Supersymmetry and Supergravity History and Perspectives

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Supersymmetry and supergravity

- **A hypothetical symmetry of Nature** which implies that every elementary particle has a partner, so called *superpartner*

  electron – *electrino*, photon – *photino*, graviton – *gravitino*, etc.

- By supersymmetry, the superpartners have properties similar to the standard particles (e.g. electric charges). The main difference between them is that the superpartners have an internal angular momentum, *the spin*, which differs by 1/2 (in quantum units) from that of the conventional particles.

  if the conventional particle has an integer spin, it is called ***Boson***, like photon (spin 1) or graviton (spin 2), then their superpartners have half integer spins (they are called ***Fermions***), and vice versa.

  Supersymmetry is thus a symmetry between **Bosons** an **Fermions,**

  which drastically constrains possible properties of the theory and makes it very appealing for explaining observable phenomena and puzzles

- **Supergravity** is a supersymmetric unifying theory of fundamental interactions (electromagnetic, weak and strong nuclear forces) which also includes gravitational forces

Supersymmetry

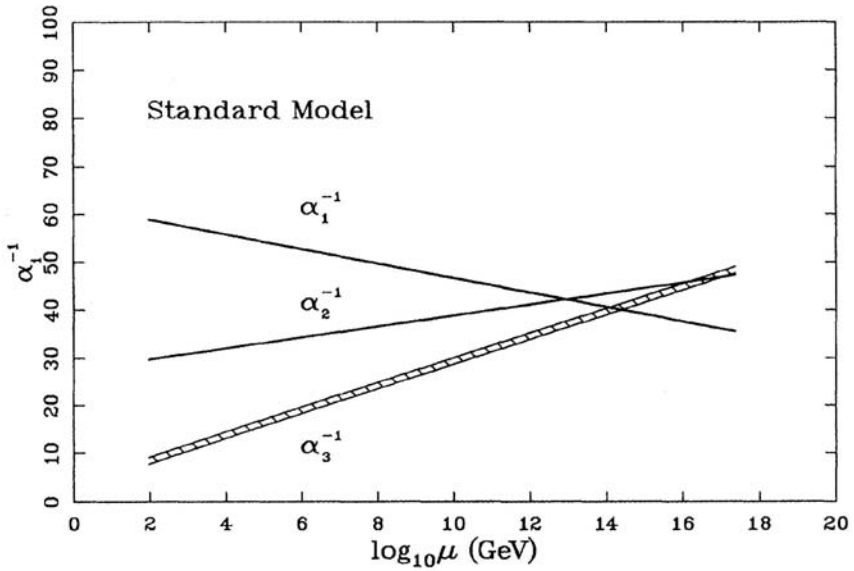
- **Supersymmetry, as the fundamental symmetry, has not been observed in Nature so far.** This means that (if it exist) it is broken, in a so called spontaneous way. A consequence of such breaking is that the superpartners have masses much larger than conventional elementary particles. This explains why the superpartners have not been captured so far in the experiment.

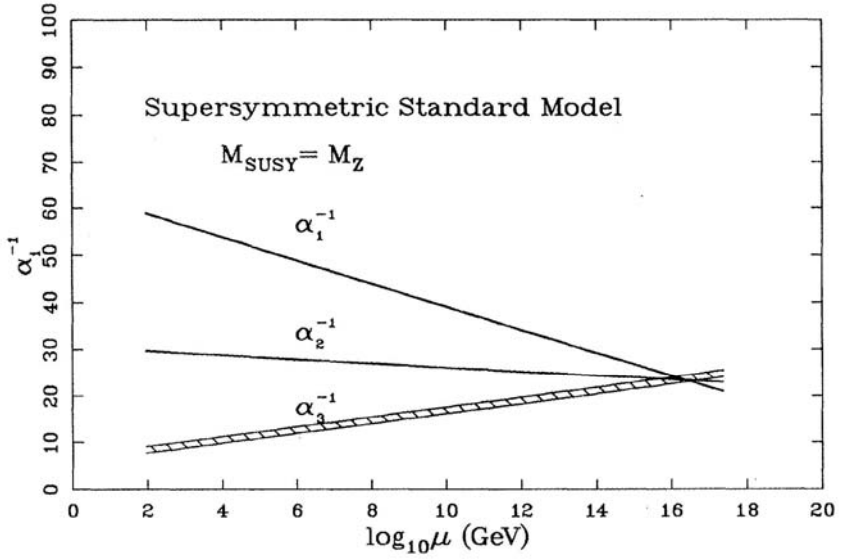
The lightest superparticle, called ***neutrolino***, is assumed to be 100 or even 1000 times heavier than the **proton** (i.e. its mass is in the range 100 GeV – 1 TeV). **Neutrolino is** a strong candidate on the role of **Dark Matter** which constitutes **~ 23%** of the Universe *(observable Matter (atoms etc.) is only* ~ 4 % and the rest ~73% is Dark Energy).

New Large Hadron Collider at CERN is aimed at looking for superparticles

Supersymmetric extension of the Standard Model

- Suggests the solution of a number of fundamental problems:
  - Mass hierarchy problem (100 Gev – 10^3 Gev and 10^{16} Gev)
  - Unification of the coupling constants of the electromagnetic, weak and strong interactions ~ 10^{16} Gev





“Applied” Supersymmetry in Nuclear Physics

- Supersymmetry between some nuclei (i.e. a relation between the energy spectra of their excitation states) was predicted in 1980 by Italian physicist ***Francesco Iachello*** (Prof. at Yale U., graduated from Torino Politecnico) and confirmed experimentally in 1999 by German experimentalists.
  - supersymmetry relates isotops of platinum Pt^{78}(194,195) and of gold Au^{79} (195,196)

Origination of supersymmetry

- supersymmetry was first revealed in two-dimensional string models in 1971 by *Ramond, Neveu, Schwarz, Gervais and Sakita*
- As a possible **fundamental symmetry of Nature supersymmetry** was first put forward in three independent papers
  - 1971, *Yu. Golfand* and *E. Likhtman* (Lebedev Institute of Physics, Moscow)
  - 1972, *D. Volkov* and *V. Akulov* (Kharkov IP&T, Ukraine)
  - 1973, *J. Wess* (Karlsruhe U.) and *B. Zumino* (CERN)

Origination of Supergravity

- In their 1972 paper Volkov and Akulov wrote

  "The gravitational interaction can be introduced into the scheme in analogous fashion…We note that if we introduce also gauge fields corresponding to the [supersymmetry] transformations, then as a consequence of the Higgs effect, a massive gauge field with spin 3/2 arises and the Goldstone particles with spin ½ vanish."

- **In 1973** Volkov and Soroka proposed (in JETP Letters) a supersymmetric extension of gravity with the Rarita-Schwinger spin 3/2 gauge field, in which supersymmetry is spontaneously broken by the *Super-Higgs mechanism*. In this model local *supersymmetry is realized non-linearly*.

Origination of Supergravity

- **In 1976** the first fully-fledged supergravity theory was constructed with supersymmetry *linearly realized* on the components of the supergravity supermultiplet comprising the graviton (spin 2) and the gravitino (spin 3/2)
  - D.Z. Freedman, P. van Nieuwenhuizen and *S. Ferrara*
  - S. Deser and *B. Zumino*
- These results made a crucial impact on further impetuous development of this field which has become an integral part of modern Unified Theory of Fundamental Interactions, in particular the one based on String Theory
  - Contribution of *JINR* theorists:
    V. Ogievetski, E. Ivanov, E. Sokatchev et.al.

Italian - *Ex* Soviet Union collaboration in supersymmetry and supergravity (personal experience)

- Before 1991 – mainly via scientific publications and "by correspondence"

Example: parallel work on compactification of extra dimensions in multi-dimensional SUGRAs in 1980-1985

D.Volkov, V.Tkach & D.S. (*Kharkov*) L.Castellani, R. D'Auria, P. Frè (*Torino*)

- After 1991 – direct contacts and collaboration within individual, bilateral and network programs

Example: INTAS projects (1993-2009)

INTAS: the International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union (NIS), was established by EC in 1993 and terminated in 2007

Italian - *Ex* Soviet Union collaborations in supersymmetry, supergravity, string theory and cosmology

- Italian Coordinators of INTAS projects:
  - Gabriele Veneziano (CERN & College de France)
  - Sergio Ferrara (INFN Frascati & CERN)
  - Augusto Sagnotti (Rome & Pisa)

Groups from the Ex-USSR involved:

JINR, Lebedev Physical Institute, Landau ITP, Tomsk Universities, Kharkov ITP and Uni, Dnepropetrovsk Uni.

Present cooperation opportunities

- Bilateral agreements (*examples*: *JINR - INFN, Ukraine Academy of Sciences - MIUR, Italy…*)
- EC Seventh Framework Programme (FP7)
  - Marie Curie International Outgoing and Incoming Fellowships (individual)

    (I. Samsonov, Tomsk Politech. Uni. comes to Padova in 2010)
  - Marie Curie International Staff Exchange Scheme

    (still to be taken advantage off)

Ukrainian State Prize in Science and Technology of 2009

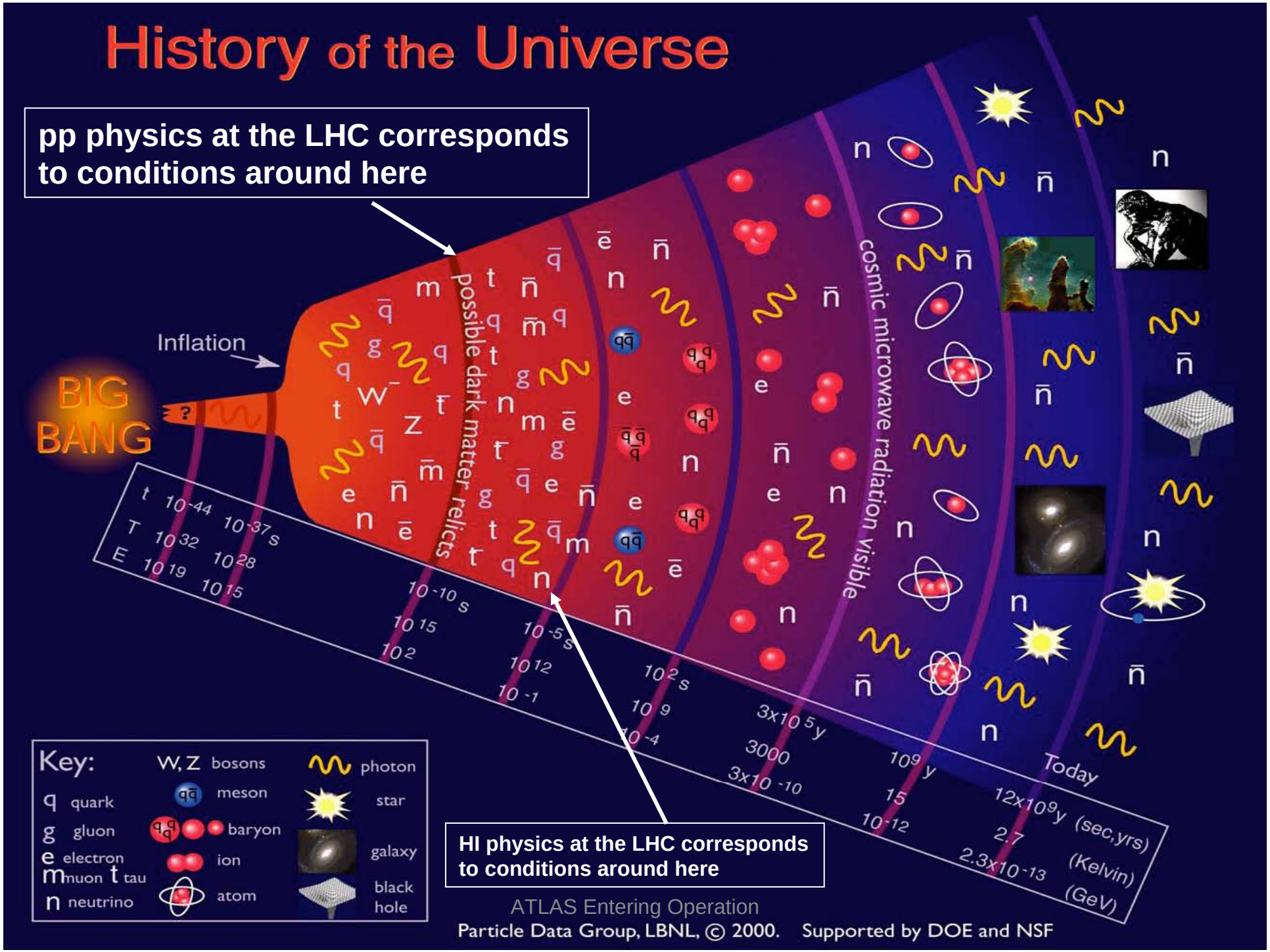
For the discovery and development of principles of supersymmetry and supergravity and their application to the construction of unified theory of fundamental interactions of elementary particles

Awarded to the Kharkov Group:

D. Volkov (1925-1996), V. Akulov, V. Soroka,

I. Bandos, V. Gershun, A. Nurmagambetov, A. Pashnev (1948-2004),

D. Sorokin, V. Tkach, A. Zheltukhin


History of the Universe
pp physics at the LHC corresponds to conditions around here
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 1032 1028
E 1019 1015
10-10 s
1015
102
10-5 s
1012
10-1
102 s
109
10-4
3x105 y
3000
3x10-10
109 y
15
10-12
12x109y (sec,yrs)
2.7
(Kelvin)
2.3x10-13
(GeV)
Today
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
HI physics at the LHC corresponds to conditions around here
ATLAS Entering Operation
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF