Ramsey-Bordé interferometry with optical clock atoms in intermediate-scale atom interferometers

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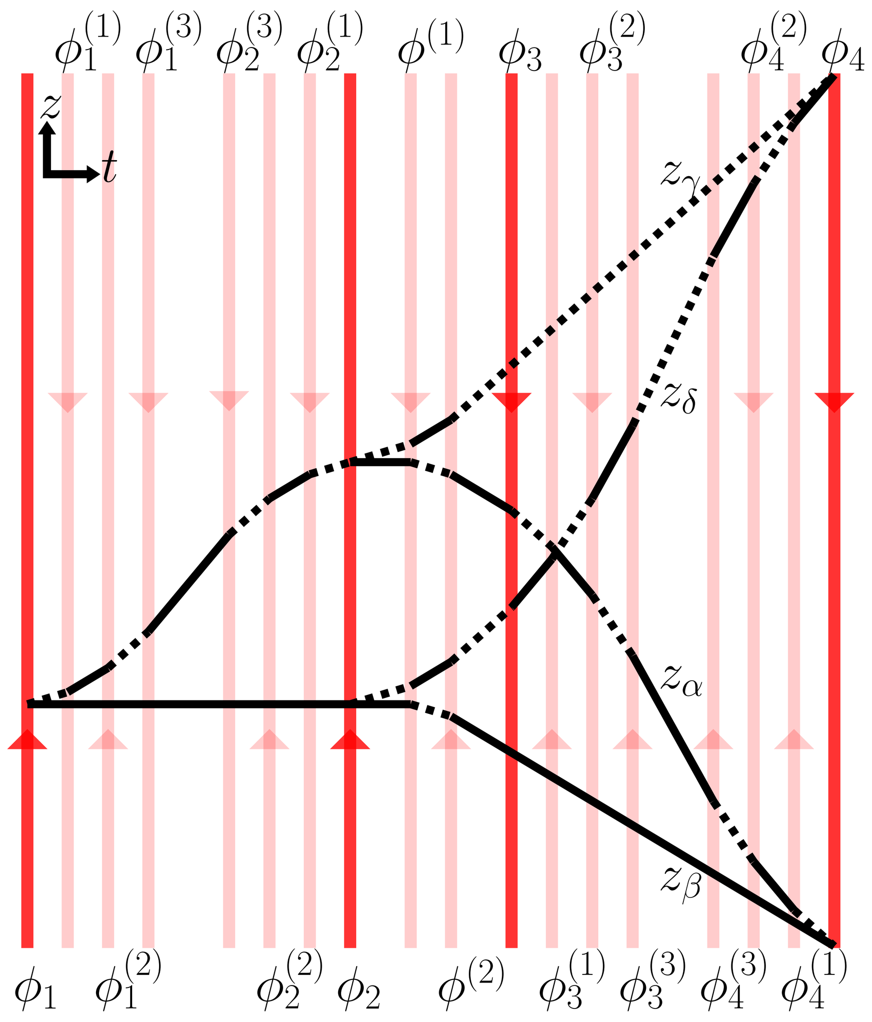
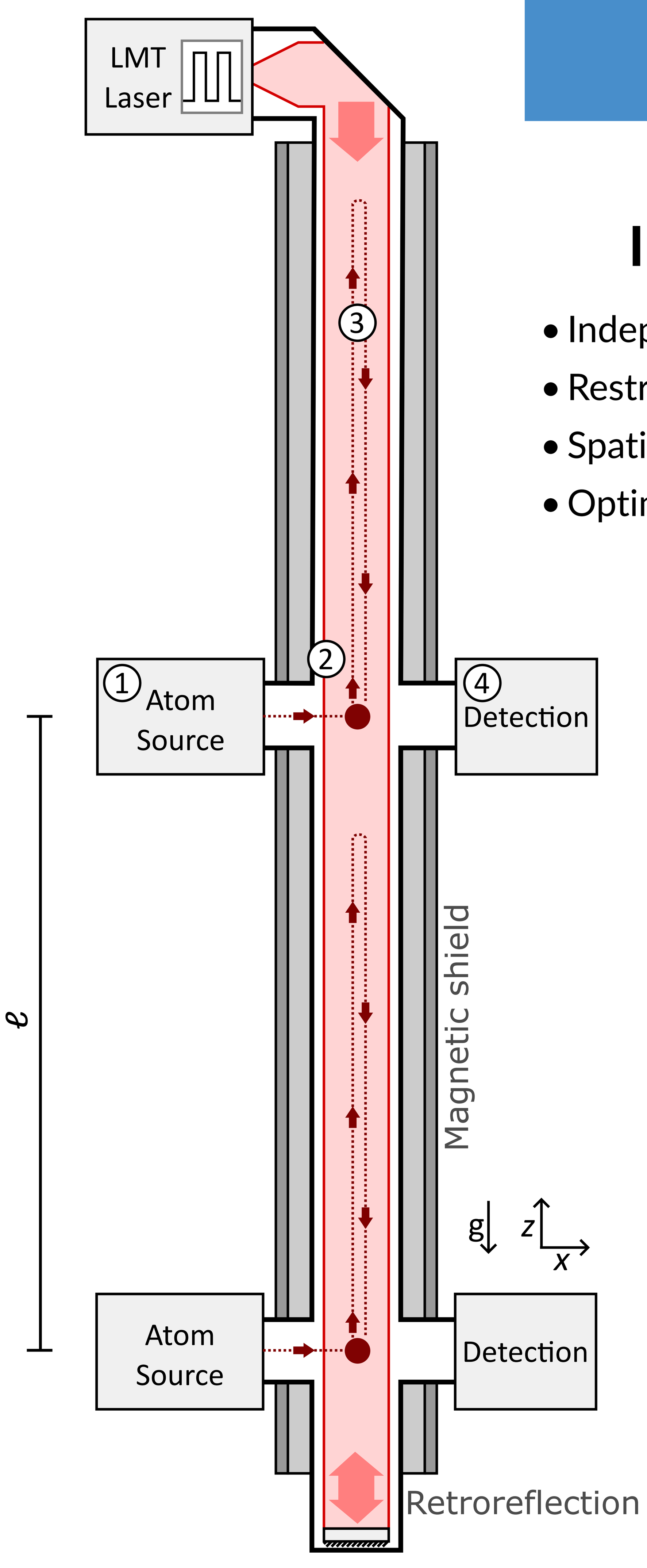
Enhanced Ramsey-Bordé scheme

- Large-momentum-transfer (LMT) between $\pi/2$-pulses
- N extra π-pulses per $\pi/2$-pulse: $(N+1)\hbar k$ beamsplitter
- M extra π-pulses deflect $|g\rangle$ and $|e\rangle$ in opposite directions
- Recoil-phase scales as $\Delta\Phi \sim (N+1)(N+2M+2)\hbar k^2 T/m$

$(N, M) = (3, 2)$ in free-fall frame

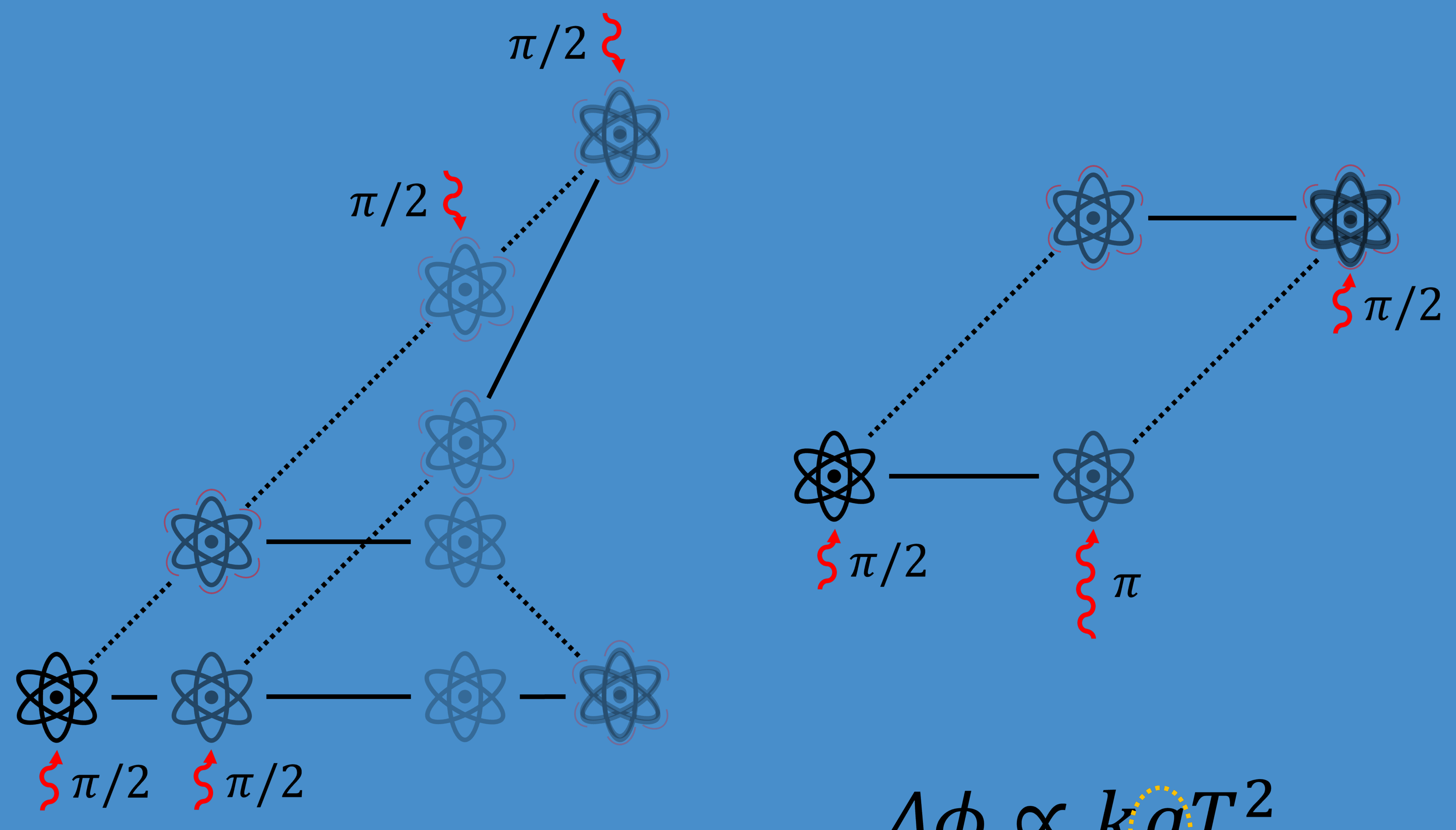




Atom interferometers can weigh atoms

Ramsey-Bordé

Kasevich-Chu



$\Delta\Phi \propto \hbar k^2 T/m$

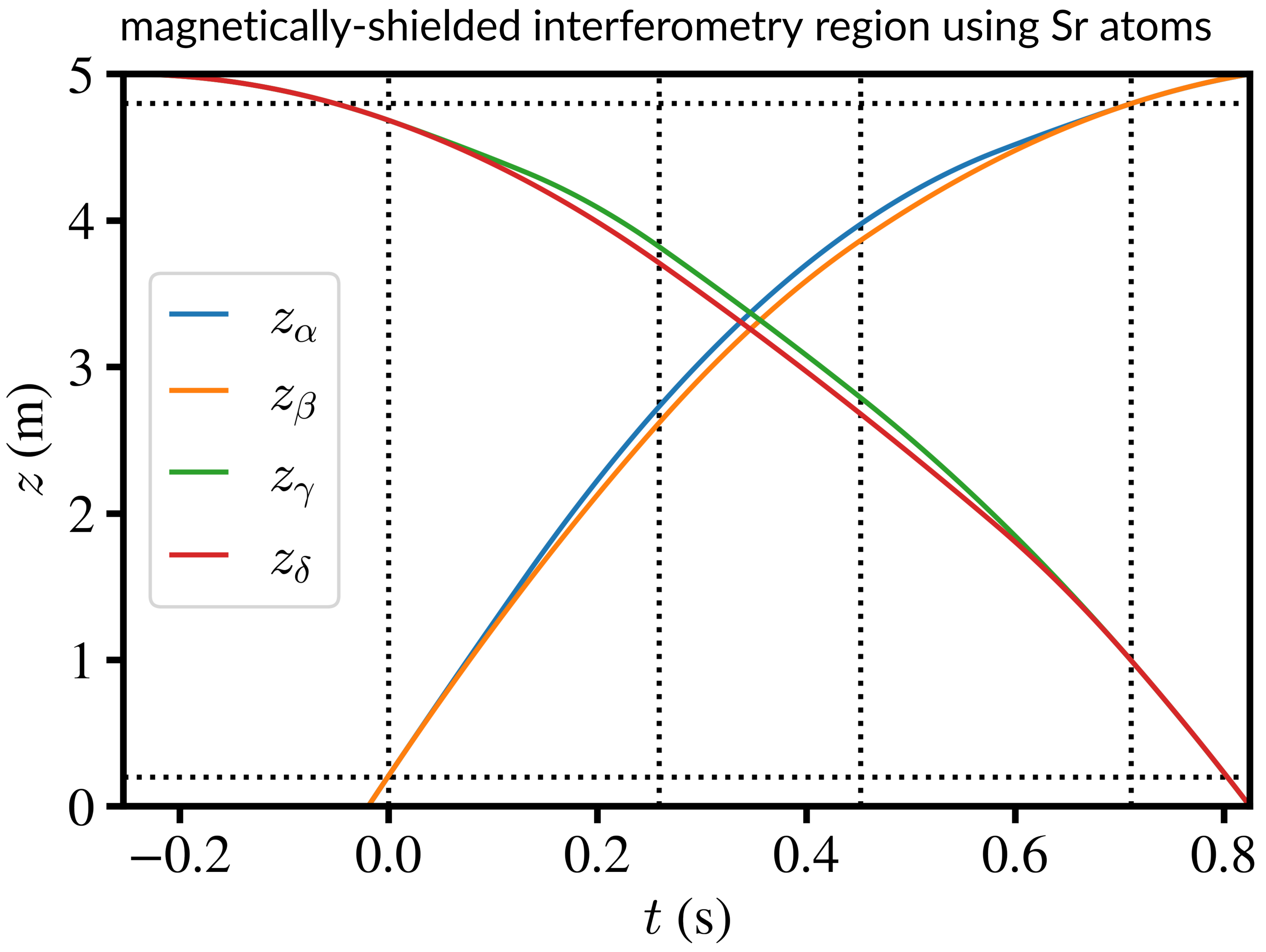
$\Delta\phi \propto kgT^2$

$$\boldsymbol{F = mg}$$

Implementation in intermediate-scale instruments

- Independently launch from top and bottom atom sources
- Restrict interferometry to magnetically-shielded region
- Spatially overlap trajectories for gravity-gradient mitigation
- Optimise recoil-phase for instrument size and atomic species by adjusting N and M

Optimal trajectories for $\ell = 5\,\mathrm{m}$ source separation and a 4.6 m magnetically-shielded interferometry region using Sr atoms



Atomic mass constant

$$m_u = \frac{m(^{12}\mathrm{C})}{12} = \frac{m(\mathrm{X})}{A_r(\mathrm{X})}$$

- $m(\mathrm{X})$ via atom interferometry
- $A_r(\mathrm{X})$ from Penning traps
- Determines masses of many particles in kg, eV/c^2, *etc.*

Fine-structure constant

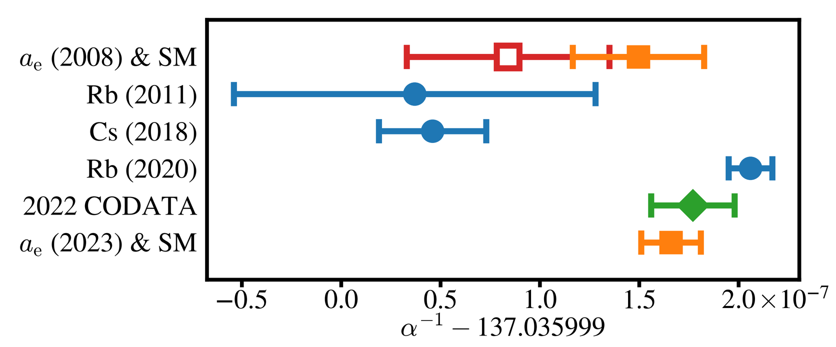
$$\alpha^2 = \frac{2R_\infty}{c} \times \frac{A_r(\mathrm{X})}{A_r(\mathrm{e})} \times \frac{h}{m(\mathrm{X})}$$

- Used in highest precision test of QED & Standard Model
- Precision currently limited by atom interferometry

Relative uncertainties of inputs

$u_r(R_\infty)$	$u_r(A_r(\mathrm{e}))$	$u_r(A_r(^{87}\mathrm{Rb}))$	$u_r(m(^{87}\mathrm{Rb}))$
1.1×10^{-12}	1.8×10^{-11}	7.0×10^{-11}	1.5×10^{-10}

- Discrepancy between values for α using Rb and Cs is $> 5\,\sigma$



Optical clock atoms

- Differential schemes with single-photon transitions are simpler for longer baselines
- Sr, Yb, & Cd have sufficiently long $|e\rangle$ lifetimes ($\gg 2\,\mathrm{s}$)
- $A_r(^{87}\mathrm{Sr})$ & $A_r(^{171,173}\mathrm{Yb})$ are precise enough to improve α

Precision for 1 mrad resolution

ℓ (m)	$\Delta m(\mathrm{Sr})/m(\mathrm{Sr})$	$\Delta m(\mathrm{Yb})/m(\mathrm{Yb})$
1	2.2×10^{-10}	3.0×10^{-10}
2	2.1×10^{-11}	3.0×10^{-11}
3	7.2×10^{-12}	1.0×10^{-11}
4	3.5×10^{-12}	5.0×10^{-12}
5	2.2×10^{-12}	3.1×10^{-12}
6	1.5×10^{-12}	2.1×10^{-12}
7	1.1×10^{-12}	1.5×10^{-12}
8	8.4×10^{-13}	1.2×10^{-12}
9	6.7×10^{-13}	9.1×10^{-13}
10	5.3×10^{-13}	7.2×10^{-13}
100	1.3×10^{-14}	1.6×10^{-14}

References & acknowledgements

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