Title: Complete phenomenological spin-Taylor waveforms for generic spins

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Abstract: The quest for gravitational waves from binary inspiral is performed via matched filtering and thus requires a detailed knowledge of the signal. For non-precessing binaries complete analytic waveforms exist from inspiral to merger and ring-down. Here we present complete waveforms for generically spinning equal mass systems.They have been constructed by bridging the gap between the analytically known inspiral phase described by spin Taylor (T4) approximants in the restricted waveform approximation and the ring-down phase. These two phases are connected by a phenomenological intermediate phase calibrated by confrontation with numerically generated waveforms.The values of the overlap integral between numerical waveforms and our semi-analitic ones range between 0.96 and 0.99.

Complete phenomenological spin-Taylor waveforms from generic spins

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Outline

1. GW's from coalescing binaries

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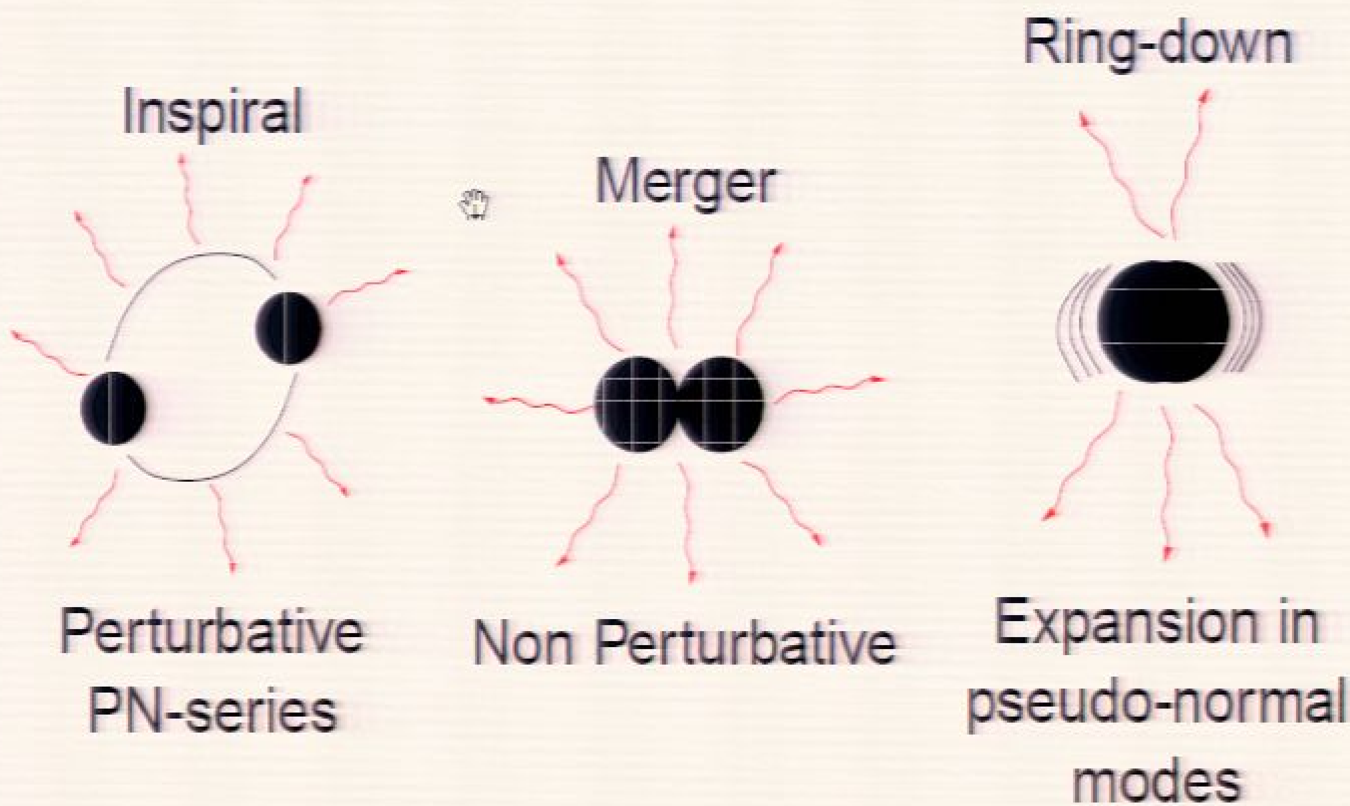
2. The PhenSpin approximant
   - Construction
   - Comparison with NR

Coalescing templates



Coalescing signal

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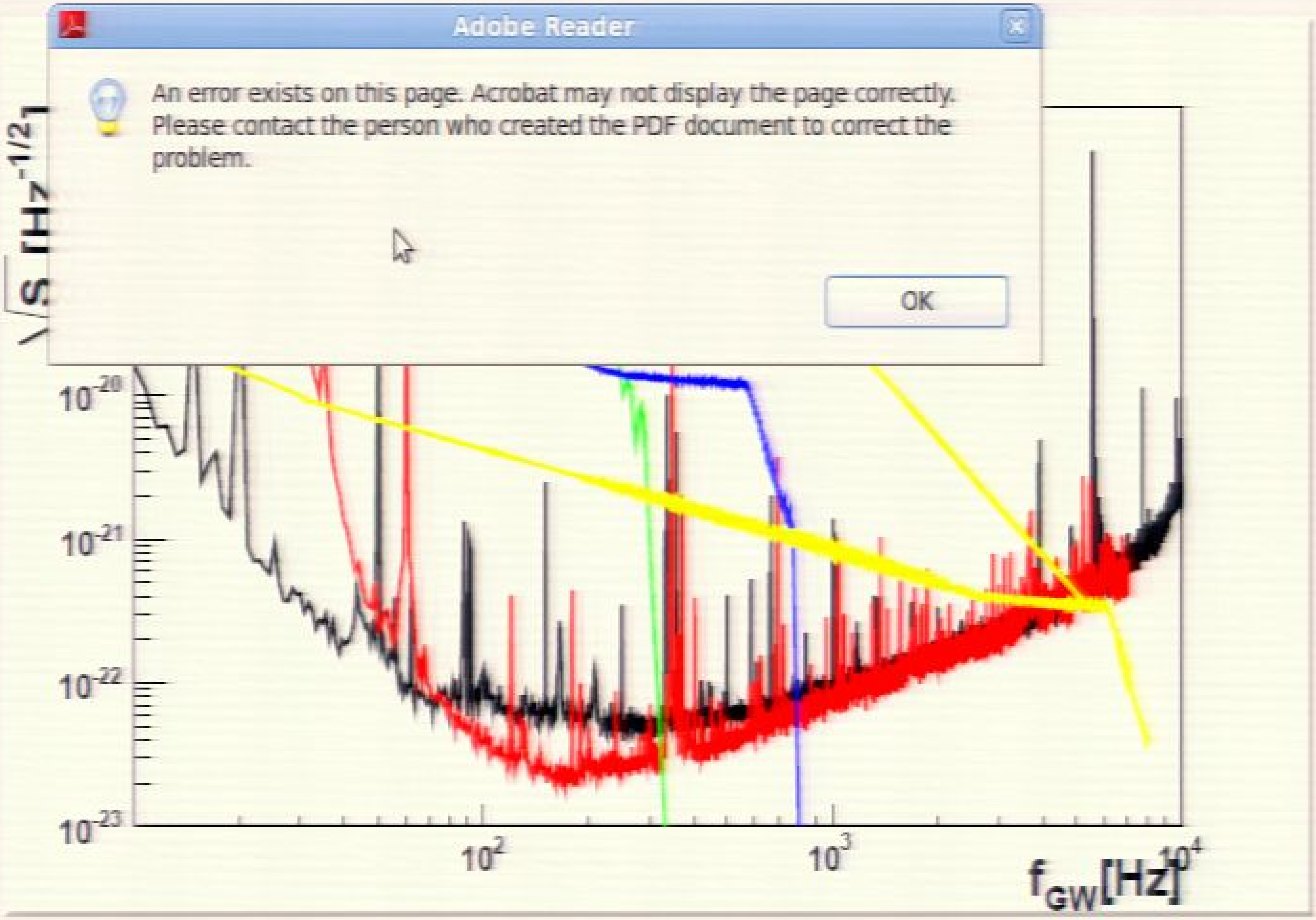
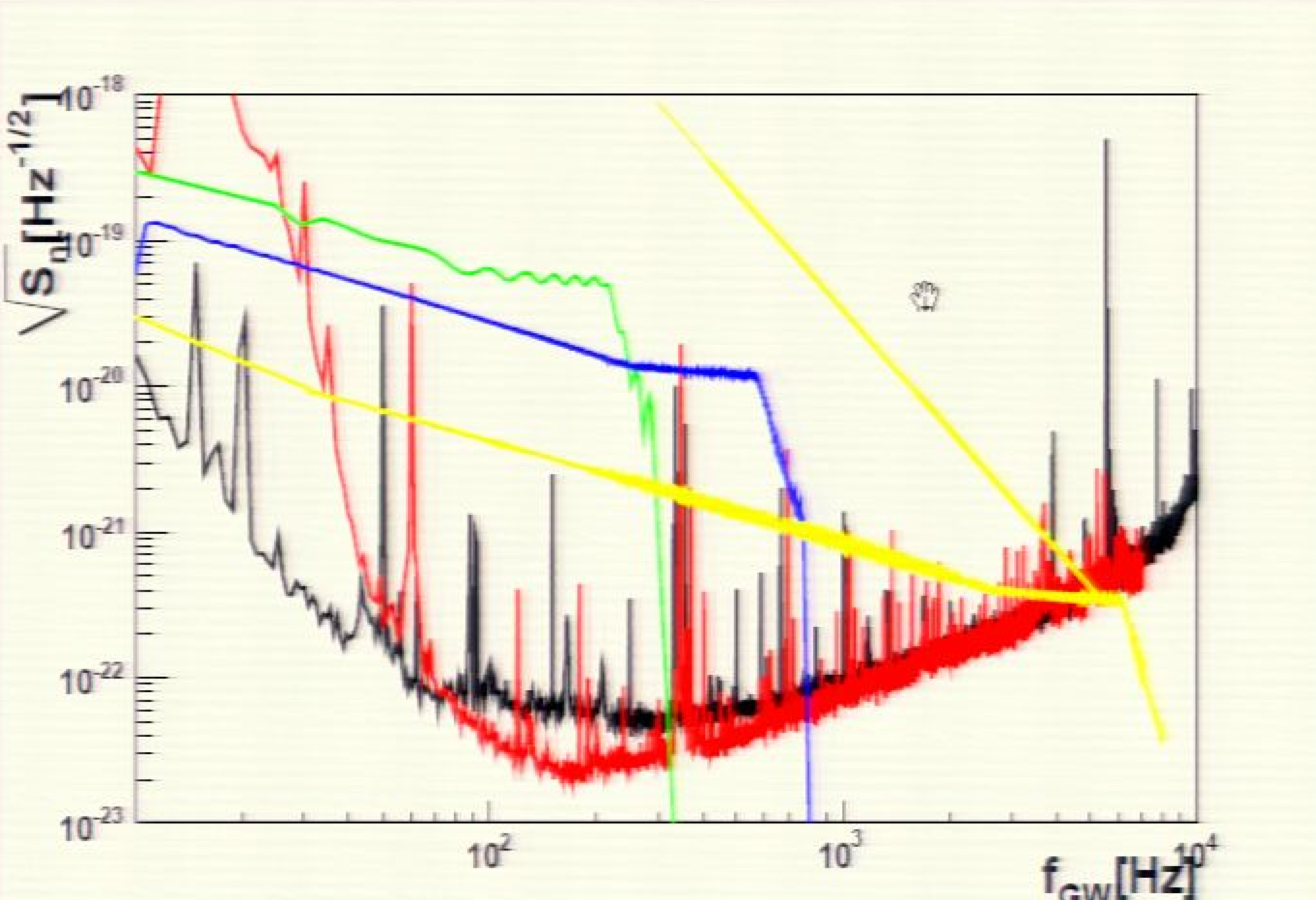


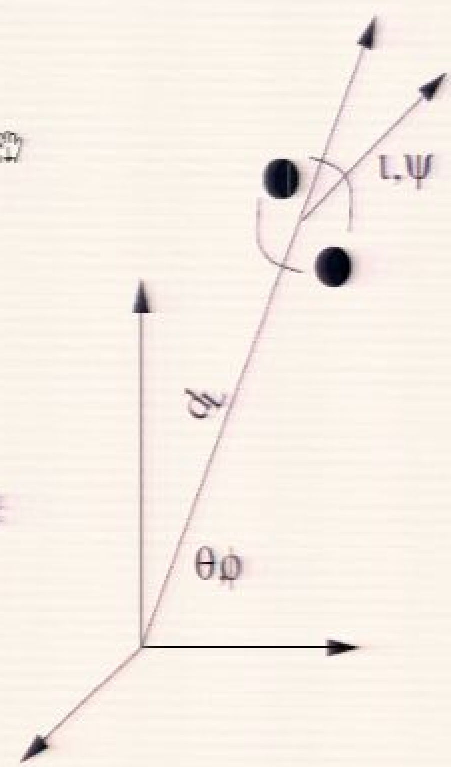
Coalescing signal



Spinning Waveforms

Matched filtering search:
Template bank exists only for spinless systems, impossible for generic spinning systems:

Spinless systems have 9 parameters:
$m1, m2$:intrinsic
$\theta, \phi, \iota, \psi, \phi_0, t_0, d_L$: extrinsic
Spin adds $2 \times 3 S_i' s$ intrinsic
and makes ϕ_0, ψ not easy to maximize over beacause of $\vec{L}, \vec{S}_i$ precession



However most Black Holes in nature should be spinning: it

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3. Work in progress/projects

PhenSpinTaylorRD I : Inspiral

- Inspiral

GW signal decomposed in spin-weighted spherical harmonics, evolved via a Spin-Taylor T4 approximant (Newtonian amplitude $\propto v^2$) until a matching frequency f_m is reached:

$$\frac{d\phi}{dt} = \frac{v^3}{m} \qquad \frac{dv}{dt} = -\frac{F(v)}{dE/dv}$$

$$h^{(insp)}_{2,2} = -2\frac{\nu M v^2}{d}\sqrt{\frac{16\pi}{5}}\times \left[\cos^4(\iota/2)\cos\left(2(\phi+\alpha)\right) + \sin^4(\iota/2)\cos\left(2(\phi-\alpha)\right)\right]$$

L, S_1, S_2 enters from 1.5PN and causes the orbital plane to precede, f_m is determined empirically

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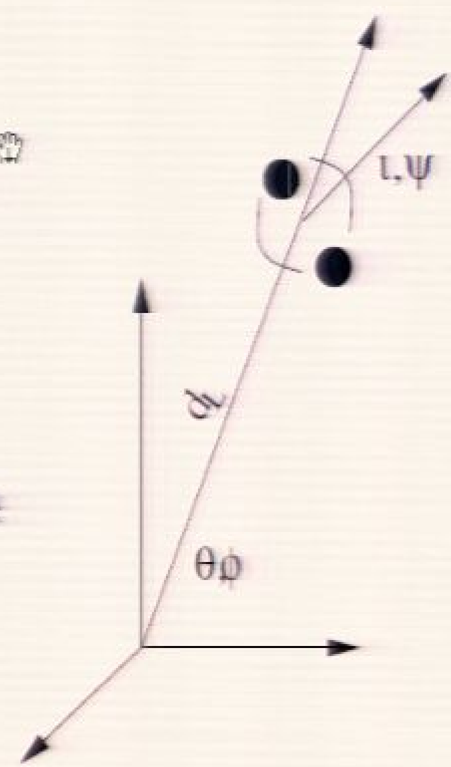

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PhenSpinTaylorRD II: Phenomenological part

- Phenomenological part

$$\frac{d\phi}{dt} = \frac{\omega_1}{1 - \frac{t}{T_A}} + \omega_0 = \frac{v^3}{m}$$

ω_0, ω_1, T_A are determined by imposing continuity of $\dot\phi, \ddot\phi, \dddot\phi$
Also $i \equiv \mathrm{acos}(\hat{L} \cdot J)$ and $\dot\alpha$ are evolved phenomenologically
Amplitude growth$\rightarrow$ ad-hoc thaming

PhenSpinTaylorRD III: Ring down

- Ring down

When $d\phi/dt$ reaches $a \times \omega_{RD}$, the ring down is attached (EOBNR inspired)

$$h_{2,2}^{(RD)} = \sum_{n>0} e^{-t/\tau_n} \left[A_n \cos(\omega_{rd\,n} t) + B_n \sin(\omega_{rd\,n} t)\right]$$

Continuity ensured by the matching of A_n, B_n

$$\omega_{RD} = \omega_{RD}(S_1, S_2, L, \eta)$$

(by E. Berti et al. PRD 06, L. Rezzolla et al. APJ 09)

Same method applied to modes

$(l, m) = (2, 2), (2, 1), (2, 0), (3, 3), (3, 2)$

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Waveform setup

Decomposition in spherical harmonics:

$$h(t) = \sum_{lm} h_{lm}(\psi(t), \mathbf{L}(t), \mathbf{S_1}(t), \mathbf{S_2}(t)) \ {}_{-2}Y^{lm}(\theta, \phi)$$

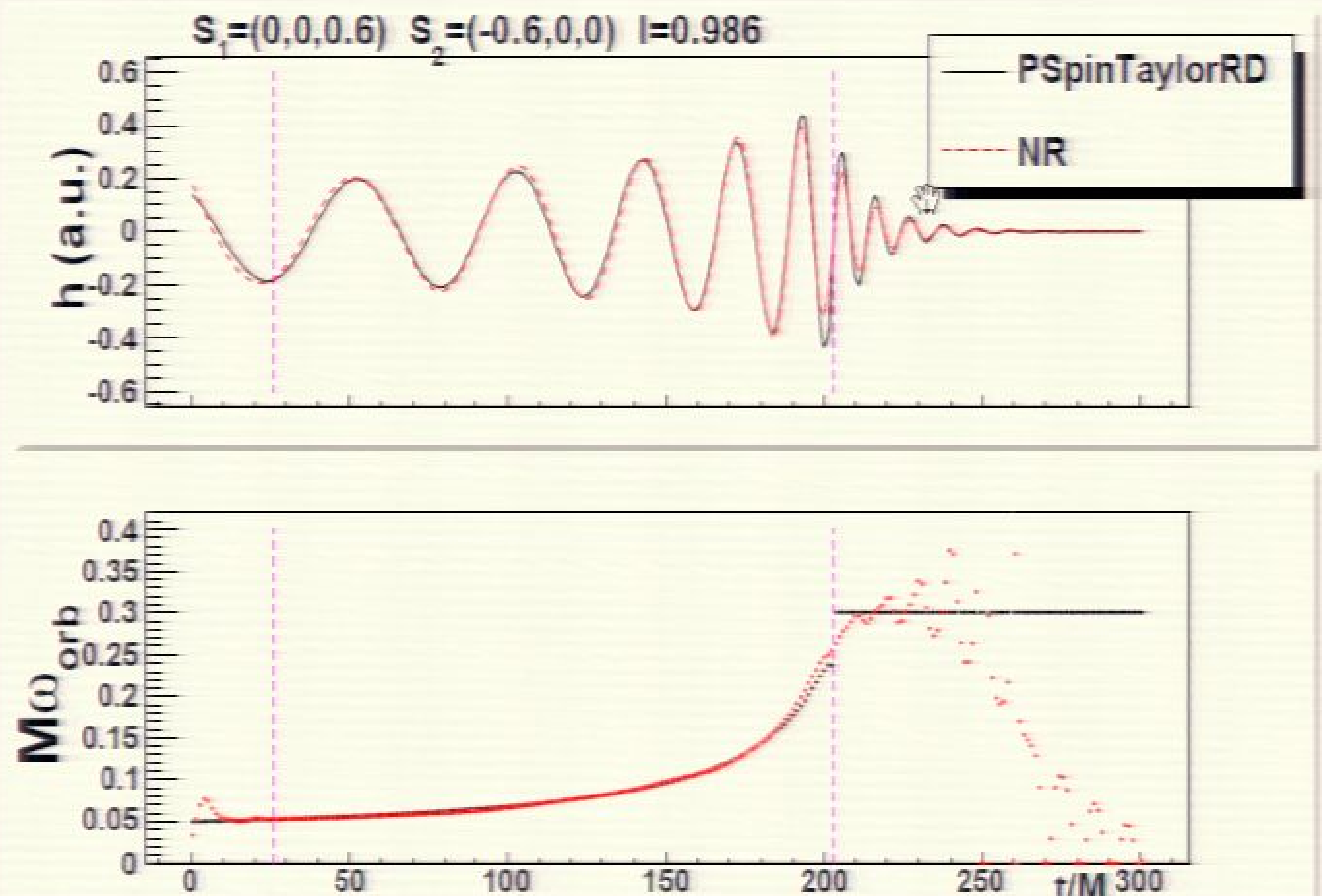
Dominant modes (for moderate precession): $l = 2$, $m = \pm 2$

Comparison with numerical waveforms from GeorgiaTech group:

equal masses, $|\mathbf{S_1}| = 0.6$, and initially $\mathbf{S}_2/m_2^2 = (-0.6, 0, 0)$

Short Waveforms

Phenomenological SpinTaylor RD vs. NR wforms by Georgia Tech ($l = 2, m = 2$ mode)



Short waveforms summary

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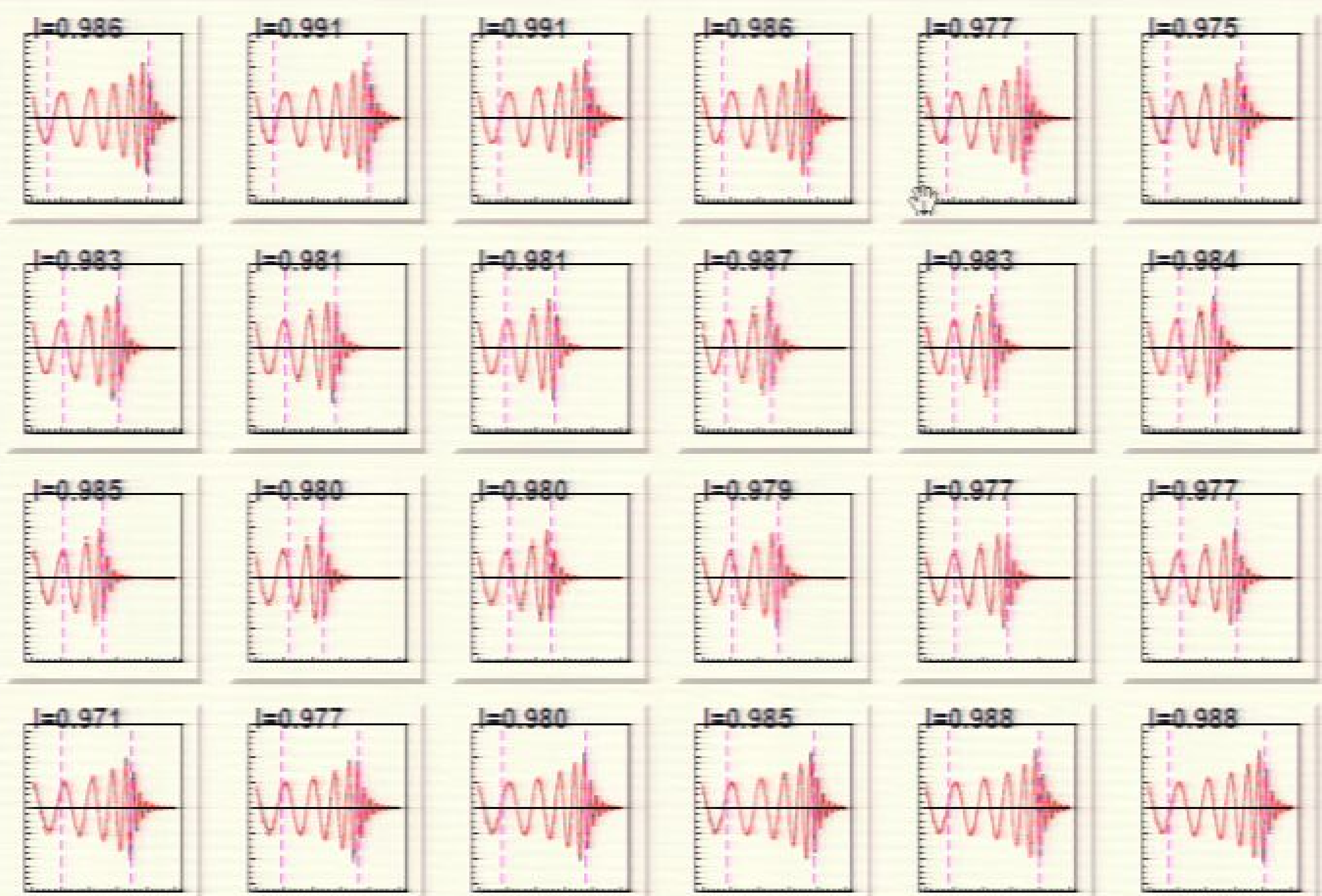
Phenomenological Spin-Taylor RD vs. NR wforms by Georgia Tech ($l = 2, m = 2$ mode) overlap$>$ 0.97



Fixing the only crucial free parameter: f_m

$$
\begin{aligned}
Mf_m = \; & a_0 + a_1(S_{1z} + S_{2z}) + a_2\delta(S_{1z} - S_{2z}) + a_3(S_1 S_2)_\perp + \\
& a_4(S_{1\perp}^2 + S_{2\perp}^2) + a_5\delta(S_{1\perp}^2 - S_{2\perp}^2) + a_6(S_{1z}^2 + S_{2z}^2) + \\
& a_7(S_{1z} S_{2z}) + a_8\delta(S_{1z}^2 - S_{2z}^2) + \dots .
\end{aligned}
$$

More numerical simulations (spins and mass ratios) needed to complete the determination of f_m

$$a_i(\delta) = a_i + \delta\, a_i^{(1)} + \delta^2\, a_i^{(2)} + \dots$$

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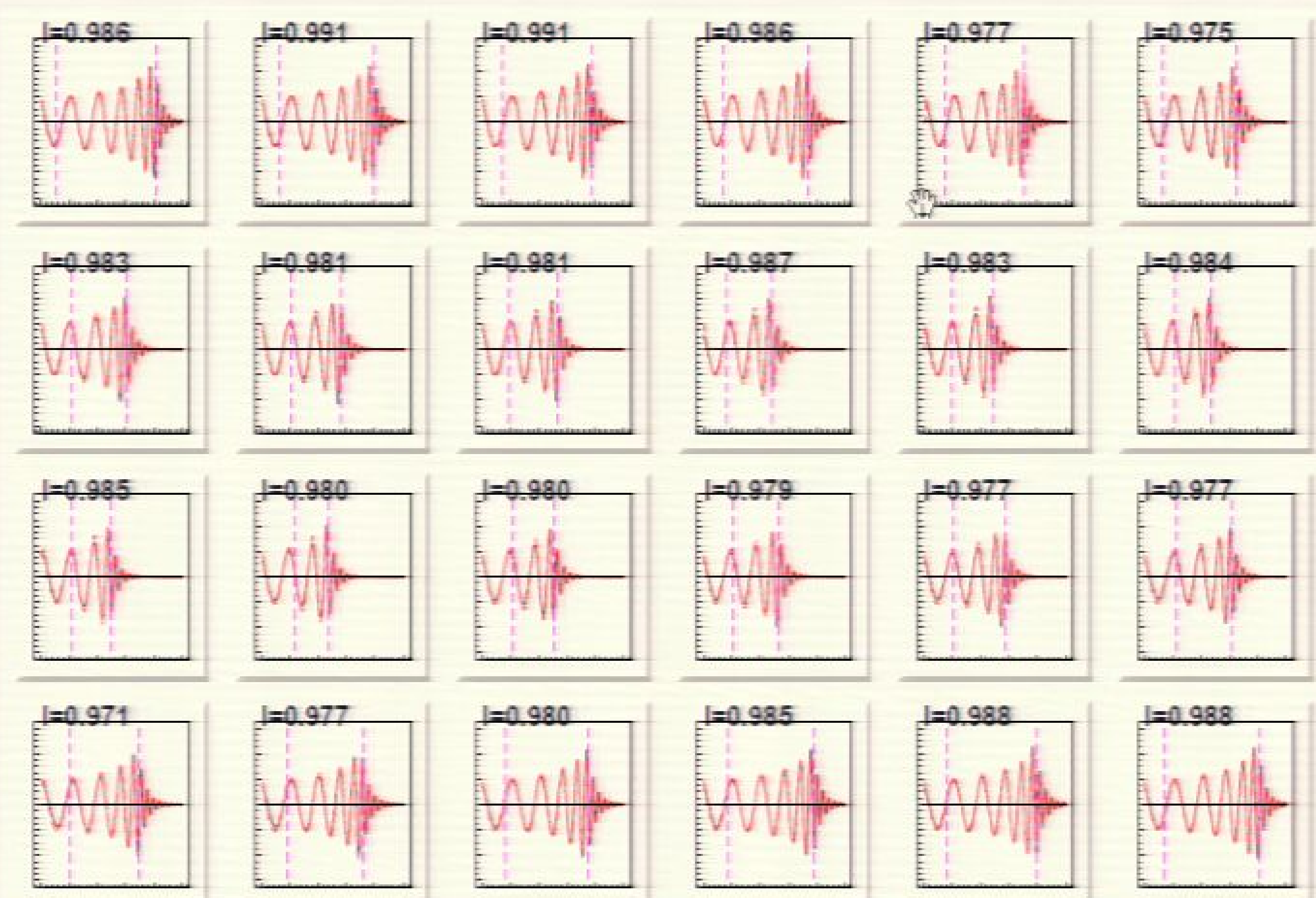

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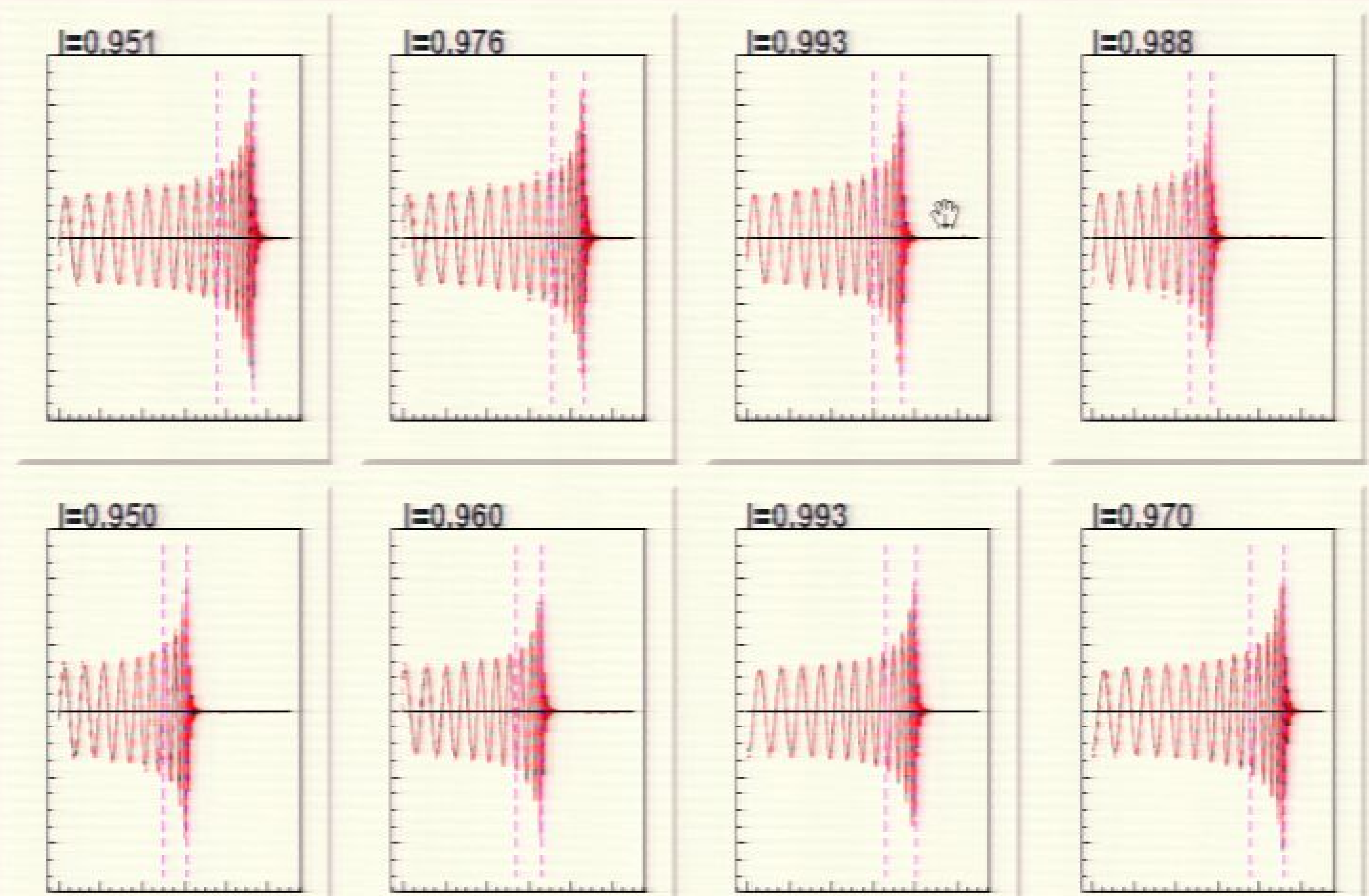
Long waveforms

No parameters have been tuned on this waveforms!

overlap > 0.95



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Fixing the only crucial free parameter: f_m

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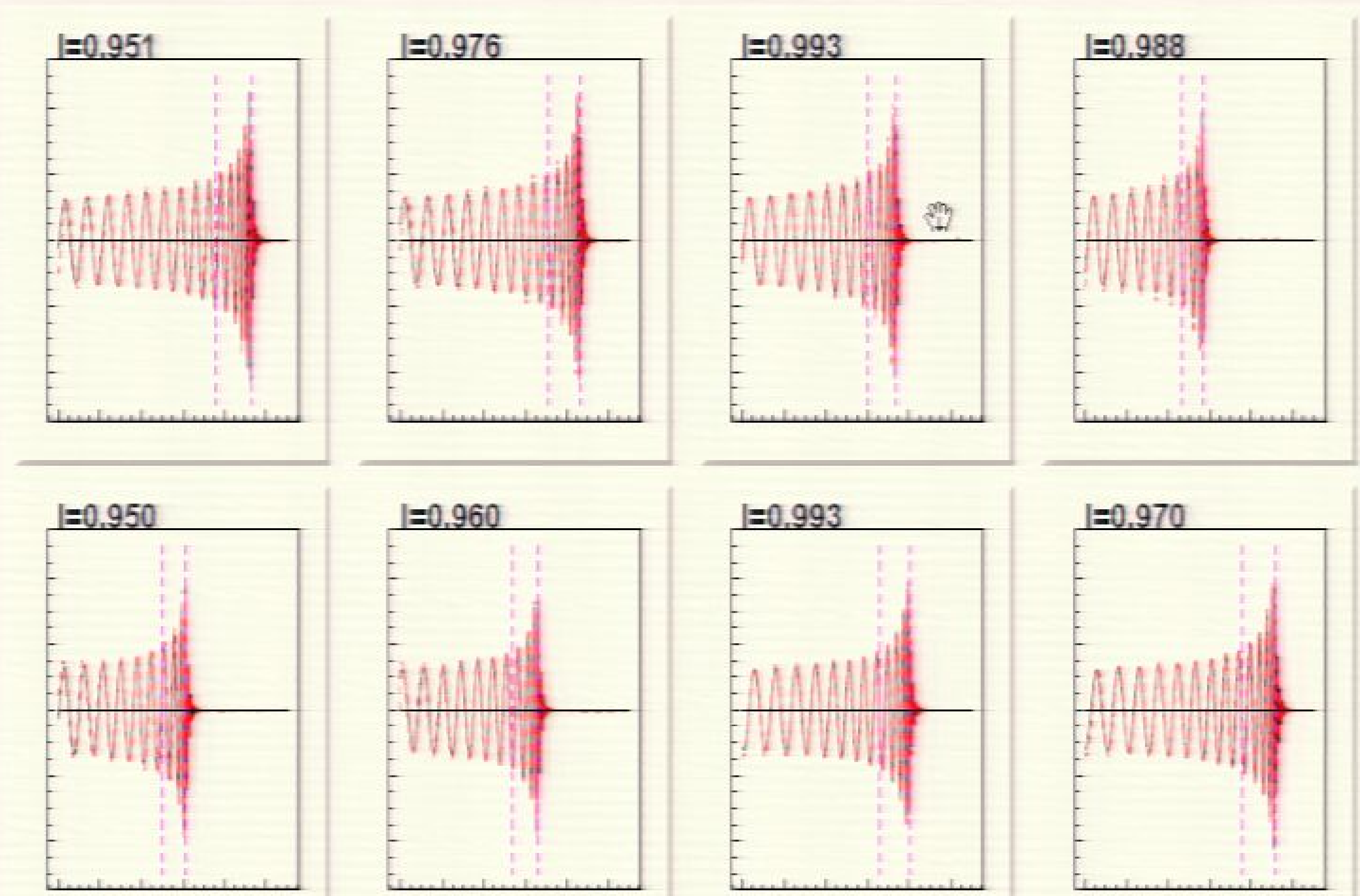

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Long Waveform

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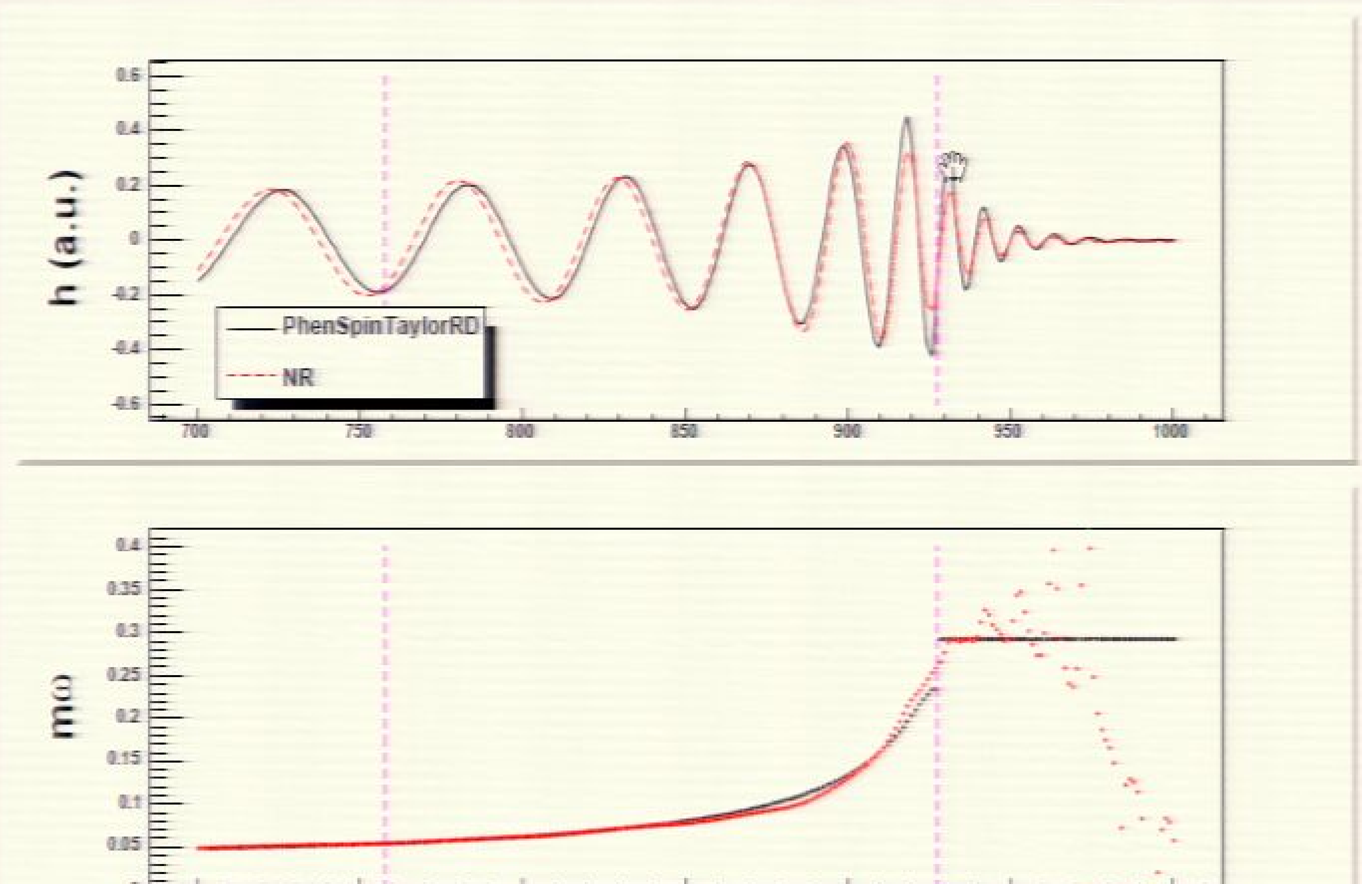
Worst case:



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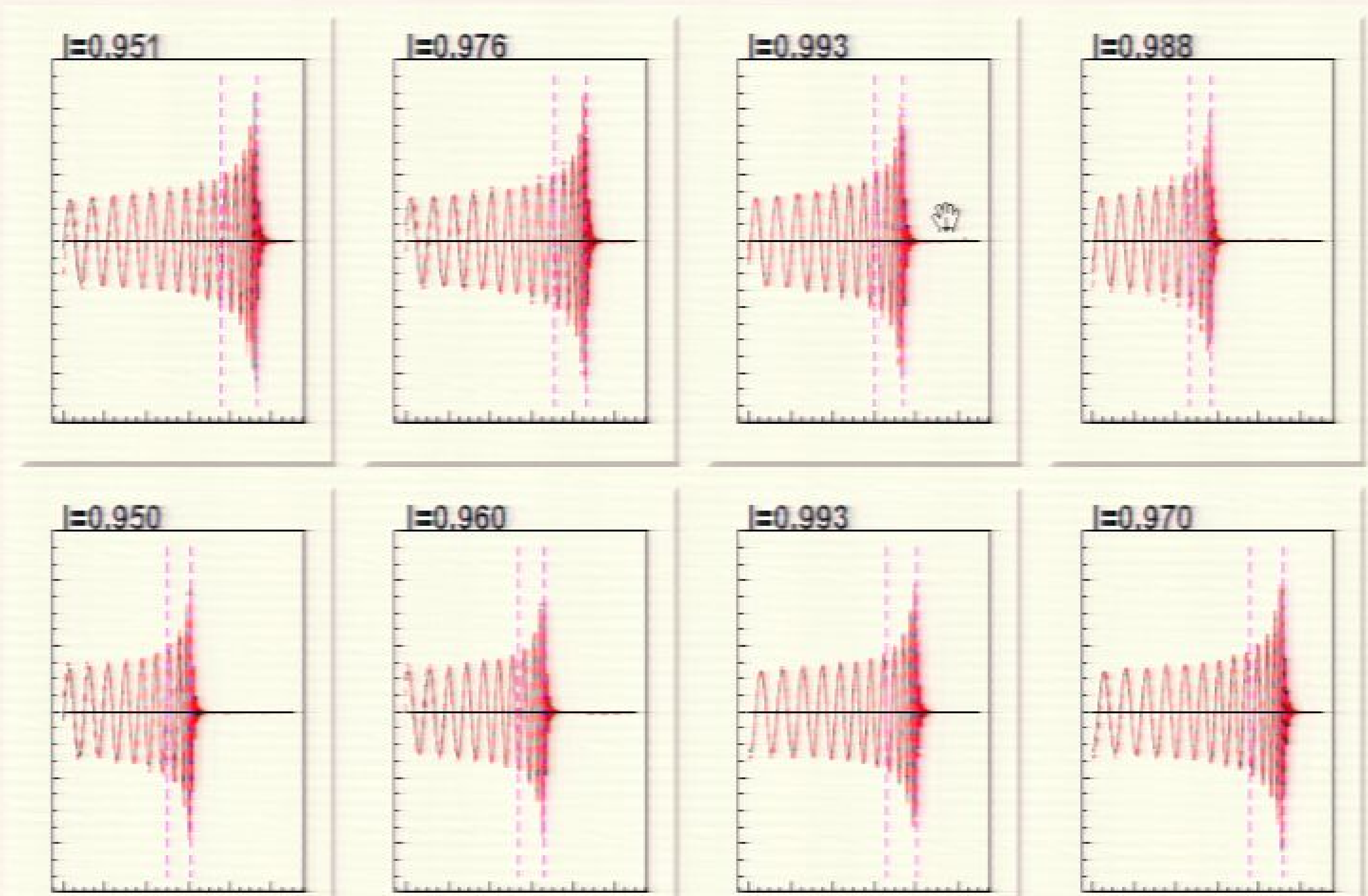
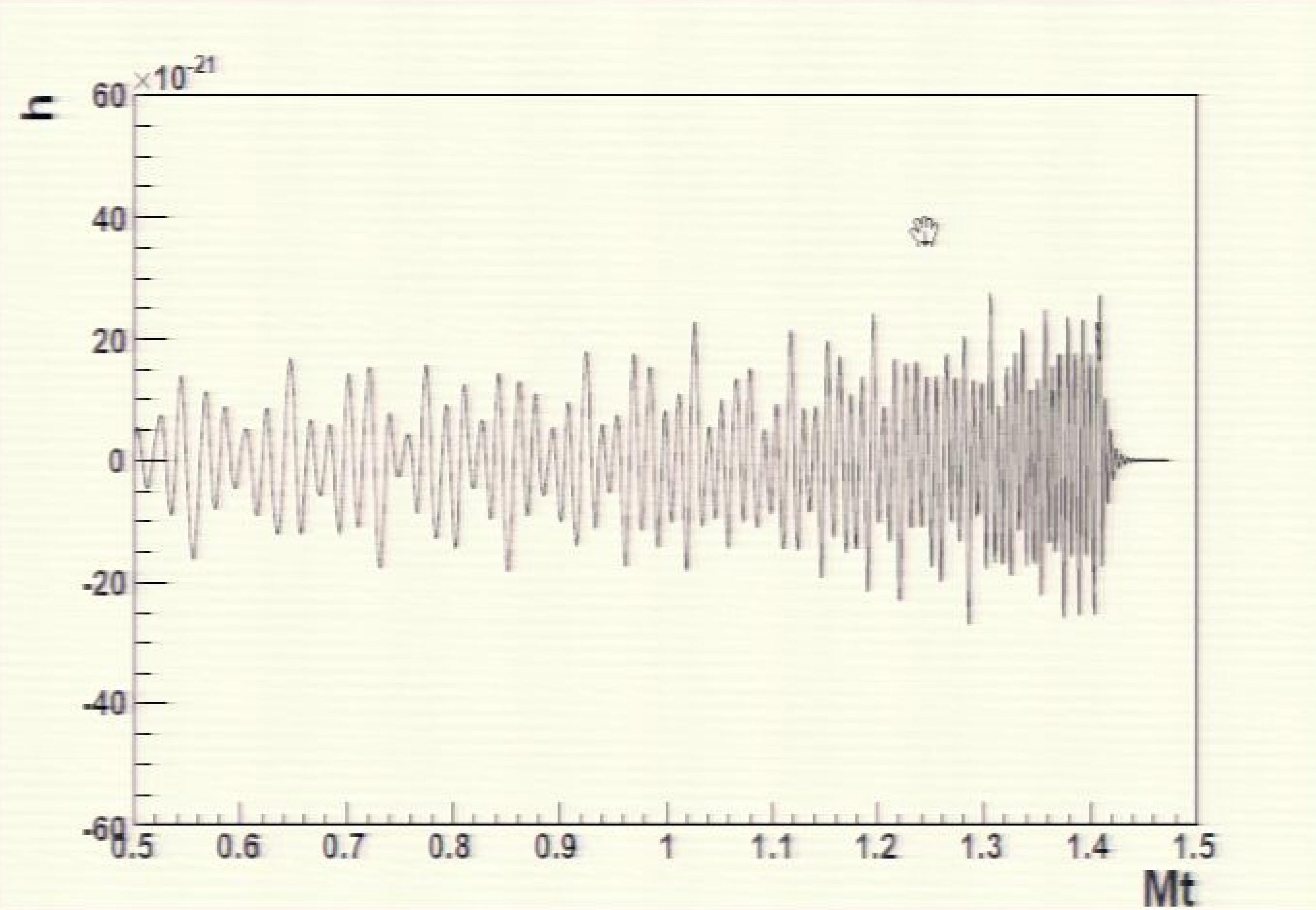


Generic spin and mass ratios

Generic waveforms can be generated
$m1/m2 = 100, S_1 = (0.9, 0, 0)$



Work in progress

- It is possible to include amplitude corrections (see improved EOB construction by Damour-Nagar PRD'09)
- generic spins (more simulations?) and unequal masses
- phenspin can be used in connection with Monte Carlo/nested sampling codes for both injection and recovery
- use as templates for aligned spin configurations

Goal: complete waveforms from insiral to merger and ring-down for generically spinning binaries