Celestial Non-Gaussianities in the Energy Flux

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Various Non-Gaussianities

In Cosmology: 3-pt correlation of scalar/gravity wave fluctuation

$$\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \zeta_{\vec{k}_3} \rangle$$

[e.g. Maldacena, 2002; Babich, Creminelli, Zaldarriaga, 2004; …]

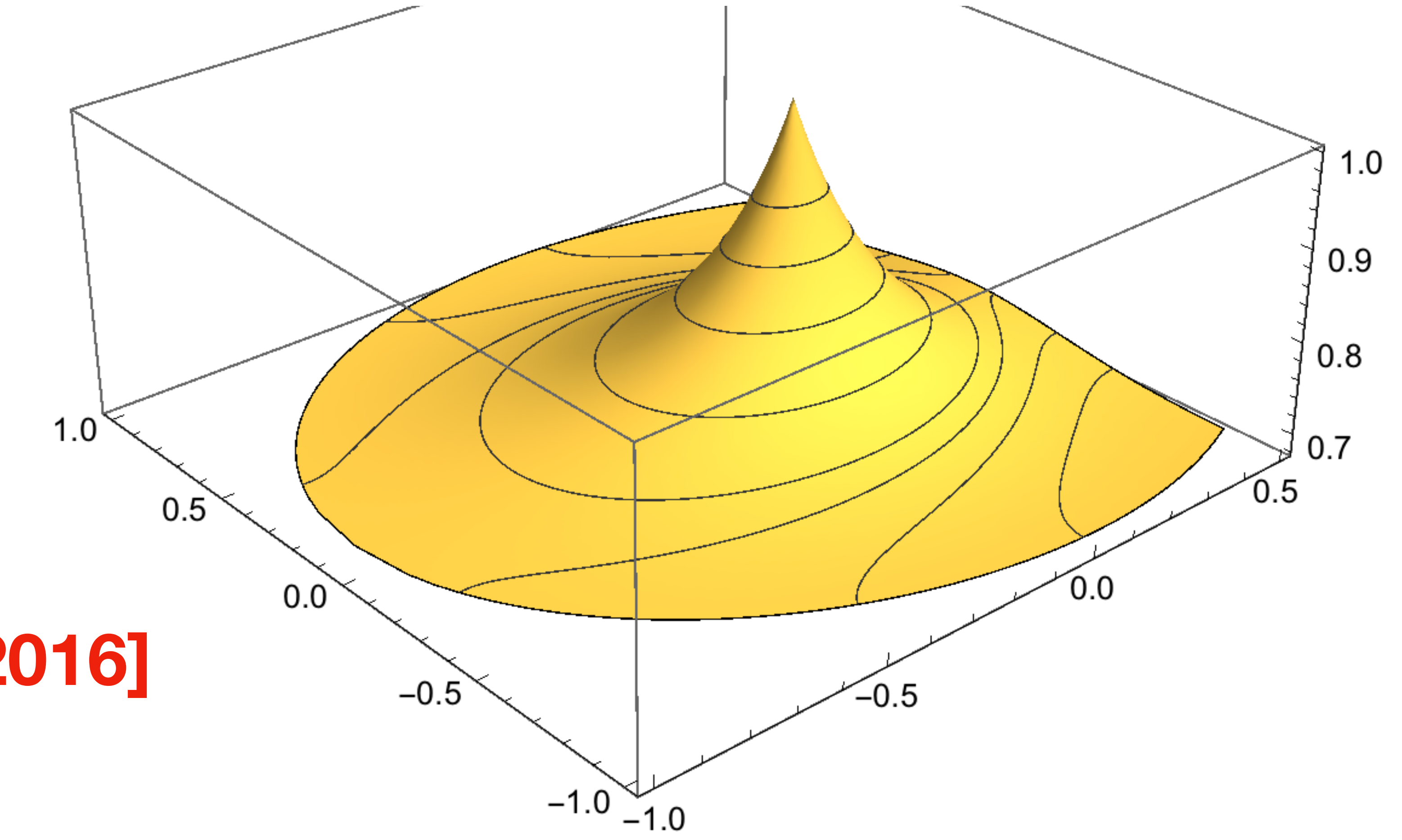
probes the non-gaussianity in the early universe
and distinguishes different inflation models

In CFT: deviation of 4-pt correlation from its “gaussian” counterpart

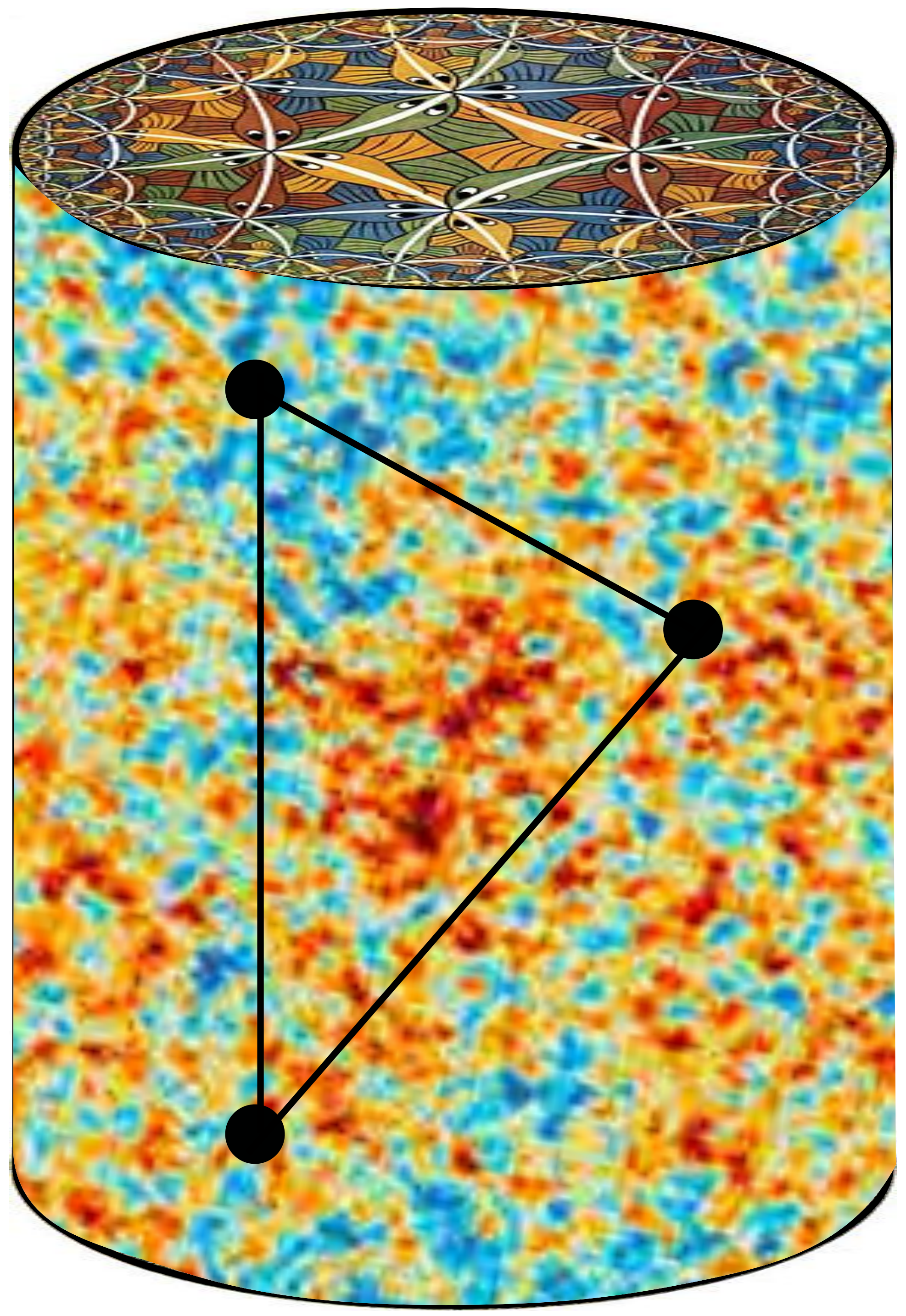
e.g. spin operators in Ising model

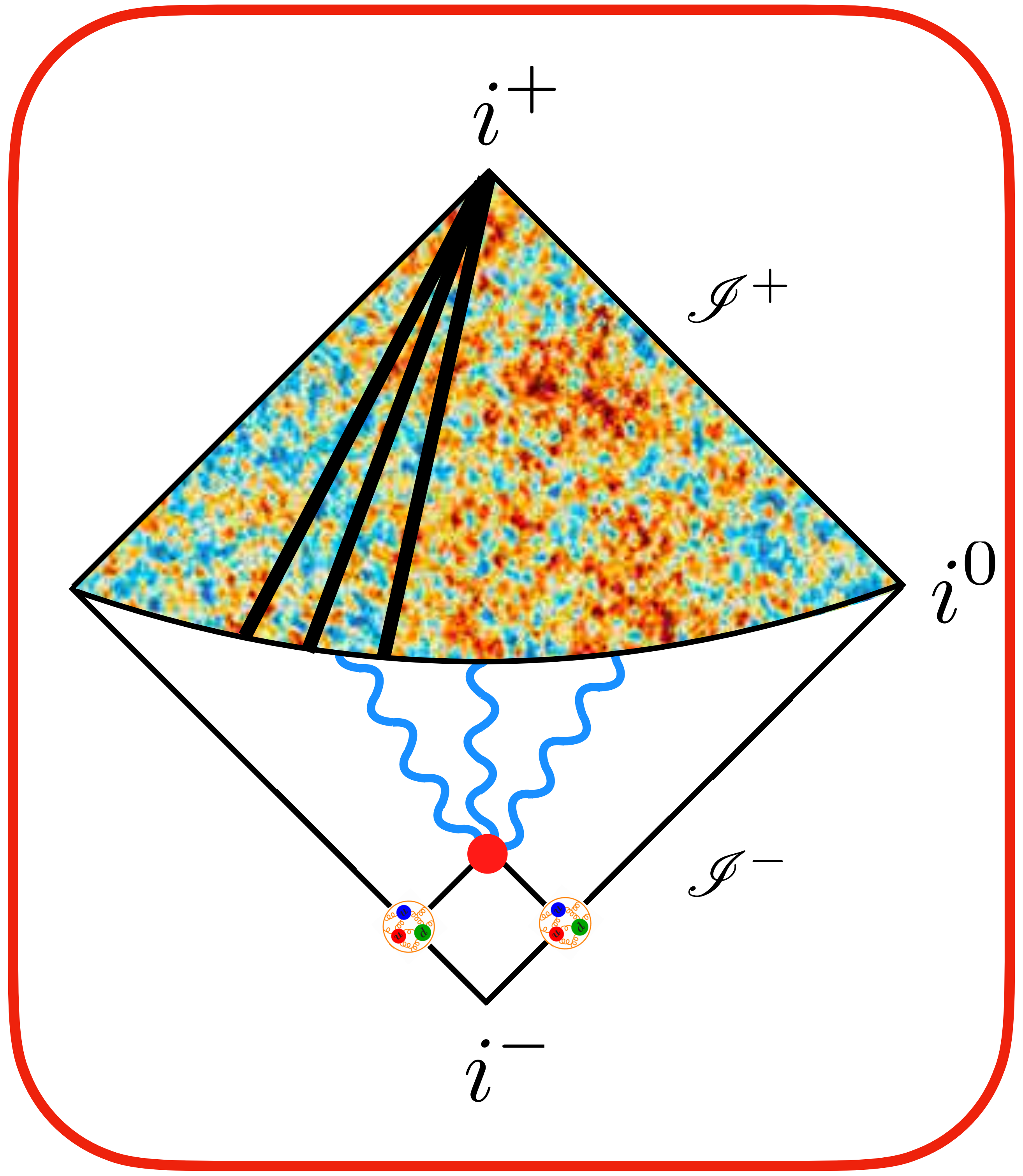
$$\frac{\langle \sigma_1 \sigma_2 \sigma_3 \sigma_4 \rangle}{\langle \sigma_1 \sigma_2 \rangle \langle \sigma_3 \sigma_4 \rangle + \langle \sigma_1 \sigma_3 \rangle \langle \sigma_2 \sigma_4 \rangle + \langle \sigma_1 \sigma_4 \rangle \langle \sigma_2 \sigma_3 \rangle}$$

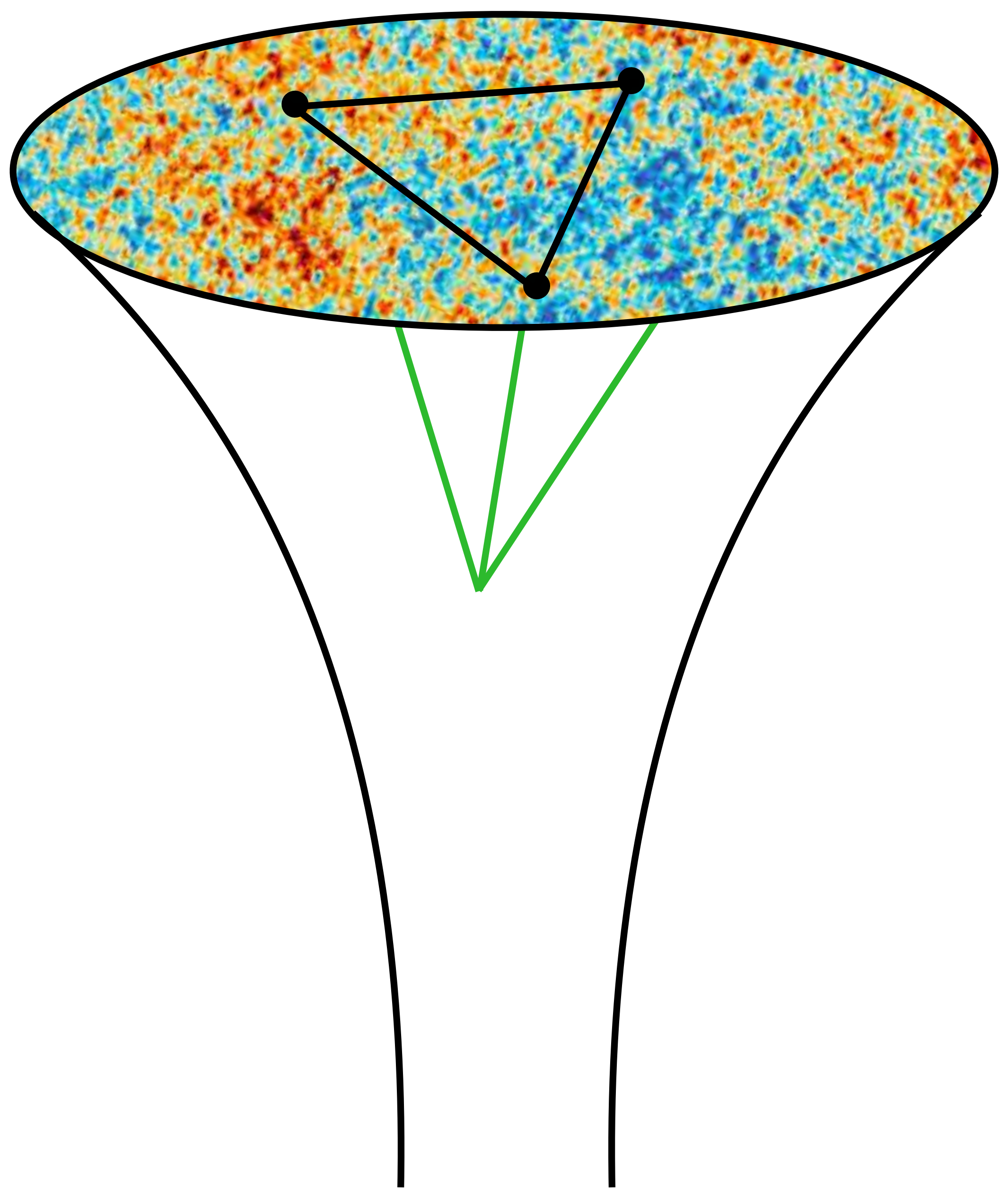
Critical 3D Ising Non-Gaussianity



[Rychkov, Simmons-Duffin, Zan, 2016]







Can we study similar concept in the flat space collider experiment?

→ Any basic building block, e.g. like spin correlation in the Ising model?

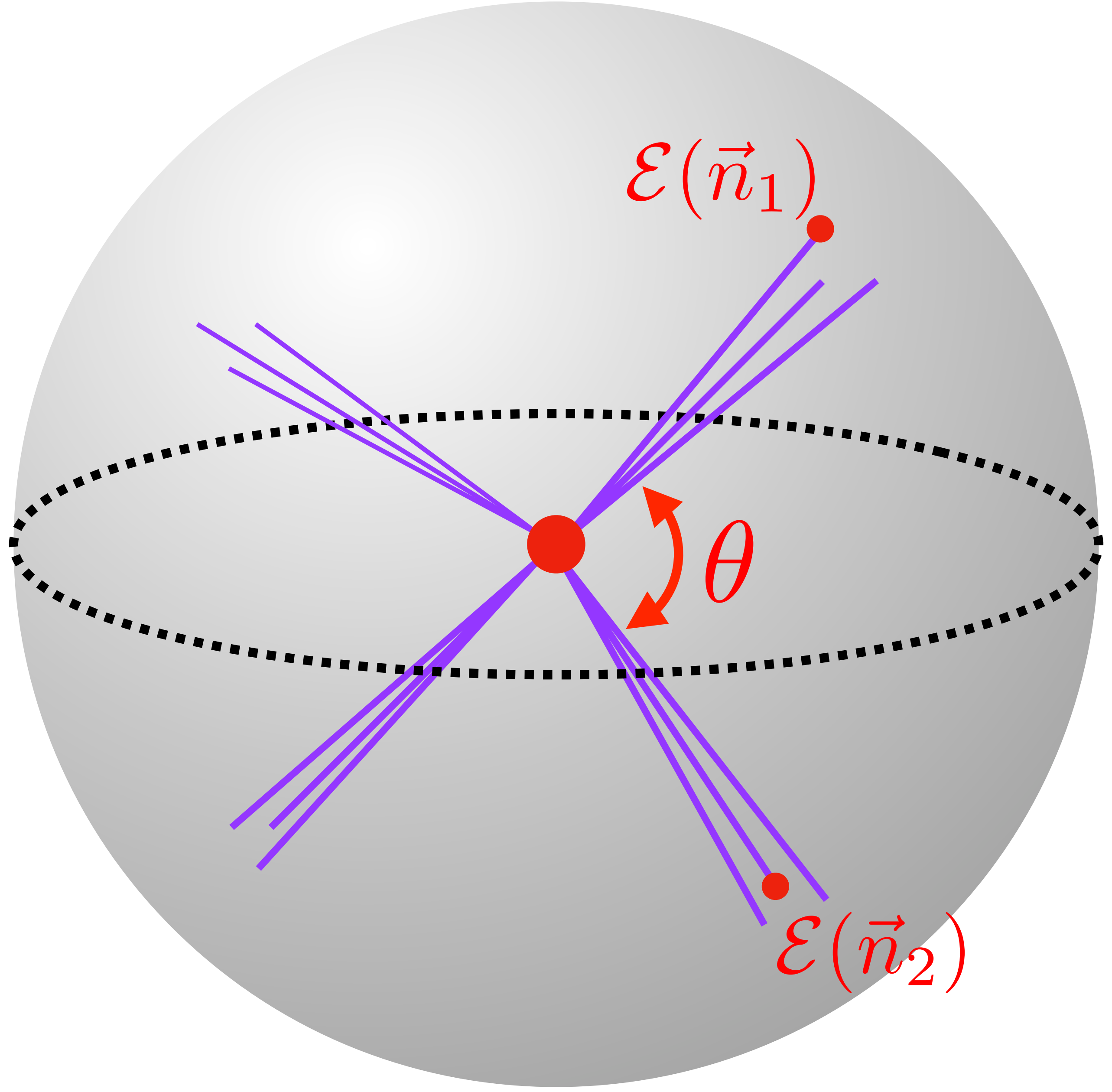
Energy-Energy Correlator (EEC)

[Basham, Brown, Ellis and Love, 1978] introduced energy-energy correlation

$$\frac{d\Sigma}{dz} = \sum_{i,j} \int d\sigma \frac{E_i E_j}{Q^2} \delta\left(z - \frac{1-\cos\theta_{ij}}{2}\right)$$

which characterizes the correlation of two energy detectors at spatial infinity (celestial sphere).

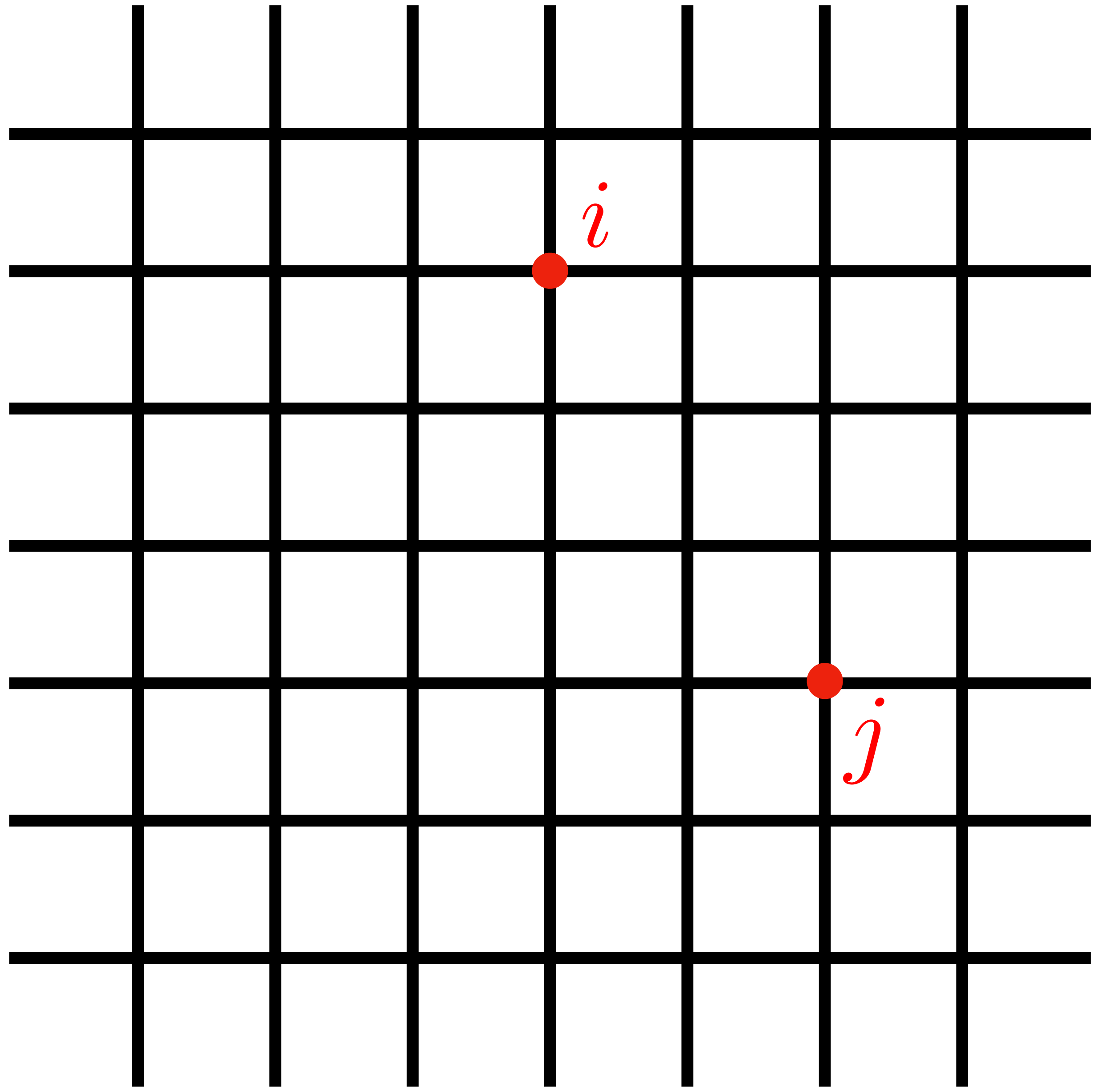
Energy Correlation on the celestial sphere



Probability Distribution	
differential cross section $d\sigma$	Boltzmann factor $e^{-\beta H}$

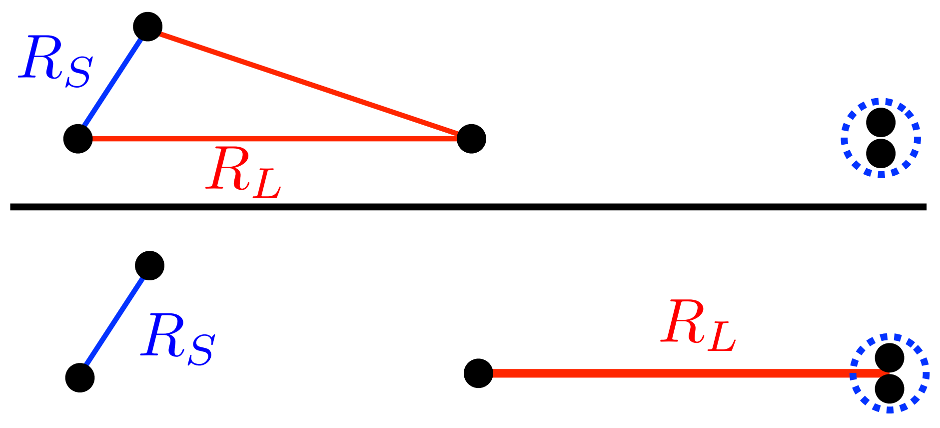
Weighting Factor	
eigenvalues of energy	eigenvalues of spin

Spin Correlation on the plane (2D Ising)

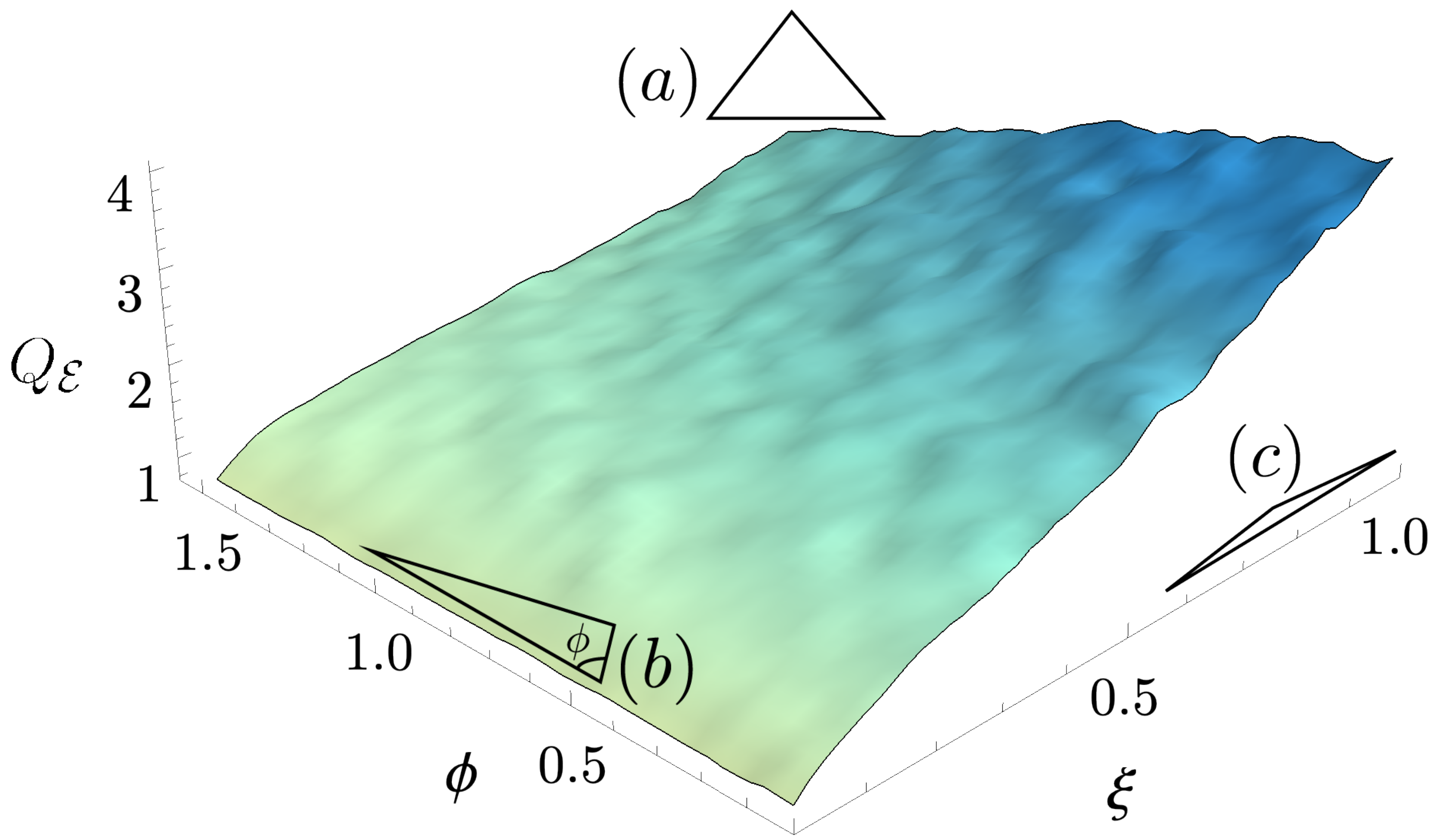


Outline

- construction of celestial non-gaussianities from EECs



- properties/shapes of celestial non-gaussianities
- celestial non-gaussianities with CMS open data
- conclusion



Construction

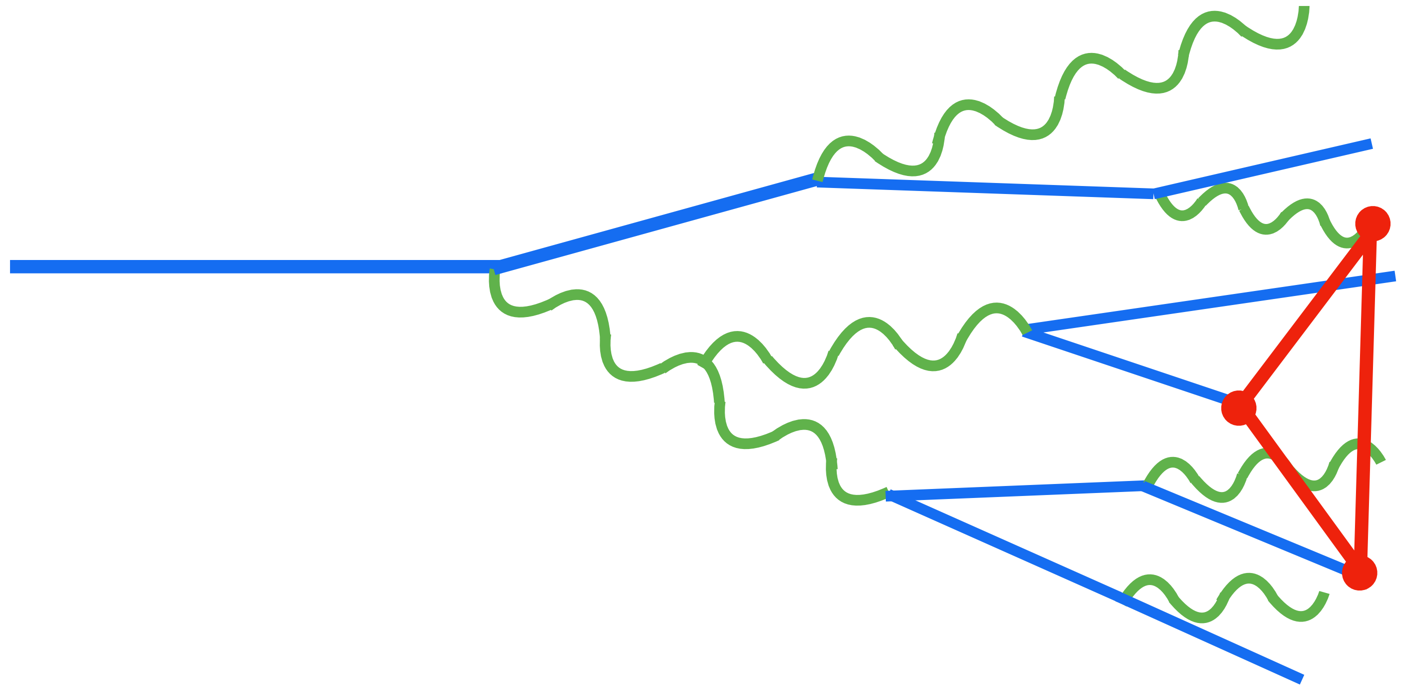
Numerator — EEEC

Kinematics of Collinear EEEC

Non-trivial shape dependence starts from 3 point in the collinear limit.

↓

shape of the triangle for collinear EEEC



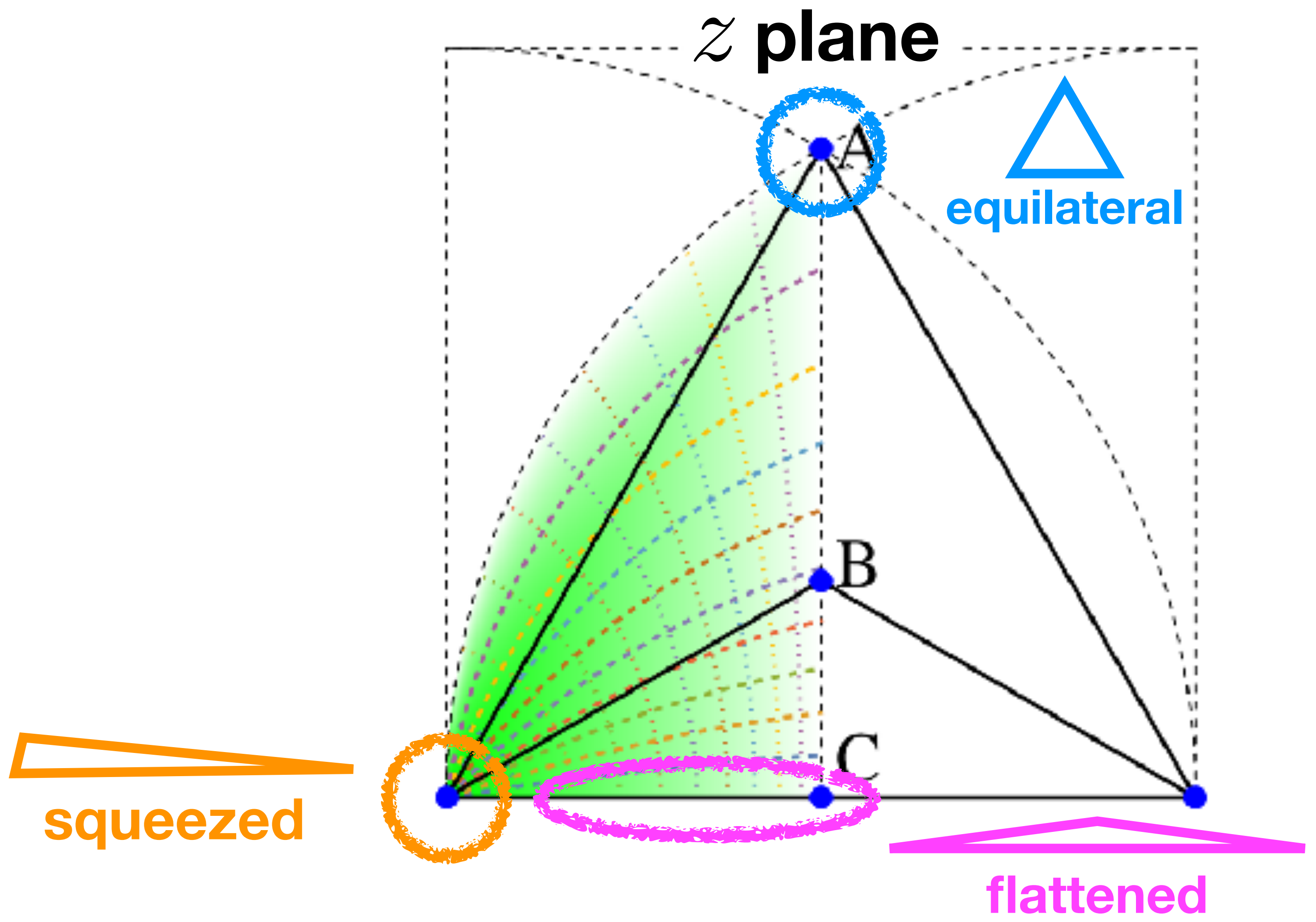
Different parameterizations:

refers to opening angles between calorimeters

(1) 3 ordered lengths $R_S < R_M < R_L$

(2) the longest length R_L and a complex number z [shape]

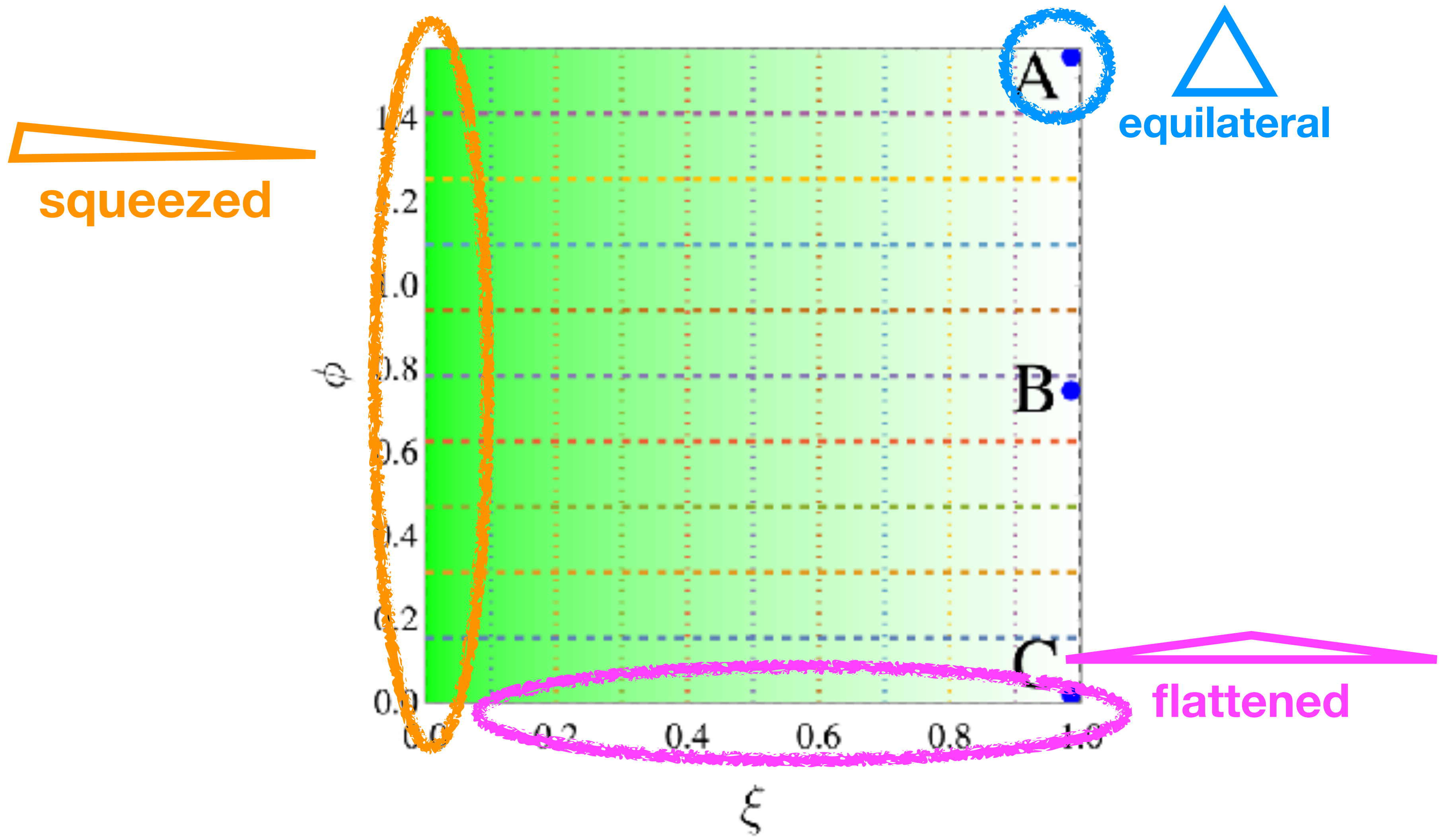
(3) coordinate change $z \to (\xi, \phi)$ [Komiske, Moult, Thaler, Zhu, 2022]



map to a square

$$\xi = |z|/|1-z|$$

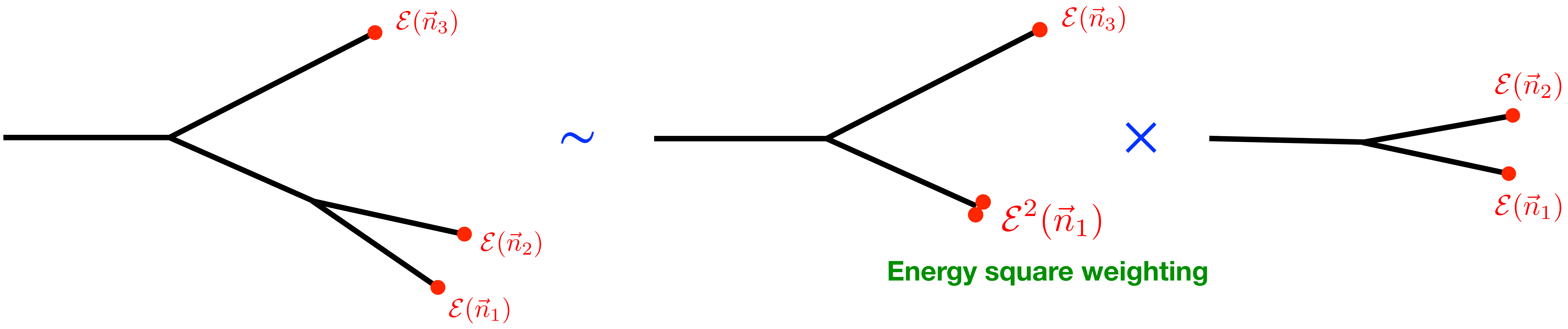
$$\phi = \arcsin\sqrt{1 - \frac{(1-|1-z|)^2}{|z|^2}}$$



Factorization of EEEC

Perturbative EEEC has divergence in the squeezed limit.

The schematic leading power factorization is



Such a factorization is also called light-ray OPE (at leading twist).

[Hofman, Maldacena, 2008; Kologlu, Kravchuk, Simmons-Duffin, Zhiboedov, 2019; HC, Moult, Zhu, 2020; Chang, Kologlu, Kravchuk, Simmons-Duffin, Zhiboedov, 2020]

Construction

Denominators

Choosing Denominators

One Aim: construct a ratio that is free of divergence

Hint from intuitive factorization in the squeezed limit:

$$\langle \mathcal{E}(\vec{n}_1)\mathcal{E}(\vec{n}_2)\mathcal{E}(\vec{n}_3)\rangle \sim \langle \mathcal{E}(\vec{n}_1)\mathcal{E}(\vec{n}_2)\rangle \, \langle \mathcal{E}^2(\vec{n}_1)\mathcal{E}(\vec{n}_3)\rangle$$

$$\mathrm{EEEC}(R_S, R_M, R_L) \sim \mathrm{EEC}(R_S) \quad \mathrm{E^2EC}(R_L)$$

Abbreviation to manifest angles

However, double energy weighting is not IR safe. $(E_a + E_b)^2 \neq E_a^2 + E_b^2$

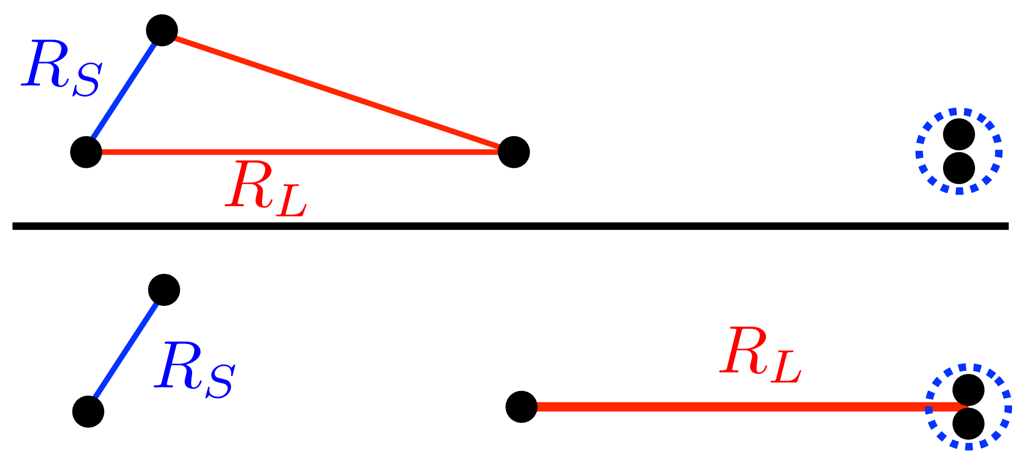
We try to remedy this by dividing another IR unsafe numerical factor

$$\langle \mathcal{E}(\vec{n}_1)\mathcal{E}(\vec{n}_2)\rangle \, \langle \mathcal{E}^2(\vec{n}_1)\mathcal{E}(\vec{n}_3)\rangle / \langle \mathcal{E}^2 \rangle$$

The intuition is that during the late time evolution, particles moving along different directions are space-like separated, so we expect, as a good approximation, different detectors are independent at that stage.

Celestial Non-Gaussianities

Proposal 1: $Q_{\mathcal{E}} =$



$$= \frac{\langle \mathcal{E}(\vec{n}_1)\,\mathcal{E}(\vec{n}_2)\,\mathcal{E}(\vec{n}_3)\rangle \ \langle \mathcal{E}^2(\vec{n}_1)\rangle}{\langle \mathcal{E}(\vec{n}_1)\,\mathcal{E}(\vec{n}_2)\rangle \ \langle \mathcal{E}^2(\vec{n}_1)\,\mathcal{E}(\vec{n}_3)\rangle}$$

deviation from flatness may come from:

- higher twist effects
- quark/gluon mixing
- ...

Proposal 2: symmetric version $\widetilde{Q}_{\mathcal{E}}$

use denominator: $\underbrace{\mathrm{EEC}(R_S)\mathrm{E}^2\mathrm{EC}(R_L)}_{\text{used in asymmetric one}} + \underbrace{\mathrm{EEC}(R_S)\mathrm{E}^2\mathrm{EC}(R_M) + \mathrm{EEC}(R_M)\mathrm{E}^2\mathrm{EC}(R_L)}_{\text{additional 2 permutations}}$

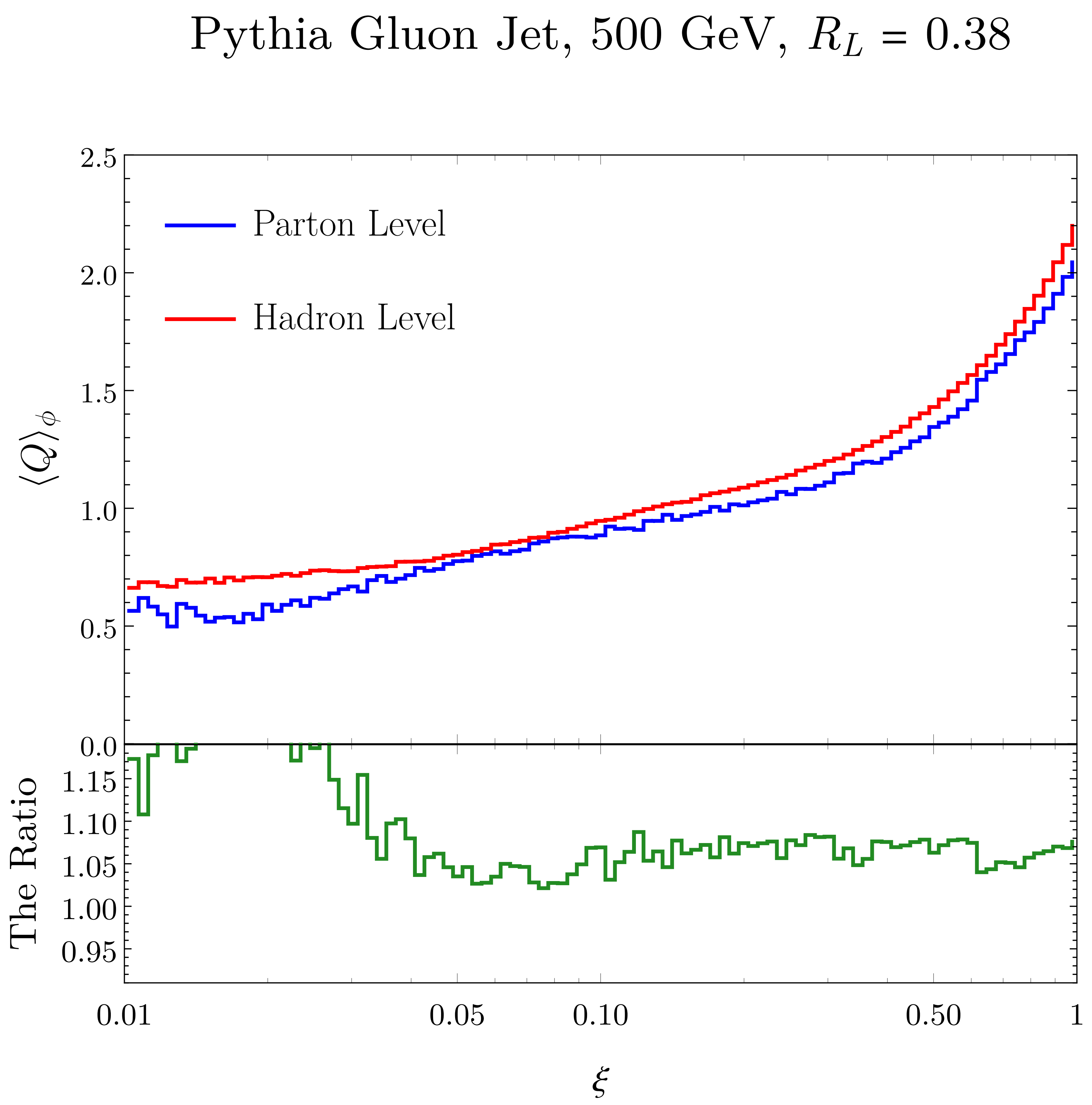
used in asymmetric one — **additional 2 permutations**

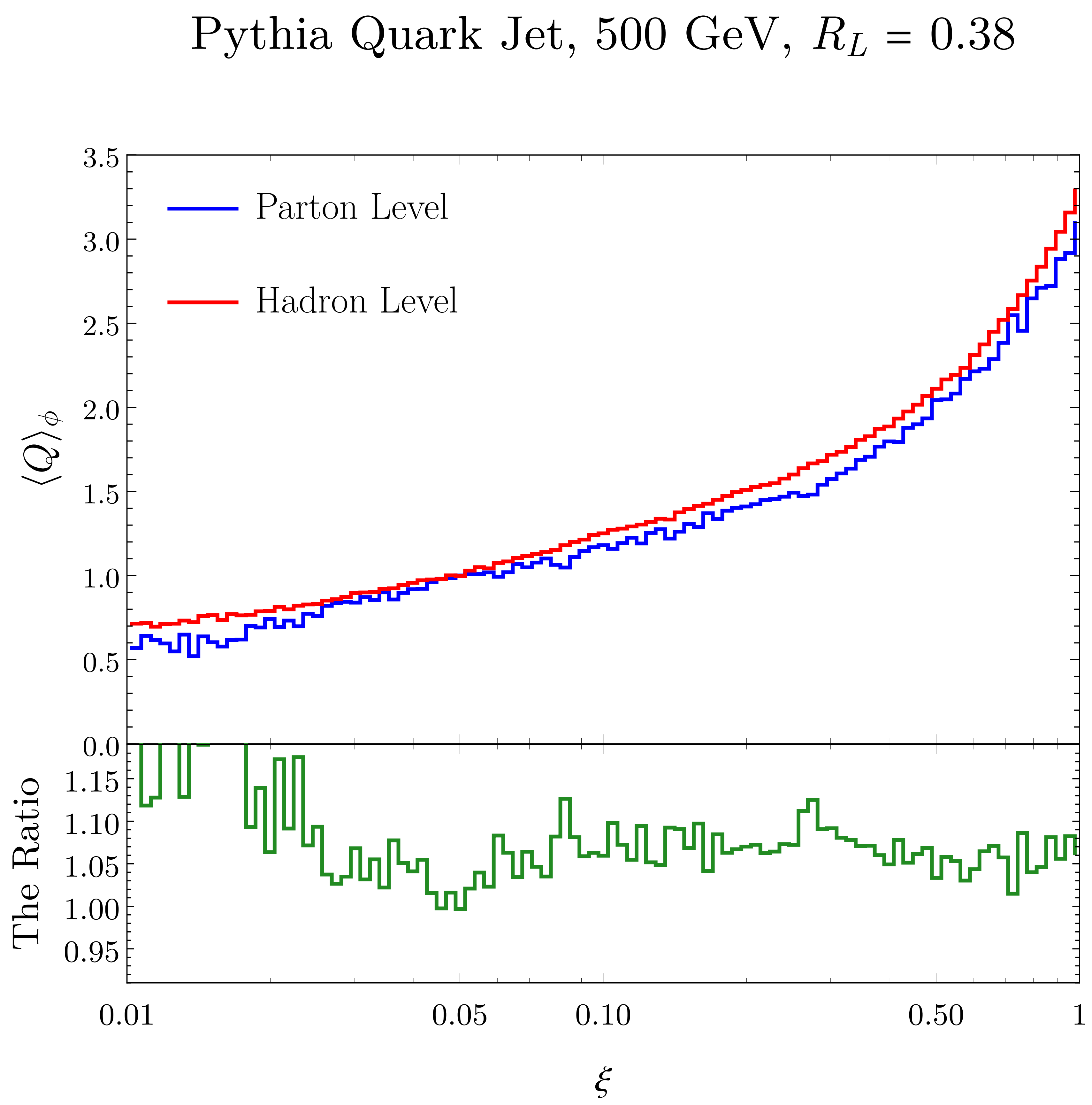
We will mainly focus on the first proposal in this talk for its simpler denominator.

Properties

Hadronization Effects

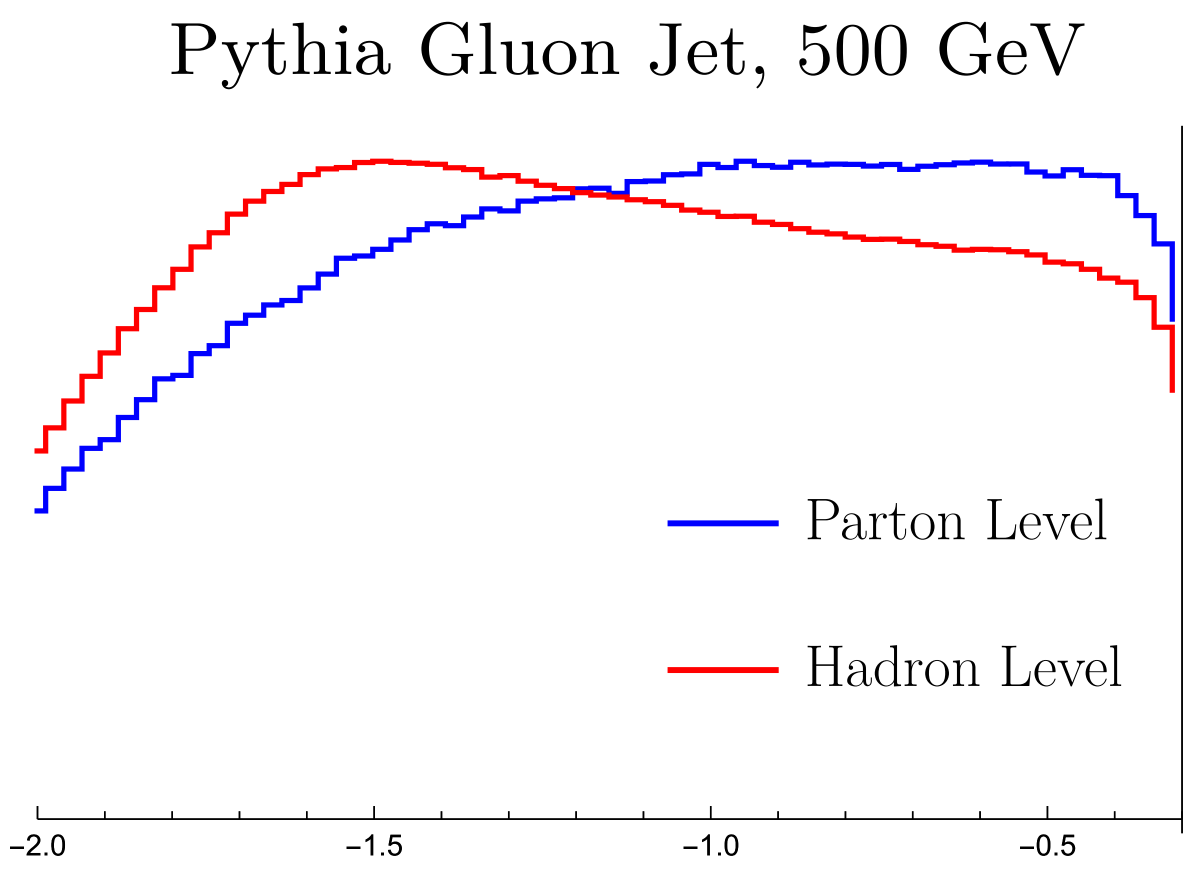
We find hadronization effects are greatly reduced using Pythia simulation.





Here, we have averaged over ϕ and kept only ξ dependence.

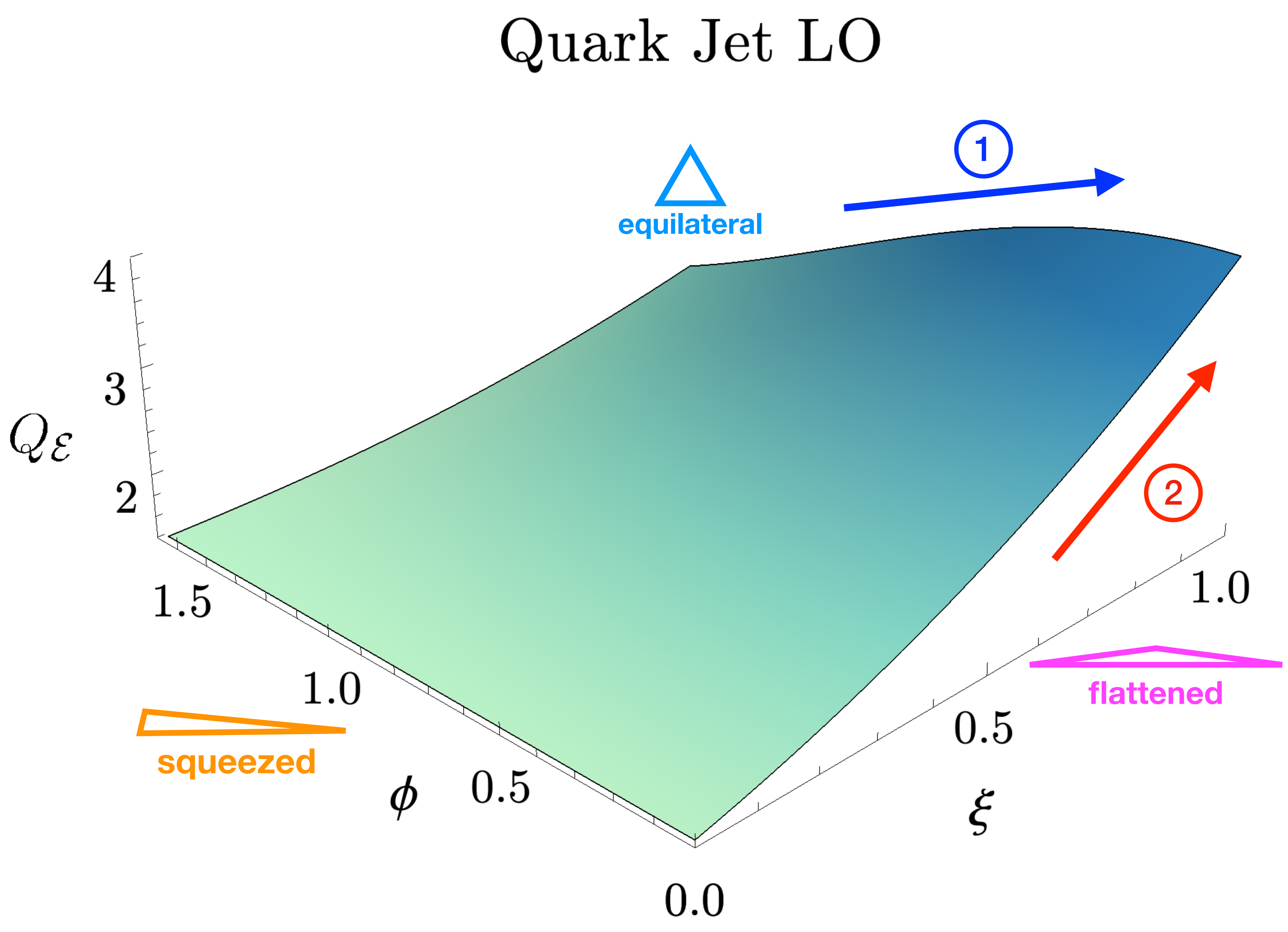
This is not the case even for the IR safe observable **EEC** in the collinear limit.



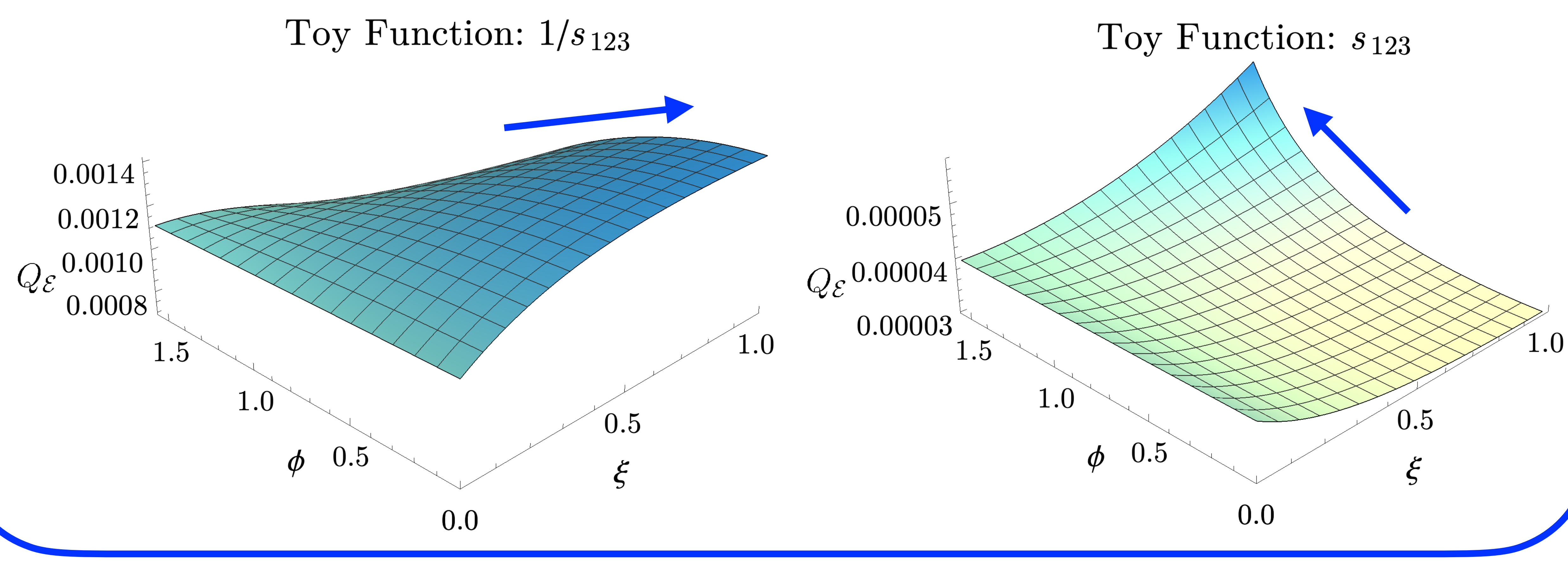
The relative normalization is not trustable in this plot.

Shape

The shape peaks at the flattened region. Here we use LO result to illustrate.

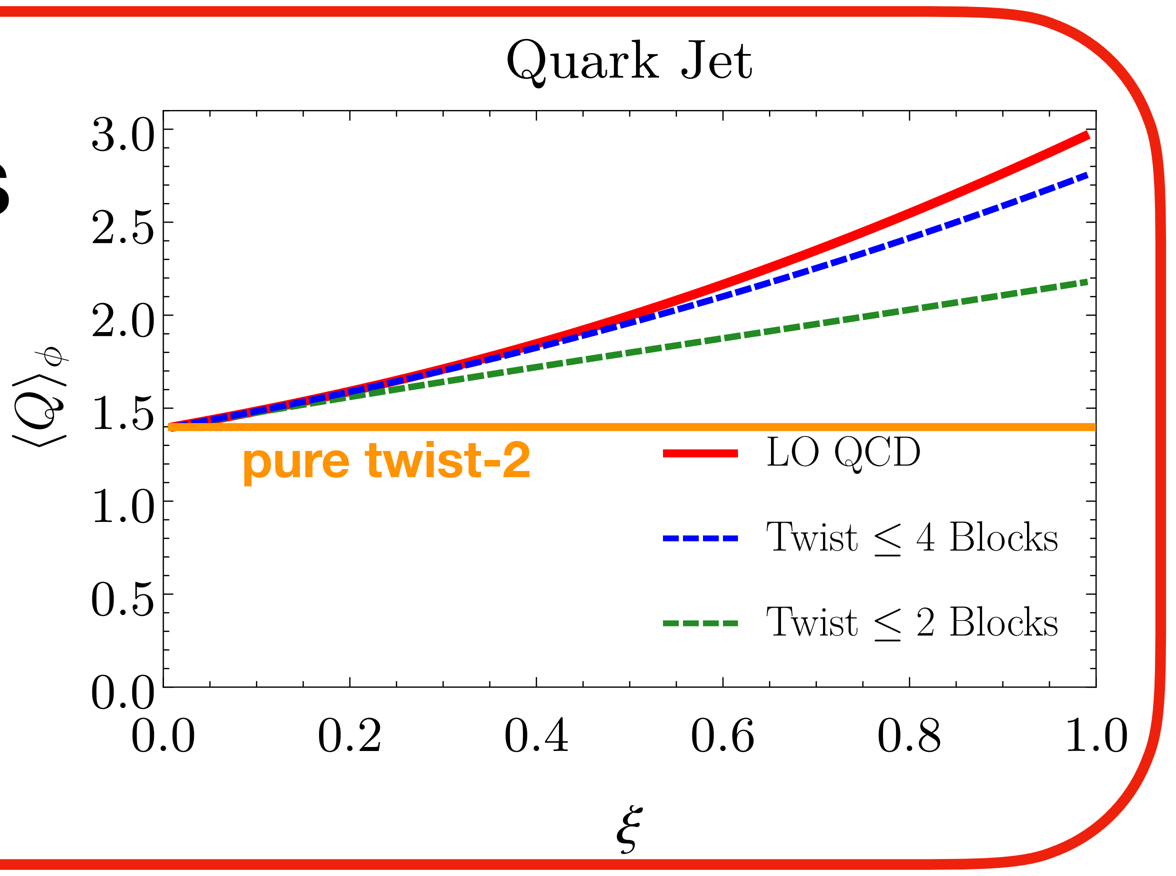


① signal of perturbative 1-particle propagator $\frac{1}{s_{123}^{n=1,2}}$



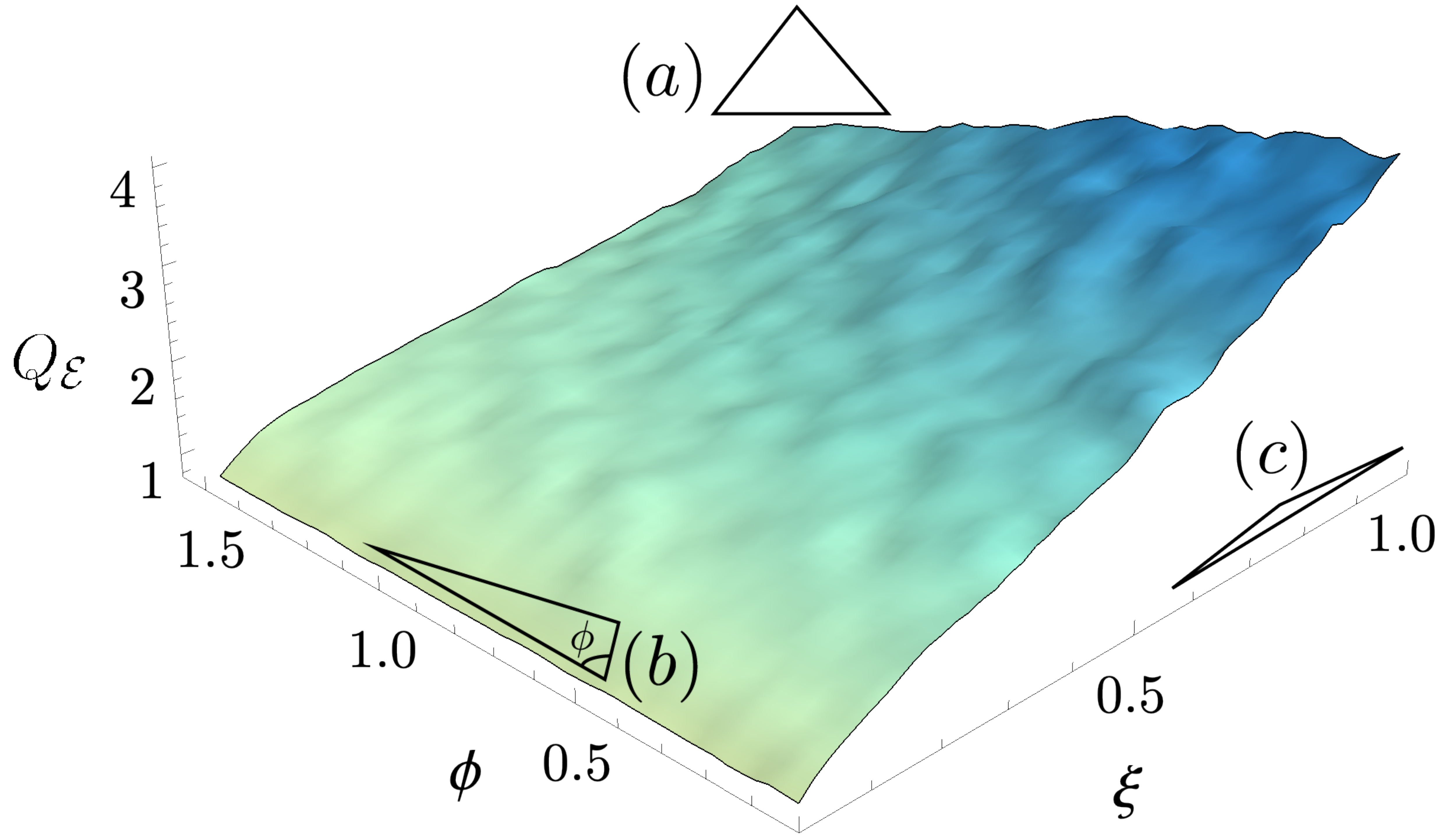
② higher twists contributions

[twist-2 descendants
+ higher twists blocks]

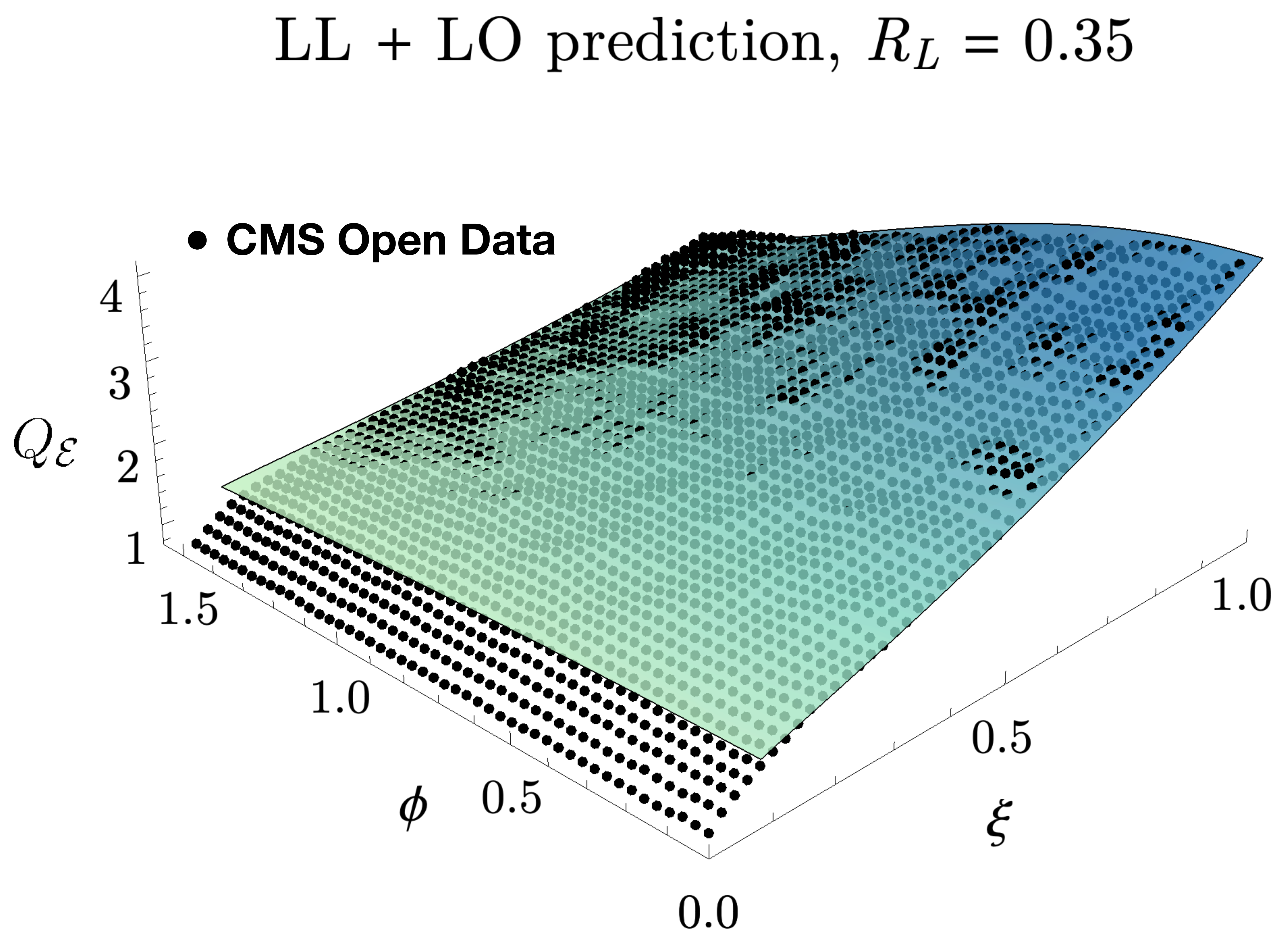


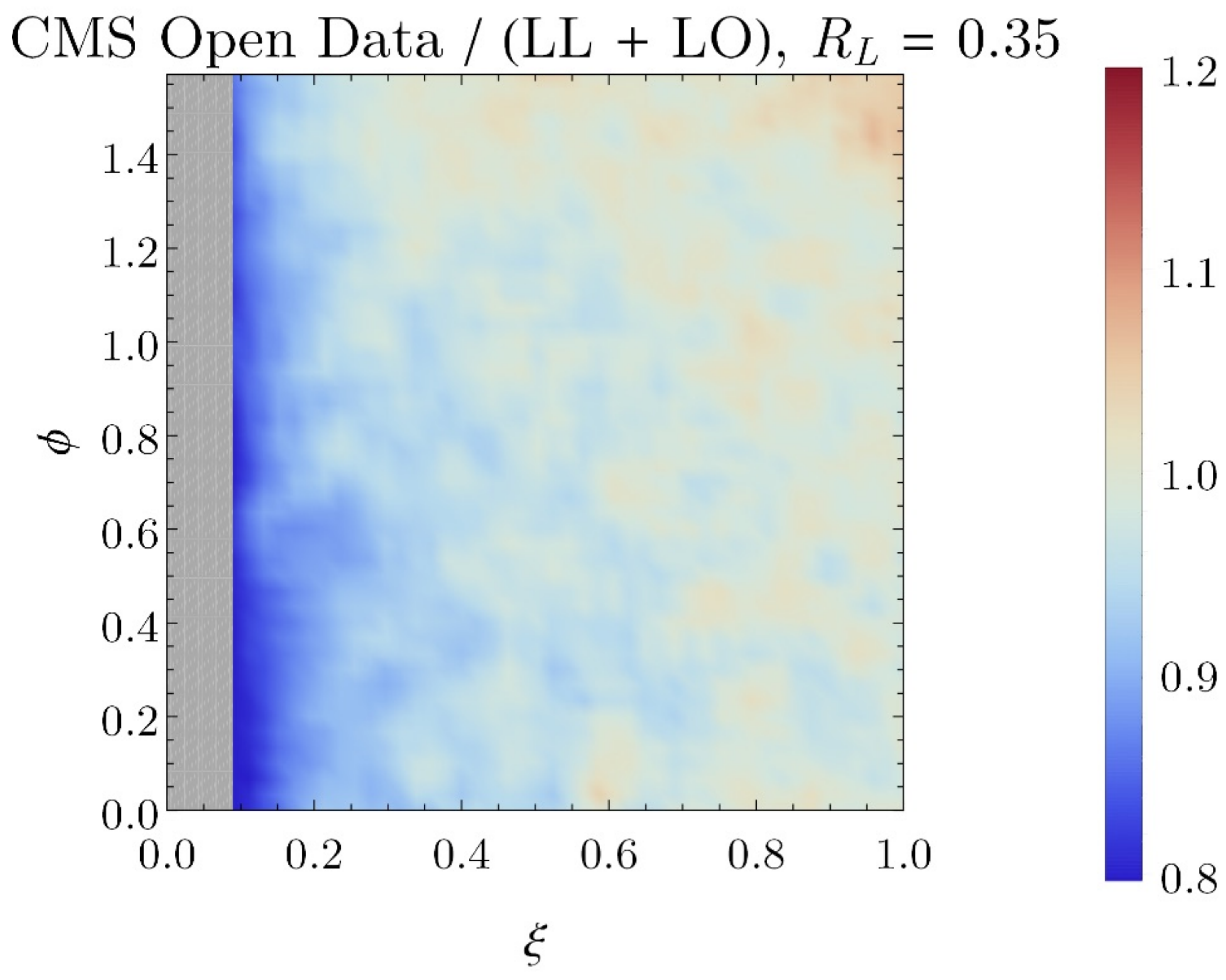
Celestial Non-Gaussianities in CMS Open Data

- CMS has released a sample of high quality data for public use.
- Packaged in "MIT Open Data", provided by Jesse Thaler and Patrick Komiske.
- Celestial non-gaussianity from the CMS open data:



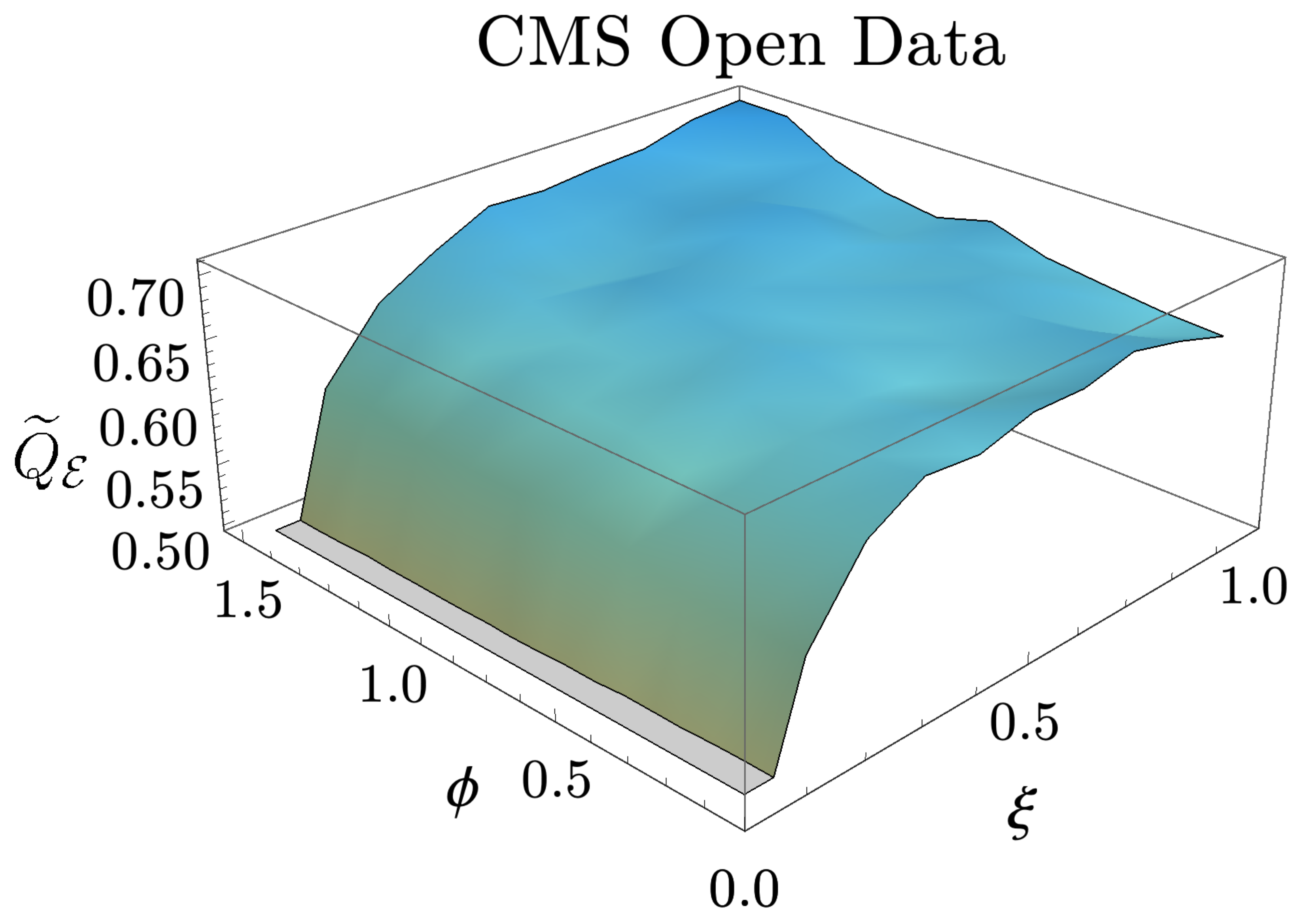
Comparing (LL + LO) with CMS Open Data



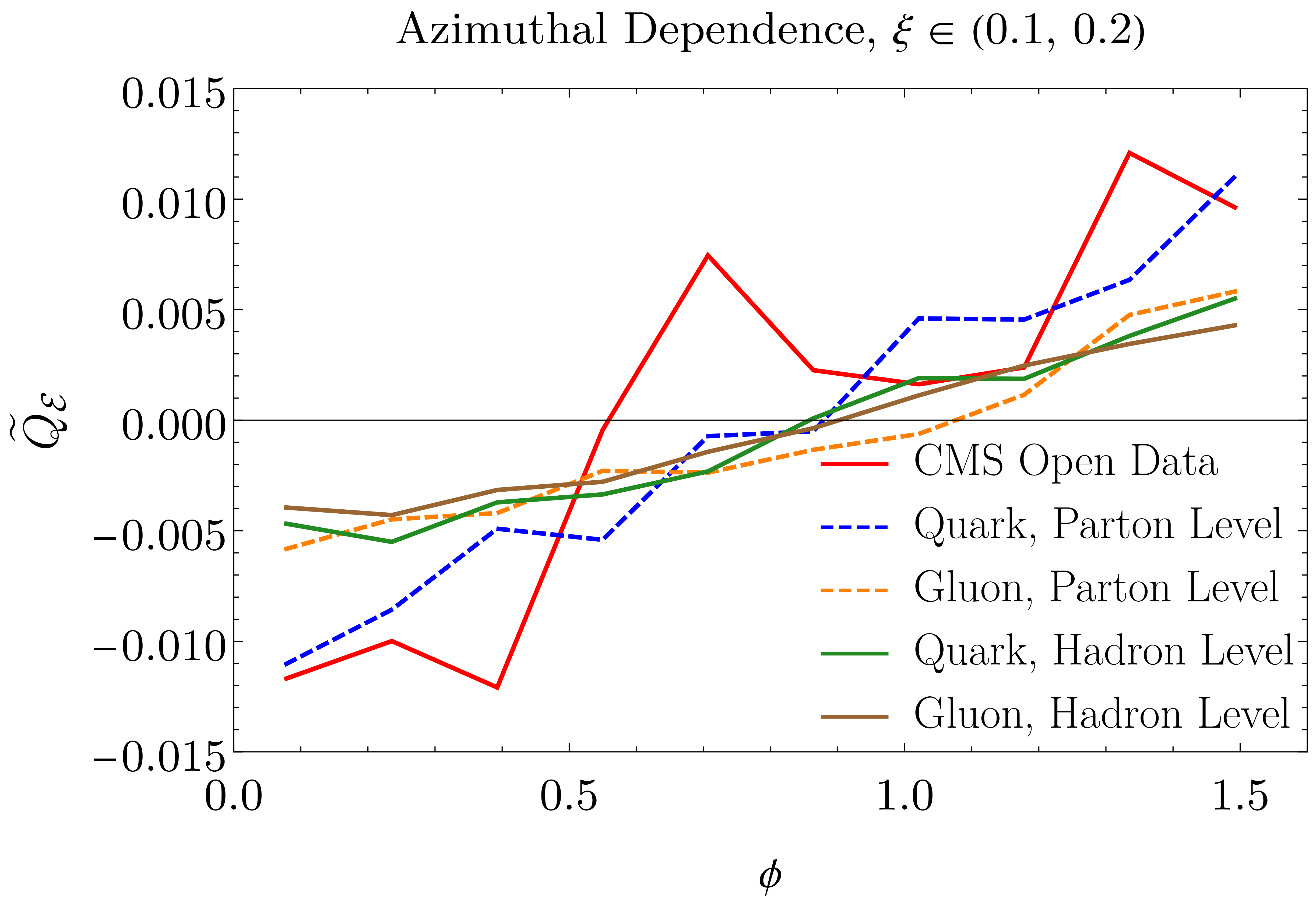


The (LL + LO) prediction is made under the 45% quark assumption.

Symmetric Version



Symmetric version is quite flat, which may be more sensitive to small effects in the 3 point correlation.



It seems there are larger spin correlation in CMS Open Data than that in Pythia simulation.

But this is a very preliminary exploration, we lack the understanding about it.

Conclusion

- We have introduced the concept of celestial non-gaussianities based on EECs.
- Celestial non-gaussianities are robust to hadronization effects.
- We found a good agreement between perturbative calculation and CMS Open Data, indicating that it might be helpful for exploring physics at high energy.
- We believe the symmetric version is worth of careful study, in particular for spin correlations.

Thanks !