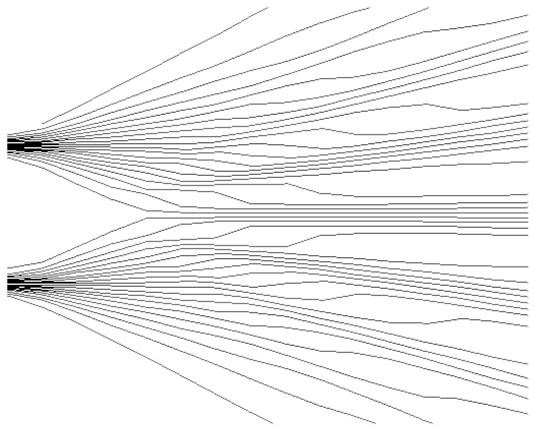
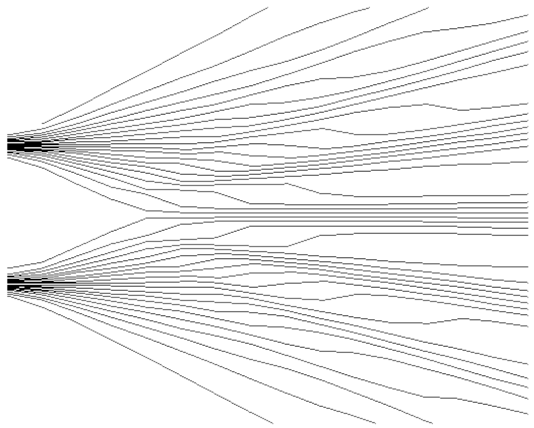


Quantizing Geometry
or
Geometrizing the Quantum?

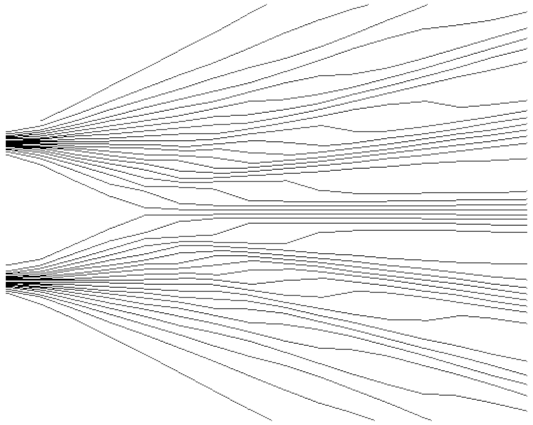
XXV Max Born Symposium
Wroclaw

Benjamin Koch



Outline

- Motivation & Idea
- The de Broglie-Bohm Interpretation (A)
- The Geometrical Toy Model (B)
- Deriving A from B
- Generalizations (n-particles & Interactions)
- Summary & Outlook



Literature

This Talk:

- B. Koch, arXiv:0901.4106;
- B. Koch, arXiv:0810.2786;

Related Ideas:

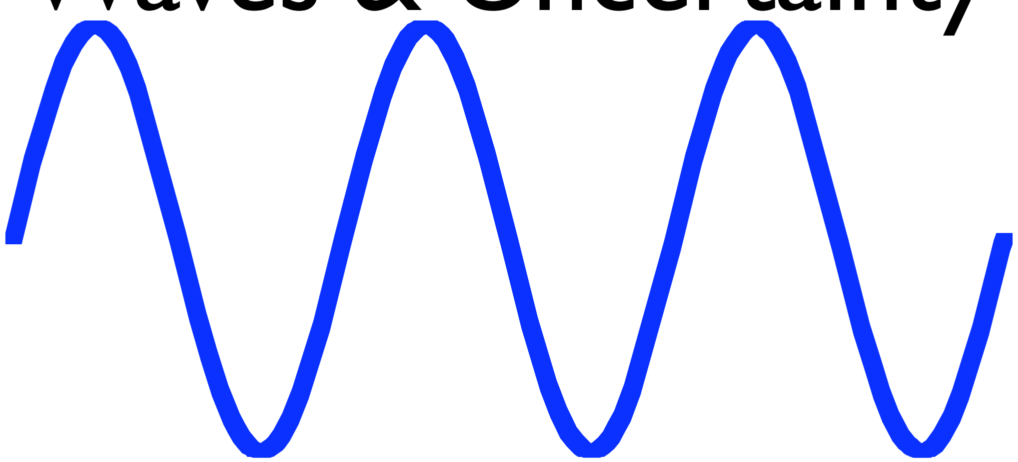
- F.&A.Shojai, Int.J.Mod.Phys.A15,1859 (2000)
- R. Carroll, arXiv:gr-qc/0406004
- J.M. Isidro et al., arXiv:0808.2351

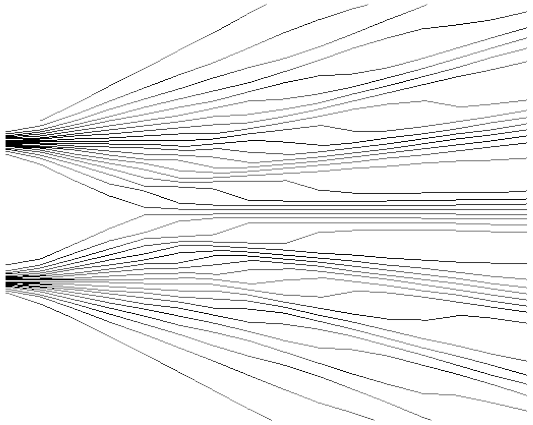
Motivation & Idea

Motivation & Idea

Quantum Mechanics

Waves & Uncertainty





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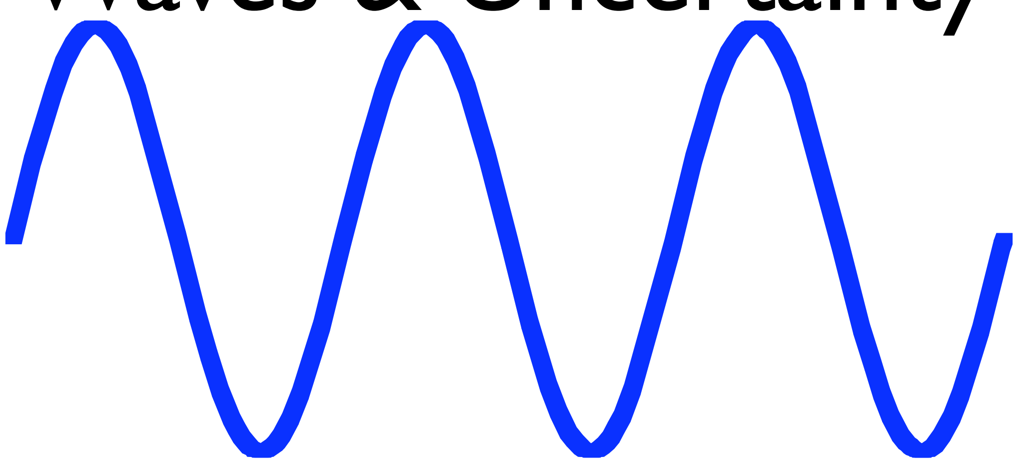
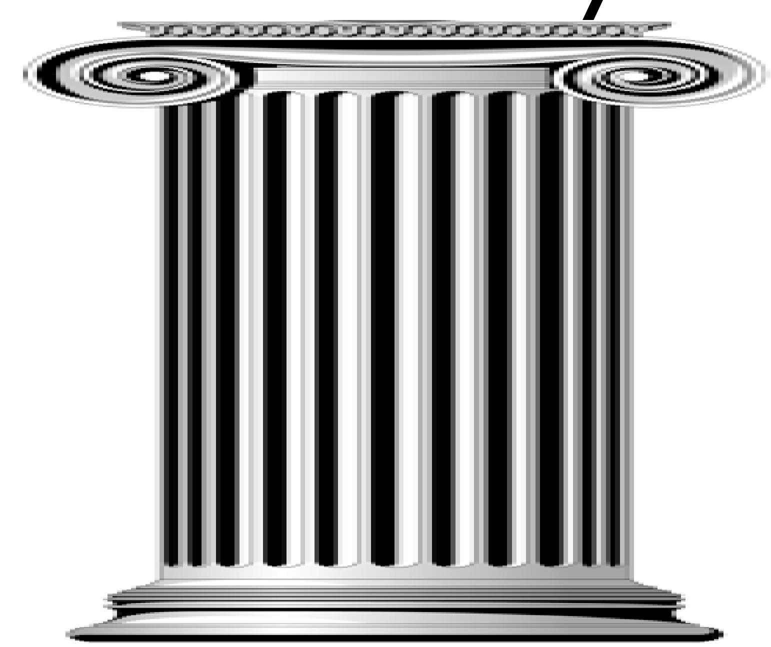
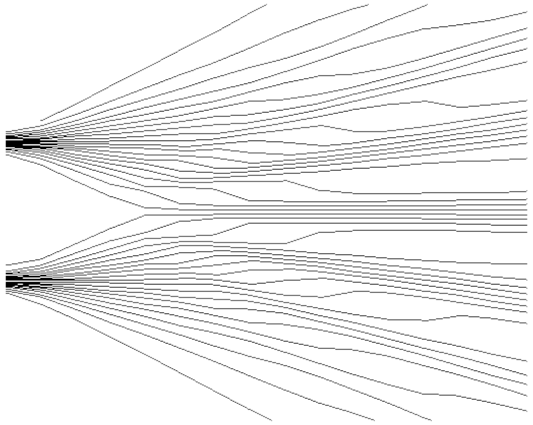


Geometry



Motivation & Idea

Quantizing Gravity:

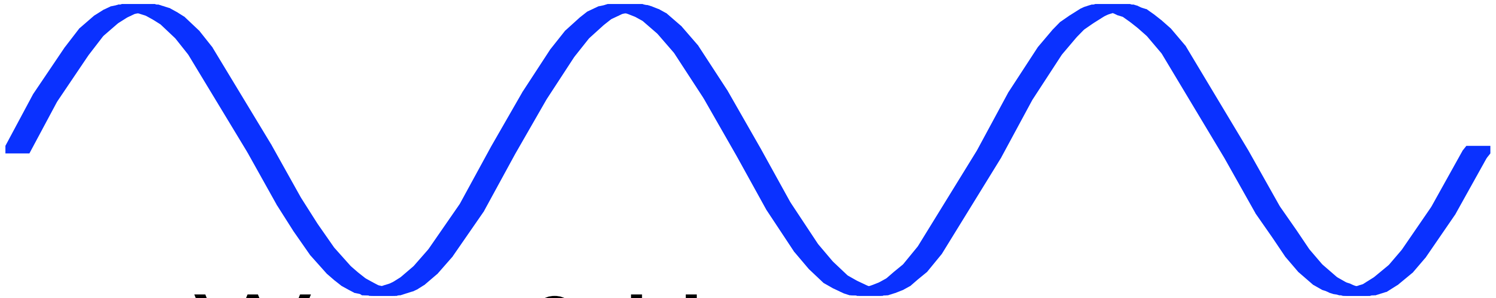


Motivation & Idea

Quantizing Gravity:

Quantum Mechanics

More Fundamental



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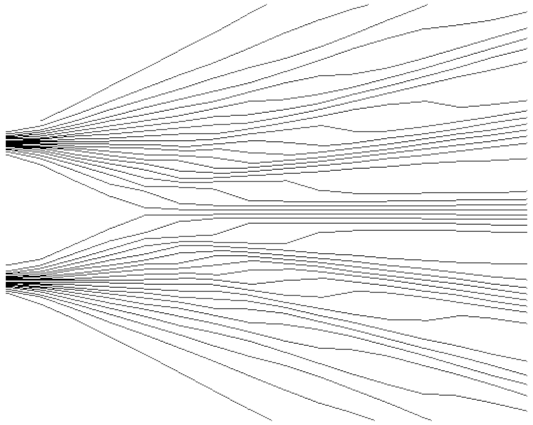

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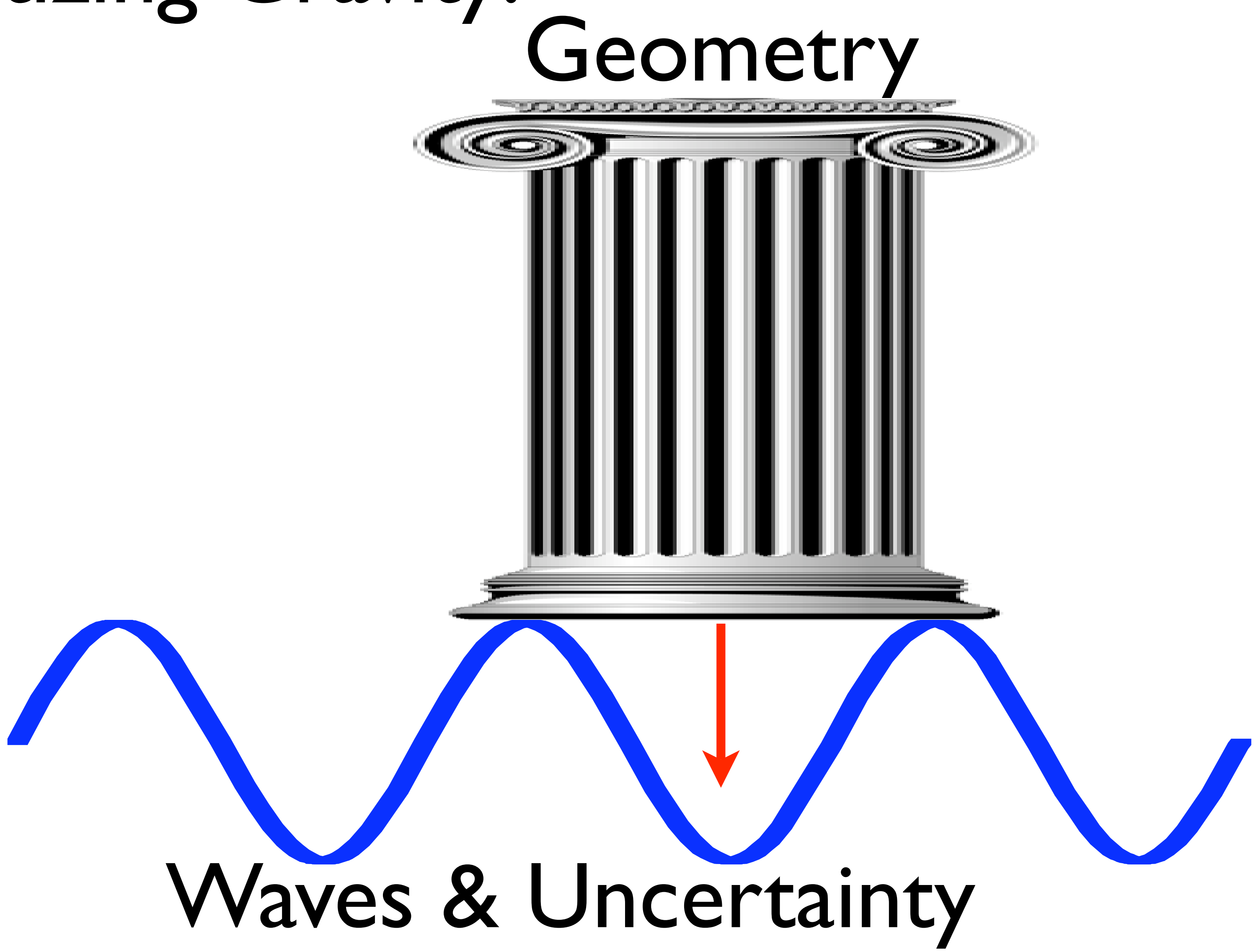

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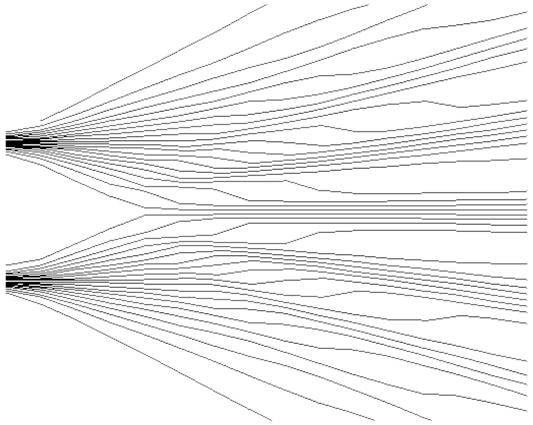

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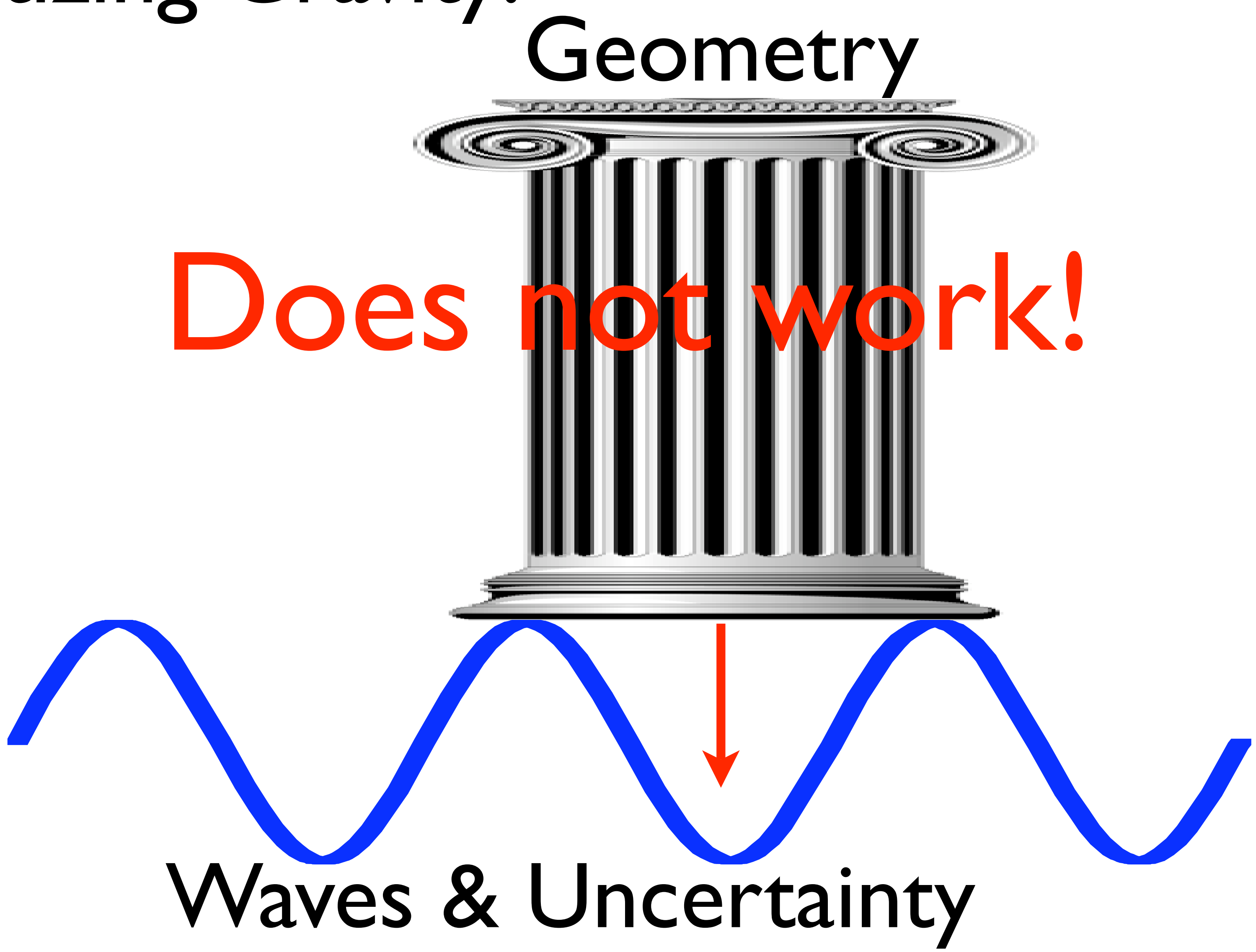

Motivation & Idea

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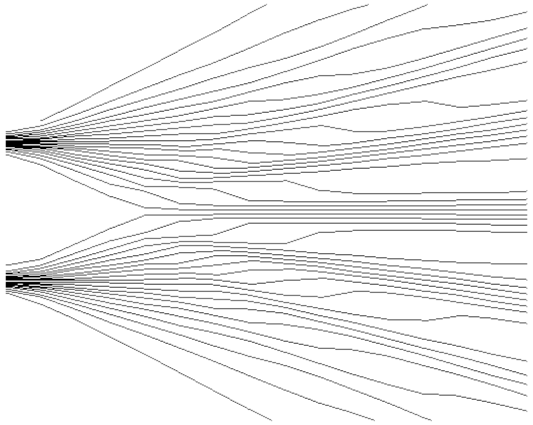

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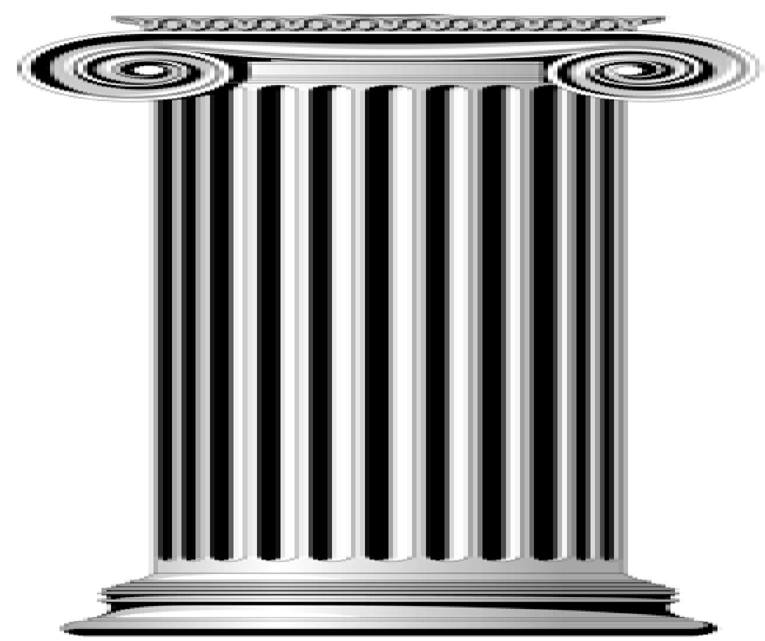

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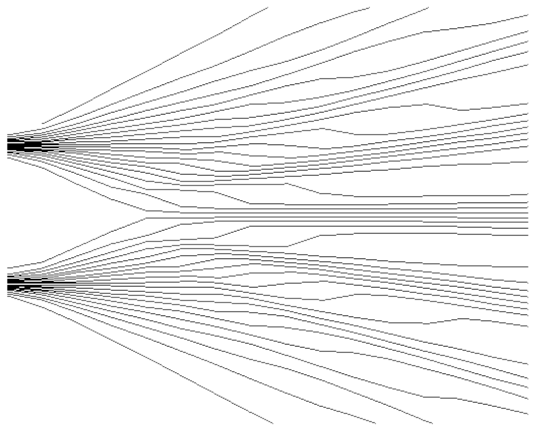

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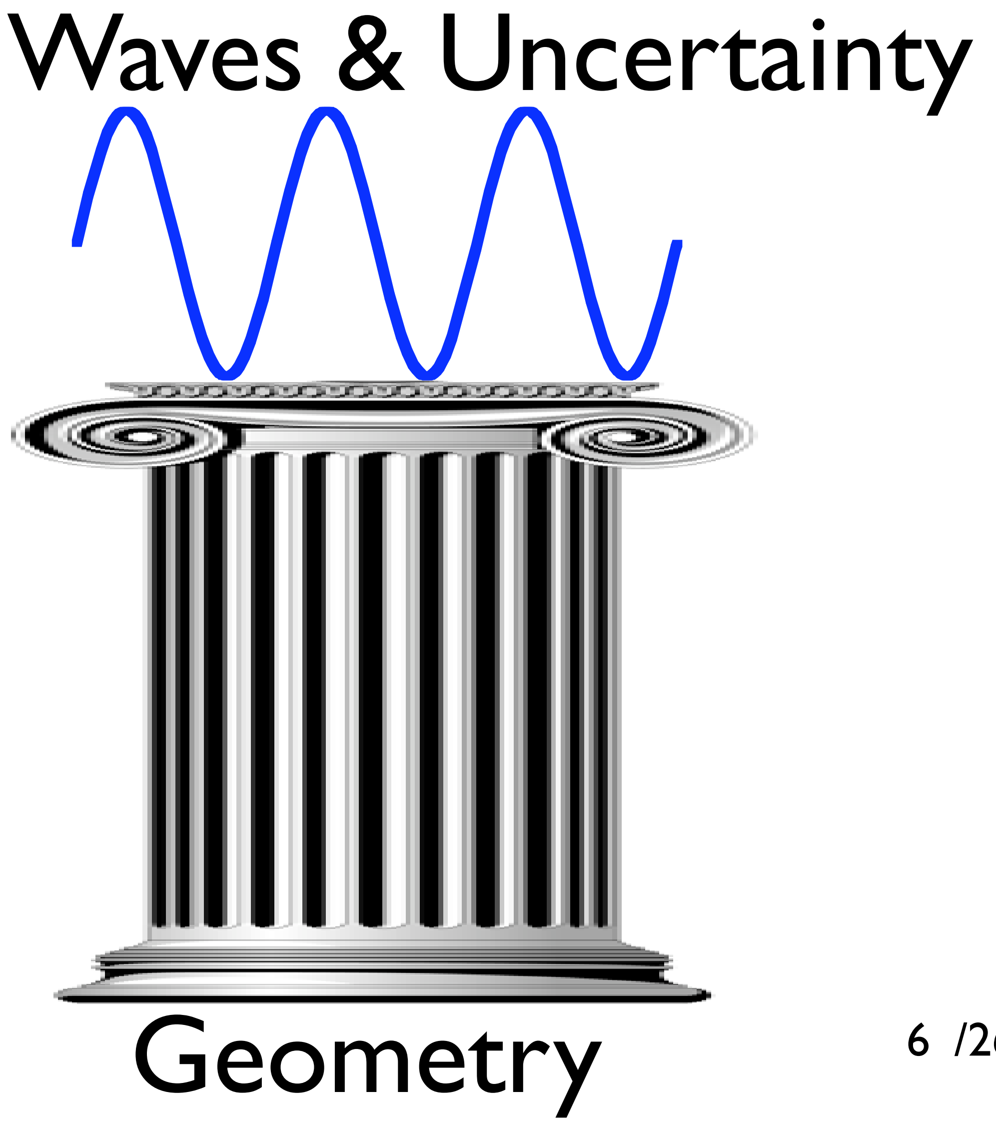

Benjamin Koch

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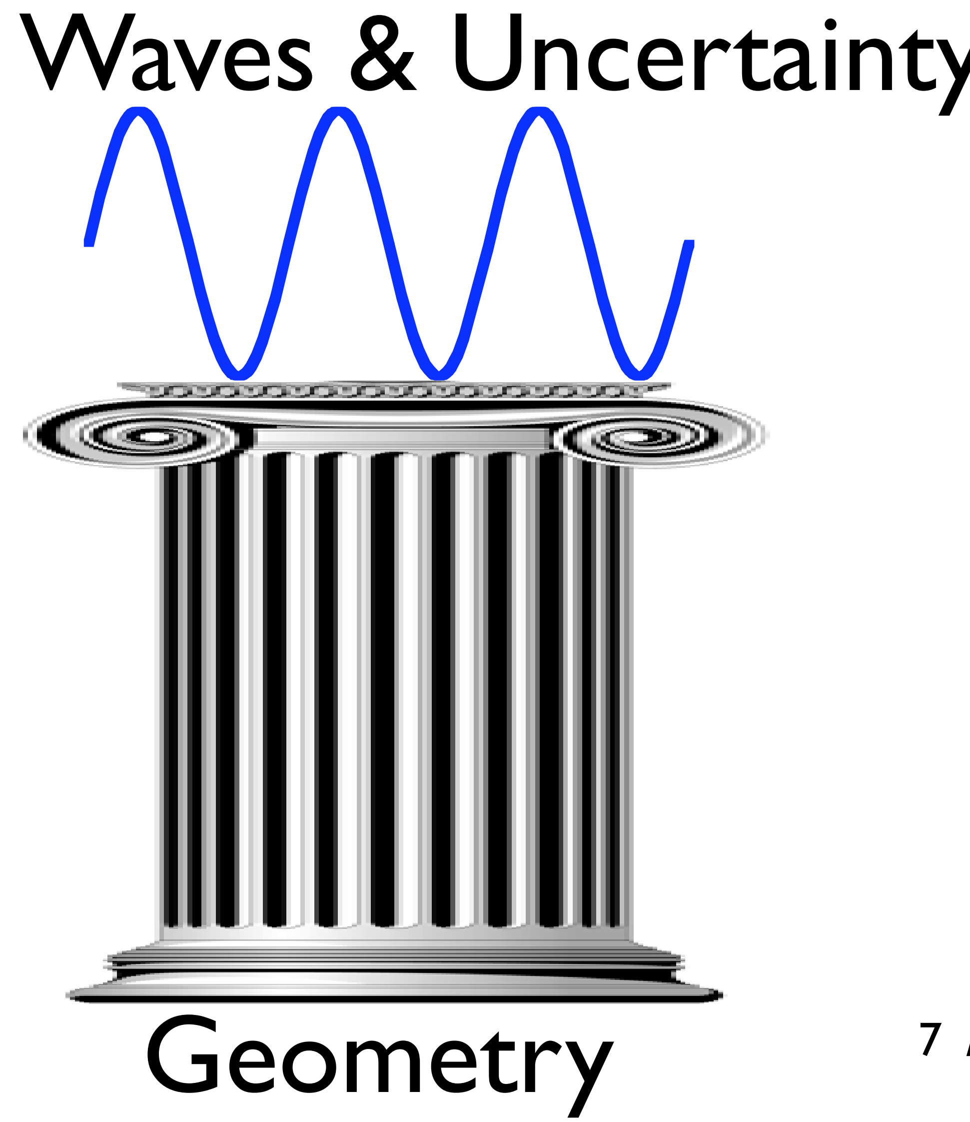

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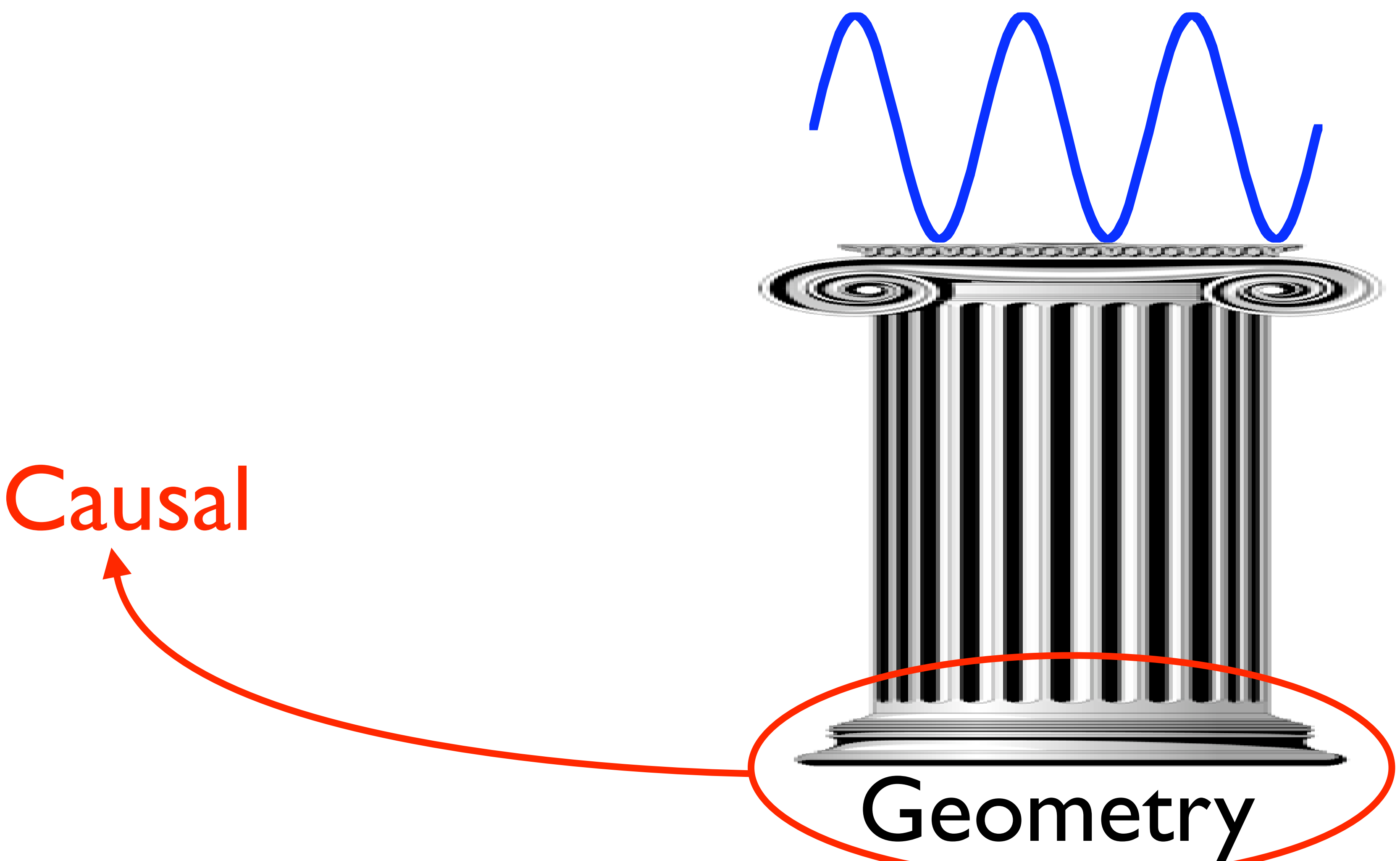

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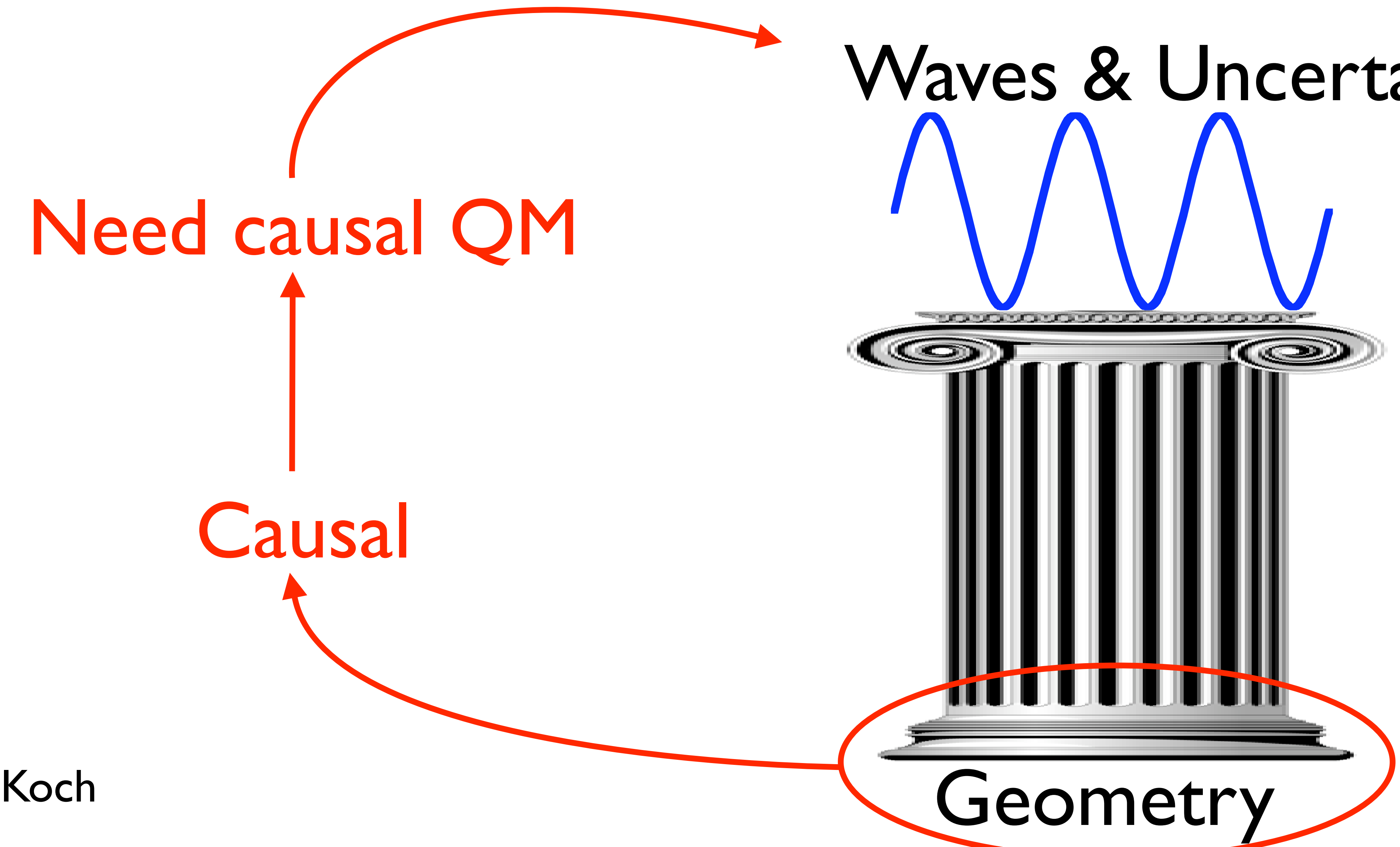
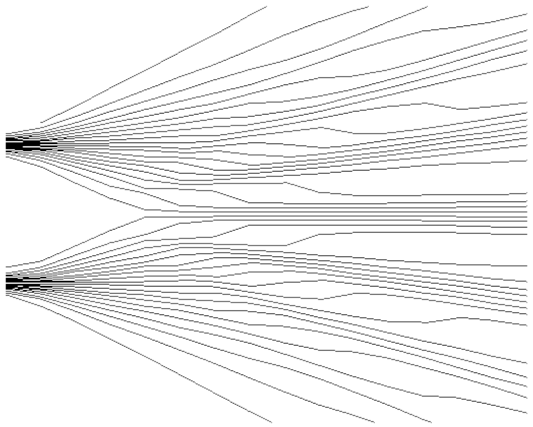


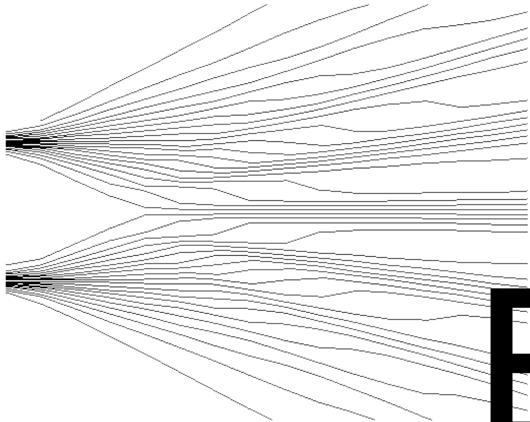


Motivation & Idea

„Geometrizing the Quantum"

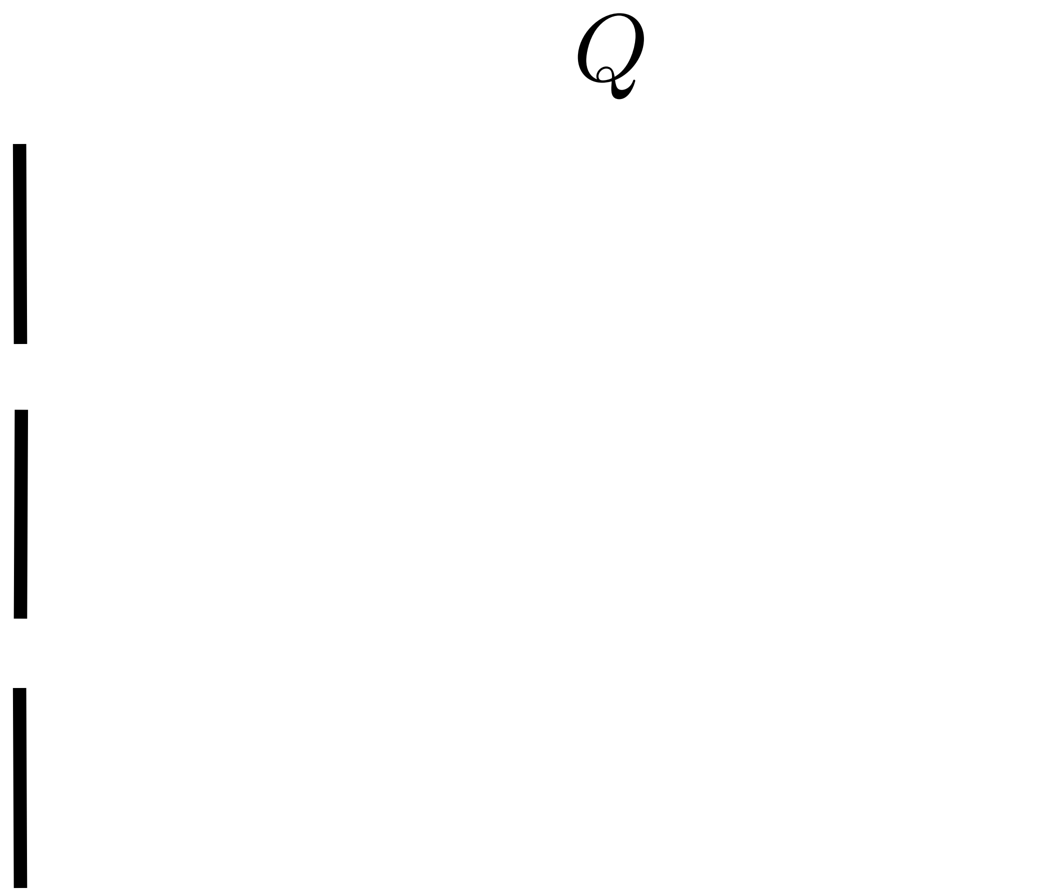
Plan:

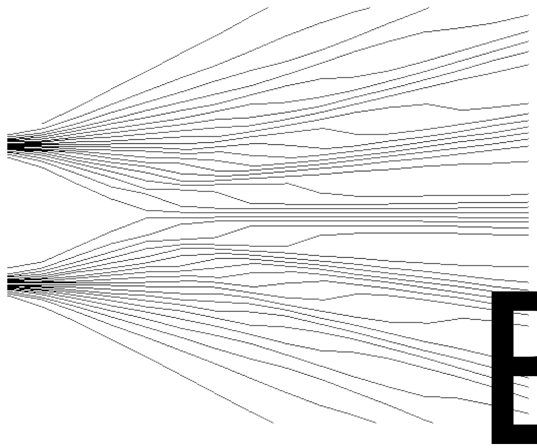
- Explain causal QM (dBB theory)
- Derive dBB from geometrical toy model



The de Broglie Bohm Interpretation

Example double slit:





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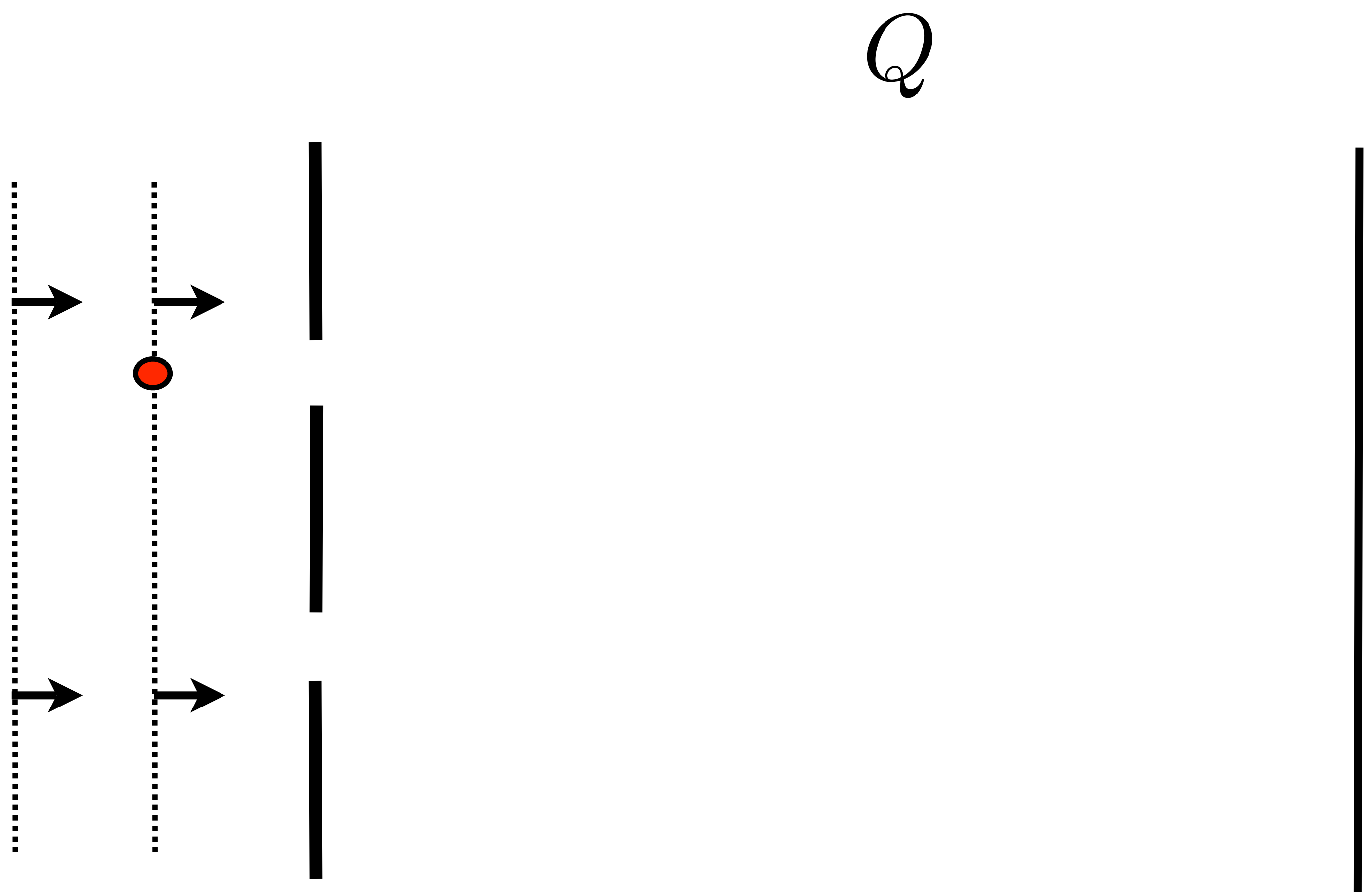
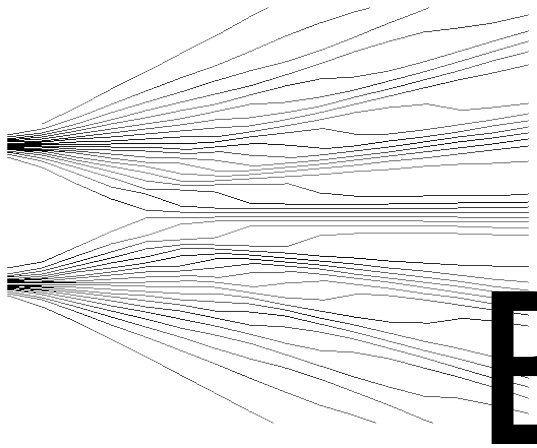


One particle in



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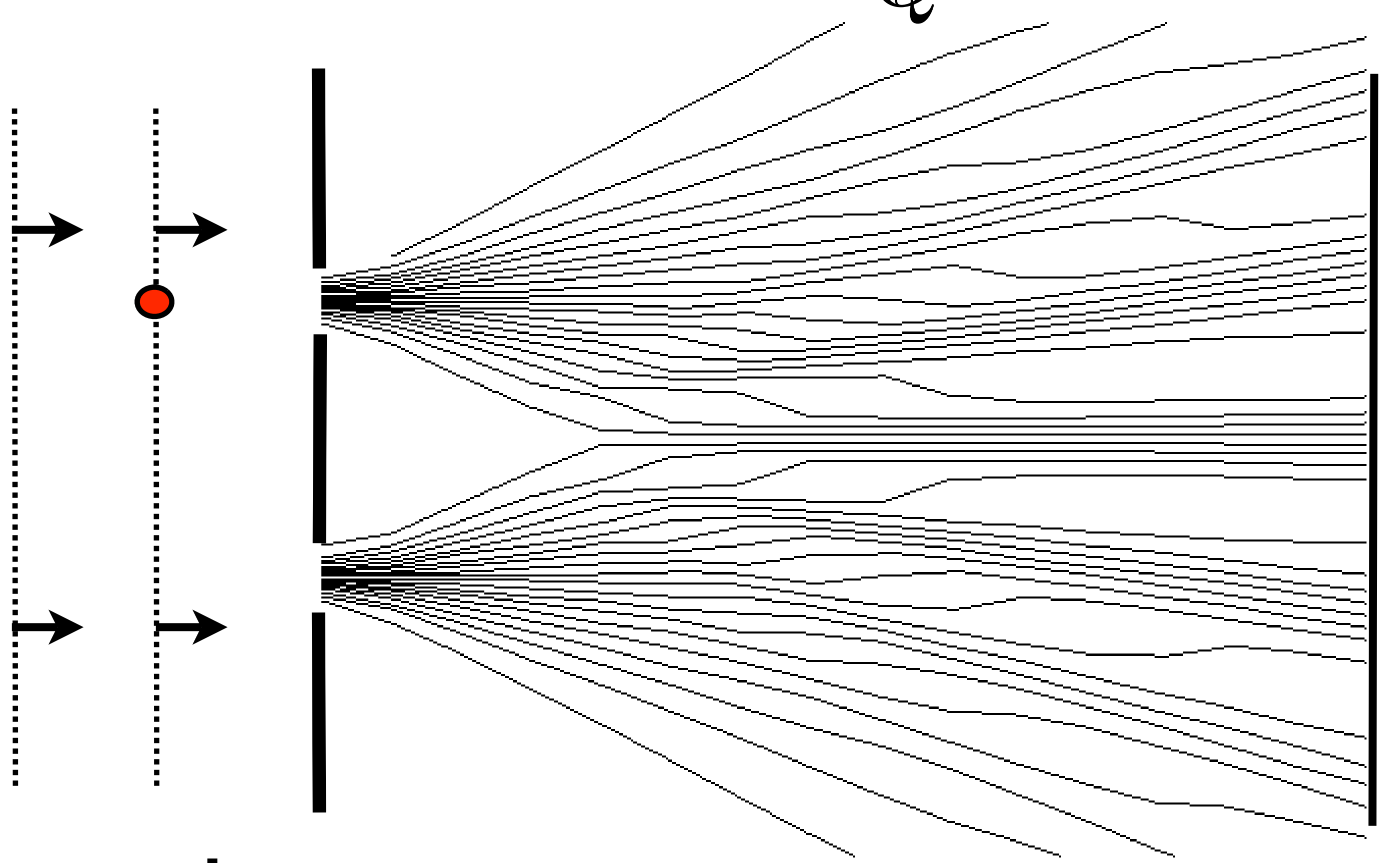

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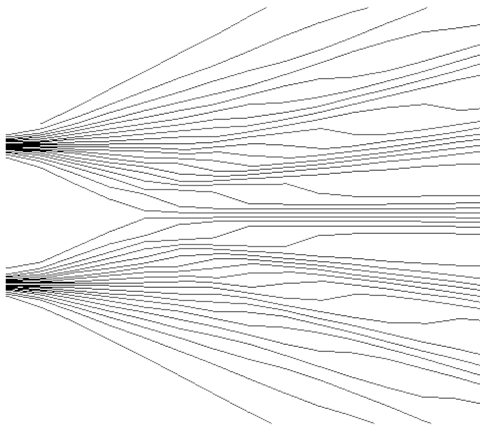

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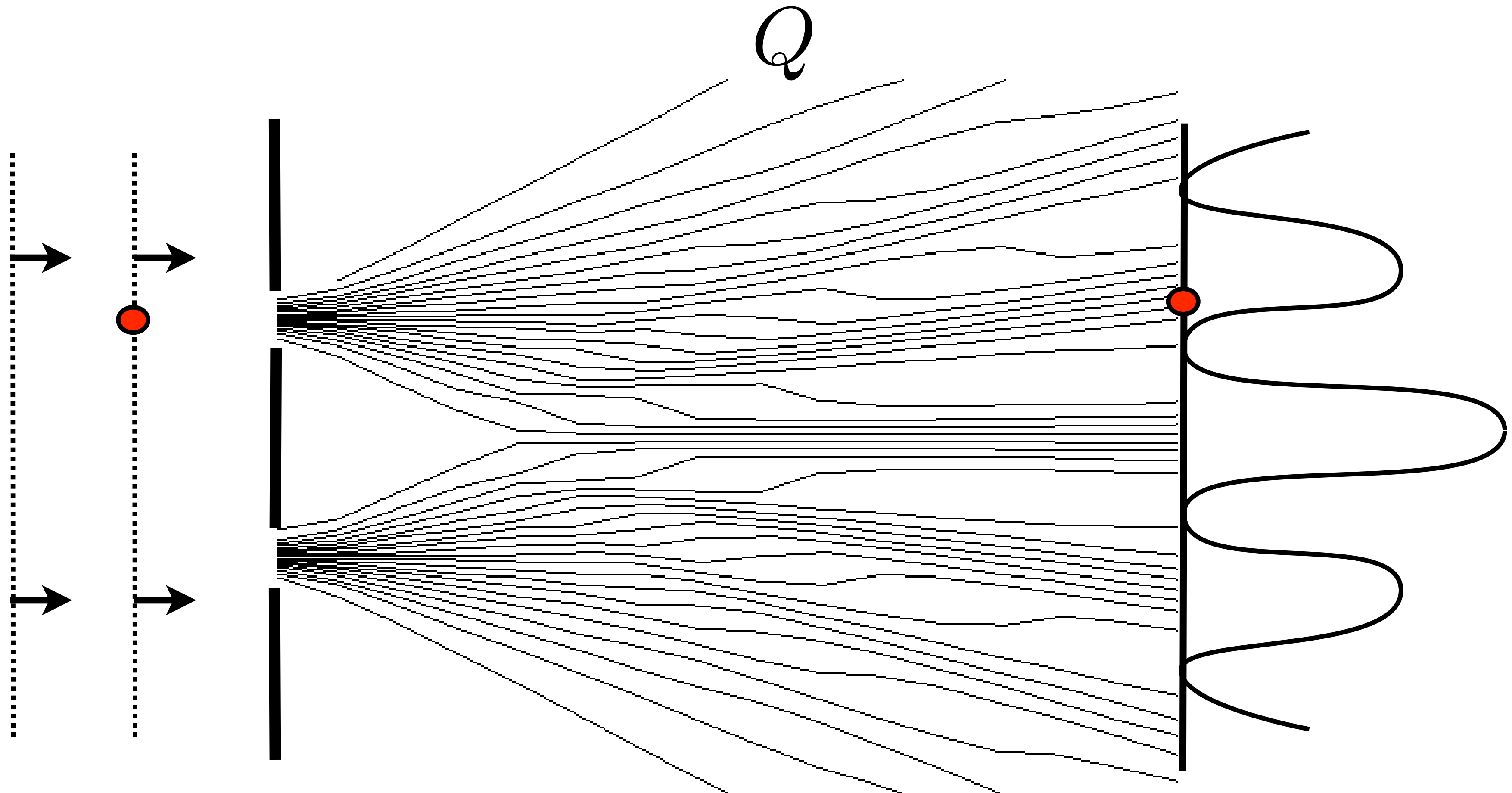
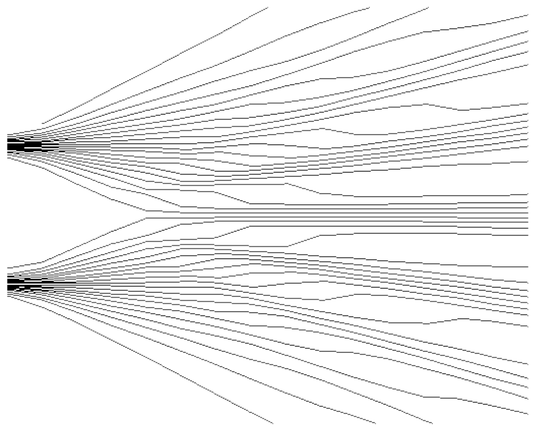


One particle in

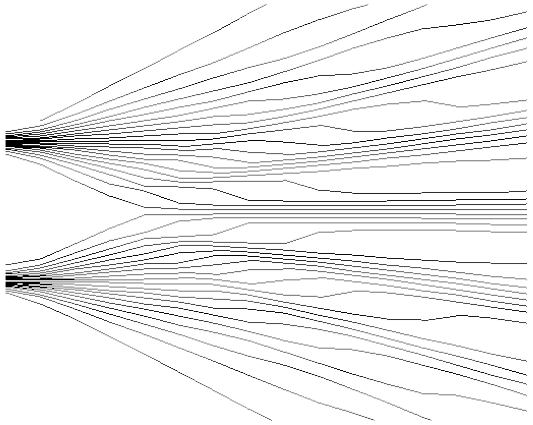
One particle out



dBB

Klein Gordon equation:

$$\left(\partial^m \partial_m + \frac{M^2}{\hbar^2}\right) \Phi(x) = 0$$



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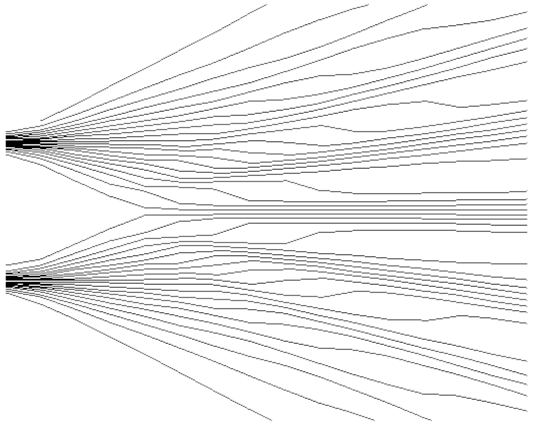
$$\Phi(x) = \sqrt{\rho}\exp(iS_Q/\hbar)$$



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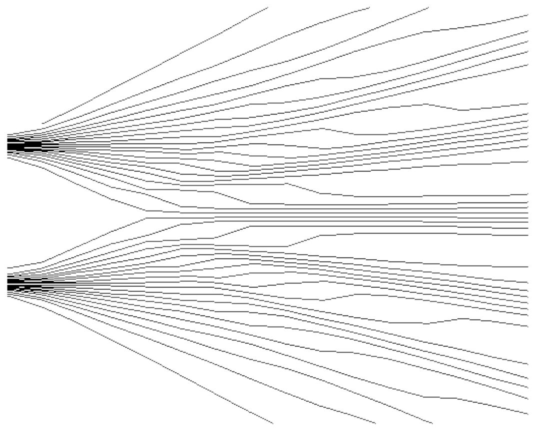

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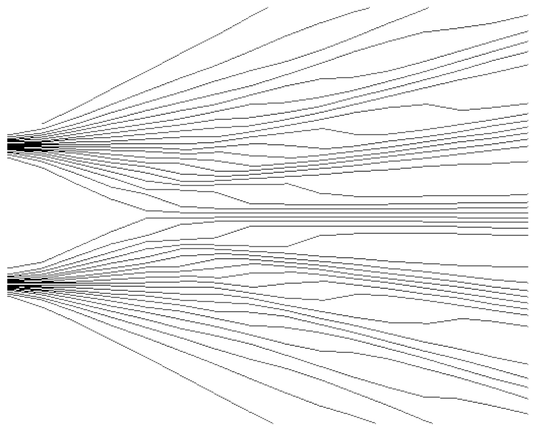
$$2MQ = (\partial^m S_Q)(\partial_m S_Q) - M^2$$ Hamilton-Jacobi

„quantum potential“ $$Q = \frac{\hbar}{2M}\frac{\partial^m \partial_m \sqrt{\rho}}{\sqrt{\rho}}$$



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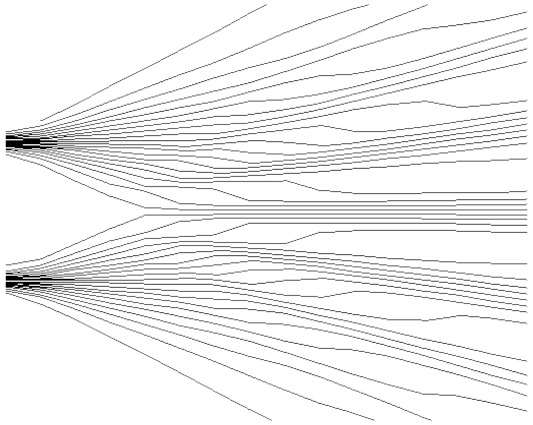

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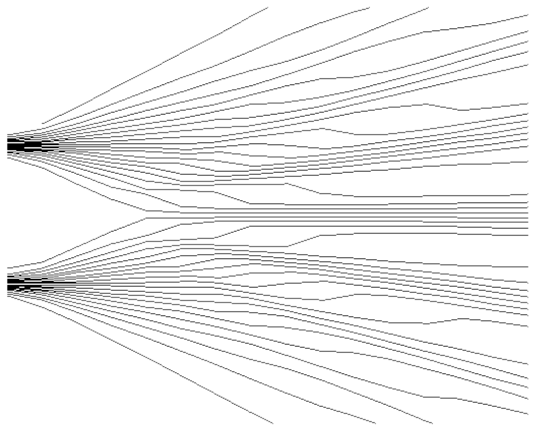
$$p^m = M\frac{dx^m}{ds} = -\partial^m S_Q$$

$$\frac{d}{ds} = \partial_m \frac{dx^m}{ds}$$



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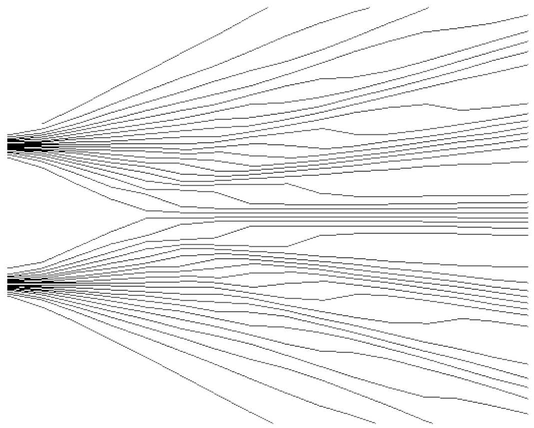
Equation of motion*:

$$M\frac{d^2x^m}{ds^2} = \partial^m Q$$

*H. Nikolic, Found. Phys. Lett. 17, 363;
*H. Nikolic, Found. Phys. Lett. 18, 123



dBB

Klein Gordon equation:

remember!

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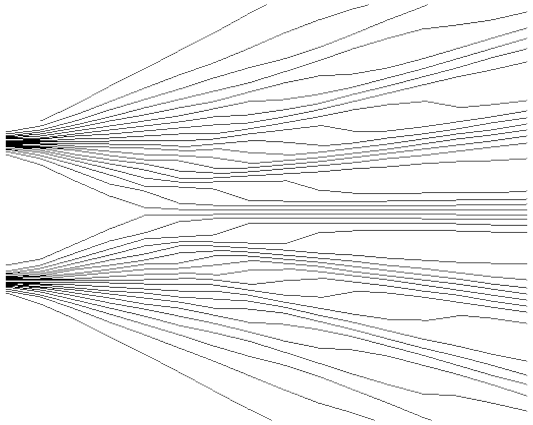

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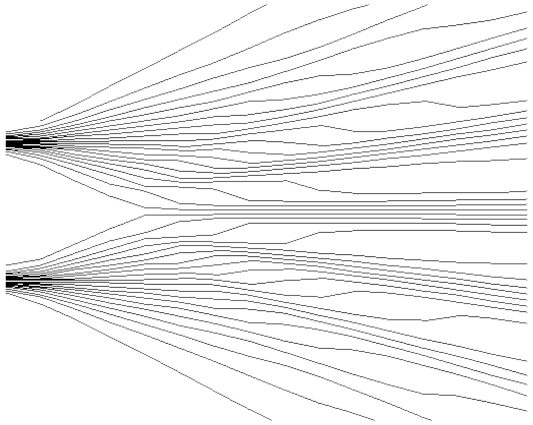

Geometrical Toy Model

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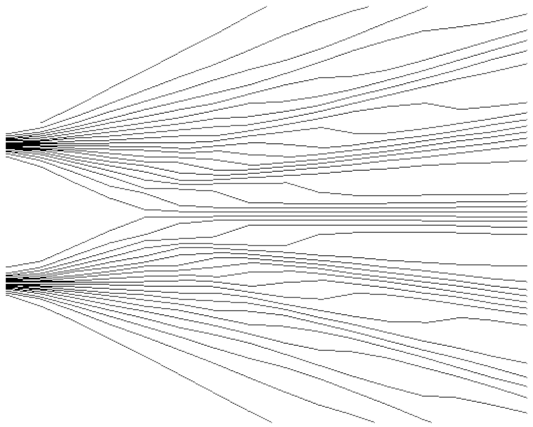

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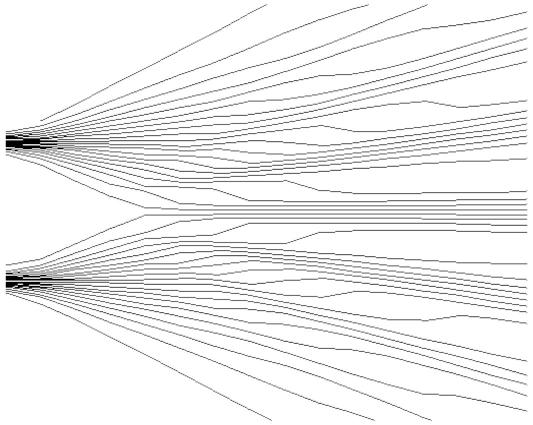
Action:

$$S = \int d^4x \sqrt{|\hat{g}|}(\hat{R} + \kappa \hat{\mathcal{L}}_M)$$

Describes matter in a curved space-time



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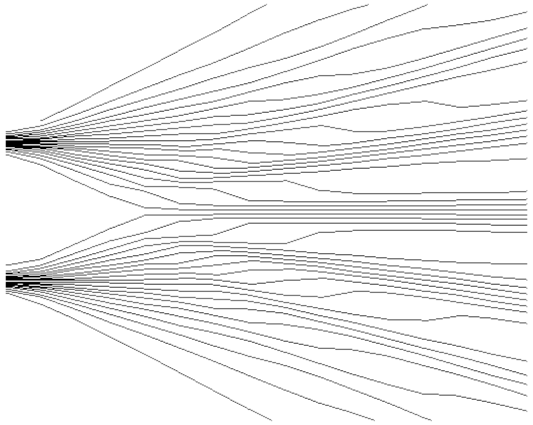
Curvature: - Metric $\hat{g}$

- Ricci scalar $\hat{R}$

Benjamin Koch



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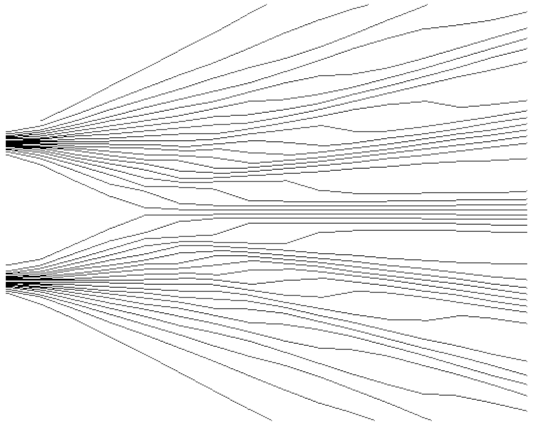
Curvature: - Metric $\hat{g}$

- Ricci scalar $\hat{R}$

Matter: - Coupling κ

- Lagrangian $\hat{\mathcal{L}}_M$



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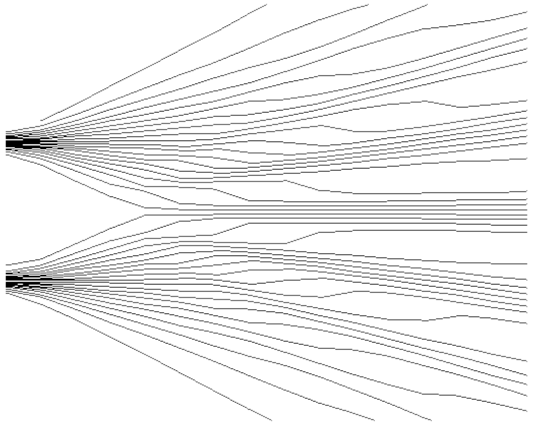

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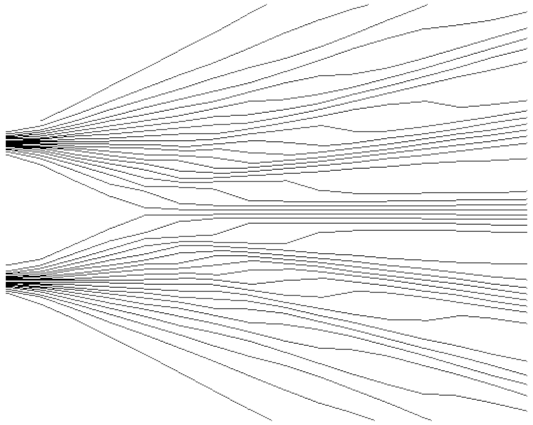
$$\hat{g}_{\mu\nu} = \phi^2\eta_{mn} \Rightarrow \quad \hat{g}^{\mu\nu} = \frac{1}{\phi^2}\eta^{mn}$$

Geometrical Toy Model



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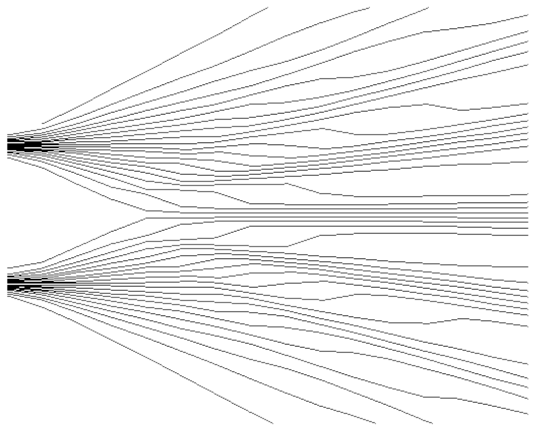
Notation, partial derivatives:

$$\partial_\mu \equiv \partial_m \quad\Rightarrow\quad \partial^\mu = \frac{1}{\phi^2(x)}\partial^m$$

Geometrical Toy Model



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Action:

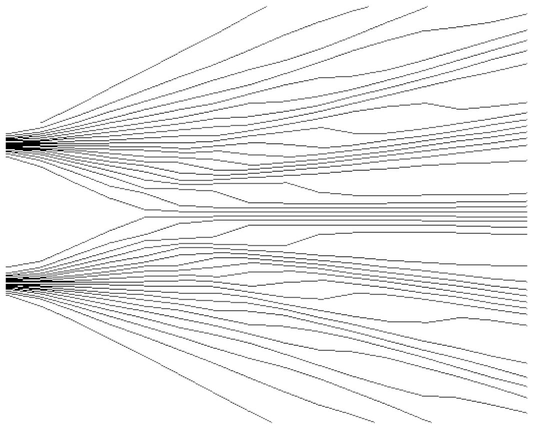
$$S = \int d^4x\sqrt{|\hat{g}|}(\hat{R} + \kappa\hat{\mathcal{L}}_M)$$

Assume conformal flatness:

$$\hat{g}_{\mu\nu} = \phi^2\eta_{mn} \Rightarrow \quad \hat{g}^{\mu\nu} = \frac{1}{\phi^2}\eta^{mn}$$

Notation, partial derivatives:

$$\partial_\mu \equiv \partial_m \quad \Rightarrow \quad \partial^\mu = \frac{1}{\phi^2(x)}\partial^m$$



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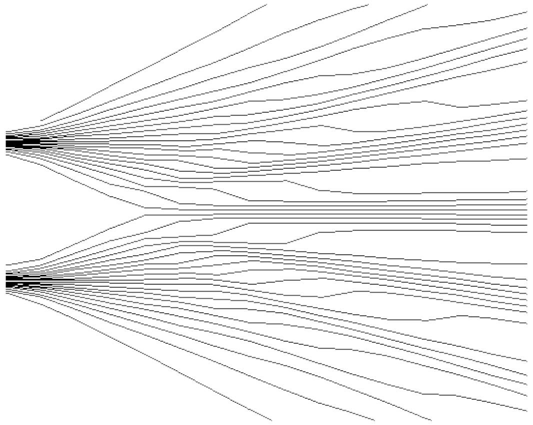

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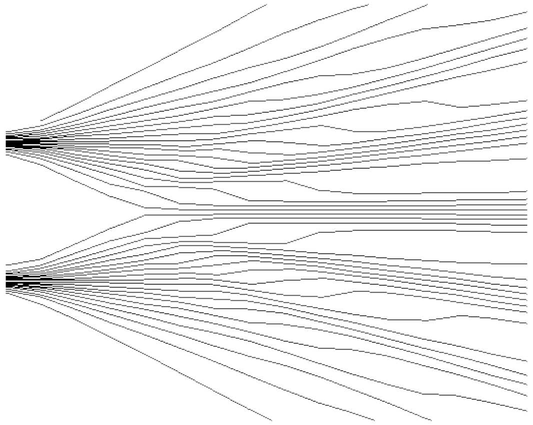

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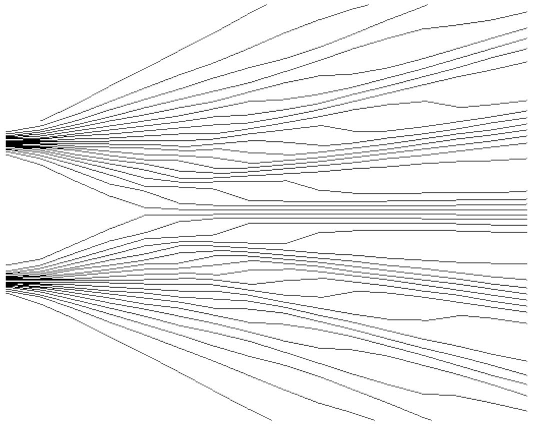

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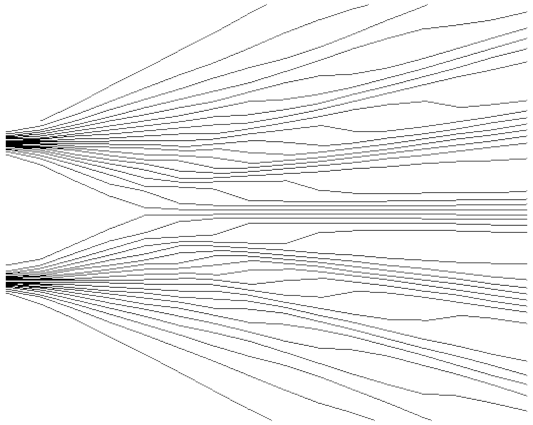

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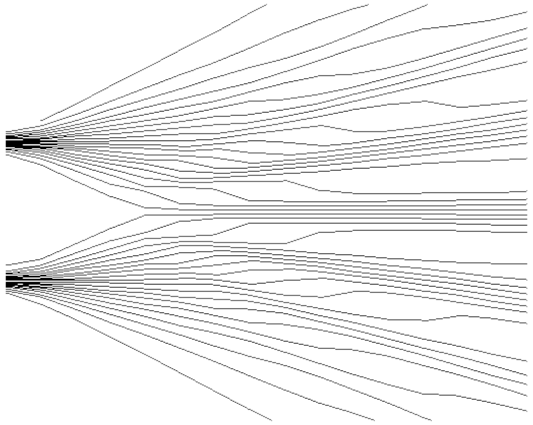

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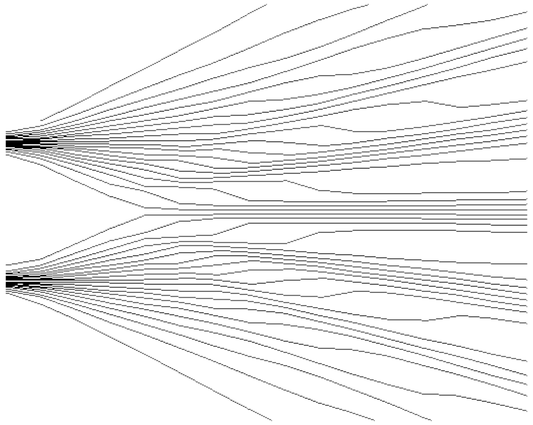

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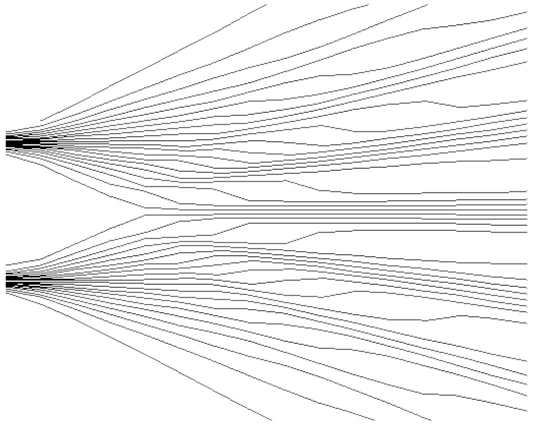

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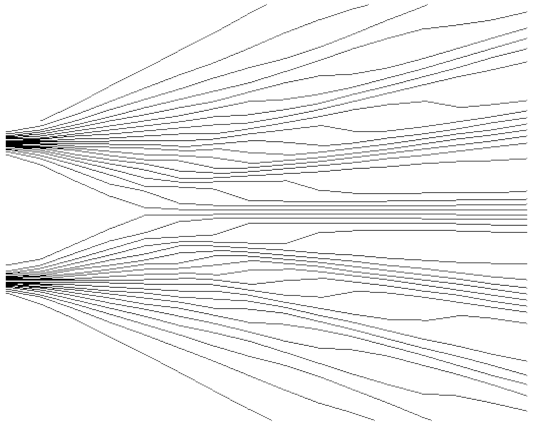

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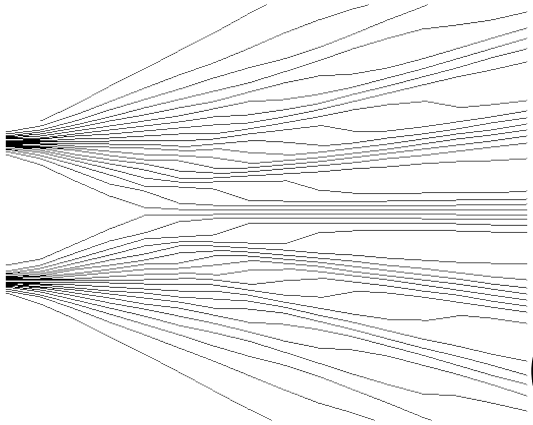
Matching dBB & Toy Model



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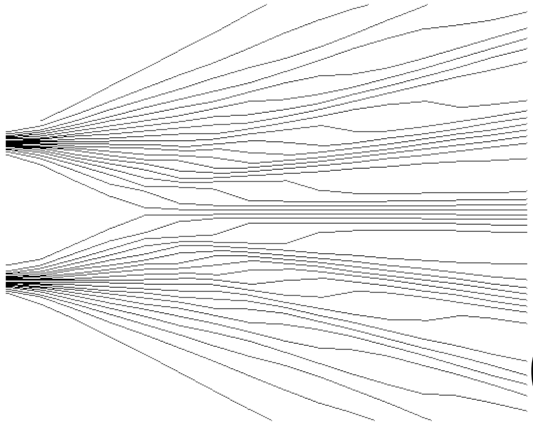

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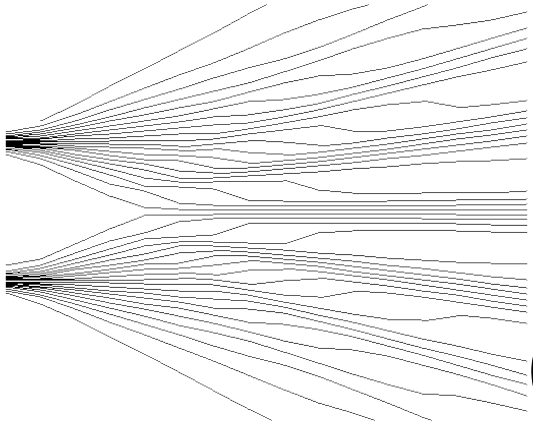

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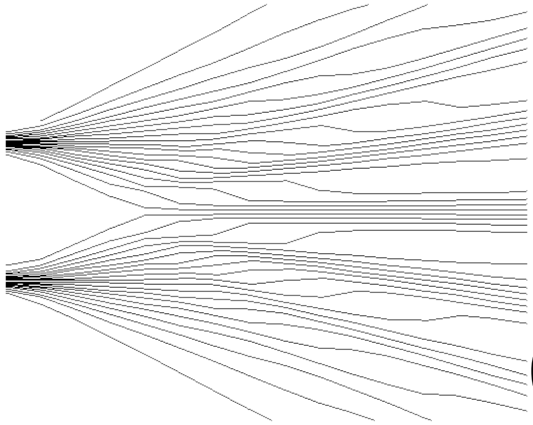

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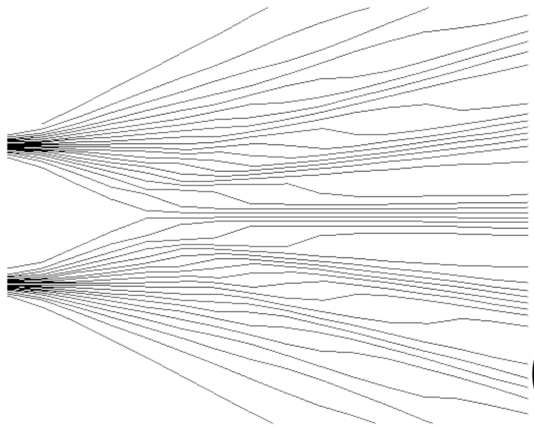
Relates Planck's quantum to negative gravitational coupling! → $\hbar^2$

Matching
dBB & Toy Model



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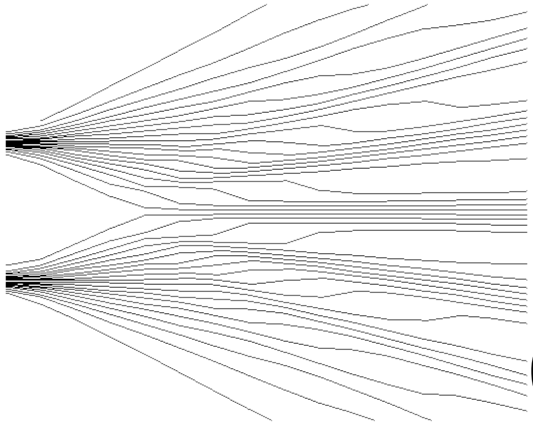

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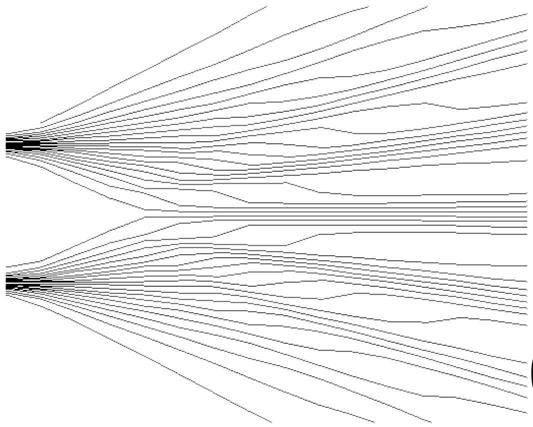

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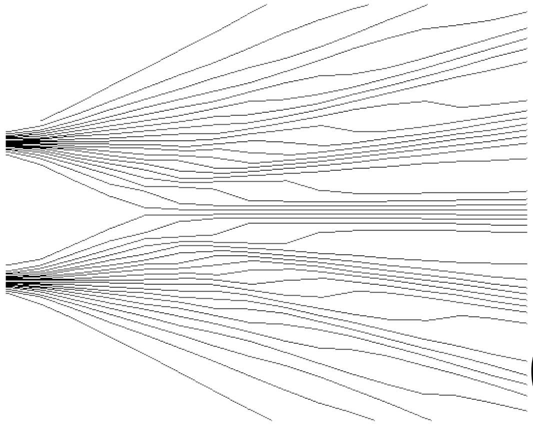

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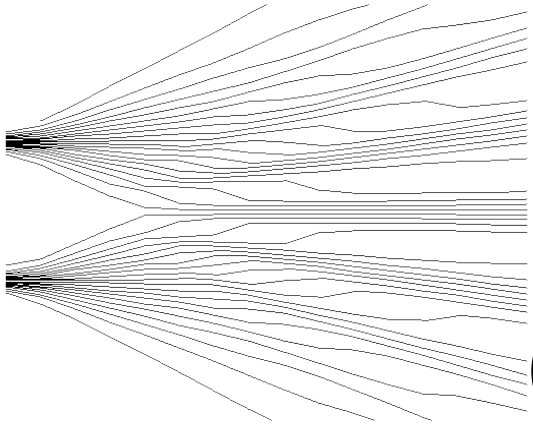

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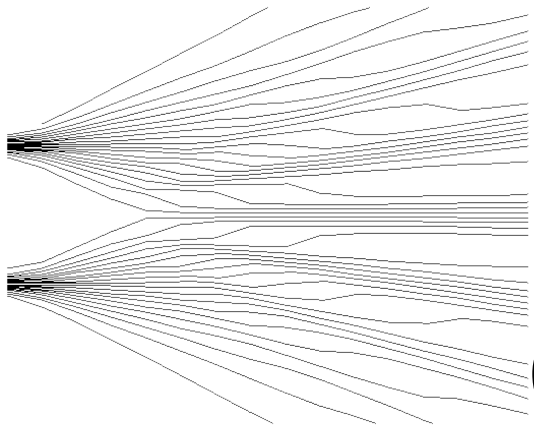

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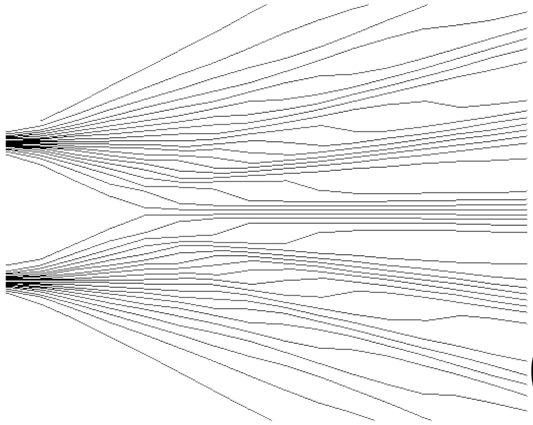
Definition of the Hamilton principal function in toy model:

$$p^m \equiv -\partial^m S_G$$

Matching dBB & Toy Model



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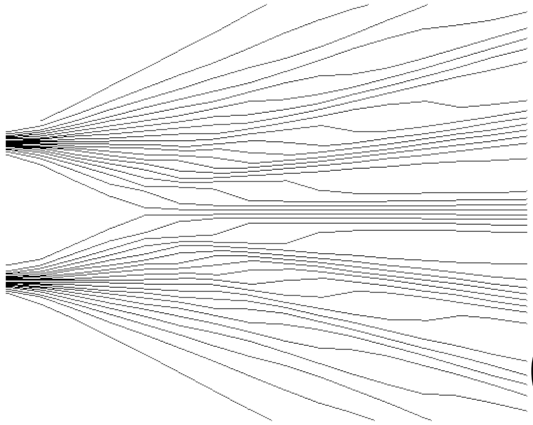

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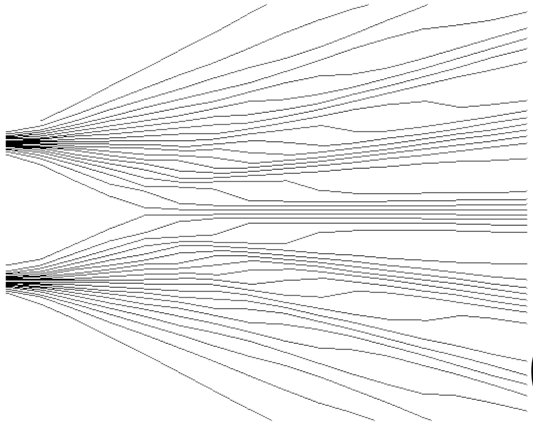

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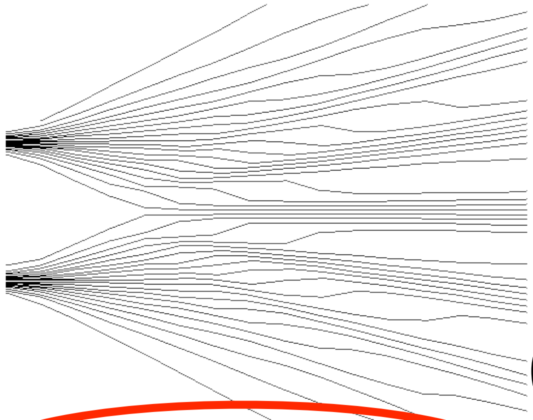

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Continuity equation:

Matching
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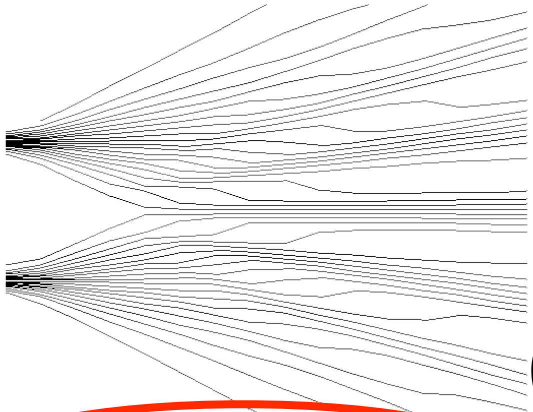

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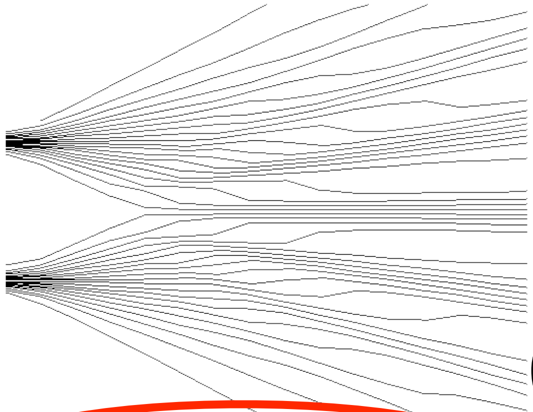
Continuity equation:

Matter Lagrangian $\hat{\mathcal{L}}_M$ induces

stress-energy tensor: $\hat{T}^{\mu\nu} = \hat{T}^{\mu\nu}(\hat{\mathcal{L}}_M)$



Matching dBB & Toy Model

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Continuity equation:

Matter Lagrangian $\hat{\mathcal{L}}_M$ induces stress-energy tensor: $\hat{T}^{\mu\nu} = \hat{T}^{\mu\nu}(\hat{\mathcal{L}}_M)$

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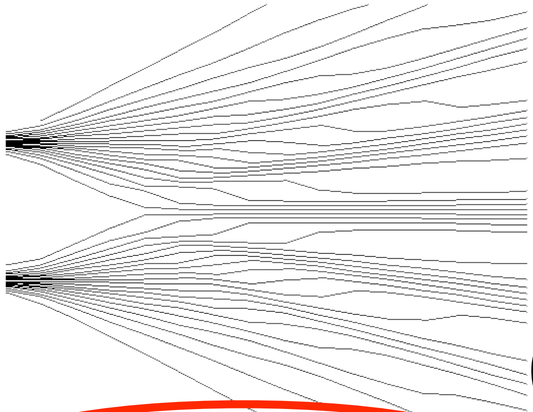

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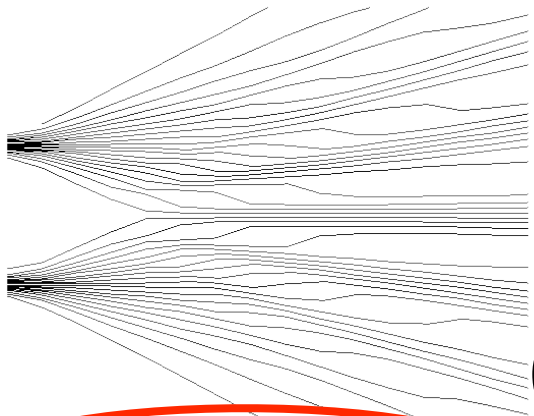

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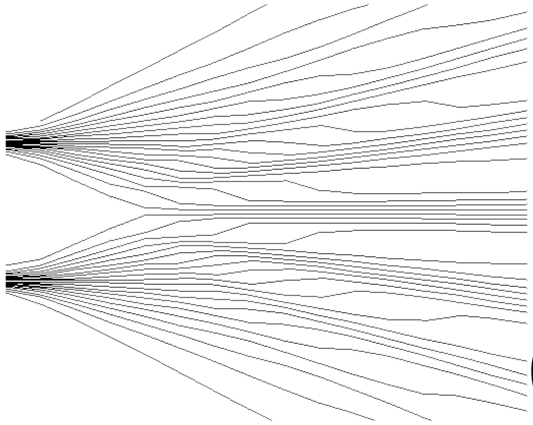

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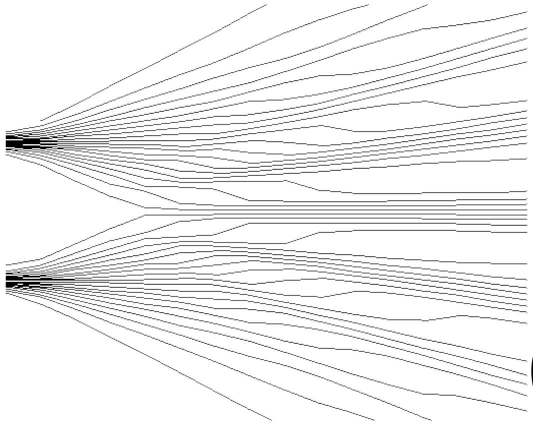

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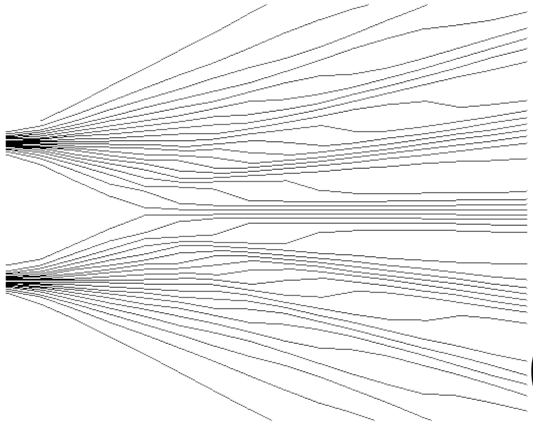

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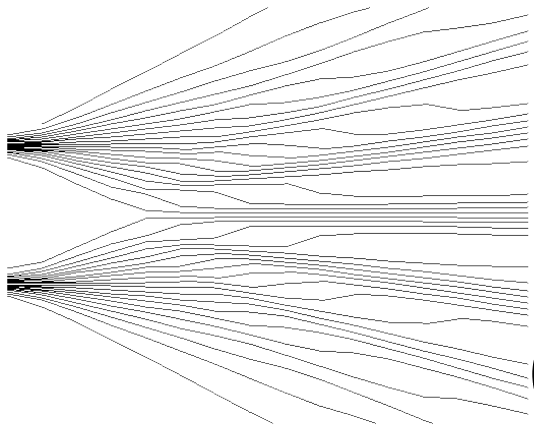
Equation of motion:

Matching dBB & Toy Model



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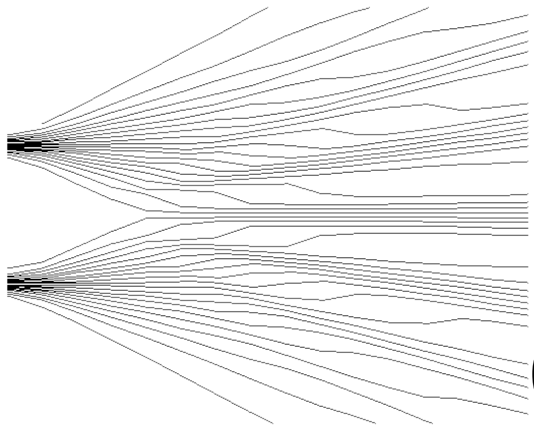

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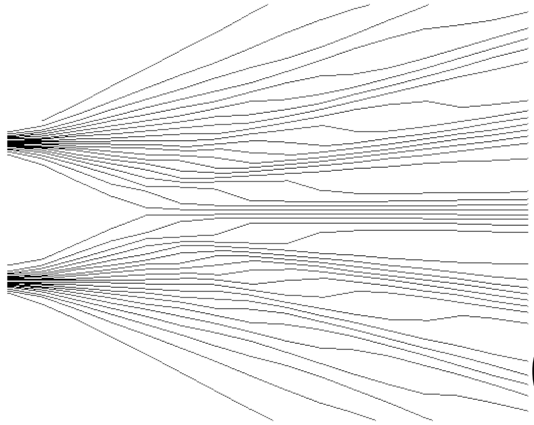

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Matching
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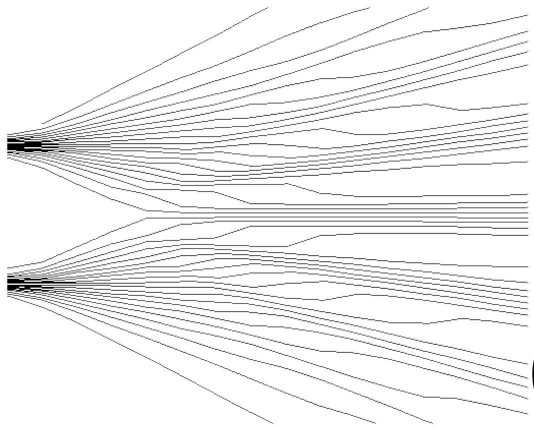

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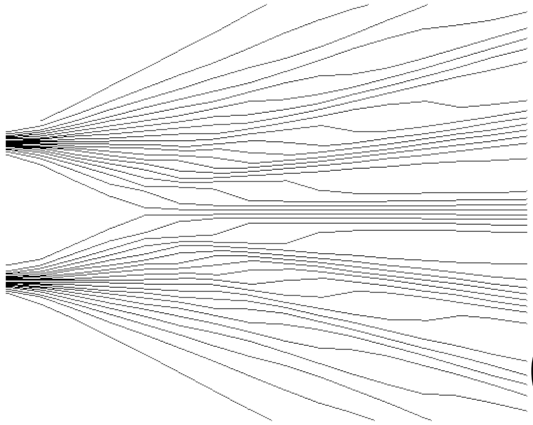

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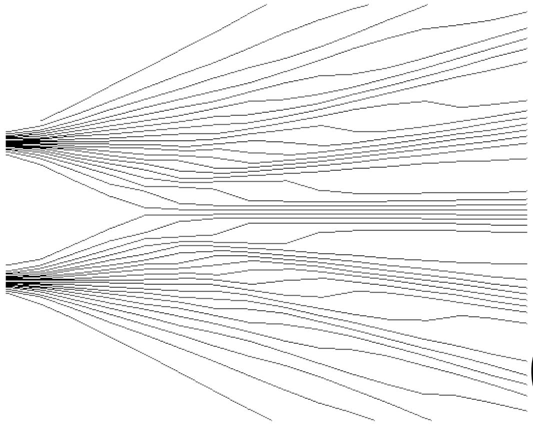

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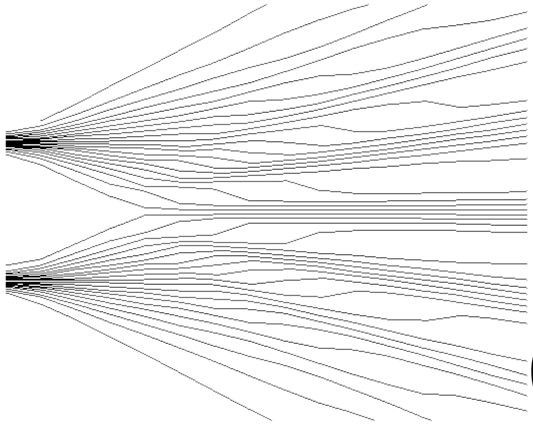

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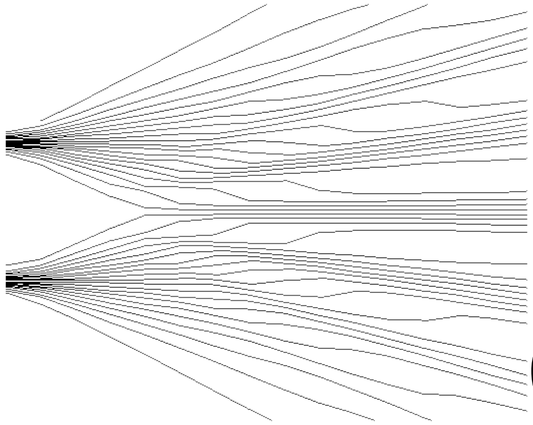

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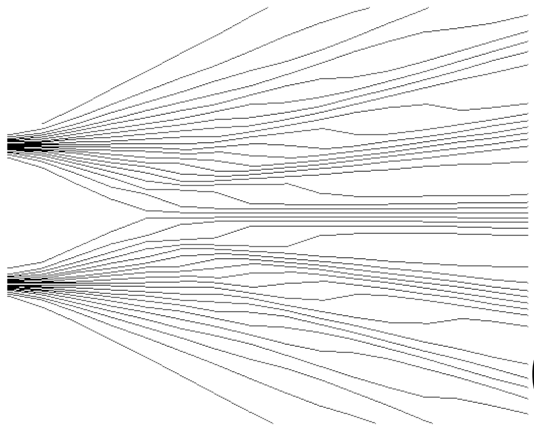

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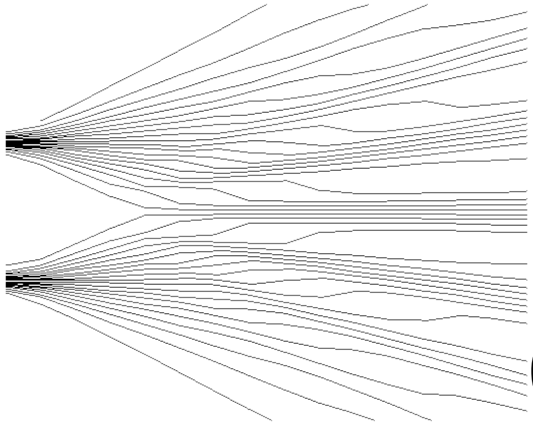

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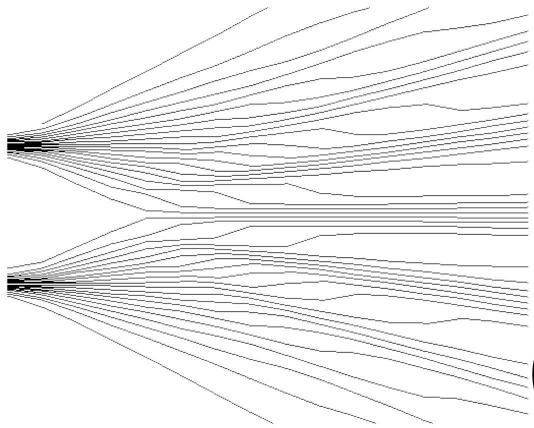

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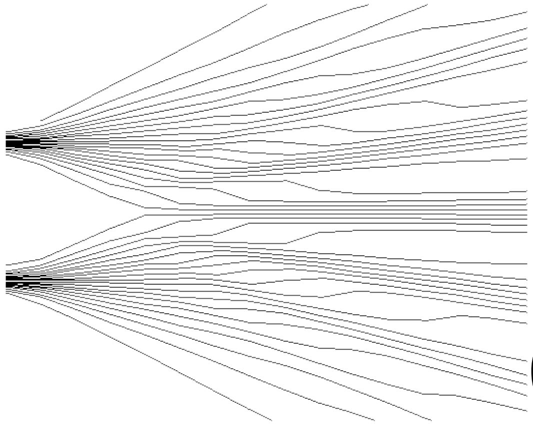

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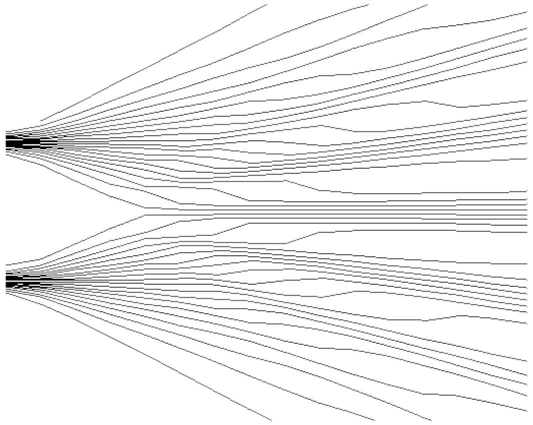
Geometrical toy model

$$\int d^4x\sqrt{\hat{g}}\hat{R} + \kappa\hat{\mathcal{L}}_M$$



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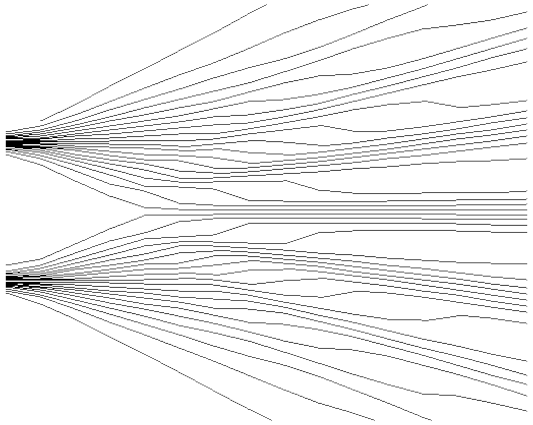

Summary & Outlook

Geometrizing the quantum works for:

- Single particle
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- Interactions with quantum field
- Fermionic dBB
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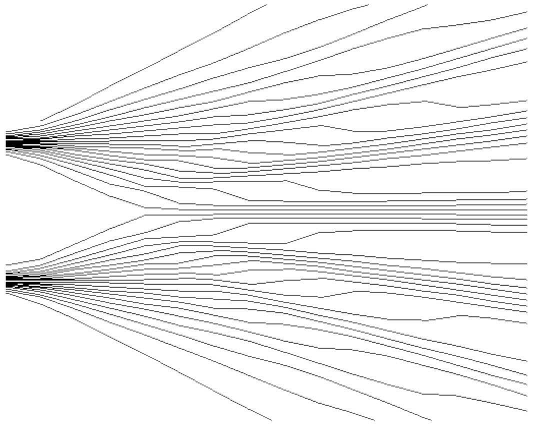
- Include gravity on geometry side ...



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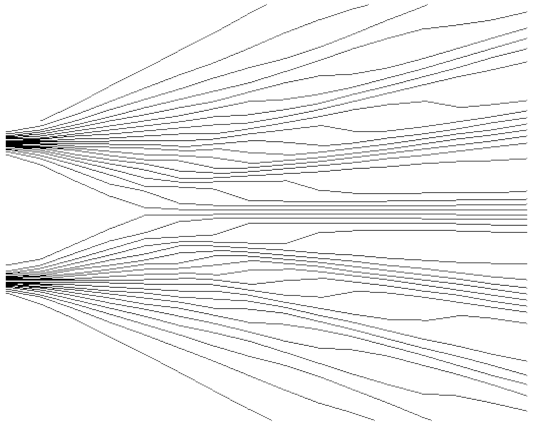

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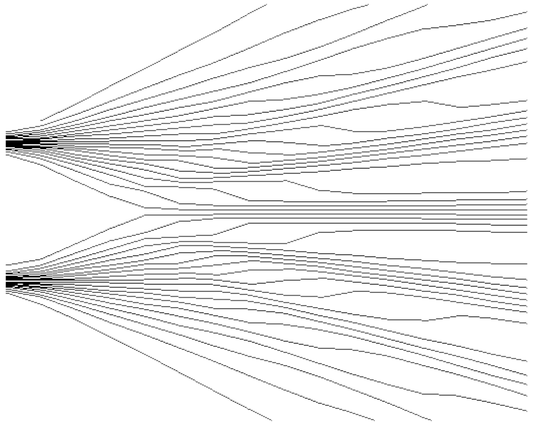

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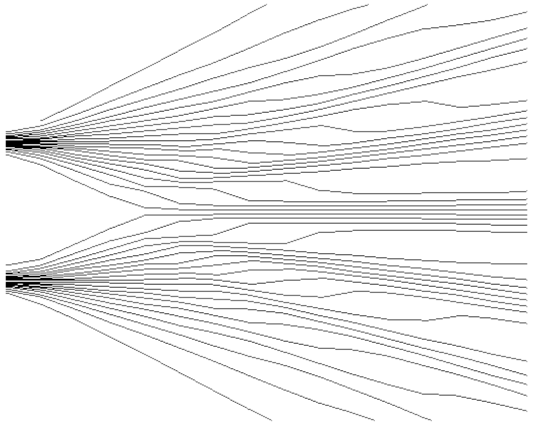

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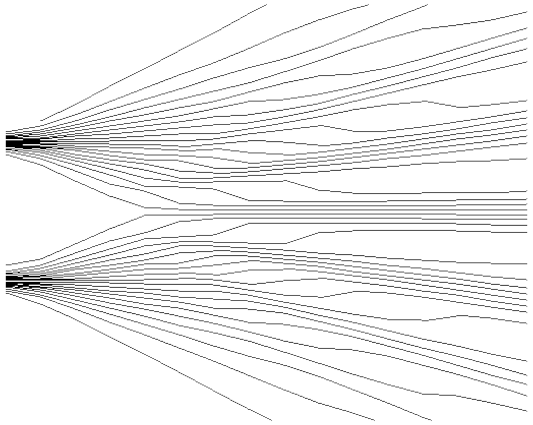

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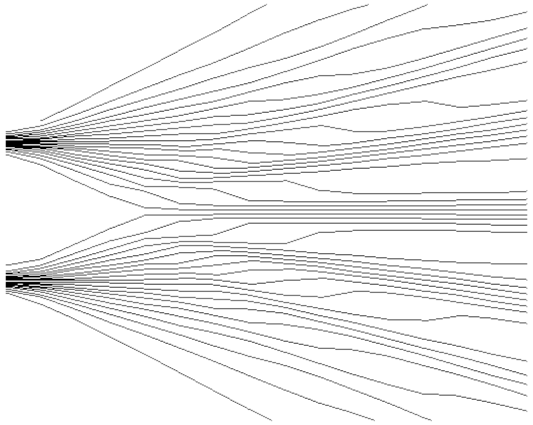

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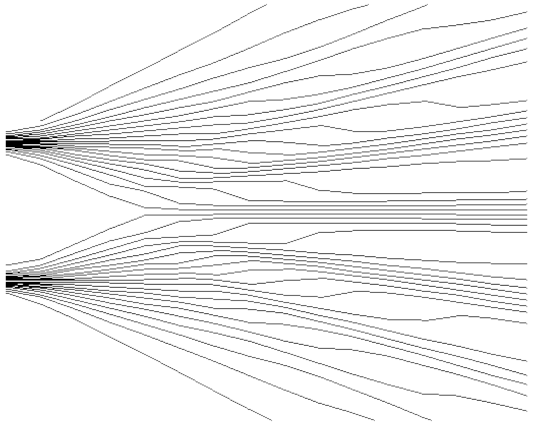
Benjamin Koch



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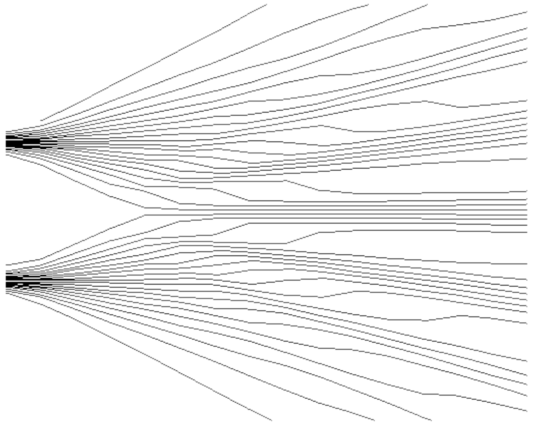
Thank you!



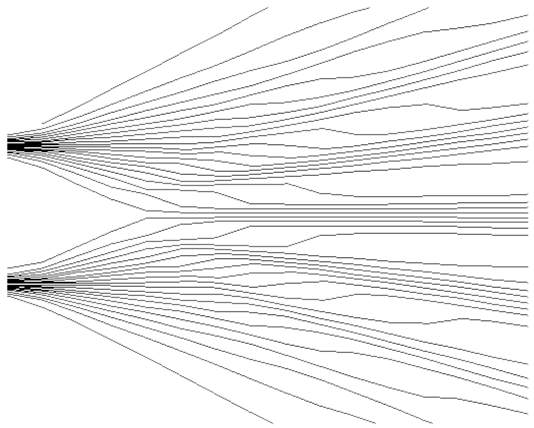
Backup

No go theorems for deterministic QM:

Bell inequalities: Do not apply because dBB is a non-local theory

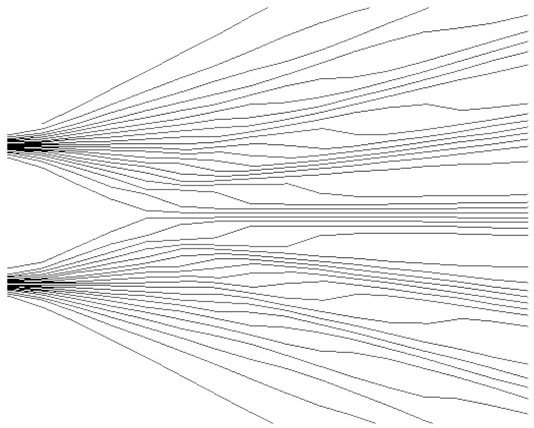
Kochen-Specker theorem:

Does not apply because dBB is a contextual theory



Motivation

Motivation QM double slit



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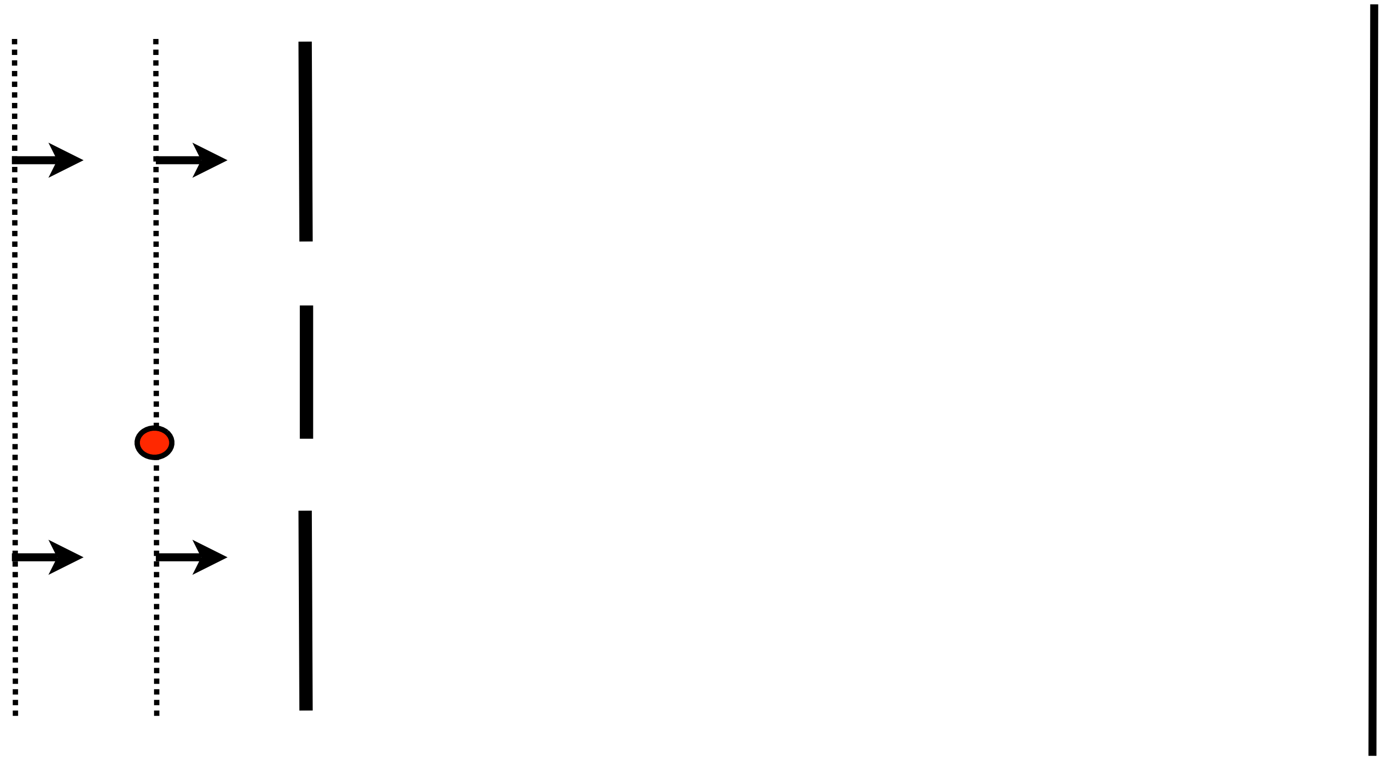


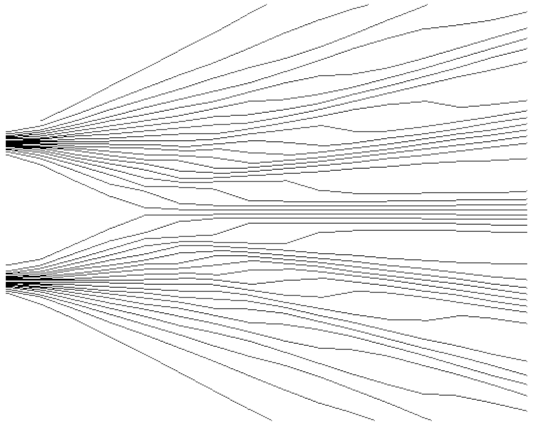
One particle in

Motivation

Motivation QM double slit

One particle in

Observe one particle



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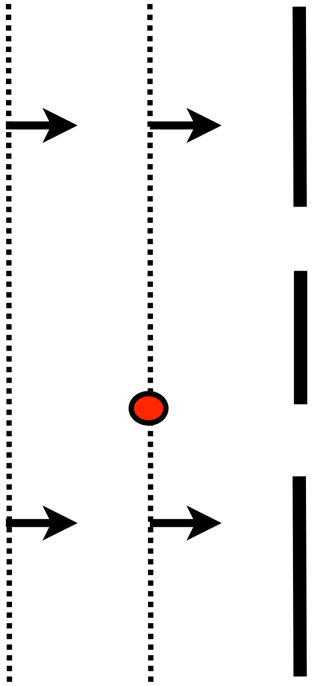
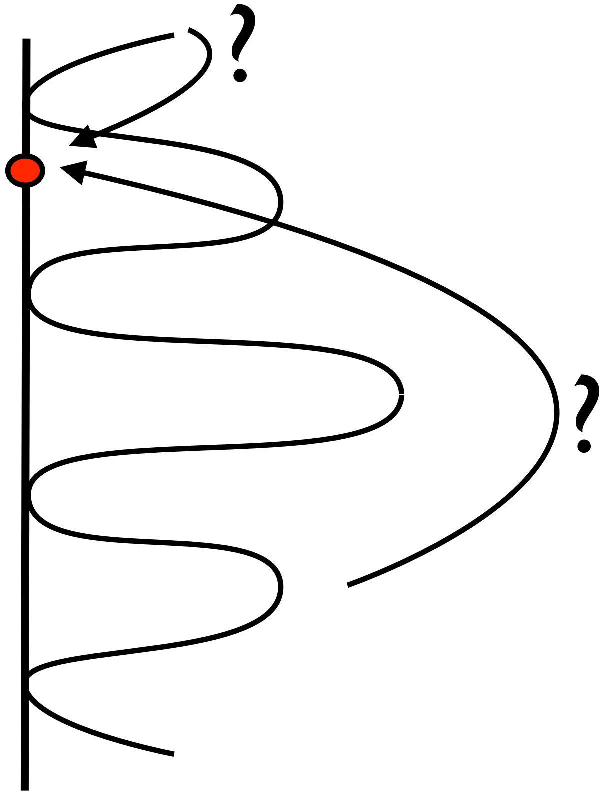


Collapse of the wave function?



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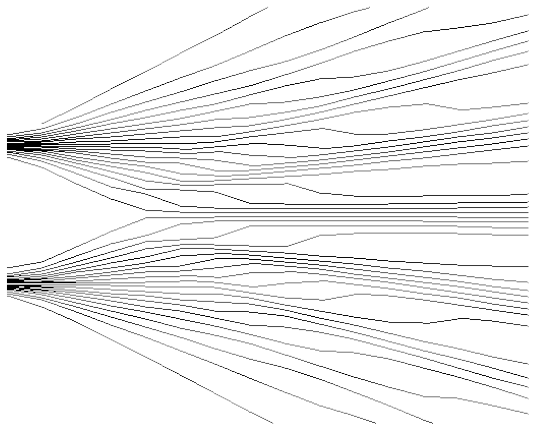

Motivation

Problem of undefined measurement process
in standard (Copenhagen) interpretation of QM

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Solution?

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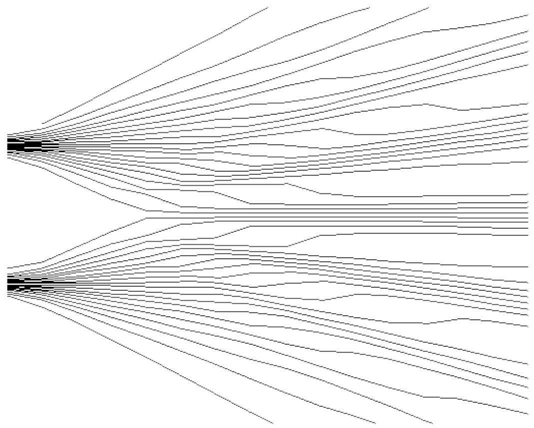
Solution?

„Shut up and calculate!“*

*David Mermin



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Alternative interpretation
- Many worlds
- dBB interpretation
- ...

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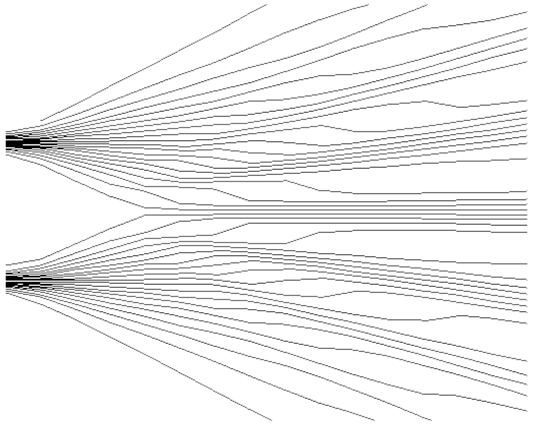

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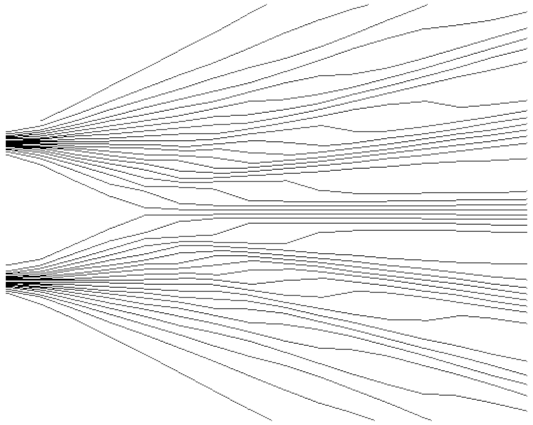


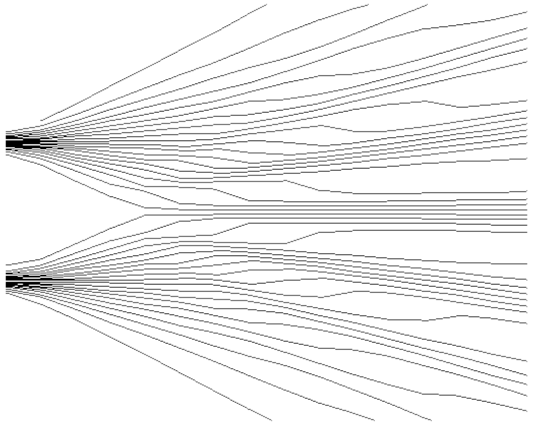
Backup

Interaction with external em-field

Klein-Gordon in dBB picture	Toy model
Minimal coupling	Canonical momentum (classical)
$\partial_m \rightarrow \partial_m + ieA_m/\hbar$	$\hat{p}^\mu \rightarrow \hat{\pi}^\mu = -(\hat{\partial}^\mu S_Q + e\hat{A}^\mu)$

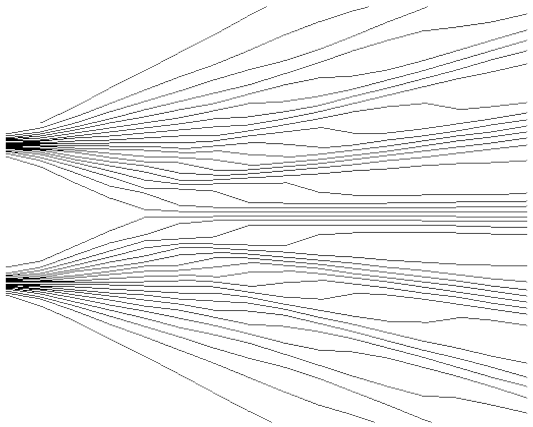
$\Downarrow$ $\Downarrow$

$$M\frac{d^2x_j^m}{ds^2} = \partial_j^m Q + e\pi_{jn}F^{mn}$$



Multi particle KG in dBB

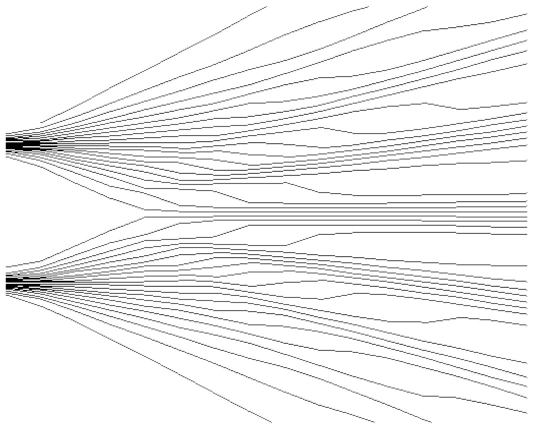
Important because:



Multi particle KG in dBB

Important because:

-The dBB theory is only consistent with QM if it includes the multi particle case.



Multi particle KG in dBB

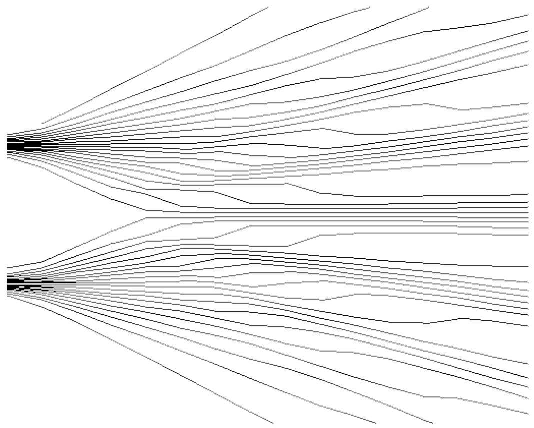
Important because:

-The dBB theory is only consistent with QM if it includes the multi particle case.

- Single particle interpretation of KG fails, multi particle description first step towards QFT

Multi particle KG in dBB

*S. Schweber, An Introduction to Relativistic QFT, Dover Publications, 1961



Multi particle KG in dBB

n-particle wave function:

$$\psi(x_1;\ldots;x_n)=\frac{\mathcal{P}_S}{\sqrt{n!}}<0|\Phi(x_1)\ldots\Phi(x_n)|n>$$

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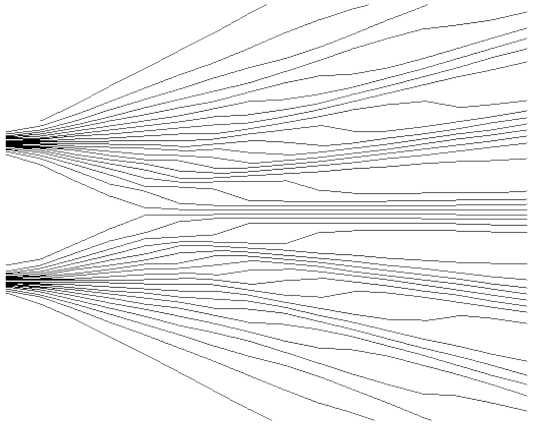

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n-particle KG equation*:

$$\left(\sum_i \partial_i^m\partial_{mi}+n\frac{M^2}{\hbar^2}\right)\psi(x_1;\ldots;x_n)=0$$

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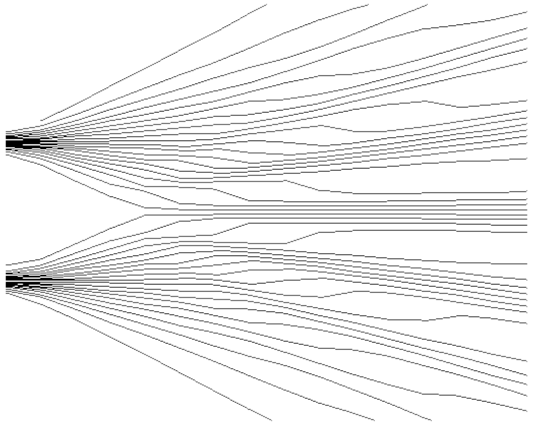

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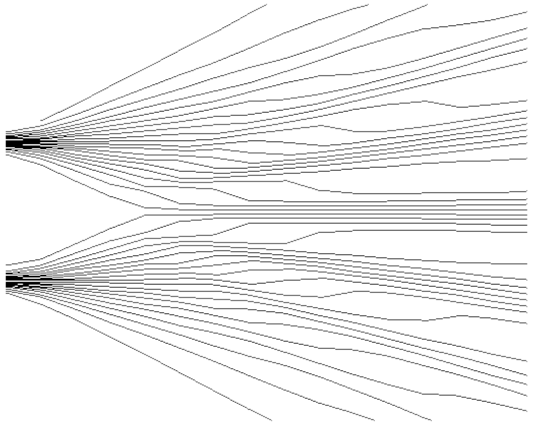

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Same splitting:

$$\psi(x_1;\ldots;x_n) = \sqrt{\rho(x_1;\ldots;x_n)}\exp(iS_Q(x_1;\ldots;x_n)/\hbar)$$

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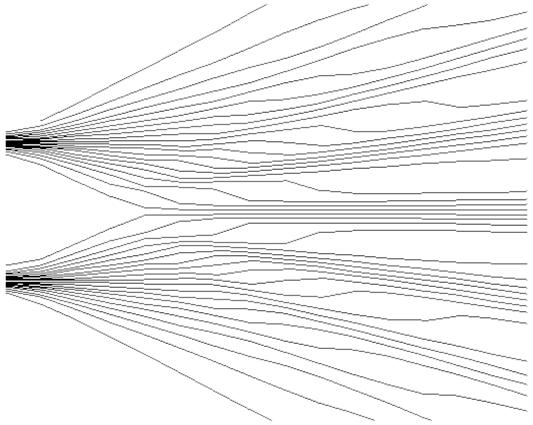

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Same momentum definition*:

$$p_j^m = -\partial_j^m S_Q(x_1;\ldots;x_n)$$

Benjamin Koch

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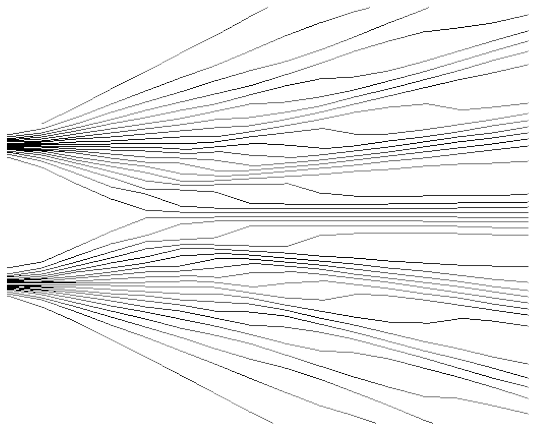

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$\Rightarrow$

$$\begin{aligned}
2MQ &= (\partial^L S)(\partial_L S) - nM^2 \quad \text{with} \\
Q &= \frac{\hbar^2}{2M}\frac{\partial^L\partial_L P}{P} \quad , \\
0 &= \partial_L\left(P^2(\partial^L S)\right) \quad , \\
p^L &= M\frac{dx^L}{ds} = -\partial^L S \quad , \\
\frac{d^2x^L}{ds^2} &= \frac{(\partial^N S)(\partial^L\partial_N S)}{M^2} \quad \text{with} \\
\frac{d}{ds} &= \frac{dx^L}{ds}\partial_L \quad .
\end{aligned}$$

Set of equations

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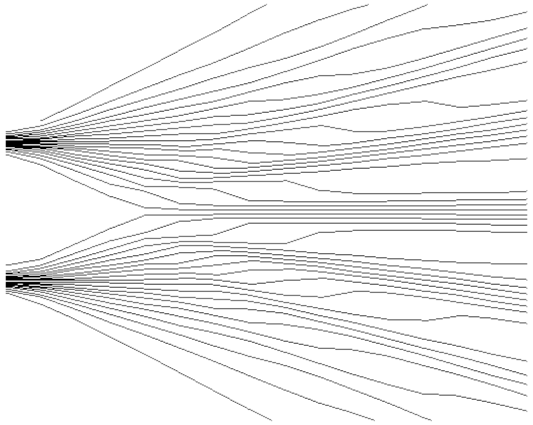
Toy model

Toy model

Action for one particle in 4n-dimensional space-time

$$S(g_{\Lambda\Delta}) = \int dx^{4n} \sqrt{\hat{g}} \{\hat{R} + \kappa \hat{\mathcal{L}}_M\}_{sym}$$



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Coordinates:

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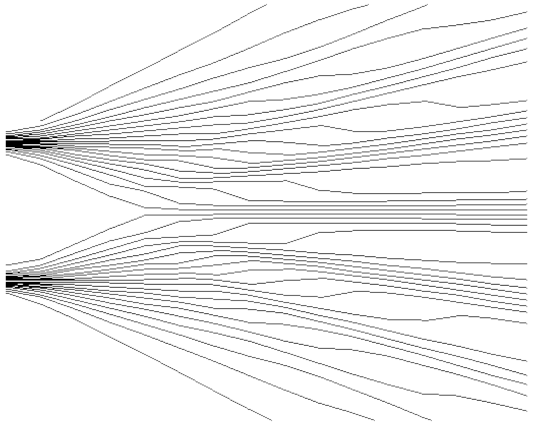

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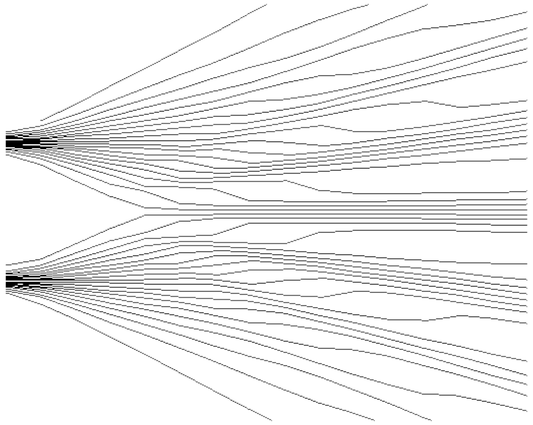

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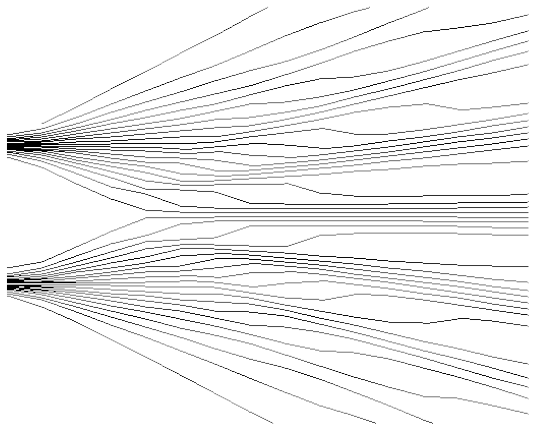
Symmetrization:

Equations of motion + conservation of $\hat{T}^{\Lambda\Delta}$



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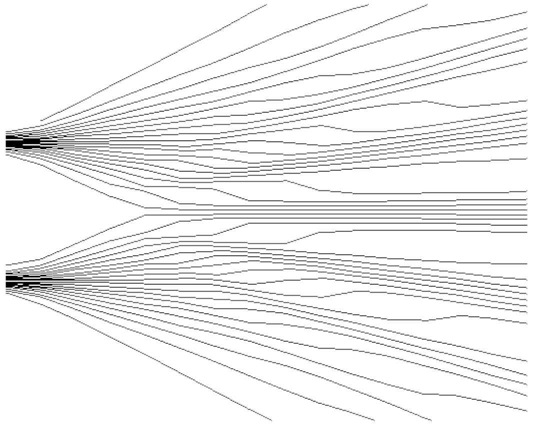
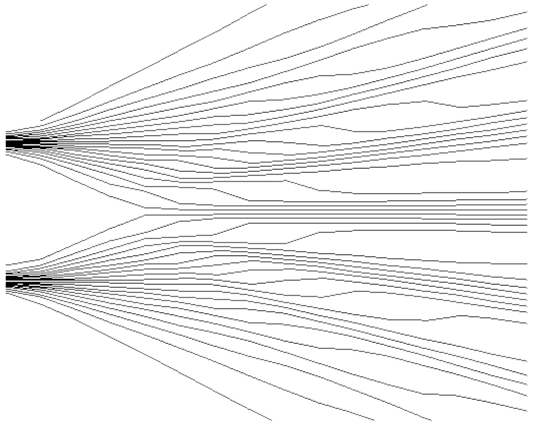


Matching multi particle dBB & Toy model

Klein-Gordon in dBB picture		Geometrical toy model
	$$\begin{aligned} \sqrt{\rho} &\equiv \phi \\ S_Q &\equiv S_G \\ \hbar^2 &\equiv \frac{2(4n-1)}{1-2n}/\kappa \\ M &\equiv M_G \end{aligned}$$	



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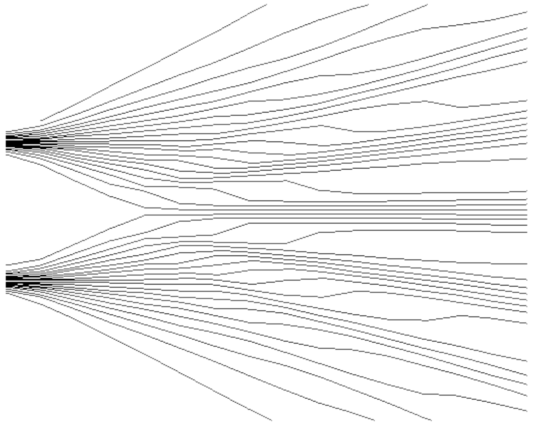
quantum phase	$S_Q \quad \equiv \quad S_G$	H-principal function
	$\hbar^2 \quad \equiv \quad \frac{2(4n-1)}{1-2n}/\kappa$	
mass	$M \quad \equiv \quad M_G$	mass



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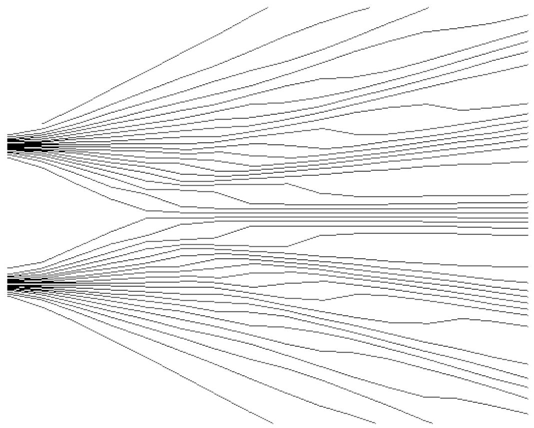

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„Running" coupling of the geometrical toy model