

Microscopic black holes at IceCube and beyond

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arXiv:1907.08628, 1912.06656
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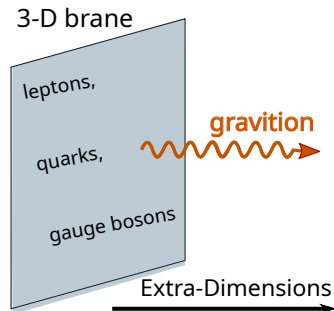
May 5th 2020



Arthur B. McDonald
Canadian Astroparticle Physics Research Institute



Large extra dimensions (LEDs)



ADD, PLB429(1998), PRD59(1999)086004
Arkani-Hamed, Dimopoulos and Dvali
(ADD), 1998

- SM particles confined to the “brane”
- Gravitons can propagate in the “bulk”
- $M_{\star} \sim \text{TeV} \ll M_{pl}$
- Solve the hierarchy problem

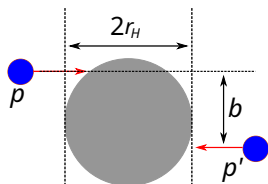
Gravitational potential

$$V(r) \sim \frac{m_1 m_2}{M_{\star}^{n+2}} \frac{1}{r^{n+1}} (r \ll R) \Leftrightarrow V(r) \sim \frac{m_1 m_2}{M_{\star}^{n+2} R^n} \frac{1}{r} (r \gg R)$$

\Rightarrow In 4D

$$M_{pl}^2 \sim M_{\star}^{2+n} R^n$$

Microscopic black hole and hoop conjecture



BH production allowed if the impact parameter

$$b \leq b_{\max} = 2r_H(E_{\text{CM}}, n, M_{\star})$$

$n=1$ killed

extra dimensions
bulk Planck scale

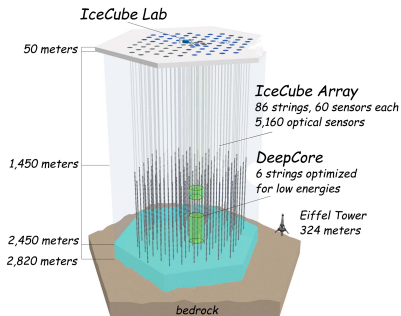
Method	Reference	n	$\log_{10}(E_{\star}/\text{eV})$	$\log_{10}(L/m)$
Grav force	[26]	2	12.5	-4.36
		3	12.4	-9.10
SN1987A	[27]	2	13.4	-6.18
		3	12.4	-9.10
		4		-11.6
		5		-12.5
		6		-13.0
		6		-13.4
NS cooling	[28]	1		-4.35
		2		-9.81
		3		-11.6
		4		-12.5
		5		-13.0
		6		-13.4
		CMS	[29]	2
3	12.9			
4	12.8			
5	12.8			
6	12.7			

$M_{\star} > 5 \sim 10$ TeV

Mack & McNeas PRD 2019/ arxiv:1809.05089

Micro black holes at IceCube

Madsen, arxiv:1901.02528



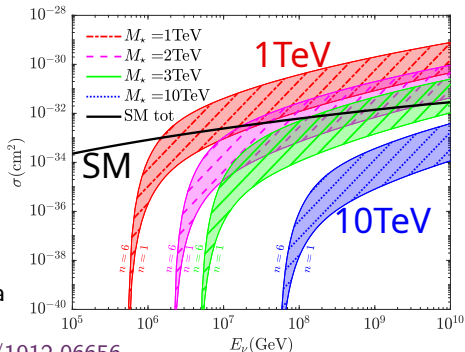
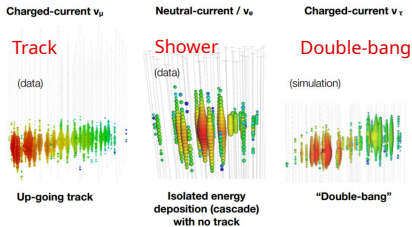
lbl.gov

Neutral-current: $\nu_l + n \rightarrow \nu_l + X$

Charged-current: $\nu_l + n \rightarrow l + X$

BH production: $\nu_l + n \rightarrow \bullet \rightarrow ?$

BlackMax(0711.3012)+Pythia8+Fluka

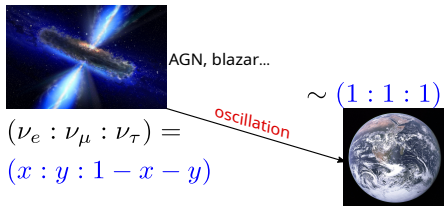


Mack, Song & Vincent JHEP 2020/1912.06656

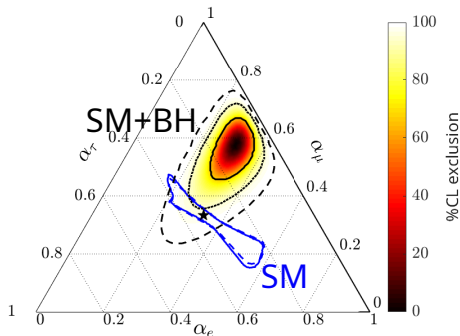
Pheno2020 Pittsburg

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Neutrino flavor composition from black holes



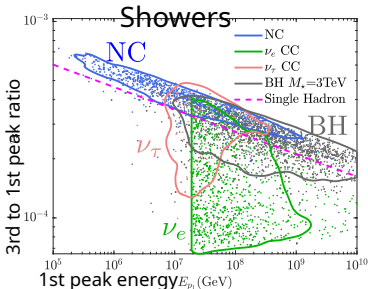
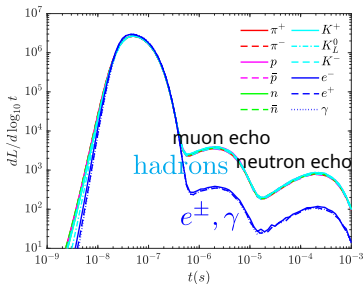
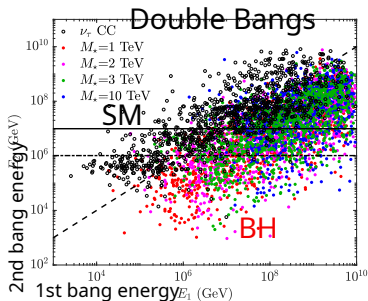
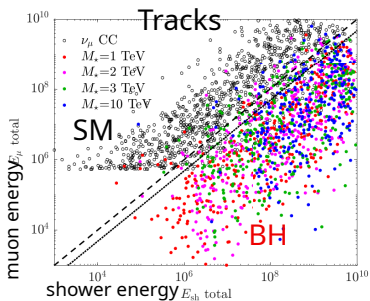
- larger track-to-shower ratio
- rarer double bang due to energy asymmetry condition



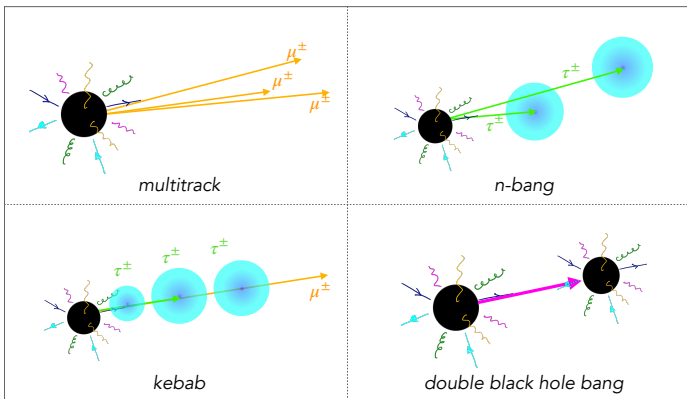
Mack, Song & Vincent JHEP 2020/1912.06656

	shower	track	double bang
ν_e SM	28.58	0	0
ν_μ SM	2.31	8.31	0
ν_τ SM	5.07	5.39	2.83
All Flavor Total SM	35.96	13.70	2.83
All Flavor Total BH	62.96	36.36	0.20

Unique signatures from black holes



Even more exciting topologies than we expect!



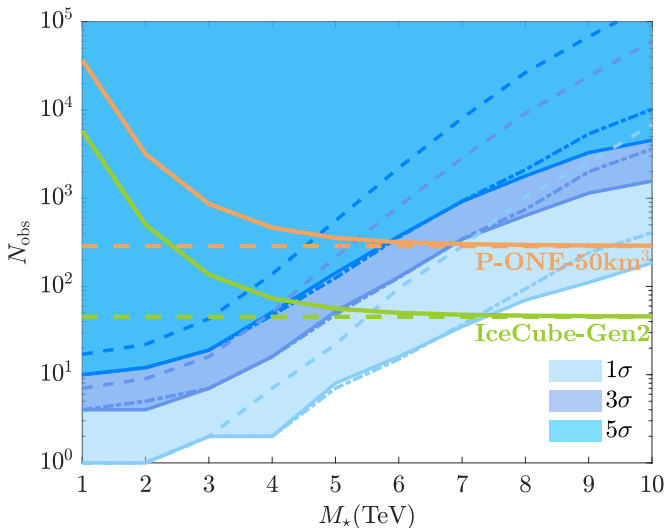
Multitrack: multiple muon or tau tracks from BH decay

n-bang: multiple tau decay hadronically

kebab: track + multiple tau decay

double BH bang: BH decay product produces new BH

Discover black holes at future neutrino telescopes

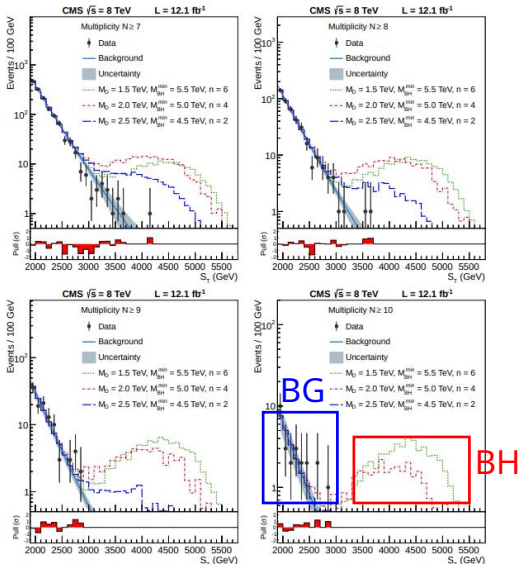


Mack, Song & Vincent JHEP 2020/1912.06656

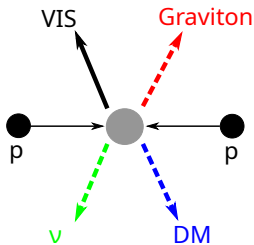
Microscopic black holes at LHC

γ +jets, W/Z + jets, $t\bar{t}$ production

CMS, arXiv:1303.5338



Non-interacting dark matter still produced!

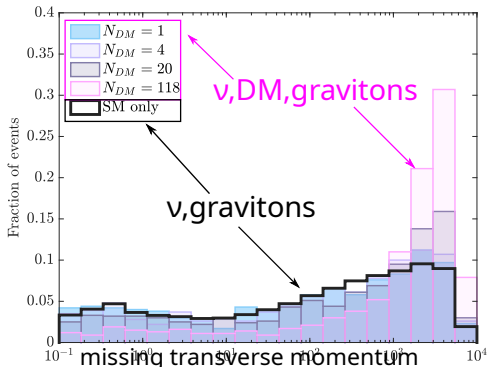


Fraction of invisible particle in BH decay

$$f_{\text{inv}} = \frac{N_\nu + N_G + N_{DM}}{N_{\text{vis}} + N_\nu + N_G + N_{DM}}$$

Graviton

$$N_G = D(D - 3)/2$$

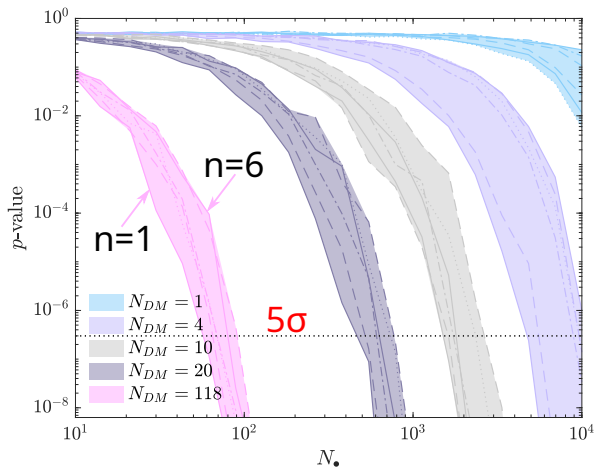


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As dark matter d.o.f. increases, mean p_\perp rises sharply

We can still probe particle dark matter in the “nightmare” scenario where DM and SM only interact via gravity!

Sensitivity to dark matter from BH production



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Only $\mathcal{O}(100)$ to $\mathcal{O}(10000)$ BHs required to resolve the dark sector if $N_{DM} \geq 4$, much below the luminosity of FCC-hh

Summary

Conclusions:

- Use BlackMax+Pythia to simulate BH production and decay
- BHs bring unique signatures to neutrino telescopes
- Microscopic BHs enable us to study particle dark matter regardless of DM-SM coupling

Outlook:

- Study DM mass and spin from extra dimension BHs at FCC
DeCoste, Song, Vincent, 200X.XXXXX
- Extra dimension BHs in the early Universe and their implications
Friedlander, Mack, Song, Vincent, 200X.XXXXX
- ...

Extra slides

