MAGIS-100

Developing the MAGIS-100 Case Study

Sam Hindley, on behalf of the MAGIS collaboration
28th April 2021

Fermilab

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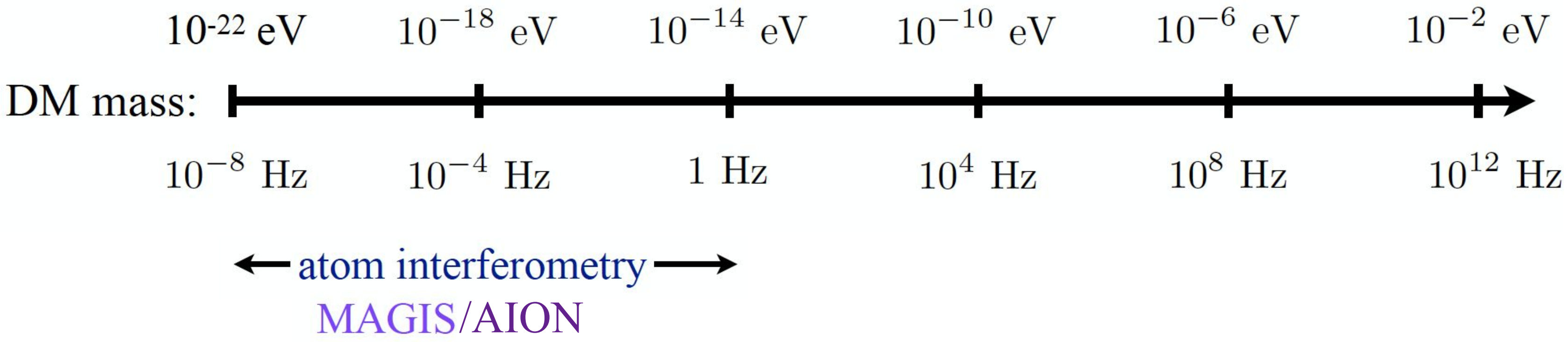
Science Case



- “Ultralight” dark matter candidates are wavelike at this energy
- 100 metre experiment applies state-of-the-art atom interferometry techniques at new length scales

Sam Hindley
sam.hindley@liverpool.ac.uk

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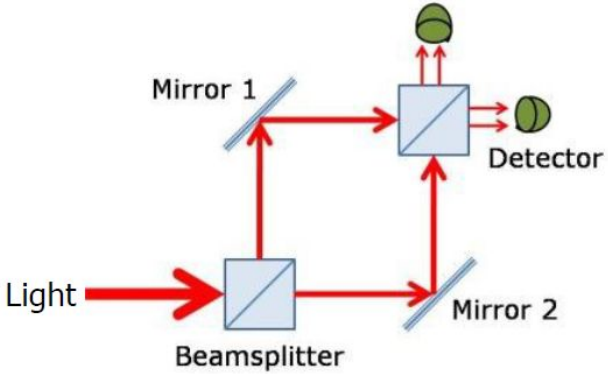
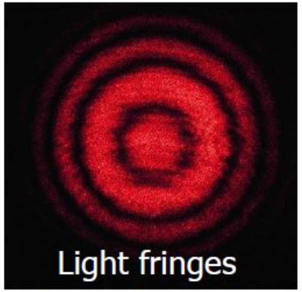
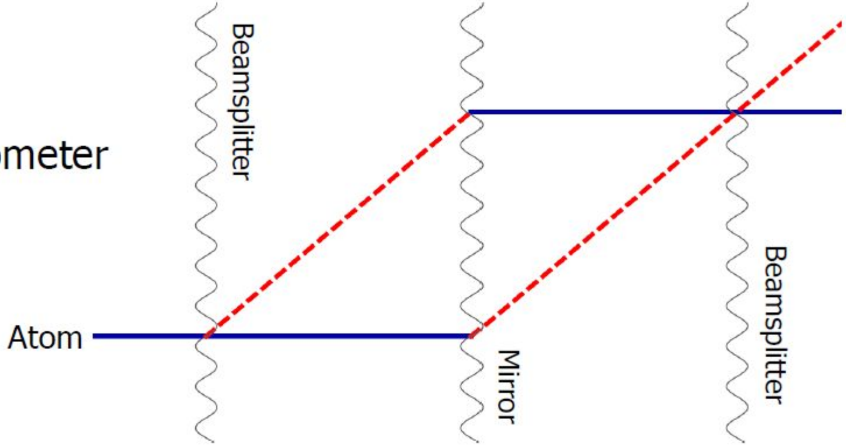
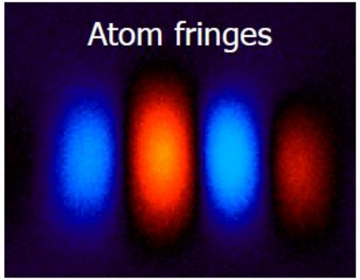
Light interferometer





Atom interferometer

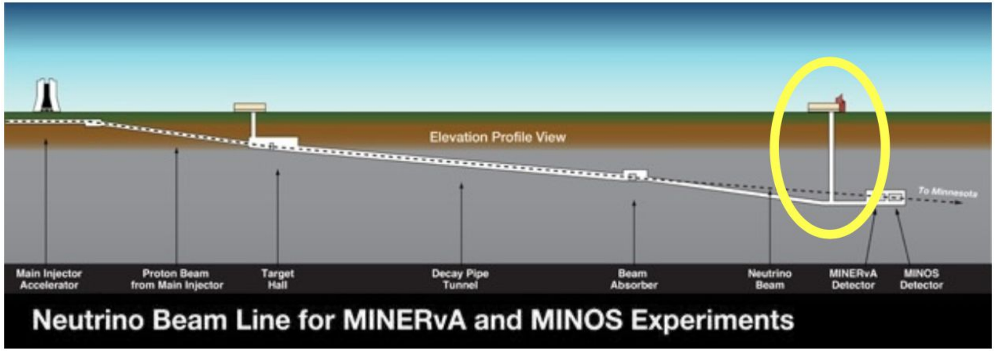


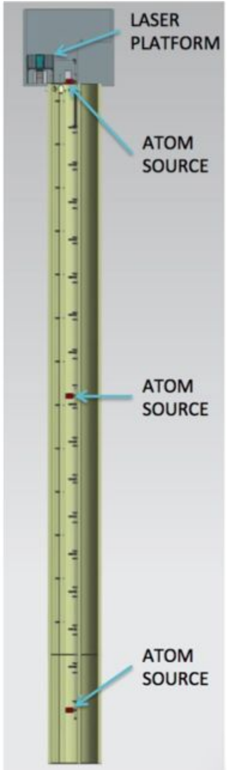


Sam Hindley
sam.hindley@liverpool.ac.uk

MAGIS-100 at Fermilab

- Currently under construction in MINOS access shaft
  - Baseline of 100 m
- 3 strontium atom sources
  - Multiple configurations
- Long baseline for gravitational wave detection





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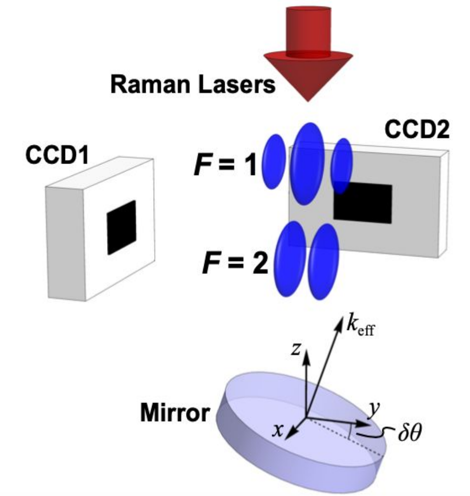
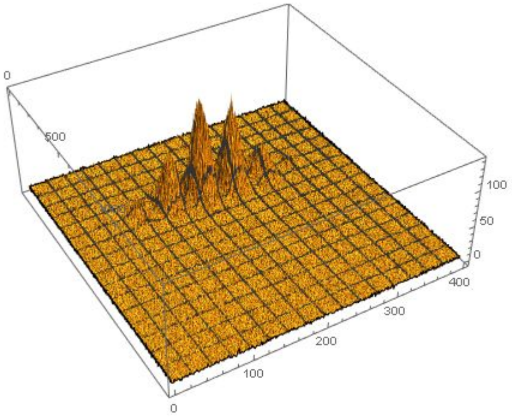
MAGIS Detection Studies

- Physical studies
  - Effects of diffusion on atoms, camera suitability
- Laser effects
  - Atom loss simulations,
- Preparing case study for mock data challenge
  - Will we be able to detect a signal if we get one





Sam Hindley
sam.hindley@liverpool.ac.uk

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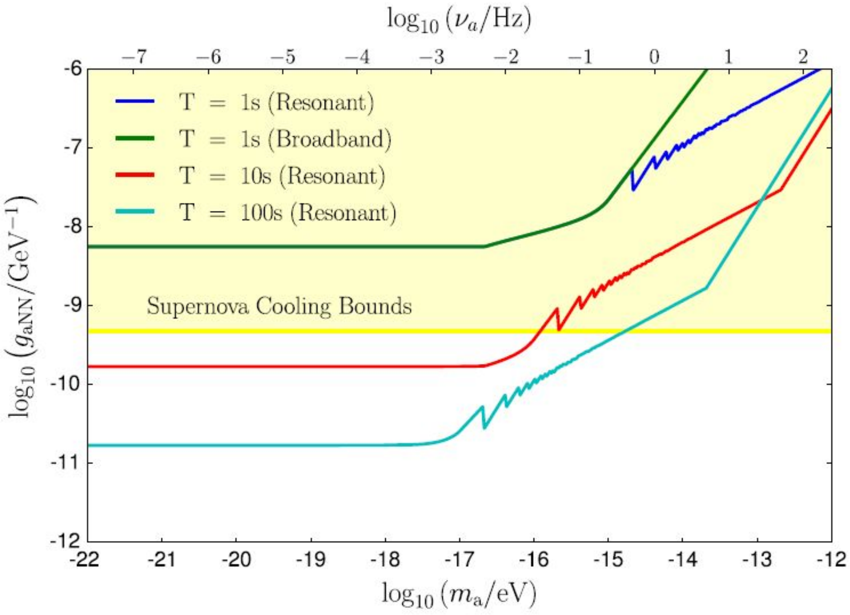
Pseudoscalar Coupling Investigation

- Axion field couples to atoms via spin interaction, induces anomalous phase shift
- Behaves as “dark magnetic field”
- Signal visible as differential phase shift between two atoms in different spin states



Spin precession experiments for light axionic dark matter, P. Graham et al, 2018

Sam Hindley
sam.hindley@liverpool.ac.uk

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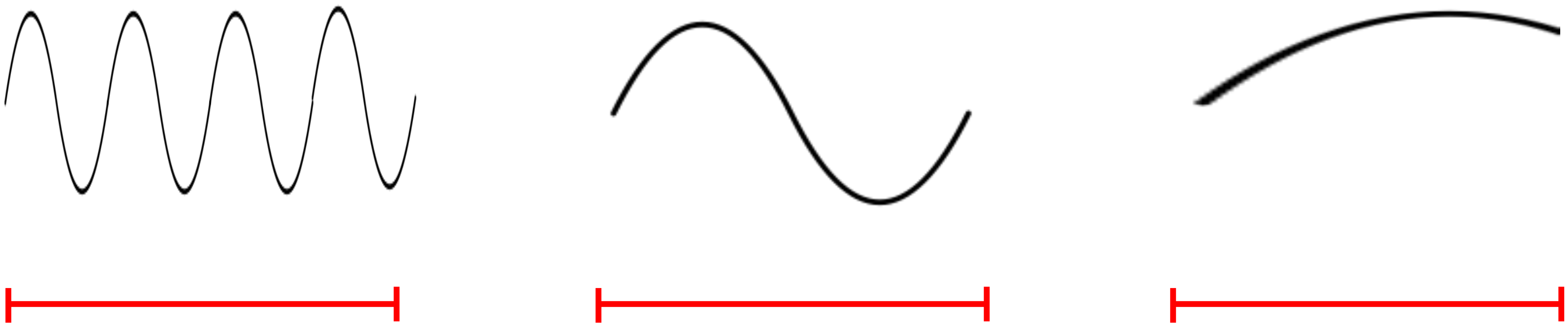
Pseudoscalar Detection

$$\Delta\phi = \underbrace{(m_{S,1} - m_{S,2})}_{\text{Spin change (=1)}} \overbrace{g_{\mathrm{aNN}}}^{\text{Axion coupling}} \underbrace{\frac{v\sqrt{2\rho_{\mathrm{DM}}}}{m_{\mathrm{a}}}}_{\text{“Interaction Rate”}} \overbrace{\sin m_{\mathrm{a}} T}^{\text{Interrogation time dependence}}.$$

Spin precession experiments for light axionic dark matter, P. Graham et al, 2018

Pseudoscalar Mass Range

Axion mass > 1/T | Axion mass = 1/T | Axion mass < 1/T



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Sam Hindley
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Pseudoscalar Detection Schemes

- Range of possible Axion masses - multiple search paradigms
- Default detection scheme is two ^{87}Sr atoms with opposed spins prepared by lasers
- Can push sensitivity to heavier axions with "resonant" spin-flipping method

$$\Delta\phi = (m_{S,1} - m_{S,2}) g_{\mathrm{aNN}} \frac{v\sqrt{2\rho_{\mathrm{DM}}}}{m_{\mathrm{a}}} \sin m_{\mathrm{a}} T.$$

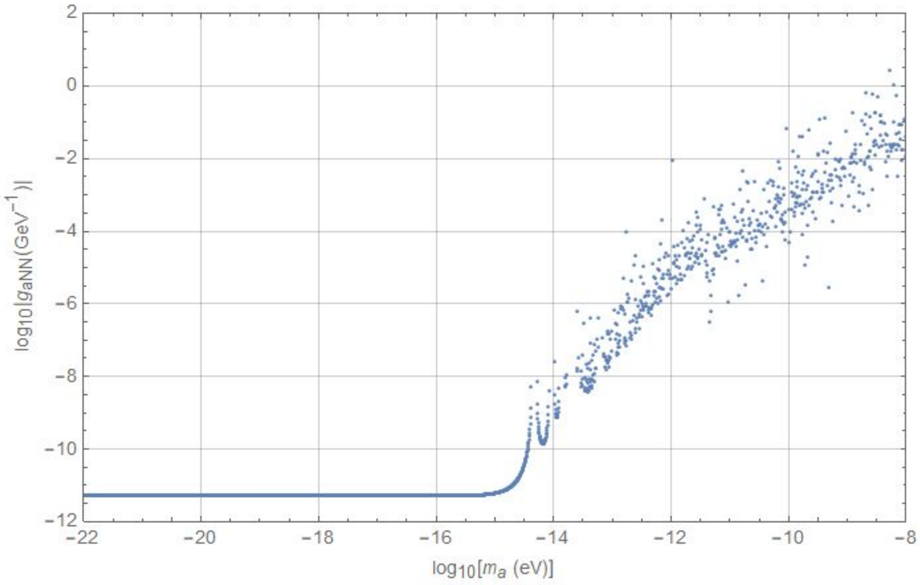
$$\sin m_a T \Rightarrow \sin m_a \frac{Q}{T}$$

Spin precession experiments for light axionic dark matter, P. Graham et al, 2018

Broadband Search Sensitivity

- Gives greater sensitivity to low mass axions - weaker sensitivity to high mass axions
- Magnitude of phase shift scales with m_a^{-1}
- Each interrogation time has cusps at $m_a T = n\pi$, run at multiple interrogation times

Broadband Detection: T = 0.9



Sam Hindley
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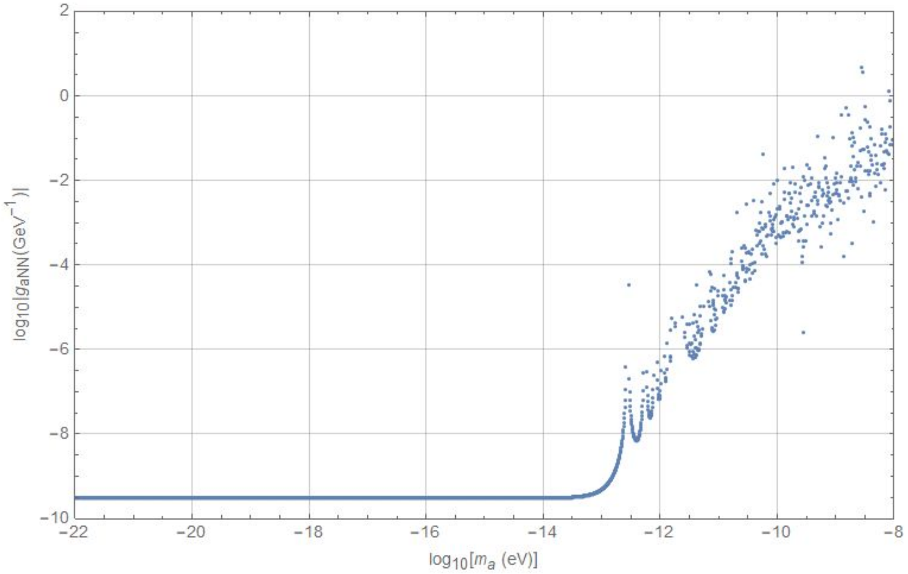
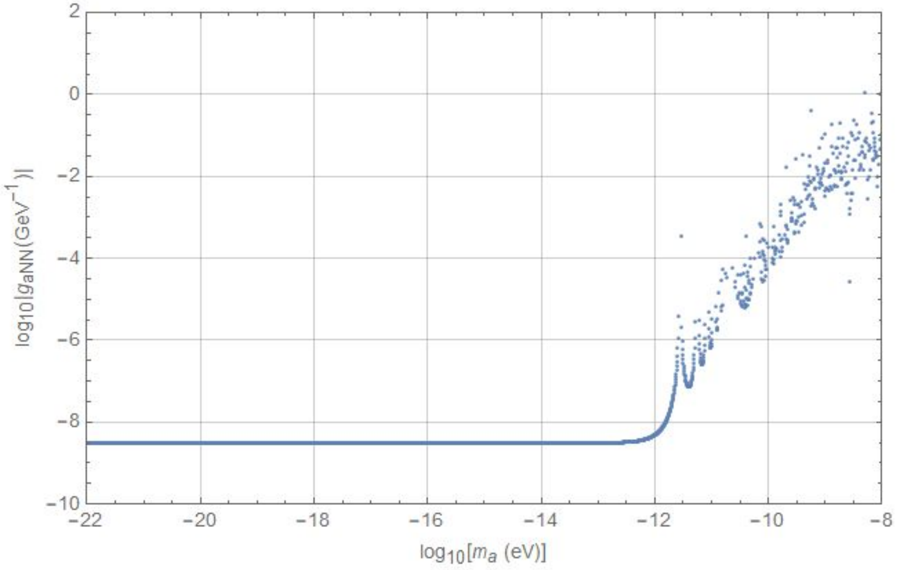
Resonant Search Sensitivity

Resonant Detection: T = 0.9, Q = 100



Resonant Detection: T = 0.9, Q = 1000



Sam Hindley
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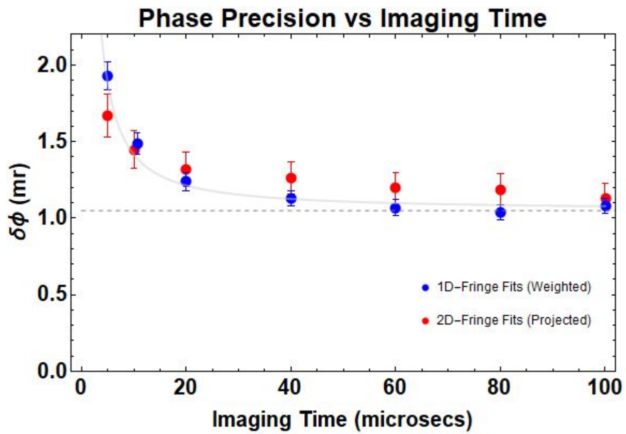
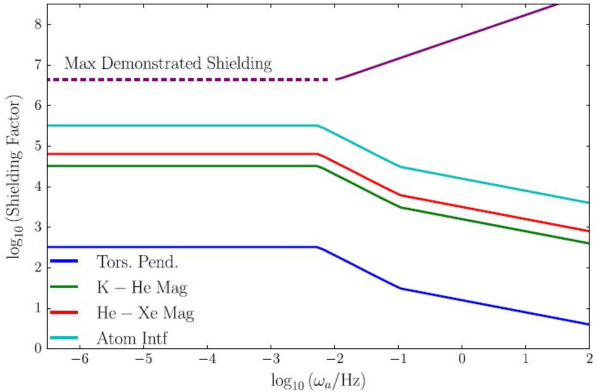
Summary & Future

- Working with MAGIS-100 software team understand atomic imaging
- Developing sensitivity analysis software for pseudoscalar coupling investigation
- Designing and reviewing experimental method for search
- Reviewing key engineering concerns before proceeding





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Sam Hindley
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Backups

Sam Hindley
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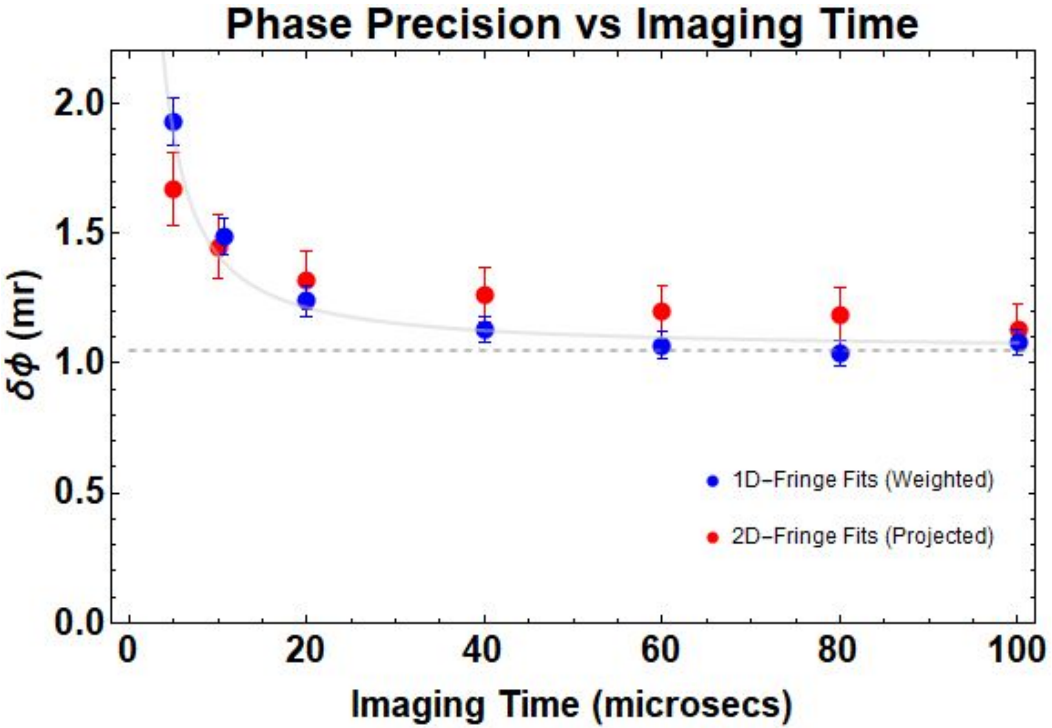
Comparison to 1D "Equivalent"



Projections are:
[analysis results] x 0.75 x 1/√2

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sam.hindley@liverpool.ac.uk

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Acknowledgements

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Fermilab

University of Liverpool

Sam Hindley
sam.hindley@liverpool.ac.uk