LS I + 61 303 Analysis Results: An Example for a Unified Analysis Framework

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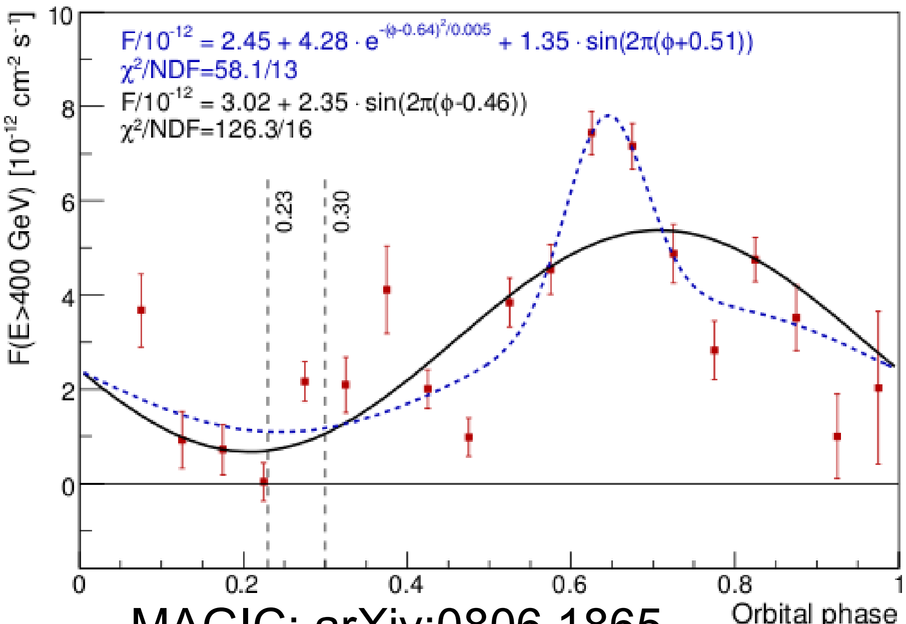
LS I +61 303 Periodic Analysis



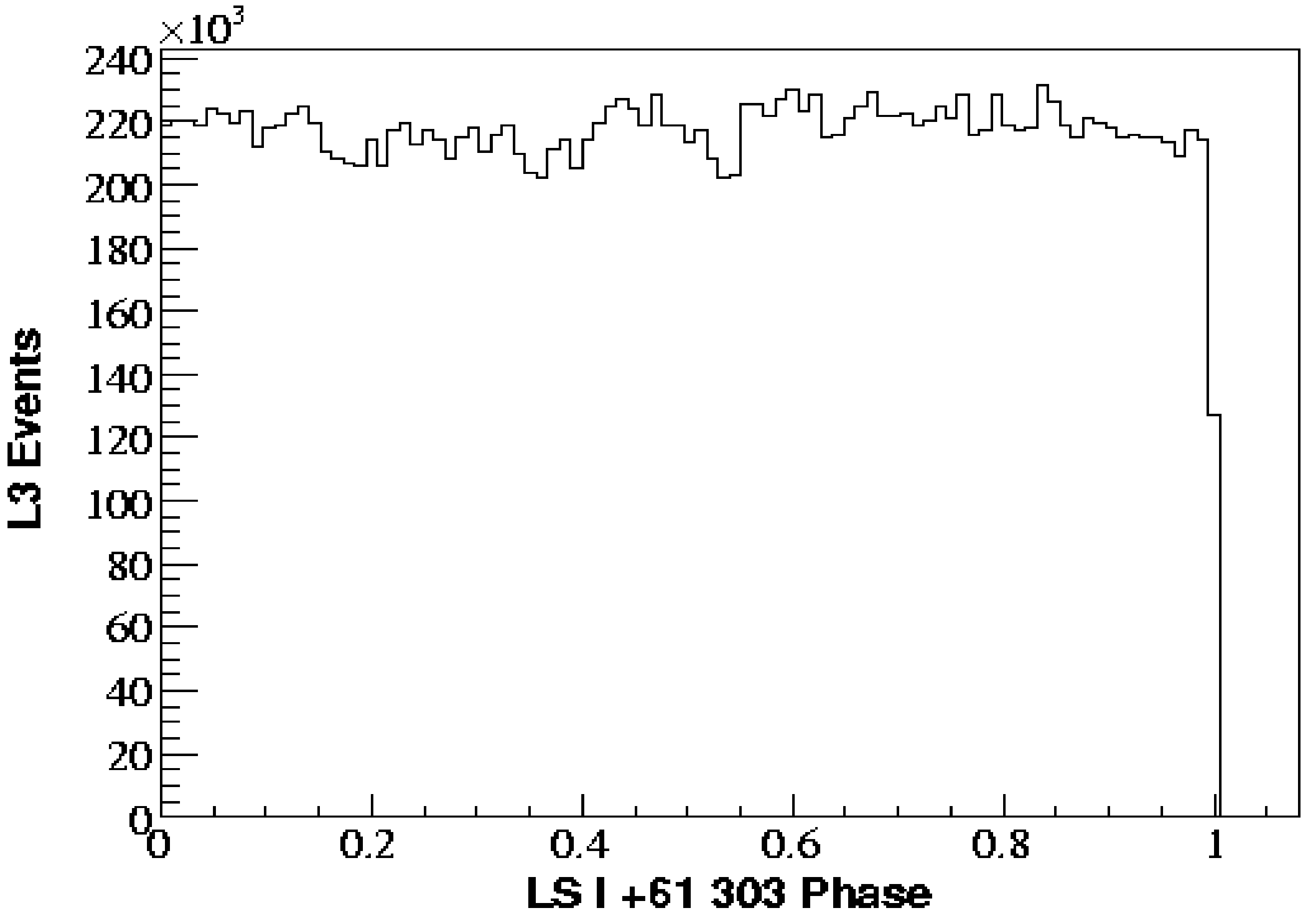
MAGIC: arXiv:0806.1865

- Binary system with 26.496d Radio Periodicity
- Clear TeV gamma ray periodicity observed by MAGIC
- Neutrino flux may also be periodic

- Analysis Goals:
  - Use the potential periodicity of neutrino emission to enhance discovery potential
  - Develop a method for time-dependent analysis which can be used in future IceCube searches

Data

- Use AMANDA 7-year dataset



- Detector livetime uniform to ~7% over phase

Method

- Adapt the unbinned maximum likelihood search method used in the AMANDA 7-year analysis: Assume signal has a Gaussian distribution in phase.

$$\mathcal{S}_i = \underbrace{\frac{1}{2\pi\sigma^2} e^{-\frac{|\vec{x}_i - \vec{x}_s|^2}{2\sigma^2}}}_{\text{Spatial likelihood}} \cdot \underbrace{P(Nch|\gamma)}_{\text{Energy-dependent likelihood}} \cdot \underbrace{\frac{1}{\sqrt{2\pi}\sigma_w} e^{-\frac{(\phi_i - \phi_o)^2}{2\sigma_w^2}}}_{\text{Time-dependent likelihood}}$$

- Final likelihood is the product over all N events:

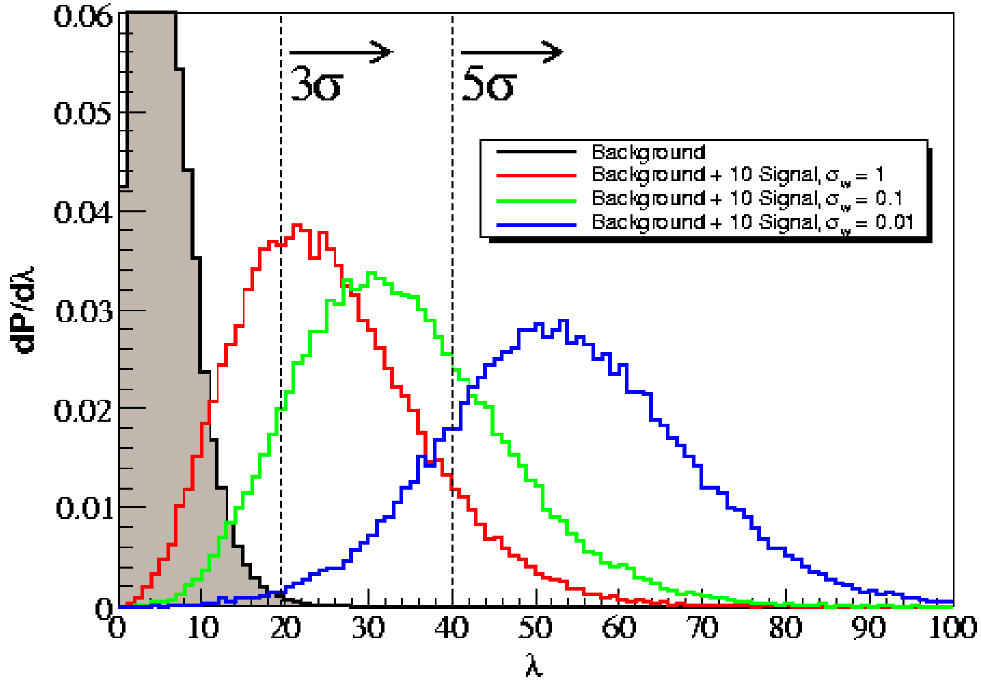
$$\mathcal{L}(\vec{x}_s, n_s, \gamma, \sigma_w, \phi_o) = \prod_{i=1}^{N} \left(\frac{n_s}{N} \mathcal{S}_i + (1 - \frac{n_s}{N}) \mathcal{B}_i \right)$$

- Maximize likelihood with respect to free parameters n_s, γ, σ_w, ϕ_o to get test statistic:

$$\lambda = -2 \cdot log \left[\frac{\mathcal{L}(0)}{\mathcal{L}(\vec{x}_s, \hat{n}_s, \hat{\gamma}, \hat{\sigma}_w, \hat{\phi}_o)} \right]$$

- First guess for σ_w, ϕ_o is important!
  - Use MINUIT only for fine-tuning

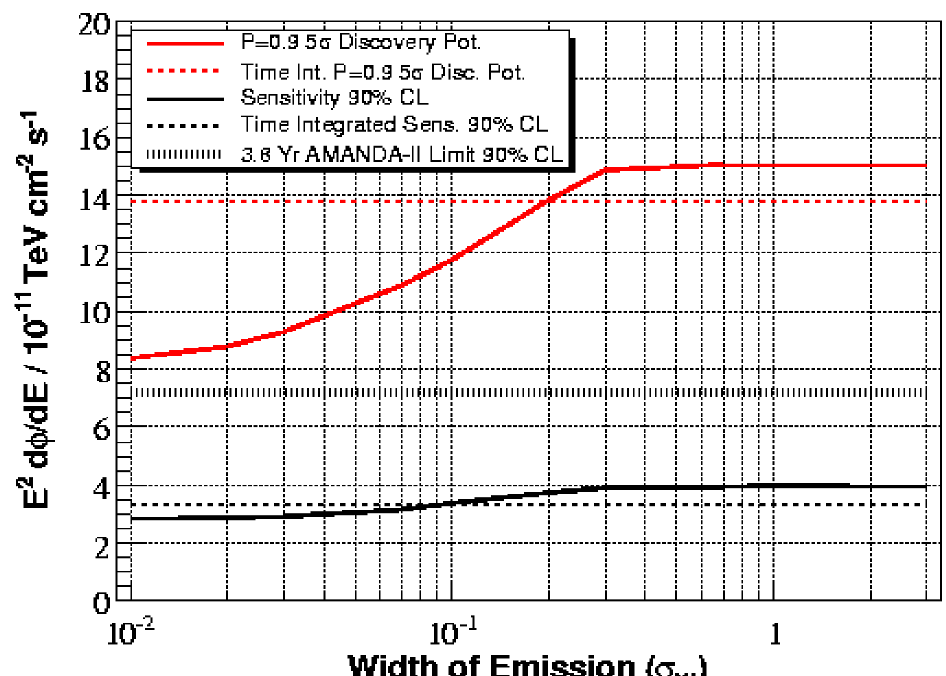
Method



- For a given flux, significance increases for smaller signal widths
  - Better S/N

- Discovery potential worse than time-integrated search for large widths due to extra degrees of freedom

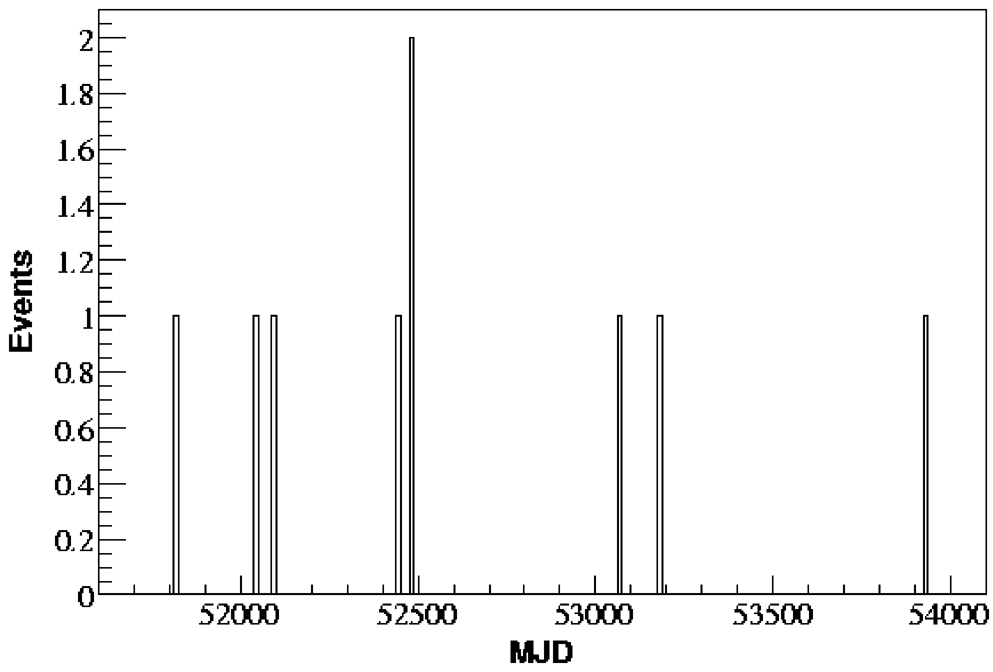
- Improves for small widths due to better S/N

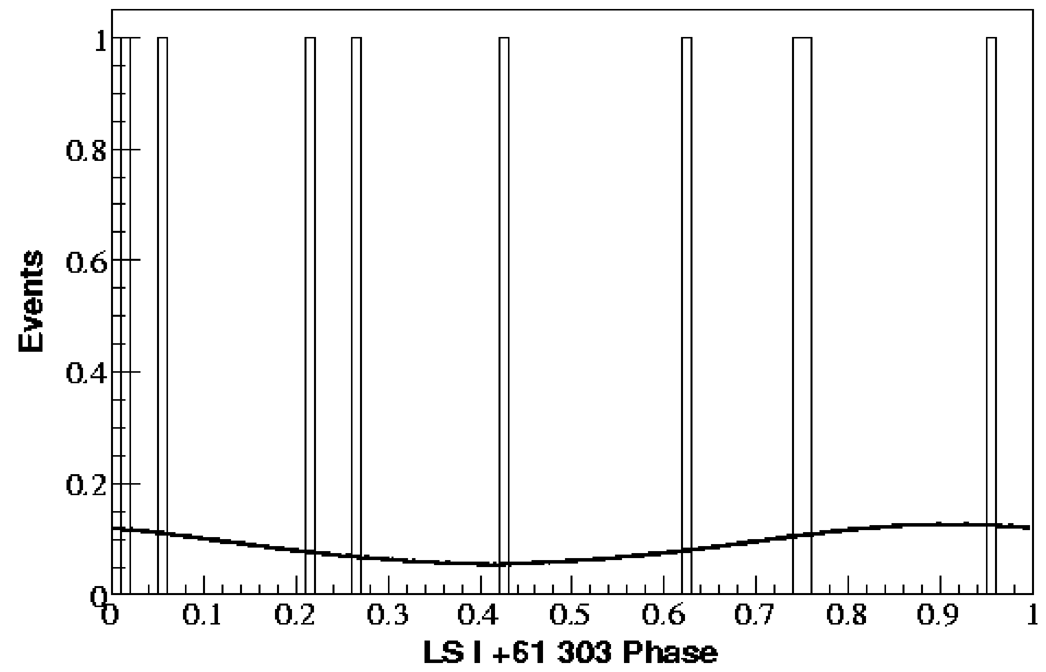


Results

- Nine events within 3 degrees, but no correlations

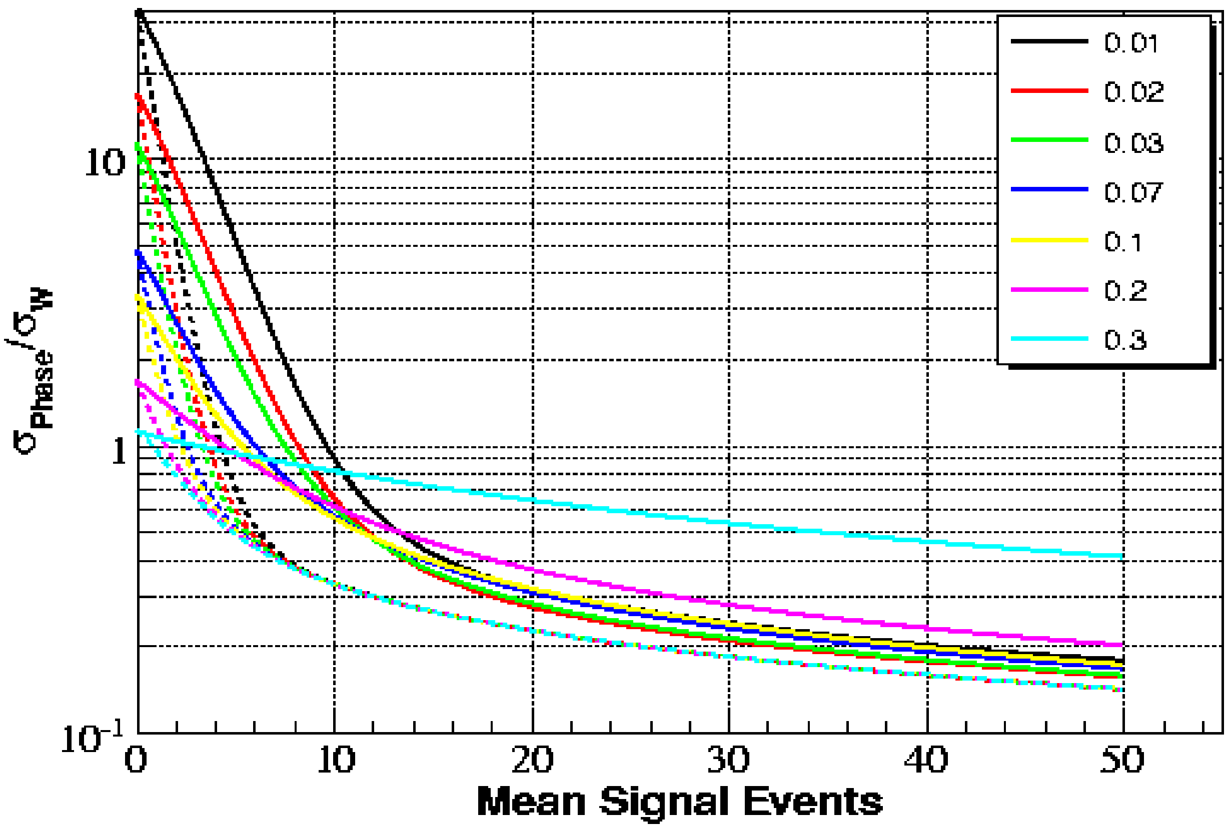
ID	Nch	Phase	Year	Day	MJD	S/B
412098	42	0.211976	2000	281	51824.115521	20.611414
3219607	60	0.269850	2001	128	52037.616956	456.237216
8383068	32	0.423660	2001	185	52094.684294	15.964889
5825816	68	0.741784	2002	173	52447.561319	85.744617
6773244	57	0.951576	2002	205	52479.615961	1000.868687
3441011	20	0.050589	2002	208	52482.239398	15.908098
1718914	155	0.011549	2004	60	53064.117002	3907.663041
2314110	79	0.621906	2004	182	53186.273009	1004.641265
6875899	35	0.756908	2006	196	53931.738032	18.372001





If there was a signal...

We would have been able to accurately measure the phase of maximum emission

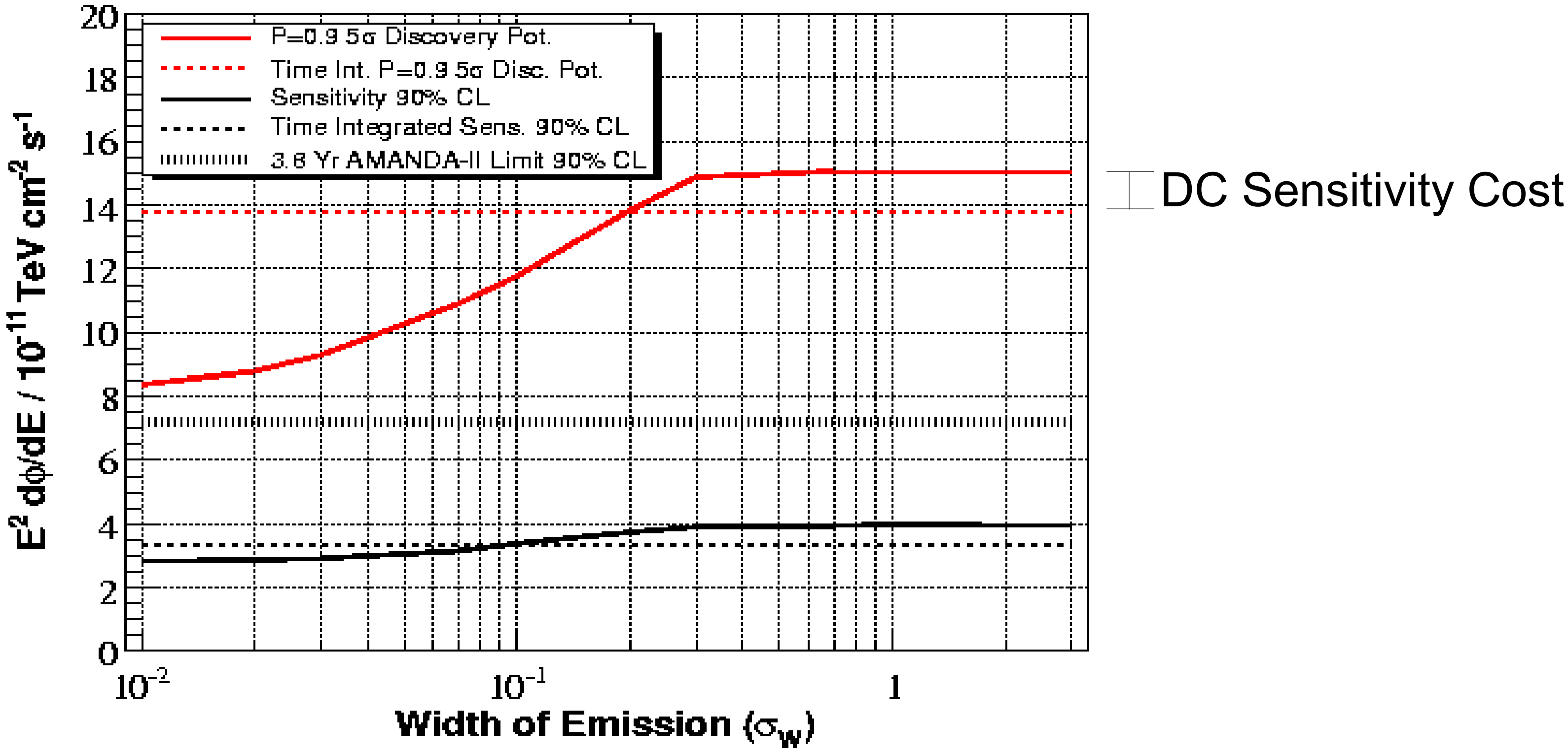


We can measure the max phase to better than σ_w given 10 signal events

For larger numbers of signal events, the phase measurement error converges to the background-free limit

Unifying Time-Integrated (DC) and Time-Dependent Analysis

- Can potentially perform time-integrated and time-dependent analyses simultaneously



- Depends on sensitivity cost for DC sources
  - Minimal for LS I +61 303 periodic search

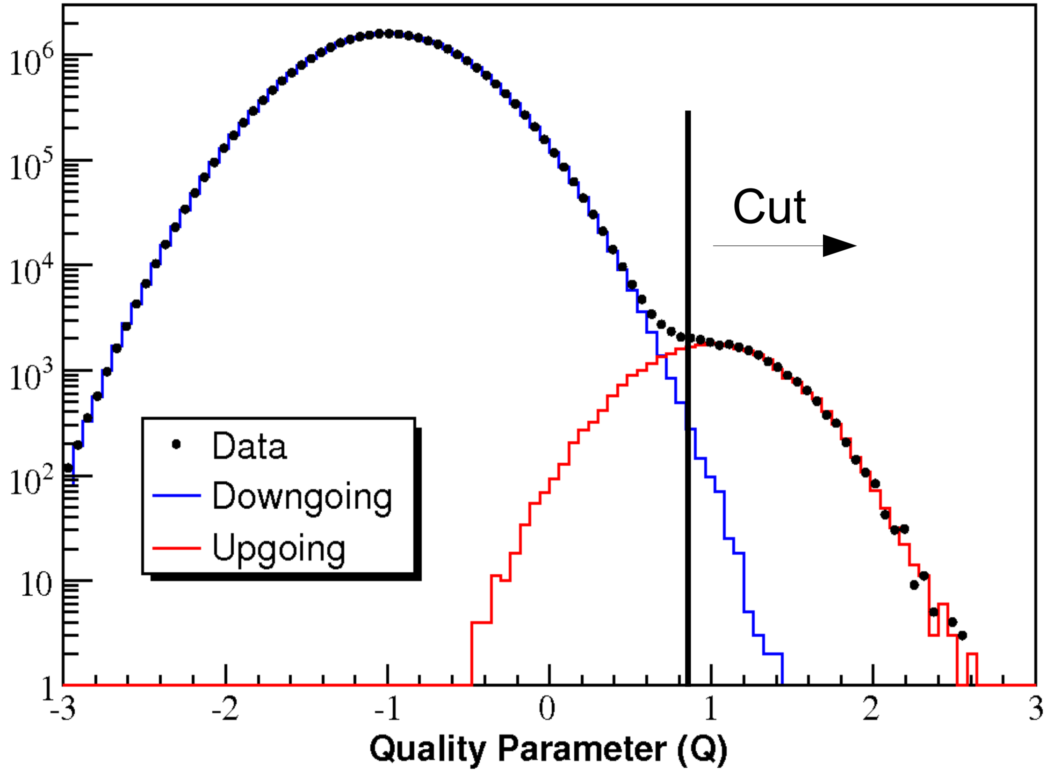
Unifying Time-Integrated (DC) and Time-Dependent Analysis

- Currently working on unifying a generic time-clustering search with standard unbinned DC search
  - Signal does not necessarily need to be a Gaussian pulse
  - Cost to DC analysis not yet clear
- Case for unified analysis: The IC22 hotspot
  - Meaning of p-value from such a search is clear, thus we can avoid the discussion of combining p-values

Extending the unbinned analysis concept

- Generically, unbinned methods are more powerful because cuts waste information
- A natural next step is abandoning the quantized cut of upgoing versus downgoing events
  - The binary division between neutrino and muon like events could be viewed as the last remnant of the binned analysis concept
  - Progress in other working groups
    - Dima: Atmospheric ν analysis
    - Nathan Whitehorn: GRB analysis

One step further - the probability that an event is neutrino like



- Instead of applying the above cut on the quality parameter Q (e.g. SVM output), each event is assigned an upgoing and downgoing likelihood

- The point source likelihood function is now

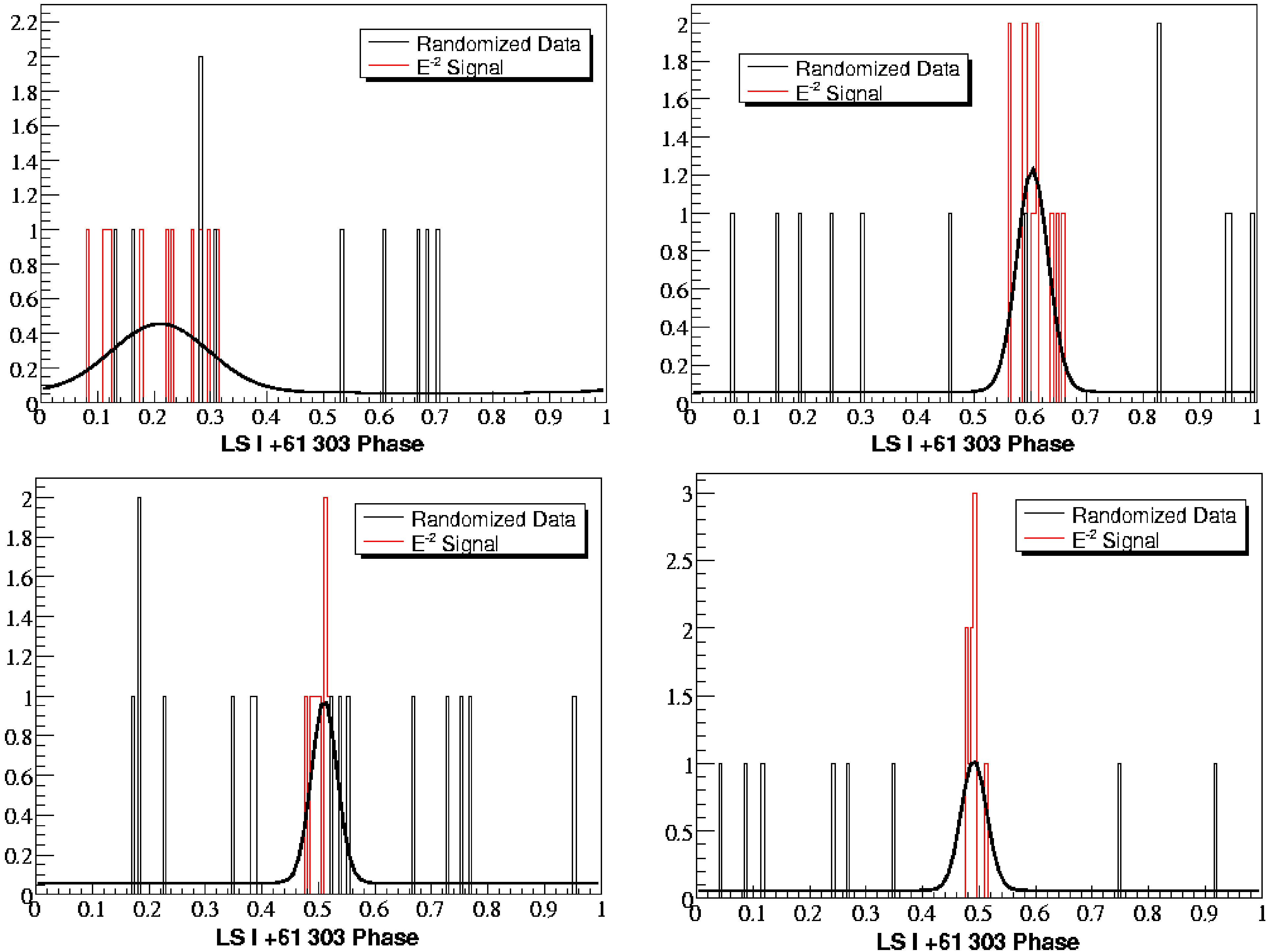
$$\mathcal{L}(\vec{x}_s, n_s, n_b, \gamma) = \prod_{i=1}^{N} \left(\frac{n_s}{N} \mathcal{S}_i + \frac{n_b}{N} \mathcal{B}_i + \frac{(1-(n_s+n_b))}{N} \mathcal{M}_i \right)$$

Signal: $$\mathcal{S}_i = \frac{1}{2\pi\sigma^2} e^{-\frac{|\vec{x}_i - \vec{x}_s|^2}{2\sigma^2}} \cdot P(Nch_i|\gamma) \cdot P(t_i) \cdot P(Q_i|Signal_\nu)$$

Atm ν Background: $$\mathcal{B}_i = \frac{P(Nch_i|Atm_\nu)}{\Omega} \cdot P(Q_i|Atm_\nu)$$

CR μ Background: $$\mathcal{M}_i = \frac{P(Nch_i|Bkgd_\mu)}{\Omega} \cdot P(Q_i|Bkgd_\mu)$$

- May especially help near/above horizon, where cuts are tight
- Elimination of event selection makes analysis much easier
  - Caveat: Requires good data/simulation agreement, and may be computationally challenging
  - What are the implications for unblinding an analysis which proposes no cuts?


Randomized Data
E^-2 Signal
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