Problems of Modern Particle Physics

and new Challenges at TeV scale

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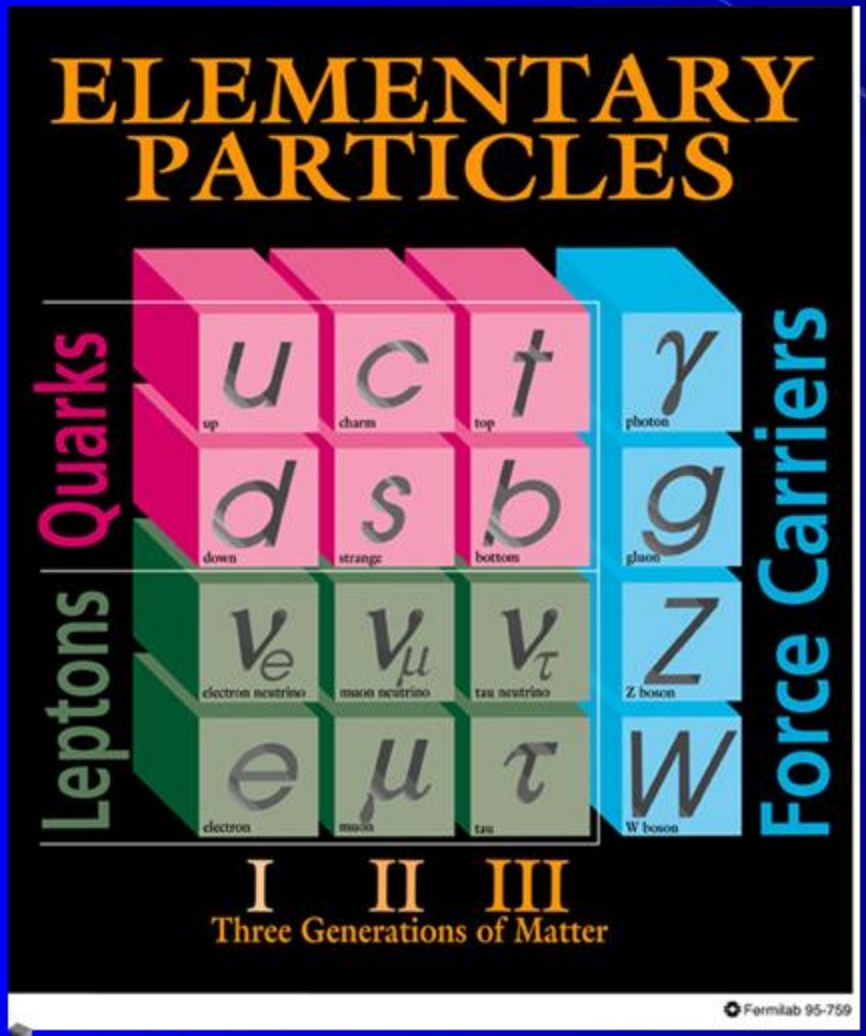
The Standard Model

SU(3)

SU(2)

U(1)

Particles



Forces

Electromagnetic

Strong

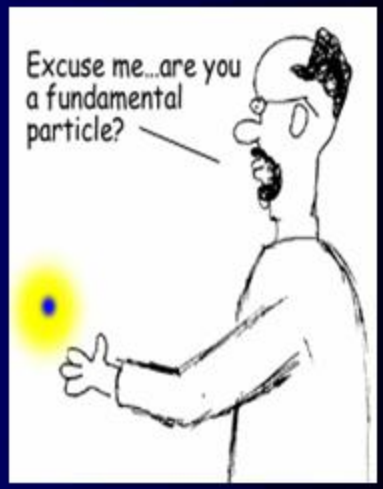
Weak

Gravity

H

The Higgs boson

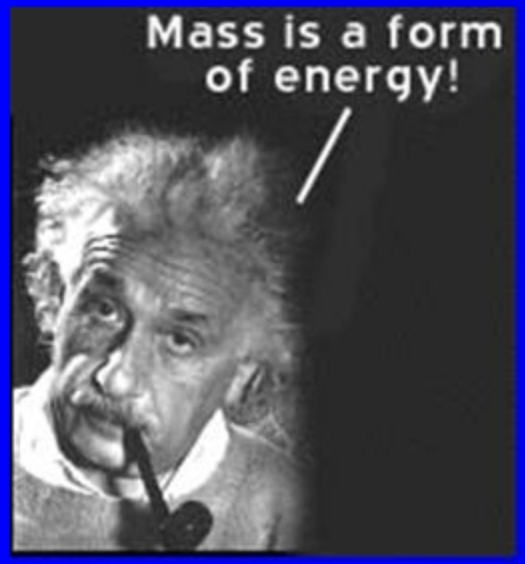
Unresolved Questions within the SM

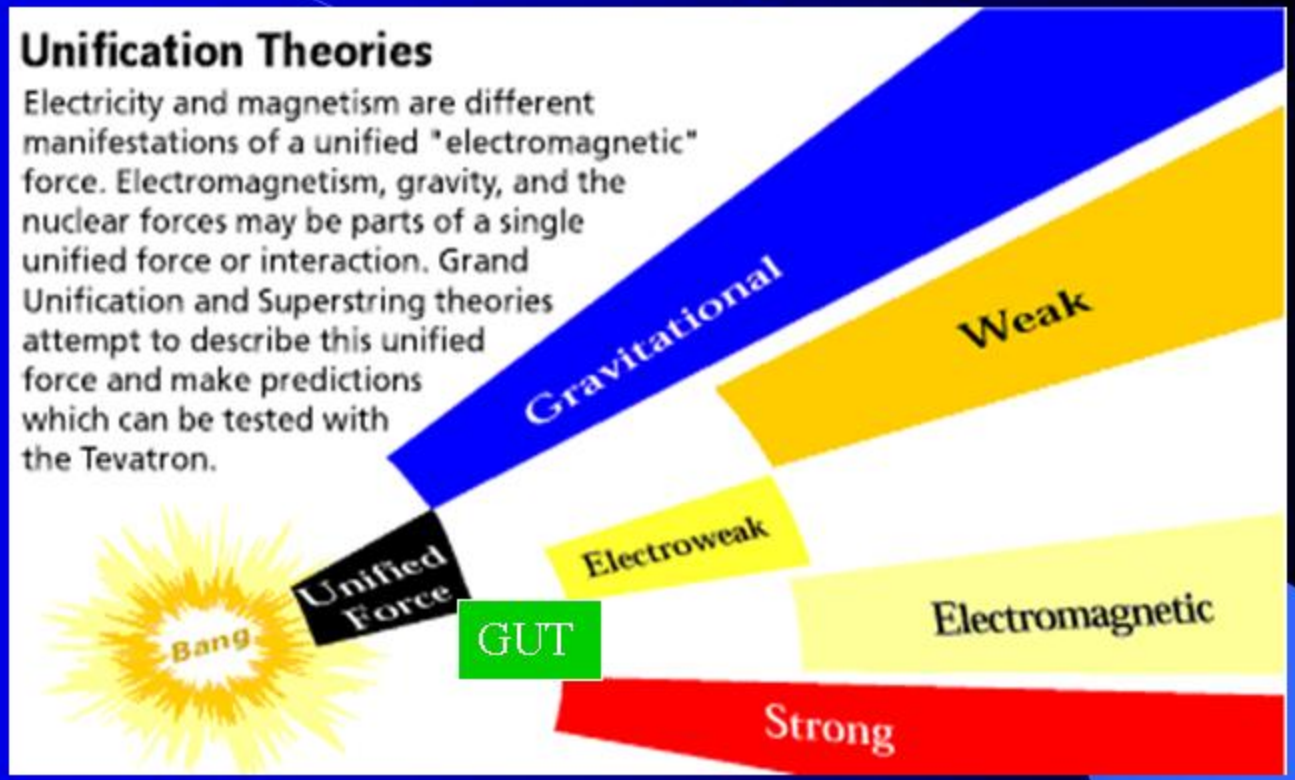


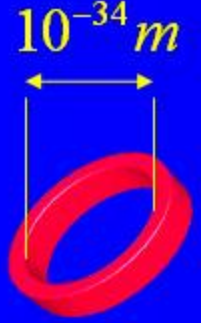
- Group Structure: Why SU(3)xSU(2)xU(1) ?
- Number of Generations: Why do we need 3 copies?
- Number of Dimensions: Do we live on a brane?
- Matter-Antimatter assymetry: Why and How?
- Symmerty Breaking: Dynamical? Spontaneous? Explicit?
- The origin of the mass spectrum?
- The origin of CP violation?

- Do we see anything beyond the SM?
- Are there new particles?
- Are there new forces?
- Are there new states of matter?
- Does one need them?

Unification Paradigm (?!)



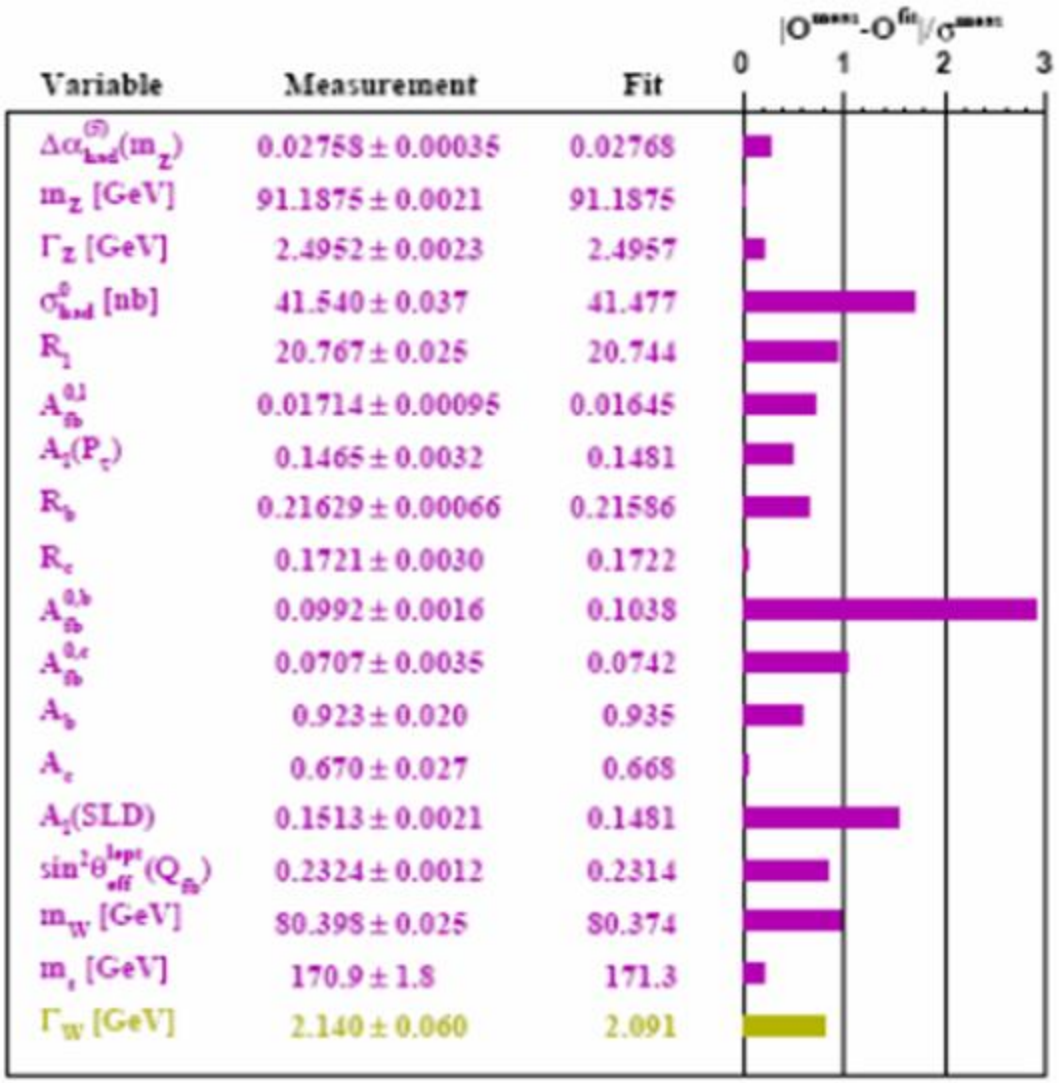




- Unification of strong, weak and electromagnetic interactions within Grand Unified Theories is the new step in unification of all forces of Nature
- Creation of a unified theory of everything based on string paradigm seems to be possible

SM Pull Distribution

SM



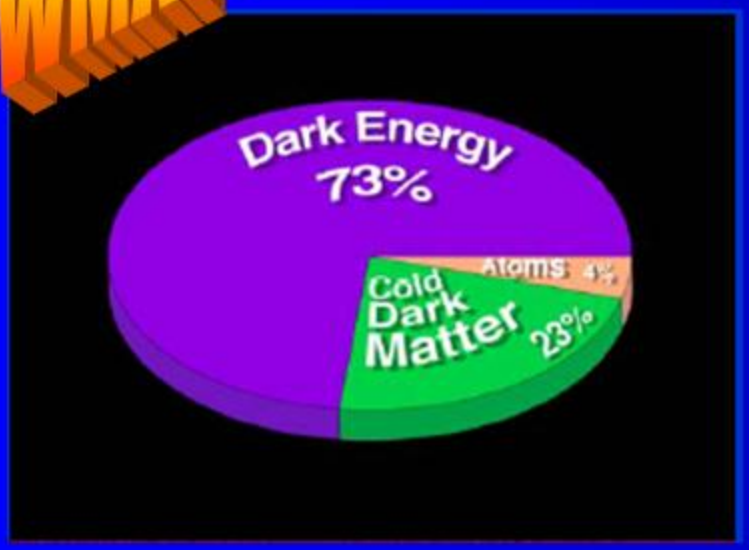
Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
m_t [GeV]	170.9 ± 1.8	171.3
Γ_W [GeV]	2.140 ± 0.060	2.091

Are there any deviation from the SM ?

- $(g-2)_\mu$ ~3σ ?
- Rare Decays (B->sγ) ?
- Neutrino masses ?

Is neutrino Majorana or Dirac particle ?

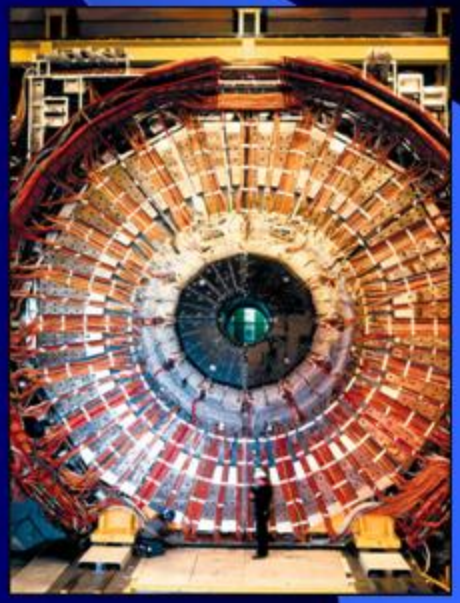
Experimental Challenge



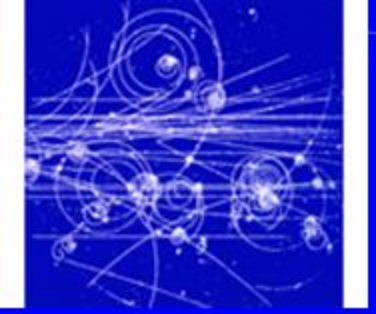
HEAVY ELEMENTS	0.03 %
MASSIVE NEUTRINOS	0.3 %
STARS	0.5 %
H AND He	4 %
DARK MATTER	23 %
DARK ENERGY	72 %

Physics beyond the SM

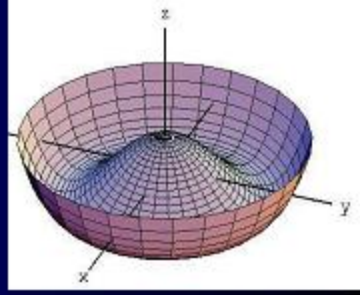
- Low Energy Supersymmetry
- Extra gauge bosons
- Axions
- Extra dimensions
- Deviation from Unitarity triangle
- Modification of Newton law
- Free quarks
- New forces / particles
- Violation of Baryon number
- Violation of Lepton number
- Monopoles
- Violation of Lorentz invariance
- Compositeness



Not found so far …



Target # 1

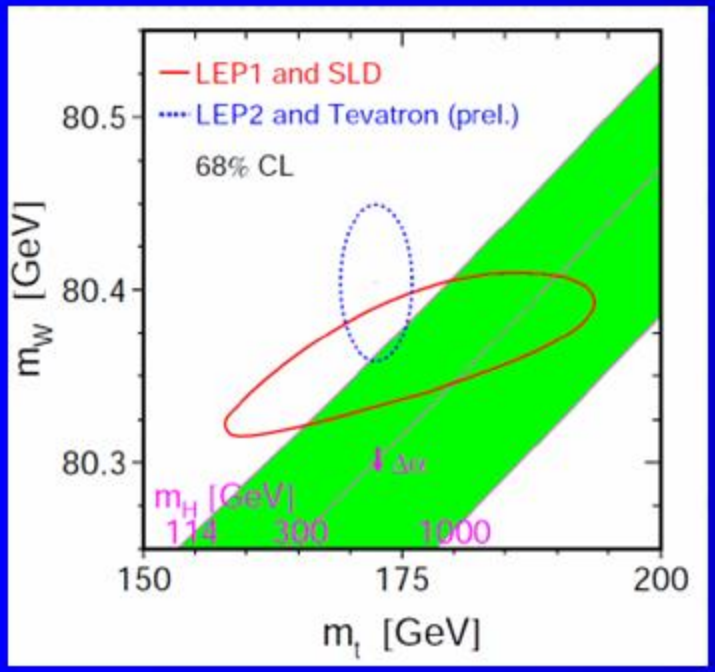


Mechanism of Electroweak Symmetry Breaking:

- The Higgs mechanism
- Alternatives

The SM Higgs Boson

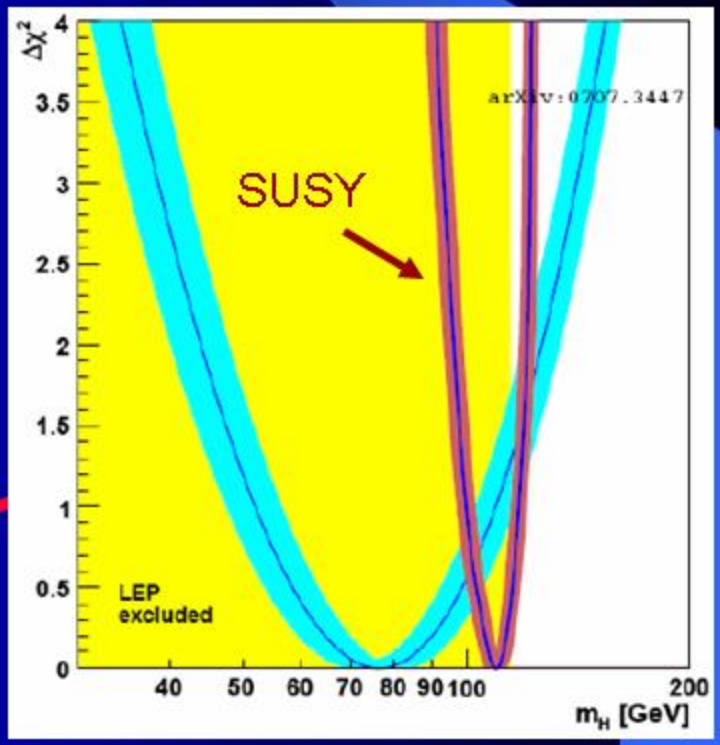
- Indirect limit from radiative corrections
- Direct limit from Higgs non observation at LEP II (CERN)
- Precision measurement of M_W and m_t



χ^2 *versus* M_H *for SM Fit*

- M_H=89 +42-30 @68%CL
- M_H < 165 GeV @95%CL

for m_{top}=172.5 GeV



If it is there we may see it soon

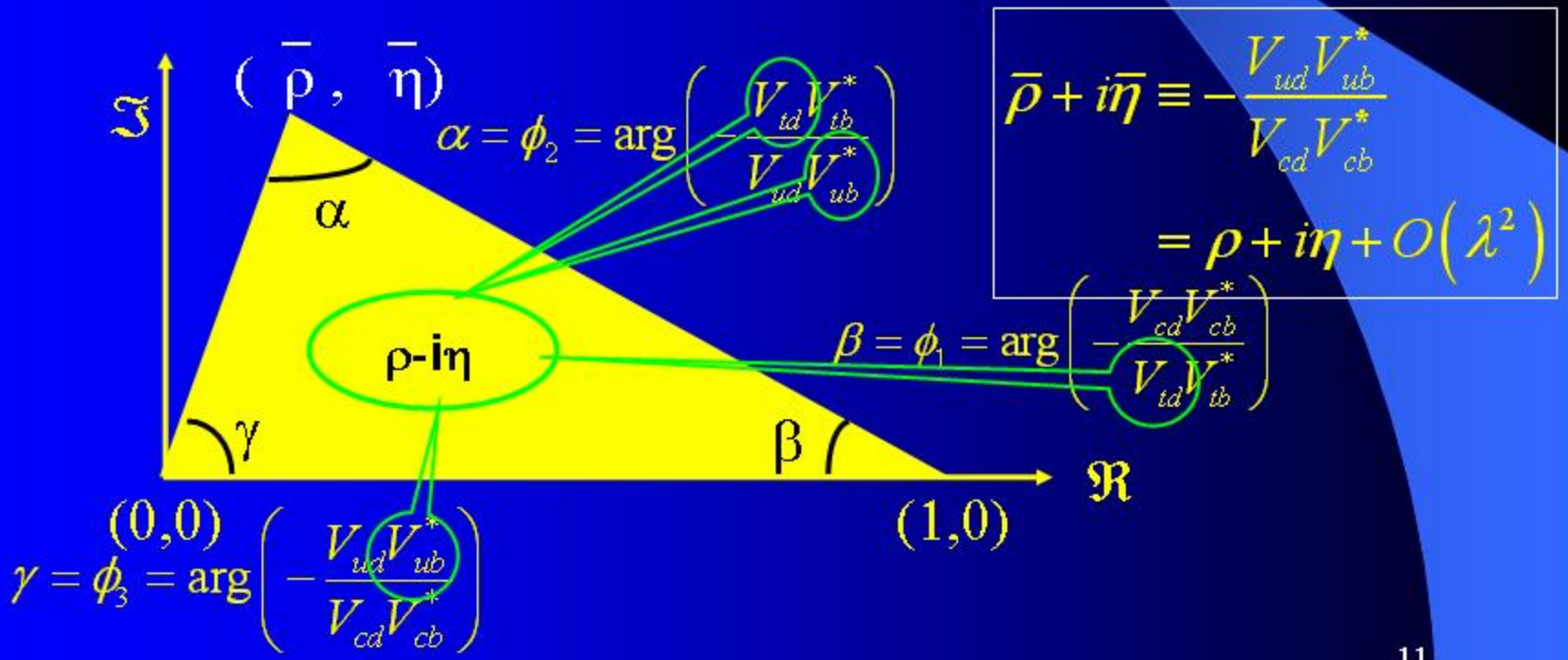
Target # 2

Flavour Mixing & CP-violation:

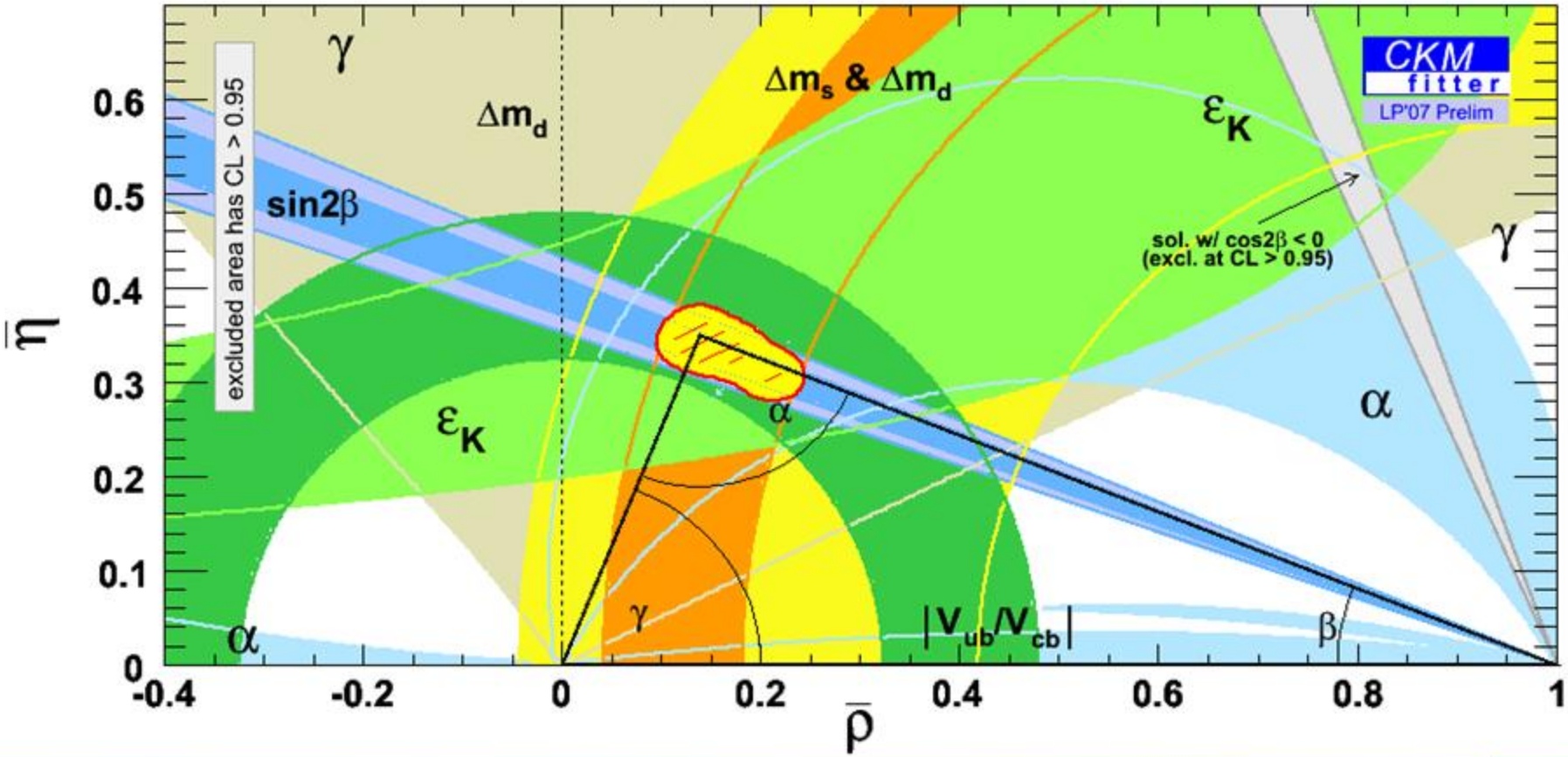
- Unitariry Triangle
- The phase in CKM mixing matrix
- Strong CP-violation ?
- Alternatives ?

The Unitarity Triangle(s)

- Graphical expression of unitarity condition(s)
  - 1 triangle has roughly equal-length sides
- CKM Unitarity violation would imply New Physics
  - Test SM + CKM by over-constraining angles and sides



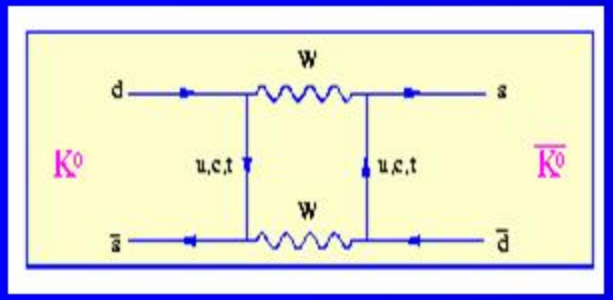
The Unitarity Triangle: all constraints

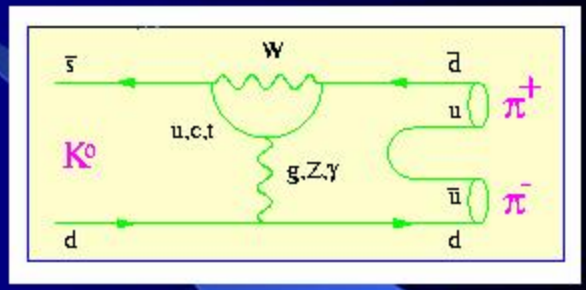


A consistent picture across a huge array of measurements

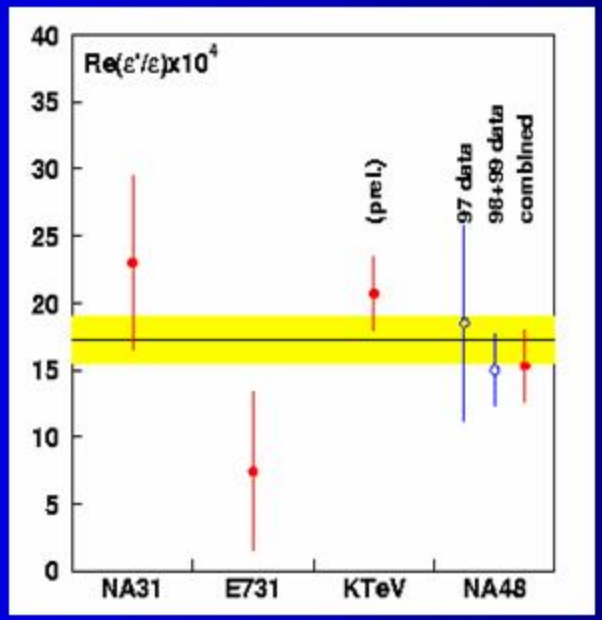
Discovery CP Violation

$$K_L = K_2^{-1} + \varepsilon\, K_1^{+1} \qquad \underbrace{\pi^+\pi^-,\ \pi^0\pi^0}_{CP=+1}$$



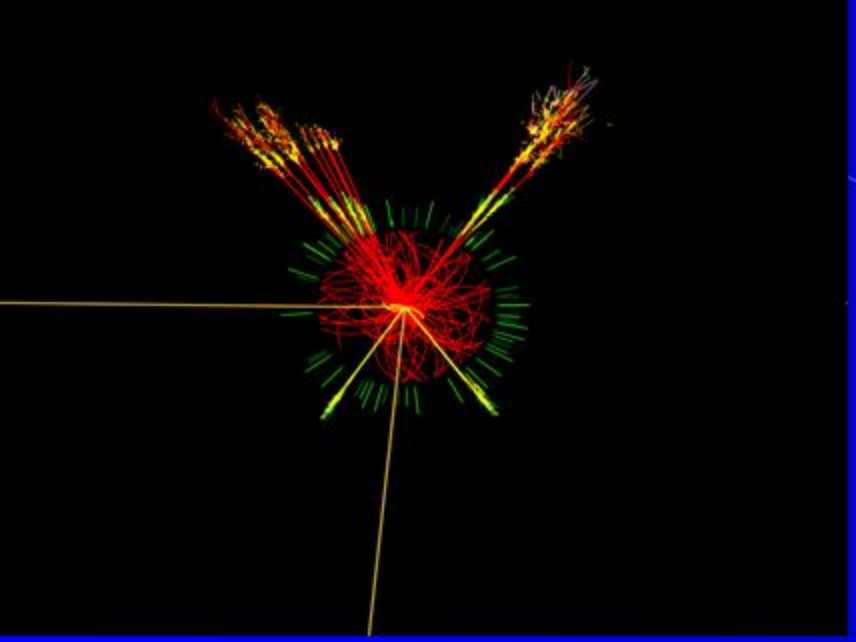


- Indirect CP violation in K-mesons and B-mesons
  PEP II (BaBar)
  KEKB (Belle)

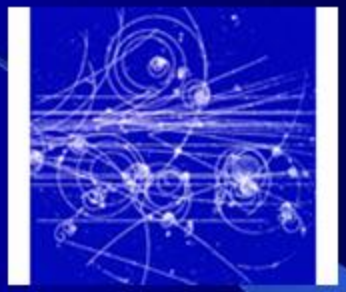


- Direct CP violation in K-mesons
  Fermilab (KTeV)
  CERN (NA48)

$$Re(\varepsilon'/\varepsilon) = (15.3 \pm 2.3)\ 10^{-4}$$



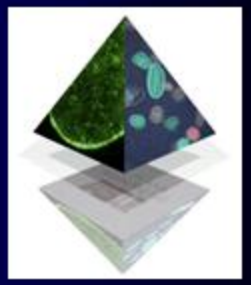
Target # 3



New physics at the TeV scale:

- Supersymmetry
- Extra Dimensions
- New Particles/Forces ?

What is SUSY?



SUSY is boson-fermion symmetry

Bosons and Fermions come in pairs

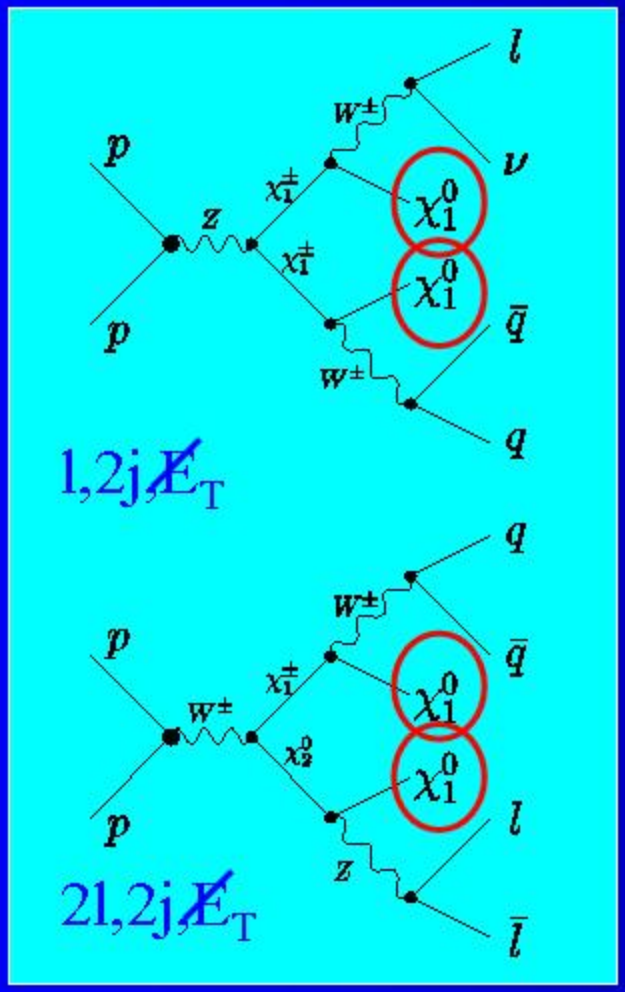
(φ, ψ) (λ, A_μ) $(\tilde{g}, g)$

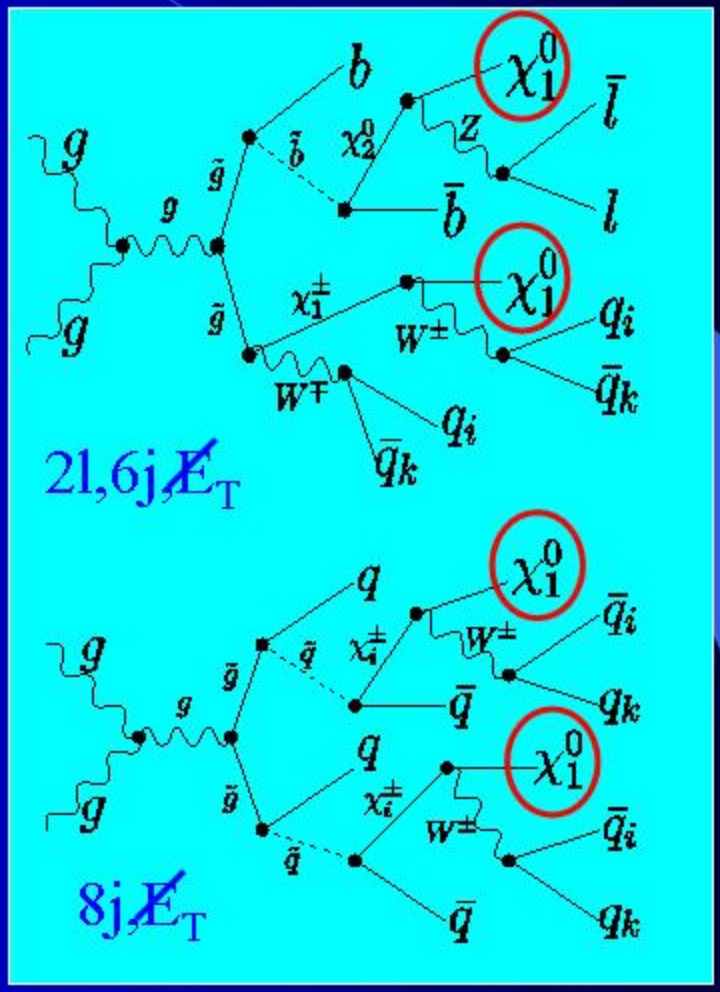
Spin 0 Spin 1/2 Spin 1/2 Spin 1 Spin 3/2 Spin 2

Scalar chiral fermion majorana fermion vector gravitino graviton

SUSY Production and Decay in Cascade Processes at LHC

weak int.'s

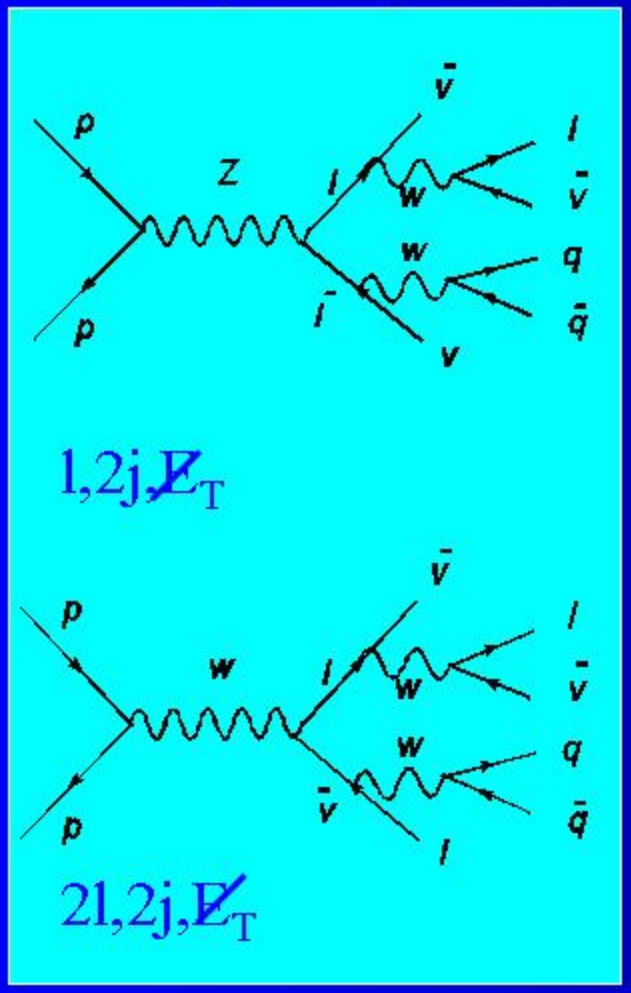


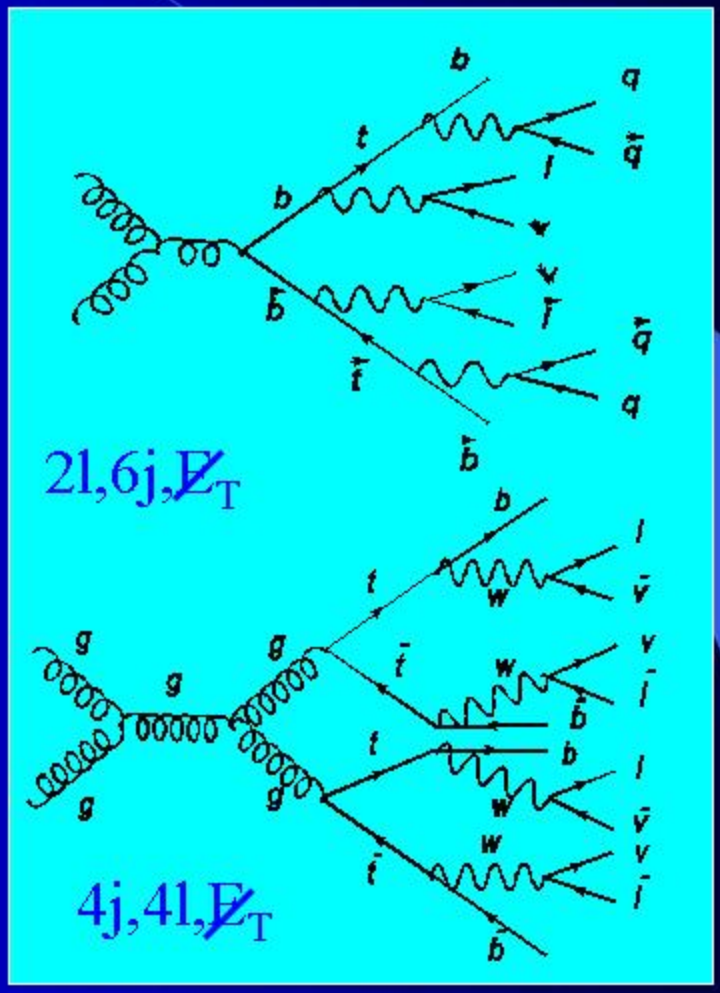


strong int.'s

Typical SUSY signature: Missing energy and transverse momentum

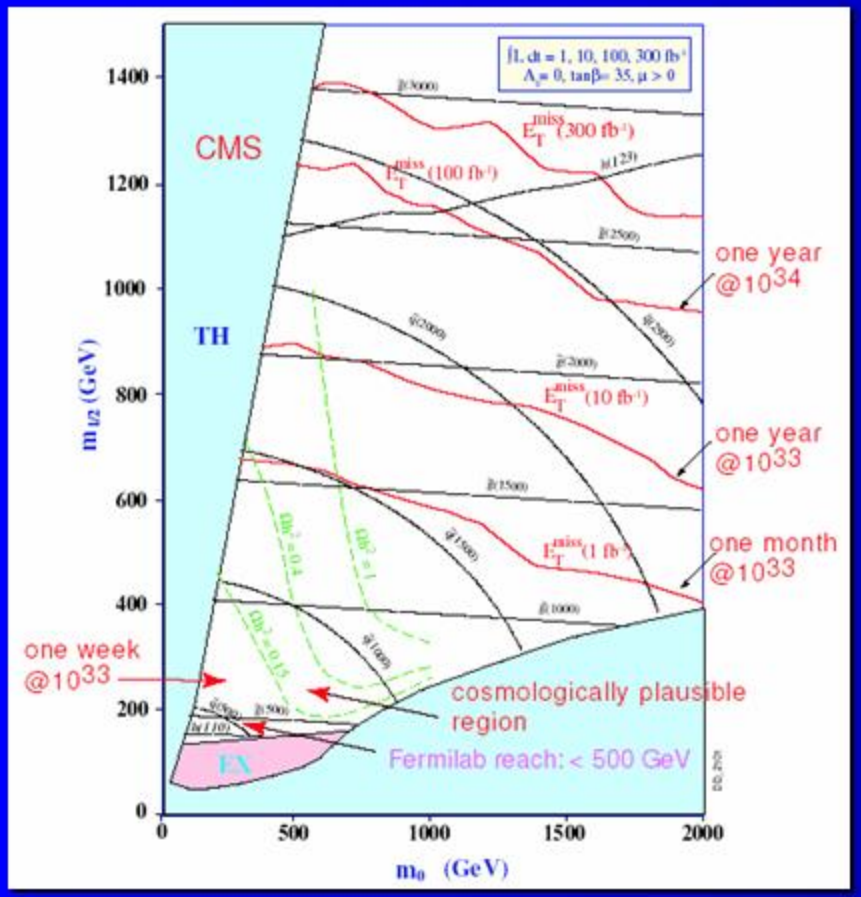
SM Background Processes for Superpartner Production



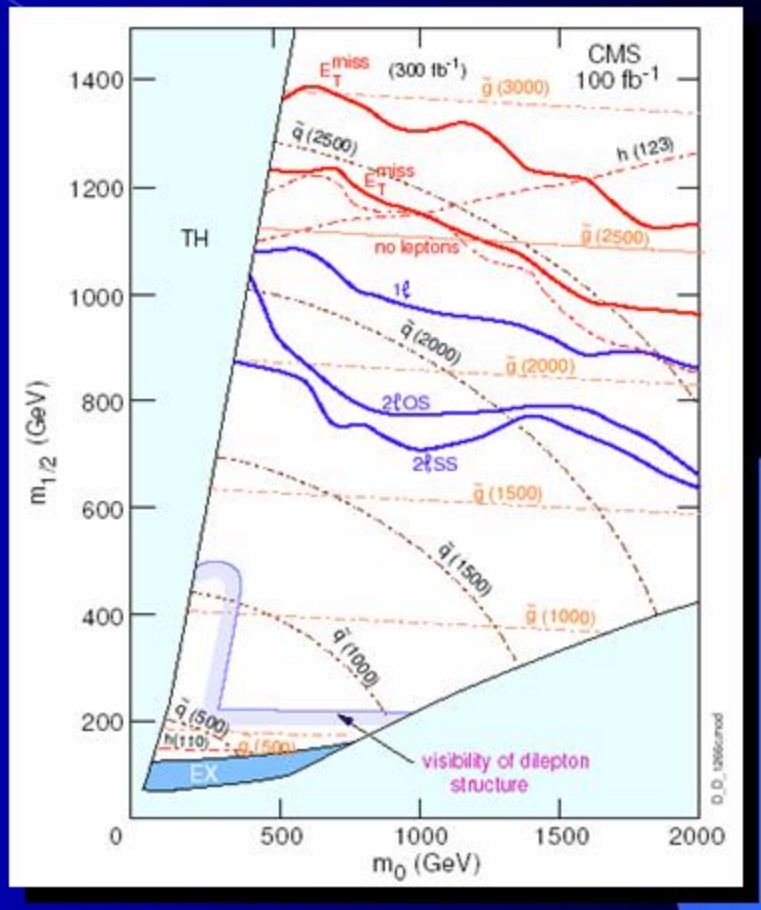


The x-sections are typically smaller than for SUSY production

SUSY Searches at LHC

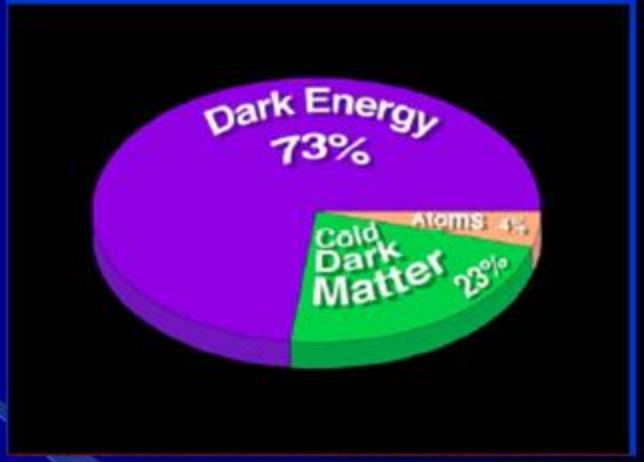


5 σ reach in jets + $\not{E}_T$ channel



Reach limits for various channels at 100 fb^{-1}

Target # 4



What is Dark Matter ?

DARK

TRANSPARENT

?

INVISIBLE

What is it made of ?

The Origin of Dark Matter

The Dark Matter is made of:

- Macro objects – Not seen
- New particles – right neutrino

Not from the SM

		Interaction
- neutralino	mSUGRA	Weak
- sneutrino		Weak
- axion (axino)	Strong CP (Light)	Very Weak
- gravitino	Gauge Mediation	Gravity
- heavy photon	Little Higgs Models	Weak
- heavy pseudo-goldstone		
- light sterile higgs	Inert Higgs Model	Very Weak

DM Detection

Direct detection

DAMA, Zeplin,
CDMS, Edelweiss

No convincing evidence so far
Hope for new results soon

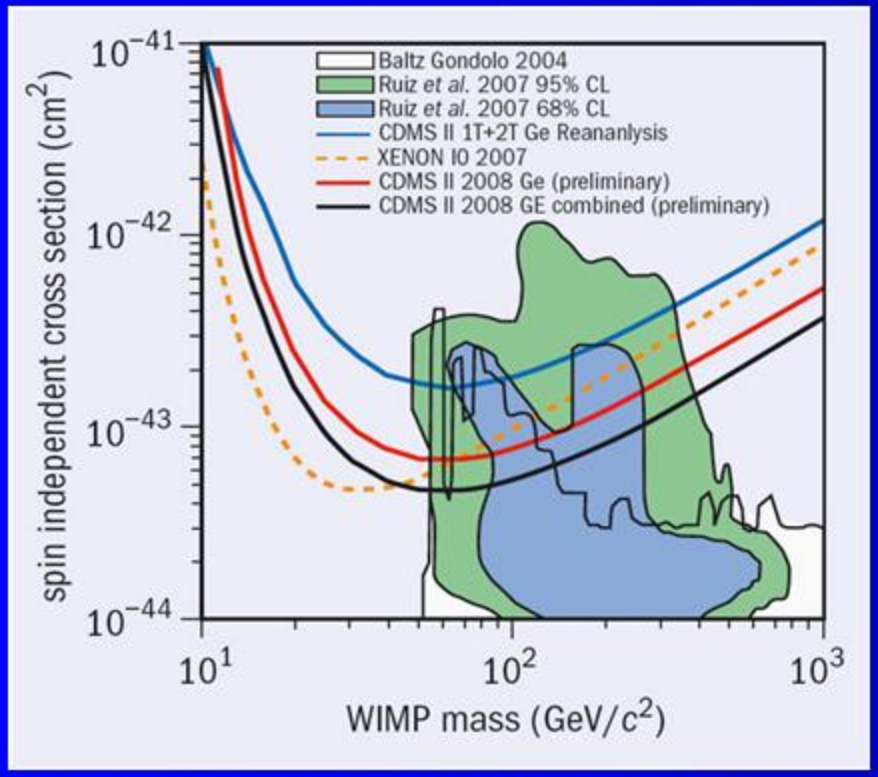
Indirect detection

- EGRET -> GLAST
Diffuse Gamma Rays
- HEAT, AMS01 -> PAMELA
Positrons in Cosmic Rays
- BESS -> AMS02
Antiprotons in Cosmic Rays

First Evidence of DM annihilation!

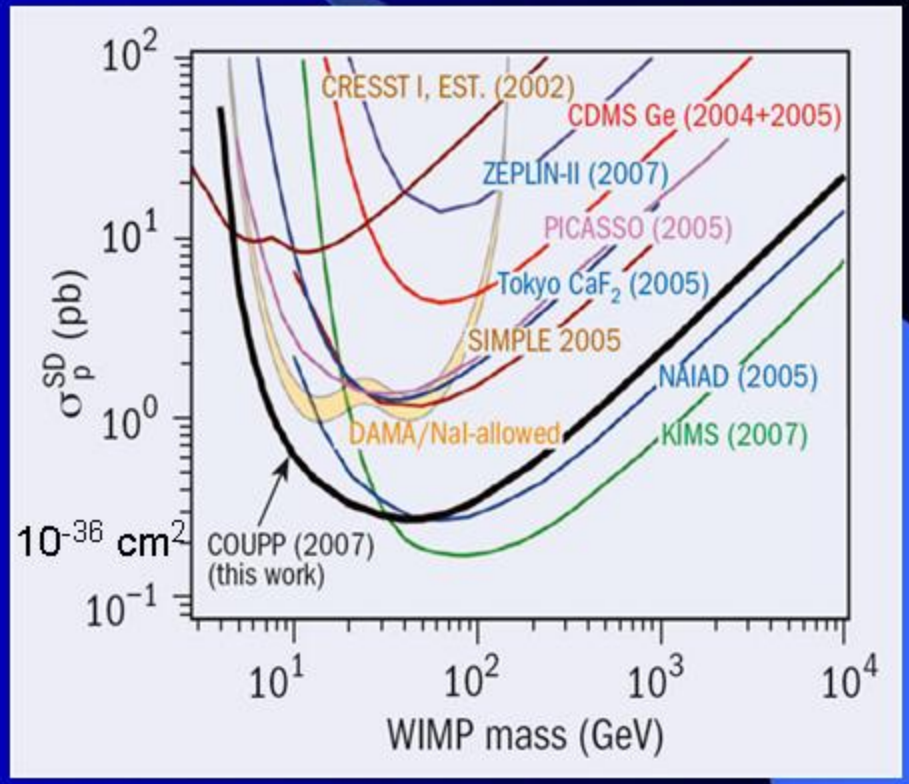
Recent Results on Direct Detection

Spin Independent



The Chicagoland Observatory for Underground Particle Physics (COUPP)

Spin Dependent



Cryogenic Dark Matter Search (CDMS)

Discovery Potential of LHC

- LHC has potential for major discoveries already in the first year of operation (1 day of LHC at 10^{33} = 10 years of previous machines)
- SUSY might be discovered "quickly", light Higgs more difficult
- Machine luminosity performance is crucial in the first year
- However: lot of data and time is needed in the beginning to

  -- commission the detectors

  -- reach the performance

  -- understand the SM physics at $\sqrt{s}$=14 TeV

The Role of ILC

Explore new Physics through high precision at high energy

Discovery Machine

$e^+e^- \rightarrow X_{new}(+Y_{SM})$

Study the properties of new particles (cross sections, BR's, quantum numbers)

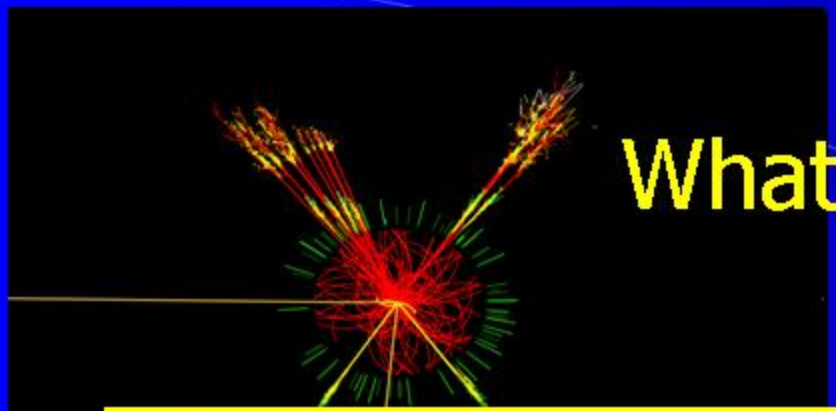
Precision Machine

$e^+e^- \rightarrow SM$

Study known SM processes to look for tiny deviations through virtual effects

Precision measurements will allow

- distinction of different physical models
- extrapolation to higher energies



What the future may bring?

- New discoveries are waiting for us
- New bunch of particles to be discovered and their properties studied
- New laws of nature to be found and understood

- Bright new technologies lead to monstrous accelerators & detectors
- The cost of accelerators & detectors exceeds scientific budget
- The construction time is comparable to professional career

What is our goal ? What do we want to achieve ? What is the right way?