Selected Topics in Elementary Particle Physics ("Haupt-Seminar")

Paola Avella, Veronika Chobanova, Luigi Li Gioi, Christian Kiesling,
Hans-Günther Moser, Martin Ritter, Pit Vanhoefer

Time: Do, 12 ct -14

Introduction: April 10, 1st seminar on April 24

Place: HS 537, Schellingstr. 4 / V

Alternative Seminar room
MPI für Physik, Föhringer Ring 6, Zi. 23

Subjects, Coaches

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Standard Model	MR, CK
Detectors	PA, HG
Accelerators	CK, MR
Higgs particle	PV
Tau decays	CK
Top physics	HG
CP Violation	LL, VC
Neutrinos	VC
Beyond the Standard Model	PV
SUSY	PV
Dark matter	MR
g-2	LL

Email Addresses of Coaches

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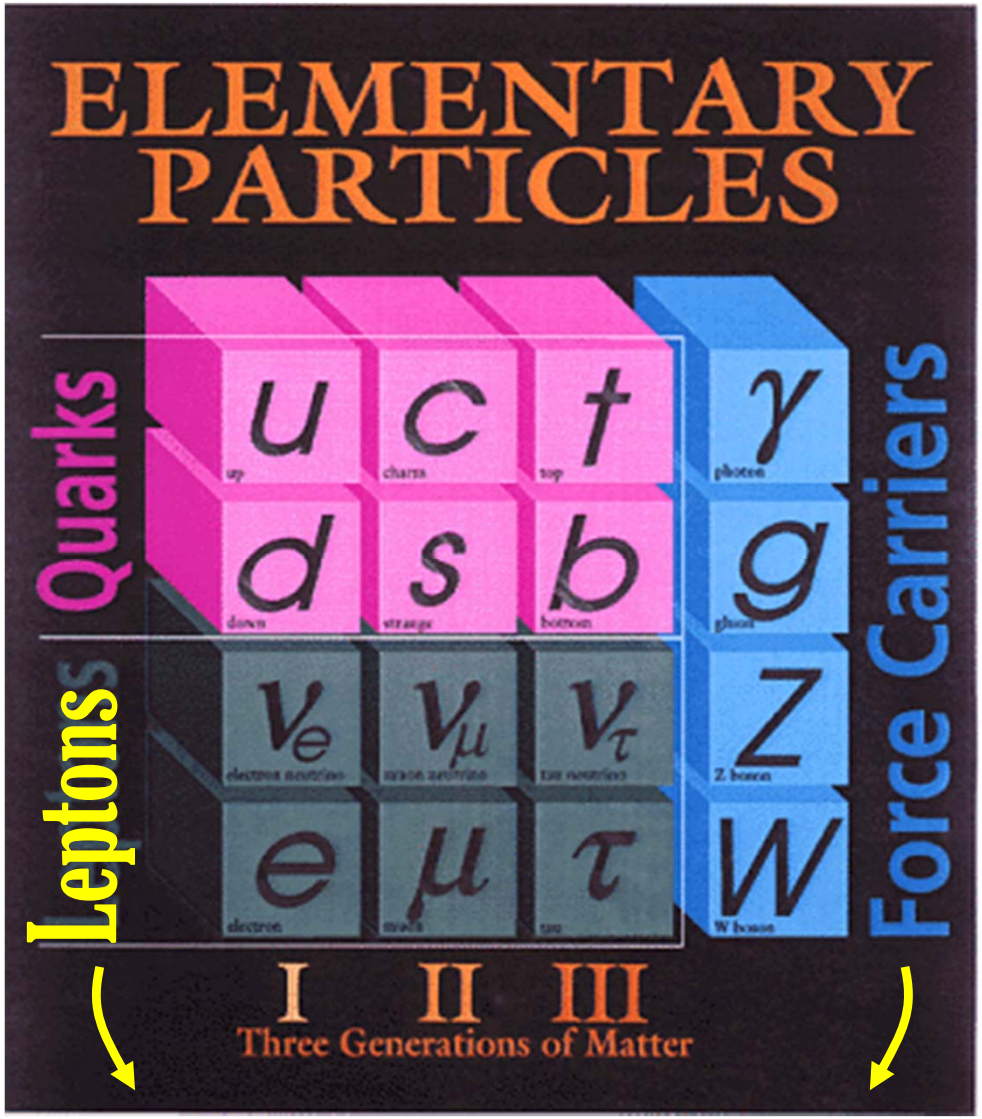
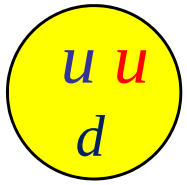
VC	Veronika Chobanova <veronika@mpp.mpg.de>
LL	Luigi Li Gioi <ligioi@mpp.mpg.de>
CK	Christian Kiesling <cmk@mpp.mpg.de>
HGM	Hans-Günther Moser <moser@mpp.mpg.de>
MR	Martin Ritter <ritter@mpp.mpg.de>
PV	Pit Vanhoefer <pvanhoef@mpp.mpg.de>

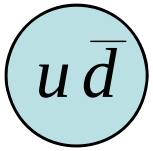
Standard Model of Particle Physics



electr. charge

+2/3				
-1/3				
0				
-1				



... , or 

...

electr. charge	Mass of particles (in GeV):			
0	0.005	1.4	175	0
0	0.006	0.3	4.5	0
0	>0	>0	>0	91
±1	0.0005	0.1	1.8	80

„particles“:
Spin 1/2
(fermions)

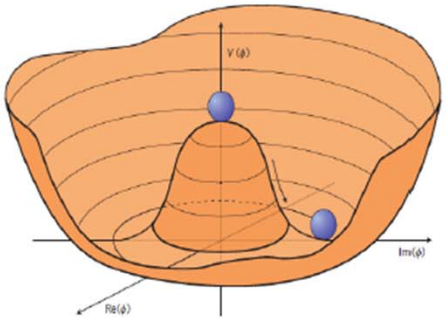
„fields“:
Spin 1
(bosons)

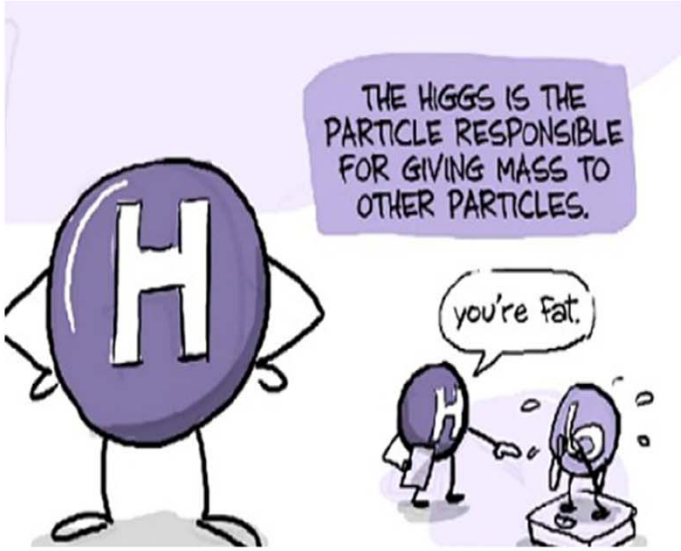
last missing particle found: *H*

the Higgs (126 GeV, Spin 0)

It‘s Finally There …

Higgs

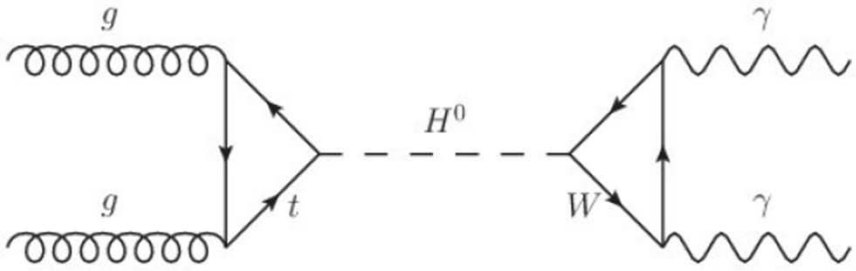


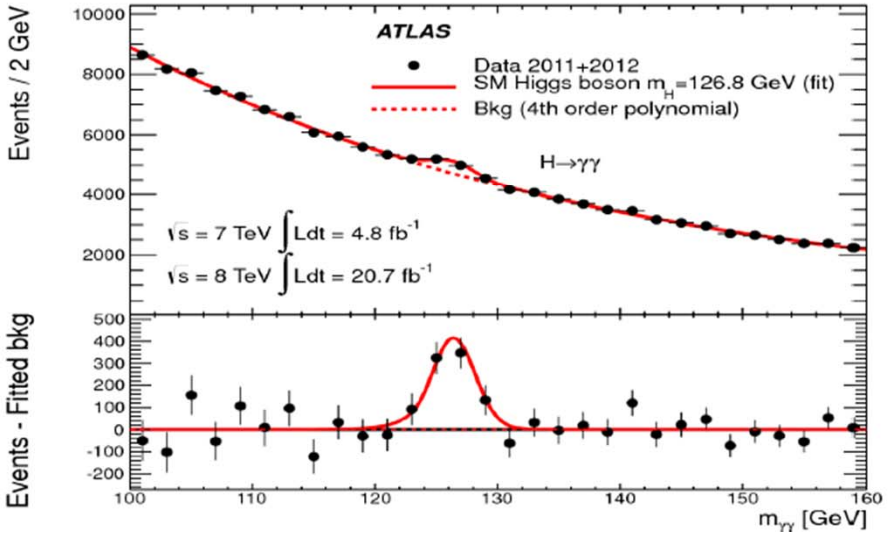


Scalar field with non-zero vev:
EW Symmetry breaking
↔ massive particles

Discovery of a Higgs particle
- last missing piece of SM
- Production mechanisms
- Higgs decays

Consequences & Outlook

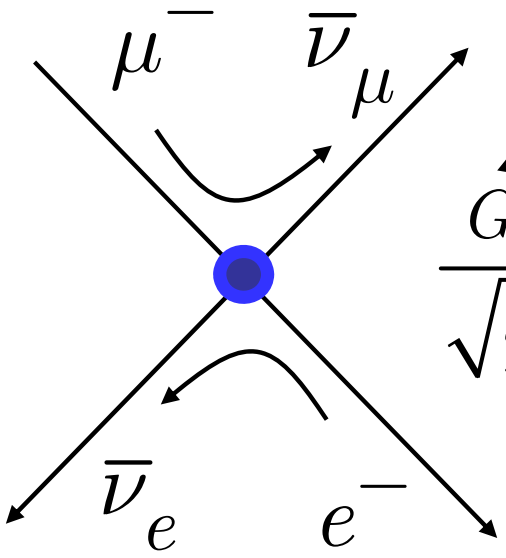




Transformations between Fermions

Changing “flavor” by **Universal Weak Interactions**

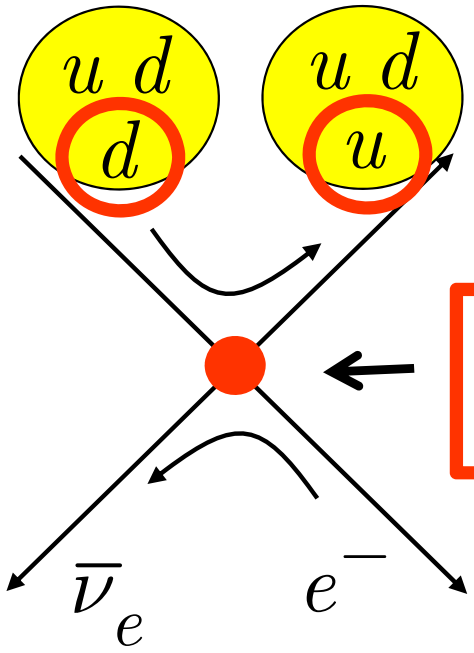
$$\mu^- \rightarrow \nu_\mu e^- \bar{\nu}_e$$



Fermi’s constant

$$\frac{G}{\sqrt{2}} = \frac{\alpha}{8\left(\sin\theta_W M_W\right)^2}$$

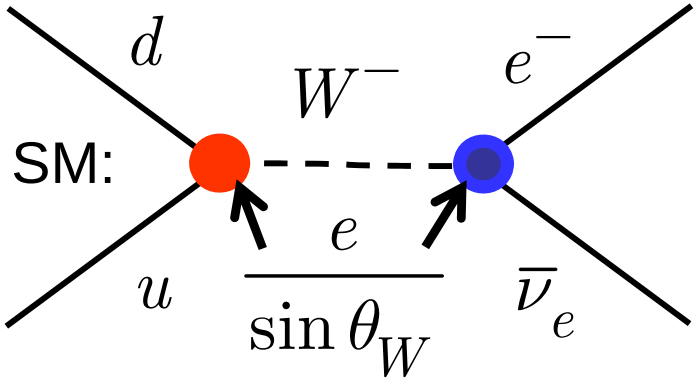
$$n \rightarrow p e^- \bar{\nu}_e$$



< 1

(Cabibbo-angle)

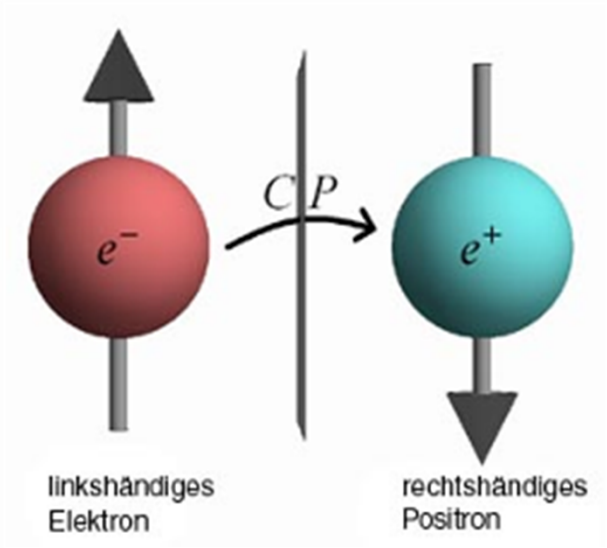
Electroweak Unification within Standard Model (SM):
Weak coupling basically same as for electromagnetism



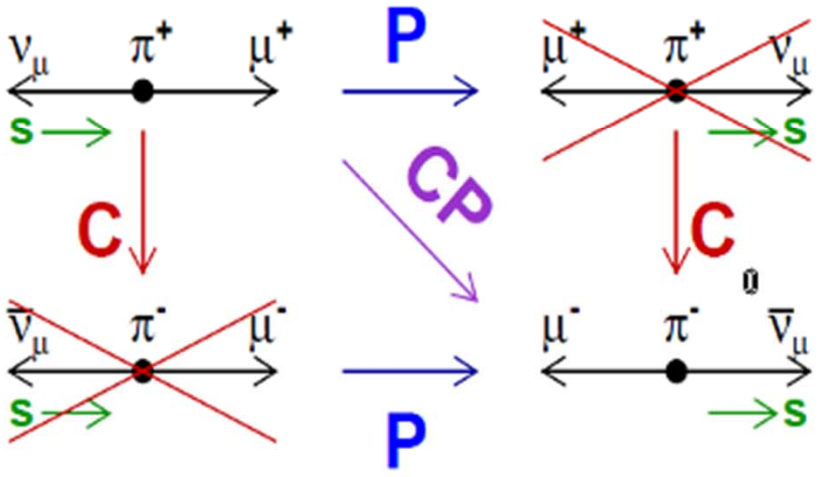
„weak“ because of propagator

CP Violation

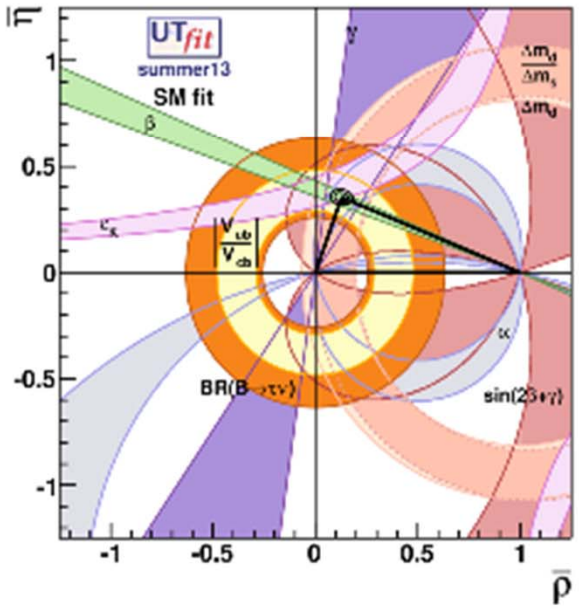
- Charge-parity (*CP*) transformation flips sign of charge and handedness of particle
- *CP* violation (*CPV*) required to explain matter dominance in the Universe today
- *C* and *P* maximally violated in the weak interaction
- *CPV* first observed in kaon decays
- *CPV* in the SM arises from a non-zero complex phase in the CKM matrix
- CKM matrix describes relations between mass and flavour eigenstates of quarks

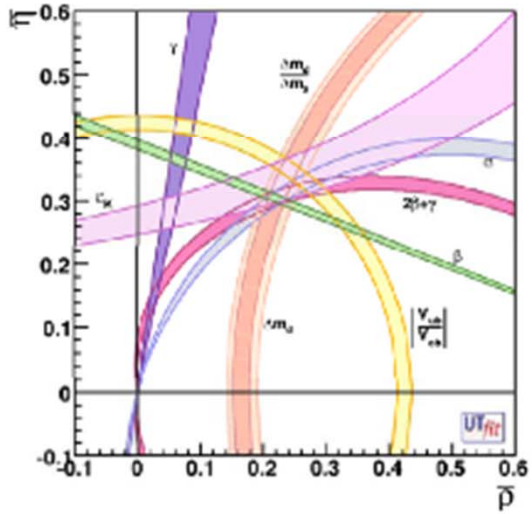


$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_{weak} = \mathbf{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{mass} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{mass}$$



CP violation: measurements

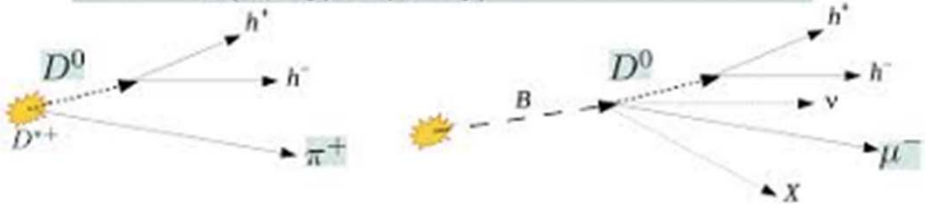


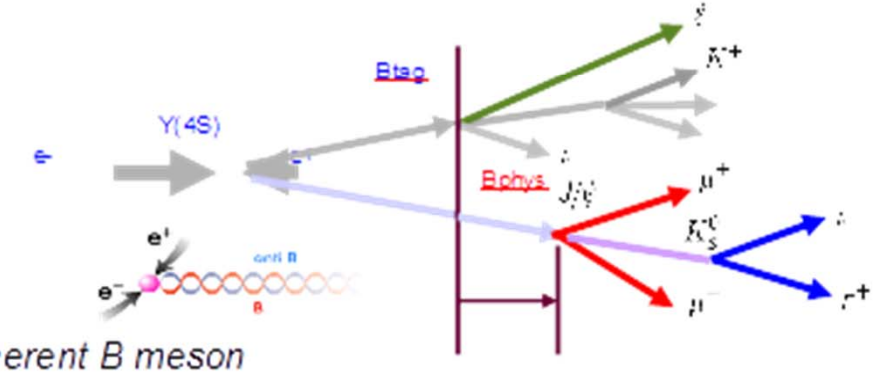


Search of New physics
in the CP sector

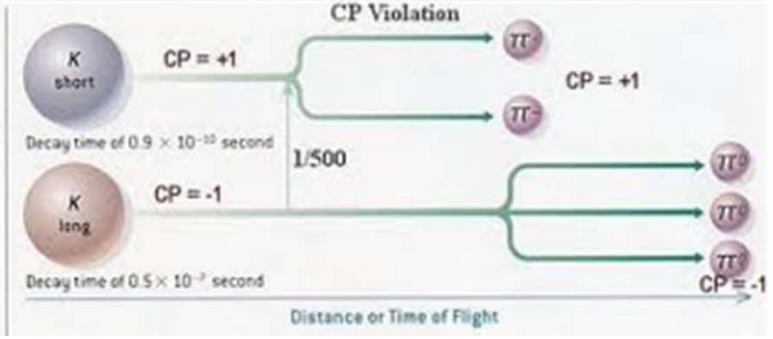
CPV measurement in B, D and K mesons

$$A(f) = \frac{N(D^0 \to f) - N(\bar{D}^0 \to f)}{N(D^0 \to f) + N(\bar{D}^0 \to f)}, \quad f = K^+K^-, \pi^+\pi^-$$





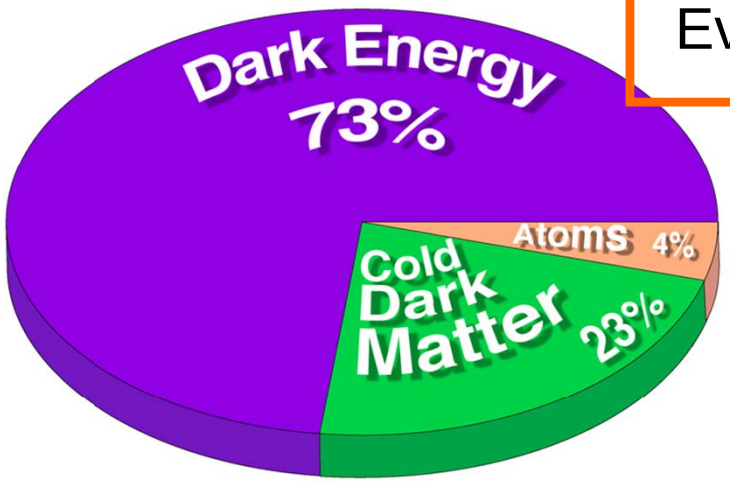
Coherent B meson pair production



Why go Beyond the SM?

The Standard Model SU_3 x SU_2 x U_1 (SM) describes all data so far

yet: cannot be the correct theory, SM only a „low energy“ approximation



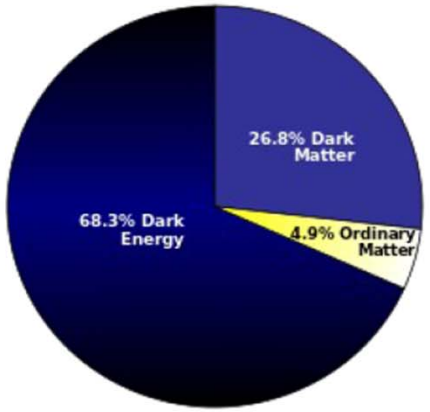
Evidence for Physics beyond the Standard Model:

- Unification of forces incomplete:
  Gravitation is not included
- „Stability“ of the Higgs mass unexplained
- Neutrinos are massive (Dirac, Majorana?)
- Baryon Asymmetry in the Universe is much too large (by 10 orders of magnitude)
- Dark Matter exists
  (only 4% of the Universe accounted for by SM)

need
very high energy
(LHC) or
very high precision
(SuperB factories)

BSM: A Necessity

Beyond SM



SM describes only 4% of the observed Universe:

Dark Matter ?, Dark Energy ??

CP Violation ?, Neutrino masses ?

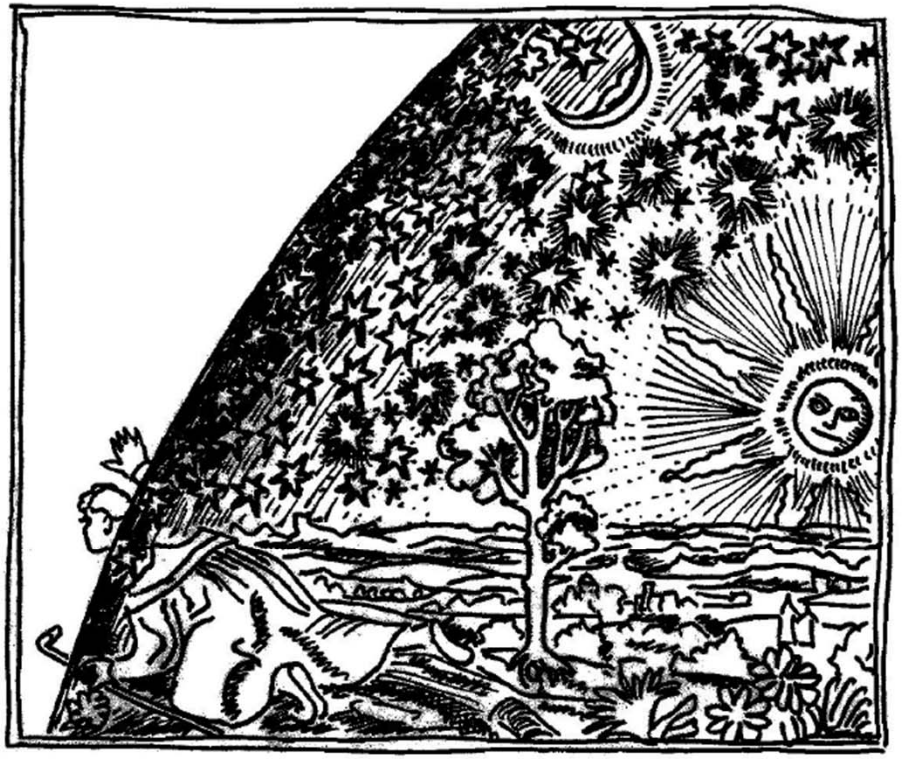
Higher energies:
→ new particles/phenomena?
SUSY, Compositnes, ...,

GUT, gravity, extra-dimensions, ...

Strong CP problem ↔ Axions

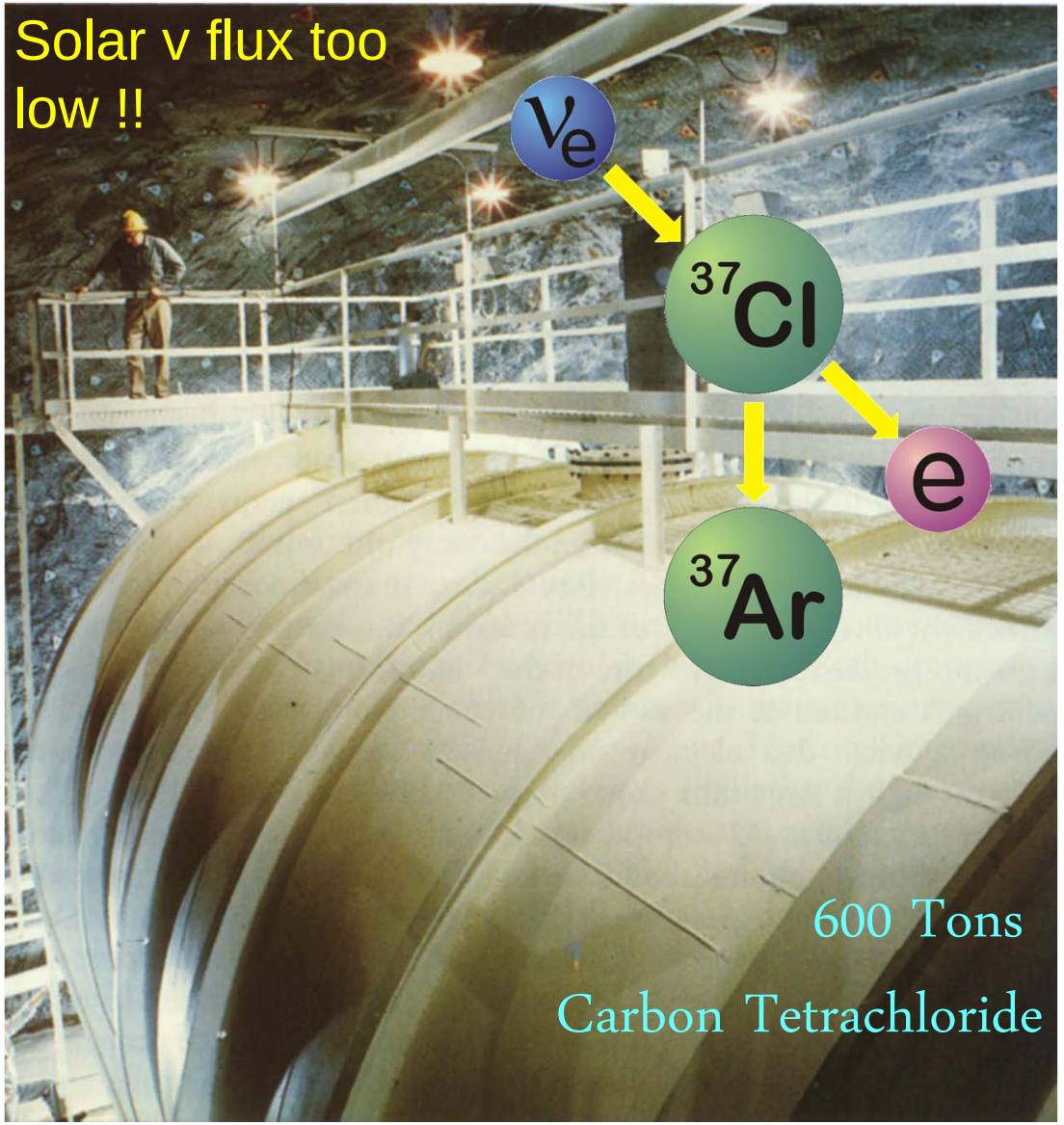
Strings,...

Many Ideas!
Experiment must determine
the true nature of nature



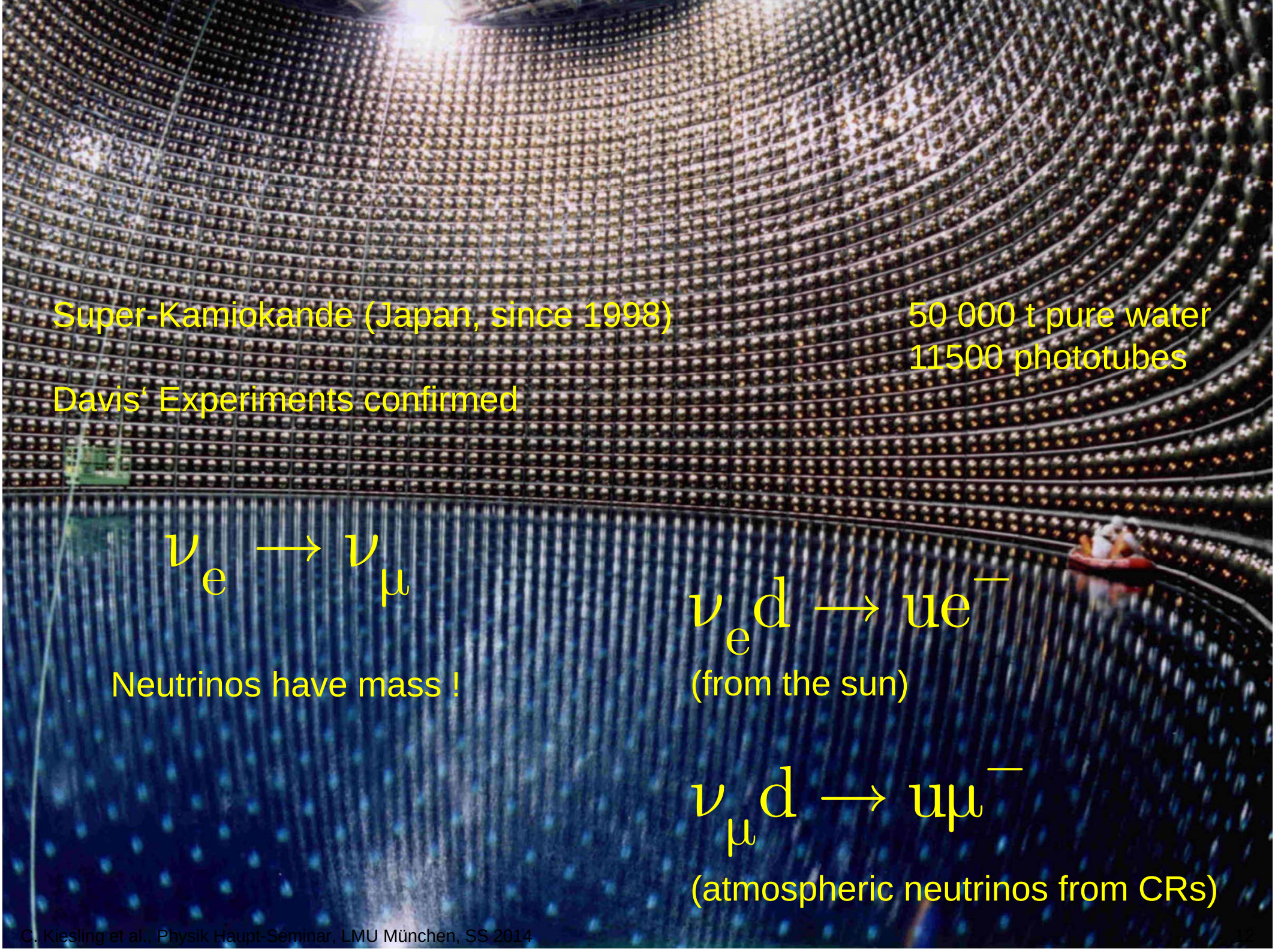
Is there anything beyond the Standard Model?

The Solar Neutrino Problem



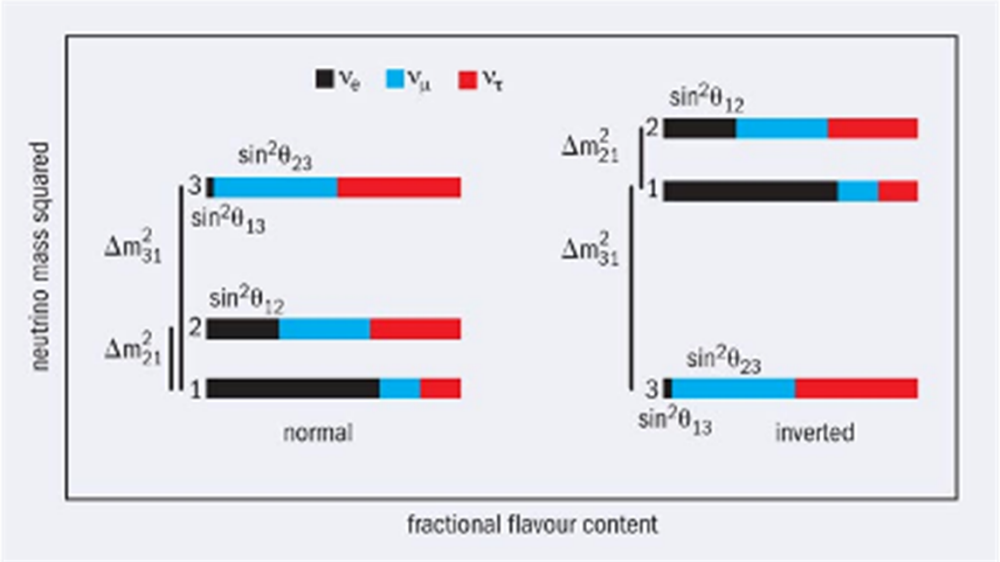
Ray Davis Jr.
Nobel-Prize 2002

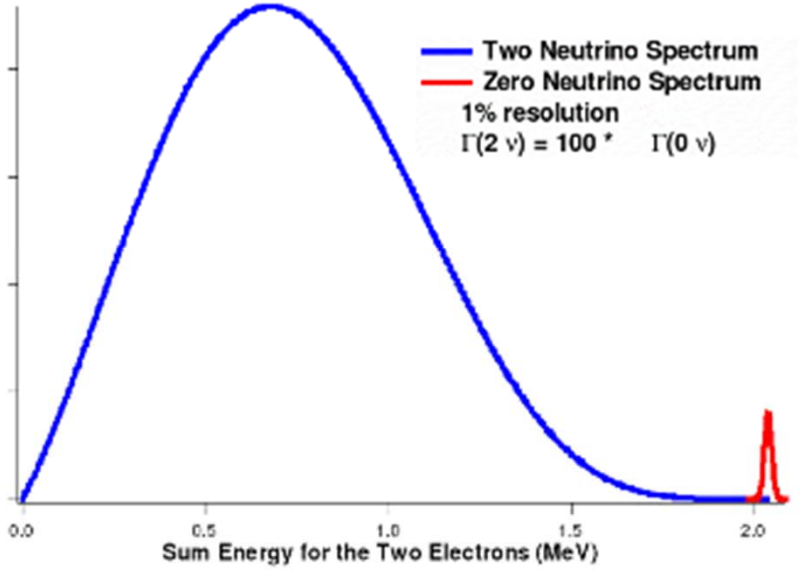
Homestake Neutrino Observatory (since 1967)

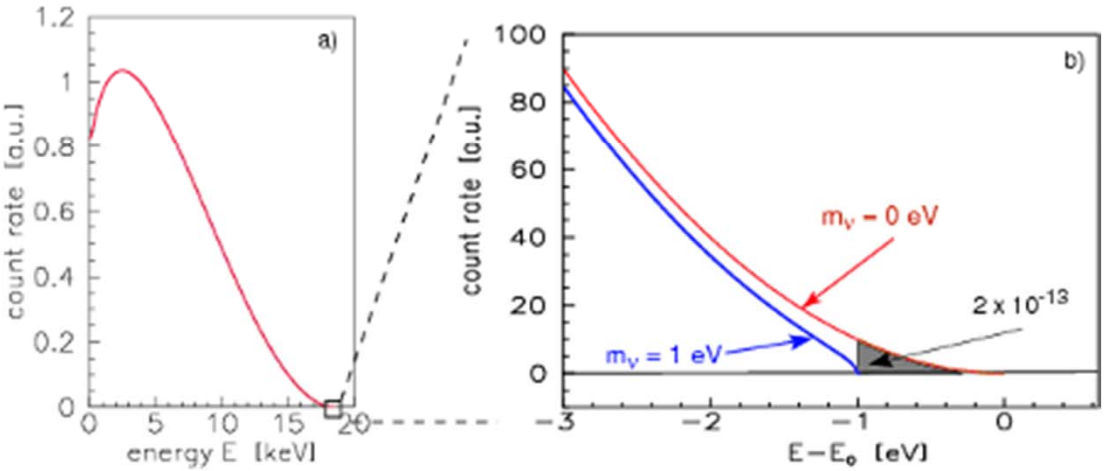

Super-Kamiokande (Japan, since 1998)
50 000 t pure water
11500 phototubes
Davis‘ Experiments confirmed
$\nu_e \longrightarrow \nu_\mu$
Neutrinos have mass !
$\nu_e d \longrightarrow u e^-$
(from the sun)
$\nu_\mu d \longrightarrow u \mu^-$
(atmospheric neutrinos from CRs)

Neutrinos

- In the SM, neutrinos massless
- Experiments show that neutrinos mix, so they must have mass
- Normal or inverted mass hierarchy?
- Is the neutrino its own antiparticle?
  → Neutrinoless double beta decay





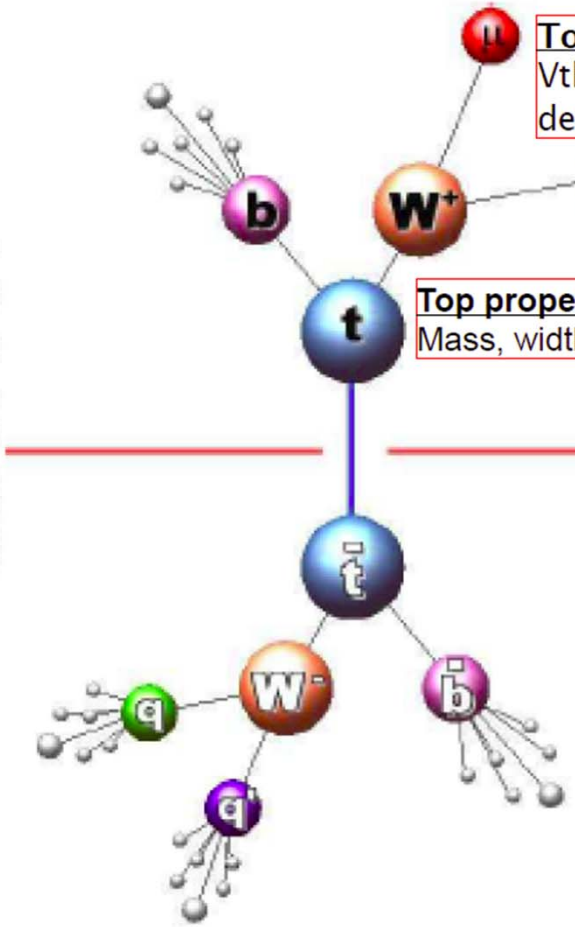


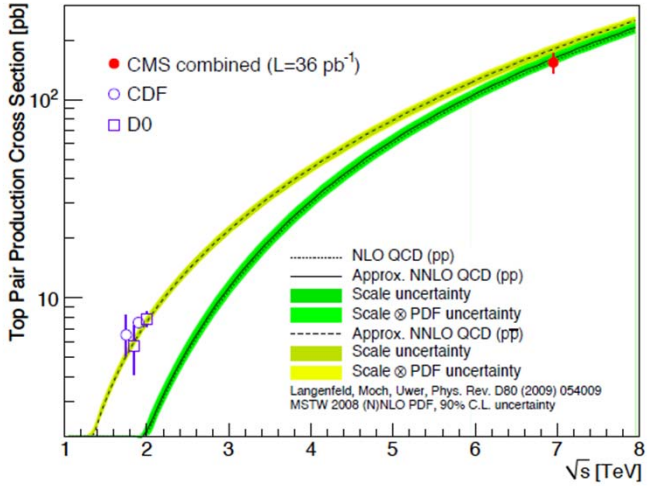
Top Quark Physics

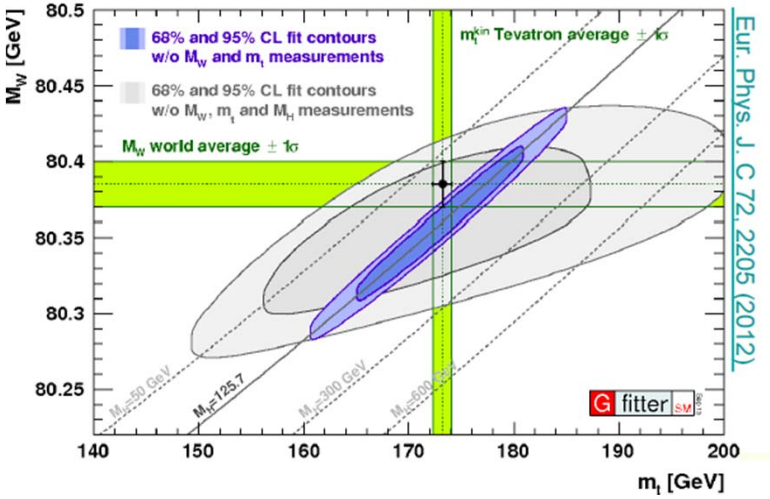
- Need for 3 generations (CP violation, Kobayashi-Maskawa 1973)

- Top quark properties
  - production
  - decay
  - mass, width,….

- Early searches and hints
- Predictions from EW precision measurements
- Discovery at Fermilab, 1995
- Top physics at LHC
- Why is top still of interest?

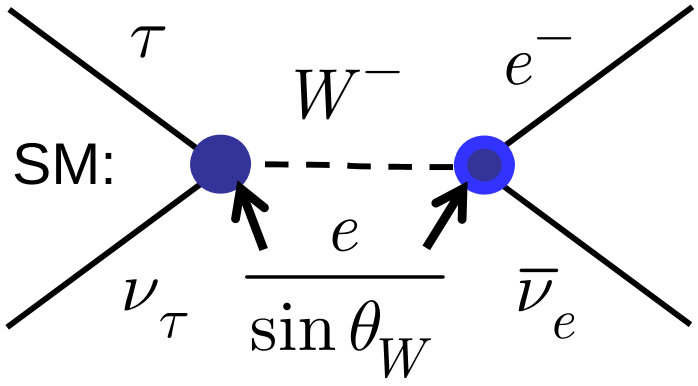




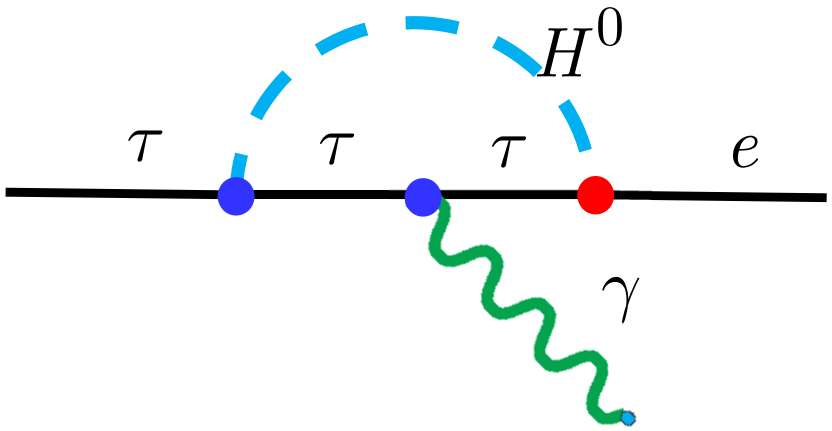


New Physics at the Loop Level ….

Rare Decays of τ leptons:



„penguins“



Principle:

Deviation of observable from the SM prediction signals NP

virtual particles in the loop reveal their existence

$\rightarrow \Lambda_{NP}$

Can reach very large scales !!

Hot topic: rare decays of tau leptons:

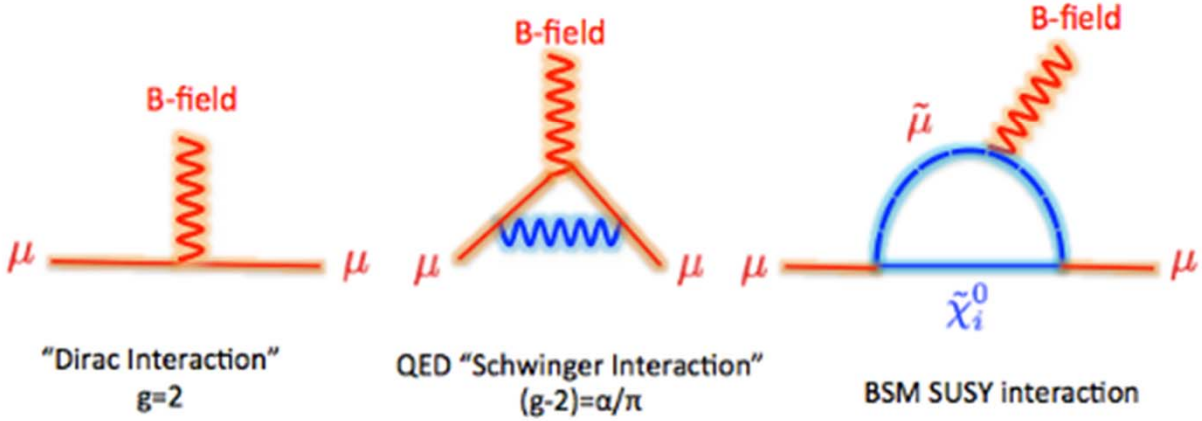
$$\left.\begin{array}{l}\tau \rightarrow \mu\gamma \\ \tau \rightarrow \mu\mu\mu \\ \tau \rightarrow \mu h^0\end{array}\right\}$$

NP could make these decays possible

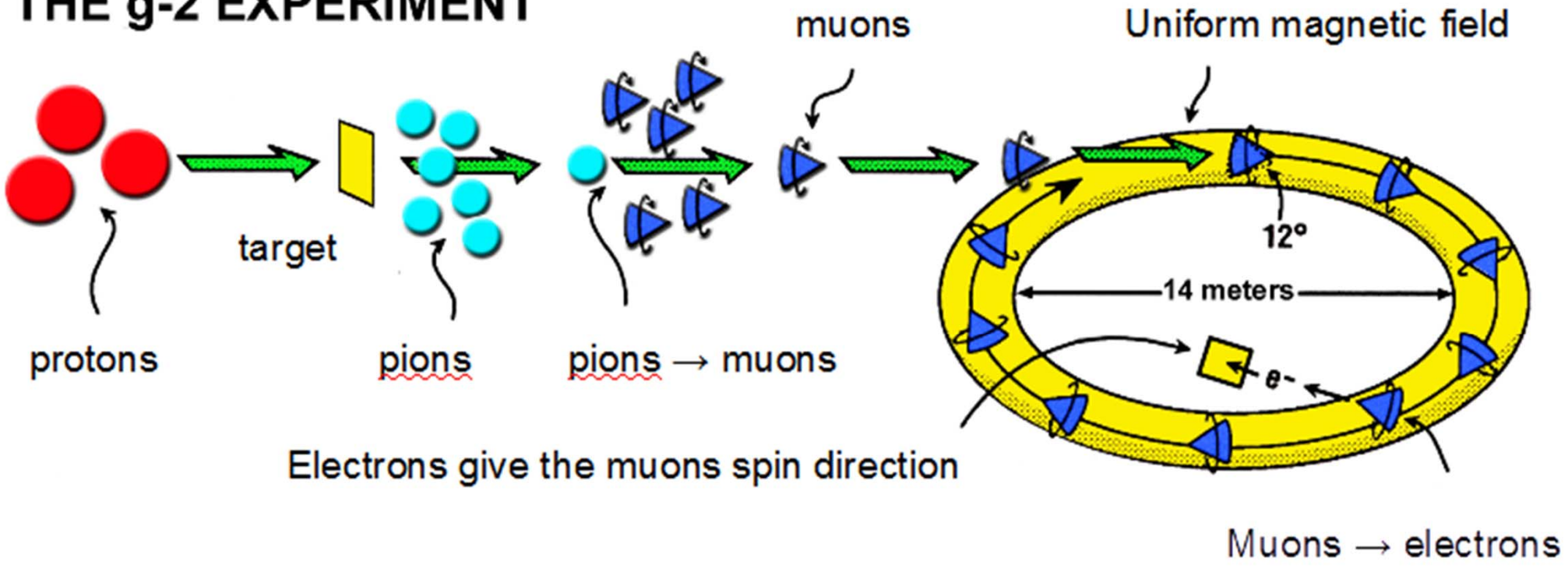
need precision (statistics) to challenge the SM

Muon magnetic moment

- g-2 measurement is sensitive to new physics
- Some tension of the last result with the SM Phys. Rev. Lett. 92, 161802 (2004)
- New experiment under construction http://muon-g-2.fnal.gov/



LIFE OF A MUON: THE g-2 EXPERIMENT

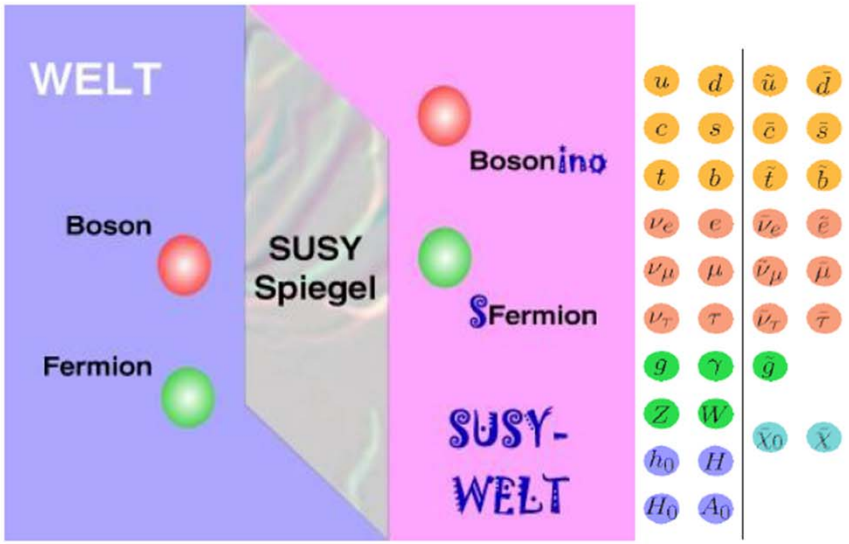


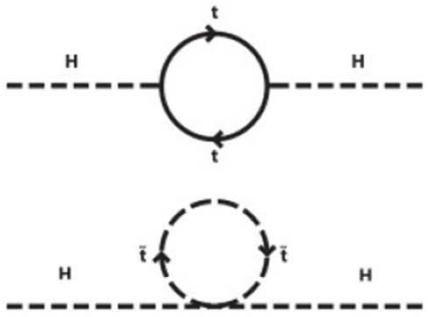
BSM: Super Symmetry

SUSY

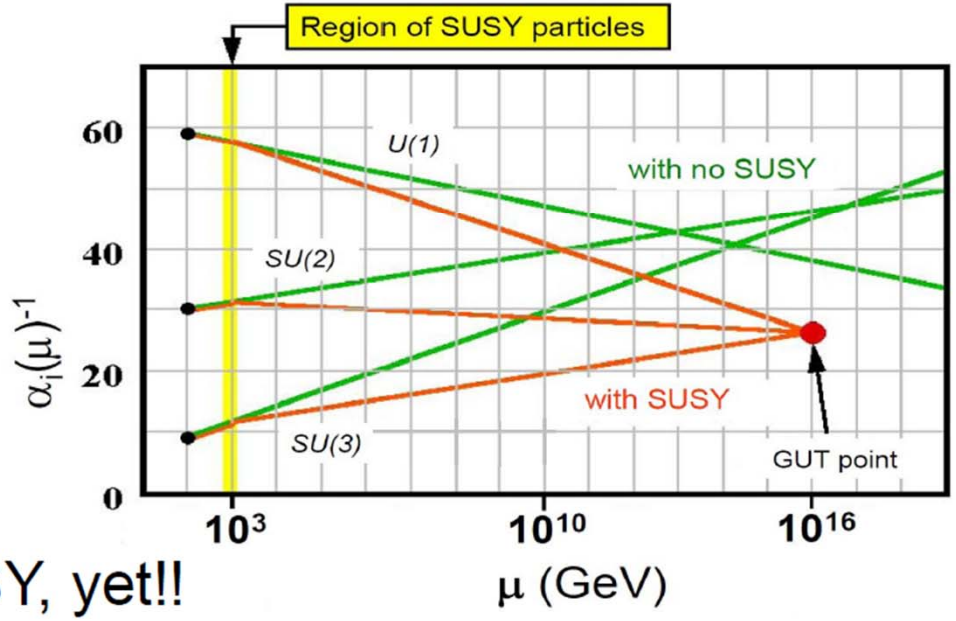
Attractive extension of the SM
Relates: fermions ↔ bosons

-solves fine tuning problem
(why is the Higgs so light?)



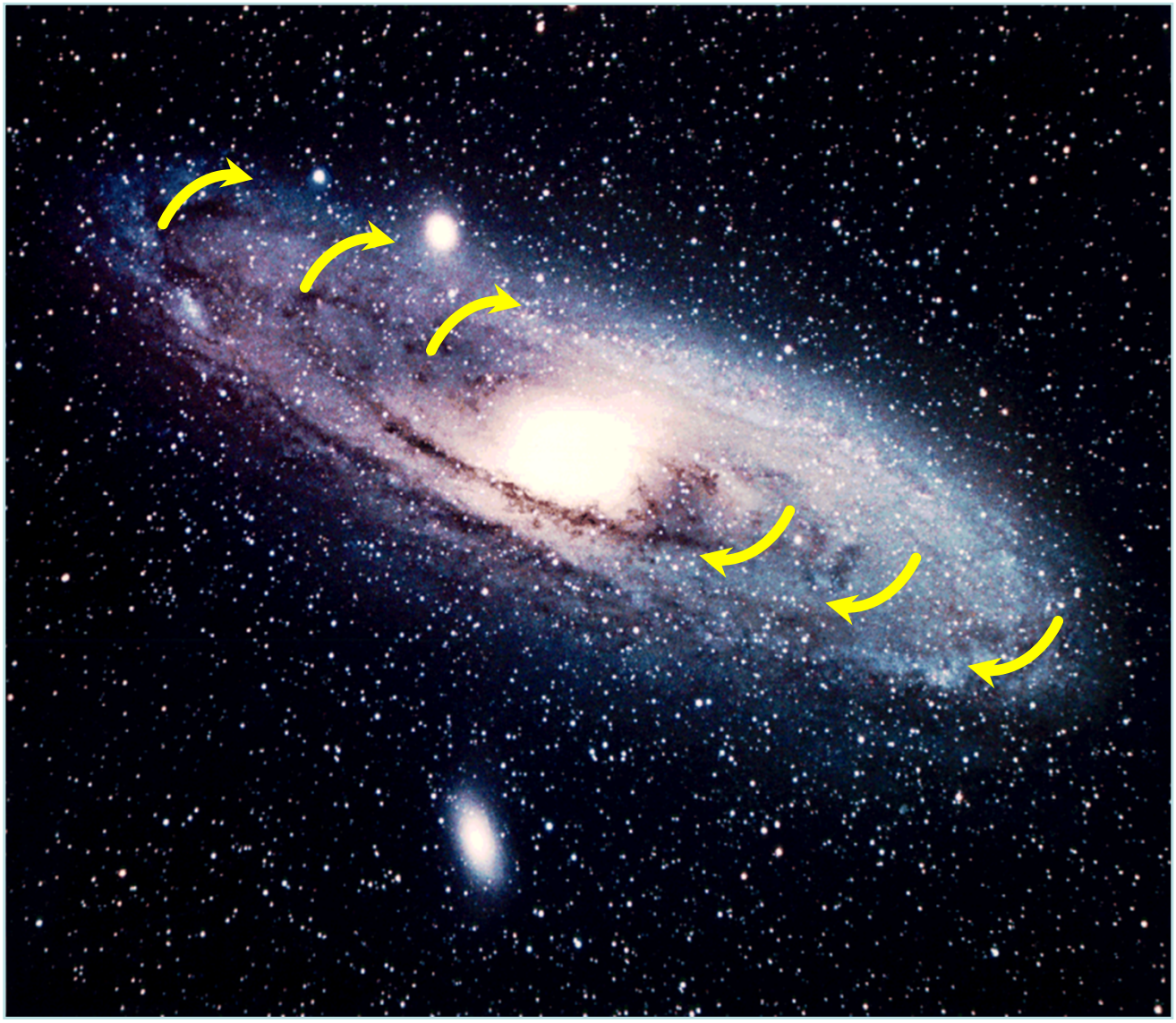


-allows for GUT



BUT: no exp. hint for SUSY, yet!!

Dark Matter in Galaxies



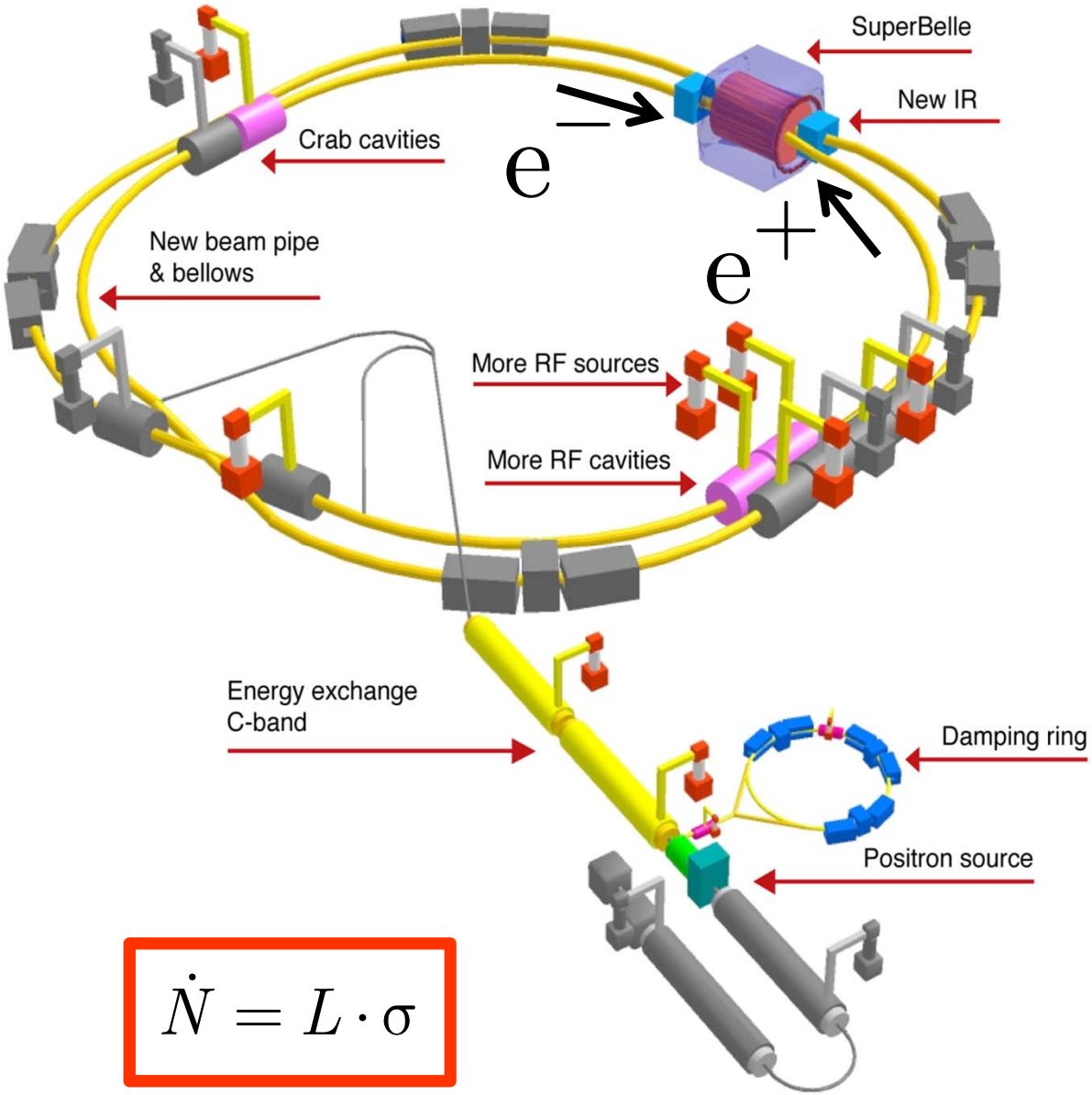
Rotational speed
of luminous matter about
200 km/sec, independent
of the radial distance

Galaktic plane is embedded
in a “Halo” of non-luminous
(„dark“) matter

Andromeda-Nebula,
distance about 2 Mio Ly

→ DM Searches

Accelerators



$$\dot{N} = L \cdot \sigma$$

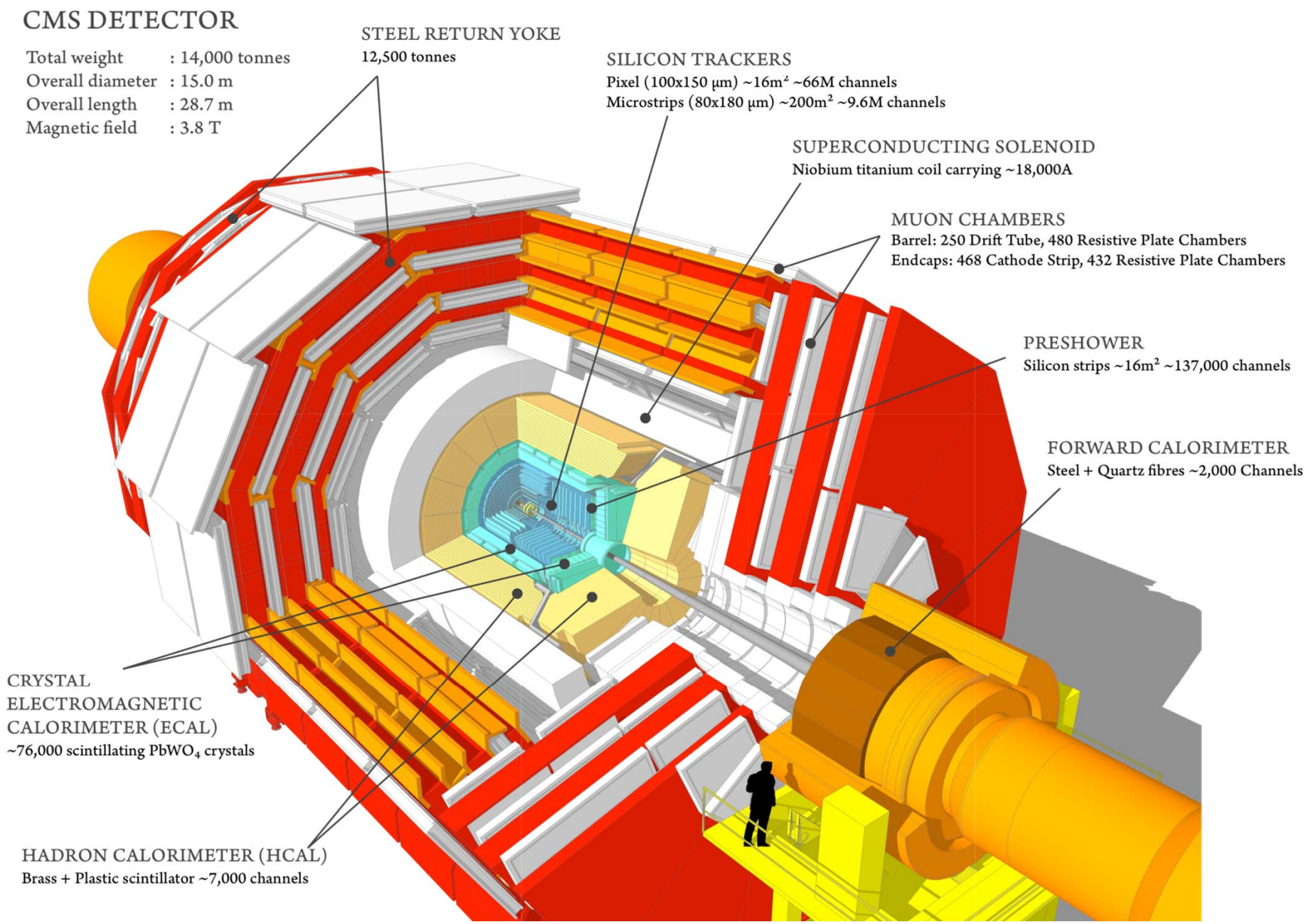
Typical accelerator complex ("collider"):

- Beam particle guns
- Pre-accelerator (linac)
- Injection system
- Magnetic guide field
- Final focus, collision point

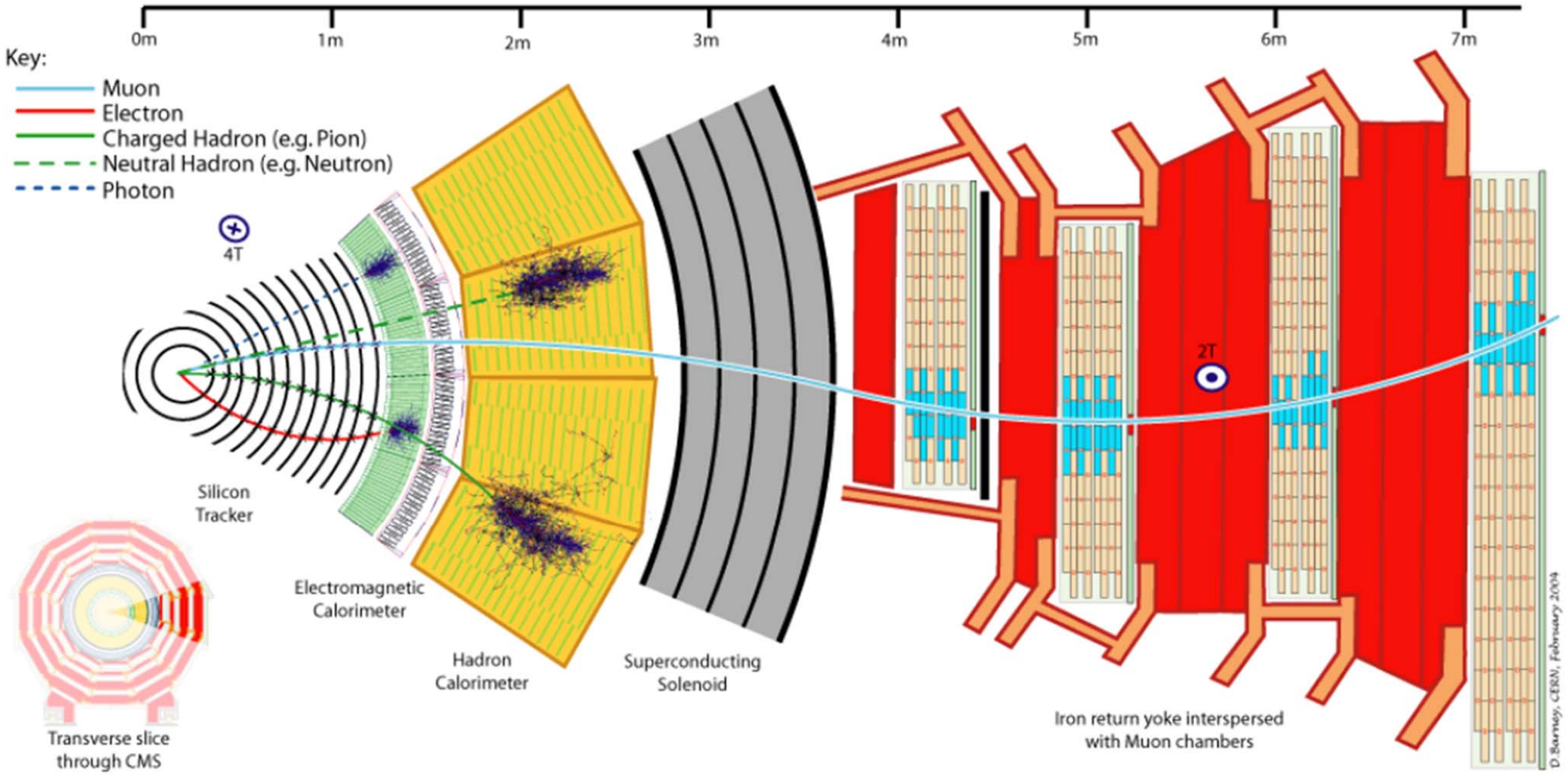
All important parameter: Luminosity

$$L = \frac{N_1 \cdot N_2}{4\pi\sigma_x\sigma_y}$$

HEP Detector Systems



System cross section



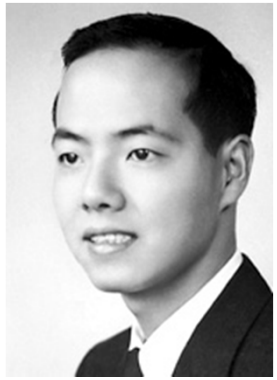
Dates for the Seminar

	PA	VC	CK	LL	HGM	MR	PV
10. April	x	x	x	x	x	x	x
24. April		x	x	x	x	x	x
8. May	x	x	x	x	x		x
15. May	x	x		x			x
22. May	x		x	x	x	x	x
5. June	x		x		x	x	x
12. June	x	x	x	x		x	
26. June	x	x					
3. July	x				x	x	
10. July	x	x		x	x	x	

x = coach present

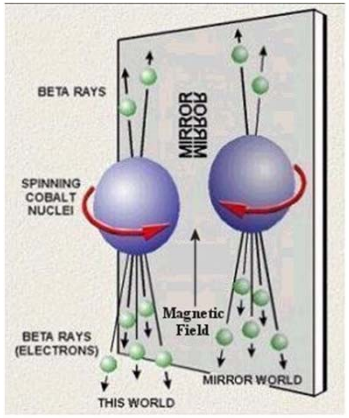
Backup

Surprising Discoveries in Weak Interactions of Quarks



T.D. Lee

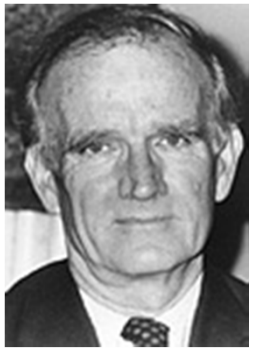
C.N. Yang



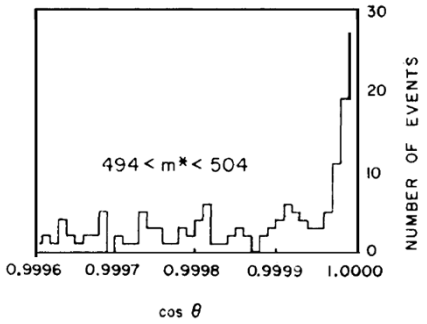
P violated maximally in weak interactions

1957

J. Cronin



V. Fitch

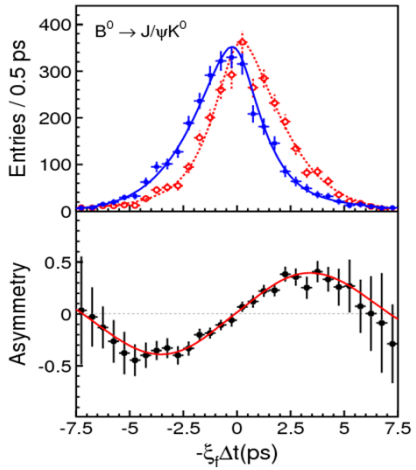


Small CP violation in neutral K system

1980

M. Kobayashi

T. Maskawa



O(1) CP violation and 3 generations of quarks

2008