The classical cosmological constant of open-closed string field theory

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Torino University and INFN

14/09/2022

Based on 2208.00410

+*work in progress*

with ***Jakub Vosmera (ETH)***

Motivations

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- A change in the closed string background can be described through a classical solution in **closed string field theory**.

- D-branes in a changing closed string background should be described within **open-closed string field theory**.

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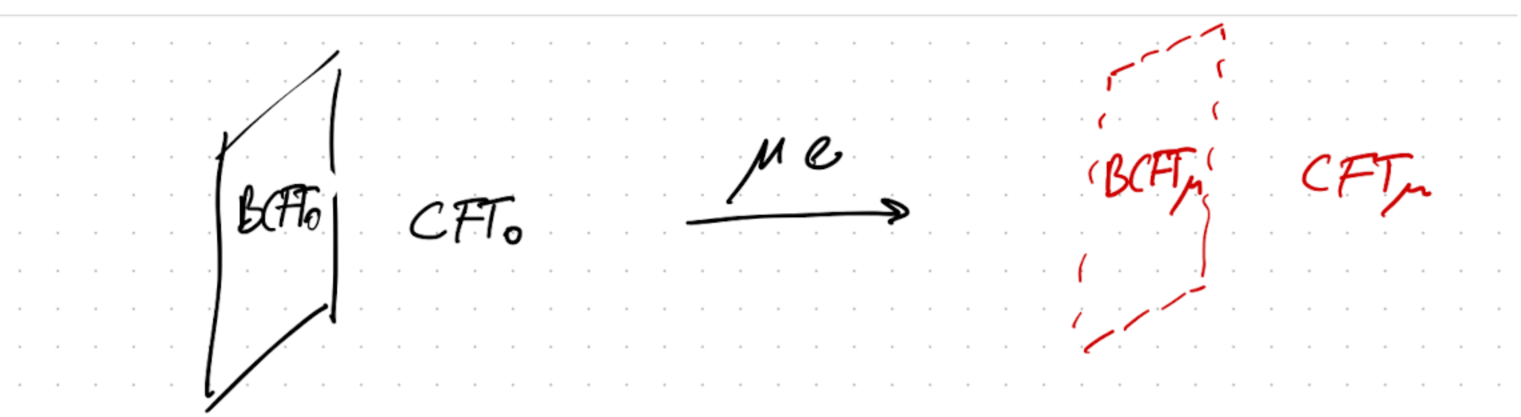
- We showed that this approach can describe the fate of D-branes after a (continuous) change of the closed string background.



CM, Vosmera
2103.04919
2103.04920
2103.04921

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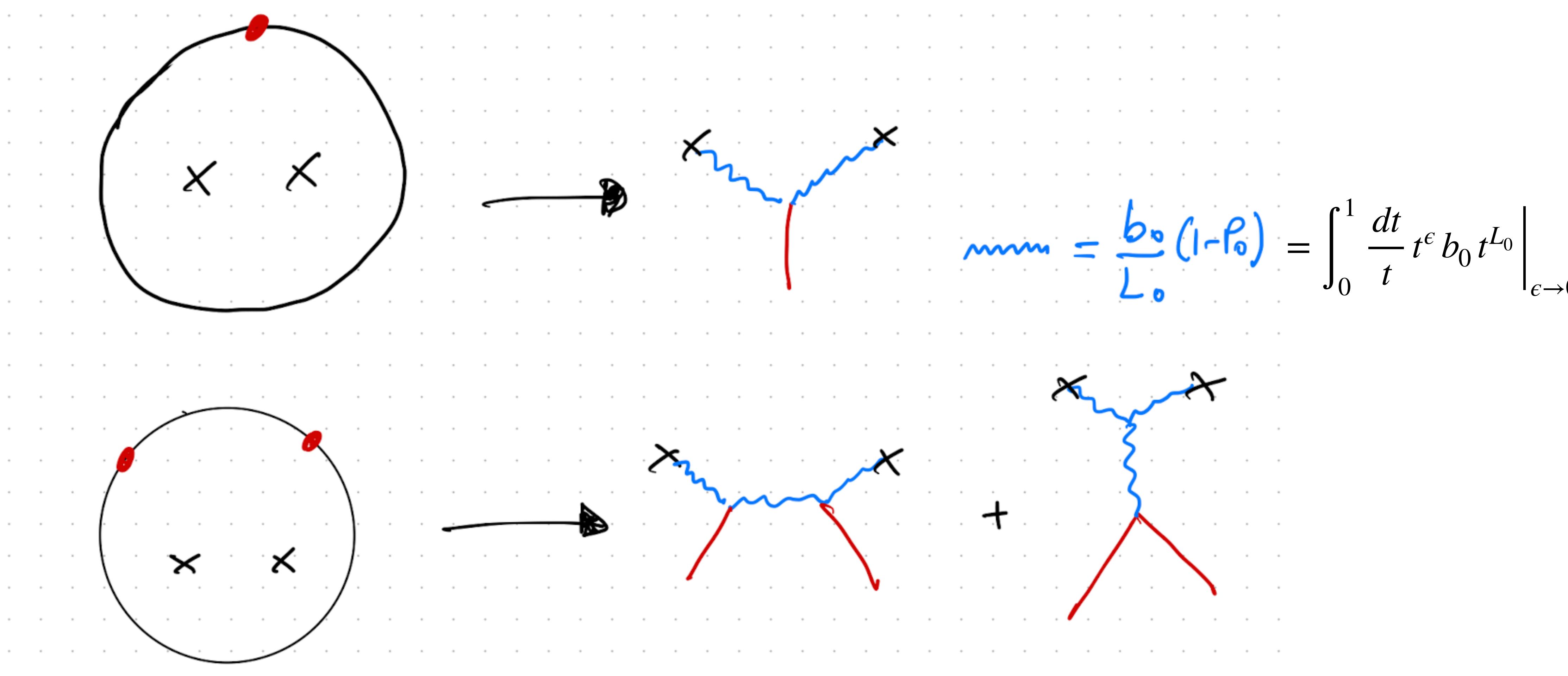
- This shift is encoded in disk amplitudes involving off-shell open strings and on-shell (deforming) closed strings. In principle all open-closed amplitudes are reproduced even at loop level, with the moduli space completely covered by the Schwinger parameters of the open string propagators. (*Zwiebach '91-'92)*



etc…

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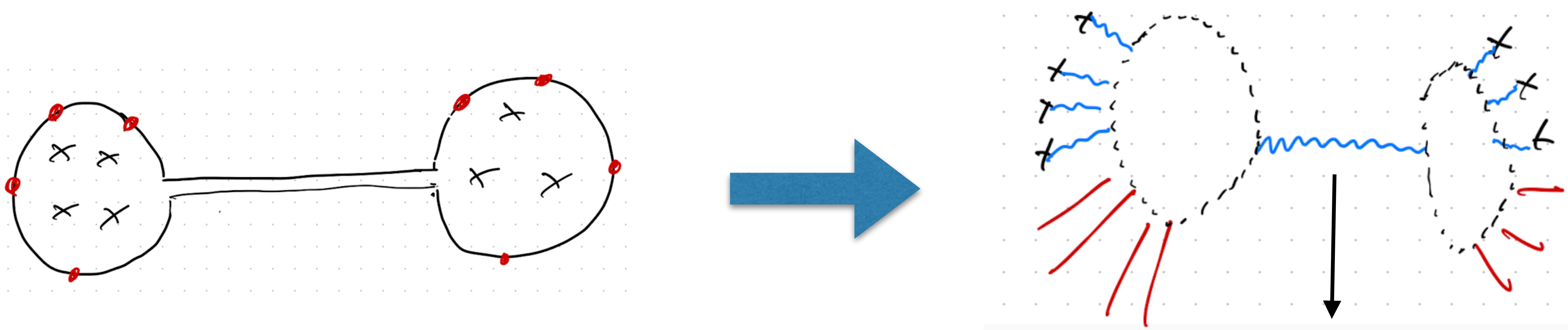
- Thanks to the open string propagators, these amplitudes are well-defined towards open string degeneration, even at zero momentum.



$$\frac{b_0}{L_0} = \frac{b_0}{L_0 + \epsilon}\bigg|_{\epsilon \to 0} = \int_0^1 \frac{dt}{t}\, t^{\epsilon}\, b_0\, t^{L_0}\bigg|_{\epsilon \to 0}$$

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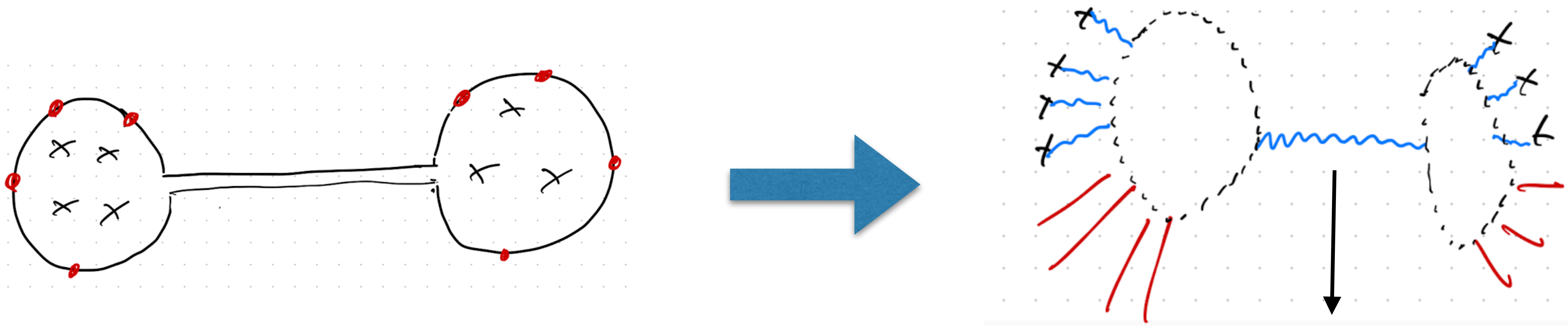

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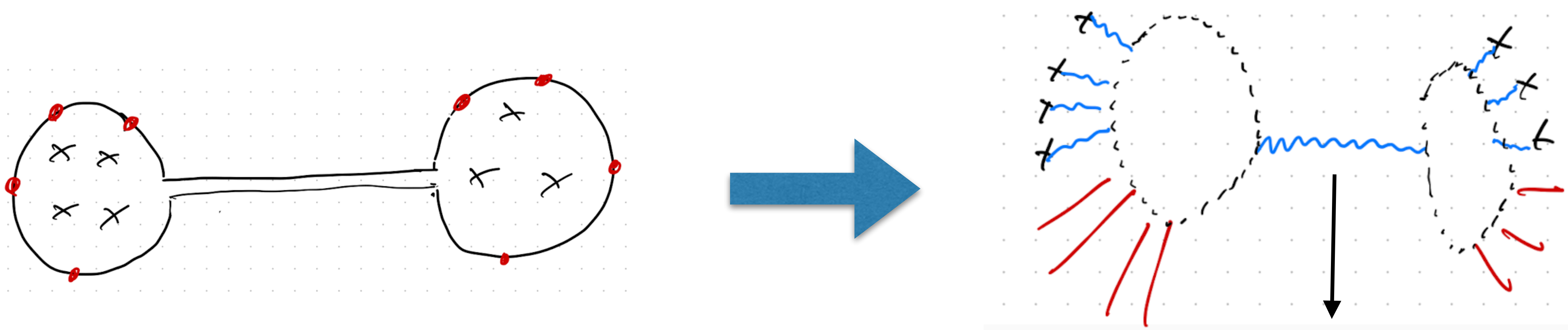

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- This can be useful, for example, to study D-instanton contributions to closed string amplitudes, instead of the full-fledged open-closed SFT.

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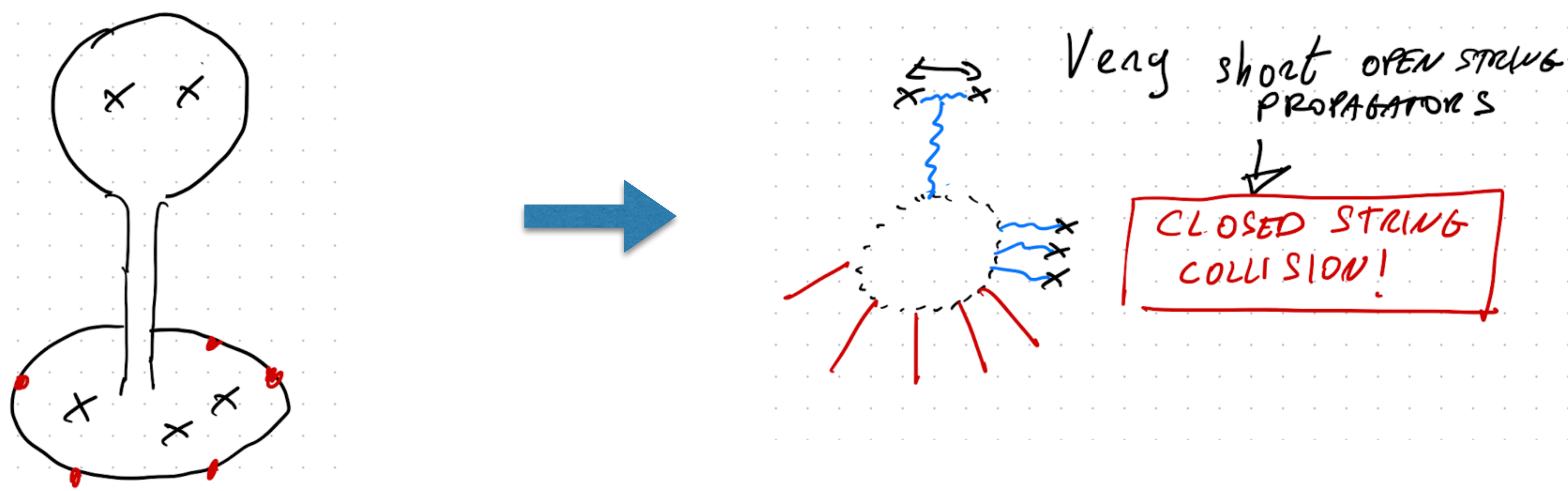
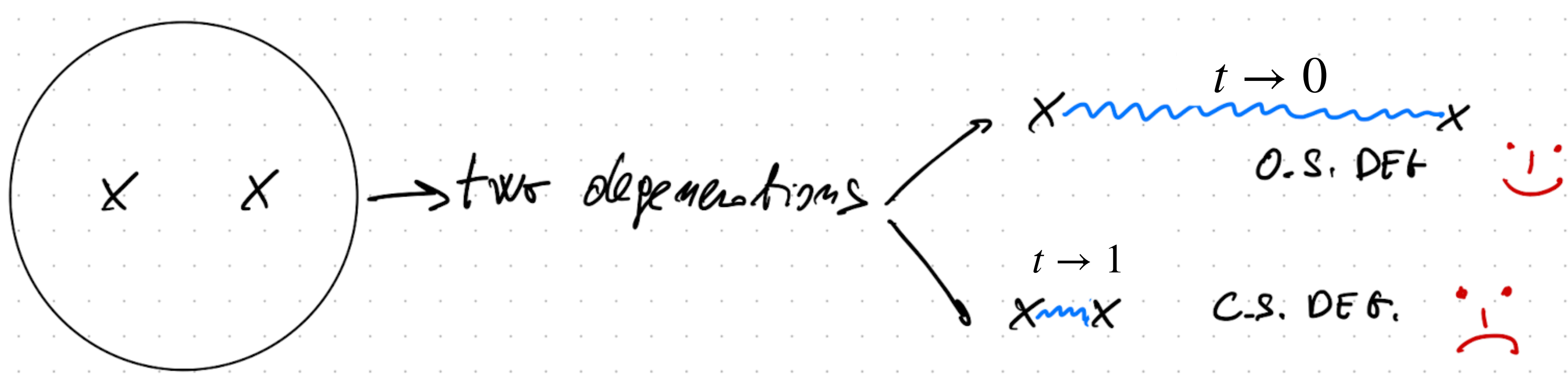
- However when closed strings are very soft (or zero momentum) the regions of closed string degenerations can produce un-tamed IR divergences



- Simplest example is the disk bulk two-point function



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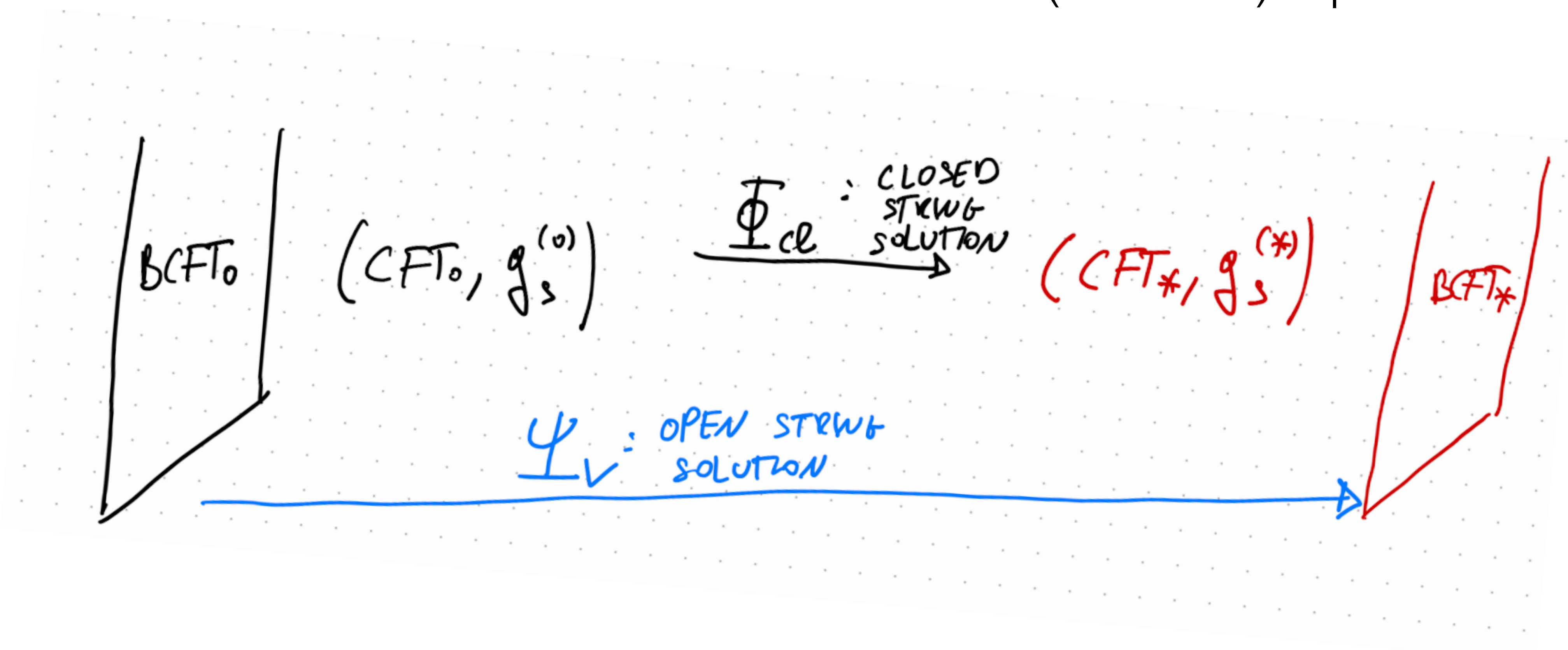

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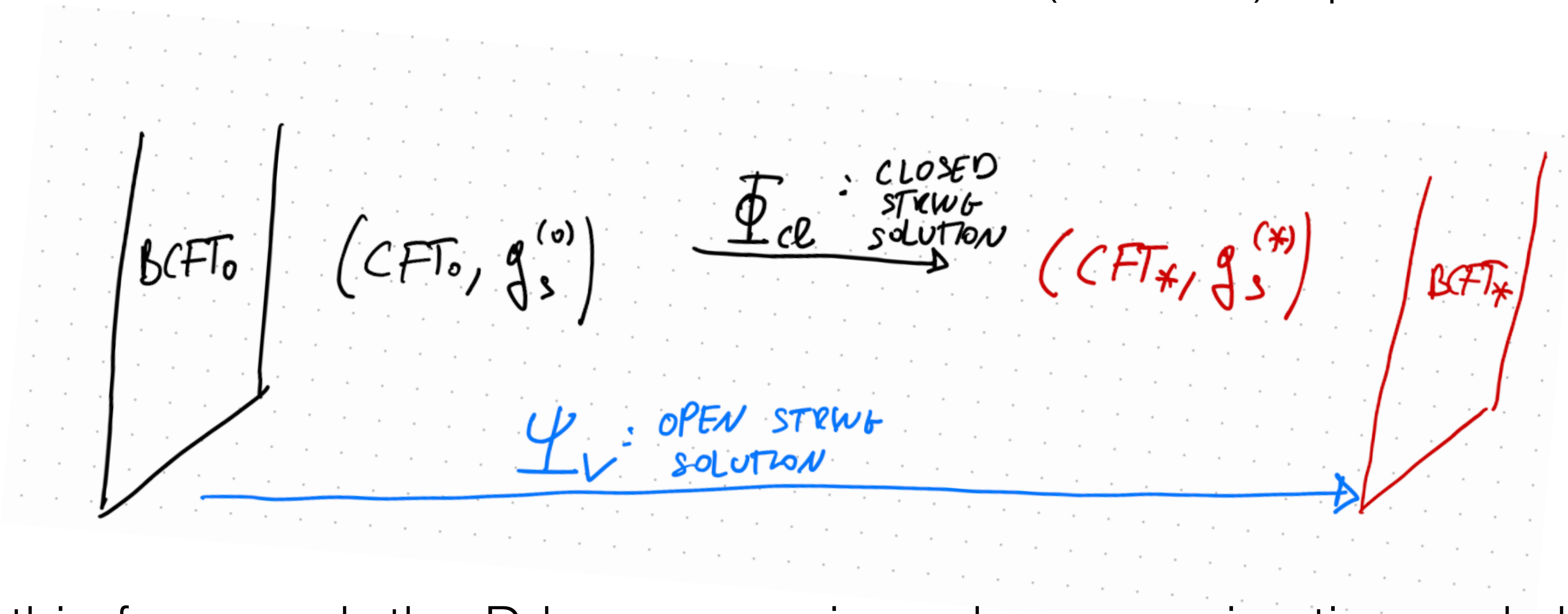

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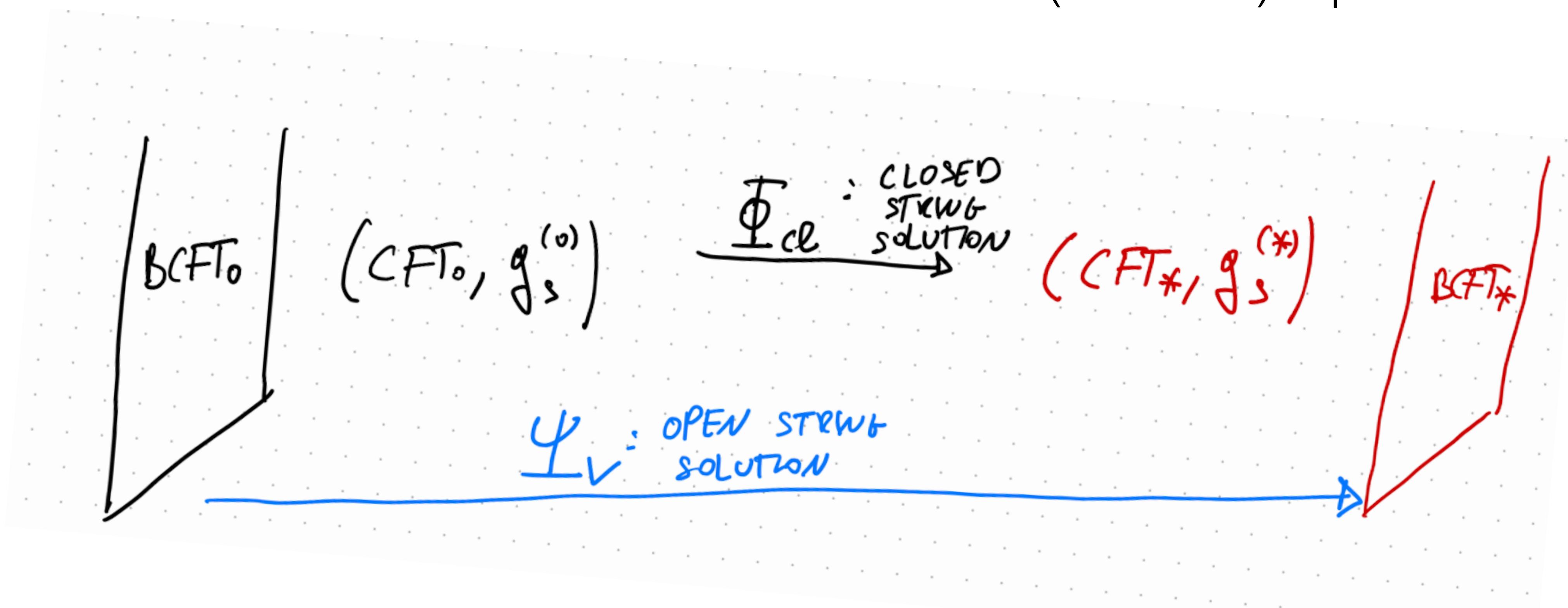

- In this framework the D-branes are in probe approximation and don't back-react on the closed string background. (*interesting to relax this in the future!)*
- (Almost) equivalent question in CFT: how a boundary state changes if I change the bulk CFT? (*Fredenhagen-Gaberdiel 0609034, 2D "bulk-boundary" RG-flows*)

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- Perturbative background shifts (accessible to explicit computations)
- Example: D-brane deformations on a Narain compactification
- Conclusion and outlook

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$$\mathcal{H}^{\mathrm{c}}: \quad b_0^-|\Phi\rangle = L_0^-|\Phi\rangle = 0\,, \qquad\qquad \omega_{\mathrm{c}}(\Phi_1,\Phi_2) = (-1)^{d(\Phi_1)}\left\langle\, \Phi_1, c_0^-\Phi_2\,\right\rangle_{\mathrm{c}}$$

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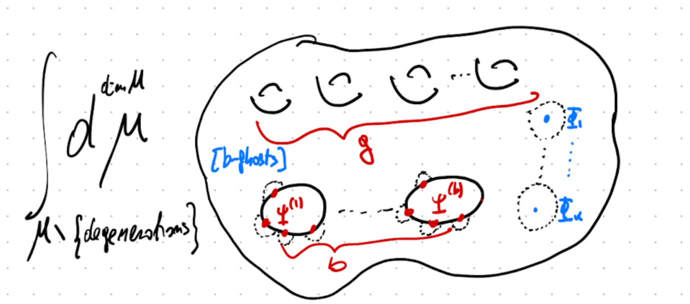
Off-shell amplitude with integration near degenerations removed



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- Geometrically

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- Notice that $S_{0,0}(\Phi)$ and $S_{0,1}(0,\Psi)$ satisfy classical master equations. They are classical closed SFT and classical open SFT respectively.

- We can isolate the **genus zero** sector which obeys the master equation

$$(S_0, S_0)_c + (S_0, S_0)_o + 2\Delta_o^{(1)} S_0 = 0 \,. \qquad S_0 \equiv \sum_{b=0}^{\infty} S_{0,b}$$

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- But it is not possible to also constrain the open strings to be classical (b=1)

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- ***Zwiebach***: This should describe open strings in a deformed closed string background (always ignoring the D-brane back-reaction)

Sphere-Disk Homotopy Algebra (SDHA)

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Notice in particular

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No OS inputs, CS output
Not considered in usual Kajiura-Stasheff OCHA

Open string theory in deformed closed string background

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- The new OSFT looks like

$$S_{\Phi_{\rm cl}}(\Psi) = Z^{(0)}_{\rm disk} + \Lambda_{\rm c}(\Phi_{\rm cl}) - \frac{1}{g_s^{(0)}} \sum_{l=0}^{\infty} \frac{1}{l+1} \omega_{\rm o}\left(\Psi, \tilde{m}_l(\Psi^{\otimes l})\right)$$

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- The $\tilde{m}_l$ obey weak- A_∞ relations ($S_{\Phi_{\rm cl}}(\Psi)$ obeys classical master eq.)

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- In particular there is a zero-product, a classical open string TADPOLE

$$\tilde{m}_0 = \sum_{k=1}^{\infty}\frac{1}{k!}m_{k,0}(\Phi_{\rm cl}^{\wedge k}) \in \mathcal{H}^{\rm o}$$

Open string vacuum shift

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$$\begin{aligned}\Lambda_{\rm o}(\Phi_{\rm cl}; \Psi_{\rm v}) &= -\frac{1}{g_s^{(0)}} \sum_{l=0}^{\infty} \frac{1}{l+1} \omega_{\rm o}\left(\Psi_{\rm v}, \tilde{m}_l(\Psi_{\rm v}^{\otimes l})\right) \\ &= -\frac{1}{g_s^{(0)}} \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \frac{1}{l+1} \frac{1}{k!} \omega_{\rm o}\left(\Psi_{\rm v}, m_{k,l}(\Phi_{\rm cl}^{\wedge k}; \Psi_{\rm v}^{\otimes l})\right)\end{aligned}$$

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$$l_{00}^* = \sum_{k=0}\frac{1}{k!}l_{k,0}(\Phi_{\rm cl}^{\wedge k}) + \sum_{k=0}\sum_{j=1}\frac{1}{k!}\frac{1}{j}\,l_{k,j}\left(\Phi_{\rm cl}^{\wedge k},\Psi_{\rm v}^{\otimes j}\right)$$

$$\boxed{l_1^*\, l_{00}^* = 0}$$

Deformed BRST invariance of the deformed boundary state!
(See Jakub talk!)

Background independence conjecture

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$$\boxed{-\frac{1}{2\pi^2 g_s^{(*)}} \langle 0 \| B_* \rangle\!\rangle = -\frac{1}{2\pi^2 g_s^{(0)}} \langle 0 \| B_0 \rangle\!\rangle + \Lambda(\Phi_{\rm cl}; \Psi_{\rm v})}$$

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- For $\Phi_{\rm cl} = 0$ we get the good old “Sen’s conjecture” of OSFT

$$\Lambda(\Phi_{\rm cl} = 0, \Psi_{\rm v}) = \frac{1}{2\pi^2 g_s^{(0)}}\Big(\langle 0 \| B_0 \rangle\!\rangle - \langle 0 \| B_* \rangle\!\rangle\Big)$$

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Sufficient conditions for exact bulk marginality

Cosmological constant, closed string part

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- Closed string part of the cosmological constant

$$-g_s^{(0)}\Lambda_{\mathrm{c}}(\mu) = \mu\,\omega_{\mathrm{c}}(V, l_{0,0}) + \frac{1}{2}\mu^2\left(\omega_{\mathrm{c}}\left(l_{0,0}\,, \frac{b_0^+}{L_0^+}\bar{P}_0^+ l_2(V,V)\right) + \omega_{\mathrm{c}}(V, l_{1,0}(V))\right) + \mathcal{O}(\mu^3)$$

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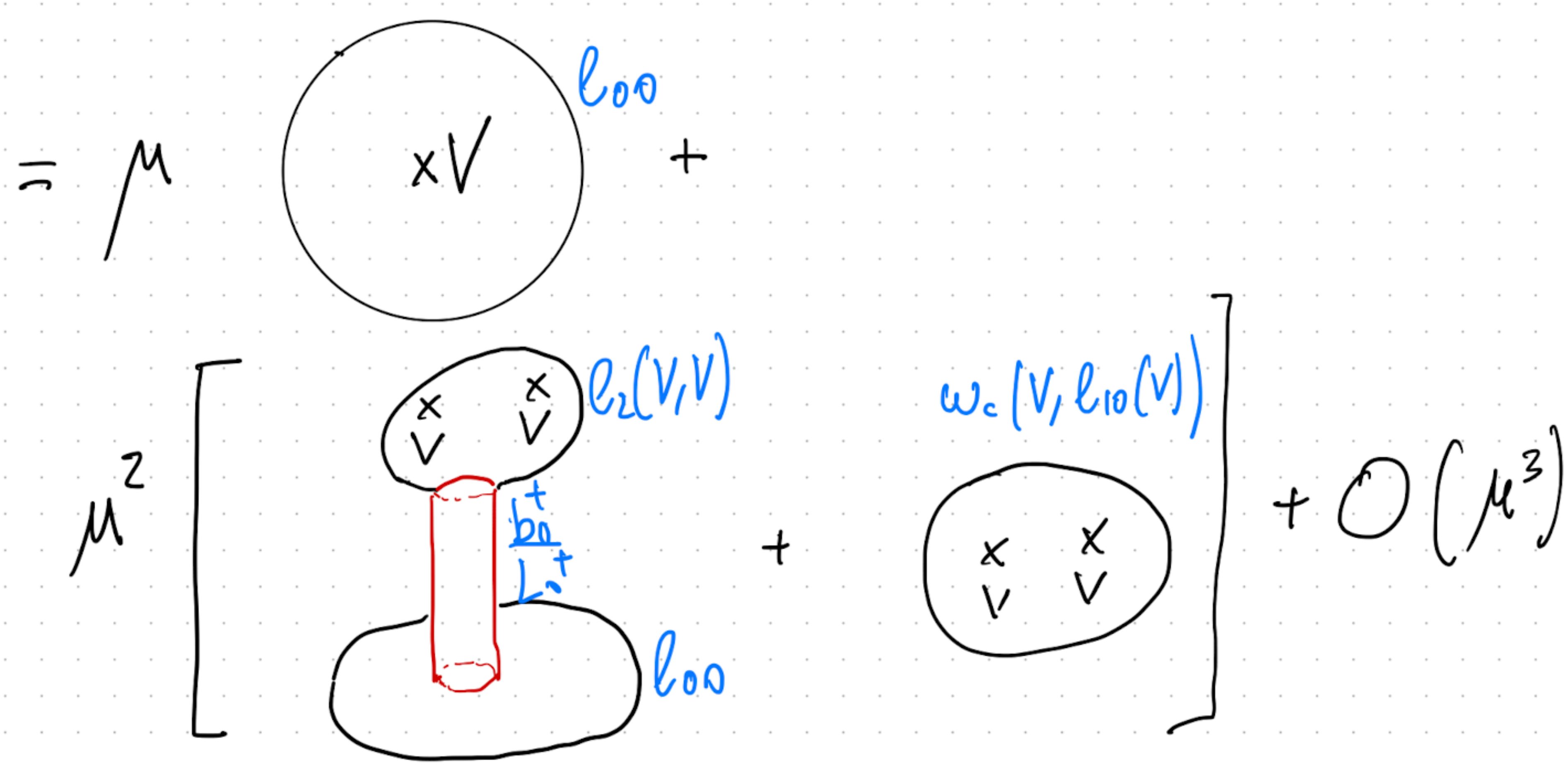

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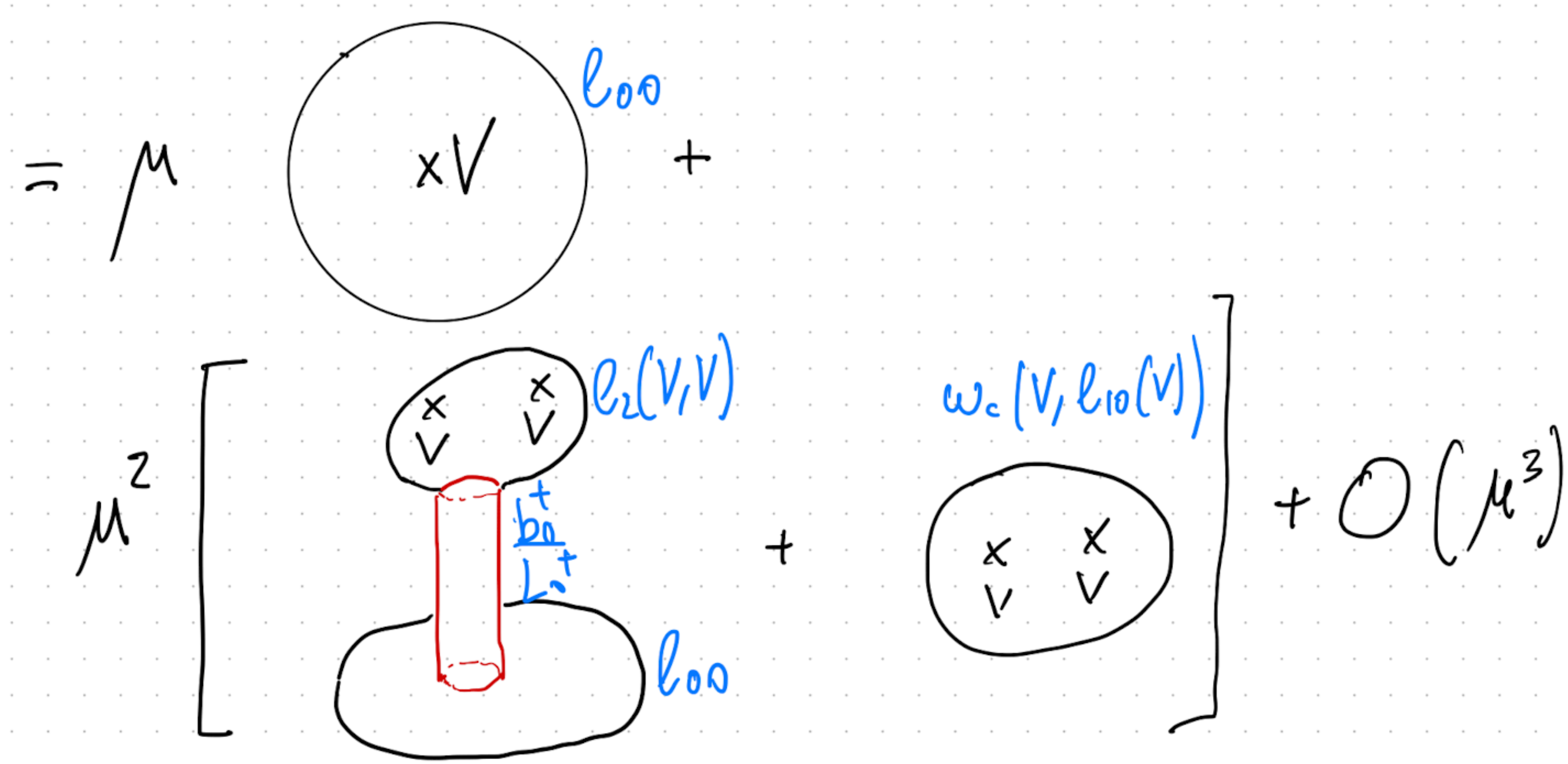

- Remember: this alone is not gauge invariant! As an amplitude it is missing the region of open string degeneration.

Open string vacuum shift solution

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- We also need the open string solution. Tadpole-sourced equation of motion

$$\tilde{m}_0 + \tilde{m}_1(\Psi) + \tilde{m}_2(\Psi, \Psi) + \ldots = 0\,.$$

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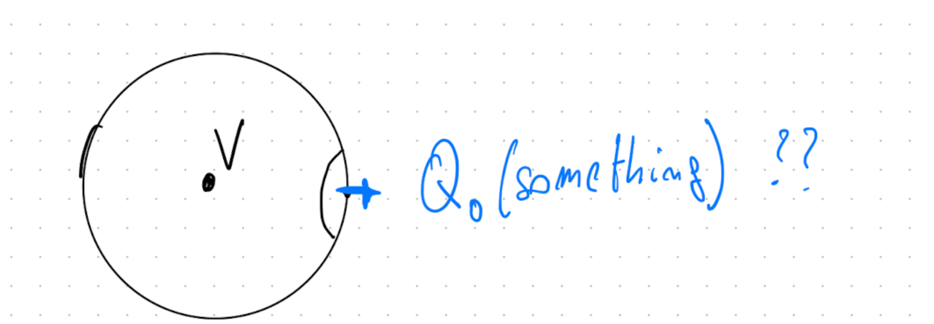

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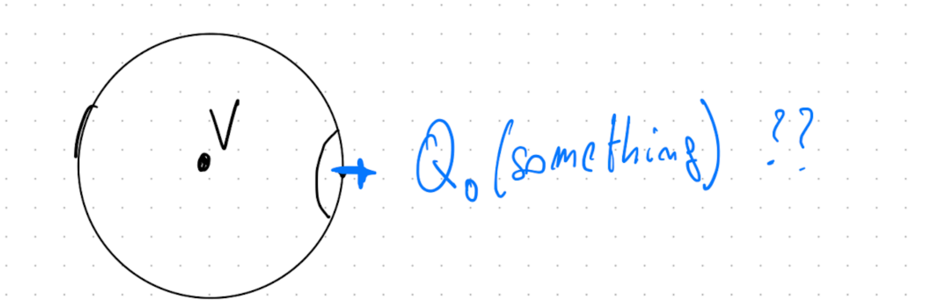

Strong condition on bulk-boundary OPE!

See 2103.04919 for examples

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- EFT interpretation: *the "massless" tadpole is zero . AKA: amplitudes between deforming closed strings and a single massless open string are zero*

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- The open string contribution to the cosmological constant is

$$-g_s^{(0)}\Lambda_{\rm o}(\mu) = \frac{1}{2}\mu^2\omega_{\rm o}\left(m_{1,0}(V), \frac{b_0}{L_0}\bar{P}_0 m_{1,0}(V)\right) + \mathcal{O}(\mu^3)$$

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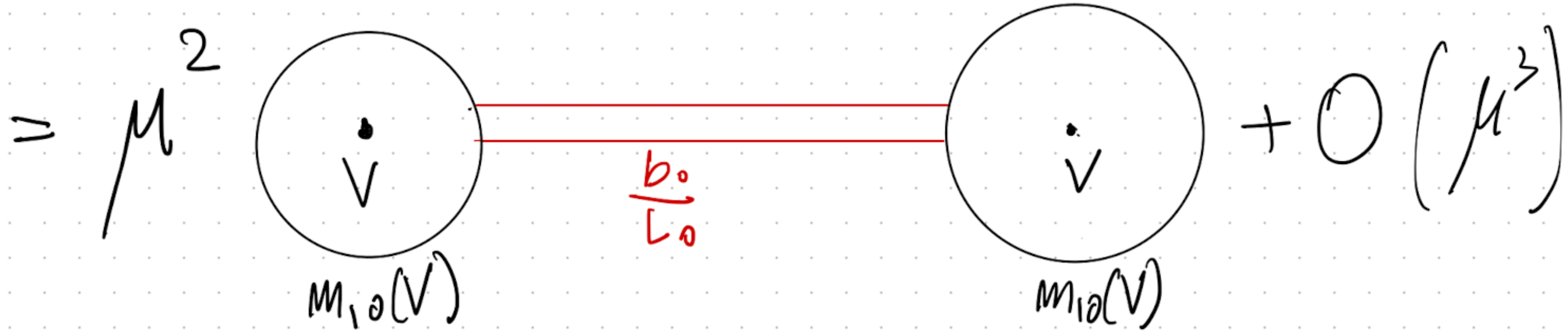

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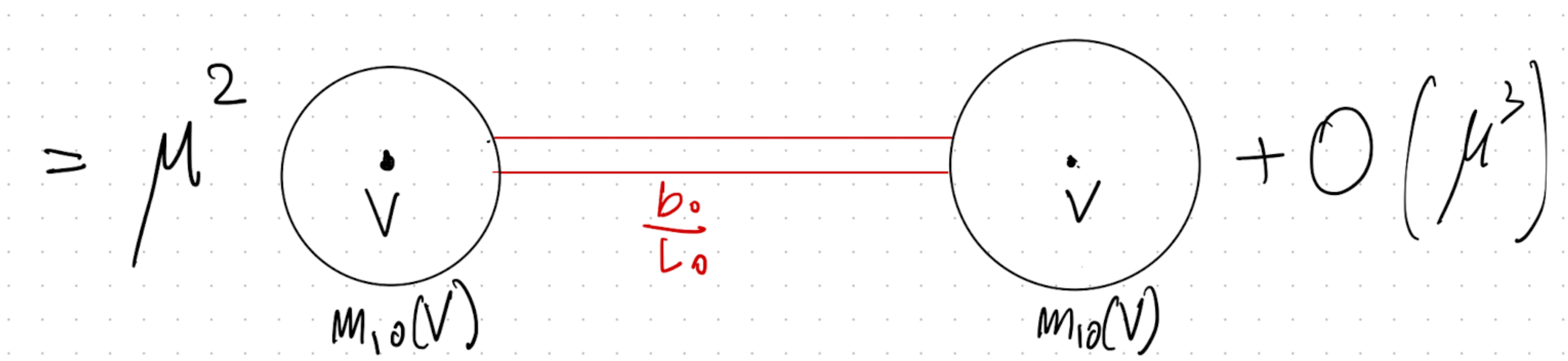

- This is giving the missing part containing open string degeneration!

Total cosmological constant

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- Notice: the two-point amplitude

$$\mathcal{A}(V_1, V_2) = \omega_{\rm c}\left(l_{0,0}\,,\,\frac{b_0^+}{L_0^+}\bar{P}_0^+ l_2(V_1,V_2)\right) + \omega_{\rm c}(V_1, l_{1,0}(V_2)) +$$
$$+ \,\omega_{\rm o}\left(m_{1,0}(V_1),\,\frac{b_0}{L_0}\bar{P}_0 m_{1,0}(V_2)\right)$$

correctly decouples BRST exact states ($V_2 = Q(\Lambda)$ (up to boundary terms) thanks to the non-trivial SDHA relation

$$[Q_{\rm c}, l_{1,0}] + l_2 l_{0,0} + l_{0,1} m_{1,0} = 0$$

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$$\times \langle\, \mathbb{V}_{1,1}(i,\bar{i})\mathbb{V}_{1,1}(is,\bar{is})\,\rangle_{\rm UHP}\Big|_{\substack{\epsilon_{\rm c}\to 0\\ \epsilon_{\rm o}\to 0}}$$

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- Witten Theory: $\lambda_o \rightarrow 1^-$, the closed string channel disappears, together with the regularization at closed string degeneration. ***Singular limit!***

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CONSISTENCY CHECK

This is independent of boundary conditions! $\tilde{\epsilon}_{ij} = \epsilon_{ik}(\Omega^T)^k{}_j, \qquad \Omega g \Omega^T = g$

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- ***Thanks, comments and suggestions are welcome!!***