

Title: An introduction to the pure-spinor formalism for the superstring - Part 1

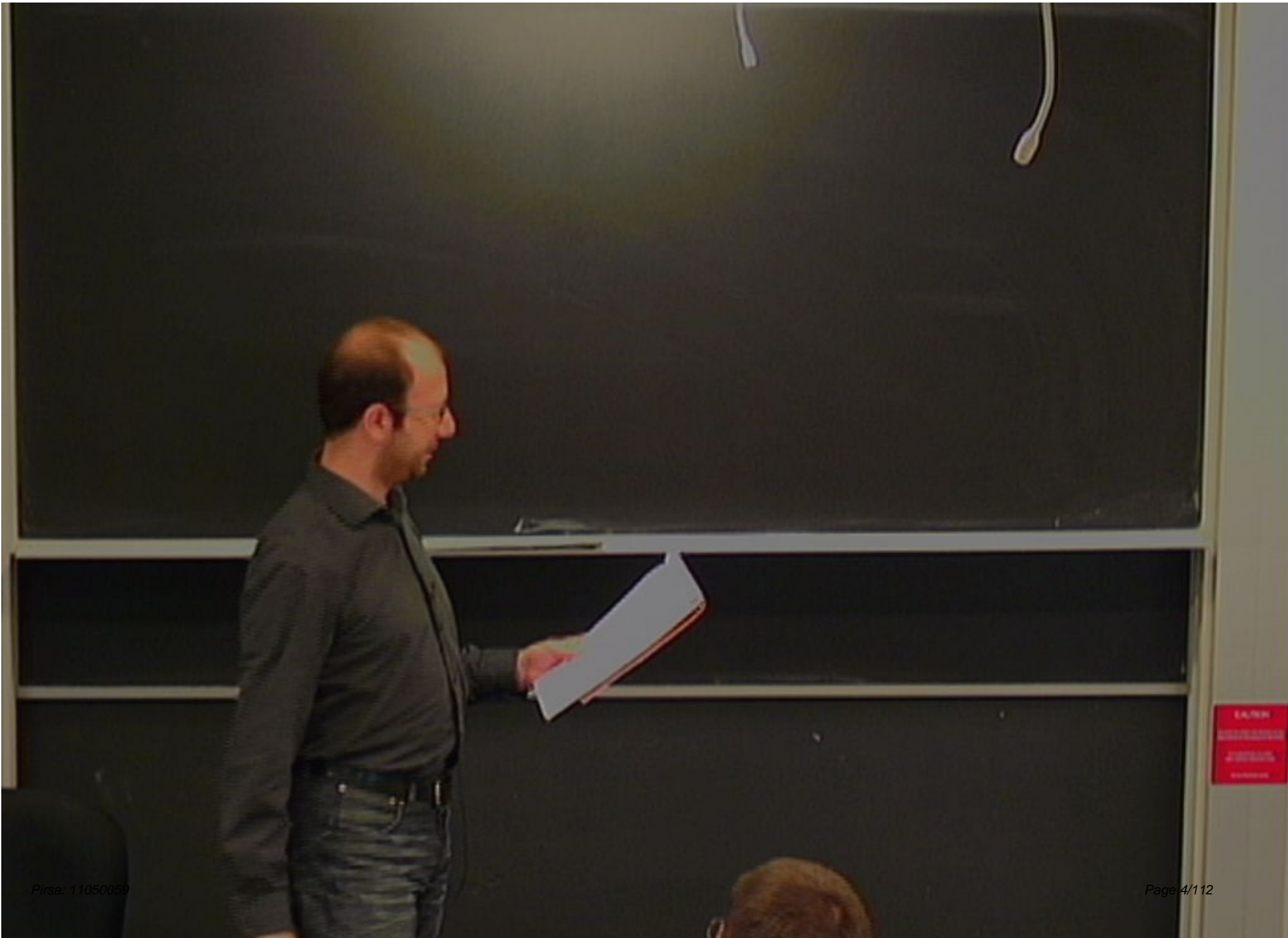
Date: May 11, 2011 11:00 AM

URL: <http://pirsa.org/11050059>

Abstract: Pure spinors, BRST cohomology and tree-level amplitudes

No Signal

VGA-1



Target space

(1)
- Round fields (2)
with same footing as the NS-NS

Superpartiele (Brink-Schwere)

$$\int d\tau (\Pi_m \dot{P}^m + e P^2)$$

Superparticle (Brink-Schwartz)

$$S = \int d\tau (\Pi_m \dot{X}^m + e P^2)$$
$$\begin{cases} \delta X^m = \frac{1}{2} \theta \gamma^m \epsilon \\ \delta \theta^\alpha = \epsilon^\alpha \end{cases}$$

X^m, θ^α Majorana-Weyl
of $SO(2,1)$

$$\Pi^m = 2e \dot{X}^m - \frac{1}{2} \theta \Gamma^m \dot{\theta}$$

Superparticle (Brink-Schwartz)

$$S = \int d\tau (\Pi_m \dot{X}^m + e \dot{P}^2)$$

$$X^m = \frac{1}{2} \theta \gamma^m \epsilon$$

$$\dot{\theta} = \dot{\epsilon}$$

κ -symmetry

$$SO^2 = P^m (\Pi_m \epsilon)$$

X^m, θ^α Majorana-Weyl of $SO(2,1)$

$$\Pi^m = 2\epsilon X^m - \frac{1}{2} \theta \Gamma^m \theta$$

Superparticle (Brent) (ve)

X^m, θ^a Majorana-Weyl
of $so(2,1)$

$$S = \int d\tau \left(\Gamma \dot{X}^m + e P^m \right)$$

$$\begin{cases} \delta X^m = \frac{1}{2} \theta \gamma^m \\ \delta \theta^a = \epsilon^a \end{cases}$$

symmetry

$$\Pi^m = 2e X^m - \frac{1}{2} \theta \Gamma^m \theta$$

$$\begin{cases} \delta \theta^a = P^m (\Gamma^m \theta)^a \\ \delta X^m = -\frac{1}{2} \theta \Gamma^m \theta \\ \delta e = 2e \theta^a \kappa_a \end{cases}$$

Superparticle (Brink-Schwartz)

X^{μ}, θ^{α} Majorana-Weyl
of $so(2,1)$

$$S = \int d\tau \left(\Pi_{\mu} \dot{X}^{\mu} - \gamma^{\alpha} \dot{\theta}^{\alpha} \right)$$
$$\begin{cases} \delta X^{\mu} = \frac{1}{2} \theta \gamma^{\mu} \epsilon^{\alpha} \\ \delta \theta^{\alpha} = \epsilon^{\alpha} \end{cases}$$

$$\Pi^{\mu} = 2c \dot{X}^{\mu} - \frac{1}{2} \theta \Pi^{\mu} \dot{\theta}$$

$$\begin{cases} \delta \theta^{\alpha} = \mathcal{P}^{\alpha}(\Pi, k) \\ \delta X^{\mu} = -\frac{1}{2} \theta \Pi^{\mu} \delta \theta \\ \delta c = 2c \theta^{\alpha} K_{\alpha}(\gamma) \end{cases}$$

$$P_m = \frac{\delta L}{\delta \dot{\theta}^m} = -\frac{1}{2} P^{mn} T_{mn} \theta \quad \Rightarrow \quad d_\alpha = p_\alpha + \frac{1}{2} P^{mn} T_{mn} \theta = 0$$

$$\{p_\alpha, \theta^\beta\} = i \delta_\alpha^\beta \quad \{d_\alpha, d_\beta\} = i P^{mn} (T_{mn})_{\alpha\beta}$$



CAUTION

$$P_m = \frac{\delta L}{\delta \dot{\theta}^m} = -\frac{1}{2} P^m T_m \theta \Rightarrow d_k = p_k + \frac{1}{2} P^m T_m \theta = 0$$

$$\{P, \theta^p\} = i S_p P$$

$$\{d_k, d_p\} = i P^m (T_m^k)_{kp}$$

$$P^2 = 0 \Rightarrow \mathcal{P}^2 = 0$$

$$\left(\begin{array}{c} + \\ + \end{array} \right)$$

$$P_m = \frac{\delta L}{\delta \dot{\theta}^m} = -\frac{1}{2} P^{mn} T_{mn} \theta \Rightarrow d_x = p_x + \frac{1}{2} P^{mn} T_{mn} \theta = 0$$

$$\{P_m, \theta^m\} = i S_m P^m$$

$$\{d_x, d_p\} = i P^{mn} (T_{mn})_{xp}$$

$$P^2 = 0 \Rightarrow \mathcal{H}^2 = 0 \quad \mathcal{H} = \left(\begin{array}{c|c} 0 & \Lambda \\ \hline 0 & 0 \end{array} \right)$$

$$P_m = \frac{\delta L}{\delta \dot{\theta}^m} = -\frac{1}{2} P^{mn} T_{mn} \theta \Rightarrow d_m = P_m + \frac{1}{2} P^{mn} T_{mn} \theta = 0$$

$$\{P_m, \theta^m\} = i S_m P^m$$

$$\{d_m, d_p\} = i P^{mn} (T_{mn})_{mp}$$

$$P^2 = 0 \Rightarrow \mathcal{P}^2 = 0 \quad \mathcal{P} = \left(\begin{array}{c|c} 0 & \Lambda \\ \hline 0 & 0 \end{array} \right)$$



$$P_m = \frac{\delta L}{\delta \dot{\theta}^m} = -\frac{1}{2} P^{mn} T_{mn} \theta \Rightarrow d_m = p_m + \frac{1}{2} P^{mn} T_{mn} \theta = 0$$

$$\{P_m, \theta^m\} = \delta_m^p$$

$$\{d_m, d_p\} = i P^{mn} (T_{mn})_{mp}$$

$$P^2 = 0 \Rightarrow \mathcal{P}^2 = 0 \quad \mathcal{P} = \left(\begin{array}{c|c} 0 & \Lambda \\ \hline 0 & 0 \end{array} \right)$$



$$P_m = \frac{\delta L}{\delta \dot{\theta}^m} = -\frac{1}{2} P^{mn} T_{mn} \theta \Rightarrow d_m = P_m + \frac{1}{2} P^{mn} T_{mn} \theta = 0$$

$$\{P_m, \theta^p\} = i \delta_m^p$$

$$\{d_m, d_p\} = i P^{mn} (T_{mn})_{mp}$$

$$P^2 = 0 \Rightarrow \mathcal{P}^2 = 0 \quad \mathcal{P} \sim \left(\begin{array}{c|c} 0 & A \\ \hline 0 & 0 \end{array} \right)$$

1-st: \mathcal{P}^2 generates K-symmetry

$$P_\alpha = \frac{\delta L}{\delta \dot{\theta}^\alpha} = -\frac{1}{2} P^{\mu\nu} T_{\mu\nu} \theta \Rightarrow d_\alpha = P_\alpha + \frac{1}{2} P^{\mu\nu} T_{\mu\nu} \theta = 0$$

$$\{P_\alpha, \theta^\beta\} = \delta_\alpha^\beta P$$

$$\{d_\alpha, d_\beta\} = \epsilon P^{\mu\nu} (T_{\mu\nu})_{\alpha\beta}$$

$$P^2 = 0 \Rightarrow \mathcal{P}^2 = 0 \quad \mathcal{P} = \left(\begin{array}{c|c} 0 & A \\ \hline 0 & 0 \end{array} \right)$$

1-st: \mathcal{P} generates K-symmetry

$$P^+ = (P^* + P^*)$$

$$(T^{++}\theta) = 0 \quad \text{K-gauge fixing}$$

$$\mathcal{P}^+ = \left(\begin{array}{c|c} 0 & 1 \\ \hline 0 & 0 \end{array} \right)$$

$$\{P_i, \theta^j\} = \delta_{ij}$$

$$\{d_\mu, d_\nu\} = c_{\mu\nu} \quad (\mu, \nu < p)$$

$$P^2 = 0 \Rightarrow \mathcal{P}^2 = 0 \quad \mathcal{P} = \left(\begin{array}{c|c} 0 & A \\ \hline 0 & 0 \end{array} \right)$$

1-st: \mathcal{P} generates K-symmetry

$$P^+ = (P^0 + P^3)$$

$$(\Pi^+ \theta) = 0 \quad \text{K-gauge fixing}$$

$$\mathcal{P}^+ = \left(\begin{array}{c|c} 0 & 1 \\ \hline 0 & 0 \end{array} \right)$$

$$\theta = \begin{pmatrix} \theta_1 \\ \theta_2 \end{pmatrix}$$

$$\theta_2 = 0$$

$$\Pi^+ = \left(\begin{array}{c|c} \gamma_i & 0 \\ \hline 0 & \gamma_i \end{array} \right)$$

$$\rightarrow S' = \int \dot{x}_\mu P^\mu + P^+ (\dot{\theta} \Pi^+ \theta) + c P^2$$

$$\theta = (\theta_i)$$
$$\rightarrow S' = \int \dot{x}_m P^2 + P^2 (\dot{\theta} \Gamma^{-1} \dot{\theta}) + e P^2$$



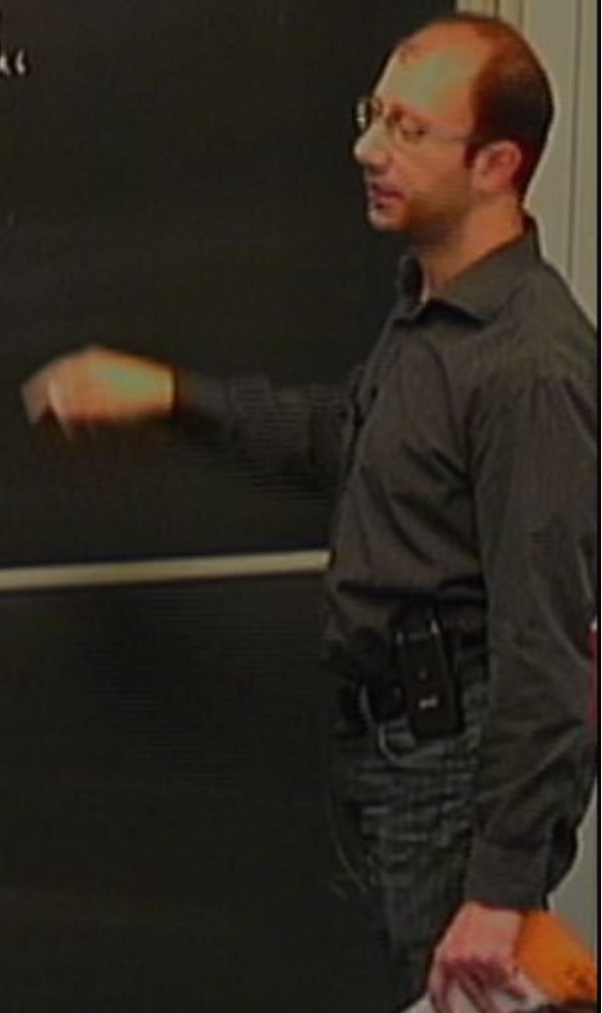
CAUTION
FIRE HAZARD
DO NOT TOUCH
ELECTRICAL EQUIPMENT

CAUTION
FIRE HAZARD
DO NOT TOUCH
ELECTRICAL EQUIPMENT

$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_n \end{pmatrix}$$

$$\rightarrow \dot{S} = \int \dot{x}_n P^n + P^*(\dot{\theta} \Gamma - \theta) + c P^2$$

$$S_i = \sqrt{P^*} (\Gamma^T - \theta)_i \quad i=1, \dots, n \quad \{S_i, S_j\} = \delta_{ij}$$



CAUTION

$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_n \end{pmatrix}$$

$$\rightarrow \dot{S} = \int \dot{x}_n P^n + P^* (\dot{\theta} \Gamma^{-1} \theta) + c P^2 = \int \dot{x} P + S \dot{S} + c P^2$$

$$S_k = \sqrt{P^*} (\Gamma^{-1} \theta)_k \quad k=1, \dots, n \quad \{S_k, S_l\} = \delta_{kl} \quad \delta_1, \delta_2, \dots, \delta_n$$



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 FÜR INGENIEURWISSENSCHAFTEN
 UND ARCHITEKTUR

$$\rightarrow \dot{S} = \int \dot{x}_m P^m + P^* (\dot{\theta} \Pi^{-1} \theta) + c P^2 = \int \dot{x}_i P^i + S \dot{S} + c P^2$$

$$S_i = \sqrt{P^i} (\Pi^{-1} \theta)_i \quad i=1, \dots, 3$$

$$\{S_i, S_j\} = \delta_{ij}$$

$\delta_i, \delta_j, \delta_k$

$$S_i \Psi_i = (\sigma_i)_{ki} \Psi_i$$

$$\square \Psi = 0$$

$$S_i \Psi_i = (\sigma_i)_{ki} \Psi_i$$

Hand pointing to the equation $\square \Psi = 0$

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$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \end{pmatrix}$$

$$\rightarrow \mathcal{S} = \int \dot{x}^2 P^2 + P^2 (\theta^T \Pi^{-1} \theta) + c P^2 = \int \dot{x}^2 P^2 + S \dot{S} + c P^2$$

$$S_k = \sqrt{P^2} \left(\frac{P^2}{\hbar} \right)_k, \quad k=1, \dots, \delta$$

$$\{S_k, S_l\} = \delta_{kl} \quad \delta_1, \delta_2, \delta_3$$

$$S_k \Psi_i = (\sigma_i)_{ki} \Psi_i \quad \square \Psi = 0$$

$$S_k \Psi_i = (\sigma_i)_{ki} \Psi_i$$

spectrum $\delta_1 + \delta_2$

$$A_k(x, \theta)$$

$$\delta A_k -$$

$$A_\alpha(x, \theta)$$

$$\delta A_\alpha = D_\alpha \Lambda(x, \theta)$$

$$D_\alpha = \frac{\partial}{\partial x^\alpha} + (\theta \Gamma^\mu)_\alpha \frac{\partial}{\partial y^\mu}$$

{D

$$A_\mu(x, \theta)$$

$$D_\mu = \frac{\partial}{\partial x^\mu} + (\theta \Gamma^\mu)_\alpha \frac{\partial}{\partial \psi^\alpha}$$

$$\{D_\mu, D_\nu\} = \Gamma_{\mu\nu}^\alpha \partial_\alpha$$

$$(\delta A_\mu - D_\nu \Lambda(x, \theta)) + ig[A_\mu, \Lambda]$$

$$\Gamma_{\alpha\beta\gamma\delta}^{\mu\nu\rho\sigma} (D_\mu A_\nu + ig A_\mu A_\nu) = 0$$

$(\Gamma_\mu)^\alpha_\beta, (\Gamma_{\mu\nu})^\alpha_\beta$ symmetric

$(\Gamma_{\mu\nu\rho\sigma})^\alpha_\beta$ antisymmetric



$$D_\alpha = \frac{\partial}{\partial x^\alpha} + (\Theta \Gamma^\mu)_{\alpha} \frac{\partial}{\partial x^\mu}$$

$$\{D_\alpha, D_\beta\} = \Gamma_{\alpha\beta}^m \partial_m$$

$$\Gamma_{\mu\nu\rho\sigma}^{\alpha\beta} (D_\mu A_\nu + ig A_\mu A_\nu) = 0$$

$(\Gamma_{\alpha\beta})^{\gamma\delta}, (\Gamma_{\alpha_1\alpha_2\alpha_3})^{\gamma\delta}$ symmetric

$(\Gamma_{\alpha_1\alpha_2\alpha_3})^{\gamma\delta}$ antisymmetric

$$(\Gamma_{\alpha\beta})_{\gamma\delta} = (\Gamma_{\alpha\beta})^{\gamma\delta}$$

$$A_\alpha(x, \theta)$$

$$D_\alpha = \frac{\partial}{\partial x^\alpha} + (\theta \Gamma^\mu)_\alpha \frac{\partial}{\partial x^\mu}$$

$$\{D_\alpha, D_\beta\} = \Gamma_{\alpha\beta}^\mu \partial_\mu$$

$$(\delta A_\alpha - D_\alpha \Lambda(x, \theta) + ig[A_\alpha, \Lambda])$$

$$\Gamma_{\mu\nu\rho\sigma}^{\alpha\beta} (D_\mu A_\nu + ig A_\mu A_\nu) = 0 = F_{\alpha\beta} \Gamma_{\alpha\beta}^{\mu\nu}$$

$(\Gamma_{\alpha\beta})^{\mu\nu}, (\Gamma_{\alpha_1 \dots \alpha_n})^{\mu_1 \dots \mu_n}$ symmetric

$(\Gamma_{\alpha_1 \dots \alpha_n})^{\mu_1 \dots \mu_n}$ antisymmetric

$$(\Gamma_{\alpha\beta})^\mu{}_\nu = (\Gamma_{\alpha\beta})_{\rho\sigma} (\Gamma^\rho)^\mu{}_\nu$$

Abelian YM

F_{μν}

Abelian YM

$$F_{\mu\nu} = (\mathcal{P}_{\mu\nu})_{\rho\sigma} A_{\rho} A_{\sigma}$$

$$\delta A_n = \partial_m \Lambda$$

W^a

Abelian YM

$$F_{\alpha\beta} = (F_{\alpha\beta})_{ij} A_n$$

$$\delta A_n = \partial_m \Lambda$$

$$W^\alpha = \frac{1}{10} (\gamma^{\mu\nu})^{\alpha\beta} (D_\mu A_\nu - \partial_\mu A_\nu)$$

$\delta W^{\alpha\beta}$

$$D_\alpha W^\beta = \frac{1}{4} (\Gamma^{\mu\nu})_{\alpha}^{\beta} F_{\mu\nu}$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

Abgleich III

$$F_{\alpha\beta} = (F_{\alpha\beta})_{\mu\nu} A_{\mu\nu}$$

$$\delta A_n = \partial_m \Lambda$$

$$W^\alpha = \frac{1}{10} (\gamma^\alpha)^{\mu\nu\beta} (D_\mu A_\nu - \partial_\mu A_\beta)$$

$\delta W^{\hat{a}0}$

$$D_\alpha W^\beta = \frac{1}{4} (\Gamma^{\mu\nu})_{\alpha}^{\beta} F_{\mu\nu}$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \end{pmatrix}$$

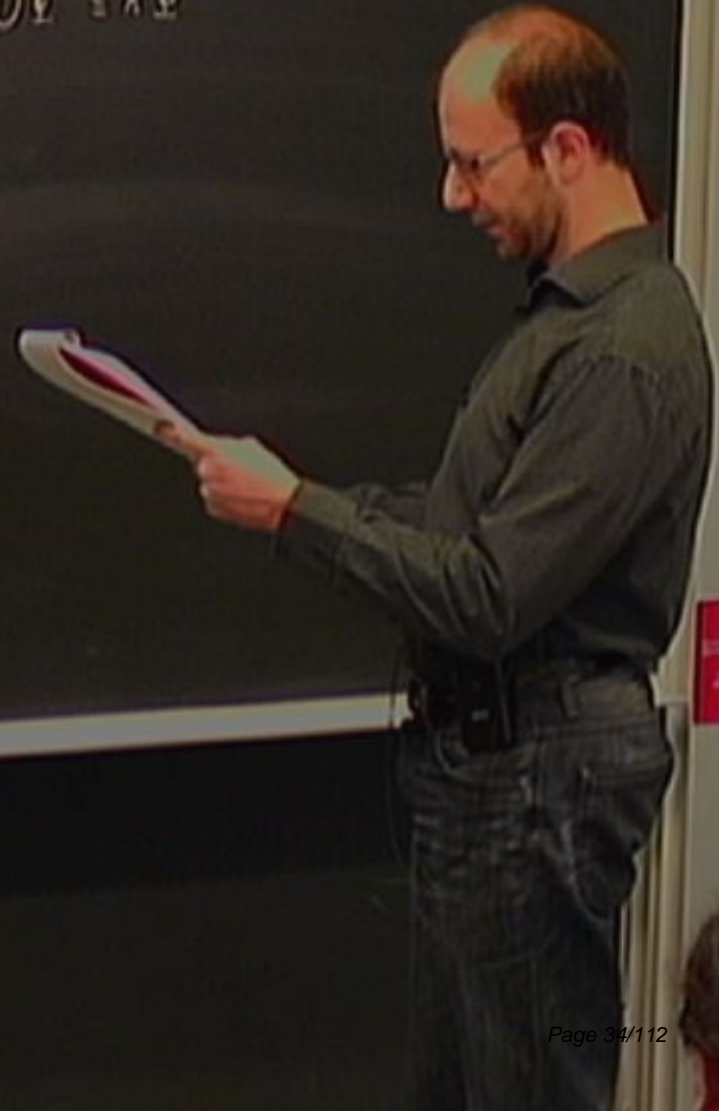
$$\rightarrow \dot{S} = \int \dot{x}_n P^n + P^* (\dot{\theta}^T - \theta) + c P^2 = \int \dot{x} P + S \dot{S} + c P^2$$

$$\text{gauge: } \theta^* A_n = 0$$

$$D = \theta^* D_i = \theta^* \frac{\partial}{\partial \theta^i}$$

$$E = \sum E^{(i)}$$

$$D E^{(i)} = \lambda E^{(i)}$$



CAUTION

CAUTION

$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_n \end{pmatrix}$$

$$\rightarrow \mathcal{J} = \int \dot{x}_n P^2 + P^* (\dot{\theta} \Gamma^{-1} \theta) + c P^2 = \int x P + S \dot{S} + c P^2$$

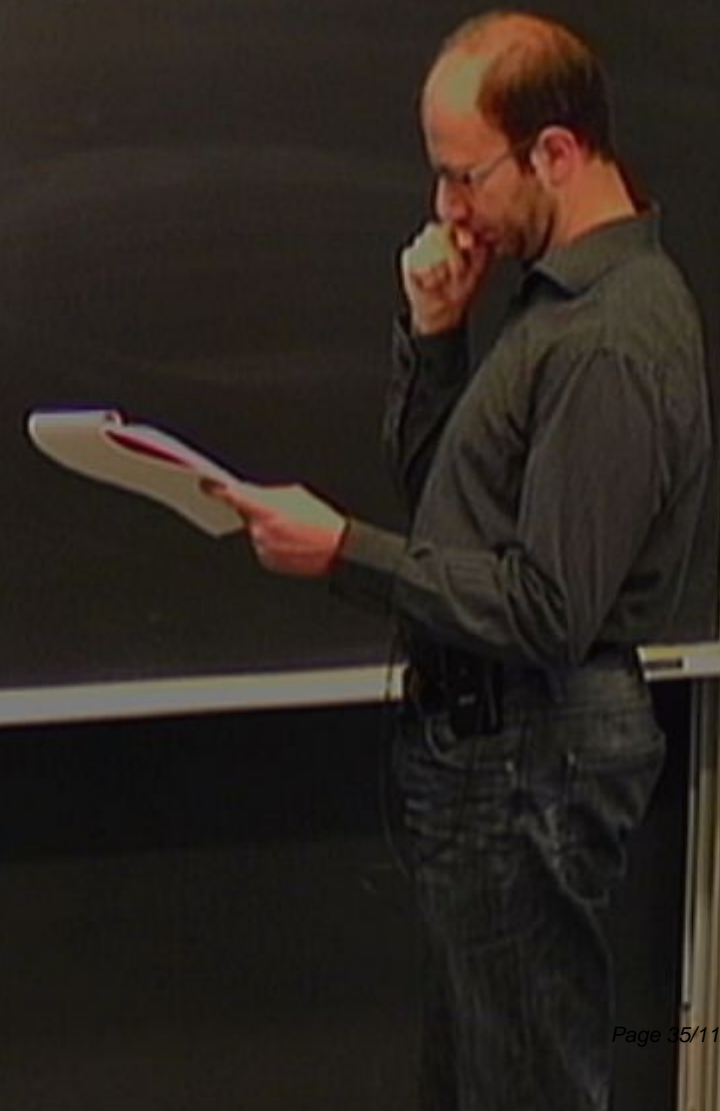
$$\text{general: } \theta^* A_n = 0$$

$$D = \theta^* D_n = \theta^* \frac{\partial}{\partial \theta^*}$$

$$E = \sum E^{(i)}$$

$$D E^{(i)} = \lambda E^{(i)}$$

$$(\theta \Gamma^{-1})_n A_n = \theta^* (D_n A_p + D_p A_n)$$



$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \end{pmatrix}$$

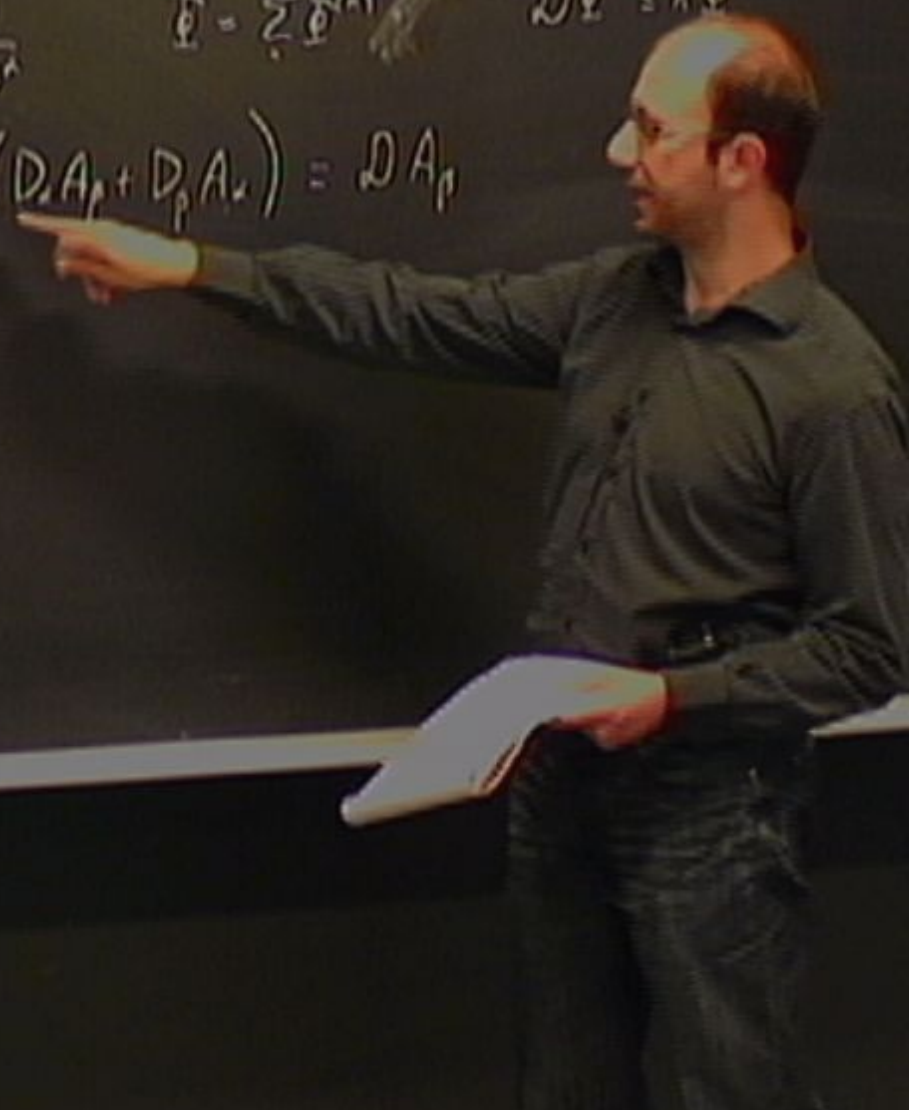
$$\rightarrow \dot{S} = \int \dot{x}_n P^n + P^* (\dot{\theta} \Gamma^* - \dot{\theta}) + c P^* = \int \dot{x} P + S \dot{S} + c P^*$$

$$\text{gauge: } \theta^* A_n = 0$$

$$D = \theta^* D_n = \theta^* \frac{\partial}{\partial \theta^*}$$

$$E = \sum E^{(n)} \quad D E^{(n)} = n E^{(n)}$$

$$(\theta \Gamma^*)_n A_n = \theta^* (D_n A_p + D_p A_n) = D A_p$$



$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \end{pmatrix} \rightarrow \mathcal{J} = \int \dot{x}_n P^2 + P^* (\theta^T \Gamma^{-1} \theta) + c P^2 = \int \dot{x}_n P + S \dot{S} + c P^2$$

$$\text{gauge: } \theta^* A_n = 0$$

$$D = \theta^* D_n = \theta^* \frac{\partial}{\partial \theta^a}$$

$$E = \sum E^{(n)} \quad D E^{(n)} = \lambda E^{(n)}$$

$$(\theta^T \Gamma^{-1})_n A_n = \theta^* (D_n A_p + D_p A_n) = D A_p$$



$$\theta = \begin{pmatrix} \theta_1 \\ \vdots \end{pmatrix} \rightarrow \dot{S} = \int \dot{x}_n P^n + P^* (\dot{\theta} \Gamma^* - \theta) + c P^2 = \int x P + S \dot{S} + c P^2$$

$$\text{guess } \theta^* A_n = 0$$

$$D = \theta^* D_n = \theta^* \frac{\partial}{\partial \theta^*}$$

$$E = \sum E^{(n)} \quad D E^{(n)} = n E^{(n)}$$

$$(\theta \Gamma^*)_n A_n = \theta^* (D_n A_p + D_p A_n) = D A_p + A_p = (1+n) A_p^{(n)}$$



$$\rightarrow \dot{S} = \int \dot{x}_n P^n + P^* (\dot{\theta} \Gamma^{-1} \theta) + c P^2 = \int \dot{x} P + S \dot{S} + c P^2$$

$$\text{gauge } \theta^* A_n = 0$$

$$D = \theta^* D_n = \theta^* \frac{\partial}{\partial \theta^n}$$

$$E = \sum E^{(n)} \quad D E^{(n)} = n E^{(n)}$$

$$(\theta \Gamma^{-1})_n A_n = \theta^* (D_n A_p + D_p A_n) = D A_p + A_p = (1+n) A_p^{(n)}$$



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$$\text{given } \theta^* A_n = 0$$

$$D = \theta^* D_n = \theta^* \frac{\partial}{\partial \theta^*}$$

$$\Phi = \sum \Phi^{(n)}$$

$$D\Phi^{(n)} = \kappa \Phi^{(n)}$$

$$(\theta \Gamma^*) A_n = \theta^* (D_n A_p + D_p A_n) = D A_p + A_p = (1 + \kappa) A_p^{(n)}$$

$$A_n^{(n)} = \frac{1}{\kappa + 1} (\Gamma^* \theta)_n A_n^{(n-1)}$$

$$D = \theta^x D_x = \theta^x \frac{\partial}{\partial \theta^x} \quad \Phi = \sum \Phi^{(k)} \quad D\Phi^{(k)} = k\Phi^{(k)}$$

$$(\theta \Gamma^m)_x A_n = \theta^x (D_x A_p + D_p A_x) = D A_p + A_p = (1+k) A_p^{(k)}$$

$$A_n^{(k)} = \frac{1}{k+1} (\Gamma^m \theta)_x A_n^{(k-1)}$$

$$A_n^{(k)} = \frac{1}{k} (\theta \Gamma_n W^{(k-1)})$$

$$W^{(k)} = -\frac{1}{2k} (\Gamma^m \theta)^x$$



$$D = \theta^x D_x = \theta^x \frac{\partial}{\partial \theta^x} \quad \Phi = \sum \Phi^{(k)} \quad D\Phi^{(k)} = k\Phi^{(k)}$$

$$(\theta T^m)_x A_n = \theta^x (D_x A_p + D_p A_x) = D A_p + A_p = (1+k) A_p^{(k)}$$

$$\begin{cases} A_n^{(k)} = \frac{1}{k+1} (\theta T^m \theta)_x A_n^{(k+1)} \\ A_n^{(k)} = \frac{1}{k} (\theta T^m W^{(k+1)}) \\ W^{(k+1)} = -\frac{1}{2k} (\theta T^m \theta)_x^2 A_n^{(k+1)} \end{cases}$$

$$D = \theta^x D_x = \theta^x \frac{\partial}{\partial \theta^x} \quad \mathbb{E} = \sum \mathbb{E}^{(k)} \quad D \mathbb{E}^{(k)} = k \mathbb{E}^{(k)}$$

$$(\theta \Gamma^m)_x A_n = \theta^x (D_x A_p + D_p A_x) = D A_p + A_p = (1+n) A_p^{(x)}$$

$$\begin{cases} A_n^{(k+1)} = \frac{1}{k+1} (\Gamma^{m+1} \theta)_x A_n^{(k)} \\ A_n^{(k)} = \frac{1}{k} (\theta \Gamma^m W^{(k+1)}) \\ W^{(k+1)} = -\frac{1}{2k} (\Gamma^{m+1} \theta)_x^2 A_n^{(k)} \end{cases}$$

$$\begin{aligned} A_n|_{\theta=0} &= a_n(i) \\ W^k|_{\theta=0} & \end{aligned}$$

$$(\Theta \Gamma^{-1})_n A_n = \theta^x (D_x A_p + D_p A_x) = D A_p + A_p = (1+n) A_p^{(x)}$$

$$\begin{cases} A_n^{(k+1)} = \frac{1}{k+1} (\Gamma^{-1} \theta)_n A_n^{(k)} \\ A_n^{(k)} = \frac{1}{n} (\Theta \Gamma_n W^{(k+1)}) \\ W^{(k+1)} = -\frac{1}{2k} (\Gamma^{-1} \theta)^x \partial_n A_n^{(k)} \end{cases}$$

$$\begin{aligned} A_n|_{0,0} &= a_n(x) \\ W^x|_{0,0} &= \lambda^x(x) \end{aligned}$$

$$(\theta \Gamma^m)_n A_n = \theta^n (D_n A_p + D_p A_n) = D A_p + A_p = (2+n) A_p$$

$$\begin{cases} A_n^{(k)} = \frac{1}{n+1} (\Gamma^m \theta)_n A_n^{(k-1)} \\ A_n^{(k)} = \frac{1}{n} (\theta \Gamma^m W^{(k-1)}) \\ W^{(k)} = -\frac{1}{2n} (\Gamma^m \theta)_n^{-1} \partial_n A_n^{(k-1)} \end{cases}$$

$$\begin{aligned} A_n|_{0,0} &= a_n(x) \\ W^k|_{0,0} &= \lambda^k(x) \end{aligned}$$

$$A_n = \frac{1}{2} (\theta \Gamma^m)_n a_n +$$



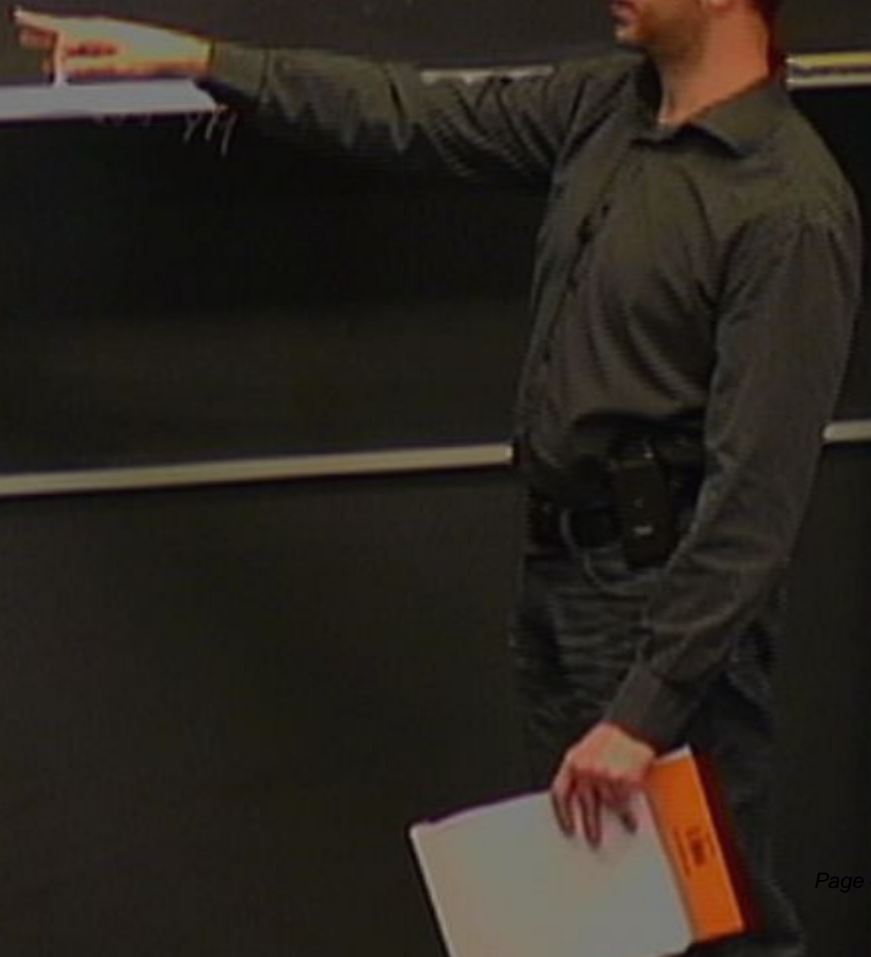
$$(\theta \Gamma^m)_\lambda A_n = \theta^* (D_\lambda A_p + D_p A_\lambda) = D A_p + H_p = (1+n) A_p$$

$$\begin{cases} A_n^{(k)} = \frac{1}{k+1} (\Gamma^m \theta)_\lambda A_n^{(k-1)} \\ A_n^{(k)} = \frac{1}{n} (\theta \Gamma^m W^{(k-1)}) \\ W^{(k)} = -\frac{1}{2n} (\Gamma^m \theta)^* \partial_n A_n^{(k-1)} \end{cases}$$

$$A_n|_{\lambda=0} = a_n(x)$$

$$W|_{\lambda=0} = \lambda^*(x)$$

$$A_n = \frac{1}{2} (\theta \Gamma^m)_\lambda a_n + \frac{1}{2} (\theta \Gamma^m)_\lambda (\theta \Gamma^m \lambda) + \dots$$



$$\begin{cases} A_n = \frac{1}{n+1} (\Gamma^m \theta)_n A_n \\ A_n^{(k)} = \frac{1}{n} (\theta \Gamma^m W^{(k-1)}) \\ W^{(k)} = -\frac{1}{2n} (\Gamma^{m+k} \theta)^k \partial_n A_n^{(k-1)} \end{cases} \quad \begin{aligned} A_n|_{\theta=0} &= a_n(x) \\ W|_{\theta=0} &= \lambda^k(x) \end{aligned}$$

$$A_n = \frac{1}{2} (\theta \Gamma^m)_n a_n + \frac{1}{3} (\theta \Gamma^m)_n (\theta \Gamma^m \lambda) + \theta^3 \partial_n a + \theta^4 \partial_n \lambda + \dots$$

spectrum $8c + 3,$ $10d$ YM A_n, λ^k
 $\sum_k \psi_k = (\sigma)_n \psi$

$$W^{a(n)} = -\frac{1}{2^n} (\Gamma^{na} \theta)^x \partial_x A_a^{(n-1)} \quad W^a|_{\theta=0} = \lambda^a(x)$$

$$A_x = \frac{1}{2} (\theta \Gamma^m)_x a_m + \frac{1}{2} (\theta \Gamma^m)_x (\theta \Gamma^m \lambda) + \theta^3 \partial_x \lambda + \theta^4 \partial_x \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma^{mnp} \theta f^{np} + \dots$$

$$S_i = \sqrt{P^i} (\Gamma^i \theta)_x \quad i=1, \dots, 8$$

$$\{S_i, S_j\} = \delta_{ij} \quad \omega, \delta_1, \delta_2$$

$$S_x \Psi_i = (\sigma_i)_{x\alpha} \Psi_i \quad \square \Psi = 0$$

$$S_y \Psi_i = (\sigma_i)_{y\alpha} \Psi_i \quad \dots$$

spectrum $8_6 + 8_1$

10d YM

A_μ, λ^a

$$\text{SYM} \rightarrow \text{min} \Leftrightarrow F_{\alpha\beta} = 0$$

$$\text{SYM} \rightarrow \text{anti-sym} \Leftrightarrow F_{\alpha\beta} = 0$$

$$4d: F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$
$$\boxed{F_{\mu\nu}^+ = 0}$$

$$\text{SYM} \rightarrow \text{v.i.m.} \Leftrightarrow F_{\alpha\beta} = 0$$

4d:

$$= F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$F_{\mu\nu} = 0$$

$$L_1 \psi = 0$$

$$L_2 \psi = 0$$

$$\text{Lax operator } [L_1, L_2] = 0$$

$$\text{SYM} \Leftrightarrow F_{\alpha\beta} = 0$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F_{\mu\nu}^+ = 0}$$

Let's operate
(2,1)

$$= 0$$

$$\text{SYM}_{\mu\nu} \Leftrightarrow F_{\mu\nu} = 0$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F_{\mu\nu}^+ = 0}$$

$$\mathcal{L}_1 \psi = 0$$

$$\mathcal{L}_2 \psi = 0$$

$$\text{Lax operator } [\mathcal{L}_1, \mathcal{L}_2] = 0$$

(z, w)

$$\begin{cases} \mathcal{L}_1 = D_z - \lambda D_w \\ \mathcal{L}_2 = D_w + \lambda D_z \end{cases}$$

$$\text{SYM}_{\mu\nu} \Leftrightarrow F_{\mu\nu} = 0$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+$$

$$\left[\begin{array}{c} F \\ F \end{array} \right]$$

$$F_{\mu\nu}^-$$

L_{λ} operators

(z, w)

$$L_1 \psi = 0$$

$$L_2 \psi = 0$$

$$[L_1, L_2] = 0$$

$$\begin{cases} L_1 = D_z - \lambda D_w \\ L_2 = D_w + \lambda D_z \end{cases}$$

$$\lambda \in \mathbb{C}$$

$$\text{SYM}_{\mu\nu} \Leftrightarrow F_{\mu\nu} = 0$$

4d: $F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$

$$F_{\mu\nu}^+ = 0$$

$$\begin{aligned} \mathcal{L}_1 \psi &= 0 \\ \mathcal{L}_2 \psi &= 0 \end{aligned}$$

\mathcal{L}_λ operators $[\mathcal{L}_1, \mathcal{L}_2] = 0$

(z, w)

$$\begin{cases} \mathcal{L}_1^{(1)} = D_z - \lambda D_w \\ \mathcal{L}_2^{(1)} = D_z + \lambda D_w \end{cases}$$

$$\lambda \in \mathbb{C}$$

$$\text{SYM}_{\mu\nu} \Leftrightarrow F_{\alpha\beta} = 0$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F_{\mu\nu}^+ = 0}$$

$$L_1 \psi = 0$$

$$L_2 \psi = 0$$

$$L_{\lambda} \text{-operator } [L_1, L_2] = 0$$

(z, w)

$$\begin{cases} L_1^{(1)} = D_z - \lambda D_w \\ L_2^{(1)} = D_z + \lambda D_w \end{cases}$$

$$\lambda \in \mathbb{C}$$

4d.

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F^+ = 0}$$

$$L_1 \psi = 0$$

$$L_2 \psi = 0$$

$$L_{\lambda} \text{-operator } [L_1, L_2] = 0$$

(z, w)

$$\begin{cases} L_1 = D_z - \lambda D_w \\ L_2 = D_w + \lambda D_z \end{cases}$$

$$\lambda \in \mathbb{C}$$

T

construction

S^1

$$\boxed{F_{\mu\nu} = 0}$$

Let operators $[L_1, L_2] = 0$

(z, w)

$$\begin{aligned} \psi_1(z) &= D_z - \lambda D_w \\ \psi_2(z) &= D_w + \lambda D_z \end{aligned}$$

$$\lambda \in \mathbb{C}$$

Twistor construction

(S^4)

\mathbb{P}^3

$$(de = 2 \cdot 0^* K_{\mathbb{P}^3})$$

$$\boxed{F_{\mu\nu} = 0}$$

Let operators $\{L_1, L_2\} = 0$

(z, w)

$$\begin{cases} L_1 = D_z - \lambda D_w \\ L_2 = D_w + \lambda D_z \end{cases}$$

$$\lambda \in \mathbb{C}$$

Twistor conjugate

$$\mathbb{P}^1 \leftarrow \mathbb{P}^1$$

\mathbb{P}^1 twistor space

$$\mathbb{P}(\Sigma^+) = \mathcal{S}(\Lambda^+) = \left\{ \text{select spin structures on } S^4 \right\}$$

$$(de = 2 \cdot \theta^* K_V(\pi))$$

$$\text{SYM} \Rightarrow \text{YM} \Leftrightarrow F_{\alpha\beta} = 0$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F_{\mu\nu}^+ = 0}$$

$$L_1 \psi = 0$$

$$L_2 \psi = 0$$

$$L_{\text{ext operator}} [L_1, L_2] = 0$$

(z, w)

$$\begin{cases} L_1 = D_z - \lambda D_{\bar{z}} \\ L_2 = D_{\bar{z}} + \lambda D_z \end{cases}$$

$$\lambda \in \mathbb{C}$$

Twistor construction

$$S^4 \leftarrow \mathbb{P}^1$$

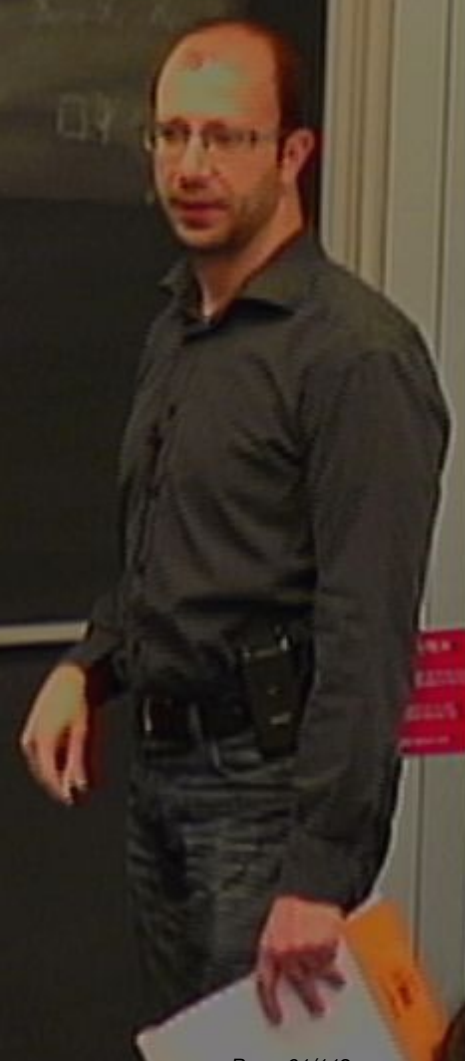
\mathbb{P}^1 twistor space

$$\mathbb{P}(\Sigma^+) = S(\Lambda^+) = \{ \text{self-dual spin structures on } S^4 \}$$

$$A_x = \frac{1}{2} (\theta \Gamma^m)_{\lambda} a_m + \frac{1}{2} (\theta \Gamma^m)_{\lambda} (\theta \Gamma^m \lambda) + \theta \gamma^{\mu} \partial_{\mu} \lambda + \theta \gamma^{\nu} \partial_{\nu} \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^{\mu} \lambda) + \theta \gamma^{\mu \nu \rho} \theta f^{\mu \nu \rho} + \dots$$

$$L(\lambda) = \lambda^{\mu} D_{\mu} \psi$$



$$A_\alpha = \frac{1}{2} (\theta \Gamma^\mu)_{\alpha} a_\mu + \frac{1}{2} (\theta \Gamma^\mu)_{\alpha} (\theta \Gamma^\nu \lambda) + \theta^\mu \partial_\mu \alpha + \theta^\mu \partial_\mu \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{\mu\nu\rho} \theta f^{\mu\nu\rho} + \dots$$

$$\mathcal{L}(\lambda) = \lambda^\alpha D_\alpha$$

$$\mathcal{L}^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^\mu \lambda \partial_\mu$$

$$\lambda \Gamma^\mu \lambda = 0 \quad \boxed{\text{Pure spinor}}$$



ΕΛΤΕΚ
 ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
 ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ
 ΠΡΟΓΡΑΜΜΑ ΚΑΤΑΡΤΙΣΗΣ ΔΙΑΣΤΗΜΑΤΟΣ
 ΕΥΡΩΠΑΪΚΟ ΚΕΝΤΡΟ ΔΙΑΣΤΗΜΑΤΟΣ

$$A_\alpha = \frac{1}{2} (\theta \Gamma^m)_{\alpha} a_m + \frac{1}{3} (\theta \Gamma^m)_{\alpha} (\theta \Gamma^n \lambda) + \theta^2 \partial \alpha + \theta^2 \partial \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{mnp} \theta f^{np} + \dots$$

$$L = \lambda^\alpha D_\alpha$$

$$L^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^m \lambda \partial_m$$

$$\lambda \Gamma^m \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$A_\alpha = \frac{1}{2} (\theta \Gamma^\mu)_{\alpha} a_\mu + \frac{1}{3} (\theta \Gamma^\mu)_{\alpha} (\theta \Gamma^\nu \lambda) + \theta^\mu \partial_\mu + \theta^\nu \partial_\nu + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{mnp} \theta f^{np} + \dots$$

$$\mathcal{L}(\lambda) = \lambda^\alpha D_\alpha$$

$$\mathcal{L}^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^\mu \lambda \partial_\mu$$

$$\lambda \Gamma^\mu \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda^\beta = (\lambda \gamma_{\mu\nu} \lambda) + \dots + (\lambda \gamma^{\mu\nu\rho} \lambda) + \dots$$



CAUTION
 UNIVERSITÄT
 WÜRZBURG
 INSTITUT FÜR
 THEORETISCHE
 PHYSIK
 LEHRSTUHL FÜR
 QUANTENFELDTHEORIE
 UNIVERSITÄT WÜRZBURG
 97082 WÜRZBURG

$$A_x = \frac{1}{2}(\theta \Gamma^m) a_m + \frac{1}{2}(\theta \Gamma^m)_\lambda (\theta \Gamma^m \lambda) + \theta \gamma^m \partial x + \theta \gamma^m \partial \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma^m \theta f^{\lambda \rho} + \dots$$

$$\mathcal{L}(\lambda) = \lambda^x D_x$$

$$\mathcal{L}^2 = 0 = \lambda^x \lambda^y \{D_x, D_y\} = \lambda \Gamma^m \lambda \partial$$

$$\lambda \Gamma^m \lambda = 0 \quad \boxed{\text{Pure}}$$

$$\lambda^x \lambda^y = (A \gamma_{xy} \lambda) + \dots + (A \gamma^{[xy]} \lambda)$$



$$A_\alpha = \frac{1}{2}(\theta\Gamma^m)\alpha_m + \frac{1}{3}(\theta\Gamma^m)\alpha_m(\theta\Gamma^n)\lambda + \theta\gamma^{\mu\nu\rho}\alpha + \theta\gamma^{\mu\nu\rho}\lambda + \dots$$

$$A_m = \alpha_m + (\theta\gamma^{\mu\nu}\lambda) + \theta\gamma^{\mu\nu\rho}\theta f^{\mu\nu\rho} + \dots$$

$$L(\lambda) = \lambda^\alpha D_\alpha \psi \quad L^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda^\alpha \Gamma^m_{\alpha\beta} \partial_m$$

$$\lambda^\alpha \Gamma^m_{\alpha\beta} \lambda^\beta = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda^\beta = (\lambda^\alpha \lambda^\beta) + \dots + (\lambda^\alpha \gamma^{\mu\nu} \lambda^\beta)$$

$$A_\alpha = \frac{1}{2} (\theta \Gamma^\mu)_\alpha a_\mu + \frac{1}{2} (\theta \Gamma^\mu)_\alpha (\theta \Gamma^\mu \lambda) + \theta \dots \partial a + \theta \dots \partial \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{mnp} \theta f^{np} + \dots$$

$$\mathcal{L}(\lambda) = \lambda^\alpha D_\alpha \dots \quad \mathcal{L}^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^\mu \lambda \partial_\mu$$

$$\lambda \Gamma^\mu \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda^\beta = (\lambda \gamma^{\alpha\beta} \lambda) + \dots \quad + (\lambda \gamma^{\alpha\beta\gamma} \lambda) + \dots$$

$$A_\alpha = \frac{1}{2} (\theta \Gamma^m)_{\alpha} a_m + \frac{1}{2} (\theta \Gamma^m)_{\alpha} (\theta \Gamma^m \lambda) + \theta \gamma^{\mu\nu} \partial_\mu a_\nu + \theta \gamma^{\mu\nu} \partial_\mu \lambda_\nu + \dots$$

$$A_m = a_m + (\theta \gamma^{\mu\nu} \lambda) + \theta \gamma_{\mu\nu\rho} \theta f^{\mu\nu\rho} + \dots$$

$$L(\lambda) = \lambda^\alpha D_\alpha \quad L^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^m \lambda \partial_m$$

$$\lambda \Gamma^m \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda^\beta = (\lambda \gamma^{\mu\nu} \lambda) + \dots + (\lambda \gamma^{\mu\nu\rho} \lambda) + \dots$$

ΕΛΠΕΩ

$$A_x = \frac{1}{2}(\theta \Gamma^m) a_m + \frac{1}{2}(\theta \Gamma^m)_\lambda (\theta \Gamma^m \lambda) + \theta \gamma^m \partial x + \theta \gamma^m \partial \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma^m \theta f^{\lambda \rho} + \dots$$

$$\mathcal{L}(\lambda) = \lambda^t D_x$$

$$\mathcal{L}^2 = 0 = \lambda^t \lambda^p \{D_t, D_p\} = \lambda \Gamma^m \lambda \gamma^m$$

$$\lambda \Gamma^m \lambda = 0 \quad [P]$$

$$\lambda^t X = (A \gamma^m \lambda) + \dots + (A \gamma^m \lambda)$$



$$A_\alpha = \frac{1}{2} (\theta \Gamma^\mu)_\alpha a_\mu + \frac{1}{3} (\theta \Gamma^\mu)_\alpha (\theta \Gamma^\nu)_\beta a_\nu + \theta \gamma^\mu \partial_\mu \lambda + \theta \gamma^\mu \partial_\mu \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^\mu)_m \lambda + \theta \gamma_{\mu\nu\rho} \theta f^{\mu\nu\rho} + \dots$$

$$\mathcal{L}(\lambda) = \lambda^\alpha \Gamma^\mu \lambda_\alpha$$

$$\mathcal{L}^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda^\alpha \Gamma^\mu \lambda_\alpha \partial_\mu$$

$$\lambda \Gamma^\mu \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda_\alpha$$

$$+ (\lambda \gamma^\mu \lambda) \partial_\mu$$

$$A_\mu = \frac{1}{2} (\theta \Gamma^\mu) a_m + \frac{1}{3} (\theta \Gamma^\mu) \lambda (\theta \Gamma^\mu \lambda) + \theta \gamma^\mu \partial \alpha + \theta \gamma^\mu \partial \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{mnp} \theta f^{np} + \dots$$

$$L(\lambda) = \lambda^\alpha D_\alpha \quad L^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^\mu \lambda \partial_\mu$$

$$\therefore \lambda \Gamma^\mu \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda^\beta = (\lambda \gamma^{\alpha\beta} \lambda) + \dots$$

$$+ (\lambda \gamma^{\alpha\beta\gamma} \lambda)$$

$$d_{1/2} \left(\mathbb{C} \left(\frac{SO(10)}{U(5)} \right) \right) = 11$$

$$\text{SYM} \iff F_{\alpha\beta} = 0$$

$$\psi =$$

4d: $F_{\mu\nu} = F_{\mu\nu}^+$

$F_{\mu\nu}^+ = 0$

$$\begin{aligned} L_1 \psi &= 0 \\ L_2 \psi &= 0 \end{aligned}$$

$$[L_1, L_2] = 0$$

$$\begin{cases} L_1 = D_e - \lambda D_{\bar{e}} \\ L_2 = D_e + \lambda D_{\bar{e}} \end{cases} \quad \lambda \in \mathbb{C}$$

Twistor construction

$$\mathbb{P}(\Sigma^+) = \mathbb{S}(\Lambda^+) = \{ \text{self-dual spin structures on } S^4 \}$$

$$\text{SYM}_{\text{vac}} \Leftrightarrow F_{\alpha\beta} = 0$$

 λ^{α}

$$\varphi = \lambda^{\alpha_1} \lambda^{\alpha_2} \lambda^{\alpha_3} \dots \varphi_{\alpha_1 \alpha_2 \alpha_3 \dots}(x)$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F_{\mu\nu}^+ = 0}$$

$$L_1 \psi = 0$$

$$L_2 \psi = 0$$

$$\oint_{S^1} \psi = \varphi_{\alpha_1 \dots \alpha_n}(x)$$

$$\gamma^{\alpha_1 \dots \alpha_n} \varphi_{\alpha_1 \dots \alpha_n}(x) = 0$$

$$[L_1, L_2] = 0$$

(2)

$$\begin{cases} L_1^{(1)} = D_e - \lambda D_{\bar{e}} \\ L_2^{(1)} = D_{\bar{e}} + \lambda D_e \end{cases}$$

 $\lambda \in \mathbb{C}$

Twistor construction

$$\mathbb{P}(\Sigma^+) = \mathbb{S}(\Lambda^+) = \left\{ \text{self-dual spin structures on } S^4 \right\}$$

$$\text{SYM} \rightarrow \text{vac} \Leftrightarrow F_{\alpha\beta} = 0$$

 λ^a

$$\varphi = \lambda^a \lambda^b \lambda^c \dots \varphi_{a_1 a_2 a_3 \dots}(x)$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F_{\mu\nu}^+ = 0}$$

$$\begin{aligned} L_1 \psi &= 0 \\ L_2 \psi &= 0 \end{aligned}$$

$$\oint_{S^1} \varphi = \varphi_{a_1 \dots a_n}(x)$$

$$\gamma^{a_1 a_2} \varphi_{a_1 a_2}(x) = 0$$

$$L_{\alpha\beta} \text{ operators } [L_1, L_2] = 0$$

(z, w)

$$\begin{cases} L_1 = D_z - \lambda D_w \\ L_2 = D_w + \lambda D_z \end{cases}$$

$\lambda \in \mathbb{C}$

Twistor construction

$$S^4 \leftarrow \mathbb{P}^1$$

\mathbb{P}^1 twistor space

$$\mathbb{P}(\Sigma^+) = S(\Lambda^+) = \{ \text{relevant spin structures on } S^4 \}$$

$$\text{SYM} \rightarrow \dots \Leftrightarrow F_{\alpha\beta} = 0$$

 λ^2

$$\varphi = \lambda^{\alpha_1} \lambda^{\alpha_2} \lambda^{\alpha_3} \dots \varphi_{\alpha_1 \alpha_2 \alpha_3}(\lambda)$$

4d:

$$F_{\mu\nu} = F_{\mu\nu}^+ + F_{\mu\nu}^-$$

$$\boxed{F_{\mu\nu}^+ = 0}$$

$L_1 \psi = 0$

$L_2 \psi = 0$

$\oint_{\mathbb{P}^1} \varphi = 0$

$\varphi_{\alpha_1 \dots \alpha_n}(\lambda)$

$\int \lambda^{\alpha_1} \dots \varphi_{\alpha_1 \dots \alpha_n}(\lambda) = 0$

$L_{\lambda} \text{-operator } [L_1, L_2] = 0$

(z, w)

$$\begin{cases} L_1 = D_z - \lambda D_w \\ L_2 = D_z + \lambda D_w \end{cases}$$

$\lambda \in \mathbb{C}$

Twistor construction

$$S^4 \leftarrow \mathbb{P}^1$$

\mathbb{P}^1 twistor space

$$\mathbb{P}(\Sigma^+) = S(\Lambda^+) = \{ \text{select spin structures on } S^4 \}$$

$$A_\mu = \frac{1}{2} (\theta \Gamma^\mu)_{\alpha\beta} a_{\alpha\beta} + \frac{1}{2} (\theta \Gamma^\mu)_{\alpha\beta} (\theta \Gamma^\mu \lambda) + \theta^\nu \partial_\nu a + \theta^\nu \partial_\nu \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{mnp} \theta f^{np} + \dots$$

$$L(\lambda) = \lambda^\alpha D_\alpha \psi$$

$$L^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^{\mu\nu} \partial_{\mu\nu}$$

$$\therefore \lambda \Gamma^{\mu\nu} \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda^\beta = (A \gamma^{\mu\nu} \lambda)_{\alpha\beta} + \dots$$

$$d_{1/2}(\mathbb{C} \ltimes \left(\frac{SO(10)}{U(5)} \right)) = \mathbb{1} \mathbb{1}$$

$$+ (A \gamma^{\mu\nu} \lambda)_{\alpha\beta}$$

$$\psi = \lambda^\alpha A_\alpha(x, 0)$$

$$L\psi = 0 \Rightarrow F_{\mu\nu} = 0$$

$$S\psi = L\psi$$

$$L = Q_{\alpha\beta\gamma\delta}$$

A Superstring

$$d_n = p_n +$$

A Superstring

$$d_n = p_n + \partial X^m (\Gamma_m \theta)_n + \frac{1}{8} (\Gamma_m \theta)_n (\theta \Gamma_m \theta)$$

$$(\Gamma_m \theta)_n = (\Gamma_m)_{np} \theta^p$$

A Superstring

$$d_{m\bar{n}} = P_{m\bar{n}} + \partial_\mu X^m (\Gamma_{m\bar{n}}^\mu)_\alpha + \frac{1}{5} (\Gamma_{m\bar{n}}^\mu)_\alpha (\partial_\mu \theta^\alpha)$$

$$S_D = \int \partial X \partial X + \rho \bar{\psi} \psi$$

A Superstring

$$d_{\mu\nu} = \eta_{\mu\nu} + \partial_\mu X^m (\Gamma_m \theta)_\nu + \frac{1}{8} (\Gamma_m \theta)_\mu (\theta \Gamma_m \theta)_\nu$$

$$S_B = \int \partial X \partial X + \rho \bar{\psi} \psi + \dot{\rho} \psi + \omega \bar{\psi} \lambda + \omega \psi \bar{\lambda}$$

A Superstring

$$d_{\alpha\beta} = p_{\alpha\beta} + \partial_\mu X^m (\Gamma_m^\alpha)_\beta + \frac{1}{8} (\Gamma_m^\alpha)_\beta (\theta \Gamma_m \partial \theta)$$

$$S_B = \int \partial X \partial X + \rho \partial \bar{\theta} + \dot{\rho} \partial \theta + \omega \partial \bar{\lambda} + \omega \partial \lambda$$

$$d_\alpha(z) d_\beta(w) = \frac{\Gamma_{\alpha\beta}^m \Gamma_m}{z-w}$$

$$(\Gamma_m^\alpha)_\beta = (\Gamma_m^\alpha)_\gamma (\Gamma^\gamma)_\beta$$

A Superstring

$$d_{\mu\nu} = P_{\mu\nu} + \partial_\mu X^\alpha (\Gamma_{\alpha\beta}^\mu \theta) + \frac{1}{8} (\Gamma_{\alpha\beta}^\mu \theta) (\theta \Gamma_{\mu\nu} \theta)$$

$$S_B = \int \partial X \partial X + \rho \bar{\psi} \psi + \dots + \omega \bar{\psi} \lambda + \omega \bar{\lambda} \psi$$

$$d_\alpha(z) d_\beta(w) = \frac{\Gamma_{\alpha\beta}^\mu \Pi_\mu}{z-w}$$

$$d_\alpha \Pi_\mu = \Gamma_{\alpha\beta}^\mu \partial \theta^\beta$$

A Superstring

$$d_{\alpha\beta} = p_{\alpha\beta} + \partial_\mu X^m (\Gamma_m^\alpha)_\beta + \frac{1}{8} (\Gamma_m^\alpha)_\beta (\theta \Gamma_m \partial \theta)$$

$$S_B = \int \partial X \partial X + \rho \bar{\partial} \theta + \dot{\rho} \partial \theta + \omega \bar{\partial} \lambda + \omega \partial \bar{\lambda}$$

$$d_\alpha(z) d_\beta(w) = \frac{\Gamma_{\alpha\beta}^m \Pi_m}{z-w}$$

$$Q = \lambda^\alpha d_\alpha$$

$$d_\alpha \Pi_m = \frac{\Gamma_{\alpha\beta}^m \partial \theta}{z-w} = \Gamma_{\alpha\beta}^m (\Gamma^m)^{\gamma\delta}$$

$$d_\alpha \partial \theta = \frac{1}{(z-w)^2}$$



A Superstring

$$d_{\alpha r} = p_{\alpha r} + \partial_r X^m (\Gamma_m \theta)_\alpha + \frac{1}{8} (\Gamma_m \theta)_\alpha (\theta \Gamma_m \theta)$$

$$S_B = \int \partial X \partial X + \rho \bar{\psi} \psi + \dot{\rho} \partial \theta + \omega \bar{\psi} \lambda + \omega \bar{\psi} \lambda$$

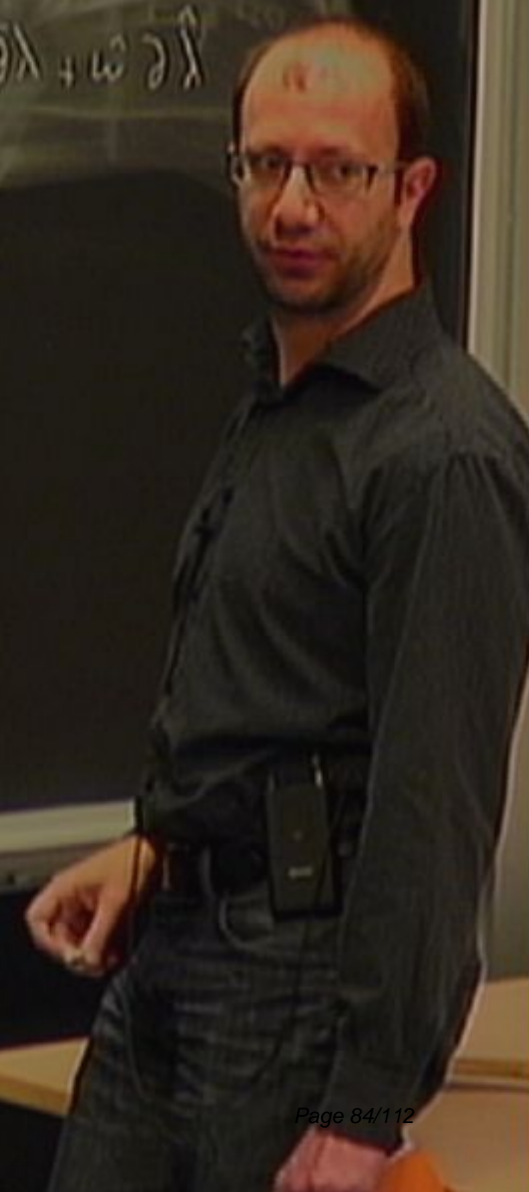
$$d_\alpha(z) d_\beta(w) = \frac{\Gamma_{\alpha\beta}^m \Pi_m}{z-w}$$

$$Q = \lambda^\alpha d_\alpha$$

$$d_\alpha \Pi_m = \frac{\Gamma_{m\alpha\beta} \partial \theta}{z-w}$$

$$d_\alpha(z) \psi$$

$$d_\alpha \theta^\alpha = \frac{1}{(z-w)^2}$$



A Superstring

$$d_{\alpha r} = p_{\alpha r} + \partial_r X^m (\Gamma_m \theta)_\alpha + \frac{1}{8} (\Gamma_m \theta)_\alpha (\theta \Gamma_m \partial \theta)$$

$$S_B = \int \partial X \partial X + \rho \bar{\partial} \theta + \dot{p} \partial \theta + w \bar{\partial} \lambda$$

$$d_\alpha(z) d_\beta(w) = \frac{\Gamma_{\alpha\beta}^m \Pi_m}{z-w}$$

$$Q = \lambda^\alpha d_\alpha$$

$$d_\alpha \Pi_m = \frac{\Gamma_{m\alpha\beta} \partial \theta}{z-w}$$

$$d_\alpha(z) U(x, \theta) \sim \frac{D_\alpha}{z}$$

$$d_\alpha \partial \theta = \frac{1}{(z-w)^2}$$

A Superstring

$$d_{\alpha r} = p_{\alpha r} + \partial_r X^m (\Gamma_m \theta)_\alpha + \frac{1}{8} (\Gamma_m \theta)_\alpha (\theta \Gamma_m \partial \theta)$$

$$S_B = \int \partial X \partial X + \rho \bar{\partial} \theta + \dot{\rho} \partial \theta + \omega \bar{\partial} \lambda + \omega \partial \hat{\lambda}$$

$$d_\alpha(z) d_\beta(w) = \frac{\Gamma_{\alpha\beta}^m \Pi_m}{z-w}$$

$$Q = \lambda^\alpha d_\alpha$$

$$d_\alpha \Pi_m = \frac{\Gamma_{m\alpha\beta} \partial \theta}{z-w}$$

$$d_\alpha(z) U(x, \theta) \sim \frac{D_\alpha U}{z-w}$$

$$d_\alpha \partial \theta = \frac{1}{(z-w)^2}$$

A Superstring

$$d_{n\alpha} = p_{n\alpha} + \partial_\alpha X^\mu (\Gamma_{\mu\alpha})_n + \frac{1}{8} (\Gamma_{\mu\alpha})_n (\theta \Gamma_{\mu\alpha} \theta)$$

$$S_B = \int \partial x \partial x + \rho \bar{\partial} \theta + \dot{\rho} \partial \theta + \omega \bar{\partial} \lambda + \dot{\omega} \partial \lambda$$

$$d_\alpha(z) d_\beta(w) = \frac{\Gamma_{\alpha\beta}^m \Gamma_{\alpha\beta}}{z-w}$$

$$Q = \lambda^\alpha d_\alpha$$

$$d_\alpha \Gamma_\alpha \sim \frac{\Gamma_{\alpha\alpha} \partial \theta}{z-w}$$

$$d_\alpha(z) \psi(x, \theta) \sim \frac{\Gamma_{\alpha\alpha}}{z}$$

$$d_\alpha \partial \theta \sim \frac{1}{(z-w)^2}$$

$$H^k(Q) = \frac{k_\alpha Q}{\Gamma_\alpha Q}$$

|

Superstrings

$$d_{n,r} = P_{n,r} + \partial_n X^m (\Gamma_m \theta)_r + \frac{1}{8} (\Gamma_m \theta)_r (\theta \Gamma_m \partial \theta)$$

$$S_B = \int \partial x \partial x + \rho \bar{\partial} \theta + \dot{\rho} \partial \theta + \omega \bar{\partial} \lambda + \dot{\omega} \partial \lambda$$

$$d_n(z) d_f(w) = \frac{\Gamma_{n,r}^m \Gamma_{r,s}}{z-w}$$

$$Q = \lambda^a d_a$$

$$d_n \Gamma_m \sim \frac{\Gamma_{m,n,r} \partial \theta}{z-w}$$

$$d_n(z) U(x, \theta) \sim \frac{D_n U}{z-w}$$

$$d_n \partial \theta^a \sim \frac{1}{(z-w)^2}$$

$$H^e(Q) = \frac{k_n(Q)}{\Gamma_n(Q)}$$

H^1



$$d_x(z) d_f(w) = \frac{\Gamma_{\text{app}} \Gamma_{\text{in}}}{z-w}$$

$$d_x \Gamma_n \sim \frac{\Gamma_{\text{app}} \partial \theta}{z-w}$$

$$d_x \partial \theta \sim \frac{1}{(z-w)^2}$$

$$Q = \lambda^n d_x$$

$$d_x(z) U(x, \theta) \sim \frac{D_x U}{z-w}$$

$$H^*(Q) = \frac{k_{\text{in}} Q}{\Gamma_{\text{in}} Q}$$

$$H^1(Q) = \{ \text{unstable fields} \}$$

$$d_n \Pi_n \sim \frac{\Gamma_{n+1} z^n}{z-w}$$

$$d_n \Pi_n \sim \frac{1}{(z-w)^2}$$

$$d_n(z) U(x, \theta) \sim \frac{D_n U}{z-w}$$

$$H^0(Q) = \frac{K_n(Q)}{\Gamma_n(Q)}$$

$$H^1(Q) = \{ \text{un-split fields} \}$$



Abelian YM

$$F_{\alpha\beta} = (F_{\alpha\beta})_{ij} A_n$$

$$\delta A_n = \partial_m \Lambda$$

$$W^\alpha = \frac{1}{10} (\gamma^\alpha)^{\mu\nu} (D_\mu A_\nu - \partial_\mu A_\nu)$$

$\delta W^{\alpha 2}$

$$D_\alpha W^\beta = \frac{1}{4} (\Gamma^{\mu\nu})_{\alpha}^{\beta} F_{\mu\nu}$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

Abelian YM

$$F_{\alpha\beta} = (F_{\alpha\beta})_{ij} A_n$$

$$\delta A_n = \partial_m \Lambda$$

$$W^\alpha = \frac{1}{10} (\gamma^\alpha)^{\beta\gamma} (D_\beta A_\gamma - \partial_\beta A_\gamma)$$

$SW \stackrel{?}{\sim}$

$$D_\alpha W^\beta = \frac{1}{4} (\Gamma^{\mu\nu})_{\alpha}^{\beta} F_{\mu\nu}$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

$$H^{\bar{g}}(Q) \neq 0 \quad \begin{cases} i=0 \\ \begin{cases} 1 \\ 2 \\ 3 \end{cases} \end{cases}$$



$$F_{\alpha\beta} = \partial_\alpha A_\beta - \partial_\beta A_\alpha$$

$$\partial_{[m} A_{n]}$$

$$W^{\alpha} = \frac{1}{10} (\gamma^{\alpha})^{\mu\nu} (D_{\mu} A_{\nu} - \partial_{\mu} A_{\nu}) \quad \delta W^{\alpha}$$

$$D_{\alpha} W^{\beta} = \frac{1}{4} (\Gamma^{\mu\nu})_{\alpha}^{\beta} F_{\mu\nu} \quad F_{\mu\nu} = \partial_{\mu} A_{\nu} - \partial_{\nu} A_{\mu}$$

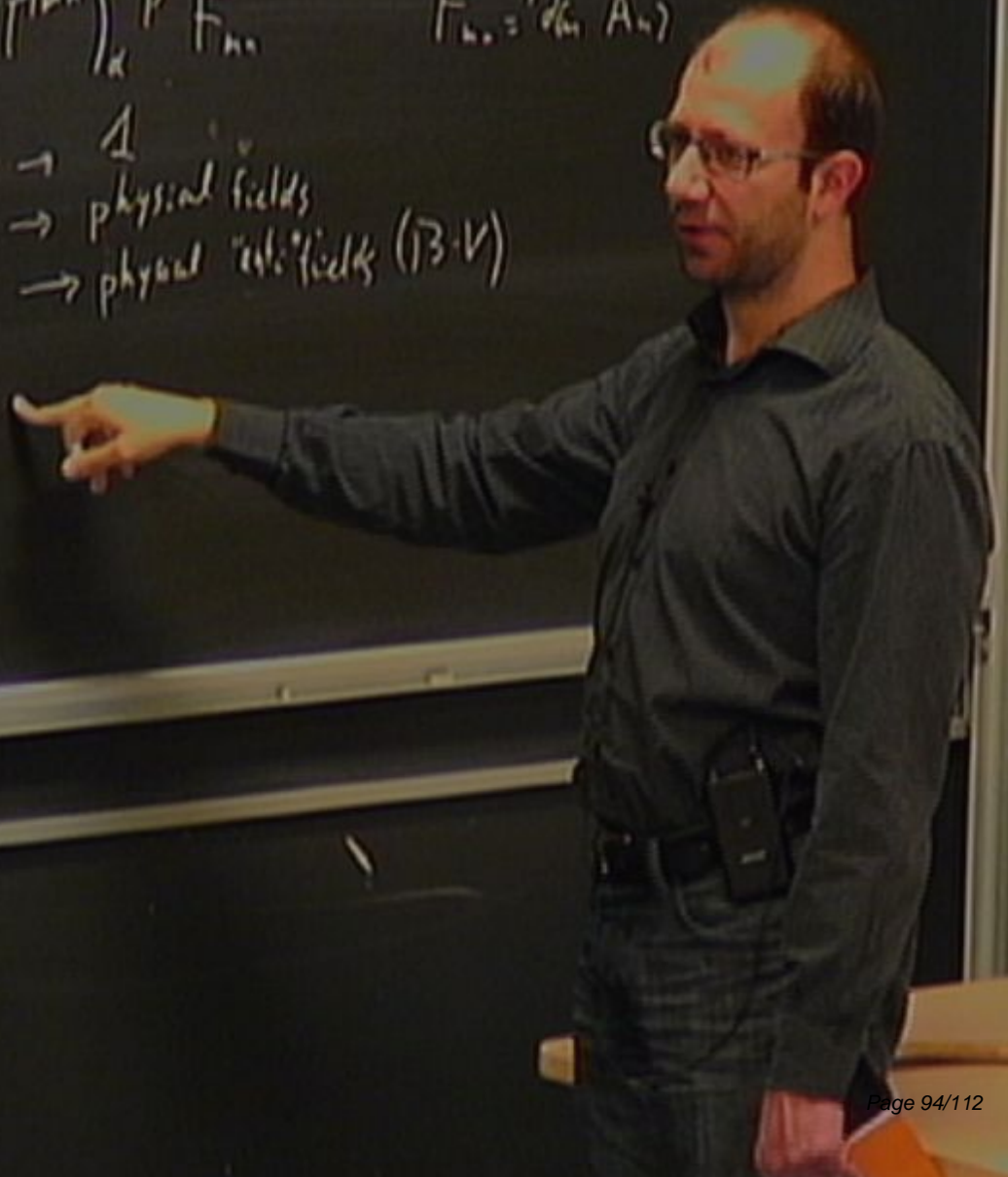
$$H^{\bar{p}}(Q) \neq 0$$

- $i=0 \rightarrow$ physical fields
- $\begin{bmatrix} 1 \\ 2 \end{bmatrix} \rightarrow$ physical "extra" fields (B-V)
- 3

$$W^{\alpha} = \frac{1}{10} (\gamma^{\alpha})^{\mu\nu} (D_{\mu} A_{\nu} - \partial_{\mu} A_{\nu}) \quad SW^{\wedge 10}$$

$$D_{\alpha} W^{\beta} = \frac{1}{4} (\Gamma^{\mu\nu})_{\alpha}^{\beta} F_{\mu\nu} \quad F_{\mu\nu} = \partial_{\mu} A_{\nu} - \partial_{\nu} A_{\mu}$$

$$H^{\bar{q}}(Q) \neq 0 \quad \begin{cases} i=0 \rightarrow 1 \\ \quad \quad \rightarrow \text{physical fields} \\ [1 \\ \quad \quad \rightarrow \text{physical "anti" fields (B-V)} \\ 2 \\ \quad \quad \rightarrow \\ 3 \end{cases}$$



$$W^{\mu} = \frac{1}{10} (\gamma^{\mu})^{\alpha\beta} (D_{\alpha} A_{\beta} - \partial_{\alpha} A_{\beta}) \quad \delta W^{\mu} \rightarrow 0$$

$$D_{\alpha} W^{\mu} = \frac{1}{4} (\Gamma^{\mu\alpha})_{\kappa}^{\beta} F_{\alpha\beta} \quad F_{\alpha\beta} = \partial_{\alpha} A_{\beta} - \partial_{\beta} A_{\alpha}$$

$$H^{\bar{g}}(Q) \neq 0 \quad \begin{cases} i=0 \rightarrow 1 \\ \quad \quad \rightarrow \text{physical fields} \\ [1 \\ \quad \quad \rightarrow \text{physical "anti" fields (B-V)} \\ 2 \\ \quad \quad \rightarrow \lambda^3 \theta^5 \\ 3 \end{cases}$$



$$1 = \langle \lambda \gamma^{\mu} \theta \lambda \gamma^{\nu} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$$

$$T_{\rho\sigma}^{\mu\nu} = \delta$$

$$1 = \langle \lambda \gamma^{\mu} \theta \lambda \gamma^{\nu} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$$

$$T_{\rho\sigma}^{\alpha\beta\gamma} = \sum_p^{(k)} \sum_{q_1}^{(l)} \sum_{q_2}^{(m)} - \# \gamma_n^{(k)} \delta_p^{(l)} (\gamma^{m\alpha})_{\sigma c}$$

$$1 = \langle \lambda \gamma^{\mu} \theta \lambda \gamma^{\nu} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$$

$$T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \sum_p^{(\mu} \sum_\sigma^{(\nu} \sum_c^{(\gamma)} - \dots)_{(\sigma\tau)}$$

$$U(x, \theta) = \lambda^{\mu} A_{\mu}(x)$$

$$1 = \langle \lambda \gamma^{\mu} \theta \lambda \gamma^{\nu} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$$

$$T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \sum_{\mu} \sum_{\nu} \sum_{\eta} \dots - \# \gamma_{\mu\nu}^{\alpha\beta} \delta_{\rho}^{\eta} (\gamma^{\eta})_{\sigma\tau}$$

$$U(x, \theta) = \lambda^{\alpha} A_{\alpha}(x, \theta) \quad \langle U(x, \theta) U(x, \theta) \rangle$$

=

$$1 = \langle \lambda \gamma^{\mu} \theta \lambda \gamma^{\nu} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$$

$$T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \sum_{\mu}^{\alpha} \sum_{\nu}^{\beta} \sum_{\eta}^{\gamma} - \# \gamma_{\mu\nu}^{\alpha\beta} \delta_{\rho}^{\eta} (\gamma^{\mu\nu})_{\sigma\tau}$$

$$U(x, \theta) = \lambda^{\mu} A_{\mu}(x, \theta) \gamma_{\mu} \theta \quad \langle T^{\mu\nu} \rangle$$

=

$$1 = \langle \lambda \gamma^{\mu} \theta \lambda \gamma^{\nu} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$$

$$T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \sum_{\mu} \sum_{\nu} \sum_{\eta} \dots = \# \gamma_{\mu\nu}^{\alpha\beta} \sum_{\rho} \sum_{\sigma} (\gamma^{\eta\rho\sigma})$$

$$U(x, \theta) = \lambda^{\mu} A_{\mu}(x, \theta) \Big| \langle U(x, \theta) U(x) \rangle$$

$$= \lambda^{\mu} \lambda^{\nu} \lambda^{\rho} f_{\mu\nu\rho}(z_1, z_2, z_3)$$

$$1 = \langle \lambda \gamma^{\alpha} \theta \lambda \gamma^{\beta} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\alpha\rho\beta} \theta \rangle$$

$$T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \sum_{\mu} \sum_{\nu} \sum_{\eta} - \# \gamma_{\mu\nu}^{\alpha\beta} \delta_{\rho}^{\eta} (\gamma^{\mu\nu})_{\sigma\tau}$$

$$U(x, \theta) = \lambda^{\alpha} A_{\alpha}(x, \theta) \Big| \langle U(x, \theta) U(x) \rangle = A$$

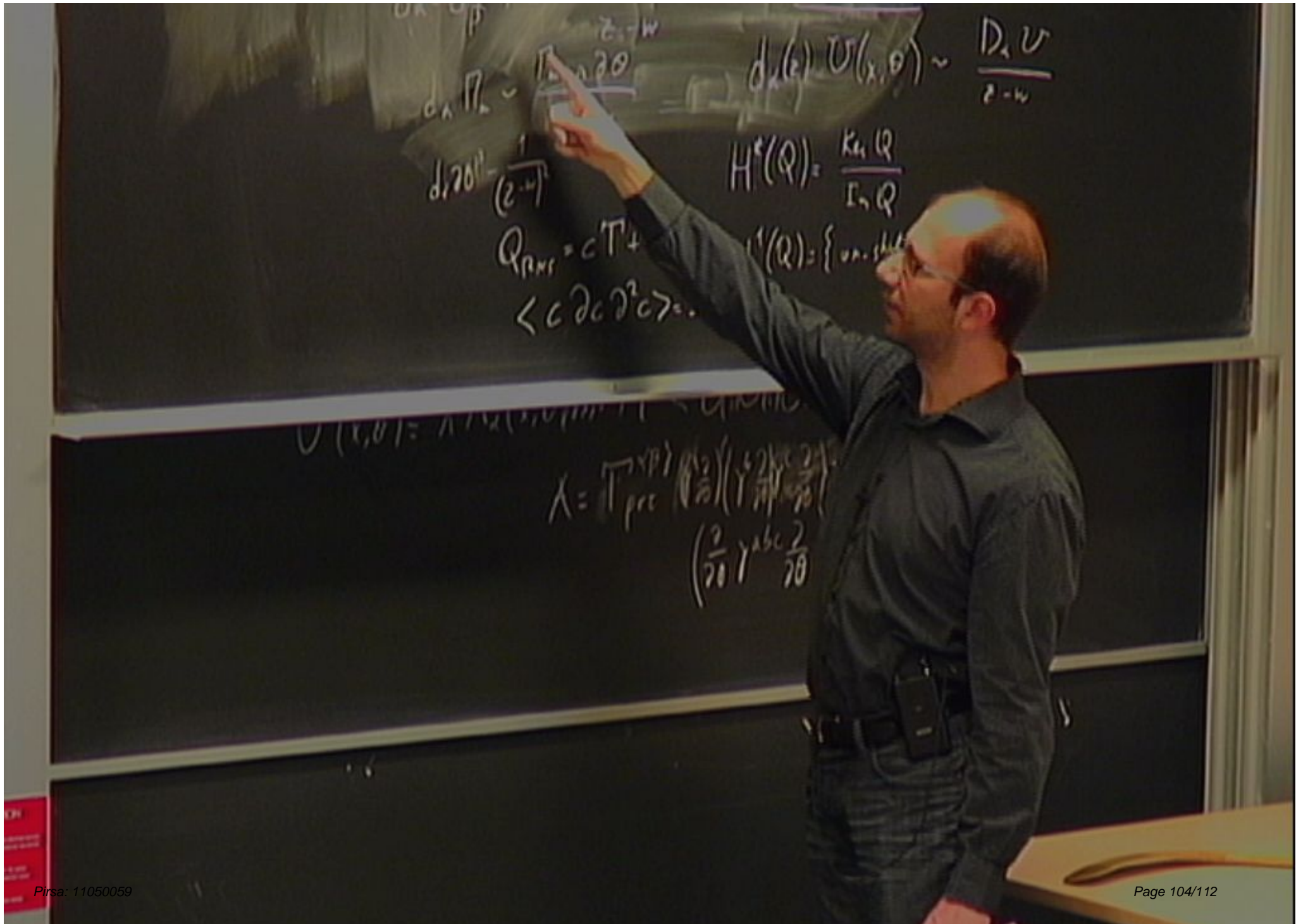
$$A = \left(\frac{\partial}{\partial \theta} \gamma^{abc} \frac{\partial}{\partial \theta} \right) f_{\alpha\beta\gamma}(z_1, z_2, z_3)$$

$$1 = \langle \lambda \gamma^{\mu} \theta \lambda \gamma^{\nu} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$$

$$T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \sum_{\mu} \sum_{\nu} \sum_{\eta} \dots = \# \gamma_{\mu\nu}^{\alpha\beta} \delta_{\rho}^{\eta} (\gamma^{\mu\nu})_{\sigma\tau}$$

$$U(x, \theta) = \lambda^{\alpha} A_{\alpha}(x, \theta) \Big| \langle U(x, \theta) U(x) \rangle = \mathcal{A}$$

$$\lambda = \begin{pmatrix} T_{\rho\sigma\tau}^{\alpha\beta\gamma} \left(\frac{\partial}{\partial \theta} \right) \left(\gamma^{\mu\nu} \right) \left(\frac{\partial}{\partial \theta} \right) \\ \left(\frac{\partial}{\partial \theta} \right) \gamma^{abc} \left(\frac{\partial}{\partial \theta} \right) \end{pmatrix} \gamma(z_1, z_2, z_3)$$



$$d_x \Pi_n = \frac{\partial \Pi_n}{\partial \theta} \approx \frac{d_x(z) \cdot U(x, \theta)}{z-w}$$
$$d_x \Pi_n = \frac{1}{(z-w)}$$
$$Q_{RMS} = cT + \dots$$
$$\langle c \partial c \partial^2 c \rangle = \dots$$
$$H^*(Q) = \frac{k_{el} Q}{\Gamma_n Q}$$
$$H^*(Q) = \{ \dots \}$$

$$U(x, \theta) = \dots$$
$$\Lambda = \begin{pmatrix} \dots \\ \dots \\ \dots \end{pmatrix}$$
$$\left(\frac{\partial}{\partial \theta} \right)^{abc} \frac{\partial}{\partial \theta}$$

$$V = \partial \theta^a A_{a\alpha} + \pi$$

$$Q_{\text{Gauss}} = c \pi + \dots$$

$$\langle c \partial c \partial^2 c \rangle = 1$$

$$H^1(Q) = \{ \text{unstable fields} \}$$

$$T_{\rho\sigma}^{\alpha\beta\gamma}$$

$$= \sum_n \sum_p \delta_p^{\alpha\beta} (\gamma^m)_{\sigma c}$$

$$U(x, \theta) = \lambda^a A_{a\alpha}$$

$$\langle U(x) U(y) U(z) \rangle = \mathcal{H}$$

$$\left(\frac{\partial}{\partial z} \right) \left(\gamma^a \right) \left(\frac{\partial}{\partial z} \right) f_{\alpha\beta\gamma}(z_1, z_2, z_3)$$

$$\left(\frac{\partial}{\partial z} \right) \gamma^{abc} \left(\frac{\partial}{\partial z} \right)$$

$$d, \partial^0 = \frac{1}{(z-w)^2}$$

$$H^k(Q) = \frac{K_{g,1} Q}{\Gamma_1 Q}$$

$$V = \partial \bar{\theta}^a A_{a\mu} + \pi^m A_m + d_n W^a + Q_{RRR} = c \pi^+ + \dots$$

$$\langle c \partial c \partial^2 c \rangle = 1$$

$$H^1(Q) = \{ \text{un. shell fields} \}$$

+ 1

$$T_{\rho\sigma\tau}$$

$$U(x, \theta) = \lambda^a$$

$$\langle U(x, \theta) U(x, \theta) \rangle = A$$

$$f_{abc}(z_1, z_2, z_3)$$

$$\left(\frac{\partial}{\partial z} \gamma^{abc} \frac{\partial}{\partial z} \right)$$

$$V = \partial \theta^{\alpha} A_{\alpha} + \Pi^m A_m + d_n W^{\alpha} + Q_{\alpha\beta\gamma} = c \Pi^{\alpha} + N^{\alpha\beta} F_{\alpha\beta}$$

$$\langle c \partial c \partial c \rangle = 1$$

$$H^1(Q) = \{ \text{un. shell fields} \}$$

$$1 = \langle \lambda \gamma^{\alpha} \theta \lambda \chi^{\beta} \theta \lambda \gamma^{\rho} \theta \theta \gamma_{\alpha\rho} \theta \rangle$$

$$\Pi^{\alpha\beta\gamma} =$$

$$= \# \gamma_n^{\alpha\beta} \delta_{\rho}^{\gamma} (\gamma^m)_{\alpha\beta}$$

$$U(x, y)$$

$$\langle U(x, y) U(x, y) \rangle = A$$

$$f_{\alpha\beta\gamma}(z_1, z_2, z_3)$$

$$\left(\frac{2}{70} \gamma_{abc} \frac{2}{70} \right)$$

$$V = \partial\theta^\alpha A_\alpha + \Pi^m A_m + d_n W^n + Q_{\text{GMS}} = cT + \langle c\partial c \rangle_{-1}$$

$$+ N^{\mu\nu} F_{\mu\nu}$$

$H^1(Q) = \{\text{unstable fields}\}$

$N^{\mu\nu} = \omega \gamma^{\mu\nu} \lambda$ $1 = \langle \lambda \gamma^\mu \theta \lambda \gamma^\nu \theta \lambda \gamma^\rho \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$

$N^{\mu\nu} \lambda = \gamma^{\mu\nu} \lambda$ $T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \int \delta_\rho^\alpha \delta_\sigma^\beta \delta_\tau^\gamma - \# \gamma_n^{\alpha\beta} \delta_\rho^\gamma (\gamma^{\mu\nu})_{\sigma\tau}$

$U(x, \theta) = \lambda^\alpha A_\alpha(x, \theta) | \langle U(x, \theta) U(x, \theta) \rangle = A$

$\lambda = \left(\begin{matrix} T_{\rho\sigma}^{\alpha\beta} \\ \left(\frac{2}{70} \gamma^{abc} \frac{2}{70} \right) \end{matrix} \right) f_{\alpha\beta}$

$$V = \partial\theta^\alpha A_\alpha + \Pi^m A_m + d_n W^n + Q_{\alpha\beta\gamma} = cT + \langle c \partial c \rangle = 1$$

$$+ N^{\mu\nu} F_{\mu\nu}$$

$$H^1(Q) = \{ \text{unstable fields} \}$$

$$N^{\mu\nu} = \omega \gamma^{\mu\nu} \lambda \quad 1 = \langle \lambda \gamma^\alpha \theta \lambda \gamma^\beta \theta \lambda \gamma^\gamma \theta \theta \gamma_{\alpha\beta\gamma} \theta \rangle$$

$$N^{\mu\nu} \lambda = \gamma^{\mu\nu} \lambda \quad T_{\rho\sigma\tau}^{\alpha\beta\gamma} = \sum_p^{\{\alpha\}} \sum_c^{\{\beta\}} \sum_d^{\{\gamma\}} \gamma^{\rho\sigma\tau} (\gamma^{\mu\nu})_{\rho\sigma}$$

$$QV = \partial U$$

$$U(x, \theta) = \lambda^\alpha A_\alpha(x, \theta) | \langle \dots \rangle = A$$

$$A_\alpha = \langle u_1, u_2, u_3 \rangle$$

$$A = T_{\rho\sigma}^{\alpha\beta\gamma} \gamma^{\mu\nu} (z_1, z_2, z_3)$$

$$V = \partial\theta^\alpha A_{\alpha} + \Pi^m A_m + d_n W^{\wedge} + Q_{\rho\sigma\tau} = cT + N^{\mu\nu} F_{\mu\nu}$$

$$\langle c\partial c \rangle = 1$$

$H^1(Q) = \{\text{unstable fields}\}$

$N^{\mu\nu} = \omega \gamma^{\mu\nu} \lambda$ $1 = \langle \lambda \gamma^\alpha \theta \lambda \gamma^\beta \theta \lambda \gamma^\rho \theta \theta \gamma_{\mu\nu\rho} \theta \rangle$

$N^{\mu\nu} \lambda = \gamma^{\mu\nu} \lambda$ $T_{\rho\sigma\tau} = \int \delta_p^{\mu} \delta_\sigma^{\nu} \delta_c^{\gamma} - \# \gamma_n^{\mu\rho} \delta_p^{\nu} (\gamma^{\mu\nu})_{\sigma c}$

$QV = \partial U$ $U(x, \theta) = \lambda^\alpha A_\alpha(x, \theta) | \langle U(x, \theta) U(x, \theta) \rangle = A$

$A_\alpha = \langle U_1 U_2 U_3 \rangle \int V_1 \dots \int V_n$ $A = \left(\frac{\partial}{\partial \theta} \gamma^{abc} \frac{\partial}{\partial \theta} \right) f_{\alpha\beta\gamma}(z_1, z_2, z_3)$

$$A_\mu = \frac{1}{2} (\theta \Gamma^\mu) a_m + \frac{1}{3} (\theta \Gamma^\mu)_\lambda (\theta \Gamma^\mu \lambda) + \theta \dots \partial a + \theta \dots \partial \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{mnp} \theta f^{np} + \dots$$

$$L(\lambda) = \lambda^\dagger D_\mu \lambda \quad L^2 = 0 = \lambda^\dagger \lambda^\rho \{D_\mu, D_\rho\} = \lambda^\dagger \Gamma^{\mu\rho} \lambda \partial_\mu$$

$$\dots \lambda^\dagger \Gamma^{\mu\rho} \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\dagger \lambda^\rho = (\lambda \gamma_{\rho\sigma} \lambda) + \dots$$

$$+ (\lambda \gamma^{\rho\sigma} \lambda)$$

$$\psi = \lambda^\dagger A_\mu(x, 0)$$

$$d_{1/2}(\mathbb{C} \times \left(\frac{SO(10)}{U(5)} \right)) = \mathbb{1} \mathbb{1}$$

$$L\psi = 0 \Rightarrow F_{\mu\rho} = 0$$

$$\delta\psi = L\psi$$

$$L = Q_{\mu RST}$$

$$A_\alpha = \frac{1}{2} (\theta \Gamma^\mu)_{\alpha} a_\mu + \frac{1}{3} (\theta \Gamma^\mu)_{\alpha} (\theta \Gamma^\nu \lambda) + \theta \dots \partial a + \theta \dots \partial \lambda + \dots$$

$$A_m = a_m + (\theta \gamma^m \lambda) + \theta \gamma_{mnp} \theta f^{np} + \dots$$

$$L(\lambda) = \lambda^\alpha D_\alpha \psi \quad L^2 = 0 = \lambda^\alpha \lambda^\beta \{D_\alpha, D_\beta\} = \lambda \Gamma^\mu \lambda \partial_\mu$$

$$\dots \lambda \Gamma^\mu \lambda = 0 \quad \boxed{\text{Pure spinor}}$$

$$\lambda^\alpha \lambda^\beta = \underbrace{(\theta \gamma^m \lambda) + \dots}_{\text{diag}(\mathbb{C} \times \frac{SO(10)}{U(5)})} + \dots$$

$$+ \underbrace{(\theta \gamma^{mnp} \lambda)}_{\dots}$$

$$\psi = \lambda^\alpha A_\alpha(x, \theta)$$

$$L\psi = 0 \Rightarrow F_{\alpha\beta} = 0$$

$$\delta\psi = L\psi$$

$$L = Q_{\alpha RST}$$

LA 75H
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 SAARLAND
 SAARBRÜCKEN