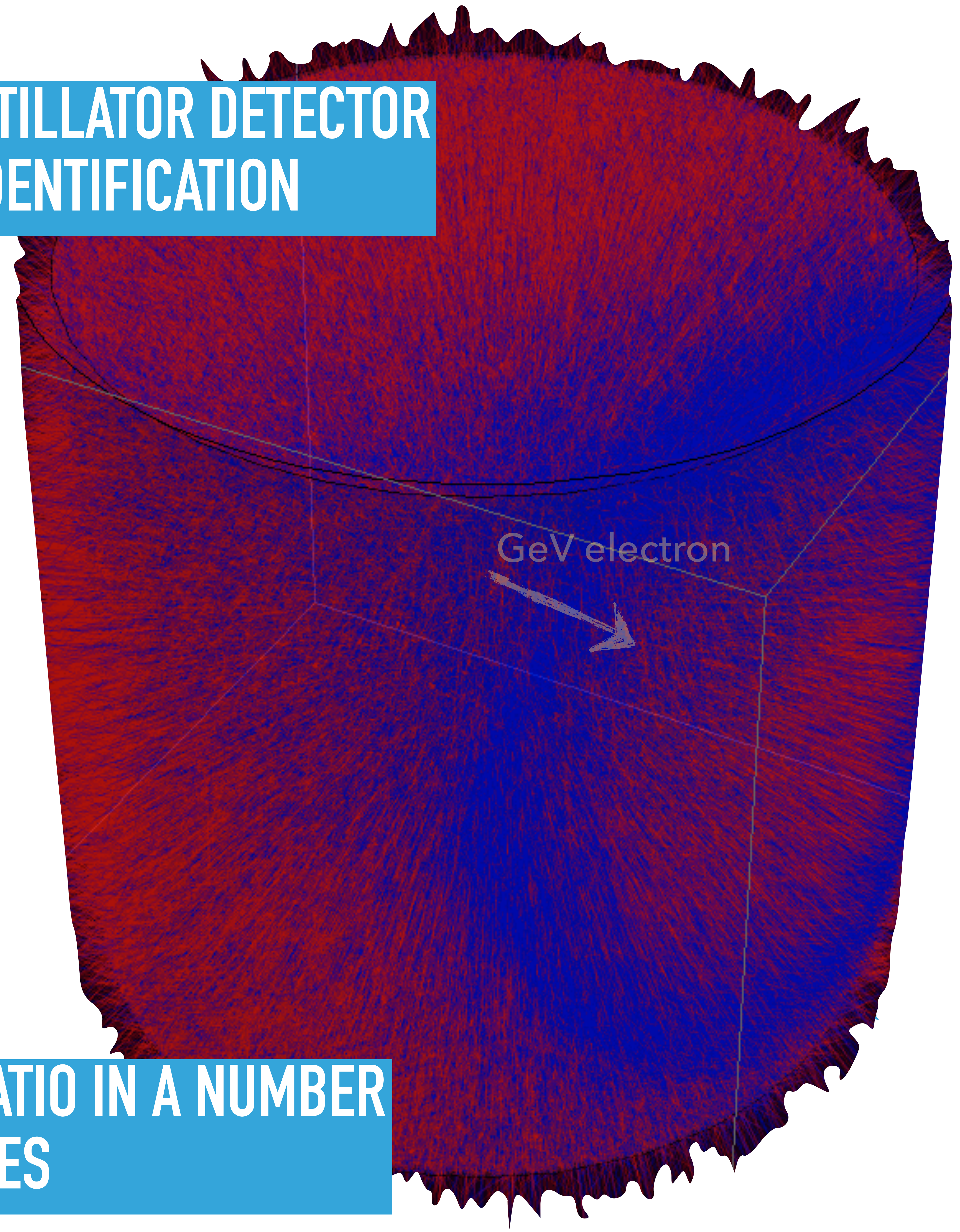
THE THEIA CONCEPT: CHERENKOV AND SCINTILLATION SEPARATION



Credit: B. Land

THE THEIA CONCEPT: CHERENKOV AND SCINTILLATION SEPARATION

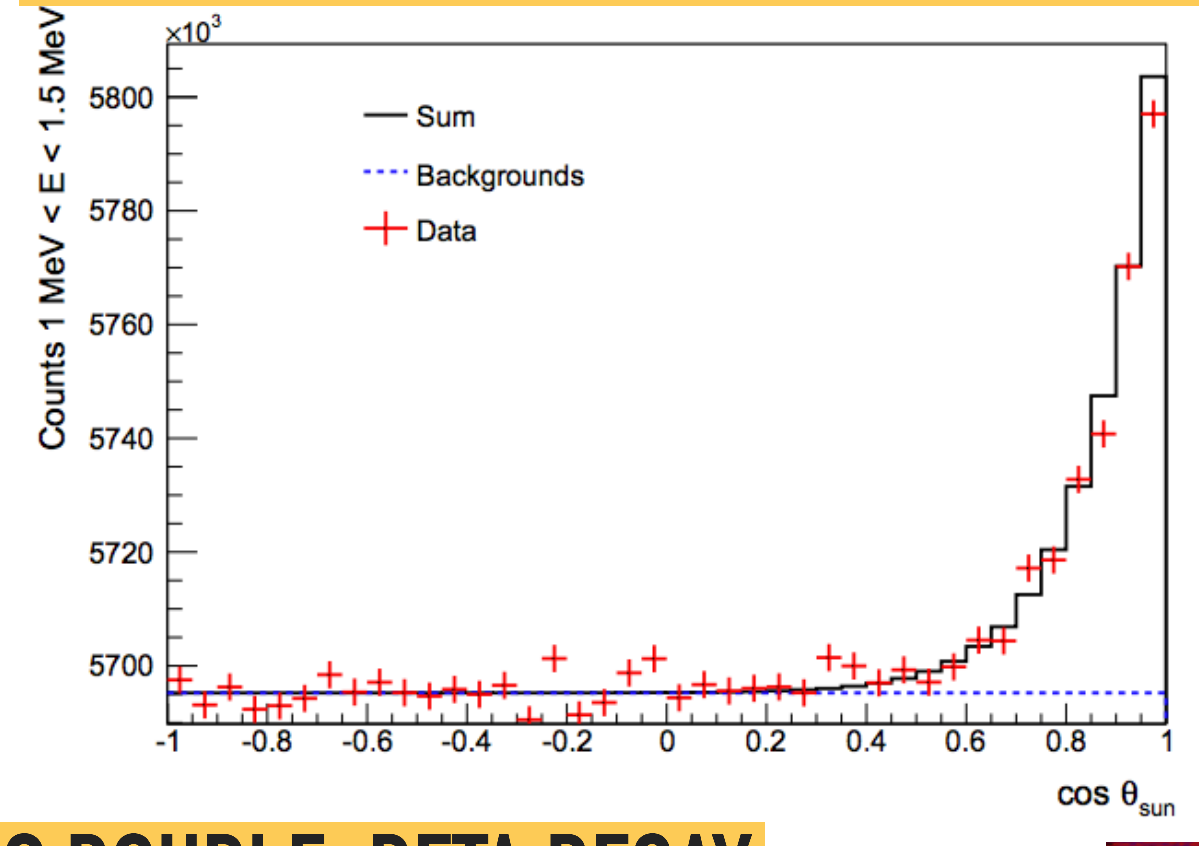
DIRECTIONALITY IN A LIQUID SCINTILLATOR DETECTOR AND ENHANCED PARTICLE IDENTIFICATION



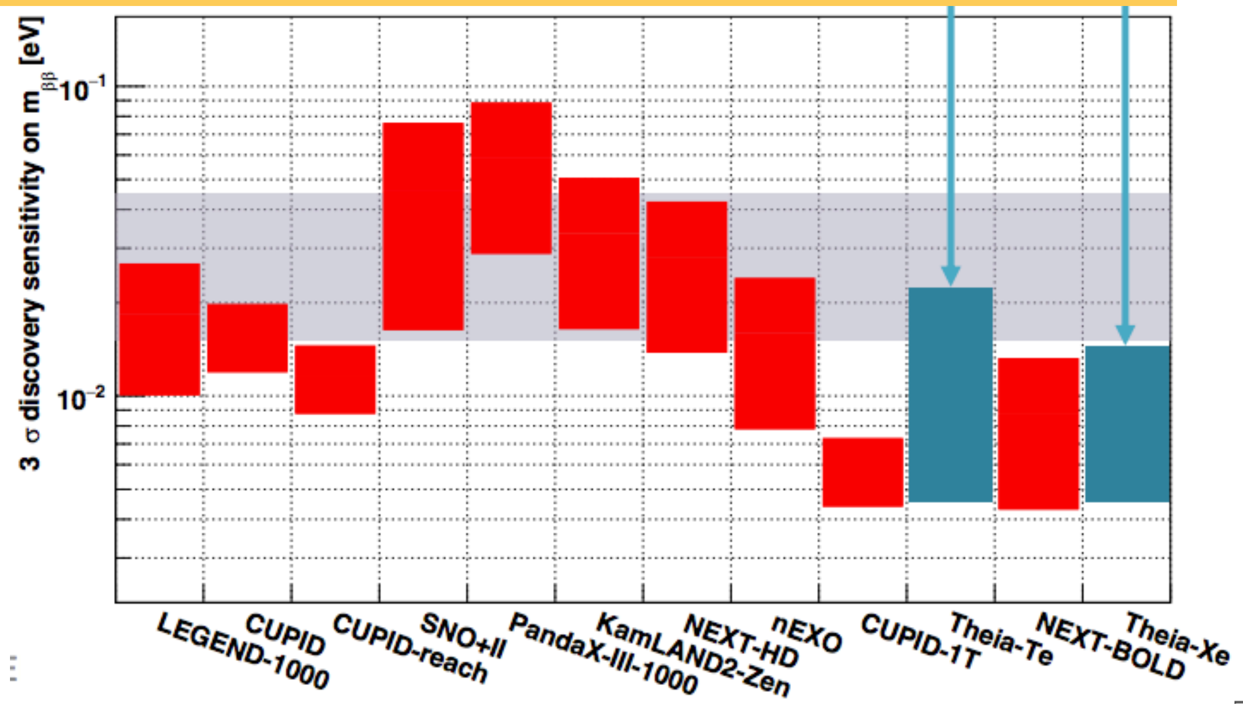
BOOST SIGNAL/BACKGROUND RATIO IN A NUMBER OF PHYSICS CASES

THE THEIA PHYSICS PROGRAM

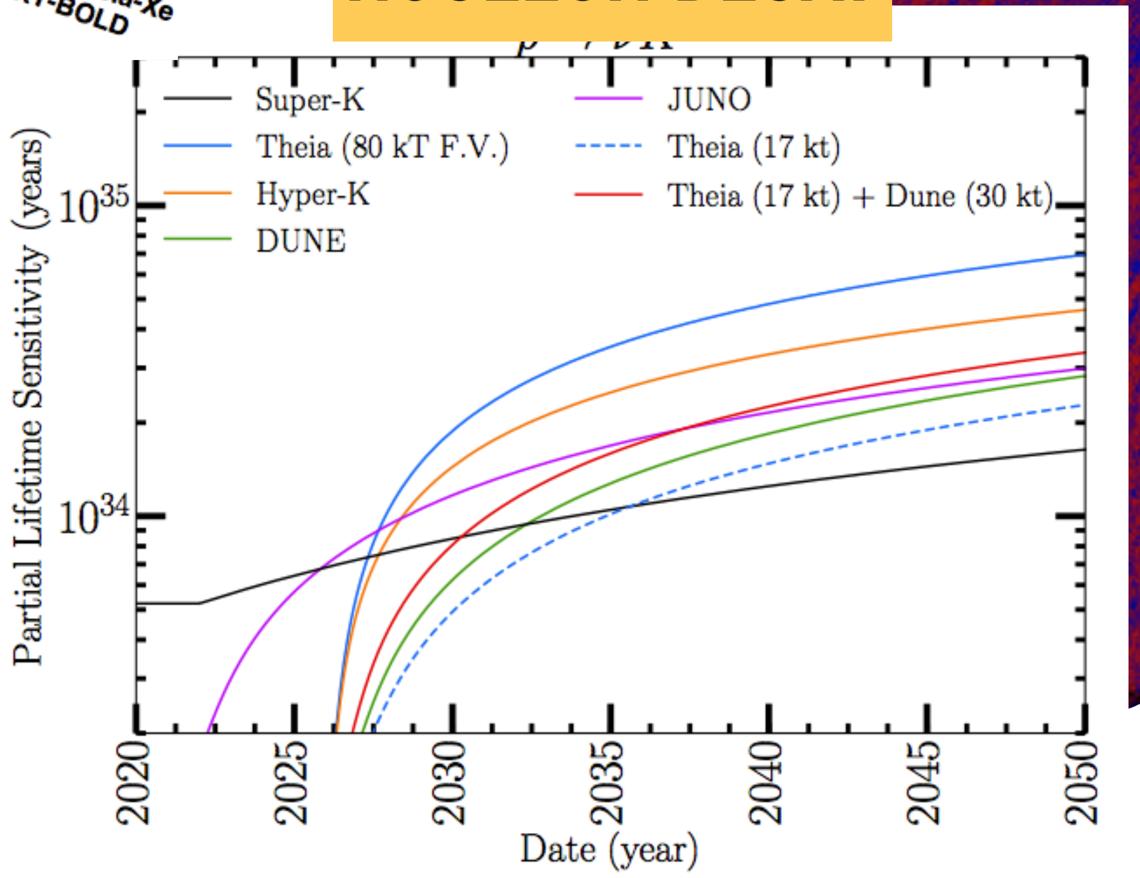
SOLAR NEUTRINOS: CNO DETECTION



NEUTRINOLESS DOUBLE-BETA DECAY

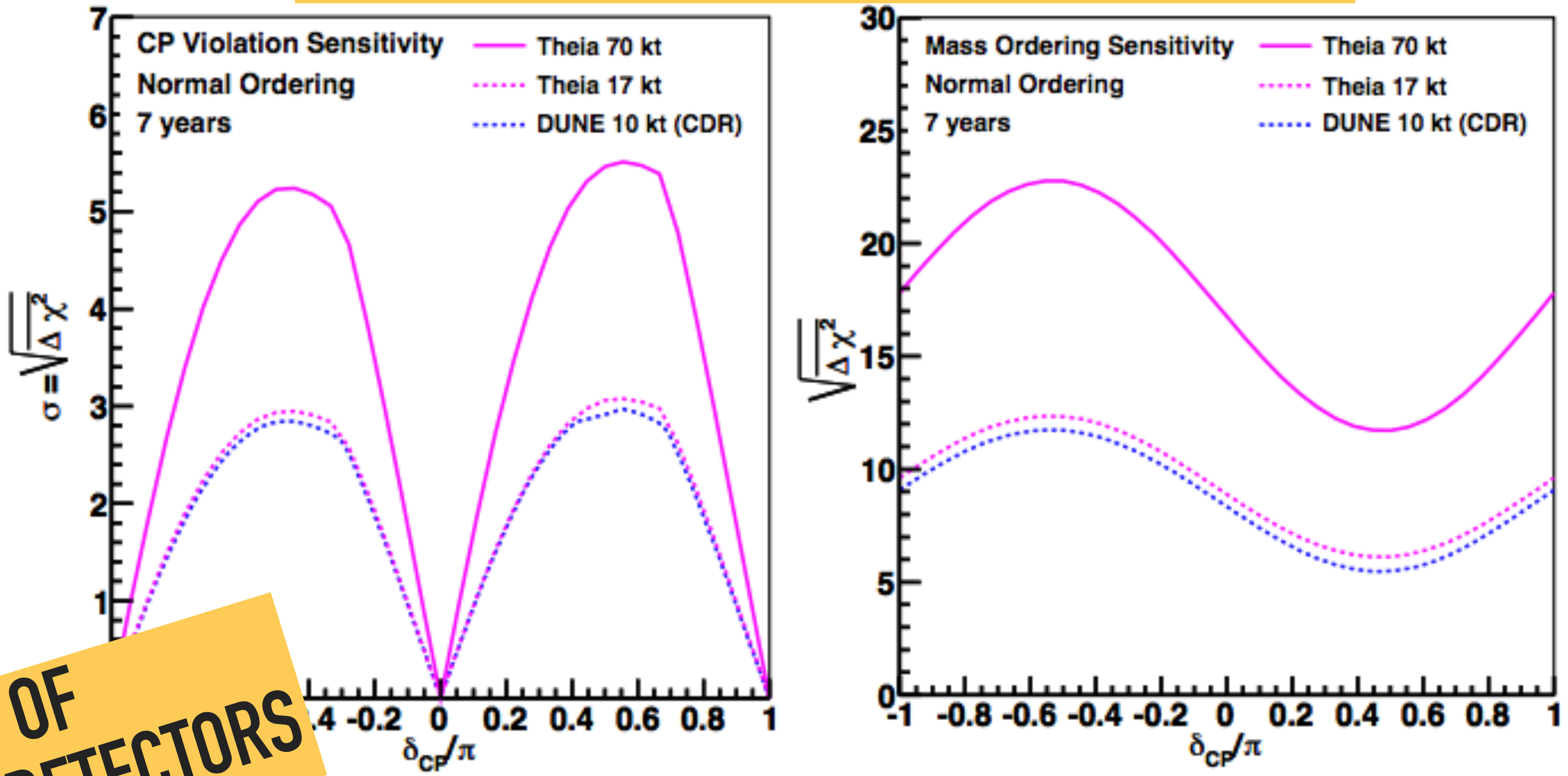


NUCLEON DECAY

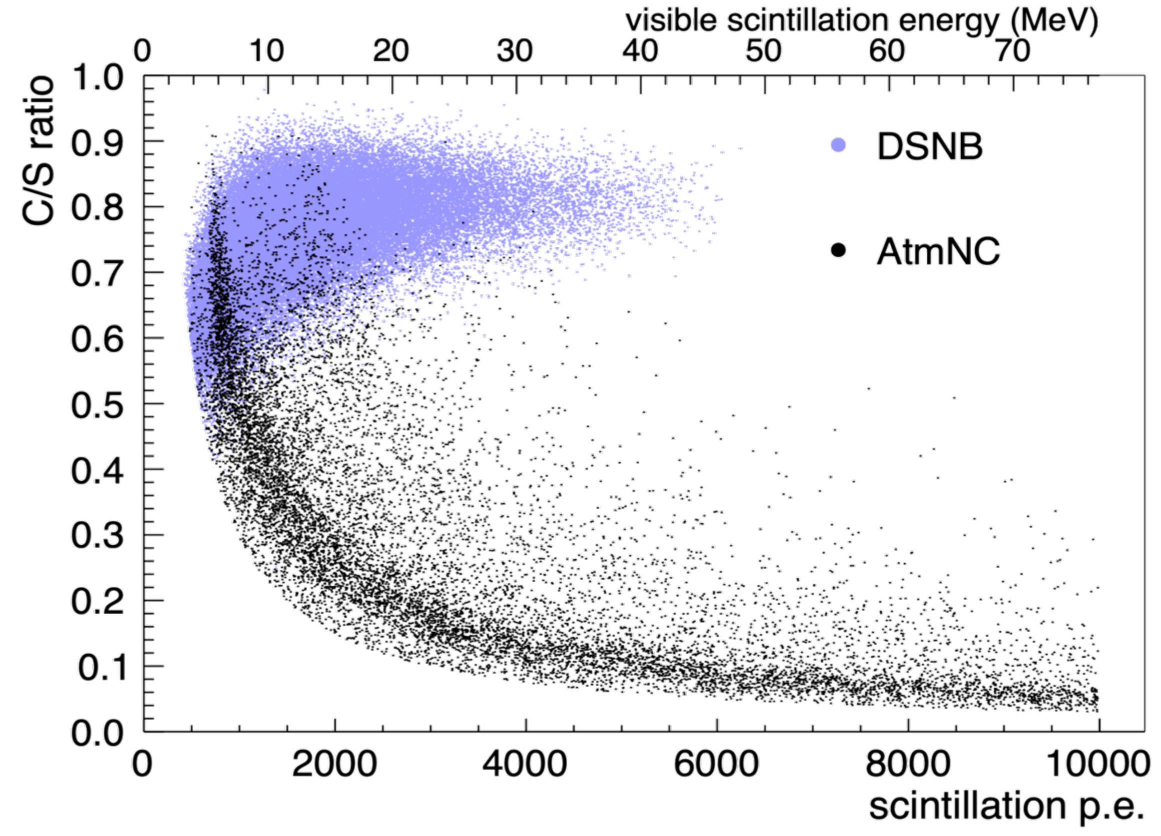


R. SVOBODA - THE SCIENTIFIC IMPACT OF WATER-BASED LIQUID SCINTILLATOR HYBRID DETECTORS

BEAM NEUTRINO OSCILLATION PHYSICS



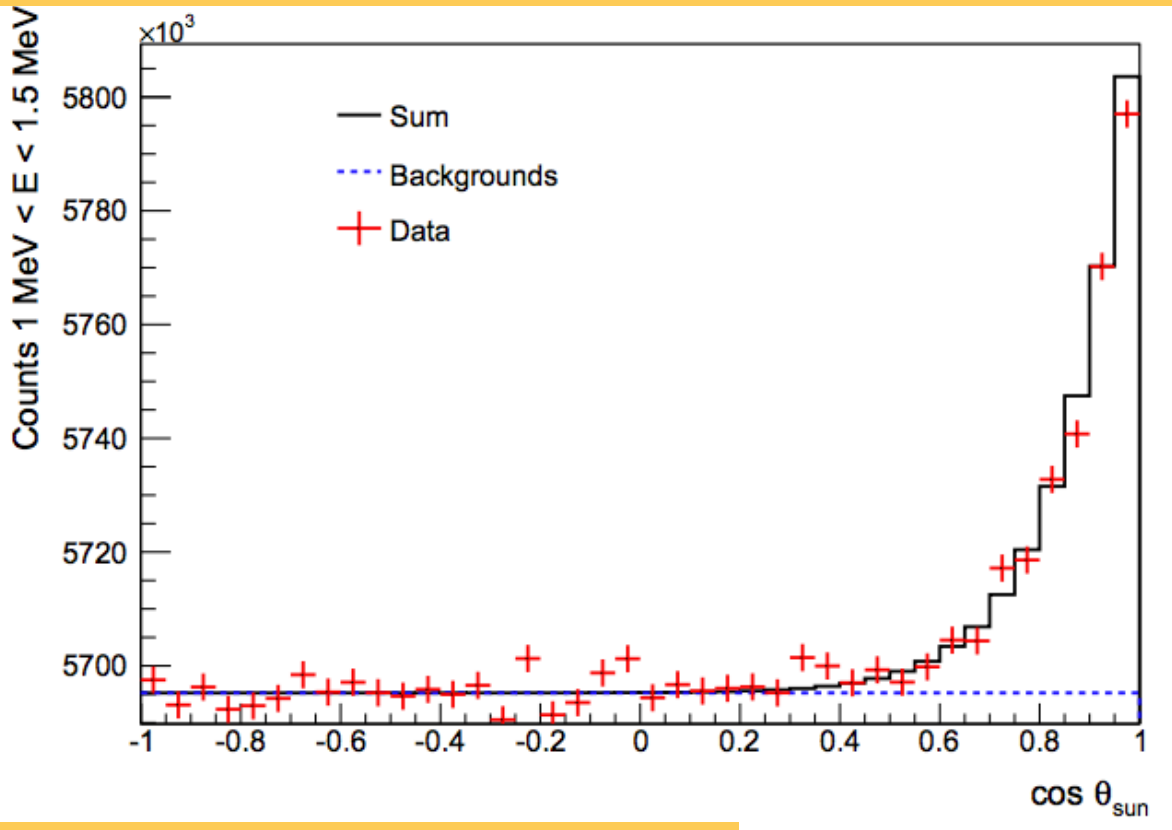
SUPERNOVA RELIC NEUTRINO DETECTION



The Theia Collaboration, arXiv:1911.03501 (2019)

THE THEIA PHYSICS PROGRAM

SOLAR NEUTRINOS: CNO DETECTION



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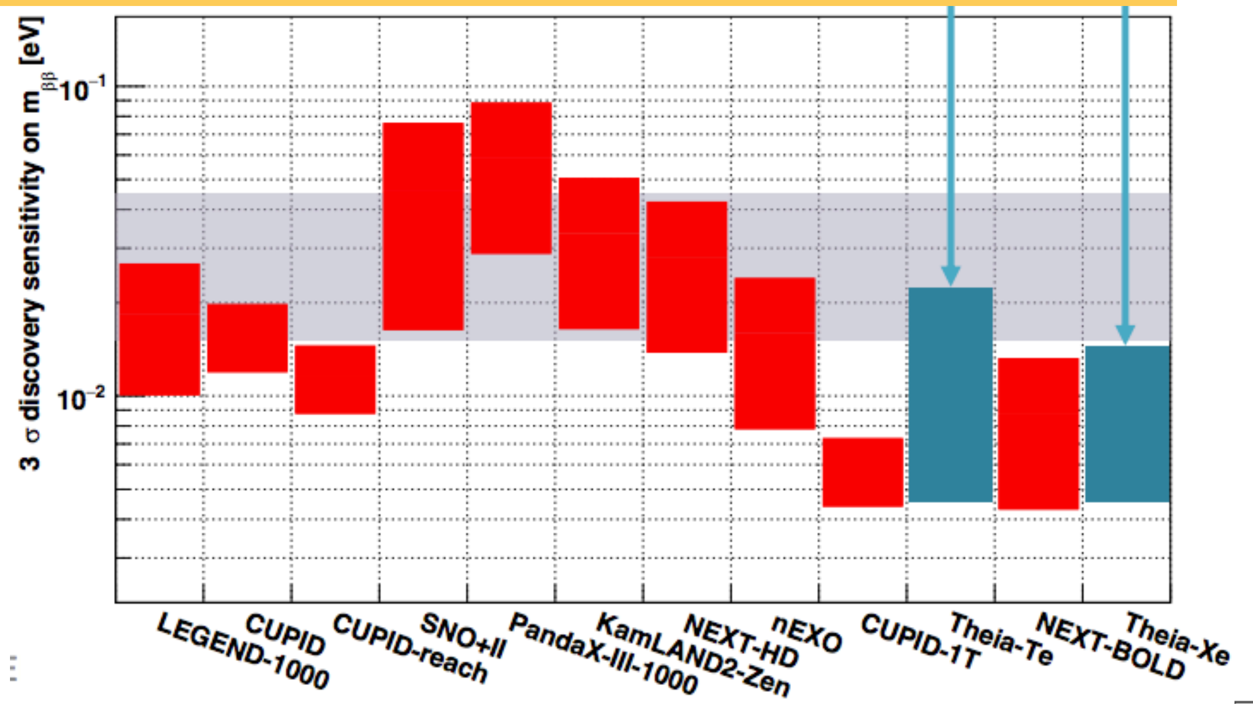

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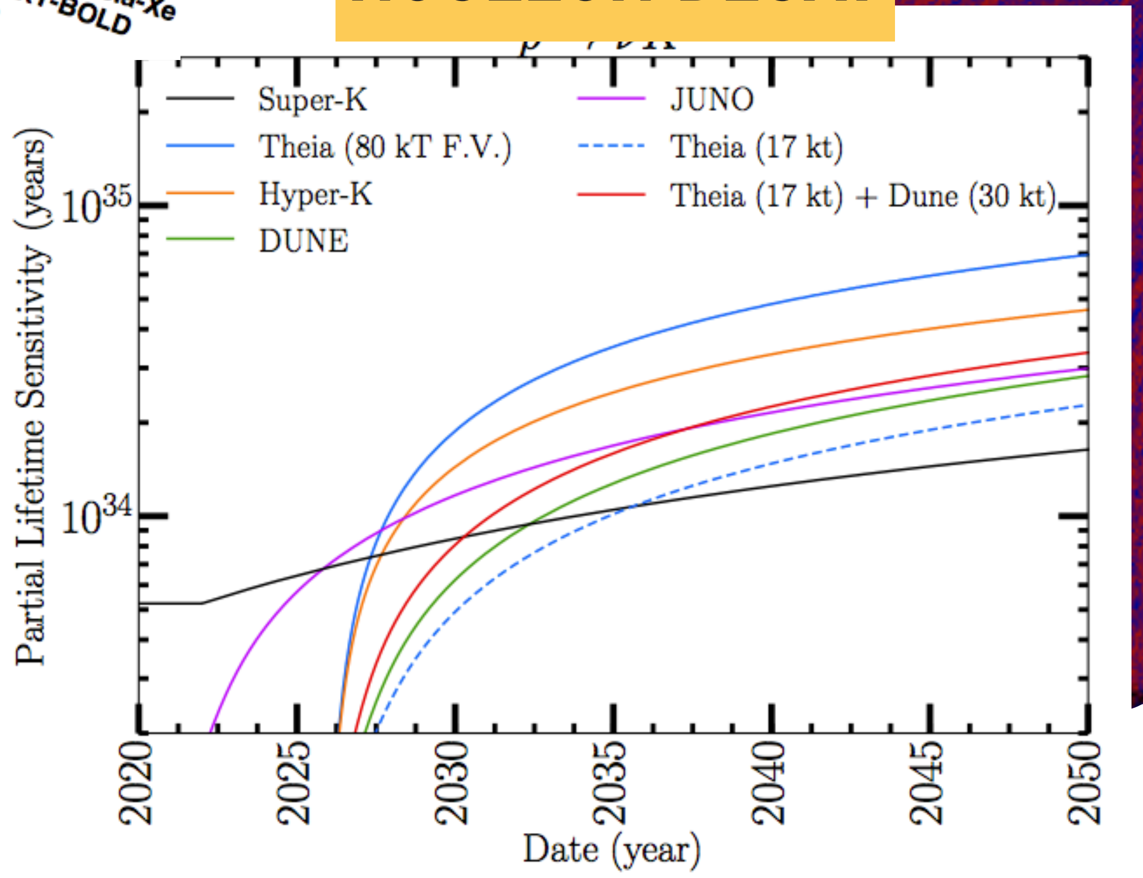
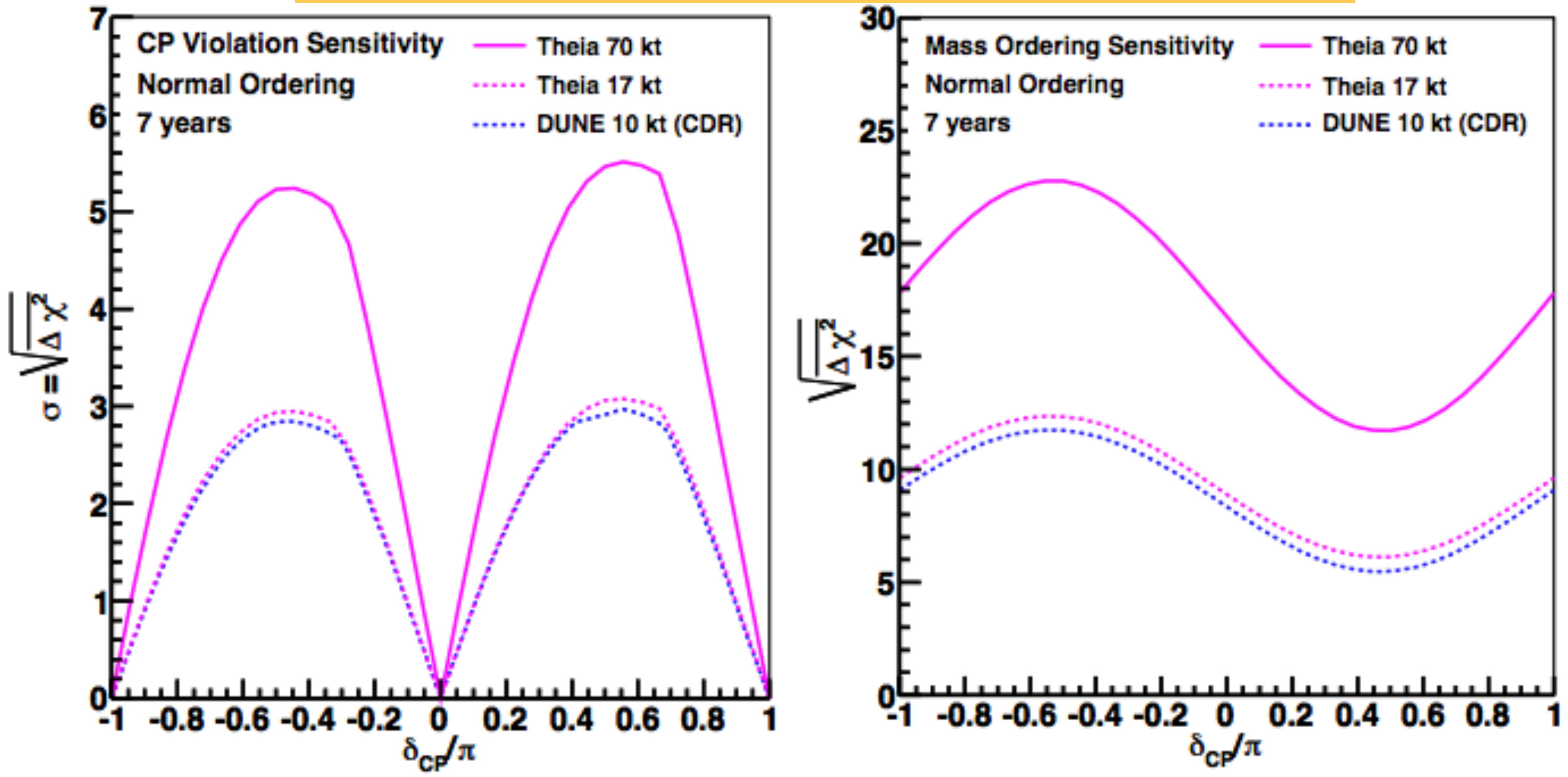
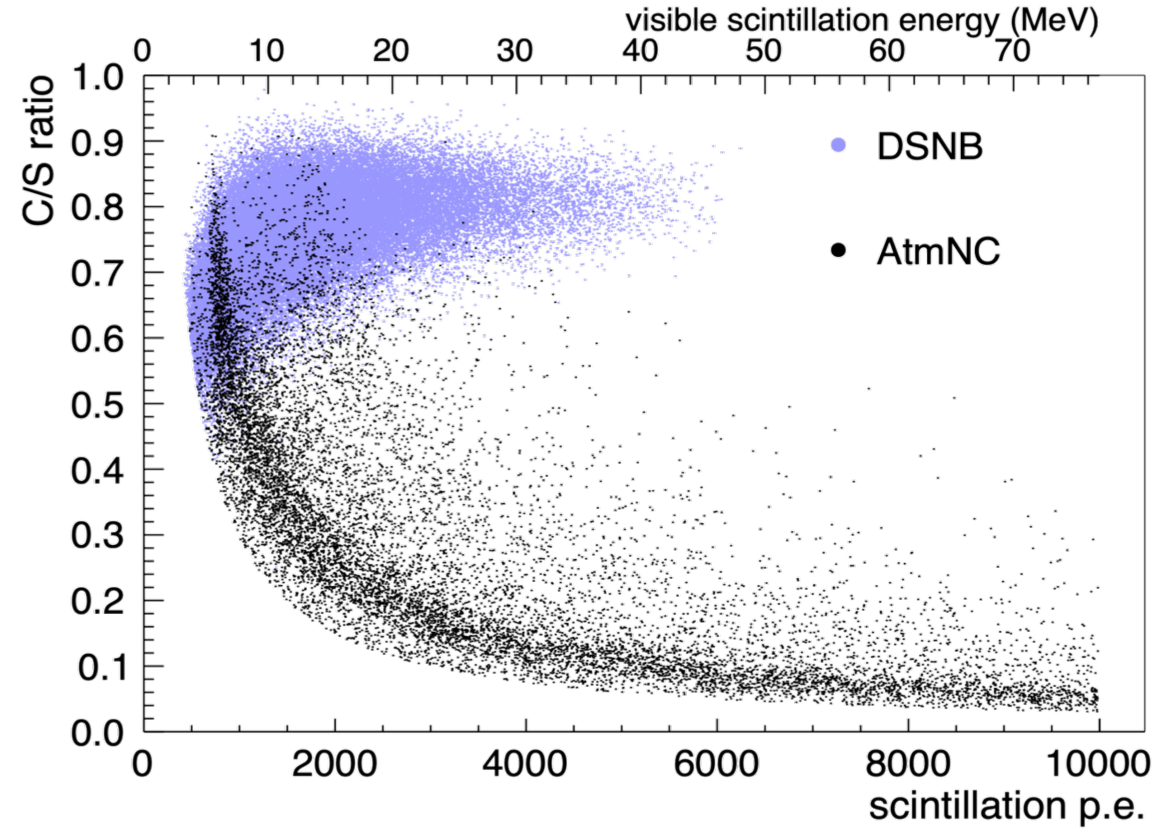


HOW DO WE GET THERE?

BEAM NEUTRINO OSCILLATION PHYSICS



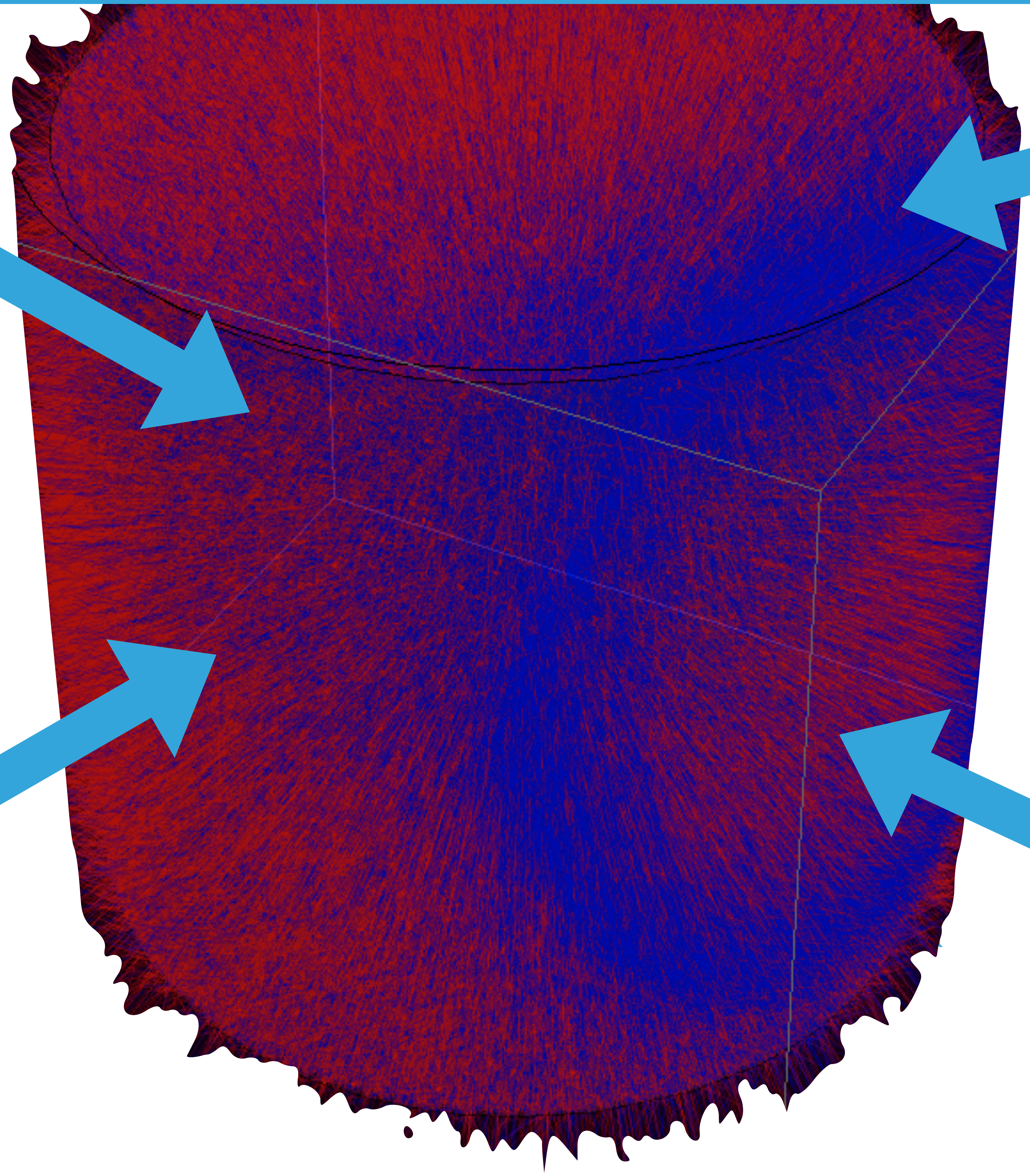
SUPERNOVA RELIC NEUTRINO DETECTION



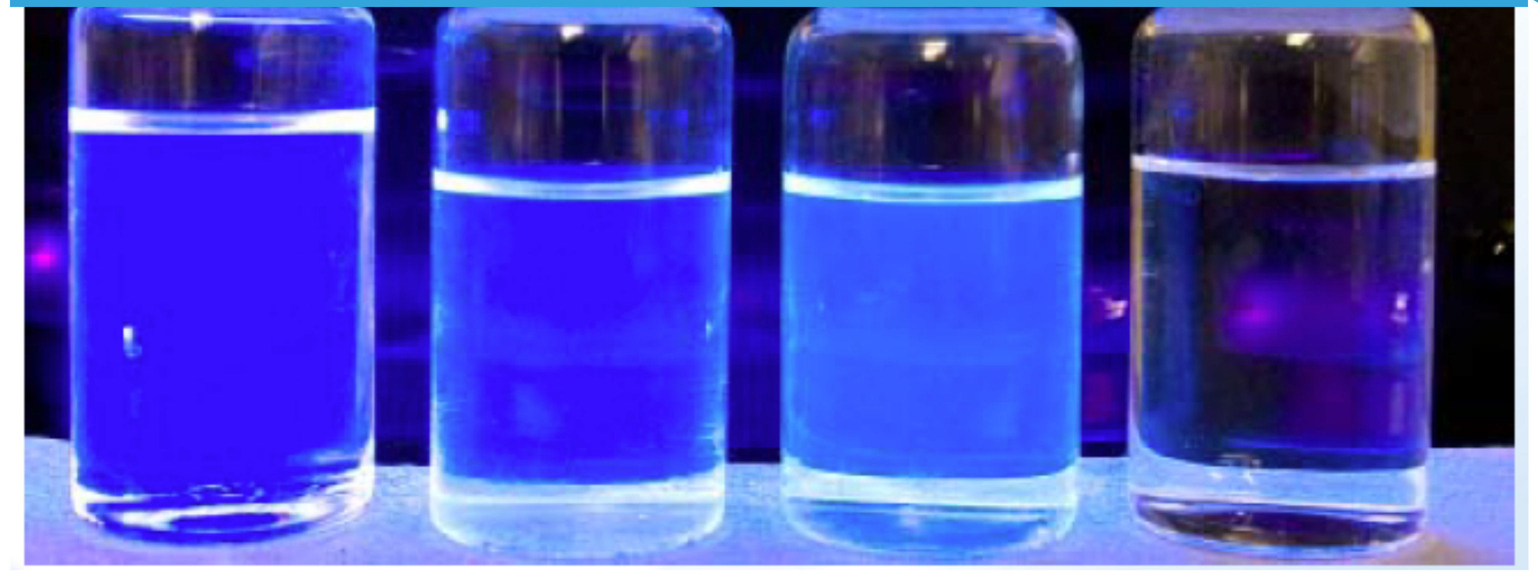
The Theia Collaboration, arXiv:1911.03501 (2019)

THE THEIA CHALLENGE

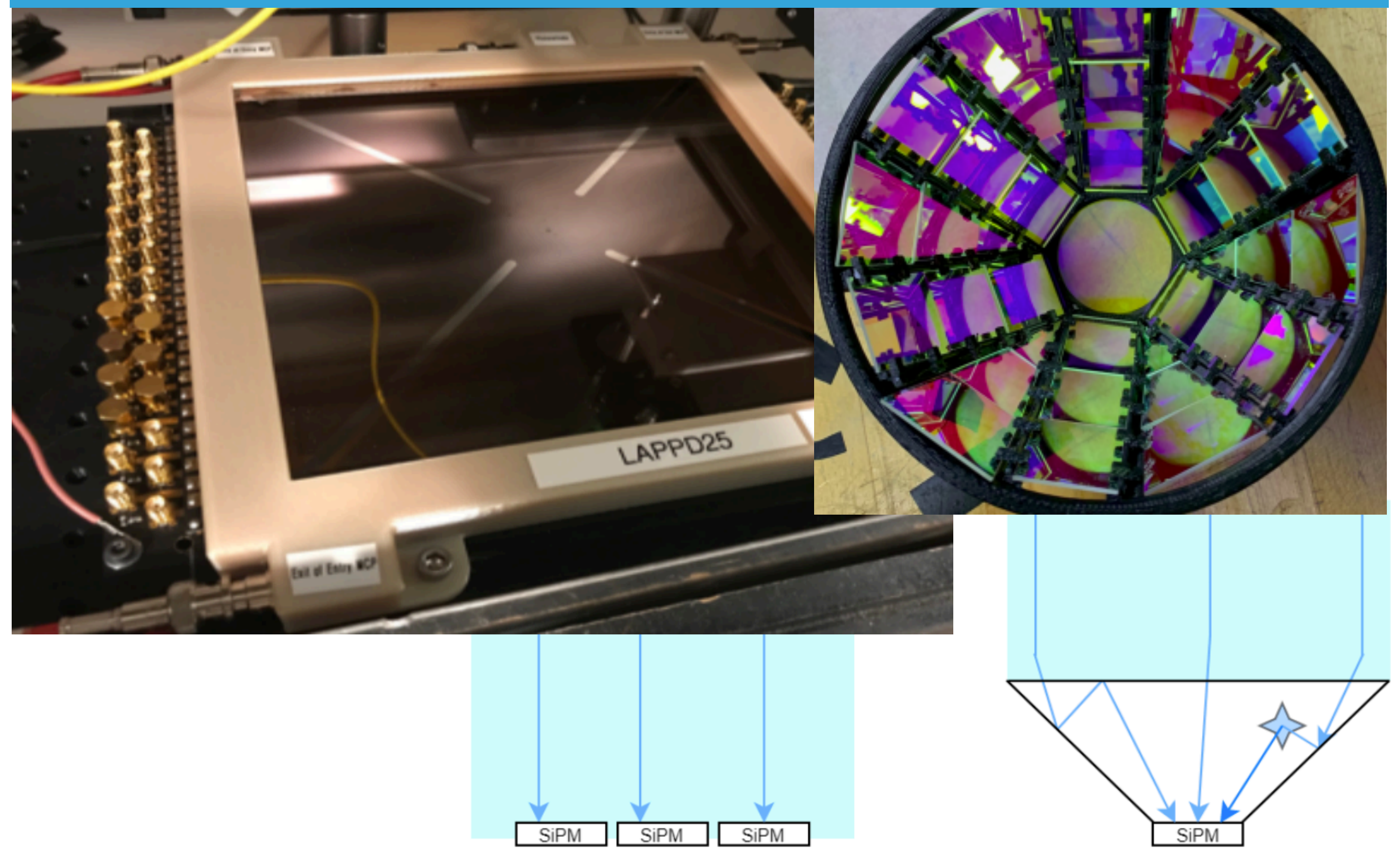
REALIZE CHERENKOV/SCINTILLATION SEPARATION AND MAXIMIZE LIGHT COLLECTION IN LARGE-SCALE SCINTILLATOR DETECTOR



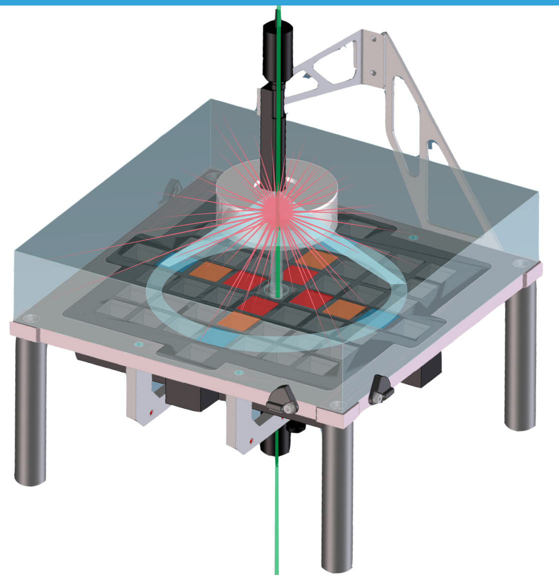
NOVEL LIQUID SCINTILLATOR MEDIUM: WATER-BASED LIQUID SCINTILLATOR



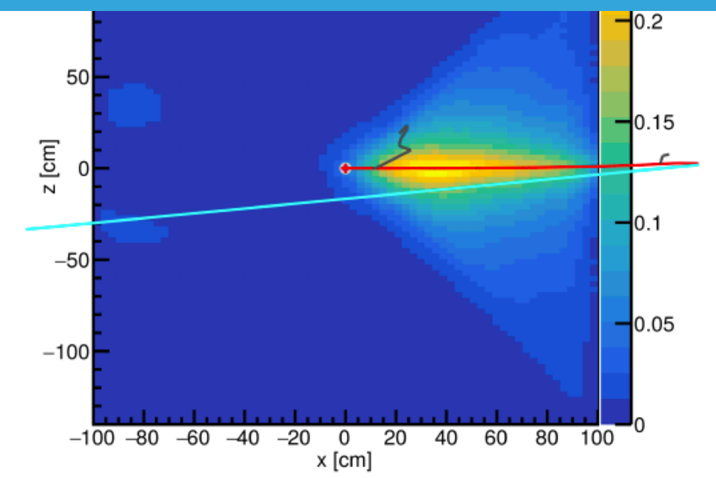
MODERN PHOTOSENSORS: LAPPD, DICHROICONS, SiPM ARRAYS



SMALL SCALE REALIZATION OF CHERENKOV/ SCINTILLATION SEPARATION: CHESS, DICHROIC FILTERS

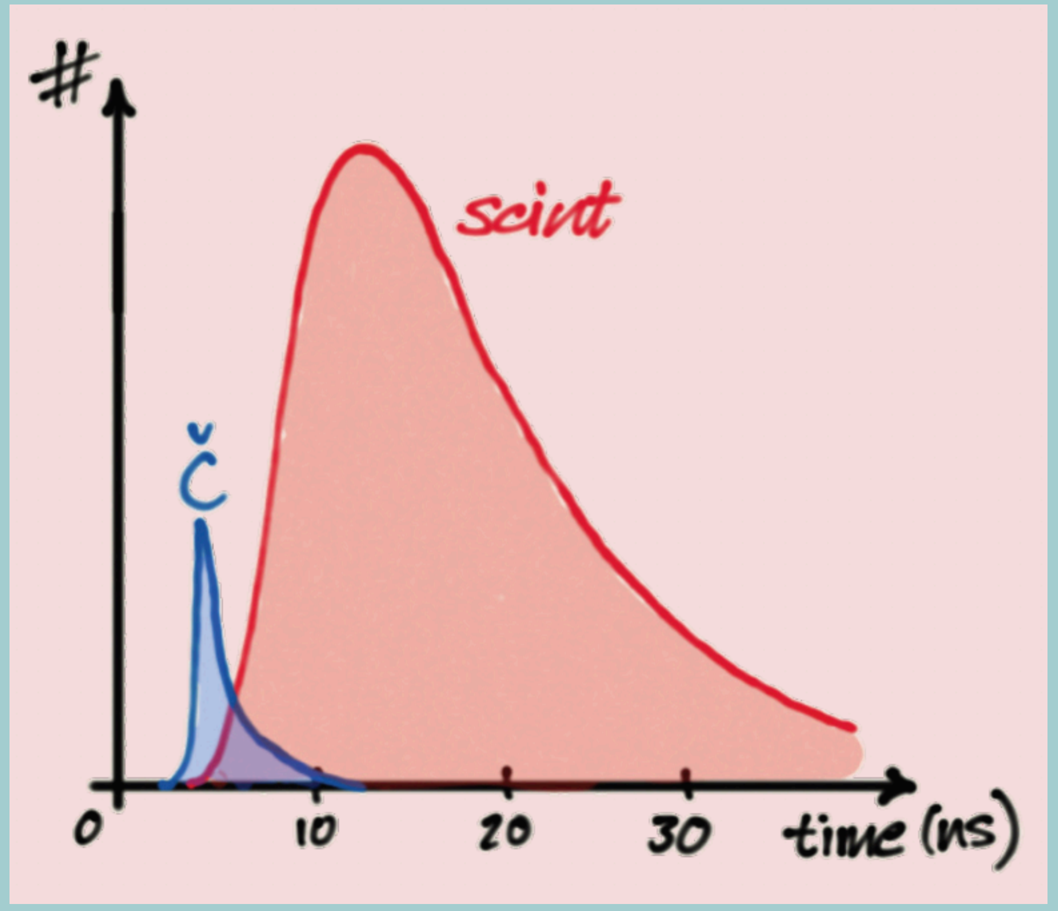


NEW RECONSTRUCTION ALGORITHMS: TOPOLOGICAL RECO., NEURAL NETS.

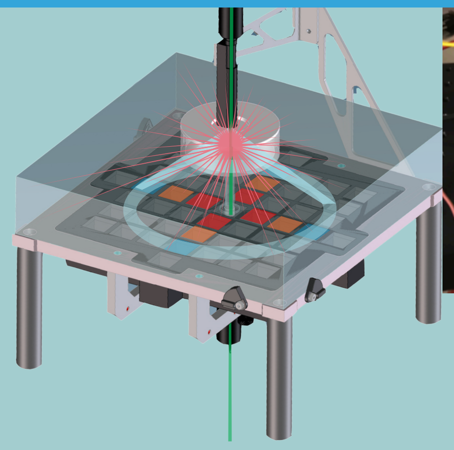
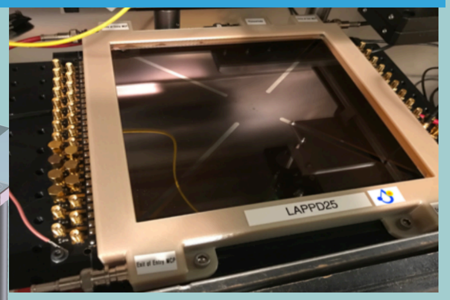


CHERENKOV AND SCINTILLATION SEPARATION STRATEGIES

TIMING



CHESS, LAPPDS

CHERENKOV AND SCINTILLATION SEPARATION STRATEGIES

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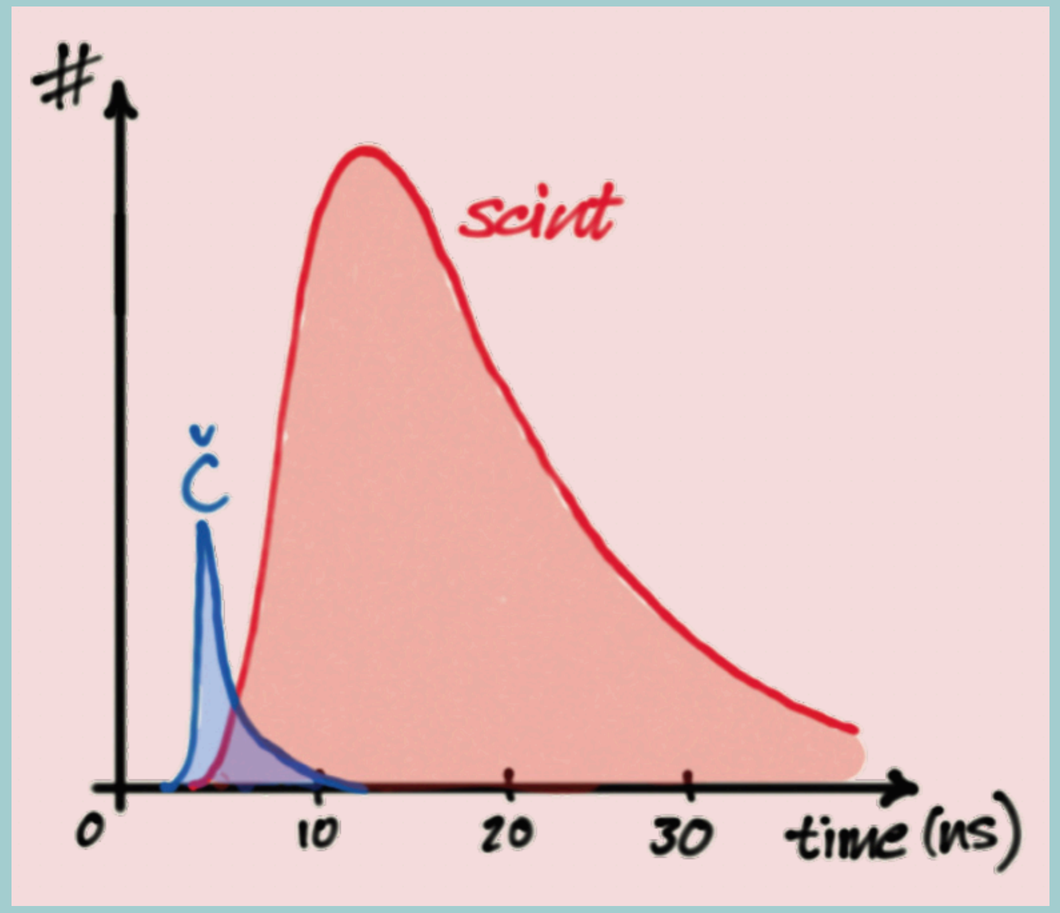
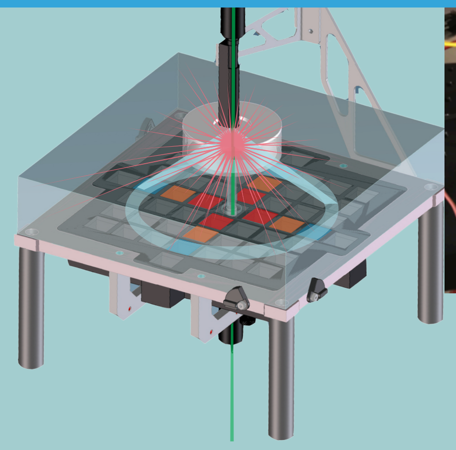
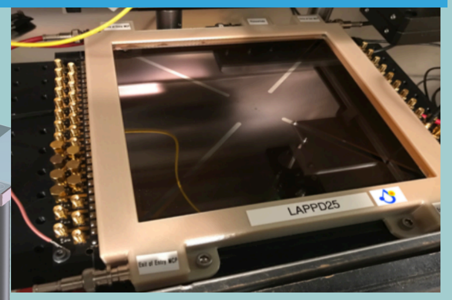


CHESS, LAPPDS





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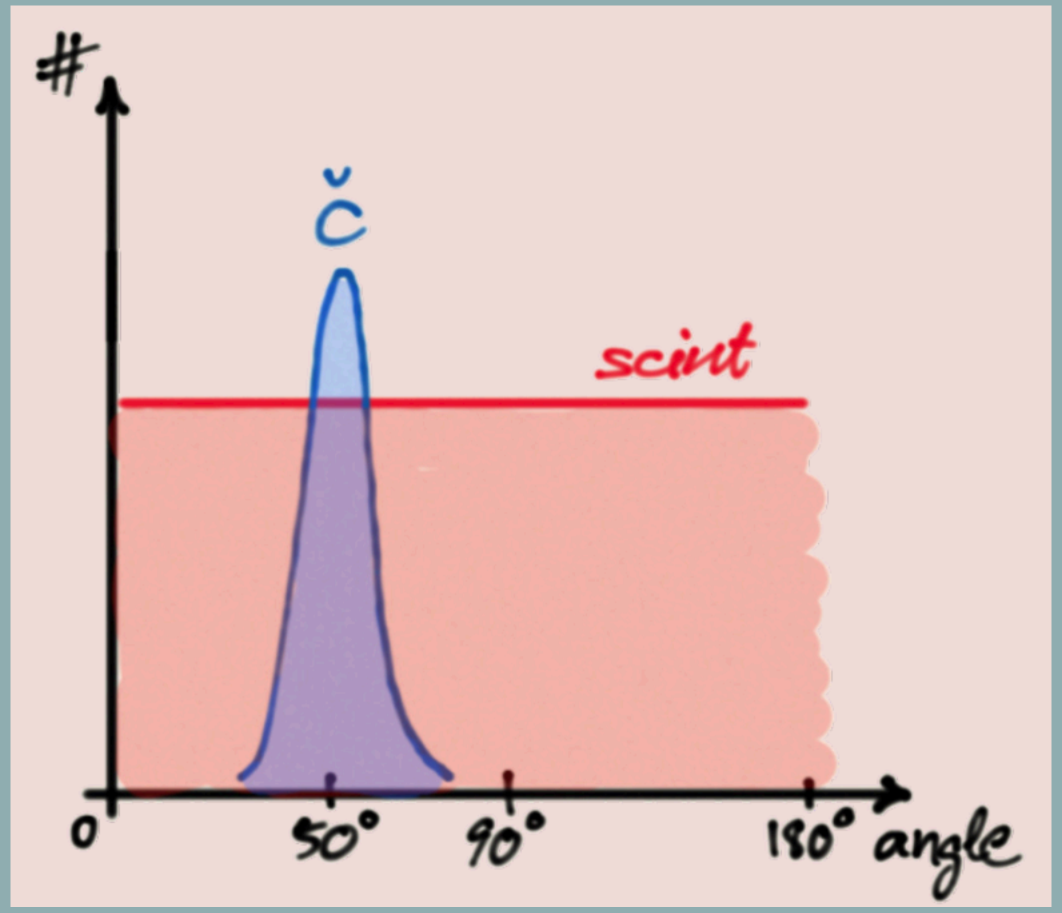
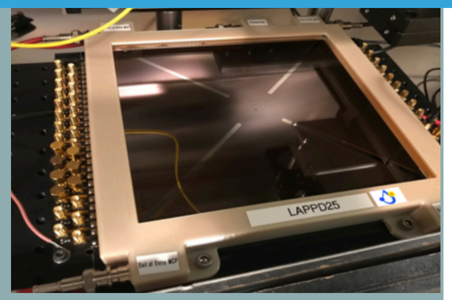
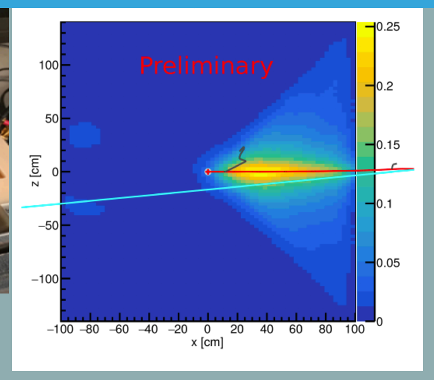


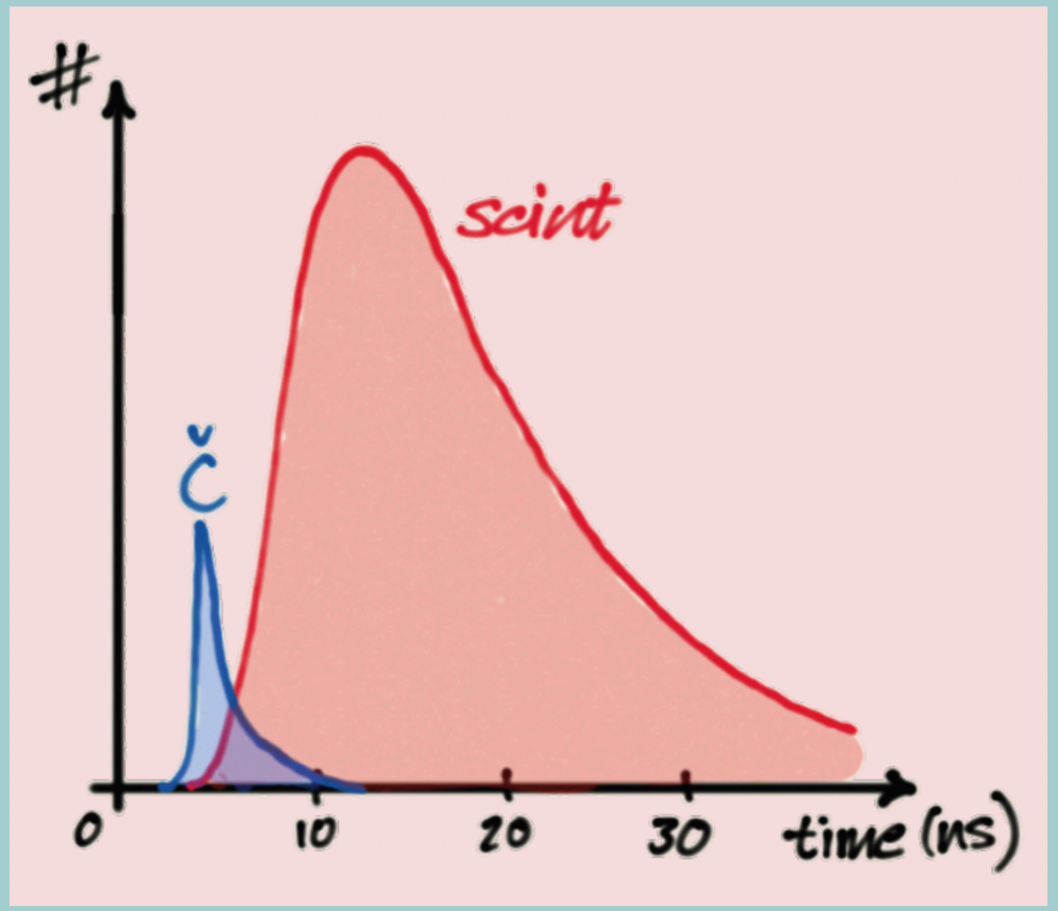
PIXELATION (LAPPDS), NEW RECONSTRUCTION ALGORITHMS



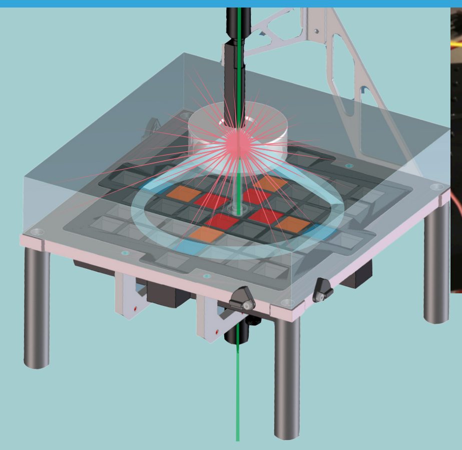


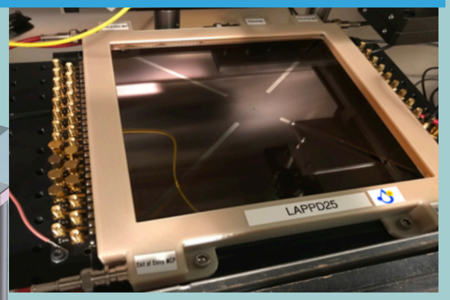
CHERENKOV AND SCINTILLATION SEPARATION STRATEGIES

TIMING



CHESS, LAPPDS





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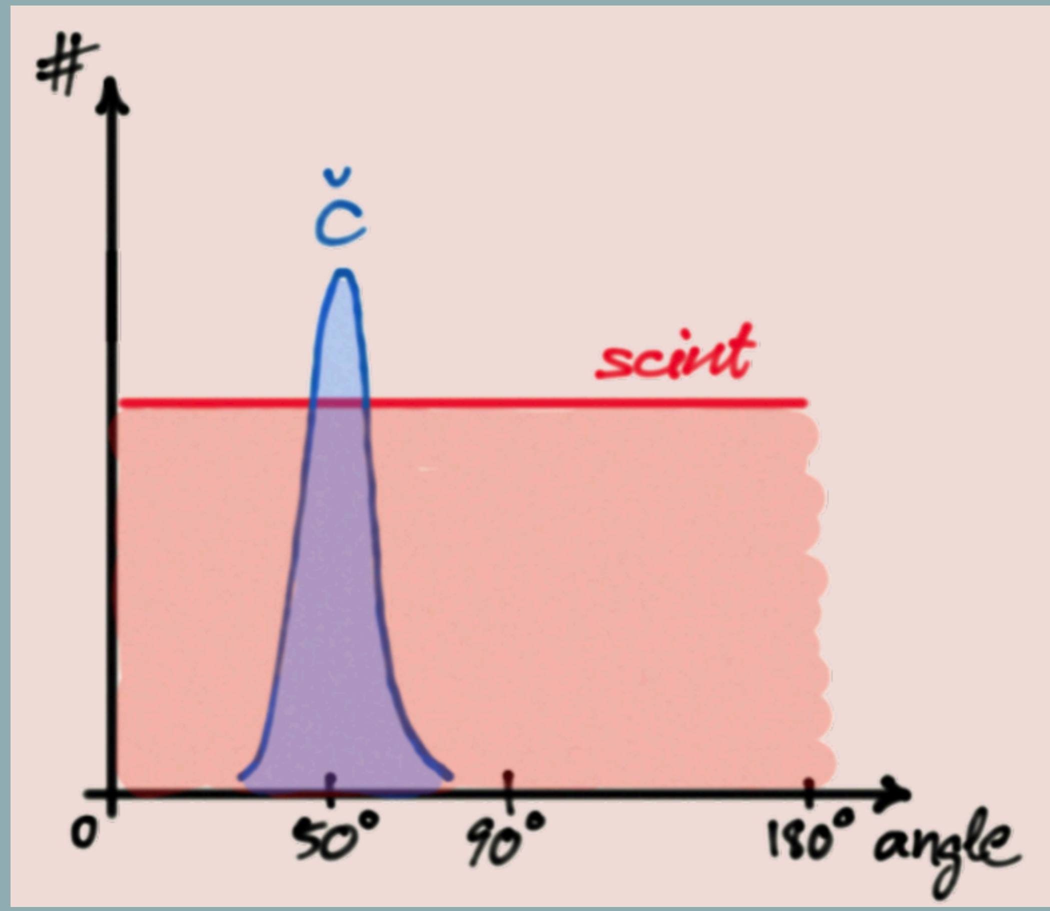
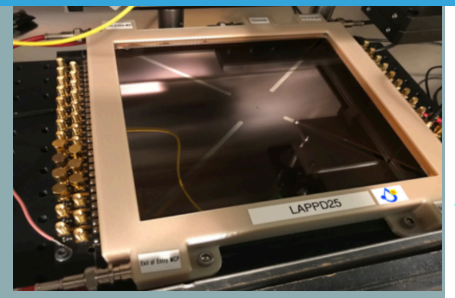
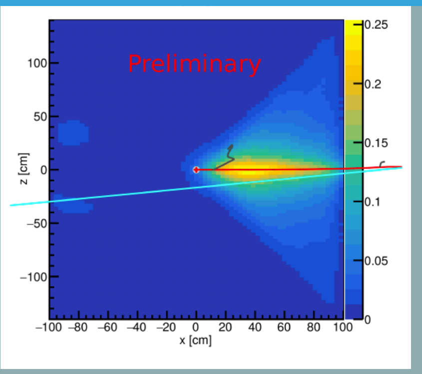
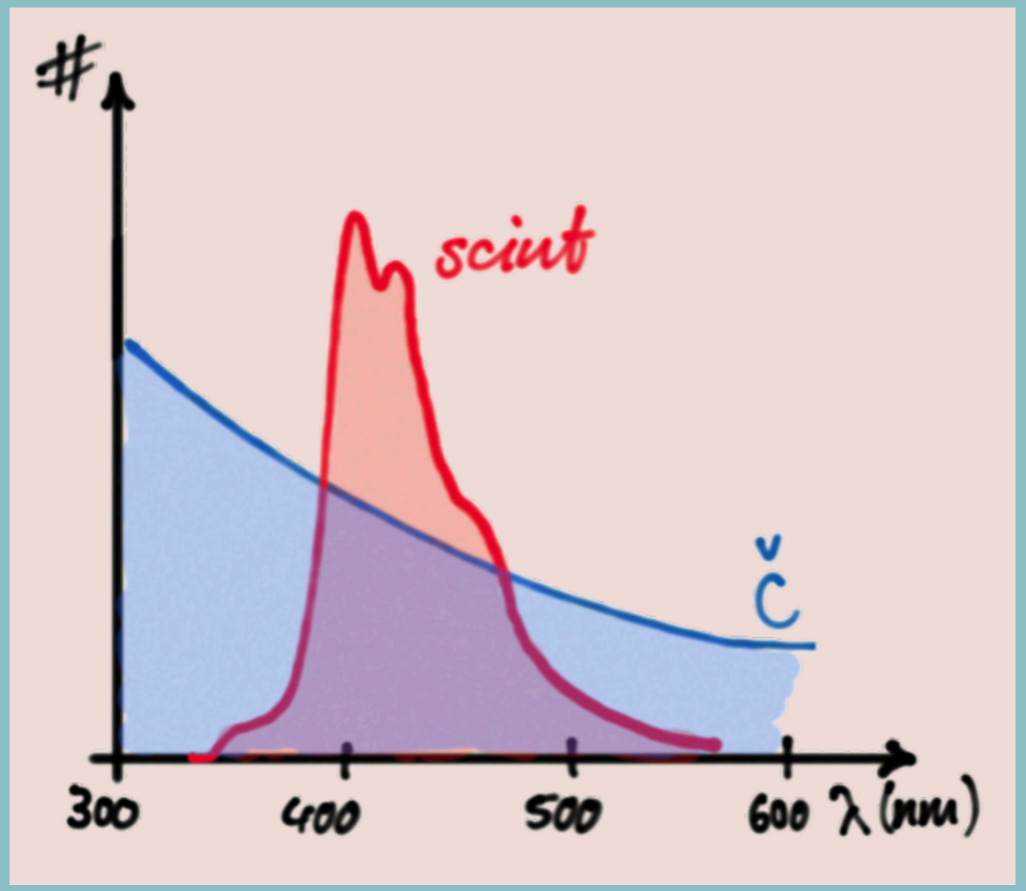


PIXELATION (LAPPDS), NEW RECONSTRUCTION ALGORITHMS

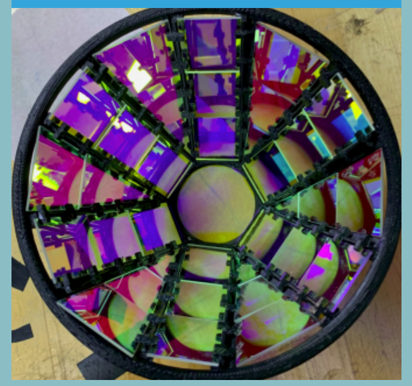




WAVELENGTH

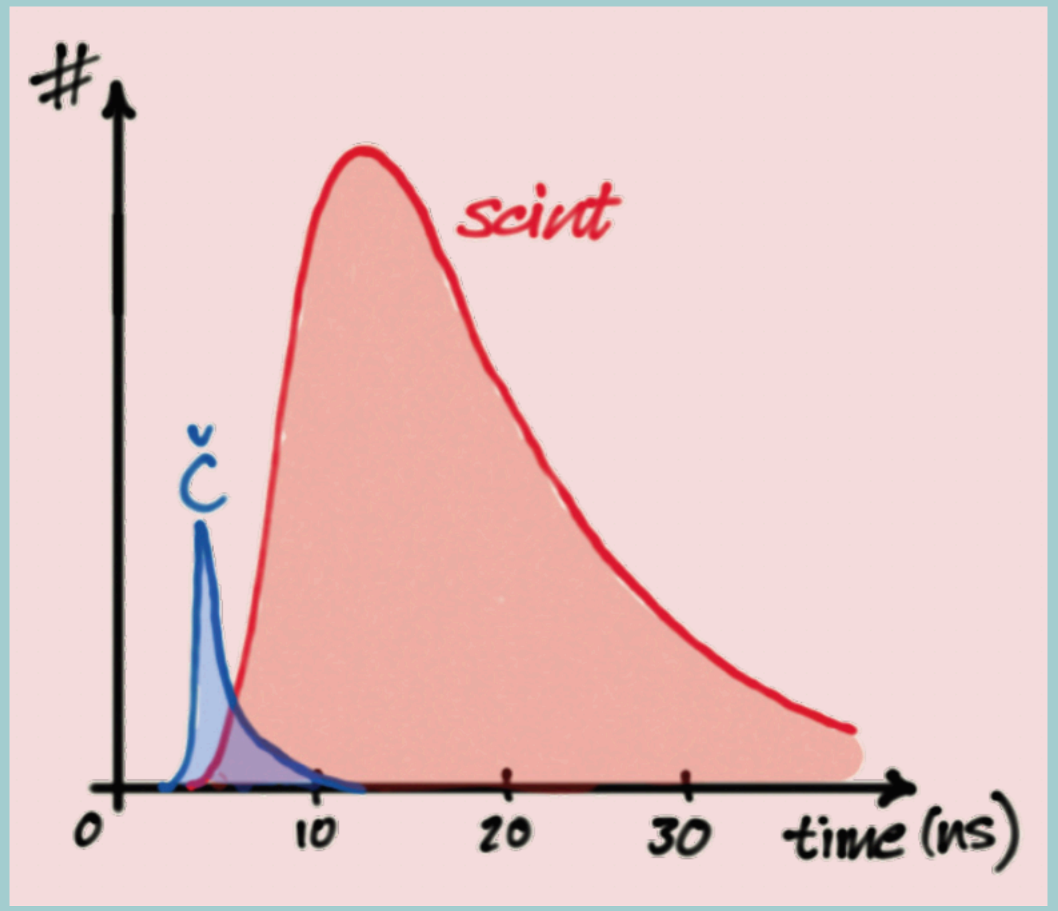


DICHROICONS

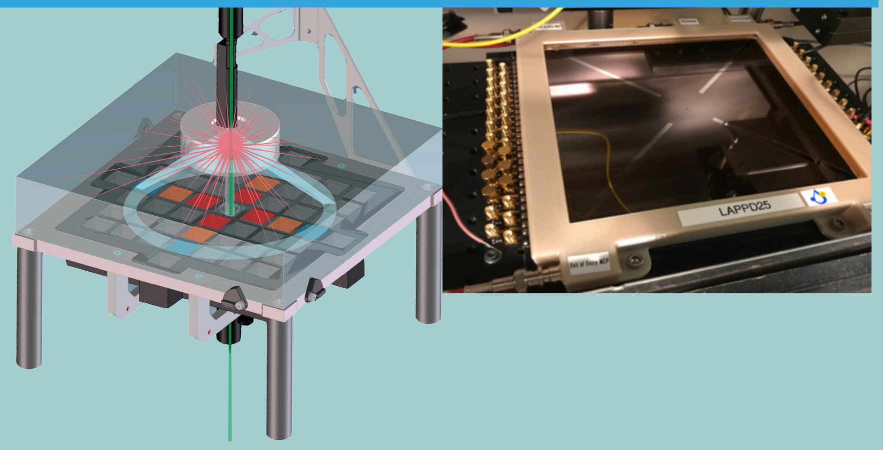


CHERENKOV AND SCINTILLATION SEPARATION STRATEGIES

TIMING



CHESS, LAPPDS



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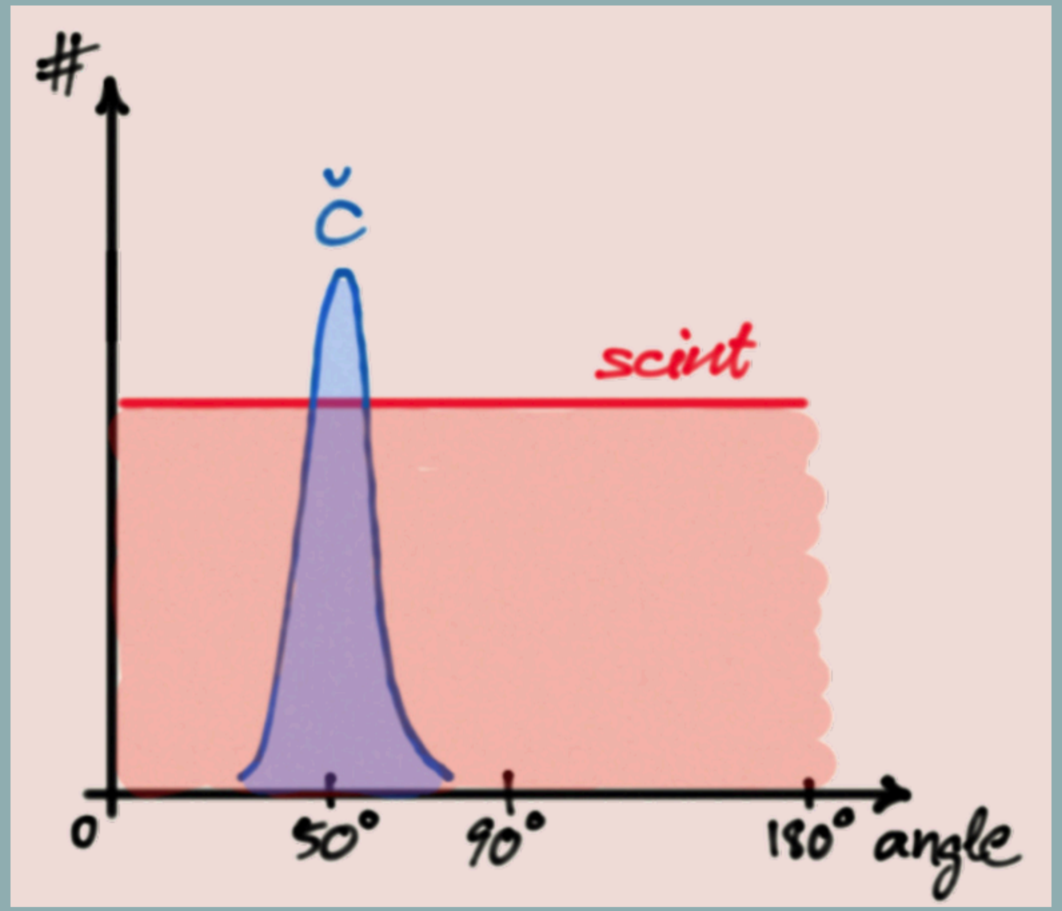
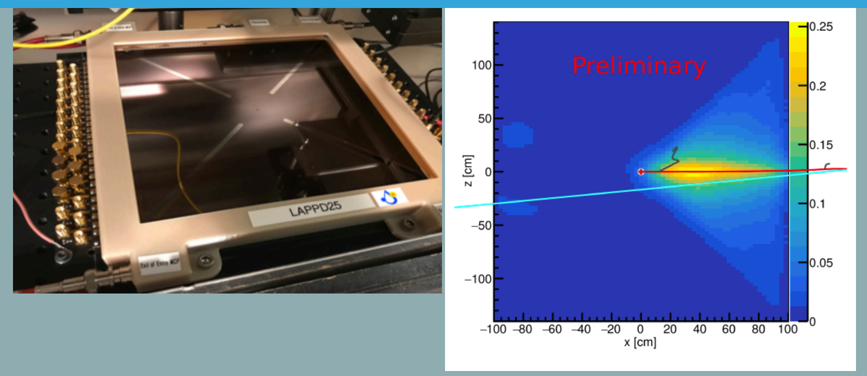


PIXELATION (LAPPDS), NEW RECONSTRUCTION ALGORITHMS



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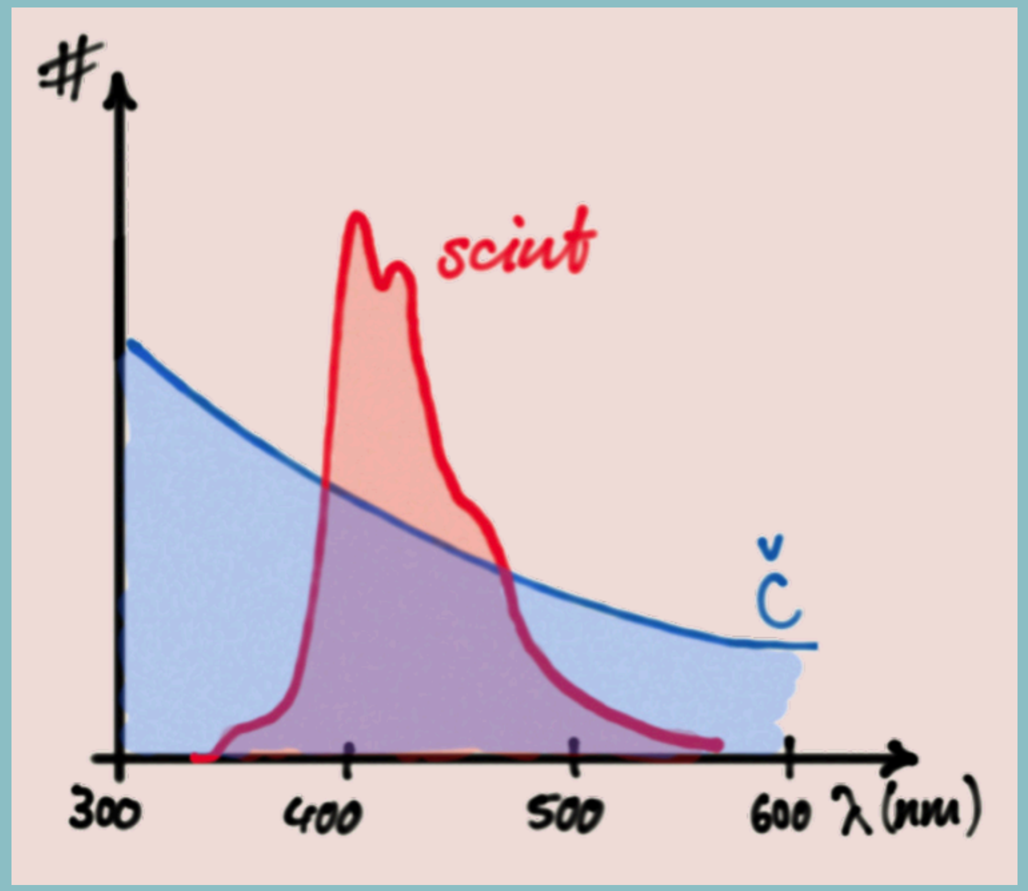
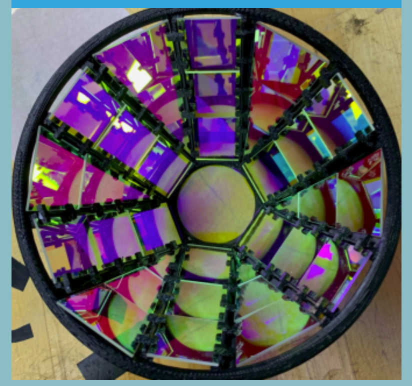


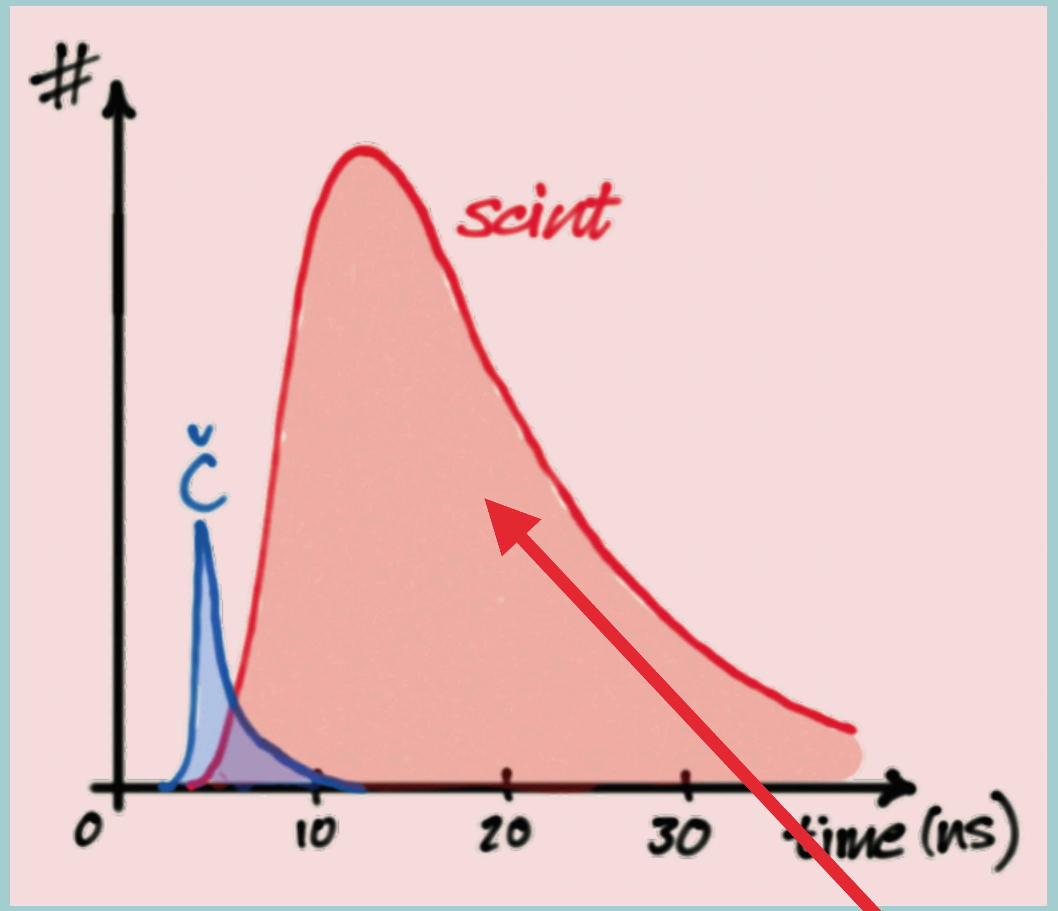
DICHROICONS



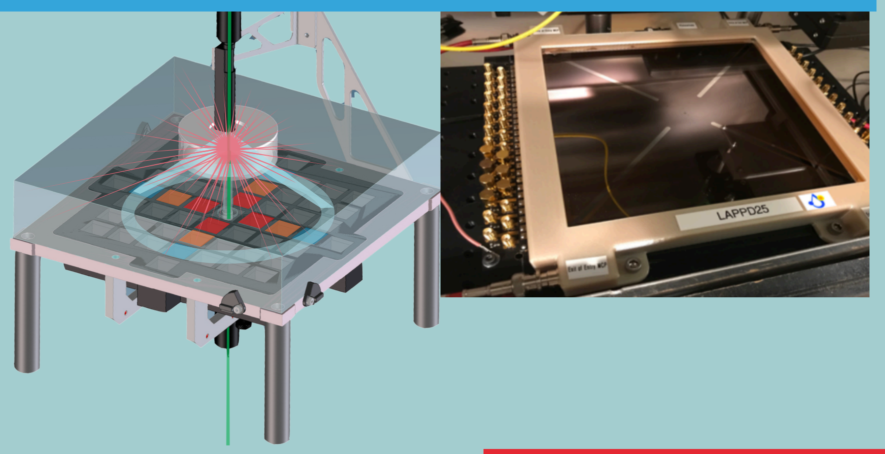
T. KAPTANOGLU – THE DICHROICON: SPECTRAL PHOTON SORTING FOR LARGE-SCALE CHERENKOV AND SCINTILLATION DETECTORS

CHERENKOV AND SCINTILLATION SEPARATION STRATEGIES

TIMING



CHESS, LAPPDS



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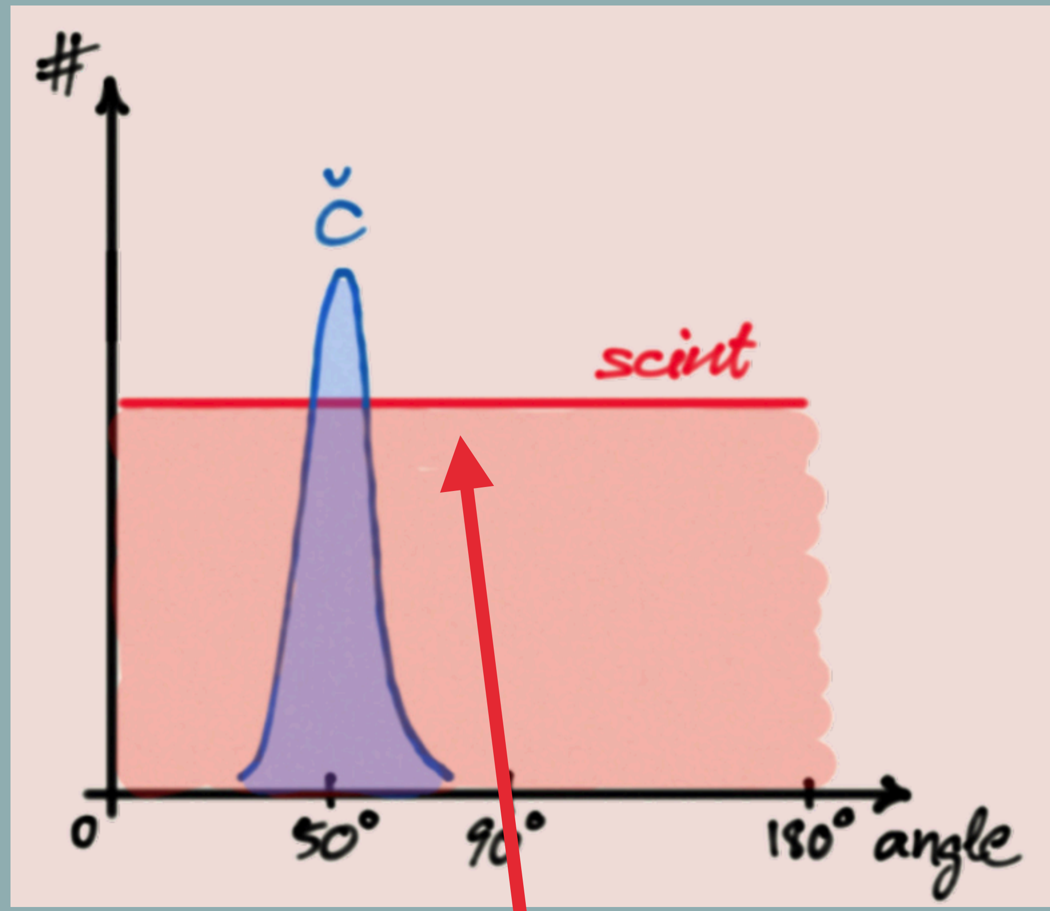
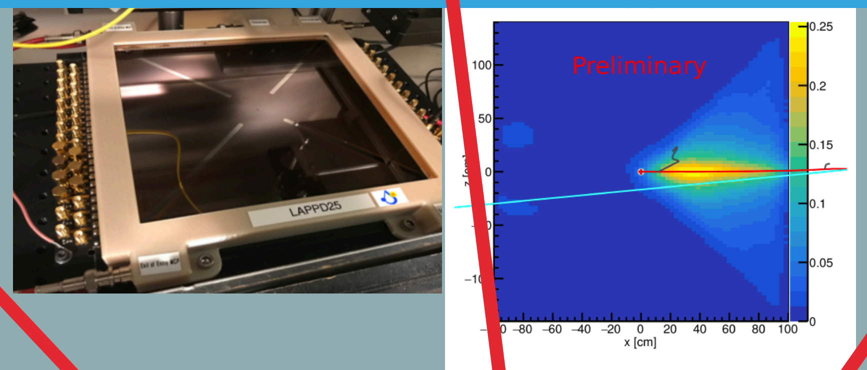


PIXELATION (LAPPDS), NEW RECONSTRUCTION ALGORITHMS



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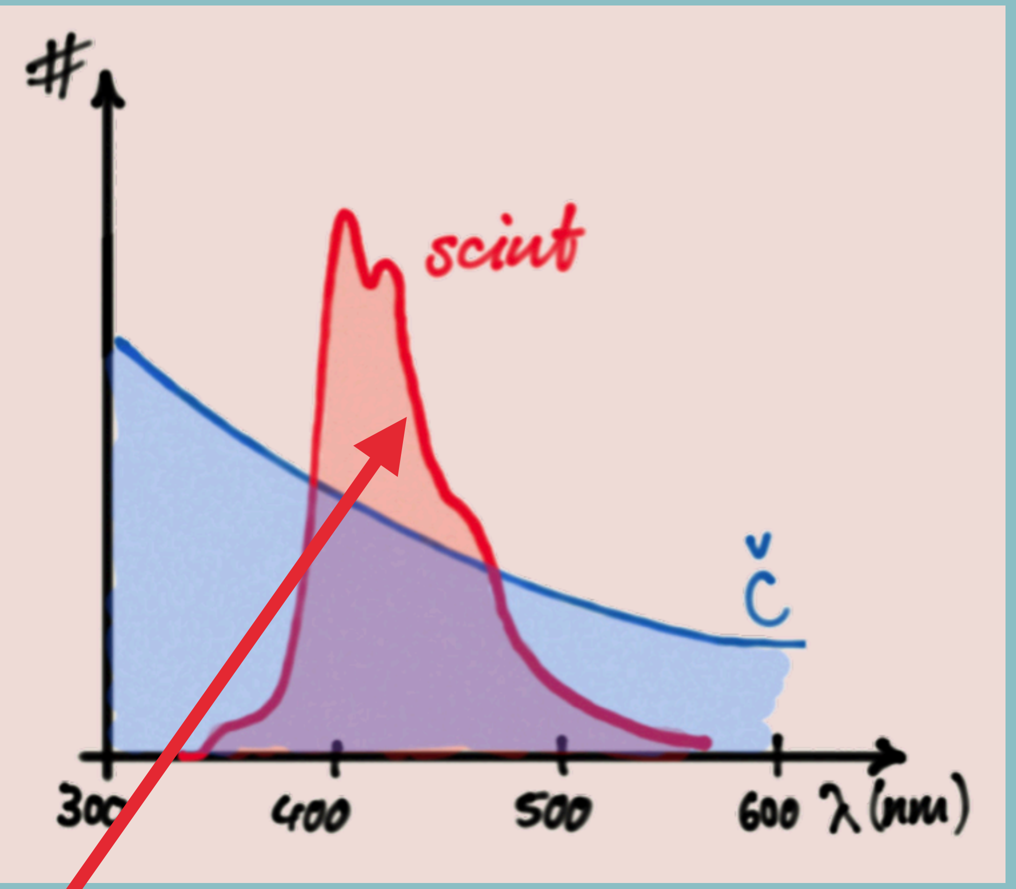

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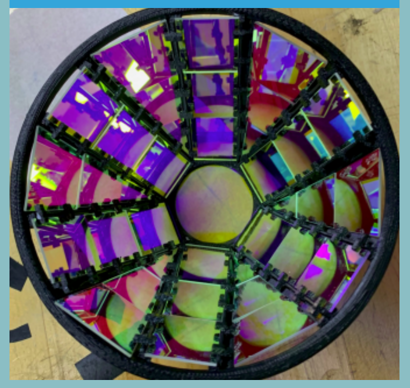
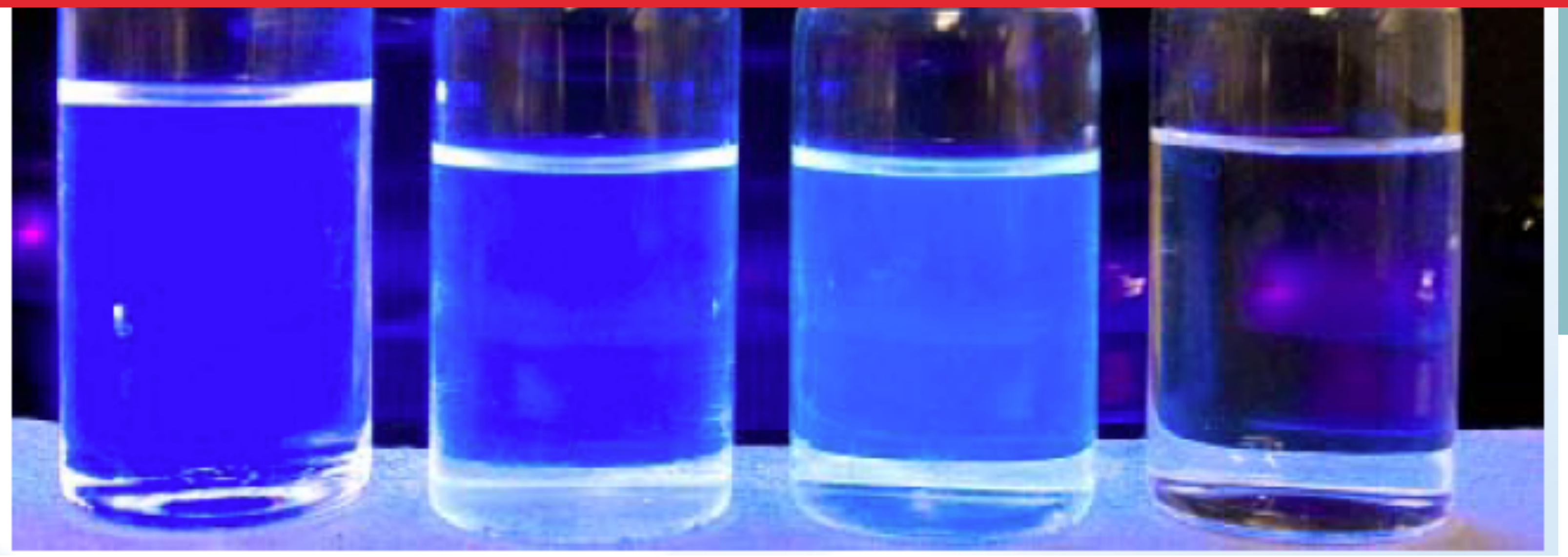
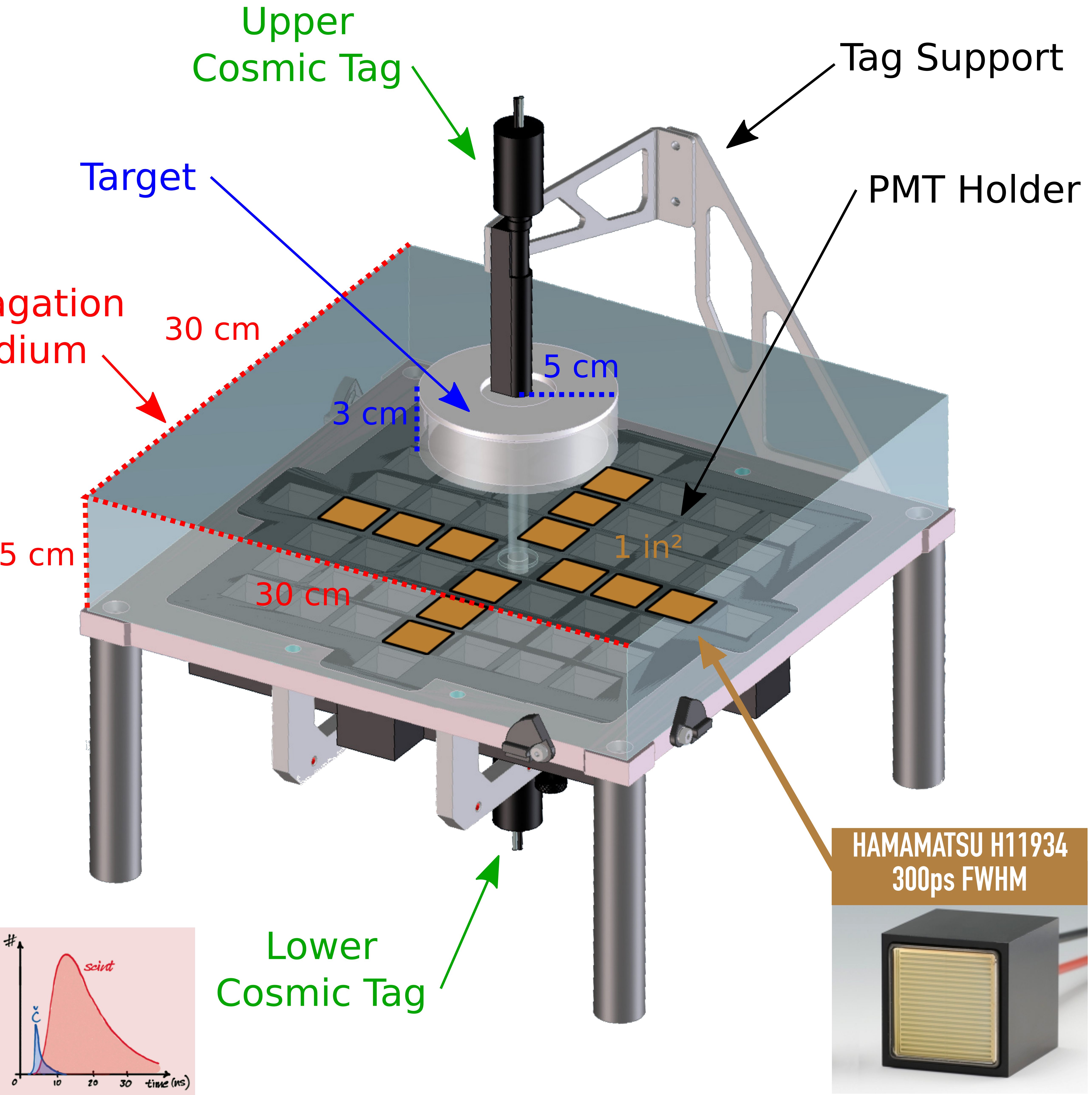


WATER-BASED LIQUID SCINTILLATOR:
LOWER SCINTILLATION LIGHT YIELD WHILE MINIMIZING PHOTON ABSORPTION

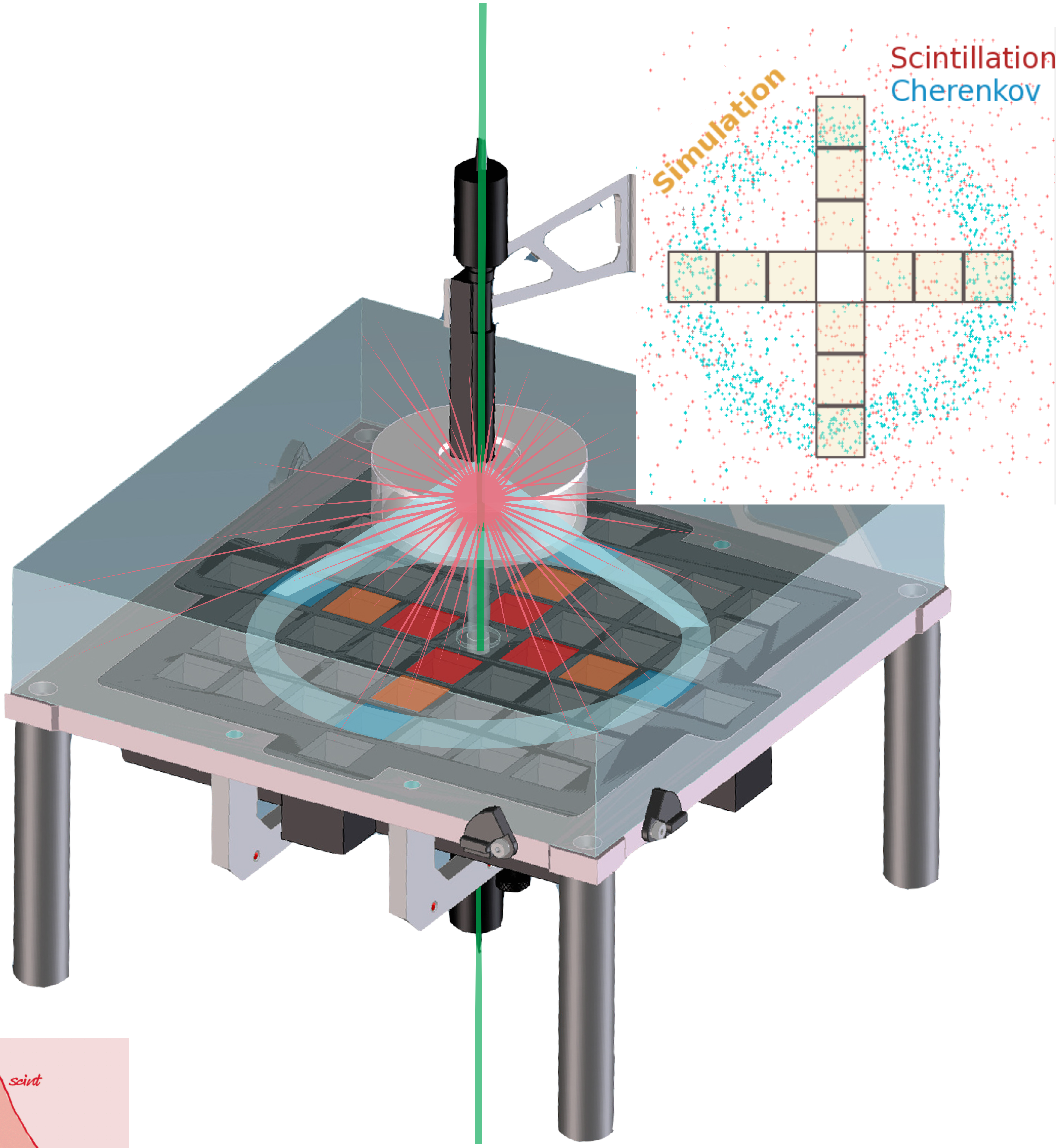


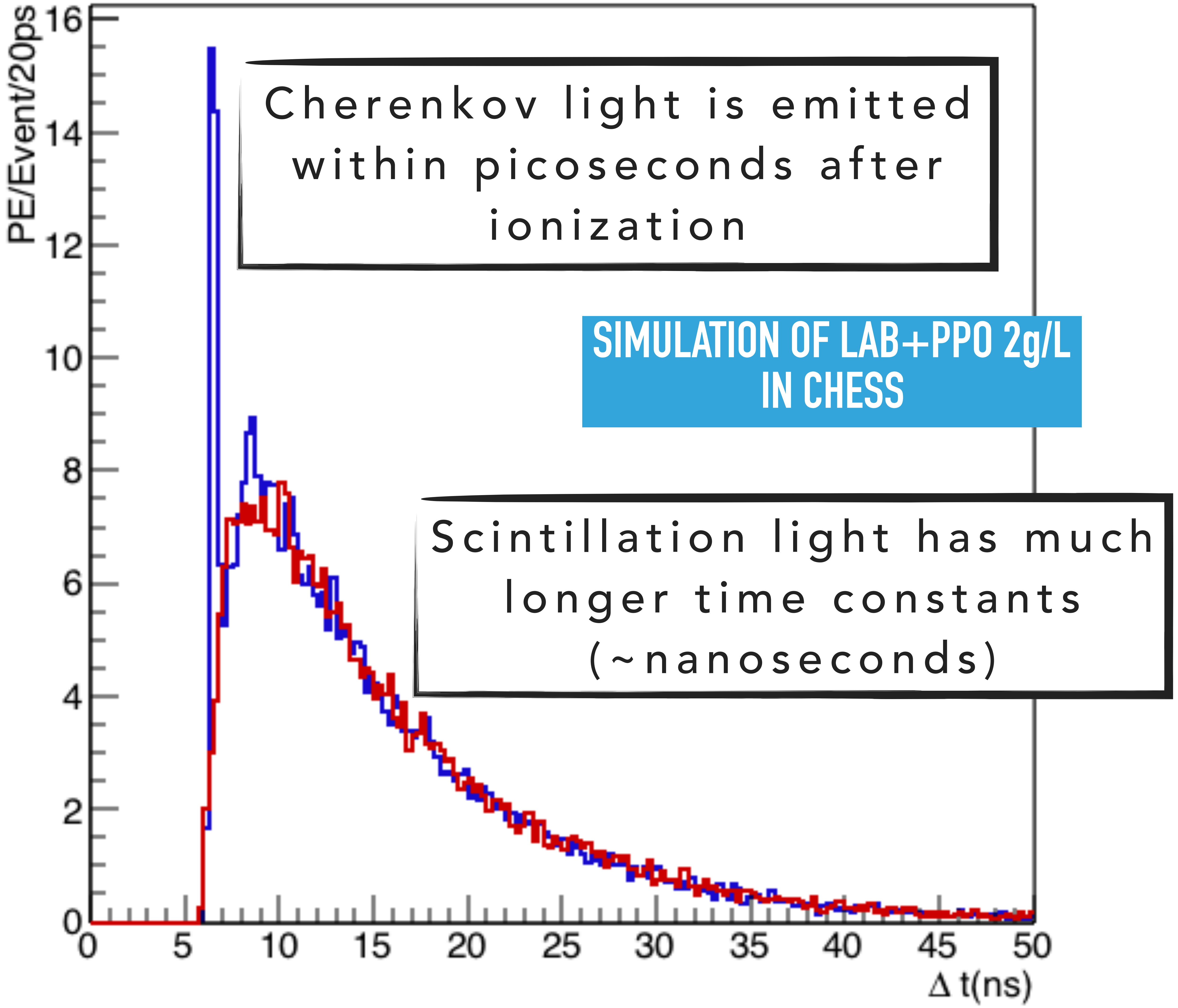
CHESS: CHERENKOV AND SCINTILLATION TIMING SEPARATION AT SMALL SCALES

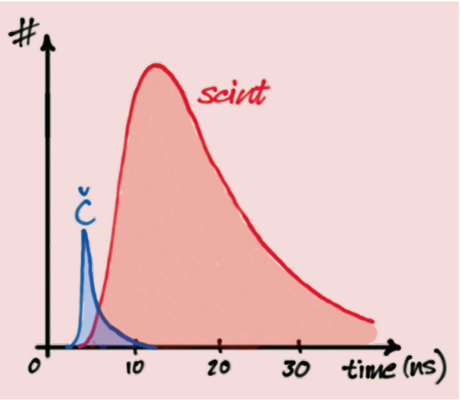


J. Caravaca et al. Eur. Phys. J. C 77: 811 (2017)
J. Caravaca et al. Phys. Rev. C 95, 055801 (2017)

CHESS: CHERENKOV AND SCINTILLATION TIMING SEPARATION AT SMALL SCALES







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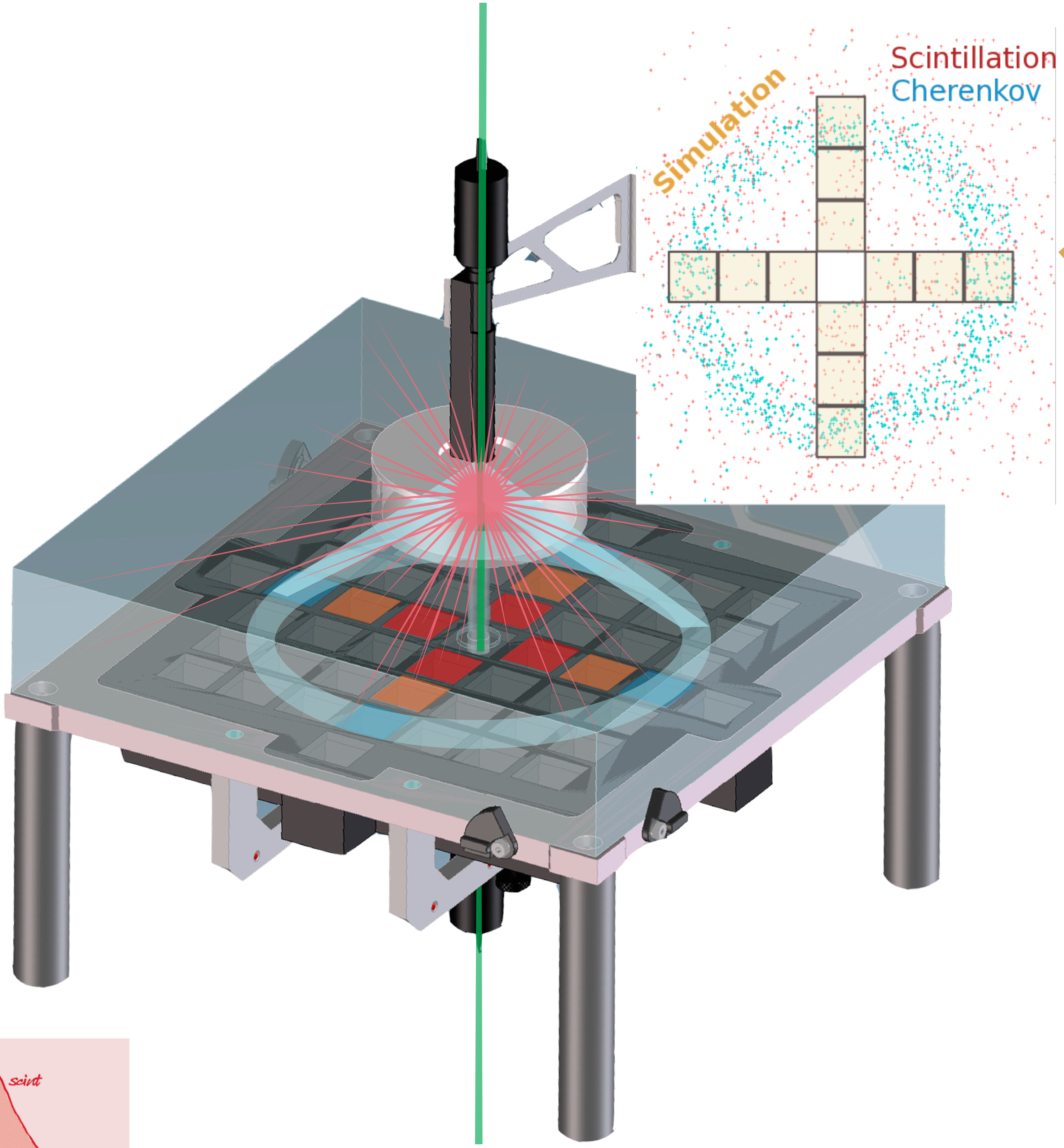
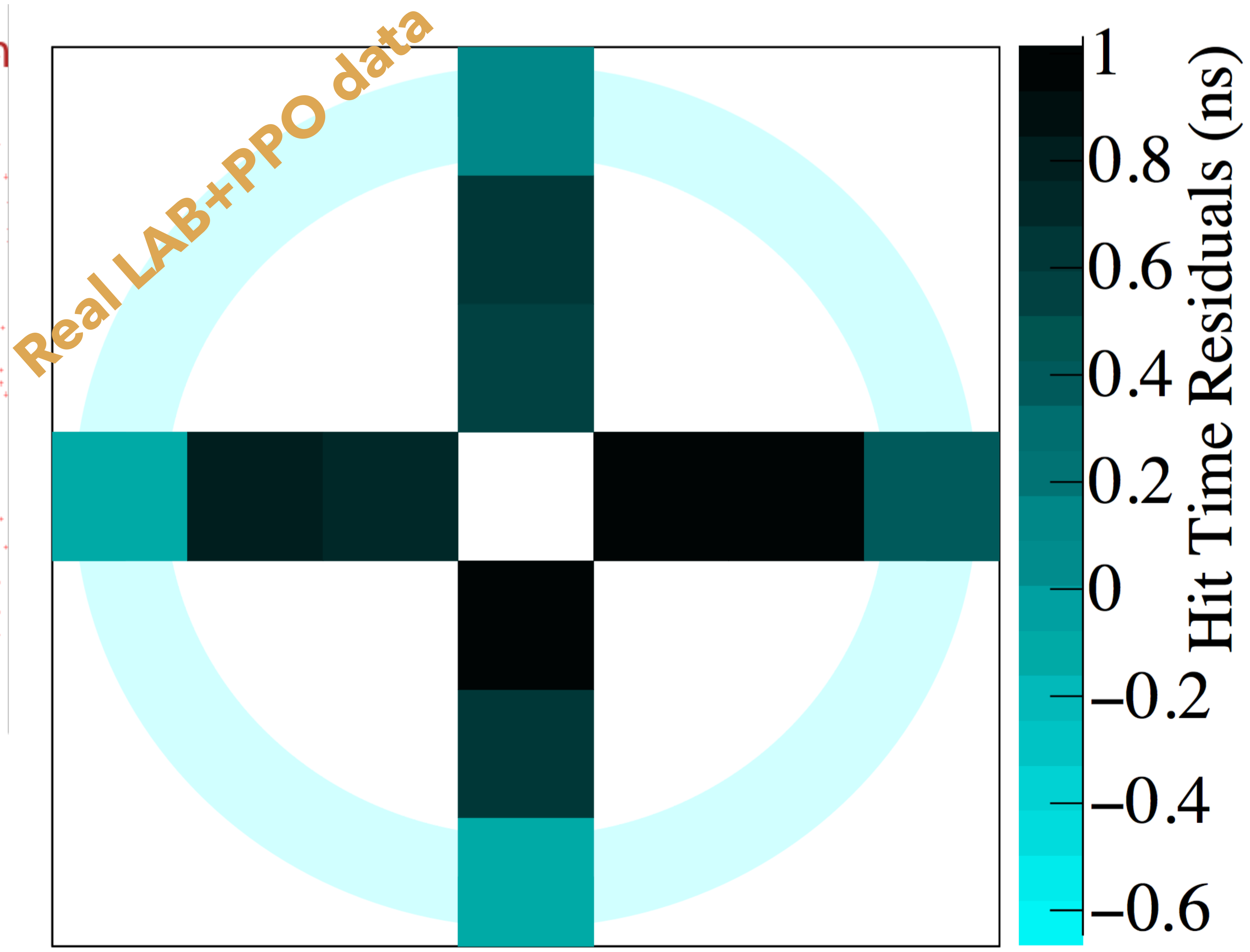
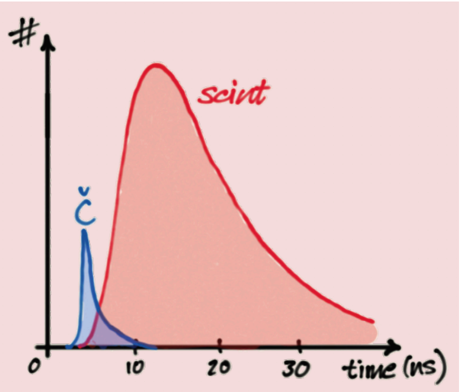
CHESS: CHERENKOV AND SCINTILLATION TIMING SEPARATION AT SMALL SCALES







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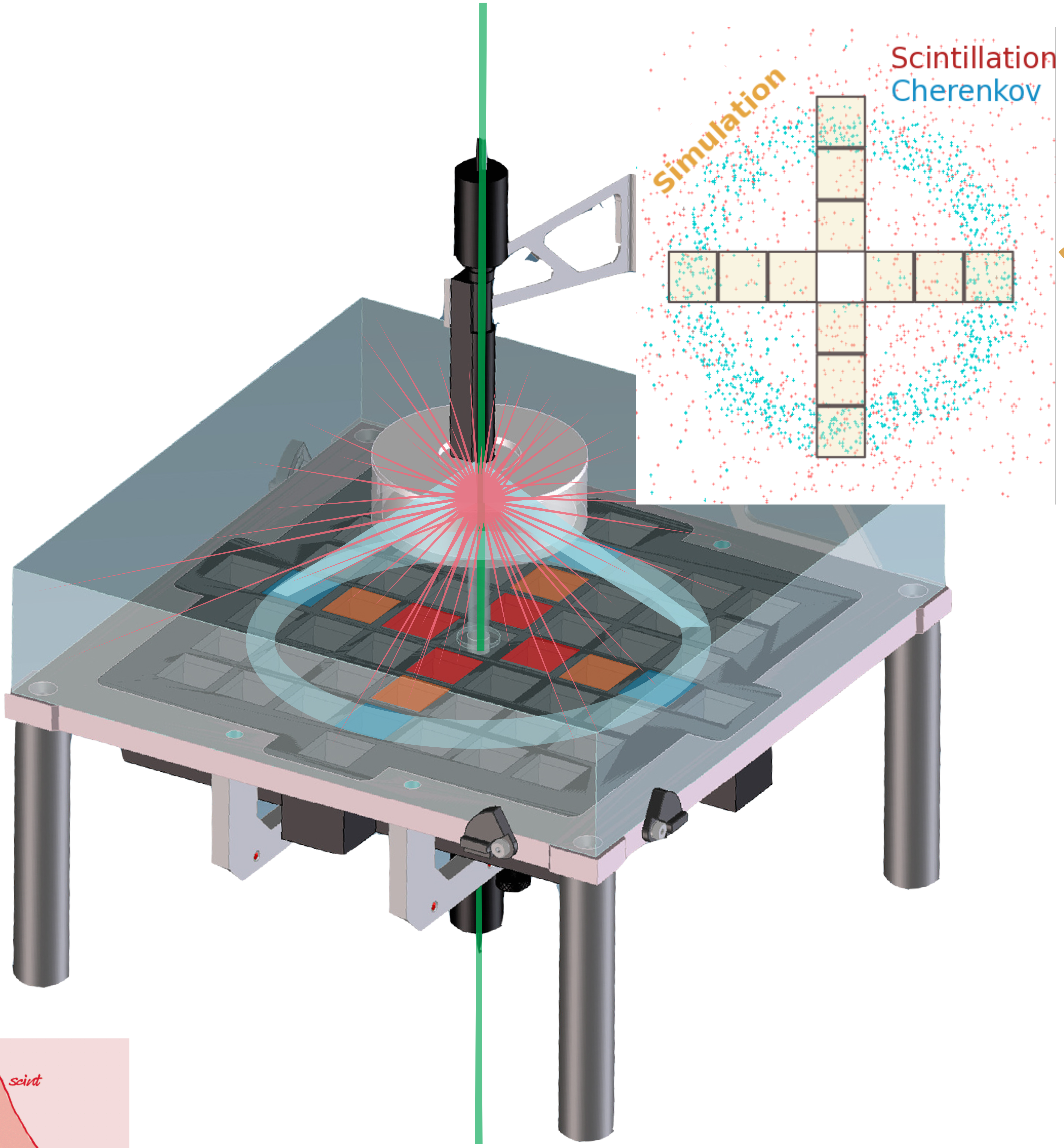
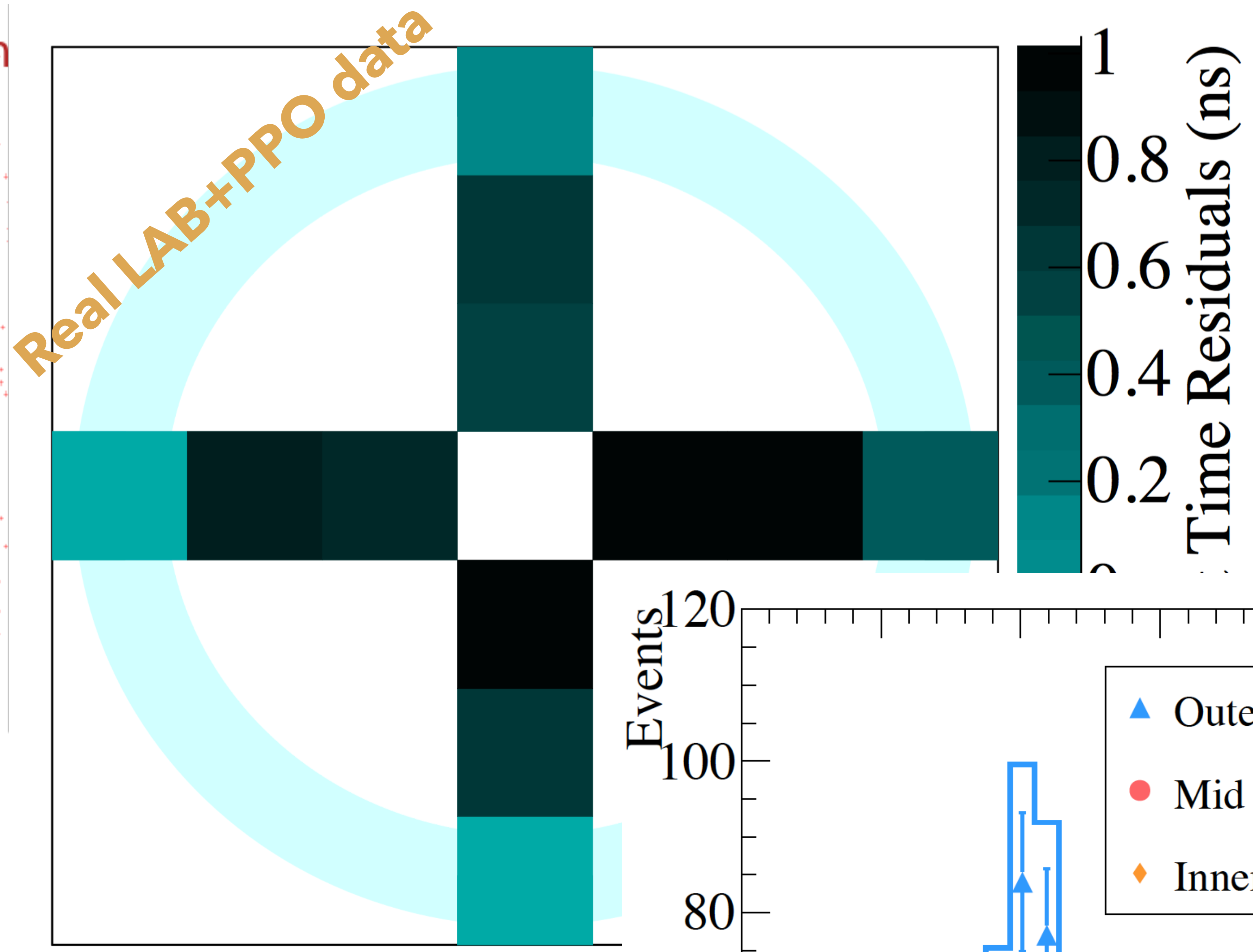
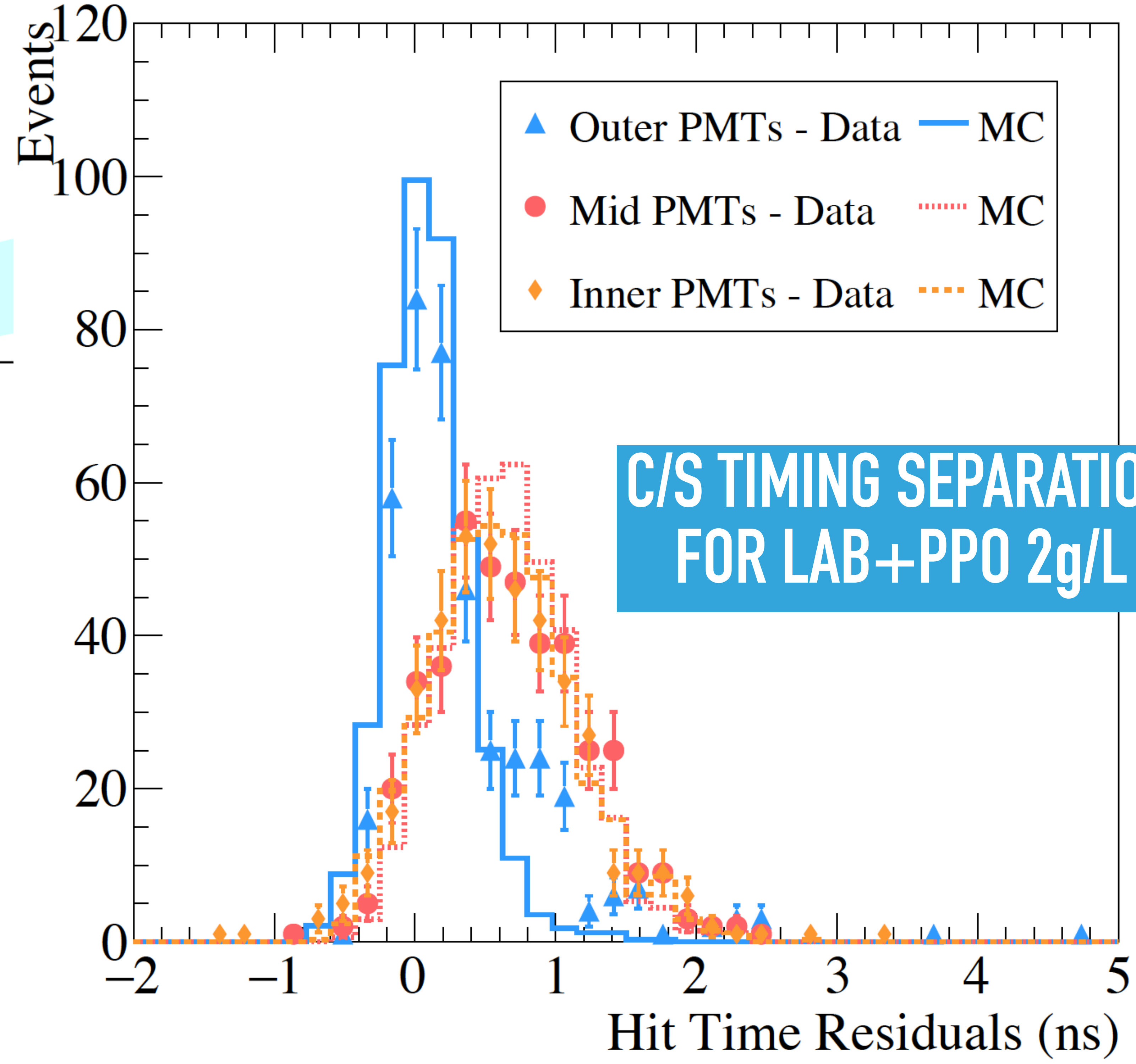
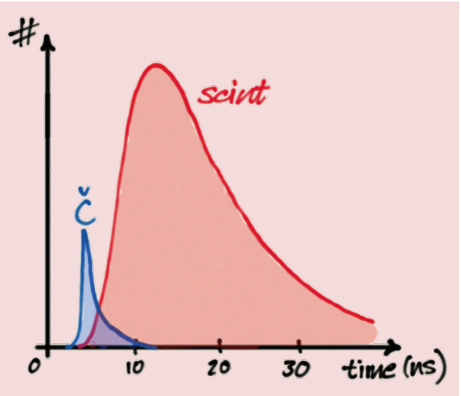
CHESS: CHERENKOV AND SCINTILLATION TIMING SEPARATION AT SMALL SCALES









C/S TIMING SEPARATION FOR LAB+PPO 2g/L

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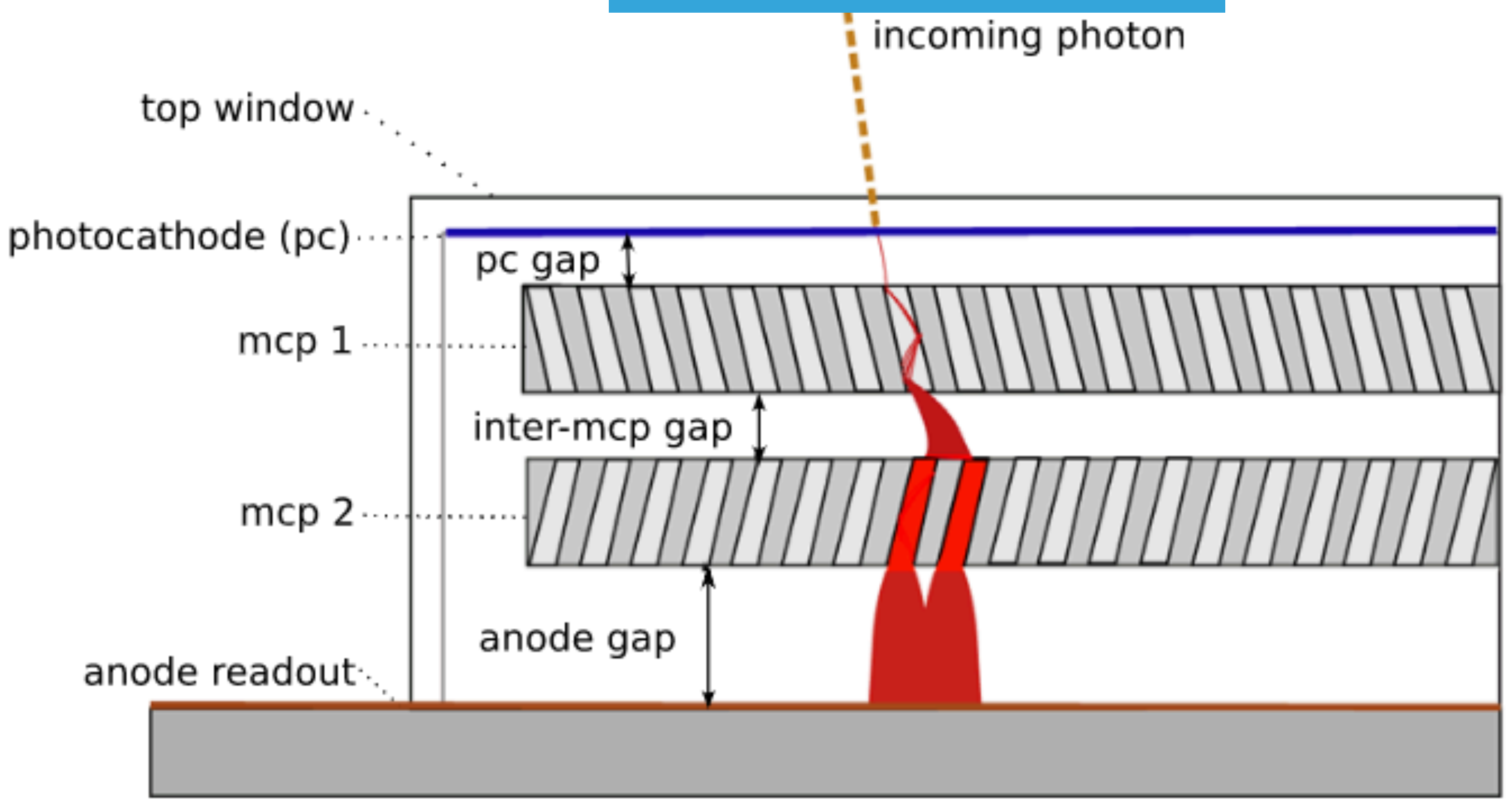
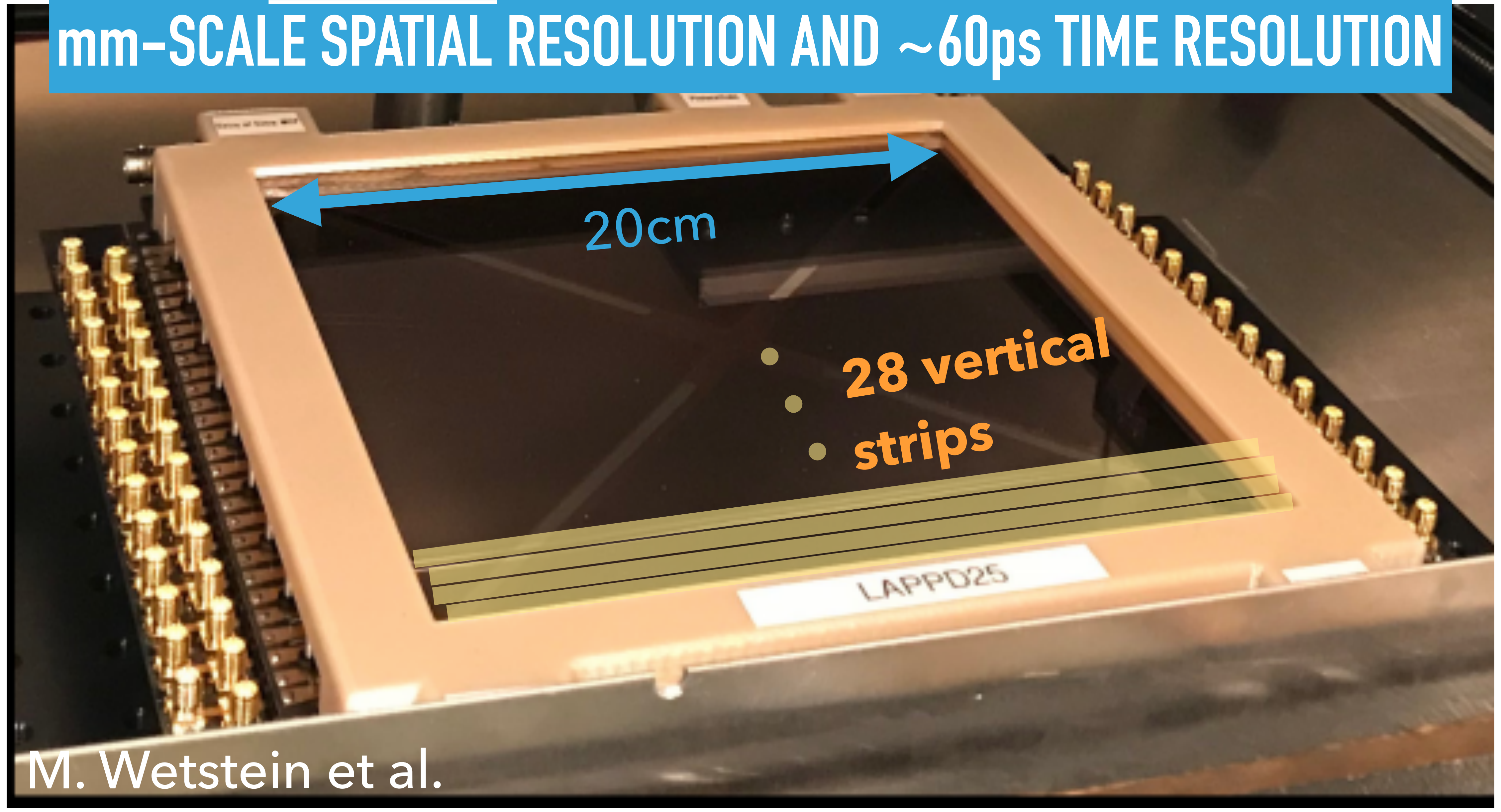
LAPPD

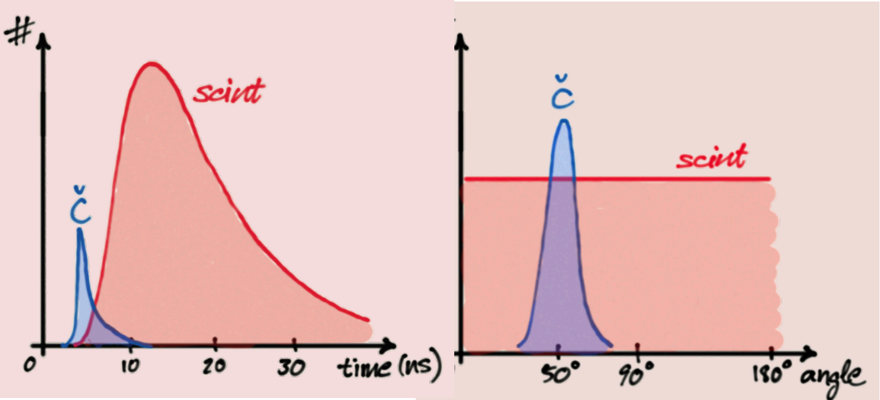
https://incomusa.com/lappd/

MCP-BASED DEVICE



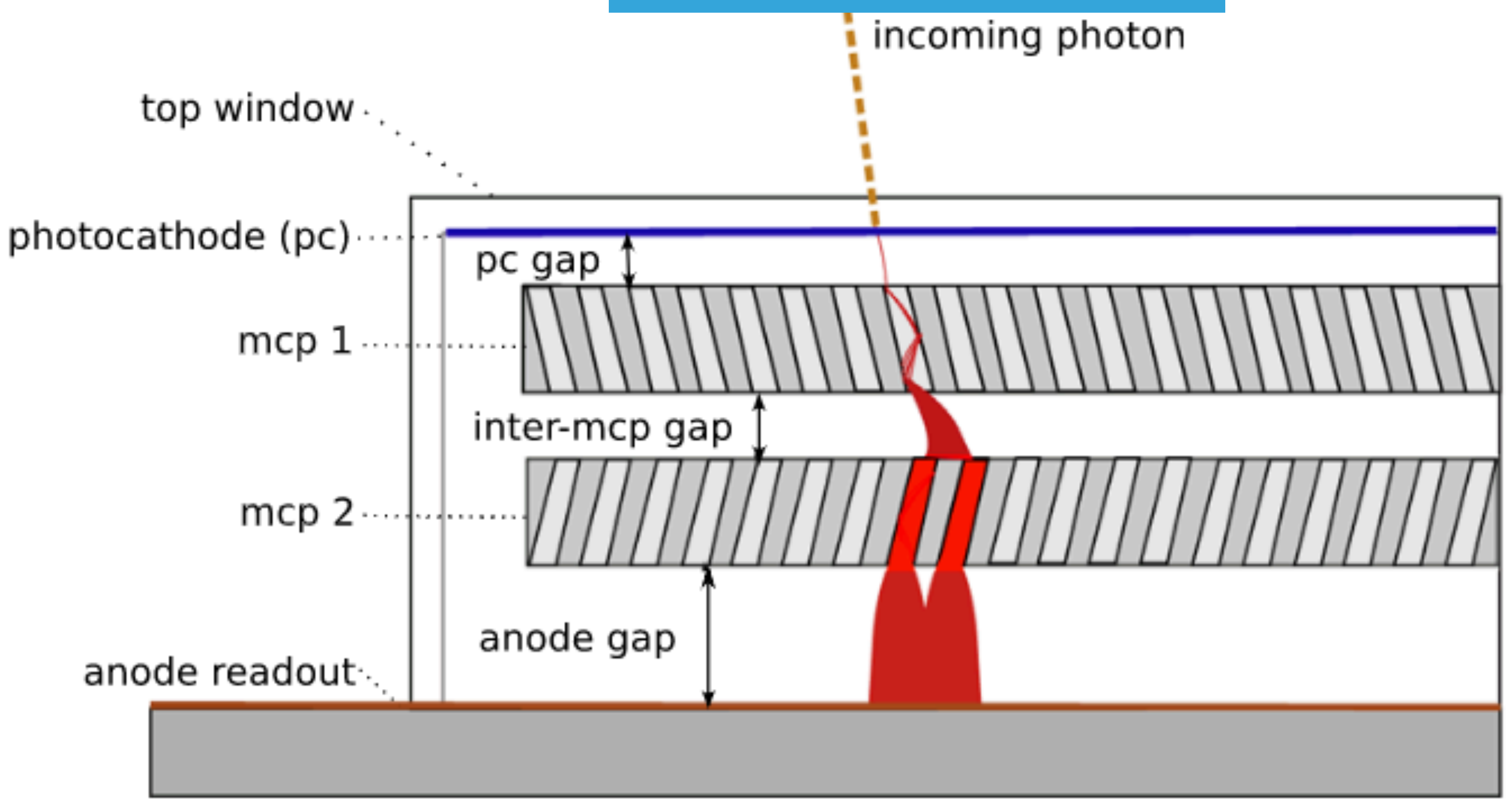
PIXELATED LARGE AREA PHOTOSENSOR WITH mm-SCALE SPATIAL RESOLUTION AND ~60ps TIME RESOLUTION



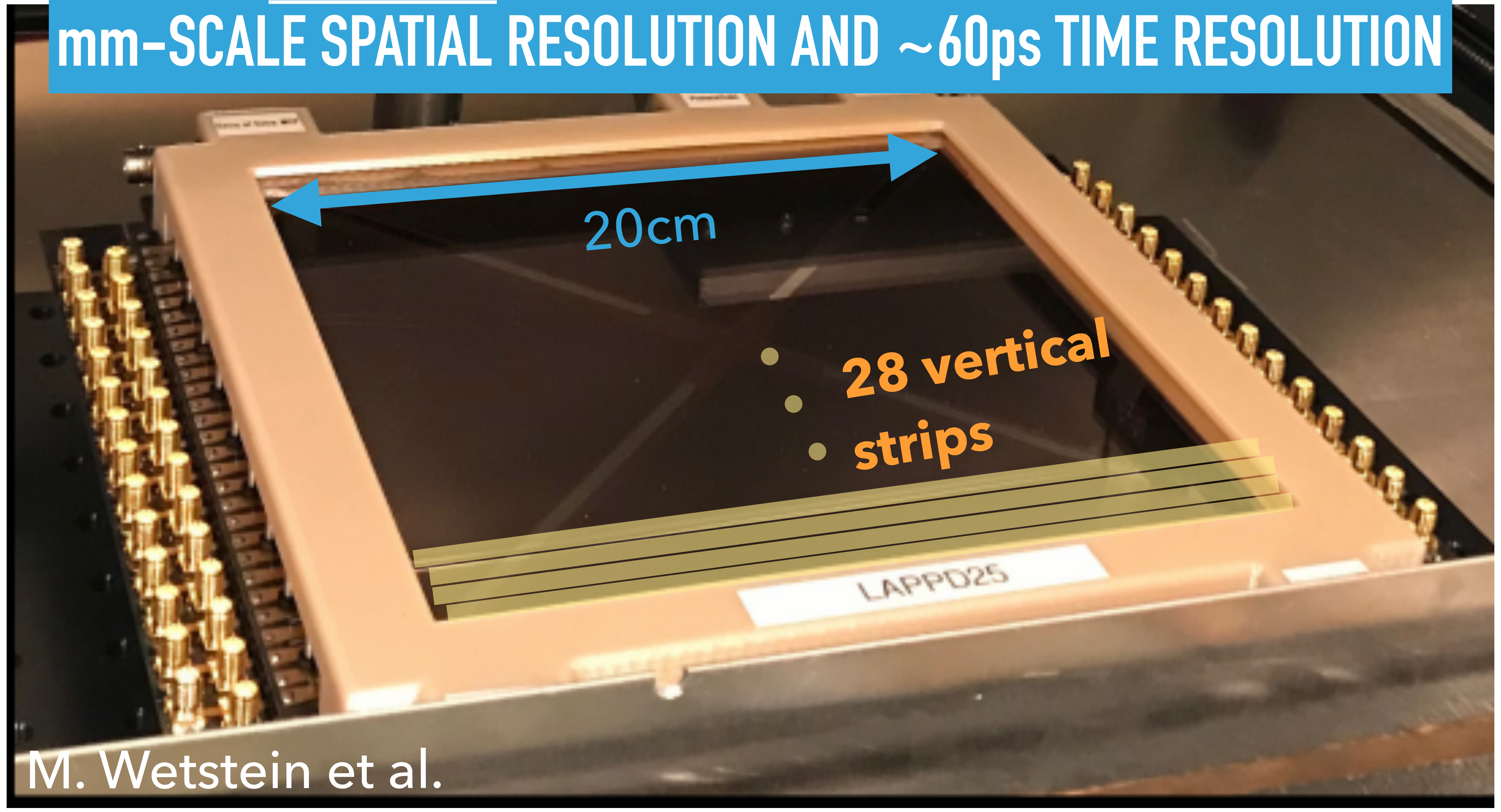


LAPPD https://incomusa.com/lappd/

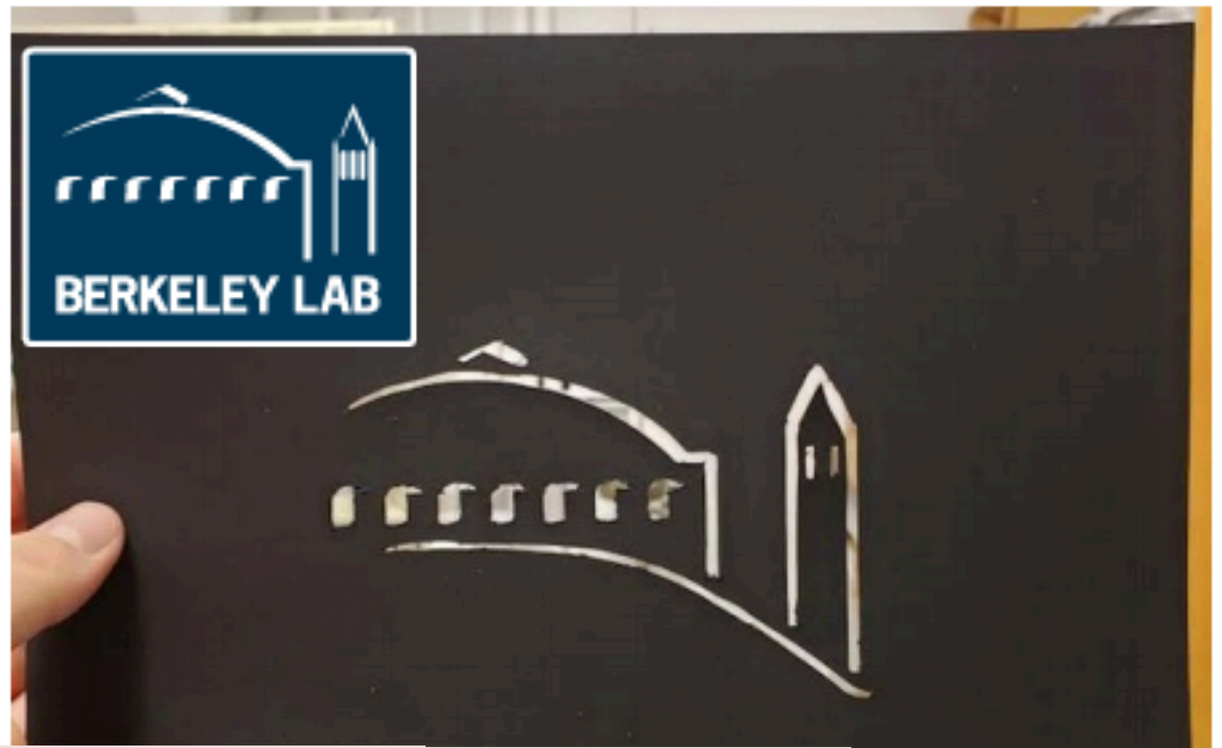
MCP-BASED DEVICE

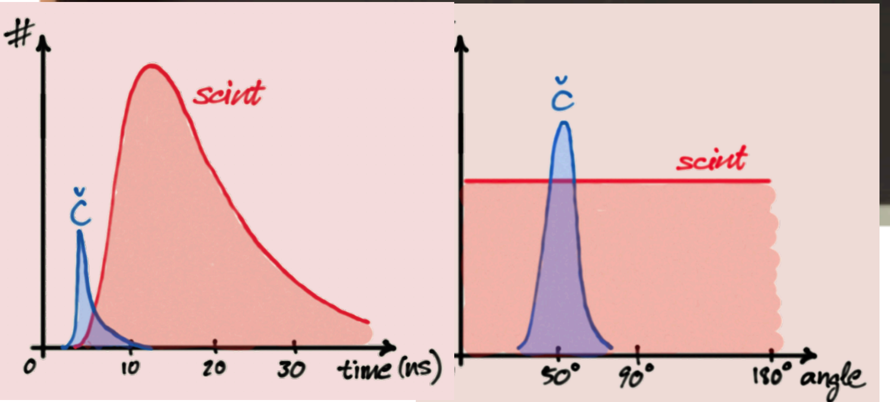


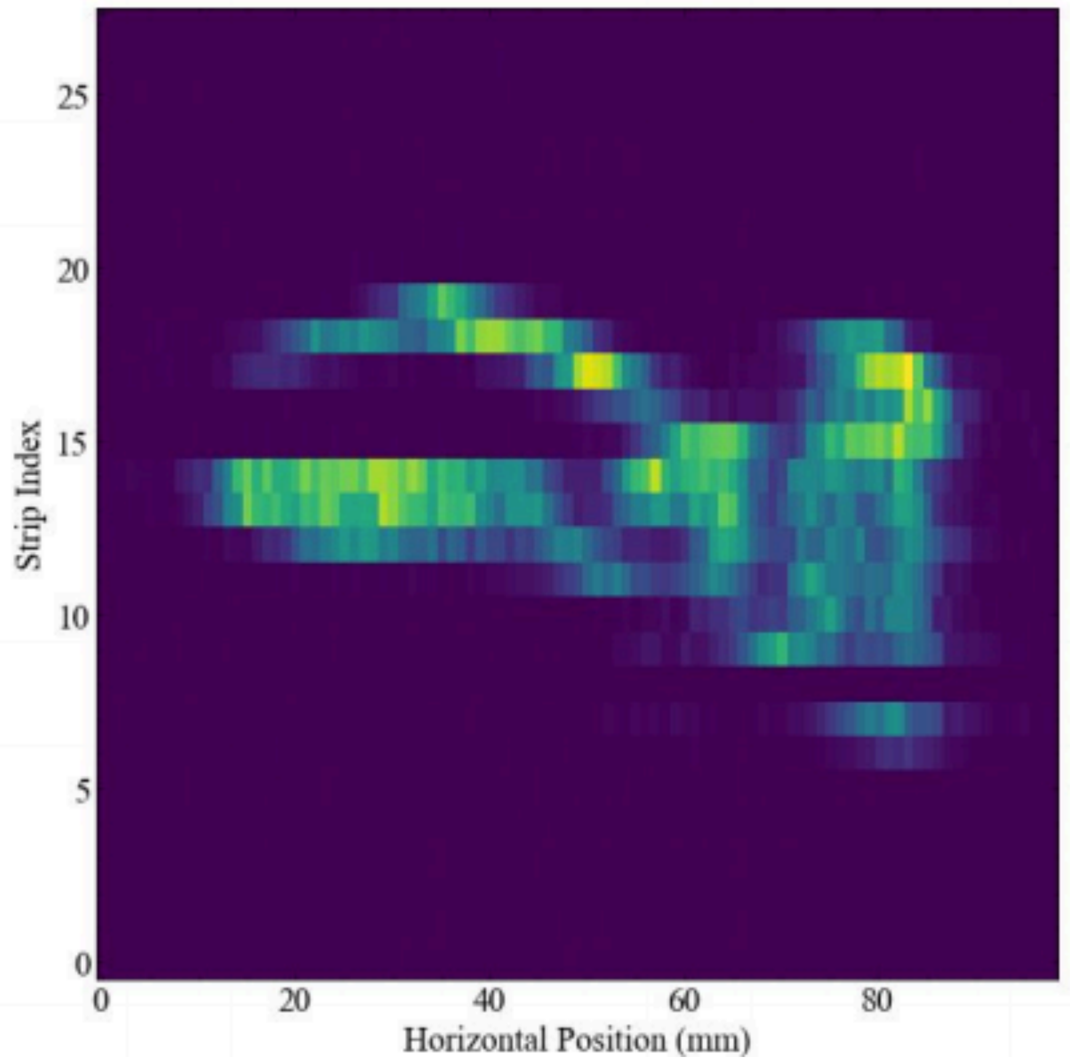
PIXELATED LARGE AREA PHOTOSENSOR WITH mm-SCALE SPATIAL RESOLUTION AND ~60ps TIME RESOLUTION



SINGLE PHOTOELECTRON STACKED IMAGE FROM LED

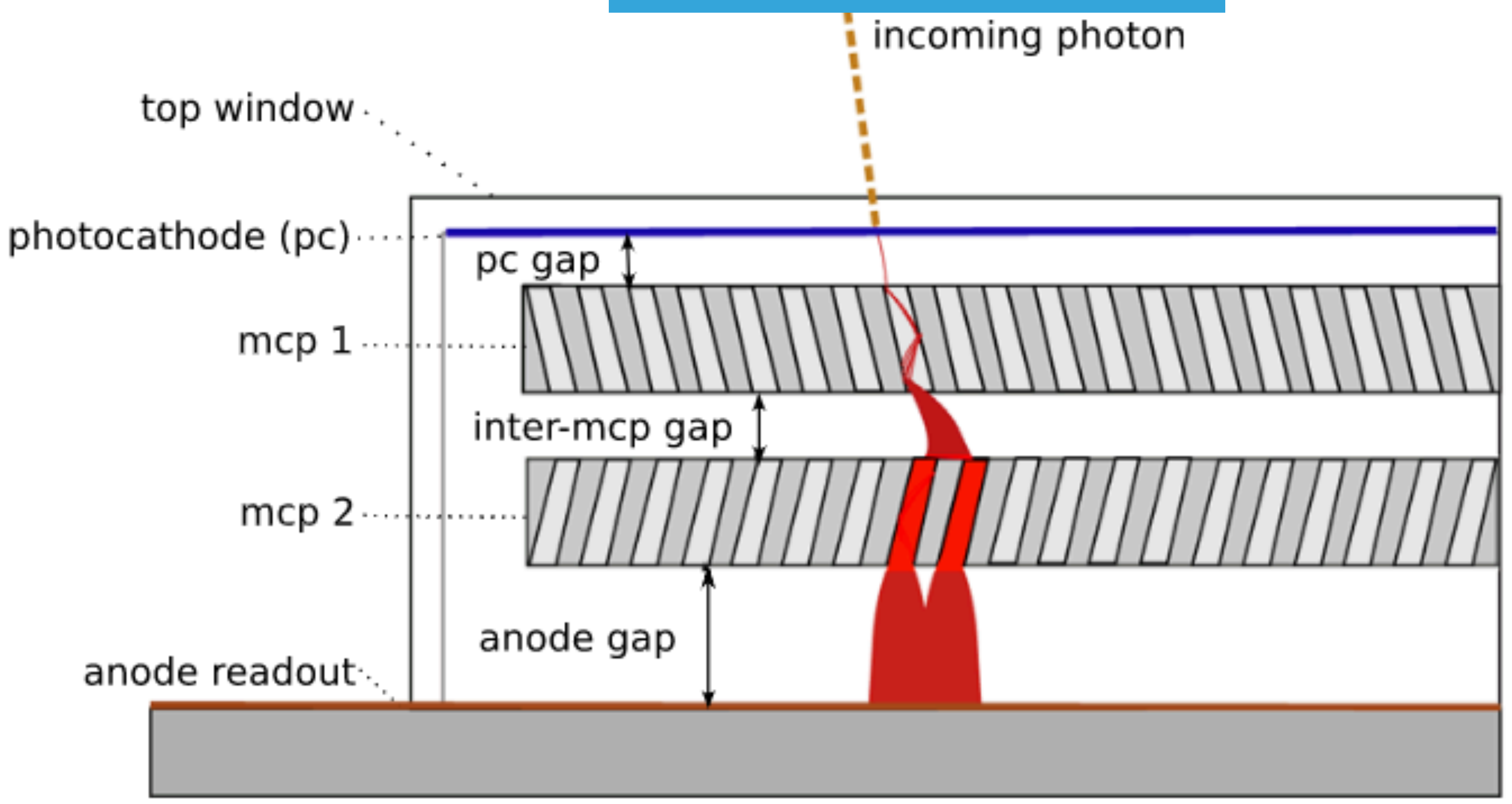




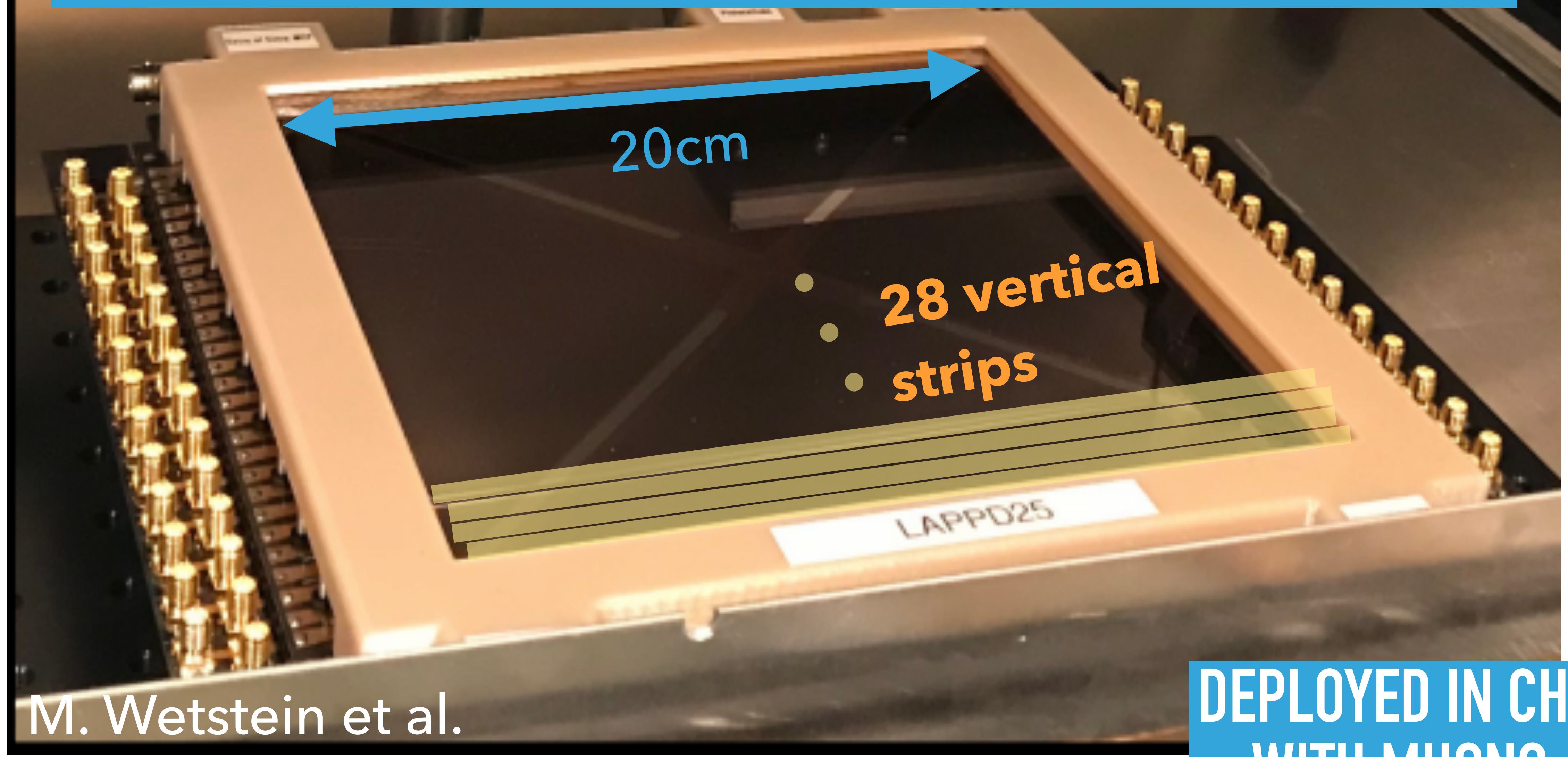


LAPPD https://incomusa.com/lappd/

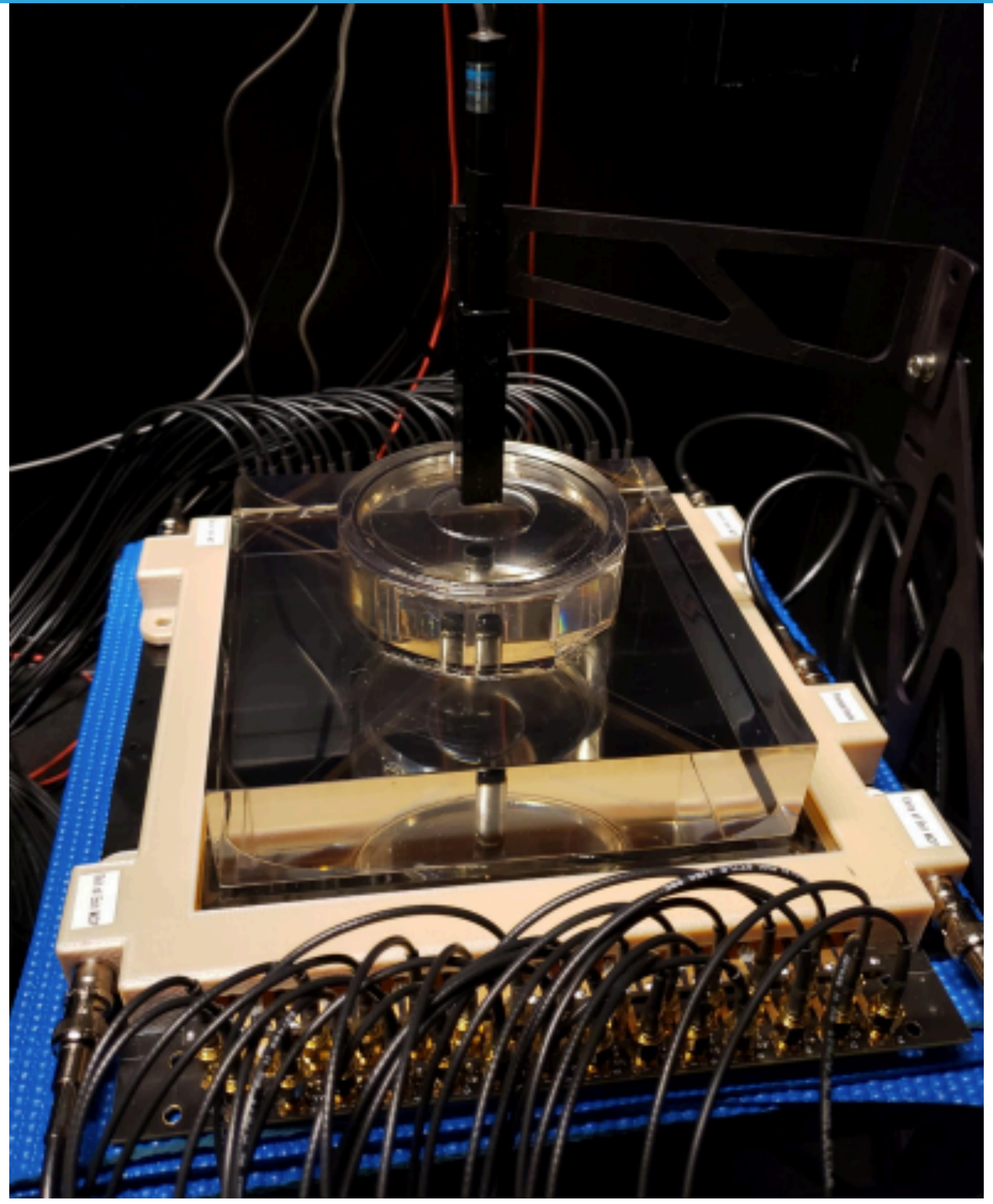
MCP-BASED DEVICE



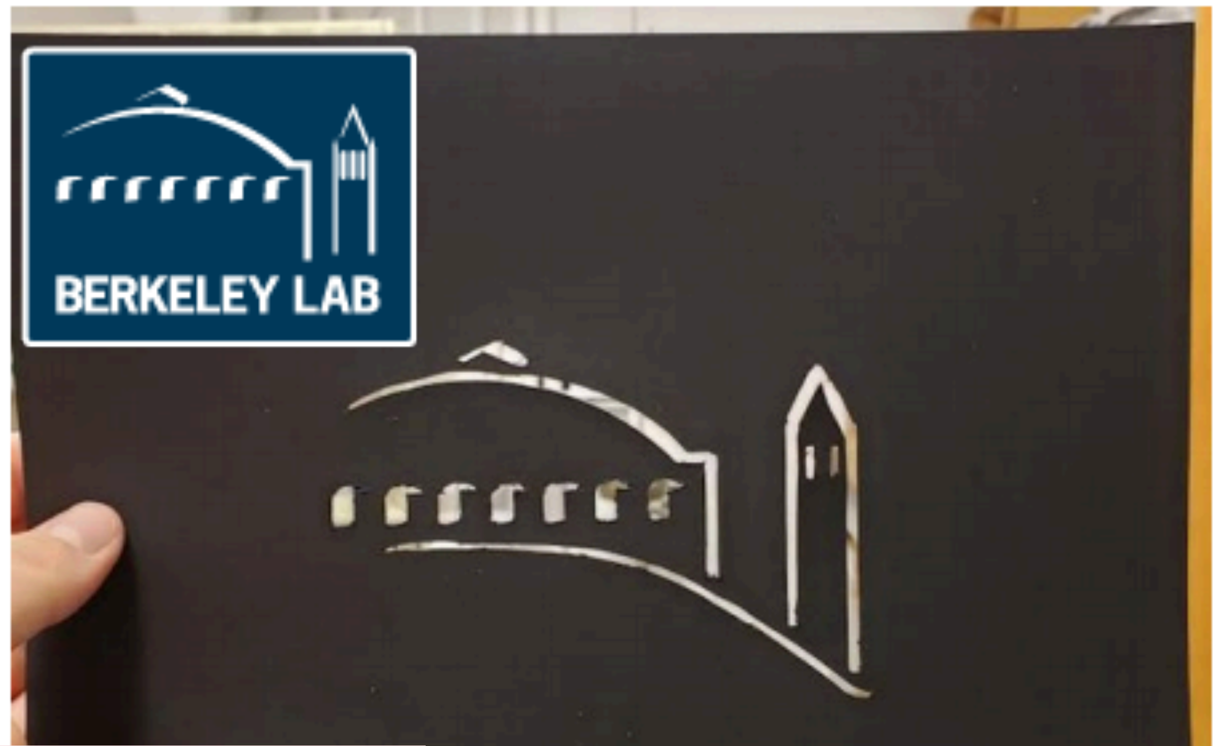
PIXELATED LARGE AREA PHOTOSENSOR WITH mm-SCALE SPATIAL RESOLUTION AND ~60ps TIME RESOLUTION

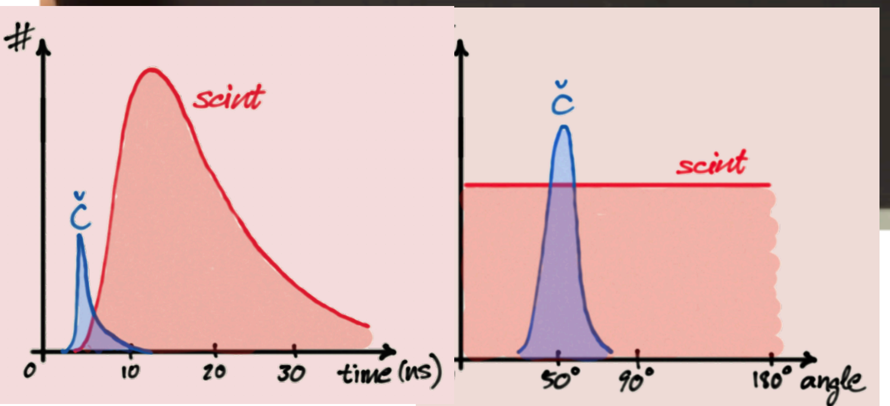


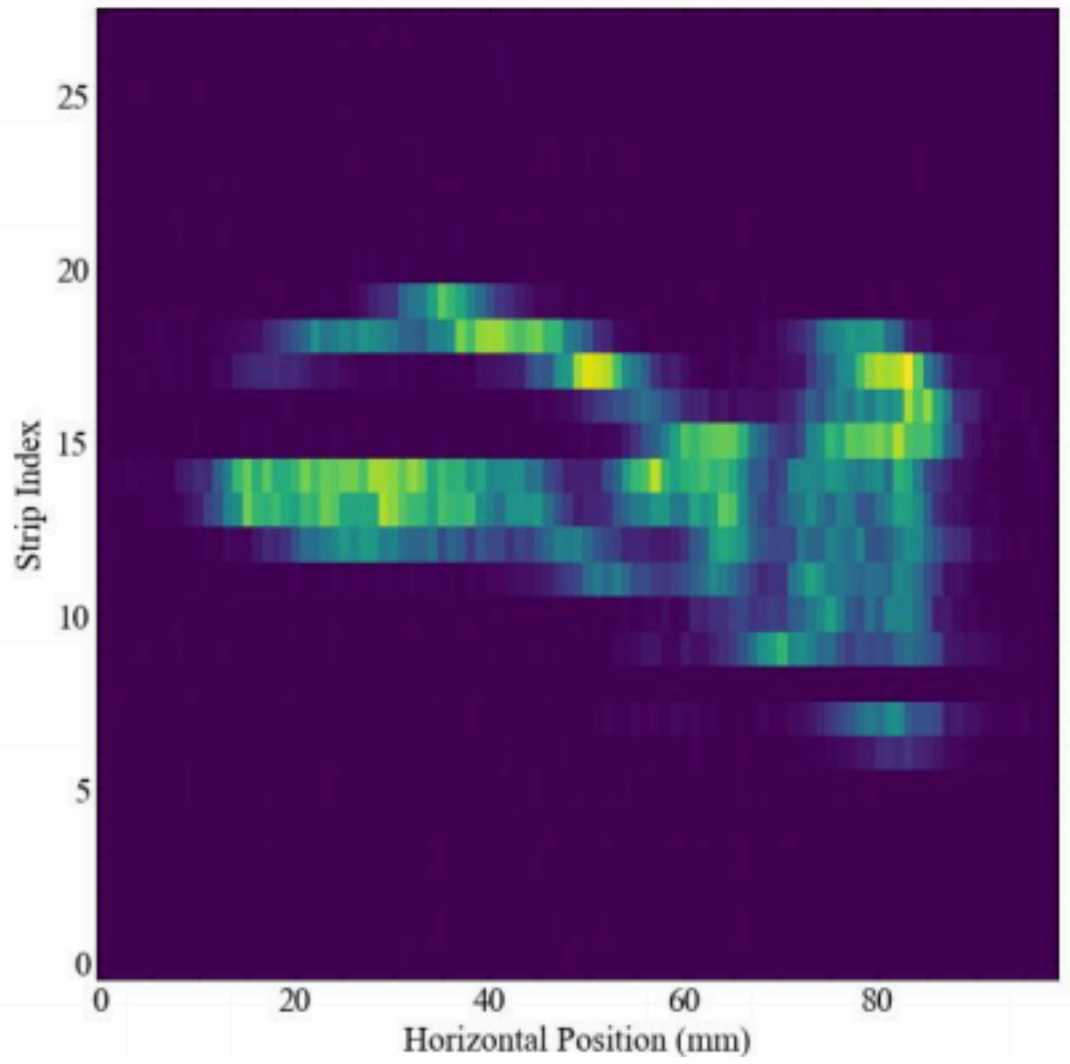
DEPLOYED IN CHESS TO GAUGE PERFORMANCE WITH MUONS AND RADIOACTIVE SOURCES



SINGLE PHOTOELECTRON STACKED IMAGE FROM LED



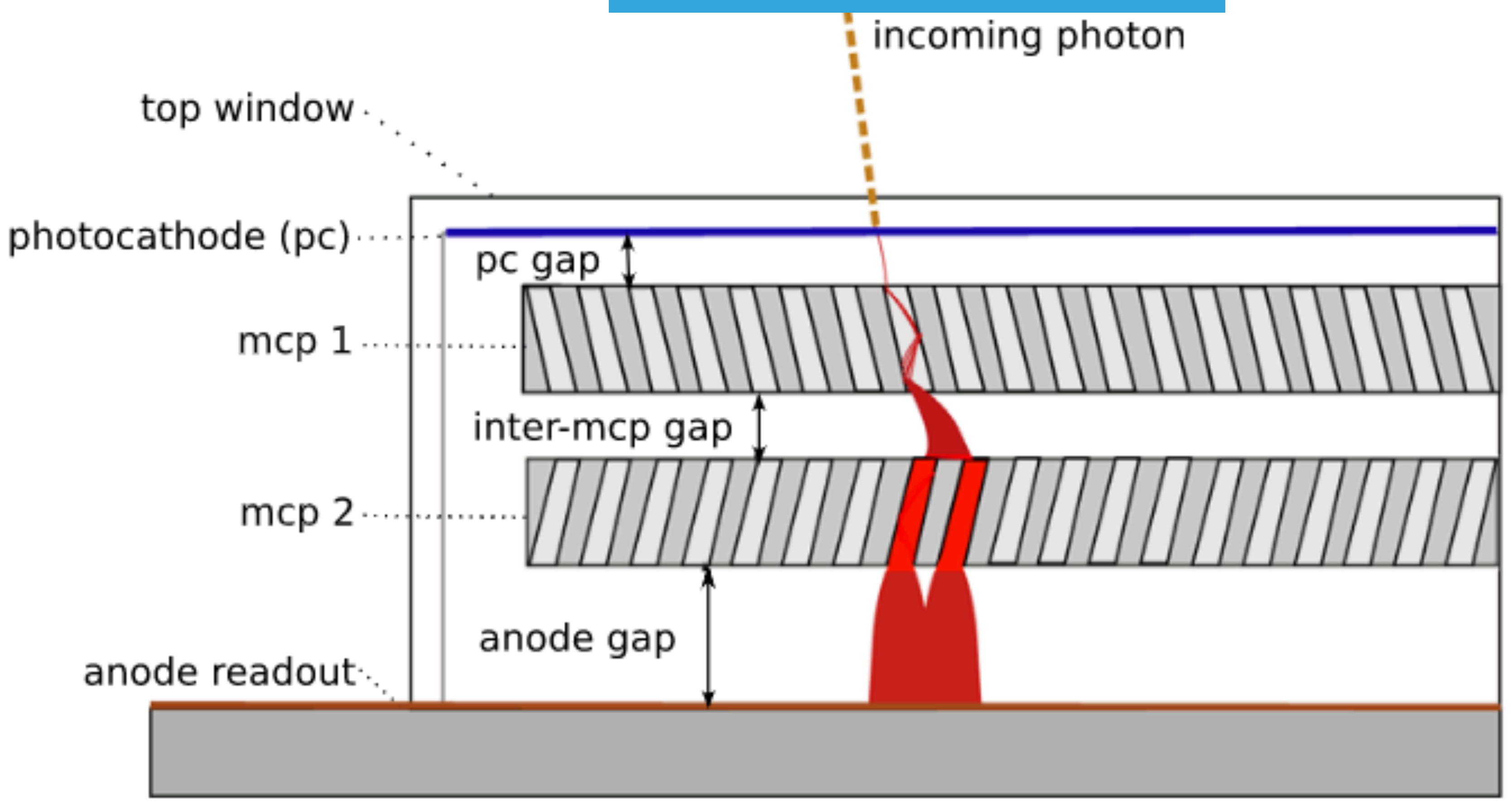




- Current challenges:
  - Multi-PE disambiguation
  - Cherenkov ring imaging from muons

LAPPD https://incomusa.com/lappd/

MCP-BASED DEVICE



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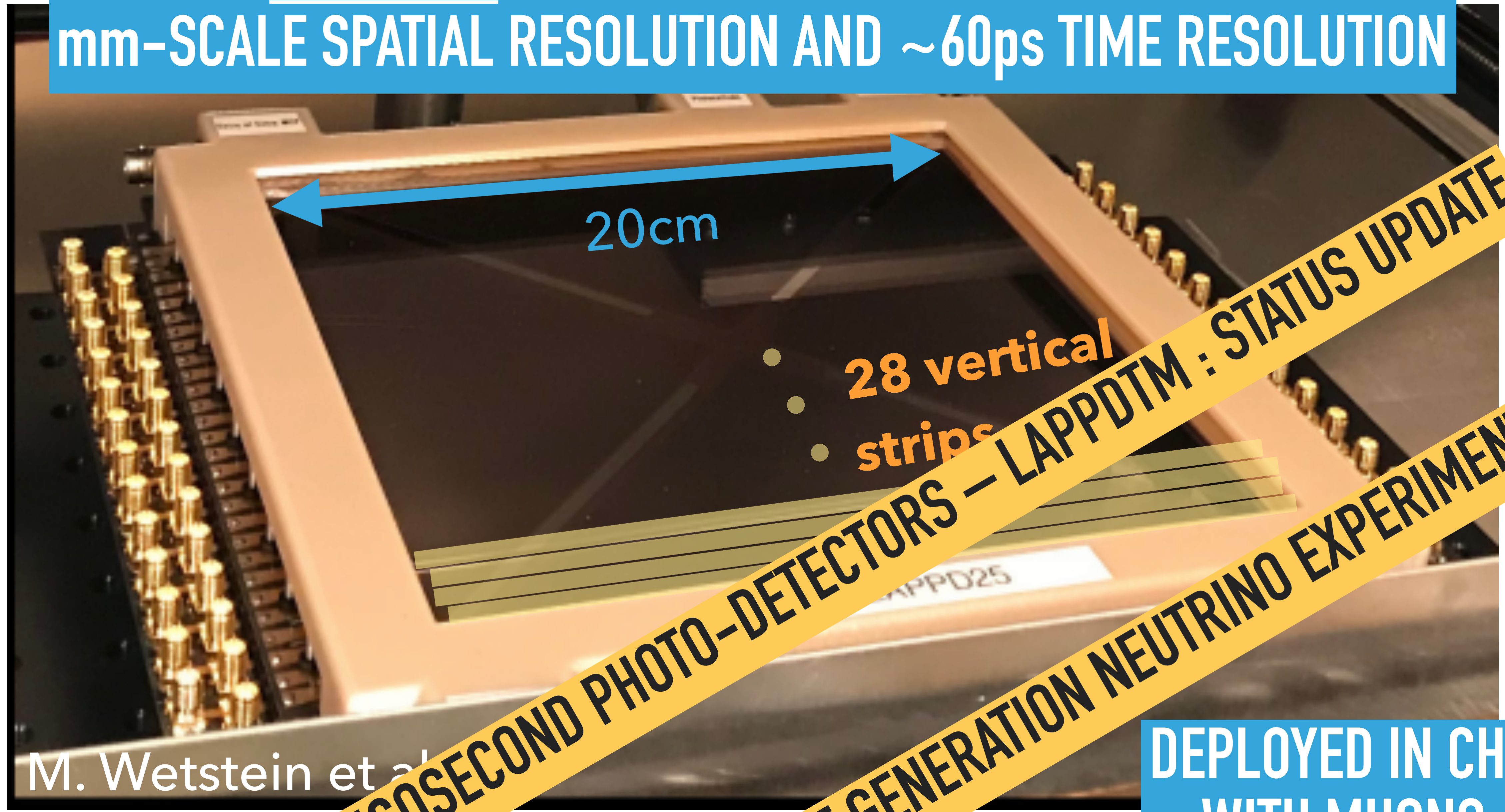
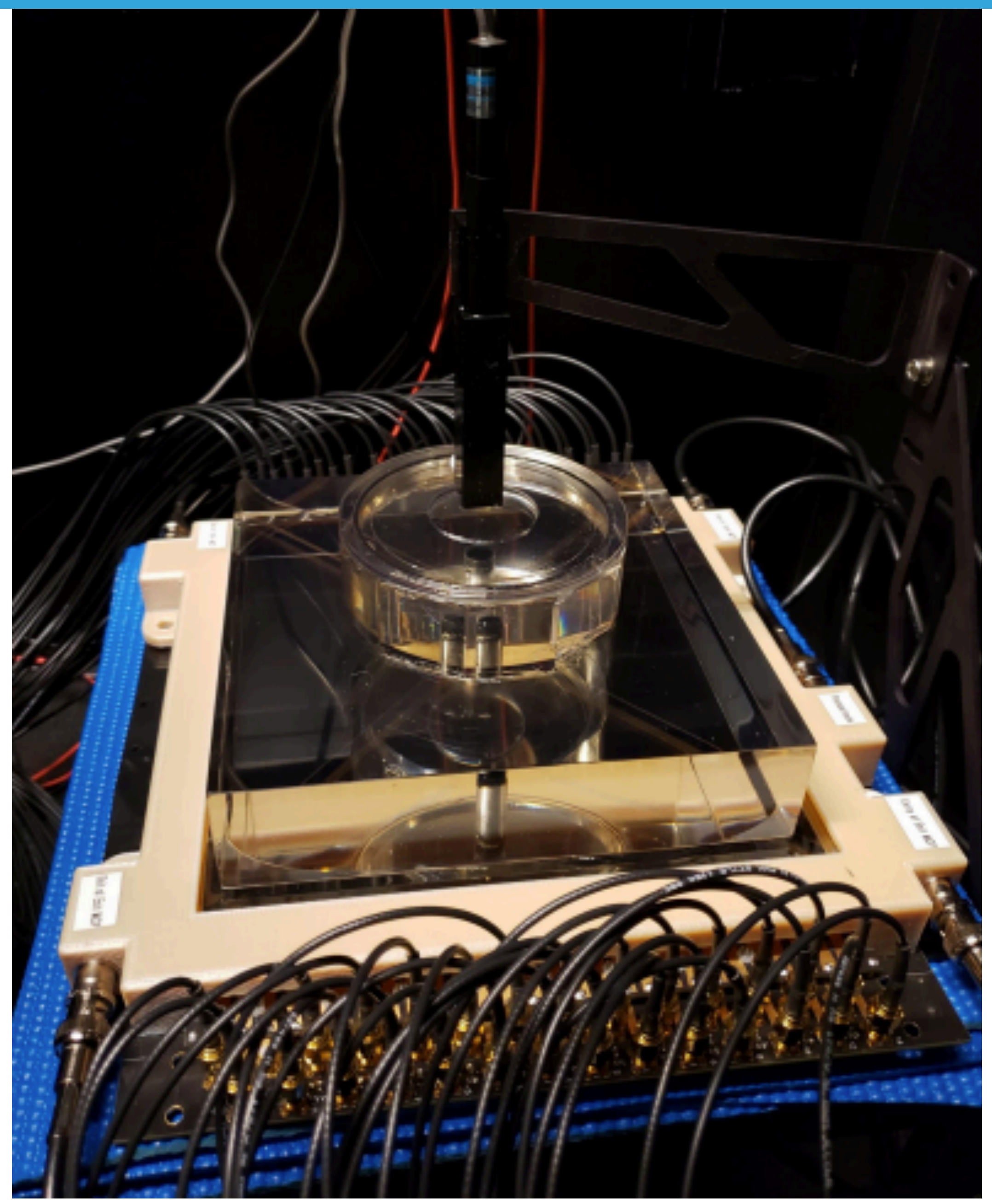


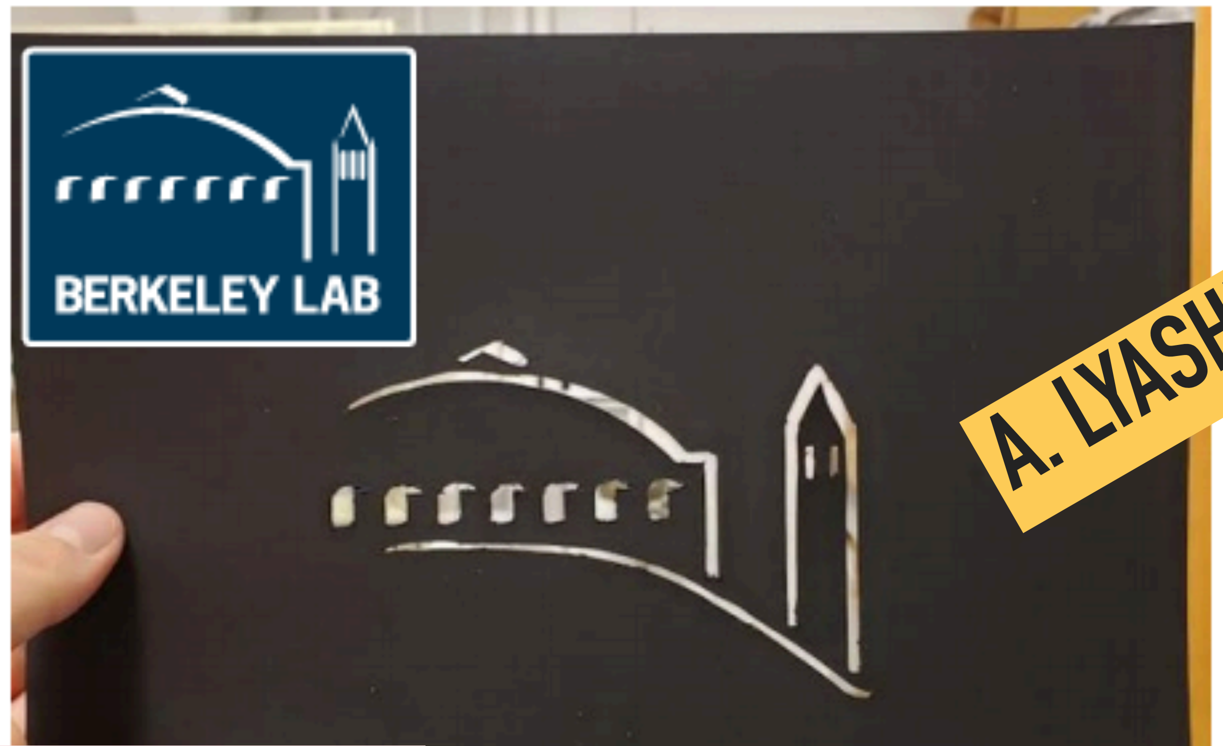
A. LYASHENKO – PRODUCTION OF LARGE AREA PICOSECOND PHOTO-DETECTORS – LAPPDTM : STATUS UPDATE

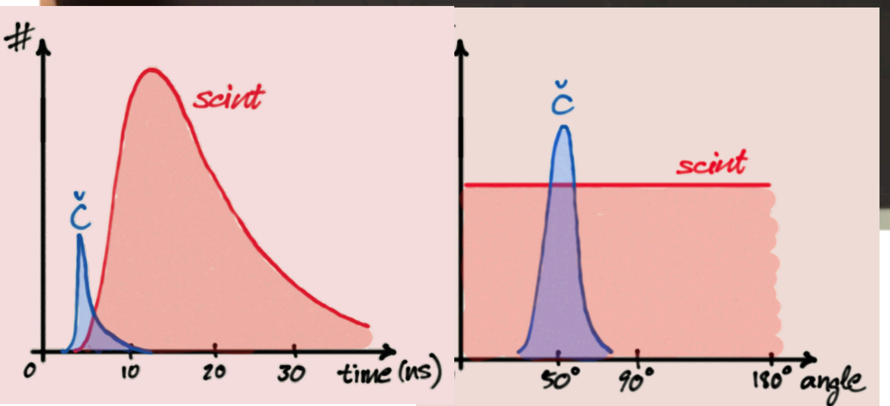
E. TIRAS – ADVANCED PHOTON DETECTION IN ANNIE FOR NEXT GENERATION NEUTRINO EXPERIMENTS

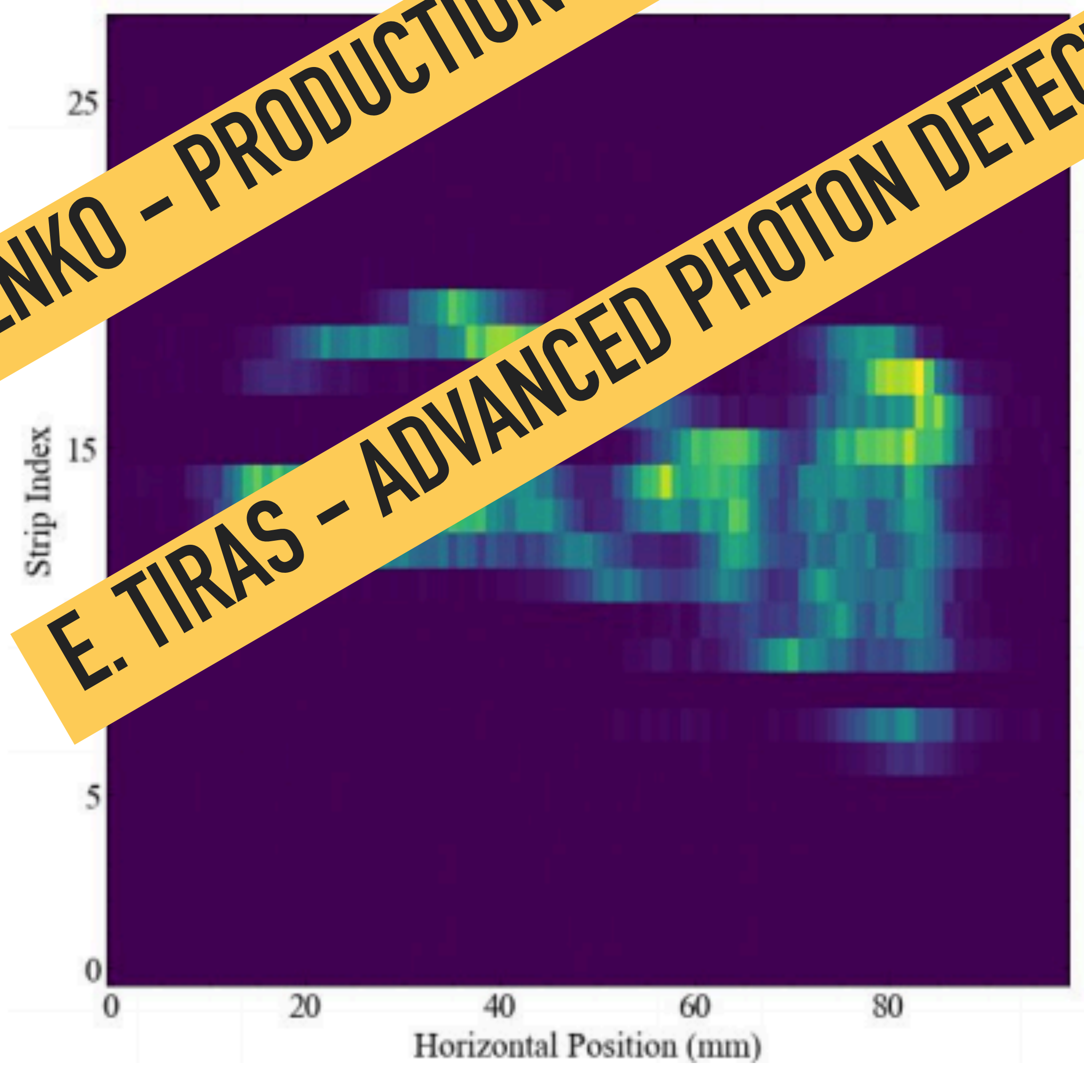
DEPLOYED IN CHESS TO GAUGE PERFORMANCE WITH MUONS AND RADIOACTIVE SOURCES



SINGLE PHOTOELECTRON STACKED IMAGE FROM



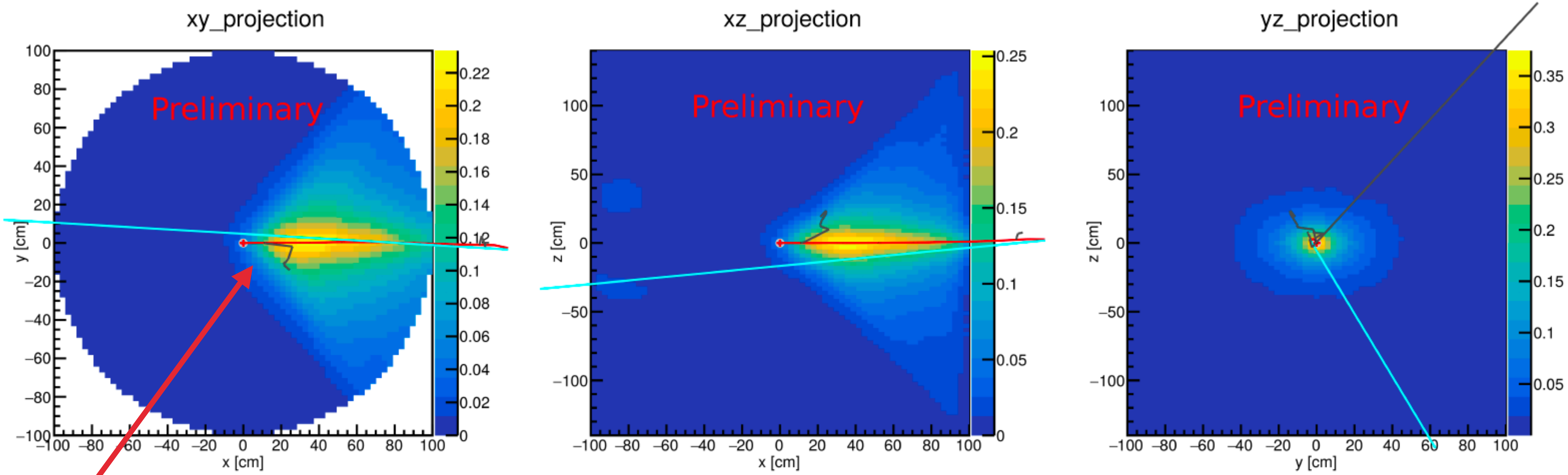




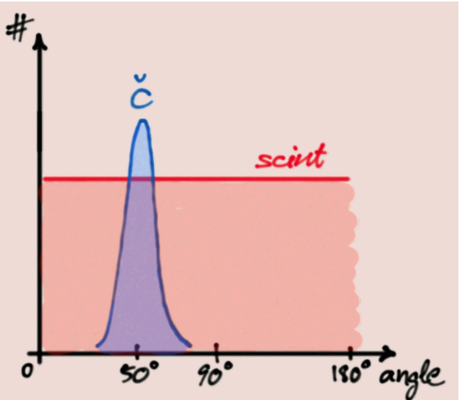
- Current challenges:
  - Multi-PE disambiguation
  - Cherenkov ring imaging from muons

TOPOLOGICAL RECONSTRUCTION (JGU MAINZ)

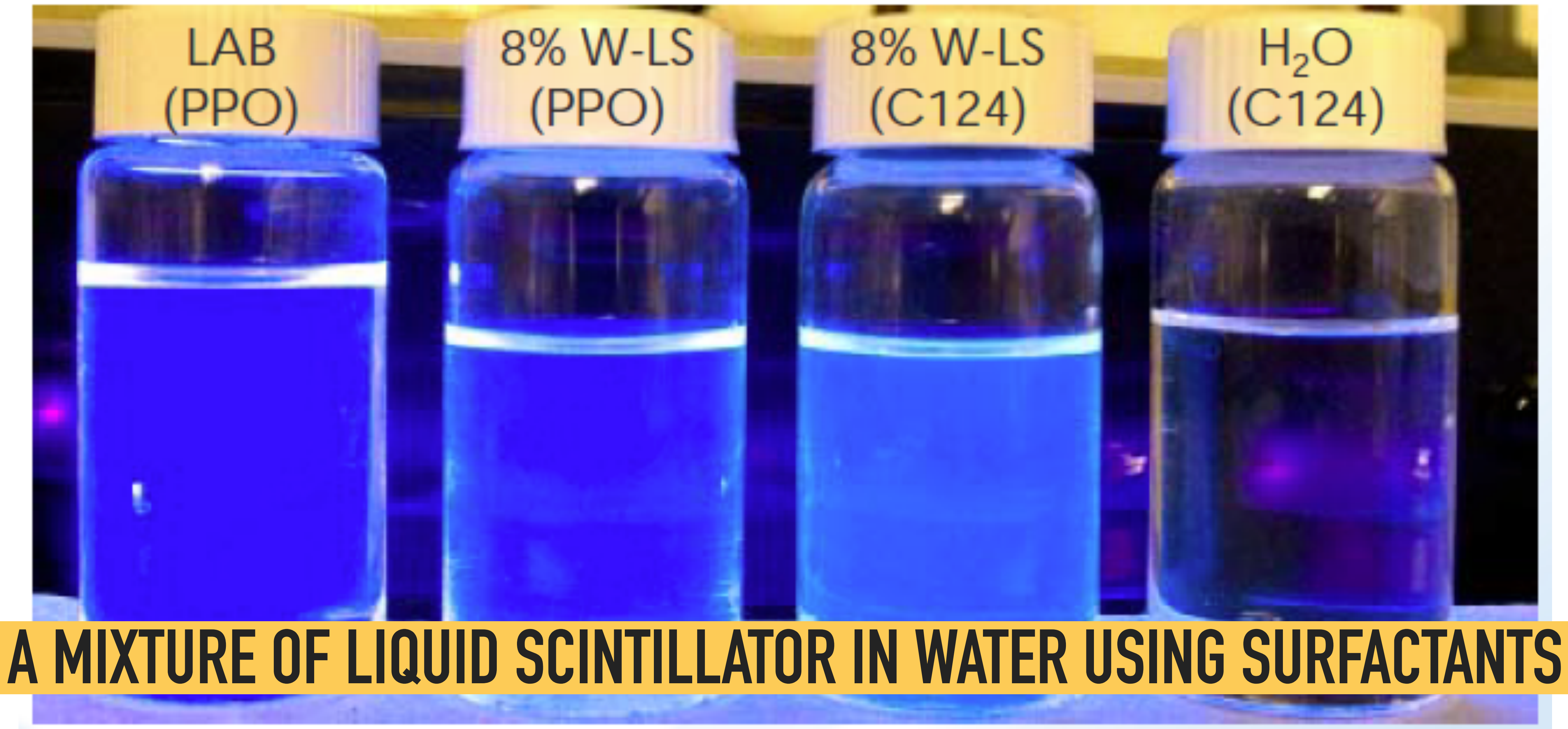
FINE-GRAINED PHOTOSENSORS COULD HELP RESOLVE THE CHERENKOV ANGULAR DISTRIBUTION AT SHORT DISTANCES



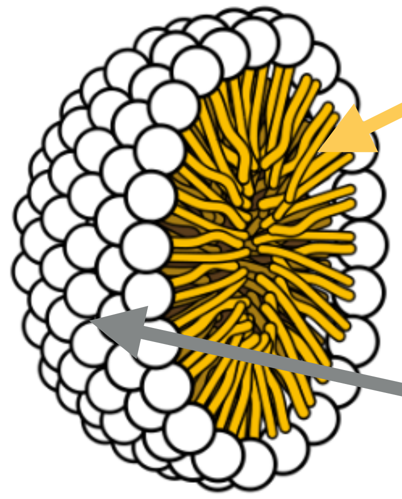
SIMULATION OF 500 MEV MUON IN 1.2m CYLINDRIC WATER TANK



WATER-BASED LIQUID SCINTILLATOR

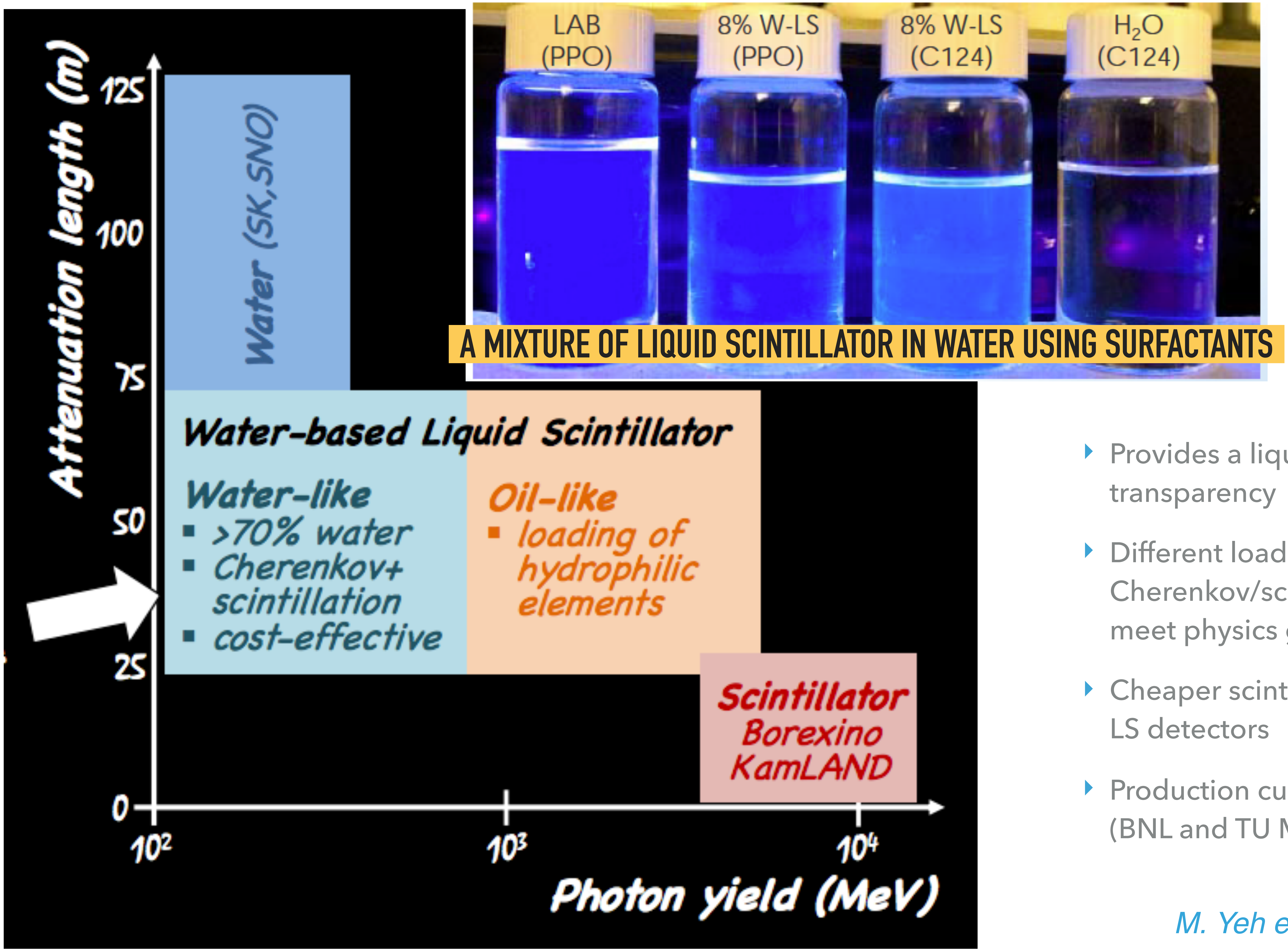


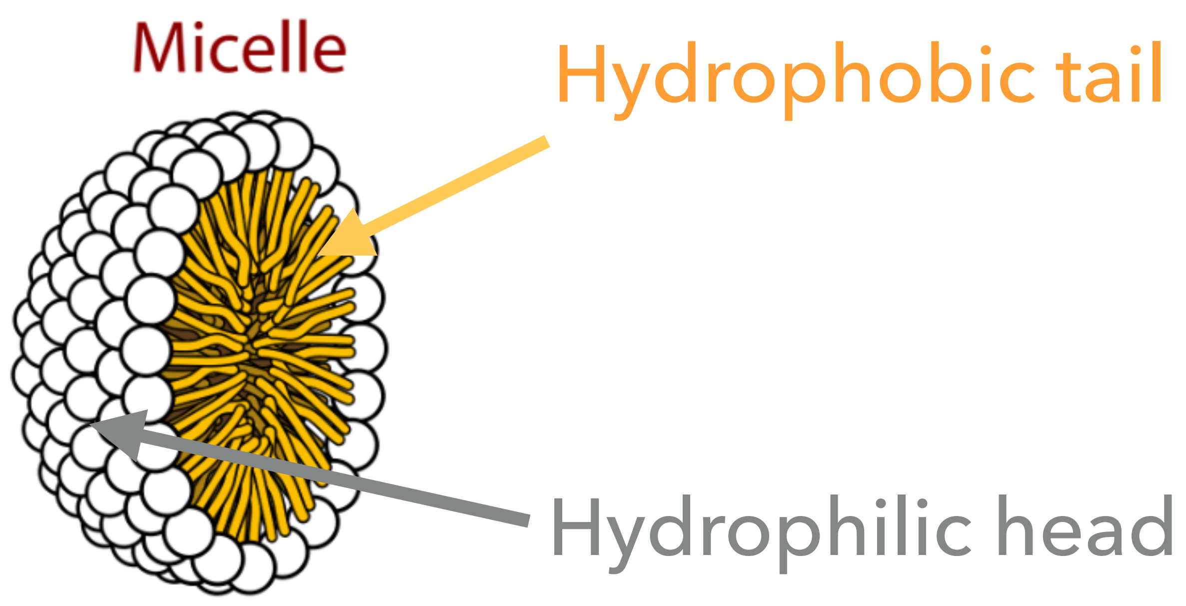
A MIXTURE OF LIQUID SCINTILLATOR IN WATER USING SURFACTANTS



M. Yeh et al Nucl. Instrum. Methods A660, 51 (2011)

WATER-BASED LIQUID SCINTILLATOR





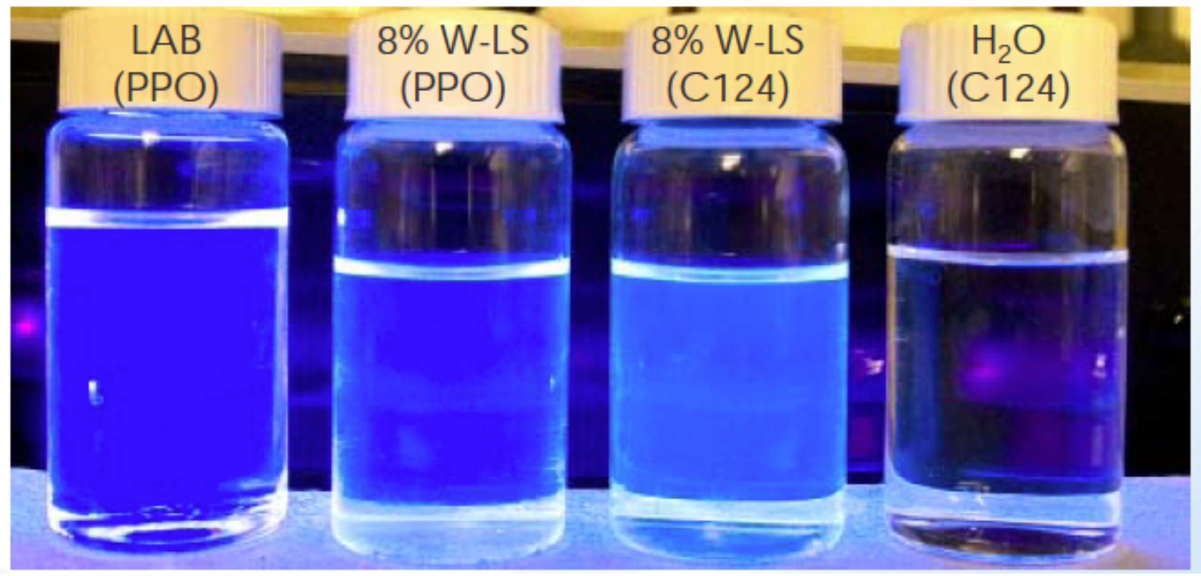
- Provides a liquid scintillator with almost water-like transparency
- Different loading fraction → Tunable Cherenkov/scintillation ratio and time profile to meet physics goals
- Cheaper scintillator media → Allows very large scale LS detectors
- Production currently in R&D phase (BNL and TU München)

M. Yeh et al Nucl. Instrum. Methods A660, 51 (2011)

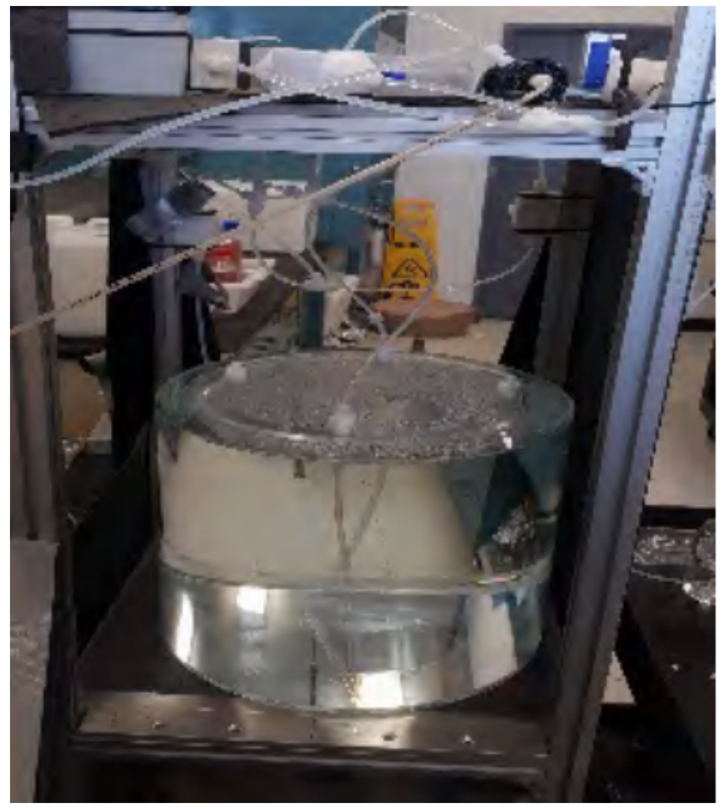
WbLS PRODUCTION

BROOKHAVEN NATIONAL LABORATORY: MOVING TOWARDS MASS PRODUCTION

~100ml-scale → first version developed few years ago



~1L-scale → Optimization, purification and characterization



~1ton → First demonstrator at BNL

WbLS PRODUCTION

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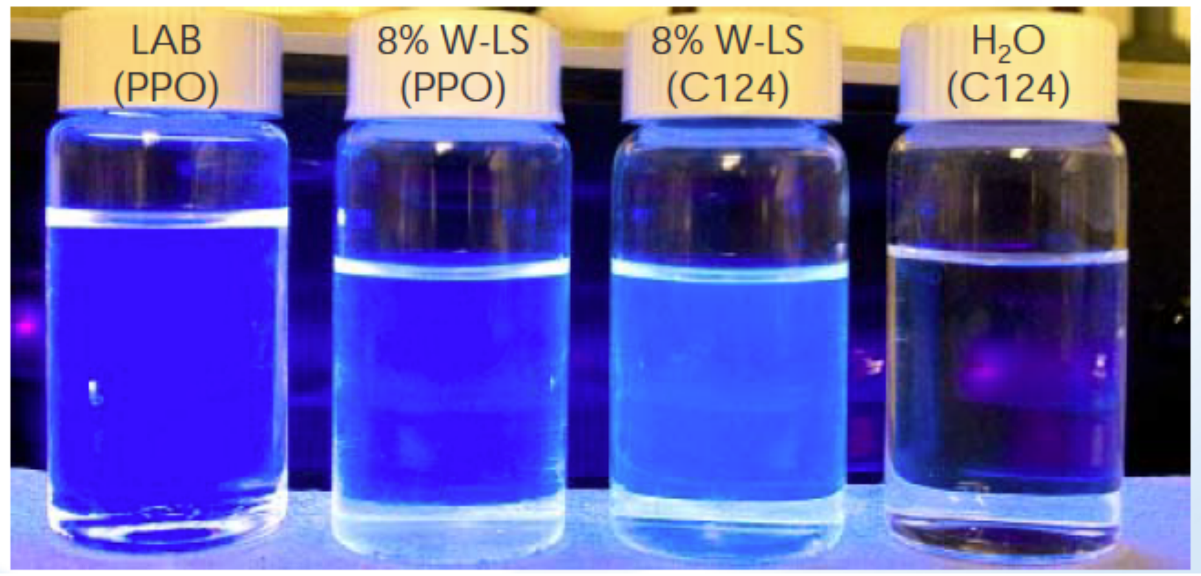

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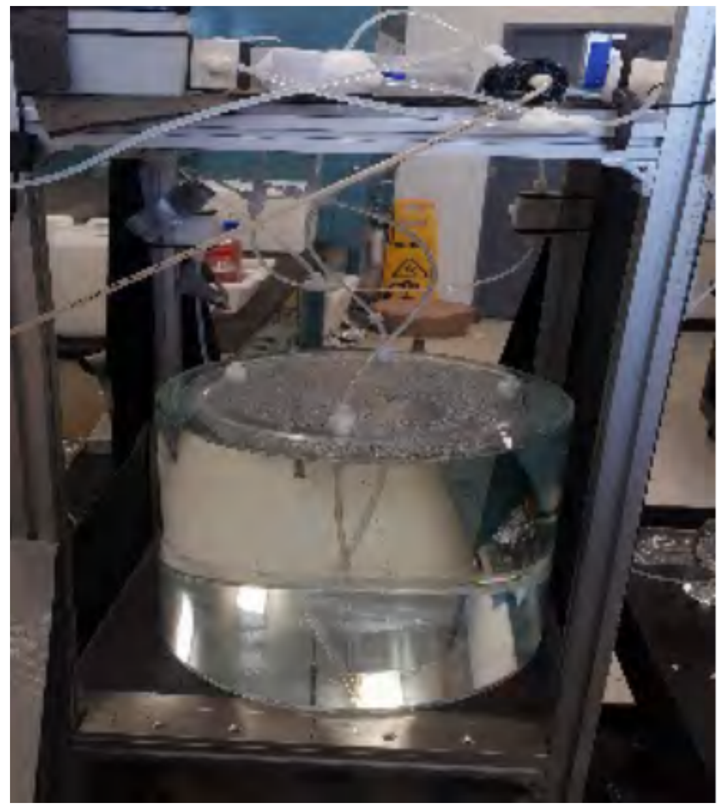
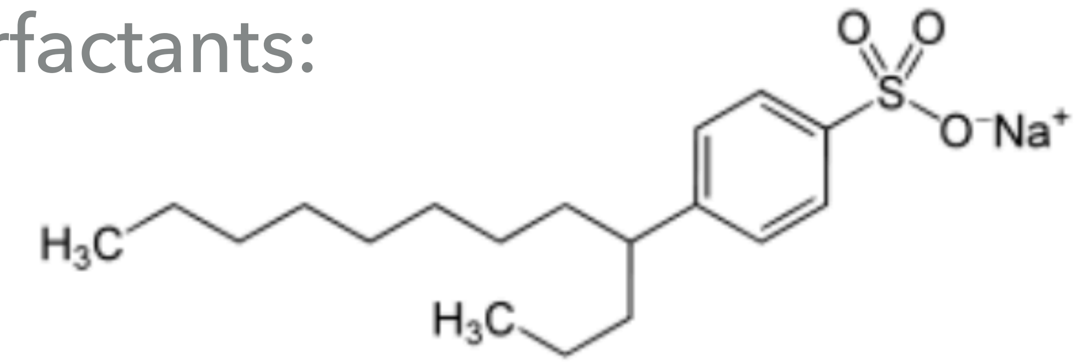


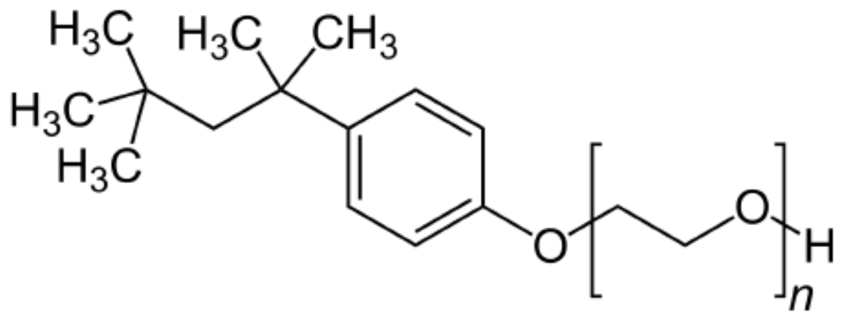
~1ton → First demonstrator at BNL

TU MÜNCHEN AND JGU MAINZ (GERMANY): WbLS PRODUCTION AND OPTIMIZATION R&D

Testing different surfactants:

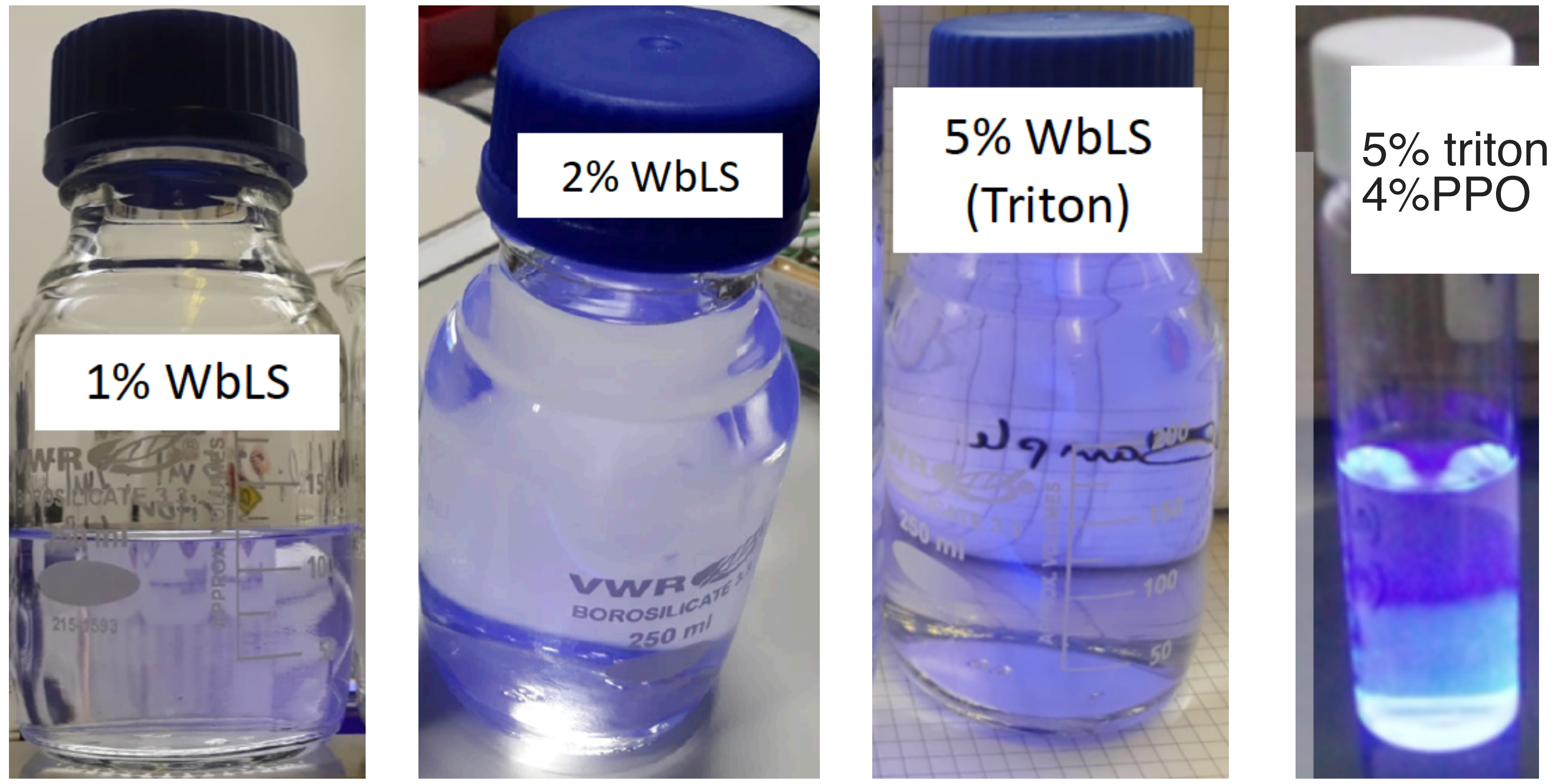


Sodium dodecylbenzenesulfonate



Triton X100

Optimized surfactant concentrations and achieved different LS loading at small scales:



WbLS CHARACTERIZATION EFFORT IN A NUTSHELL

Light yield
Emission spectrum
Attenuation length
Time profile
Particle identification
Cherenkov and scintillation separation

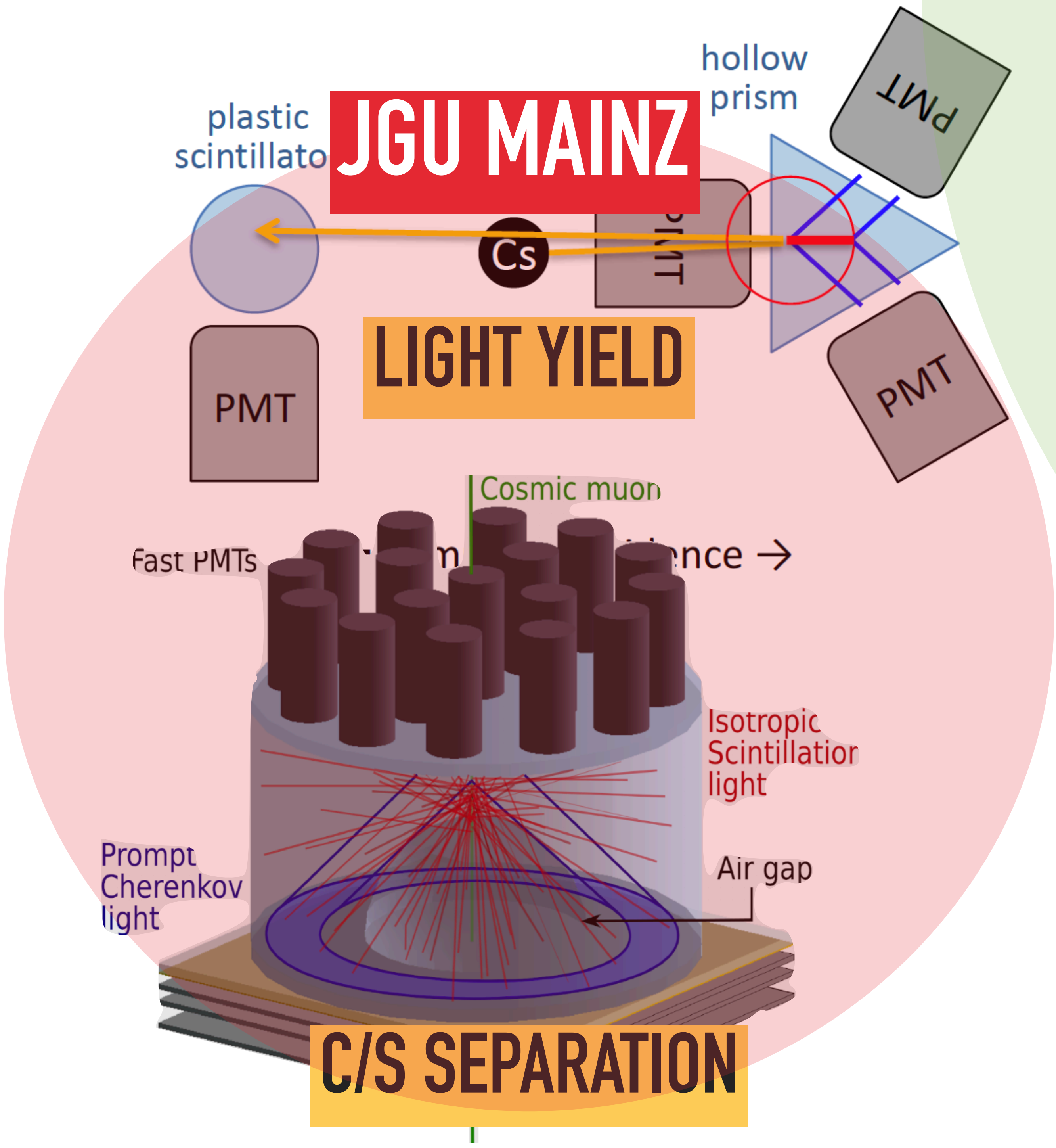
UC BERKELEY & LBNL

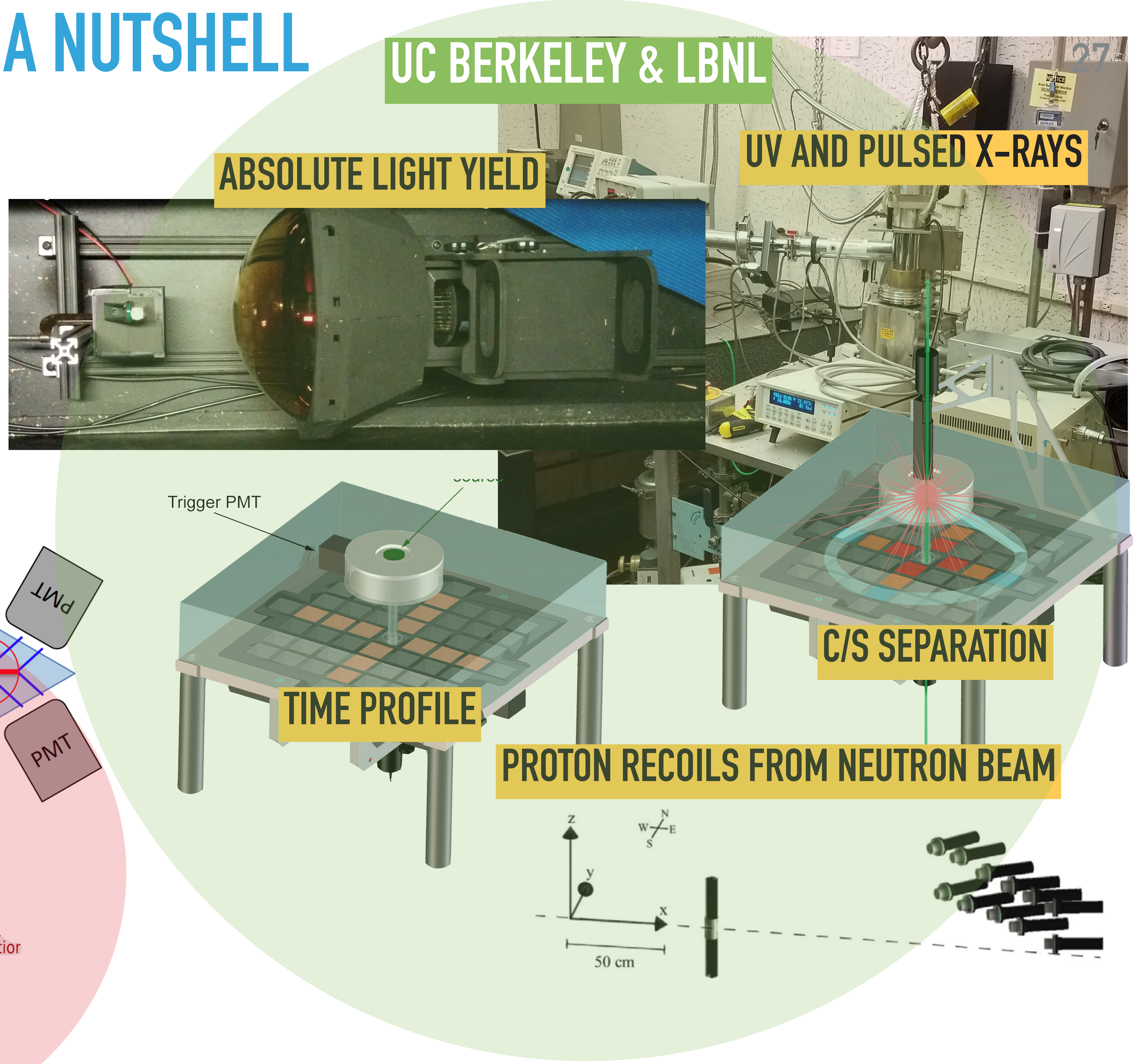
JGU MAINZ

BROOKHAVEN LABORATORY

UC DAVIS

TU MÜNCHEN

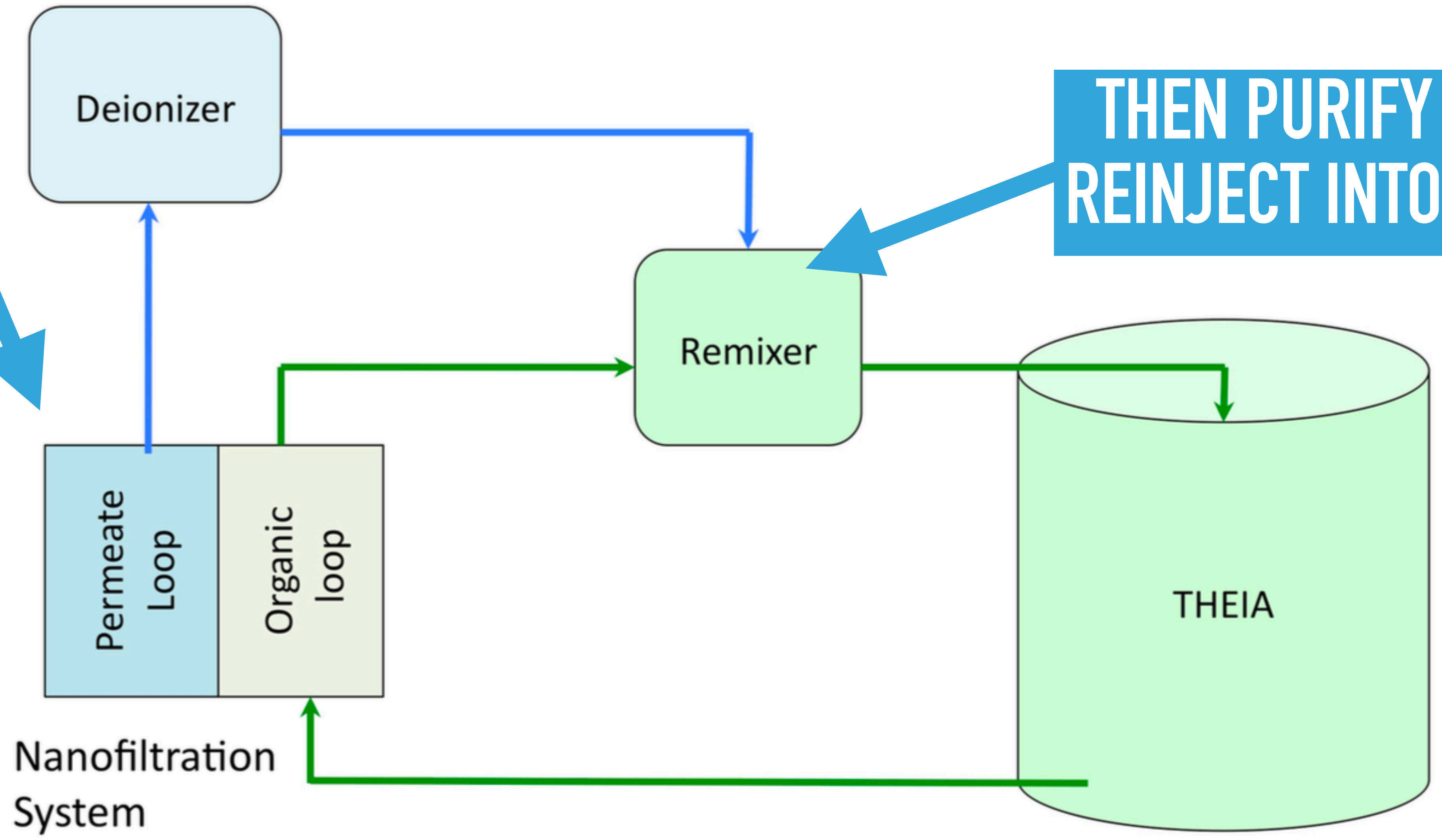




WbLS PURIFICATION

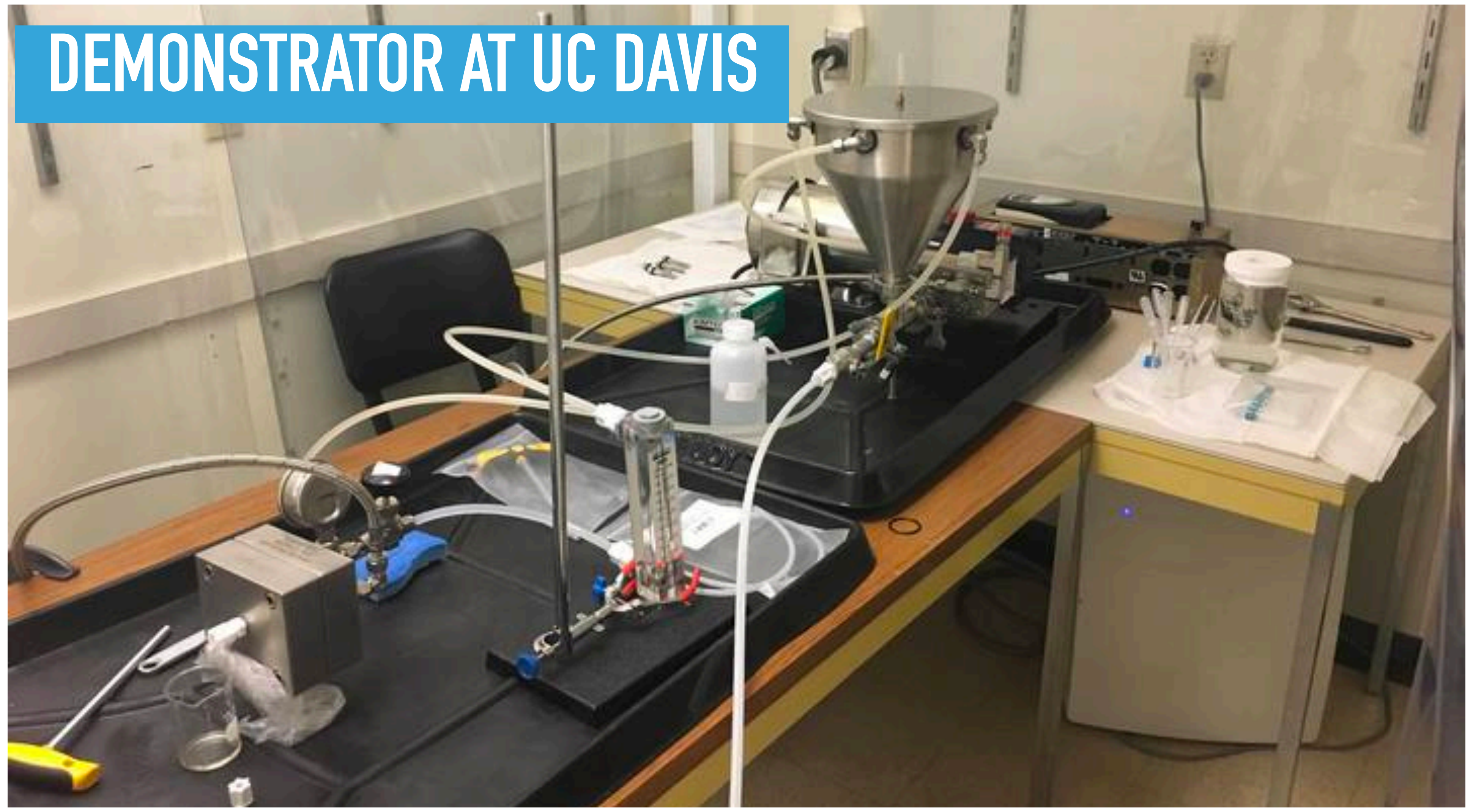
SEPARATE WATER FROM LS BY NANOFILTRATION

THEN PURIFY WATER AND REINJECT INTO THE SYSTEM



THEIA recirculation concept

DEMONSTRATOR AT UC DAVIS



Credit: L. Pickard — UC Davis

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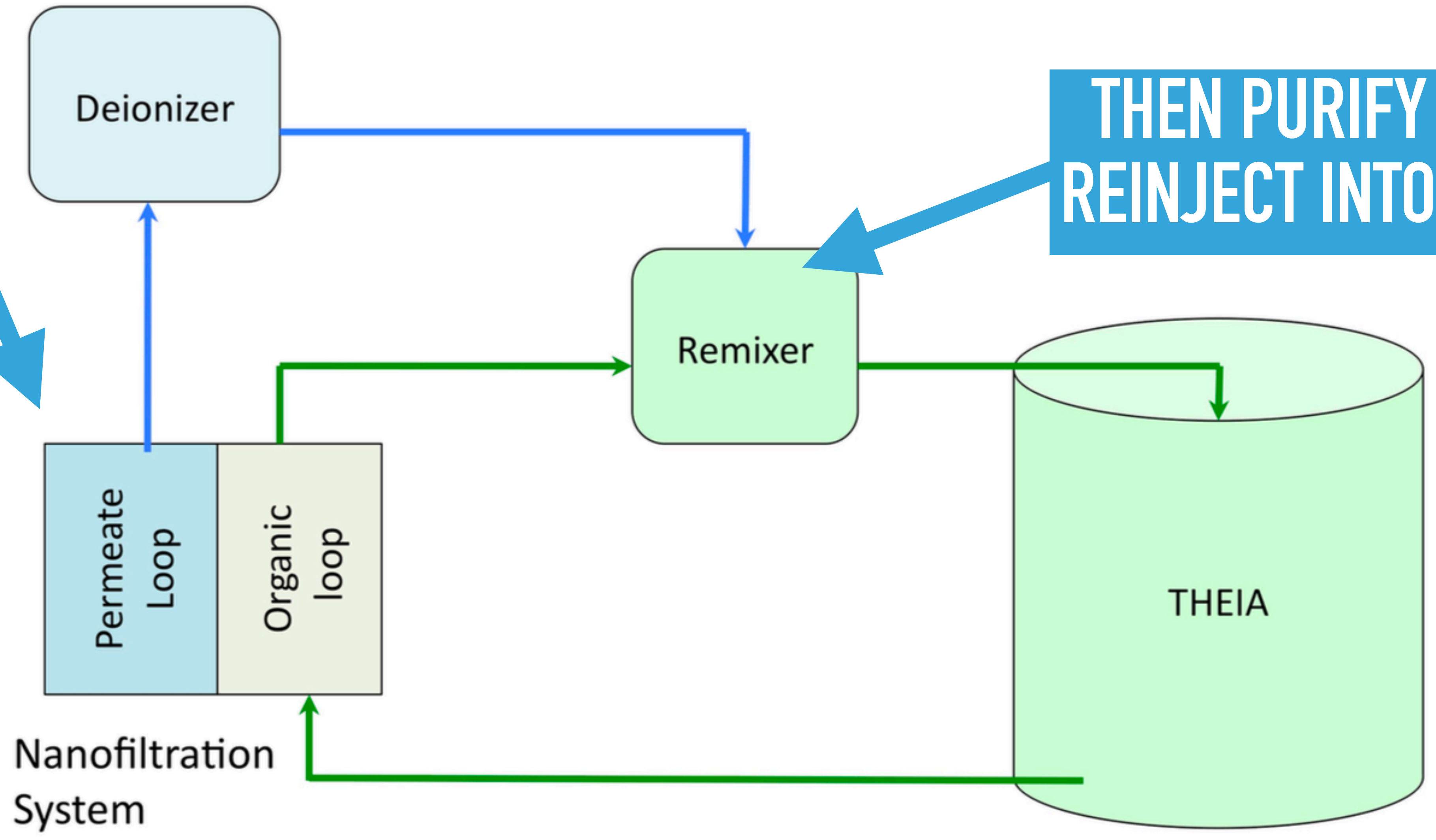
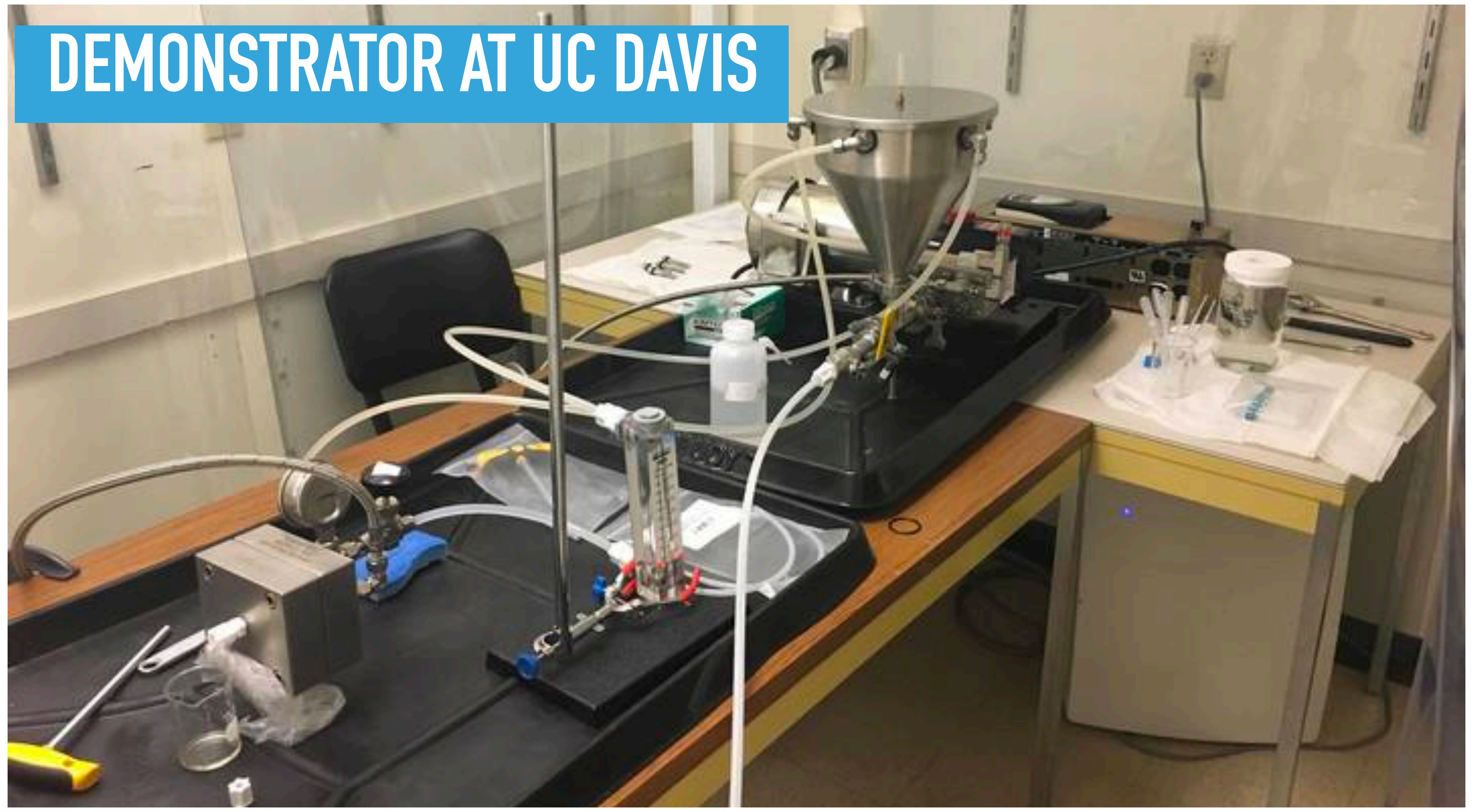
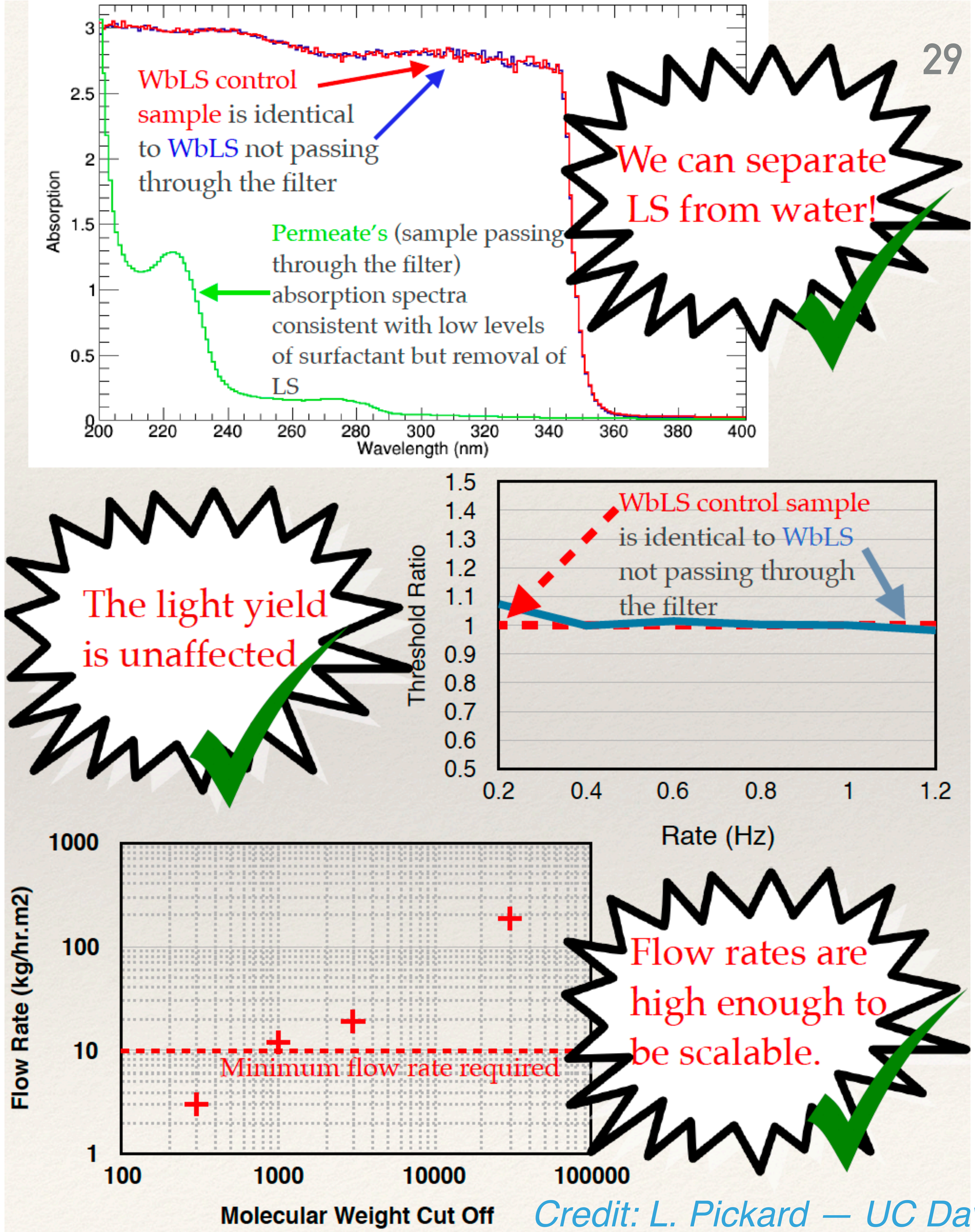


THEIA recirculation concept

DEMONSTRATOR AT UC DAVIS





Credit: L. Pickard — UC Davis

WbLS COMPATIBILITY

WbLS-COMPATIBLE HAMAMATSU PMTs

WBLS-RESISTANT HOUSING

Tested for:

- Long term submersion
- High pressures
- High/low and changing temperatures ($55^{\circ}/-20^{\circ}$)

WbLS COMPATIBILITY

WbLS-COMPATIBLE HAMAMATSU PMTs

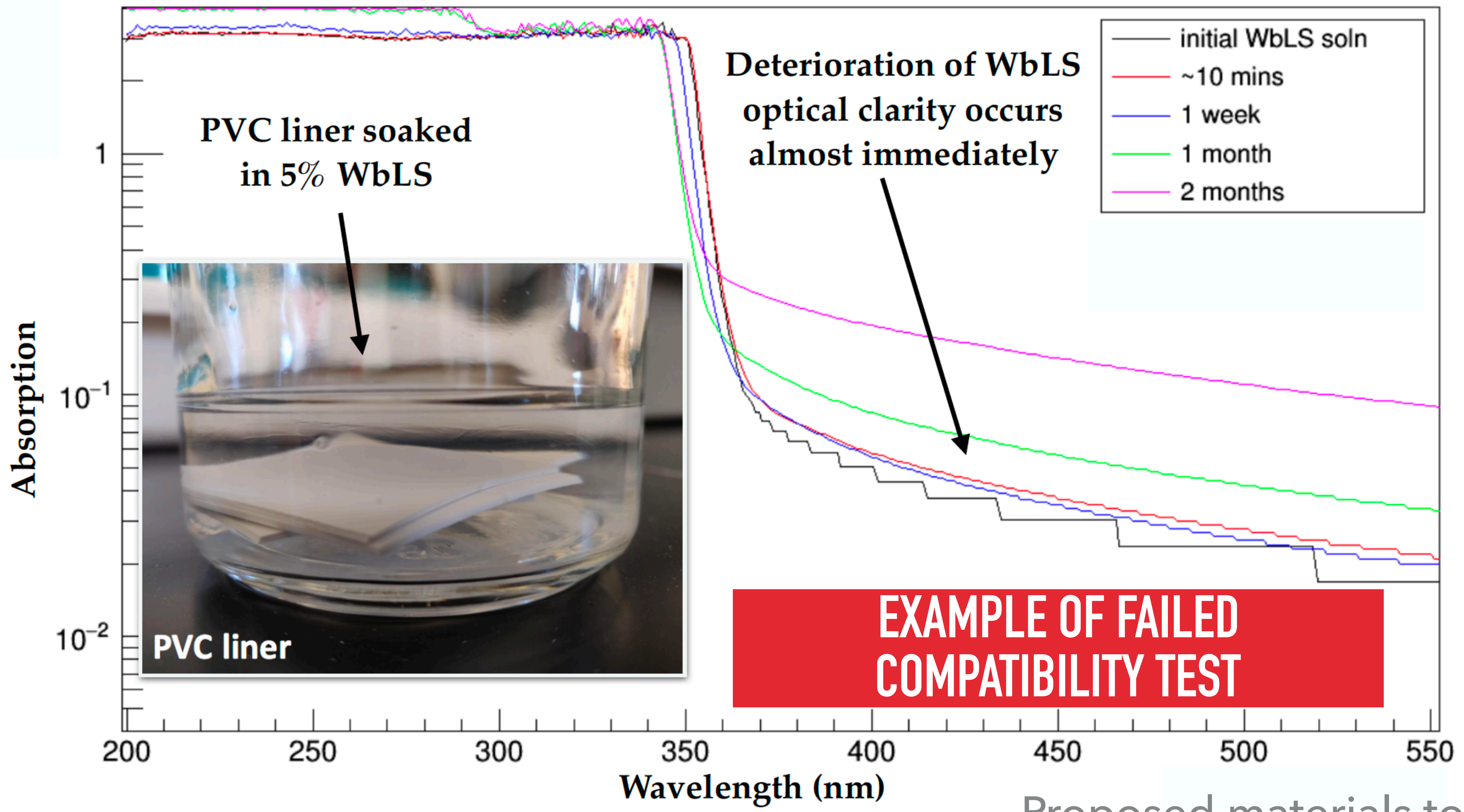
WBLS-RESISTANT HOUSING

Tested for:

- Long term submersion
- High pressures
- High/low and changing temperatures (55°/-20°)

COMPATIBILITY TESTS AT UC DAVIS

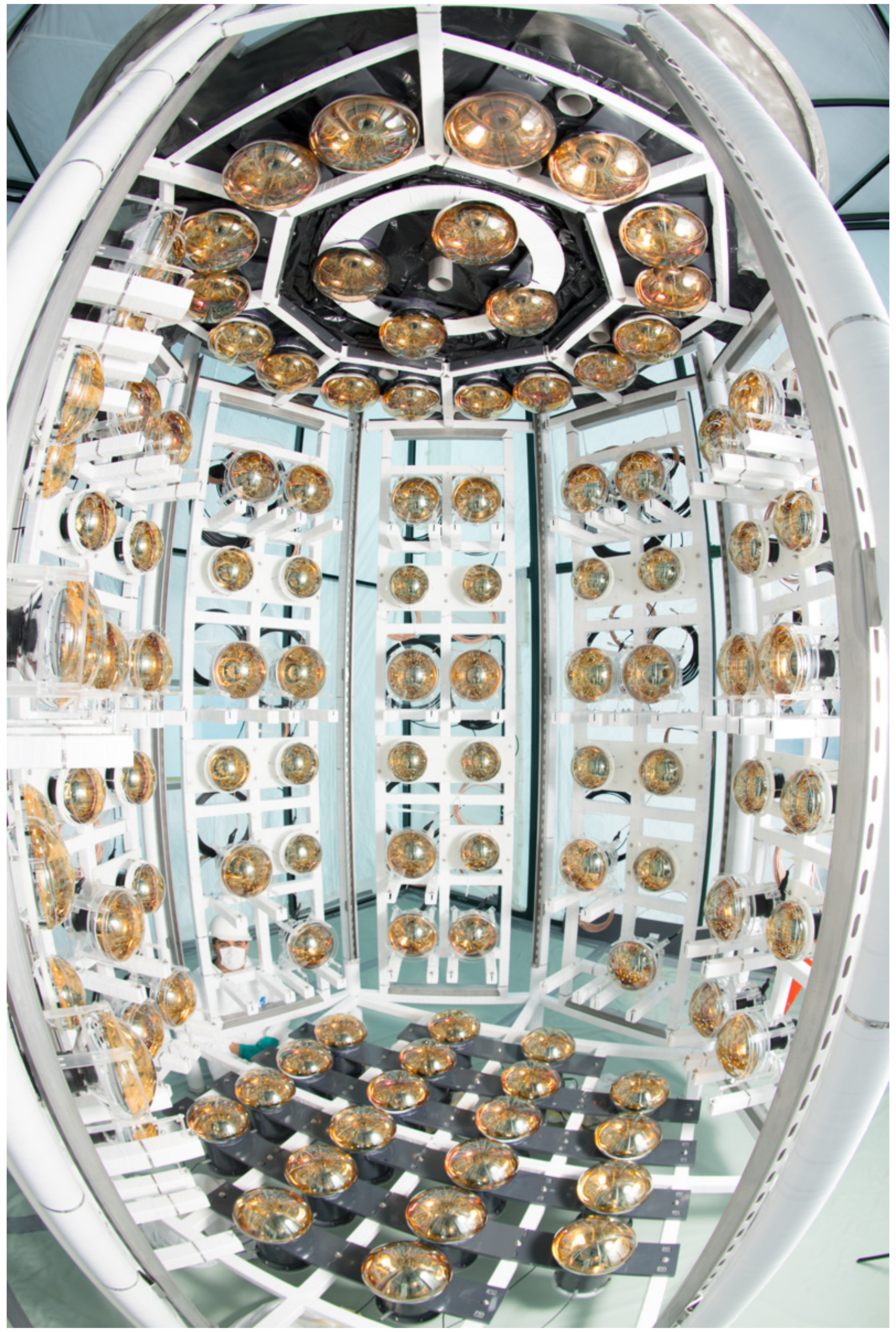
Soak materials in WbLS 5% and monitor absorbance



Proposed materials to be tested:

- PPS
- PCB
- Polyolefin
- Urethane resin
- PMT glass (see next slide)
- Stainless steel
- Teflon
- All proposed balloon materials
- …

NEXT-GEN DEMONSTRATORS

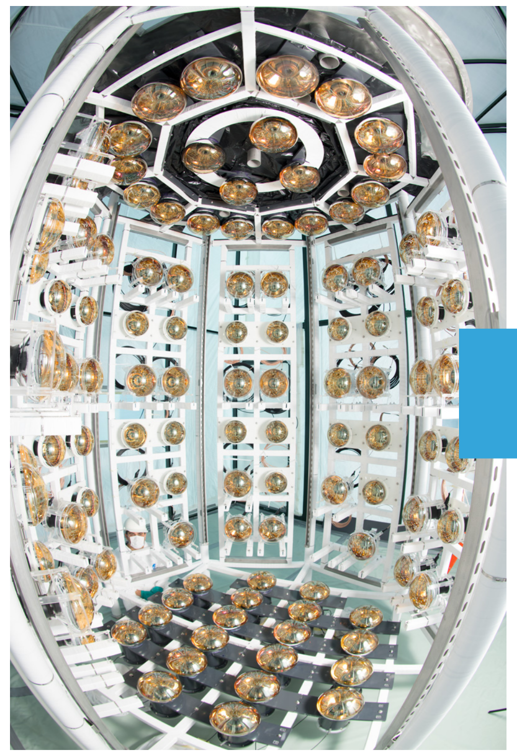


- 26-ton Cherenkov detector located in a neutrino beam (Fermilab)
- First usage of LAPPDs for neutrino physics
- Currently filled with Gd-doped water → It will characterize WbLS performance for first time in large-scale detector

The ANNIE Col., arXiv:1707.08222 [physics.ins-det] (2017)

NEXT-GEN DEMONSTRATORS

annie

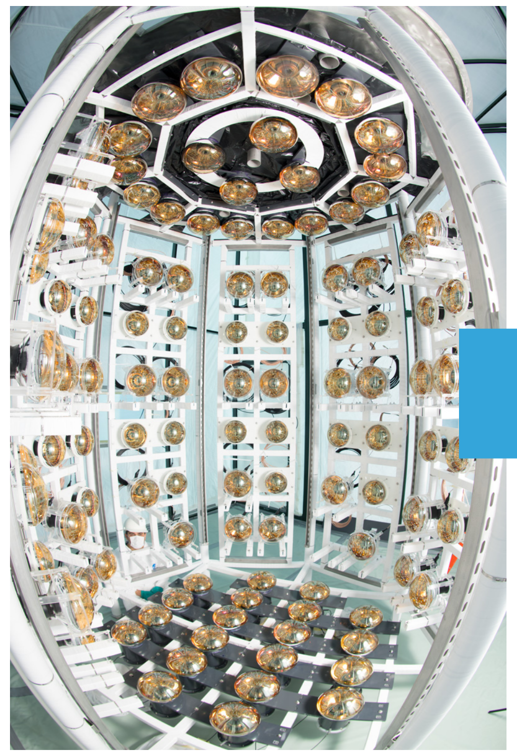


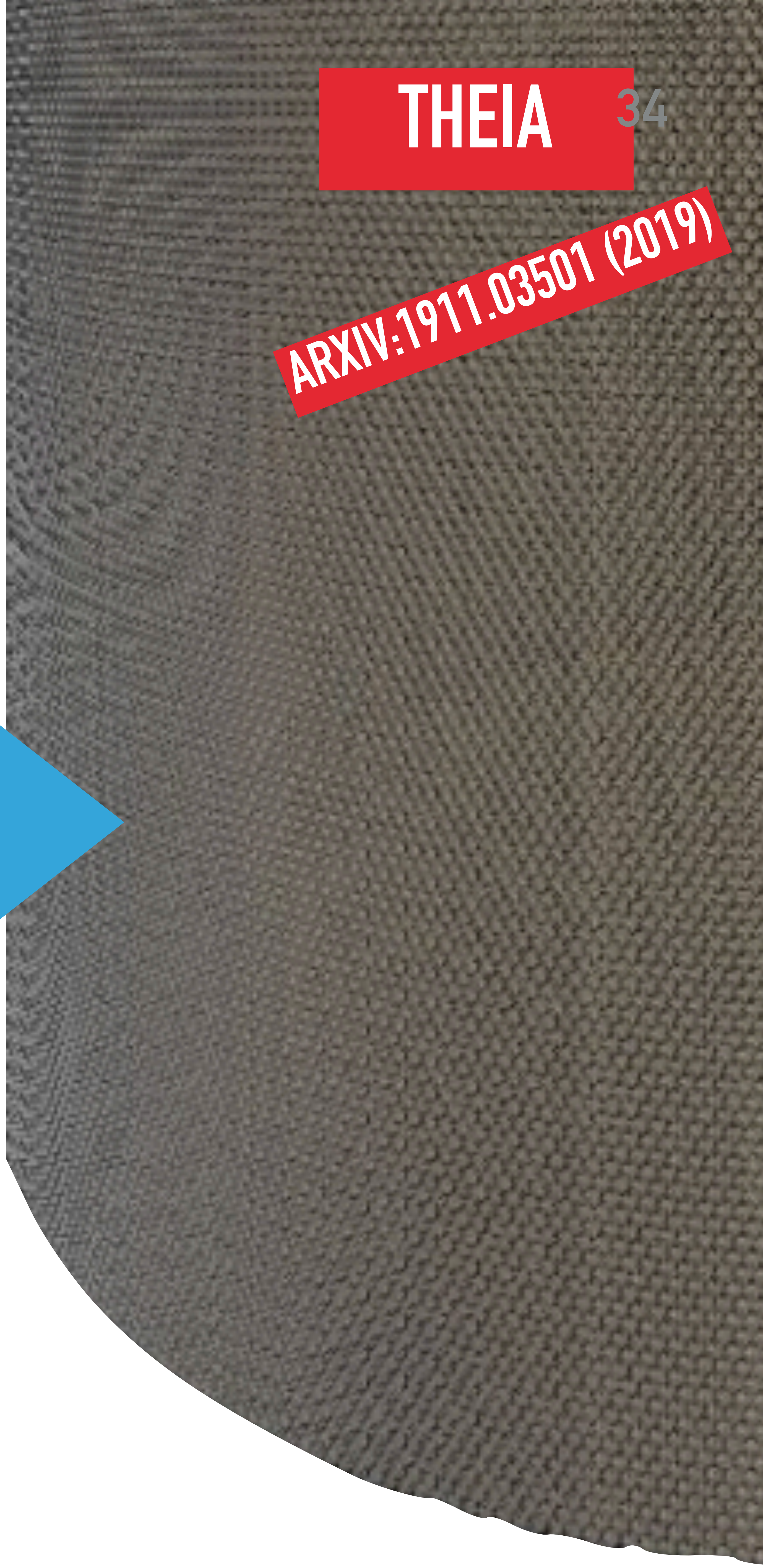
- Kiloton Cherenkov detector located underground in the UK
- Testbed for novel technologies: WbLS, LAPPDs, etc.
- Could inform Theia design

arXiv:1502.01132 [physics.ins-det] (2015)

NEXT-GEN DEMONSTRATORS

annie





SIMULATING THE THEIA DETECTOR

Credit: B. Land

https://github.com/benland100/chroma

SIMULATING THE THEIA DETECTOR

- Monte Carlo simulation of a Theia-sized liquid scintillator detector is very computer intensive
- Exploring alternatives using GPU power → Chroma
    - Capable of tracking millions of photons in seconds (x100 faster than Geant4)

Credit: B. Land

https://github.com/benland100/chroma

SUMMARY

- Theia is a new optical detector concept that exploits both Cherenkov and scintillation light
- A broad R&D effort is ongoing towards the Theia realization:
  - Implementation of fast photosensors
  - Production and characterization of water-based liquid scintillators
  - Wavelengths sorting with dichroicons
  - Potential large-scale demonstrators for a staged approach

THE THEIA COLLABORATION

THEIA: An Advanced Optical Neutrino Detector

M. Askins,[1,2] Z. Bagdasarian,[3] N. Barros,[4,5,6] E.W. Beier,[4] E. Blucher,[7] R. Bonventre,[2] E. Bourret,[2] E. Callaghan,[1,2] J. Caravaca,[1,2] M. Diwan,[8] S.T. Dye,[9] J. Eisch,[10] A. Elagin,[7] T. Enqvist,[11] V. Fischer,[12] K. Frankiewicz,[13] C. Grant,[13] D. Guffanti,[14] C. Hagner,[15] A. Hallin,[16] C. M. Jackson,[17] R. Jiang,[7] T. Kaptanoglu,[4] J.R. Klein,[4] Yu. G. Kolomensky,[1,2] C. Kraus,[18] F. Krennrich,[10] T. Kutter,[19] T. Lachenmaier,[20] B. Land,[1,2] K. Lande,[4] J.G. Learned,[9] V. Lozza,[5,6] L. Ludhova,[3] M. Malek,[21] S. Manecki,[22,18,23] J. Maneira,[5,6] J. Maricic,[9] J. Martyn,[14] A. Mastbaum,[24] C. Mauger,[4] F. Moretti,[2] J. Napolitano,[25] B. Naranjo,[26] M. Nieslony,[14] L. Oberauer,[27] G. D. Orebi Gann,[1,2] J. Ouellet,[28] T. Pershing,[12] S.T. Petcov,[29,30] L. Pickard,[12] R. Rosero,[8] M. Sanchez,[10] J. Sawatzki,[27] S.H. Seo,[31] M. Smiley,[1,2] M. Smy,[32] A. Stahl,[33] H. Steiger,[27] M. R. Stock,[27] H. Sunej,[8] R. Svoboda,[12] E. Tiras,[10] W. Trzaska,[11] M. Tzanov,[19] M. Vagins,[32] C. Vilela,[34] Z. Wang,[35] J. Wang,[12] M. Wetstein,[10] M.J. Wilking,[34] L. Winslow,[28] P. Wittich,[36] B. Wonsak,[15] E. Worcester,[8,34] M. Wurm,[14] G. Yang,[34] M. Yeh,[8] E.D. Zimmerman,[37] S. Zsoldos,[1,2] and K. Zuber[38]

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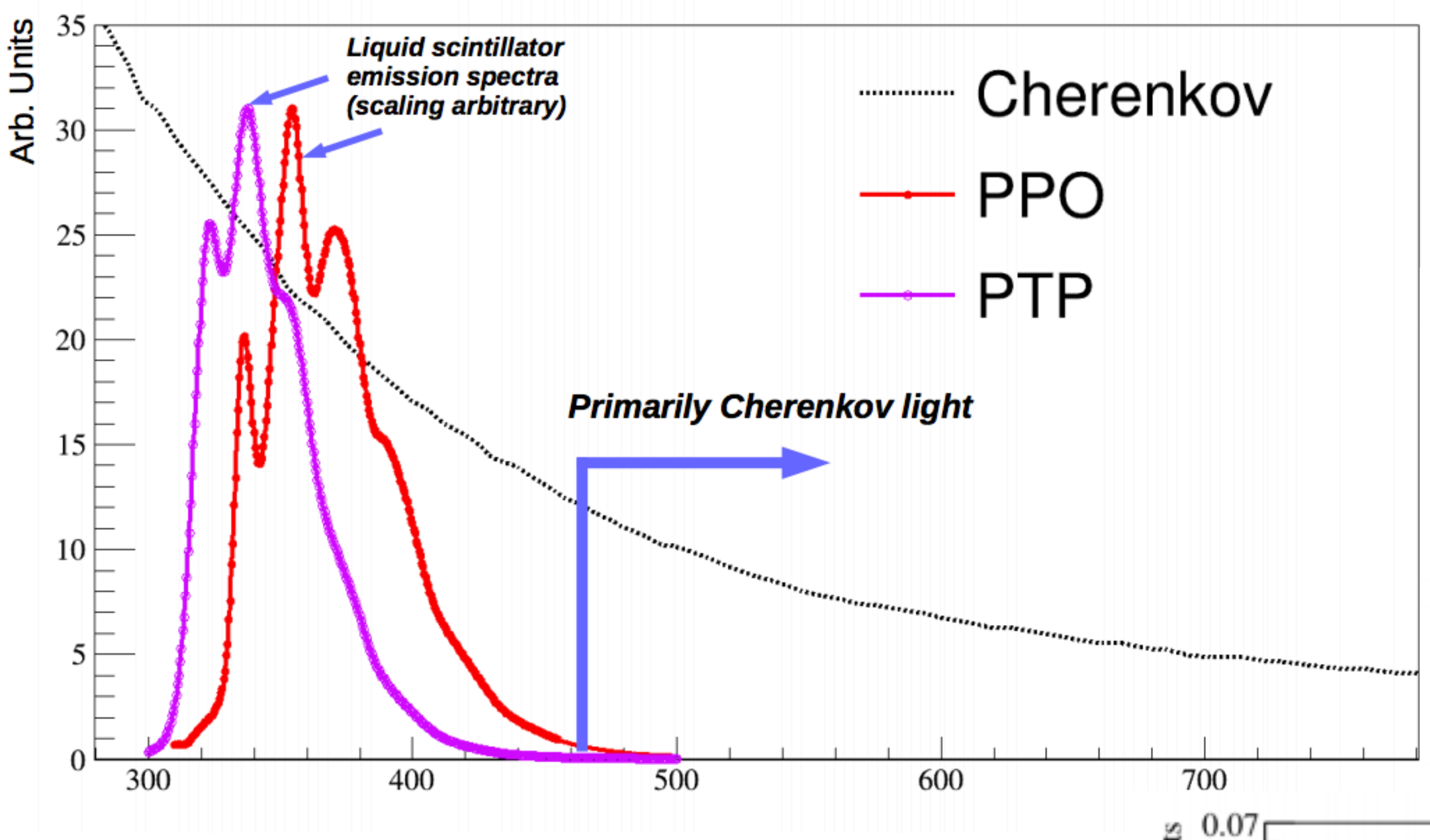
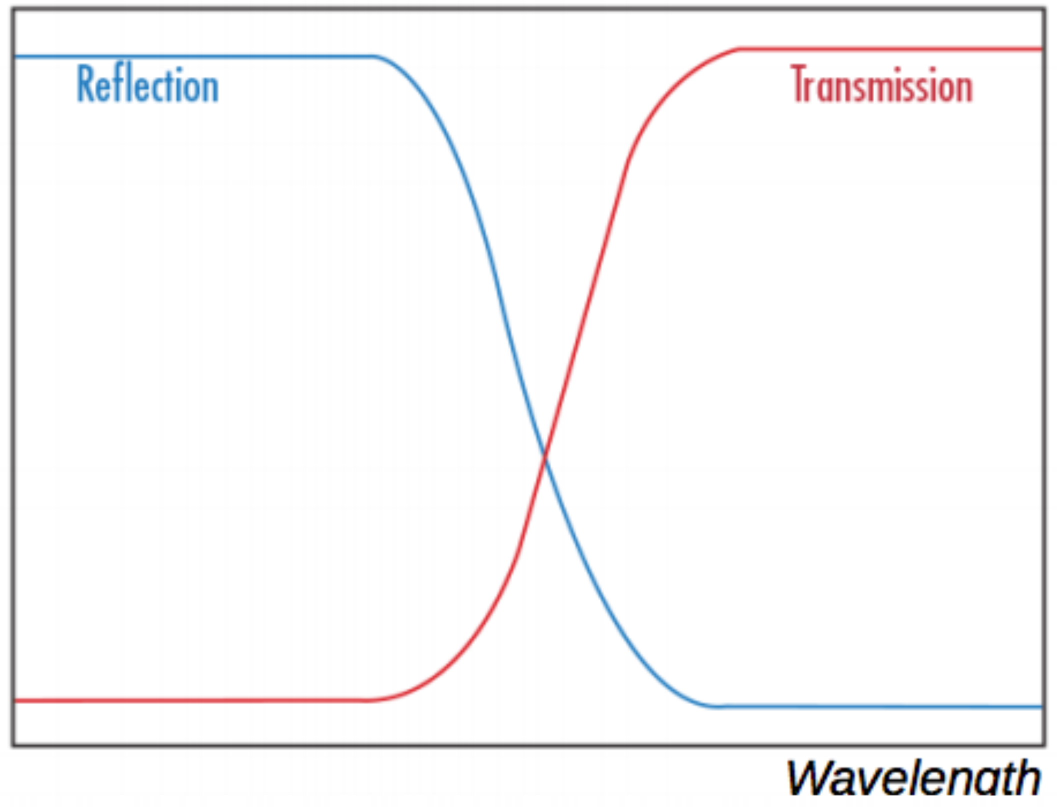
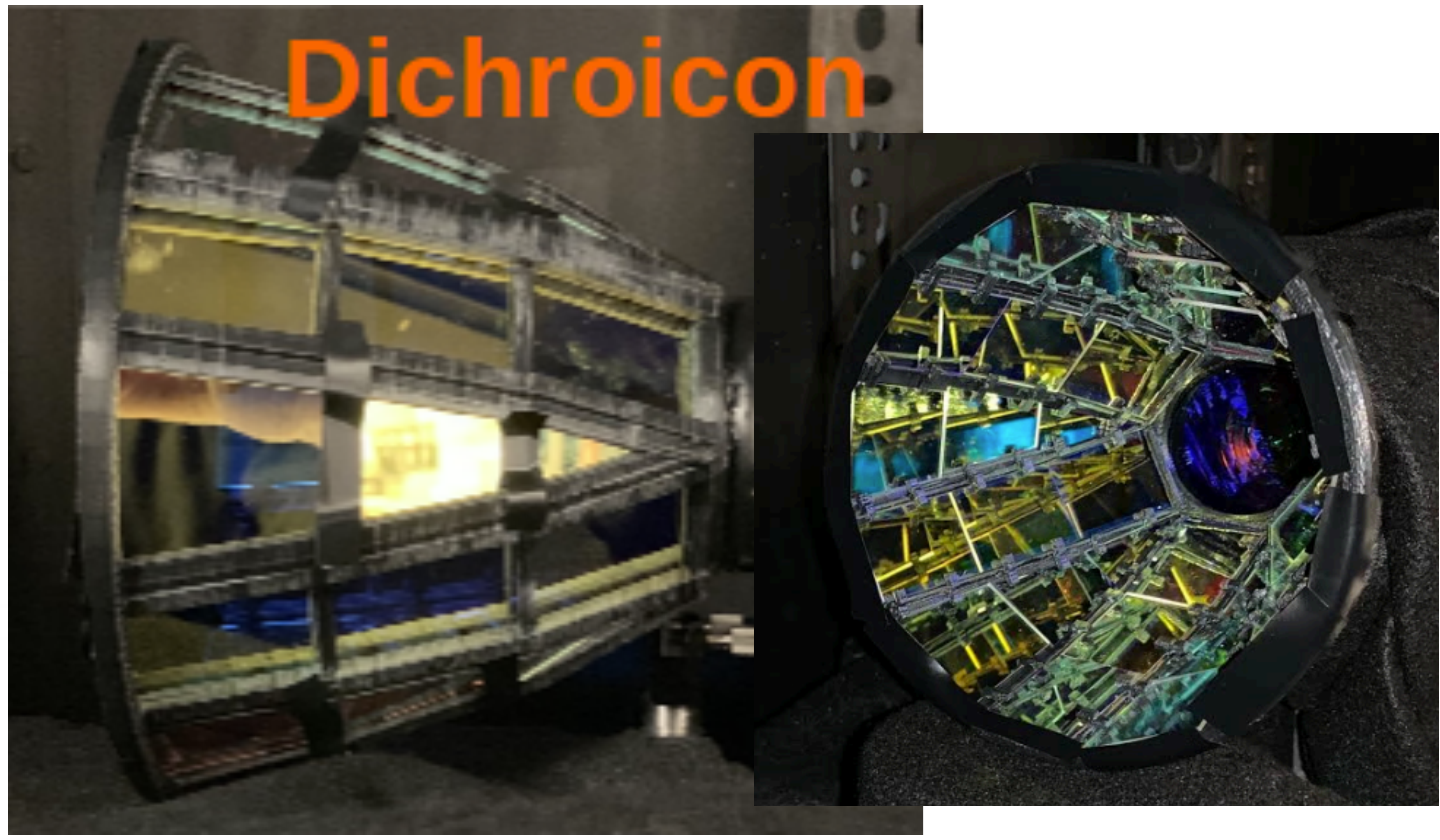
- C. Aberle et al., arXiv:1307.5813 [physics.ins-det] (2013)
- L. J. Bignell et al., JINST 10 P12009 (2015)
- R. Bonventre and G. Orebi Gann, Eur. Phys. J. C (2018) 78: 435

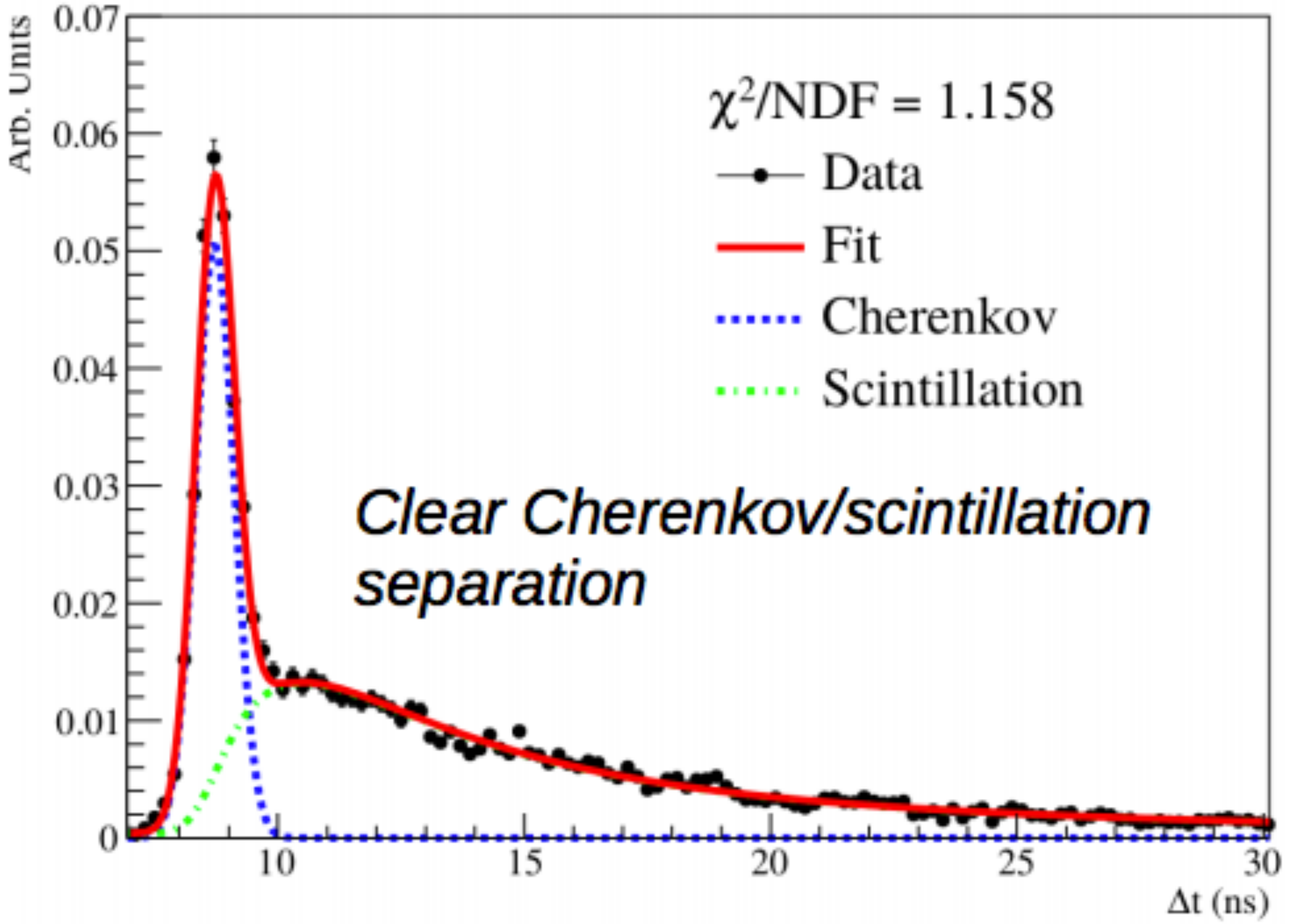
BACKUP SLIDES

DICROICONS: CHERENKOV AND SCINTILLATION WAVELENGTH SEPARATION









T. Kaptanoglu, M. Luo, J. Klein, JINST 14 no. 05 T05001 (2019)