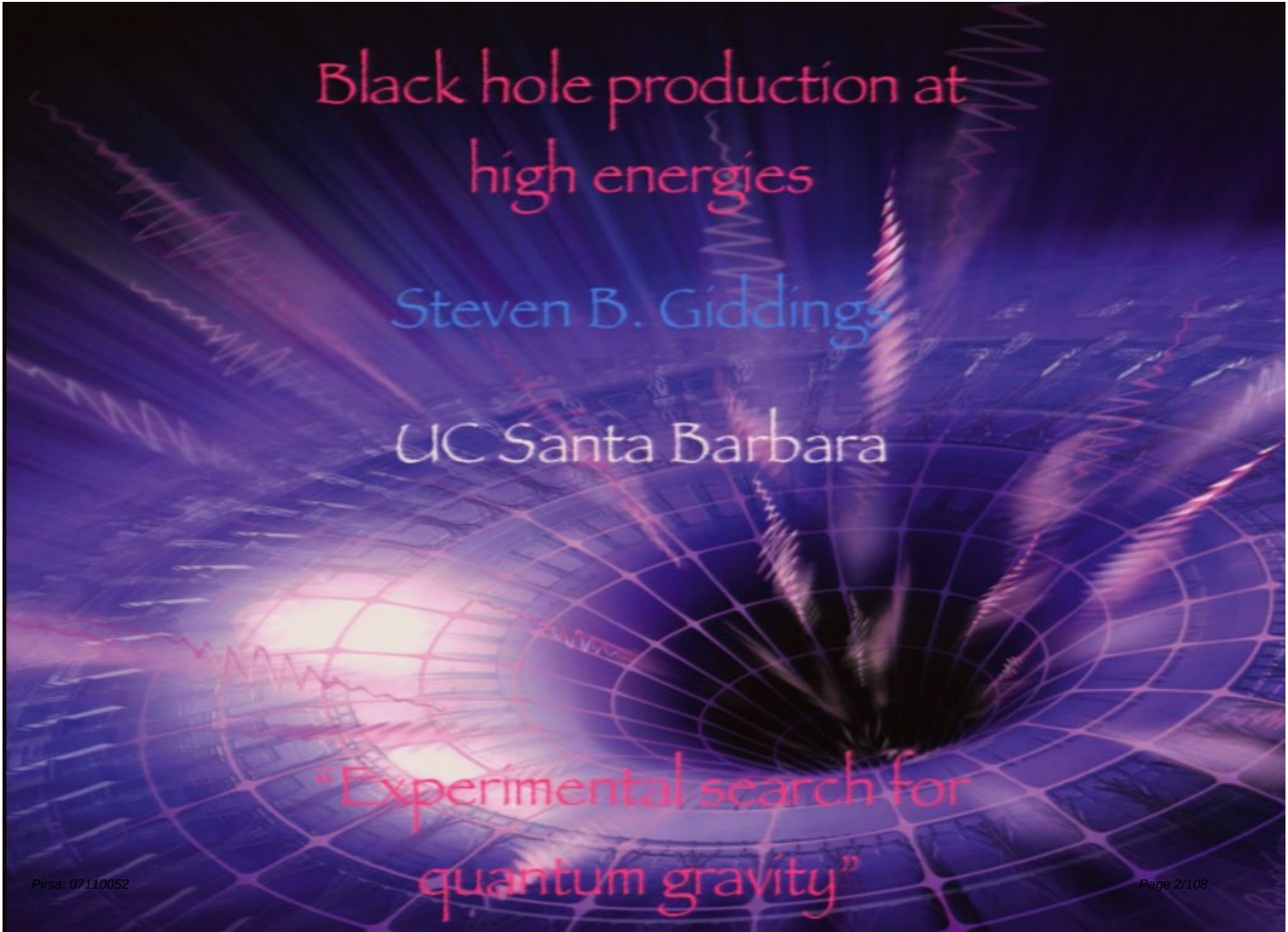
Title: Black hole production at high energies

Date: Nov 08, 2007 10:00 AM

URL: http://pirsa.org/07110052

Abstract: I will survey some of the physics of TeV-scale black hole production, as well as outstanding issues. I will also discuss some of the conceptual issues surrounding high-energy black hole production.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Steven B. Giddings
UC Santa Barbara
"Experimental search for quantum gravity"

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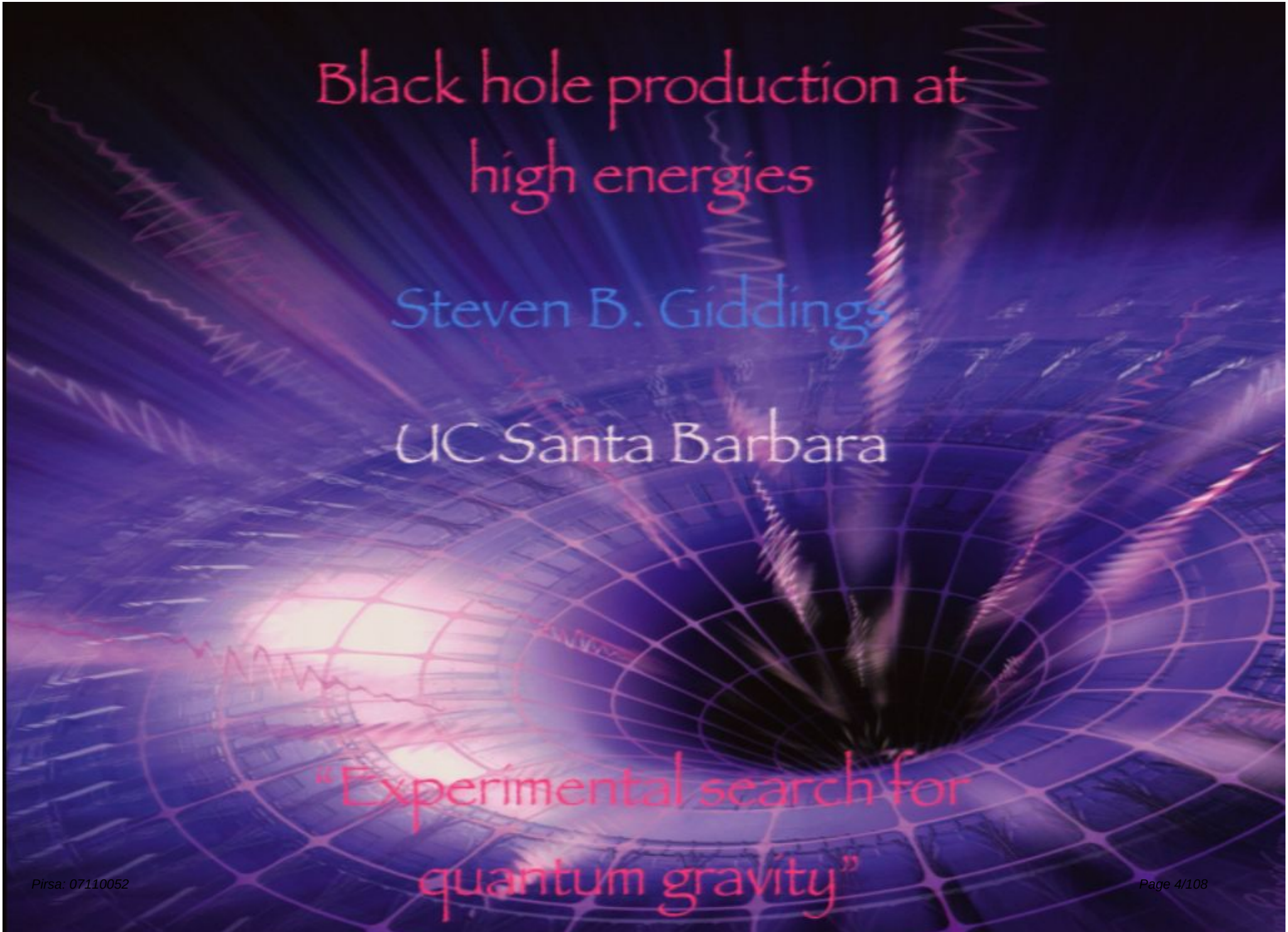
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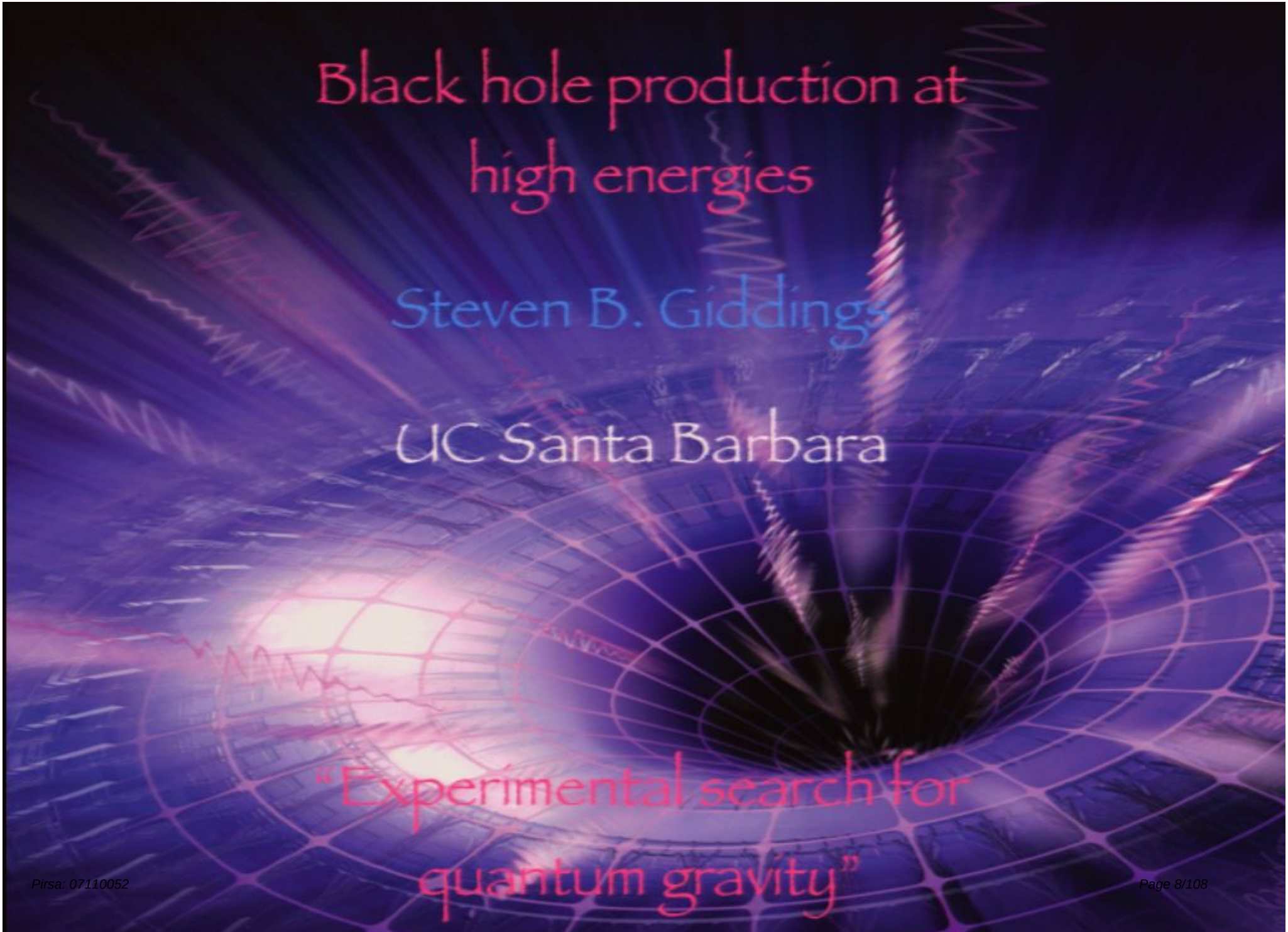
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Will give a brief summary...

(Recent review: arXiv:0709.1107)

The basic idea:

at collision energies

$$E \gtrsim M_P$$

can form black holes;

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can form black holes;

in TeV-scale gravity scenarios, M_P could be as small as $\sim 1\,TeV$

Banks & Fischler

SBG & E. Katz

Possible scenarios:

- Large extra dimensions
- Large warping

$$ds^2 = e^{2A(y)} dx_4^2 + g_{mn} dy^m dy^n$$

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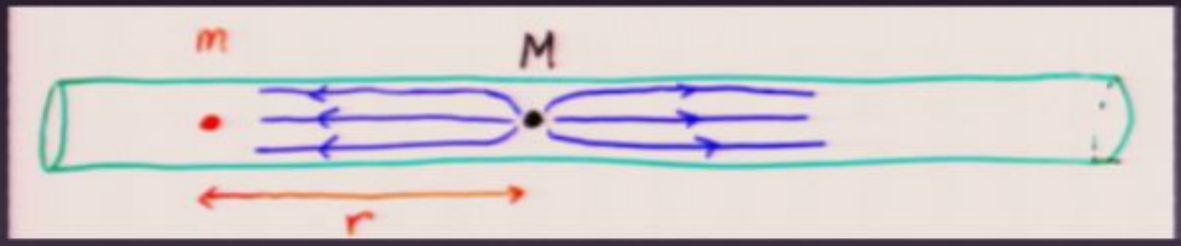

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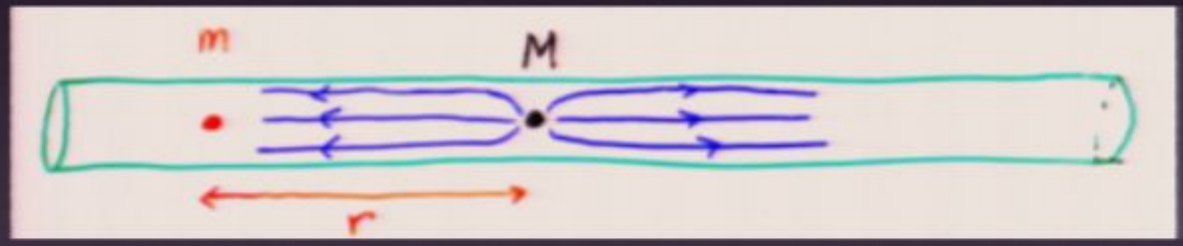

+ brane world, to make gauge thy 4d

...many such scenarios being investigated, particularly in string theory

Focus on model independent features of black hole production;

Small expansion parameter: M_P/E

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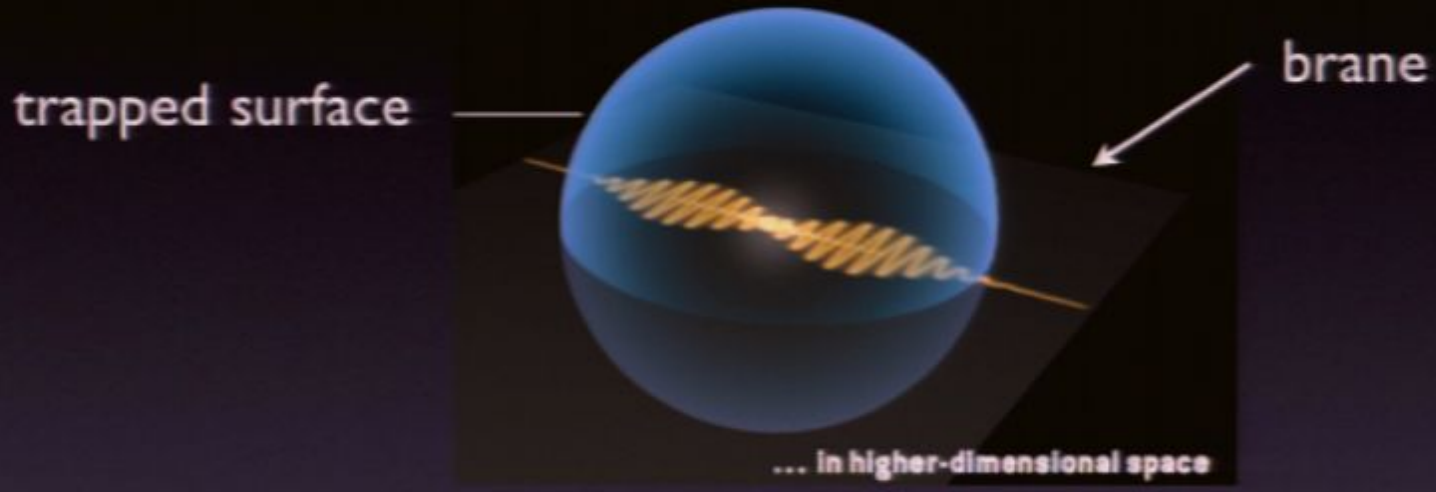
There are of course possible model dependent (and quantum gravity dependent) effects, in particular at

$$E \sim M_P$$

The basic phenomenological scenario:



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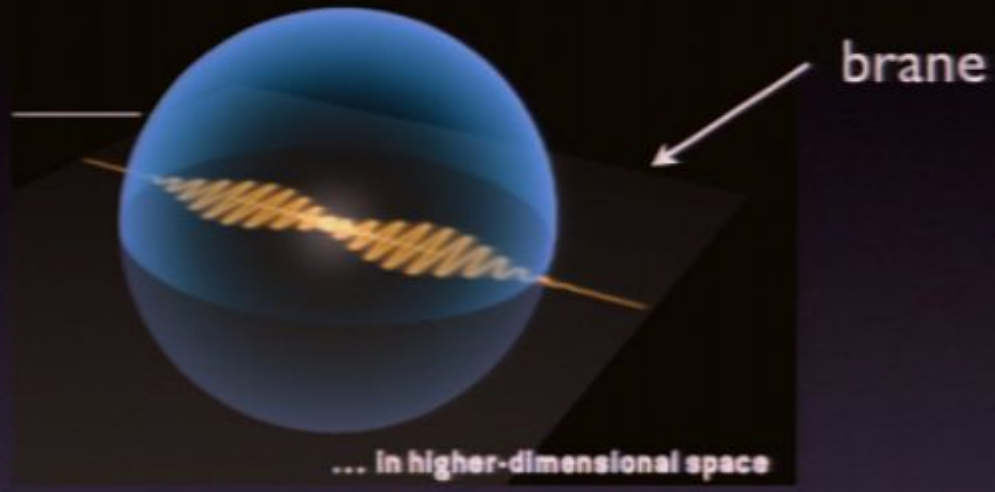

Formation

Decay

1. Balding
2. Spindown
3. Schwarzschild
4. Planck

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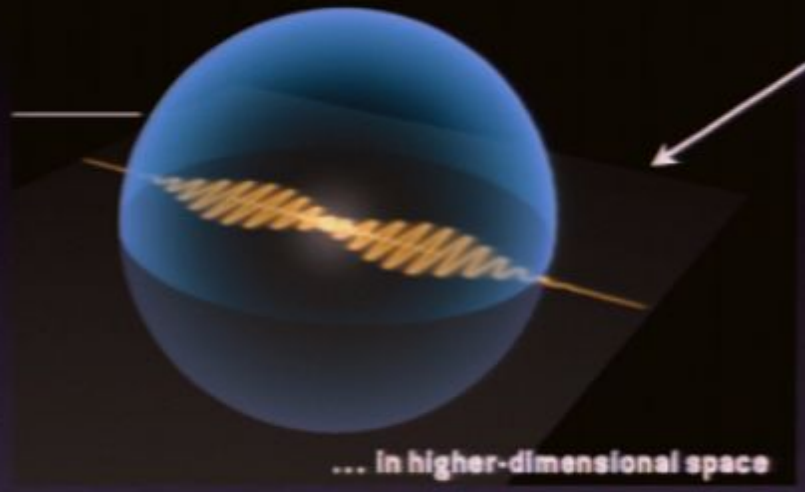

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Will summarize, indicating improvements in understanding and needs

Build on original results: SBG & Thomas hep-ph/0106219
Dimopoulos and Landsberg hep-ph/0106295

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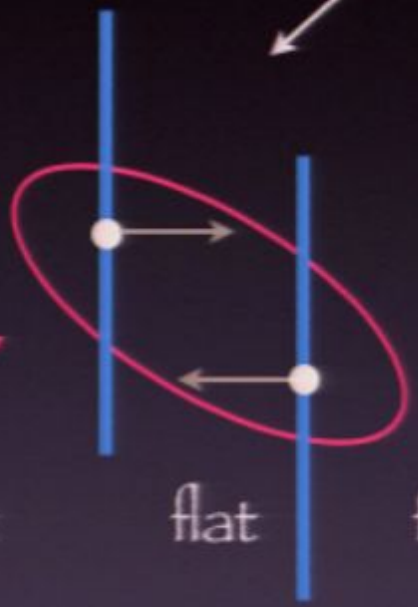
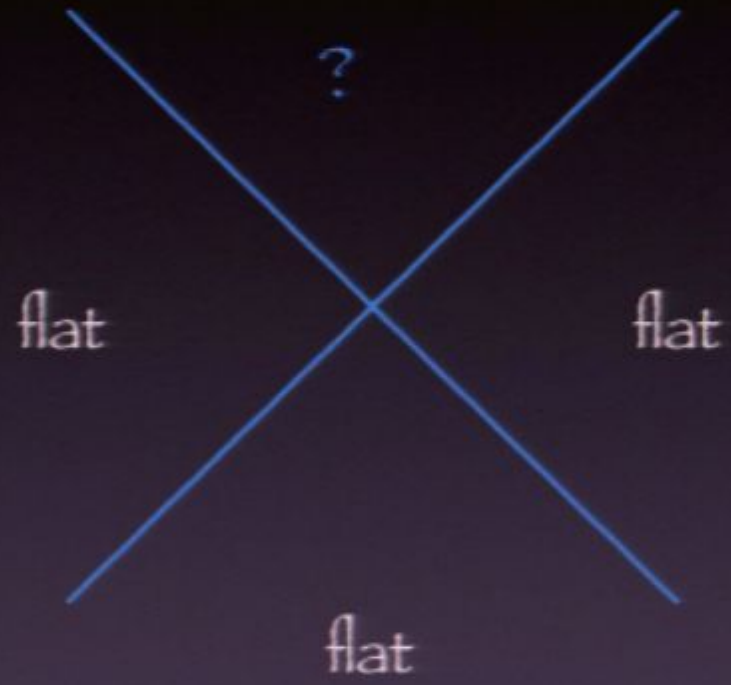


Trapped surface (aka black hole);
forms "before" collision

Penrose
SBG & Eardley
Yoshino & Nambu

Spacetime picture



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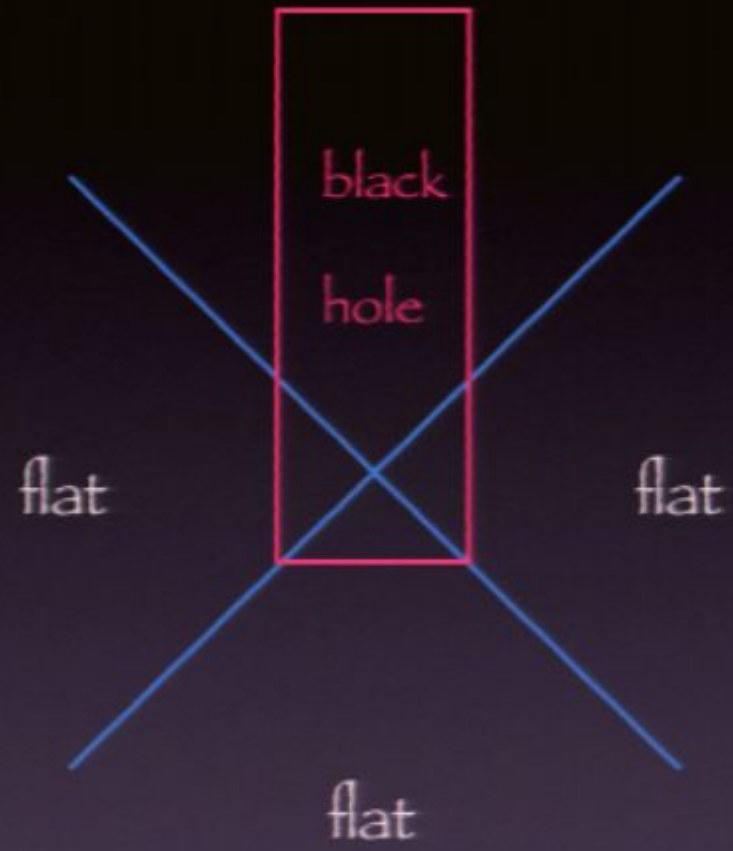

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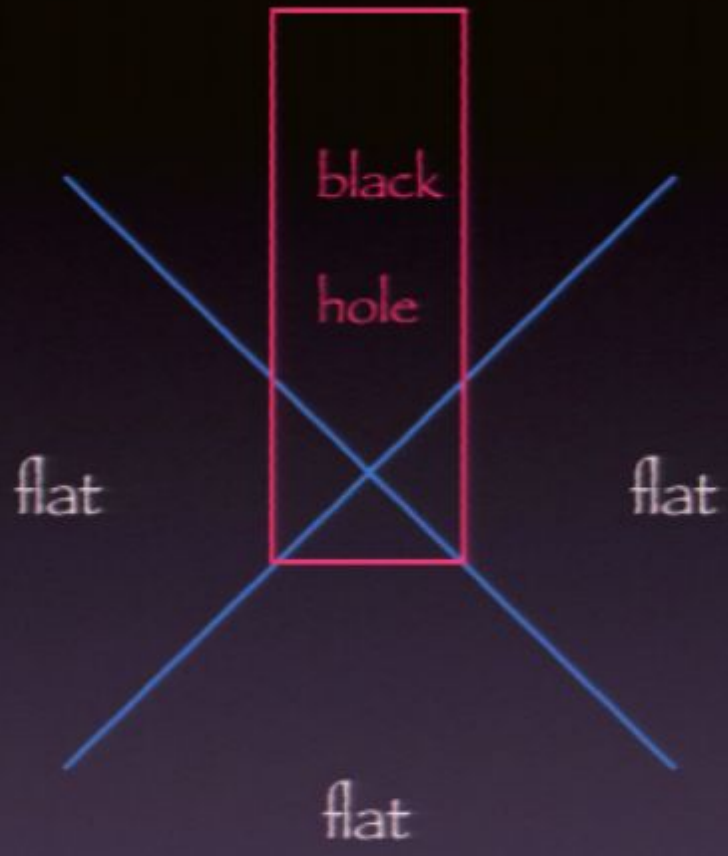

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since trapped surface forms in flat region, can compute its size. This gives

1. Cross section
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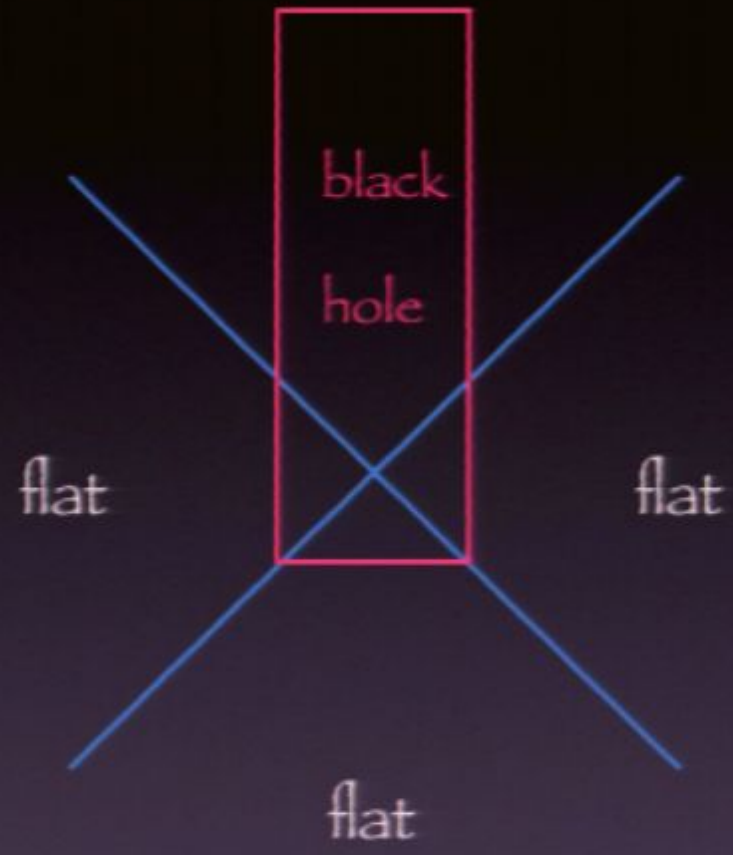

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3.09 in D=10

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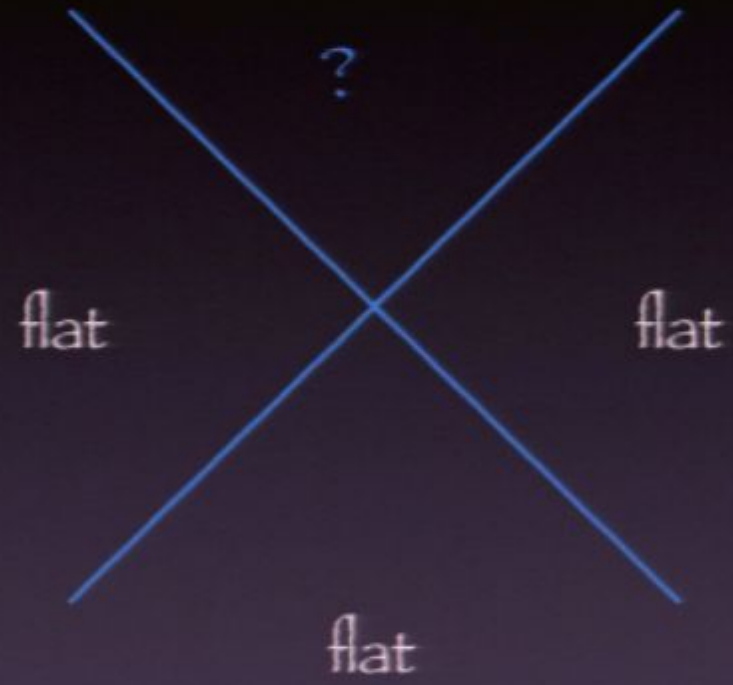

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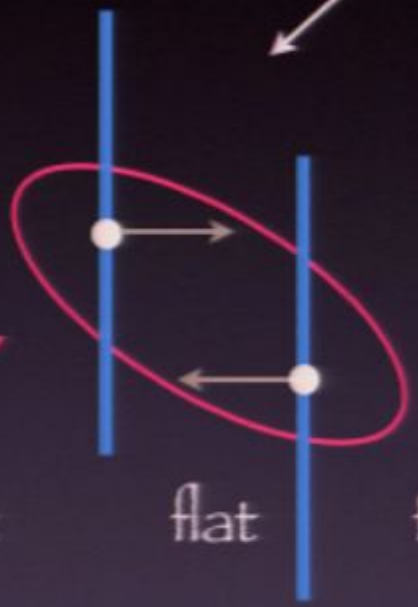

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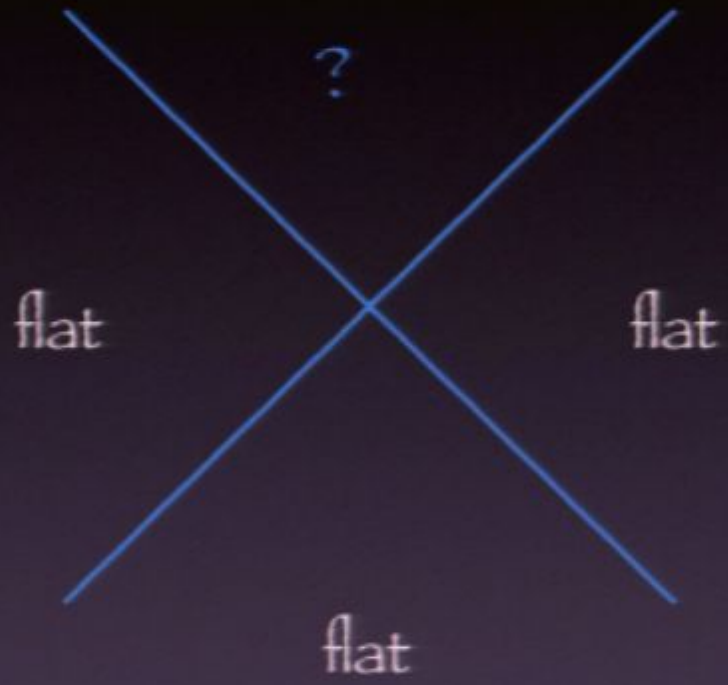

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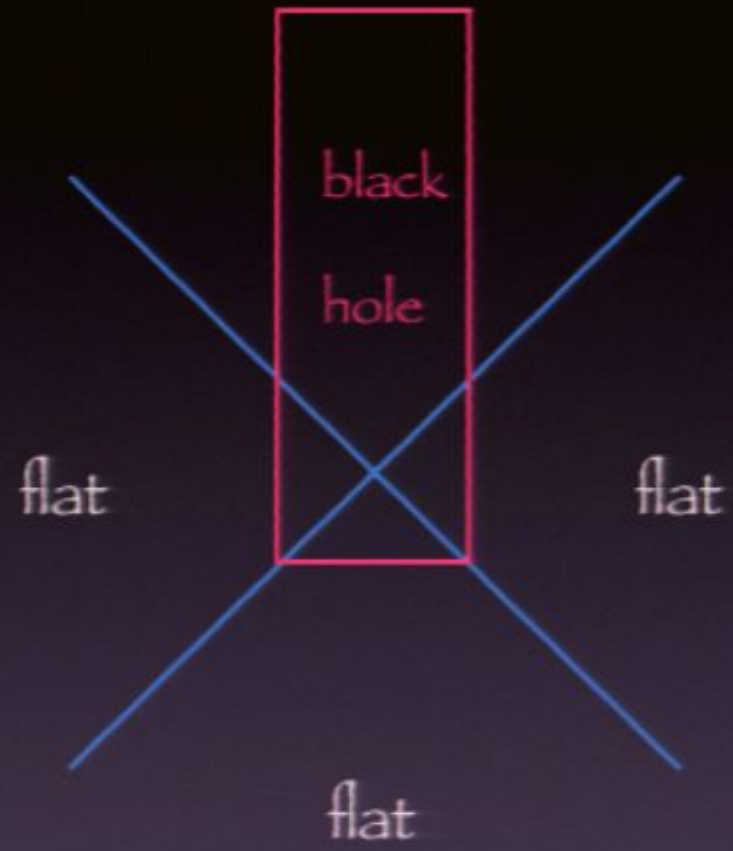

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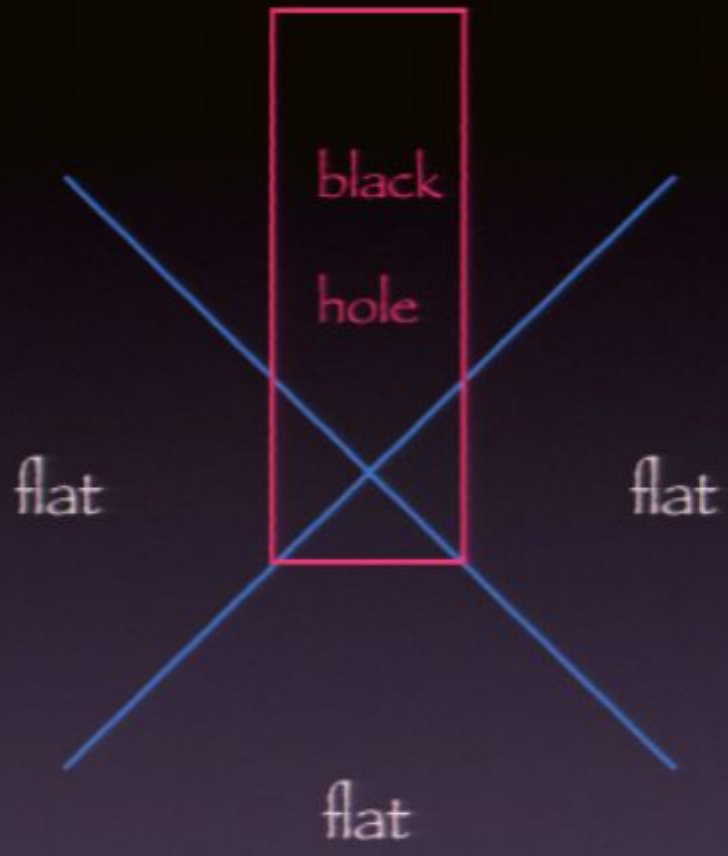

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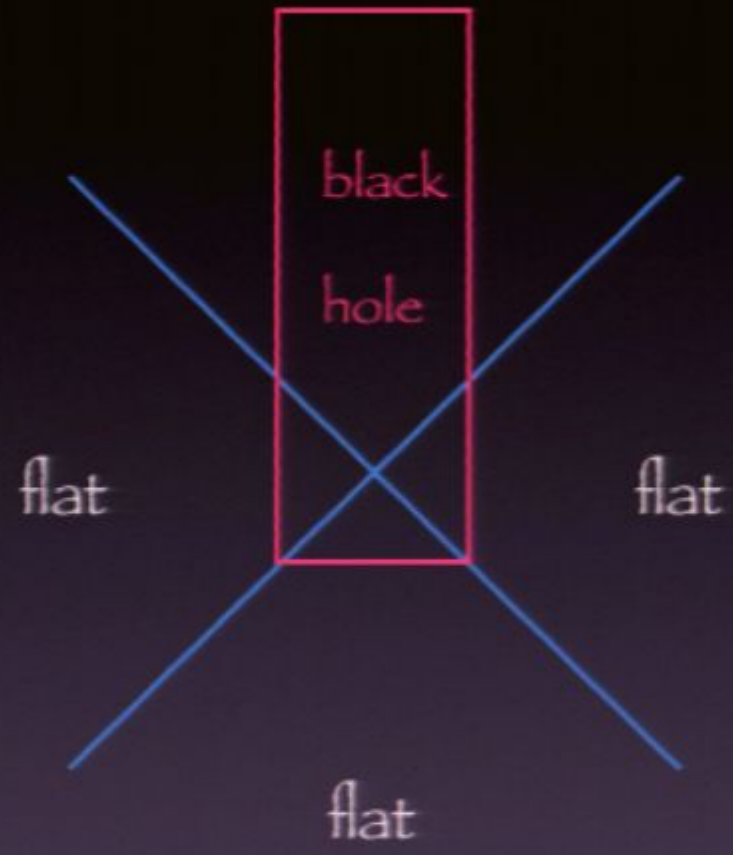

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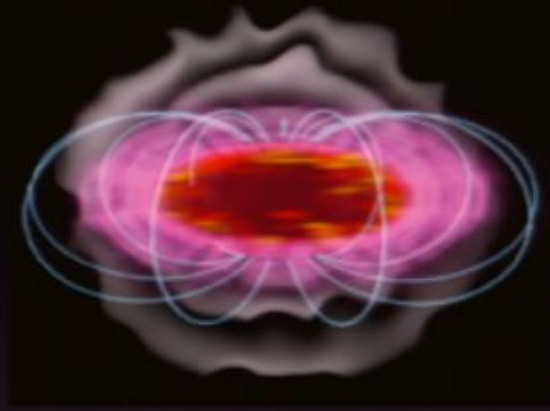
Must fold with PDFs to get rate at LHC ...
but first, discuss aspects of decay

Decay: 1. Balding

"Black hole has no hair"



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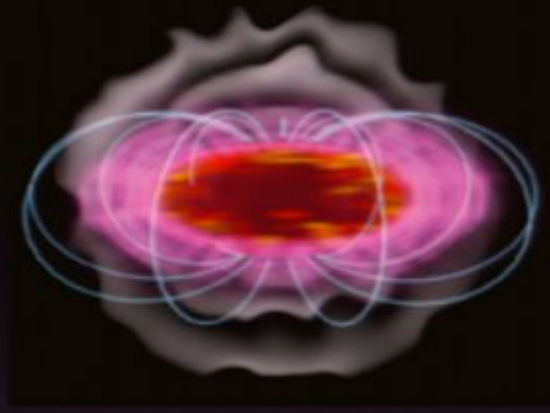

"Black hole has no hair"

- So black hole first sheds multipole moments of all fields (also, charge, color)

- Classical process, timescale $t \sim R_S$

Balding, cont'd

- Emit grav., EM, etc radiation
- Result: spinning (Kerr) BH
- Lower bd on area from A_{TS}

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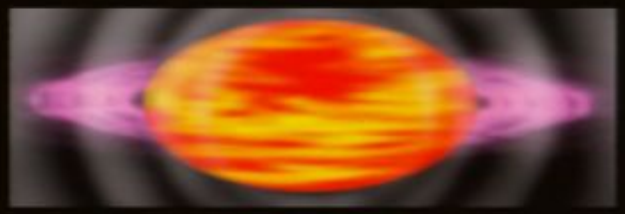
Possible future improvements: numerical study? (essentially classical process) -- explicit description of formation

Decay: 2. Spindown



- Spinning black hole begins to Hawking radiate
- Preferentially sheds angular momentum
- Time scale: $t \sim E^{D-1/D-3}$
- Must calculate higher-D Hawking emission rates
- HARD PROBLEM! (~thermal, +gray body)
- Initial estimates based on extrapolation from 4d: SBG & Thomas

Spindown, cont'd

Much ongoing work:

Casals, Creek, Dolan, Kanti, Winstanley

Ida, Oda, & Park +others ...

Spindown, cont'd

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Indeed, a recent claim (Ida, Oda, & Park), based on gray body factors and numerical evolution:

$> 50\%$ of mass lost during spindown.

Spindown, cont'd

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Indeed, a recent claim (Ida, Oda, & Park), based on gray body factors and numerical evolution:

$> 50\%$ of mass lost during spindown.

But bear in mind:

1) depends on rather arbitrary definition of end of spindown;

2) continued uncertainties over bulk emission

Spindown, cont'd

- This does suggest looking for characteristic radiation patterns, as proposed in SBG & Thomas

- Also, spindown/higher dim effects modify ratio vector:spinor:scalar; vectors and spinors dominate

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Future improvements:

Carefully check and bring this story to completion, specifically working out signatures

Decay: 3. Schwarzschild

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- Possibly subdominant, <50%??

- Hawking emission (power spectrum, relative emission rates, ...) better understood

- Approx. thermal spectrum (w/ gray body modification) at $T_H \propto 1/R_S \propto M^{-1/D-3}$

- Multiplicities approx. thermal, but e.g. suppression of low-E gauge bosons, etc.

Future improvements needed:

Full study of evolution through spindown and Schwarzschild phases, properly incorporating gray body factors, and integrating over evolution, to determine

energy spectrum

relative multiplicities

event shapes (angular distribution, etc.)

Decay: 4. Planck

- When the BH reaches $M \sim M_P$, known physics breaks down

- The most interesting phase

- Expect: a few particles/strings w/ $E \sim M_P$ but who knows?

Experimental expectations:

Threshhold for BH production

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still $M_D \gtrsim 1TeV$ (SUSY 2007; PDB conventions)

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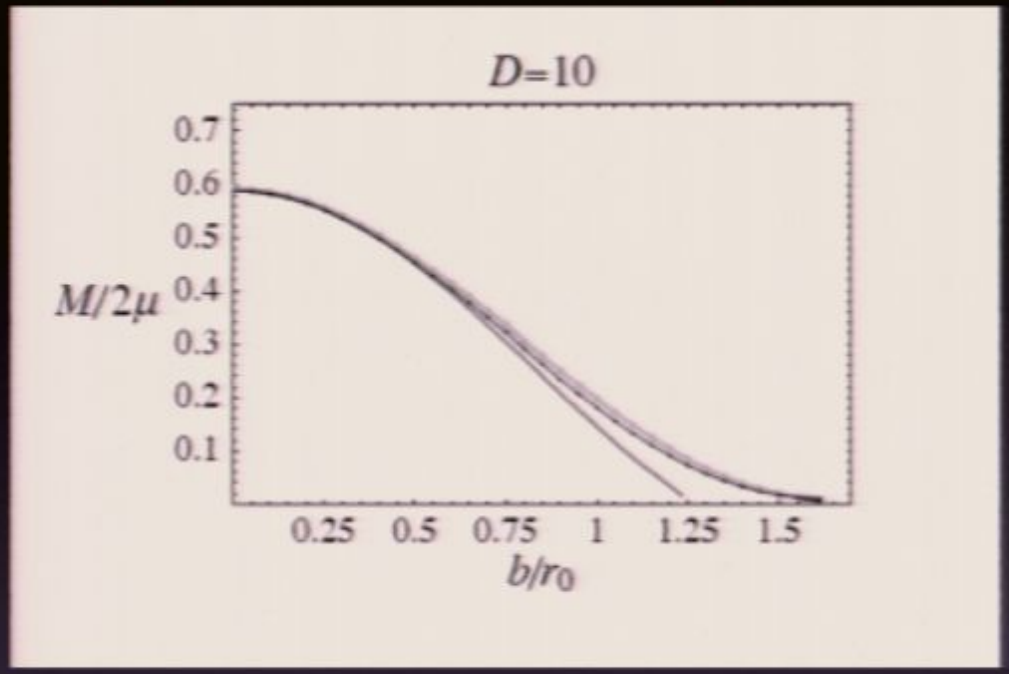
Event rates originally estimated to approach 1 Hz ...

But greater inelasticity from higher D can reduce ...



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- represents a lower bound. E.g. in 4D, lb is .71E; improved estimates (D'Eath): .84E

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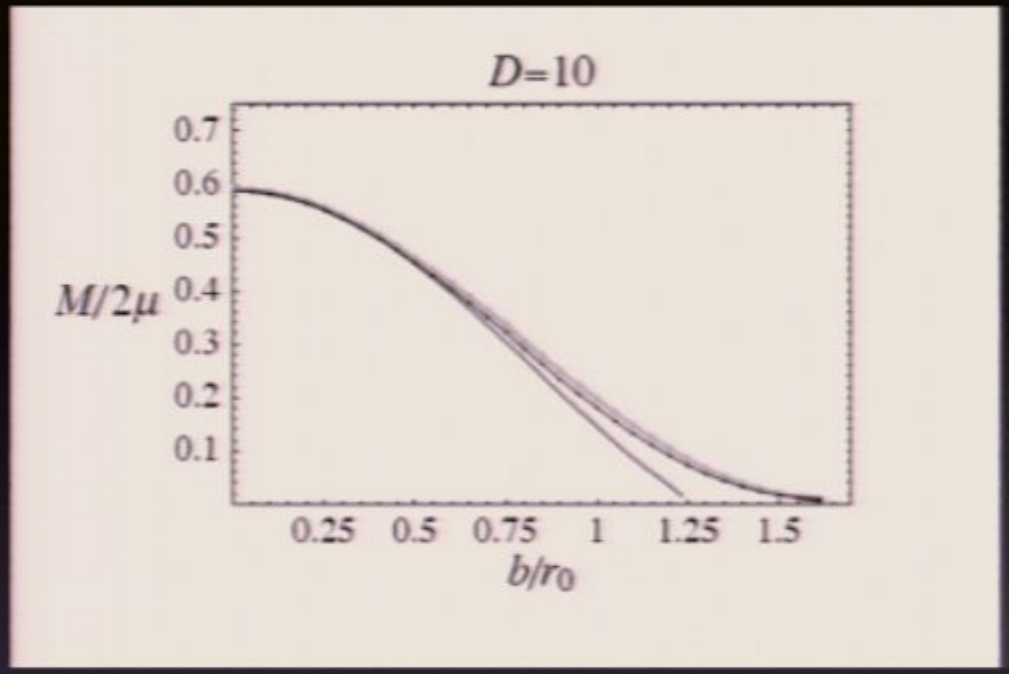

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So: rough estimate:

$$(I): \quad M = .6E\ , b < .5R_S \quad ; \quad M = 0\ , b > .5R_S$$

$$(II): \quad M = .7E\ , b < .5R_S \quad ; \quad M = 0\ , b > .5R_S\ .$$

Fold in PDFs (courtesy T. Rizzo), find:

$$(I) : \sigma = 1.8 \times 10^2 fb \Rightarrow 1BH/10min$$

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(At nominal LHC luminosity of $10^{34}/cm^2 s$)

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... still very respectable!

Explicit signatures?

Event generators

TRUENOIR

CHARYBDIS

Catfish

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... just Schwarzschild, not spindown

So, given importance of spindown, this suggests more work is needed for detailed quantitative predictions

Nonetheless, striking qualitative signatures can be inferred

- potentially large cross-section (.02 Hz ?)
- (increase of cross section w/ energy)
- relatively high sphericity
- high multiplicity of primaries
- hard transverse leptons and hard jets -- many
- ~thermally-determined ratios of species
- angular distributions characterizing spindown
- jet suppression

...

What about cosmic rays?

(SBG & Thomas; Feng & Shapere; Anchordoqui & Goldberg; Kowalski, Ringwald, & Tu; Alvarez-Muniz, Feng, Halzen, Han, Hooper, ...)

$$\nu + N \rightarrow BH + X$$

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could see (or rule out) at Auger, IceCube, ...?

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Lykken, Mena, and Razzaque: cosmogenic ν

flux suppressed through annih. w/ $\bar{\nu}$'s

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If we're very lucky we might see some hints from Auger, otherwise will have to wait and see what LHC brings -- not long to wait!

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On the theory side: building detailed TeV-scale gravity models has been very challenging, but much progress and ongoing developments ...

warped/flux compactifications;
brane world constructions, etc.

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Black hole information paradox

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Apparently must abandon a cherished principle of physics:

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...widespread belief

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3) Where does GR+local QFT fail?

- what is the correspondence limit for new physics?

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... suggests intrinsically gravitational effect;

non-perturbative

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"the locality bound"

(extends off shell?)

Locality is a cornerstone of QFT -- can we believe this?

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How do we characterize locality?

1) Scattering behavior:

Local QFT

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Froissart

$$T(s,t) < E^N$$

Polynomial bddness --
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$$T(s,t) \sim e^{R_S(E)\sqrt{t}}$$

(work w/ M. Srednicki, to appear)

2) Commutativity of local observables

1) Scattering behavior:

Local QFT

$$\sigma_T \leq c(\ln E)^{D-2}$$

Froissart

$$T(s,t) < E^N$$

Polynomial bddness --
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However:

- approximately local ("proto-local") observables can apparently be constructed

SBG, Marolf & Hartle, hep-th/0512200,
M. Gary & SBG hep-th/0612191

- but limitations on locality also from strong gravitational effects (locality bound, etc.)

Of course, there are other reasons to suspect nonlocality:

- ideas of holography (though haven't yet sharply resolved info paradox)

- conundrums of cosmology: landscape, Boltzmann brains, etc.; possible resolution through breakdown of local QFT

SBG, hep-th/0703116

Arkani-Hamed et. al, arXiv:0704:181

SBG & Marolf, arXiv:0705:1178

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indications of breakdown of perturbative gravity, thus role for non-perturbative gravity, which could well be fundamentally nonlocal

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Proposal: information escapes through such nonlocality of nonperturbative gravity; this becomes important on timescales $t \lesssim M^3$

Conclusions:

- If TeV-scale gravity is correct, BH production could be an spectacular effect
- While more work needed to understand detailed signatures, semi-quantitative arguments indicate they should be prominent
- Whether or not BH production is accessible in the near future, its possibility raises profound theoretical issues that may help guide the next revolution in quantum gravity