J. Caravaca, B. Land, G. D. Orebi Gann, F. Descamps, J. Wallig, M. Yeh

Latests results from CHESS with WbLS

THEIA Collaboration Meeting — April 13th, 2018

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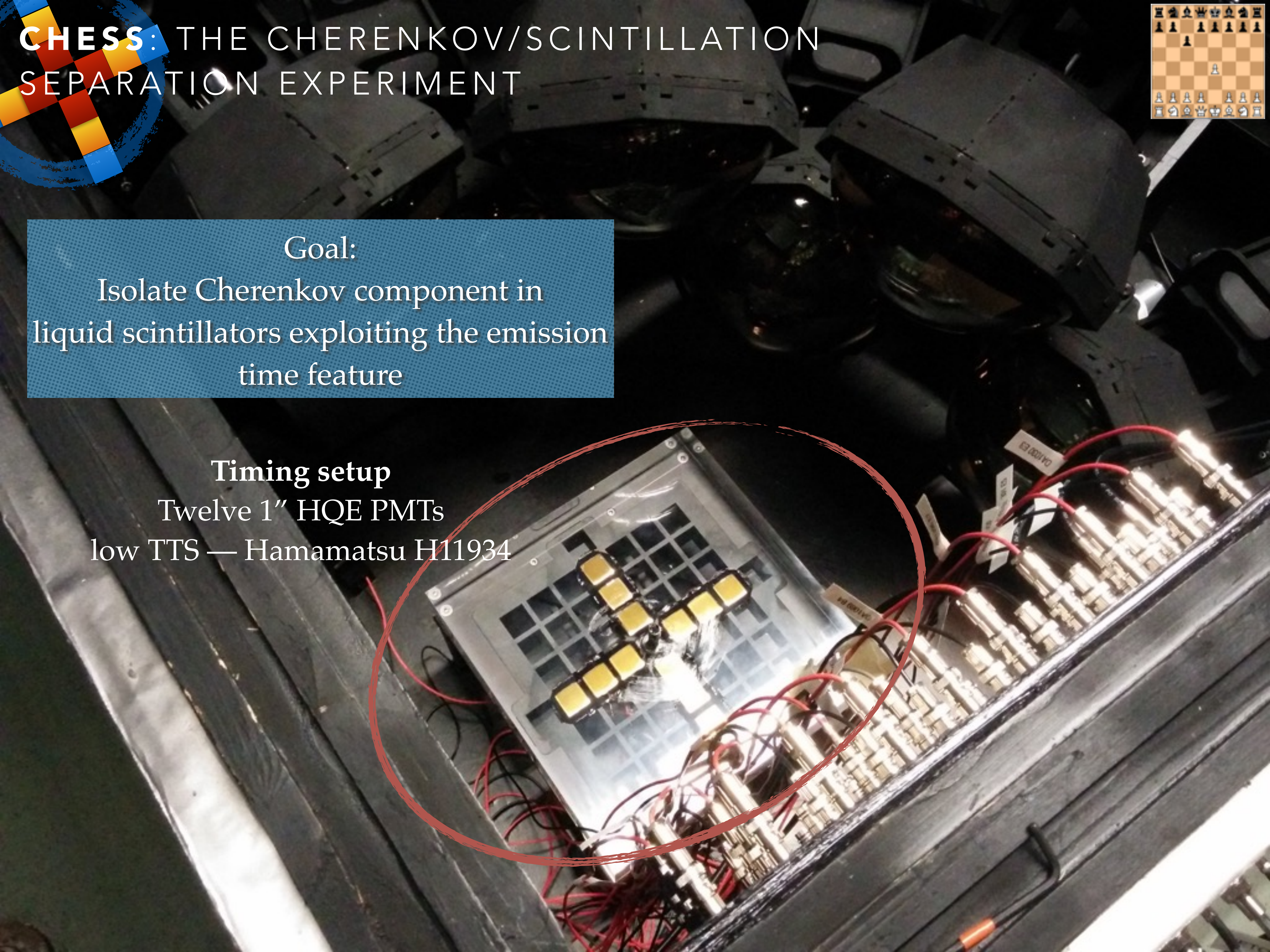
Introduction

- What is CHESS?
    - Setup description
- Previously on CHESS:
    - C/S separation in pure LAB and LAB-PPO 2g/L
- Currently on CHESS:
    - WbLS preliminary results
    - Time profile characterization
- Next steps with CHESS

CHESS: THE CHERENKOV/SCINTILLATION SEPARATION EXPERIMENT

Goal:
Isolate Cherenkov component in liquid scintillators exploiting the emission time feature



Timing setup
Twelve 1″ HQE PMTs
low TTS — Hamamatsu H11934

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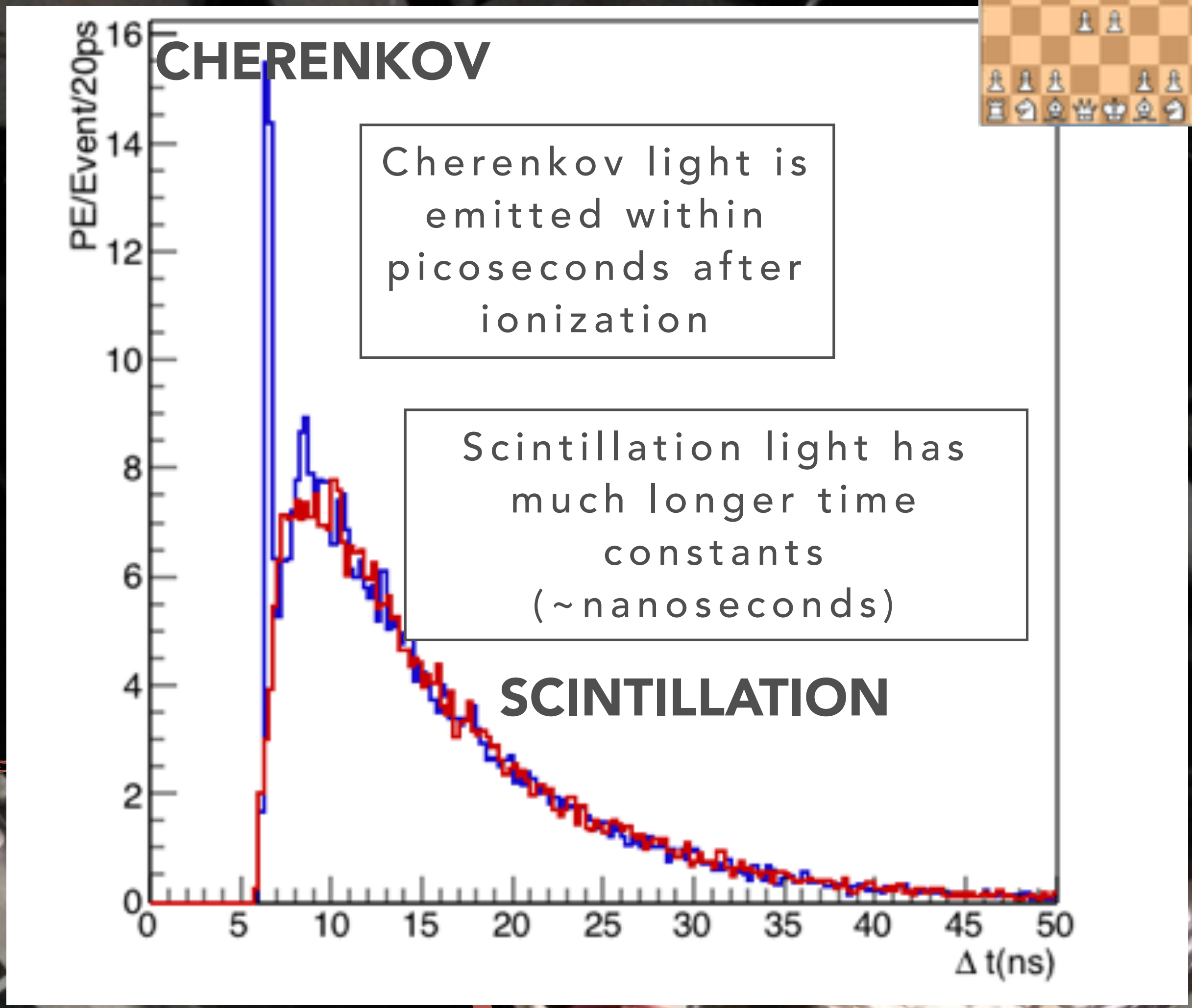
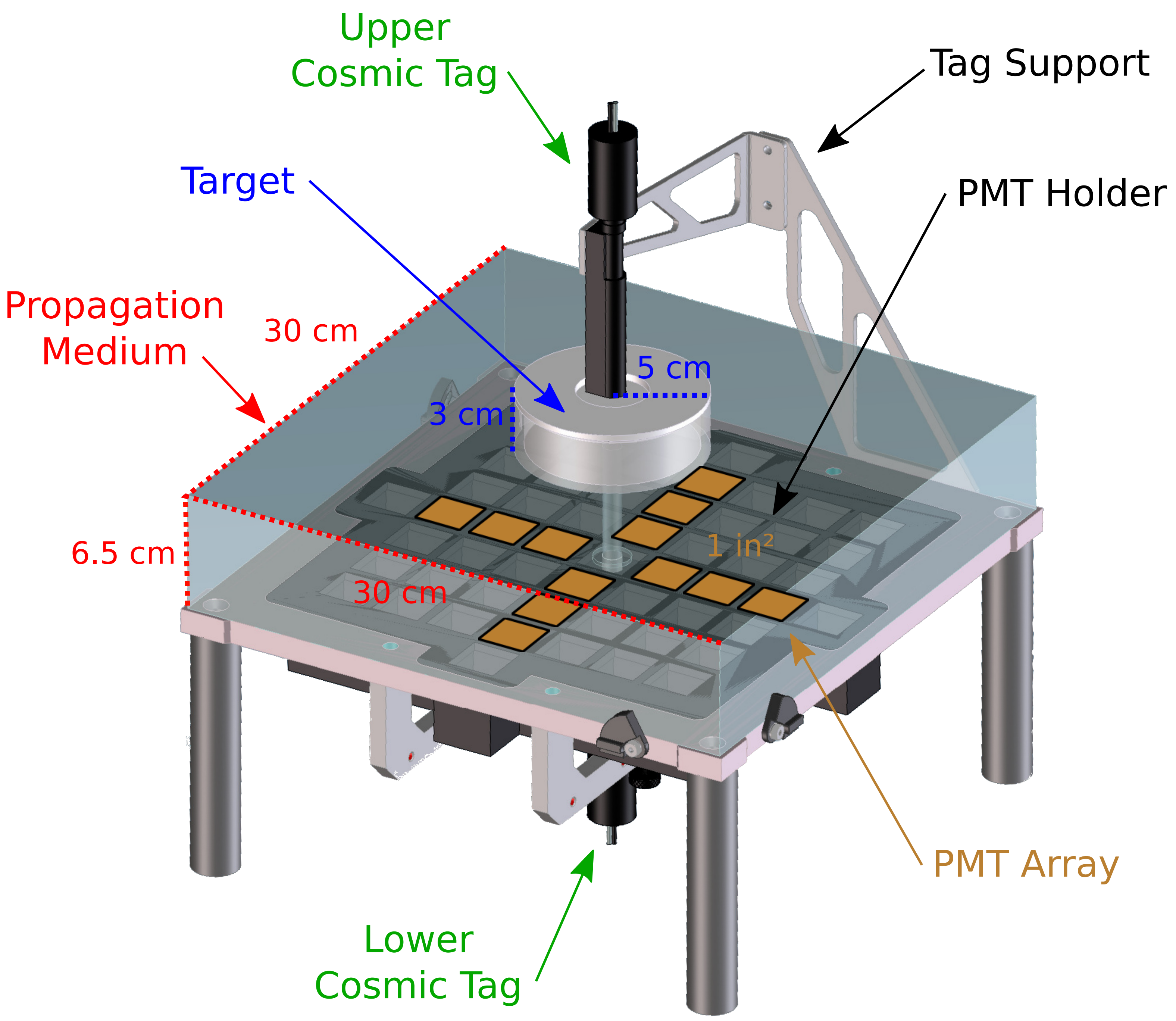


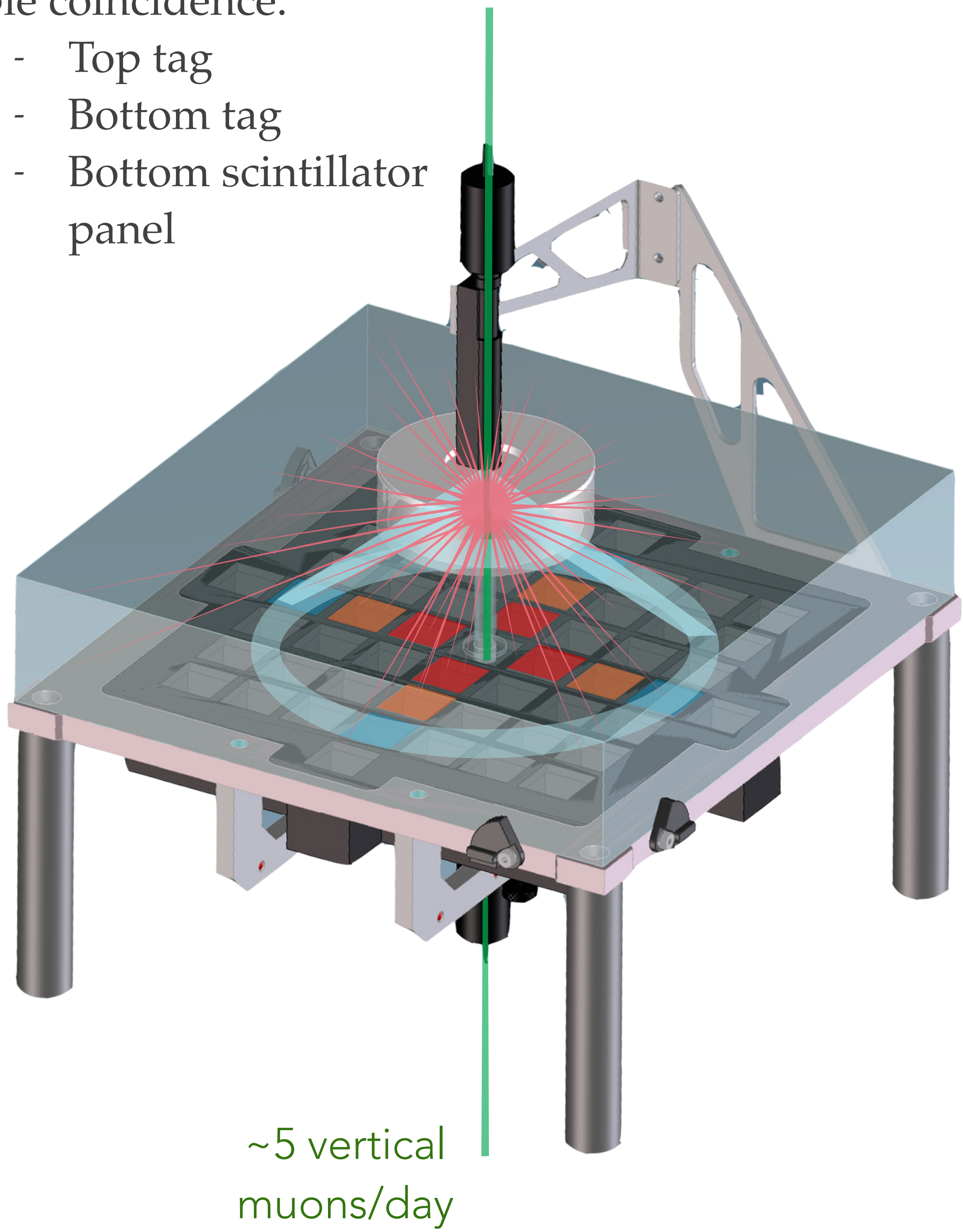
CHESS approach



CHESS approach

Select vertical muons by triple coincidence:

- Top tag
- Bottom tag
- Bottom scintillator panel



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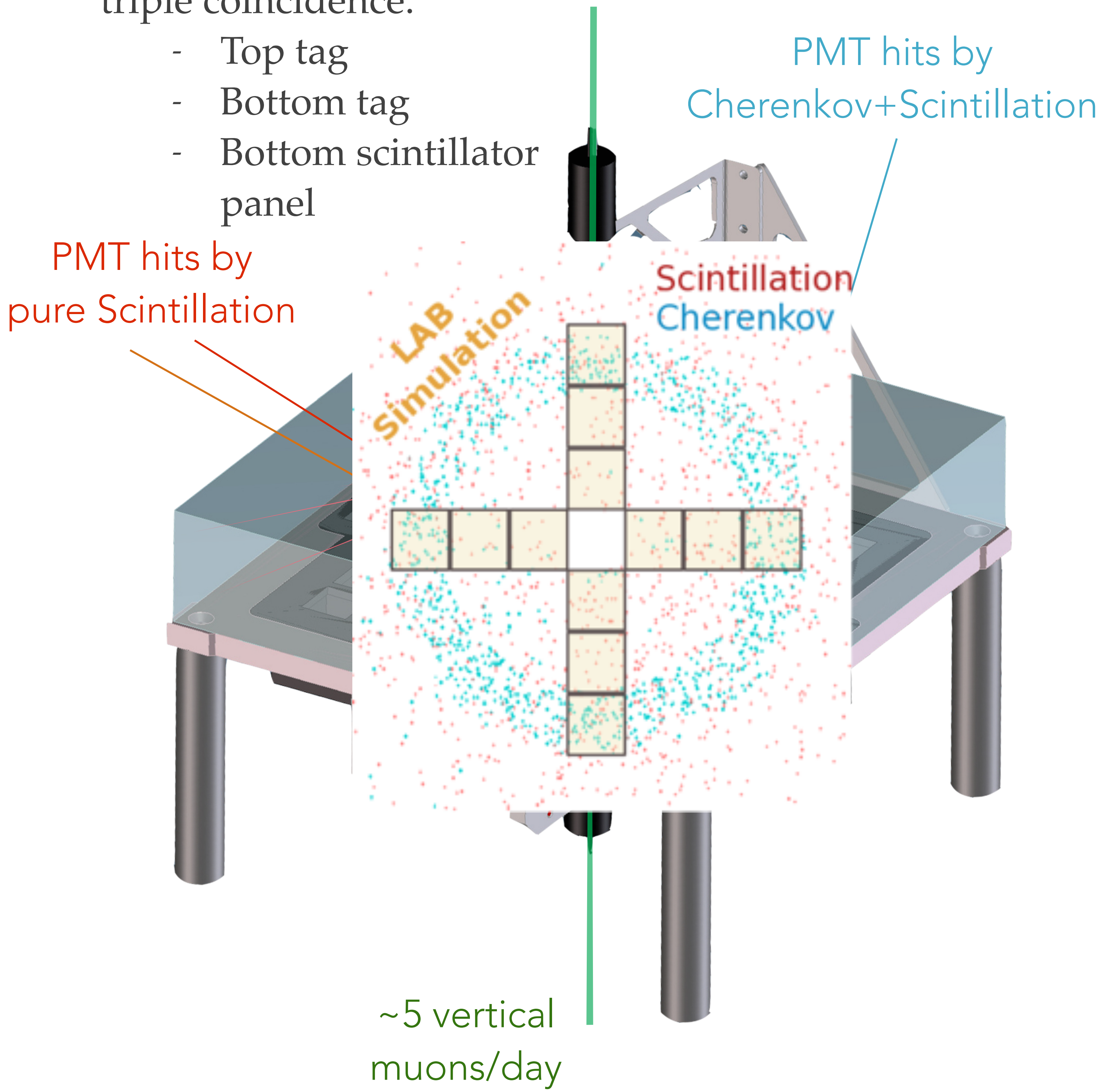

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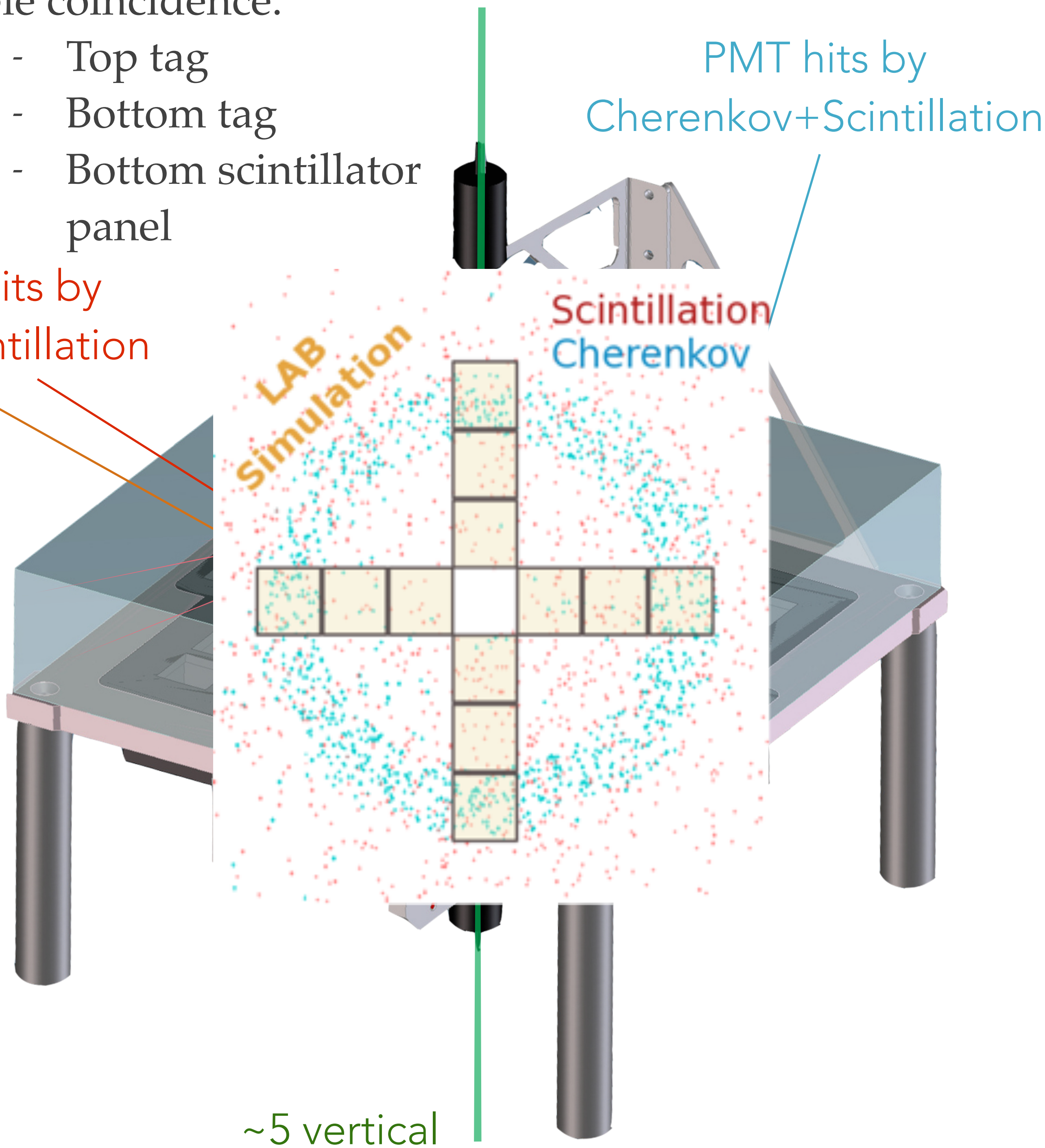
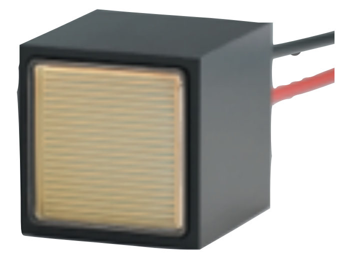
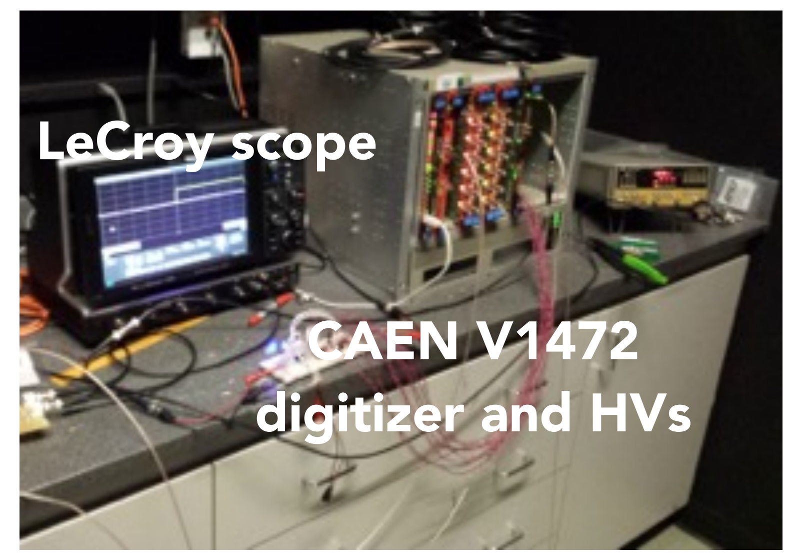




Hamamatsu H11934

- High QE: 42% at ~400nm
- **Low TTS ~ 300ps FWHM**
- **Rise time ~ 1.5ns**

- CAEN digitizer V1742:
  5GHz (0.2ns) sampling rate



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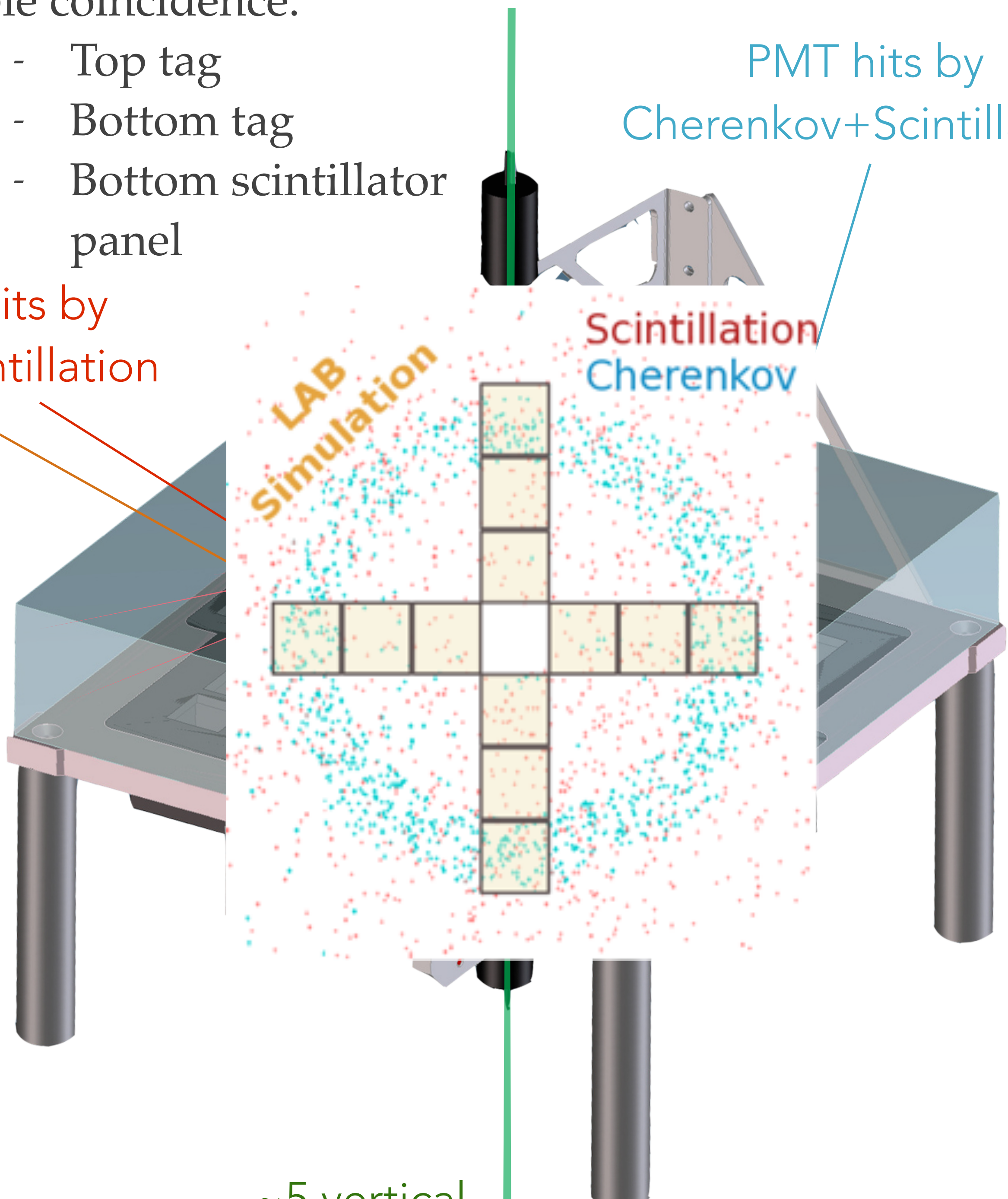

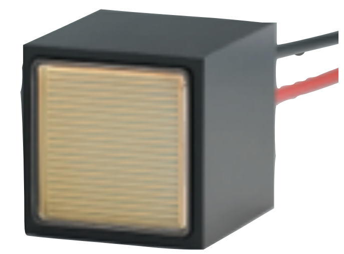

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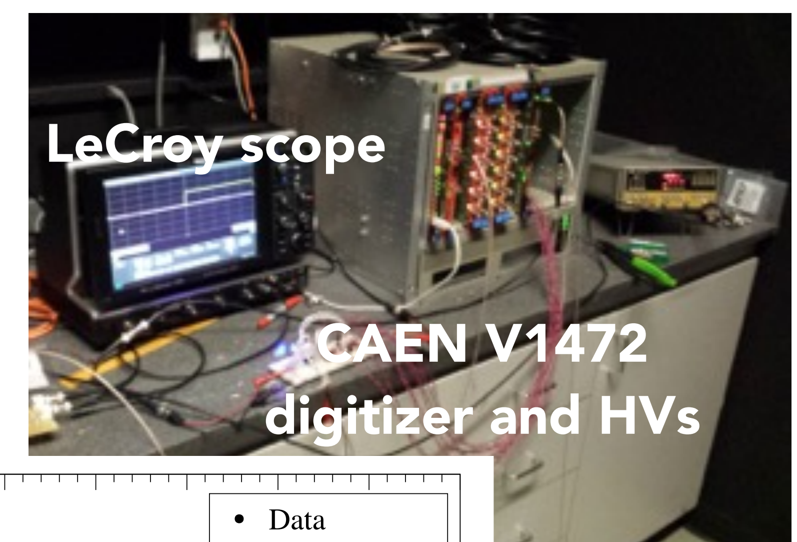
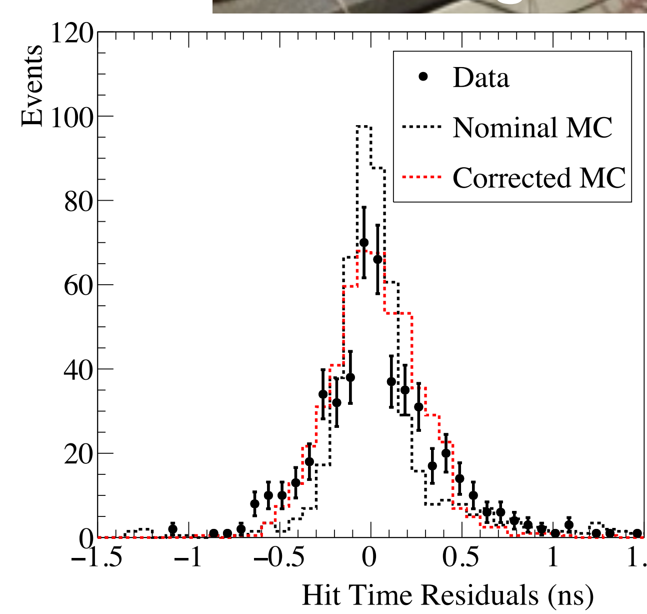


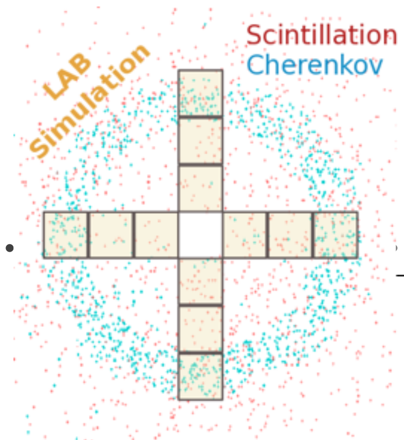


338 ± 12 ps FWHM

Previously on CHESS

- Run calibration campaign using water target, 90Sr source, LED source, and different PMT configurations → Obtained PMT gains and measured time delays
- Optimize/understand setup using complete RAT-PAC-based MC simulation
- Image Cherenkov rings in LAB and LAB-PPO from muons and characterize separation

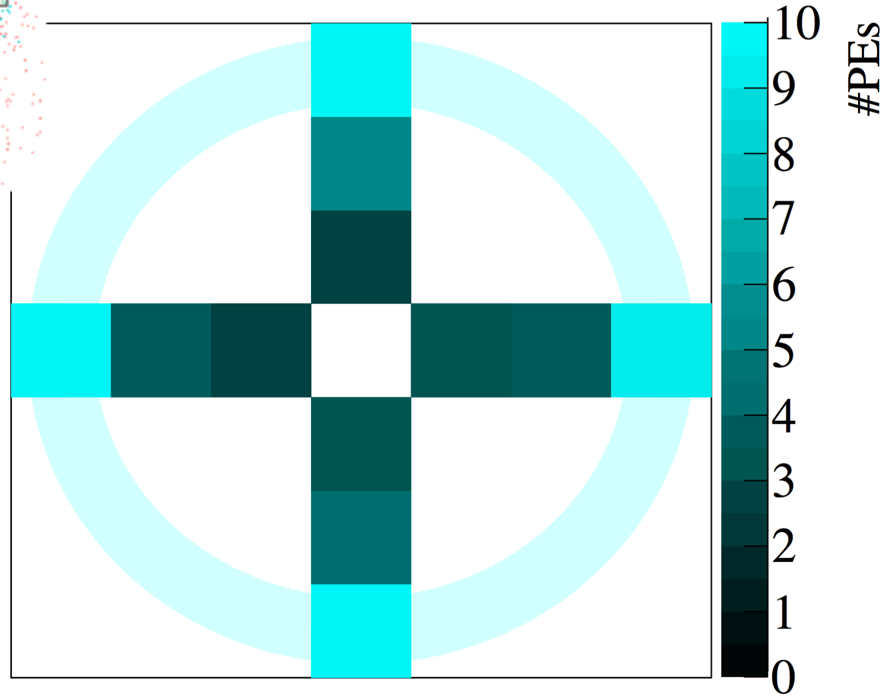
Ring imaging in organic LS

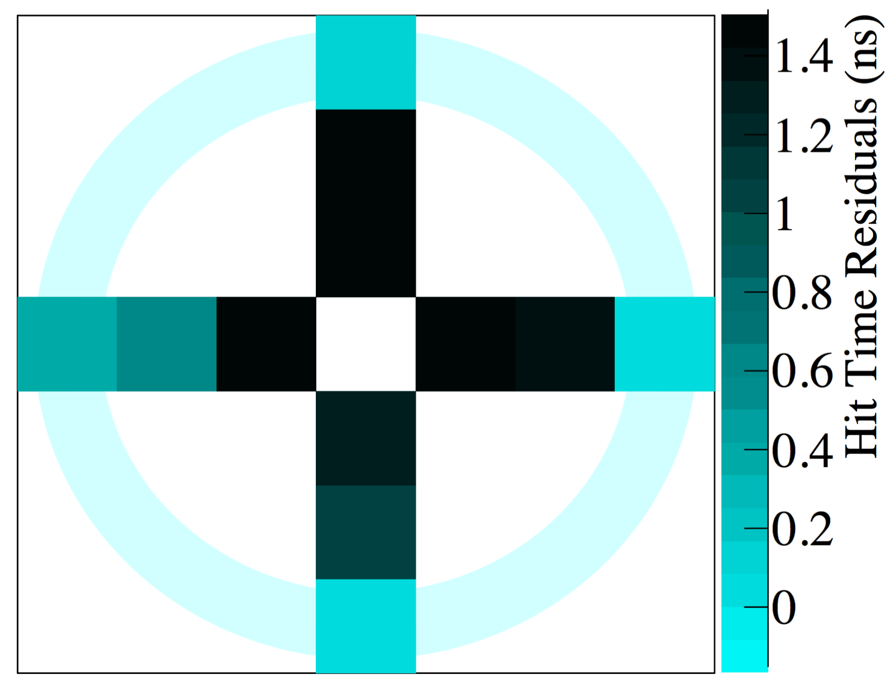


~one month-worth of data → Average NPEs and PE time

<Number of photoelectrons> | <Hit time residuals> | Events

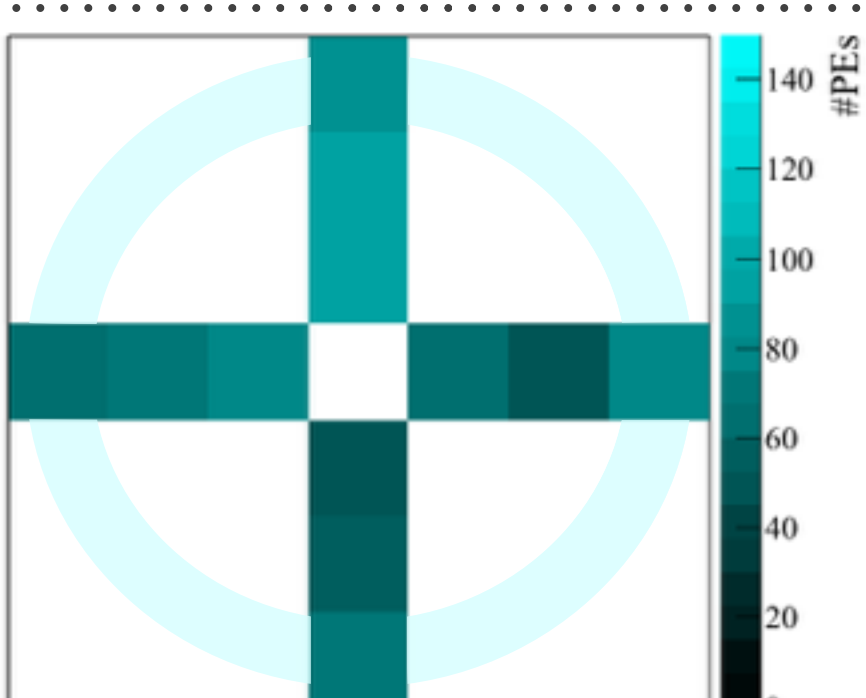
LAB

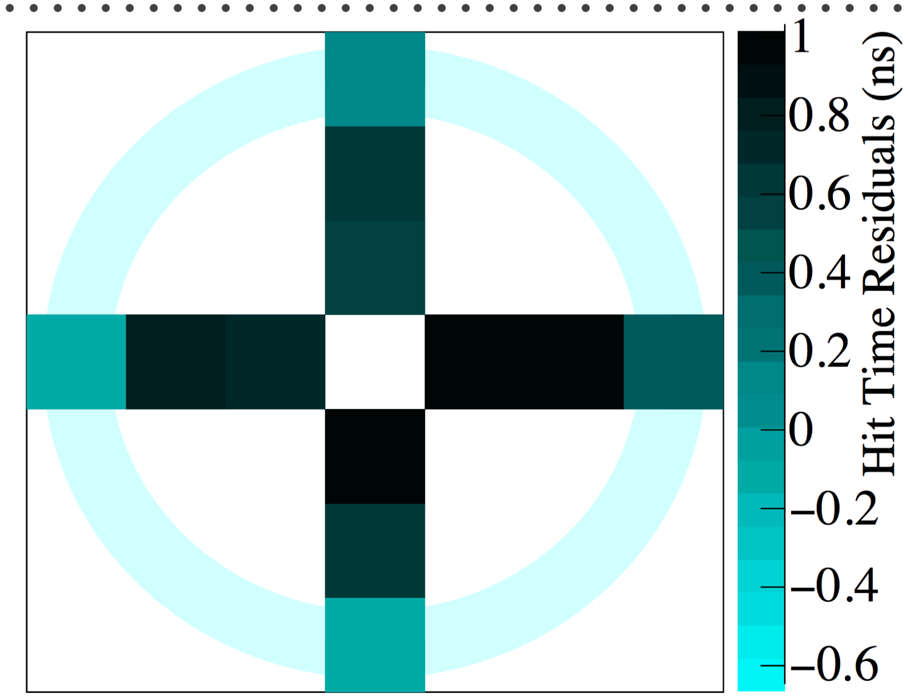




Events: 117

LABPPO 2g/L

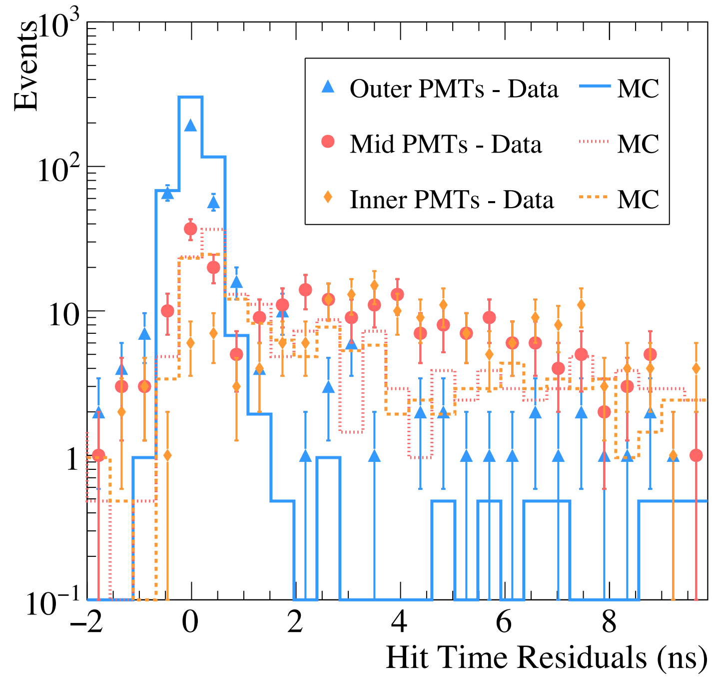
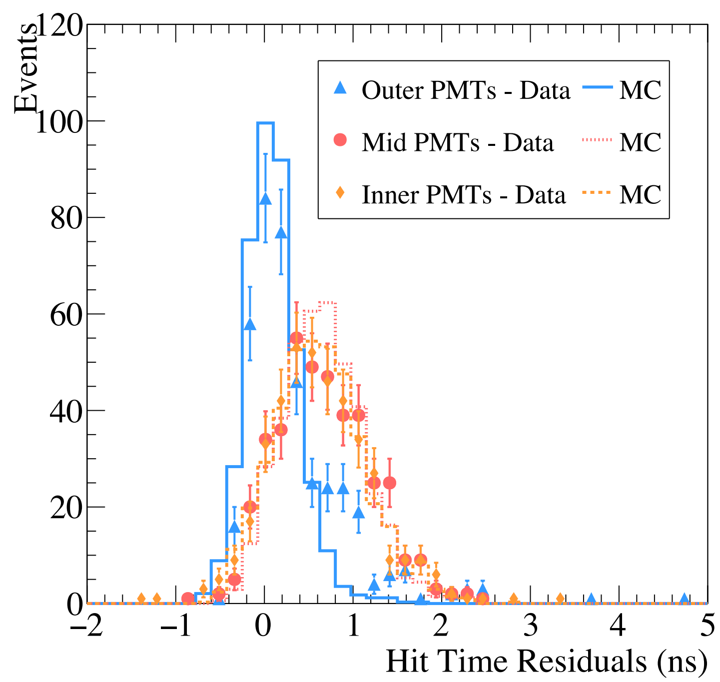




Events: 103

C/S separation results in LS

Calculated optimal separation at 0.4ns

<table>
<tr><th></th><th>Hit time residuals</th><th>C. efficiency</th><th>Scint. contamination</th></tr>
<tr><td>LAB</td><td>
</td><td>83±3 (stat+syst)%</td><td>11±1 (stat+syst)%</td></tr>
<tr><td>LABPPO 2g/L</td><td>
</td><td>70±3 (stat+syst)%</td><td>36±5 (stat+syst)%</td></tr>
</table>

CHESS with WbLS

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- Various recent measurements of light yield and time profile → LAB and LAB-PPO are well understood, so we used the existing models to build our MC
- This is different with WbLS → Important to characterize time profile and light yield at microphysical scale
- Decided to simplify our setup to perform these measurements

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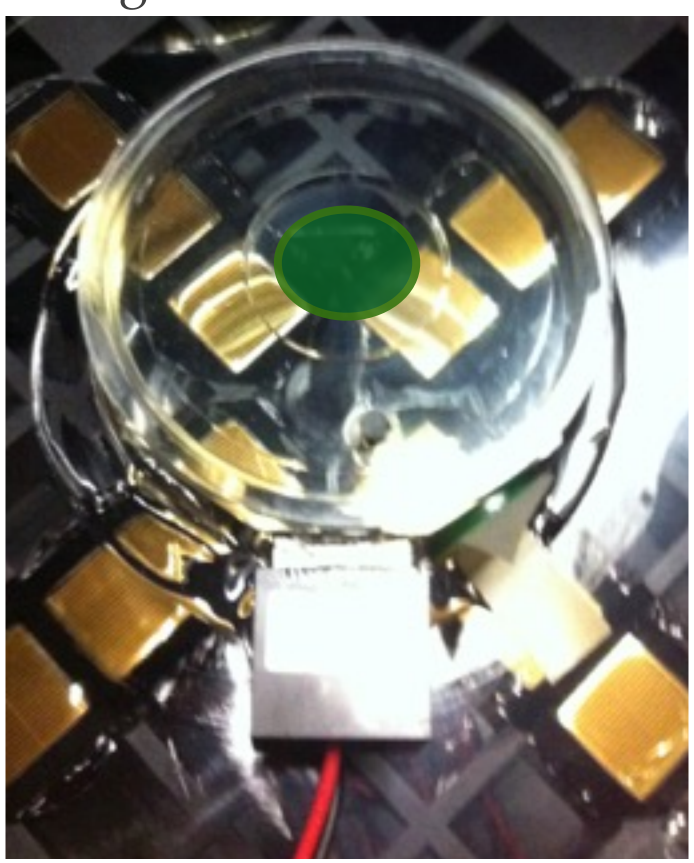
Deploy ^{90}Sr source on top of the target vessel → ~2MeV end point



Deploy **water-based LAB-PPO 2g/L** at 3 different concentrations: **1%, 5% and 10%**

Trigger off tag coupled to target → Same low TTS PMT than array

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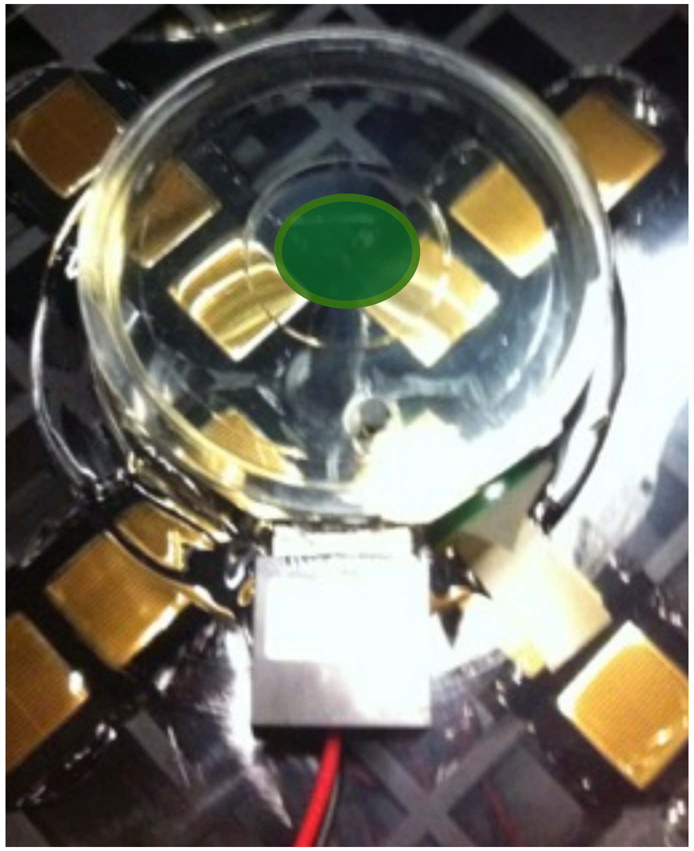

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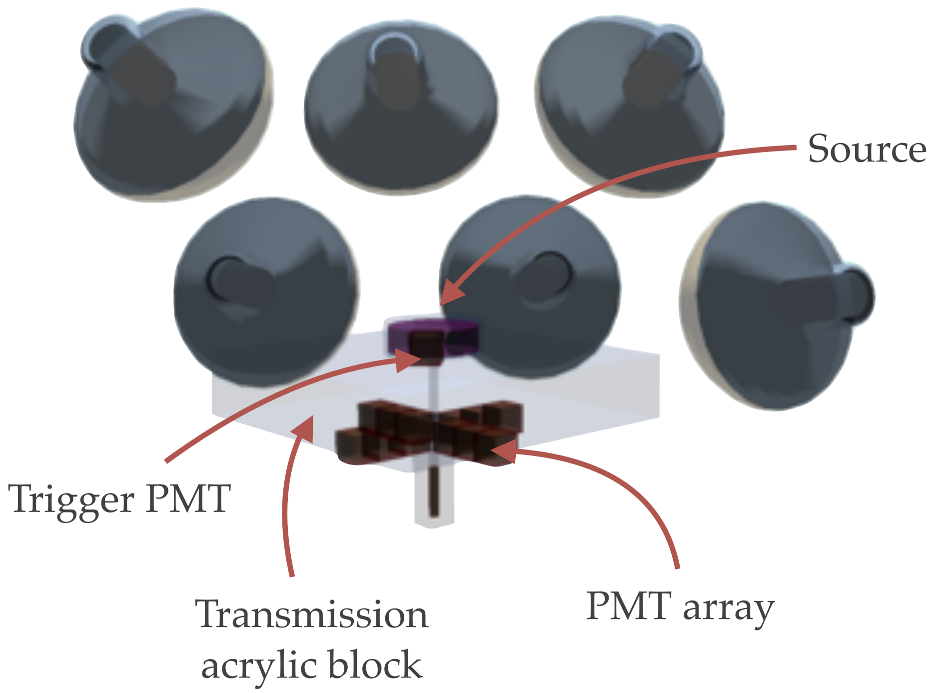
Strategy → Extract **microphysical** parameters of WbLS by fitting using complete MC model

RAT-PAC MC model

- Detailed geometry
- Beta decay generator
- Modified GLG4Scint
- Optical properties
- PMT 3D model
- DAQ simulation



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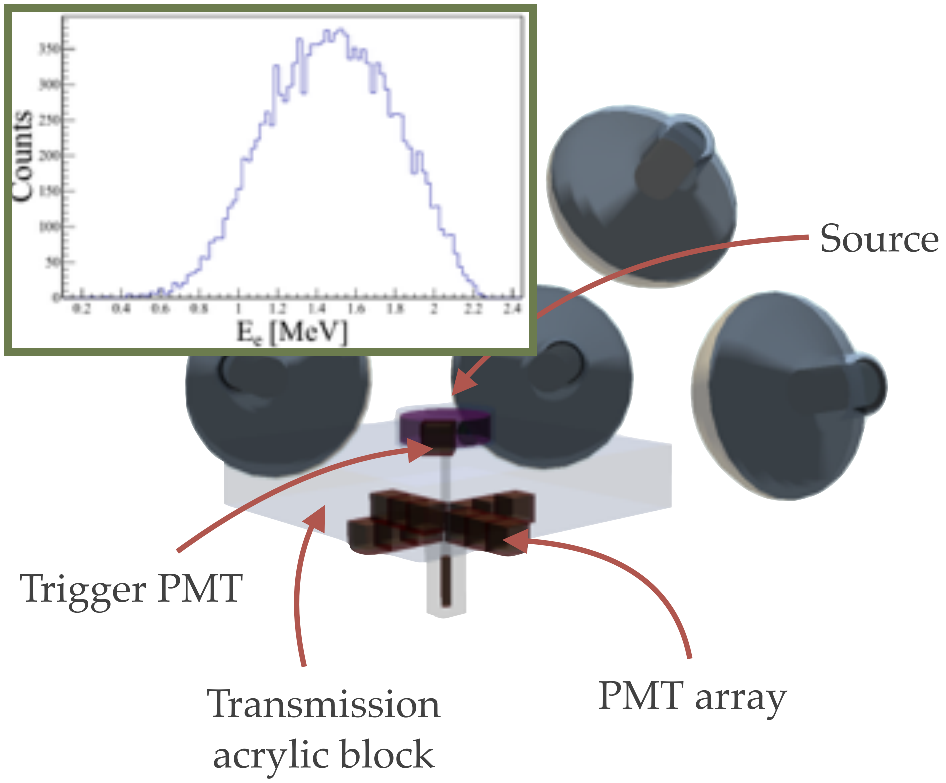

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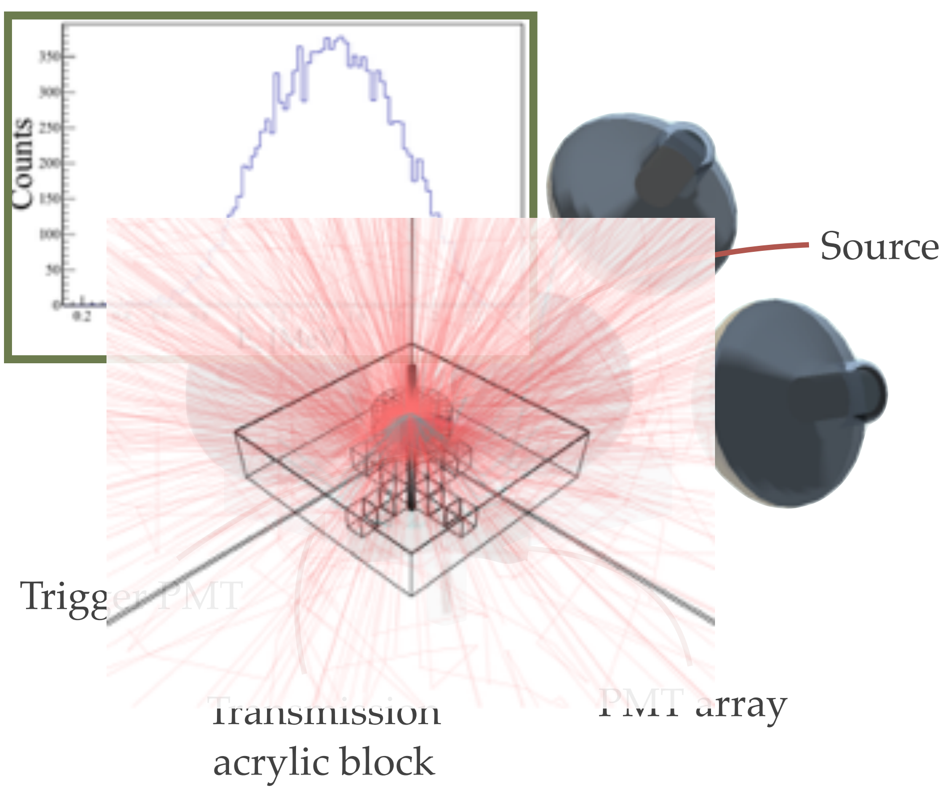

Using modified version of GLG4Scint as scintillation model (SNO+RAT):

- Birks constant = 0.0798 mm/MeV [1]
- LAB-PPO emission spectrum [2]
- Absorption [2]
- Reemission → Using LABPPO values
  - Probability
  - Emission spectrum
  - Time profile = emission time profile
- Multi-component

[1] B. von Krosigk, et al., Eur. Phys. J. C 73, 2390 (2013).
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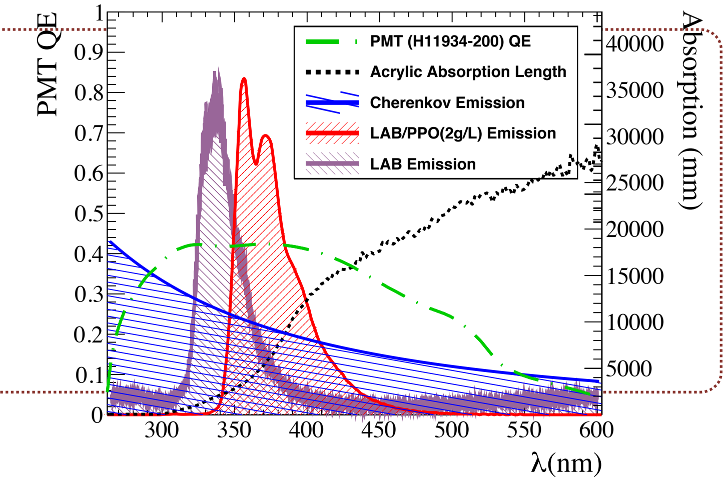
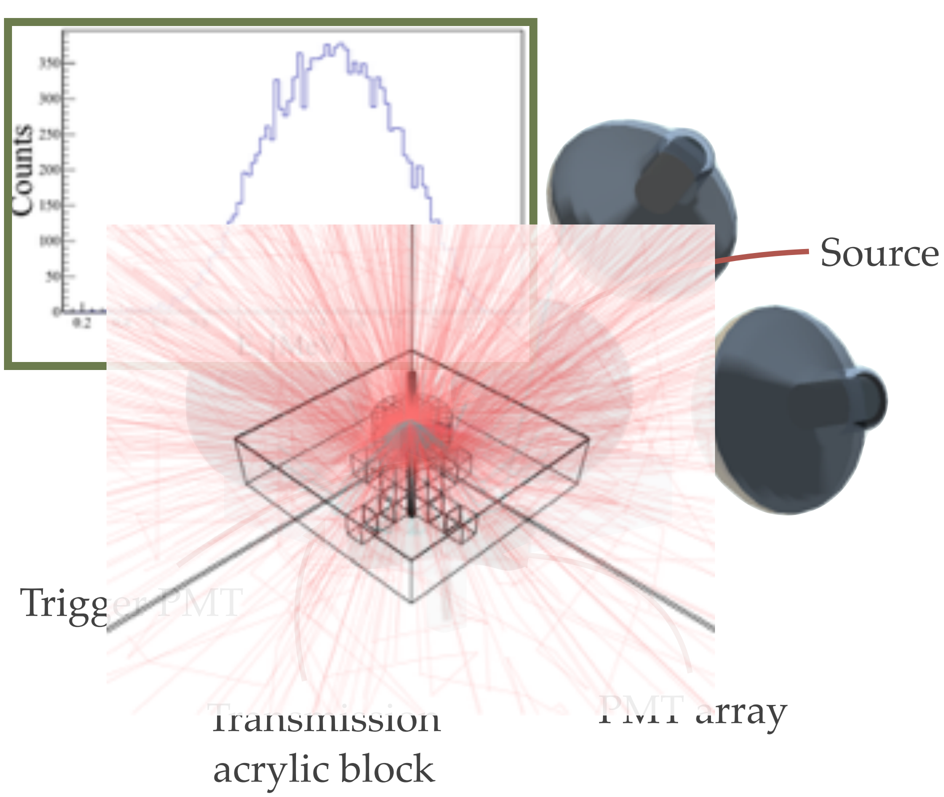
Optics from specifications and custom measurements:
- Refractive indices
- Absorptions
- PMT QEs





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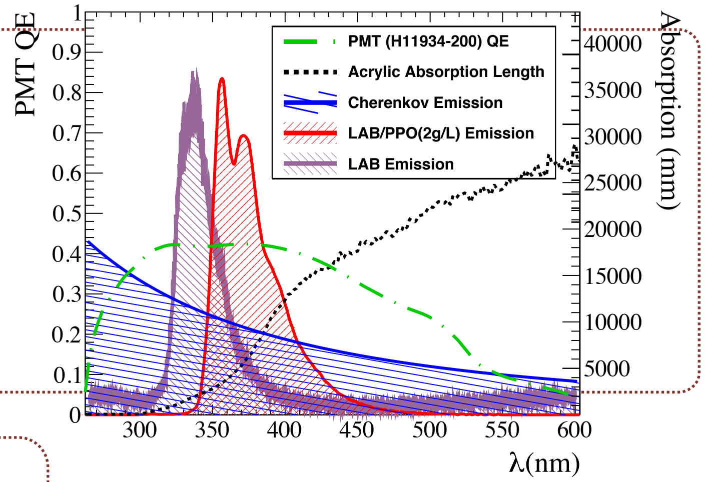

3D PMT optical model in RAT-PAC:
- Inner PMT tracking
- Complete geometry:
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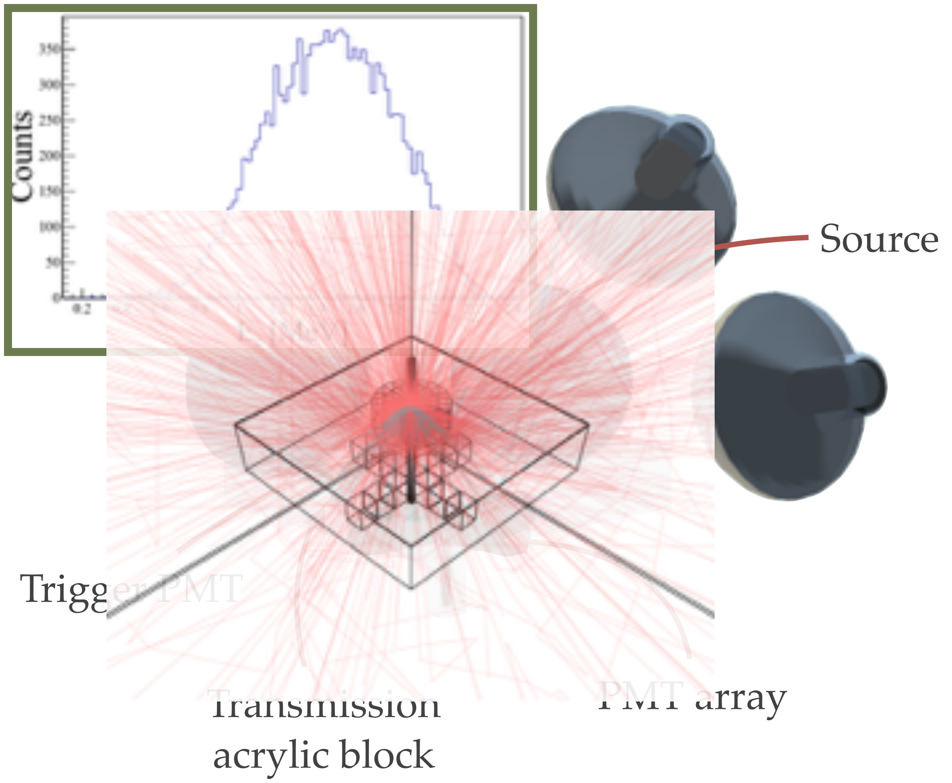
  - Mirror (only R7081)
  - Case (only H11934)



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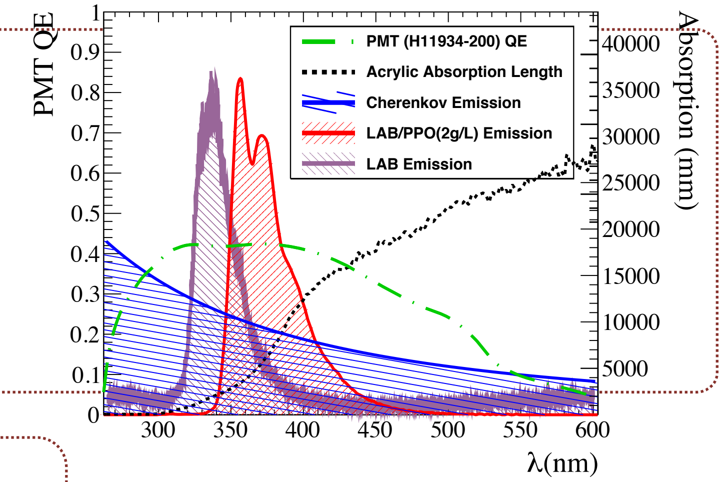

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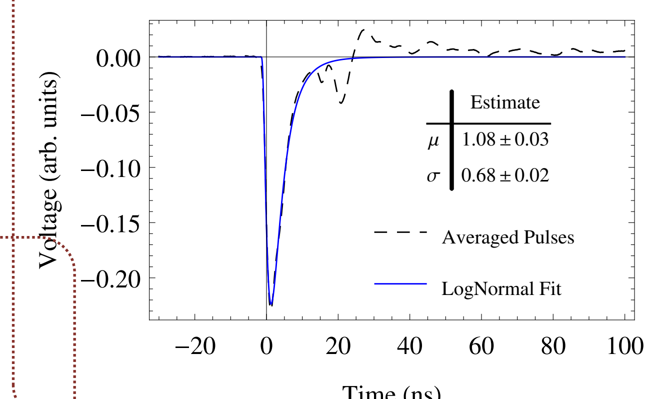
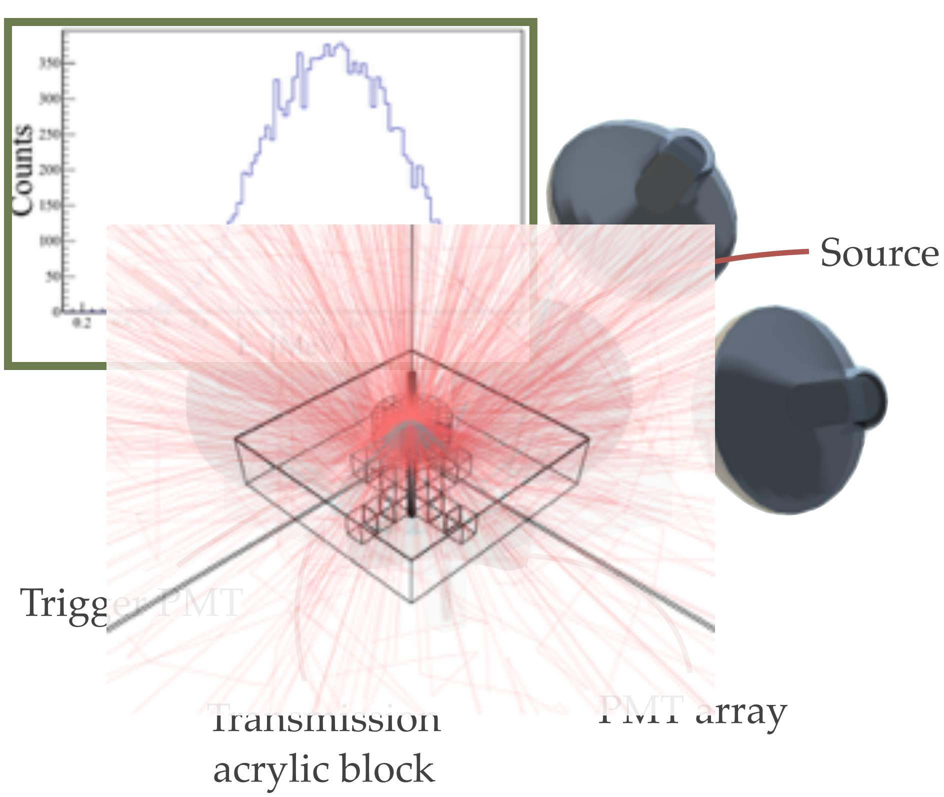
DAQ:
- Waveform
- Gain
- TTS





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LAB-PPO 2g/L with ^{90}Sr source

Time profile model: 3 exp. decay + rise time

$$\rho(t) \propto (1 - e^{-t/\tau_r}) \times \sum_i^3 A_i e^{-t/\tau_i}$$

$\tau_r = 0.7$ ns
$\tau_1 = 4.3$ ns
$\tau_2 = 16$ ns
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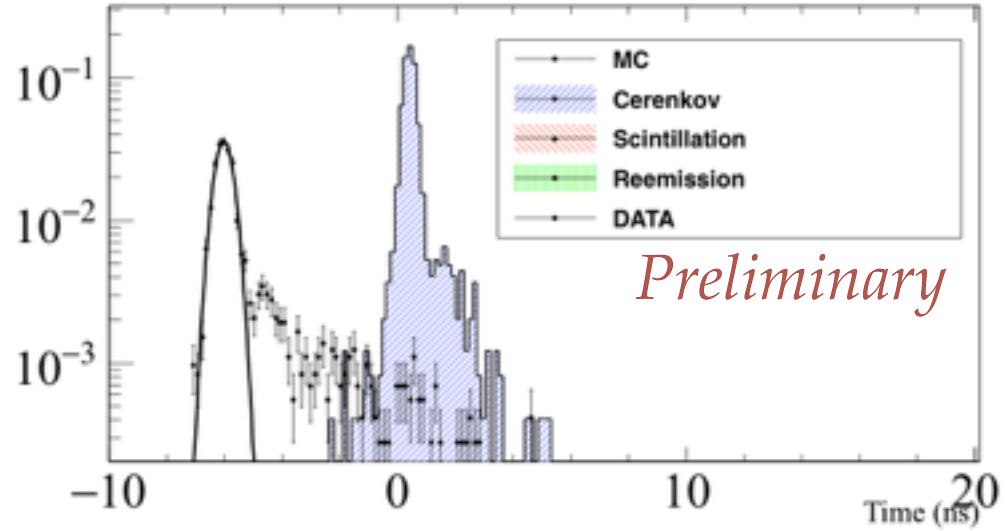
H. M. O'Keeffe et al. Nucl. Instum. Methods A640, 119 (2011)

- Run benchmark with LAB-PPO
- Calculated time residuals wrt trigger time
- Re-measured time resolution with new setup (trigger and lower light yield regime) using source water data

μ_{DT} = -6.52ns, **σ_{DT} = 320 ps**
μ_{MC} = -0.1, σ_{MC} = 209 ps



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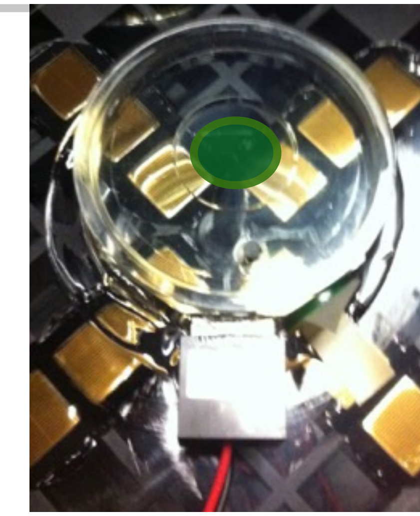

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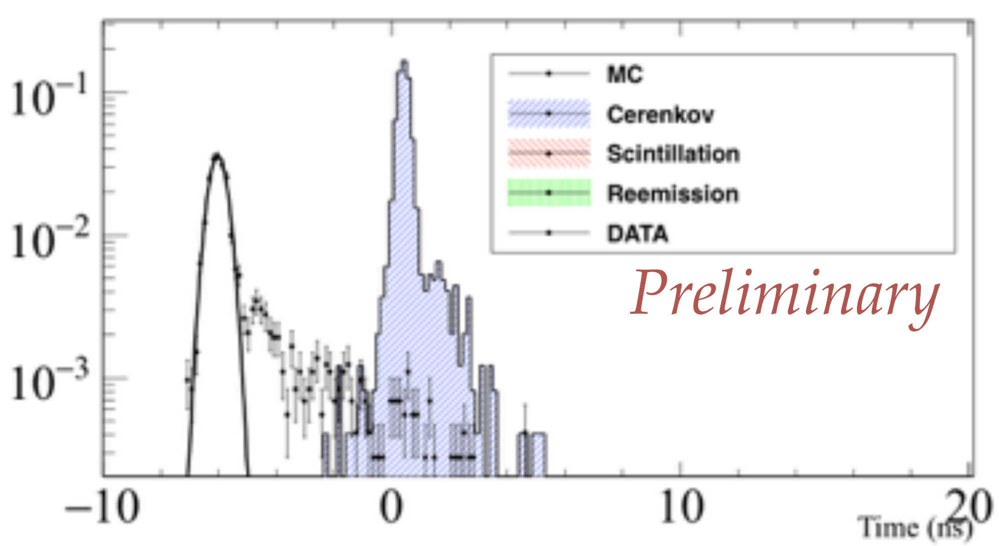
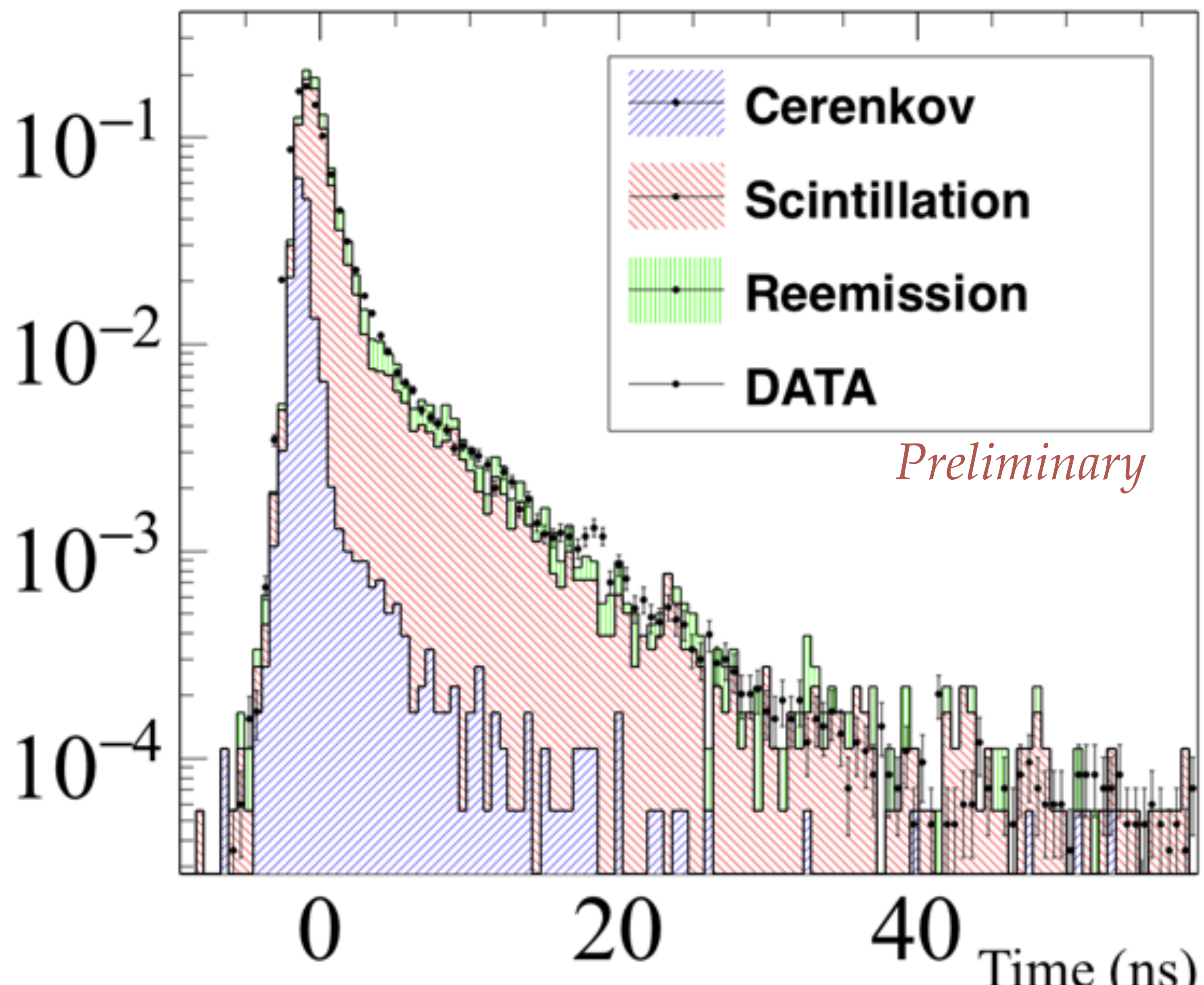
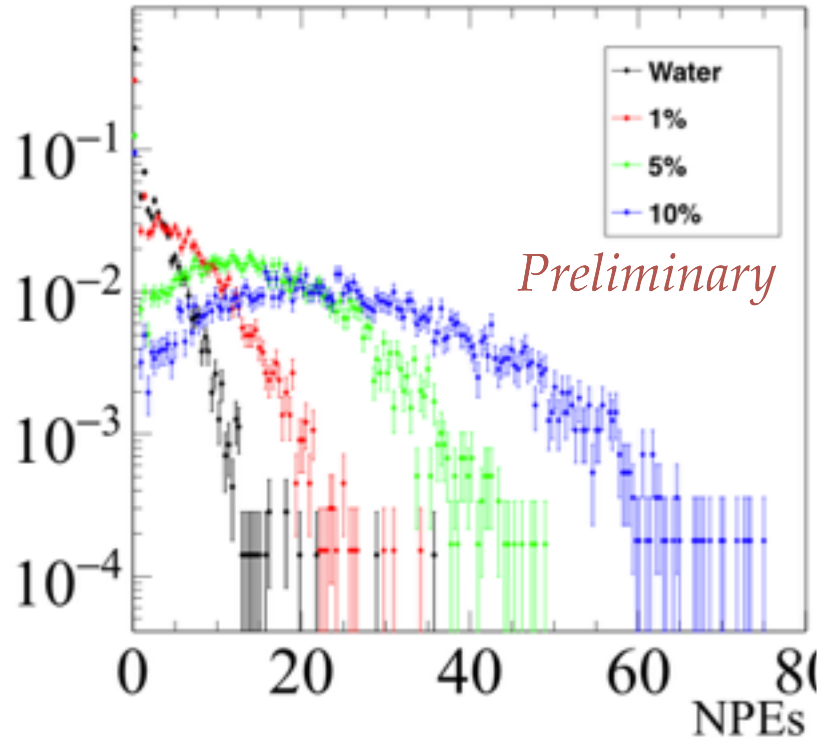
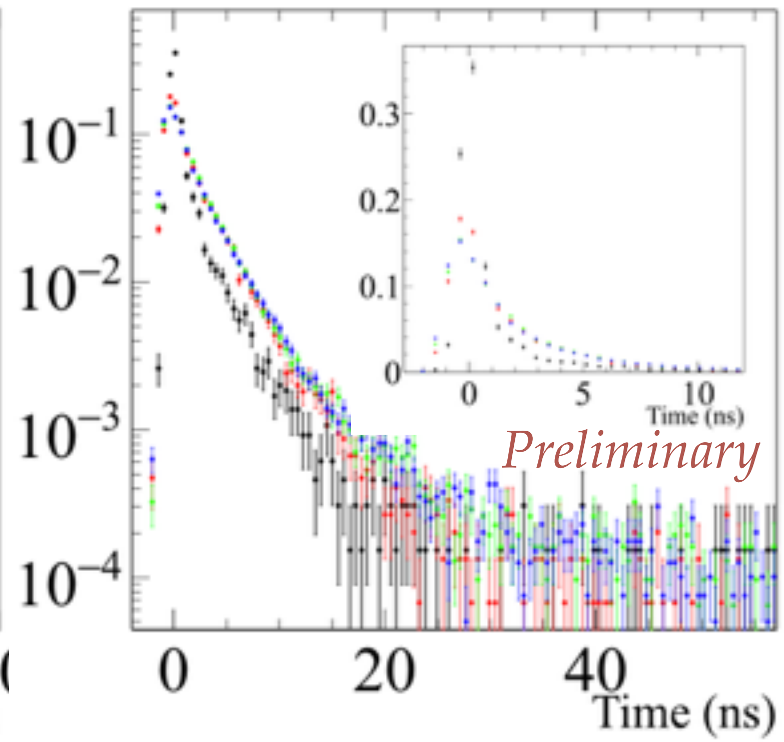




WbLS data with ^{90}Sr source

- Deploy WbLS with different concentrations of LAB-PPO 2g/L and compare with water
- Light yield increases with %, but similar time profile





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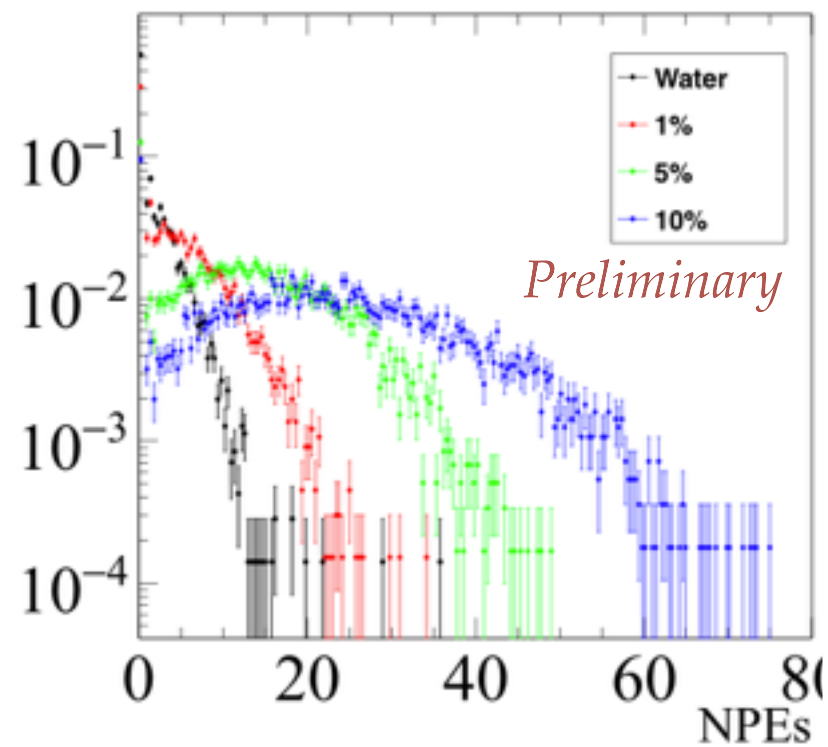
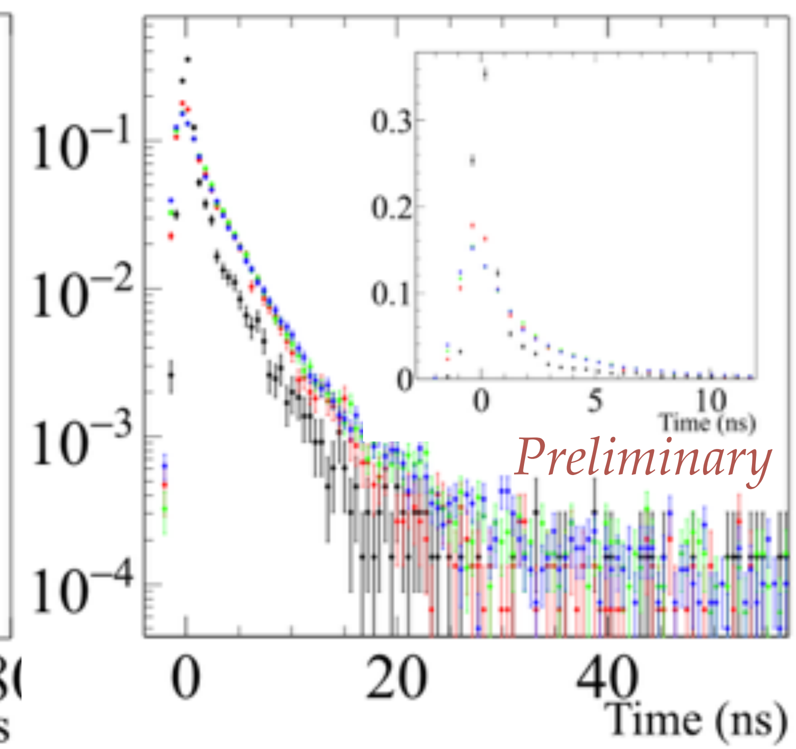
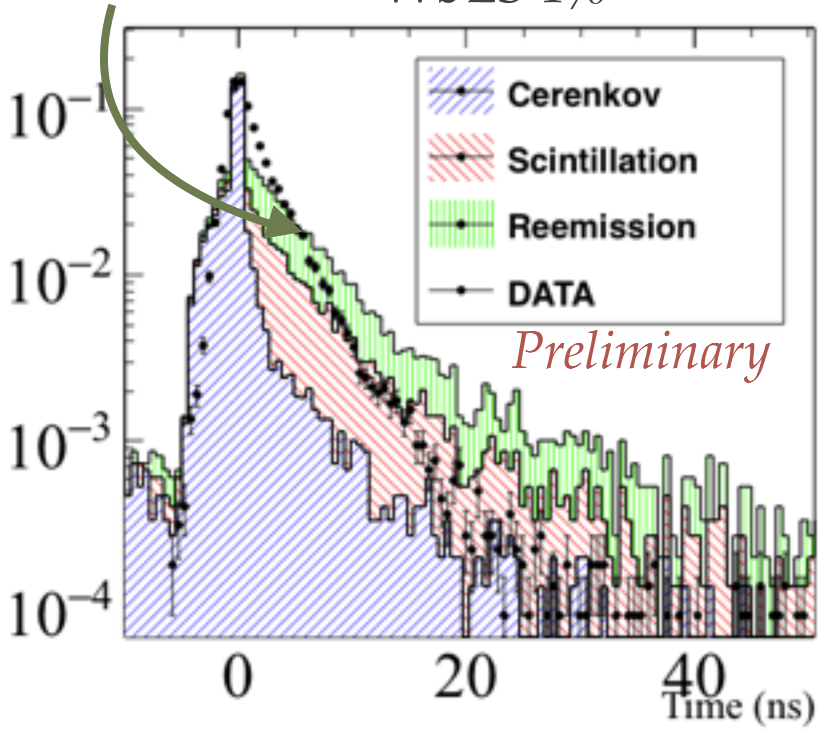
- WbLS profile does not agree with LABPPO → Much faster



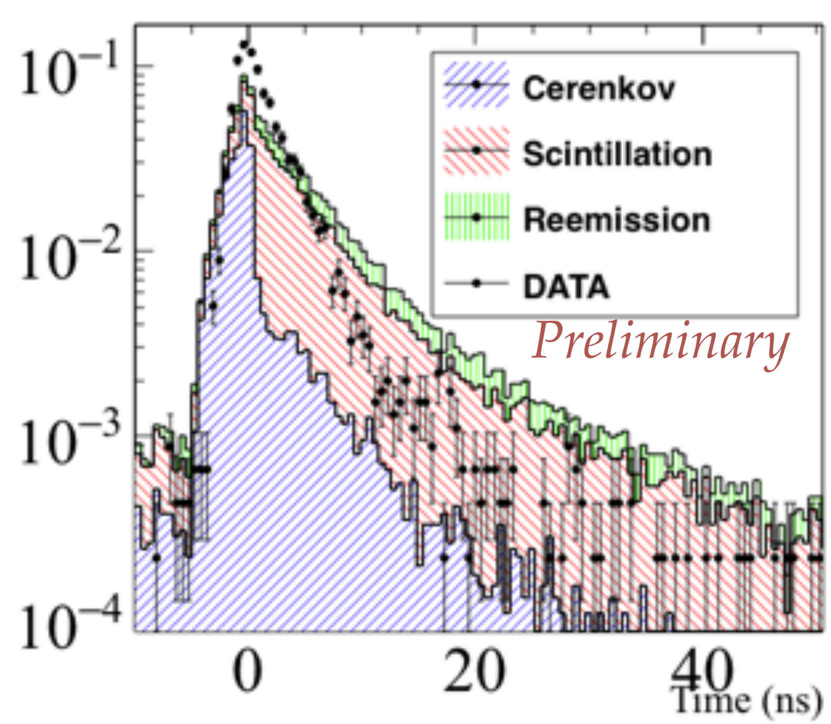


Most of reemission component is Cherenkov reemission → Does not scale with loading

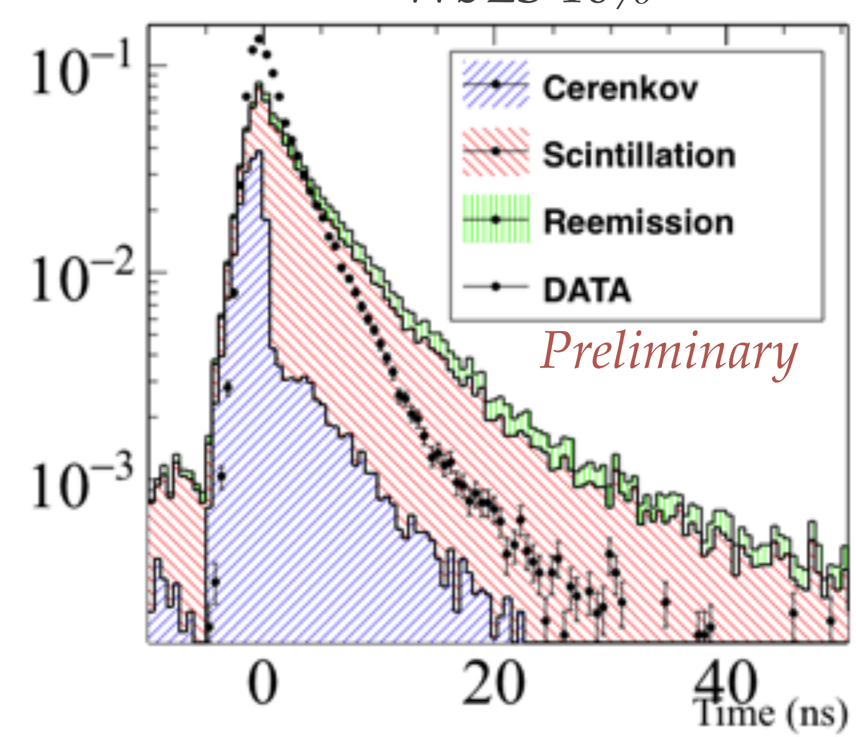
WbLS 1%



WbLS 5%



WbLS 10%



Time profile measurement strategy

Fitted time profile model → 2 exps. + rise time:

$$f(t) = (1 - e^{-t/\tau_r})(A_1 e^{t/\tau_1} + A_2 e^{t/\tau_2})$$

- Fit time profile model using MC → Includes trigger and multiPE effects
- Measure WbLS 10% time profile → Minimize reemission

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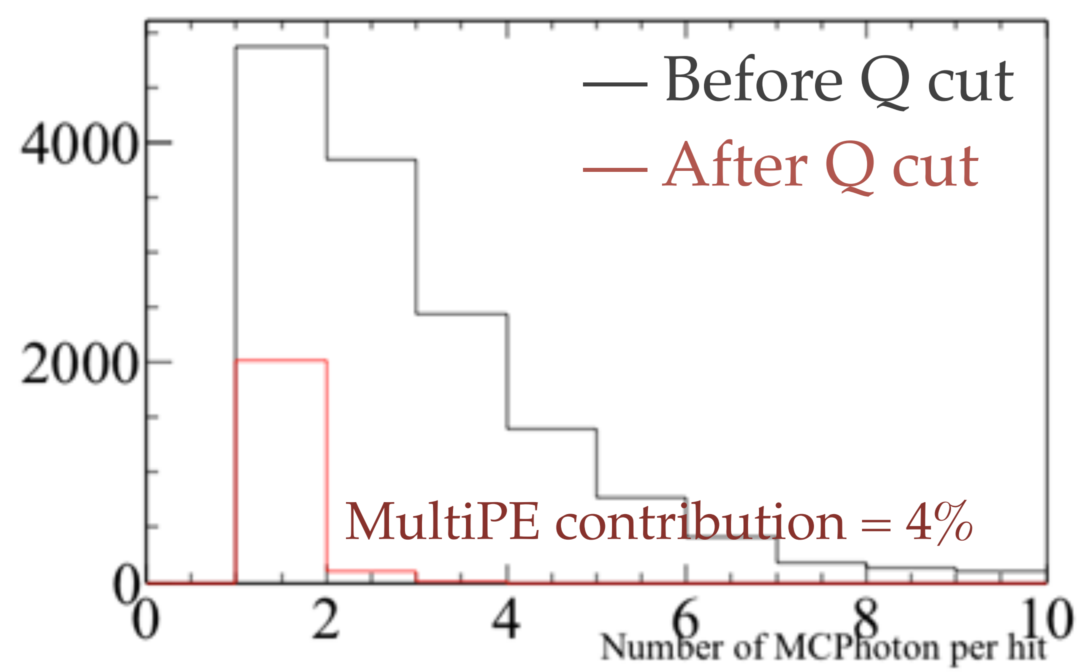
MC PE multiplicity



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- 'Shape-only' analysis → Normalize by area and scan 4 time profile parameters: τ's and A_1

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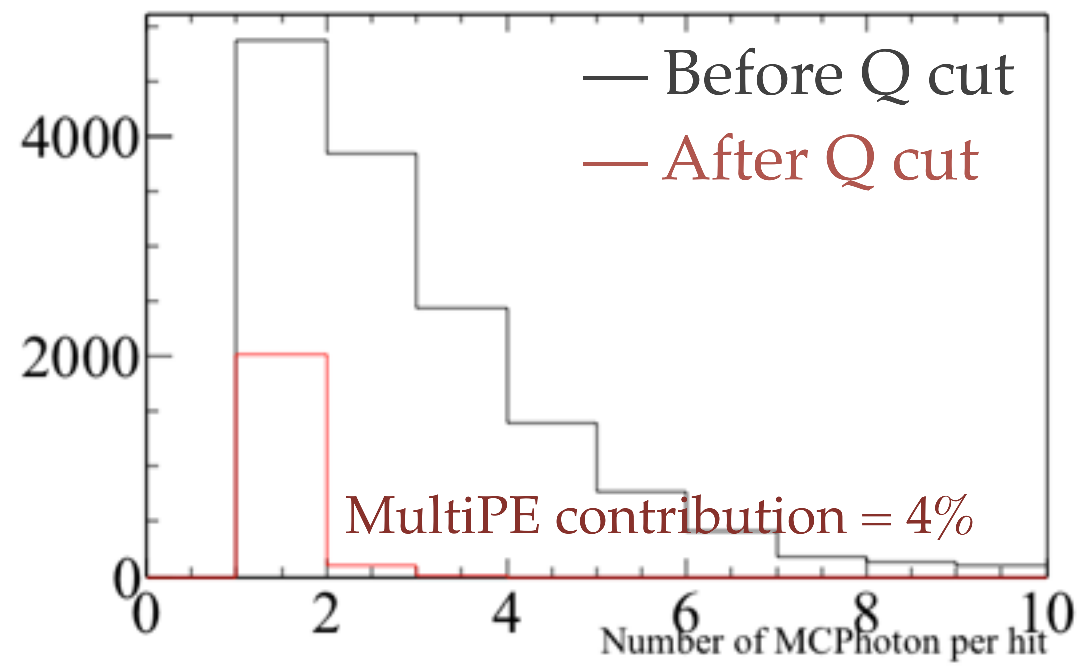
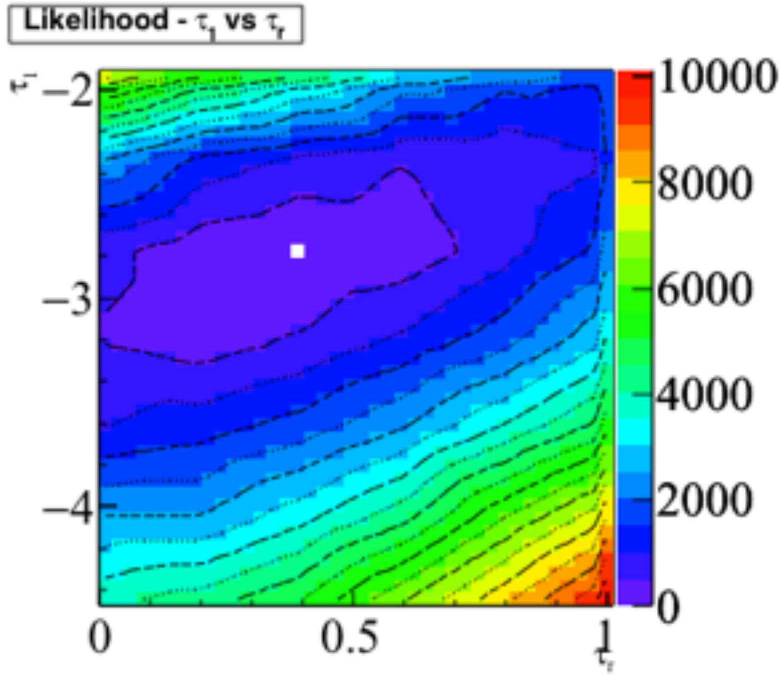
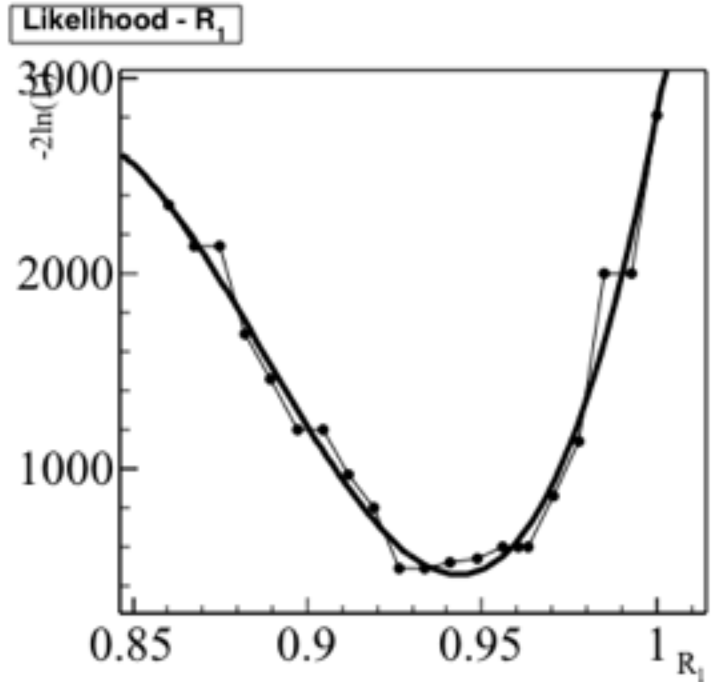
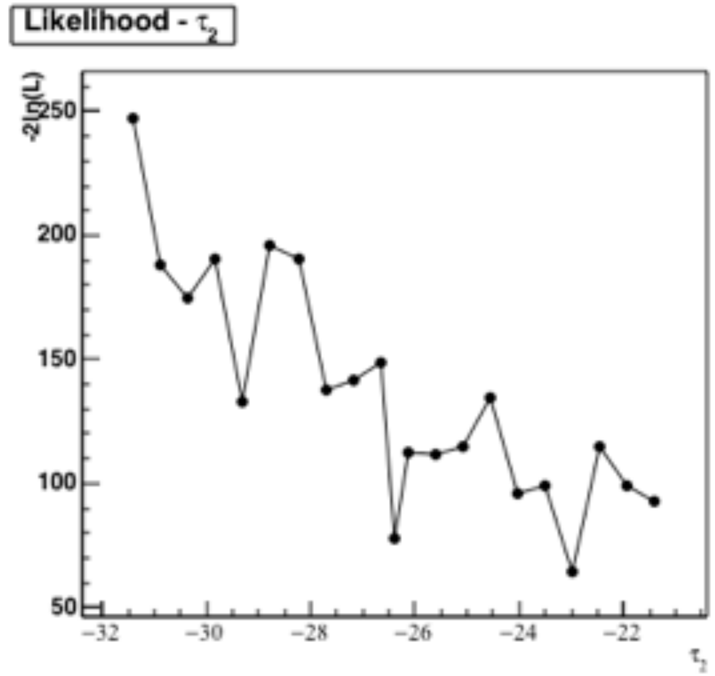
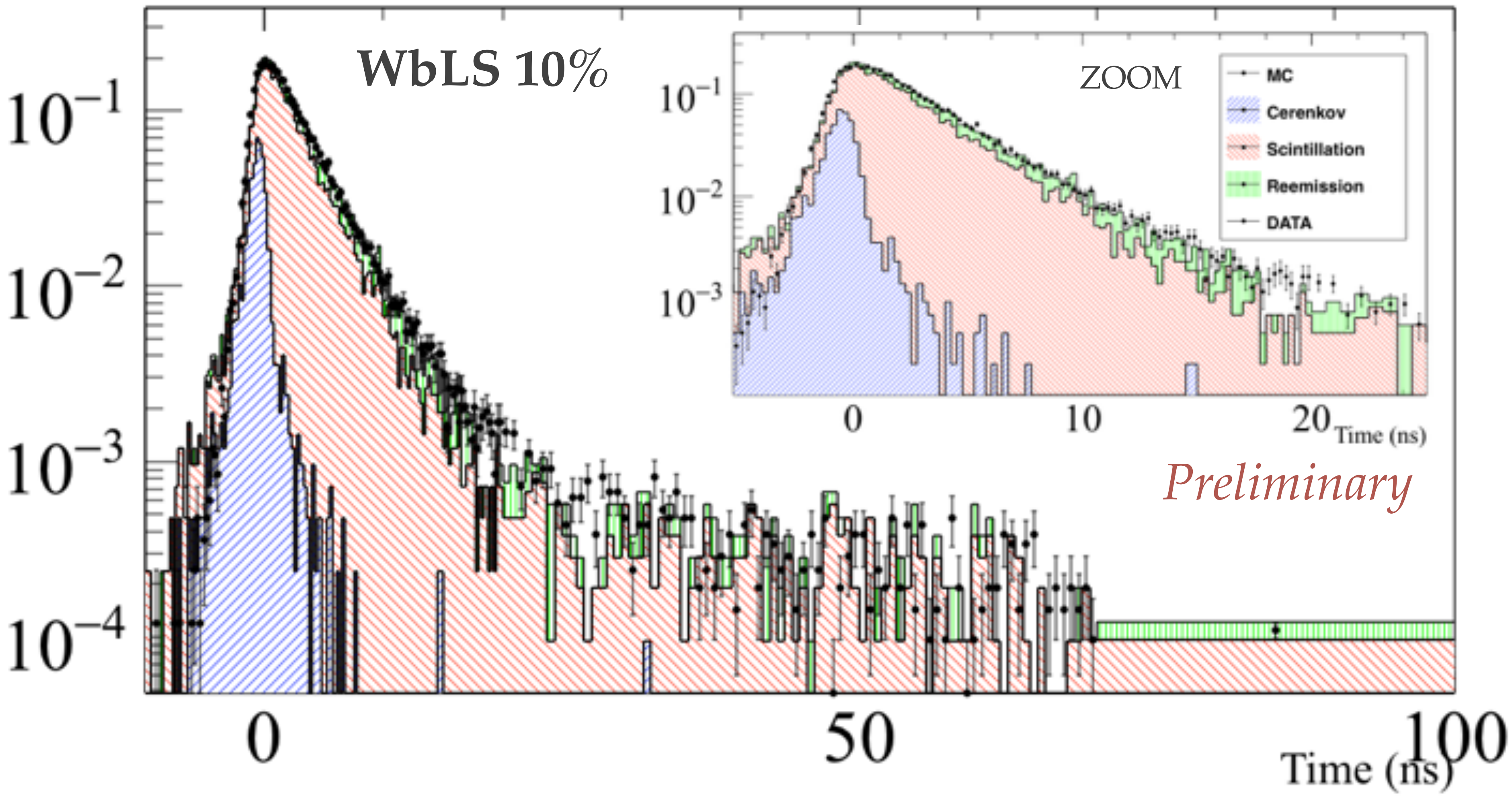








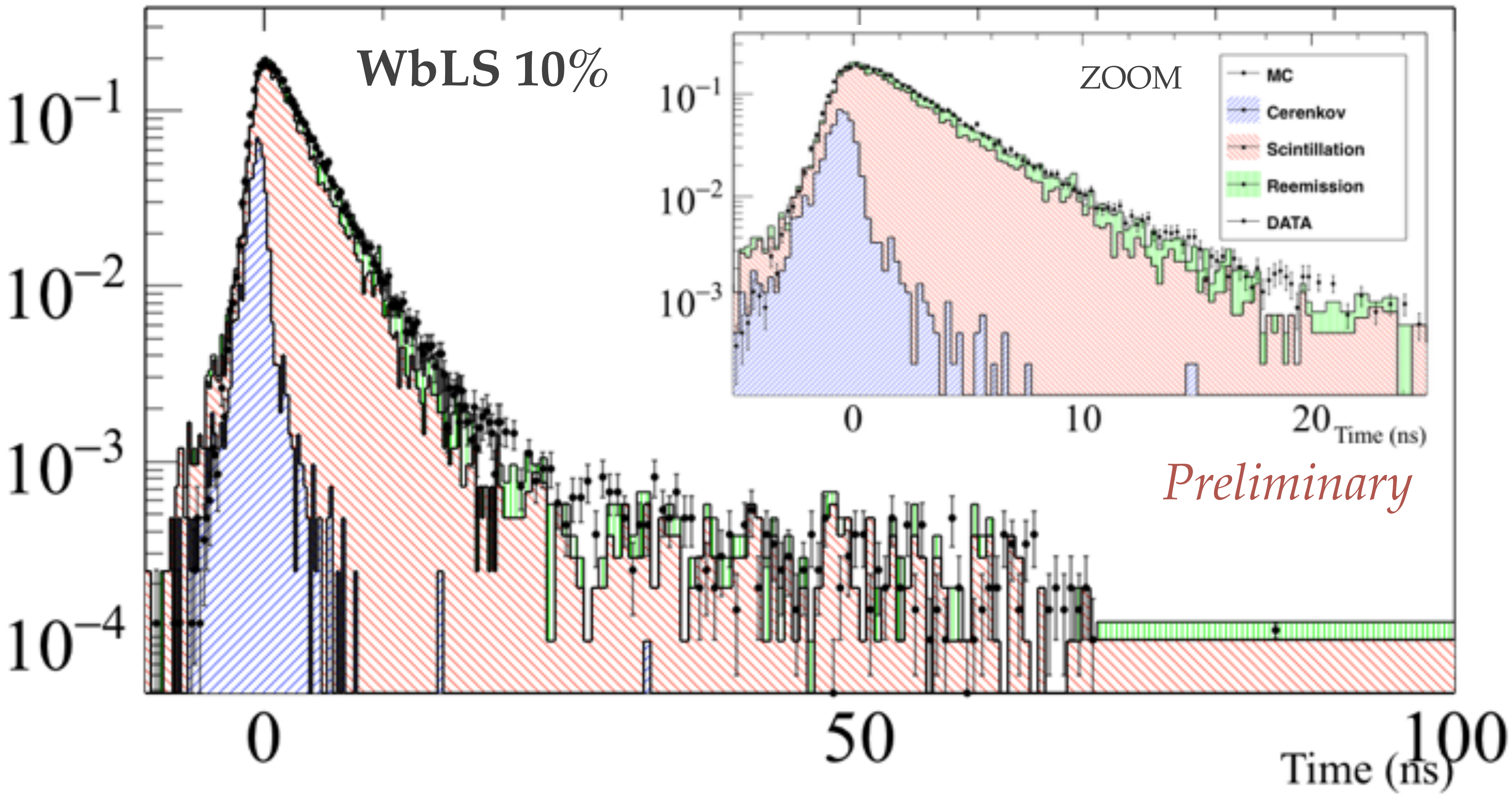
Time profile measurement results



Fit results:
- τ_r = 0.39
- τ_1 = -2.77
- τ_2 = -21.40
- R_1 = 0.94

Estimation of uncertainties → Work in progress…

Time profile measurement results



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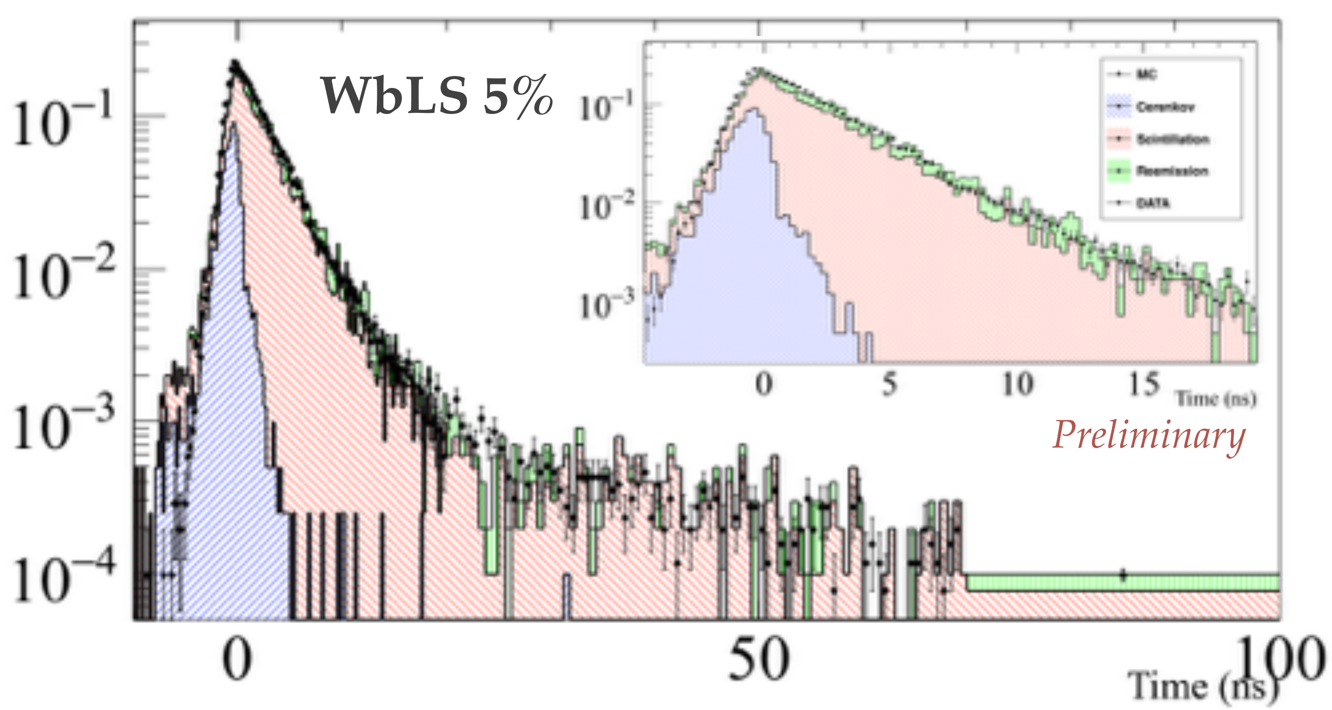
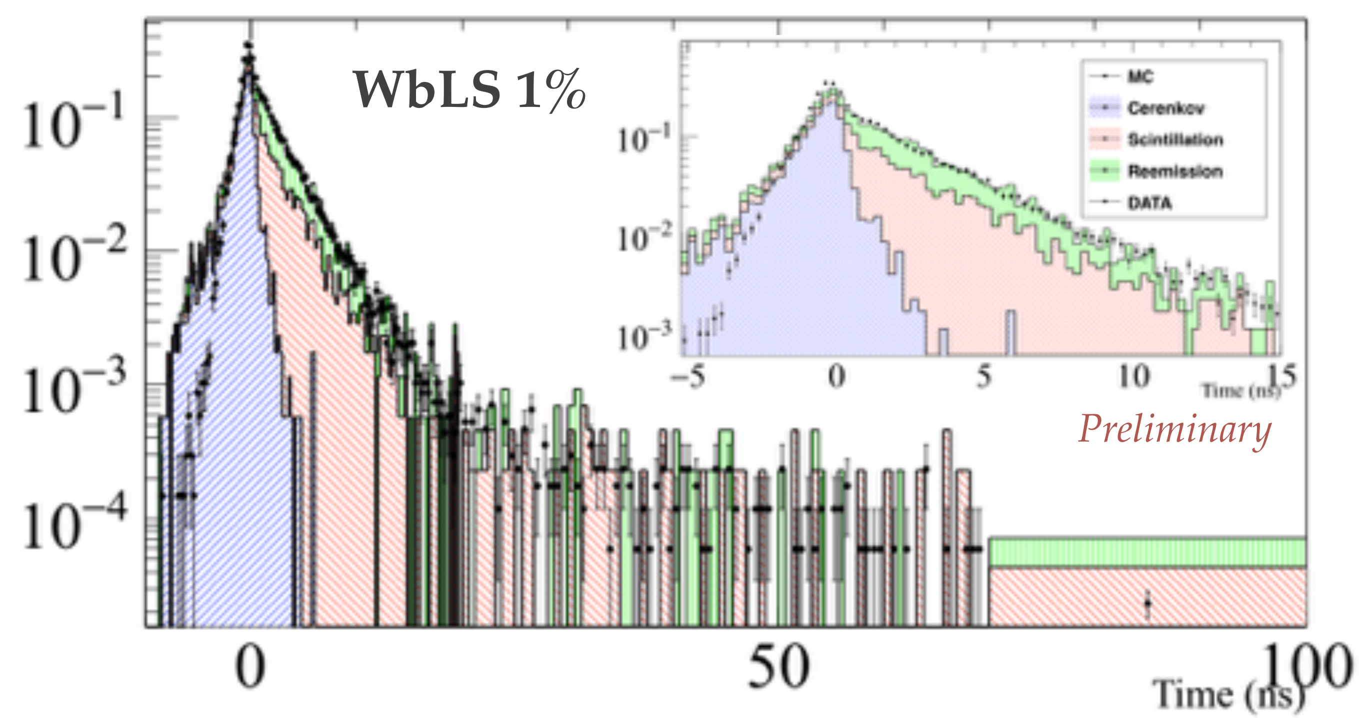
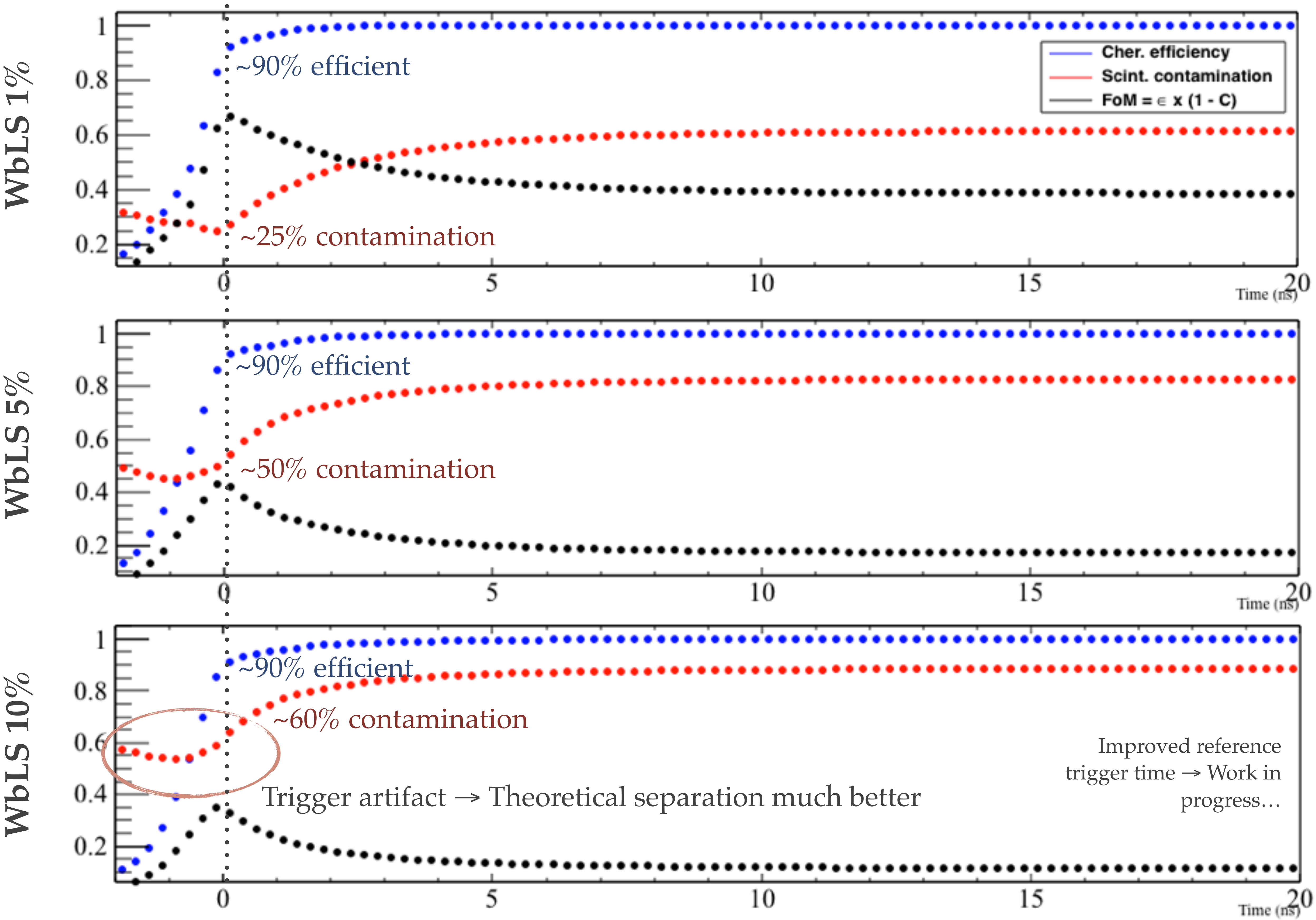
Use other sample as model cross-check:



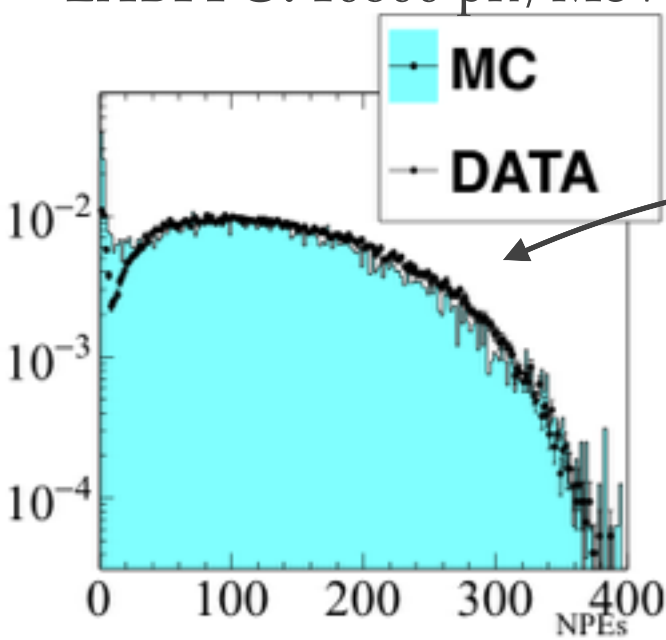


MC-driven C/S separation

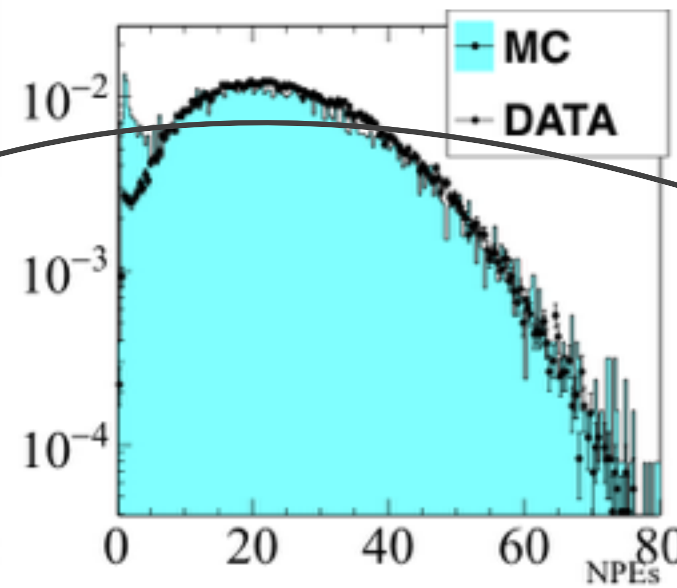


WbLS light yield

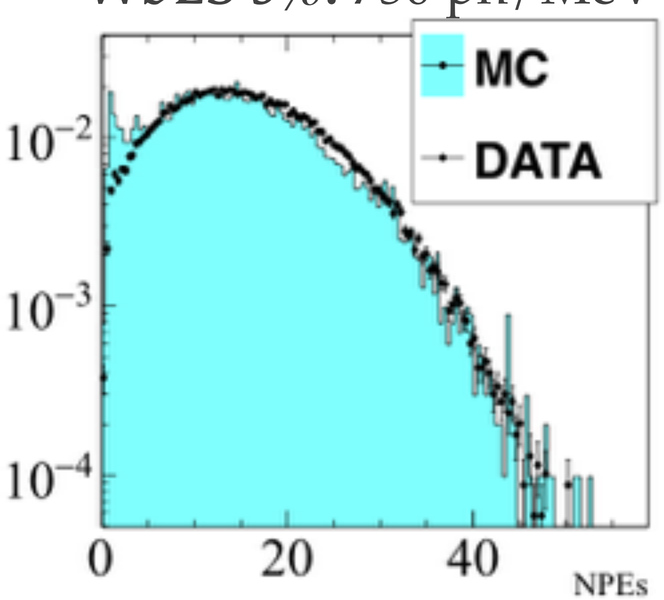
LABPPO: 10800 ph/MeV



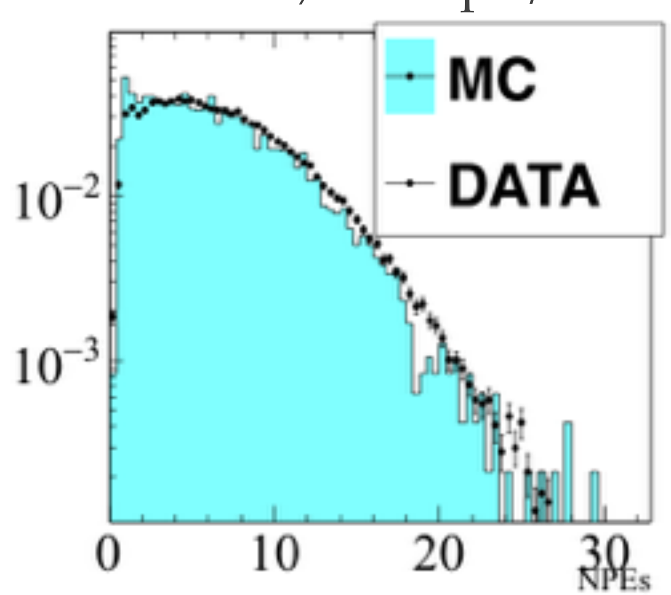
WbLS 10%: 1500 ph/MeV



WbLS 5%: 750 ph/MeV

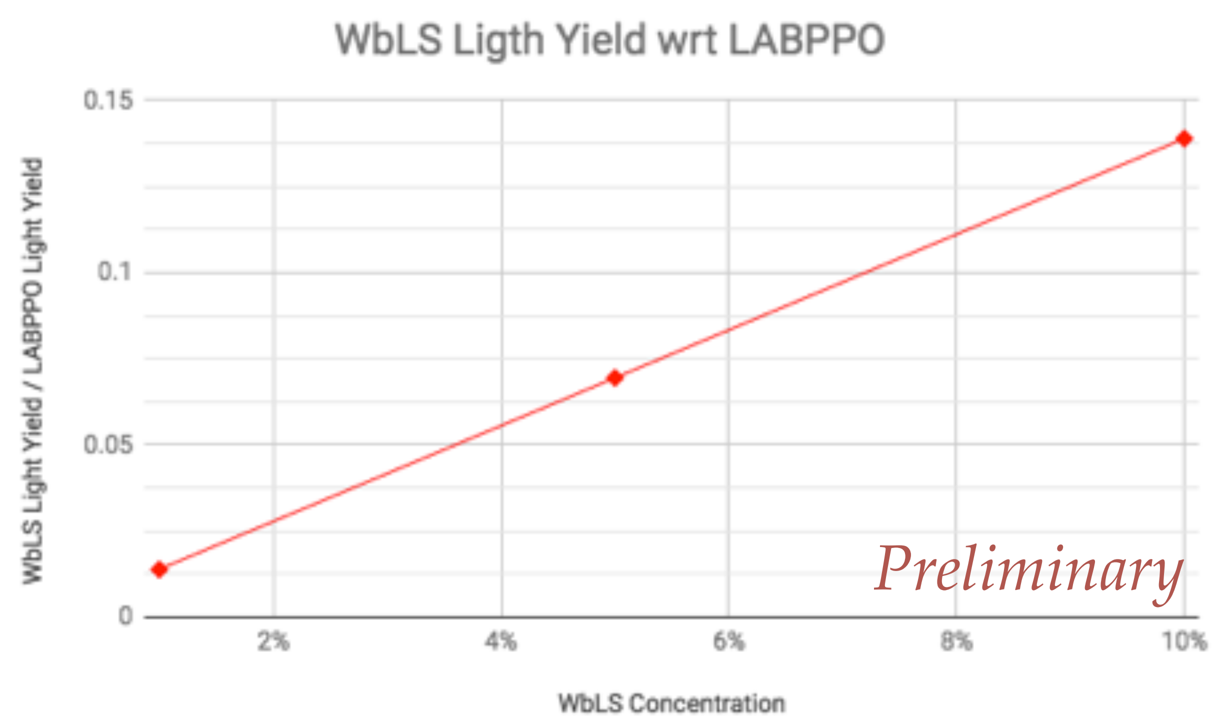


WbLS 1%: 150 ph/MeV

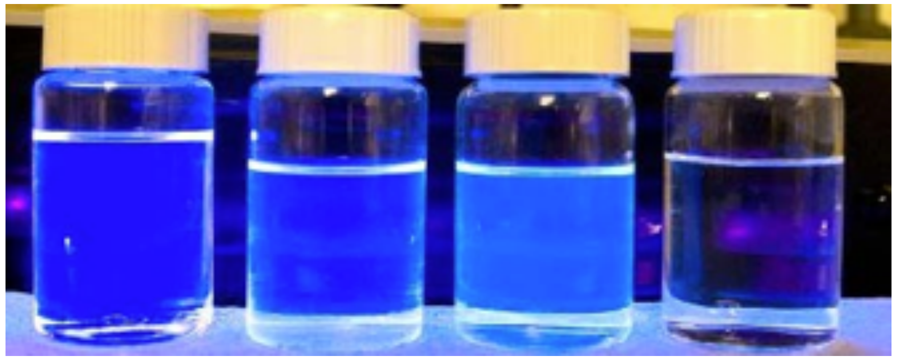


Total number of PEs in PMT array

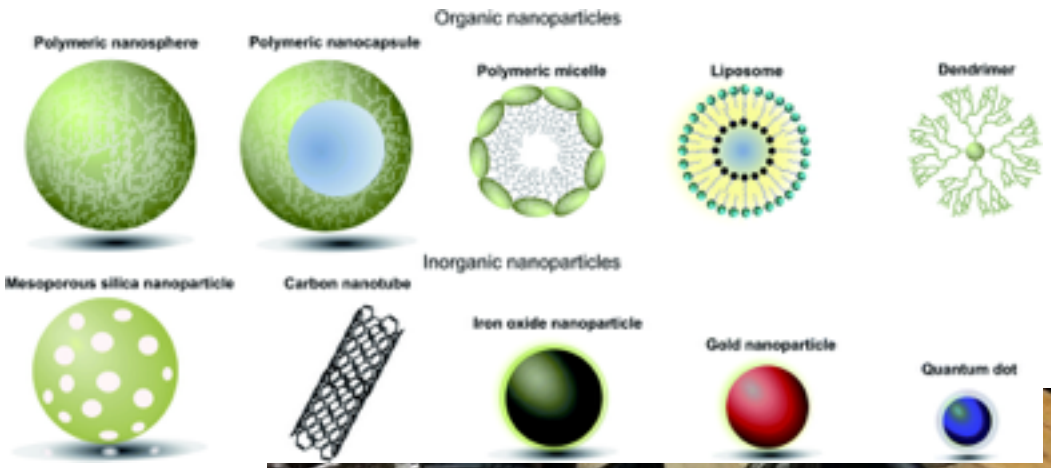
- Consider LAB-PPO and WbLS emission profile the same
- Set LAB-PPO light yield to 10800 ph/MeV
- Adjust PMT collection efficiencies to match data
- Scan LY parameter for WbLS

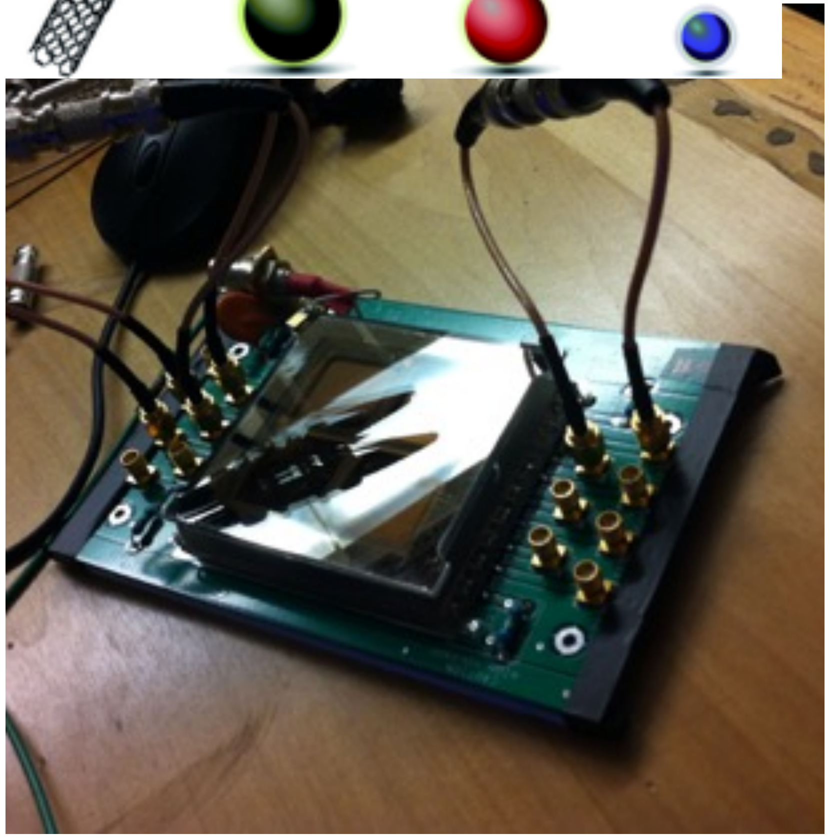


Moving forward



- Finalize WbLS studies
- Upgrade setup with more 1” PMTs
- Deploy different cocktails: pure LS, WLS, mineral oils, etc.
- MCP deployment
- LS metal loading
- …





Summary

- CHESS showed Cherenkov ring imaging from cosmic muons in LS using low TTS PMTs
- Demonstrated C/S separation in LAB and LAB-PPO 2g/L
- Deployed beta source → Complementary to previous muons studies
- Measured WbLS time profile → Faster than LAB-PPO 2g/L

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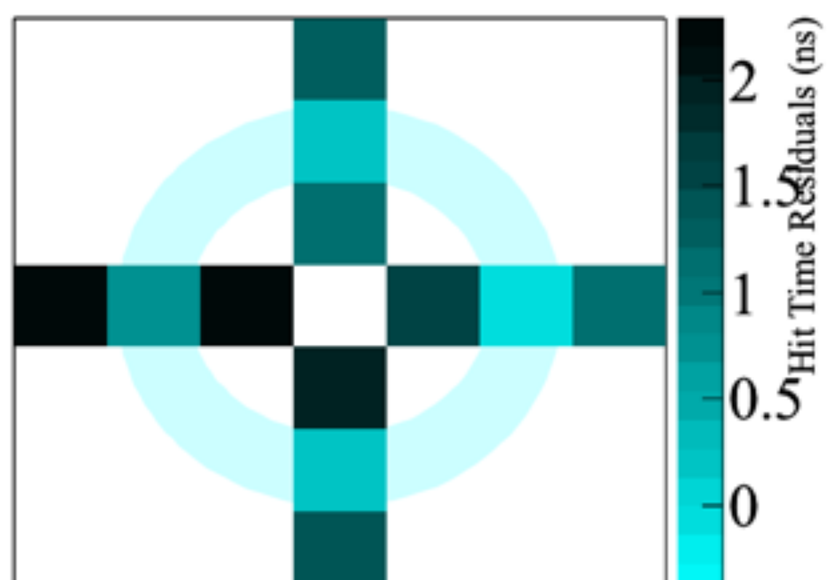
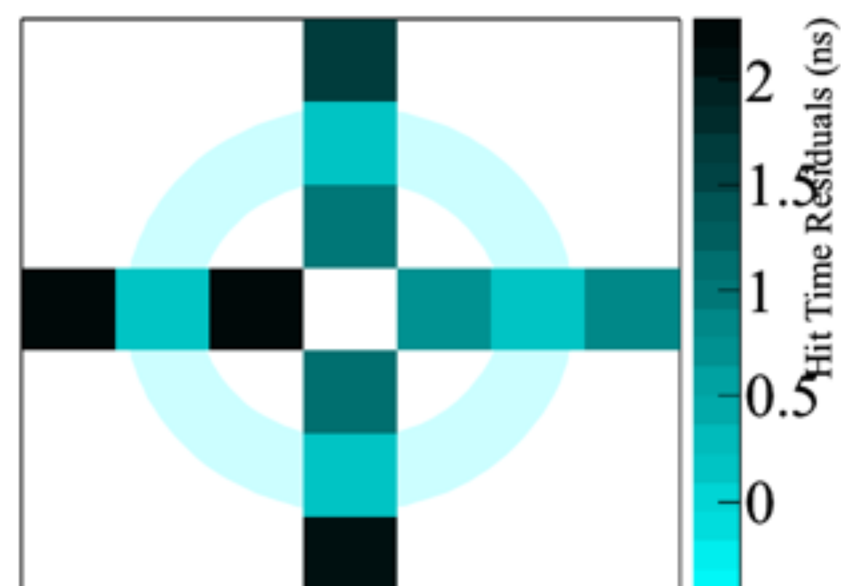
WbLS 1%

WbLS 5%



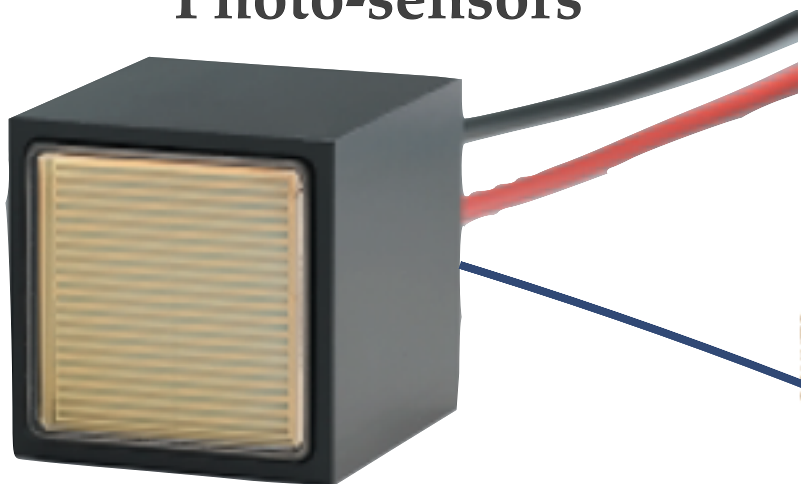
WbLS 10%

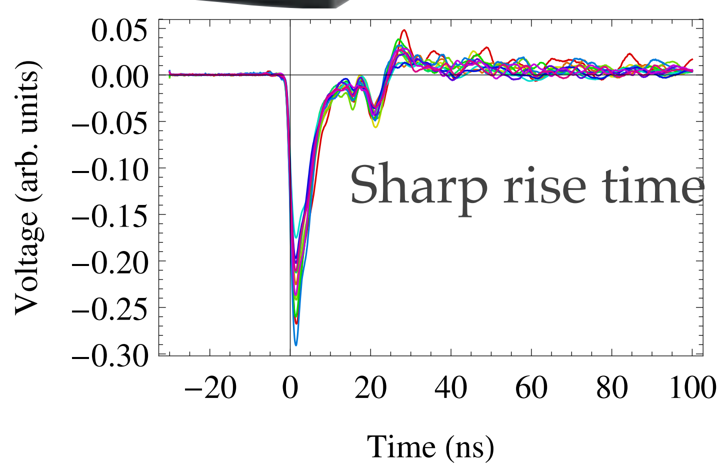


Backup

Reaching the required time resolution

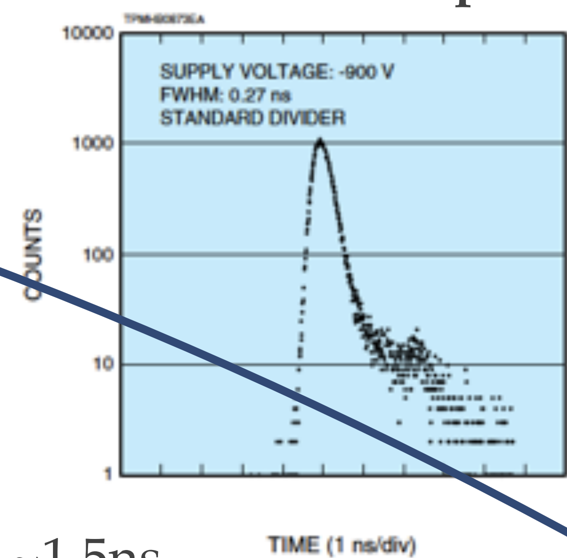
Photo-sensors





Sharp rise time → ~1.5ns

Low TTS → **300ps FWHM**

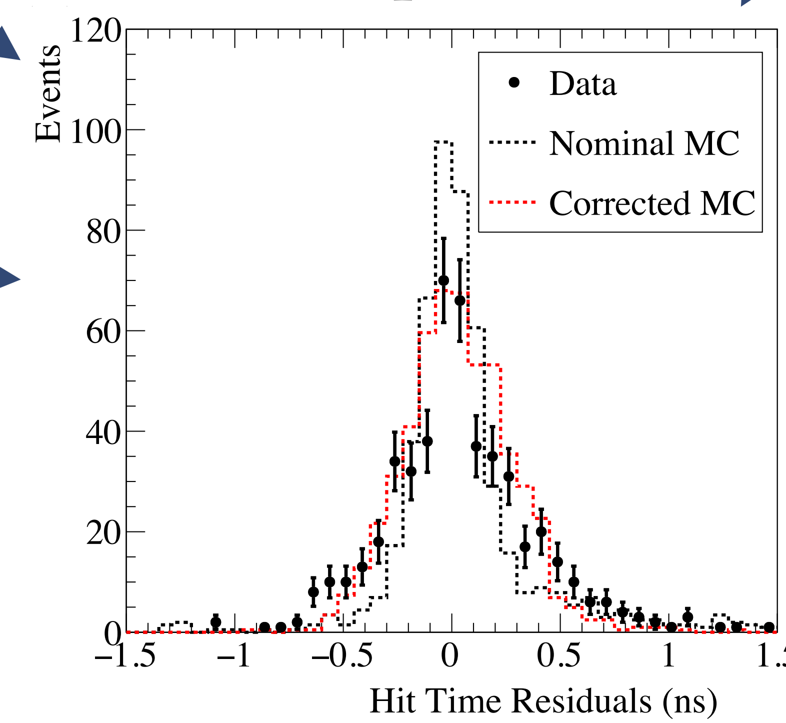


Timing measurement

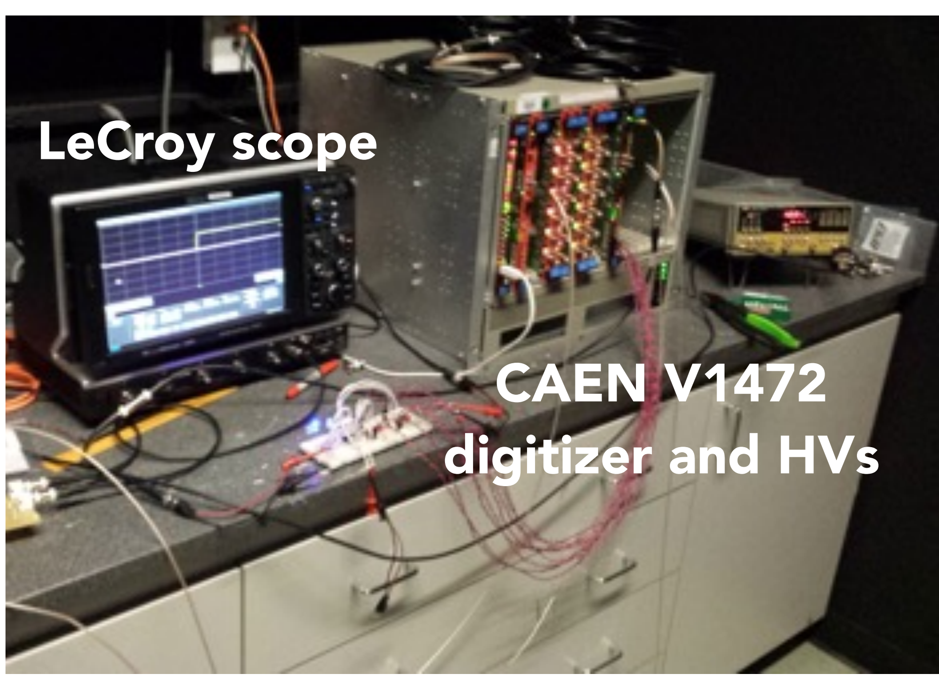
- Measure time of the earliest PE → Time-at-fixed threshold
- Event time defined as the median of the 4 earliest hits
- Correct time residuals for ToF and delays

Estimated time resolution from vertical cosmic muons in a water target:

338 ± 12 ps FWHM



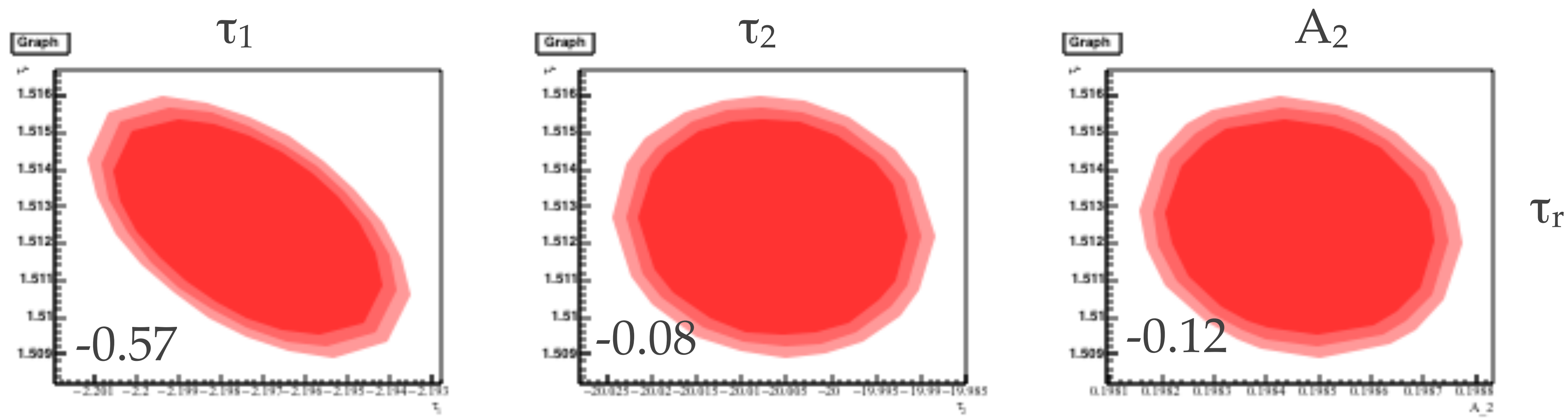
DAQ

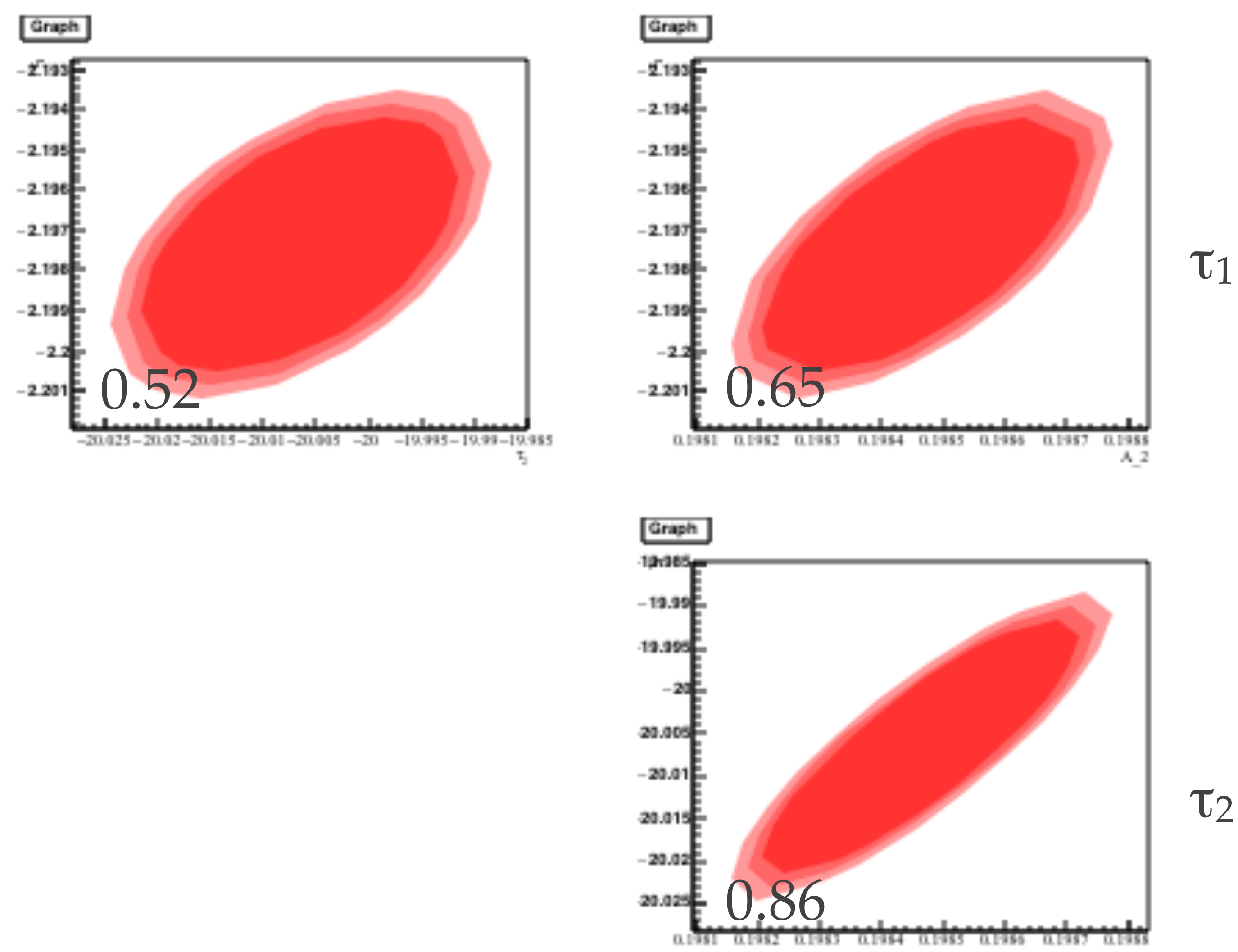


- CAEN digitizer V1742:
  - **5GHz (0.2ns) sampling rate**
  - Buffer limited to ~200ns at max. rate
  - Induces dead time → Not a limitation for our prototype
- LeCroy scope issues trigger

Parameter correlations

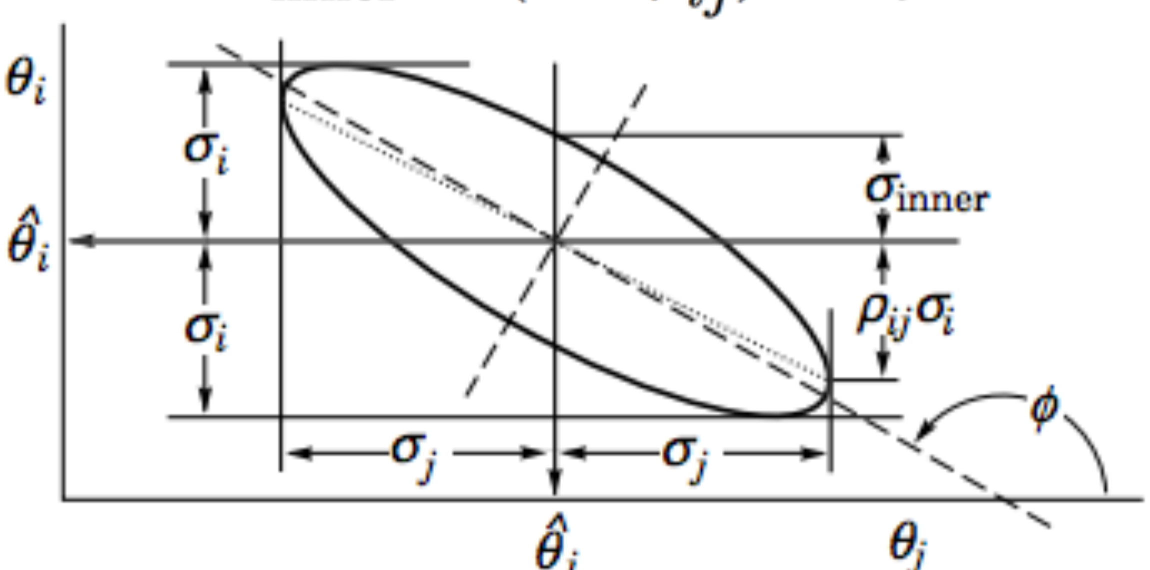
The analytical model is used to precisely compute the correlations:



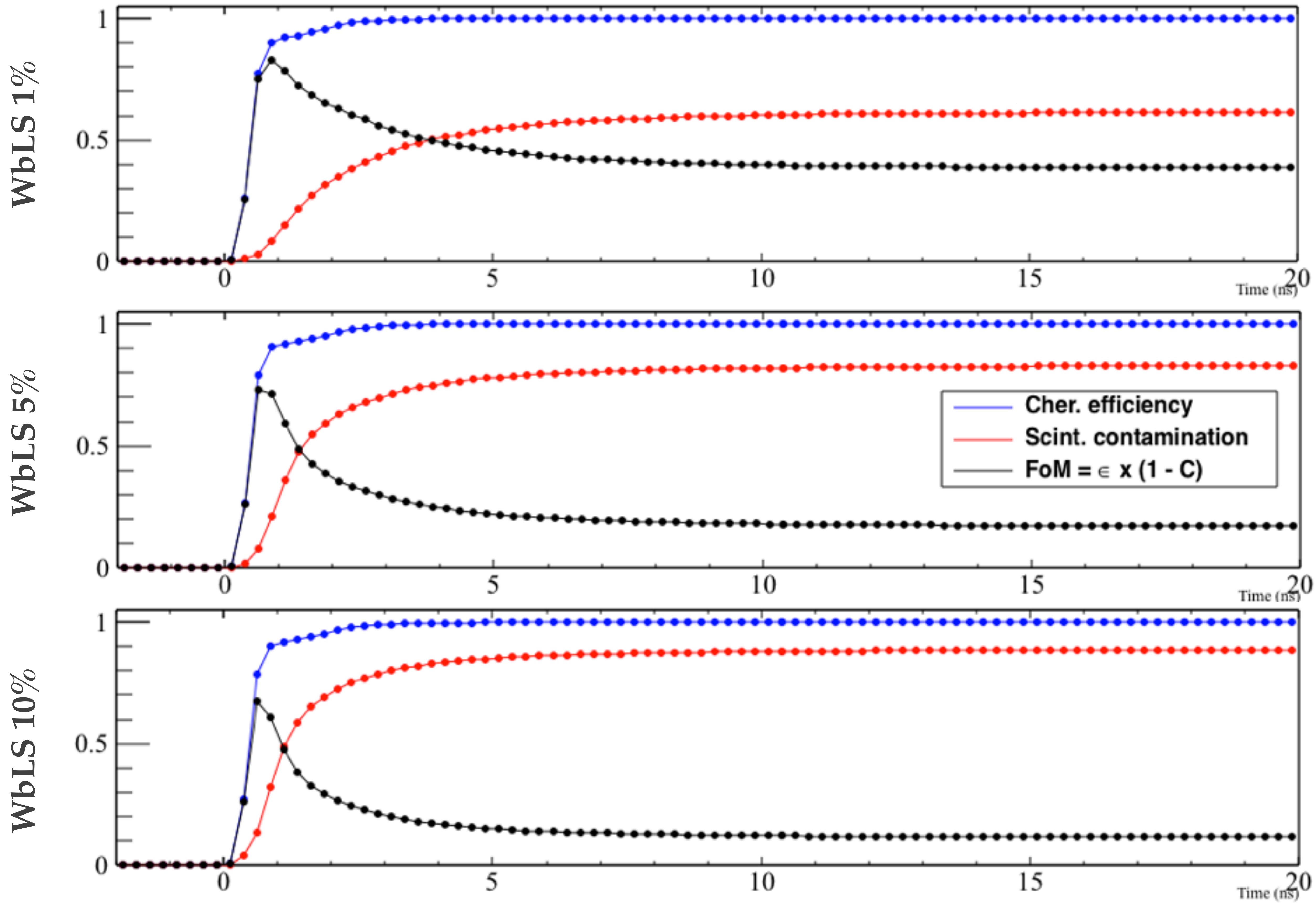


We can calculate the total error
by taking into account the correlation:

$$\sigma_{\text{inner}} = (1 - \rho_{ij}^2)^{1/2}\sigma_i$$



MCTruth C/S separation



LAB-PPO: Y vs τ

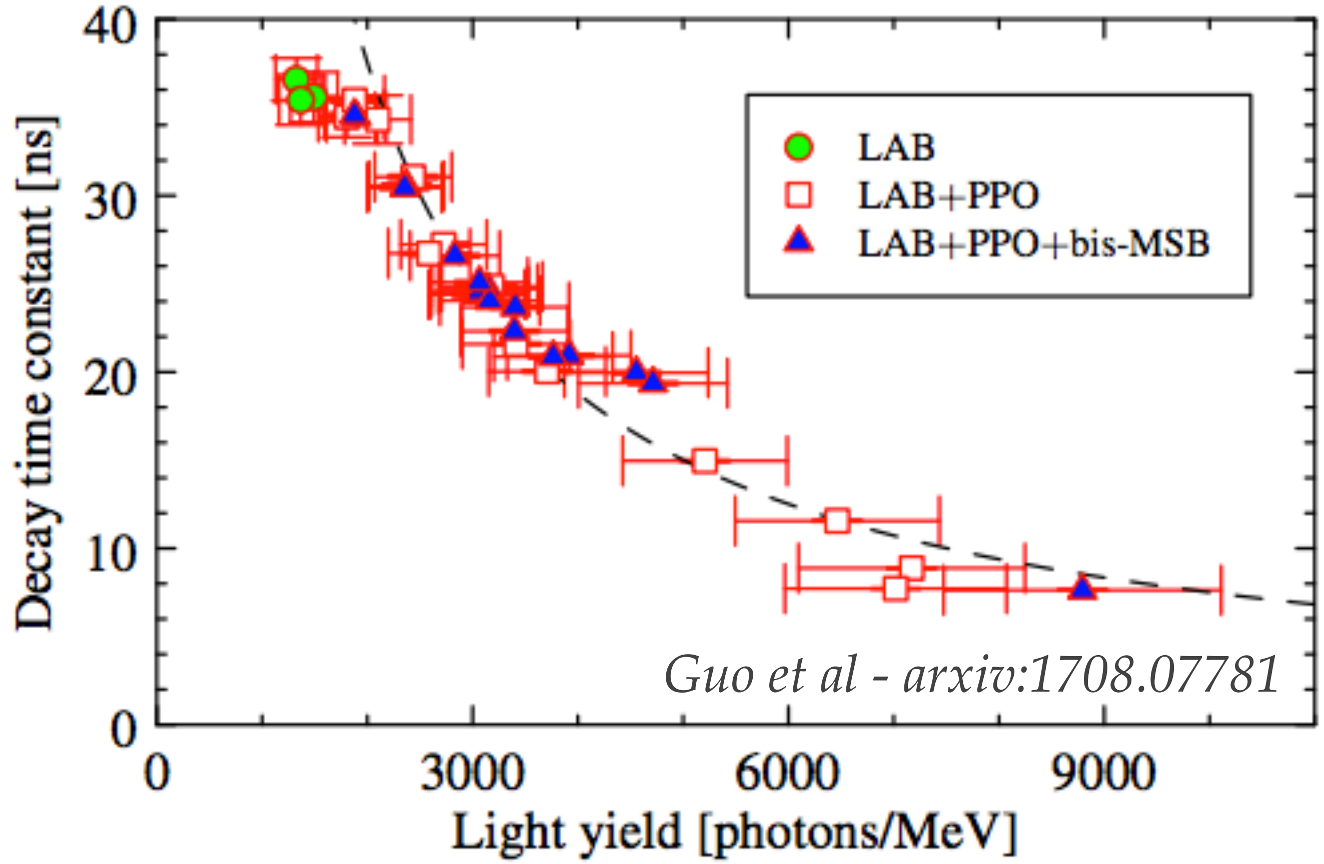


Figure 6: Decay time constants versus scintillation light yield of different concentrations of LAB, PPO, and bis-MSB solution. The dashed black line shows the fit of an inversely proportional function.