AMON

Astrophysical Multimessenger Observatory Network

Searching for primordial black hole evaporation signal with AMON

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Introduction - Theory

- Primordial Black Holes (PBHs) could have been formed in the early Universe from gravitational collapse of matter-energy density fluctuations or cosmic phase transitions with: M_{PBH} >=M_{Planck}=2x10^8kg

- Hawking 1974 – black body radiation with a temperature:

$$T_H = M_{Planck}^2 / [8\pi M]$$

- PBH loses its mass due to Hawking radiation:

$$dM / dt \propto -\underset{\uparrow}{\alpha}(M) / M^2$$

Number of available degrees of freedom (dof)

- Evaporation is runaway process

Introduction - Theory

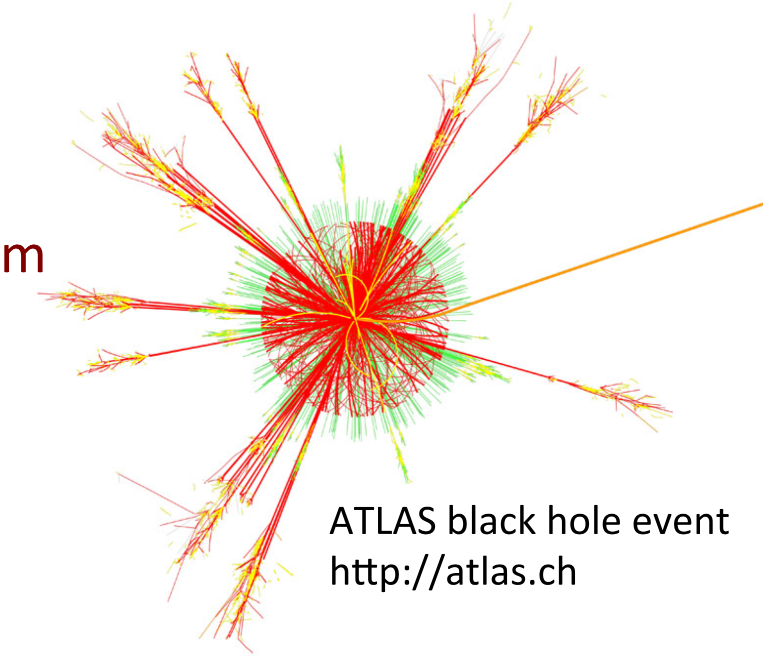
- Radiates all standard model particles (number of degrees of freedom increases with increasing T_H)

- Non-thermal particle spectrum due to the fragmentation of quarks into hadrons, photons, neutrinos etc. above Λ_{QCD} ~200 MeV

- **Final spectrum originates mostly from decay of hadrons**

↓

Need models to calculate the final spectrum



ATLAS black hole event
http://atlas.ch

Introduction - Theory

- PBH lifetime depends on its initial mass:

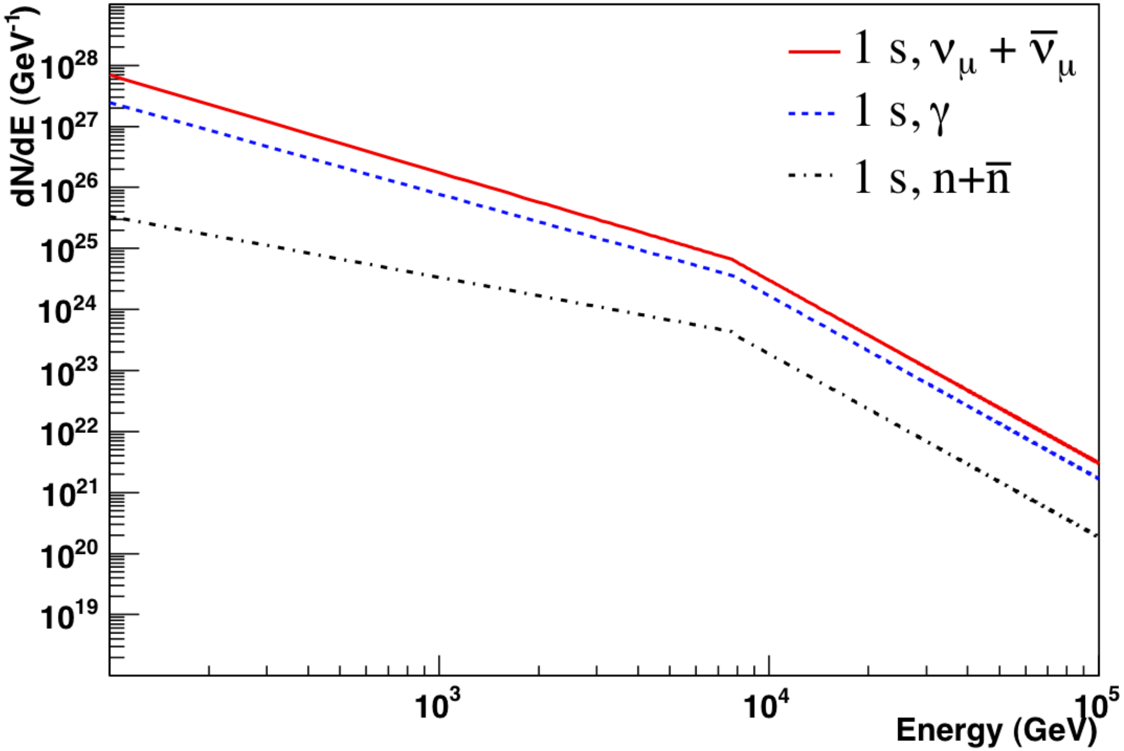
$$\tau \sim M^3 / \alpha(M)$$

$M_{PBH} < 5 \cdot 10^{11}$ kg – already evaporated
$M_{PBH} \sim 5 \cdot 10^{11}$ kg – final stage of evaporation now

- Comparable with IceCube (1 km^3 of ice) compressed into sphere with 10^{-15} m radius!

Spectrum

- Standard model of particle physics (124 dof)
- Non-charged, non-rotating black hole (good approximation)
- Based on MacGibbon & Webber (Phys. Rev. D, Vol41, 10, 3052, 1990)
- ϒ, ν, n are of interest for multimessenger searches (e.g. AMON)

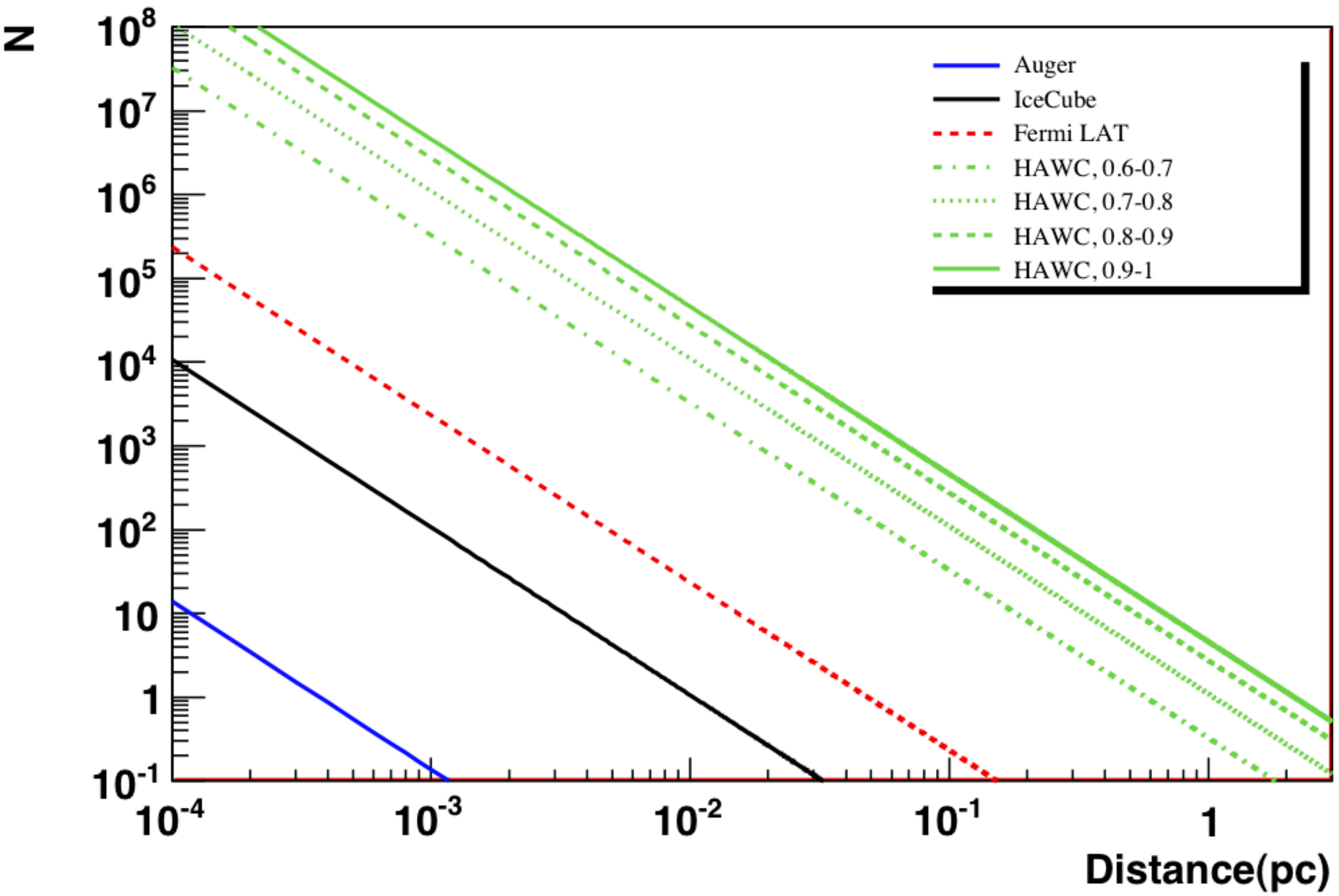


Searches for PBH evaporation signal

- Utilize AMON & look for multimessenger bursts from subthreshold data streams (within some short time interval Δt and from the same direction)
- short temporal structure of the anticipated PBH evaporation signal provides a very low false positive rate for any possible detection.
- expected number of particle x from a PBH at distance r at the detector:

$$N_x(r,\Delta t) = \frac{1}{4\pi r^2}\int_0^{\Delta t} dt \int_0^{\infty} dE \underbrace{\frac{d^2 N_x}{dEdt}\left(E,t\right)}_{\text{Spectrum}} \underbrace{A(E,\theta)}_{\text{Detector response}}$$

Expectations



Number of detected events at each experiment, Δt=5s

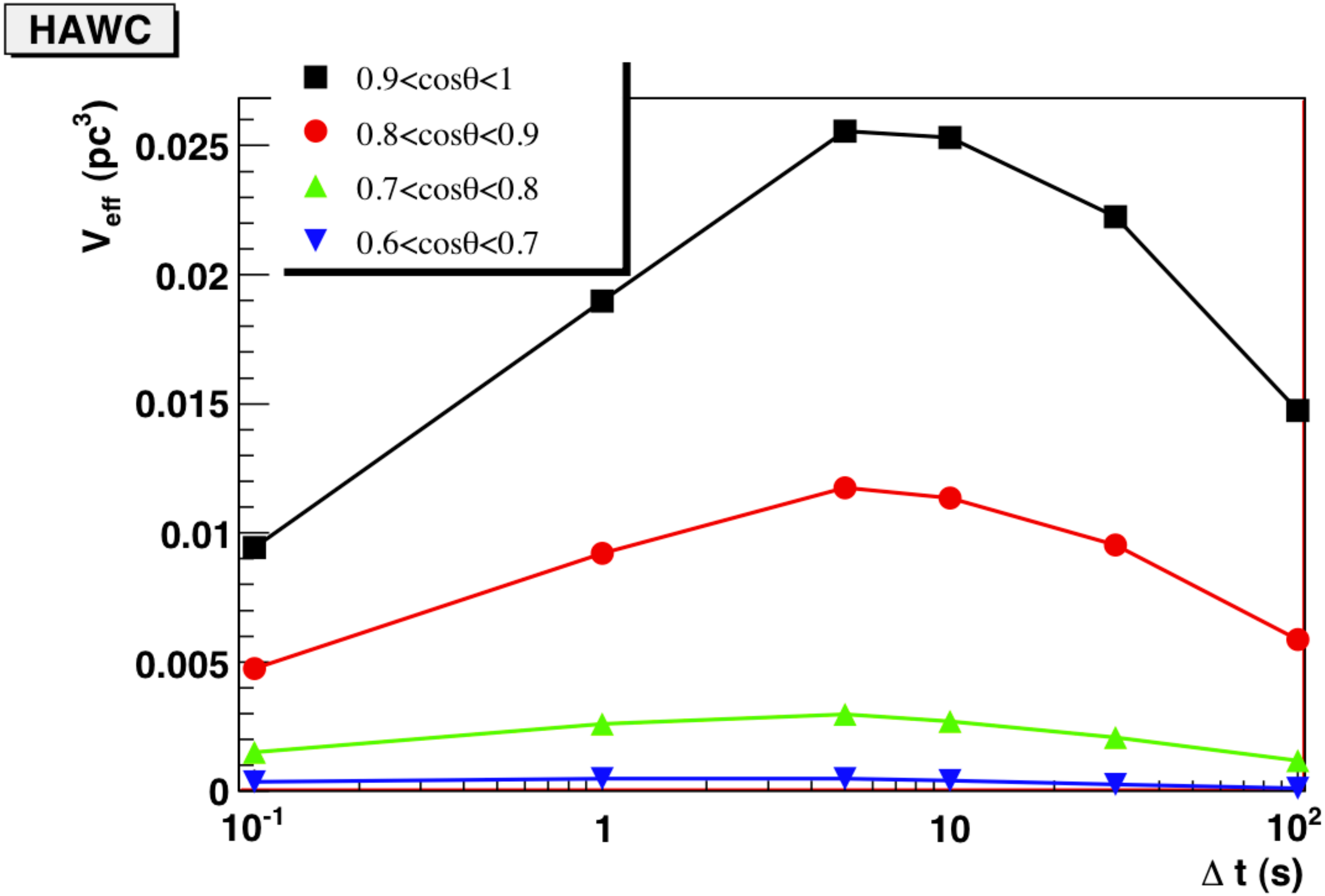
Expectations

- total number of bursts of size b observed over time τ:

$$n(b,\Delta t) = \underset{\text{PBH density}}{\underset{\uparrow}{\rho_{PBH}}}\,\tau\,\underset{\text{Effective volume}}{\underset{\nwarrow}{V_{eff}}}$$

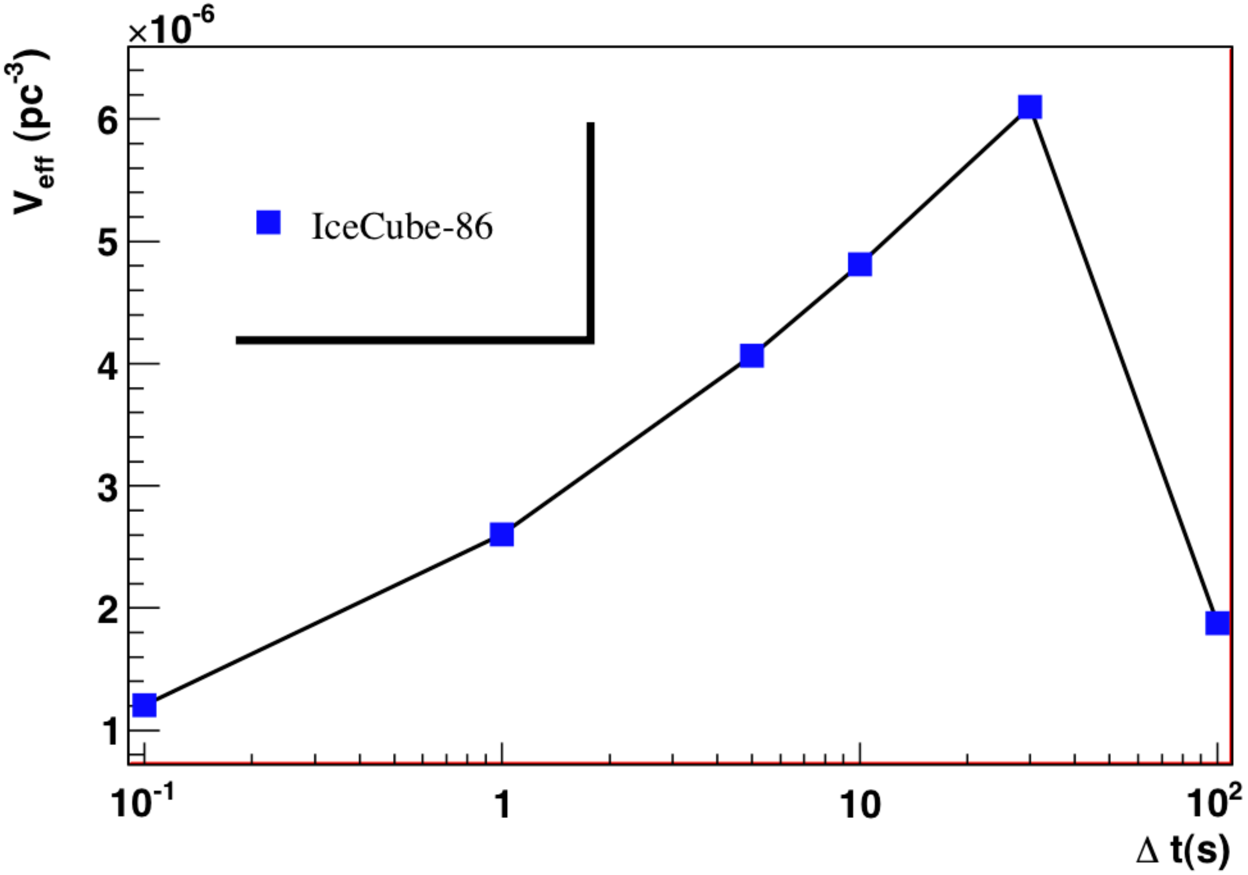
- Single detector: - above threshold data b>=a
- AMON approach - multiple detectors (i=1, M>=2), subthreshold data, each detects bursts with size b_i >=a_i:
- Choose the time window that maximizes V_{eff} while keeping background rate low

Sensitivity - HAWC



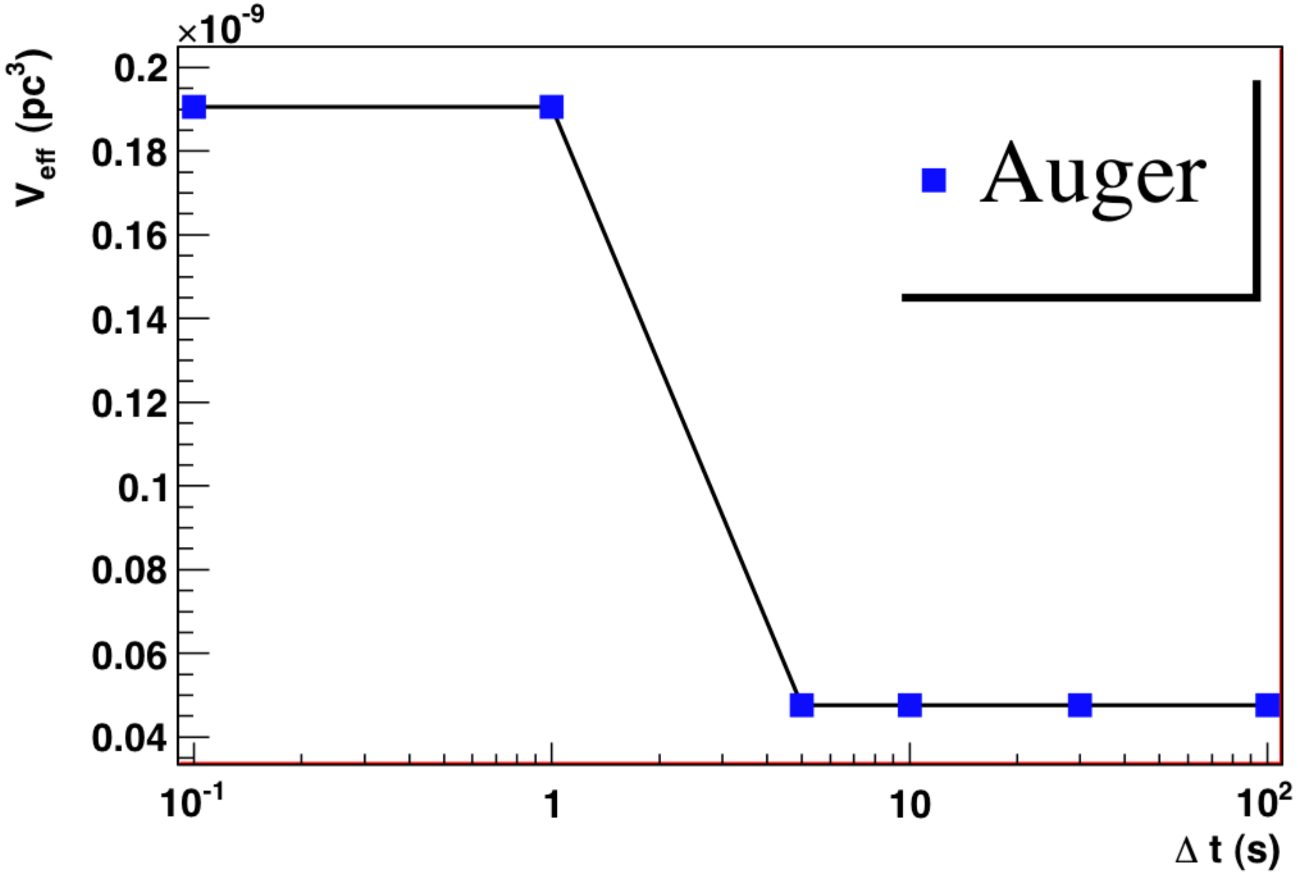
V_{eff} changes with Δt and b (burst size requirement: f(BG, Δt))

Sensitivity - IceCube



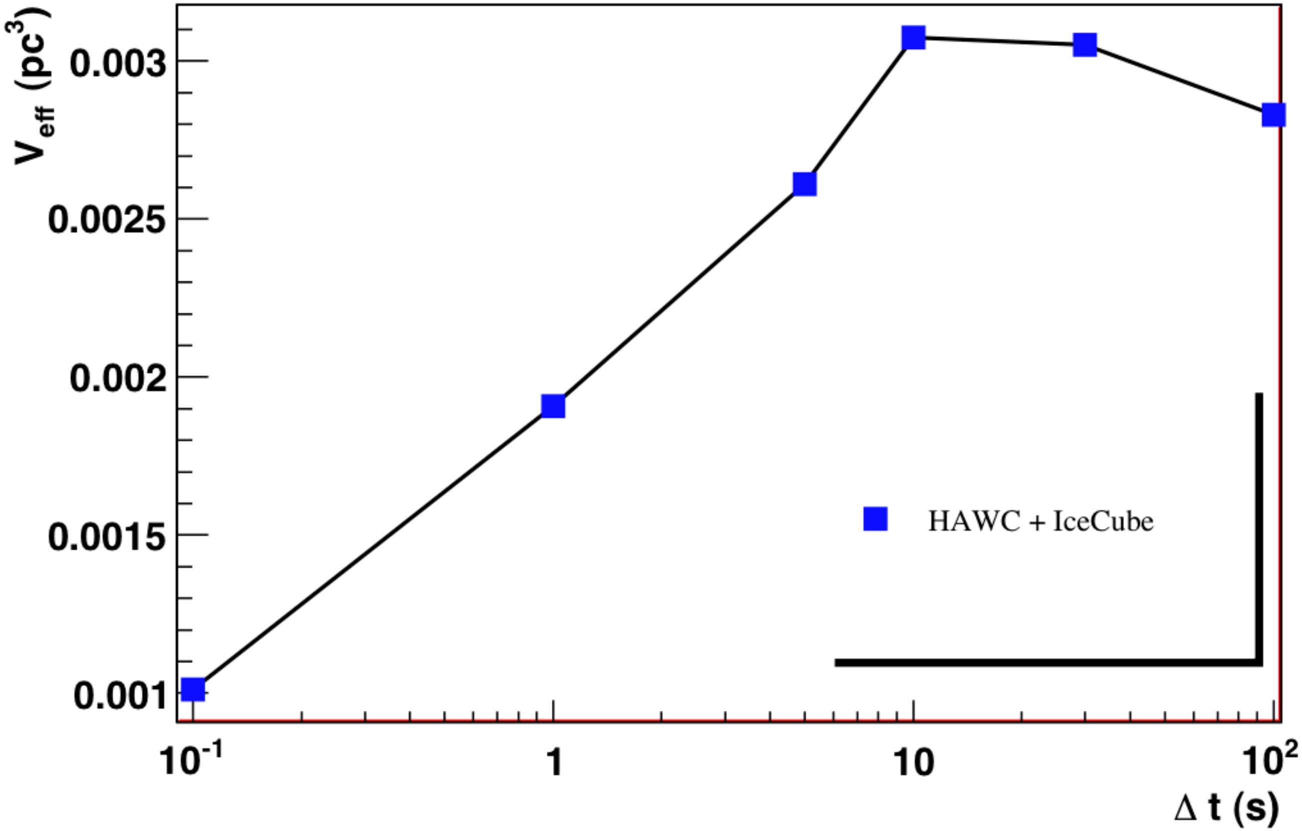
V_{eff} changes with Δt and b (burst size requirement: f(BG, Δt))

Sensitivity - Auger



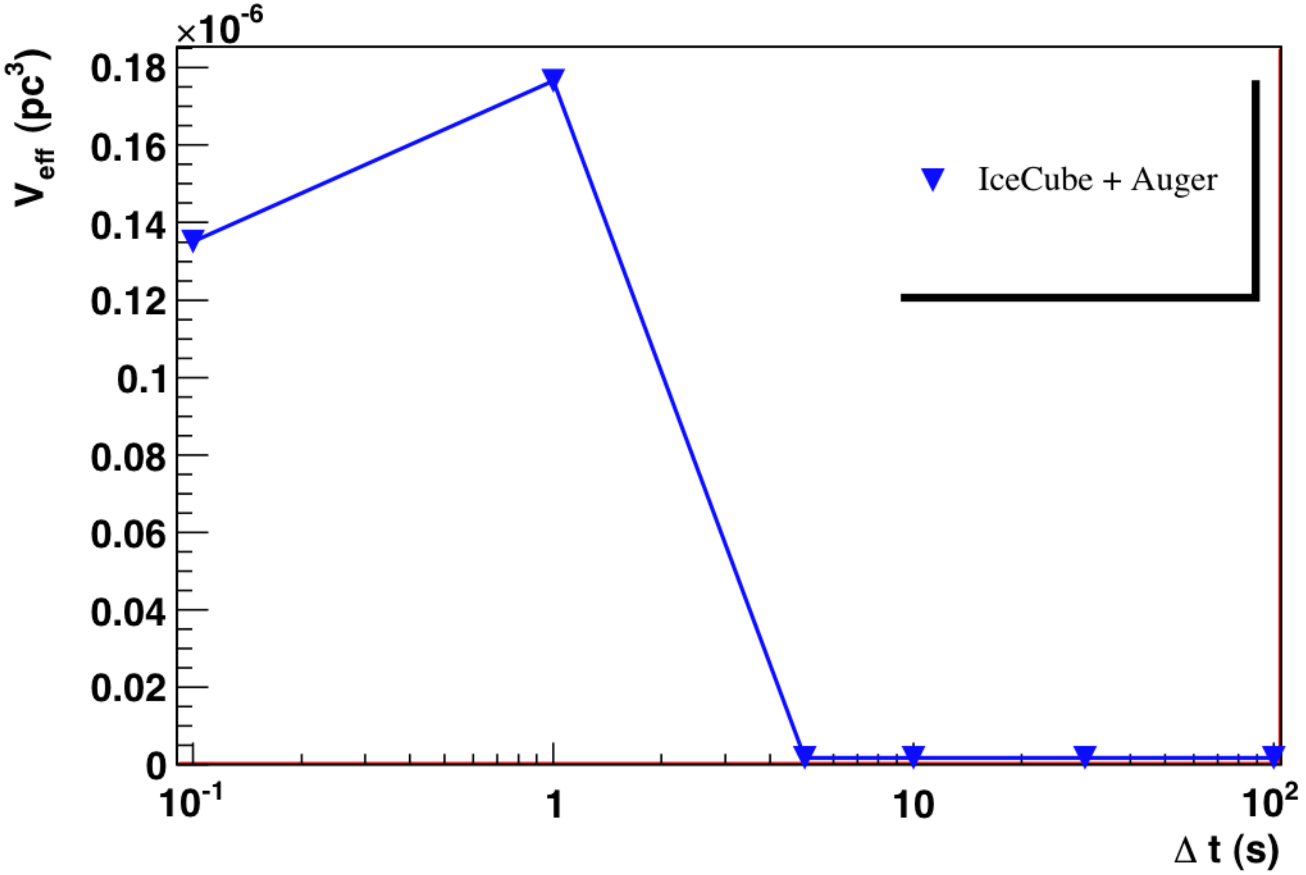
V_{eff} changes with Δt and b (burst size requirement: f(BG, Δt))

Sensitivity – HAWC+IceCube



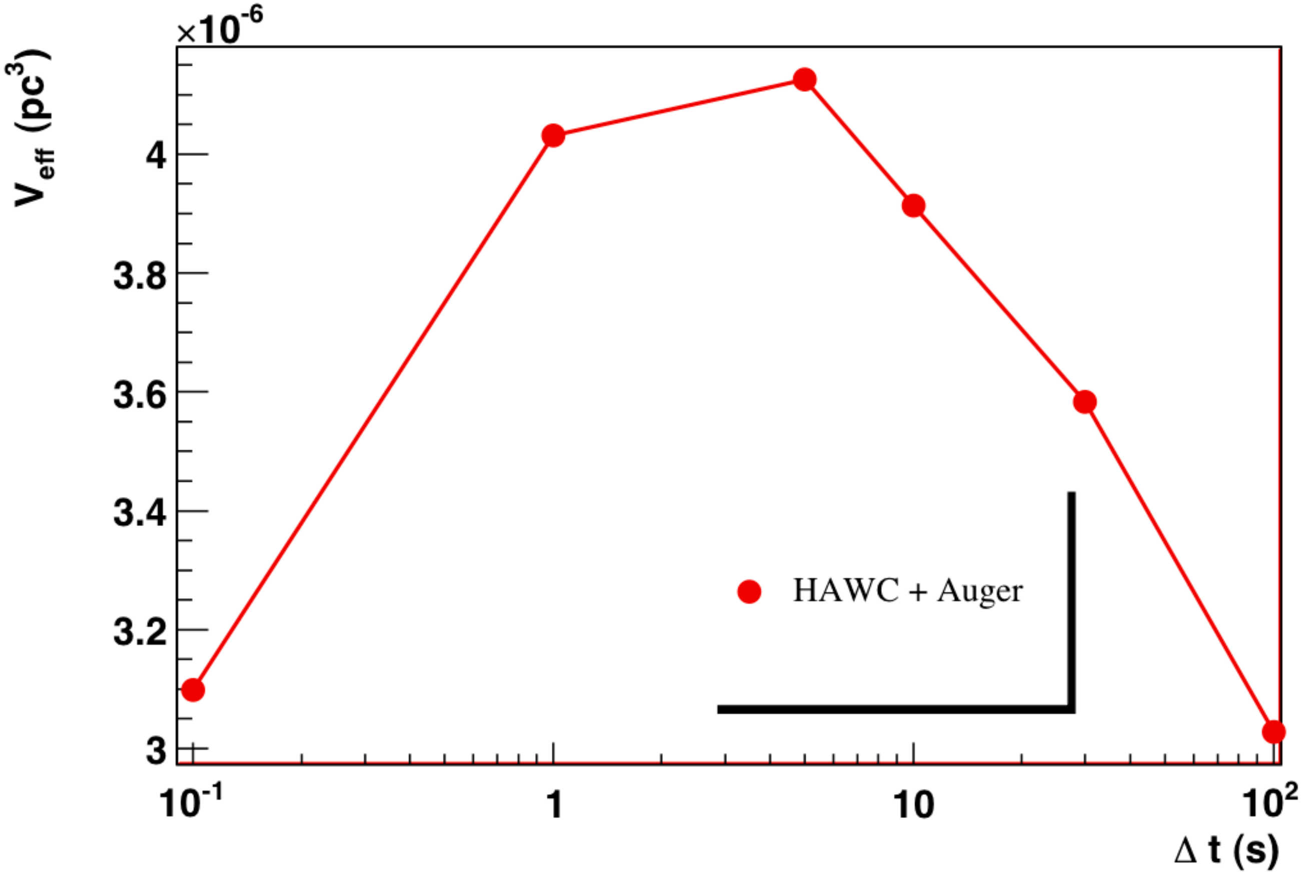
Subtreshold: N_ν>=1, N_γ>=18, Δt=10s

Sensitivity – IceCube + Auger



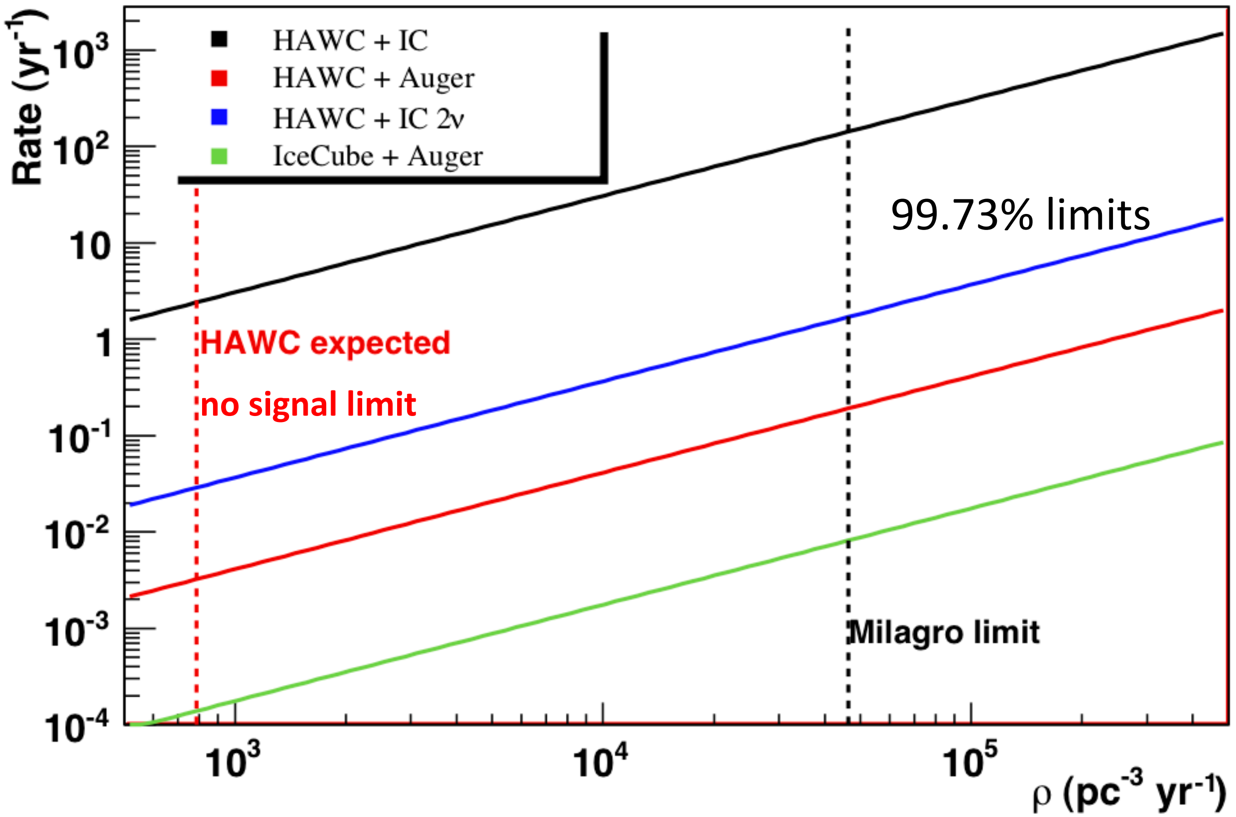
Subtreshold: N_ν>=1, N_n>=1, Δt=1s

Sensitivity – HAWC + Auger



Subtreshold: N_γ>=15, N_n>=1, Δt=5s

Expected limits and number of detections



- In case that HAWC detects burst(s), multimessenger signal is needed to probe PBH signature
- From 2 to 200 possible coincidences within projected HAWC and current Milagro limit within a year of joint observation

Summary

- Detection of PBHs would be a scientific breakthrough (Hawking's hypothesis of black hole radiation, cosmological models of phase transitions, physics at the highest energy scale & quantum gravity).

- Final PBH explosion produces jets of particles detectable by HAWC, IceCube and Pierre Auger

- HAWC alone may provide the best limit at very high energies in case of no bursts. AMON approach is needed in case of burst detection.

- With AMON, a distinctive PBH evaporation signature may be probed by conducting coincidence analysis from a few years of subthreshold neutrino, gamma-ray and neutron data.

Extra slides

Expectations

- total number of bursts of size b observed over time τ:

$$n(b,\Delta t) = \underset{\substack{\uparrow \\ \text{PBH density}}}{\rho_{PBH}}\,\tau\, \underset{\substack{\nwarrow \\ \text{Effective volume}}}{V_{eff}}$$

$$V_{eff} = \int d\Omega \int_0^\infty dr r^2 P(b, N_x(r,\Delta t))$$

- probability of observing a burst of size b within Δt:

$$P(b, N_x) = e^{-N_x} N_x^b / b!$$

Sensitivity

- Single detector:
  - above threshold data b>=a

$$V_{eff} = \frac{1}{16\pi^{3/2}} \sum_{a}^{\infty} \Gamma(b-3/2) I^{3/2} \Omega$$

$$I = \int_{0}^{\Delta t} dt \int_{0}^{\infty} dE \frac{d^2 N_x}{dEdt}\left(E,t\right) A(E,\theta)$$

- AMON approach - multiple detectors (i=1, M>=2), each detects bursts with size b_i >=a_i:

$$V_{eff} = \frac{1}{16\pi^{3/2}} \Omega_{overlap} \sum_{\vec{b}\geq\vec{a}} \Gamma\big(\sum_{i\leq M} b_i - 3/2\big) \frac{1}{\prod_{i\leq M} b_i} \prod_{i\leq M} \left(\frac{I_i}{\sum_{i\leq M} I_i} \right)^{b_i} \big(\sum_{i\leq M} I_i\big)^{3/2}$$

  -subtreshold data $\vec{b} \geq \vec{a}$

- Choose the time window that maximizes V_{eff} while keeping background rate low