液体キセノン中のシンチレーション光速度の測定

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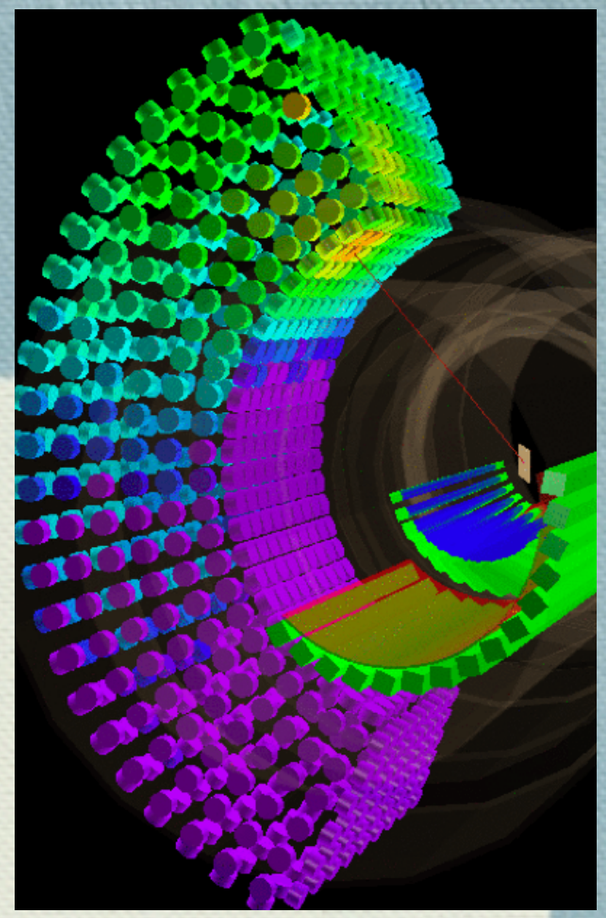
MEG LXe γ-Detector

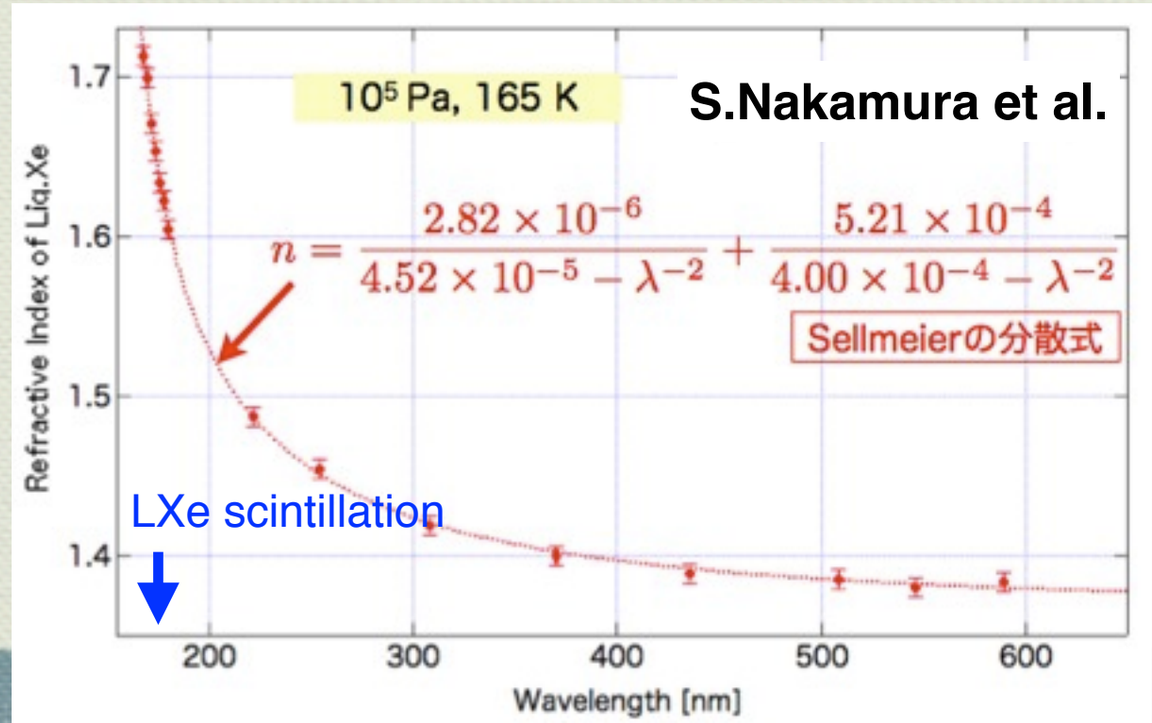


- Liquid xenon γ-detector for MEG experiment
  - World's largest LXe scintillation detector
  - C-shape 900L-LXe is surrounded by 846PMTs.
- Detector performance optimization requires correct understanding of optical property of LXe.
  - Absorption, scattering, reflection, refractive index, speed of light, ...
- Large scale of MEG LXe detector would enable to directly measure speed of light.

- **MEG関連講演 23pBA**

Speed of Scintillation Light

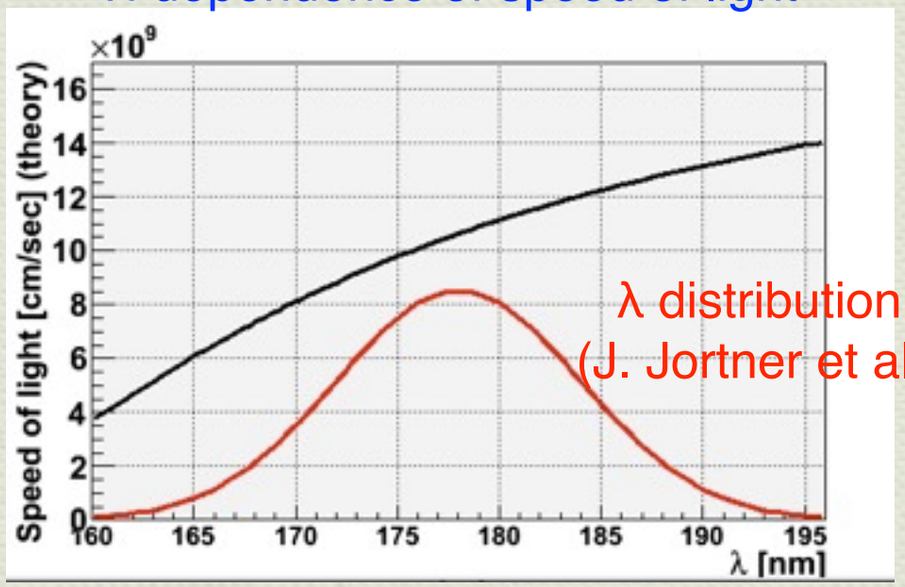
- Scintillation photons measured in our detector should fly at group velocity instead of phase velocity.
  - **Phase velocity** : $v = c / n =$ **1.83×10^{10} cm/sec**
  - **Group velocity**: $v = c / n_g = c / (n - \lambda dn/d\lambda) = c / n - c / (\lambda dn/d\lambda)$
- Large λ-dependence of refractive index around $\lambda_{scintillation}$ (178nm)



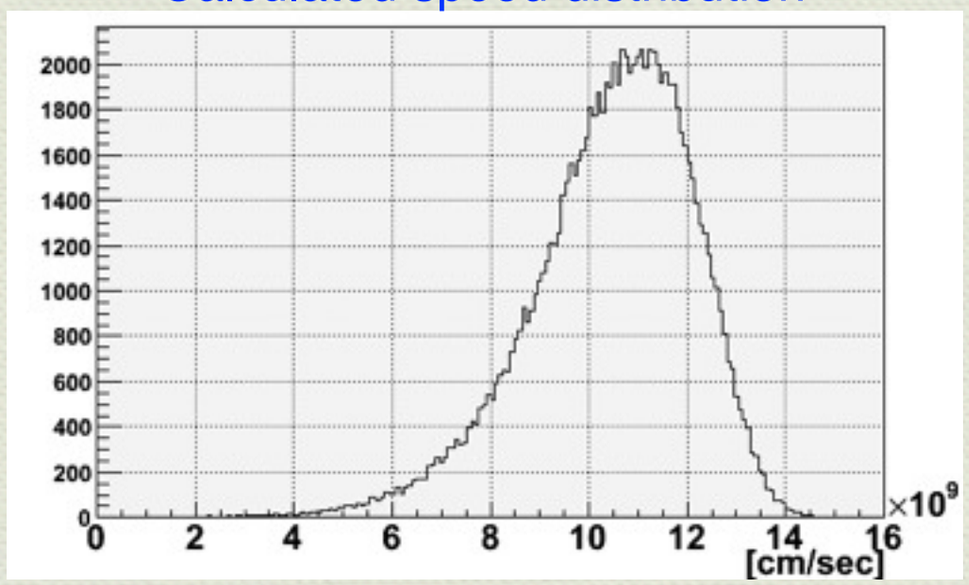
Speed of Scintillation Light

- Group velocity of LXe scintillation light
  - Average : 1.04×10^{10} cm/sec
  - **Peak : 1.10×10^{10} cm/sec**

λ-dependence of speed of light



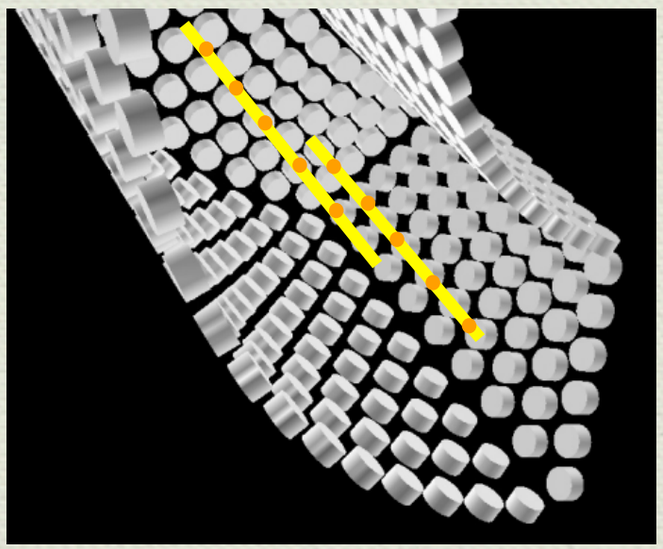
Calculated speed distribution

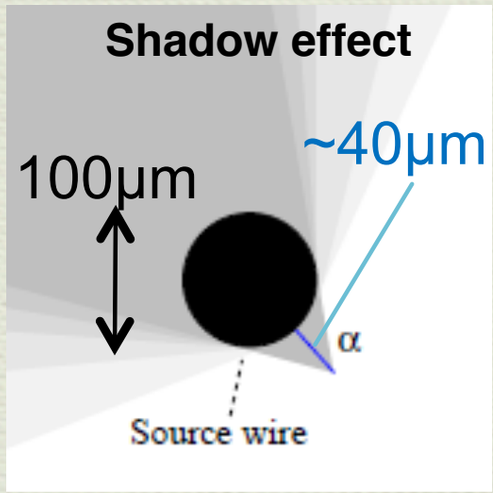


Measurement in LXe Detector

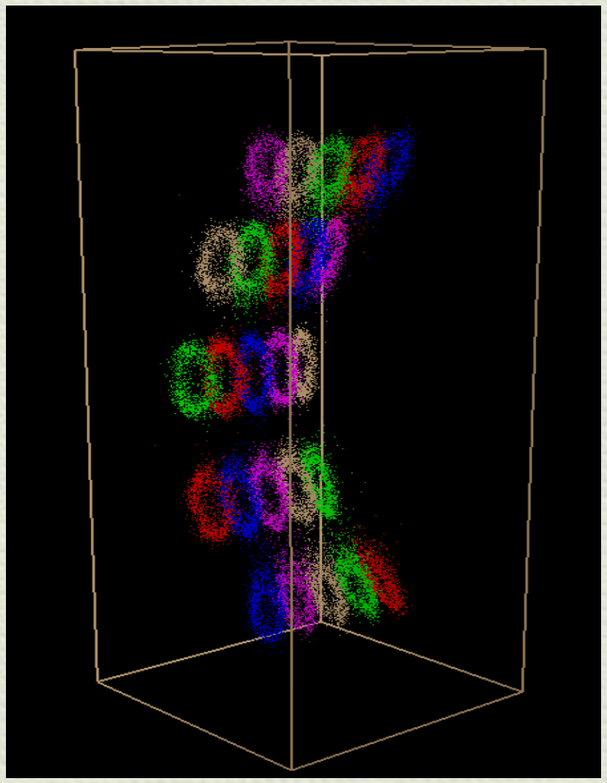
- Alpha spot-sources on thin tungsten wires stretched in LXe to calibrate and monitor PMTs in MEG experiment.
- Can be used as spot light source for speed measurement

^{241}Am spot-source on 100μm-Φ W wire



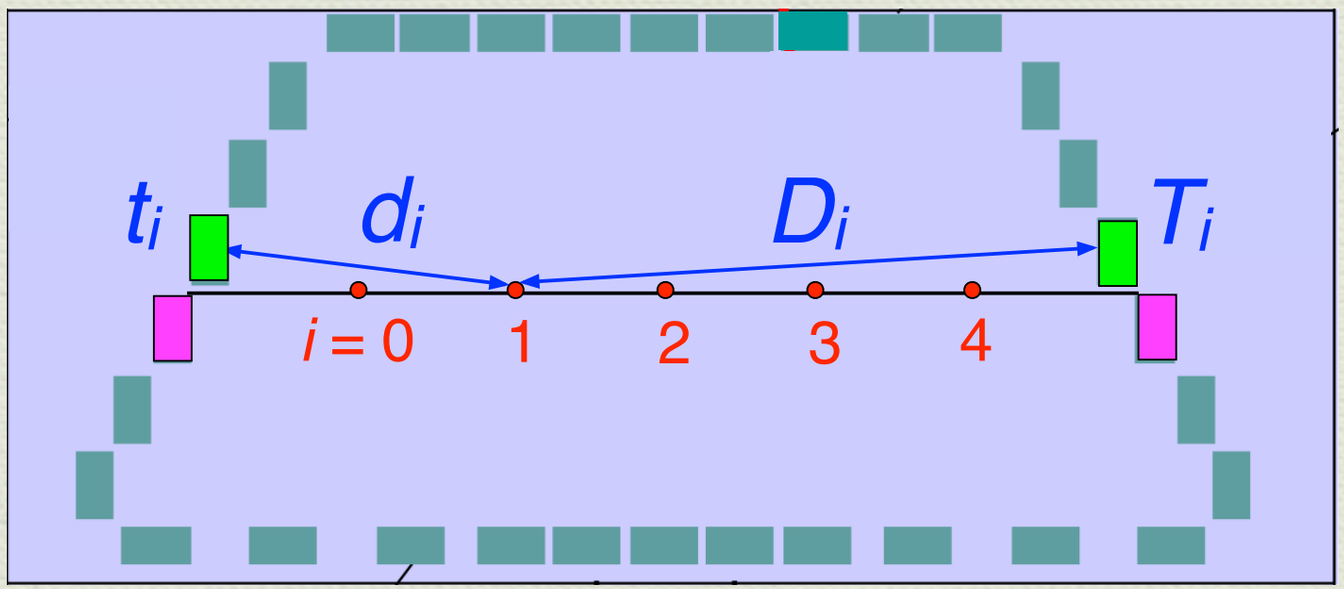


Reconstructed position of alpha event



Measurement in LXe Detector

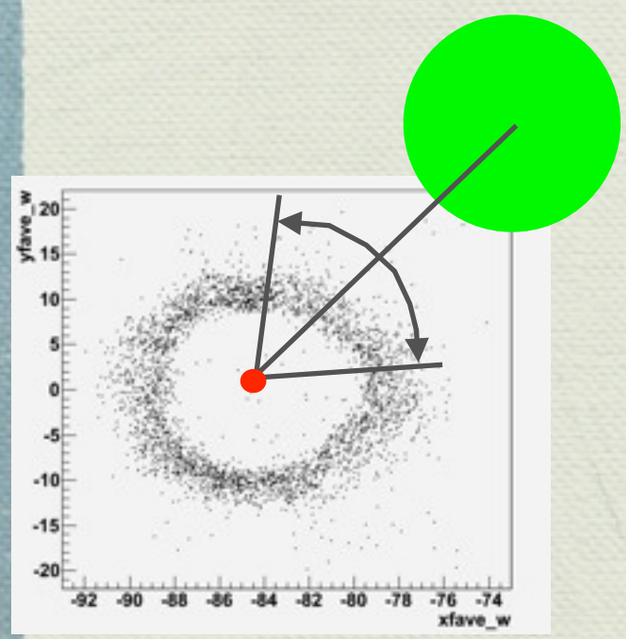
- Measure time-distance correlation using different alpha sources on a wire.
- Use only PMTs around wire end to minimize systematic effect due to reflection and scattering

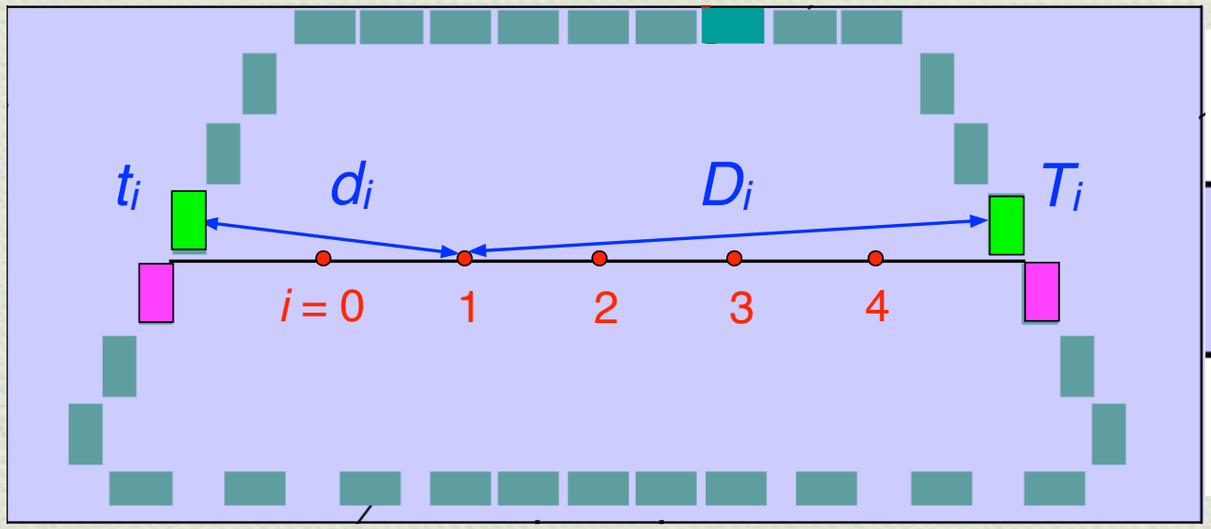


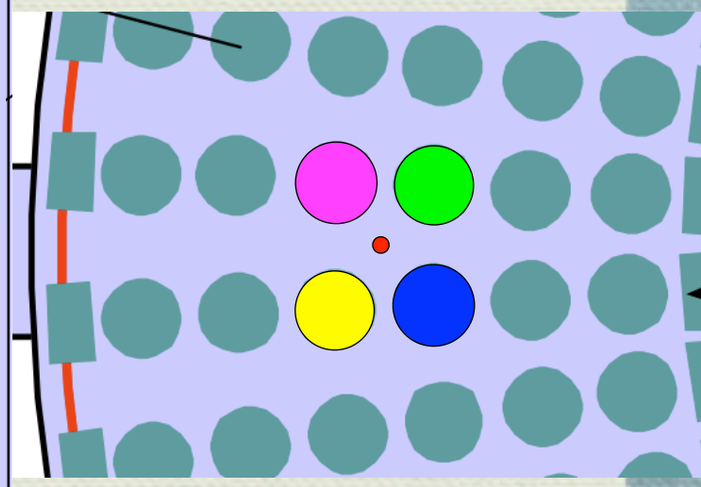
$$V = (D_i - d_i) / (T_i - t_i) \quad i = 0,..4$$

Measurement in LXe Detector

- Take difference bw/ a pair of PMTs facing each other such that same events in reconstructed ring can be selected.
- Slope in time-distance correlation is independent of time offset in each PMT.

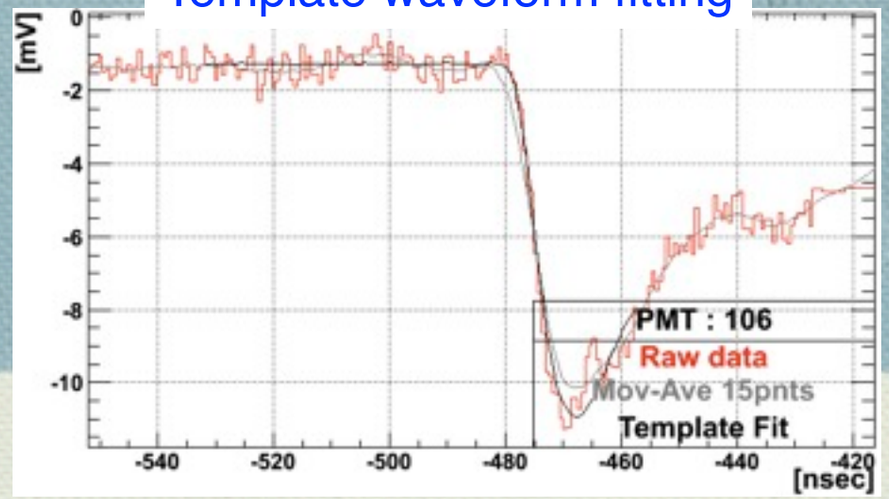




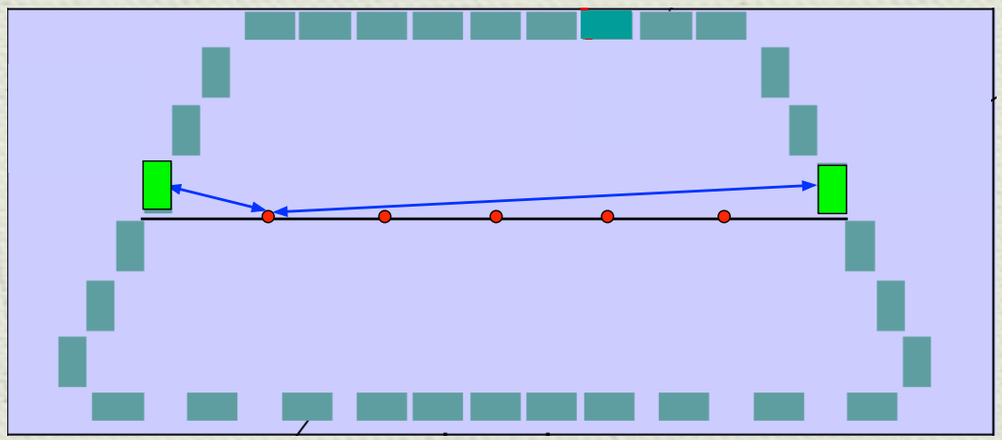


Analysis

Template waveform fitting

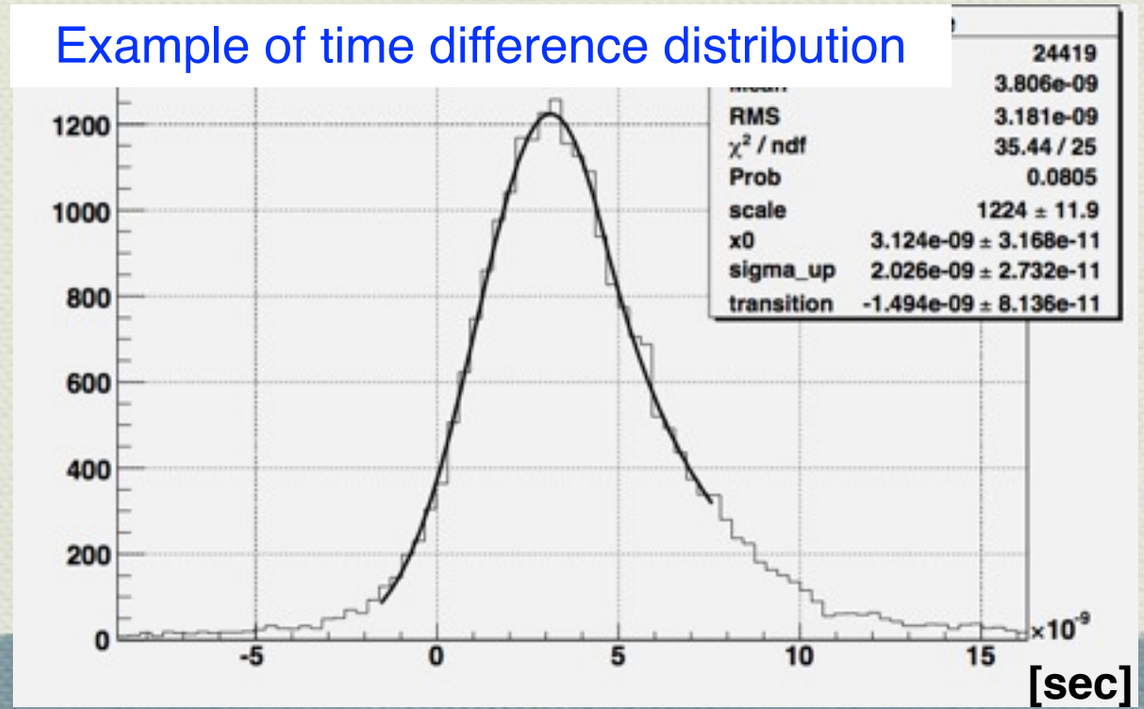


- Data sample
  - alpha source data taken during MEG physics run 2009
- PMT time is measured with template waveform fitting.
- Measured time difference shows wide and asymmetric distribution.
- Peak time is used for speed measurement.



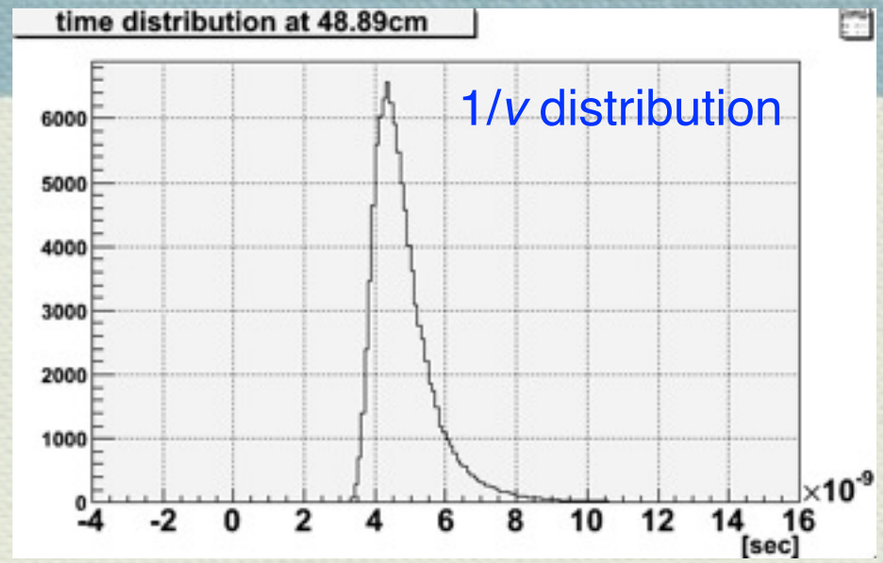
Distance difference = 48.9cm

Example of time difference distribution

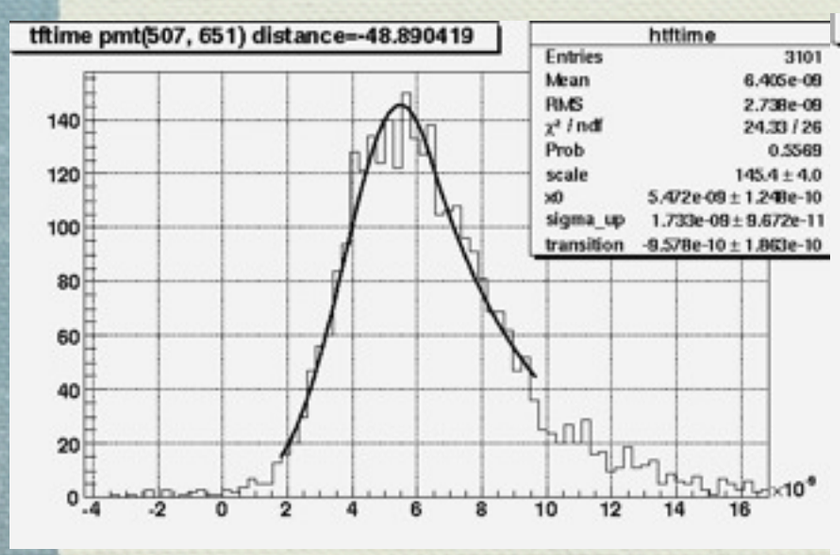


Time Distribution

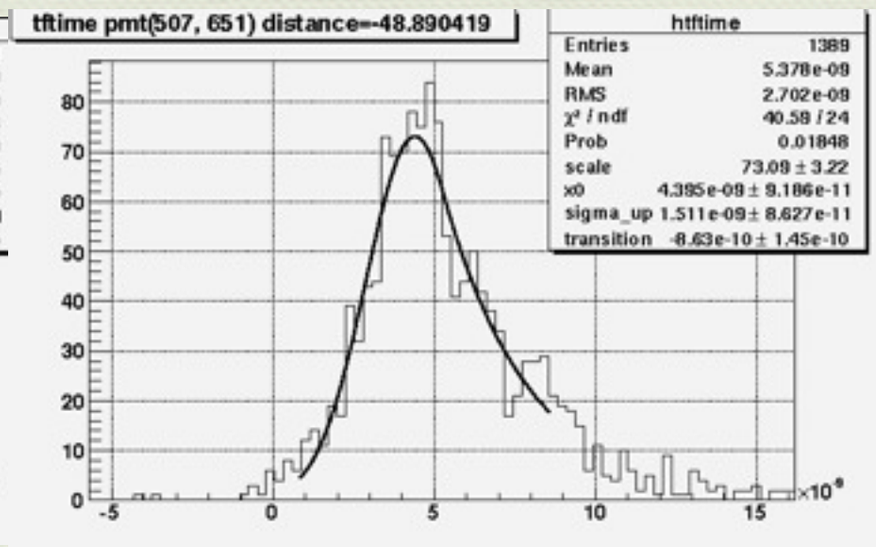
- Wide and asymmetric distribution
  - Wavelength distribution
  - Timing resolution of waveform analysis
  - Effect of reflection and scattering



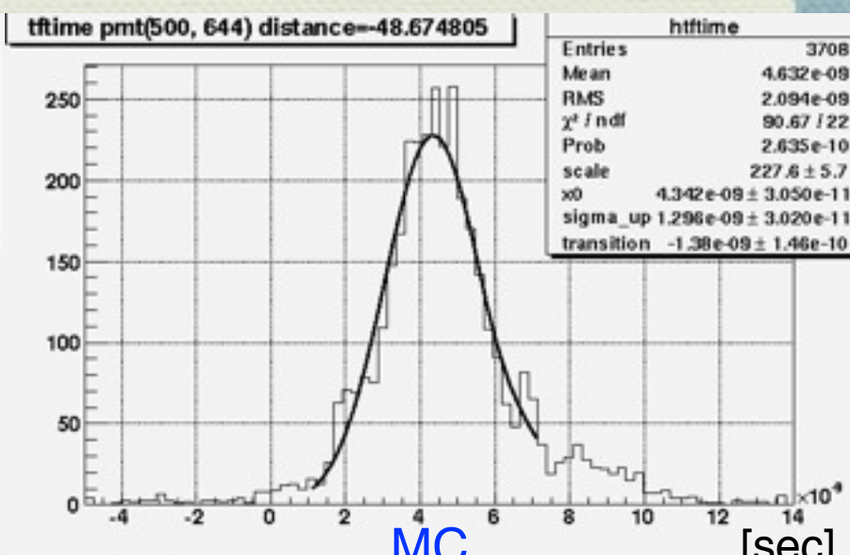
- Distribution is reproduced in MC simulation.



Data



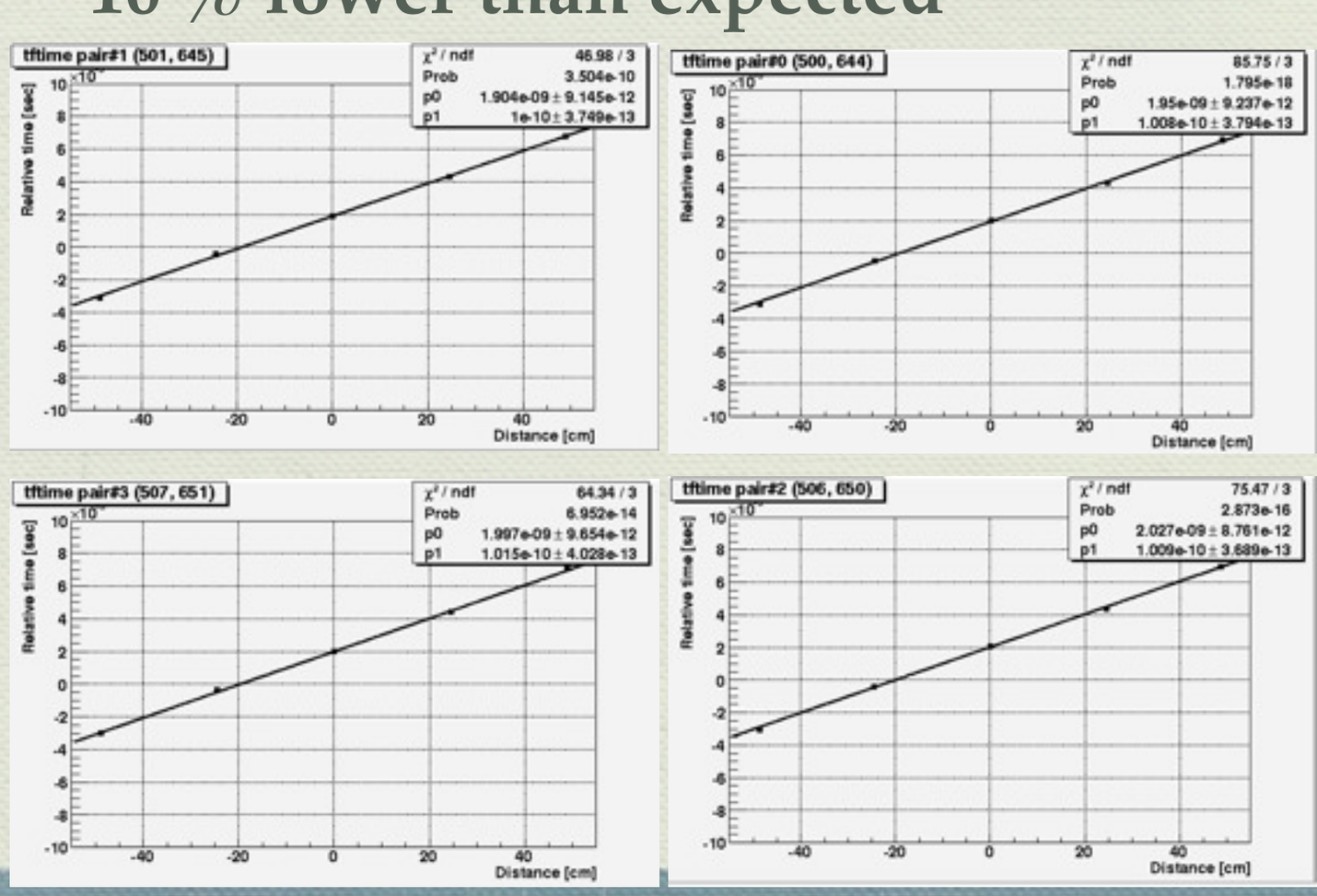
MC

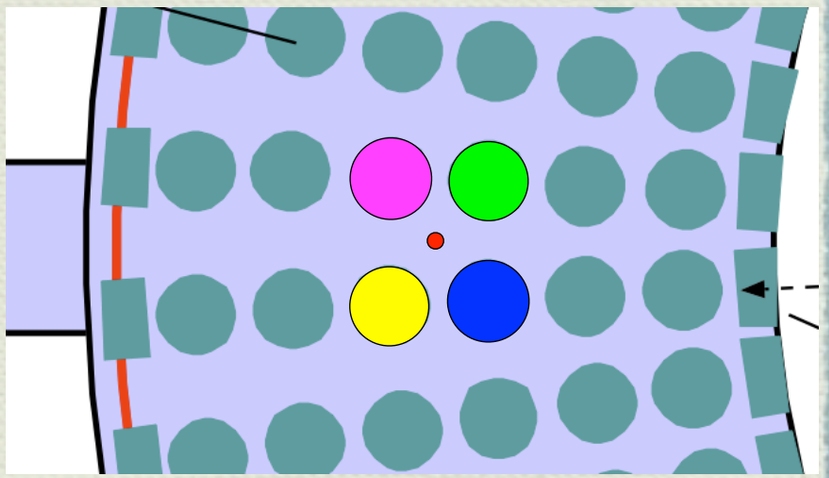


MC
w/o scattering/reflection

Result (preliminary)

- Clear liner correlation bw/ distance and time difference
- Measured speed: **0.99×10^{10} cm/sec**
- **~10 % lower than expected**





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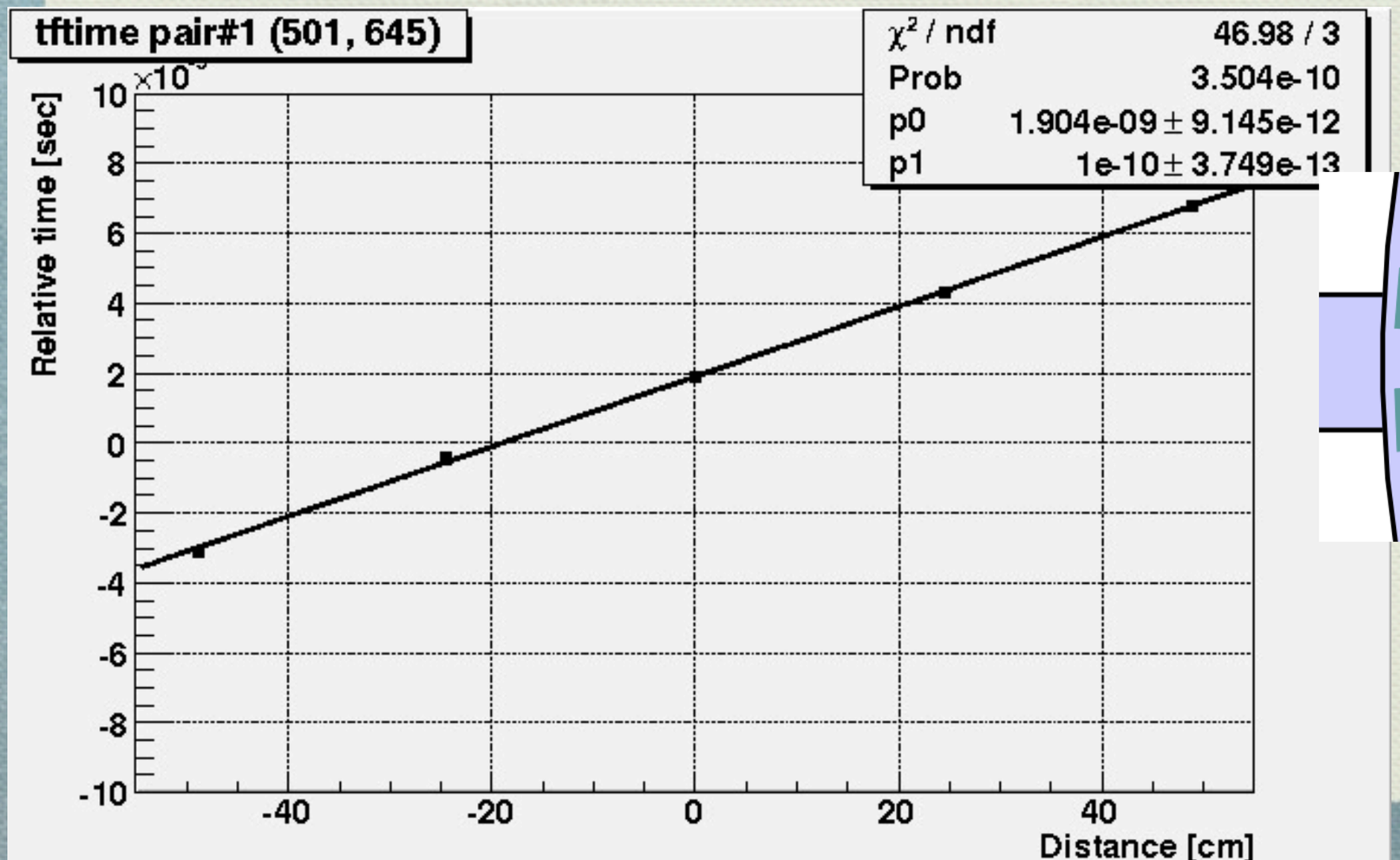

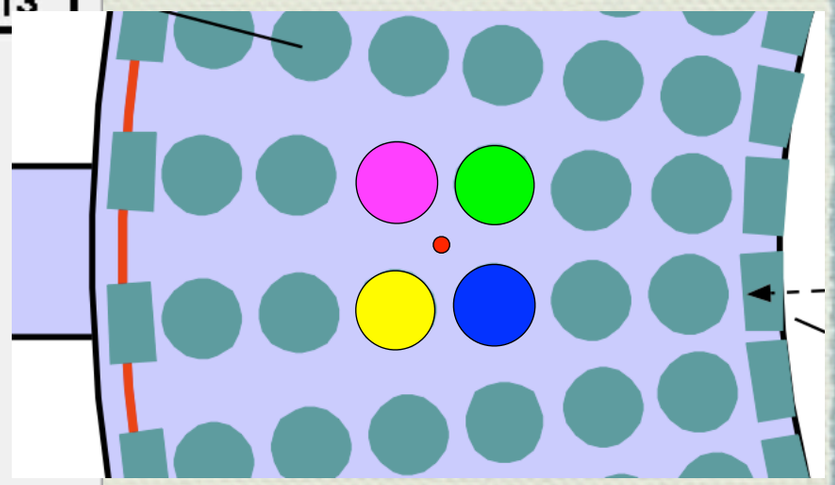

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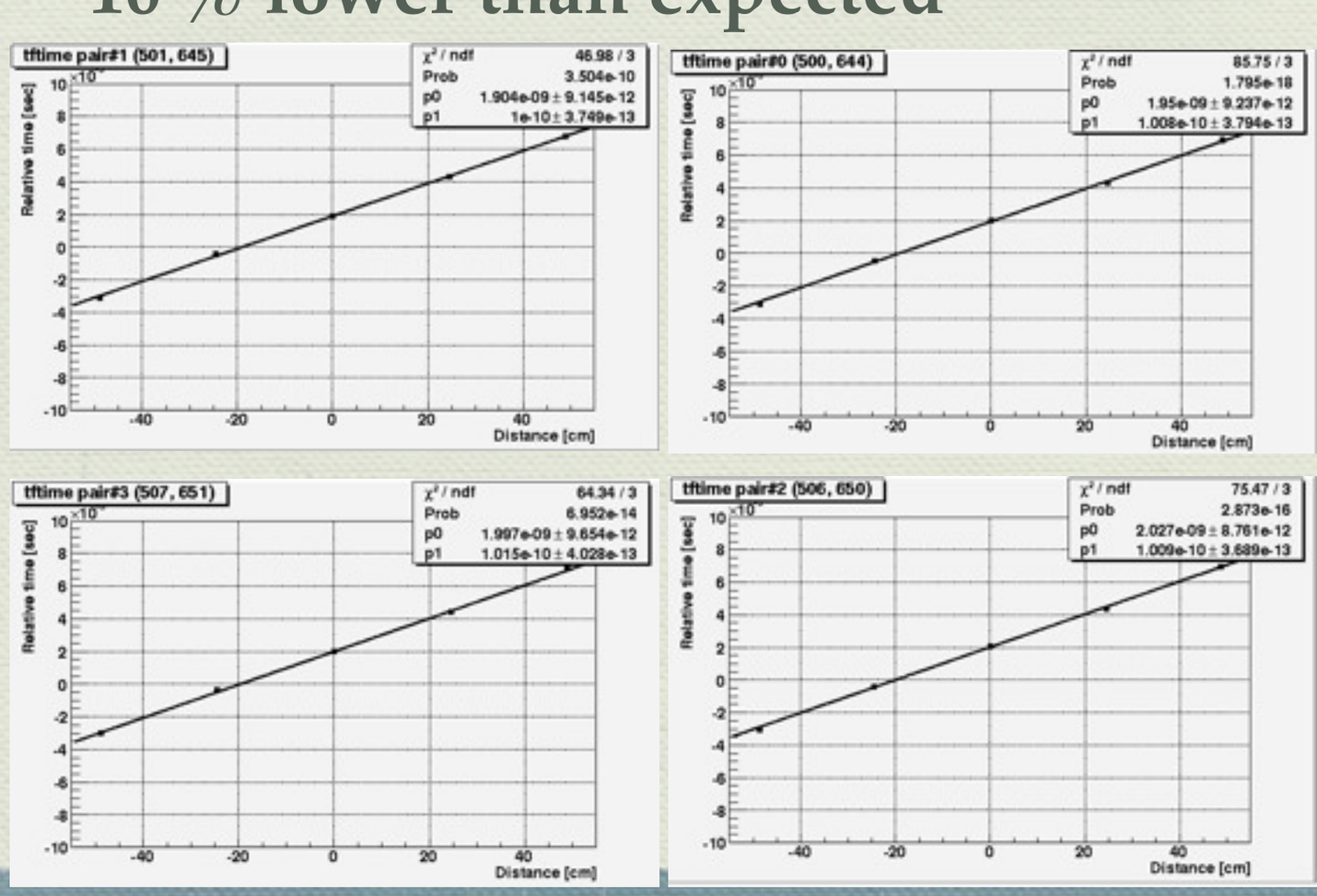

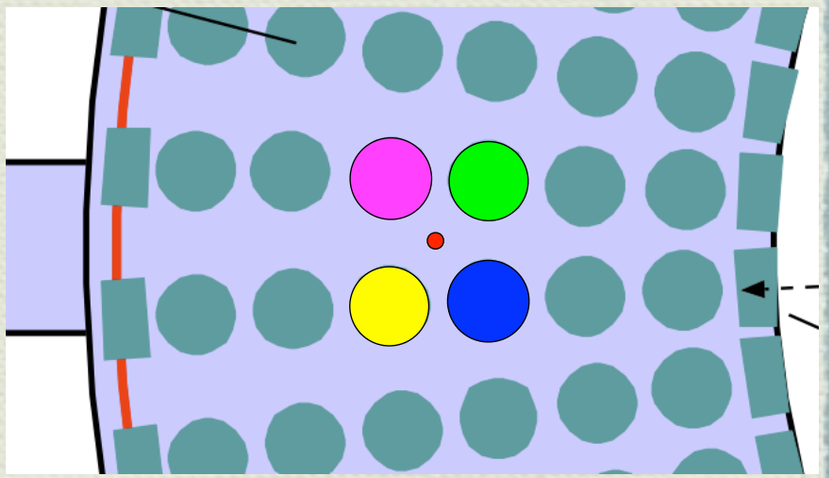

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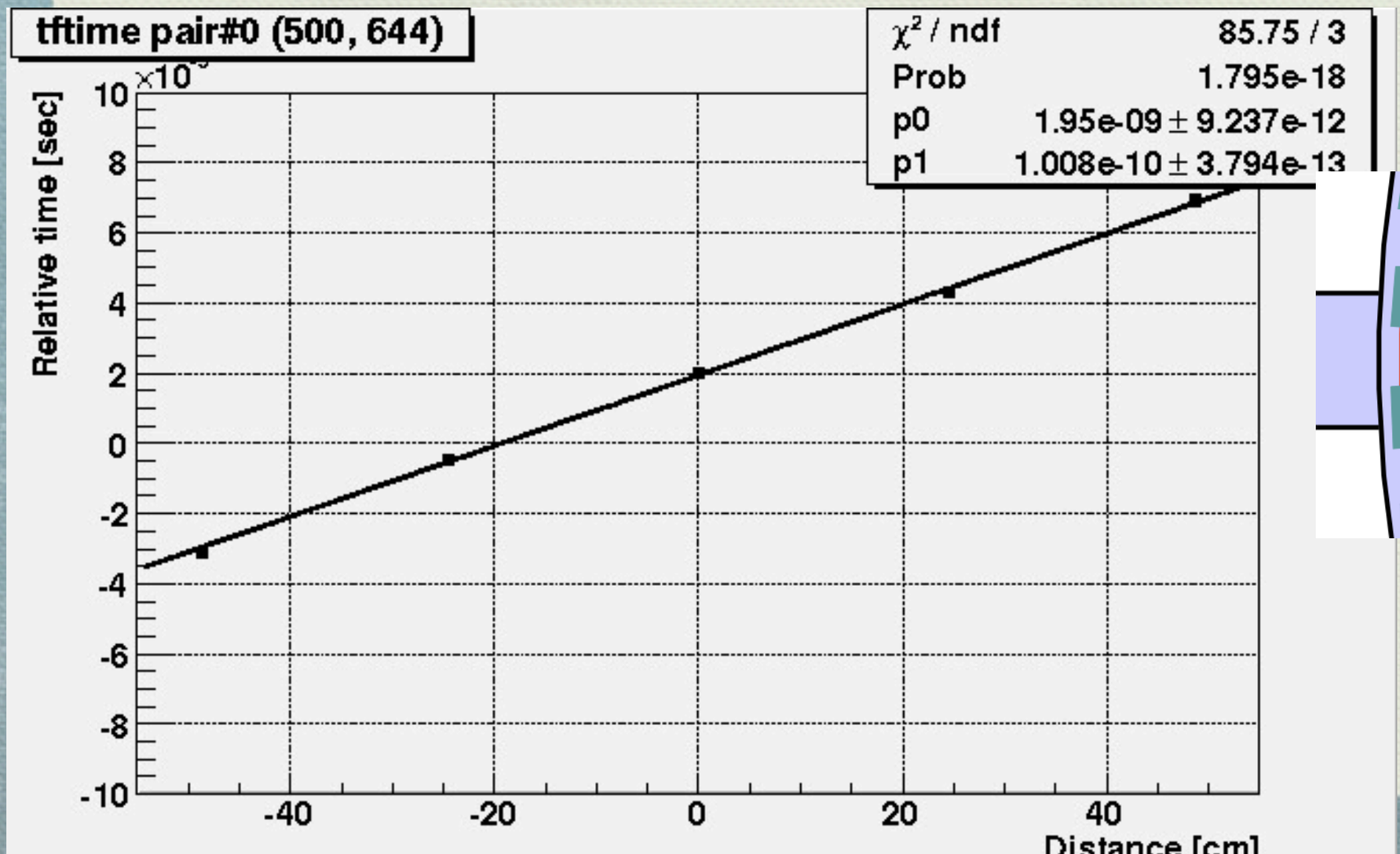

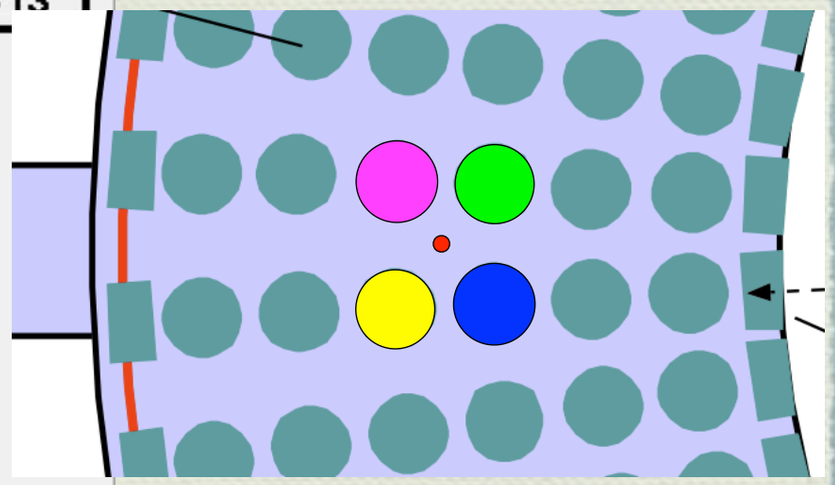

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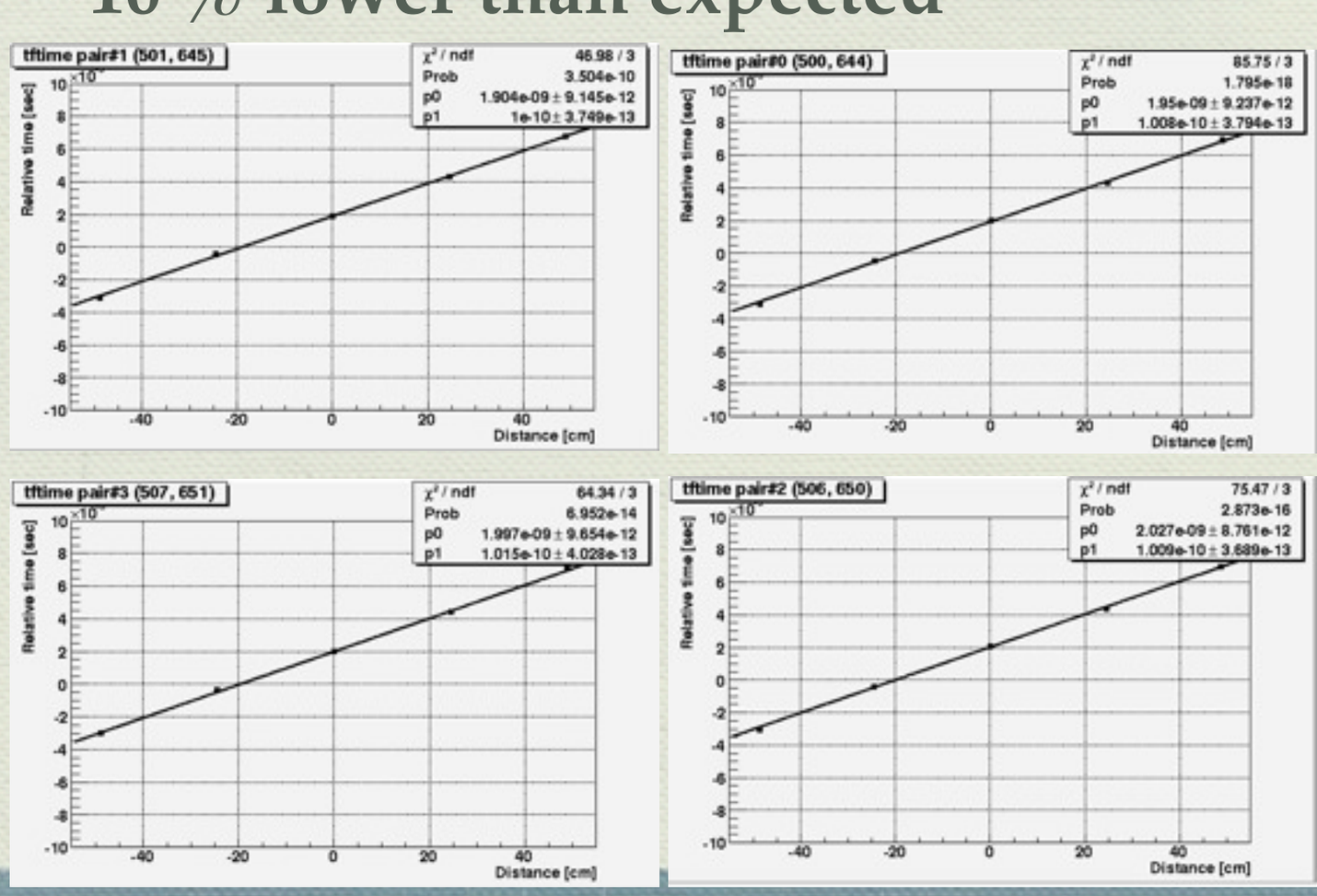

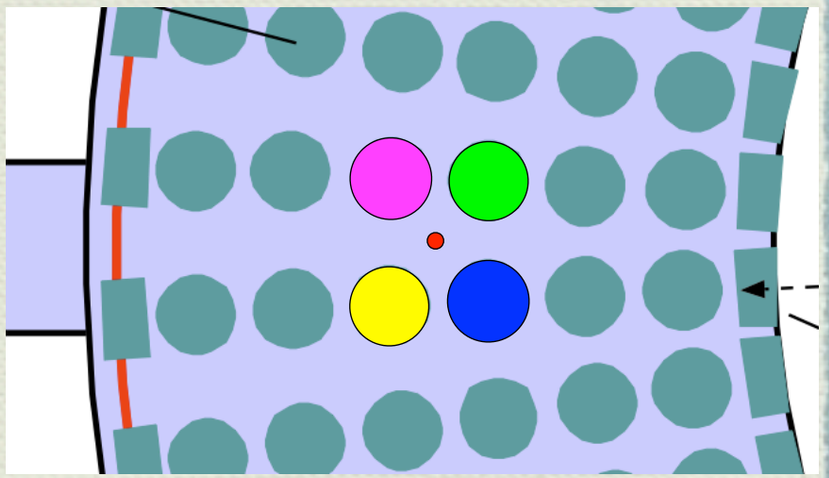

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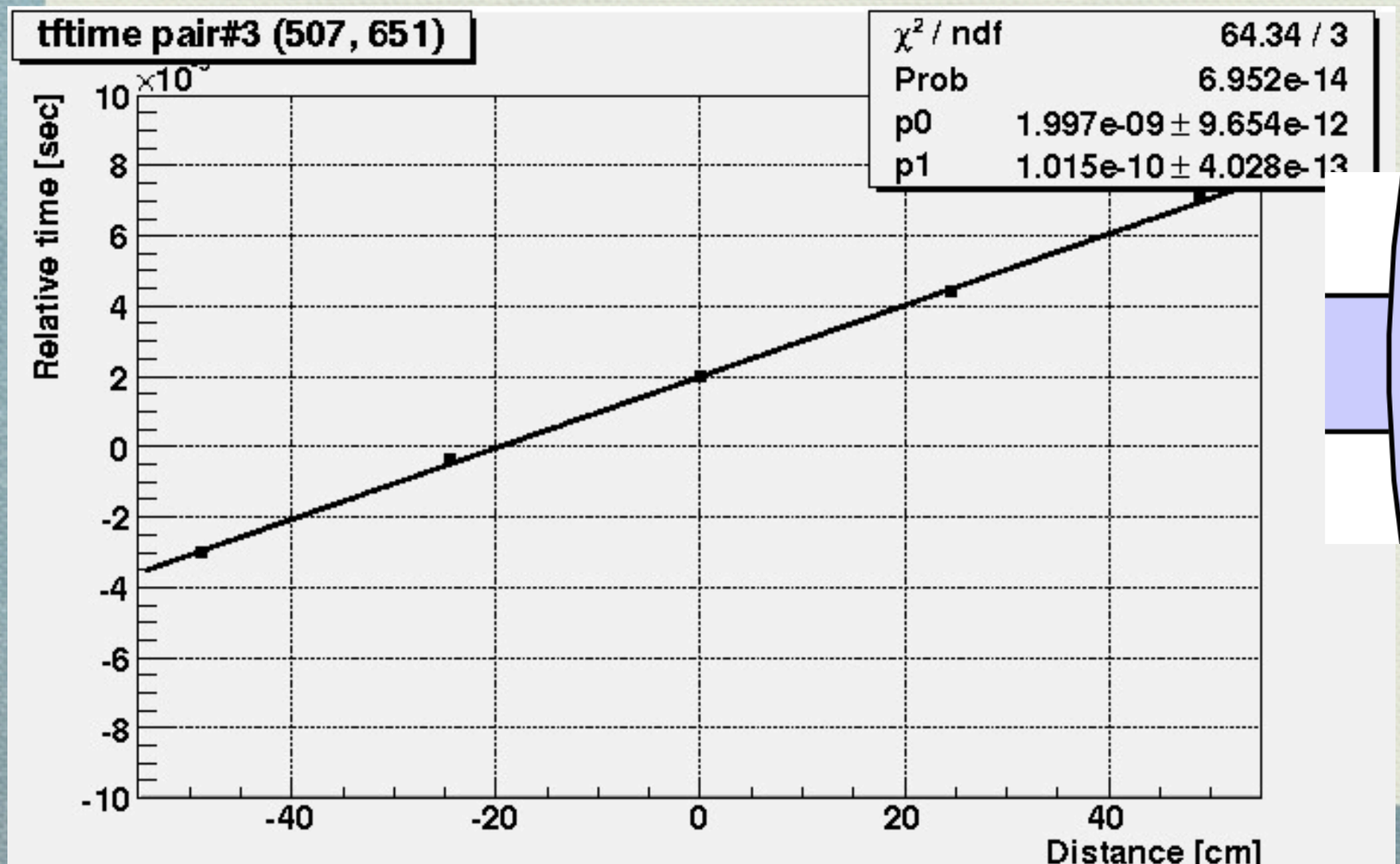

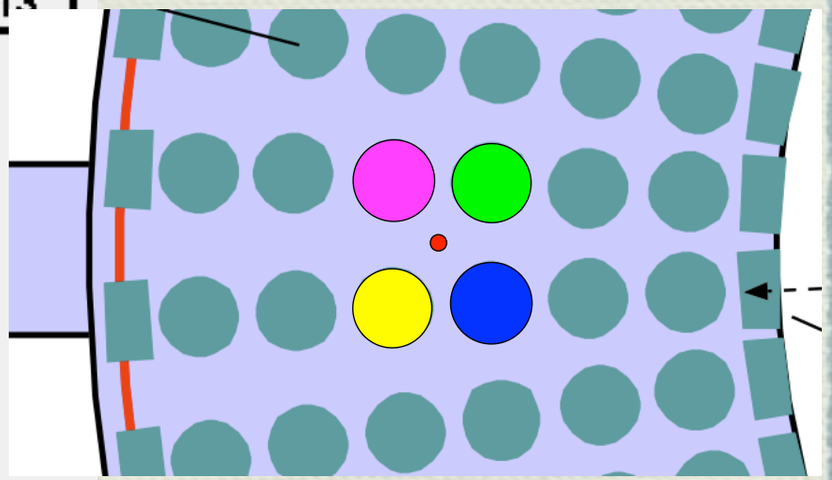

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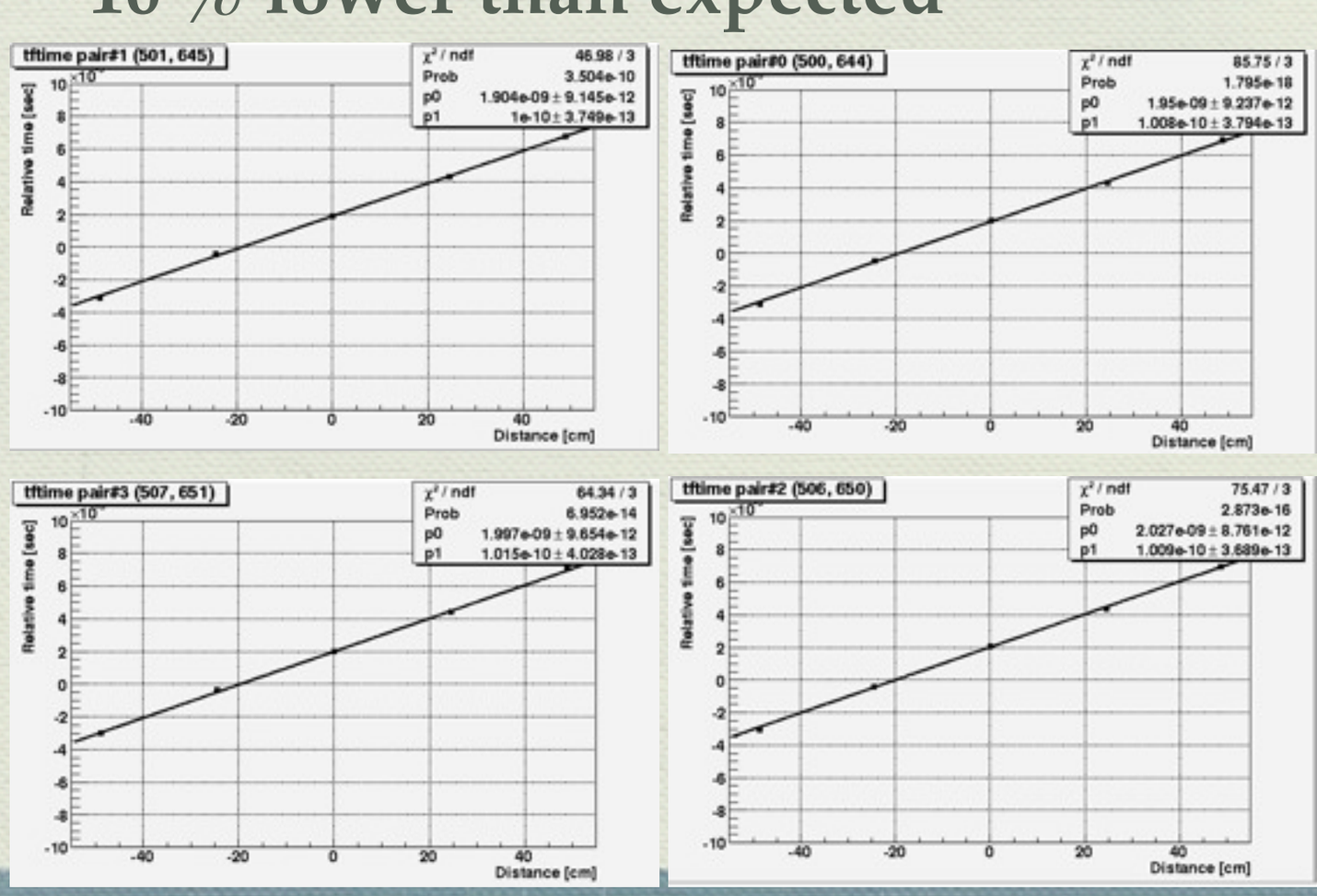

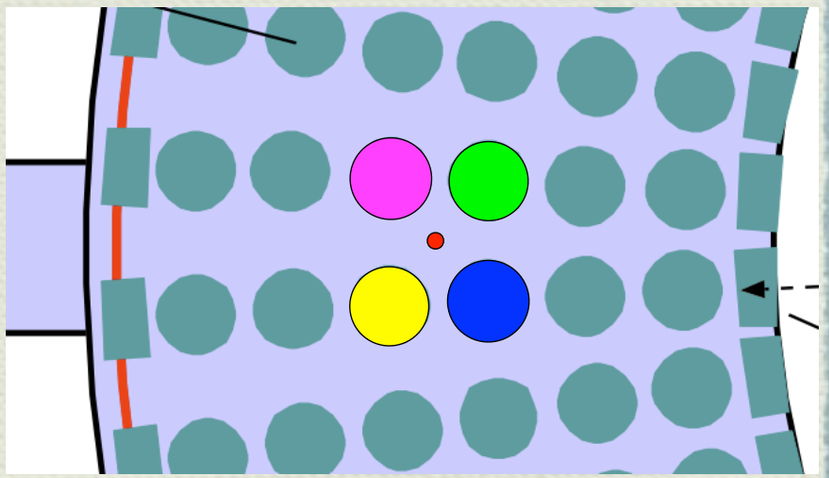

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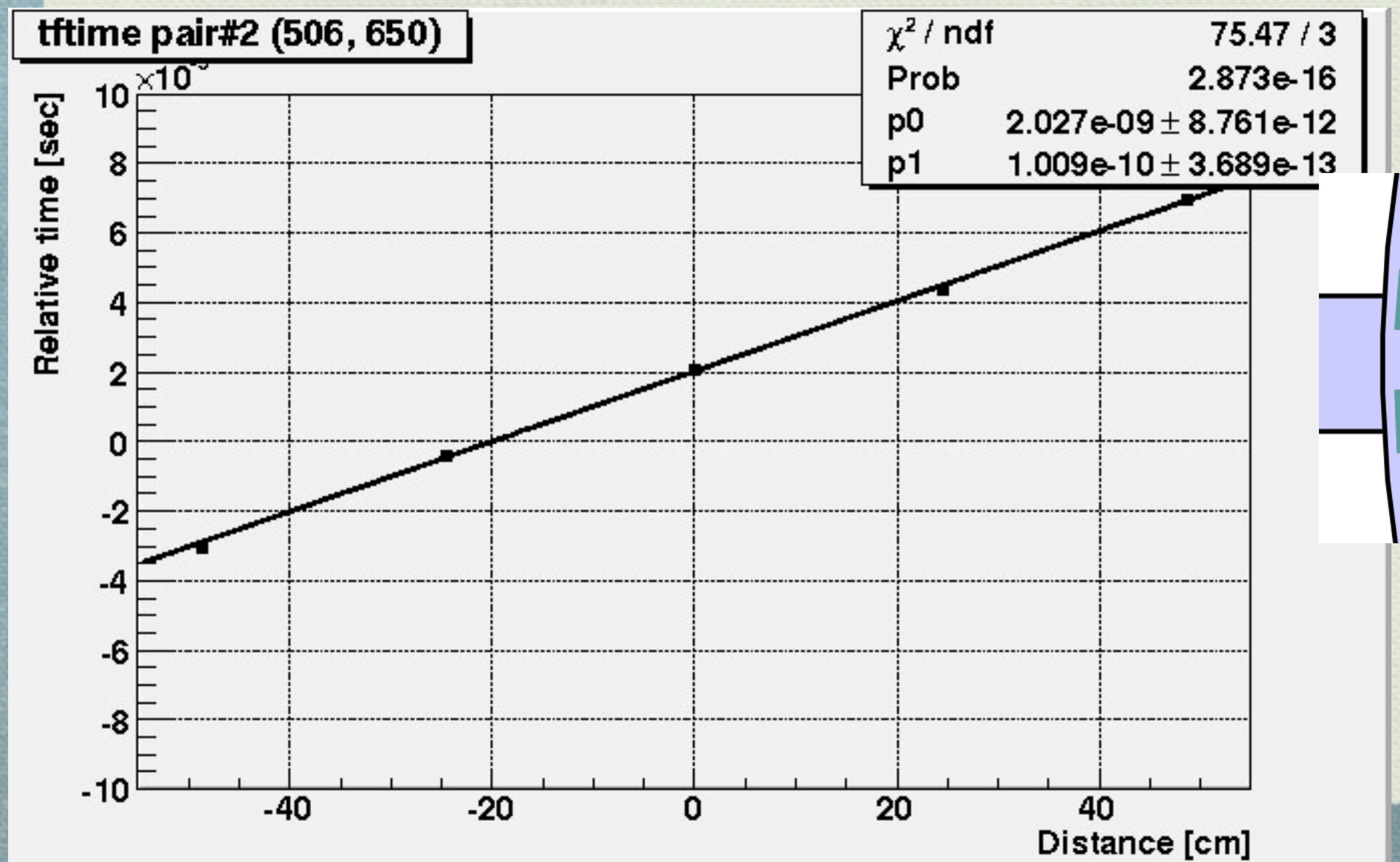

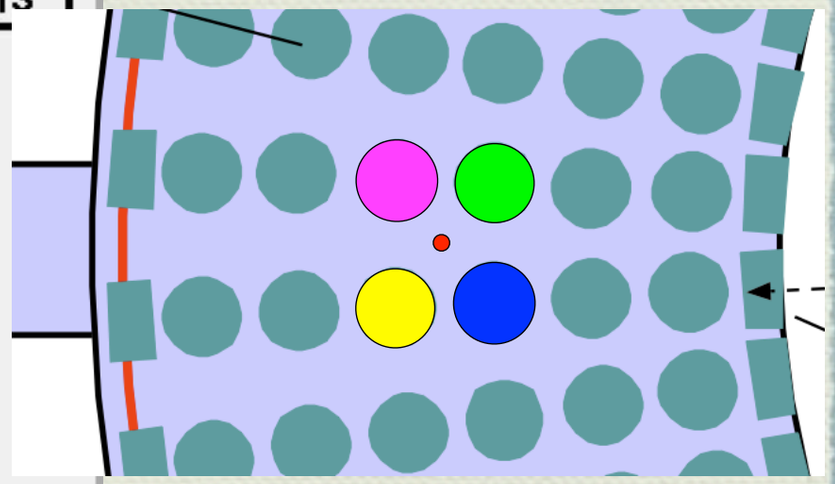

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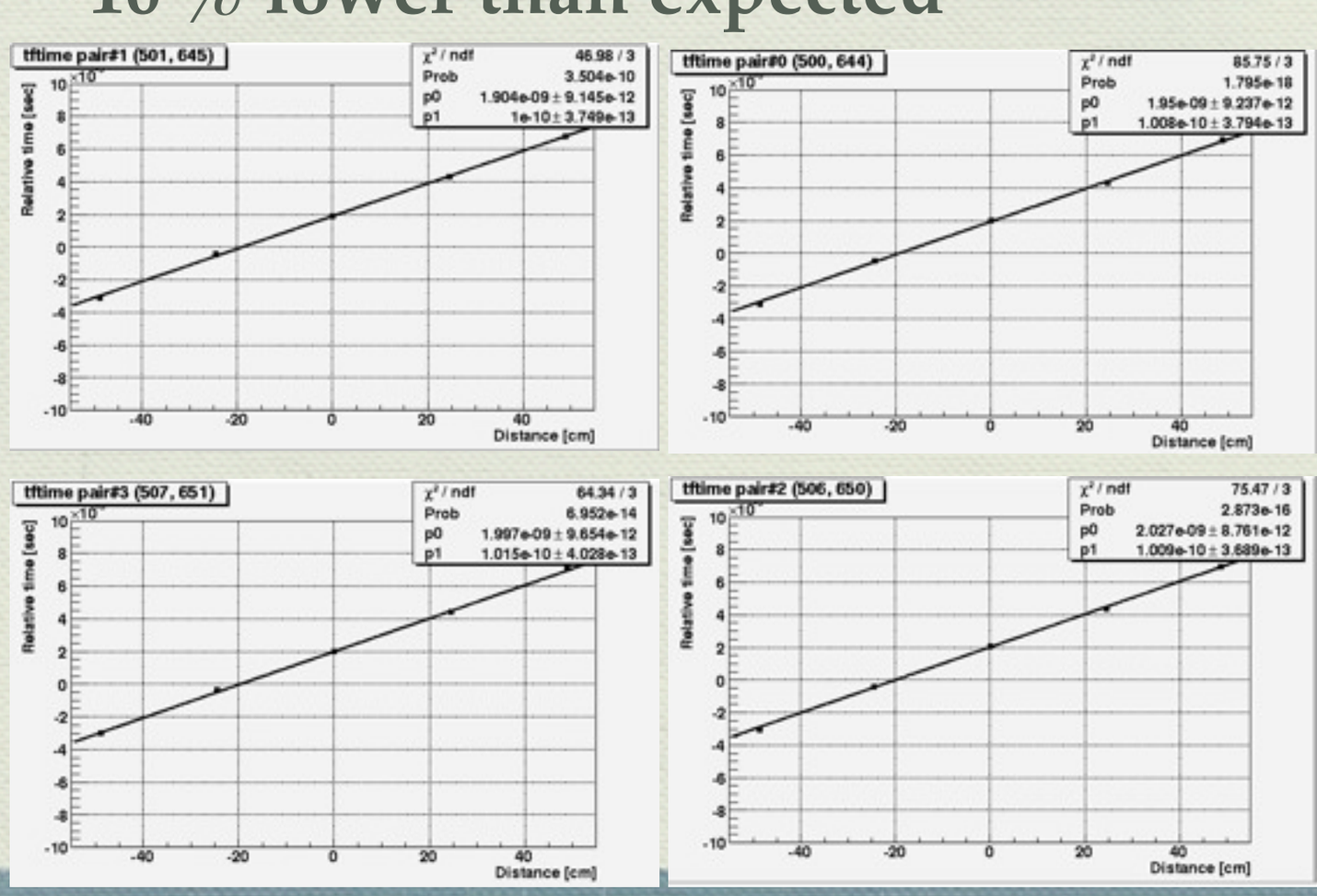

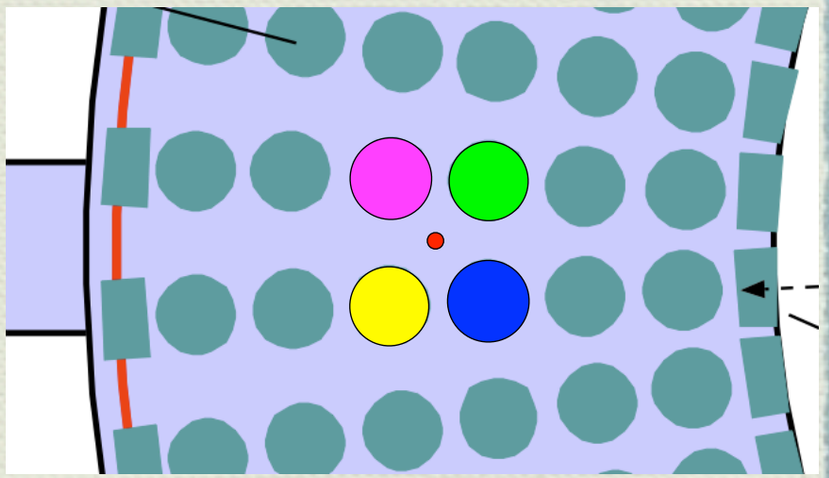

Result (preliminary)

Data sample	Speed [cm/s]	Ratio to expectation
Oct. 2008	0.91×10^{10}	0.83
Dec. 2008	0.89×10^{10}	0.81
Dec. 2008 (high PMT gain)	0.85×10^{10}	0.77
Dec. 2009 (new digitizer)	0.99×10^{10}	0.90
Dec. 2009 (new digitizer+high gain)	0.99×10^{10}	0.90
MC	1.08×10^{10}	0.98
MC w/o scattering and reflection	1.14×10^{10}	1.04

- Several data samples with different conditions are analyzed.
- $\mathbf{V_{expected} \sim V_{MC} > V_{2009} > V_{2008}}$
  - LXe light yield in 2009 is 40% higher than in 2008.

How to Interpret Discrepancy?

- Possible systematics in the measurement
  - Time walk effect
  - Difference of waveform digitizer
  - Photoelectron statistics
  - Scattering/reflection
- Discrepancy seems too large to explain with systematics in the measurement.
- Speed is really changed?
  - Effect of purity?
    - LXe light yield in 2009 is 40% higher than in 2008.
    - Refractive index or wavelength modified?
  - γ-timing reconstruction is optimized at **~0.8×10^{10} cm/sec.**

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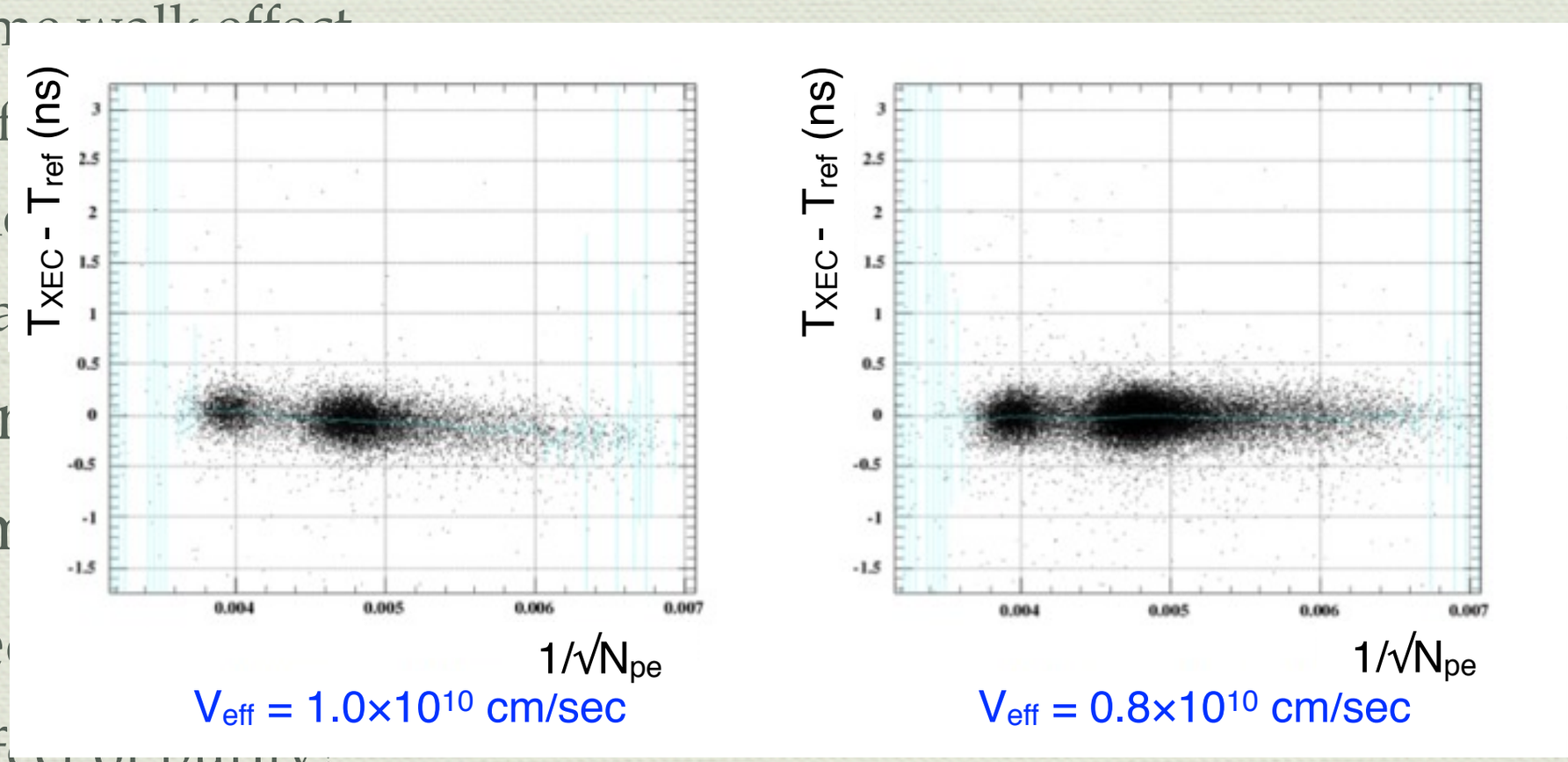

Summary

- Speed of scintillation light in LXe is measured with MEG LXe detector.
- Measurements give lower speed than expected, while measurement in MC shows a good agreement with expectation.
  - 10% lower in run 2009
  - 20% lower in run 2008
- Systematics in the measurement are being investigated, but discrepancy seems a bit too large to explain with systematics.
- Theoretical mechanism to change the speed is not understood yet.
- Same measurements are planned in GXe to validate the method.