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THE EFFECT OF THE CHOICE OF PRIOR ON MEASUREMENTS OF SPIN

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based on work with Chris Biwer, Duncan Brown, Ben Farr, and Frank Ohme

MOTIVATION

- The direction and magnitude of black hole spins can help distinguish the formation channel of observed binary black hole (BBH) mergers
- Problem: BH component spins are difficult to measure in gravitational waves (GWs)
- Leading-order spin terms enter the GW phase at 1.5PN order, with precession effects starting at 2PN

EFFECTIVE SPINS

- Dominant spin contribution is the *effective spin*:

$$\boxed{\chi_{\rm eff} = \frac{m_1 \chi_1^z + m_2 \chi_2^z}{m_1 + m_2}}$$

- Dominant precession effects given by [1]:

$$\boxed{\chi_p = \max\left\{ \frac{A_1}{q^2 A_2} \chi_1^\perp, \quad \chi_2^\perp \right\}}$$

Definitions

$$|\vec{\chi}_i| \equiv \left|\vec{S}_i\right| / m_i^2 \in [0, 1)$$

$$\chi_i^z \equiv \vec{\chi}_i \cdot \vec{L}$$

$$\chi_i^\perp \equiv \sqrt{(\chi_i^x)^2 + (\chi_i^y)^2}$$

$$q \equiv m_1 / m_2 \geq 1$$

$$A_1 \equiv 2 + 3q/2$$

$$A_2 \equiv 3 + 3/2q$$

[1] P. Schmidt et al., PRD 91 024043 (2015)

PARAMETER ESTIMATION

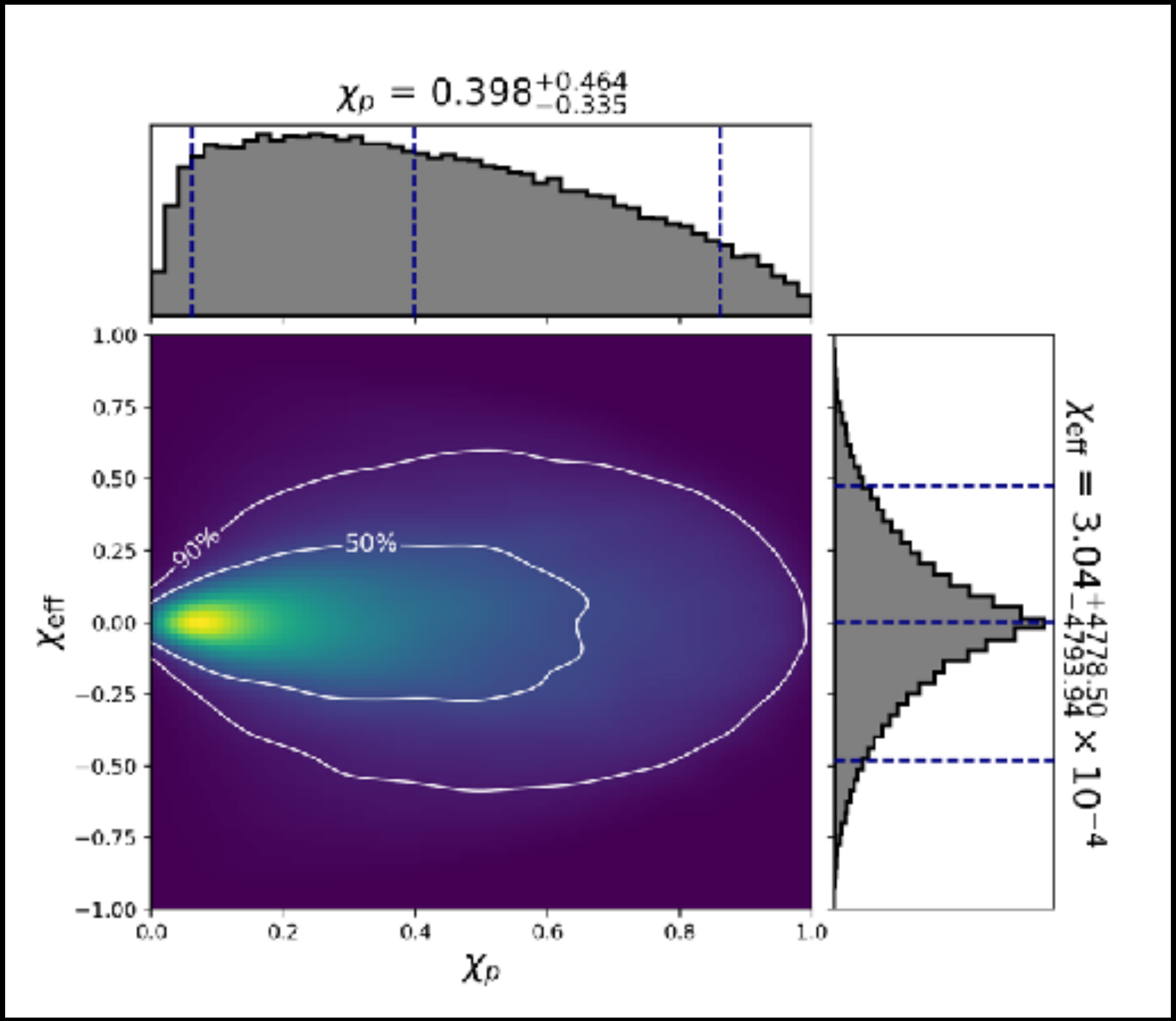
- GW source parameters estimated using Bayesian inference
- Probability that a signal h in data s has parameters $\vartheta = \{m_1, m_2, \chi_1, \chi_2, \ldots\}$ given by:

$$P\left(h[\vec{\vartheta}]\middle|s\right) = \frac{P(s|h[\vec{\vartheta}])}{P(s|0)} \boxed{P(h[\vec{\vartheta}])}$$

Prior probability that a signal exists with parameters ϑ.

- Ideally, we would choose the prior to be $\propto$ the distribution of signals in the universe
- Problem: We don't know the distribution of spins

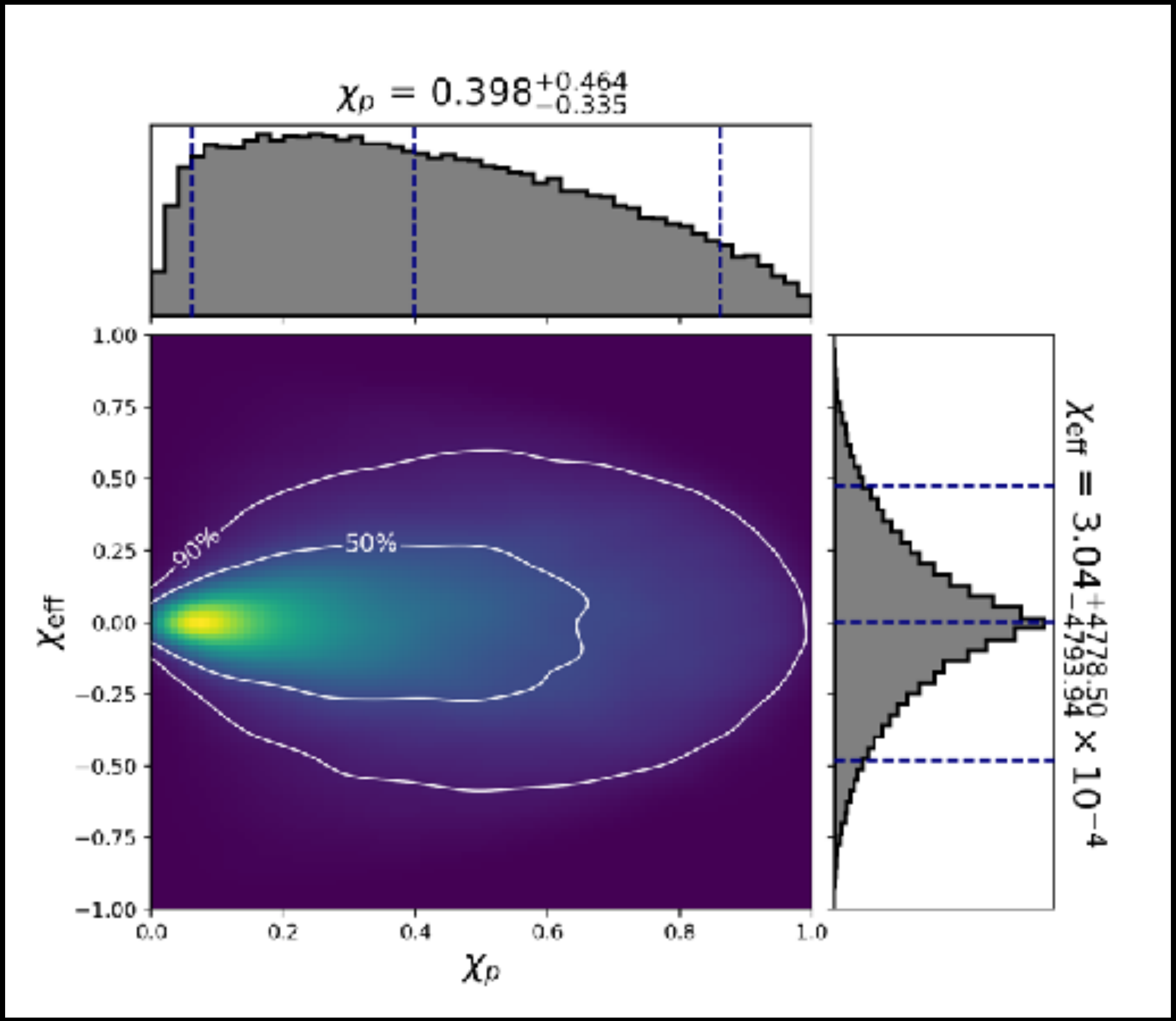
ISOTROPIC PRIOR



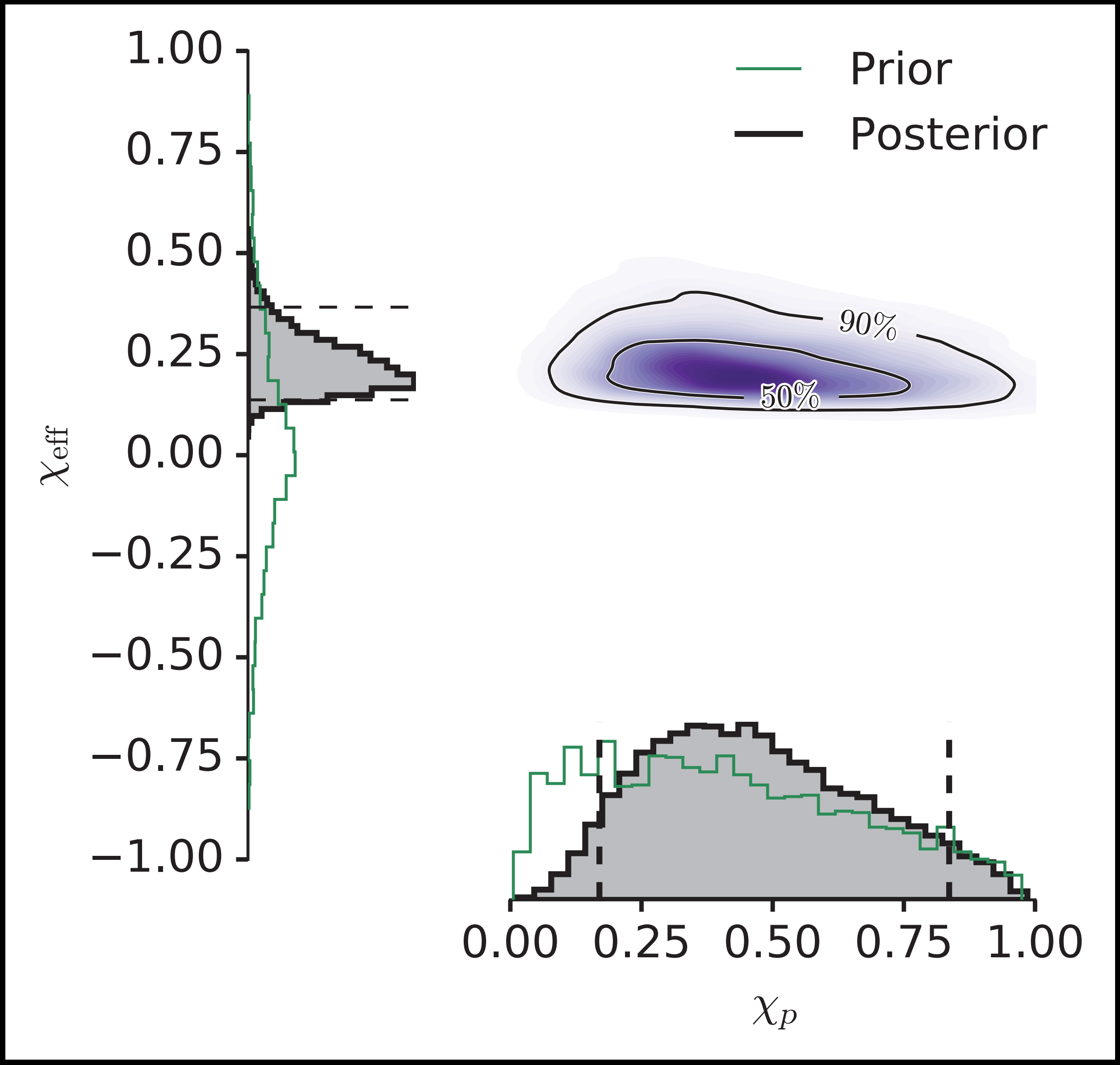
- **Isotropic prior**: isotropic in orientation and uniform in magnitude
- Currently used for the spins of each BH component

GW151226

Isotropic prior



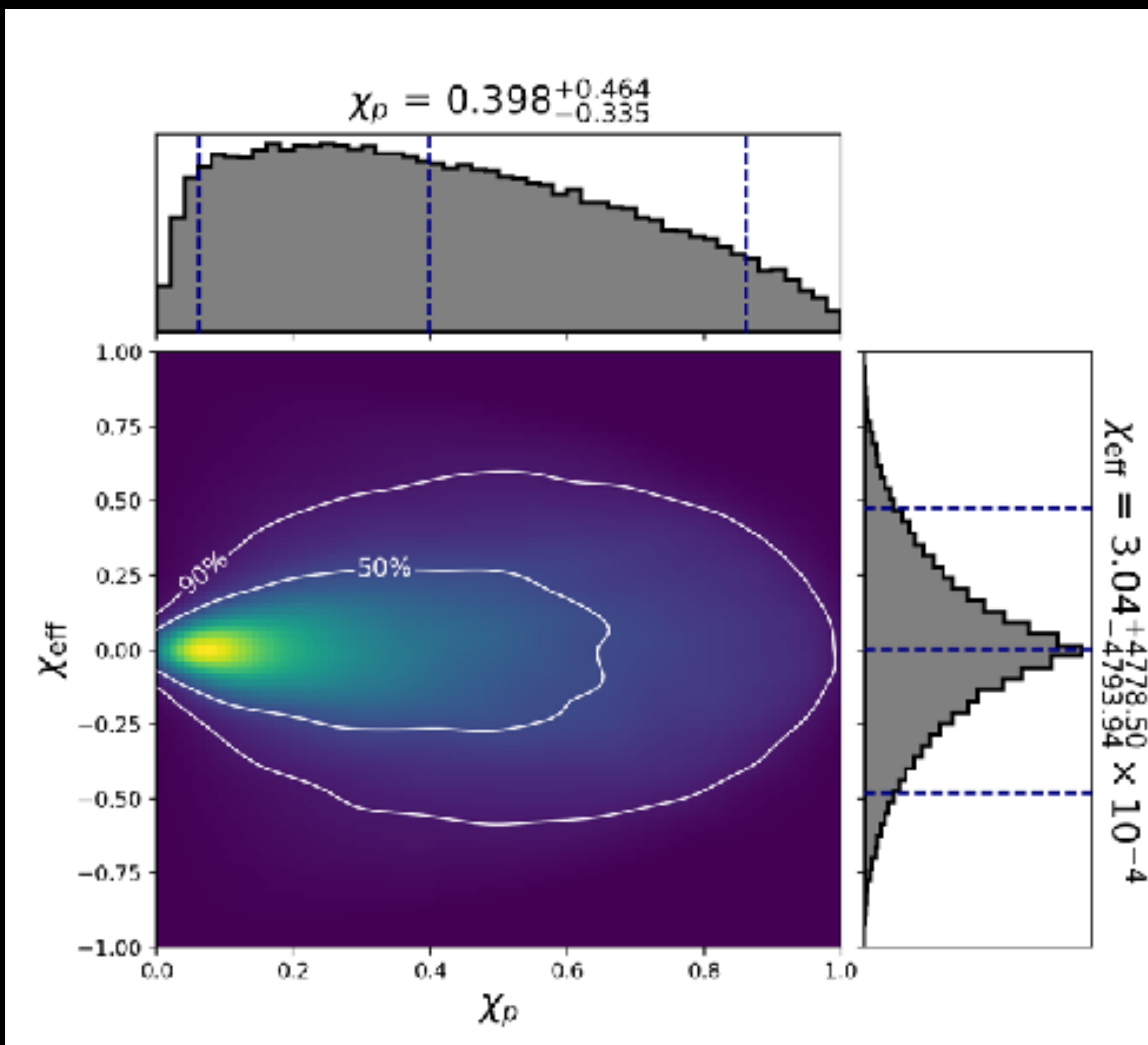
GW151226 posterior



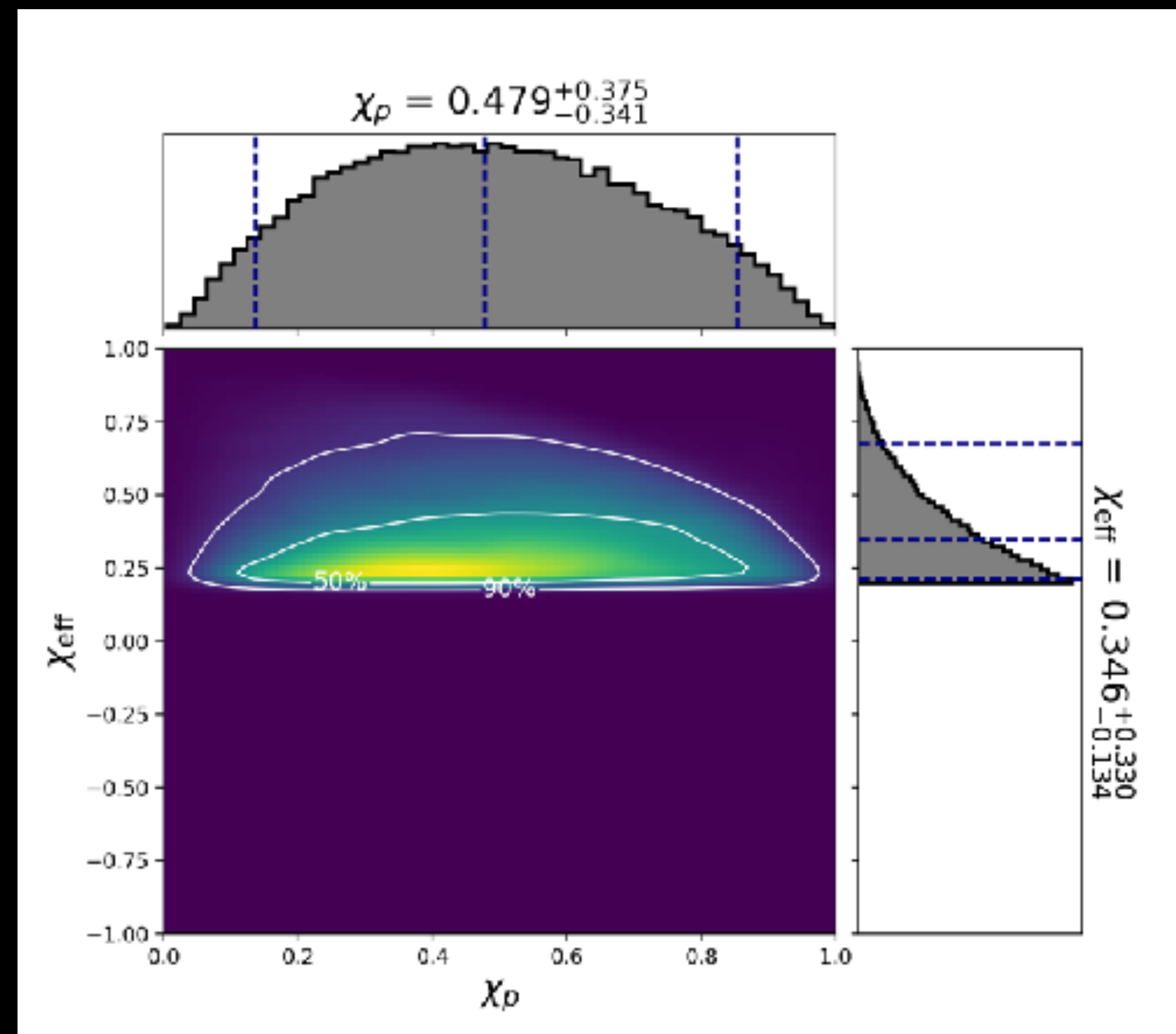
LSC+Virgo, PRL 116, 241103 (2016)

PARAMETER CORRELATIONS

Isotropic prior

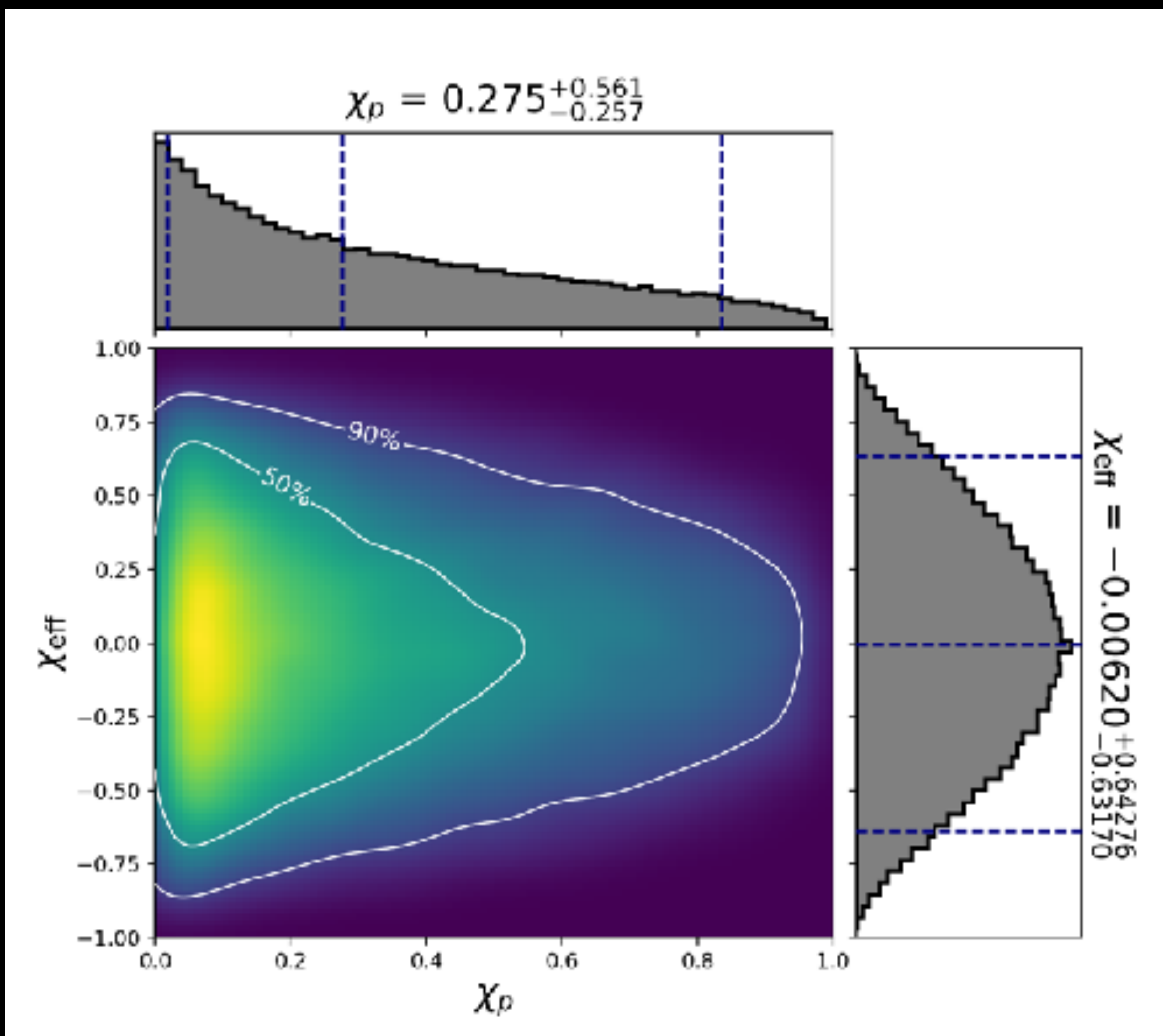


Isotropic with $\chi_{\rm eff} \geq 0.2$



INDEPENDENT PRIOR

Independent χ_p, χ_{eff} prior

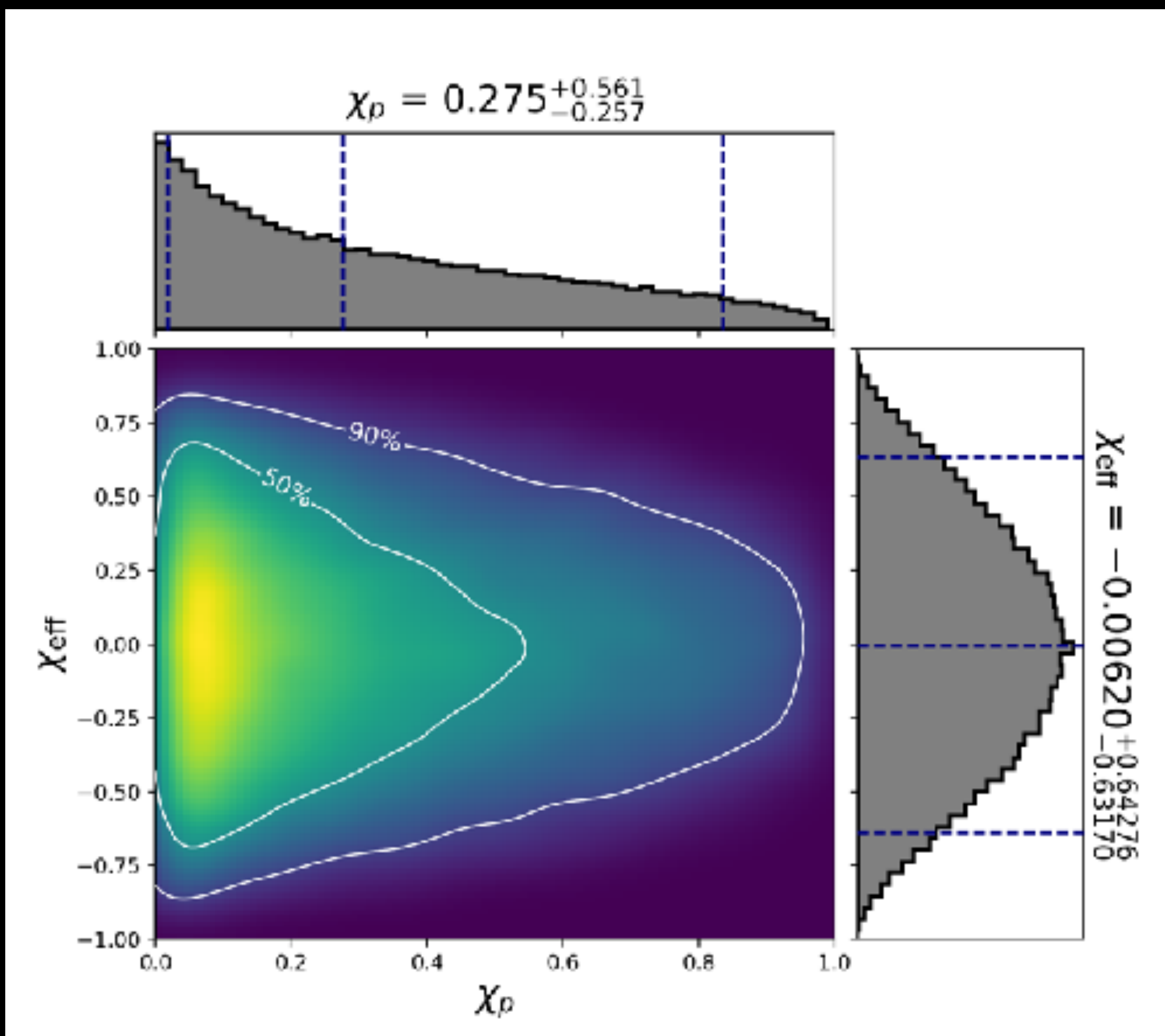


- Consider a prior uniform* in χ_p, χ_{eff}
- Not astrophysical, but uninformative in the spin parameters we measure best.
- χ_p, χ_{eff} are independent

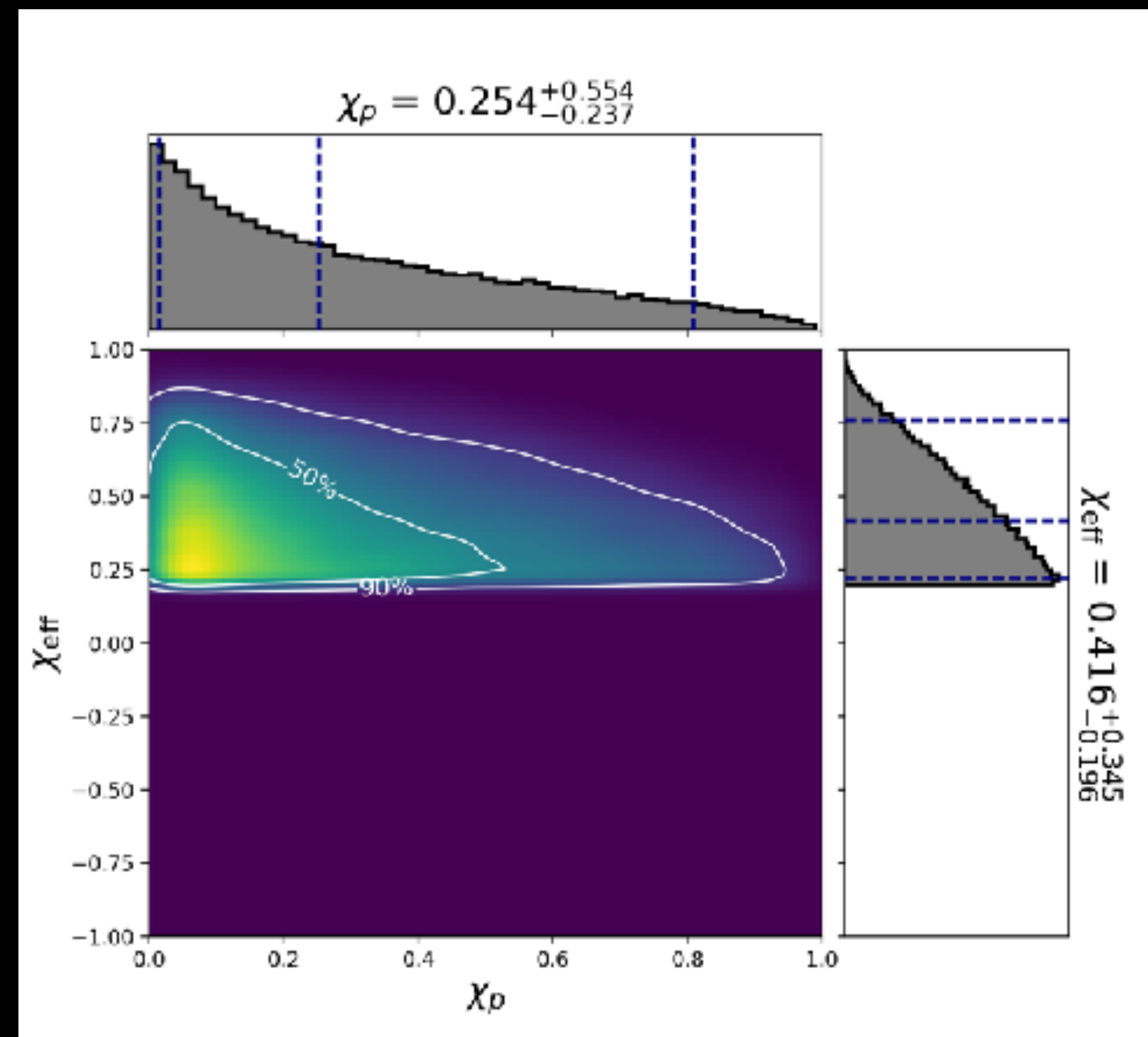
*Note: the 1D marginal distributions are not uniform because the spin magnitudes of each BH must be < 1.

INDEPENDENT PRIOR

Independent χ_p, χ_{eff} prior



with $\chi_{eff} \geq 0.2$



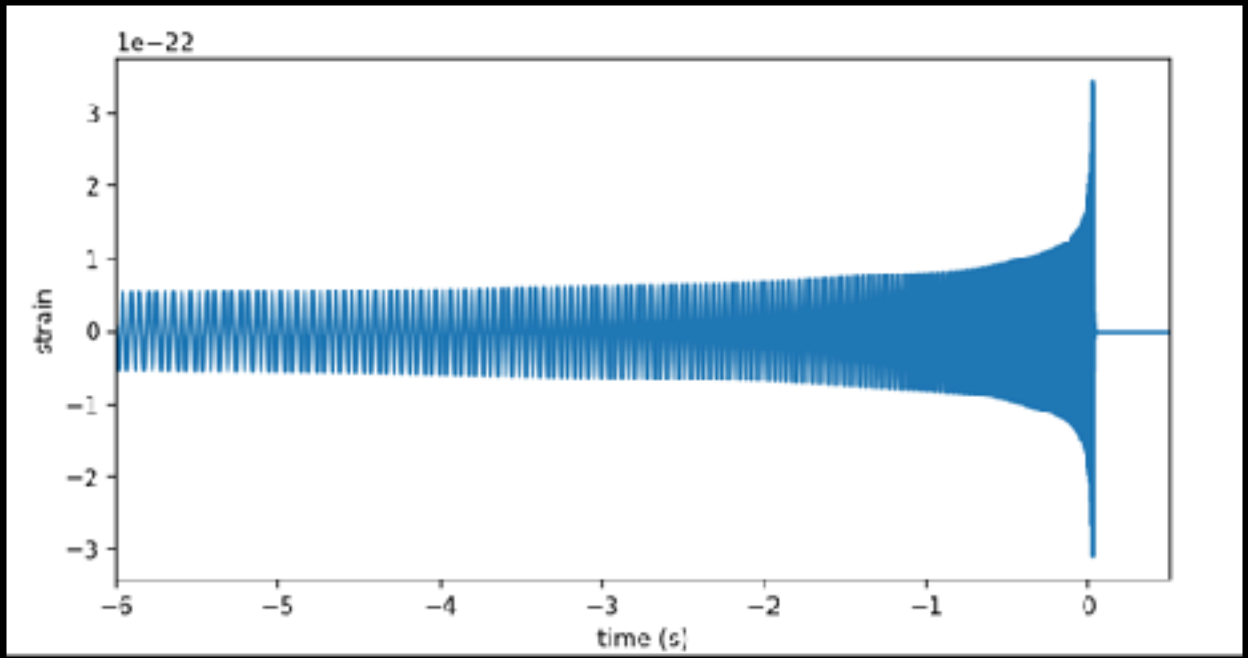
*Note: the marginal distributions are not uniform because the spin magnitudes of each BH must be < 1.

SIMULATED SIGNALS

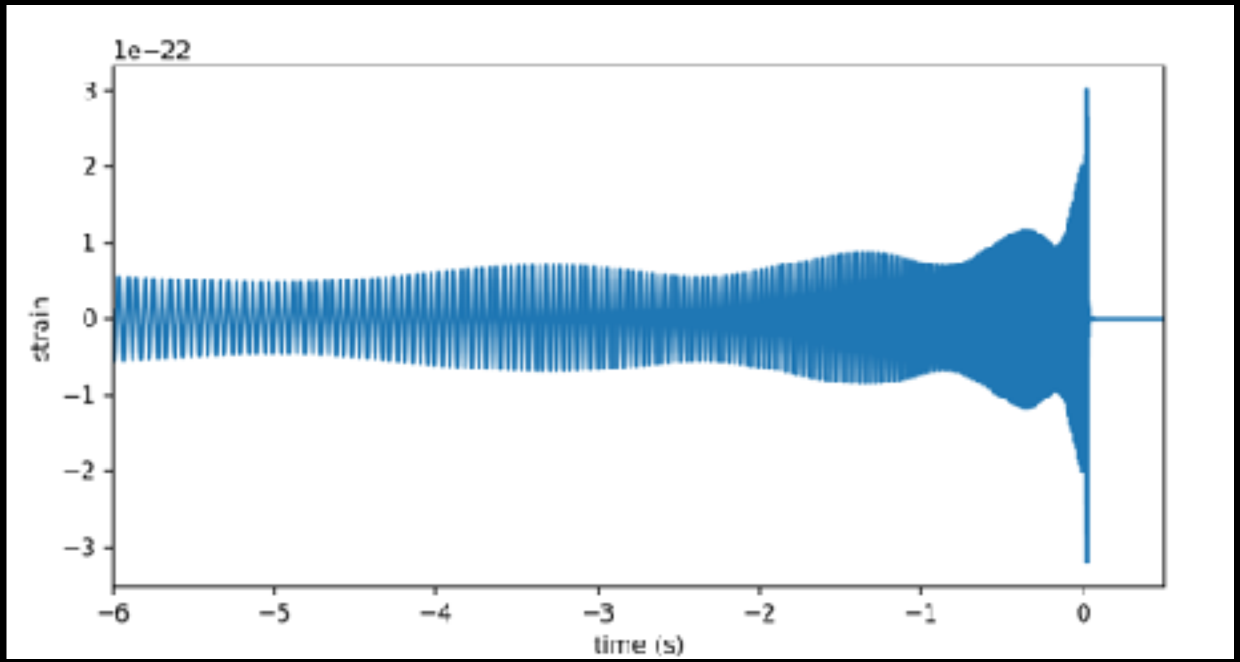
- Create 2 simulated GW151226-like signals using IMRPhenomPv2
- Both have:

- $m_1 = 16\ M_\odot$
- $m_2 = 8\ M_\odot$
- inclination = $\pi/4$
- sky-location consistent with GW151226
- SNR ~ 13
- $\chi_{\mathrm{eff}} = 0.4$

- One has $\chi_p = 0.04$



- The other has $\chi_p = 0.4$

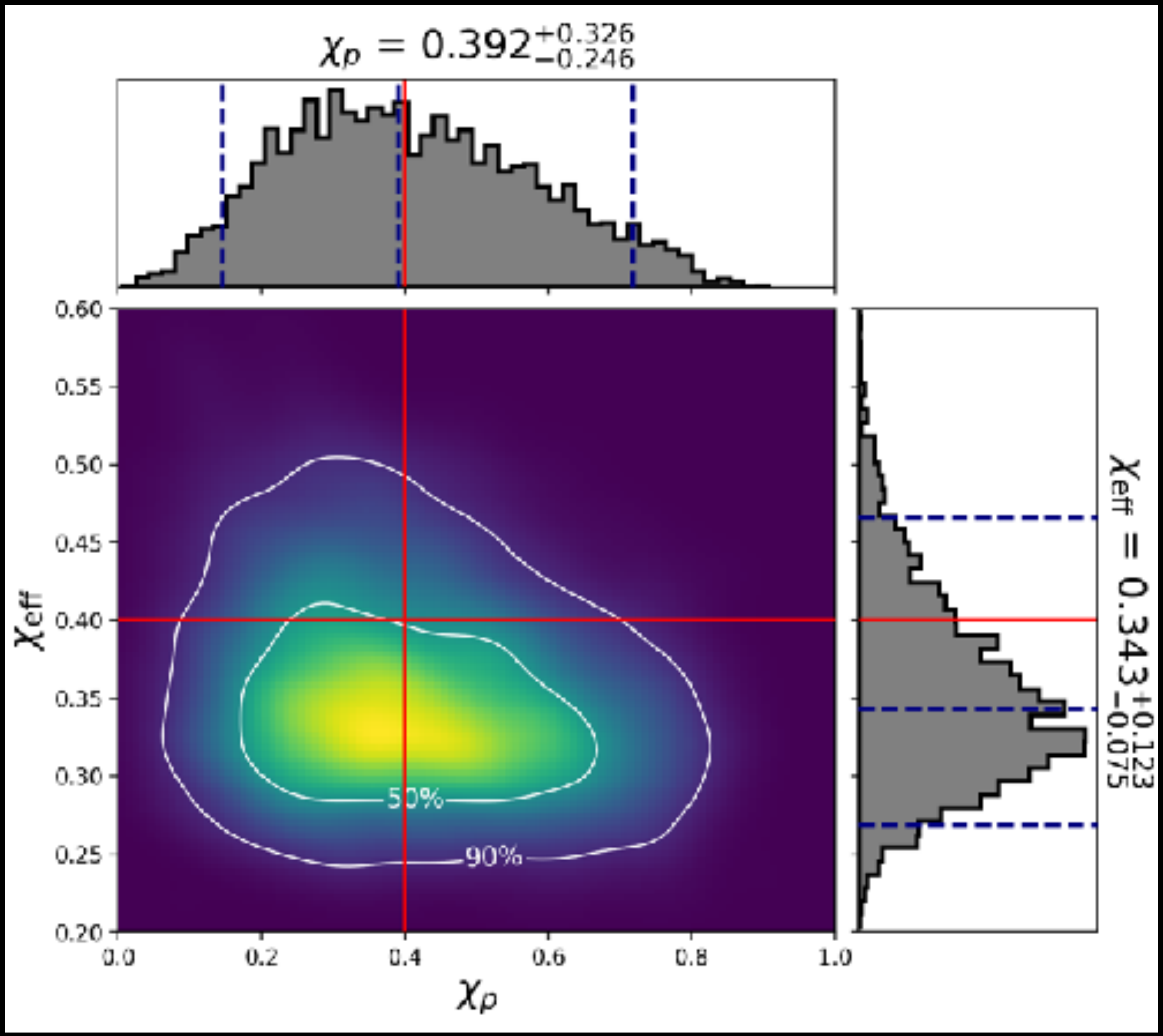


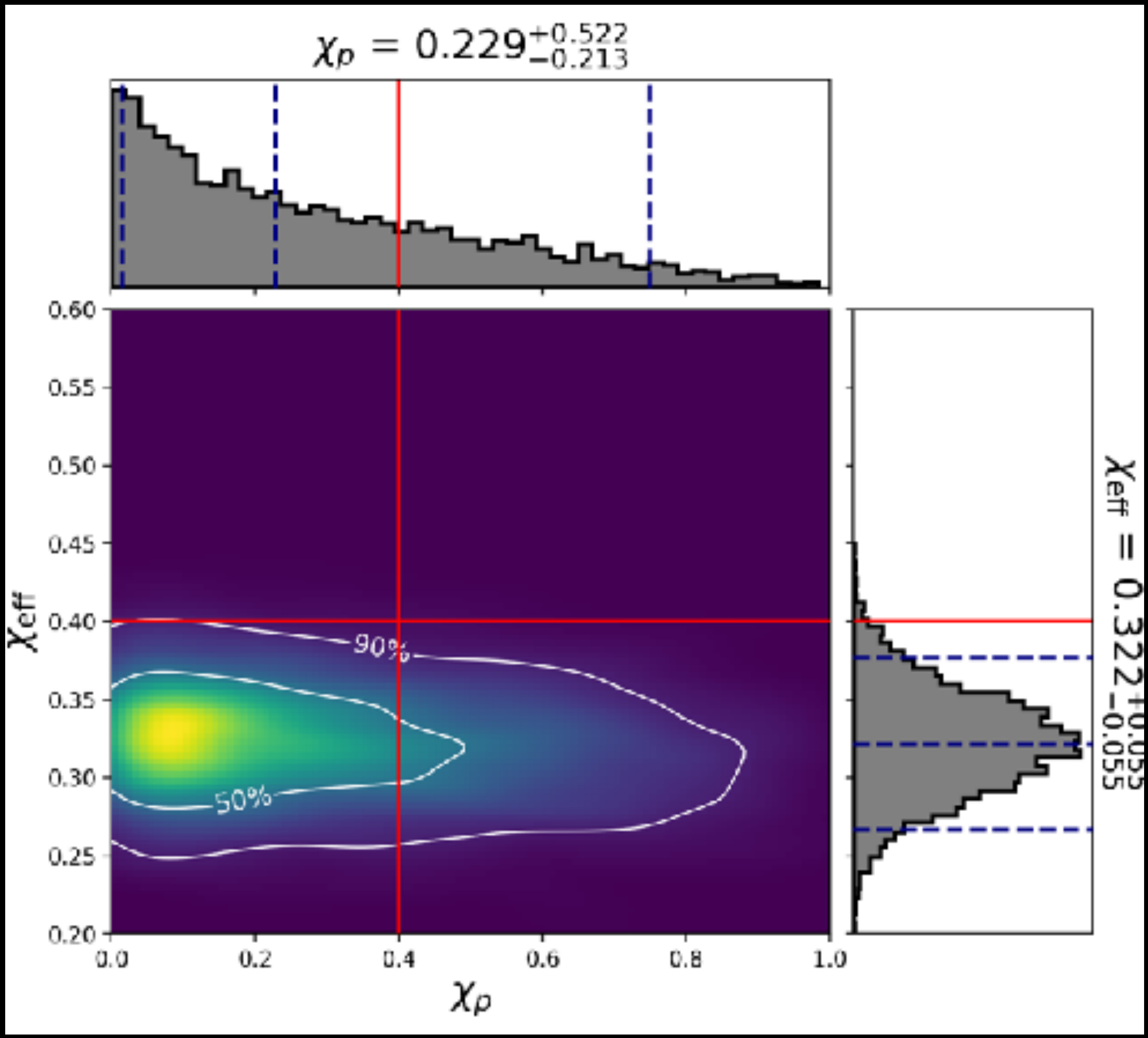
SIMULATED SIGNALS

- Signals injected into zero noise realization
- Run parameter estimation with PyCBC Inference on each simulation using O1 PSD
- For each simulation, do:
  - One run using isotropic spin prior
  - One run using independent spin prior
- Priors on other parameters are same as used for GW151226
  - uniform in m_1, m_2 with chirp mass $\mathcal{M} \in [9.5, 10.5)$ $M_\odot$ and mass ratio $q \in [1, 18)$

PRELIMINARY RESULTS: $\chi_p = 0.4$

Isotropic prior	Independent χ_p, χ_{eff} prior

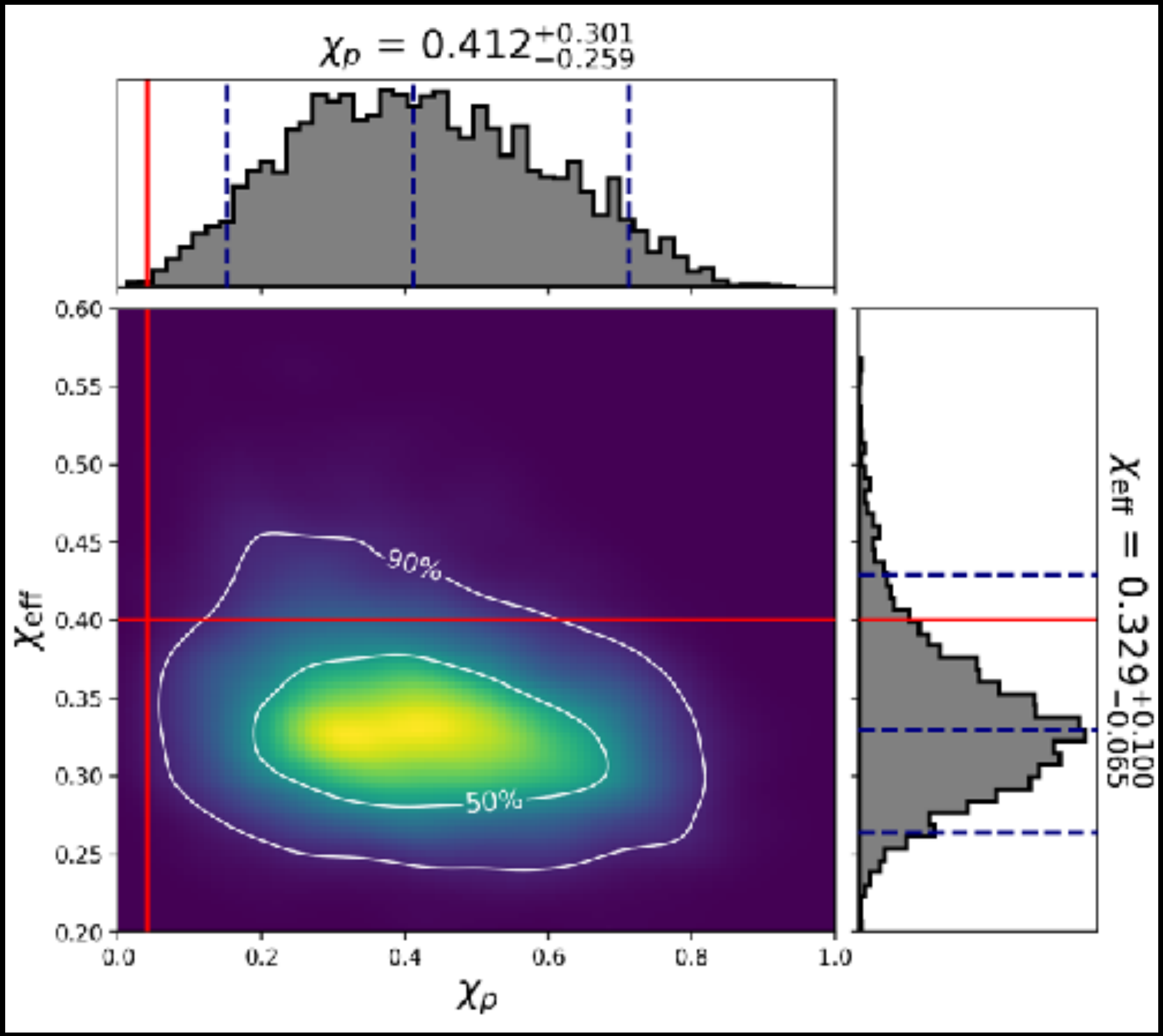




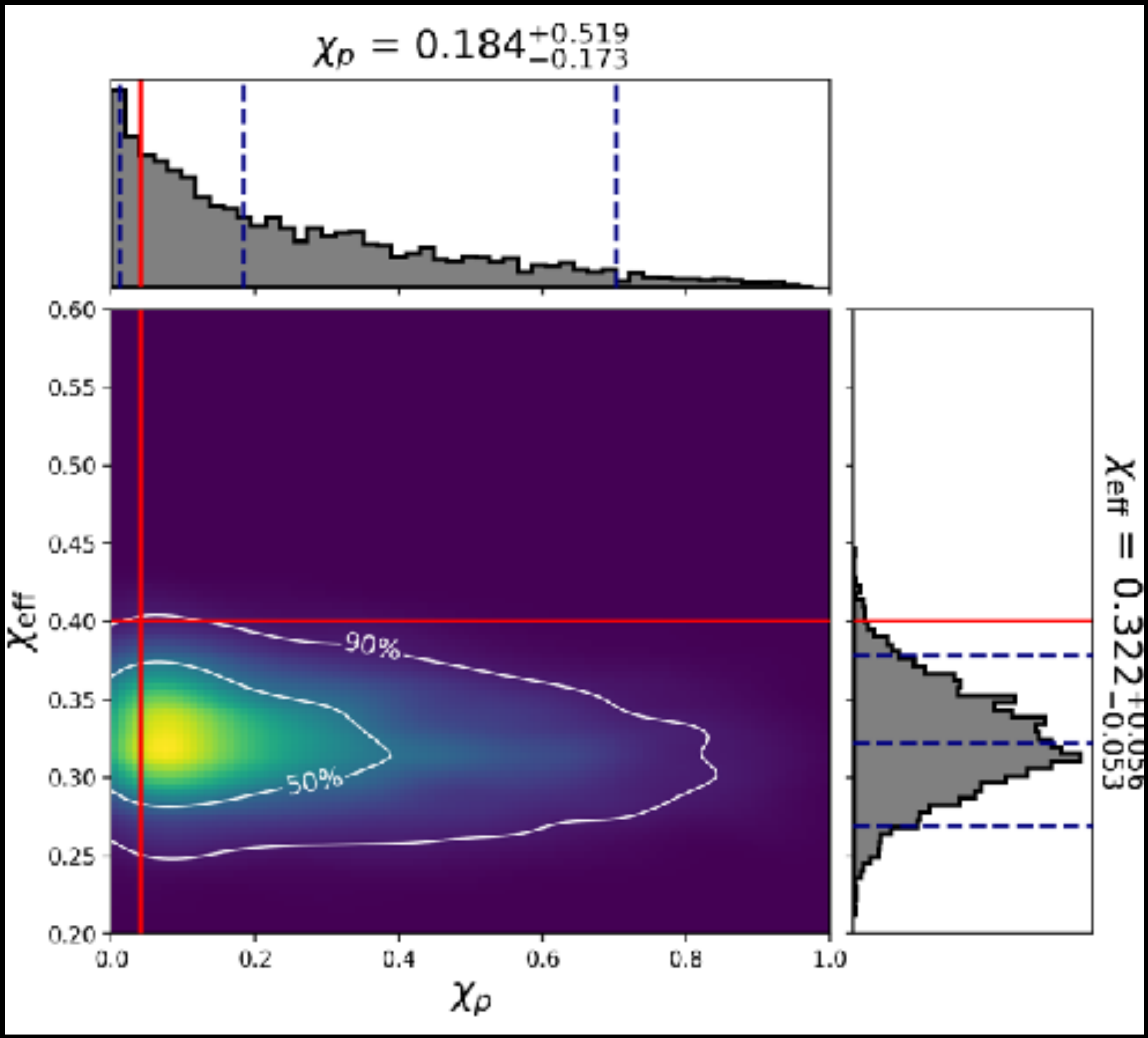
Red lines indicate signal's parameters.

PRELIMINARY RESULTS: $\chi_p = 0.04$

Isotropic prior



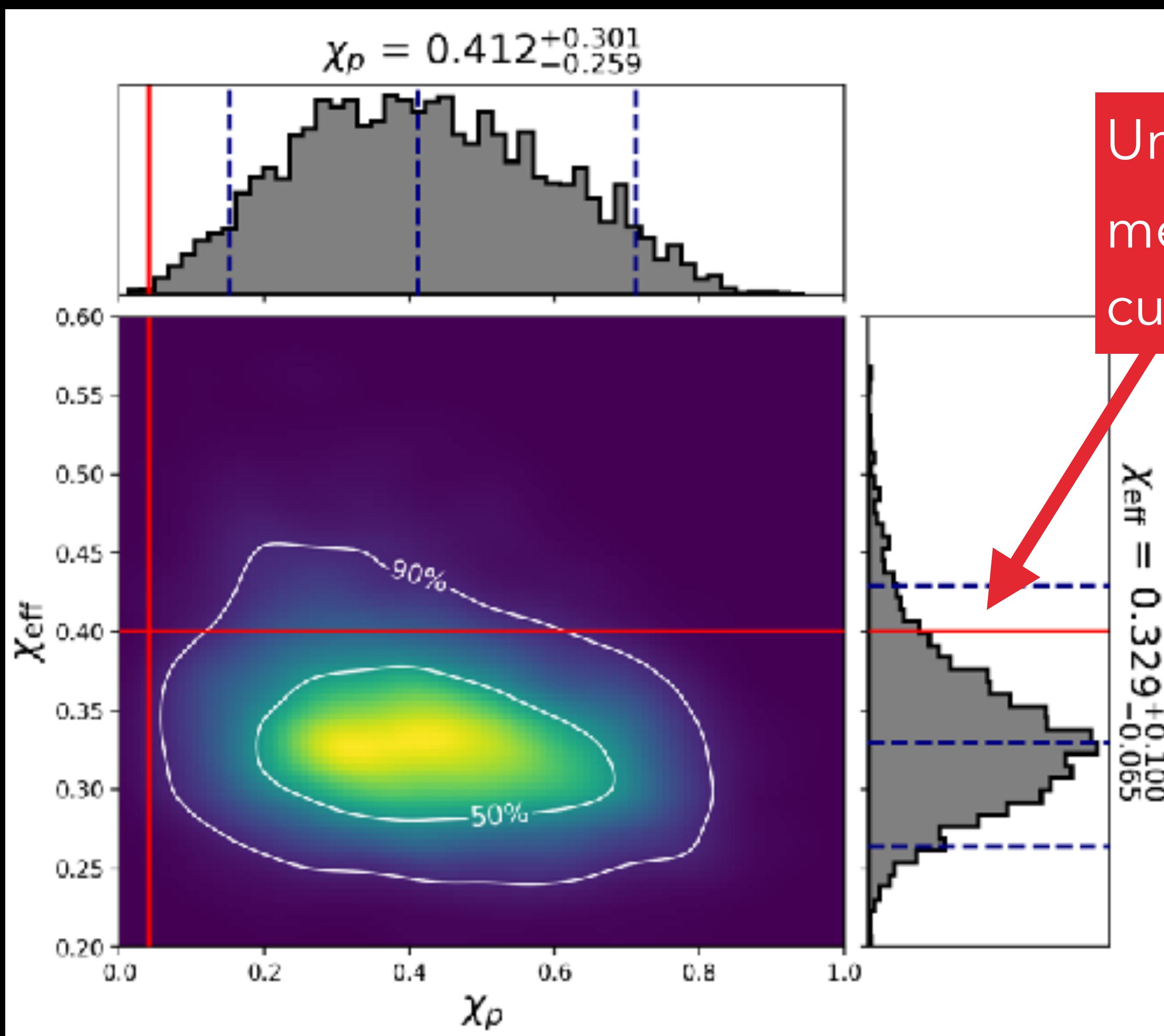
Independent χ_p, χ_{eff} prior



Red lines indicate signal's parameters.

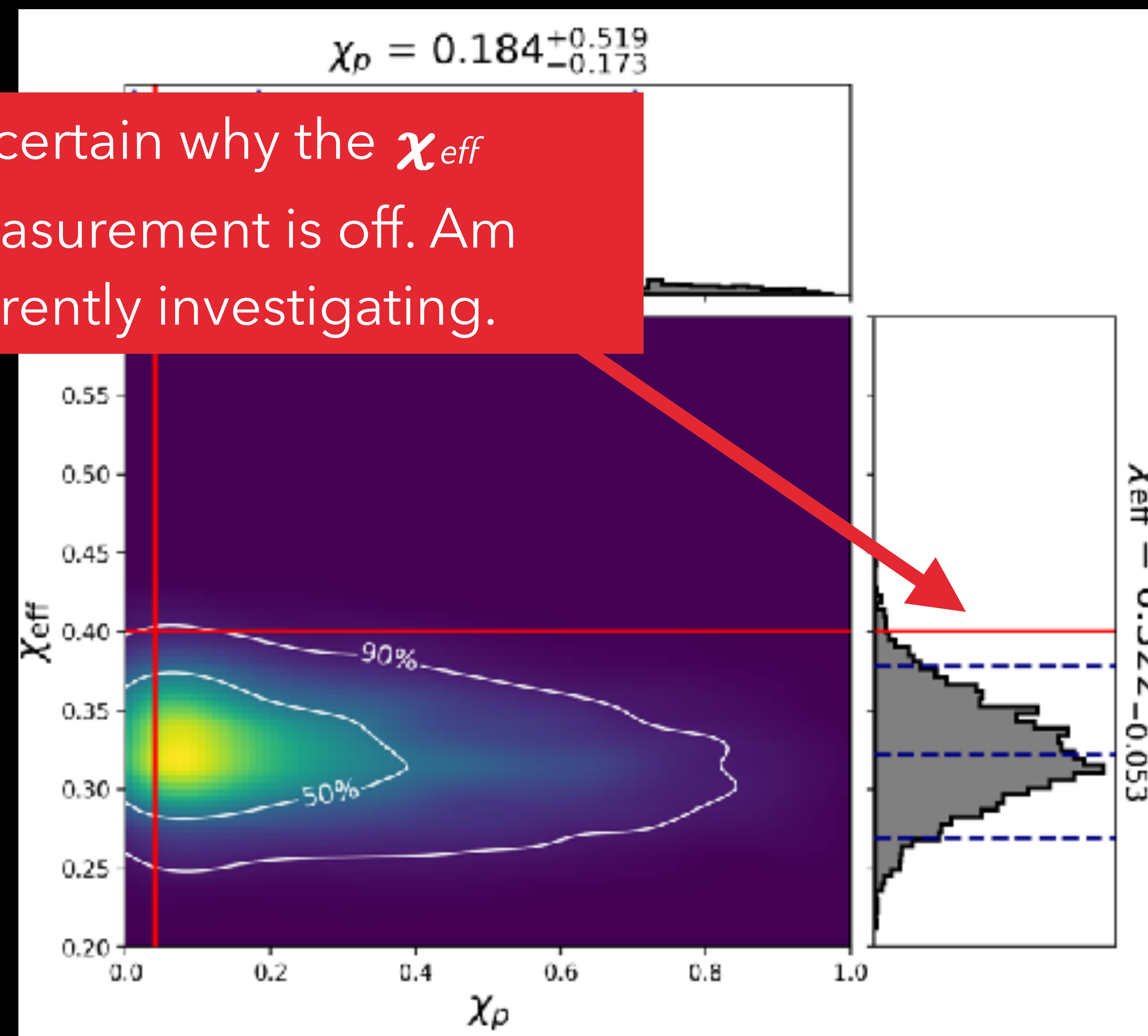
PRELIMINARY RESULTS: $\chi_p = 0.04$

Isotropic prior



Independent χ_p, χ_{eff} prior

Uncertain why the χ_{eff} measurement is off. Am currently investigating.



Red lines indicate signal's parameters.

SUMMARY

- At current sensitivity, spin measurements are strongly influenced by prior.
- Current priors are not very astrophysically motivated.
- Since the data will be slow to inform us about spins, we should do a better job of using several different priors to quantify their effects.
- We will perform a more systematic study of the independent χ_{p}, χ_{eff} prior.