TeV-scale Black Holes

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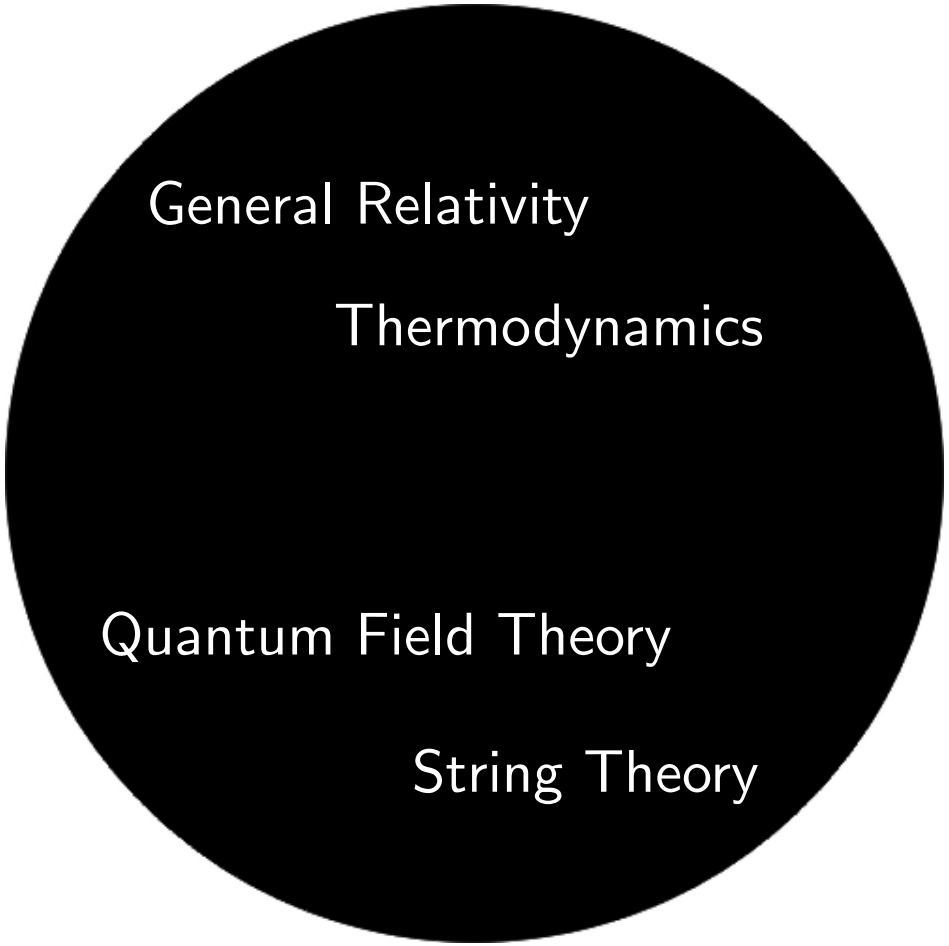
University of Arizona

SH, Ben Koch and Marcus Bleicher: hep-ph/0507138, hep-ph/0507140

Black Holes as Physics Meeting Point



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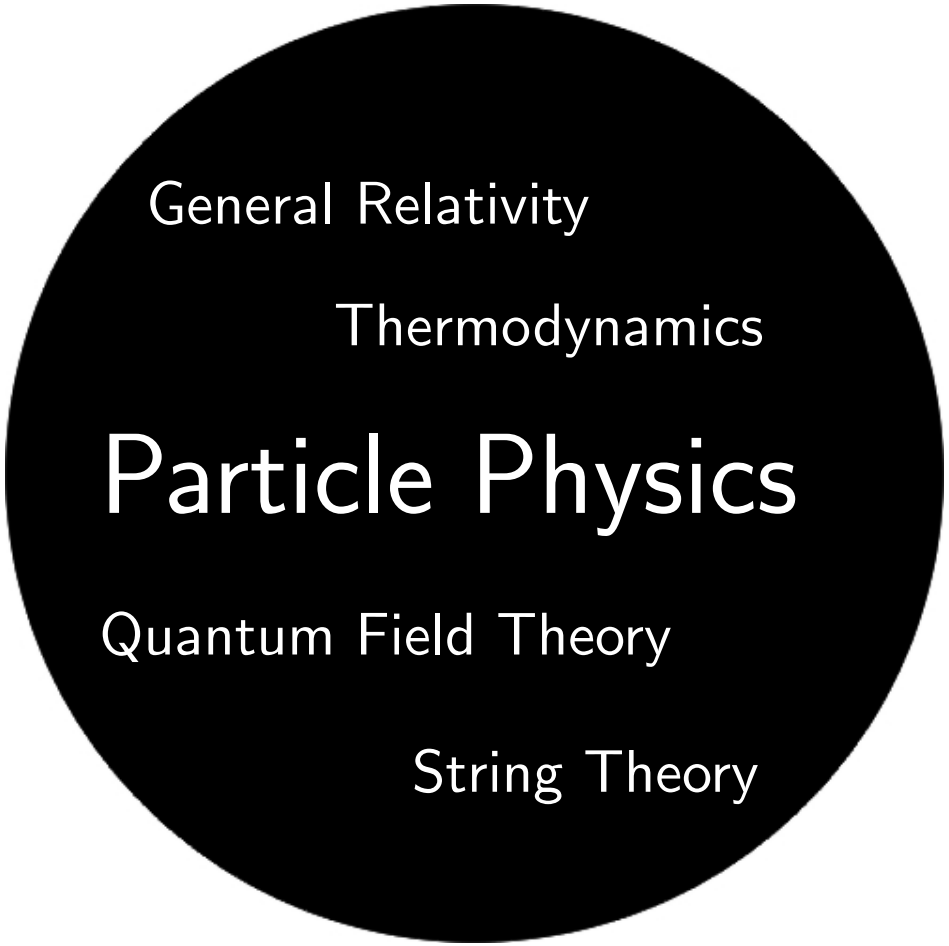

Why Extra Dimensions

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Top down

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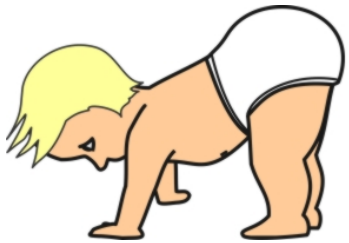
Top down

Bottom up



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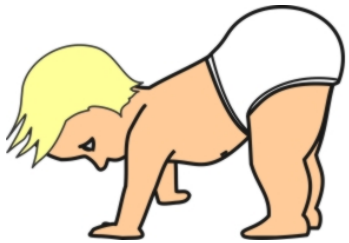
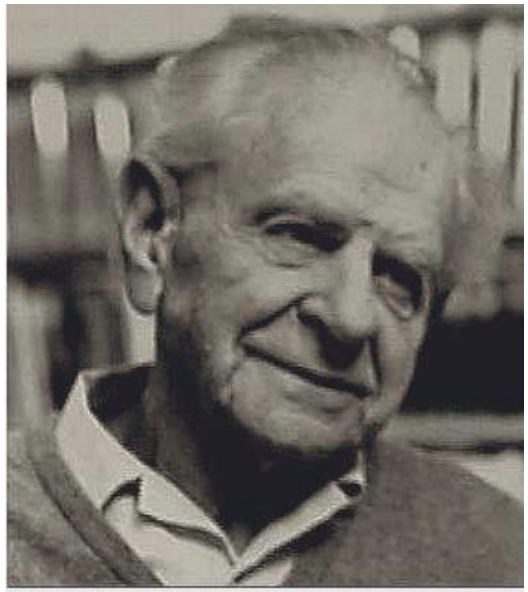


Why Extra Dimensions

Top down

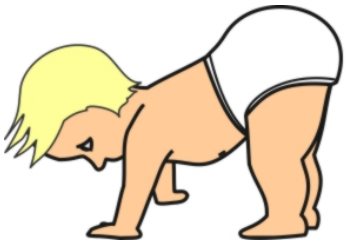
"Science may be described as the art of systematic over-simplification."



Sir Karl Popper (1902-1994)

Extra Dimensions

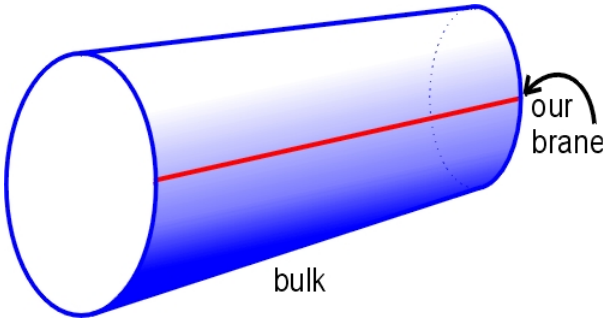
Bottom up



Karl Popper, The Observer, August 1982

The ADD-Model

- $d+3$ space like dimensions (bulk)
- Compactified to radius R
- Only gravitons are allowed into all dimensions
- SM particles bound to 3-dimensional submanifold (brane)



Arkani-Hamed, Dimopoulos and Dvali, Phys. Lett. B **429**, 263 (1998)
Antoniadis, Arkani-Hamed, Dimopoulos and Dvali, Phys. Lett. B **436**, 257 (1998)
Arkani-Hamed, Dimopoulos and Dvali, Phys. Rev. D **59**, 086004 (1999)

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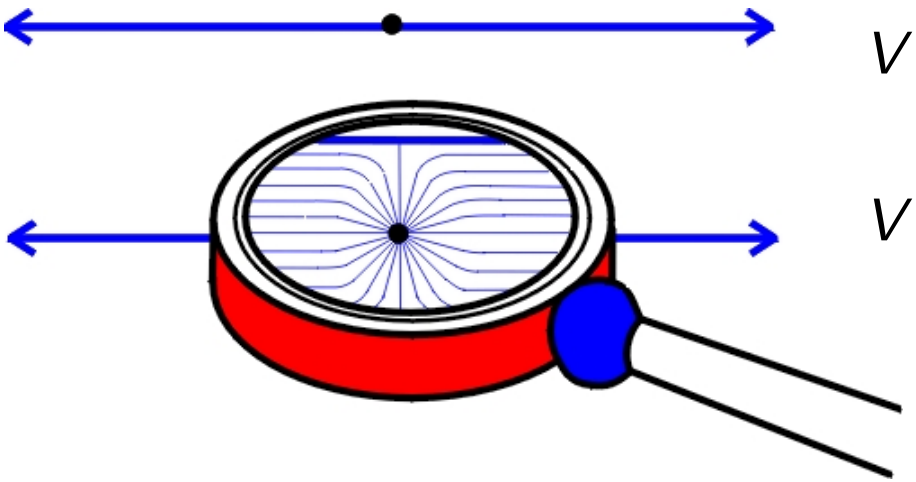

$$V \sim \frac{1}{m_p^2}\frac{1}{r}$$

$$V \sim \frac{1}{M_f^{d+2}}\frac{1}{r^{d+1}} \rightarrow \frac{1}{M_f^{d+2}}\frac{1}{R^d}\frac{1}{r}$$

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- Large radii $1/R \sim$ eV .. 10 MeV

Black Holes in Extra Dimensions

In large extra dimensions (ADD)

- Gravity stronger at small distances $\Rightarrow$ horizon radius larger
- For mass $M \sim 1$ TeV :

$$R_H \sim 2 \times 10^{-38}\text{fm} \quad \text{without} \quad R_H \sim 2 \times 10^{-4}\text{fm} \quad \text{with extra dim.}$$

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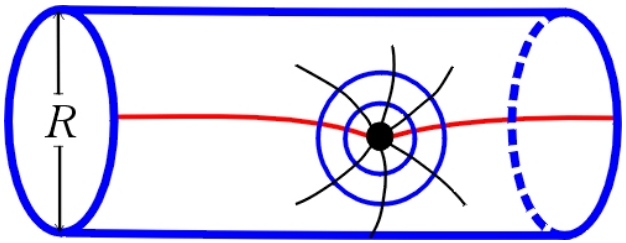

Collider produced black holes

radius $R_H \ll R$

masses $\sim$ TeV

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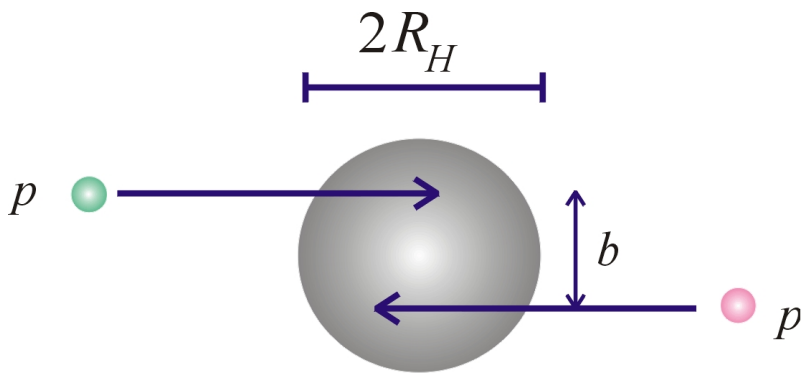
- At the LHC partons can come closer than their Schwarzschild horizon $\longrightarrow$ a black hole can be created!

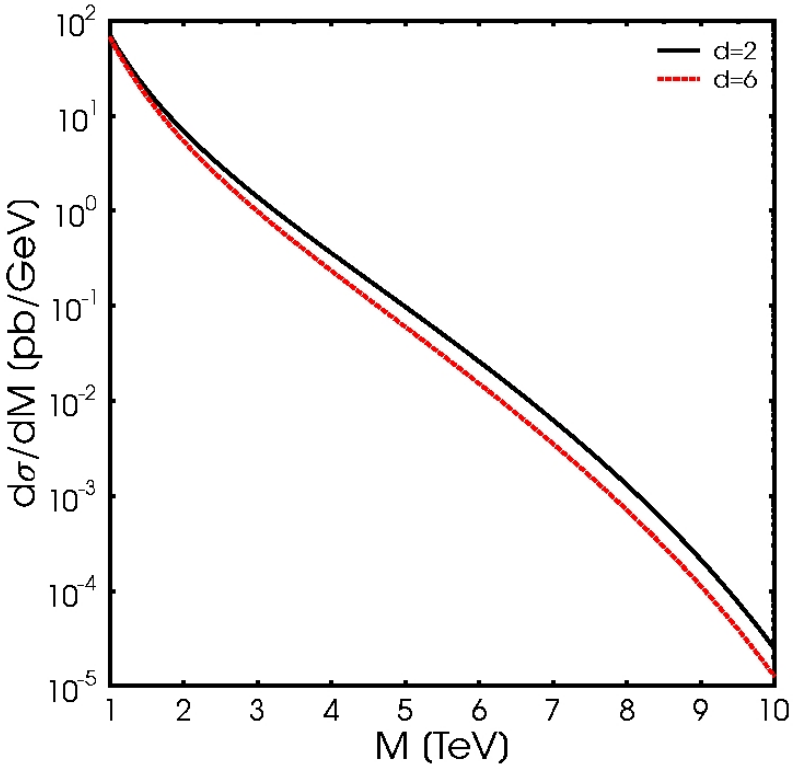


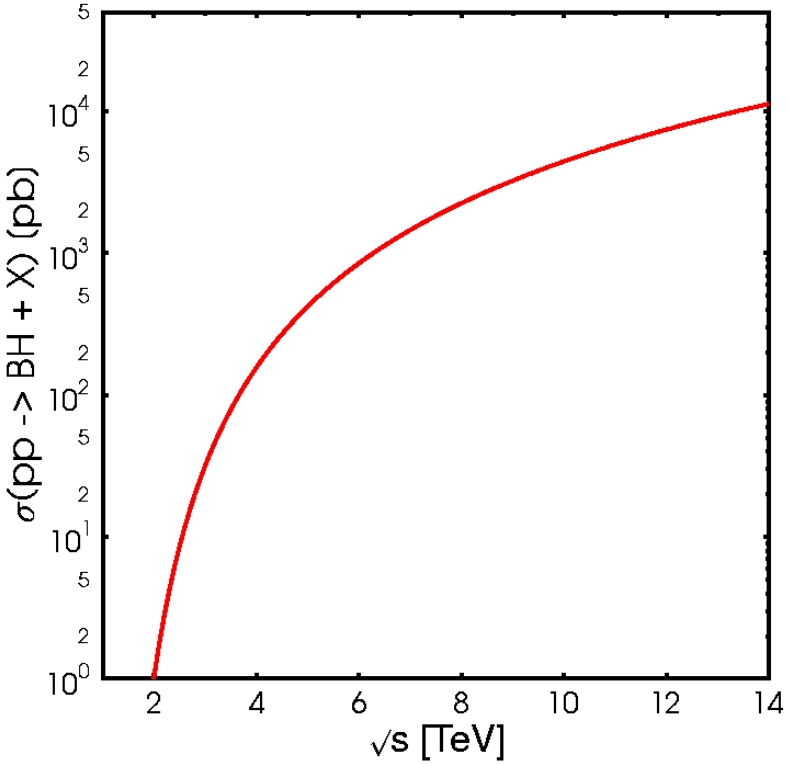
Dimopoulos and Landsberg, Phys. Rev. Lett. **87**, 161602 (2001)
Giddings and Thomas, Phys. Rev. **D 65** 056010 (2002)

Cross-section of Black Holes

- Cross section $\sigma \sim \pi R_H^2$ is function of $\sqrt{s}$
- Threshold $\Theta(M - M_{min})$, one expects $M_{min} \sim M_f$
- Model with colliding wave-packets in Aichelburg-Sexl geometry and examine spacetime for horizons
- Integrate over PDFs for hadron collisions

Production of Black Holes





⟶ estimation yields $\approx 10^9$ black holes per year, one per second

Evaporation of Black Holes

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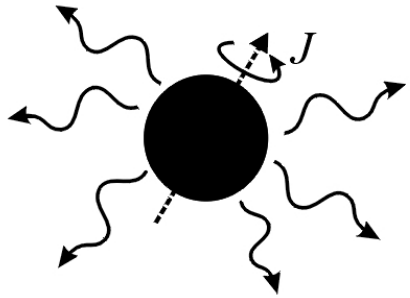

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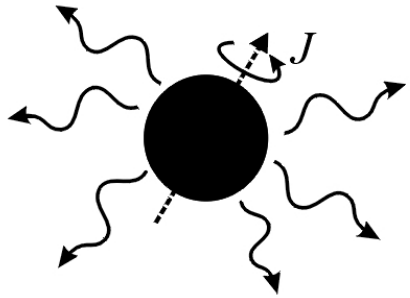
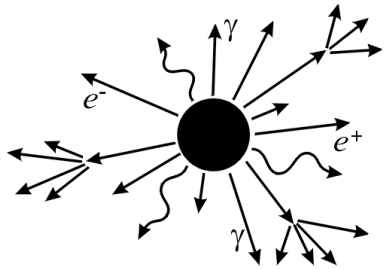
   Black hole thermo: $T = \kappa/2\pi$ and $dS/dM = 1/T$





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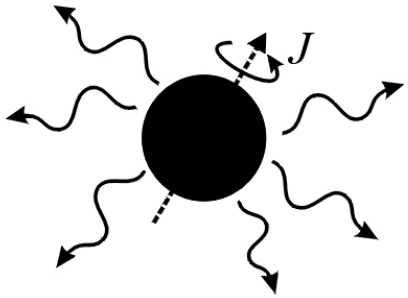

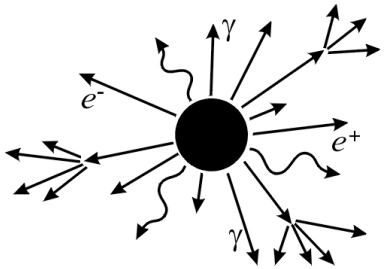

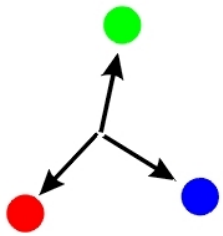

or  ?

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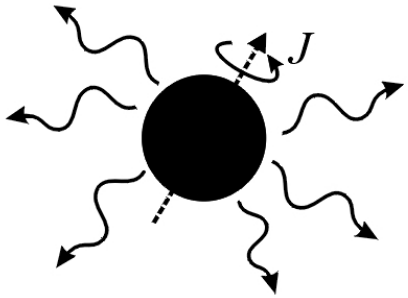

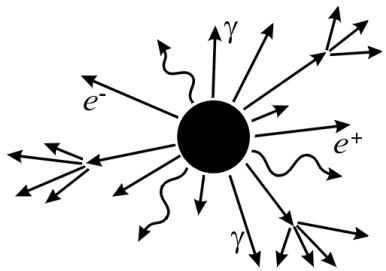

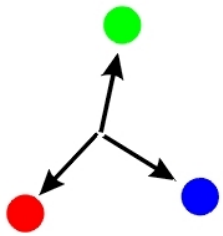

or  ?

Numerical investigation: black hole event generator CHARYBDIS

Tanaka *et al*, [arXiv:hep-ph/0411095]; Harris *et al*, [arXiv:hep-ph/0411022]

Why Black Hole Remanants

Information loss, modified gravity, hair ...

A simple argument:

- Compton-wavelength $\lambda \sim 1/E$, Schwarzschild-radius $R_H \sim E/m_p^2$
- R_H should not be $< \lambda$, because of the uncertainty principle

$\longrightarrow$ But would happens for black hole with $E < m_p$

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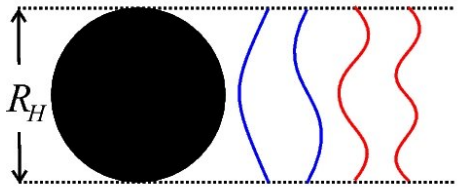


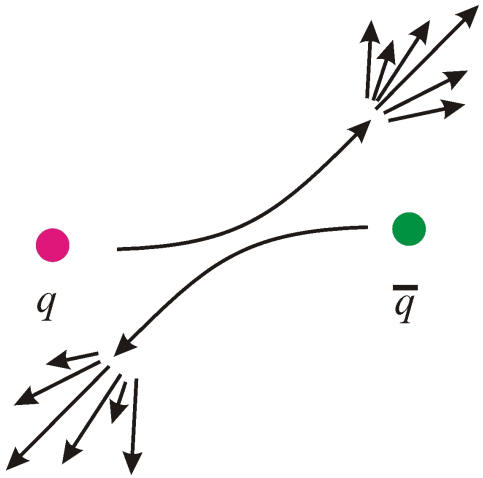
- Evaporation of $\lambda > R_H$ not possible
- Emission of $E \sim 1/\lambda$ larger than $M \sim R_H m_p^2$ is not possible

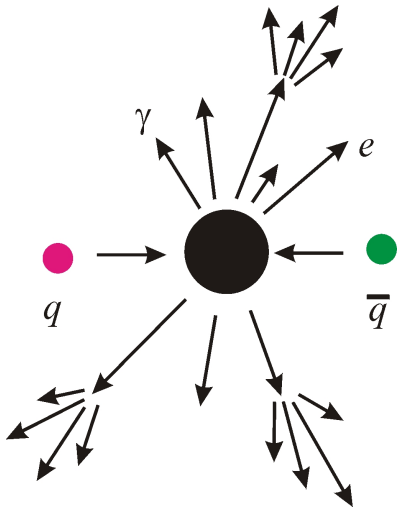
$\longrightarrow$ Evaporation stops when largest possible wavelength carries already too much energy

$\longrightarrow$ Black hole becomes stable at $M \sim m_p$

Observables of Black Holes

- Multi-jet like events
- Momentum cut-off at $\sim M_f$
- Thermal spectrum $\longrightarrow$ yields d and M_f



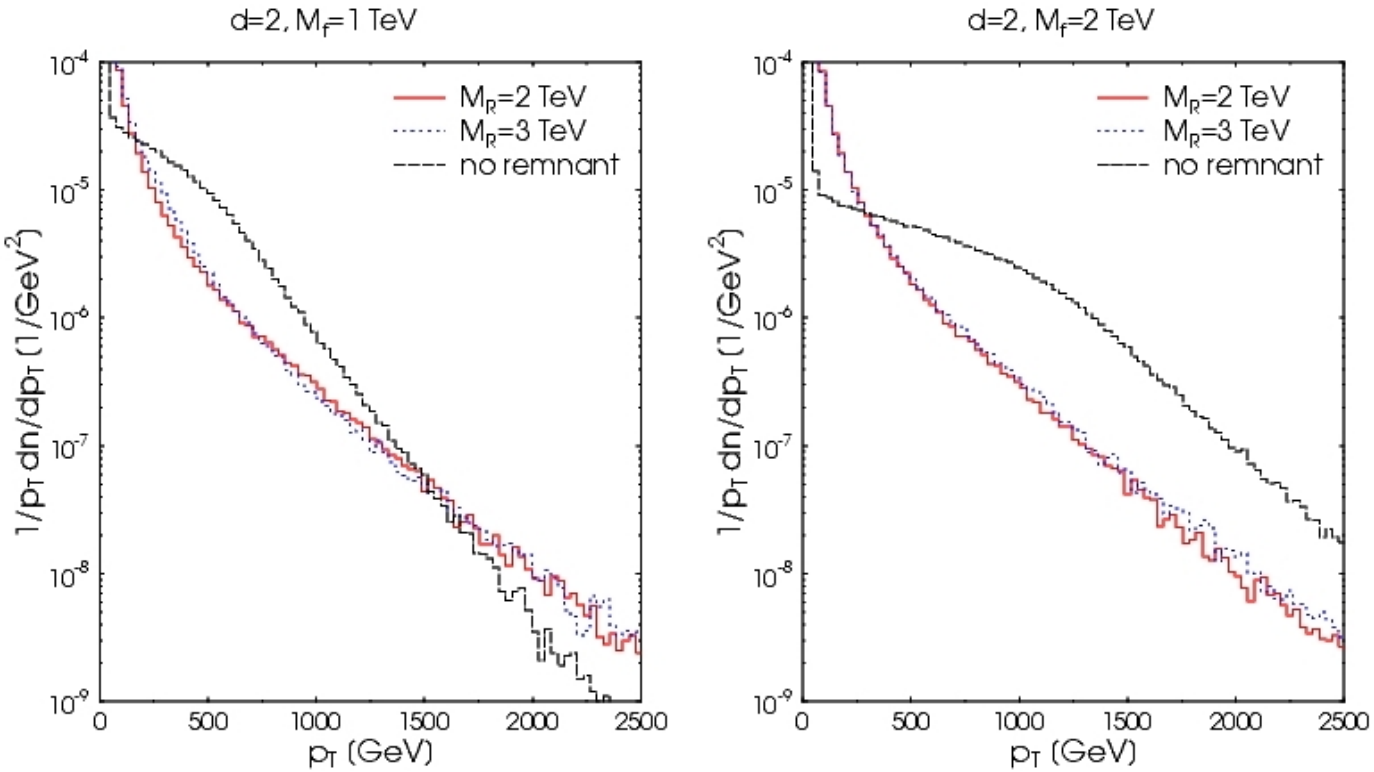


Observables of Black Holes

- Multi-jet like events
- Momentum cut-off at $\sim M_f$
- Thermal spectrum $\rightarrow$ yields d and M_f

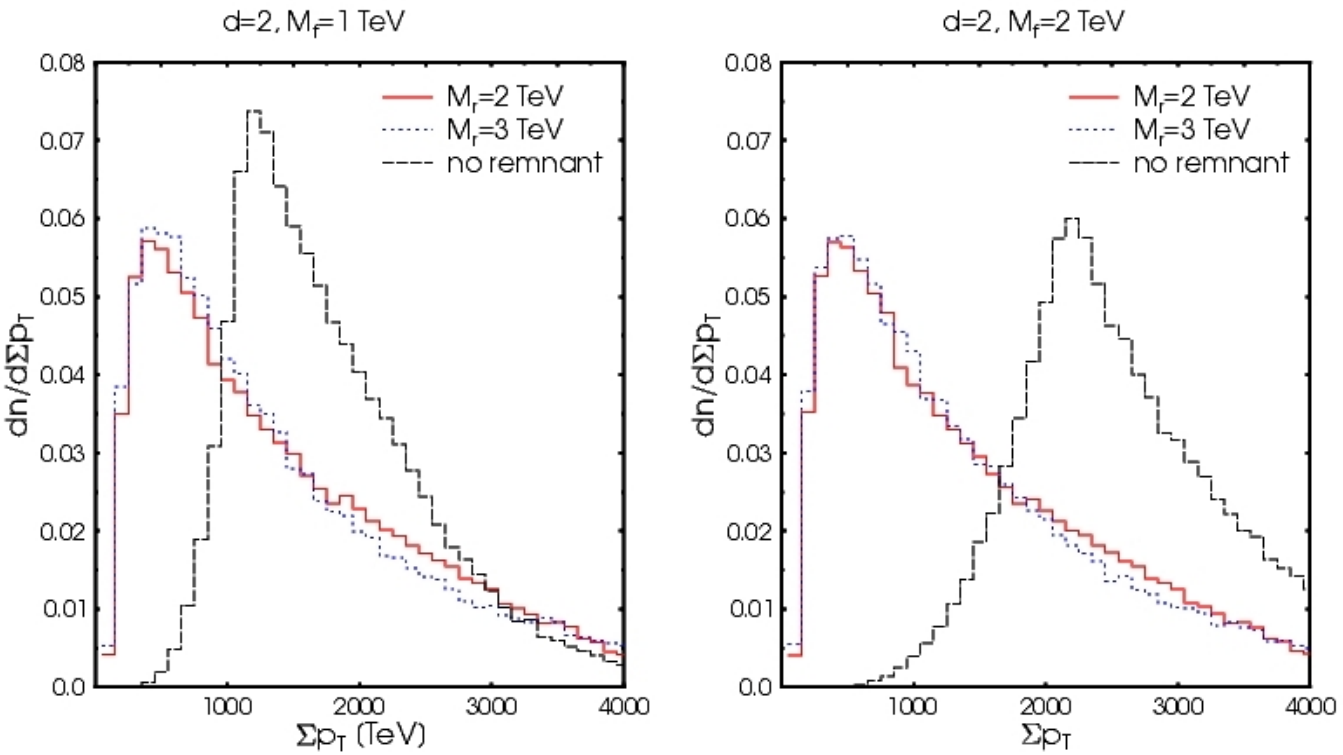
$\longrightarrow$ Are significantly modified through the formation of a remnant!

p_T-Spectrum of decay products before fragmentation



- Final decay makes an important contribution to p_T-spectrum
- Remnant production makes a significant difference
- After fragmentation, difference is less prominent but still present

$\sum p_T$-Spectrum of black hole event



- Missing p_T is increased in presence of remnants

Summary

- Effective models with extra dimensions quantify first effects beyond the standard model
- Black hole production will become important with strong gravitational effects
- Numerical tools for black hole events available
- New: Signatures of black hole event with possible remnant are significantly modified

$\longrightarrow$ Exciting test for the onset of quantum gravity

More details: hep-ph/0507138, hep-ph/0507140