Pheno Constraints from Charged Black Hole Evaporation in de Sitter

Seminar series on string phenomenology

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1910.01648 [hep-th]

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Goals

- Understand how charged BH decay in dS depends on particle spectrum
- Demand ‘sensible’ decay -> constrain particle spectrum
- Constraint interesting for dark energy and inflationary era, Supergravity and would-be string theory dS constructions,..

Charged BHs in flat space

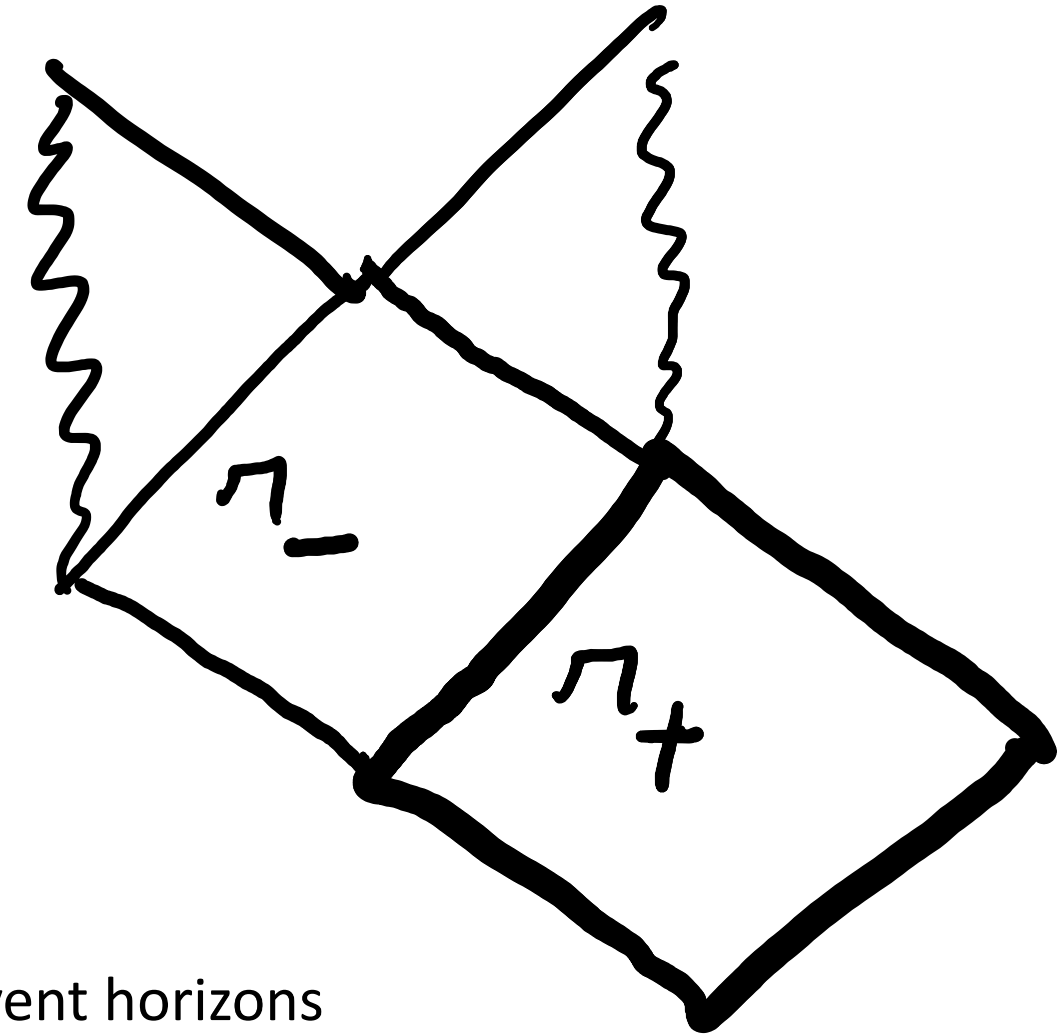
$$S = \int d^4x\sqrt{-g}\left[-\frac{R}{16\pi G_N} + \frac{1}{4g^2}F_{\mu\nu}F^{\mu\nu}\right]$$

$$ds^2 = -U(r)dt^2 + \frac{dr^2}{U(r)} + r^2 d\Omega,$$

$$U(r) = 1 - \frac{2G_N M_{BH}}{r} + \frac{G_N g^2 Q_{BH}^2}{4\pi r^2}$$

$$M \equiv G_N M_{BH}$$

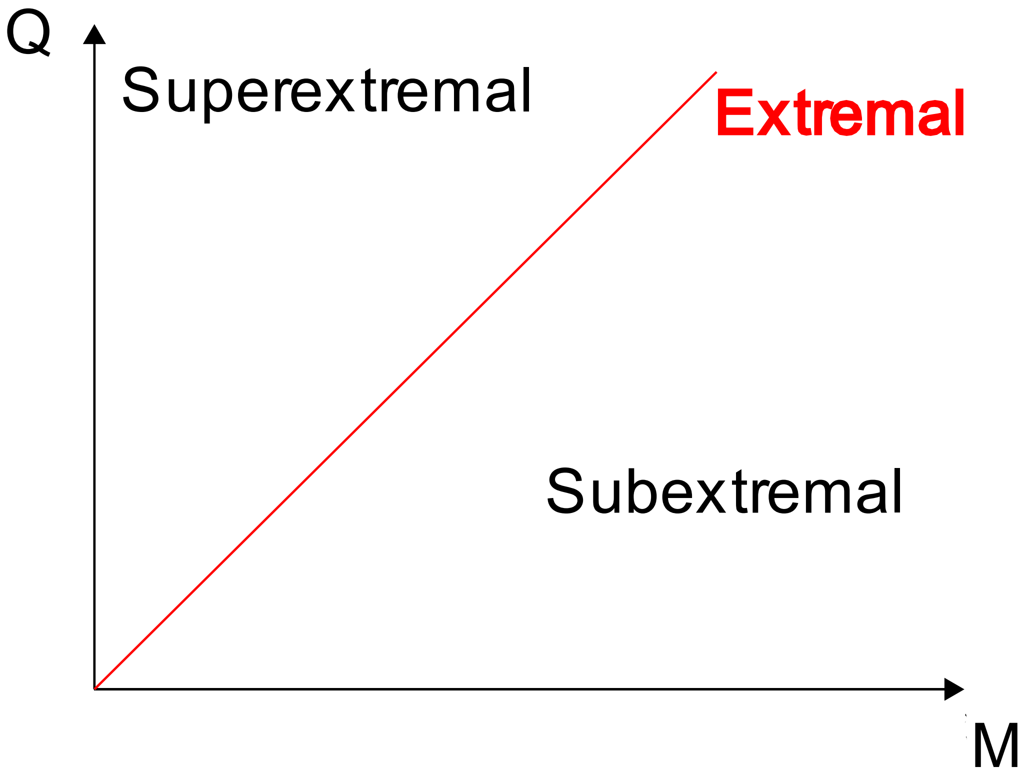
$$Q^2 \equiv \frac{G_N g^2 Q_{BH}^2}{4\pi}$$



Charged black holes generically have two event horizons

$$r_\pm = M \pm \sqrt{M^2 - Q^2}$$

Charged black holes in flat space



Classically stable, will evaporate due to quantum effects

$$r_{\pm} = M \pm \sqrt{M^2 - Q^2}$$

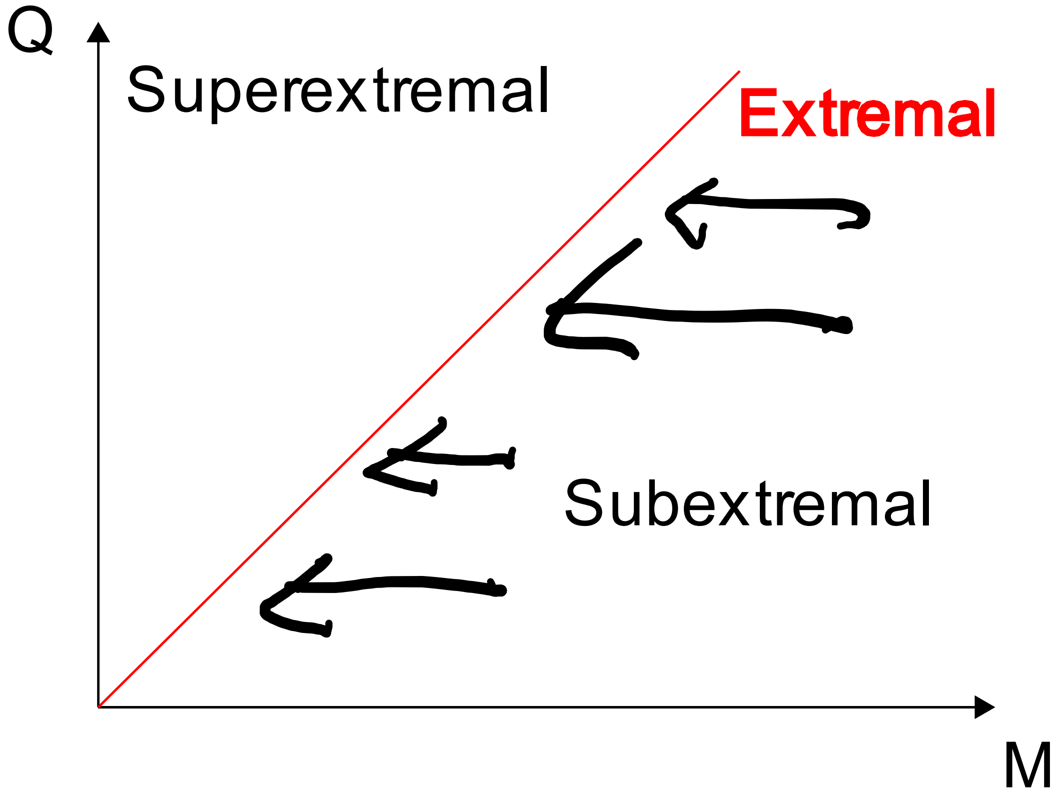
Two sources for black hole evaporation

- Hawking radiation
- Schwinger effect

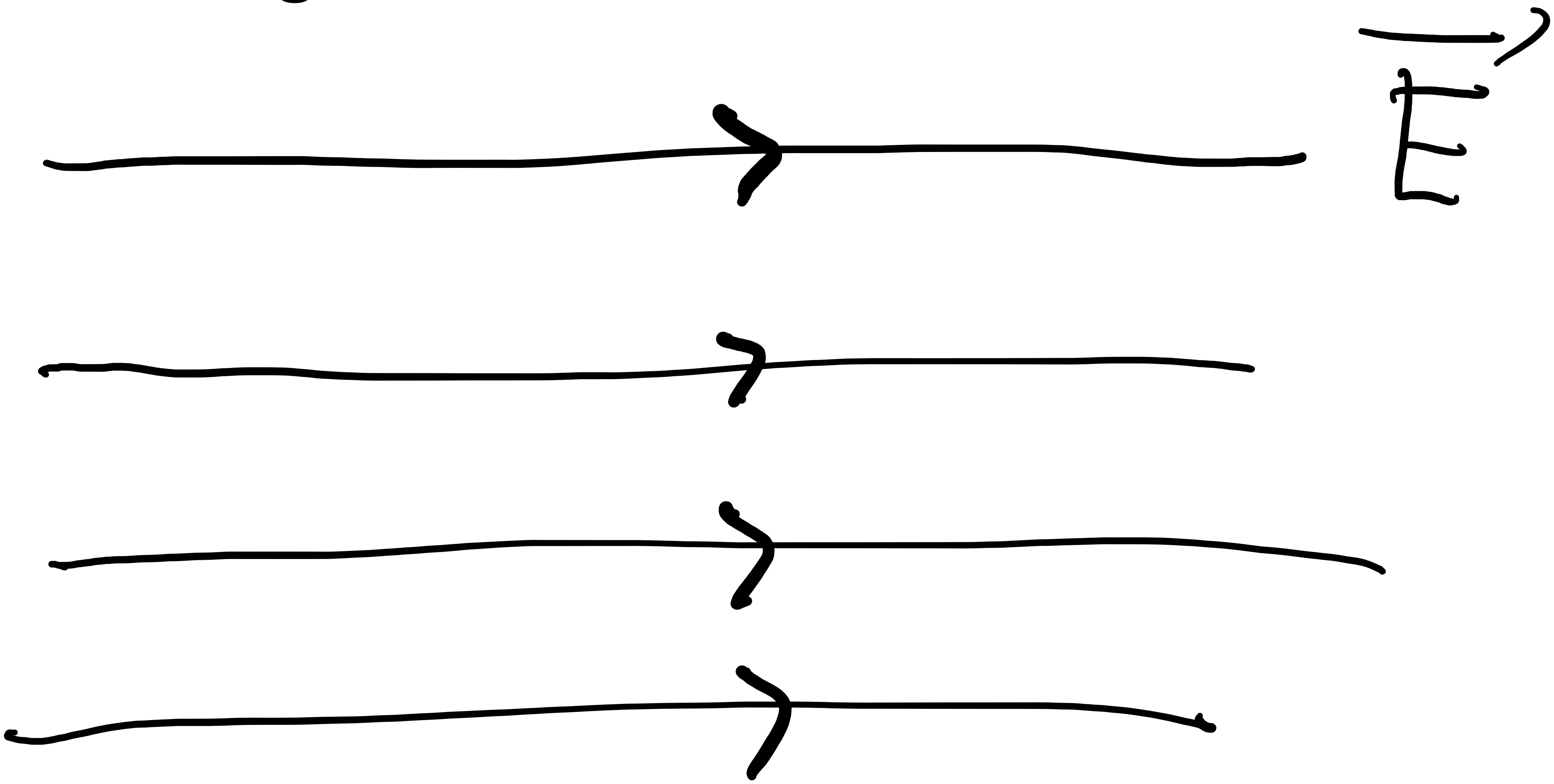
Black hole evaporation (Hawking)

$$\dot{M} \equiv \frac{dM}{dt} \sim -\sigma T_{BH}^4$$

$$T_{BH} = \frac{r_+ - r_-}{4\pi r_+^2}$$



Schwinger effect



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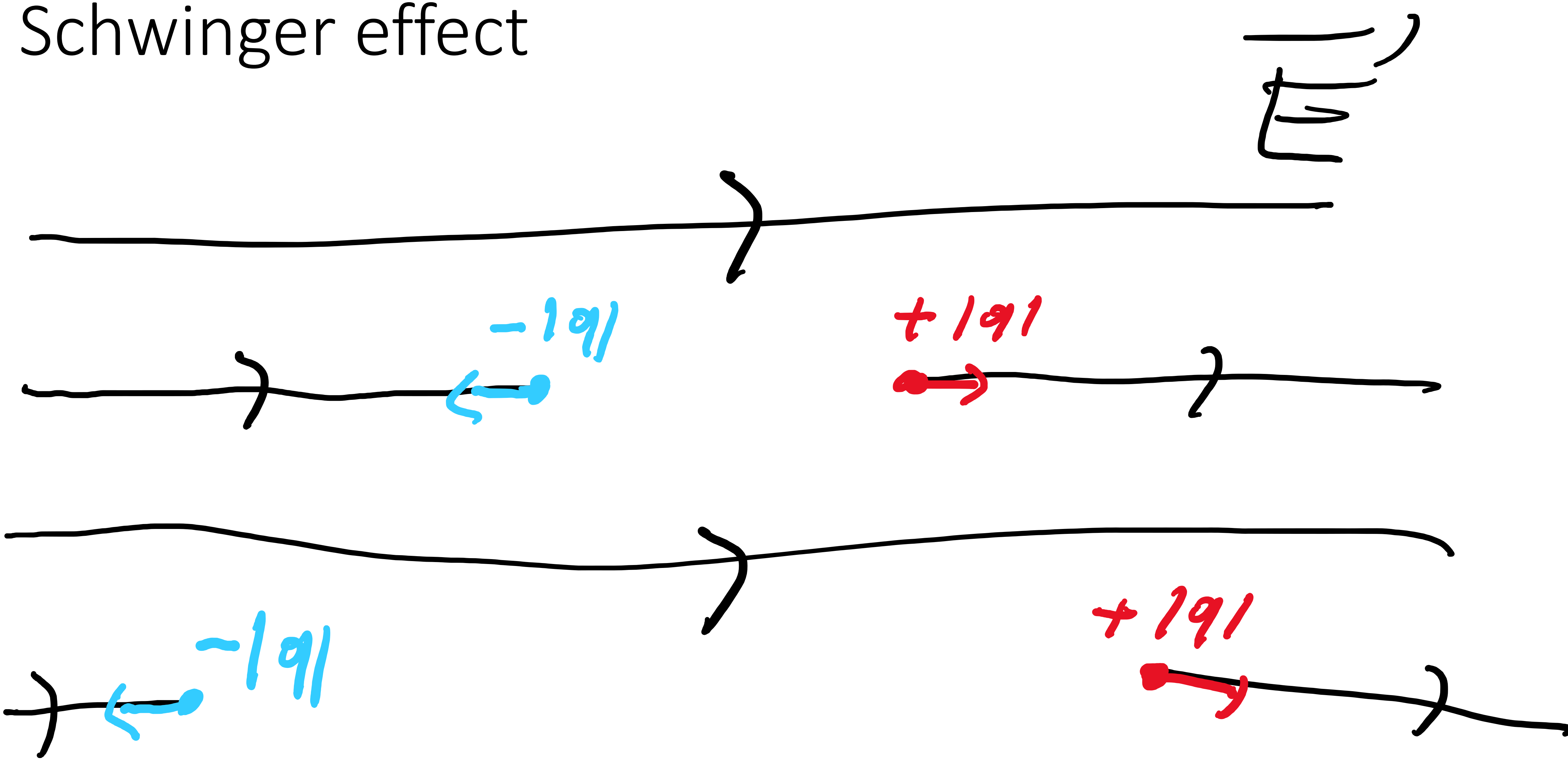
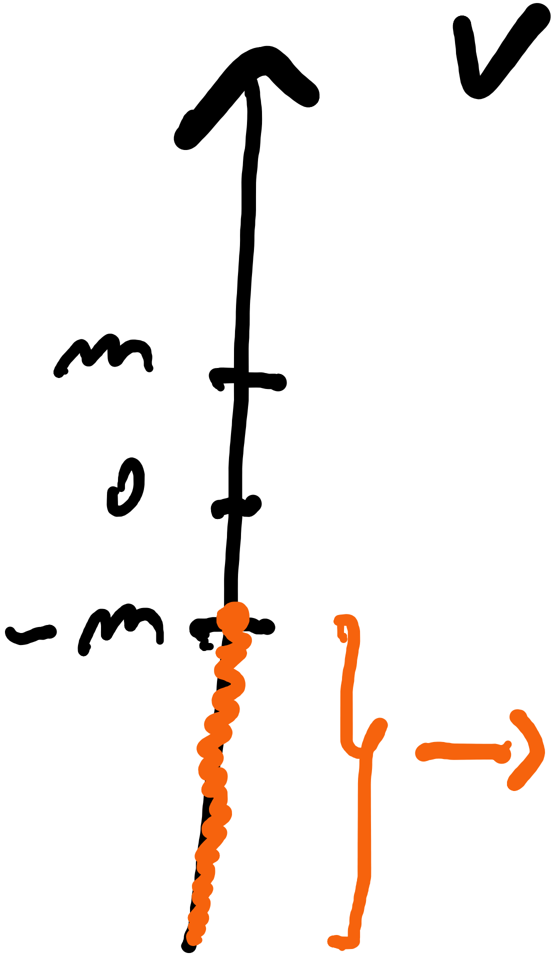
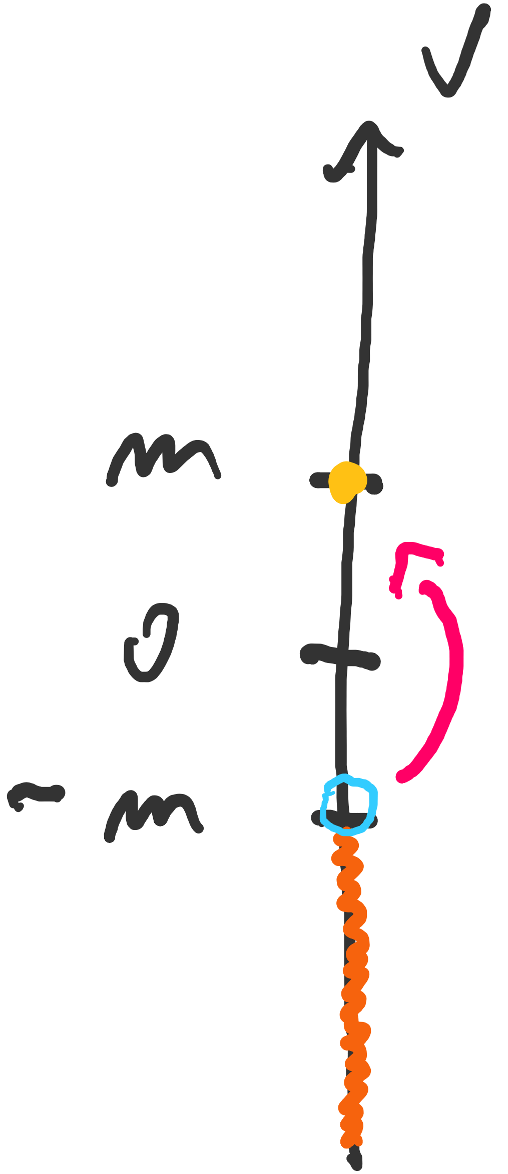




Particle mass m
charge $+|q|$

Dirac sea filled with 'virtual particles'

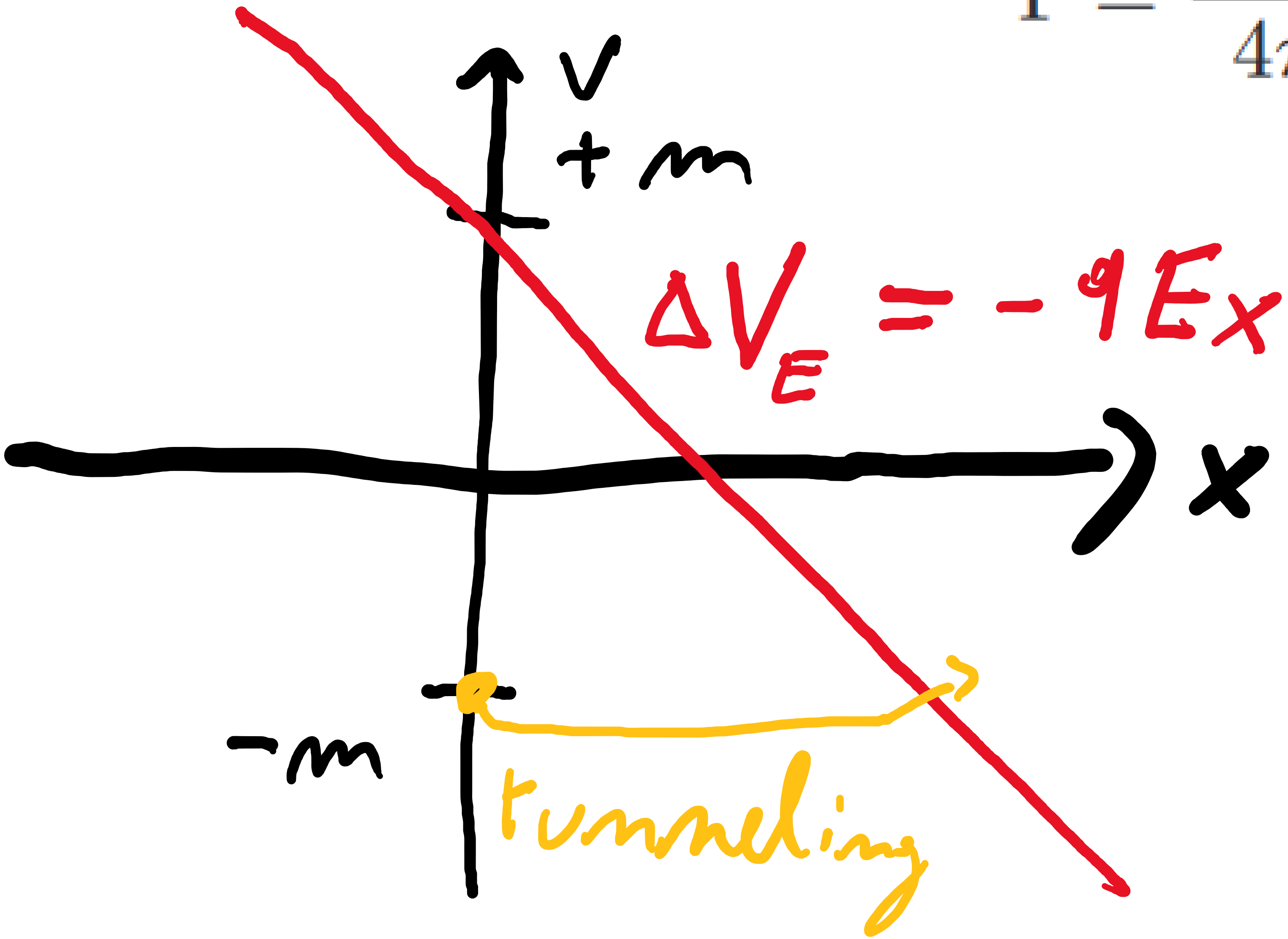


Particle mass m charge $+|q|$

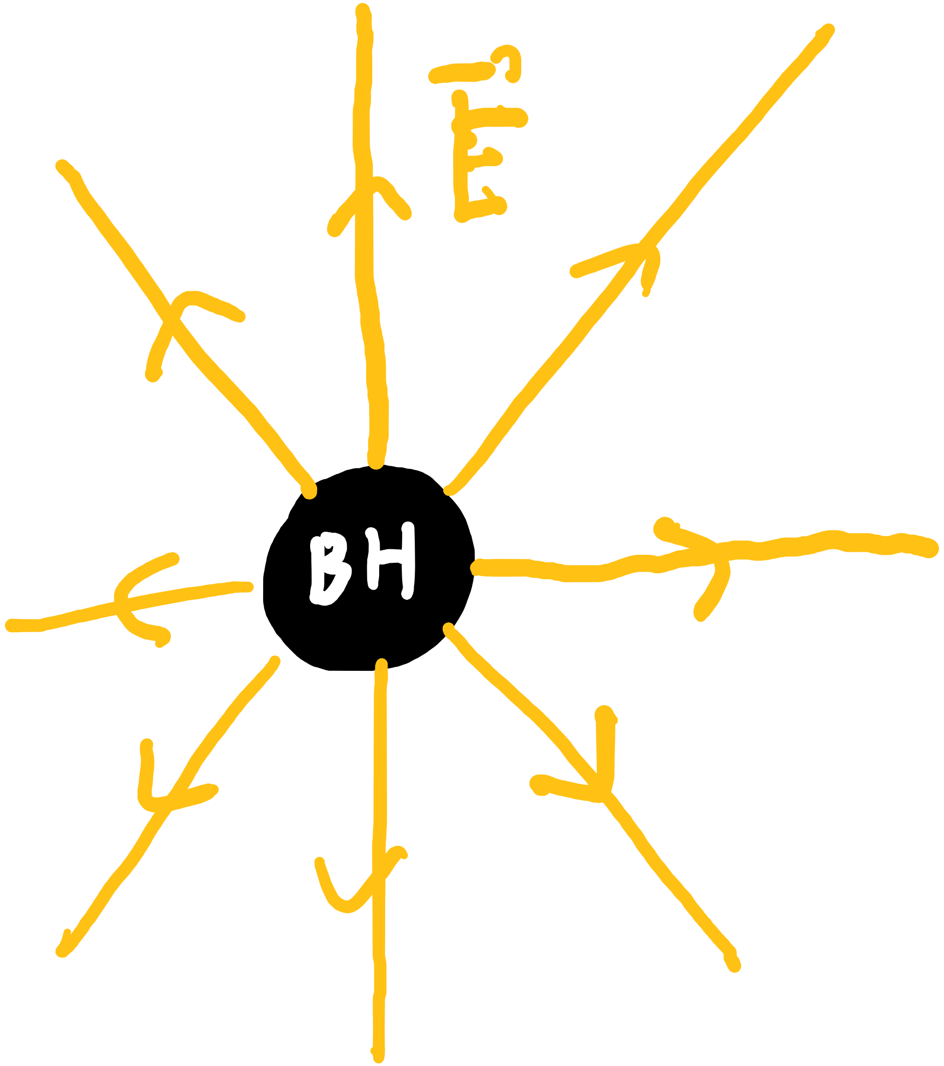
pump in energy

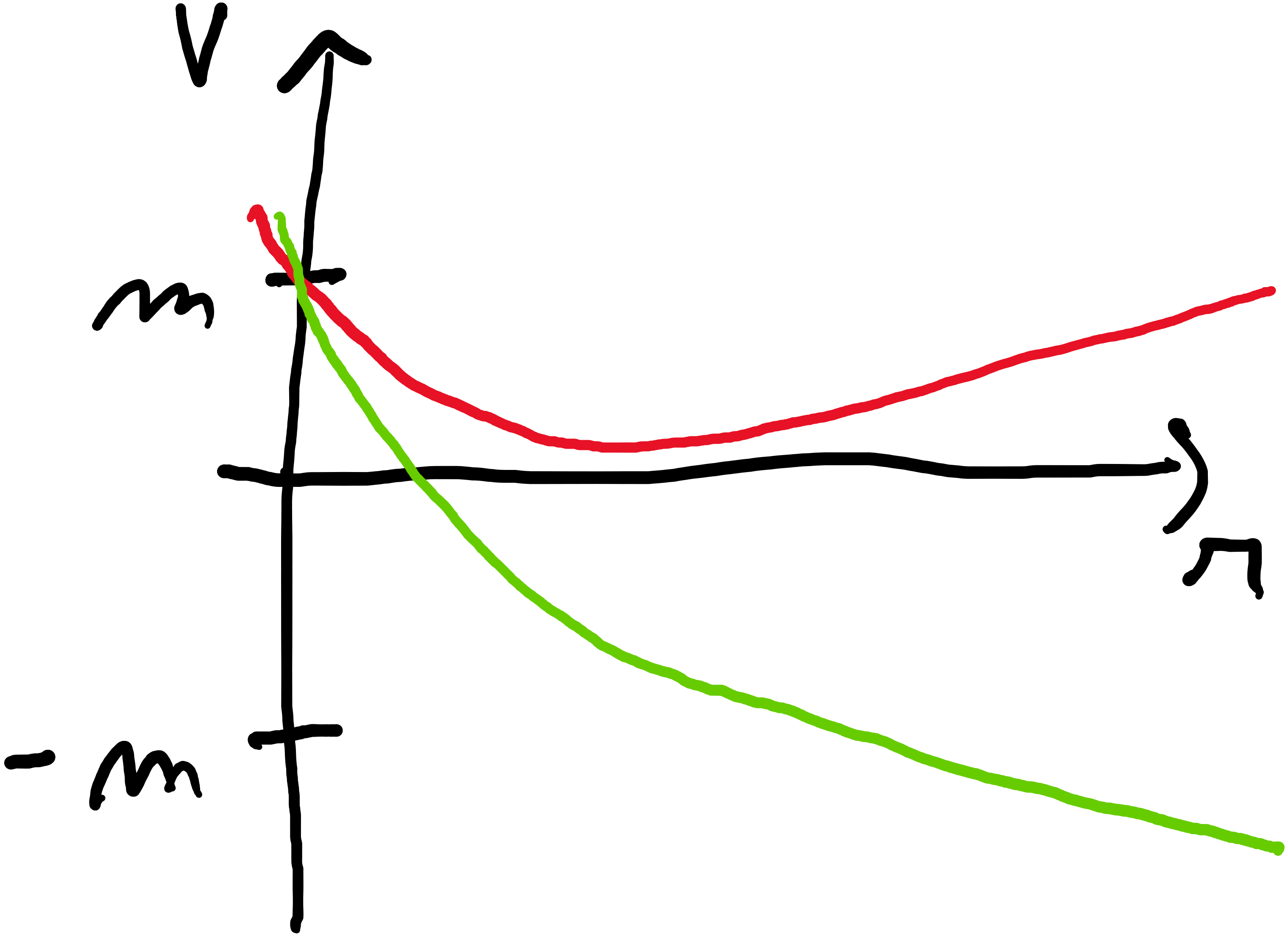
'Hole' antiparticle mass m charge $-|q|$

$$\Gamma = \frac{(qE)^2}{4\pi^3} \exp\left(-\frac{\pi m^2}{qE}\right)$$

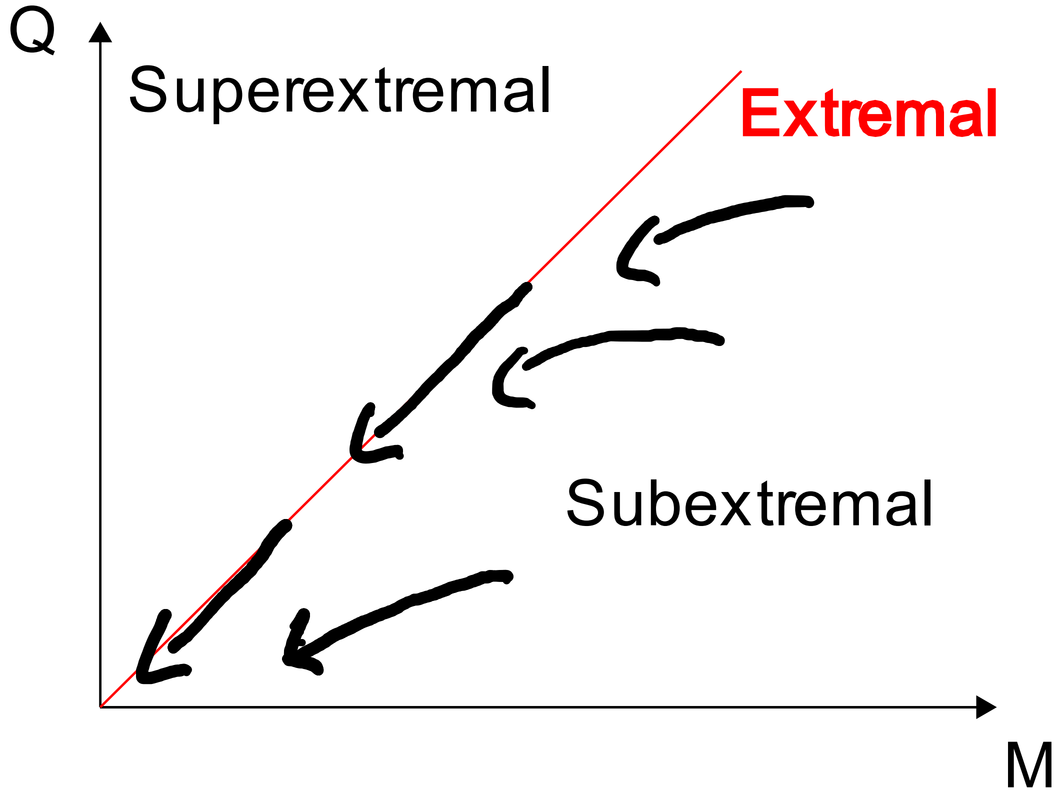


Schwinger effect (black hole)





Black hole evaporation (Hawking+Schwinger)



$$m \leq \sqrt{2} g q M_p$$

De Sitter space

De Sitter space

Homogeneous isotropic spacetime expanding at a constantly accelerating rate.

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G_N}\left(\mathcal{R} - 2\Lambda\right) + \mathcal{L}_{\mathrm{matter}}\right]$$

Cosmological constant

$$\Lambda = \frac{3}{l^2}$$

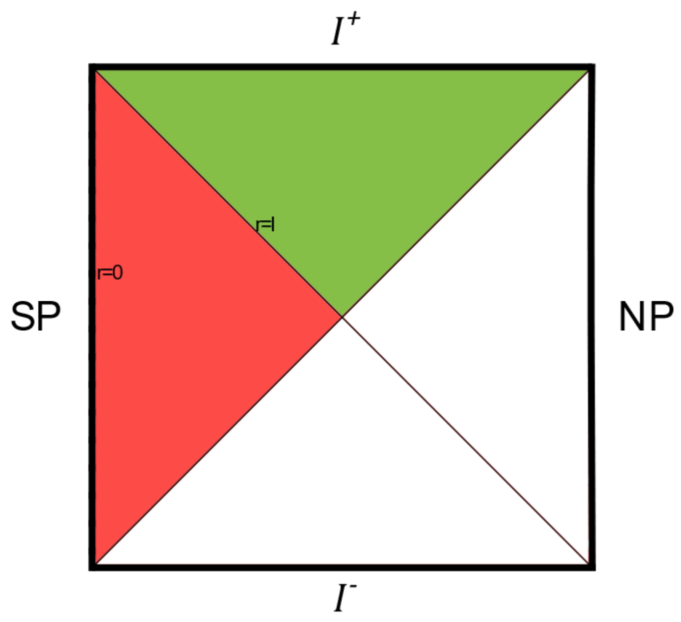
$$ds^2 = -\left(1 - \frac{r^2}{l^2}\right)dt^2 + \left(1 - \frac{r^2}{l^2}\right)^{-1}dr^2 + r^2 d\Omega_{d-2}^2$$

Hubble parameter

$$H = \frac{1}{l}$$

De Sitter as thermal bath

$$ds^2 = -\left(1 - \frac{r^2}{l^2}\right) dt^2 + \left(1 - \frac{r^2}{l^2}\right)^{-1} dr^2 + r^2 d\Omega_{d-2}^2$$



$$T_{dS} = \frac{1}{2\pi l}$$

$$S_{dS} = \frac{A}{4G_N} = \frac{\pi l^2}{G_N}$$

Black holes in de Sitter space

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G_N}\left(-R+\frac{6}{l^2}\right)+\frac{1}{4g^2}F_{\mu\nu}F^{\mu\nu}\right]$$

Black holes in de Sitter space

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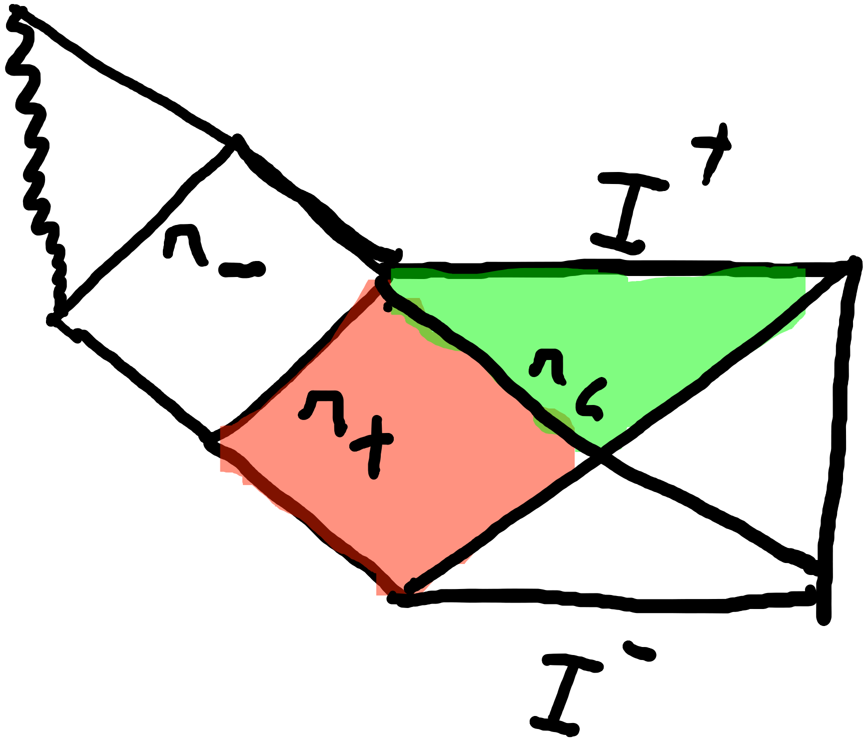
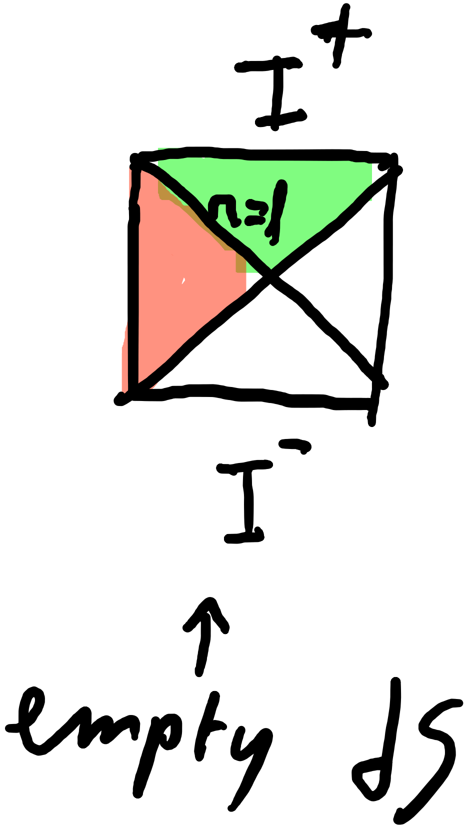
$$ds^2 = -U(r)dt^2 + \frac{dr^2}{U(r)} + r^2 d\Omega,$$

$$U(r) = 1 - \frac{2G_N M_{BH}}{r} + \frac{G_N g^2 Q_{BH}^2}{4\pi r^2} - \frac{r^2}{l^2}$$

$$M \equiv G_N M_{BH} \qquad Q^2 \equiv \frac{G_N g^2 Q_{BH}^2}{4\pi} \qquad l = 1$$

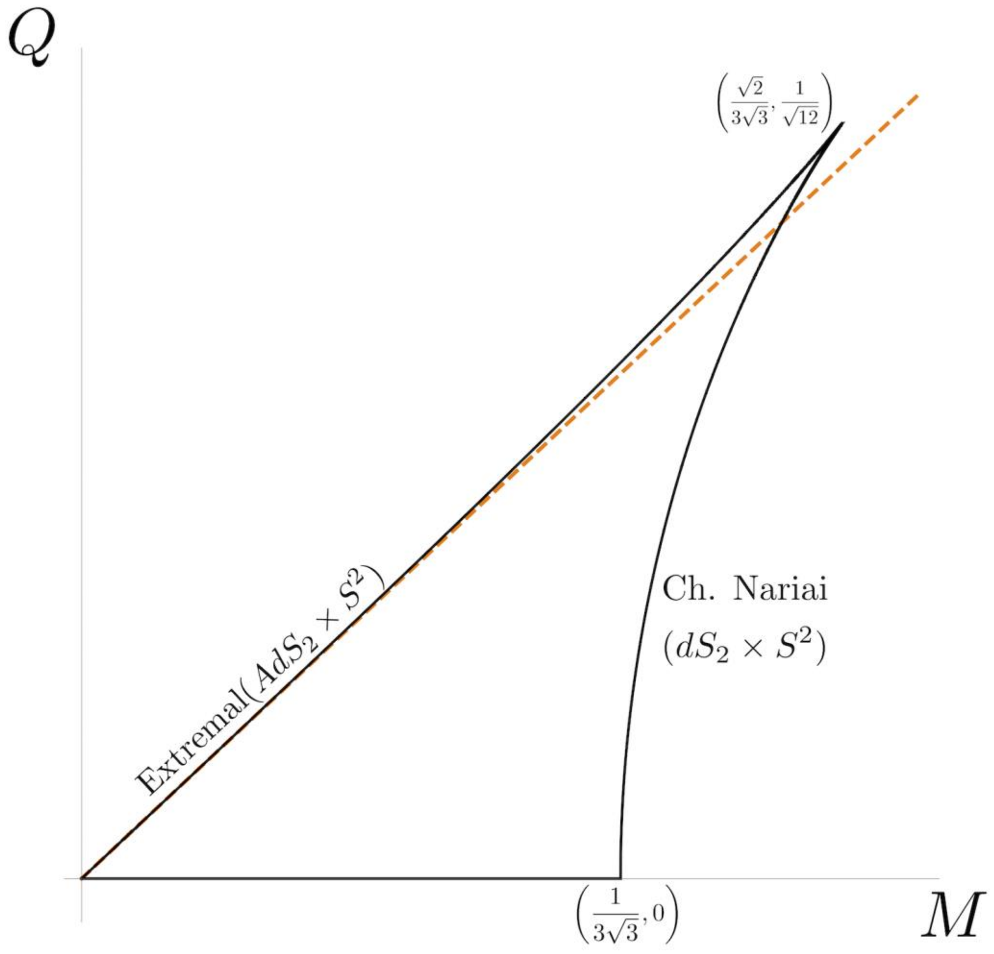
Black holes in de Sitter space





There are now three horizons. Size cosmic horizon backreacts, shrinks, due to presence black hole $r_c \leq l$

Black holes in de Sitter space



Total entropy given by

$$S = \frac{\pi}{4G_N}\left(r_+^2 + r_c^2\right)$$

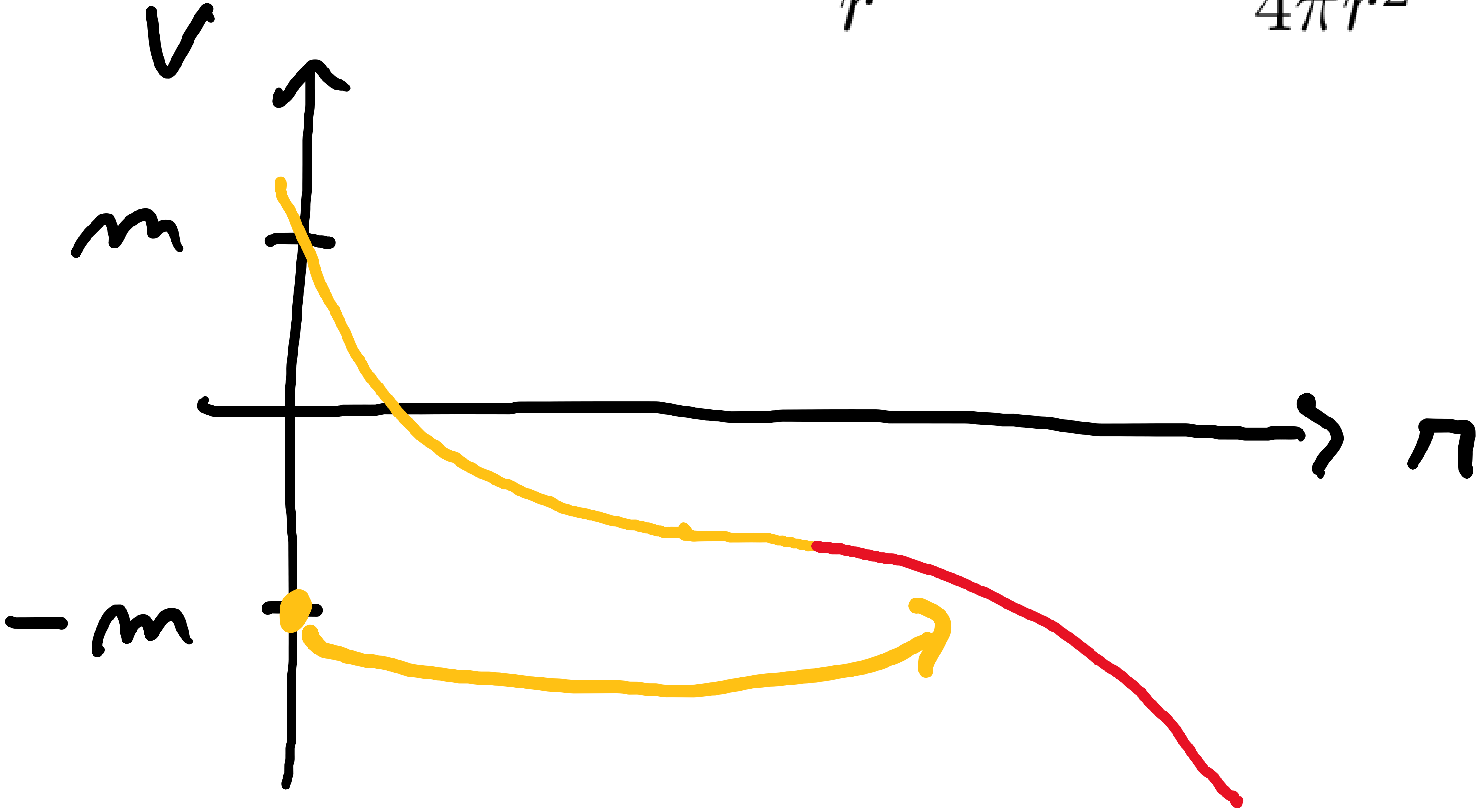
But empty de Sitter space has highest entropy due to backreaction cosmic horizon.

2 Hawking radiation

$$\dot{M} \equiv \frac{dM}{dt} \sim \sigma \left(T_c^4 - T_{BH}^4 \right)$$

Schwinger effect can always take place

$$U(r) = 1 - \frac{2G_N M_{BH}}{r} + \frac{G_N g^2 Q_{BH}^2}{4\pi r^2} - \frac{r^2}{l^2}$$



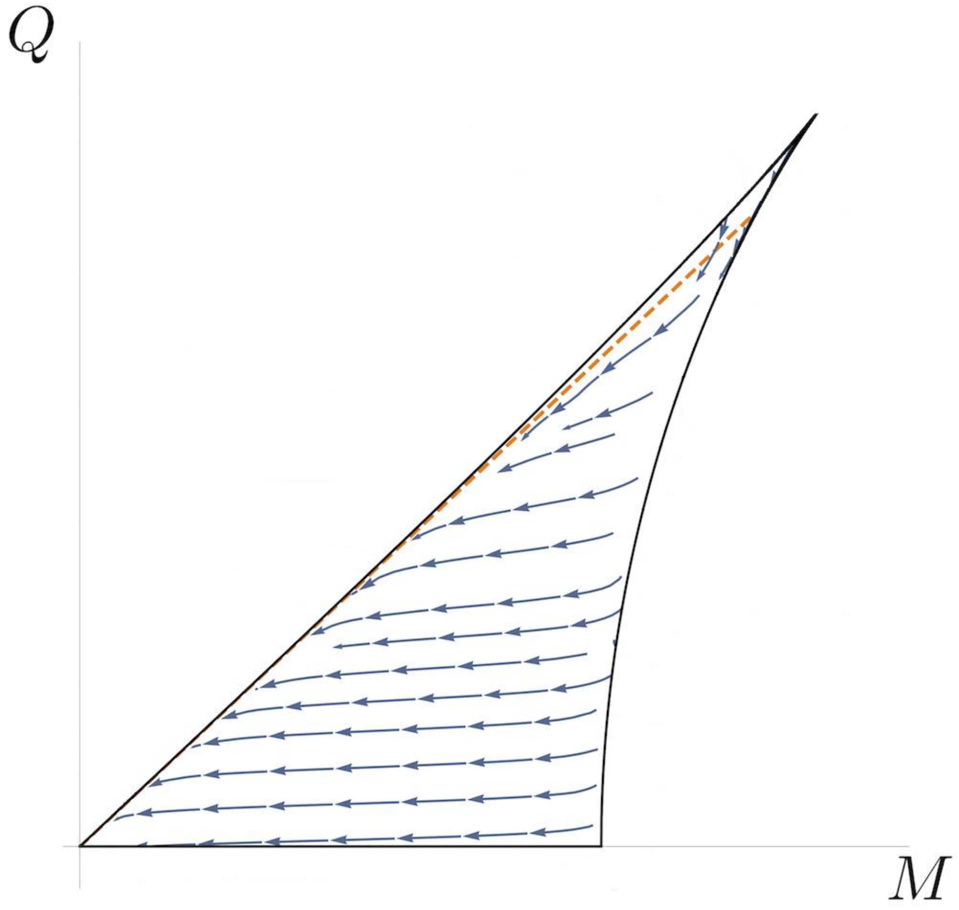
Schwinger: distinguish two evaporation regimes

$$\Gamma = \frac{(qE)^2}{4\pi^3} \exp\left(-\frac{\pi m^2}{qE}\right)$$

Quasistatic $\quad m^2 \gg qE$

Very rapid $\quad m^2 \ll qE$

Quasistatic $m^2 \gg qE$



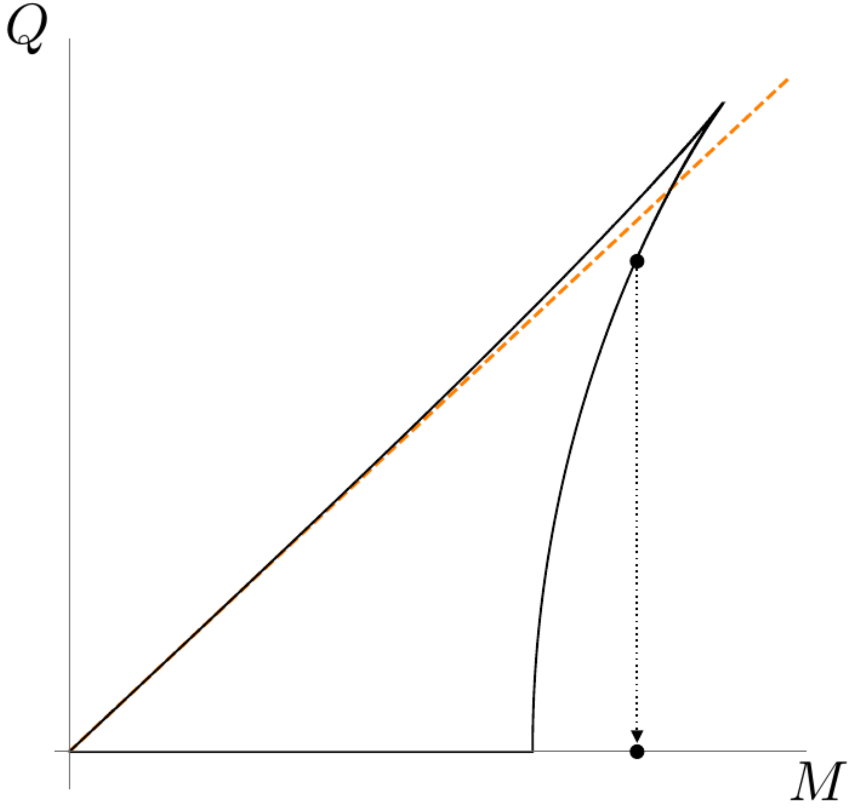
$$\frac{dM}{dQ} = \frac{\dot{M}}{\dot{Q}} = G\sqrt{U(r_g)}\frac{\mathscr{T}}{\mathscr{J}} + \frac{Q}{r_g}$$

$$\mathscr{T} = \frac{\sigma}{(4\pi)^3}\left[r_c^2 U'(r_c) - r_+^2 U'(r_+)\right]$$

$$\mathscr{J} = \sqrt{\frac{g^2 G}{4\pi\ell^2}}\frac{2}{\sqrt{U(r_g)}r^2}\frac{r_c^2\, r_+^2}{r_c^2 + r_+^2}\int_{r_+}^{r_c} dr'\,\Gamma(r')$$

Rapid regime $\quad m^2 \ll qE$

Difficult to analyse in general, focus on upper charged Nariai branch

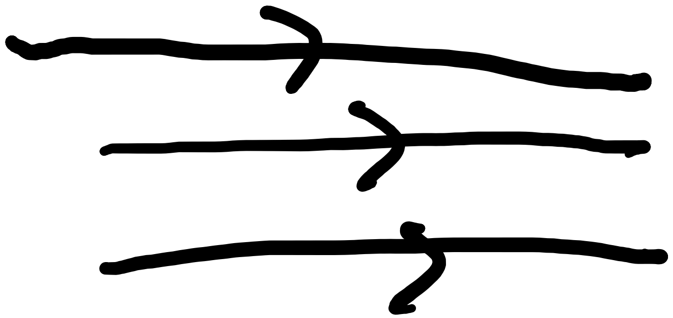


Charged Nariai Schwinger $m^2 \ll qE$

Have exact expression Schwinger current, discharge happens instantaneously compared to Hubble time, No exponential suppression + particle production boosted by de Sitter background,

Charged upper Nariai Schwinger $m^2 \ll qE$

constant $\vec{E}$ on $dS_2 \times S^2$



$\vec{E}$

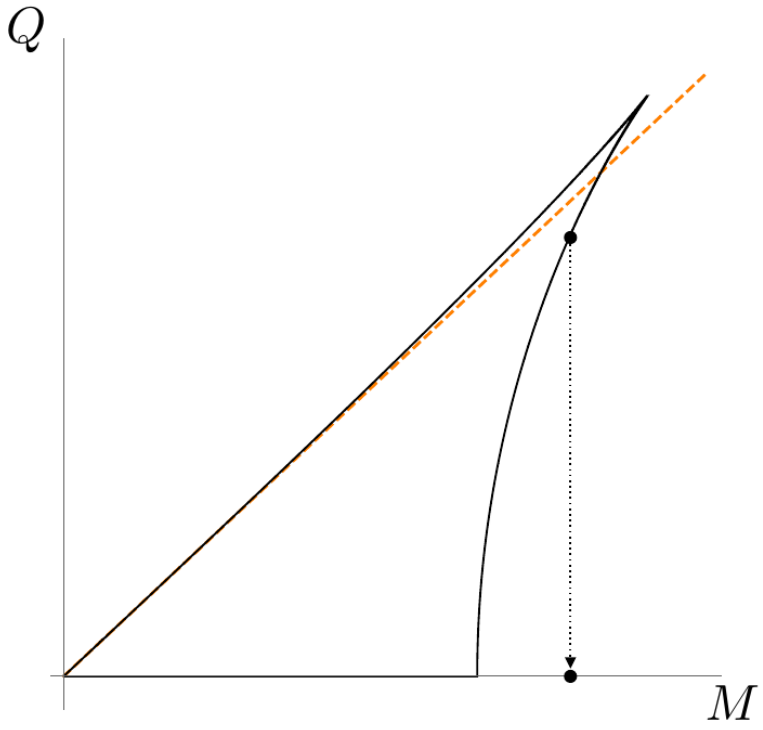
$E = \sqrt{6} M_P g H$

$\Downarrow$

$\boxed{\text{Neutral Radiation}}$

$\rho_{Rad} = \rho_E$

Solve Einstein eqn with energy density, pressure of radiation, singularity theorems guarantee that this will evolve into a future singularity rather than evaporate back to empty de Sitter space,



Demand black holes evaporate back to empty de Sitter space = avoid rapid regime

$$m^2 \gtrsim q\, g M_P H$$

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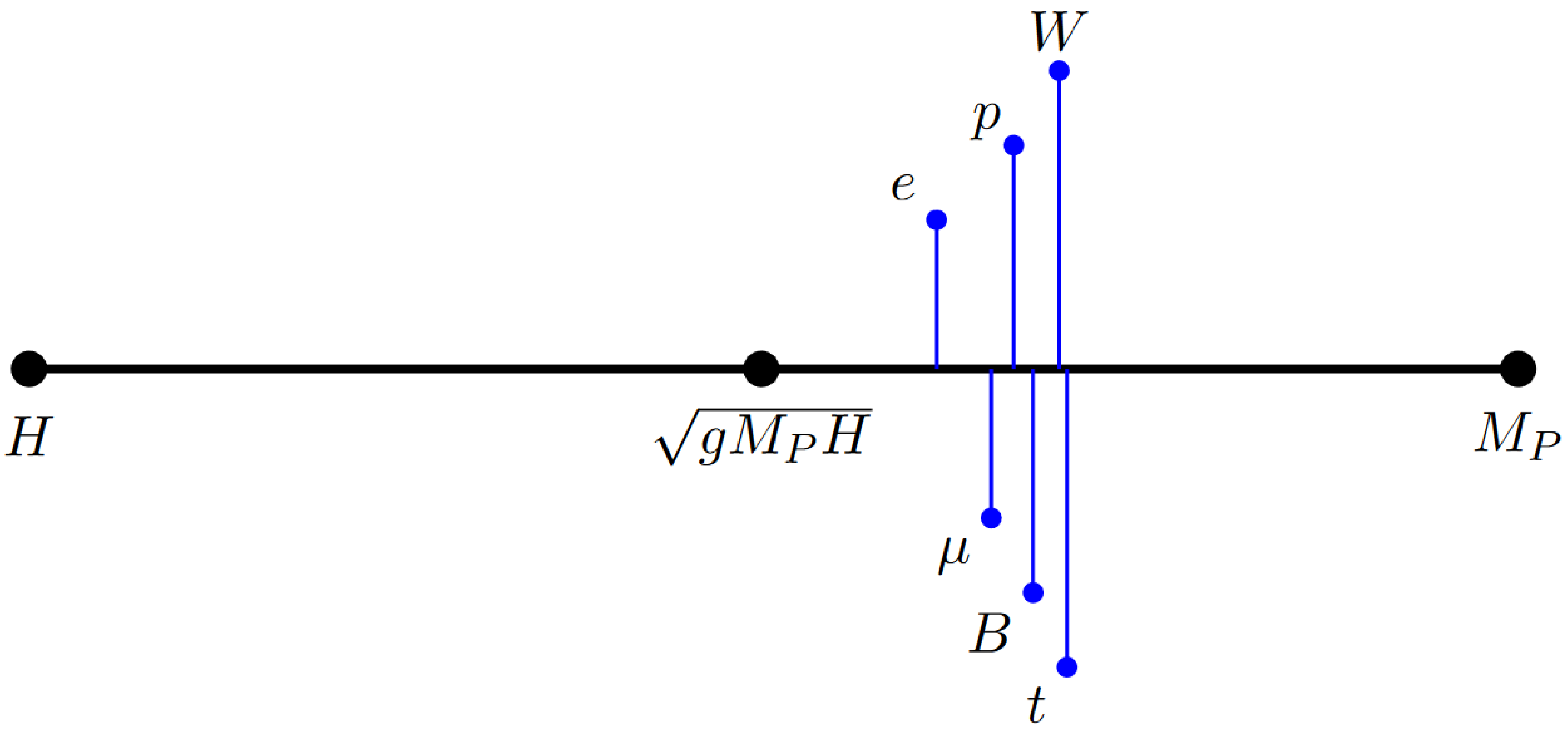
Real world $\sqrt{g M_P H} \sim 10^{-3}\, eV$

Electron m=0,5MeV so satisfies this bound

All particles must obey this bound.

Impossible when decoupling gravity.

Hierarchy



Inflation

Before EW symmetry breaking charged particles massless

$$m^2 \gtrsim q\, g M_P H$$

Issue with bound when H at inflationary scale?

Inflation

One way out: inflation lasts shorter than BH discharge time, in this case our analysis makes no sense

$$g \leq \frac{H}{N_e^2 M_P}$$

With N_e number of e-foldings inflation

EFT cut-off

Magnetic WGC provides UV cut-off scale EFT

$$\Lambda \leq g M_p$$

dS-corrected version argued by [Huang, Li, Song '06]

$$\Lambda \leq \frac{g}{2\sqrt{G}} \sqrt{1 + \sqrt{1 - \frac{8G}{g^2 L^2}}}.$$

Can combine with our bound rewritten in terms gauge coupling

$$g \lesssim \frac{m^2}{q M_P H}$$

To bound EFT scale in terms charge carrier

Supergravity models

[Cribiori, Dall'Agata, Farakos 2011.06597]

Studied class of N=2 gauged SuGra models w dS cricital points

EFT UV cut-off scale below Hubble scale (from mWGC)

-> No sensible dS EFT description

These models all have massless charged gravitinos

-> Agree with prediction from our bound!

Further application of bound to SuGra and would-be string constructions would be interesting

Conclusion

Black holes in de Sitter space should not evaporate too quickly

$$m^2 \gtrsim q\, g M_P H$$

This constraint interesting for pheno, SuGra and would-be string constructions