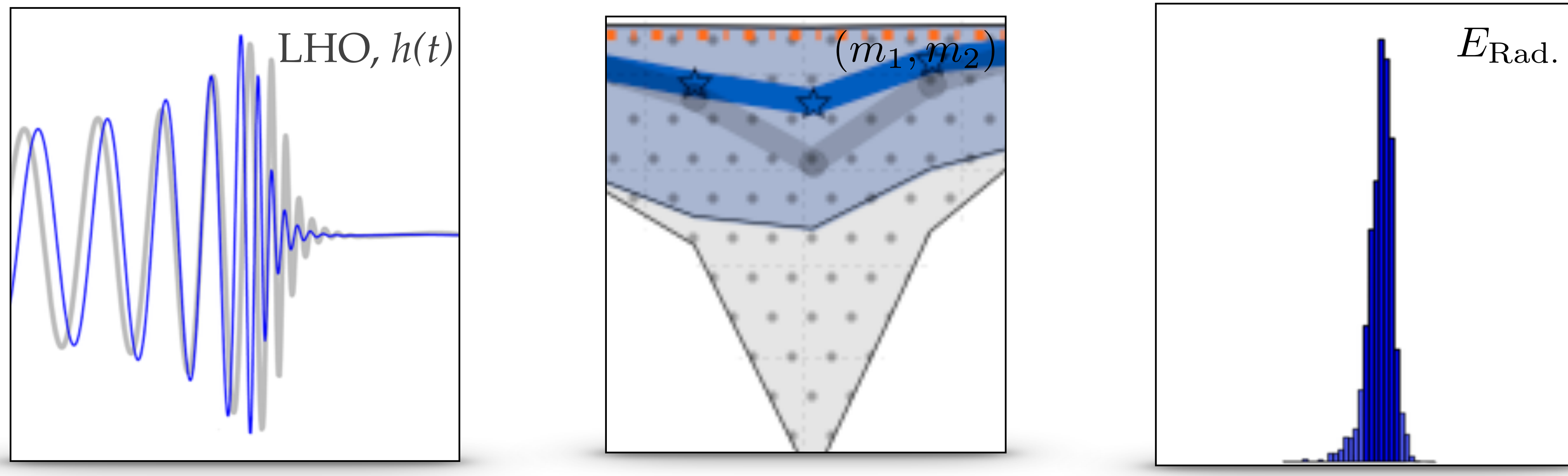

Global "Workhorse models" → *Parameter Estimation (PE)* → *PE Post-Processing*

In the context of GW150914

Learning from Gravitational Wave Detections Parameter Recovery with IMRPhenomPv2

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LSC LIGO Scientific Collaboration

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GR21

Wednesday, July 13th 2016

The Role of Global Models: Confront Uncertainty

- **Before GW150914:**
  - Uncertain of BBH existence and merger within observable universe
  - Uncertainties about total mass, mass ratio and spins
- **After GW150914:**
  - Comparable mass BBH systems exist and merge within our observable universe.
  - Uncertainties about total mass, mass ratios, and spins persist.

- **Scientific need:** "Global GW Models" intend to cover a very large parameter region, but are limited to regions of suggested use. They can be used to detect and characterize signals, even when detailed physics may not be known. They help enable followup modeling.

- **Primary Global Models used for GW150914:**
  - **PhenomPv2**: simplified precessing BBH systems   current focus
  - **SEOBNRv2(ROM)**: spin-aligned BBH systems (Pürrer, Taracchini, Pan, others)

IMRPhenomPv2: Construction and Review Notes

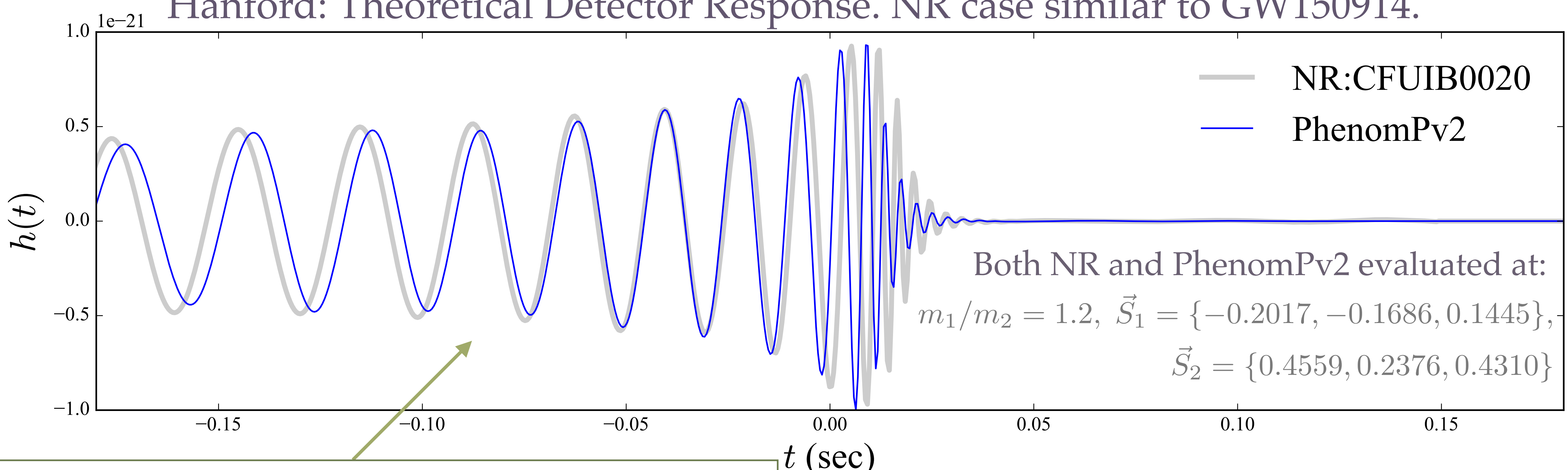
- **Construction:**
  - **Foundational idea** — Waveform multipole moments can be transformed from one decomposition frame (i.e. choice of right handed axes) to another via a weighted sum. In this sense, multipoles from one frame can be rotated or "twisted" into another.
  - **PhenomPv2 Approach** — A non-precesssing model, IMRPhenomD (Khan, Husa et al 2015), is used to produce a waveform in the "co-precessing" frame, which is coordinate frame aligned with the orbital angular momentum. The non-precessing waveform is "twisted up" using PN formulae to rotate from the co-precessing frame to the observer's frame. (Schmidt, Hannam et al 2014)
  - **Technical Resources** — Patricia Schmidt's PhD thesis, The PhenomP paper, DCC document
- **Notes from LIGO Review:**
  - Faithfulness comparisons to NR waveforms: maximum mismatch < 1% for inclinations < pi/12, **mass ratios <= 5 and maximum opening angle (beta) < pi/4**.
  - The mismatch increases as the **inclination**, mass ratio, and/or beta increase; at mass ratio 5, the mismatch can be as much as ~6% for edge-on (inclination angle = pi/2) and beta = pi/4.
  - See LIGO review page for PhenomPv2 for additional details.

PhenomPv2 Open Question: Systematics

- **Core Question:** For GW150914, can we trust and approximate model to recover a signal with full physics? Approximate model *vs.* Full Physics
- **Approach to Answer:** Apply PE to theoretical detected responses in zero noise — "Inject full NR", and use Bayesian Inference with PhenomPv2.
- **Things to Consider:** Mass-ratio, higher modes, Polarization:

$$h(t) = A\cos(2\psi) + B\sin(2\psi)$$

Hanford: Theoretical Detector Response. NR case similar to GW150914.

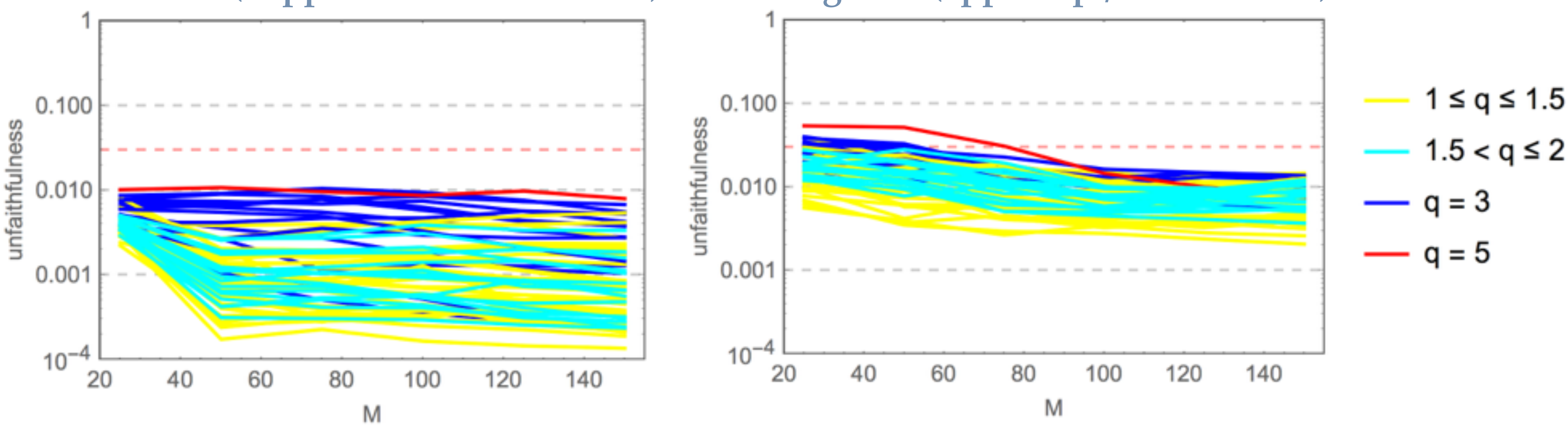


Must match conventions & optimize extrinsics!

PhenomPv2 Systematics: Expectations

- Typically high faithfulness at inclination angles near 0(=“Face-On”) or pi (=“Face-Off”) implies no biases.
- Typically lower faithfulness near inclination angle of pi/2 (=“Edge-On”) implies possible biases.

Face-On (=approx. zero Inclination) | Edge-On (approx. pi/2 inclination)



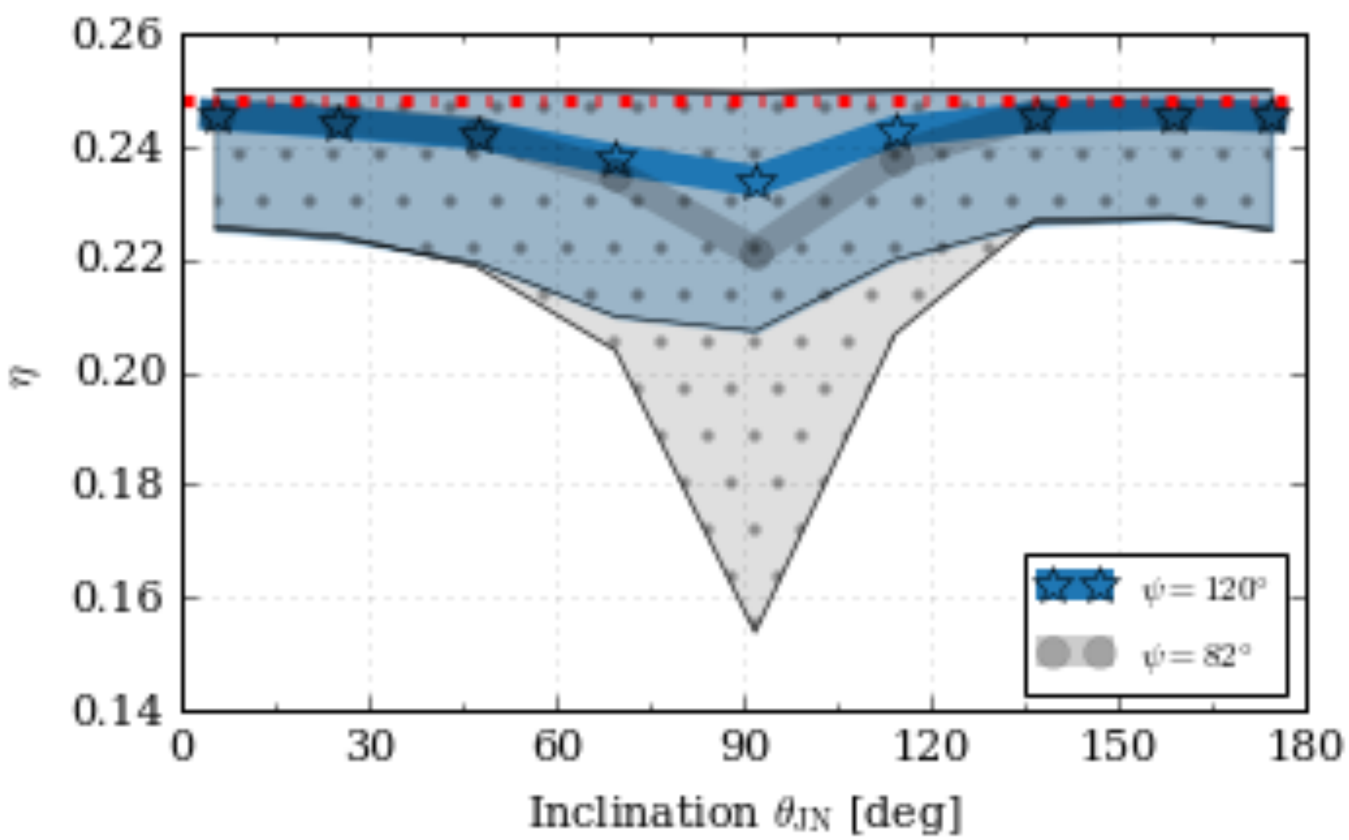
(Comparison to SXS 32 runs: Alejandro Bohe, PhenomPv2 code review)

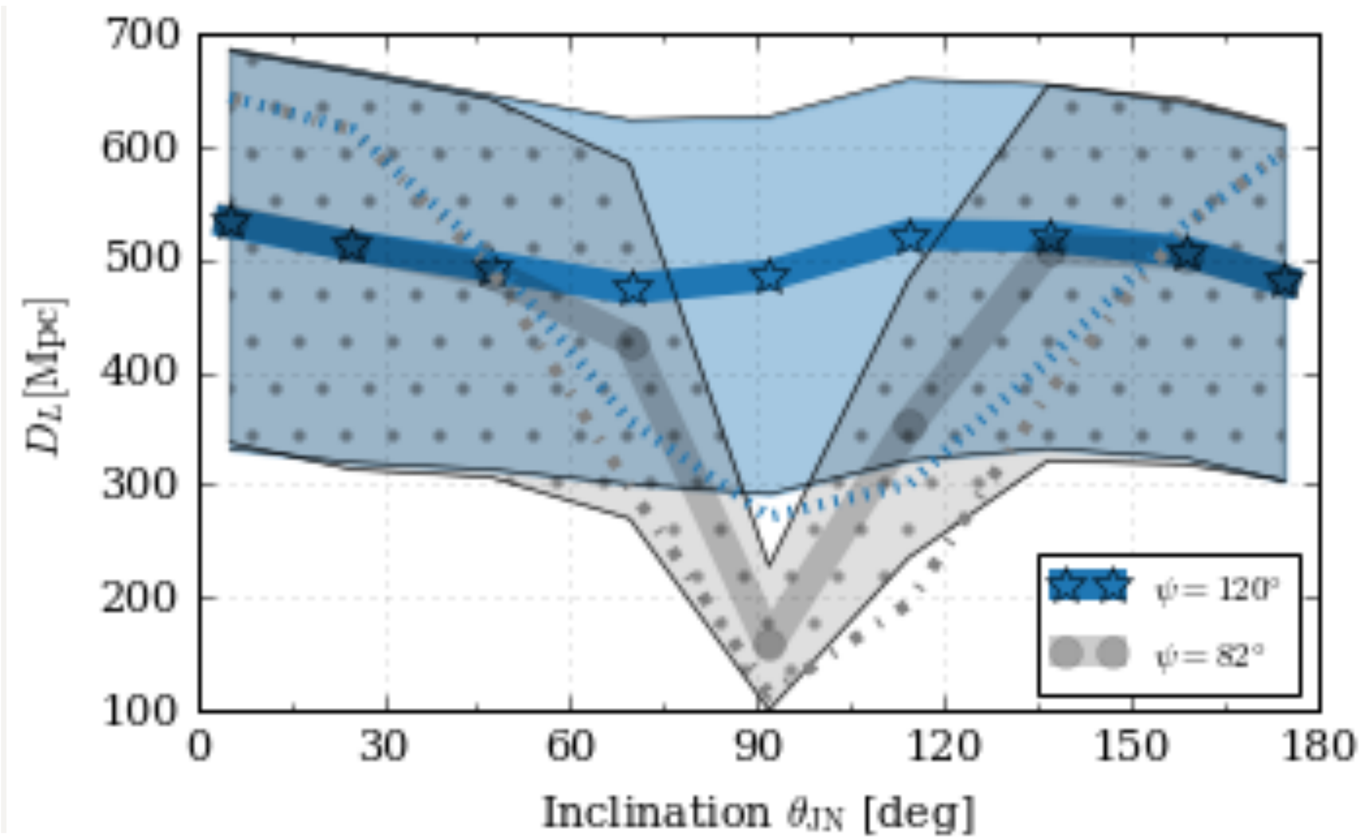
- **Case Example:** The effect of inclination & polarization on PE results.

Effects of Inclination & Polarization: GW150914

Simulation Used: CFUIB0020 (See slide 4)

For nearly face-off signals, polarization angle, ψ, is degenerate with arrival phase.





- No biases found for nearly face-on or nearly face-off signals. Therefore no bias expected for GW150914.
- A region of approx. 30 degrees which experiences weak to moderate parameter bias. How many signals may be affected?

Fraction of Signals Affected: A Rough Estimate

Assumptions: Single Detector, SNR 25, Isotropic Event Rate (estimate courtesy of Frank Ohme)

- The detector response, $h(t) = F_+ h_+(t) + F_\times h_\times(t)$, can be written as
$$h(t) = A_{\rm GW}(t)\, A_{\rm sky}\, A_{\rm pol}\, \cos(\Phi_{\rm GW}(t) + \Phi_0)$$
- Here, $A_{\rm GW}(t)$ is the time-dependent amplitude that depends on the binary's masses and spins, $A_{\rm sky}$ depends solely on the sky location, and $A_{\rm pol}$ describes the amplitude variation with inclination and polarization.
- Assuming that the region of mild bias is encompassed by a 30x30 degree black in inclination and polarization space, one can use the above expression to argue that

At most 1% of signals may be affected

PhenomPv2: Key Points & Next Steps

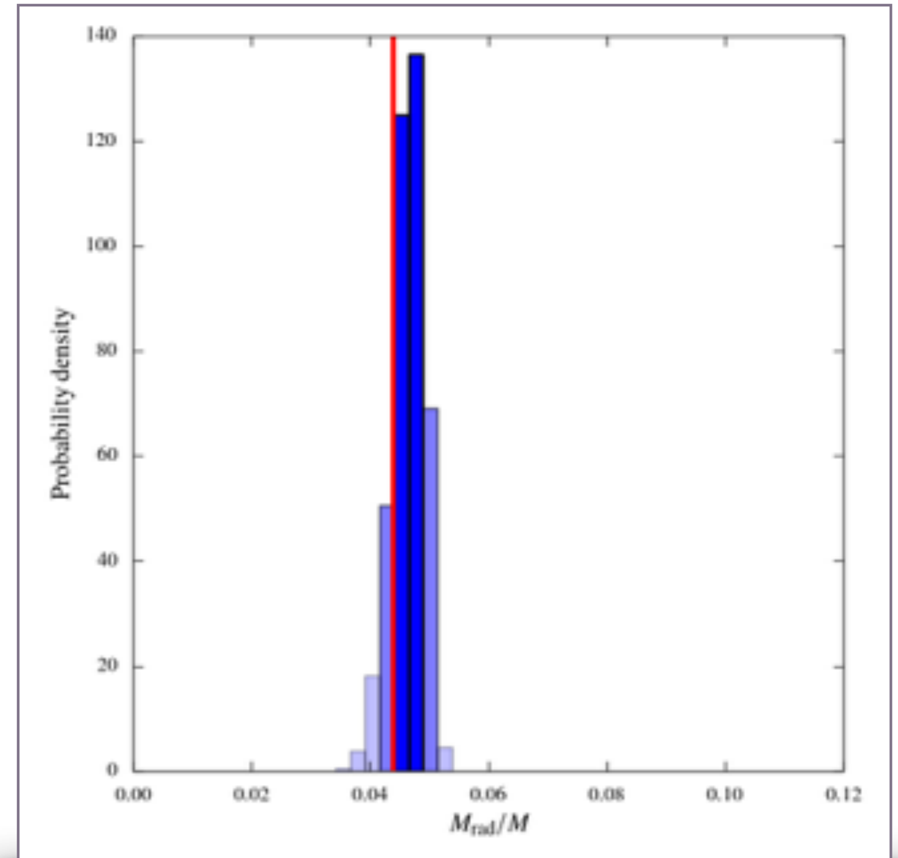
- **Systematics and the Effects of Inclination & Source Polarization:**
  - For GW150914, can we trust and approximate model to recover a signal with full physics? Yes. **There is no evidence of bias for near face-off injections of NR waveforms.**
  - **Slight** biases exist at edge-on, but it is likely that at most **1%** of potential signals would be affected for Advanced LIGO.
- **Success of PhenomPv2 for GW150914:**
  - It was one of the two primary models, and the first available precessing model used for GW150914 parameter estimation.
  - SEOBNRv2 and PhenomPv2 played a key role in or understanding of where to run followup simulations.
- **Next Steps for PhenomP:**
  - Extend the model to higher mass ratios.
  - Add higher multipoles, and more accurate PN for precession angles.
  - **Integrate new approaches. We can do better.**

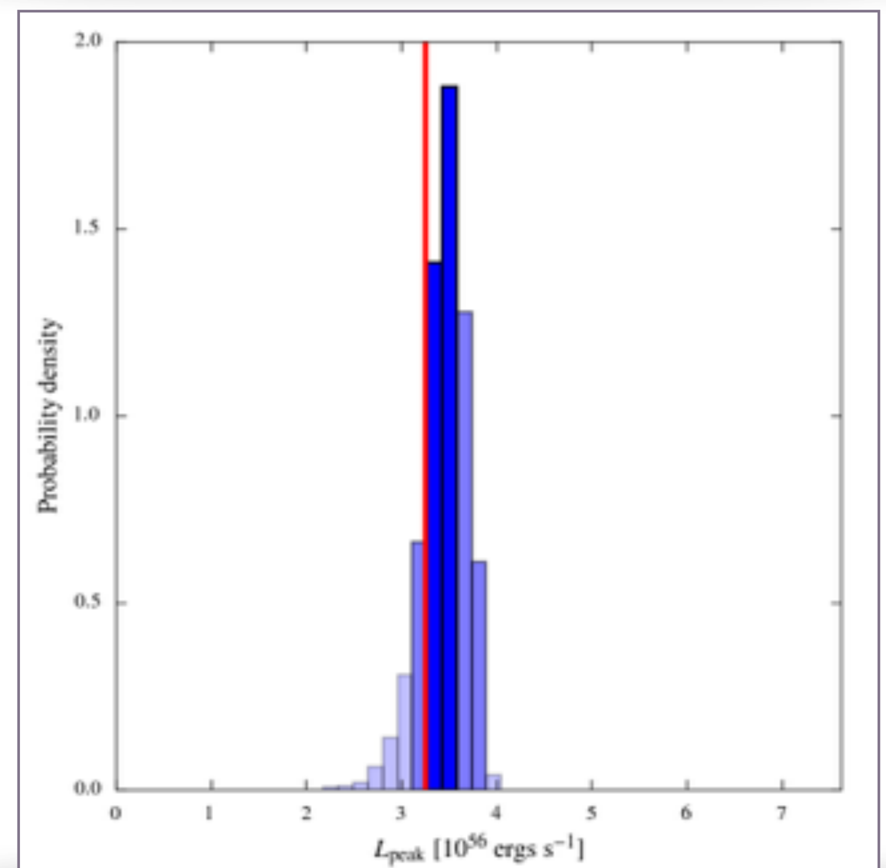
*Postface: **Radiated Quantities***

PE Post-Processing: Continuing to Learn More

Concept — GW models and Bayesian PE provide a mapping between initial system parameters (masses, spins, etc.) and signal morphology. NR simulations empower us to create additional mappings between initial parameters, and additional physical parameters:

- **Final Mass and Spin (Healy, Lousto, many others)**
- **Energy Radiated (Husa, Healy, Lousto)**
- **Peak Luminosity (London, Husa, et al — In Preparation)**
- **IMR Consistency, Tests of GR … the list goes on …**





Credit: Nathan J-M, Peak Lum. Review