# Simulating Physics Beyond the Standard Model

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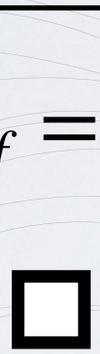
D·IAS

# Study SUSY with $N_f = 1$ Lattices

- Simulate SUSY without the need to simulate SUSY
- Two-index anti-symmetric fermions

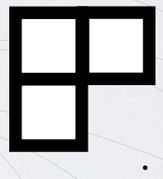
QCD

$N_f = 1$



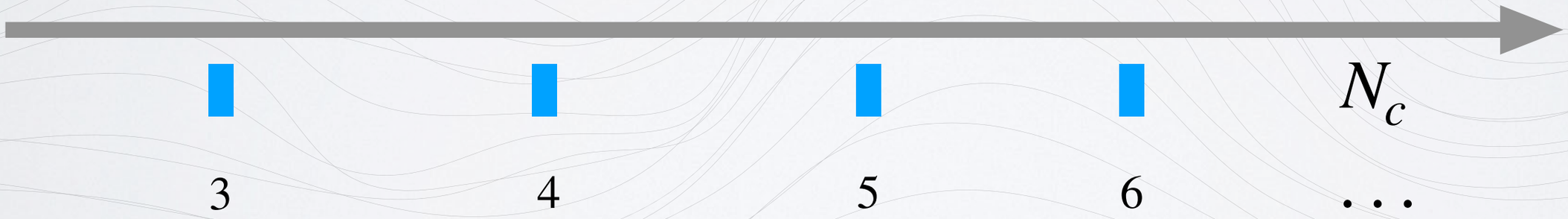
**Good proxy for SUSY?**

SYM



$\mathcal{N} = 1$

$\cdots$




previous work
Corrigan & Ramond, 1979
hep-th/0309252 hep-th/0403071
hep-th/0603045 hep-th/0609187
hep-lat/0810.0161

# Study SUSY with $N_f = 1$ Lattices

- Simulate SUSY without the need to simulate SUSY
- Two-index anti-symmetric fermions
  - Study spectrum and compare to EFT

$$\frac{M_{PS}}{M_S} = 1 - \frac{22}{9N_C} - \frac{4}{9}\beta + \mathcal{O}(1/N_C^2)$$

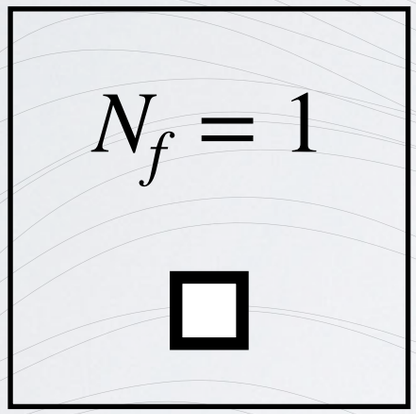
hep-th/0309252

  - @ Lattice: Compute masses and check the ratio

# Study SUSY with $N_f = 1$ Lattices

- Simulate SUSY without the need to simulate SUSY
- Two-index anti-symmetric fermions

QCD

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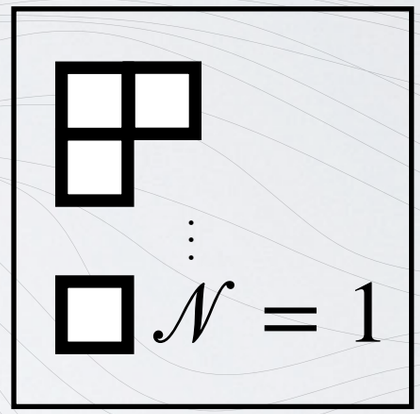


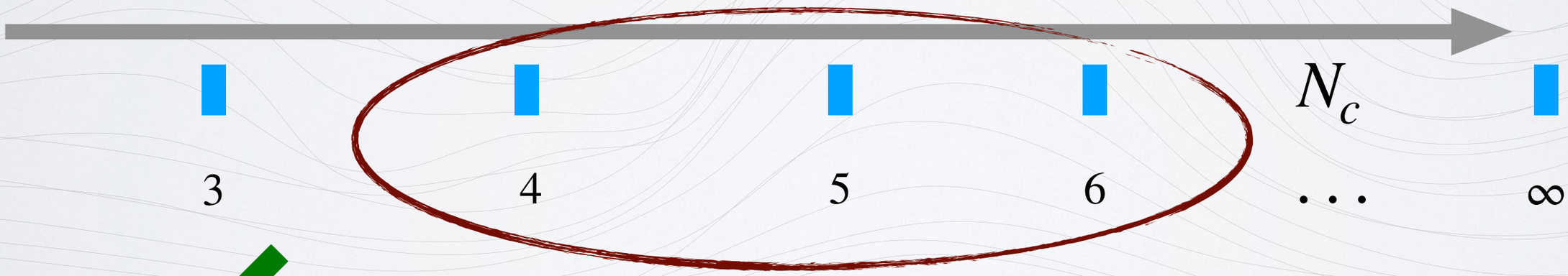


Next

Phys.Rev.D 107 (2023) 11
hep-lat/2302.10514

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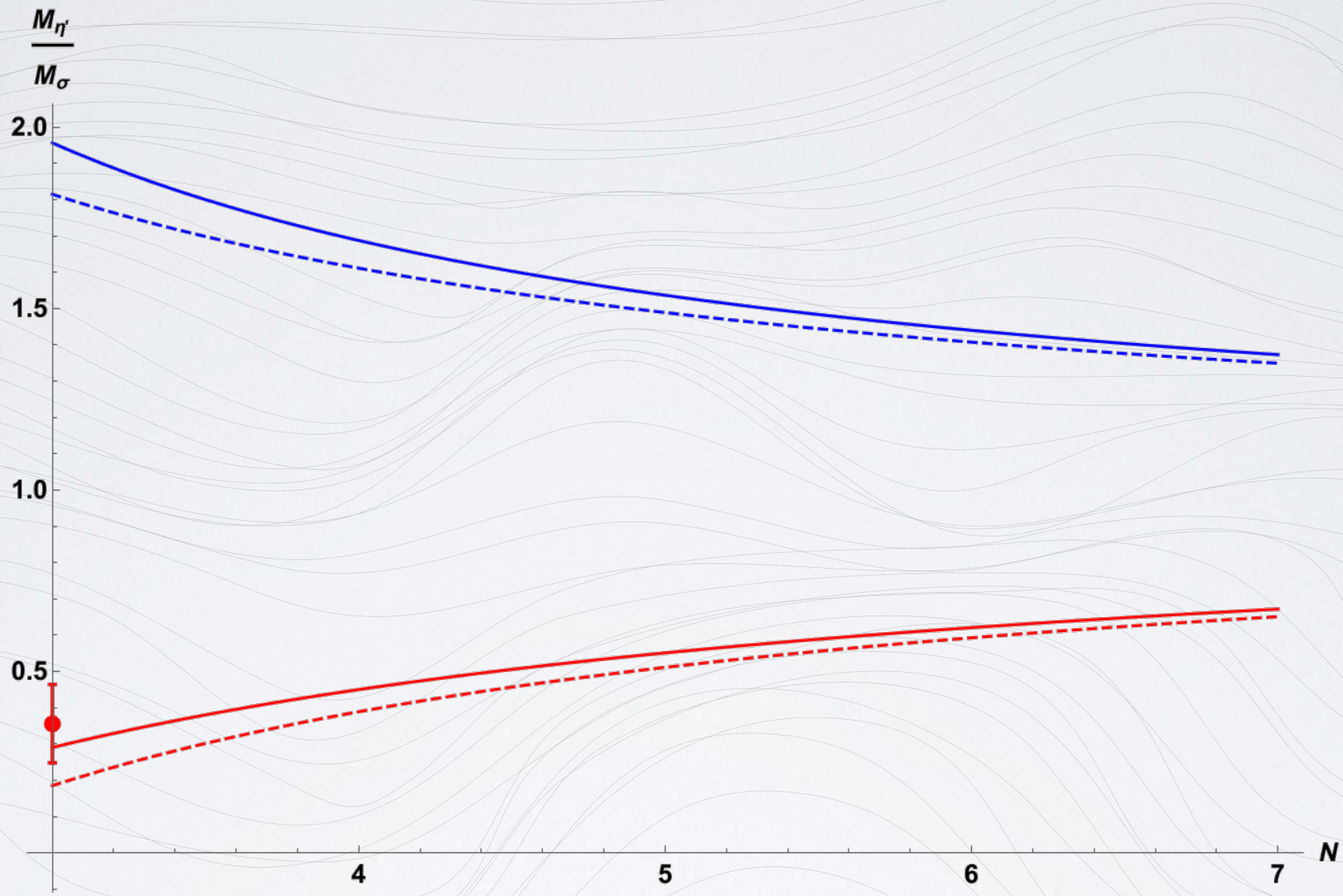
hep-lat/0810.0161

# Comparison of EFT and Lattice



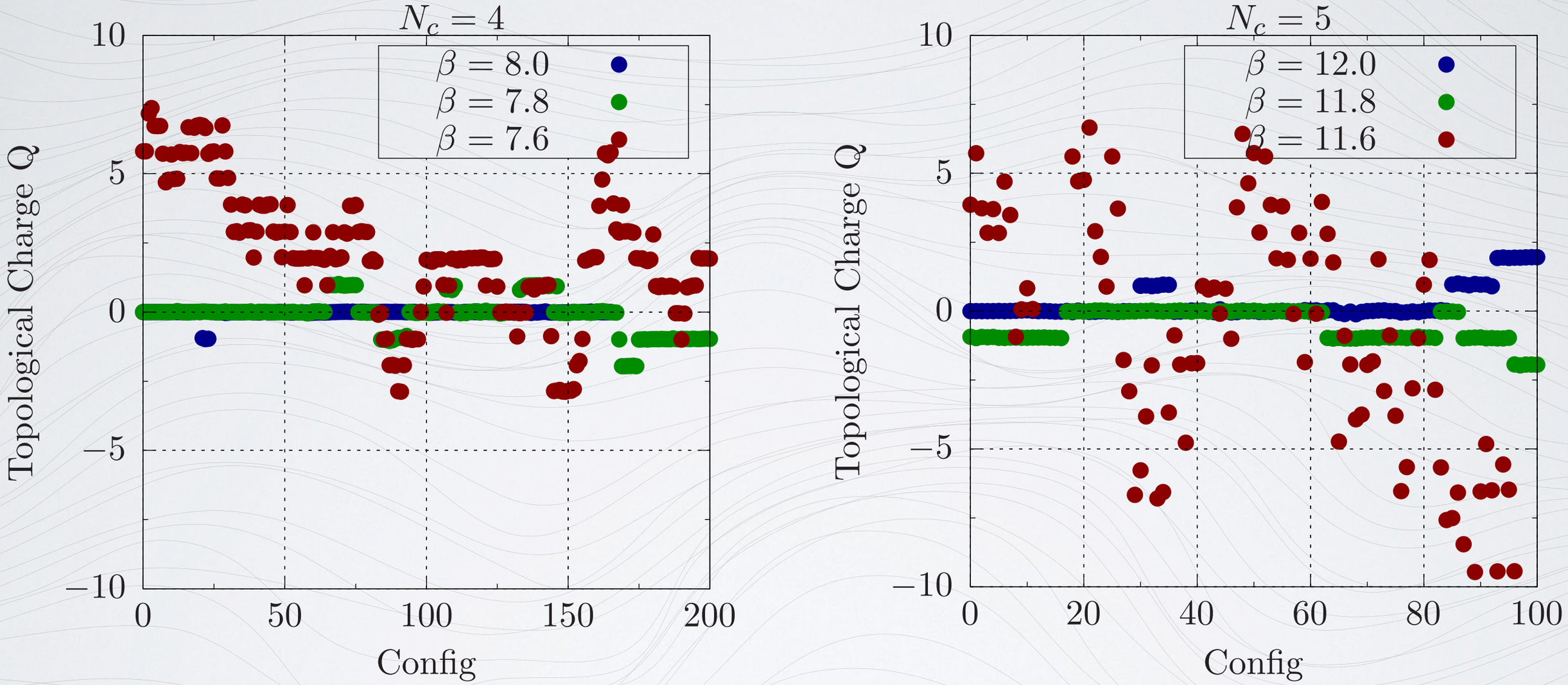

Sannino
hep-th/2402.05850

- Lattice with $2\sigma$
- Suggested expansion: $\frac{M_{PS}}{M_S} = \frac{1 - 2/N_C}{1 + \frac{4}{9N_C}}$

# Going to larger $N_C$

- Our setup ($N_C = 3$)
  - Gauge: Symanzik improved gauge action ($\beta = 4.5$)
  - Fermion: $\mathcal{O}(a)$ improved Wilson fermions ($c_{sw} = 1$)
  - $a \sim 0.06$ fm
- For $N_C > 3$
  - Keep bare 't Hooft coupling fixed, i.e. $g_0^2 N_C =$ const.
  - Naive couplings:
    - $N_C = 4 \rightarrow \beta = 8$
    - $N_C = 5 \rightarrow \beta = 12.5$
    - $N_C = 6 \rightarrow \beta = 18$

# Going to larger $N_C$




- Topological charge is **frozen** for naive choice of coupling
- Need to go to coarser lattices
- NB: Matching condition: $t^2\langle E\rangle = 0.3 \cdot 3/8 \cdot (N_C - 1/N_C)$

# Going to larger $N_C$

- **Our setup** ($N_C = 4, 5, 6$)
  - Gauge: Symanzik improved gauge action
  - Fermion: $\mathcal{O}(a)$ improved Wilson fermions ($c_{sw} = 1$)
  - Aim for $a \sim 0.1$ fm
- **Runs:**
  - Code: **HiRep** on LUMI-G (Thanks to Sofie!!)
  - 6 Masses and volumes ($m_\pi L > 4$)
  - Going from $N_C = 3$ to $N_C = 4$ scales roughly by factor 3
  - Larger $N_C$ slower and slower

# Current Status

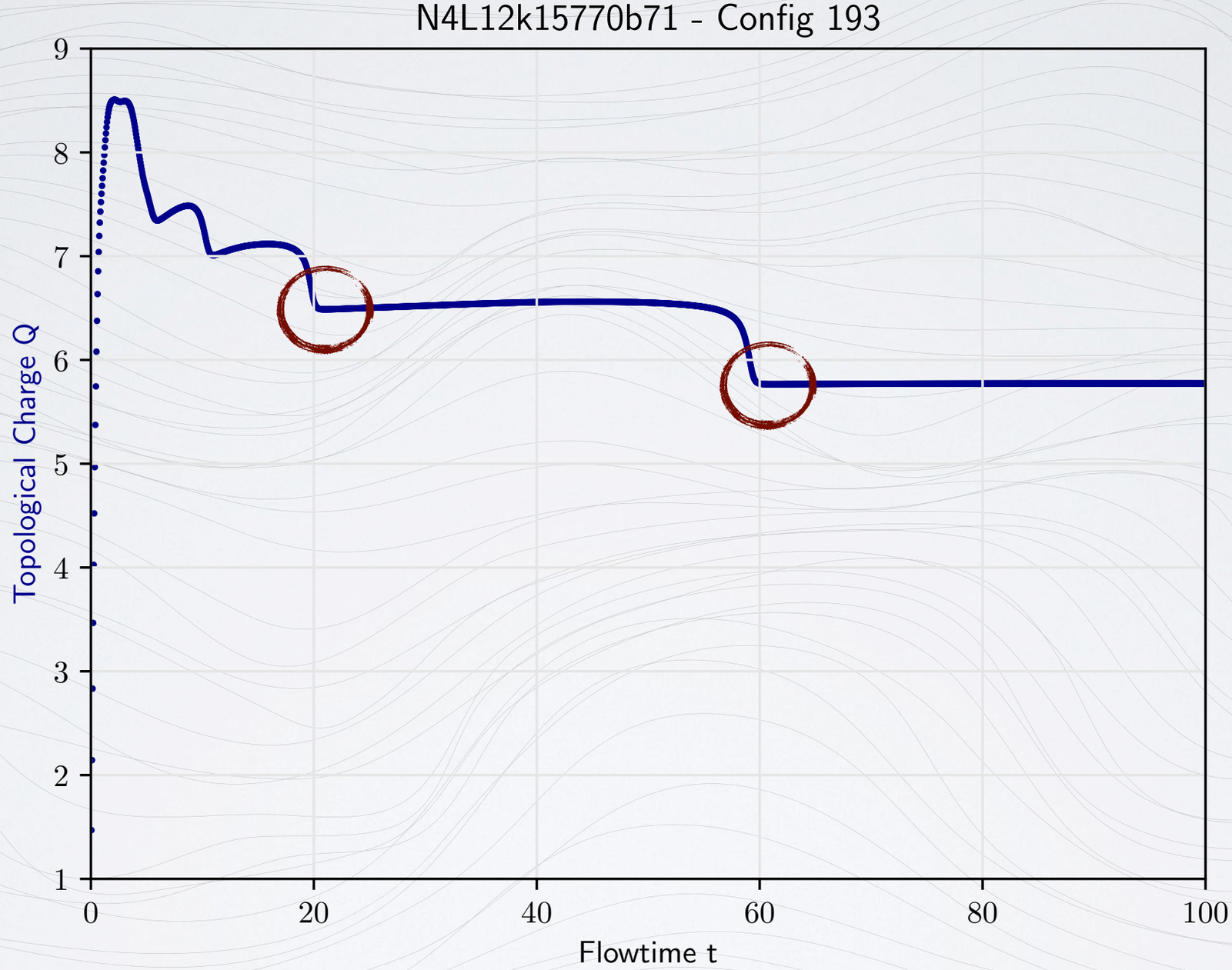
| $L/a$ | $am_\pi$ | $N_C = 4$ | $N_C = 5$ | $N_C = 6$ |
|---|---|---|---|---|
| 12 | 0.40 | 4120 | 2112 | 516 |
| 14 | 0.35 | 2552 | 1152 | 184 |
| 16 | 0.30 | 2148 | 680 | 124 |
| 18 | 0.28 | 1284 | 344 | 88 |
| 20 | 0.25 | 876 | 256 | 120 |
| 24 | 0.20 | 1100 | 256 | 84 |

- Current number of  trajectories ($\tau = 2$)
- Saving every 4th trajectory
- Typically 200 trajectories needed for thermalisation

# While we wait …

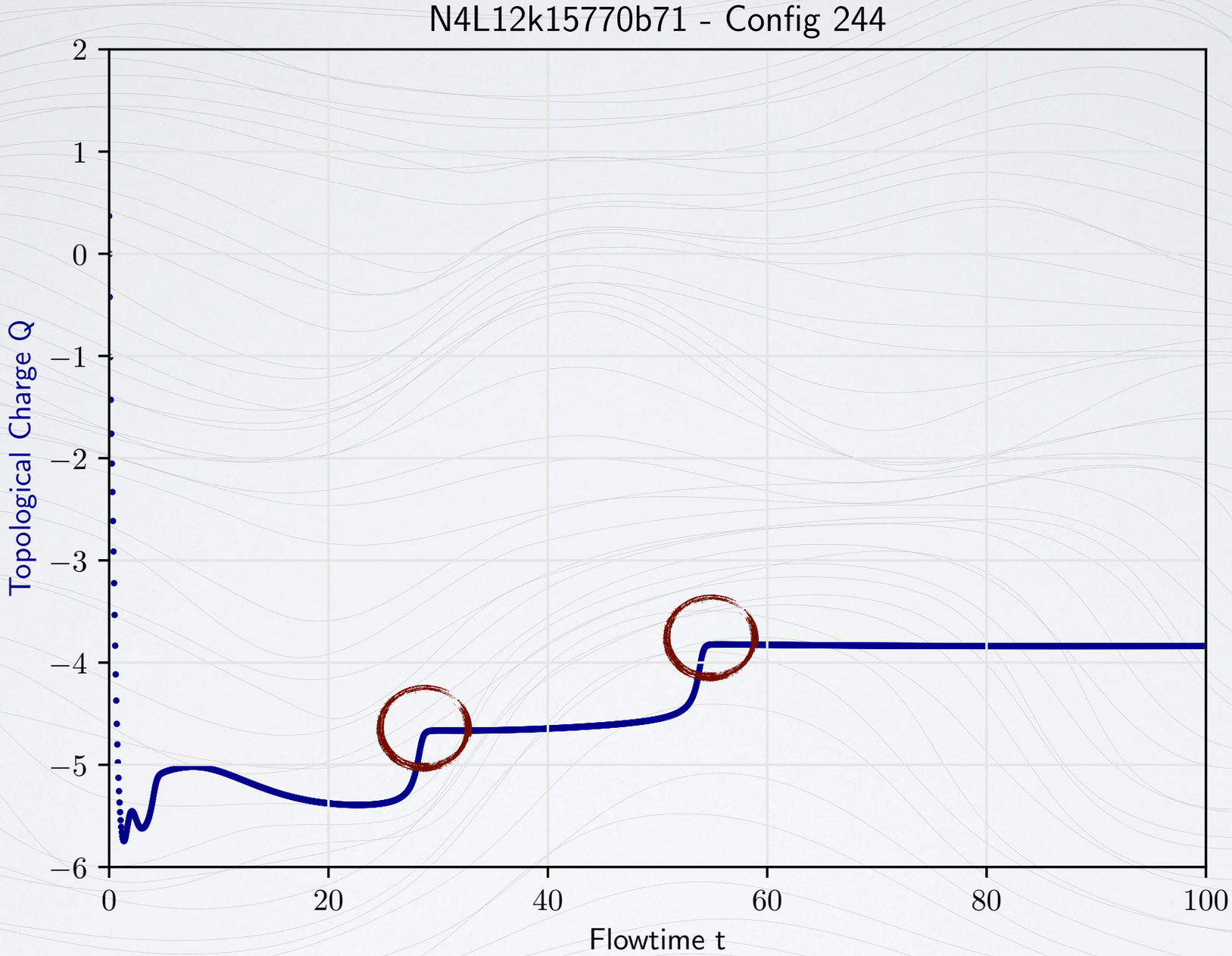
- **Interesting side project**
  - Non-integer topological charge for two-index sym.
  - Studied for $N_C = 3$ by Fodor et.al in JHEP 08 (2009) 084
  - Relevant for SUSY to obtain a non-zero gluino condensate
  - Fractional charges observed for coarse lattices only
- **Expand to larger $N_C$**
  - Just measure the topological charge for large $N_C$ ensembles
  - Check if fractional charges appear
  - Flow long enough to have a smooth configuration
- **Generated 5 ensembles (physical vol. and pion matched)**

# Wilson flow




- What is happening to the topological charge?
- For reference: $t_0/a^2 = 0.9$

# Wilson flow

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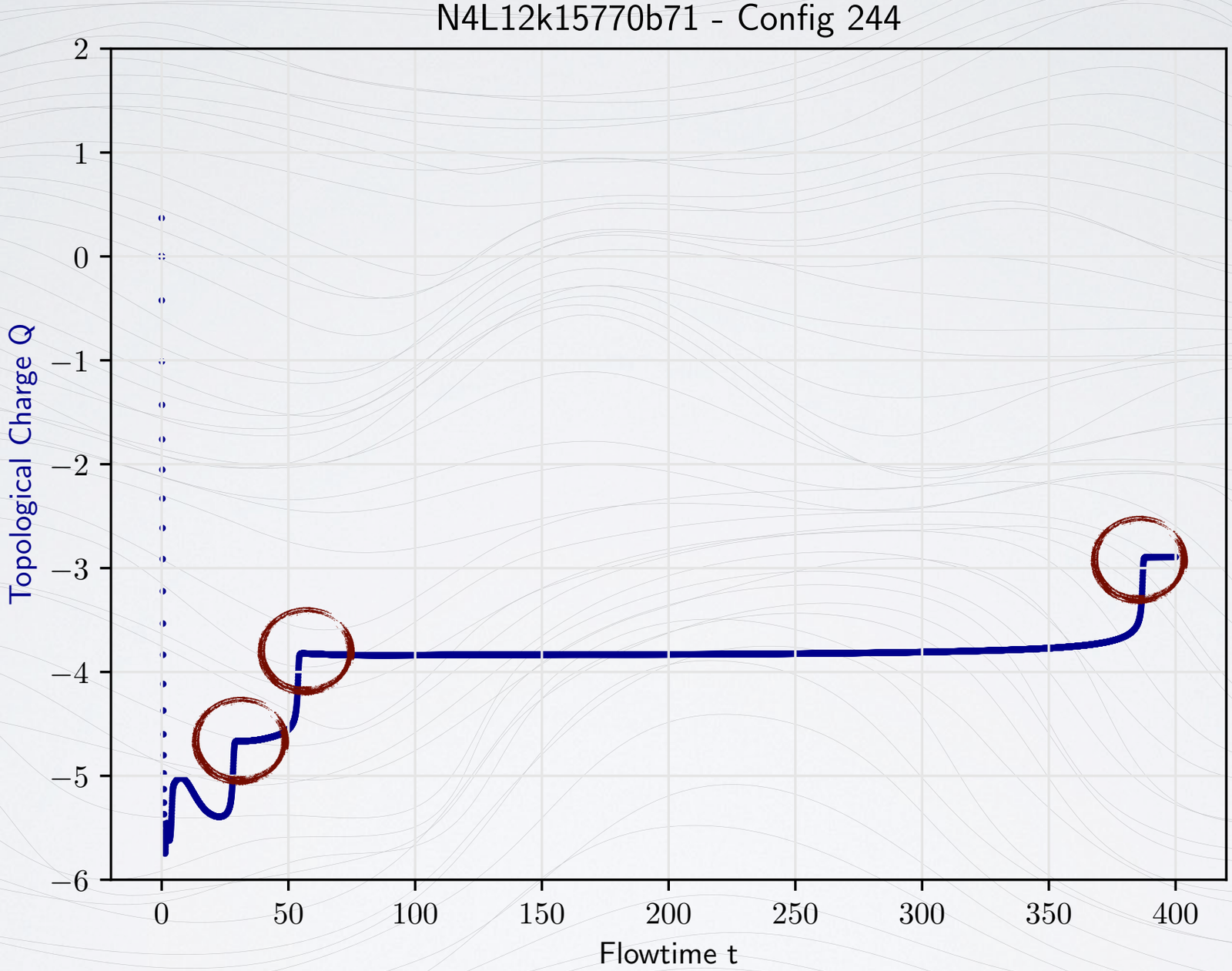
# Wilson flow




- Jumps appear even at very large flow times ( $> 400\, t_0/a^2$ )

# Smoothness

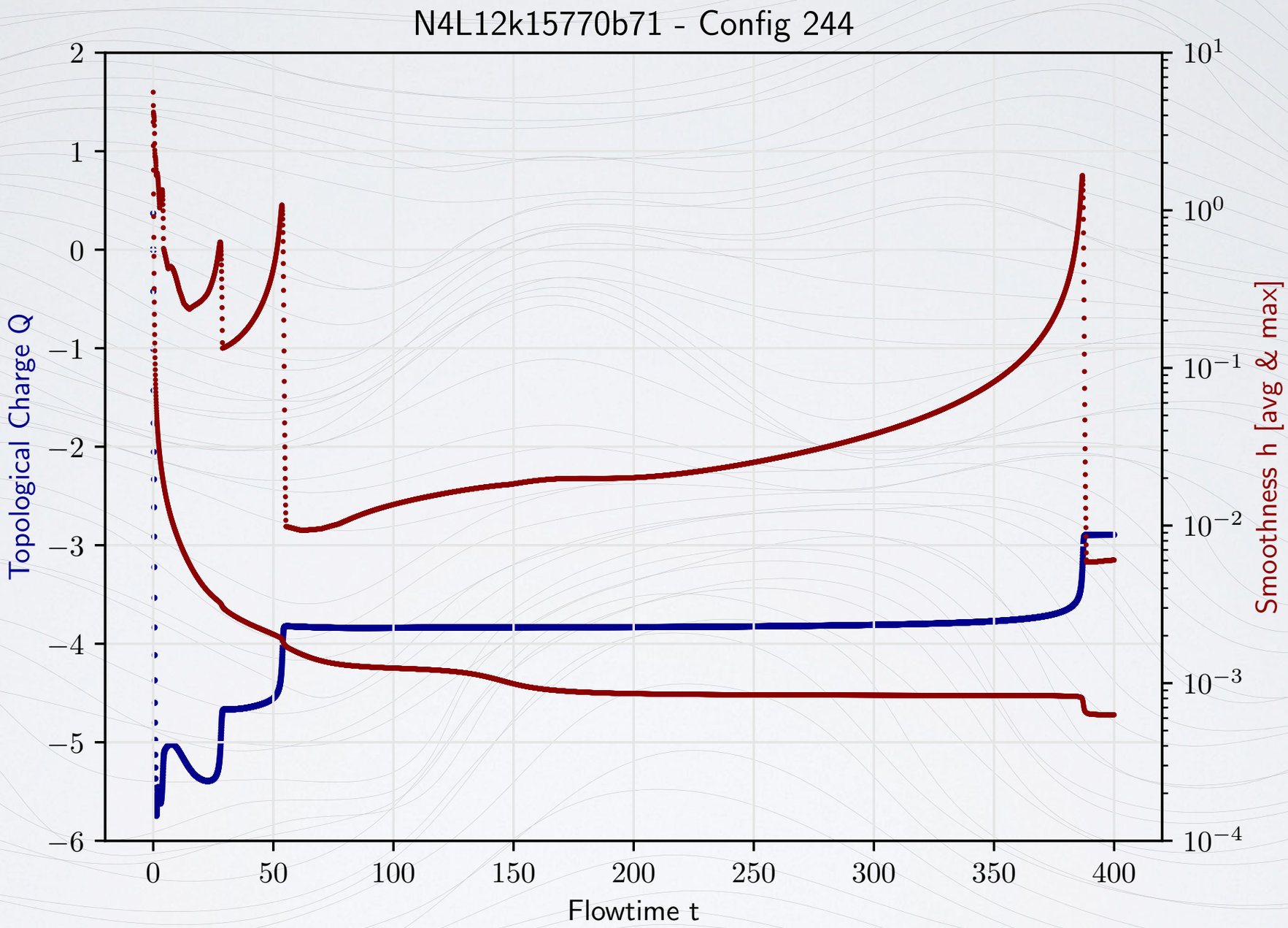
- Smoothness

$$h = \max\{\mathrm{Re}\,\mathrm{Tr}\,(\mathbf{1} - P_{\mu\nu})\}$$

Lüscher, hep-lat 1006.4518

  - Empirical threshold of $h < 0.067$ for $\mathbf{SU}(3)$
  - After threshold topological charge is not supposed to change
  - Aim: Find similar threshold for $\mathbf{SU}(N_C)$
  - **Average** of $h$ is related to Energy density

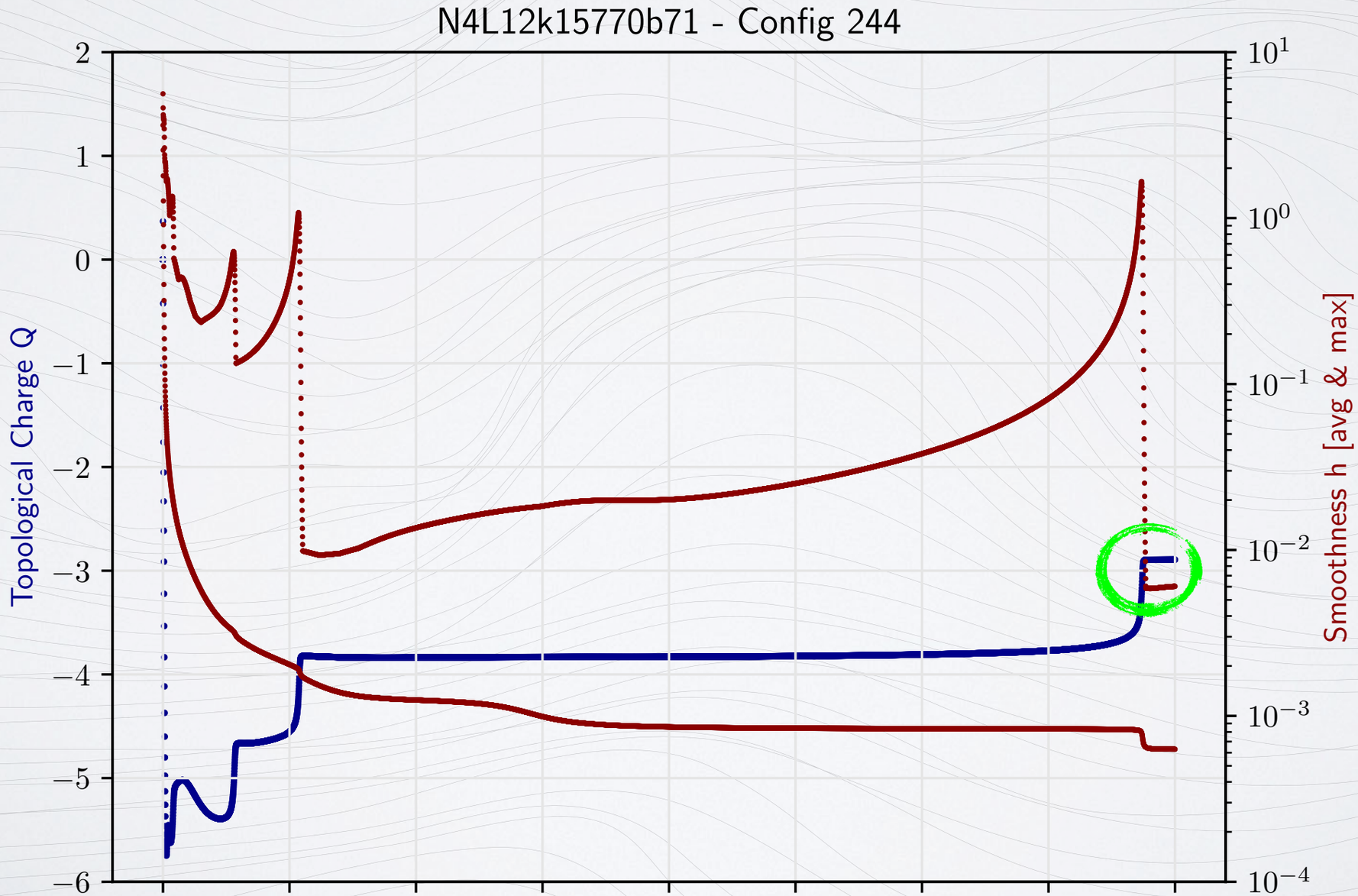
# Wilson flow



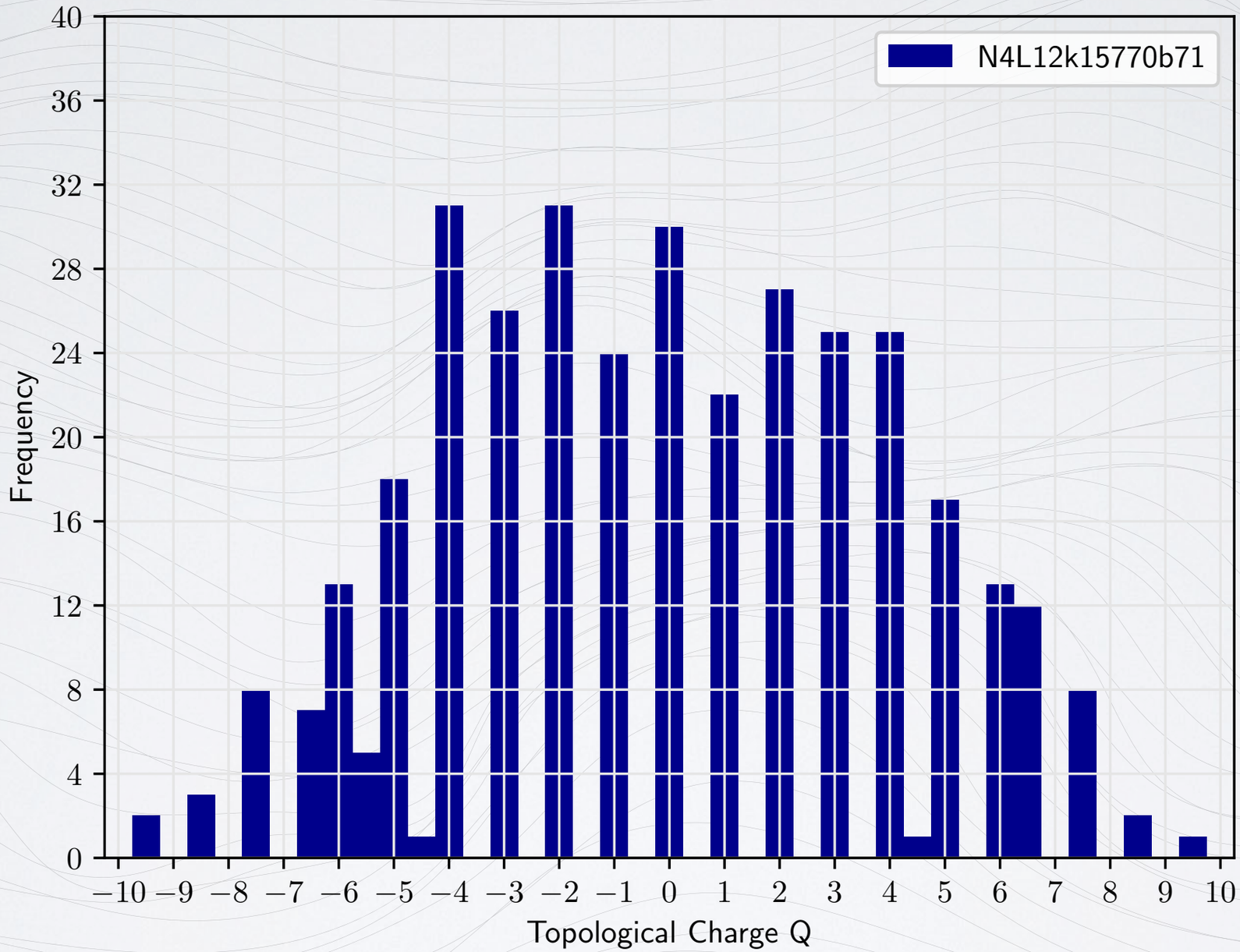

- Jumps of the smoothness coincide with topo. charge changes
- When to measure the topological charge?

# Wilson flow

- **Strategy (Still under development!)**
  - Measure topological charge when $h$ is minimal
  - Ensure that flow time is large enough ( $> 50$)

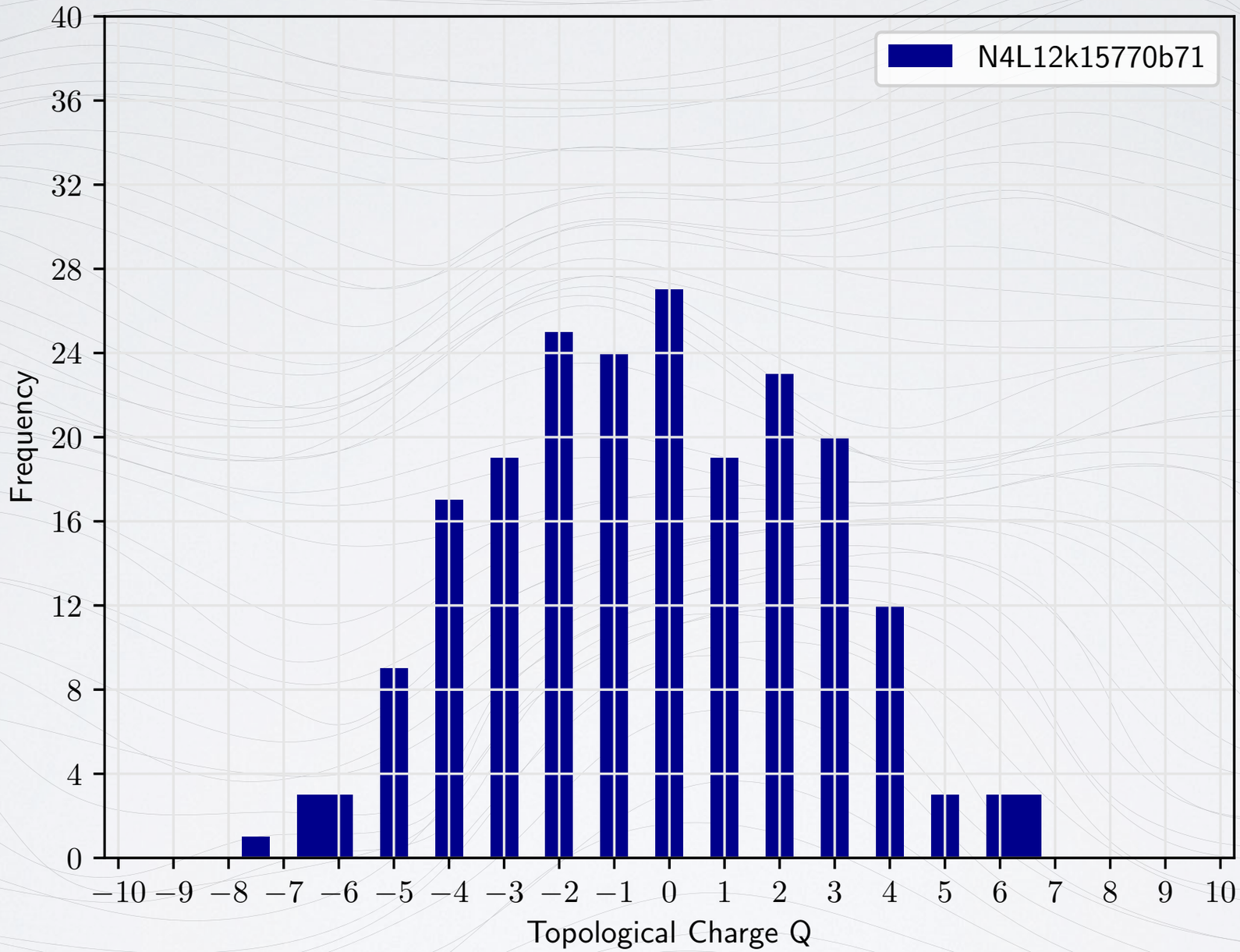


# Histograms



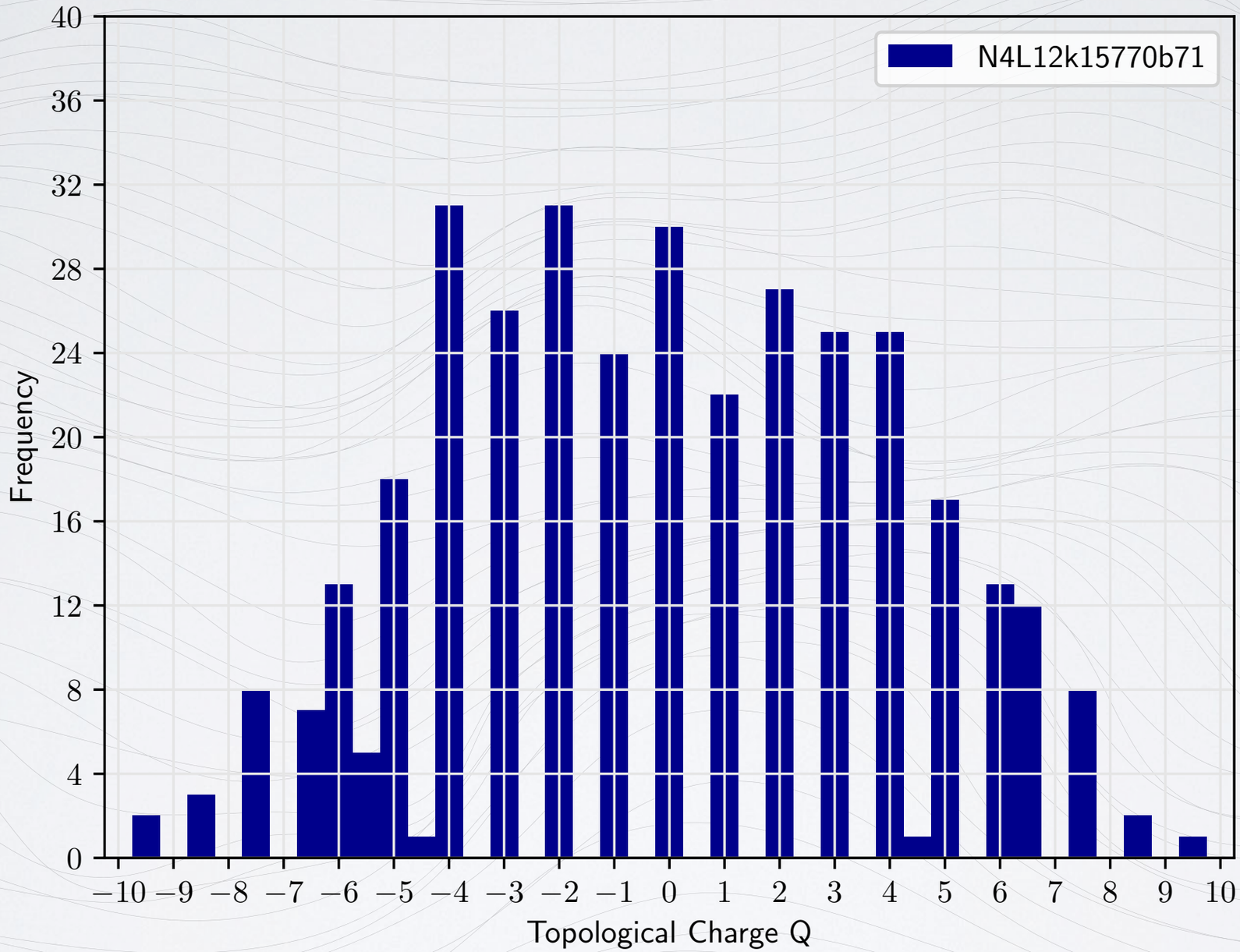

- Coarsest setup
- Fractional charges visible for large $|Q|$

# Histograms



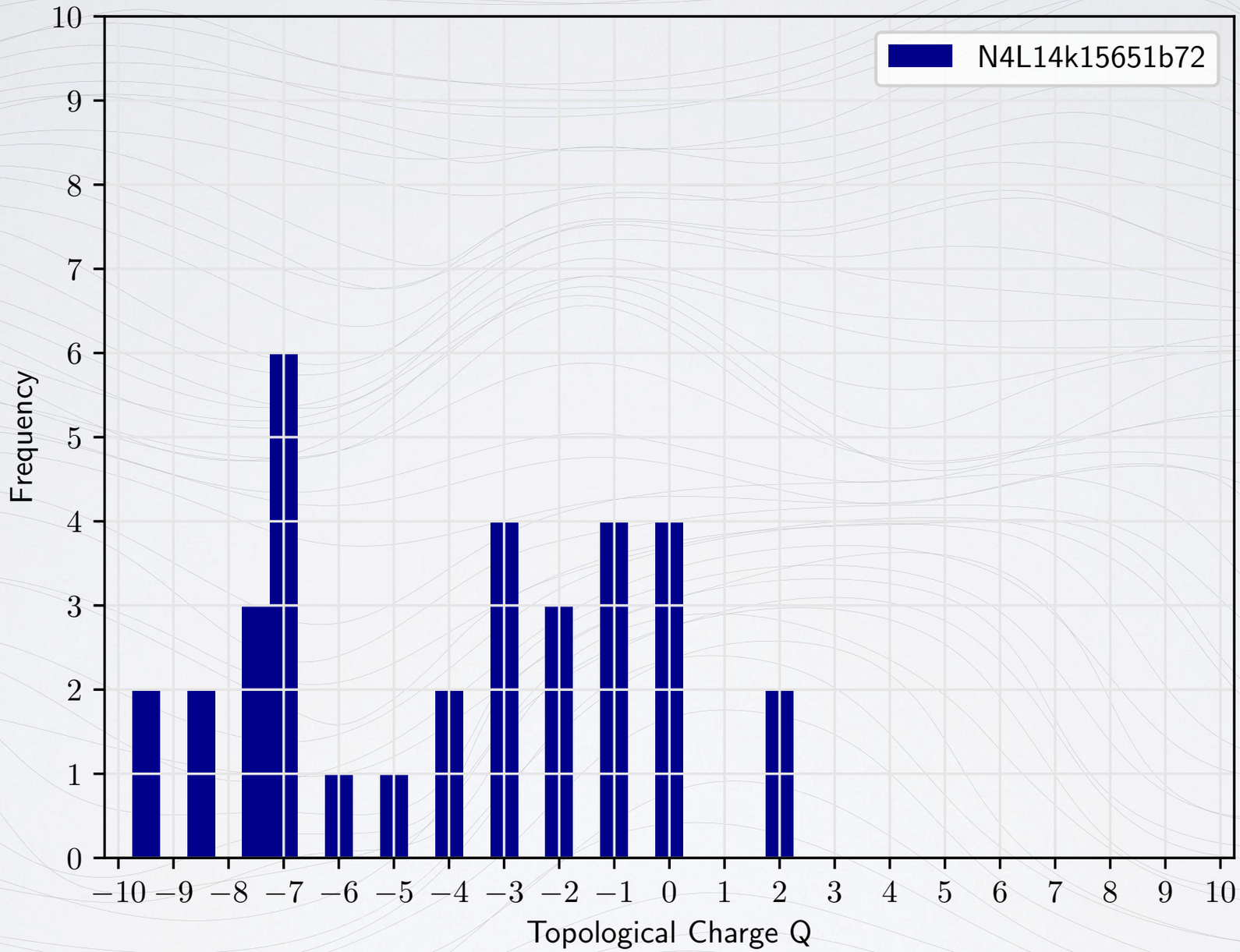

- Excluding all configs with $h > 0.01$
- Few fractional charges still visible for large $|Q|$

# Histograms



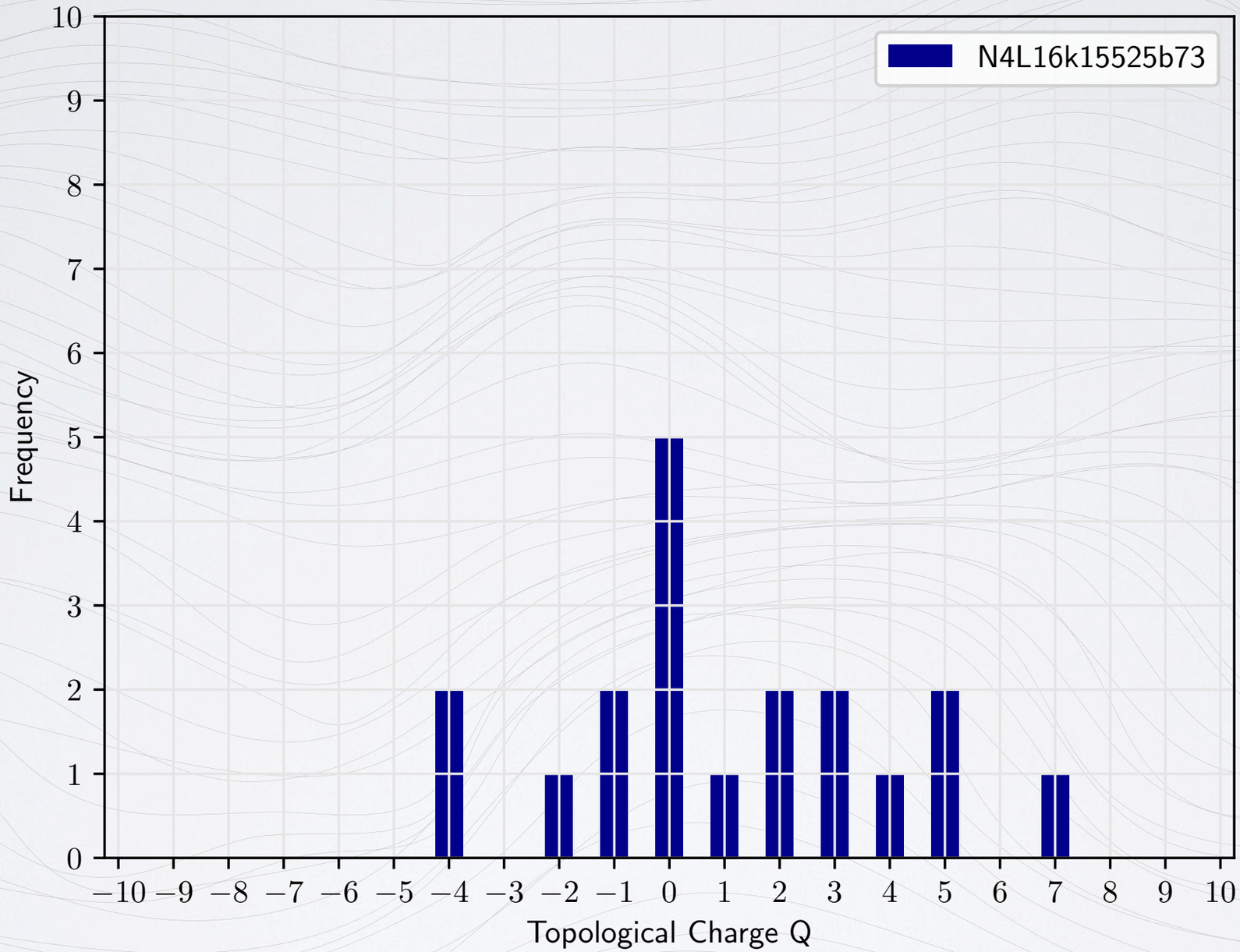

- Excluding all configs with $h > 0.067$ ($\mathbf{SU}(3)$ value)
- Few fractional charges still visible for large $|Q|$

# Histograms




- Finer setup
- Fractional charges visible for large $|Q|$

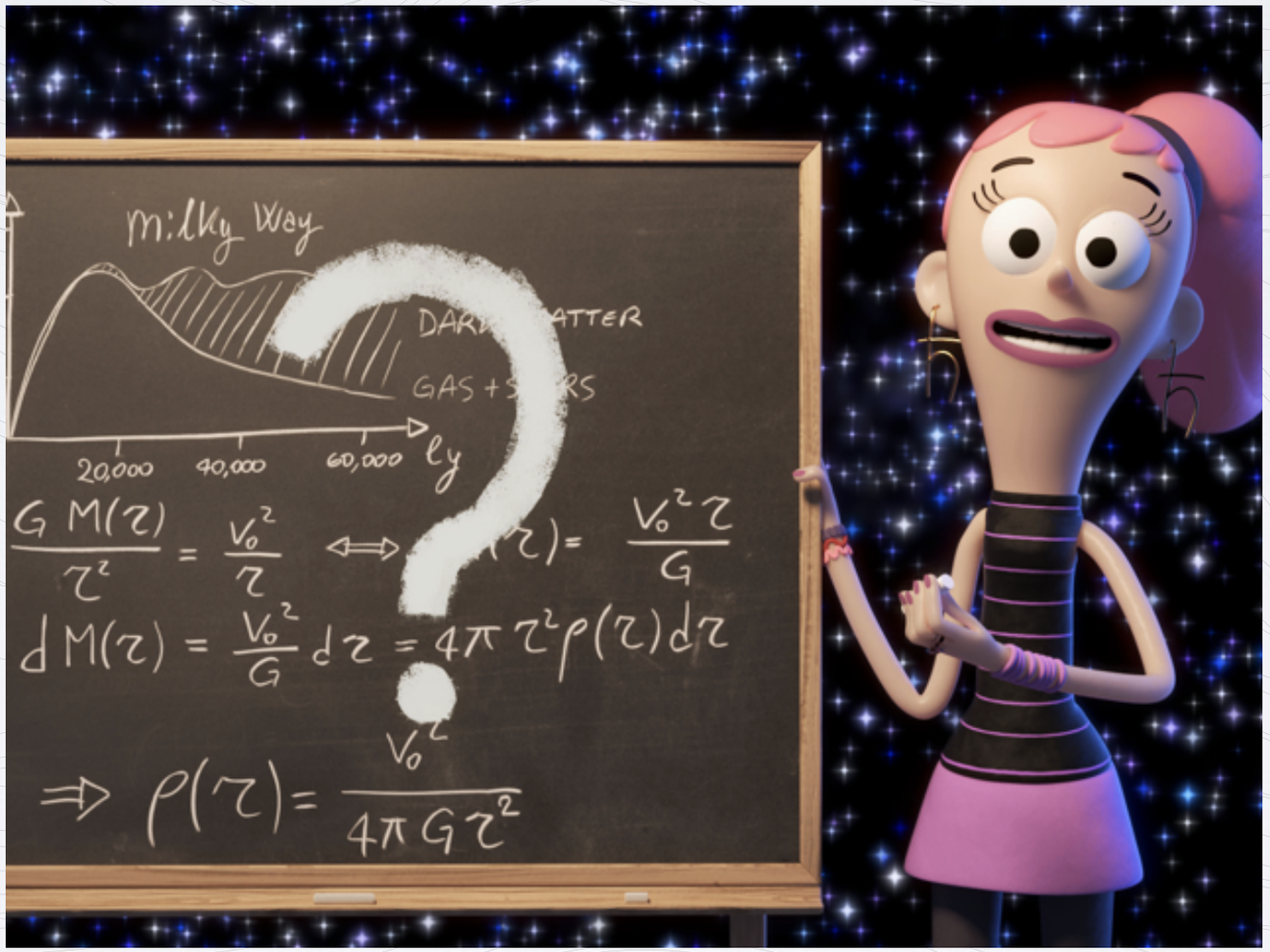
# Histograms




- Even finer setup
- **No** fractional charges visible for large $|Q|$

# Questions?

Thank you for your attention!




Quantum Kate (orig. Kvante Karina): CP3 Outreach http://www.kvantebanditter.dk/en