Supersymmetry and how it helps us understand our world

Spitalfields Day

Gauge Theory, String Theory and Unification,

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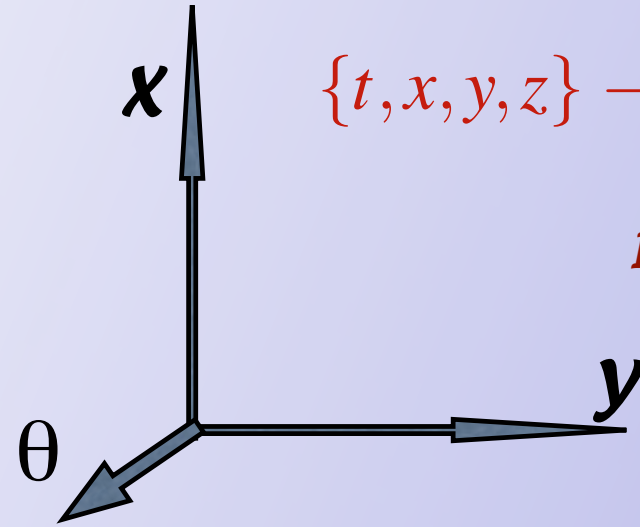
What is supersymmetry?

Supersymmetry, if it holds in nature, is part of the quantum structure of space and time. In everyday life, we measure space and time by numbers,
"The linear dimension of this building is 40 meters, its area is 1600 square meters."
Numbers are classical concepts. Our basic way of thinking about space and time has not been affected by physics revolutions of the 20th century: quantum mechanics and Einstein's relativity.



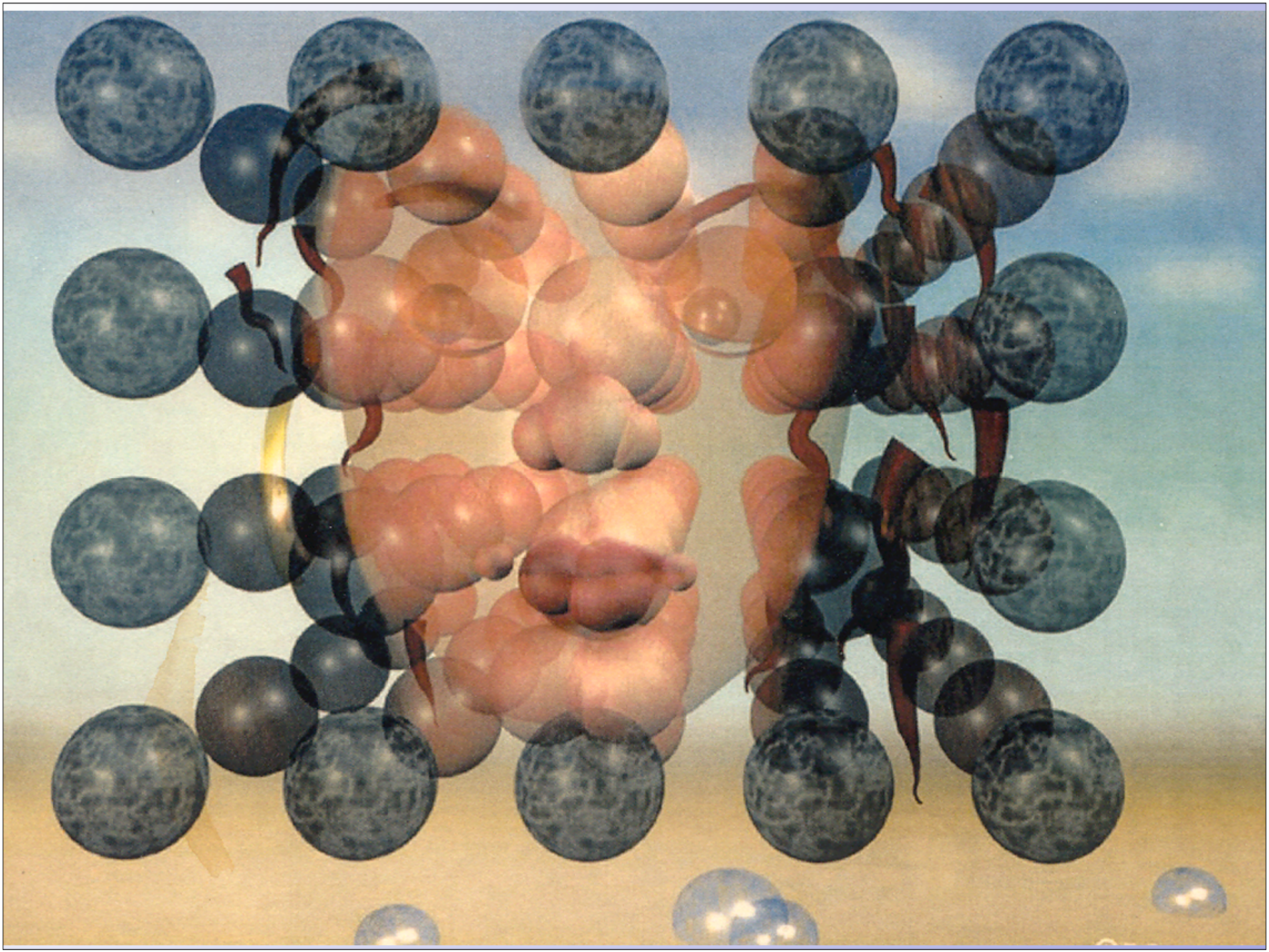
$$\{t, x, y, z\} \longrightarrow \{t, x, y, z;\ \theta^i_\alpha\}$$

In 1+3 dimensions

"fermion" direction of the superspace ⟶

$$\theta^2 = 0$$

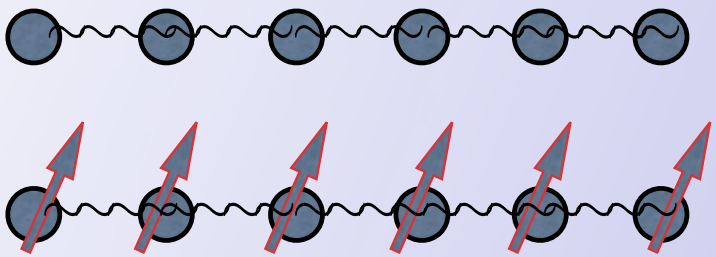
Supersymmetry introduces, apart from the three obvious dimensions plus time, new "quantum" dimensions, not measurable by ordinary numbers.
They are "quantum" (or "fermionic" dimensions, like the spin of the electron.

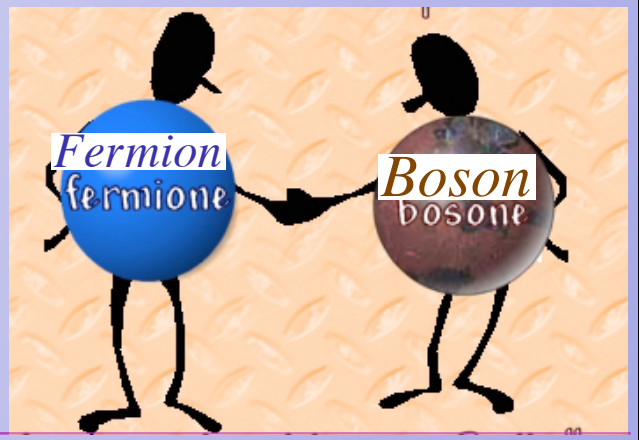


✷ Particles vibrating in the new dimesnions look in detectors like new elementary particles.

Thus, quantum dimensions would be manifested in the existence of new elementary particles, which would be produced in accelerators and whose behavior would be governed by supersymmetric laws.

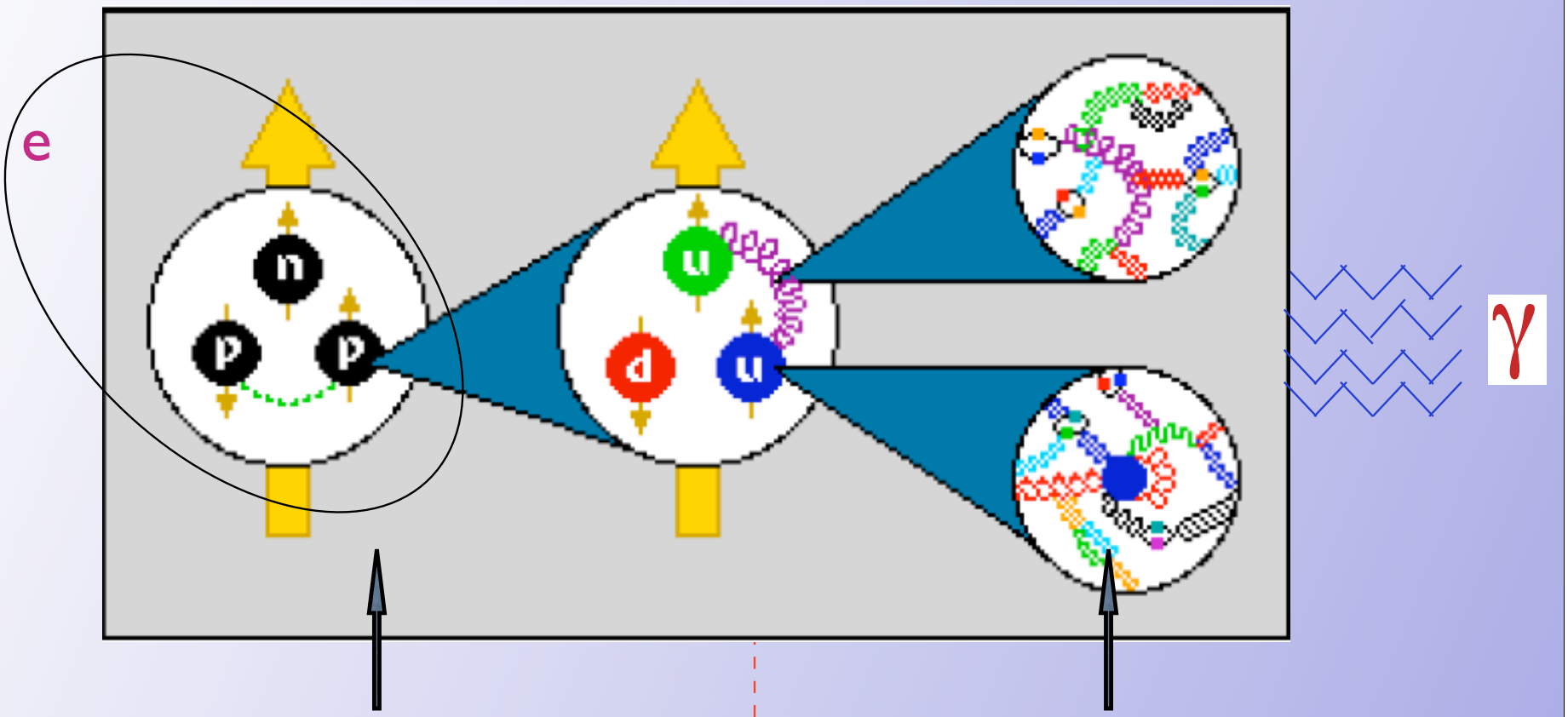
Supersymmetry entails that for every particle that has been found there are mirror particles that are identical in all respects except for their spin. Bosons of spin 1 — the photon, W, Z, and gluon — have spin 1/2 partners called the photino, wino, and gluino. Fermions of spin 1/2 — leptons and quarks — have spin 0 partners called the sleptons and squarks.





Fermions

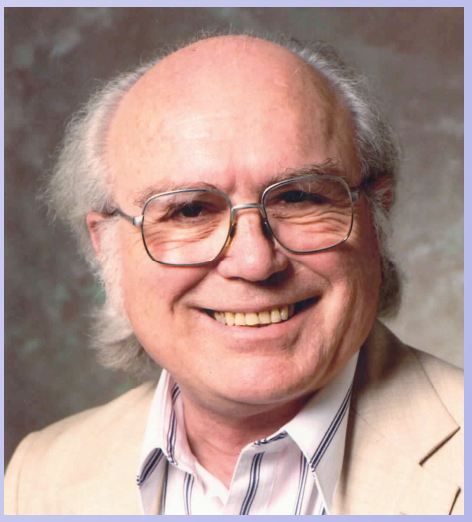
Bosons



Spin 1/2, 3/2, … Building blocks of matter …
Absolute individualists:
Pauli's Exclusion Principle

Spin 0, 1, … Force mediators/helpers in delicate issues… Love to congregate and mimic each other:
Huge ensembles -> Classical

Can there be any symmetry between bosons and fermions?



Golfand & Likhtman, 71

Wess & Zumino, 73

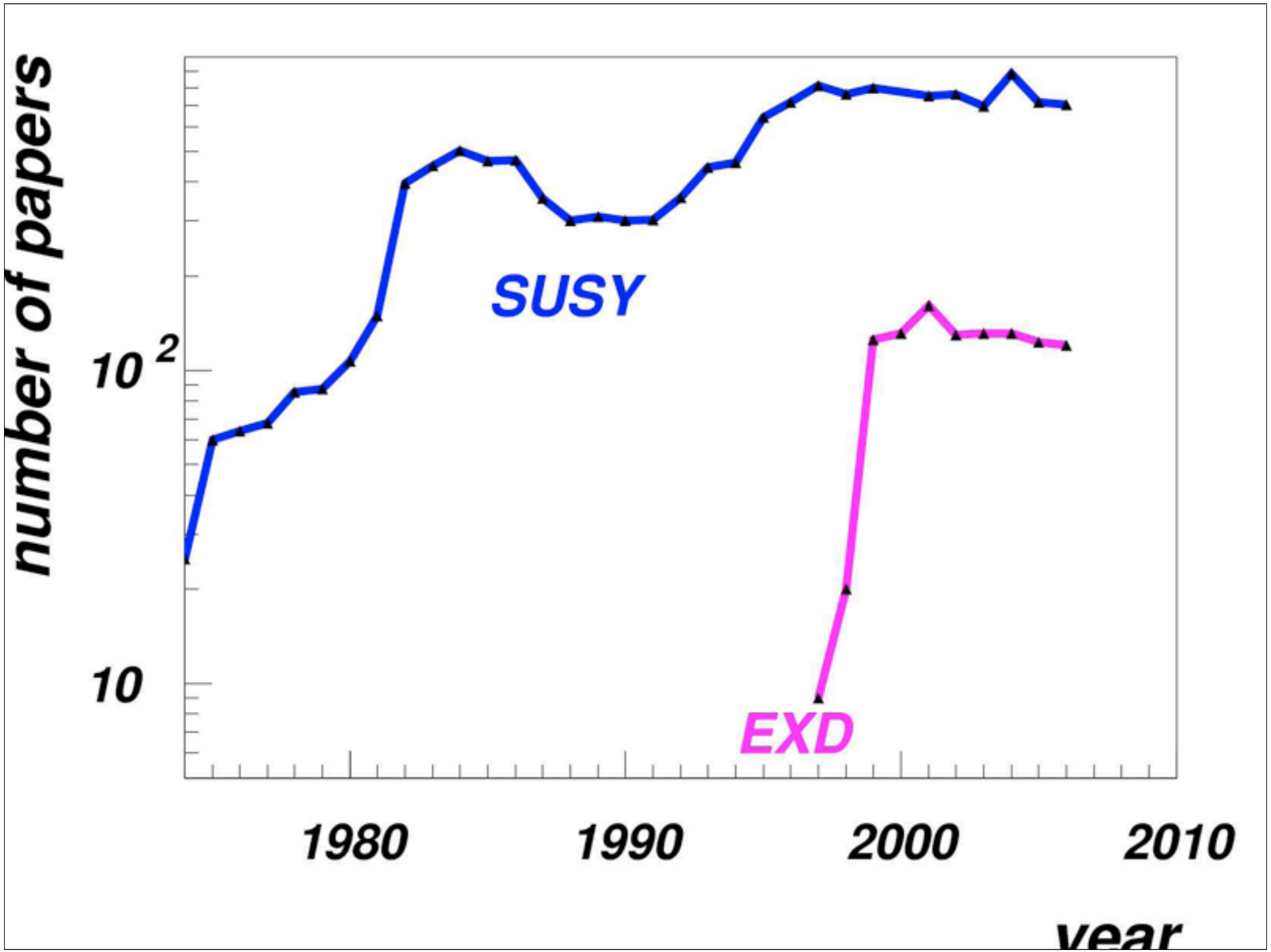
1970's: YES!

$$E = mc^2$$

Cultural icon of the 20th century

$$\{\bar{Q}_{\dot{\alpha}}, Q_{\beta}\} = 2\sigma^{\mu}_{\dot{\alpha}\beta} P_{\mu}$$ ⟵ Of the 21st ?

Defying the Coleman-Mandula theorem!


number of papers
10 2
10
SUSY
EXD
1980
1990
2000
2010
year

Spin:	0	½	1	
selectron	$\tilde{e}$ ←	e		electron
smuon	$\tilde{\mu}$ ←	μ		muon
stau	$\tilde{\tau}$ ←	τ		tau
sneutrino	$\tilde{\nu}$ ←	ν		neutrino
squark	$\tilde{q}$ ←	q		quark
wino		$\tilde{W}$ ←	W	W
zino		$\tilde{Z}$ ←	Z	Z
photino		$\tilde{\gamma}$ ←	γ	photon
gluino		$\tilde{g}$ ←	g	gluon
Higgs	H^0 →	$\tilde{H}$		Higgsino
Charged Higgs	$H^{\pm}$	$\tilde{H}^{\pm}$		Charged Higgsino

Mix → neutralino

LHC ...

or NOT?

✶✶✶ Why do we need SUSY ? ✶✶✶

Supersymmetric model-building

Hierarchy problem: $M_{part} \approx$ 1-100 GeV

while $M_{Planck} \approx 10^{19}$ GeV

$\mathcal{E}_{vac} \approx 0$

Cold Dark Matter

More efficient decoupling of high energies: Comes at a price

▲▲▲▲▲▲▲▲▲

Lots of problems +

SUSY partners to be discovered

A tool for solving otherwise unsolvable problems of strong coupling dynamics

Costs nothing;

Enormous progress since mid-1990's!

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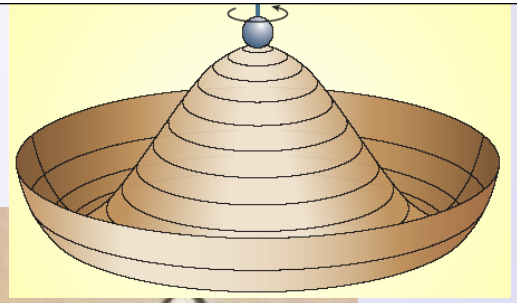
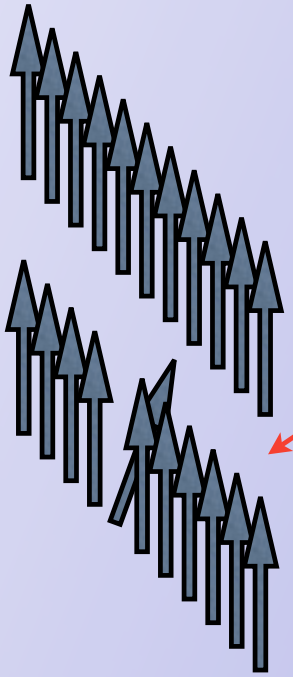


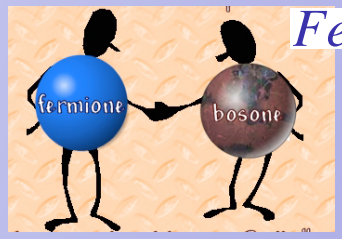
Spontaneous symmetry breaking



magnon

=gapless excitation

Goldstone boson → Goldstino



Fermion

gravitino goldstino gravitino goldstino

= massive gravitino

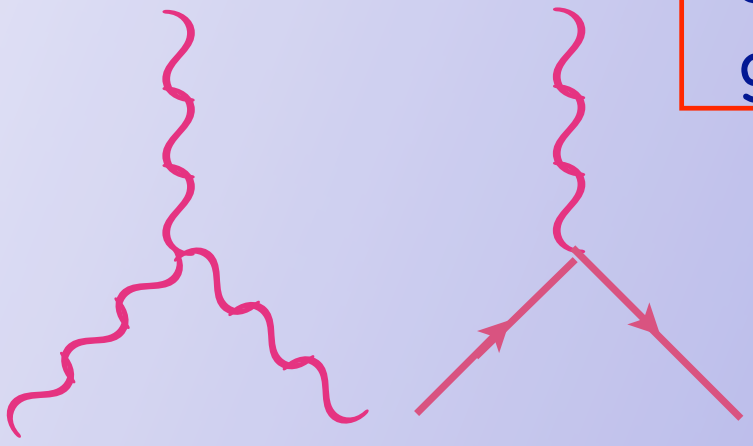
$$\mathcal{L} = -\frac{1}{4g^2} G^a_{\mu\nu} G^{\mu\nu\, a} + \frac{i}{2} \bar{\lambda} \not{D} \lambda$$

gluon

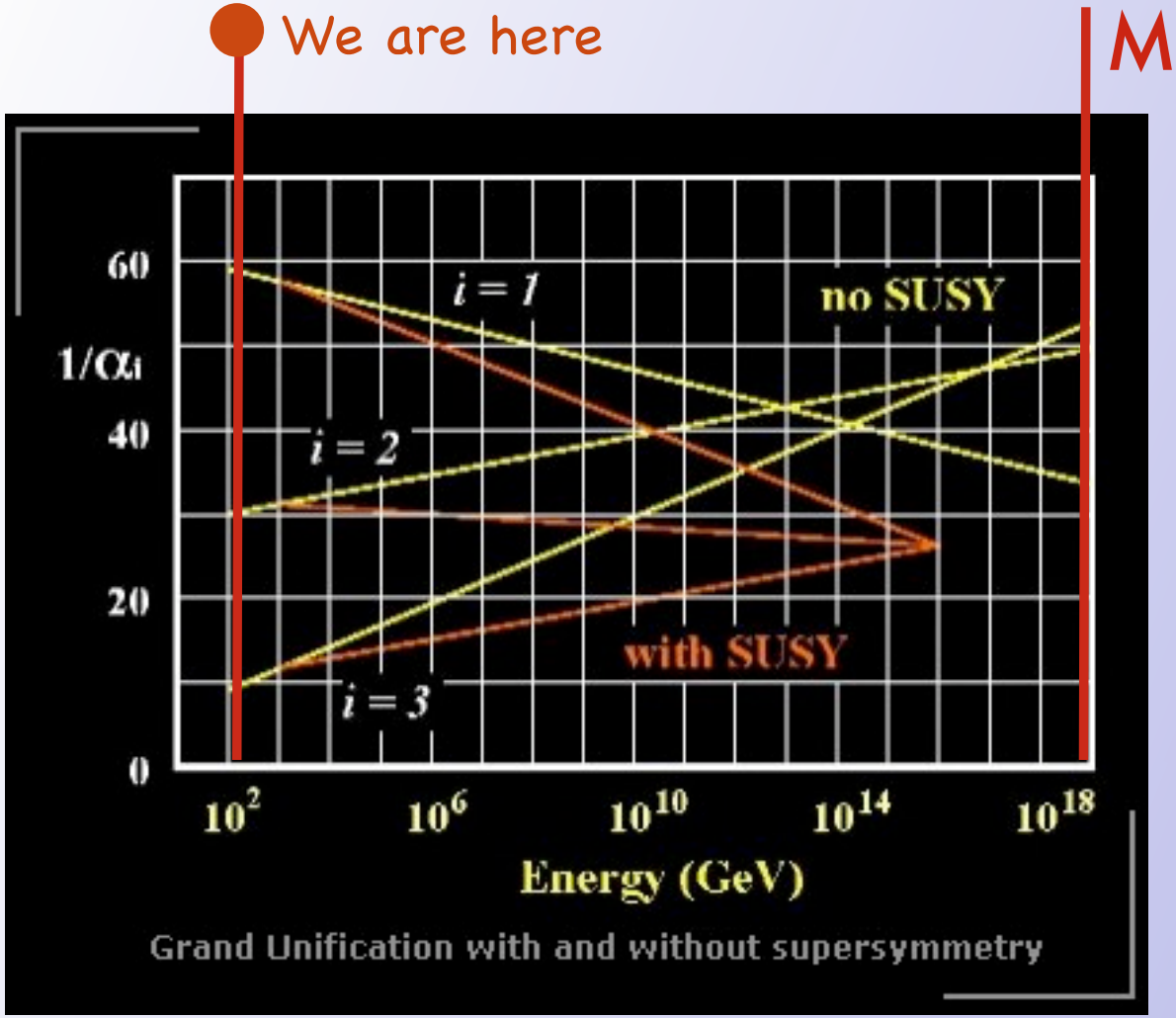
gluino

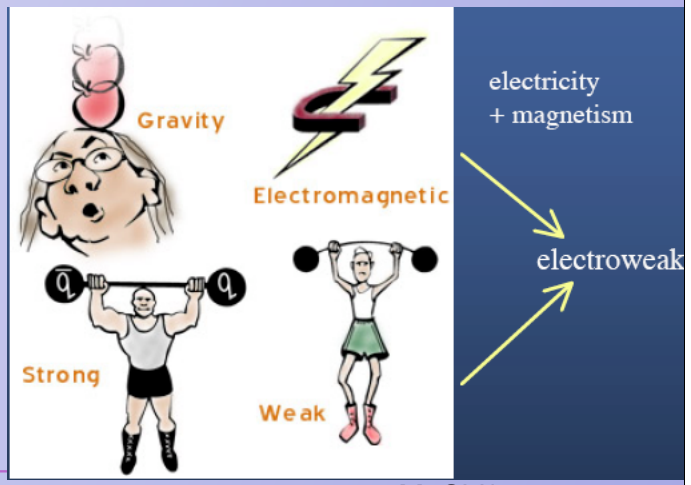
SUSY Yang-Mills

supersymmetric gluodynamics



A success of SUSY: gauge coupling unification





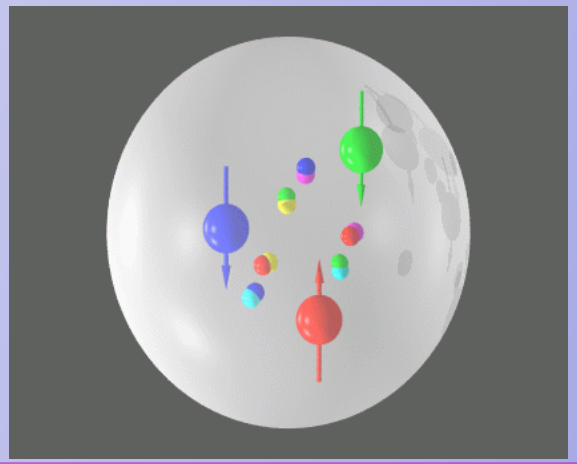
✶✶✶ SUSY as a tool in strongly coupled gauged theories: QCD and the like ✶✶✶

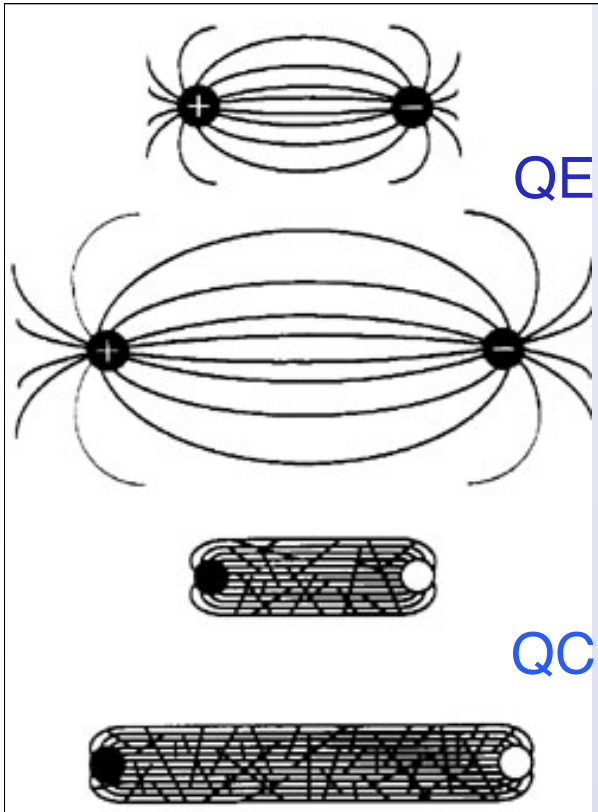
Quantum Chromodynamics (QCD):

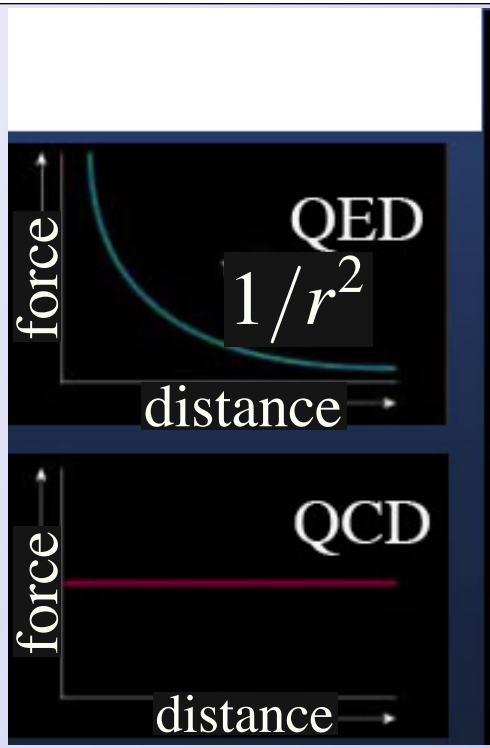
- Quantum Field Theory of **Strong Interactions** of quarks and gluons,
- Interaction mediated by exchange of gluons
- Gluons carry color charges;

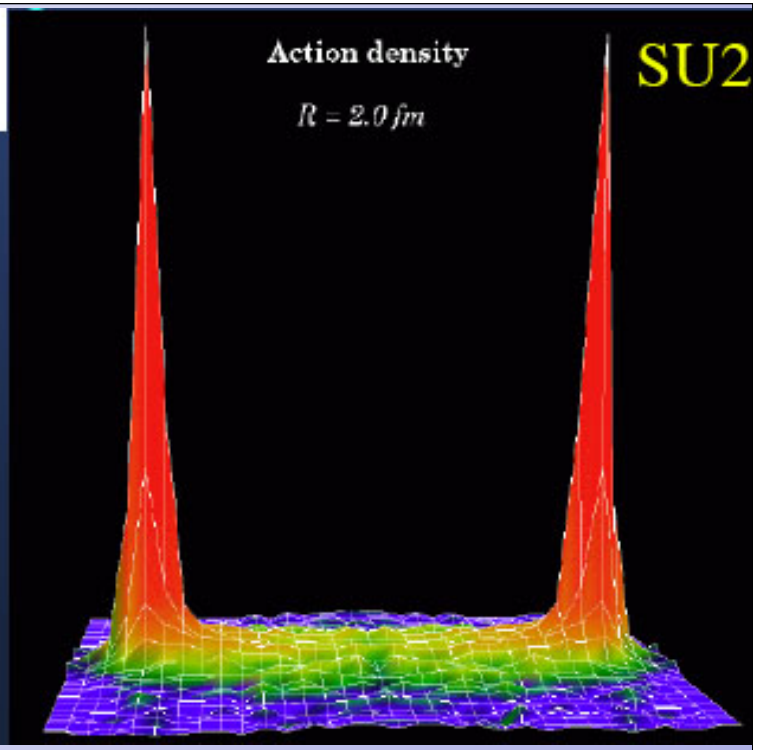
Special Properties of QCD:

- "Asymptotic Freedom,"
- **Color Confinement**: Hadrons are always "white,"
- Linear potential between quarks.









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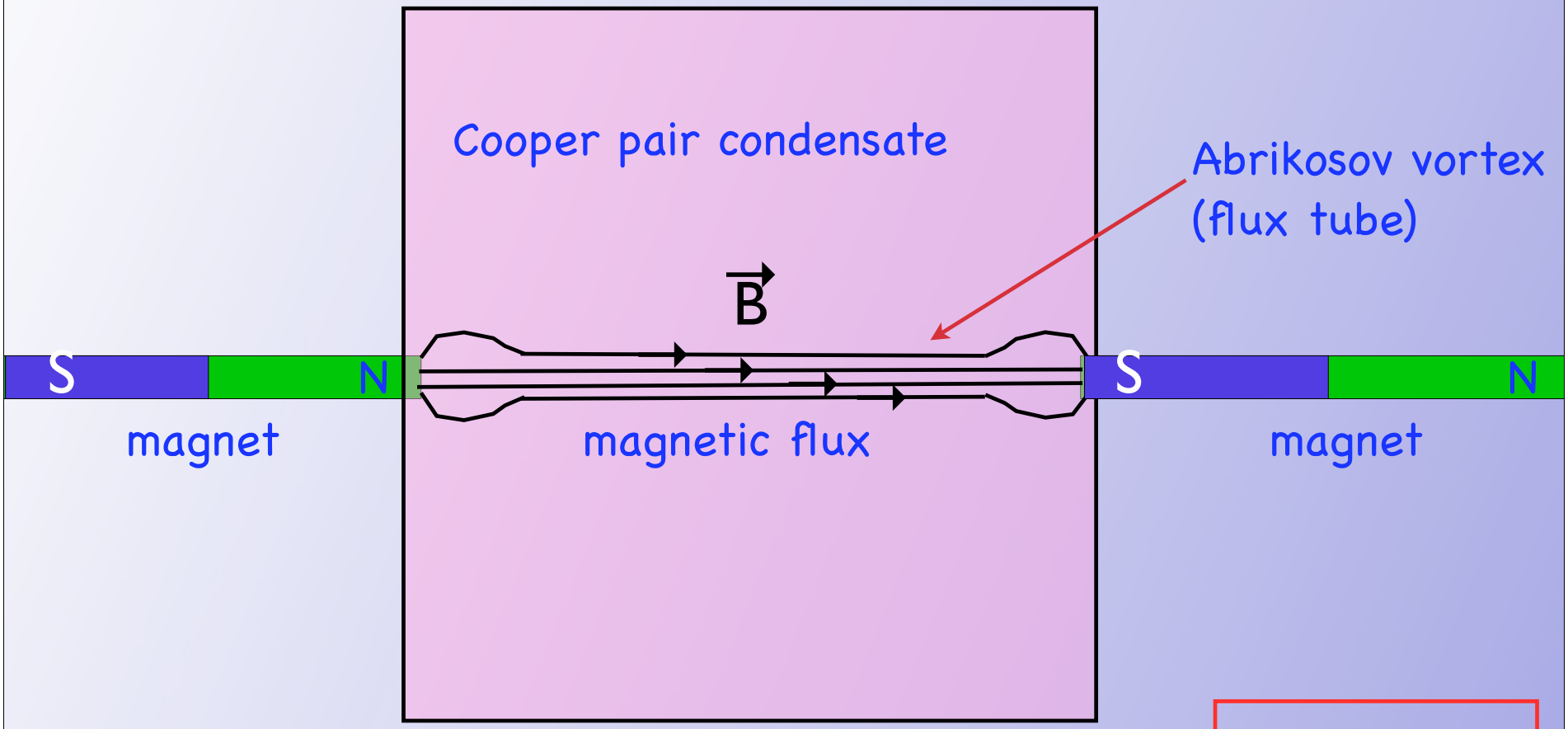
Nature keeps surprising us !!!

☞ Are we aware of precedents?

☞ Yes, the Meissner effect! 1930s, 1960s



Superconductor of
the 2nd kind

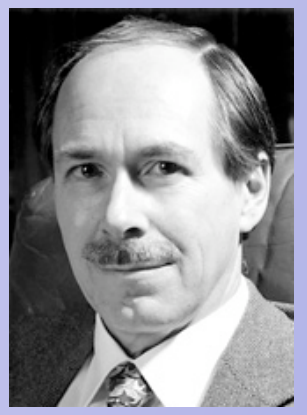
Abelian ☚

Dual Meissner effect for confinement conjectured

1970s

Mandelstam

Nambu



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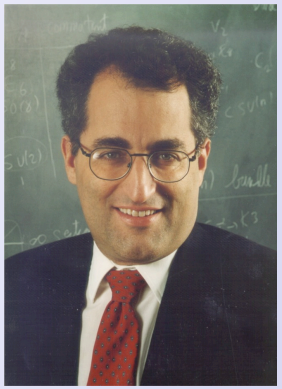
✶✶✶ First demonstration of the dual Meissner effect: Seiberg & Witten, 1994 ✶✶✶

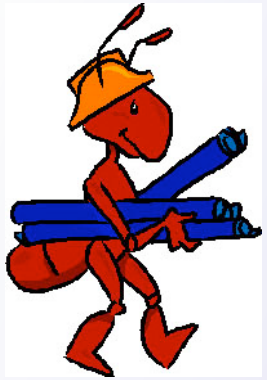


$\mathcal{N}=2$ (extended) SUSY ➔ SU(2) →U(1), monopoles ➔

Monopoles become light ➔ $\mathcal{N}=1$ deform. forces M condensatition ➔

U(1) broken, electric flux tube formed ➔

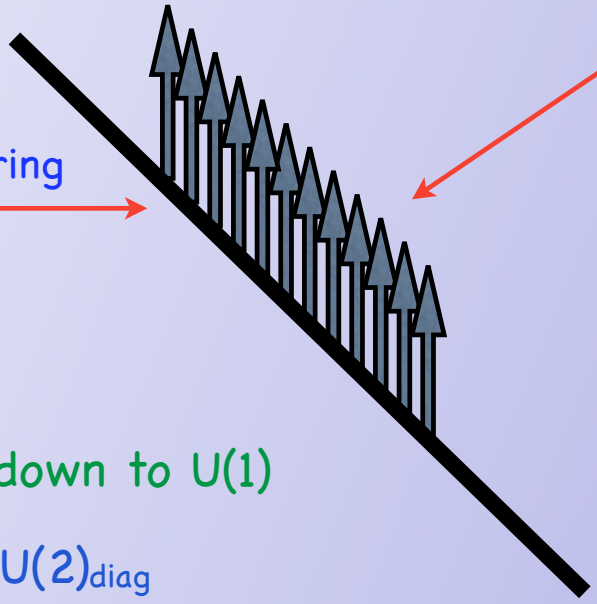
☺☹ ☺☹ Abelian ... (Abrikosov)



1994-present: In search of non-Abelian dual Meissner effect (non-Abelian flux tubes)

Auzzi et al,
Shifman & Yung
Hanany & Tong

Non-Abelian string



Internal d.o.f

- $SU(2)_{diag}$ broken on the string down to U(1)
- $SU(2)\times U(1)_{gauge}\times SU(2)_{flavor}\to SU(2)_{diag}$

Deform & dualize

$\mathcal{N}=1$ SQCD N_c+N flavors

N flavors are endowed with a mass term m_q

keep N_c flavors massless $\langle Q\tilde{Q}\rangle\neq 0$

Conclusions/Predictions:

☺ Most likely, SUSY will be discovered at LHC

☺ In any case, SUSY-based methods will proliferate