Outlook: The Next Twenty Years

Hitoshi Murayama

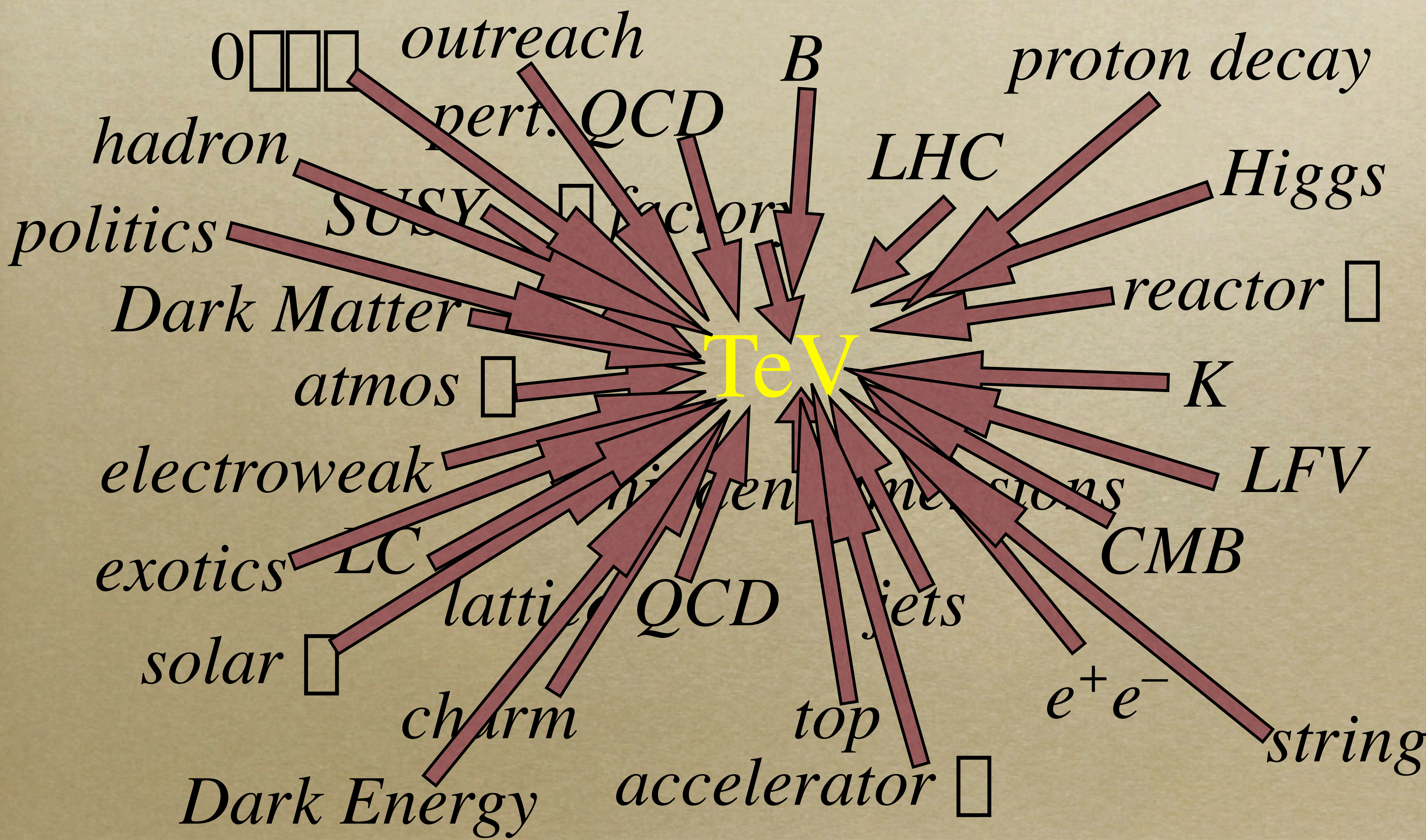
Lepton Photon ‘03

Fermilab, Aug 16, 2003

Is it bright?

Or dark?

Our Field


0
outreach
B
proton decay
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Dark Matter
TeV
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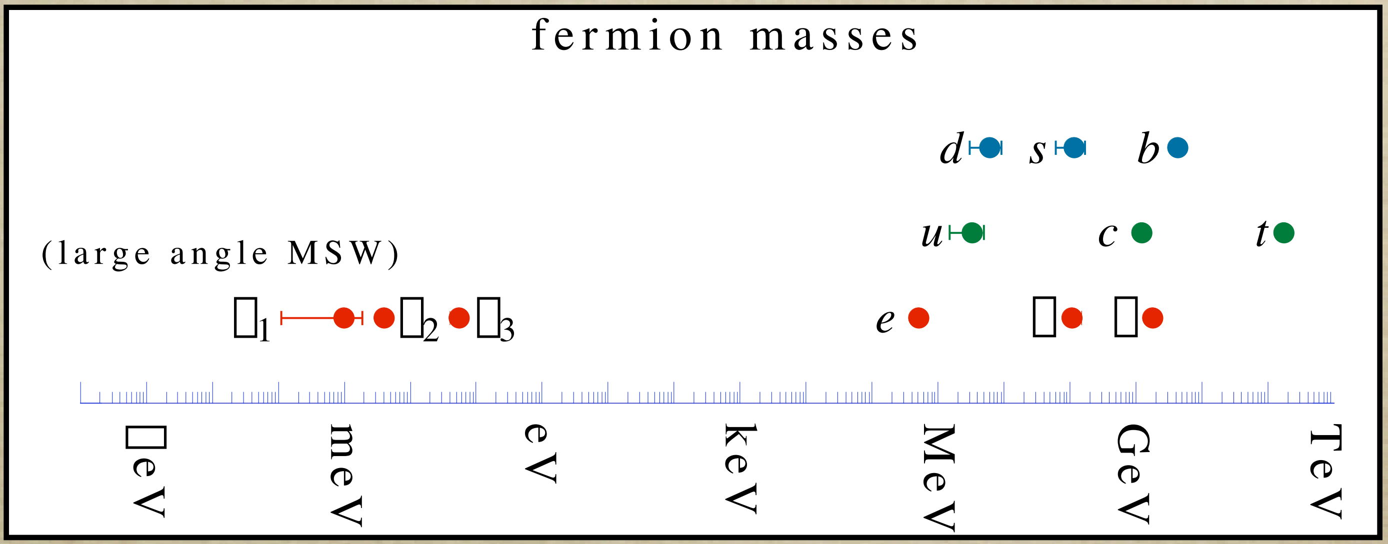
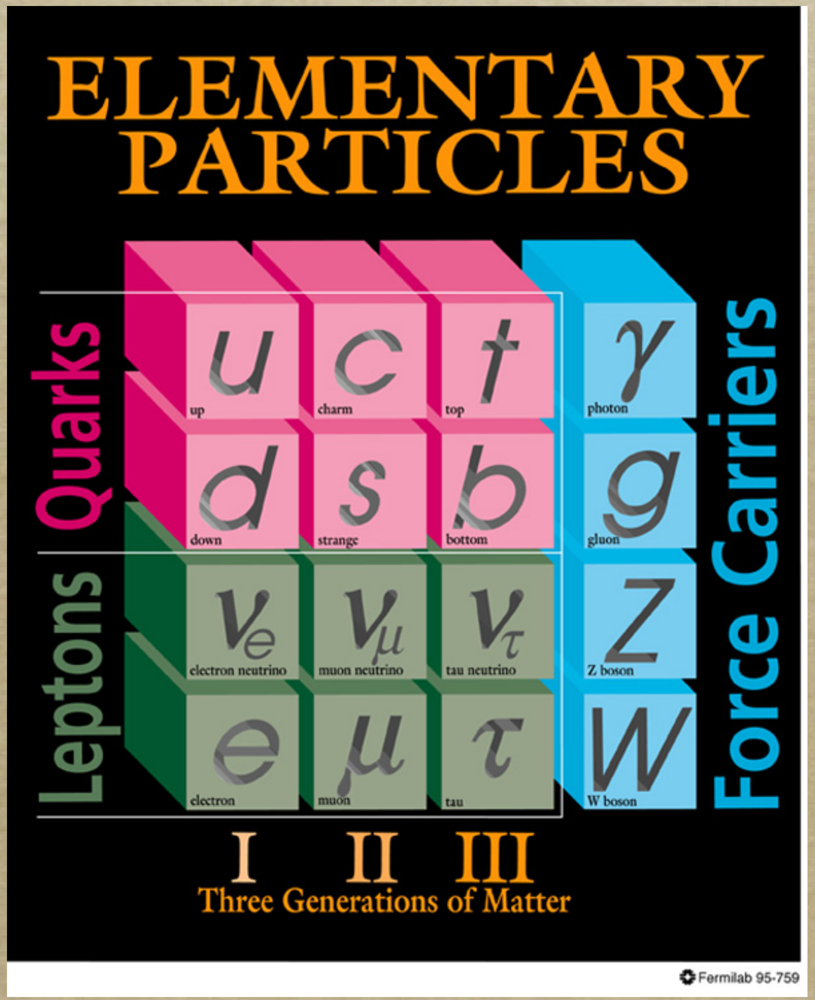
electroweak
LFV
hidden dimensions
CMB
exotics
LC
lattice QCD
jets
solar
e^+e^-
charm
top
string
accelerator
Dark Energy

Big Questions –Horizontal–

- *Why are there three generations?*
- *What physics determines the pattern of masses and mixings?*
- *Why do neutrinos have mass yet so light?*
- *What is the origin of CP violation?*
- *What is the origin of matter anti-matter asymmetry in Universe?*

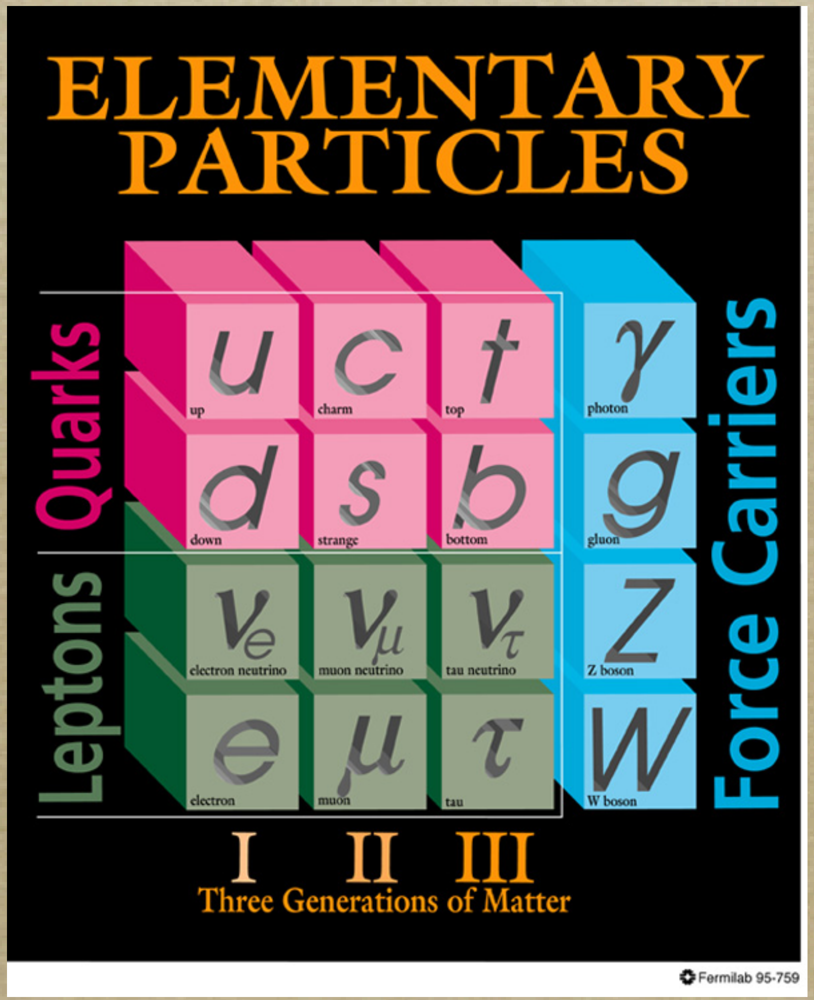




Big Questions
–Vertical–

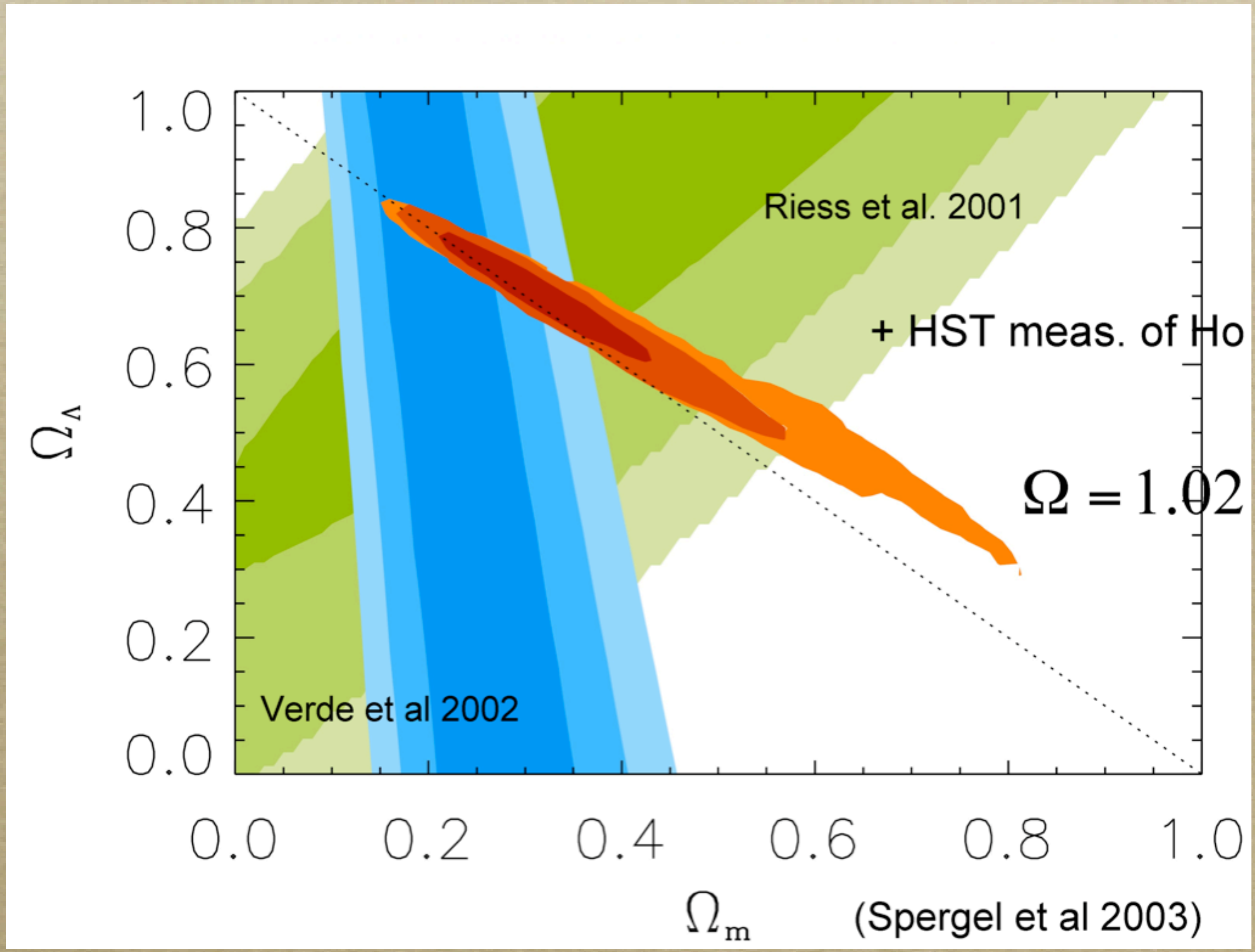
- *Why are there three unrelated gauge forces?*
- *Why is strong interaction strong?*
- *Charge quantization*
- *anomaly cancellation*
- *quantum numbers*
- *Is there a unified description of all forces?*
- *Why is* $m_W \ll M_{Pl}$*?* (*Hierarchy Problem*)

$$Q(\mathbf{3},\mathbf{2},+\frac{1}{6}),\quad u(\mathbf{3},\mathbf{1},+\frac{2}{3}),\quad d(\mathbf{3},\mathbf{1},-\frac{1}{3}),$$
$$L(\mathbf{1},\mathbf{2},-\frac{1}{2}),\quad e(\mathbf{1},\mathbf{1},-1)$$



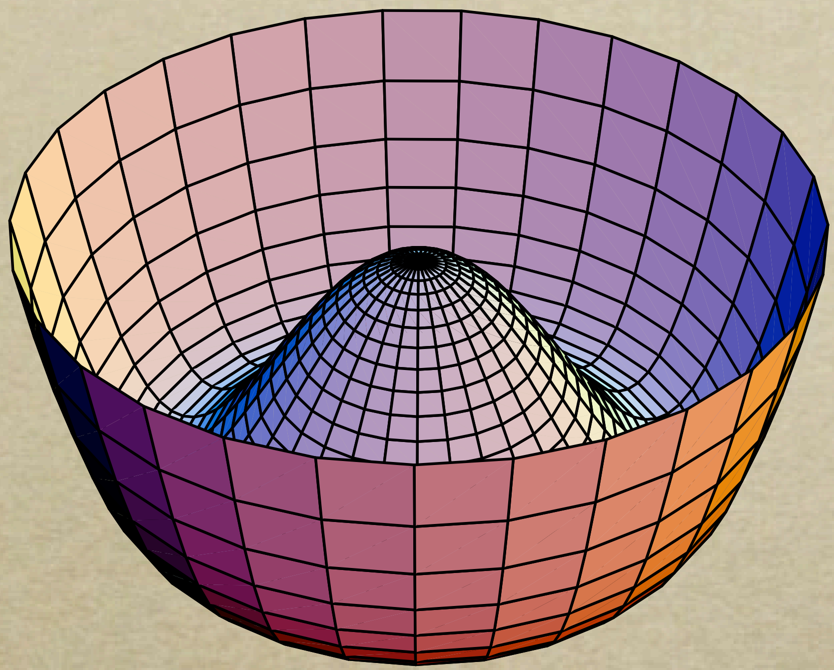
Big Questions –From the Heaven–

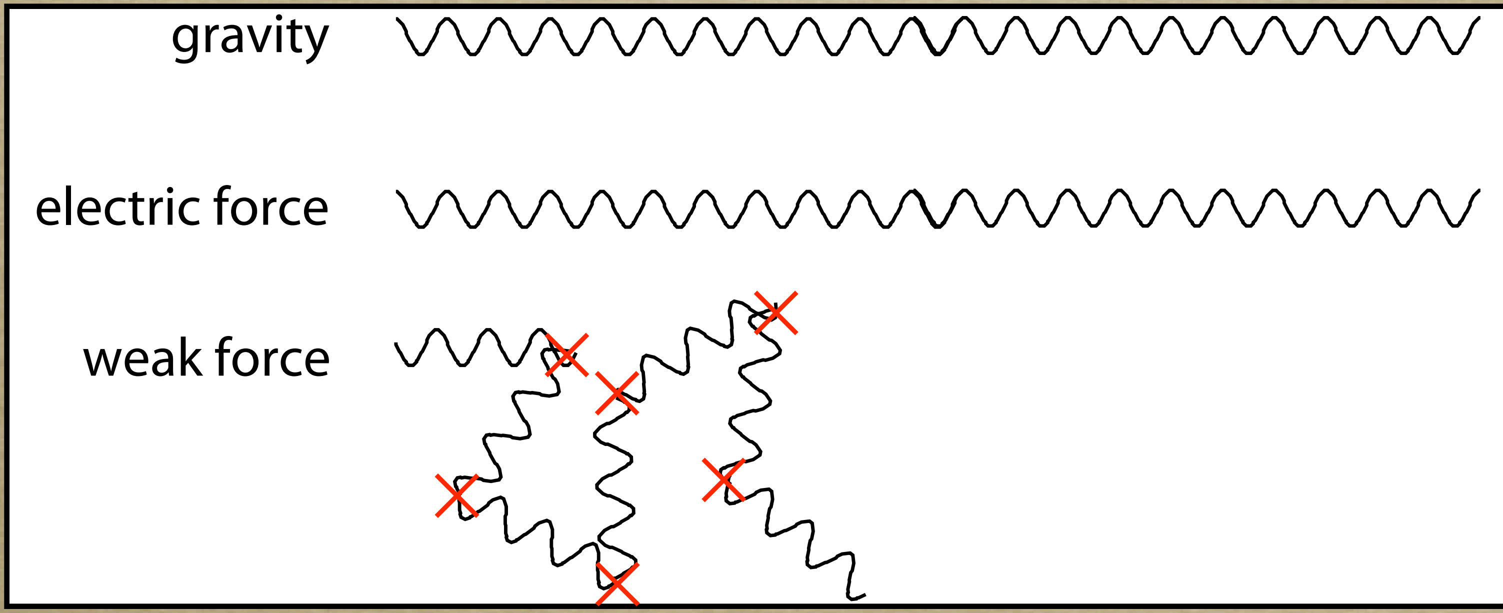
- *What is Dark Matter?*
- *What is Dark Energy?*
- *Why now? (Cosmic coincidence problem)*
- *What was Big Bang?*
- *Why is Universe so big? (flatness problem, horizon problem)*
- *How were galaxies and stars created?*



Big Questions –From the Hell–

- *What is the Higg boson?*
- *Why does it have negative mass-squared?*
- *Why is there only one scalar particle in the Standard Model?*
- *Is it elementary or composite?*
- *Is it really condensed in our Universe?*





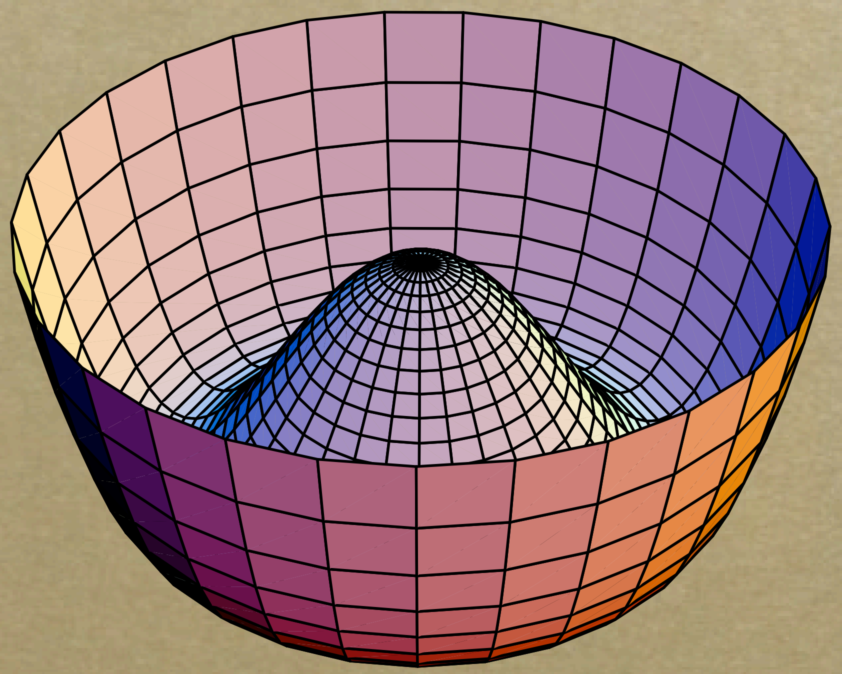
Outlook

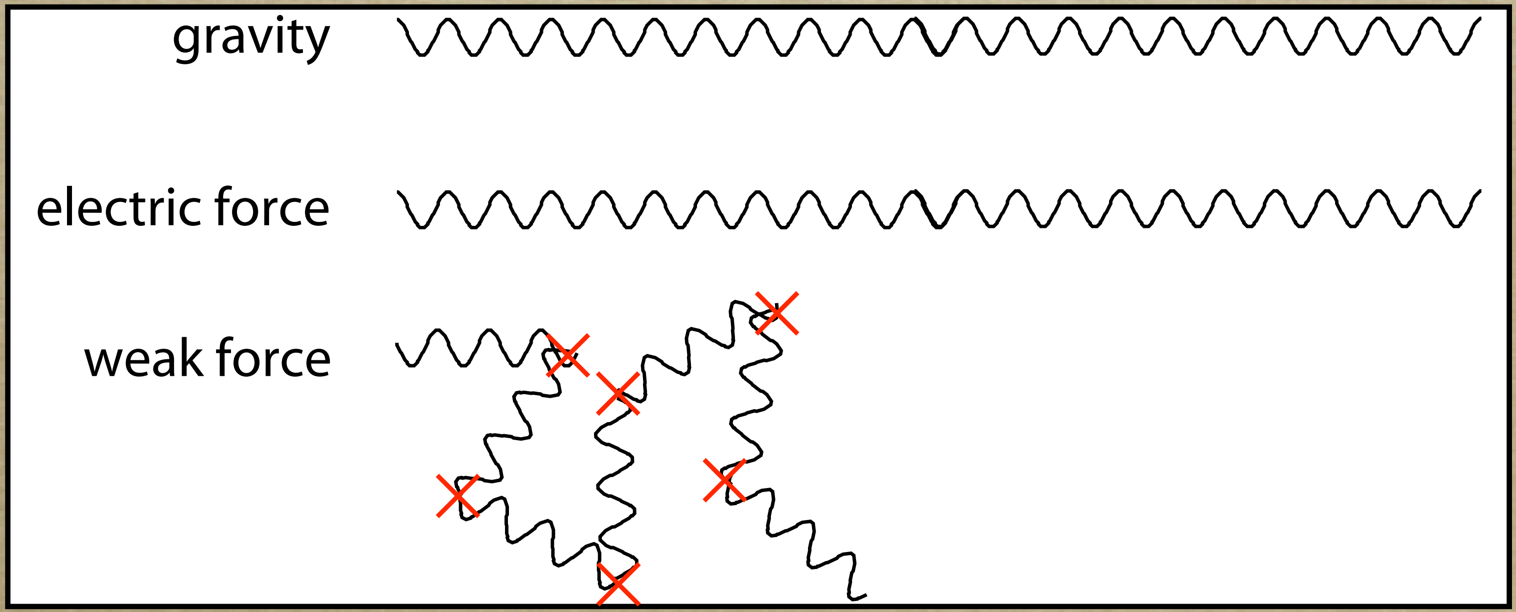
- *We do not have right to expect that any of these big questions can be answered*
- *Nonetheless there is a good potential for us to answer some of them*
- *How exactly do we do it?*
- *Use supersymmetry as an example, but I expect similar stories with any scenario of TeV-scale physic*

Outline

- *Introduction*
- *Hell*
- *Heaven*
- *Vertical*
- *Horizontal*
  - *Flavor*
  - *Leptogenesis*
- *Conclusion*

Hell

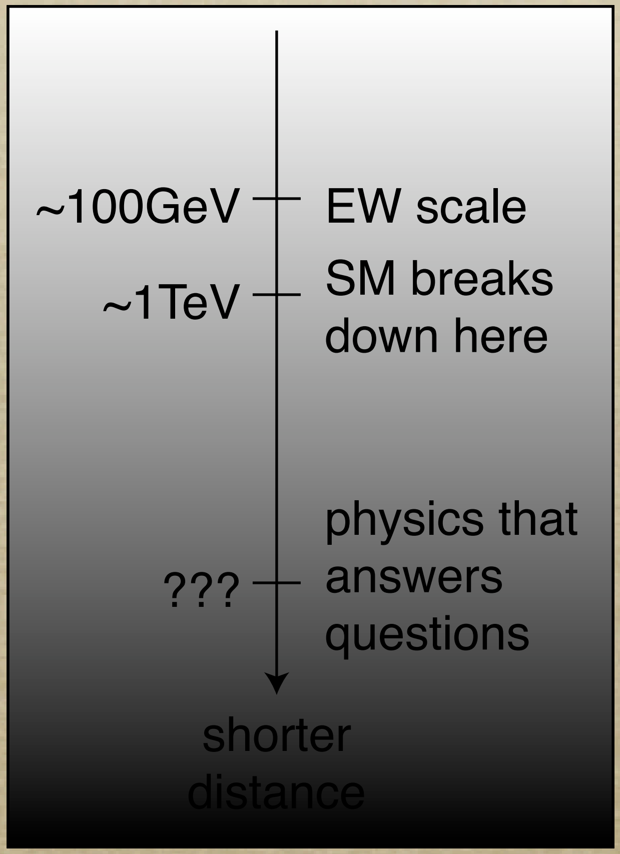




The Main Obstacle

- *We look for physics beyond the Standard Model that answers these big questions*
- *By definition, that is physics at shorter distances*
- *Then the Standard Model must survive down to whatever shorter distance scale*
- *Hierarchy problem is the main obstacle to do so*

⇒ *We can't even get started!*



Once upon a time, there was a hierarchy problem...

- *At the end of 19th century: a "crisis" about electron*
  - *Like charges repel: hard to keep electric charge in a small pack*
  - *Electron is point-like*
  - *At least smaller than* 10^{-17}cm
- *Need a lot of energy to keep it small!*

$$\Delta m_e c^2 \sim \frac{\alpha}{r_e} \sim \text{GeV}\,\frac{10^{-17}\,\text{cm}}{r_e}$$

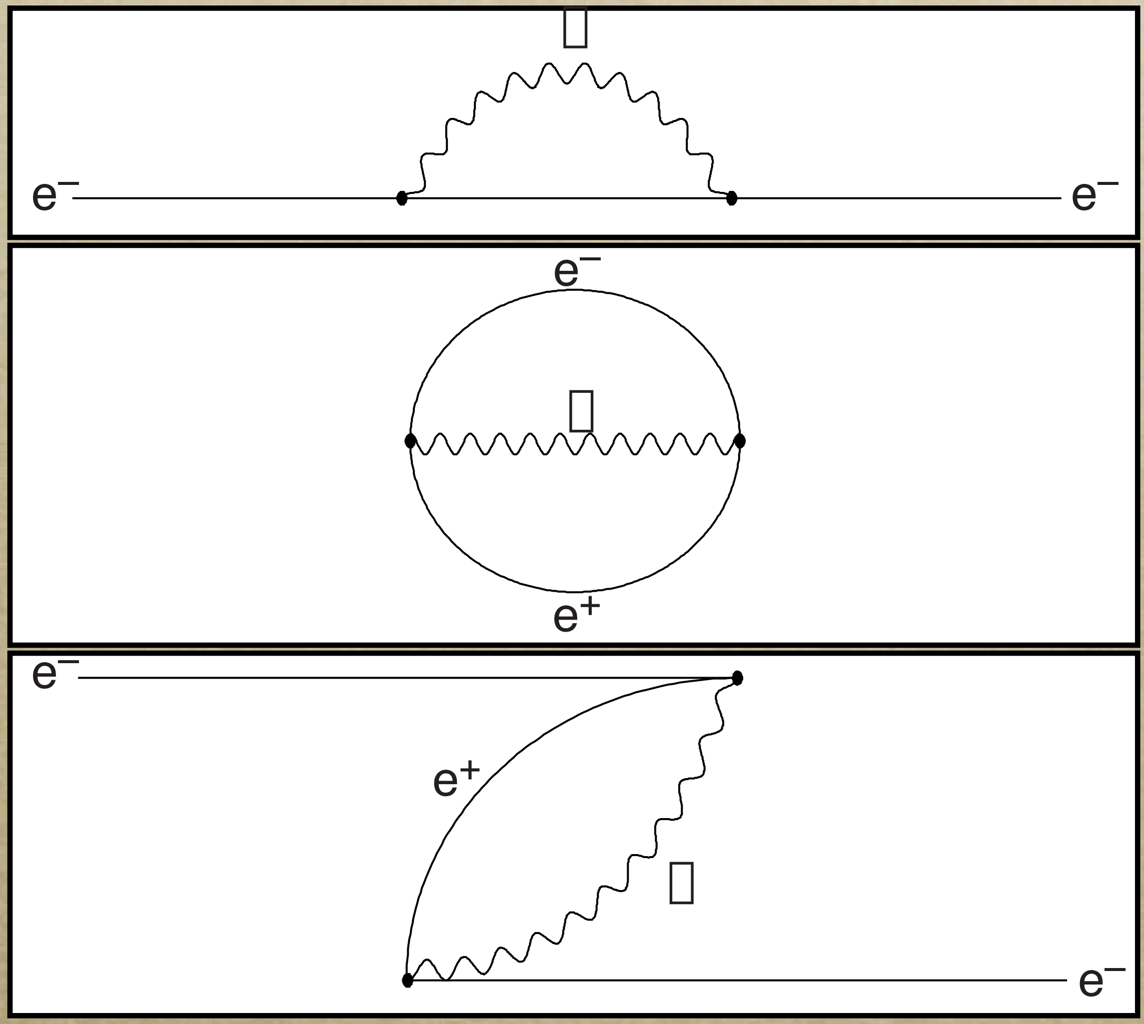
- *Correction* $\Delta m_e c^2 > m_e c^2$ *for* $r_e < 10^{-13}\text{cm}$
- *Breakdown of theory of electromagnetism*

  $\Rightarrow$ *Can't discuss physics below* 10^{-13}cm

Anti-Matter Comes to Rescue by Doubling of #Particles

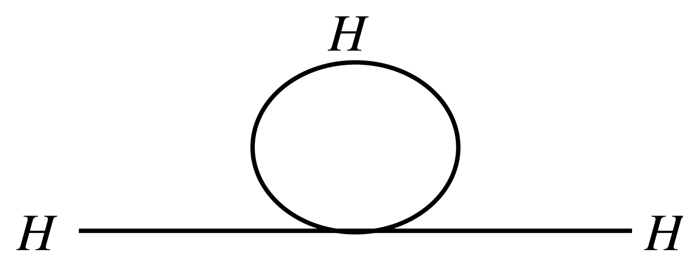
- *Electron creates a force to repel itself*
- *Vacuum bubble of matter anti-matter creation/ annihilation*
- *Electron annihilates the positron in the bubble*

$\Rightarrow$ *only 10% of mass even for Planck-size*



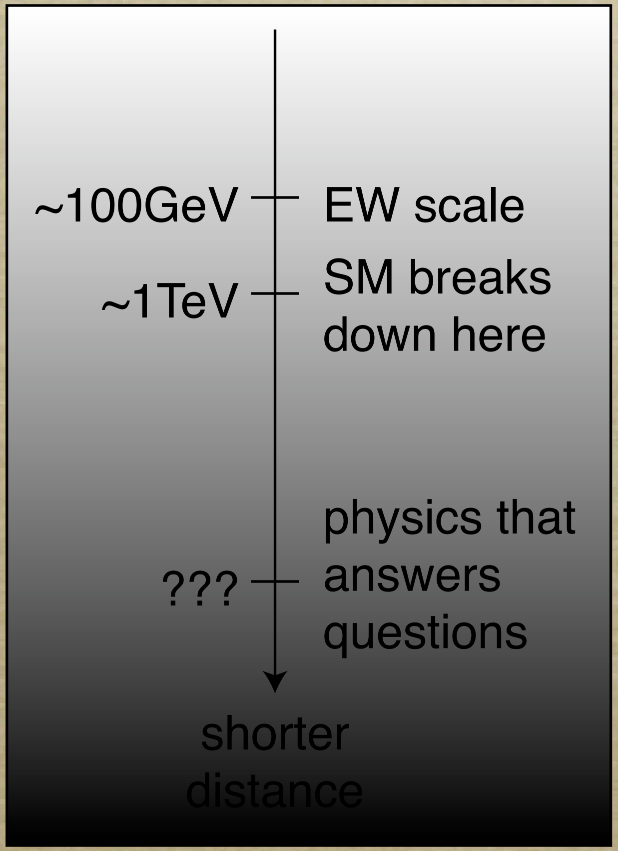
$$\frac{\Delta m_e}{m_e} \sim \frac{\alpha}{4\pi} \log(m_e r_e)$$

Higgs repels itself, too



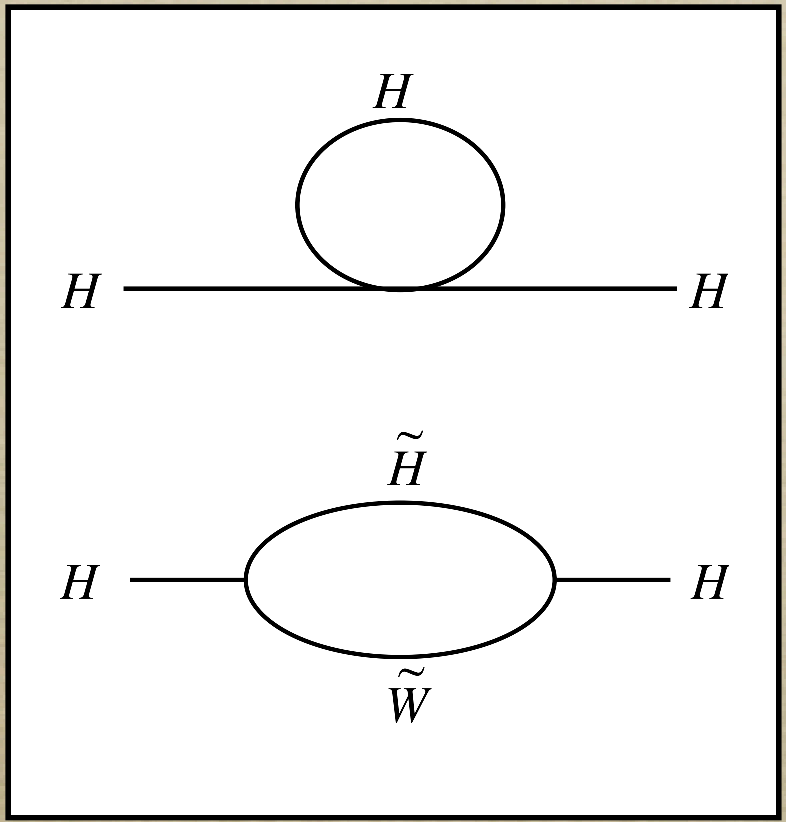
$$\delta m_H^2 c^4 \sim \left(\frac{\hbar c}{r_H}\right)^2$$

- *Just like electron repelling itself because of its charge, Higgs boson also repels itself*
- *Requires a lot of energy to contain itself in its point-like size!*
- *Breakdown of theory of weak force*
- *Can't get started!*



History repeats itself?

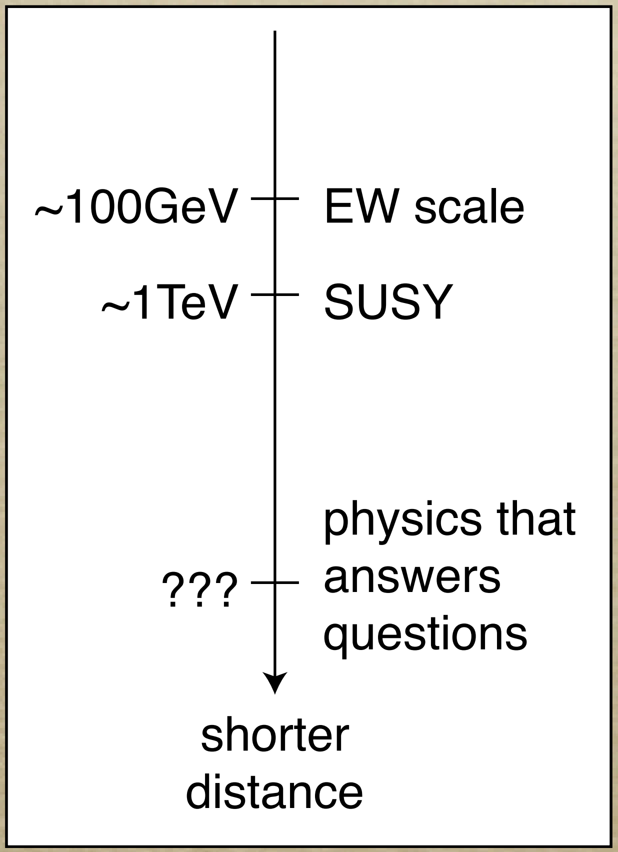
- *Double #particles again ⇒ superpartners*
- *"Vacuum bubbles" of superpartners cancel the energy required to contain Higgs boson in itself*
- *Standard Model made consistent with whatever physics at shorter distances*



$$\Delta m_H^2 \sim \frac{\alpha}{4\pi} m_{SUSY}^2 \log(m_H r_H)$$

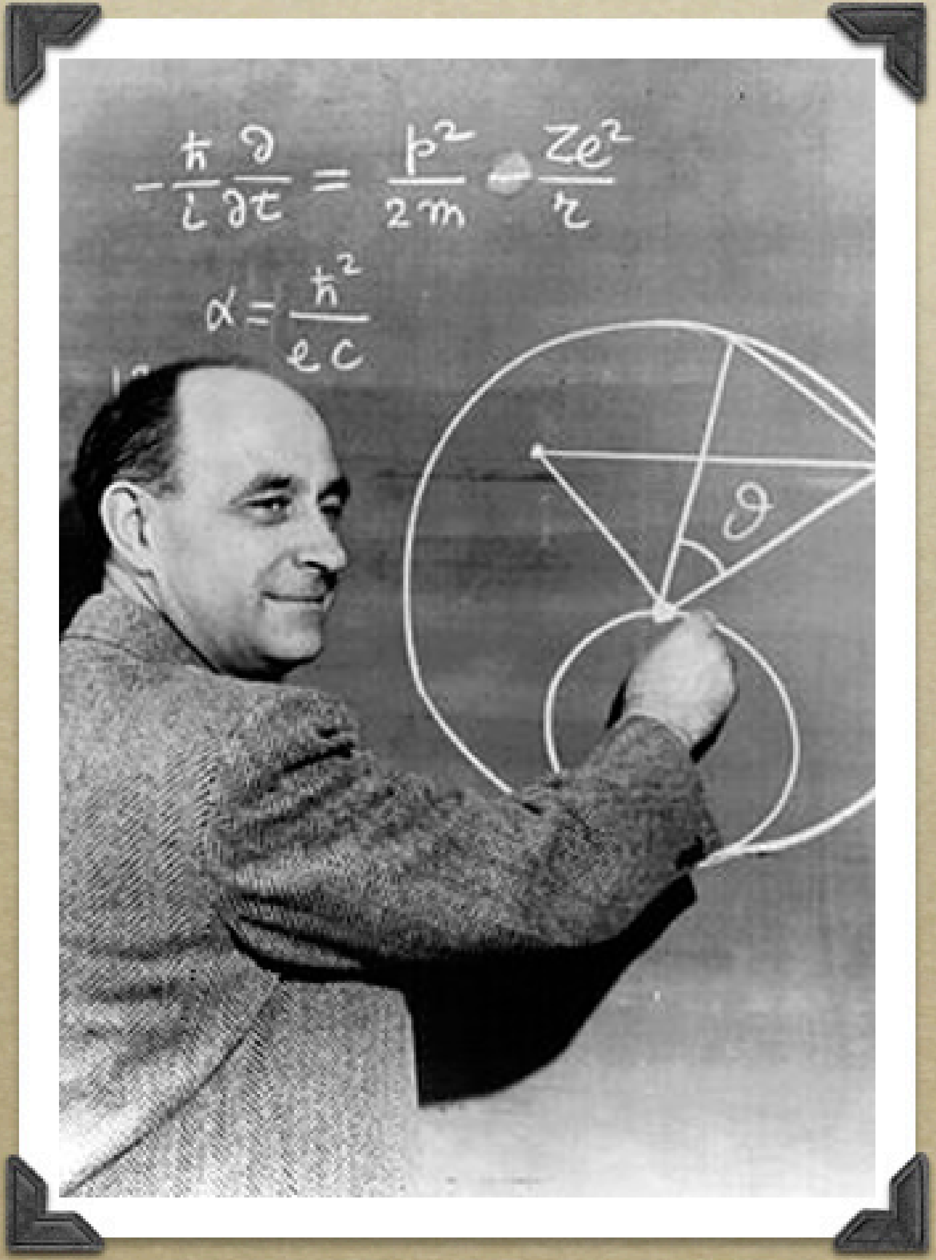
Opening the door

- *Once the hierarchy problem solved, we can get started to discuss physics at shorter distances.*
- *It opens the door to the next level:*
  Hope to answer big questions
- *The solution to the hierarchy problem itself, e.g., SUSY, provides additional probe to physics at short distances*



Fermi's dream era

- *Fermi formulated the first theory of the weak force* (1933)
- *The required energy scale to study the problem known since then:* ~TeV
- *We are finally getting there!*



Three Directions

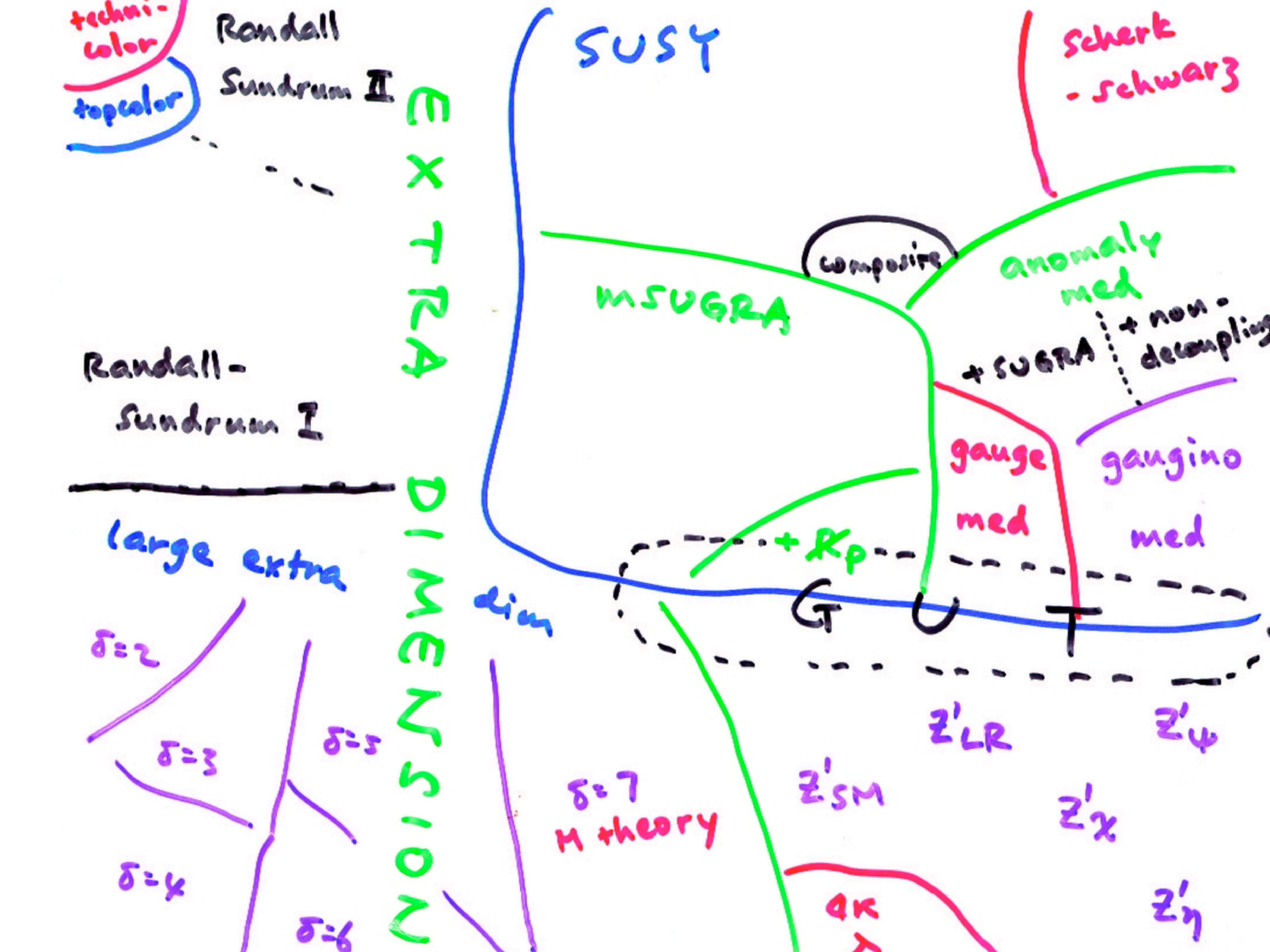
- *History repeats itself*
  - *Crisis with electron solved by anti-matter*
  - *Double #particles again* ⇒ *supersymmetry*
- *Learn from Cooper pairs*
  - *Cooper pairs composite made of two electrons*
  - *Higgs boson may be fermion-pair composite*

    ⇒ *technicolor*
- *Physics as we know it ends at* TeV
  - *Ultimate scale of physics: quantum gravity*
  - *May have quantum gravity at* TeV

    ⇒ *hidden dimensions* (0.01 cm *to* 10^{17} cm)

More Directions

- *Higgs boson as a Pseudo-Nambu-Goldstone boson (Little Higgs)*
- *Higgs boson as an extra-dimensional gauge boson (Gauge-Higgs Unification)*
- *No Higgs and $W^{\pm}$ as Kaluza-Klein boson*
- *technicolorful supersymmetry*


techni-color
topcolor
Randall Sundrum II
EXTRA DIMENSION
SUSY
Scherk-Schwarz
composite
anomaly med
mSUGRA
+ SUGRA
+ non-decouplin
Randall-Sundrum I
gauge med
gaugino med
large extra dim
+ $\not{R}_p$
GUT
δ=2
δ=3
δ=5
δ=4
δ=6
δ=7
M theory
Z'_{LR}
Z'_{ψ}
Z'_{SM}
Z'_{χ}
Z'_{η}
4K

bosonic TC
composite Higgs
TC-TC
hypercolor
supercolor
techni-GIM
extended TC
pseudo NGB
NOT YET THOUGHT OF
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NOT YET THOUGHT OF
effective SUSY
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MSSM +νR
unnified SM
axigluon
sterile ν
heavy Majorons
6th gen
5th gen
4th gen
lepto quark
vector-like family
fractionally charged
milli-charged
mono-pole
X Y
S, T, U
shadow matter
mirror symmetry
triplet Higgs
doubly charged Higgs
Type I
Type II
general 2HDSM
spontaneous CP
superweak
milli-weak
Weinberg's 3HD
Majoron
axion
familon
NGB
saxion axino
worm-hole
quintessence
k-essence
Extra dim
composite W, Z
contact int.
string
hetero tic
matrix M
IIB
IIA
F
I
N=2
N=4
N=8

Task

- *Find physics responsible for Higgs BEC*
- *We can eliminate many possibilities at LHC*
- *But new interpretations necessarily emerge*
- *Race will be on:*
  - *theorists coming up with new interpretations*
  - *experimentalists excluding new interpretations*

  ⇒ *A loooong process of elimination*
- *Crucial information is in details*
- *Elucidate what that physics is*

  ⇒ *Reconstruct the Lagrangian from measurements*

Absolute confidence is crucial for a major discovery

- *As an example, supersymmetry*
- *"New York Times" level confidence*

"The other half of the world discovered"

still a long way to

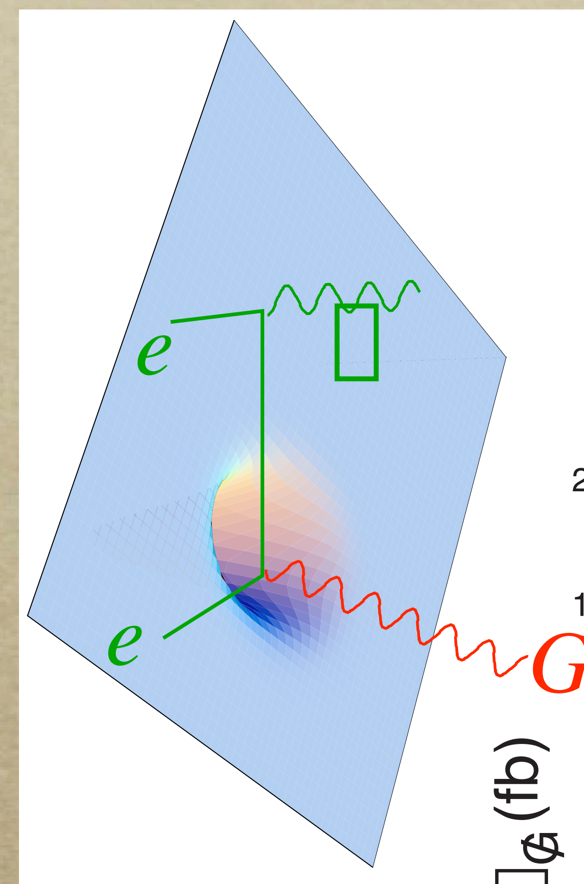
- *"Halliday-Resnick" level confidence*

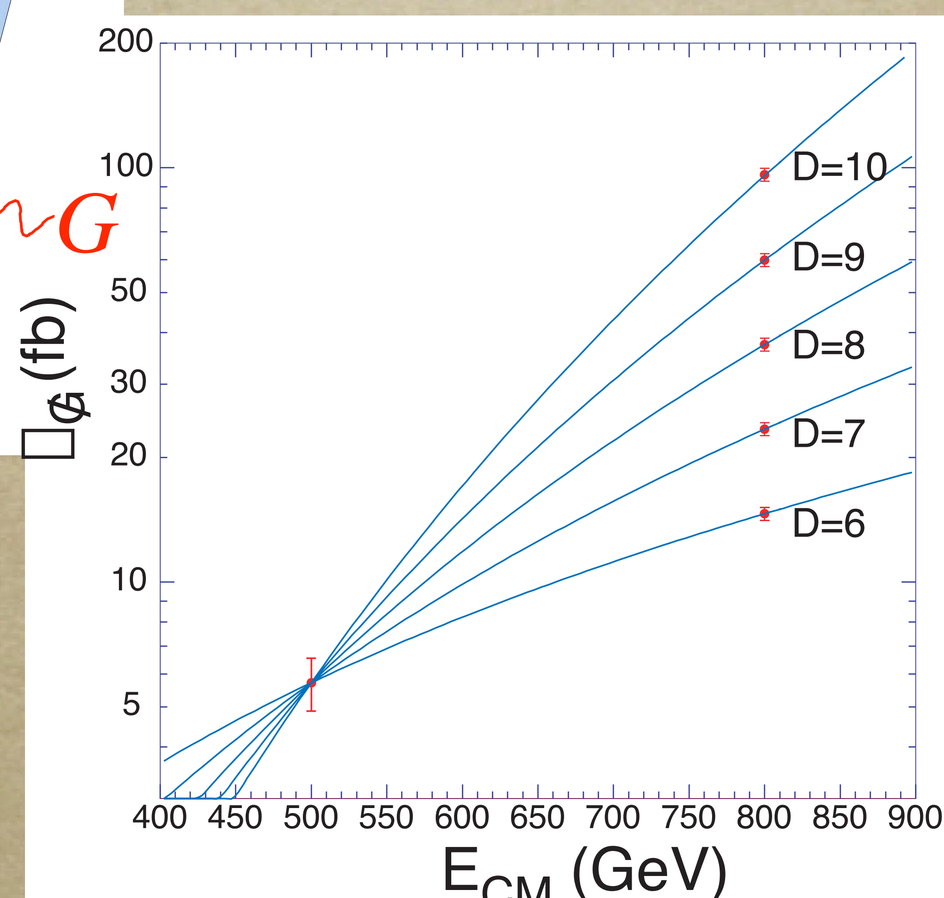
"We have learned that all particles we observe have unique partners of different spin and statistics, called superpartners, that make our theory of elementary particles valid to small distances."

Hidden Dimensions

- *Hidden dimensions*
- *Can emit graviton into the bulk*
- *Events with apparent energy imbalance*

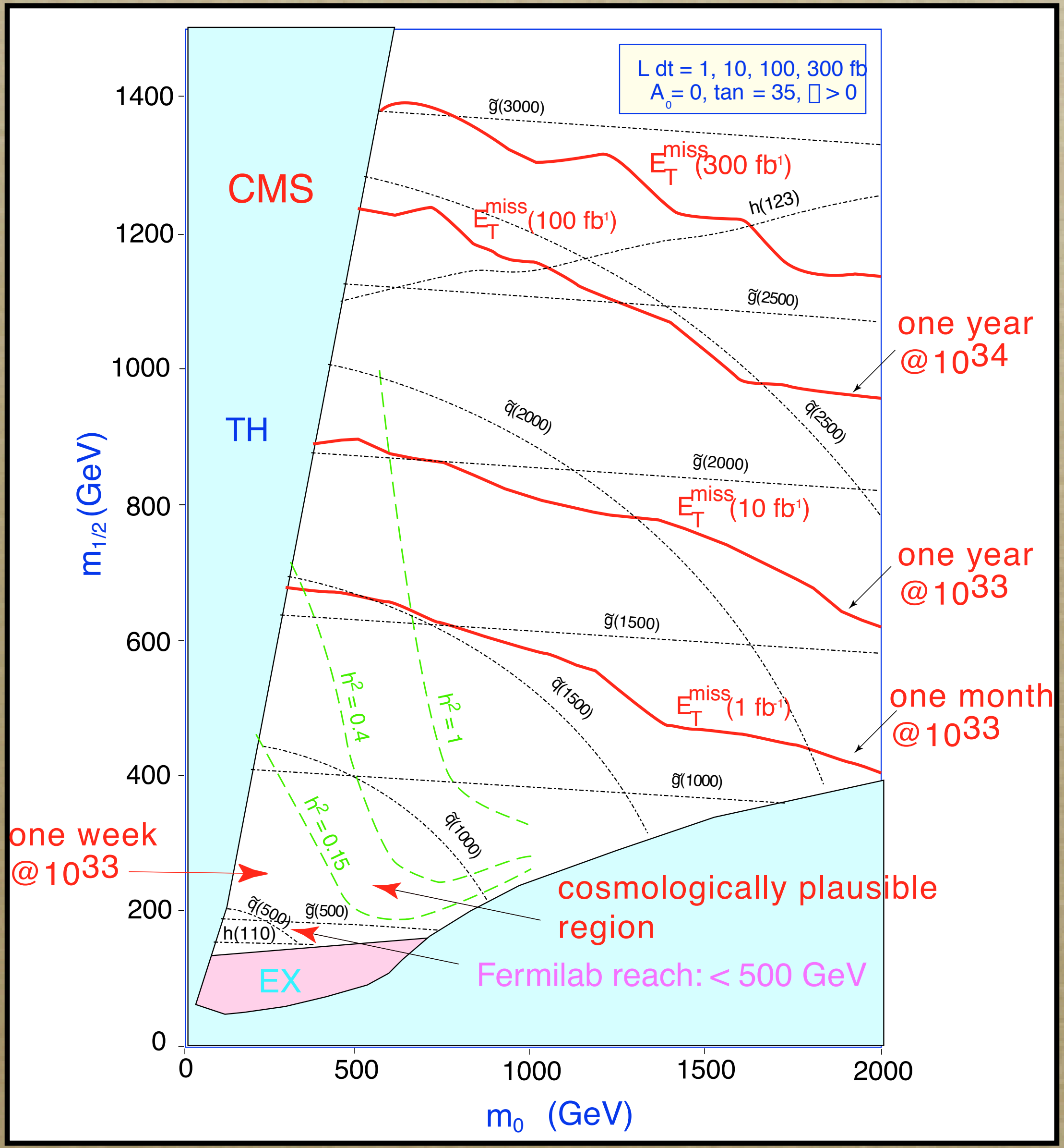
□ *How many extra dimensions are there?*



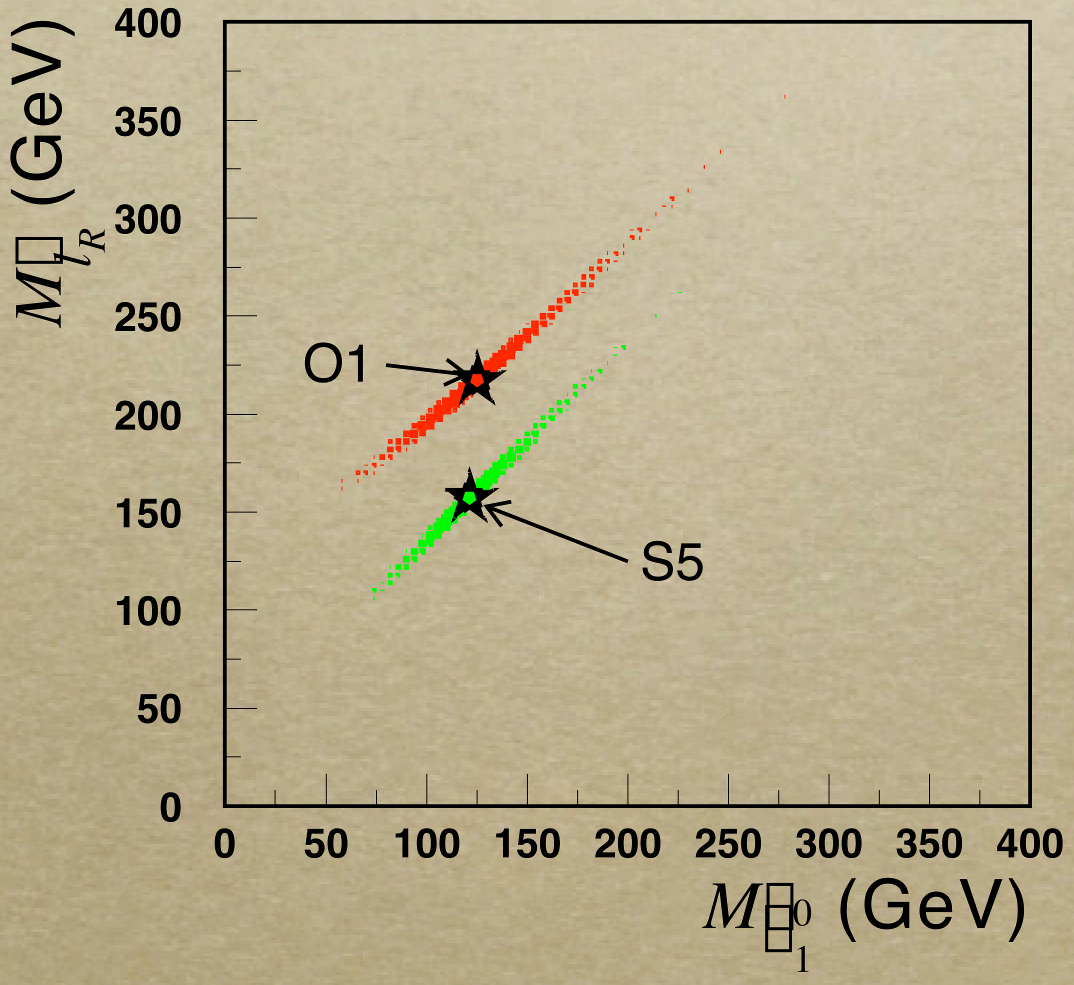


Supersymmetry

Tevatron/LHC will discover supersymmetry



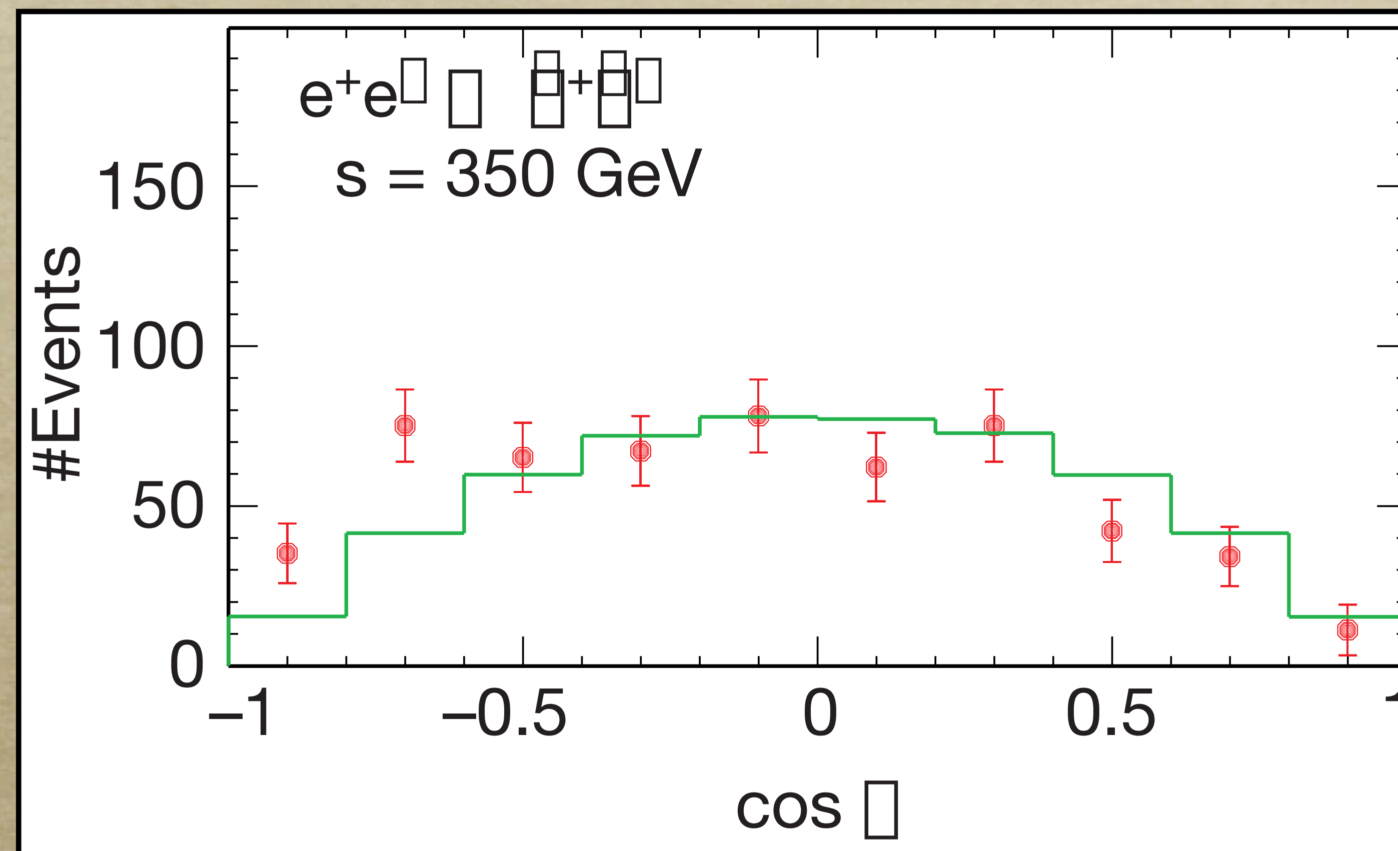
Can do many measurements at LHC

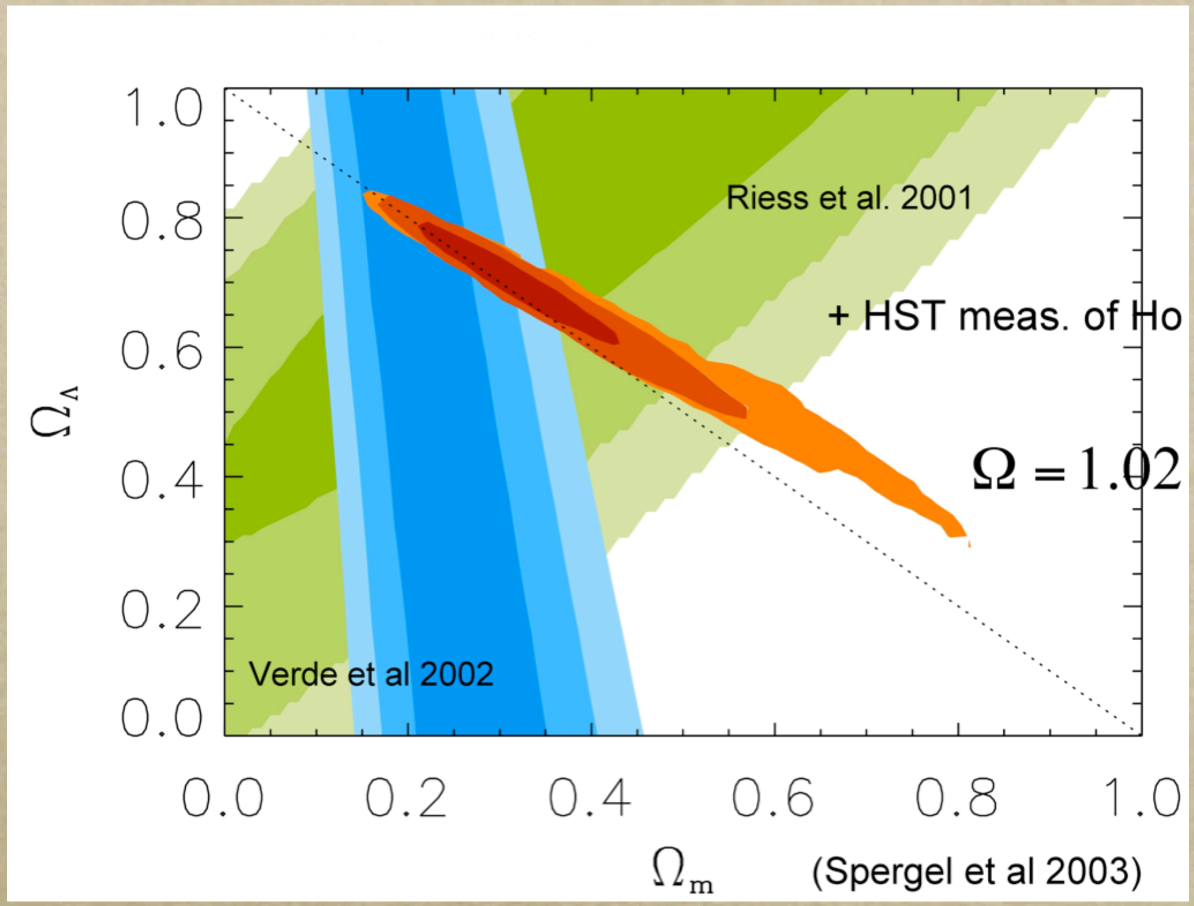


Prove Superpartners have different spin

- *Discovery at Tevatron Run II and/or LHC*
- *Test they are really superpartners*
    - *Spins differ by* 1/2
    - *Same* SU(3)×SU(2)×U(1) *quantum numbers*
    - *Supersymmetric couplings*

Spin 0?




Riess et al. 2001
+ HST meas. of Ho
$\Omega = 1.02$
Verde et al 2002
Ω_Λ
Ω_m
(Spergel et al 2003)

Heaven


Dark Energy
Dark Matter
stars
baryon
neutrinos
dark matter
dark energy

Cosmic Microwave Background

- *WMAP satellite result released Feb 10, 2003*

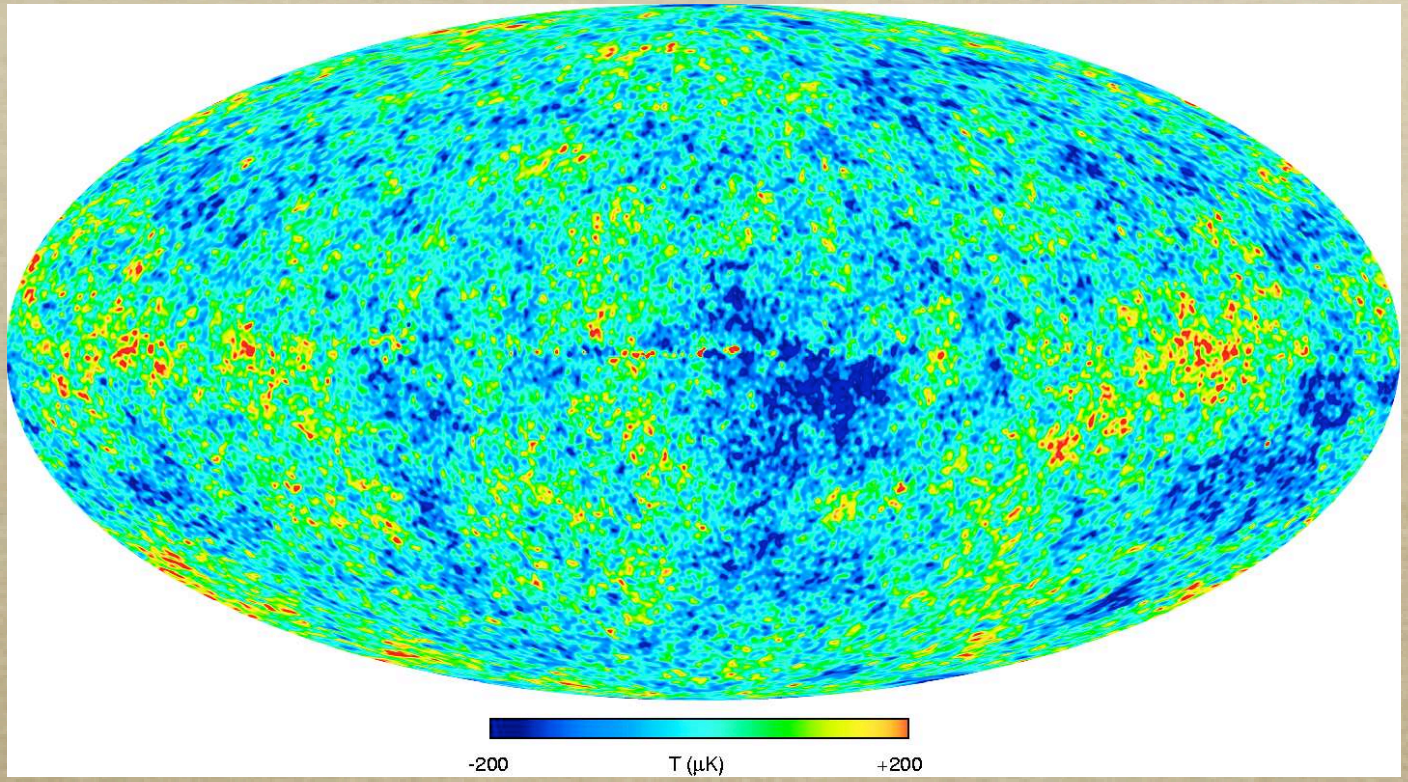
  h=0.71±0.04

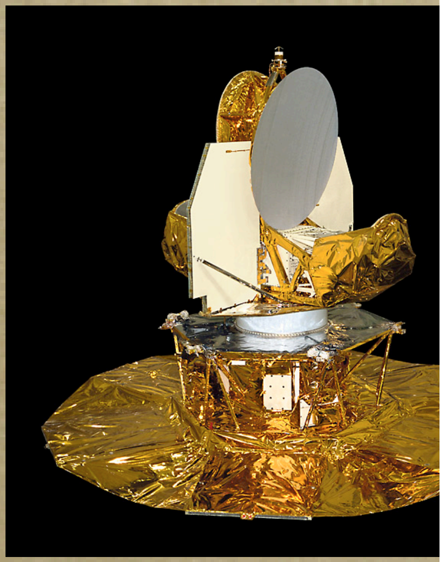
  $\Omega_M h^2$=0.135±0.009

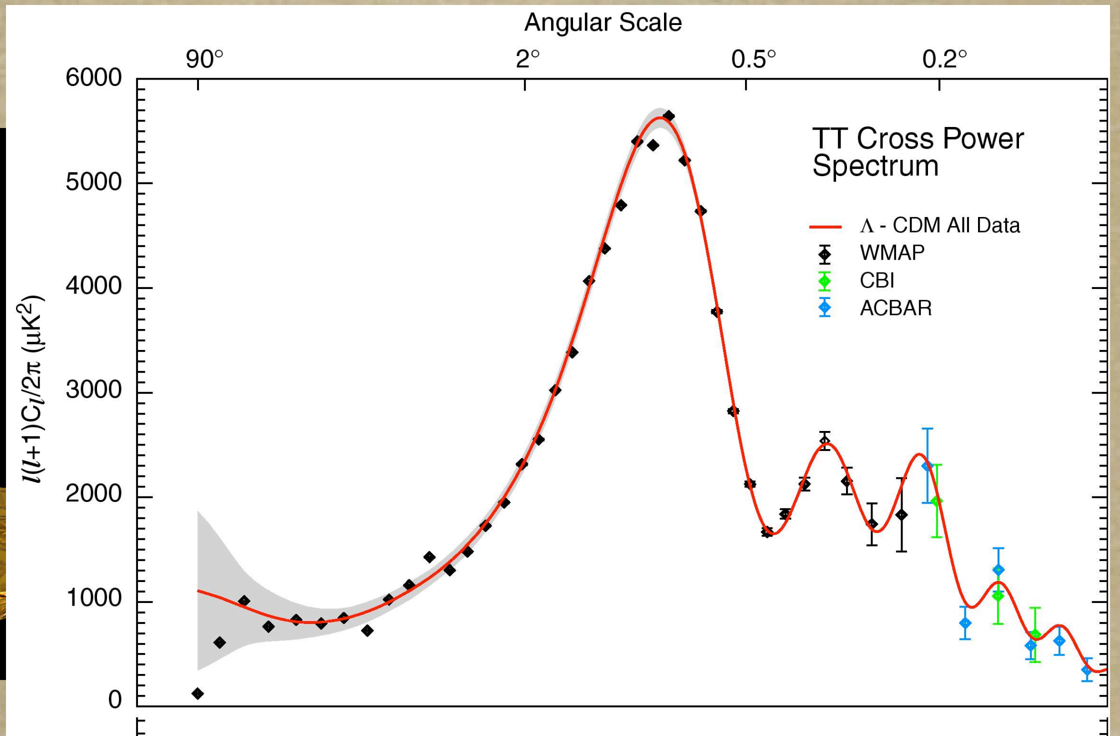
  $\Omega_b h^2$=0.0224±0.0009

  Ω_{tot}=1.02±0.02

- *Yet another big step in precision cosmology*
- >12□ *signal for non-baryonic dark matter*

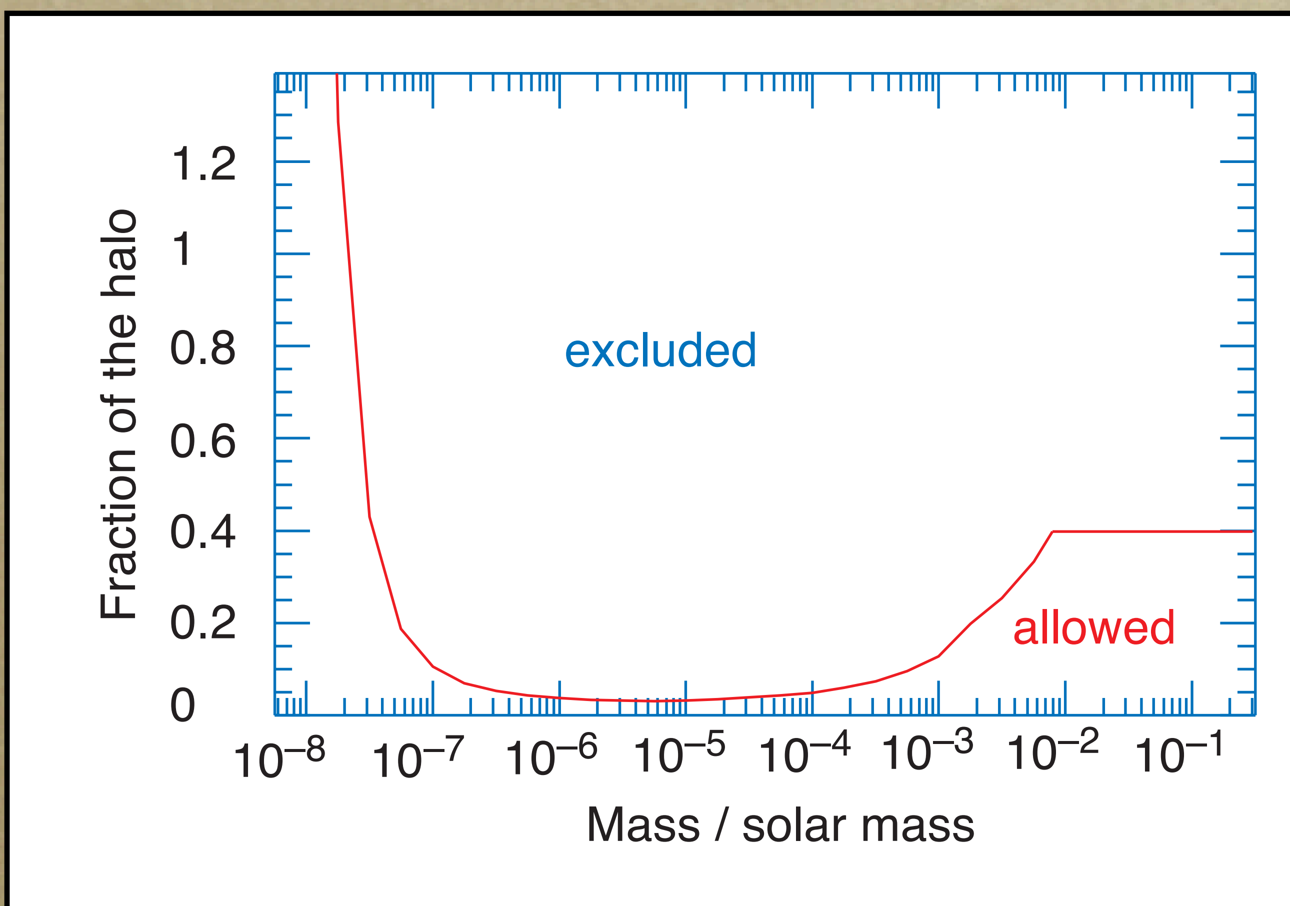






Particle Dark Matter

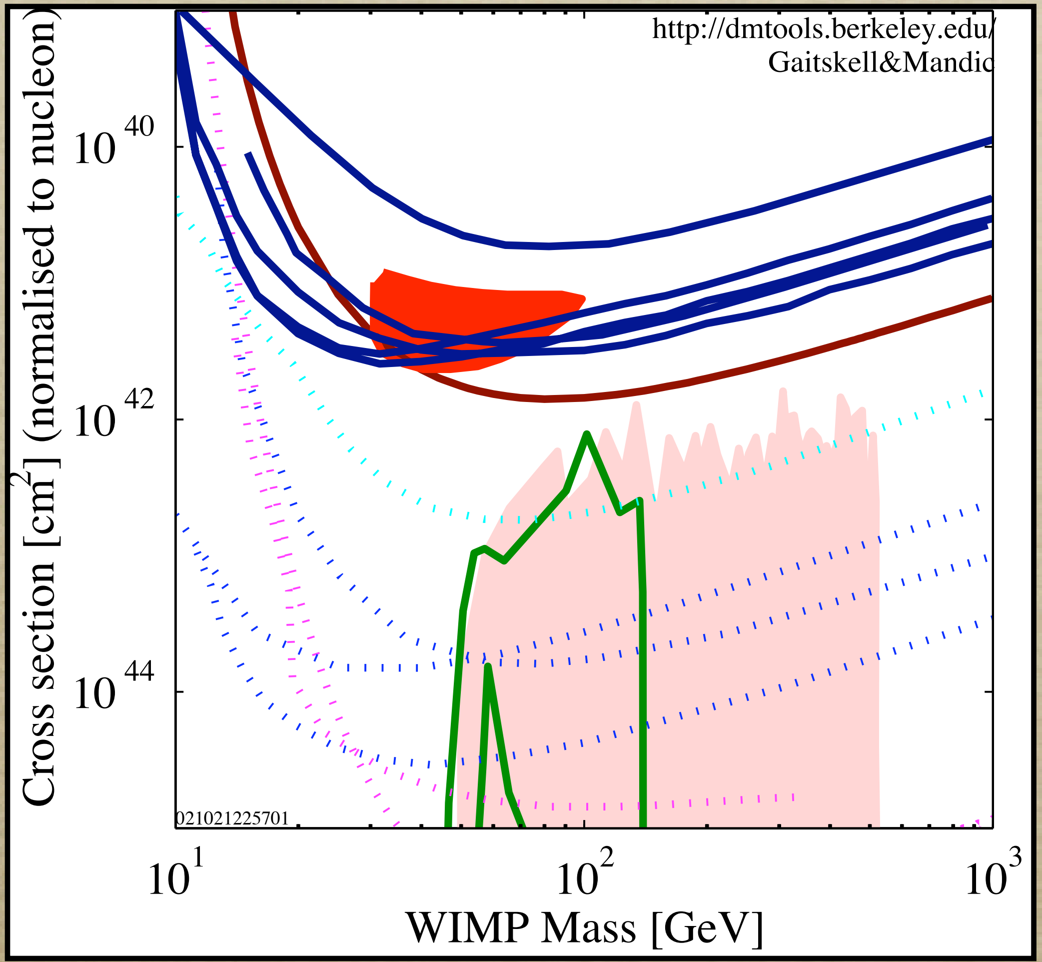
It is not dim small stars/planets (e.g., MACHOs)



- *WIMP (Weakly Interacting Massive Particle) strongly favored*
- *Stable heavy particle produced in early Universe, left-over from near-complete annihilation*
- $$\Omega_M = \frac{0.756(n+1)x_f^{n+1}}{g^{1/2}\sigma_{ann} M_{Pl}^{3}} \frac{3s_0}{8\pi H_0^2} \approx \frac{\alpha^2/(TeV)^2}{\sigma_{ann}}$$
- TeV=10^{12}eV *the correct energy scale*

Particle Dark Matter

- *Stable, TeV-scale particle, electrically neutral, very weakly interacting*
- *No such candidate in the Standard Model*
- *Lightest Supersymmetric Particle (LSP): superpartner of a gauge boson in most models*
- *LSP a perfect candidate for WIMP*

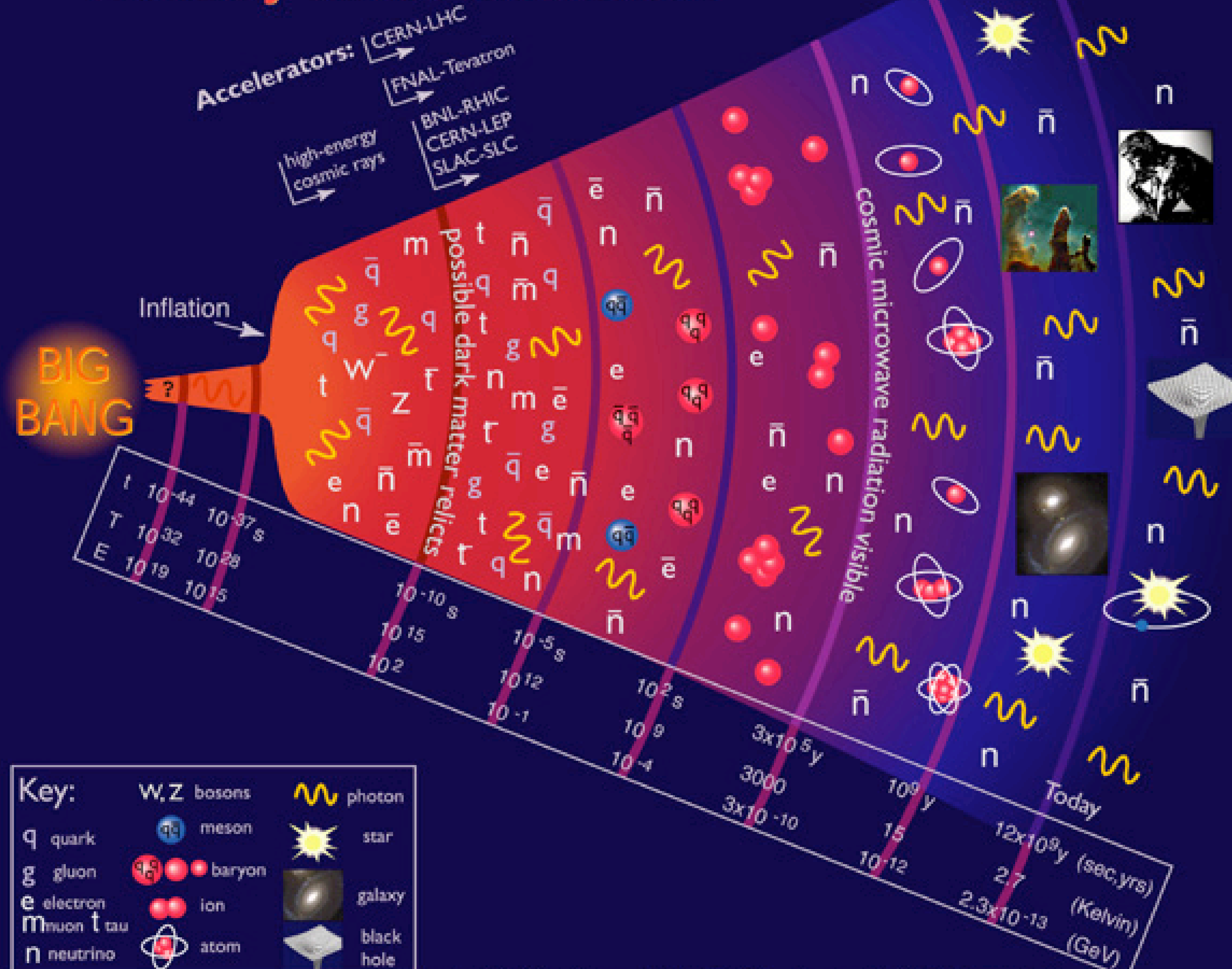


- *Detect Dark Matter to see it is there.*
- *Produce Dark Matter in accelerator experiments to see what it is.*

Dark Matter: Synergy at TeV

- *Dark Matter likely to be TeV-scale electrically neutral weakly interacting particle (e.g., LSP, Lightest KK)*
- *Accessible at accelerators (LHC & LC)*
- *Precision measurement at LC of its mass, couplings in order to calculate its cosmic abundance*
- *If it agrees with cosmological observations, we understand Universe back to* 10^{-12} *sec after the Big Bang*

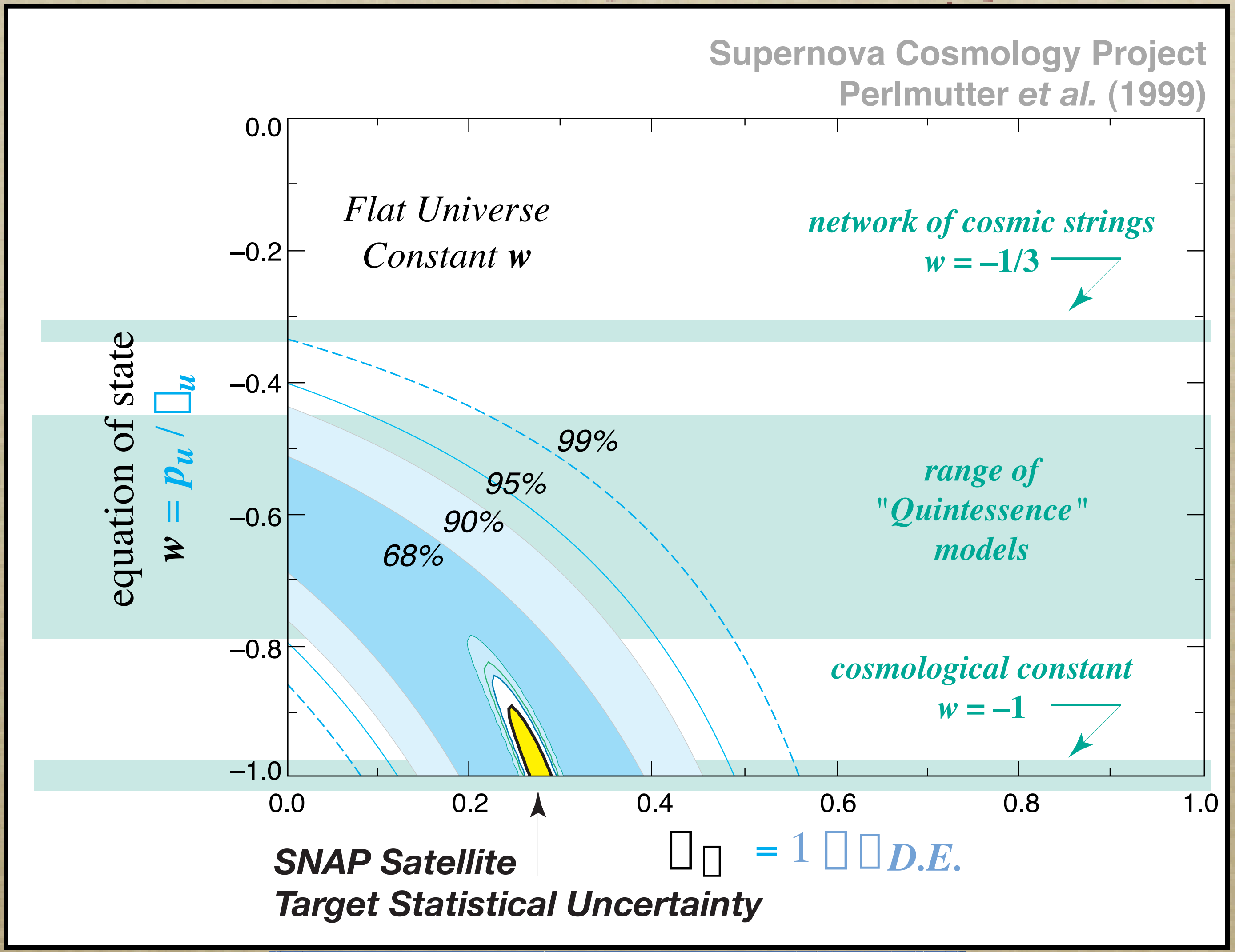
History of the Universe

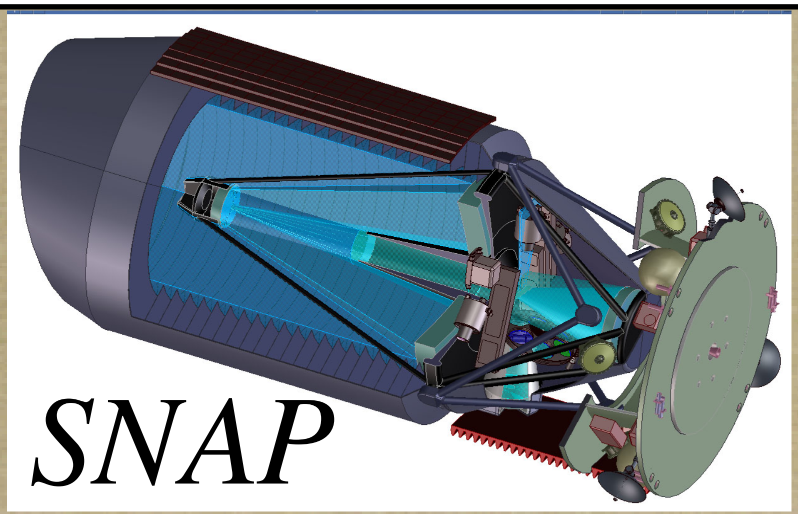


Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Dark Energy

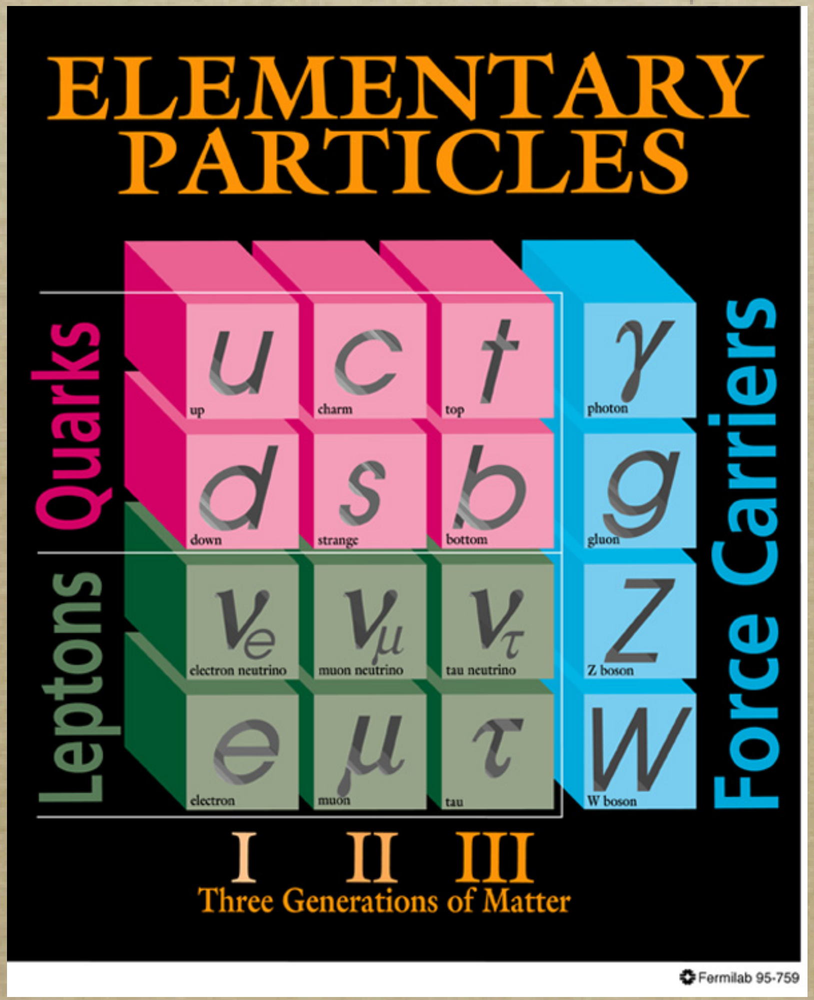
- *Why do we see matter and cosmological constant almost equal in amount?*
- *"Why Now" problem*
- *Actually a triple coincidence problem including the radiation*
- *If there is a deep reason for* $□_□$~((TeV)^2/M_{Pl})^4, *coincidence natural*
- *Indeed,* $□_□$~(2meV)^4 *vs* (TeV)^2/M_{Pl}~0.5meV





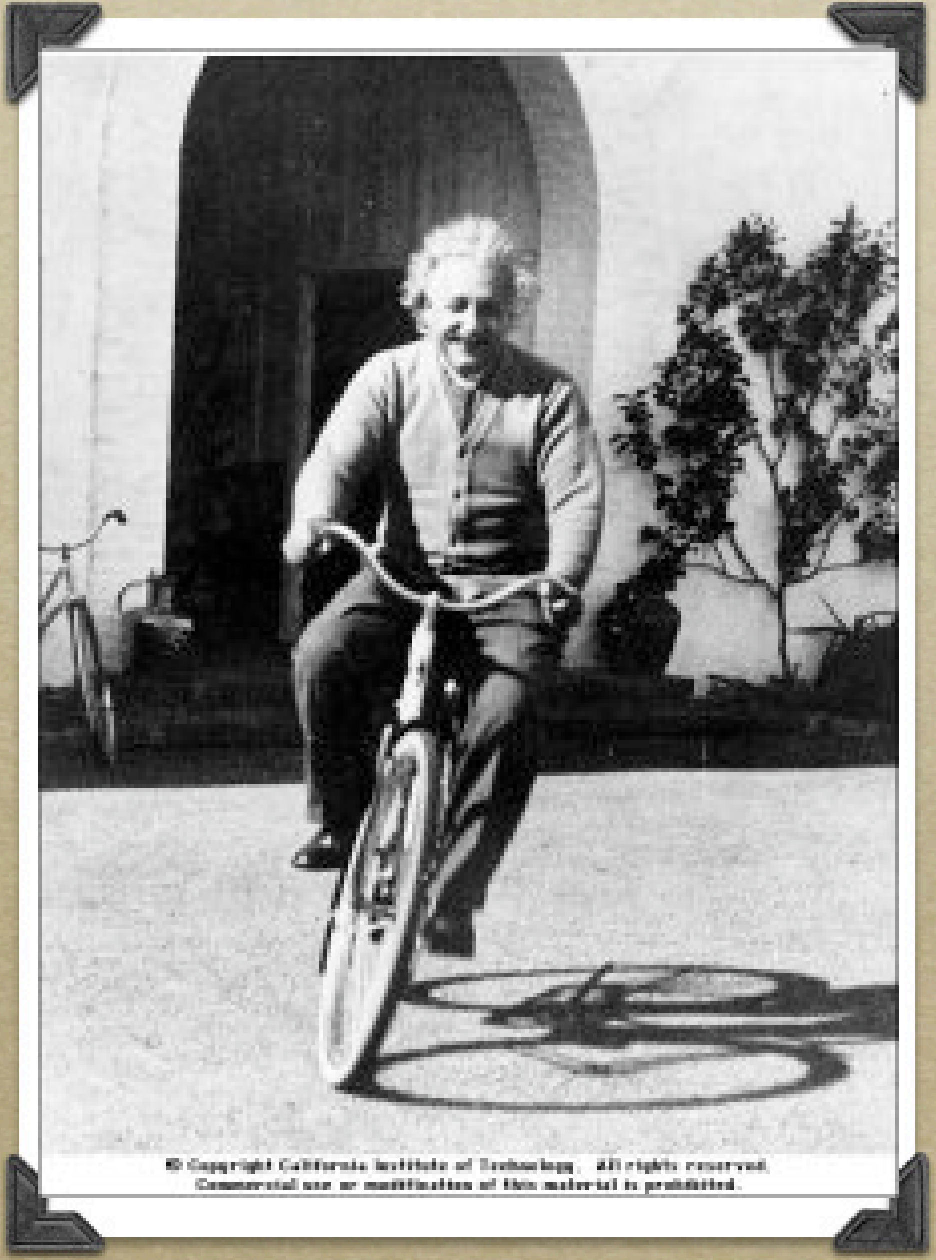
Vertical

$$Q(\mathbf{3},\mathbf{2},+\frac{1}{6}),\quad u(\mathbf{3},\mathbf{1},+\frac{2}{3}),\quad d(\mathbf{3},\mathbf{1},-\frac{1}{3}),$$
$$L(\mathbf{1},\mathbf{2},-\frac{1}{2}),\quad e(\mathbf{1},\mathbf{1},-1)$$

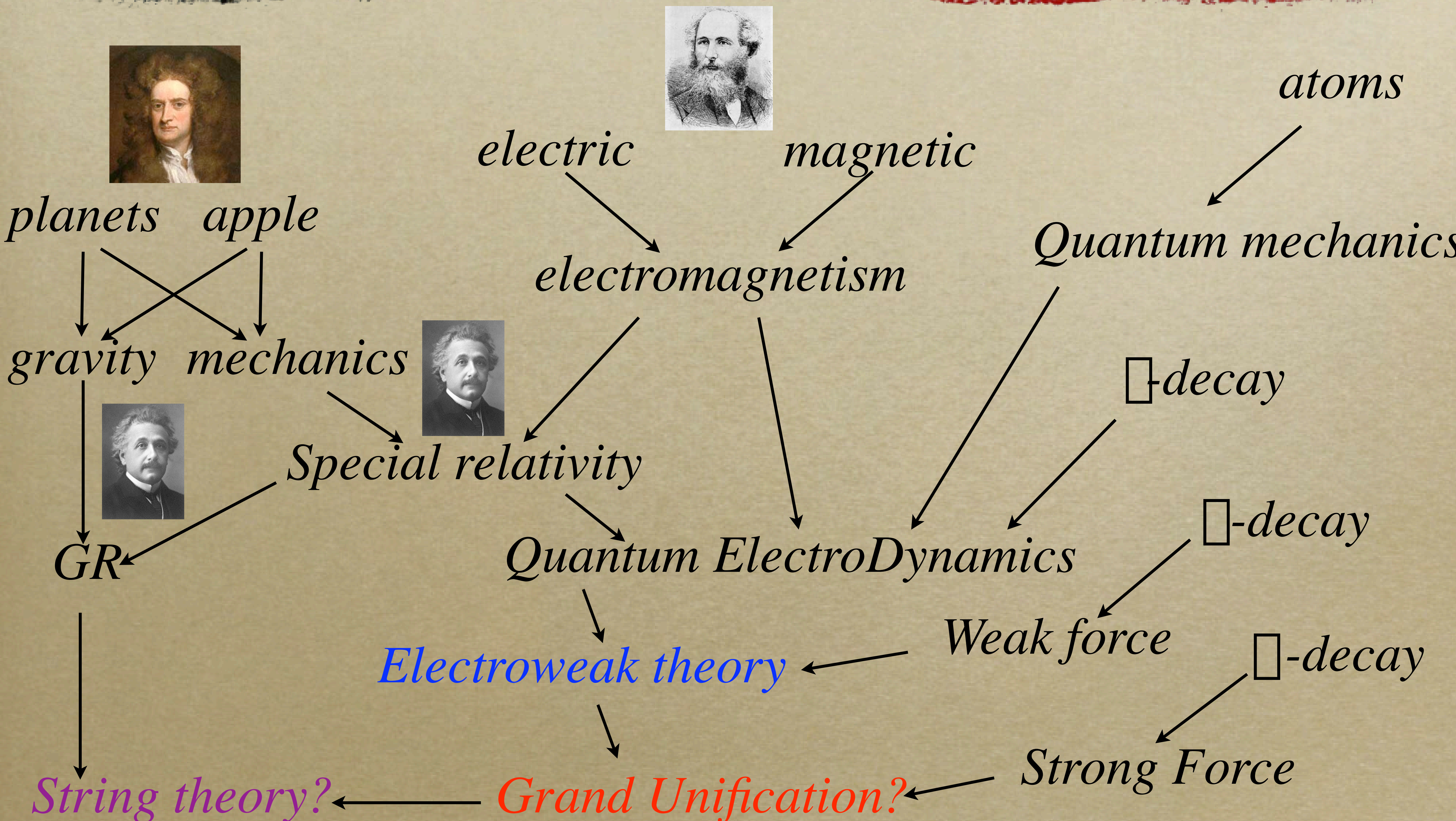


Einstein's Dream

- *Is there an underlying simplicity behind vast phenomena in Nature?*
- *Einstein dreamed to come up with a unified description*
- *But he failed to unify electromagnetism and gravity (GR)*

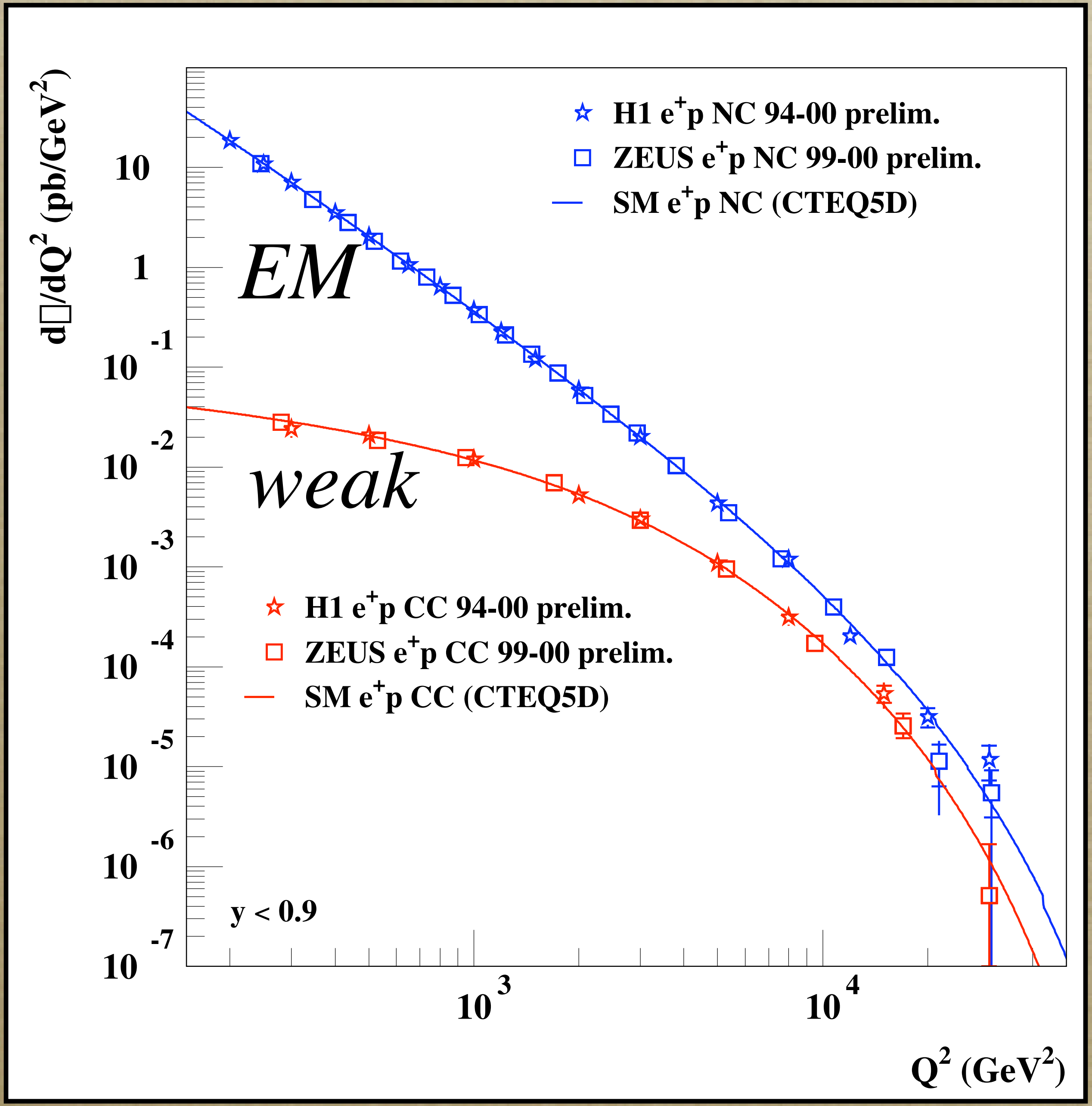


History of Unification



We are just about to achieve another layer of unification

HERA ep collider



- *Unification of electromagnetic and weak forces*

→ *electroweak theory*

- *Long-term goal since '60s*
- *We are getting there!*
- *The main missing link: Higgs boson*

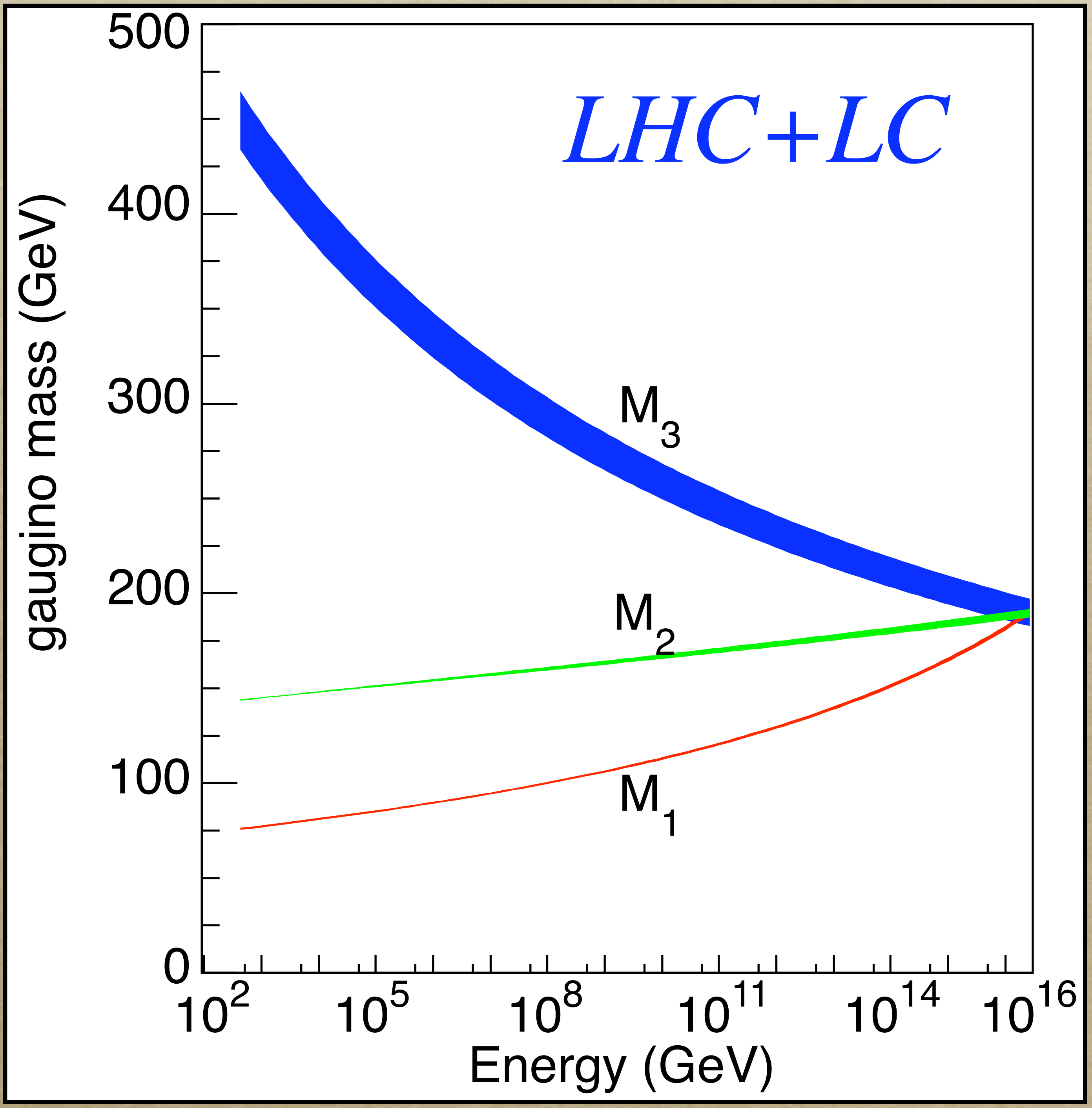
Superpartners as probe

- *Most exciting thing about superpartners beyond existence:*

They carry information of small-distance physics to something we can measure

"Are forces unified?"

Need to see proton decay!



Rare Effects from High-Energies

- *Effects of physics beyond the SM as effective operators*

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cdots$$

- *Can be classified systematically* *(Weinberg)*

$$\mathcal{L}_5 = (LH)(LH) \to \frac{1}{\Lambda}(L\langle H\rangle)(L\langle H\rangle) = m_\nu \nu\nu$$

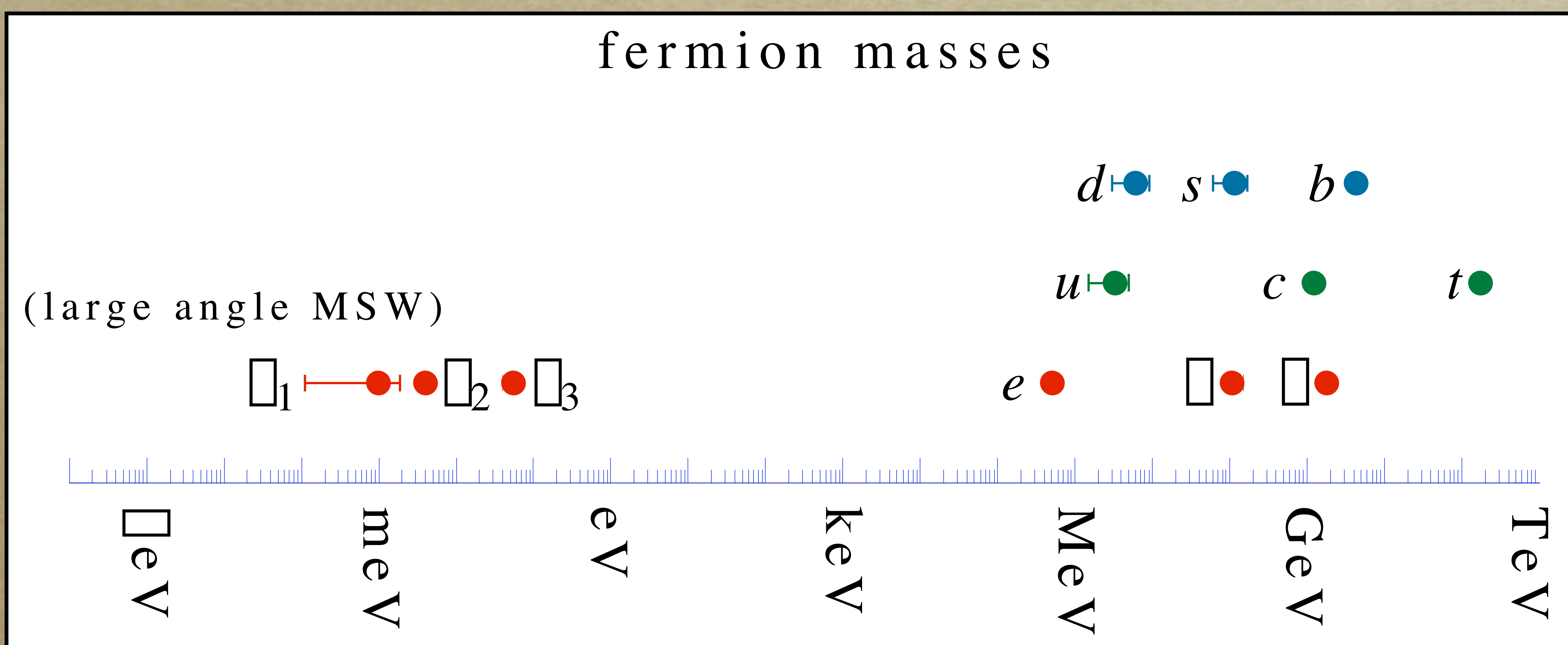
$$\begin{aligned} \mathcal{L}_6 \quad = \quad & QQQL, \bar{L}\sigma^{\mu\nu}W_{\mu\nu}He, \\ & W^\mu_\nu W^\nu_\lambda B^\lambda_\mu, (H^\dagger D_\mu H)(H^\dagger D^\mu H), \cdots \end{aligned}$$

Unique Role of Neutrino Mass

$$\mathcal{L}_5 = (LH)(LH) \rightarrow \frac{1}{\Lambda}(L\langle H\rangle)(L\langle H\rangle) = m_\nu \nu\nu$$

- *Lowest order effect of physics at short distances*
- *Tiny effect* $(m_\nu/E_\nu)^2 \sim (\mathrm{eV/GeV})^2 = 10^{-18}$!
- *Interferometry (i.e., Michaelson-Morley)!*
  - *Need coherent source*
  - *Need interference (i.e., large mixing angles)*
  - *Need long baseline*
- *Nature was kind to provide all of them!*
- *"neutrino interferometry" (a.k.a. neutrino oscillation) a unique tool to study physics at very high scales*
- *Data suggest* $\Lambda \sim 10^{15}$GeV!

Horizontal

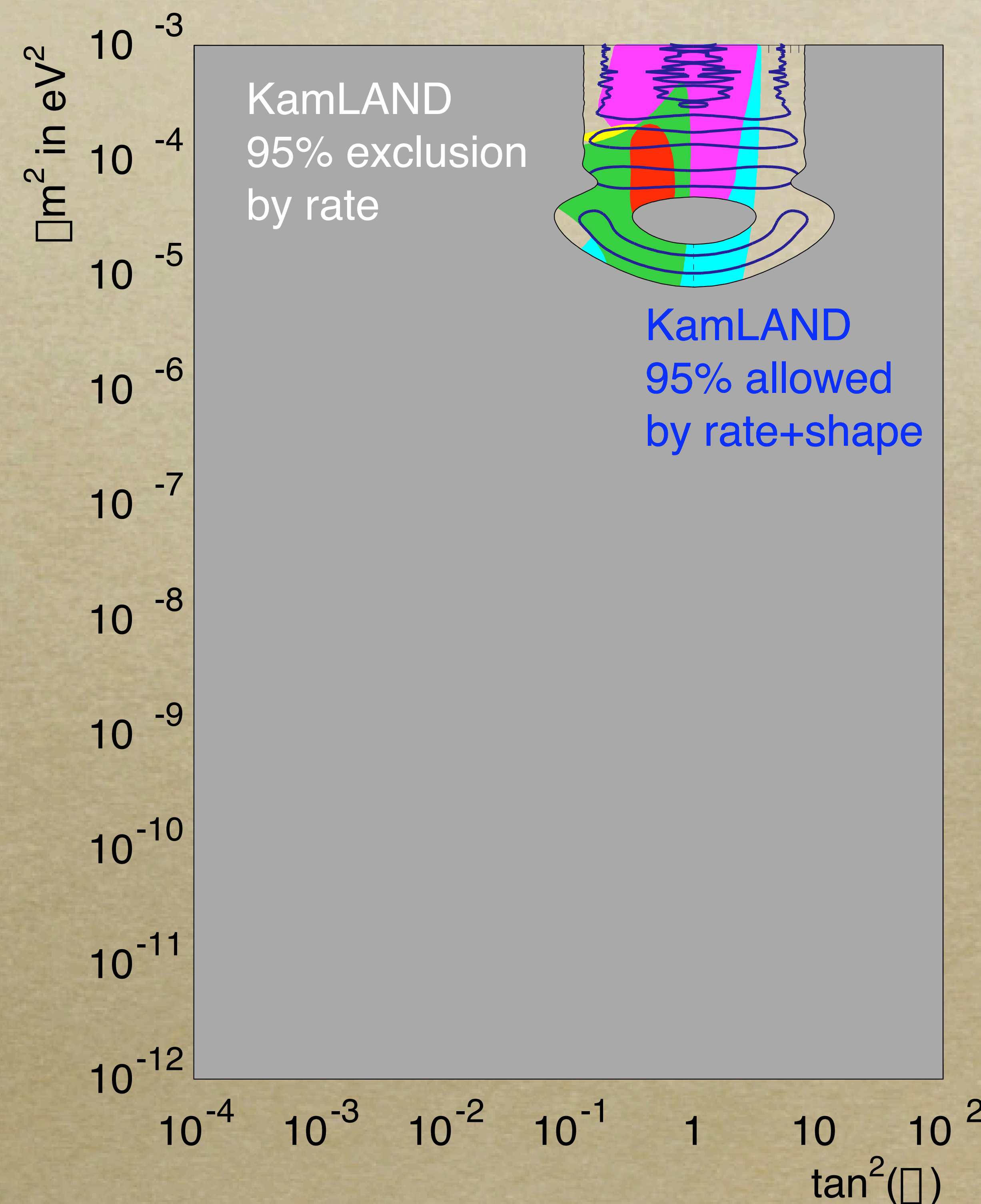


fermion masses
d
s
b
u
c
t
(large angle MSW)
e
eV
meV
eV
keV
MeV
GeV
TeV

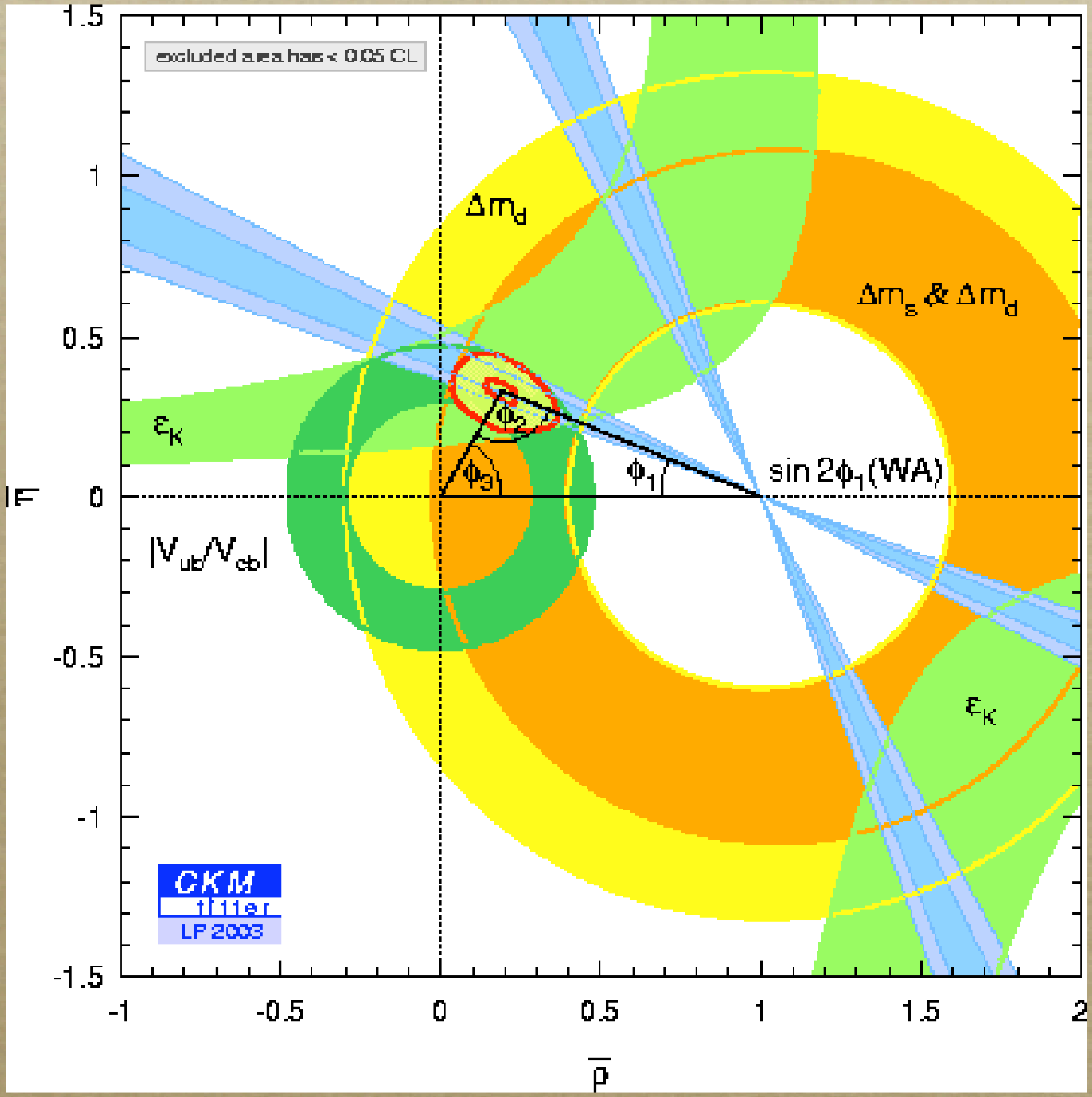
Historic Era in Flavor Physics

Lepton Sector

- *1956 Cowan and Reines detect neutrinos from a nuclear reactor*
- *1998 SuperK announcement of oscillation in atmospheric neutrinos*
- *2002 SNO establishes flavor conversion in solar neutrinos*
- *2002 KamLAND decides the solution to the solar neutrino problem*



Historic Era in Flavor Physics



Quark Sector

- *1964 Fitch and Cronin discover CP violation (indirect CP in neutral K)*
- *1999 CPLEAR establishes T violation in K mixing*
- *2000 KTeV/NA48 establish direct CP violation in □/□*
- *2002 BABAR/Belle establish indirect CP violation in B_d meson, confirming Kobayashi-Maskawa theory*

Question of Flavor

- *What distinguishes different generations?*
  - *Same gauge quantum numbers, yet different*
- *Hierarchy with small mixings:*

  $\Rightarrow$ *Need some ordered structure*
- *Probably a hidden flavor quantum number*

  $\Rightarrow$ *Need flavor symmetry*
  - *Flavor symmetry must allow top Yukawa*
  - *Other Yukawas forbidden*
  - *Small symmetry breaking generates small Yukawas*

Broken Flavor Symmetry

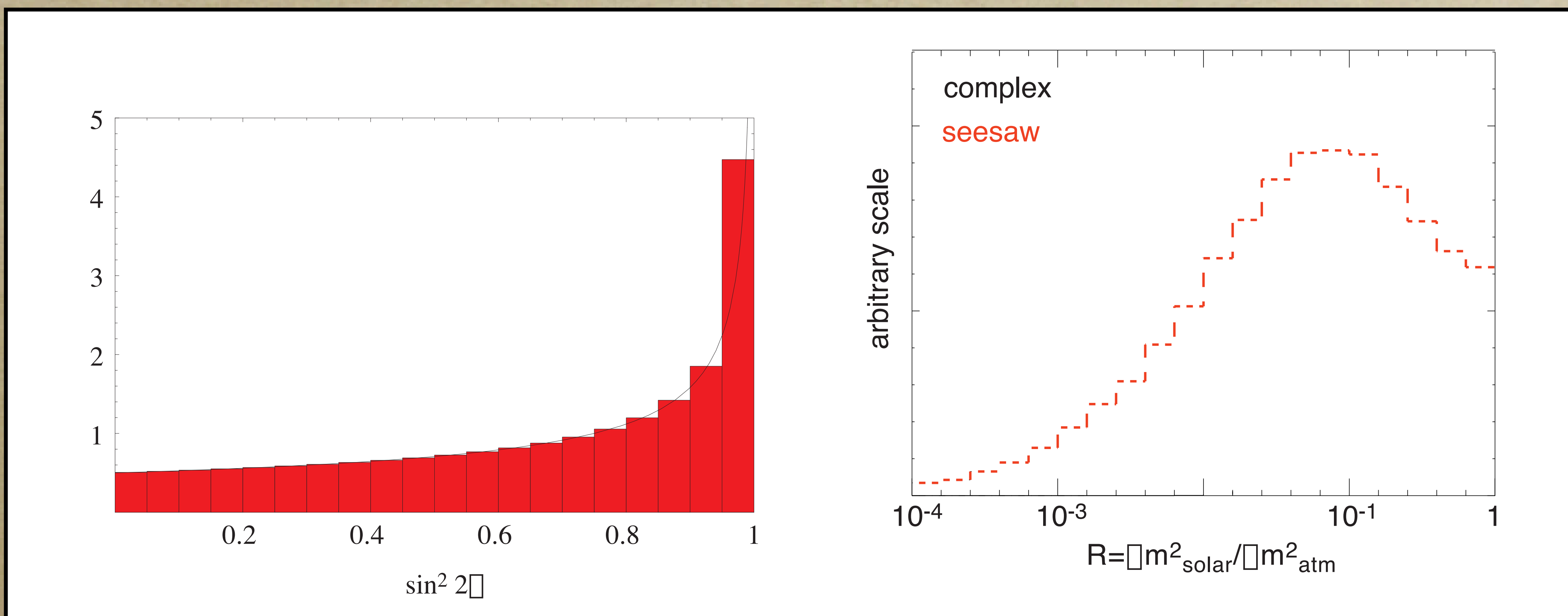
- *Flavor symmetry broken by a VEV* $\langle \epsilon \rangle \sim 0.02$
- SU(5)-*like:*
  - $10(Q, u_R, e_R)$ (+2, +1, 0)
  - $5^*(L, d_R)$ (+1, +1, +1)
  - $$M_u \sim \begin{pmatrix} \epsilon^4 & \epsilon^3 & \epsilon^2 \\ \epsilon^3 & \epsilon^2 & \epsilon \\ \epsilon^2 & \epsilon & 1 \end{pmatrix}, M_d \sim \begin{pmatrix} \epsilon^3 & \epsilon^3 & \epsilon^3 \\ \epsilon^2 & \epsilon^2 & \epsilon^2 \\ \epsilon & \epsilon & \epsilon \end{pmatrix}, M_l \sim \begin{pmatrix} \epsilon^3 & \epsilon^2 & \epsilon \\ \epsilon^2 & \epsilon^2 & \epsilon \\ \epsilon^3 & \epsilon^2 & \epsilon \end{pmatrix}$$
  - $m_u : m_c : m_t \sim m_d^2 : m_s^2 : m_b^2 \sim m_e^2 : m_\mu^2 : m_\tau^2 \sim \epsilon^4 : \epsilon^2 : 1$
  - *Not bad!*

New Data from Neutrinos

- *Neutrinos are already providing significant new information about flavor symmetries*
- *Given LMA, all mixings except U_{e3} large*
- $$\begin{pmatrix} e & \mu & \tau \end{pmatrix} \begin{pmatrix} big & big & small \\ big & big & big \\ big & big & big \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} \qquad \frac{\Delta m^2_{solar}}{\Delta m^2_{atm}} \sim 0.01 - 0.2$$
-
  - *Two mass splittings not very different*
  - *Atmospheric mixing maximal*
- *Any new symmetry or structure behind it?*

Is There A Structure In Neutrino Masses & Mixings?

- *Monte Carlo random complex* 3□3 *matrices with seesaw mechanism*



Apparently no particular structure in neutrino mass matrix needed! Anarchy

Different Flavor Symmetries

Altarelli-Feruglio-Masina hep-ph/0210342

Model	parameters	d_{23}	$\Delta m^2_{12}/\lvert\Delta m^2_{23}\rvert$	U_{e3}	$\tan^2\theta_{12}$	$\tan^2\theta_{23}$
A	$b=0$	O(1)	O(1)	O(1)	O(1)	O(1)
SA	$b=1$	O(1)	$O(d^2_{23})$	$O(\lambda)$	$O(\lambda^2/d^2_{23})$	O(1)
~~H_{II}~~	~~$a=1, b=2$~~	~~$O(\lambda^2)$~~	~~$O(\lambda^4)$~~	~~$O(\lambda^2)$~~	~~O(1)~~	~~O(1)~~
~~H_I~~	~~$a=1, b=2$~~	~~0~~	~~$O(\lambda^6)$~~	~~$O(\lambda^2)$~~	~~O(1)~~	~~O(1)~~
IH		$O(\lambda^4)$	$O(\lambda^2)$	$O(\lambda^2)$	$1+O(\lambda^2)$	O(1)

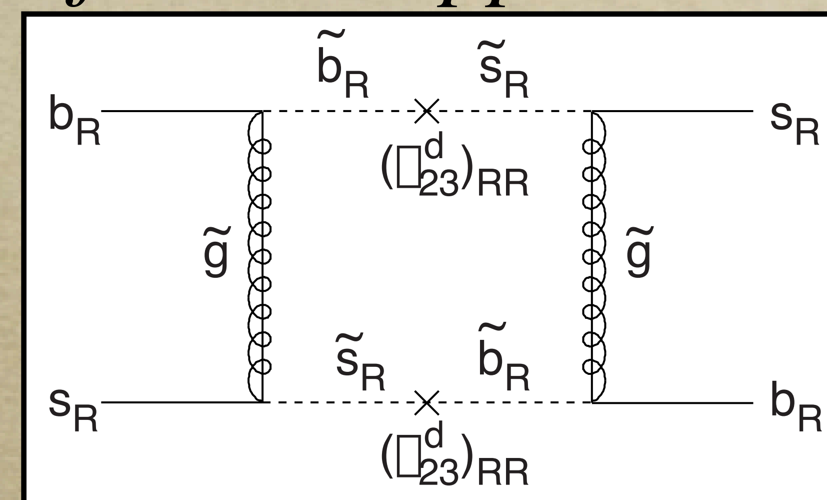
$\theta_{13} \approx O(1)$? $O(\lambda)$? (λ^2)?

$\sin^2 2\theta_{23} = 1.00 \pm 0.01$? $\Rightarrow$ new symmetry

Program:More flavor parameters

- *Squarks, sleptons also come with mass matrices*
- *Off-diagonal elements violate flavor: suppressed by flavor symmetries*

$$M^2_{\tilde{Q}} \sim M^2_{\tilde{L}} \sim \begin{pmatrix} 1 & \square & \square^2 \\ \square & 1 & \square \\ \square^2 & \square & 1 \end{pmatrix}$$



- *Look for flavor violation due to SUSY loops*
- *Then look for patterns to identify symmetries*
  - *⇒ Repeat Gell-Mann–Okubo!*
- *Need to know SUSY masses or TeV-scale physics*

To Figure It Out…

- *Models differ in flavor quantum number assignments*
- *Need data on θ_{13}, matter effect, CP violation, B/K-physics, Lepton Flavor Violation, EWSB, proton decay*
- *Archaeology*
- *We will learn insight on origin of flavor by studying as many fossils as possible*
  - *cf. CMBR in cosmology*

Large □$_{23}$ and quarks

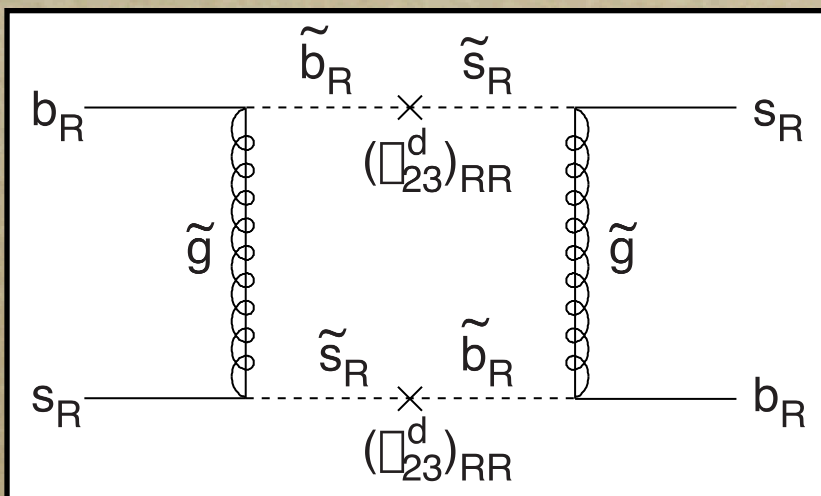
- *Near-maximal mixing between □$_{□}$ and □$_{□}$*
- *Make it SU(5) GUT*
- *Then a large mixing between s_R and b_R*
- *Mixing among right-handed fields drop out from CKM matrix*
- *But mixing among superpartners physical*

$$\begin{pmatrix} \tilde{s}_R \\ \tilde{s}_R \\ \tilde{s}_R \\ \tilde{\nu}_\mu \\ \tilde{\mu} \end{pmatrix} \longleftrightarrow \begin{pmatrix} \tilde{b}_R \\ \tilde{b}_R \\ \tilde{b}_R \\ \tilde{\nu}_\tau \\ \tilde{\tau} \end{pmatrix}$$

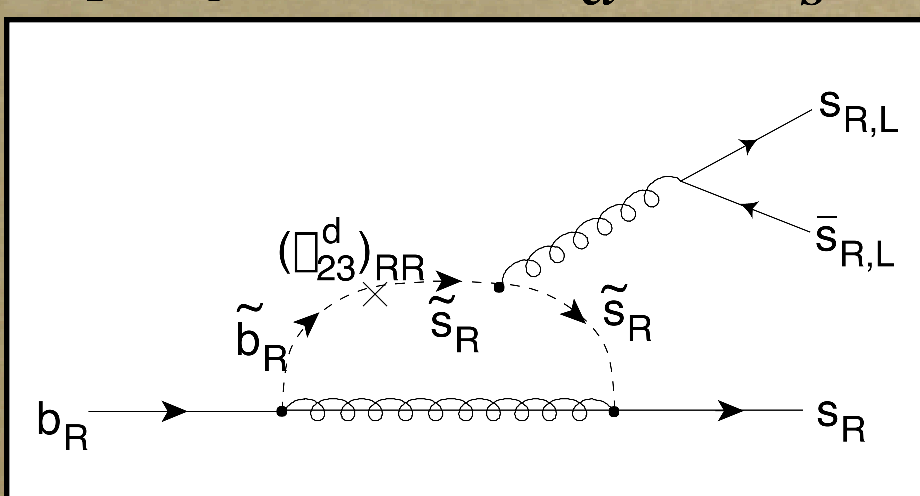
• O(1) *effects on b   s transition possible*
• *Expect CP violation in neutrino sector especially if leptogenesis*

Consequences in B physics

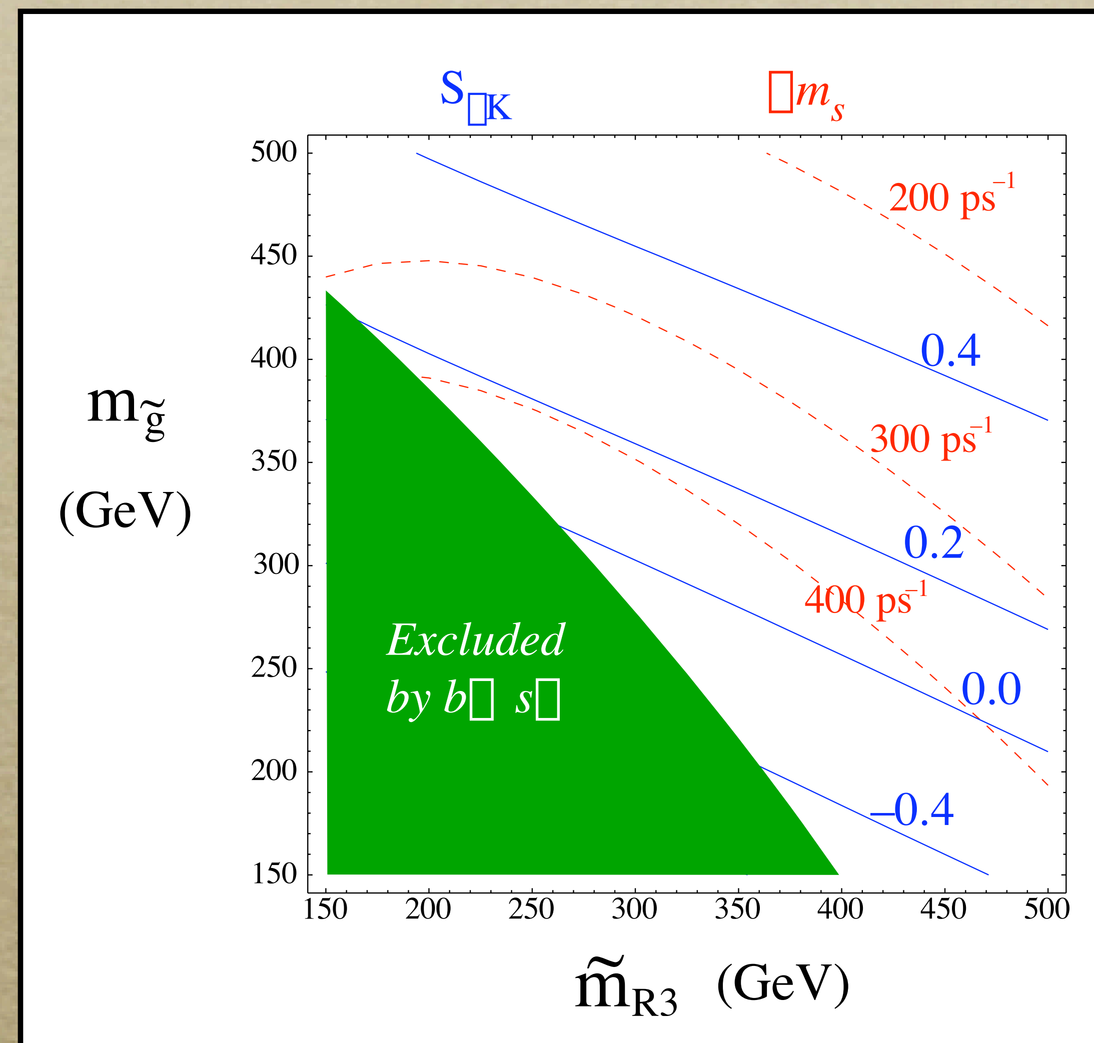
- *CP violation in B_s mixing ($B_s \to J/\psi\,\phi$)*



- *Addt'l CP violation in penguin $b \to s$ ($B_d \to \phi K_s$)*



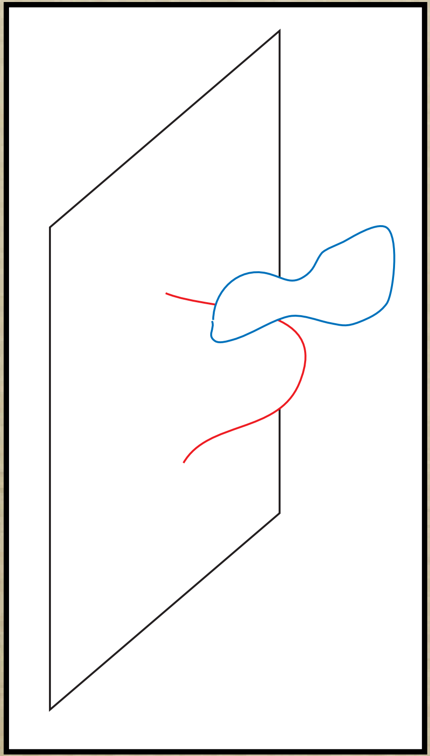
- *$B_d \to X_s l^+ l^-$*

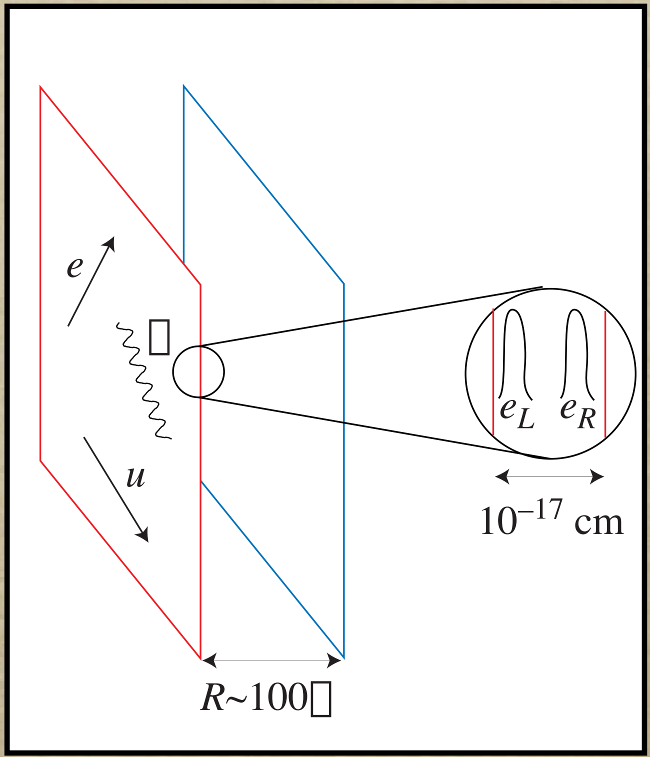


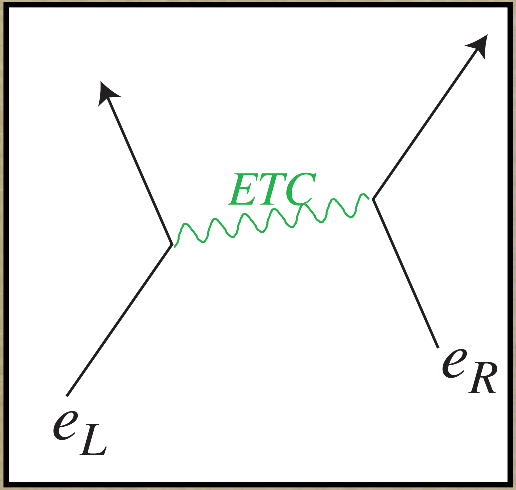
Probes if quarks and leptons have common origin of flavor

Dynamics behind flavor symmetry?

- *Once flavor symmetry structure identified (e.g., Gell-Man–Okubo), what is dynamics? (e.g., QCD)*
- *Supersymmetry*:
  – *Anomalous* U(1) *gauge symmetry with Green-Schwarz mechanism*
- *Large Extra Dimensions*:
  – *Fat brane with physically separated left- and right-handed particles*
- *Technicolor*:
  – *New broken gauge symmetries at* 100TeV *scale*







Leptogenesis

Baryon Asymmetry
Early Universe

10,000,000,001

q

10,000,000,000

$\bar{q}$

Baryon Asymmetry
Current Universe

1

us

q $\bar{q}$

The Great Annihilation

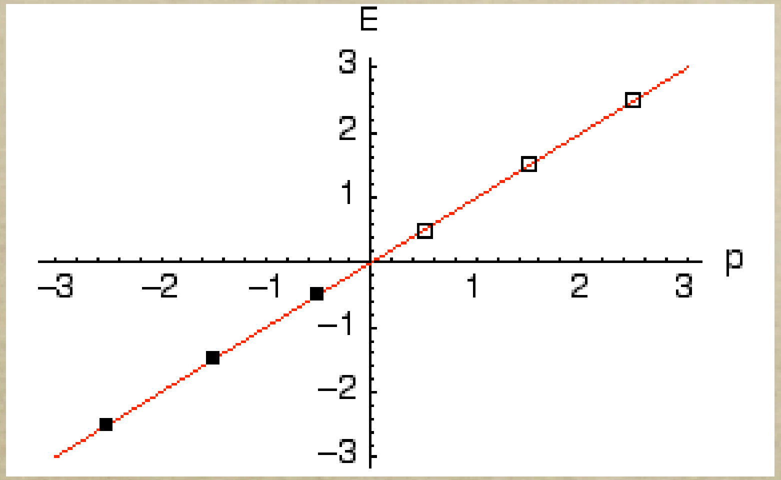
Sakharov's Conditions for Baryogenesis

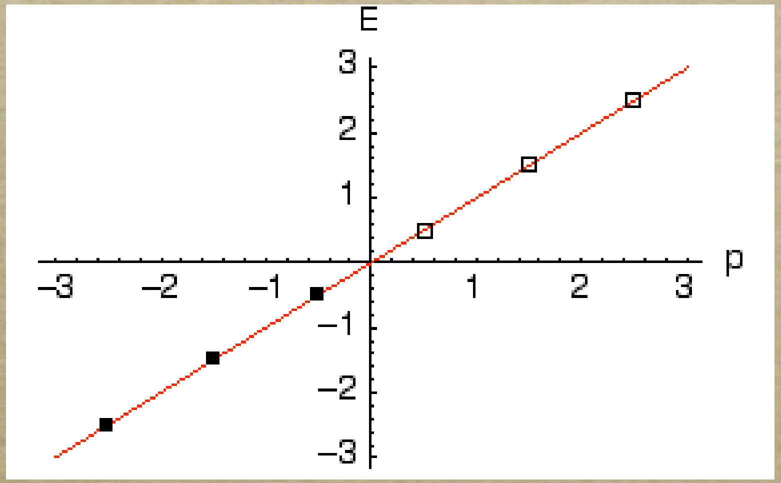
- *Necessary requirements for baryogenesis:*
  - *Baryon number violation*
  - *CP violation*
  - *Non-equilibrium*

    $\Rightarrow \Gamma(\Delta B>0) > \Gamma(\Delta B<0)$
- *Possible new consequences in*
  - *Proton decay*
  - *CP violation*

Electroweak Anomaly

- *Actually, SM violates B (but not B–L).*
  - *In Early Universe (T* > 200GeV*), W/Z are massless and fluctuate in W/Z plasma*
  - *Energy levels for left-handed quarks/ leptons fluctuate correspon-dingly*

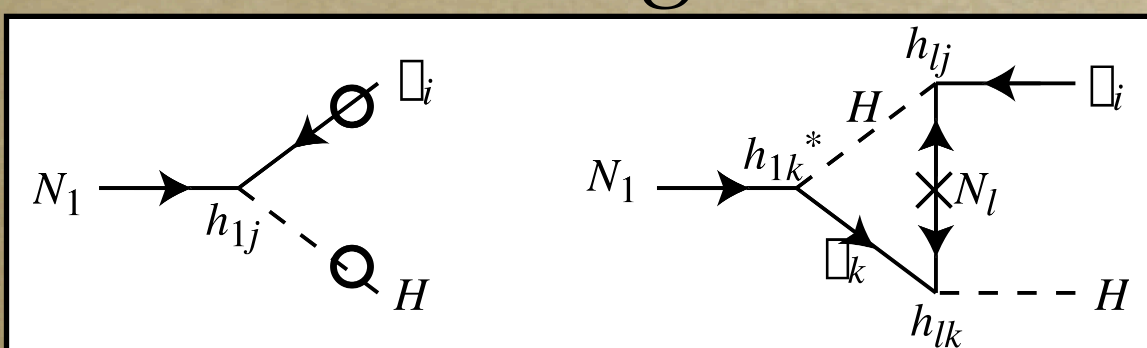




$$\square L = \square Q = \square Q = \square Q = \square B = 1 \Rightarrow B = L = 0$$

Leptogenesis

- *You generate Lepton Asymmetry first.*
- *L gets converted to B via EW anomaly*
    - *generate L from the direct CP violation in right-handed neutrino decay*



$$\varepsilon = \frac{\Gamma(N_1 \to \ell_i H) - \Gamma(N_1 \to \bar{\ell}_i H)}{\Gamma(N_1 \to \ell_i H) + \Gamma(N_1 \to \bar{\ell}_i H)} \sim \frac{1}{8\pi} \frac{\mathrm{Im}(h_{13} h_{13} h_{33}^* h_{33}^*)}{|h_{13}|^2} \frac{M_1}{M_3}$$

- *Two generations enough for CP violation because of Majorana nature (choose 1 & 3)*

Can we prove it experimentally?

- *Unfortunately, no: it is difficult to reconstruct relevant CP-violating phases from neutrino data*
- *But: we will probably believe it if*
  - 0□□□ *found*
  - *CP violation found in neutrino oscillation*

$$P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) = -16 s_{12} c_{12} s_{13} c_{13}^2 s_{23} c_{23}$$
$$\sin\delta \sin\left(\frac{\Delta m_{12}^2}{4E} L\right) \sin\left(\frac{\Delta m_{13}^2}{4E} L\right) \sin\left(\frac{\Delta m_{23}^2}{4E} L\right)$$

  - *EW baryogenesis ruled out*
  - *Archeological evidences e.g,* B_d □ K_s

Conclusion

Bottomline: Synergy

- *Big questions* = *ambitious questions*
- *Need to clear the cloud of TeV-scale physics to obtain clear views*
- *Many different approaches will converge to reveal the big picture*
- *Hard, ambitious, but conceivable*
- *Expect similar story with ANY scenario of TeV-scale physics*

Outlook: The Next Twenty Years

...is bright!