

# **CERN - Nordic Lattice Meeting**

## **Report of Contributions**

Contribution ID: 1

Type: **not specified**

## Gradient flow as a renormalization tool.

*Tuesday, 3 June 2025 09:30 (30 minutes)*

The Gradient Flow is a smoothing technique that has been studied for its properties in the field of renormalization. In combination with the short flow-time expansion, it provides a renormalization scheme in which hadronic matrix elements on the lattice evolve along the flow time, gradually removing UV divergences. In this renormalization scheme, some of lattice challenges—such as mixing with lower dimensions operators are either avoided or shifted to the perturbative matching part of the procedure.

I will first introduce the Gradient Flow methodology and provide some insight to the small flow-time expansion. I will then present our approach for determining matrix elements of four-quark operators that describe neutral meson mixing and meson lifetimes. While meson mixing calculations are well-established on the lattice and serve as a validation of our procedure, a lattice determination of matrix elements for heavy meson lifetimes remains an open challenge. Preliminary results for mesons composed of a charm and strange quark are presented, along with prospects for extending the determination to B mesons.

**Author:** RAGO, Antonio (University of Southern Denmark (DK))

**Presenter:** RAGO, Antonio (University of Southern Denmark (DK))

Contribution ID: 2

Type: **not specified**

## Smoothing effect of gradient flow in QCD-like theories

*Monday, 2 June 2025 15:00 (30 minutes)*

Recent advances in algorithms and hardware have facilitated large-scale lattice studies of QCD-like theories, including the Corrigan-Ramond large-N limit of Yang-Mills coupled to a single fermion in the two-index antisymmetric representation, which provides a path to studying  $\mathcal{N} = 1$  SUSY Yang-Mills at large-N. In this talk, we explore the topological properties of gauge configurations generated for  $N_C = 4, 5, 6$ , where fractional topological charges could, in principle, arise. To test this, we combine a gluonic definition of the topological charge with gradient flow to suppress UV noise, comparing standard and over-improved flow actions to distinguish genuine topological features from lattice artifacts. Our results confirm the absence of fractional topological objects, indicating that such configurations are likely suppressed as the continuum limit is approached.

**Authors:** JÄGER, Benjamin; DELLA MORTE, Michele (University of Southern Denmark (DK)); BUTTI, Pietro (Quantum Field Theory Center IMADA); MARTINS, Sofie Antonia (University of Southern Denmark); TSANG, Tobias (CERN)

**Presenter:** BUTTI, Pietro (Quantum Field Theory Center IMADA)

Contribution ID: 3

Type: **not specified**

## Confined-deconfined interface tension and latent heat in SU(N) gauge theory

Wednesday, 4 June 2025 11:45 (30 minutes)

We present lattice results for the confined-deconfined interface tension and the latent heat of pure SU(N) gauge theory up to  $N=10$  (16) and investigate their asymptotic  $N$ -dependency. We determine the interface tension with the *mixed phase* or *interface capillary wave* method, introduced in the field theory context by Moore and Turok (1997). The method bypasses supercritical slowing down and yields as byproduct accurate data on the  $N_t$ -dependency of the critical inverse gauge coupling. We use the latter to determine the lattice beta function values required to compute the latent heat from the plaquette discontinuity across the confined-deconfined phase transition.

**Authors:** SALAMI, Ahmed; RUMMUKAINEN, Kari; Dr RINDLISBACHER, Tobias (University of Bern)

**Presenter:** Dr RINDLISBACHER, Tobias (University of Bern)

Contribution ID: 4

Type: **not specified**

## Chiral perturbation theory predictions of finite-volume effects in QCD+QED

*Monday, 2 June 2025 16:45 (30 minutes)*

In this talk I will discuss electromagnetic finite-volume effects from the perspective of chiral perturbation theory, with particular emphasis on different QED prescriptions. The finite-volume effects associated to sea and valence quarks will additionally be separated through partial quenching. This is e.g. relevant for understanding volume dependence in QED-disconnected diagrams calculated on the lattice.

**Author:** HERMANSSON TRUEDSSON, Nils

**Presenter:** HERMANSSON TRUEDSSON, Nils

Contribution ID: 5

Type: **not specified**

## Sphaleron rate for first-order phase transitions

*Wednesday, 4 June 2025 11:15 (30 minutes)*

In the Standard Model, there is no true electroweak phase transition making electroweak baryogenesis unviable. However, many extensions of the SM have a first-order phase transition and can be mapped to a dimensionally reduced effective 3D Higgs+SU(2) theory. Different extensions can map to the same effective Higgs+SU(2) theory with just differing effective couplings. Thus, simulating the effective theory, we can compute the sphaleron rate with many different values of the couplings that map to different underlying extensions.

In this talk I present our new results from computing the sphaleron rate in the entire parameter region interesting for first-order phase transitions. Using this we can obtain a requirement for the strength of the phase transition needed to prevent sphalerons to wash out any generated baryon asymmetry, important for baryogenesis scenarios.

**Author:** ANNALA, Jaakko

**Presenter:** ANNALA, Jaakko

Contribution ID: 6

Type: **not specified**

## The three-loop hadronic vacuum polarization in chiral perturbation theory

*Monday, 2 June 2025 16:15 (30 minutes)*

The HVP is a prime example of the synergy between lattice QCD and effective field theories, and of hadronic contributions to fundamentally non-hadronic processes like the muon  $g - 2$ . It is a rich source of physics, even more so with the confidence and precision left behind now that the controversy surrounding its measurement is dying down.

We bring the ChPT prediction for the HVP up to three-loop order (NNNLO) for pions in the isospin limit (the simplest, and dominant, case). This order is in fact the leading one for the four-particle cut of the amplitude, associating it with a clean and interesting observable. It also sets the stage for an ambitious attempt at obtaining finite-volume corrections, as has been successfully done at lower orders. The calculation is interesting in its own right, representing one of very few ventures into three-loop ChPT and involving some master integrals that have seemingly never been evaluated before in any theory.

**Author:** SJÖ, Mattias (CPT, Aix-Marseille University)

**Co-authors:** LUPO, Alessandro (CPT, Aix-Marseille Université); Dr PORTELLI, Antonin; SZABO, Kalman; LELLOUCH, Laurent (CNRS and Aix-Marseille U.); VANHOVE, Pierre (Université Paris-Saclay (FR))

**Presenter:** SJÖ, Mattias (CPT, Aix-Marseille University)

Contribution ID: 7

Type: **not specified**

## Expanded Ensemble Method for Bubble Nucleation

*Wednesday, 4 June 2025 09:30 (30 minutes)*

Many extensions of the Standard Model feature first-order phase transitions at the electroweak scale. The bubble nucleation rate is one of the key parameters in determining the produced gravitational wave background. The most important part of the nucleation rate computation is the determination of the probability of the critical bubble configurations. In many physically interesting scenarios these are extremely suppressed and multicanonical methods are necessary.

In multicanonical MCMC we sample an alternative probability distribution, one that has been weighted using a suitable function of some order parameter, a measurable that can distinguish the two phases. While this removes the obvious Boltzmann suppression of the critical configurations, it does not affect barriers associated with the *condensation transition*. The condensation transition marks the point where the preferred configurations change from delocalised fluctuations of the metastable phase to a single localised bubble of the stable phase. This barrier increases with the system volume and causes exponential slowing down.

The root of the problem lies in the fact that the typical volume averaged order parameter can not distinguish delocalised fluctuations and small bubbles. In this talk I will present an effective trick for evading this deficiency, using the method of expanded ensembles and weighted order parameters.

**Author:** HÄLLFORS, Jaakko

**Co-author:** RUMMUKAINEN, Kari

**Presenter:** HÄLLFORS, Jaakko

Contribution ID: 8

Type: **not specified**

## Pure SU(N) gauge theory with a twist

*Monday, 2 June 2025 14:00 (30 minutes)*

For the confined phase of pure SU(N) gauge theory, we generalize a method to produce a system that possesses two differently ordered phases simultaneously. Between these two ordered phases there naturally lies an interface which we call the order-order (o-o) interface. The interface is formed by placing a twist in the lattice. This twist creates a discontinuity in the measured Polyakov loop ordering indicating the existence of said interface. In the literature the measurement of the unique o-o interface tension for SU(3) is performed by calculating the difference in free energy of the twisted and non-twisted lattices. We measure the surface tension of such interfaces in SU(N > 3) gauge theory, and utilize an additional method by measuring the transverse fluctuations of the o-o interface.

**Author:** HAARTI, Aaron (University of Helsinki)

**Presenter:** HAARTI, Aaron (University of Helsinki)

Contribution ID: 9

Type: **not specified**

## Entanglement Entropy in $O(N)$ Models

*Monday, 2 June 2025 14:30 (30 minutes)*

Entanglement is a characteristic property of all quantum systems. Due to its close relation to correlations, entanglement measures can be used to study many interesting phenomena such as confinement. On the lattice, a group of entanglement measures, referred to as the Rényi entropies, can be computed with the replica trick. In recent years, we have seen significant progress on this front.

In my talk, I will present our group's work on measuring entanglement entropy (the 2nd Rényi entropy) in  $O(N)$  scalar field theories. Despite their simplicity,  $O(N)$  models allow for the study of several interesting phenomena: they can be asymptotically free and can undergo spontaneous symmetry breaking in different ways. We will study these properties through entanglement entropy and be able to do so at non-zero densities by using a worm algorithm.

**Authors:** RAJALA, Aatu; JOKELA, Niko; Dr RINDLISBACHER, Tobias (University of Bern)

**Presenter:** RAJALA, Aatu

Contribution ID: 10

Type: **not specified**

## Anisotropic Lattice Studies of Thermal QCD

*Wednesday, 4 June 2025 10:00 (30 minutes)*

We present an overview of the FASTSUM collaboration's ongoing program to investigate QCD at non-zero temperature (and chemical potential) using anisotropic Wilson-fermion lattices. Our simulations employ an  $O(a^2)$ -improved gauge action together with an  $O(a)$ -improved, stout-smearred Wilson-fermion action. By using lattices with spatial spacing  $a_s \approx 0.11$  fm and anisotropies  $\xi = a_s/a_t = 3.5$  (Generation 2) and 7.0 (Generation 3), we gain enhanced temporal resolution that is crucial for extracting in-medium effects, in particular spectral functions.

Generation 2 ensembles, with pion masses of 384 MeV (Gen2) and 236 MeV (Gen2L), are now being extended toward the physical point (Gen2P). Generation 3 is being expanded to further refine the temporal resolution.

In this talk, we will present recent results obtained on these ensembles

**Author:** JÄGER, Benjamin

**Presenter:** JÄGER, Benjamin

Contribution ID: 11

Type: **not specified**

## Resolving the critical bubble in SU(8) deconfinement transition

*Wednesday, 4 June 2025 09:00 (30 minutes)*

Strongly coupled confining models are promising Dark Matter candidates. They have the benefit of potentially producing detectable gravitational waves during a first order confinement phase transition. To estimate the resulting gravitational wave spectrum, phase transition parameters like the nucleation rate are needed. With the nonperturbative nature of these transitions, nucleation rate has so far been estimated with semi-classical methods.

We demonstrate that lattice methods can be used to estimate the nucleation rate in the case of strongly coupled confining transition. With four dimensional multicanonical simulations, we are able to calculate the critical bubble probability in SU(8) deconfinement transition, which gives an estimate for the rate. To fit the bubbles on the lattice, large volumes are required, and to accurately resolve the critical bubble configurations, improvements to the usual Polyakov loop order parameter are needed.

**Authors:** WEIR, David (University of Helsinki); RUMMUKAINEN, Kari; SEPPÄ, Riikka

**Presenter:** SEPPÄ, Riikka

Contribution ID: 12

Type: **not specified**

## Long distance contributions to neutral $D$ -meson mixing from lattice QCD

*Tuesday, 3 June 2025 11:15 (30 minutes)*

The study of neutral  $D$ -meson mixing provides a unique probe of long-distance effects in the charm sector, where Standard Model contributions are dominated by nonperturbative effects. In this talk, we present a recent proposal (arXiv:2504.16189) to extract the long-distance contribution to the  $D^0 - \bar{D}^0$  mixing amplitudes from Euclidean lattice correlation functions by means of spectral reconstruction techniques. After outlining the general formalism describing neutral meson mixing in the charm sector, we discuss the definition and renormalization of the  $C = 1$  operators in the weak effective Hamiltonian. We then describe our approach for computing the relevant lattice correlators, including the use of variance-reduction strategies to improve signal quality. Finally, we focus on practical methods for extracting the underlying spectral densities, highlighting challenges and prospects for a first-principles determination of long-distance mixing amplitudes.

**Author:** DI CARLO, Matteo**Presenter:** DI CARLO, Matteo

Contribution ID: 13

Type: **not specified**

## Controlling Systematics in B-physics on the Lattice

The heavy flavor sector of the Standard Model is a promising avenue for uncovering physics beyond the Standard Model, given persistent tensions between theory and experiment. Precise Standard Model predictions require reliable control of non-perturbative effects, which lattice QCD can provide. However, handling heavy quarks on the lattice introduces significant systematic uncertainties.

We present our strategy and proof of concept for mitigating the dominant sources of uncertainty in lattice QCD calculations of B-physics observables, enabling precise and controlled Standard Model predictions.

**Author:** KUBERSKI, Simon

**Presenter:** KUBERSKI, Simon

Contribution ID: 14

Type: **not specified**

## The $\rho$ and $K^*$ resonances from lattice QCD at physical quark masses

*Tuesday, 3 June 2025 11:45 (30 minutes)*

Hadron spectroscopy and the study of QCD resonances on the lattice have made significant progress in recent years. A key development is our recent calculation of the  $\rho$  and  $K^*$  resonances at physical quark masses using Domain-Wall Fermions. In this talk, I will present the details of this calculation, including our approach to estimating systematic uncertainties through an AIC-based importance sampling strategy. I will also discuss how this work marks a critical step toward achieving precision calculations of semileptonic decays involving multi-hadron final states, such as  $B \rightarrow K^*$  decays.

**Author:** ERBEN, Felix Benjamin**Presenter:** ERBEN, Felix Benjamin

Contribution ID: 15

Type: **not specified**

## Radiative corrections to neutron beta decays

*Tuesday, 3 June 2025 14:00 (30 minutes)*

In this brief overview I will talk about the phenomenological relevance of neutron beta decays and the current status. Particular focus will be put on the role of lattice QCD in future precision determinations of radiative corrections. This presentation is within the framework of a 'dream' project of NOLA.

**Author:** HERMANSSON TRUEDSSON, Nils

**Presenter:** HERMANSSON TRUEDSSON, Nils

**Session Classification:** "Dream Projects"

Contribution ID: 16

Type: **not specified**

## A new approach to control correlations and excited states

*Tuesday, 3 June 2025 10:00 (30 minutes)*

At a given statistic, reliable extractions of masses and amplitudes from Euclidean time correlation functions faces two challenges:

- 1) the accurate estimation of correlation matrices and
- 2) control over contamination of excited states that are not taken into account in the parameterisation of the data.

We present a new and simple-to-use method which addresses both of these well-known issues by applying a (linear and invertible) filter to the correlation functions. Since this method is based on a transformation of the data rather than a regularisation of the correlation matrix, it introduces no additional systematic errors or modifications to the interpretation of goodness-of-fit tests. We further discuss how the filter parameter can be optimised. We stress that for this data-analysis method no additional correlation functions need to be generated.

**Authors:** Dr PORTELLI, Antonin; TSANG, Tobias (CERN)

**Presenter:** TSANG, Tobias (CERN)

Contribution ID: 17

Type: **not specified**

## Welcome

*Monday, 2 June 2025 13:50 (10 minutes)*

**Presenter:** TSANG, Tobias (CERN)

Contribution ID: 18

Type: **not specified**

## Hidden dynamics in latent spaces: a physicist's detour in modern AI

*Tuesday, 3 June 2025 14:45 (30 minutes)*

In the AI era, modern architectures achieve remarkable results that are reshaping how we do science, often relying on pragmatic principles that are typically poorly understood. Autoencoder technology is based on the concept of a latent space where hidden variables capture correlations in observed data. From a physicist's perspective, "marginalization of hidden variables" takes the name of integrating out microscopic degrees of freedom.

In this talk, I'll explore how latent spaces encode effective dynamics across three domains: epidemiology, where unobserved contagion mechanisms are modeled via latent neural ODEs; finance, where stochastic fluctuations are disentangled from hidden equilibria; and a more standard lattice QFT perspective, where autoencoders mimic RG blocking and offer insight into learning dynamics. Rather than seeking unification, the goal is to show how shared ideas and tools bridge these diverse applications.

**Author:** BUTTI, Pietro (Quantum Field Theory Center IMADA)

**Presenter:** BUTTI, Pietro (Quantum Field Theory Center IMADA)

**Session Classification:** "Dream Projects"

Contribution ID: **20**

Type: **not specified**

## **Lattice Gradient flow for phenomenology**

*Tuesday, 3 June 2025 16:15 (20 minutes)*

tbd

**Author:** RAGO, Antonio (University of Southern Denmark (DK))

**Presenter:** RAGO, Antonio (University of Southern Denmark (DK))

**Session Classification:** "Dream Projects"

Contribution ID: 21

Type: **not specified**

## **Livestream of Fermilab g-2 Experimental result**

*Tuesday, 3 June 2025 17:00 (1 hour)*