The shape of a more fundamental theory?

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Abstract
I suggest a minimal practical formal structure for a more fundamental theory than the Standard Model + GR and review a mechanism that produces such a structure. The proposed mechanism has possibilities of producing non-canonical phenomena in SU(2) and SU(3) gauge theories which might allow conditional predictions that can be tested.

These slides and other writings are posted on my web page
http://www.physics.rutgers.edu/~friedan/#Perimeter

During my visit to PI, I hope also to discuss informally a separate project in pure QFT, a scheme to construct a new kind of QFT of extended objects (also described on my web page).
For the last 45 years, our most fundamental theory has been the Standard Model + General Relativity.

SM+GR is an effective QFT with UV cutoff $\approx (10^3 \text{GeV})^{-1}$.

GR can be considered an effective QFT because quantum corrections in GR are completely negligible at this huge distance $(10^3 \text{GeV})^{-1} = 10^{16} \ell_P$.

SM+GR describes almost all physics at distances $> (10^3 \text{GeV})^{-1}$.

Only dark matter, neutrino mixing, and some CP violation are unexplained.
I am interested in the possibility of formal fundamental physics:

1. hypothesize a “more fundamental” formal machinery that can “produce” the Standard Model + General Relativity

2. predict consequences beyond the SM+GR that can be checked experimentally

Some prototypes of formal fundamental physics:

- GR from Newtonian Gravity + Special Relativity
- Grand Unification from the SM

Note: the testable prediction of Grand Unification is *conditional*. The RG acting on the space of grand unified theories can produce the SM. *If* the RG does produce the SM, then it also predicts proton decay (which unfortunately has not been seen).
In the 45 years since the SM was finished, no attempt at formal fundamental physics has worked.

One natural response is to give up, at least for now, perhaps hoping that experiment will eventually give more guidance.

Alternatively, one might reconsider the assumptions that have guided the enterprise.

An analogy: hiking up a mountain without a map or a GPS. If after 45 years no measurable altitude has been gained, maybe it is time to backtrack and reconsider previous choices of direction.

We might especially question the truisms and mathematical idealizations that have governed the enterprise.
Truism: Quantum Gravity is needed

On the contrary,

1. The smallest distance presently accessible to experiment is $L_{\text{exp}} \approx (10^3 \text{GeV})^{-1} = 10^{16} \ell_P$ so it is implausible that any proposed Quantum Gravity can be checked experimentally.

2. It is a presumptuous extrapolation to assume that Quantum Mechanics is valid over 16 orders of magnitude in distance below where there is evidence.
A leading edge experiment has size $L$ and probes distances $< L$.

QFT describes the preparation of initial scattering states and the detection of final scattering states at scale $L$.

Scattering amplitudes describe physics at distances $< L$.

An effective QFT is the minimal formalism at distances $> L$, where an effective QFT is a QFT with UV cutoff $L$.

An effective S-matrix is the minimal formalism at distances $< L$, where an effective S-matrix is an S-matrix with IR cutoff $L$.

$L$ is a sliding scale. What we mean by “short distance physics” is relative. $L$ is pushed smaller and smaller as physics progresses.
A minimal practical formalism:

<table>
<thead>
<tr>
<th>distance in $\ell_P$</th>
<th>$10^1$</th>
<th>$10^4$</th>
<th>$10^7$</th>
<th>$10^{10}$</th>
<th>$10^{13}$</th>
<th>$10^{16}$</th>
<th>$10^{19}$</th>
<th>$10^{22}$</th>
<th>$10^{25}$</th>
<th>$\cdots$</th>
</tr>
</thead>
</table>

For every $L \gg 1$ there is

- \( \text{QFT}(L) = \) an effective QFT with UV cutoff $L$ describing all physics at distances $> L$, and

- \( \text{S-matrix}(L) = \) an effective S-matrix with IR cutoff $L$ describing physics at distances $< L$,

such that \( \text{QFT}(L) \) and \( \text{S-matrix}(L) \) agree at distances $\approx L$. 
And they must satisfy consistency conditions for $L' < L$,

$$
\begin{array}{c}
L' \\
\downarrow \\
\text{QFT}(L) \\
\downarrow \\
L \\
\end{array}
\quad \quad
\begin{array}{c}
\text{QFT}(L') \\
\end{array}
$$

\[ \text{QFT}(L') \supset \text{QFT}(L) \quad \text{(i.e., via the RG from } L' \text{ to } L) \]

\[ \text{S-matrix}(L) \supset \text{S-matrix}(L') \quad \text{(via the “S-matrix RG”)} \]
There is no assumption of Quantum Mechanics (QFT) all the way down. For short distance physics, there is only an S-matrix($L$). We can send things in and measure what comes out. There is no mechanical model of short distance physics.

Now a *mechanism* is needed that will *produce* this formal structure.
I came to these ideas during the period 1977 – 2002 in the process of formulating such a mechanism.

The mechanism is a certain mathematically natural 2d nonlinear model (2d-NLM), called the \( \lambda \text{-model} \), whose target manifold is the space of classical space-time fields describing the classical string background.

At every \( L \gg 1 \), the \( \lambda \)-model produces the quantum string background:

- an effective QFT(\(L\)) in the form of a functional measure on the manifold of space-time fields with UV cutoff \(L\)

- an effective 2d-QFT of the string worldsheet, giving an effective string S-matrix(\(L\)) with IR cutoff \(L\).
I suggest exploring the $\lambda$-model because

1. It produces consistent realizations of the formal structure described above: $\text{QFT}(L) + \text{S-matrix}(L)$ for $L \gg 1$.

2. The mechanism for producing QFT does not necessarily correspond to canonical quantization.

There are concrete possibilities that 2d effects in the $\lambda$-model will produce non-canonical degrees of freedom and interactions in the effective $\text{QFT}(L)$ providing testable conditional predictions.
The 2d-RG as a mechanism for space-time physics (1977–79)

In the general renormalizable 2d-NLM

\[
\int \mathcal{D}X \ e^{- \int d^2 z \ g_{\mu \nu}(X) \partial X^\mu \bar{\partial} X^\nu} \quad X(z, \bar{z}) \in M
\]

the coupling constants are given by a Riemannian metric \( g_{\mu \nu}(X) \) on the target manifold \( M \).

The 2d-RG

\[
\Lambda \frac{\partial}{\partial \Lambda} g_{\mu \nu}(X) = - R_{\mu \nu}(X) + O(R^2)
\]

drives the 2d-NLM to a solution of \( R_{\mu \nu} = 0 \)
This was very exciting.

The 2d-RG became a \textit{mechanism} that \textit{produces} solutions of a GR-like space-time field equation.

It suggested the possibility of actually answering the question

\begin{quote}
\textit{Where does space-time field theory come from?}
\end{quote}

or even

\begin{quote}
\textit{Where do the laws of physics come from?}
\end{quote}

with a quite unexpected mechanism, the 2d-RG.
The 2d-RG incorporated into string theory (1981–85)

- 2d scale invariance = the 2d-RG fixed point equation \( \beta = 0 \) as consistency condition for the string S-matrix recipe

- A string background = a 2d-NLM of the worldsheet with degrees of freedom \( X^\mu(z, \bar{z}) \) etc. such that the 2d coupling constants are the space-time metric \( g_{\mu\nu}(X) \) plus non-abelian gauge fields, scalar fields, fermion fields, etc.

- The \( \beta = 0 \) equation of this 2d-NLM (generalizing \( R_{\mu\nu} = 0 \)) is a semi-realistic classical field equation which includes GR and potentially the SM

- The string S-matrix at low momentum agrees with the S-matrix of the perturbative canonical quantization of the classical field equation \( \beta = 0 \).
Questions (1987)

1. $\beta = 0$ is a only consistency condition for the string recipe. How does the 2d-RG act in string theory as a mechanism?

2. Where does quantum field theory come from?
   What produces a functional integral over space-time fields?

3. What is the quantum string background?
   It should be given by a quantum state of a QFT, as opposed to the classical string background given by a classical field solving $R_{\mu\nu} = 0$.

4. What produces an effective string S-matrix with IR cutoff in effective quantum background described by an effective QFT with UV cutoff?
These questions led in a direction that deviated from the mainstream of string theory, rejecting several truisms about string theory that were being cemented in the mid-1980s:

1. The asymptotic string S-matrix is a “theory of everything”.

2. The string backgrounds are the solutions of \( \beta = 0 \), the Calabi-Yau manifolds \( (R_{\mu\nu} = 0) \) and generalizations.

3. The low momentum physics of string theory is the QFT that happens to have the same low momentum scattering amplitudes as the string S-matrix.
The \( \lambda \)-model (1988-2002)

Consider a 2d-NLM of the string worldsheet, writing

\begin{align*}
\lambda^i &= \text{the 2d coupling constants} \\
\phi_i(z, \bar{z}) &= \text{the 2d scaling fields} \\
|\phi_i\rangle &= \text{the states on the circle}
\end{align*}

Each \( \phi_i \) corresponds to a mode of the space-time fields, e.g.,

\[
\phi_i(z, \bar{z}) = e^{ip(i)_\mu X^\mu} h^{(i)}_{\mu\nu} \partial X^\mu \bar{\partial} X^\nu \quad i \leftrightarrow p(i), \ h^{(i)}_{\mu\nu}
\]

The 2d-scaling-dimensions are

\[
\dim(\phi_i) = 2 + \delta(i) \quad \dim(\lambda^i) = -\delta(i)
\]

with

\[
\delta(i) = p(i)^2
\]
Inserting the perturbations

\[ e^\int d^2 z \, \lambda^i \phi_i(z, \bar{z}) \]

makes the coupling constants \( \lambda^i \) a system of local coordinates on the space of nearby 2d-QFTs.

The marginal couplings, \( \delta(i) = 0 \), parametrize the \( \beta = 0 \) submanifold of the 2d-QFTs.
Let \((ds)^2 = \mu^2 |dz|^2\) be the 2d metric.

Let \(\Lambda^{-1} \ll \mu^{-1}\) be a 2d UV cutoff.

The cutoff string propagator (the cutoff 2d-cylinder) is

\[
\sum_i |\phi_i\rangle \frac{1 - \left(\frac{\Lambda}{\mu}\right)^{-\delta(i)}}{\delta(i)} \langle \phi_i |
\]

Only the modes with \(\left(\frac{\Lambda}{\mu}\right)^{-\delta(i)} < 1\) propagate. Defining

\[
L^2 = \ln \left(\frac{\Lambda}{\mu}\right) \left(\frac{\Lambda}{\mu}\right)^{-\delta(i)} = e^{-L^2 \delta(i)} = e^{-L^2 p(i)^2}
\]

so the condition for propagation is

\[
\delta(i) > L^{-2} \quad \text{which is} \quad p(i)^2 > L^{-2}
\]

So a 2d UV cutoff \(\Lambda^{-1}\) is an IR cutoff \(L\) on the string S-matrix.
An effective 2d-QFT with 2d UV cutoff $\Lambda^{-1}$ gives an effective string S-matrix ($L$).

What are the effective 2d coupling constants at scale $\Lambda^{-1}$?

The effect of a perturbation $\int \lambda_i^i \phi_i$ at 2d scale $\Lambda^{-1}$ is suppressed by the 2d-RG running from $\Lambda^{-1}$ to $\mu^{-1}$

$$\lambda^i = \left( \frac{\Lambda}{\mu} \right)^{-\delta(i)} \lambda_i^i \quad \text{dim}(\lambda^i) = -\delta(i)$$

If $\left( \frac{\Lambda}{\mu} \right)^{-\delta(i)} \ll 1$ then $\lambda^i$ is effectively irrelevant. The effectively marginal couplings are those satisfying $\left( \frac{\Lambda}{\mu} \right)^{-\delta(i)} \approx 1$, which is

$$\delta(i) < L^{-2} \quad \delta(i) = p(i)^2$$

Thus the 2d UV cutoff $\Lambda^{-1}$ acts as a UV cutoff $L$ on the space-time fields describing the effective 2d-QFT, which is the classical string background.
Now let the $\lambda^i$ vary on the worldsheet, becoming sources $\lambda^i(z, \bar{z})$.

Make the $\lambda^i(z, \bar{z})$ fluctuate at 2d distances $< \Lambda^{-1}$, governed by the 2d-NLM

$$
\int \mathcal{D}\lambda \ e^{-\int d^2z \ g_{\text{str}}^{-2} G_{ij}(\lambda) \partial \lambda^i \bar{\partial} \lambda^j} \ e^{\int d^2z \ \lambda^i(z, \bar{z}) \phi_i(z, \bar{z})}
$$

where

- $G_{ij}(\lambda) =$ the natural metric on the manifold of 2d-QFTs
- $g_{\text{str}} =$ the string coupling constant
- $\lambda^i(z, \bar{z}) \in \mathcal{M} =$ the target space
  - = the manifold of classical string backgrounds
  - = the manifold of worldsheet 2d-QFTs
  - = the manifold of classical space-time fields.

This 2d-NLM is the $\lambda$-model.
on the 2d distance scale:

\[
\begin{array}{c}
\lambda\text{-model} \\
0 \quad \Lambda^{-1} \quad \text{effective 2d-QFT} \\
\end{array}
\]

\[L^2 = \ln \left( \frac{\Lambda}{\mu} \right) \gg 1\]

The \(\lambda\)-fluctuations at 2d distances \(< \Lambda^{-1}\) produce an effective 2d-QFT with UV cutoff \(\Lambda^{-1}\).

This effective 2d-QFT in turn gives an effective string S-matrix \((L)\) with IR cutoff \(L\).
The $\lambda$-model is designed precisely to implement the “S-matrix RG”. (The basic calculation is in the Appendix.)

Roughly:
The $\lambda$-fluctuations are designed precisely to replicate the froth of small handles.

Integrating out the $\lambda$-fluctuations between 2d scales

$$\Lambda'^{-1} < \Lambda^{-1} \quad \text{(so } L' > L)$$

takes the effective S-matrix($L'$) with larger IR cutoff $L'$ to the effective S-matrix($L$) with smaller IR cutoff $L$

$$\text{S-matrix}(L') \supset \text{S-matrix}(L)$$

by, in effect, integrating out the froth of small handles at 2d scales between $\Lambda'^{-1}$ and $\Lambda^{-1}$, thereby integrating out the string modes with $p(i)^2$ from $L'^{-2}$ up to $L^{-2}$. 
The 2d-NLM (like any 2d-NLM) is specified by two pieces of data

- the metric \( g_{\text{str}}^{-2} G_{ij}(\lambda) \) on the target manifold

- a measure \( d\lambda \rho(\lambda) \) on the target manifold \( \mathcal{M} \) which gives the functional volume element

\[
\int \mathcal{D}\lambda = \prod_{(z,\bar{z})} \int_{\mathcal{M}} d\lambda(z,\bar{z}) \rho(\lambda(z,\bar{z}))
\]

\( d\lambda \rho(\lambda) \) is called the *a priori* measure.

At 2d scale \( \Lambda^{-1} \), a point \((z,\bar{z})\) represents a 2d block \( \Lambda^{-1} \times \Lambda^{-1} \). The measure \( d\lambda \rho(\lambda) \) summarizes the fluctuations inside a block.

\( d\lambda \rho(\lambda) \) evolves under the 2d-RG, diffusing in the target manifold \( \mathcal{M} \) due to the \( \lambda \)-fluctuations. At the same time, it is driven by the beta-function \( \beta^i(\lambda) \) because the \( \lambda^i \) are not exactly marginal, they flow with the 2d scale \( \Lambda^{-1} \).
\( d\lambda \rho(\lambda) \) evolves by the driven diffusion equation

\[
\Lambda \frac{\partial}{\partial \Lambda} \rho(\lambda) = \nabla_i \left( g_{\text{str}}^{ij} \partial_j + \beta^i \right) \rho(\lambda)
\]

(taking \( d\lambda \) to be the metric volume element on \( \mathcal{M} \)).

\( d\lambda \rho(\lambda) \) at scale \( \Lambda^{-1} \) is produced by integrating out the \( \lambda \)-fluctuations from 2d distance \( \approx 0 \) up to \( \Lambda^{-1} \), driving it to the equilibrium measure

\[
d\lambda \rho(\lambda) \rightarrow d\lambda \ e^{-\frac{1}{g_{\text{str}}^2} S(\lambda)} \quad \text{where} \quad G_{ij} \beta^j = \partial_i S
\]

Recall that the \( \lambda^i \) are the spacetime field modes with UV cutoff \( L \).

So \( d\lambda \rho(\lambda) \) is the functional integral of an effective QFT(\( L \)) with classical action \( \frac{1}{g_{\text{str}}^2} S(\lambda) \).

In this way the \( \lambda \)-model produces a QFT(\( L \)) at every \( L \gg 1 \).
S-matrix($L$) and QFT($L$) agree on amplitudes at scale $\approx L$ because the scattering amplitudes of S-matrix($L$) near the IR cutoff $L$ are given by the 2d correlation functions near the 2d UV cutoff $\Lambda^{-1}$, which are determined by the a priori measure $d\lambda \rho(\lambda)$, which is QFT($L$).
The $\lambda$-model is a nonperturbative 2d-NLM, with possibilities of nonperturbative semi-classical effects:

- winding modes associated to $\pi_1$ of the target manifold $\mathcal{M}$
- 2d instantons associated to $\pi_2(\mathcal{M})$

where $\mathcal{M} =$ the manifold of space-time fields

$\pi_k$ (the manifold of $SU(N)$ gauge fields in $\mathbb{R}^4) = \pi_{k+3}(SU(N))$

So there are winding modes ($k = 1$) when $\pi_4(SU(N)) \neq 0$

$$\pi_4(SU(2)) = \mathbb{Z}_2$$

and there are 2d instantons ($k = 2$) when $\pi_5(SU(N)) \neq 0$

$$\pi_5(SU(2)) = \mathbb{Z}_2 \quad \pi_5(SU(3)) = \mathbb{Z}$$
The winding modes for $SU(2)$ and the 2d-instantons for $SU(2)$ and $SU(3)$ offer possibilities of conditional predictions.

*If the $\lambda$-model produces SM+GR then it also produces*

- non-canonical degrees of freedom from the $\mathbb{Z}_2$ winding mode in the manifold of $SU(2)$ gauge fields on $\mathbb{R}^4$

- non-canonical interactions from the 2d instanton in the manifold of $SU(2)$ gauge fields and the 2d instantons in the manifold of $SU(3)$ gauge fields on $\mathbb{R}^4$
\[ \mathbb{Z}_2 \text{ winding mode in the manifold of } SU(2) \text{ gauge fields on } \mathbb{R}^4 \]

Let \( A(x_+, x_-, u) \) be a zero-size instanton at \( x_+ \) and a zero-size anti-instanton at \( x_- \) with relative orientation \( u \in SU(2)/\mathbb{Z}_2 \).

\[
\mathcal{L}(x) = \frac{1}{8\pi} \text{tr} \left( F_{\mu\nu}(x) F^{\mu\nu}(x) \right) = \delta^4(x - x_+) + \delta^4(x - x_-)
\]

\[
\mathcal{L}^{\text{top}}(x) = \frac{1}{8\pi} \text{tr} \left( F_{\mu\nu}(x) \ast F^{\mu\nu}(x) \right) = \delta^4(x - x_+) - \delta^4(x - x_-)
\]

The winding mode representing the nontrivial element in \( \pi_1 = \mathbb{Z}_2 \) is the closed loop

\[
\theta \mapsto A(x_+, x_-, u(\theta)) \quad u(0) = -u(2\pi) = 1
\]

with \( u(\theta) \) a geodesic connecting \( 1 \) to \( -1 \in SU(2) \).

This loop has zero length, so the winding mode will be a 2d field of scaling dimension \( = 0 + \) quantum corrections, so it has a chance of participating in the \textit{a priori} measure which is the space-time QFT.
The $\mathbb{Z}_2$ winding mode is *bi-local* in space-time, depending on the two space-time points $x_+, x_-$. 

The 2d instantons for $SU(2)$ and $SU(3)$ gauge fields are nontrivial 2-spheres in slightly more complicated configurations of zero-sized instantons and anti-instantons.
To do:

A huge amount of foundational technical work remains to be done.

More urgent is to find out if the $\lambda$-model can in fact make conditional predictions of observable non-canonical effects in $SU(2)$ and $SU(3)$ gauge theory in 4 dimensions.

1. Figure out how to calculate semi-classical corrections to the \textit{a priori} measure of a 2d-NLM coming from the winding modes and 2d instantons.

2. Calculate the corrections to the canonical SM
   - from the bi-local winding mode in the manifold of $SU(2)$ gauge fields.
   - from the multi-local 2d instantons in the manifolds of $SU(2)$ and $SU(3)$ gauge fields.
Especially tantalizing is the top-down construction of QFT\((L)\).

The \(\lambda\)-model operates from 2d distance \(\approx 0\) up to 2d distance \(\Lambda^{-1}\).

\[
L^2 = \ln \left( \frac{\Lambda}{\mu} \right)
\]

So it builds QFT\((L)\) from space-time distance \(\approx \infty\) down to \(L\).

Unnaturalness might be natural in QFT\((L)\).
Appendix

- The $\lambda$-model as S-matrix RG (the basic calculation)
- Some philosophy
- Some motivations
- Some truisms about string theory
The $\lambda$-model as S-matrix RG (the basic calculation)

Calculate the cutoff integral over the moduli of a small handle.

Make a small handle by identifying the boundaries of two holes of radius $r$ around nearby points $z_1, z_2$ in the worldsheet.

$$(z - z_1)(z - z_2) = q = r^2 e^{i\theta}$$

Integrate over the moduli $z_1, z_2, q$, summing over states on the boundaries (the $\theta$ integral projecting on the spin-0 states).

$$\int d^2 z_1 \int d^2 z_2 \int_{\Lambda^{-1}}^{1} \frac{1}{r} dr$$

$$\sum_{i_1, i_2} r^{-\delta(i_1)} \phi_{i_1}(z_1, \bar{z}_1) G^{i_1 i_2} r^{-\delta(i_2)} \phi_{i_2}(z_2, \bar{z}_2)$$

The cutoff-dependence comes from the approximately marginal fields, the $\phi_i$ with $\delta(i) \approx 0$. 
\[ \int d^2 z_1 \int d^2 z_2 \ln (\Lambda |z_1 - z_2|) G_{i_1 i_2}^{i_1 i_2} \phi_1(z_1, \bar{z}_1) \phi_2(z_2, \bar{z}_2) \]

Cancel the small handle with the \(\lambda\)-model 2-point function

\[ \int d^2 z_1 \int d^2 z_2 \left< \lambda^{i_1}(z_1, \bar{z}_1) \lambda^{i_2}(z_2, \bar{z}_2) \right> \phi_1(z_1, \bar{z}_1) \phi_2(z_2, \bar{z}_2) \]

This works to first order in the sum over handles in any classical background \(\lambda\), therefore the interacting 2d-NLM with target metric \(G_{ij}(\lambda)\) removes the cutoff dependence to all orders, therefore replicates exactly the sum over small handles.
Influences include Bohr’s philosophy that a fundamental theory should be expressed in terms of what is observable, and by Heisenberg’s S-matrix philosophy.

But I prefer pragmatic versions of these philosophies.

I try to adopt a useful interpretation of ‘what is observable’, rather than an extreme, idealized interpretation.

For example, the route of Bohr and Heisenberg to Quantum Mechanics was guided by a focus on observable transitions, but in the end QM described the world by quantum states and transition amplitudes, which are not observable. On the other hand, these idealizations have been so successful that they are essential to a practical version of what is observable, at least at the scales where there is evidence.
The idealized version of the S-matrix philosophy would replace Quantum Mechanics entirely with an asymptotic S-matrix.

This totalitarian philosophy has re-appeared from time to time when Quantum Mechanics has seemed to hit a wall at the frontier of fundamental physics. But each time, QM has managed to surmount the apparent wall.

It seems to me crazy to imagine doing all of our current Physics with only an S-matrix, even in principle.

On the other hand, a pragmatic version of the S-matrix philosophy seems reasonable. An effective S-matrix is a practical formulation of what we can actually observe at distances smaller than the limit of our best quantum mechanical model.
Another guiding principle was avoidance of premature mathematical idealization. Eventually, a successful fundamental theory may be formulated in beautiful mathematics. But there is no telling how far away that is, or which mathematically beautiful forms will prove useful for fundamental physics.

I avoided in particular the mathematical idealizations of the asymptotic S-matrix and of continuum QFT. Practical S-matrices have IR cutoffs. Practical QFTs have UV cutoffs, including 2d-QFTs of the string worldsheet.

I especially avoided the idealization of the asymptotic string S-matrices. Their backgrounds are the classical $R_{\mu\nu} = 0$ space-time geometries and generalizations. No room is left for the production of a QFT at large distance. A QFT has to be associated by hand to the asymptotic string S-matrix, by matching the low momentum scattering amplitudes.
Some motivations

By the late 1970s, there seemed good motivation to find a mechanism besides the RG that produces effective QFTs. The space of effective QFTs looked too big. The RG offered no compelling physical selection principle except perhaps naturalness.

More recently, experiment has been weighing against naturalness as a selection principle, strengthening the motivation for a QFT production mechanism.

In the 1980s, there were several motivations for using the string theory S-matrix for short distance physics.

String theory constructs S-matrices without assuming a short distance QFT.

And, of course, the string scattering states include massless particles, including a spin-2 graviton, so are suitable for short distance scattering in backgrounds described by SM+GR.
Two more of the motivations for short distance string theory:

In the original general 2d-NLM, $R_{\mu\nu} = 0$ was not quite Einstein’s equation. The $\beta = 0$ equation for the 2d-NLM of the string worldsheet is a potentially realistic space-time field equation.

The fixed points $\beta = 0$ of the general 2d-NLM have unstable directions. The string worldsheet 2d-NLM eliminates the unstable directions (tachyons).
Several truisms about string theory were cemented in the mid-1980s that I considered (and consider) to be misleading misconceptions.

They concern the role of the string S-matrix, the nature of the string background, and especially the relation of QFT to the string S-matrix.

These truisms have been fruitful for mathematics, but not for fundamental physics.

It is not easy to deviate from widely held truisms. Physicists are human. Collective adherence to truisms provides psychological and social comfort. But it is not the business of theoretical physicists to be comfortable before experiment shows them to be right.
A string S-matrix is (potentially) a TOE.

No. This is a version of the idealized S-matrix philosophy. We do physics with quantum mechanics (and its classical approximation in the appropriate regimes). It is a ridiculous fantasy to imagine that all of real world physics could be done with an S-matrix.

An S-matrix is the same as a quantum mechanics. An S-matrix necessarily derives from a QFT.

No. An S-matrix can be derived from a quantum mechanics, but not vice versa. A quantum mechanics can give an S-matrix, but an S-matrix does not give a quantum mechanics. Quantum mechanics gives a time evolution operator $U(t, t_0)$ between any two times. The idealized S-matrix is the limit $U(+\infty, -\infty)$ acting on asymptotic scattering states.

An effective S-matrix at scale $L$ is a finite-time evolution operator acting on effective scattering states at scale $L$. There might or might not be a quantum mechanics at distances $< L$. 
The low momentum/large distance limit of string-theory is a quantum field theory.

No. The low momentum string S-matrix amplitudes correspond to the amplitudes of a quantum field theory. This is very suggestive, but string theory does not produce an actual QFT. String theory does not produce a hamiltonian or a functional integral over fields.

A solution of $R_{\mu\nu} = 0$ (or a generalization) is a string background

No. 2d CFTs are backgrounds for asymptotic string S-matrices. We need a version of string theory in which the background is a state in a QFT.