First Search for Kaluza-Klein Gravitons Using Planck Data

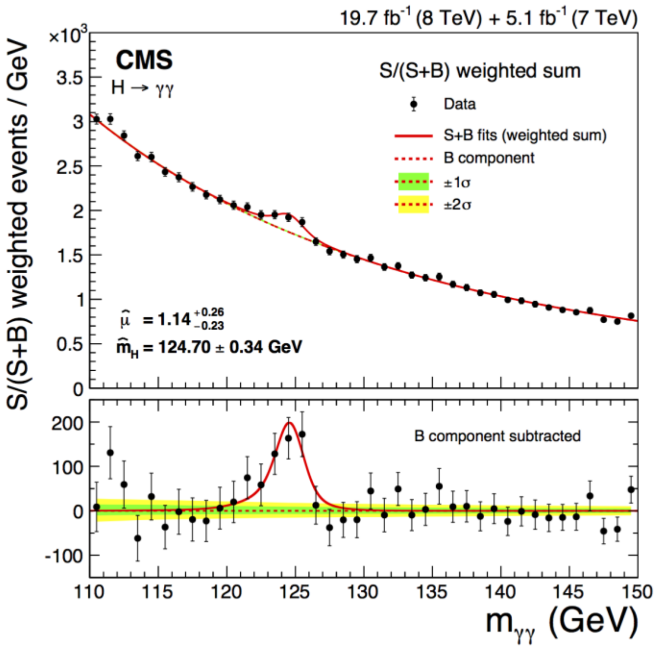
The 2026 Phenomenology Symposium

Alexander P. Cassem

Tufts University, Institute of Cosmology

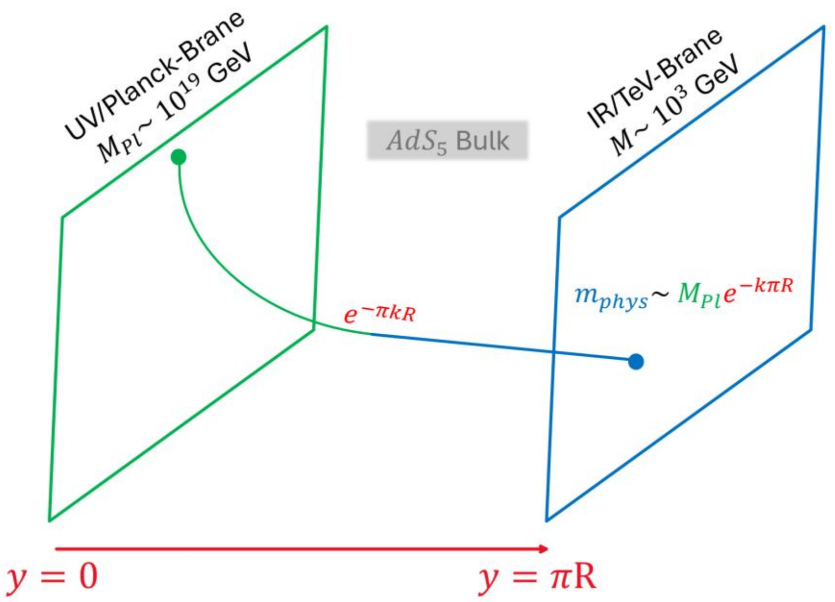
May 12, 2026

Based on upcoming arxiv: 2605.abcd w/ Soubhik Kumar

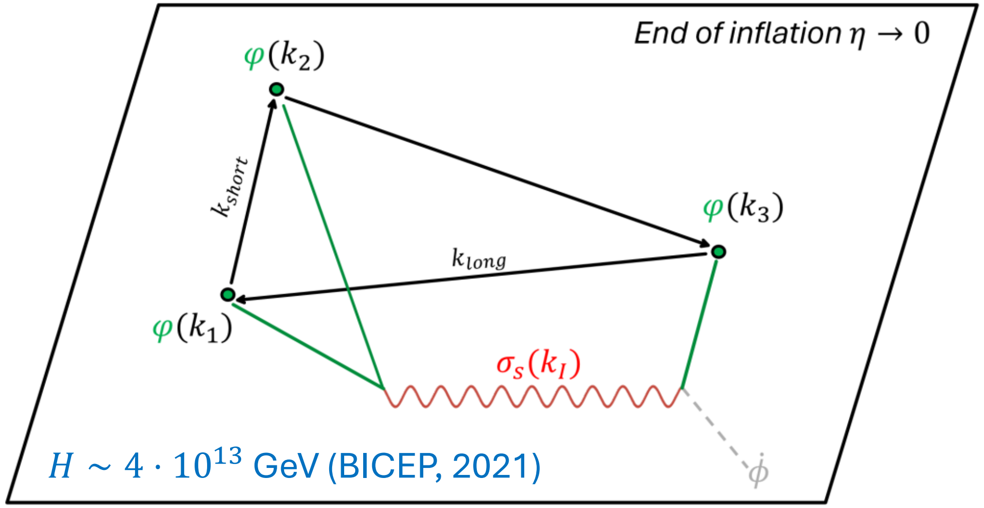


Higgs at LHC
(Atlas & CMS, 2012)

Hierarchy Problem!



RS-Geometries
(Randall, Sundrum, 1999)



Cosmological Collider

(Arkani-Hamed & Maldacena, 2015)

Observables

$\langle \varphi_1 \varphi_2 \varphi_3 \rangle$

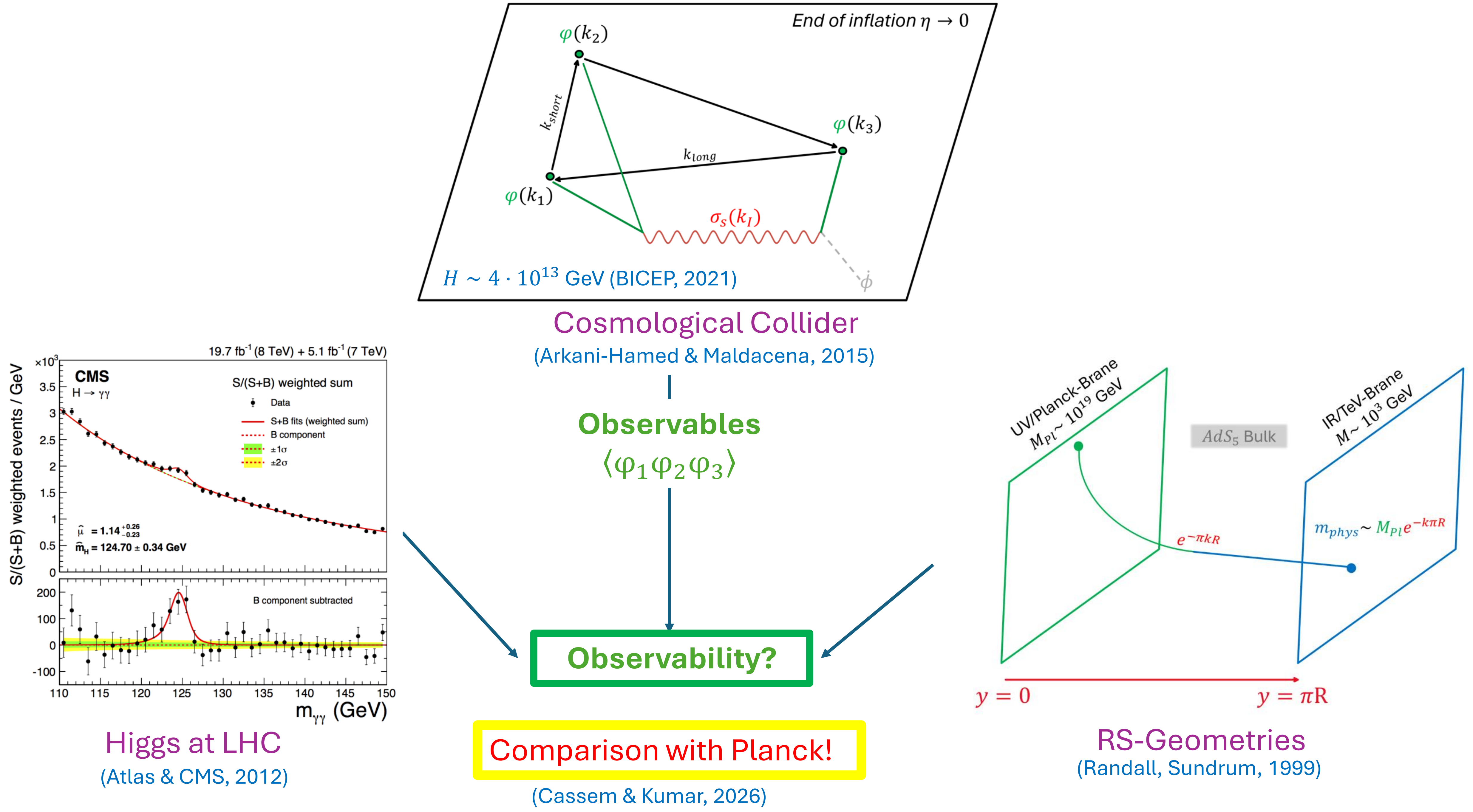
Hierarchy Problem!

Higgs at LHC

(Atlas & CMS, 2012)

RS-Geometries

(Randall, Sundrum, 1999)

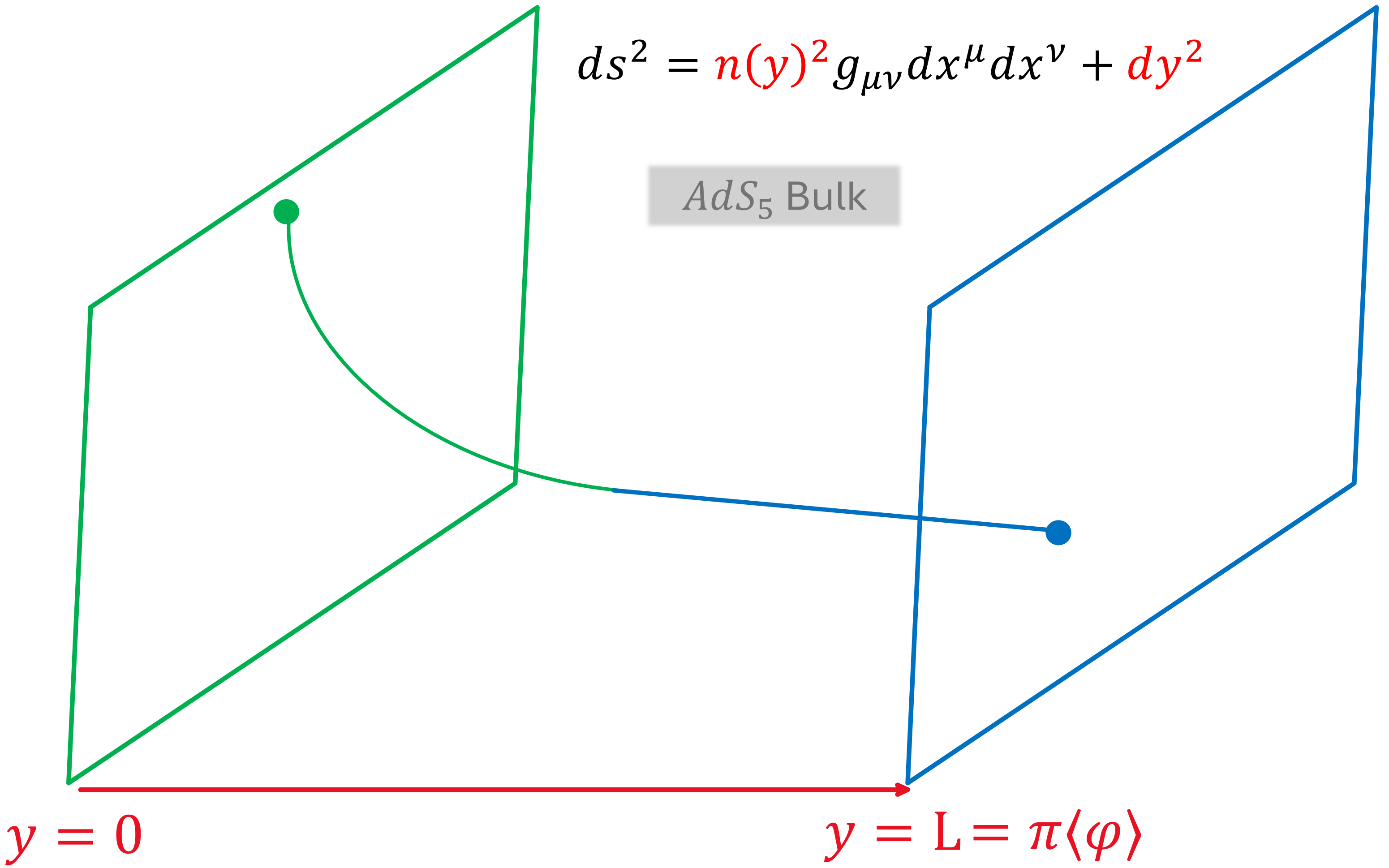


End of inflation $\eta \to 0$
$\varphi(k_2)$
$\varphi(k_3)$
$\varphi(k_1)$
k_{short}
k_{long}
$\sigma_s(k_I)$
ϕ
$H \sim 4 \cdot 10^{13}$ GeV (BICEP, 2021)
Cosmological Collider
(Arkani-Hamed & Maldacena, 2015)
Observables
$\langle \varphi_1 \varphi_2 \varphi_3 \rangle$
Observability?
Comparison with Planck!
(Cassem & Kumar, 2026)
19.7 fb^{-1} (8 TeV) + 5.1 fb^{-1} (7 TeV)
CMS
H → γγ
S/(S+B) weighted sum
Data
S+B fits (weighted sum)
B component
±1σ
±2σ
$\hat{\mu}$ = 1.14$^{+0.26}_{-0.23}$
$\hat{m}_H$ = 124.70 ± 0.34 GeV
B component subtracted
S/(S+B) weighted events / GeV
$m_{\gamma\gamma}$ (GeV)
Higgs at LHC
(Atlas & CMS, 2012)
UV/Planck-Brane
$M_{Pl} \sim 10^{19}$ GeV
AdS_5 Bulk
IR/TeV-Brane
$M \sim 10^3$ GeV
$e^{-\pi kR}$
$m_{phys} \sim M_{Pl} e^{-k\pi R}$
$y = 0$
$y = \pi R$
RS-Geometries
(Randall, Sundrum, 1999)

5D Geometries (dS_4-slice):

$$S = \int d^4x \int_{-L}^{L} dy\, \sqrt{-G}\left(M_5^3 R_5 - \Lambda_5\right)$$
$$+\int d^4x \int_{-L}^{L} dy\sqrt{-G}\left(-\frac{1}{2}G^{MN}\partial_M\Phi\partial_N\Phi - V(\Phi)\right) + \int d^4x \int_{-L}^{L} dy\sqrt{-G}\left[\left(\mathcal{L}_\phi - V_0(\Phi)\right)\delta(y) + \left(\mathcal{L}_\sigma - V_L(\Phi)\right)\delta(y-L)\right]$$

$$ds^2 = n(y)^2 g_{\mu\nu}dx^\mu dx^\nu + dy^2$$



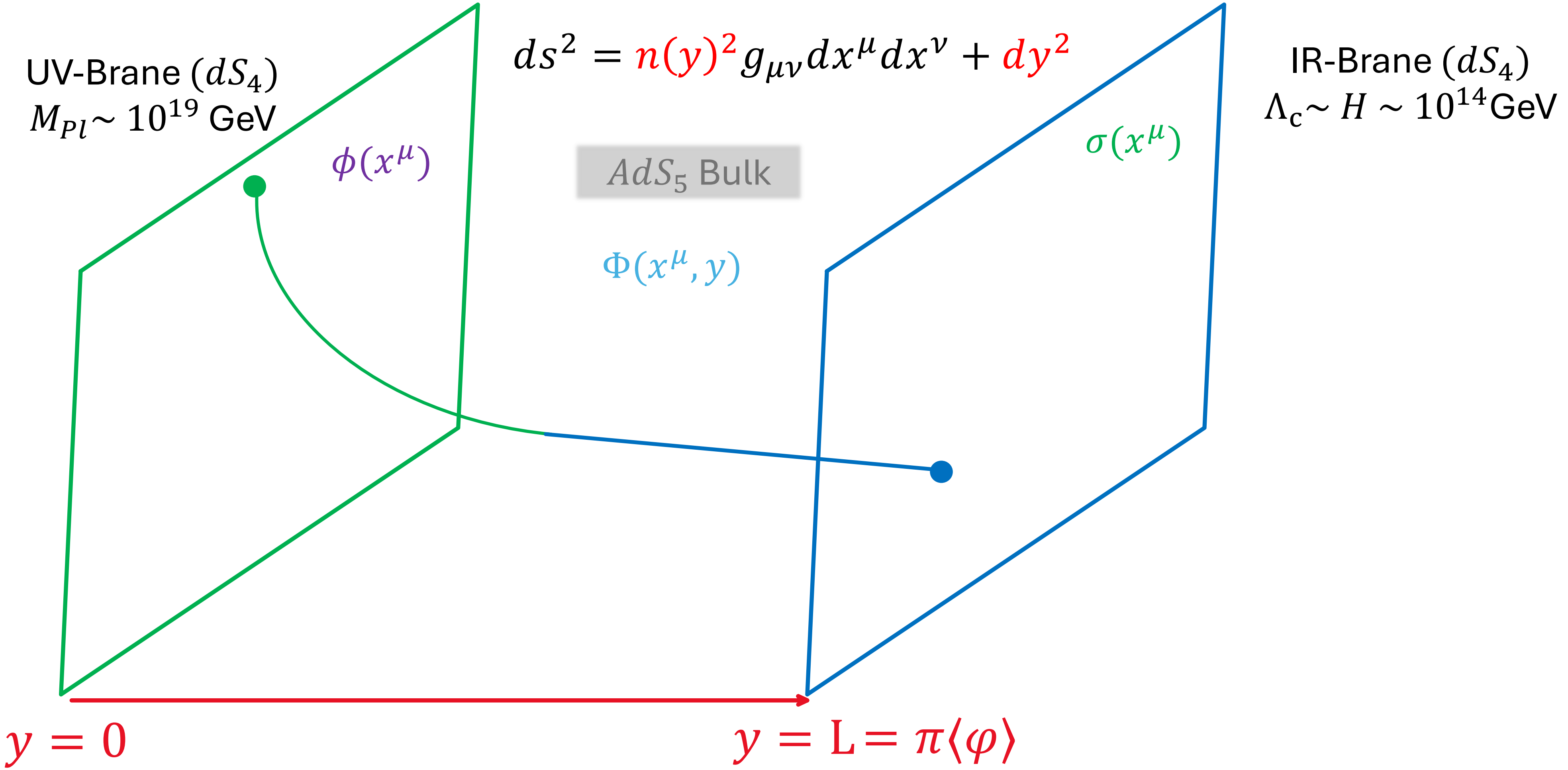
(Kumar & Nee 2025)

5D Geometries (dS_4-slice):

$$S = \int d^4x \int_{-L}^{L} dy \sqrt{-G}\left(M_5^3 R_5 - \Lambda_5\right)$$

$$+\int d^4x \int_{-L}^{L} dy\sqrt{-G}\left(-\frac{1}{2}G^{MN}\partial_M\Phi\partial_N\Phi - V(\Phi)\right) + \int d^4x \int_{-L}^{L} dy\sqrt{-G}\left[\left(\mathcal{L}_\phi - V_0(\Phi)\right)\delta(y) + \left(\mathcal{L}_\sigma - V_L(\Phi)\right)\delta(y-L)\right]$$

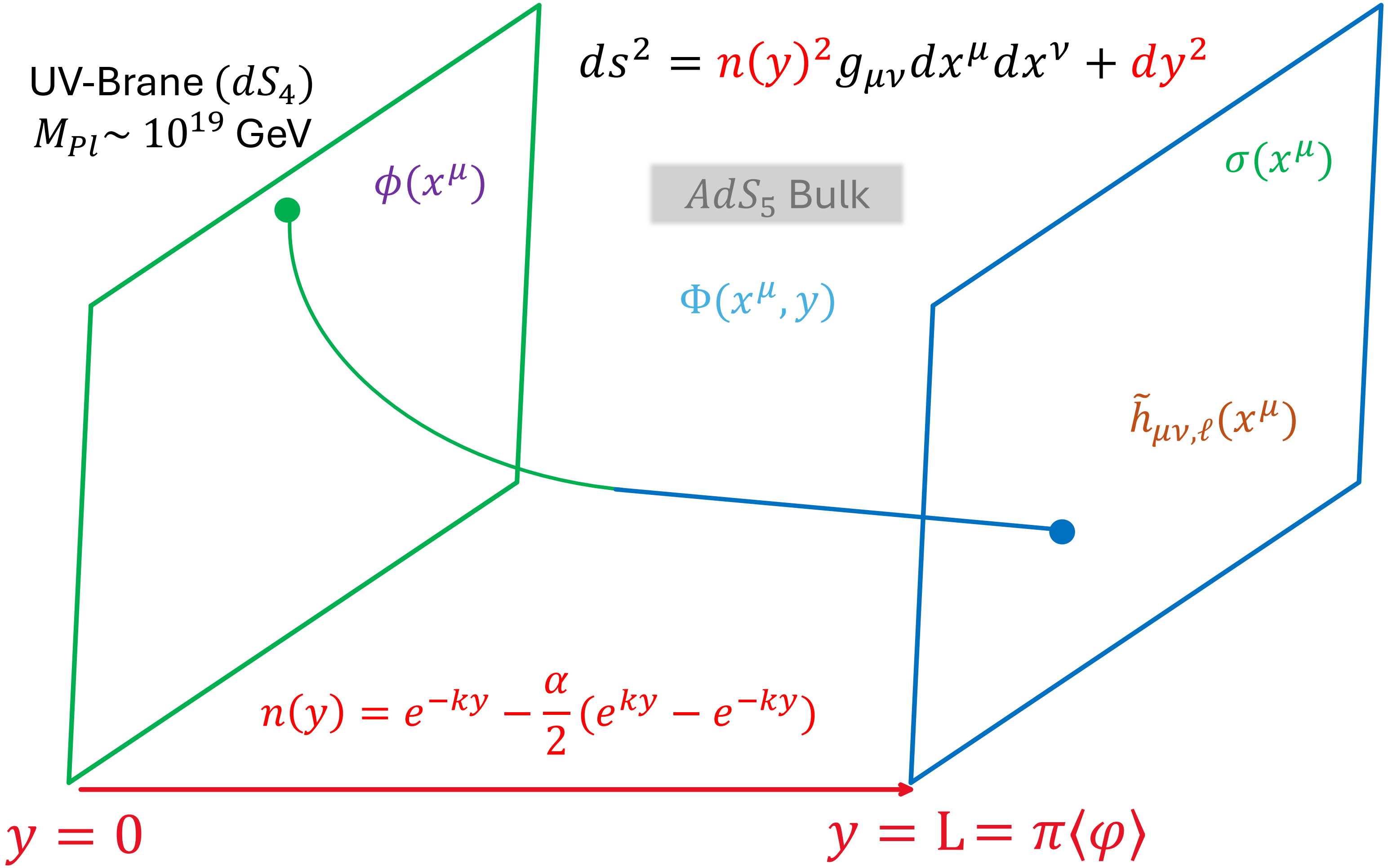
$$ds^2 = n(y)^2 g_{\mu\nu}dx^\mu dx^\nu + dy^2$$



(Kumar & Nee 2025)

5D Geometries (dS_4-slice):

$$S = \int d^4x \int_{-L}^{L} dy\, \sqrt{-G}\left(M_5^3 R_5 - \Lambda_5\right)$$
$$+\int d^4x \int_{-L}^{L} dy \sqrt{-G}\left(-\frac{1}{2} G^{MN}\partial_M\Phi\partial_N\Phi - V(\Phi)\right) + \int d^4x \int_{-L}^{L} dy\sqrt{-G}\left[\left(\mathcal{L}_\phi - V_0(\Phi)\right)\delta(y) + \left(\mathcal{L}_\sigma - V_L(\Phi)\right)\delta(y-L)\right]$$



IR-Brane (dS_4)

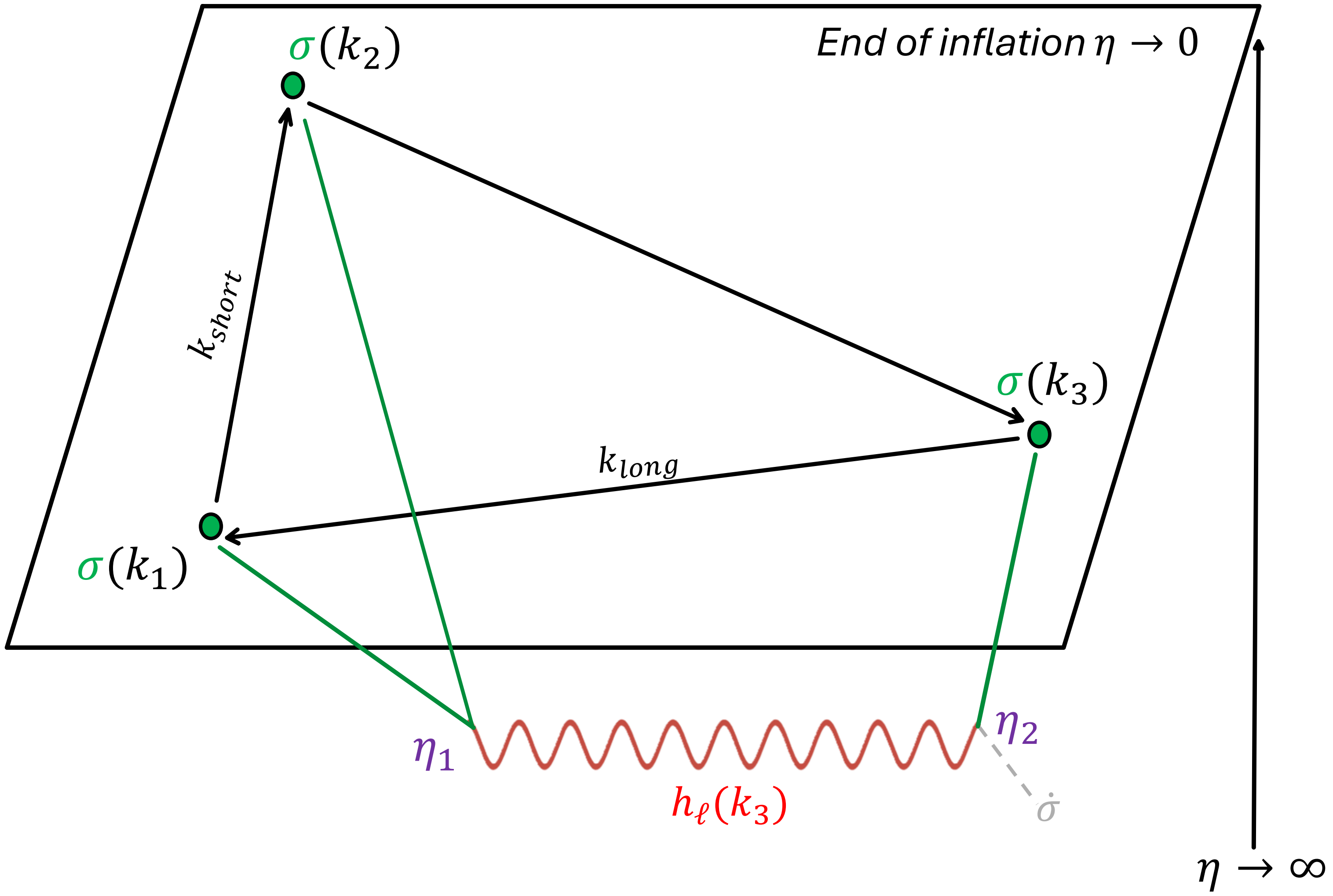
$\Lambda_c \sim H \sim 10^{14}$GeV

$$\mathcal{L}_{int} = \frac{\lambda_{\varphi\sigma}\delta\varphi}{2\langle\varphi\rangle}\sqrt{-g}\, g^{\mu\nu}\nabla_\mu\sigma\nabla_\nu\sigma - \frac{\chi_l(L)}{2M_4}\int d^4x\sqrt{-g}\, \tilde{h}_{\mu\nu,l}\nabla^\mu\sigma\nabla^\nu\sigma$$

	Benchmark
m_φ/H	1.7
m_{KK}/H	1.7

(Kumar & Nee 2025)

Cosmological Collider:



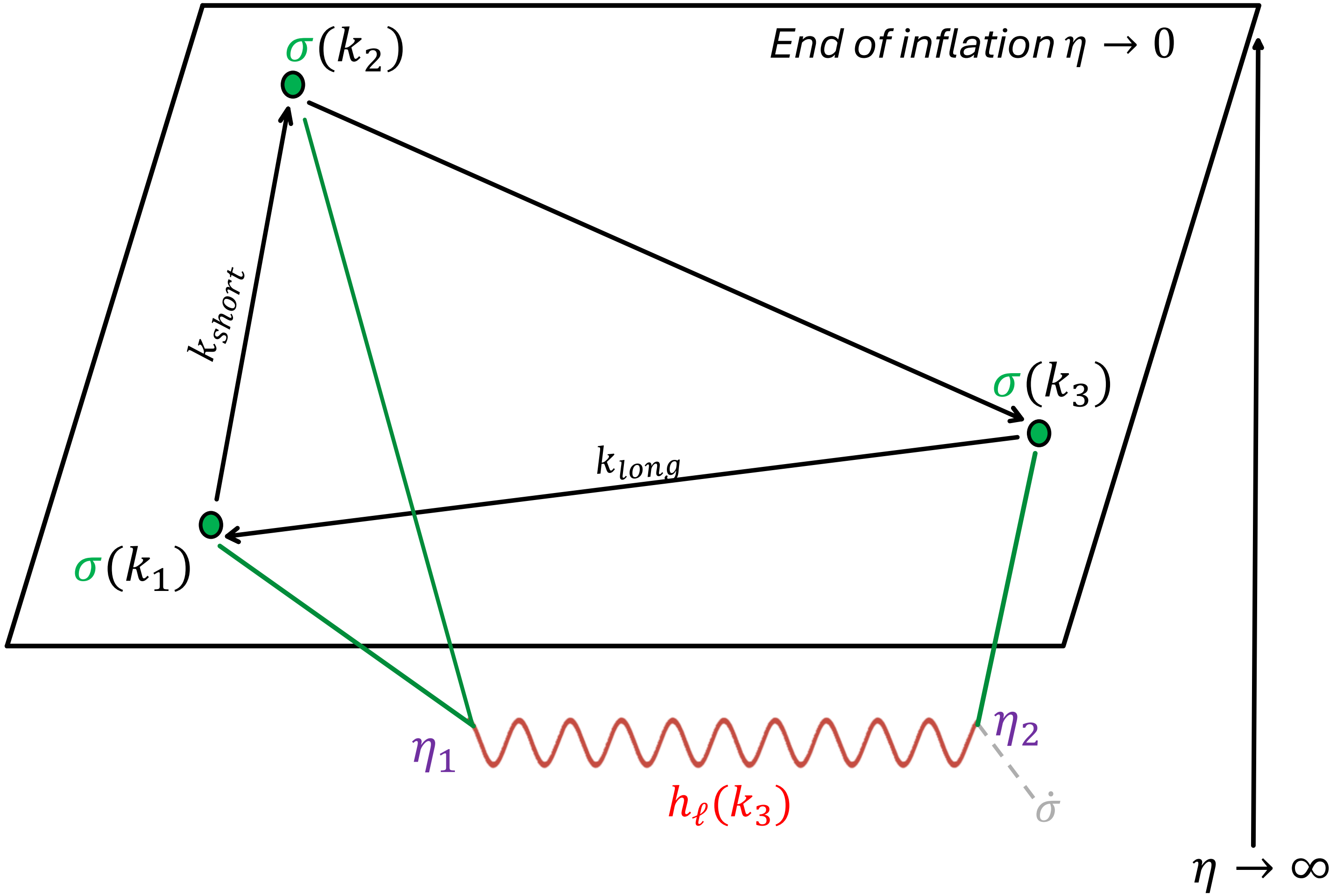
- Correlators on (semi)-de Sitter (dS) background.
- Bispectrum (3-point) and trispectrum (4-point) predicts ***particle production*** that we can see in the CMB.
- Non-trivial angular dependence for spinning-exchange.

$$\langle \delta\sigma(k_1)\delta\sigma(k_2)\delta\sigma(k_3)\rangle' \equiv B_\sigma(k_1, k_2, k_3) \propto f_{NL}\frac{S(k_1, k_2, k_3)}{(k_1 k_2 k_3)^2}$$

(Arkani-Hamed & Maldacena, 2015)

Cosmological Collider:

$$\langle \sigma_1 \sigma_2 \sigma_3 \rangle = (ia)(ib) \int_{\infty}^{0} d\eta_1 d\eta_2 V_a [G_a(k_1, \eta_1) G_a(k_2, \eta_1)] D_{ab}(k_I, \eta_1, \eta_2) V_b [G_b(k_3, \eta_2)]$$



$$V \sim h^{\mu\nu} \nabla_\mu \sigma \nabla_\nu \sigma \sim a^{-4}(\eta) h^0_{\eta\eta}(k) \partial_\eta \delta\sigma \partial_\eta \delta\sigma$$

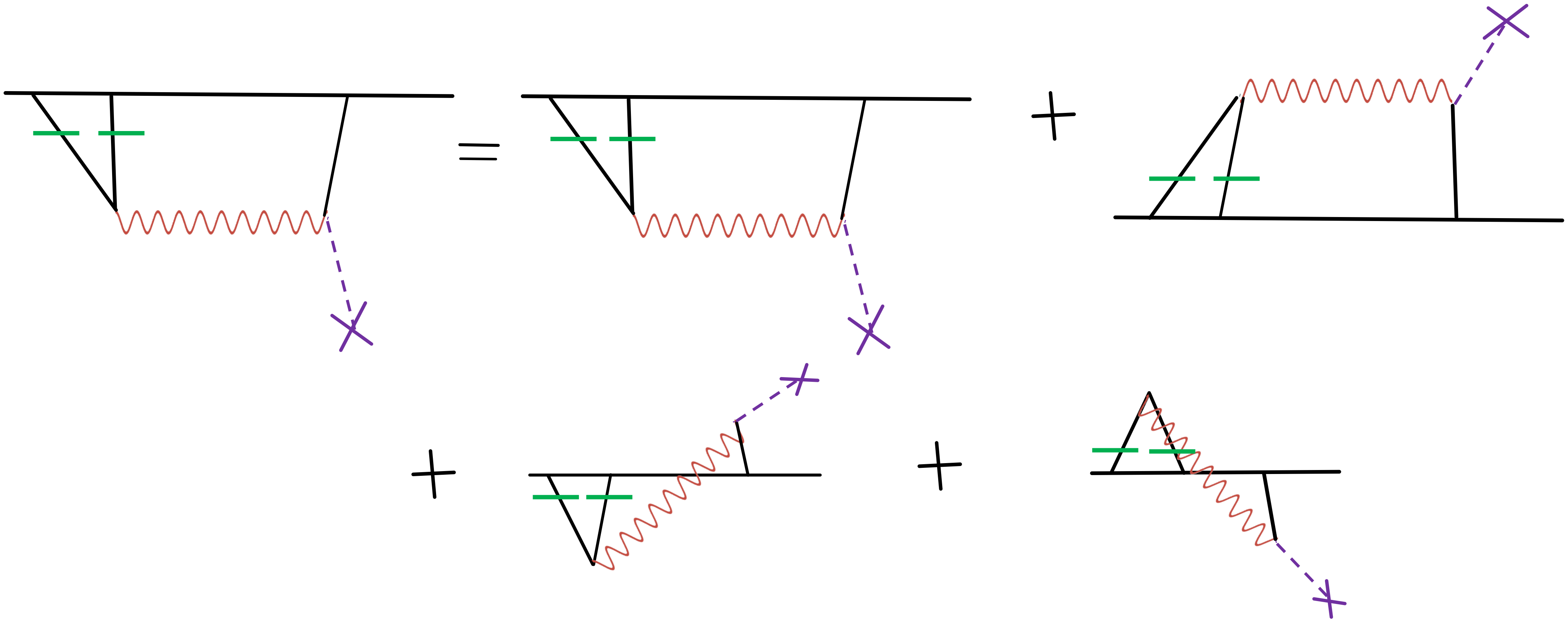
$$V \sim h^{\mu\nu} \nabla_\mu \sigma \nabla_\nu \sigma \sim a^{-2}(\eta) \dot{\bar{\sigma}} \delta\sigma h^0_{\eta\eta}(k)$$

(Arkani-Hamed & Maldacena, 2015)

Cosmological Collider (example):

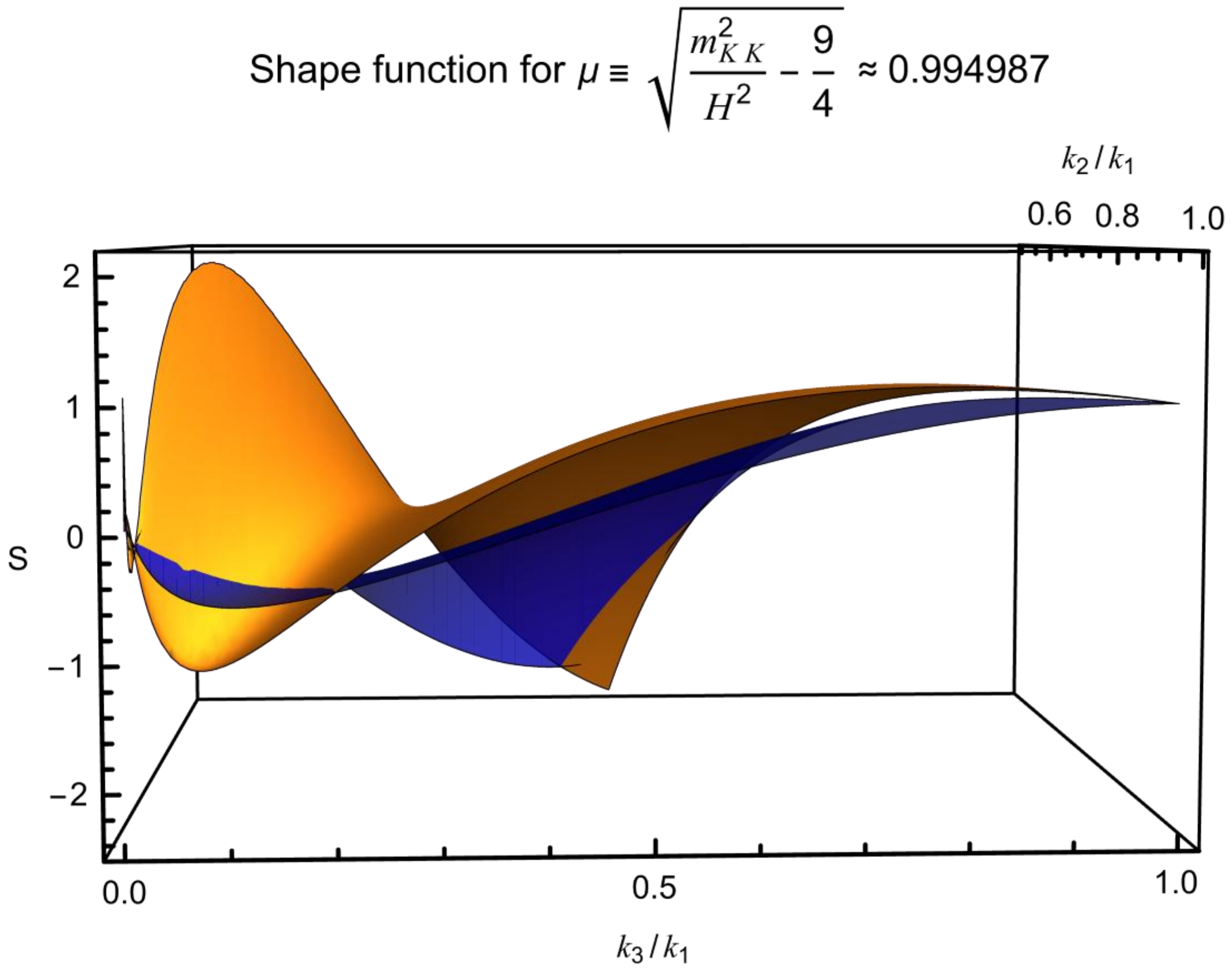
$$V \sim h^{\mu\nu}\nabla_\mu\sigma\nabla_\nu\sigma \sim a^{-4}(\eta)h^0_{\eta\eta}(k)\partial_\eta\delta\sigma\partial_\eta\delta\sigma \qquad V \sim h^{\mu\nu}\nabla_\mu\sigma\nabla_\nu\sigma \sim a^{-2}(\eta)\dot{\bar{\sigma}}\delta\sigma h^0_{\eta\eta}(k)$$

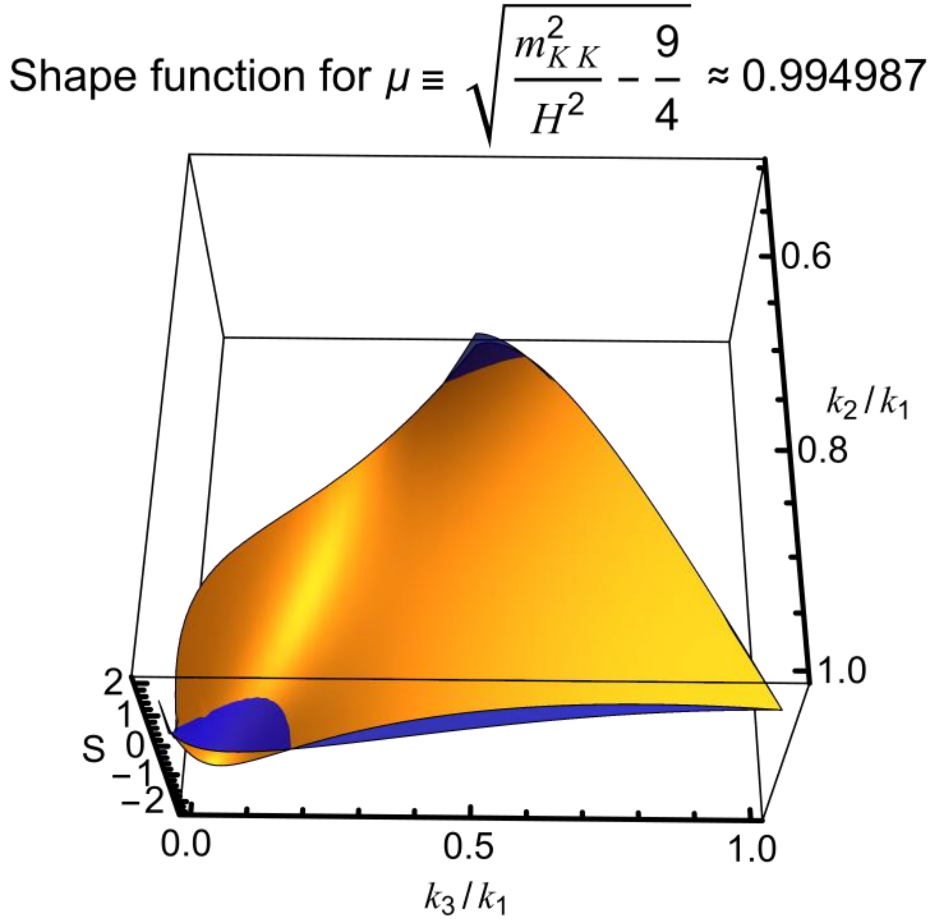
$$\langle\sigma_1\sigma_2\sigma_3\rangle \sim (ia)(ib)\dot{\bar{\sigma}}\int_\infty^0 d\eta_1 d\eta_2\, \partial_{\eta_1}G_a(k_1,\eta_1)\partial_{\eta_1}G_a(k_2,\eta_2)D_{ab}(k_3;\eta_1,\eta_2)\, G_b(k_3,\eta_2)\eta^{-2}$$



(Lee, Baumann, and Pimentel, 2015)

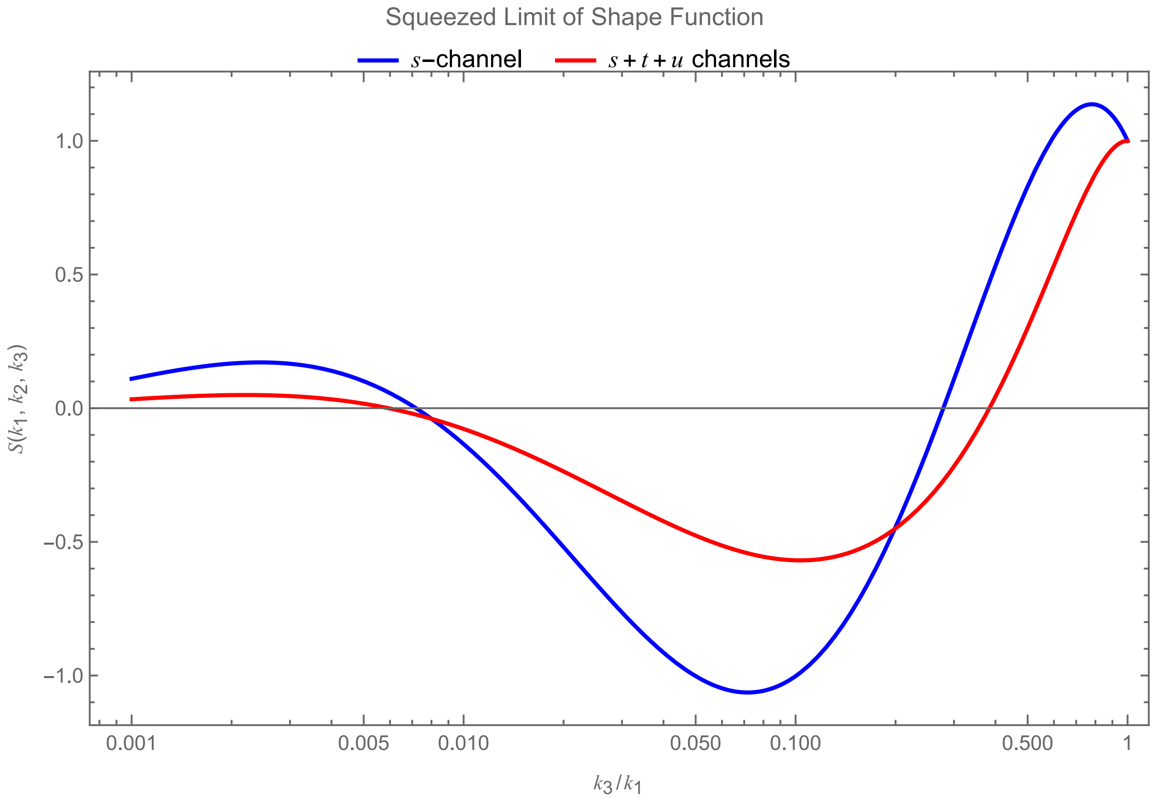
Results: Shape function

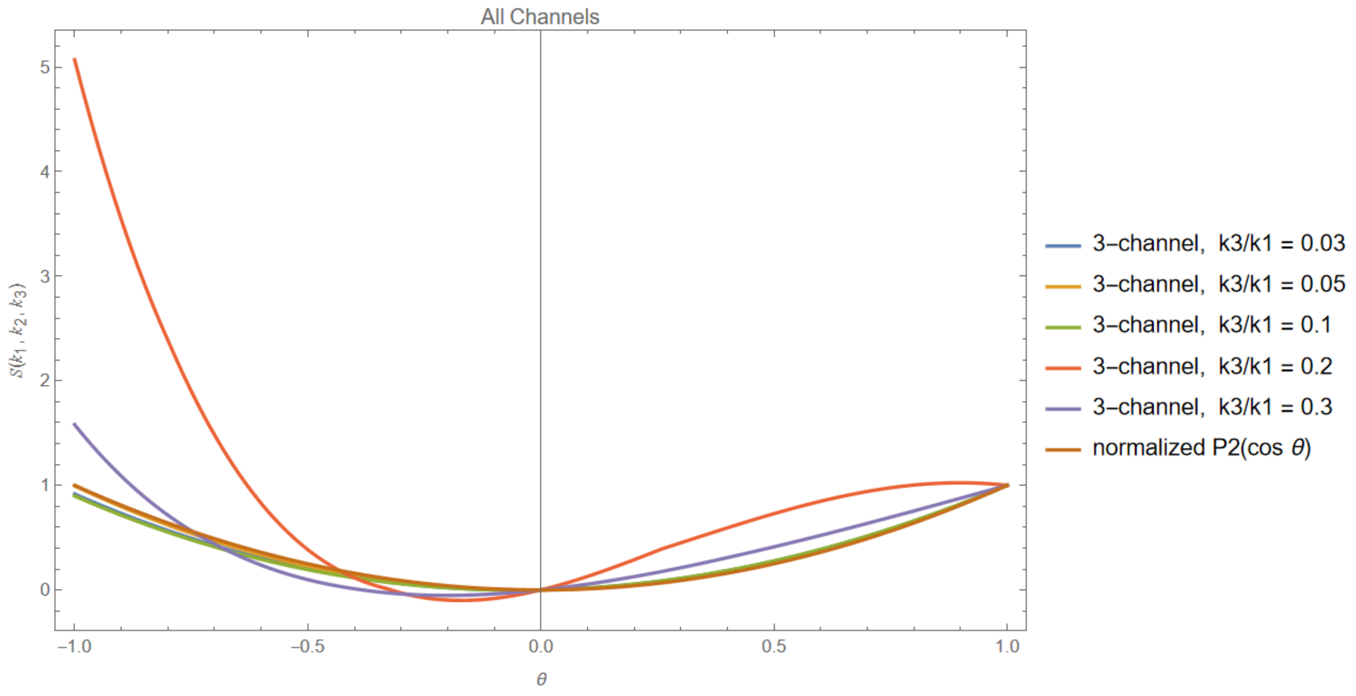




$$f_{NL} \approx -179.109 \pm 102.47$$

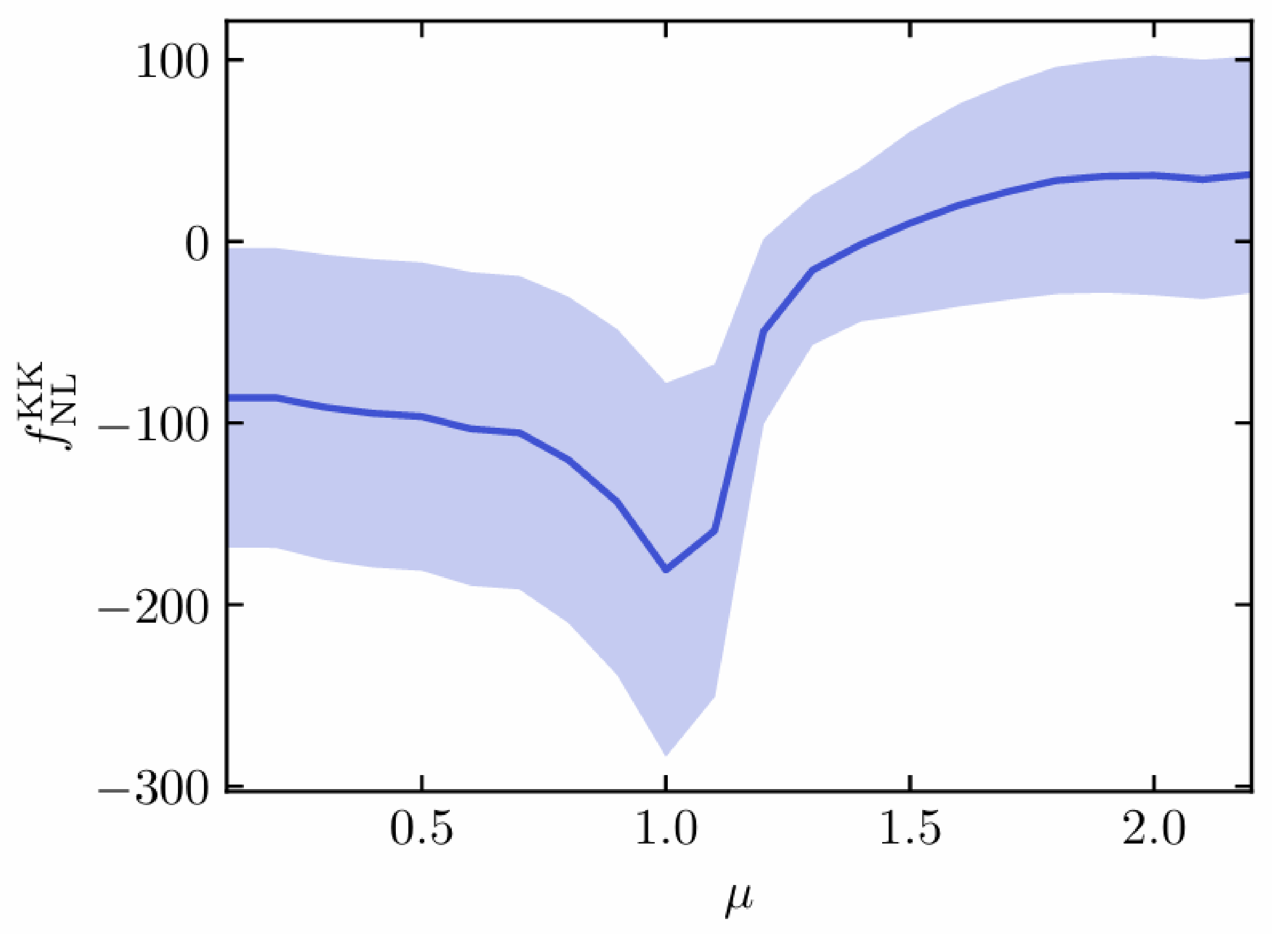
Results: Squeezed limit and Angular Dependence





$$f_{NL} \approx -179.109 \pm 102.47$$

Different masses?



- There is a 1.8 σ (local) preference for $\mu \approx 1$.
- Could we generate this?

(Kumar, Lu, Xianyu, Zhang, 2026)

Conclusions:

- We used an RS-model during inflation to make predictions

but…

- Need to use the cosmological collider to probe such predictions

Which could be seen by Planck:

- Were we found mild *local* detection, but nothing conclusive.
- Not shown: difference(!) between EFT of Inflation and our work and comments on bootstrap approach (in back-ups 😅).

- *Inclusion of chemical potentials??*
- *(Currently) computing the trispectrum…*
- *Resonance at 1-loop??*

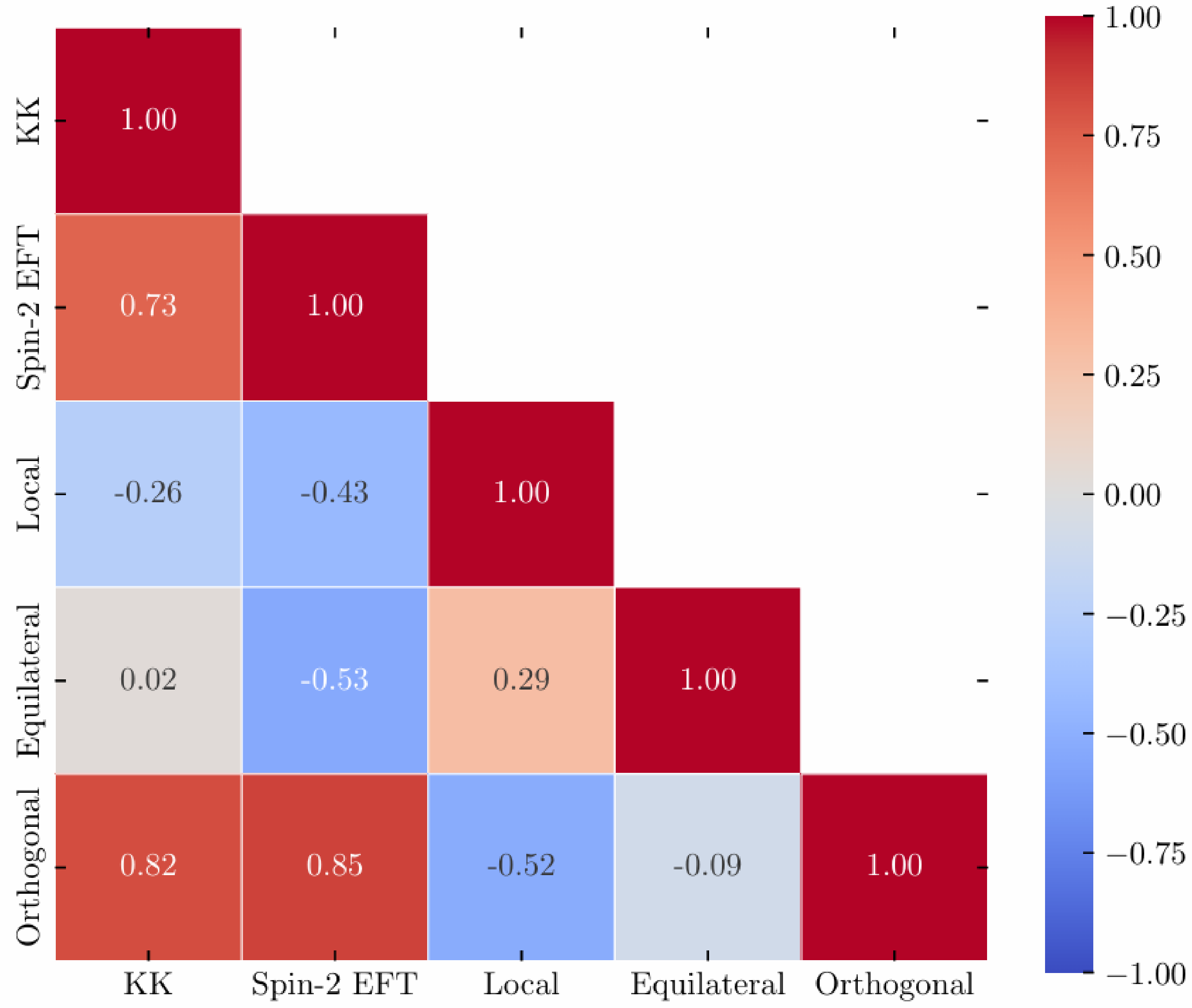
Thank you.

Special thanks to the Institute of Cosmology and to those in the institute for help and support!

Welcome to the back-up slides :D
(and extra “goodies”)

EFT of Inflation "tadpole" problem:

- We have *partial* overlap with the following shapes:

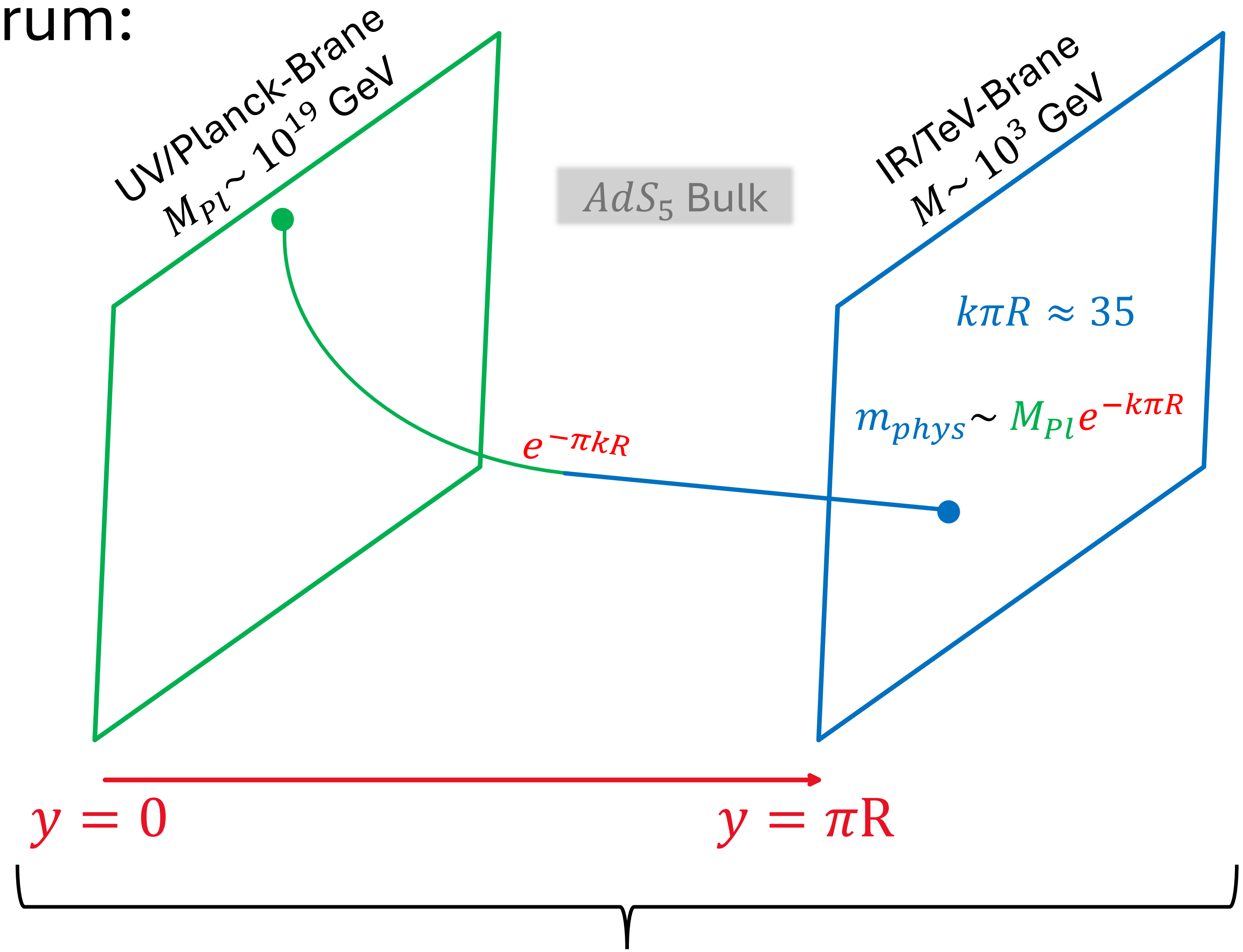


- Under EFT of Inflation:
  - the scalar operator $\phi g^{\mu\nu}\nabla_\mu\sigma\nabla_\nu\sigma$ has a tadpole that can be field re-defined away, and matches usual EFT expectations.
  - But for $h^{\mu\nu}\nabla_\mu\sigma\nabla_\nu\sigma$, it drops the tadpole, but discards the associated Goldstone interactions.
- Under usual EFT considerations:
  - Impose $g\dot{\bar{\sigma}}^2\delta_\mu^0\delta_\nu^0 + J_{\mu\nu}^c \sim 0$

(Weinberg, 2008; Cheung, Creminelli, Fitzpatrick, Kaplan, and Senatore, 2007)

5D Geometries:

- Randall-Sundrum:



$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^{\mu}dx^{\nu} + dy^2$$

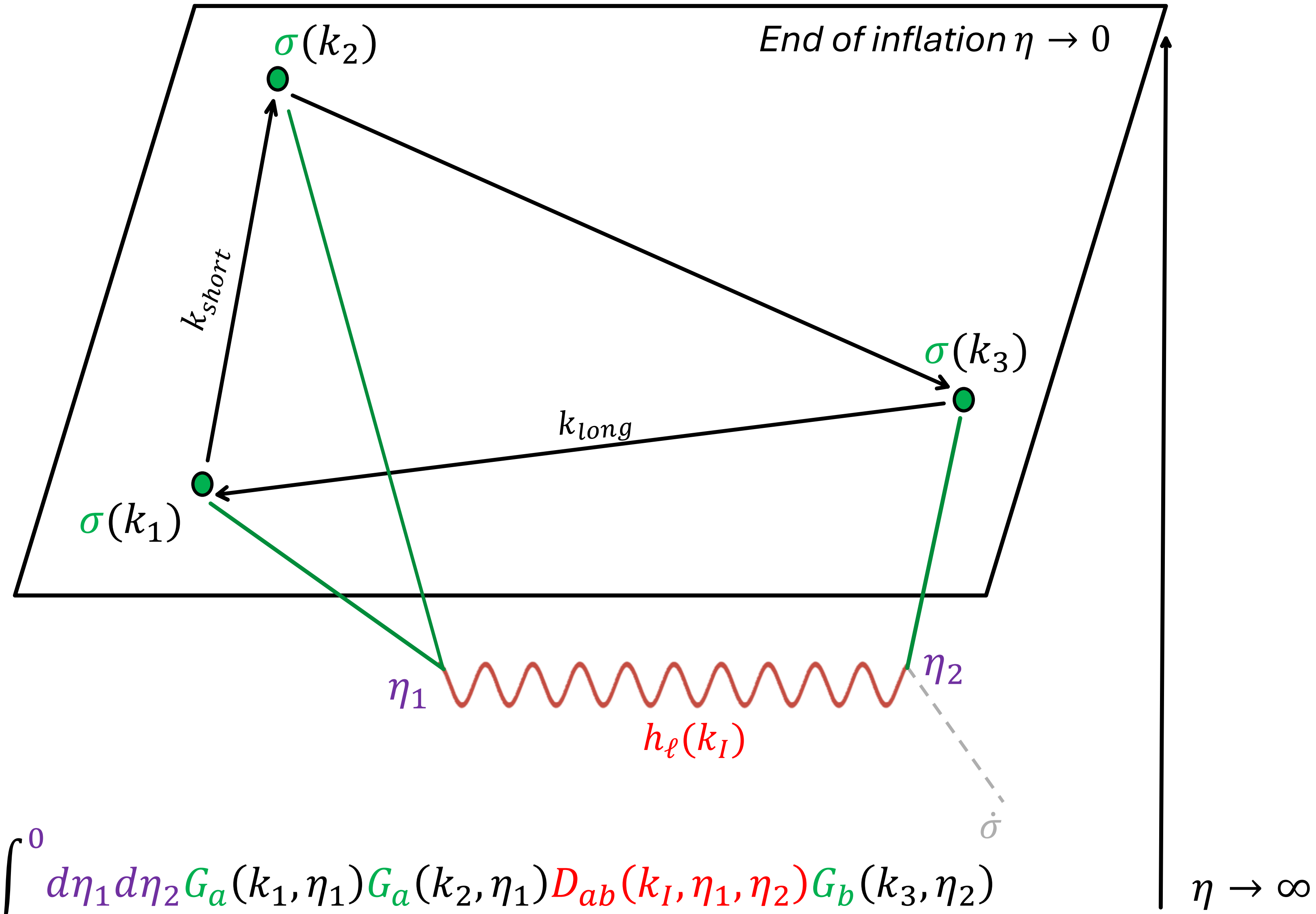
(Randall, Sundrum, 1999)

5D Geometries (dS_4-slice) Holographic dual:

5D warped AdS (orbifold) with UV/IR branes ↔ 4D large-N CFT with a UV cutoff and IR confinement

5D AdS Side	4D CFT Side
UV Brane	UV cutoff/elementary sector
IR Brane	Confinement scale Λ
IR-localized fields	Composite CFT bound states
Radion	Dilaton/pseudo-dilaton
KK-gravitons	Spin-2 glueballs
GW stabilization	Deformation triggering confinement

Cosmological Collider:



$$\langle \sigma_1 \sigma_2 \sigma_3 \rangle = \frac{\dot{\sigma} g^2}{M_4^2} P(k) \int_\infty^0 d\eta_1 d\eta_2 G_a(k_1, \eta_1) G_a(k_2, \eta_1) D_{ab}(k_I, \eta_1, \eta_2) G_b(k_3, \eta_2)$$

(Arkani-Hamed & Maldacena, 2015)

Schwinger-Keldysh propagators:

$$D_{++}(\eta_1, \eta_2, k) = f_k(\eta_1)\bar{f}_k(\eta_2)\theta(\eta_1 - \eta_2) + f_k(\eta_2)\bar{f}_k(\eta_1)\theta(\eta_2 - \eta_1)$$
$$D_{--}(\eta_1, \eta_2, k) = f_k(\eta_1)\bar{f}_k(\eta_2)\theta(\eta_2 - \eta_1) + f_k(\eta_2)\bar{f}_k(\eta_1)\theta(\eta_1 - \eta_2)$$
$$D_{+-}(\eta_1, \eta_2, k) = f_k(\eta_2)\bar{f}_k(\eta_1),$$
$$D_{-+}(\eta_1, \eta_2, k) = f_k(\eta_1)\bar{f}_k(\eta_2).$$

$$\tilde{h}_{\eta\eta,l} \equiv \tilde{h}_{0,l} = \mathcal{A}_2 N_2 z^{3/2} H^{(1)}_{i\mu_l}(z)$$
$$\tilde{h}_{1,l}(\eta, k) = -\frac{i}{2}\mathcal{A}_2 N_2 z^{1/2}\left(z\left(H^{(1)}_{i\mu_l+1}(z) - H^{(1)}_{i\mu_l-1}(z)\right) + H^{(1)}_{i\mu_l}(z)\right)$$
$$\tilde{h}_{2,l} = -\frac{1}{12\sqrt{z}}\mathcal{A}_2 N_2\left[6z\left((2 + i\mu_l)H^{(1)}_{i\mu_l+1}(z) - (2 - i\mu_l)H^{(1)}_{i\mu_l-1}(z)\right) + (9 - 8z^2)H^{(1)}_{i\mu_l}(z)\right]$$
$$G_{\mathrm{a}}(k, \eta) = \frac{H^2}{2k^3}(1 - i\mathrm{a}k\eta)\exp(i\mathrm{a}k\eta)$$

Note on bootstrapping:

$$\mathcal{I}_{ab}^{p_1p_2}(u_1,u_2) \equiv (-ab)k_s^{5+p_{12}} \int_{-\infty}^{0} \mathrm{d}\eta_1 \int_{-\infty}^{0} \mathrm{d}\eta_2 (-\eta_1)^{p_1}(-\eta_2)^{p_2} e^{iak_{12}\eta_1+ibk_{34}\eta_2} D_{ab}(\eta_1,\eta_2,k_s),$$

$$\mathcal{I}_{\pm\pm}^{p_1,p_2}(u,1) = \frac{\pm i e^{\mp i(p_1+p_2)\pi/2}}{2^{7/2+p_2}\pi^{1/2}} \frac{\Gamma(\frac{5}{2}+p_2-i\nu)\Gamma(\frac{5}{2}+p_2+i\nu)}{\Gamma(3+p_2)} \left(e^{\pi\nu}\mathcal{Y}_{\pm}^{p_1}(u) + e^{-\pi\nu}\mathcal{Y}_{\mp}^{p_1}(u)\right)$$
$$+ \frac{e^{\mp i(p_1+p_2)\pi/2}\Gamma(5+p_1+p_2)\, u^{5+p_1+p_2}}{2^{5+p_1+p_2}\left[\left(\frac{5}{2}+p_2\right)^2+\nu^2\right]} {}_3F_2\left[\begin{matrix}1,\ 3+p_2,\ 5+p_1+p_2\\ \frac{7}{2}+p_2-i\nu,\ \frac{7}{2}+p_2+i\nu\end{matrix}\middle| u\right], \tag{3.20}$$

$$\mathcal{I}_{\pm\mp}^{p_1,p_2}(u,1) = \frac{e^{\mp i(p_1-p_2)\pi/2}}{2^{7/2+p_2}\pi^{1/2}} \frac{\Gamma(\frac{5}{2}+p_2-i\nu)\Gamma(\frac{5}{2}+p_2+i\nu)}{\Gamma(3+p_2)} \left(\mathcal{Y}_{+}^{p_1}(u) + \mathcal{Y}_{-}^{p_1}(u)\right), \tag{3.21}$$

$$\mathcal{Y}_{\pm}^{p}(u) = 2^{\mp i\nu}\left(\frac{u}{2}\right)^{5/2+p\pm i\nu} \Gamma(5/2+p\pm i\nu)\Gamma(\mp i\nu)\,{}_2F_1\left[\begin{matrix}\frac{5}{2}+p\pm i\nu,\ \frac{1}{2}\pm i\nu\\ 1\pm 2i\nu\end{matrix}\middle| u\right], \tag{3.22}$$