

# Implication of Microscopic Black Holes in Colliders and Cosmology

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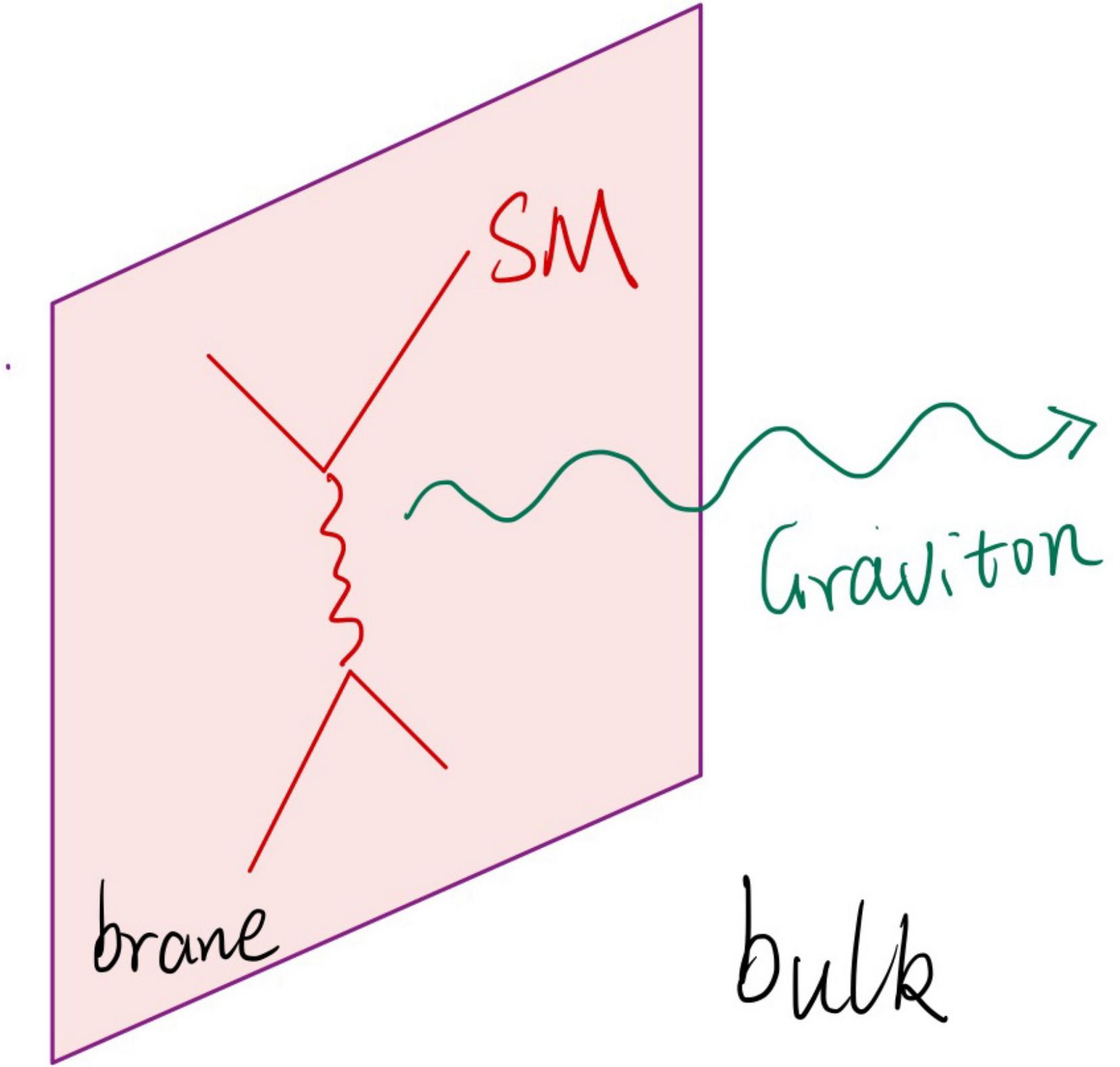
Dec 9, 2020



Arthur B. McDonald  
Canadian Astroparticle Physics Research Institute

# Large Extra Dimensions (LEDs)

- SM particles are confined to the 3D “brane”
- Gravitons can propagate in the 3+n D “bulk”



Arkani-Hamed, Dimopoulos, Dvali' 1998

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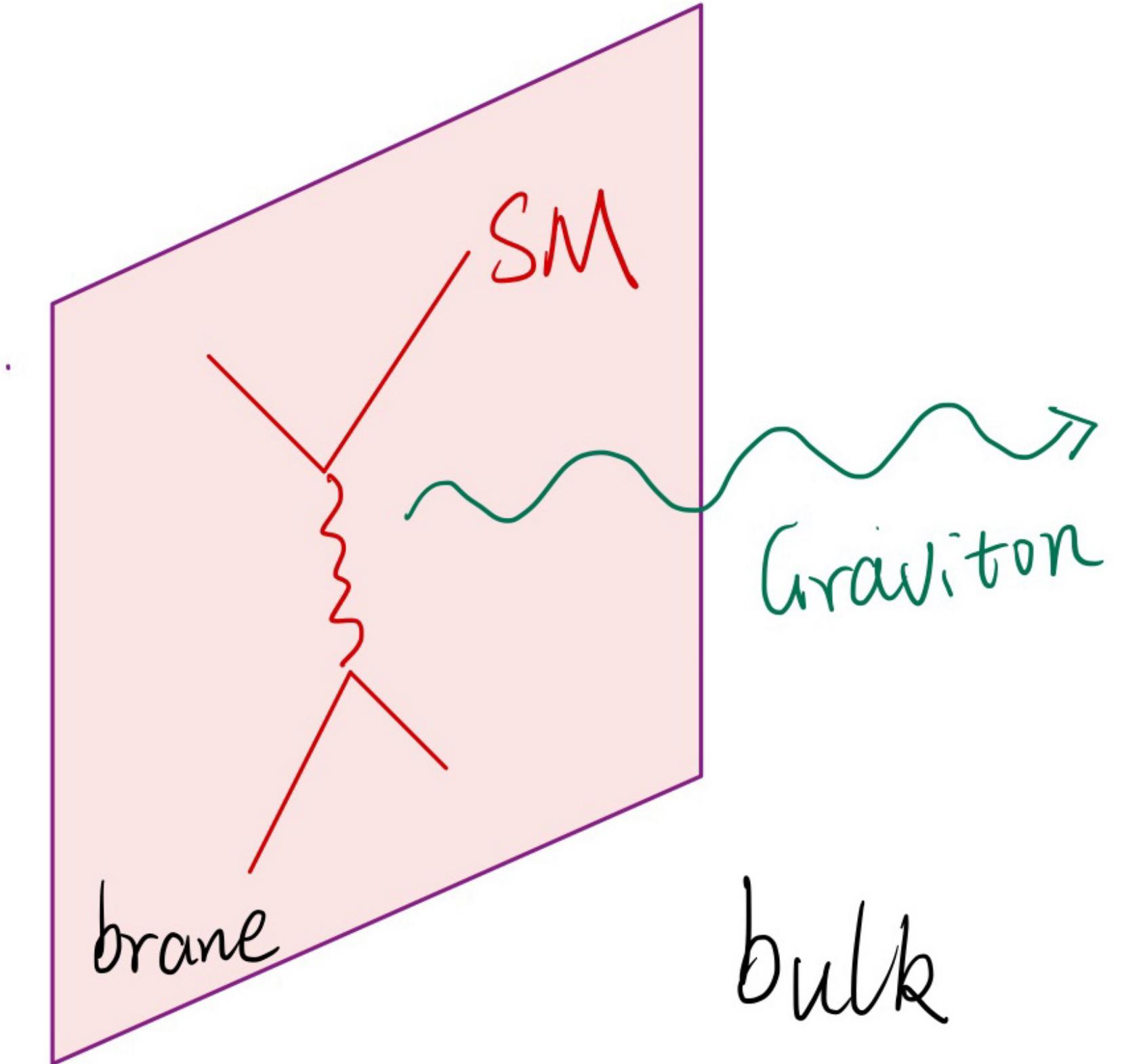
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Gravitational potential

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

Match two conditions at  $\textcolor{blue}{r} \sim R$

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



Arkani-Hamed, Dimopoulos, Dvali' 1998

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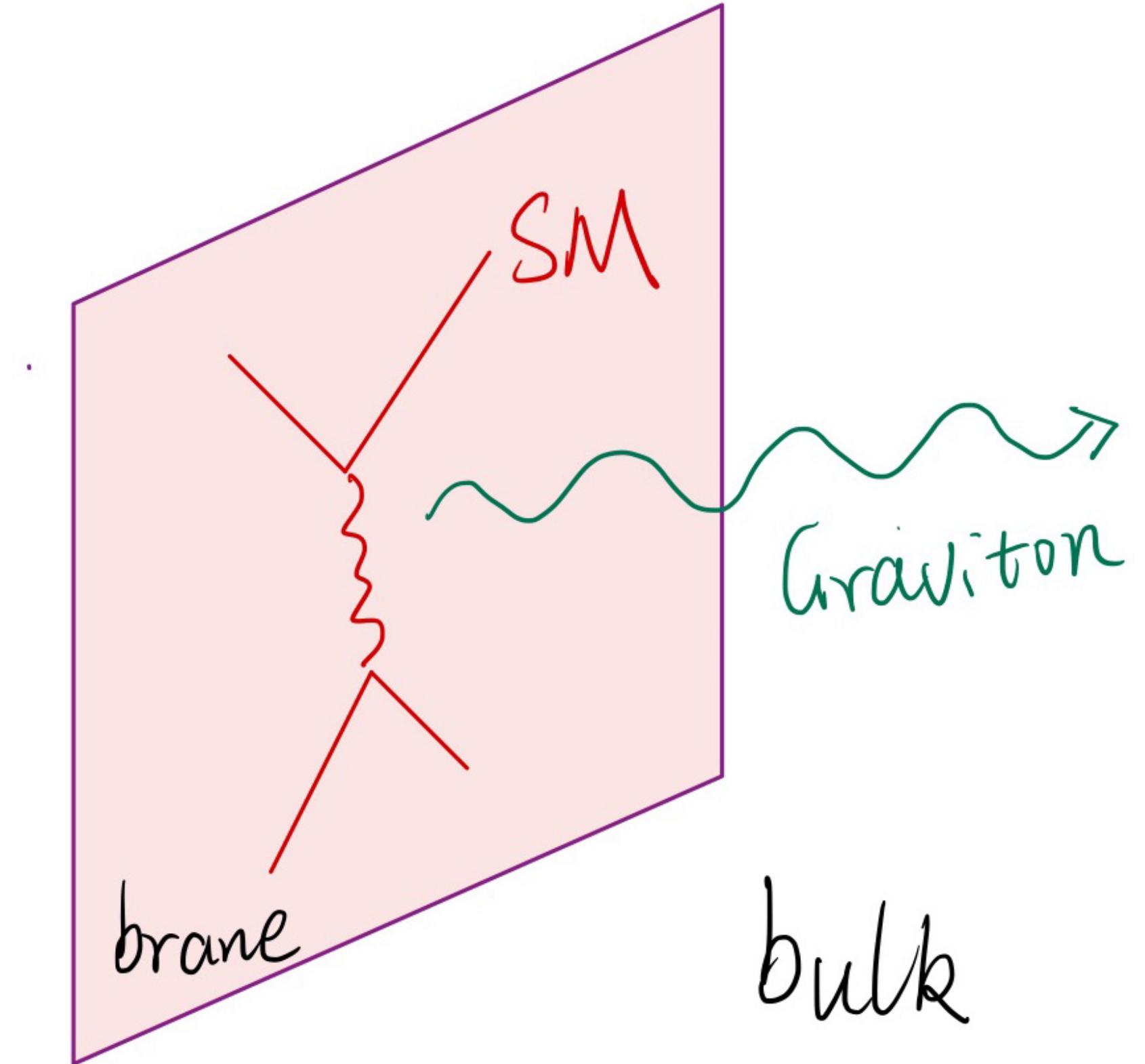
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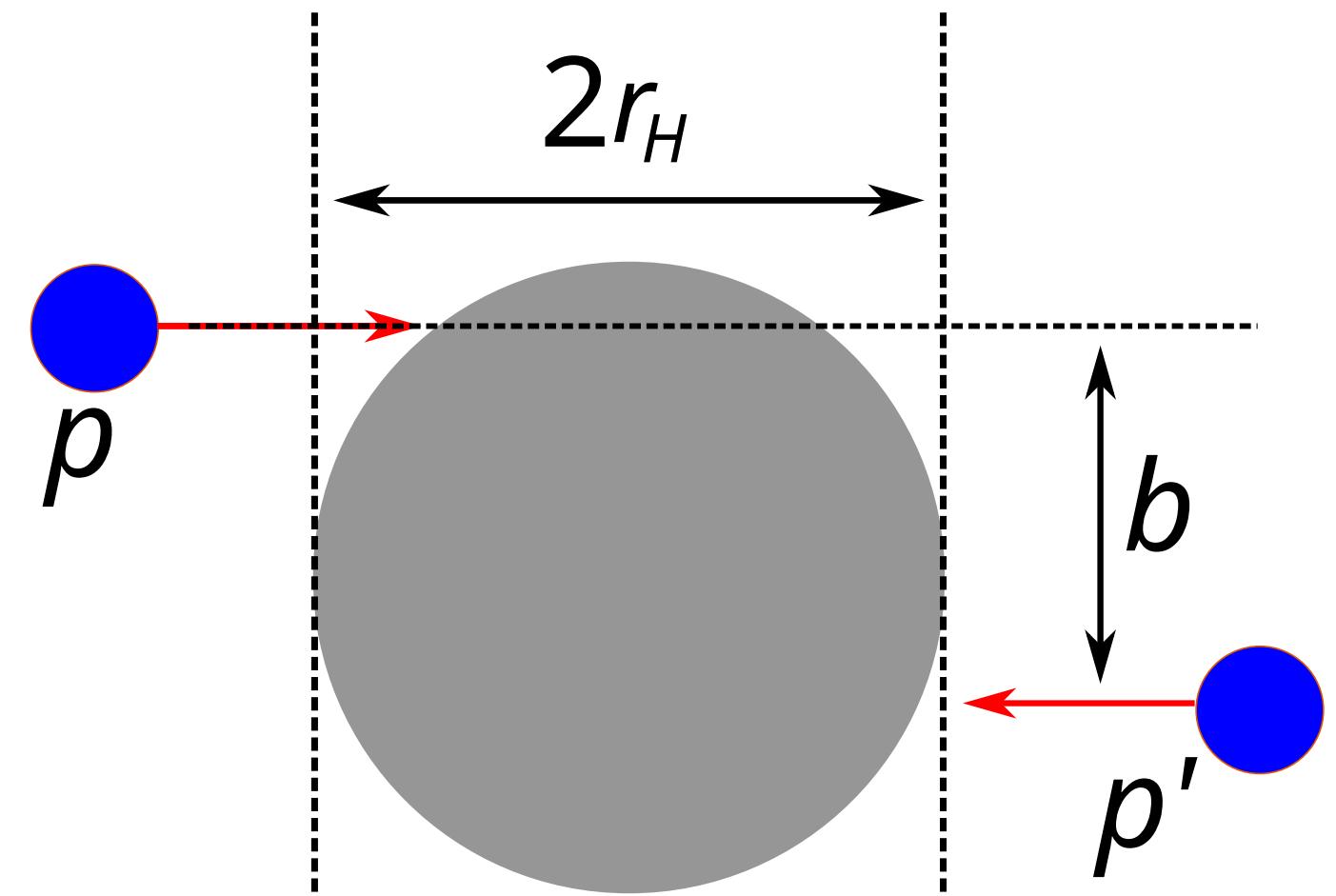
- The bulk Planck scale  $M_\star \sim \text{TeV} \ll M_{pl}$
- Solve the hierarchy problem



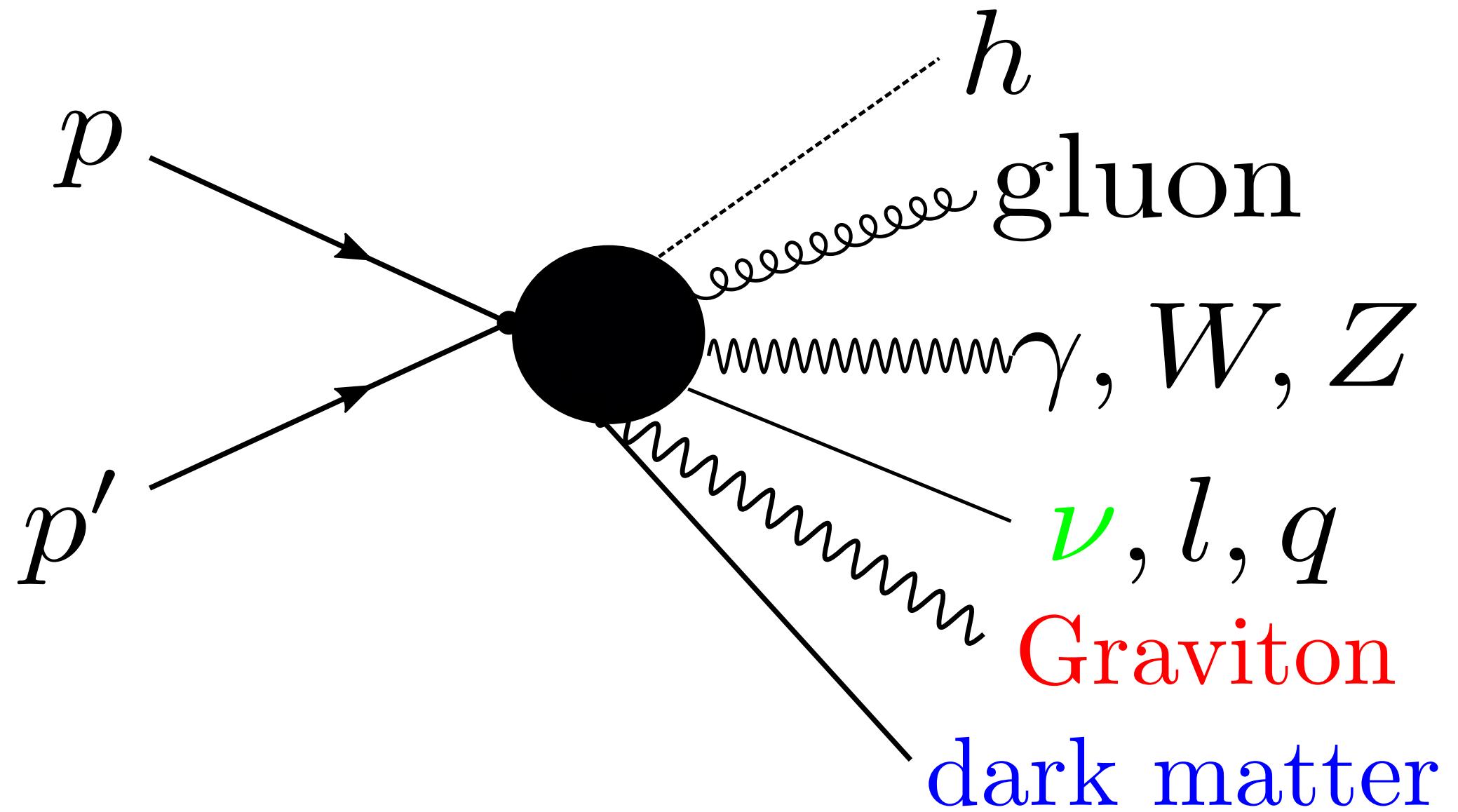
Arkani-Hamed, Dimopoulos, Dvali' 1998

# Microscopic Black Holes and Hoop conjecture

- BH production allowed if  $b < b_{\max}$  or  $E_{cm} \gtrsim M_\star$
- BHs can be produced in **high energy** particle collisions:
  - Cosmic neutrino-nucleon scattering
  - $pp$  collision in FCC
  - High energy cosmic ray detection
  - Cosmic ray-cosmic ray collision
  - **Hot plasma in the early Universe**
  - ...



# Hawking radiation



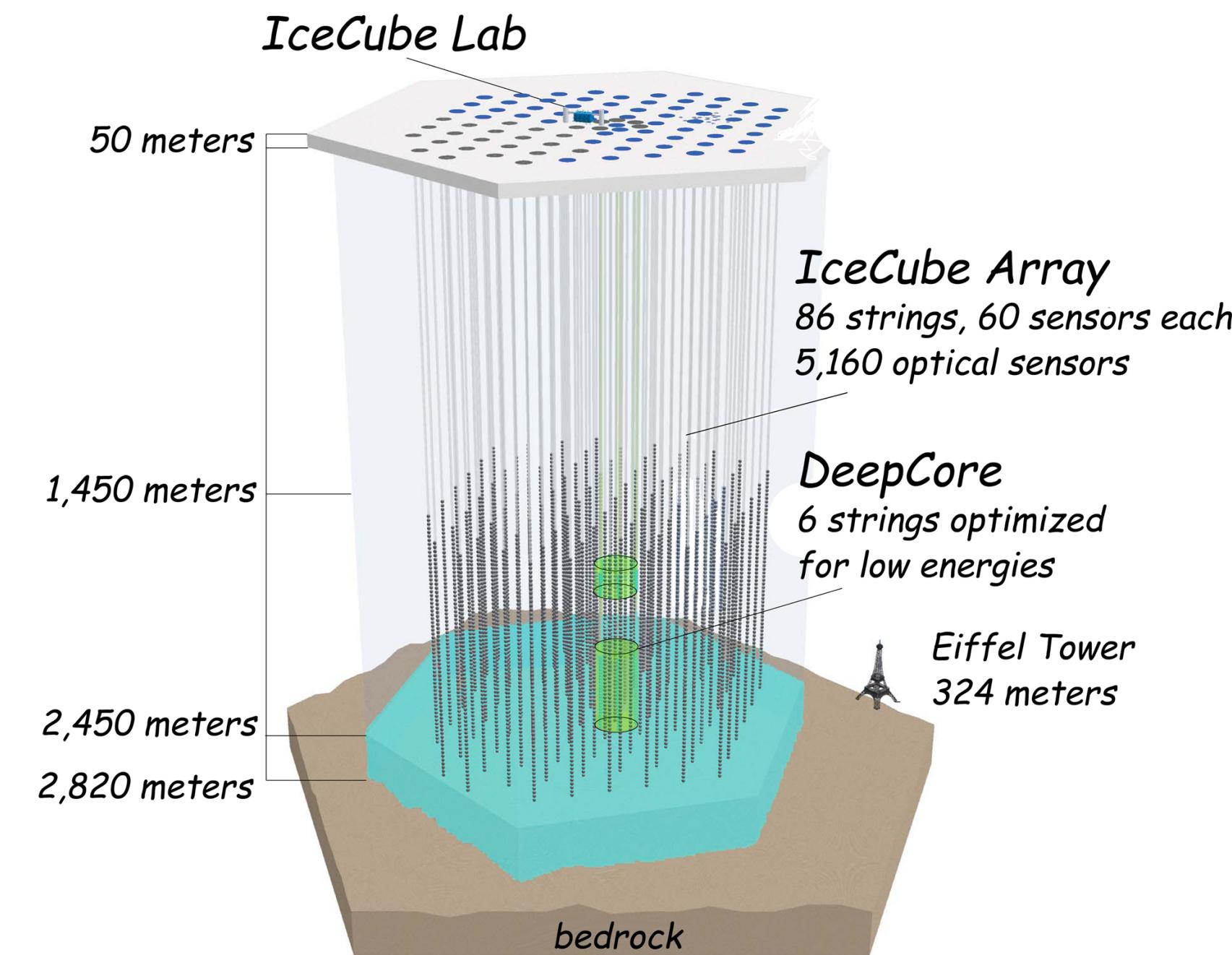
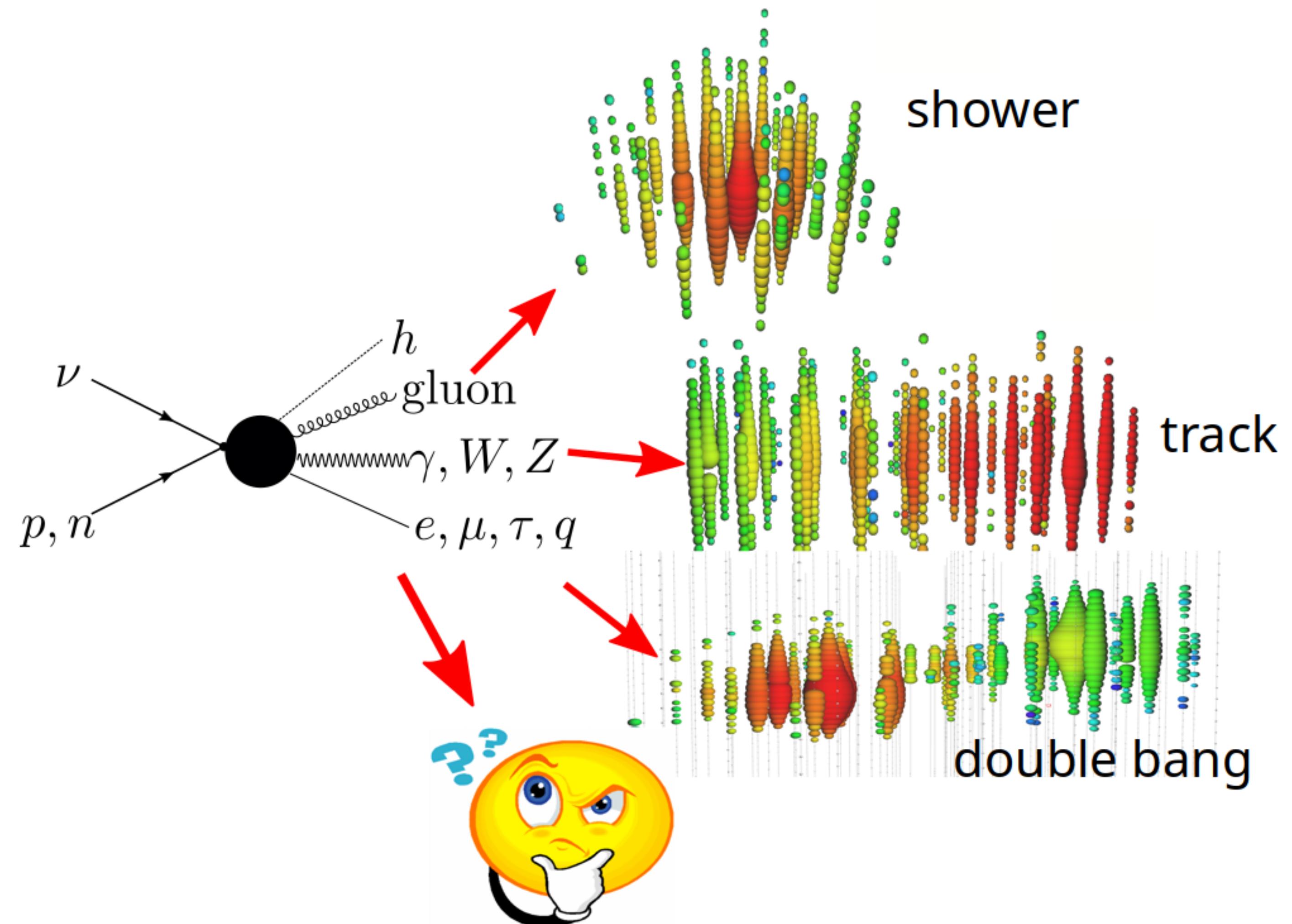
- BHs decay to all possible degree of freedom
- $n = 1$  excluded by **solar-scale gravity**
- LHC exclude  $M_\star > 5 \sim 10$  TeV depending on  $n$

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

CMS	[29]	2	13.0	$M_\star > 5 \sim 10$ TeV
		3	12.9	
		4	12.8	
		5	12.8	
		6	12.7	

Mack, McNees' 2018

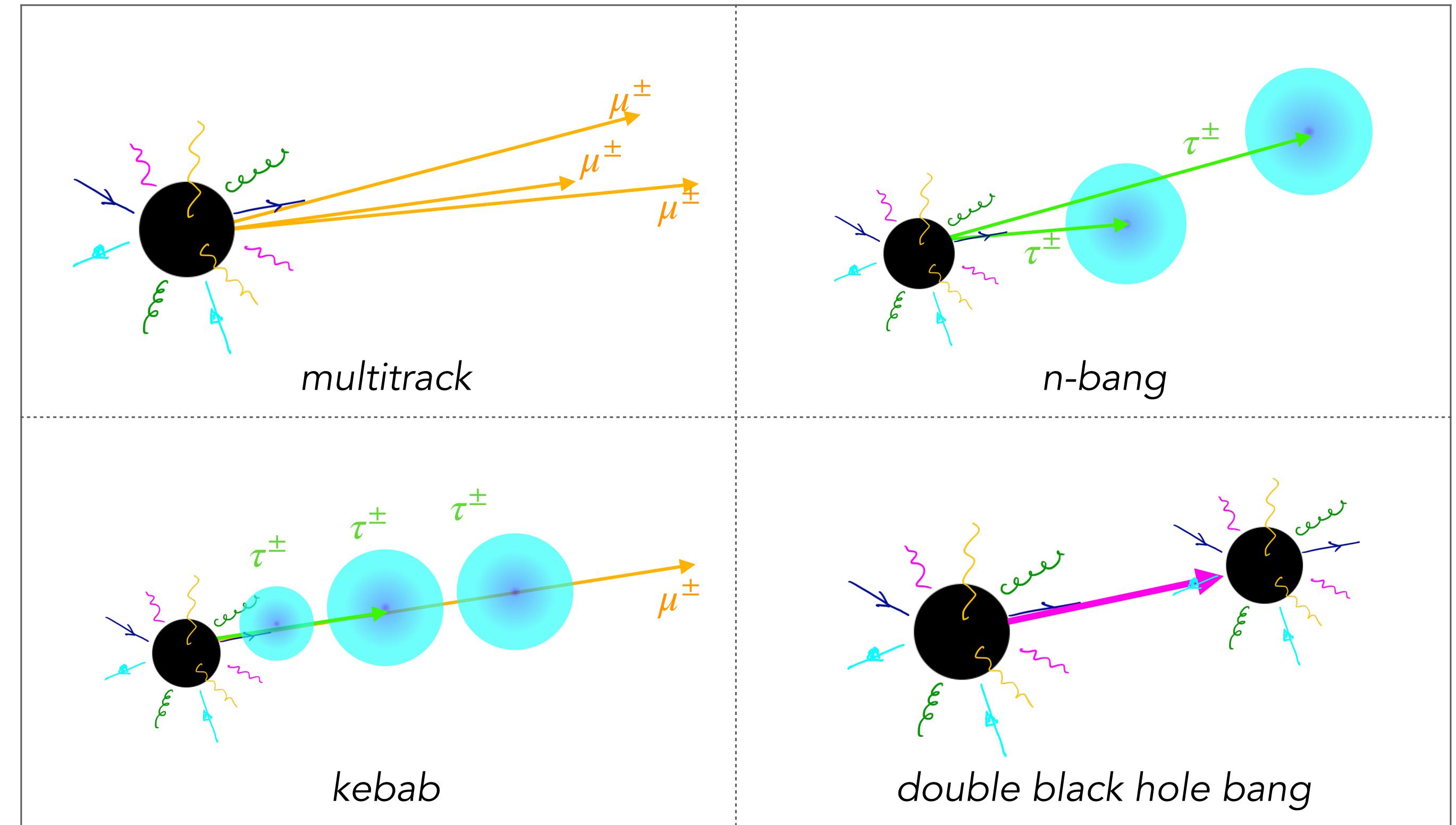
# Micro Black Holes at IceCube



# Micro Black Holes at IceCube

**New topologies not expected in SM!**

- **Mutitrack**: BHs produce multiple muons or taus
- **N-bang**: Multiple taus decay
- **Kebab**: Multiple taus decay along with a track
- **Double BH bang**: BH decay product produces another BH

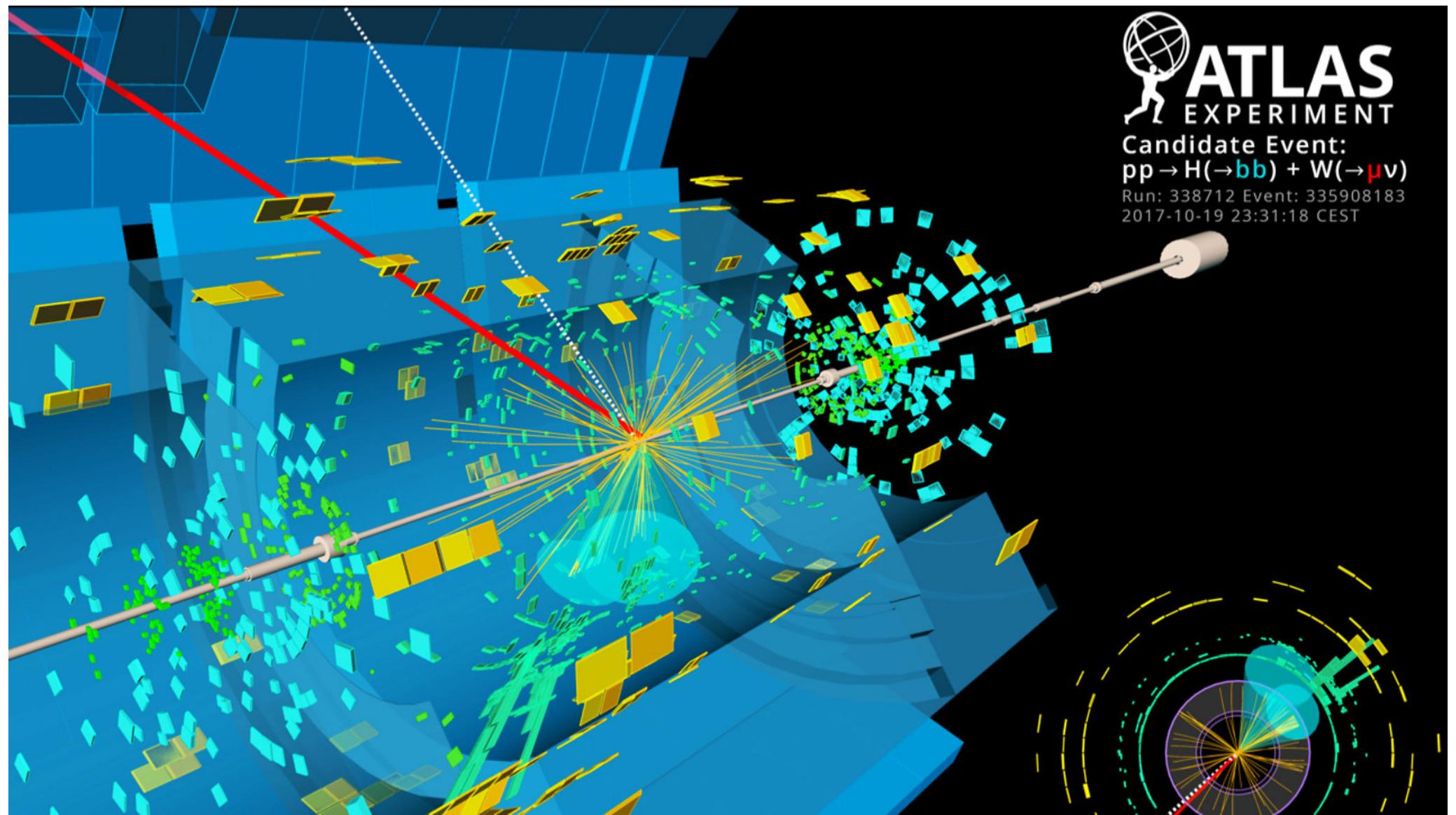


Mack, Song, Vincent' JHEP 2019

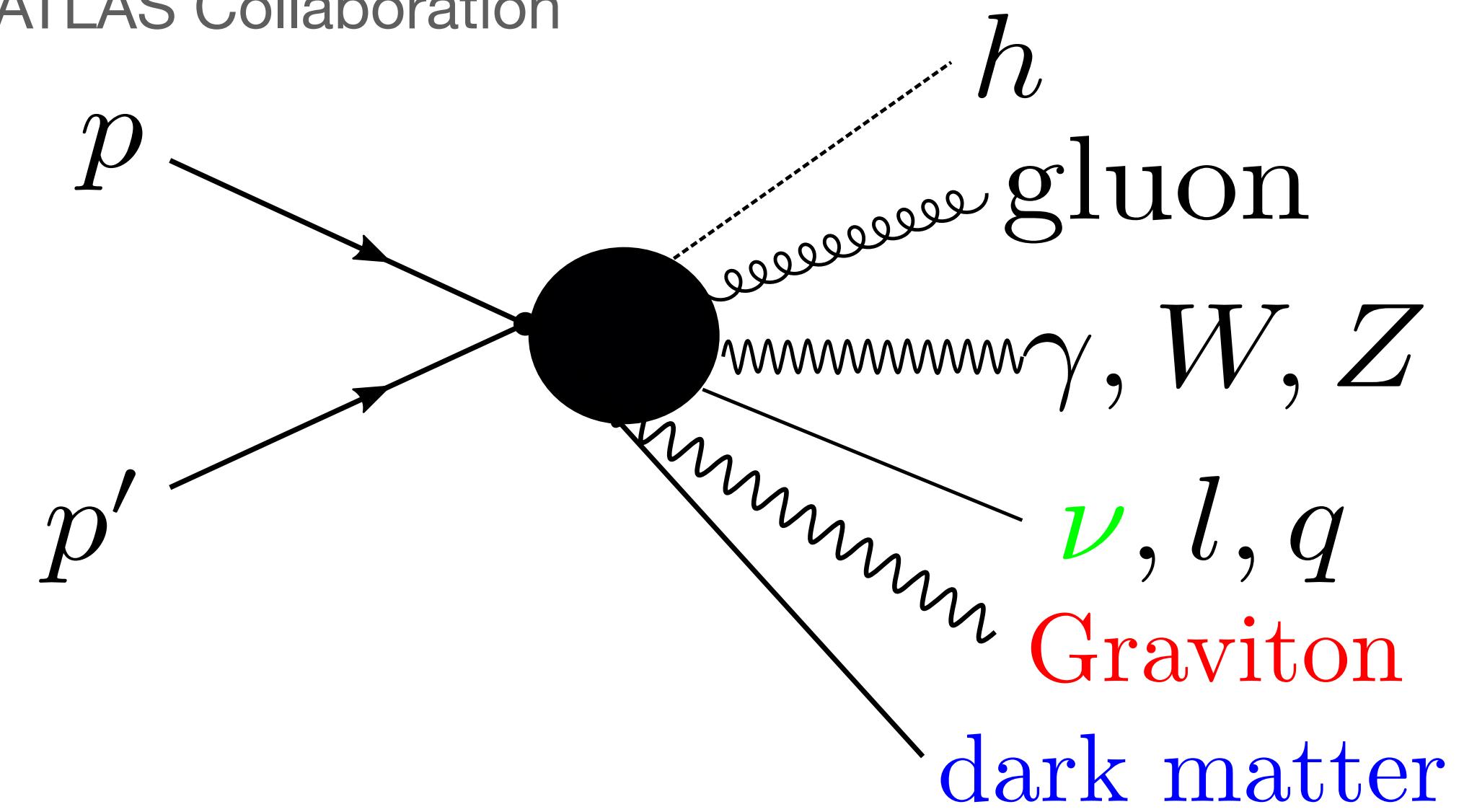
# Micro Black Holes at Colliders

**Dark matter contributes to missing transverse momentum at colliders!**

- $N_{DM} = 1$ : a scalar
- $N_{DM} = 4$ : Dirac fermion
- $N_{DM} = 20$ : simple dark sector
- $N_{DM} = 118$ : a copy of SM



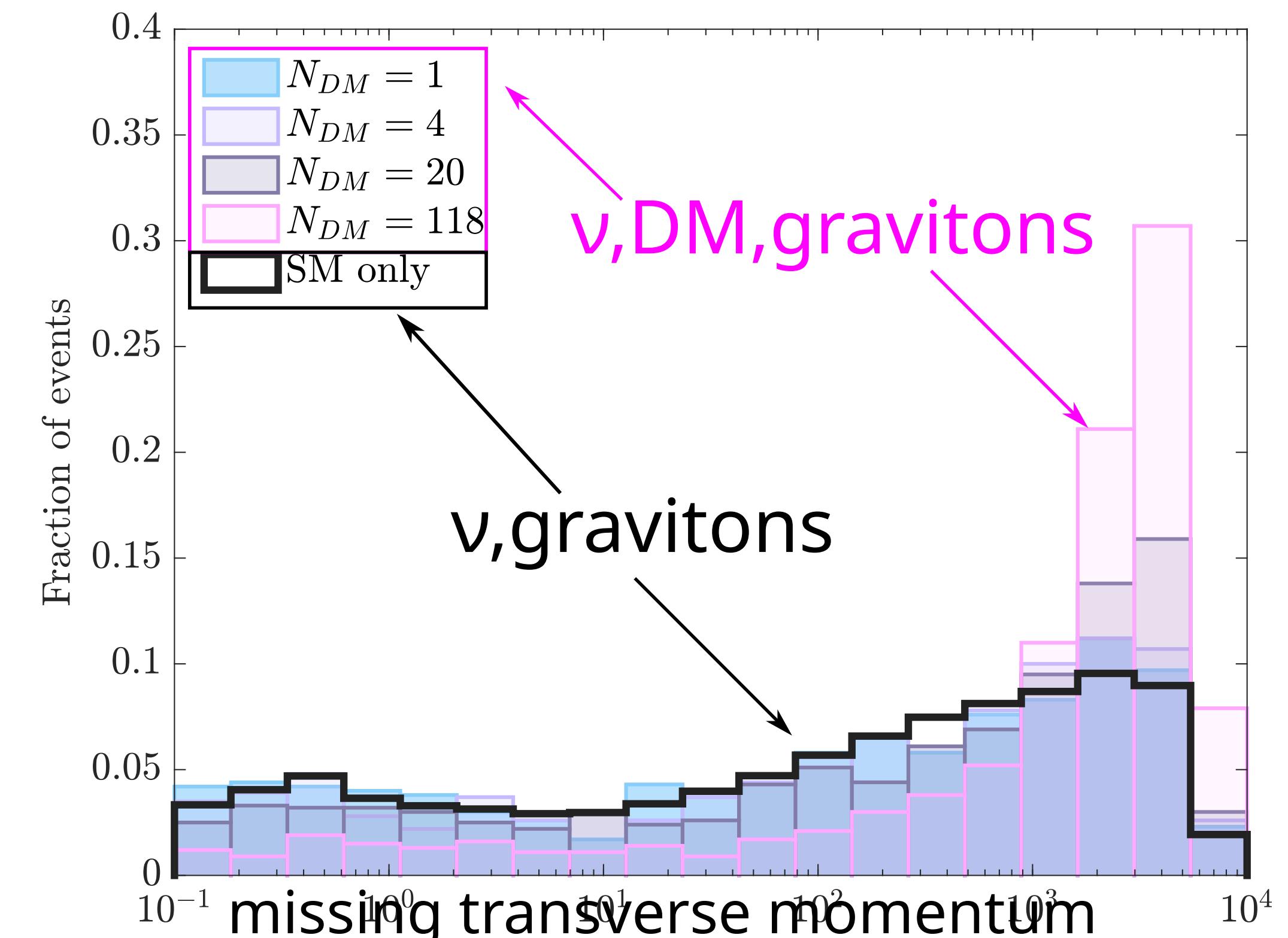
ATLAS Collaboration



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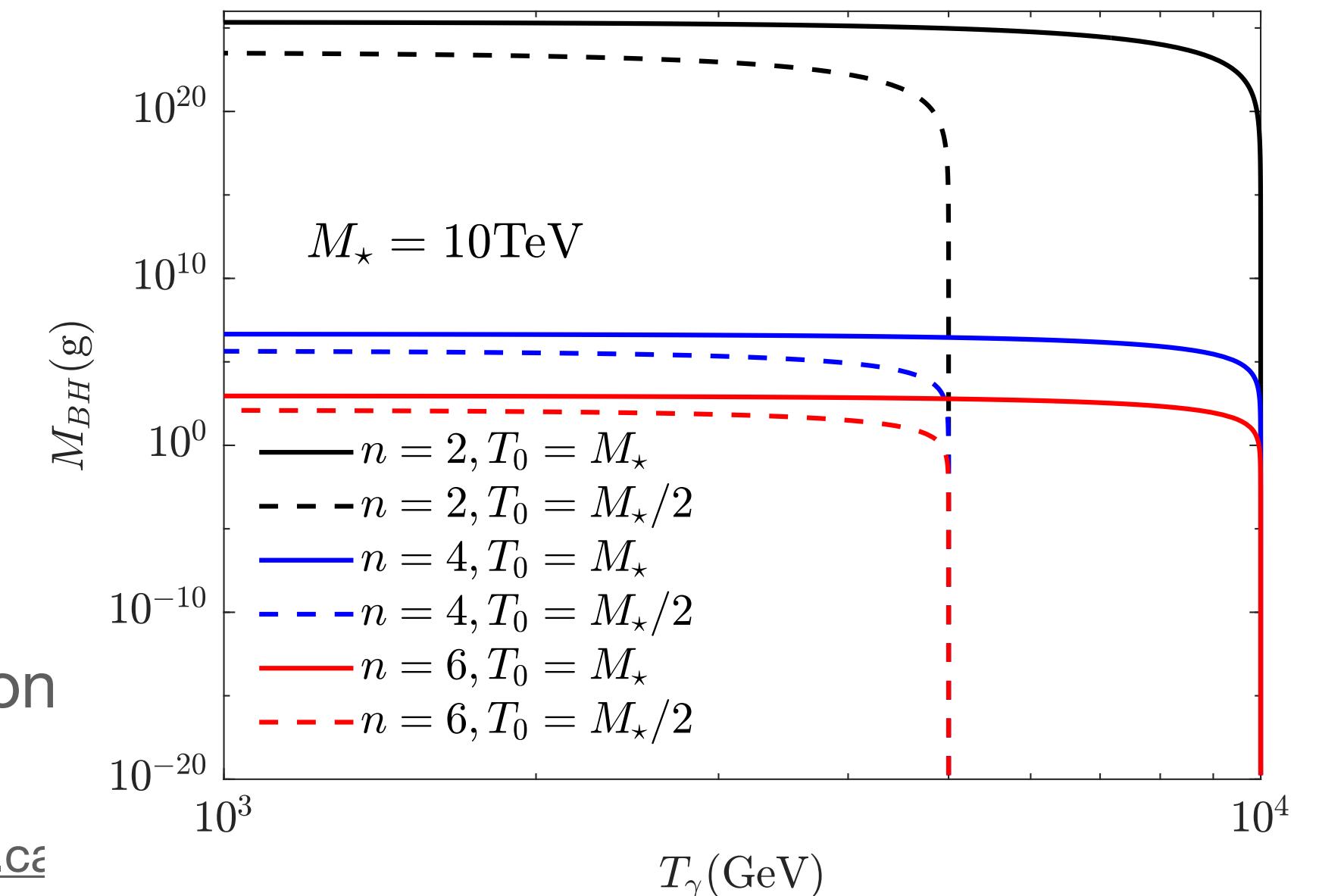
- Missing  $p_{\perp}$  from BH decay to **DM+SM** vs BH decay to SM
- Dark sector can be inferred from missing  $p_{\perp}$  distributions
- Only  $\mathcal{O}(100)$  to  $\mathcal{O}(10000)$  BHs required to resolve the dark sector if  $N_{DM} \geq 4$  at FCC



Song, Vincent' PRL 2020

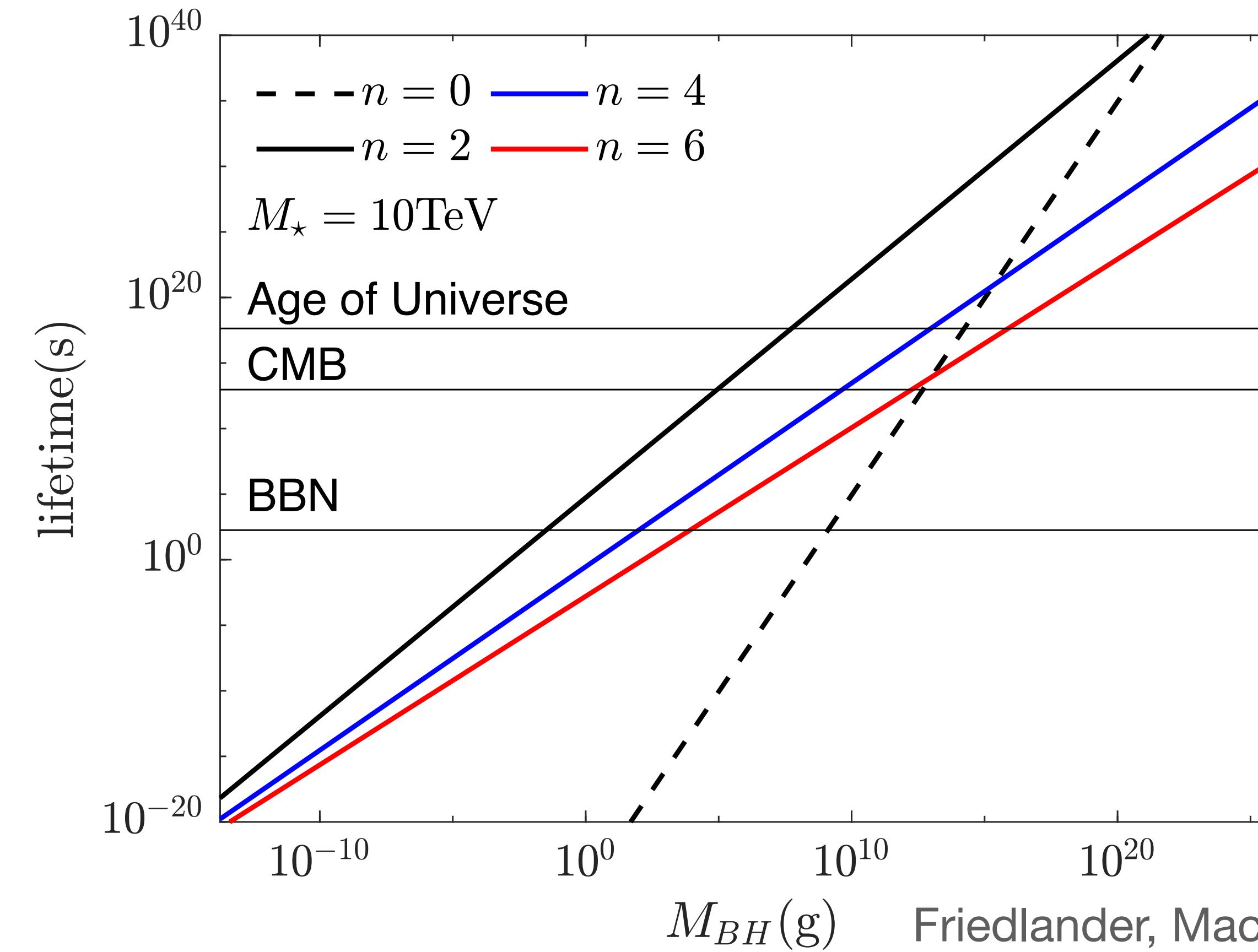
# Macro Black Holes in the Early Universe

- Microscopic BHs created in particle collisions in the plasma
- BHs produced at  $T_\gamma < M_\star$  due to Boltzmann distribution
- BHs **accrete** instead of decay if  $T_{BH} < T_\gamma$
- BH mass after accretion only depends on  $T_\gamma$  at production



Friedlander, Mack, Schon, **Song**, Vincent, in preparation

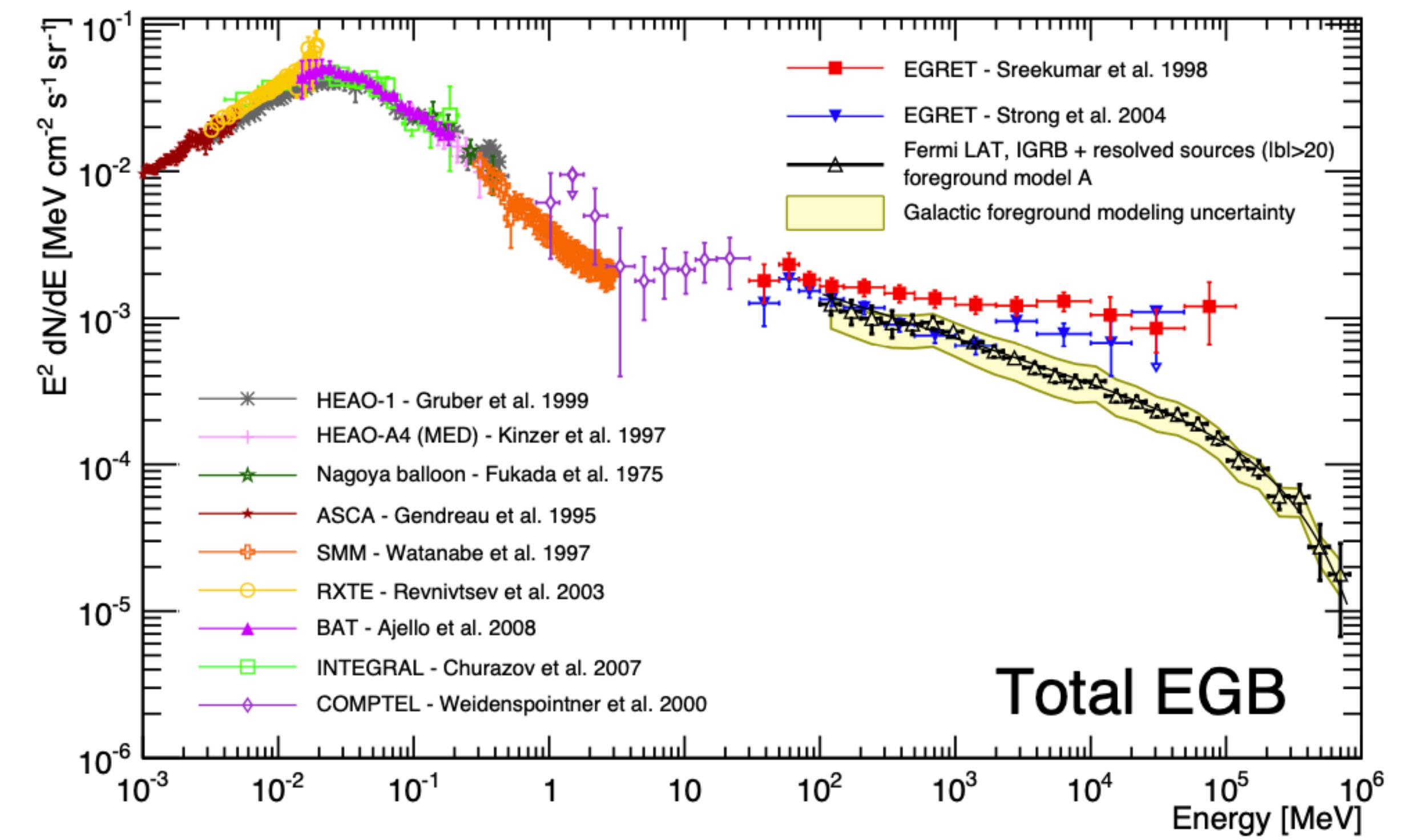
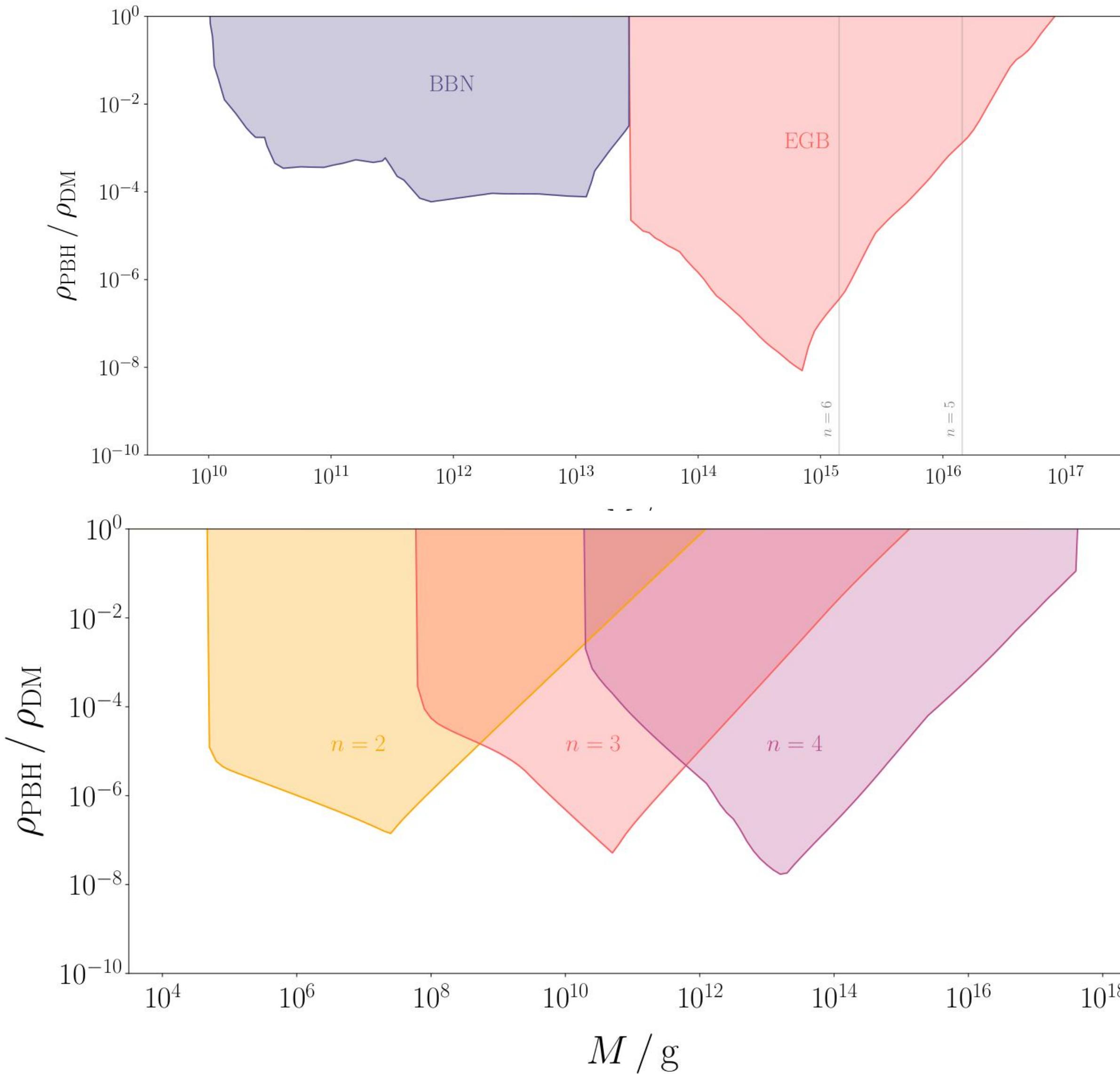
# Lifetime of Black Holes



- The lifetime of LED black holes can be much longer than 4d black holes, depending on the number of extra dimensions

# Extragalactic Photon Background

FermiLAT' 2014



Johnson' 2020

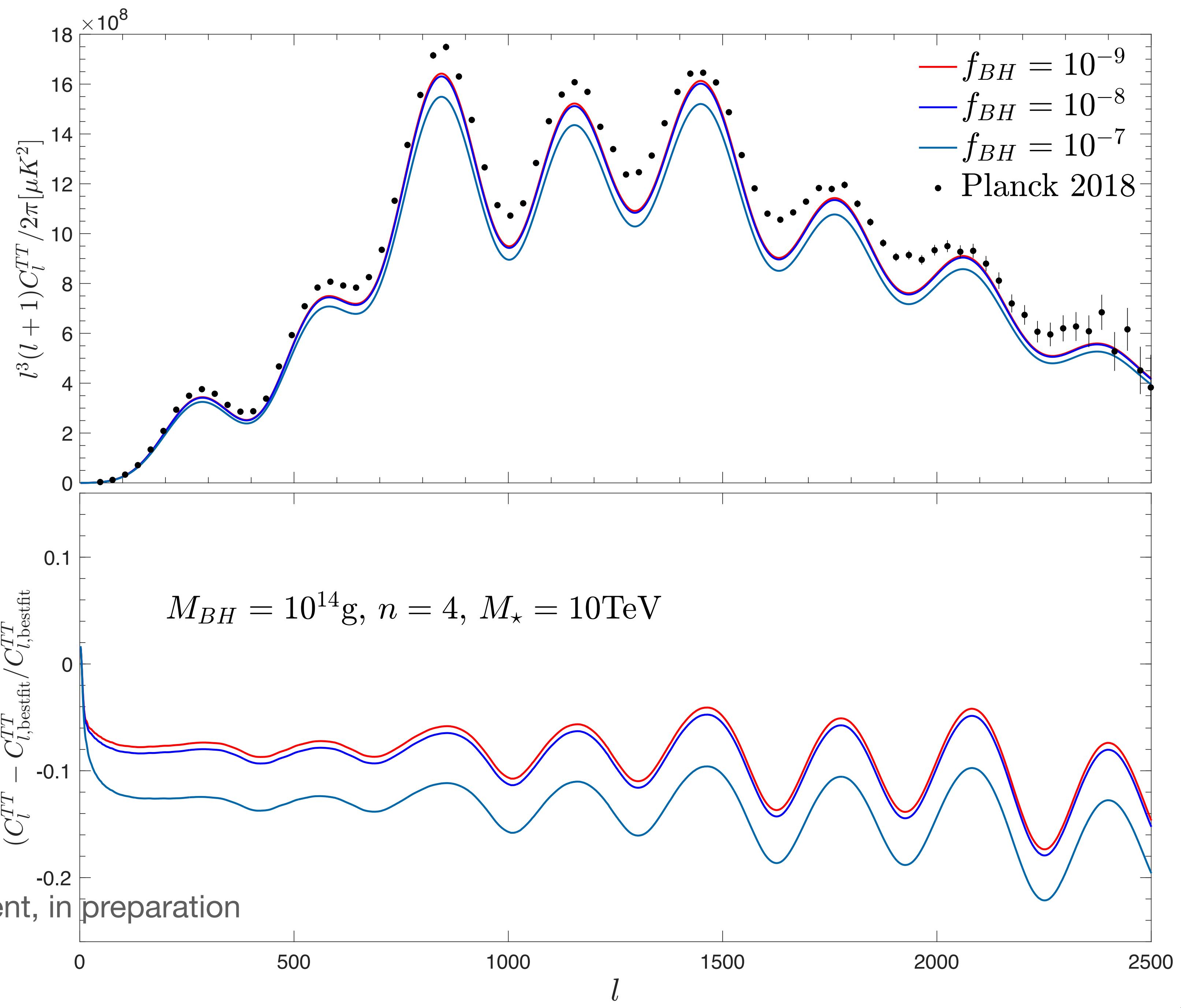
[jiang.song@queensu.ca](mailto:jiang.song@queensu.ca)

# CMB

- BHs inject energy into the plasma from Hawking radiation
- High- $l$  anisotropies **damped** due to Thomson scattering
- Implement LED BHs with **ExoClass**

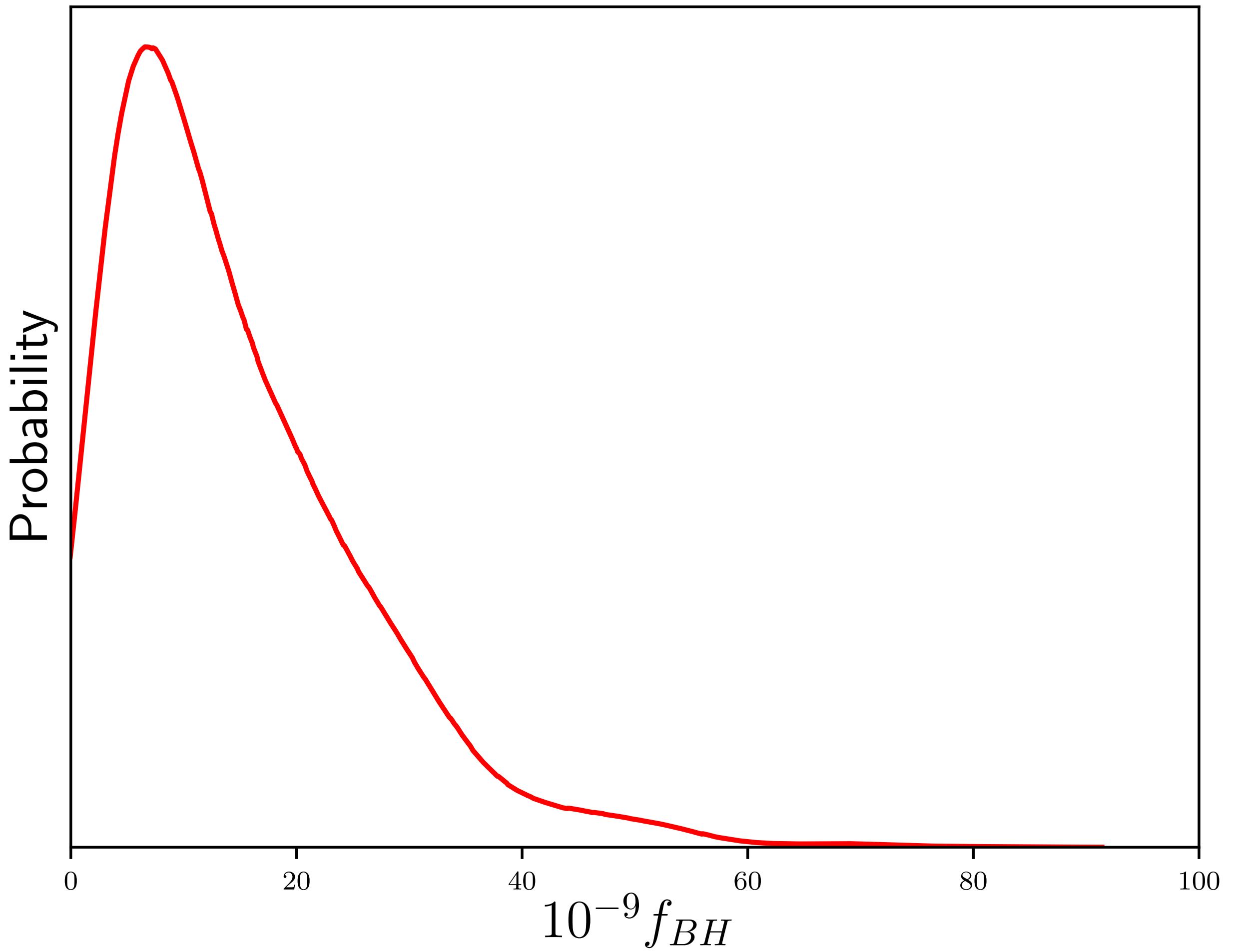
Stocker et al 2018

Friedlander, Mack, Schon, **Song**, Vincent, in preparation



# CMB Constraints

- ExoClass+MontePython to infer the posterior of BH fraction
- $f_{BH} > 10^{-7}$  strongly disfavoured for  $10^{14}\text{g}$  BH in  $n = 4$  extra dimensions



# Conclusions and Prospects

- Microscopic BHs can be produced in particle collisions if *large extra dimensions* exist
- Micro BHs produce *unique signatures* in neutrino telescopes
- Micro BHs may unveil the *dark sector* at future colliders
- BHs produced in the early Universe will be constrained by cosmological observations