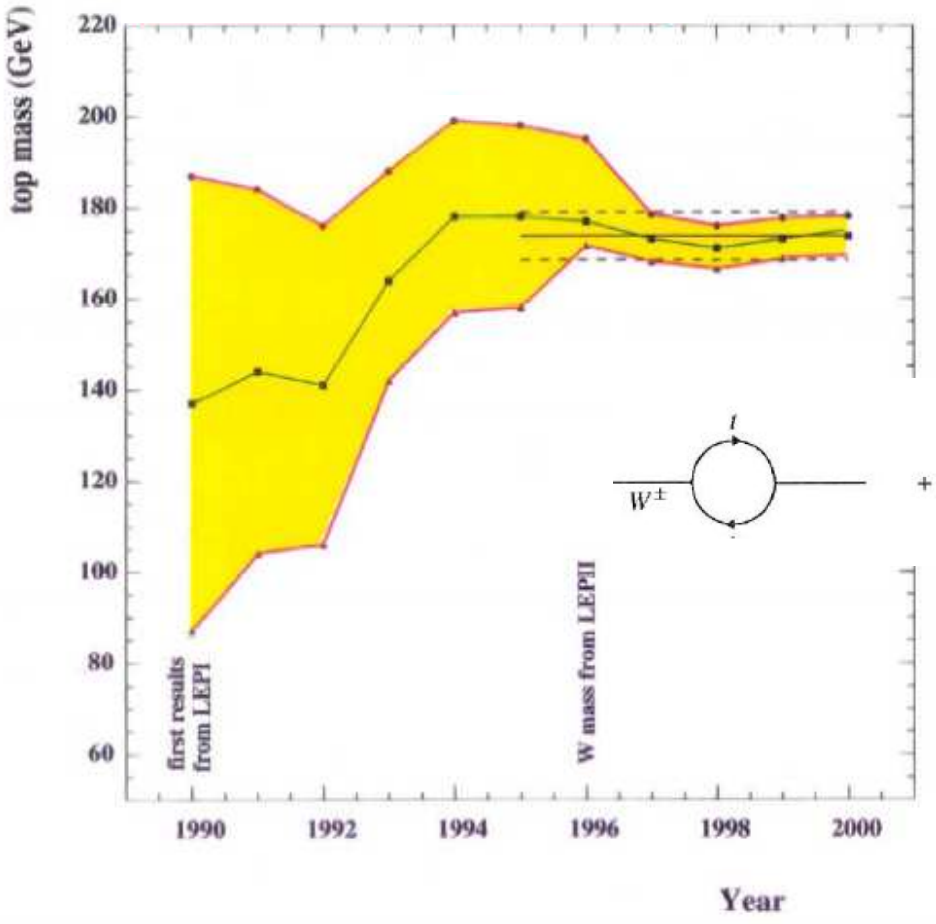
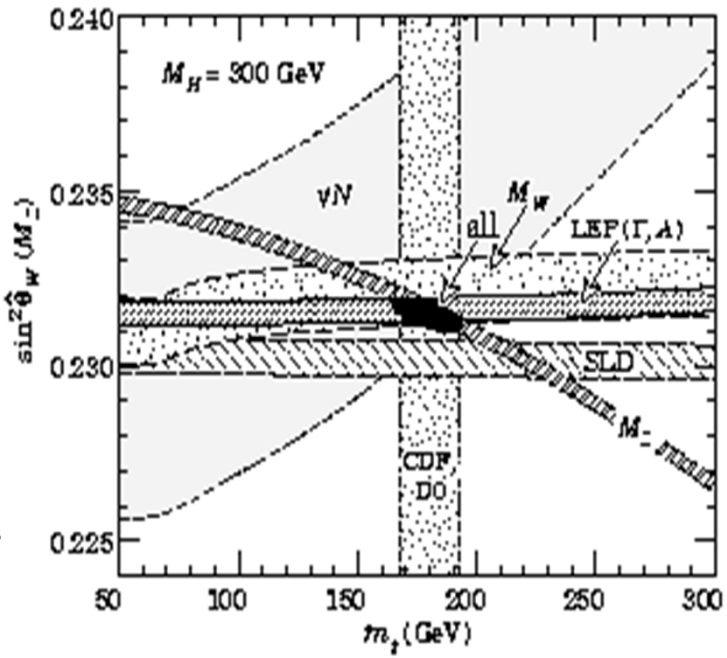
The quest for the top quark

Electroweak precision measurements at LEP/CERN sensitive to top quark mass and Higgs mass (indirect effects) already before top discovery

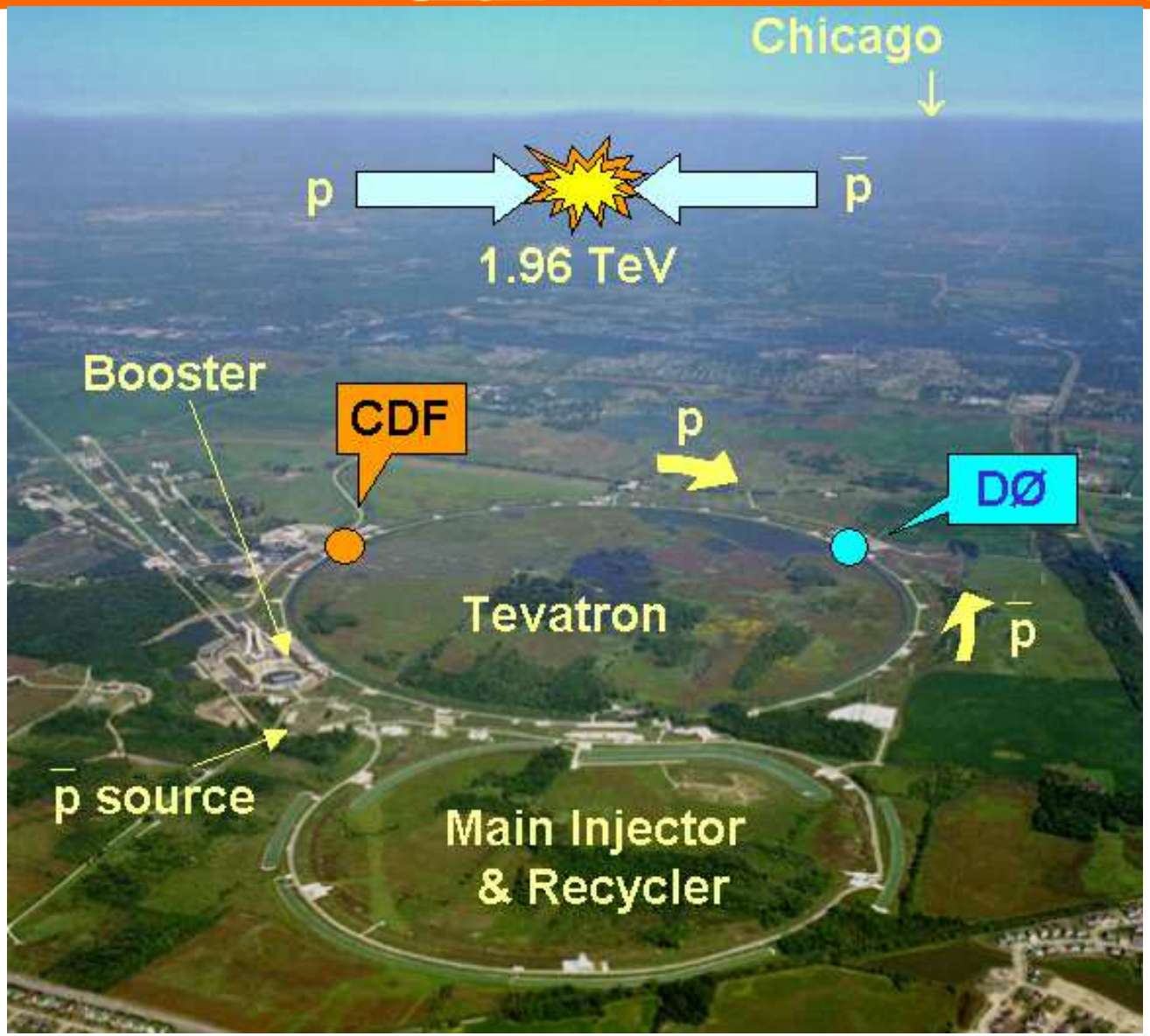




$$\propto \left(\frac{M_t}{M_W}\right)^2, \ln\left(\frac{M_h}{M_W}\right)$$

-> $M_t \sim 170$ GeV

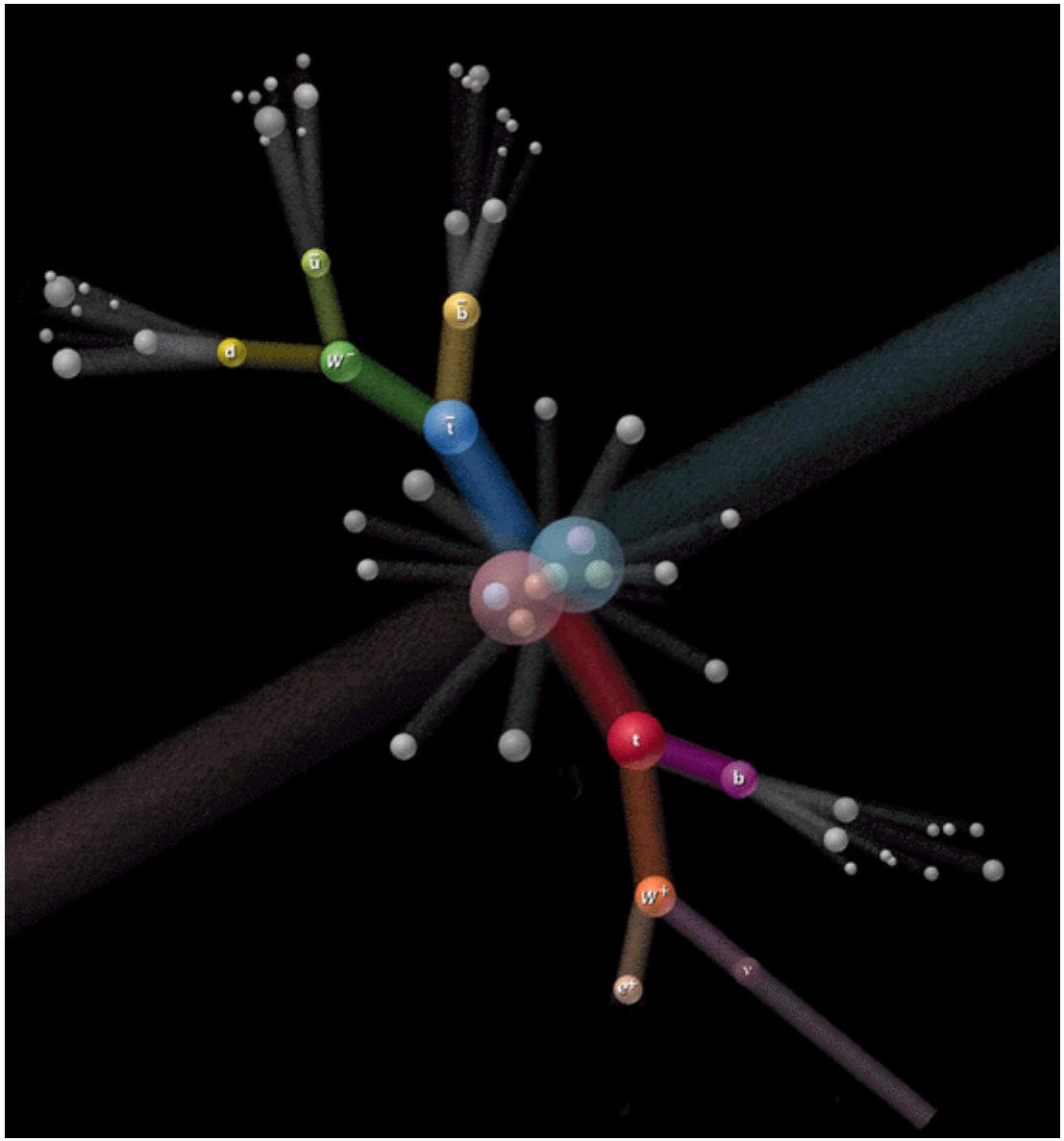
The Tevatron (Fermilab)



data taking ended in 2011

analysis still ongoing

Top quark discovery (Fermilab 1995)



Top quark actually found where expected!

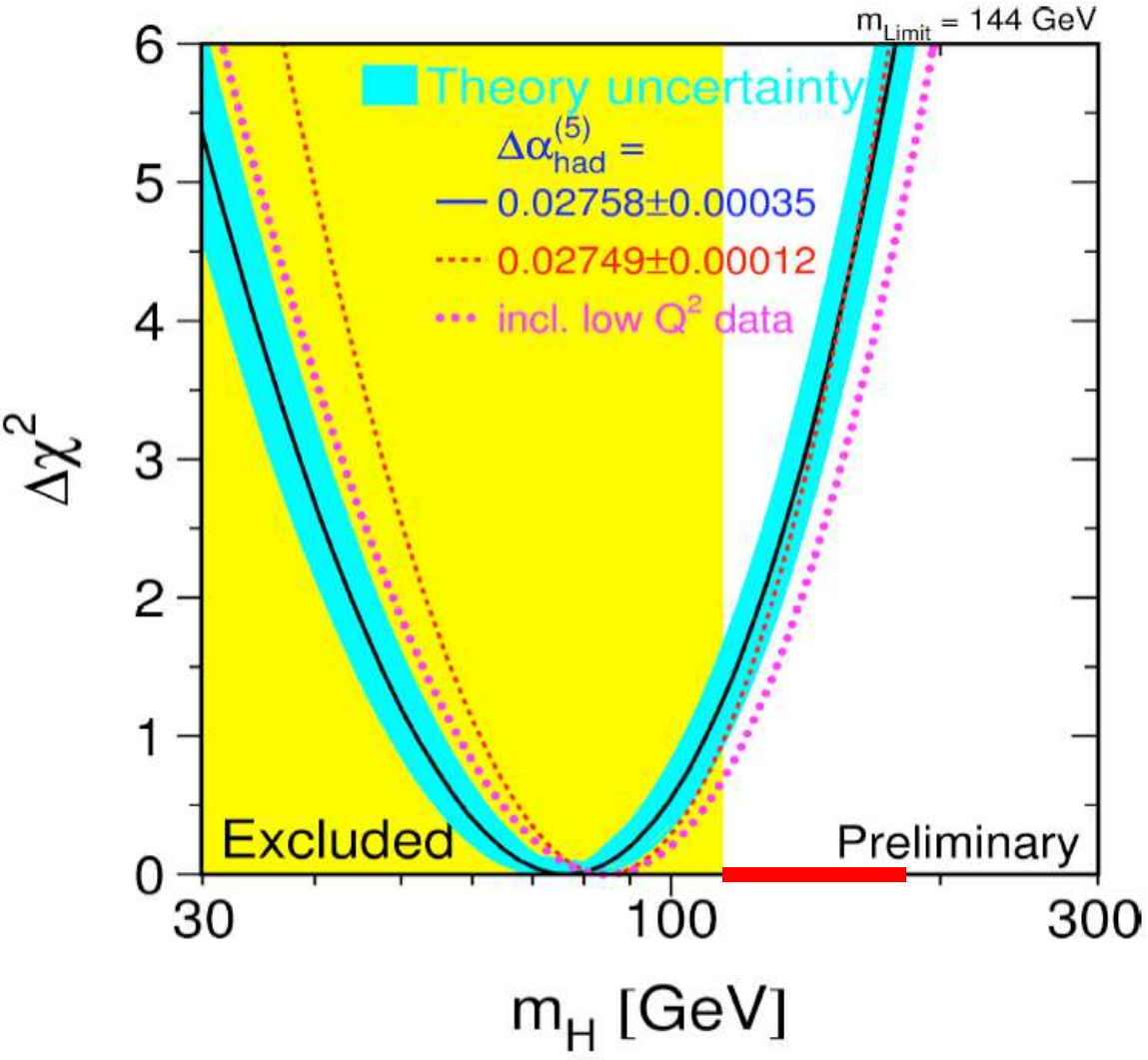
Tevatron at Fermilab (CDF + D0)

measured mass value: (PDG18)

M_{top} = 173.0 ± 0.4 GeV

it works!

Precision @ LEP, and Higgs



insert measured top mass into precision measurements at LEP

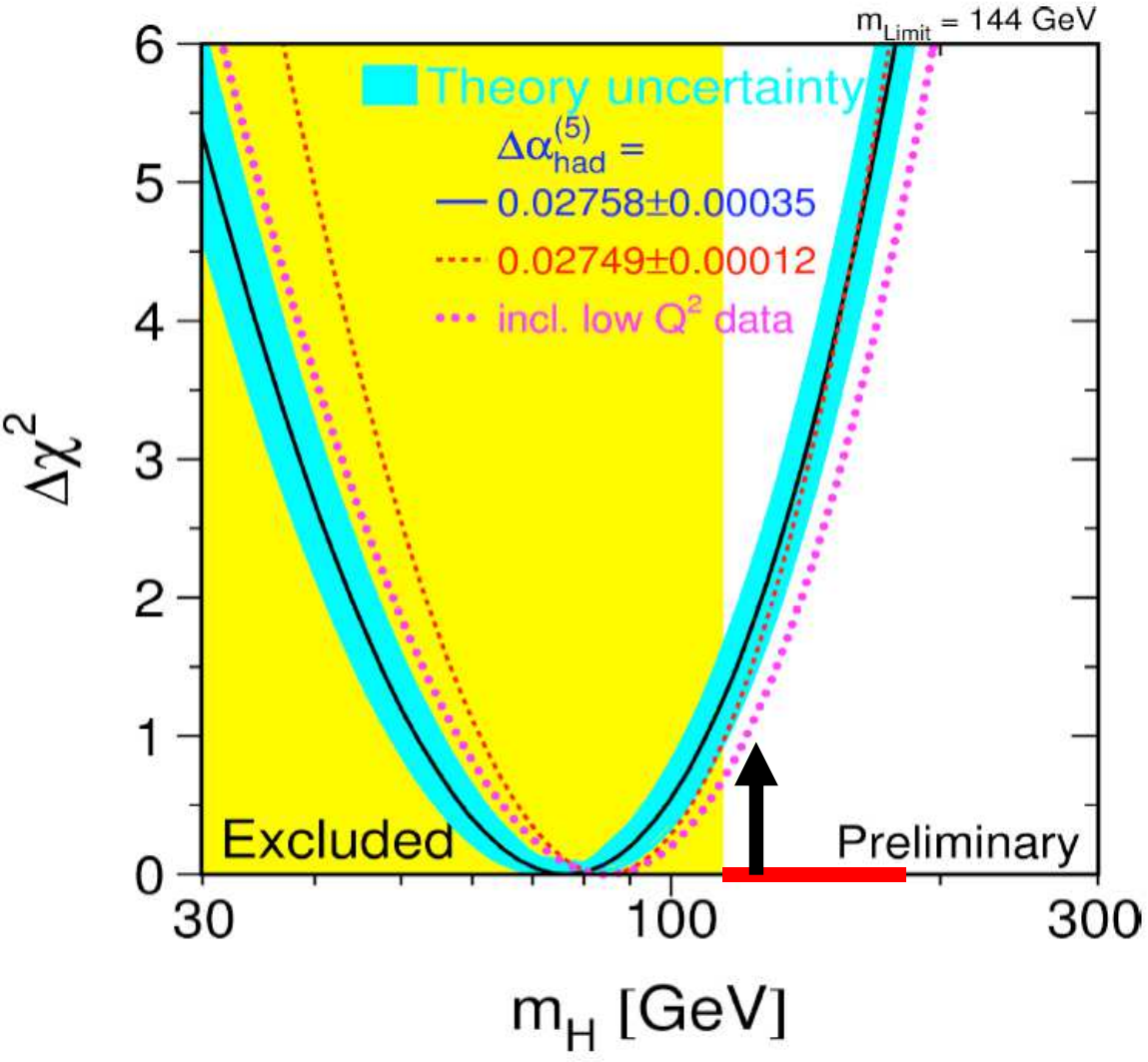
-> now sensitive to Higgs mass

m_H < 182 GeV at 95% CL

LEP direct lower limit:

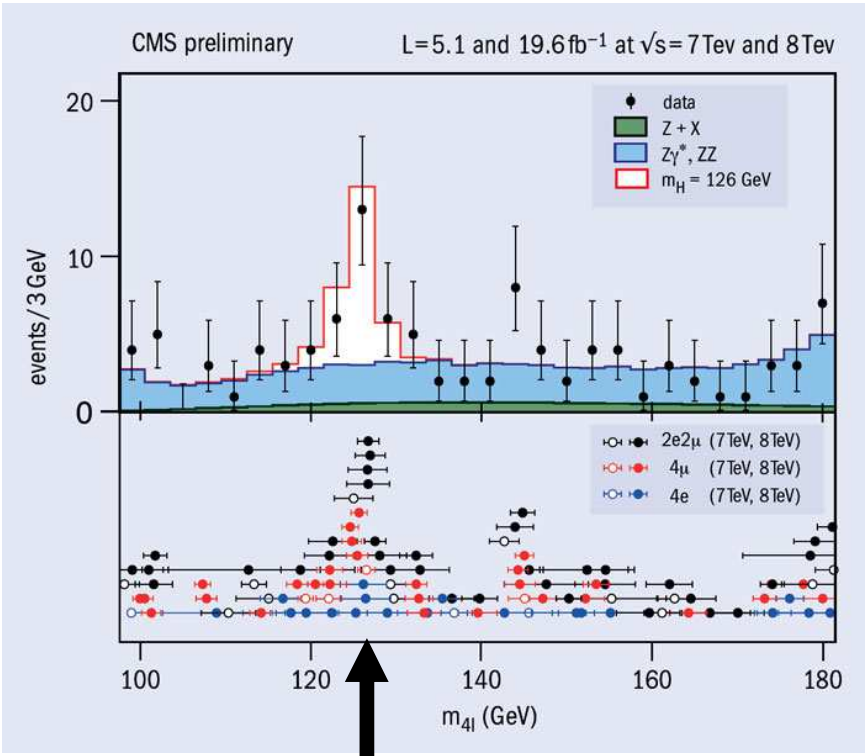
m_H > 114 GeV at 95% CL

Precision @ LEP and Higgs at LHC



and there it was!

H->ZZ*-> 4 leptons



$m_H = 125.7 \pm 0.4$ GeV

Special Fundamental Physics Prize 2013

for their leadership role in the scientific endeavour
that led to the discovery of the new Higgs-like particle
by the ATLAS and CMS collaborations at CERN's Large Hadron Collider.

by the Milner Foundation

Peter Jenni, ATLAS

Tejinder Singh Virdee, CMS

Lyn Evans, LHC

Fabiola Gianotti, ATLAS

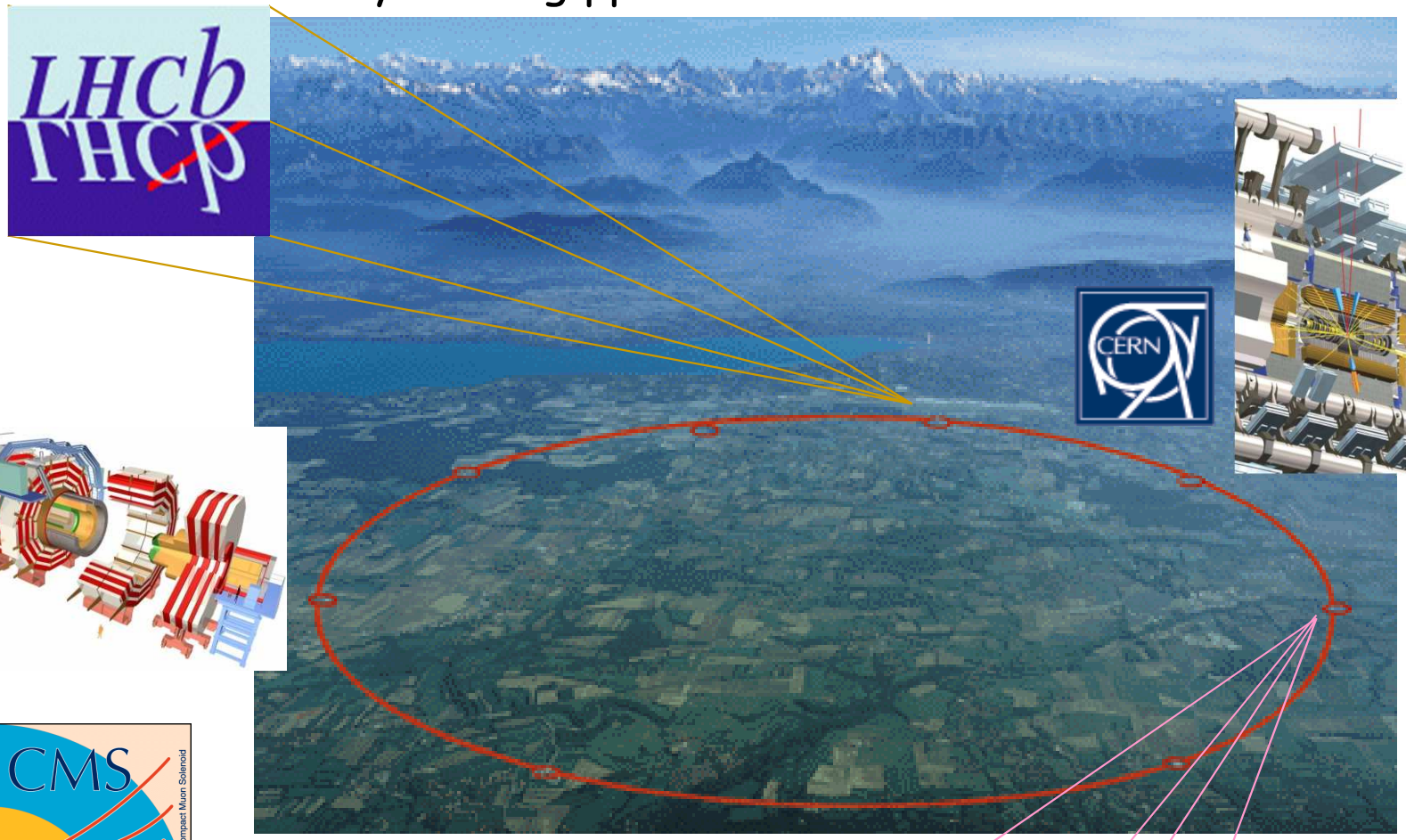
Joe Incandela, CMS

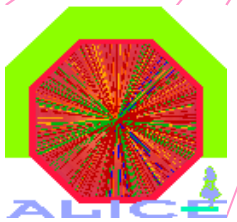
Michel Della Negra CMS

Guido Tonelli, CMS

The LHC Project

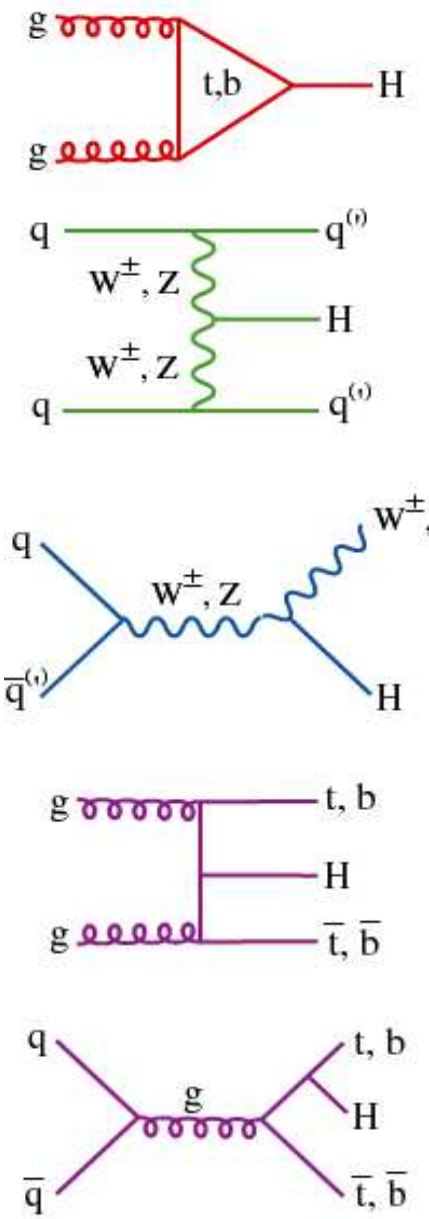
recently running pp collisons @ 13 TeV -> 14 TeV soon

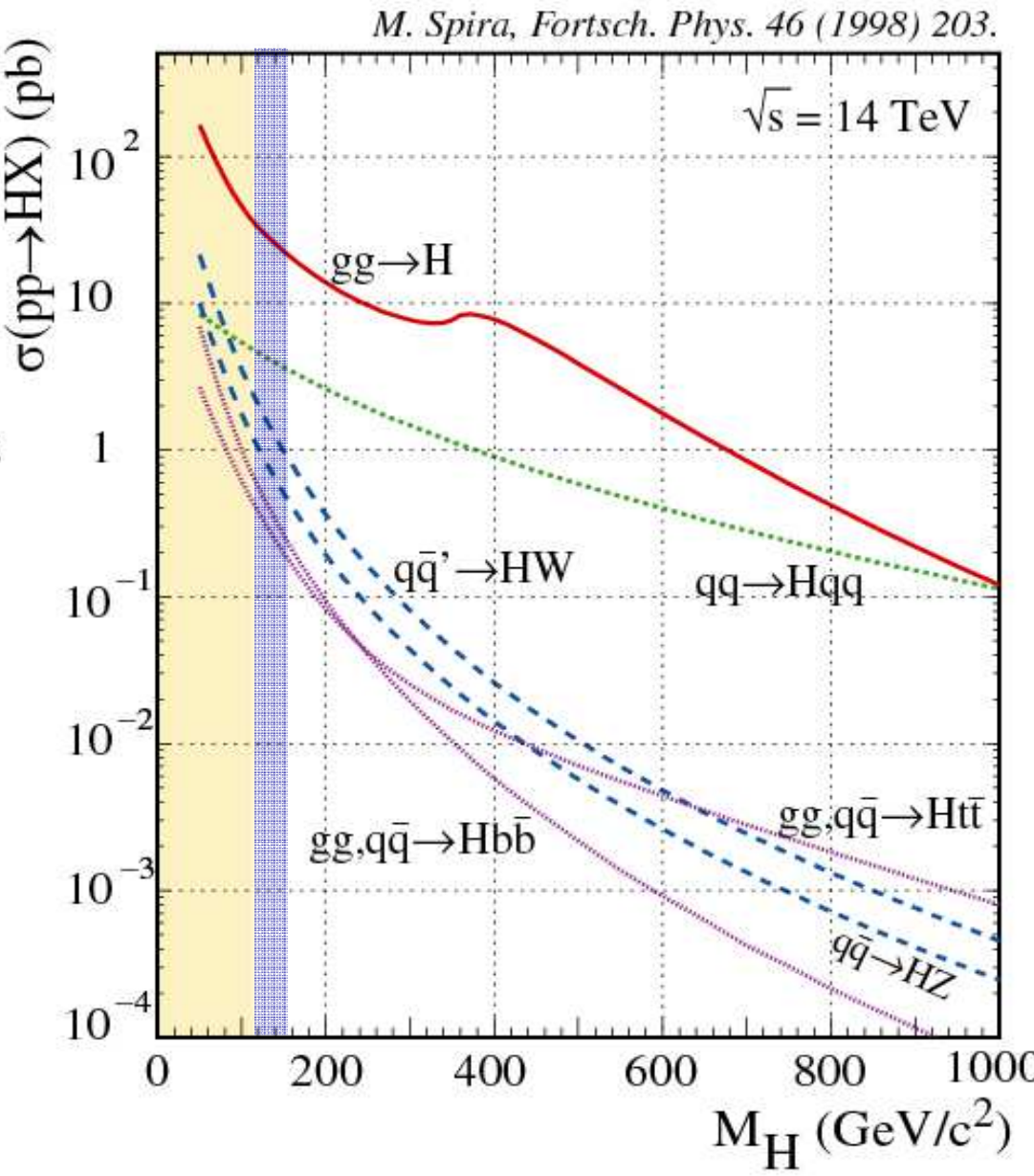




Higgs production at LHC

measure as many as possible to check Higgs properties

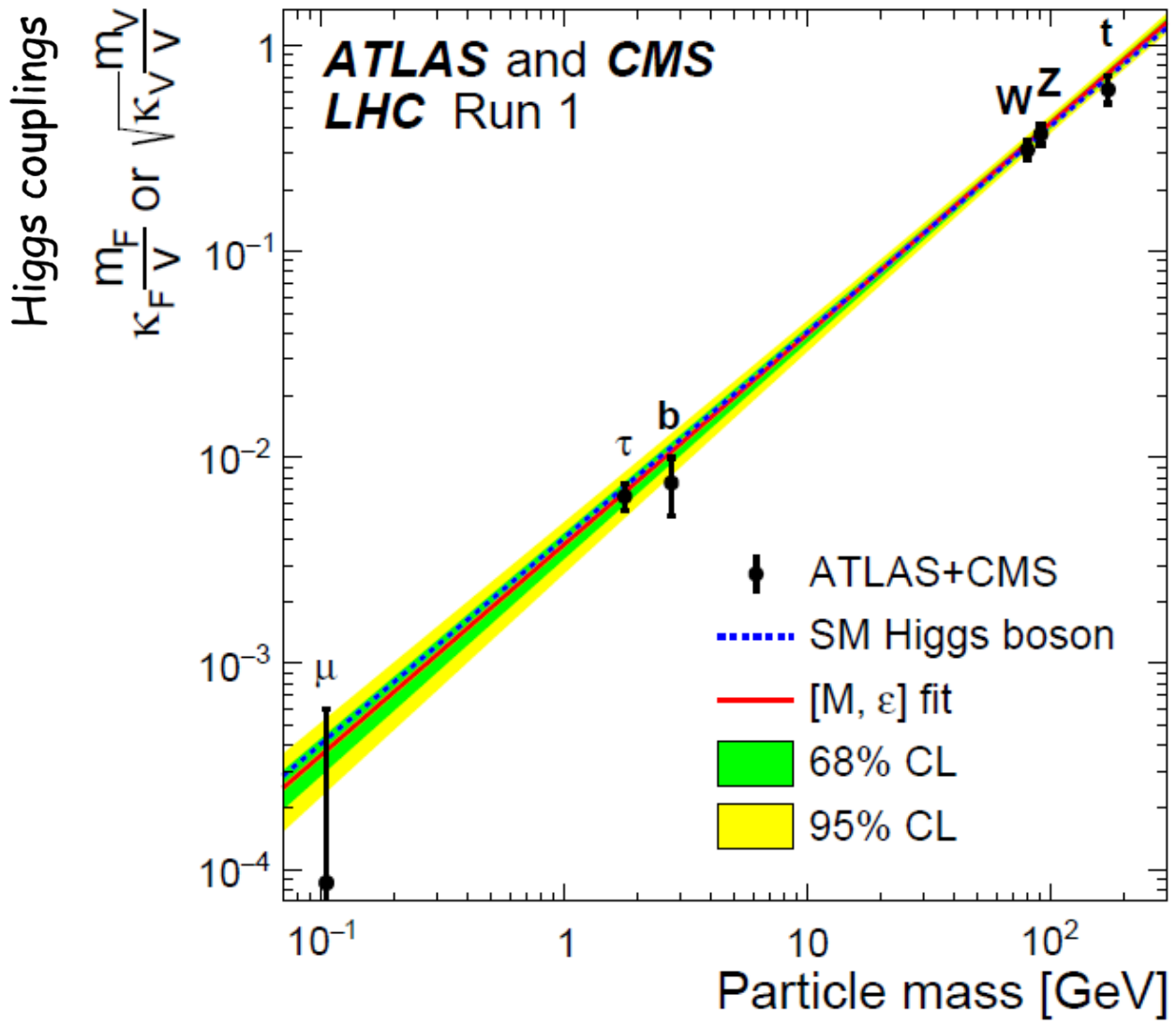




Direct measurements of Higgs Yukawa couplings

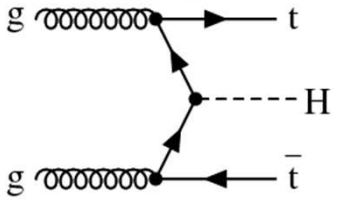
examples

ATLAS and CMS, JHEP08 (2016) 045

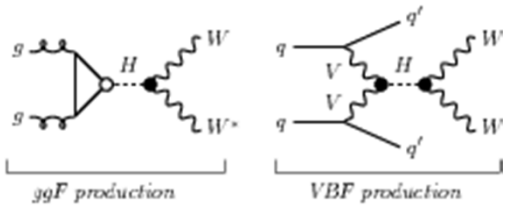


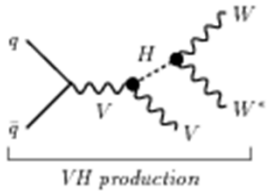
Direct measurements of Higgs Yukawa couplings

examples



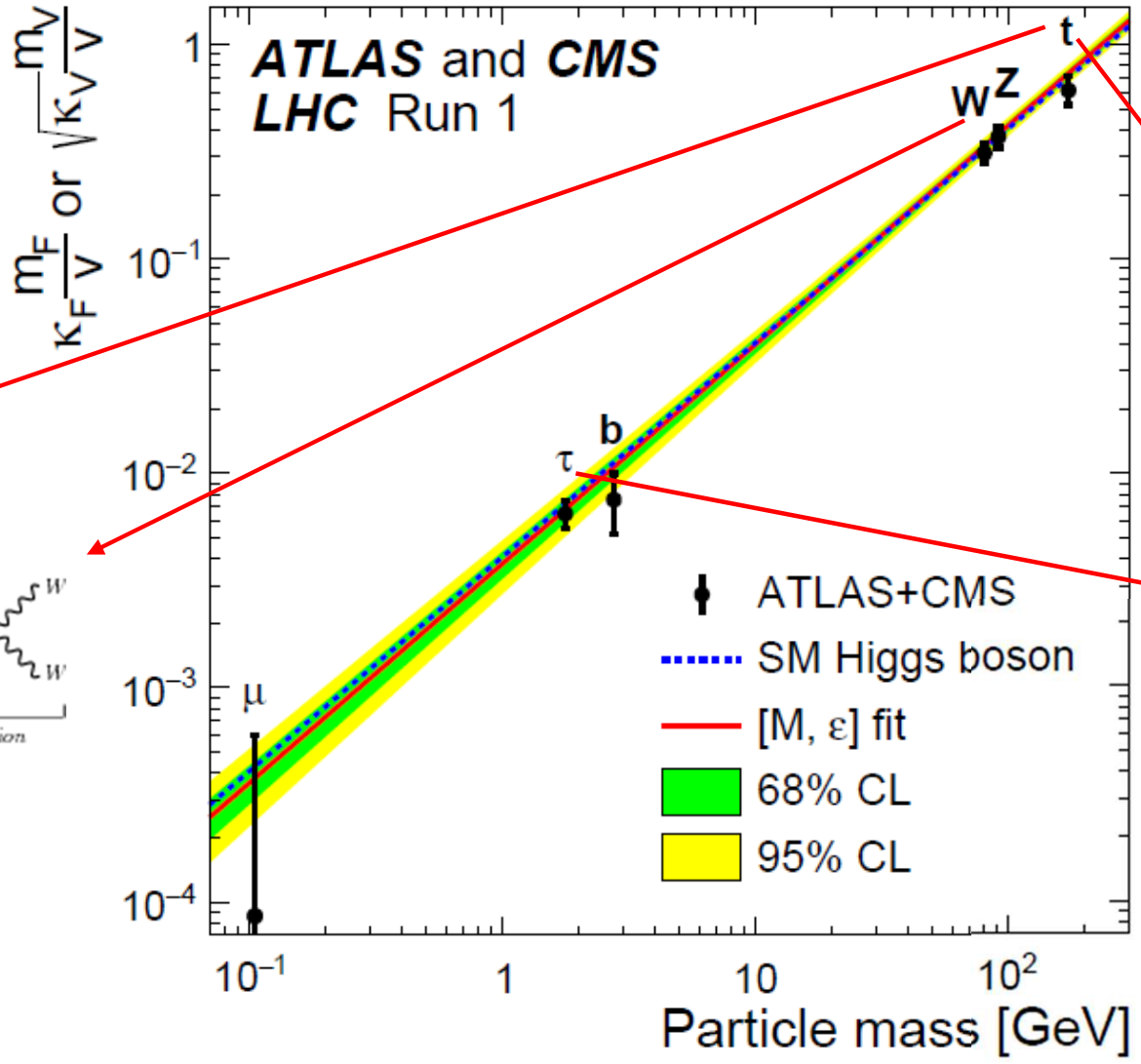
5.8 σ observed
(June 2018)

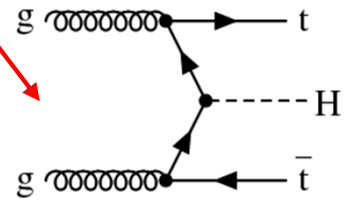




5.9 σ observed
(December 2014)

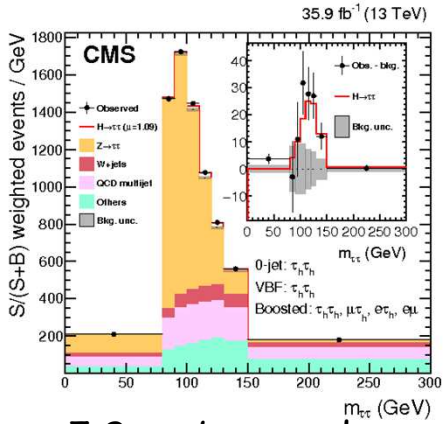
ATLAS and CMS, JHEP08 (2016) 045





5.2 σ observed
(April 2018)

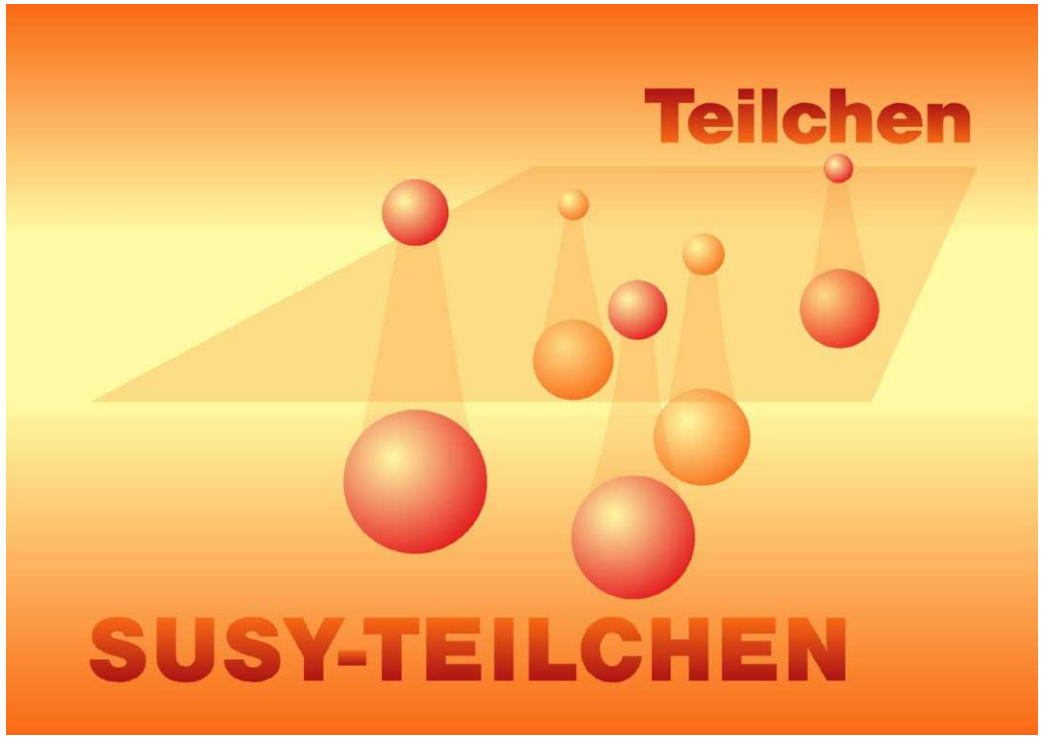
H -> ττ



5.9 σ observed
(August 2017)

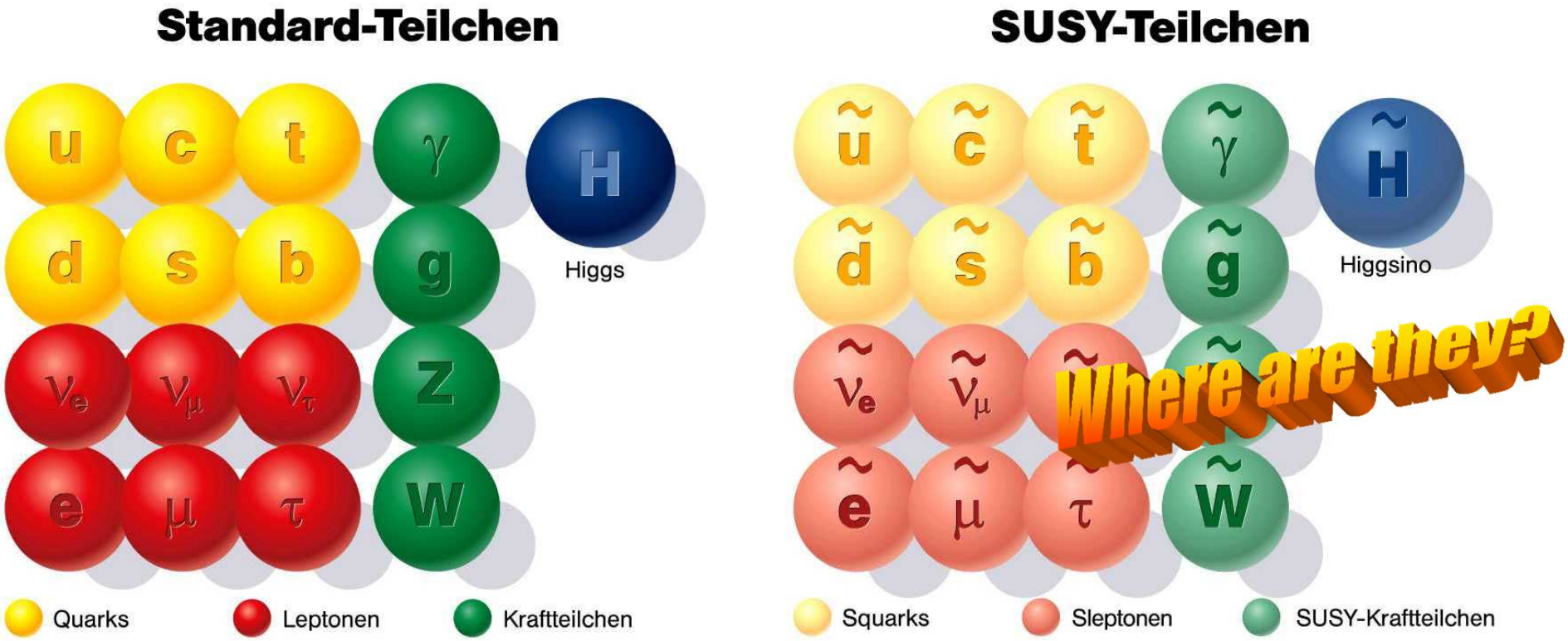
Supersymmetry

- A way to solve theoretical problems with Unification of Forces: Supersymmetry
- For each existing particle, introduce similar particle, with spin different by 1/2 unit

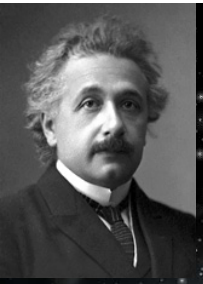


Supersymmetry

- double number of particles:



- not seen at LEP, HERA, Tevatron ... -> must be heavy!
- **(still) hope to see them at LHC ! ?**



Albert Einstein
(Nobel 1923,
for photo-electic
effekt)

Illustration: A. Simonnet (SSU)

Black Hole merger

We can hear the universe!

Rainer Weiss

Kip Thorne

Barry Barish

(Nobel 2017)

INSPIRAL

MERGER

RINGDOWN

LIGO 2016

HANFORD, WASHINGTON

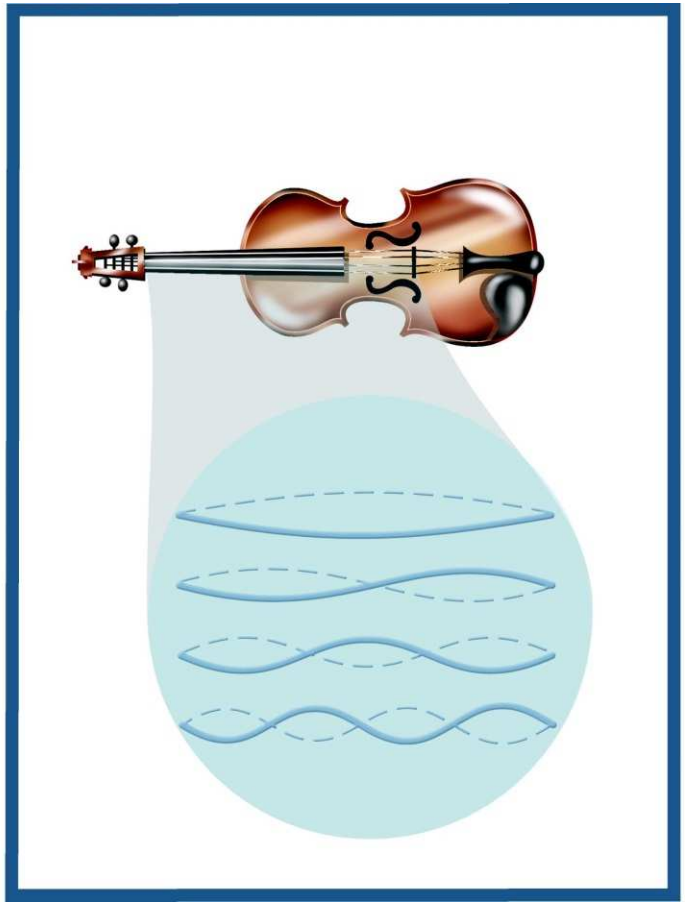
LIVINGSTON, LOUISIANA

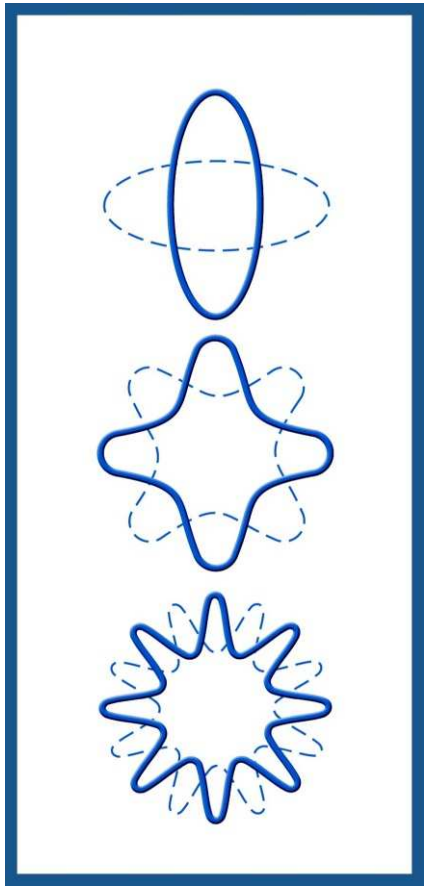
Challenge:

How to merge this with the Standard Model of particle physics?

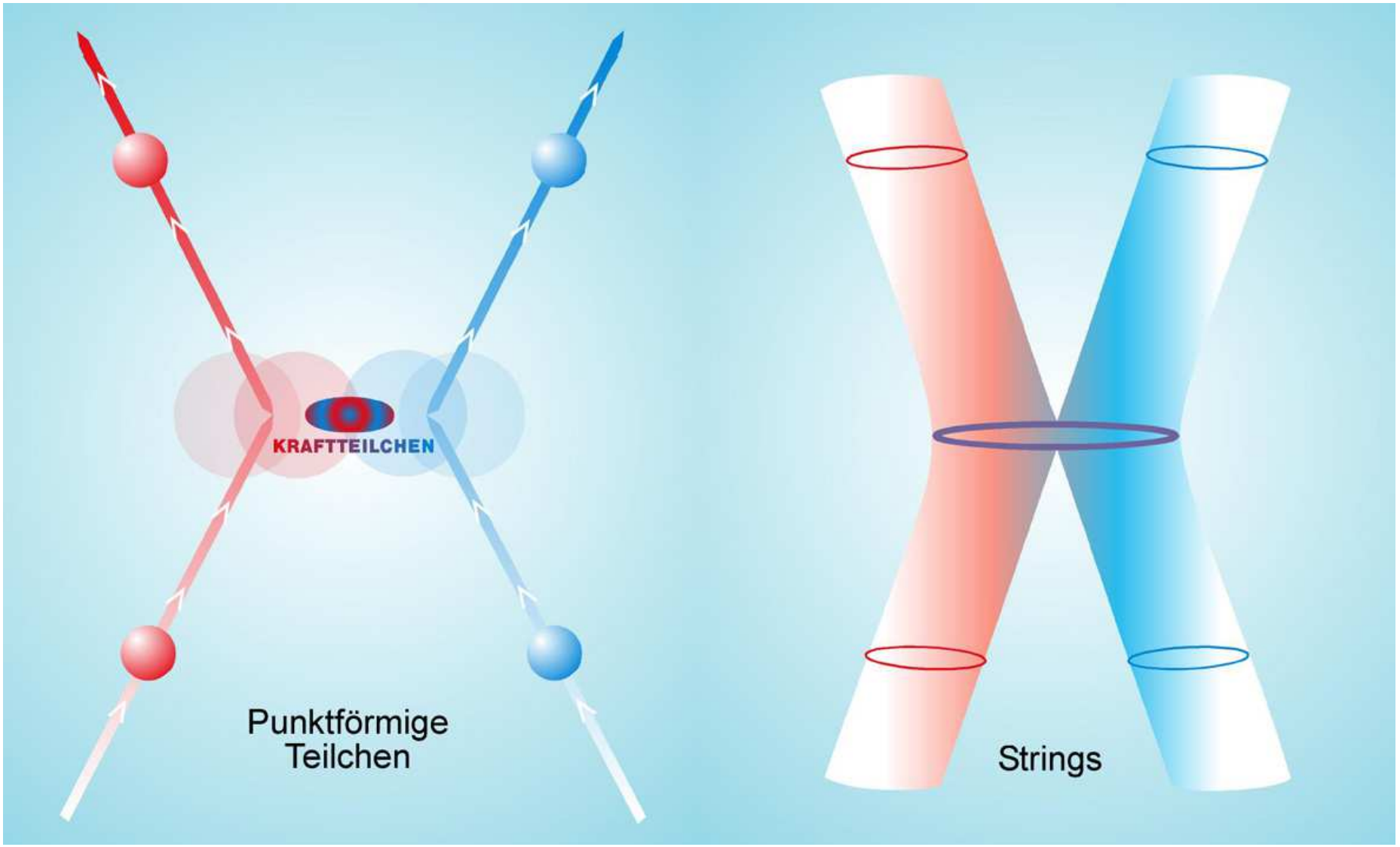
Unification and Superstrings

To include gravity in unification of forces, need Superstrings (Supersymmetric strings)



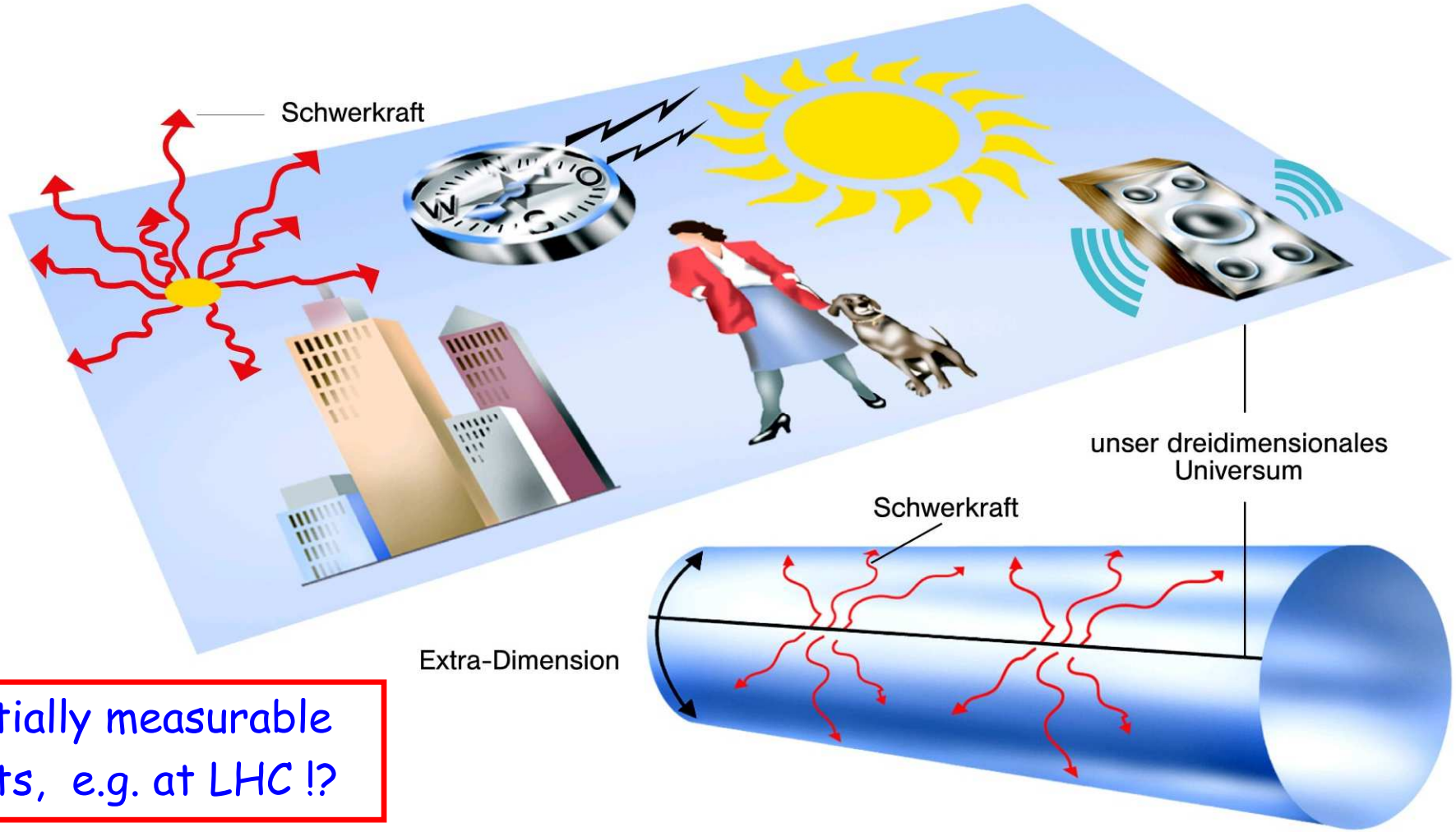


Superstring interaction



Extra Dimensions?

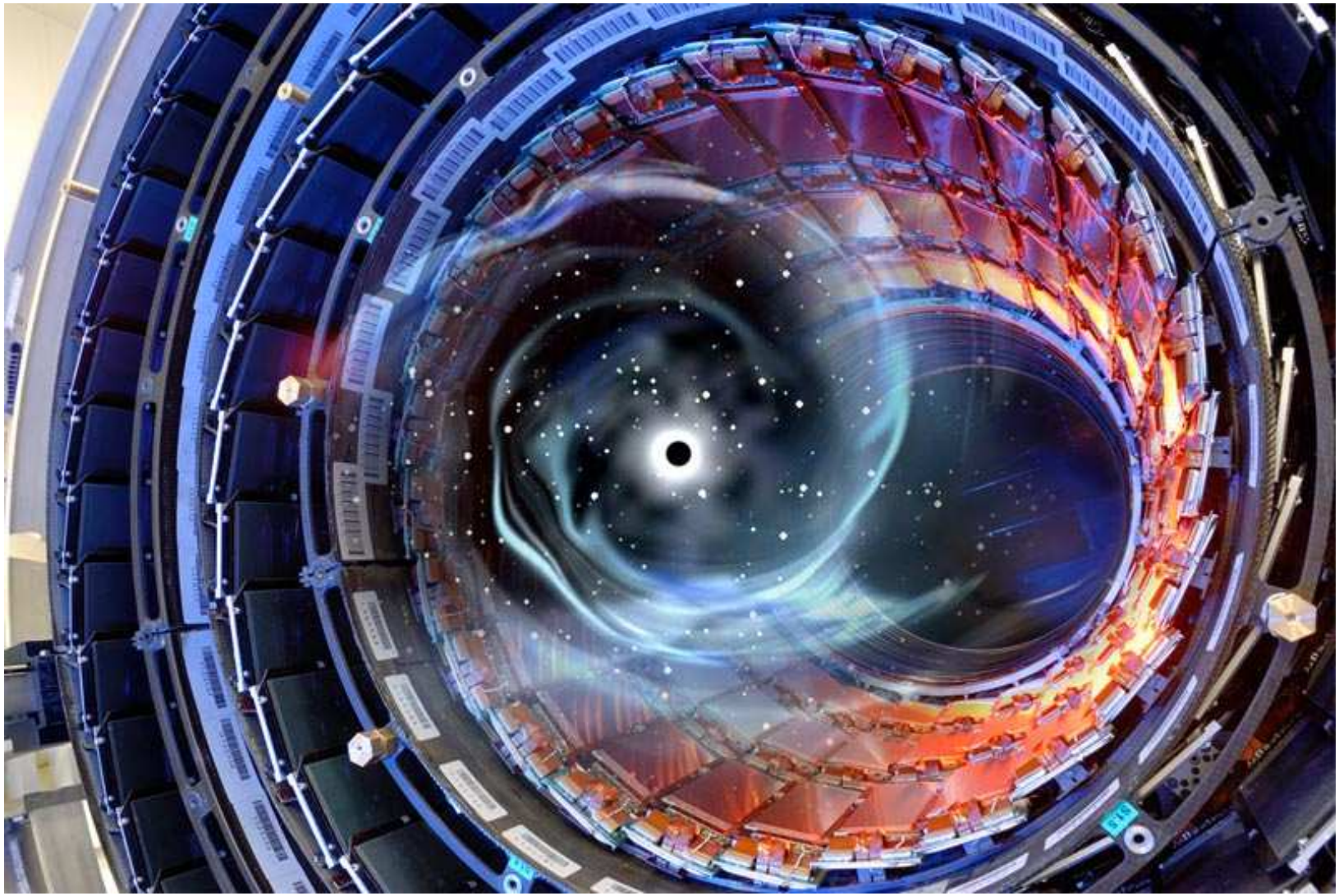
- Superstrings require more than 3+1 dimensions (10 or 11)
- additional "extra" dimensions -> "curled up" (?)



potentially measurable effects, e.g. at LHC !?

extra dimensions -> micro black holes?

extremely short-lived - no indications so far

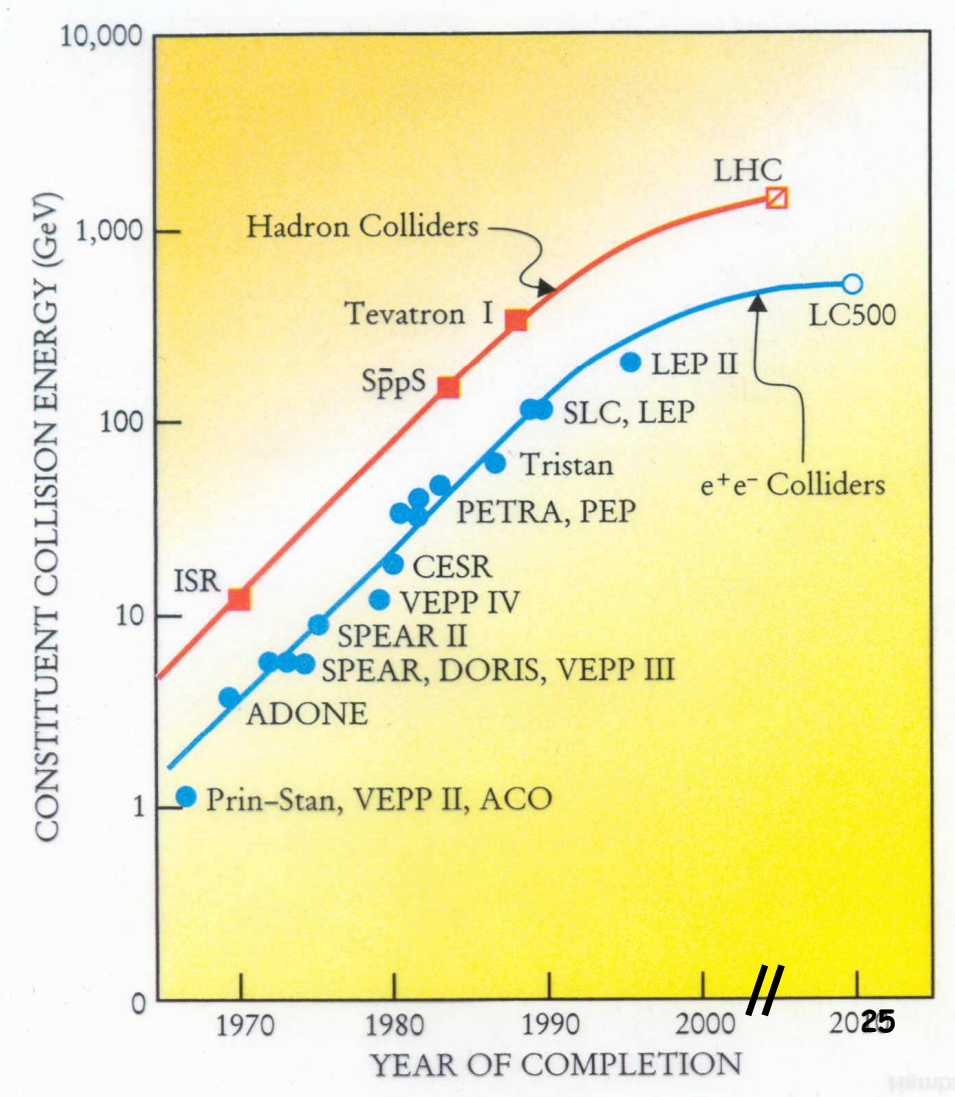


The case for an e+e- Linear Collider

- Historically, hadron (proton) and electron colliders have yielded great symbiosis:
- hadron colliders: discoveries at highest energies
- electron colliders: discoveries and precision measurements
- latest example: Tevatron/LEP (top), now Higgs at LHC

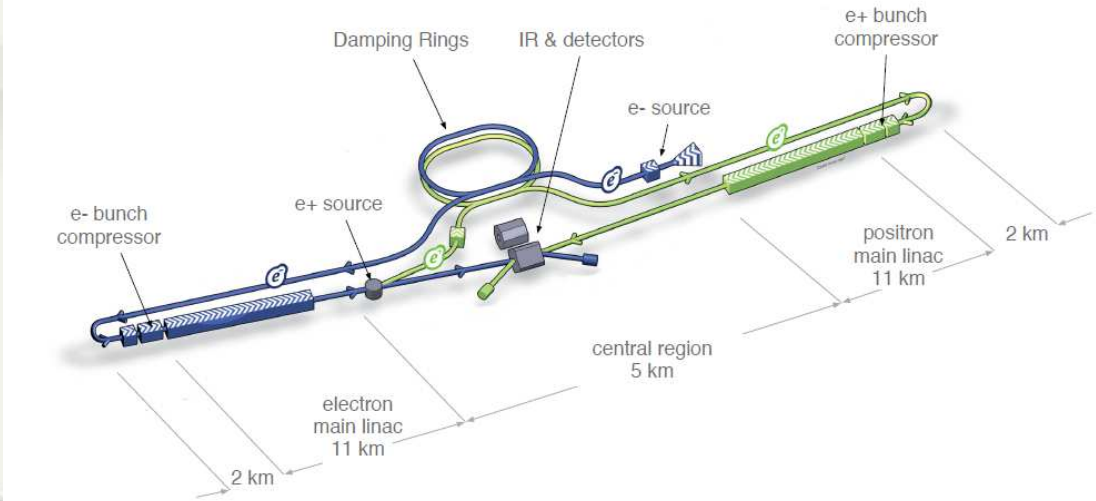
⇒ **International Linear Collider!**

decision unfortunately further delayed



The ILC

"NEW DIRECTIONS IN SCIENCE ARE LAUNCHED BY NEW TOOLS MUCH MORE OFTEN THAN BY NEW CONCEPTS. THE EFFECT OF A CONCEPT-DRIVEN REVOLUTION IS TO EXPLAIN OLD THINGS IN NEW WAYS. THE EFFECT OF A TOOL-DRIVEN REVOLUTION IS TO DISCOVER NEW THINGS THAT HAVE TO BE EXPLAINED." FREEMAN DYSON, Imagined Worlds

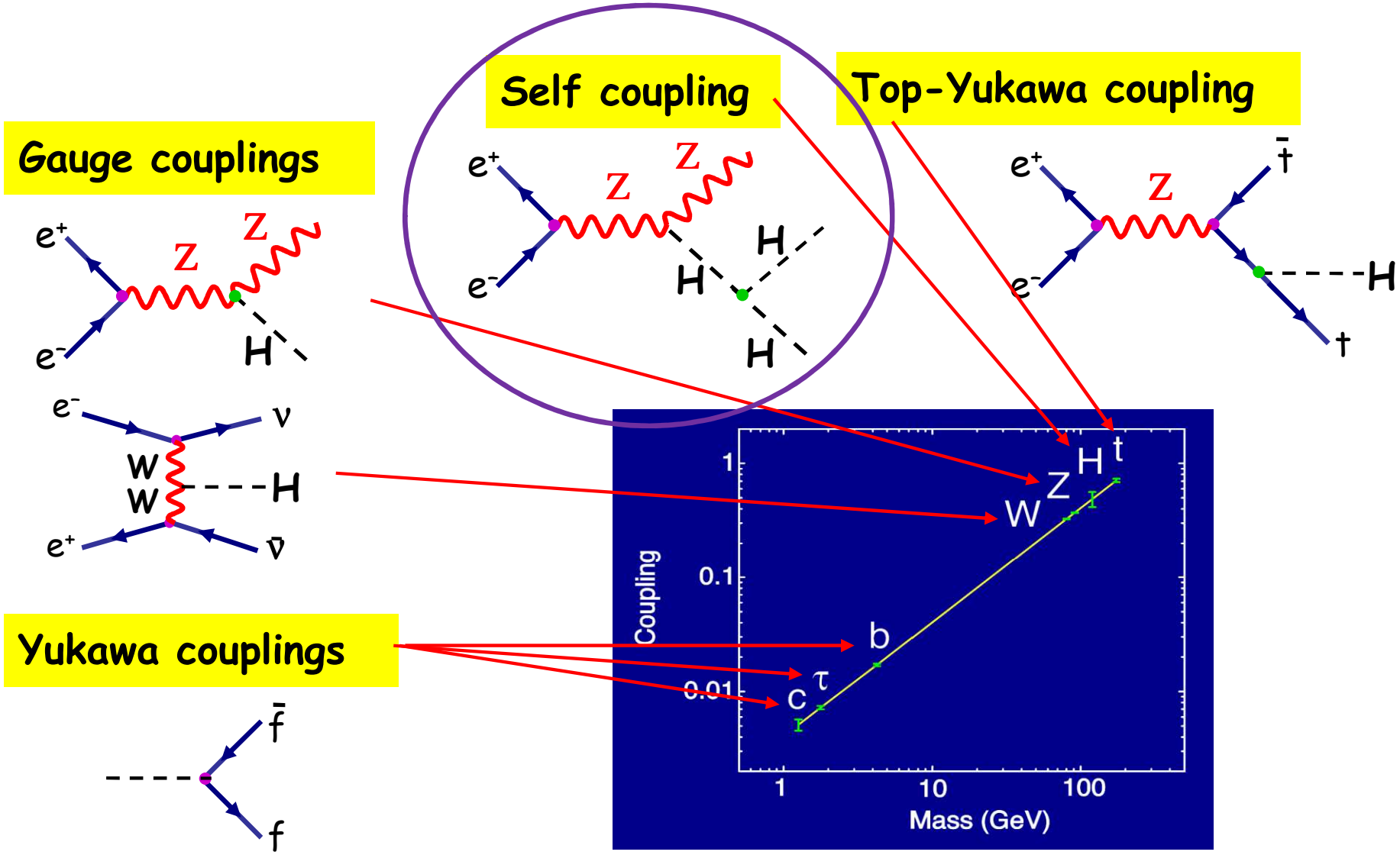


Technical Design Report released (June 2013)

Hosting in Japan being discussed

(+ alternatives, e.g. CLIC)

Example: Higgs Physics at the ILC

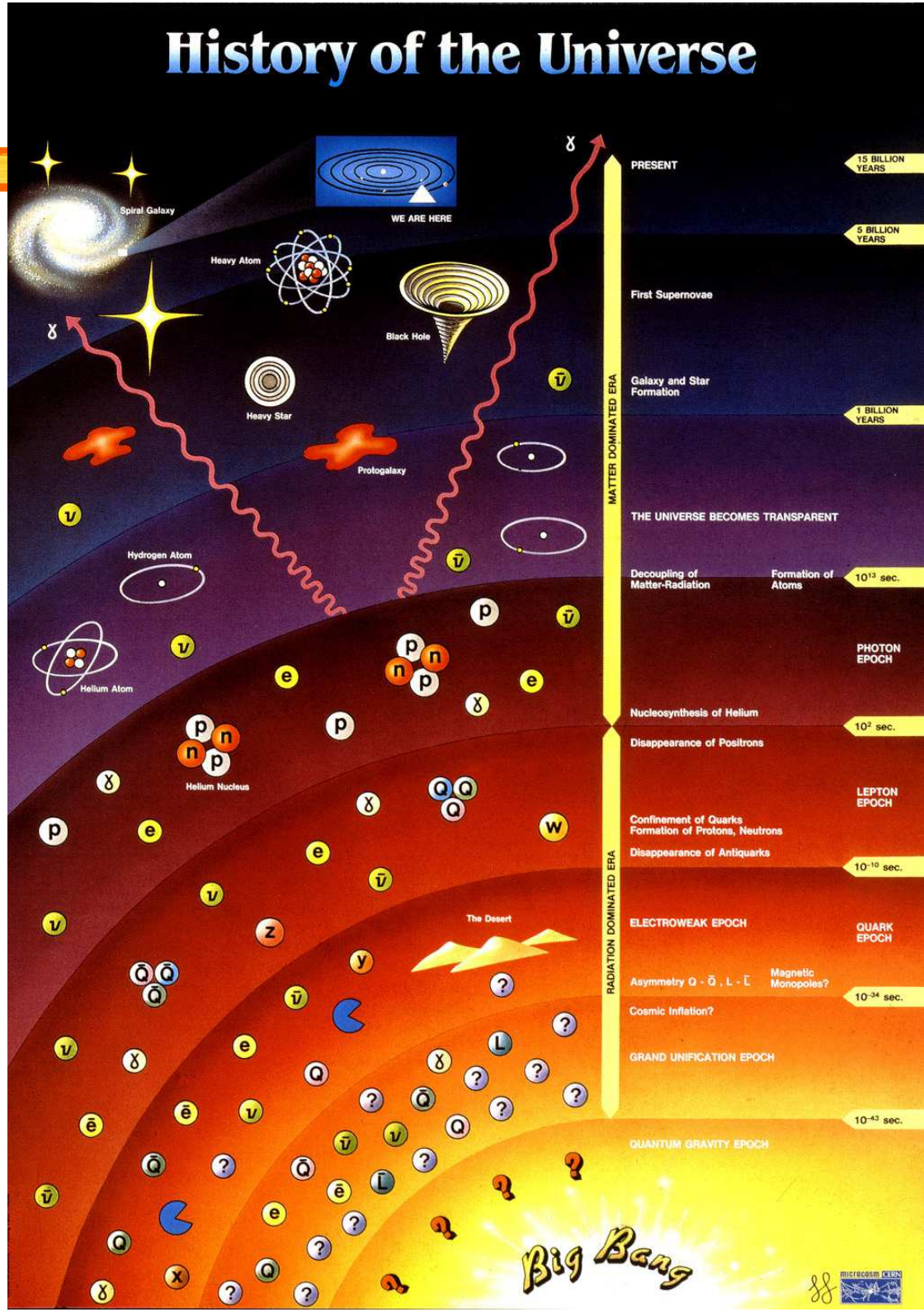


all measurable with very high precision!

Cosmology

Direct link between Particle Physics and Cosmology

increasing energy
-> going further backwards in time in the universe
-> getting closer to the Big Bang



The Big Bang

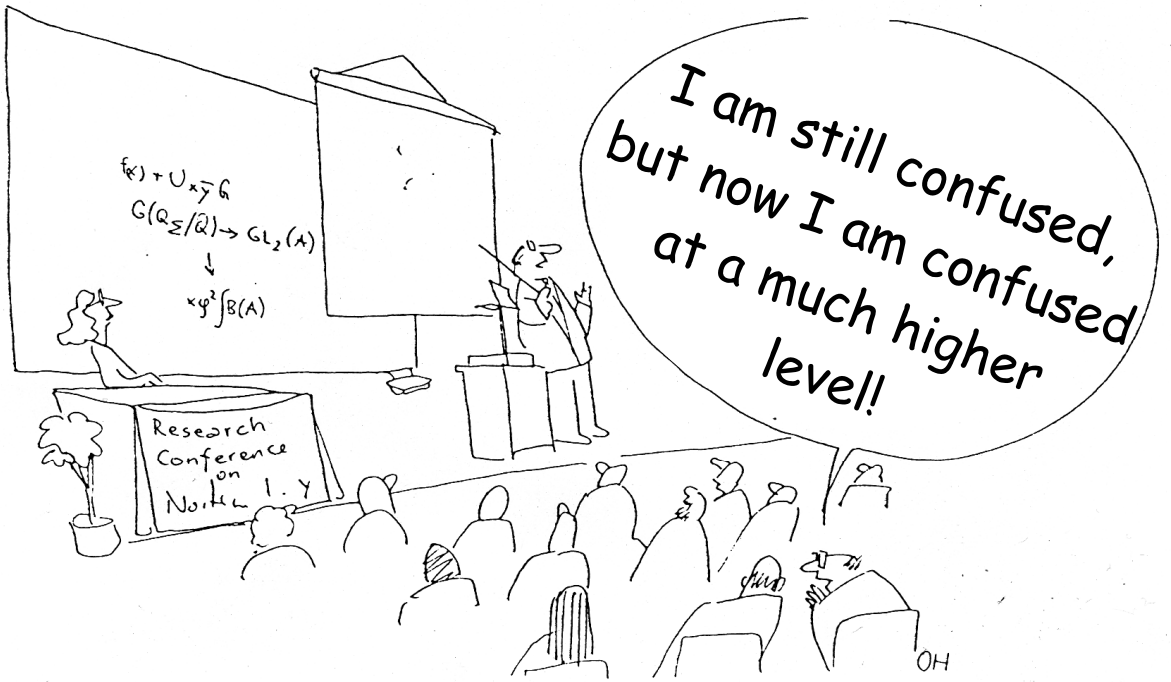
- Galaxy formation

1000 M years

Galaxies begin to form

Elementary Particle Physics is exciting!

- We already know a lot, but many open issues



- Exciting new insights expected for the coming decade (e.g. HL-LHC, Belle II) !

Join the Fun!