HIGGS PRODUCTION AND DECAY FROM TEV SCALE BLACK HOLES AT LHC [a]

ARIF EMRE ERKOCA

(University of Arizona)

- We propose that the shape of the transverse momentum distributions of particles at large p_T at the LHC can be used as a signal for the black hole production.
- We find that in pp collisions the black hole production enhances the chance of detecting the Higgs boson.

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[a] Erkoca, Nayak and Sarcevic, **Phys.Rev.D 79, 094011 (2009)**

OUTLINE

- Introduction
- Properties of Higher Dimensional Mini-Black Holes
- Particle Emission From Black Holes
- Cross Sections of Decay Products of Higgs emitted from Black Holes
- Parametrization
- Results

A Brief Introduction and Overview

- Hierarchy Problem

$$M_{Pl} \sim 10^{16} TeV \quad M_{EW} \sim 1 TeV$$

- can be solved by assuming the existence of extra dimensions in the Universe [a].

$$M_{Pl}^2 \sim M_P^{2+n} R^n$$

- If $M_P = 1$TeV and n is ranging from 2 to 7, R extends from 1 mm to 1 fm. Then, in the pp collisions if the impact parameter, $b \leq R_{BH} \ll R$, the black hole production becomes possible.
- Decay by Hawking radiation; emission of elementary particles with rest mass less than T_{BH}.

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[a] Nima Arkani-Hamed et al., Phys. Lett. B, 429(1998)

Properties of Higher-Dimensional Mini Black Holes [a]

- **Larger, colder and live longer compared to 4-D ones with the same mass.**

$$R_{BH} = \frac{1}{\sqrt{\pi} M_P} \left(\frac{M_{BH}}{M_P} \right)^{\frac{1}{n+1}} \left(\frac{8\Gamma\left(\frac{n+3}{2}\right)}{n+2} \right)^{\frac{1}{n+1}}$$

$$T_{BH} = \frac{n+1}{4\pi R_{BH}}$$

$$\tau_{BH} = \frac{1}{M_P} \left(\frac{M_{BH}}{M_P} \right)^{\frac{n+3}{n+1}}$$

Table 1: Black Hole radius and temperature for different values of n

n	1	2	3	4	5	6	7
$R_{BH}(10^{-4} fm)$	**4.06**	**2.63**	**2.22**	**2.07**	**2.00**	**1.99**	**1.99**
$T_{BH}(GeV)$	**77**	**179**	**282**	**379**	**470**	**553**	**629**

[a] P.Kanti,Int.J.Mod.Phys. A 19(2004)4899

- Emission depends on the spin, energy of the emitted particles and the dimensionality of spacetime.

$$\frac{dN}{dt} = \sigma(w) \frac{1}{exp(\omega/T_{BH}) \pm 1} \frac{d^{n+3}k}{(2\pi)^{n+3}}$$

$$\frac{dE}{dt} = \sigma(w) \frac{\omega}{exp(\omega/T_{BH}) \pm 1} \frac{d^{n+3}k}{(2\pi)^{n+3}}$$

  where $\sigma(w)$ is the greybody factor due to the traversing of the emitted particle through a strong gravitational field before reaching the observer; depends on the energy of the particle, its spin s and the number of extra dimensions, n.

- Greybody factor for scalar fields decreases as n increases; while the ones for fermions and gauge bosons are enhanced up to intermediate energies and also decrease at high energies.

- high energy limit :

$$\sigma = \pi \frac{n+3}{n+1} \left(\frac{n+3}{2} \right)^{\frac{2}{n+1}} R_{BH}^2$$

Particle Emission From Black Holes

$$E\frac{d\sigma}{d^3p} = \frac{1}{(2\pi)^3}\sum_{a,b}\int_{(M_{BH}^{min})^2}^{s}\frac{dM_{BH}^2}{s}\int_{\frac{M_{BH}^2}{s}}^{1}\frac{dx_1}{x_1}f_a(x_1,Q^2)\hat{\sigma}f_b(x_2,Q^2)\frac{gp^\mu u_\mu\sigma\gamma\tau_{BH}}{exp(\frac{p^\mu u_\mu}{T_{BH}})\mp 1}$$

where $\hat{\sigma}$ is the parton level black hole production cross section, σ is the greybody factor, f_a and f_b's are the parton distribution functions, x_1 and x_2 are the momentum fractions of the colliding partons which satisfy $x_1x_2s = M_{BH}^2$, $\sqrt{s}$ is the center of mass energy of the colliding hadrons, M_{BH}^{min} is the minimum black hole mass, τ_{BH} is the decay time of black hole, γ is the Lorentz factor, g is the internal degrees of freedom, and p^μ is the four momentum of the emitted particle and u^μ is the four velocity of the black hole. Hence,

$$E\frac{d\sigma}{d^3p} = \frac{d\sigma}{2\pi p_T dp_T dy}$$

Assumptions

- $\hat{\sigma} \sim \pi R_{BH}^2$
- **Stationary Black Holes**
- **geometric optics limits for greybody factors**

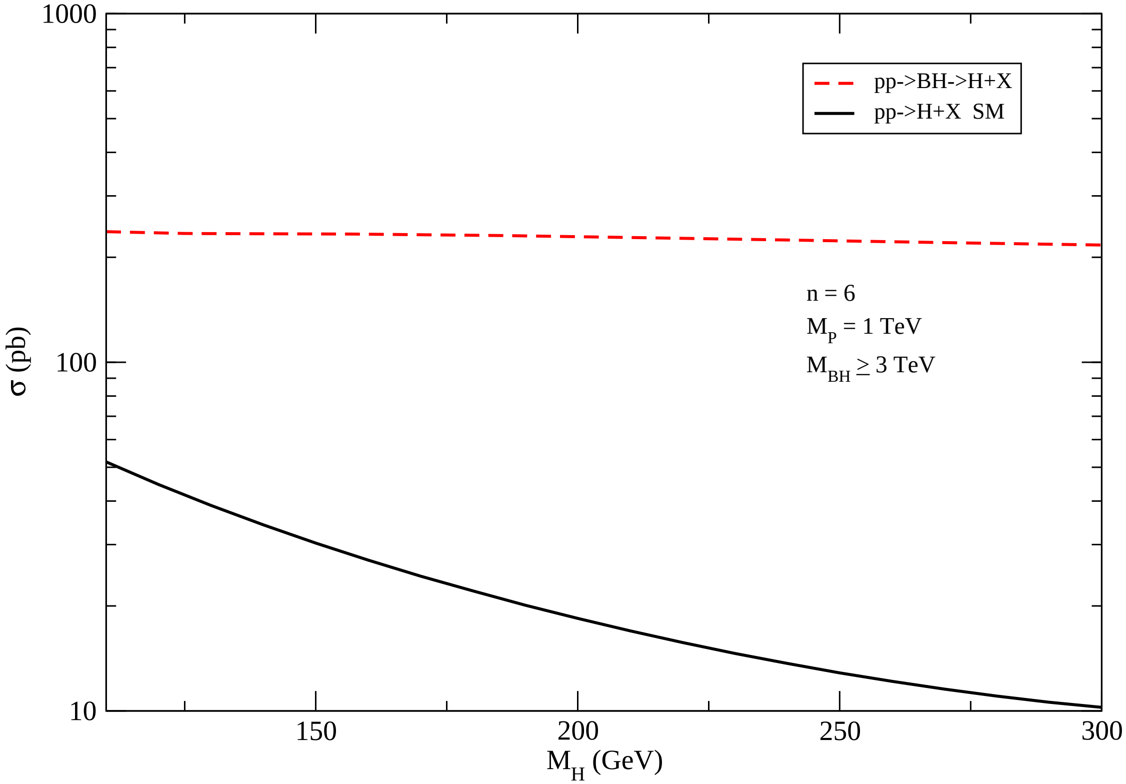

Figure 1: Total production cross section for Higgs from black holes at LHC compared with the standard model prediction

V. Ravindran, J. Smith and W. L. van Neerven, Nucl. Phys. B 665, 325 (2003).

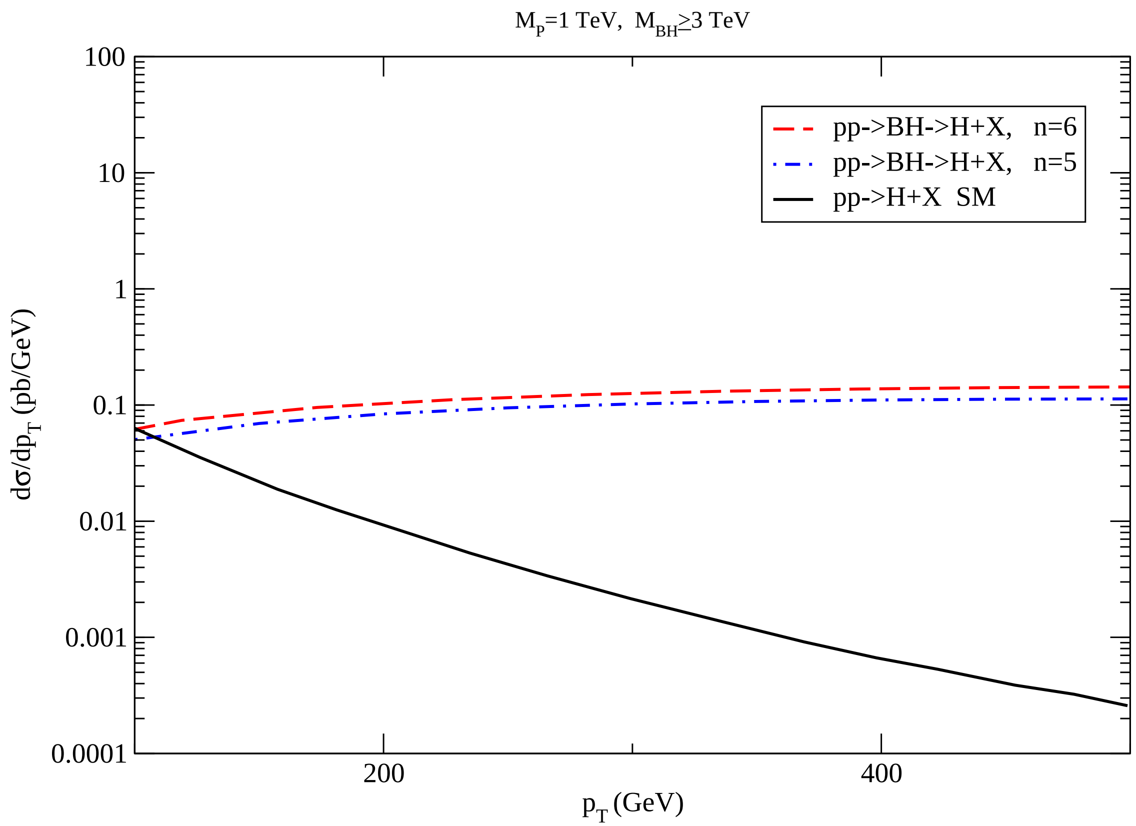

Figure 2: Transverse momentum distribution for the production cross section of Higgs from black holes at LHC compared with the standard model prediction

V. Ravindran, J. Smith and W. L. van Neerven, Nucl. Phys. B 634, 247 (2002).

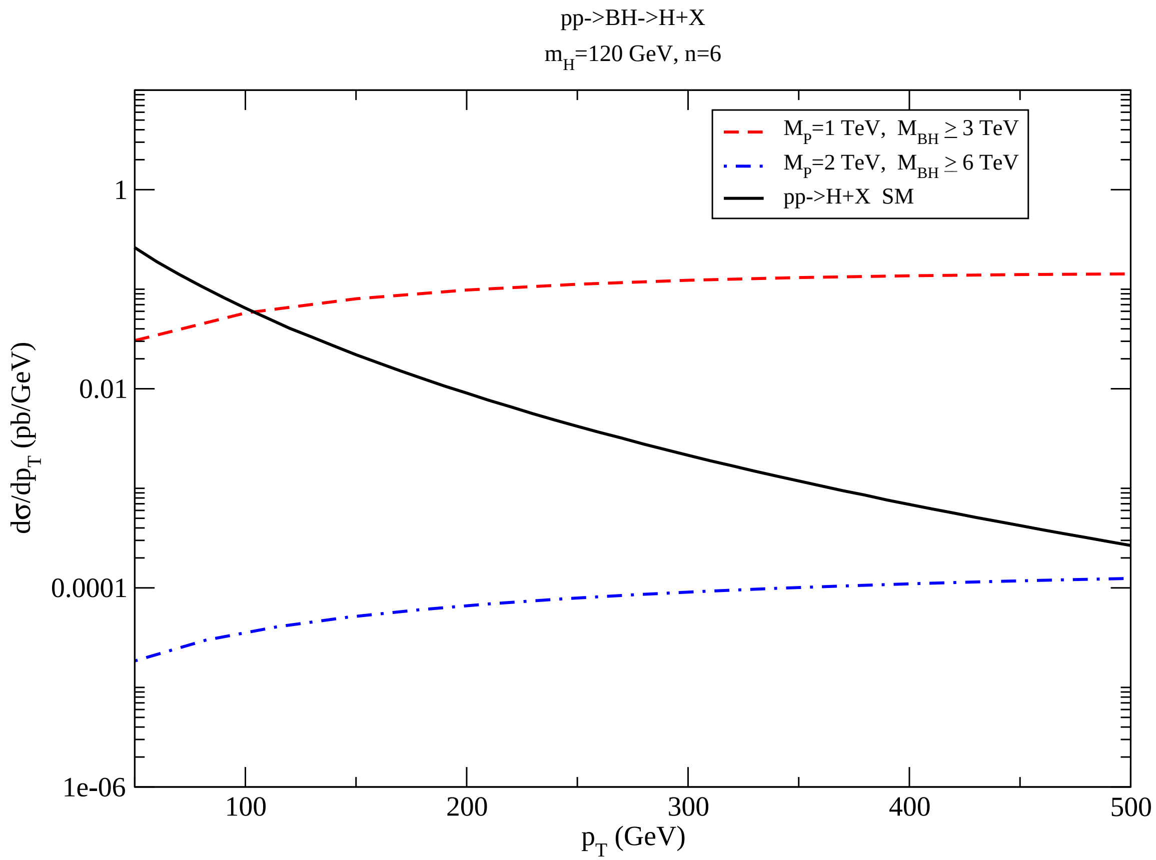

Figure 3: Transverse momentum distribution for the production cross section of Higgs from black holes for different Planck scales and minimum black hole masses at LHC

Cross Sections of Decay Products of Higgs emitted from Black Holes

$$E_1 E_2 \frac{d\sigma}{d^3p_1 d^3p_2} = \int \frac{d^3p}{E} \left(E \frac{d\sigma}{d^3p} \right)_{BH \to H} \left(\frac{B}{\Gamma} E_1 E_2 \frac{d\Gamma}{d^3p_1 d^3p_2} \right)_{H \to 1+2}$$

where Γ is the decay rate, B is the decay branching fraction, subscripts 1 and 2 refer to the decay products, E and $p = |\vec{p}|$ are the energy and the momentum of the Higgs boson, respectively ($E = \sqrt{p^2 + m_H^2}$).

$$E_1 \frac{d\sigma}{d^3p_1} = \frac{B}{p_1 \sqrt{1 - 4m^2/m_H^2}} \int_{E_{min}}^{E_{max}} \left(E \frac{d\sigma}{d^3p} \right)_{BH \to H} dE$$

where m is the mass of the decay product of Higgs,

$$E_{min} = \left(\frac{E_1 - p_1 \sqrt{1 - 4m^2/m_H^2}}{2} \right) (\frac{m_H}{m})^2$$

$$E_{max} = \left(\frac{E_1 + p_1 \sqrt{1 - 4m^2/m_H^2}}{2} \right) (\frac{m_H}{m})^2$$

Pair Production from Higgs from Black Holes

Using new variables

$$Q^\mu = p_1^\mu + p_2^\mu \quad \text{and} \quad 2k^\mu = p_1^\mu - p_2^\mu,$$

we find

$$Q^0 \frac{d\sigma}{d^3Q} = B \left(E \frac{d\sigma}{d^3p} \right)_{BH \to H} .$$

So, the cross section for the pair produced by the decay of Higgs emitted from black holes is simply the cross section of Higgs from black holes multiplied by the decay branching fraction.

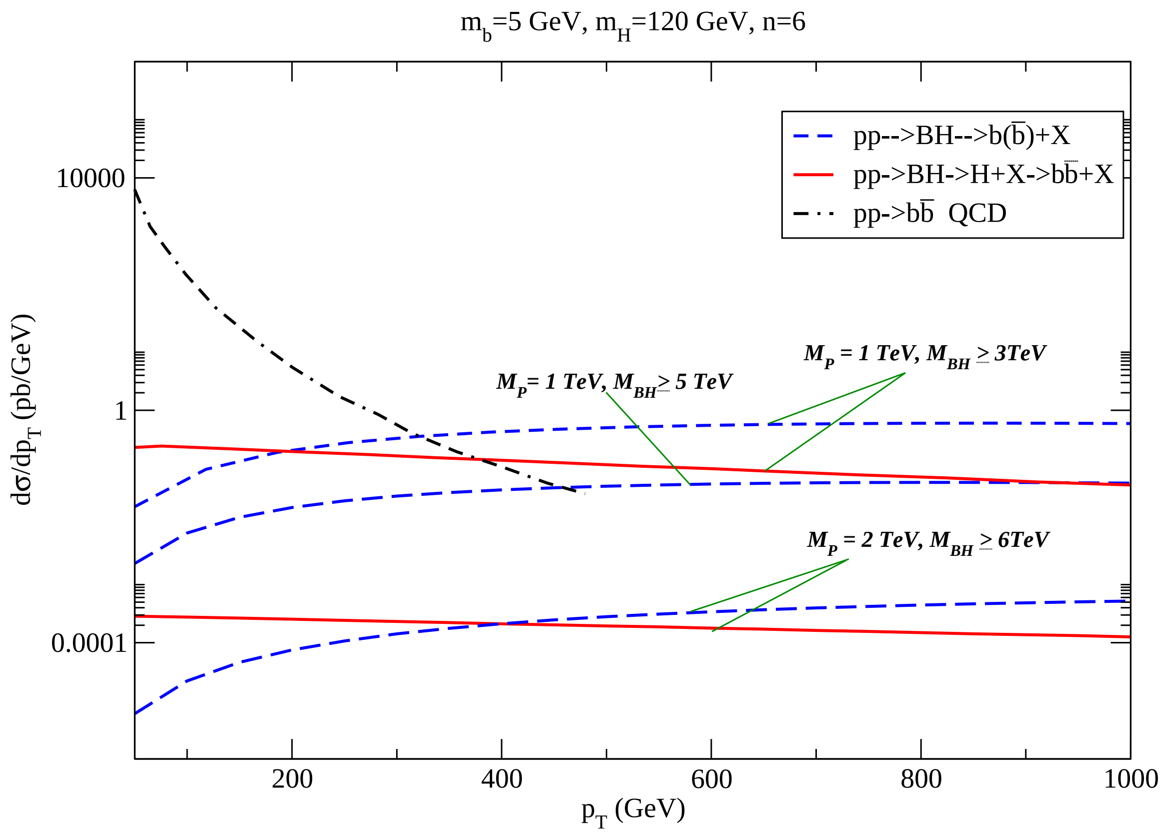

Figure 4: Transverse momentum distribution for b quark production cross section from black holes at different M_P and minimum black hole masses at LHC.

P. Nason et al., hep-ph/0003142.

Parametrization :

- For direct production from black holes

$$\frac{1}{g}\frac{d\sigma}{dp_T} = A_0 + A_1 \times p_T + A_2 \times p_T^2$$

set 1 : $p_T < 500$ GeV, set 2 : $p_T > 500$ GeV

- bosons set 1:

$$A_0(pb/GeV) = 1.823 \times 10^{-2}, \quad A_1(pb/GeV^2) = 5.425 \times 10^{-4},$$

$$A_2(pb/GeV^3) = -5.786 \times 10^{-7}$$

bosons set 2:

$$A_0(pb/GeV) = 1.358 \times 10^{-1}, \quad A_1(pb/GeV^2) = 6.185 \times 10^{-5},$$

$$A_2(pb/GeV^3) = -7.318 \times 10^{-8}$$

- fermions set 1:

$$A_0(pb/GeV) = -1.56 \times 10^{-2},\ A_1(pb/GeV^2) = 2.903 \times 10^{-4},$$

$$A_2(pb/GeV^3) = -1.819 \times 10^{-7}$$

fermions set 2:

$$A_0(pb/GeV) = -1.54 \times 10^{-2},\ A_1(pb/GeV^2) = 2.755 \times 10^{-4},$$

$$A_2(pb/GeV^3) = -1.63 \times 10^{-7}$$

- For $pp \longrightarrow BH \longrightarrow H + X \longrightarrow 12 + X$

$$\frac{1}{B}\frac{d\sigma}{dp_T} = A_0 + A_1 \times p_T + A_2 \times p_T^2$$

When $p_T < 1TeV$,

$$A_0(pb/GeV) = 3.899 \times 10^{-1},\ A_1(pb/GeV^2) = -5.648 \times 10^{-4}$$

$$A_2(pb/GeV^3) = 2.541 \times 10^{-7}$$

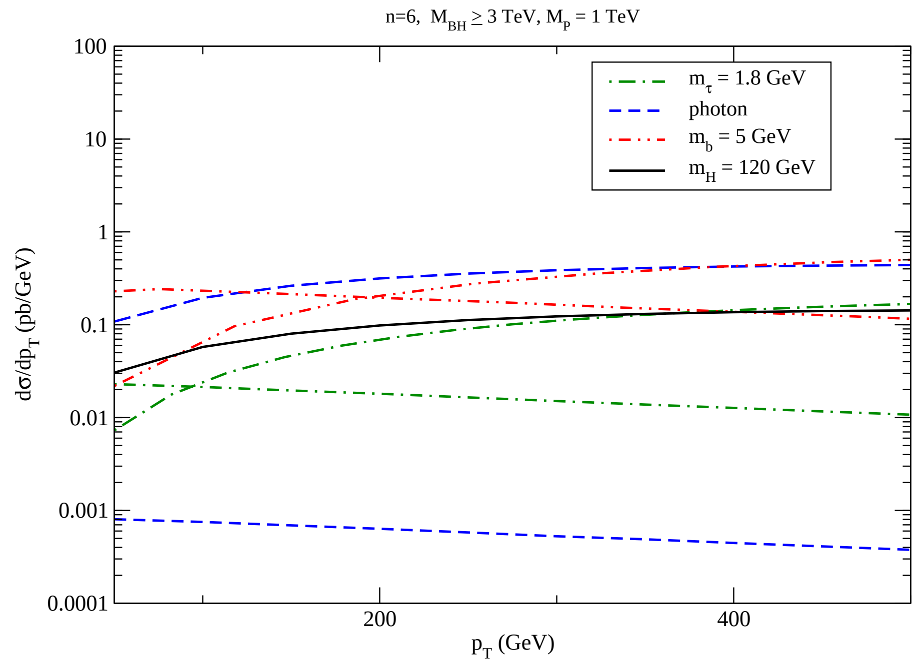

Figure 5: Transverse momentum distribution for the bottom quarks, tau lepton, the Higgs and single photon. The upper curves at large p_T for each particle correspond to the direct production from black hole evaporation whereas the lower ones correspond to the decay of Higgs from black holes.

Results:

- p_T distributions of elementary particles emitted from black holes can give clear evidence for black hole production.
- Black hole production can significantly impact Higgs search at LHC.
- The decay modes of Higgs emitted from the black holes can also be useful in the study of black holes at LHC. As an example, the number of diphoton events due to the decay of Higgs emitted from black holes can be 5 times more than that of due to the decay of Higgs in Standard Model.
- If the Higgs is heavy, the decays into W boson and top quark become important and for $p_T > 200GeV$ they may dominate over the standard model predictions.

- The cross sections depend crucially on the fundamental Planck scale and the minimum black hole mass.
- One can also consider : rotation effects, energy dependent greybody factors, time dependence, quantum effects,.....

THANK YOU !

ARIF EMRE ERKOCA
aeerkoca@physics.arizona.edu
1(520)440-0285