Planar abelian mirror duals of 3d CS quiver theories

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based on [2411.05620], [2505.02913] and [2506.05465]
with S. Benvenuti, R. Comi, G. Pedde-Ungureanu, S. Rota, A. Shri.

The main takeaway of this talk is that a very large class of 3d $\mathcal{N} = 2$ CS theories admits a purely abelian and planar dual.

Such abelian-planar duals can be generated through $\mathcal{N} = 4 \to \mathcal{N} = 2$ breaking real mass deformations starting from known $\mathcal{N} = 4$ mirror pairs.

Building on insights from the supersymmetric case, we propose a planar abelian dual of $\mathcal{N} = 0$ QCD with bosons and fermions.

Let me first briefly review IR and mirror dualities.

IR dualities: Two QFTs may be different in the UV but flow to the same IR CFT; they belong to the same universality class.

First example: in the conformal window $4d$ $\mathcal{N}=1$ SQCD $SU(N_c)$ and N_f flavors, and the dual mSQCD $SU(N_f-N_c)$ with N_f flavors and extra singlets Φ with $\mathcal{W}=\Phi_{i,j}q_i\tilde{q}_j$, flow to the same IR SCFT [Seiberg '94].

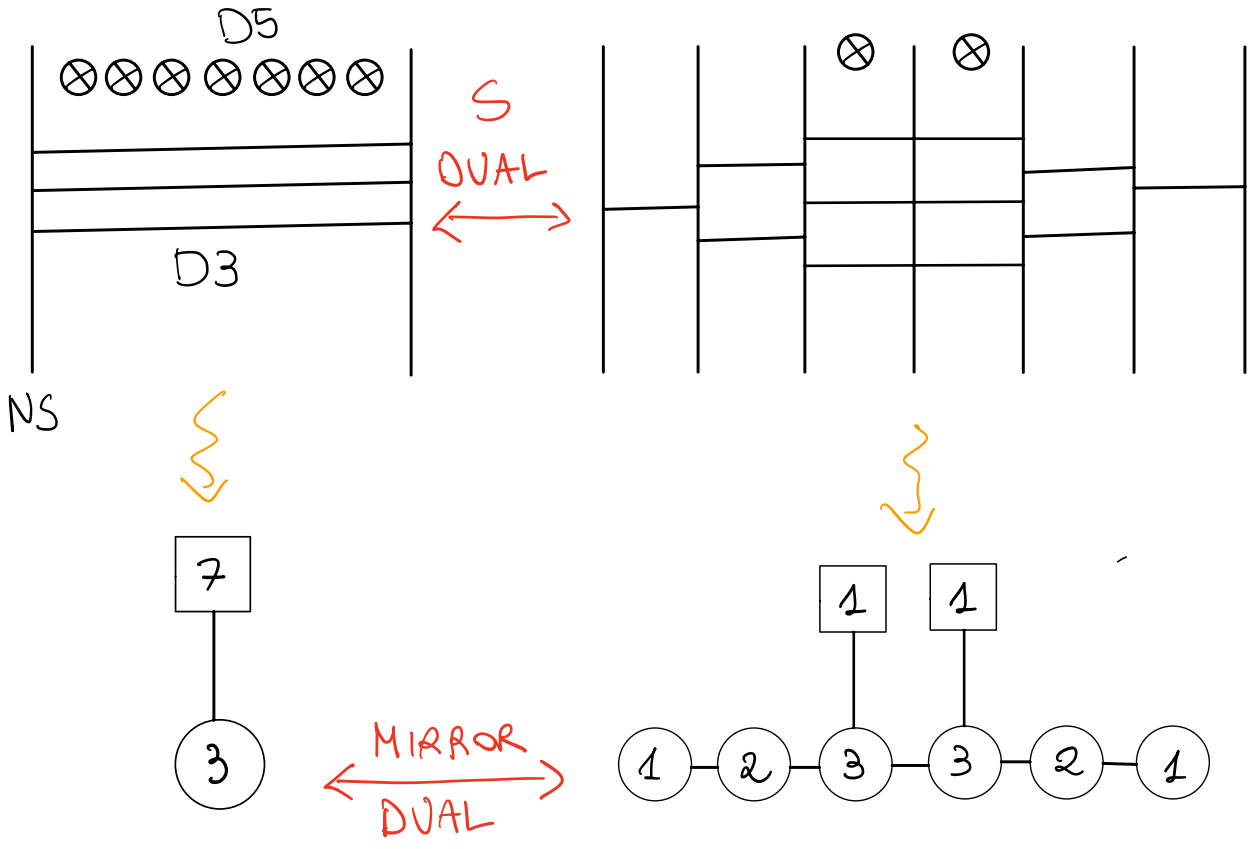
Since then a plethora of interrelated IR dualities in various dimensions have been discovered, including non-supersymmetric dualities [Giombi-Minwalla-Prakash-Trivedi-Wadia-Yin'11],[Aharony-Gur-Ari-Yacoby'11],[Seiberg-Senthil-Wang-Witten'16],[Karch-Tong'16],[Benini'17],....

Tests of IR dualities must be non-perturbative such as anomaly matching, operator map, or superconformal indices and other RG invariant partition functions.

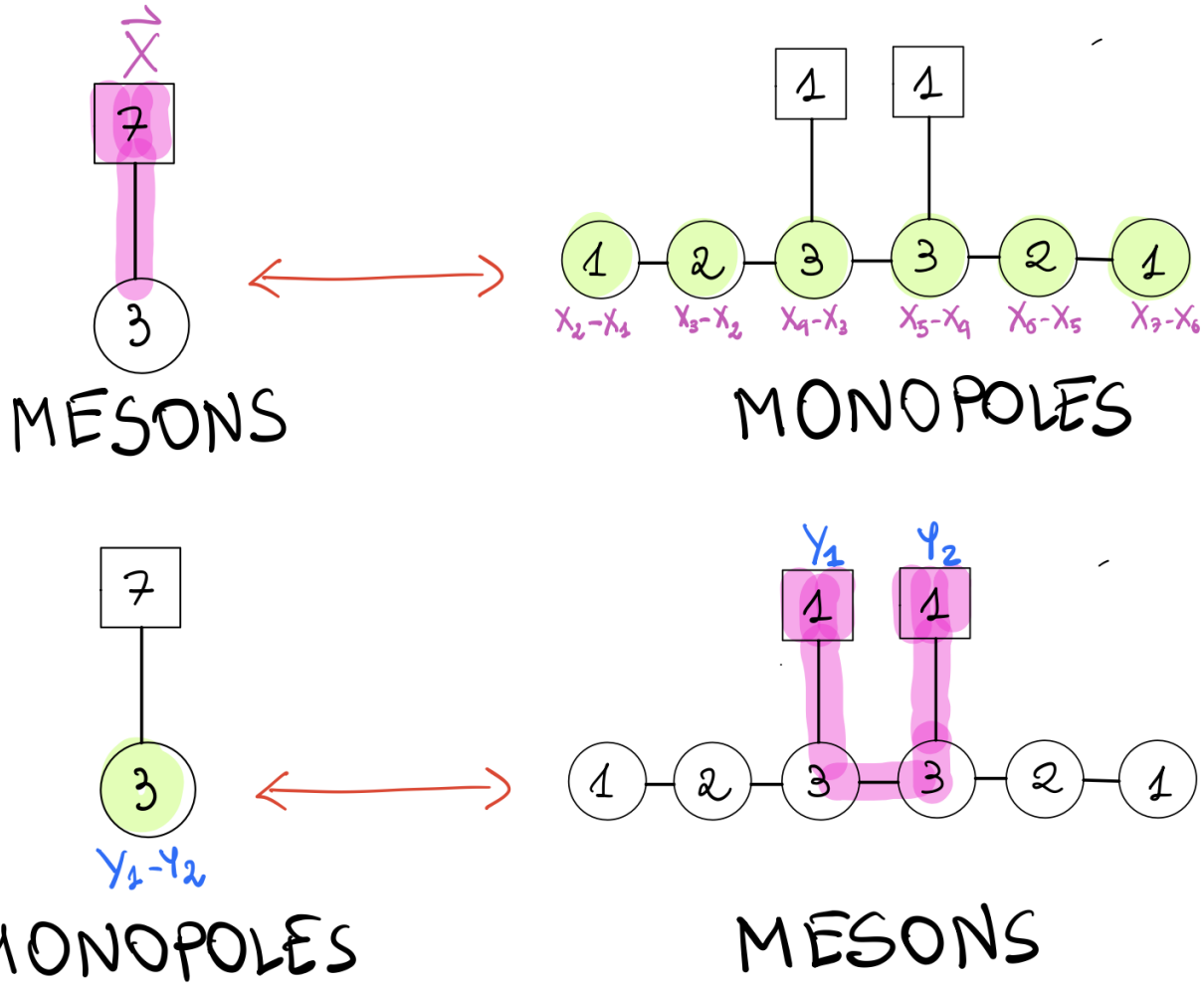
We will focus on 3d mirror dualities, first conjectured by [Intriligator-Seiberg'96] and much studied since then.

Large families of 3d $\mathcal{N} = 4$ theories can be realized in Type IIB with D3 branes suspended between NS and D5 branes: $SL(2, Z)$ duality in Type IIB string theory induces mirror dualities in 3d gauge theories [Hanany-Witten'96]:

For example, the $\mathcal{N} = 4$ $U(N)$ SQCD mirror pair is realised as:

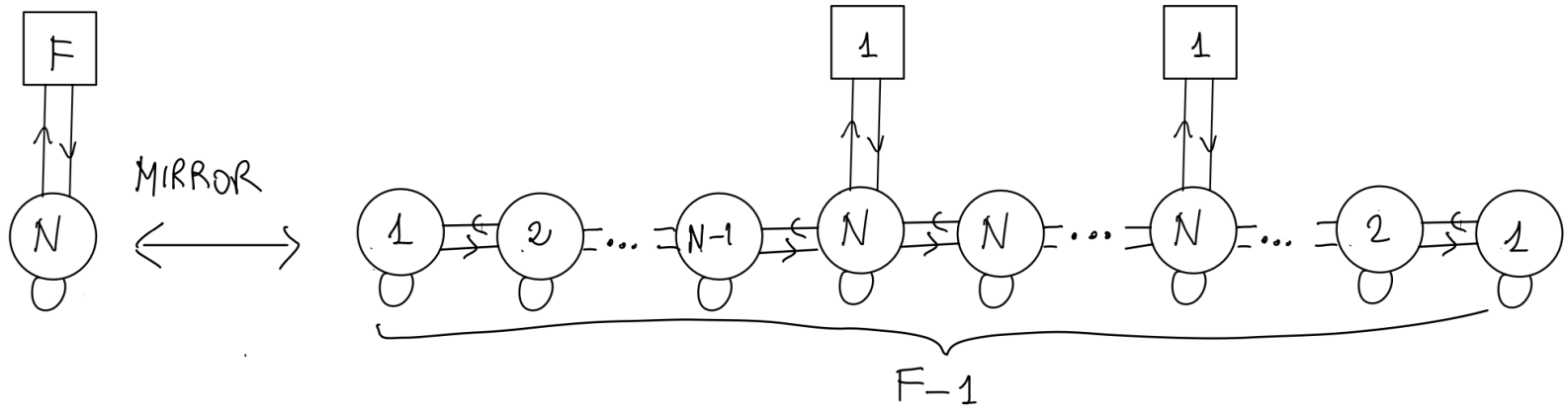


•Characteristic feature: flavor symmetries map to enhanced topolgical symmetries, mesons are mapped to monopoles, local disorder operators charged under the topological symmetry.



•There is now a purely field-theoretic derivation of mirror dualities in terms of a minimal set of basic Seiberg-like dualities, the so-called mirror dualization algorithm [Hwang-SP-Sacchi '21] (more on this later..).

Let's now start from our $\mathcal{N}=4$ SQCD mirror pair in the $\mathcal{N}=2^*$ set-up [Tong'00]:



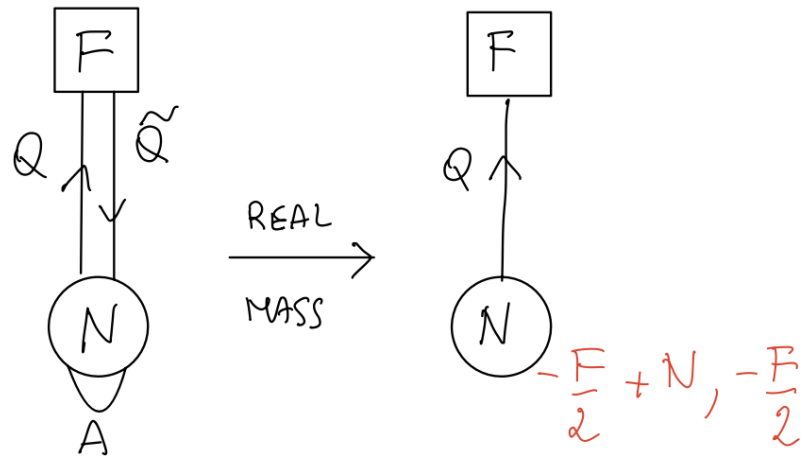
we take $U(1)_C \in SU(2)_C$ and $U(1)_H \in SU(2)_H$ of the non-Abelian $\mathcal{N}=4$ R-symmetry $SU(2)_C \times SU(2)_H$ and define

$$U(1)_R = U(1)_{C+H} \qquad \text{and} \quad U(1)_\tau = U(1)_{H-C},$$

What happens if we turn on a large real mass $U(1)_\tau$ breaking $\mathcal{N}=4 \to \mathcal{N}=2$?

On the electric we assign $U(1)_\tau$ axial charges $1, -\frac{1}{2}, -\frac{1}{2}$ to $A, Q, \tilde{Q}$, naively the deformation integrates out all the matter fields leaving a TQFT.

We move onto the Coulomb branch to reach an interacting vacuum, for example we can land on the chiral SQCD:

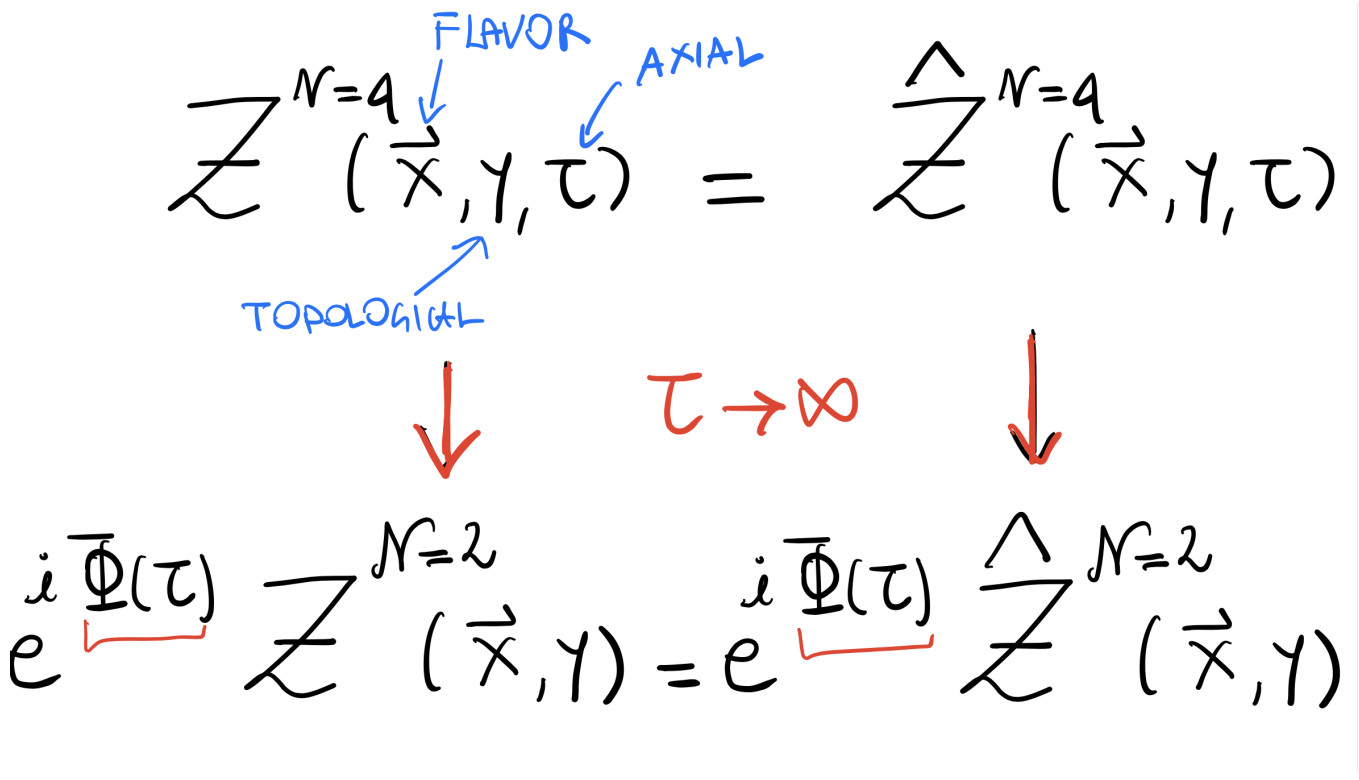


- All the fund. chirals remain massless.
- Each antifund. is integrated out, generating $-1/2$ CS-level.
- The adjoint is integrated out yielding a N CS level only for $SU(N) \subset U(N)$.

In the mirror dual we can move in many possible ways on the Coulomb branch (many gauge groups) to keep some matter fields massless...

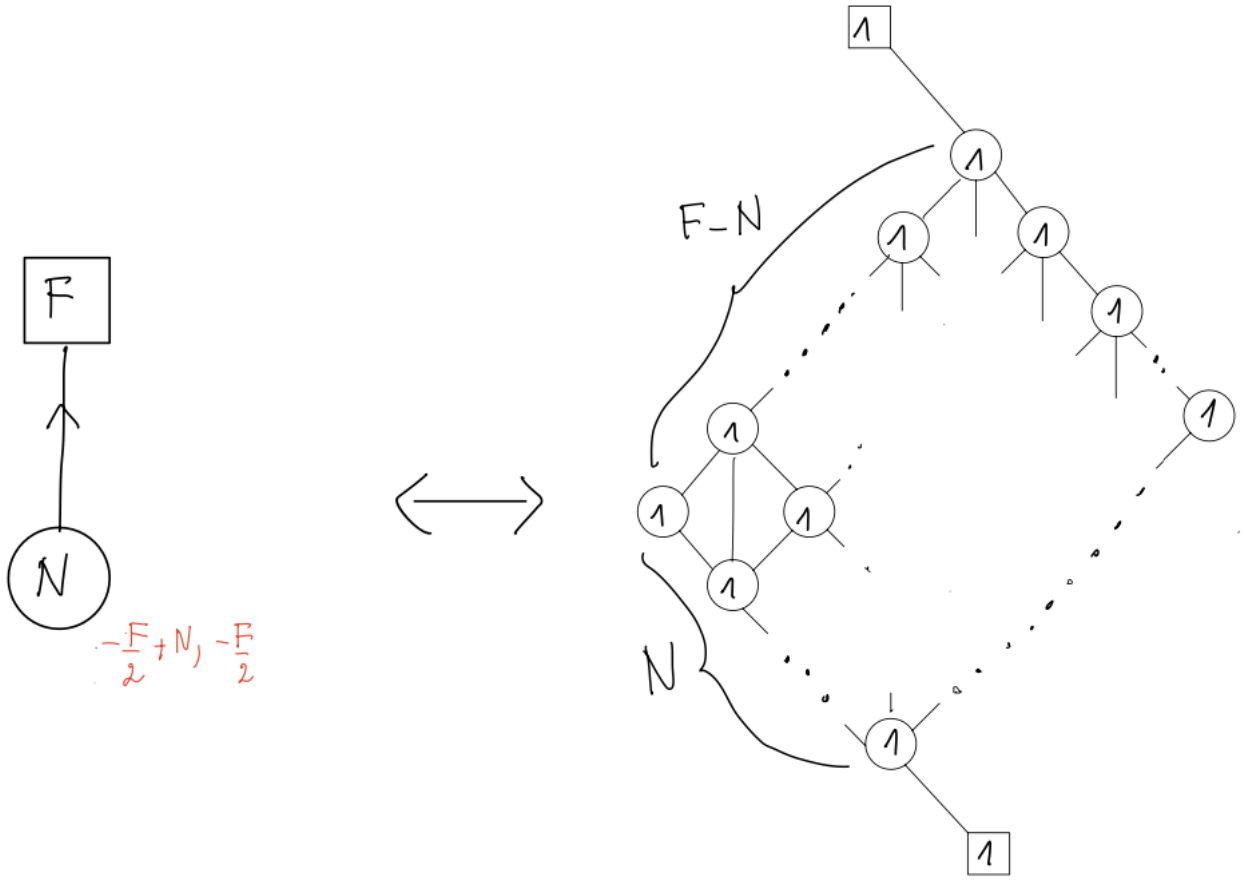
...How can we be sure we are on the dual of the deformed theory?

An important clue comes from the study of the S^3_b partition function [Kapustin-Willett-Yaakov '10, Hama-Hosomichi-Lee '11]:



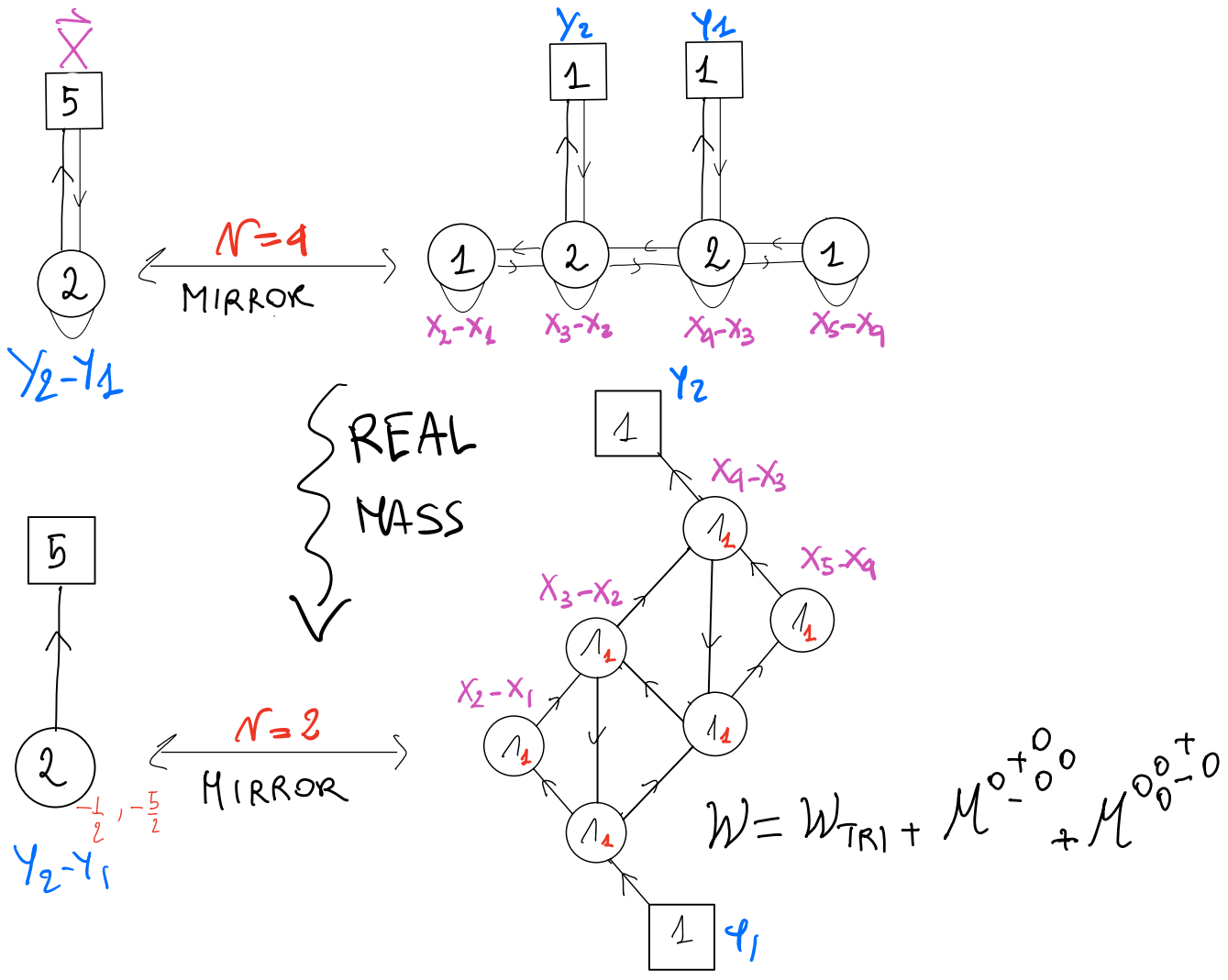
Following [Benini-Closset-Cremonesi '11, Aharony-Razamat-Seiberg-Willett '13] we identify the dual vacuum as the one with matching oscillatory phase!

Surprise: the mirror dual of the chiral SQCD is a completely abelian and planar quiver theory!



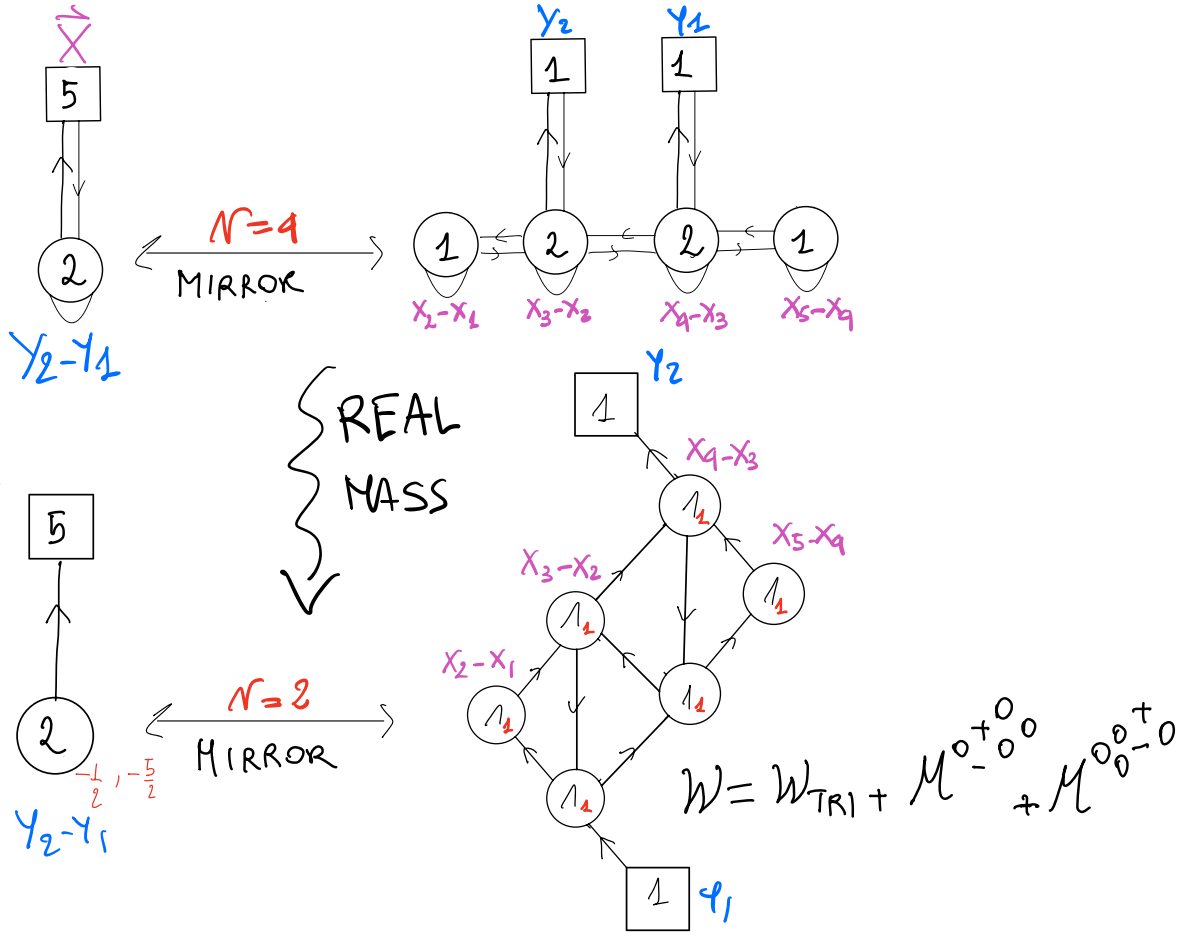
- This is the dual with the matching phase $\Phi(\tau)$.
- Every $U(k)$ gauge group is Higgsed to $U(1)^k$.
- Matching of the superconformal index for low values of N and F (thanks to the knowledge of exact parameter map).

Let's consider the $U(2)$ SQCD with $F = 5$ flavors:



- A monopole superpotential for each column is generated.
- $\mathcal{W}_{\text{TRI}}$ denotes cubic couplings among chirals in triangular loops.
- All nodes have CS-level 1 and there are mixed CS couplings.
- All data are encoded in the planar quiver.

The chiral SQCD has a manifest $SU(5) \times U(1)$ global symmetry:

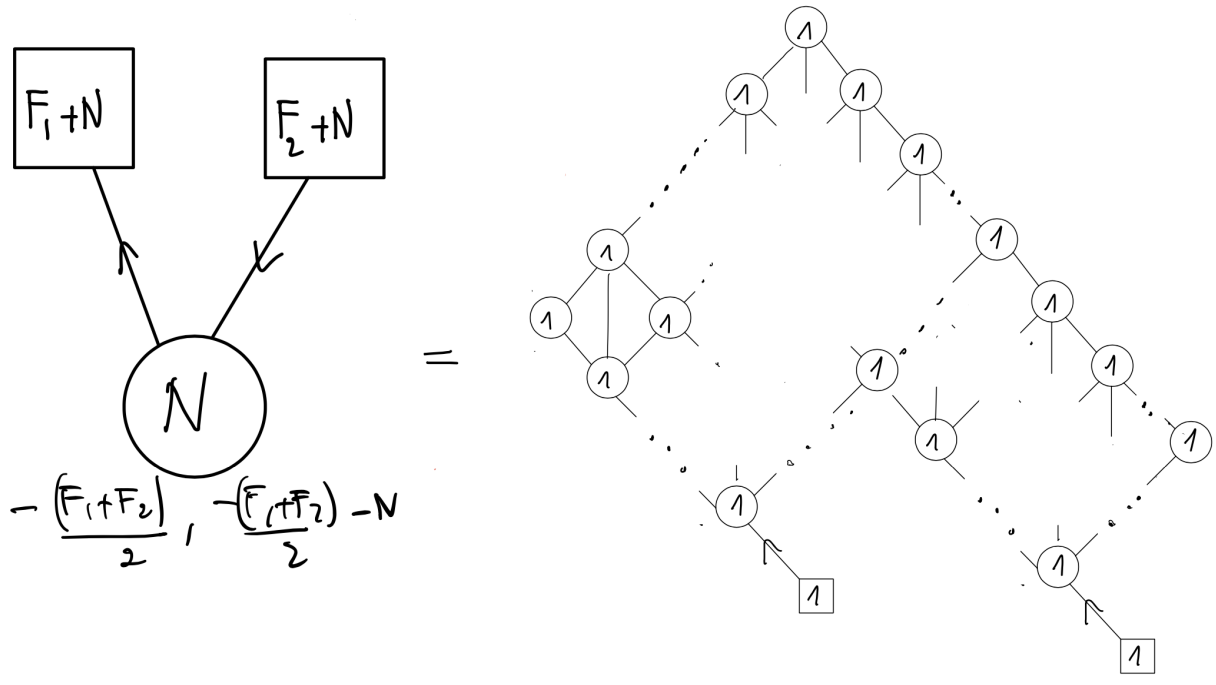


On the mirror side this is realized as:

- Flavor symmetry reduced by $\mathcal{W}_{\text{TRI}}$ and gauge transf. to $U(1)$.
- Monopole superpotential breaks $U(1)^k_{\text{top}} \to U(1)_{\text{top}}$ in each column. Then there is enhancement: $U(1)^{F-1}_{\text{top}} \to SU(F)$.

Mirror-like map: The SQCD single gauge invariant (dressed) monopole maps to the only meson in the dual (up to F-term relations).

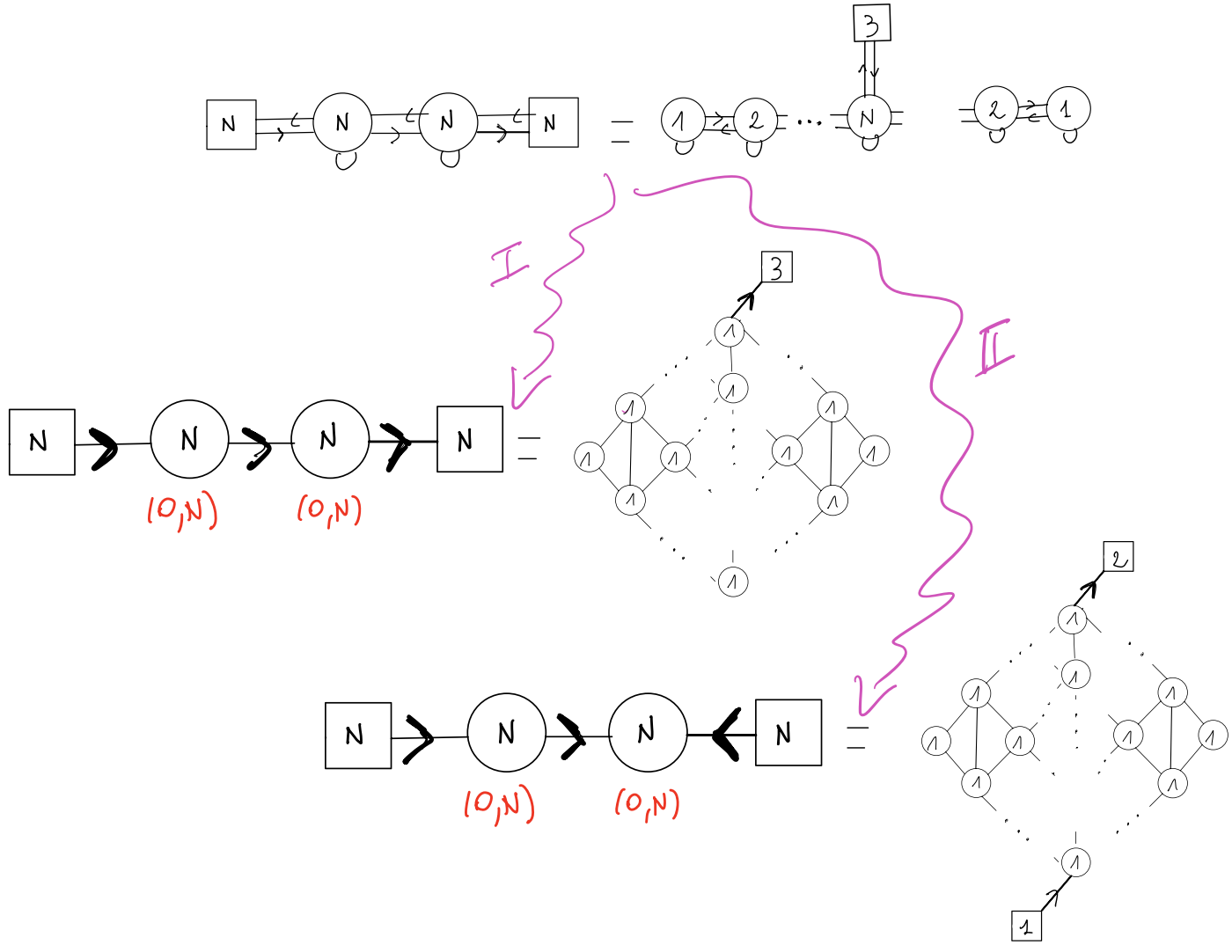
Starting from $\mathcal{N} = 4$ theories we can perform real mass deformations preserving different amounts of fund. and antifund. chirals.
For example:



we can then perform further real masses to access more general CS levels.

Identifying the corresponding vacuum on the mirror dual side remains quite subtle!

The signs of the arrows play a crucial role, there is a notion of balanced nodes and symmetry enhancement:



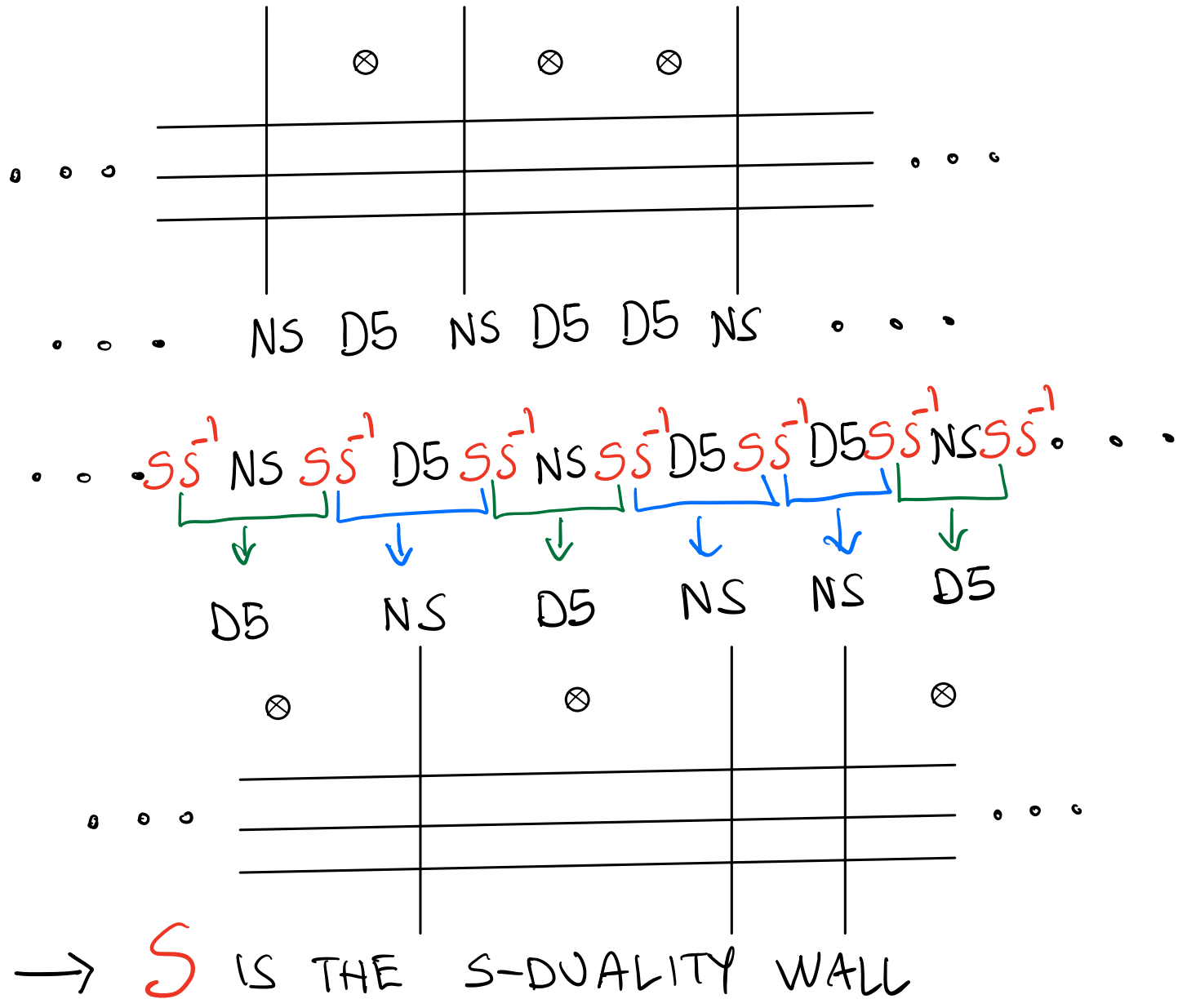
The procedure of starting from $\mathcal{N} = 4$ mirror pairs and performing real masses is effective, but undeniably tedious and complicated,

it's like finding a needle in a haystack!

What we seek instead is a more systematic and streamlined strategy to find the planar dual of a chiral quiver.

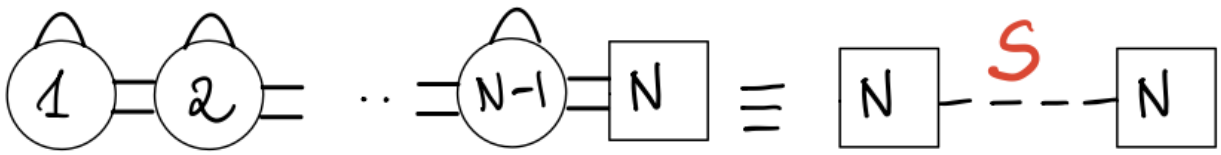
$\mathcal{N} = 4$ (and recently some $\mathcal{N} = 2$) mirror dualities can be derived by means of the mirror dualization algorithm.

On a brane setup engineering a 3d $\mathcal{N} = 4$ quiver, we can perform S-duality locally on each 5-brane: [Gaiotto-Witten'08]

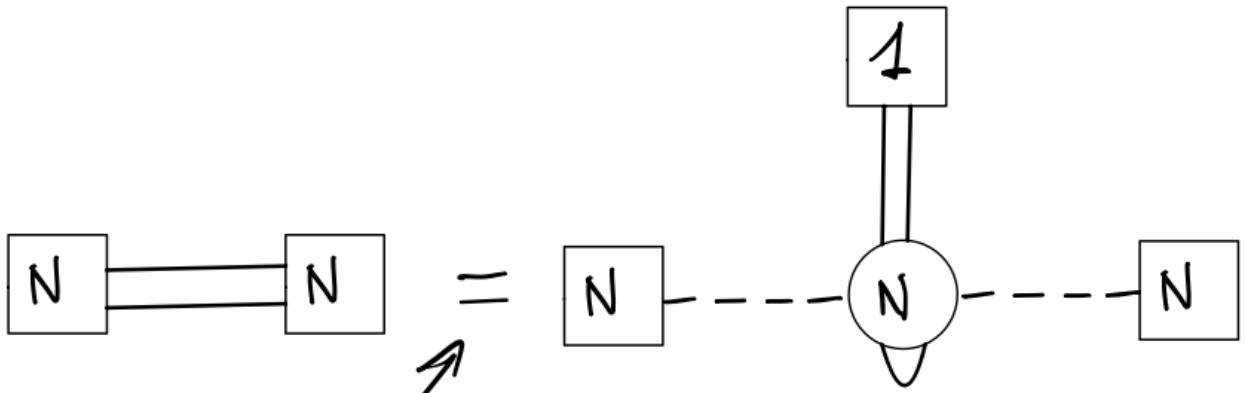


The mirror dualization algorithm implements at the field theory level the local action of S-duality [Hwang-SP-Sacchi '21]:

- S IS REALIZED BY THE GAIOTTO-WITTEN T[SU(N)]:

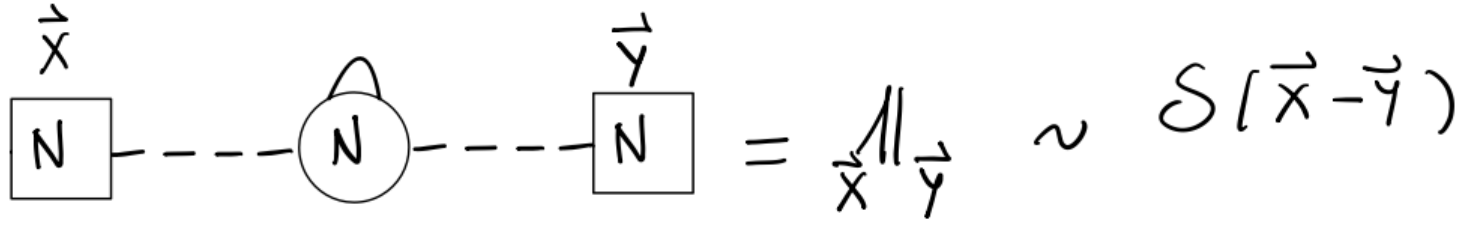


- BASIC DUALITY MOVE NS = S^{-1} D5 S:

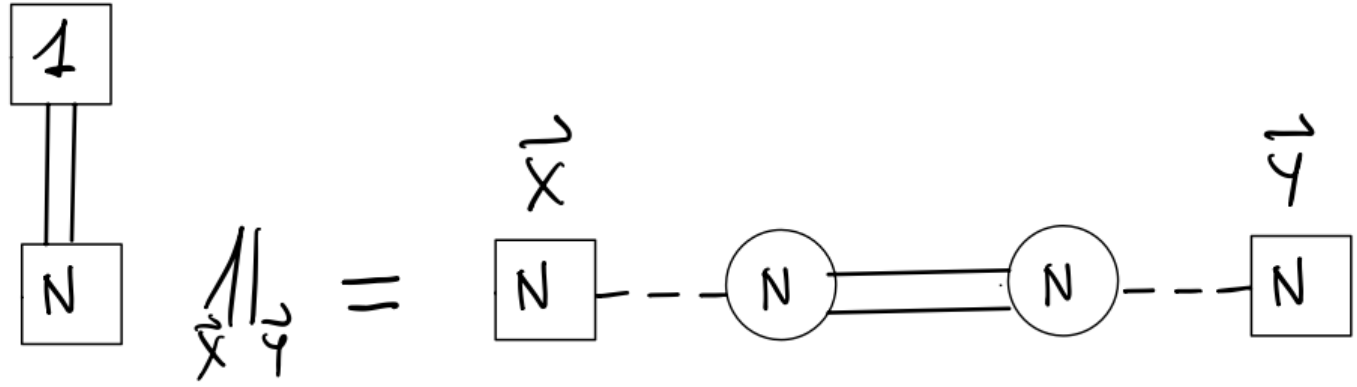


IR DUALITY PROOF ASSUMES ONLY SEIBERG-LIKE DUALITIES

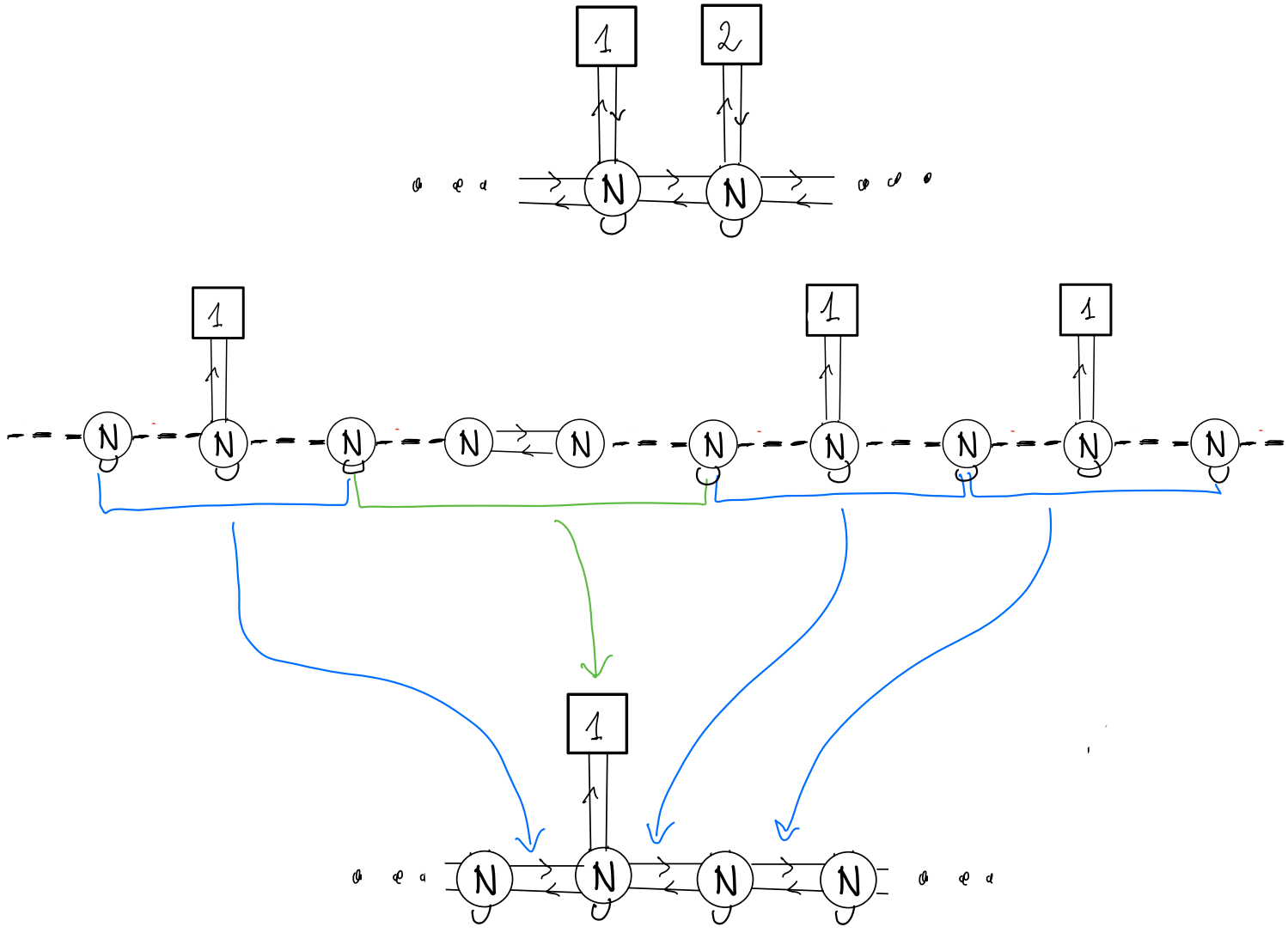
- FUSION TO IDENTITY $SS^{-1} = 1$:



- INVERSE DUALITY MOVE $DS = S^{-1}NSS$:



The dualization algorithm at work:



→ FOR NON-CONST. RANKS, IMPLEMENT SEQUENTIAL HIGGSING USING HW DUALITY MOVES

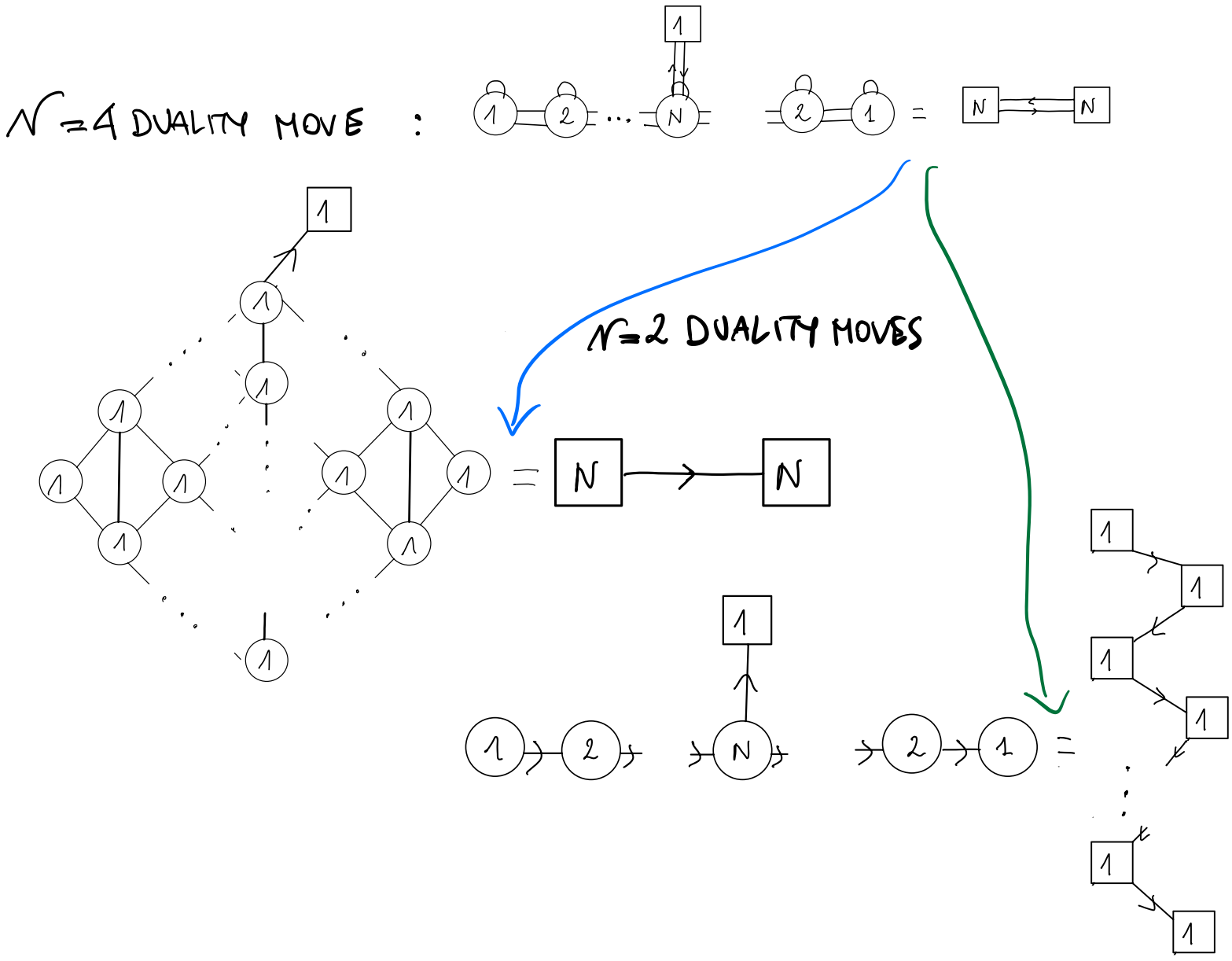
The dualization algorithm:

- Provides a purely field-theoretical proof of mirror dualities assuming only basic Seiberg-like dualities.
- Can be implemented at the level of indices/partition functions, yielding integral identities.
- Provides the exact map of all fugacities and all the background CS-couplings.

Generalizations:

- Algorithm for $SL(2,\mathbb{Z})$ dualities [Comi-Hwang-Marino-SP-Sacchi '22]
- Algorithm for bad theories [Giacomelli-Hwang-Marino-SP-Sacchi '23,'24], for USp theories [Comi-Giacomelli-Garavaglia-SP, in progress], for star-shaped quivers [Comi-Giacomelli-Garavaglia-SP-Singh,'25].
- Algorithm for $\mathcal{N}=2$ dualities with generalized quivers [Benvenuti-Comi-SP '23].

We established a dualization algorithm to generate abelian planar duals. All $\mathcal{N} = 4$ ingredients (blocks and moves) have $\mathcal{N} = 2$ counterparts. For example, the basic move becomes:

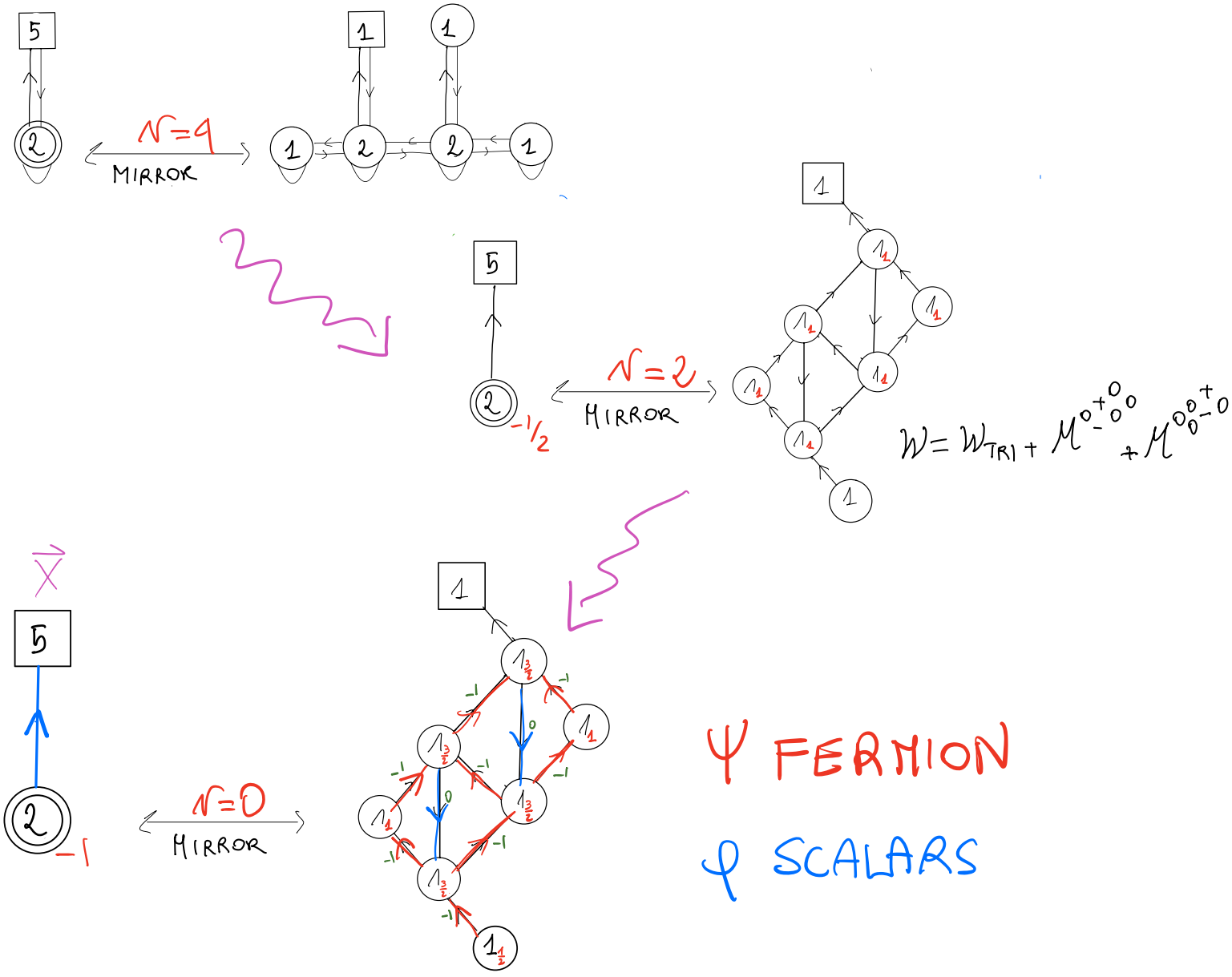


The algorithm systematically constructs the abelian planar dual of a generic chiral theory.

This suggests that abelian-planar duality is a much broader phenomenon than originally anticipated.

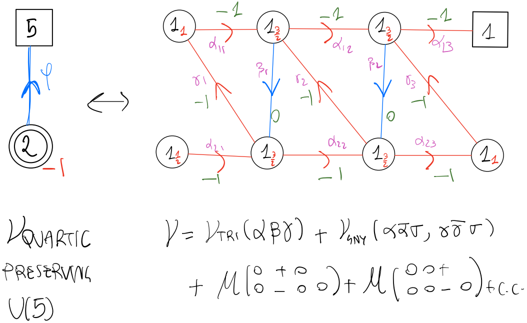
Can this paradigm survive without supersymmetry?

Let's try to perform a further deformation to $\mathcal{N} = 0$, we give negative/positive mass to fermions on the chiral/planar side:



Disclaimer: We did not perform a detailed analysis of the RG flow induced by the SUSY-breaking deformation, instead, we used it to formulate our proposal.

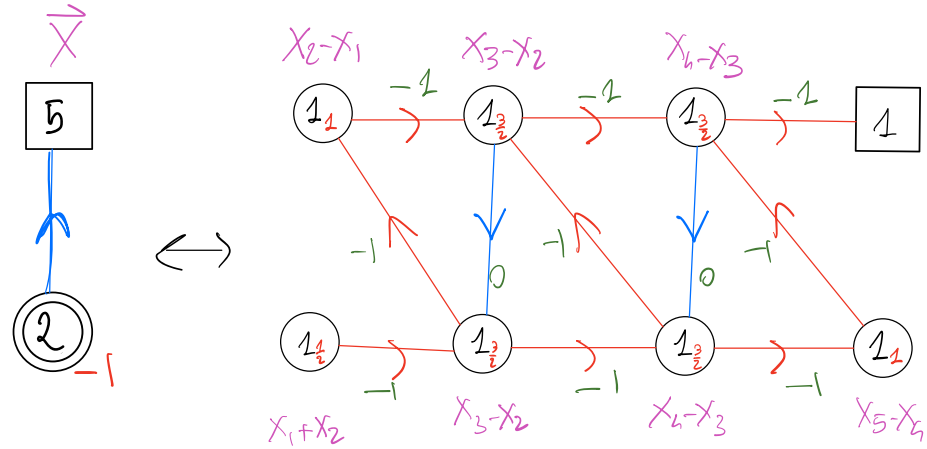
We then tested this proposal by establishing an operator map and checking its consistency under further massive deformations.



On the planar side:

- No mesonic symmetries: #Lines-#Gauge nodes-#Triangles $= 0$.
- Monopole interaction breaks to $U(1)^{N_s}_{top}$ the topological symmetry, then we claim it further enhances as $U(1)^{N_s}_{top} \to U(N_s)/\mathbb{Z}_N$.

Operator map:



25 MESONS — SPIN ZERO DRESSED MONOPOLES

$\varphi_2 \bar{\varphi}_1 \longleftrightarrow \mathcal{M}$

$\varphi_3 \bar{\varphi}_1 \longleftrightarrow \mathcal{M}$

⋮

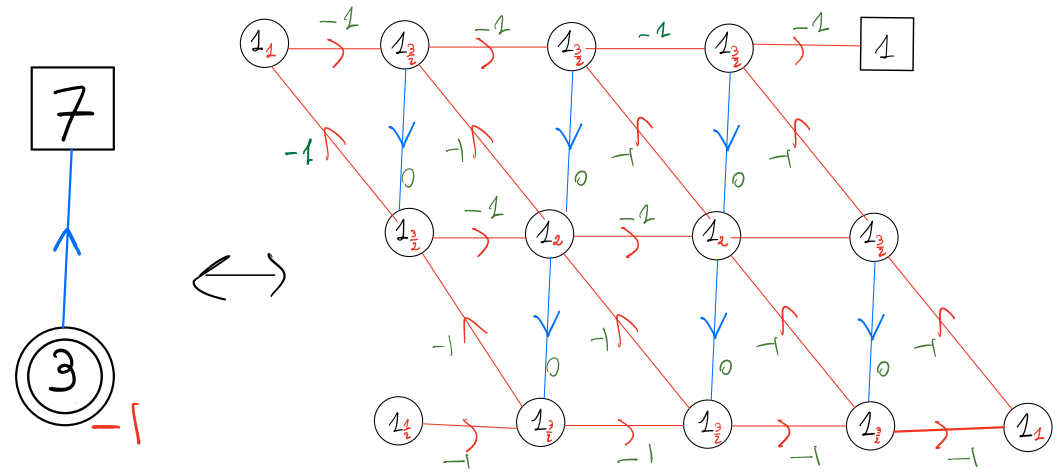
10 BARIONS — SPIN ZERO DRESSED MONOPOLES

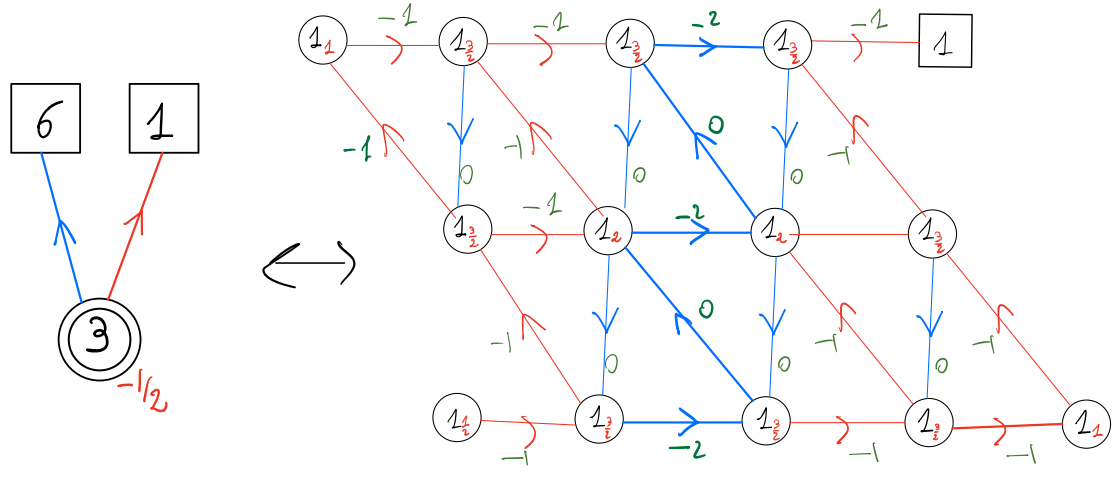
$\varphi_2 \varphi_1 \longleftrightarrow \mathcal{M}$

⋮

(CURRENTS $\longleftrightarrow$ SPIN ONE MONOPOLES)

More general duals with bosons and fermions:





It appears that by trading a boson for a fermion,
a fermionic column on the planar side is bosonized.

Conclusions and outlook

Non-abelian 3d Chern-Simons dynamics can often be encoded in completely abelian planar quivers

$\mathcal{N} = 2$ duals arise either from real-mass deformations of known $\mathcal{N} = 4$ mirror pairs or from the chiral-planar dualization algorithm.

The same structure appears to extend beyond supersymmetry. We proposed planar duals for $\mathcal{N} = 0$ QCD with bosons and fermions and provided a consistent operator map.

- Can we find an abelian-planar dual for every 3d Chern-Simons matter theory? See also recent work [Benvenuti-Comi-Pedde Ungureanu-Rota-Shri'26], [Benvenuti-Cagioni-Rota-Shri'26].
- Is there a stringy realization of chiral-planar dualities, as hinted by the structure of the algorithm?
- Line operators in chiral-planar dualities.
  [Benvenuti-Brolis-Cagioni-Garavaglia-Rota-SP, in progress].