

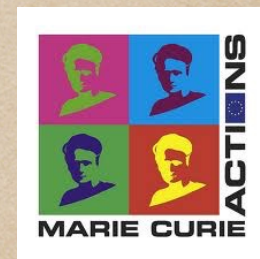
Matter does not matter: Universality in ultra-relativistic black-hole collisions

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Overview

- Motivation
- High-energy collisions of matter balls
- The impact of BH spins on collisions
- Unequal-mass BH collisions
- Preliminary results: BH collisions in $D > 4$
- Conclusions

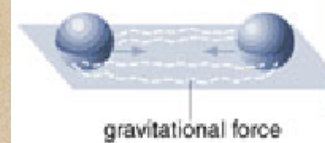
Motivation

- Tests of the Hoop conjecture Thorne 1972
- TeV Gravity

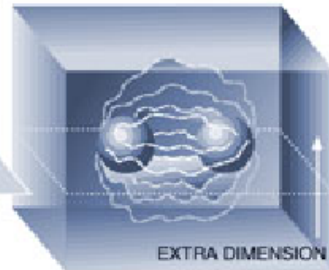
Black Holes on Demand

Scientists are exploring the possibility of producing miniature black holes on demand by smashing particles together. Their plans hinge on the theory that the universe contains more than the three dimensions of everyday life. Here's the idea:

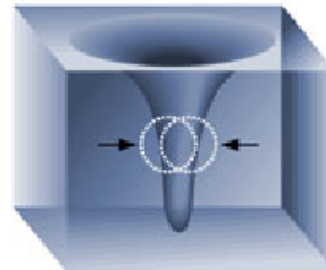
Particles collide in three dimensional space, shown below as a flat plane.



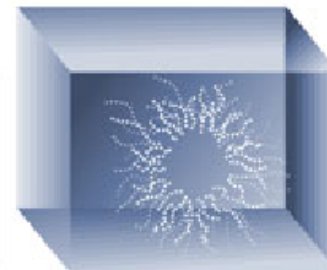
As the particles approach in a particle accelerator, their gravitational attraction increases steadily.



When the particles are extremely close, they may enter space with more dimensions, shown above as a cube.



The extra dimensions would allow gravity to increase more rapidly so a black hole can form.



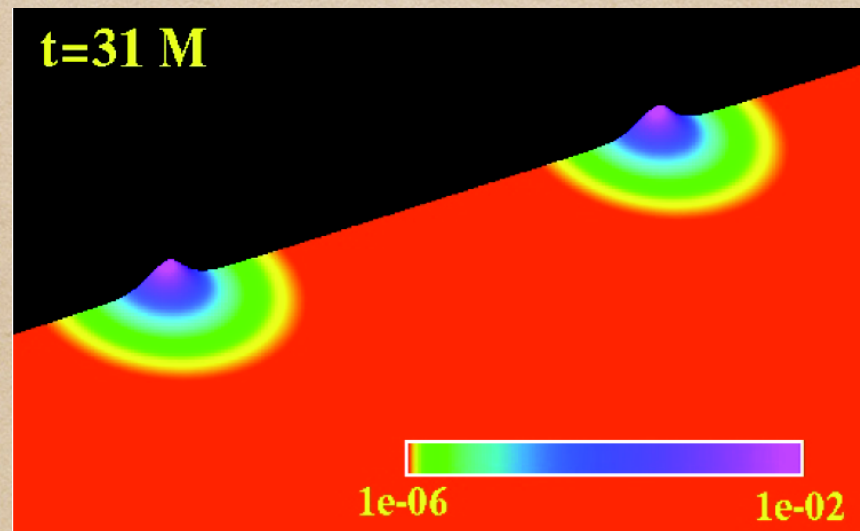
Such a black hole would immediately evaporate, sending out a unique pattern of radiation.

- AdS/CFT correspondence
Study quark-gluon plasma through BH collisions in AdS
e.g. Bantilan & Romatschke 1410.4799
Impact of charge on the collisions / thermalization
- Explore GR in the most non-linear regime

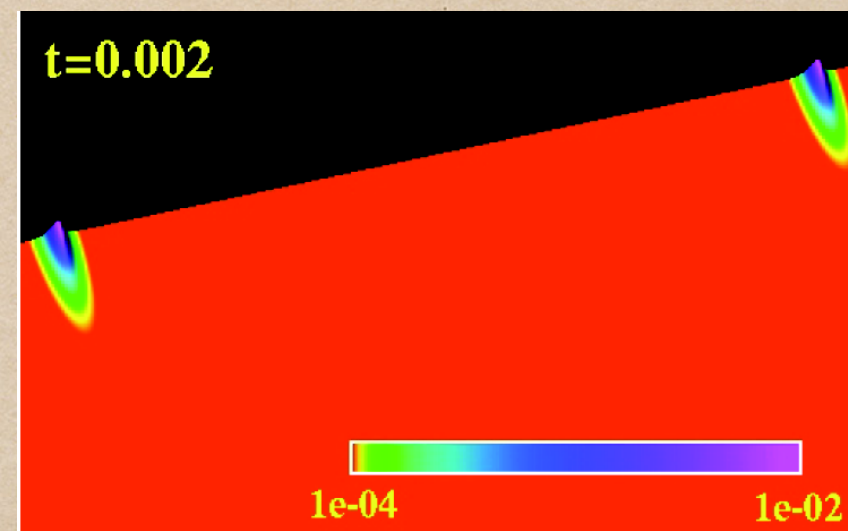
Collisions of matter balls

- Einstein + minimally coupled, complex scalar field

Choptuik & Pretorius PRL (2010)



$$\gamma = 1$$



$$\gamma = 4$$

BH formation threshold: $\gamma_{\text{thr}} = 2.9 \pm 10\% \sim \gamma_{\text{Hoop}}/3$

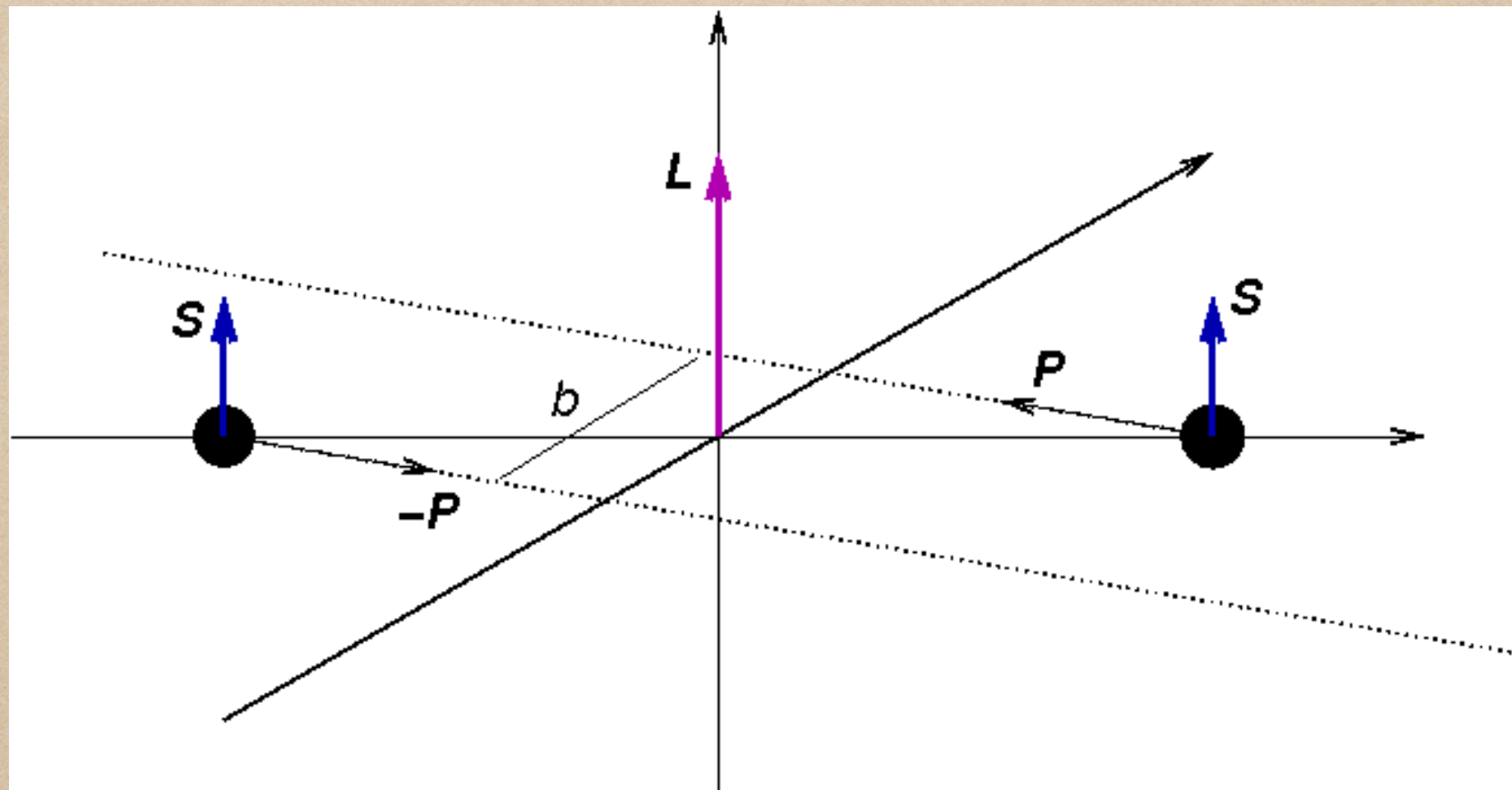
- Einstein + perfect fluid balls

East & Pretorius PRL (2013), Rezzolla & Tanaki CQG (2013)

- BH formation also compatible with Hoop predictions
- Signature of Type I critical behavior

Collisions of spinning BHs in D=4

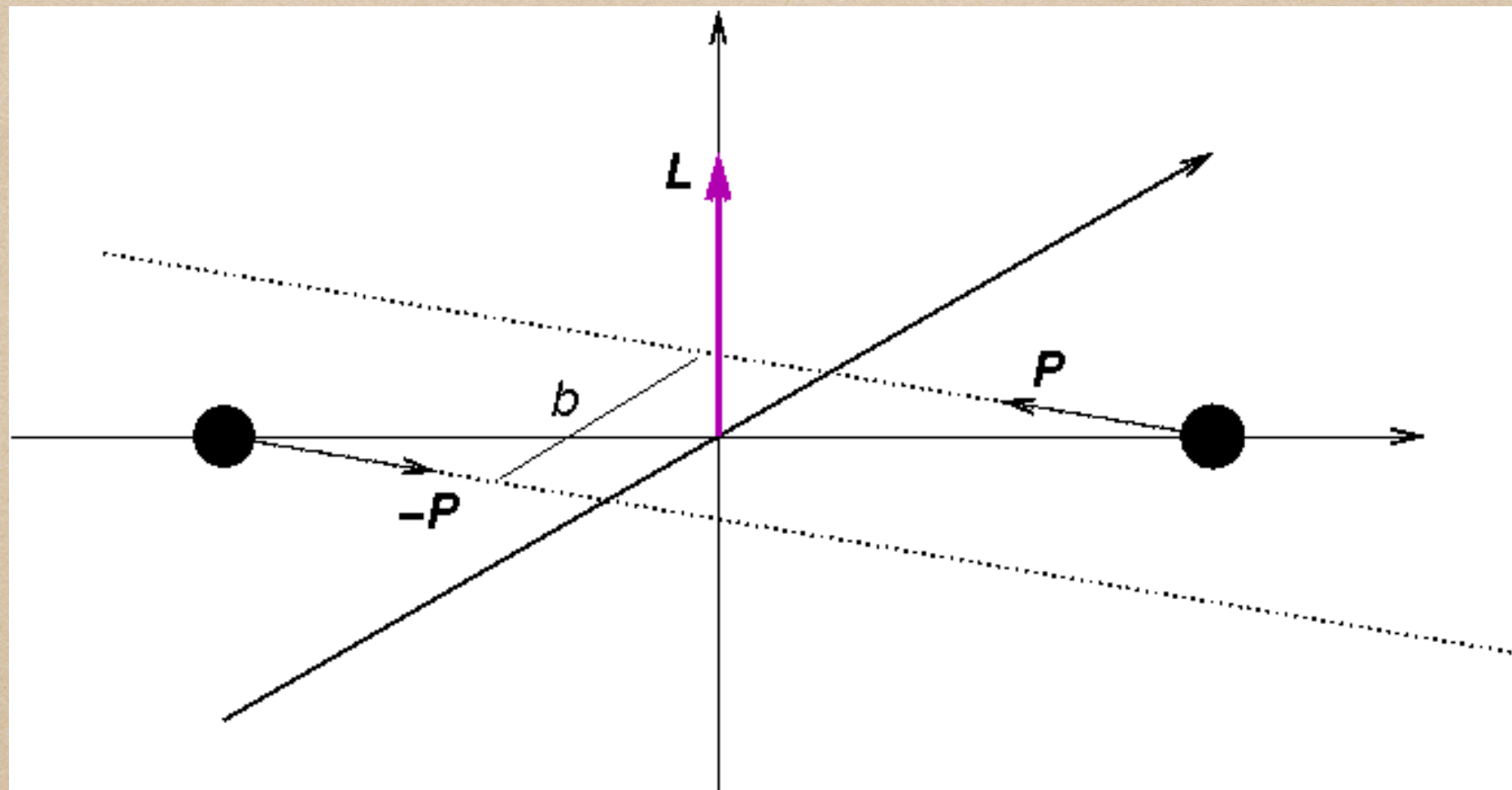
- Orbital hang-up: Campanelli et al. PRD (2006)
- Equal-mass BHs, Boost $\gamma = 1/\sqrt{1-v^2}$
Impact parameter $b = L/P$



- How are scattering threshold and radiated GW energy affected?

Collisions of spinning BHs in D=4

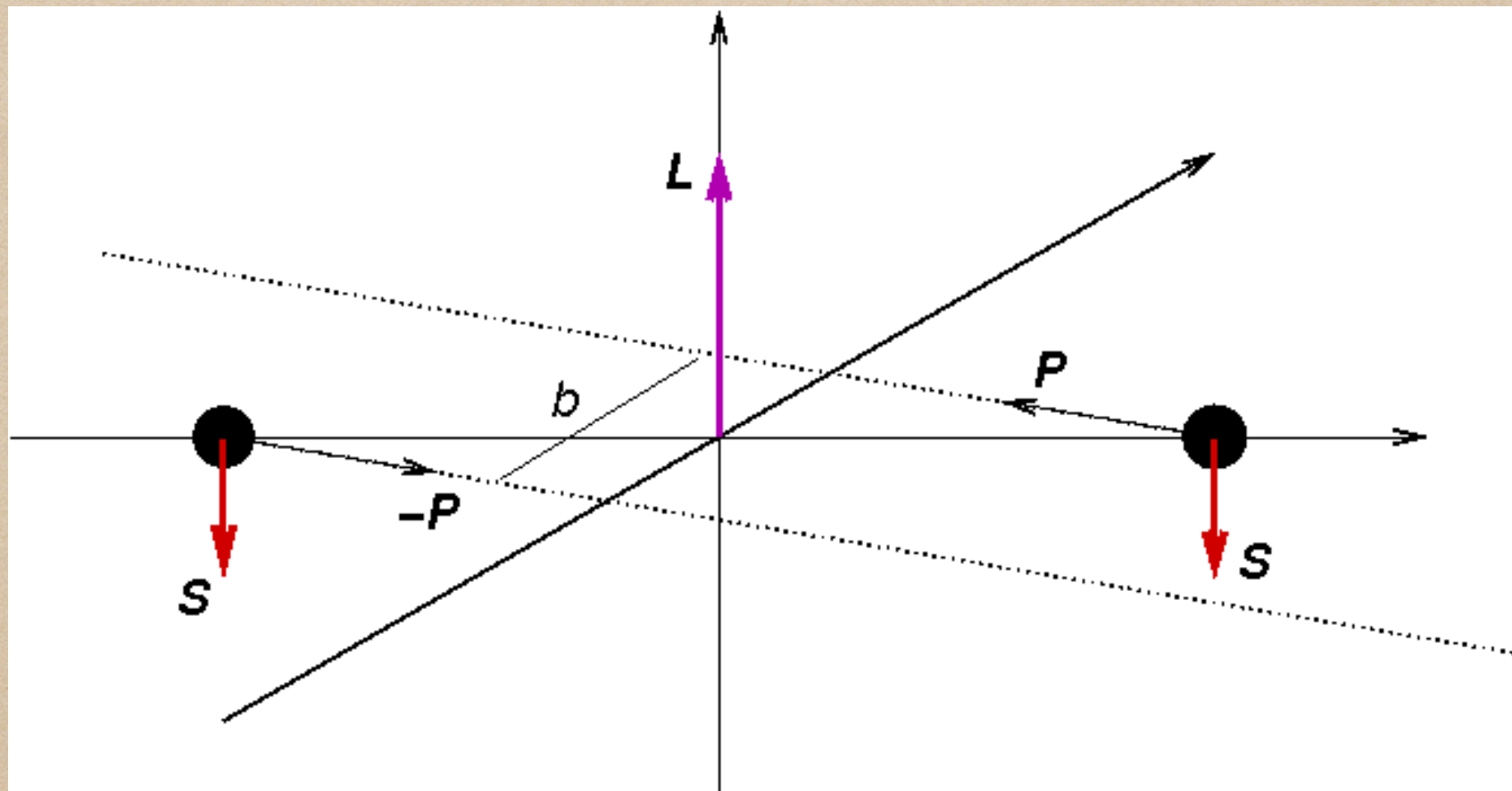
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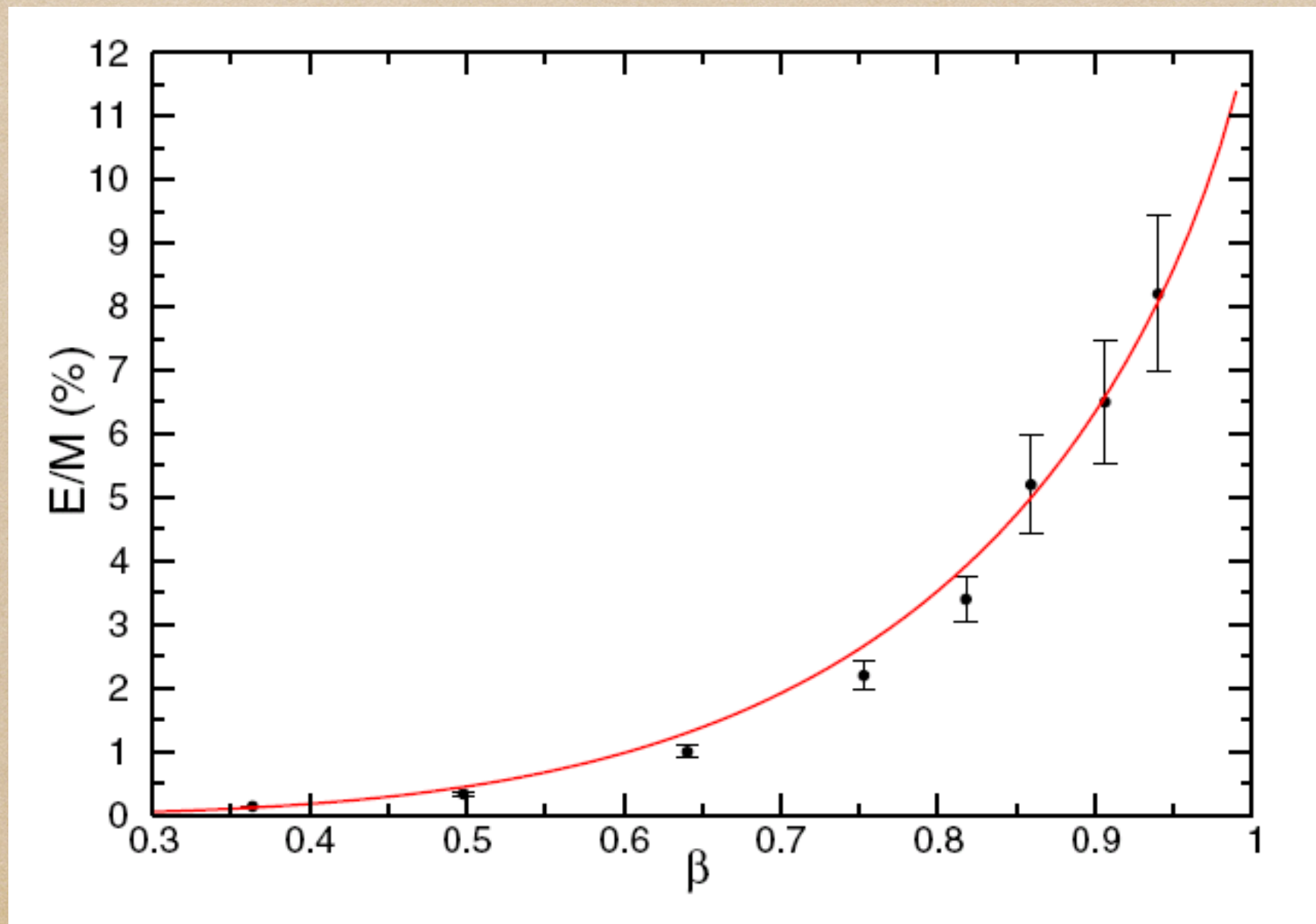
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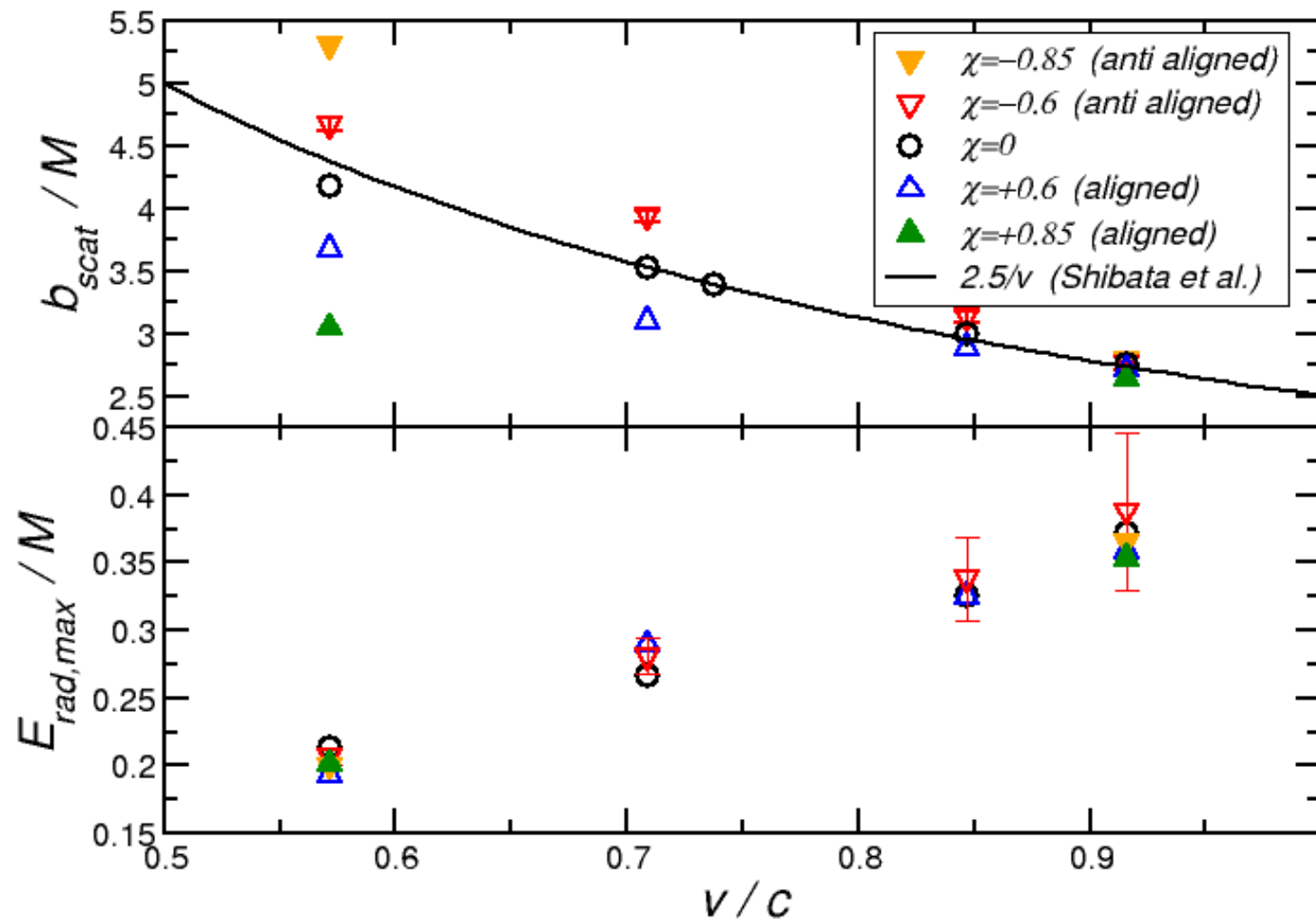
Boosted BH head-on collisions in D=4

- BSSN, Cactus, Carpet, Moving Puncture, TwoPunctures, AHFinderDirect
- Equal-mass BHs, no spin $\lim_{\beta \rightarrow 1} E_{\text{rad}} = 14 \pm 3 \%$



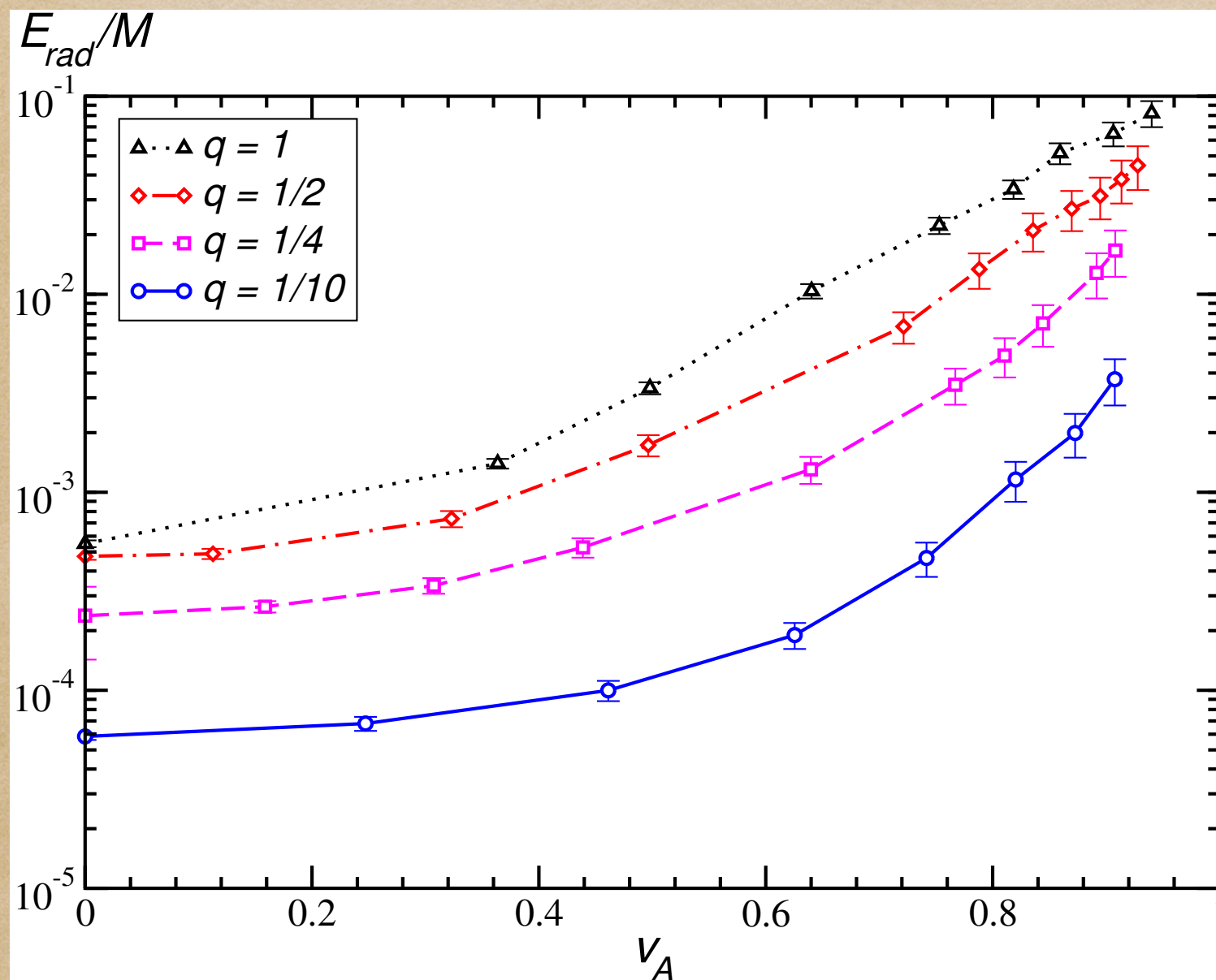
Grazing collisions in D=4

- **Spins:** aligned, zero, anti aligned US, Berti, Cardoso, Pretorius PRL '13
- $b_{\text{scat}}, E_{\text{rad}}$: spin effects washed out as $v \rightarrow c$



Unequal-mass head-on collisions in $D=4$

- No spins, center-of-mass frame US, Berti, Cardoso, Pretorius PRD '16
- Mass ratio $q = m_2/m_1 \leq 1$



$$E(q = 1) \rightarrow 12.7 \pm 1.5 \%$$

$$E(q = 1/2) \rightarrow 11.2 \pm 2.7 \%$$

$$E(q = 1/4) \rightarrow 11.6 \pm 3.0 \%$$

$$E(q = 1/10) \rightarrow 12.0 \pm 3.0 \%$$

Conclusions

- All studies confirm: "Matter/structure does not matter"

- Boson star collisions
- Fluid balls
- Black-hole spins
- Different masses

In the limit $v \rightarrow c$ collisions appear to be universal

- How about higher dimensions?