D-brane Instanton Effects in String Theory

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Veneziano amplitude at 50

$$A(s,t,u) = \frac{\beta}{\pi}\left[B(1-\alpha(s), 1-\alpha(t)) + B(1-\alpha(t), 1-\alpha(u)) + B(1-\alpha(s), 1-\alpha(u))\right] \qquad (3)$$

where we have introduced the Euler B-function $B(x,y) = \frac{\Gamma(x)\Gamma(y)}{\Gamma(x+y)}$.

Scanned from the original manuscript of the paper "Construction of a crossing-symmetric, Regge-behaved amplitude for linearly rising trajectories" by Gabriele Veneziano, 1968

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- String theory beyond perturbation theory: dualities & branes

- Focus on brane instantons

Instantons in string theory

- Instantons, saddle points of euclidan theory, a useful object in non-perturbative physics

BPST; 't Hooft

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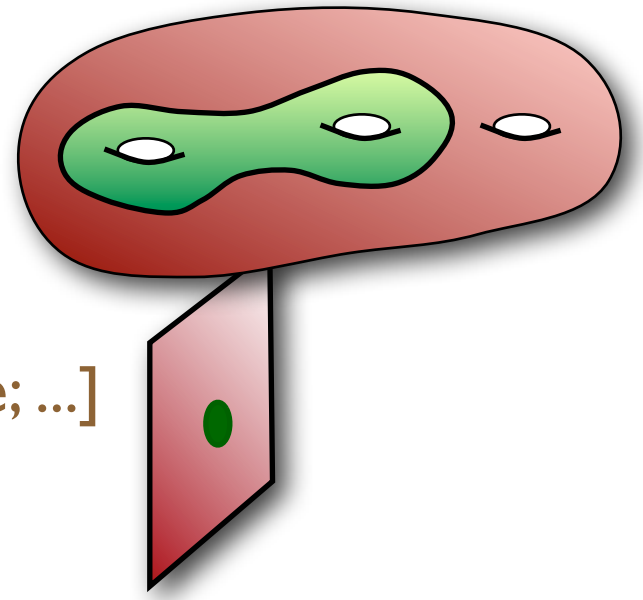
• In string theory, extended objects wrapped on extra dimensions

Worldsheet instantons: pert in gs

Brane instantons: non-pert in gs

[Becker's, Strominger; Witten; Harvey, Moore; ...]



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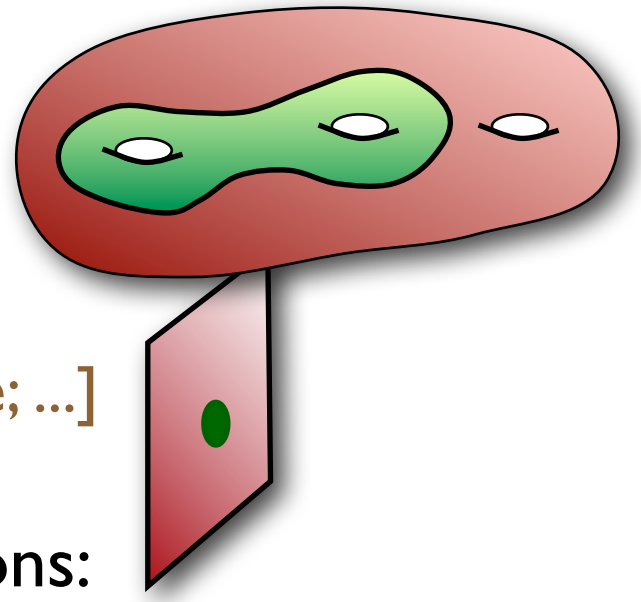

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• Brane instantons & "small" gauge instantons: A unified story

Witten '95

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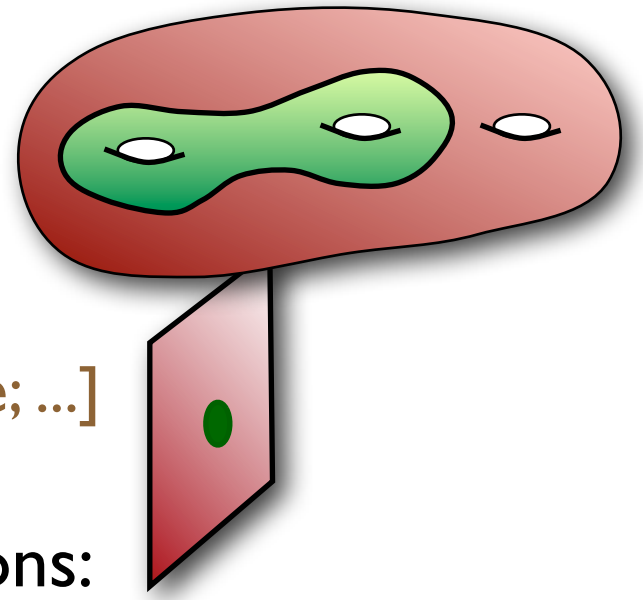

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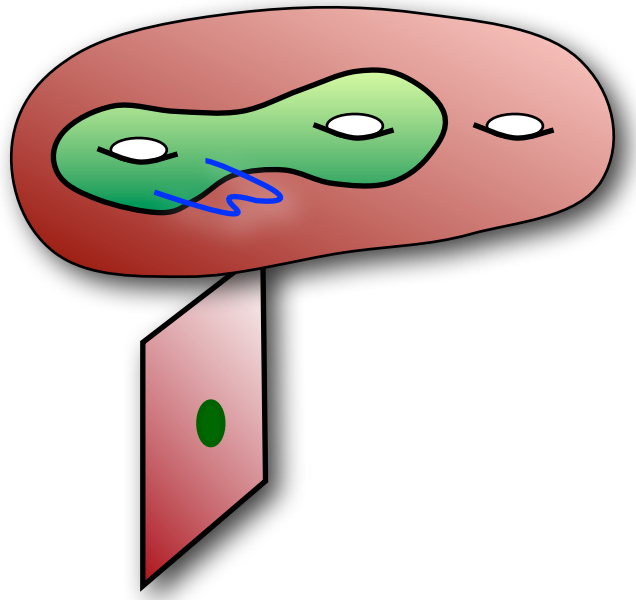
• Focus on D-brane instantons, exploit open string description

Polchinski '95

D-brane instantons

- Instanton modes from open strings



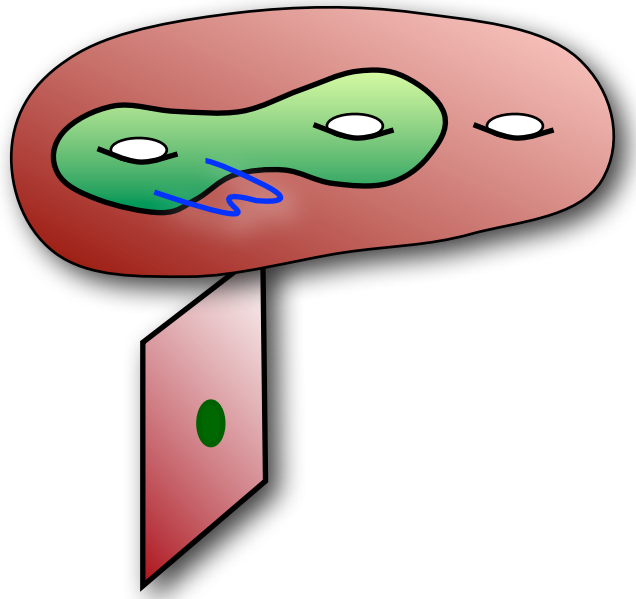
D-brane instantons

- Instanton modes from open strings

  neutral bosonic: integrate over "moduli"

  neutral fermionic: type of 4d terms

  charged: couplings to gauge dof



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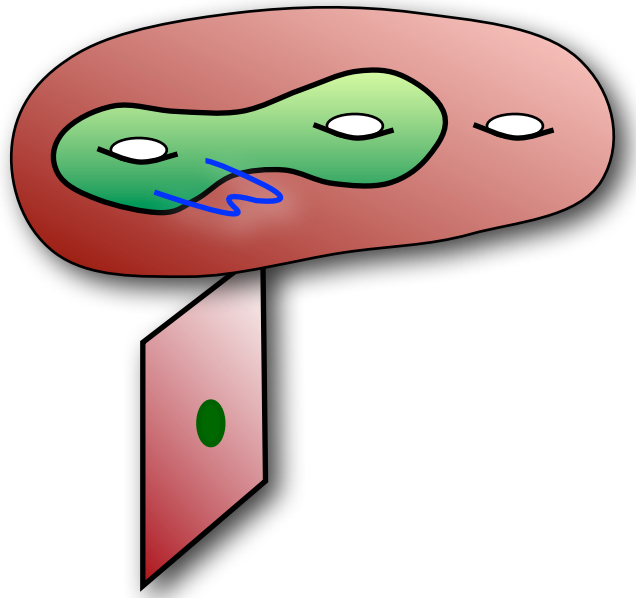

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$$\text{“} \int d^4x\, A\, e^{-bT}\mathcal{O} \text{”}$$

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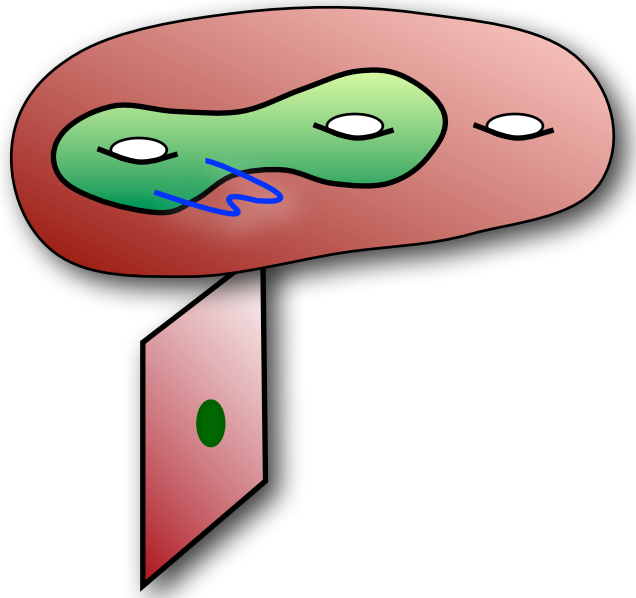

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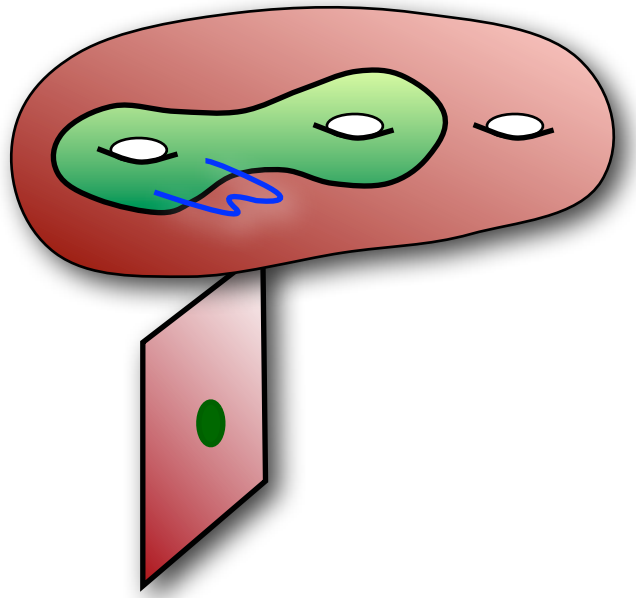

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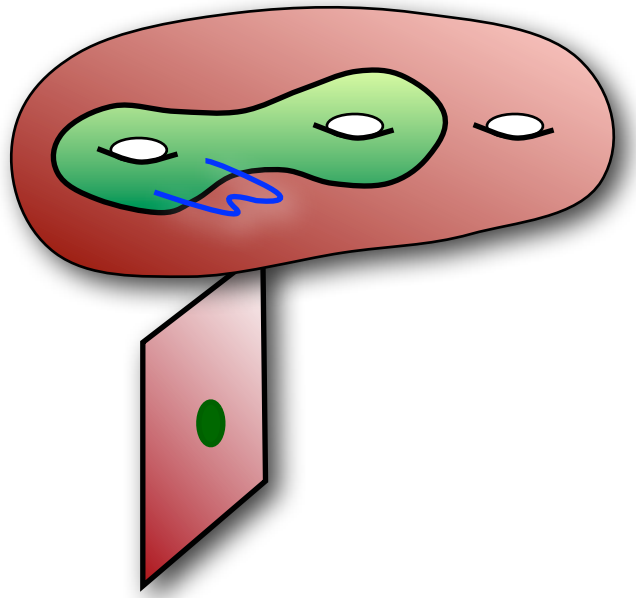

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- Tons of applications

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  - Particle-instanton duality:

  Particle loop in S^1 compactification = Tower of instantons in "T-dual"

underlies many recent proposals e.g. WGC for instantons

Applications: In dualities

Particle loop in S^1 compactification = Tower of instantons in "T-dual"

- M-th on T^2 $\Rightarrow$ 10d type IIB R^4 terms — Green, Gutperle, Vanhove
- M5-brane on T^2 $\Rightarrow$ D3-brane R^2 terms — Bachas, Bain, Green
- M-th on $CY_3 \times S^1 \Rightarrow$ A-model topological string — Gopakumar, Vafa
- M-th on $CY_3 \times S^1/Z_2 \Rightarrow$ unoriented A-model — Piazzalunga, AU
- IIB on conifold$\times S^1 \Rightarrow$ D2-brane instantons on conifold — Ooguri, Vafa
- 5d QFT on $S^1 \Rightarrow$ Seiberg Witten — Nekrasov
- 4d QFT on $S^1 \Rightarrow$ Wall-crossing — Gaiotto, Moore, Neitzke
- M-th on $CY_3 \times T^2 \Rightarrow$ (p,q) string instantons — Collinucci, Soler, AU
- HW on K3 $\times S^1 \Rightarrow$ D7-brane R^4 terms — Petersson, Soler, AU
- ...

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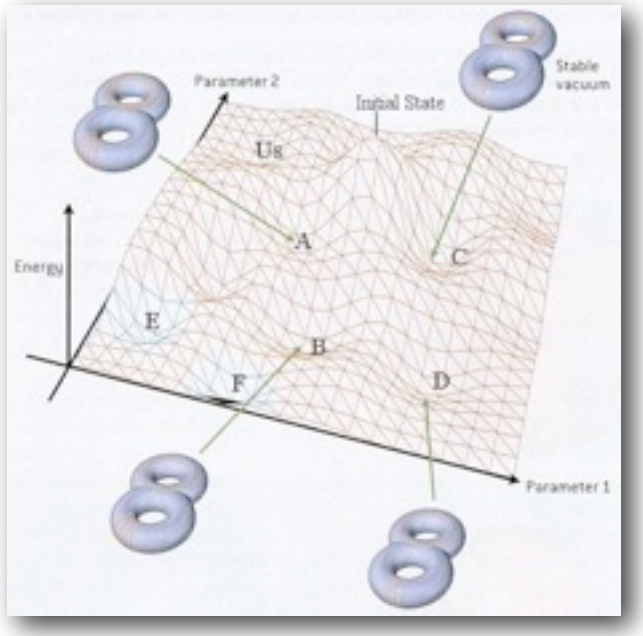

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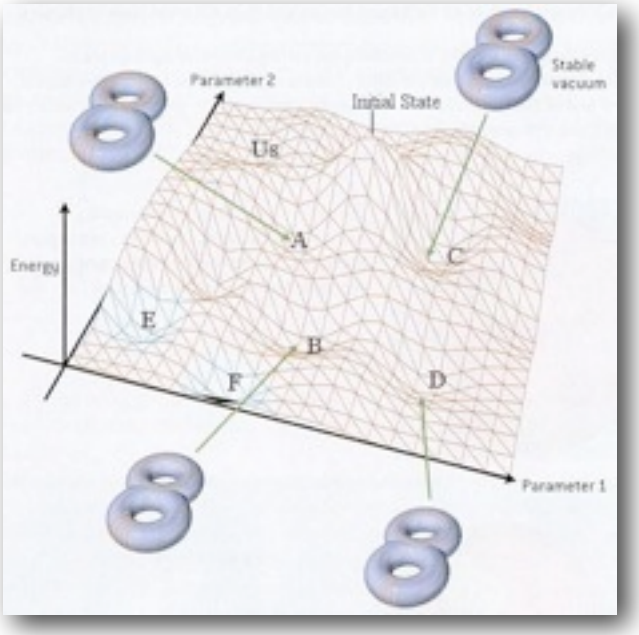
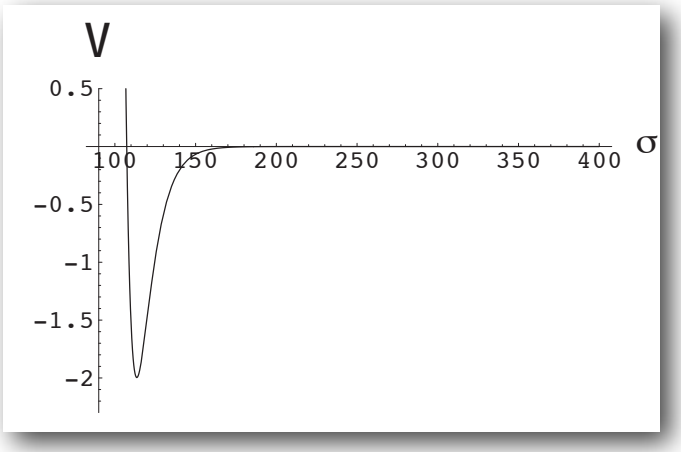
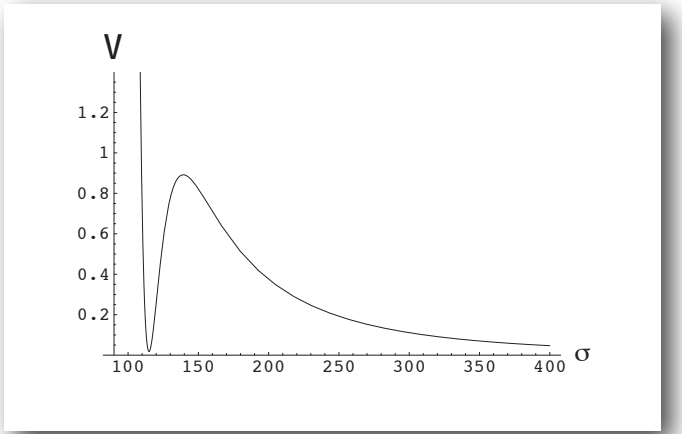
- Contemplate instanton effects

  KKLT; Large volume [Quevedo et al], ...







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  top Yukawa, mu-term, ...

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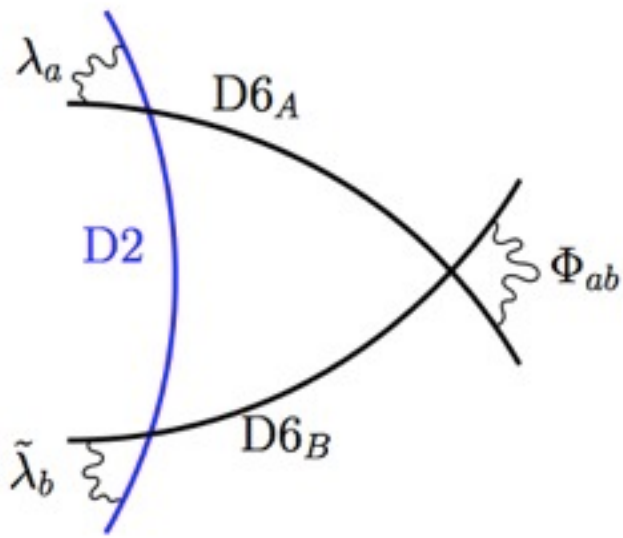

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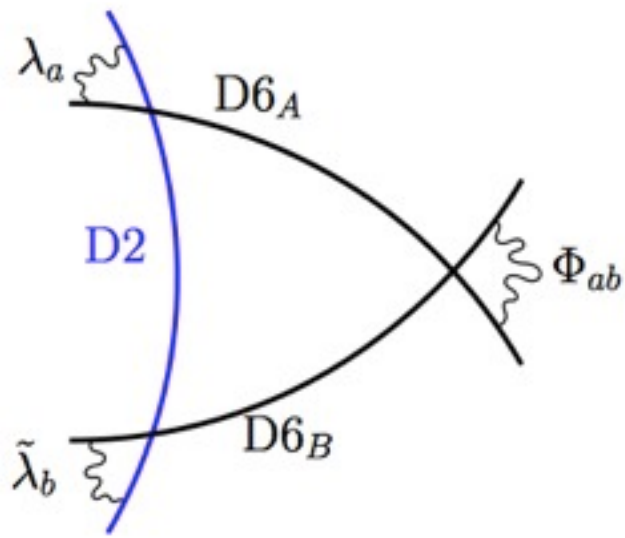

- Integration over instanton fermion zero modes leads to insertions of charged 4d fields

$$W_{\rm inst} = \Phi_1 \dots \Phi_n \, e^{-U}$$

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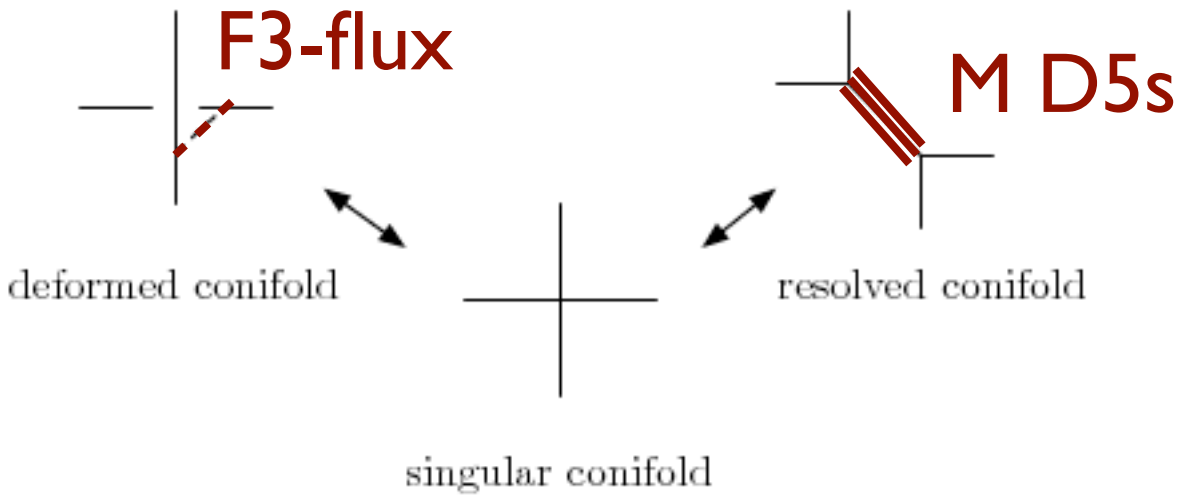
  Non-perturbative SYM condensate in terms of dual deformed geometry

  e.g. Klebanov, Strassler



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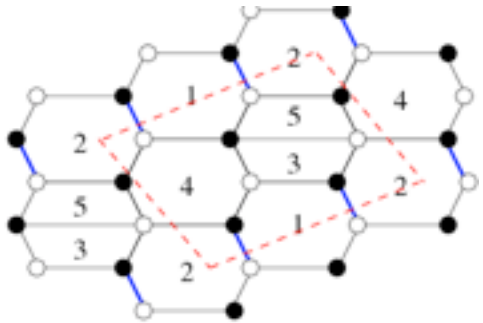

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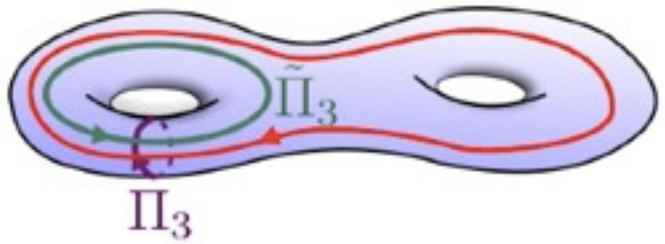

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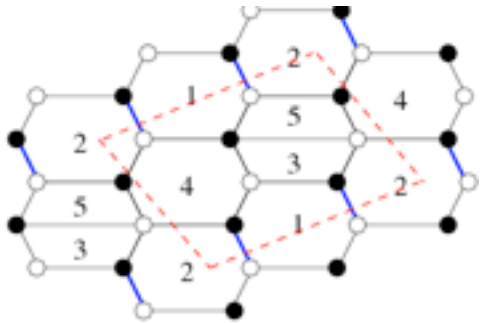

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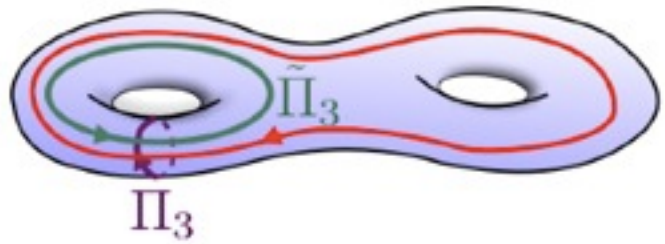
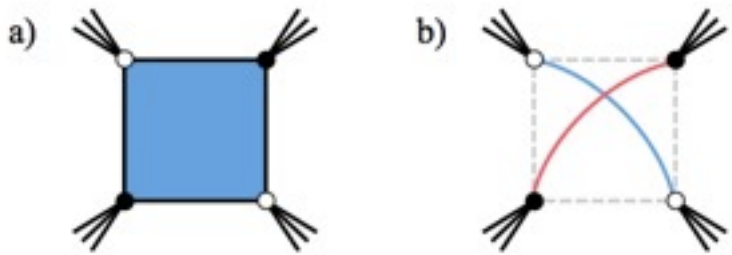
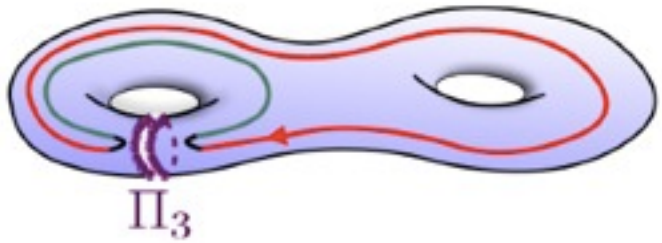


Instantons + backreaction





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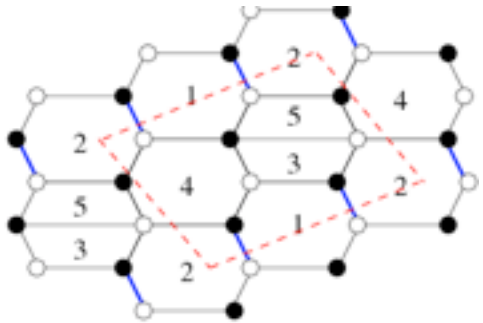

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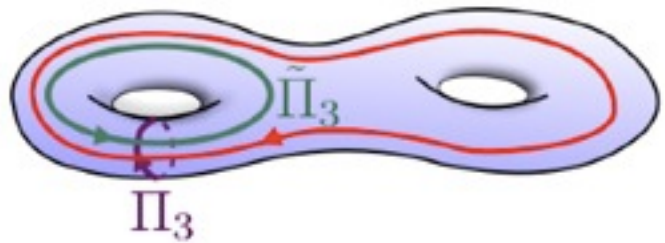

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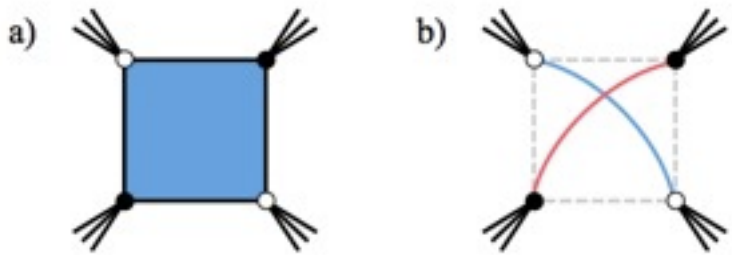

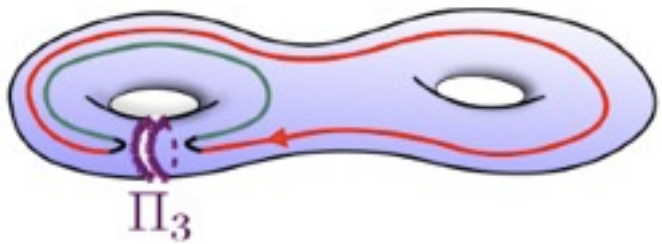

Result in geometries associated to higher-genus bipartite graphs

introduced by Arkani-Hamed et al; Franco et al

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