Macroscopicity of matter wave interference

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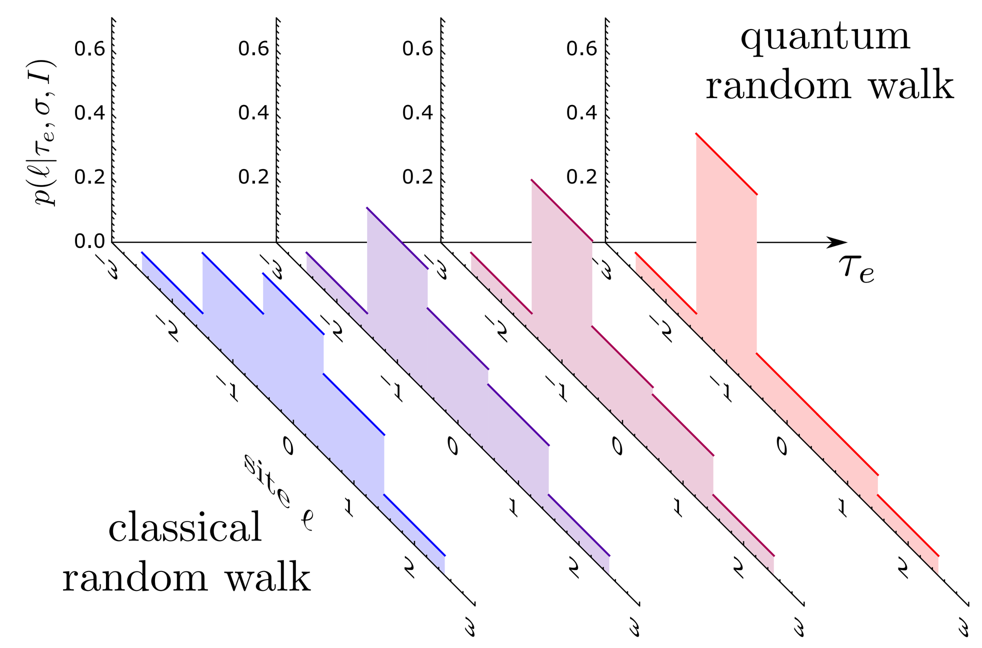
Introduction

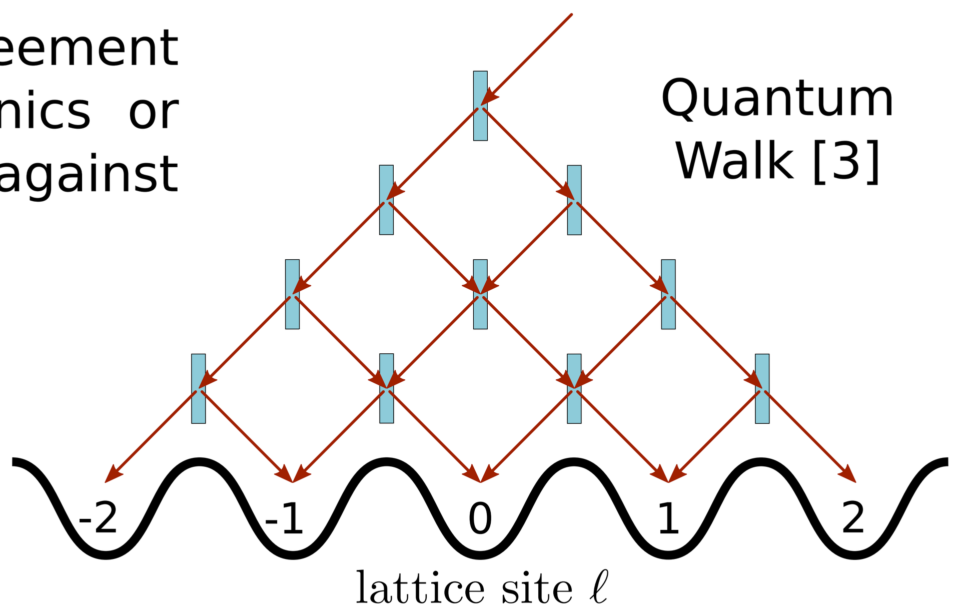
We discuss a measure for the macroscopicity reached in quantum superposition experiments [1] that quantifies how empirical evidence gathered in an experiment falsifies macrorealistic modifications of quantum mechanics. We extend this notion by establishing a general scheme based on Bayesian hypothesis testing in the parameter space characterizing the macrorealistic modifications.
A conventional approach would be based on dichotomous Bayesian model selection [2]: by gauging, whether pure quantum mechanics $\mathfrak{Q}$ **or** Newtonian dynamics $\mathfrak{N}$ are more likely to have produced the experimental data:

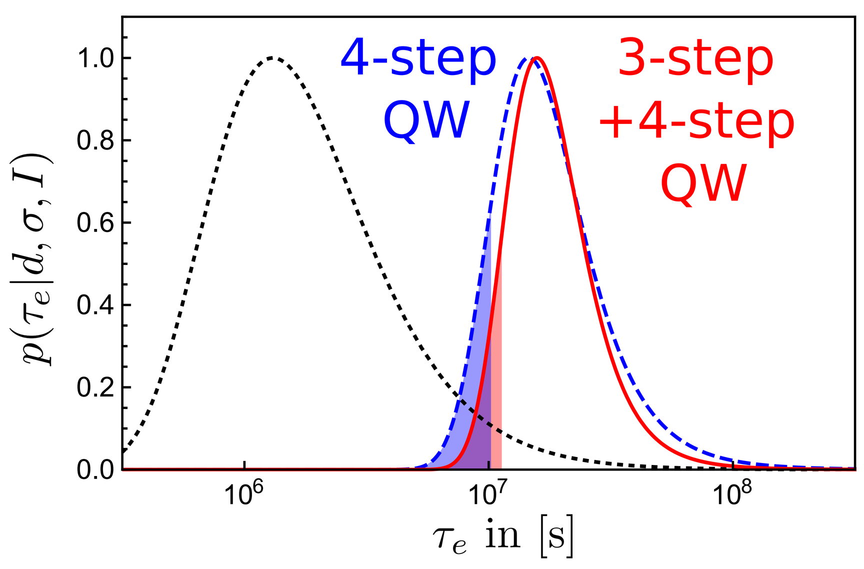
$$o(H|d,\sigma,I) = \frac{P(H_{\mathfrak{N}}|d,\sigma,I)}{P(H_{\mathfrak{Q}}|d,\sigma,I)}$$

But experimental results are never in agreement with idealized unitary quantum mechanics or pure Newtonian mechanics. Instead, test against a general decoherence model:

$$o(\tau_e^*|d,\sigma,I) = \frac{P(H_{\tau_e^*}|d,\sigma,I)}{P(\overline{H}_{\tau_e^*}|d,\sigma,I)}$$





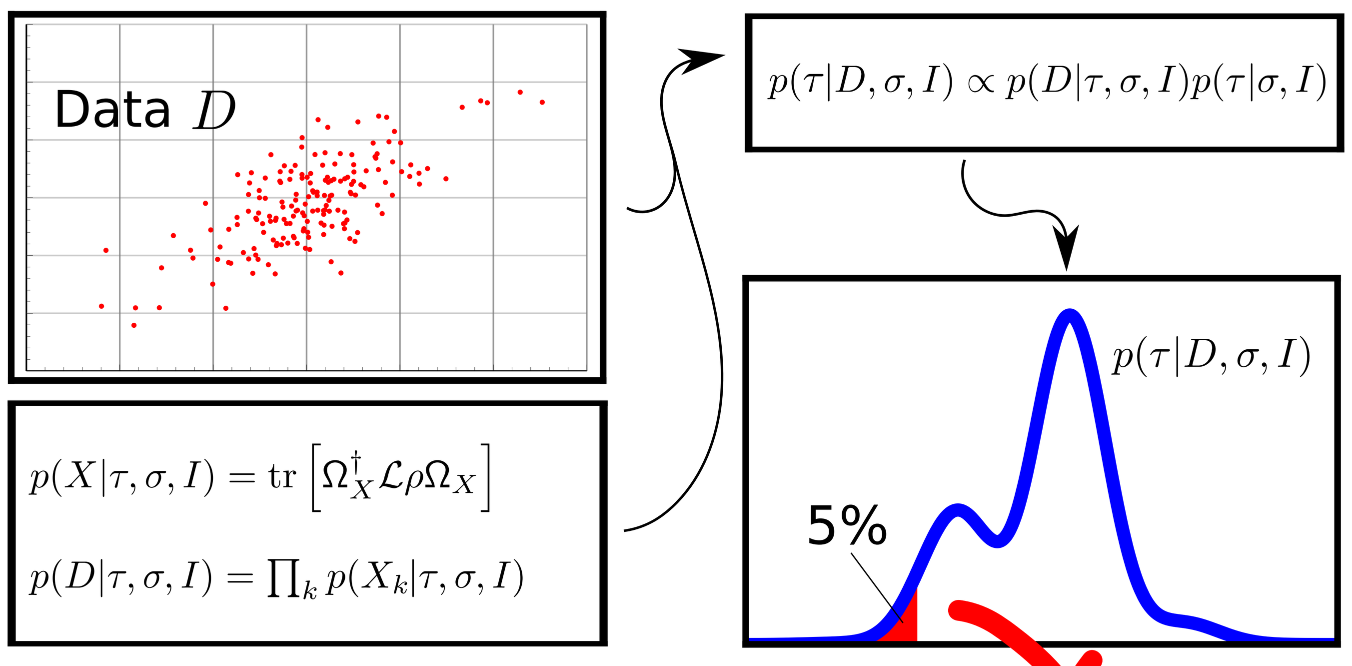


Hypothesis test on minimally invasive modifications of QM

Hypothesis to be falsified: *"The Schrödinger equation does not hold on a fundamental level, but it is augmented by a nonunitary term characterized by the time scale $\tau \leq \tau_m$, given the parameter set σ."*

We characterize generic minimally invasive modifications [4] of the von Neuman equation for arbitrary mechanical many-body states ρ, which...

...are Galilean invariant
...predict coherence decay amplifying with system size
...exhibit scale invariance

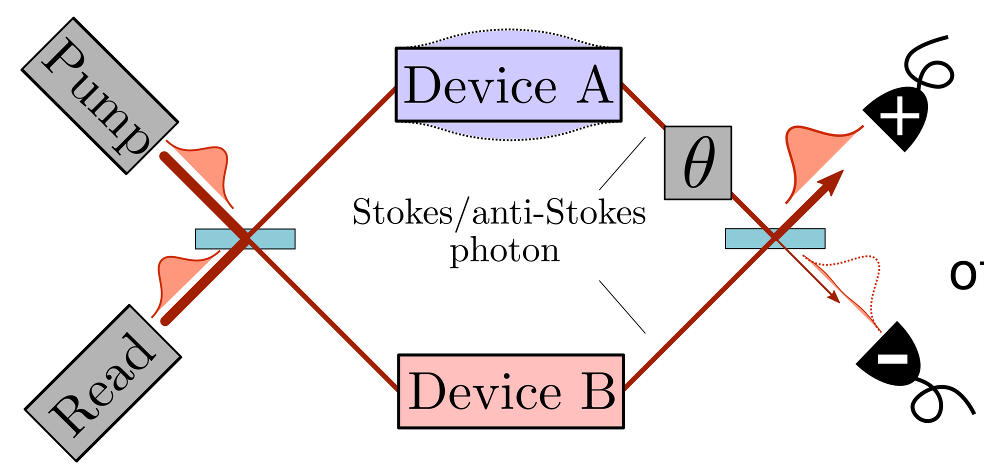


$$\mu = \max_\sigma \left[\log_{10}\left(\frac{\tau_m(\sigma)}{1\,\mathrm{s}}\right)\right]$$

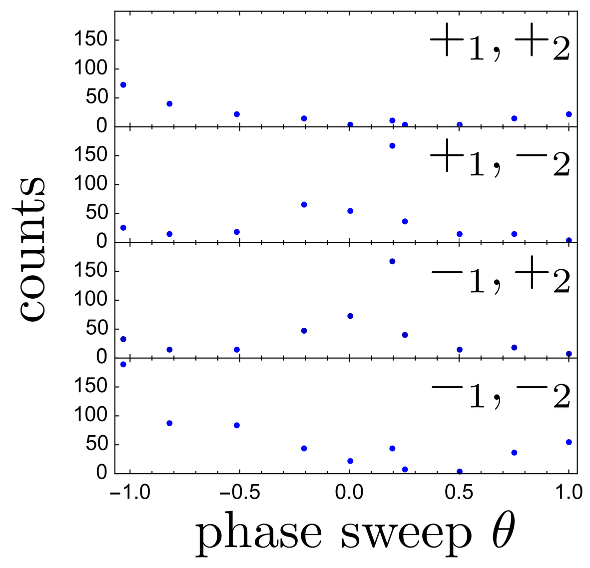
$$\mathcal{L}\rho = \frac{1}{i\hbar}[\mathsf{H},\rho] + \frac{1}{\tau_e}\int d^3s d^3\mathbf{q}\, g(s,q)\left[\mathsf{L}(\mathbf{s},\mathbf{q})\rho\mathsf{L}^\dagger(\mathbf{s},\mathbf{q}) - \frac{1}{2}\left\{\mathsf{L}^\dagger(\mathbf{s},\mathbf{q})\mathsf{L}(\mathbf{s},\mathbf{q}),\rho\right\}\right]$$

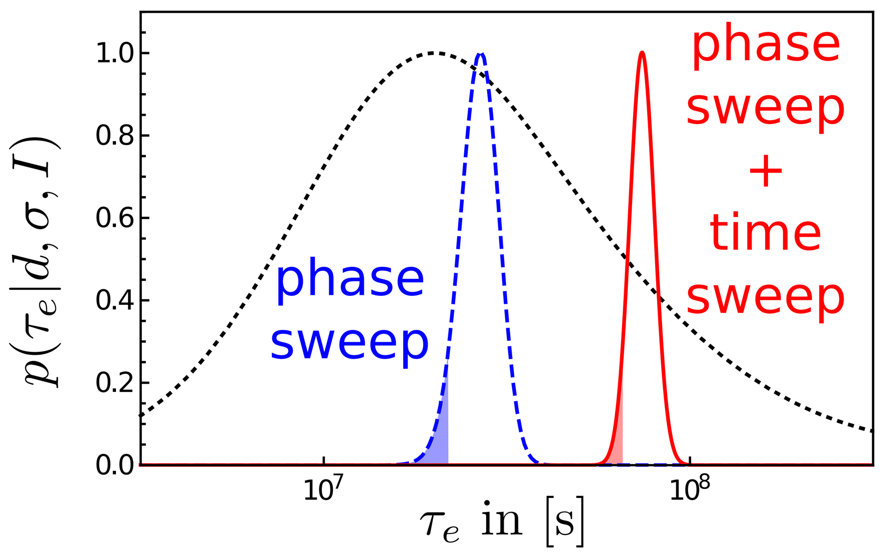
with $g(s,q) = \frac{1}{(2\pi\sigma_s\sigma_q)^3}e^{-s^2/2\sigma_s^2 - q^2/2\sigma_q^2}$ and $\mathsf{L}(\mathbf{s},\mathbf{q}) = \frac{m}{m_e}\int d^3\mathbf{q}e^{i\mathbf{p}\cdot\mathbf{s}/\hbar}\mathsf{c}^\dagger(\mathbf{p})\mathsf{c}(\mathbf{p}-\mathbf{q})$

Entangled nanobeams

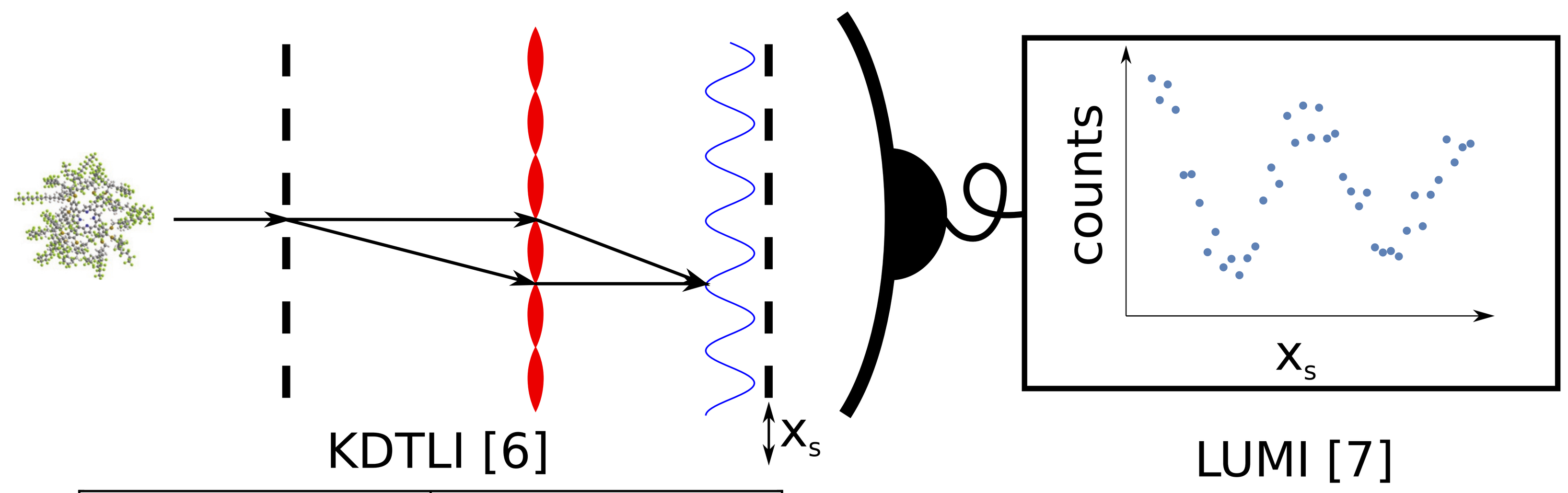


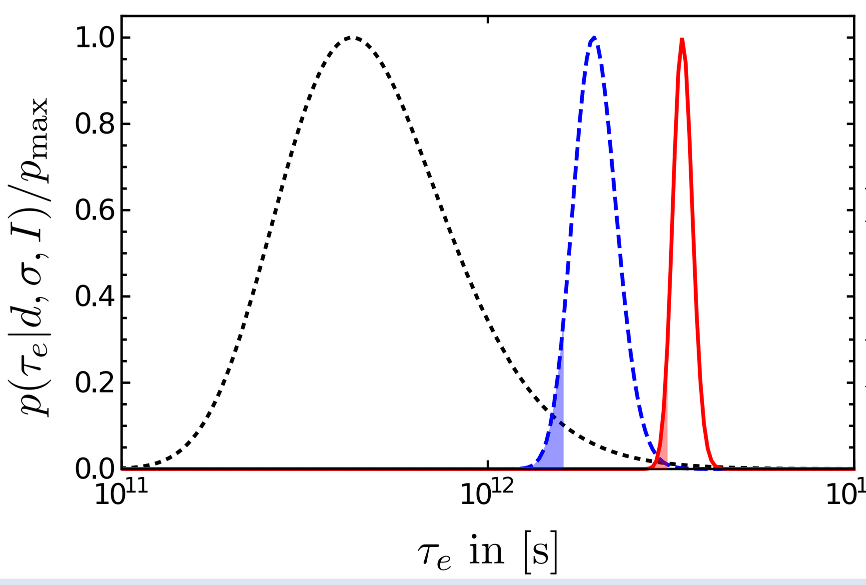
Coincidence measurement of stokes/anti-Stokes photons [5]

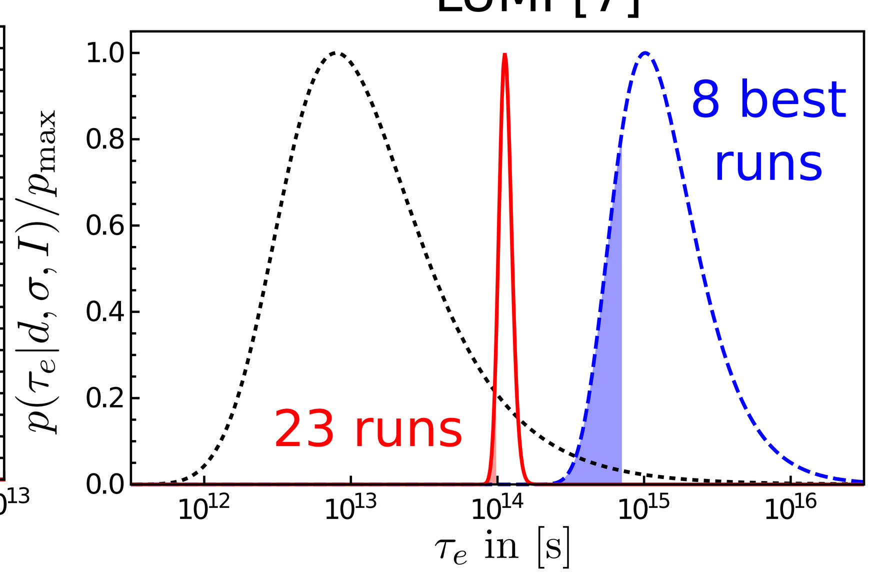




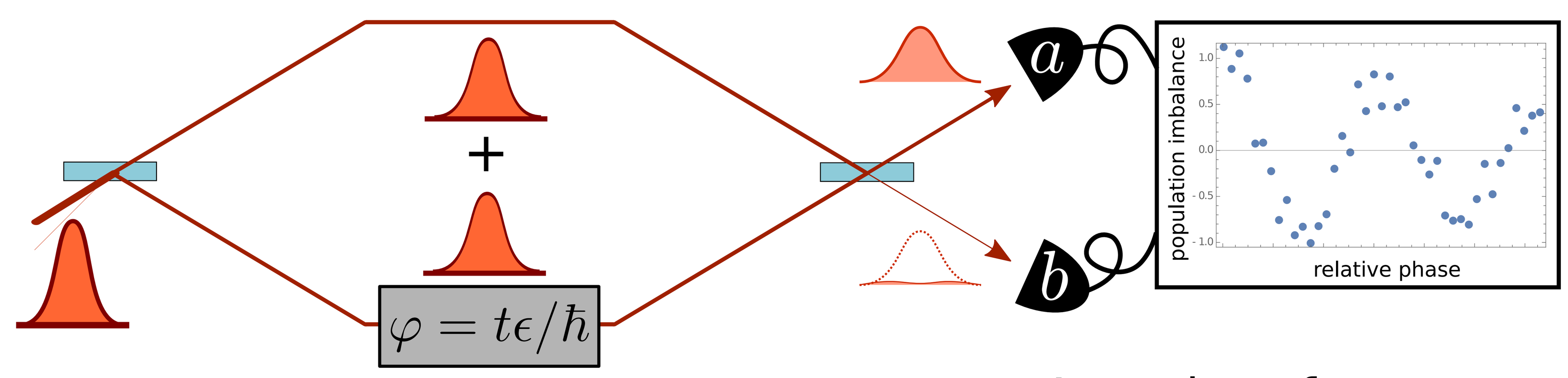
Near field interferometry with molecules

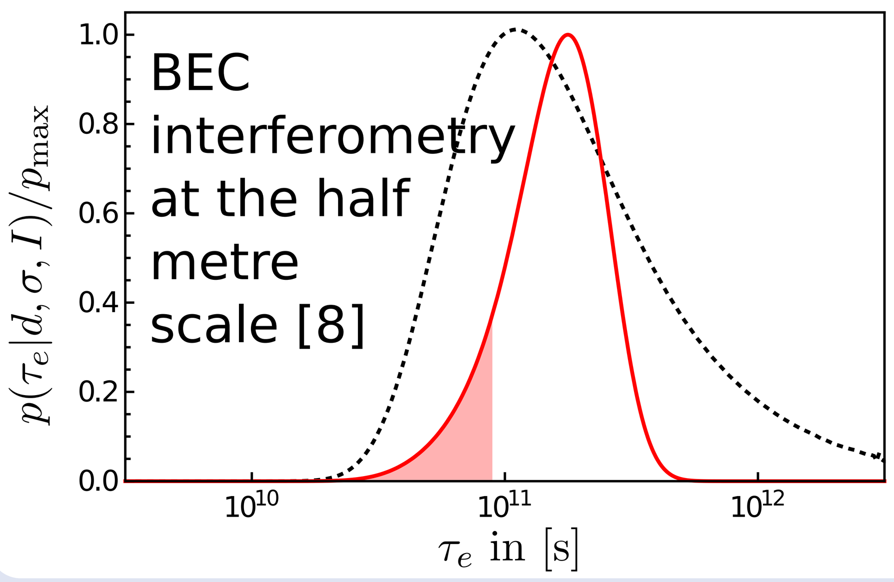


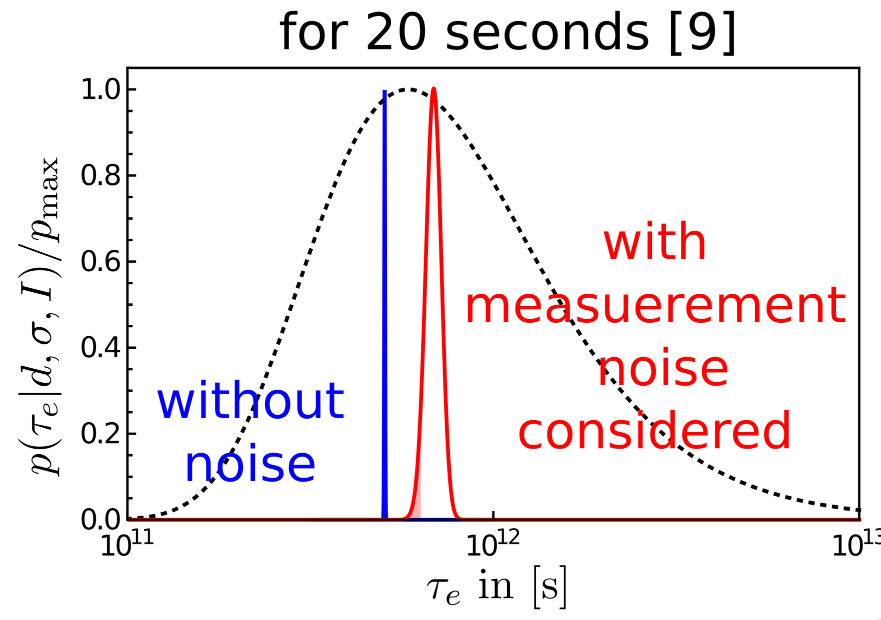




Mach-Zehnder interferometry with atoms



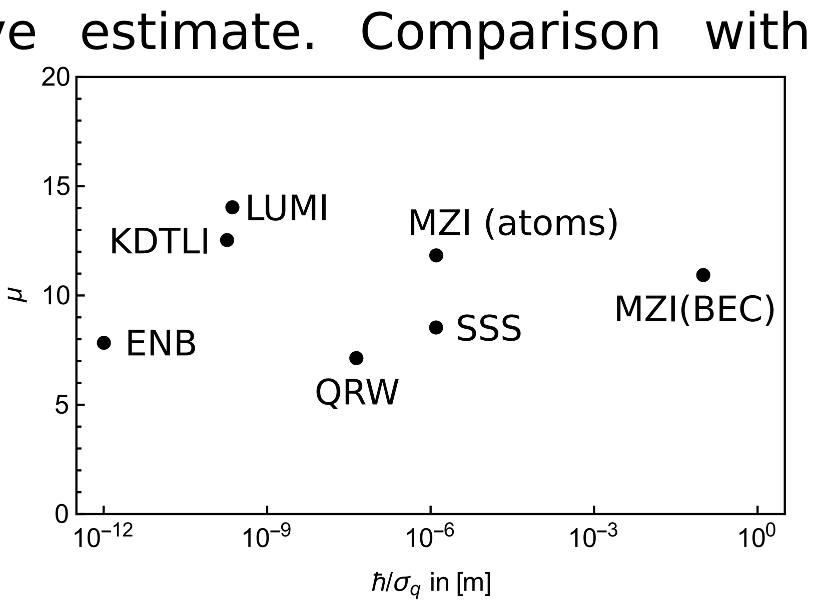




Posterior convergence

Lowest five percent quantile ensures conservative estimate. Comparison with asymptotic Gaussian posterior detects improper data postselection (Bayesian consistence):

Experiment	FWHM	asymptotic FHWM	HD	μ
KDTLI [6]	$5.02 \cdot 10^{11}$ s	$5.14 \cdot 10^{11}$ s	0.046	12.5
LUMI_8 [7]	$1.94 \cdot 10^{15}$ s	$6.66 \cdot 10^{15}$ s	0.52	14.8
LUMI_{23} [7]	$2.63 \cdot 10^{13}$ s	$2.76 \cdot 10^{13}$ s	0.079	14.0
MZI(atoms) [9]	$7.85 \cdot 10^{10}$ s	$7.69 \cdot 10^{10}$ s	0.018	10.9
MZI(BEC) [8]	$1.69 \cdot 10^{11}$ s	$1.74 \cdot 10^{11}$ s	0.13	11.8



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