Higgs inflation under SM criticality

Higgs-portal DM, neutrinos & hill-climbing

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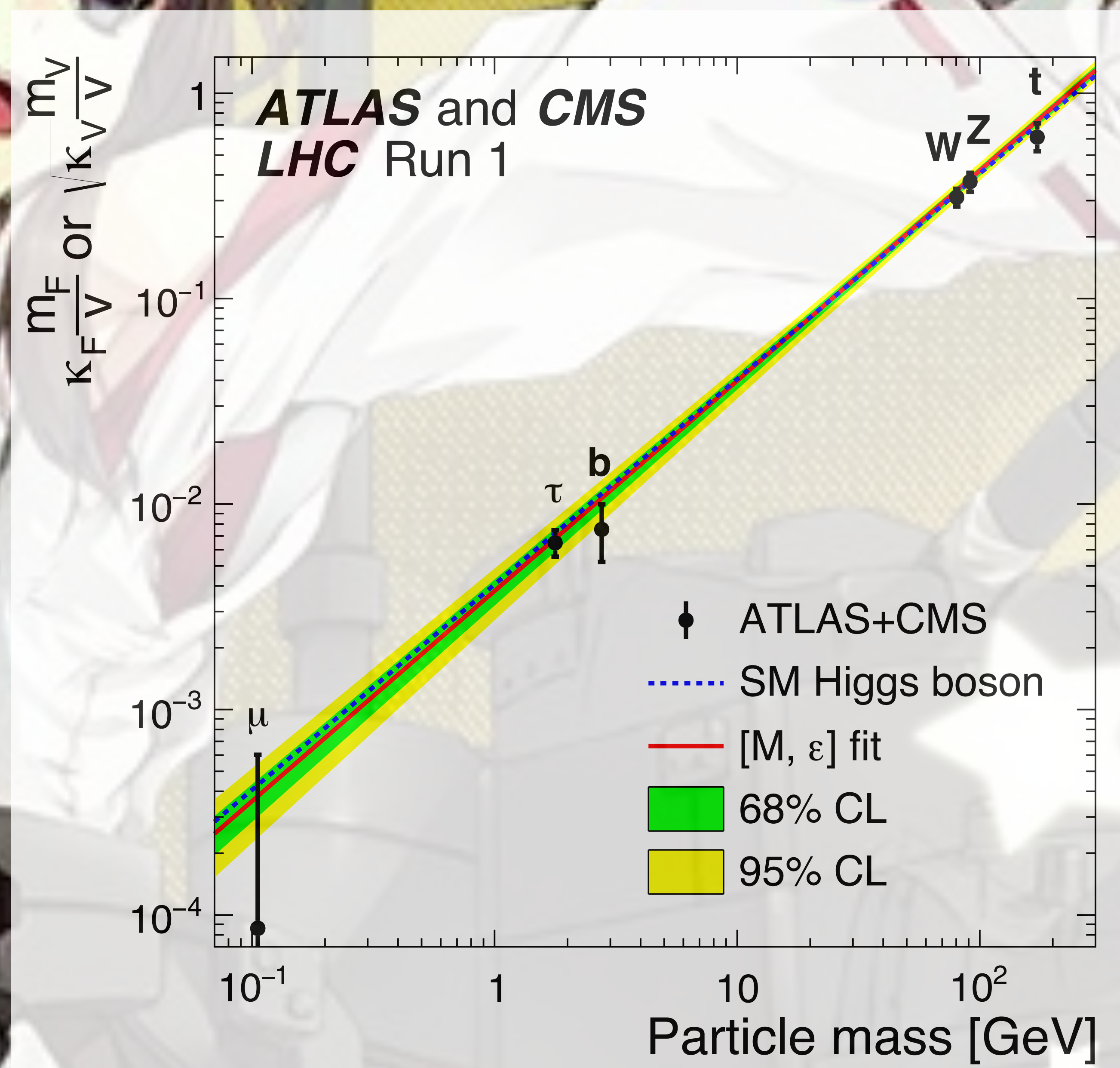
Picture: Yoshida fire festival

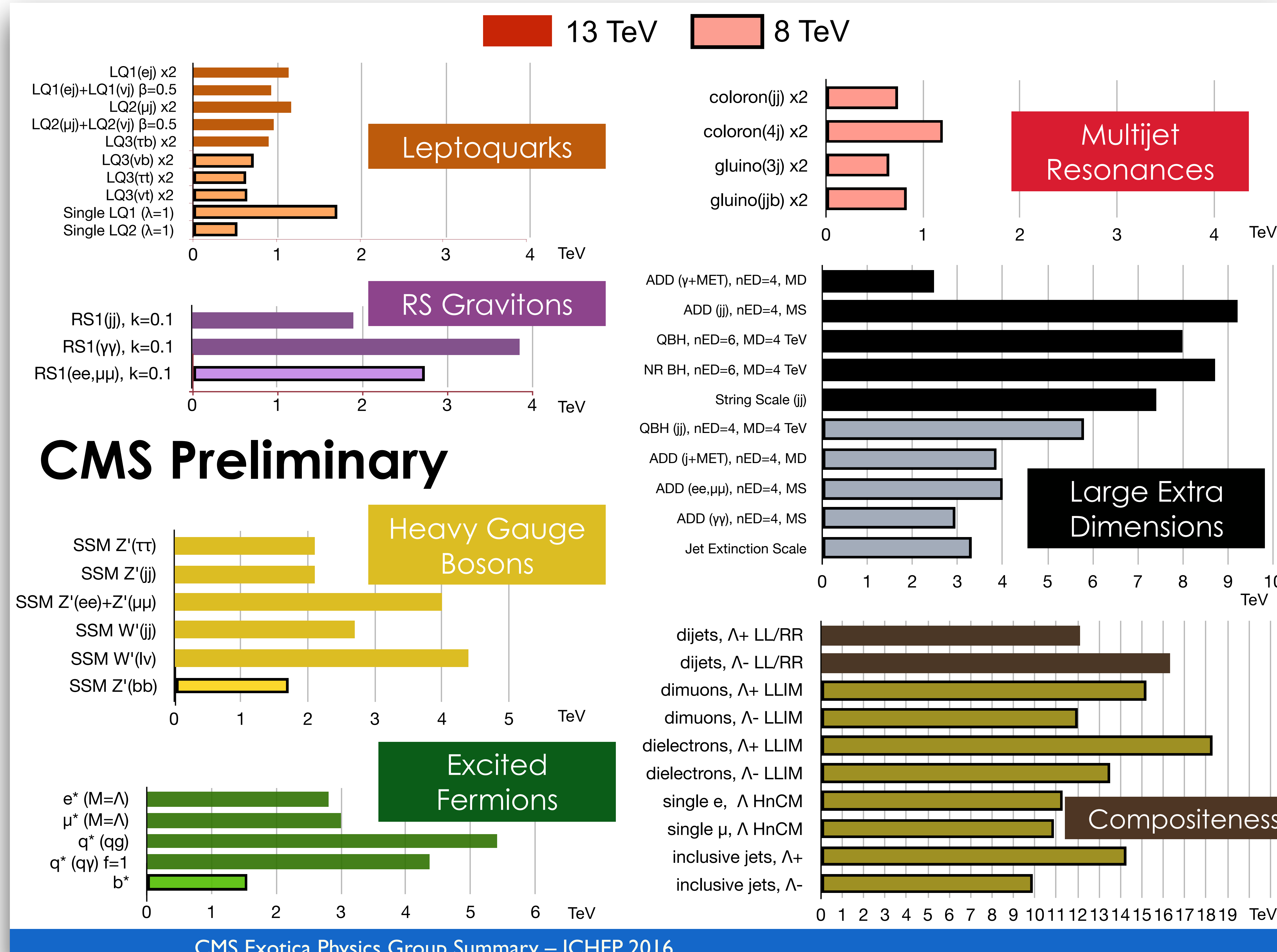
We have witnessed great victory of SM



ATLAS & CMS (2016)

Picture from web

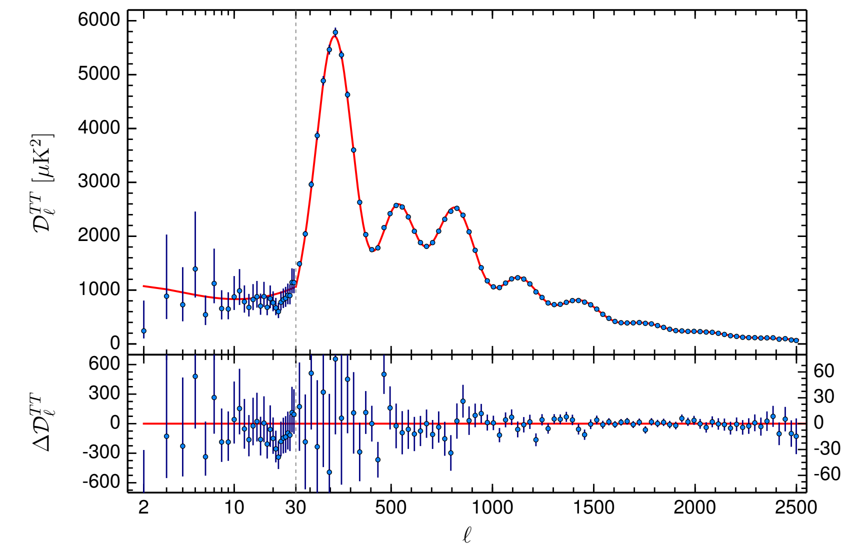
And nothing else



What’s next?

Clear & present BSM new physics in the sky

- Hundreds of data points beautifully fit by just 6 parameters



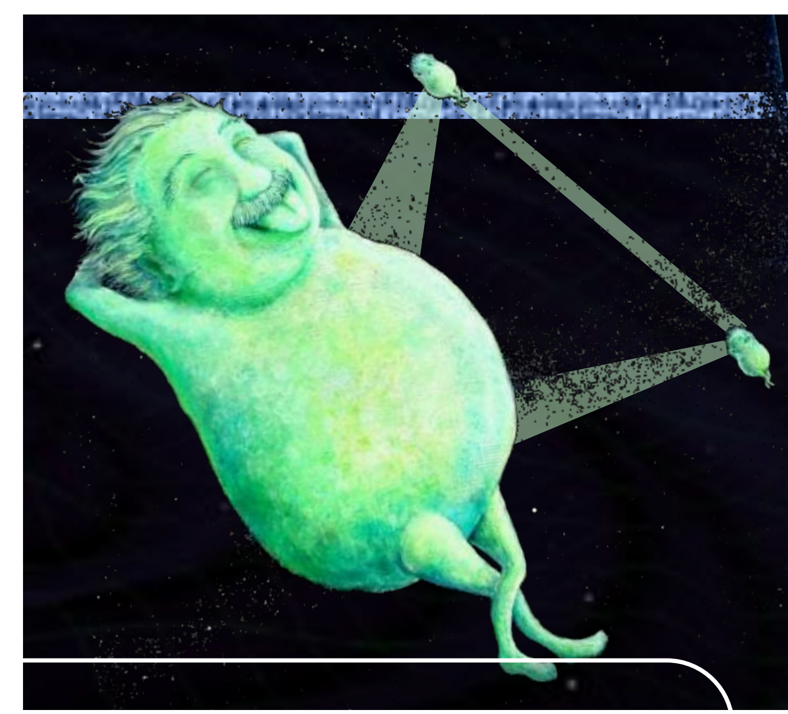
Parameter	TT+lowP 68 % limits
$\Omega_b h^2$	0.02222 ± 0.00023
$\Omega_c h^2$	0.1197 ± 0.0022
$100\theta_{MC}$	1.04085 ± 0.00047
τ	0.078 ± 0.019
$\ln(10^{10} A_s)$	3.089 ± 0.036
n_s	0.9655 ± 0.0062
H_0	67.31 ± 0.96
Ω_Λ	0.685 ± 0.013
Ω_m	0.315 ± 0.013

Planck (2016)

- Today's topic:
  - ★ **Inflation** (1st half)
  - ★ + **DM** & neutrinos (2nd half)

Further development in near future expected

- Cosmic **graviton** background:
  - **Indirectly** from *r*
    - CMB B-mode immediately (Recall BICEP2 festival)
  - Even **direct** observation
    - by (Ultimate) DECIGO
- Handle on **quantum gravity**



from DECIGO website

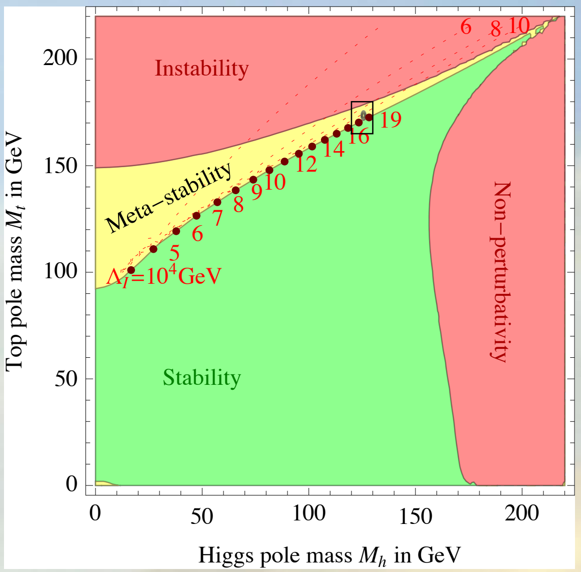
Plan

1. **Multiple-point principle** (MPP)
   PREdicted Higgs mass

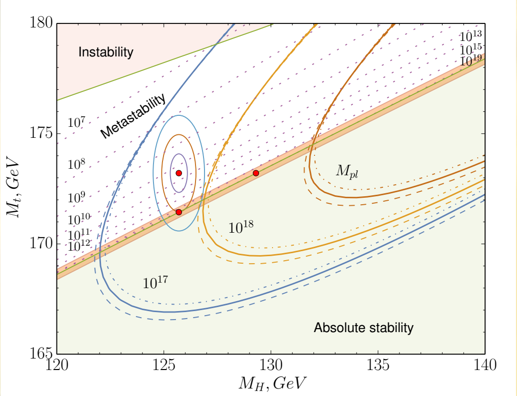
2. Hill-climbing **Higgs inflation**

3. Lower bound: $\boldsymbol{r > 10^{-3}}$
   even with **Higgs-portal DM**

We are put on the edge



Buttazzo et al. (2013)



Bednyakov et al. (2015)

Observational fact

\+ Extrapolation towards **Planck scale**

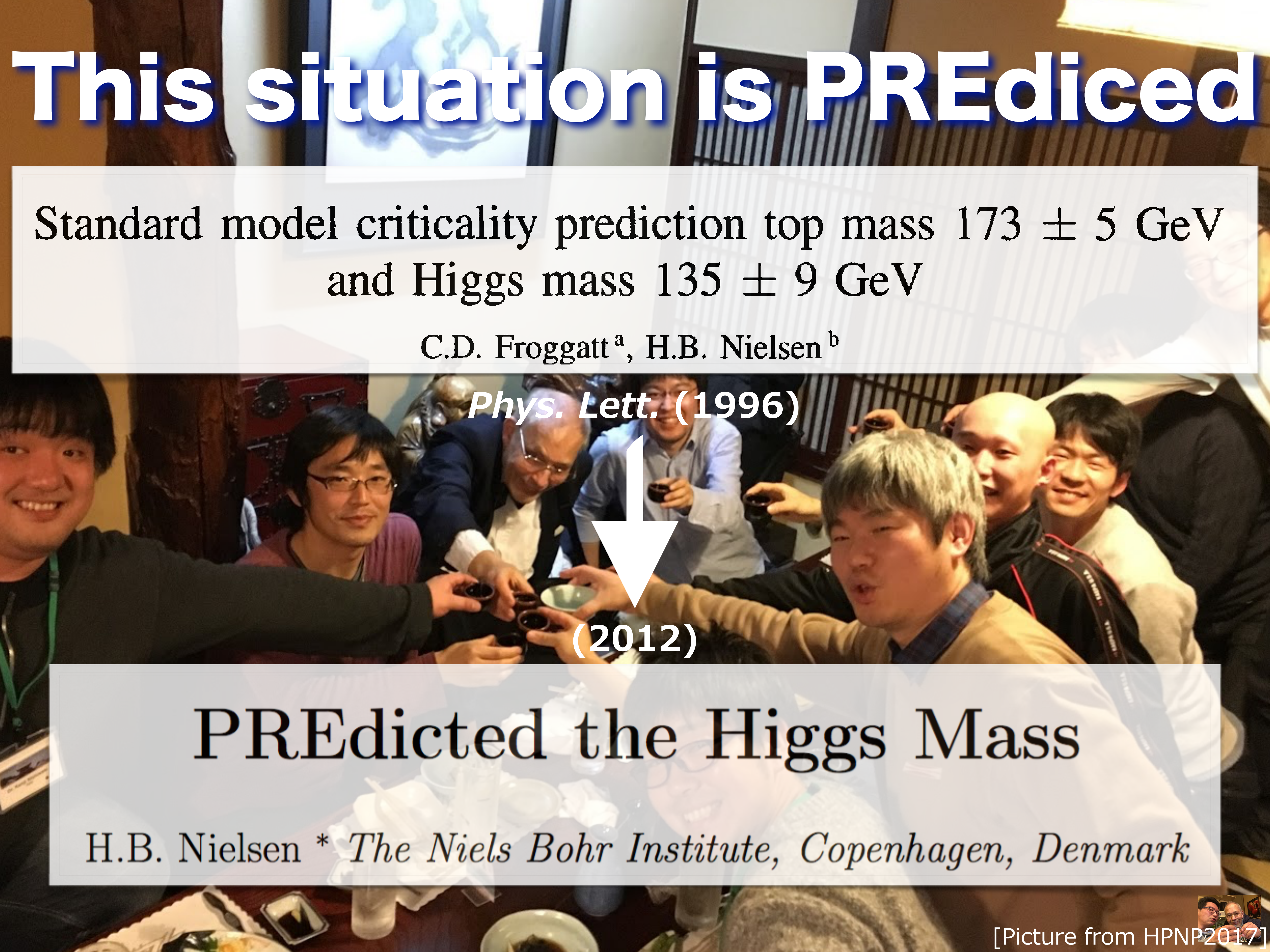
Our Universe

- ✦ On the edge of **vacuum instability**
- ✦ **Triple coincidence** at M_P:
  - ★ $\lambda \sim \beta_\lambda \sim m^2_{\text{bare}} \sim 0$

[Hamada, Kawai, **KO**, 2013]

picture from web

This situation is PREdiced



Standard model criticality prediction top mass 173 ± 5 GeV and Higgs mass 135 ± 9 GeV

C.D. Froggatt [a], H.B. Nielsen [b]

Phys. Lett. (1996)

(2012)

PREdicted the Higgs Mass

H.B. Nielsen * *The Niels Bohr Institute, Copenhagen, Denmark*

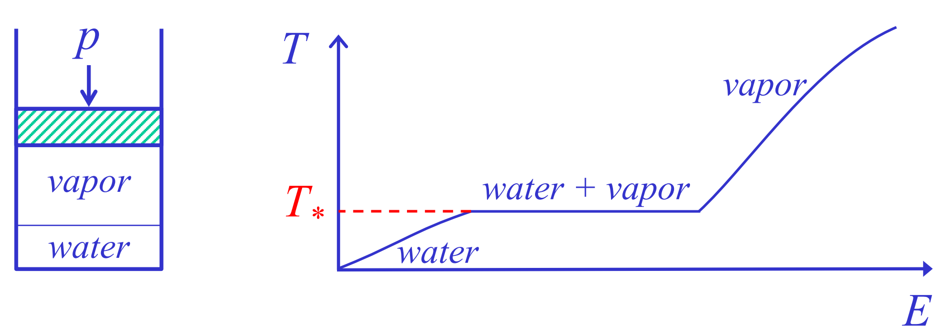
[Picture from HPNP2017]

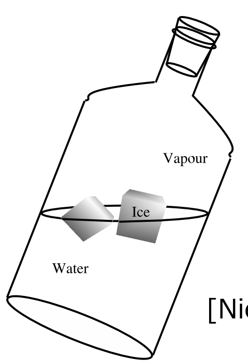
MPP in a slide

Frogatt & Nielsen (1996)

[Review in Hamada, Kawai, **KO**, 1501.04455]

- QFT partition function $Z = \int D\varphi \, e^{-S[\varphi]}$
  - ★ Corresponds to canonical formalism in statistical mechanics
- Micro-canonical more fundamental: $\int d\beta \, dE$ (canonical) → (micro-canonical)
  - ★ Its QFT version corresponds to **integrating over all couplings**: $\int d\Lambda \int dm^2 \int d\lambda \cdots$.
- In statistical mechanics, **co-existing multiple-phases** lead to constant T_* for wide range of E.





[Nielsen et al., 2017]

  - In QFT language, corresponds to **co-existing degenerate vacua**.
  - Couplings automatically selected by $\int d\Lambda \int dm^2 \int d\lambda \cdots$ to realize it.
- Requirement of another degenerate vacuum at M_P lead to Higgs mass PREdiction.

Backup

Frogatt & Nielsen (1996)

[Review in Hamada, Kawai, **KO**, 1501.04455]

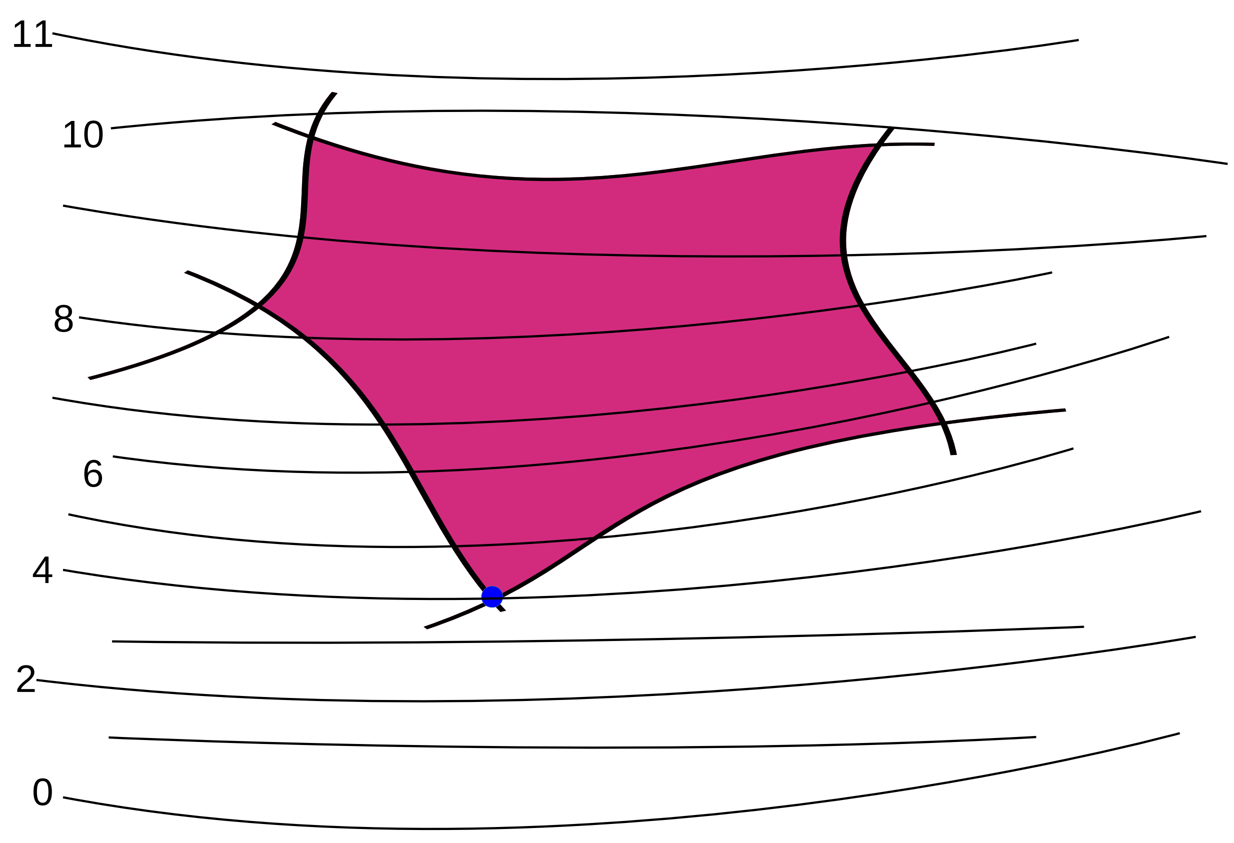
	Canonical	Micro-canonical
Statistical mechanics	$Z(\beta) = \boxed{\sum_n} e^{-\beta H_n}$	Thermodynamic limt
	$\overline{\Omega}(E) = \boxed{\int \mathrm{d}\beta \int \mathrm{d}\mathcal{E}}\, e^{\mathcal{S}(\mathcal{E}) - \beta(\mathcal{E} - E)}$ $\longrightarrow$	$\Omega(E) = \sum_n \delta(H_n - \boxed{E})$
QFT	$Z(\{\lambda\}) = \int \boxed{[\mathrm{d}\varphi]}\, e^{-S(\{\lambda\})[\varphi]}$	
	$\overline{\Omega}(I_0, I_2, I_4, \dots) = \boxed{\left(\int \mathrm{d}\Lambda \int \mathrm{d}m^2 \int \mathrm{d}\lambda \cdots\right)} e^{\Lambda I_0 + m^2 I_2 + \lambda I_4 + \cdots} Z(\Lambda, m^2, \lambda, \dots)$	

$$\longrightarrow \quad \Omega(I_0, I_2, I_4, \dots) = \int [\mathrm{d}\varphi]\, e^{-\int \mathrm{d}^D x\, (\partial\varphi)^2} \delta\left(\int \mathrm{d}^D x - I_0\right) \delta\left(\int \mathrm{d}^D x\, |\varphi|^2 - I_2\right) \delta\left(\int \mathrm{d}^D x\, |\varphi|^4 - I_4\right) \cdots$$

Generalized MPP

Nielsen (2012)

- If you minimize <u>any</u> quantity by integral $\underline{\int d\Lambda \int dm^2 \int d\lambda \cdots}$, you end up with a tip of **multiple criticality**.



From Nielsen et al. (2017)

The more-multiple criticality, the better

- Already tri-citicality at M_P: $\underline{\lambda \sim \beta_\lambda \sim m^2_{bare} \sim 0}$.

[Hamada, Kawai, **KO**, 2013]

- Why not also $\underline{F(\varphi) \sim 0}$ in front of Ricci scalar R?
  $\rightarrow$ Next part