Beaming in AdS/CFT

[work in progress...]

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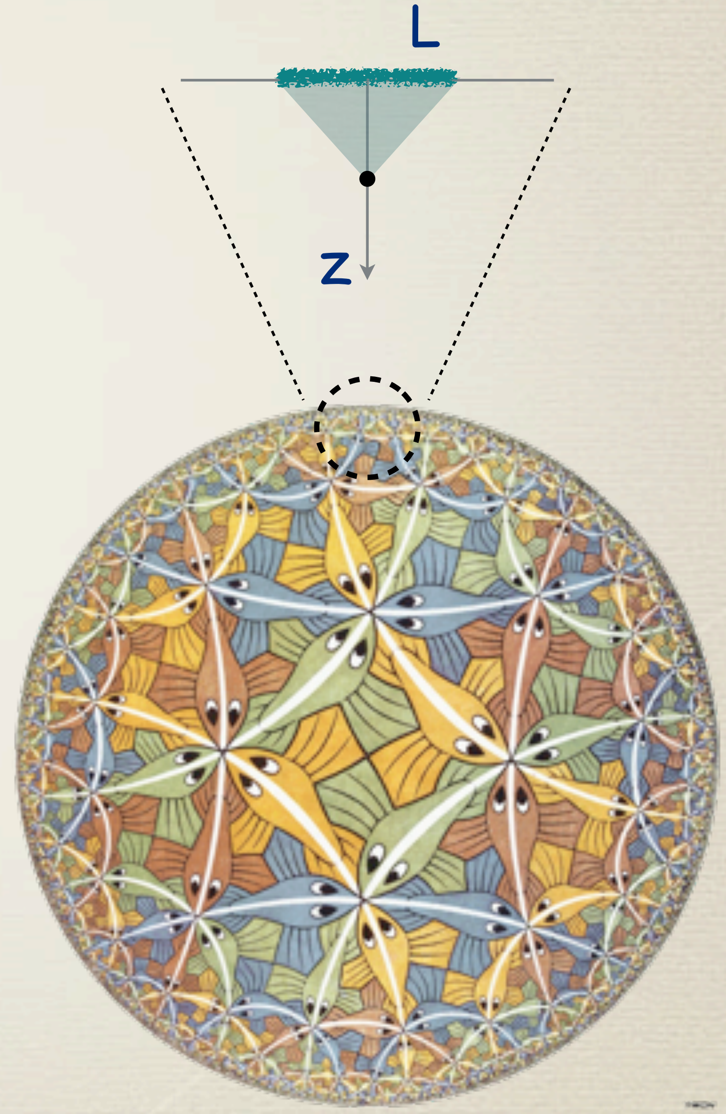
Motivation:

To further our understanding of the AdS/CFT dictionary.

eg. recall UV/IR (scale/radius) duality:



- statement of scale/radius duality:

  bulk excitation at radial position z in AdS is manifested by CFT excitation on scale $L \sim z$

  [Susskind & Witten]

- provides useful intuition:

  eg. object falling into a black hole ↔ CFT excitation spreads and thermalizes

  [Banks, Douglas, Horowitz, Martinec]

- tells when interaction is possible:
  - different-scale CFT excitations at same position don't interact (since in bulk dual, radially separated)
  - conversely, we'd expect that same-scale CFT excitations at same position do interact.

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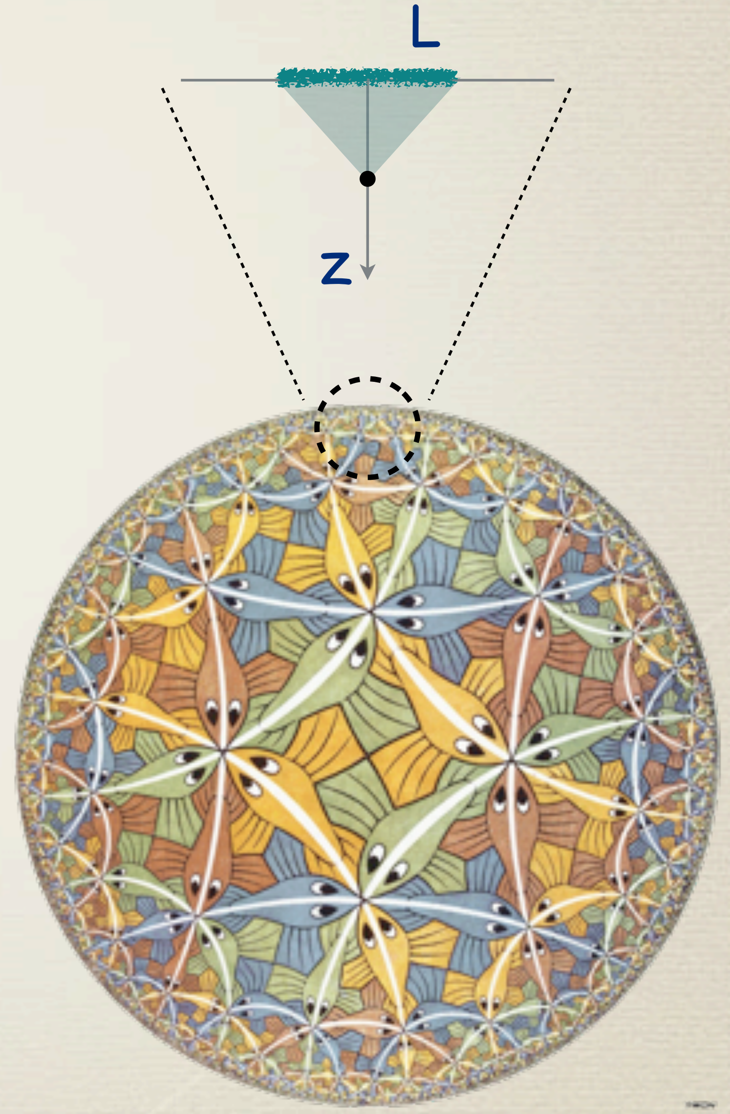

* statement of scale/radius duality:
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– But this is not necessarily correct...

Outline:

- Motivation

    revisiting the UV/IR relation

  counter-example to conventional expectations:

- Synchrotron radiation in AdS/CFT

    review of set-up

    puzzle

- Proposal for beaming mechanism

    expectations

    construction & tests

- Concluding remarks

    summary, outlook, caveats

    implications

Synchrotron radiation in AdS/CFT

Recall work of Athanasiou, Chesler, Liu, Nickel, Rajagopal (1001:3880)

* Consider a quark in uniform circular motion in strongly coupled CFT; how does it radiate?
* dual to bulk string in AdS, ending on the quark;
* the string backreacts on the spacetime and induces nontrivial bdy stress tensor.

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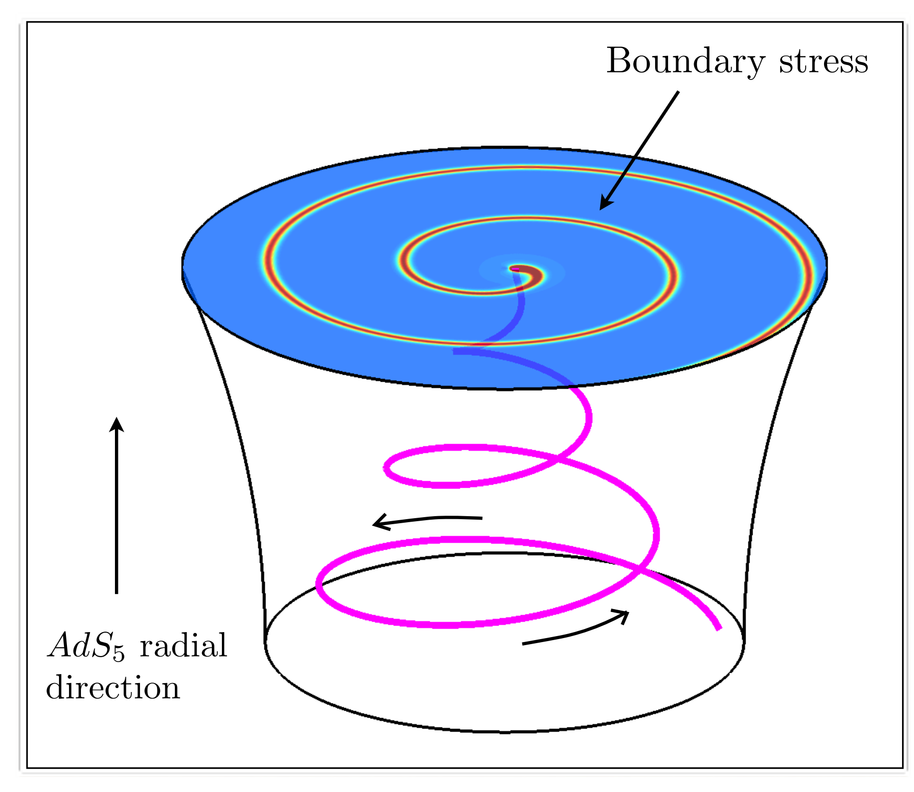
cartoon taken from [ACLNR]

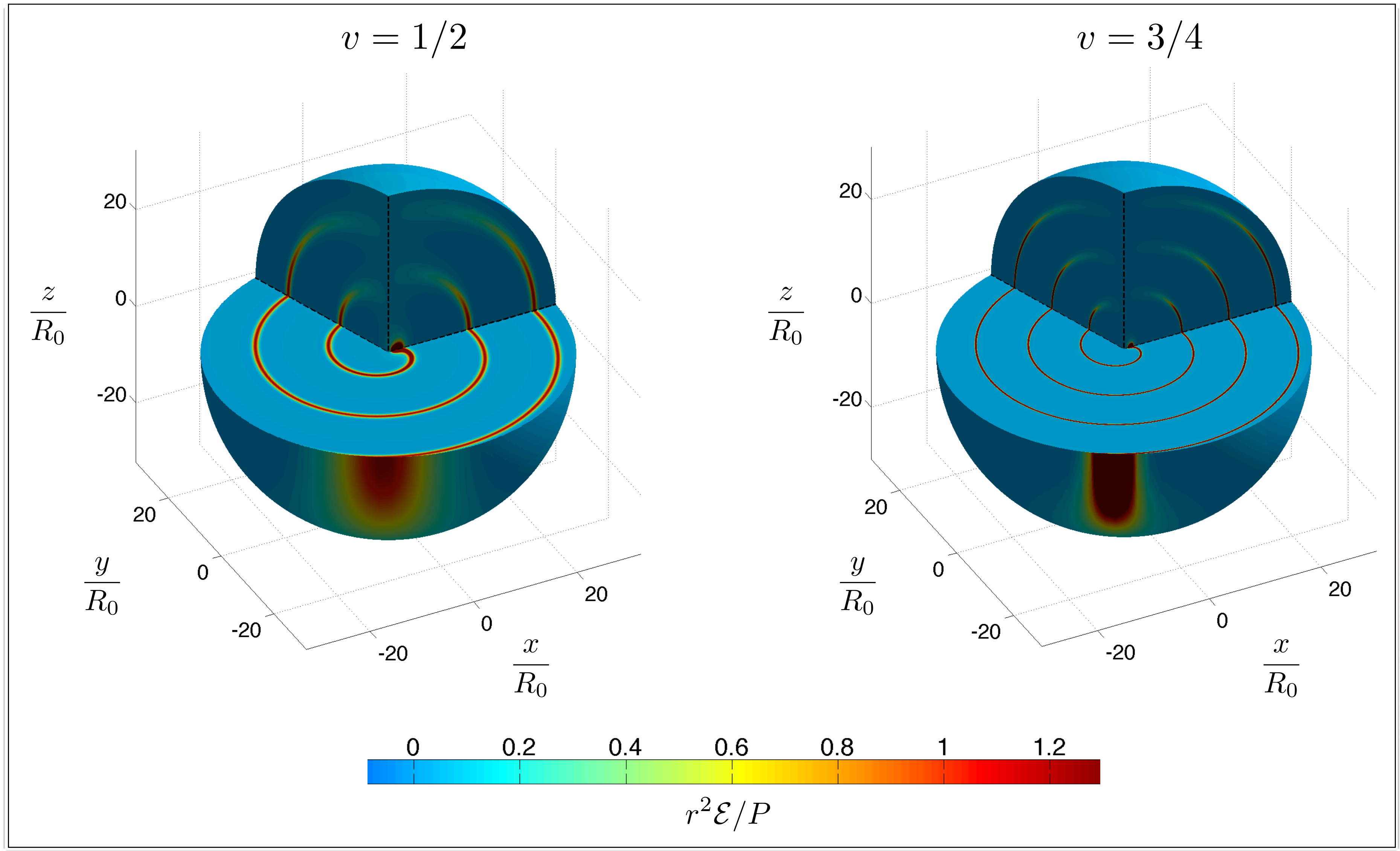


Energy density on boundary:

- exhibits tightly-collimated beam (similar to synchrotron radiation)
- propagates radially outward at speed of light, indep. of quark vel. v
- despite the strong coupling, at T=0, radiation does not diffuse (though for T>0, radiation does thermalize).

Synchrotron radiation in AdS/CFT

snapshot of boundary energy density taken from [ACLNR]



- ✶ spiral arms (peaks) retain same width and profile along full spiral
- ✶ peak spacing and width decreases with increasing quark velocity v

Puzzle:

[ACLNR] emphasize that the CFT behavior is surprising: why doesn't the radiation propagating through strongly coupled medium diffuse?

i.e. why is $T_{\mu\nu}$ sharply localized to arbitrary distances?

However, this seems just as bizarre from the bulk perspective:

consider metric perturbation $h_{\mu\nu}$ due to string in AdS.

Why/how does $h_{\mu\nu}$ remain so sharply localized, even when sourced deep in the bulk?

Naive answer:

Since collimated beam in synchrotron radiation arises due to Lorentz beaming, it seems natural to expect that this effect also ensures localization of $h_{\mu\nu}$

Indeed, string moves relativistically
(norm of transverse velocity of string $\rightarrow 1$ as $z \rightarrow \infty$ i.e. away from AdS bdy)

However:

* beaming along transverse velocity would point away from boundary
* for fixed beam angle, shadow on bdy would increase with depth of source

Outline:

* Motivation
  - revisiting the UV/IR relation
* Synchrotron radiation in AdS/CFT
  - review of set-up
  - puzzle
* Proposal for beaming mechanism
  - expectations
  - construction
  - tests
* Concluding remarks

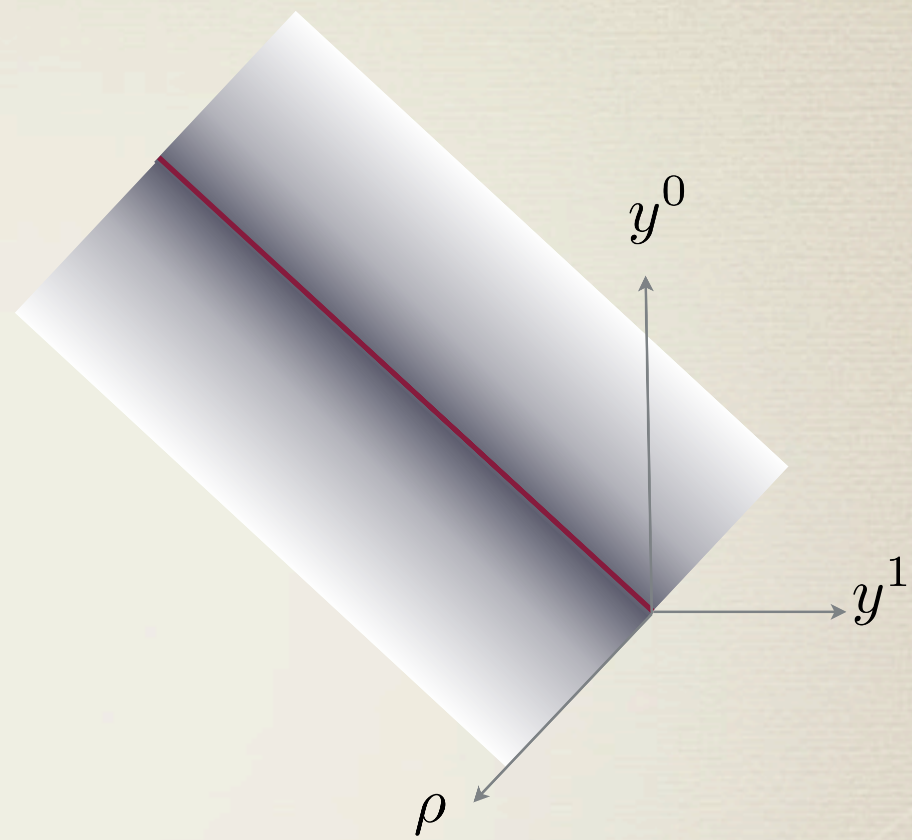
Expectations for beaming mechanism:

- Note: backreaction due to a null particle is given by a gravitational shock wave (GSW)
  - GSW has support on transverse null plane
- Treat string as composed of relativistic point particles, each producing a GSW
  - assume transverse velocity is approx. = 1
  - ignore interaction between different bits of string
- Superpose individual GSWs
  - the greatest backreaction of the string will be given by where the GSWs intersect (constructive interference)

Proposal: this gives qualitative features of backreaction.

Gravitational shock wave (GSW)

* given by generalizing Aichelburg-Sexl metric to AdS; construct via:
  boosting BH w/ mass→0 & boost→∞
  gluing 2 AdS spacetimes across null plane
  [Dray, `t Hooft; Horowitz, Itzhaki; Gubser, Pufu, Yarom; ...]
* GSW supported on null 'plane'
  transverse to spatial velocity
* profile of GSW:
  * singular on particle trajectory
  * polynomial falloff
  * e.g. for particle moving along $y_+ = 0$, GSW is:



$$y_\pm \equiv y_0 \pm y_1$$

$$\rho^2 = \sum_{i=2}^{d-1} y_i^2$$

$$ds^2 = \frac{4\,\eta_{\mu\nu}\,dy^\mu\,dy^\nu}{(1-\eta_{\alpha\beta}\,y^\alpha\,y^\beta)^2} + \delta(y_+)\,\frac{f(\rho)}{(1+y_+\,y_- - \rho^2)}\,dy_+^2$$

* more general construction:
  generate by spacelike transverse geodesics

String transverse velocity

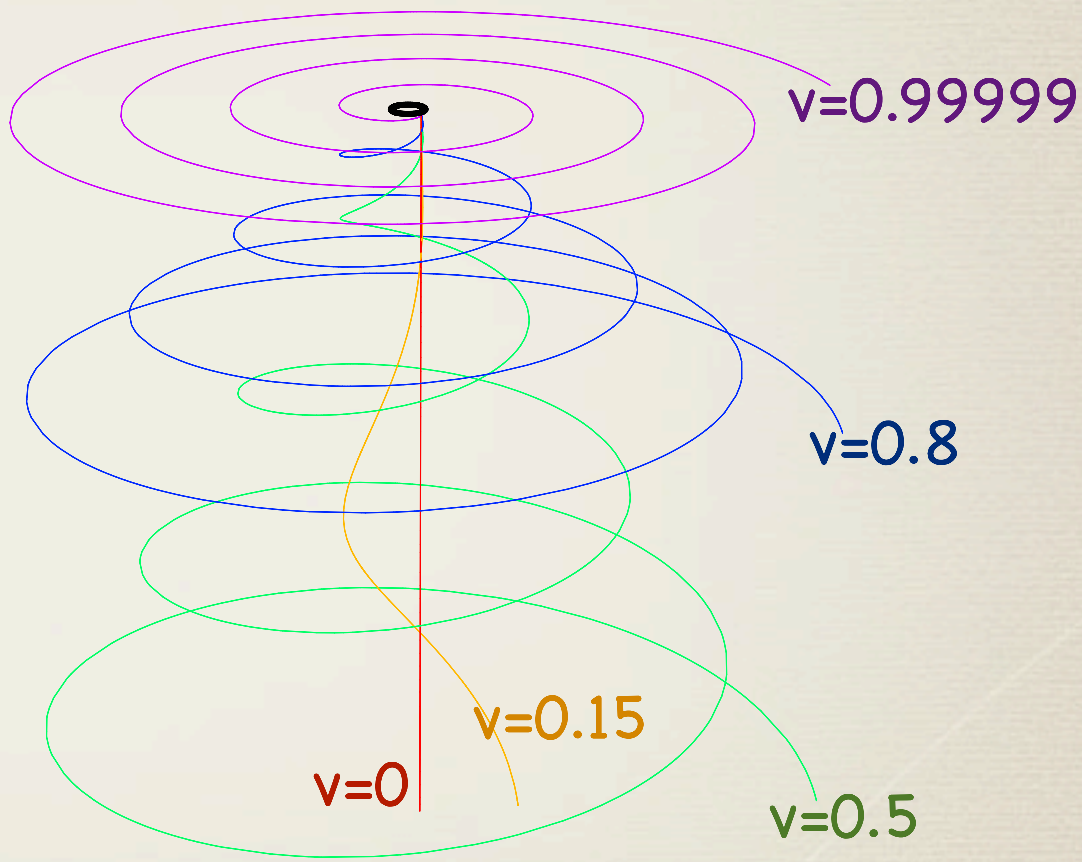
for quark moving with velocity **v** in a circle of radius R_0,

string profile for various v:

$$X^M(t,z) = \left(t, R(z), \frac{\pi}{2}, \phi(z) + \omega_0, z\right)$$

$$R(z) = \sqrt{R_0^2 + v^2\,\gamma^2\,z^2}$$

$$\phi(z) = -z\,\gamma\,\omega_0 + \arctan\left(z\,\gamma\,\omega_0\right)$$



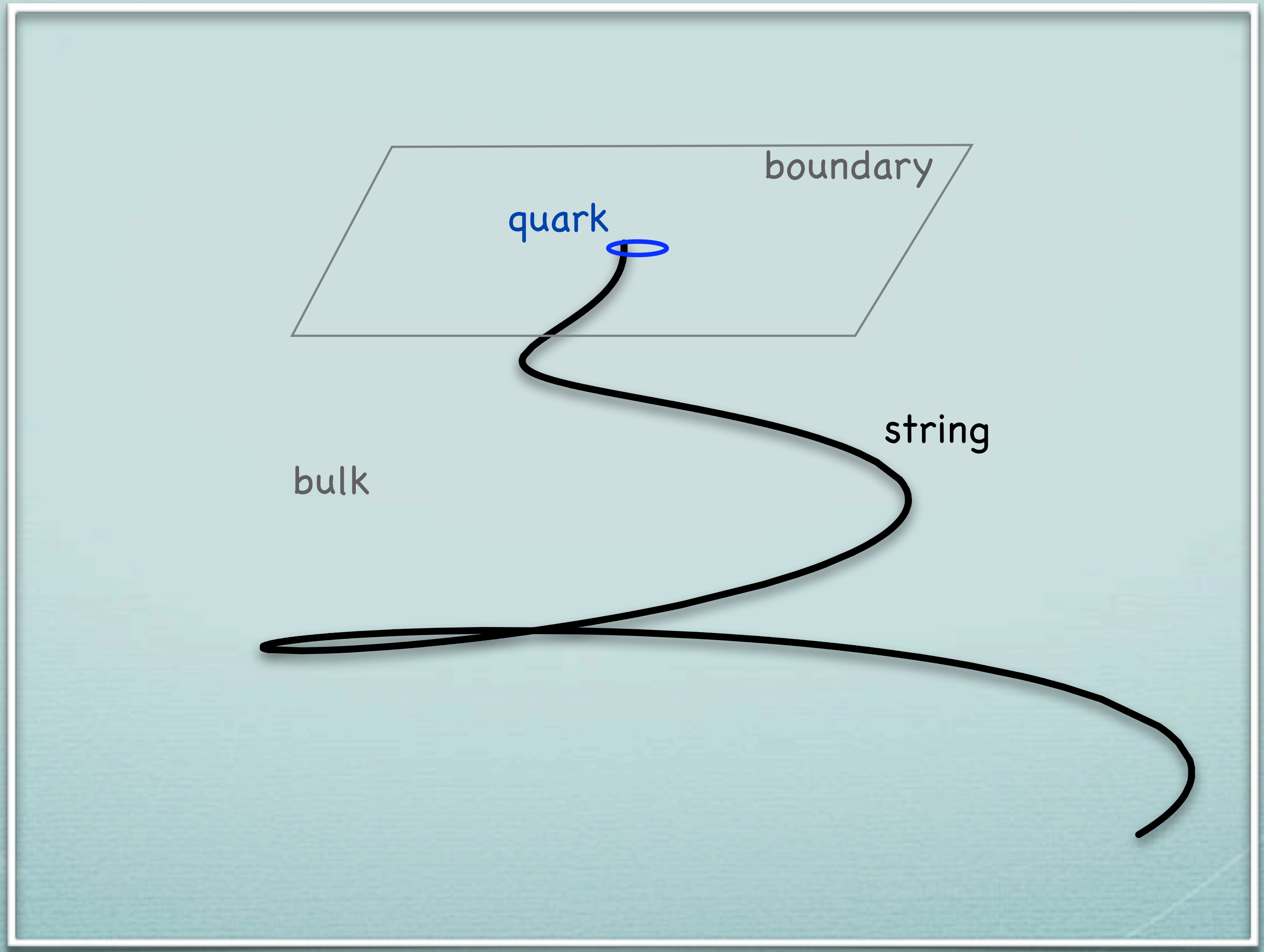
transverse velocity of string:

$$V_\perp^2(z) = v^2\,\frac{1 + v^2\,\gamma^4\,z^2/R_0^2}{1 + v^4\,\gamma^4\,z^2/R_0^2}$$

Hence string is more relativistic deeper in the bulk.

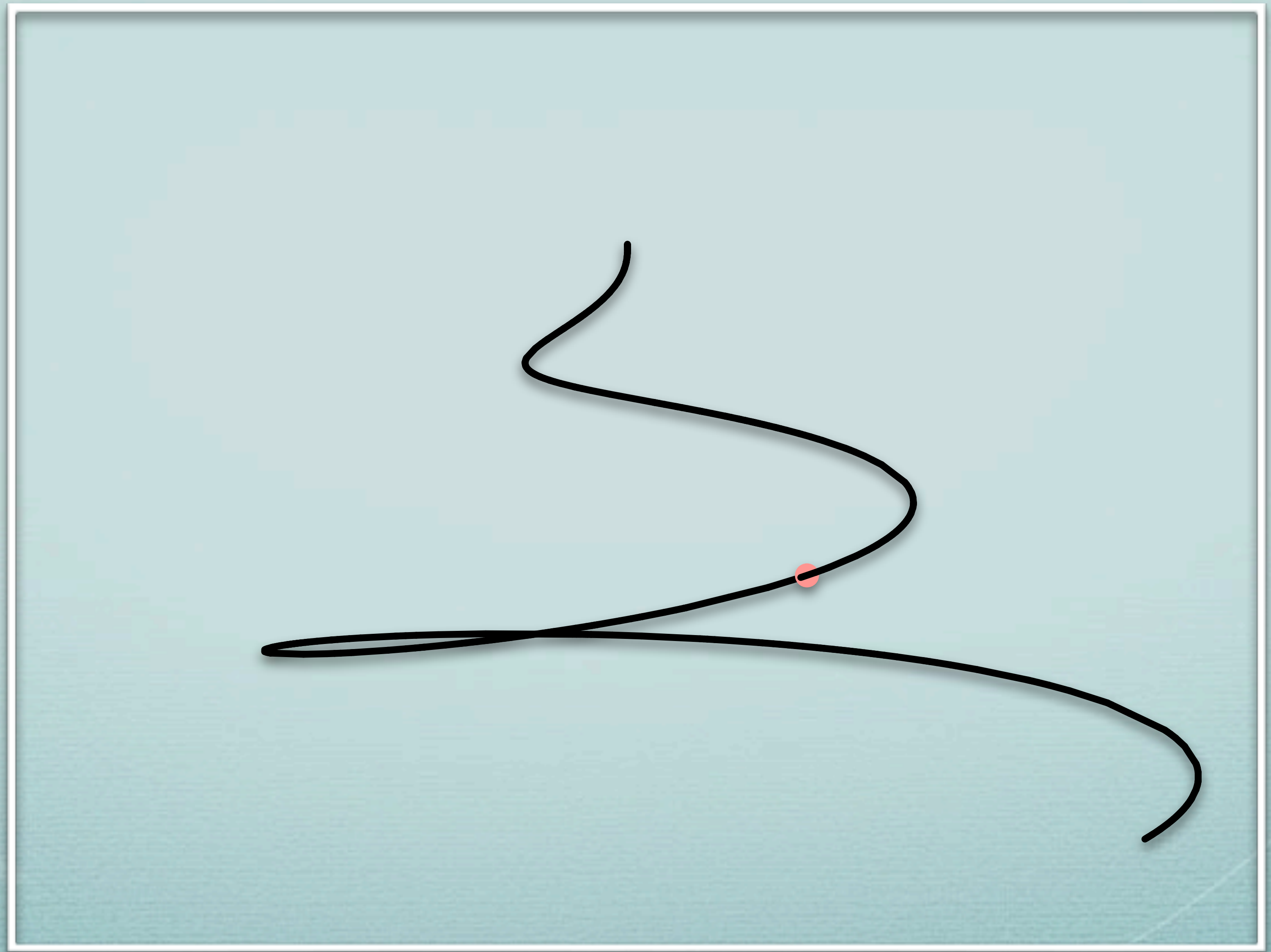
Gravitational shock wave construction

Start with a string in AdS (at some time t).



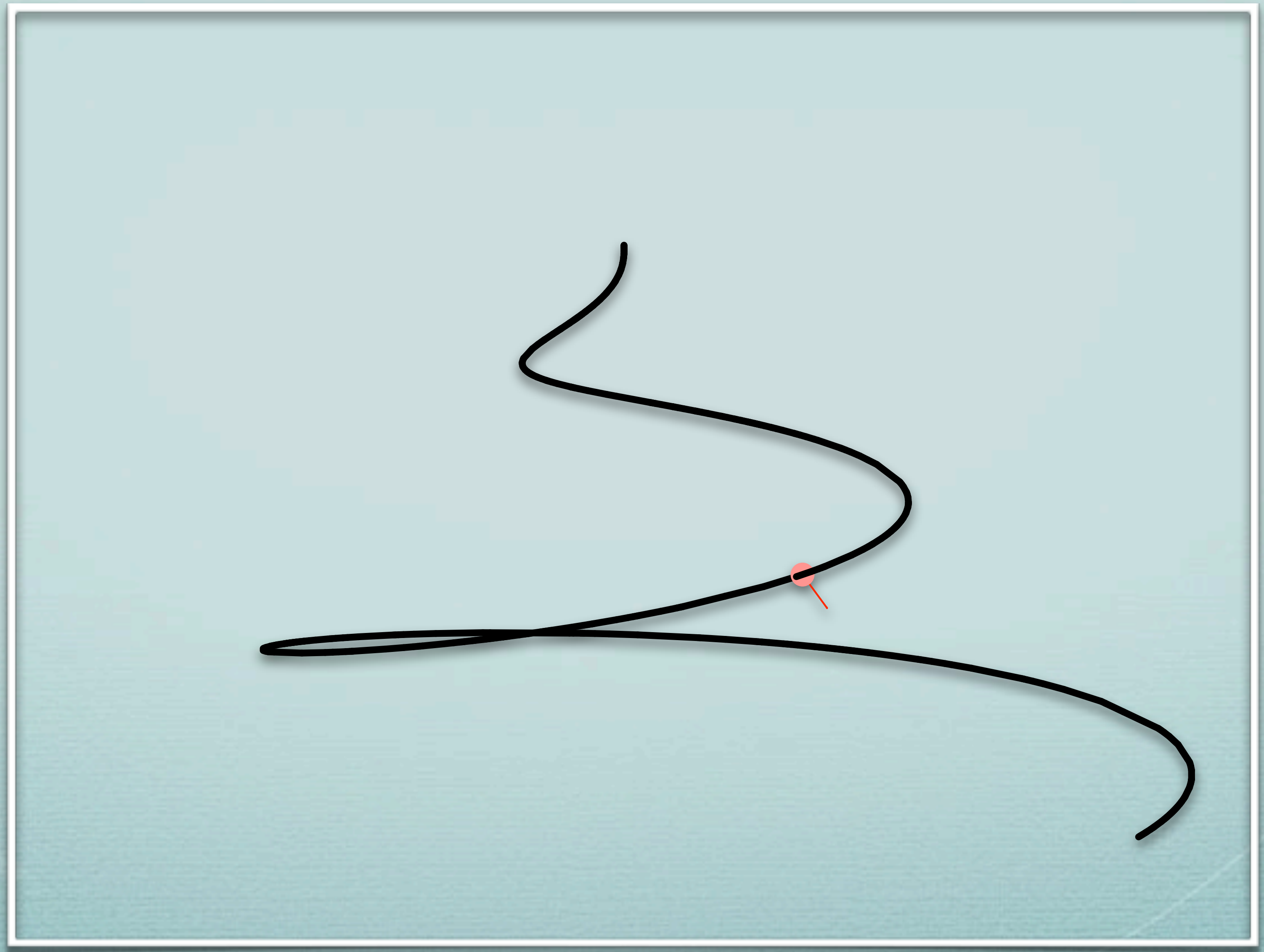
Gravitational shock wave construction

Pick a point p_i on the string parameterized by (t,z)



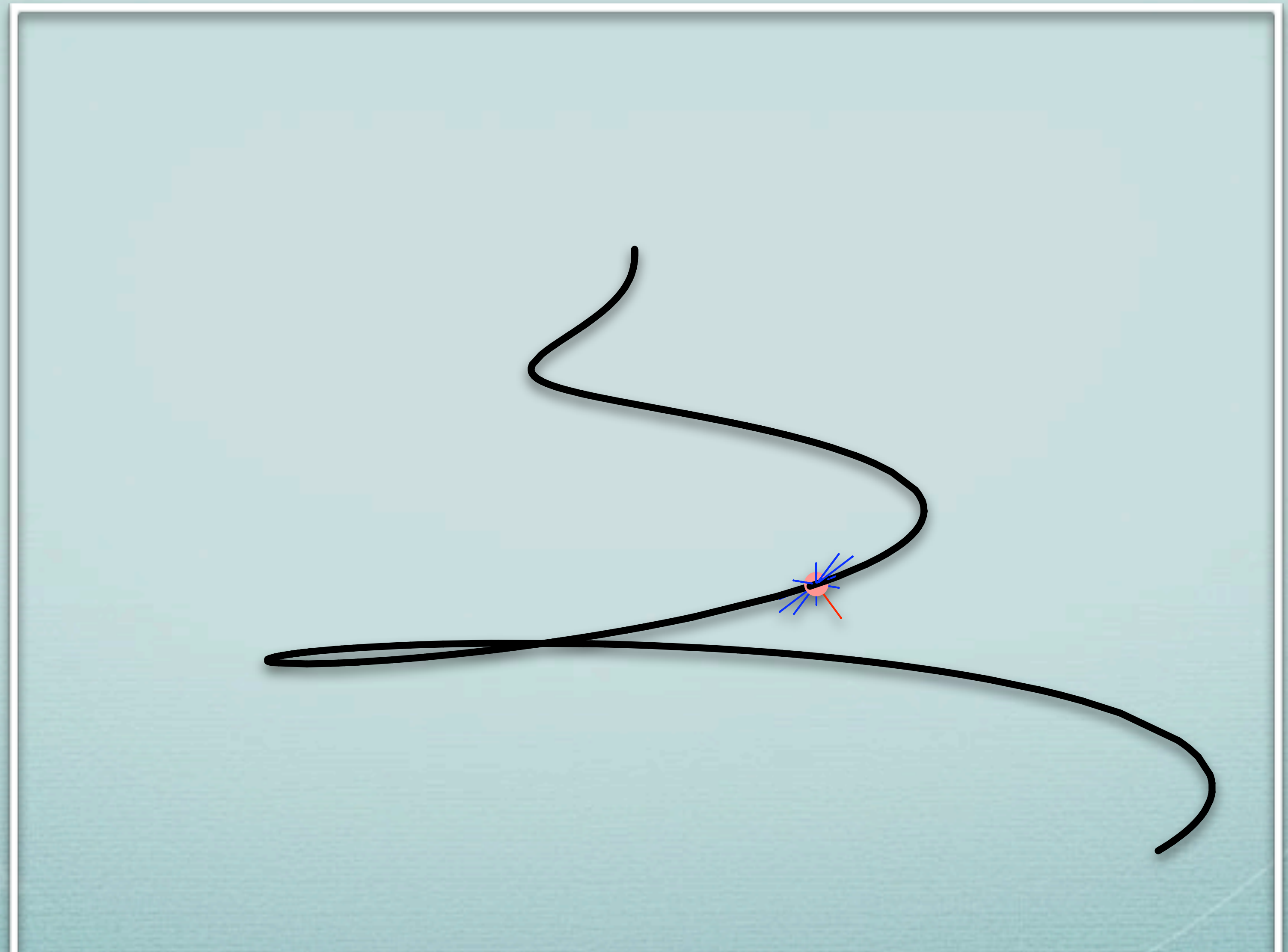
Gravitational shock wave construction

At p_i, construct the transverse velocity $\vec{V}_\perp$



Gravitational shock wave construction

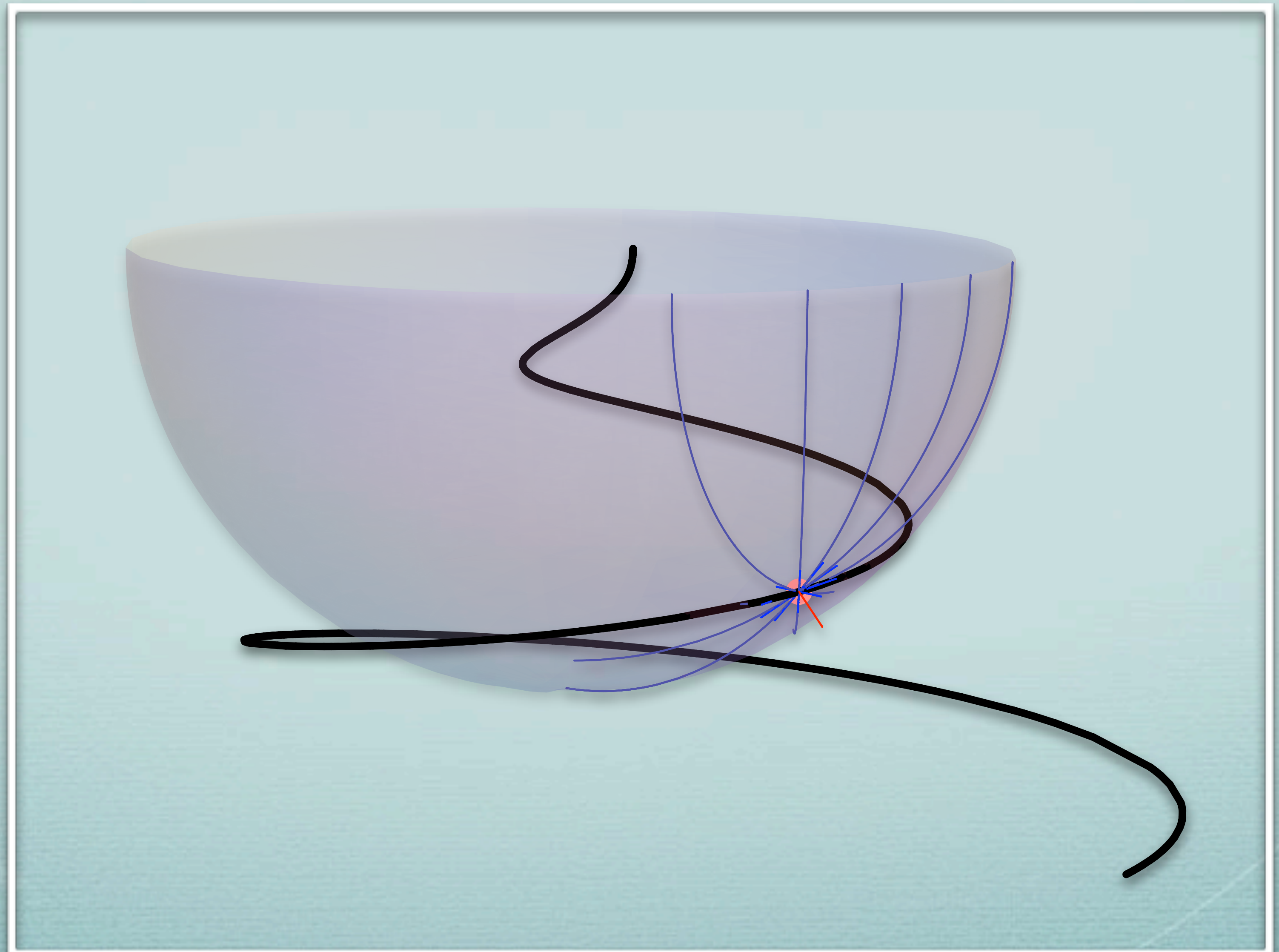
Take normal vectors w_i to the transverse velocity $\vec{V}_\perp$



Sunday, August 15, 2010

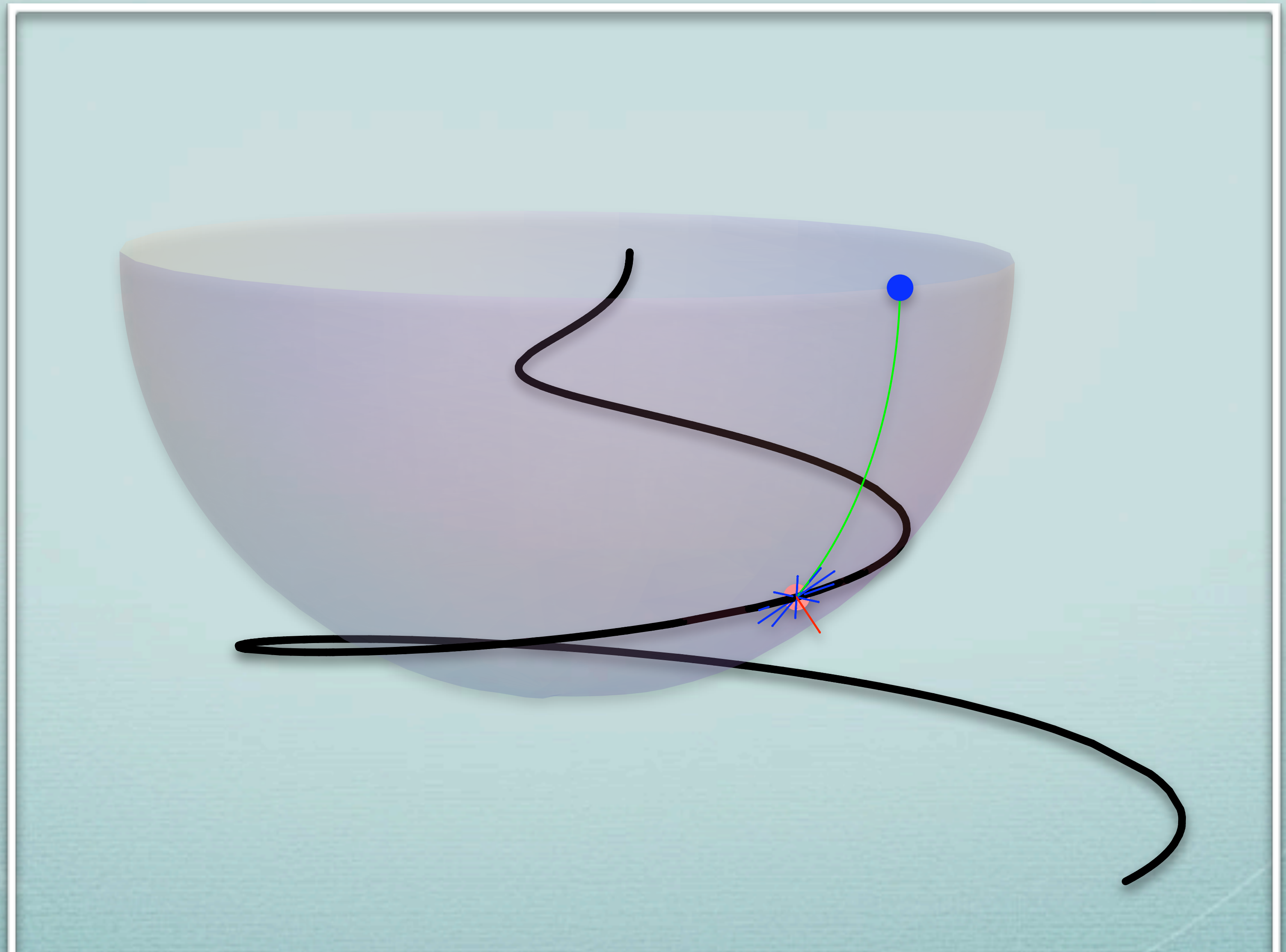
Gravitational shock wave construction

and construct spacelike geodesics emanating from p_i in the directions w_i (these generate the gravitational shock wave).



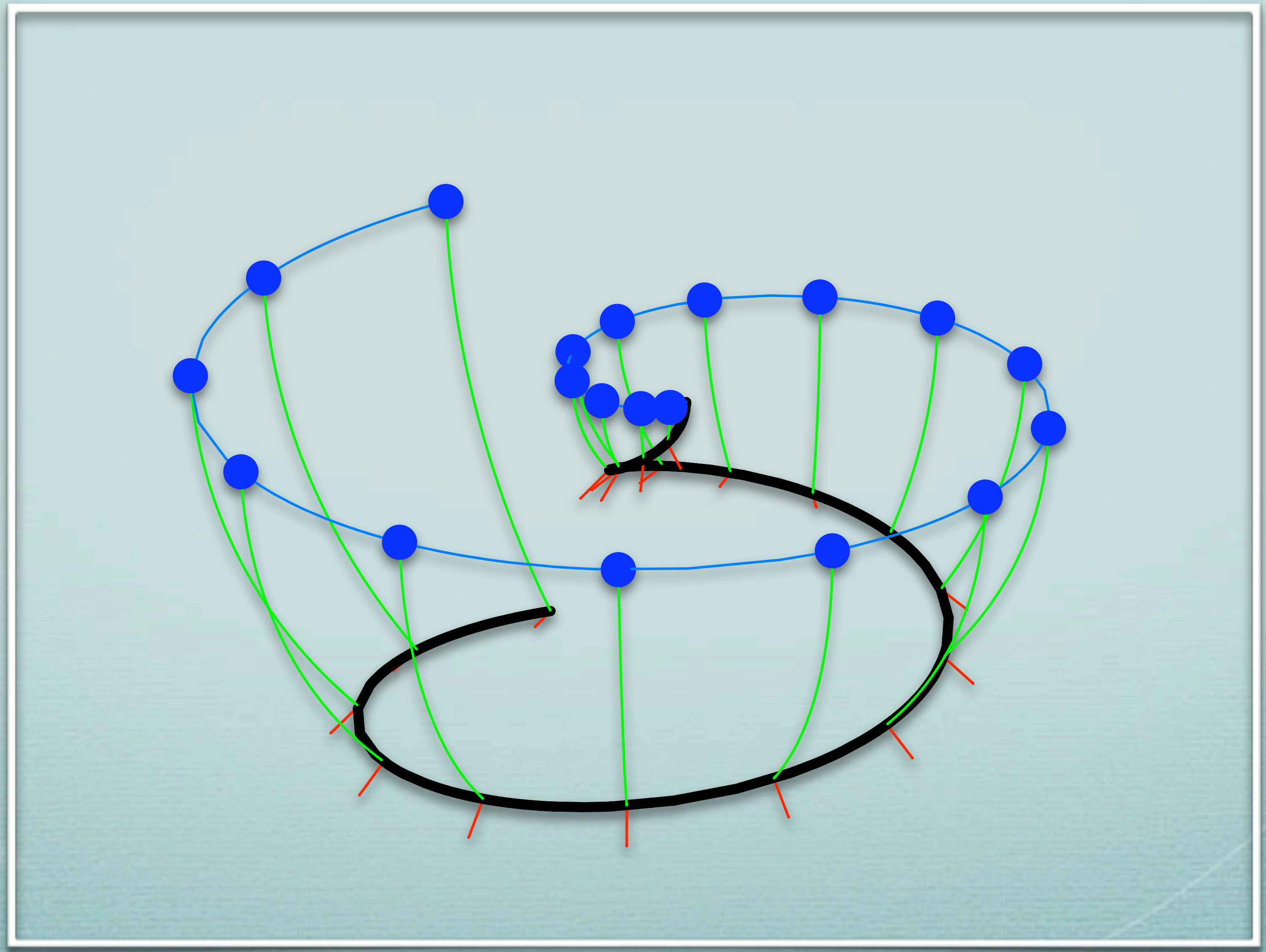
Gravitational shock wave construction

Finally, the dominant part comes from steepest geodesic to boundary, and lights up point p_0



Gravitational shock wave construction

Repeat with all points along the string...



Results:

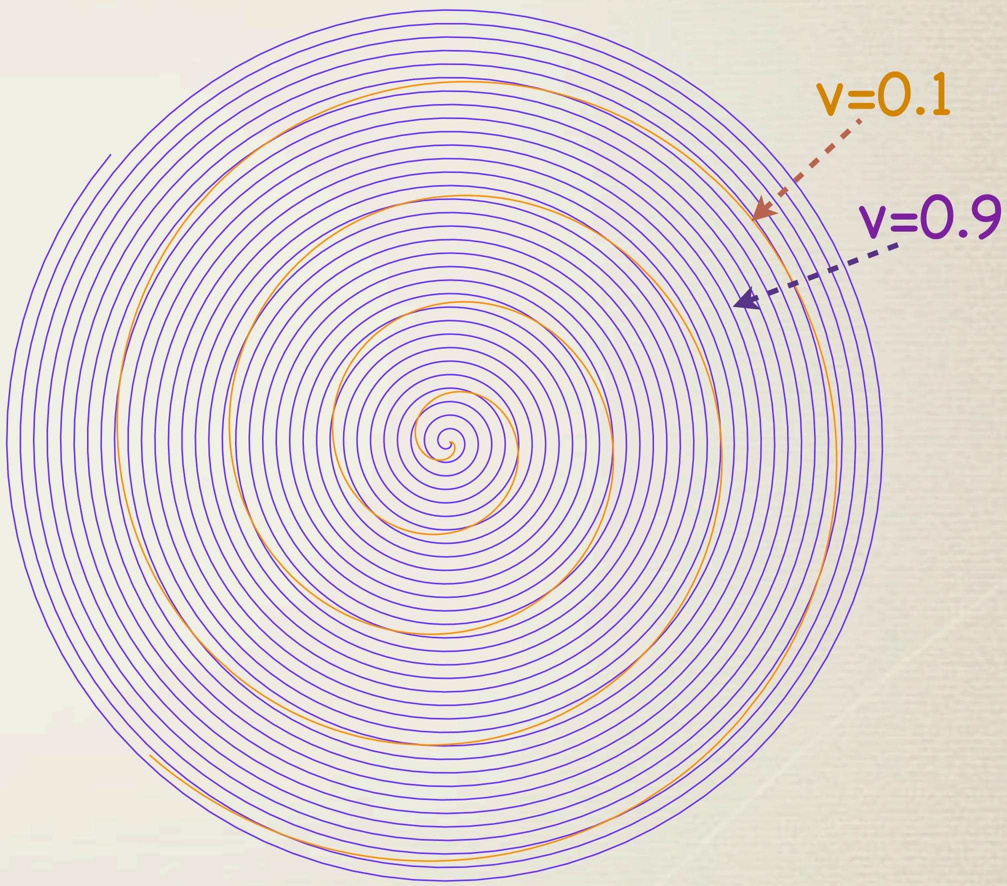
The bdy lightup induced by string would then look like:

* bdy $T_{\mu\nu}$ supported on a spiral
* spiral arms scale linearly:

$$R(\phi) \sim \phi$$

* spacing L depends on v as:

$$L = \frac{2\,\pi\,R_0}{v}$$



* spiral arms move outward at speed of light (independently of quark velocity v).

Results:

superposition of GSWs gives finite-width spiral:

e.g. for v=1/2:

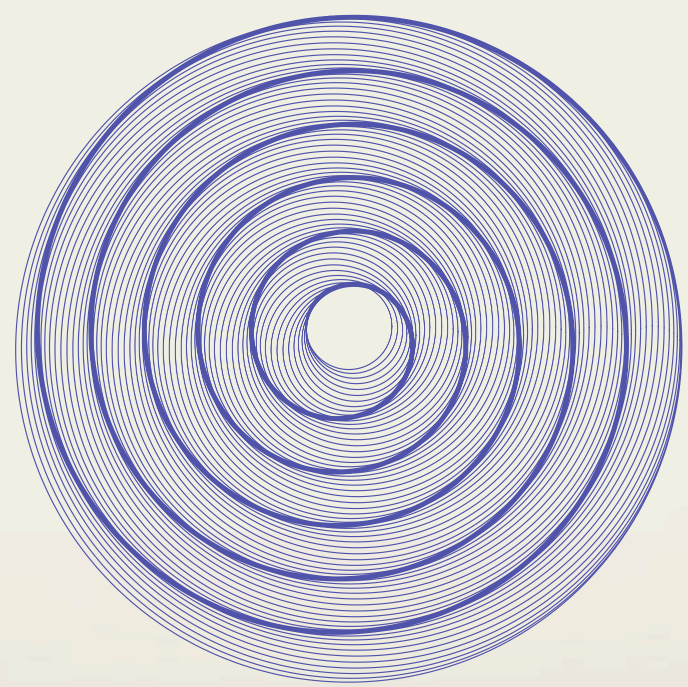
* each GSW = circle
* combined effect = spiral
* finite width emerges naturally from superposition
* width and arm separation depends on v

Results:

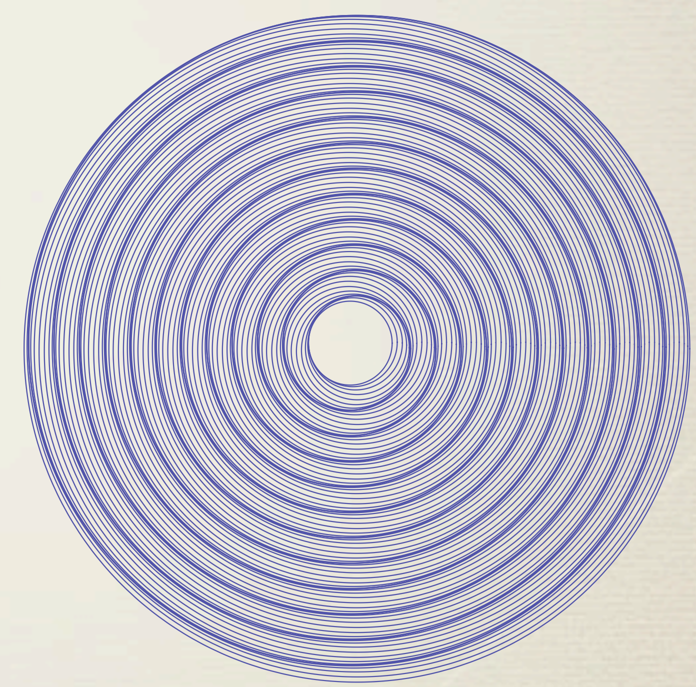
Spiral width decreases with increasing velocity:

v=0.5

v=0.7



v=0.9



In complete qualitative agreement with results of [ACLNR]

Summary:

Assumption that backreaction of string is given by {GSW} (= superposition of gravitational shock waves) from individual string bits reproduces [ACLNR]'s observed features of spatial distribution of boundary $T_{\mu\nu}$:

- correct spiral shape
  - spiral arms radius grows linearly with azimuthal angle
  - separation between spiral arms scales inversely with quark velocity
  - width of spiral arms decreases with quark velocity
- correct time-dependence
  - 'radiation' propagates radially outward at speed of light

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* correct time-dependence
  `radiation' propagates radially outward at speed of light

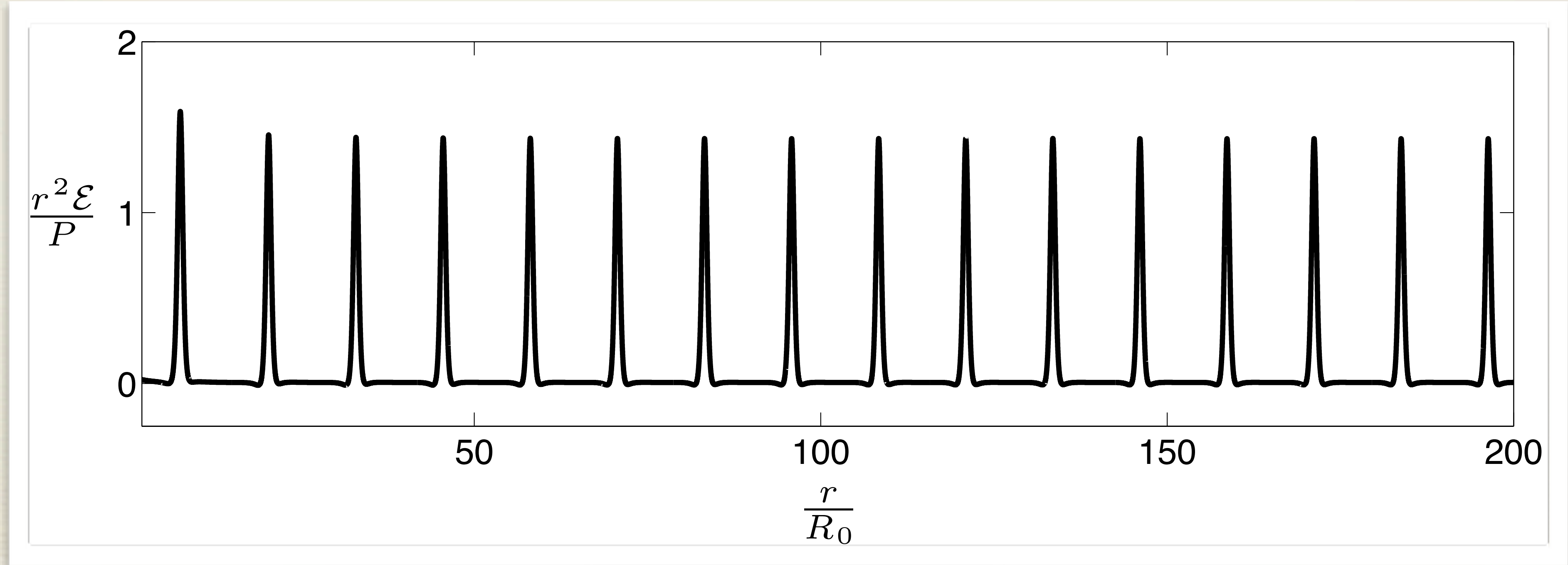
So this is promising as a possible beaming mechanism.

Outlook:

Albeit encouraging, more still remains to be checked:

* correct energy density radial profile?
  - details of peak profile
  - falloff with r

radial dependence of boundary energy density taken from [ACLNR]



* correct dependence on inclination angle θ?

Caveats:

In general, we should not expect precise agreement with {GSW} predictions, since

* near bdy, string need not move relativistically
  hence central part of spiral is not trustworthy
* GSWs need not superpose linearly
  this may modify the spiral peak profile
* there are interactions between string bits
  e.g. for 4-d straight string, the tension cancels energy density, so string only produces conical deficit

It would be useful to characterize to what extent is the {GSW} a good approximation in a given setup.

Implications:

- Useful calculational method: far easier to compute {GSW} than full backreaction of string (i.e. solving linearized E.eq. for bulk stress tensor)

- Allows better geometrical understanding in other situations
  - thermalization of synchrotron radiation at non-zero temperature
  - diffusion wake (& sonic boom) of a moving quark [Yaffe, Chesler; Gubser, Yarom; ...]

- observable effects for e.g. cosmic strings?

  not discussed in literature (more pronounced in higher dimensions)

- new insight into (violations of) scale/radius duality

  beaming of deep-bulk excitations towards AdS boundary