recap:

II B on CY_3 M

BH $AdS_2 \times S^2$

$Q = \int_{S^2 \times \Sigma} F^{(5)}$

$Z = Q \cdot \Pi = \int_\Sigma \Omega$

$S = e^{K}|Z|^2$

$Q_A \cdot D_i \Pi^A = D_i Z = 0$

SUSY RR flux vac AdS_4

$Q = \int_\Sigma H_{RR}^{(3)}$

$W = \int H_{RR}^3 \wedge \Omega$

$+V = e^K(g^{i\bar{j}} D_i W D_{\bar{j}} W^* - 3|W|^2) + D^2$

$D_i W = 0$

CY facts:

$e^{-K} = \int_M \Omega \wedge \Omega$

$H^{3,0}, H^{2,1}, H^{1,2}, H^{0,3}$

$\Omega \quad D_i\Omega \quad D_i D_j \Omega \quad D^3\Omega$

$\|W\|^2 = e^K |W|^2$

$$dN(\varphi)\Big|_{Q\to\infty} = \int d^{b_3}Q\ \delta^{(2n)}(DW(\varphi))\ |\det_{ij} \partial_i D_j W|$$

Mathematically identical

Physically?

$Q_A = 2\,\mathrm{Re}\, u\, \eta_{AB} \Pi^B(\varphi)$ $\qquad H_{RR}^3 = 2\,\mathrm{Re}\,\bar{u}\,\Omega^{(3)} \in H^3(M, \mathbb{Z})$

Tricks: (simplicity following from fact that problem is at 1 pt φ_0)

1. $K(\varphi_0) = 0$ $\qquad g_{i\bar{j}}(\varphi_0) = \partial_i \partial_{\bar{j}} K$

$e_I^i D$ $\qquad \qquad = e_i^{\ I} e_{\bar{j}}^{\ \bar{J}} \delta_{I\bar{J}}$

2. Q, H_{RR} $\longrightarrow$ $W(\varphi_0) = \int H \wedge \Omega \quad \leftarrow 2$ $\qquad 2 + 2n = b_3$.

$F_I := D_I W(\varphi_0) = \int H \wedge D_I \Omega \quad \leftarrow 2n$

$D_I D_J W$

b_3 real fluxes:

$$\frac{\partial(W, F_I, \bar{W} F_{\bar{I}})}{\partial H} = J$$

$$= \int d^2W\, d^{2n}F \;\; \delta^{(2n)}(F) \det\begin{pmatrix} \bar D D W & D D W \\ \bar\partial D W^* & \partial \bar D W^* \end{pmatrix} \rightarrow |W|^{2n}(\det g_{I\bar J})$$

$\downarrow$ vol.

$$|J|^2 = \det \frac{\partial(W,F)}{\partial H} \wedge \frac{\partial(\bar W,\bar F)}{\partial H} = \begin{array}{c|cccc} & \bar W & \bar F & W & F \\ \hline W & \int\Omega\wedge\bar\Omega & \cancel{\int\Omega\wedge D\bar\Omega} & \cdots & \\ F_I & & \cdots & \cdots & \end{array}$$

$= 1$ (const)

Facts!

dependent $\rightarrow$ $D_I D_J W = \mathcal{F}_{IJK} \bar F_{\bar K} g^{K\bar K}$

$\bar\partial_{\bar I} D_J W = g_{\bar I J} W$

$$\boxed{dN(\varphi, W) = |W|^{2n}(\mathrm{vol}).}$$ (uniform).

these are finite.

Reviews
9601395
0504194

QCD and Collider Physics.

Energy Frontier

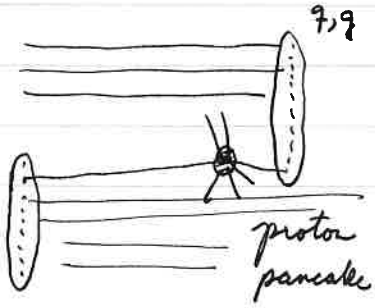
Tevation $\longrightarrow$ 1TeV $\rightarrow$ $\leftarrow$ 1TeV

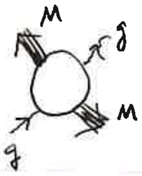
$p \rightarrow \; \leftarrow \bar p$

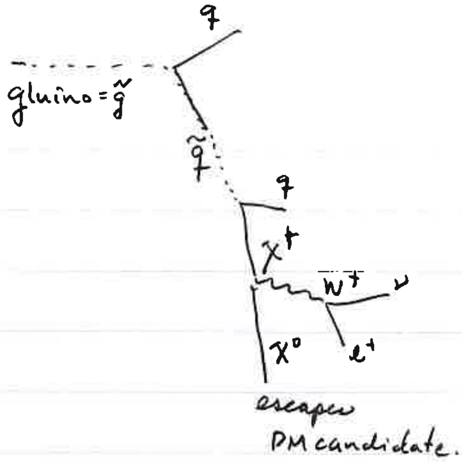
LHC $\longrightarrow$ 7TeV $\rightarrow$ $\leftarrow$ 7TeV

$p \rightarrow \; \leftarrow \bar p$

Luminosity up by x100.







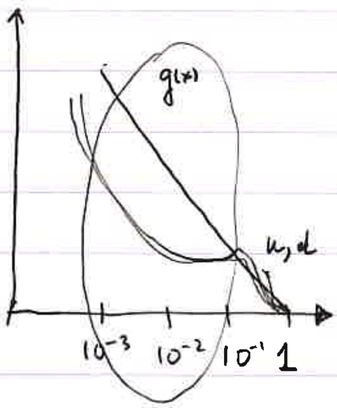
eventually heavy → many light SM particles.

$$\sigma(\cdots) = \sum_{a,b} \int dx^1 dx^2 \, f_a(x^1) f_b(x^2) \boxed{\hat{\sigma}(x^1, x^2, \ldots)}$$

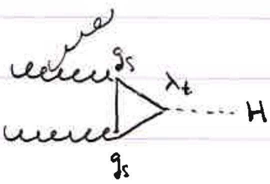
$a, b = q_i, g$

partonic cross section

scale, involving power → Q^2

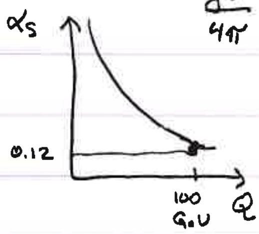


Higgs boson: $gg \to H$



$$\hat{\sigma}(H+X) = \sigma_0 \alpha_s^2 \times (1 + \underbrace{B\alpha_s}_{0.8} + \underbrace{C\alpha_s^2}_{0.2} + \cdots)$$

$\frac{g_s^2}{4\pi} = \alpha_s$



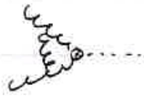
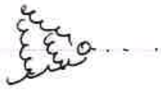
Leading order: $\sigma_0 \alpha_s^2 \times 1$.

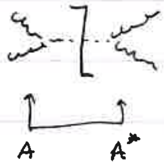
$m_H < 200$ GeV

$2m_t = 350$ GeV

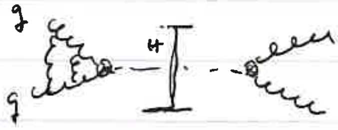
$m_t >> m_H$

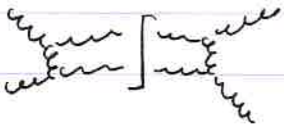
$C(m_t) = H\, tr(G_{\mu\nu} G^{\mu\nu})$

$\sigma \sim |A|^2$ $\quad A_{gg\to H} =$  $+ g_s^2$  $+ g_s^4$ 

$\rightarrow$ $|$  $|^2 =$  "cut symbol"

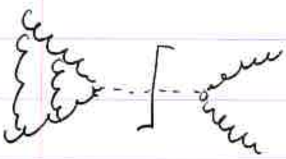
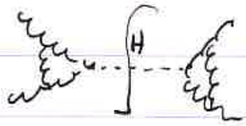
NLO:

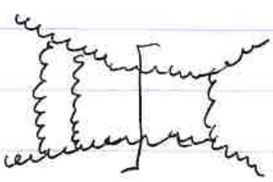
virtual  dim. reg $\rightarrow \frac{1}{\varepsilon^2}$ $\quad D = 4 - 2\varepsilon$

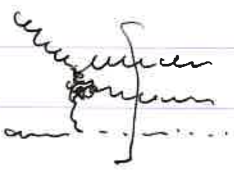
real 

$|A(gg \to H + g)|^2$

NNLO:

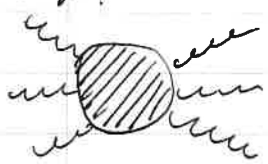
 +  doubly virtual $\frac{1}{\varepsilon^4}$

 virtual/real $\pm \frac{1}{\varepsilon^4}$

 doubly real $\frac{1}{\varepsilon^4}$

Stop pert when # terms $\sim \frac{1}{\alpha}$

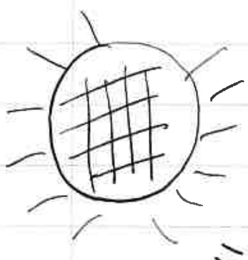
# of diagrams large:



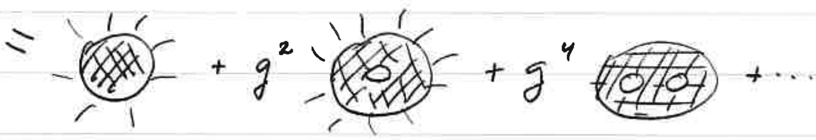
	diagrams	max # terms
6 gluons	1220	2^*
7 gluons	2480	5

$\Rightarrow$ diagrams are not efficient.

Task:



mostly massless $q, g, \ell^{\pm}, \nu$
occasionally $t, \tilde{g}, \tilde{q}$



$= A(\{k_i^\mu, \varepsilon_i^\mu, a_i\})$

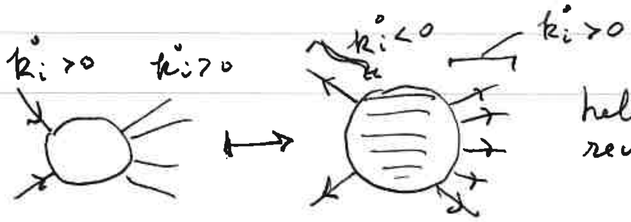
adjoint color index.

Simplify by pulling apart = decompositions

- Color
- Helicity

$\to A(k_i) \to$ use analytic information: · poles = factorization
· branch cuts = unitarity.

"Crossing Symmetry"
All momenta outgoing

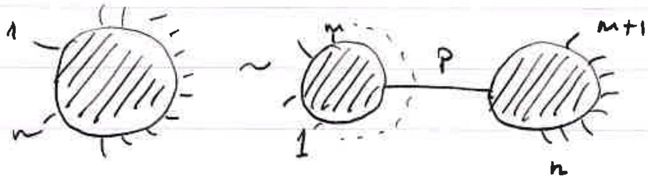


helicities reverse!

Factorization

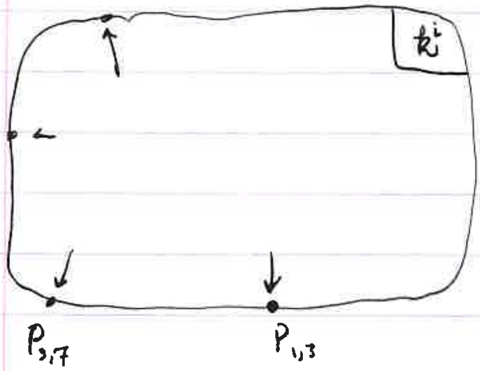
Multi particle

$$(k_1 + \cdots + k_m)^2 \simeq 0$$

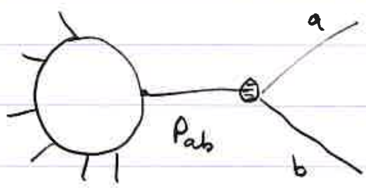


$$p^\mu = -(k_1^\mu + \cdots + k_m^\mu)$$

$$A_n^{tree}(1,\ldots,n) \sim \sum_{h=\pm 1} A_{m+1}^{tree}(1,\ldots,m,-p)\, \frac{i}{p^2_{1-m}}\, A_{n-m+1}^{tree}(m+1,\ldots,n,-p)$$



Collinear



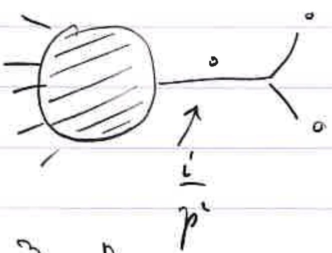
$P_{ab}^2 \to 0$ $\qquad P_{ab} = k_a + k_b$

$$\boxed{\begin{aligned} k_a &\simeq z(k_a+k_b) \\ k_b &\simeq (1-z)(k_a+k_b) \end{aligned}}$$

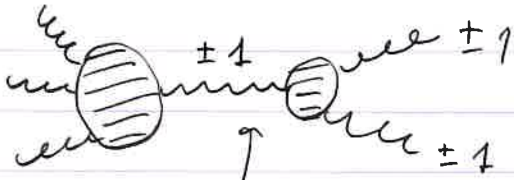
$k_a^2 = k_b^2 = 0$

$P_{ab}^2 = (k_a + k_b)^2 = 2k_a k_b = 0$ collinear

Massless ϕ^3



Gauge Thy.



absorbed into $g(x)$.

$\frac{1}{\sqrt{P_{ab}^2}}$ ← angular momentum obstacle.

⟵ $\boxed{|A|^2 \sim \frac{1}{P_{ab}^2}}$ collinear singularity.

Color:

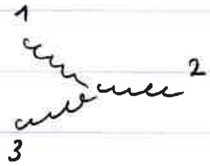
$$A_n^{tree}\left(\sum_i k_i, a^i\right) = g_s^{n-2} \sum_{\sigma \in S_n/Z_n} \mathrm{Tr}\left(T^{a_{\sigma(1)}} T^{a_{\sigma(2)}} \cdots T^{a_{\sigma(n)}}\right)$$

color $a^i = 1, \ldots, N_c^2-1$ $SU(N_c)$.

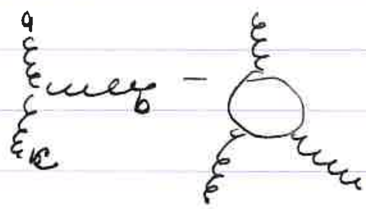
$SU(N_c)$ generators Chan-Paton

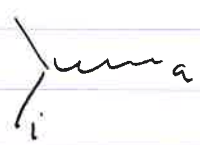
$$\times A_n^{tree}(\sigma(1^{h_1}), \ldots, \sigma(n^{h_n}))$$

Compute $A_n^{tree}(\sigma(1^{h_1}), \ldots, \sigma(n^{h_n}))$

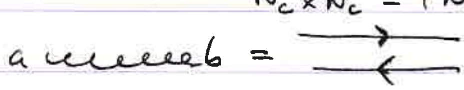
Feynman  $= f^{a_1 a_2 a_3} \eta^{\mu_1\mu_2}(k_1^{\mu_2} - k_2^{\mu_3}) + \text{cyclic}$

 $= f f \cdot \eta\eta + \cdots$

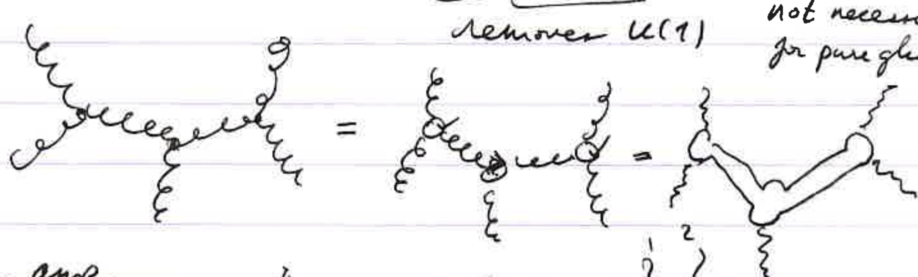
$f^{abc} \simeq \mathrm{Tr}([T^a, T^b]T^c) =$ 

$(T^a)^j{}_i =$  ← color

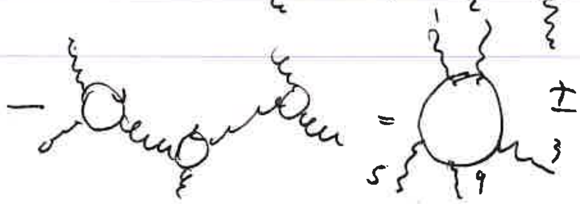
$N_c \times \bar{N}_c = (N_c^2-1) \oplus 1$

$\delta^{ab} =$  $\underbrace{-\frac{1}{N_c} \supset \subset}_{\text{removes } U(1)}$

not necessary for pure glue.

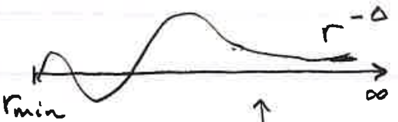


5 gluon amp.

 $\pm$ perms

6/29/05

Polchinski 2



hard wall

$\phi|_{r_{min}} = 0$

$AdS_5 \times S^5 \longleftarrow R^4 = 4\pi\alpha'^2\lambda$

$x, r \;\; \theta$

$\lambda = \frac{g^2}{4\pi} N_c$

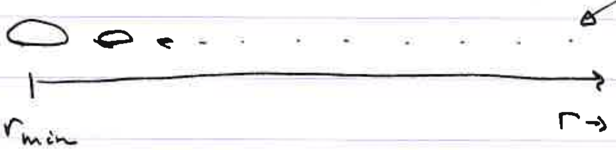
$$\Phi(r,x,\theta) = e^{ik\cdot x}\,\xi(r,\theta) = e^{ik\cdot x}\phi(r)\,Y(\theta) \xrightarrow[r\to\infty]{} \phi \to \begin{cases} r^{\Delta-4} & m_5^2 = \Delta(\Delta-4) \\ r^{-\Delta} & \text{normalizable} \end{cases}$$

$$\nabla_{10}^2 \Phi = 0 \;\rightarrow\; \nabla^2_{AdS_5}\left(e^{ik\cdot x}\phi(r)\right) = m_5^2\, e^{ikx}\phi(r) \qquad \cancel{m_5^2 =}$$

$$\downarrow$$

$$\left(\frac{R}{r}\right)^2 \eta^{\mu\nu}\partial_\mu\partial_\nu + \frac{1}{r^3}\partial_r r^5 \partial_r$$

$$\phi(r) = \frac{1}{r^2} J_{\Delta-2}\left(\frac{R}{r^2}K\right) \qquad K = \sqrt{-k^2}$$

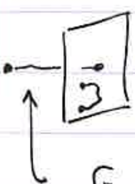


same size in

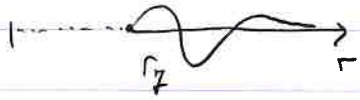
$dx' = \frac{R}{r}dx$

$\sqrt{\alpha'}$

~ Reduced QCD on r.

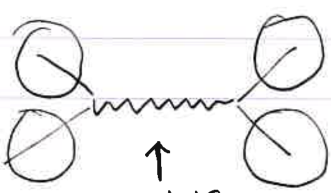


D3 - D7 string.

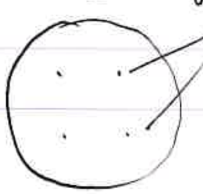


$\frac{r_7}{2\pi\alpha'} = m_q$

Will scatter these.



$E \to$ large String...



Vertex Ops.

Assume $\lambda \gg 1 \Rightarrow$ string in approx. flat space.

$\underline{X}(\sigma)$

$$S_{ws} = \frac{1}{4\pi\alpha'}\int d^2\sigma \, \underset{\sim R^2}{G_{\mu\nu}} \, \partial_a X^\mu \partial_a X^\nu$$

$$\Rightarrow \quad S_{ws} \sim \frac{R^2}{\alpha'} = \sqrt{\lambda}$$

$\Rightarrow$ use saddle point approx. $\rightarrow$ almost flat space.

$$\underline{X}^M(\sigma) = x^M + \underset{\text{Gaussian}}{\underline{X}^{M'}(\sigma)}$$

$$\int [dx]\, e^{-S_{ws}} V_1 V_2 \cdots = \int d^{10}x \underbrace{\int [dx']\, e^{-S_{ws}} V_1 \cdots}_{\text{Flat space calc.}}$$

$$= \int d^{10}x \sqrt{-G}\, S_{local}(x) \quad (\text{define } S_{local}).$$

$p_r \sim \frac{1}{R}$ (small.)

$$\boxed{= \int (2\pi)^4 \delta(\Sigma K)\, dr\, d\theta \sqrt{-G} \prod_i \phi_i(r) Y_i(\theta)\, S_{10}\left(\frac{KR}{r}\right)}$$

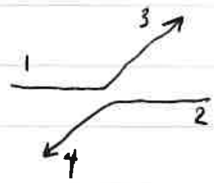
save a line formula.

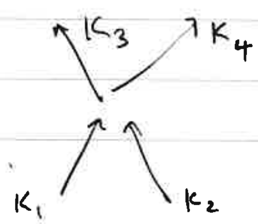
$\tilde{K} = \frac{KR}{r}$

K 4-d momentum ~~seen by inertial~~ observer

$\tilde{K}$ momentum seen by inertial observer.

$2 \to 2$ "exclusive", large energy, fixed angle.





$$s = -(K_1 + K_2)^2 = E^2 \text{ (c.o.m.)}$$

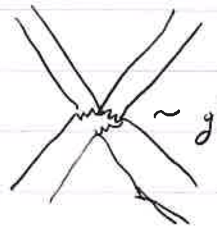
$$t = -(K_1 - K_3)^2$$

$A \sim E^{4-\sum_i n_i}$ ← # of partons

in QCD

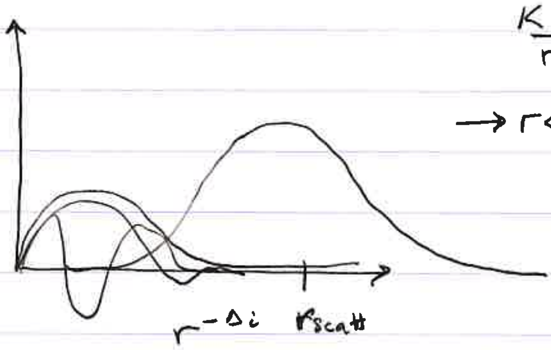
in FSST

$$A \sim e^{-O(E^2)}$$



$$A \sim e^{-O(E^2)} \quad \text{FSST.}$$

What happen in AdS/QCD?



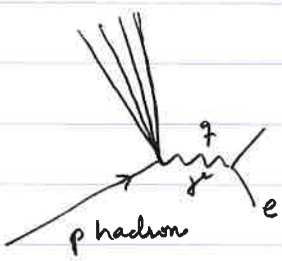
$$\frac{KR}{r} > \frac{1}{\sqrt{\alpha'}}$$

$$\to r < KR\sqrt{\alpha'} = r_{scatt} \propto E$$

Convolution is dominated by scales of order r_{scatt}.

$$\frac{KR}{r_{scatt}} = \frac{1}{\sqrt{\alpha'}} \qquad r^3 dr \sim r_{scatt}^{4-\sum_i \Delta_i} \propto \boxed{E^{4-\sum_i \Delta_i}} \ !$$

Deep inelastic scattering (QCD ≠ AdS/QCD)

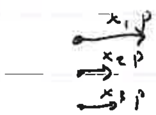


⇐ sum cross-section over all x.

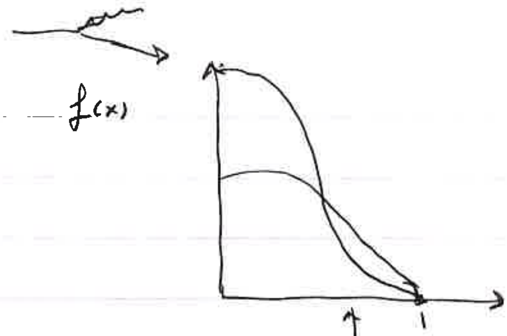
$$\propto \operatorname{Im} \langle \text{hadron} | j_\mu(q)\, j_\mu(q) | \text{hadron} \rangle$$

$$= F_1(x,q^2)\left(g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right) + 2\frac{x}{q^2} F_2(x,q^2) \left(P_\mu + \frac{q_\mu}{2x}\right)\left(P_\nu + \frac{q_\nu}{2x}\right)$$

q^2, $x = \dfrac{-q^2}{2p\cdot q}$ $\qquad 0 \le x \le 1$



$x_1 + x_2 + x_3 = 1$

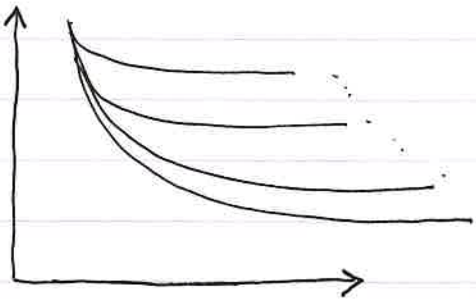


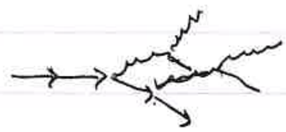
$q^2 = 2\Delta$ for fixed x.

How about in AdS/QCD?

Can't couple string to external operators.

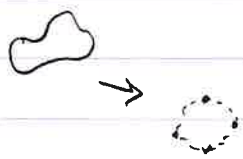
j's $\rightarrow$ non-normalizable mode. $A_\mu(r)$.





strong coupling.

turning on WS coupling.



$\int_0^\infty \frac{dt}{t} e^{-t}$ $u = \ln(t) \rightarrow e^u = t$ resolution of $\gamma^{p,q}$

$du = \frac{dt}{t}$

$\downarrow$

$\int_{-\infty}^{\infty} du \, e^{-e^u}$

$\cancel{v = e^u \quad dv = e^u du = v du}$

$\int_0^\infty$ $u = \ln(t)$ $du = \frac{dt}{t}$ $\int_{-\infty}^{\infty} du \, e^{-e^u} =$

$\cancel{\int \frac{dt}{t}}$

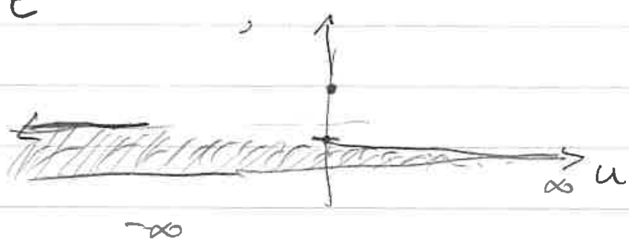
0

$\underline{e^{-e^u}} = \begin{cases} u \to 0 & \frac{1}{e} \\ u \to \infty & 0 \\ u \to -\infty & 1 \end{cases}$

$v = e^u$ $\int \frac{dv}{v} e^{-v}$

$dv = e^u du$

$\frac{dv}{v} = du$



Douglas III.

IIb conclusion

- $W \sim 0$
- non susy

- other distributional models
  - M thy
  - Het
  - IIa
  - gauge sector
- next?
  - formal developments
  - cosmological weights
  - interpretation.

IIb ~~const~~ KKLT

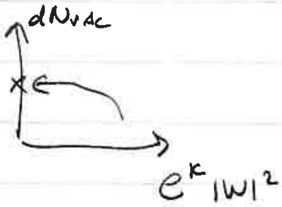
$$(H^{NS}, H^{RR}) \to (W,\ F_i = D_i W,\ Z_i = D_0 D_i W)$$

$$Z_{ij} = D_i D_j W = \mathcal{F}_{ijk} \bar{Z}^k$$

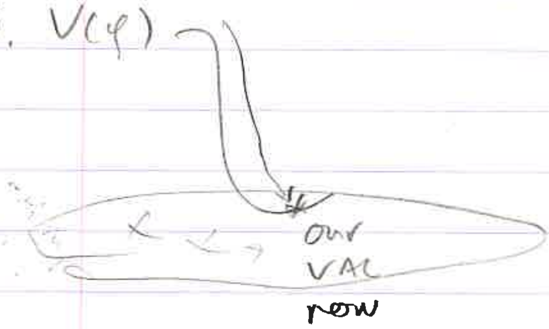
$$dN_{vac}(\varphi, L) = \int d^2W\, d^{2n+2}F\, d^{2n}Z\ \delta(F_i)\ |\det \partial D W|\ \delta^2(W)$$

$$W = \overbrace{\int (F^{RR} - \tau F^{NS}) \wedge \Omega(z)}^{W_{flux}} + e^{-S}$$

$$D_S W = 0 \qquad |W_{flux}| \sim |e^{-S}| \ll 1$$



1. initial wfn
   Tye
2. eternal inflation
   Guth
   Linde
3. $V(\varphi)$



$$V = e^K (g^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2)$$

$$= |F|^2 - |W|^2$$

$$\partial_i V = Z_{ij} \bar{F}^j - 2\bar{W} F^i$$

$$\partial_i \partial_j V = (M - 2W)(M + W)$$

$$+ \begin{pmatrix} 0 & V_{ijk} F^k \\ \bar{V}_{ijk} \bar{F}^k & 0 \end{pmatrix}$$

$$+ R_{ij\bar{k}\bar{l}} \bar{F}^i F^l$$

$$- F_i \bar{F}_j - g_{ij} |F|^2$$

6/30/05

Polchinski III AdS/QCD

~~powers~~ vs ~~and~~ exponentials in amplitudes

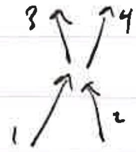
Notions ~~in EFT~~. Lagrangian fixed points

write ~~latest~~ papers formula

$$A_4 = (2\pi)^4 \delta(\Sigma p) \int dr\, d^5\theta \sqrt{-G} \times \left(\prod_i \phi_i(r)\, Y_i(\theta)\right) S_{10}(kR/r)$$

Regge scattering: $s \to \infty$, t fixed.

gentle scattering

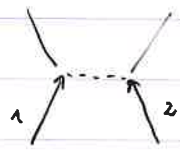


Dual of Raychadhuri Eqn

When is Effective Field Theory Valid?

Mellin transformation

$$A(s,t) = \sum_j C_j(t)\, s^{\alpha_j(t)}$$



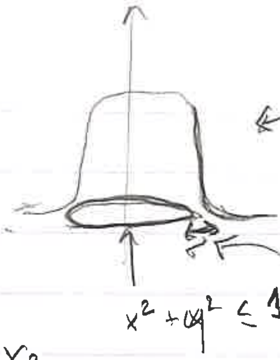
(QCD field theory). $\propto s^J$ (fixed power J)

relative rapidity λ: $e^\lambda \propto s$

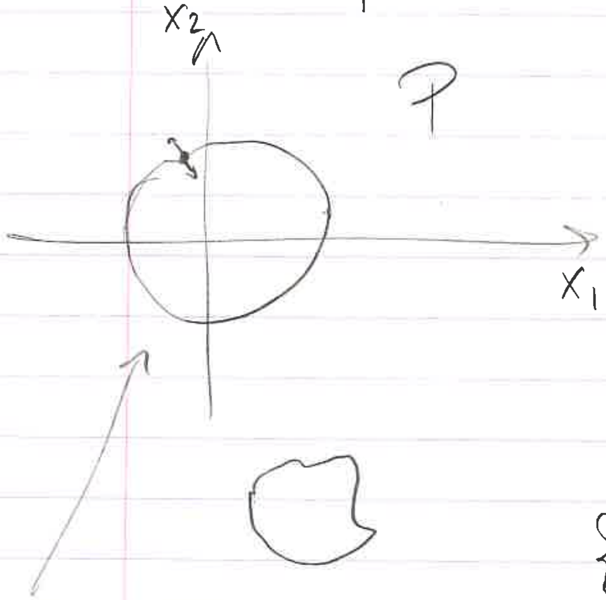
(Flat space string theory has $J \to \infty$.)

If $t = m^2$ for particle of spin $J \Rightarrow \alpha(m^2) = J$ for some trajectories e.g. $[x_i, x_j] = i\varepsilon_{ijk}x^k$.

$x_i \star x_j - x_j \star x_i = i\varepsilon_{ijk}x^k$



for large "N" $\sigma \sim \sqrt{\theta}$



P

$(x_1(\lambda), x_2(\lambda))$.

$[x_1, x_2]$.

g

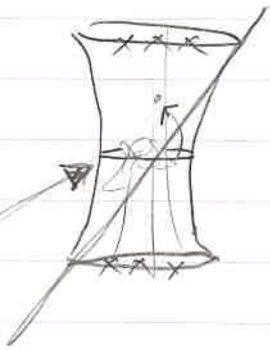
$\{f : P \to \mathbb{R}.\}$

$\{f, g\}_p$

Bousso III

SLAC
Penrose
diagram.

de Sitter.

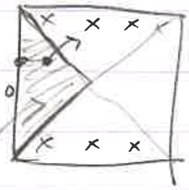


$\Lambda > 0 \qquad l = \sqrt{\frac{3}{\Lambda}}$

$$ds^2 = l^2\left[-dT^2 + \cosh^2 T \, d\Omega_3^2\right]$$

$$= l^2 \frac{1}{\sinh \eta}\left[-d\eta + \underbrace{d\Omega_3^2}_{d\chi^2 + \sin^2\chi \, d\Omega_2^2}\right]$$

$\eta \in (0, \pi)$



Penrose dS

(N) $r = 0$

$r = q(S)$

nobody c

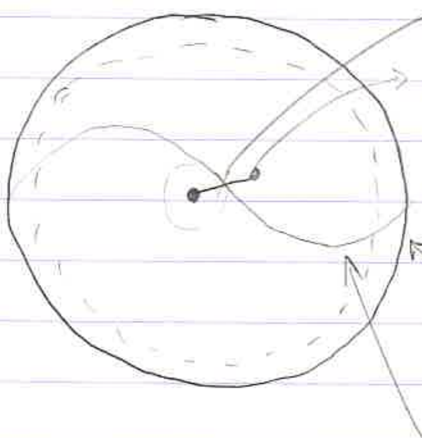
causal diamond.

- BH's w/ $R > \sqrt{\frac{3}{\Lambda}}$?
- ➡ Big Crunch.
- nobody can measure outcome / nobody can set up experiment.
- What about observables in causal diamond?

NO.

Nf:

$$ds^2 = l^2\left[-(1-r^2)dt^2 + \frac{dr^2}{(1-r^2)} + r^2 d\Omega_2^2\right]$$



string connecting 2 friends.

BH's $\leftrightarrow$ dS-space.

$T = \frac{\kappa}{2\pi} = \frac{1}{2\pi R}$

wavelength ~ R.

$A_c + S_{friend}$

$\downarrow$

$A_0 - A_c \geq S_{friend}.$

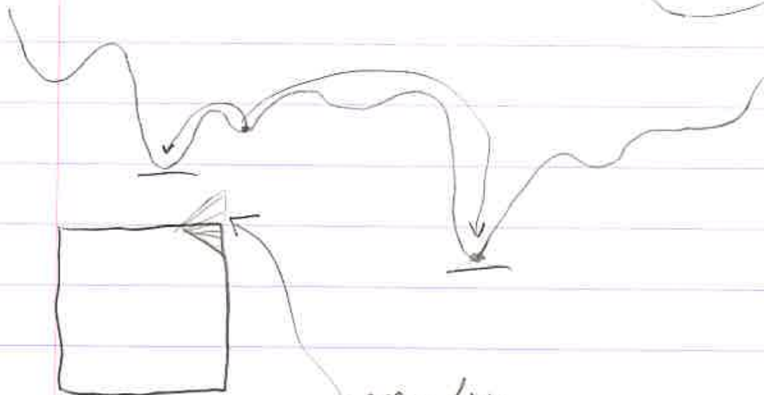
$$\boxed{S_{friend} \leq 2\pi M l.}$$

No exact observables:

Maximal entropy: $\boxed{\frac{A_0}{4} \sim \pi\ell^2 = \frac{3\pi}{\Lambda} \sim S_{max}}$ event horizon → × global observables

⇒ in principle, no infinitely accurate experiments.

- finite max entropy ⇒ finite accuracy.
- temperature → ~~sdow~~ slow erosion
  → Knock out $e^{-\beta E}$ → big black hole



open frw.

Flat FRW universes with

$$w = \frac{P}{\rho} \; ; \quad -1 \le w \le 1 \quad w \in [-1,1]. \quad \varepsilon = \frac{3}{2}(w+1) \quad w \in [0,3].$$

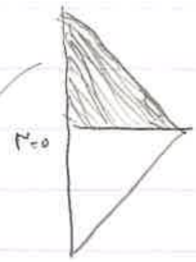
metric: $$ds^2 = -dt^2 + a^2(t)\, d\vec{x}^{\,2} = a^2(\eta)\left[-d\eta^2 + dr^2 + r^2 d\Omega^2\right].$$

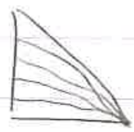
EE → $$a(t) = t^{1/\varepsilon} \; ; \quad \rho(t) = \frac{3}{8\pi(\varepsilon t)^2} \; ; \quad \eta = \frac{\varepsilon}{\varepsilon - 1}\, t^{\frac{\varepsilon - 1}{\varepsilon}}$$

$\varepsilon = 1$: acceleration ↔ deceleration transition.

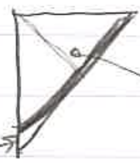
$\varepsilon > 1 \quad \ddot{a} < 0 \quad \eta \in (0, \infty)$.

$\varepsilon < 1 \quad \ddot{a} > 0 \quad \eta \in (-\infty, 0)$





no event horizon. $\varepsilon > 0$



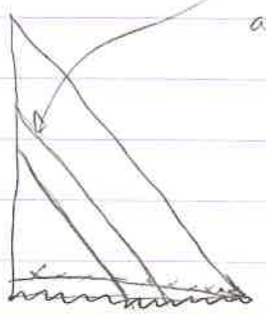
event horizon @ $\eta + r = 0$. $\varepsilon < 1$

L_{planck}

(quintessence)

Bousso thinks there are no observables here either because of Page theorem.

collects only a finite part of an infinite system.



$\varepsilon \ll 1$

Q-space:

apparent horizon $R_A = \sqrt{\frac{3}{8\pi G}} = \varepsilon t$

event horizon $\longrightarrow \frac{R_A}{R_E} = 1 - \varepsilon \; ; \quad t_H = R_A$

$$\frac{t_H \dot{R}_A}{R_A} = \varepsilon \ll 1$$ — things are changing slowly. I.e. ~ dS at any given time.

$$T = \frac{1}{2\pi R_A(t)} = \frac{1}{2\pi\varepsilon t} \qquad S = \pi R_A^2$$

Like vac energy, but light is sensitive to this.

- finite entropy problem is gone.
- erosion?

$$E \sim \frac{1}{R(t)}, \quad \frac{\#}{\text{time}} = H \sim \frac{1}{R(t)}$$

$$\text{total energy} \xrightarrow{dS} \infty$$

$$\text{total energy} \xrightarrow{Q} \frac{1}{\varepsilon}\frac{1}{R_A}$$

$$\Gamma = e^{-E/T} \sim e^{2\pi\varepsilon T E}$$

$\int \Gamma\, dt$ also small.

$\Rightarrow$ erosion goes away.

$$\Gamma(S) \sim e^{-2\pi S} \quad \text{constant.}$$

P(radiating a complex apparatus)

$\boxed{\text{complex matter system}}$