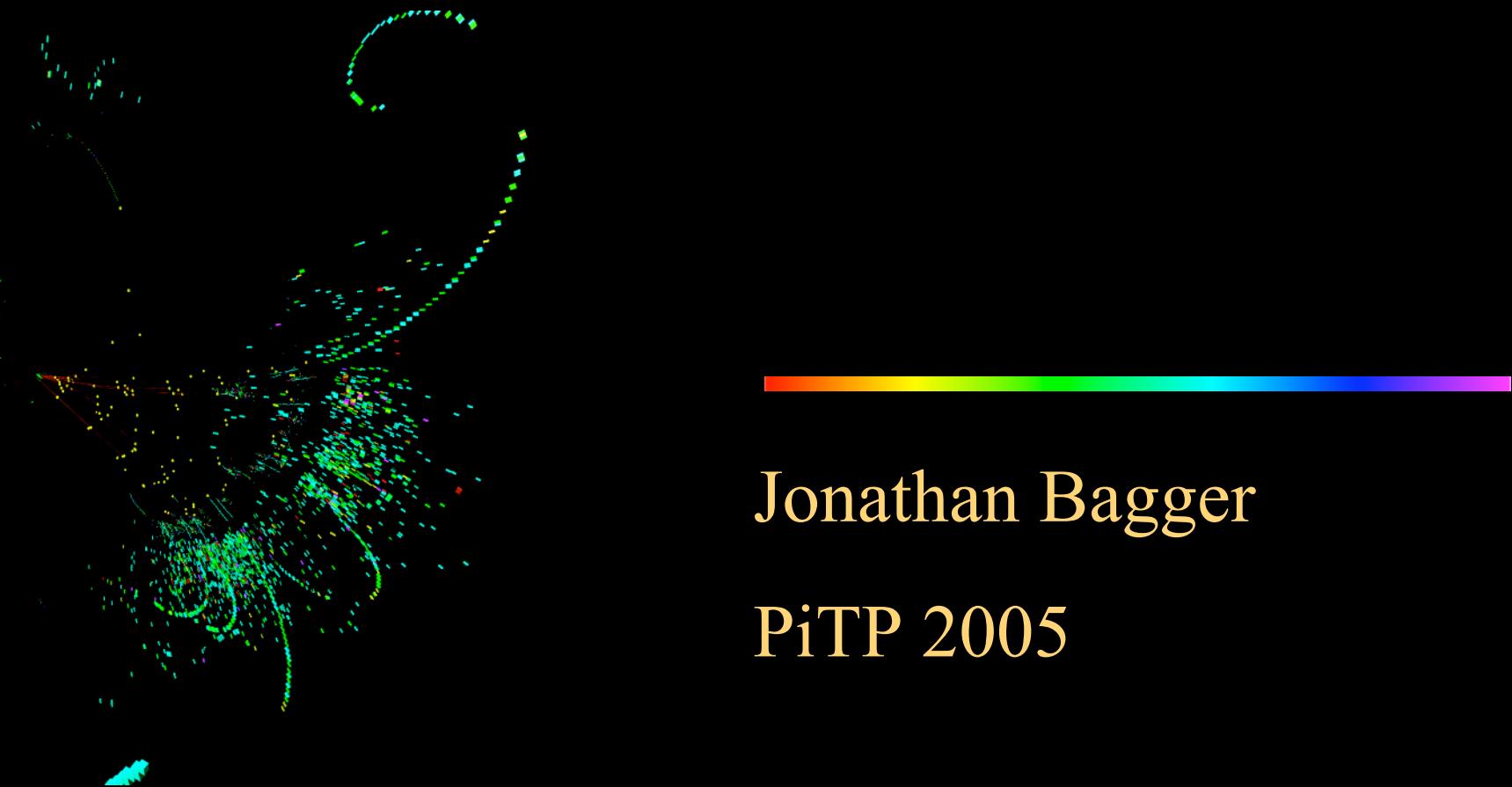


# Matter, Energy, Space and Time

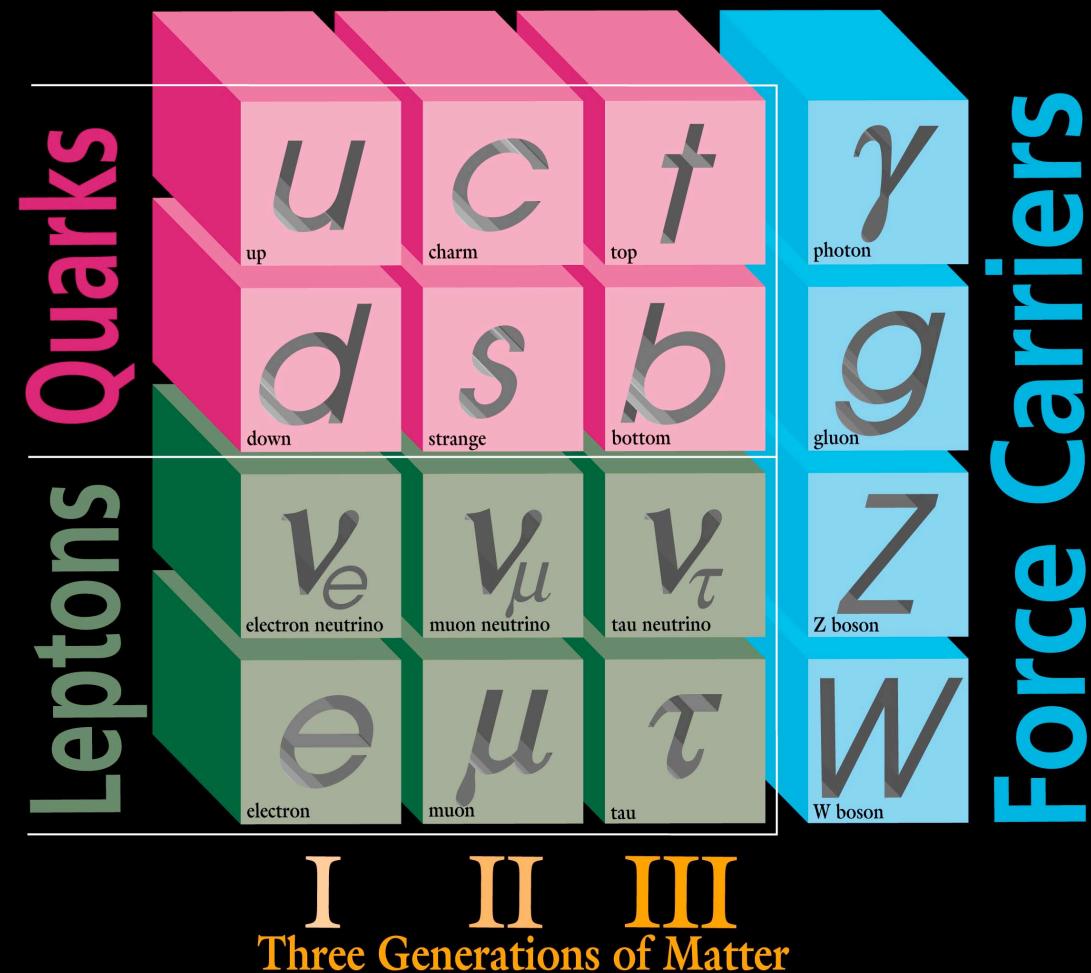
*Particle Physics in the 21st century*



Jonathan Bagger

PiTP 2005

# Standard Model



# Experimental Confirmation

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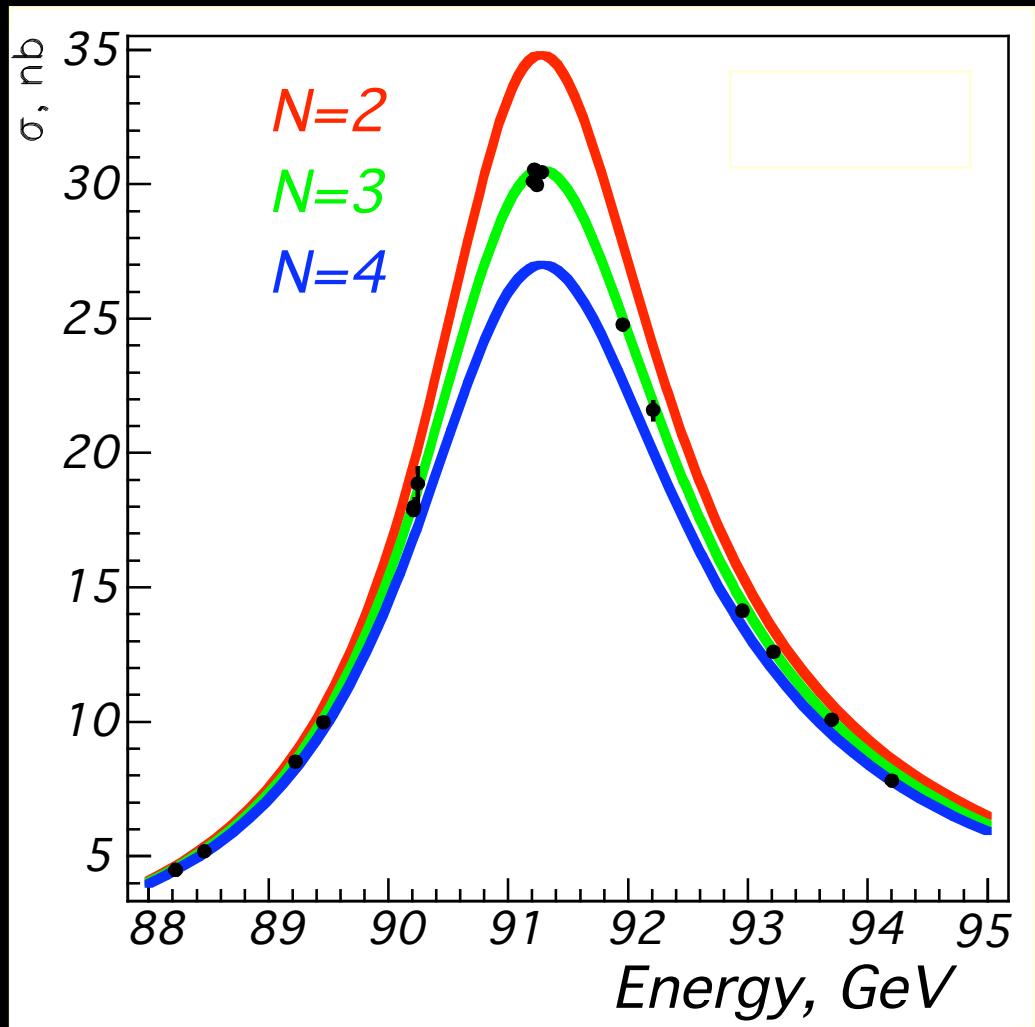


# Precision Tests

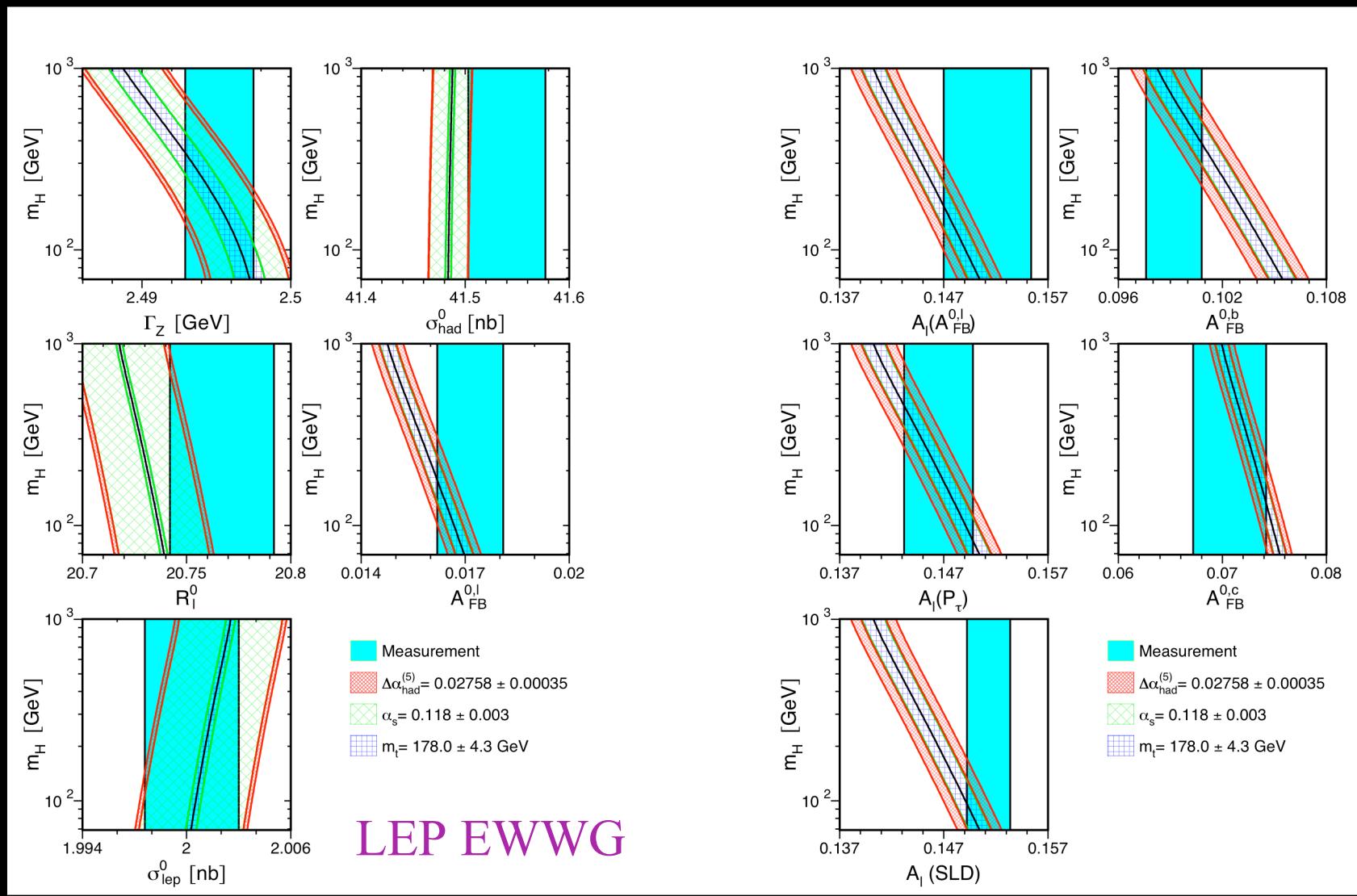


$$N_v = 2.994 \pm 0.012$$

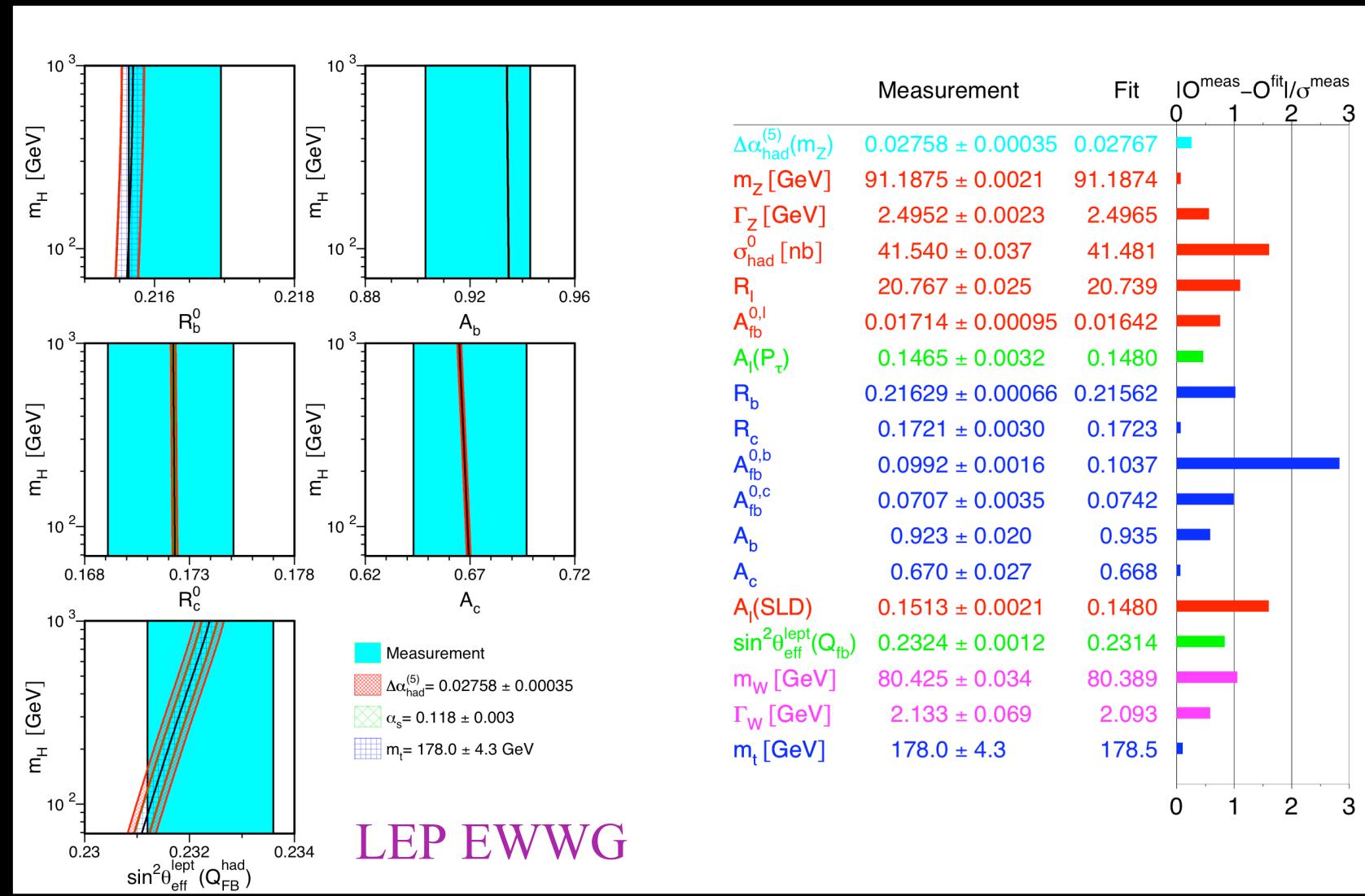
DELPHI



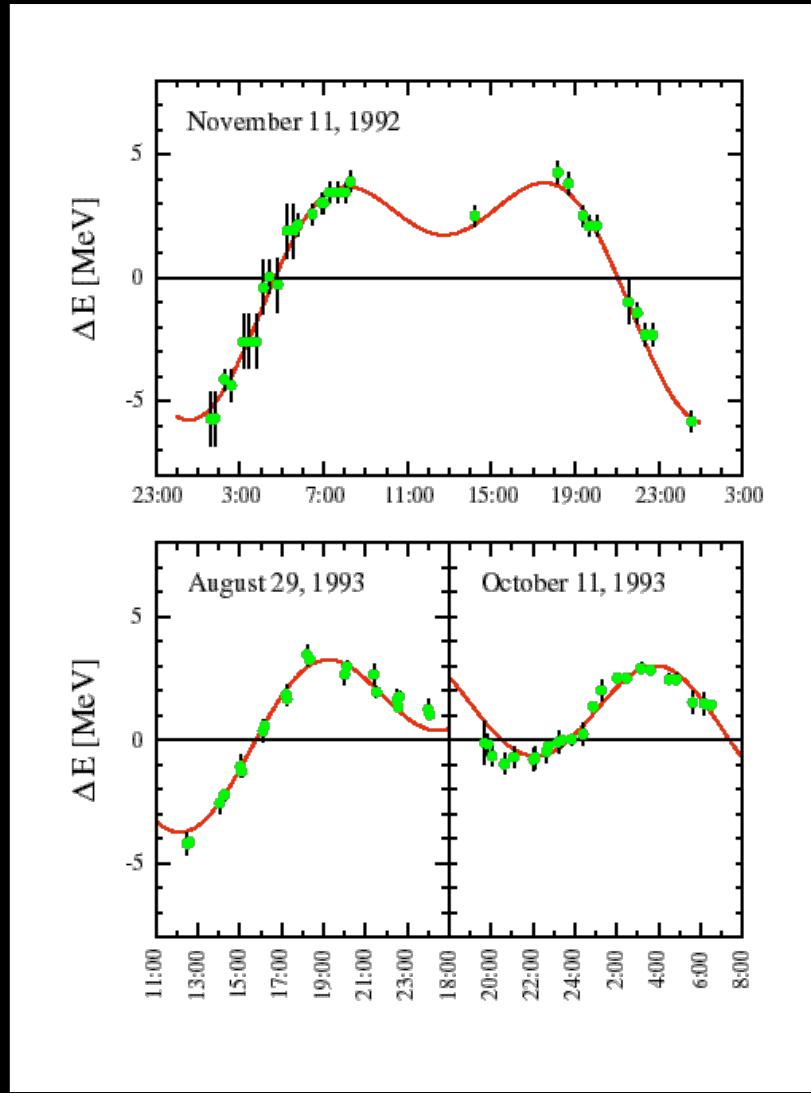
# Precision Tests



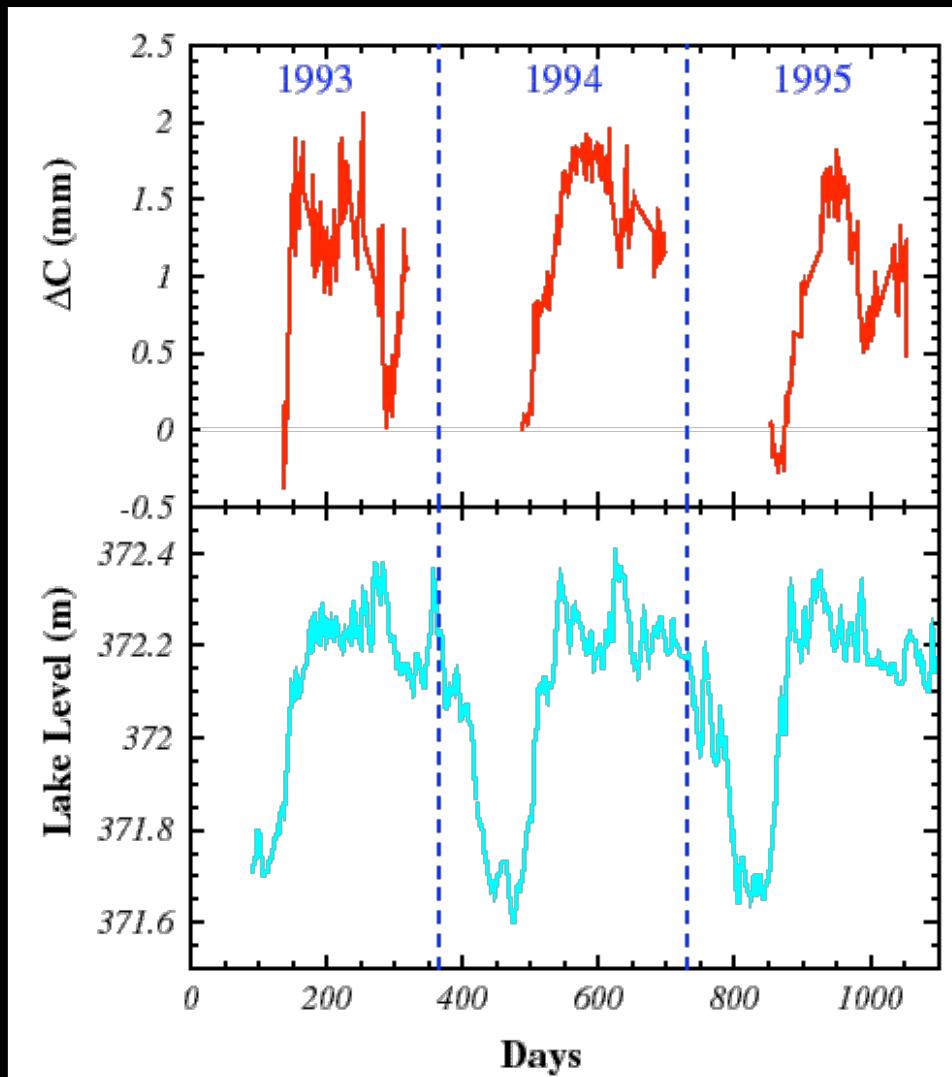
# Precision Tests



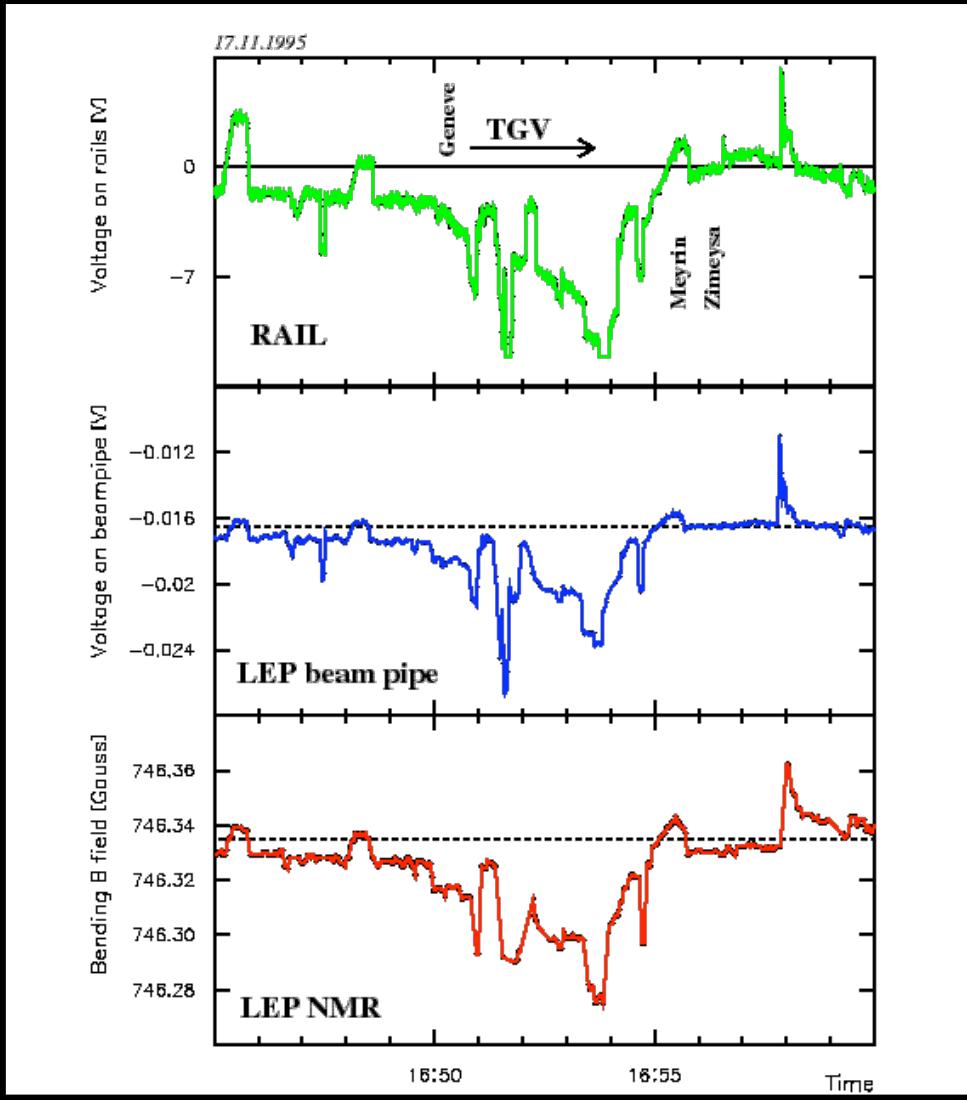
# Tide Effect



# Lake Effect



# TGV Effect

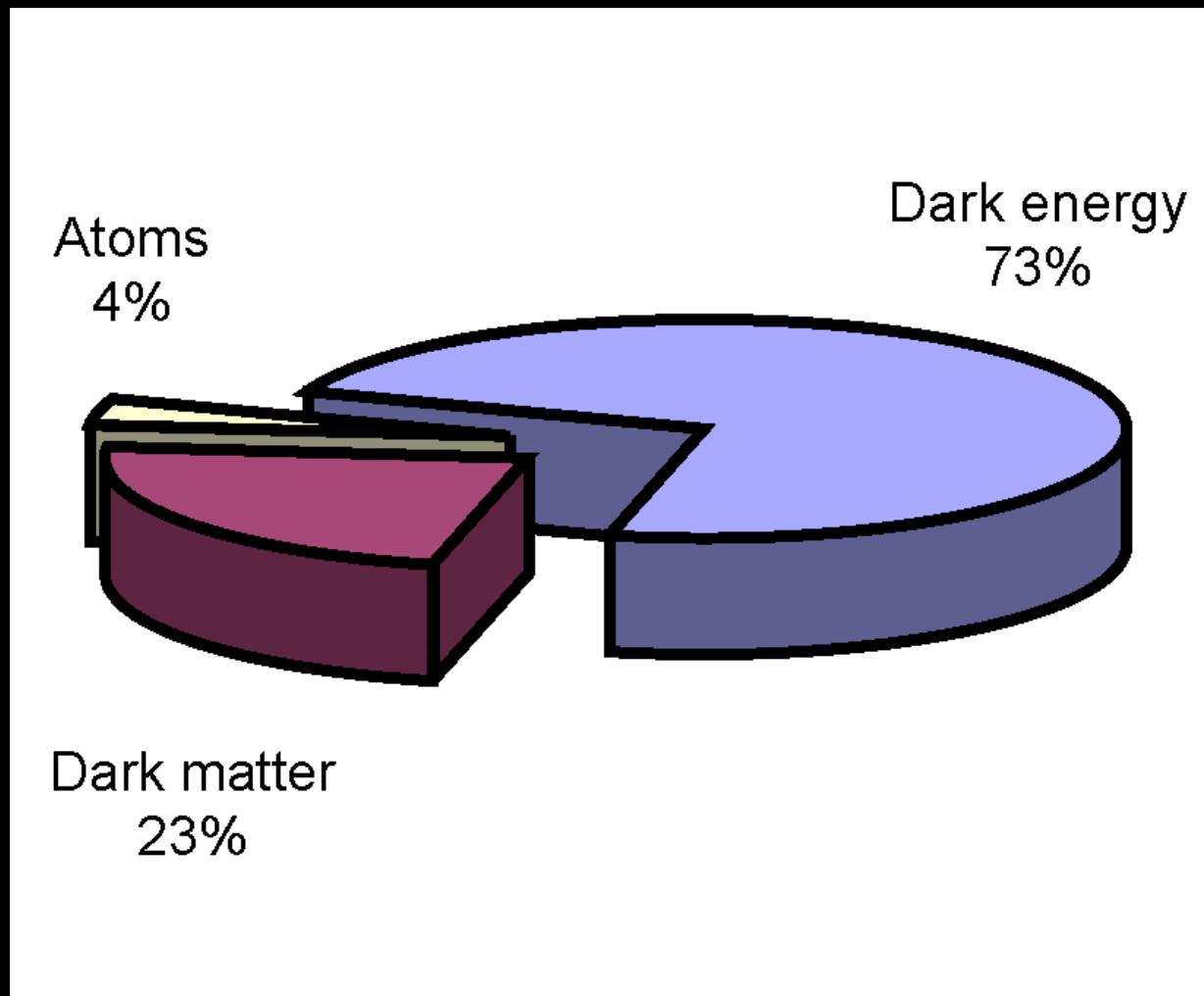
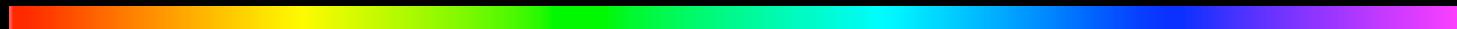


# But ...



The Standard Model contains the  
seeds of its own destruction ...

# Dark Matter / Dark Energy



# Dark Matter



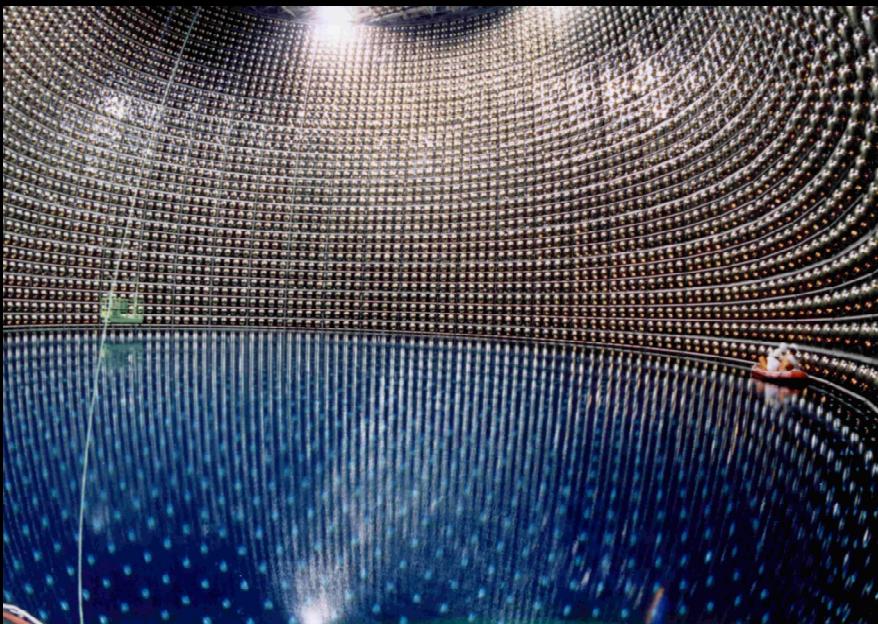
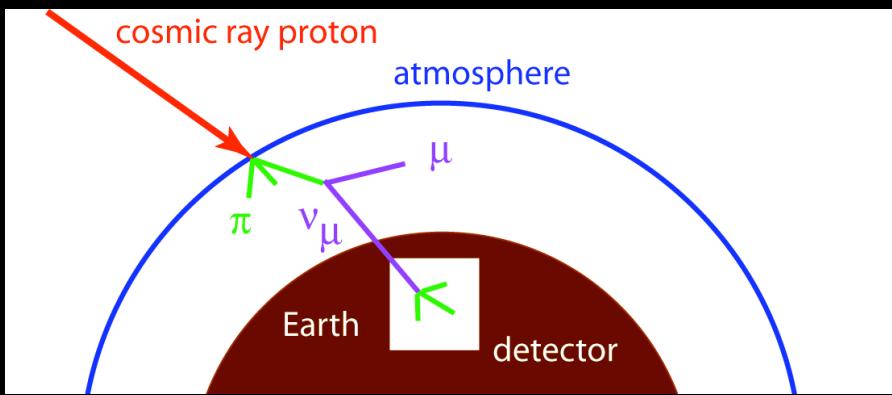
Hubble

# Dark Matter

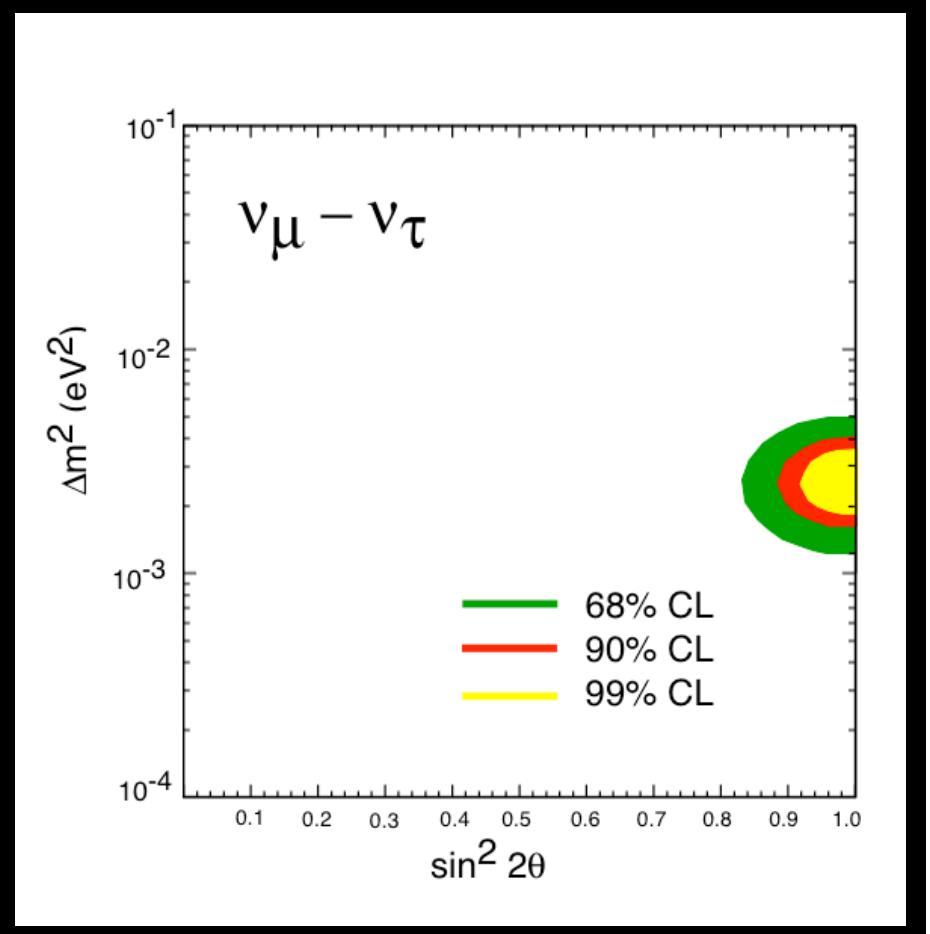


Hubble

# Neutrino Mass



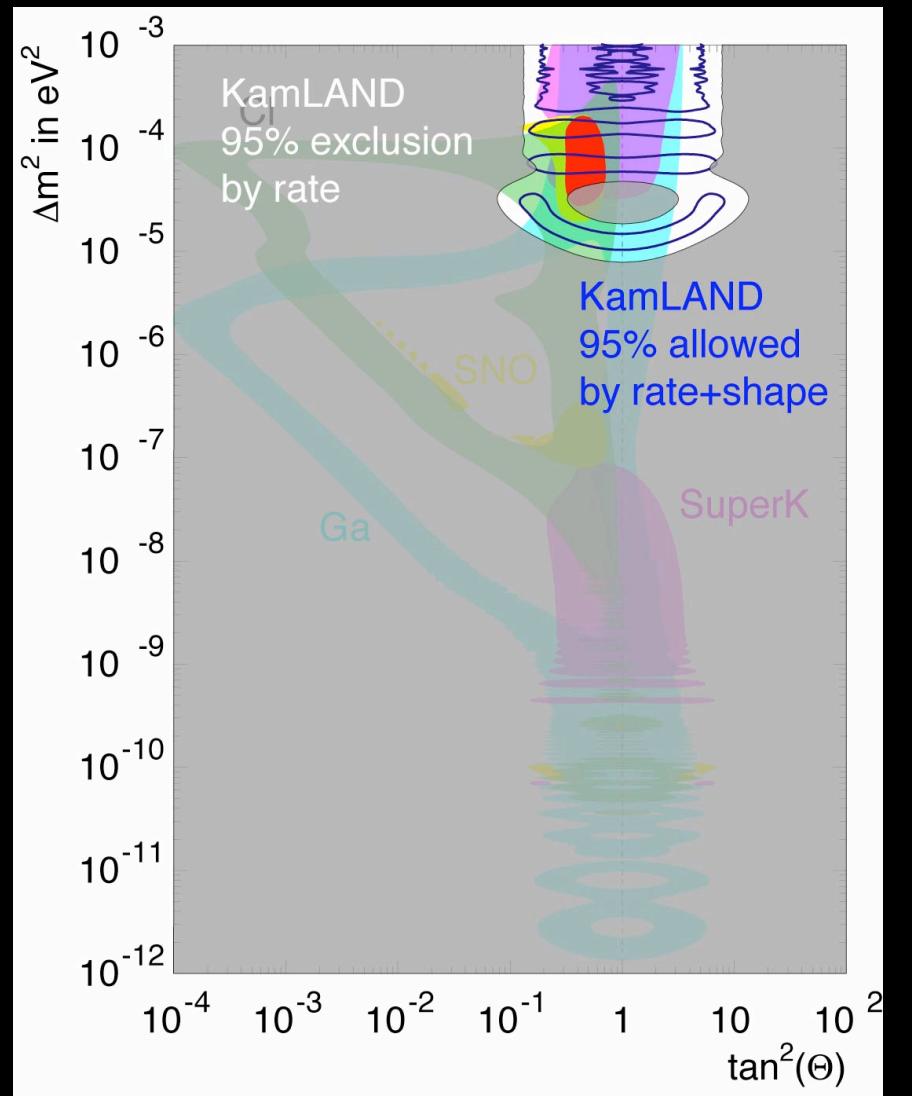
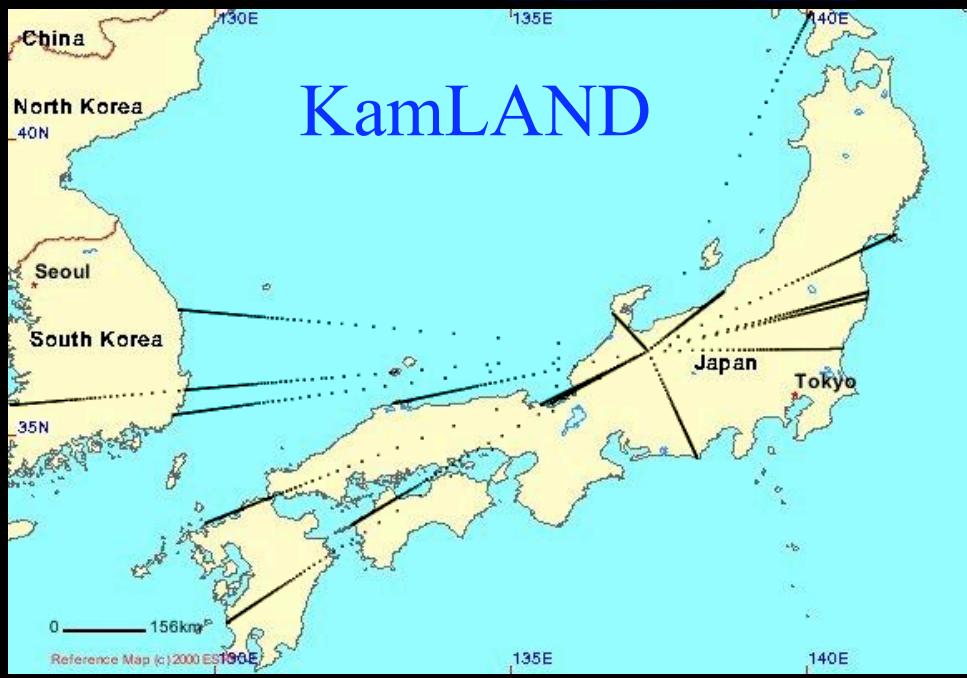
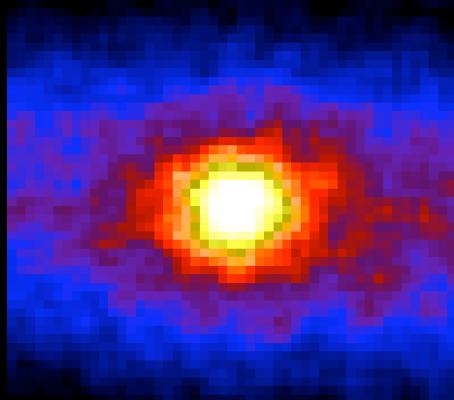
Super-Kamiokande



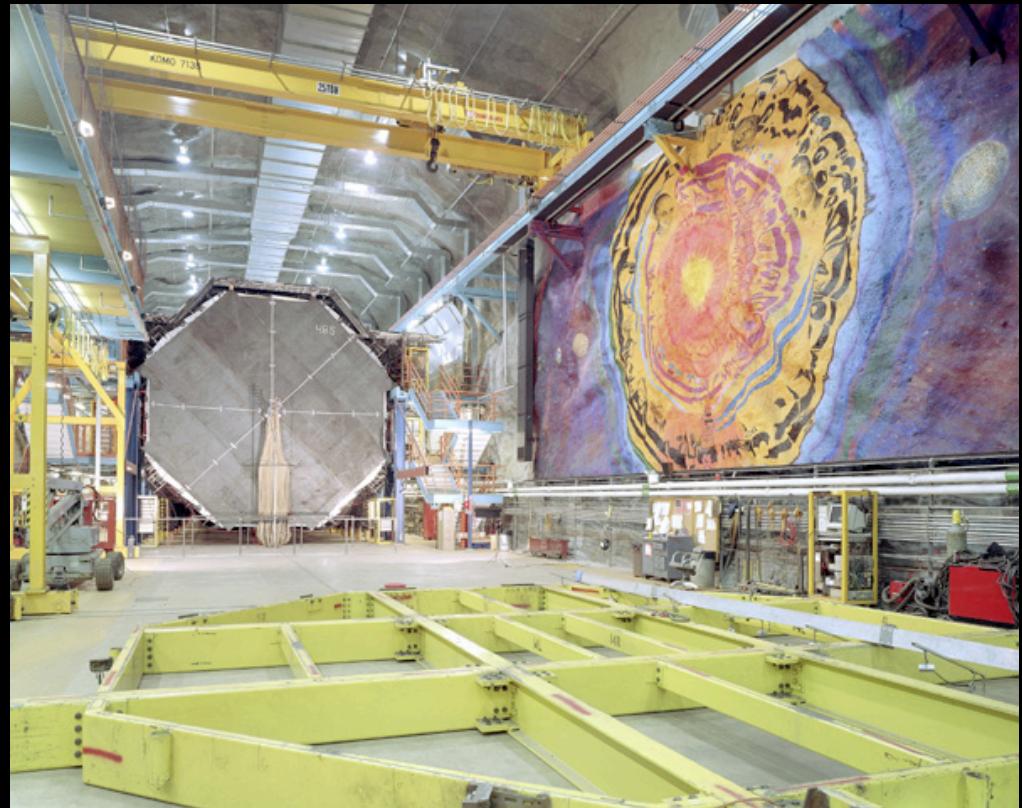
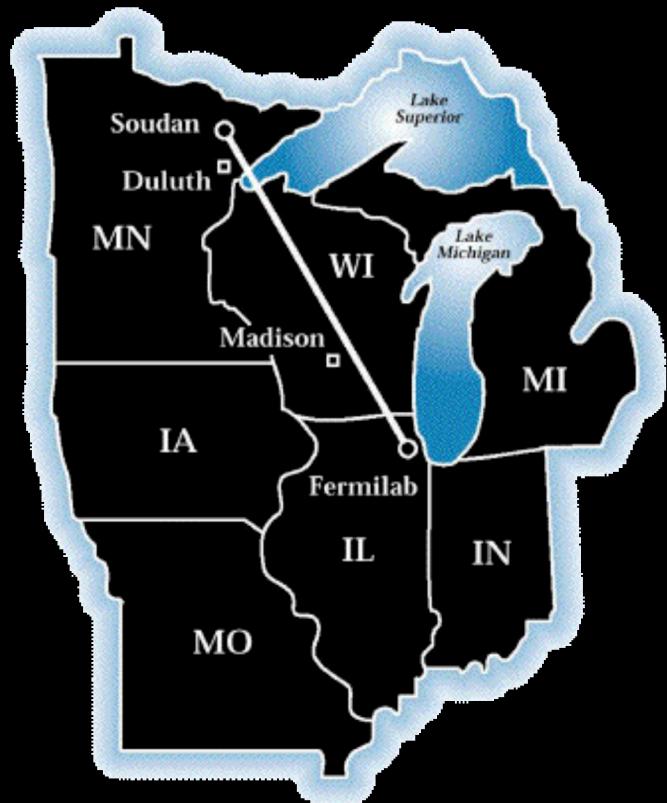
# Neutrino Mass



The Sun



# Neutrino Mass



# Matter / Antimatter

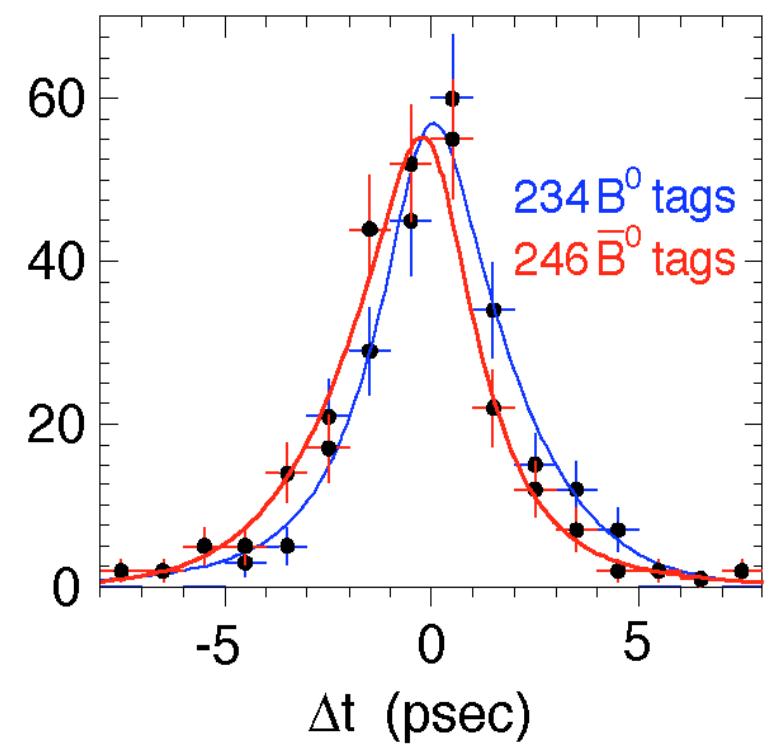
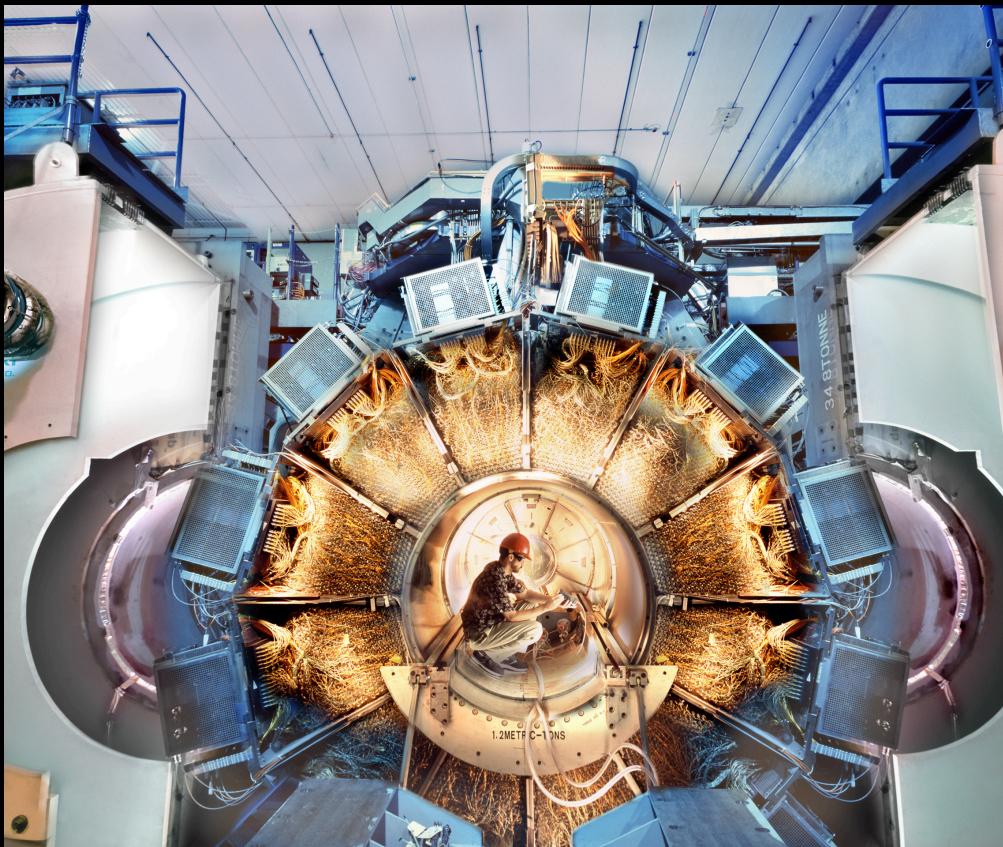


10,000,000,001

10,000,000,000

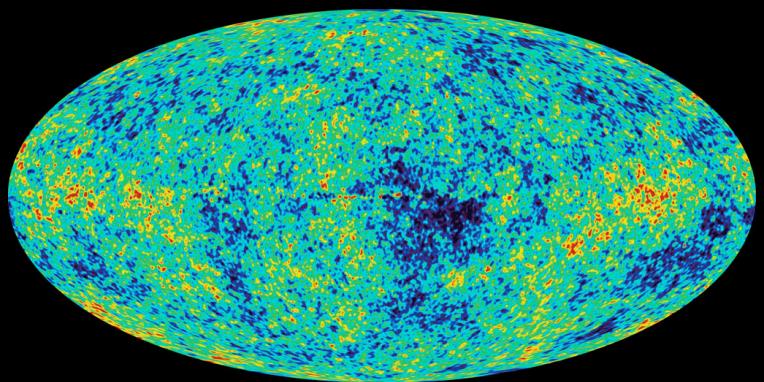
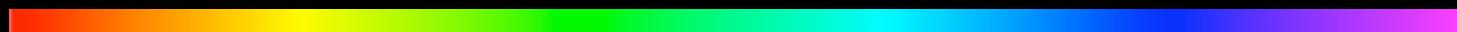
## Early Universe

# Matter / Antimatter

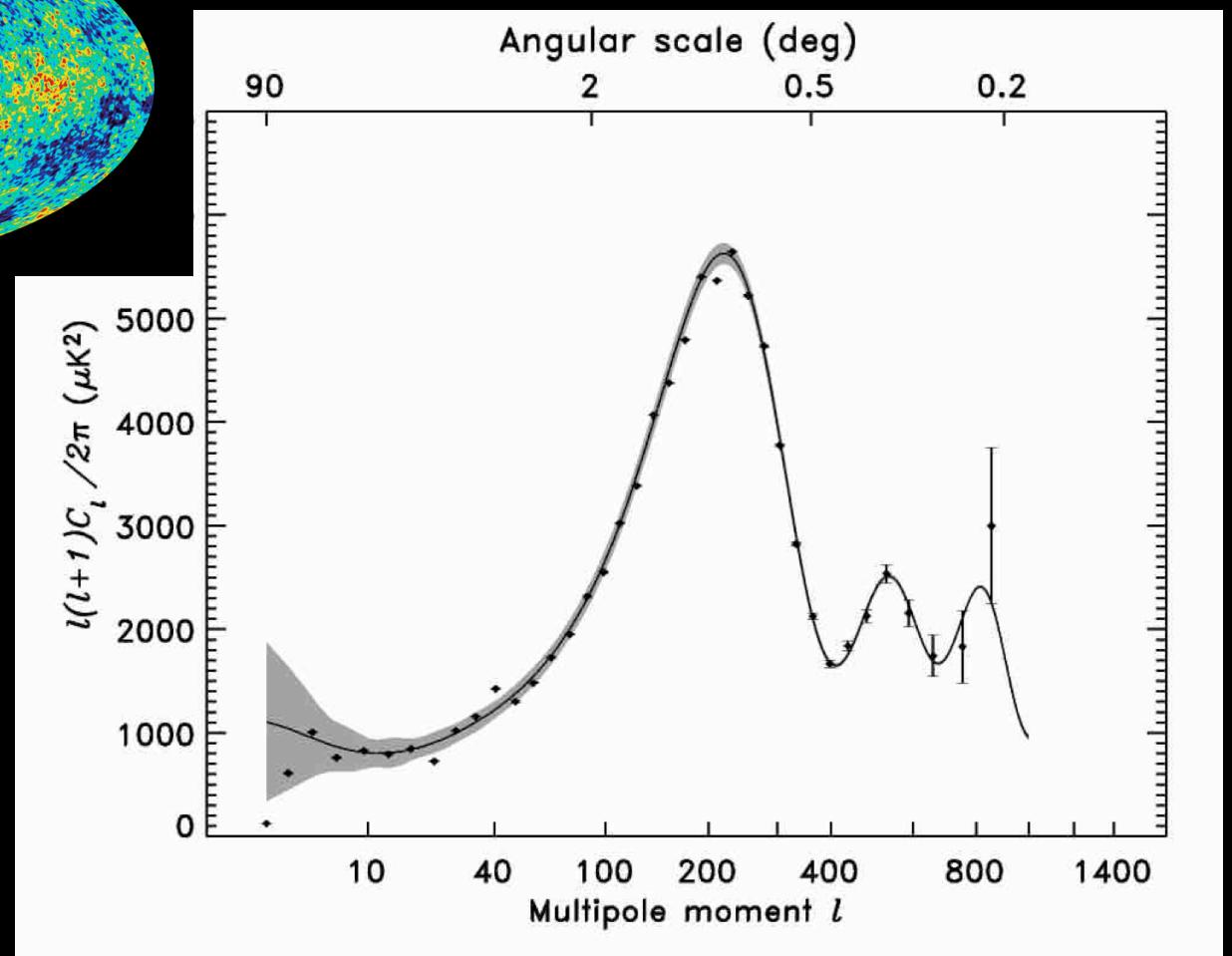


SLAC and KEK B Factories

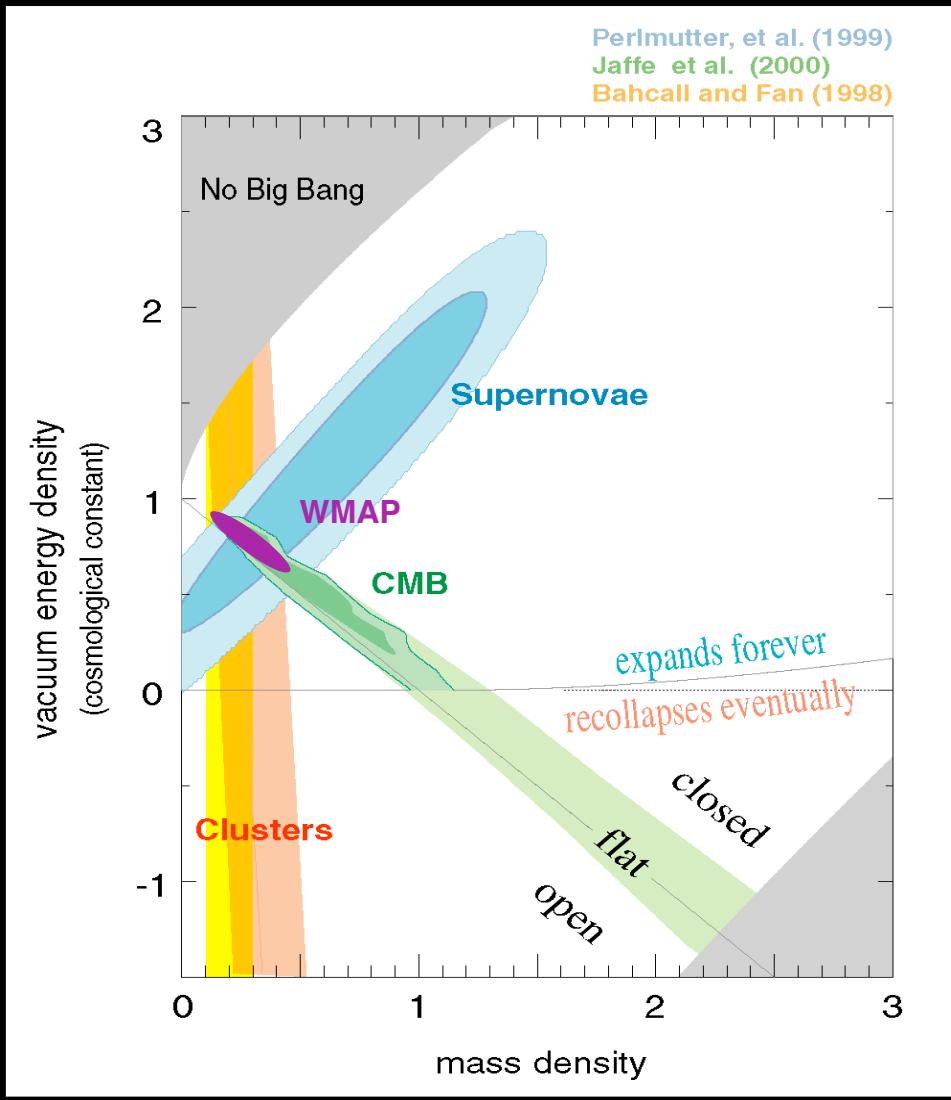
# Inflation



WMAP



# Dark Energy



# Dark Energy



- Vacuum energy?

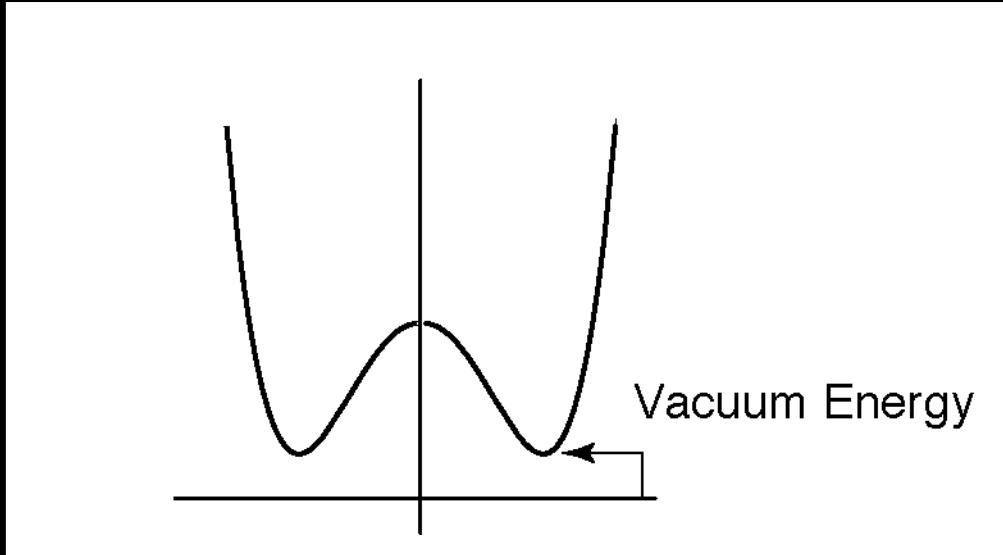
$$\langle T_{\mu\nu} \rangle \propto \eta_{\mu\nu}$$

- Negative pressure?

$$\eta_{\mu\nu} = \begin{pmatrix} 1 & & & \\ & -1 & & \\ & & -1 & \\ & & & -1 \end{pmatrix} \propto \begin{pmatrix} \rho & & & \\ & p & & \\ & & p & \\ & & & p \end{pmatrix}$$

# Dark Energy

- Scalar field ...



Inflation?

# Dark Energy



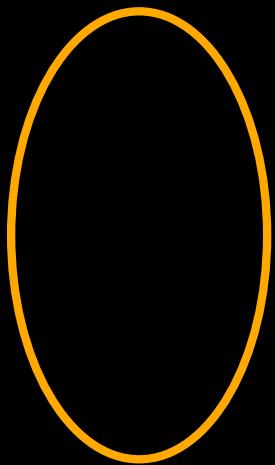
- Dark energy is renormalized:

$$\rho \sim M_{Pl}^4$$

Observed value:

$$\rho \sim ((\text{TeV})^2/M_{Pl})^4$$

- Off by a factor of  $10^{120}$  ...



*The worst prediction in physics!*

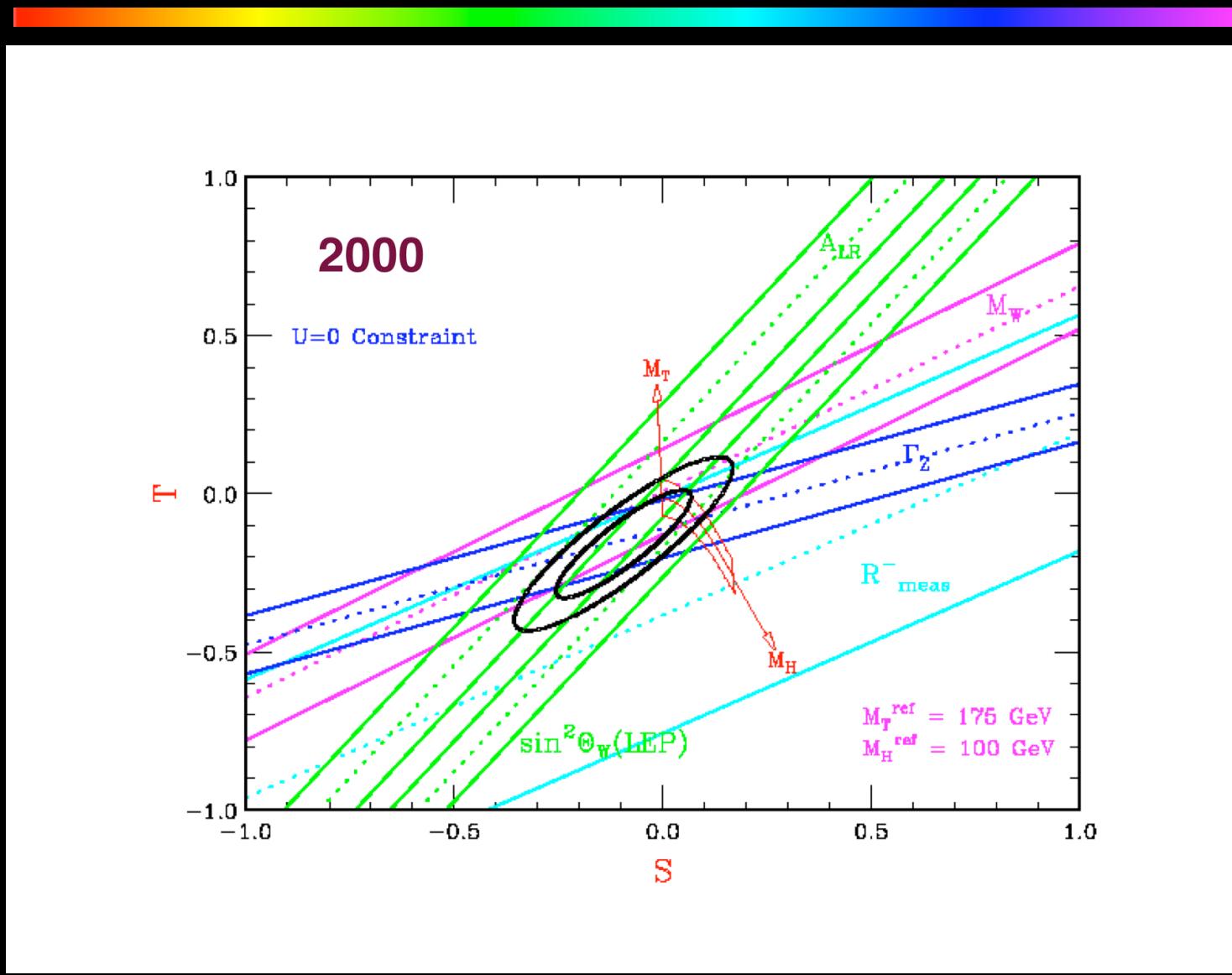
# Things to Come

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- Cracks are appearing in the edifice
  - No dark matter in Standard Model
  - No neutrino masses in Standard Model
  - Not enough CP violation in Standard Model
  - No inflaton in Standard Model
  - Dark energy ?



# Precision Measurements



# Precision Measurements

