EOS

Testbed for Hybrid Neutrino Detection Technology

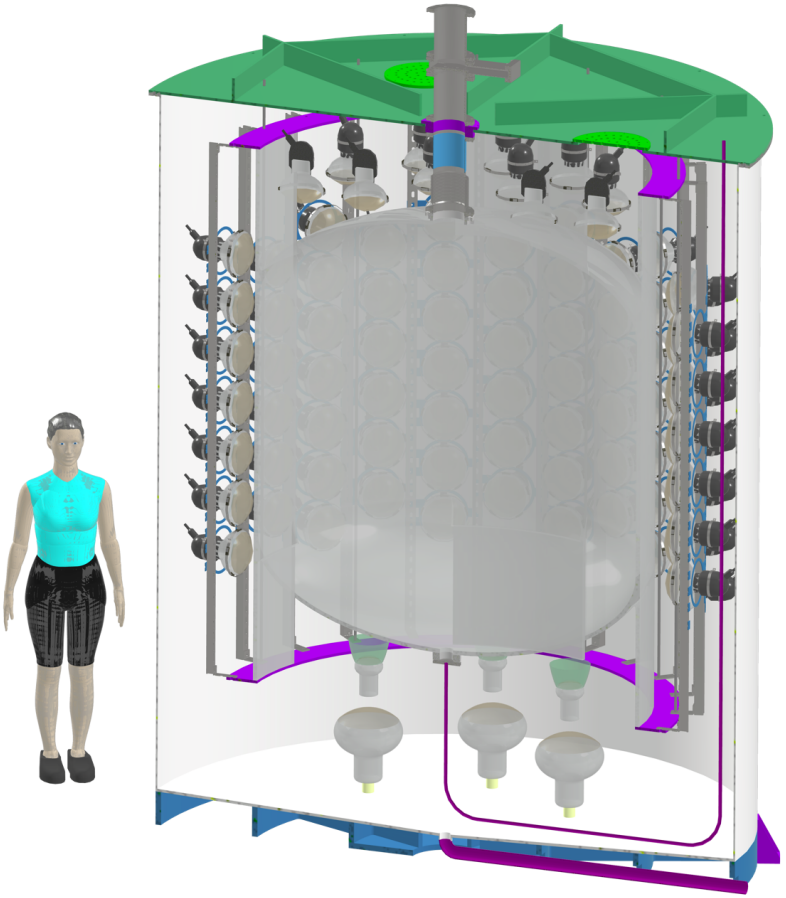
Tanner Kaptanoglu

for the EOS collaboration

UC Berkeley and LBNL

Snowmass Early Career

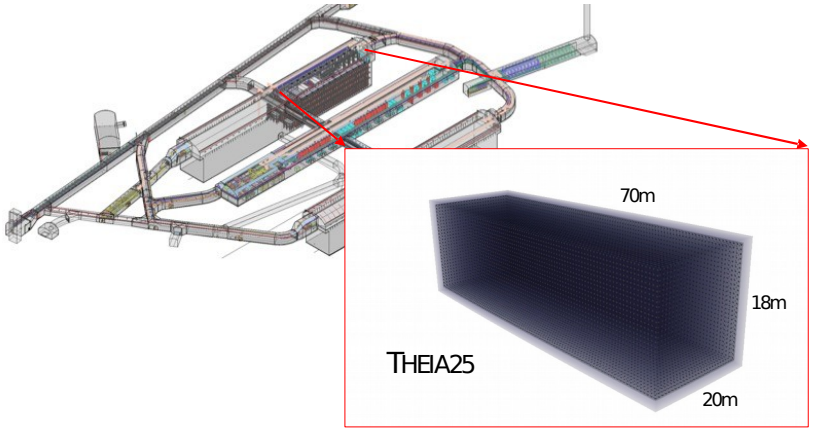
7/24/2022



Motivation

- Hybrid detectors distinguish Cherenkov & scintillation light for:

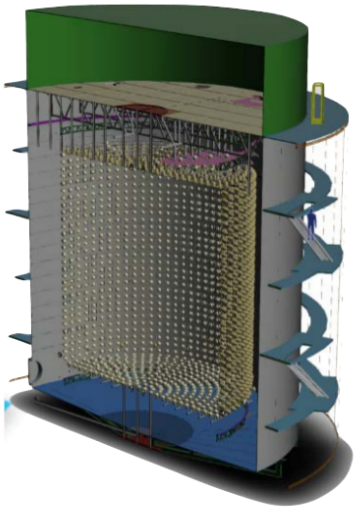
  → Improved energy / vertex resolution
  → Dir. reconstruction using Cher. light
  → Improved signal sensitivity & bkg. rejection
  → Additional particle ID

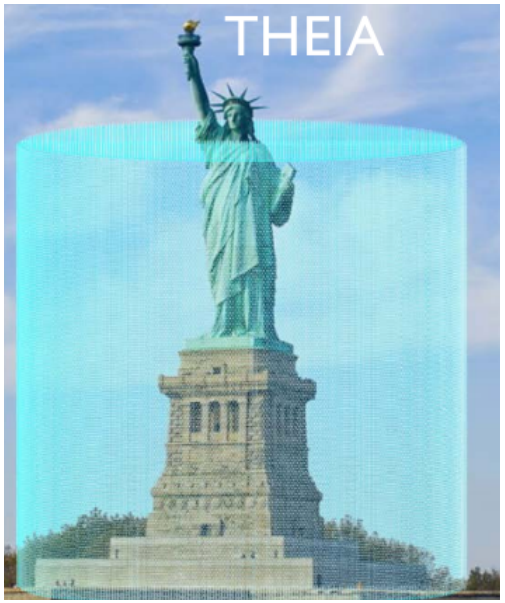


- Future ktonne-scale detectors, such as THEIA, would leverage hybrid detection to provide broad physics program

  SNOWMASS 20O, G. D. Orebi Gann: Theia

- Utilize hybrid detector technology to enhance program for far-field reactor monitoring (nonproliferation) [1]



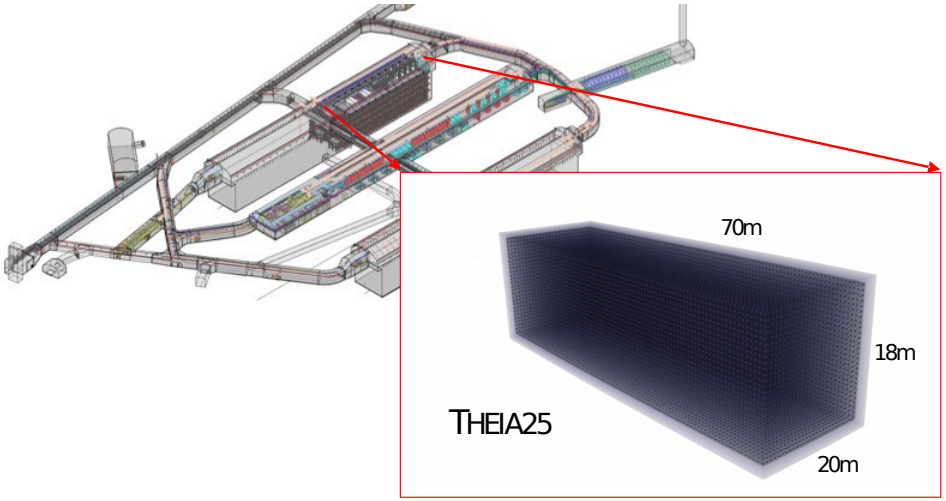


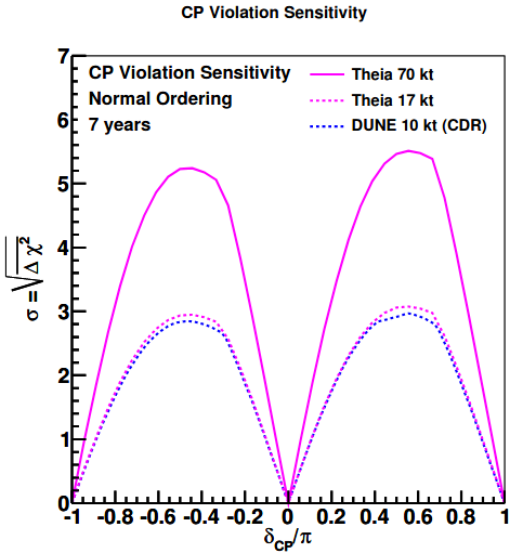
[1] T. Akindele et al, SNOWMASS white paper: A Call to Arms Control: Synergies between Nonproliferation Applications of Neutrino Detectors and Large-Scale Fundamental Neutrino Physics Experiments

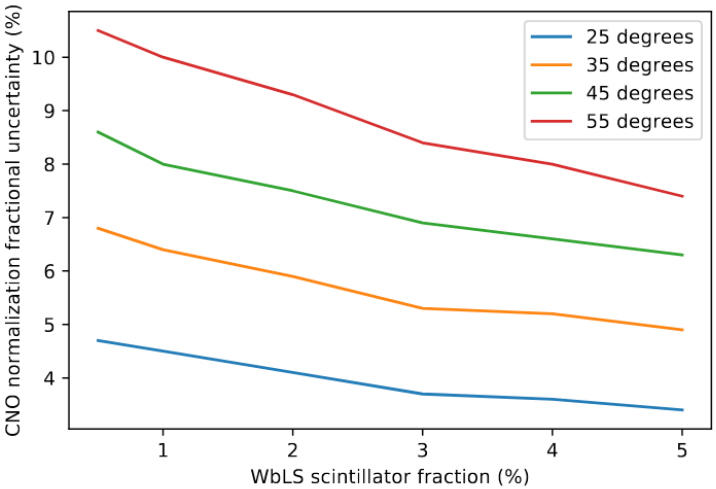
Motivation

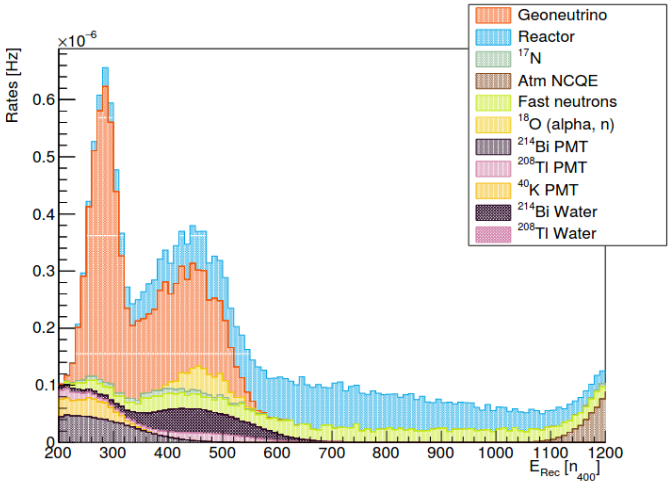
- THEIA physics program [1]:

  → Long baseline oscillations
  SNOWMASS 20H, L. Pickard: High energy physics program at Theia
  → Low energy solar neutrinos [2]
  → Geo & reactor neutrinos [3]
  SNOWMASS 20H, Z. Bagdasarian: Low-energy neutrino physics at Theia
  → 0νββ, supernova neutrinos, and more!









[1] Theia White Paper, EPJC 80 416 (2020) [2] R. Bonventre, G.D. Orebi Gann, EPJC 78 435 (2018)
[3] S. Zoldos, Z. Bagdasarian, et al. arXiv:2204.12278 [hep-ex] (2022)

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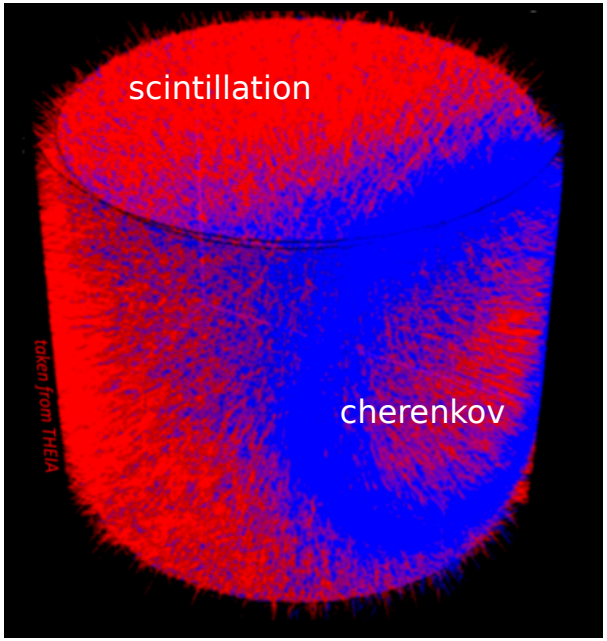

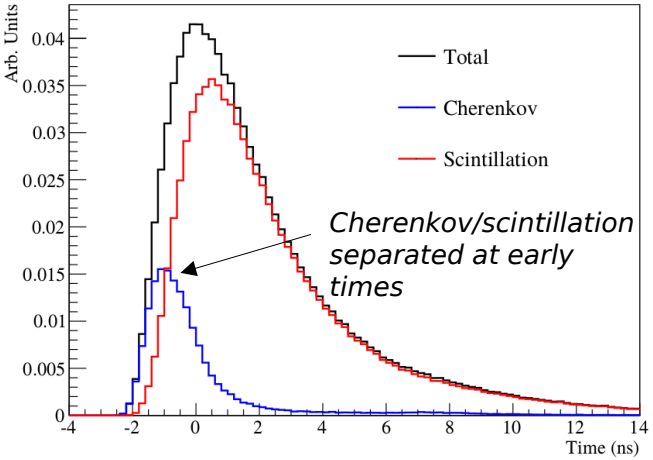

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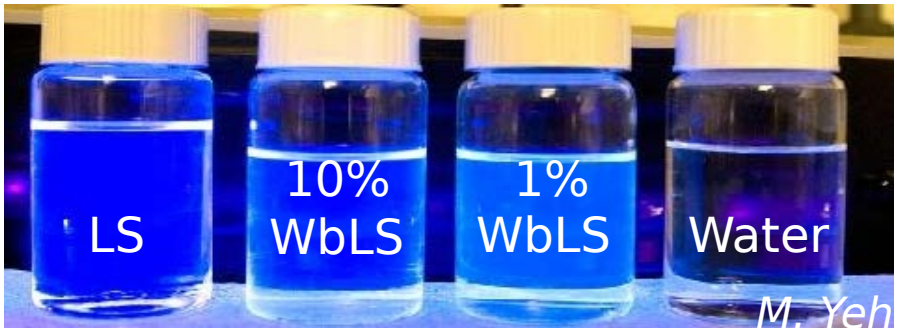
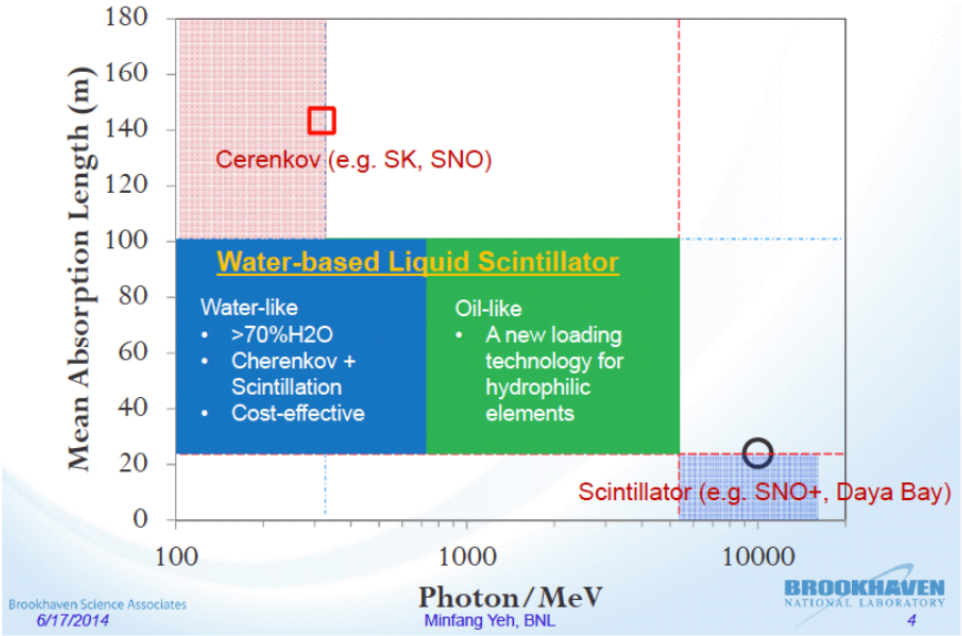
- Novel target mediums (such as WbLS) provide many benefits

  SNOWMASS 30R, M. Yeh: Development and production of high-performance water based liquid scintillators for particle physics experiments





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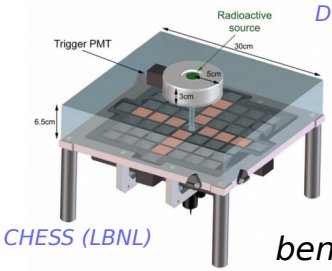
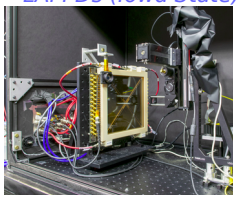
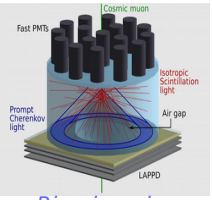


CHESS (LBNL)

Dichroicon (UPenn)

LAPPDs (Iowa State)





Ring imaging (Mainz)

bench-top scale (~0.1 - 10L)

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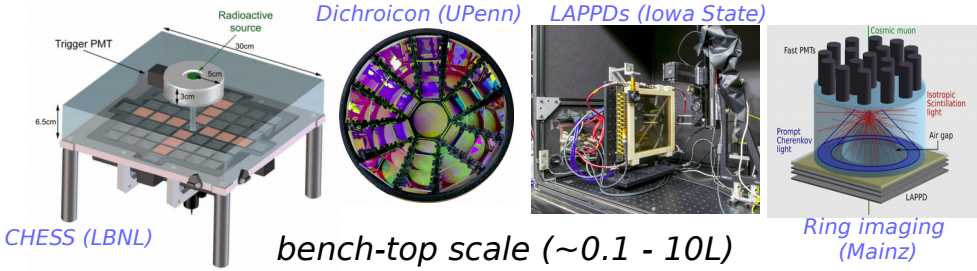

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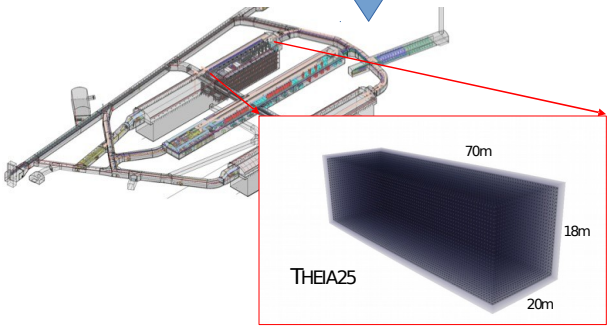
???

tonne scale



ktonne scale

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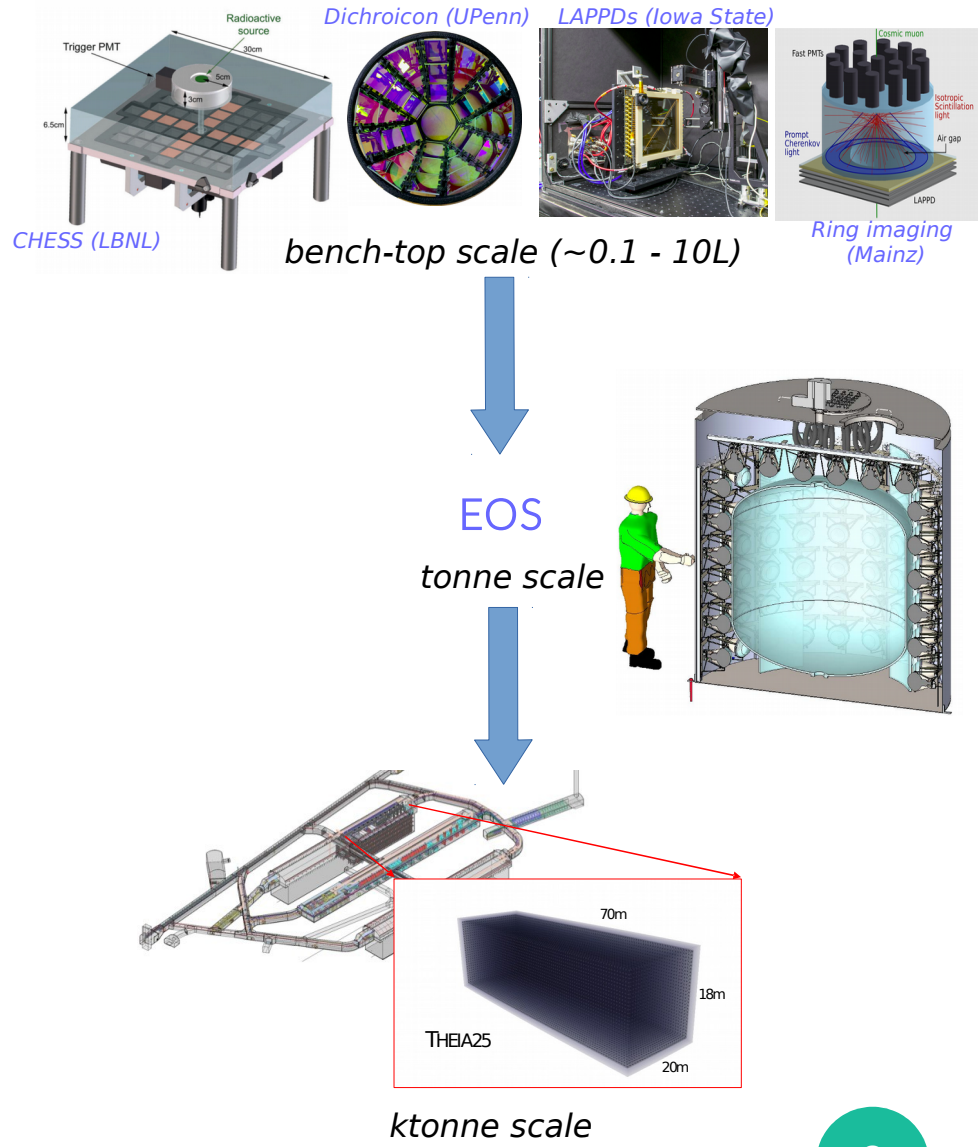

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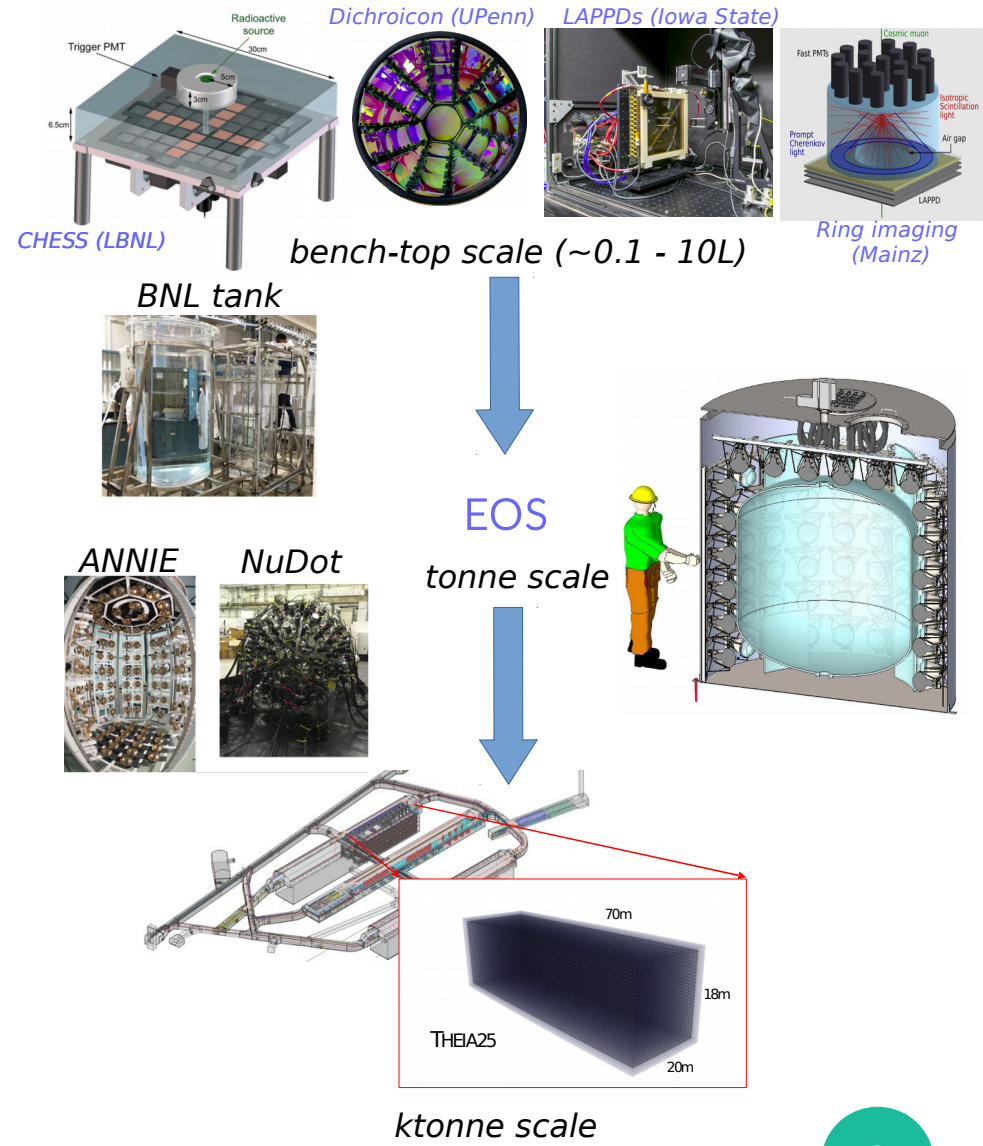

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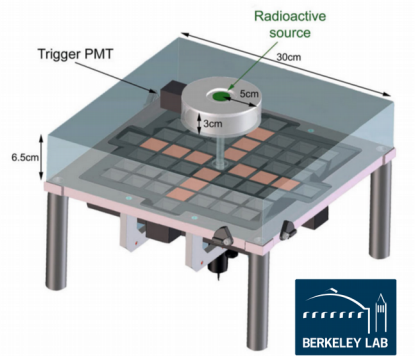
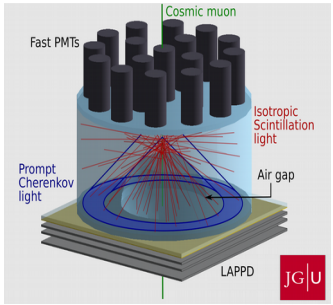
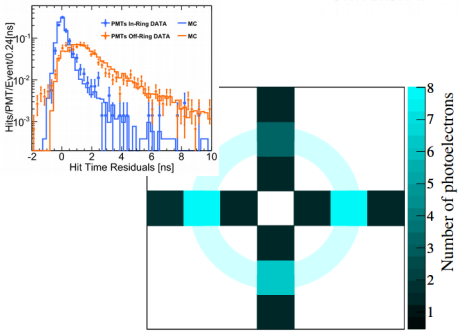
Hybrid Detector R&D Program

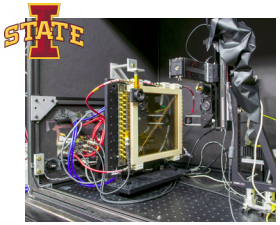


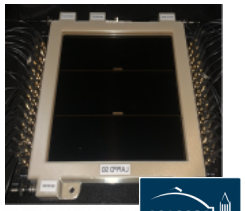


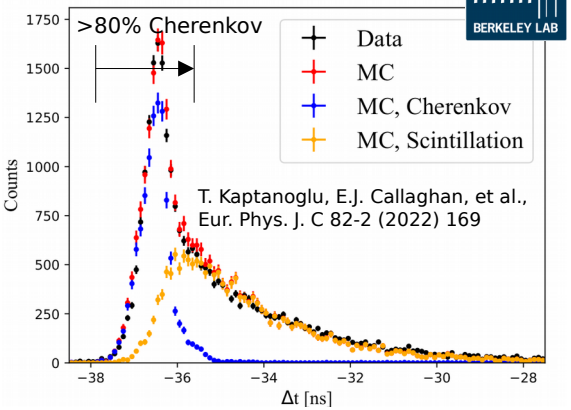
JOHANNES GUTENBERG UNIVERSITÄT MAINZ



Ring imaging

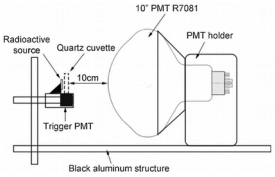




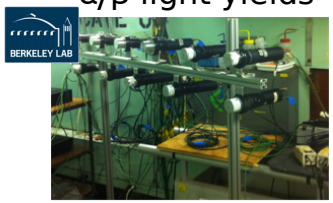


Fast timing with LAPPDs

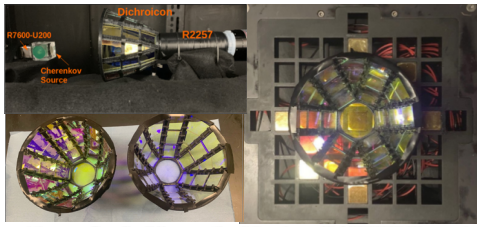
Long arm scattering

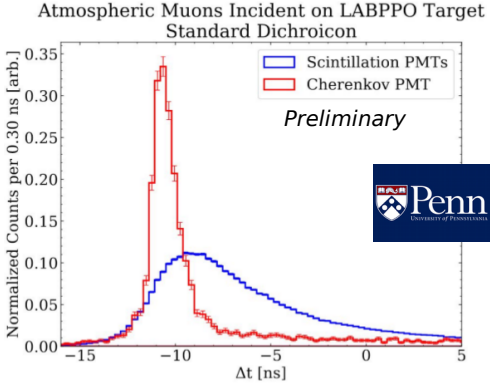


α/β light yields

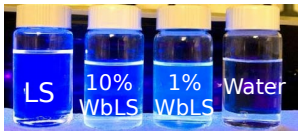


Proton light yield





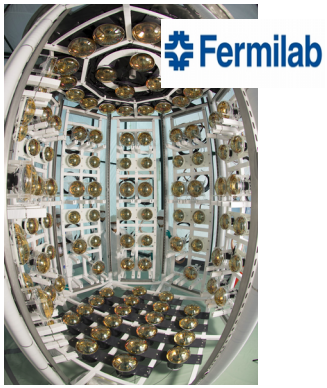
Spectral sorting with dichroicons



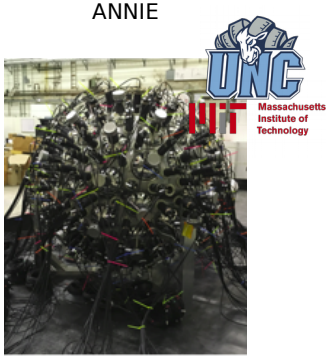
BROOKHAVEN NATIONAL LABORATORY

WbLS Synthesization

BNL Tank



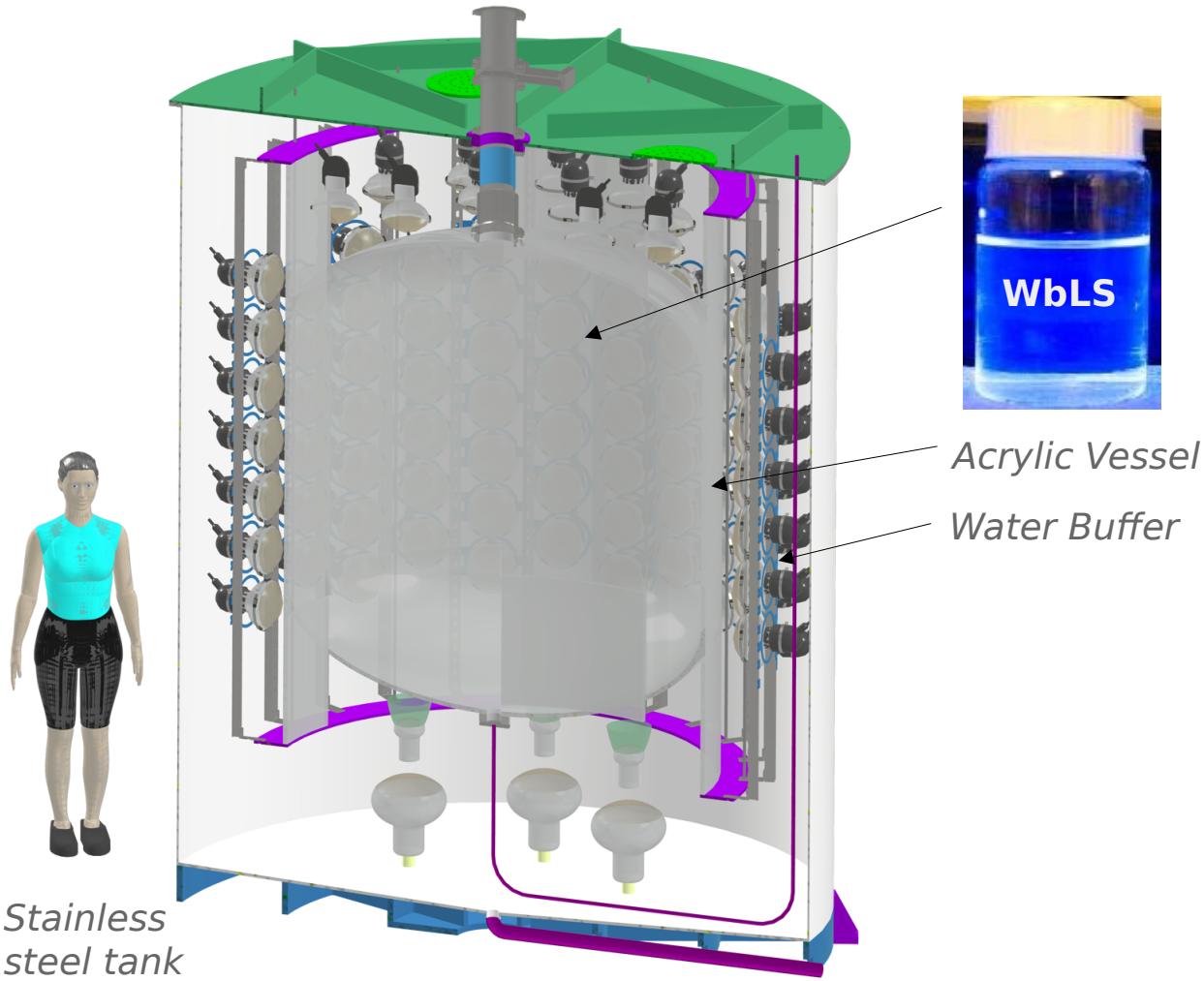
ANNIE



NuDot

Introducing EOS

- EOS is a ~4 tonne hybrid detector being constructed at UC Berkeley



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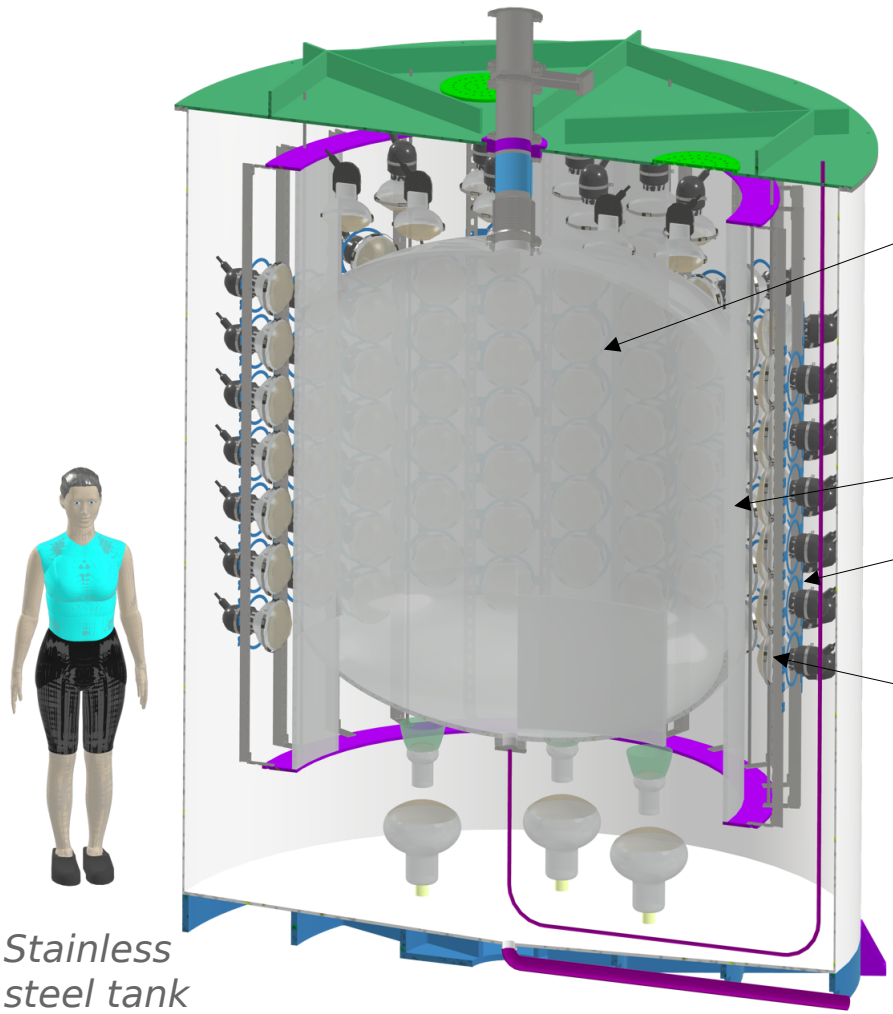
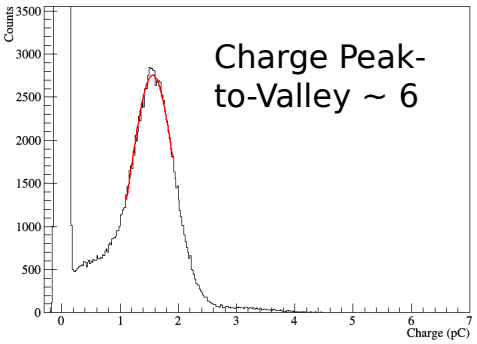


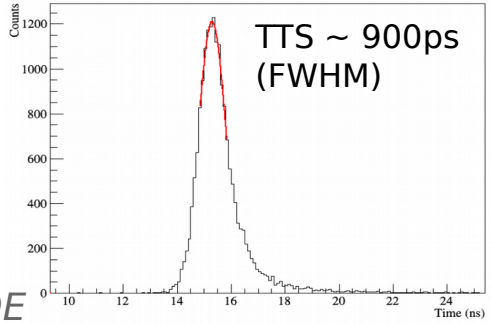
Stainless steel tank

Acrylic Vessel

Water Buffer

~200x R14688 Hamamatsu HQE 8'' state-of-the-art PMTs





Advanced PMT testing facility for fast ex-situ characterization of:
→ PMT gain
→ SPE timing/charge
→ Dark rate, after-pulsing rate
→ Magnetic shielding effects

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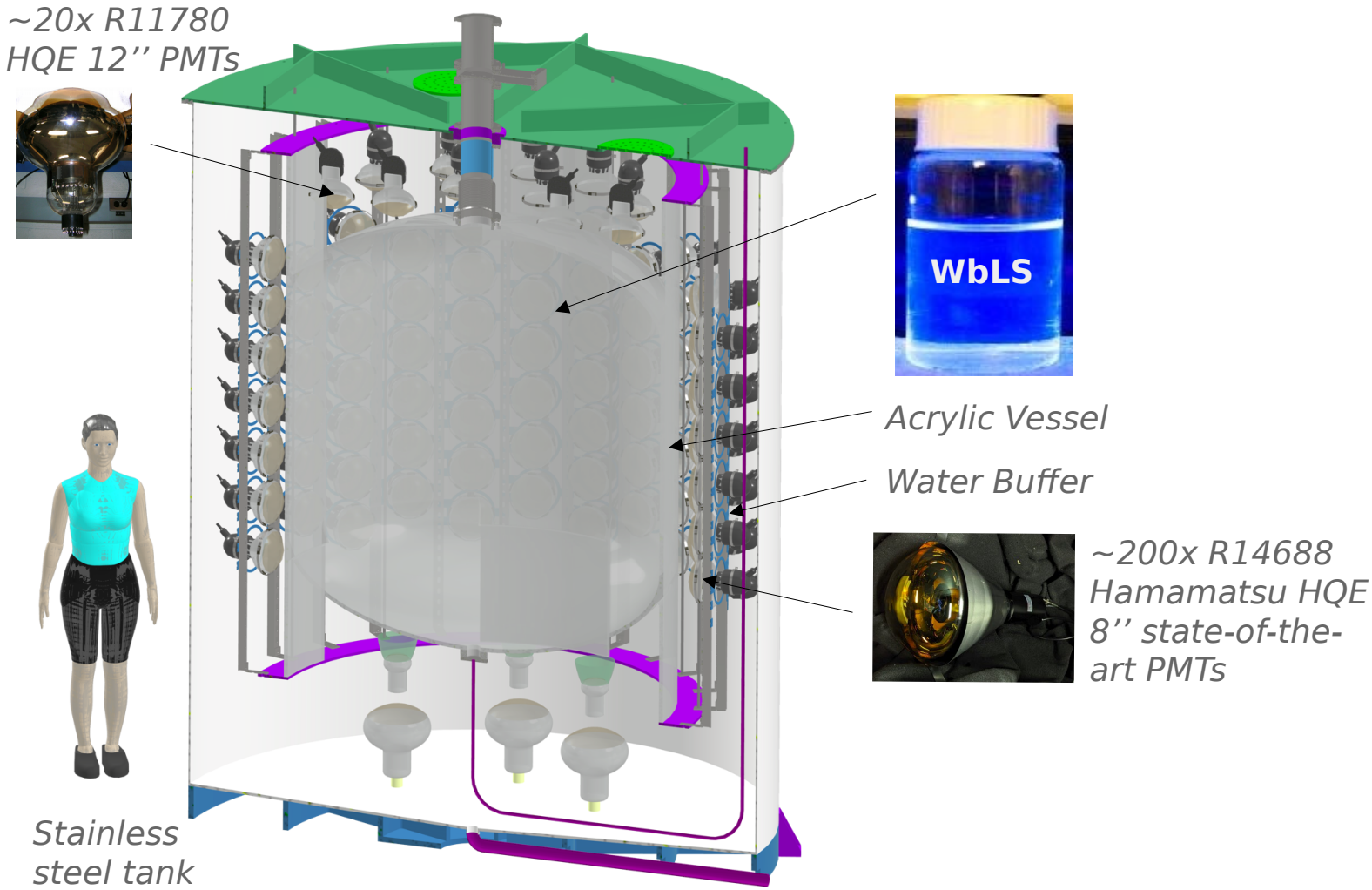

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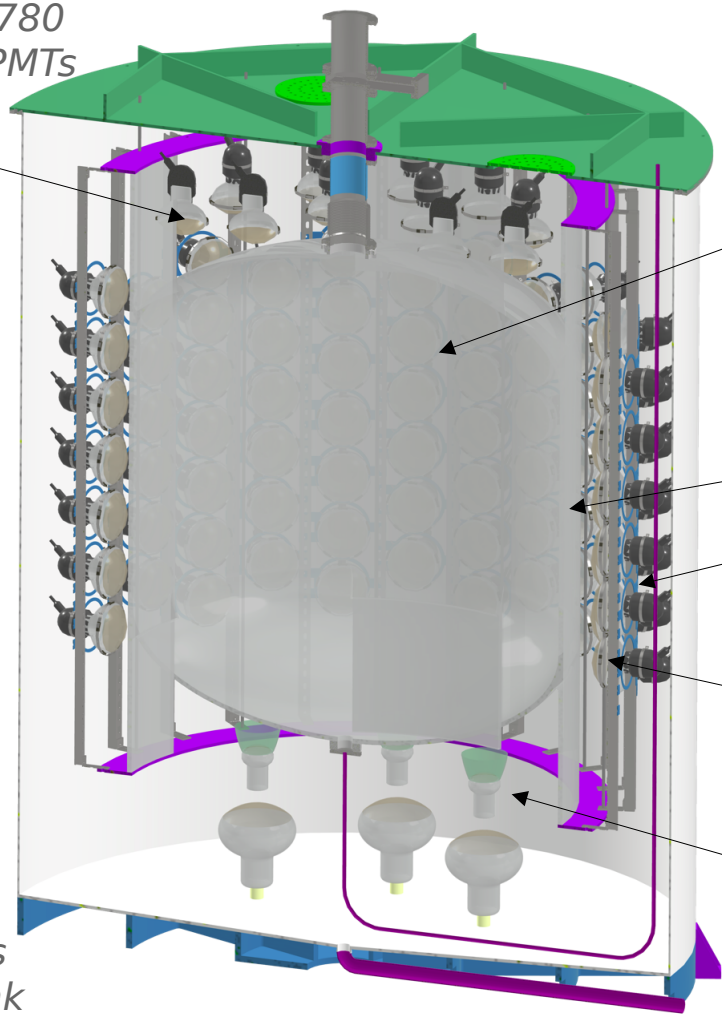
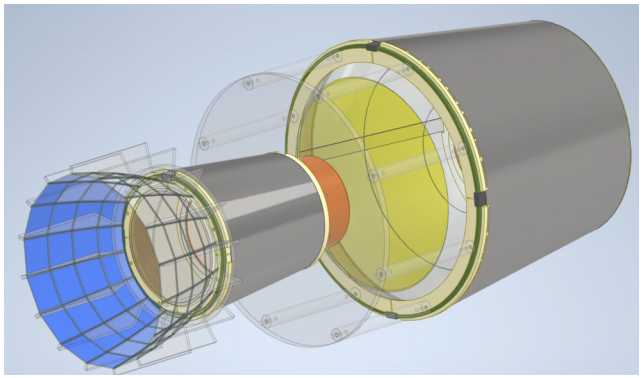


Dichroicon module



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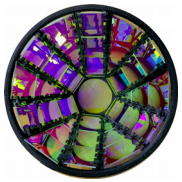

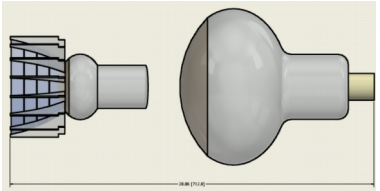

Dichroicons + PMTs at bottom of detector

Stainless steel tank

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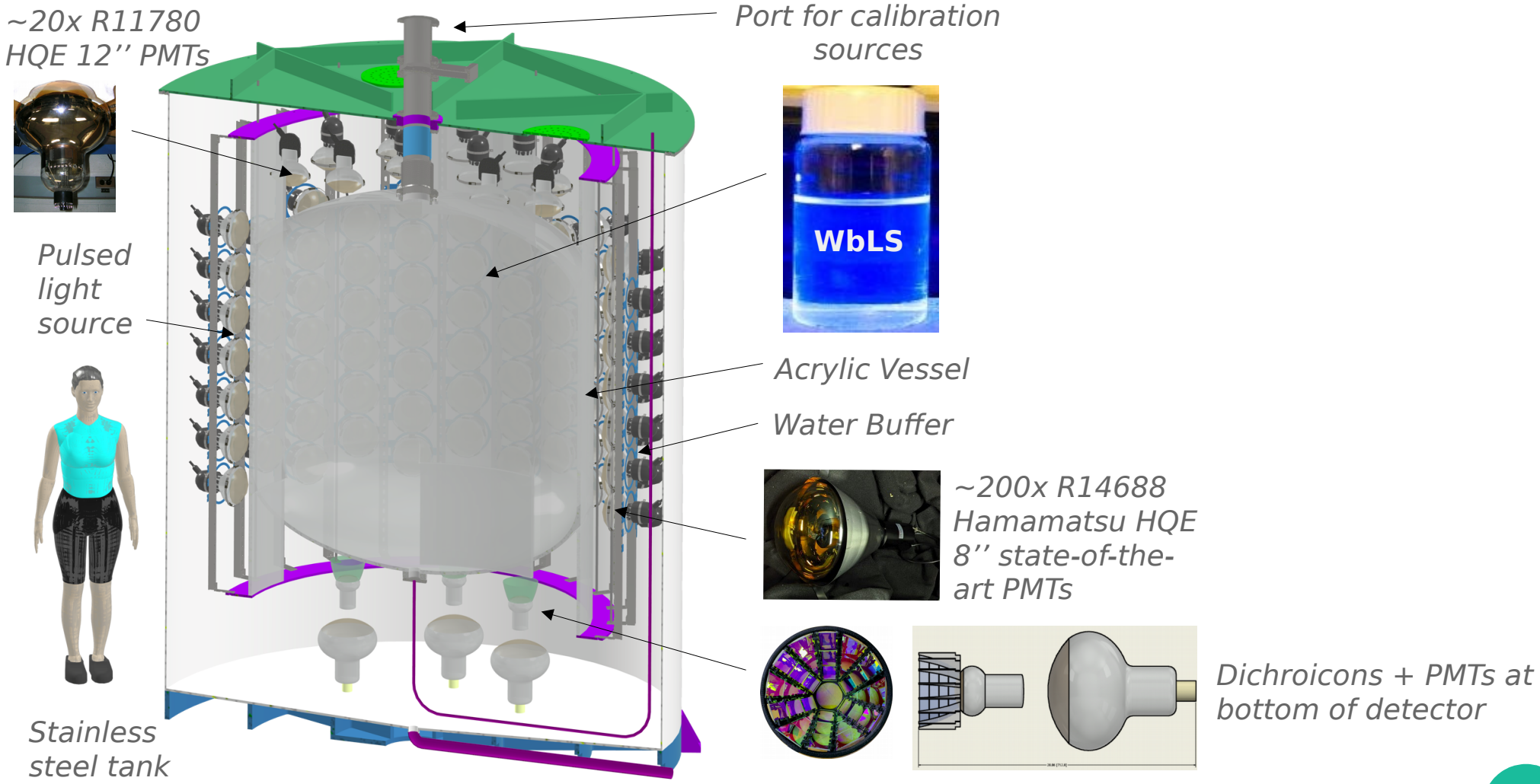

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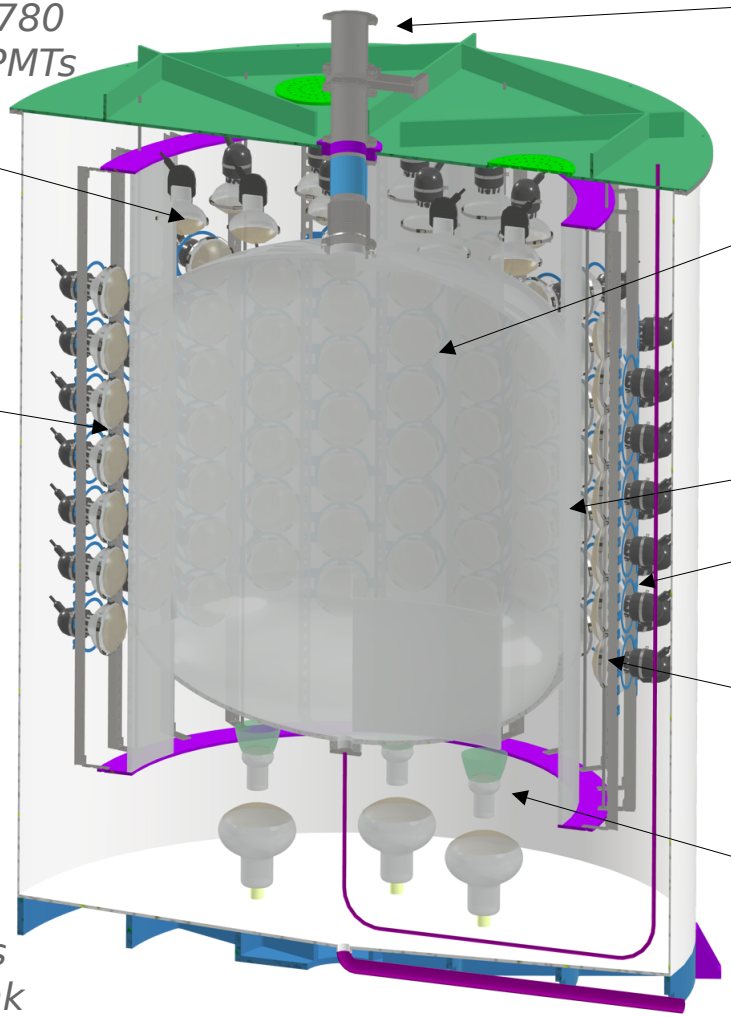
Pulsed light source

Stainless steel tank



Port for calibration sources

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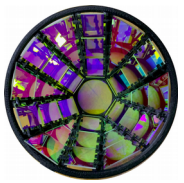

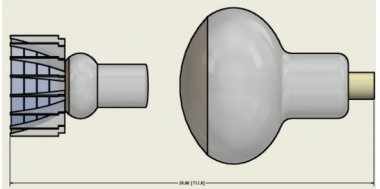

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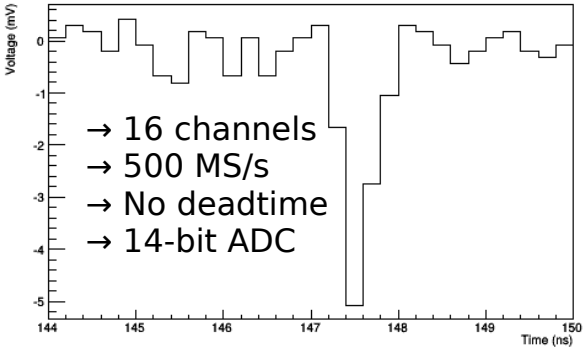
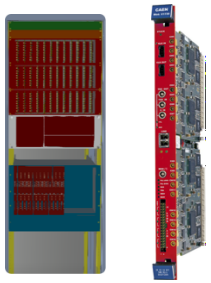


CAEN V1730S digitizers



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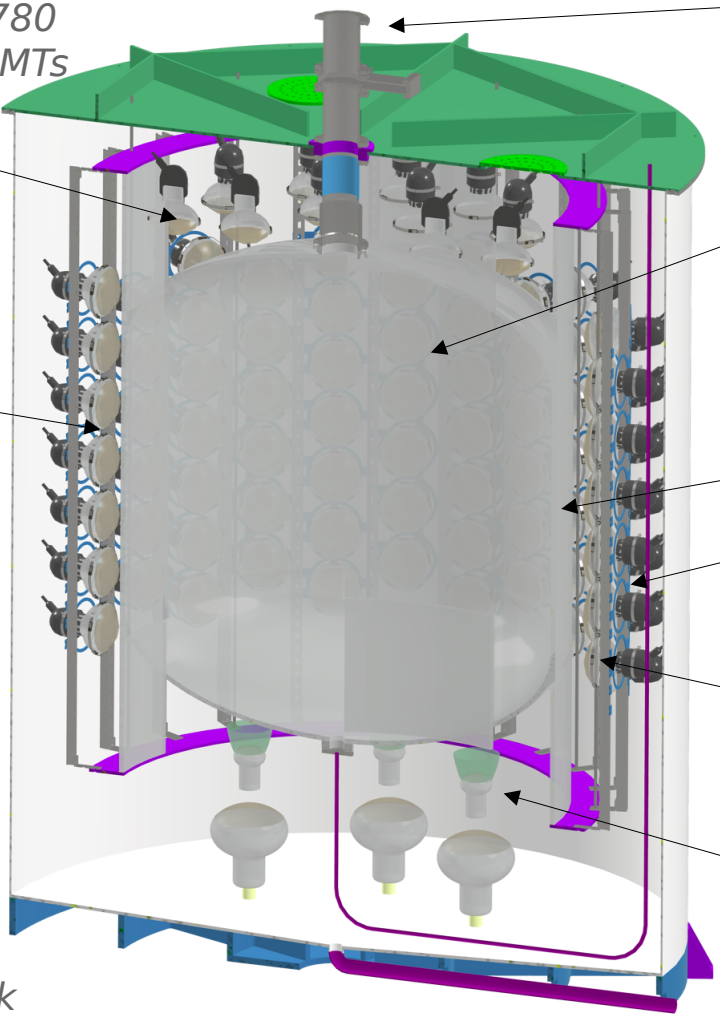
Port for calibration sources

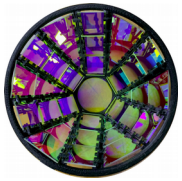
Pulsed light source

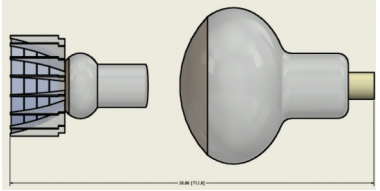


Acrylic Vessel

Water Buffer

~200x R14688 Hamamatsu HQE 8'' state-of-the-art PMTs



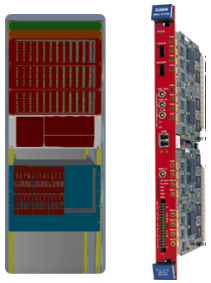


Dichroicons + PMTs at bottom of detector

Stainless steel tank

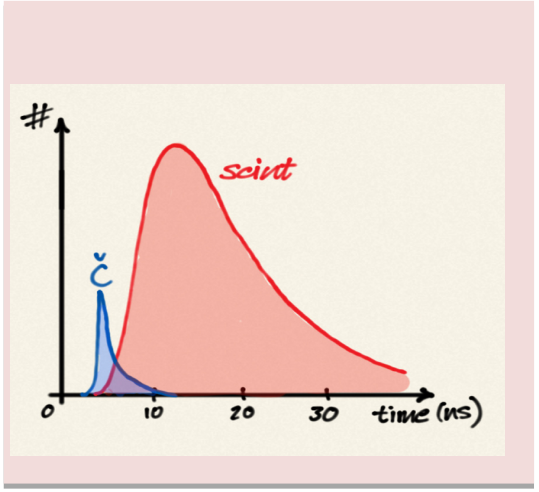
- EOS is a *flexible* testbed for hybrid detector technology!
  - → Novel target mediums
  - → Fast-timing, high QE PMTs
  - → Spectral sorting
  - → Novel readout solutions
  - → Advanced recon. alogorithms

CAEN V1730S digitizers

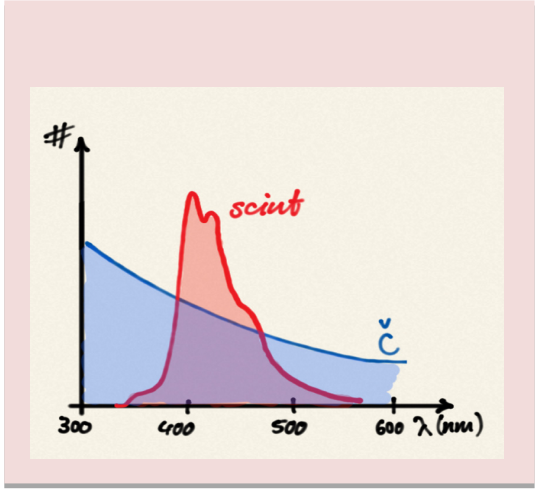


Goals

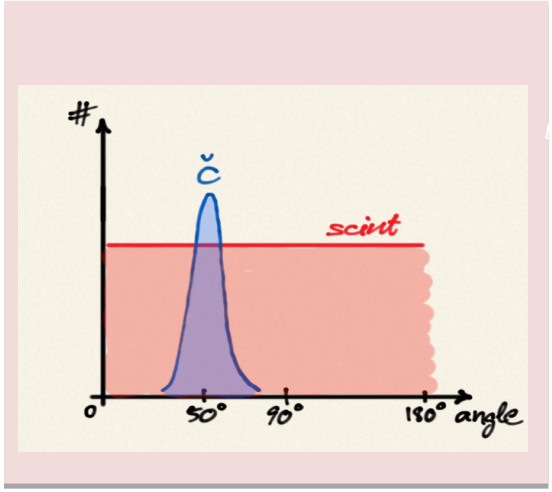
- Demonstrate Cherenkov and scintillation separation at the tonne-scale



→ Fast timing PMTs
→ Slow WbLS



→ Dichroicons

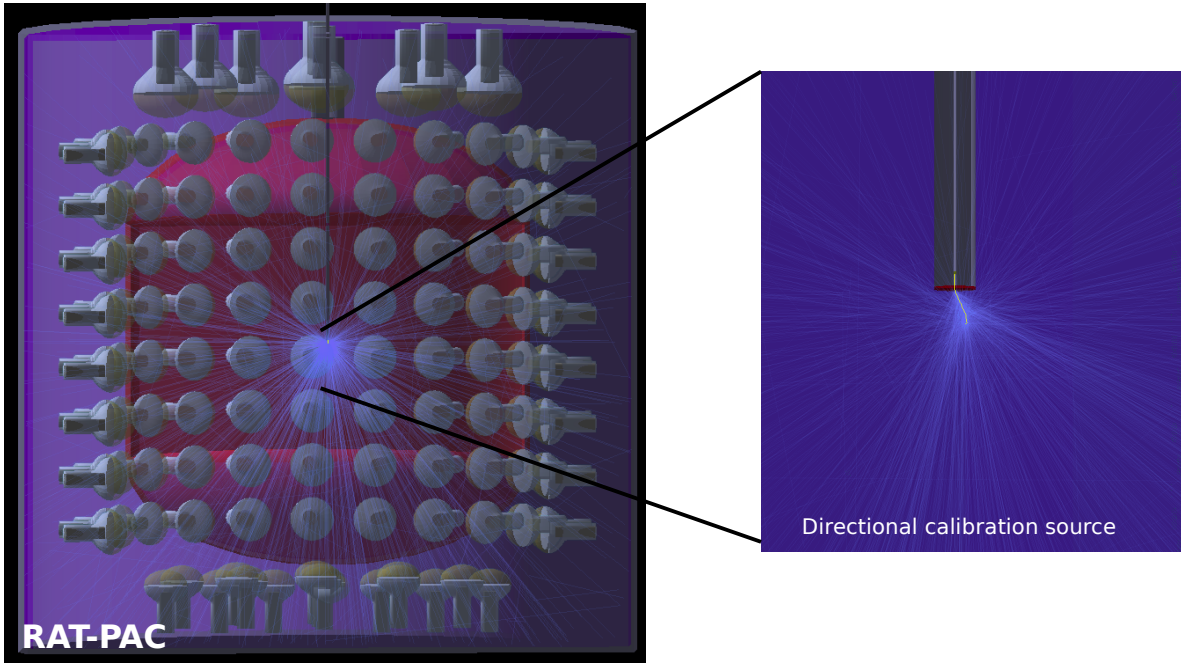


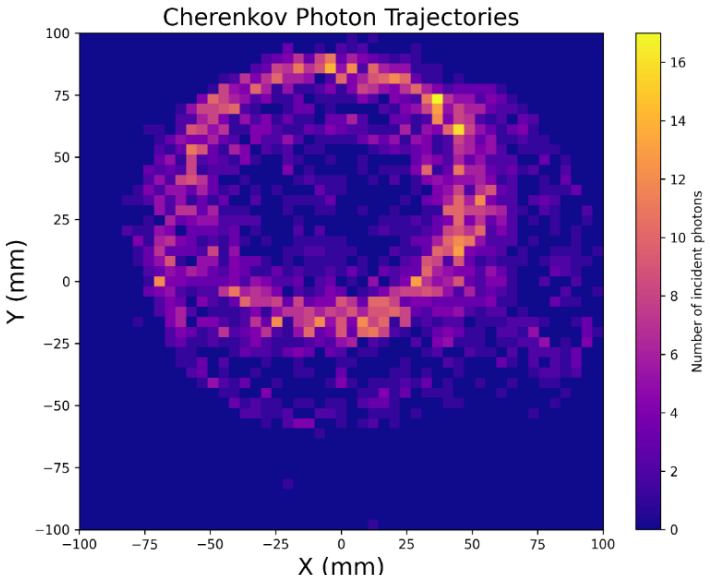
→ WbLS
→ Improved recon. methods

Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale

  → Using deployed (directional) calibration source

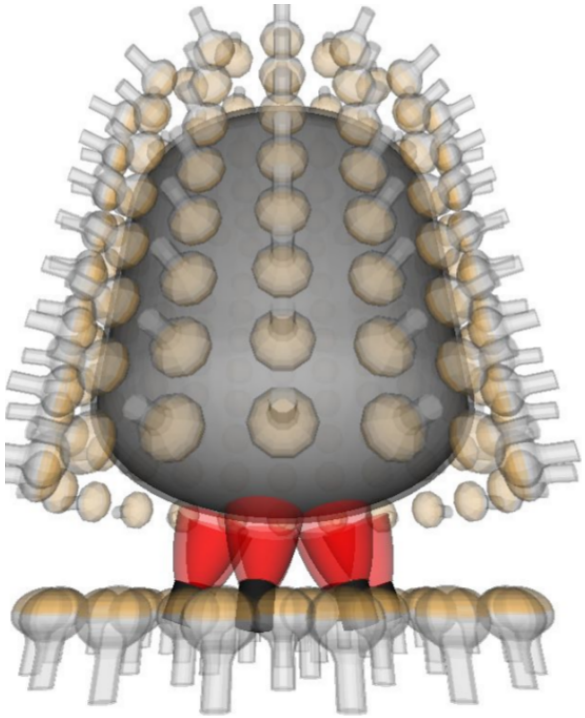




Goals

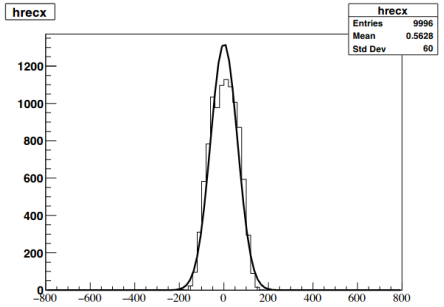
- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:

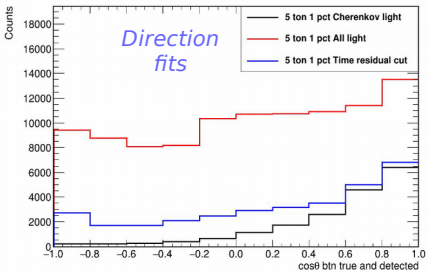
  → Use Cherenkov light to perform direction reconstruction against scint. background
  → Show improved position resolution (better than water Cherenkov detector)



Chroma

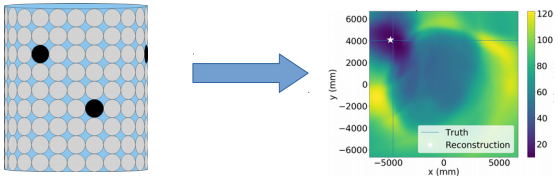
Likelihood based recon.





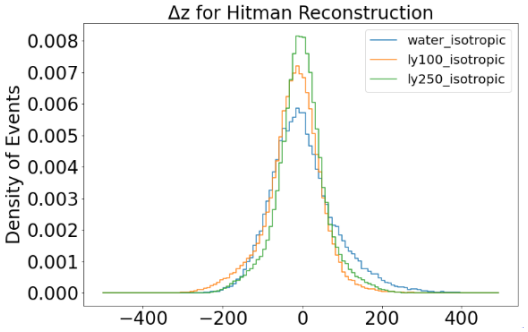
Z. Bagdasarian (UC Berkeley)
G. Yang (UC Berkeley)

"Hitman" ML-based recon.



Detector response
(t, q, nPMT)

Particle Hypothesis
(r, θ, E)



G. Wendel (Penn State)

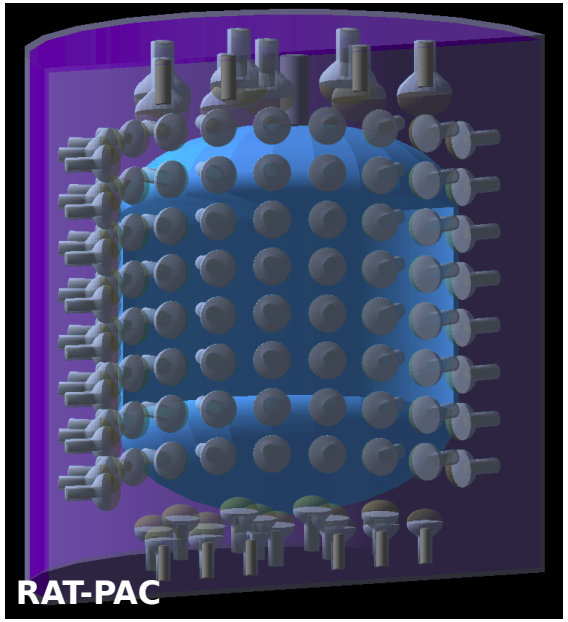
Goals

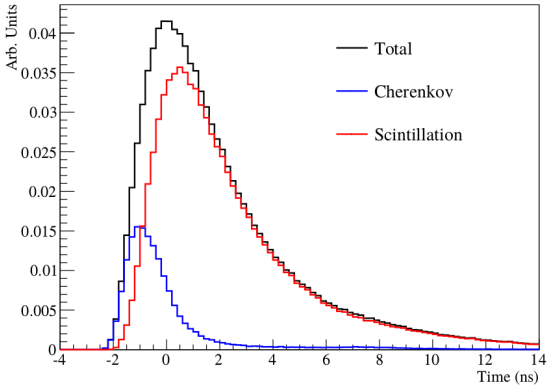
- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:

  → Use Cherenkov light to perform direction reconstruction against scint. background
  → Show improved position resolution (better than water Cherenkov detector)

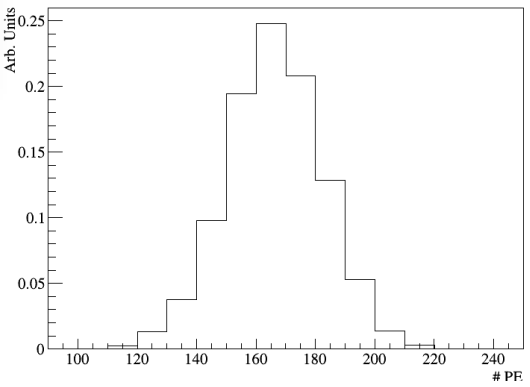
- Validate a detailed WbLS optical model at a large scale

  → Light yield, quenching
  → Emission timing
  → Absorption and scattering





PMT hit-times



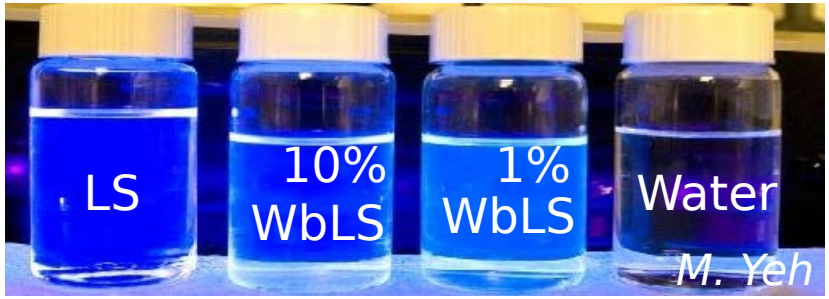
#PE detected

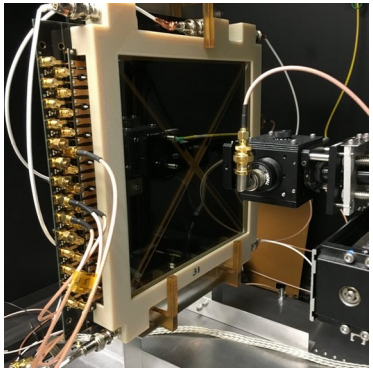
Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:

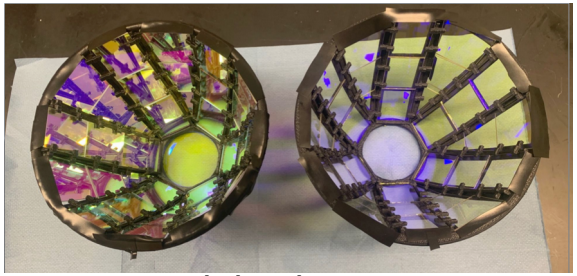
  → Use Cherenkov light to perform direction reconstruction against scint. background
  → Show improved position resolution (better than water Cherenkov detector)
- Validate a detailed WbLS optical model at a large scale
- Performance testing for range of detector configurations

  → Vary WbLS concentration, change/add photodetectors, utilize spectral sorting, etc.





LAPPD



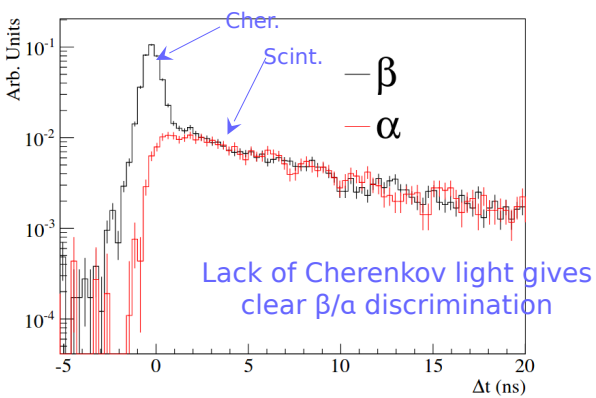
Dichroicons

Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:

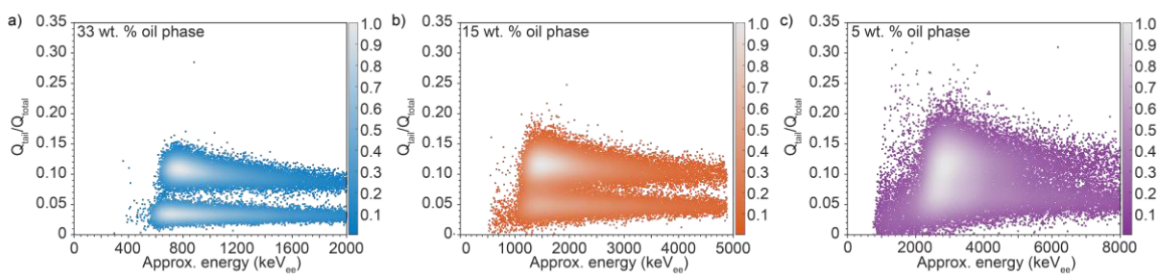
  → Use Cherenkov light to perform direction reconstruction against scint. background
  → Show improved position resolution (better than water Cherenkov detector)

- Validate a detailed WbLS optical model at a large scale
- Performance testing for range of detector configurations
- Stretch goal: particle ID (neutron / γ / β / α)



β/α discrimination [1]

n/γ discrimination [2]



20J, T. Akindele, Enhanced Particle Identification in Water-based Liquid Scintillator

[1] T. Kaptanoglu et al., *Phys. Rev. D 101, 072002 (2020)*
[2] M. J. Ford, O. A. Akindele, et al., *arXiv:2202.07625 [physics.ins-det]*

Goals

- Demonstrate Cherenkov and scintillation separation at the tonne-scale
- Develop reconstruction algorithms to:

  → Use Cherenkov light to perform direction reconstruction against scint. background
  → Show improved position resolution (better than water Cherenkov detector)

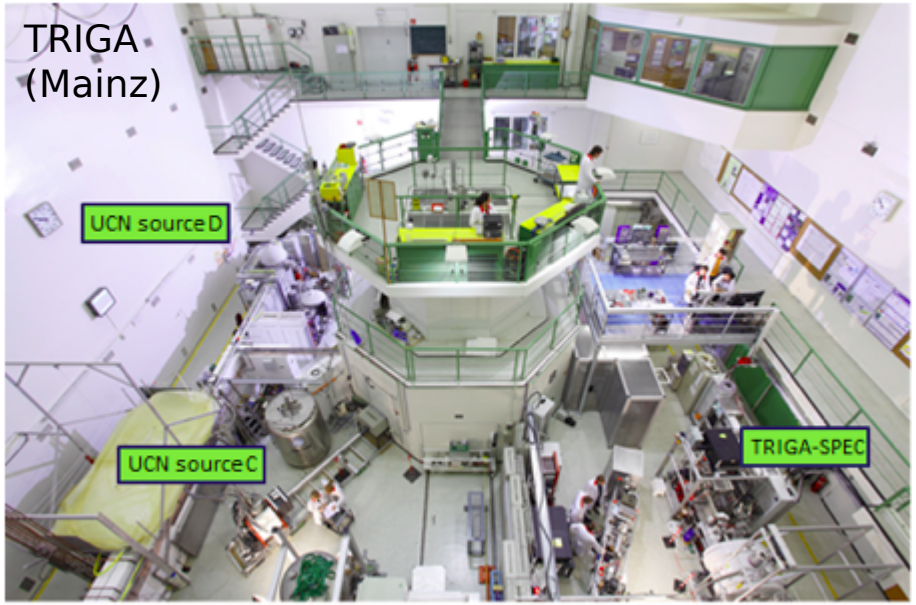
- Validate a detailed WbLS optical model at a large scale
- Performance testing for range of detector configurations
- Stretch goal: particle ID (neutron / γ / β / α)
- Ultimately, enable broad, world-leading nonproliferation + physics program!

Future Goals

- EOS will be transportable for possible deployments:

  → Close (few-m to few-100m) to a reactor core, for hybrid neutrino event reconstruction demonstration

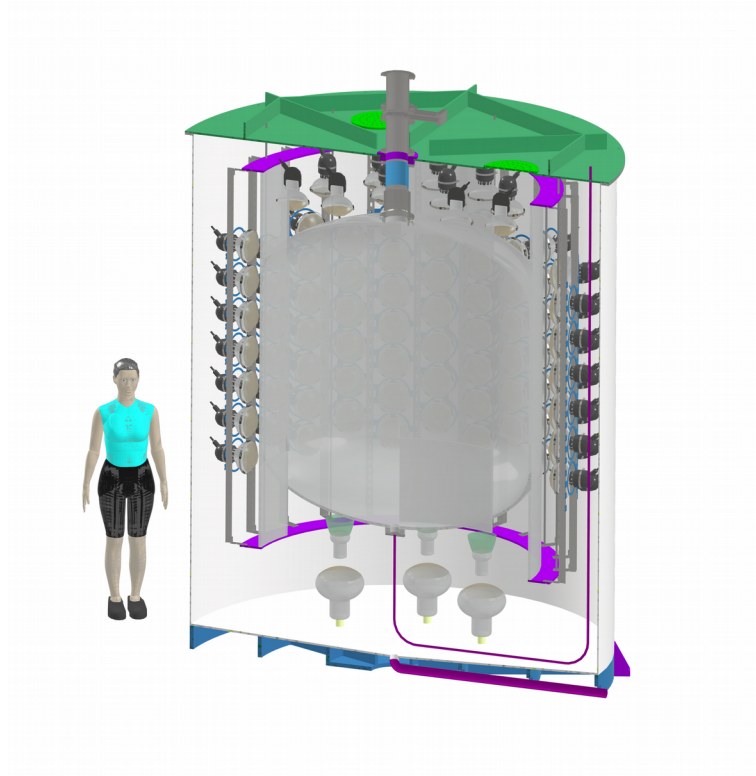
  → In a particle test beam, e.g. FNAL, CERN, SNS for characterization of high-energy events

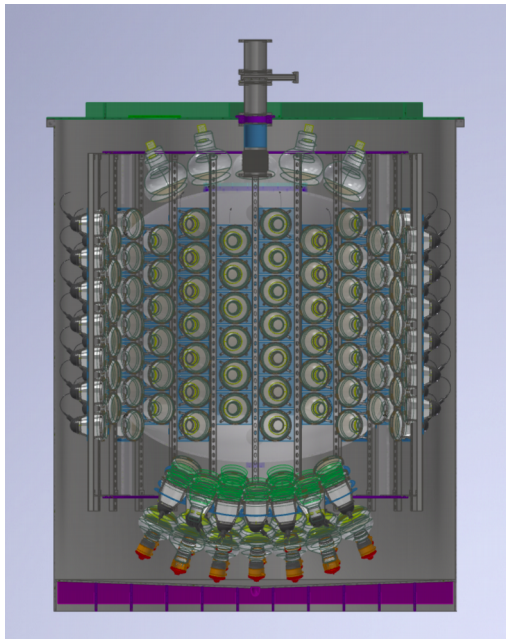


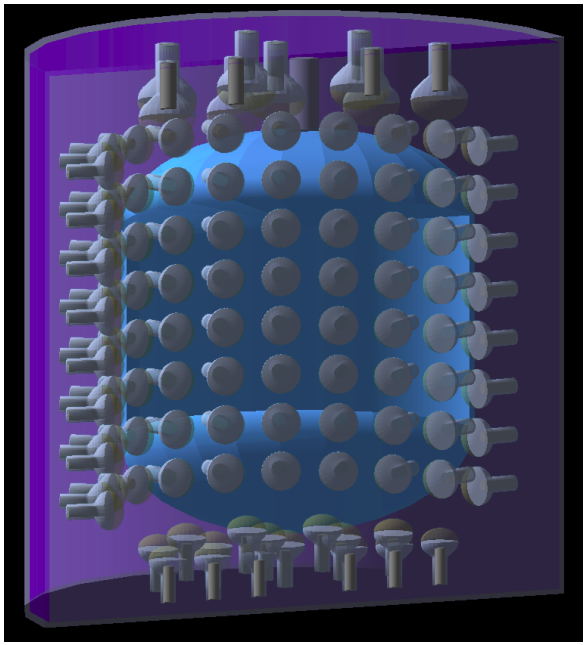
https://www.prisma.uni-mainz.de/facilities/triga-reactor-and-neutron-source/

3 Year Timeline

- 2022: Design optimization and purchasing of key equipment
- 2023: Construction, PMT and WbLS deployment
- 2024: Data-taking with deployed radioactive source







International Collaboration:

More than 20 institutions in 6 countries!

USA

Germany

Portugal

Finland

Turkey

Canada

Conclusions

- Tonne-scale demonstration of WbLS is a key step toward THEIA
- EOS will provide a flexible test-bed for developing technologies: fast photodetectors, WbLS, dichroicons, and more
- EOS construction will begin soon in 2023!

Acknowledgements

- Gabriel Orebi Gann
- Orebi Gann group
- DOE for support for R&D work
- NNSA for support for EOS