MARYLAND CENTER FOR FUNDAMENTAL PHYSICS

(Supersymmetric) Grand Unification at the Cosmological Collider

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In collaboration with Arushi Bodas, & Raman Sundrum (ArXiv 2406.xxxx)

Cosmological Collider Physics

Basic Idea

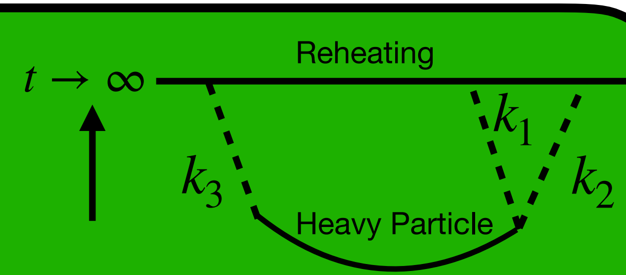
- Cosmological particle production during inflation, analogous to hawking radiation.

$$m < H_{\text{inf}} < 5 \times 10^{13}\ GeV$$

- In LSS, and the CMB we measure quantum fluctuations of the inflaton, $\delta\phi$.

- If the heavy particle can decay into the inflatons they can imprint themselves on Non-Gaussianities (NGs).

$$\langle \delta\phi_{\vec{k}_1} \delta\phi_{\vec{k}_2} \delta\phi_{\vec{k}_3} \rangle =$$



X. Chen, Y. Wang, 0911.3380
Nima Arkani-Hamed, J. Maldacena, 1503.08043

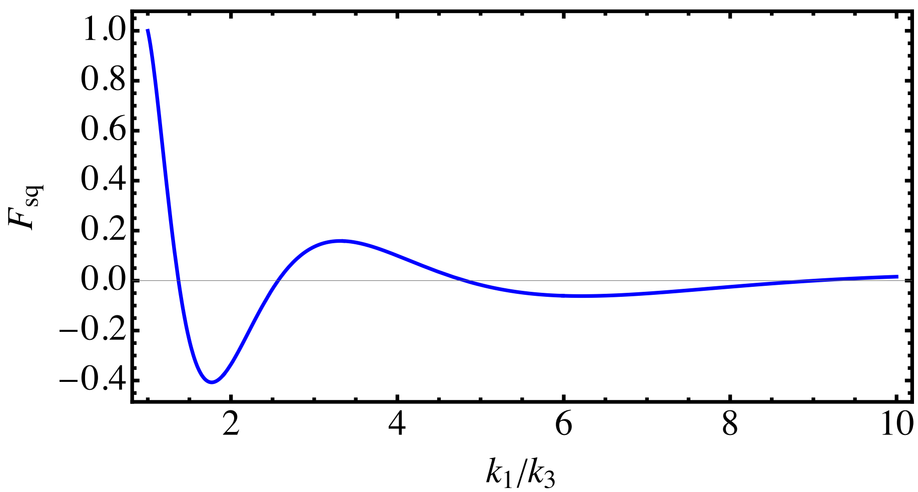
Cosmological Collider Physics

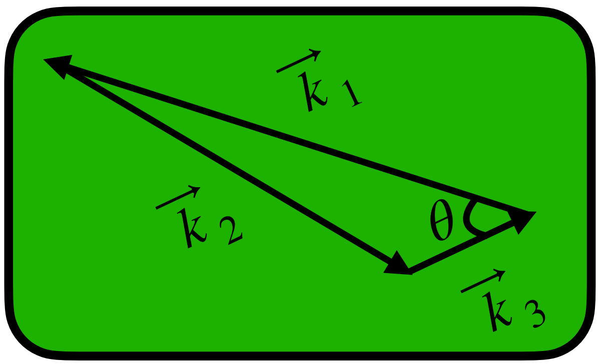
Basic Idea II

- In the cosmological collider we look for an oscillation in the squeezed limit.

$$F \equiv \frac{5}{12}\dot{\phi}_0 \frac{\langle \delta\phi_{\vec{k}_1} \delta\phi_{\vec{k}_2} \delta\phi_{\vec{k}_3} \rangle'}{\langle \delta\phi_{\vec{k}_1} \delta\phi_{-\vec{k}_1} \rangle' \langle \delta\phi_{\vec{k}_3} \delta\phi_{-\vec{k}_3} \rangle'} \sim e^{-\pi \frac{m}{H}} \left(\frac{k_1}{k_3} \right)^{-3/2 + i\frac{m}{H}}$$

- We have to live in a narrow window $m \sim H_{\text{inf}}$.





S. Kumar and R. Sundrum, Seeing Higher-Dimensional Grand Unification In Primordial Non-Gaussianities,

Cosmological Collider Physics

Exciting Prospect, but luck required

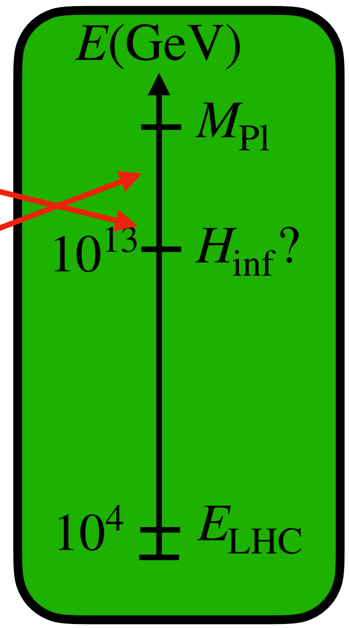
- Opportunity to probe physics at higher scales than any terrestrial collider.
- Theoretically motivated targets?

$$M_{\text{GUT}} \sim 10^{14}\text{GeV}$$

- Has been studied. Can't see spin-1

$$M_{\text{SUSY,GUT}} \sim 10^{16}\text{GeV}$$

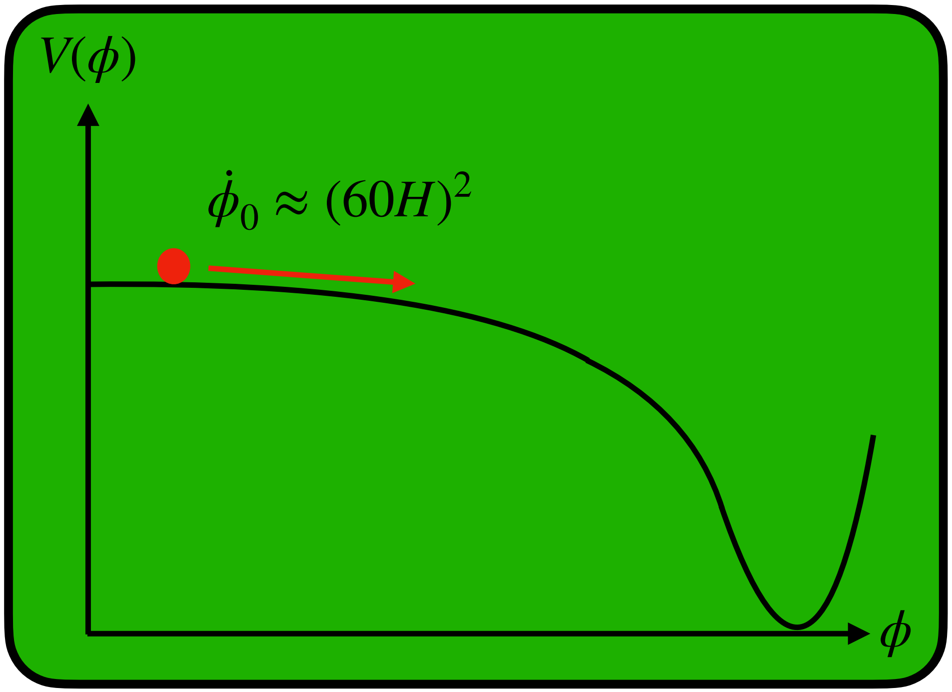
- Scale is too high!
- I show how to increase scale, and see spin-1.



Cosmological Collider Physics

Chemical Potential

- There is a higher scale in inflation.



Cosmological Collider Physics

Chemical Potential

L.-T. Wang and Z.-Z. Xianyu, In search of large signals at the cosmological collider

A. Bodas, S. Kumar, and R. Sundrum, The scalar chemical potential in cosmological collider physics

- There is a higher scale in inflation.

$$\dot{\phi}_0 \approx (60H)^2$$

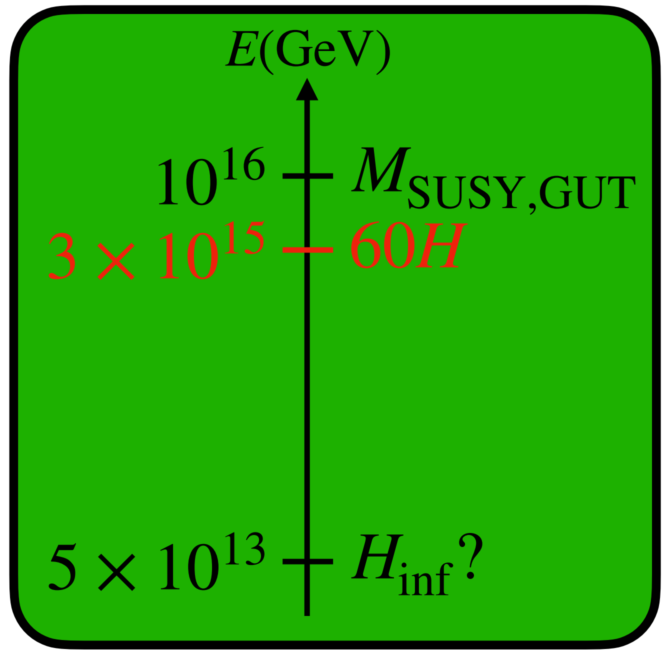
- The chemical potential mechanism utilizes this scale.

$$\lambda = \frac{\dot{\phi}_0}{\Lambda} \lesssim 60H$$

- Introduces a source for the heavy particles. Leads to Unsuppressed production for $m < \lambda$.

$$\mathscr{L} \sim \chi e^{-i\phi/\Lambda} \sim \chi e^{-i\lambda t}$$

$$\mathscr{L} \sim \partial_\mu \phi A^\mu (\partial\phi)^2 e^{-i\phi/\Lambda}$$



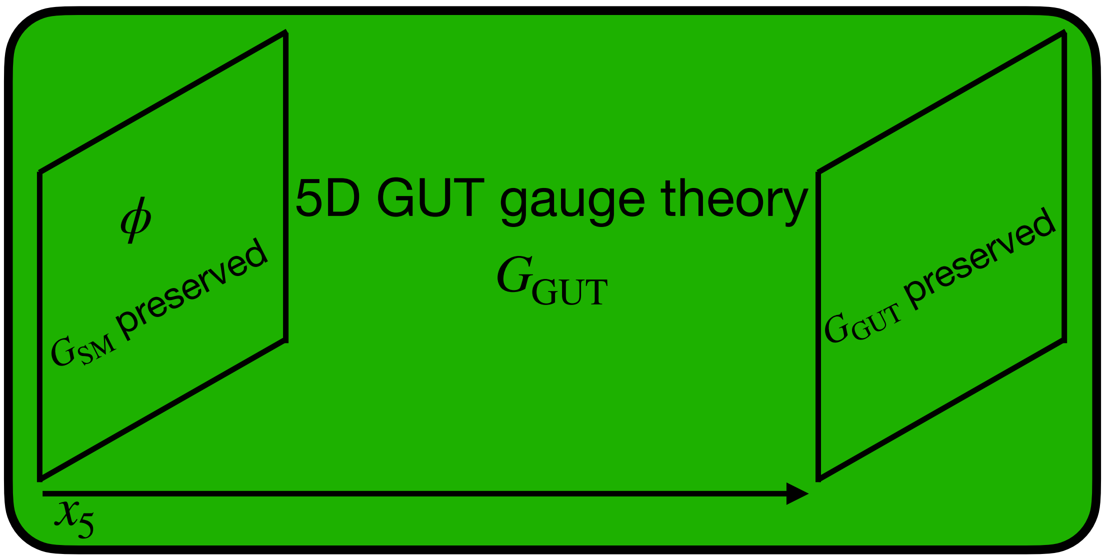
Y. Kawamura, Prog. Theor. Phys. 105, 999 (2001)

L. J. Hall and Y. Nomura, Grand unification in higher dimensions, Annals of Physics 306

Orbifold GUTs

Motivation

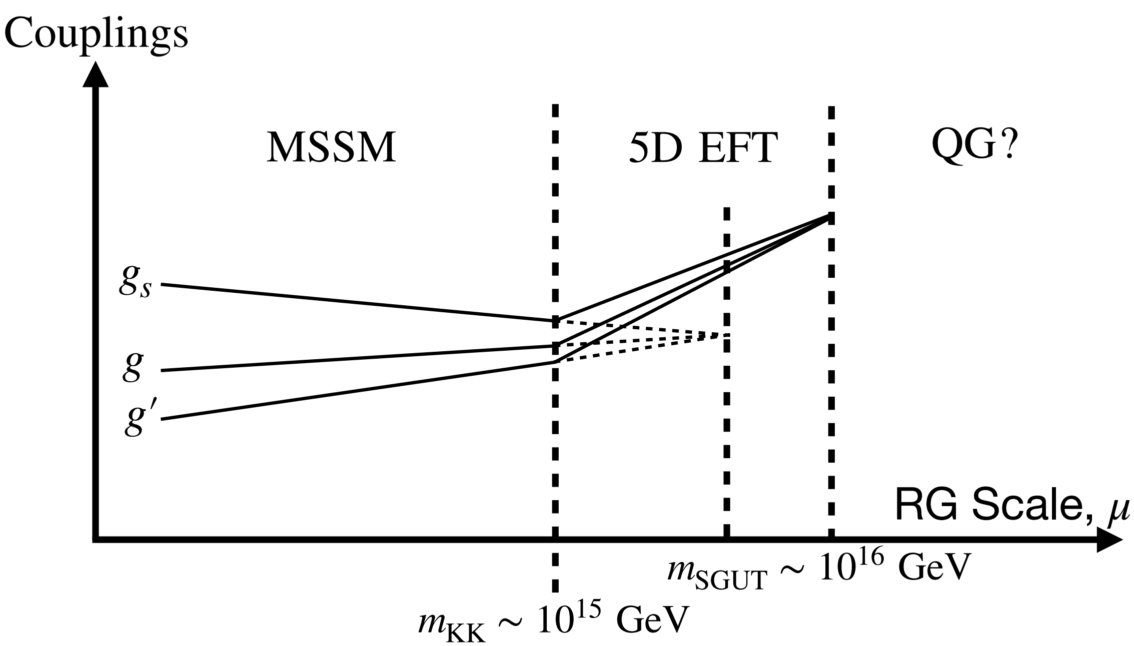
- Gauge symmetry broken by boundary conditions on a brane.
- Solves doublet-triplet splitting and proton decay.
- Inflaton lives on a brane.



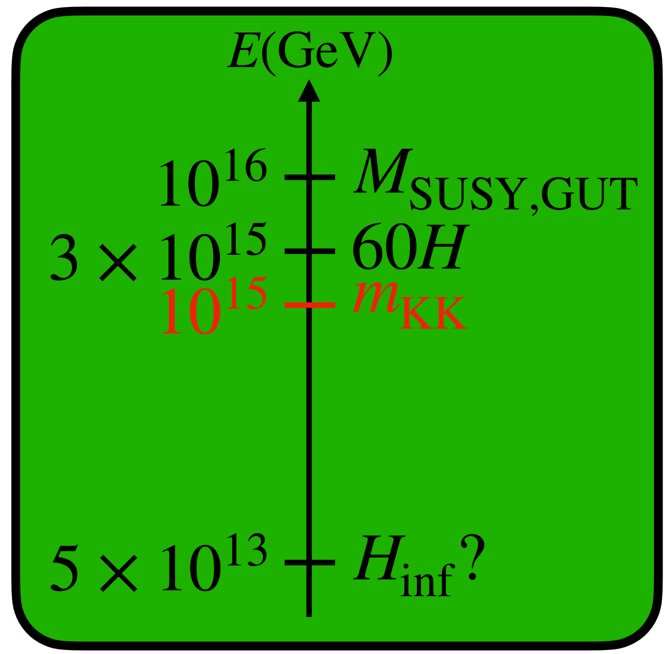
Orbifold GUTs

Gauge Coupling Running

- In orbifold GUTs the KK scale is lower than the usual unification scale



Adapted from - L. J. Hall and Y. Nomura, Grand unification in higher dimensions, Annals of Physics 306 (July, 2003) 132–156



Orbifold GUTs

Implementing the coupling

- Chemical Potential Coupling

$$S_{\text{brane}} = c \int d^4x \partial_\mu \phi \partial_5 A^\mu(x,0)(\partial\phi)^2 e^{-i\phi/\Lambda}$$

- Shift symmetry protecting flatness of slow-roll potential

$$\phi \to \phi + c$$
$$A_\mu \to e^{ic/\Lambda} A_\mu$$

- Requires a complex vector that is a SM gauge singlet. We consider trinification

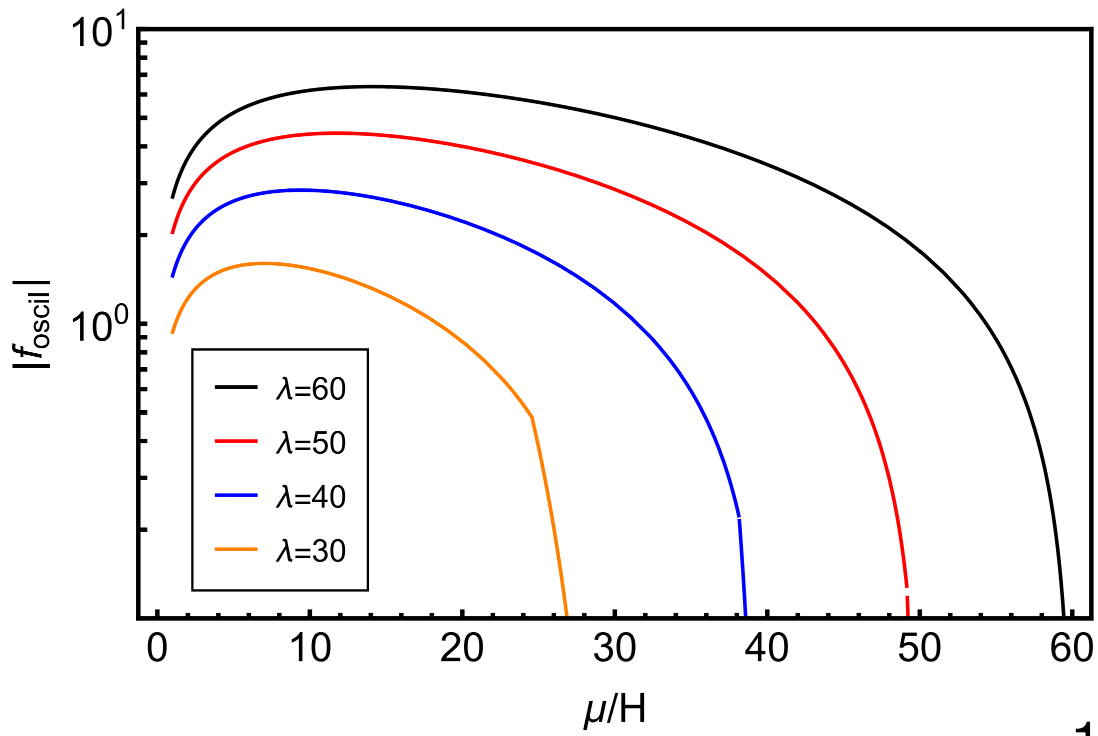
$$G_{\text{GUT}} = SU(3)_C \times SU(3)_L \times SU(3)_R/\mathbb{Z}_3$$

Results I

Signal Size

- We calculated NG in the EFT of a vector coupled to inflation with a chemical potential ($\mu = \sqrt{m^2 - 1/4}$).

$$F = f_{\mathrm{oscil}}(\mu, \lambda, \theta)\left(\frac{k_1}{k_3}\right)^{-5/2+i(\mu-\lambda)}$$

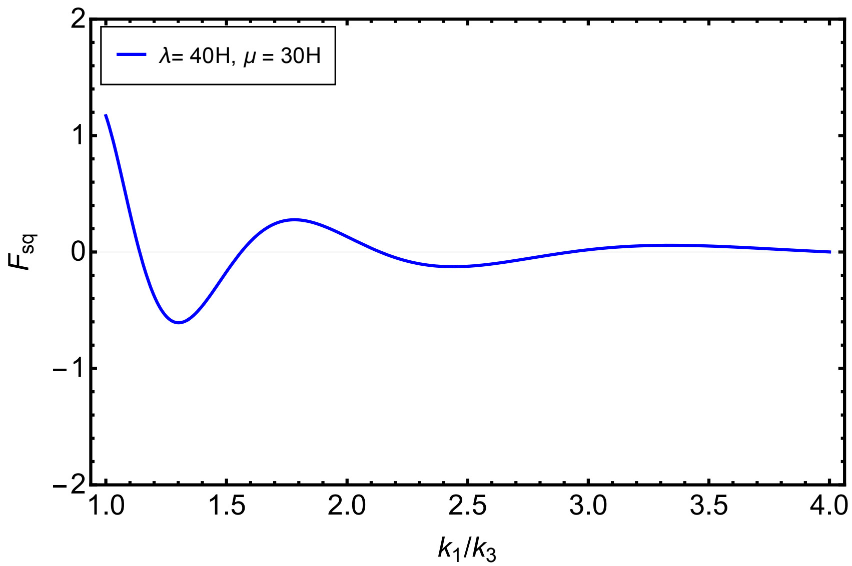


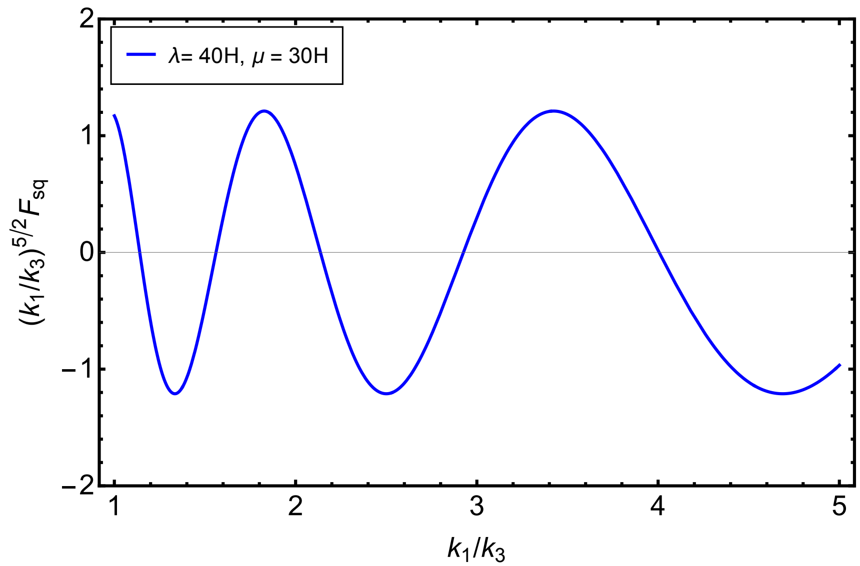
- Signals of this size potentially detectable in LSS.

Results II

Signal Frequency

- Observation of frequency will tell us $\mu - \lambda$.





- There is a possibility of separating mass and chemical potential.
- Some detective work required to determine spin.

Summary, & future work

- Cosmological Collider Physics presents an opportunity to probe physics at very high scales.
- SUSY GUTs are generally considered to be out of reach.
- Non SUSY GUTs have small signals.
- We have shown that a chemical potential can be applied to spin-1 particles within EFT control.
- Such a model can give observably large signals for spin-1 particles with masses $\mathcal{O}(\text{few} \times 10^{15}\ \text{GeV})$.
- The mechanism can be applied to any model with vectors at masses above the Hubble scale.

Thanks for listening

Backup Slides

Results III

Separating mass from chemical potential

- If a small squeezing limit exists

$$\frac{k_1}{k_3} < \frac{\lambda}{2\mu}$$

- The frequency changes

$$F \equiv \left(1 + 2\frac{k_1}{k_3}\right)^{-i\lambda}$$

- Observation of the frequency in the small and large squeezing will allow a measurement of the mass and chemical potential

N. Arkani-Hamed and J. Maldacena, Cosmological collider physics, 2015.

H. Lee et al, Non-gaussianity as a particle detector,

S. Kumar and R. Sundrum, Heavy-Lifting of Gauge Theories By Cosmic Inflation

Results IV

Determining Spin

- In original paper it was claimed for spin s, observation of angular dependence would tell you spin.

$$F \propto P_s(\cos\theta) e^{-\pi\mu} \left(\frac{k_1}{k_3}\right)^{-3/2+i\mu}$$

- Later reference pointed out a cancellation between diagrams gave a different dilution factor, and angular dependence for odd spin. In particular for spin 1

$$F \propto \sin^2\theta e^{-\pi\mu} \left(\frac{k_1}{k_3}\right)^{-5/2+i\mu}$$

- In our work we have found

$$F \propto \left[A + B\cos^2\theta\right] e^{-\pi\mu} \left(\frac{k_1}{k_3}\right)^{-5/2+i\mu}$$

Observational Prospects

Ongoing & Planned LSS experiments

G. Cabass et al, Boss constraints on massive particles during inflation: The cosmological collider in action, 2024

A. Loeb and M. Zaldarriaga, Measuring the small-scale power spectrum of cosmic density fluctuations through 21cm tomography prior to the epoch of structure formation

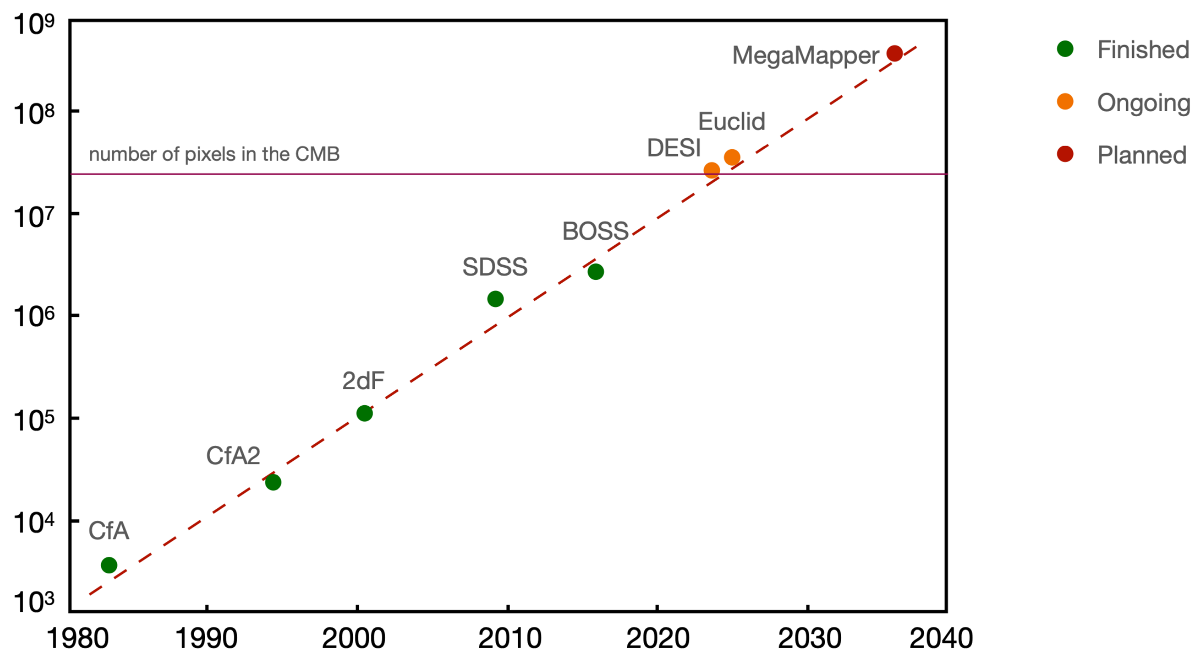
- First analysis recently performed on BOSS data for spin-0 exchange.
- MegaMapper (2030s) will probe

$$|f_{\text{oscil}}| \sim \mathcal{O}(1)$$

- In the future 21-cm cosmology can probe

$$|f_{\text{oscil}}| \sim \mathcal{O}\left(10^{-2}\right)$$

Number of galaxy spectra as a function of time



Graph from talk - https://indico.cern.ch/event/1073672/attachments/2319217/3948806/CERNcolloquium.pdf