TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

INSTITUTE for THEORETICAL PHYSICS
Vienna University of Technology

Bachelor- / Projekt- / Masterarbeiten aus Fundamentale Wechselwirkungen

Pascal Anastasopoulos, Daniel Grumiller, Andreas Ipp,
Anton Rebhan, Stefan Stetina, Timm Wrase

Projektarbeit:

- Black Hole Physics (136.025)
- Symmetrien in den fundamentalen Wechselwirkungen (135.026)
- Teilchenphysik (135.027)
- Thermal Field Theory (136.023)

23. Oktober 2017

Bachelor- / Projektarbeit

- Wissenschaftliches Arbeiten
  - Einlesen in bestehende Literatur (~1 paper + Referenzen)
  - Darauf aufbauend eigenständige Arbeit
  - Gesamtaufwand: 6-8 Wochen Vollzeitäquivalent

- Bachelorarbeit
  - Umfang: 20-50 Seiten
  - Gesetzt in TeX, LyX
  - Richtig zitieren (kein Plagiat!)

Fundamentale Wechselwirkungen

- Gravitation (→ Schwarze Löcher, Kosmologie)
- Elektromagnetische Kraft (→ QED Plasma)
- Schwache Kernkraft
- Starke Kernkraft (→ Neutronensterne, Quark Gluon Plasma)

Vereinheitlichte Beschreibung:

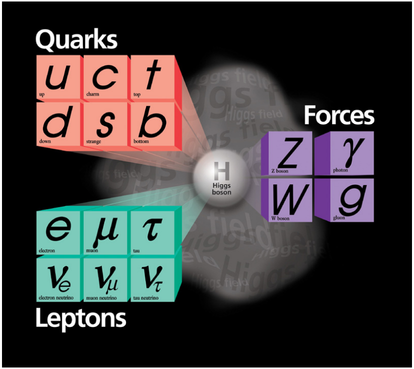
- Stringtheorie
- AdS/CFT-Korrespondenz

PrA Teilchenphysik
PrA Thermische Feldtheorie

Anton REBHAN

Institut für Theoretische Physik

Standardmodell der Teilchenphysik



Alle bekannten Elementarteilchen (hunderte!) aus diesen aufgebaut Theoretische Beschreibung durch **Quantenfeldtheorie** (nicht-Abelsche Eichtheorien)

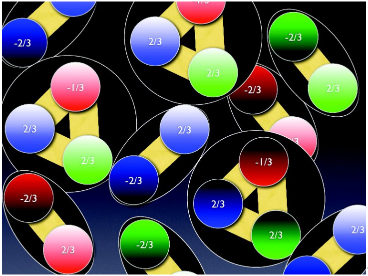
Bspe. für PrA:

- Asymptotic Freedom analysed in Coulomb gauge
- Polarization effects in light-by-light scattering (BA mit wiss. Veröffentlichung)
- nonlinear (Born-Infeld) electrodynamics

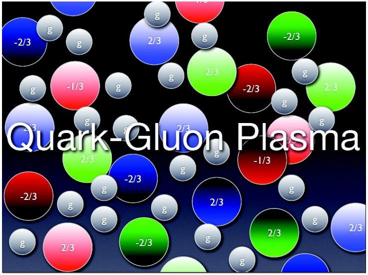
Quark-Gluon-Plasma

Confinement $\Rightarrow$
Hadronen (Bindungszustände von Quarks) können nicht "ionisiert" werden!

Aber bei ultrarelativistischen Temperaturen ($T_c \approx 2 \cdot 10^9$ K) steigt die Dichte ($\propto T^3$) so, dass Quarks nicht mehr wissen, an wen sie gebunden sind $\rightarrow$ **Deconfinement**

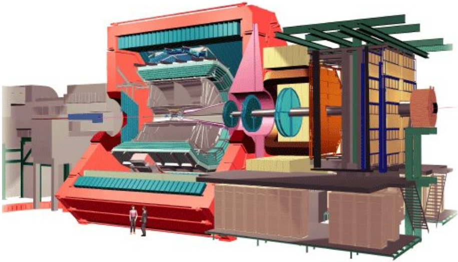


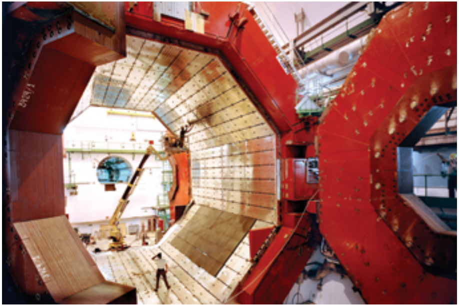
$\longrightarrow$



ALICE

Am LHC des CERN: **A** **L**arge **I**on **C**ollider **E**xperiment
(zusätzlich zu CMS und ATLAS)

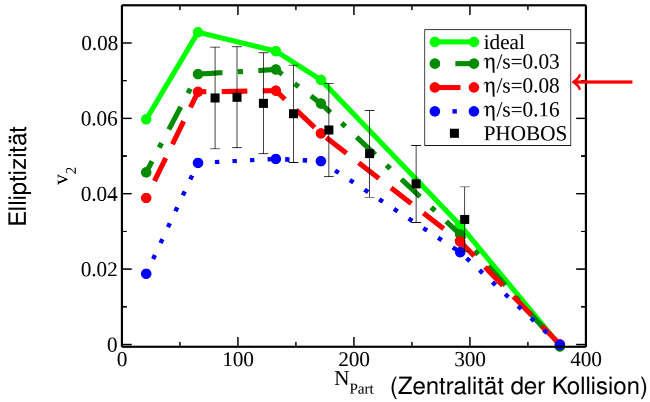




Pb+Pb mit 5.5 TeV/Nukleon

Hydrodynamische Simulationen

P. Romatschke & U. Romatschke, Phys.Rev.Lett.99:172301,2007:
Hydrodynamische Simulation mit verschiedenen Werten von spezifischer Viskosität η/s:

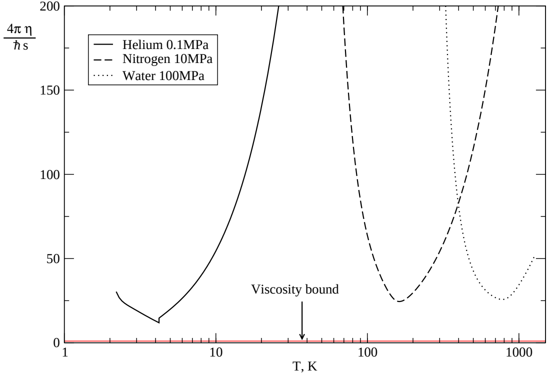


Perfekteste Flüssigkeit?

Spezifische Viskosität des QGP liegt gerade bei (vermutetem) Minimalwert, der quantenfeldtheoretisch möglich ist

$$\eta/s\hbar \geq \frac{1}{4\pi} \approx 0.08$$

Kovtun, Starinets & Son (2005), Phys.Rev.Lett.94:111601



Superstring-Verbindung

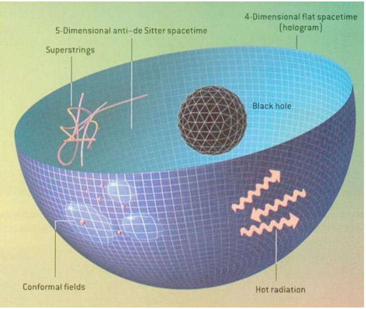
Hypothetischer Minimalwert für spezifische Viskosität

$$\eta/s\hbar = \frac{1}{4\pi} \approx 0.08$$

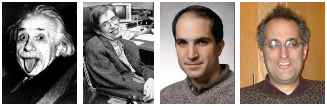
realisiert in einer besonders symmetrischen Variante der Quark-Gluon-Theorie bei unendlich starker Kopplung

(maximal supersymmetrisch, im Limes unendlich vieler Farbladungen)

Ergebnis basiert auf Maldacena-Vermutung der Superstring-Theorie



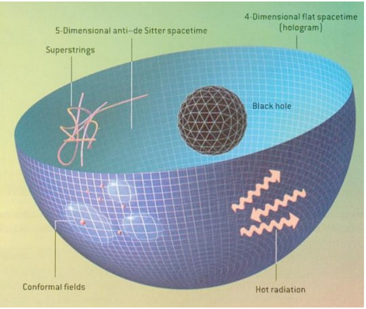
"Holographische Dualität" dieser Theorie zu Superstring-Theorie in einem 10-dimensionalen Raum ($AdS_5 \times S_5$) mit schwarzem Loch, mit Hawking-Temperatur gleich der Temperatur des (supersymmetrischen) Quark-Gluon-Plasma



Einstein Hawking Maldacena Witten

- Inzwischen verallgemeinert auf andere stark gekoppelte Theorien;
  andere Größen (Thermalisierungszeit, jet quenching & Mach cones, Phasendiagramm)
- neuerdings auch Festkörperphysik (quantum criticality) und kalte Atome

Superstring-Verbindung



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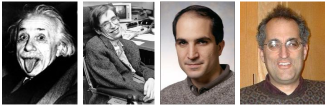

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Themen:

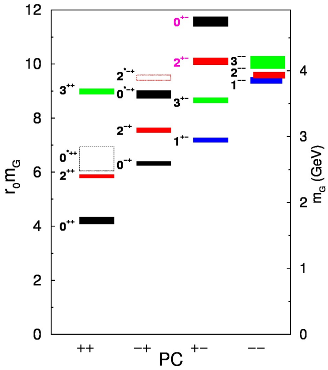
- Aspekte von Gravitations-dualen ("top-down") Modellen
- phänomenologische "bottom-up" Modelle
- Gravitations-duale Beschreibung von Hadronphysik, e.g. Glueballs

Glueballs

Gittereichtheorie sagt
Bindungszustände von Gluonen
und deren Massen vorher
– aber leider nicht die Zerfallsmuster

$m_{0++} \sim 1.7\ m_{\text{Proton}}$
$m_{2++} \sim 2.4\ m_{\text{Proton}}$
$m_{0-+} \sim 2.6\ m_{\text{Proton}}$
$m_{1-+} \sim 3.0\ m_{\text{Proton}}$
...

Morningstar & Peardon hep-lat/9901004



Dissertationsprojekt (Frederic Brünner):
Gauge/gravity duality $\rightarrow$ Zerfallsmuster von Spin 0 und Spin 2-Glueballs

Glueballs

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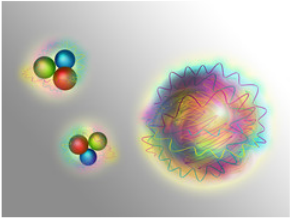
Los

2015-10-12 [Florian Aigner | Florian Aigner]

A Particle Purely Made of Nuclear Force

Scientists at TU Wien (Vienna) have calculated that the meson f0(1710) could be composed of pure force.



Nucleons consist (left) of quarks (matter particles) and gluons (force particles). A glueball (right) is made up purely of gluons.

For decades, scientists have been looking fo
glueball is an exotic particle, made up entire
Glueballs are unstable and can only be dete
not yet fully understood.

Professor Anton Rebhan and Frederic Brünr
to calculate glueball decay. Their results agr
strong evidence that a resonance called "f0(
sought glueball. Further experimental results

Forces are Particles too

Protons and neutrons consist of even smalle
strong nuclear force. "In particle physics, eve

Glueballs

Gittereichtheorie sagt
Bindungszustände von Gluonen
und deren Massen vorher
– aber leider nicht die Zerfallsmuster

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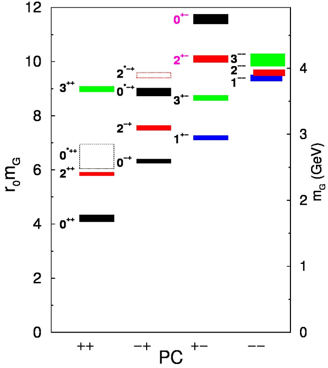
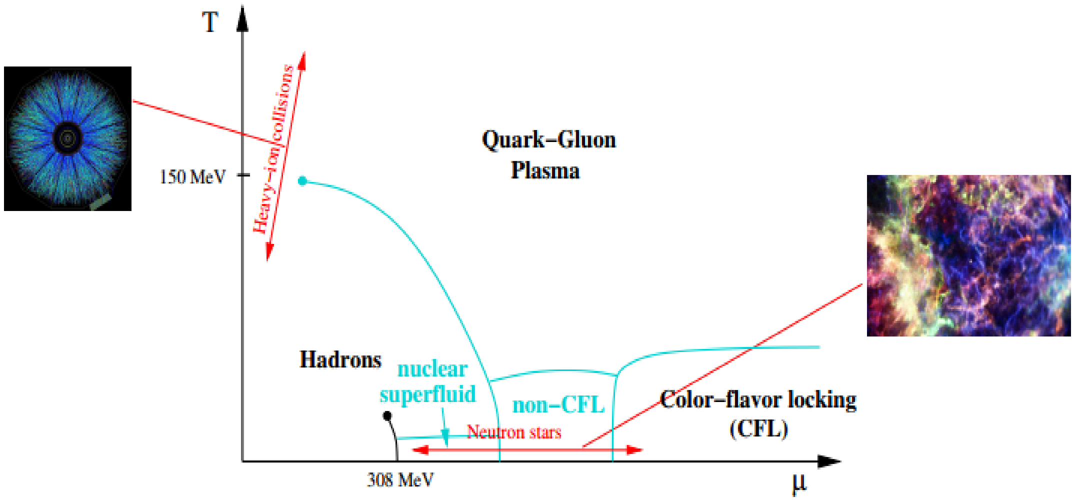


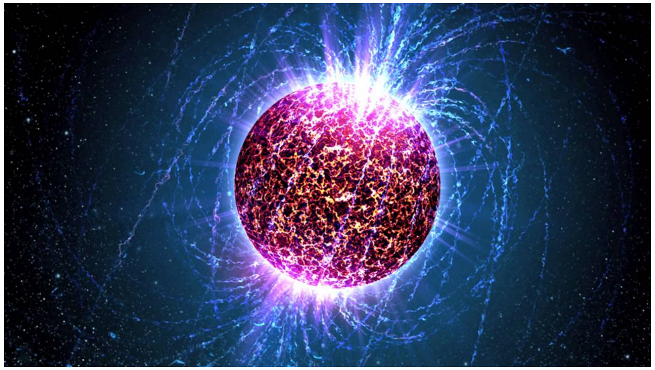
Dissertationsprojekt (Frederic Brünner):
Gauge/gravity duality → Zerfallsmuster von Spin 0 und Spin 2-Glueballs

laufende PrA–DA: Mitarbeit an Vorhersagen für Spin-1-Glueball

Dense Matter in Neutron Stars



Rebhan, Stetina, Haber,
Schmitt (Southampton)



Neutron stars are an **unique laboratory for dense QCD**

In this project work you can learn about:

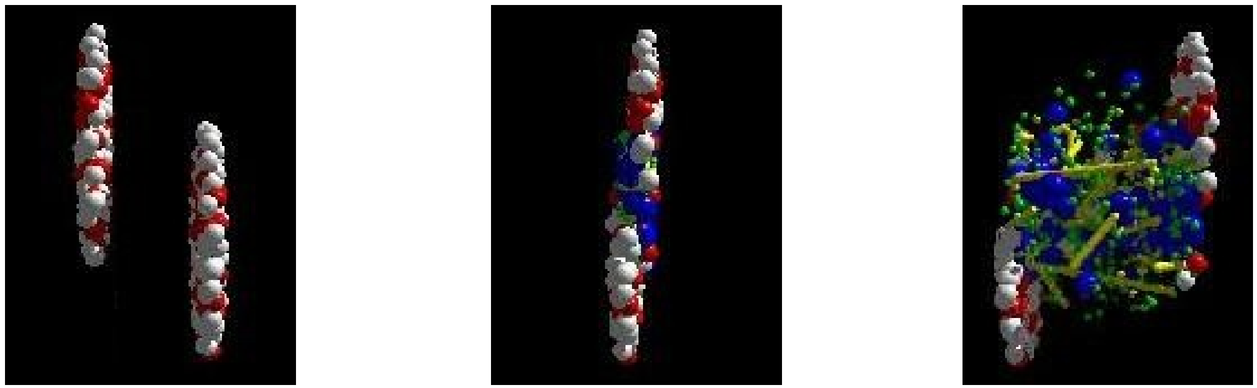
- Dense matter in neutron stars
- **Superfluidity** and **superconductivity** in neutron stars and field theory
- Basics of **thermal quantum field theory** (TQFT, bosonic + possibly fermionic)
- **Goldstone theorem** and abelian Higgs mechanism
- How to use Mathematica and Latex to perform and present your calculations

Knowledge of quantum mechanics and statistical physics is necessary,
first knowledge of TQFT and Mathematica is beneficial,
goal of project can be scaled to your prior knowledge.

Project supervised by Alexander Haber, Prof. Rebhan
if interested: contact **alexander.haber@tuwien.ac.at** or visit me at DB10A06

Quark-Gluon-Plasma

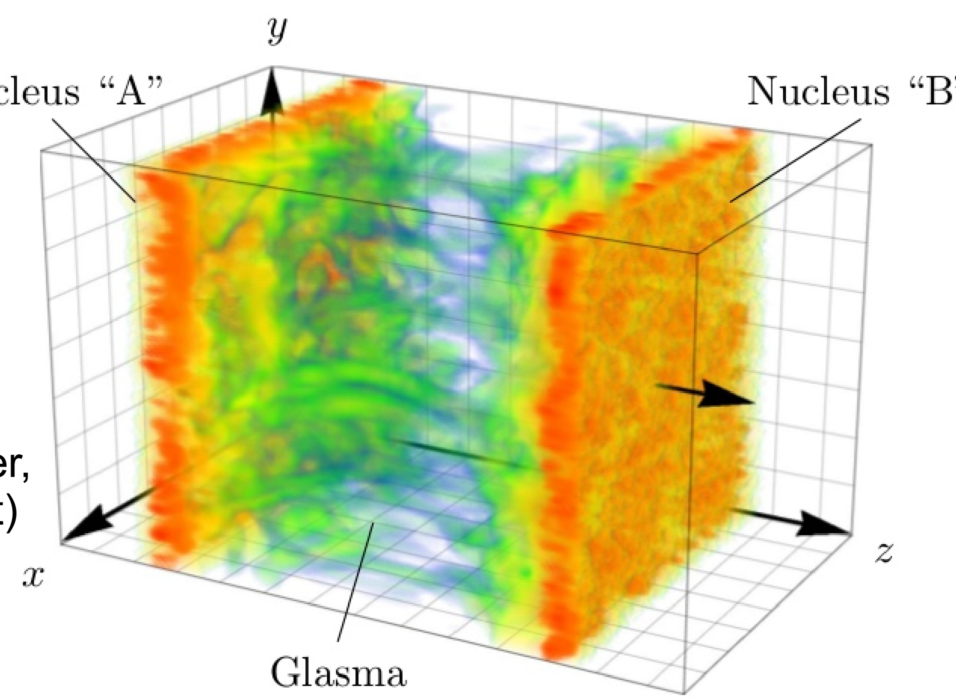
Schwerionenkollisionen am CERN LHC:



(Simulation by UrQMD group, Frankfurt)

Colored Particle-In-Cell
Simulation von “Glasma”

Effekte der starken
Wechselwirkung



(David Müller,
Doktorarbeit)

Andreas Ipp

Mögliche (Bachelor-) / Projekt- / Masterarbeiten

- Boltzmanngleichung, Hydrodynamik
  (Gleichungen und Simulationen für alternative Beschreibungen des Plasmas)
- Optimierung und dispersionsfreie Propagation
  (Cherenkov Instabilität, richtungsabhängige Dispersion)
- Gluonenverteilung aus dem Glasma
  (Besetzungszahlen von Gluonen im MV-Modell bestimmen)
- Fermionen auf dem Gitter
  (Fermionproduktion mittels male/female Fermionen)
- Quanteneffekte für Kerne mit endlicher Dicke
  (JIMWLK Evolutionsgleichungen erweitern)

Voraussetzungen:
Quantentheorie, Relativitätstheorie,
(Quantenelektrodynamik, Quantenfeldtheorie, Quantenchromodynamik)
Programmieren,
Wille, sich in umfangreicheres Themengebiet einzuarbeiten

Andreas Ipp

PA Black Hole Physics (136.025)

Daniel Grumiller

Institut für Theoretische Physik
Technische Universität Wien

October 23, 2017

FWF

grumil@hep.itp.tuwien.ac.at,
http://quark.itp.tuwien.ac.at/∼grumil

Gauge/gravity correspondence

Fundamental physics papers with > 8000 citations (source: INSPIRE, Oct. 23, 2017):

1. J. Maldacena 1998, "The Large N limit of superconformal field theories and supergravity" (13148 citations)
2. S. Weinberg 1967, "A Model of Leptons" (10890 c.; 1979 Nobel prize)
3. S. Perlmutter et al. & A. Riess et al. 1998, Accelerated expansion ($\sim$10300 c.; 2011 Nobel prize)
4. M. Kobayashi, T. Maskawa 1973, "CP Violation in the Renormalizable Theory of Weak Interaction" (9250 c.; 2008 Nobel prize)
5. T. Sjöstrand et al. 2006, PYTHIA Physics & Manual (8999 c.)
6. E. Witten 1998, "Anti-de Sitter space and holography" (8612 c.)
7. S. Agostinelli et al. 2003, GEANT4: A simulation toolkit (8345 c.)
8. WMAP collaboration 2003, First year observations (8272 c.)

Gravity in $d+1$ dimensions $\leftrightarrow$ Gauge theory in d dimensions

Selected holographic topics

Possible topics for bachelor theses:

- Soft hairy black holes
- Holographic entanglement entropy
- Quantum gravity in lower dimensions
- AdS_3/CFT_2
- Non-AdS holography
- Higher spin gravity
- Classical solutions

Selected holographic topics

Possible topics for bachelor theses:

- Soft hairy black holes
- Holographic entanglement entropy
- Quantum gravity in lower dimensions
- $\text{AdS}_3/\text{CFT}_2$
- Non-AdS holography
- Higher spin gravity
- Classical solutions

Additional people you may consult if you have further questions:

- Faculty: Radoslav Rashkov
- Postdocs: Hernán González, Wout Merbis
- PhDs: Christian Ecker, Jakob Salzer, Friedrich Schöller, Philipp Stanzer, Raphaela Wutte
- Visitors: Daniel Fernandez

Specific examples

Paper-and-pencil type of projects:

- New entropy formulas for black holes

  For specific black holes and cosmological spacetimes in 2+1 dimensions 1603.04824, 1611.09783:

  $$S_{3d} = 2\pi\, J_0^{(1)} + \dots$$

  For rotating black holes in 3+1 dimensions 1709.09667:

  $$S_{4d} = 4\pi\, J_0^{(1)} J_0^{(2)} + \dots$$

  where $J_0^{(i)}$ are related to zero modes of "soft hair" $\hat{u}(1)$ current algebra generators

  - How general are these formulas?
  - (How) do they generalize to higher dimensions?
  - What can we learn about black hole microstates?

Specific examples

Paper-and-pencil type of projects:

- New entropy formulas for black holes
- Generalized holography

  AdS/CFT appears to work well — but how general is holography?
  In particular:

  - Are there different versions of AdS/CFT? (see e.g. 1608.01308)
  - Does holography work in flat space? (see e.g. 1609.06203)
  - Does holography work in our Universe (de Sitter)?
  - Does holography work in non- or ultra-relativistic limits?
  - Do such generalizations work for spins higher than two? (see e.g. 1612.02277)

Can get lot of mileage from toy models in 1+1 and 2+1 spacetime dimensions!

Specific examples

Paper-and-pencil type of projects:

- New entropy formulas for black holes
- Generalized holography
- Quantum null energy condition

  Classical energy conditions pivotal in various proofs by Hawking, Penrose and others (e.g. singularity theorems)
  All of them violated through quantum effects!
  Bousso et al conjectured Quantum Null Energy Condition (QNEC):

$$\langle T_{kk} \rangle \geq \frac{S''}{2\pi A}$$

  see 1706.09432 for a proof and refs.

  - Physical interpretation of (non-)saturation of QNEC?
  - Explicit examples in lower dimensions?
  - Limitations of proof/counterexamples?
    e.g. valid in Galilean CFTs? (see 1410.4089)

Specific examples

Paper-and-pencil type of projects:

- New entropy formulas for black holes
- Generalized holography
- Quantum null energy condition

Numerical projects:

- Einstein toolkit (suggested by Christian Ecker [CE])

  Neutron star merger simulations with Einstein toolkit:
  - install and test Einstein toolkit
  - redo existing merger simulations
  - test and interpret simulations on VSC
  - simulations for holographic equation of state

  see e.g. 1509.08804, 1605.03424, 1611.01519, 1707.00521

Specific examples

Paper-and-pencil type of projects:

- New entropy formulas for black holes
- Generalized holography
- Quantum null energy condition

Numerical projects:

- Einstein toolkit (suggested by Christian Ecker [CE])
- Strongly coupled matter on curved backgrounds (suggested by CE)
    - Neutron stars: all fundamental interactions relevant!
    - Gravitational effects on equation of state?
    - Holographic model: strongly interacting CFT on curved background
    - Can have black hole in bulk and at boundary! (and "black funnel")
    - Equation of state stiffer? (as indicated from recent observations)

  see e.g. 0908.2270, 0909.0005, 1102.4337, 1208.6291, 1304.1162, 1405.2078

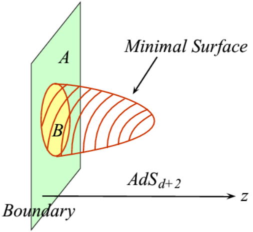
Specific examples

Paper-and-pencil type of projects:

- New entropy formulas for black holes
- Generalized holography
- Quantum null energy condition

Numerical projects:

- Einstein toolkit (suggested by Christian Ecker [CE])
- Strongly coupled matter on curved backgrounds (suggested by CE)
- Holographic entanglement entropy (HEE)
  Ryu–Takayanagi conjecture (hep-th/0603001):



$$S_{\text{EE}} = \frac{\text{Area}_{\text{min}}}{4}$$

numerical determination of HEE
analyze HEE in systems with matter
see e.g. 1609.03676, 1708.09376

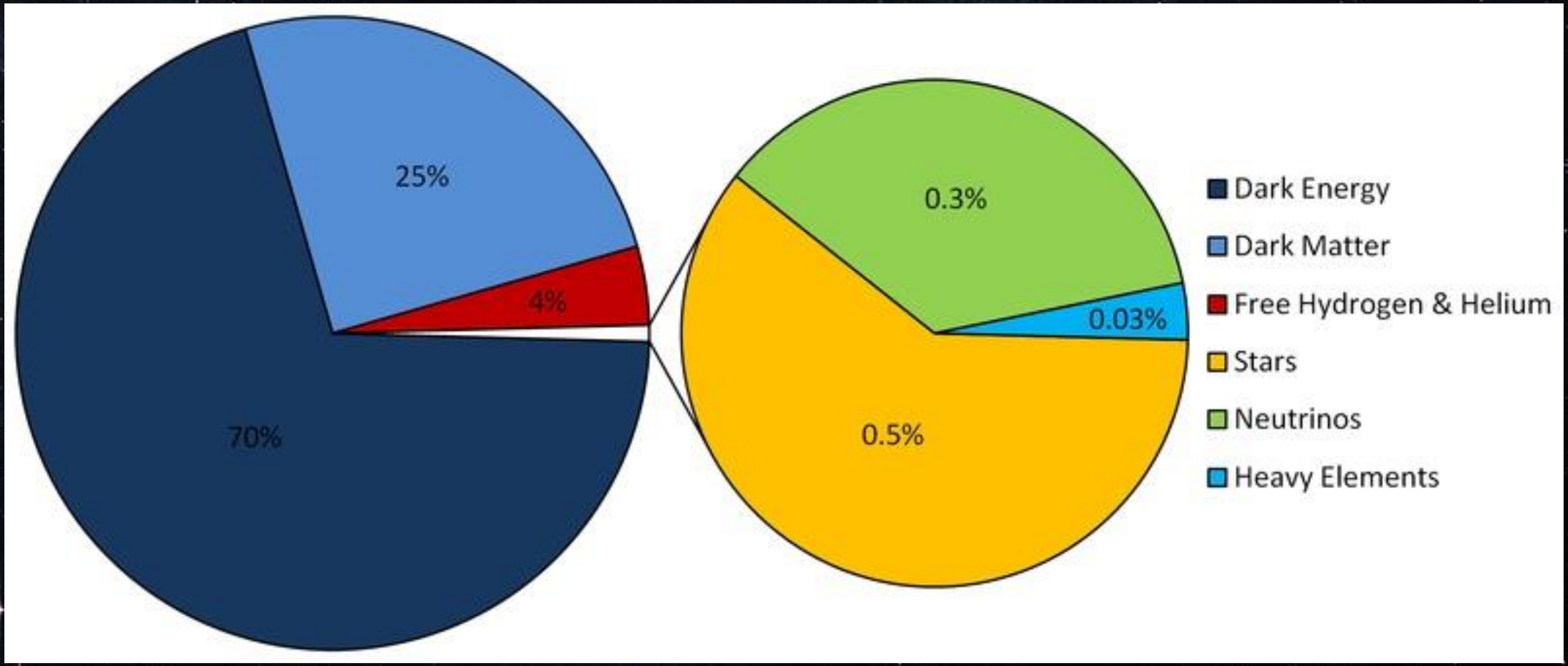
Projektarbeiten in Kosmologie und Stringtheorie

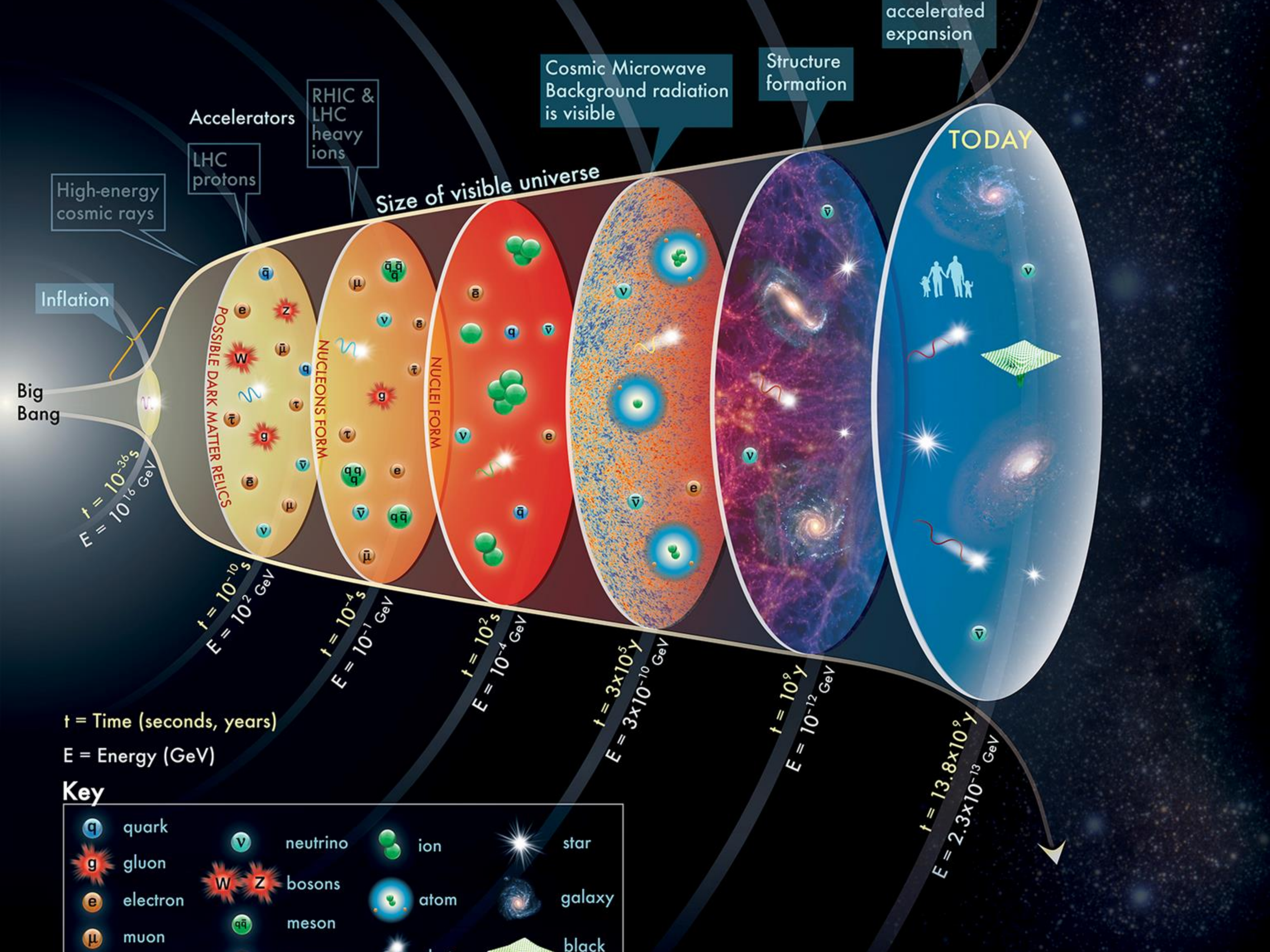
Timm Wrase

http://hep.itp.tuwien.ac.at/~wrasetm/

136.012 Kosmologie und Teilchenphysik

Energieverteilung in heutigen Universum





accelerated expansion
Cosmic Microwave Background radiation is visible
Structure formation
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Inflation
Size of visible universe
TODAY
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s
E = 10^16 GeV
t = 10^-10 s
E = 10^2 GeV
t = 10^-4 s
E = 10^-1 GeV
t = 10^2 s
E = 10^-4 GeV
t = 3x10^5 y
E = 3x10^-10 GeV
t = 10^9 y
E = 10^-12 GeV
t = 13.8x10^9 y
E = 2.3x10^-13 GeV
t = Time (seconds, years)
E = Energy (GeV)
Key
quark
gluon
electron
muon
neutrino
bosons
meson
ion
atom
star
galaxy
black

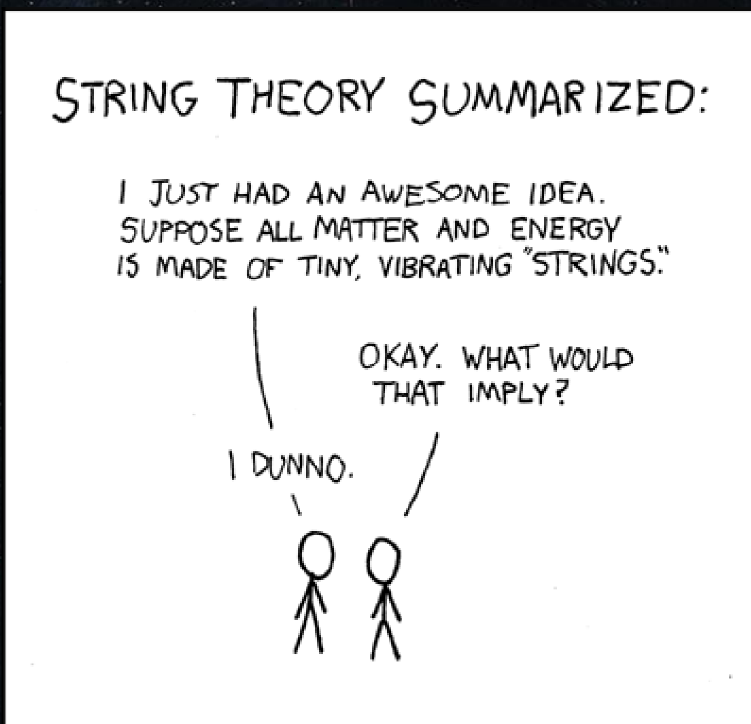
Voraussetzungen und mögliche Themen

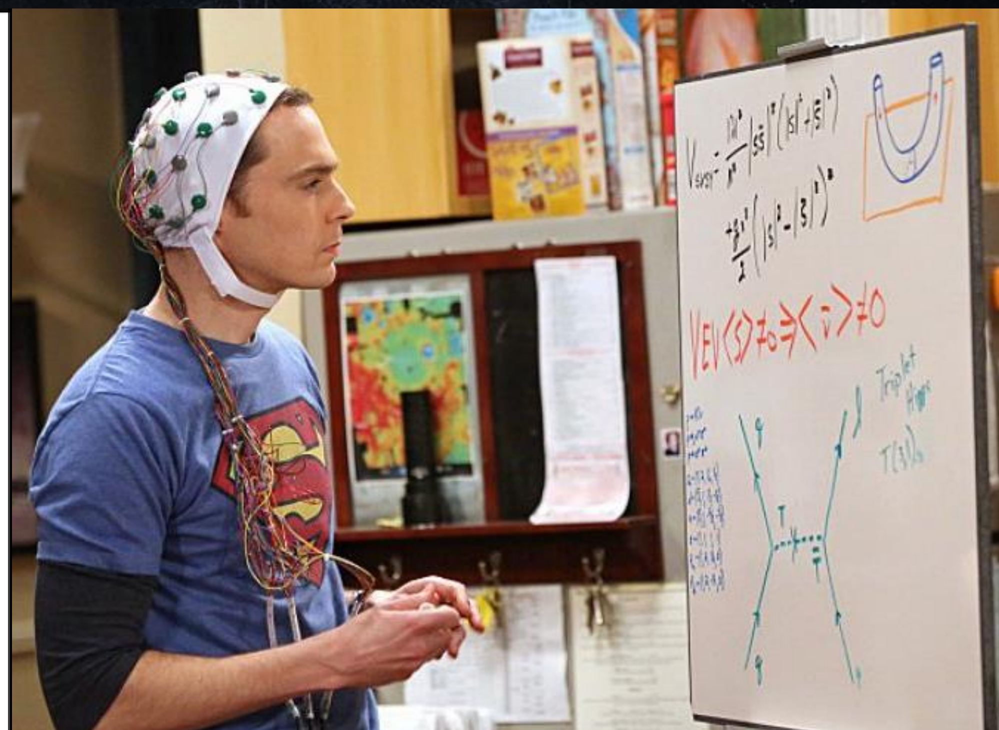
- Spezielle Relativitätstheorie (ART)
- Kosmologie und Teilchenphysik

1. Was passiert mit unserem Universum in der Zukunft?
2. Warum ist die dunkle Energie so klein?
3. Untersuchung von Inflationsmodellen in der Supergravitation.
4. …..

Stringtheorie an der TU Wien

http://hep.itp.tuwien.ac.at/string/index.html





Voraussetzungen und mögliche Themen

- Quantenfeldtheorie (konforme Feldtheorie)
- 132.071 Arbeitsgemeinschaft für fundamentale Wechselwirkungen
- (Supersymmetrie/Supergravitation)

1. Ausarbeitung bestimmter Aspekte der Supersymmetrie
2. Untersuchung des Teilchenspektrums und deren Symmetrien
3. ….

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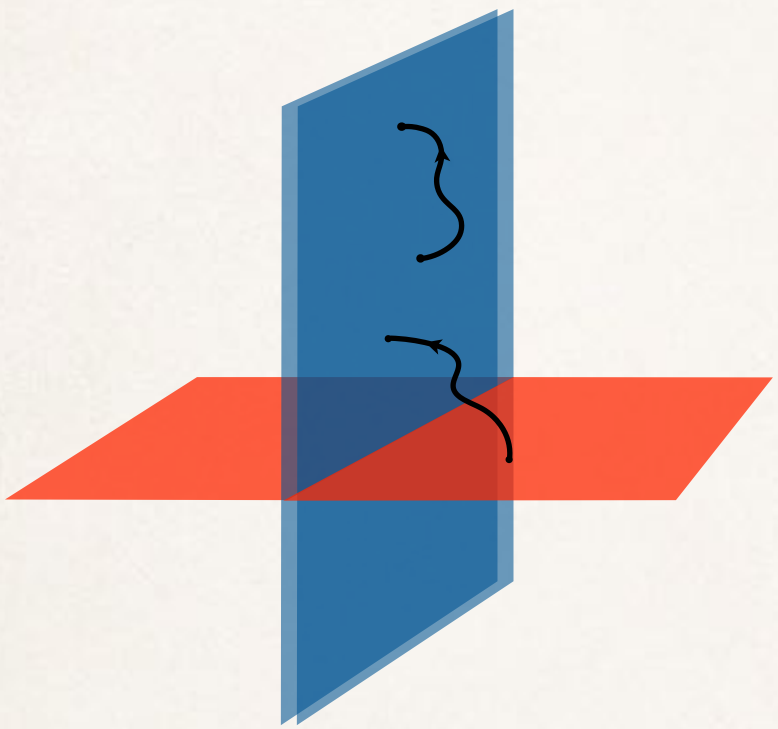
FWF
Der Wissenschaftsfonds.



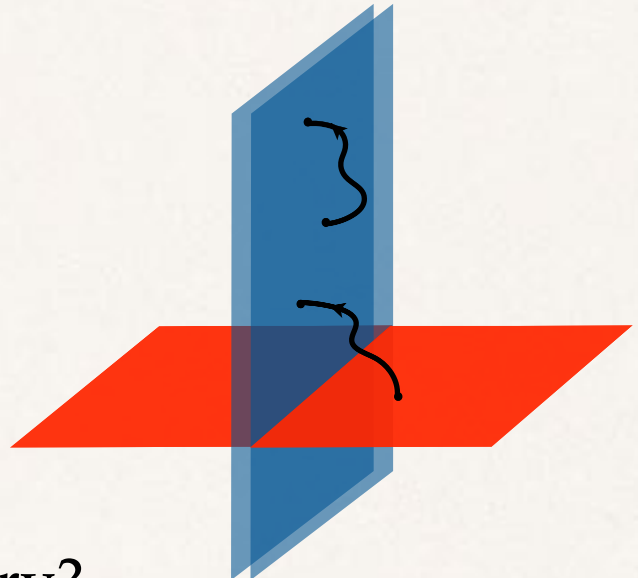
String Phenomenology

Pascal Anastasopoulos

09/10/2017

A theory of.. strings (and branes)

- String theory has only two ingredients:
  - Strings (closed and open)
  - hyperplanes (D-branes)



- Can we embed Standard Model in string theory?
  - Yes!

A theory of.. strings (and branes)

- String theory has only two ingredients:
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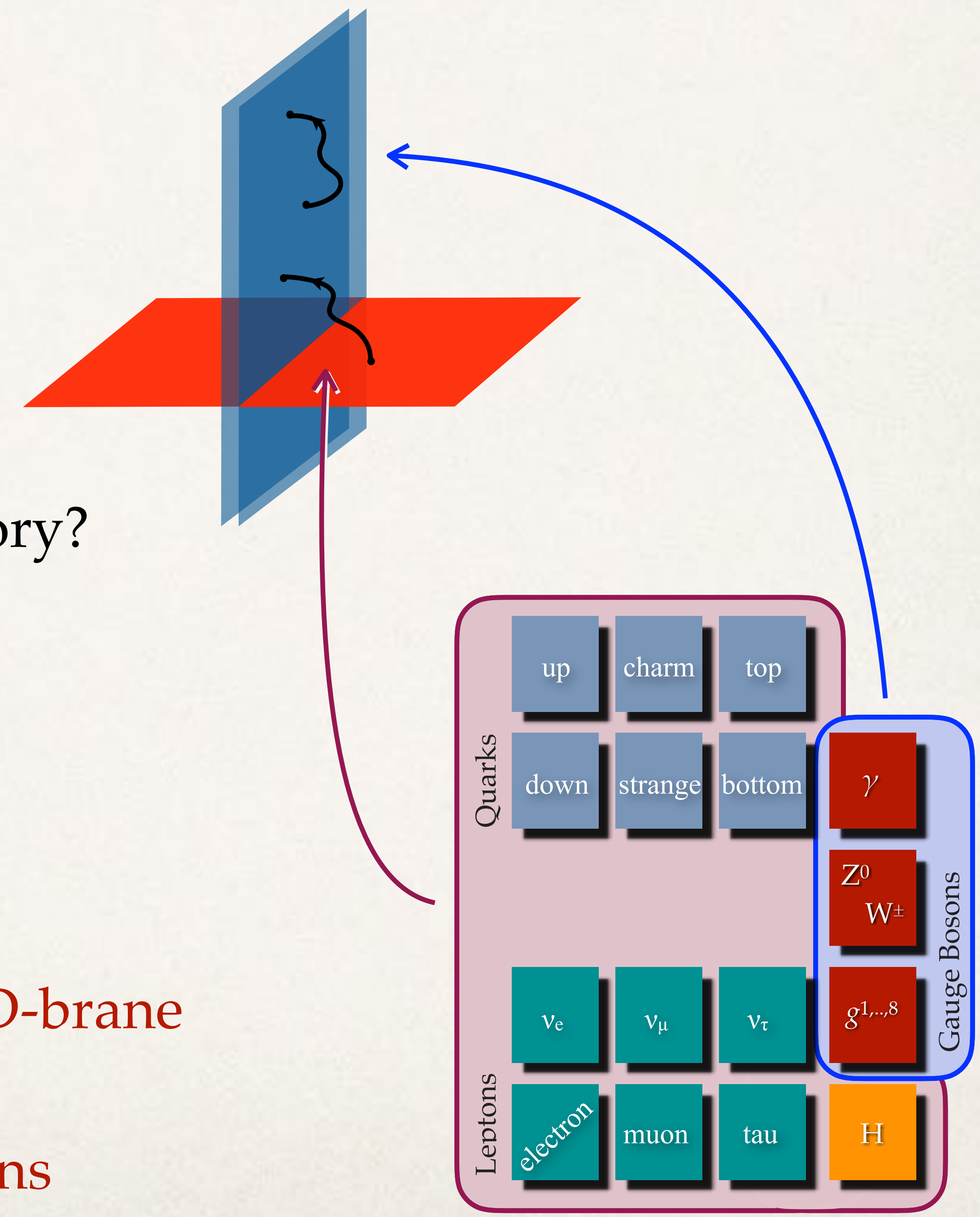
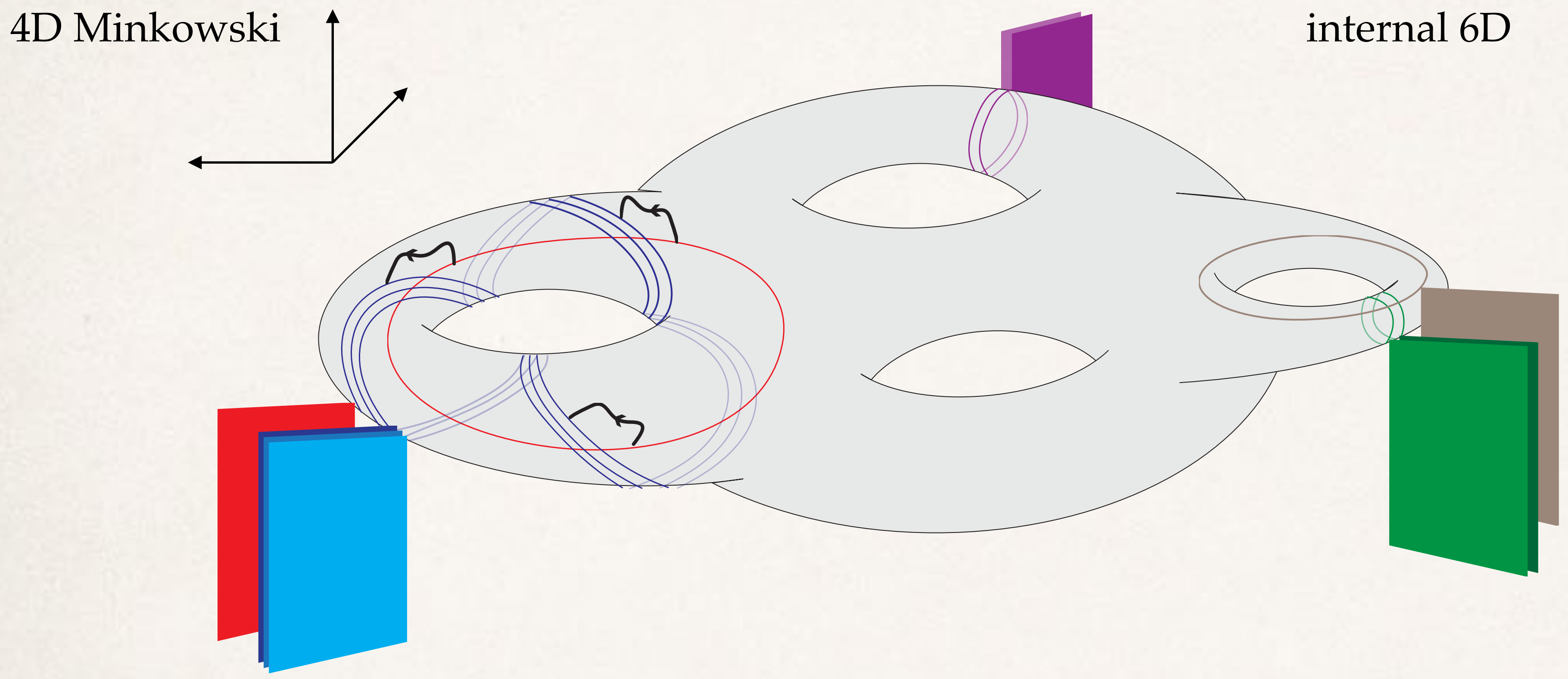
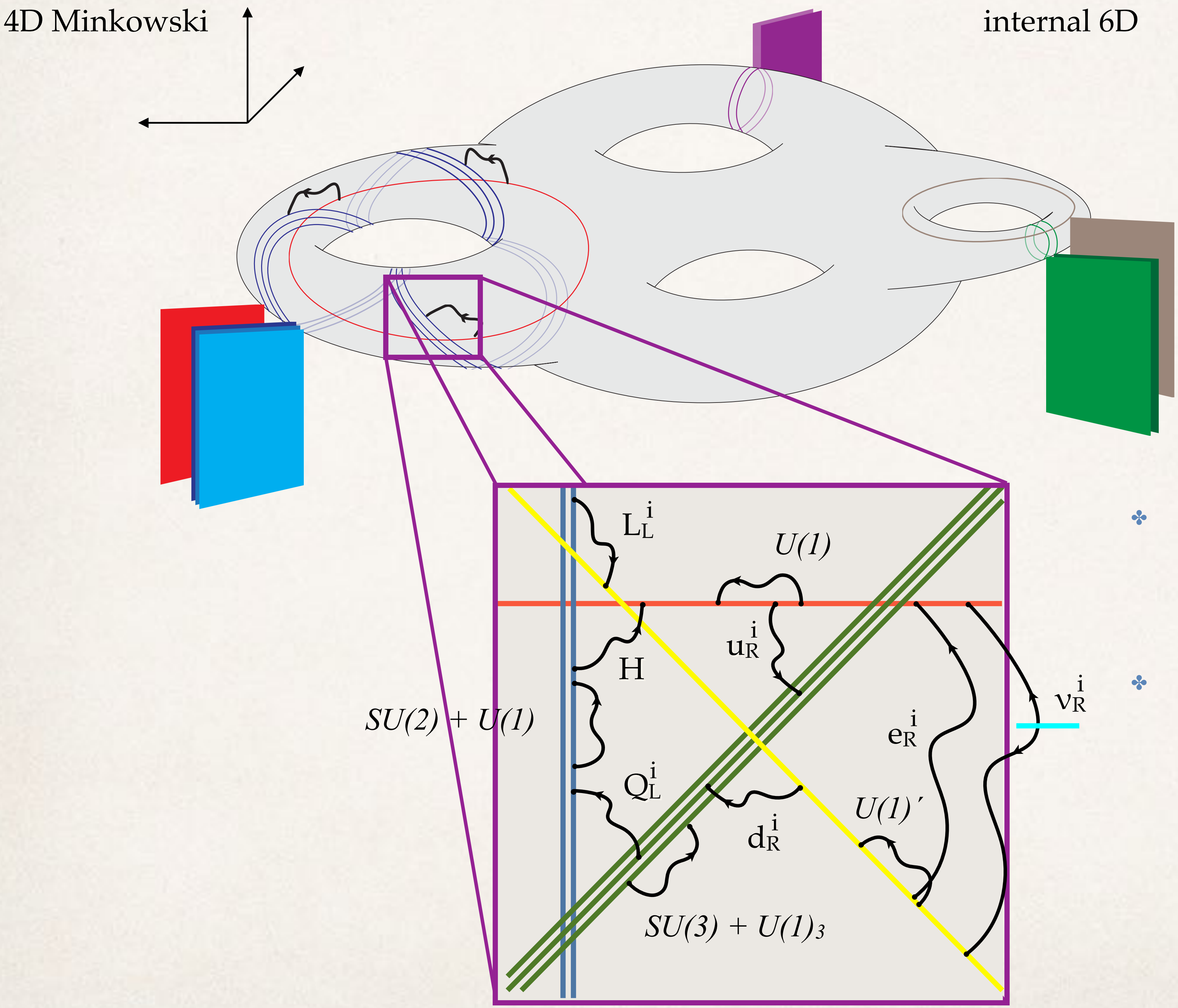


- Can we embed Standard Model in string theory?
  - Yes!
- Particles of SM
  - gauge fields → strings on the same D-brane
  - matter fields → strings at intersections

D-brane realisation of the SM



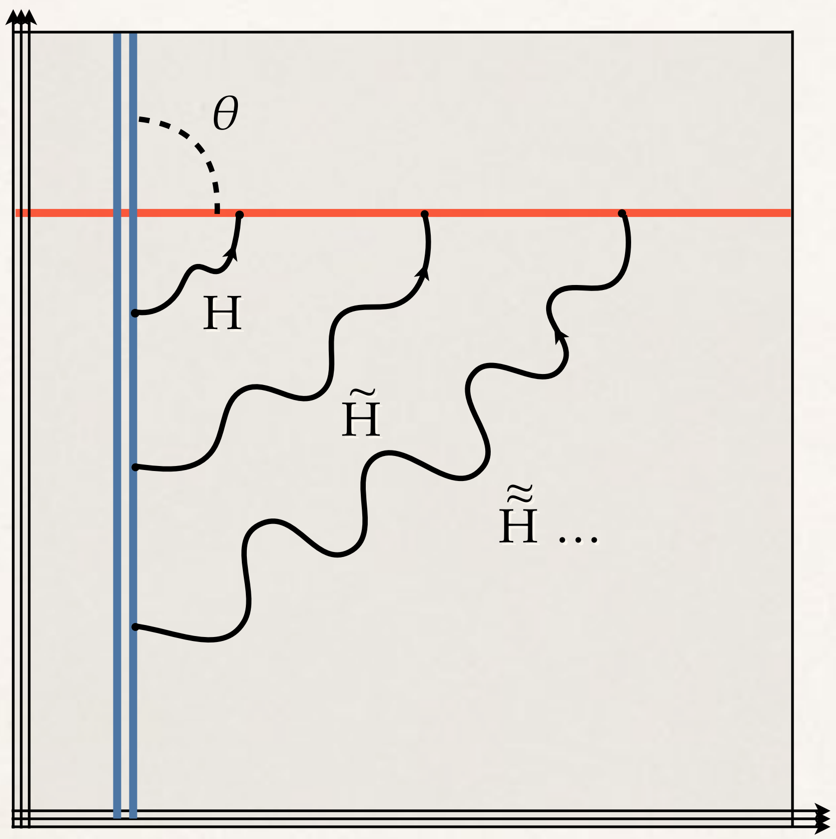
D-brane realisation of the SM



- Standard Model is localised at a small area.
- We can focus there and study the phenomenological consequences.

Towers of massive copies at intersections

- Strings vibrate. The frequencies are not random. They are proportional to the angle θ.
- Each vibrating string is a massive copy of the same massless field.



Example:

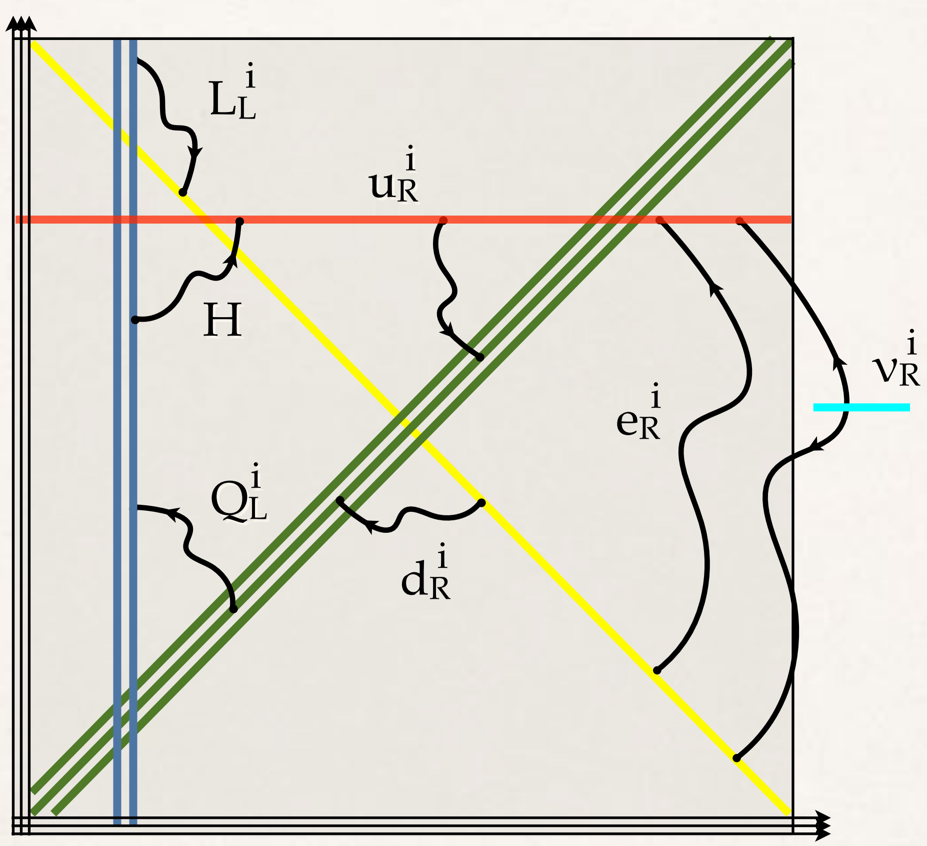
- The "zero" mode H is massless: $M^2 = 0$.
- The "first" $\tilde{\mathrm{H}}$ is massive: $M^2 = \theta M_s^2$.
- The "second" $\tilde{\tilde{\mathrm{H}}}$ is massive: $M^2 = 2\theta M_s^2$.

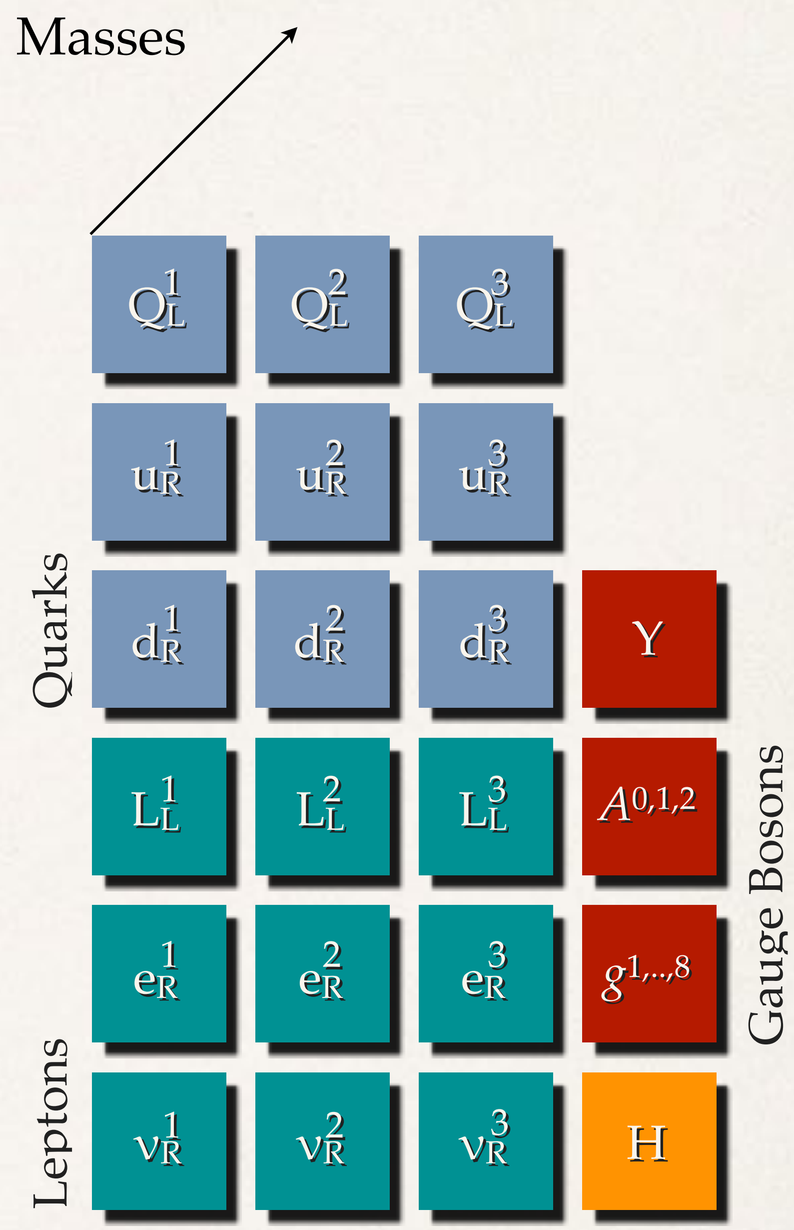
etc etc…

- Such towers of states appear at each intersection.

Consequences and predictions

- The Standard Model revised.
- At each intersection we have towers of states.





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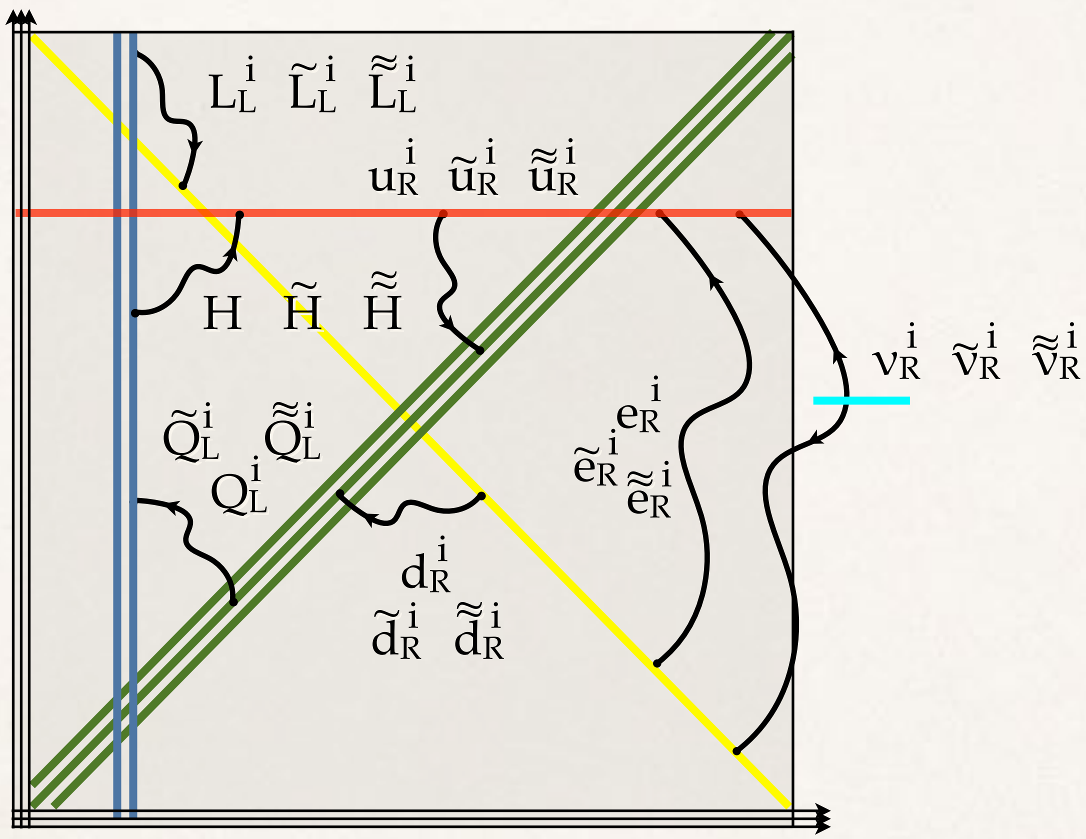

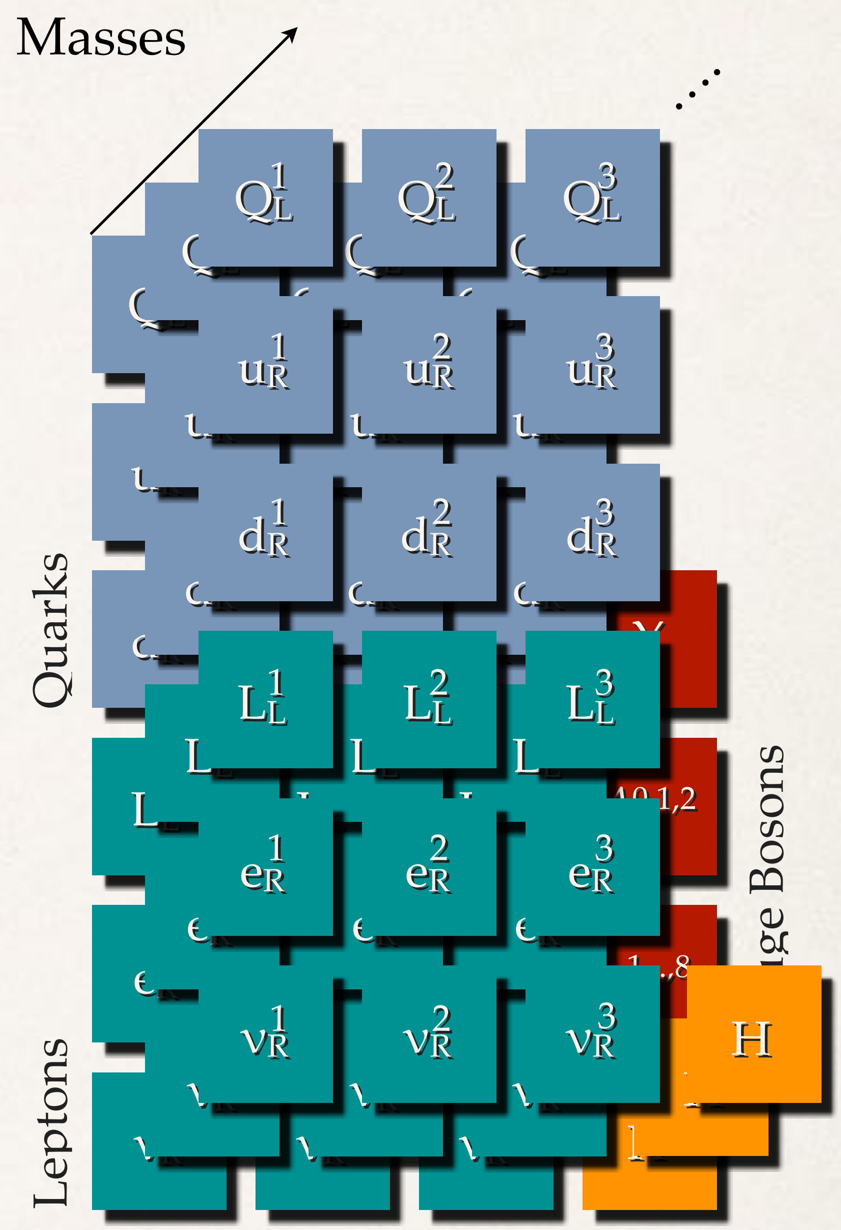

- Our aim is to study the phenomenological consequences of these massive copies of the Standard Model matter particles.
- If the string scale is at few TeV range such particles might be visible at experiments.

Aims

- We are planning to
  - study specific D-brane realisations of the Standard Model.
  - enlarge the massless spectrum by including massive copies of the SM fields.
  - study interactions & specific decays which might be visible at LHC.
- The student who will complete a Bachelor thesis on the field will familiarise with
  - Field theory (the Standard Model, effective actions).
  - String theory
    - basics: NS & R sectors, D-branes, intersecting D-branes.
    - model building, (string) phenomenology.