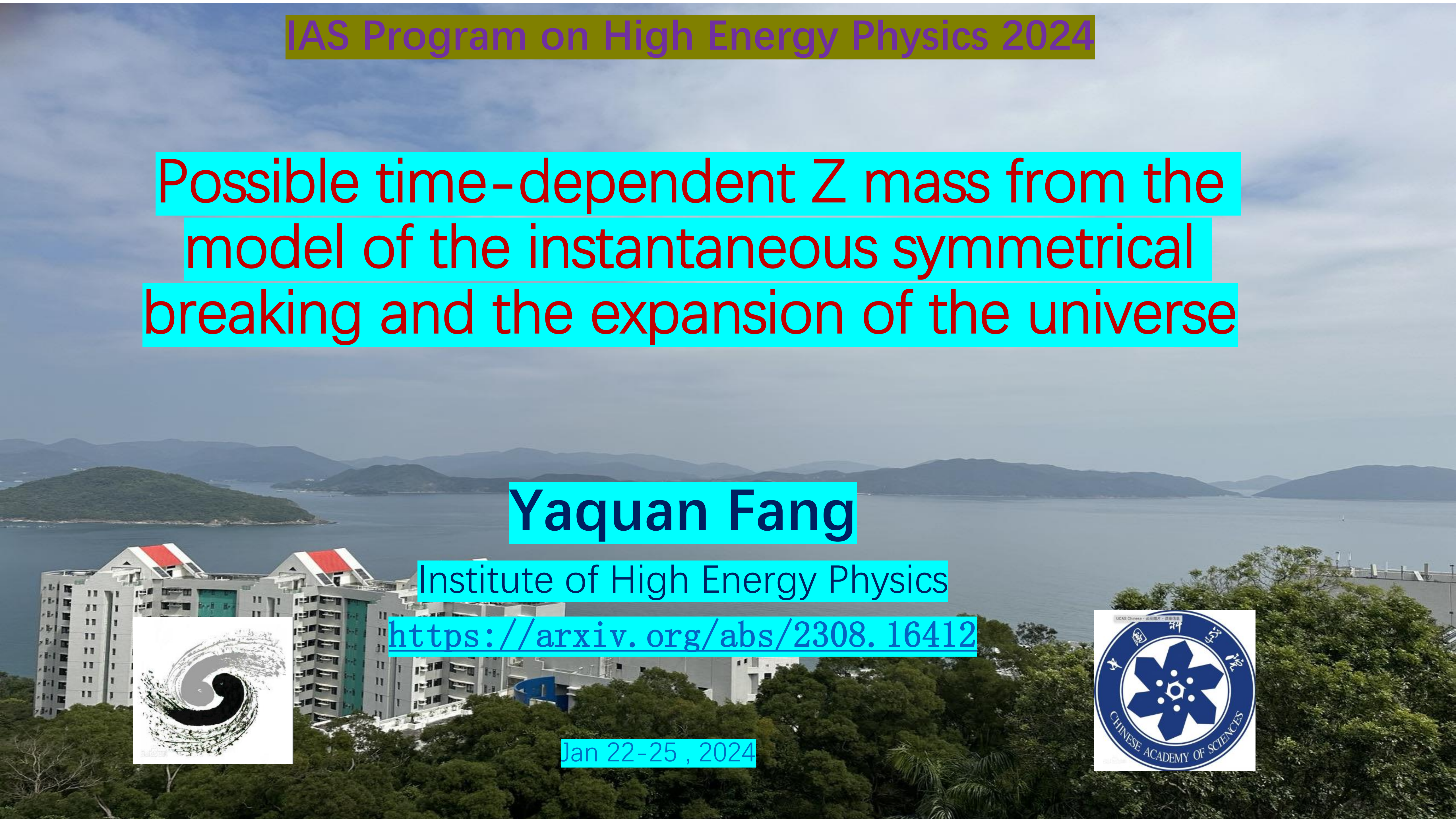

IAS Program on High Energy Physics 2024

Possible time-dependent Z mass from the model of the instantaneous symmetrical breaking and the expansion of the universe

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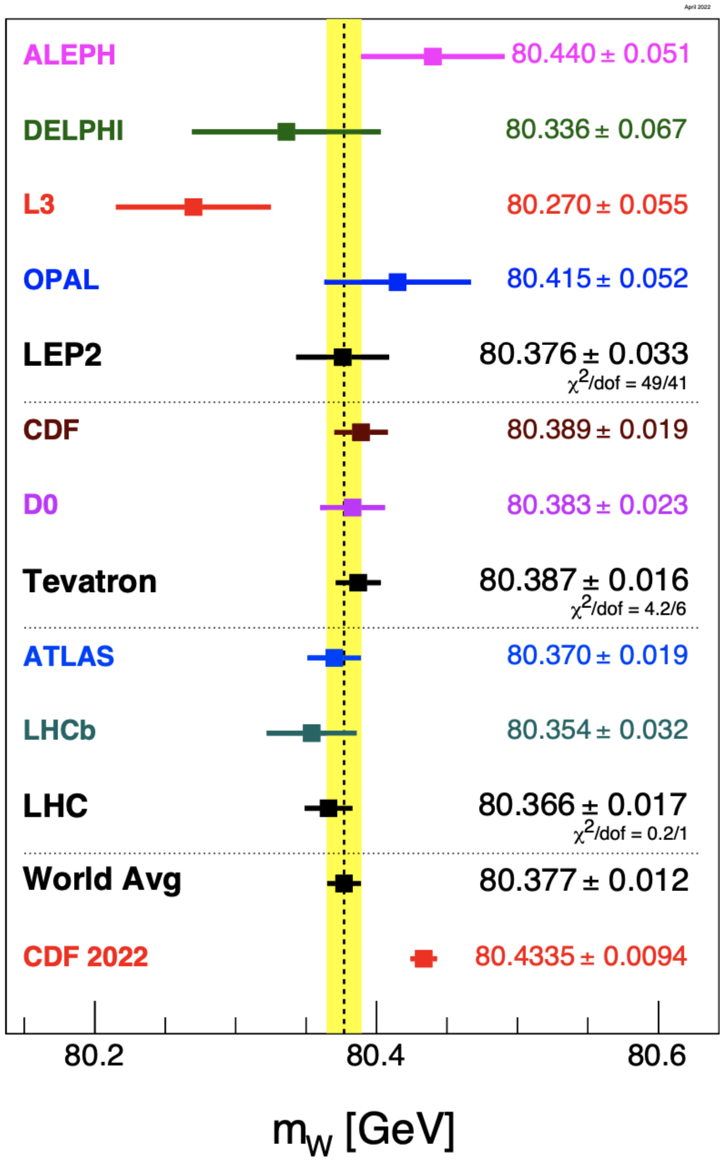
Institute of High Energy Physics

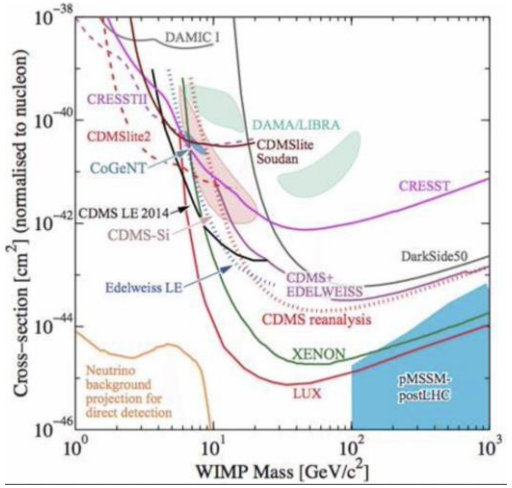
https://arxiv.org/abs/2308.16412

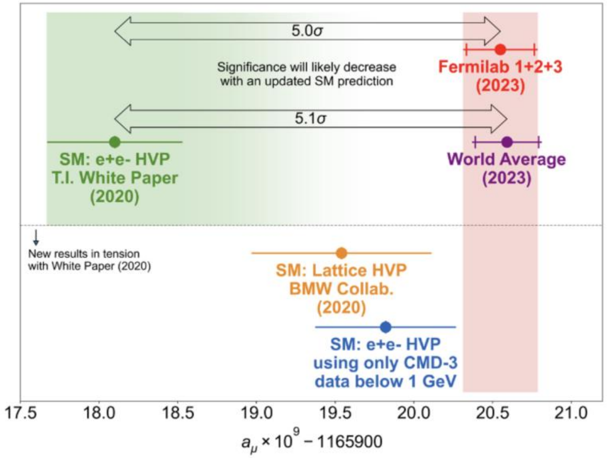
Jan 22-25 , 2024

Motivation

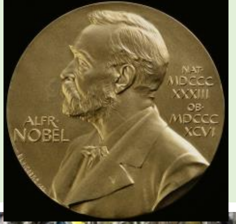
- ➢ The mechanism of electroweak symmetry breaking has been verified with the ATLAS and CMS experiment at the LHC in 2012
  - ✓ Higgs discovery & the Standard Model success
- ➢ However, issues or questions are still in puzzle:
  - ✓ Why cannot observe the dark matter while it is demanded in the Astrophysics?
  - ✓ Excess at Muon g-2
  - ✓ Incompatibility of the W-mass measurements from CDF



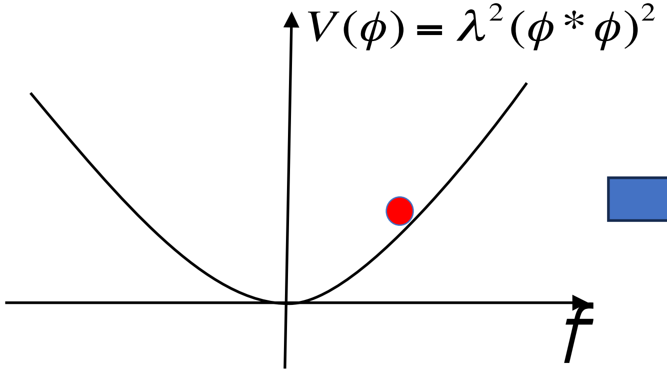


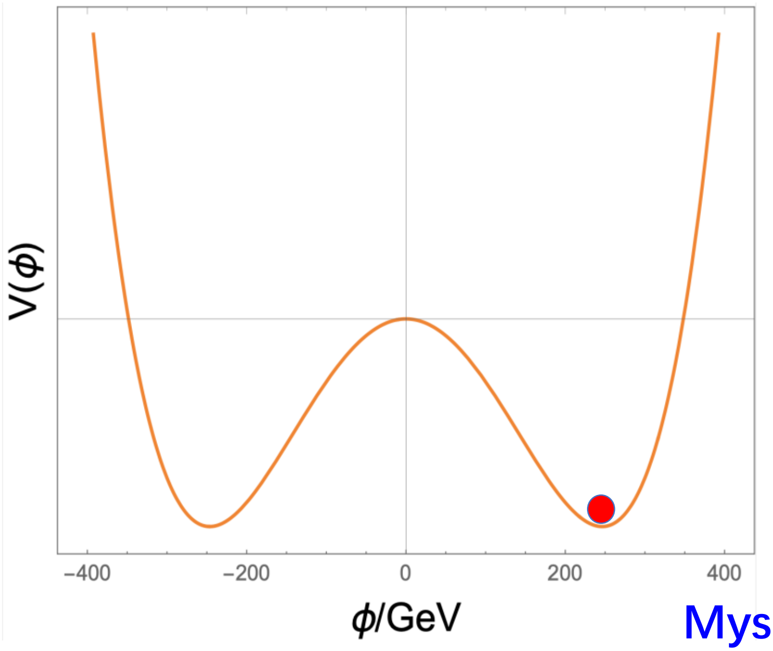


Higgs Potential: Stable Symmetry Breaking (SSB)



Symmetry breaking leads to mass





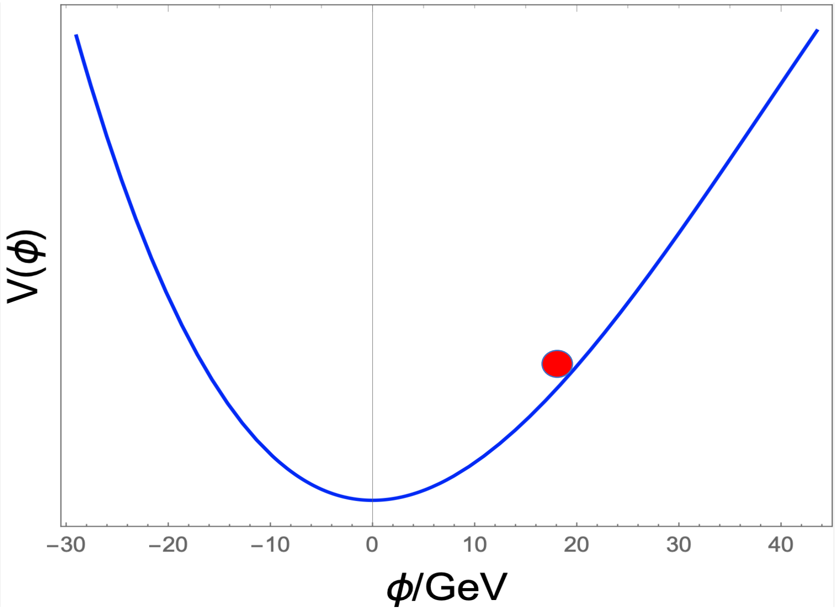
- **Proposed by Peter Higgs et al.**
- **The vacuum expectation value (VEV)~246 GeV**
  - ✓ **Stable Symmetry breaking (SSB)**
  - ✓ **Lead to observable mass for fundamental particles.**
- **However,**
  - ✓ **could not find the experimental evidence of the dark matter coupling with the fundamental particles.**

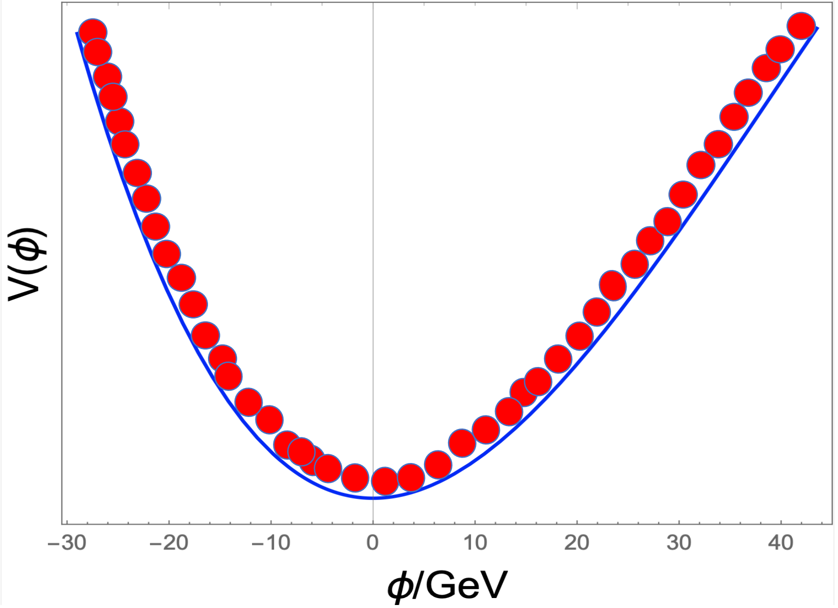
Mysterious term: (Where $\mu^2<0, \lambda^2>0$)

$$L = (\partial^\mu + ieA^\mu)\Phi^*(\partial_\mu - ieA_\mu)\Phi - \boxed{\mu^2\Phi^*\Phi} - \lambda^2(\Phi^*\Phi)^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

What is the Instantaneous Symmetry Breaking (ISB) ?

Assume there is an asymmetrical potential:



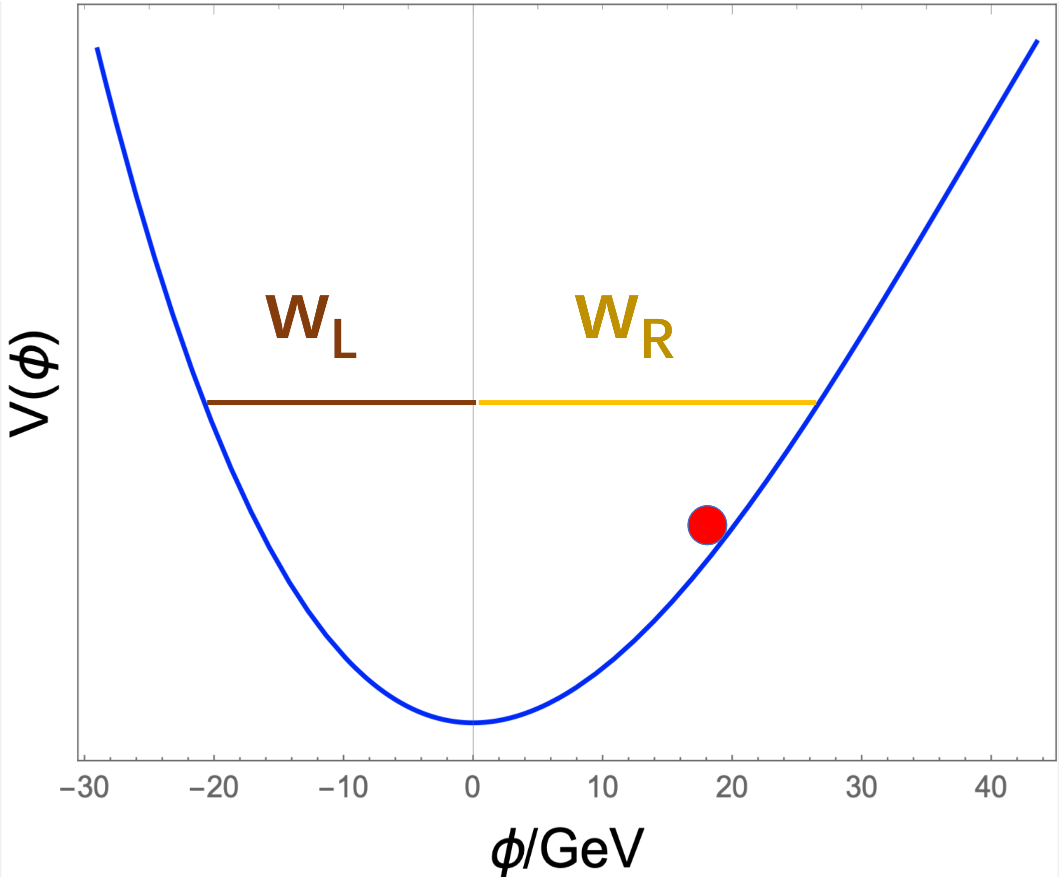


- For a symmetry breaking with the above asymmetrical potential (left plot), the “ball” will go to the center, yielding a VEV=0.
- Now assume the Symmetry breaking with very high frequency (right plot):
  - ✓ Instantaneously, (the balls show) asymmetrical behavior due to asymmetrical potential, → has mass effect, involves the gravitational force.
  - ✓ but since VEV = 0 for each breaking, it cannot interact with any fundamental particle (non-observable)
  - ✓ Does not need to follow QFT.

Asymmetrical Potential: Instantaneous Symmetry Breaking (ISB)

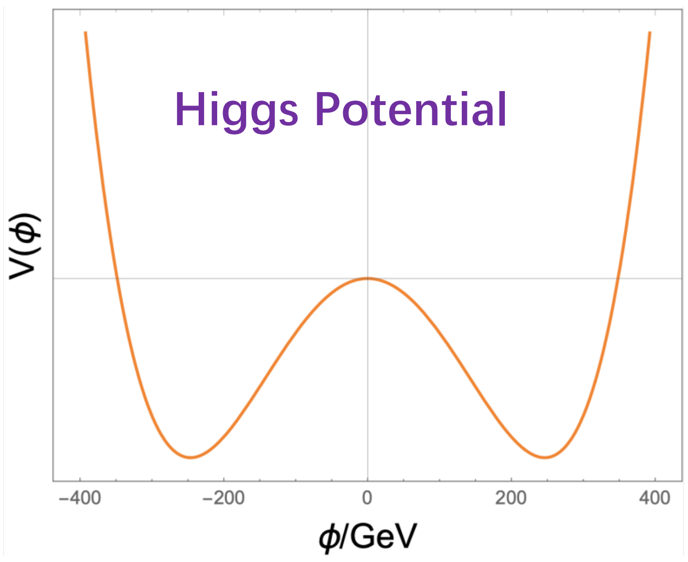
Asymmetry leads to mass effect

The potential here just a way showing how the symmetry breaks.



- ➢ The double Gaussian centered at zero is used as an model to represent the asymmetrical potential.
  - ✓ VEV = 0 and non-observable mass.
- ➢ When $W_L=W_R$, it degenerates into a single Gaussian and symmetrical.
- ➢ When W_R goes higher and higher, the potential is more and more asymmetrical.
  - ✓ So W_R-W_L can serve an indicator qualifying the asymmetry.
- ➢ Imagine the vacuum with this potential vibrates with very high frequency f_d,
  - ✓ f_d*(W_R-W_L) can be used to describe the effect of mass for the non-observable matter (i.e. dark matter).
  - ✓ It characterizes the asymmetry of ISB.
- ➢ Unfortunately, this potential is not renormalizable.

Combination of Different Potentials



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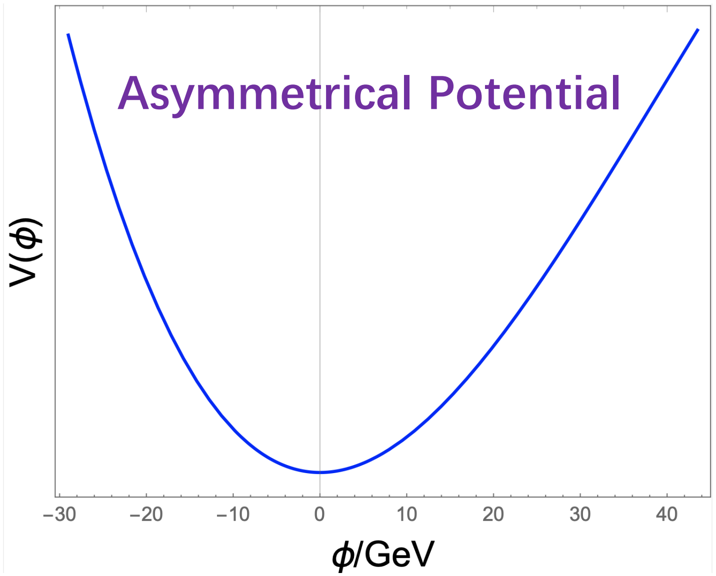
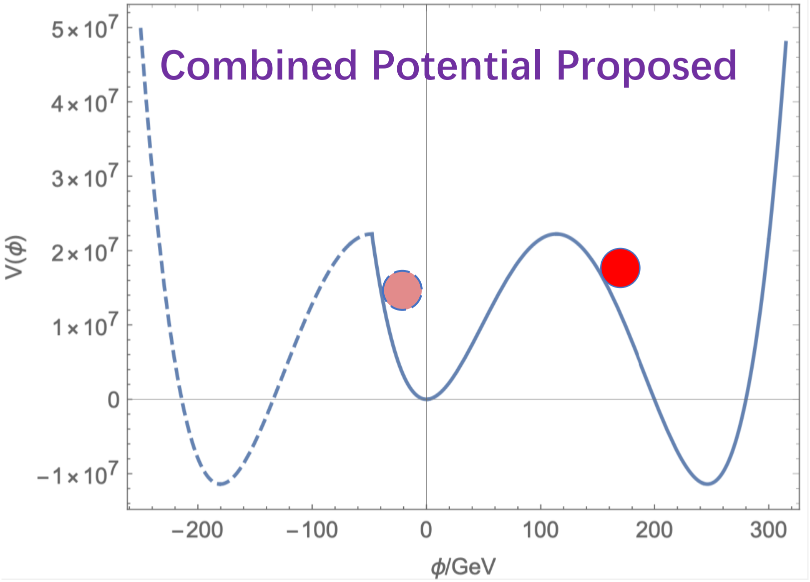
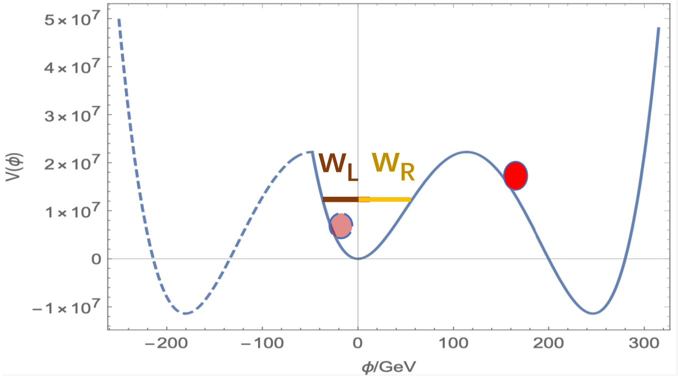


⟹



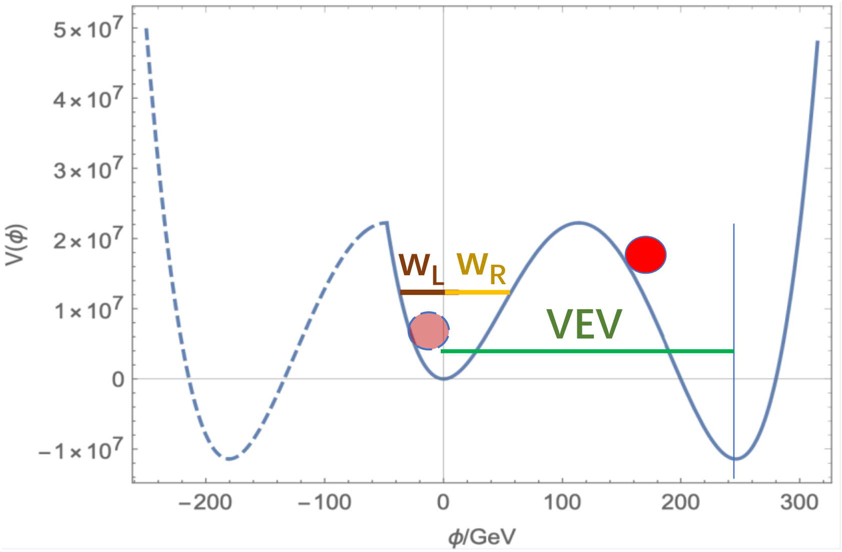
- The vacuum with the potential shown in the right plot vibrates.
  - ✓ The frequency is very high
  - ✓ Only few vibrations with strong strength can break through the central pitfall, end up with SSB.
  - ✓ The ISB at the central potential with high frequency will render the effect of the mass, but no coupling with fundamental particles (can not be observed, <VEV>=0)
- If the central potential is absorbed to one point, the model can be simplified as the Higgs potential.

Two Parameters for ISB/the Relation with the Dark Matter and Dark Energy



- **Frequency**： the symmetry in particular for ISB is breaking very intensively
  - ✓ Most within the central potential, only very few beyond the central potential causing the production of mass/matter.
    - The former ：f_d (frequency for dark matter); The latter: f_m (frequency for the matter)
  - ✓ During the expansion of the universe: the frequency of dark matter is larger than that of matter $f_d > f_m$
- **The expected strength**： is to describe the capacity of the symmetry breaking :
  - ✓ For ISB, it can be characterized with $(W_R+W_L)/2$.
    - The source of the dark energy for ISB
      - ☐ If the dark energy is higher (equivalently $W_{R/L}$ is higher), it is easier to break through the central well to produce more visible matter.
      - ☐ $f_d \frac{1}{2}(W_L + W_R)$ can be used to describe the overall strength of the dark energy
  - ✓ For SSB, VEV can be employed to describe this capacity.

Some Derivations



Input of current ratios:
Dark matter : 27%
Dark Energy : 68%
Matter : 5%

Dark matter vs Dark energy : $$\frac{f_d\cdot(W_R-W_L)}{f_d\cdot\frac{1}{2}(W_R+W_L)} \sim \frac{M_{dark\,matter}}{M_{dark\,energy}}$$

Dark matter vs matter : $$\frac{f_d\cdot(W_R-W_L)}{f_m\cdot VEV} \sim \frac{M_{dark\,matter}}{M_{matter}}$$

- ✓ $W_R = 1.5\,W_L$
- ✓ $\frac{W_L}{VEV} \sim 10.8\,\frac{f_m}{f_d}$
- ✓ $W_L < VEV$ *for the expanded universe*:

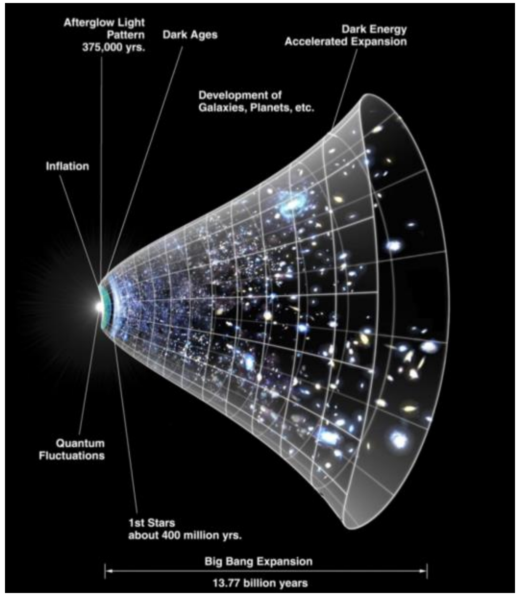
$\frac{f_d}{f_m} > 10.8$

- ✓ If $W_L \sim O(1)$ *MeV, mass of electron*:,

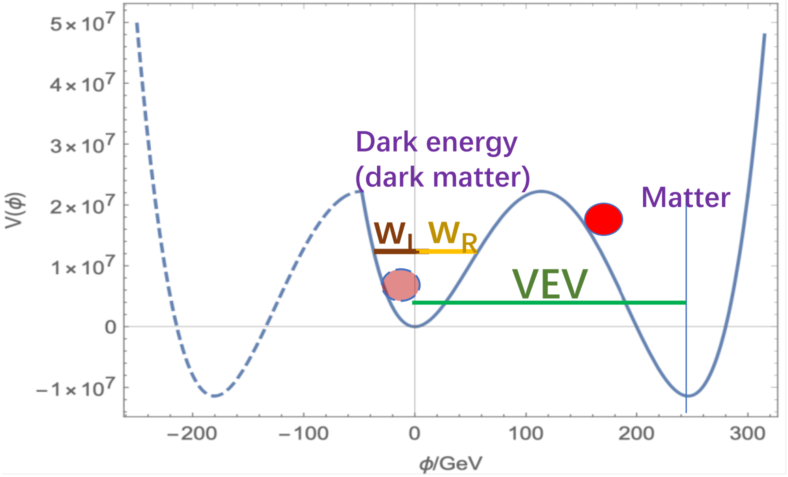
  $\frac{f_d}{f_m} \sim O(10^6)$

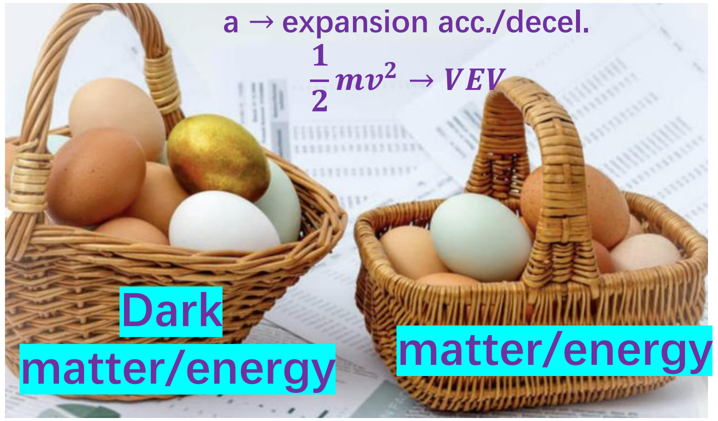
  - ✓ The ratio is very amazing

Universe Model： Expansion and Contraction



Conservation law ： $f_d \cdot \frac{1}{2}(W_R + W_L) + f_m \cdot VEV = constant$

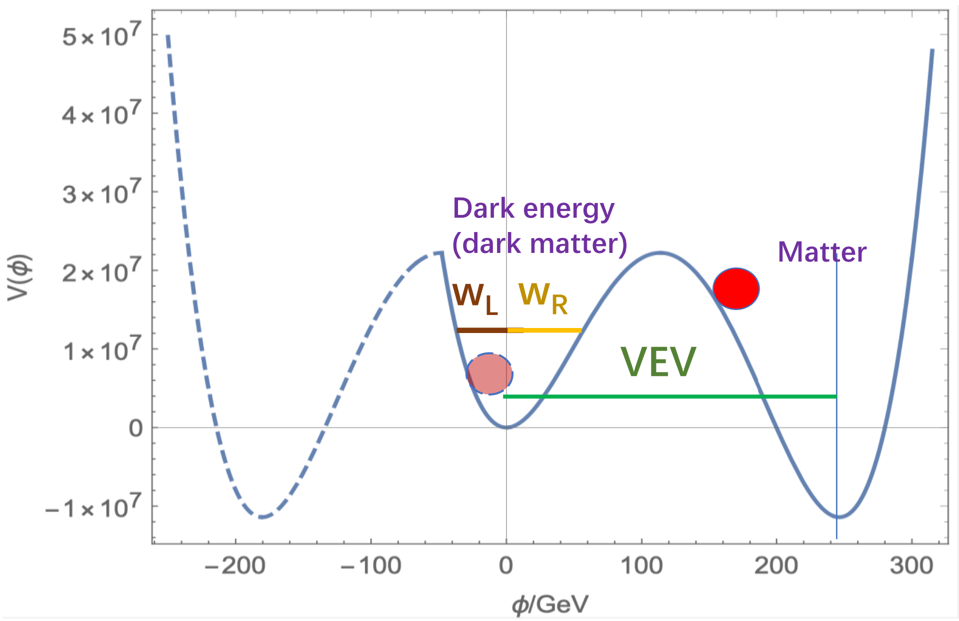




- ➢ From the conservation law： the overall capacity of symmetry breaking for the matter increases/decreases, the one for the dark energy decreases/increases.
- ➢ The universe has four phases :
  - ✓ Expanding acceleratively：more ISB can go beyond the central potential, VEV goes higher, $f_{d/m}$ goes lowers.
    - ✓ More and more energetic in Symmetry breaking resulting in higher SSB.
  - ✓ Expanding deceleratively：Less ISB can go beyond the central potential, VEV goes lower, $f_{d/m}$ higher
  - ✓ Contracting acceleratively : SSB absorbed into ISB, W_L/W_R decreases & f_d increases.
  - ✓ Contracting deceleratively： W_L/W_R increases, SSB show up & f_d decreases.

} Not discussed

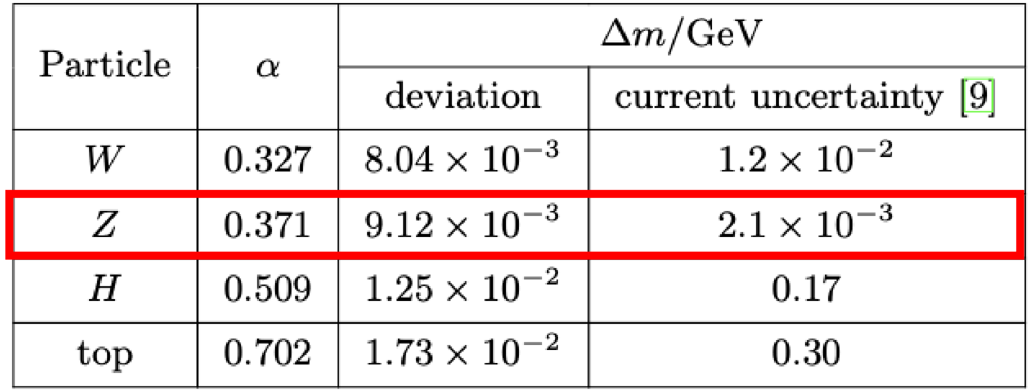
Where are we now and how to verify it ?



$$m = \alpha V$$

$$\frac{\Delta m}{m} = \frac{\Delta V}{V}$$

Z is the best choice



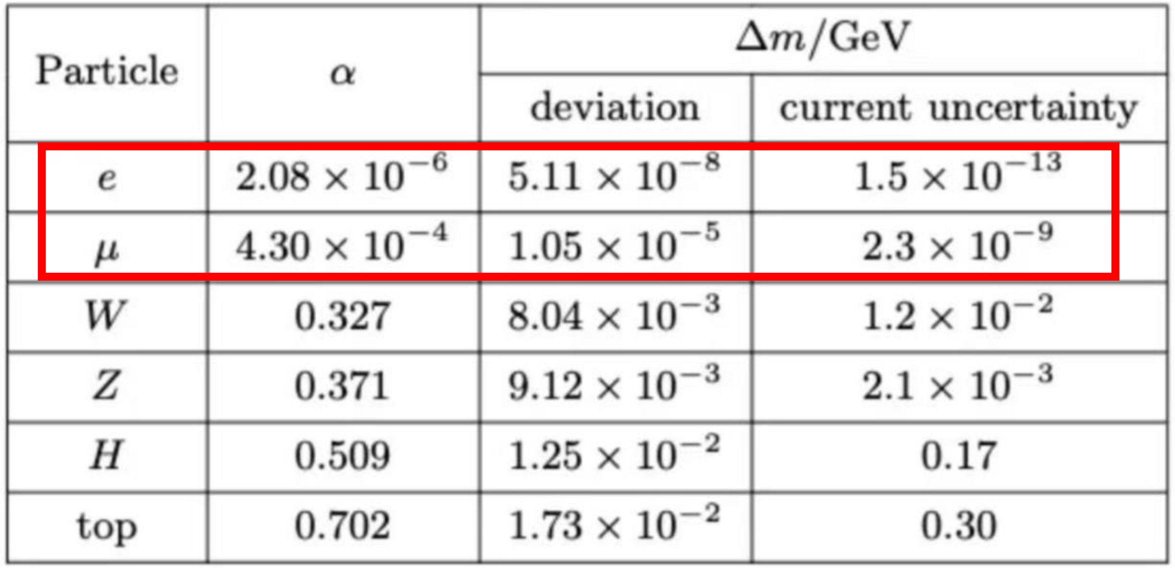
Particle	α	$\Delta m/\mathrm{GeV}$	
		deviation	current uncertainty [9]
W	0.327	8.04×10^{-3}	1.2×10^{-2}
Z	0.371	9.12×10^{-3}	2.1×10^{-3}
H	0.509	1.25×10^{-2}	0.17
top	0.702	1.73×10^{-2}	0.30

- The masses of the fundamental particles are proportional to VEV (V)
  - VEV varies at the different phases of the universe : e.g. VEV increases when the universe expands acceleratively, leading to the variation of the masses for the fundamental patricles.
- By measuring the mass for these heavy fundamental particles over time, it is possible to figure it out where we are.
  - The top-right table shows one example: the expected deviations of the masses for W,Z,H and top assuming $\frac{\Delta V}{V} \sim 10^{-4}$ and the current precisions from the colliders.

Why don't we consider electron and muon?

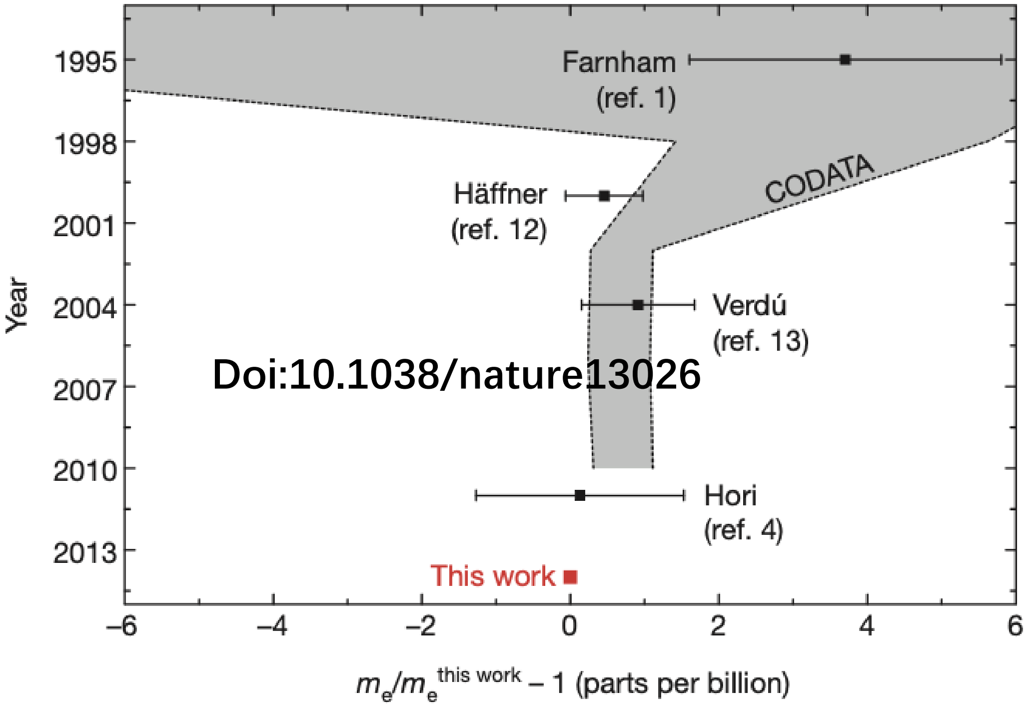
$$m = \alpha V$$

$$\frac{\Delta m}{m} = \frac{\Delta V}{V}$$



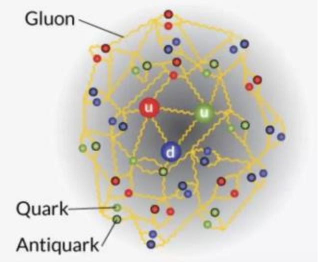
Particle	α	$\Delta m/\mathrm{GeV}$	
		deviation	current uncertainty
e	2.08×10^{-6}	5.11×10^{-8}	1.5×10^{-13}
μ	4.30×10^{-4}	1.05×10^{-5}	2.3×10^{-9}
W	0.327	8.04×10^{-3}	1.2×10^{-2}
Z	0.371	9.12×10^{-3}	2.1×10^{-3}
H	0.509	1.25×10^{-2}	0.17
top	0.702	1.73×10^{-2}	0.30

$$m_e = \frac{g}{2}\frac{e}{q}\frac{\nu_{\mathrm{cyc}}}{\nu_L} m_{\mathrm{ion}} \equiv \frac{g}{2}\frac{e}{q}\frac{1}{\Gamma} m_{\mathrm{ion}}$$



Doi:10.1038/nature13026

- ➢ Although the deviations are expected to be much larger for the mases of electron and muon given $\frac{\Delta V}{V} \sim 10^{-4}$
- ➢ The $m_{e/\mu}/m_p$ are actually measured:
  - ✓ It is difficult to say whether these follow $m = \alpha V$ for the proton and the impact could be cancelled as well.



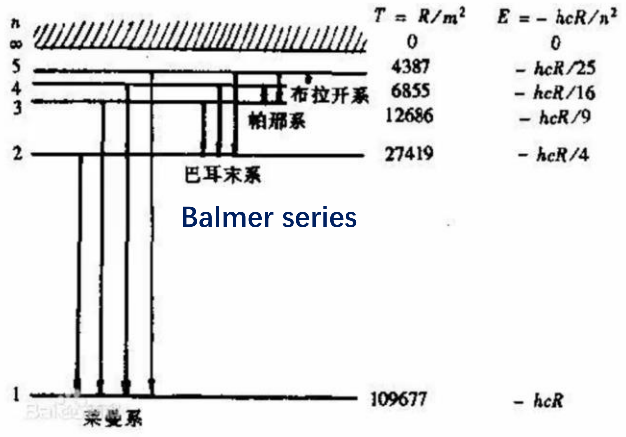
But the measurements of Rydberg constant hint ……

Rydberg Constant

$$R_\infty = \frac{m_e e^4}{8\varepsilon_0^2 h^3 c}$$

In the science of spectroscopy, under physics, the Rydberg constant is a physical constant relating to atomic spectra. It is denoted by R_∞ for heavy atoms and R_H for Hydrogen. Rydberg constant was first arising from the Rydberg formula as a fitting parameter. Later, Neils Bohr calculated it from fundamental constants.

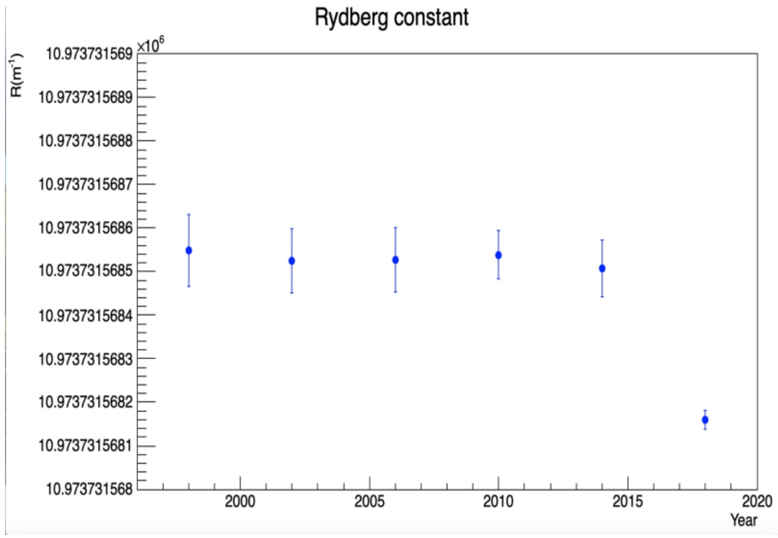
PDG book: $R_\infty = 10973731.568508(65)\ m^{-1}\ (2018)$



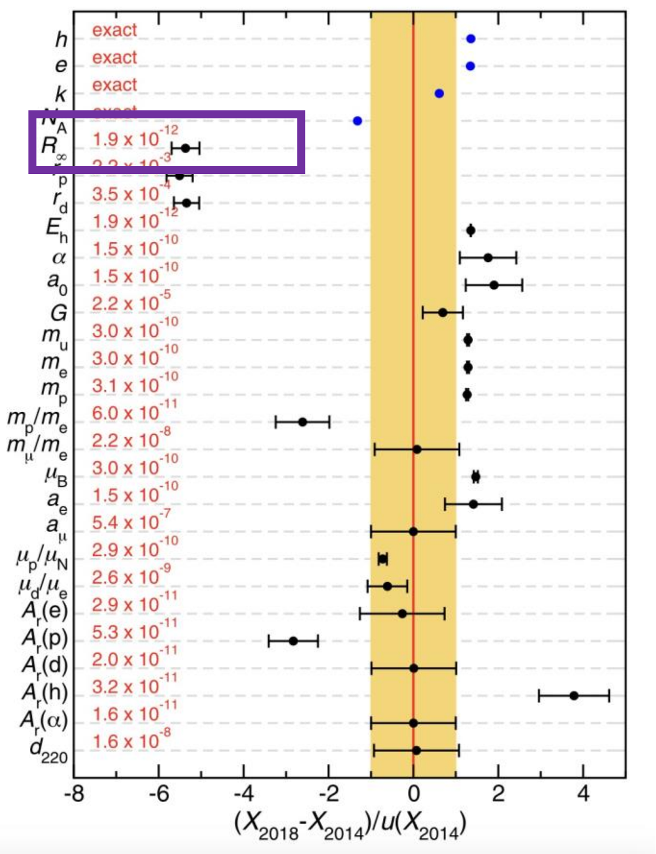
Balmer series

Raman series

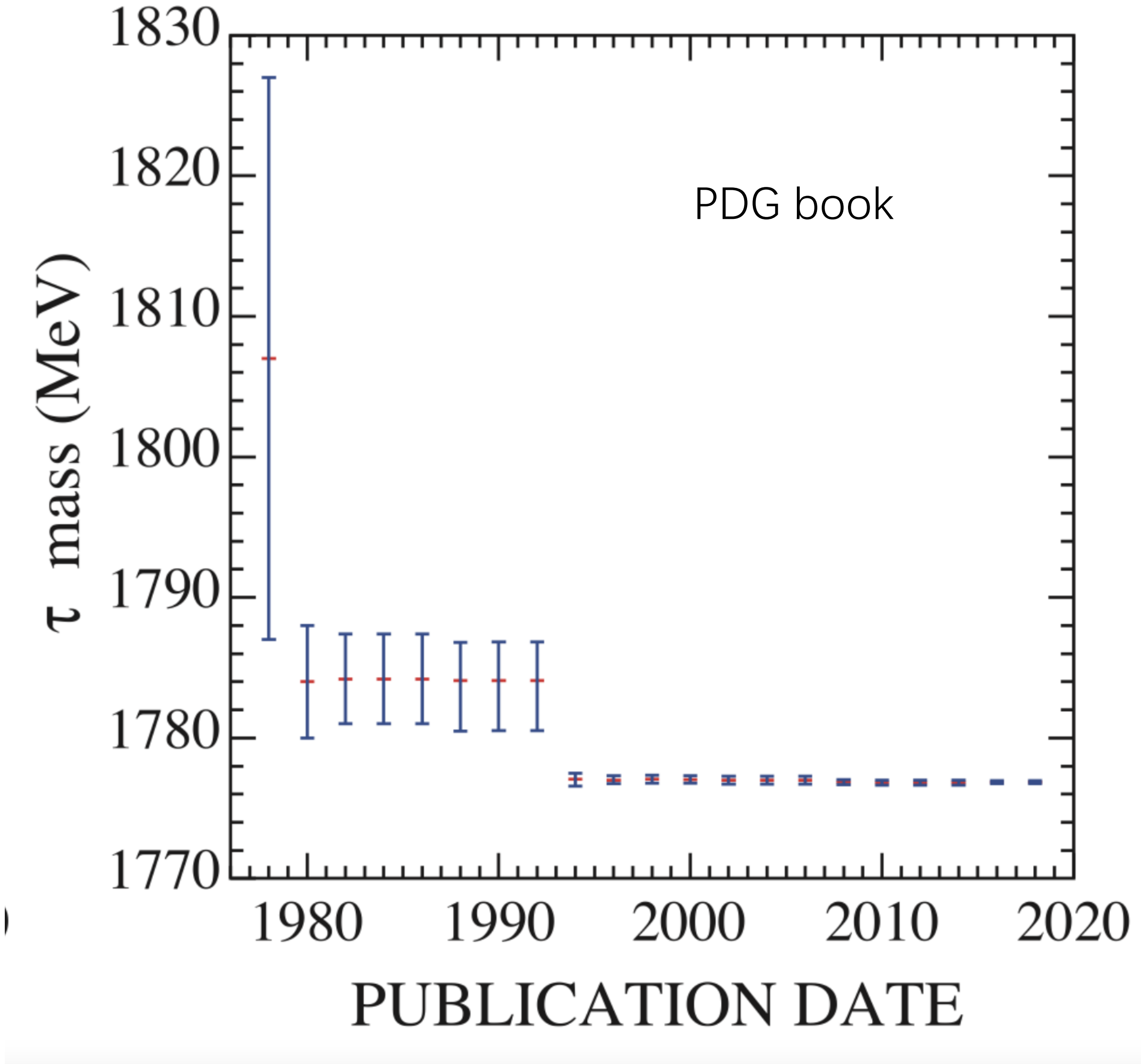
- From the formula, Rydberg constant is proportional to the mass of the electron.
- If the Rydberg constants varies with time, it perhaps indicates that the mass of the electron varies as well.
- The Rydberg constant measured in 2018 deviate from that in 2014 with 5.3σ



J. Phys. Chem. Ref. Data **50**, 033105 (2021)
https://doi.org/10.1063/5.0064853

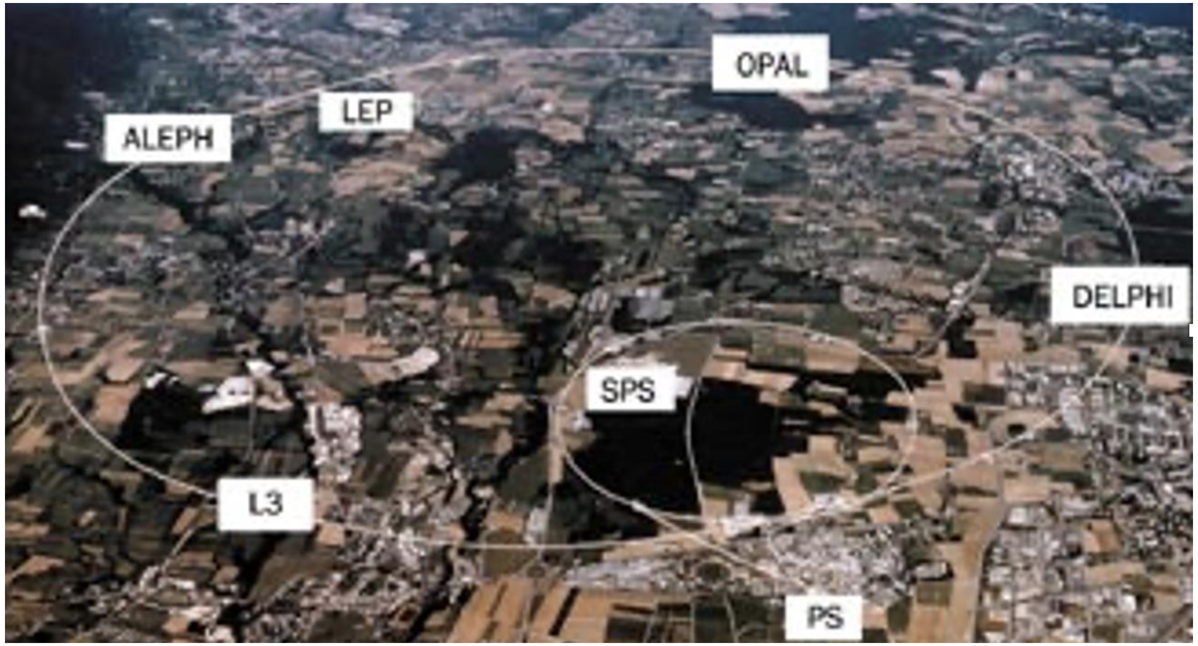


Tau mass measurements



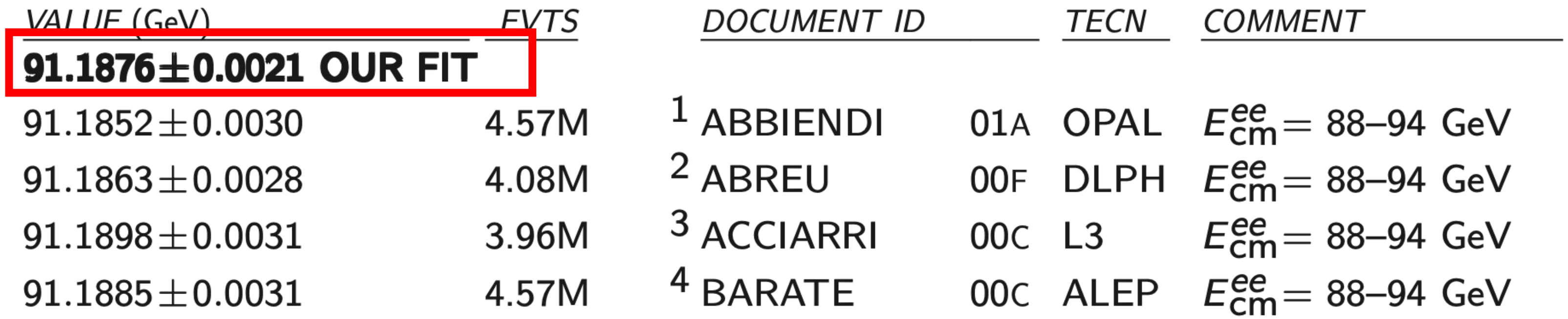
PDG book

LEP : the Precise Measurement of Z Mass



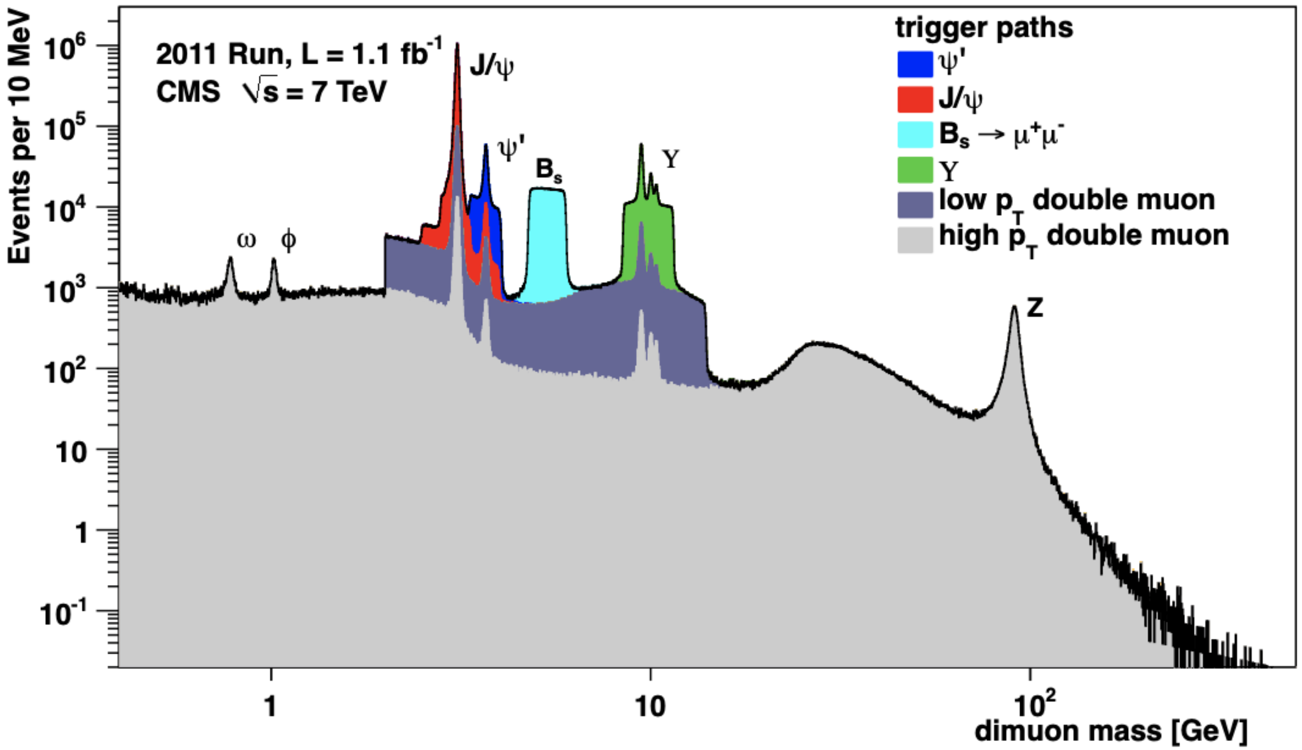
- LEP ran in 1990s, around 30 years from now :
  - ✓ Four experiments located at the ring : ALEPH, OPAL, DELPHI and L3.
  - ✓ With the energy scan, 2 MeV precision can be reached on the measurement of Z mass by combining 4 experiments.

PDG from LEP experiments:



VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
91.1876±0.0021 OUR FIT					
91.1852±0.0030	4.57M	[1] ABBIENDI	01A	OPAL	E^{ee}_{cm} = 88–94 GeV
91.1863±0.0028	4.08M	[2] ABREU	00F	DLPH	E^{ee}_{cm} = 88–94 GeV
91.1898±0.0031	3.96M	[3] ACCIARRI	00C	L3	E^{ee}_{cm} = 88–94 GeV
91.1885±0.0031	4.57M	[4] BARATE	00C	ALEP	E^{ee}_{cm} = 88–94 GeV

LHC : Measurement of Z Mass with ATLAS/CMS



- Can’t perform the energy scan to measure the Z mass at the LHC.
- No official precise measurements of the Z mass available have been done at ATLAS/CMS.
  - ✓ Perhaps can not exceed the LEP measurements and no much interest.
- It is not easy to treat the calibrations and systematics.

CEPC/Fcc-ee ：Measurements of Z Mass with unprecedent precisions

CEPC

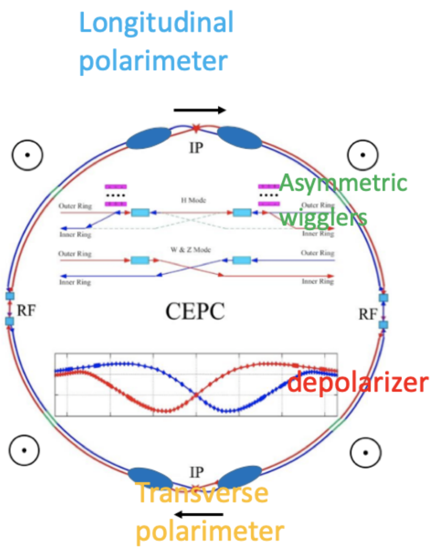
Z mass and Z-width measurement

Siqi Yang (USTC)

Beam energy control

- **CEPC CDR in 2018: beam momentum scaling uncertainty 0.5 MeV**
- **Updated uncertainty: 0.1 MeV**
- **Meausrement on Mz and Γz will be systematic dominant**

	CEPC 2018 CDR	Updated
ΔM_Z	0.5 MeV	0.1 MeV
$\Delta \Gamma_Z$	0.5 MeV	0.025 MeV



More details in Duan's Hongkong IAS workshop talk:
https://indico.cern.ch/event/1096427/contributions/4663325

FCC study: arXiv:1909.12245

Fcc-ee

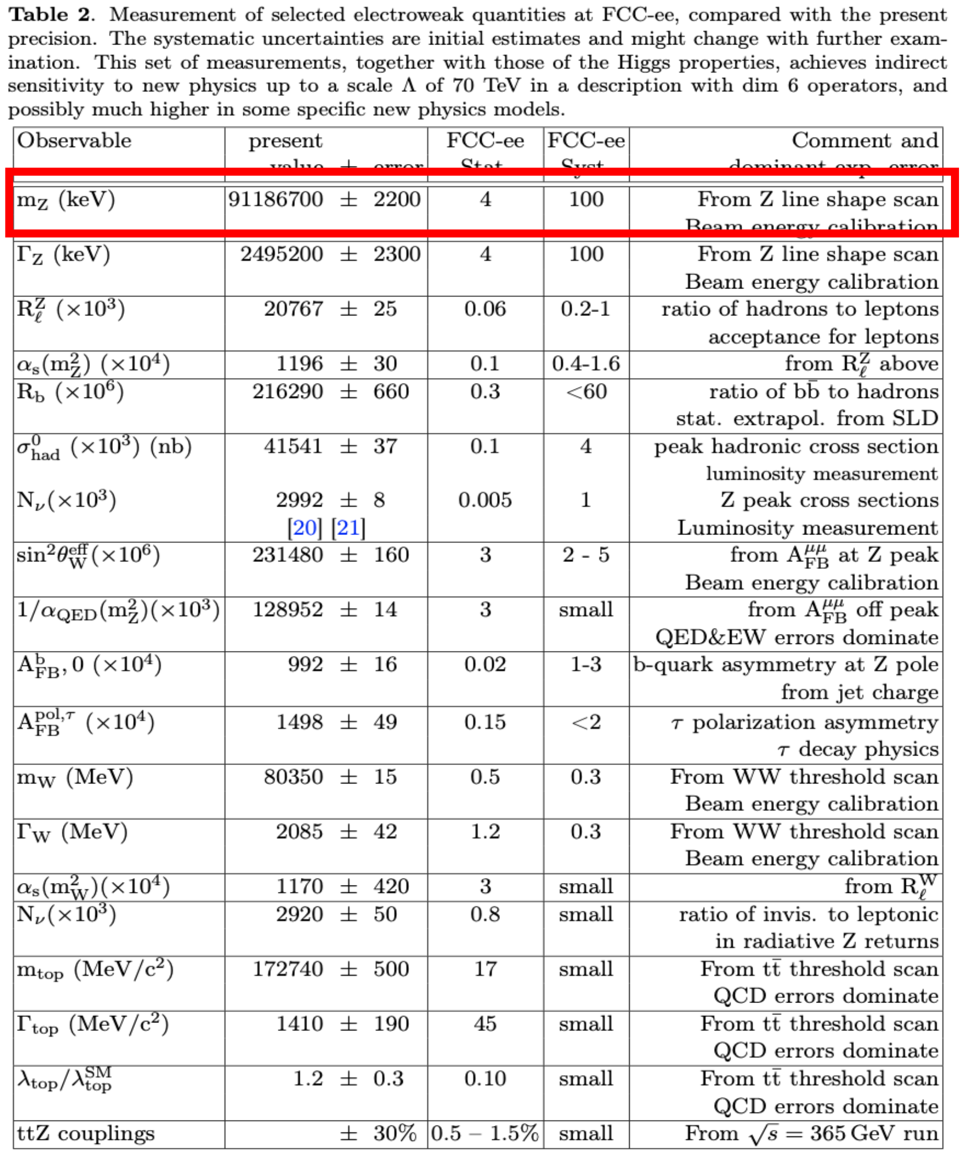
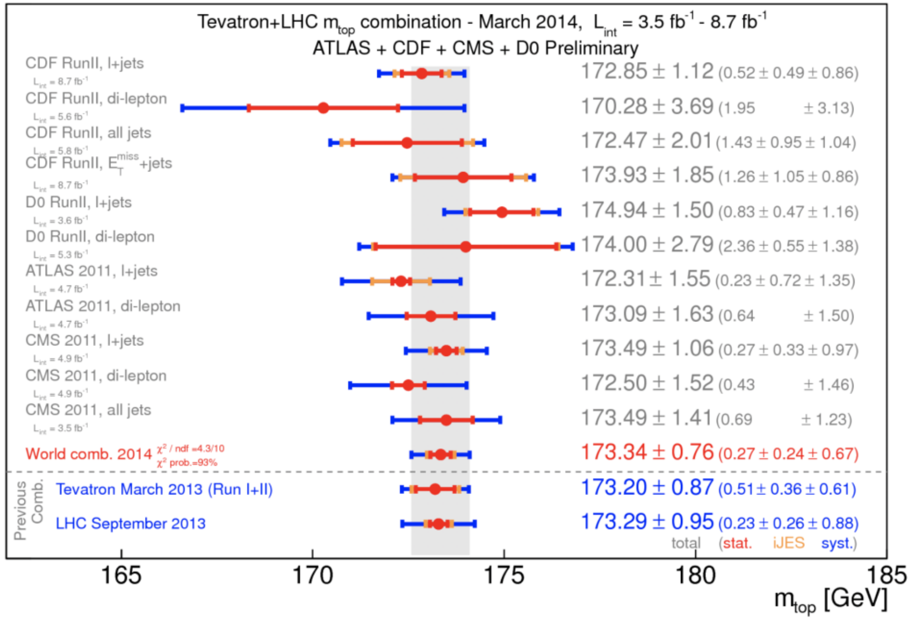


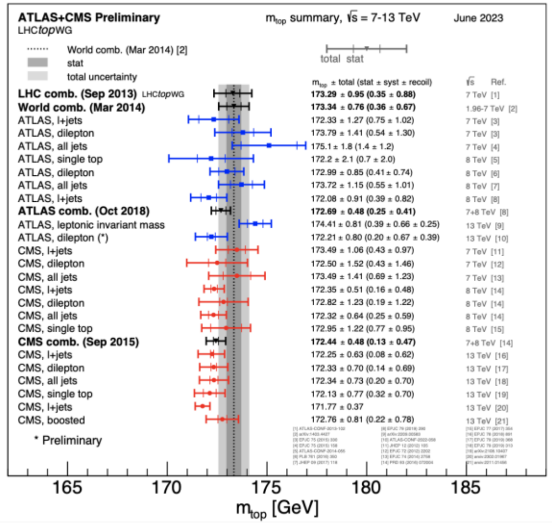
Table 2. Measurement of selected electroweak quantities at FCC-ee, compared with the present precision. The systematic uncertainties are initial estimates and might change with further examination. This set of measurements, together with those of the Higgs properties, achieves indirect sensitivity to new physics up to a scale Λ of 70 TeV in a description with dim 6 operators, and possibly much higher in some specific new physics models.

Observable	present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and dominant exp. error
m_Z (keV)	91186700 ± 2200	4	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	4	100	From Z line shape scan Beam energy calibration
R_ℓ^Z ($\times 10^3$)	20767 ± 25	0.06	0.2-1	ratio of hadrons to leptons acceptance for leptons
$\alpha_s(m_Z^2)$ ($\times 10^4$)	1196 ± 30	0.1	0.4-1.6	from R_ℓ^Z above
R_b ($\times 10^6$)	216290 ± 660	0.3	<60	ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD
σ_{had}^0 ($\times 10^3$) (nb)	41541 ± 37	0.1	4	peak hadronic cross section luminosity measurement
$N_\nu(\times 10^3)$	2992 ± 8 [20] [21]	0.005	1	Z peak cross sections Luminosity measurement
$\sin^2\theta_W^{eff}(\times 10^6)$	231480 ± 160	3	2 - 5	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952 ± 14	3	small	from $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
$A_{FB}^b, 0$ ($\times 10^4$)	992 ± 16	0.02	1-3	b-quark asymmetry at Z pole from jet charge
$A_{FB}^{pol,\tau}$ ($\times 10^4$)	1498 ± 49	0.15	<2	τ polarization asymmetry τ decay physics
m_W (MeV)	80350 ± 15	0.5	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085 ± 42	1.2	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1170 ± 420	3	small	from R_ℓ^W
$N_\nu(\times 10^3)$	2920 ± 50	0.8	small	ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	17	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV/c^2)	1410 ± 190	45	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	0.10	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	0.5 – 1.5%	small	From $\sqrt{s} = 365$ GeV run

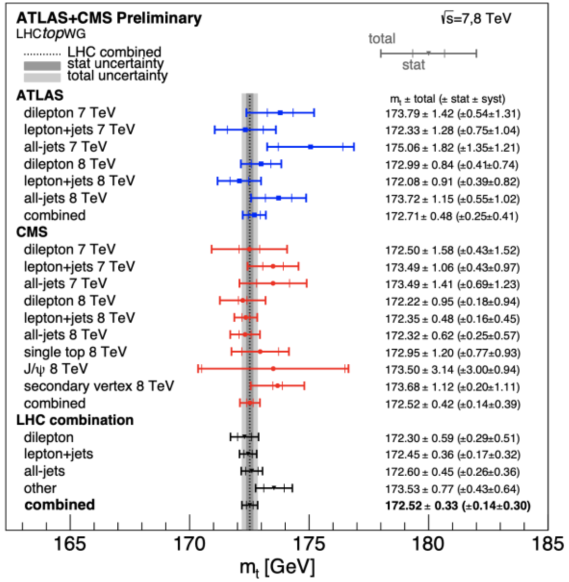
- The precision of O(0.1) MeV is expected at CEPC/Fcc-ee
  - ✓ One order of magnitude better than LEP.

Top Mass Measurements at Tevatron/LHC





ATLAS-CONF-2023-066



Experiment	Year	Mean (GeV)	Total Sys. (GeV)	Stat. (GeV)	Syst. (GeV)
Tevatron (1407.2682)	1.96 TeV (1986/92- 2011)	174.34	0.64		
ATLAS	7/8TeV (2011-2012)	172.69	0.48	0.25	0.41
CMS	7/8TeV (2011-2012)	172.44	0.48	0.13	0.47
ATLAS+CMS ATLAS-CONF-2023-066	7/8TeV (2011-2012)	172.52	0.33	0.14	0.30
ATLAS (by hand)	13 TeV (2013-2018)	173.32	0.65	0.18	0.59
CMS	13 TeV (2013-2018)	172.17	0.24	0.07	0.23
ATLAS+CMS (by hand)	13 TeV (2013-2018)	172.31	0.23	0.06	0.22

- To some extent, measured top quark also has a trend of the reduced mass as a function of time.
- However, the uncertainty is significant.

CEPC/ILC/CLIC/Fcc-ee : Measurements of top Mass

EPJC 83, 269 (2023)

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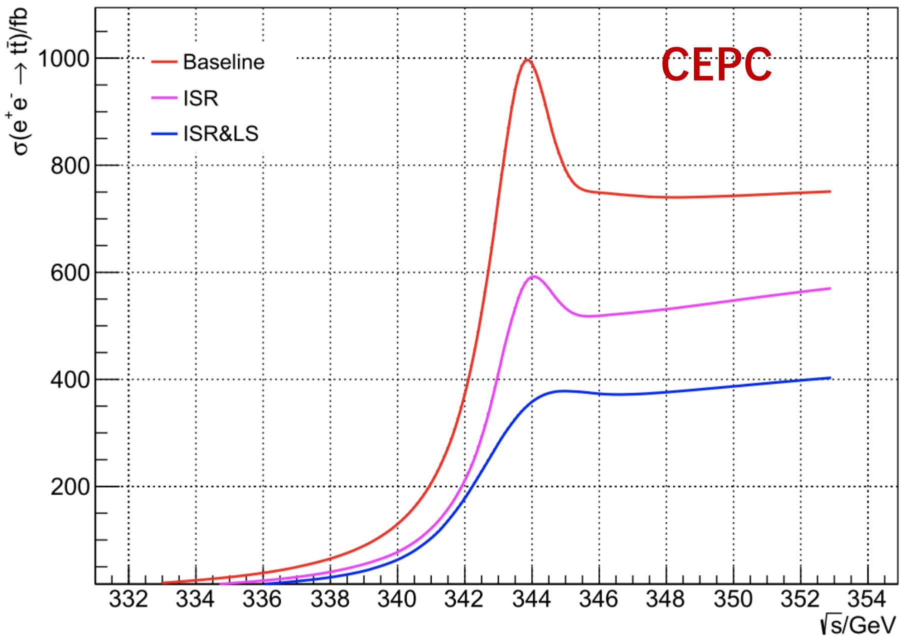


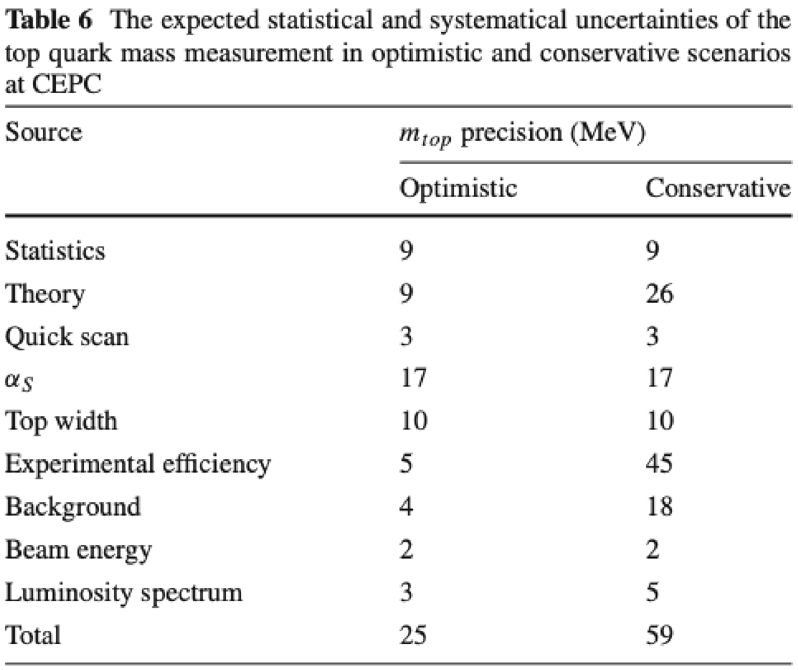
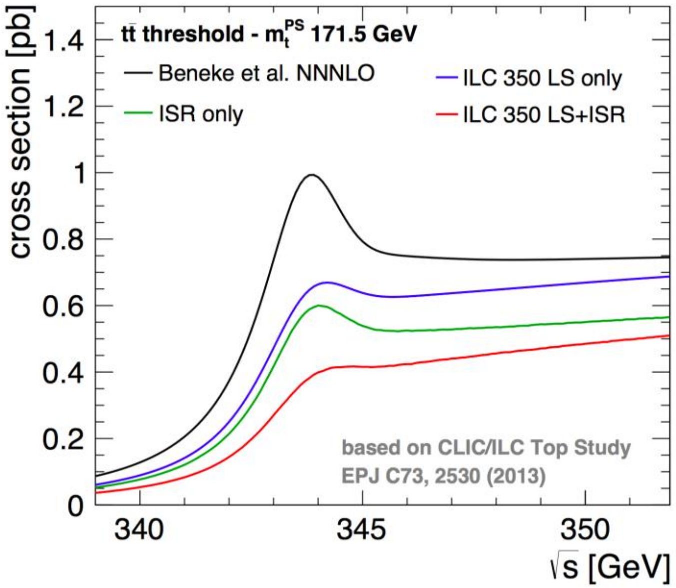
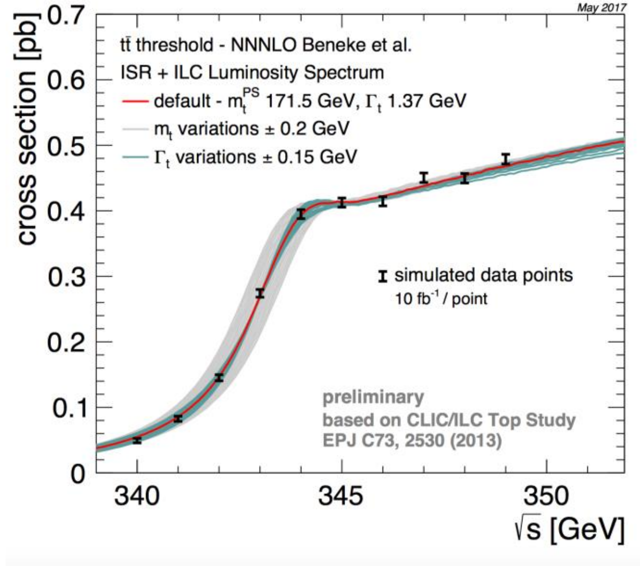


Table 6 The expected statistical and systematical uncertainties of the top quark mass measurement in optimistic and conservative scenarios at CEPC

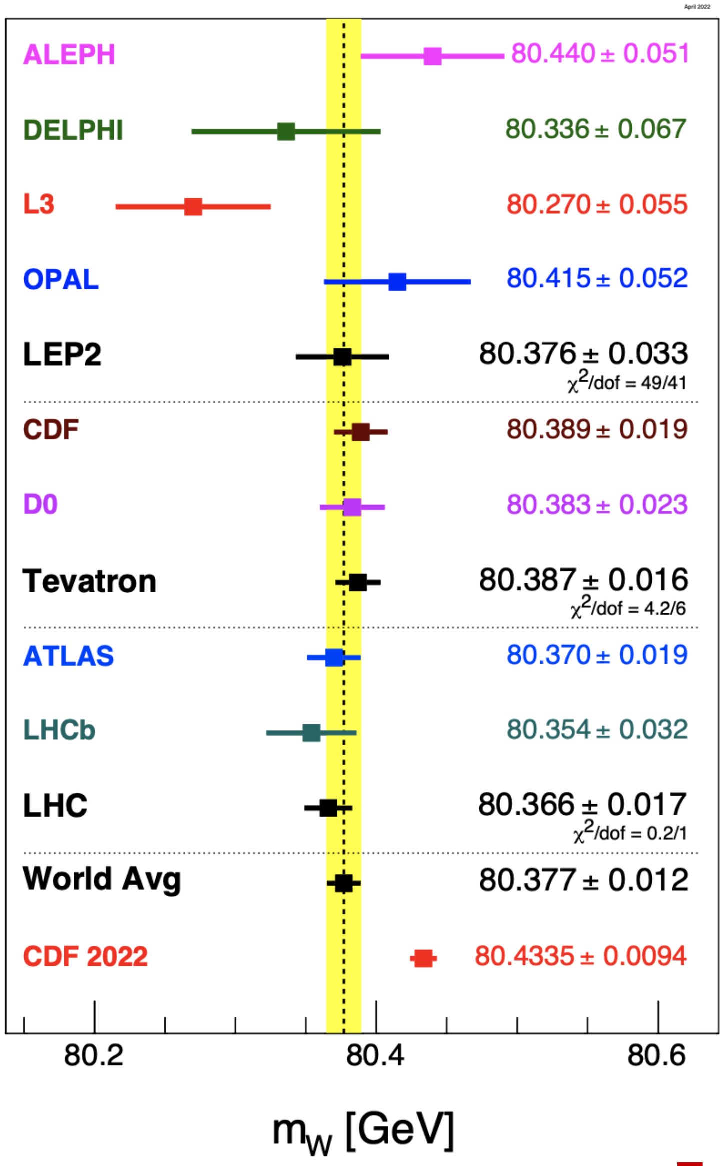
Source	m_{top} precision (MeV)	
	Optimistic	Conservative
Statistics	9	9
Theory	9	26
Quick scan	3	3
α_S	17	17
Top width	10	10
Experimental efficiency	5	45
Background	4	18
Beam energy	2	2
Luminosity spectrum	3	5
Total	25	59



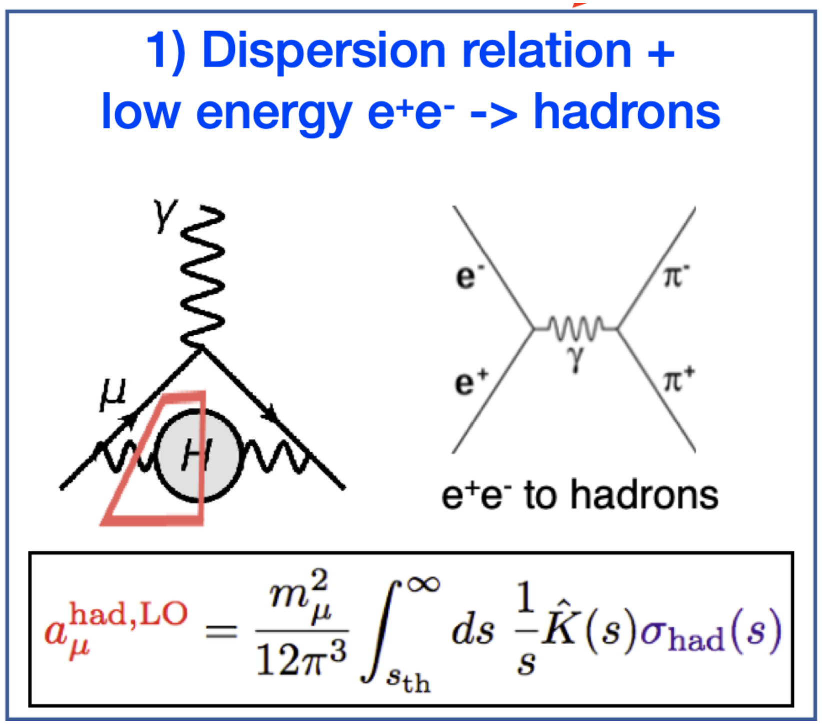


- **The precision of O(10) MeV can be reached at e^+e^- colliders.**
  - ✓ **One order of magnitude better than LHC.**

Hints from W mass measurements and muon g
2

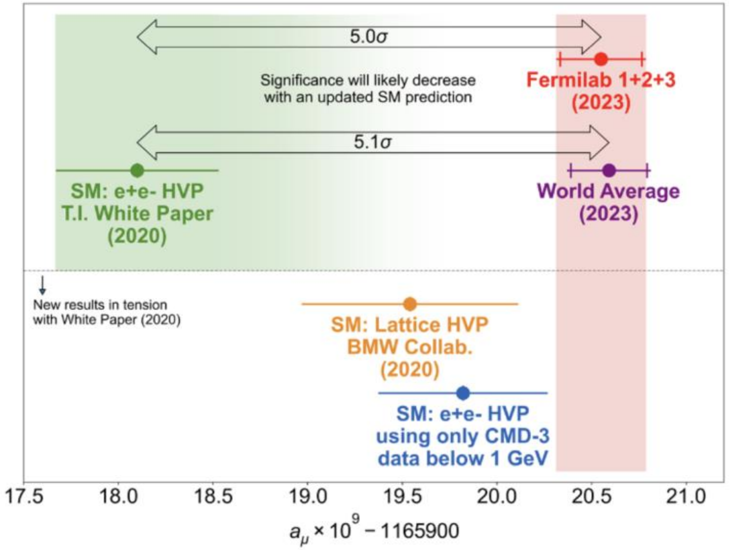


- If the deviation of the w mass for CDF is true, we may expect the measured Z mass from LHC(ATLAS/CMS) will be lower than LEP
  - ✓ CEPC/FCC-ee can deliver very precise measurements of W mass as well.
- The phase of the universe could be decelerated expanding
- It could also have some impact on the theoretical computation of $\alpha_{\mu}^{had,LO}$
  - ✓ contribute the deviation from theoretical computation.



1) Dispersion relation + low energy e+e- -> hadrons

$$a_{\mu}^{\mathrm{had,LO}} = \frac{m_{\mu}^{2}}{12\pi^{3}} \int_{s_{\mathrm{th}}}^{\infty} ds\ \frac{1}{s} \hat{K}(s) \sigma_{\mathrm{had}}(s)$$



Two deviation of W-mass supports the excess of muon g-2

S8 from Astrophysics

S8 tension

https://arxiv.org/abs/2203.06142v1
https://arxiv.org/abs/2206.11794

Early universe S8 results (from CMB)

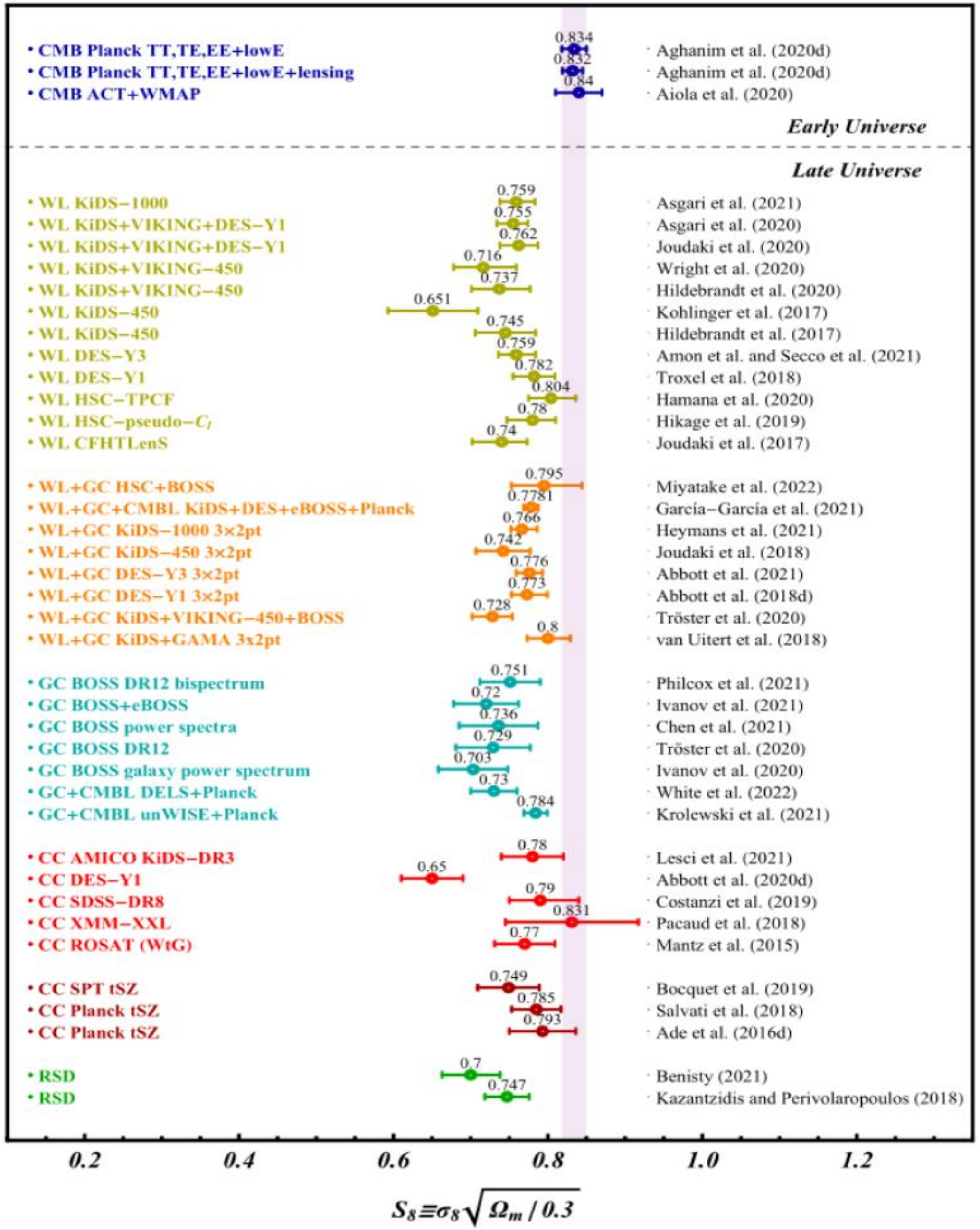
And

Late universe S8 results(from weak gravitational lensing events)

Are different: 3sigma.

While, the main concern for this issue is on the methods of weak gravitational lensing:

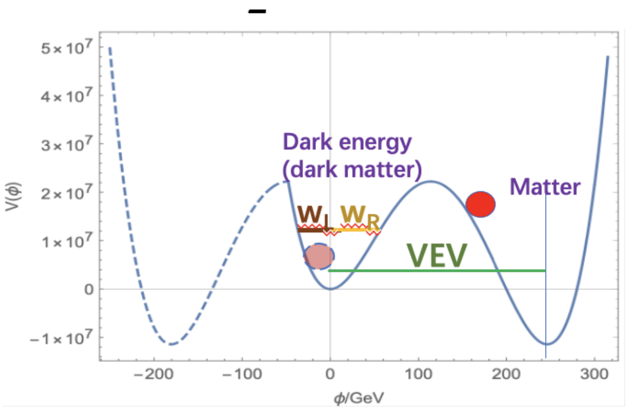
Modelling of this is very complicated.



Is it possible that Early Universe and/or Late Universe experience expansions both acceleratively and deceleratively ?

Conclusion

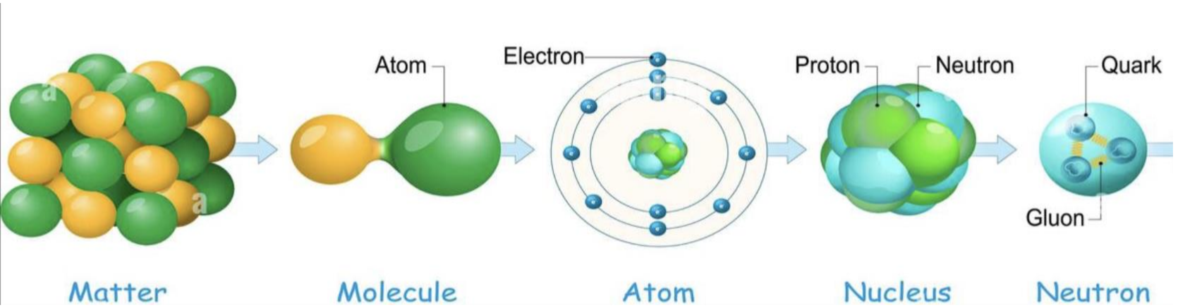
- ➢ A model combing Higgs potential and asymmetrical potential is proposed to
  - ✓ Try to explain the non-existence of the observed dark matter and source of dark energy
    - Dark matter describes the extent of the ISB.
      - ISB and VEV = 0 lead to the mass effect involving gravitational force but not observable.
        - no couplings with fundamental particles.
    - The strength of the symmetry breaking (ISB) of the vacuum is the source of the dark energy
      - Beyond the central potential is energy/matter
      - Within the central potential is called dark energy
      - The frequency of ISB is at least 10^6 larger than SSB



- ➢ Predict :
  - ✓ the possible mass changes of the fundamental particles over time.
  - ✓ Variation of dark matter/dark energy over time.
- ➢ All the evidences point to reduced masses ⟶ decelerative expansion of the current Universe;
- ➢ Propose to check:
  - Possible variation of the measured Z mass at the ATLAS/CMS and compare it with the previous LEP measurements.
    - More precise measurement will be delivered at the CEPC/Fcc-ee in the future.
  - Check the possible variations of ratio of dark matter, dark energy and matter from experimental astrophysics.

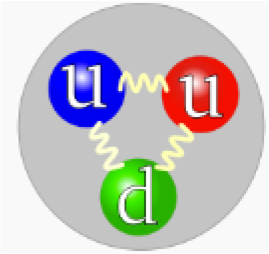
backup slides

Background: Standard Model

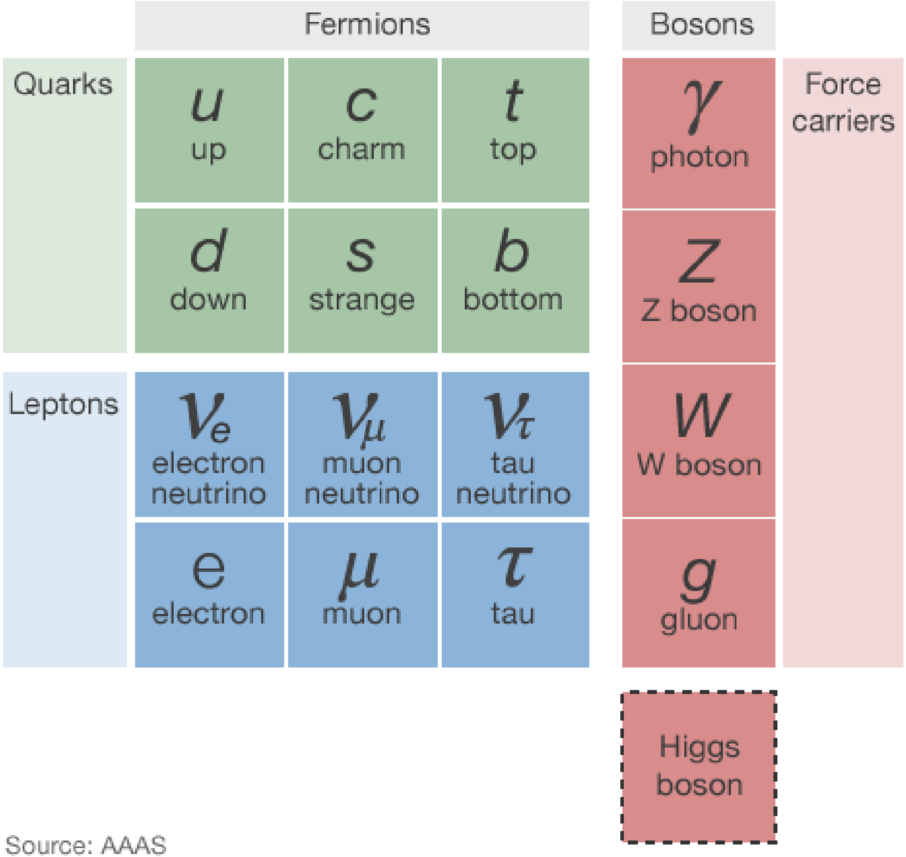


✓ **What ?**

e.g. proton : **up-up-down**

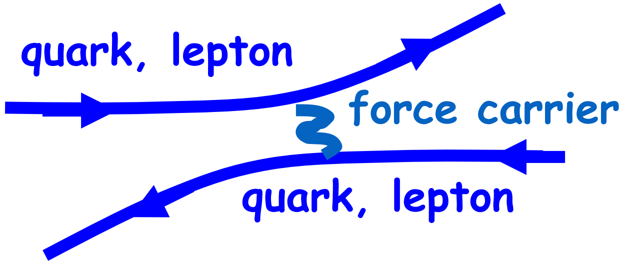


✓ **How ?**



	Fermions			Bosons	
Quarks	u up	c charm	t top	γ photon	Force carriers
	d down	s strange	b bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	
				Higgs boson	

Source: AAAS



quark, lepton

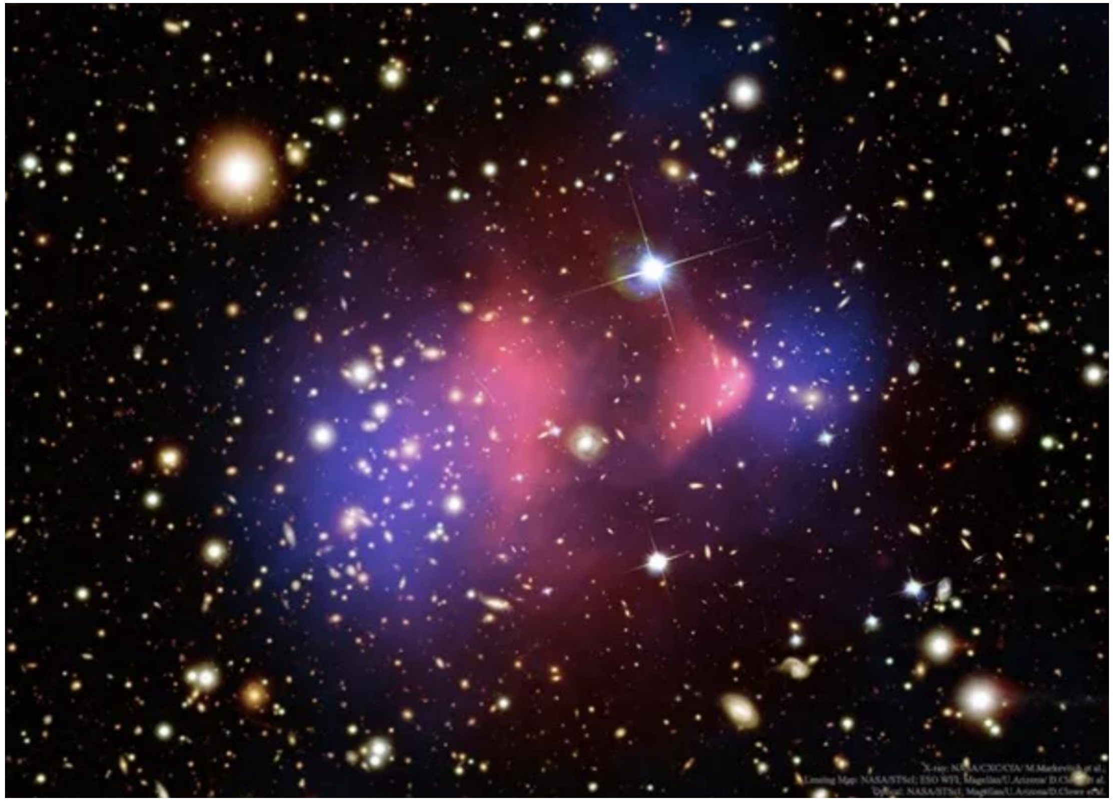
force carrier

quark, lepton

力(Force)	载体(Carrier)
强(Strong)	胶子Gluons (g)
电磁(EM)	Photon 光子
弱(Electro-Weak)	玻色子bosons W/Z
引力(Gravitation)	?

Is the mass of the fundamental particles are fixed ?

Background: Dark Matter and Dark Energy



X-ray: NASA/CXC/CfA/ M.Markevitch et al.;
Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/ D.Clowe et al.
Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.

Dark Matter : In order to hold the Universe, more matter than observed is needed to provide attractive force.

Dark Energy : In order to keep the expansion of the Universe, more energy is needed to provide source energy.

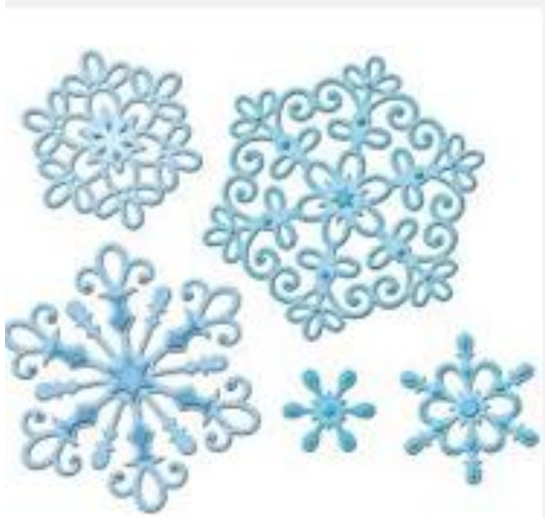
Dark Matter : 27%
Dark Energy : 68%
Matter : 5%

But neither of them has been observed !

Introduction : Symmetry

Symmetry happens everywhere in our world

It means the invariance



How mass is generated : massless or massive ?

Gauge Symmetry :

Lagrangian is invariant under some phase transition

- EM force :
  - Massless photon A_μ U(1)
- Strong interaction: G_μ^a SU(3)
  - 8 massless gluons
- EW interaction: SU(2)
  - However massive W/Z (1983 at CERN).