New developments in 5d SCFTs and 5-brane webs

Sung-Soo Kim
University of Electronic Science and Technology
2019-07-23
@APCTP, Pohang

Based on works with
Hirotaka Hayashi, Kimyeong Lee, Futoshi Yagi, and Hee-Cheol Kim

Plan of talk

- Review of 5d N=1 superconformal theories (SCFTs)

  Patrick's talk

- String theory construction of 5d SCFTs: 5-brane webs

- Recent development:

5d superconformal theories (SCFTs)

5d N=1 Supersymmetric gauge theory

5d N=1 supersymmetric gauge theories with gauge group G: 8 supercharges

Spacetime symmetry:

$$SO(4,1) \times SU(2)_R$$

Particle contents for 5d N=1 theories with gauge group G

Matter content

Vector multiplet: $A_\mu, \phi; \quad \lambda$

Hypermultiplet: $q^A; \quad \psi$ (A=1,2 $SU(2)_R$ index)

Scalar VEVs parametrize

Coulomb branch is parametrized by vev of vec. mult. scalar ϕ

Higgs branch is parametrized by vev of hypermultiplet

Hanany, Sperling,Cabrera, Zafrir, Mekareeya, Yagi, …

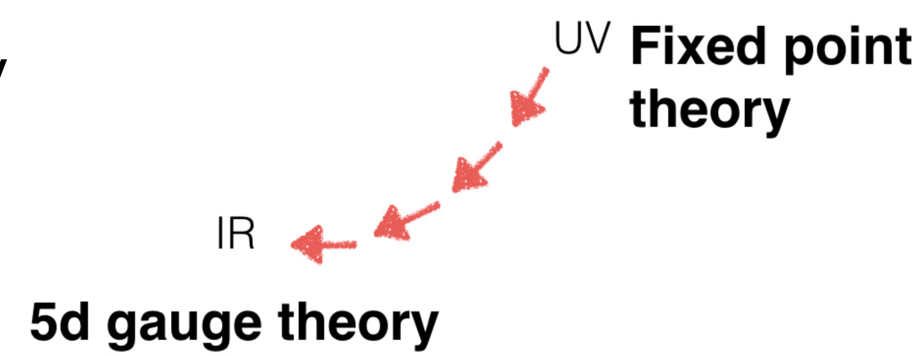
5d Superconformal theories (SCFTs)

Properties:

- only 8 supersymmetries: **N=1**
- Superconformal algebra F(4)
- Bosonic subalgebra: SO(5,2) x $SU(2)_R$
- It is strongly coupled at the conformal fixed points
- No marginal deformation
- Relevant deformation with mass parameters

$$\delta\mathcal{L} = -\frac{1}{4g_{YM}^2}F_{\mu\nu}F^{\mu\nu}$$

yielding gauge theory descriptions at low energy
(can flows to gauge theory in IR)



All are associated with global symmetries

[Cordova, Dumitesceu, Intriligator], ...

- some admits different relevant deformations: **duality** at the UV fixed point

5d Superconformal theories (SCFTs)

IR theory's point of view:
as the infinite coupling limit (of low E effective theory), a SCFT arises at UV fixed point.

In fact, a large class of 5d N=1 theories have **non-trivial UV fixed point**

[96 Seiberg]
[96 Morrison-Seiberg]
[97 Intriligator-Morrison-Seiberg]

At UV fixed point, **global symmetry is enhanced**

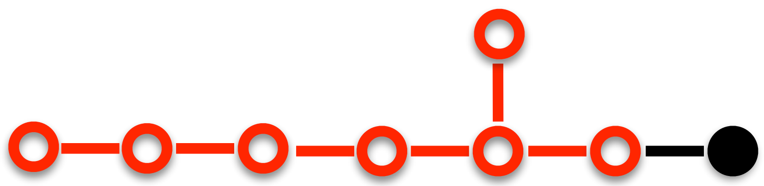
$$G_{\mathrm{Hypers}} \times U(1)_{\mathrm{Instantons}} \subset G_{\mathrm{Global}}$$

massless hypers + massless instanton

An example: $SU(2)$ theory with $N_f \leq 7$ hypermultiplets in fund. representation (flavors)

$$SO(2N_f) \times U(1)_I \subset E_{N_f+1}$$

flavor symmetry Instanton number



Prepotential

- Along the **Coulomb branch** (G -> U(1)$^{\mathrm{rank(G)}}$), the theory is described by abelian low energy effective theory which is characterized by prepotential.

- Prepotential is at most cubic and 1-loop exact:

$$\mathcal{F} = \frac{1}{2g_0^2} h_{ij}\phi^i\phi^j + \frac{\kappa}{6} d_{ijk}\phi^i\phi^j\phi^k + \frac{1}{12}\left(\sum_{\mathrm{Roots}} |R\cdot\phi|^3 - \sum_f \sum_{w\in W_f} |w\cdot\phi + m_f|^3\right)$$

$$h_{ij} = \mathrm{Tr}(T_iT_j),\ d_{abc} = \frac{1}{2}\mathrm{Tr}T_a(T_bT_c + T_cT_b), \quad W_f = \text{Weight of } G \text{ in the rep. } r_f$$

[96 Morrison-Seiberg]
[97 Intriligator-Morrison-Seiberg]

Magnetic monopole string tension: $\phi_{D_i} = \partial_i\mathcal{F}$

Effective coupling: $\tau_{ij} = \partial_i\partial_j\mathcal{F}$

Coulomb branch metric: $d^2s = \tau_{ij}\, d\phi^i d\phi^j$

An example: SU(2) Prepotential

- With massless hypers

$$\mathcal{F}_{SU(2)} = \frac{1}{g_0^2} a^2 + \frac{1}{6}(8 - N_f) a^3$$

Magnetic monopole string tension: $\phi_{D_i} = \partial_i \mathcal{F}$ $\qquad \frac{a}{2}\left(\frac{4}{g_0^2} + (8 - N_f)a\right)$

Effective coupling: $\tau_{ij} = \partial_i \partial_j \mathcal{F}$ $\qquad \frac{2}{g_0^2} + (8 - N_f)a$

Notice that $N_f > 8$, Coulomb branch is not well defined
—> theory is not well defined.

Leading to a way to classifying theories based on effective coupling

[97 Intriligator-Morrison-Seiberg]

Classifications

- **Coulomb branch metric (or effective coupling) is non-negative everywhere**

[Intriligator-Morrison-Seiberg]

: Intriligator-Morrison-Seiberg (IMS) classification / bound

However, many theories beyond the IMS bound were found

[Bergman, Zafrir, ….]

- **Subsector where monopole tensions are non-negative: Physical Coulomb branch.**

Coulomb branch metric (or effective coupling) is non-negative in physical Coulomb brach

[Jafferson, HC Kim, Vafa, Zafrir]

- **Geometric classification**
- **Classifying KK theories; combined fiber diagram**

[Jafferson, Katz, HC Kim, Vafa]
[Del Zotto, Heckman Morrison]
[Bhardwaj, Jefferson]

[Apruzzi, Lawrie, Lin, Schafer-Nameki, Wang]

Type IIB 5-branes

M-theory/String constructions

5d SCFTs can be engineered by M-theory or string theory.

M- theory on non-compact Calabi-Yau 3 fold (CY3)

[Witten'96],[Morrison,Seiberg'96],
[Douglas,Katz,Vafa'96]
[Katz,Klemm,Vafa'96],

M2 wrapping compact 2-cycles <==> BPS particle mass
= vol(2-cycles)

M5 wrapping compact 4-cycles <==> monopole string tension
= vol(4-cycles)

Type IIB 5-brane configuration

[Aharony,Hanany'97]
[Aharony,Hanany,Kol'97],
[DeWolfe,Hanany,Iqbal,Katz'99]

BPS configuration with D5 and NS5 branes with their bound states

Two descriptions are equivalent.

[Leung,Vafa'97]

Type IIB (p,q) 5-brane

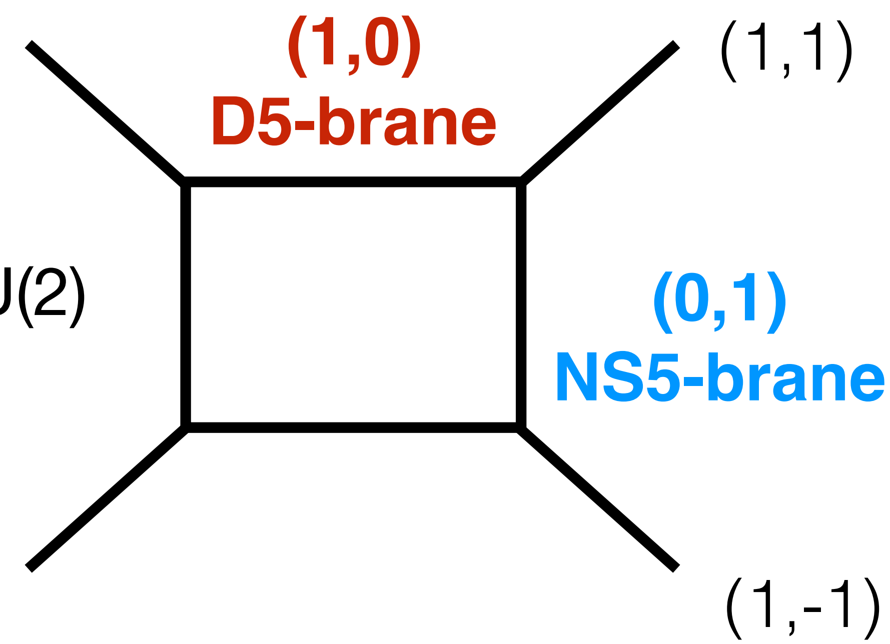
D5 and NS5 make a configuration looks like a web: **(p,q) 5-brane web**

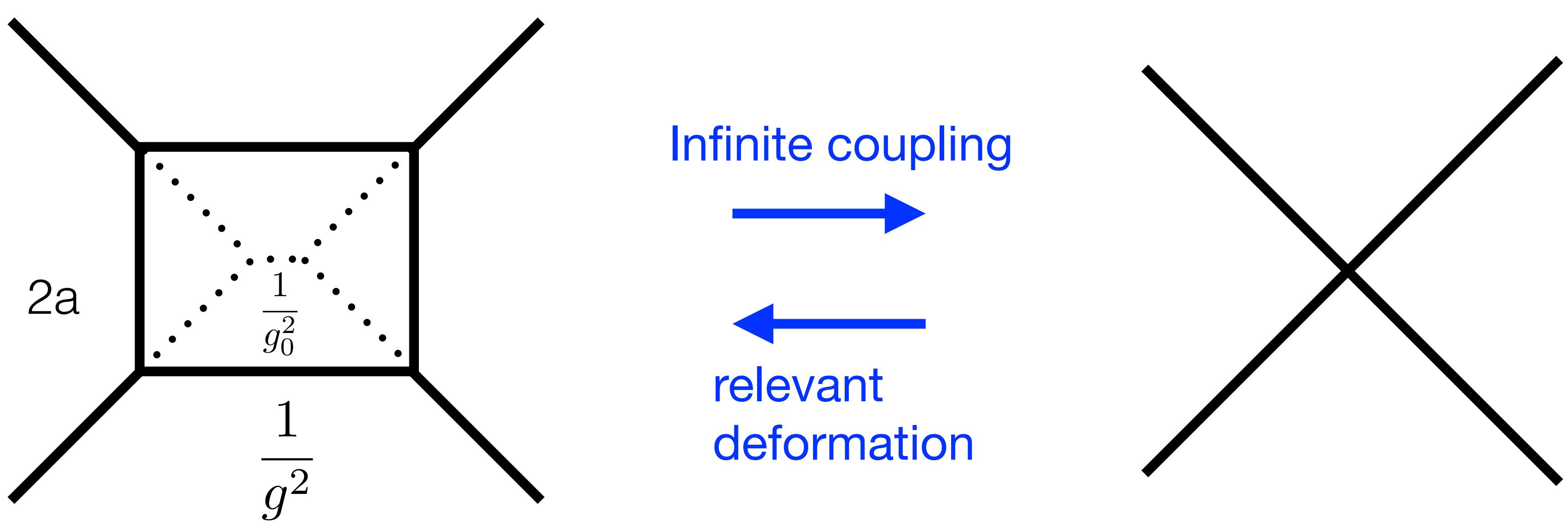
junctions with fixed angles and conserved charges

	0	1	2	3	4	5	6	7	8	9
NS5	x	x	x	x	x	x				
D5	x	x	x	x	x		x			
(p,q)	—	—	—	—	—	-	-			

5d world vol. (p,q) plane

e.g., pure SU(2)

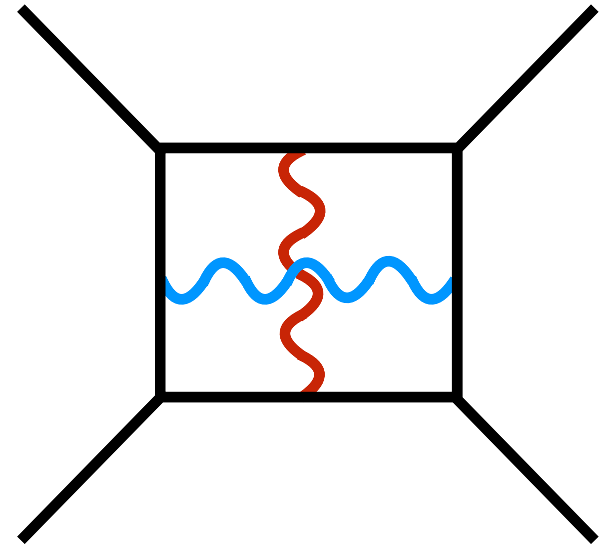




Coulomb branch **UV fixed point**

5-brane web and prepotential

- Coulomb branch : a = < ϕ >/2



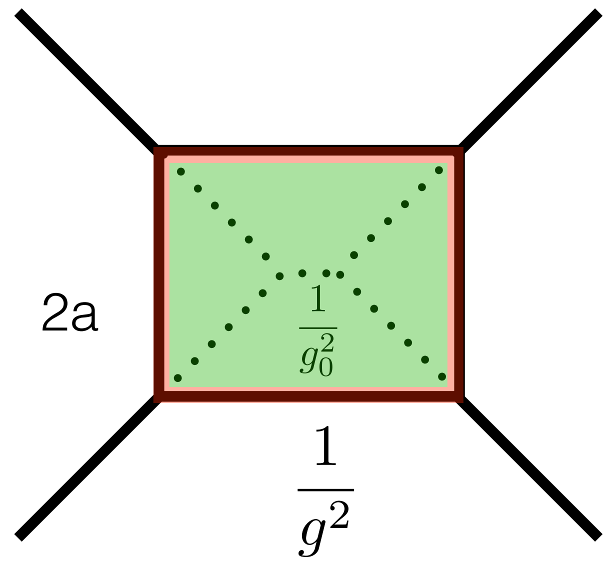
F1 SU(2) **W-bosons**

D1 SU(2) **Instantons**

- **Monopole string tension**

$$\phi_{D_i} = \partial_i \mathcal{F}$$

Area = D3 brane



- **Effective couplings**

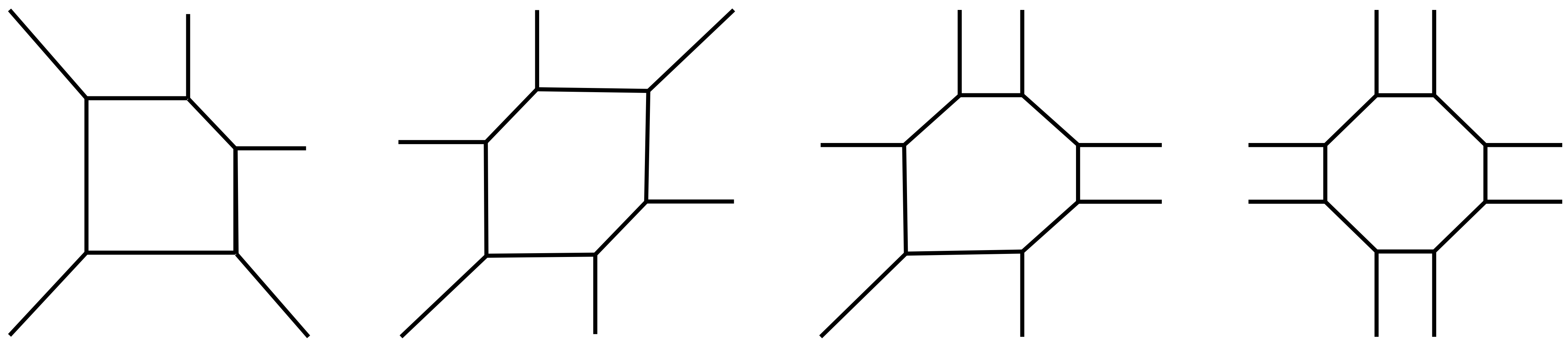
$$\tau_{ij} = \partial_i \partial_j \mathcal{F}$$

circumference / perimeter

(if the brane configuration is known)
prepotential can be reconstructed from 5-brane webs

Rank 1 theories

SU(2) theory with $N_f \leq 7$ flavors

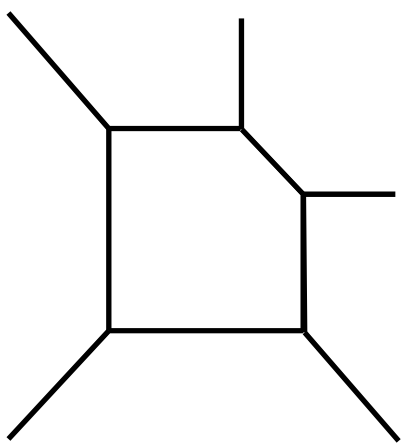


$N_f = 1$ $N_f = 2$ $N_f = 3$ $N_f = 4$

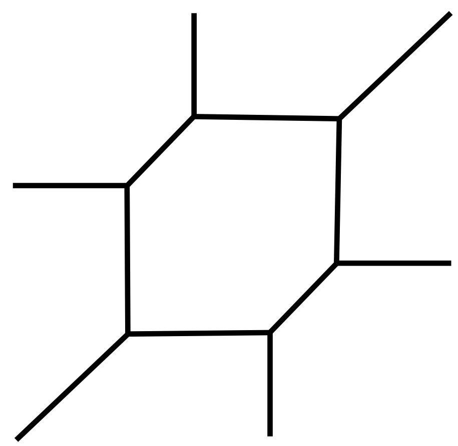
For other cases, a bit more complicated but possible,
by introducing 7-branes (where 5-branes end)

Rank 1 theories

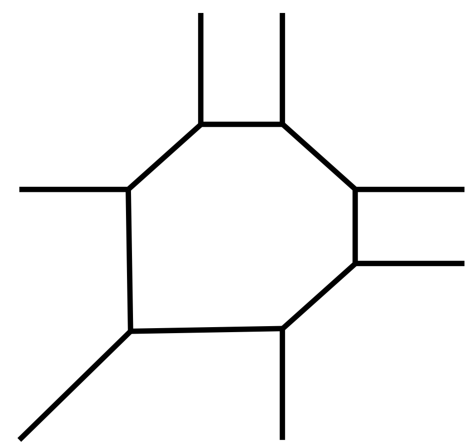
SU(2) theory with $N_f \leq 7$ flavors



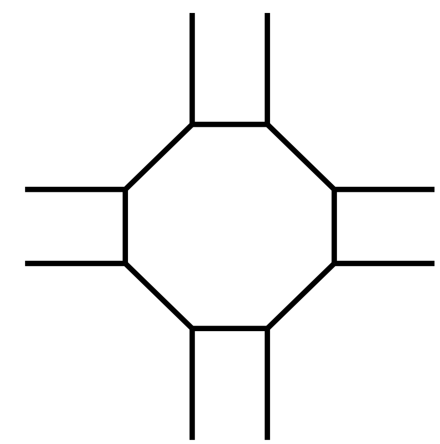
$N_f = 1$



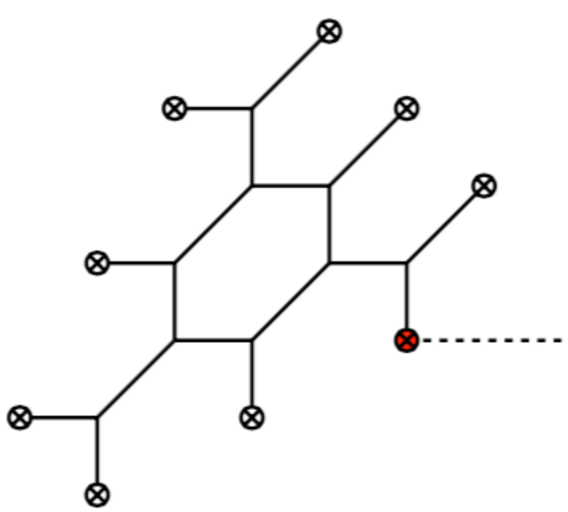
$N_f = 2$



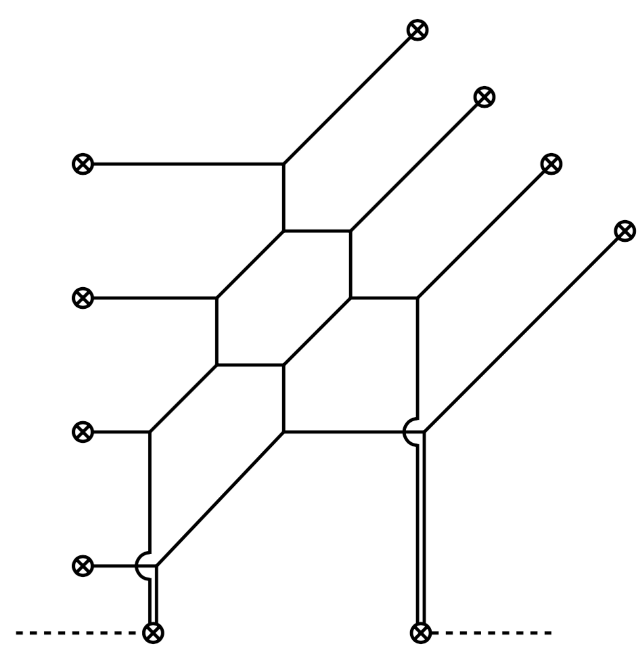
$N_f = 3$



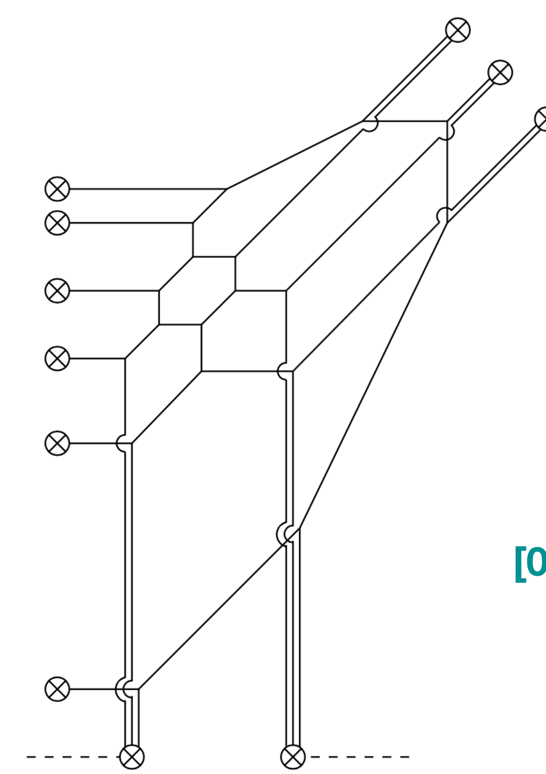
$N_f = 4$



$N_f = 5$



$N_f = 6$



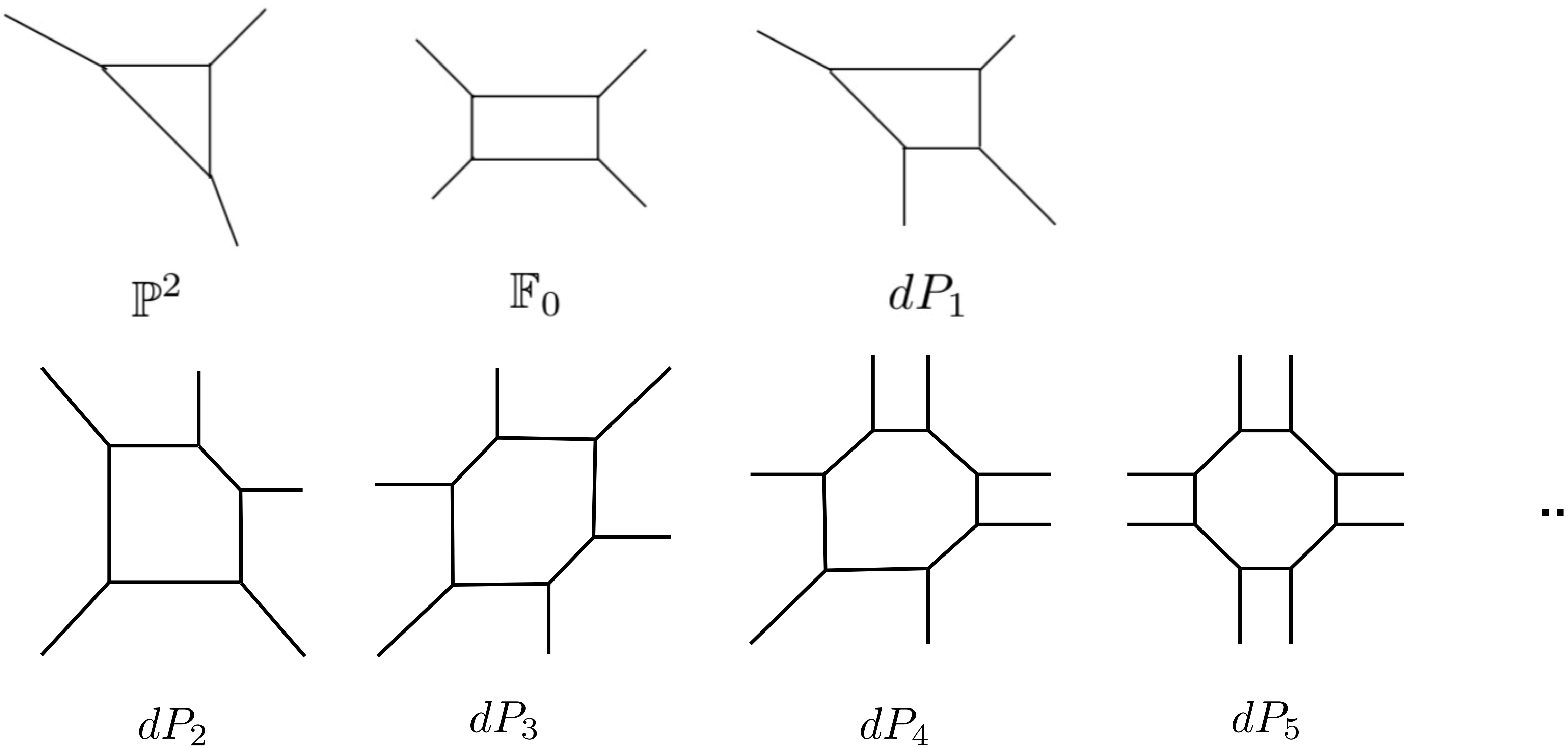
$N_f = 7$

[09 Benini-Benvenuti -Tachikawa]

CY geometry

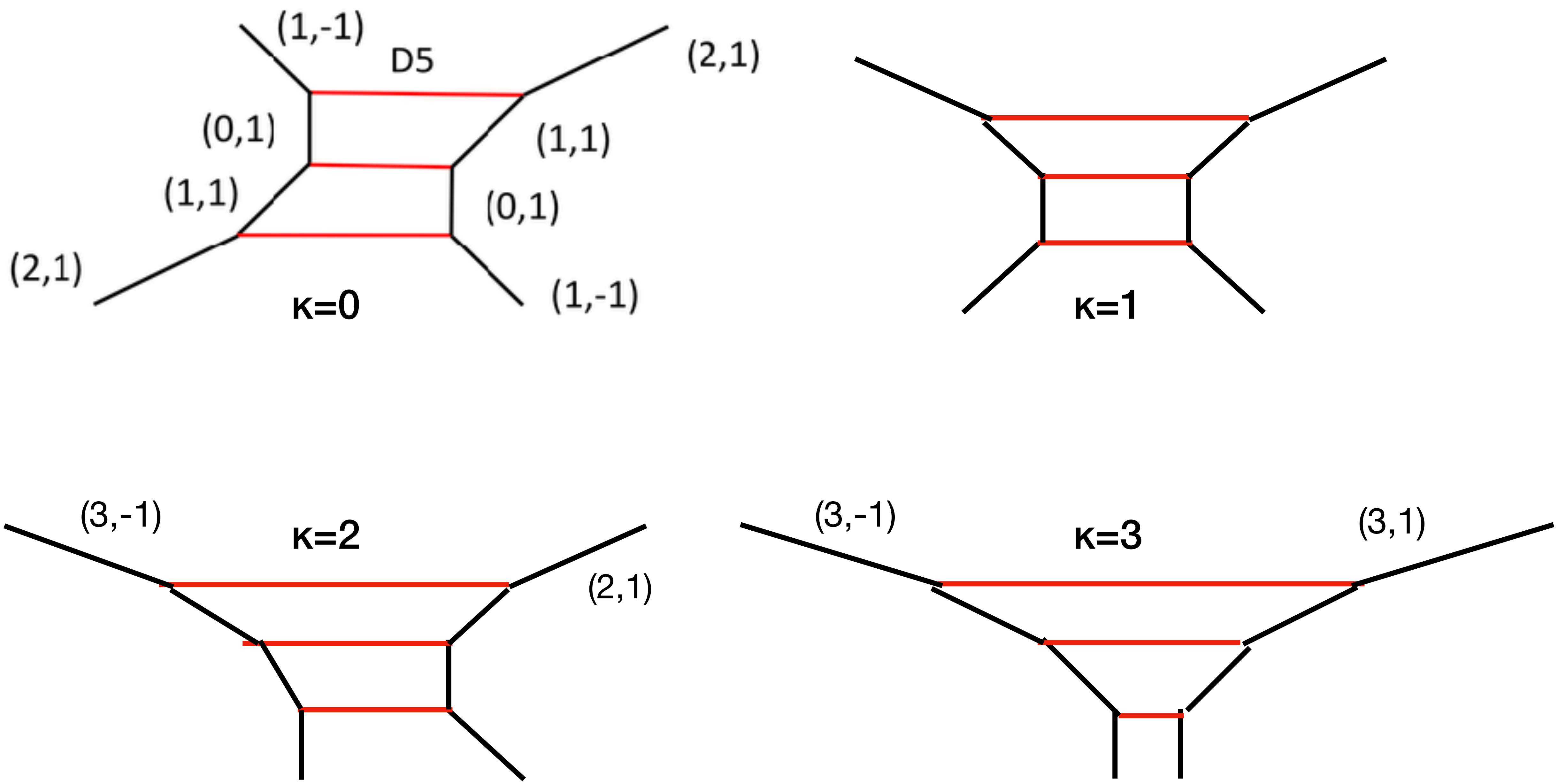
SU(2) theory with $N_f \leq 7$ flavors

All rank 1 SCFTs are engineers by CY3s of Hirzebruch / del Pezzo surfaces



Triple intersection number of four cycles in CY geometry —> **prepotential**

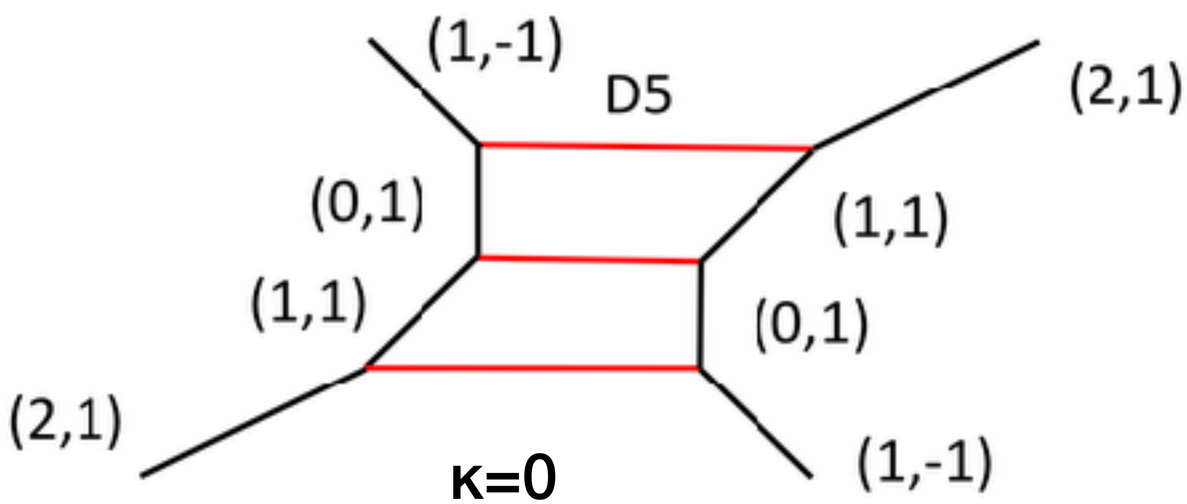
- 5d pure SU(3) gauge theory with κ=0,1,2,3



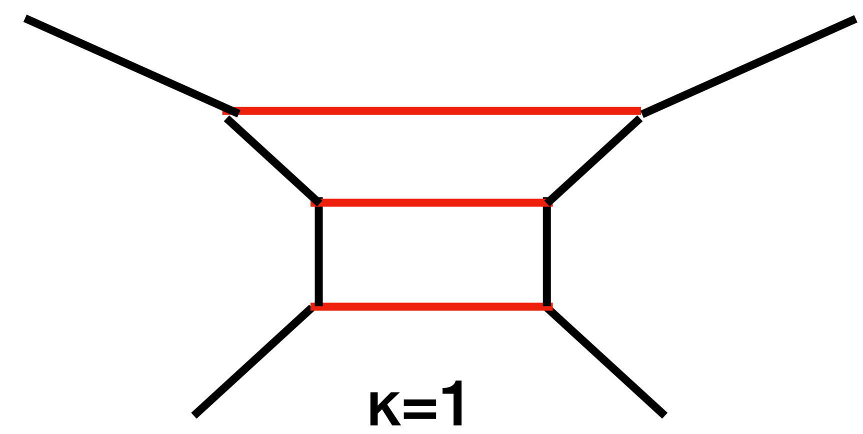
CS levels are confirmed by comparing areas with monopole string tensions

- 5d pure SU(3) gauge theory with κ=0,1,2,3

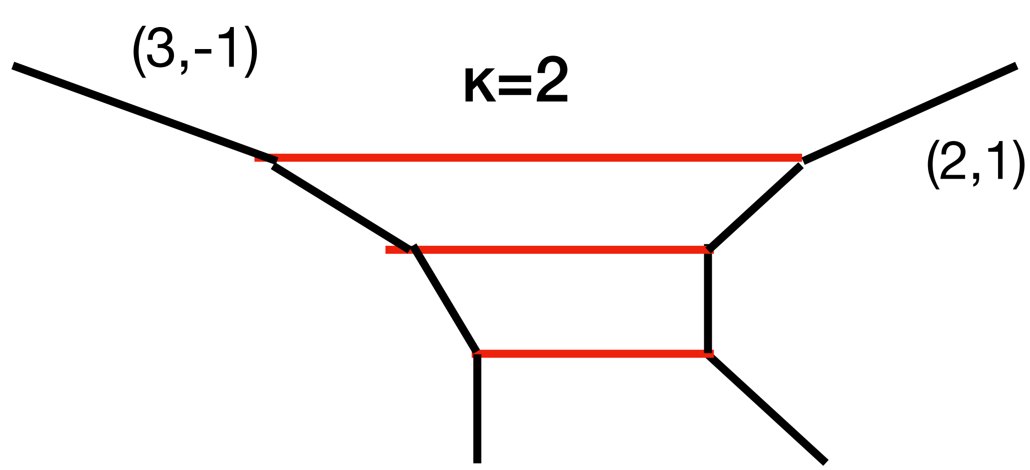
Rank 2 or higher can be obtained by gluing rank 1 geometries



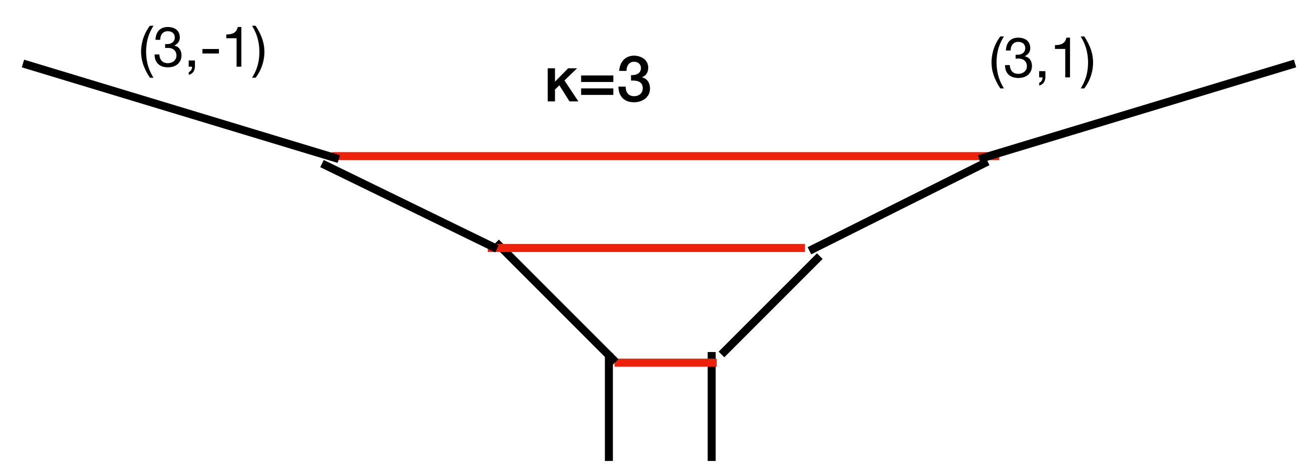
$\mathbb{F}_1 \cup dP_1$



$\mathbb{F}_2 \cup \mathbb{F}_0$



$\mathbb{F}_3 \cup dP_1$



$\mathbb{F}_4 \cup \mathbb{F}_2$

5-branes provide a powerful tool to study 5d theories:

Especially, non-perturbative aspects can be seen.

A window to reveal rich physics

- Enhanced global symmetries
- Can compute Partition function using topological vertex
- various duality: S-duality, UV duality
- KK theories (marginal): 6d N=1 theories on a circle (with T-dual)

Classification of Rank 2 theories:

from **geometry** [Jefferson, Katz, Kim, Vafa `18]

and also from **5-brane webs** [Hayashi, SSK, Lee, Yagi '19]

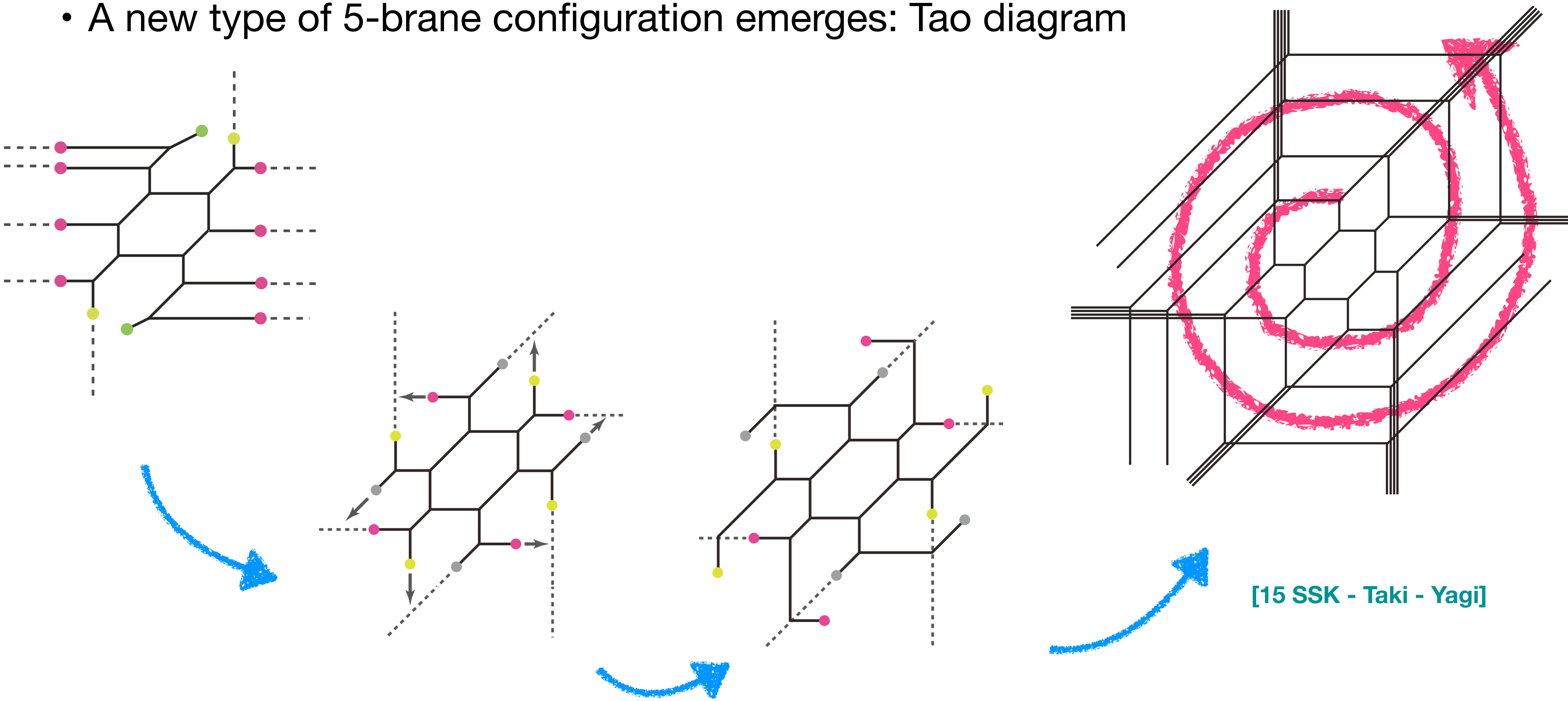
Marginal theories and 5-brane web

6d theory on a circle

- It is known that

SU(2) theory with $N_f = 8$ flavors <==> 6d **E-string** theory on a circle

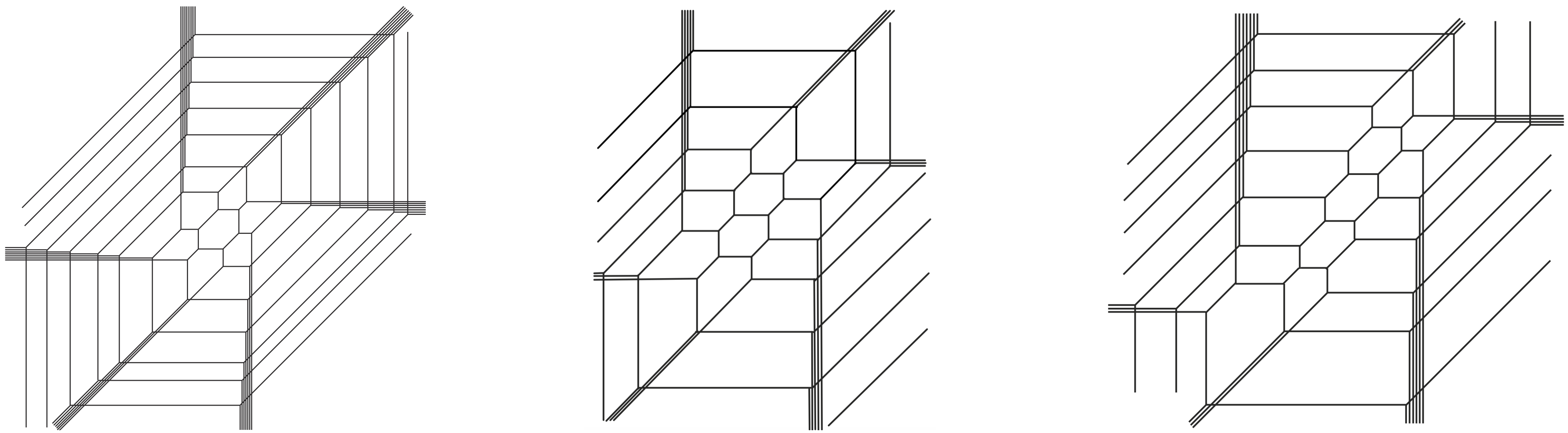
- A new type of 5-brane configuration emerges: Tao diagram



[15 SSK - Taki - Yagi]

generalization and 5d/6d

A straightforward generalization is possible:



5d SU(N) theory with N_f= 2N+4 <==> 6d Sp(N-2) with N_f= 2N+4 and Tensor

[15 Hayashi-SSK-Lee-Taki-Yagi]

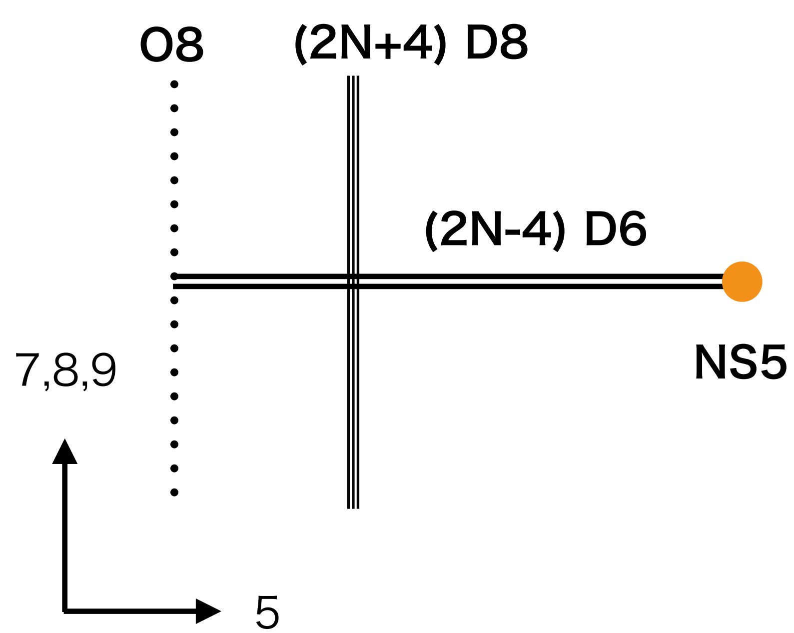
- It is an example that is out of IMS classification [97 Intriligator-Morrison-Seiberg]
- consistent with instanton operator analysis and new classification.

[15 Yonekura] [17 Jefferson-HC Kim-Vafa-Zafrir]

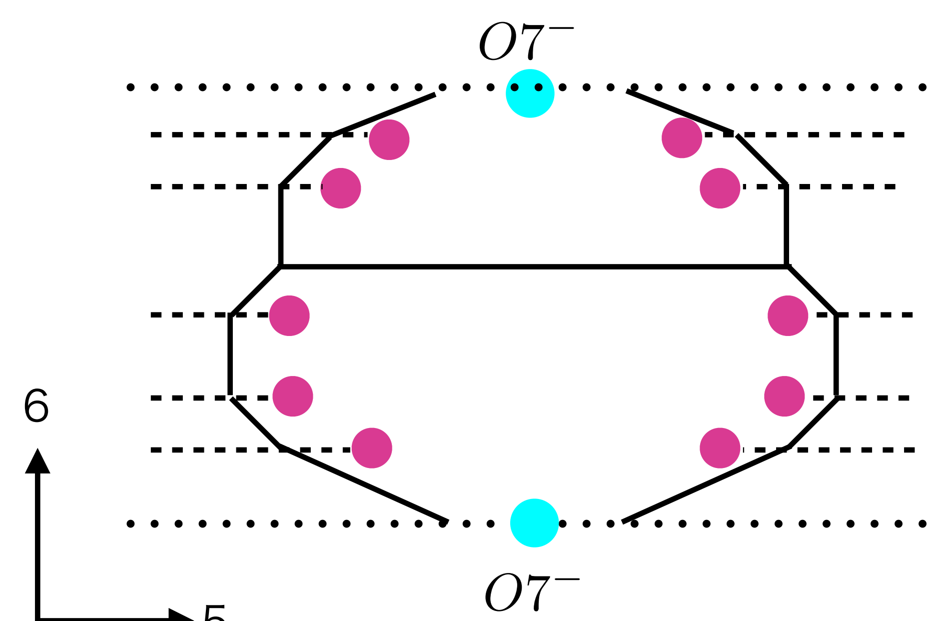
generalization and 5d/6d

- T-dual picture of 6d Sp(N-2) theory with Nf= 2N+4 suggests that three different theories, in fact, have the same UV fixed point in 6d

$6d\ Sp(N-2),\ N_f = 2N+4$
w/tensor



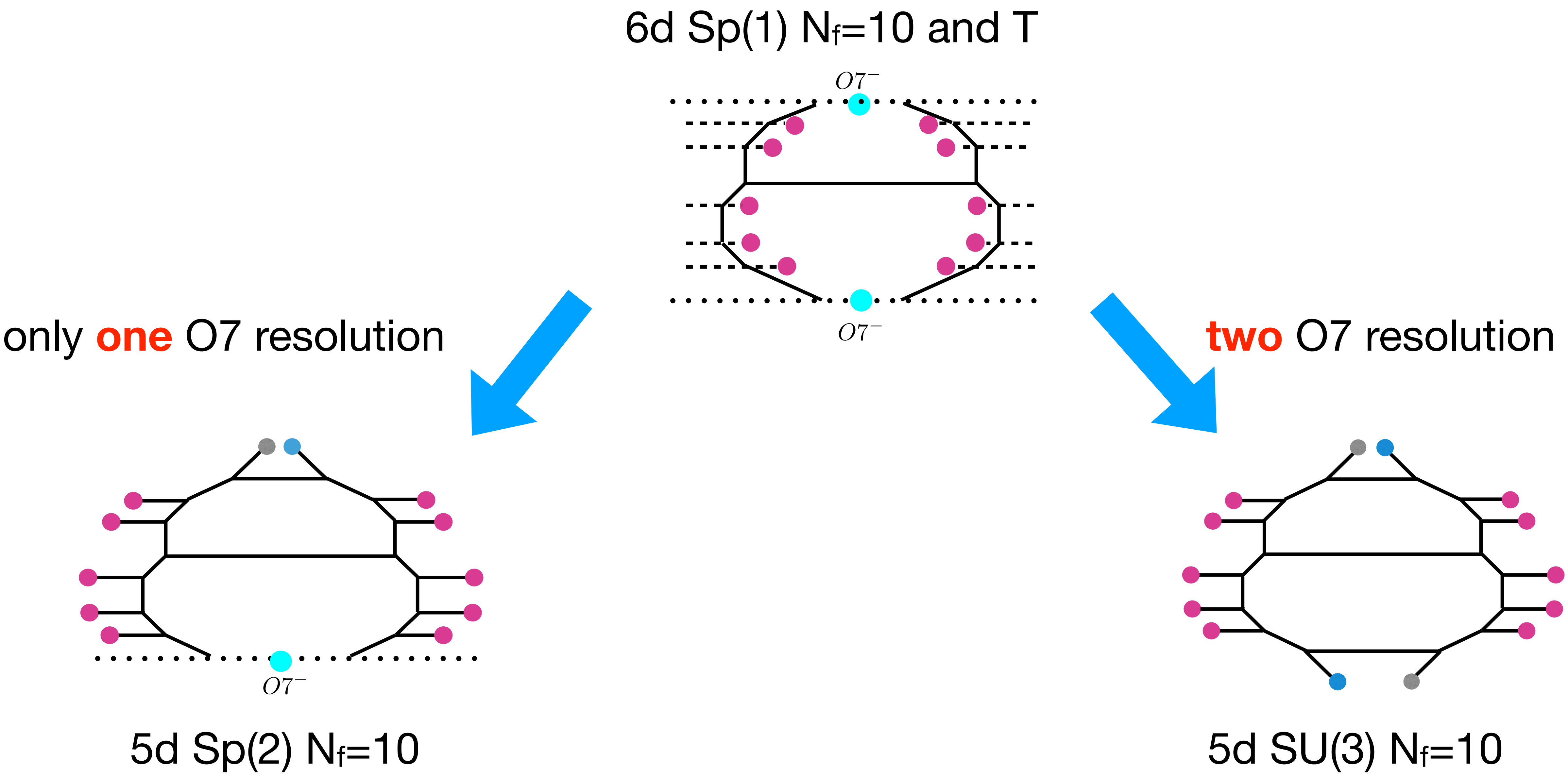
T-duality along x_6
(N=3)
O8 —> two O7



- O7 can be resolved into [1,1] and [1,-1] 7-branes

UV duality

- T-dual picture of 6d Sp(N-2) theory with Nf= 2N+4 suggests that three different theories, in fact, have the same UV fixed point in 6d



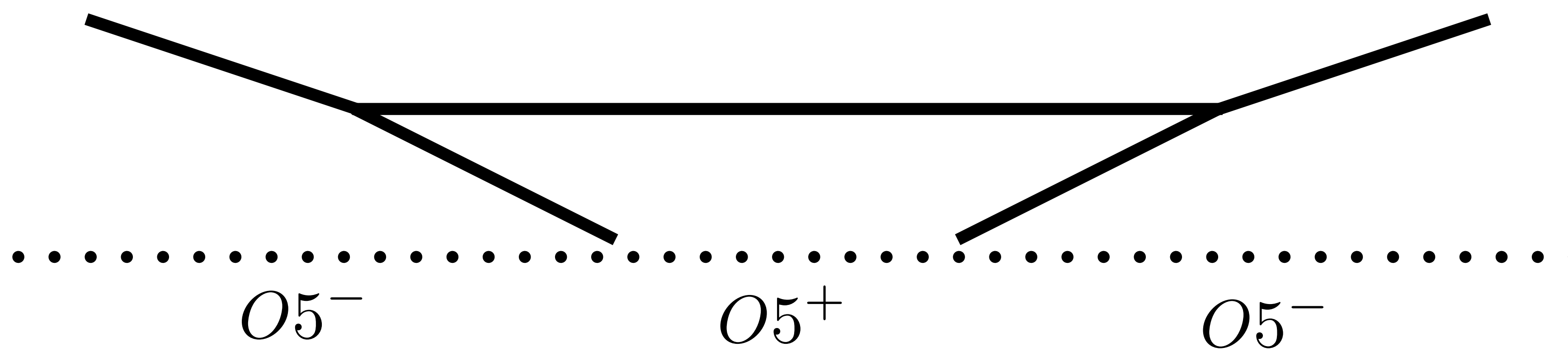
Elliptic genus and partition functions agree.

New developments

- Topological Vertex Formulation w/ O5
- Exceptional gauge group G2 and duality
- theories of higher CS level
- hypermultiplet in rank-3 antisymmetric representation

Topological vertex with O5-plane

5d N=1 pure Sp(1) gauge theory



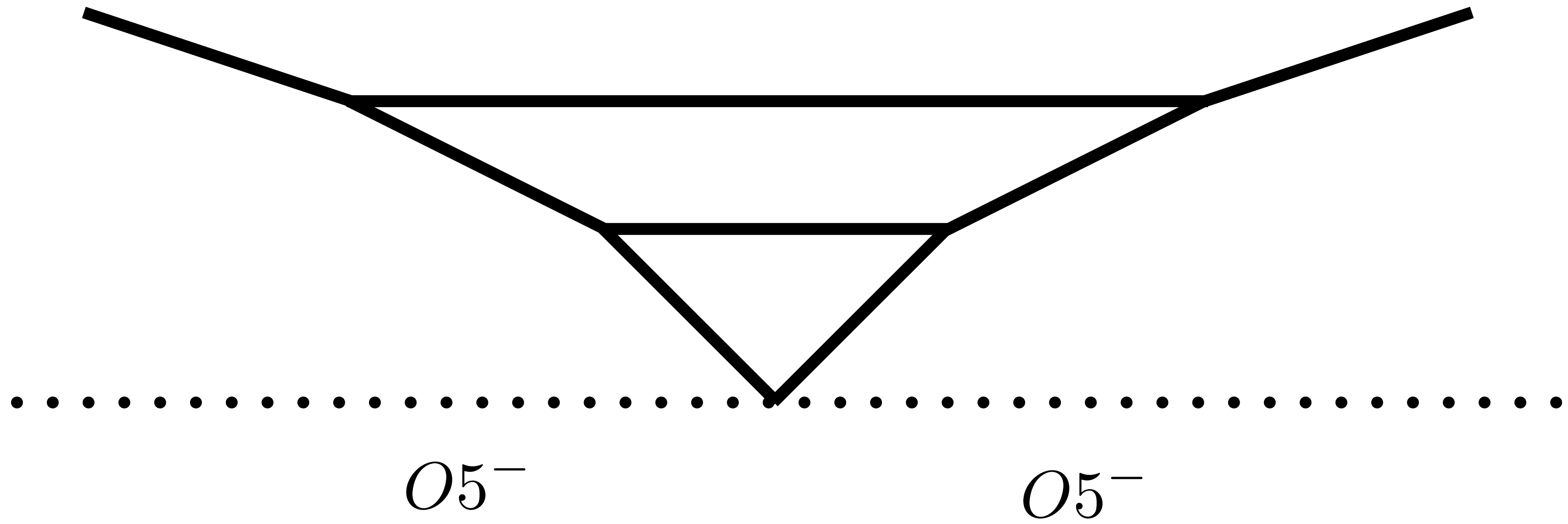
- Non-toric
- O5: branes and their mirrors are discontinuous.

One can still compute Partition function …

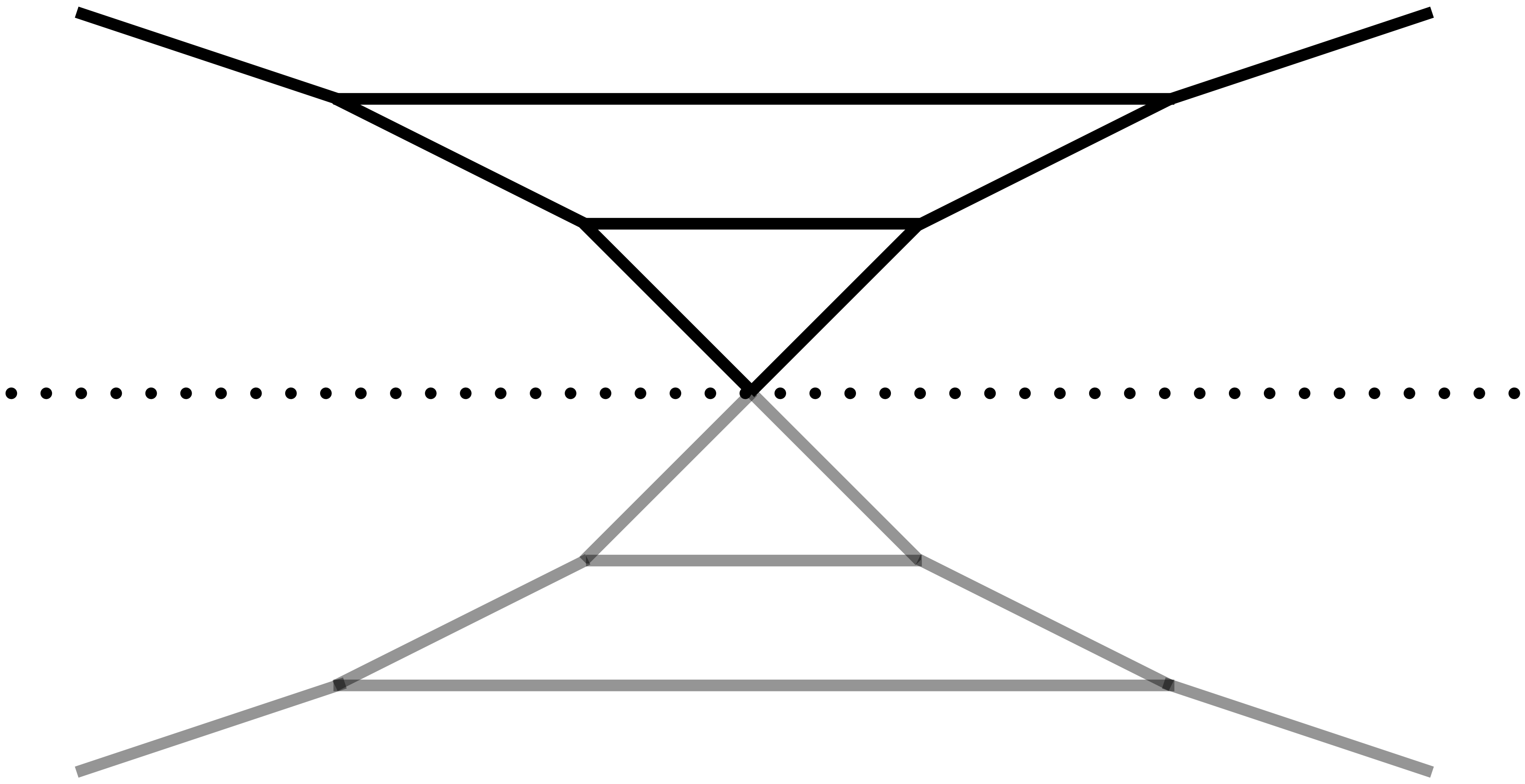
[SSK, Yagi '17]

Using DIM [Bourgine, Fukuda, Matsuo, Zhu]

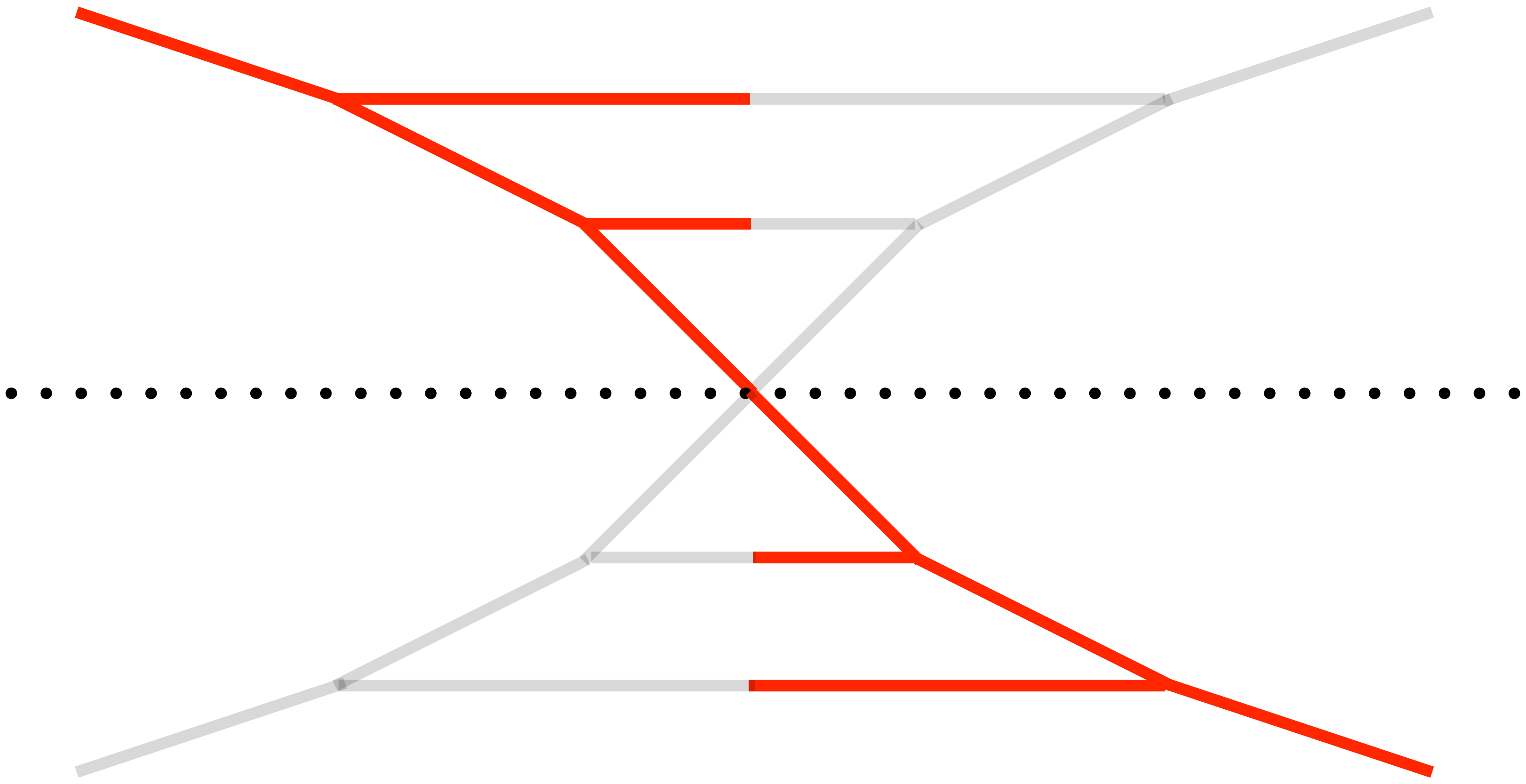
Use "flopped" diagram



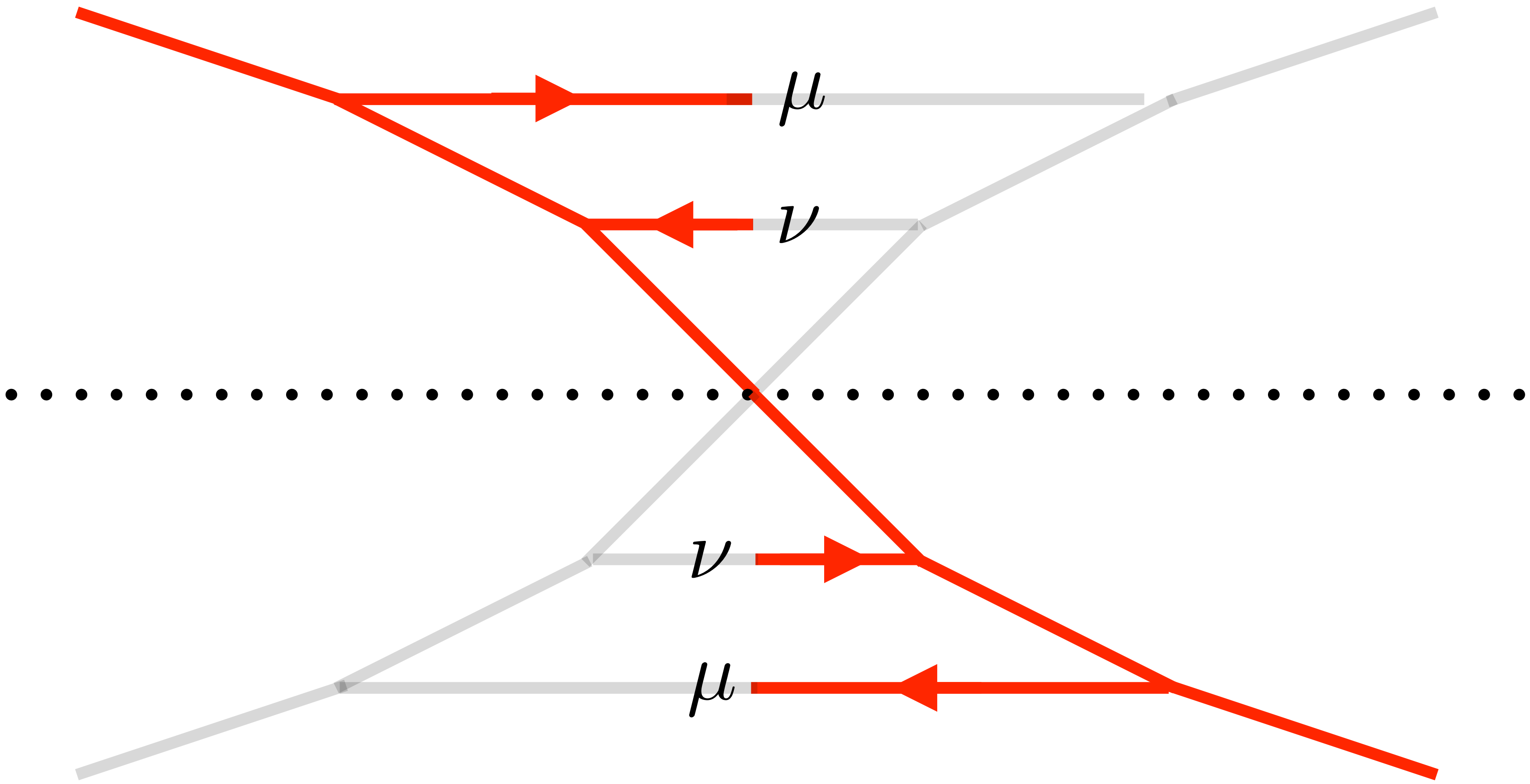
mirror image



“Fundamental region”

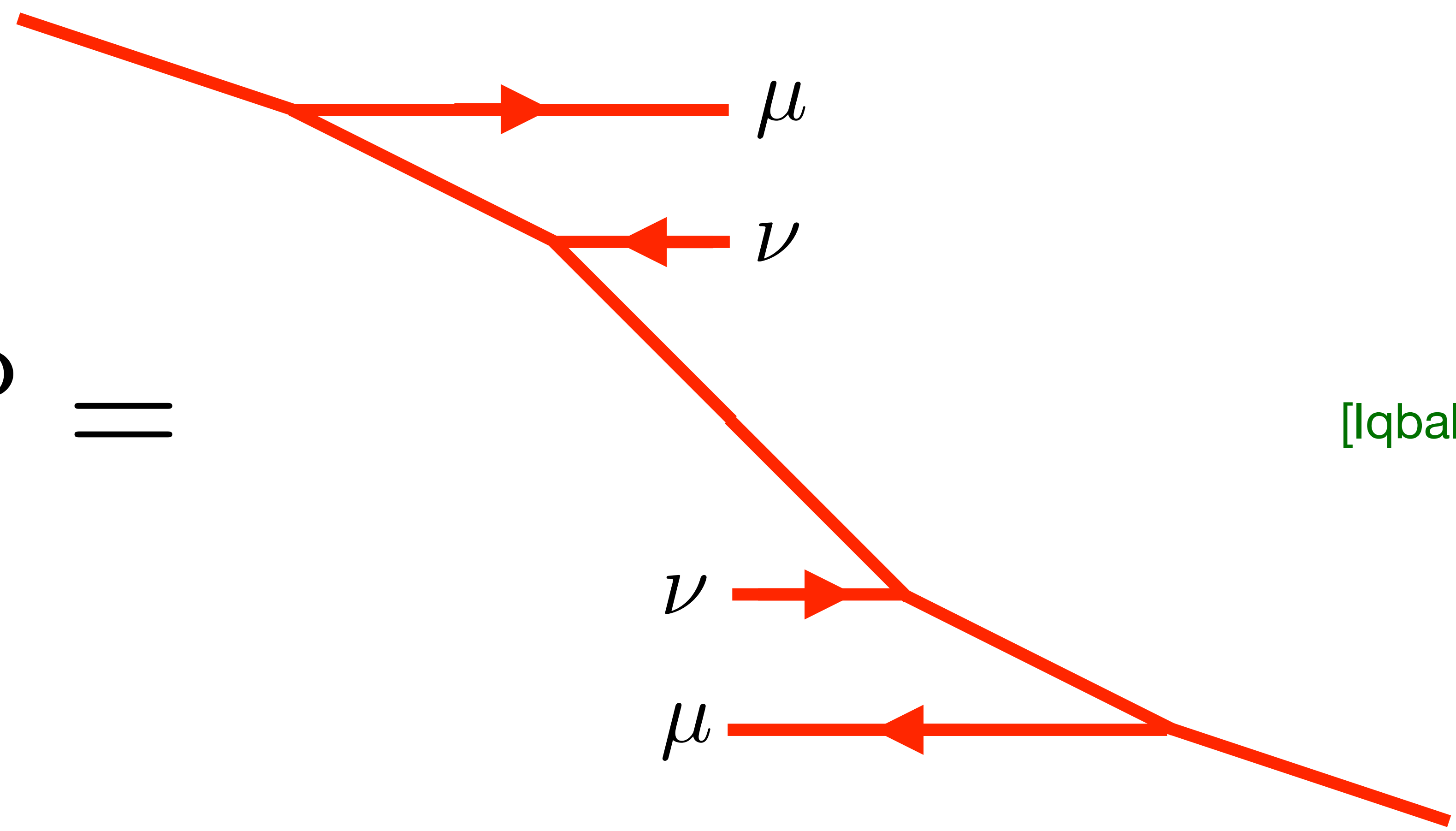


Young diagram assigned to the cut edge



This is strip diagram

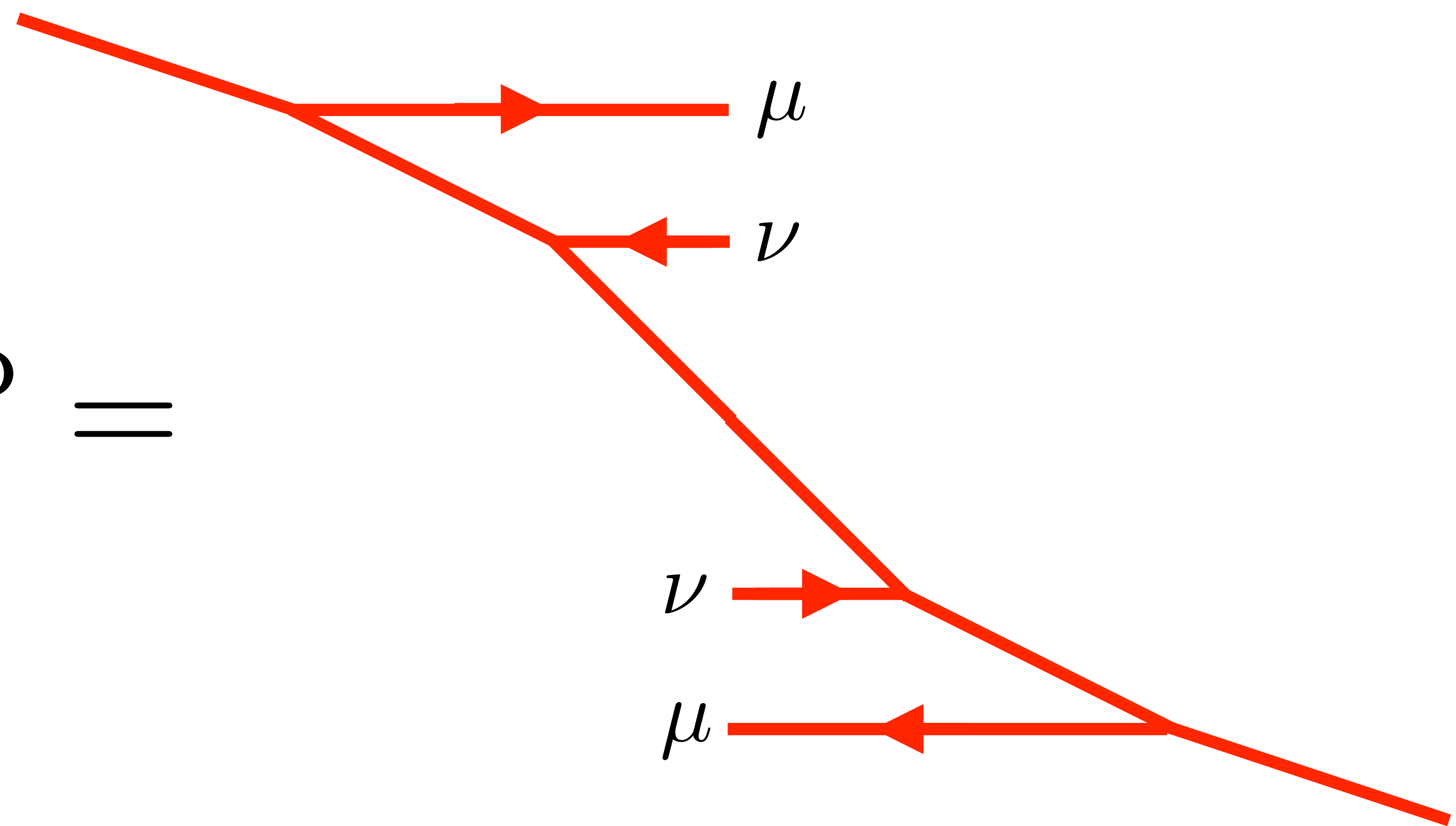
$$Z^{\text{strip}}_{\mu\nu} =$$



[Iqbal, Kashani-Poor '04]

“Glue” the cut edge

$$Z^{\text{strip}}_{\mu\nu} =$$



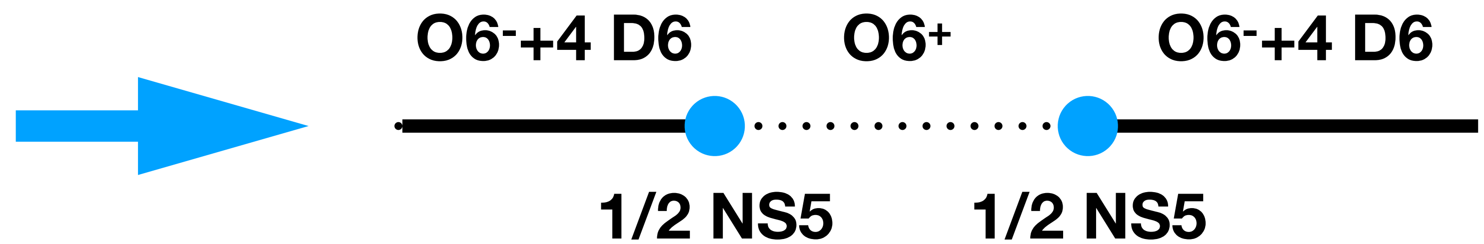
$$Z = \sum_{\mu,\nu} Z^{\text{strip}}_{\mu\nu} E_\mu E'_\nu$$

[SSK, Yagi ’17]

Agreed with the known results.

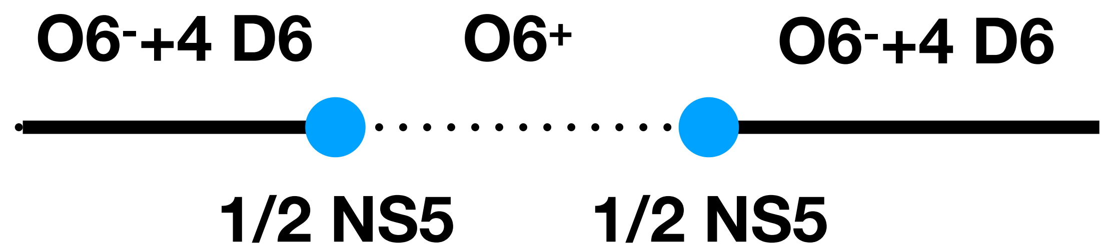
Application: E-string theory

M5 probing D_4 singularity

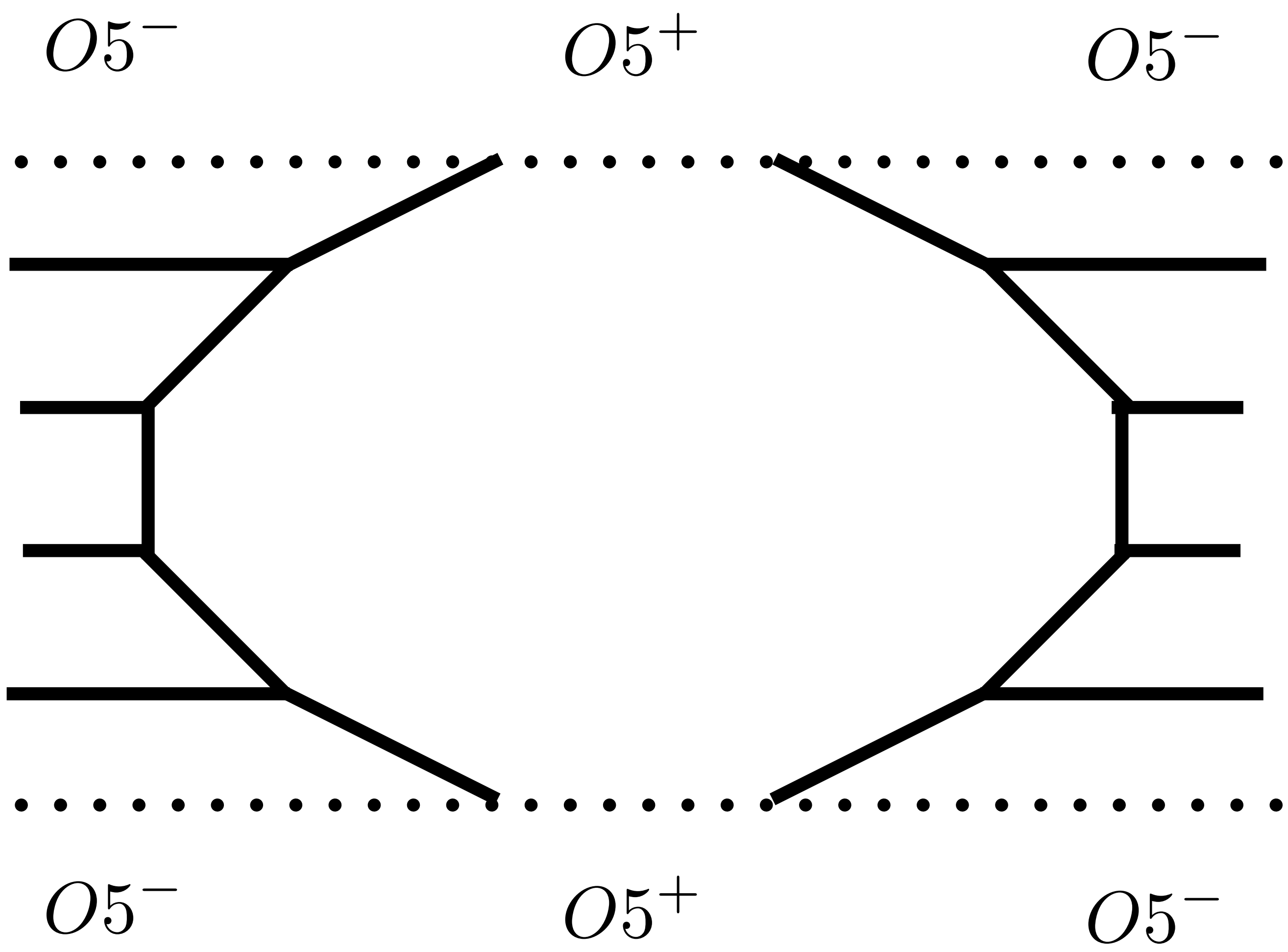


(Minimal (D_4,D_4) conformal matter theory)

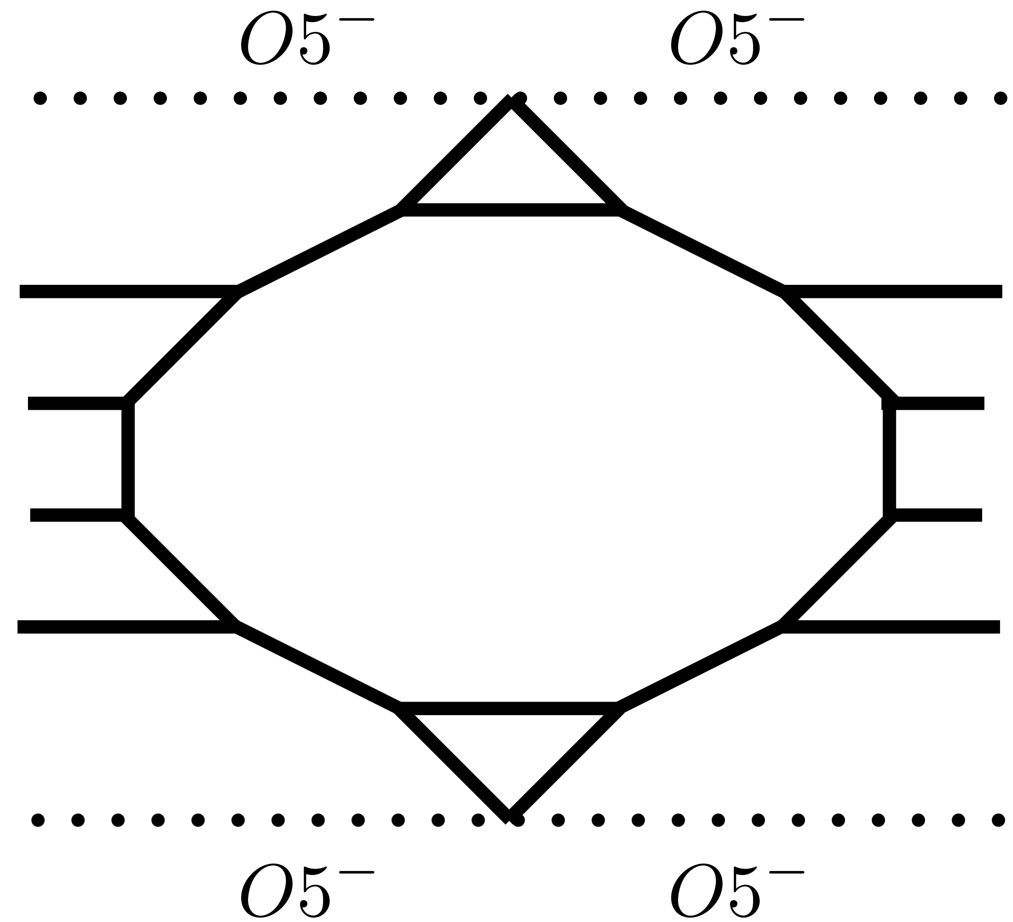
[Heckman, Morrison, Vafa '13]
[Del Zotto, Heckman, Tomasiello, Vafa '14]



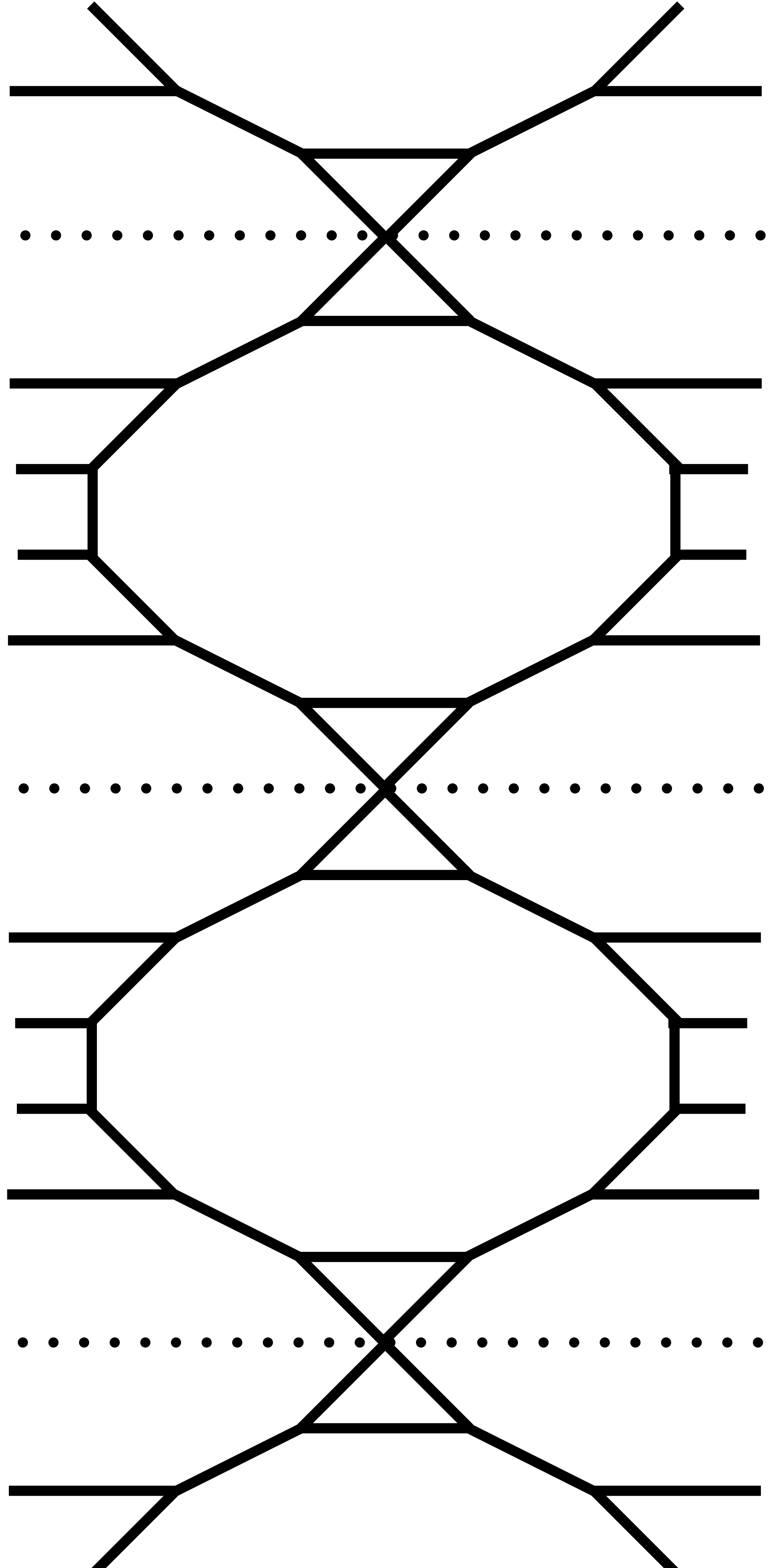
T-dual picture:

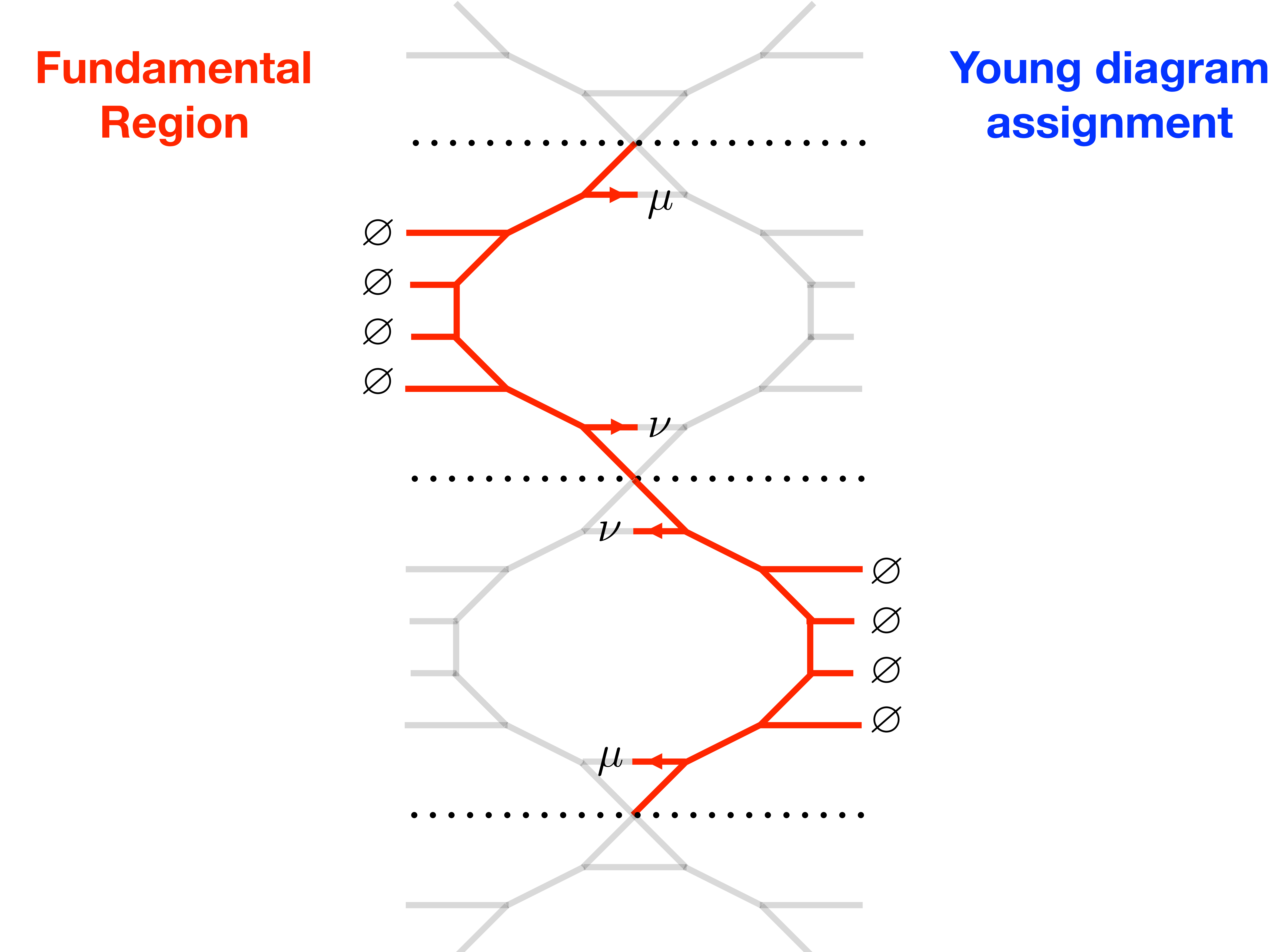


Use flop transition



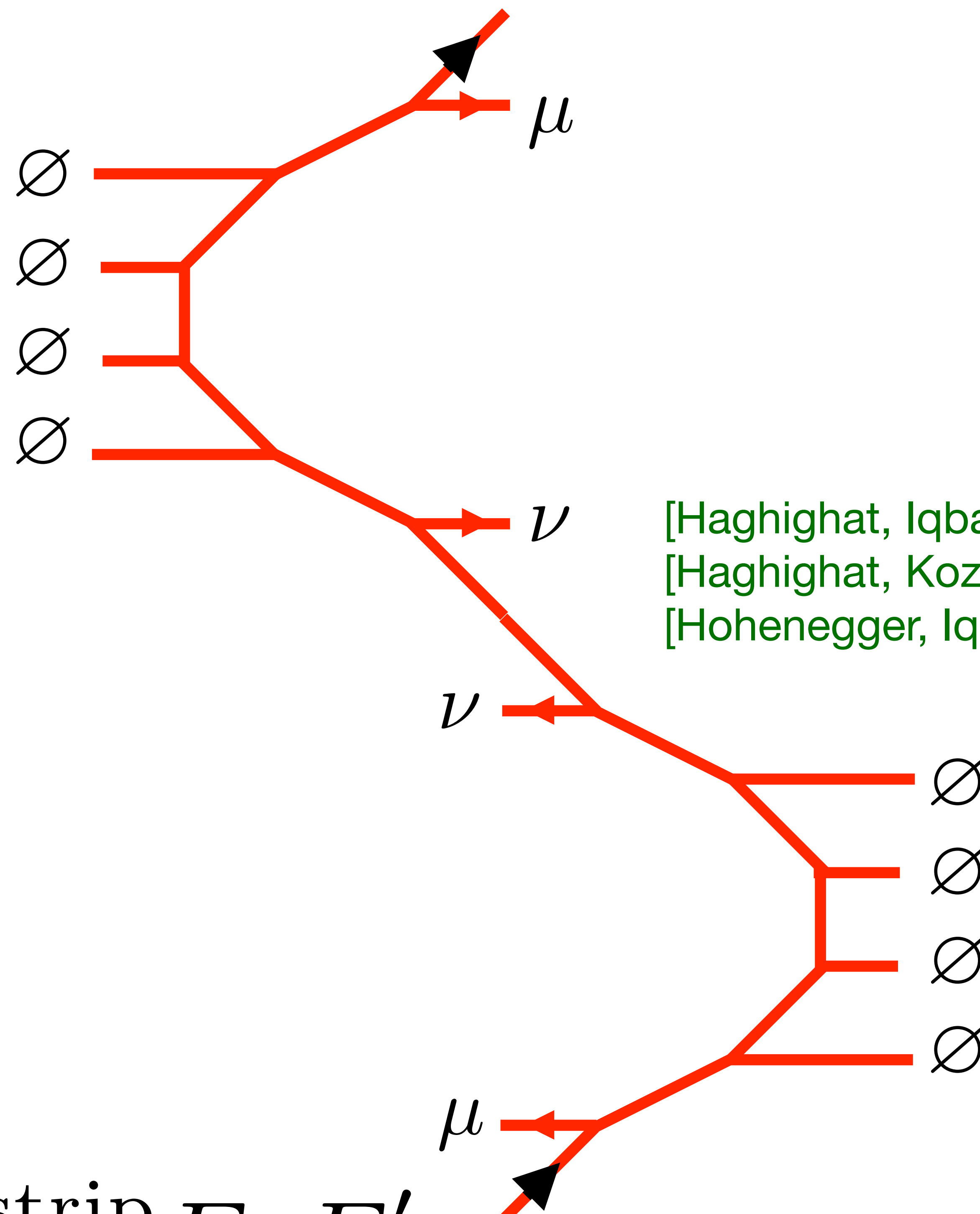
Mirror images




Fundamental Region
Young diagram assignment
μ
$\varnothing$
$\varnothing$
$\varnothing$
$\varnothing$
ν
ν
$\varnothing$
$\varnothing$
$\varnothing$
$\varnothing$
μ

The same type of strip that appeared in M-string!

$$Z^{\text{strip}}_{\mu\nu} =$$



[Haghighat, Iqbal, Kozcaz, Lockhart, Vafa ’13]
[Haghighat, Kozcaz, Lockhart, Vafa ’13]
[Hohenegger, Iqbal ’13]

$$Z = \sum_{\mu,\nu} Z^{\text{strip}}_{\mu\nu} E_\mu E'_\nu$$

E-string Partition Function

$$Z = \sum_{\mu_1,\mu_2} \left(\frac{\mathfrak{q}^2 x_2}{x_1^3}\right)^{|\mu_1|} \left(\frac{\prod_{i=1}^8 y_i}{x_1 x_2^5}\right)^{|\mu_2|} f_{\mu_1}^{-4} f_{\mu_2}^{-4} \times \prod_{I=1}^{2} \left(\prod_{i=1}^{8} \frac{\Theta_{\mu_I \varnothing}(x_I y_i^{-1})}{\Theta_{\mu_I \varnothing}(x_I y_i)} \prod_{J=1}^{2} \frac{\Theta_{\mu_I \mu_J}(x_I x_J)}{\Theta_{\mu_I \mu_J^t}(x_I x_J^{-1})} \right),$$

$$\Theta_{\mu\nu}(Q) \equiv \prod_{n=0}^{\infty} R_{\mu\nu}(Q\mathfrak{q}^{2n}) R_{\mu^t\nu^t}(Q^{-1}\mathfrak{q}^{2n+2}), \qquad R_{\lambda\mu}(Q) = \prod_{i,j=1}^{\infty} \left(1 - Q\, g^{i+j-\mu_i-\lambda_j-1}\right).$$

$$x_1 = \mathfrak{q}^{\frac{1}{2}} e^{-a} \prod_{i=1}^{8} e^{-\frac{1}{4}m_i} \qquad x_2 = \mathfrak{q}^{\frac{1}{2}} e^{+a} \prod_{i=1}^{8} e^{-\frac{1}{4}m_i} \qquad y_i = \mathfrak{q}^{\frac{1}{2}} e^{-m_i} \prod_{j=1}^{8} e^{-\frac{1}{4}m_j}$$

a: Coulomb moduli, $\mathfrak{q}$: Instanton Factor, m_i: mass, $g = e^{-\epsilon_1} = e^{+\epsilon_1}$

Checked the consistency up to 3-instanton

[C. Hwang, J. Kim, S. Kim, and J. Park '14] [SSK, Taki, Yagi '15]

5 brane webs
for
5d G2 theories

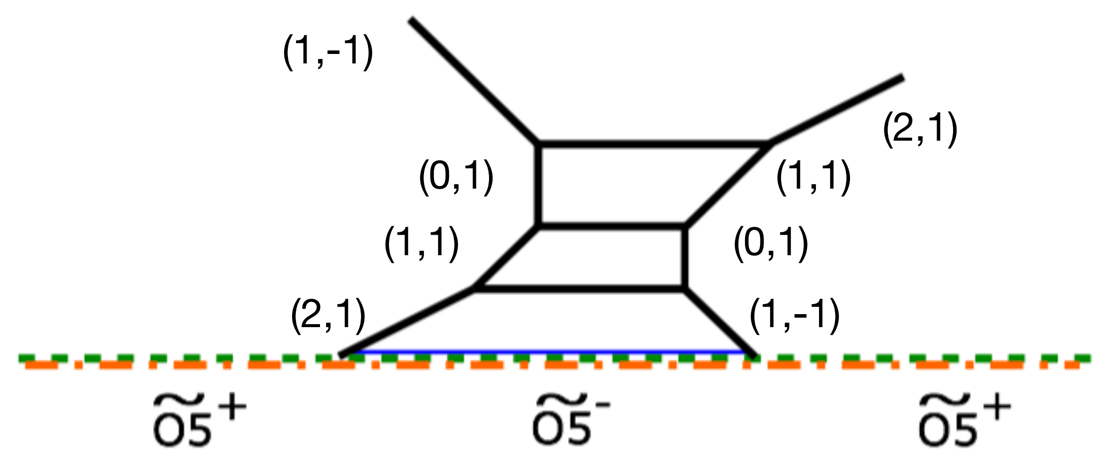
5d SO(7) gauge theories

$\widetilde{O5}^{-}$ = **$O5^{-}$ + 1/2 D5 + 1/2 D7 cut**

$\widetilde{O5}^{+}$ = **$O5^{+}$ + 1/2 D7 cut**

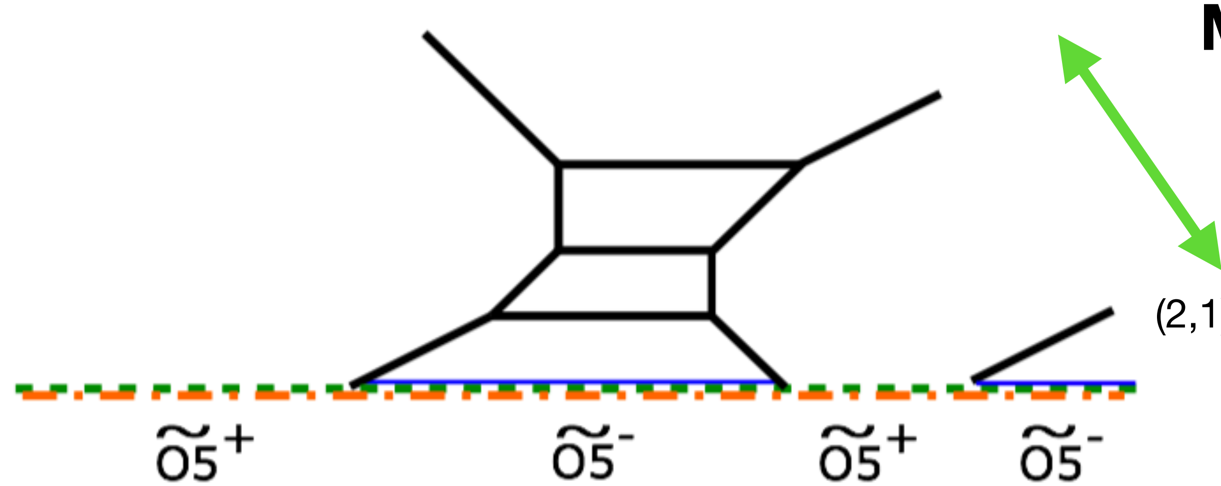
[Zafrir'15]

Pure SO(7)



SO(7) + spinor matter

Ms: mass of Spinor



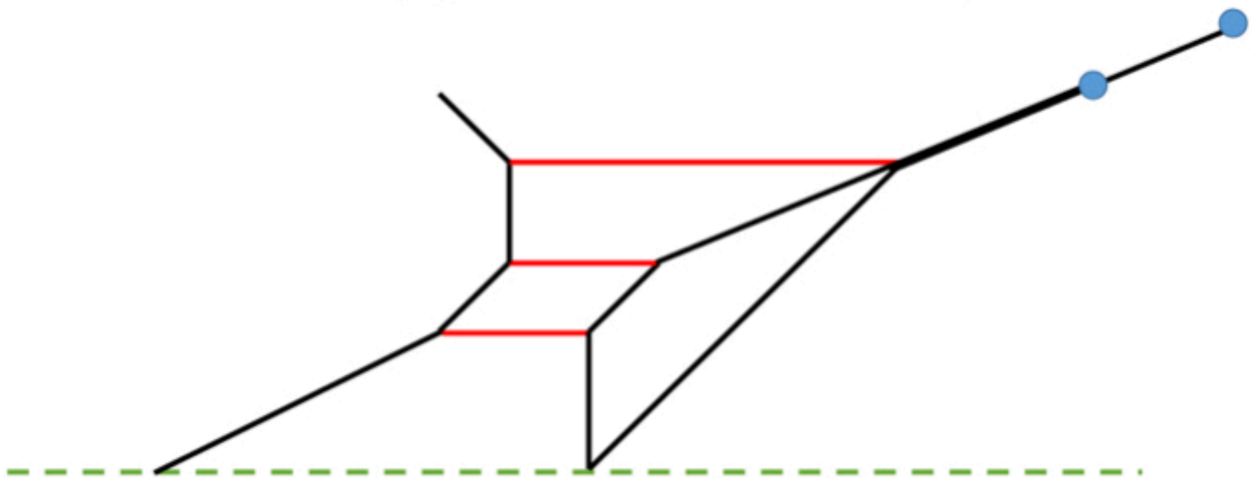
Sp(0) instantons=spinors

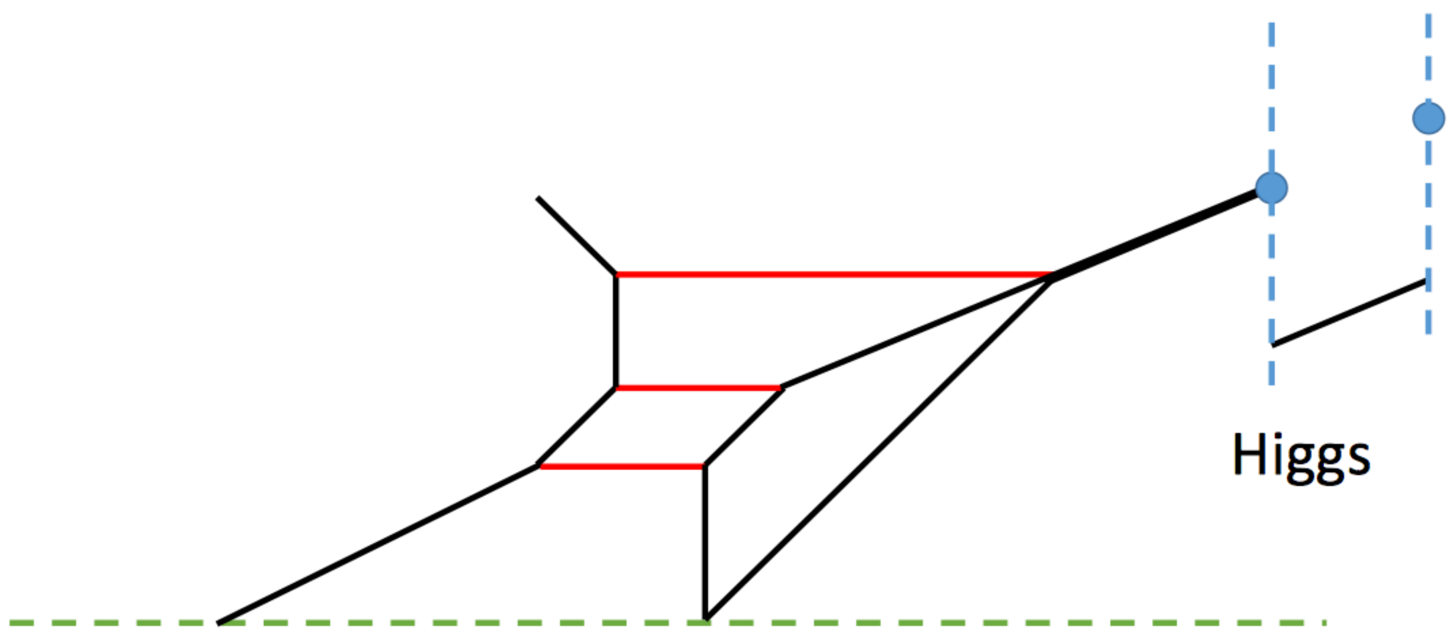
G_2 = Higgsing of SO(7) with spinor

Ms —> 0 : Higgs branch

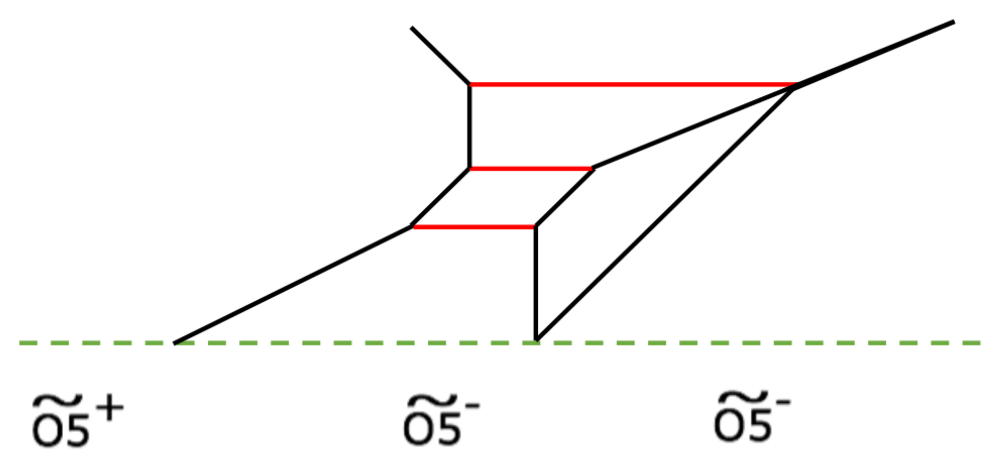
[Hayashi-SSK-Lee-Yagi’17]

5d SO(7) with a massless spinor



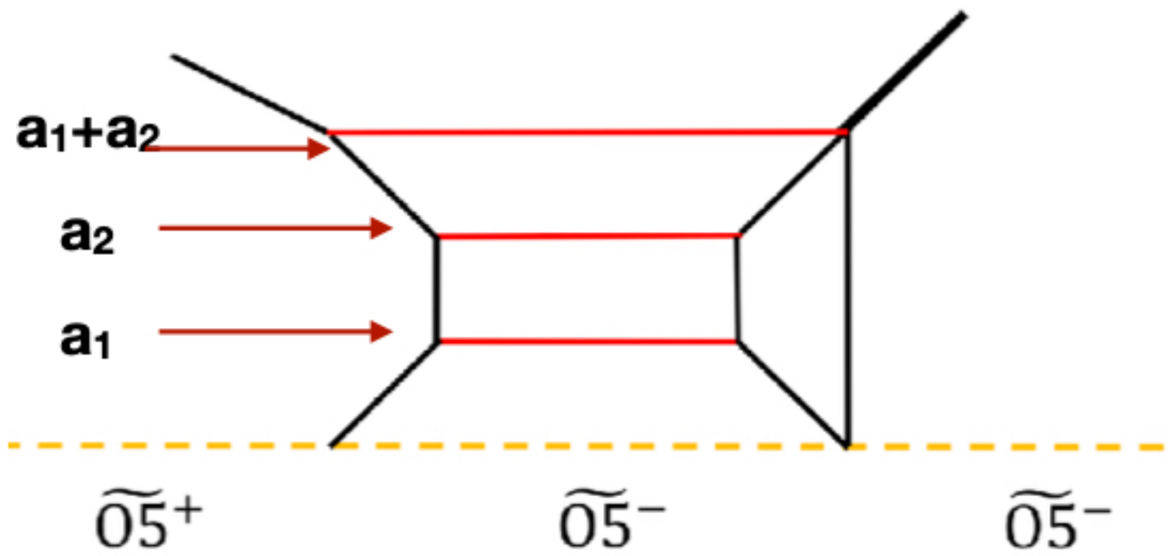


5d G_2 without matter



Pure G_2 gauge theory

After an SL(2,Z)



Areas = monopole string tension from the prepotential $\mathscr{F}$

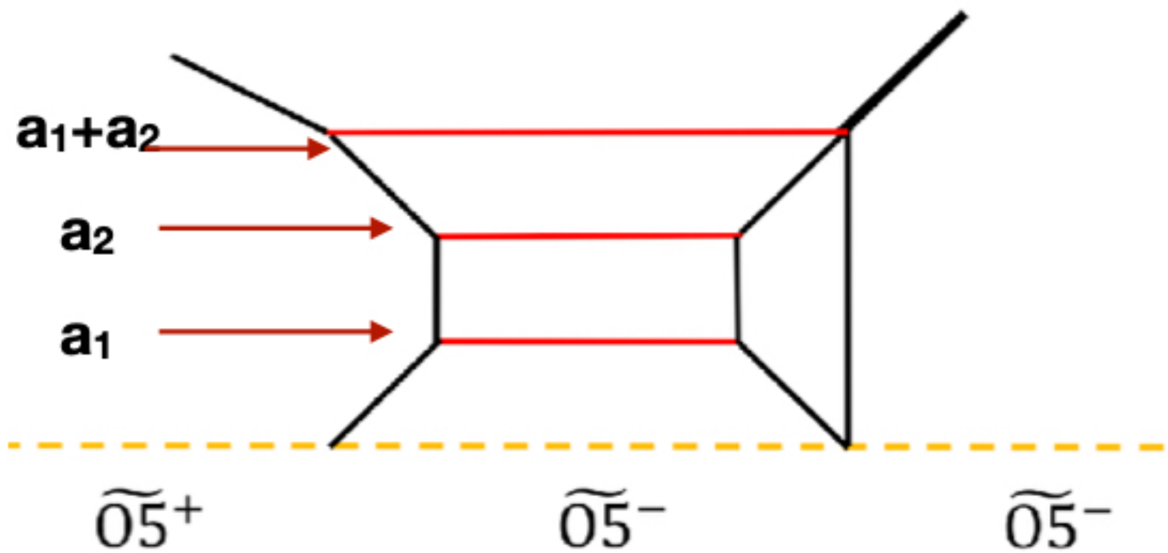
$$2\phi_1 - 3\phi_2 = a_2 - a_1, \quad -\phi_1 + 2\phi_2 = a_1$$

$$\mathscr{F}_{G_2} = m_0(\phi_1^2 - 3\phi_1\phi_2 + 3\phi_2^2) + \frac{4}{3}\phi_1^3 - 4\phi_1^2\phi_2 + 3\phi_1\phi_2^2 + \frac{4}{3}\phi_2^3$$

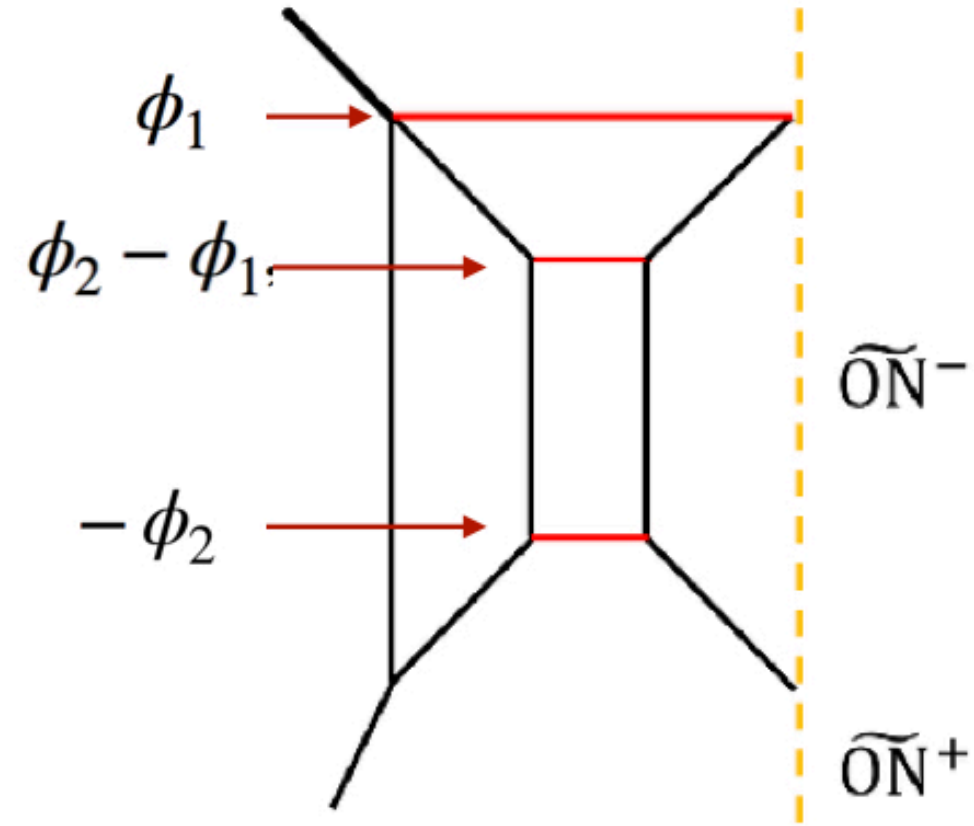
Pure G_2 gauge theory

S-Duality -> $SU(3)_7$

After an SL(2,Z)



[Jafferson, Katz, HC Kim, Vafa]



Areas = monopole string tension from the prepotential $\mathscr{F}$

3 color D5 branes!

$$\mathscr{F}_{SU(3)_7} = m_0(\phi_1^2 - \phi_1\phi_2 + \phi_2^2) + \frac{4}{3}\phi_1^3 + 3\phi_1^2\phi_2 - 4\phi_1\phi_2^2 + \frac{4}{3}\phi_2^3$$

$$2\phi_1 - 3\phi_2 = a_2 - a_1, \quad -\phi_1 + 2\phi_2 = a_1$$

$$\mathscr{F}_{G_2} = m_0(\phi_1^2 - 3\phi_1\phi_2 + 3\phi_2^2) + \frac{4}{3}\phi_1^3 - 4\phi_1^2\phi_2 + 3\phi_1\phi_2^2 + \frac{4}{3}\phi_2^3$$

Parameter map:

$$m_0^{SU(3)} = -\frac{m_0^{G_2}}{3},$$
$$\phi_1^{SU(3)} = \phi_2^{G_2} + \frac{1}{3}m_0^{G_2},$$
$$\phi_2^{SU(3)} = \phi_1^{G_2} + \frac{2}{3}m_0^{G_2},$$

5 brane webs
with hypermultiplets in the
Rank 3 antisymmetric
representation

SU(6) with hypermultiplet in the rank-3 antisymm. repre (TAS)

Hypermultiplets possible to describe on a 5-brane web are
Fundamental, Antisymmetric, Symmetric
with/without orientifolds

[Bergman, Zafrir, Rodriguez-Gomez]

Recent classification suggests SU(6) + TAS

[Jafferson, HC Kim, Vafa, Zafrir]

$N_{\mathbf{TAS}}$	$N_{\mathbf{Sym}}$	$N_{\mathbf{AS}}$	$N_{\mathbf{F}}$	CS
2	.	.	.	0
3/2	.	.	5	0
3/2	.	.	3	2
3/2	.	.	.	9/2
1	.	1	4	0
1	.	1	3	3/2
1	.	1	.	4
1	.	.	10	0
1	.	.	9	3/2
1/2	1	.	1	0
1/2	1	.	.	3/2
1/2	.	2	2	3/2
1/2	.	2	2	1/2
1/2	.	2	.	7/2
1/2	.	1	9	0
1/2	.	1	8	3/2
1/2	.	.	13	0
1/2	.	.	9	3

SU(6) with hypermultiplet in the rank-3 antisymm. repre (TAS)

5-brane webs for TAS:

Use the decomposition

[Tachikawa, Terashima]

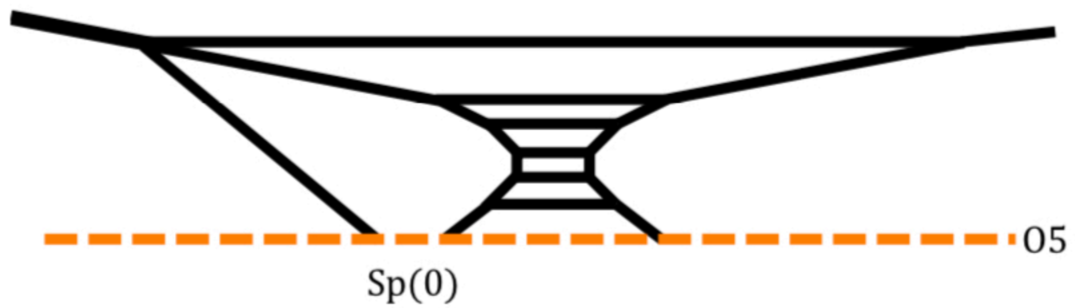
$$\begin{aligned} SO(12) &\supset SU(6)\times U(1) \\ \mathbf{32}' &= \mathbf{20}_0 \oplus \mathbf{6}_{-2} \oplus \bar{\mathbf{6}}_{2}, \\ \mathbf{66} &= \mathbf{1}_0 \oplus \mathbf{15}_2 + \overline{\mathbf{15}}_{-2} + \mathbf{35}_0. \end{aligned}$$

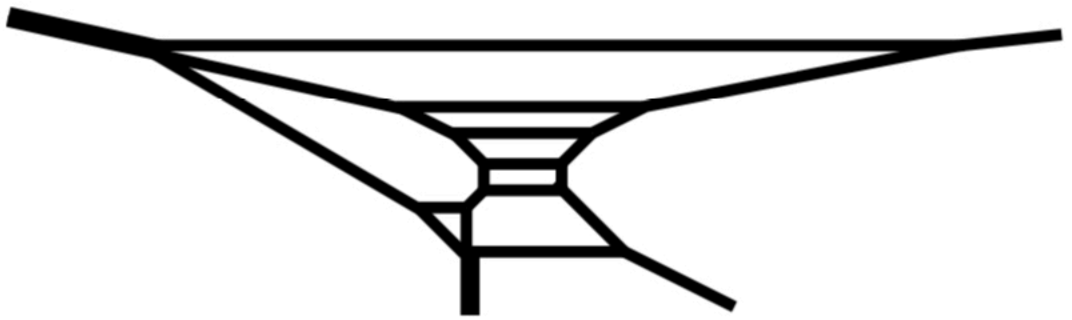
As 5-brane web for SO(12) + 1 conj spinor is known

Decoupling of U(1) d.o.f. leads to SU(6) with TAS (20 dim'l)

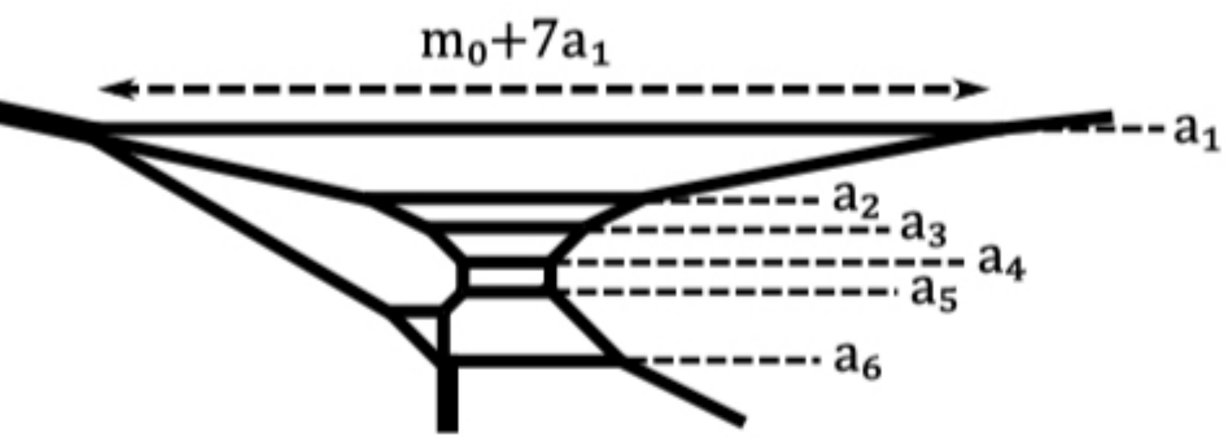
SU(6)+1/2 TAS

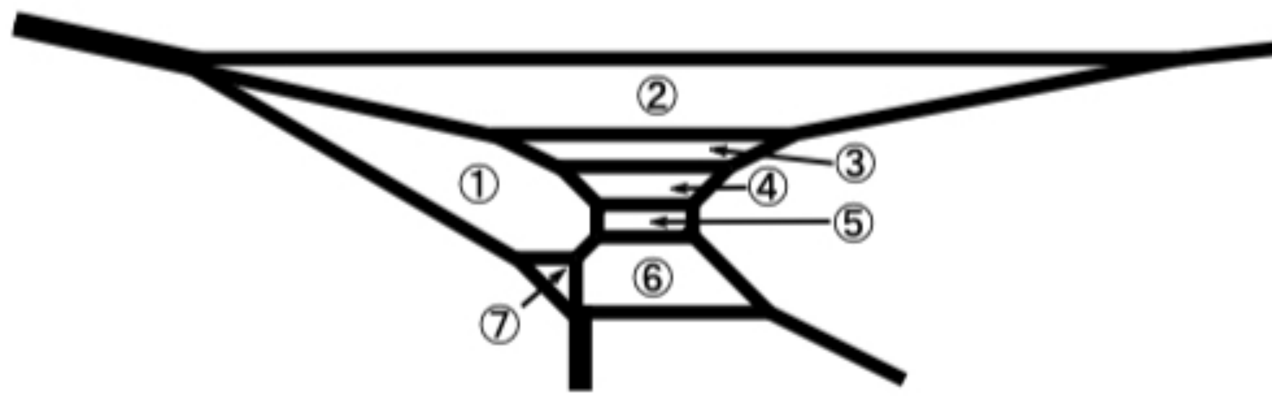
SO(12) with 1/2 hyper in conj. spinor repre.





SU(6)+1/2 TAS





$$\mathcal{F}^{SU(6)_\kappa}_{N_{\mathbf{TAS}}=\frac{1}{2}} = \frac{1}{2}m_0\sum_{i=1}^{6}a_i^2 + \frac{\kappa}{6}\sum_{i=1}^{6}a_i^3 + \frac{1}{12}\left(2\sum_{1\le i<j\le 6}(a_i-a_j)^3 - \sum_{2\le i<j\le 6}(a_1+a_i+a_j)^3\right),$$

$$\frac{\partial\mathcal{F}^{SU(6)_\kappa}_{N_{\mathbf{TAS}}=\frac{1}{2}}}{\partial\phi_1} = ① + ②, \quad \frac{\partial\mathcal{F}^{SU(6)_{\frac{5}{2}}}_{N_{\mathbf{TAS}}=\frac{1}{2}}}{\partial\phi_2} = ③, \quad \frac{\partial\mathcal{F}^{SU(6)_{\frac{5}{2}}}_{N_{\mathbf{TAS}}=\frac{1}{2}}}{\partial\phi_3} = ④, \quad \frac{\partial\mathcal{F}^{SU(6)_{\frac{5}{2}}}_{N_{\mathbf{TAS}}=\frac{1}{2}}}{\partial\phi_4} = ⑤, \quad \frac{\partial\mathcal{F}^{SU(6)_{\frac{5}{2}}}_{N_{\mathbf{TAS}}=\frac{1}{2}}}{\partial\phi_5} = ⑥ + ⑦.$$

SU(6)+1/2 TAS

$SU(6)_{5/2}$ + 1/2 TAS Partition function:

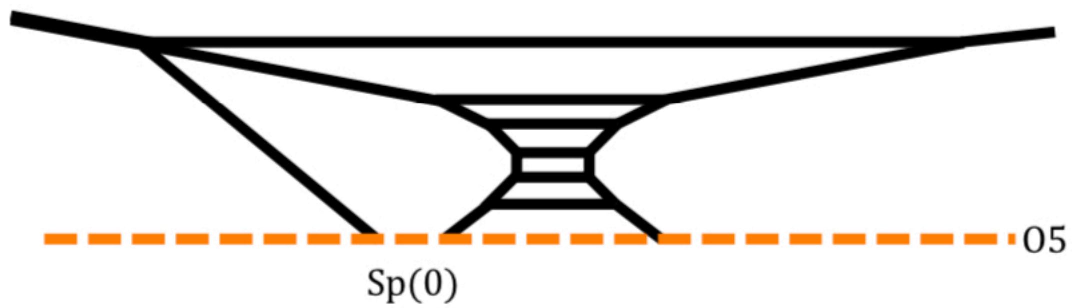
$$Z_{\text{Nek}} = Z_{\text{pert}}\left(1+\sum_{k=1}^{\infty} q^k Z_k\right),$$

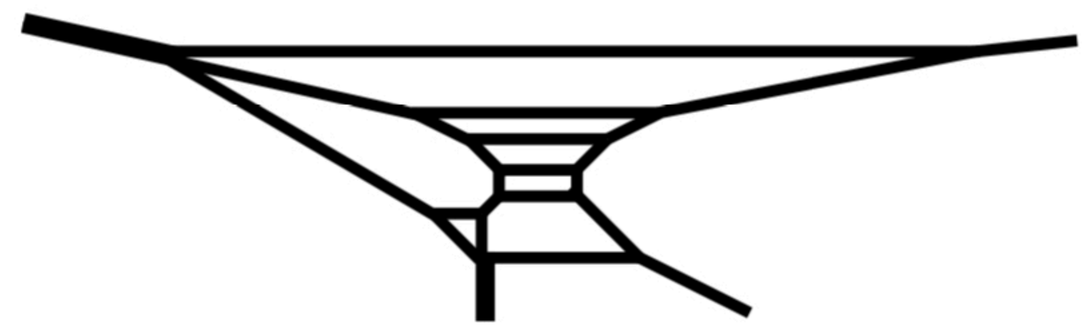
$$Z_{\text{pert}} = \text{PE}\left[\frac{g}{(1-g)^2}\left(2\sum_{1\le i<j\le 6} A_i {A_j}^{-1} - \sum_{1=i<j<k\le 6} A_i A_j A_k + \mathcal{O}({A_1}^8)\right)\right].$$

$$Z_1 = -\sum_{\ell=1}^{6} \frac{g}{(1-g)^2}\frac{A_\ell^5}{\prod_{i\neq \ell}(A_i - A_\ell)^2}\left[1 - \sum_{i\neq\ell} {A_i}^{-1} A_\ell + \sum_{i\neq \ell} A_i A_\ell^2 - A_\ell^3\right]$$

SU(6)+1/2 TAS

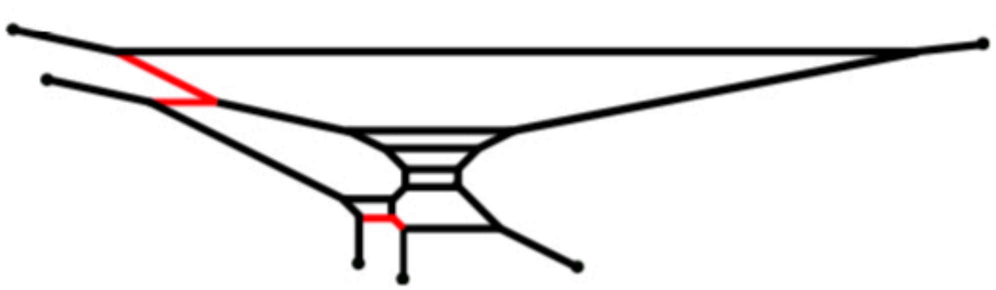
SO(12) with 1/2 hyper in conj. spinor representation

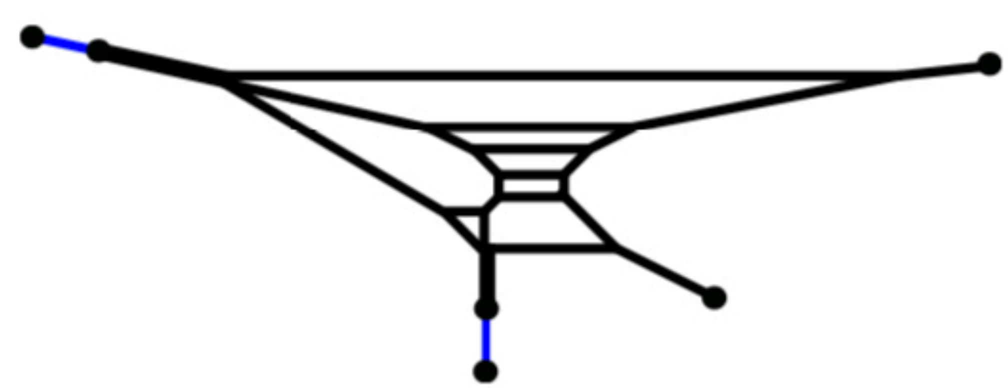




There is another way: SU(6)- SU(3) quiver and its Higgsing

$SU(6)_{\frac{5}{2}} - SU(3)_0$

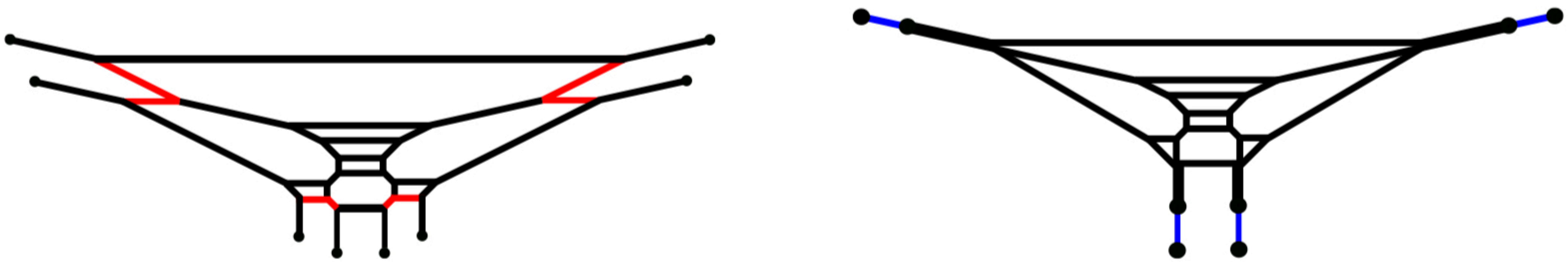




$$[SU(6)_\kappa] - SU(3)_0 \xrightarrow{\text{Higgsing}} [SU(6)_\kappa] - [1/2\,\mathbf{TAS}].$$

SU(6)+1 TAS

In a similar way, a Higgsing of SU(3)-SU(6)- SU(3) quiver lead to SU(6)+ 1TAS

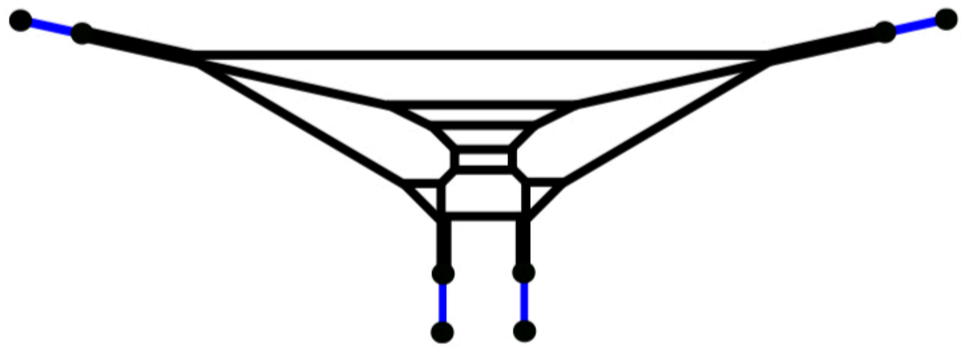


(a) (b)

$SU(3)_0 - SU(6)_3 - SU(3)_0$

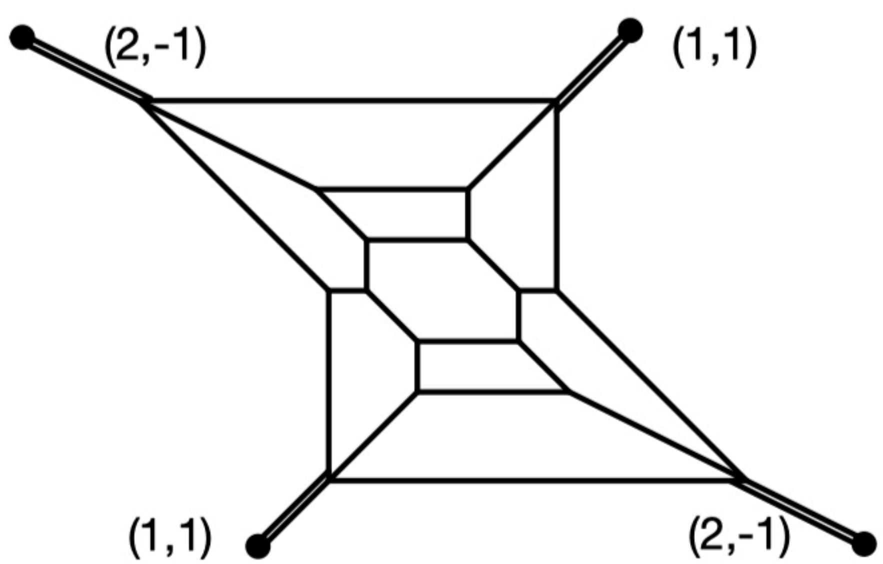
$SU(6)_3 \quad [1\mathbf{TAS}]$

SU(6)+1 TAS



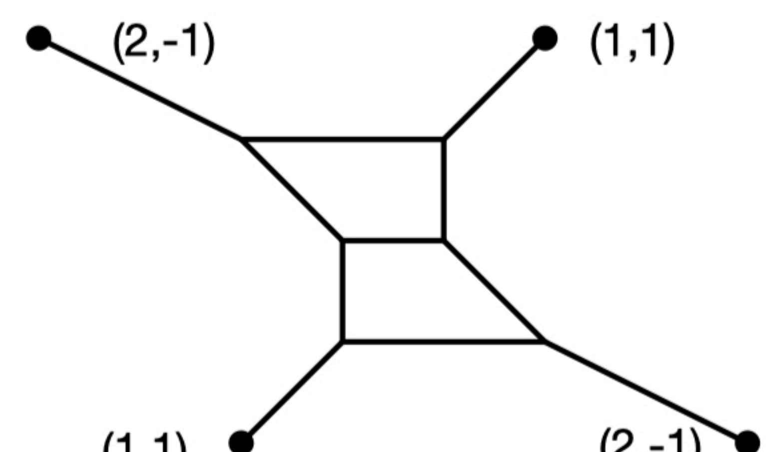
(b)

$SU(6)_3$ + 1 TAS. It has a particular shape



(a)

$SU(6)_0 + 1\mathbf{TAS}$

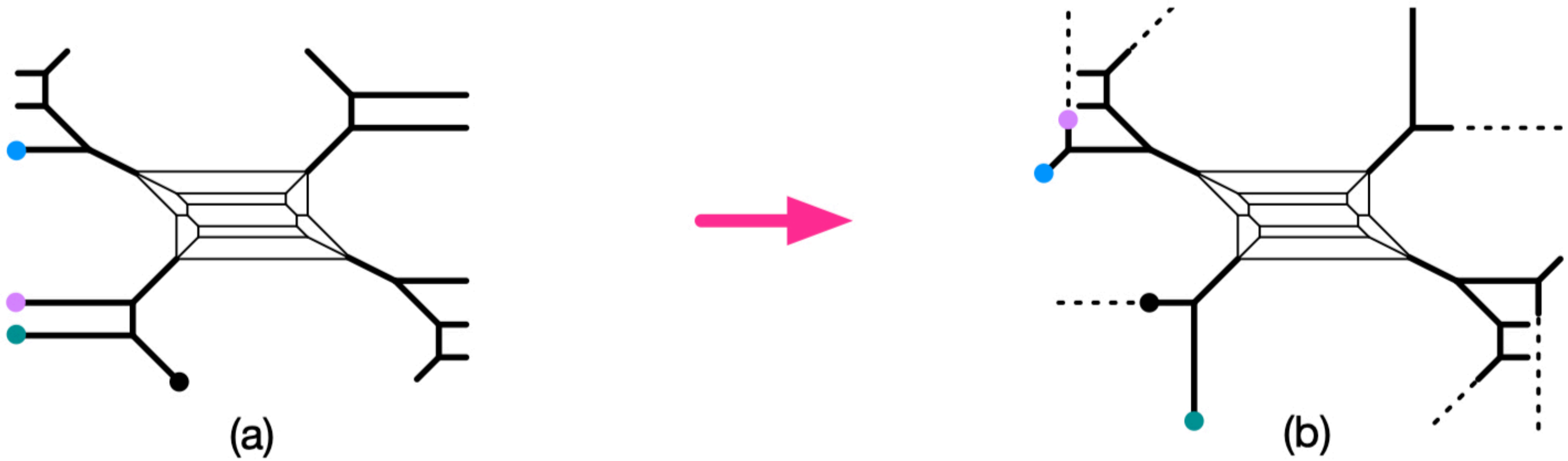


(b)

pure $SU(3)_0$

SU(6)+1 TAS

Earlier: $SU(3)_0$+10**F** is a marginal theory as 6d Sp(1) +10**F** on a circle



$SU(6)_0$+1**TAS**+10**F** is also a marginal theory

$$5d \quad [1\mathbf{TAS}] - SU(6)_0 - [10\mathbf{F}] \quad \xrightarrow{\text{UV completion}} \quad 6d \quad [10\mathbf{F}] - Sp(2) - SU(2),$$

Conclusion

- 5d SCFTs
  - Rich physics: dualities, global symmetry enhancement, non-Lagrangian theories, non-perturbative aspects, …

- 5-brane webs for higher CS and other hypermultiplets are obtained

- Based on web diagram, the Partition functions are doable.

- But still more to be discovered (Type IIB 5-brane web and interplay between 6d)

- 5-Brane configuration suggests various a way of writing the prepotential F which makes enhanced global symmetry manifest [work in progress]

- Geometry for 5-brane webs with orientifolds [work in progress]