MAX-PLANCK-GESELLSCHAFT

Dimers & Orientifolds

Daniel Krefl
(MPI Munich)

in collaboration
with

Sebastian Franco, Amihay Hanany, Jaemo Park, Angel M. Uranga and David Vegh

based on

arXiv: 0707.0298

Motivation

What we want:

The low-energy gauge theory of a bunch of D3-branes probing an arbitrary orientifolded toric CY singularity.

Motivation

What we want:

The low-energy gauge theory of a bunch of D3-branes probing an arbitrary orientifolded toric CY singularity.

Why we want it:

- Expect DSB theories without runaway.
- Orientifold projection crucial for D-instanton induced couplings.
- To enjoy the (expected) beauty of the construction.

Motivation

What we want:

The low-energy gauge theory of a bunch of D3-branes probing an arbitrary orientifolded toric CY singularity.

Why we want it:

- Expect DSB theories without runaway.
- Orientifold projection crucial for D-instanton induced couplings.
- To enjoy the (expected) beauty of the construction.

How to obtain it:

Extending dimer technics!

Recap of Dimers

Recall:

Low-energy gauge theory of a bunch of D3-branes probing flat space is N=4 SYM with superpotential:

$$W = \Phi_1 \Phi_2 \Phi_3 - \Phi_1 \Phi_3 \Phi_2$$

(Note: Traces are implicit in this talk!)

MAX-PLANCK-GESELLSCHAFT

Recap of Dimers

Recall:

Low-energy gauge theory of a bunch of D3-branes probing flat space is N=4 SYM with superpotential:

$$W = \Phi_1 \Phi_2 \Phi_3 - \Phi_1 \Phi_3 \Phi_2$$

Note:

Each field occurs exactly twice. Once in a positive and once in a negative term!

Recap of Dimers

Especially:

This property is preserved under orbifolding and higgsing (i.e. blowdowns)!

=> Hence, is a characteristic of gauge theories arising from probes of toric CY singularities!

Recap of Dimers

Especially:

This property is preserved under orbifolding and higgsing (i.e. blowdowns)!

=> Hence, is a characteristic of gauge theories arising from probes of toric CY singularities!

=> Allows to give isomorphisms between the superpotential and bipartite graphs!

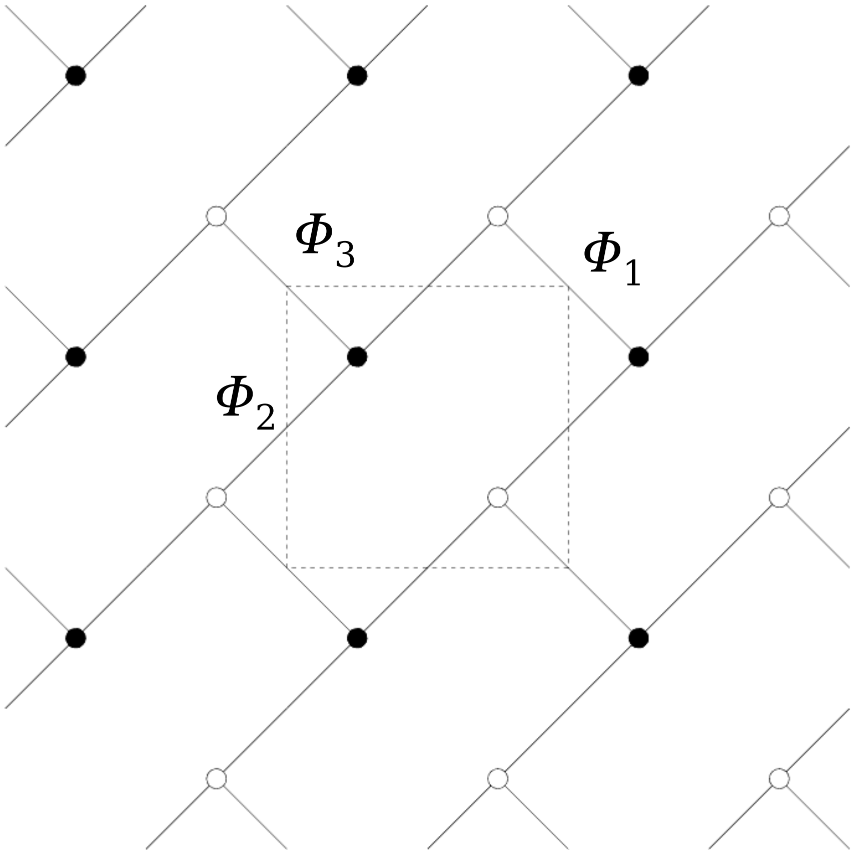
Recap of Dimers

The Dimer:

Bipartite graph on a torus:

Vertices	:	Superpotential terms
Edges	:	Fields
Faces	:	Gauge groups

[Franco, Hanany, Kennaway, Vegh and Wecht '05]



Example: $\mathbb{C}^3$

Recap of Dimers

MAX-PLANCK-GESELLSCHAFT

The Dimer:

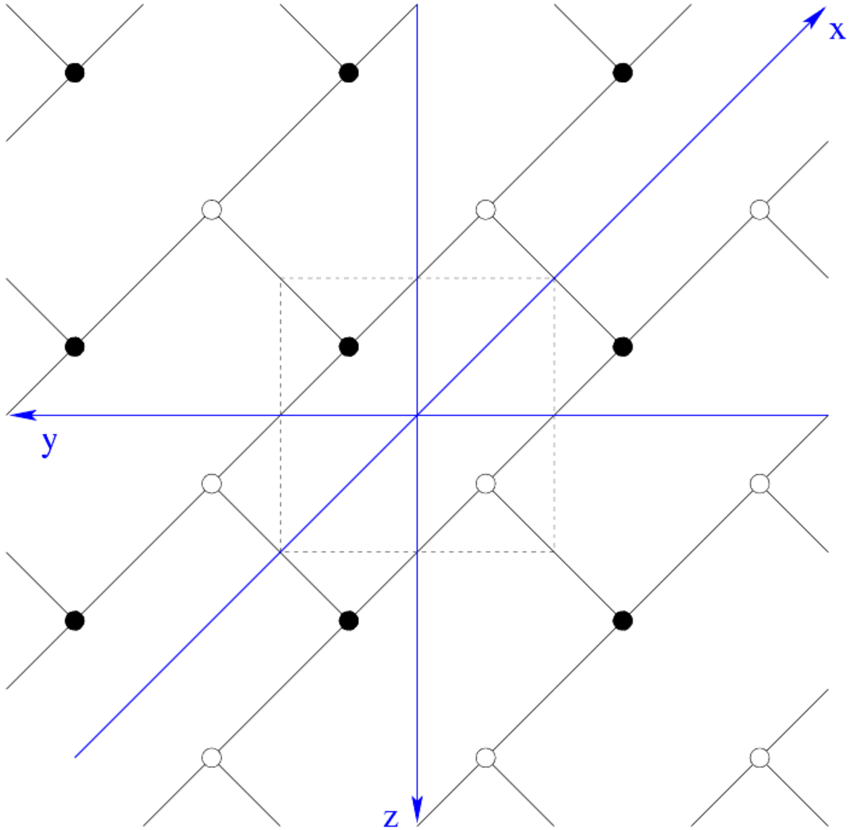
Bipartite graph on a torus:

Vertices	:	Superpotential terms
Edges	:	Fields
Faces	:	Gauge groups

[Franco, Hanany, Kennaway, Vegh and Wecht '05]

Mesonic operators:

Closed loops running through faces



$Example\!: \mathbb{C}^3$

Orientifolds

Recall:

The orientifold action is given by: $\omega\,\sigma\,(-1)^{F_L}$

(i.e. worldsheet orientation reversal + involution of the internal background)

Orientifolds

Recall:

The orientifold action is given by: $\omega\,\sigma\,(-1)^{F_L}$

(i.e. worldsheet orientation reversal + involution of the internal background)

Up to recently:

Appart from orbifolds and generalized conifolds, only a few other orientifolded D3-probe models were constructed via higgsing.

But: In general higgsing becomes very quickly very messy!

Orientifolds

Recall:

The orientifold action is given by: $\omega\,\sigma\,(-1)^{F_L}$

(i.e. worldsheet orientation reversal + involution of the internal background)

Up to recently:

Appart from orbifolds and generalized conifolds, only a few other orientifolded D3-probe models were constructed via higgsing.

But: In general higgsing becomes very quick very messy!

TODO:

Let's find a better way via dimers!

Orientifolding Dimers

Tactic:

Translate known orientifolds of simple theories to the dimer, and hopefully there is some systematics!

Orientifolding Dimers

Tactic:

Translate known orientifolds of simple theories to the dimer, and hopefully there is some systematics!

Simplest example:

Flat space! A possible geometric action:

$$\sigma(x,y,z) \rightarrow (-x,-y,-z)$$

Orientifolding Dimers

MAX-PLANCK-GESELLSCHAFT

Tactic:

Translate known orientifolds of simple theories to the dimer, and hopefully there is some systematics!

Simplest example:

Flat space! A possible geometric action:

$$\sigma(x,y,z)\rightarrow(-x,-y,-z)$$

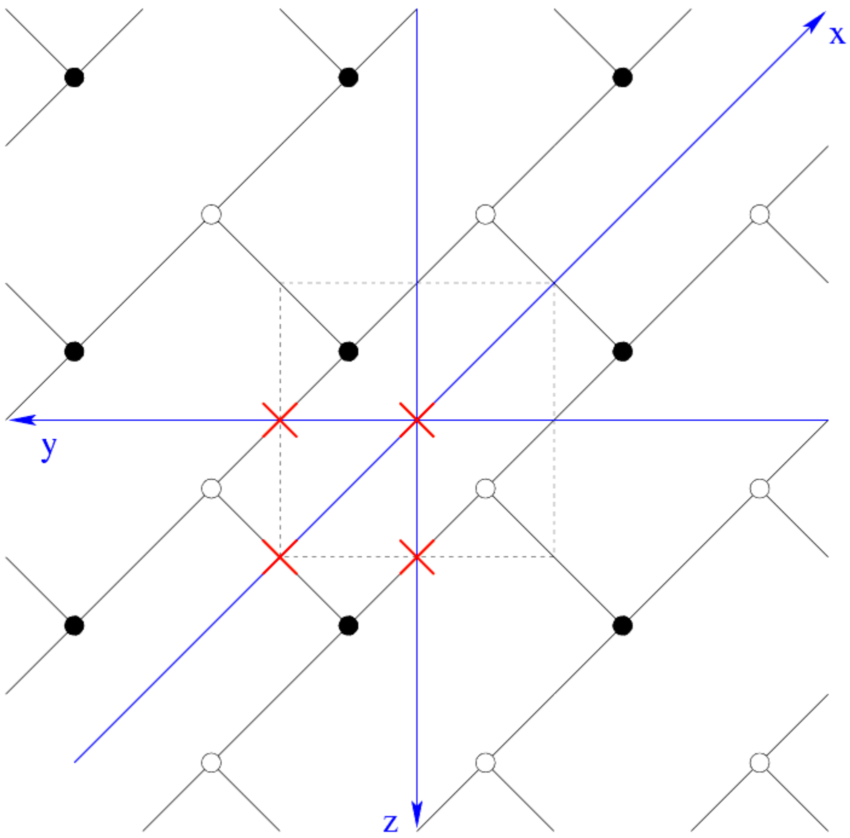
How can one infer the "qualitatively" corresponding action on the dimer ?

=> Use the mesonic operators corresponding to the coordinates !
(Note: Sign transformation will be more involved due to mixture with Chan-Paton action!)

Orientifolding Dimers

Action on the dimer:

Point reflection !



Orientifolding Dimers

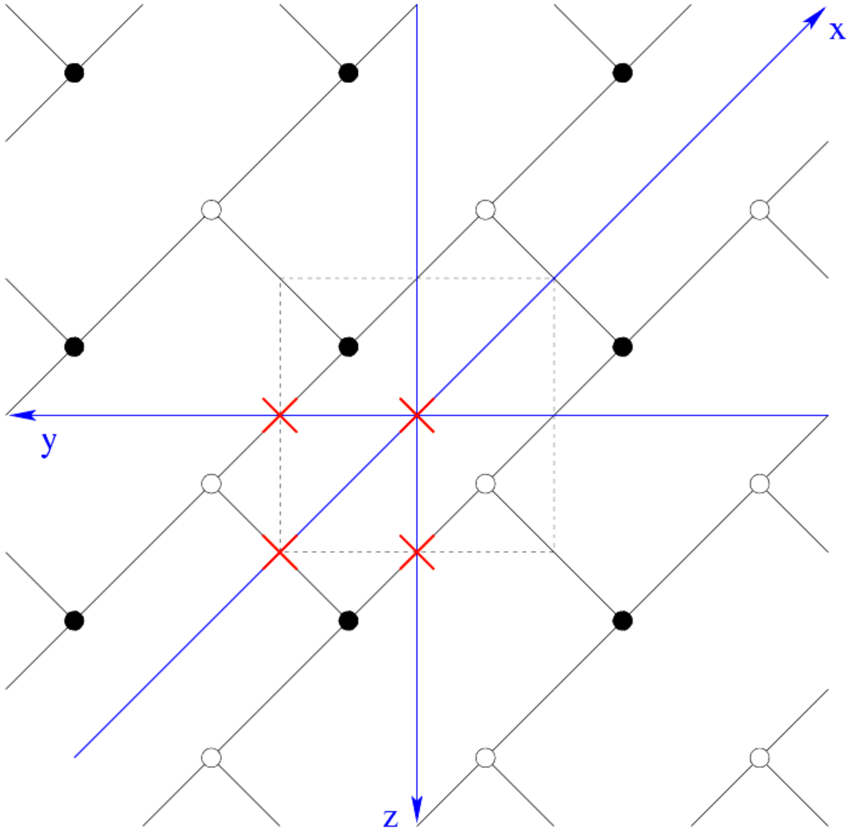
Action on the dimer:

Point reflection !

Under the reflection:

Faces mapped to themselves:
=> Enhanced gauge groups!

Edges mapped to themselves:
=> 2-tensors!



Orientifolding Dimers

Action on the dimer:

Point reflection !

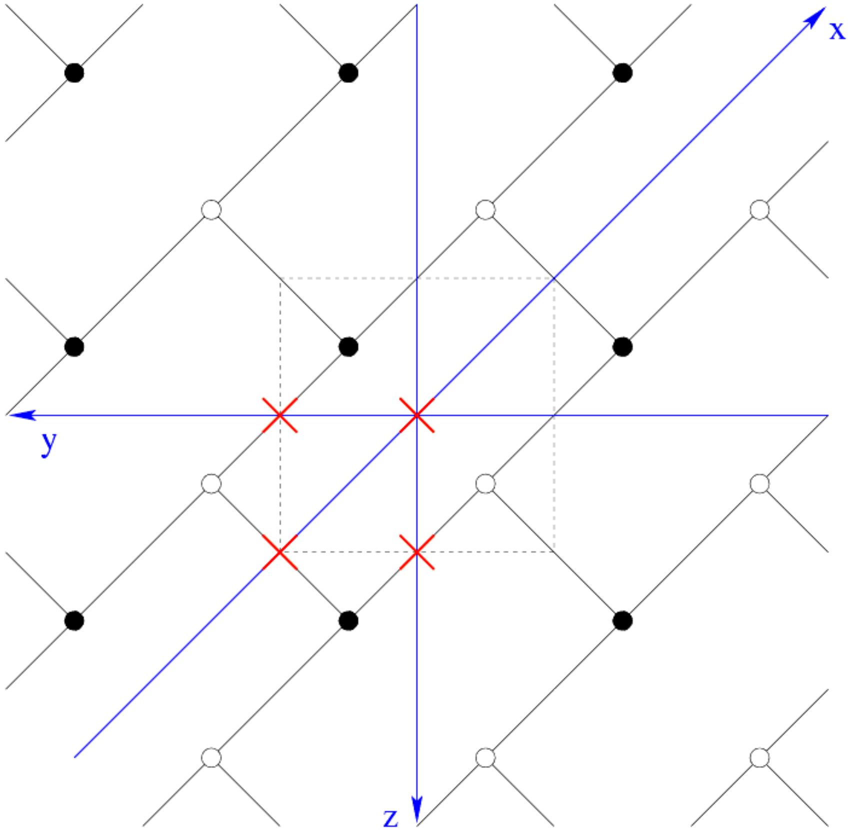
Under the reflection:

Faces mapped to themselves:
=> Enhanced gauge groups!

Edges mapped to themselves:
=> 2-tensors!

Note:

We can have at most four fixed elements!



Orientifolding Dimers

Chan-Paton action:

How to determine **SO** vs. **Sp** and **symmetric** vs. **anti-symmetric** ?

Orientifolding Dimers

Chan-Paton action:

How to determine **SO** vs. **Sp** and **symmetric** vs. **anti-symmetrics** ?

Sign assignment:

Assign signs to the fixed points !

(Note: They do not necessarily correspond to physical charges)

Orientifolding Dimers

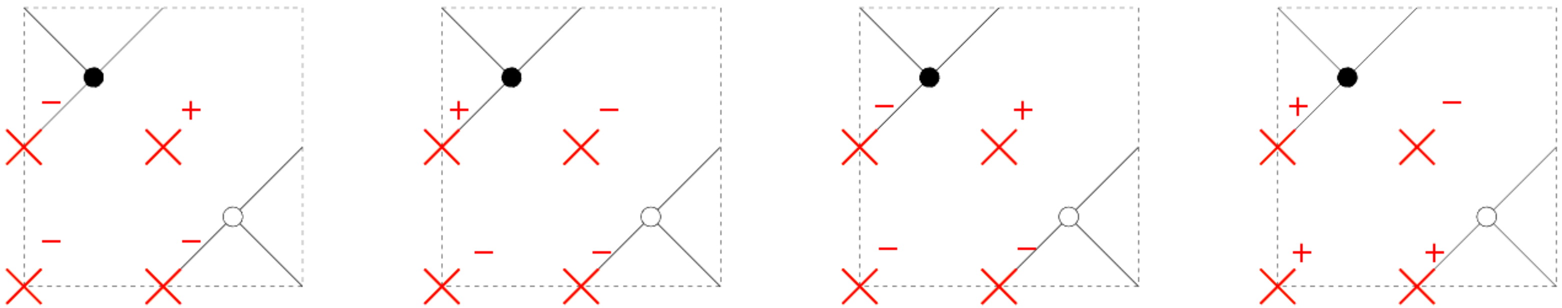
Chan-Paton action:

How to determine **SO** vs. **Sp** and **symmetric** vs. **anti-symmetrics** ?

Sign assignment:

Assign signs to the fixed points !
(Note: They do not need necessarily correspond to physical charges)

Example:



Reproduce known SUSY orientifolds of flat space! => We are on the right track!

Orientifolding Dimers

What about even sign setups ?

=> Non-susy models !

What about even sign setups ?

=> Non-susy models !

=> Introduce global constraint on signs:

For 2k superpotential terms, k mod 2 determines if an even or odd sign setup preserves susy!

Orientifolding Dimers

What about even sign setups ?

=> Non-susy models !

=> Introduce global constraint on signs:

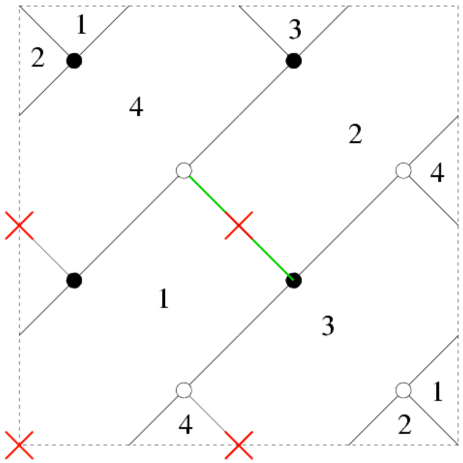
For 2k superpotential terms, k mod 2 determines if an even or odd sign setup preserves susy!

Why does this hold in general ?

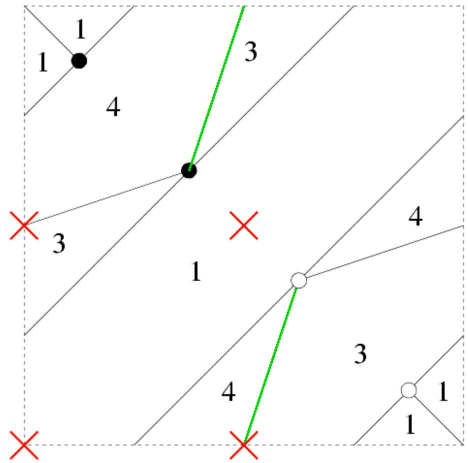
The constraint is compatible with higgsing!

Orientifolding Dimers

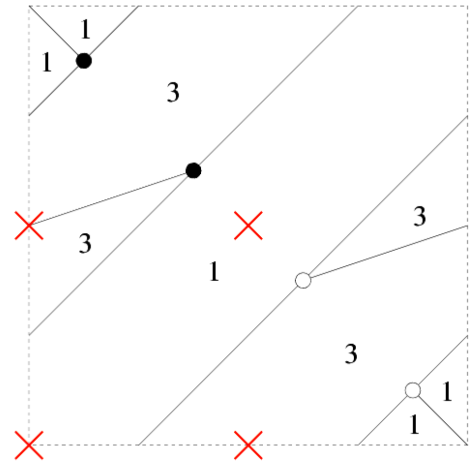
Some more examples:



$\mathbb{C}^3/(\mathbb{Z}_2 x \mathbb{Z}_2)$



SPP



$\mathbb{C}^2/\mathbb{Z}_2 x\ \mathbb{C}$

This almost trivially reproduces the orientifold models obtained originally via higgsing in [Park, Rabadan, and Uranga '00]

Orientifolding Dimers

What about other involutions?

It seems that the point reflections correspond to involutions sending all coordinates to themselves up to sign.

What about involutions exchanging coordinates?

For example in flat space:

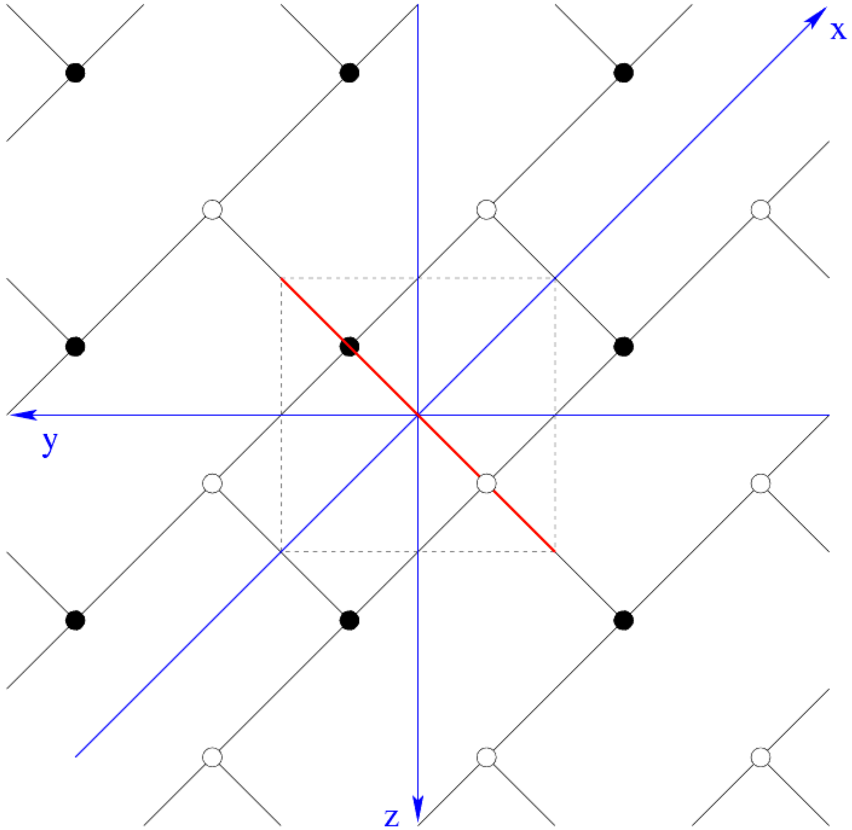
$$\sigma(x,y,z)\to(x,z,y)$$

Orientifolding Dimers

Action on the dimer:

Line reflection !

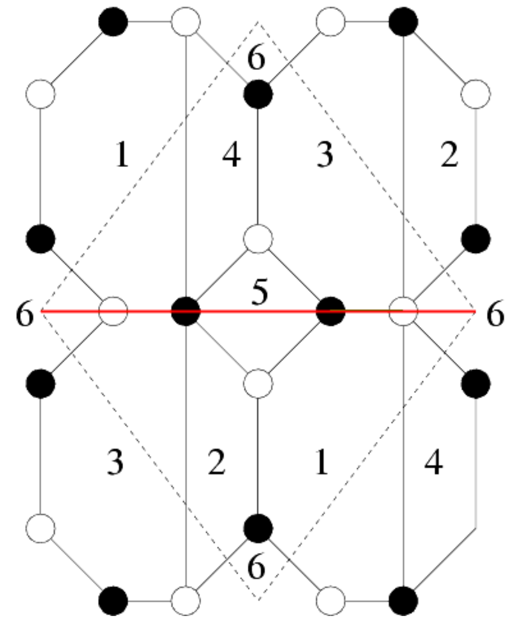
The rest is as before,
but there is no global sign
constraint !



Orientifolding Dimers

Another example:

dP_3^{II}



Something to be aware of:
In some models anomaly cancellation might require the introduction of extra D7-branes!

Orientifolding Dimers

Pre-conclusion:

- We have our recipe to obtain orientifolds of arbitrary toric CY 3-folds!
- One can recover in this way essentially all known orientifolded models + many more!

Orientifolding Dimers

MAX-PLANCK-GESELLSCHAFT

Pre-conclusion:

- We have our recipe to obtain orientifolds of arbitrary toric CY 3-folds!
- One can recover in this way essentially all known orientifolded models + many more!

What I haven't told:

- We were also able to conjecture rules for the meson sign transformations!
- There is also a mirror IIA intersecting brane description a la [Hori, Vafa '00] [Feng, He, Kennaway and Vafa '05]

MAX-PLANCK-GESELLSCHAFT

Application I: DSB

DSB models:

Recently, there were some attempts to construct known field theory models which feature DSB via branes at orientifolded singularities.
[Antebi and Volansky '07] [Wijnholt '07]

Application I: DSB

DSB models:

Recently, there were some attempts to construct known field theory models which feature DSB via branes at orientifolded singularities.
[Antebi and Volansky '07] [Wijnholt '07]

This should be straight forwardly achievable via our new dimer tools!

Application I: DSB

DSB models:

Recently, there were some attempts to construct known field theory models which feature DSB via branes at orientifolded singularities.
[Antebi and Volansky '07] [Wijnholt '07]

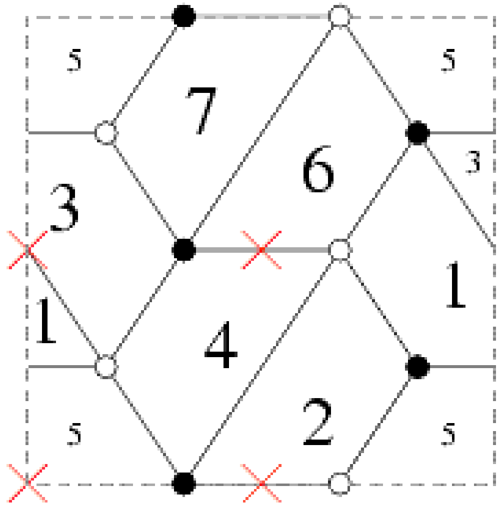
This should be straight forwardly achievable via our new dimer tools!

Indeed:

We can easily construct consistently such models.

Application I: DSB

Example:



PdP_4^I

Choosing,

$$n_2 = n_4 = 0, n_5 = N, n_1 = N + 4$$

we obtain the well-known SU(5) model with chiral 10+5 which features DSB
[Affleck, Dine and Seiberg '84]

Application II: D-instantons

Recall:

A contribution to the 4D superpotential can only be generated by a stringy D-instanton if it possesses 2 uncharged fermionic zero modes.

=> In absence of fluxes or other zero mode lifting mechanisms, only O(1) D-instantons can contribute!
[see Ibanez, Schellekens, Uranga '07 for a general discussion]

Application II: D-instantons

Recall:

A contribution to the 4D superpotential can only be generated by a stringy D-instanton if it possesses 2 uncharged fermionic zero modes.

=> In absence of fluxes or other zero mode lifting mechanisms, only O(1) D-instantons can contribute!
[see Ibanez, Schellekens, Uranga '07 for a general discussion]

Integration over the charged zero modes will then induce a non-trivial superpotential contribution, if a suitable coupling between the charged zero modes and a 4D chiral operator is present!
[Ganor '96]

Application II: D-instantons

=> To solve:

- Finding the invariant cycles which support proper D-instantons.
- Inferring if suitable couplings between the charged zero modes and 4D chiral fields are present.

Might the dimer be helpful for that too ?

Application II: D-instantons

=> To solve:

- Finding the invariant cycles which support propper D-instantons.
- Inferring if suitable couplings between the charged zero modes and 4D chiral fields are present.

Might the dimer be helpful for that too ?

Dimers & D-instantons:

Yes. It becomes (almost) trivial to find stringy instanton contributions to the superpotential in local models.

Why?

Application II: D-instantons

D-instantons in local models:

For obvious reasons, we consider only D-instantons with compact support:

Fractional D-instantons, i.e. bound states of D(-1), E1 and E3 instantons.

MAX-PLANCK-GESELLSCHAFT

Application II: D-instantons

D-instantons in local models:

For obvious reasons, we consider only D-instantons with compact support:

Fractional D-instantons, i.e. bound states of D(-1), E1 and E3 instantons.

=> Map to faces in the dimer.
(If the face is simultaneously occupied by a fractional brane, this gives a gauge instanton)

MAX-PLANCK-GESELLSCHAFT

Application II: D-instantons

D-instantons in local models:

For obvious reasons, we consider only D-instantons with compact support:

Fractional D-instantons, i.e. bound states of D(-1), E1 and E3 instantons.

=> Map to faces in the dimer.
(If the face is simultaneously occupied by a fractional brane, this gives a gauge instanton)

=> Instanton face should be on top of a fixed point/line with minus sign!

Application II: D-instantons

D-instantons in local models:

For obvious reasons, we consider only D-instantons with compact support:

Fractional D-instantons, i.e. bound states of D(-1), E1 and E3 instantons.

=> Map to faces in the dimer.
(If the face is simultaneously occupied by a fractional brane, this gives a gauge instanton)

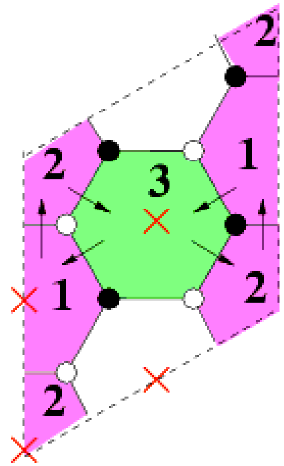
=> Instanton face should be on top of a fixed point/line with minus sign!

=> Possible couplings are then easy to infer!

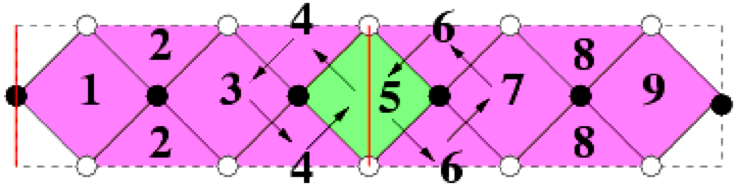
Application II: D-instantons

Examples:

We can straight forwardly reproduce



$\mathbb{C}^3/(\mathbb{Z}_2 x \mathbb{Z}_2)$



$Conifold/\mathbb{Z}_5$

[Argurio, Bertolini, Franco and Kachru '07]

[Argurio, Bertolini, Ferretti, Lerda and Peterson'07]

Conclusion

The message (you should remember):

Dimers present the so far most powerful (and simplest) tool to investigate the low-energy gauge theory of D3-branes probing an arbitrary (orientifolded) toric singularity!