DE LA RECHERCHE À L'INDUSTRIE

cea

EUROPEAN STRATEGY IN PARTICLE PHYSICS

Philippe CHOMAZ

www.cea.fr

Irfu

EUROPEAN STRATEGY

2102 Preparation of the French proposals

- **April 2012: IN2P3-Irfu prospective**

2012-2013 European process lead by CERN Council

- **Organization**
  - Bottom-up: ESPG ES Preparatory Group
  - Top-Down: ESG European Strategy Group

- **Steps**
  - September 2012: Open symposium, Kracow
  - December 2012; ES Briefing Book by ESPG
  - January 2013: ESG meeting, Erice
  - March 2013: Proposal of the strategy by ESG, CERN
  - May 2013: Unanimous adoption by Council, Brussels

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  - ➔ June 2014: Cern Medium Term Plan adopted

2014 Coherence with international priorities

- **May 2014: American strategy P5**
- **Coherence with Asia projects** (Japan, China, Corea, India,…)

- I -

WHERE DO WE STAND ?

STANDARD MODEL OF MICROSCOPIC WORLD NOW COMPETE

STANDARD MODEL OF PARTICLE PHYSICS

A coherent picture of the universe at small scale

STANDARD MODEL

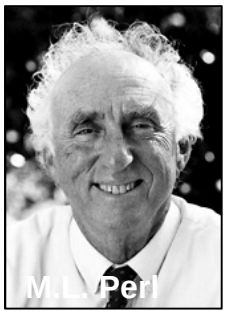
A coherent picture of the universe at small scale

- Elementary particles of matter : Fermions

$\begin{pmatrix} e \\ \nu_e \end{pmatrix}$ $\begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}$ $\begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$ — 6 Leptons ℓ — 6 Quarks q — $\begin{pmatrix} u \\ d \end{pmatrix}$ $\begin{pmatrix} c \\ s \end{pmatrix}$ $\begin{pmatrix} t \\ b \end{pmatrix}$

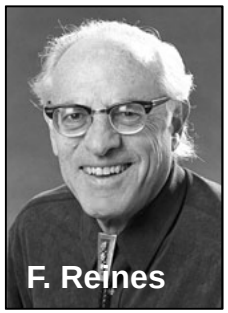

J.J. Thomson


CD Anderson


M.L. Perl


M.Gell-Mann

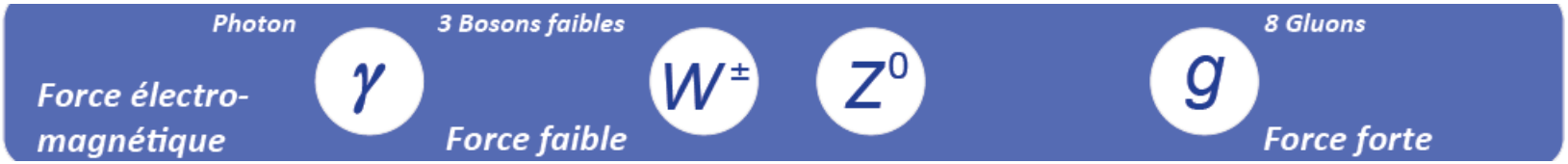

W. Pauli

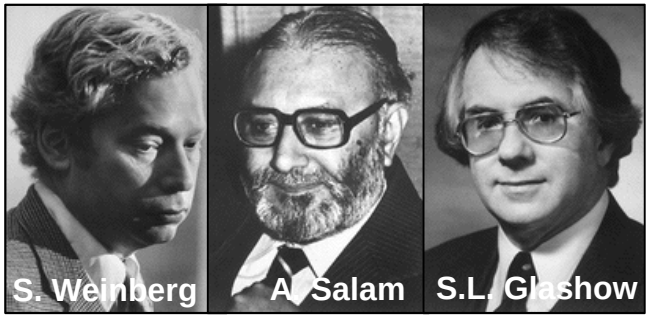

F. Reines

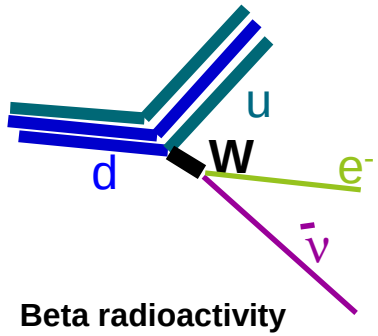
A coherent picture of the universe at small scale

- Elementary fermions form matter

- Gauge boson carry forces







Beta radioactivity

STANDARD MODEL

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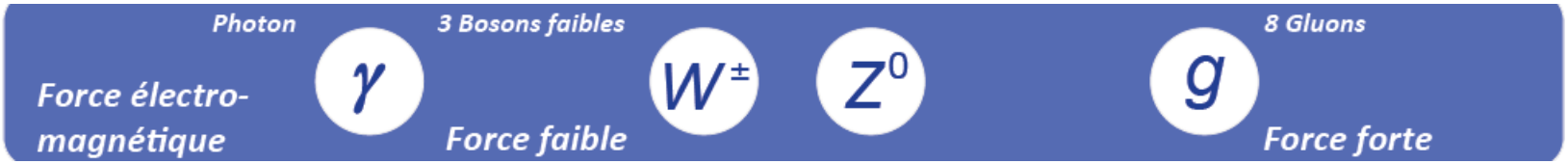
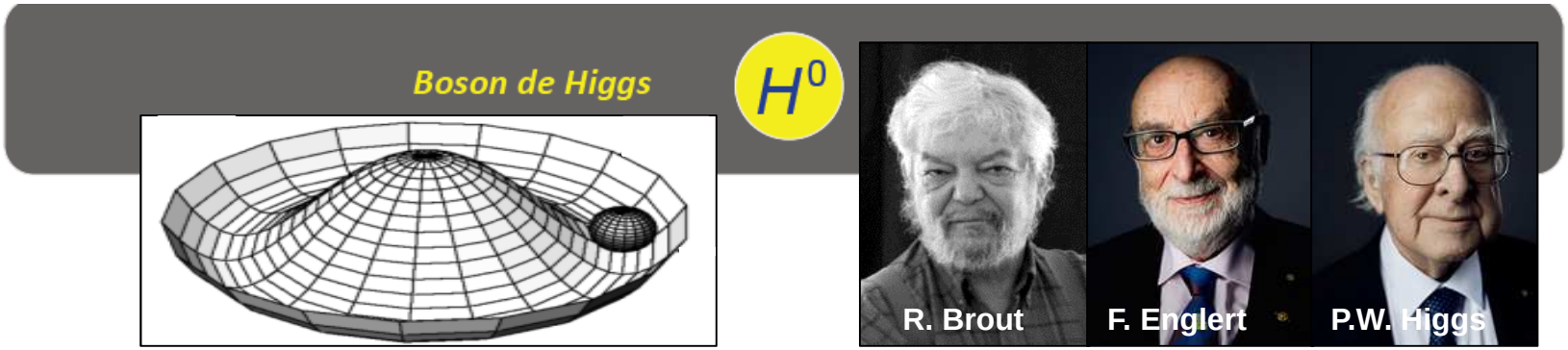
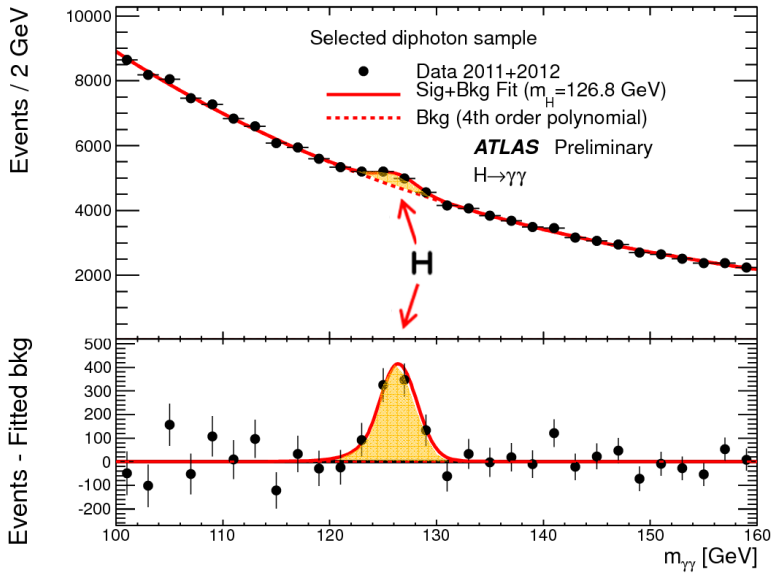


- Spontaneous symmetry breaking of the Brout-Englert-Higgs field provide a mass to W&Z and so a finite range to the weak interaction



MAJOR DISCOVERY

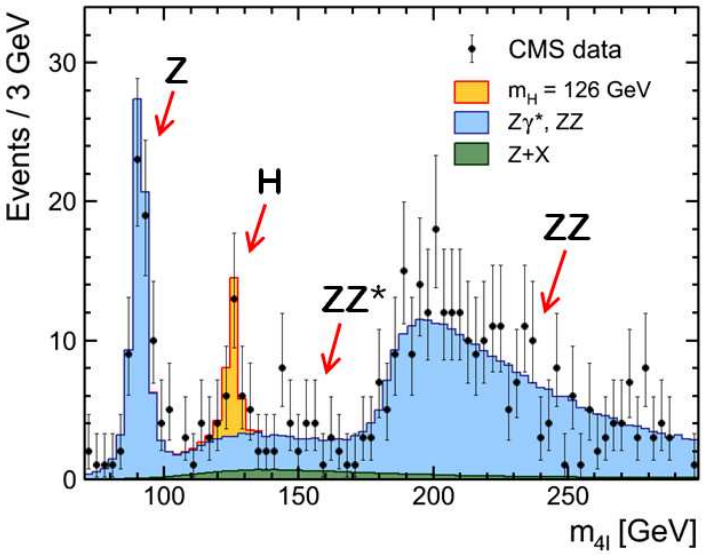
ATLAS



disintegration in 2 photons

(>7 standard deviations)

CMS



disintegration in 4 leptons

(>7 standard deviations)

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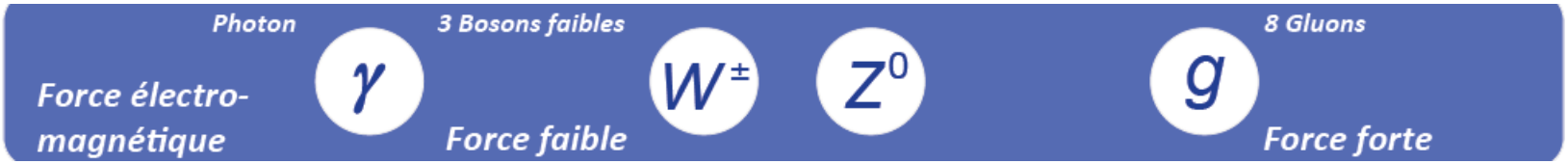

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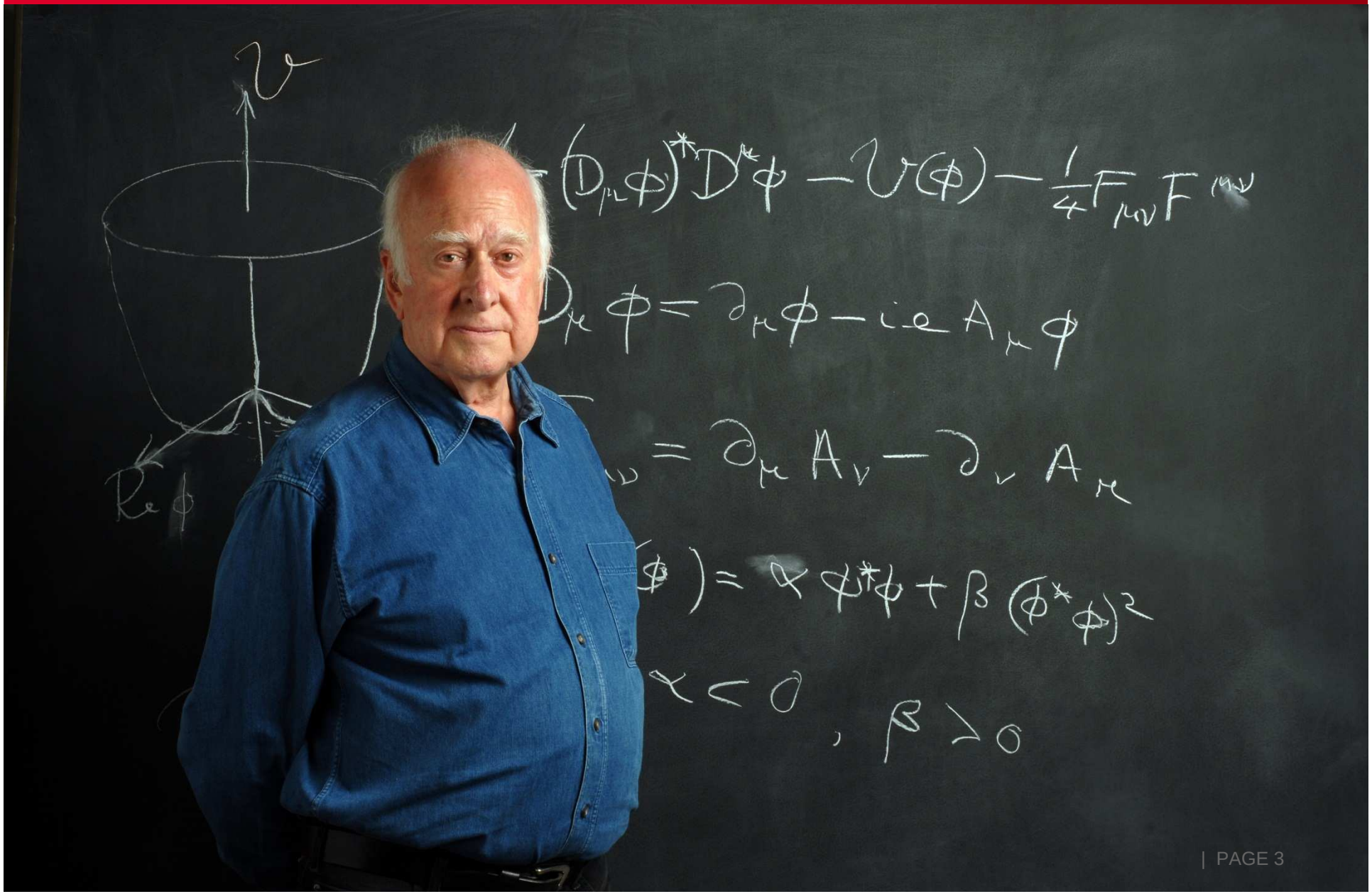
The standard model now complete (29 parameters)

STANDARD MODEL: A BEAUTIFUL THEORY



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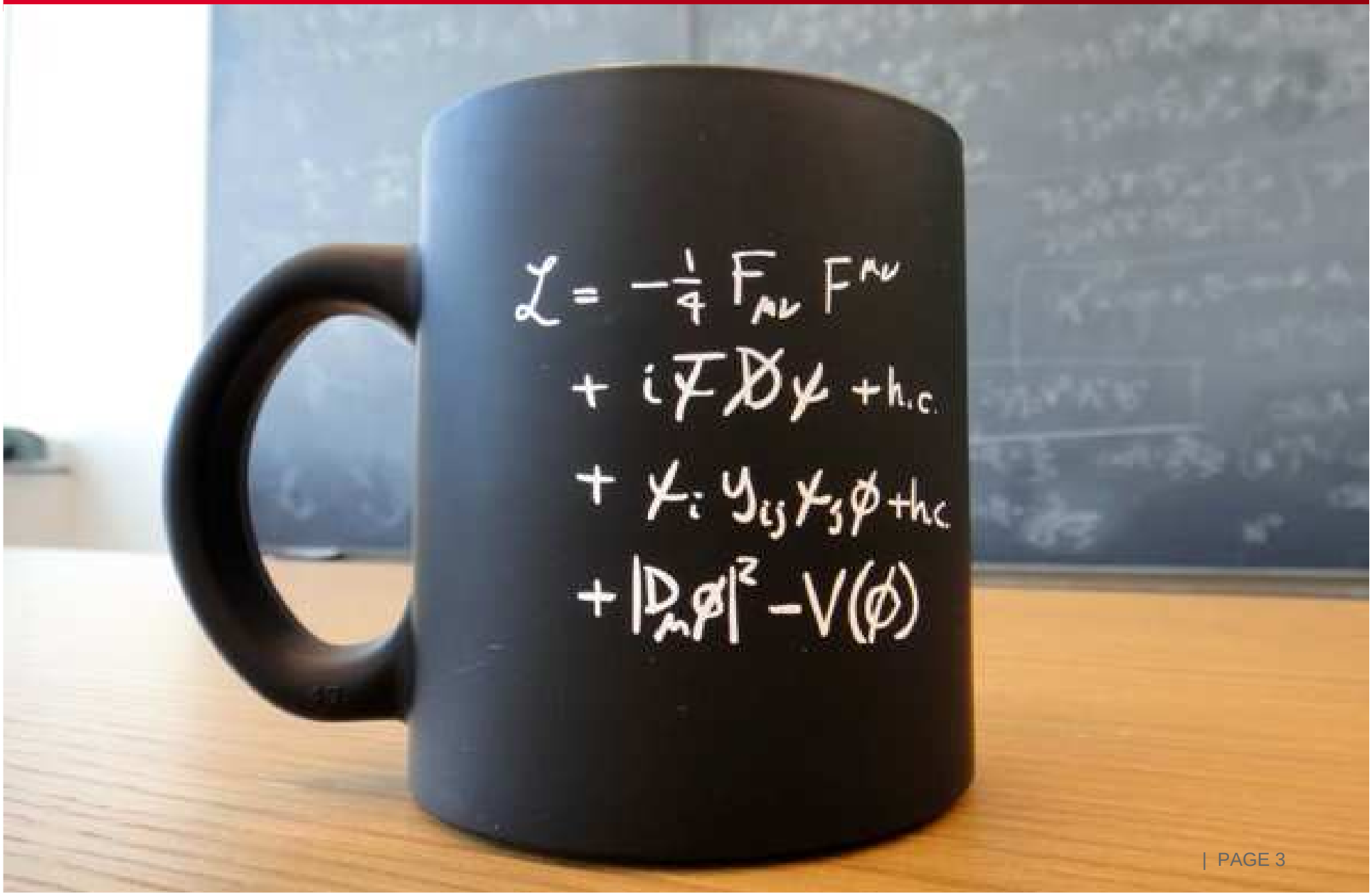

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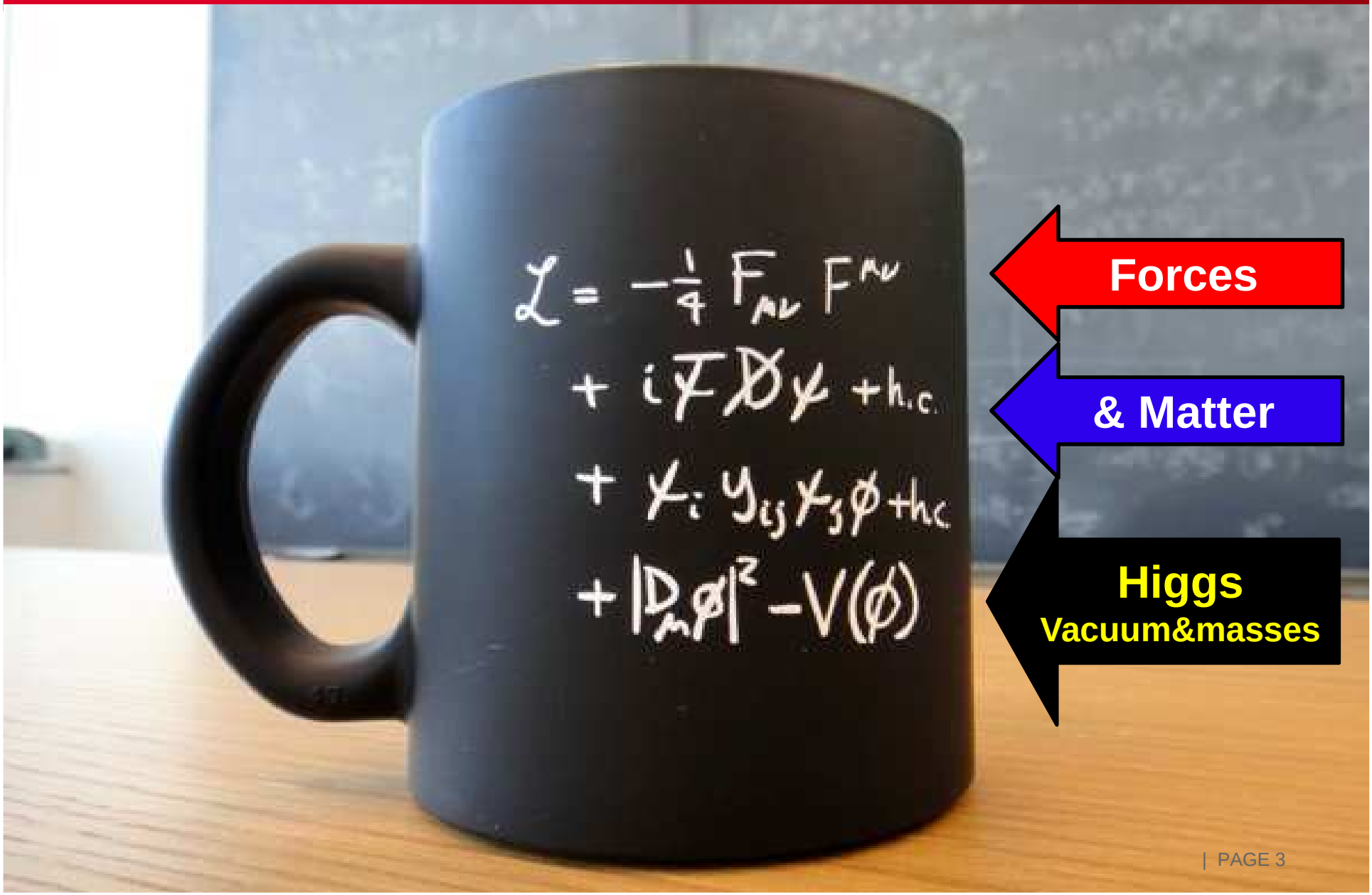
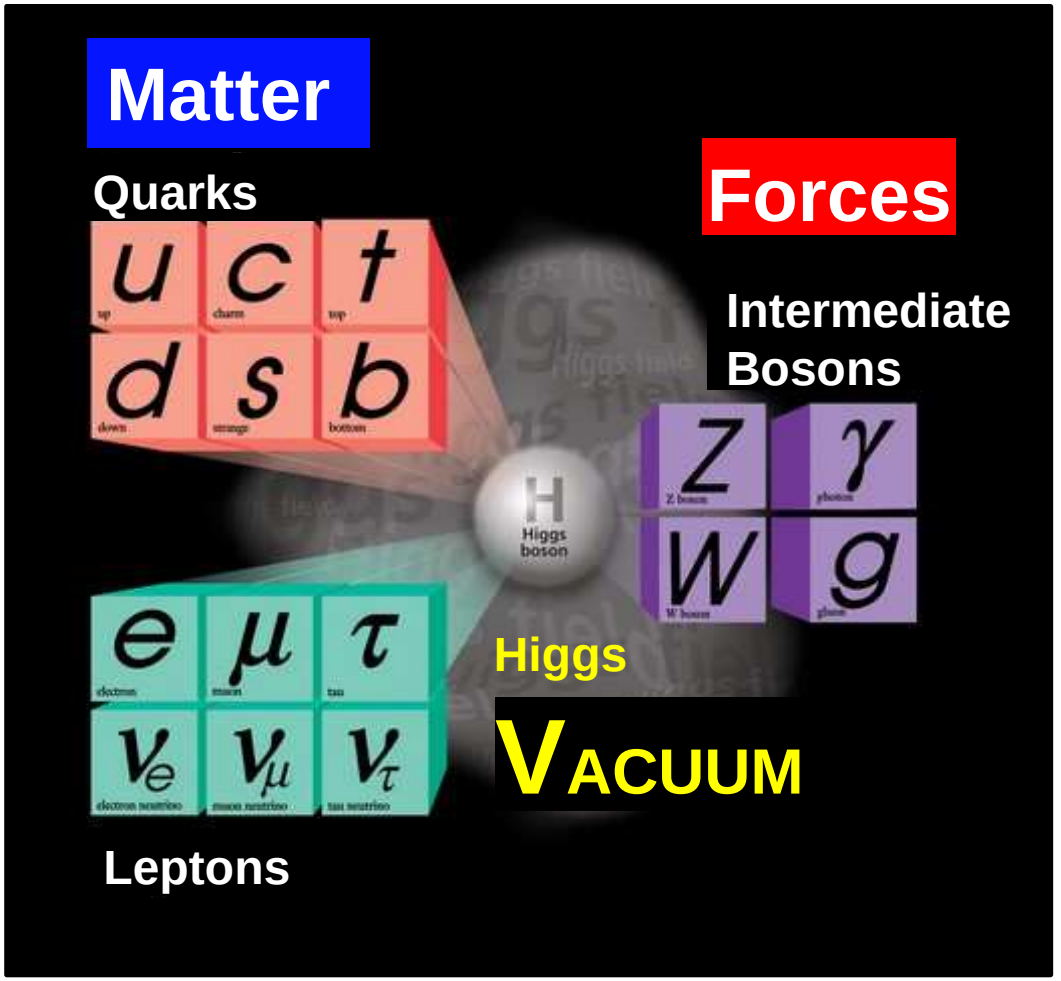


- II -

WHAT NEXT ?

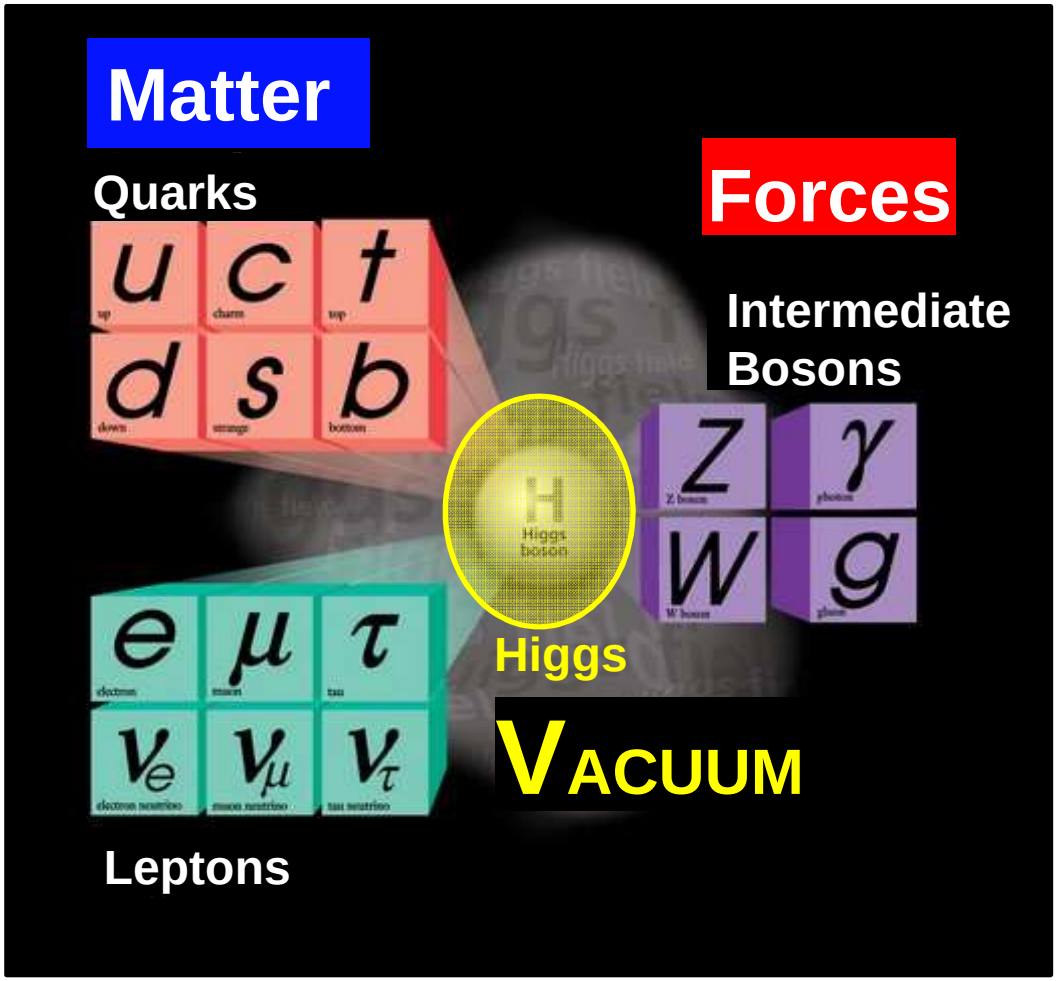
EXPLORE NEWLY
DISCOVERED TERRITORIES

EXPLORE RECENTLY DISCOVERED TERRITORIES



EXPLORE RECENTLY DISCOVERED TERRITORIES

- **New Higgs sector**
  - Properties
  - Couplings
  - Symmetry breaking
  - Vacuum stability



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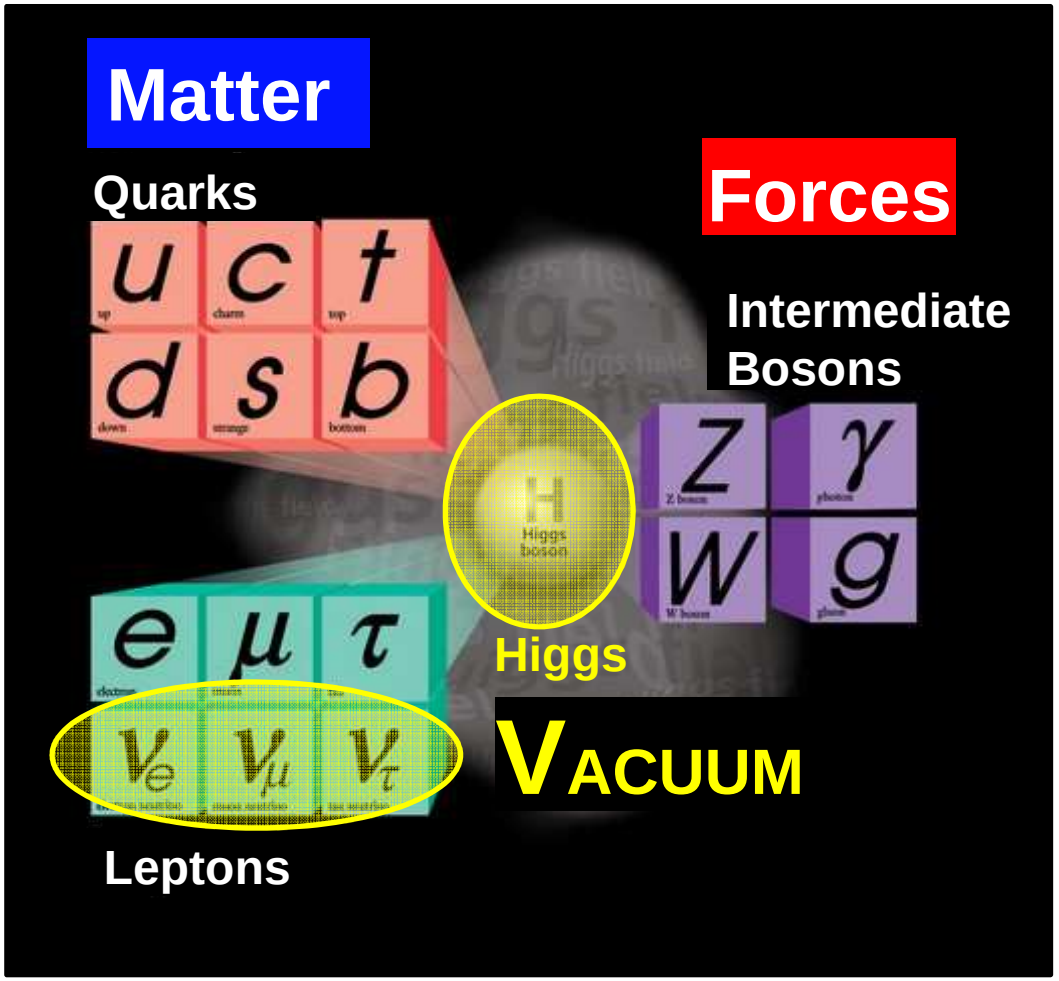

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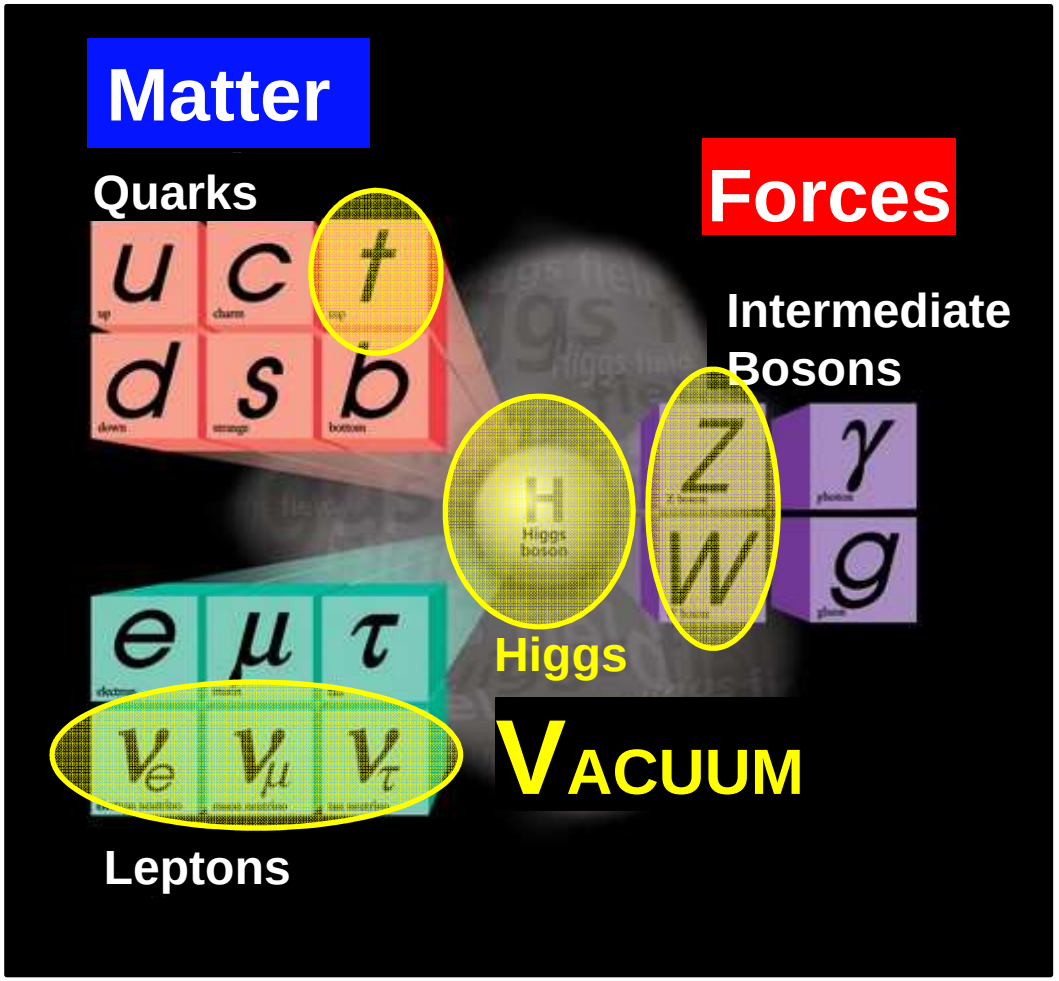

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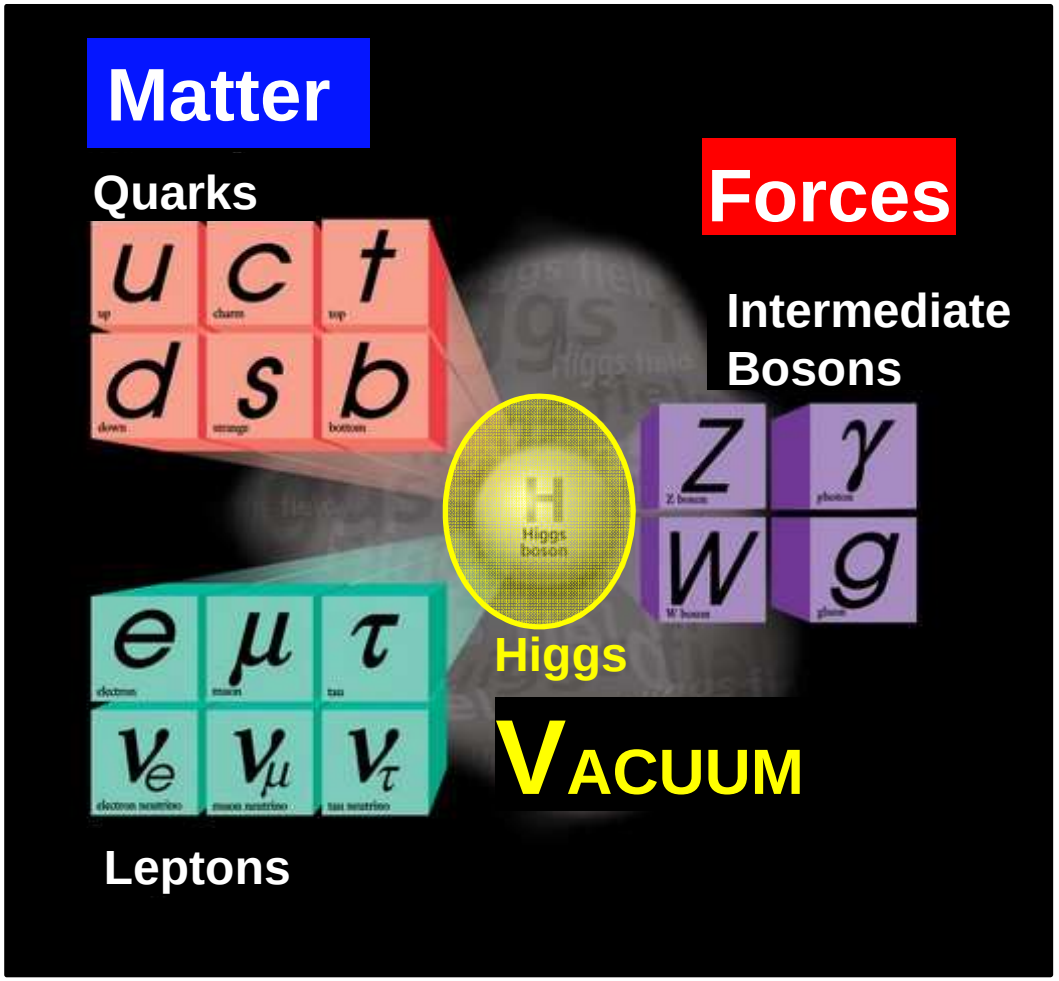
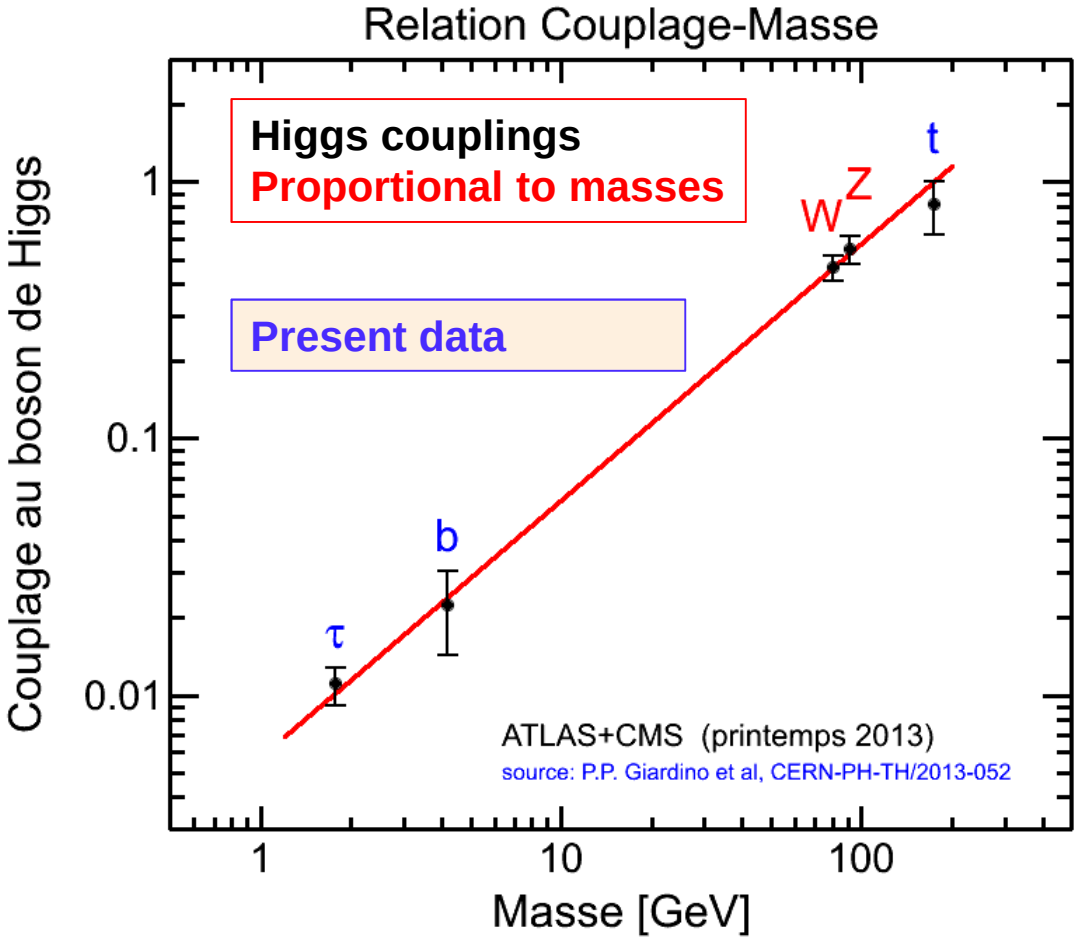


SIGNATURE OF HIGGS BOSON

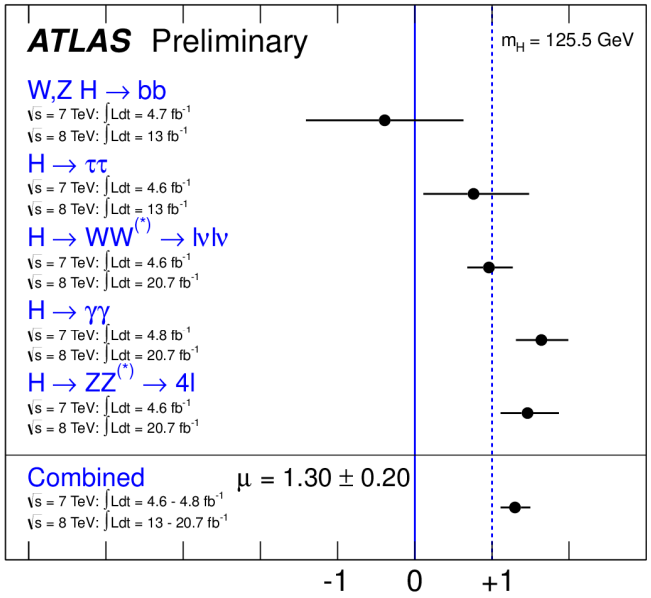
Couplings from production and decay



2009 - 2012
30 fb^{-1} at 7/8 TeV
Discovery of Higgs boson
couplings to W and Z +- 30%

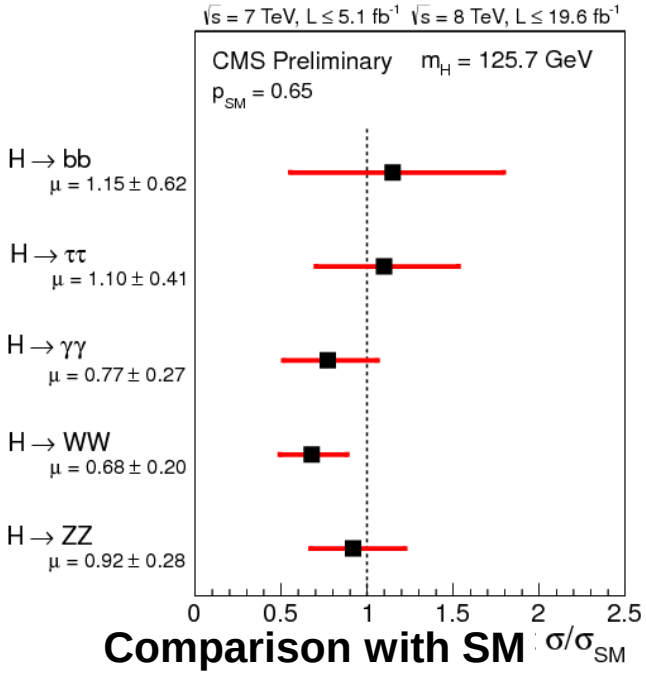
COUPLING FROM DECAY

ATLAS



Comparison with SM (μ)

CMS



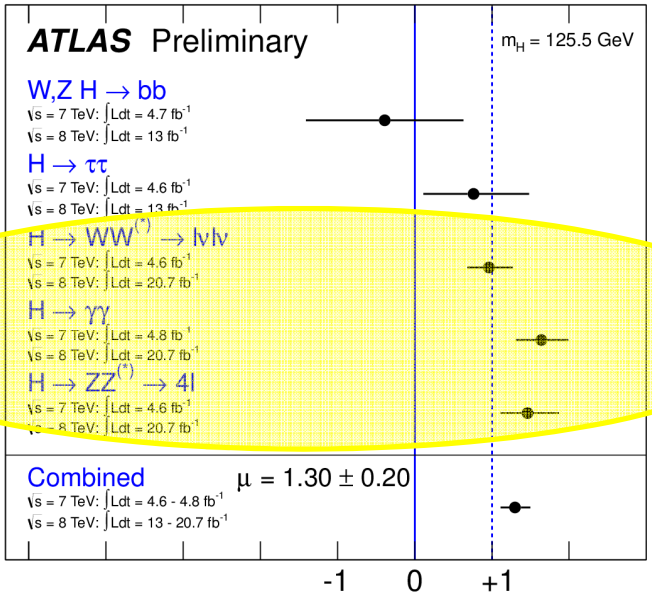
Comparison with SM σ/σ_{SM}

Present Higgs properties compatible with the standard model

Best precision on W, Z, γ only 30%

COUPLING FROM DECAY

ATLAS



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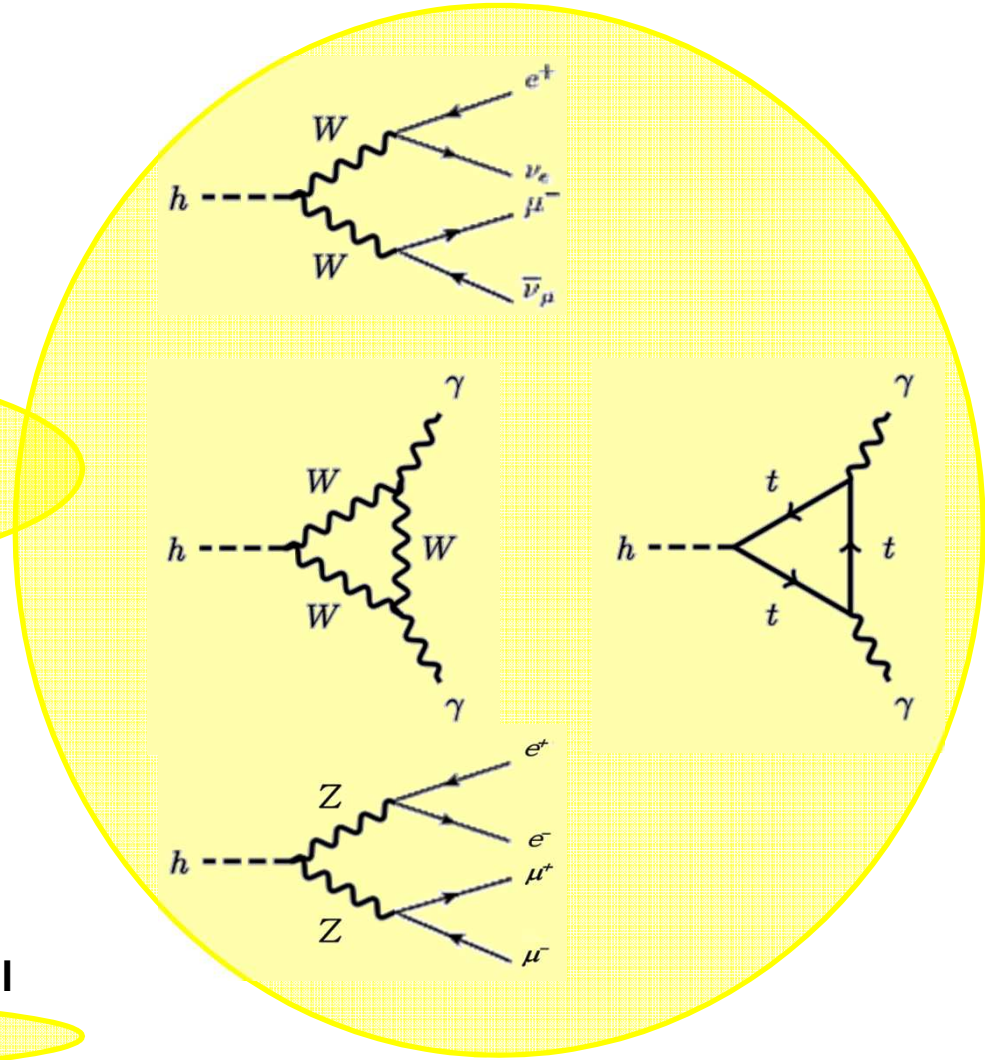

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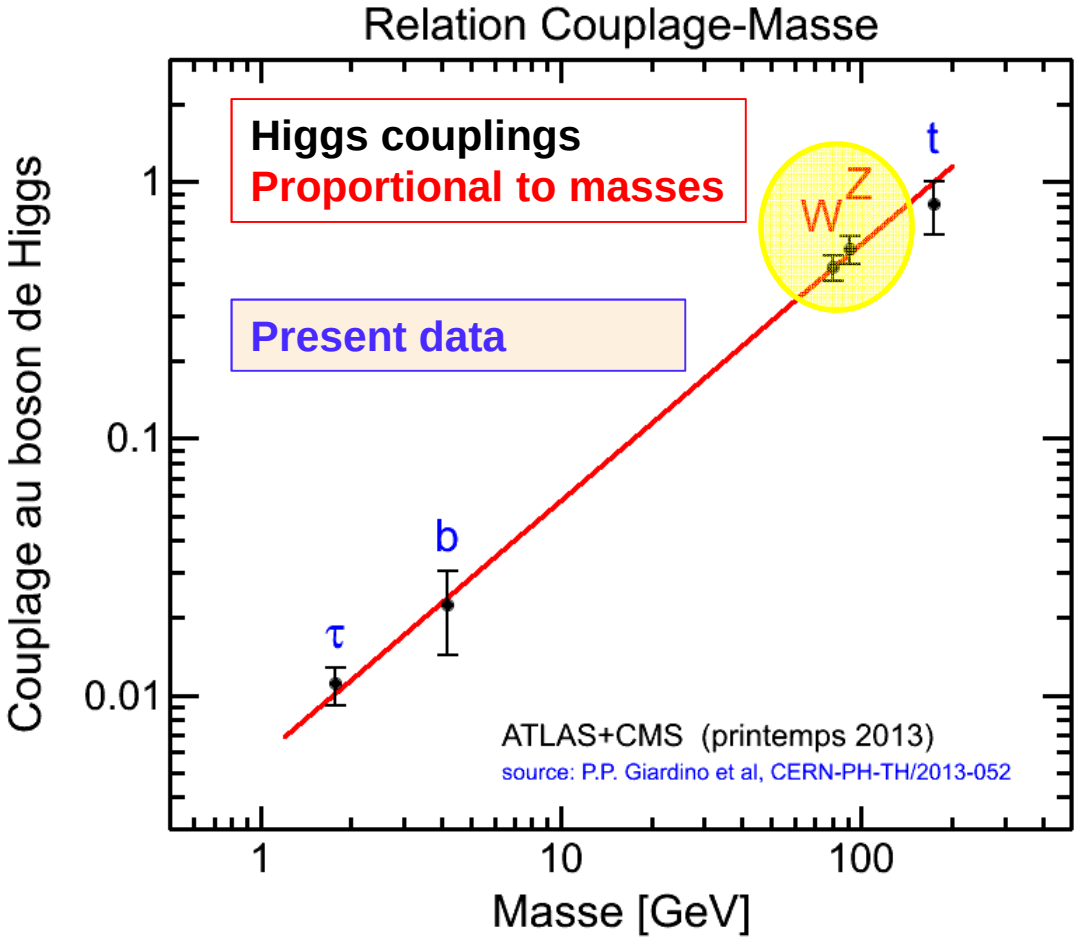

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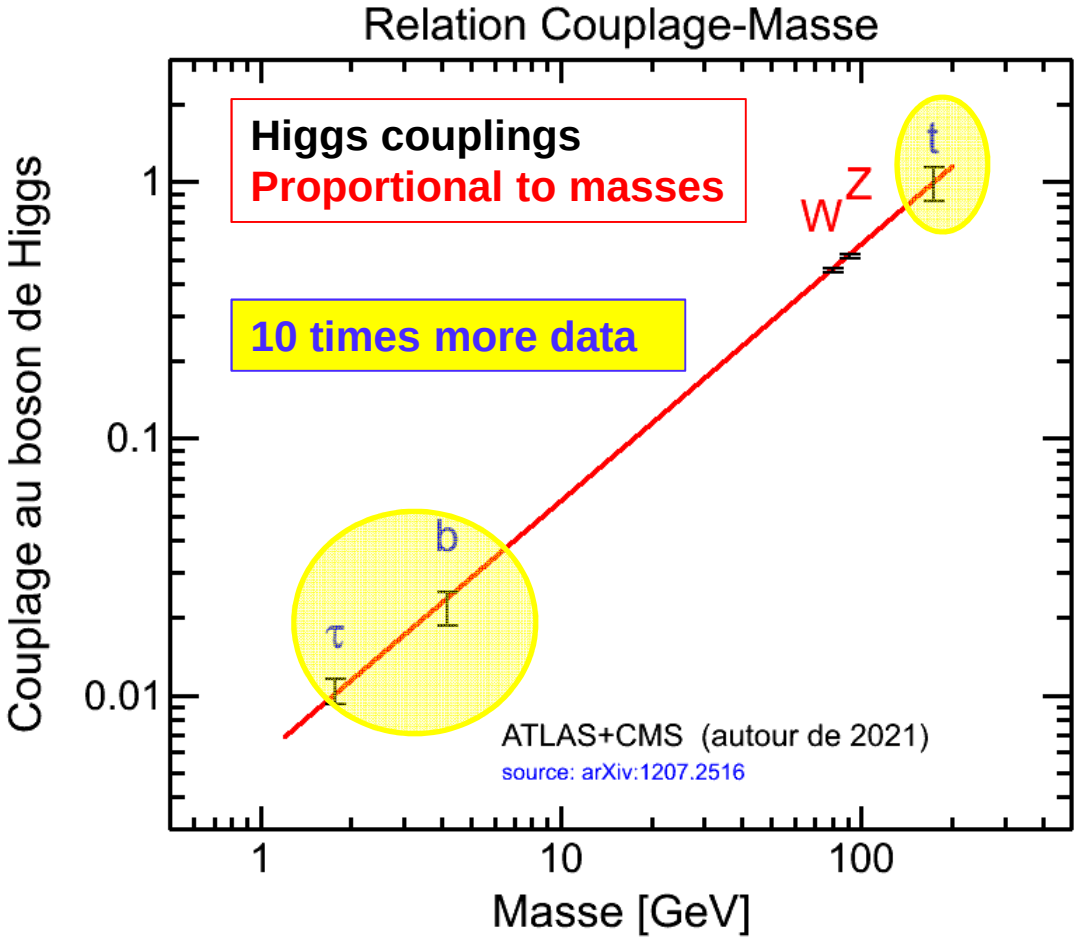
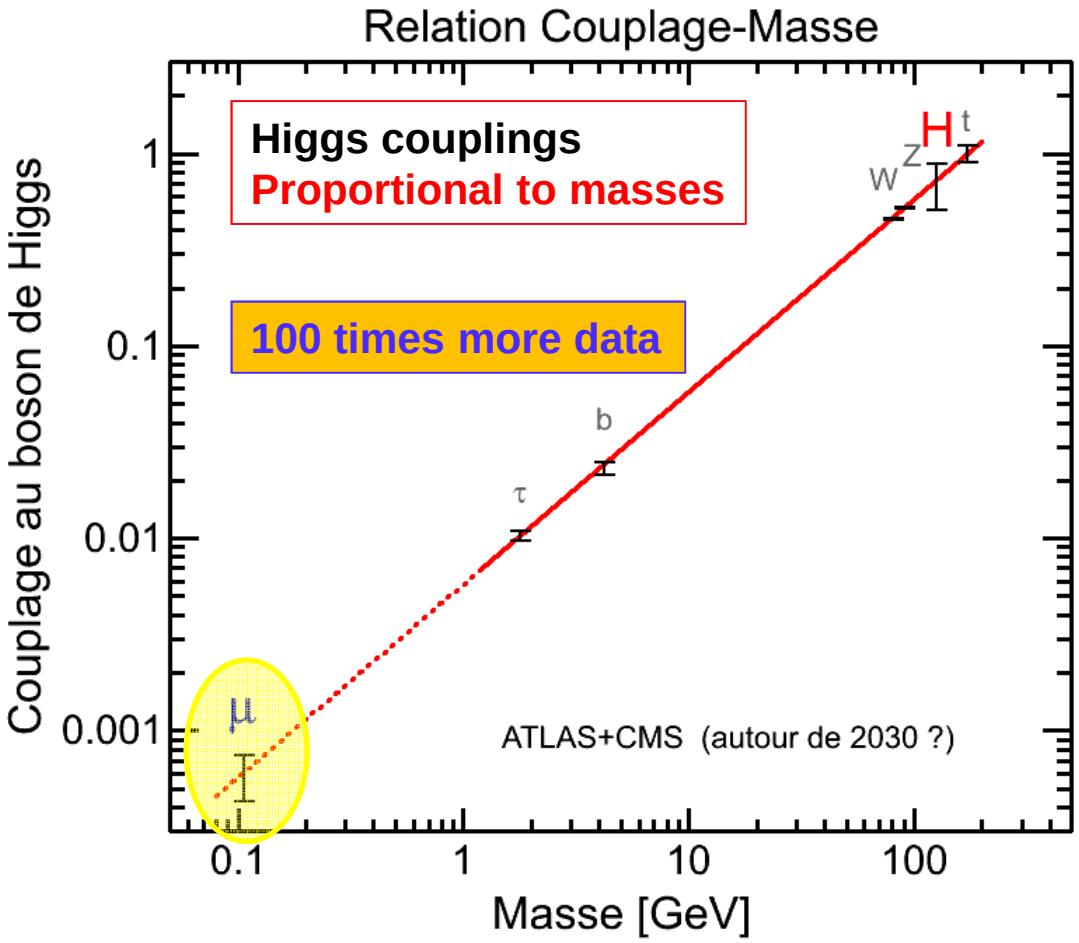
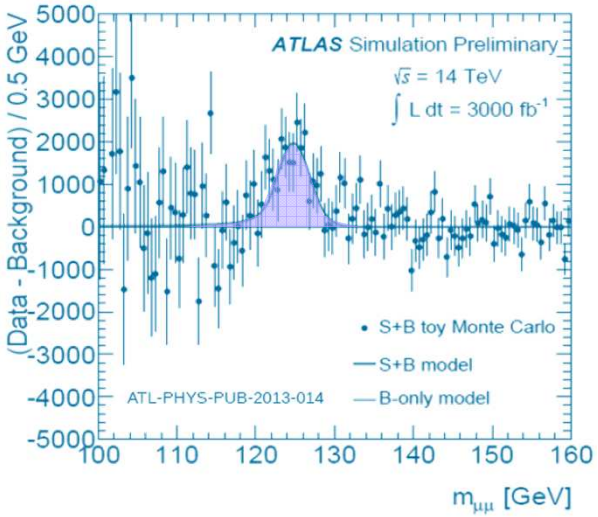


2009 -2012
30 fb^{-1} at 7/8 TeV
Discovery of Higgs boson
couplings to W and Z

300 fb^{-1} at 13/14 TeV
Precision couplings to W and Z
Coupling to fermions lepton tau and quarks t and b

SIGNATURE OF HIGGS BOSON





3000 fb^{-1} data at 14 TeV
Couplings to 8 particles,
Coupling to lepton mu

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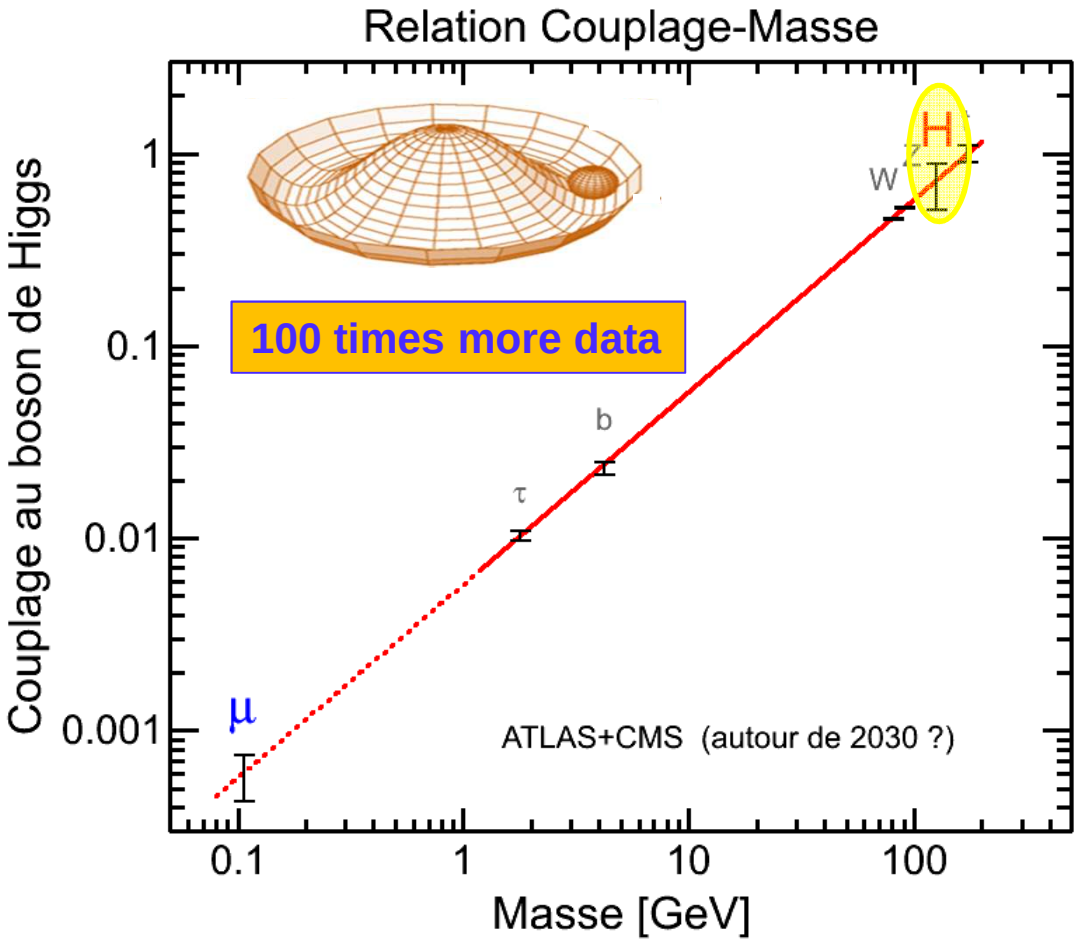

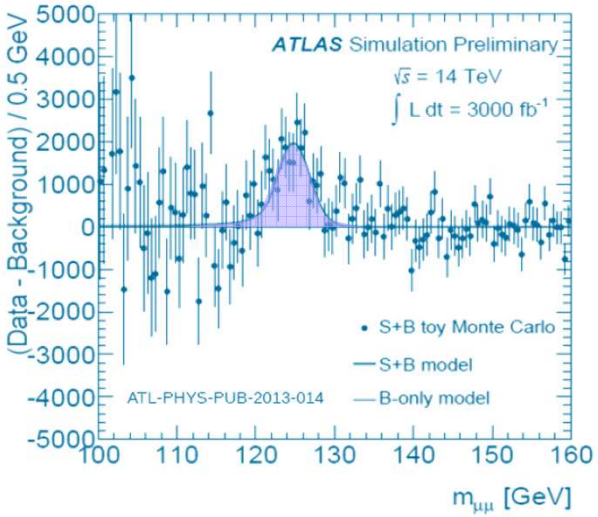

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self coupling and Higgs potential

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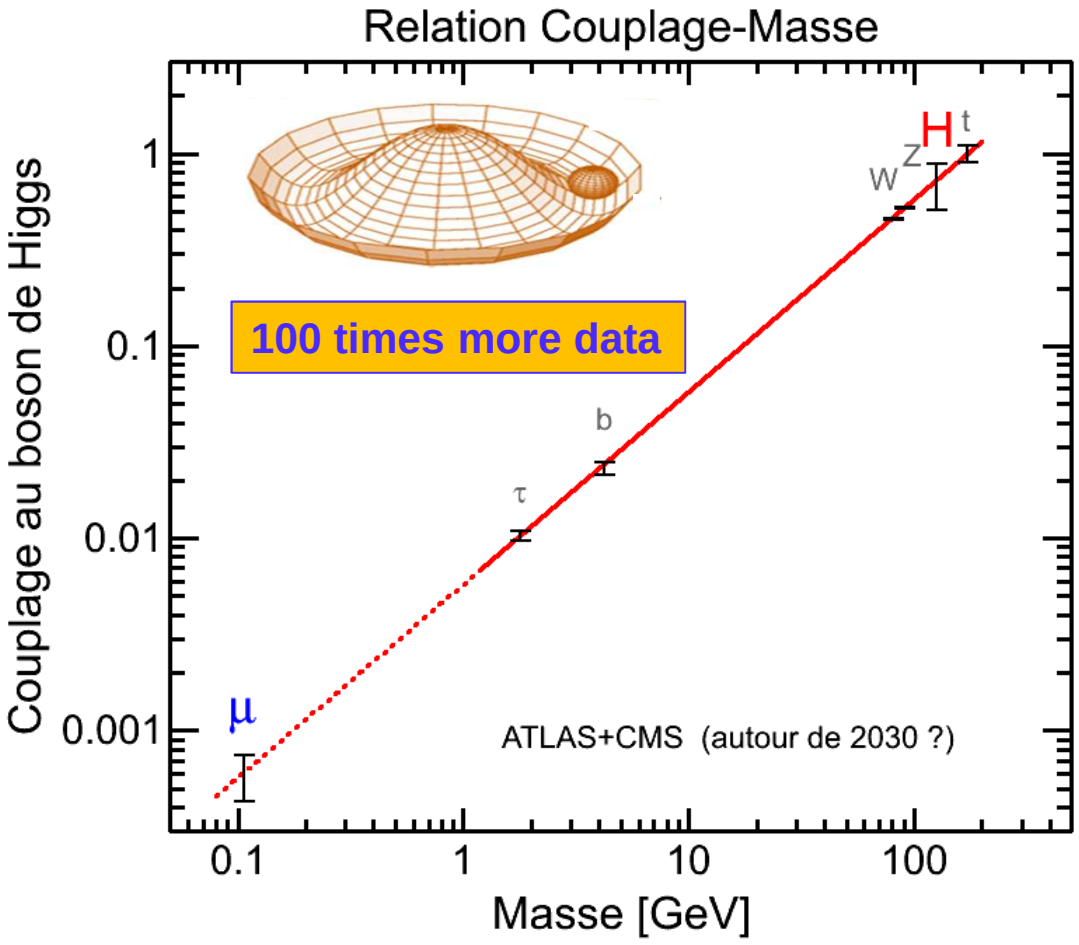
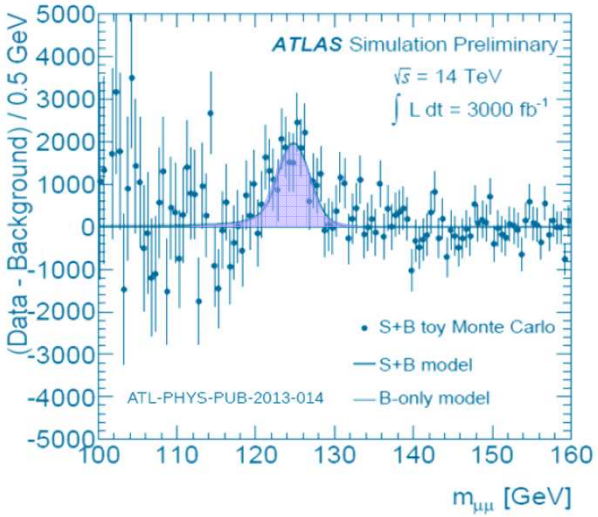




3000 fb^{-1} data at 14 TeV

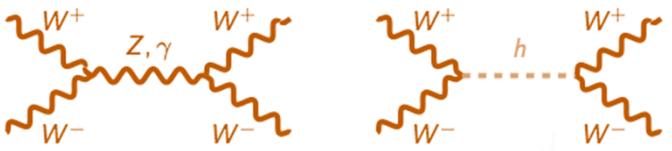
Couplings to 8 particles,

Coupling to lepton mu

self coupling and Higgs potential

Total and invisible width

Unitarity test in boson scattering



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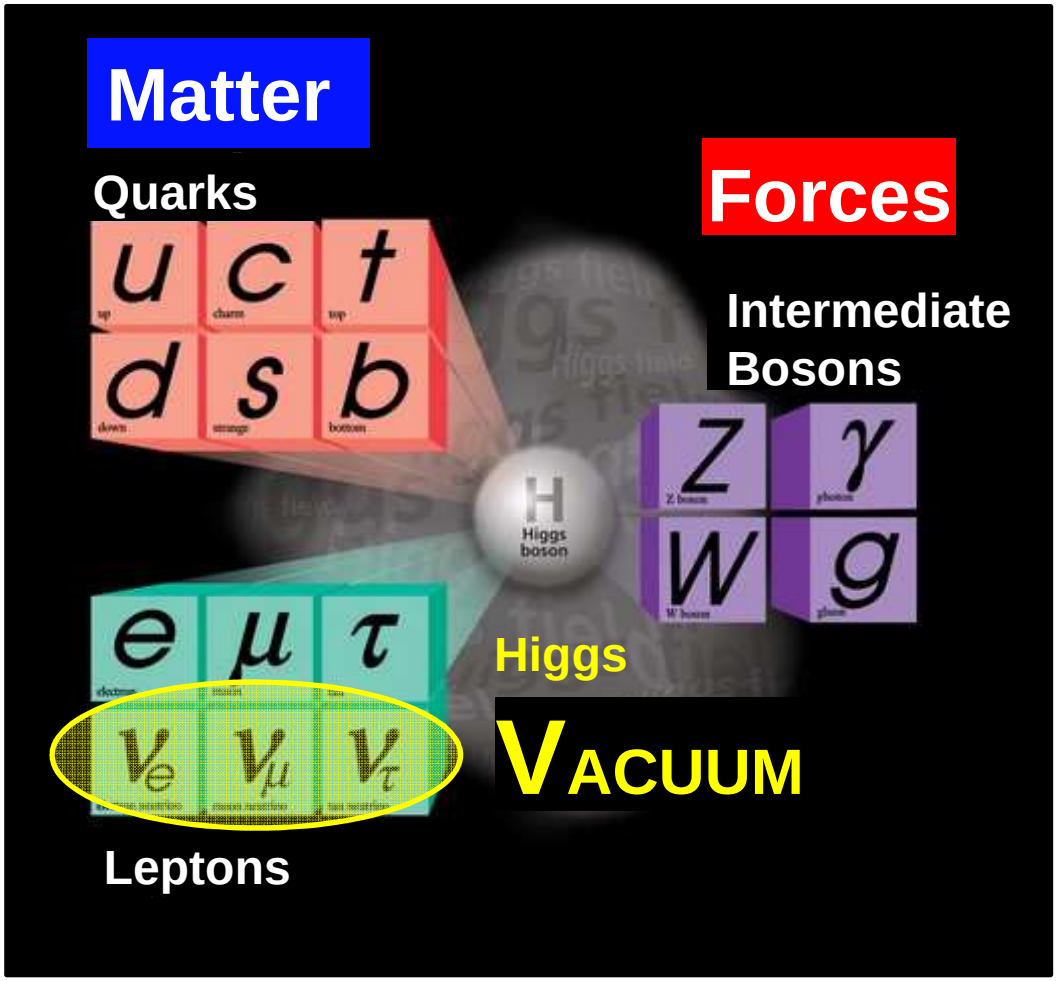


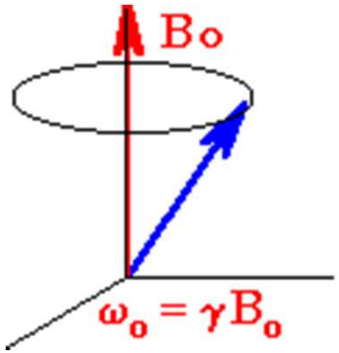
Pontecorvo–Maki–Nakagawa–Sakata matrix

weak interaction Eigenstates

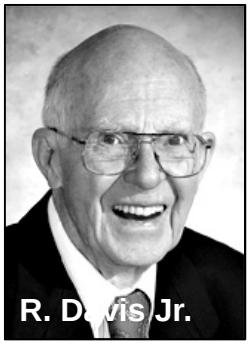
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{bmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass Eigenstates

3 Euler angles θ_{12}, θ_{23}, θ_{13} , 1 phase δ_{13}



Oscillation analogous to Larmor precession


R. Davis Jr.


M. Koshiba

- Oscillation discovered with solar and atmospheric neutrinos

NEUTRINO MIXING AND CP VIOLATION

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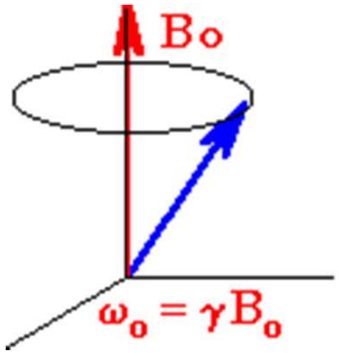

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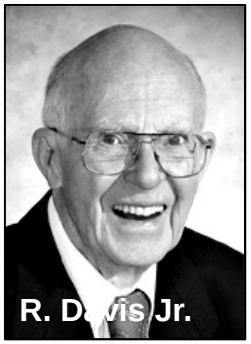
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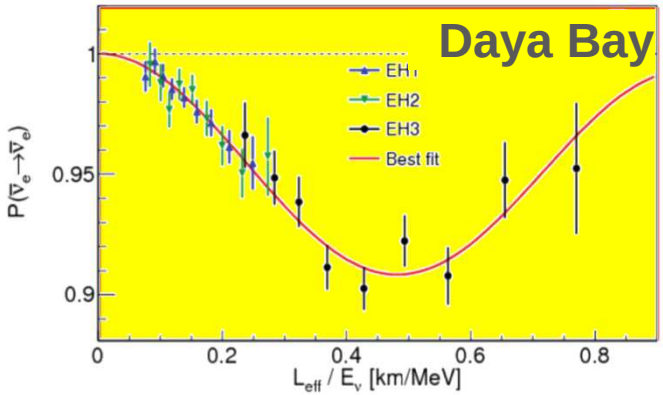

- Oscillation discovered with solar and atmospheric neutrinos
- θ_{13} discovered in 2012 with reactor and accelerator neutrinos

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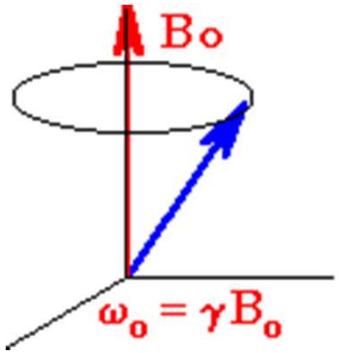


Oscillation analogous to Larmor precession

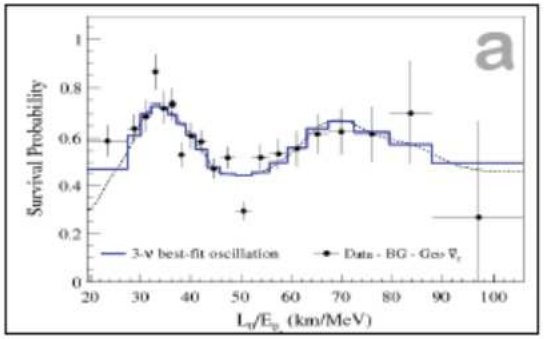
- Analogous to the Cabibo, Kobayashi, Maskawa mixing and CP violation in the quark sector
- ➔ Matter – Antimatter Asymmetry


M. Kobayachi

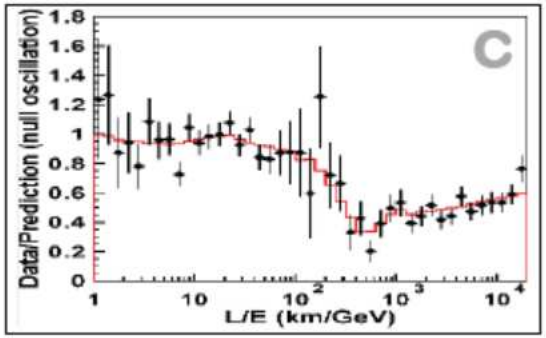

T. Maskawa

$\alpha \rightarrow \beta$ transitions and dominant oscillation parameters probed so far:

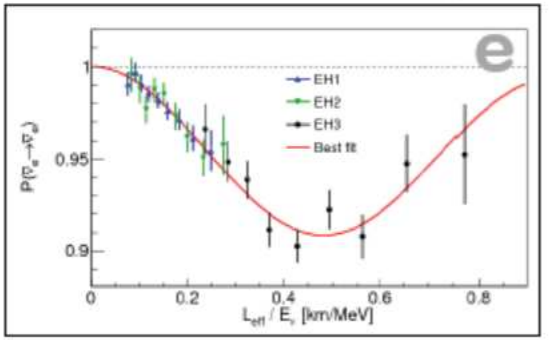
$e \rightarrow e$ (δm^2 , θ_{12})



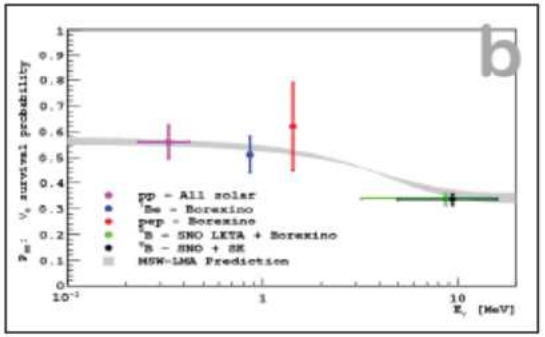
$\mu \rightarrow \mu$ (Δm^2 , θ_{23})



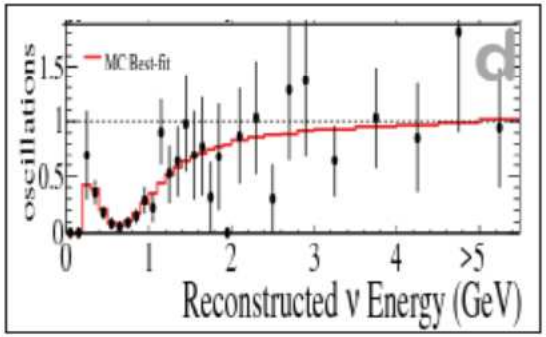
$e \rightarrow e$ (Δm^2 , θ_{13})



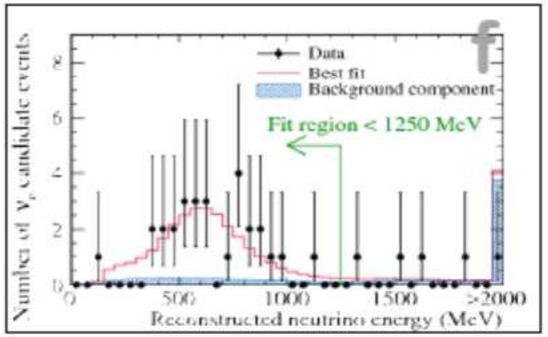
$e \rightarrow e$ (δm^2 , θ_{12})



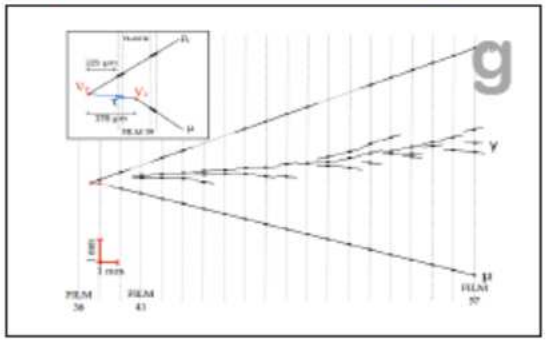
$\mu \rightarrow \mu$ (Δm^2 , θ_{23})



$\mu \rightarrow e$ (Δm^2 , θ_{13} , θ_{23})



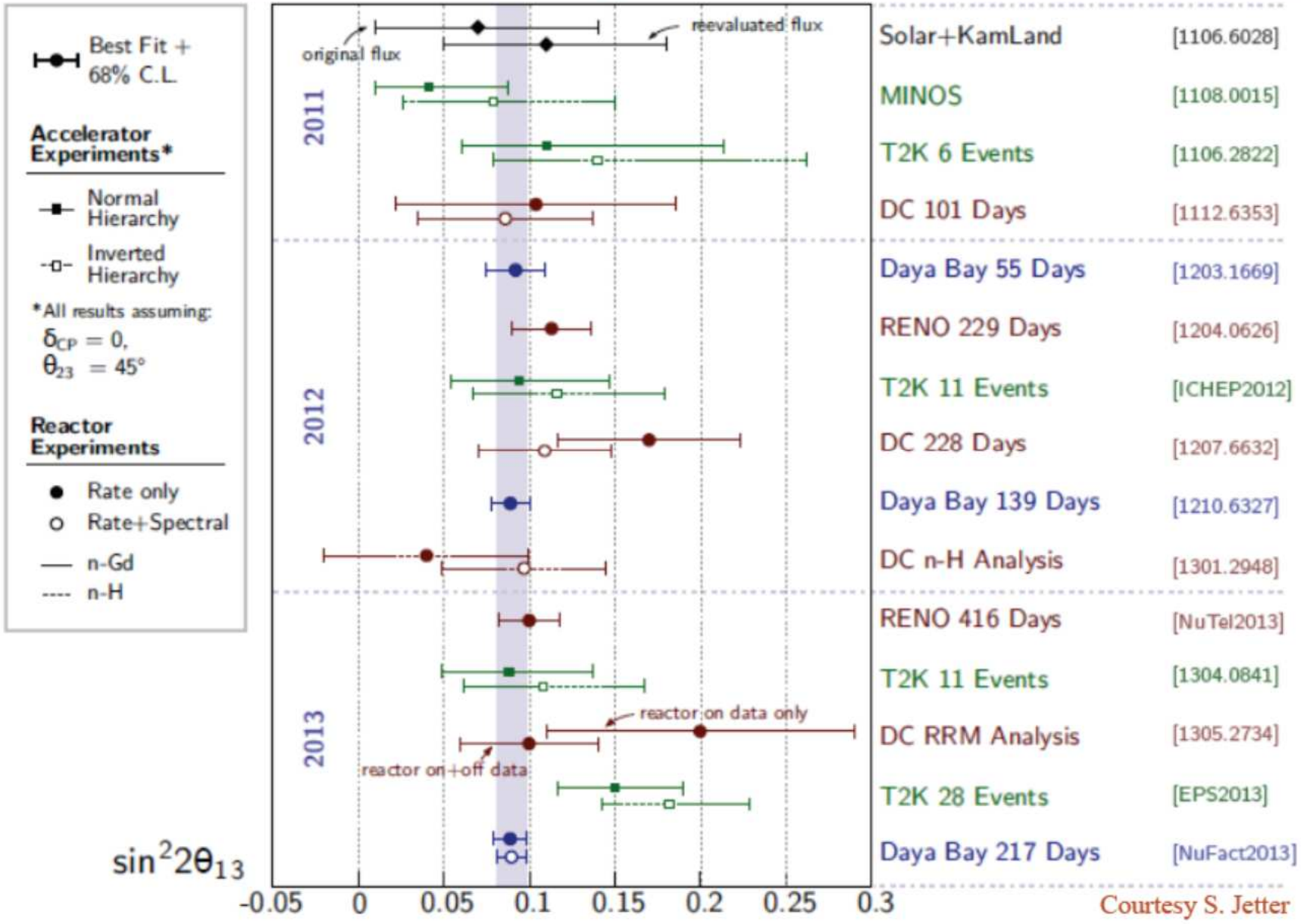
$\mu \rightarrow \tau$ (Δm^2 , θ_{23})



Data from various types of neutrino experiments: (a) solar, (b) long-baseline reactor, (c) atmospheric, (d) long-baseline accelerator, (e) short-baseline reactor, (f,g) long baseline accelerator (and, in part, atmospheric).

(a) KamLAND [plot]; (b) Borexino [plot], Homestake, Super-K, SAGE, GALLEX/GNO, SNO; (c) Super-K atmosph. [plot], MACRO, MINOS etc.; (d) T2K (plot), MINOS, K2K; (e) Daya Bay [plot], RENO, Double Chooz; (f) T2K [plot], MINOS; (g) OPERA [plot], Super-K atmospheric.

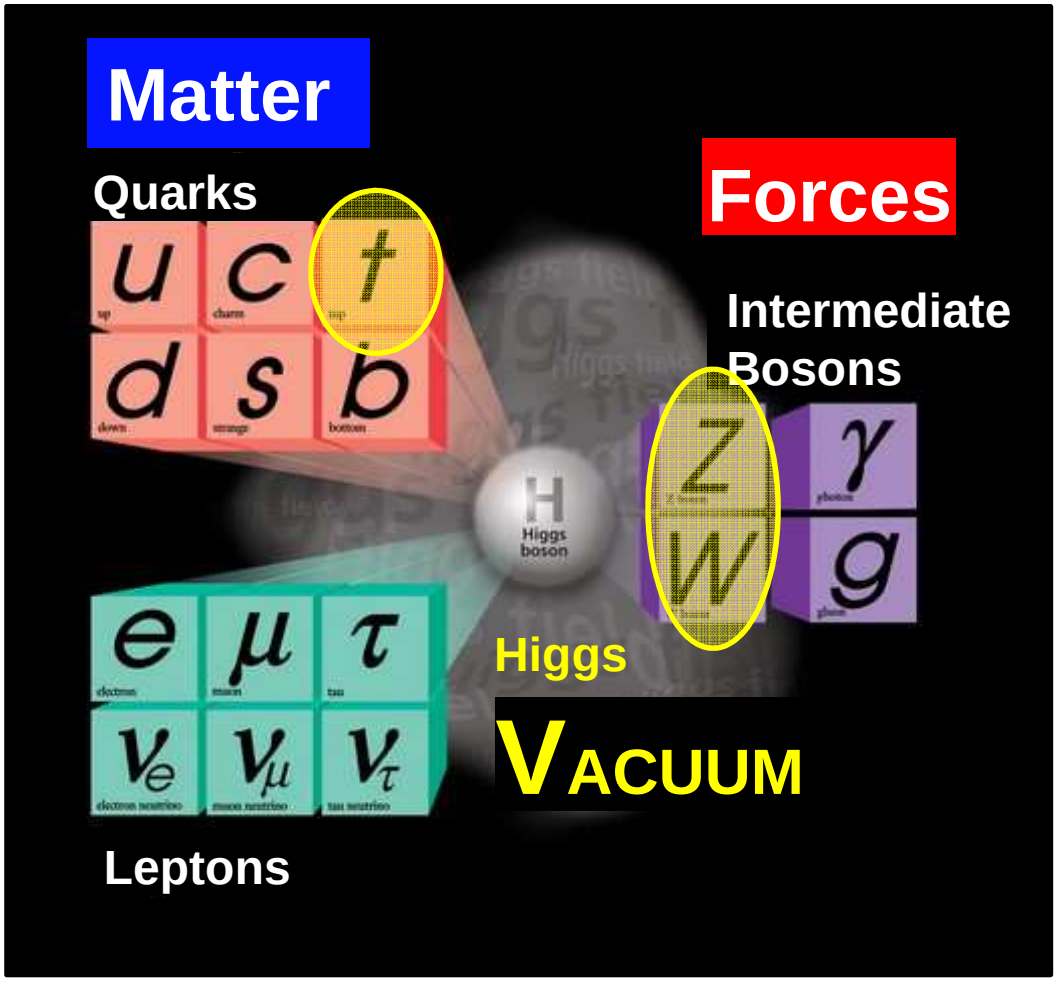
The θ_{13} Revolution



Courtesy S. Jetter

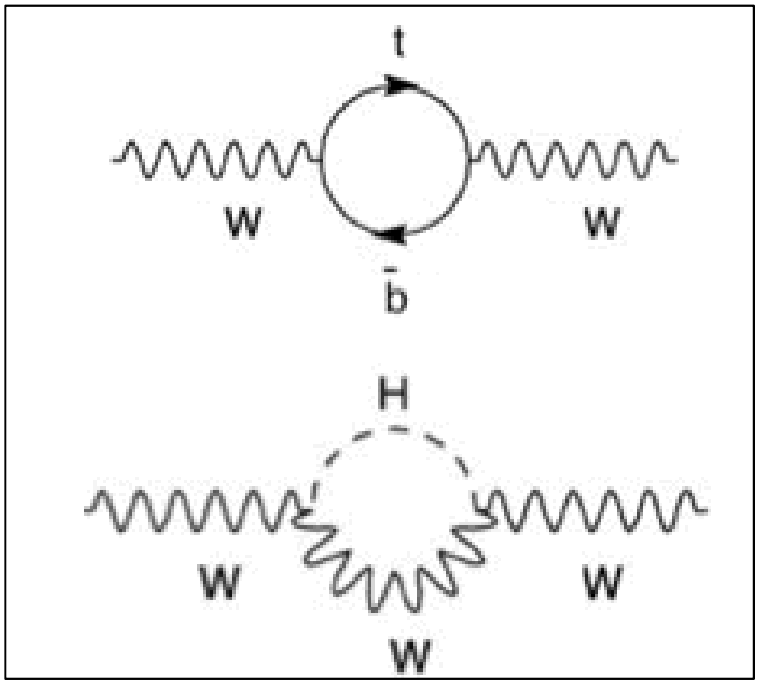
EXPLORE RECENTLY DISCOVERED TERRITORIES

- **New Higgs sector**
  - Properties
  - Couplings
  - Symmetry breaking
  - Vacuum stability
- **Neutrino sector**
  - Majorana/Dirac
  - Masses & mixings
  - CP violation
- **SM tests**
  - Top, W & Z
  - Precision measurements



COHERENCE TEST OF STANDARD MODEL

- W mass correlated to the Higgs and top masses



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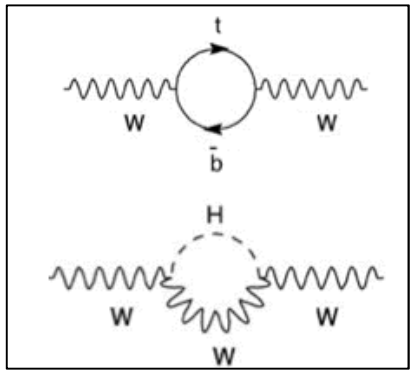

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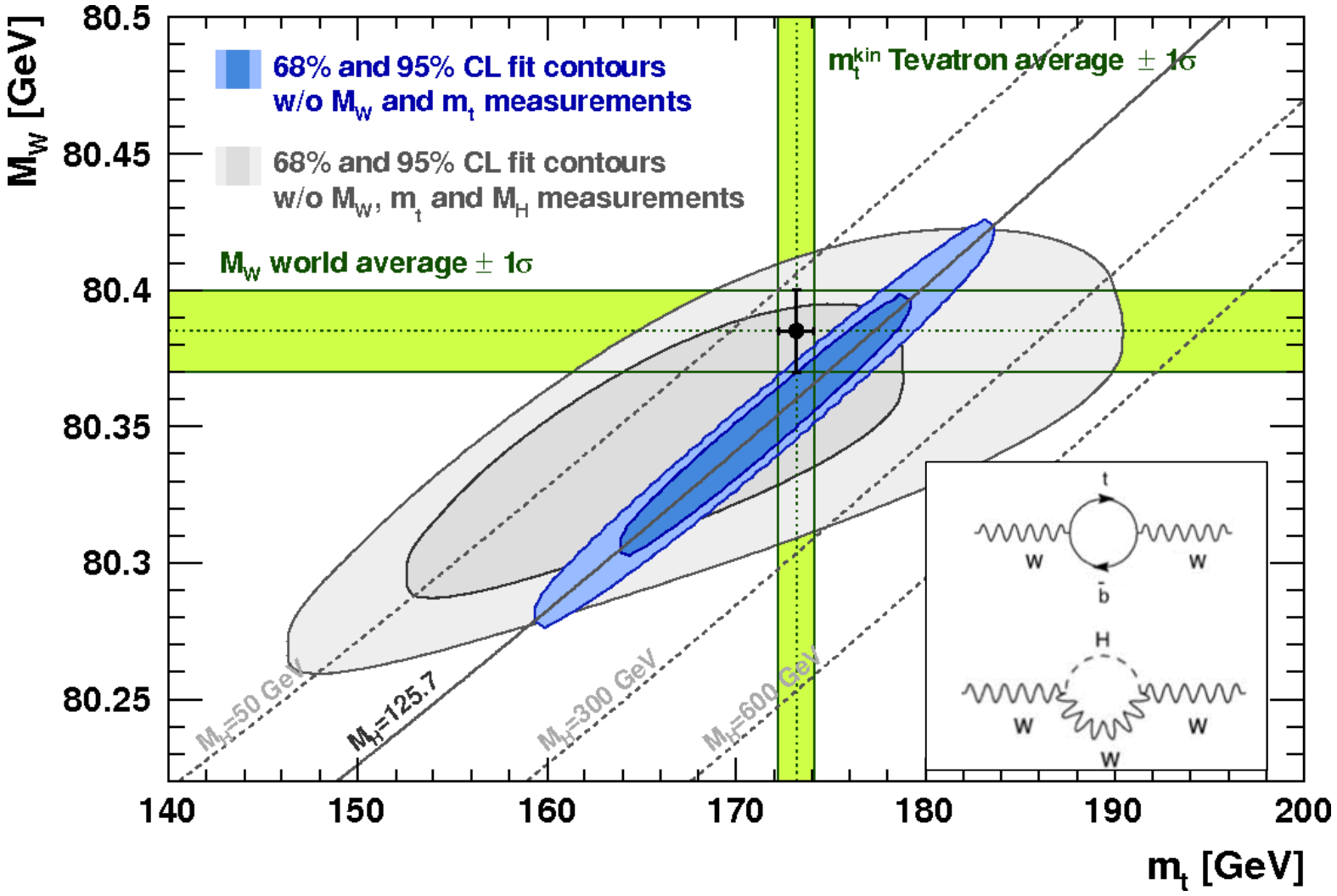
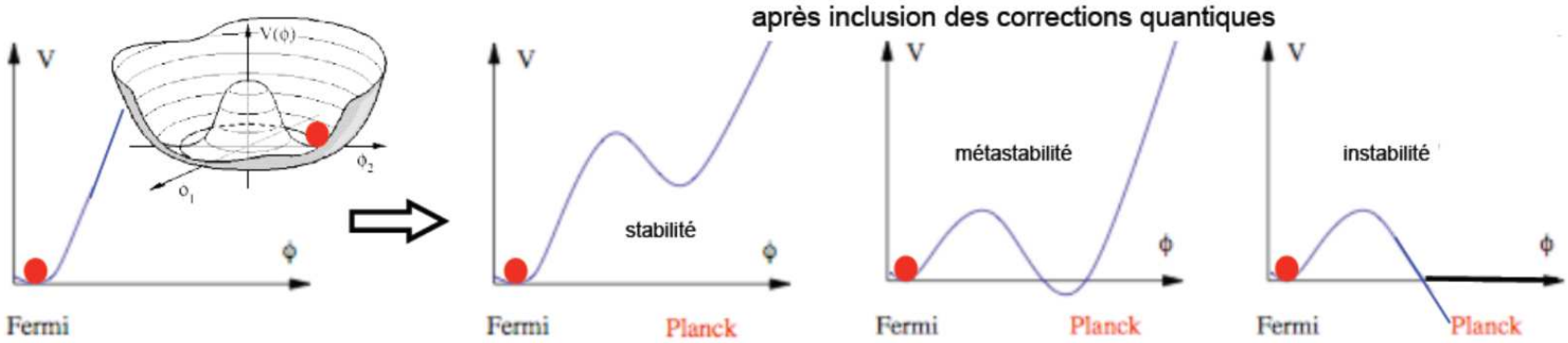
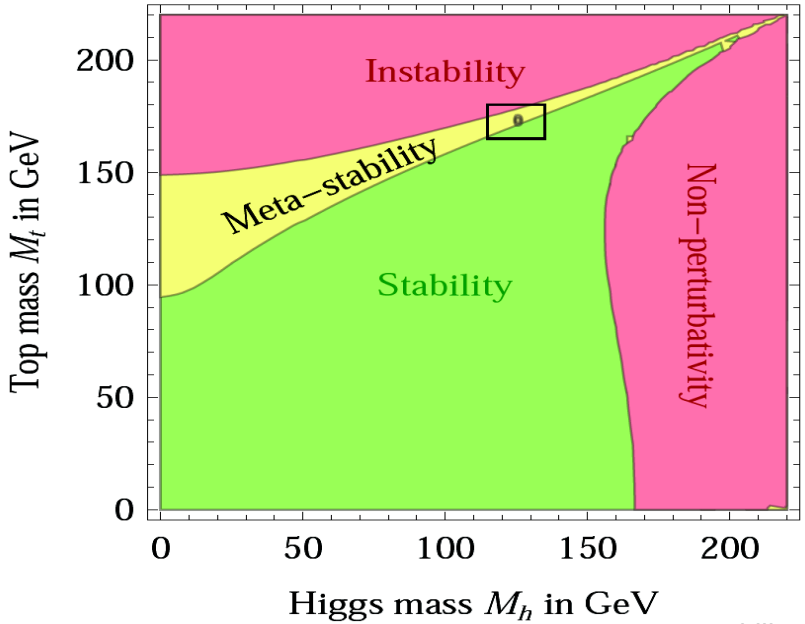


VACUUM STABILITY

- Is our Universe stable ?
  - Extrapolation at high energy using Higgs and top masses



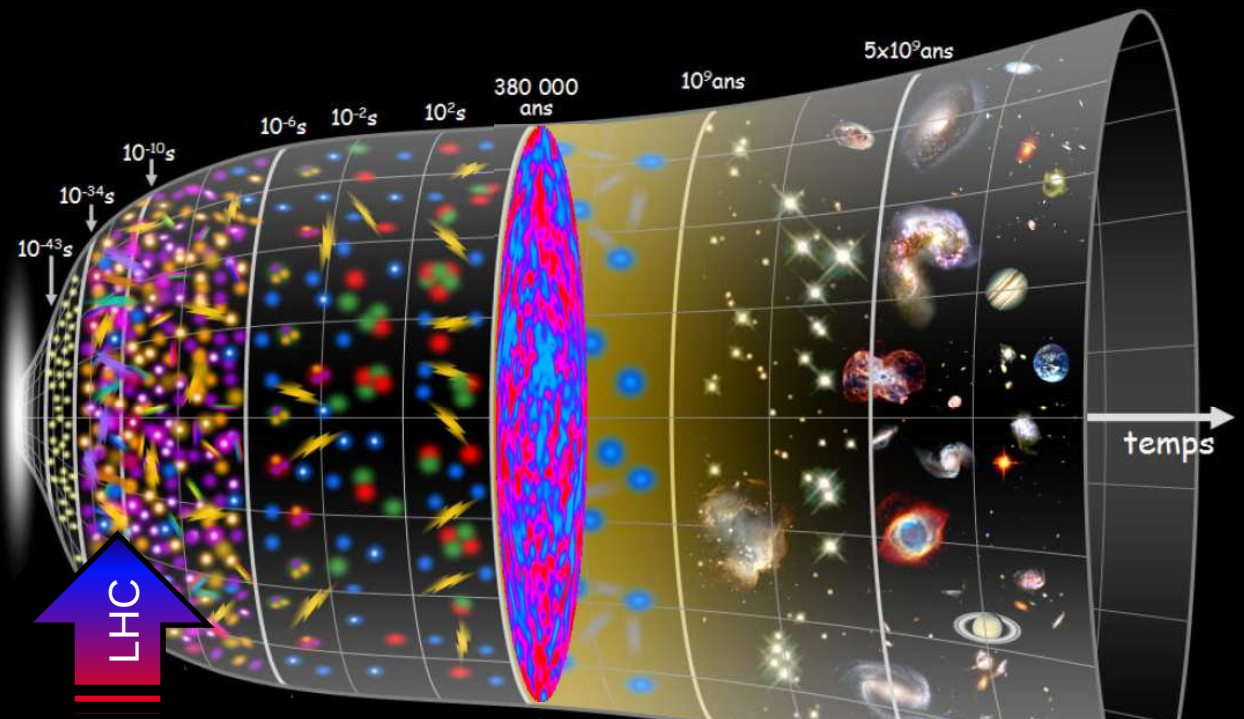


- III -

WHAT NEXT ?

THE BIG PICTURE

THE BIG PICTURE



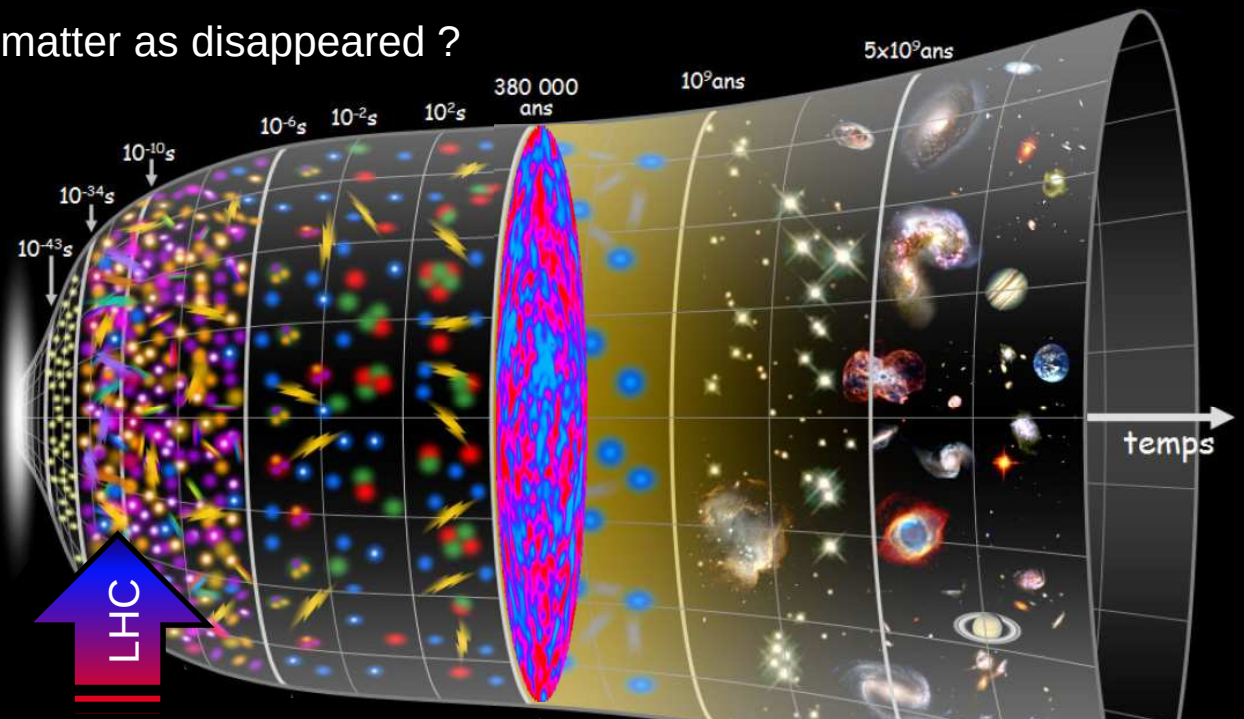
THE BIG PICTURE: STANDARD MODEL INCOMPLETE

Why the Universe is Accelerating ?

What the Dark Matter made of ?

Why antimatter as disappeared ?

What is the origin of inflation ?



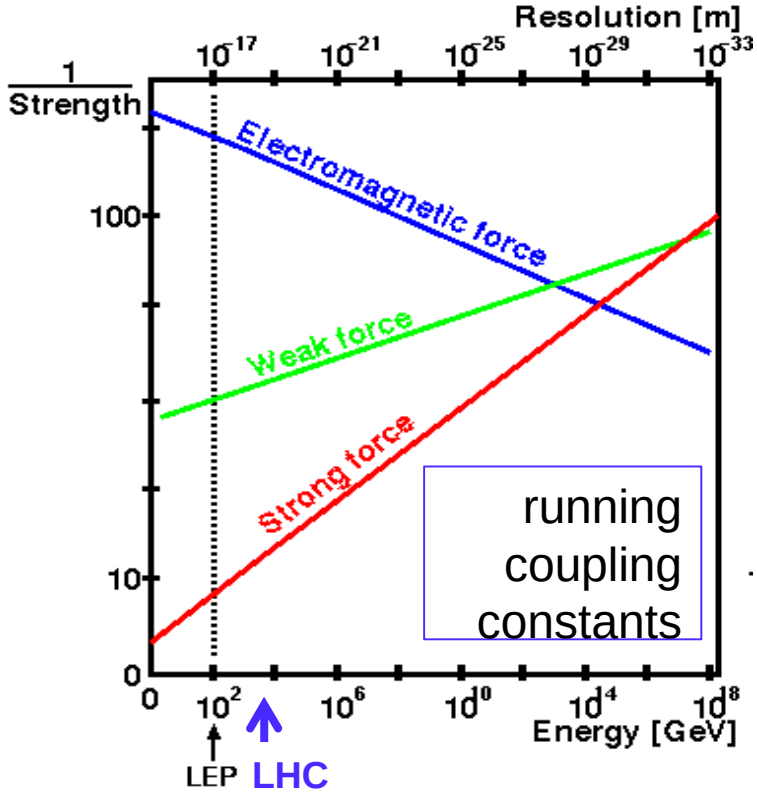
What is the theory beyond standard model :

- Extrapolating it at small scale & high energy
- With a microscopic description of gravity
- With a Gran Unification of Forces

SMALL SCALE & HIGH ENERGY EXTRAPOLATION
GRAND UNIFICATION

SMALL SCALE & HIGH ENERGY EXTRAPOLATION GRAND UNIFICATION

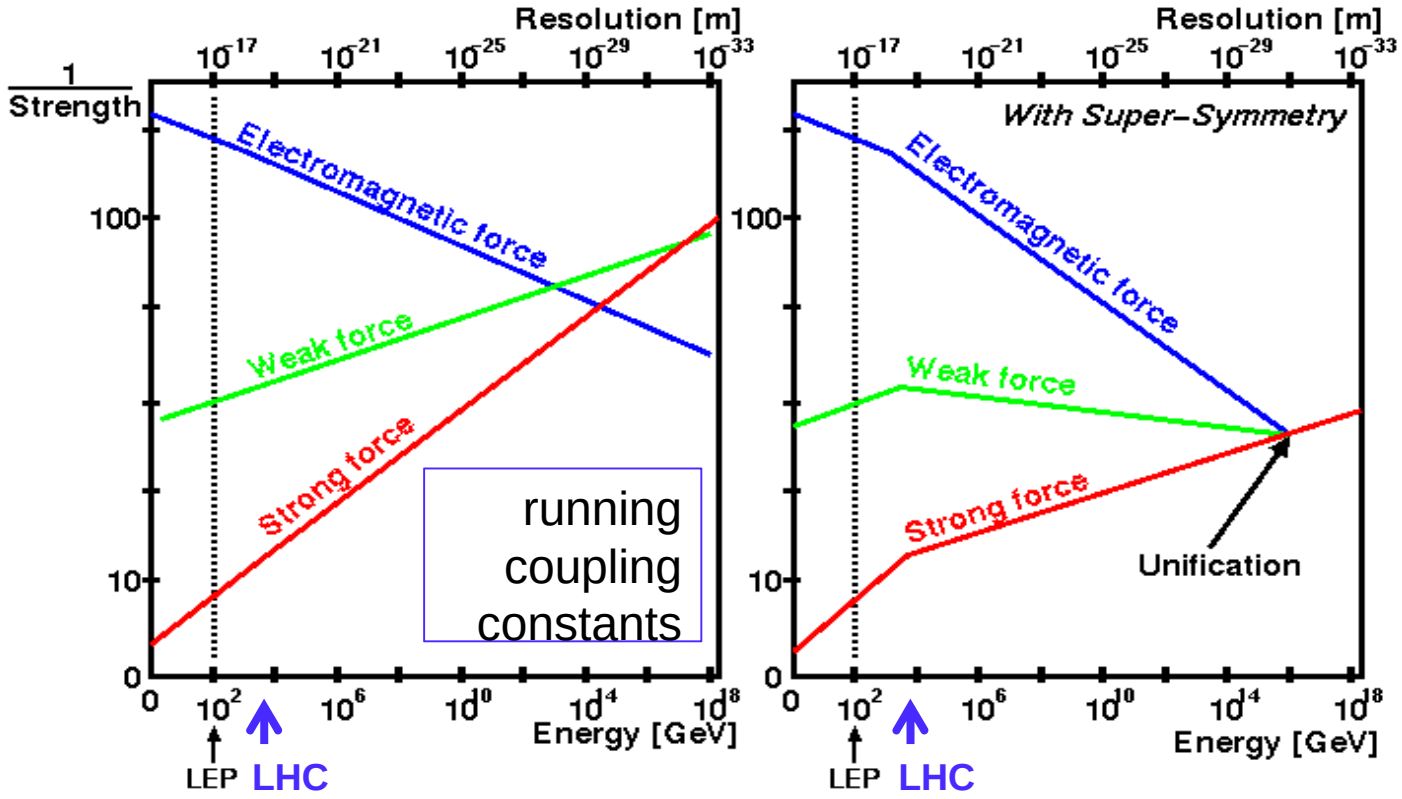
- Interaction strength varies with energy scale depending on available quantum numbers and particle species



Without new degree of freedom strong, weak and electromagnetic forces do not converge to a unified interaction

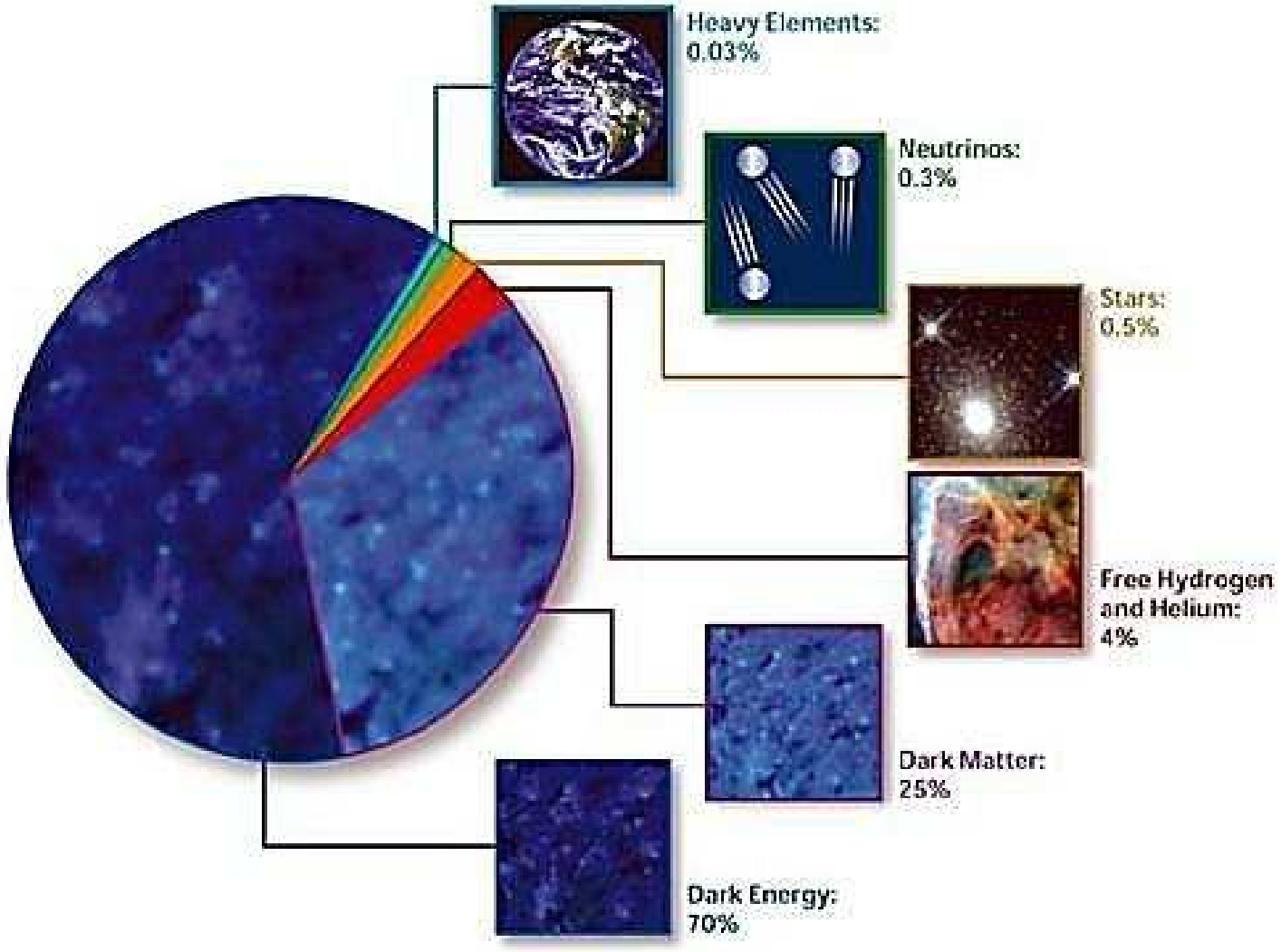
SMALL SCALE & HIGH ENERGY EXTRAPOLATION GRAND UNIFICATION

- Interaction strength varies with energy scale depending on available quantum numbers and particle species



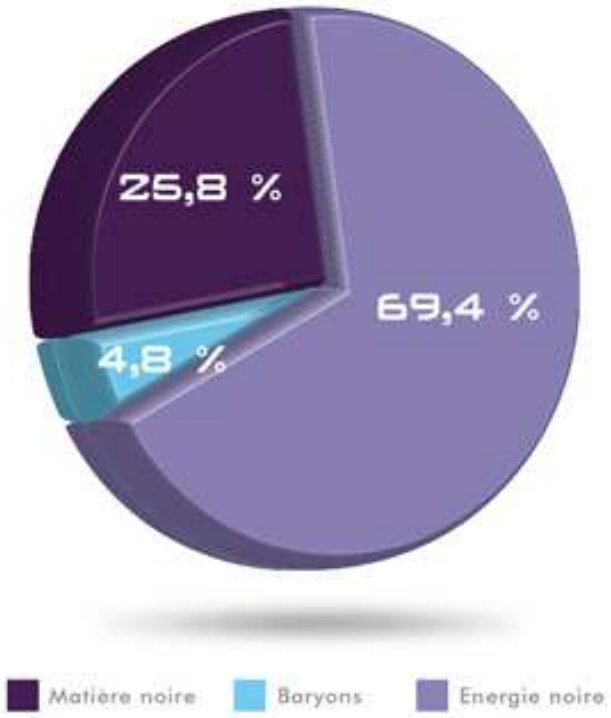
- **With new particle (eg super-symmetric) forces can unify**

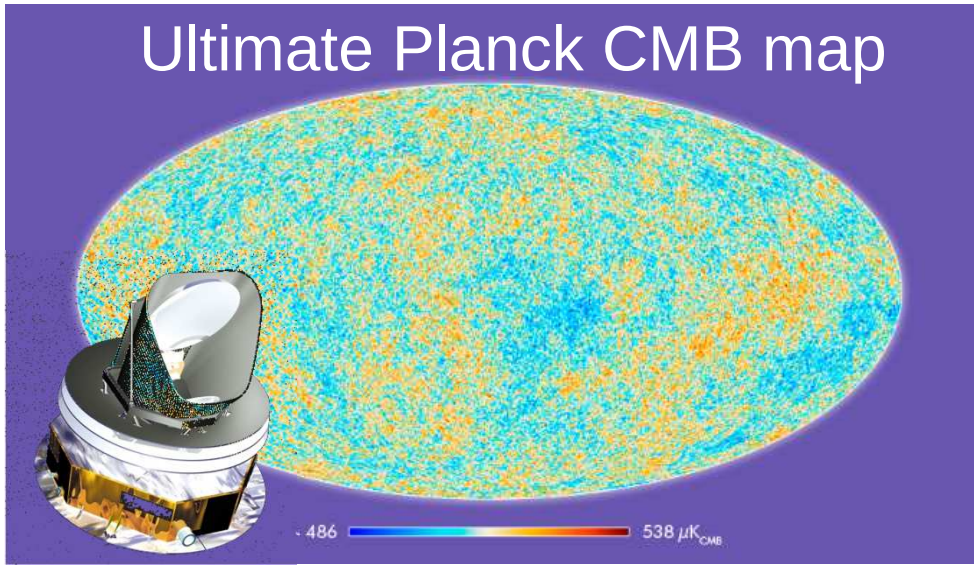
DARK UNIVERSE AND INFLATION



DARK UNIVERSE AND INFLATION

- 26% Dark Matter
  - New particles
- 69% Dark Energy
  - New fields & laws



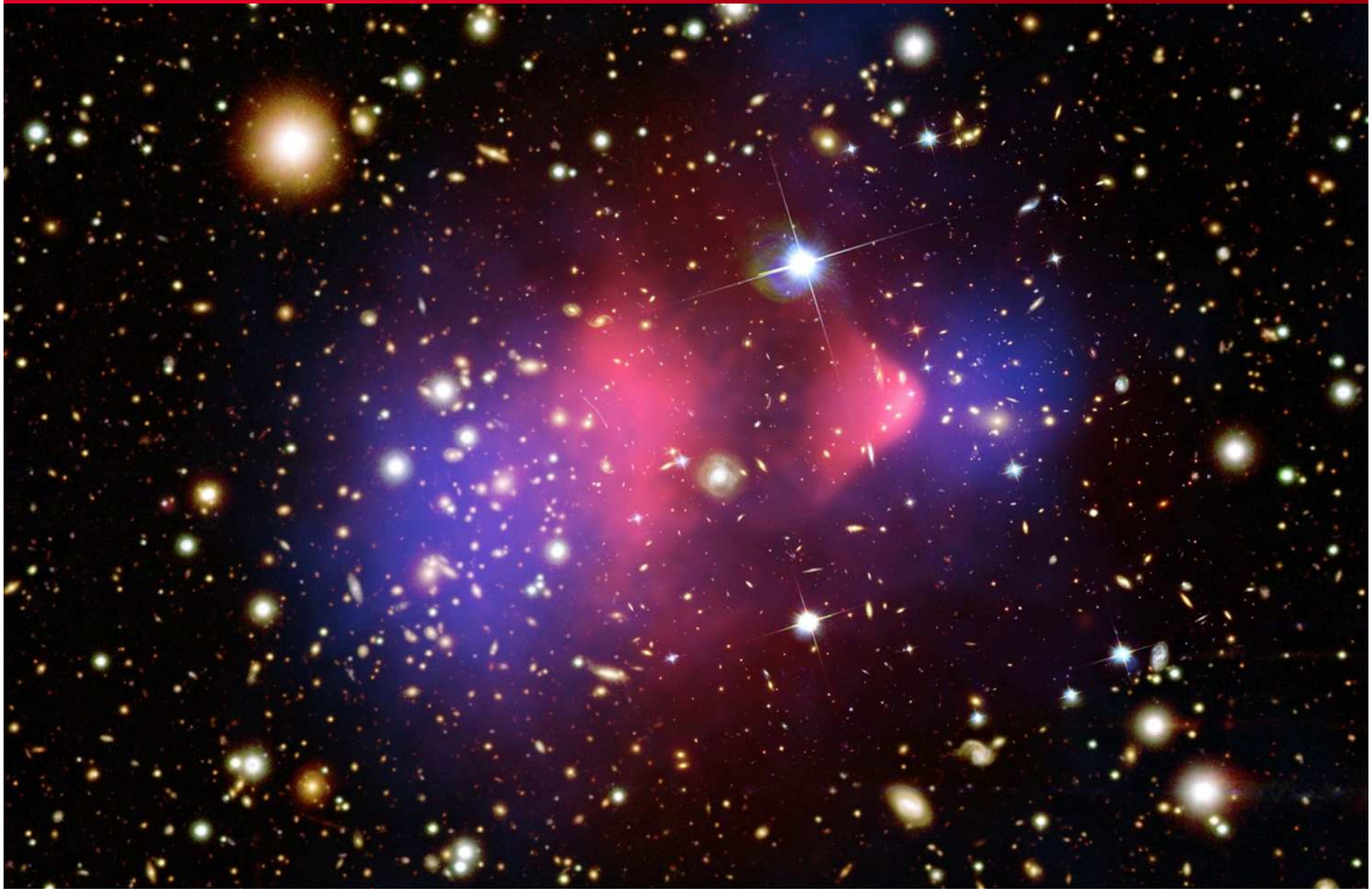


- Inflation (Fluctuation & polarisation)
  - New fields & laws
- Number of relativistic particle (neutrino) at 3000° (1/4 eV)
  N=3.30+/-0.27
  - Possible sterile neutrinos ?

DE LA RECHERCHE À L'INDUSTRIE

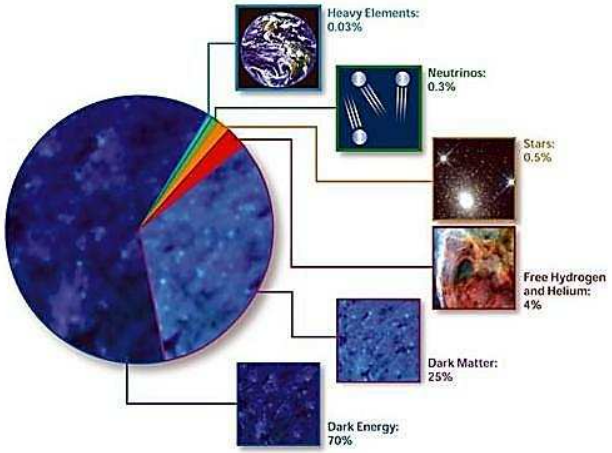
cea

DARK MATTER A WEAKLY INTERACTING GAS



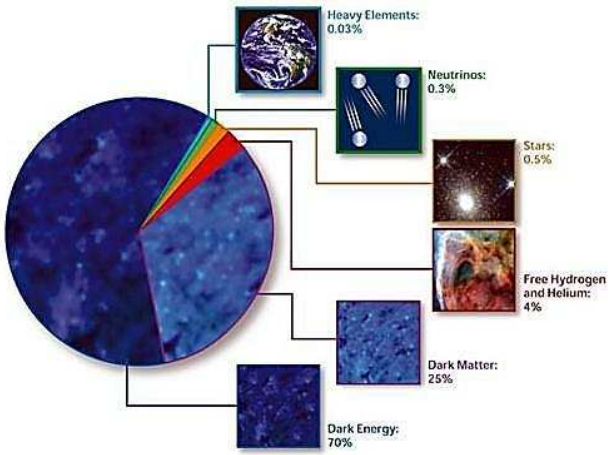
THE BIG PICTURE: STANDARD MODEL INCOMPLETE

- Small scale & high energy extrapolation, grand unification, gravity
- Dark matter
- Accelerating universe: Dark energy & inflation
- Antimatter disappearance



THE BIG PICTURE: STANDARD MODEL INCOMPLETE

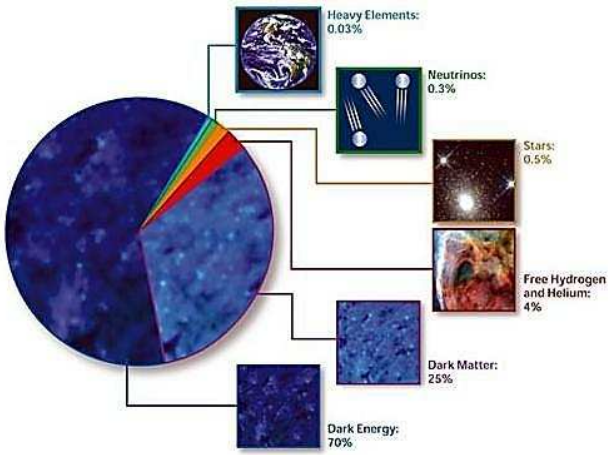
- Small scale & high energy extrapolation, grand unification, gravity
  - **New degrees of freedom & Laws**
- Dark matter
  - **New particles**
- Accelerating universe: Dark energy, inflation
  - **New fields & laws**
- Antimatter disappearance
  - **New symmetry violations**



New Physics (New Particles & phenomena) beyond Standard Model should exist

THE BIG PICTURE: STANDARD MODEL INCOMPLETE

- Small scale & high energy extrapolation, grand unification, gravity
  - **New degrees of freedom & Laws**
- Dark matter
  - **New particles**
- Accelerating universe: Dark energy, inflation
  - **New fields & Laws**
- Antimatter disappearance
  - **New symmetry violations**



New Physics (New Particles & phenomena) beyond Standard Model should exist

But at which energy scale

Direct Exploration of Higher Energy Scales

Precision measurements & rare process studies

- IV -

WHAT NEXT ?

THE 2013 EUROPEAN STRATEGY IN PARTICLE PHYSICS

A GLOBAL STRATEGY

In europe ie @Cern

Priority 1: Full exploitation of LHC with high luminosity upgrades

- Study of the new Higgs territory and test of standard model
- Search for new physics at the energy frontier around 14TeV

Priority 2: R&D and plans for possible future CERN machines

- Prepare a post LHC propositions to explore the energy frontier
- International collaboration on high field magnets and cavities

In the world

Priority 3: Discuss possible linear collider in Japan

- Precision machine for Higgs studies and standard model tests

Priority 4: major participation in neutrino projects in US and Japan

- CP violation and mass hierarchy
- R&D platform at CERN

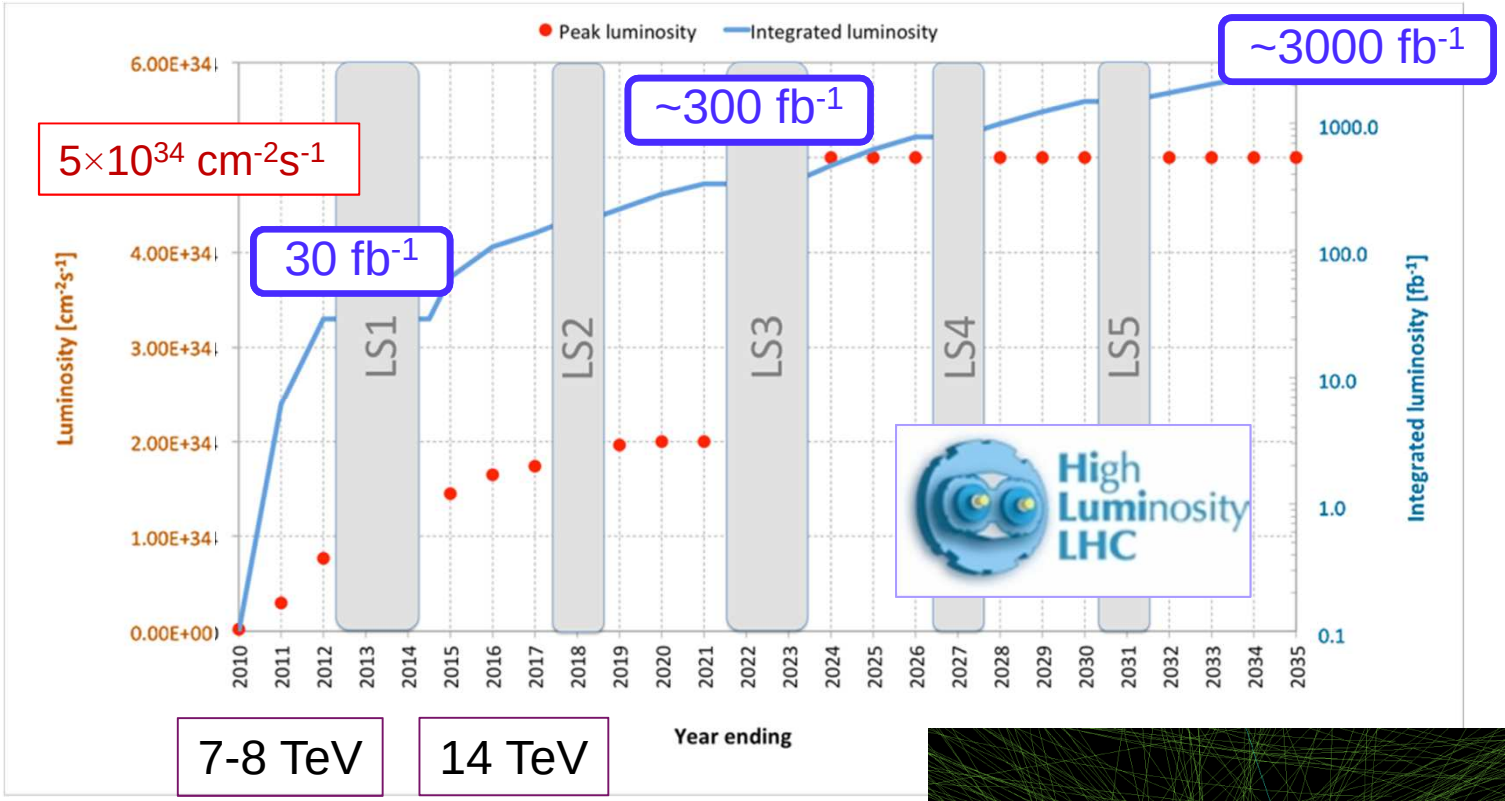
FULL EXPLOITATION OF LHC

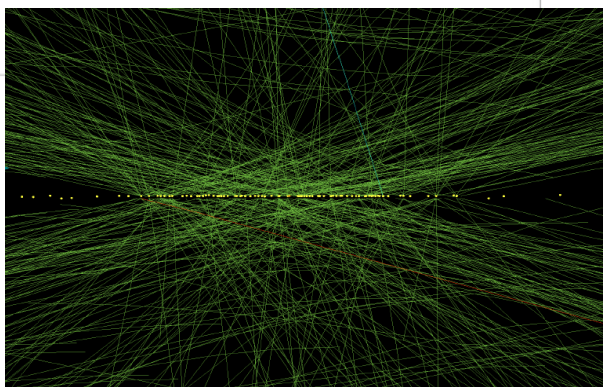
Priority 1: Full exploitation of LHC with high luminosity upgrades

- Study of the new Higgs territory and test of standard model
- Search for new physics at the energy frontier around 14TeV

Priorité 1) *The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.*
Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. *This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

FULL EXPLOITATION OF LHC



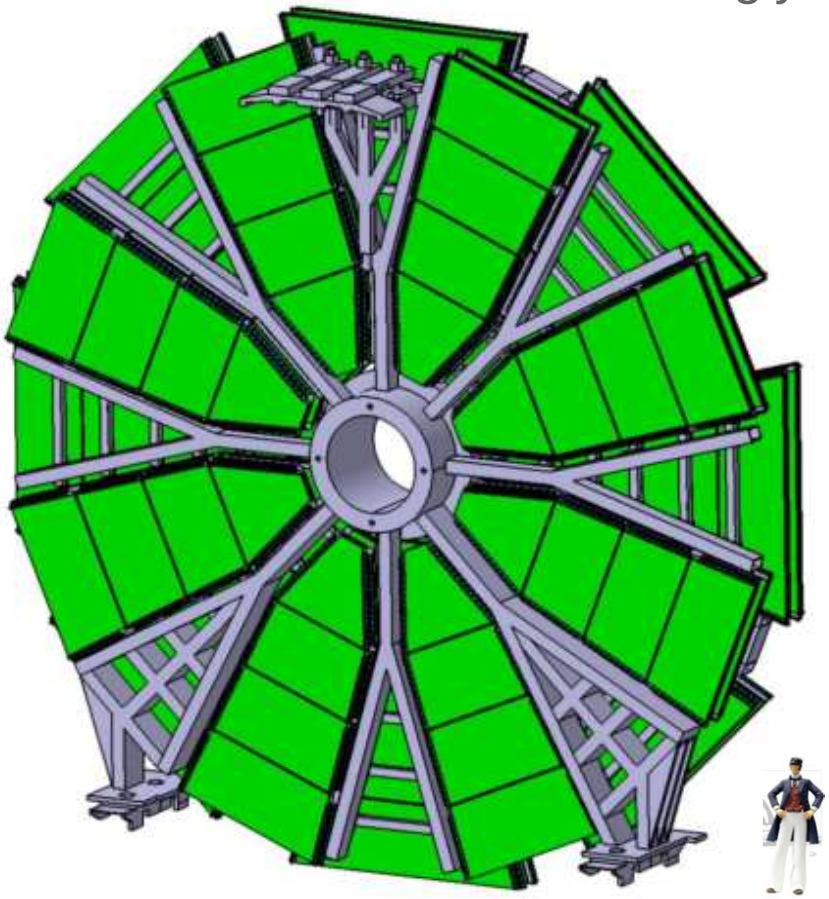


- 140 collisions per crossing => important upgrade of the detectors
- Important increase of luminosity thanks to new technologies

AN EXAMPLE OF LHC UPGRADE

Replacement of detectors parts to allow high flux

- CNRS/IN2P3 and CEA/Irfu strongly involved in upgrades (TGI budgets)



Ex: Replacement of ATLAS “small” weels

- using advance tracking technology
- invented in France
- and transferred to French industry

10 000 m² micromegas

Priority 2: R&D and plans for possible future CERN machines

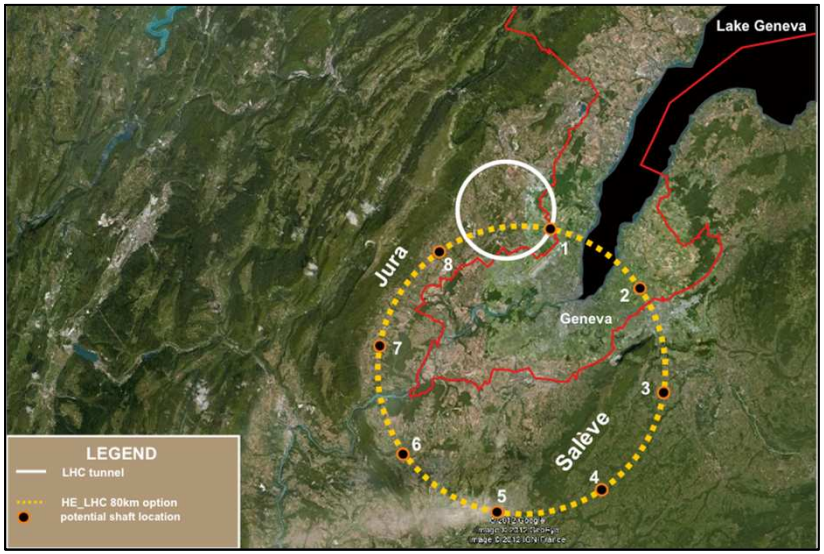
- Prepare a post LHC propositions to explore the energy frontier
- International collaboration on high field magnets and cavities

Priorité 2) *To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available.* ***CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.***

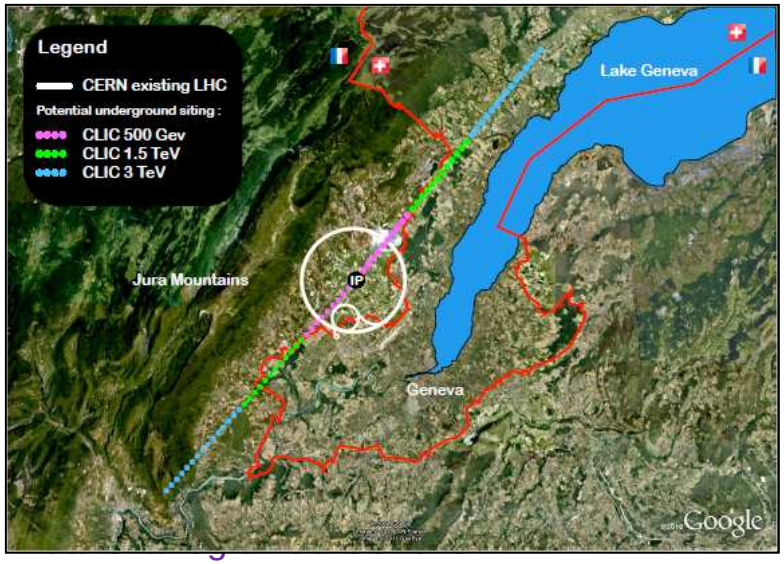
PRECISION AND ENERGY FRONTIERS

“Science fiction” projects at the technology frontier
Design Studies and Ambitious R&D

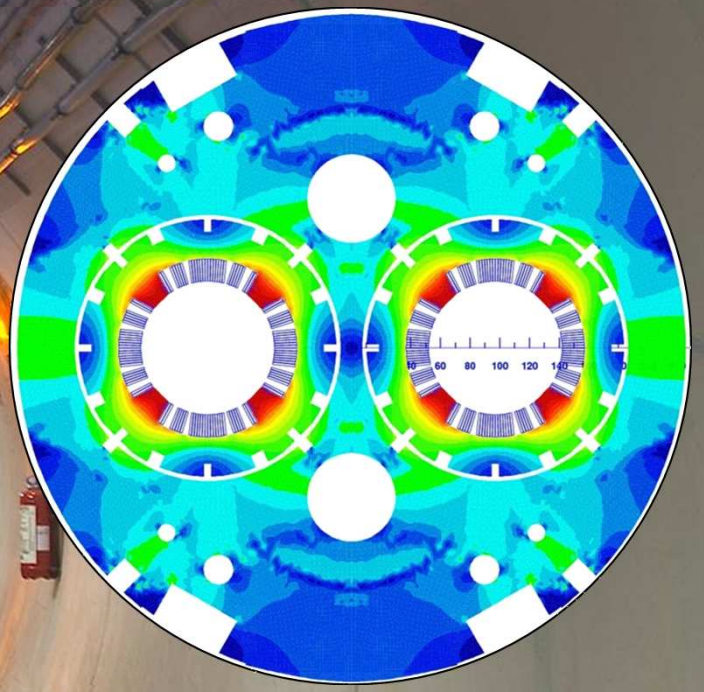
- An Ultra large collider to reach 100TeV an order of magnitude larger thenLHC
  ➔ **Energy frontier**



- A linear e+ e- collider at high energy
  ➔ **Precision frontier**



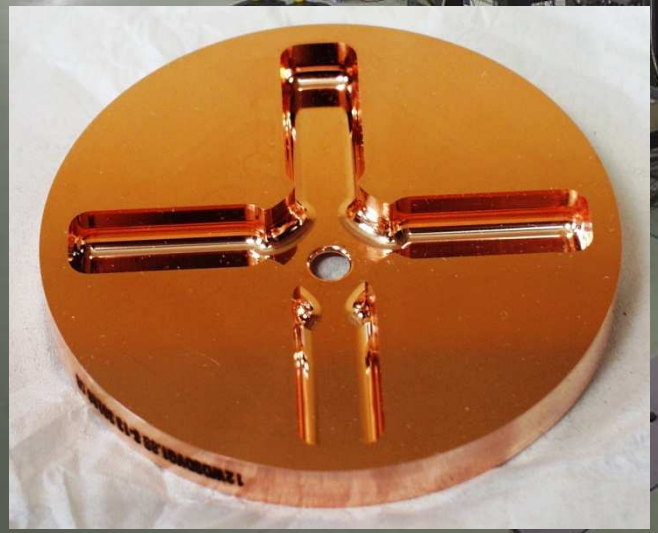
STRONG R&D ON HIGH FIELD MAGNETS



Strong collaboration between France & CERN

- **Large aperture quadripoles NbTi, 5,9T @ 1,9K ➔ high luminosity**
- **Dipole Nb3Sn, 13T @ 4.2K ➔ High energy**
- **HTc (YBaCuO) Insert 5T ➔High energy**

R&D COMPACT LINEAR COLIDER



Strong collaboration (exceptional contribution) :

- **Electron accelerator CALIFES**
- **Innovative accelerating structure with the French industry**
- **Development of 12GHz-10MW klystron**

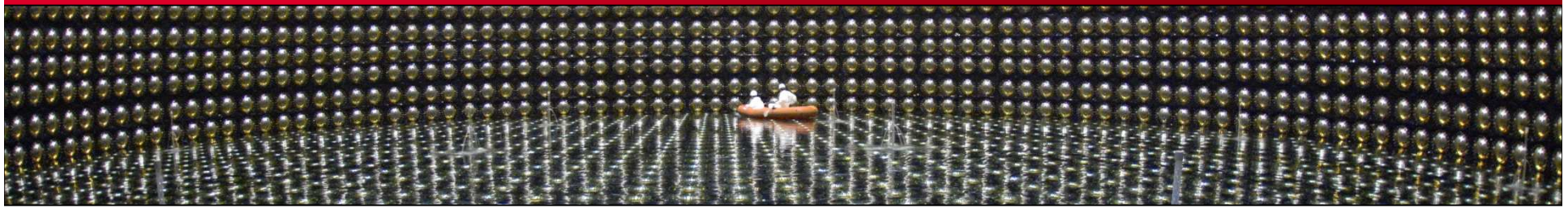
ILC ET PROJETS NEUTRINOS LONG-BASELINE

Priority 3: Discuss possible linear collider in Japan

- Precision machine for Higgs studies and standard model tests

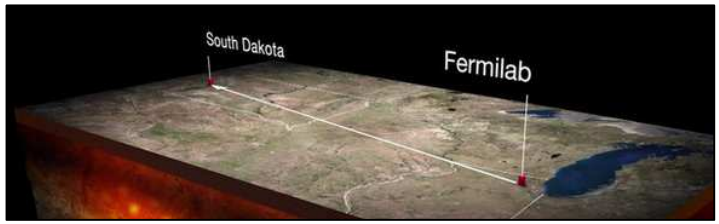
> ***Priorité 3)*** *There is a* ***strong scientific case for an electron-positron collider****, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate.* ***Europe looks forward to a proposal from Japan to discuss a possible participation.***

LONG-BASELINE NEUTRINOS



Priority 4: major participation in neutrino projects in US and Japan

- CP violation and mass hierarchy
- R&D platform at CERN



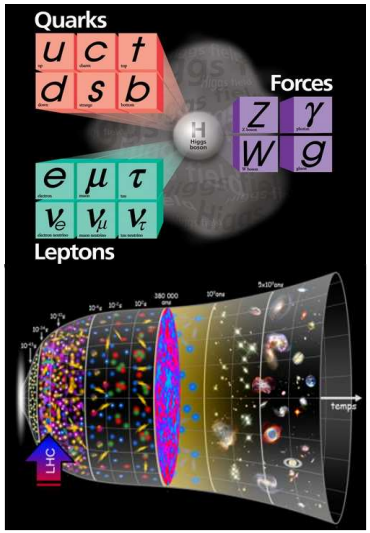
Priorité 4) *Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments.* ***Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.***

- IV -

CONCLUSION

TIME OF
EXTRAORDINARY
DISCOVERIES

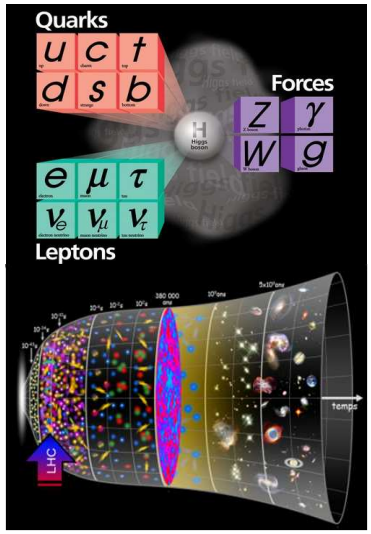
EUROPEAN STRATEGY: A GLOBAL VISION

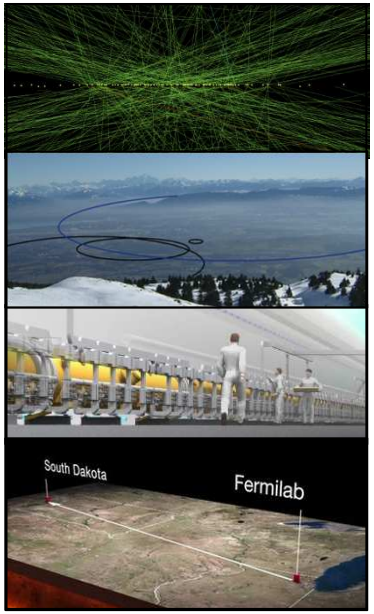


Science drivers

- **Discoveries open of new territories to be explored**
  Higgs, neutrinos, top, W&Z, precision measurements
- **Unsolved mysteries: physics beyond standard model**
  - Small scale extrapolation, grand unification, gravity
  - Dark matter, Dark energy and inflation
  - Antimatter disappearance

EUROPEAN STRATEGY: A GLOBAL VISION





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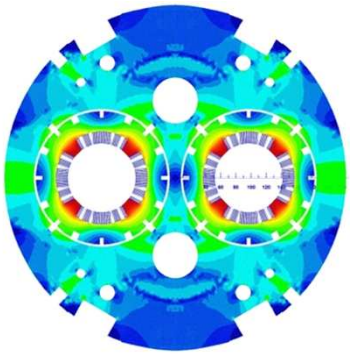

Global projects in Europe @ CERN

- **LHC @14TeV and upgrade up to 30th**
  - Higgs and new physics
- **Long term future:** Explore the energy frontier

Global Projects in other regions

- **Possible linear collider in Japan:** Higgs and precision
- **Possible neutrino oscillation projects:** CP & masses

Smaller scale projects

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex

Etablissement public à caractère industriel et commercial | RCS Paris B 775 685 019

Direction des Sciences de la matière
Institut de Recherche sur les lois Fondamentales de l'Univers
Direction