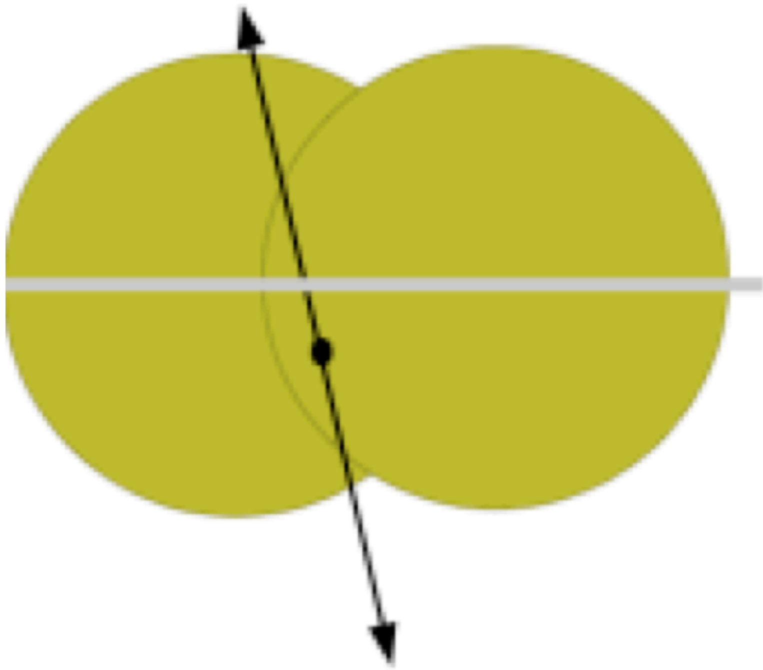
Heavy Ion Collisions and Strong Coupling

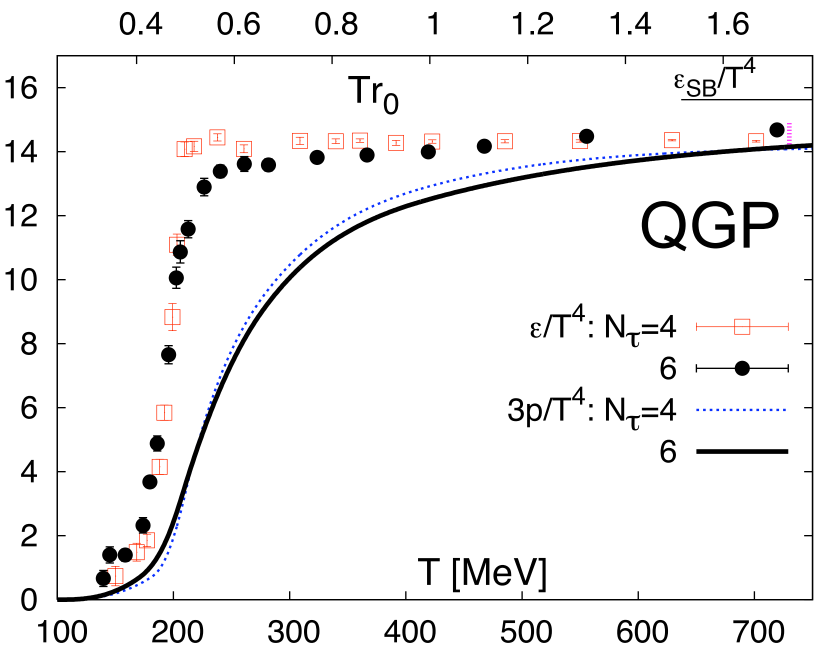
Jorge Casalderrey Solana

MARIE CURIE ACTIONS

PEOPLE

HICs and Flow



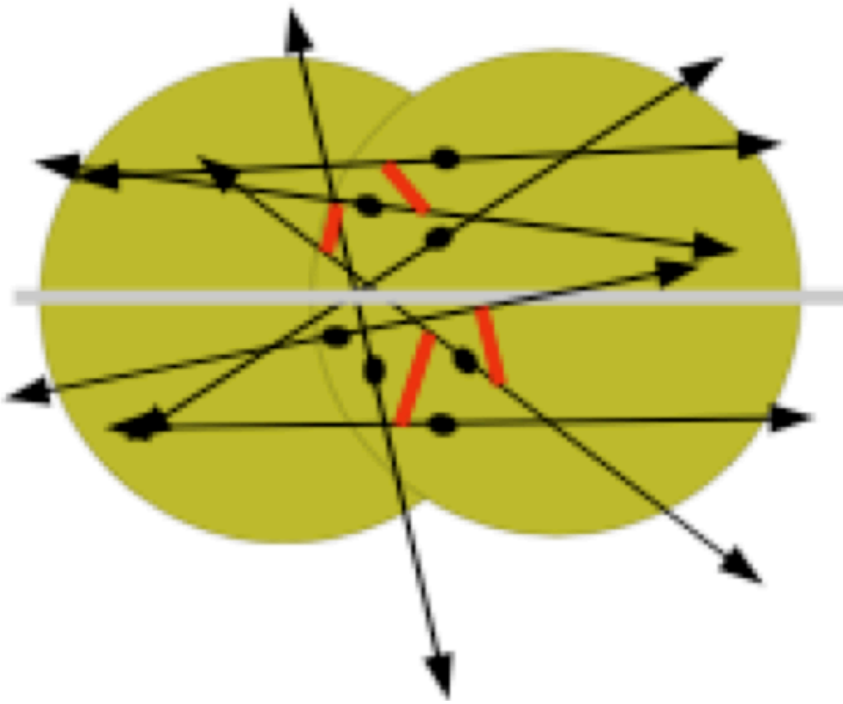


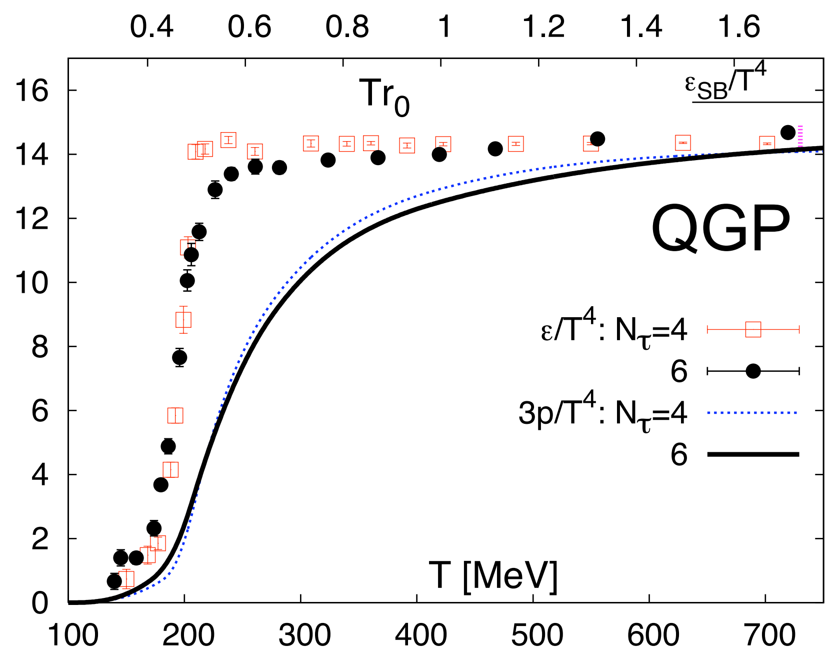
Cheng

$$\frac{dN}{dp_T d\phi} = \frac{1}{2\pi}\frac{dN}{dp_T}\left[1 + 2v_2(p_T)\cos\left(2\phi\right) + \ \ldots\right]$$

- Collectivity: anisotropy in space is transferred to momentum
- It is well described by (almost) ideal hydrodynamics. Deviations from ideal are parameterized by the viscosity.
- At RHIC it is much smaller than any other known substance. Perturbative estimates lead to a much larger value.

HICs and Flow





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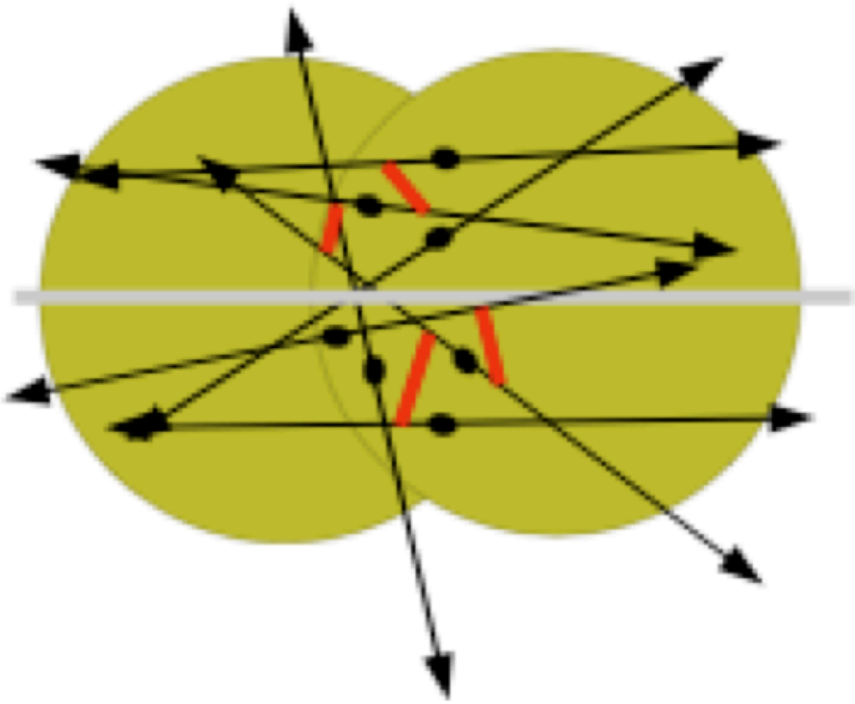

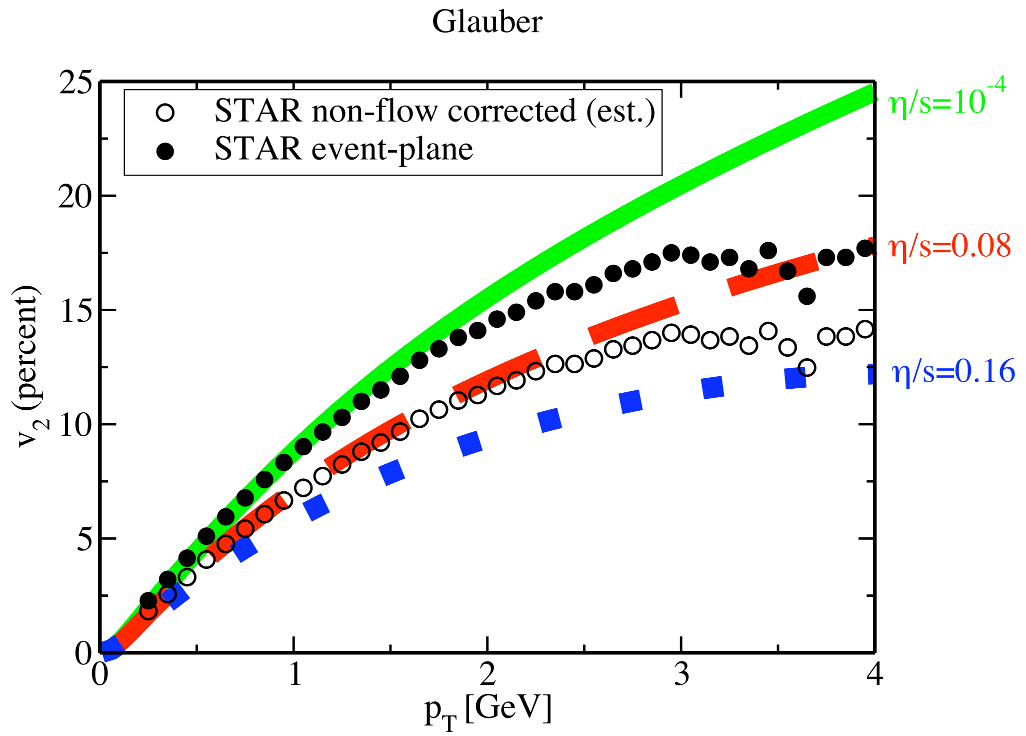

Romatschke

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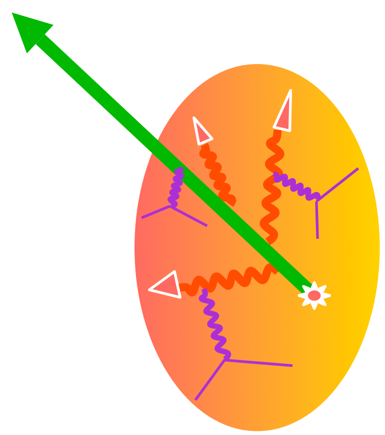
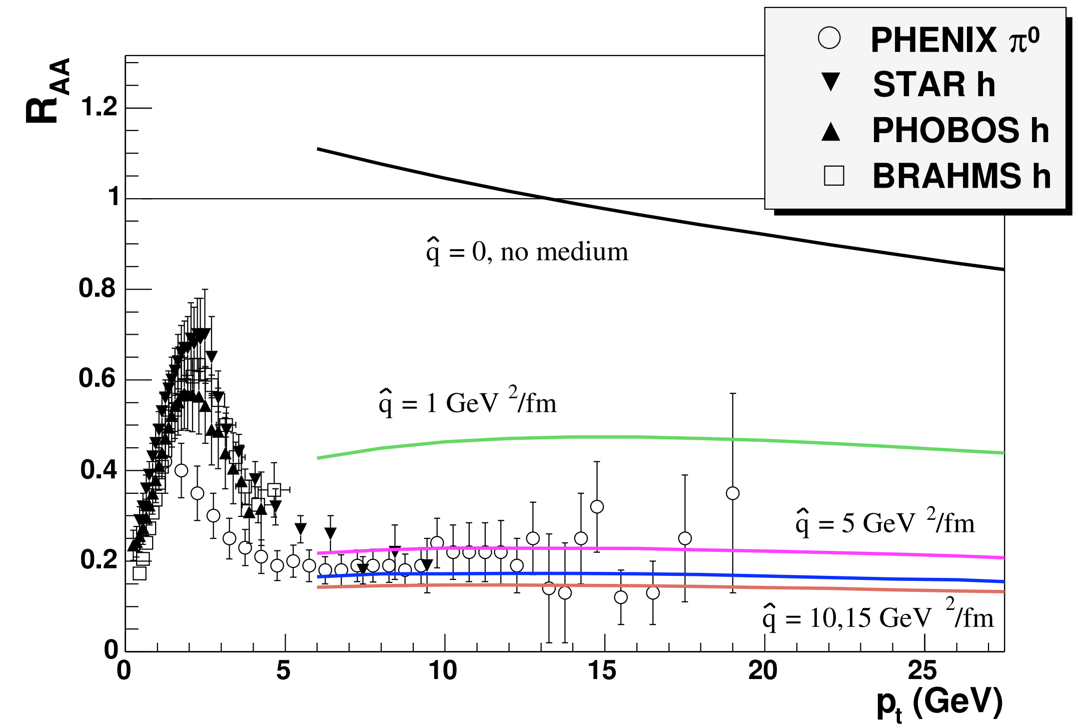
HICs and Jet Quenching





Eskola et al.

$$R_{AA} = \frac{\text{Number of particles in A} - \text{A}}{\text{Number of collision} \times \text{Number of particles in p} - \text{p}}$$

- Matter is very opaque to high energy probes.
- It is hard to accommodate this fact with perturbation theory.
- The coupling seems to be large (or, at least, not small)
- It is desirable to find a strong coupling technique which allows to compare to perturbative calculations. (opposite limit)

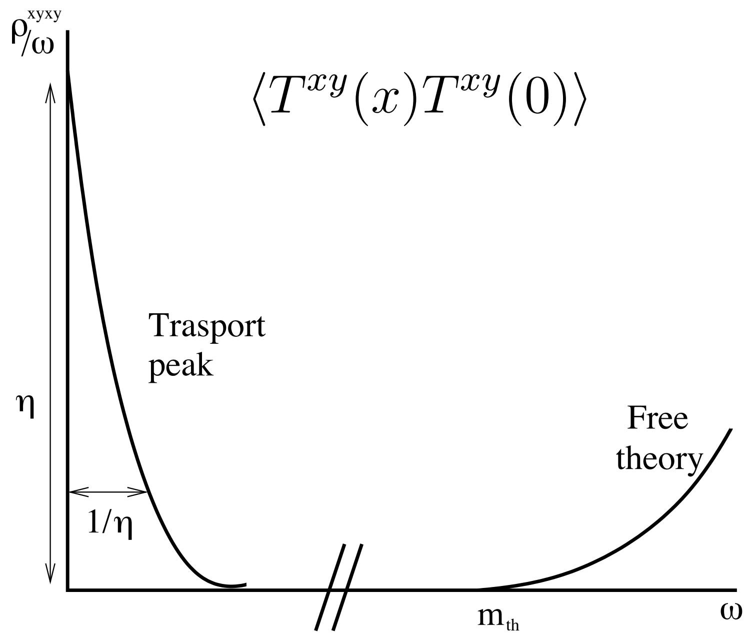
Strong Coupling

This is not just a quantitative issue:

there are qualitative differences at strong coupling!

Quasiparticles

Teaney

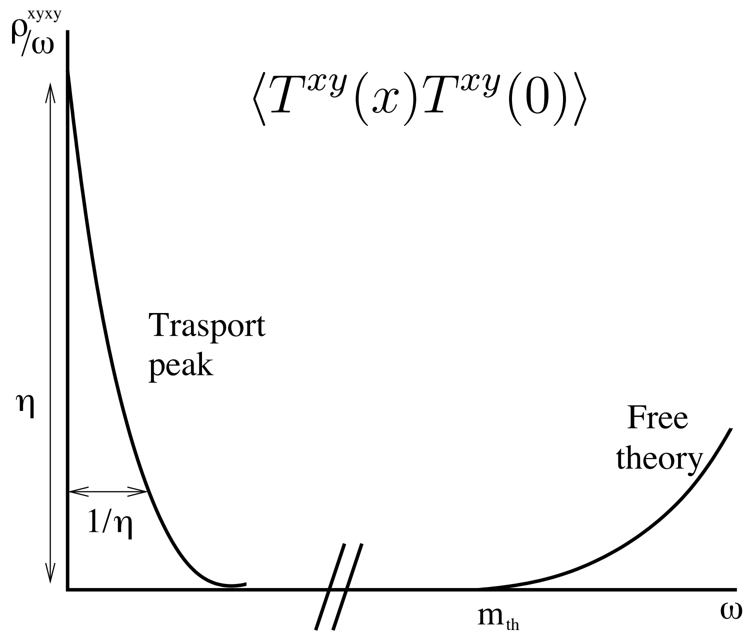


- Quasiparticles: long lived excitations (mean free path large with respect to interparticle distance and interaction range)

$$\lambda_{mfp} \gg \frac{1}{\mu} \gg d \quad \overset{\text{finite T FT}}{\underset{\text{small coupling}}{\Longrightarrow}} \quad \frac{1}{g^4 T} \gg \frac{1}{gT} \gg \frac{1}{T}$$

- The separation of scales happens only at small coupling!

Quasiparticles



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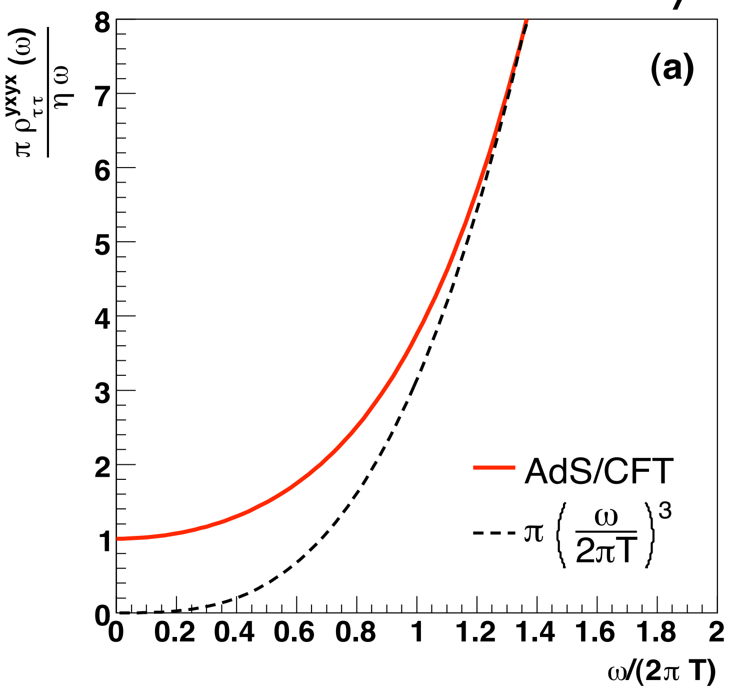

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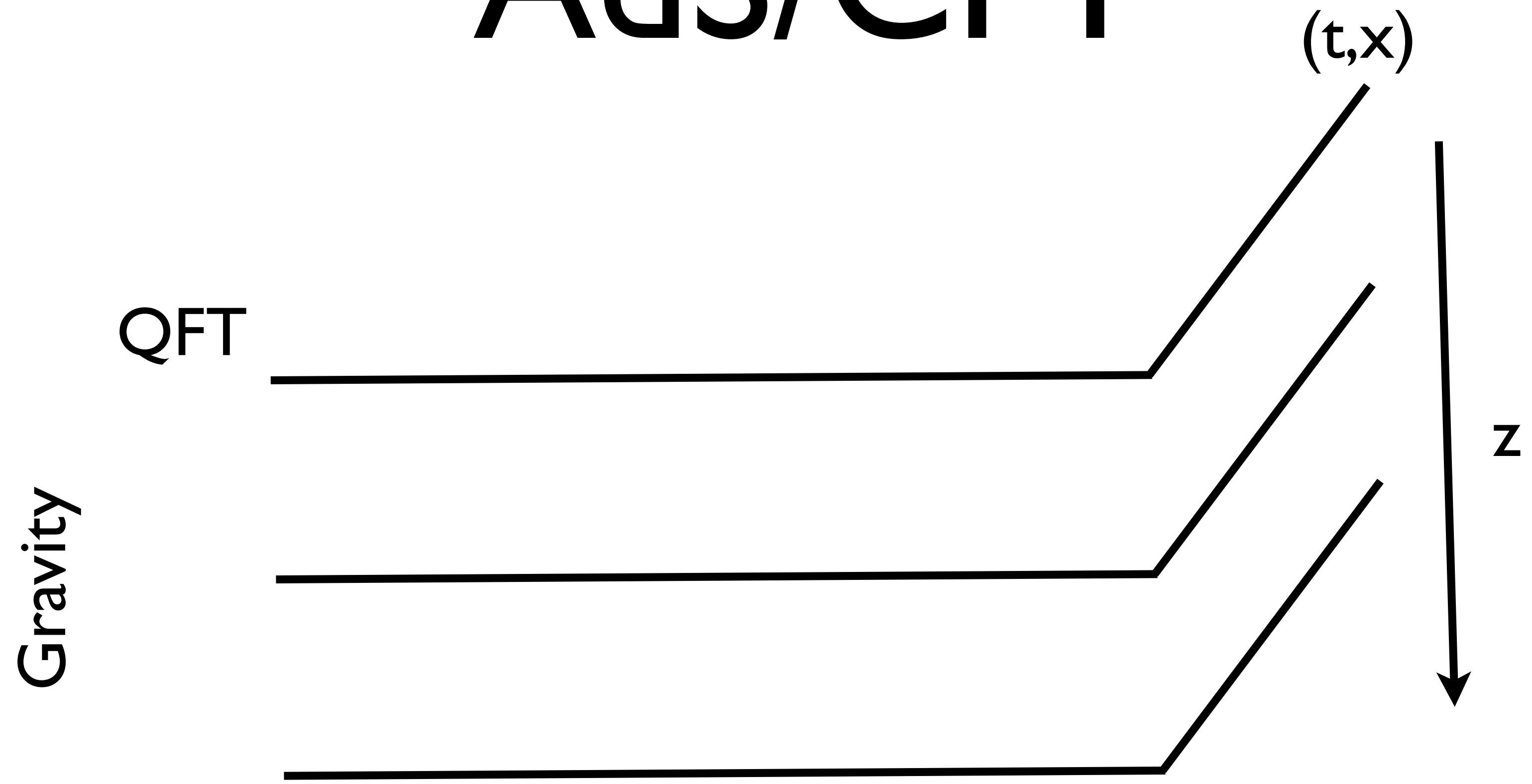
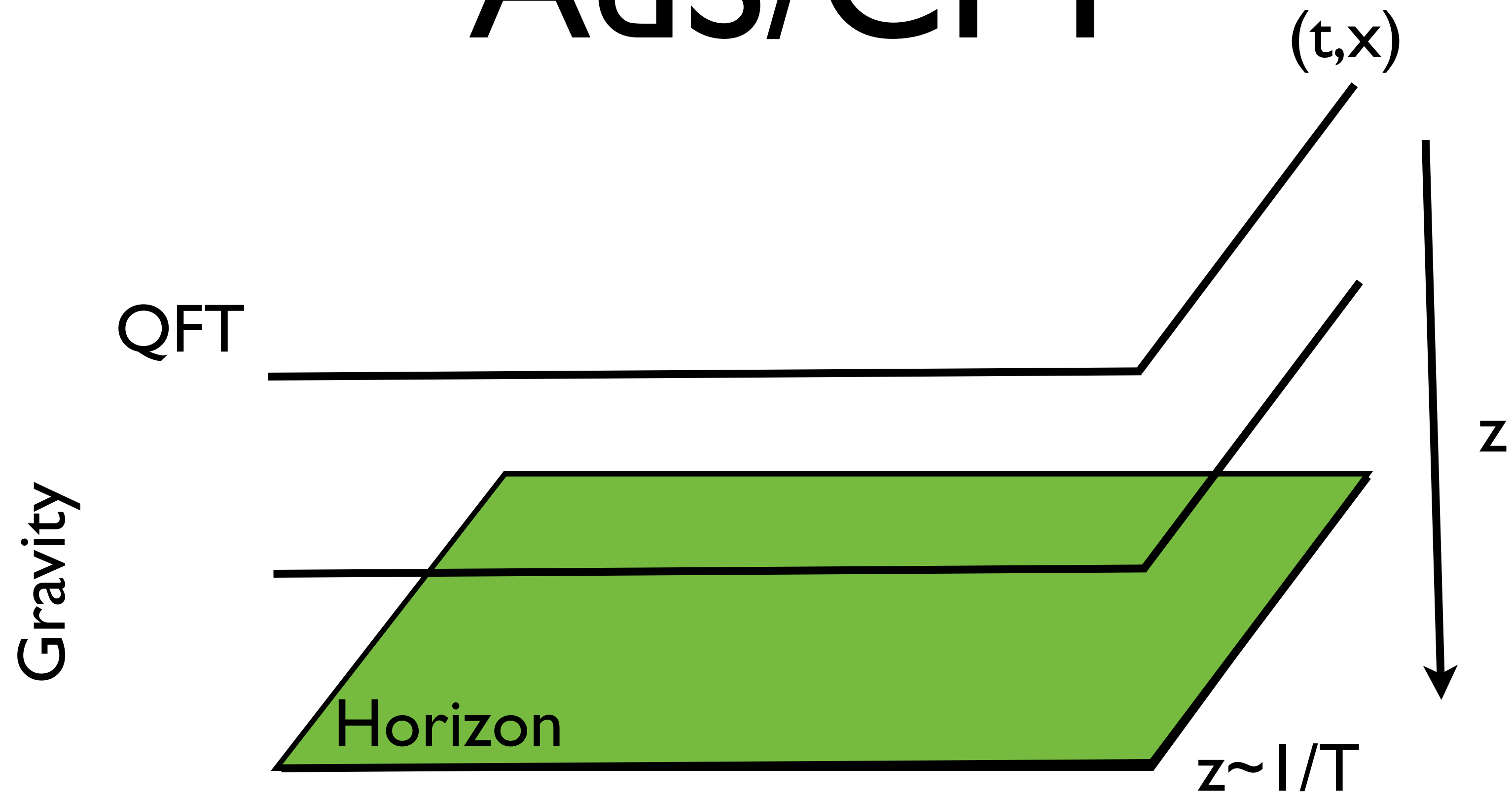
- The separation of scales happens only at small coupling!
- N=4 SYM at infinite coupling does not have quasiparticles (generic feature of strong coupling)
- In this talk we will address another generic feature.

AdS/CFT



- A concrete example is N=4 SYM with $N_c \to \infty$ and strong coupling $\lambda \to \infty$.
- The field theory lives at the boundary z=0
- Finite temperature is introduced via a "black brane".
- Fundamental matter by D7 branes that end at a scale 1/m.
- Mesons are (quantized) vibrations of the membrane. They survive in the deconfined plasma (for small enough T).
- Heavy quarks correspond to classical strings that end on the brane

AdS/CFT



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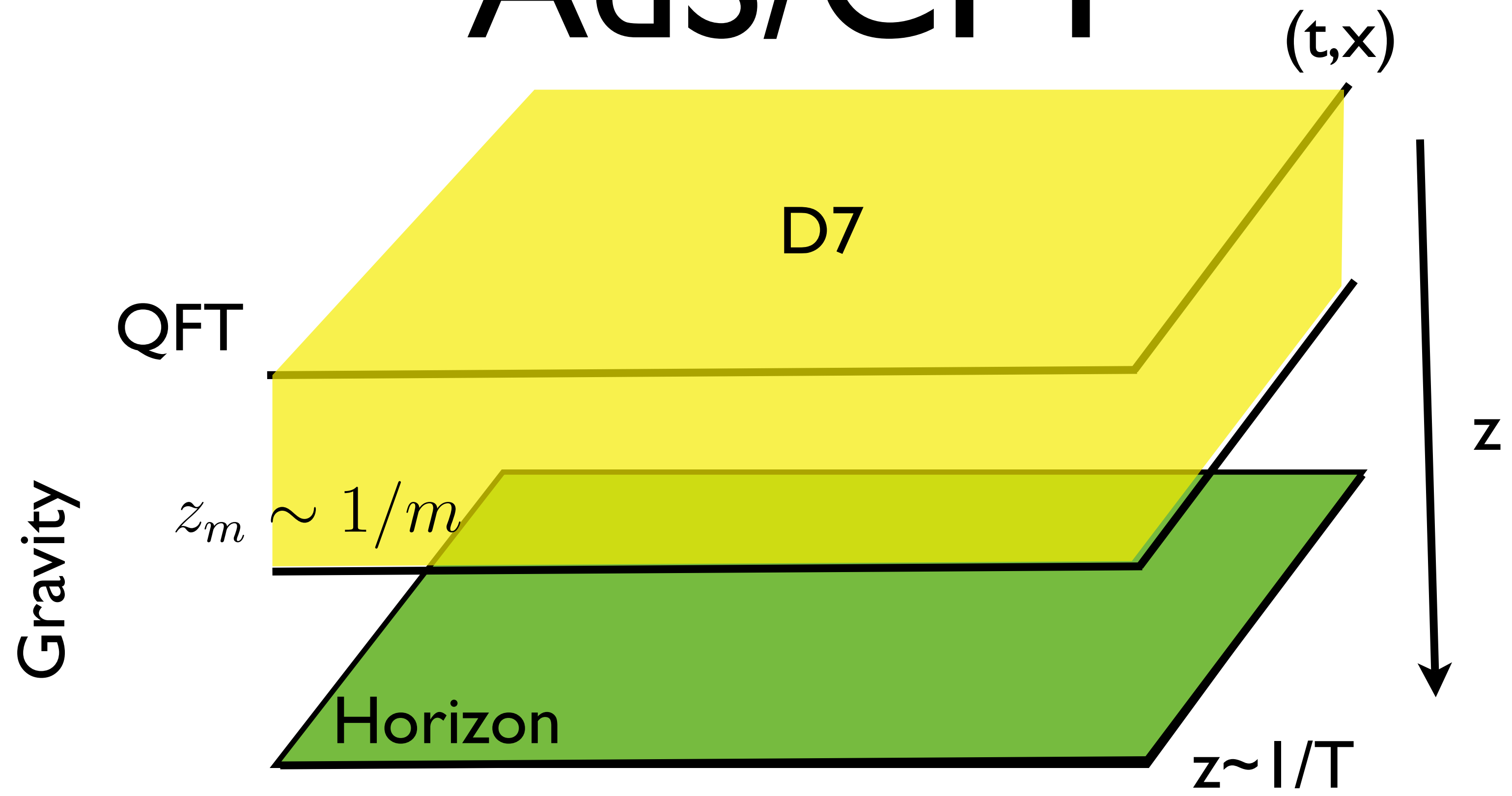

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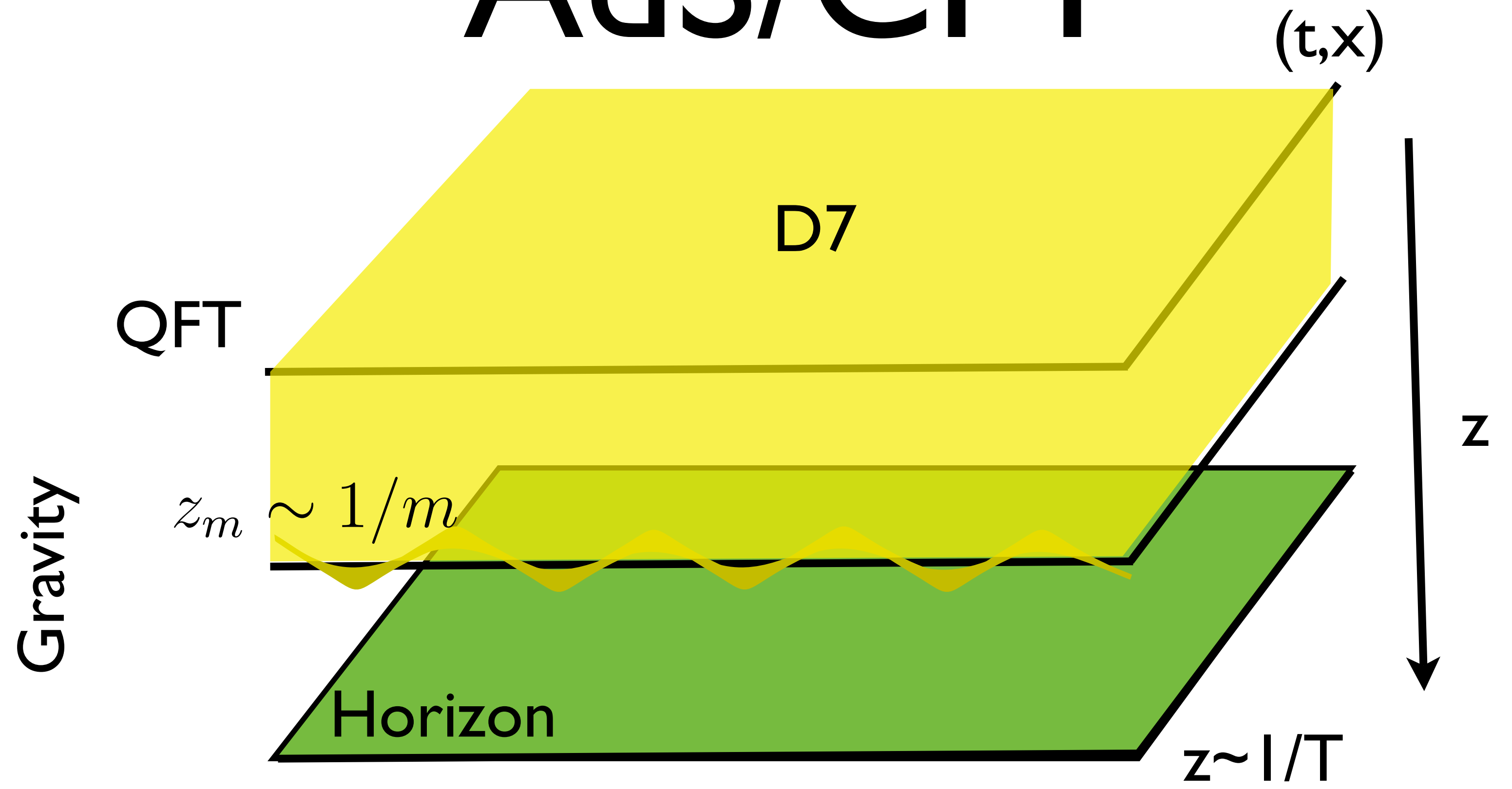

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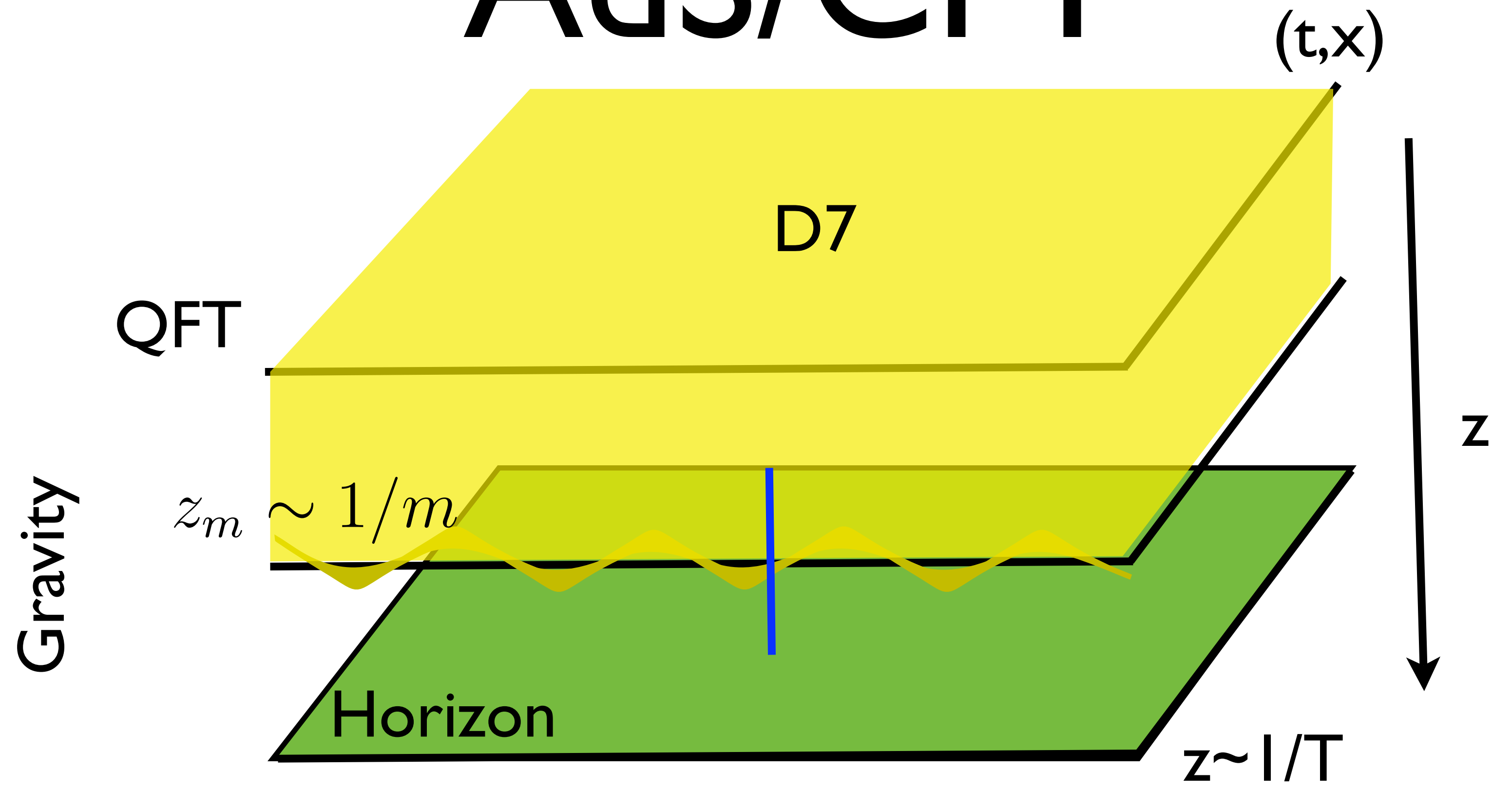

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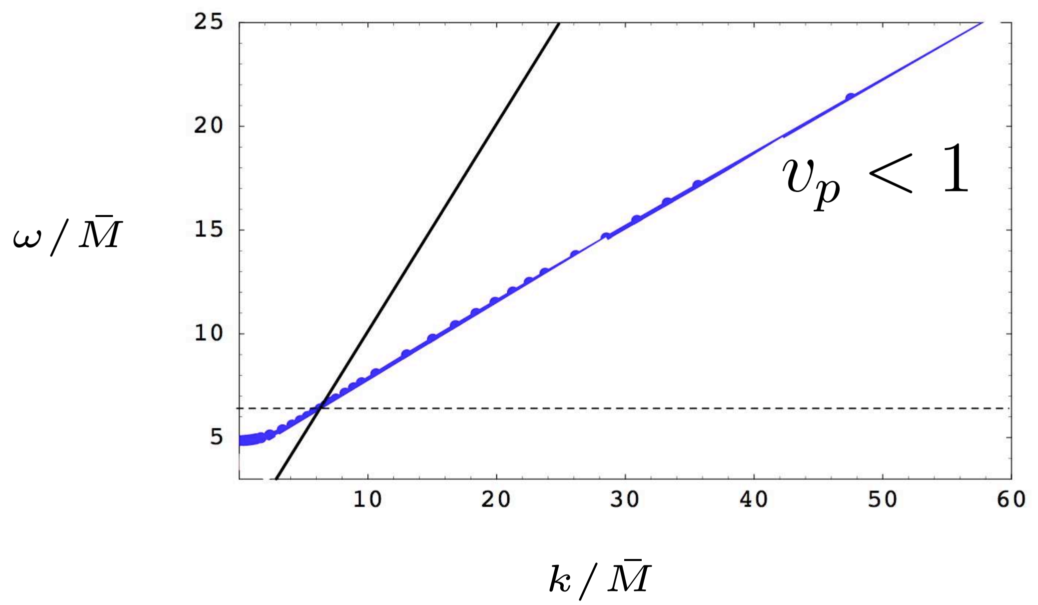
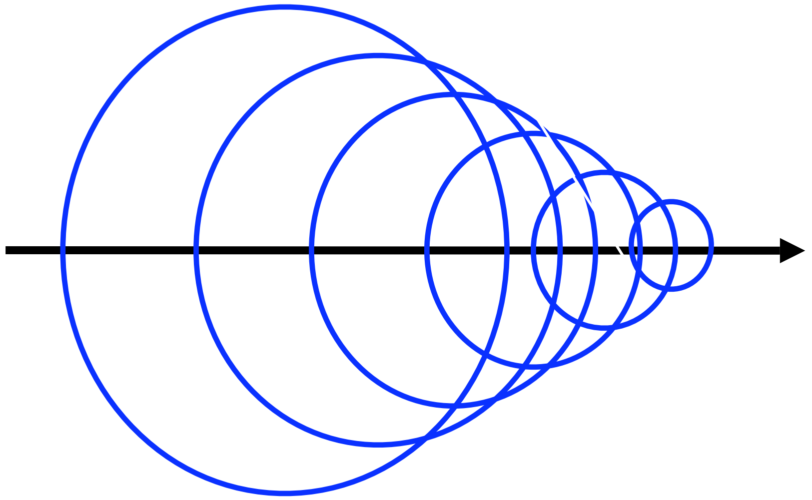
Cherenkov Meson Radiation

JCS, D. Fernandez, D. Mateos

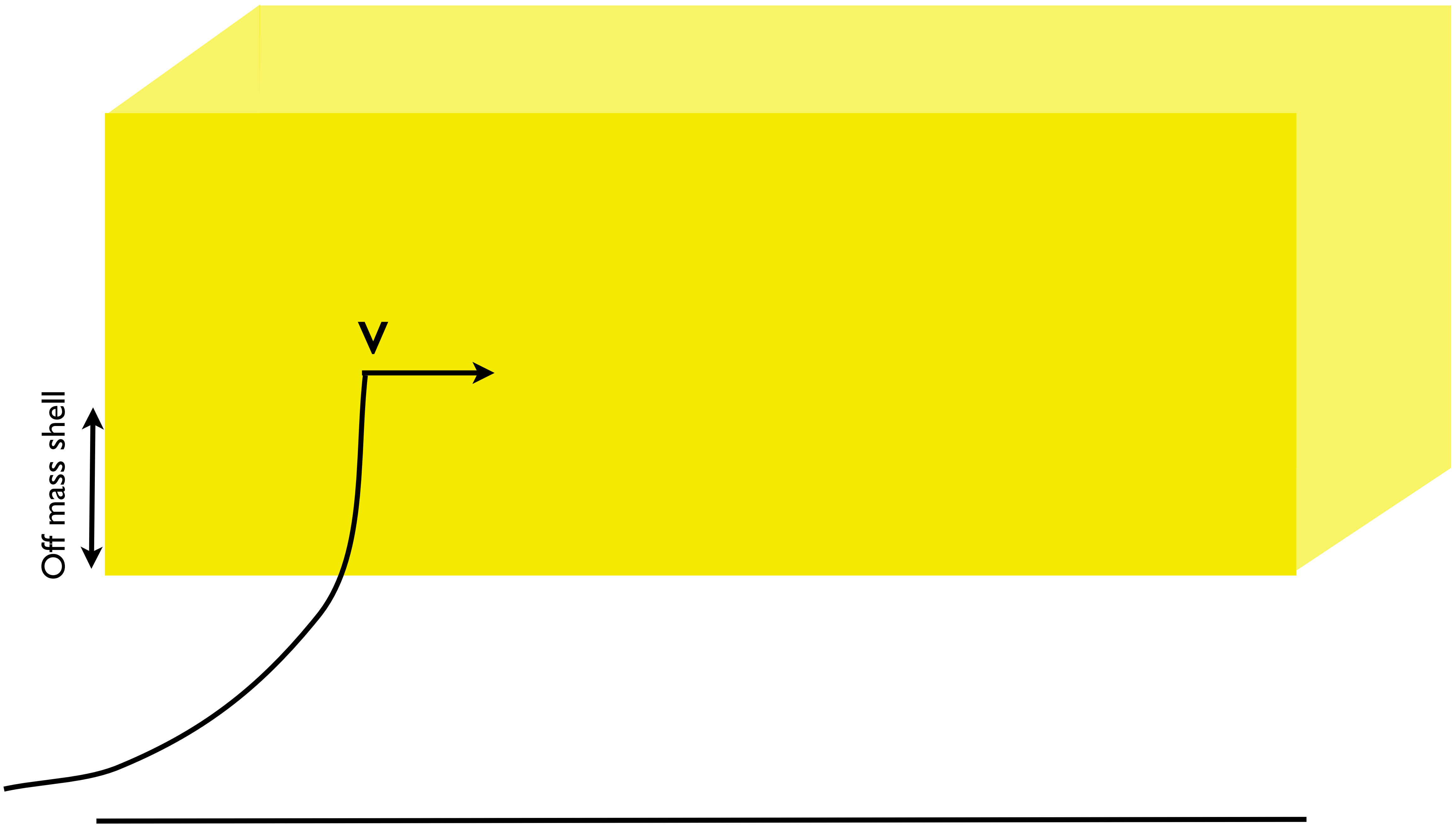


- There is a maximum speed of propagation
- The dispersion relation becomes space-like; this is the necessary condition for Cherenkov emission
- If a probe couples to mesons, it will Cherenkov-radiate



$$\cos\theta = \frac{v_p}{v_s}$$

A (new) Source for E-loss



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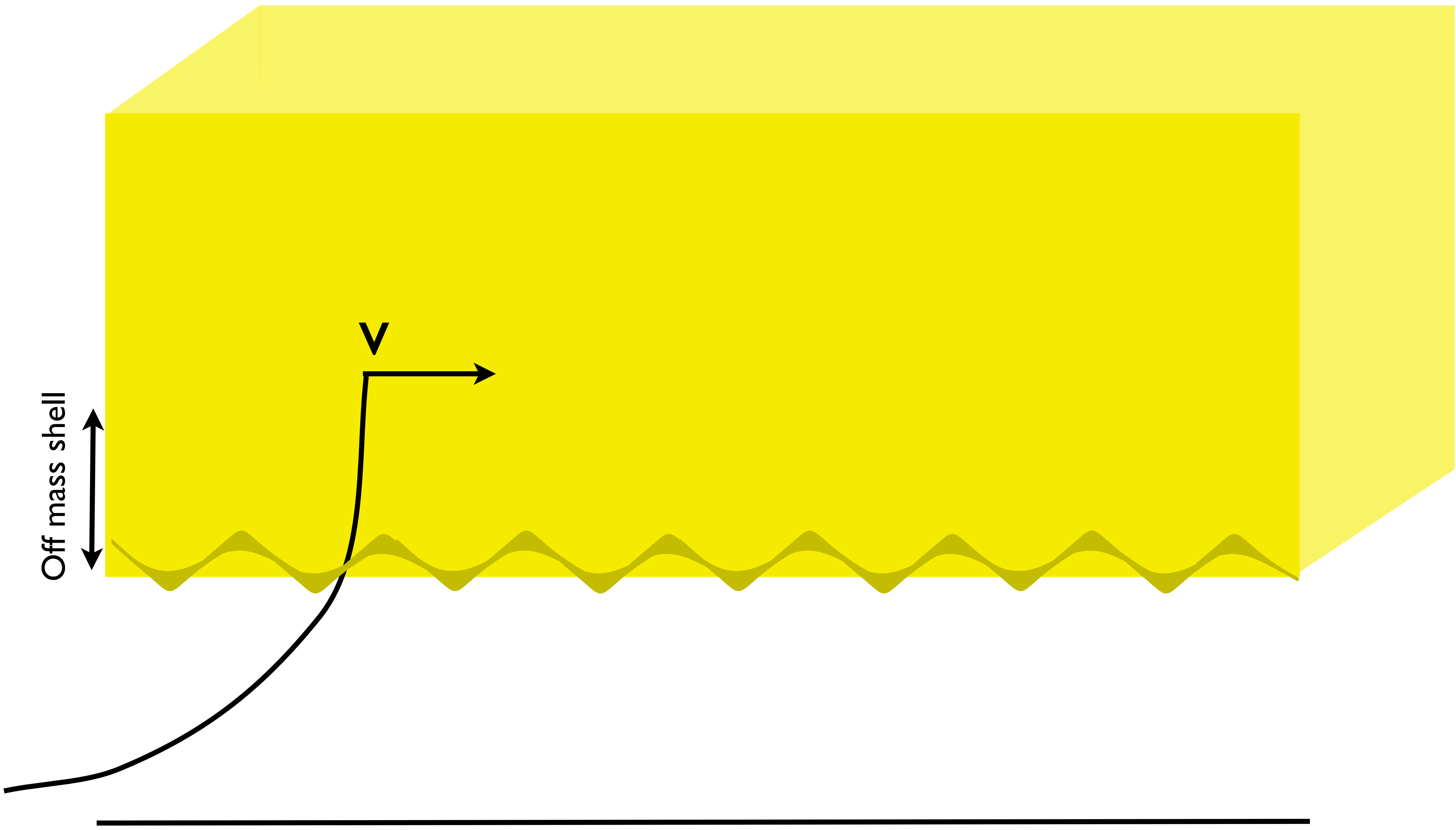

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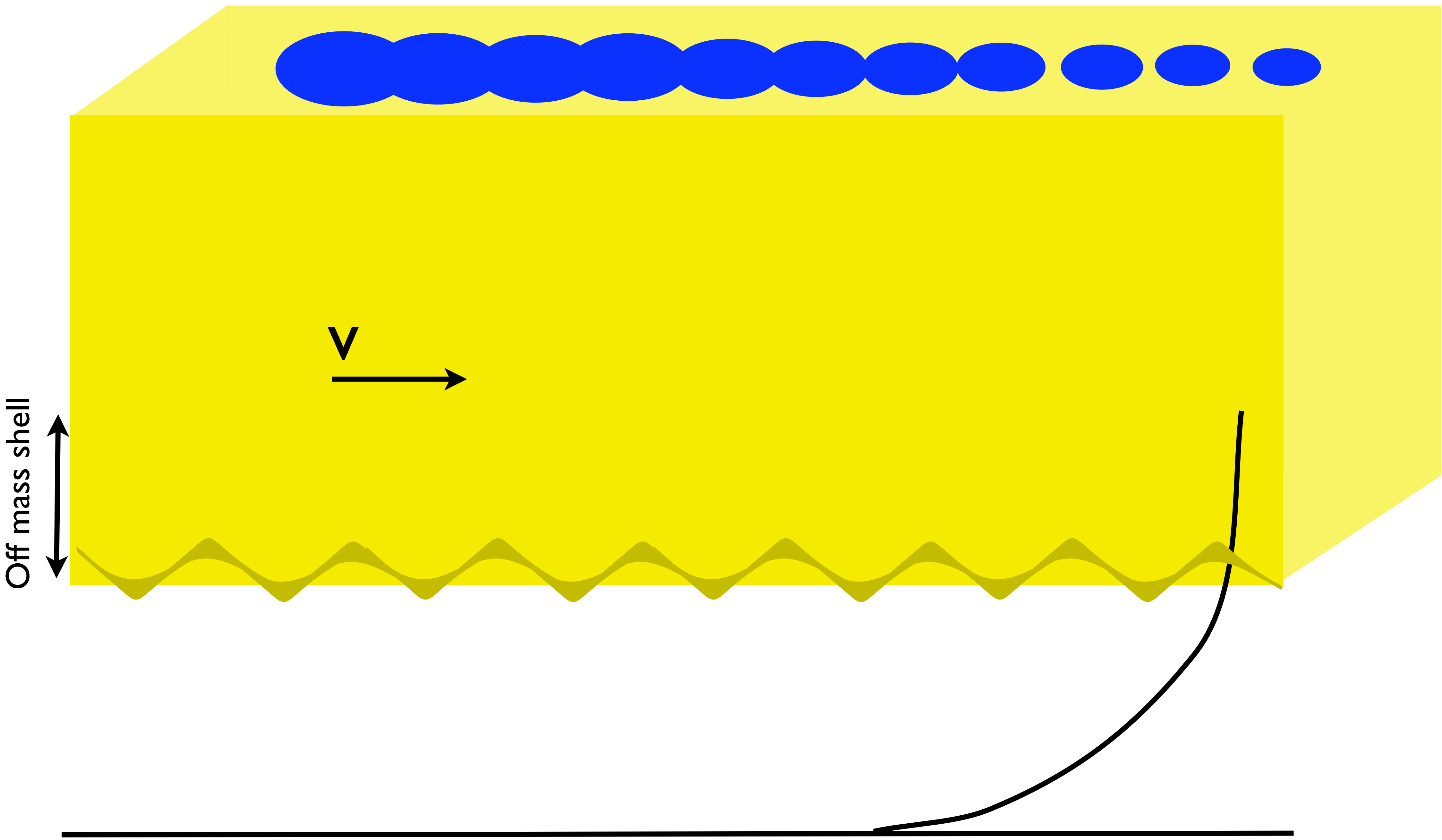

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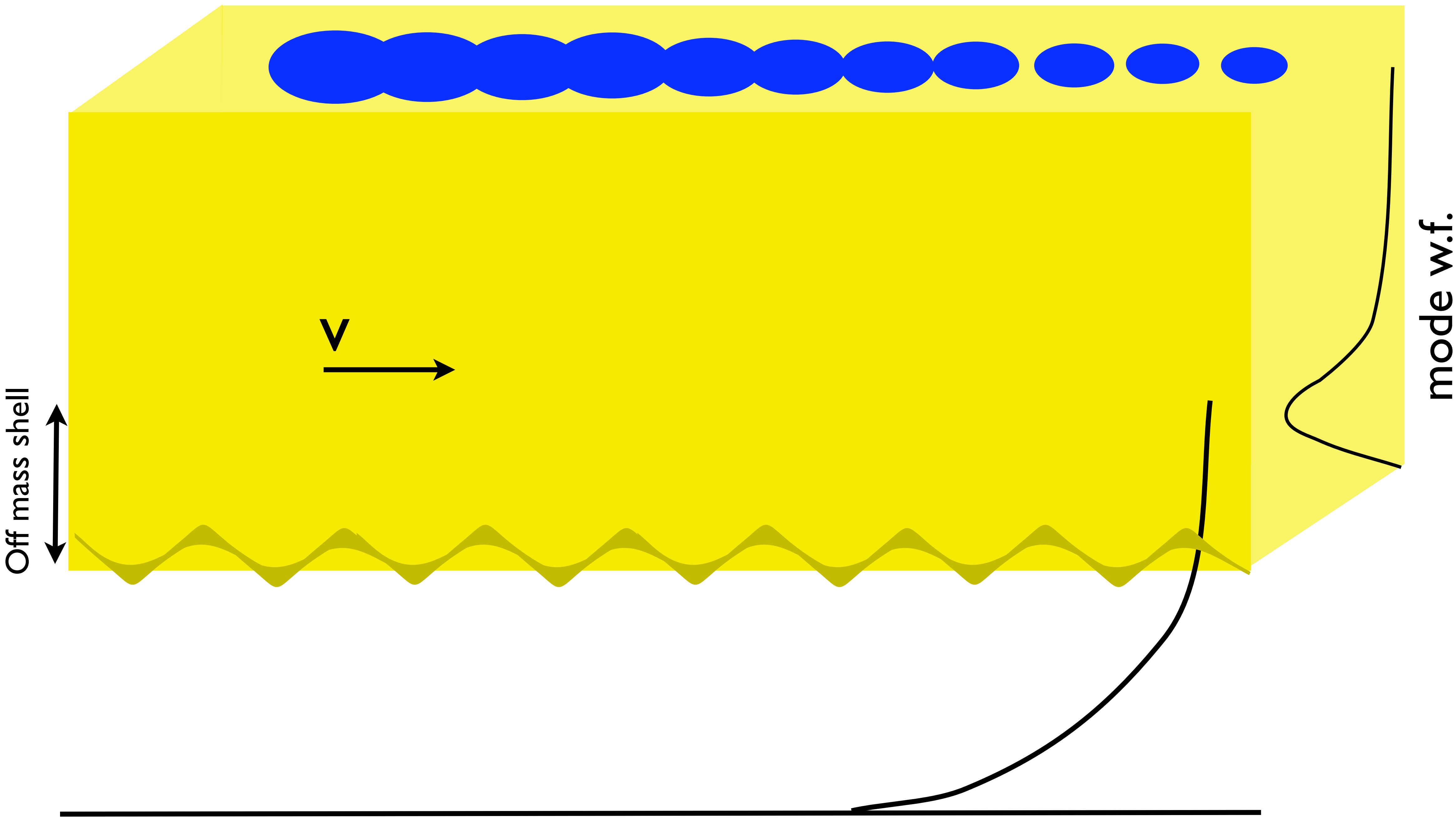

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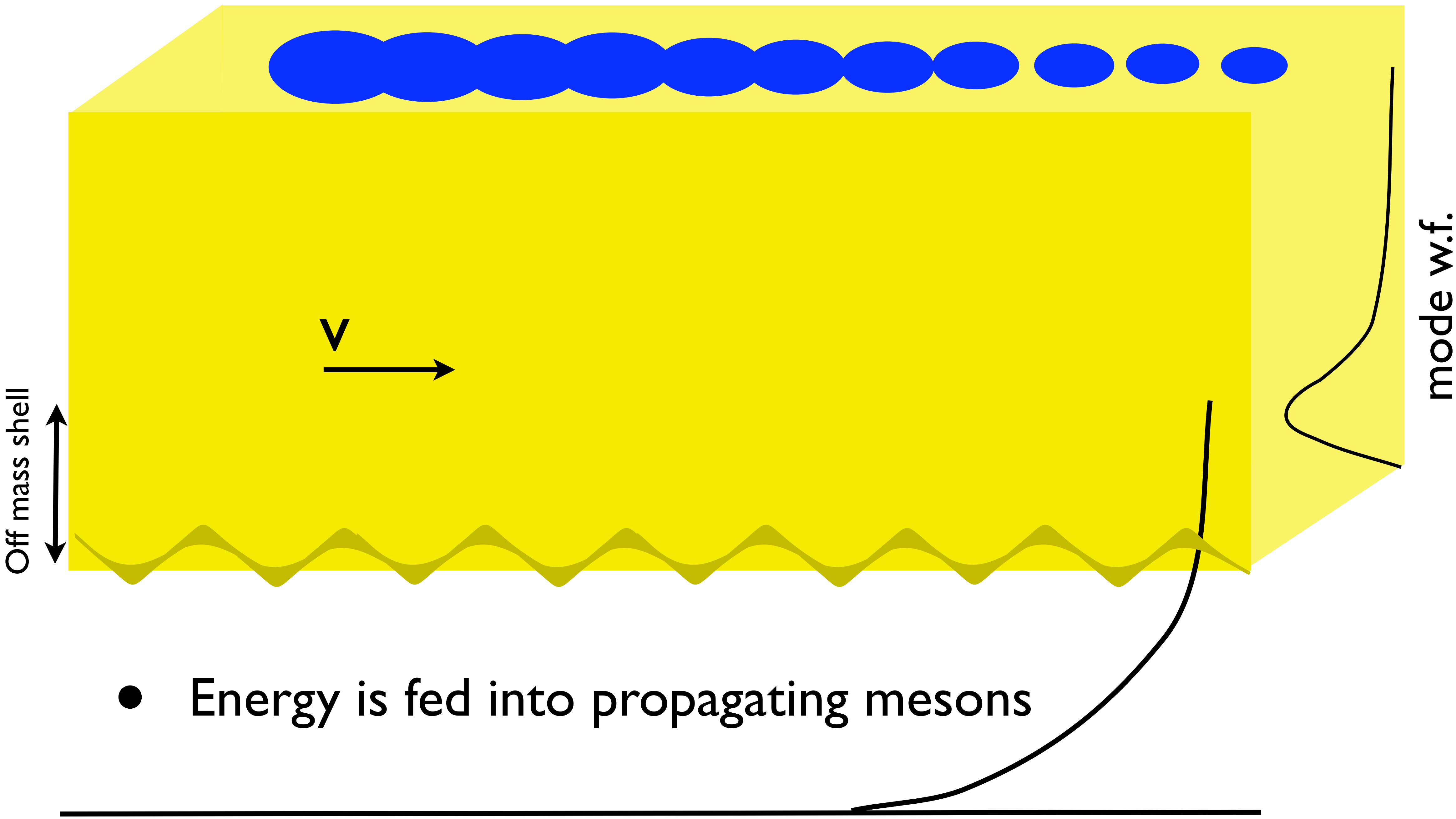

- Energy is fed into propagating mesons

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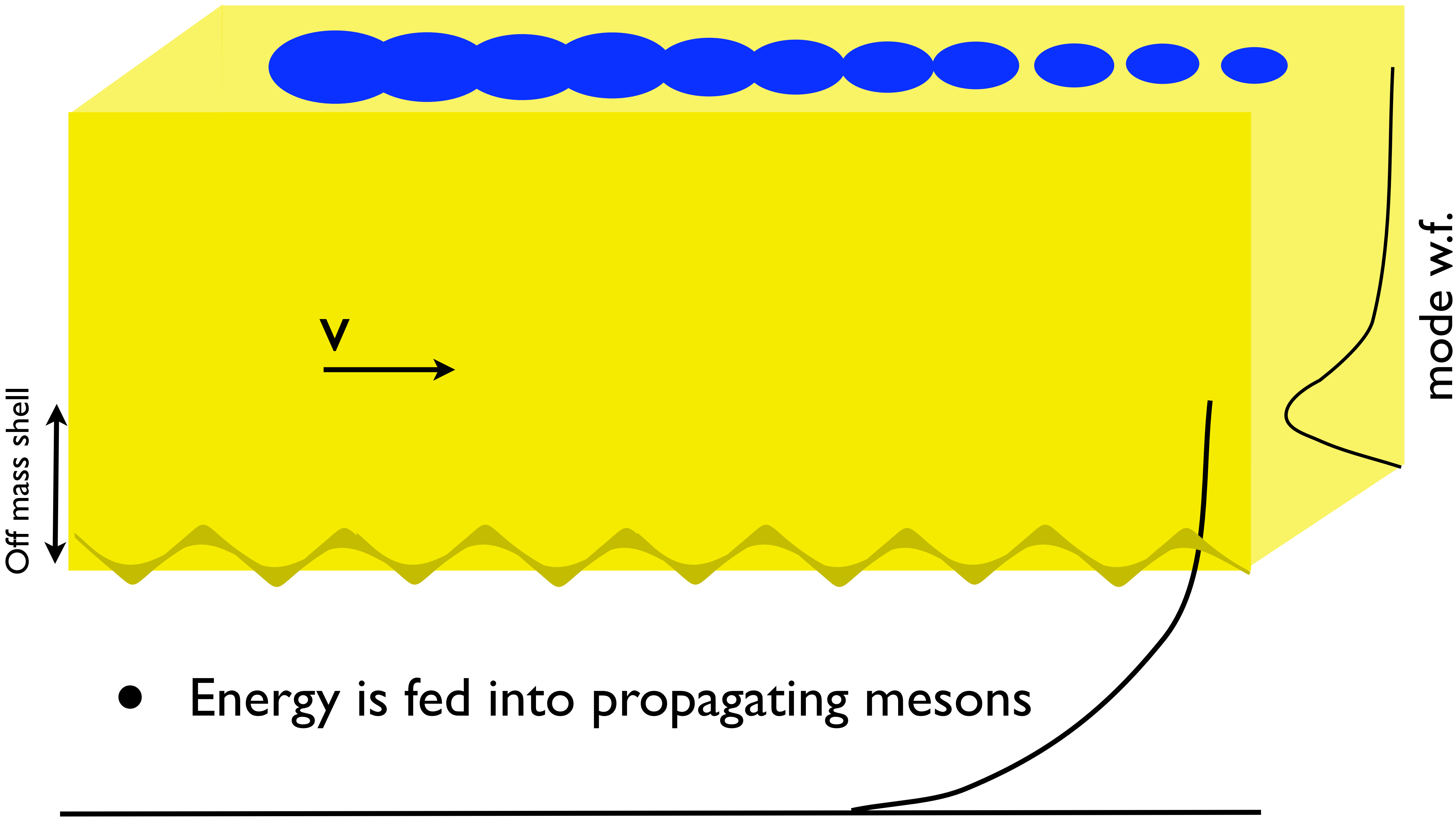
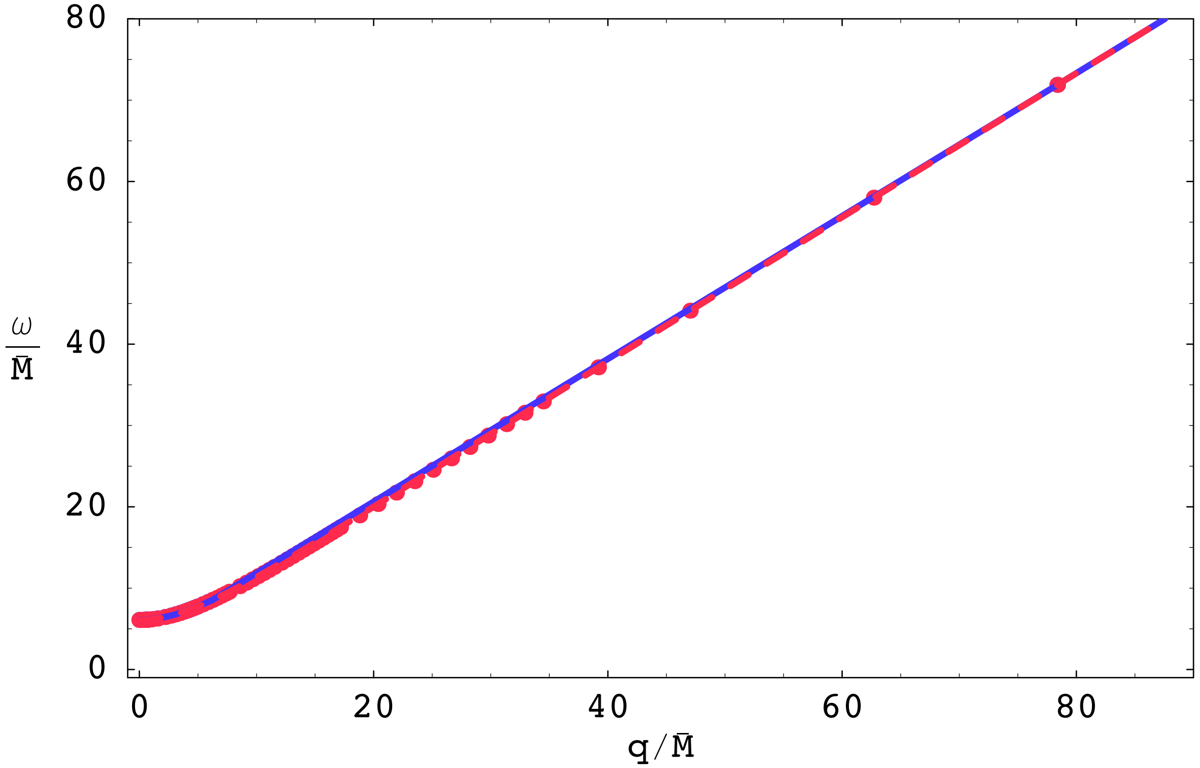
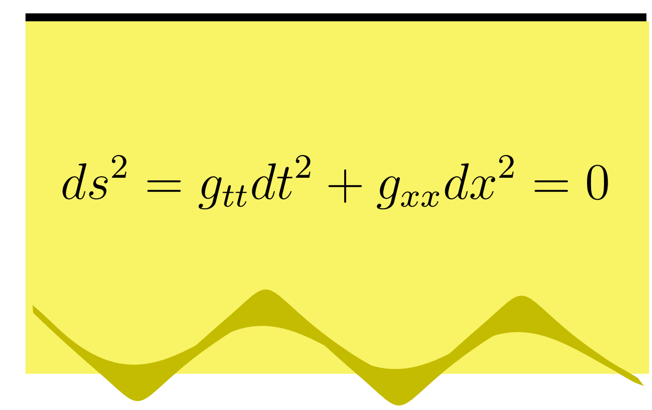


- Energy is fed into propagating mesons

- Additional energy loss mechanism to the drag-like dragging string
- It has a non-trivial velocity dependence.

Dispersion Relations





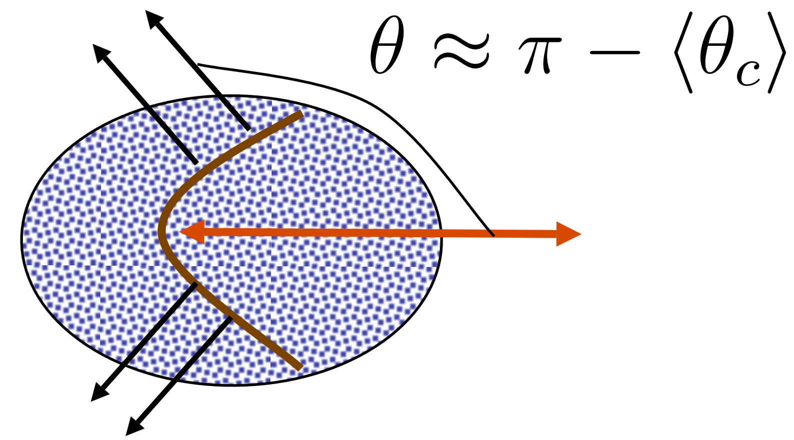
$z_m \sim 1/m$

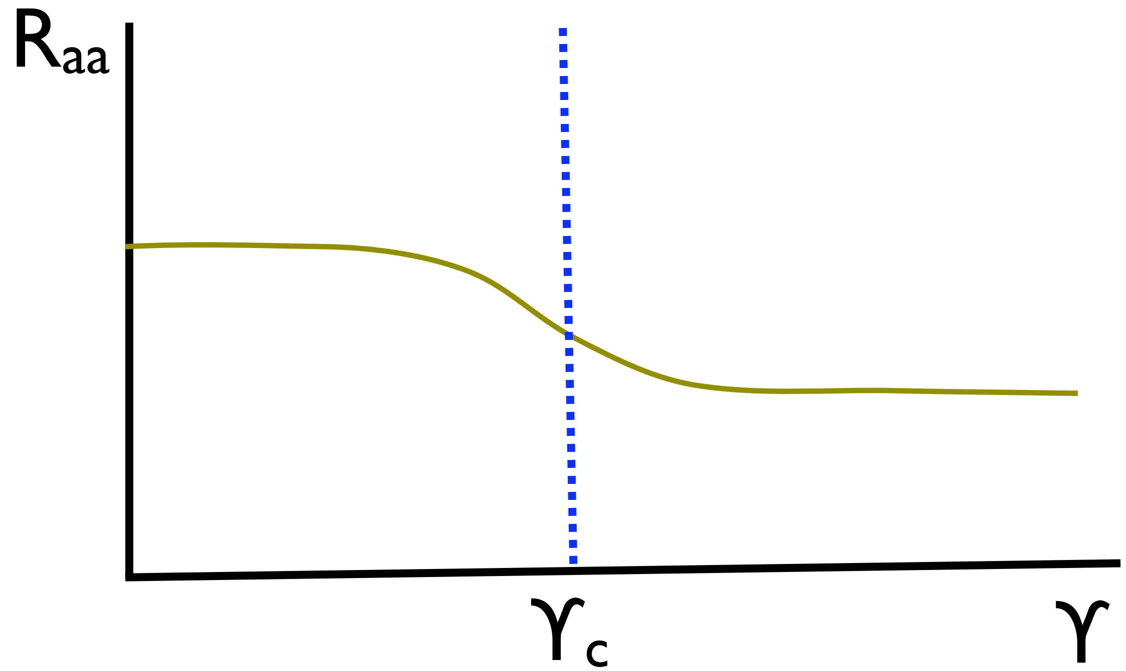
$$c(z) = \sqrt{\frac{g_{tt}}{g_{xx}}}$$

- There is a maximum speed of propagation
- It is determined by the speed of light at the tip of the deformed brane
- This is a universal feature for meson probes in any theory with a gravity dual with $N_c \rightarrow \infty$

Phenomenological Consequences

- There are evidences that J/Ψ survives deconfinement
- If J/Ψ has a modified dispersion relation:
- Non trivial angular distribution of J/Ψ associated to a high p_T particle





- R_{aa} has a non trivial velocity dependence.

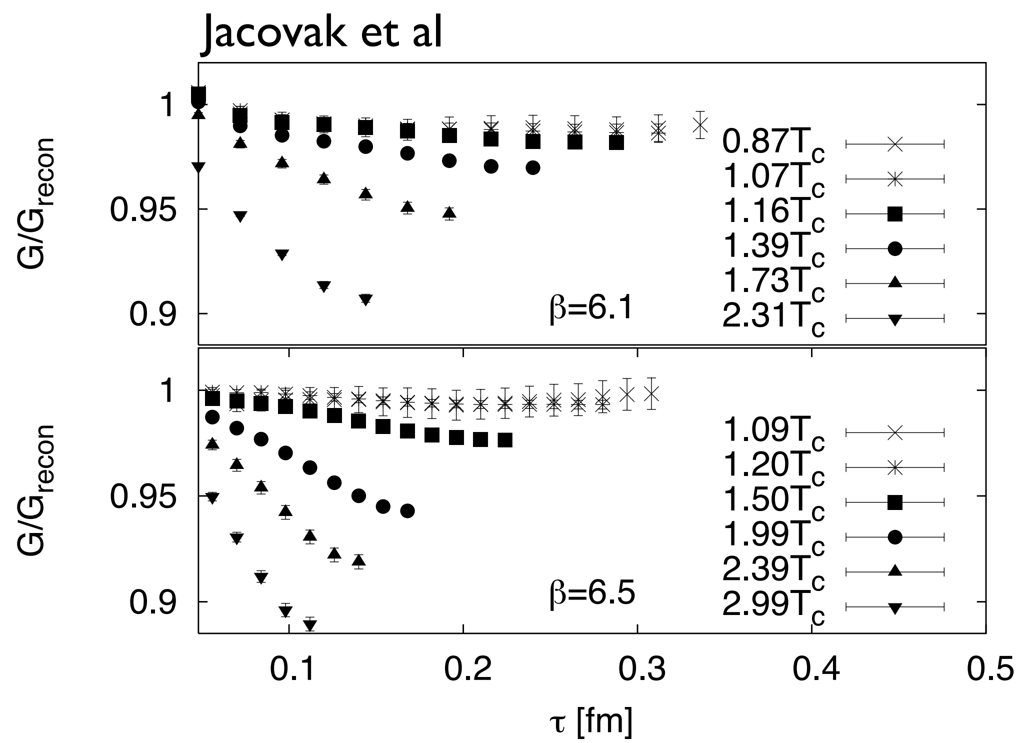
- Estimates on the magnitude of these effects are in progress (JCS, Fernandez, Mateos)

Conclusions

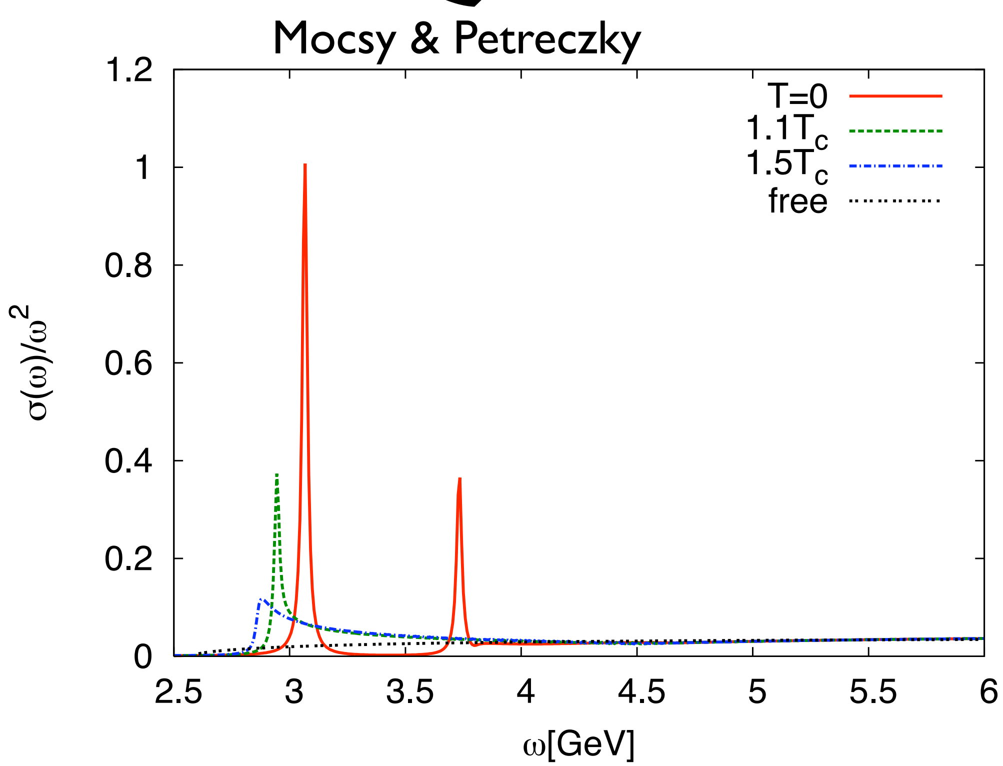
- It is important to understand generic features of strongly coupled gauge theory plasmas
- All gauge theories with a gravity dual lead to a space like dispersion relation for mesons
- If QCD mesons survive deconfinement and have this dispersion relation there will be:
  - Non trivial angular distributions of (heavy) mesons associated to a high energy particle
  - A velocity dependent component in the energy loss of probes with a threshold ($v>v_p$).

Backup

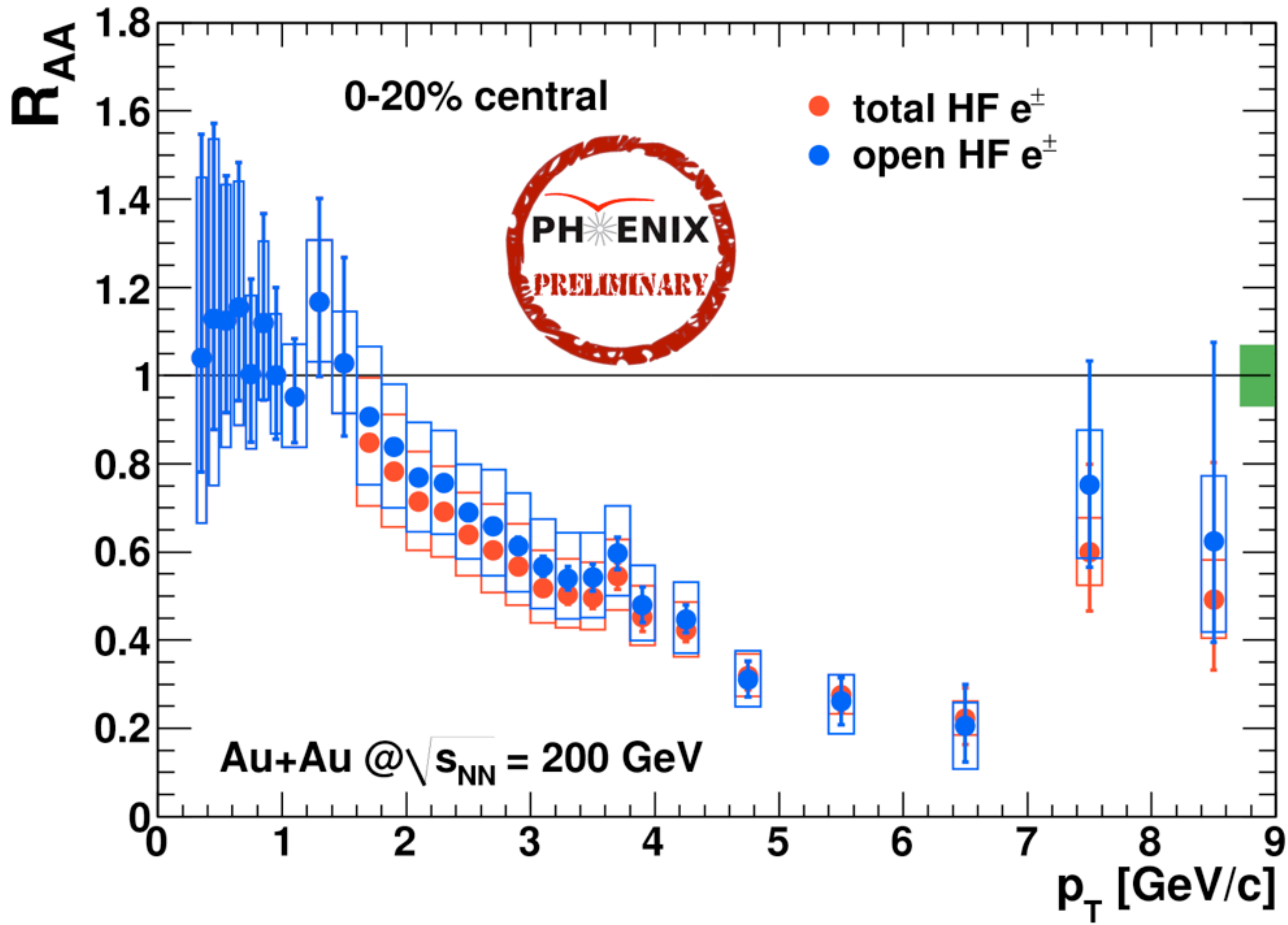
Quarkonia in Hot QCD



model
⇒



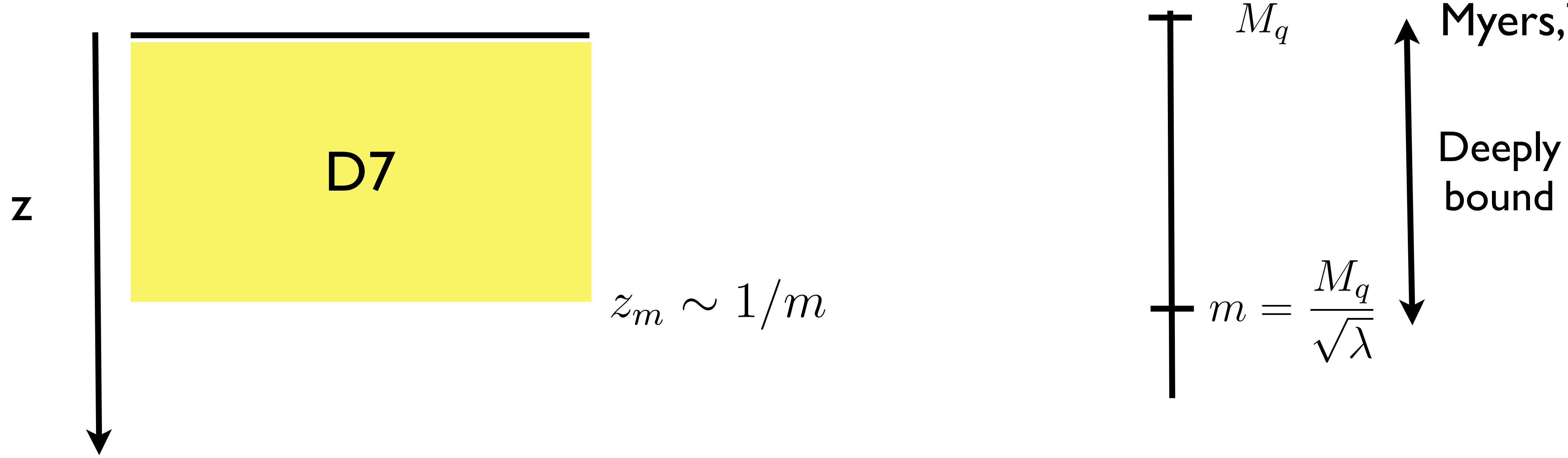
- Lattice charmonium correlators show small modifications up to $T=1.5\ T_c$
- J/ψ may survive the deconfinement transition.
- The extraction of the dissociation temperature depends on models. There is an uncertainty on its value from different groups $T_{diss}=1.2 \div 2\,T_c$
- AdS/CFT allows to study dynamical meson properties on a strongly coupled environment



R_AA
0-20% central
total HF e±
open HF e±
PHENIX
PRELIMINARY
Au+Au @√s_NN = 200 GeV
p_T [GeV/c]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6
7
8
9

Mesons in AdS/CFT. T=0

Mateos, Myers, Thomson



- Fundamental matter by D7 branes: "memebranes" that end at a scale 1/m.
- Mesons are (quantized) vibrations of the membrane. The vibration modes are the meson masses.
- Deeply bound mesons observed. Very different for heavy quark mesons in QCD
- Meson radius ~1/m

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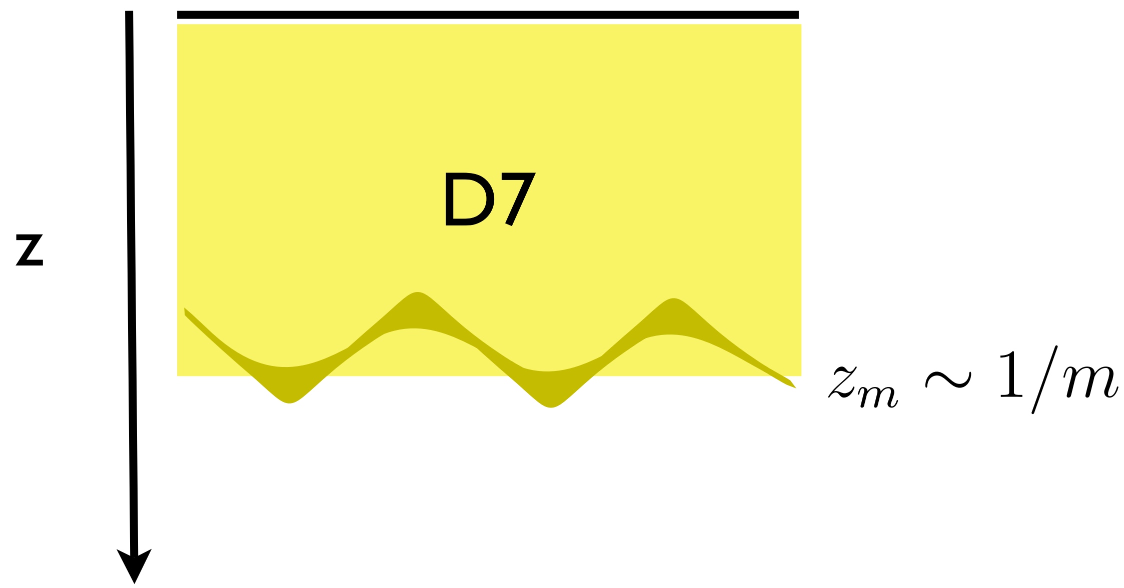

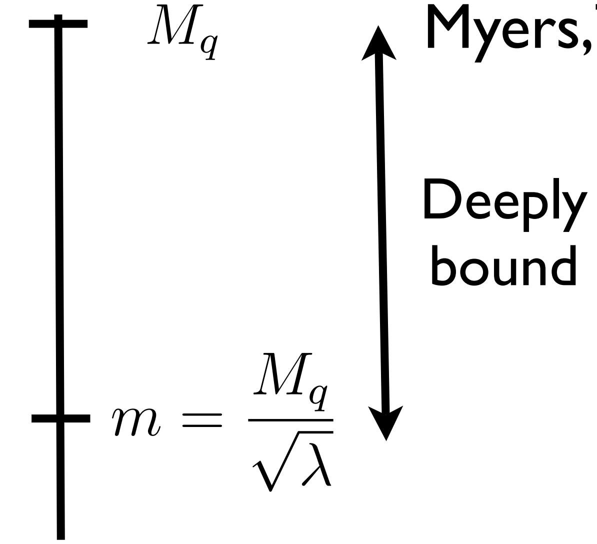

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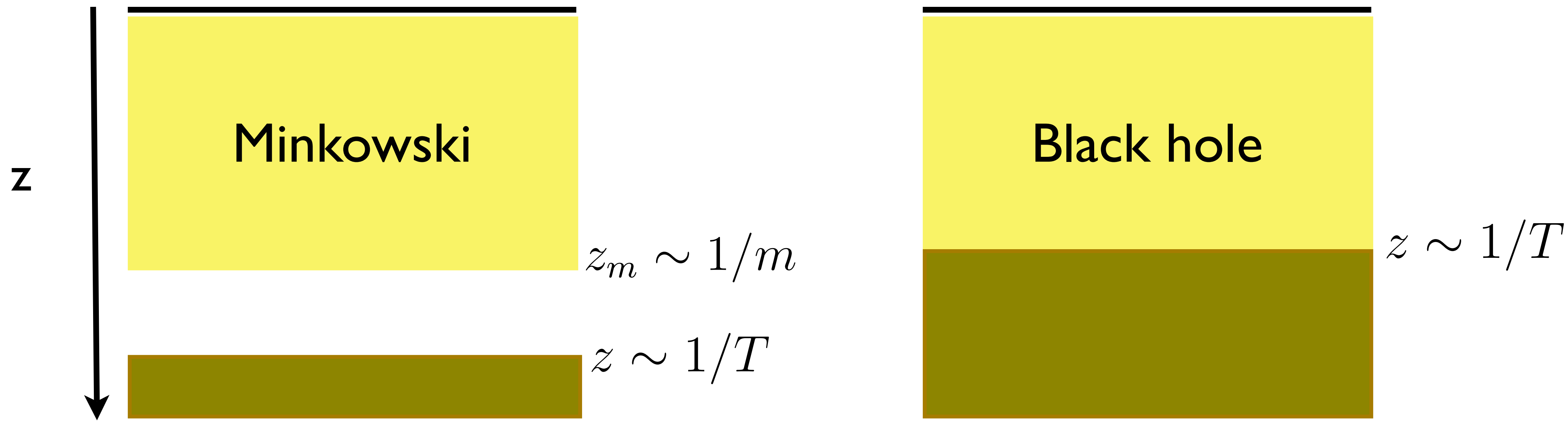
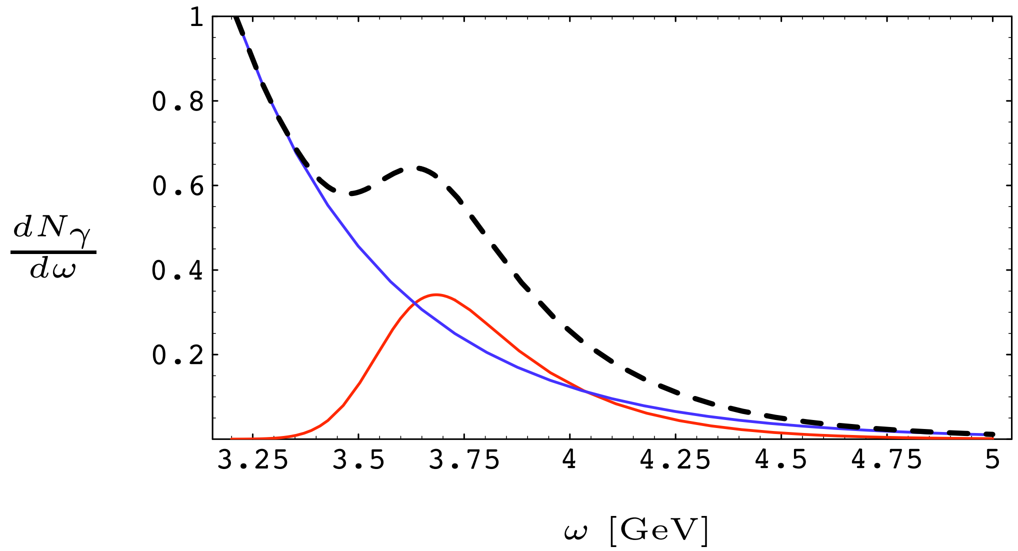
Mesons in AdS/CFT. T≠0



- If the temperature is smaller than meson 1/radius (mass) there mesons at finite T
- At higher T the mesons melt (the fluctuations fall in the BH)
- We can use it as a model for mesons in a deconfined plasma
- While bound, mesons remain infinitely narrow ($1/N_c$)

Photons from J/ψ



Crossing at $\omega_{peak} \geq M_{J/\psi}$

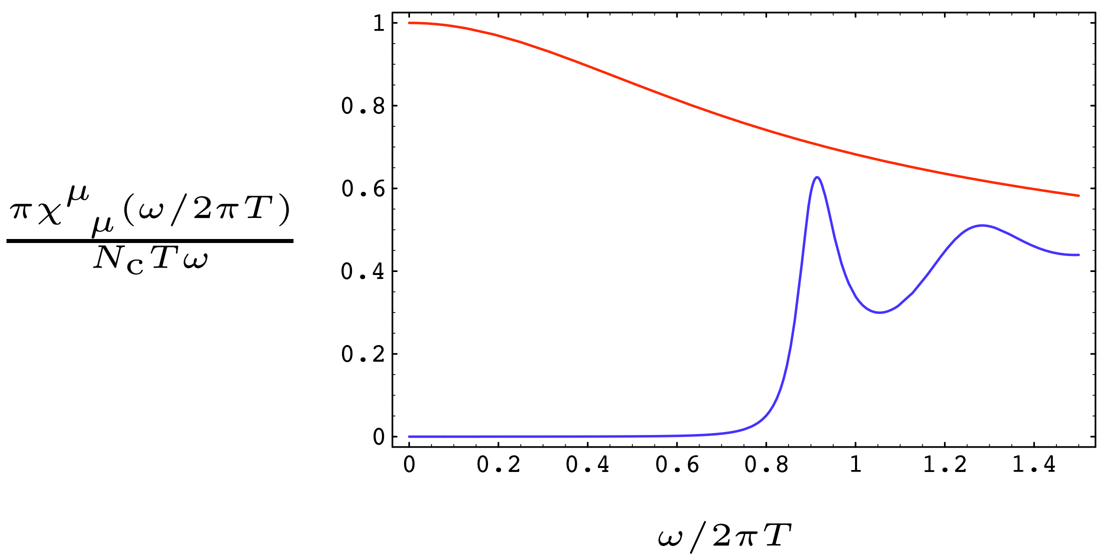
ω_{peak} grows as T decreases

$v_{lim} \to 1$

- We expect and enhancement in the photon spectrum (even a peak) in the region of 3-4 GeV
- Uncertainties in in-medium J/ψ makes quantitative predictions hard...
- From the models in the market, we searched from a scenario in which a peak is observed at the LHC

  (statistical hadronization with the largest possible c-c cross section)
- The magnitude depends a lot on the model
- The observation of the peak would signal the modified dispersion relation

Fixed T



- At a fixed temperature there is a peak in the photon spectrum
- The magnitude (in this model) is comparable with the (strongly coupled) light quark thermal emission.
- The enhancement is a consequence of the modified dispersion relation.
- This feature must be there for all models with gravity duals!

Strong Coupling

- Several experimental measurements (flow, quenching, HQ v_2)are hard to understand with perturbative techniques.
- The achieved temperatures T≤600 MeV are comparable to Λ_{QCD}. The coupling is not small (μ_D~T)
- It is desirable to find a strong coupling technique which allows to compare to perturbative calculations. (opposite limit)

This is not just a quantitative issue:

there are qualitative differences at strong coupling!