SUPER-WEAK FORCE AND COSMIC INFLATION

Zoltán Trócsányi

Eötvös University and MTA-DE Particle Physics Research Group

based on 1812.11189, 1902.02791, 1911.07082

Theory Seminar, Budapest, 6 January 2020

OUTLINE

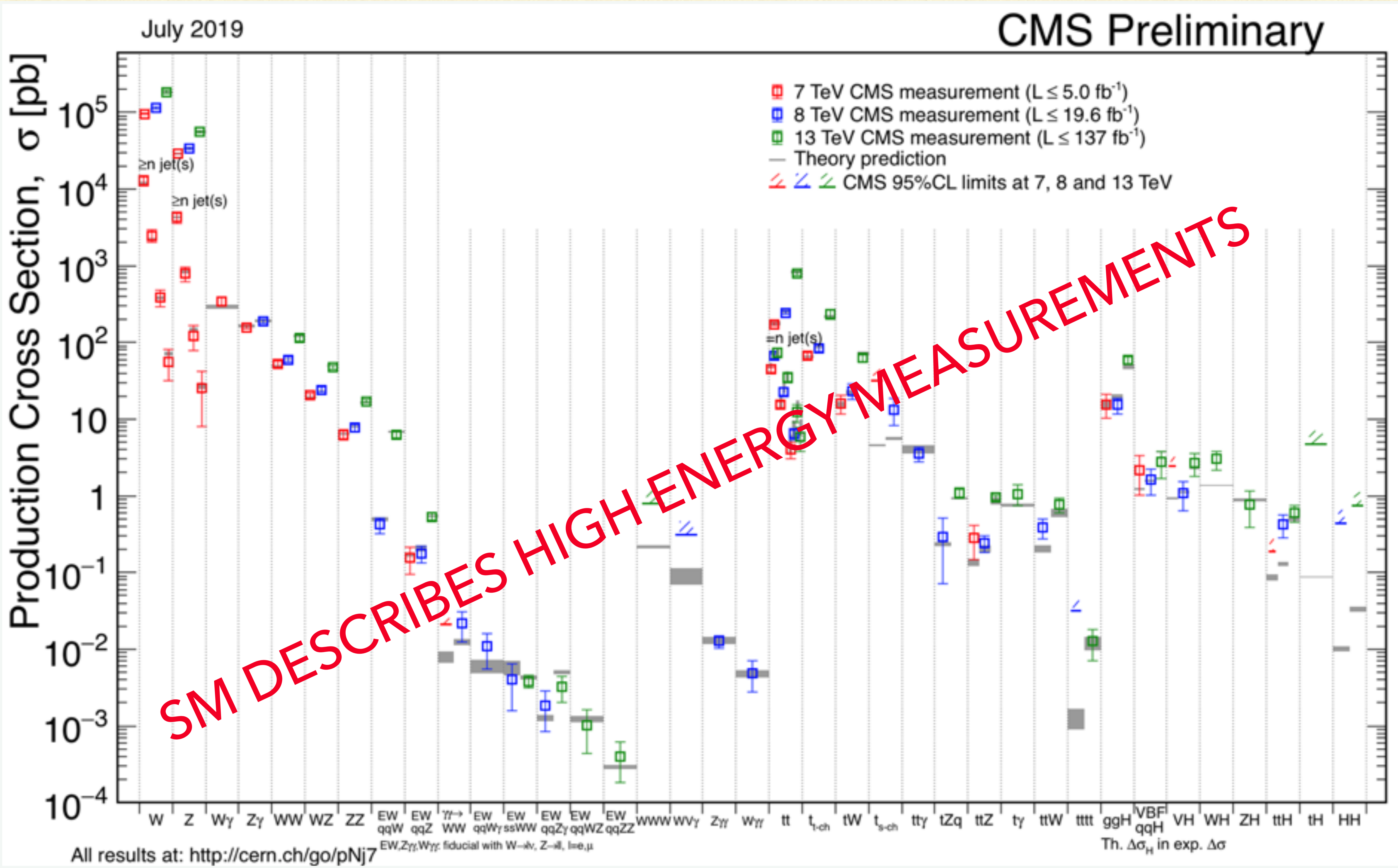
1. Status of particle physics
2. $U(1)_Z$ extension of SM
3. Constraints on the parameter space
4. Particle physics model of cosmic inflation

Status of particle physics

Status of particle physics: energy frontier

- LEP, LHC: SM describes final states of particle collisions precisely

SM@LHC: theory vs. 36 measurements at CMS

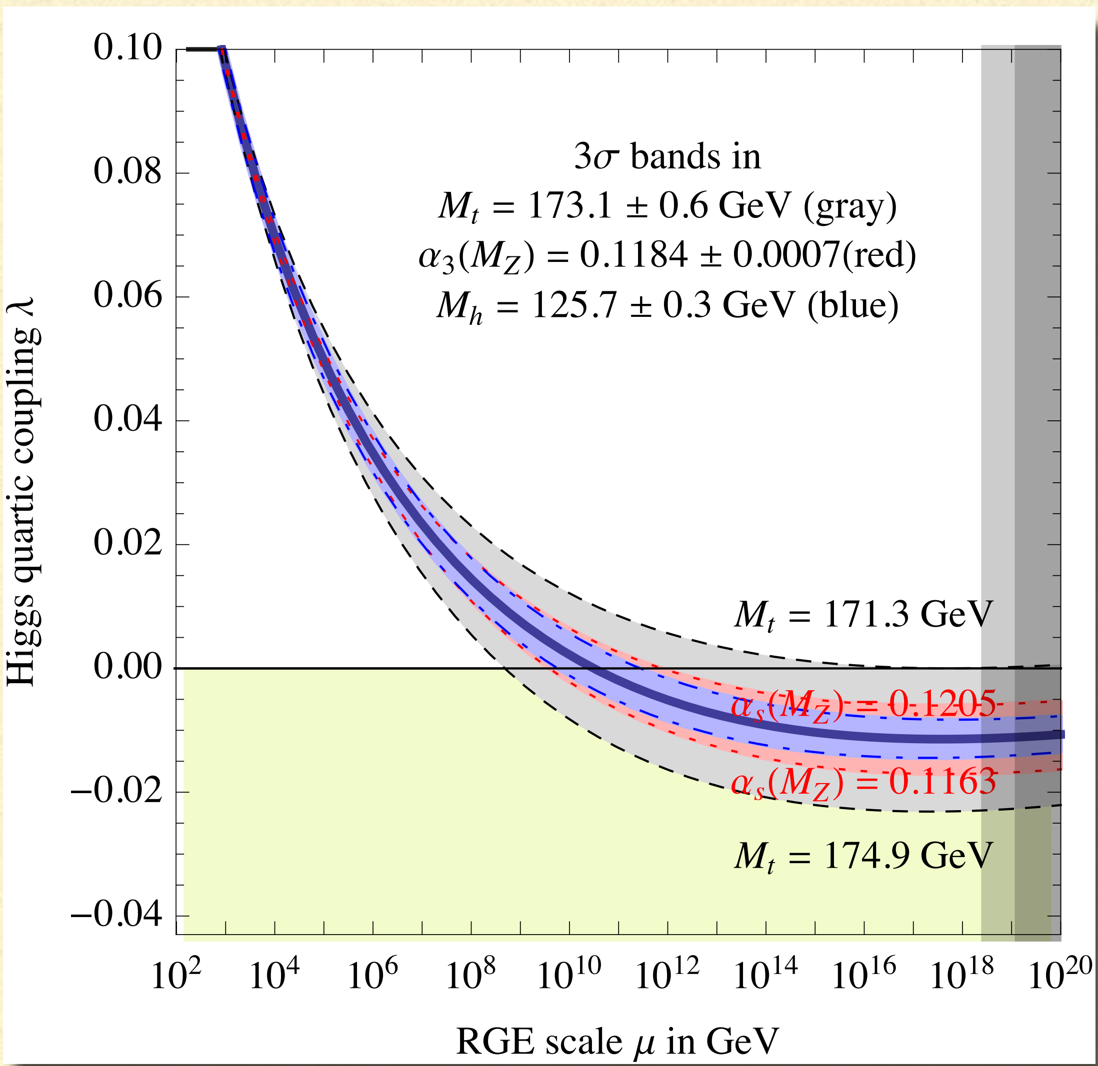


Status of particle physics: energy frontier

- LEP, LHC: SM describes final states of particle collisions precisely

- SM is unstable

SM is unstable



Degrassi et al., arXiv:1205.6497

Status of particle physics: energy frontier

- LEP, LHC: SM describes final states of particle collisions precisely

- SM is unstable

- No proven sign of new physics beyond SM at colliders*

*There are some indications below discovery significance (such as lepton flavor non-universality in meson decays)

Status of particle physics: cosmic and intensity frontiers

- Universe at large scale described precisely by cosmological SM: ΛCDM (Ω_m =0.3)
- Neutrino flavours oscillate
- Existing baryon asymmetry cannot be explained by CP asymmetry in SM
- Inflation of the early, accelerated expansion of the present Universe

$U(1)_Z$ extension of SM

Extension of SM

- There are many extensions proposed, mostly with the aim of predicting some observable effect at the LHC – but there are none so far, so we may look elsewhere

- SM is highly efficient – let us stick to efficiency

the only exception of economical description is the relatively large number of Yukawa couplings

Extension of SM

- Neutrinos must play a key role

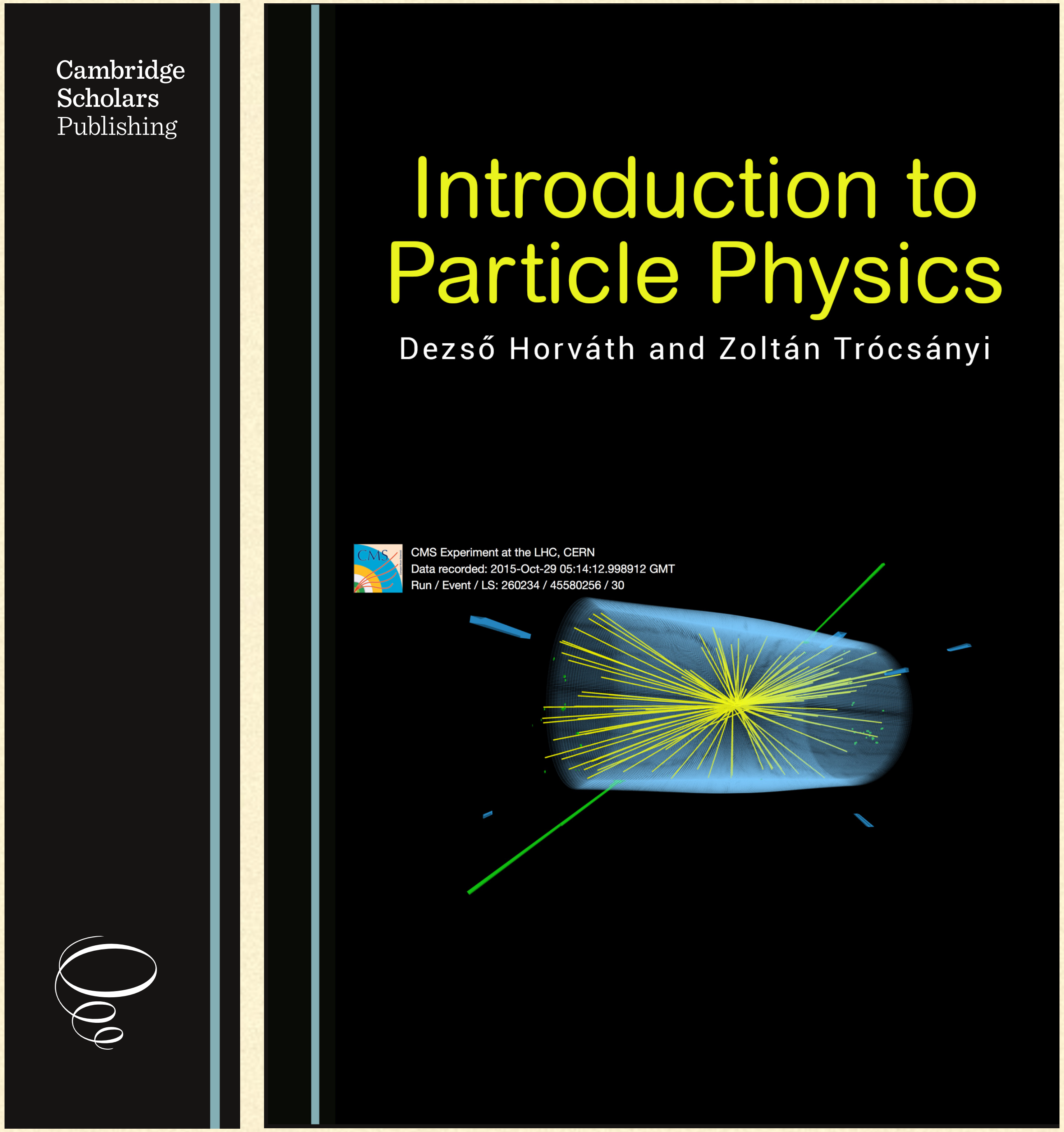
  with non-zero masses they must feel another force apart from the weak one, such as Yukawa coupling to a scalar, which requires the existence of right-handed neutrinos

- Simplest extension of $G_{SM}=SU(3)_c\times SU(2)_L\times U(1)_Y$ is to $G=G_{SM}\times U(1)_Z$

  renormalizable gauge theory without any other symmetry

- Fix Z-charges by requirement of
  - gauge and gravity anomaly cancellation and
  - gauge invariant Yukawa terms for neutrino mass generation

Focus only on addition to the SM, find SM in this new book:



Fermions
(with new highlighted)

- fermion fields:

$$\psi^f_{q,1} = \begin{pmatrix} U^f \\ D^f \end{pmatrix}_{\mathrm{L}} \qquad \psi^f_{q,2} = U^f_{\mathrm{R}}\,, \qquad \psi^f_{q,3} = D^f_{\mathrm{R}}$$

$$\psi^f_{l,1} = \begin{pmatrix} \nu^f \\ \ell^f \end{pmatrix}_{\mathrm{L}} \qquad \boxed{\psi^f_{l,2} = \nu^f_{\mathrm{R}}\,,} \qquad \psi^f_{l,3} = \ell^f_{\mathrm{R}}$$

where

$$\psi_{\mathrm{L/R}} \equiv \psi_{\mp} = \frac{1}{2}\,(1 \mp \gamma_5)\,\psi \equiv P_{\mathrm{L/R}}\psi$$

(ν_{L} can ν_{R} can also be Majorana neutrinos: Weyl-spinors embedded into *different* Dirac spinors)

- covariant derivative (includes kinetic mixing):

Lagrangian (not considering QCD)

- Dirac:

$$\mathcal{L}_{\mathrm{D}} = \mathrm{i} \sum_{f=1}^{3} \sum_{j=1}^{3} \Big(\overline{\psi}^{f}_{q,j}(x) \not{D}^{(j)} \psi^{f}_{q,j}(x) + \overline{\psi}^{f}_{l,j}(x) \not{D}^{(j)} \psi^{f}_{l,j}(x) \Big)$$

$$D^{(j)}_{\mu} = \partial_{\mu} + \mathrm{i} g_{\mathrm{L}}\, \boldsymbol{T} \cdot \boldsymbol{W}_{\mu} + \mathrm{i} g_{Y}\, y_j B_{\mu} + \mathrm{i} g_{Z}\, z_j Z_{\mu}$$

- Gauge fields:

$$\mathcal{L}_{B,Z,W} = -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} Z_{\mu\nu} Z^{\mu\nu} - \frac{1}{4} \boldsymbol{W}_{\mu\nu} \cdot \boldsymbol{W}^{\mu\nu} - \frac{\sin\theta_Z}{2} B_{\mu\nu} Z^{\mu\nu}$$

$$\longrightarrow \mathcal{L}_{B,Z,W} = -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} Z_{\mu\nu} Z^{\mu\nu} - \frac{1}{4} \boldsymbol{W}_{\mu\nu} \cdot \boldsymbol{W}^{\mu\nu}$$

$$D^{(j)}_{\mu} = \partial_{\mu} + \mathrm{i} g_{\mathrm{L}}\, \boldsymbol{T} \cdot \boldsymbol{W}_{\mu} + \mathrm{i} g_{Y}\, y_j B'_{\mu} + \mathrm{i}\big(\overbrace{g'_Z\, z_j - g'_Y\, y_j}^{\equiv g'_Z r_j + (g'_Z - g'_Y) y_j}\big) Z'_{\mu}$$

Scalars

- Standard Φ complex SU(2)$_L$ doublet and new χ complex singlet:

$$\mathcal{L}_{\phi,\chi} = [D_\mu^{(\phi)}\phi]^* D^{(\phi)\,\mu}\phi + [D_\mu^{(\chi)}\chi]^* D^{(\chi)\,\mu}\chi - V(\phi,\chi)$$

- with scalar potential

$$V(\phi,\chi) = V_0 - \mu_\phi^2|\phi|^2 - \mu_\chi^2|\chi|^2 + \left(|\phi|^2, |\chi|^2\right)\begin{pmatrix}\lambda_\phi & \frac{\lambda}{2}\\ \frac{\lambda}{2} & \lambda_\chi\end{pmatrix}\begin{pmatrix}|\phi|^2\\ |\chi|^2\end{pmatrix}$$

Scalars

- Standard ϕ complex SU(2)$_L$ doublet and new χ complex singlet:

$$\mathcal{L}_{\phi,\chi} = [D_\mu^{(\phi)}\phi]^* D^{(\phi)\,\mu}\phi + [D_\mu^{(\chi)}\chi]^* D^{(\chi)\,\mu}\chi - V(\phi,\chi)$$

- with scalar potential

$$V(\phi,\chi) = V_0 - \mu_\phi^2|\phi|^2 - \mu_\chi^2|\chi|^2 + (|\phi|^2, |\chi|^2) \begin{pmatrix} \lambda_\phi & \frac{\lambda}{2} \\ \frac{\lambda}{2} & \lambda_\chi \end{pmatrix} \begin{pmatrix} |\phi|^2 \\ |\chi|^2 \end{pmatrix}$$

- After SSB, G → SU(3)$_c$×U(1)$_{QED}$:

$$\phi = \frac{1}{\sqrt{2}}\,\mathrm{e}^{\mathrm{i}\boldsymbol{T}\cdot\boldsymbol{\xi}(x)/v}\begin{pmatrix} 0 \\ v + h'(x) \end{pmatrix} \;\&\; \chi(x) = \frac{1}{\sqrt{2}}\,\mathrm{e}^{\mathrm{i}\eta(x)/w}(w + s'(x))$$

Fermion-scalar interactions

- Standard Yukawa terms:

$$\mathcal{L}_{\mathrm{Y}} = -\left[c_D\,(\bar{U},\,\bar{D})_{\mathrm{L}}\begin{pmatrix}\phi^{(+)}\\ \phi^{(0)}\end{pmatrix} D_{\mathrm{R}} + c_U\,(\bar{U},\,\bar{D})_{\mathrm{L}}\begin{pmatrix}\phi^{(0)\,*}\\ -\phi^{(+)\,*}\end{pmatrix} U_{\mathrm{R}} + c_\ell\,(\bar{\nu}_\ell,\,\bar{\ell})_{\mathrm{L}}\begin{pmatrix}\phi^{(+)}\\ \phi^{(0)}\end{pmatrix}\ell_{\mathrm{R}}\right] + \mathrm{h.c.}$$

- lead to fermion masses after SSB:

$$\mathcal{L}_{\mathrm{Y}} = -\left(1+\frac{h(x)}{v}\right)\left[\bar{D}_{\mathrm{L}}\,M_D\,D_{\mathrm{R}} + \bar{U}_{\mathrm{L}}\,M_U\,U_{\mathrm{R}} + \bar{\ell}_{\mathrm{L}}\,M_\ell\,\ell_{\mathrm{R}}\right] + \mathrm{h.c.}$$

- Neutrino Yukawa terms $(z_\chi = -2z_{\nu_{\mathrm{R}}})$:

$$\mathcal{L}_{\mathrm{Y}}^{\nu} = -\sum_{i,j}\left(\underbrace{(c_\nu)_{ij}\bar{L}_{i,\mathrm{L}}\cdot\tilde{\phi}\,\nu_{j,\mathrm{R}}}_{\text{(Dirac mass terms)}} + \underbrace{\frac{1}{2}(c_{\mathrm{R}})_{ij}\,\overline{\nu^c_{i,\mathrm{R}}}\nu_{j,\mathrm{R}}\,\chi}_{\text{(Majorana mass terms)}}\right) + \mathrm{h.c.}$$

Anomaly free charge assignment

field	$SU(3)_c$	$SU(2)_L$	y_j	$z_j^{(a)}$	$z_j^{(b)}$	$r_j = z_j/z_\phi - y_j^{(c)}$
$U_L,\ D_L$	3	2	$\frac{1}{6}$	Z_1	$\frac{1}{6}$	0
U_R	3	1	$\frac{2}{3}$	Z_2	$\frac{7}{6}$	$\frac{1}{2}$
D_R	3	1	$-\frac{1}{3}$	$2Z_1 - Z_2$	$-\frac{5}{6}$	$-\frac{1}{2}$
$\nu_L,\ \ell_L$	1	2	$-\frac{1}{2}$	$-3Z_1$	$-\frac{1}{2}$	0
ν_R	1	1	0	$Z_2 - 4Z_1$	$\frac{1}{2}$	$\frac{1}{2}$
ℓ_R	1	1	-1	$-2Z_1 - Z_2$	$-\frac{3}{2}$	$-\frac{1}{2}$
ϕ	1	2	$\frac{1}{2}$	z_ϕ	1	$\frac{1}{2}$
χ	1	1	0	z_χ	-1	-1

(a) anomaly free charges (b) from neutrino-scalar interactions (c) from re-parametrization of couplings

Anomaly free charge assignment

field	$SU(3)_c$	$SU(2)_L$	y_j	$z_j^{(a)}$	$z_j^{(b)}$	$r_j = z_j/z_\phi - y_j^{(c)}$
$U_L,\ D_L$	3	2	$\frac{1}{6}$	Z_1	$\frac{1}{6}$	0
U_R	3	1	$\frac{2}{3}$	Z_2	$\frac{7}{6}$	$\frac{1}{2}$
D_R	3	1	$-\frac{1}{3}$	$2Z_1 - Z_2$	$-\frac{5}{6}$	$-\frac{1}{2}$
$\nu_L,\ \ell_L$	1	2	$-\frac{1}{2}$	$-3Z_1$	$-\frac{1}{2}$	0
ν_R	1	1	0	$Z_2 - 4Z_1$	$\frac{1}{2}$	$\frac{1}{2}$
ℓ_R	1	1	-1	$-2Z_1 - Z_2$	$-\frac{3}{2}$	$-\frac{1}{2}$
ϕ	1	2	$\frac{1}{2}$	z_ϕ	1	$\frac{1}{2}$
χ	1	1	0	z_χ	-1	-1

(a) anomaly free charges (b) from neutrino-scalar interactions (c) from re-parametrization of couplings

Anomaly free charge assignment

field	$SU(3)_c$	$SU(2)_L$	y_j	z_j [(a)]	z_j [(b)]	$r_j = z_j/z_\phi - y_j$ [(c)]
$U_L,\ D_L$	3	2	$\frac{1}{6}$	Z_1	$\frac{1}{6}$	0
U_R	3	1	$\frac{2}{3}$	Z_2	$\frac{7}{6}$	$\frac{1}{2}$
D_R	3	1	$-\frac{1}{3}$	$2Z_1 - Z_2$	$-\frac{5}{6}$	$-\frac{1}{2}$
$\nu_L,\ \ell_L$	1	2	$-\frac{1}{2}$	$-3Z_1$	$-\frac{1}{2}$	0
ν_R	1	1	0	$Z_2 - 4Z_1$	$\frac{1}{2}$	$\frac{1}{2}$
ℓ_R	1	1	-1	$-2Z_1 - Z_2$	$-\frac{3}{2}$	$-\frac{1}{2}$
ϕ	1	2	$\frac{1}{2}$	z_ϕ	1	$\frac{1}{2}$
χ	1	1	0	z_χ	-1	-1

(a) anomaly free charges (b) from neutrino-scalar interactions (c) from re-parametrization of couplings

After SSB neutrino mass terms appear

$$\mathcal{L}_{\mathrm{Y}}^{\nu} = -\frac{1}{2}\sum_{i,j}\left[\left(\overline{\nu_{\mathrm{L}}},\, \overline{\nu_{\mathrm{R}}^{c}}\right)_i M(h,s)_{ij} \begin{pmatrix} \nu_{\mathrm{L}}^{c} \\ \nu_{\mathrm{R}} \end{pmatrix}_j + \mathrm{h.c.}\right]$$

where

$$M(h,s)_{ij} = \begin{pmatrix} 0 & m_{\mathrm{D}}\left(1+\frac{h}{v}\right) \\ m_{\mathrm{D}}\left(1+\frac{h}{v}\right) & M_{\mathrm{M}}\left(1+\frac{s}{w}\right) \end{pmatrix}_{ij}$$

6x6 symmetric matrix (m_{D} complex, M_{M} real)

in diagonal: Majorana mass terms (so ν_{L} massless!)

but ν_{L} and ν_{R} have the same q-numbers,
can mix, leading to type-I see-saw

Neutrino masses

First diagonalize m_{D} and M_{M} by defining

$$\nu'_{\mathrm{L},i} = \sum_j (U_{\mathrm{L}})_{ij} \nu_{\mathrm{L},j} \quad \text{and} \quad \nu'_{\mathrm{R},i} = \sum_j (O_{\mathrm{R}})_{ij} \nu_{\mathrm{R},j}$$

so

$$\mathcal{L}_{\mathrm{Y}}^{\nu} = -\frac{1}{2} \sum_{i,j} \left[\left(\overline{\nu'_{\mathrm{L}}}, \overline{\nu'^{c}_{\mathrm{R}}} \right)_i M'(h,s)_{ij} \begin{pmatrix} \nu'^{c}_{\mathrm{L}} \\ \nu'_{\mathrm{R}} \end{pmatrix}_j + \text{h.c.} \right]$$

where

$$M'(h,s) = \begin{pmatrix} 0 & mV\left(1+\frac{h}{v}\right) \\ V^{\dagger} m \left(1+\frac{h}{v}\right) & M\left(1+\frac{s}{w}\right) \end{pmatrix}$$

with m and M diagonal, $V = U_{\mathrm{L}}^{T} O_{\mathrm{R}}$ unitary matrix

Effective light neutrino masses

If $m_i << M_j$, can integrate out the heavy neutrinos

$$\mathcal{L}^{\nu}_{\mathrm{dim}-5} = -\frac{1}{2}\sum_i m_{\mathrm{M},i}\left(1+\frac{h}{v}\right)^2\left(\overline{\nu'^{c}_{i,\mathrm{L}}}\nu'_{i,\mathrm{L}} + \mathrm{h.c.}\right)$$

where $m_{M,i}$ are Majorana masses, eigenvalues of

$m_{\mathrm{D}}^{\dagger} M_{\mathrm{M}}^{-1} m_{\mathrm{D}}$, suppressed by m_i/M_i

Effective light neutrino masses

If $m_i << M_j$, can integrate out the heavy neutrinos

$$\mathcal{L}^{\nu}_{\mathrm{dim-5}} = -\frac{1}{2}\sum_i m_{\mathrm{M},i}\left(1+\frac{h}{v}\right)^2\left(\overline{\nu'^{c}_{i,\mathrm{L}}}\nu'_{i,\mathrm{L}} + \mathrm{h.c.}\right)$$

where $m_{M,i}$ are Majorana masses, eigenvalues of

$m_{\mathrm{D}}^{\dagger} M_{\mathrm{M}}^{-1} m_{\mathrm{D}}$, suppressed by m_i/M_i

if m_i ~ O(100keV) and M_j ~ O(100GeV), then

$m_{M,i}$ ~ O(0.1eV)

Mixing in the neutral gauge sector

$$\begin{pmatrix} W^3_\mu \\ B'_\mu \\ Z'_\mu \end{pmatrix} = \underline{O}(\sin\theta_\mathrm{W}, \sin\theta_\mathrm{T}) \begin{pmatrix} Z_\mu \\ T_\mu \\ A_\mu \end{pmatrix}$$

- QED current remains unchanged:

$$\mathcal{L}_\mathrm{QED} = -eA_\mu J^\mu_\mathrm{em}$$

$$J^\mu_\mathrm{em} = \sum_{f=1}^{3}\sum_{j=1}^{3} e_j \Big(\overline{\psi}^f_{q,j}(x)\gamma^\mu\psi^f_{q,j}(x) + \overline{\psi}^f_{l,j}(x)\gamma^\mu\psi^f_{l,j}(x)\Big)$$

Neutral current interactions

- current with Z^0 remains unchanged, but mixes with new current J_T of new couplings:

$$\mathcal{L}_Z = -eZ_\mu\Big(\cos\theta_\mathrm{T} J_Z^\mu + \sin\theta_\mathrm{T} J_T^\mu\Big) = -eZ_\mu J_Z^\mu + \mathrm{O}(\theta_\mathrm{T})$$

$$\mathcal{L}_T = -eT_\mu\Big(-\sin\theta_\mathrm{T} J_Z^\mu + \cos\theta_\mathrm{T} J_T^\mu\Big)$$

both can be written as *v-a* interactions for non-chiral fields:

$$J_X^\mu = \sum_f \overline{\psi}_f(x)\gamma^\mu\big(v_f^{(X)} - a_f^{(X)}\gamma_5\big)\psi_f(x)$$

with $X = Z$ or T and summation over q and l flavors

Possible choice for free parameters

The unknown scalar mass M_h or M_H and mixing angles, VEV ratio, new gauge coupling:

$$\sin\theta_S\,,\;\; \sin\theta_T\,,\;\; \tan\beta\,,\;\; \tau$$

$$\tan\beta = \frac{w}{v} \qquad \tau = 2\frac{\gamma'_Z \tan\beta}{\sqrt{1+\gamma_Y^2}} \qquad \gamma_i = g_i/g_{\mathrm{L}}$$

$$\tau = \frac{M_{Z'}}{M_W}\cos\theta_{\mathrm{W}} \simeq \frac{M_T}{M_{Z^0}}$$

Possible consequences with 5 new parameters

- The lightest stable new particle is a natural candidate for WIMP dark matter if it is sufficiently stable.

- Majorana neutrino mass terms are generated by the SSB of the scalar fields, providing the origin of neutrino masses and oscillations.

- Diagonalization of neutrino mass terms leads to the PMNS matrix, which in turn can be the source of lepto-baryogenesis.

- The vacuum of the χ scalar is charged ($z_j = -1$) that may be a source of accelerated expansion of the universe as seen now.

- The second scalar together with the established BEH field may be the source of inflation in the curvaton scenario.

Credibility requirement

Is there any region of the parameter space of the model that is not excluded by experimental results, both established in standard model phenomenology and elsewhere?

Answer is not immediate, extensive studies are needed

In order not to violate ew constraints, we need

$\gamma_Z, \sin\theta_\mathrm{T} \lesssim 10^{-4}$

super-weak force

UV behavior

with Zoltán Péli

Perturbative RG flows

- New couplings are small, hence can use PT
- All β-functions derived at one loop
- Constrain scalar couplings by assuming that the new model remains perturbative and stable up to M_{Pl}:

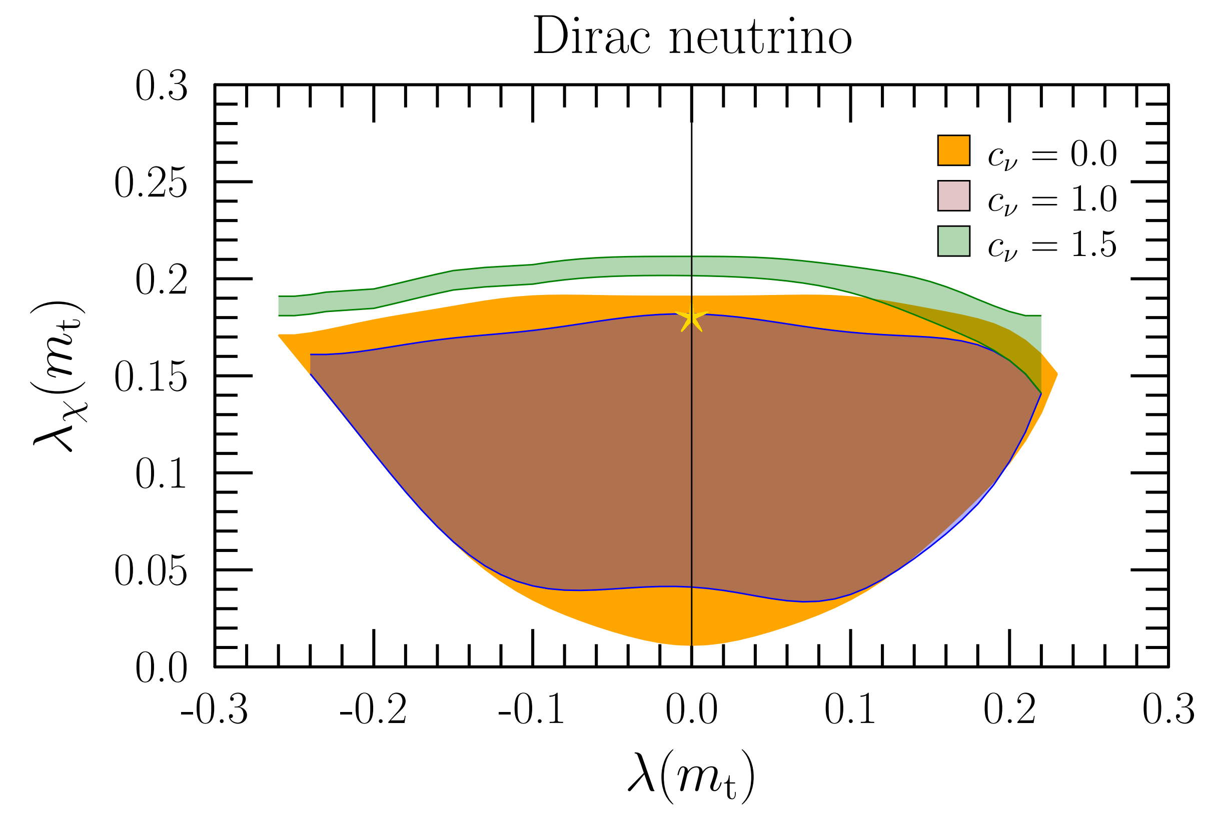
$$\begin{array}{rcll} \lambda_\phi & > & 0, & \\ \lambda_\chi & > & 0, & \\ 4\lambda_\chi\lambda_\phi - \lambda^2 & > & 0, & \text{if} \quad \lambda < 0 \end{array}$$

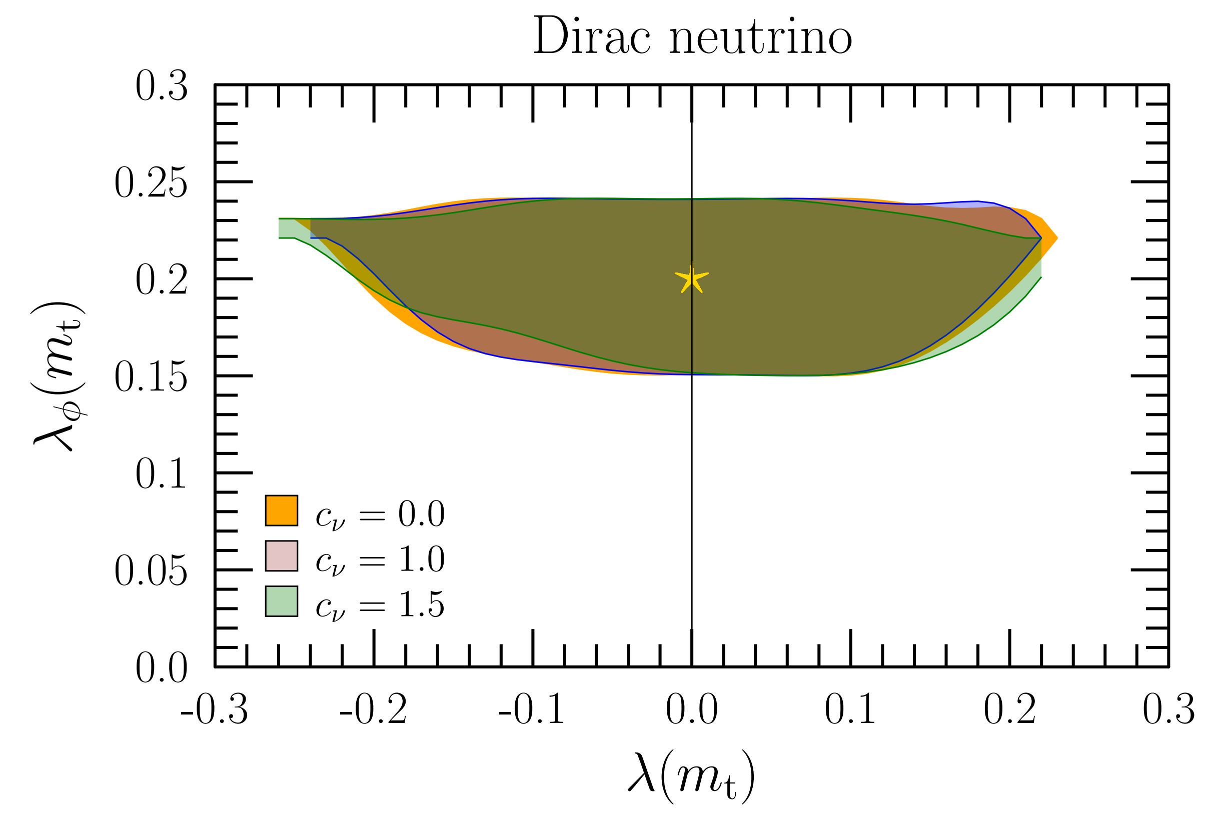
- Among new couplings the flow is most sensitive to the largest neutrino Yukawa c_N
- Require correct Higgs mass and VEV and $w(m_t)>0$

$$v(M_Z) = 246 \text{ GeV} \quad \text{and} \quad M_h(M_Z) = 125 \text{ GeV}$$

Constraining the Parameter Space of the Scalar Couplings

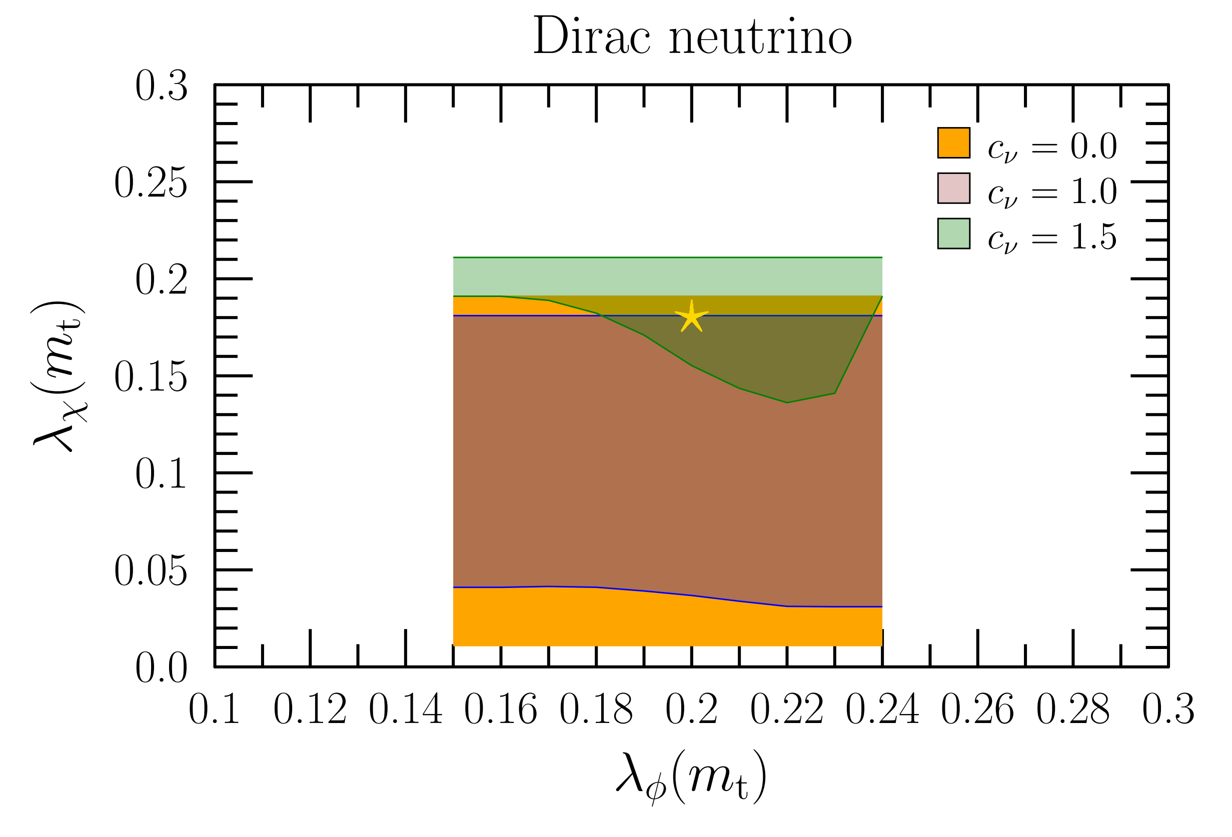
unknown initial values: $\lambda_\phi(m_t), \quad \lambda_\chi(m_t), \quad \lambda(m_t), \quad c_\nu(m_t)$

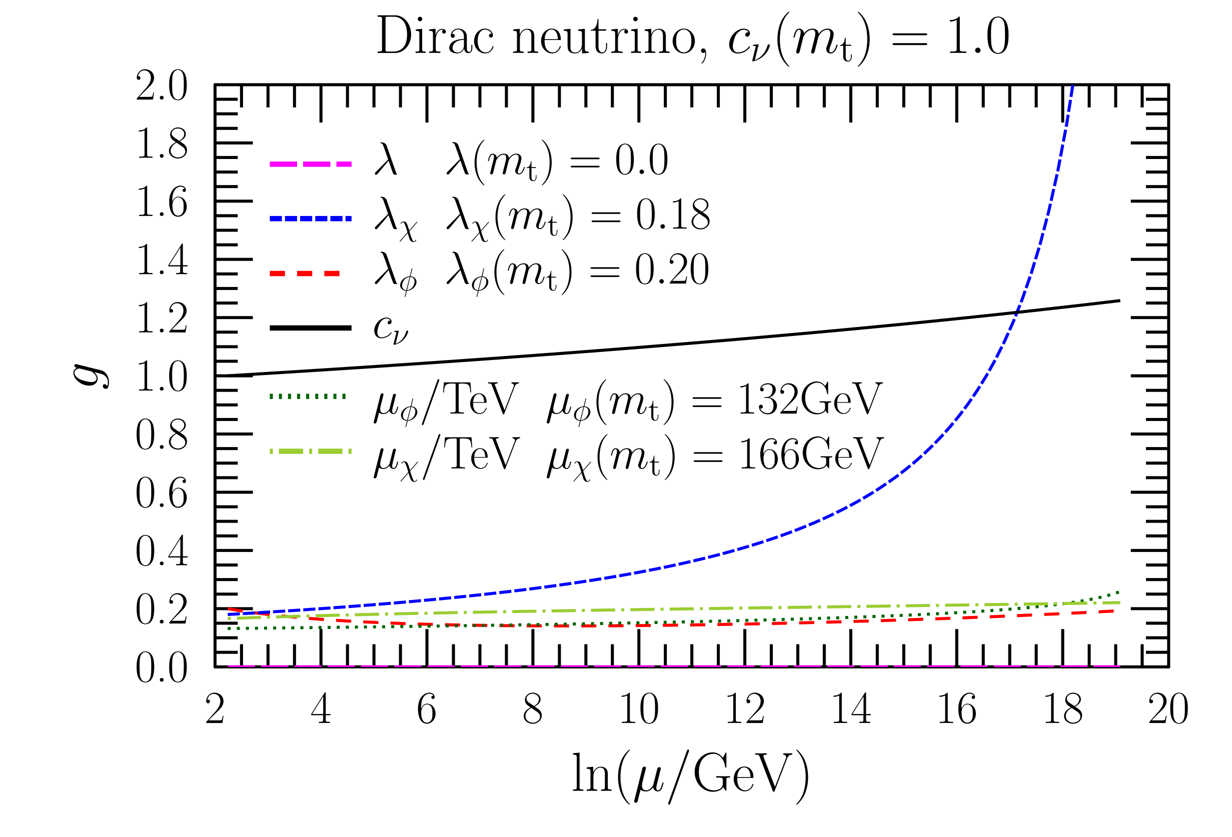




CONSTRAINING THE PARAMETER SPACE OF THE SCALAR COUPLINGS

unknown initial values: $\lambda_\phi(m_t), \quad \lambda_\chi(m_t), \quad \lambda(m_t), \quad c_\nu(m_t)$





Particle physics model of cosmic inflation

with Zoltán Péli and István Nándori

Cosmic Inflation in a Nutshell

Inflation could explain the

- flatness problem: the case of flat universe is an unstable fix point – how can we observe a flat Universe now?
- horizon problem: on our horizon ($d_H(t) = \int_0^{t'} dt'/a(t')$) we see causally disconnected patches of the Universe – how can those be in almost perfect thermal equilibrium?
- almost perfect thermal equilibrium: can we explain primordial fluctuations?

Cosmic Inflation in a Nutshell

Inflation could explain the scale of anisotropy in the CMB:

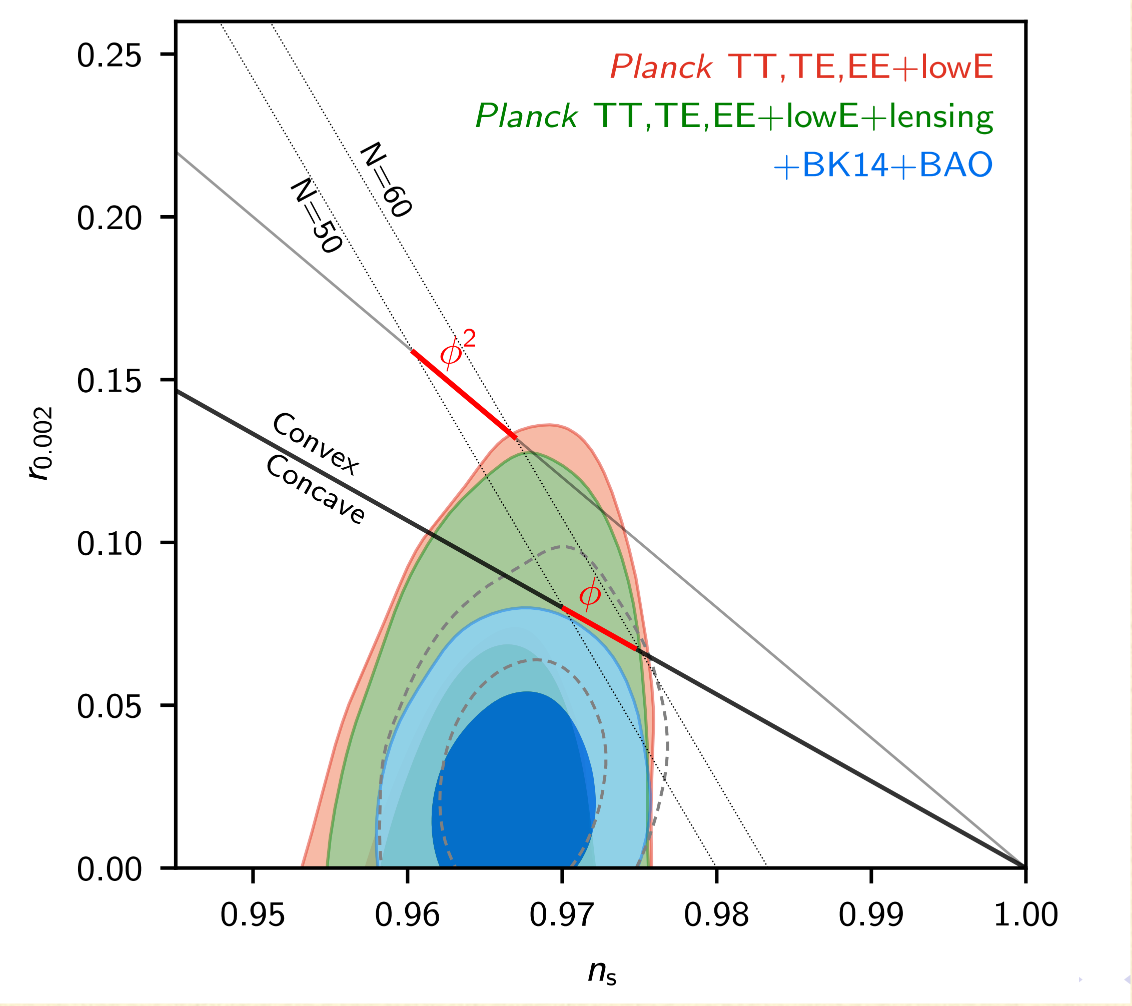
- during inflation the horizon of the observable universe decreases ($dt/a = e^{-Ht}dt$)
- the wavelengths of fluctuations can become larger than the observable universe: causally connected patches become disconnected
- after inflation ends, these fluctuations become observable again with the increasing size of the horizon in a radiation and matter dominated universe
- the power spectra of scalar fluctuations of the metric and tensor fluctuations of gravity can be related to measurable quantities

$$\langle 0|\phi(\tau,x)\phi(\tau,y)|0\rangle = \int \frac{dk}{k} P(k) e^{ik\cdot(x-y)}, \quad d\tau = \frac{dt}{a}$$

COSMIC INFLATION IN A NUTSHELL

- One such quantity is the **tensor to scalar ratio** $r = P_T/P_S$ (ratio of the corresponding power spectra, compatible with zero)

- The other one is the **scalar tilt** n_S: $n_s - 1 = \frac{d \ln P_S}{d \ln k}$ is the **exponent in the** power function that describes the **power spectrum of scalar fluctuations** (n_S = 0.966)

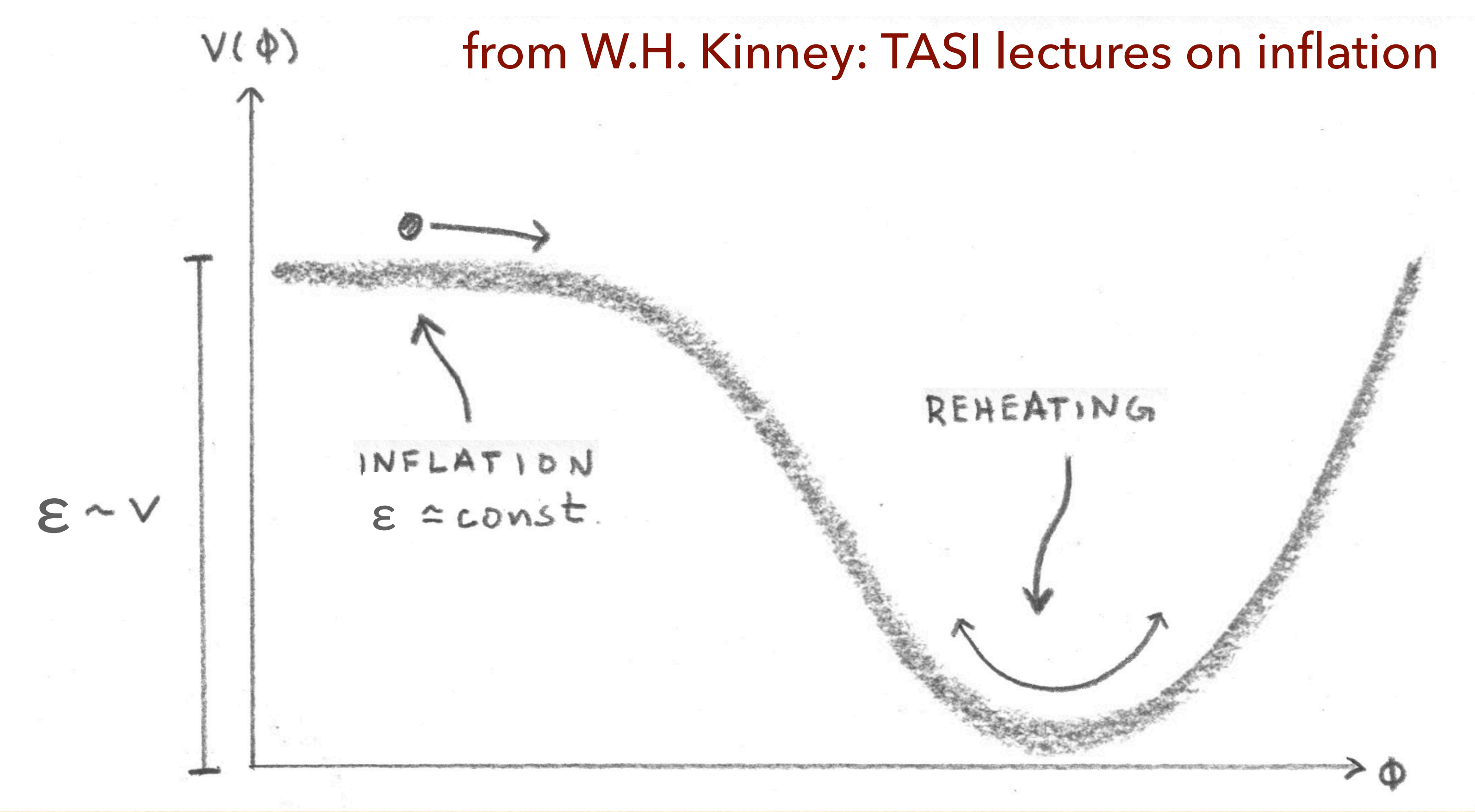


SLOW-ROLL MODEL IN A NUTSHELL

One or more scalar field(s) coupled to gravity can cause inflation as the equation of state (p = - ε) implies negative pressure, leading to exponential increase of the scale factor: $a \propto e^N$ (N is the e-fold number)

The minimum has to be sufficiently far for $N > 60$ (observables are constructed from the slow-roll parameters taken 50–60 e-folds before the end of inflation)

How can such a potential energy emerge?



Slow Roll with Two Fields

$$V(\phi,\chi) = V_0 - \mu_\phi^2|\phi|^2 - \mu_\chi^2|\chi|^2 + \frac{1}{2}(|\phi|^2,|\chi|^2)\underbrace{C}_{\begin{pmatrix} 2\lambda_\phi & \lambda \\ \lambda & 2\lambda_\chi \end{pmatrix}}\begin{pmatrix} |\phi|^2 \\ |\chi|^2 \end{pmatrix}$$

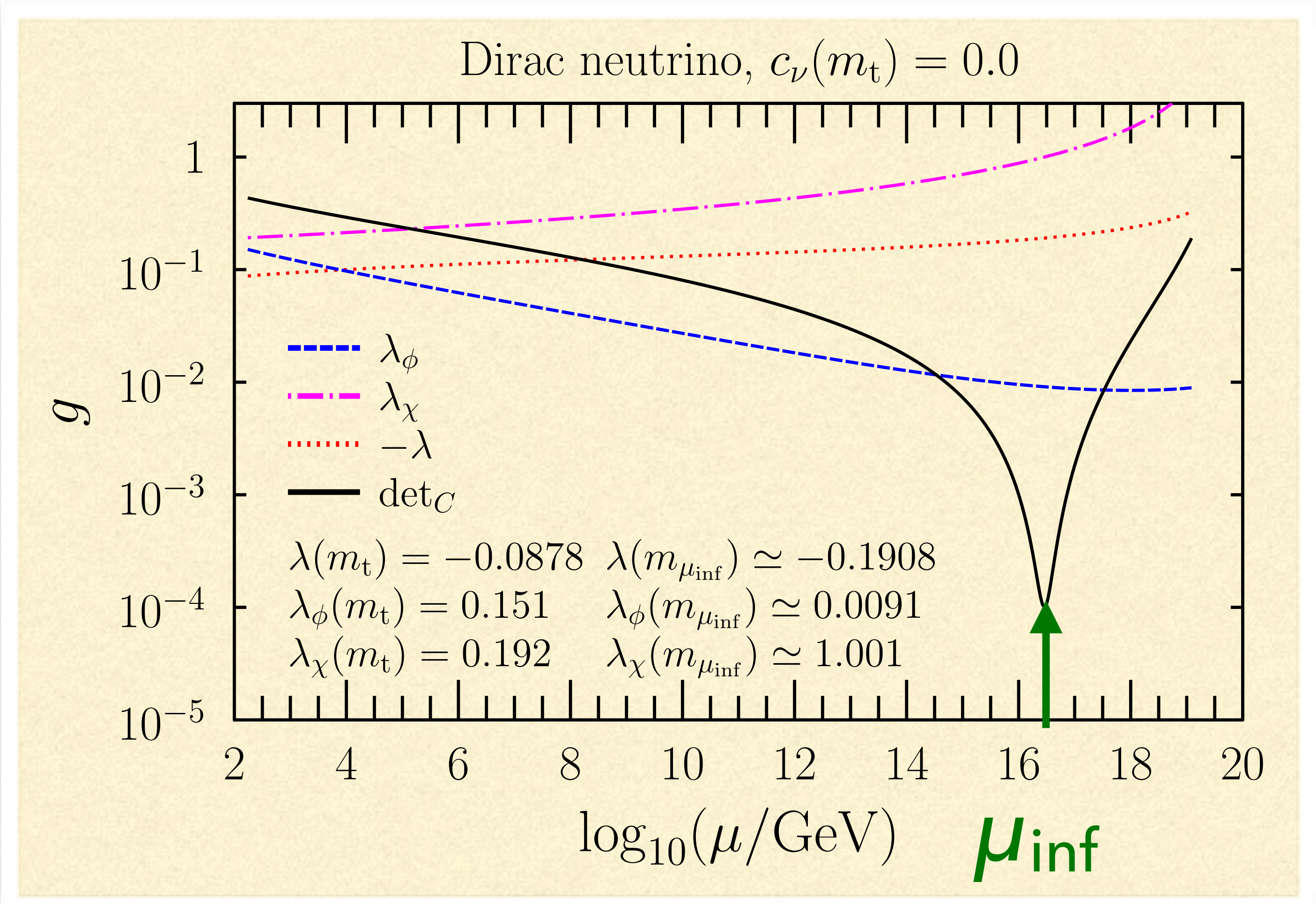
- VEVs are proportional to $(\det_C)^{-1/2}$

$$v = \sqrt{\frac{2\lambda_\chi\mu_\phi^2 - \lambda\mu_\chi^2}{4\lambda_\phi\lambda_\chi - \lambda^2}}, \qquad w = \sqrt{\frac{2\lambda_\phi\mu_\chi^2 - \lambda\mu_\phi^2}{4\lambda_\phi\lambda_\chi - \lambda^2}}$$

- The couplings run according to the RGEs

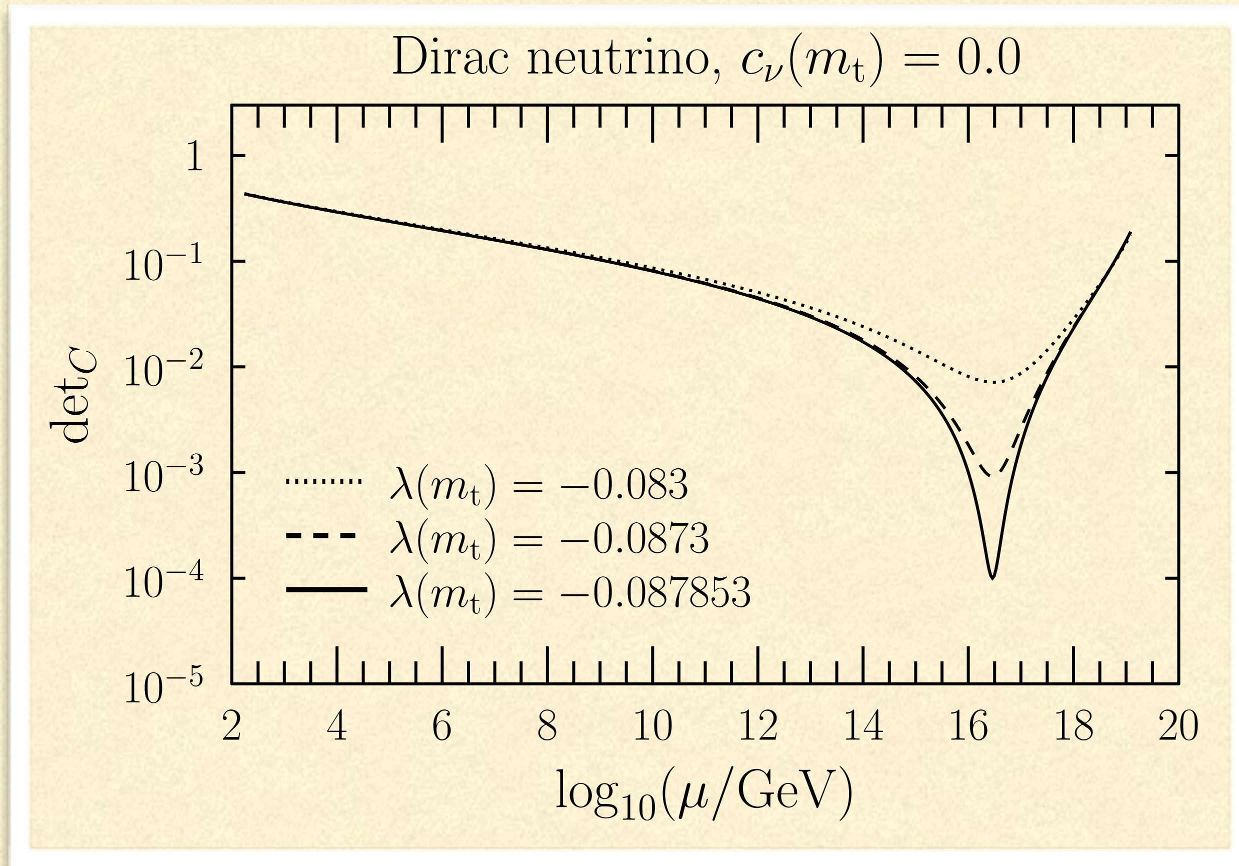
Slow Roll with Two Fields

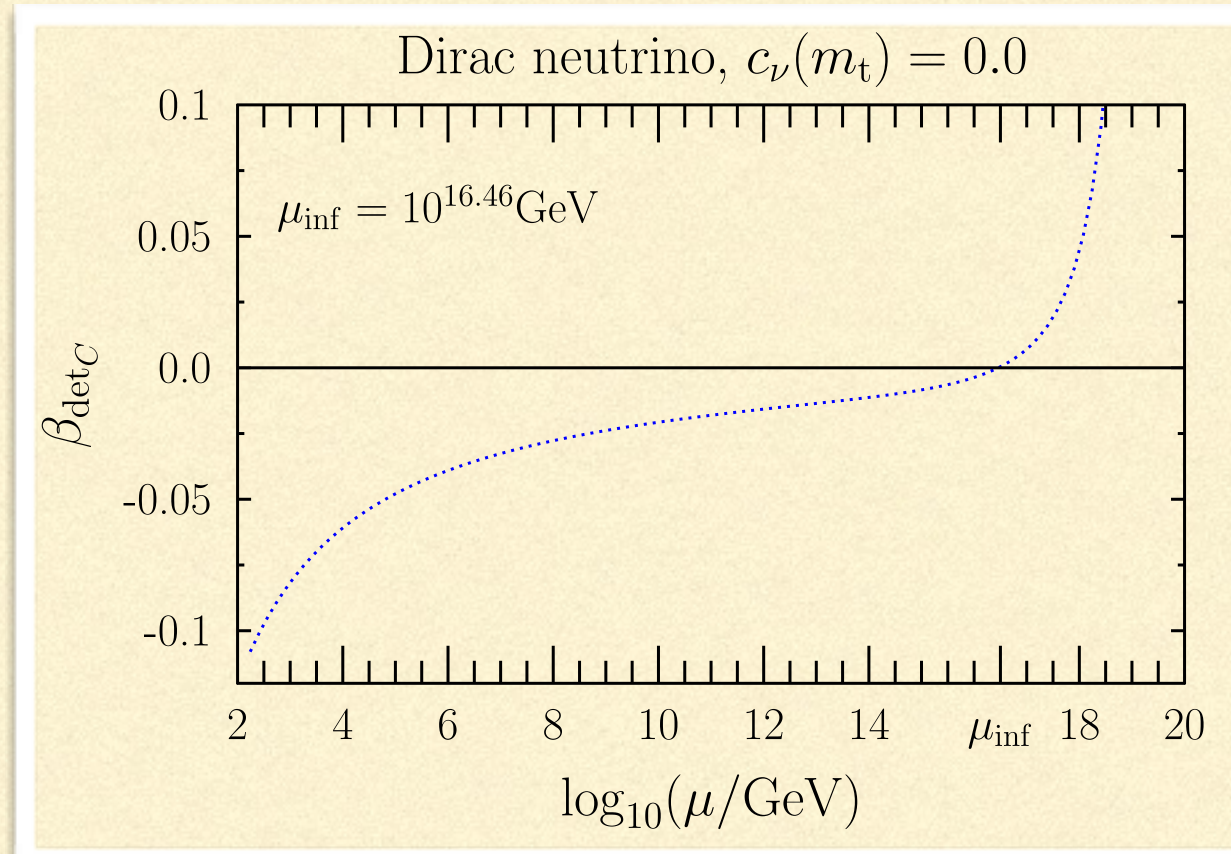
- The determinant of the coupling matrix in the denominator becomes very small in a certain region of the parameter space
- As a result, the VEVs become large, O(10^5GeV) at the scale of inflation $\mu_{\rm inf}$



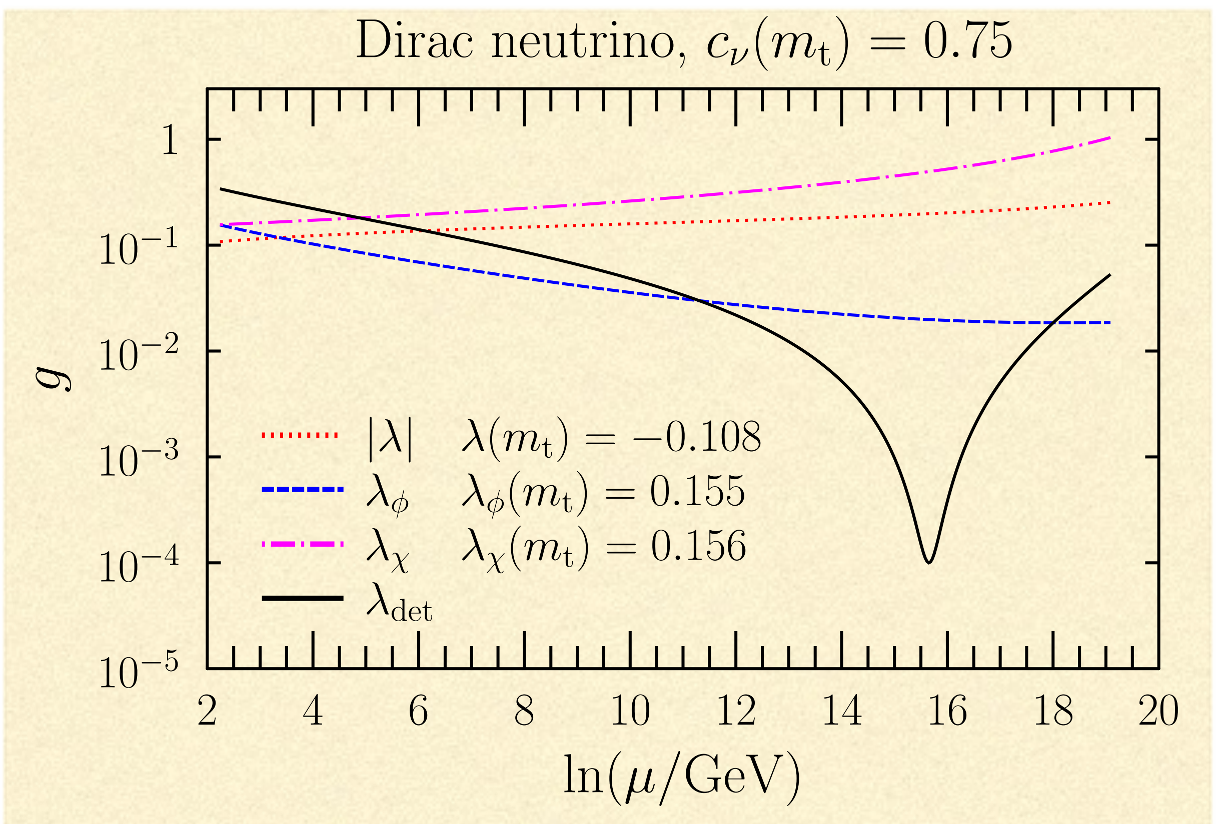
is this wedge real?

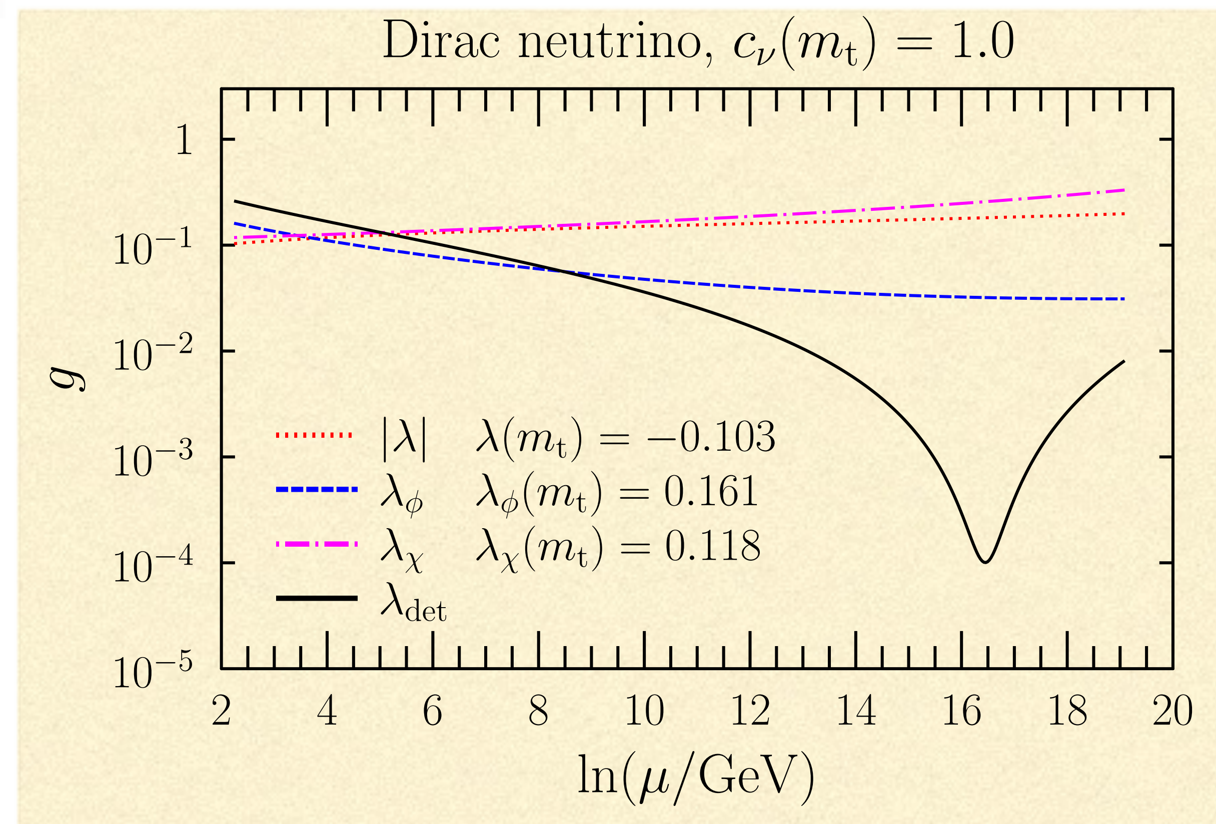
Running of the Determinant of the Scalar Couplings





Running of the Determinant of the Scalar Couplings



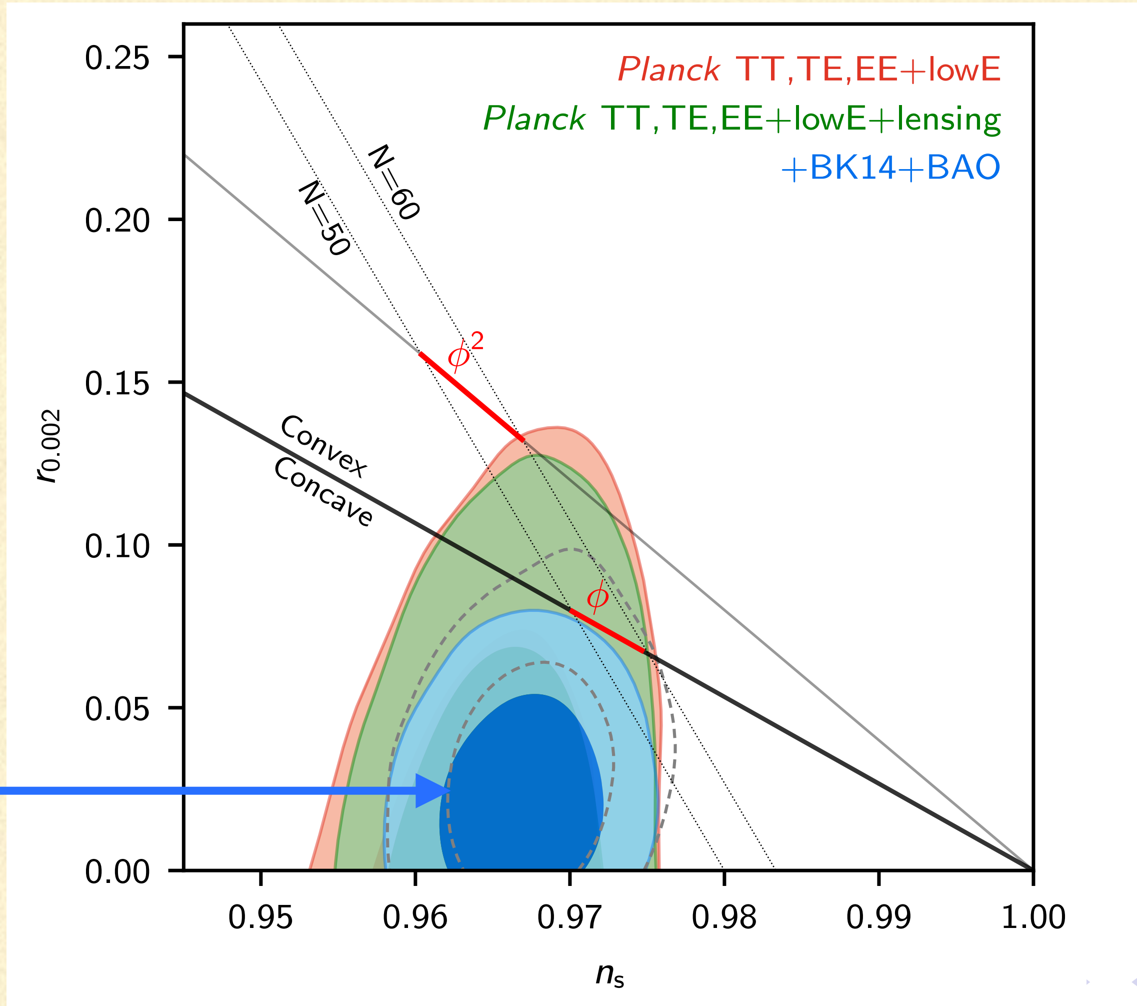


SLOW ROLL WITH ONE FIELD

- Traditional normalization of V with one field is

$$V_0 \simeq r \left(1.6 \cdot 10^{16} \text{ GeV}\right)^4$$

→ r has to be sizable, somewhat in contradiction with current trend of measurements (compatible with $r = 0$)



- with multiple fields we can separate the value of r and V_0

Slow Roll with Two Fields

- Introduce local rotation:

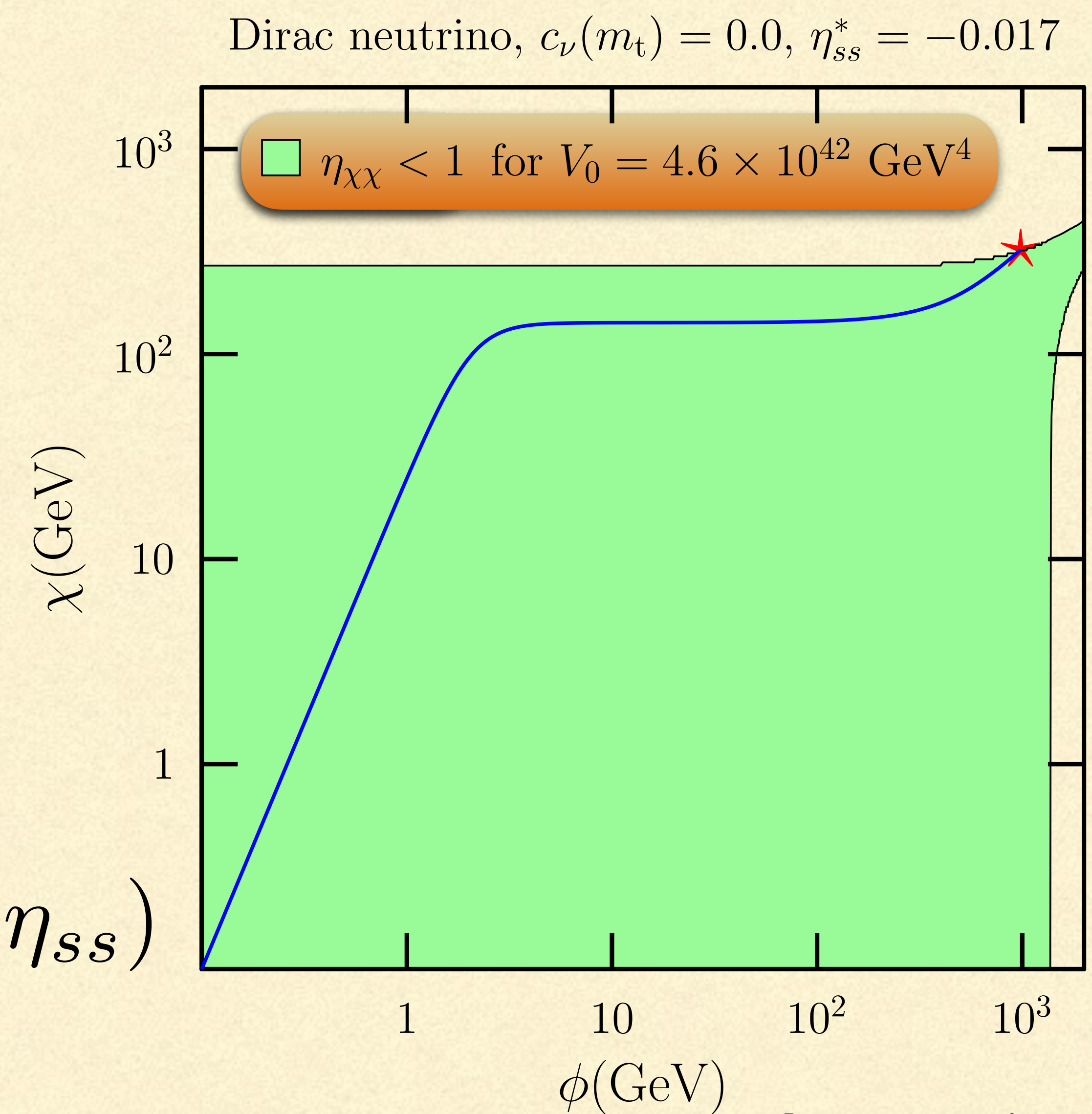
$$(\phi, \chi) \to (\sigma, s)$$

to adiabatic and entropy fields

- Slow-roll parameters with multiple fields:

$$\epsilon = \frac{3}{2}\left(\frac{p}{\rho} + 1\right) \simeq \frac{1}{2} m_P^2 \left(\frac{\partial_\sigma V}{V}\right)^2$$

$$\eta_{ij} \simeq m_p^2 \frac{\partial_{ij} V}{V} \quad (\eta_{\phi\phi} + \eta_{\chi\chi} = \eta_{\sigma\sigma} + \eta_{ss})$$



- trajectory at μ_{inf}, stops at

$$\eta_{ij} = 1 \quad (\epsilon \simeq 0)$$

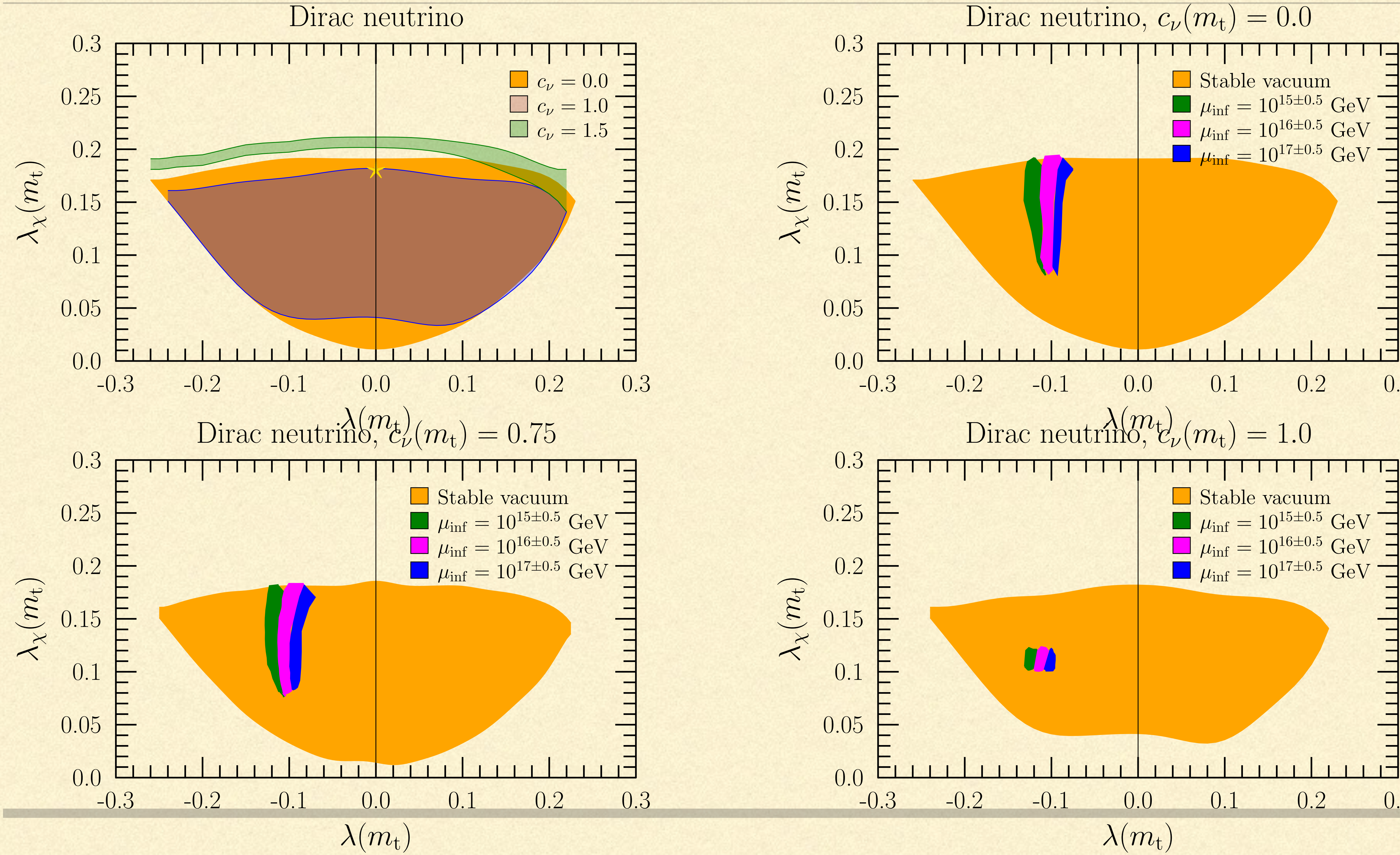
$r = 16\epsilon(\sin\Delta)^2$, assume that $\Delta^* = 0$

→ V_0 obtained from $n_s - 1 = \eta^*_{ss}$

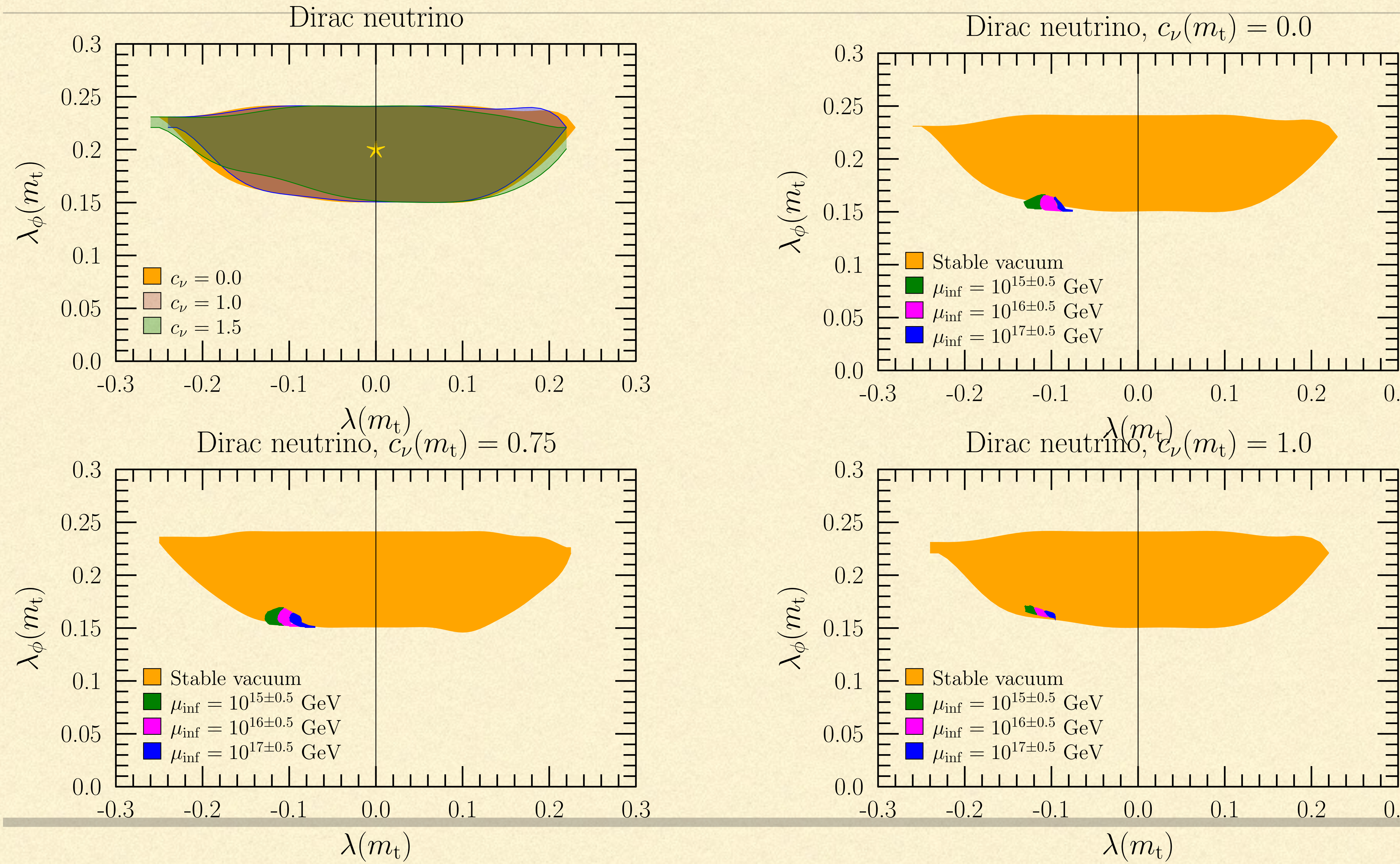
Constraining the parameter space from cosmic inflation

with Zoltán Péli and István Nándori

CONSTRAINING THE PARAMETER SPACE OF THE SCALAR COUPLINGS FROM INFLATION



Constraining the Parameter Space of the Scalar Couplings from Inflation



Conclusions

- Established observations require physics beyond SM, but do not suggest a rich BSM physics
- $U(1)_Z$ extension may explain all known results
- Anomaly cancellation and neutrino mass generation mechanism are used to fix the supercharges (Z-charges) up to reasonable assumptions
- May explain the origin of inflationary potential for curvaton model
- Parameter space can and need be constrained from existing experimental results (e.g. searches in missing energy events)

The end