

# Black Hole production at colliders

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based on work with

**Daisuke Ida** (Gakushuin) and **Seong Chan Park** (Seoul)

Phys. Rev. D67 (2003) [hep-th/0212108]

Phys. Rev. D71 (2005) [hep-th/0503052]

Phys. Rev. D73 (2006) [hep-th/0602188]

and also

**Nobuchika Okada** (KEK)

“Alternative Signature of TeV Strings”

Phys. Rev. D66 (2002) [hep-ph/0111298]

**Manuel Drees** and **Christian Alig** (Bonn)

“QCD Effects in the Decays of TeV Black Holes”

hep-ph/0610269

# Outline

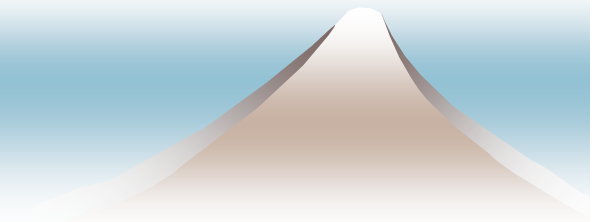
## ▲ Motivation

- **Planck scale** can be as low as **TeV**
- TeV gravity **inevitably** leads to **BH production**

## ▲ What we found on

- Production: BHs are produced with large  $J$ .
- Evaporation:  $J$  does make a big difference.

## ▲ Summary & Outlook



# Planck (string) scale can be as low as TeV

- in **large extra dimensions** (ADD) Arkani-Hamed, Dimopoulos, Dvali 98  
→ Talks by Magass, Godang, Gough Eschrich, ...
- @IR brane in **warped** comp'n (RS) Randall, Sundrum 99  
→ Talks by Bourilkov, Soni, Landsberg, ...

▲ TeV gravity **inevitably** leads to  
**BH production** at  $E \gg \text{TeV}$ .

- Classical cross section **proven** to grow:  $\sigma \propto E^2/(1+n)$   
Eardley, Giddings 02  
Yoshino et al. 02, 05
- BH production **dominates** over all other interactions: “The end of short distance physics”  
Giddings, Thomas 01
- LHC will become a **black hole factory**.  
Dimopoulos, Landsberg 01

# Is TeV gravity “natural” ?

- ▲ Yes! It's as natural as  $M_p \sim 10^{18} \text{GeV}$ .
  - ADD: We may need  $R \sim 10^6 l_p$ . So what?  
Anyway,  $R$  is a **modulus**. When **lifting up flat direction**, it's all common to have a huge shift.
    - Note: Here we don't have a **subtraction between large numbers** to yield a small number.
  - RS: Warped comp'n, “throat”, appears now everywhere in string theory. **Generically**, space is warped under the presence of **flux**.
  - More radically, take  $17 \lesssim n \lesssim 39$ ,  
then  $1 \lesssim M_* R_c \lesssim 10$ .

Hewett, Lillie, Rizzo 05



# Motivation in terms of Correspondence principle

(explanation with a fixed string coupling)

	Classical gravity	Quantum gravity
Perturbative	(easy)	<b>LOW</b> energy/mass <b>string</b> picture
Non-perturbative	<b>High</b> energy/mass <b>black hole</b> picture	Intermediate scale <b>Final theory</b>

- ◆ Yet **no** theory **at the correspondence scale**.
  - Correspondence: extrapolations from **both** pictures give **same order** of physical quantities:  $T$ ,  $S$ ,  $\sigma$ , etc.
  - **This** is the region of **true interest**.
- ◆ **QG corrections** will be seen as **deviation** from semi-classical black hole picture.
- ◆ Want to make **predictions** in BH picture **as precisely as possible!!**

# Conventional wisdom before us

## ▲ Basics

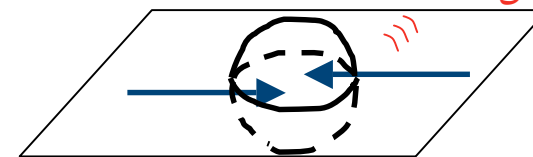
Dimopoulos, Landsberg O 1; Giddings, Thomas O 1; ...

- 4 phases: Balding, spin-down, Schwarzschild, and Plack
- Decay spectrum is governed by Hawking radiation
- decay proportional to #(dof)  
 $h : q : l : \nu = 4 : 72 : 18 : 12$
- BH radiates mainly into SM particles on the brane
- BH **angular momentum** was thought to be negligible

## ▲ At LHC

- Produced every second
- $M \sim 1-10$  TeV
- $T \sim$  few hundred GeV - TeV
- Tens of multiple emissions
- Life time  $\sim 10^{-27}$ sec

Fig in higher dim **Hawking radiation**



3-brane

# Outline

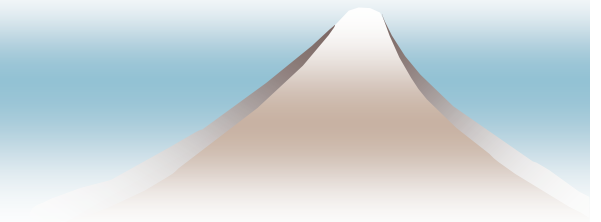
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# What we found

Ida, K.O. Park 02, 05, 06

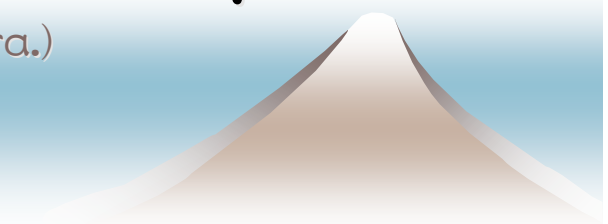
## ▲ Production

- BHs are produced with **large angular momentum:**

$$d\sigma/dJ \sim J/s \quad \text{for } J < s^{(2+n)/2(1+n)} \quad (\text{in Planck unit})$$

## ▲ Evaporation

- Obtained quark/lepton/vector **field equations on the brane** for the first time (for Schwarzschild too)
- Able to compute **greybody factors** from it
- Non-trivial **angular dependence** for **Hawking radiation** (Criticism by Kanti et al. on the up-down asymmetry neglects our explicit comment on it and seems to be based on misunderstanding.)
- BH **time evolution** is obtained from **full spectra.** (Currently we are the only ones who have full spectra.)
- **Spin down phase** is important

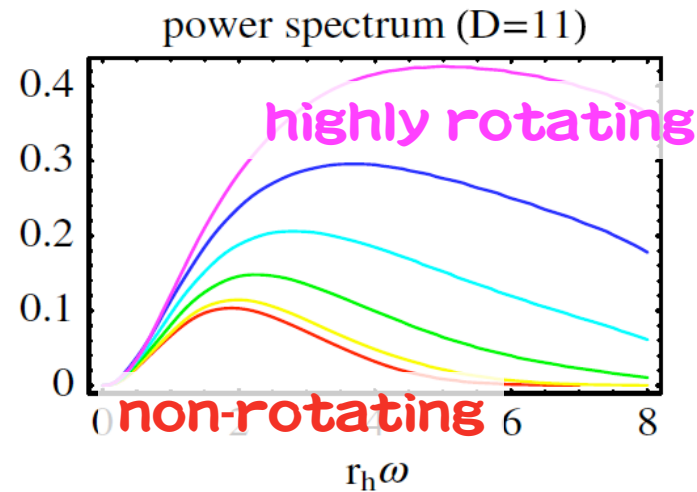
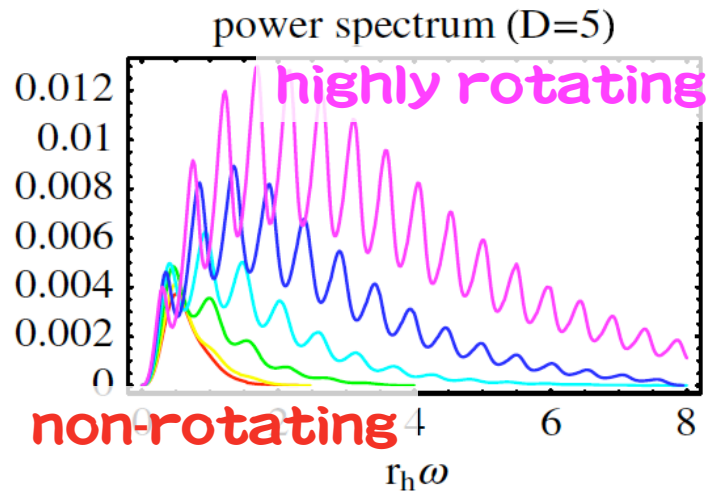




# Hawking radiation spectra

Ida, K.O. Park 06

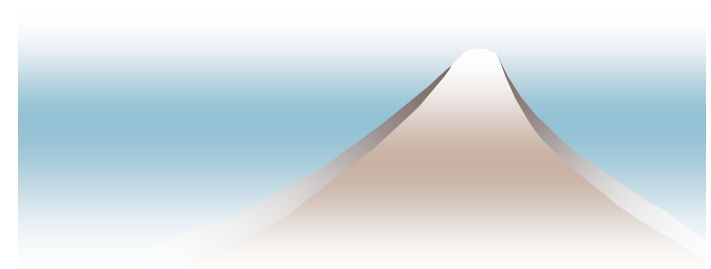
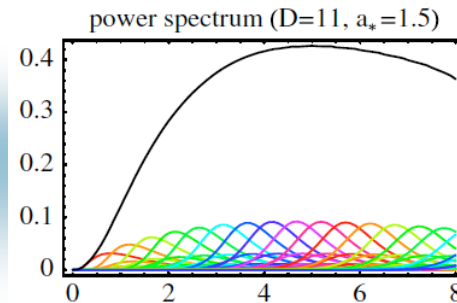
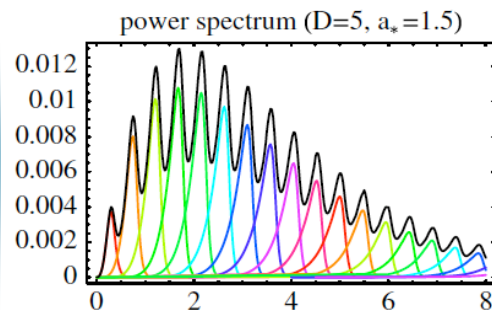
**BH angular momentum makes great difference!**



Can also **distinguish** RS/ADD!

(Figs for spinor are shown; similar for vector.)

Cf. contributions from each angular mode:

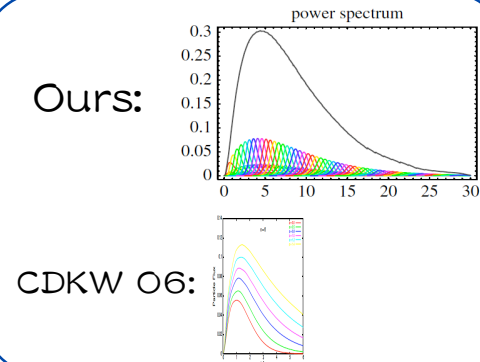
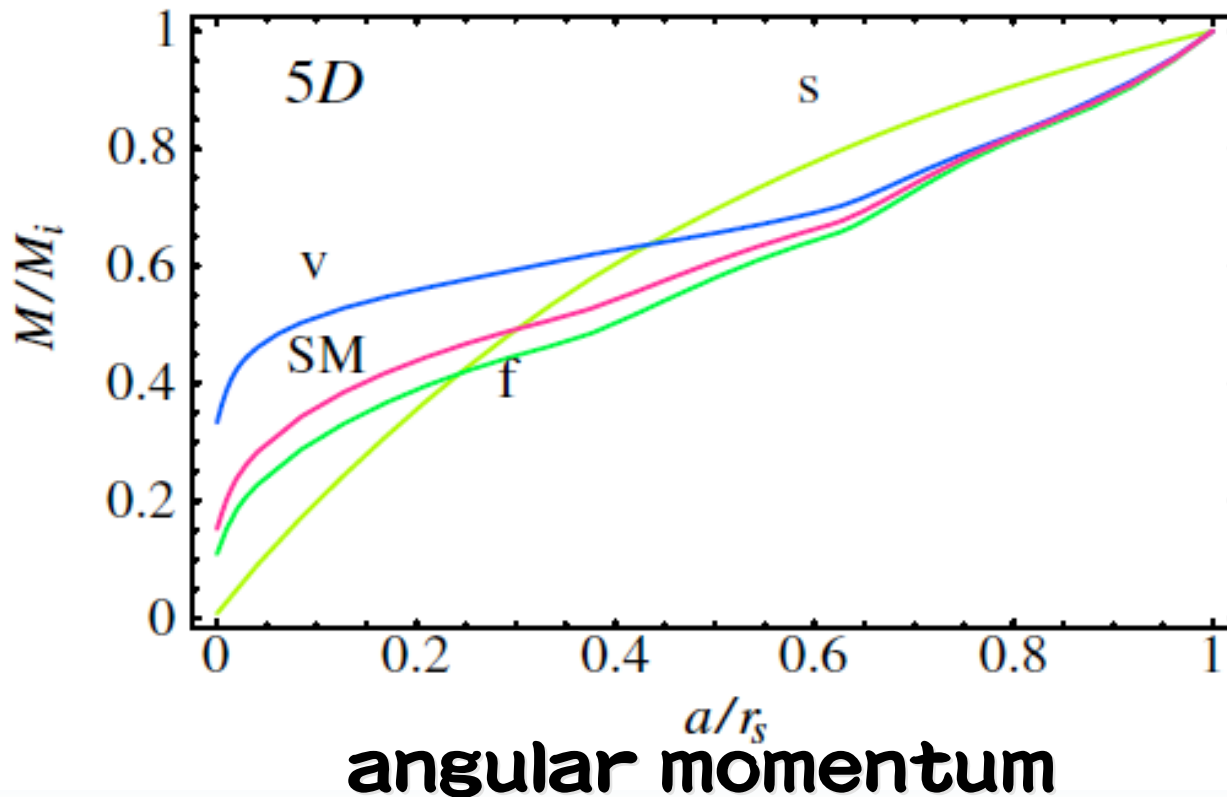


# Time evolution available from **full** spectra

Ida, KO, Park 06

**Spin-down phase** is not only non-negligible but **important**.

mass



**More than half of total mass**

is radiated during spin-down phase

# Quark Gluon Plasma does not form after BH@LHC

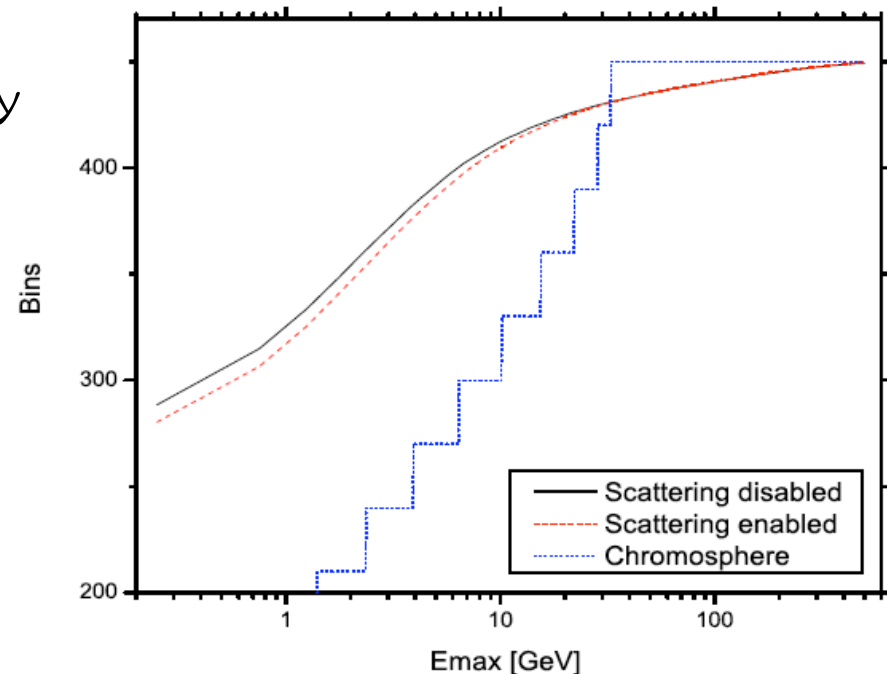
Alig, Drees, K.O. 06

▲ performed a real-time simulation on the **final state QCD scatterings** after BH decay,

- improving an algorithm for heavy ion collisions,
- with a code written by us from scratch.

▲ Result: I do not explain, but if you believe me, see →

▲ If not, read: Alig, Drees, K.O. hep-ph/0610269.



# Summary & Outlook

- ▲ TeV gravity inevitably leads to **BH production**.
  - (**Black ring** and objects with more complex topology may form.)
- ▲ BH is produced with **large angular momentum**.
  - Hawking radiation is highly **anisotropic**.
- ▲ **Time evolution** can be followed from **full** spectra.
  - **Spin down phase** shown to be important.
- ▲ **Chromosphere** does **not** form.
- ▲ **Balding phase** still being disputed
- ▲ Radiation now can be computed up to **Planck phase**.
- ▲ Comparison with this prediction will guide the way to **quantum gravity!**

