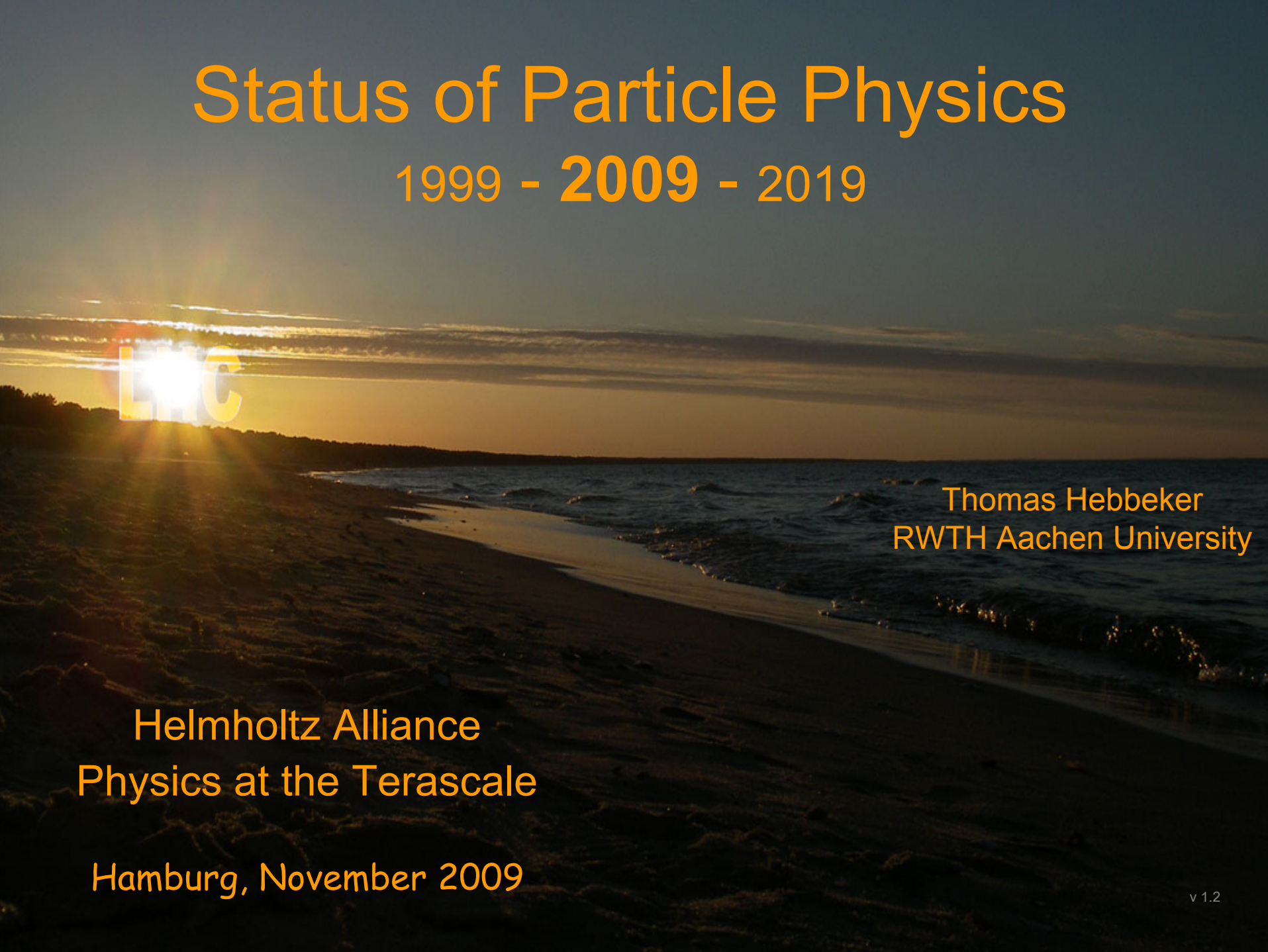
Status of Particle Physics

1999 - **2009** - 2019



Thomas Hebbeker
RWTH Aachen University

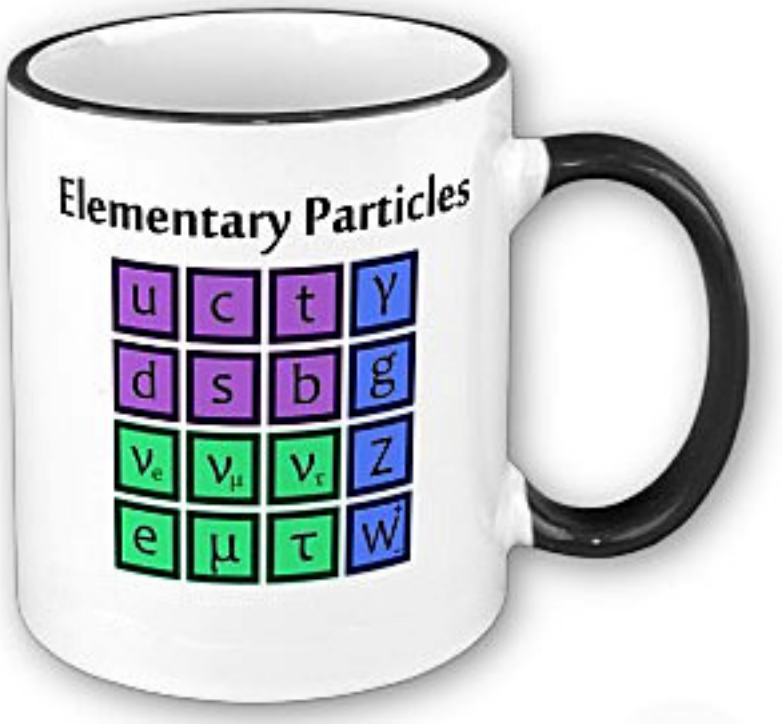
Helmholtz Alliance
Physics at the Terascale

Hamburg, November 2009

v 1.2


CMS
collisions,
pleeeaaase !
LHC-B
ALICE
ATLAS

Standard Model + fundamental questions



great success:

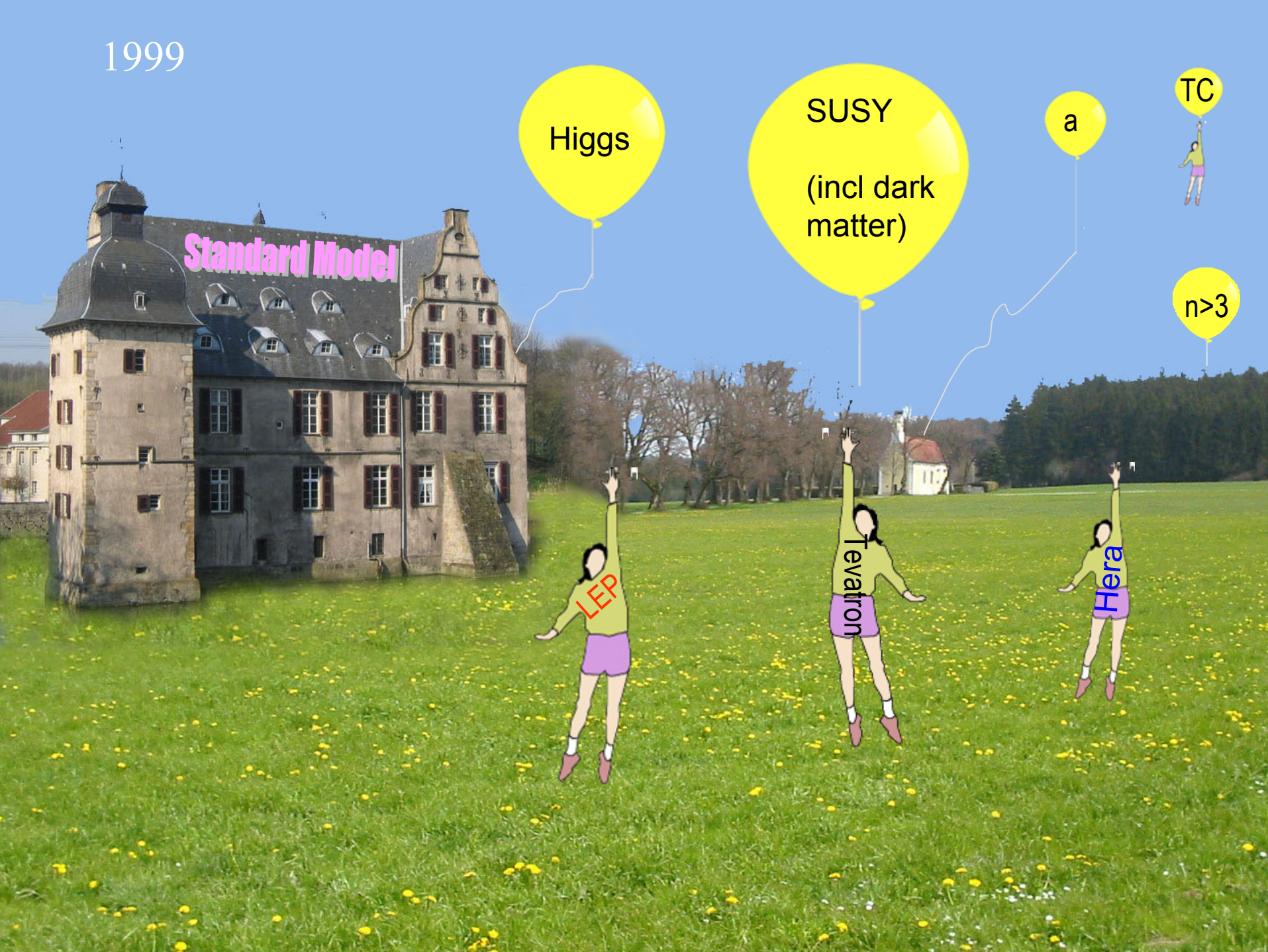
agrees with experiment

$$Q = 10^{-X}\,eV - 10^{11}\,eV$$

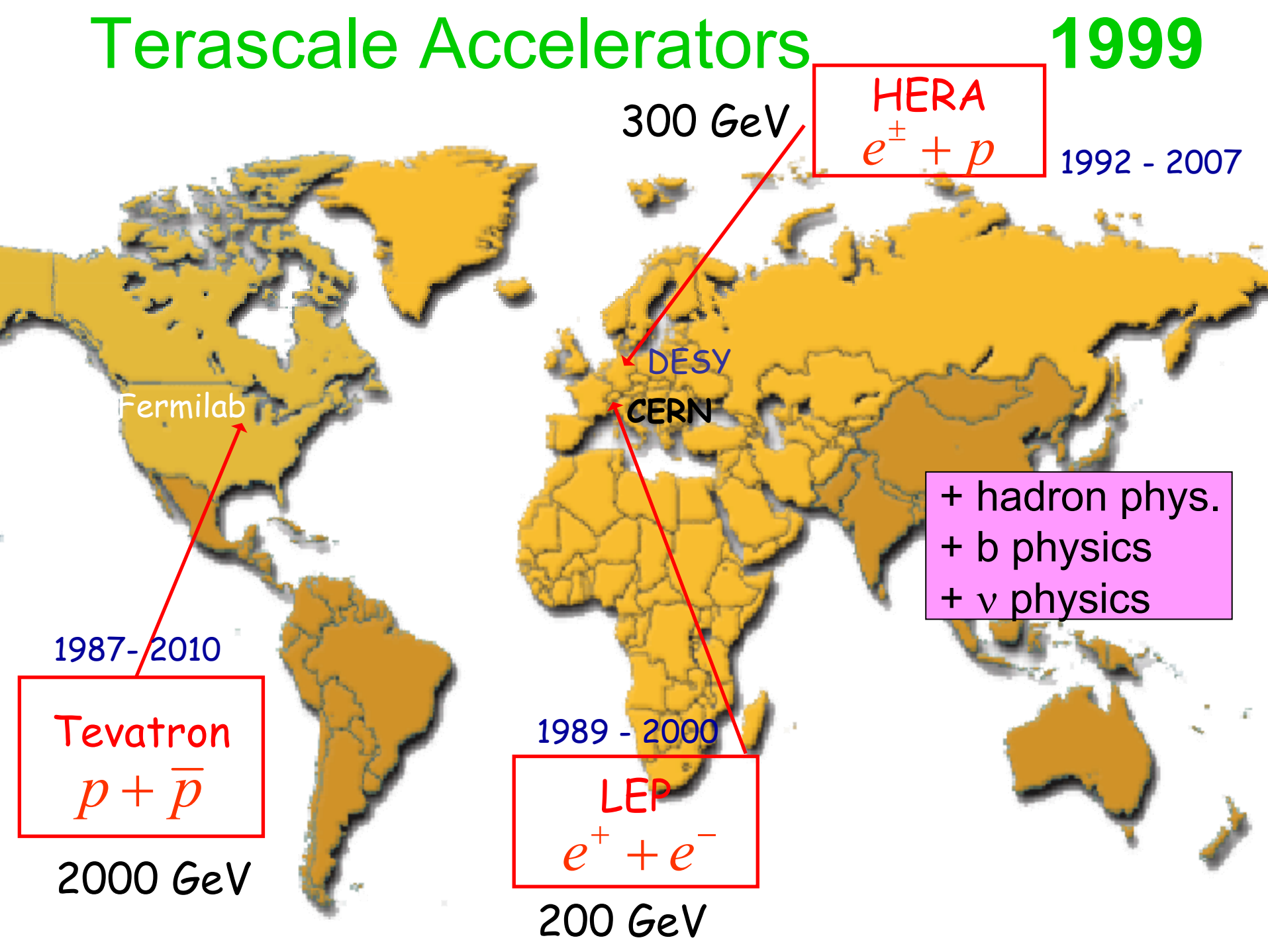
precision: percent or better

puzzles:

- how come model works ?
  does Higgs prevent breakdown ?
- other particles / forces ?
- cosmology !


1999
Standard Model
Higgs
SUSY
(incl dark matter)
a
TC
n>3
LEP
Tevatron
Hera

Terascale Accelerators 1999

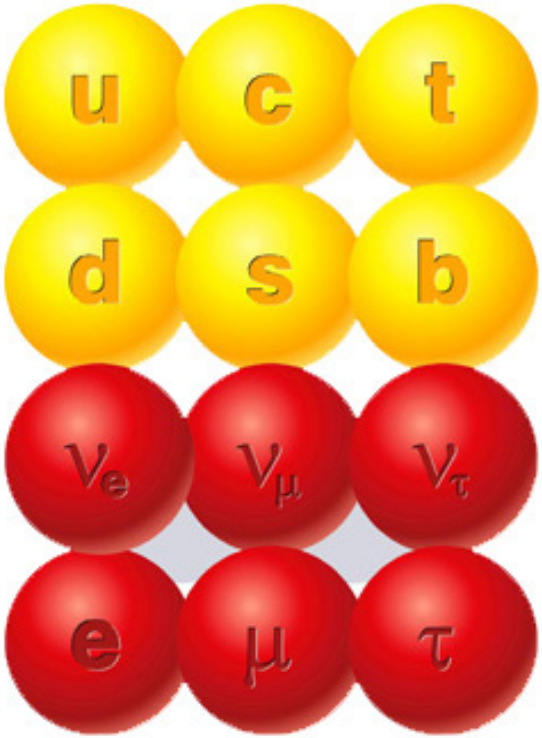


... the world's single largest scientific installation, an $8.4 billion Superconducting Super Collider to be built in Dallas, Texas, with completion set for 1999.

(1993)

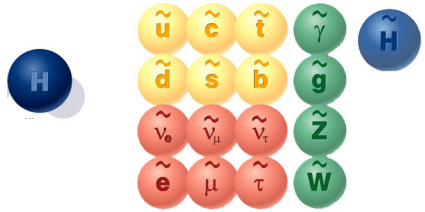
Highlights of the last 10 years

(not all at terascale …)



- particle properties
- electroweak interactions
- strong interactions

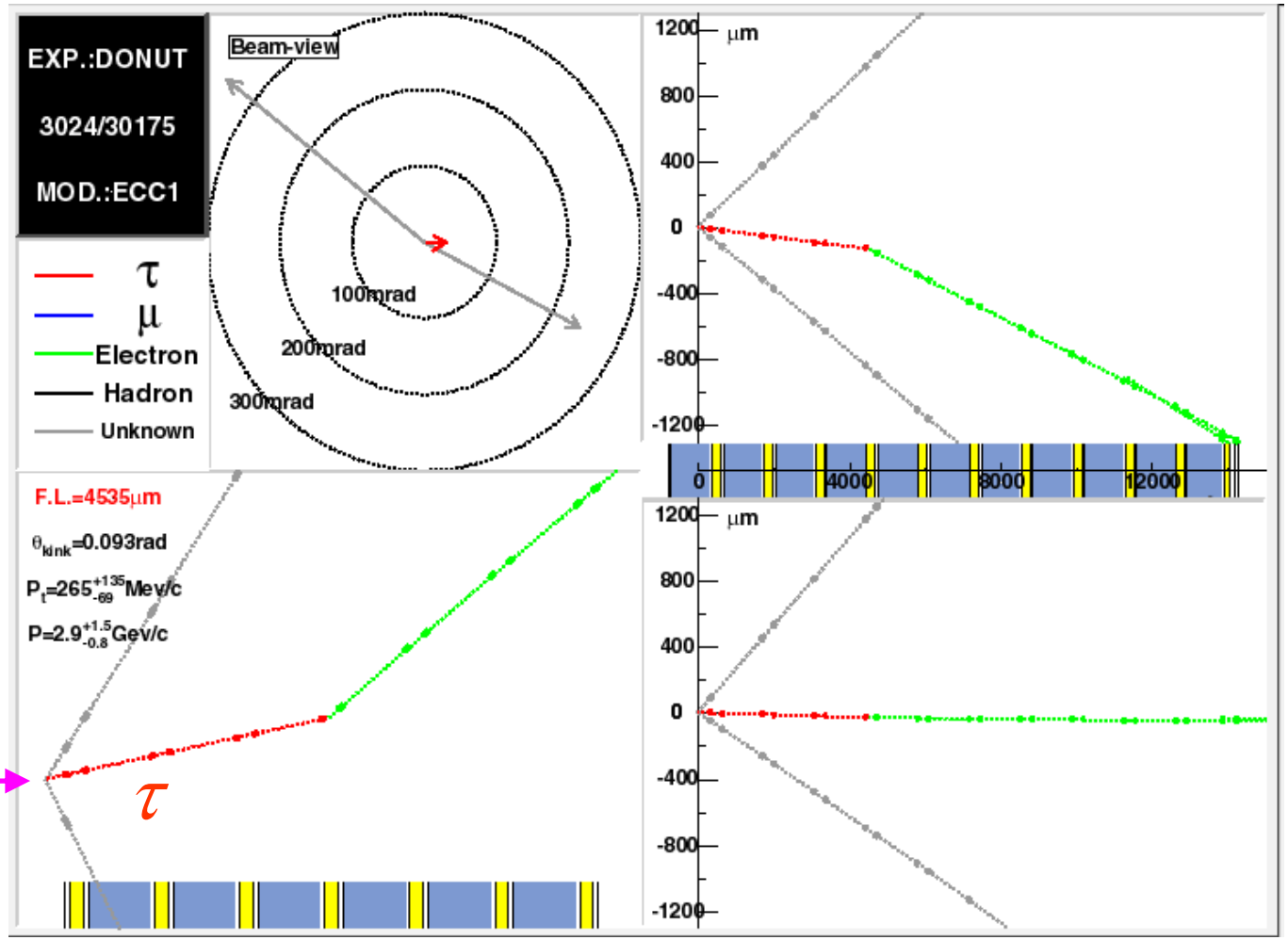
  bound states
- searches



theory:
precision calculations
essential

particle properties

Tau Neutrinos – direct detection



ν_τ

τ

Direct Observation of NU Tau

final results 2008:

9 ν_τ CC events

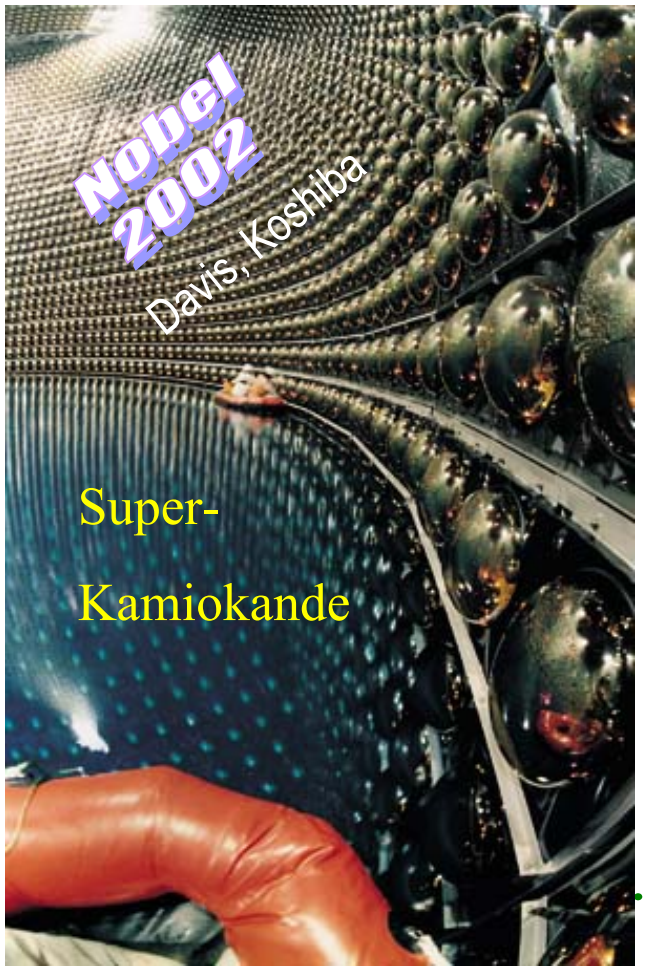
1.5 events bkg

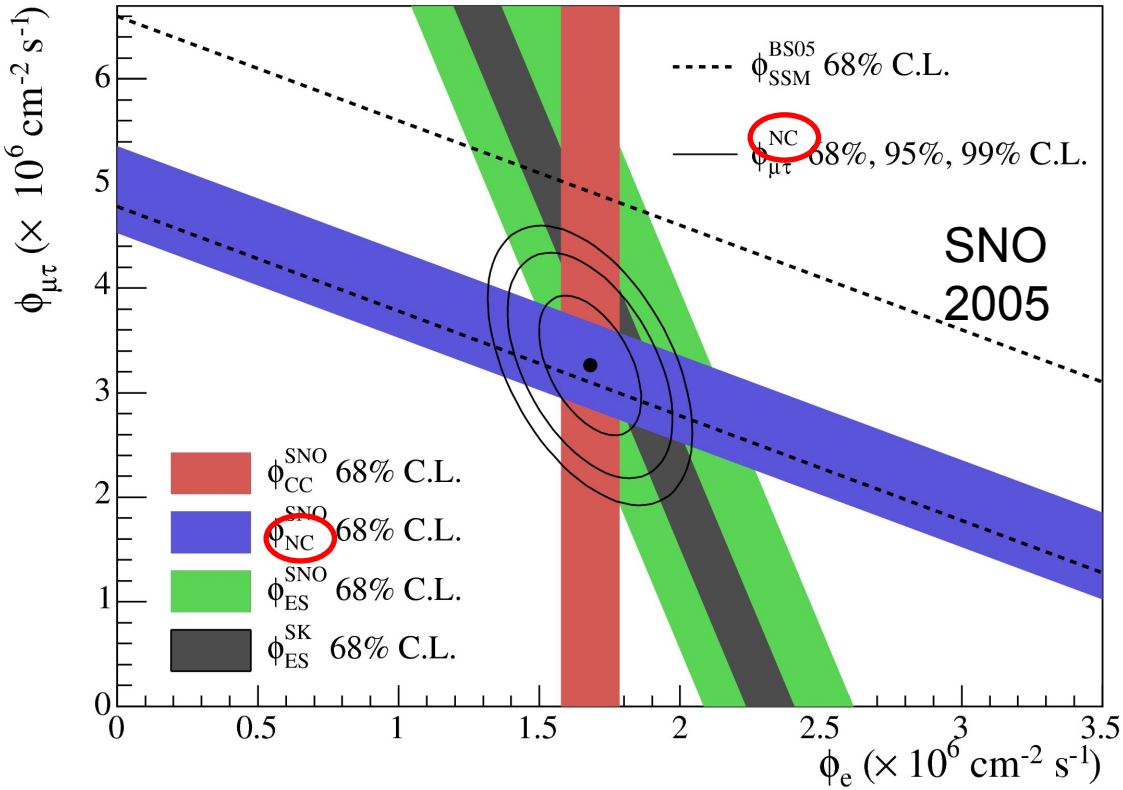
Tau neutrinos exist !

particle properties

Neutrinos: oscillations and masses

atmospheric: $\nu_\mu \rightarrow \nu_x$ solar: $\nu_e \rightarrow \nu_x$ +reactors +accelerators



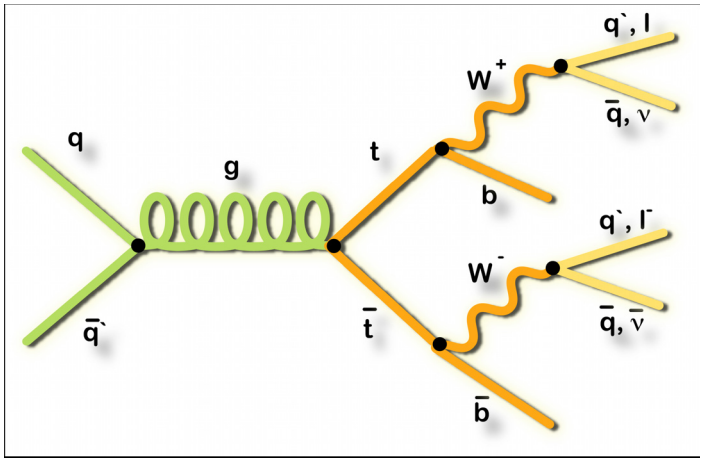


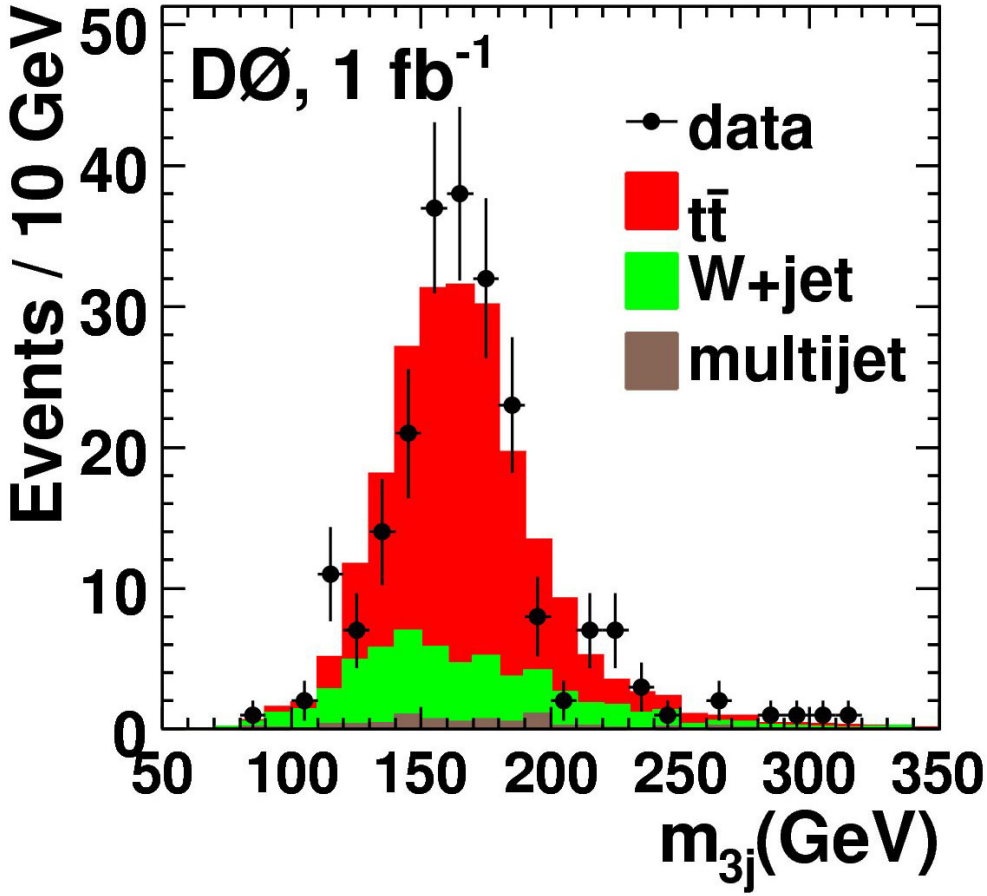
- sun is doing all right !
- neutrinos oscillate

→ neutrino masses not all zero

particle properties

Top Quark





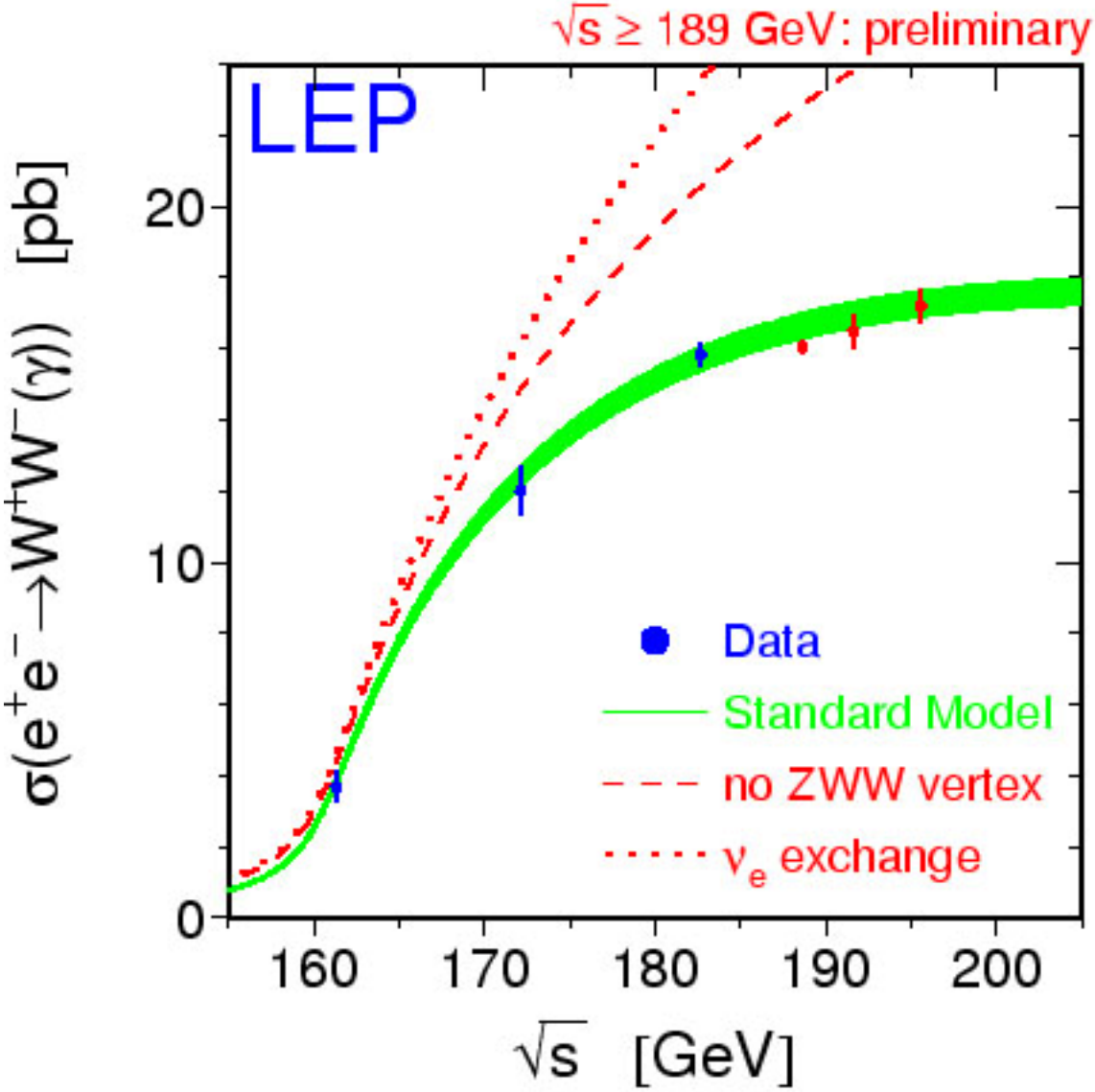
- top properties as expected
- $m_{top} = 173.1 \pm 1.3\,GeV$

CDF+D0

best known quark mass

electroweak interactions

Weak triple boson couplings



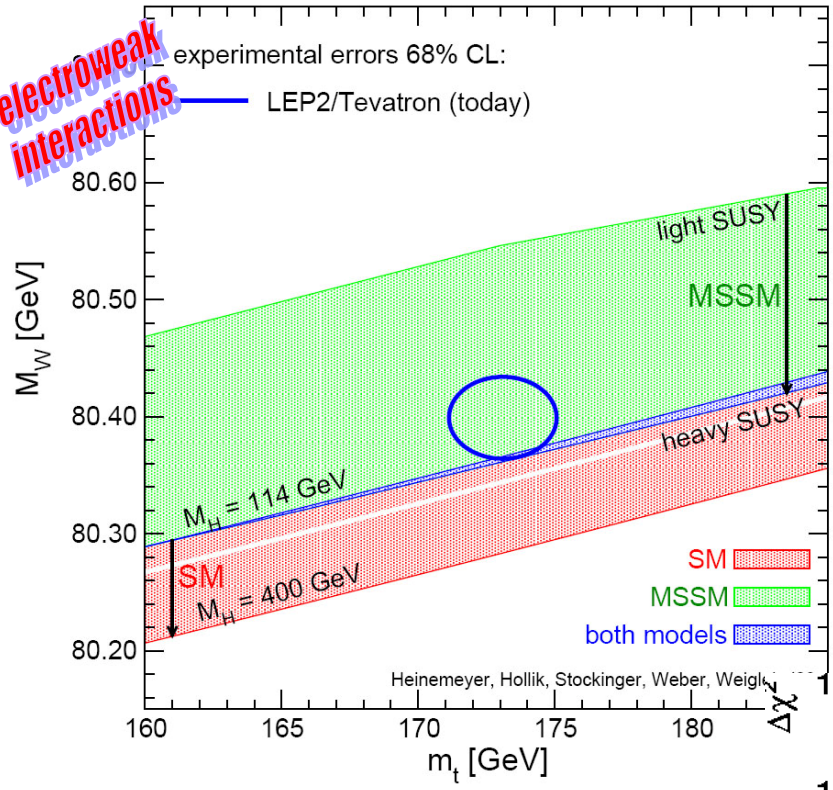
Nobel 1999

t'Hooft, Veltman

- SM confirmed:

  ZWW and γWW

Constraints on SM Higgs

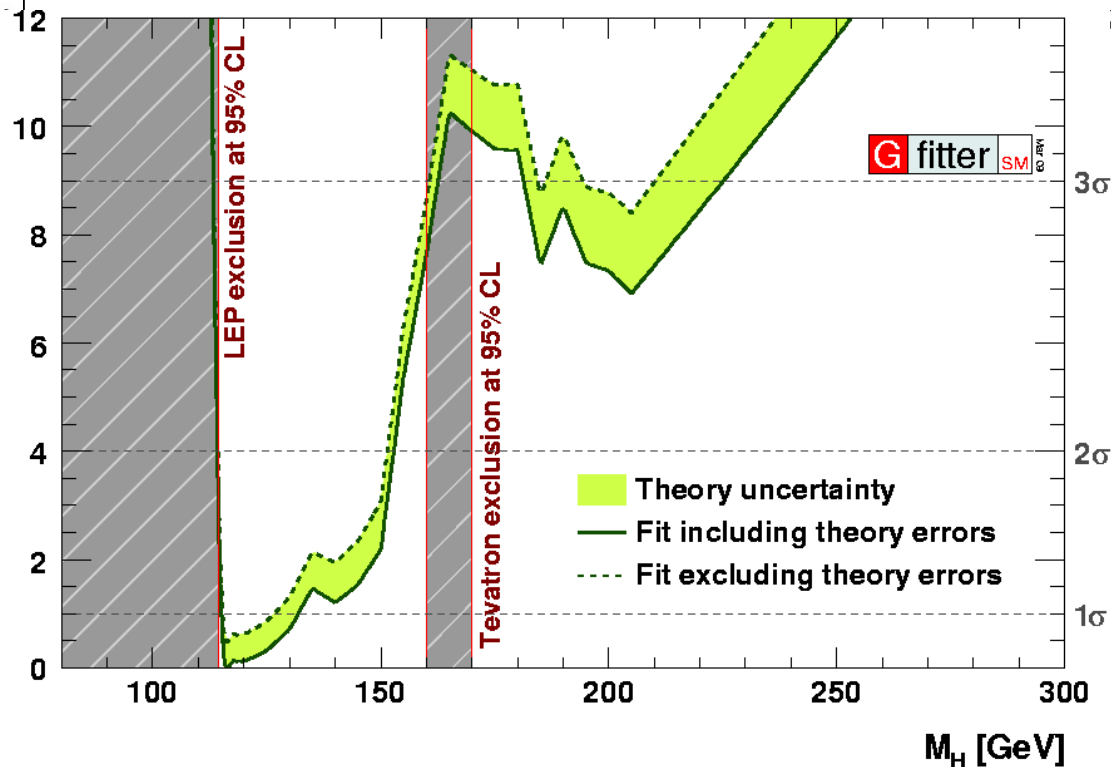


$$m_W = 80.399 \pm 0.023\ GeV$$

$$m_t = 173.1 \pm 1.3\ GeV$$

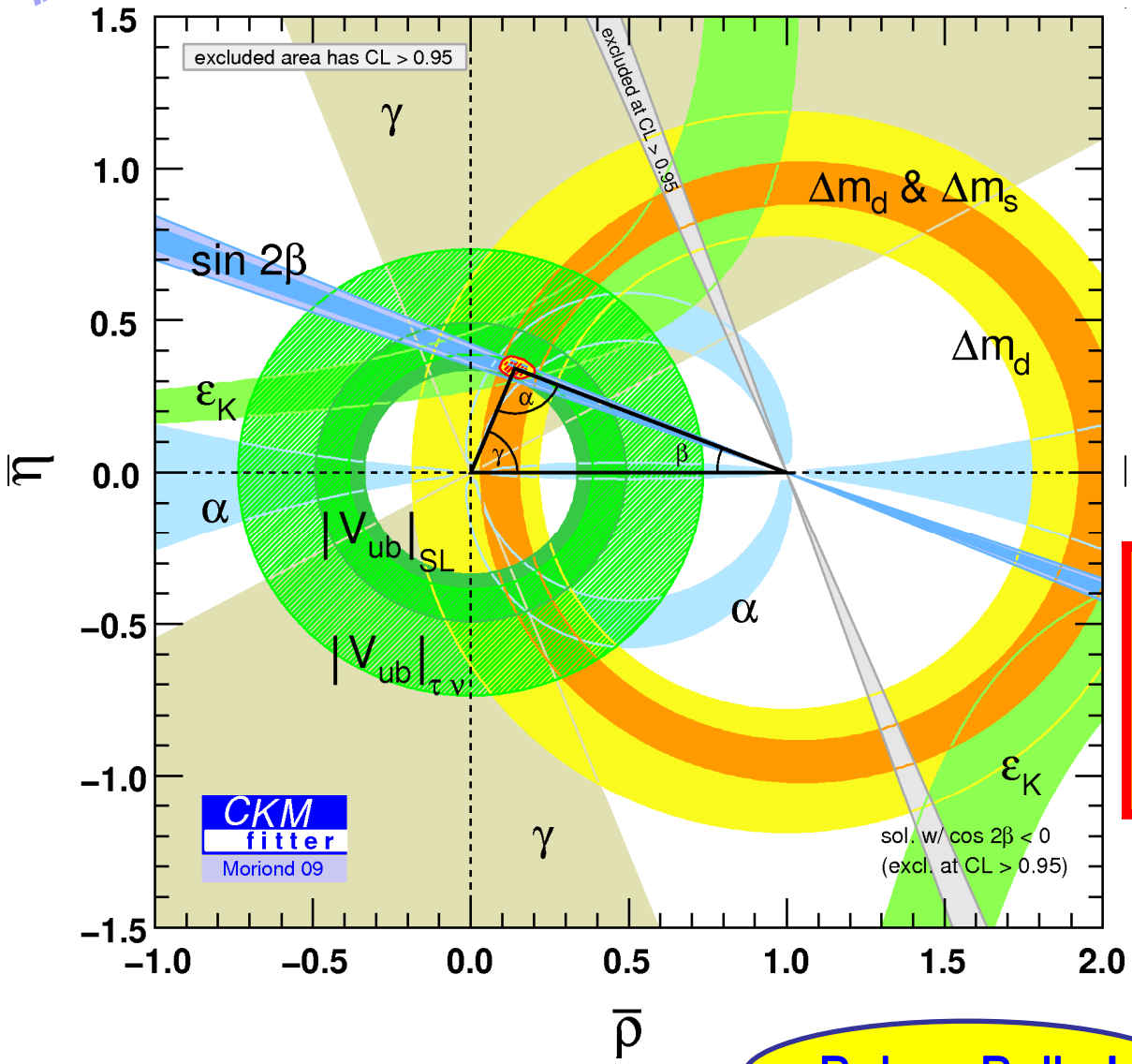
- tight constraints:

$$m_H = 115 - 150\ GeV$$



electroweak interactions

CKM matrix and CP violation



Nobel 2008

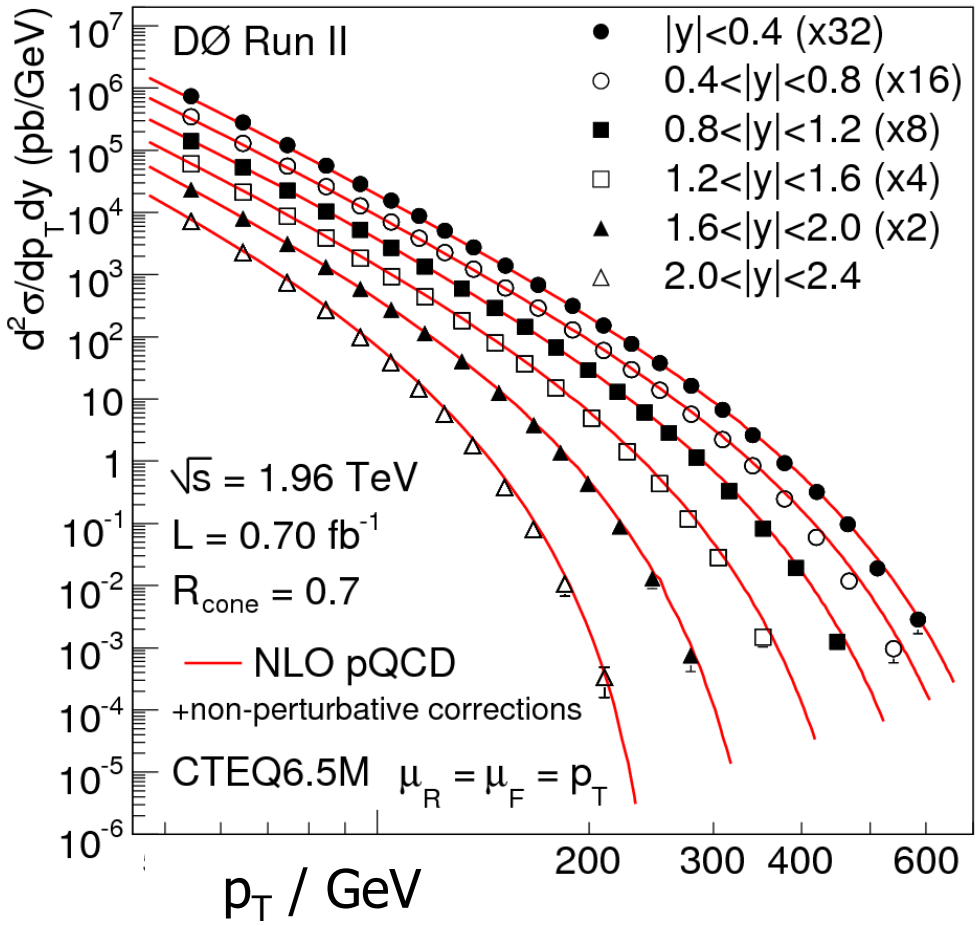
Kobayashi, Maskawa

- precise measurements
- CP in B sector
- all fits together

Babar, Belle !

strong interactions

QCD



Nobel 2004

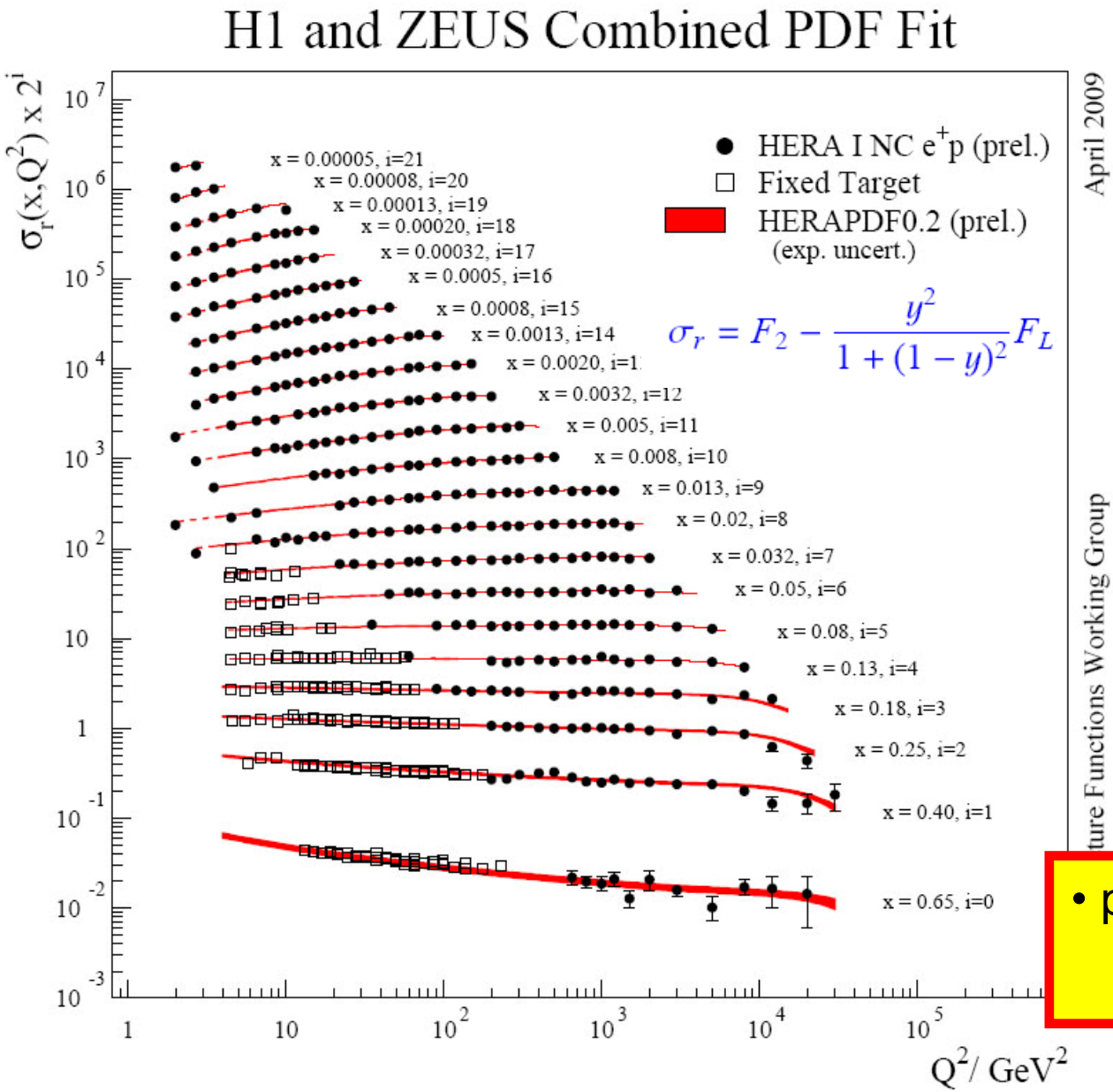
Gross, Politzer, Wilczek

- many successfull tests
- $\alpha_s = 0.1184 \pm 0.0007$ Bethke

world average

bound states

proton structure

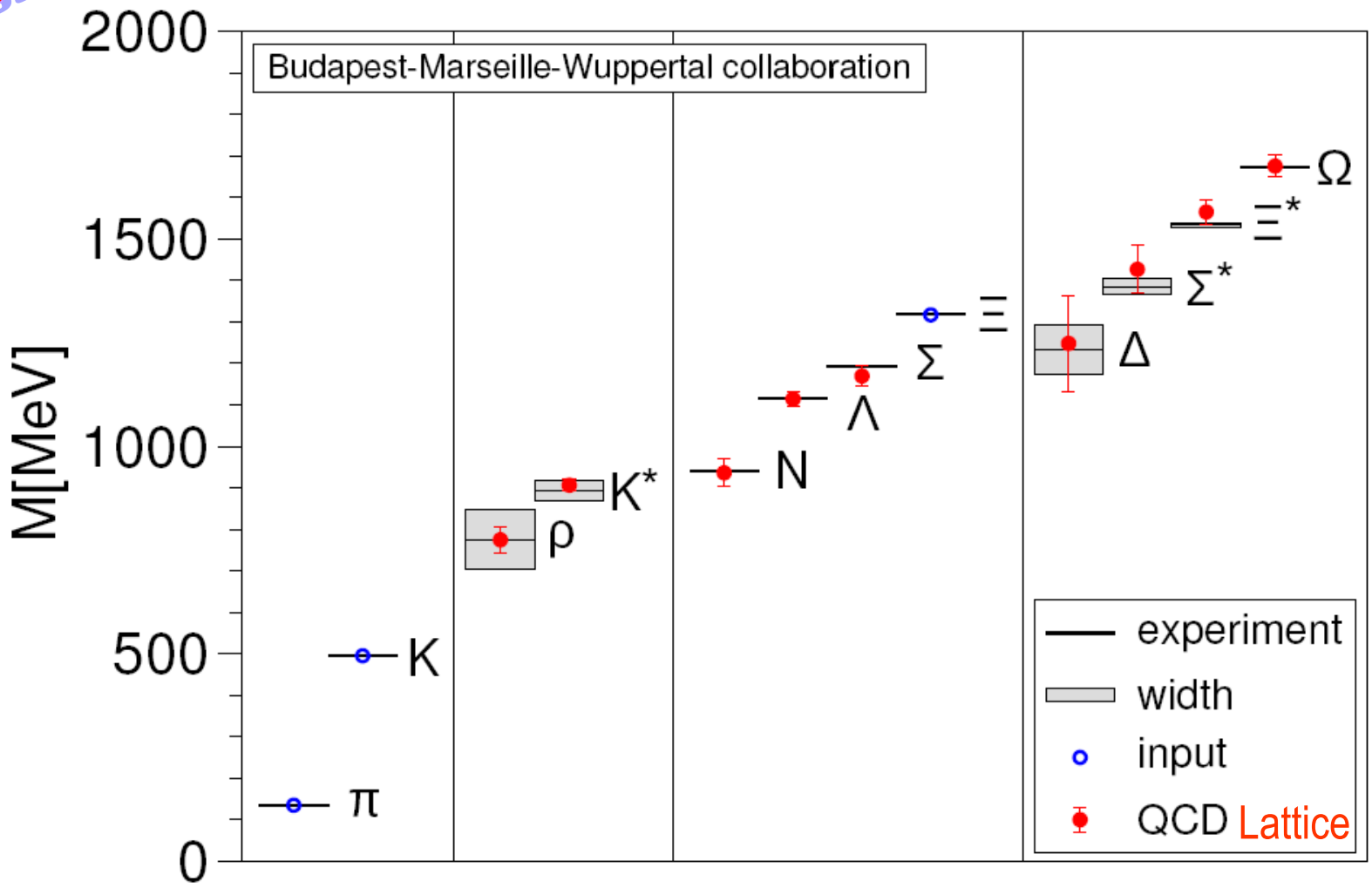


- proton well measured

  important for p p !

bound states

Hadron masses



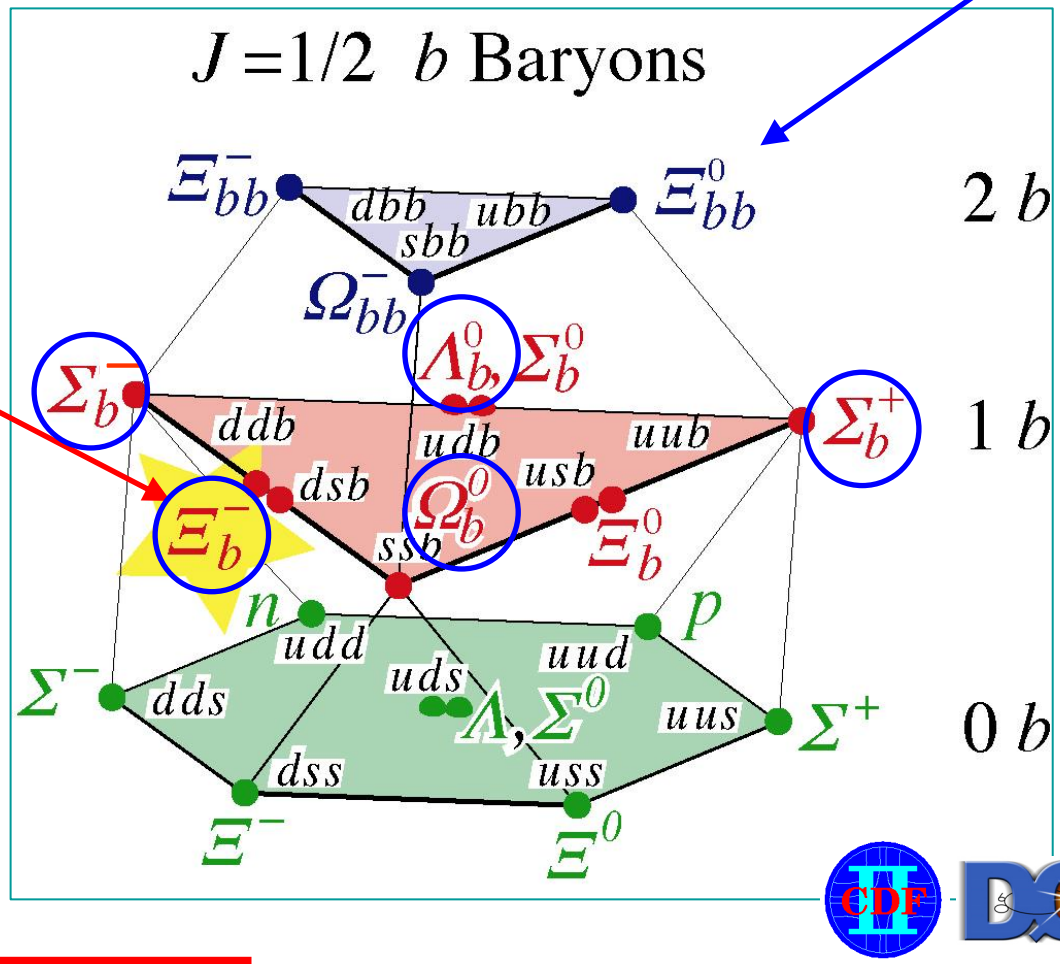
impressive success of lattice calculations

bound states

Heavy Baryons and Mesons

not yet

first baryon with quarks from all three families !



also:

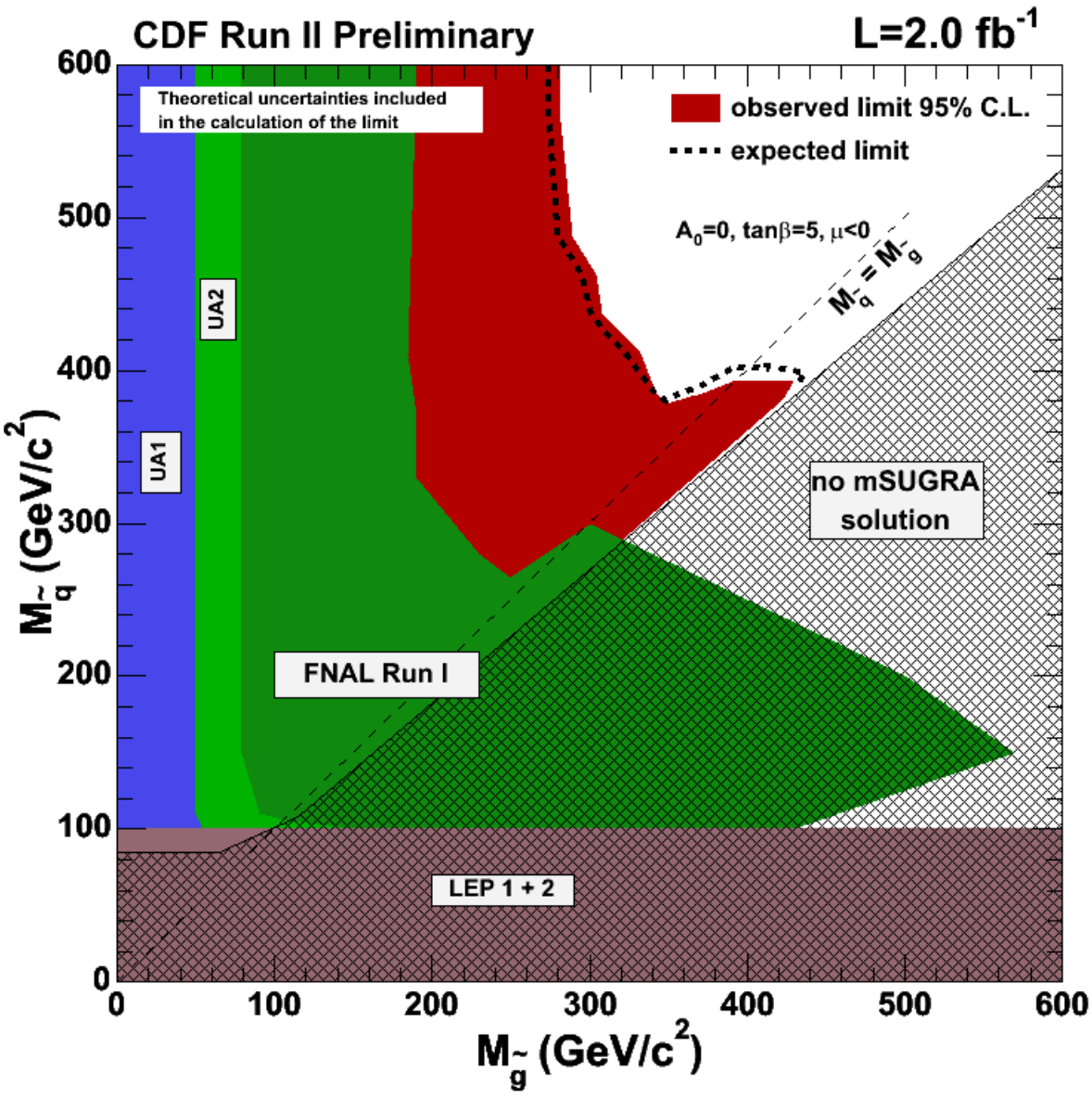
$$B_c = \bar{b}c$$

- completing quark model picture
- masses agree with theory

but: X(3872) ?

searches

Many many Searches …
(example: SUSY)

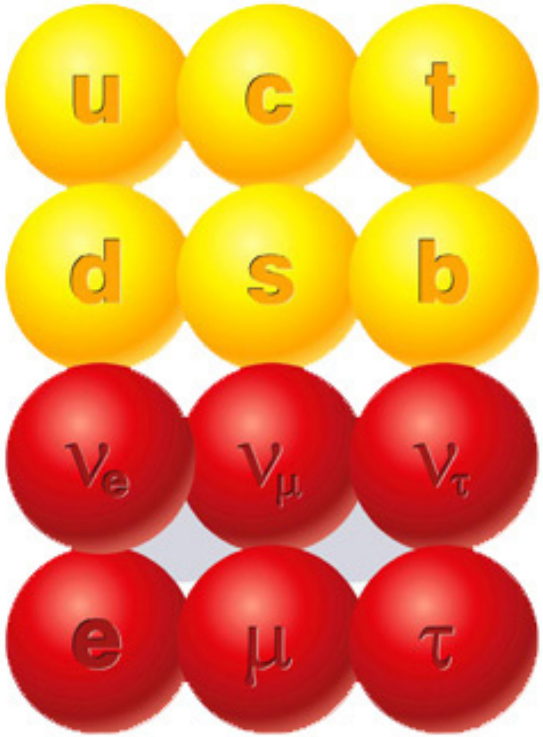


squark, gluino mass limits:

up to ~ 400 GeV

- no discovery yet
- many stringent limits

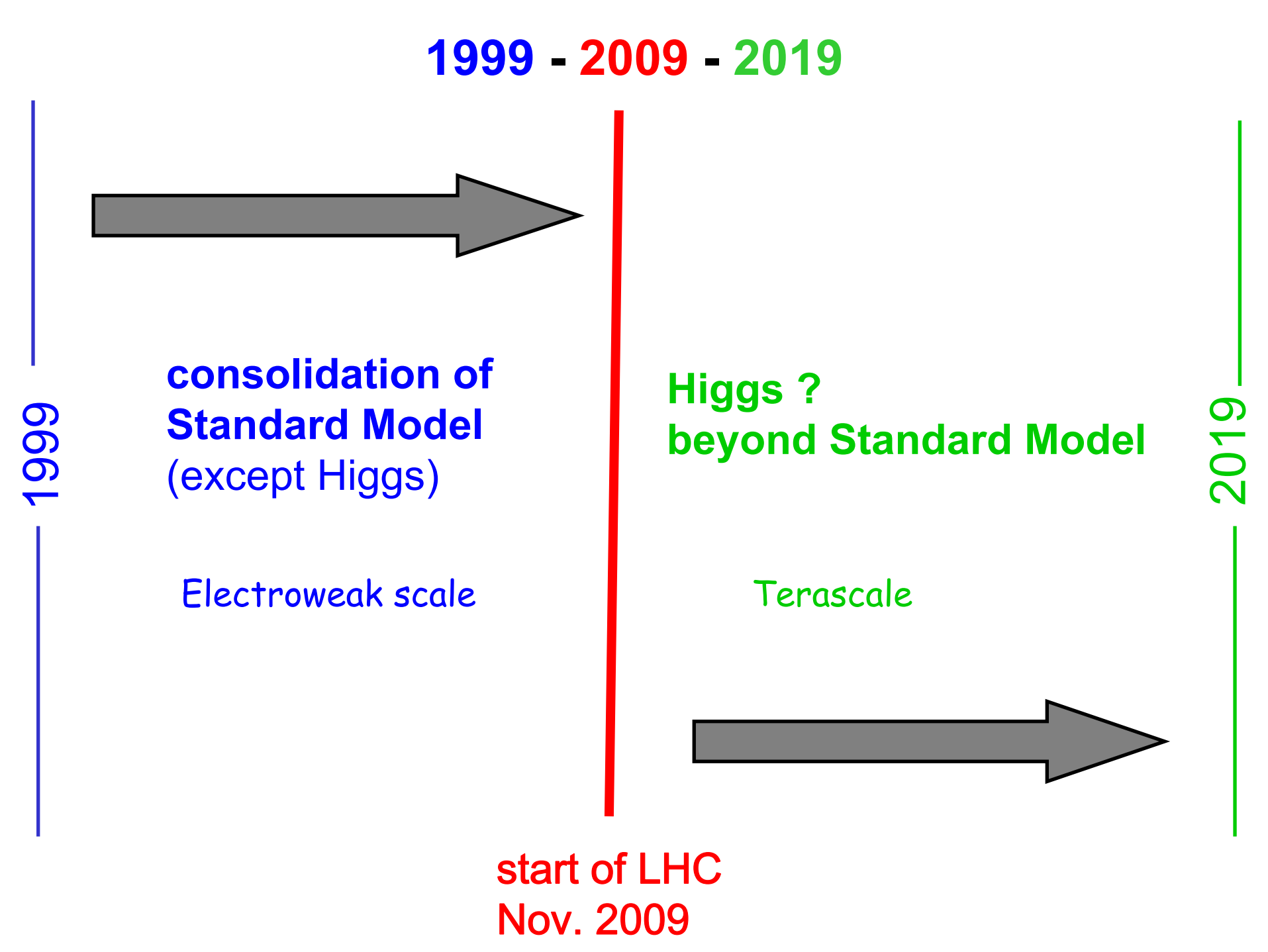
Highlights of the last 10 years

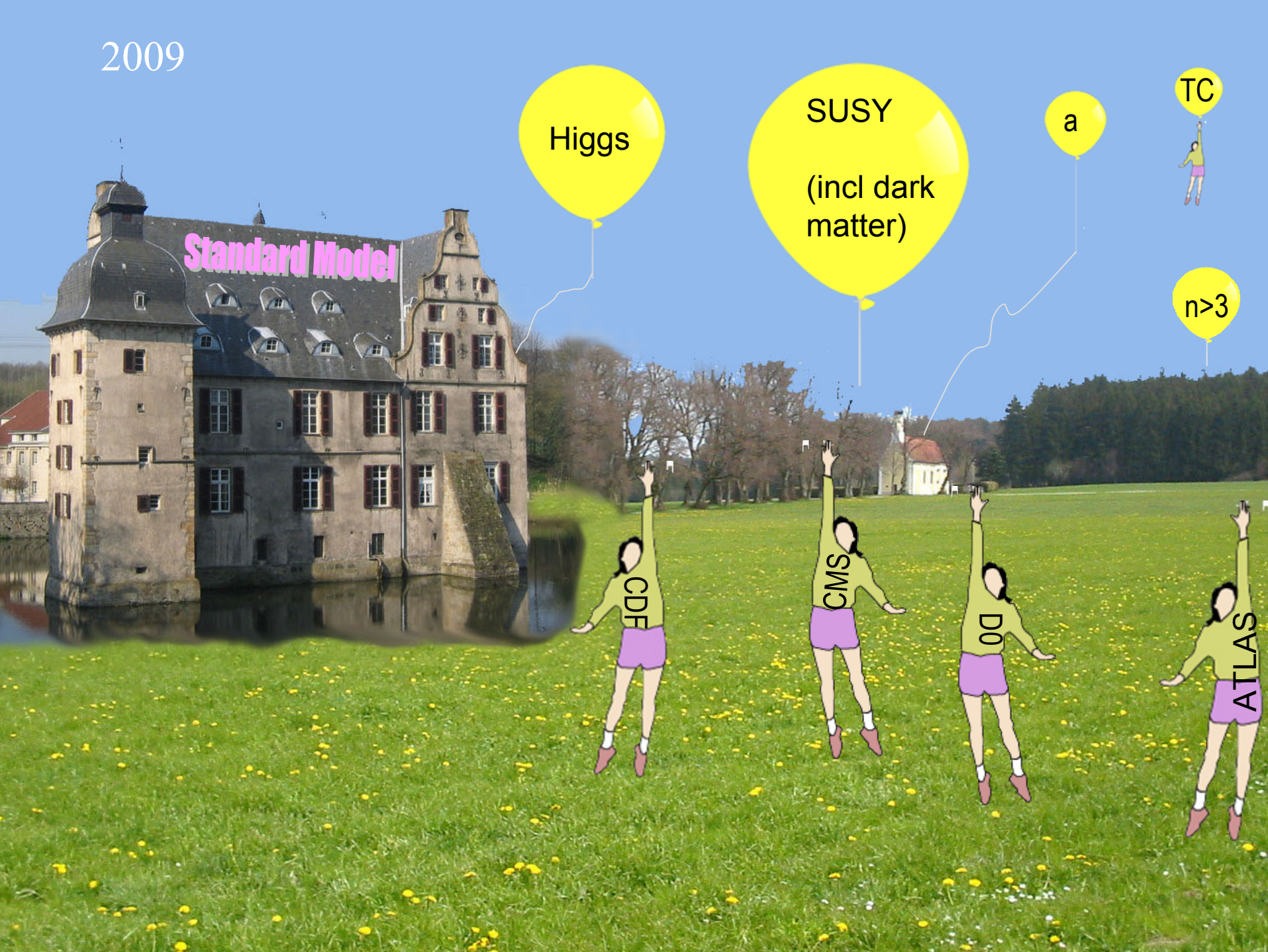


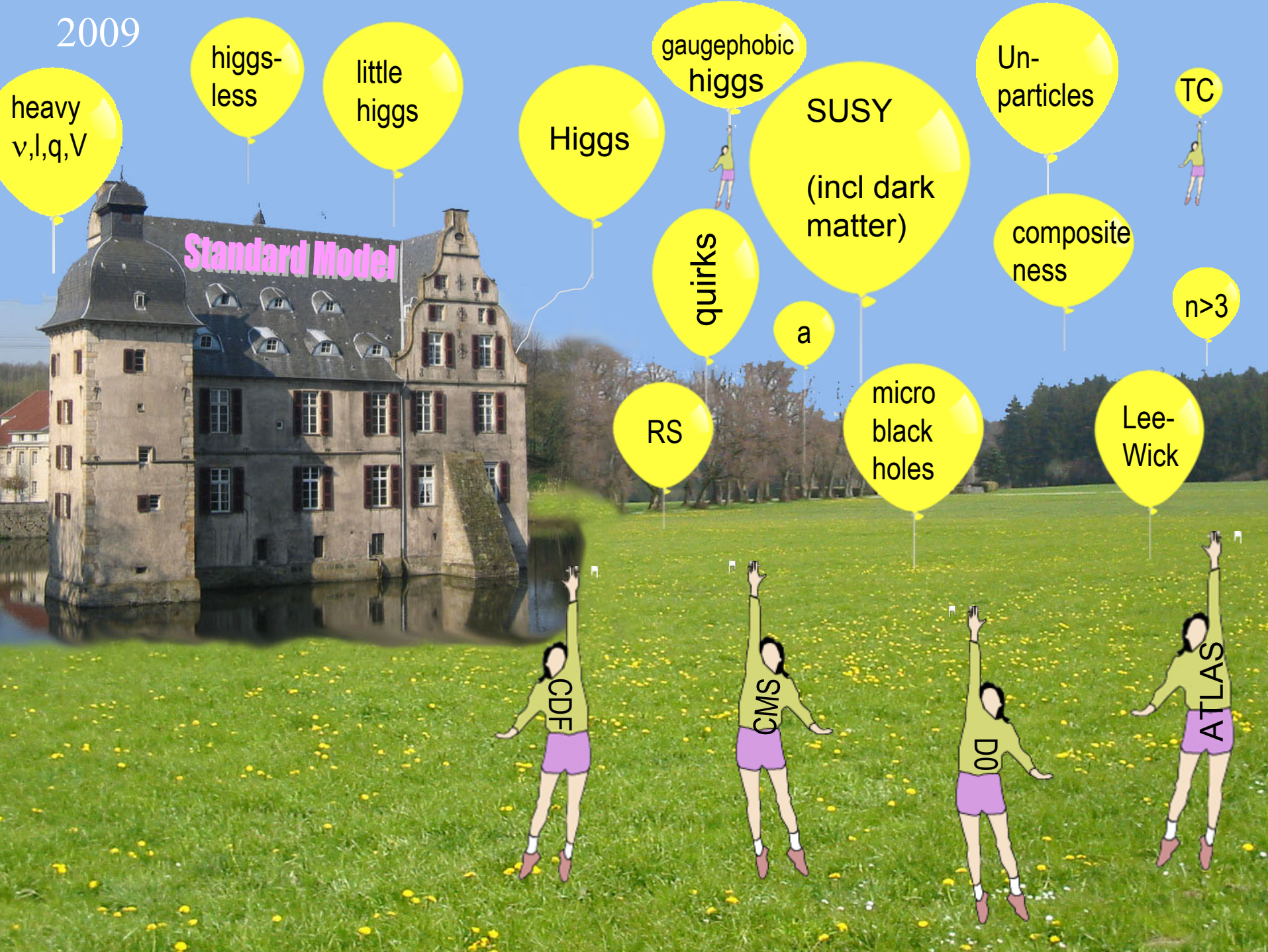
- particle properties
- electroweak interactions
- strong interactions

  bound states
- searches

A lot has been achieved !

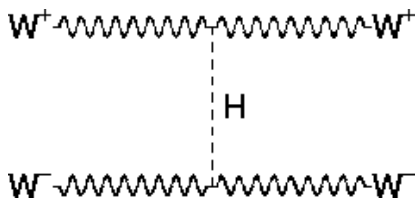

1999 - 2009 - 2019
1999
consolidation of
Standard Model
(except Higgs)
Electroweak scale
Higgs ?
beyond Standard Model
Terascale
2019
start of LHC
Nov. 2009


2009
Higgs
SUSY
(incl dark matter)
a
TC
n>3
Standard Model
CDF
CMS
D0
ATLAS


2009
heavy
ν,l,q,V
higgs-
less
little
higgs
Higgs
gaugephobic
higgs
SUSY
(incl dark
matter)
Un-
particles
TC
Standard Model
quirks
composite
ness
n>3
a
RS
micro
black
holes
Lee-
Wick
CDF
CMS
D0
ATLAS

Are we sure what to expect ?

- SM: cross sections violate unitarity for $s \approx TeV^2$



something must happen !

- Masses: complicated … different mechanisms:

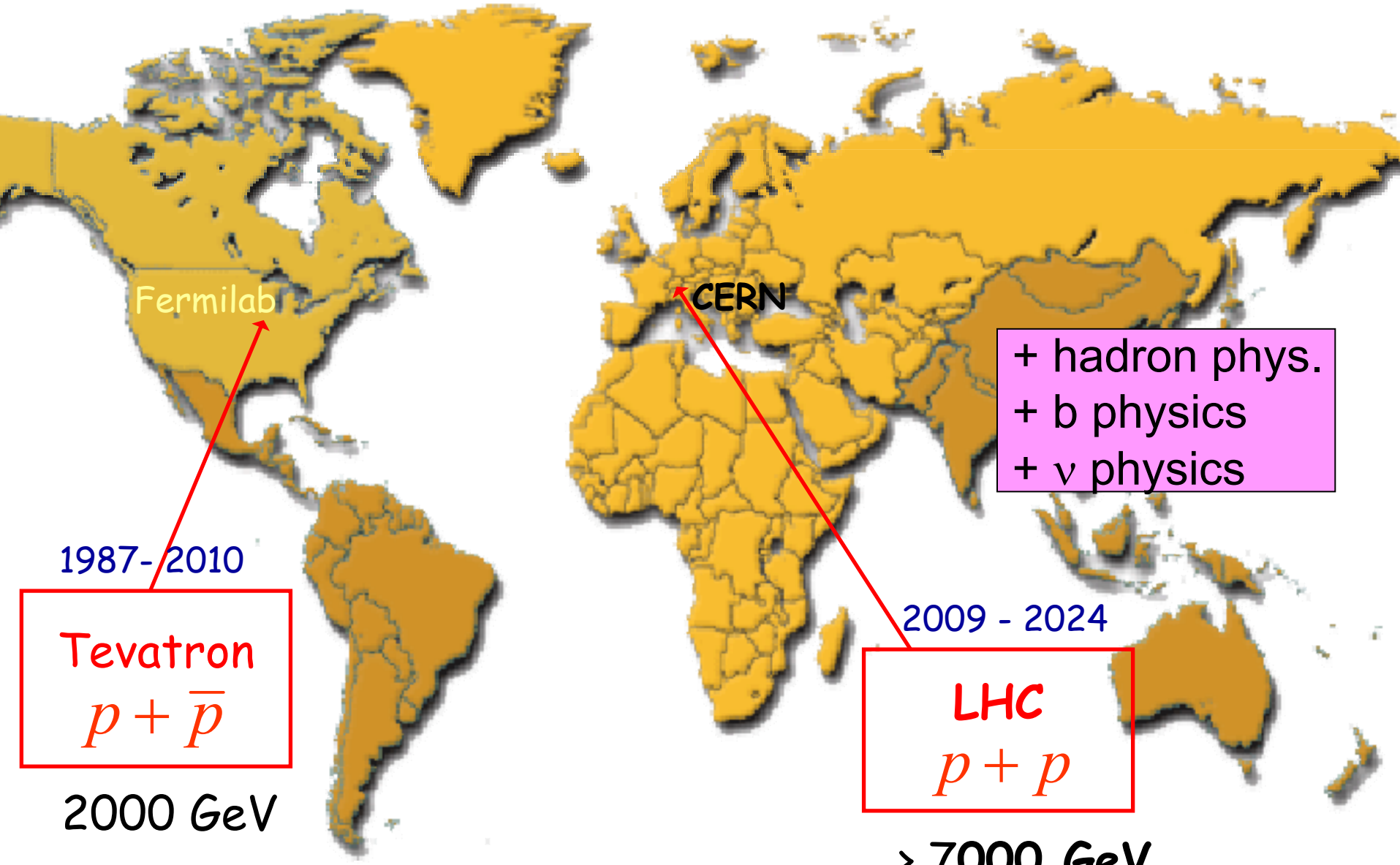
  - Higgs – gauge coupling (W,Z)
  - Higgs – Yukawa coupling (fermions)
  - Higgs self coupling (H)
  - Soft SUSY breaking terms (SUSY mass terms)

SUSY to stabilize Higgs mass

can that be the final answer ?

be open minded and be prepared for the really new !

Terascale Accelerators 2009



LHC machine

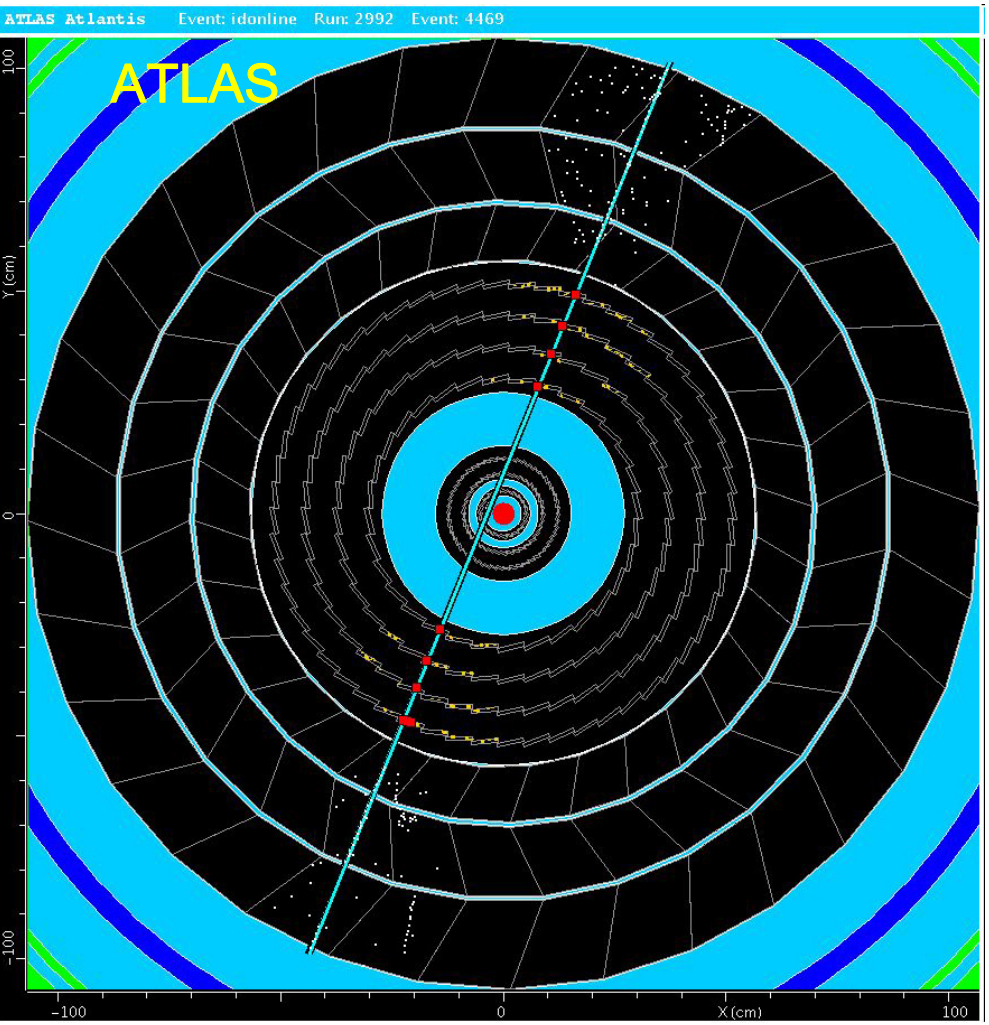
Rolf Heuer, DG of CERN

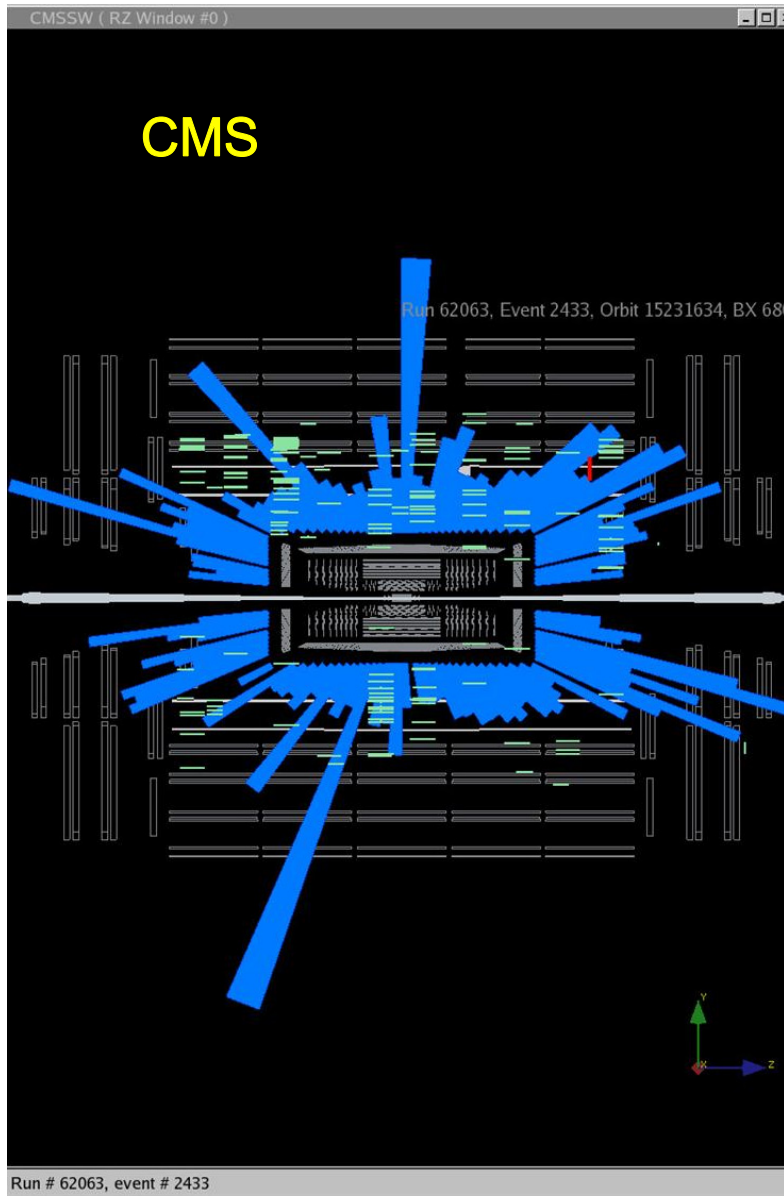
ready !

LHC detectors

beam splash 2008

cosmics

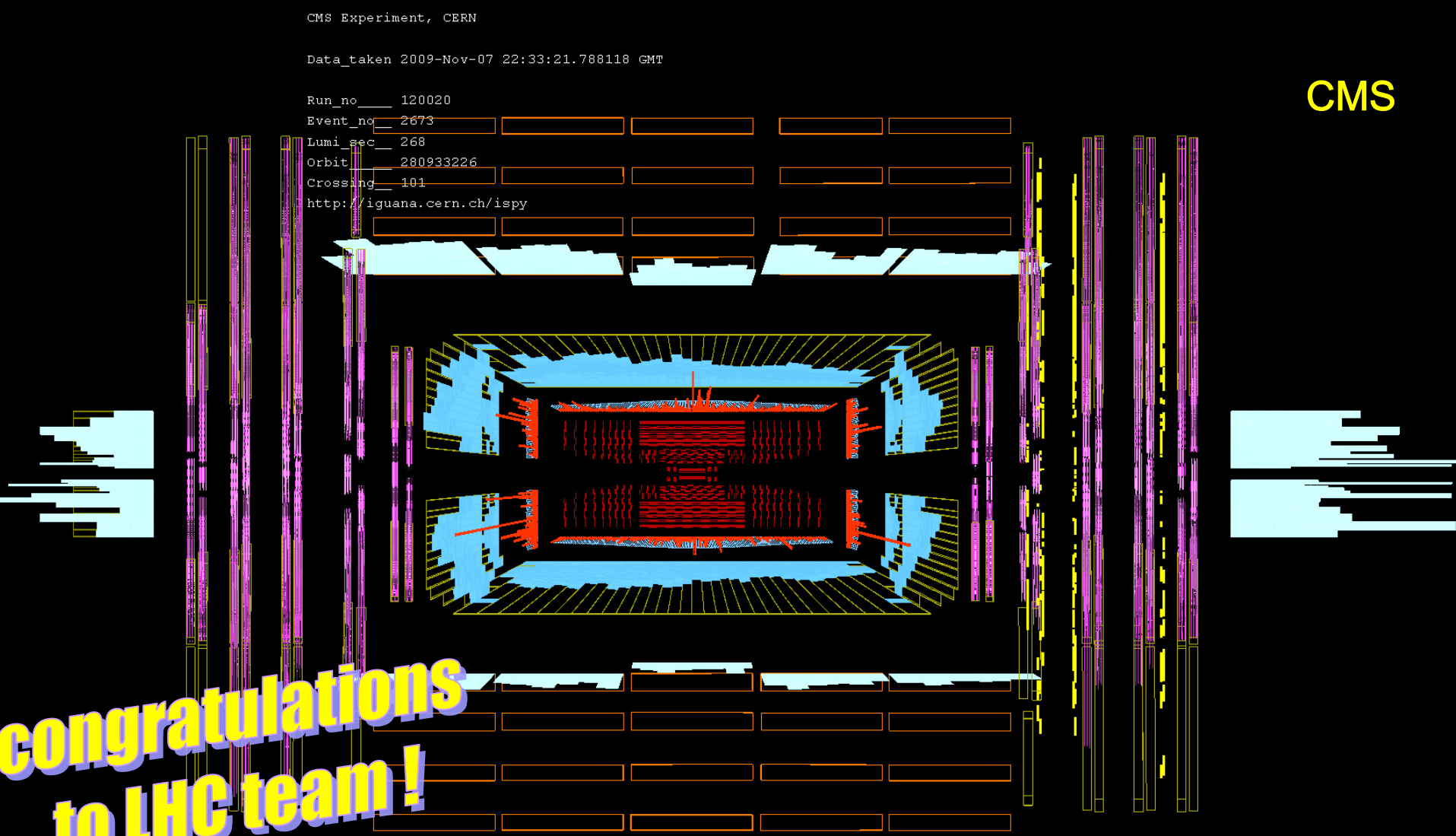




ready !

LHC detectors

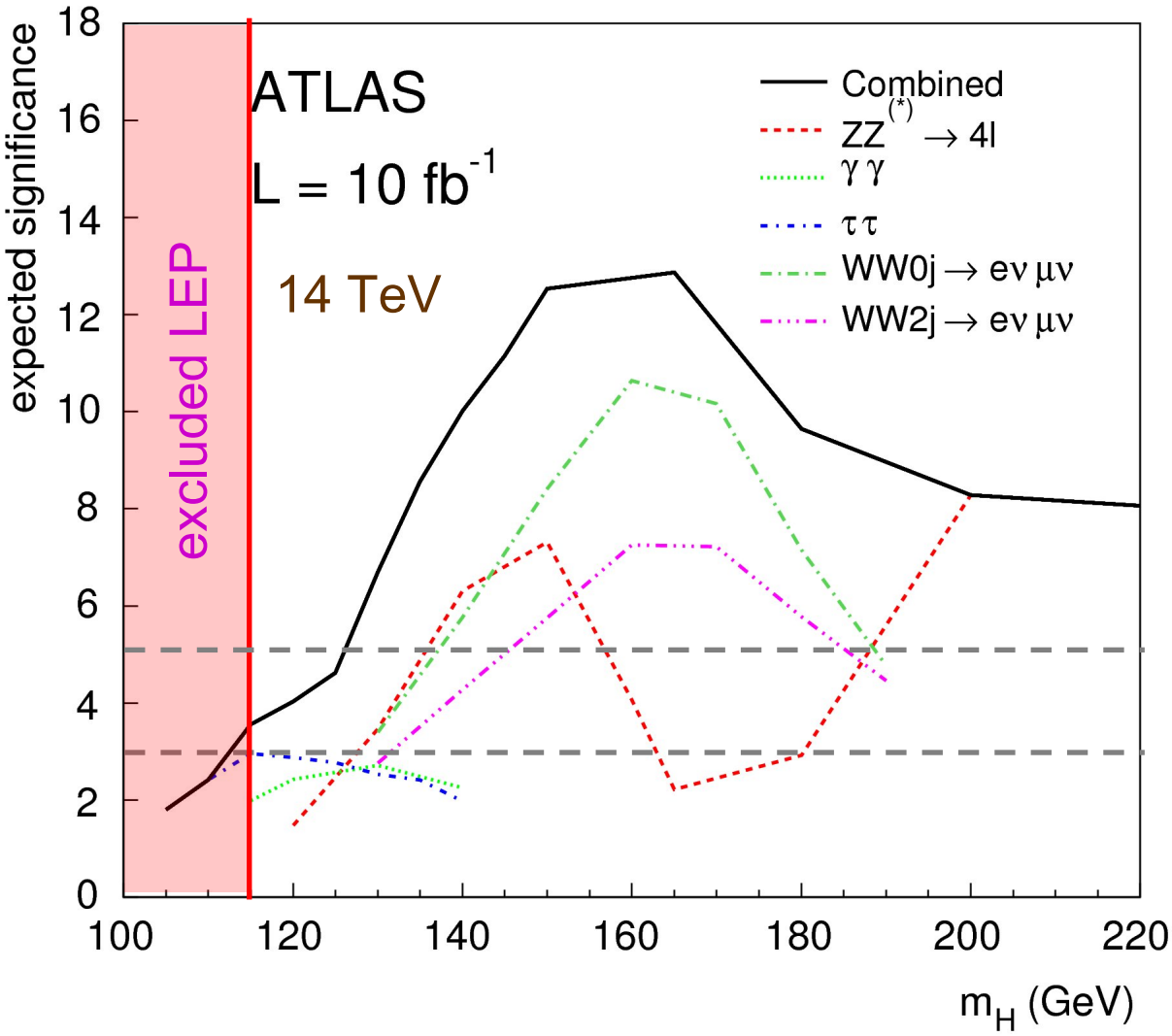
beam splash 2009-11-07



CMS

congratulations to LHC team !

SM higgs search at LHC



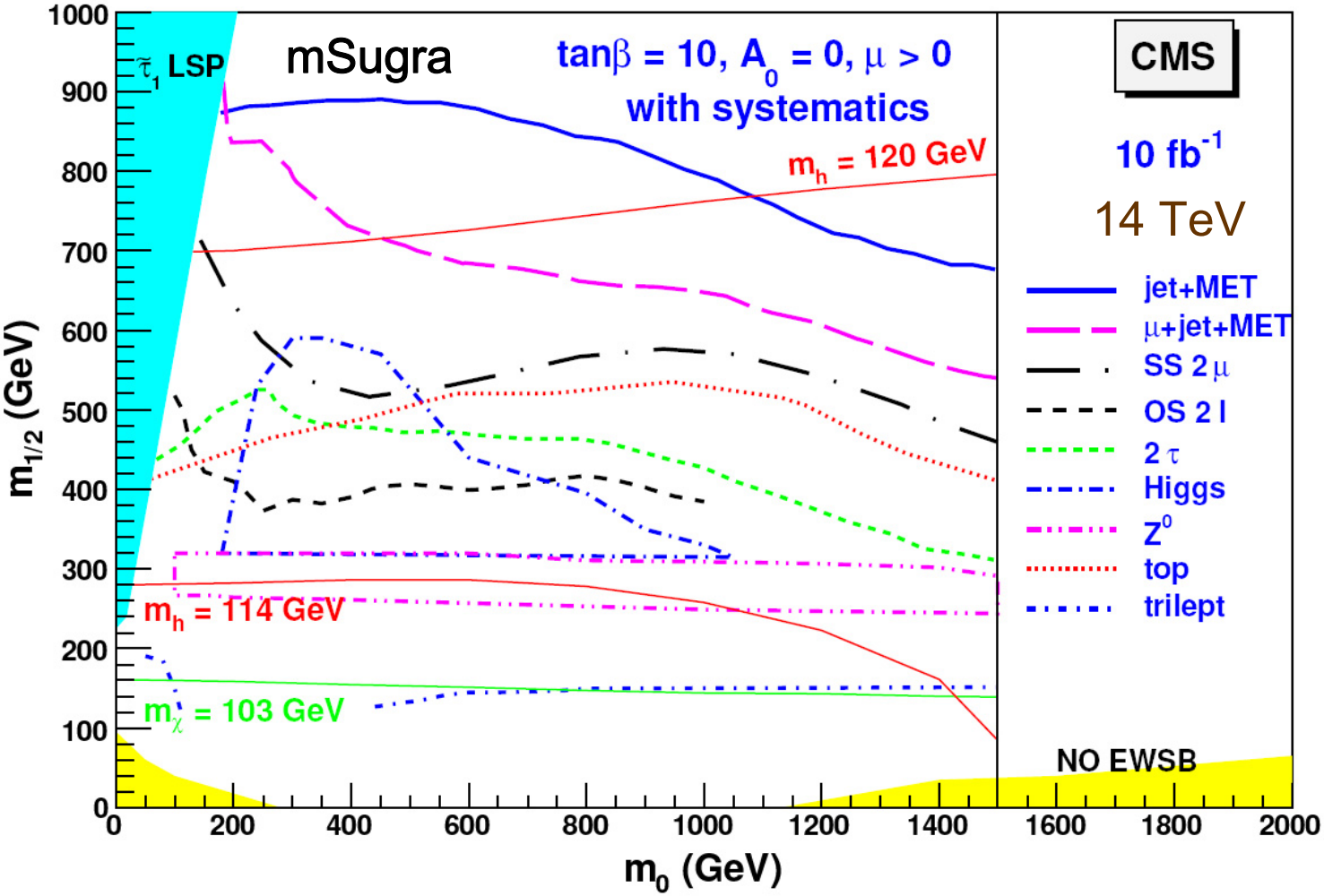
final answer !

need a couple of fb^{-1}

not in first year of LHC

! experimentum crucis !

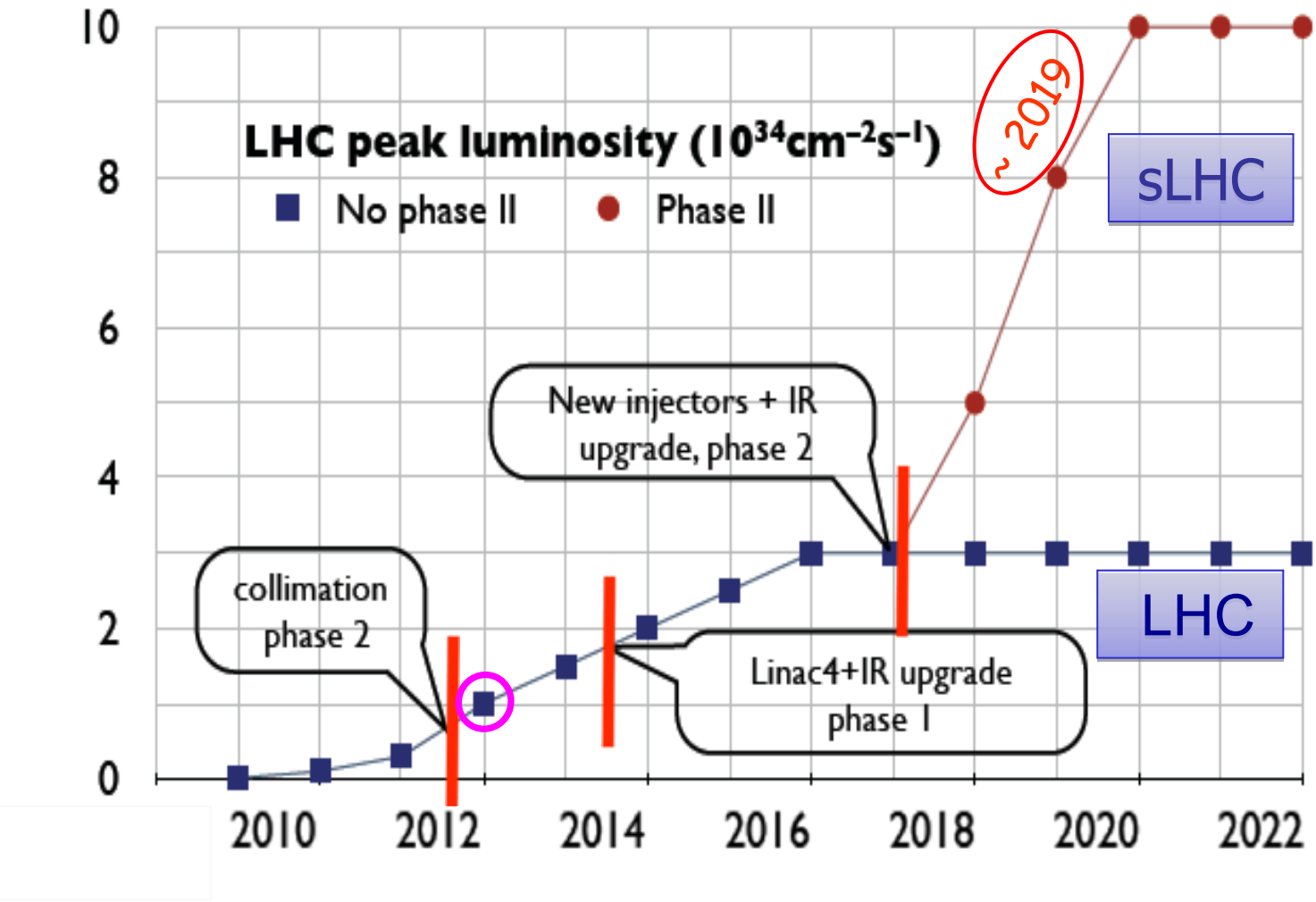
Supersymmetry at LHC ?



big jump in sensitivity: $\tilde{q}, \tilde{g} \sim 2\,TeV\,(10\,fb^{-1})$

no guarantee that Supersymmetry is within reach

SLHC



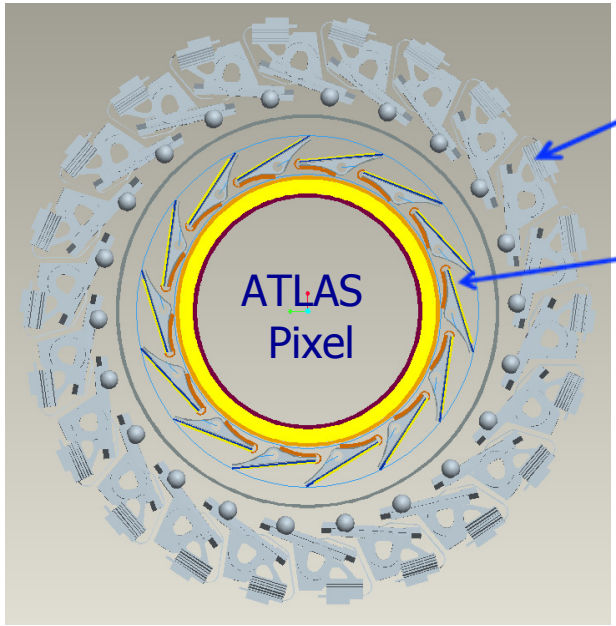
> 3000 / fb per exp.

extend mass reach by about 25%

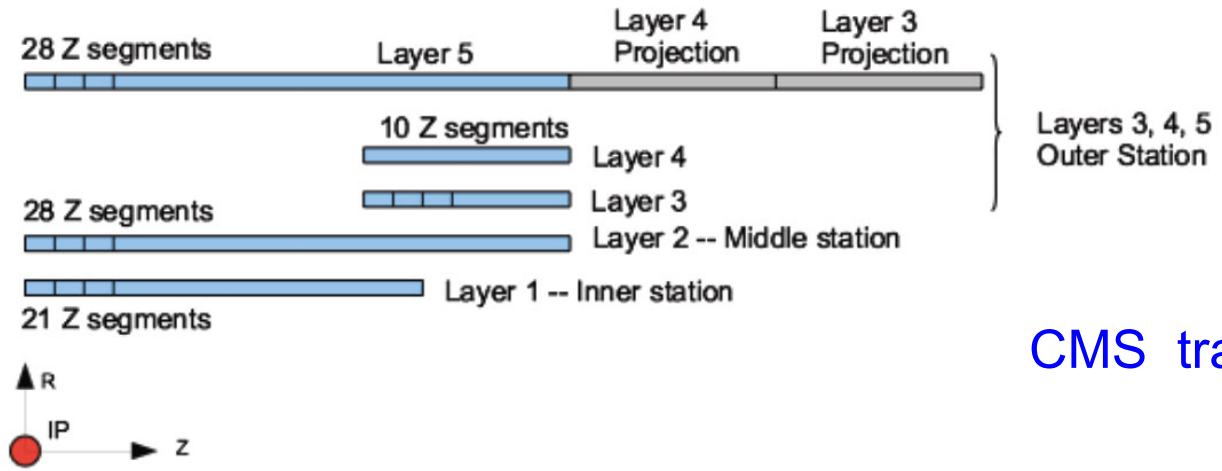
example squark/gluino: 3 TeV → 3.75 TeV

(s)LHC detector upgrades

phase I



phase II



?

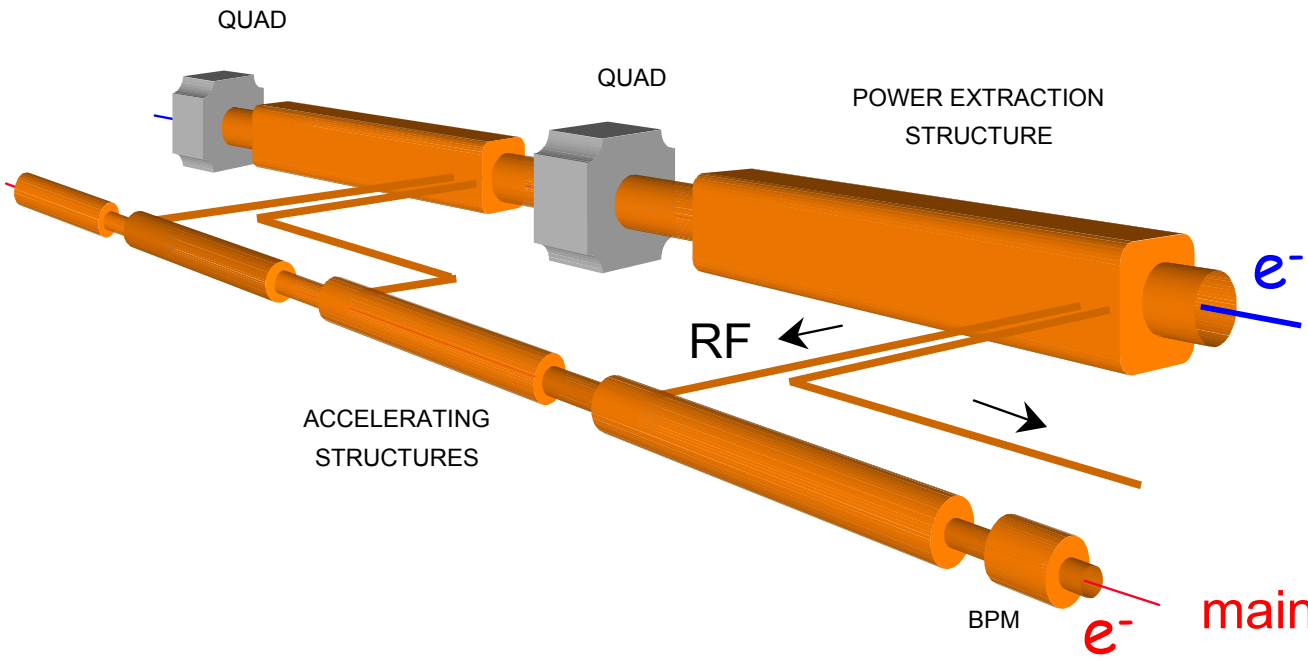
CMS tracker

e^+e^- linear collider

precision measurements

ILC	**500-1000**	**GeV c.m.**	**technical design**
CLIC	**3000**	**GeV c.m.**	**R & D**

choice depends on LHC results !



drive beam (decelerator)
~ 100 A, ~ 1 GeV

main beam (accelerator)
~ 1A, ~ 1000 GeV

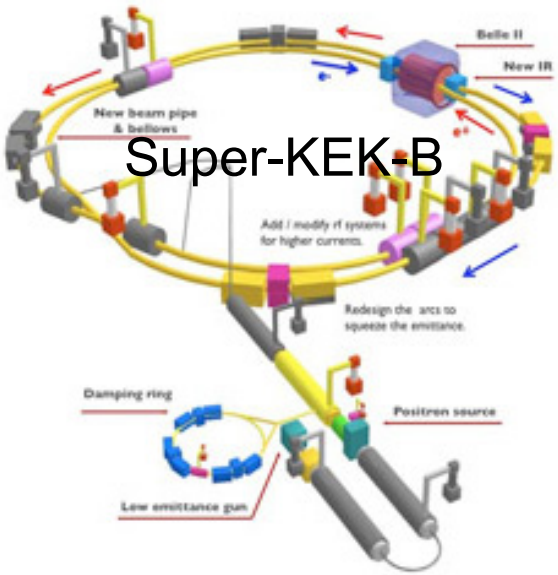
NO collisions by 2019 !

2009-2019

neutrinos, bottom, light hadrons

+ reactor based ν exp.
+ accelerator based ν exp.

LHCb

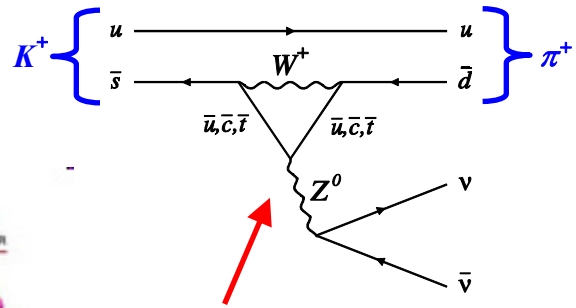


Super-KEK-B

$e^+ e^-$ $10^{36} / cm^2 / s$

or Super-B

$K^+ \to \pi^+ \nu\bar{\nu}$



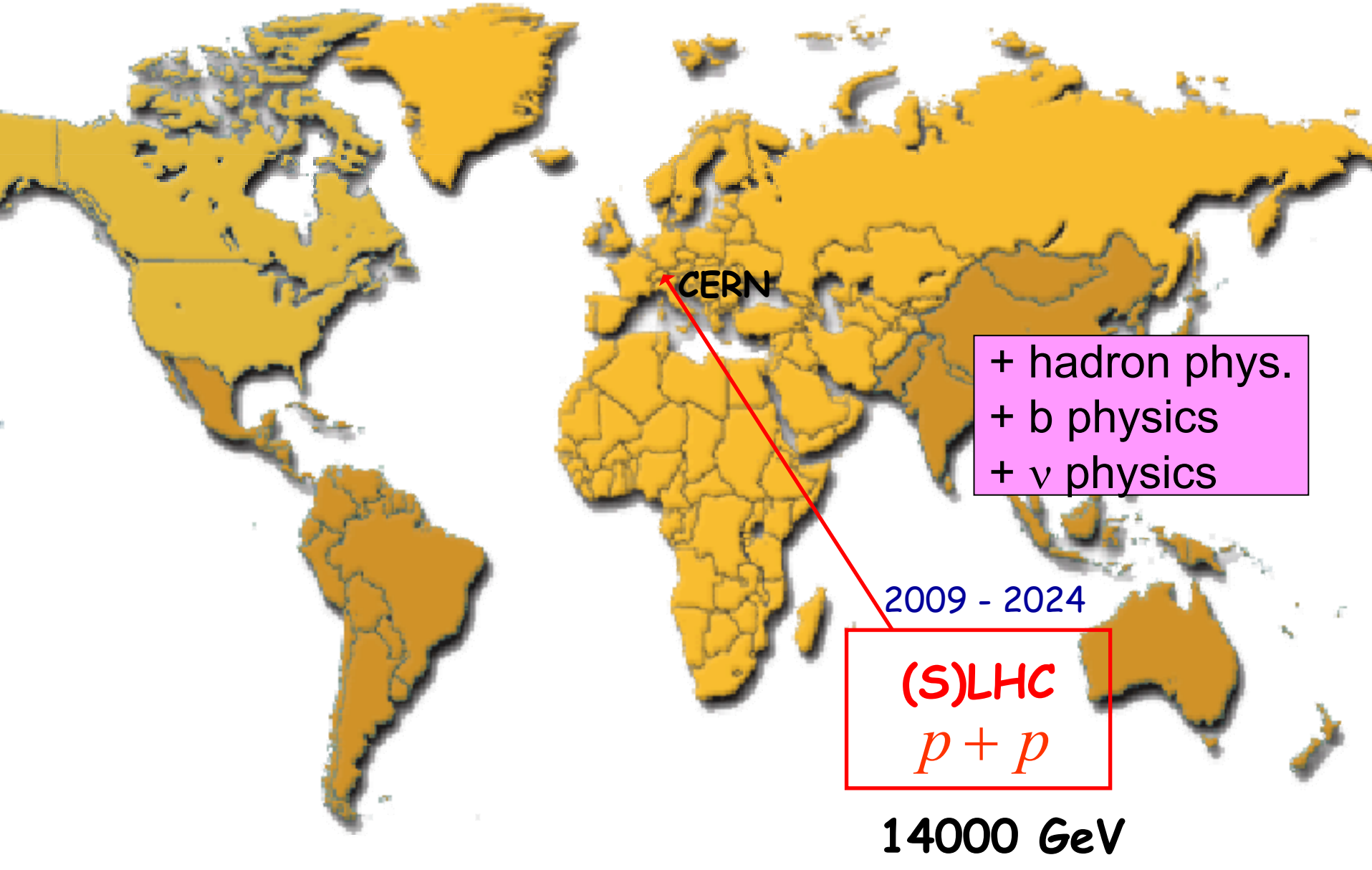
new physics ?

rare decays
heavy ions
…

+ axion searches, rare muon decays, …

2019

Terascale Accelerators 2019




instead of a summary…
collisions,
pleeeaaase !
Thanks !