CHESS:
CHErenkov / Scintillation Separation Experiment

Gabriel D. Orebi Gann

FROST-ii workshop, Oct 23rd, Mainz

On behalf of the CHESS group: J. Caravaca, F. B. Descamps, B. J. Land, J. Wallig, M. Yeh and G. D. Orebi Gann

Benefits of Signal Separation

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- Scintillation component boosts intrinsic light yield
- High transparency ⟹ good light collection
  - ➡ Low energy threshold
  - ➡ Good energy (& vertex) resolution

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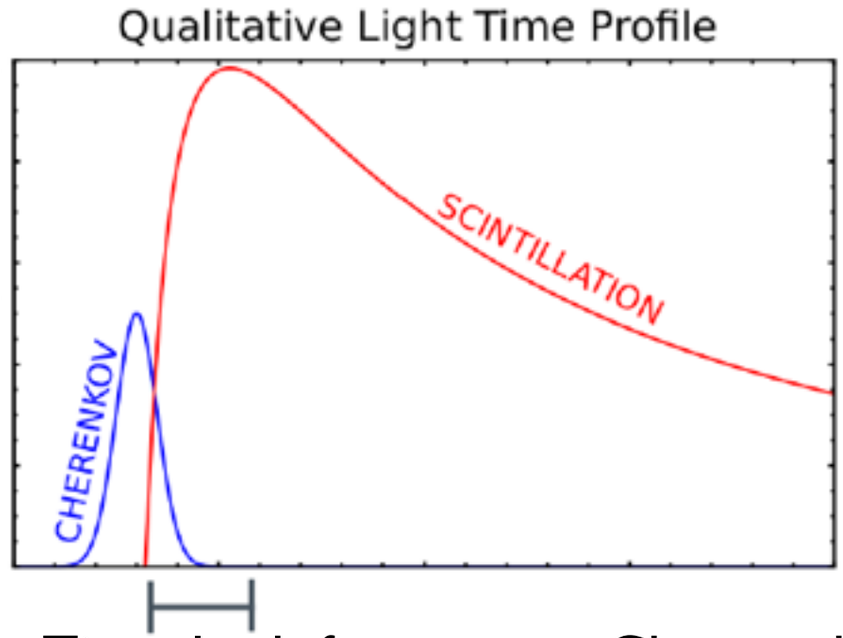
All while retaining topological information from Cherenkov component

- Directionality for low-energy
  - NLDBD vs solar ν
  - Solar ν vs radioactivity (CNO, MSW transition)
- Particle identification via ring imaging for high-energy (e vs μ)
- Particle ID via Cher/scint ratio (e+ vs recoil for antinu bkg rejection)

Cherenkov/scintillation separation

Charge: look for Cher ring superimposed on isotropic scint "bkg"



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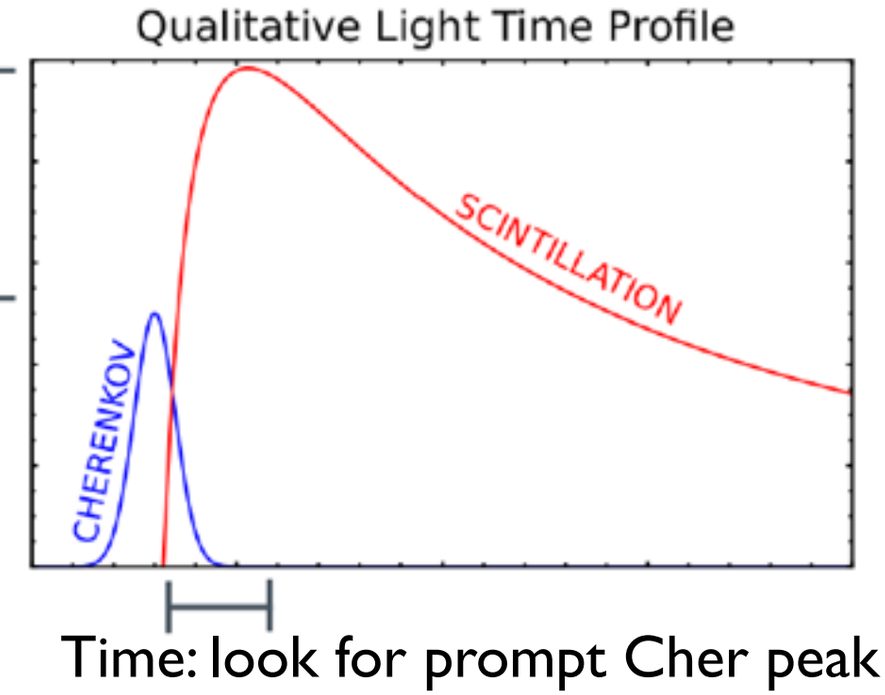

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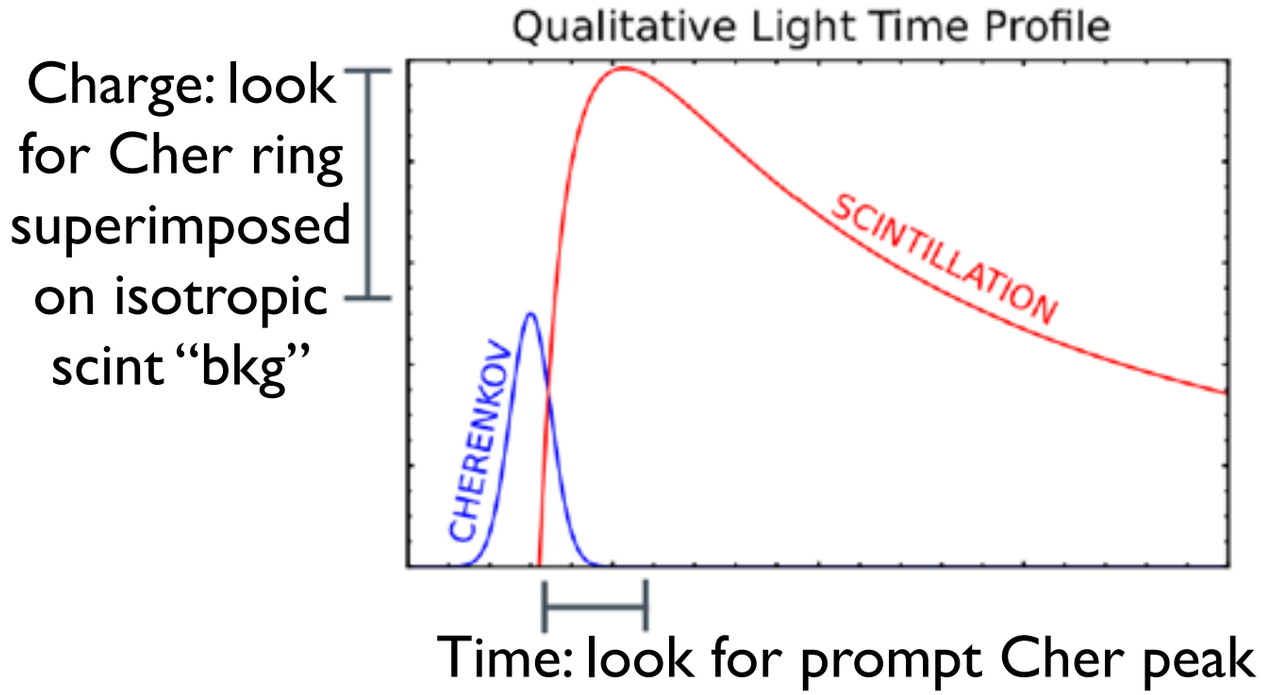

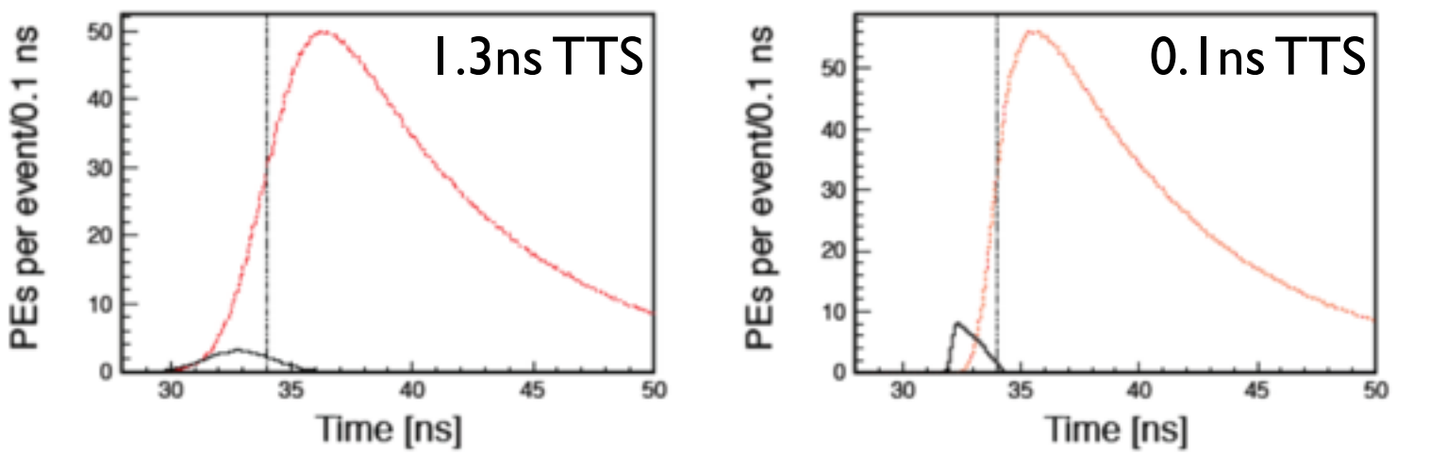

C. Aberle et al, JINST 9 P06012 (2014)

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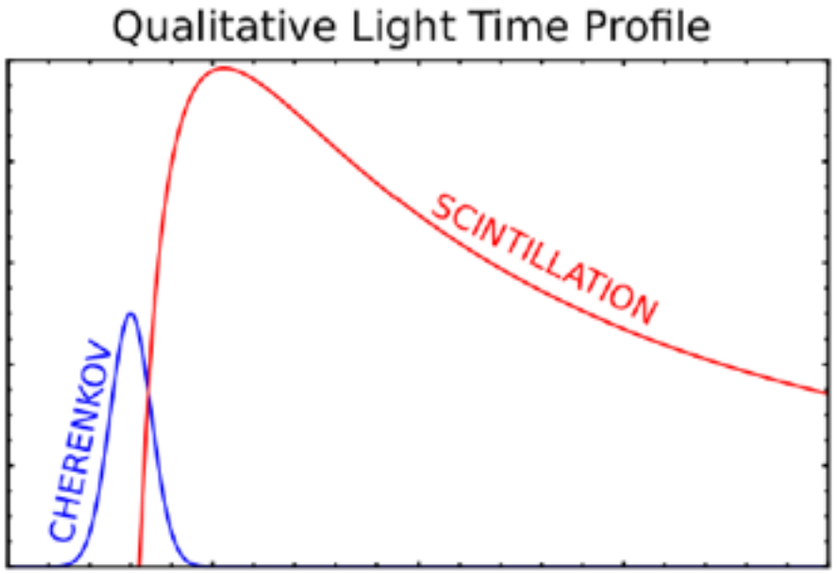
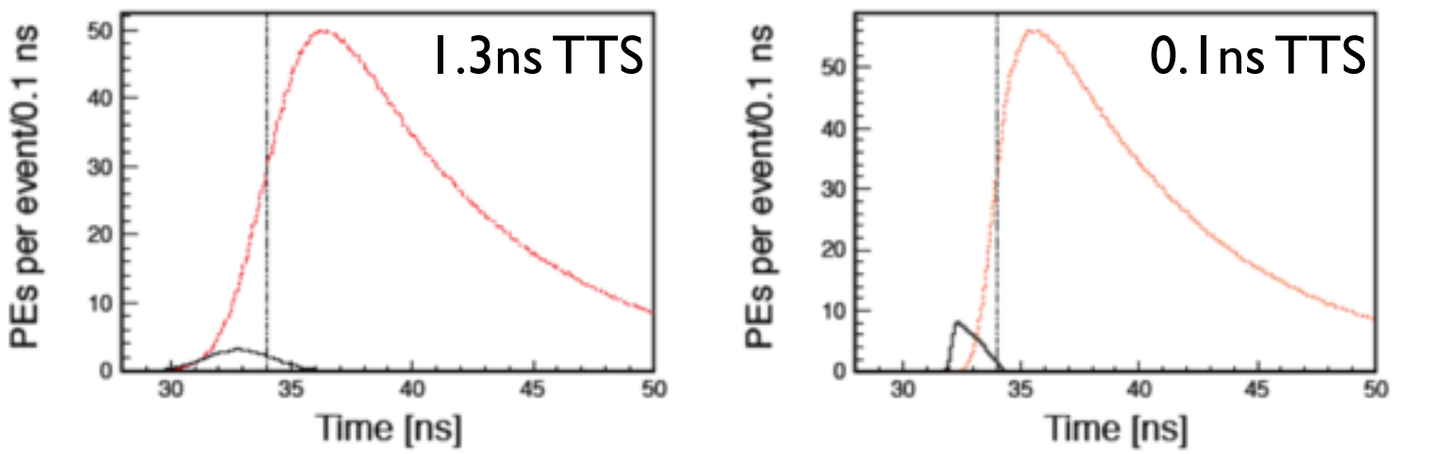
  - Tune relative light yields
  - Readout sensitivity





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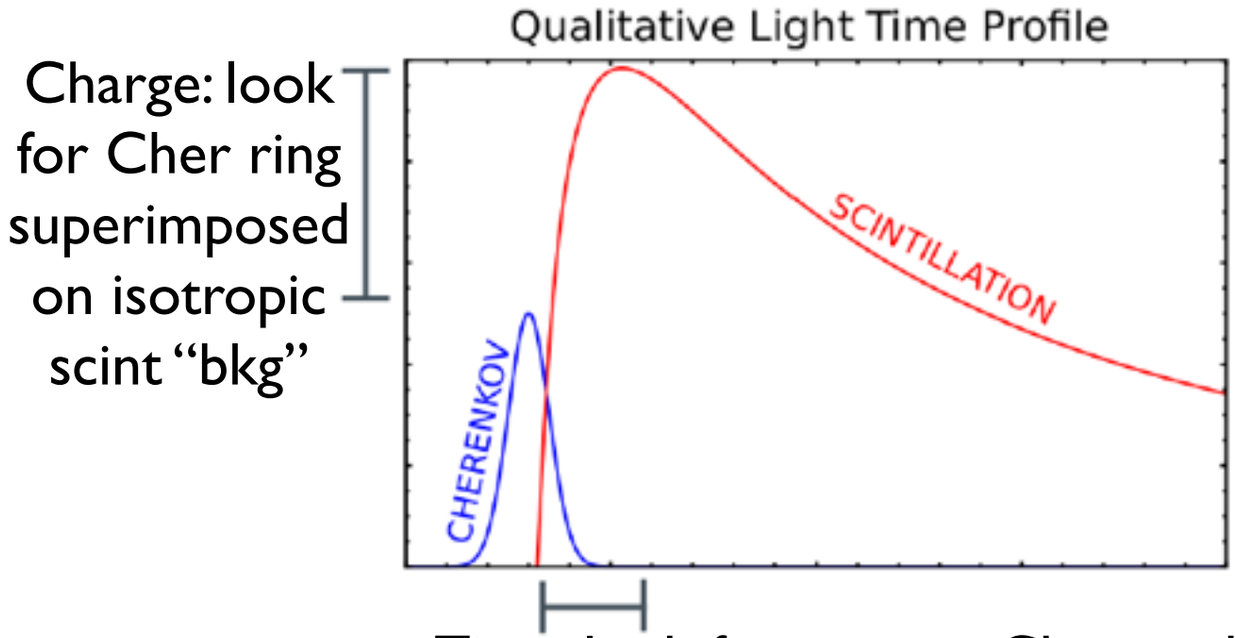

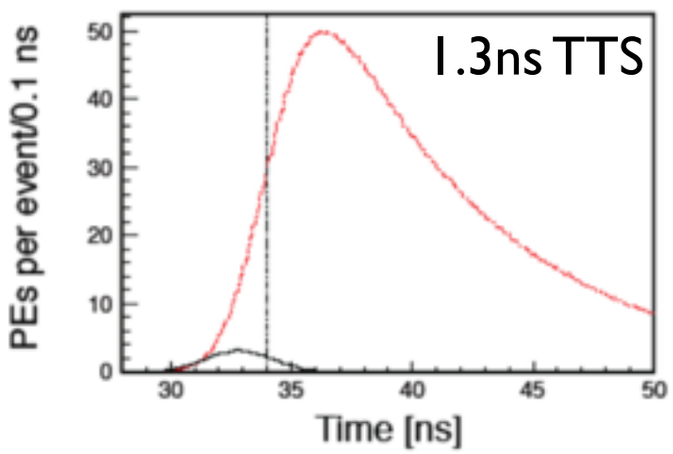

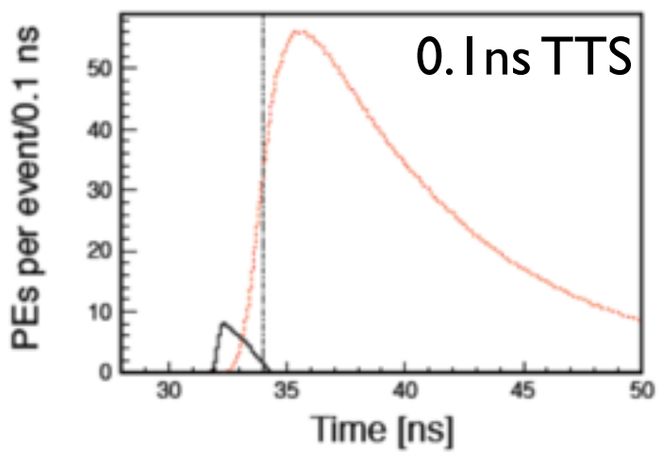

Cherenkov (prompt, scarce)

Scintillation (delayed, abundant)

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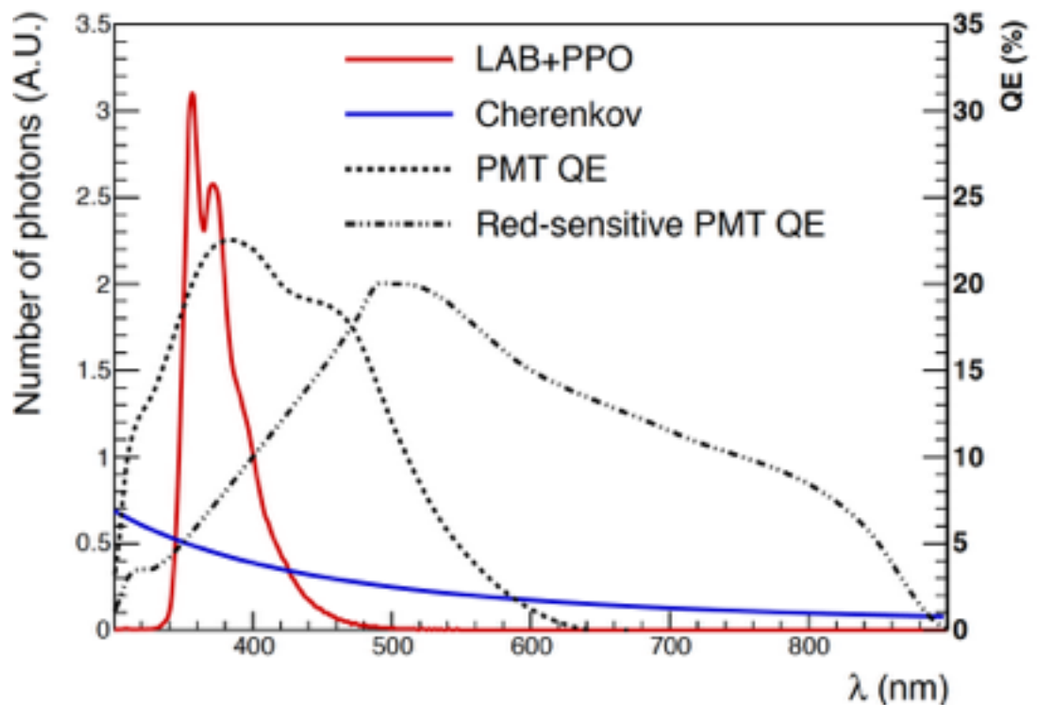

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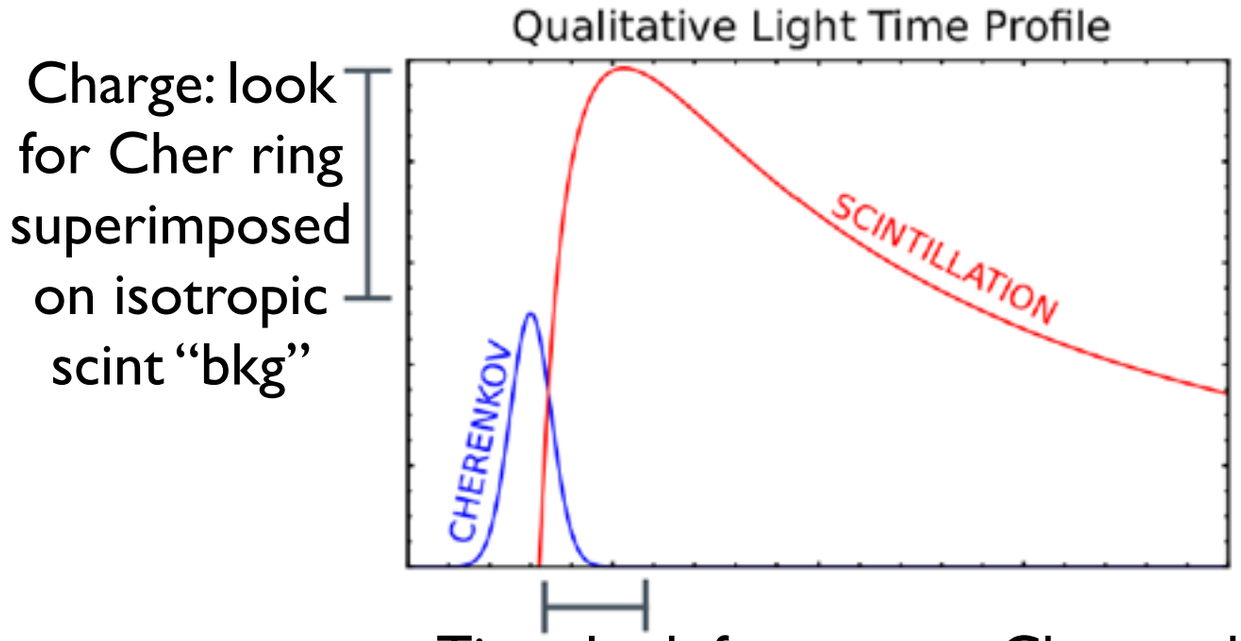

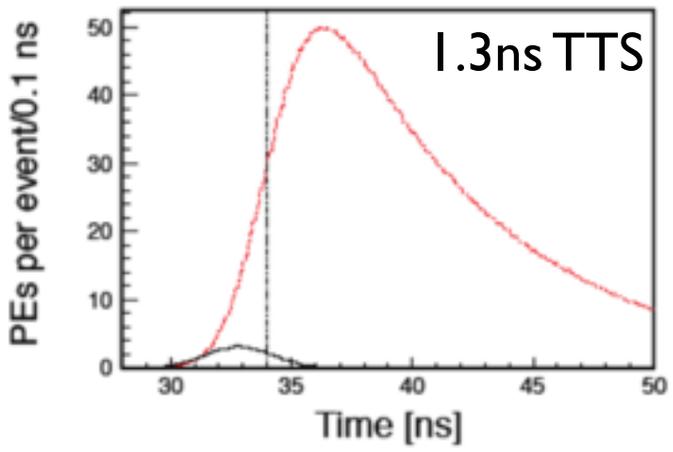

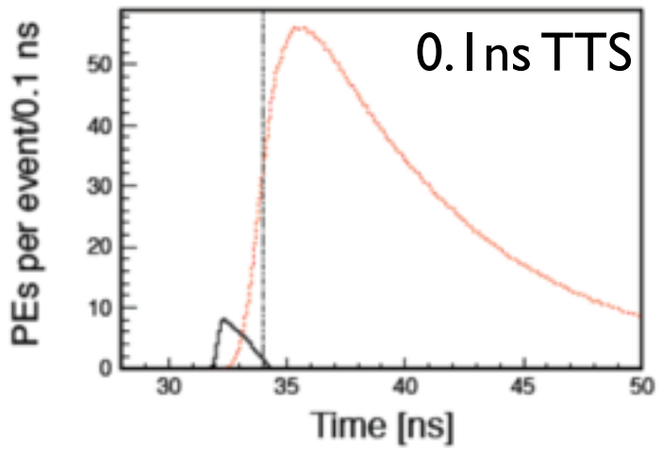

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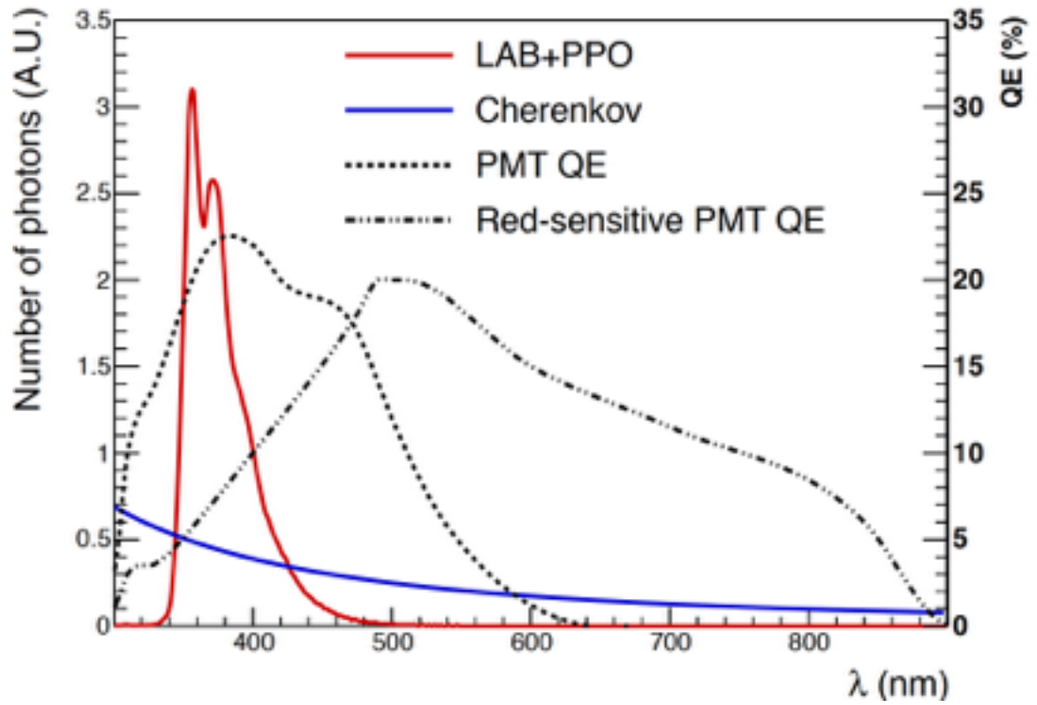

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Cosmic Muon Ring-Imaging Experiment at Berkeley

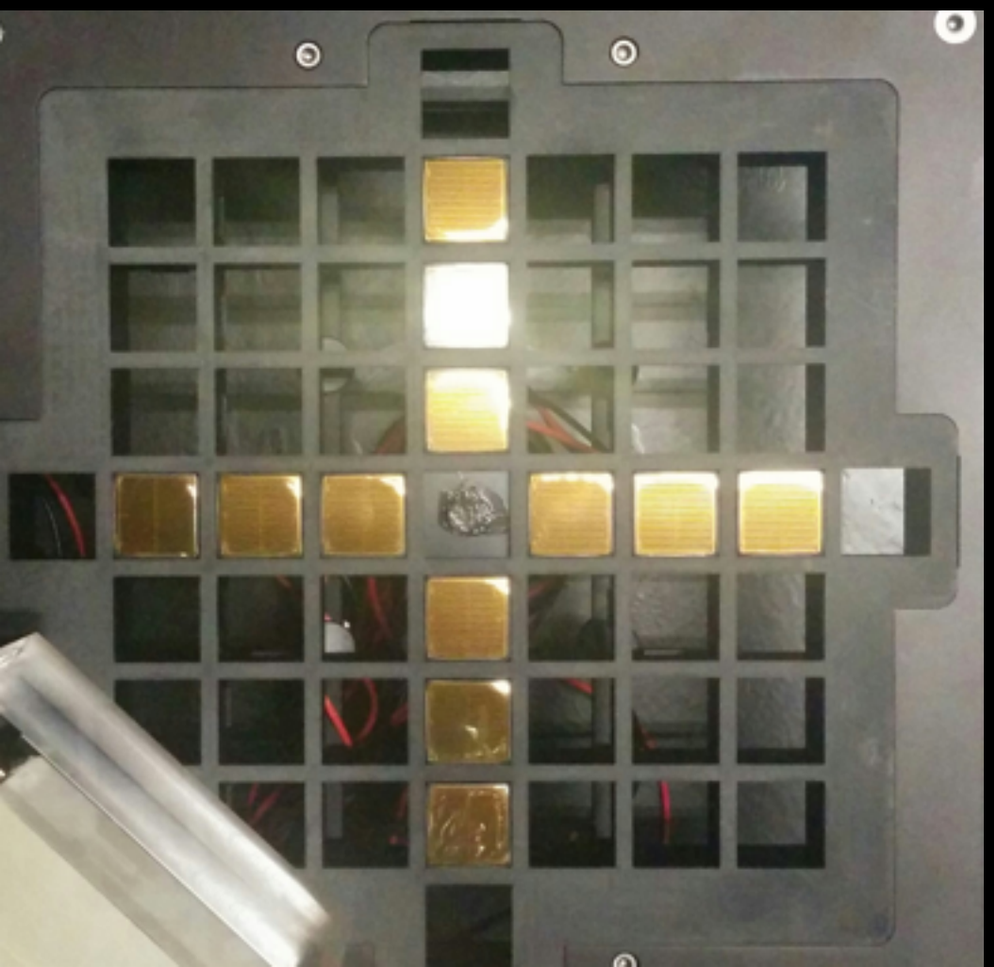
CHESS:
CHErenkov-Scintillation Separation

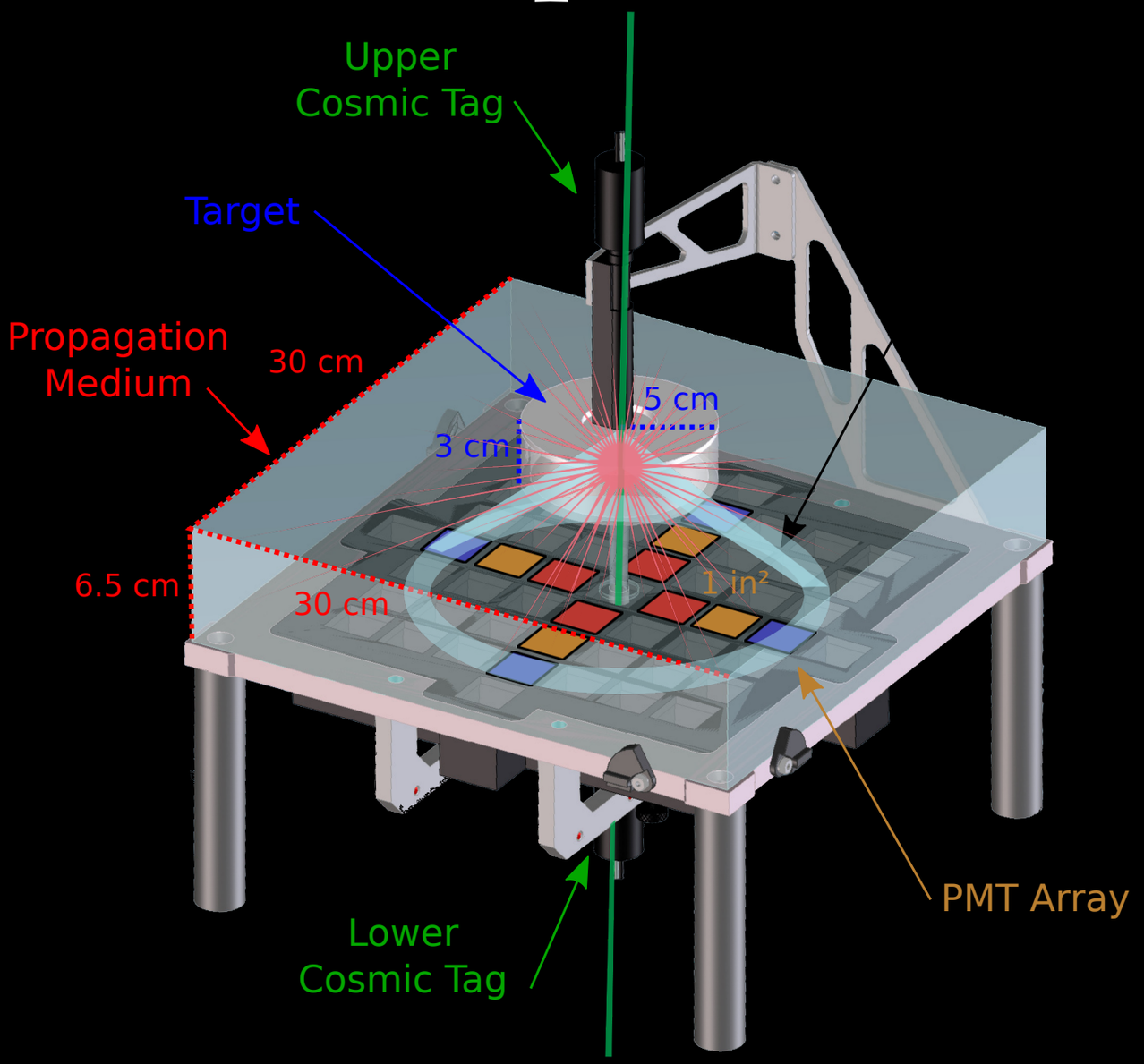
Supported by LBNL LDRD (FY '15-16)
arXiv: 1610.02029

Select vertical cosmic muon events

Image Cherenkov ring in Q and T on fast-PMT array

Allows charge- and time-based separation





12 1-inch H11934 PMTs (300ps FWHM, 42% QE)
CAEN V1742 (5GHz)
675 samples (135ns window)
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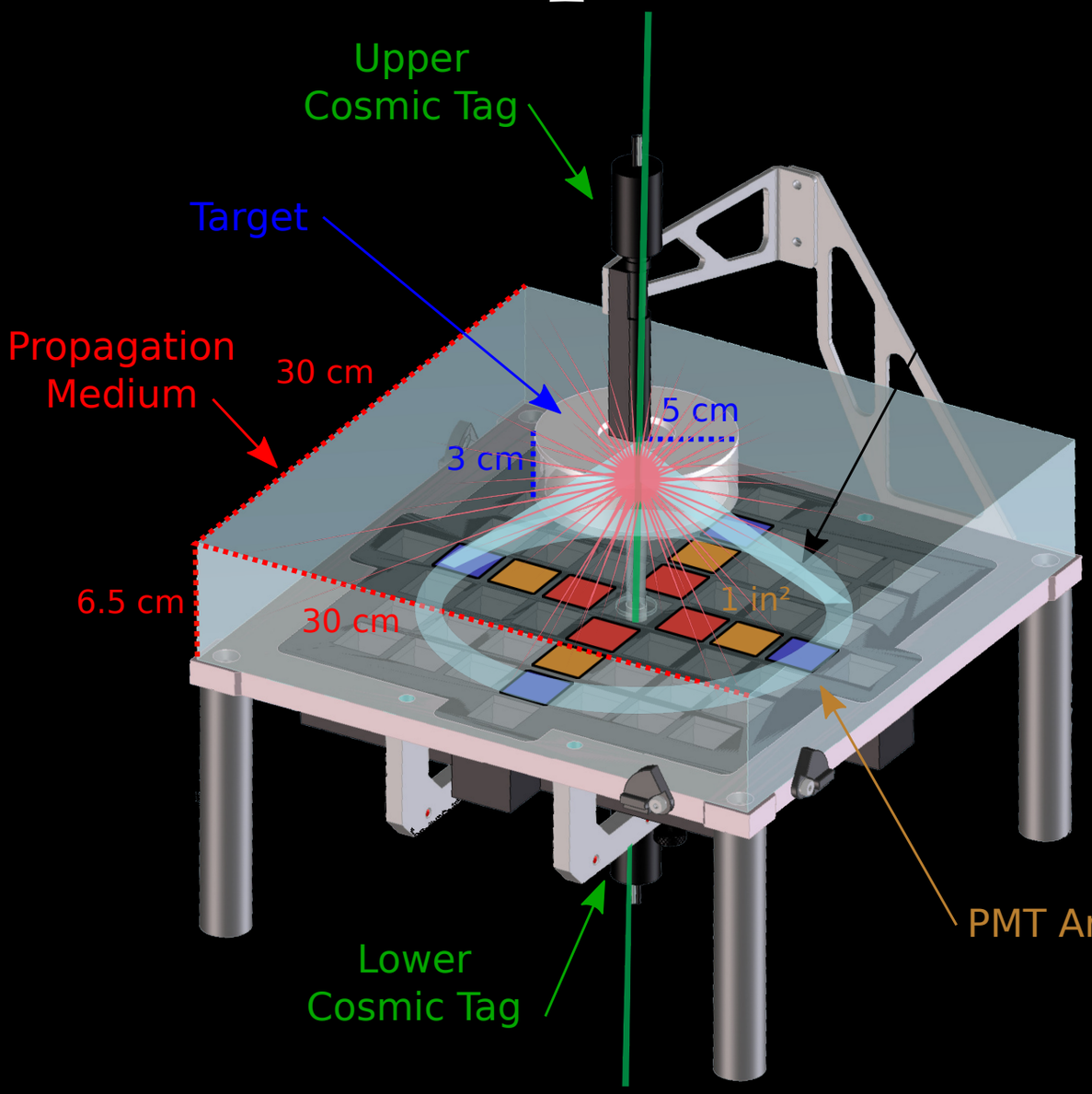

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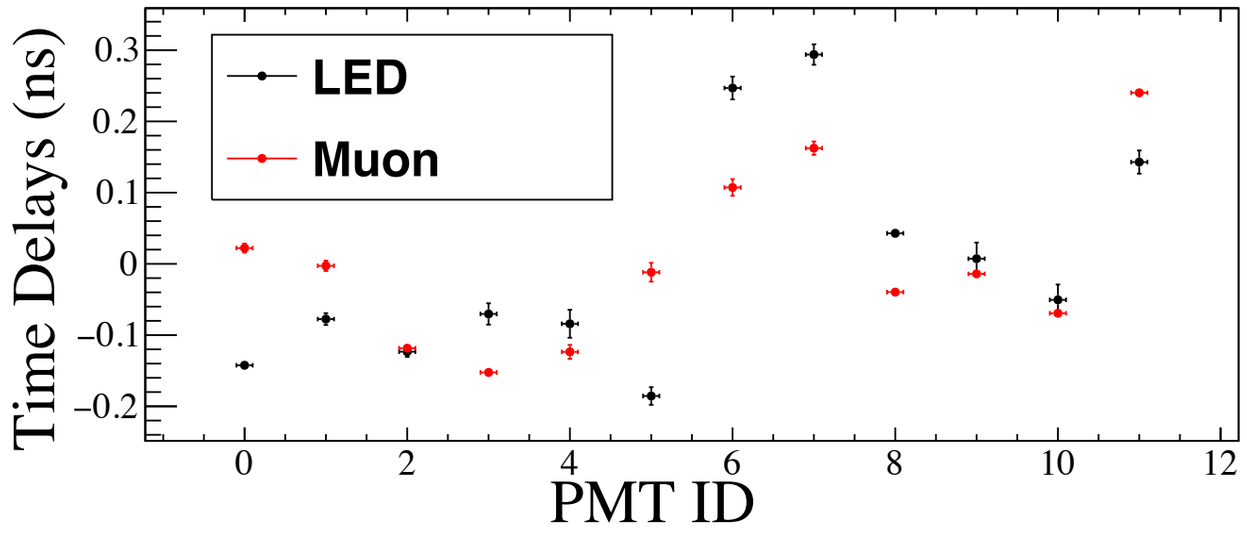

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  - Cherenkov light is well understood
  - Extract parameters per PMT
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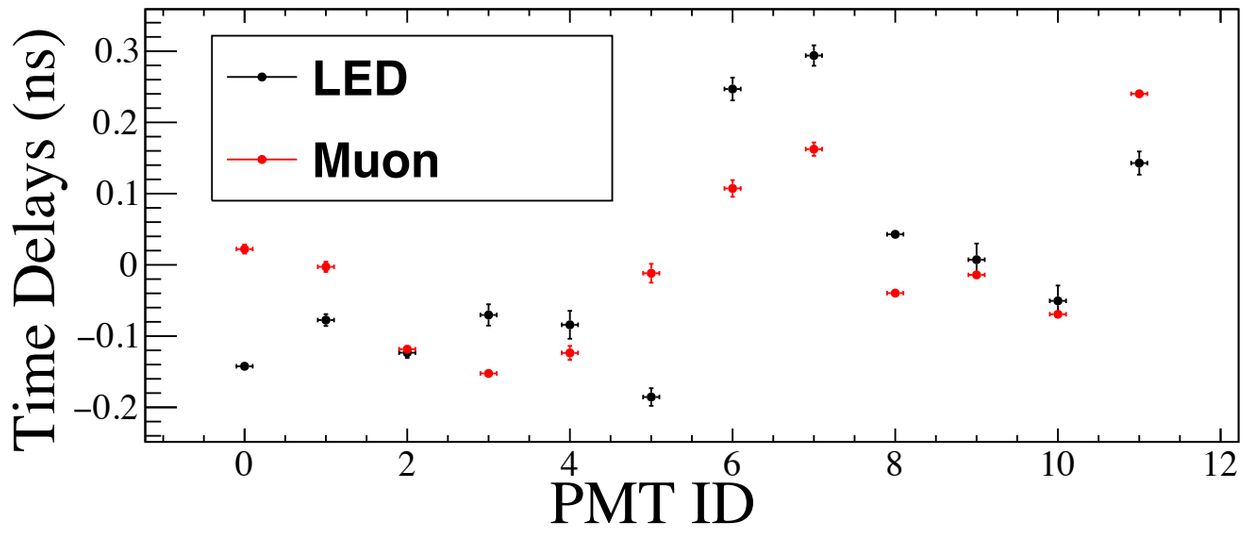

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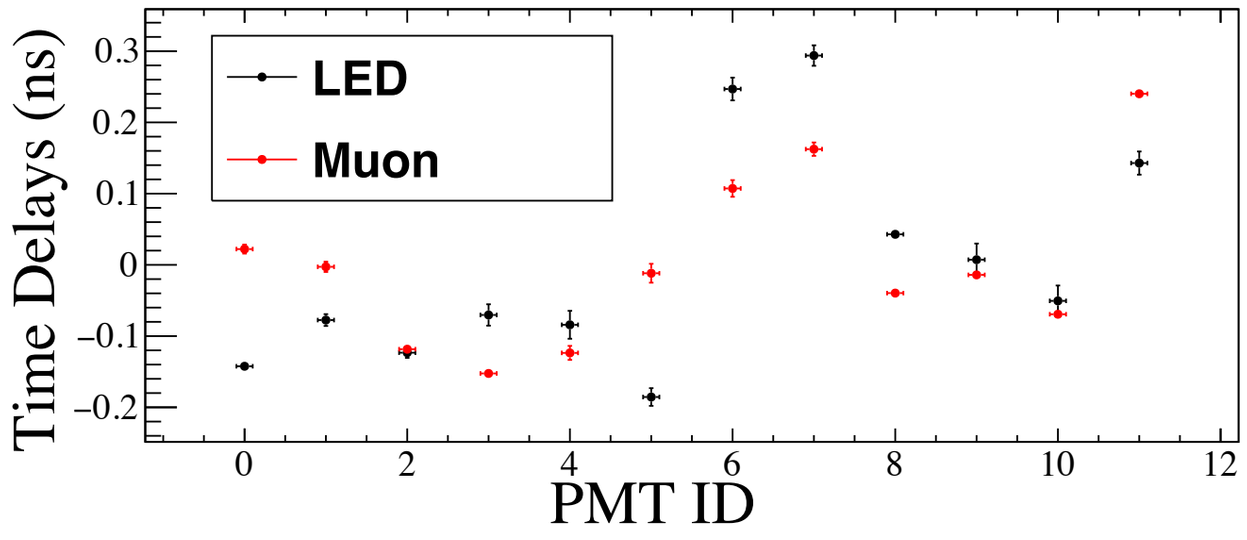

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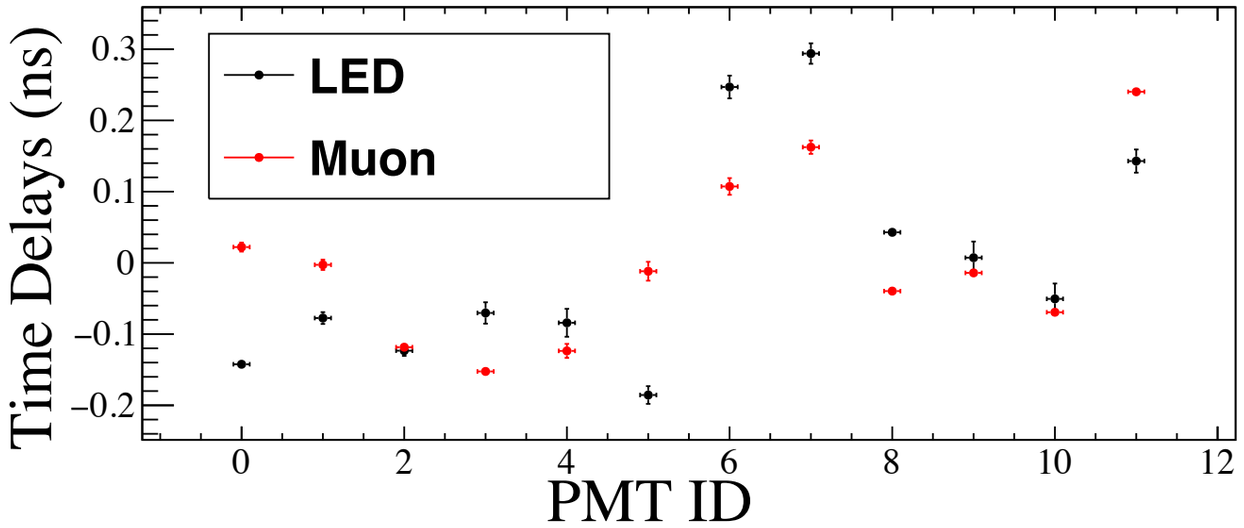
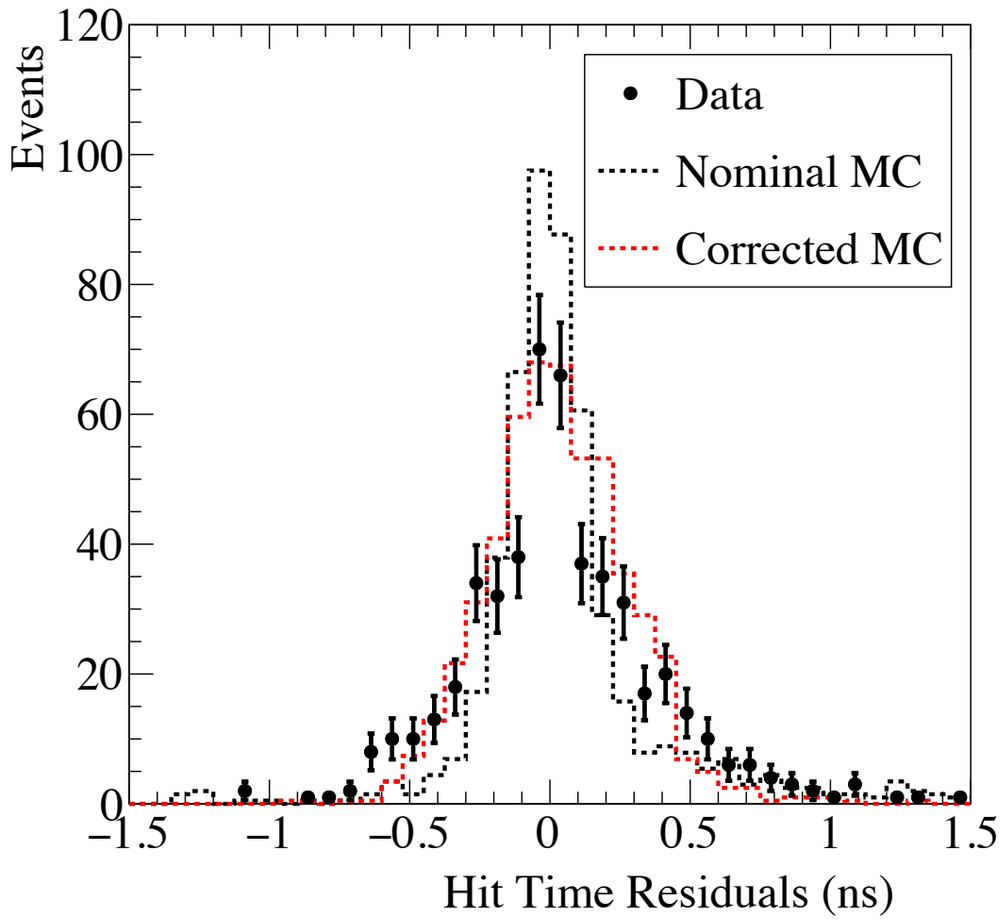
Detailed geometry, material properties, optics, scintillation yield and time profile, DAQ effects (TTS, pulse shapes, electronics noise, SPE…)





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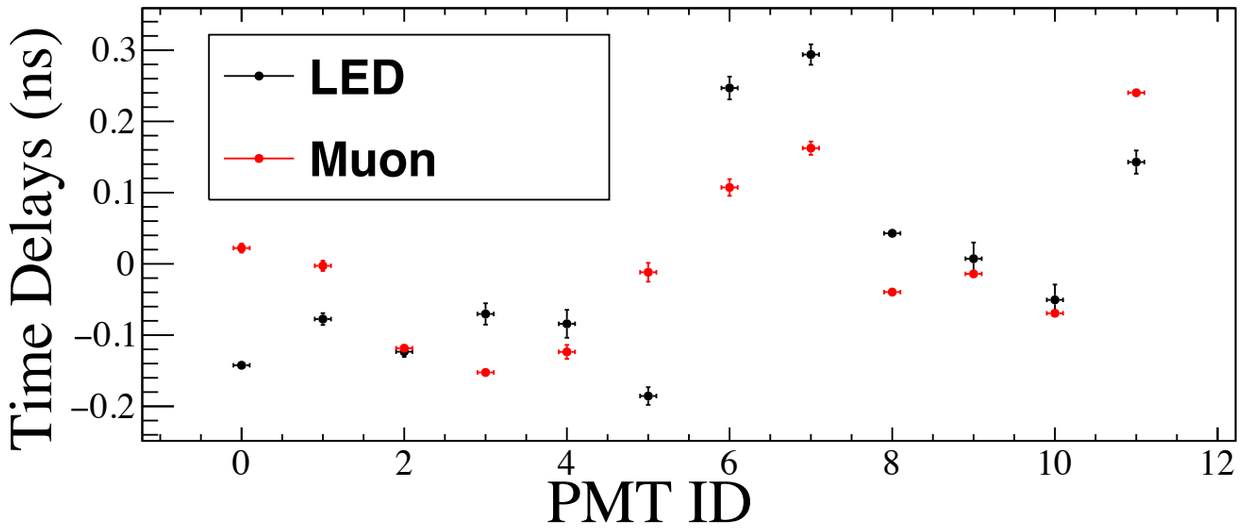

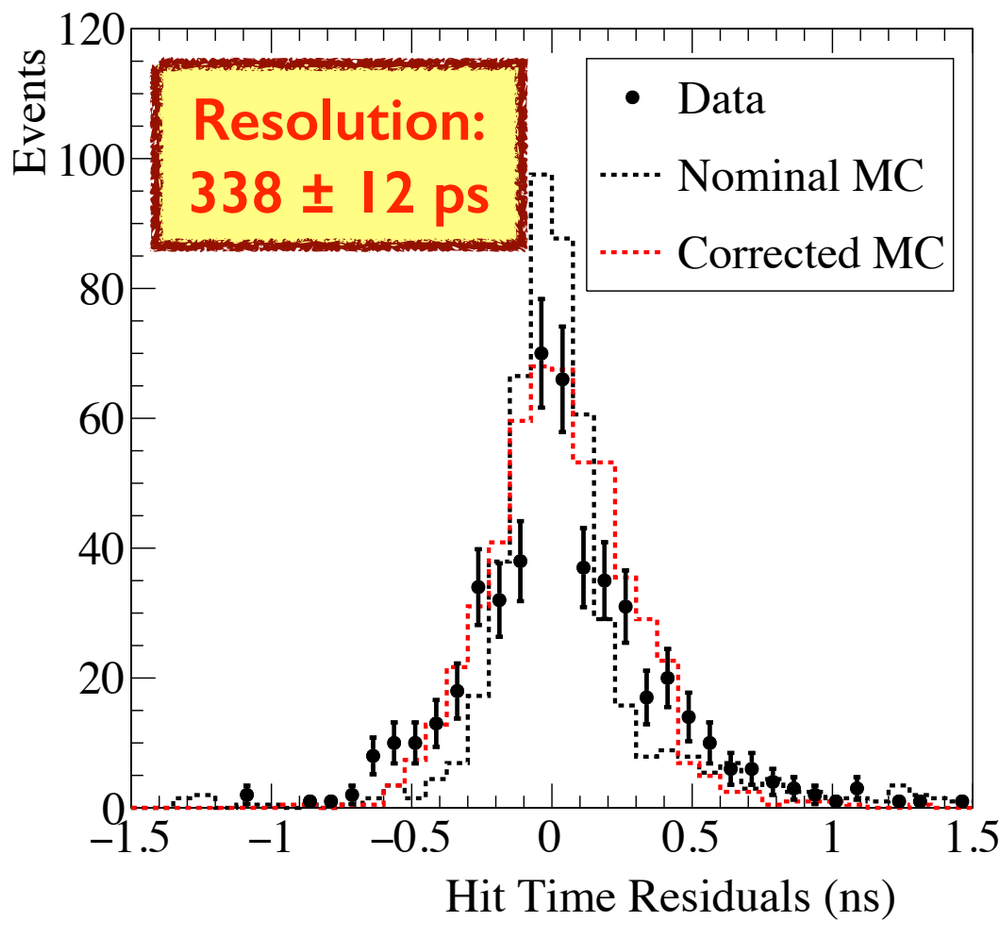

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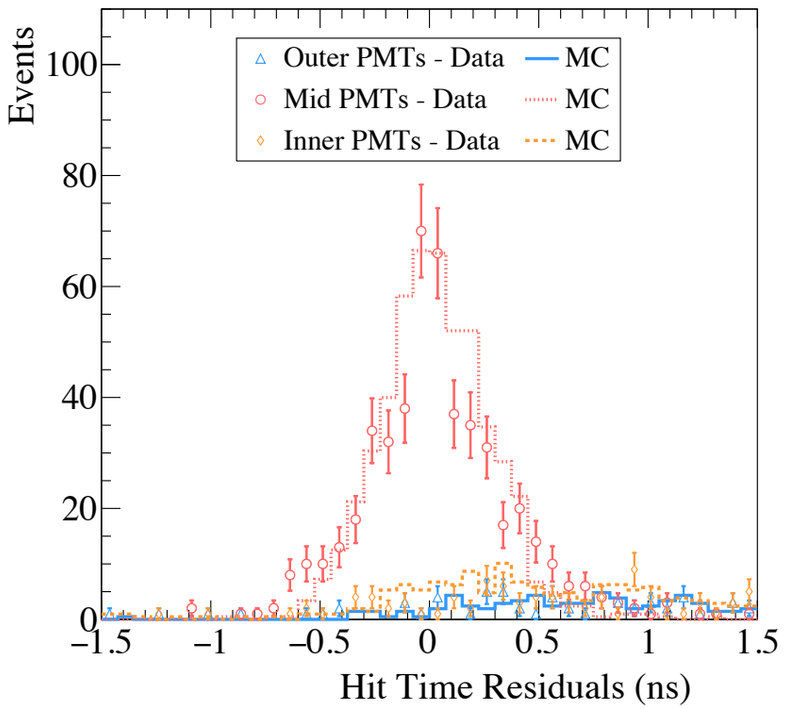
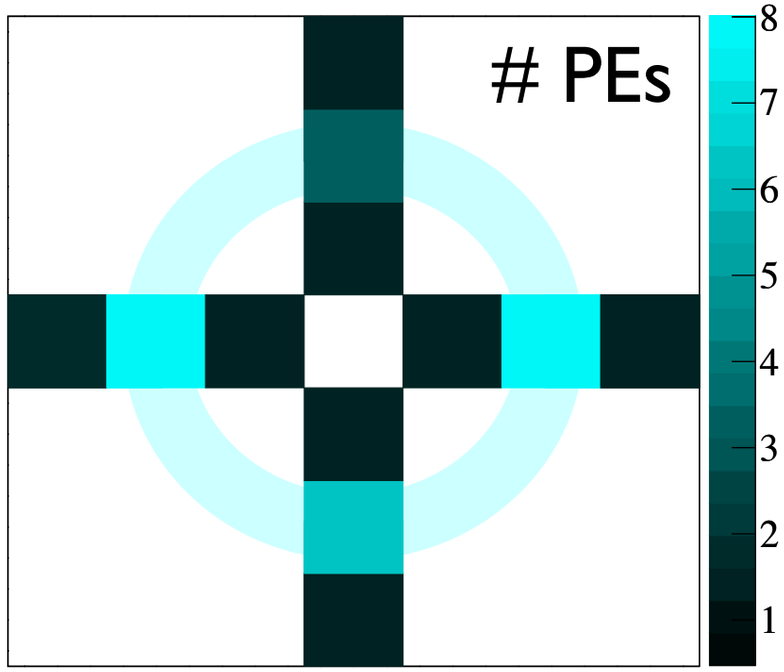
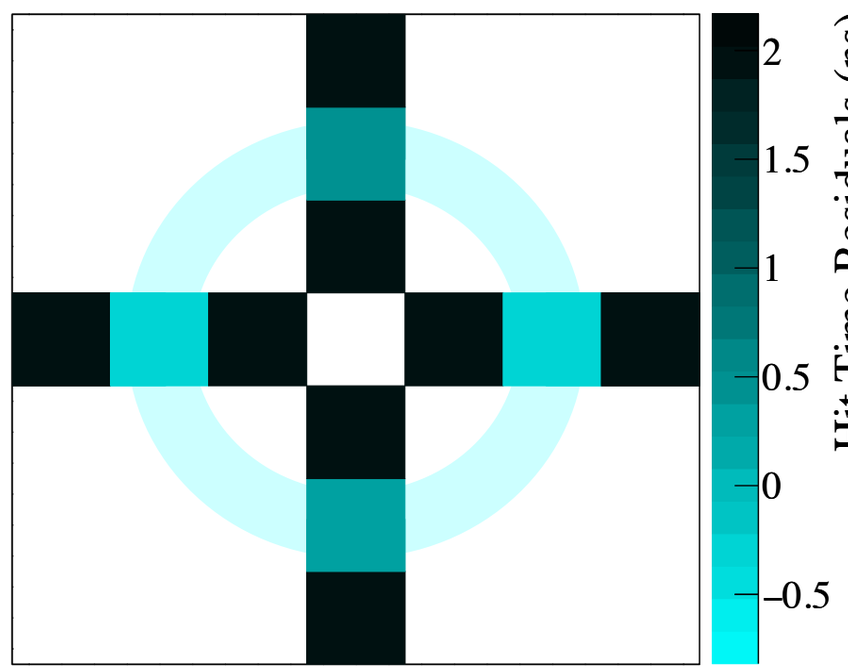
CHESS Water Data

Typical ring candidate event







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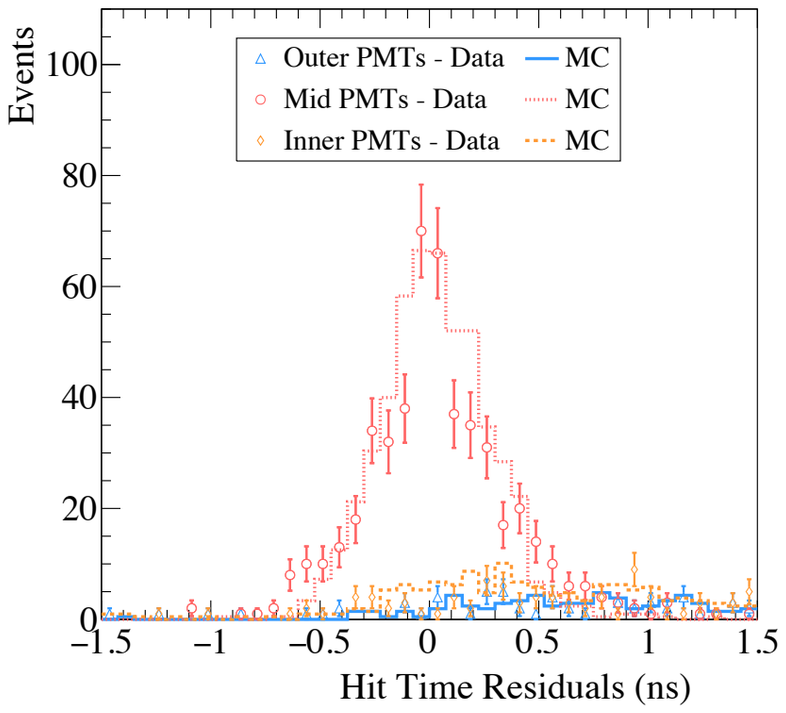
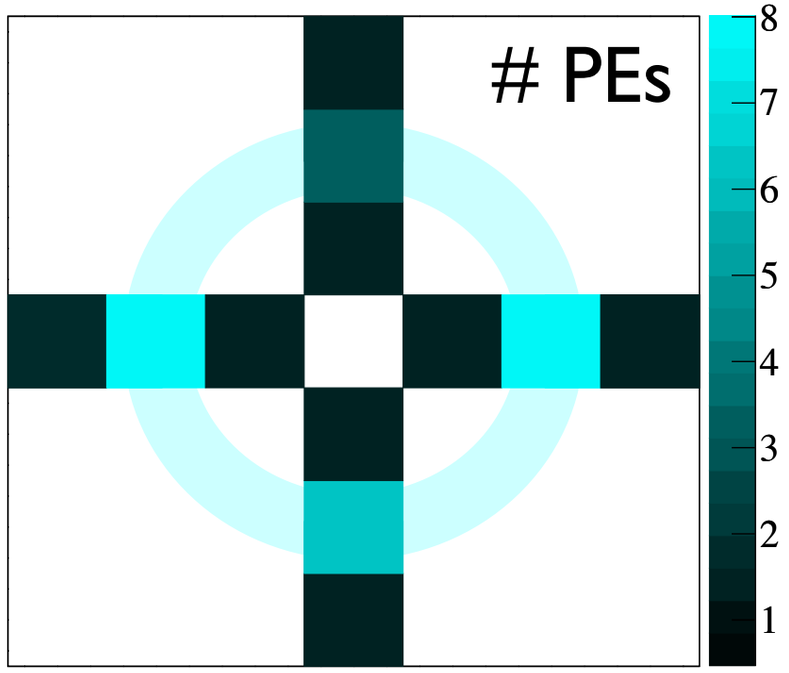
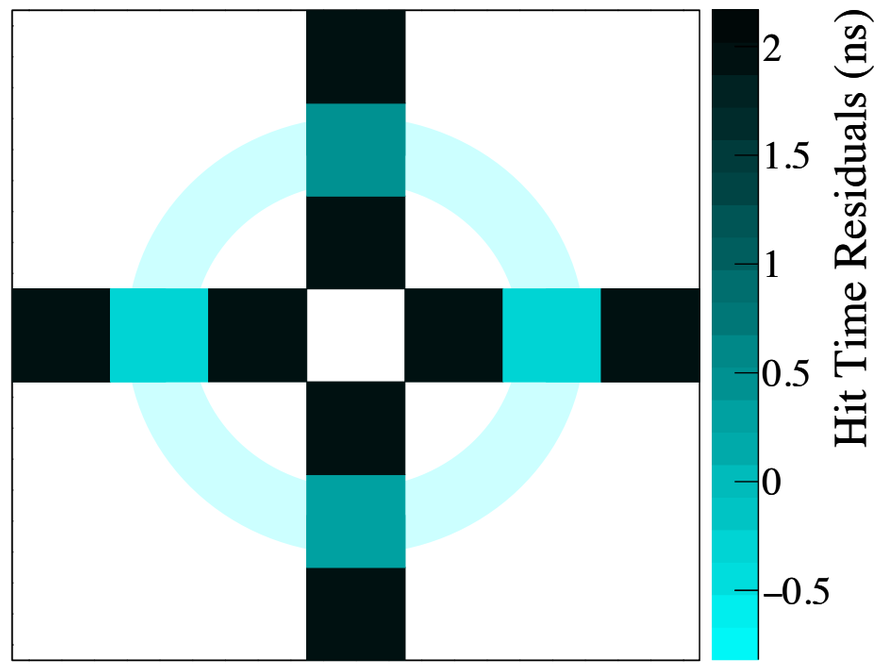
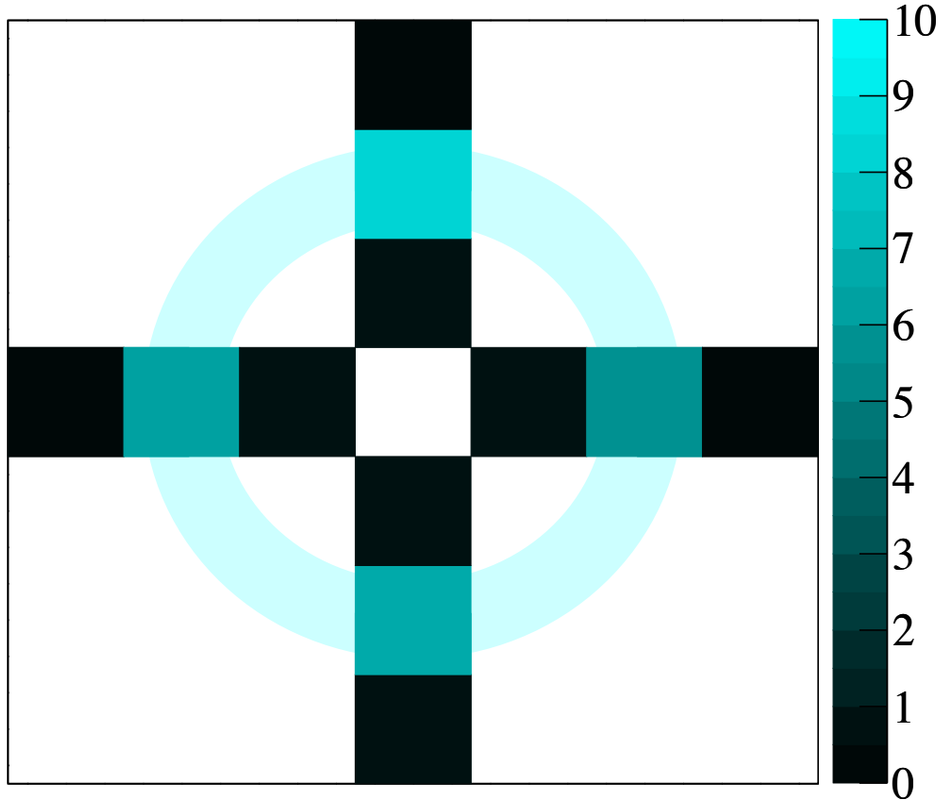
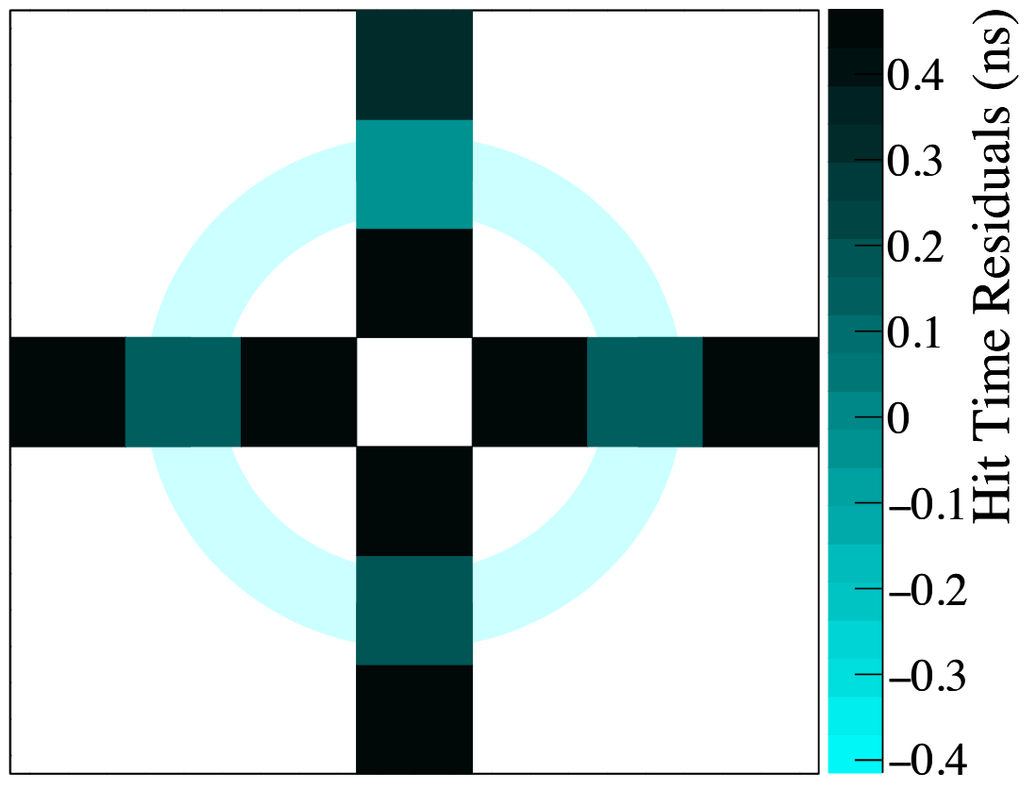








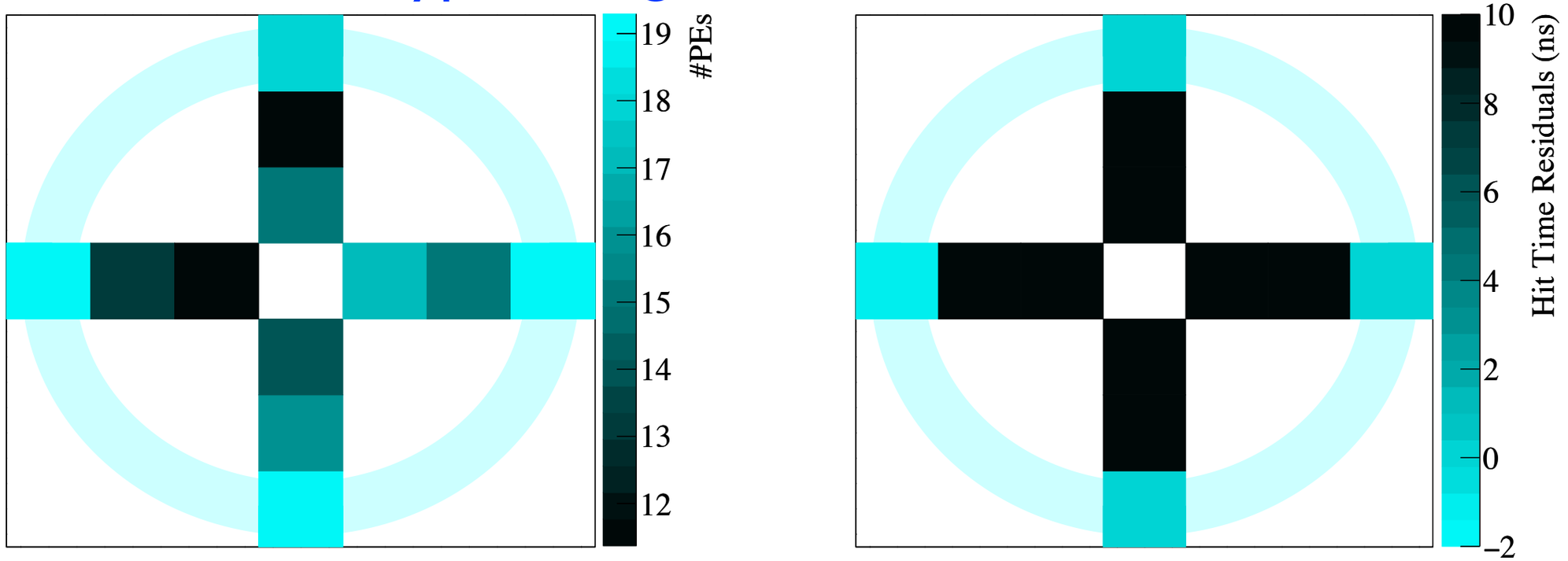
Average across (clean) data set



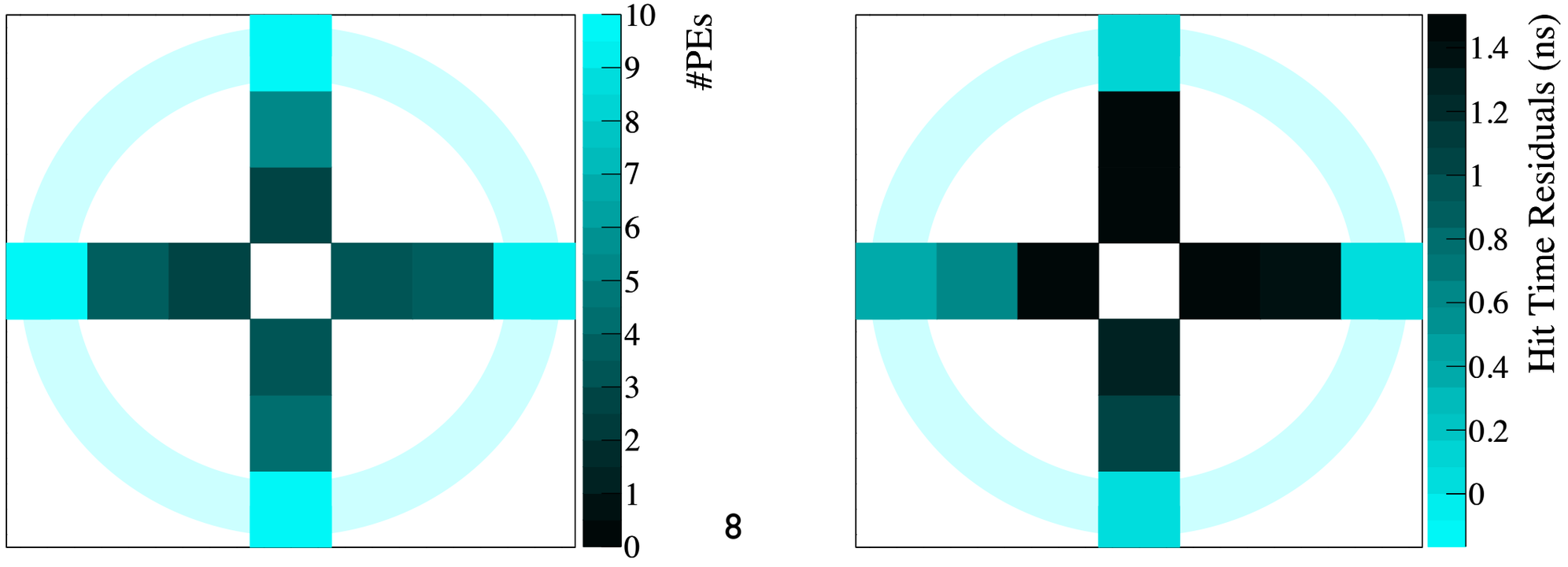
arXiv: 1610.02011

CHESS Results: Pure LAB

Typical ring candidate event



Average over data set (117 events)



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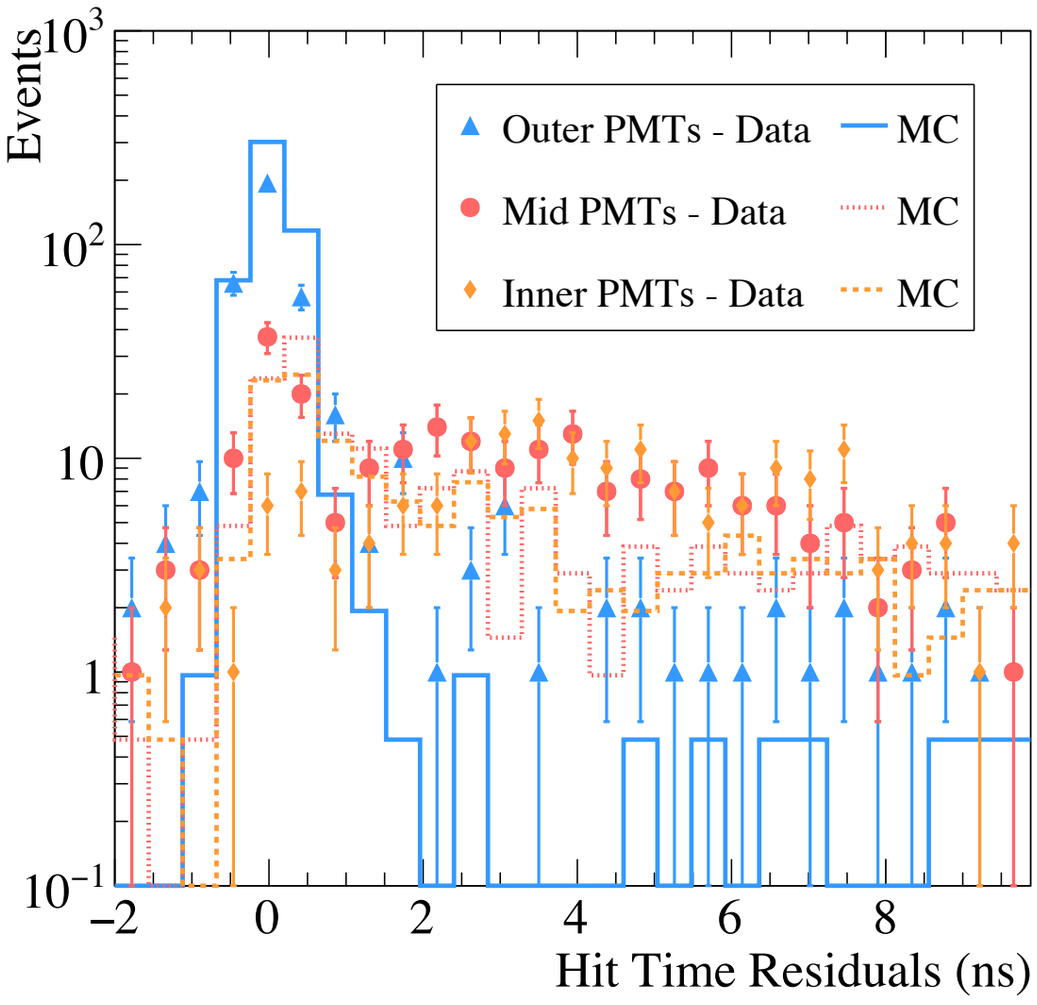
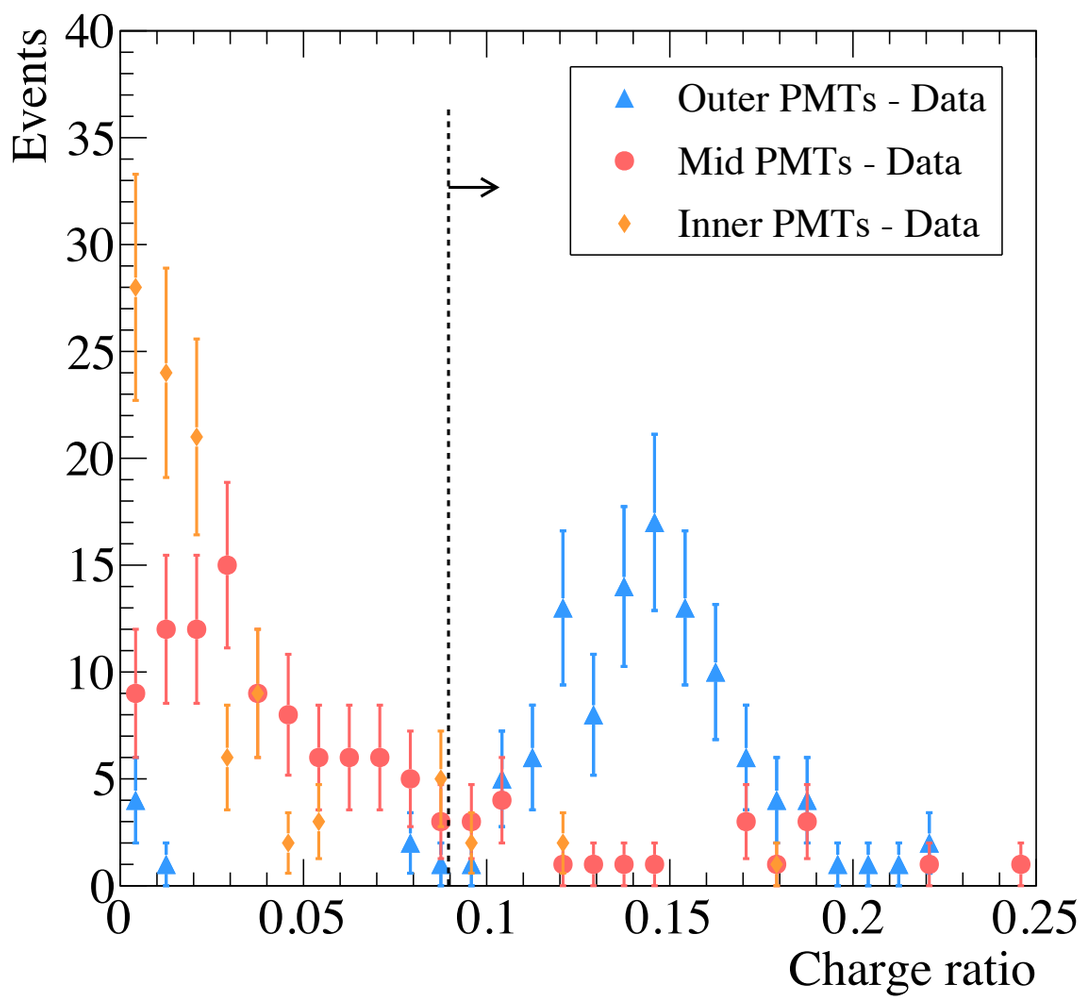
Separation in Pure LAB



Time at fixed threshold
Corrected by ToF, channel delays



Ratio of charge in prompt, 5ns window
to charge in total (135ns) window

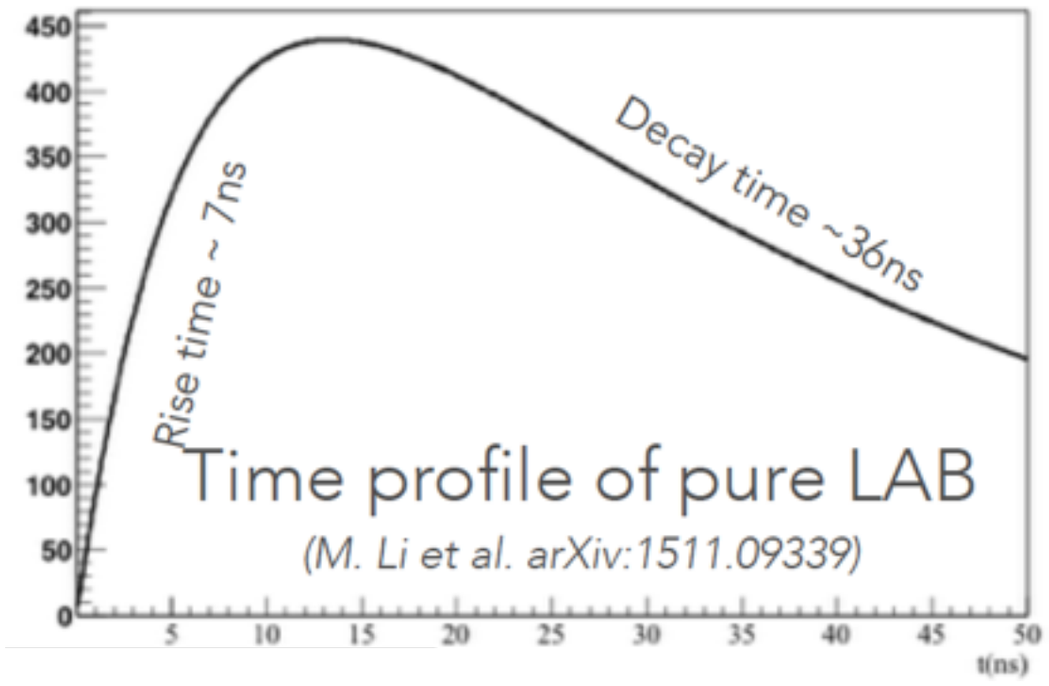
arXiv: 1610.02029

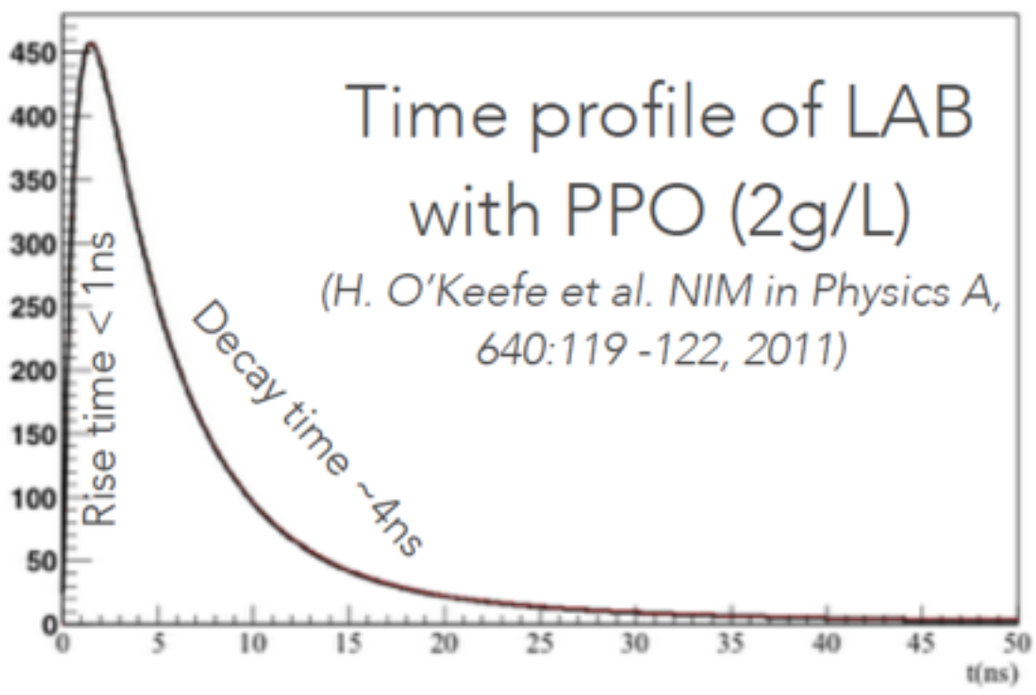
Addition of Fluor

Addition of PPO to LAB (at 2g / L)

- Increases light yield by ~ factor of 10
- Shortens scintillation time profile significantly

⇒ Separation more challenging in both charge and time





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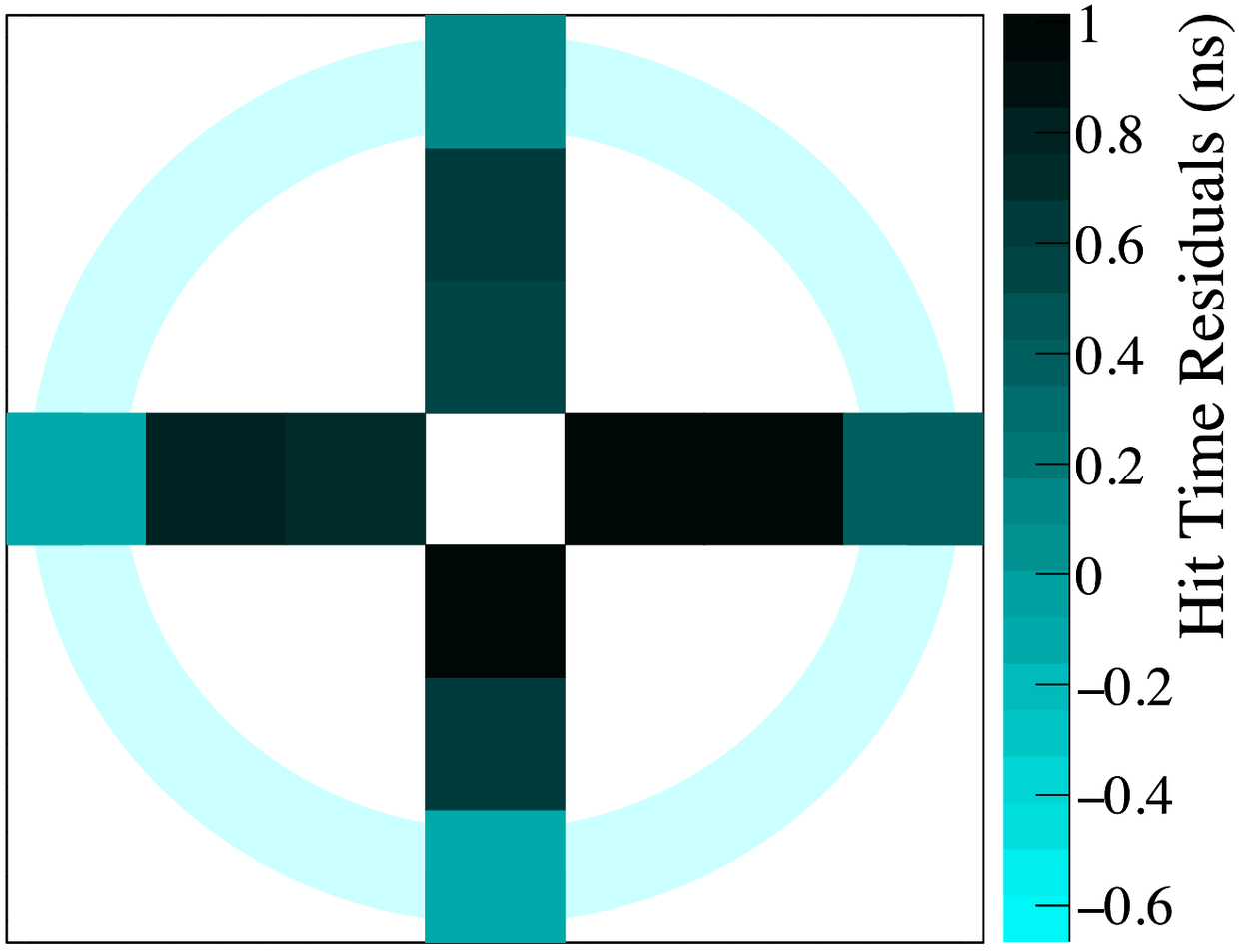
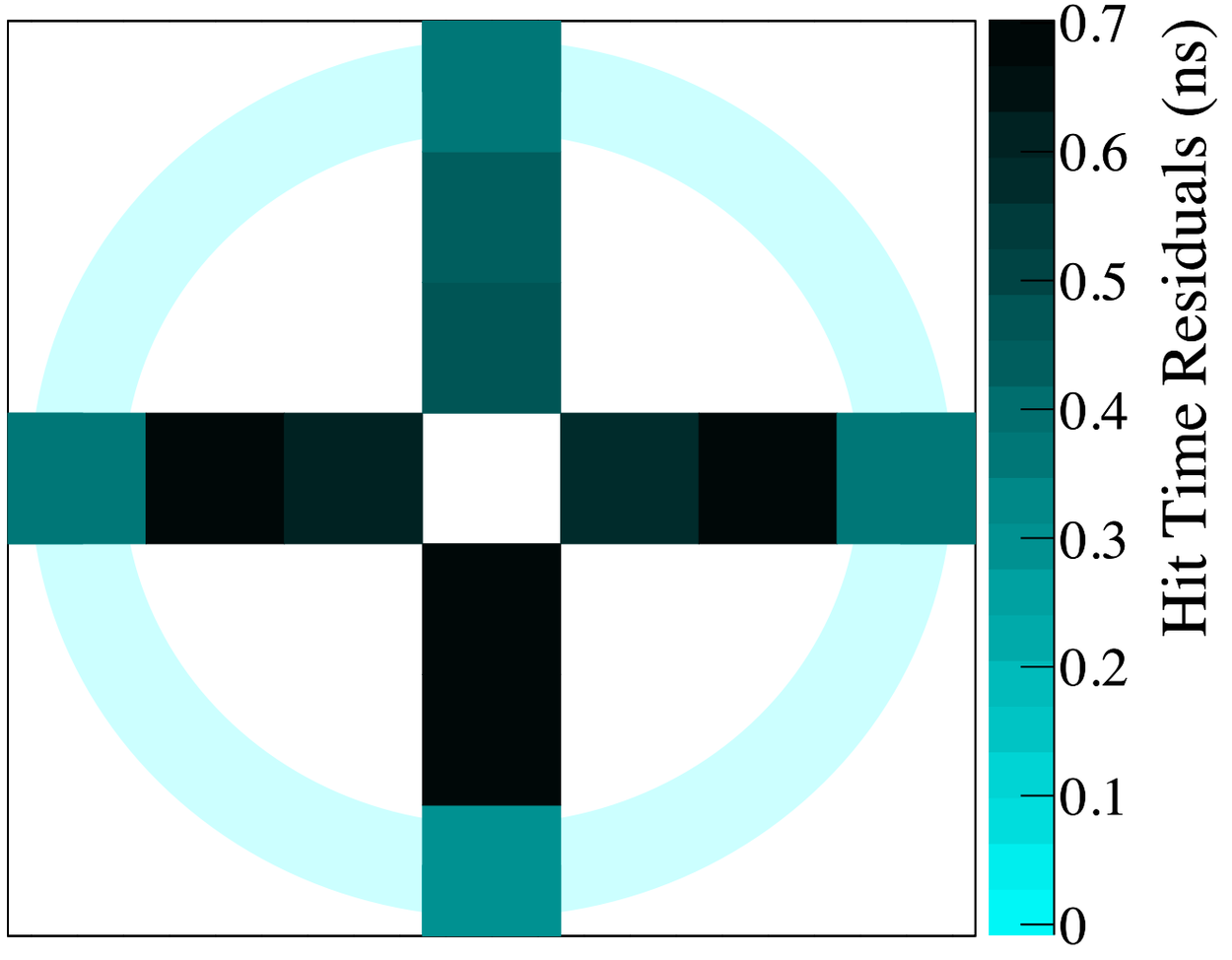


Average over data set (103 events)



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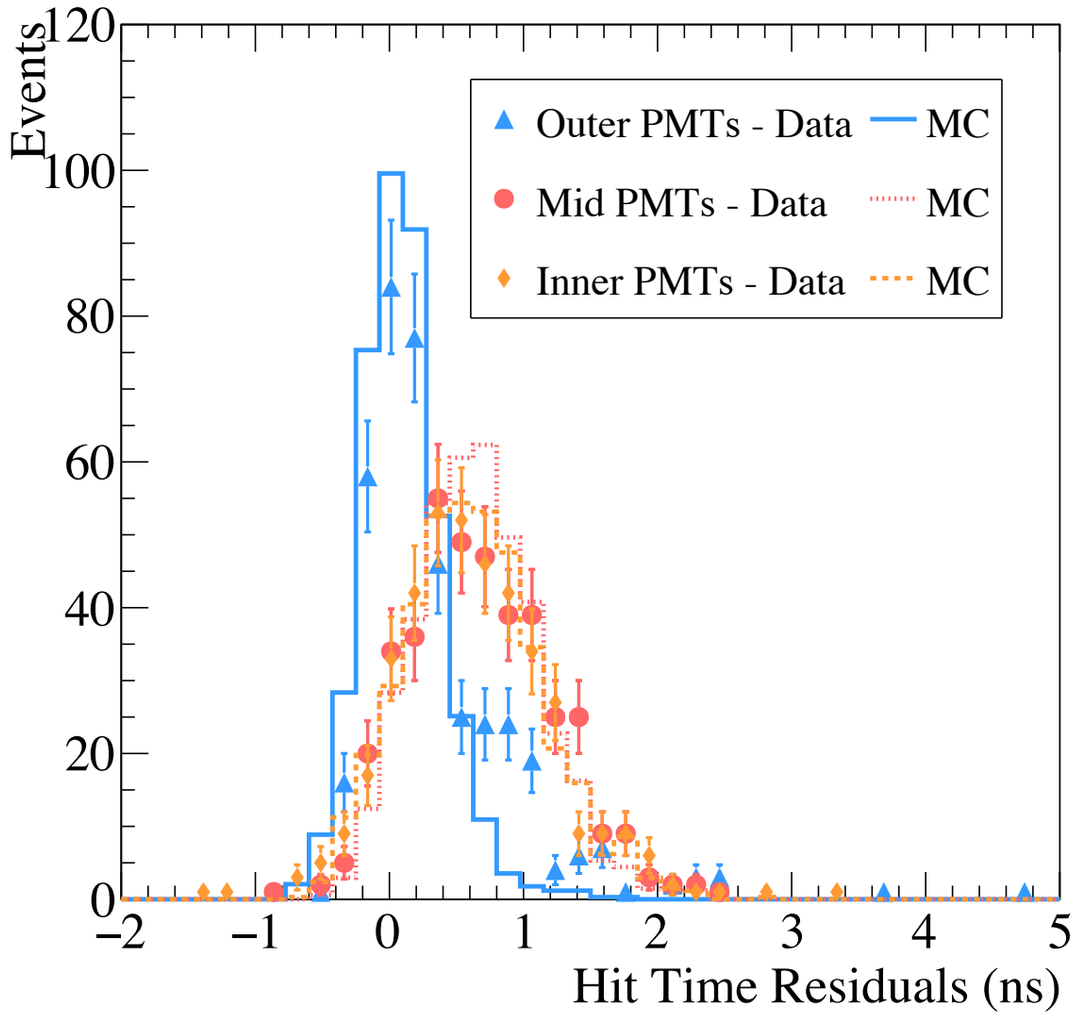

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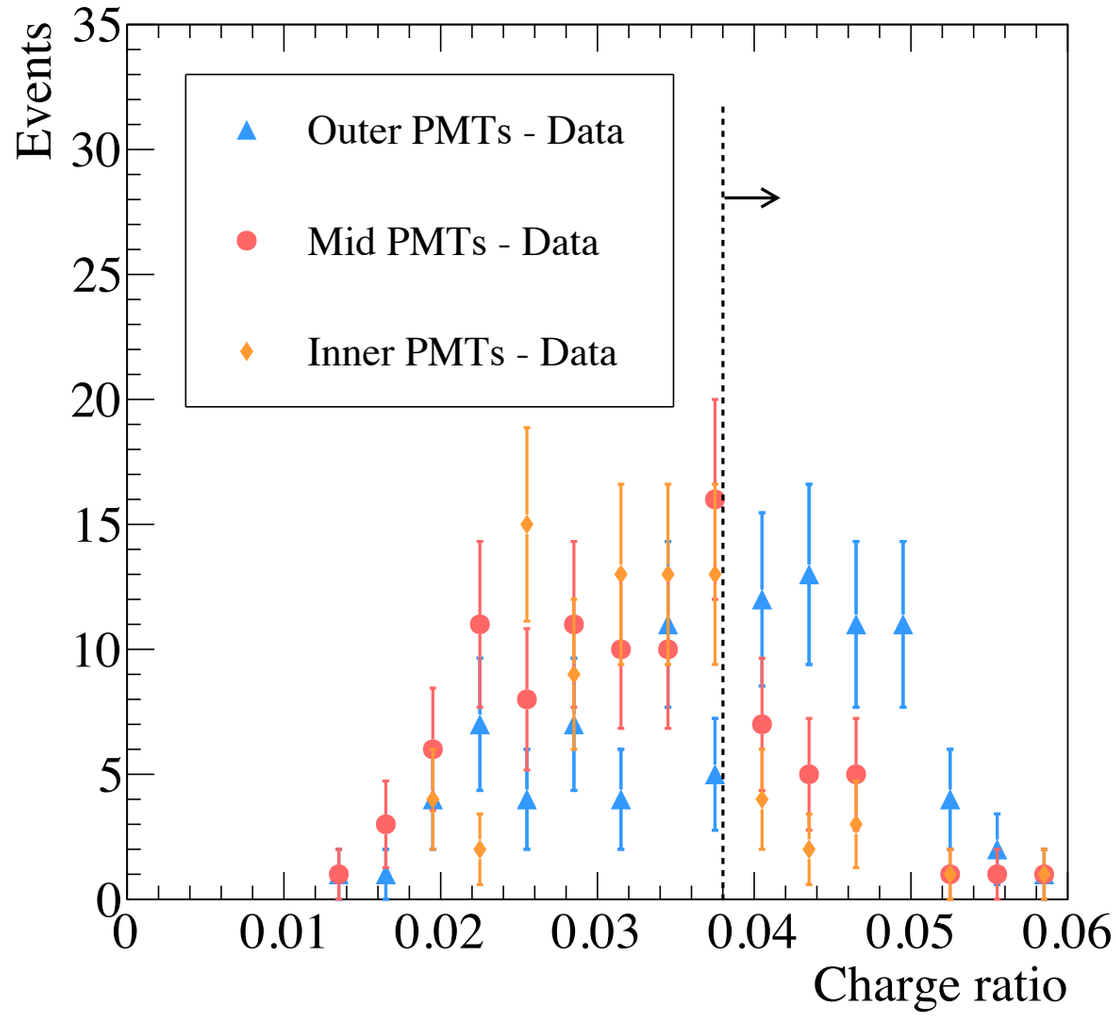

Ratio of charge in prompt, 5ns window
to charge in total (135ns) window

NOTE: Rise time = 0.75 ± 0.25 ns

arXiv: 1610.02011

CHESS Separation

Apparatus designed such that Cherenkov ring falls on "outer" PMTs
Expect ~5-10 PEs per outer PMT due to Cherenkov photons

⇒ Hit-time of outer PMTs is due to Cherenkov photon

Hit-time of inner / middle PMTs is due to scintillation
Define a threshold (in hit time or Qratio) to calculate separation

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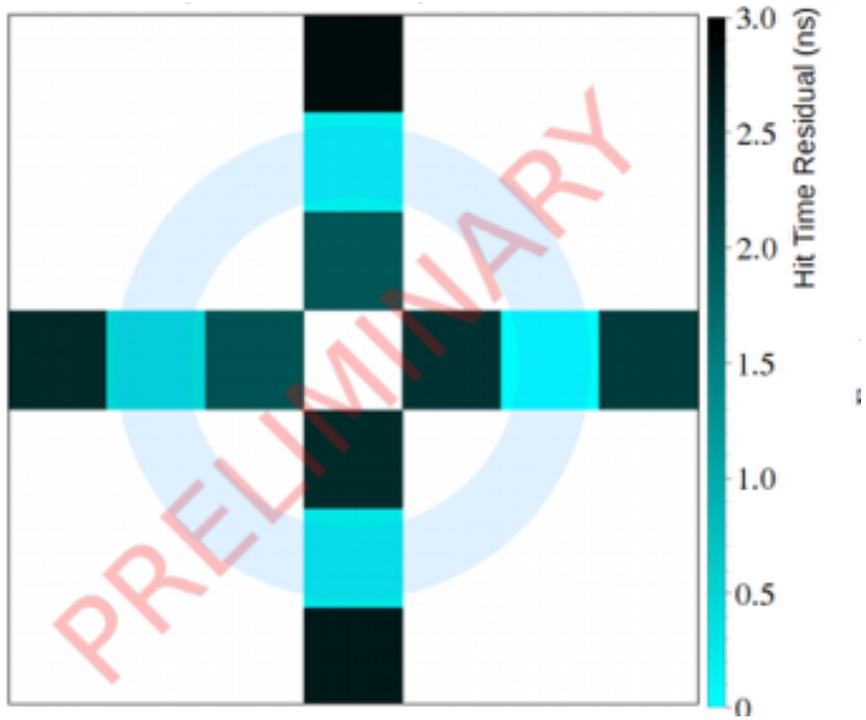
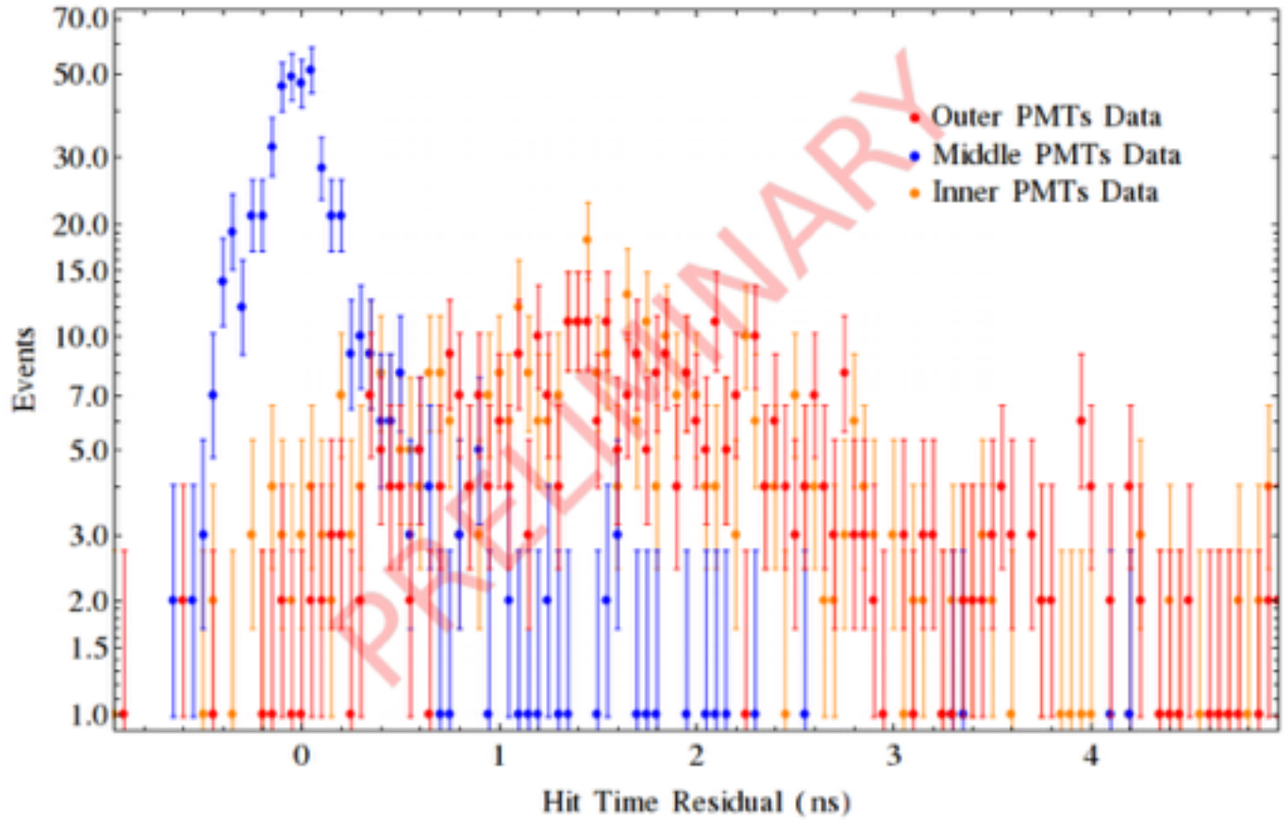
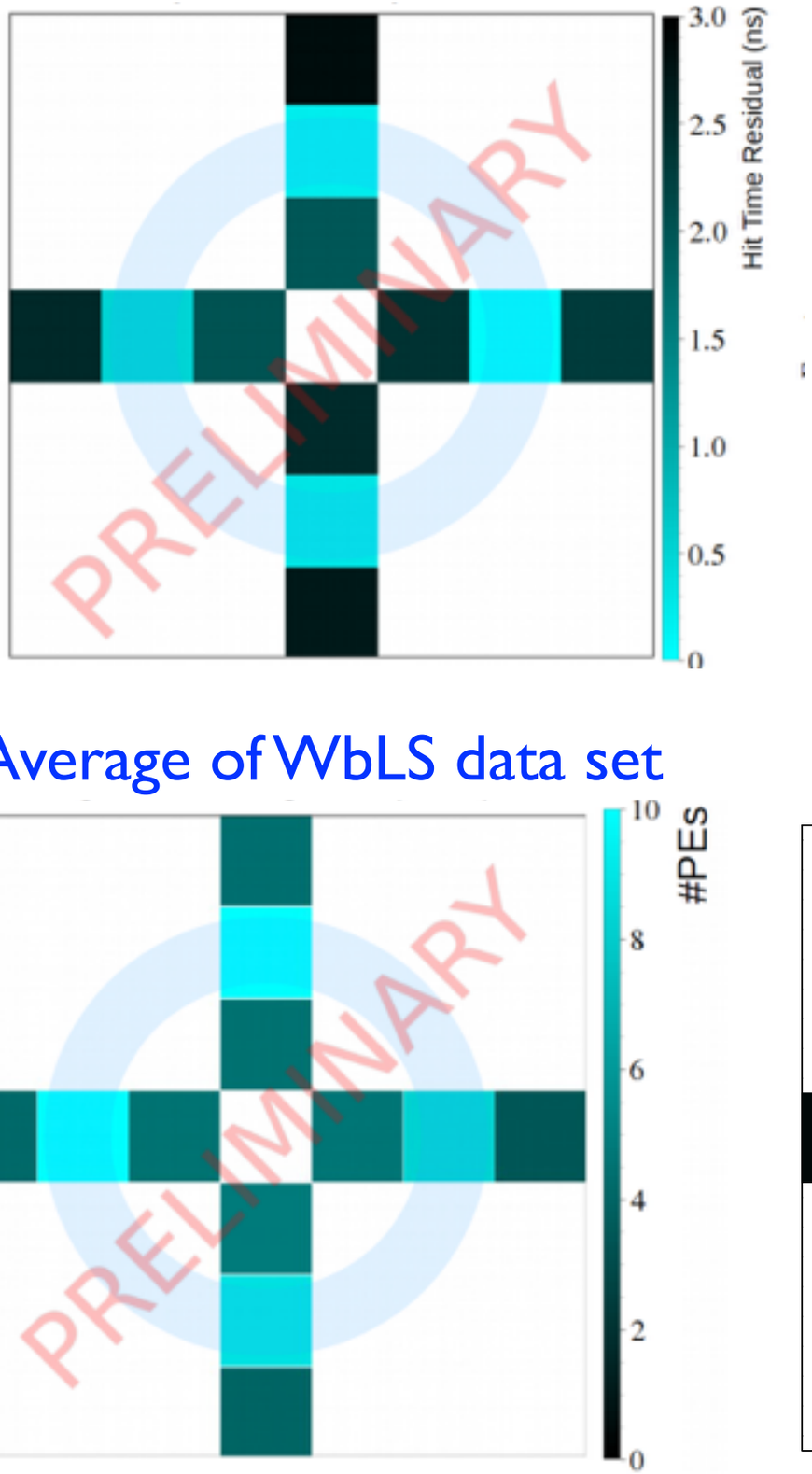
	LAB Time-based	LAB Charge-based	LAB/PPO Time-based	LAB/PPO Charge-based
Cherenkov detection efficiency	83 ± 3 %	96 ± 2 %	70 ± 3 %	63 ± 8 %
Scintillation contamination	11 ± 1 %	6 ± 3 %	36 ± 5 %	38 ± 4 %

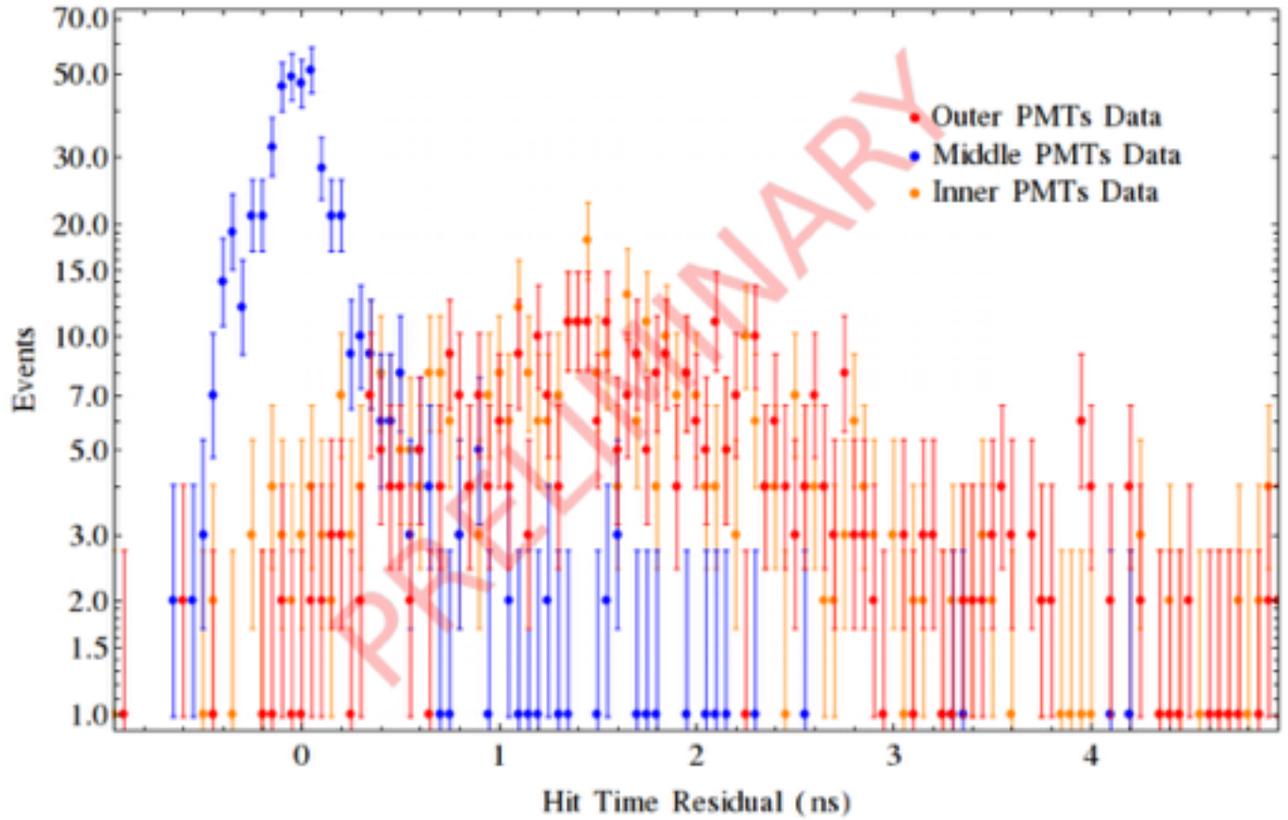
CHESS Results: 1% WbLS





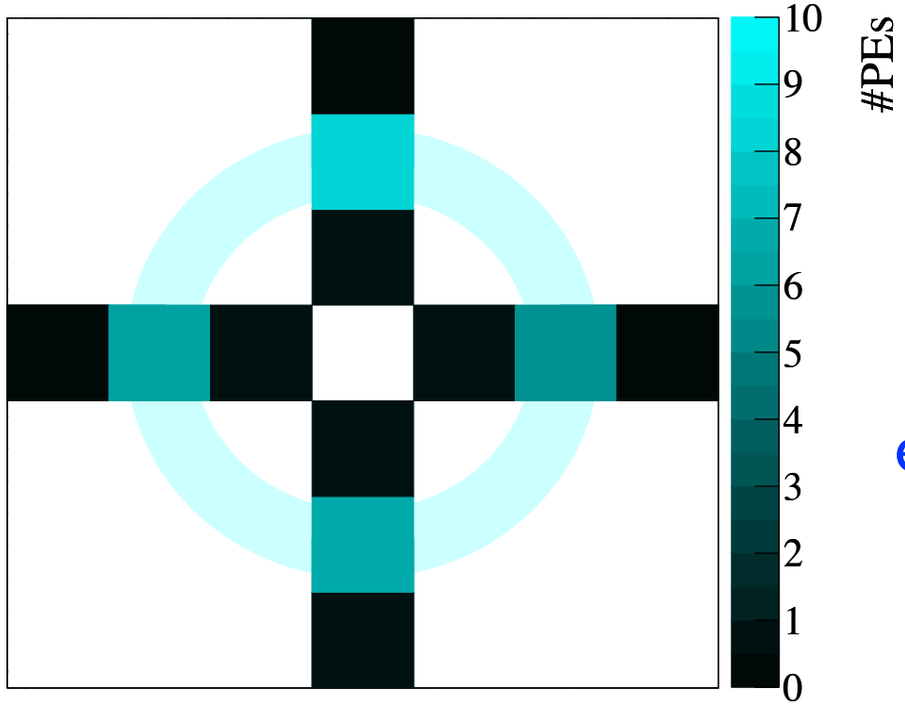
CHESS Results: 1% WbLS





Average of WbLS data set

Average of water data set



Charge rings:
Clearly seeing
scintillation light
even at 1% LS fraction

CHESS: Future plans

- Achieved successful detection of Cherenkov component in LAB and LAB + 2g/L PPO

- Full study of Cher / scint separation in WbLS
  - Quantify impact of LS fraction
  - Quantify impact of fluor type & fraction
  - Quantify impact of isotope loading

- Expand setup to include additional measurements
  - Light yield
  - Scintillation timing profile
  - Particle identification capabilities (α-β, β-γ separation)

- Optimize THEIA target using output from these results
  - Physics sensitivity: solar, DSNB, NLDBD

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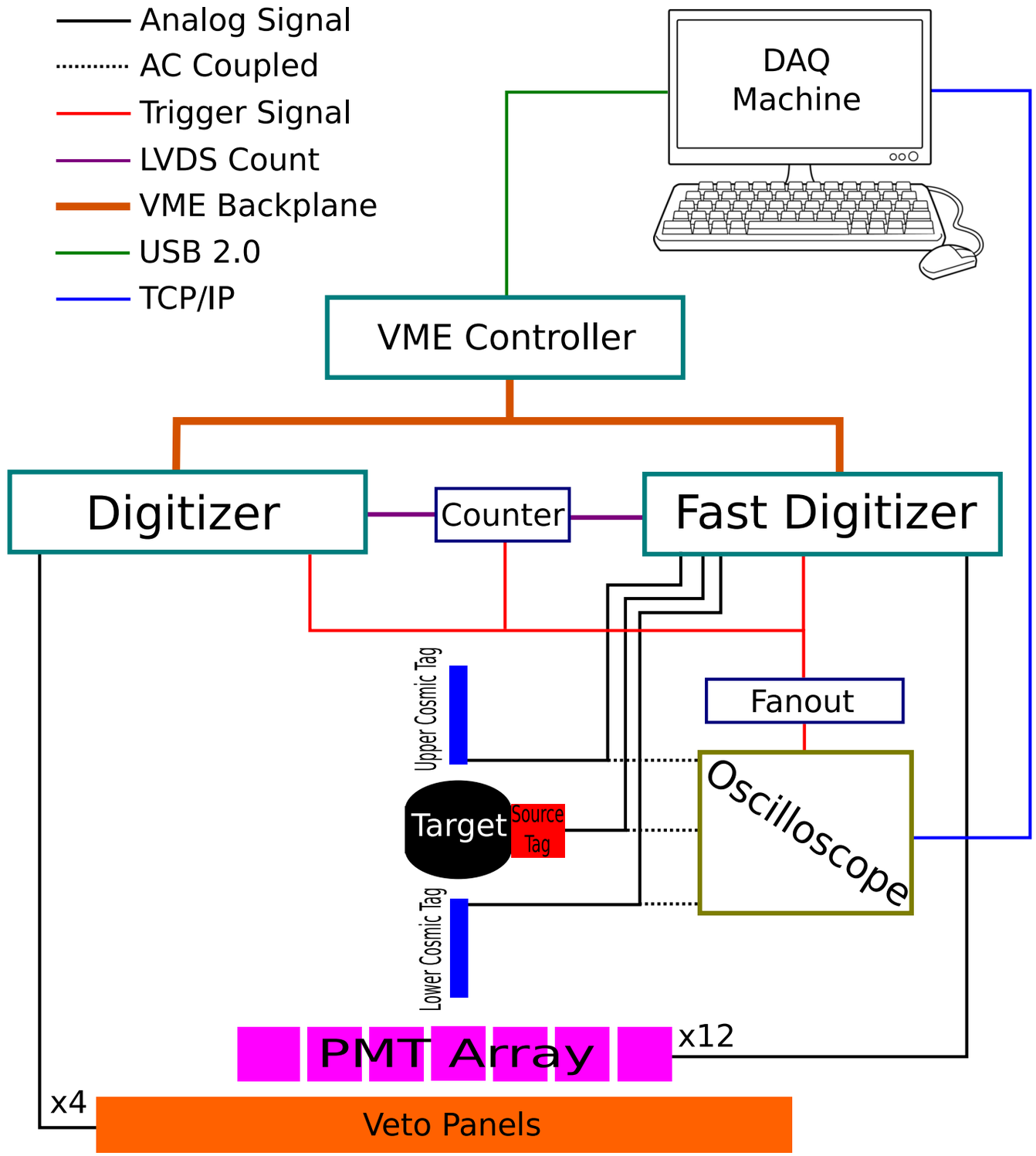
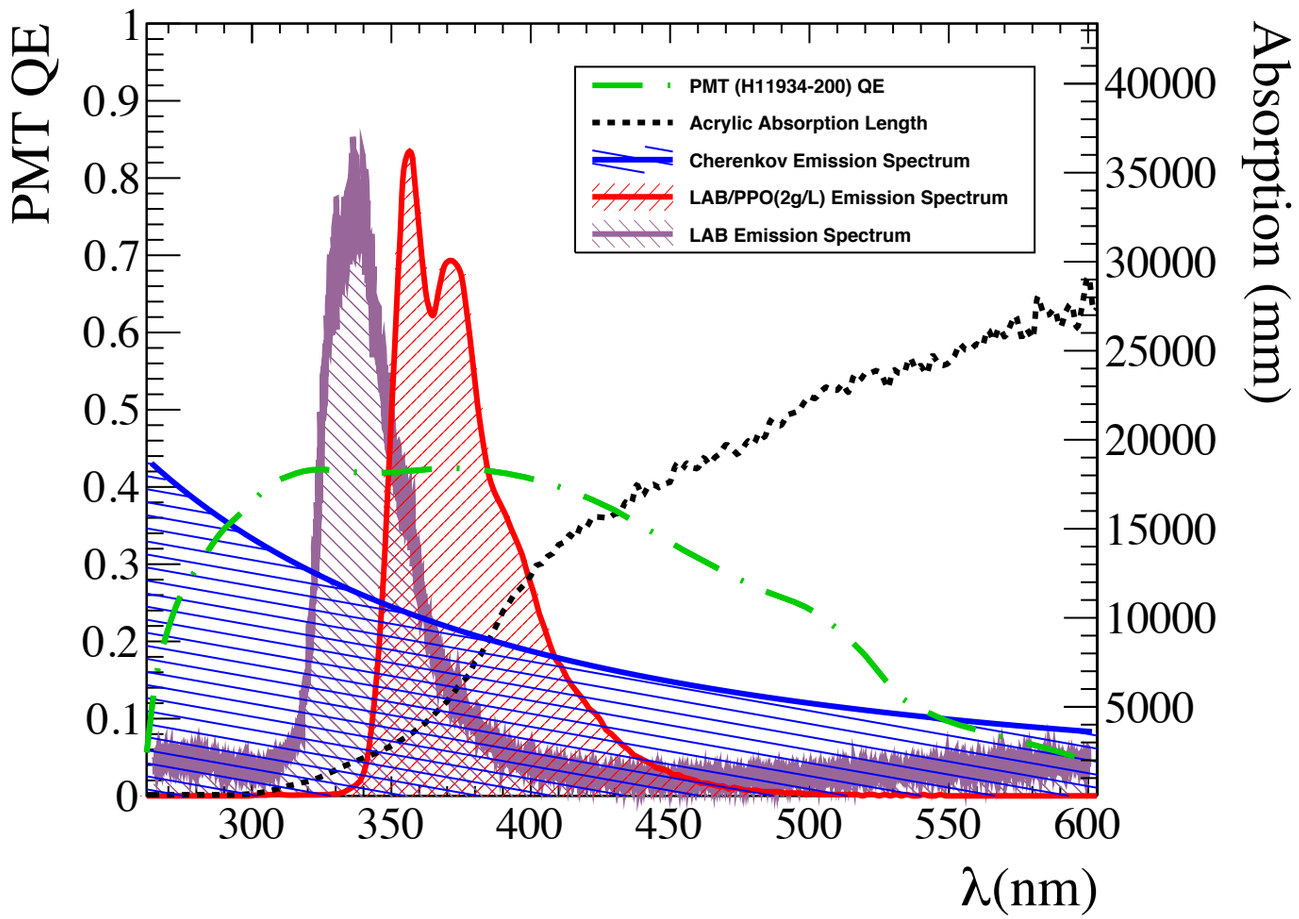
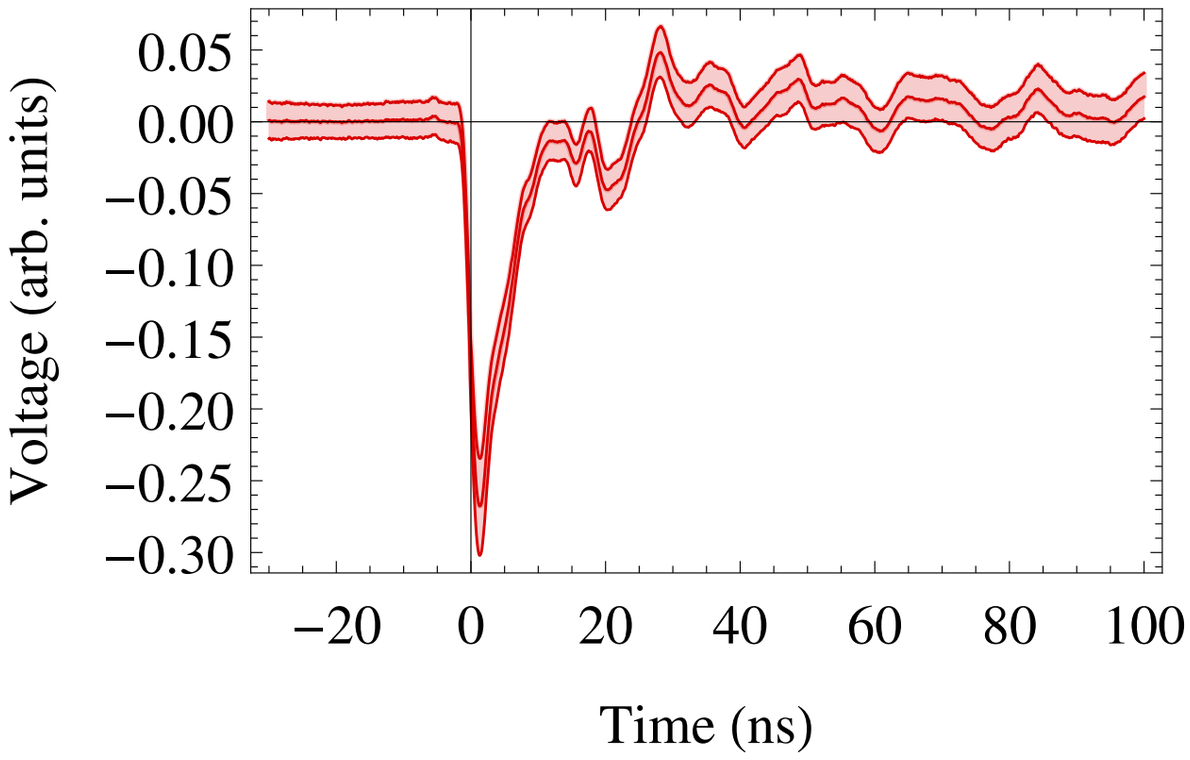
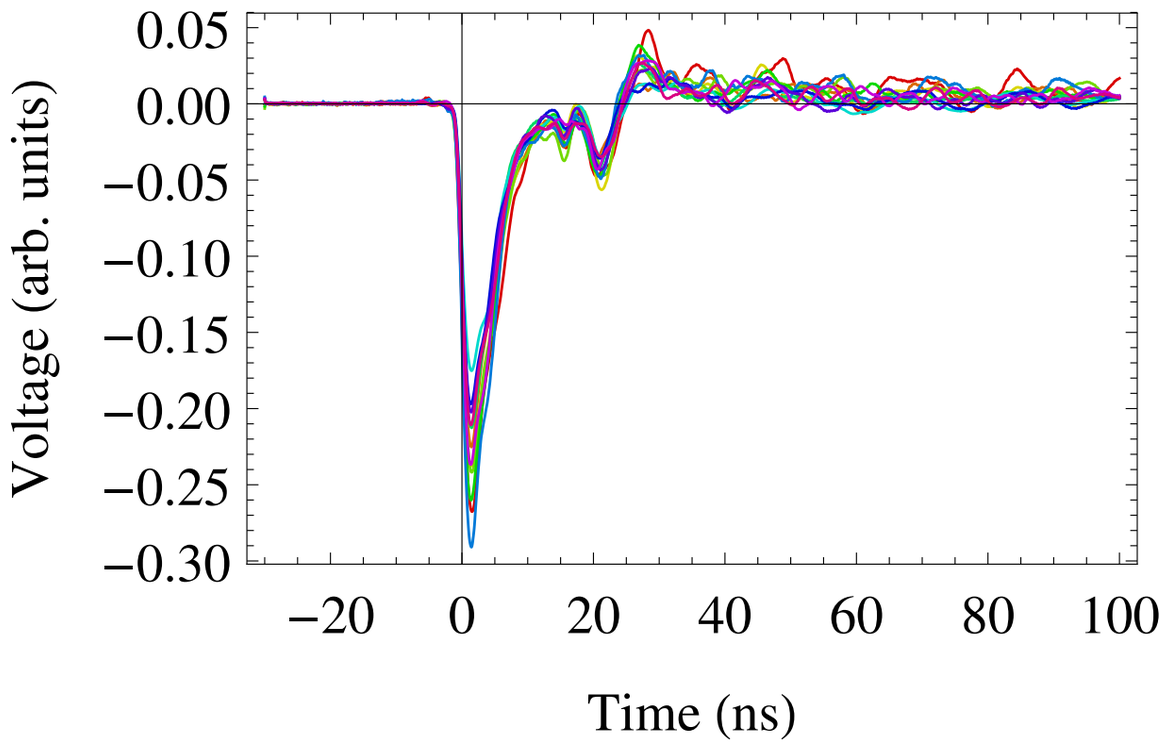
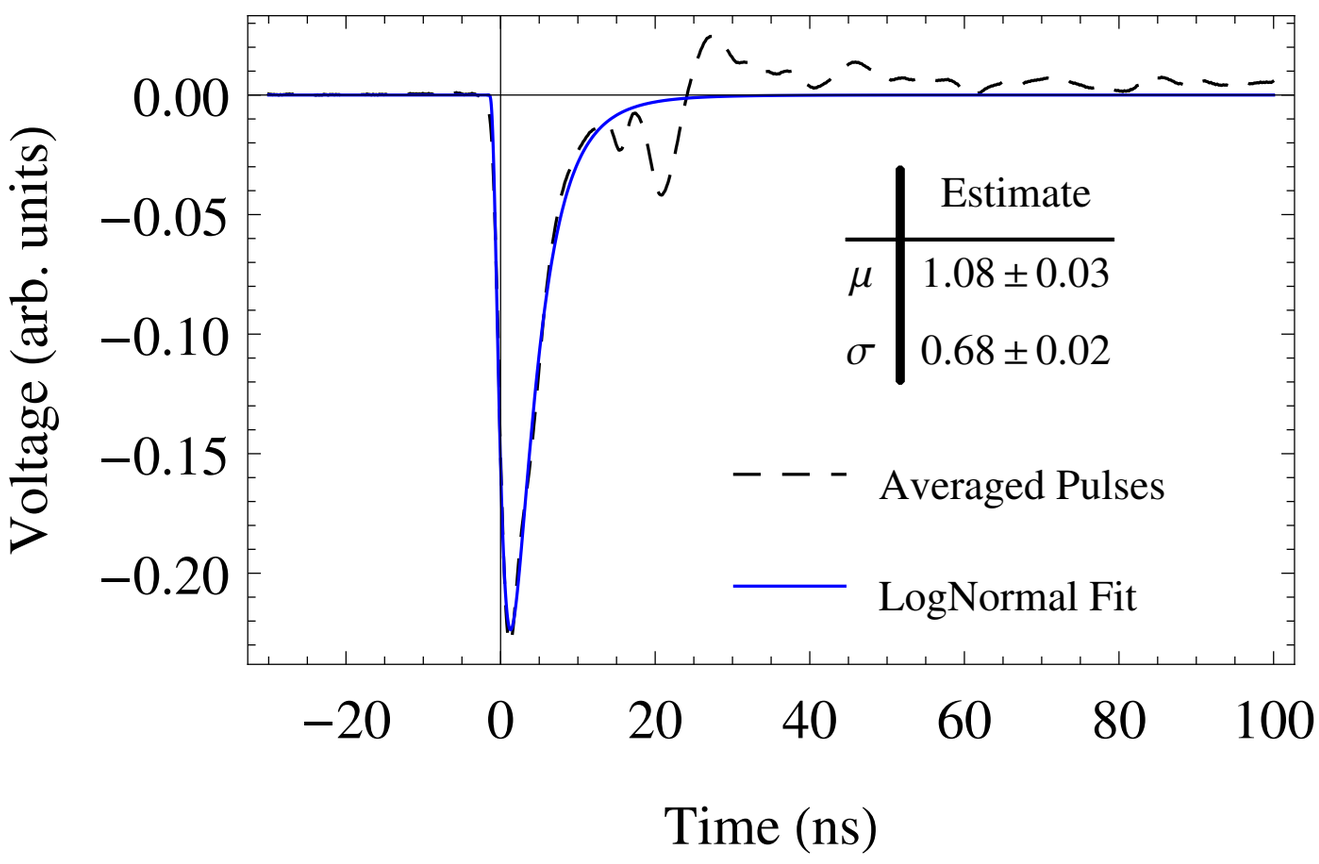
Back up

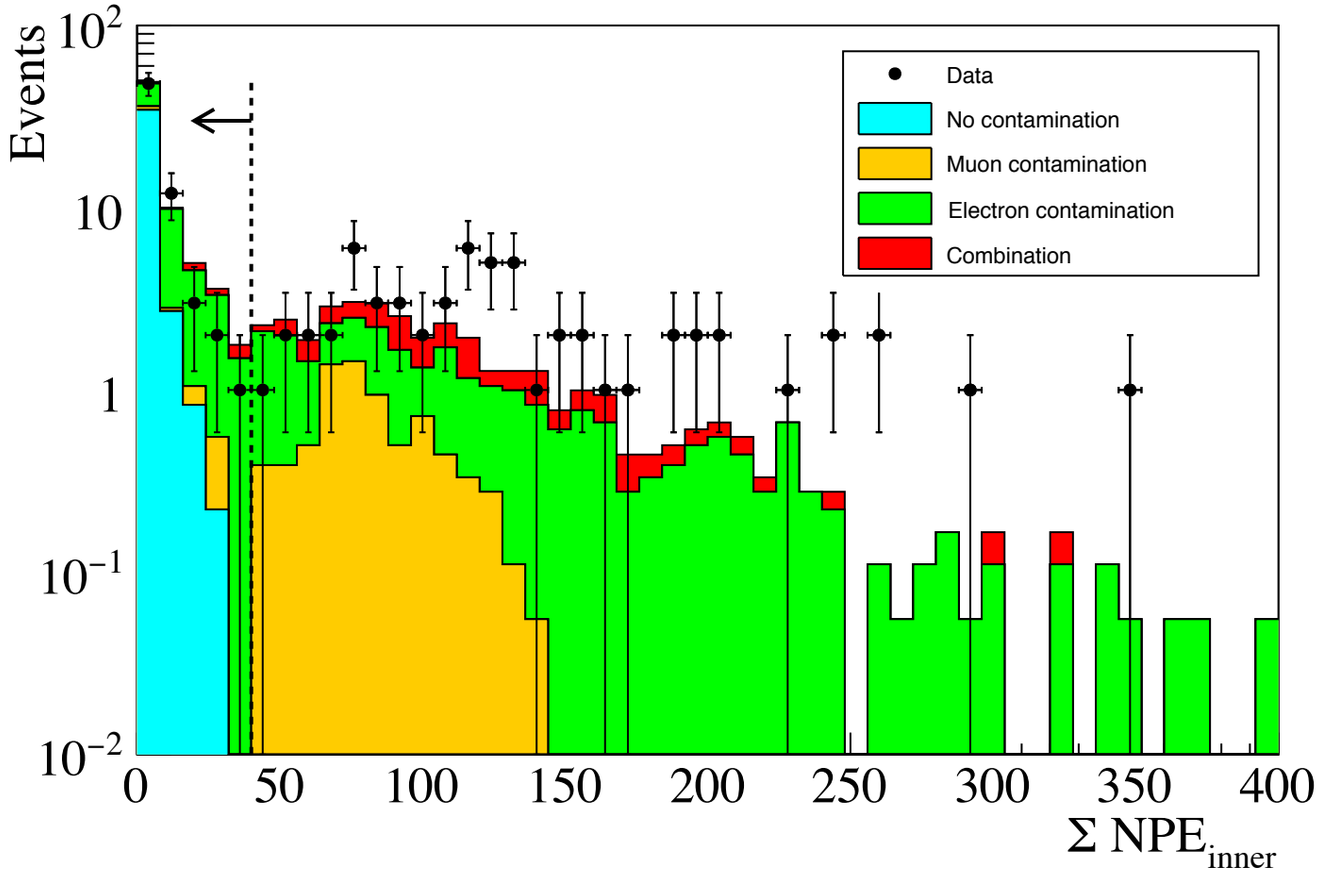

Analog Signal
AC Coupled
Trigger Signal
LVDS Count
VME Backplane
USB 2.0
TCP/IP
DAQ
Machine
VME Controller
Digitizer
Counter
Fast Digitizer
Upper Cosmic Tag
Fanout
Target
Source
Tag
Oscilloscope
Lower Cosmic Tag
PMT Array
x12
x4
Veto Panels

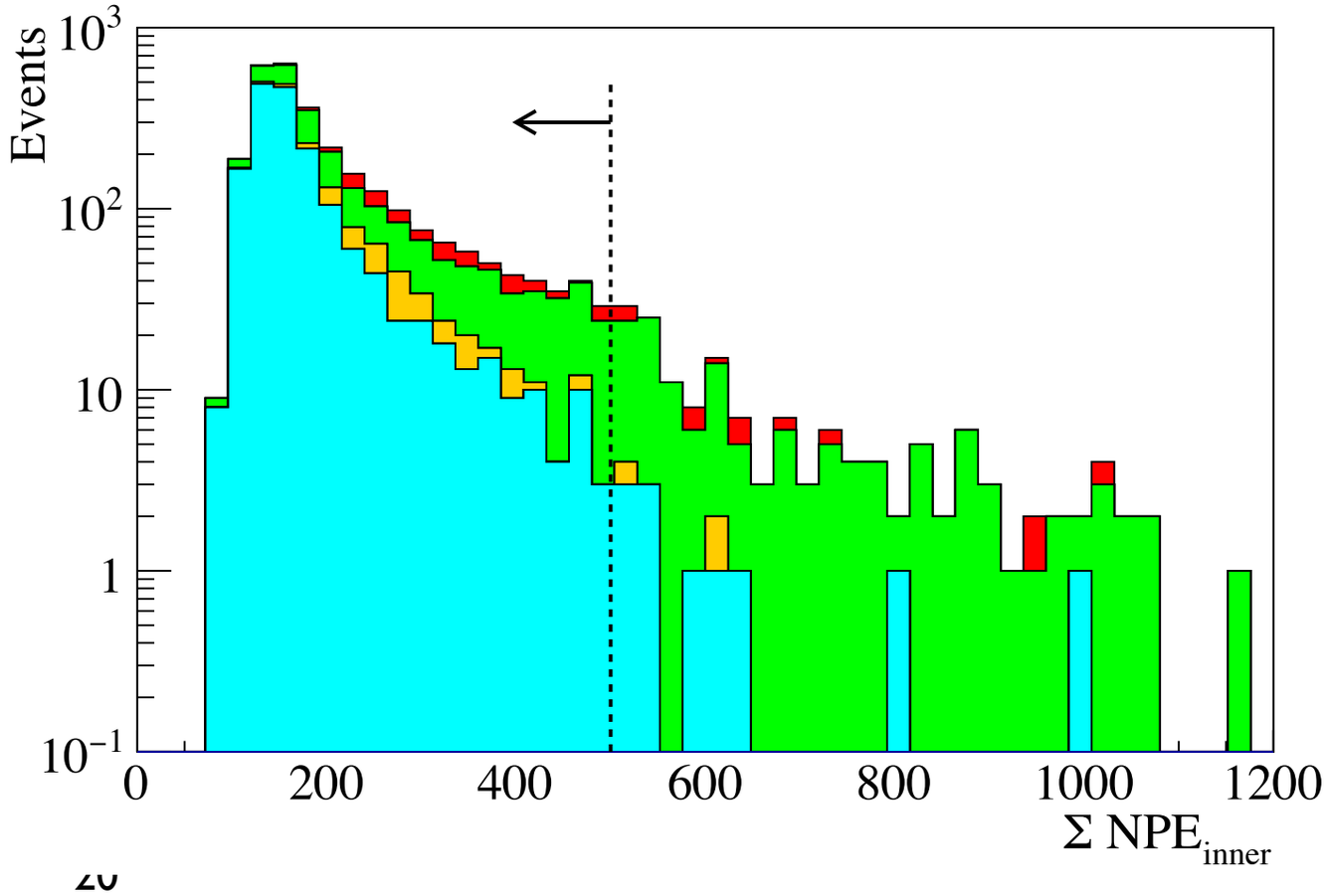

PMT QE
Absorption (mm)
λ(nm)
PMT (H11934-200) QE
Acrylic Absorption Length
Cherenkov Emission Spectrum
LAB/PPO(2g/L) Emission Spectrum
LAB Emission Spectrum
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
40000
35000
30000
25000
20000
15000
10000
5000
300
350
400
450
500
550
600

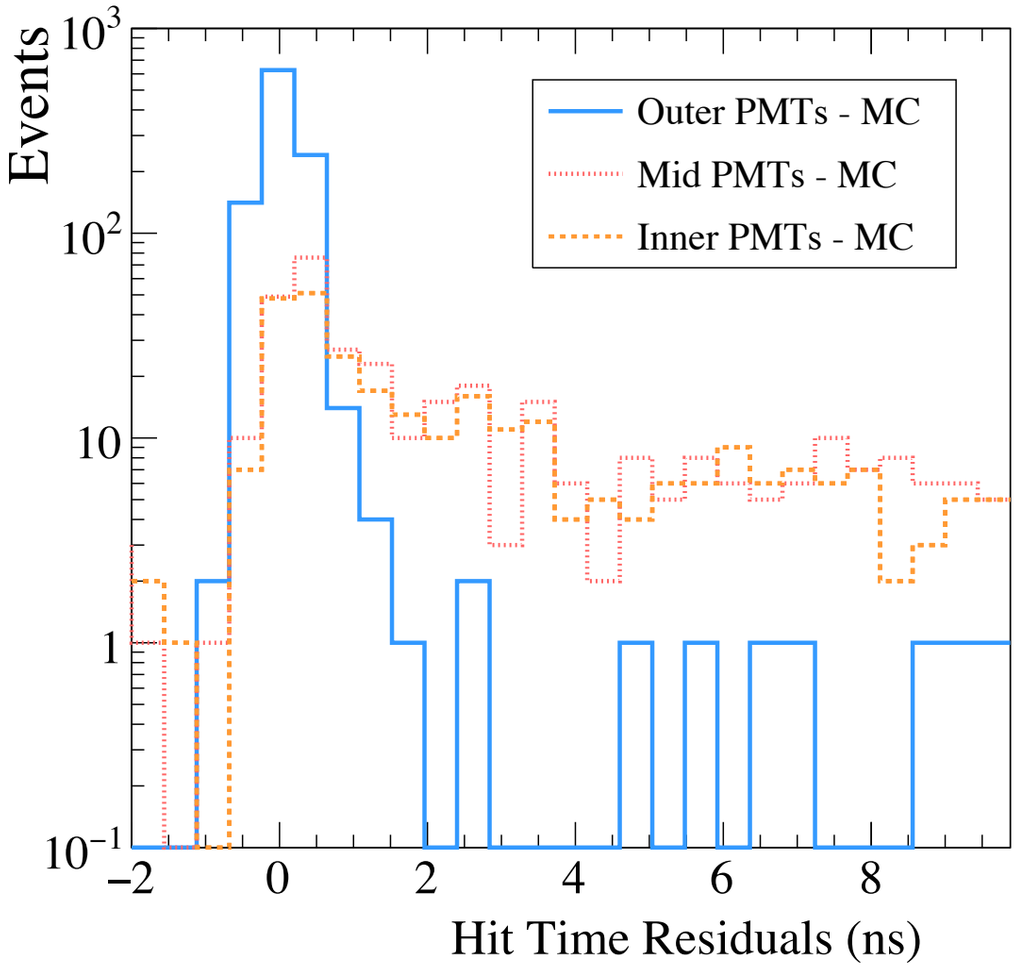

Voltage (arb. units)
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
−20
0
20
40
60
80
100
Time (ns)

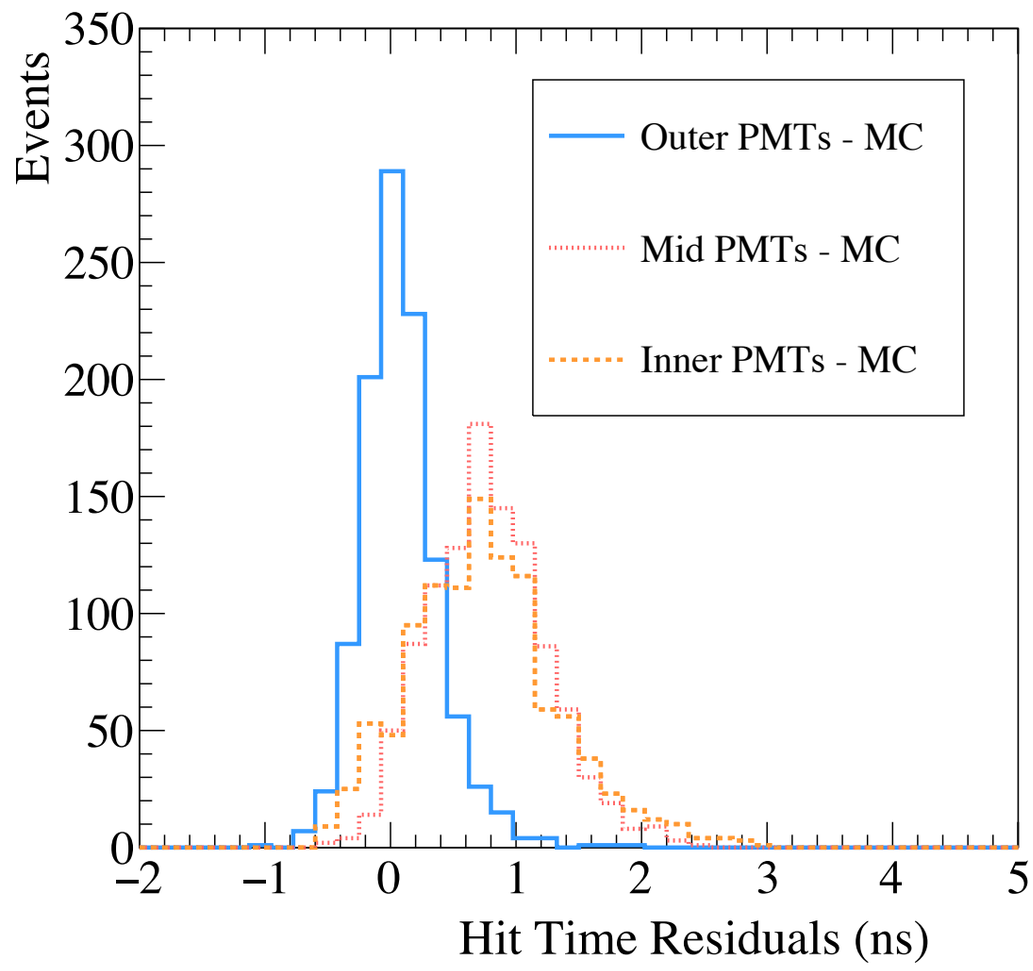

Voltage (arb. units)
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
−20
0
20
40
60
80
100
Time (ns)


Voltage (arb. units)
0.00
−0.05
−0.10
−0.15
−0.20
Estimate
μ
1.08 ± 0.03
σ
0.68 ± 0.02
Averaged Pulses
LogNormal Fit
−20
0
20
40
60
80
100
Time (ns)


Events
10^2
10
1
10^{-1}
10^{-2}
0
50
100
150
200
250
300
350
400
Σ NPE$_{\text{inner}}$
Data
No contamination
Muon contamination
Electron contamination
Combination


Events
10^3
10^2
10
1
10^{-1}
0
200
400
600
800
1000
1200
Σ NPE$_{\text{inner}}$


Events
10^3
10^2
10
1
10^{-1}
Outer PMTs - MC
Mid PMTs - MC
Inner PMTs - MC
−2
0
2
4
6
8
Hit Time Residuals (ns)


Events
350
300
250
200
150
100
50
0
Outer PMTs - MC
Mid PMTs - MC
Inner PMTs - MC
−2
−1
0
1
2
3
4
5
Hit Time Residuals (ns)