# On small Black Holes and stable Higher Spin States in Heterotic Strings


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and M.B., L. Lopez and R. Richter arXiv:1010.1177 [hep-th]

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# Foreword

- Recent interest in Black-Hole production at LHC [Giudice, Rattazzi, Wells; Giddings, Thomas; Dimopoulos, Landsberg; Meade, Randall; Kanti] ... not without some worries [Giddings, Mangano] and disturbing features
- Large Extra Dimensions (LED), TeV scale Gravity and Strings [Arkani-Hamed, Dimopoulos, Dvali; Antoniadis; ...]
- String/BH correspondence [Dabholkar, Harvey; Horowitz, Polchinski; Damour, Veneziano; 't Hooft; Susskind; ...]
- (non)BPS BH's and Higher Spins in String Theory [Dabholkar; Sen; Callan, Maldacena; Cvetic, Youm; Strominger, Vafa; ...]
- Higher Spin States are a hallmark of String Theory!!! [Veneziano, Shapiro-Virasoro, ... A. Sagnotti, O. Schlotterer, D. Lüst, ...]

# Plan of the Talk

- Small BH's, TeV gravity and Large Extra Dimensions
- (BPS) BH's and HS's in (Heterotic) Strings
- Vertex Operators, BRS conditions, Supermultiplets
  - BPS states with charge and spin
  - First Massive Level
  - Second Massive Level
  - Tri-linear couplings
- Scattering Amplitudes and (Pair) Production
  - 2 vector bosons - 2 small BPS BH's ('hidden'/'visible')
  - 2 gravitons - 2 small BPS BH's
- Cross Sections
  - Energy and Angular distributions
  - Caveat / comments on LED scenari
- Conclusions and Outlook

# BH production and decay in High Energy collisions

LED scenari $M_{Pl} = M_d (M_d L)^{d-4}$, $M_d << M_{Pl}$ for $L >> 1/M_d$

For large BH's with $M_{BH} >> M_d$, partonic cross-section

$$\sigma_{ij \to BH}(s) = \mathcal{F}_d(s) \left[ \sqrt{s} / M_d^{d-2} \right]^{\frac{2}{d-3}}$$

For small BH's need (acrobatic) extrapolation or ... String Theory

At colliders, expect BH production for $b < R_H(E, J)$ [Thorne; ...]

Spectacular Experimental Signatures for $M_d \approx 1 TeV$

[Giudice, Rattazzi, Wells; Giddings, Thomas; Dimopoulos, Landsberg; Maede, Randall; Kanti ...]

- Very large cross sections, LHC rates up to 1 Hz
- Growth with Energy (!?) of parton cross sections
- Large multiplicities, high sphericity
- Suppression of hard processes for $E$ above threshold

... Self-completeness of (non)-perturbative (Super) Gravity?

[Bern, Dixon, ...; MB, Ferrara, Kallosh; Dvali, Gomez; ...]

# BPS BH's and Higher Spins in Heterotic Strings

BH's solutions in String Theory:

- Large BH's, finite-area horizon in sugra approximation
- Small BH's, zero-area horizon in sugra approximation

Fundamental strings correspond to small BH's.
Heterotic strings on $T^6$ tori: $\mathcal{N} = 4$ in $D = 4$
Perturbative spectrum, level matching [Narain, Sarmadi, Witten; ...]
$4(N_L - \delta_L) + \alpha' |\mathbf{p}_L|^2 = \alpha' M^2 = 4(N_R - 1) + \alpha' |\mathbf{p}_R|^2$
6 'central' charges $\mathbf{p}_L$, 22 'matter' charges $\mathbf{p}_R$, *i.e.* $\mathbf{Q} = (\mathbf{m}, \mathbf{n}, \mathbf{r})$
only massless, 1/2 BPS and long mltp's. [For 1/4 BPS need $\mathbf{P} \neq 0$]
$\mathbf{Q} \cdot \mathbf{Q} = \frac{\alpha'}{2} |\mathbf{p}_L|^2 - \frac{\alpha'}{2} |\mathbf{p}_R|^2 = 2\mathbf{mn} - |\mathbf{r}|^2 = 2(N_R - 1) - 2(N_L - \delta_L)$
1/2 BPS states:
$N_L = \delta_L$, $M^2_{BPS} = |\mathbf{p}_L|^2 \rightarrow \mathbf{Q} \cdot \mathbf{Q} \geq -2$, $J \leq N_R + 1$
$\mathbf{Q} \cdot \mathbf{Q} < -2 \rightarrow$ non-BPS, yet 'extremal' if $M^2 = |\mathbf{p}_R|^2$
At fixed $M_{Pl}$, $M_s = g_s^{(4)} M_{Pl} \rightarrow 0$ for $g_s^{(4)} \rightarrow 0$ (boundary) !

# (Thermo)statical properties

For 'large' charges, neglecting spin$^\dagger$

$$d^{Het}_{1/2BPS}(N_R) \approx \exp(4\pi\sqrt{N_R}) = \exp S^{Wald}_{BH}$$

$S^{Macro}_{BH} = S^{micro}_{BH}$, 'mini BH's' with two charges, horizon stretched by higher curvature $\alpha'$ corrections* [Sen; Dabholkar; Kallosh, Maloney; Prester; ...]

Yet $T_{BH} = 0$ for all 'extremal' (NOT necessarily BPS) BH's $\rightarrow$ NO Hawking radiation.

For $J^{Max} > 1$, 1/2 BPS HS multiplets with $(2J+1)(8_B - 8_F)$ states:

$$\{(J+1), 4(J+\frac{1}{2}), 6(J), 4(J-\frac{1}{2}), (J-1)\} \quad SO(6) \rightarrow SO(5)$$

In $D = 4$, susy incompatible with horizon 'rotation' [Cvetic, Youm; Peet; ...]

... (in)stability of HS BPS states?

$^\dagger$ otherwise $C_R = 24 \rightarrow C_R = 21$, yet helicity Str's $\mathcal{B}^{(J)}_4 = (2J+1)\mathcal{B}^{(0)}_4$

*absent in $\mathcal{N} = 8, 6, 5$ SUGRA's IF UV finite [Bern, Dixon, ...; MB, Ferrara, Kallosh]

# (Thermo) Dynamical Properties

- For near-extremal BH's, $T_{BH} \neq 0$: gray-body factor, Hawking radiation [Callan, Maldacena; Hashimoto, Klebanov; Garousi, Myers; ...]
- Dynamics of very massive string states [Iengo, Russo; Chialva; ...]
- Size and energy distribution, string/BH form factors [Cornalba, Costa, Penedones, Vieira; Chialva; ...]
- Production of massive string states at colliders in un-oriented brane worlds [Dudas, Mourad; MB, Santini; Anchordequoi, Goldeberg, Lüst, Nawata, Schlotterer, Stieberger, Taylor; ...]
- BH S-matrix [Veneziano, Wosiek; ...], High Energy collisions [Amati, Ciafaloni, Veneziano; Gross, Mende],
- Our aim here: pair production of small charged BPS BH's [Gingrich; ...; MB, Lopez] and BPS HS states [wip] in Heterotic Strings ...
- CAVEAT: Mass scales and Large Extra Dimensions

# Mass scales and Large Extra Dimensions

In Heterotic Strings $g_s^2/\hat{V}_{int} = g_{_{YM}}^2$ so that

$$M_s^2 = g_{YM}^2 M_{Pl}^2$$

To have $M_{BH} \sim M_s \sim TeV$, need implausibly small gauge coupling $g_{_{YM}} \sim 10^{-15} \rightarrow$ very difficult to accommodate LED.
In theories with open and un-oriented strings $g_s \hat{V}_\perp / \hat{V}_{T^6} = g_{YM}^2$ with $\hat{V}_\perp$ volume of internal space transverse to 'visible' D-branes

$$M_s^2 = g_{YM}^4 M_{Pl}^2 \frac{\hat{V}_{int}^2}{\hat{V}_\perp^2}$$

compatible with reasonably small $g_{_{YM}}$, low string scale (*i.e.* BH or HS masses) and large extra (transverse) directions. BH's as bound-states of D-branes, dynamical properties more involved!

# Vertex Operators and BRST invariance

Two-charge massive 1/2 BPS states in NS sector ($N = 0, ..9$)

$$V^{(-1)}_{1/2BPS} = \Phi^{(N_R)}_{N,A_1 \ldots A_n} e^{-\varphi} \psi^N e^{i\mathbf{p}_L \mathbf{X}_L} \prod_{r=1}^{n} \bar{\partial}^{\ell_r} X^{A_r} e^{i\mathbf{p}_R \mathbf{X}_R} e^{ip\cdot X}$$

with $p^2 = -M^2 = -|\mathbf{p}_L|^2$ and $\Phi^{(N_R)}[\bar{\partial}^{\ell} X^A]$ polynomial of degree $N_R = \Sigma_r \ell_r = 1 + \mathbf{nm} - \frac{1}{2}|\mathbf{r}|^2$ in derivatives of R-moving (internal) bosonic coordinates $A = 0, \ldots 25$ ($A \to \mu, i, a$)

$$J = J_L + J_R \qquad J^{Max}_R = N_R \qquad J^{Max}_{L,1/2BPS} = 1$$

Further BRST conditions (schematically)

$$P^M_L \Phi^{(N_R)}_{M,A_1 \ldots A_n} = 0 \qquad P^{A_r}_R \Phi^{(N_R)}_{M,A_1..A_r..A_n} = 0 \quad \forall r$$

$$\eta^{A_r A_s} \Phi^{(N_R)}_{M,A_1..A_r..A_s..A_n} = 0 \quad \forall r, s$$

# (No) tri-linear amplitudes among 1/2 BPS states

$$V^{(-1)}_{1/2BPS} = A_M \psi^M e^{-\varphi} e^{iPX} V_{_R}$$

where $\psi^M = (\psi^\mu, \psi^i)$ and $V_{_R}$ Right-moving part (bosonic string)

$$P^2 = 0 = p^2 + |p_{_L}|^2 \qquad P^M A_M = p^\mu a_\mu + p^i_{_L} \phi_i = 0$$

*i.e.* Left-moving part identical to massless in $D = 10$.

$$G_{_L}(z_1, z_2, z_3) = \langle c V^{(-1)}_{_L}(z_1) c V^{(0)}_{_L}(z_2) c V^{(-1)}_{_L}(z_3) \rangle$$

where $V^{(0)}_{_L}(z) = A_M(\partial X^M + iP\psi\psi^M)e^{iPX}$. Contractions yield

$$G_{_L} = [A_1(P_2 - P_3)A_2 A_3 + A_2(P_3 - P_1)A_3 A_1 + A_3(P_1 - P_2)A_1 A_2]\delta(\sum_i P_i)$$

independent of $z_i$, totally anti-symmetric and vanishing on-shell.

# First massive level, NS sector (Left-movers)

$$V_H = H_{(MN)|}[\partial X^M \partial X^N + iP\psi\psi^M \partial X^N + \psi^M \partial \psi^N] e^{iPX}$$

massive spin 2, 44 physical polarizations and

$$V_C = C_{[LMN]}(\partial X^L + iP\psi\psi^L)\psi^M \psi^N e^{iPX}$$

massive 3-form, 84 physical polarizations
Altogether 128 bosonic and as many fermionic dof's ($256 = 2^8$)
Tri-linear couplings = Physical (Left-moving) Amplitudes

$$G_L^{HAA} = H_{MN} F_1^{ML} F_{2L}^N \quad \text{with} \quad F_{MN} = P_M A_N - P_N A_M$$

and

$$G_L^{CAA} = (P_1 - P_2)^L A_1^M A_2^N C_{LMN}$$

both symmetric under 1-2 exchange and gauge invariant

$$\psi^i_{-3/2}|0\rangle \longrightarrow 8 = \yng(1)$$

$$\alpha^i_{-1}\psi^j_{-1/2}|0\rangle \longrightarrow 64 = \bullet + \yng(2) + \yng(1,1)$$

$$\psi^i_{-1/2}\psi^j_{-1/2}\psi^k_{-1/2} \longrightarrow 56 = \yng(1,1,1)$$

| d.o.f | $SO(9)$ | $SO(8)$ |
|---|---|---|
| 84 | $\yng(1,1,1)$ | $\yng(1,1,1) + \yng(1,1)$ |
| 44 | $\yng(2)$ | $\bullet + \yng(1) + \yng(2)$ |

Table: First massive level (NS sector), SO(9) irreps

# Second massive level, NS sector (Left-movers)

$$\psi^i_{-5/2}|0\rangle \longrightarrow 8 = \yng(1)$$

$$\alpha^i_{-1}\psi^j_{-3/2}|0\rangle \longrightarrow 64 = \bullet + \yng(2) + \yng(1,1)$$

$$\alpha^i_{-2}\psi^j_{-1/2}|0\rangle \longrightarrow 64 = \bullet + \yng(2) + \yng(1,1)$$

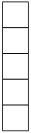
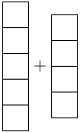
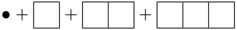
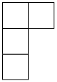
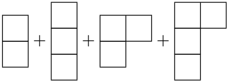
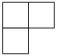
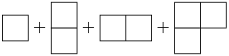
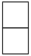
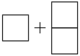
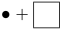
$$\psi^i_{-3/2}\psi^j_{-1/2}\psi^k_{-1/2}|0\rangle \longrightarrow 224 = \yng(1) + \yng(1,1,1) + \yng(2,1)$$

$$\alpha^i_{-1}\alpha^j_{-1}\psi^k_{-1/2}|0\rangle \longrightarrow 288 = \yng(1) + \yng(3) + \yng(2,1)$$

$$\alpha^i_{-1}\psi^j_{-1/2}\psi^k_{-1/2}\psi^l_{-1/2}|0\rangle \longrightarrow 448 = \yng(1,1) + \yng(1,1,1,1) + \yng(2,1,1)$$

$$\psi^i_{-1/2}\psi^j_{-1/2}\psi^k_{-1/2}\psi^l_{-1/2}\psi^m_{-1/2}|0\rangle \longrightarrow 56 = \yng(1,1,1,1,1)$$

# Second massive level, $SO(9)$ decomposition

| d.o.f | $SO(9)$ | $SO(8)$ |
| --- | --- | --- |
| 126 |  |  |
| 156 |  |  |
| 594 |  |  |
| 231 |  |  |
| 36 |  |  |
| 9 |  |  |

## Second massive level (Left-Movers), BRS conditions

$$P^L A_{[LMNPQ]} + E_{[MNPQ]} = 0$$

$$iP^N E_{M[NPQ]} + S_{(M[P)Q]} + C_{M[PQ]} = 0$$

$$iP^Q C_{M[PQ]} + M_{MP} + 2L_{PM} = 0$$

$$iP^M C_{M[PQ]} + 2L_{[PQ]} + \eta^{MN} E_{M[NPQ]} = 0$$

$$iP^Q S_{(MP)Q} + M_{(MP)} = 0$$

$$iP^N L_{MN} = 0$$

$$W_M + iP^N M_{MN} + \eta^{PQ} S_{(MP)Q} = 0$$

$$2iP^M W_M + \eta^{MN} M_{MN} - 2\eta^{MN} L_{MN} = 0$$

# Second massive level (Left-Movers), Vertex operators

$$S^{(156)}_{(MNP)|}(\partial X^M \partial X^N \psi^P + \ldots) e^{-\varphi} e^{iPX}$$

$$A^{(126)}_{[MNPQR]} \psi^M \psi^N \psi^P \psi^Q \psi^R e^{-\varphi} e^{iPX}$$

$$E^{(594)}_{(M[N)PQ]}(\partial X^M \psi^N \psi^P \psi^Q + \ldots) e^{-\varphi} e^{iPX}$$

$$C^{(231)}_{(M[N)P]}(\partial \psi^M \psi^N \psi^P + \ldots) e^{-\varphi} e^{iPX}$$

$$B^{(36)}_{[MN]}(\partial \psi^M \partial X^N + \ldots) e^{-\varphi} e^{iPX}$$

$$V^{(9)}_M (\partial^2 \psi^M + \ldots) e^{-\varphi} e^{iPX}$$

# R-movers 3-point couplings

For totally symmetric traceless tensors $H^i_{(A_1 \dots A_{s_i})|}$ (not necessarily first Regge trajectory) with $t_i$ such that $\sum_i s'_i$ even, $s'_i = s_i - t_i$

$$G_R = \sum_{t_i \leq s_i} \sqrt{\alpha'}^{\sum_i t_i} \prod_i \binom{s_i}{t_i} \binom{s_i - t_i}{s'_{i,i+1}} P_{23}^{A_1} \dots P_{23}^{A_{t_1}} H^1_{A_1 \dots A_{t_1}}{}^{D_1 \dots D_{s'_{31}}}{}_{F_1 \dots F_{s'_{12}}}$$

$$P_{31}^{B_1} \dots P_{31}^{B_{t_2}} H^2_{B_1 \dots B_{t_2}}{}^{F_1 \dots F_{s'_{12}}}{}_{E_1 \dots E_{s'_{23}}} P_{12}^{C_1} \dots P_{12}^{C_{t_3}} H^3_{C_1 \dots C_{t_3}}{}^{E_1 \dots E_{s'_{23}}}{}_{D_1 \dots D_{s'_{31}}}$$

with $s'_{ij} = (s'_i + s'_j - s'_k)/2$ and $P^A_{ij} = P^A_i - P^A_j$, (anti)symmetric under exchange of two identical vertex operators (say 1 and 2), for $s_3$ even (odd)

For non-abelian current algebras

at $N_R = 1$ currents $J^a$ yield $f_{abc} = Tr(T_a[T_b, T_c])$

at $N_R = 2$ primary $H_a = d_{abc} J^b J^c$ with $d_{abc} = Tr(T_a\{T_b, T_c\})$, symmetric coupling to two currents, similar to open strings

# Amplitudes for scalar mini BH's

Tree level amplitudes for pair production of charged scalar BH's

$$\mathcal{A}_{vv\to\Phi\bar{\Phi}} = \int d^2z \langle V_\Phi(p_1) V_v(k_2; a_2) V_v(k_3; a_3) V_{\bar{\Phi}}(p_4)\rangle$$

$$\mathcal{M}_{hh\to\Phi\bar{\Phi}} = \int d^2z \langle V_\Phi(p_1) V_h(k_2; h_2) V_h(k_3; h_3) V_{\bar{\Phi}}(p_4)\rangle$$

$V_v$, $V_h$, $V_\Phi$, $V_{\bar{\Phi}}$ vertex operators for vector bosons, gravitons and small BPS BH's. Relevant integrals ($\alpha' = 2$)

$$\mathcal{I}(a, n, b, m) = \int d^2z |z|^a |1 - z|^b z^n (1 - z)^m$$

produce Shapiro-Virasoro-like 'form factors'

$$\mathcal{F}_{SV} = \frac{\Gamma(1 + k_2 k_3)\Gamma(k_2 p_1)\Gamma(k_2 p_4)}{\Gamma(2 - k_2 k_3)\Gamma(-k_2 p_1)\Gamma(-k_2 p_4)}$$

up to rational function of p's

# Three simple cases with $N_R = 2$

- 2 Vectors - 2 small BH amplitude: mutually neutral case
- 2 Vectors - 2 small BH amplitude: mutually charged case
- 2 Gravitons - 2 small BH amplitude

# 2 Vectors - 2 small BH: mutually neutral case

Small BH's charged wrt $U(1)^6$ ('hidden' gauge group) but neutral wrt to G ('visible' non-abelian gauge group) of the incoming gauge bosons

$$\mathcal{A}^{ij,a,b,kl}_{vv\to\Phi\bar{\Phi}}(p_i) = \frac{6g^2_{YM}}{M_s^2}(2\pi)^4\delta(\Sigma_i p_i)(\tilde{a}_2\tilde{a}_3)\mathcal{F}_{SV} F \delta^{ik}_{\perp}\bar{\delta}^{jl}_{\perp}\delta^{ab}$$

$\delta^{ik}_{\perp} = \delta^{ik} - p^i_L p^k_L/M^2$, $\bar{\delta}^{jl}_{\perp} = \delta^{jl} - p^j_R p^l_R/|\mathbf{p}_R|^2$
$F = (k_2 p_1)(k_3 p_1)/(k_2 k_3)$ ubiquitous kinematical factor
$\tilde{a}_i = a_i - (p_4 a_i/p_4 k_i)k_i$ manifestly gauge invariant
'Formal' field theory limit $\alpha' \to 0$ ($M_s \to \infty$) with fixed $M$,
$\mathcal{F}_{SV} \to 1$: graviton exchange, suppressed by $g^2_{YM}/M_s^2 \sim 1/M^2_{Pl}$

## 2 Vectors - 2 small BH: mutually charged case

Small BH's charged wrt to incoming gauge bosons (G group)

$$\mathcal{A}^{ika,b,c,jld}_{vv\to\Phi\bar{\Phi}}(p_i) = \frac{g^2_{YM}}{M_s^2}(2\pi)^4\delta(\Sigma_i p_i)\delta^{ij}_{\perp}\bar{\delta}^{kl}_{\perp}(\tilde{a}_2\tilde{a}_3)F\mathcal{F}_{\mathcal{SV}}\mathcal{I}$$

where

$$\mathcal{I} = \Big\{ T_{13}T_{24} + 2T_{[13][24]} + \frac{2(2+\alpha' k_3 p_4)}{\alpha' k_3 p_1}[T_{13}T_{24} + T_{[13][24]}] + \frac{(4+\alpha' k_3 p_4)(2+\alpha' k_3 p_4)}{\alpha' k_3 p_1(2-\alpha' k_3 p_1)} T_{13}T_{24} + (2\leftrightarrow 3)\Big\} + T_{14}T_{23}$$

with $T_{ij} = tr(T_{a_i}T_{a_j})$ and $T_{[ij][kl]} = tr([T_{a_i}, T_{a_j}][T_{a_k}, T_{a_l}])$
'Formal' field theory limit $\alpha' \to 0$ ($M_s \to \infty$) with fixed $M$, $\mathcal{F}_{SV} \to 1$, only terms with 'poles' survive, SYM theory result.
Relative suppression $\mathcal{A}_{neutral}/\mathcal{A}_{charge} \sim 1/M_s^2$.

## 2 Gravitons - 2 small BH's

Use 'factorized' graviton polarization tensors $h^{(2\lambda)}_{\mu\nu} = a^{(\lambda)}_{\mu} a^{(\lambda)}_{\nu}$
$\mathcal{M}^{ij,kl}_{hh\to\Phi\bar{\Phi}}(p_i) = 6 \cdot \frac{16\pi}{M^2_{Pl}}(2\pi)^4\delta(\Sigma_i p_i)\mathcal{F}_{SV} F \delta^{ik}_{\perp}\bar{\delta}^{jl}_{\perp}\left[(\tilde{h}_2\tilde{h}_3) + \mathcal{H}\right]$
where $\tilde{h}_{i\mu\nu} = \left(\delta_{\mu}{}^{\rho} - \frac{k_{i\mu}p_4^{\rho}}{p_4 k_i}\right)\left(\delta_{\nu}{}^{\sigma} - \frac{k_{i\nu}p_4^{\sigma}}{p_4 k_i}\right) h_{\rho\sigma}$ manifestly gauge invariant and $\mathcal{H}$ higher-derivative $\alpha'$ corrections

$$\mathcal{H} = \frac{\alpha'}{2}\left\{-(k_2k_3)(\tilde{h}_2\tilde{h}_3) + (k_2k_3)(h_2h_3) - (k_3h_2h_3k_2) + \left[\frac{(k_2k_3)(p_1h_2h_3p_4) - (p_4h_3k_2)(p_1h_2k_3)}{k_3p_4} + (2\leftrightarrow 3)\right]\right\}$$

'Formal' field theory limit $\alpha' \to 0$, $\mathcal{F}_{SV} \to 1$, gravitational amplitude $\tilde{h}_2\tilde{h}_3 \sim$ square of gauge theory amplitude $\tilde{a}_2\tilde{a}_3$ [Kawai, Lewellen, Tye; Choi, Shim, Song; ...]

Again relative suppression $\mathcal{M}/\mathcal{A}_{charge} \sim 1/M_s^2$

# Differential Cross Section

Average over initial helicities and sum over final scalar BH states get differential cross section for the charged case

$$\frac{d\sigma}{d\Omega} = \frac{3g_{YM}^4 d(N_R)^2}{(8\pi)^4 M_s^2}\sqrt{1-\mu^2}\left[(1-\mu^2)^2(1-x^2)^2+\mu^4\right]\langle\mathcal{I}^2\rangle_c$$

$$\frac{\hat{s}^3 \sin^2(\pi\hat{s})}{(1+\hat{s})^2}\left|\sum_{n=0}^{\infty}\frac{\mathcal{R}_n(\hat{s})}{(a_n+bx)}\right|^2\left|\sum_{k=0}^{\infty}\frac{\mathcal{R}_k(\hat{s})}{(a_k-bx)}\right|^2$$

$\hat{w}=\alpha' w/4$, $\mu = M/E \leq 1$, $a_n = n+\hat{s}/2$, $b=(\hat{s}/2)\sqrt{1-\mu^2}$,
$\mathcal{R}_n(w) = (-1)^n(w-1)\ldots(w-n)/n!$, $x=\cos\theta$.

- Threshold at $\mu = 1$
- Modulation by the Regge poles, *i.e.* string excitations
- NO (significant) growth with energy, Regge behaviour (exponentially suppressed) in UV!

# Conclusions and Outlook

- Huge suppression of processes mediated by gravitons, but relative suppression wrt 'charged' ones $\sim 1/M_s^2$
- Regge poles and soft UV behaviour rather than growth with CM Energy
- 1/2 BPS HS states look perturbatively stable ... may need to reconsider microscopic derivation of BH Entropy
- Similar results for FHSV model with $\mathcal{N} = 2$ ($Z_2$ shift-orbifold)
- Extremal (and thus charged) non BPS: similar story (stable)
- Non-extremal: M and S depend on $g_s$ and moduli ... further dynamical test for string/BH correspondence principle
- Very difficult to accommodate LED and low string tension in Heterotic Strings, yet ... Local GUTs and Heterotic Landscape [H. P. Nilles, M. Ratz, ...] or add NS5-branes [I. Antoniadis, K. Benakli, ...]