This chapter represents the most recent view about elementary particle massivation in TGD framework. This topic is necessarily quite extended since many several notions and new mathematics is involved. Therefore the calculation of particle masses involves five chapters. In the following my goal is to provide an up-to-date summary whereas the chapters are unavoidably a story about evolution of ideas.

The identification of the spectrum of light particles reduces to two tasks: the construction of massless states and the identification of the states which remain light in p-adic thermodynamics. The latter task is relatively straightforward. The thorough understanding of the massless spectrum requires however a real understanding of quantum TGD. It would be also highly desirable to understand why p-adic thermodynamics combined with p-adic length scale hypothesis works. A lot of progress has taken place in these respects during last years.

Zero energy ontology providing a detailed geometric view about bosons and fermions, the generalization of S-matrix to what I call M-matrix, the notion of finite measurement resolution characterized in terms of inclusions of von Neumann algebras, the derivation of p-adic coupling constant evolution and p-adic length scale hypothesis from the first principles, the realization that the counterpart of Higgs mechanism involves generalized eigenvalues of the K\"ahler-Dirac operator: these are represent important steps of progress during last years with a direct relevance for the understanding of particle spectrum and massivation although the predictions of p-adic thermodynamics are not affected.

Since 2010 a further progress took place. These steps of progress relate closely to ZEO, bosonic emergence, the discovery of the weak form of electric-magnetic duality, the realization of the importance of twistors in TGD, and the discovery that the well-definedness of

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charge forces the modes of K\"ahler-Dirac operator to 2-D surfaces - string
world sheets and possibly also partonic 2-surfaces. This allows to assign
to elementary particle closed string with pieces at two parallel space-time
sheets and accompanying a K\"ahler magnetic flux tube carrying monopole
flux.

Twistor approach and the understanding of the solutions of K\"ahler-Dirac
Dirac operator served as a midwife in the process giving rise to the birth
of the idea that all fundamental fermions are massless and that both
ordinary elementary particles and string like objects emerge from them.
Even more, one can interpret virtual particles as being composed of
these massless on mass shell particles assignable to wormhole throats.
Four-momentum conservation poses extremely powerful constraints on loop
integrals but does not make them manifestly finite as believed first.
String picture is necessary for getting rid of logarithmic divergences.

The weak form of electric-magnetic duality led to the realization that
elementary particles correspond to bound states of two wormhole throats
with opposite K\"ahler magnetic charges with second throat carrying weak
isospin compensating that of the fermion state at second wormhole throat.
Both fermions and bosons correspond to wormhole contacts: in the case of
fermions topological condensation generates the second wormhole throat.
This means that altogether four wormhole throats are involved with both
fermions, gauge bosons, and gravitons (for gravitons this is unavoidable in
any case). For p-adic thermodynamics the mathematical counterpart of
string corresponds to a wormhole contact with size of order CP_2 size
with the role of its ends played by wormhole throats at which the
signature of the induced 4-metric changes. The key observation is that for
massless states the throats of spin 1 particle must have opposite

three-momenta so that gauge bosons are necessarily massive, even photon and
other particles usually regarded as massless must have small mass which in
turn cancels infrared divergences and give hopes about exact Yangian
symmetry generalizing that of ${\cal N}=4$ SYM. A the level
of effective space-time assiged to many-sheeted space-time this symmetry
is broken. Besides this there is weak
\blockquote{stringy} contribution to the mass assignable to the magnetic flux tubes
connecting the two wormhole throats at the two space-time sheets.

\vm{\it 1. Physical states as representations of super-symplectic and Super
Kac-Moody algebras}\vm

The basic constraint is that the super-conformal algebra involved must have
five tensor factors. The precise identification of the Kac-Moody type
algebra has however turned out to be a surprisingly difficult task. The
latest view is as follows. Electroweak algebra $U(2)_{ew} =SU(2)_L\times
U(1)$ and symplectic isometries of light-cone boundary ($SU(2)_{rot}\times
SU(3)_c$) give 2+2 factors and full supersymplectic algebra involving
only covariantly constant right-handed neutrino mode would give 1 factor.
This algebra could be associated with the 2-D surfaces X^2 defined by the
intersections of light-like 3-surfaces with $\delta M^4_{\pm}\times CP_2$.
These 2-surfaces have interpretation as partons.

For conformal algebra there are several candidates. For symplectic algebra
radial light-like coordinate of light-cone boundary replaces complex
coordinate. Light-cone boundary $S^2\times R_+$ allows extended conformal
symmetries which can be interpreted as conformal transformations of S^2
depending parametrically on the light-like coordinate of R_+. There is
infinite-D subgroup of conformal isometries with S^2 dependent radial
scaling compensating for the conformal scaling in S^2. K\"ahler-Dirac
equation allows ordinary conformal symmetry very probably liftable to

imbedding space. The light-like orbits of partonic 2-surface are expected to allow super-conformal symmetries presumably assignable to quantum criticality and hierarchy of Planck constants. How these conformal symmetries integrate to what is expected to be 4-D analog of 2-D conformal symmetries remains to be understood.

Yangian algebras associated with the super-conformal algebras and motivated by twistorial approach generalize the super-conformal symmetry and make it multi-local in the sense that generators can act on several partonic 2-surfaces simultaneously. These partonic 2-surfaces generalize the vertices for the external massless particles in twistor Grassmann diagrams. The implications of this symmetry are yet to be deduced but one thing is clear: Yangians are tailor made for the description of massive bound states formed from several partons identified as partonic 2-surfaces.

\vm{\it 2. Particle massivation}\vm

Particle massivation can be regarded as a generation of thermal mass squared and due to a thermal mixing of a state with vanishing conformal weight with those having higher conformal weights. The obvious objection is that Poincare invariance is lost. One could argue that one calculates just the vacuum expectation of conformal weight so that this is not case. If this is not assumed, one would have in positive energy ontology superposition of ordinary quantum states with different four-momenta and breaking of Poincare invariance since eigenstates of four-momentum are not in question. In Zero Energy Ontology this is not the case since all states have vanishing net quantum numbers and one has superposition of time evolutions with well-defined four-momenta. Lorentz invariance with respect to the either boundary of CD is achieved but there is small breaking of Poincare invariance characterized by the inverse of p-adic prime p characterizing the particle. For electron one has $1/p=1/M_{127}\sim

10^{-38}$.

One can imagine several microscopic mechanisms of massivation. The following proposal is the winner in the fight for survival between several
competing scenarios.

\begin{enumerate}

\item Instead of energy, the Super Kac-Moody Virasoro (or equivalently
super-symplectic) generator L_0 (essentially mass squared) is thermalized
in p-adic thermodynamics (and also in its real version assuming it exists).
That mass squared, rather than energy, is
a fundamental quantity at CP_2 length scale is also suggested by a
simple dimensional argument (Planck mass squared is proportional to $\hbar$
so that it should correspond to a generator of some Lie-algebra (Virasoro
generator L_0!)). What basically matters is the number of tensor factors
involved and five is the favored number.

\item There is also a modular contribution to the mass squared, which can
be estimated using elementary particle vacuum functionals in the conformal
modular degrees of freedom of the partonic 2-surface. It dominates for
higher genus partonic 2-surfaces. For bosons both Virasoro and modular
contributions seem to be negligible and could be due to the smallness of
the p-adic temperature.

\item A natural identification of the non-integer contribution to the
conformal weight is as stringy contributions to the vacuum conformal
weight (strings are now \blockquote{weak strings}). TGD predicts Higgs particle and
Higgs is necessary to give longitudinal polarizations for gauge bosons. The
notion of Higgs vacuum expectation seems to replaced by an analog of Higgs
vacuum expectation which gives space-time correlate for the stringy mass

formula in case of fundamental fermions. Also gauge bosons usually
regarded as exactly massless particles would naturally receive
small mass
from p-adic thermodynamics. The theoretetical motivation for a
small mass
would be exact Yangian symmetry which broken at the QFT limit of
the theory using GRT limit of many-sheeted space-time.

\item Hadron massivation requires the understanding of the CKM
mixing of
quarks reducing to different topological mixing of U and D type
quarks.
Number theoretic vision suggests that the mixing matrices are
rational or
algebraic and this together with other constraints gives strong
constraints
on both mixing and masses of the mixed quarks.

\end{enumerate}

p-Adic thermodynamics is what gives to this approach its predictive
power.

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\item p-Adic temperature is quantized by purely number
theoretical constraints (Boltzmann weight $exp(-E/kT)$ is replaced
with
p^{L_0/T_p}, $1/T_p$ integer) and fermions correspond to $T_p=1$
whereas $T_p=1/n$, $n>1$, seems to be the only reasonable choice for
gauge
bosons.

\item p-Adic thermodynamics forces to conclude that CP_2 radius
is
essentially the p-adic length scale $R \sim L$ and thus of order
$R
\simeq 10^{3.5} \sqrt{\hbar G}$ and therefore roughly $10^{3.5}$
times
larger than the naive guess. Hence p-adic thermodynamics describes
the
mixing of states with vanishing conformal weights with their Super
Kac-Moody Virasoro excitations having masses of order $10^{-3.5}$
Planck
mass.

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