Search for Black Holes at LHC

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- *Introduction*
- *Simulation of Black Holes (BH)*
- *Experimental Search*
- *Grey Body Factors*
- *Summary*

In (n+4) Dimensions $M_p \sim$ TeV

Extra space dimensions $\xrightarrow{\text{@ LHC}}$ *quantum sized* BH

Event horizon: $R_H \sim \frac{1}{M_p}\left(\frac{M_{BH}}{M_p}\right)^{\frac{1}{n+1}}$

Semiclassical ($M_{BH} > M_P$) cross section $\sigma \approx \pi R_H^2$

$$\sigma \sim \begin{cases} \text{nb} & : \text{ for } M_p = \ 2 \text{ TeV} \ , \ n = 7 \\ 100 \text{ fb} & : \text{ for } M_p = \ 6 \text{ TeV} \ , \ n = 3 \end{cases}$$

BH $\xrightarrow{\text{decay}}$ $jets + leptons + \gamma + \ldots$

$$T_H \sim \frac{n+1}{R_H}$$

Experimental Signatures

- *Large cross section*
- *Large* E_T
- *Large Mulitiplicity*
- *High sphericity events*

$$\text{BH decay phases} \begin{cases} \text{Balding} \\ \text{Hawking Evaporation} \begin{cases} \text{Spin} - \text{down} \\ \text{Swcharzschild} \end{cases} \\ \text{Planck Phase} \end{cases}$$

Simulation of BH decay in Herwig

- *Spinless* Black Hole.
- *Hawking Evaporation* Phase $\rightarrow$ (main) Mass Loss.
- Includes the BH *Recoil*.
- *Time Evolution* $T_H(t)$.
- BH $\rightarrow$ *SM* particles on the *brane*.
- *Black-body* approximation for BH evaporation.

See more on *Grey Body Factors*

- The flavor independent nature of BH decays.
- The generated events are passed through the

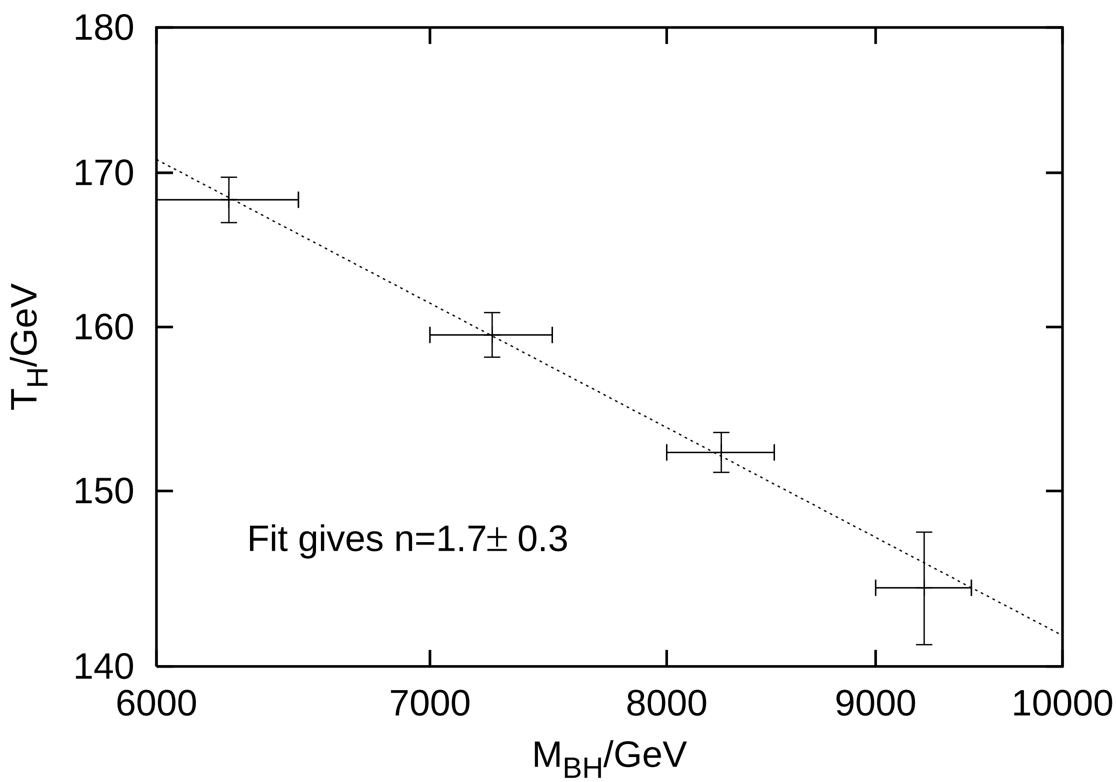
ALTFAST

Problem of Determination of n with Standard Method

It is assumed that the BH spends most of its time near the initial T_H.

- Use e, γ spectrum $\rightarrow$ Estimate T_H.
- Ignoring time variation of T_H.
- $\log(T_H) \sim \frac{-1}{n+1} log(M_{BH}) \rightarrow$ Find n .

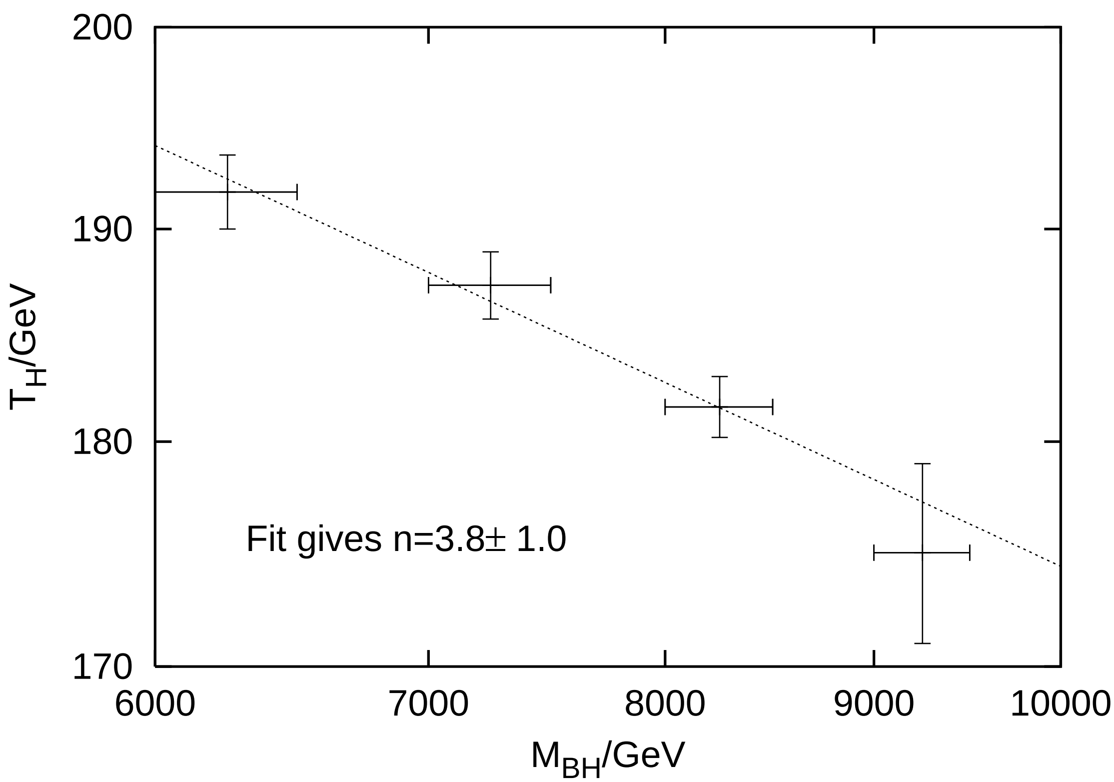
For $n = 2$ and $M_p = 1$ TeV;
Fit gives $n = 1.7 \pm 0.3$



It is not possible to ignore the time variation of T_H

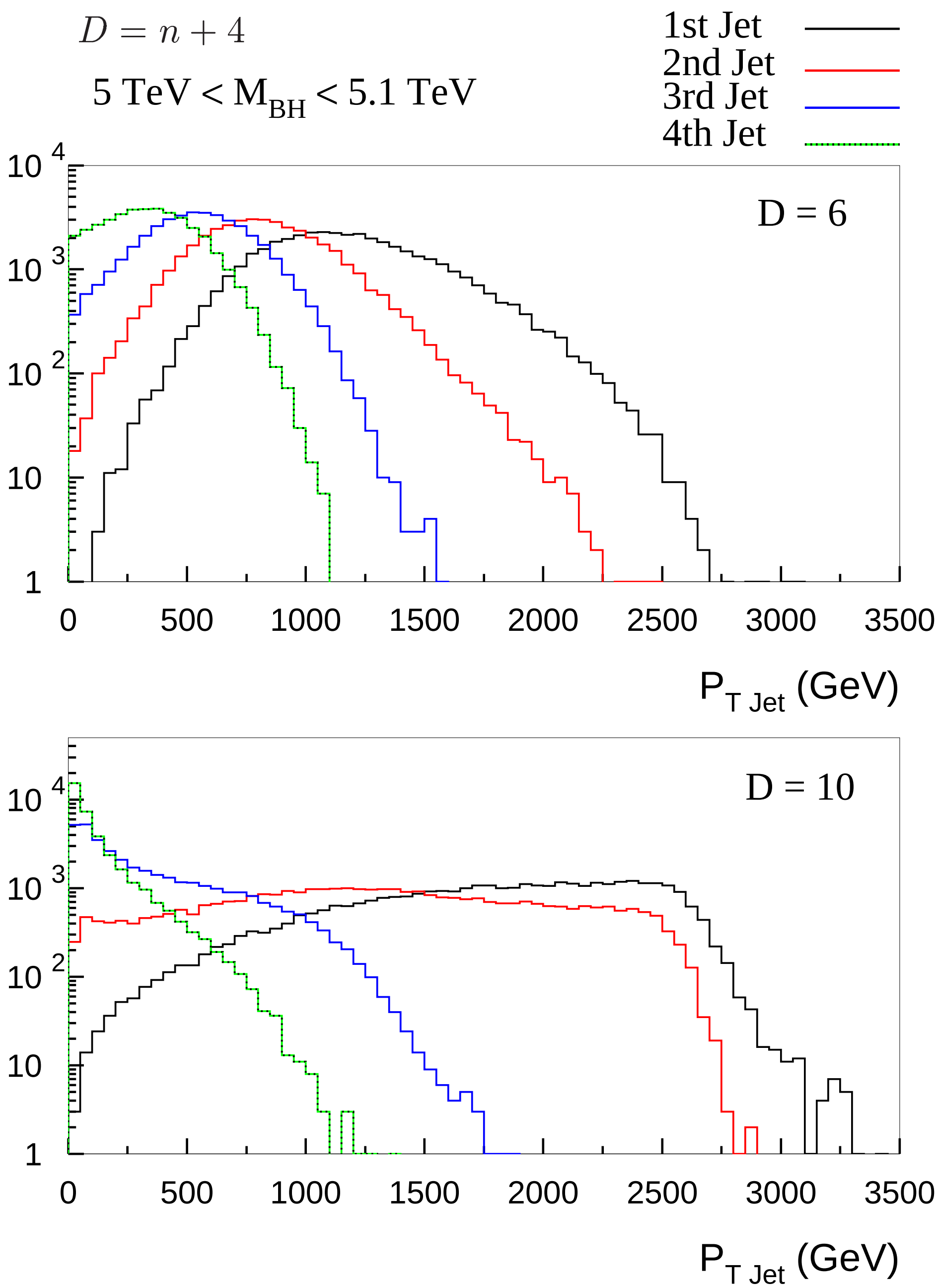
For $n = 2$ and $M_p = 1$ TeV with time variation;

Fit gives $n = 3.8 \pm 1.0$ (Chris Harris)

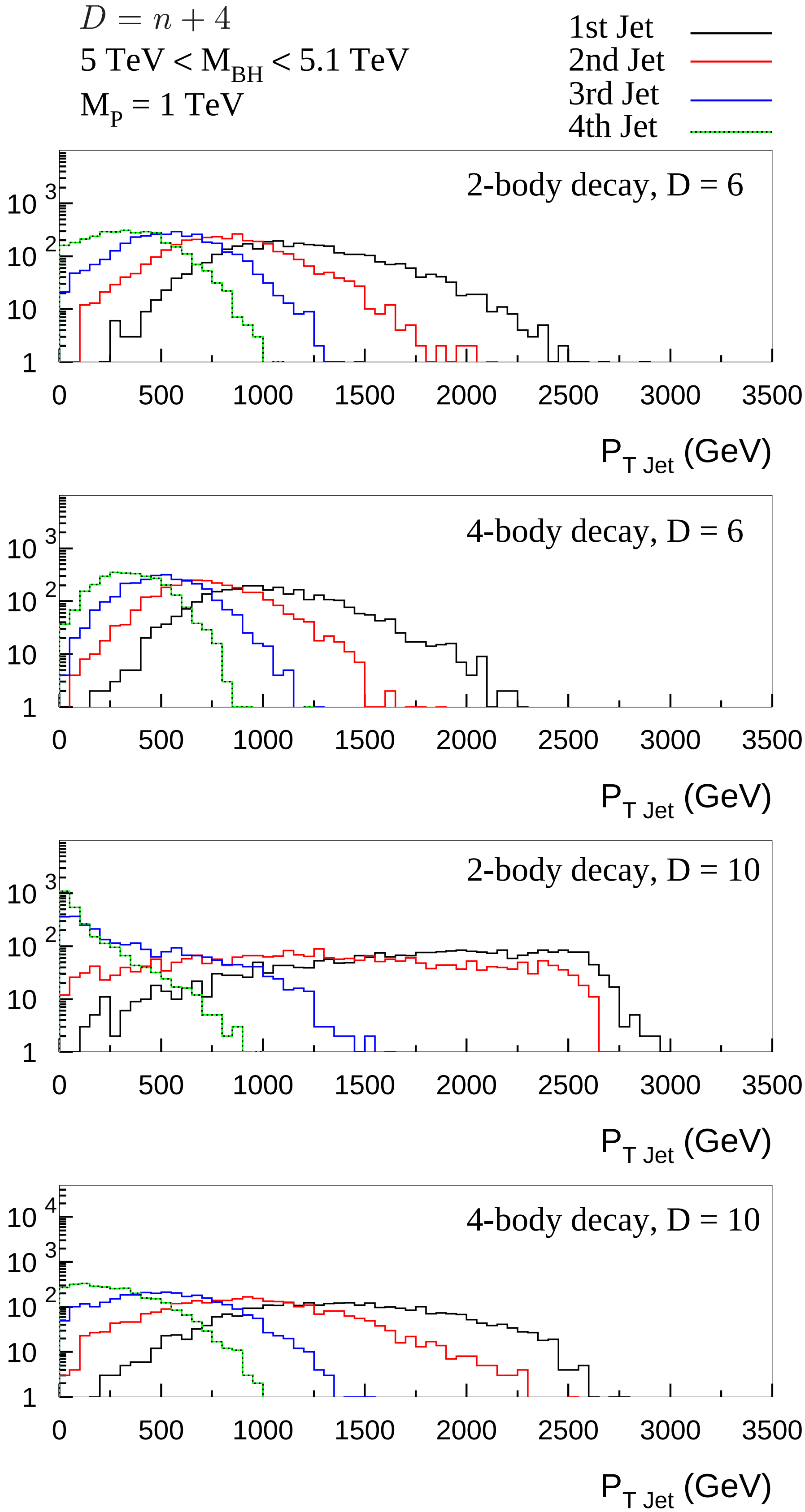


Find a *(kinematic) variable* of the BH which *depends* (stongly) on n $\rightarrow$ measure directly the true *number of space* dimensions.

2-body Remnant BH



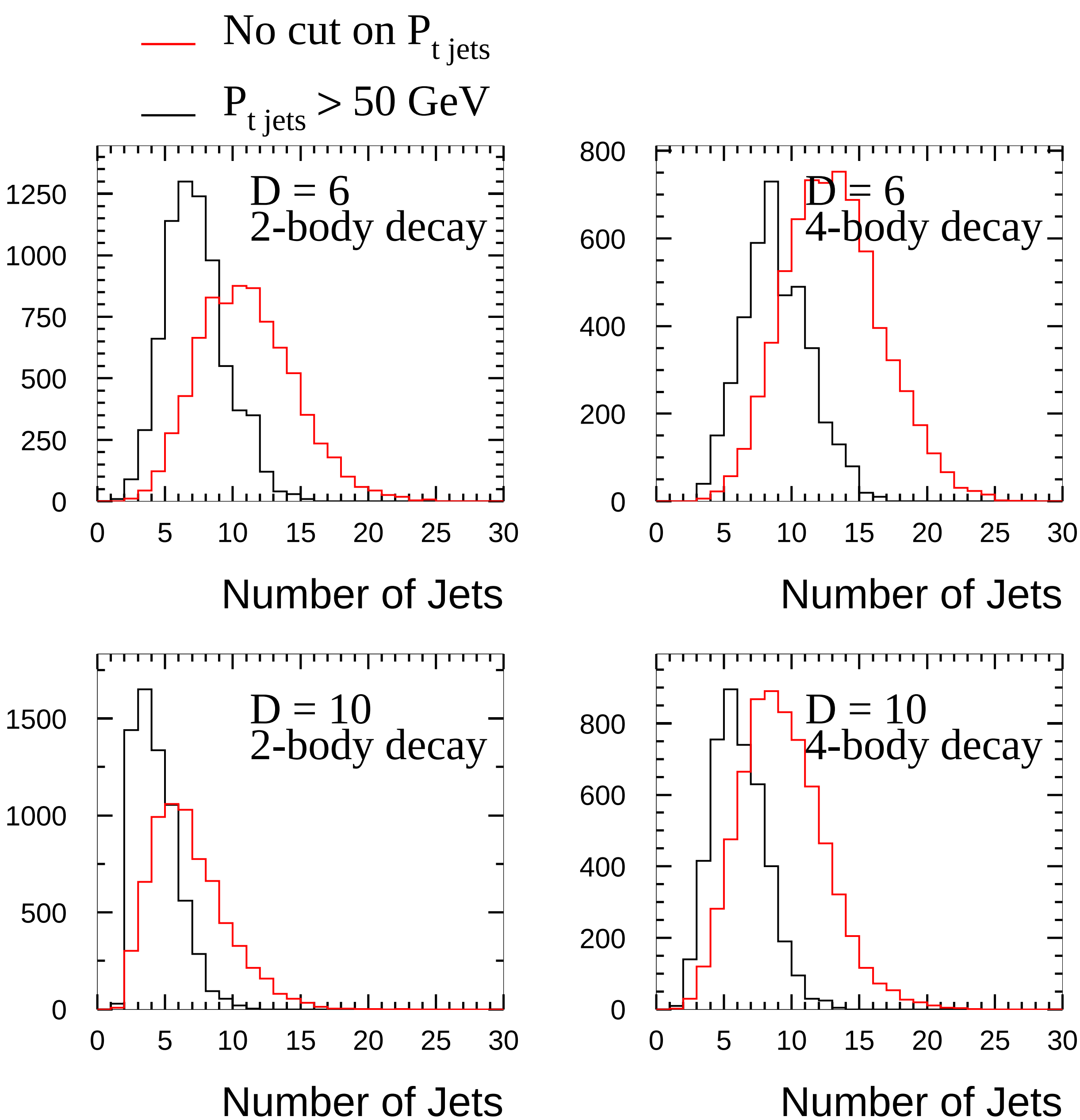
2-body and 4-body remnant BH



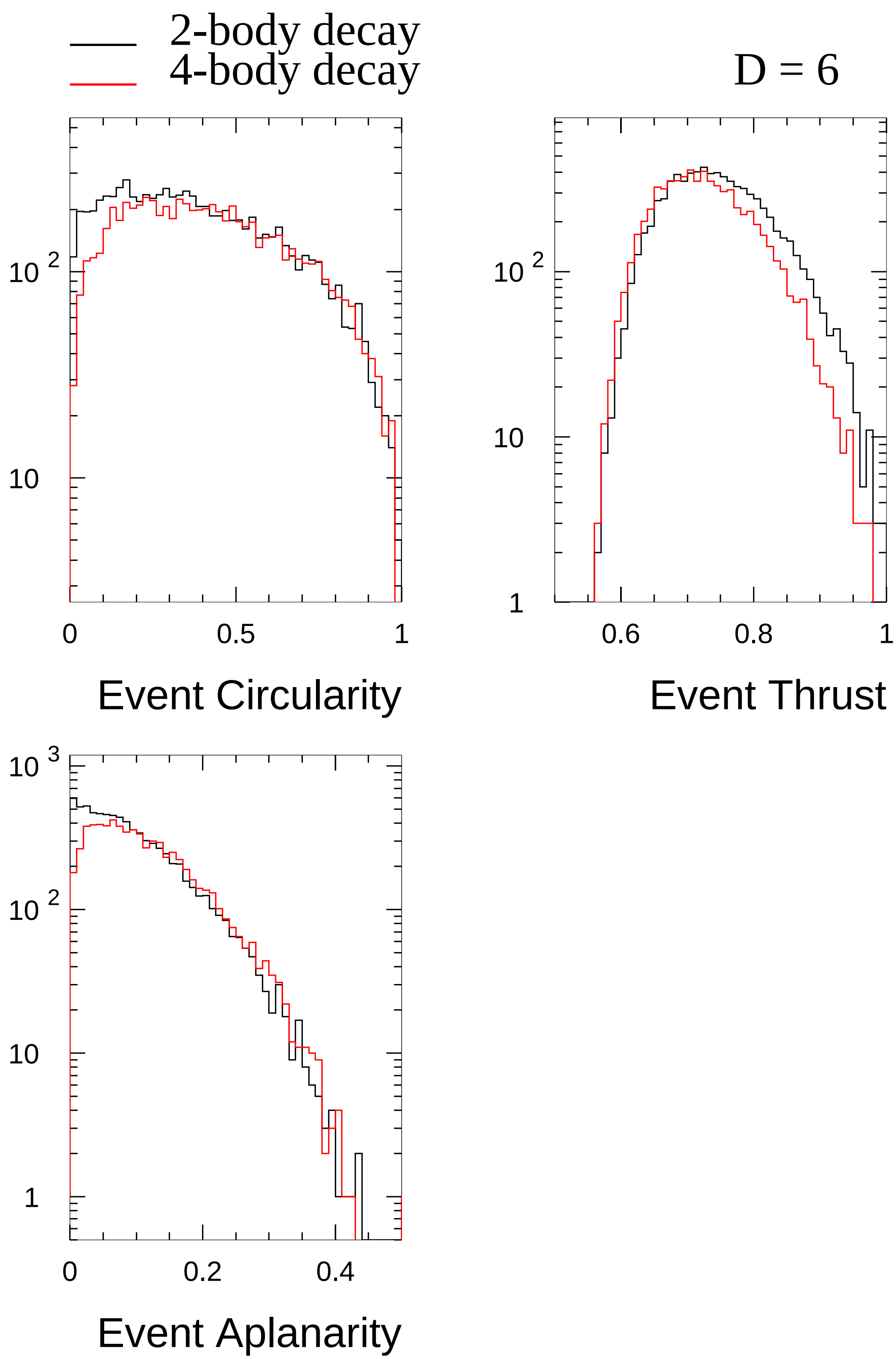
Jet Multiplicity for 6 and 10 Dimension BH

Average Multiplicity $>> 1$

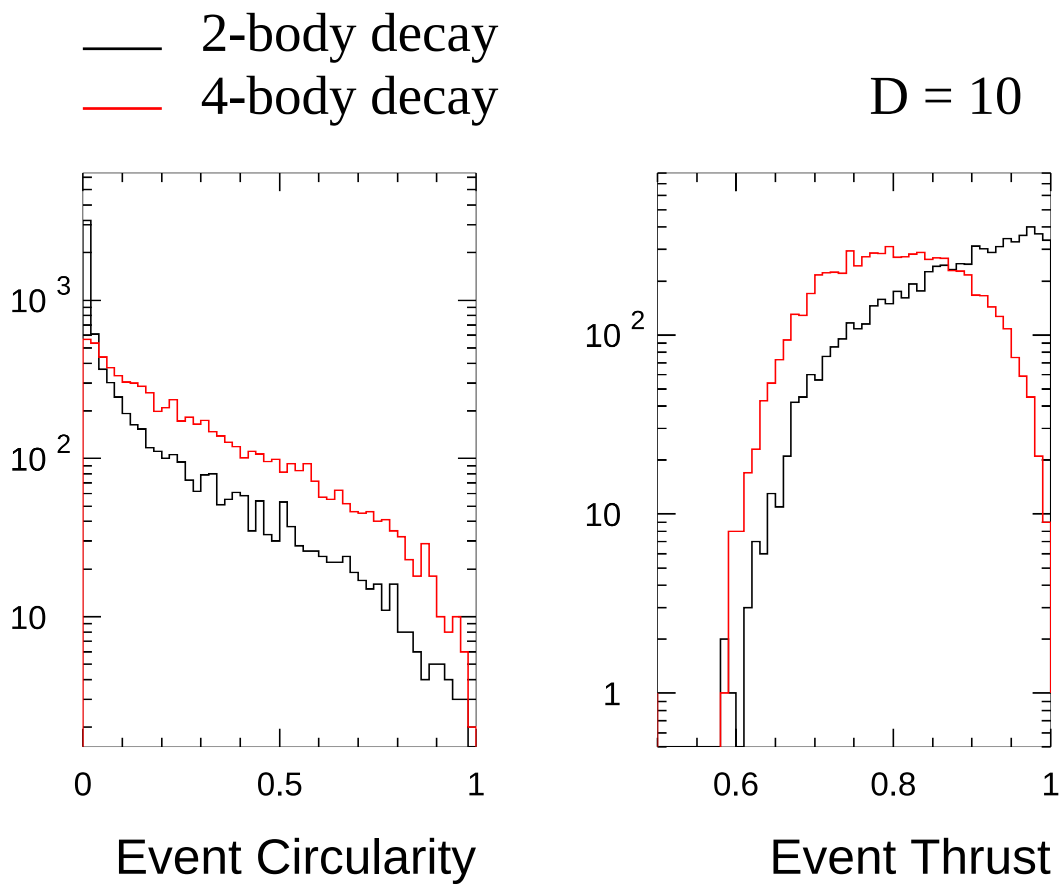
$D = n + 4$

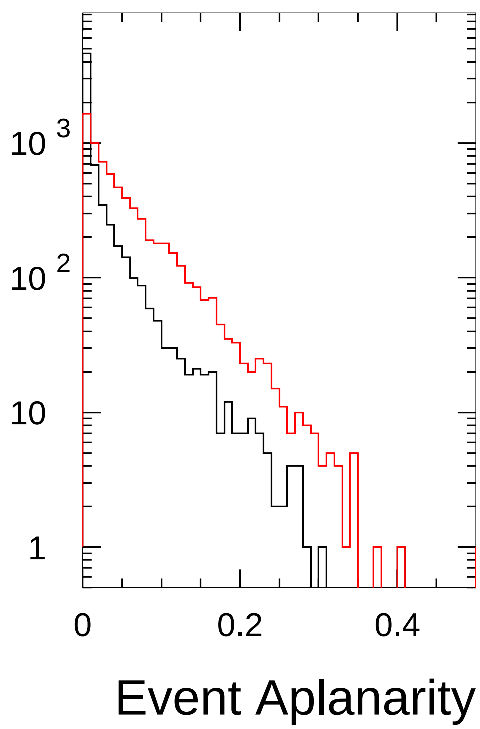


Event Shape for 6 Dimensional BH



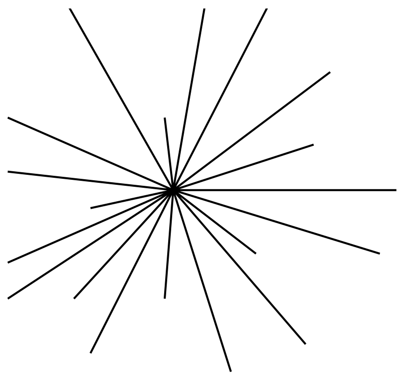
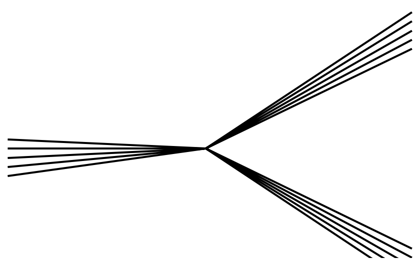
Event Shape for 10 Dimensional BH

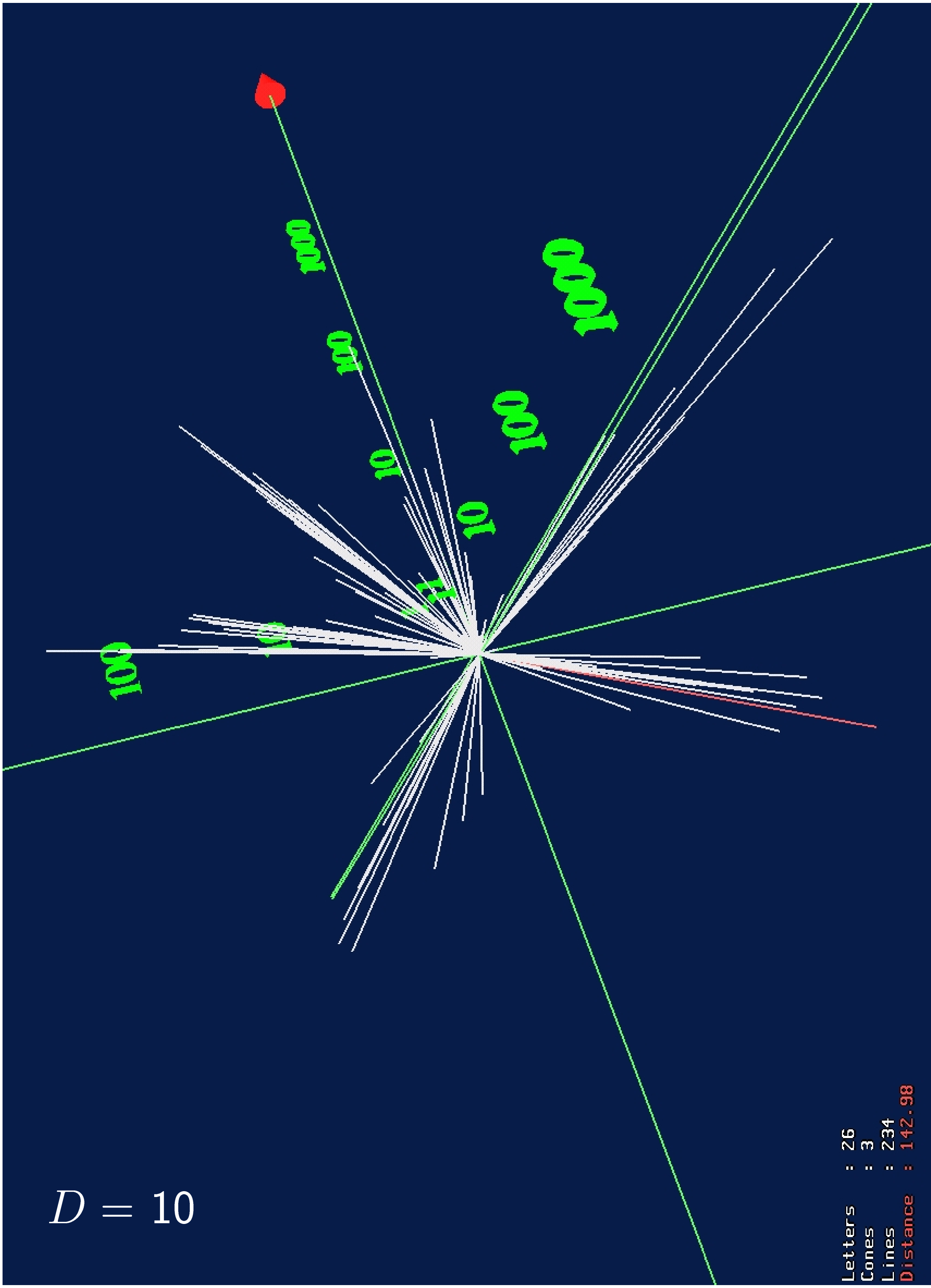




Relatively similar distributions for for $D = 8$ BH.

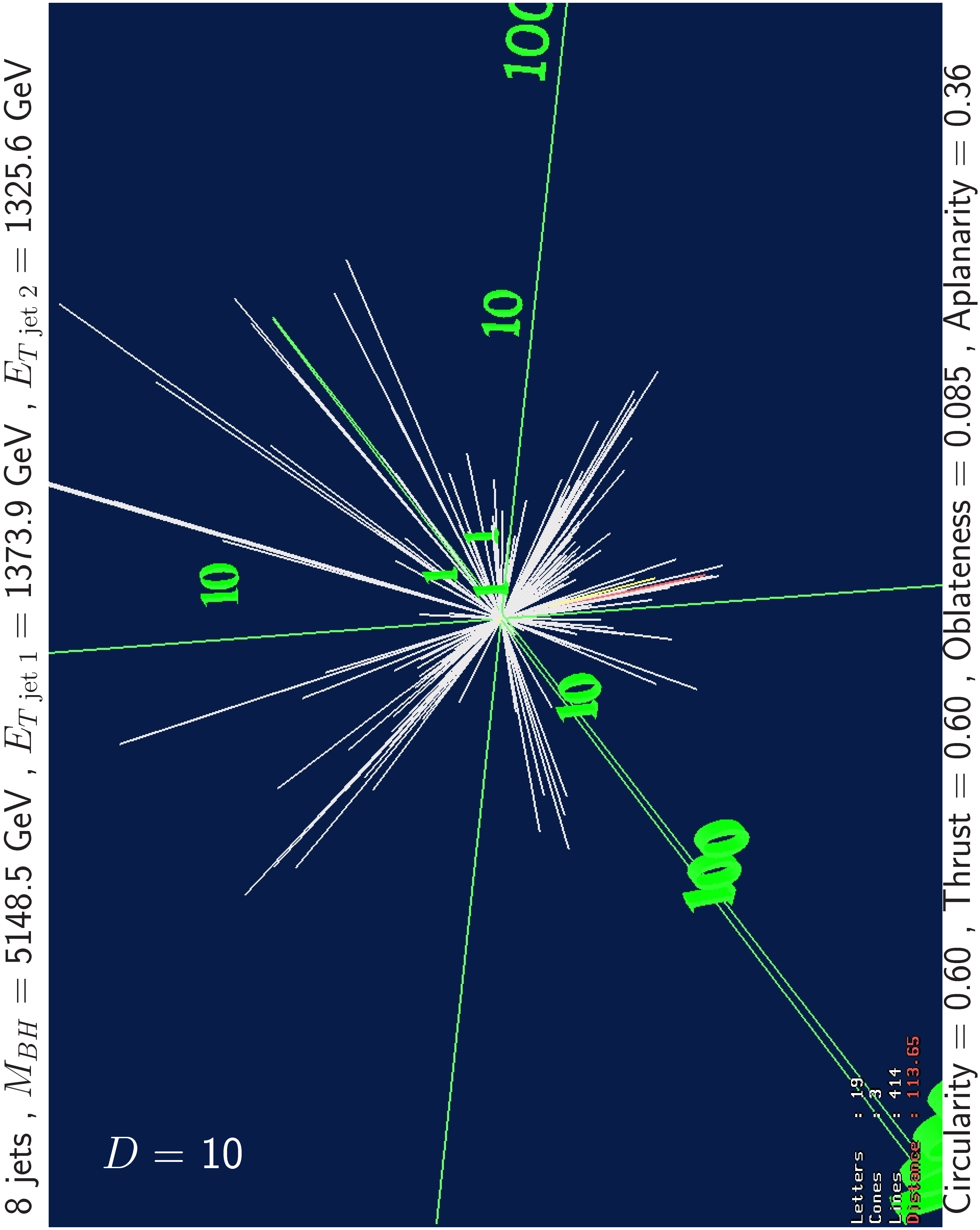
Hard to distinguish 8-D from 10-D BH

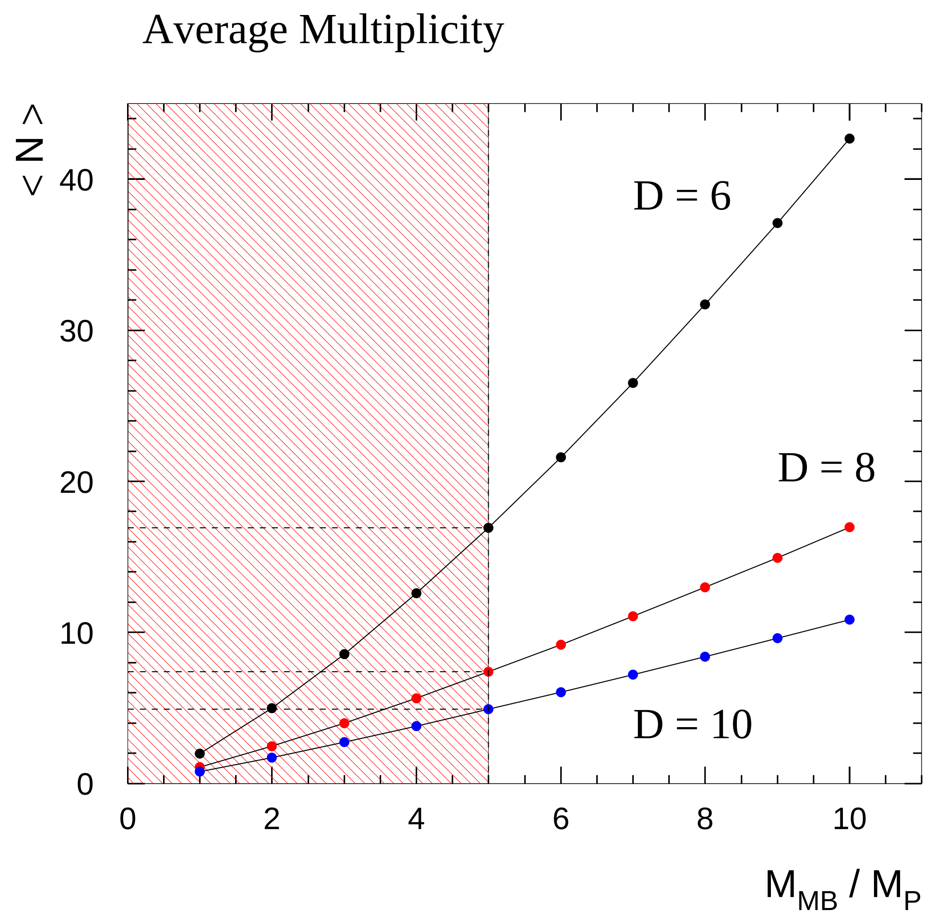
	Thrust	Oblateness	Sphericity	Apalnarity
Particle Trajectory	T	O	S	A
	$\to \frac{1}{2}$	$\to 0$	$\to 1$	$\to \frac{1}{2}$
	$\to 1$	$\to 0$	$\to 0$	$\to \frac{1}{2}$
	$\sim \frac{3}{4}$	$\sim \frac{1}{4}$	$\sim \frac{1}{2}$	$\to 0$
2-body , $D =$ 6	0.74	0.22	0.38	0.01
4-body , $D =$ 6	0.73	0.20	0.41	0.11
2-body , $D =$ 10	0.88	0.23	0.25	0.02
4-body , $D =$ 10	0.80	0.23	0.25	0.05



10 jets , $M_{BH} = 5180.7$ GeV , $E_{T\,\mathrm{jet}\,1} = 1410.7$ GeV , $E_{T\,\mathrm{jet}\,2} = 834.7$ GeV

Circularity = 0.31 , Thrust = 0.67 , Oblateness = 0.28 , Aplanarity = 0.13


8 jets , M_{BH} = 5148.5 GeV , $E_{T\,\mathrm{jet}\,1}$ = 1373.9 GeV , $E_{T\,\mathrm{jet}\,2}$ = 1325.6 GeV
Circularity = 0.60 , Thrust = 0.60 , Oblateness = 0.085 , Aplanarity = 0.36
$D = 10$
Letters : 19
Cones : 3
Lines : 414
Distance : 113.65



- For the *majority* of the decay (Semi-classical regime)
  - ▷ Average Multiplicity $>> 1$
  - ▷ $M_{BH} >> M_p$ and $M_{BH} >> T_H$.

- These conditions start *breaking down* towards the *end of the decay*. (Theoretically invalid regime)

- *Most* of the *problems* are for the low multiplicity events $\longrightarrow$ higher *dimensional* BH.

More study needs to be done!

Grey Body Factors

▷ Modify the spectrum of emitted particles from that of the perfect thermal *black-body*.

→ Changing energies → multiplicity of particles from a BH

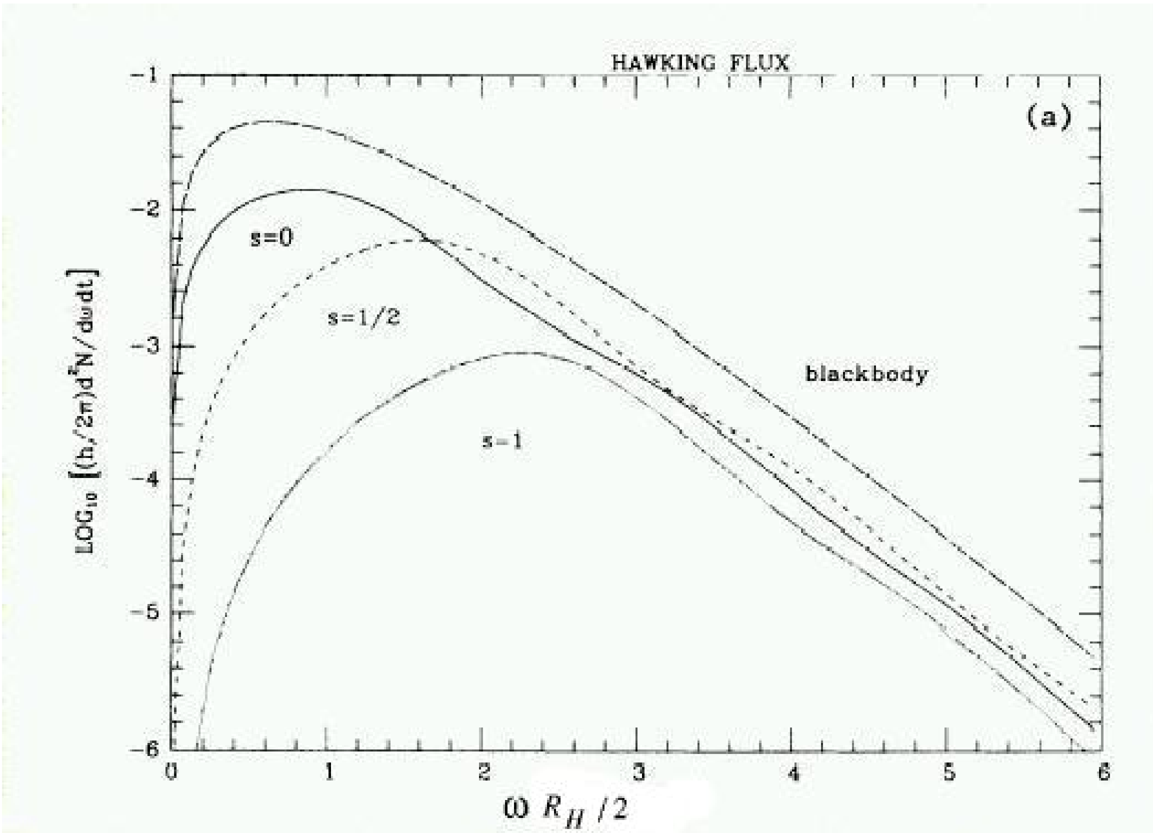
▷ They *differ* for *different spins* → in different numbers of dimensions the *relative ratios* of scalars:fermions:gauge bosons will be *different*.

May change the BH event signature

Decay Spectrum: $$\frac{dN_{i,\omega,l,m}}{d\omega dt} = \frac{1}{2\pi}\frac{\gamma_{i,\omega,l,m}}{\exp(\omega R_H) \mp 1}$$

- $\gamma_{i,\omega,l,m}$ Grey-body factors
- i : particle type
- l, m : angular momentum quantum numbers

Energy Spectrum for black body, $s = 0$, $s = \frac{1}{2}$, and $s = 1$ Particles in 4-Dimension



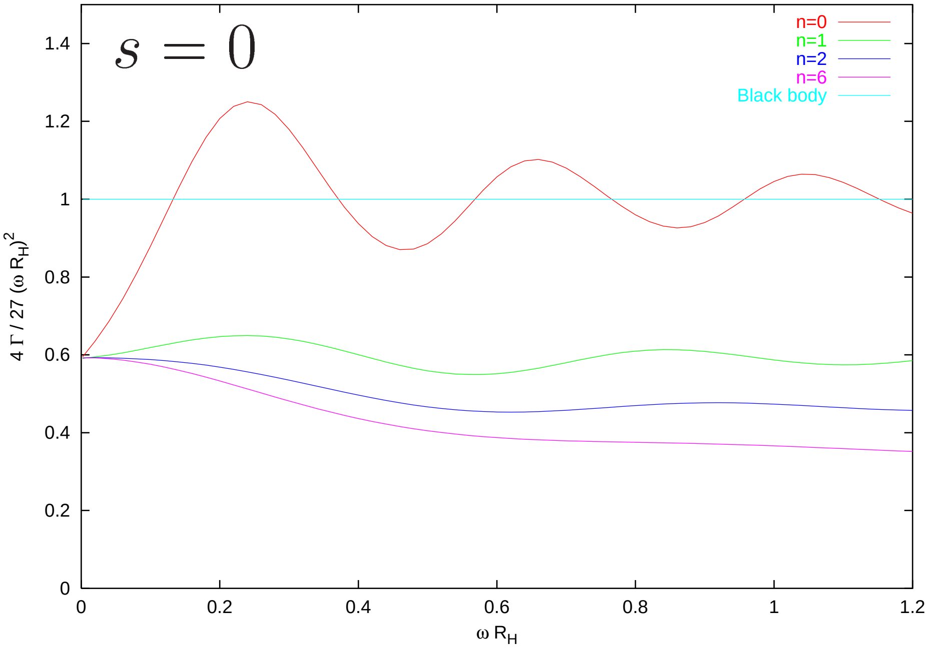
MacGibbon and Webber (Phys. Rev. D. 41, 3052 (1990)

▷ It seems no one has done full numerical *solutions* in (4+n) *dimensions.*

▷ Chirs Harris has done numerical solutions in (4+n) dimensions for fermions and scalars. He is working on vector bosons.

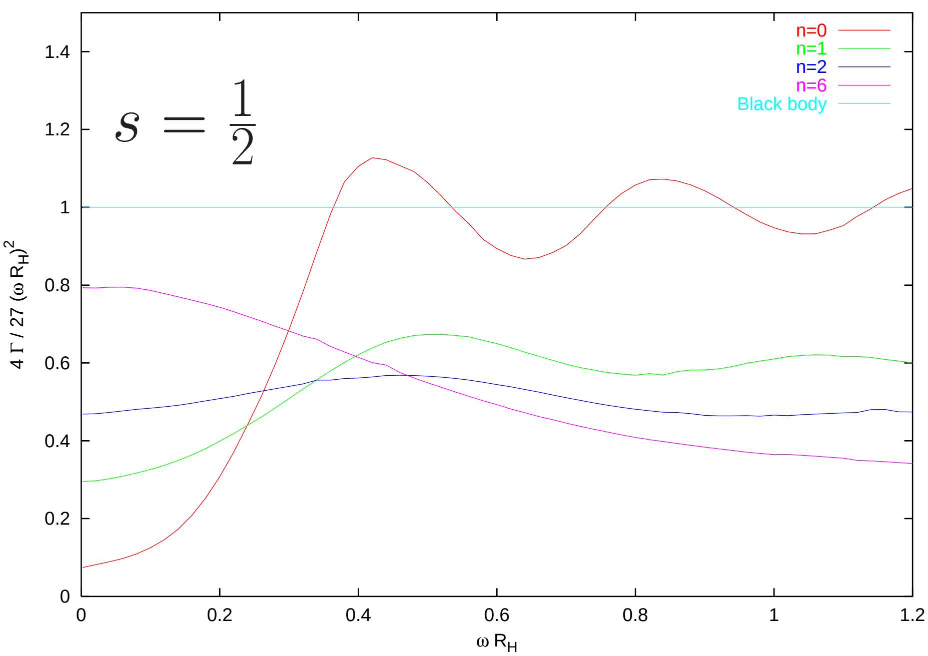
Grey Body Factor (Chris Harris)

The numerical solution for the grey-body in (4+n) D



The region up to about $\omega R_H \sim 0.25$ is important

Above this the exponential behaviour $dN/d\omega \sim \gamma \exp(-\omega R_H)$ kills the overall spectrum pretty quickly.



Summary

- The semi-classical conditions
  $M_{BH} >> M_p$, $M_{BH} >> T_H$, <Multiplicity> $\gg 1$
  start *breaking down* towards the end of the BH decay.

- Majority of the *low multiplicity* events, especially those in *higher dimensions*, tends toward the regime where the semi-classical approximation fails.

  It would be difficult to distinguish higher dimensional BH from each other!

- More study needs to be done!

- The *numerical solution* for $s = 0$ and $s = \frac{1}{2}$ grey-body factor is done.

- Work on $s = 1$ grey body factor is still in *progress*.

  ▷ use the *correct ratios* of different particle types emitted with different numbers of dimensions.

  ▷ it will be possible to emit each particle species with the *correct spectrum* (*grey body effect*).