Proton decay in the minimal realistic SO(10) GUT

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SO(10)

(non-SUSY minimal renormalizable)

- Embedding of the Standard model

$$SU(3)_c \times SU(2)_L \times U(1)_Y \in SO(10)$$

  - Charge quantization
  - Anomaly cancellation
  - Existence of the monopole

- All fermion fields from one generation + right-handed neutrino N_R in 16_F.

$$16_F = L_L \oplus \overline{d}_L \oplus Q_L \oplus \overline{u}_L \oplus \overline{e}_L \oplus N_L^c$$

SO(10)

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- Gauge fields in 45_G, it accommodates SM gauge fields + leptoquarks, diquarks (carry colour and flavour) with masses ~ symmetry breaking scale

$$\begin{gathered} 45_G = G^b_\mu \oplus A^a_\mu \oplus B_\mu, Y_\mu \oplus (3,1,\tfrac{2}{3}) \oplus \boxed{(3,2,-\tfrac{5}{6})} \\ \boxed{\oplus\,(3,2,\tfrac{1}{6})} \oplus (1,1,1) + h.c. \end{gathered}$$

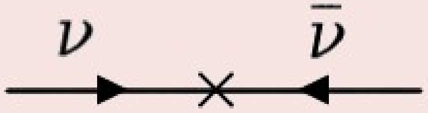
Mediate proton decay

SO(10)

(non-SUSY minimal renormalizable)

- Scalar sector is richer in comparison with the SM. In the minimal realistic setting it contains:
  - 45_S (SO(10) breaking, preserves rank)
  - 126_S (intermediate symmetry breaking, breaks rank, renormalizable Yukawa interaction)
  - 10_S (SM breaking, realistic fermionic spectrum)

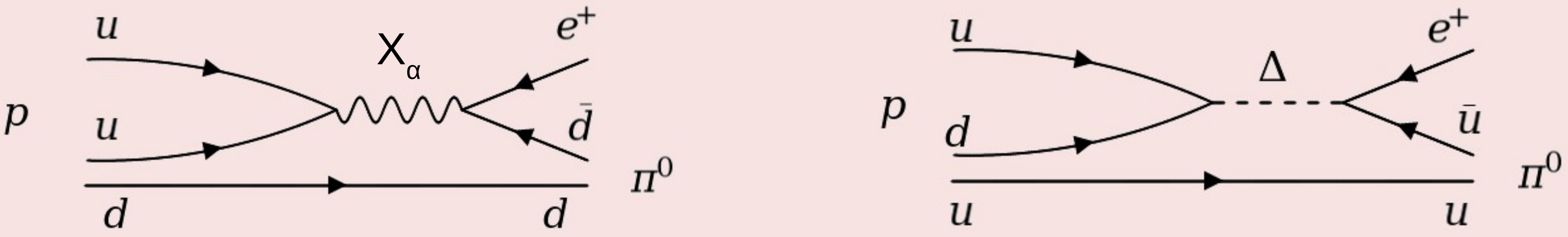
Neutrino mass generation – type I (N_R) and type II (triplet in 126_S)



Baryon number violation

Gauge & scalar leptoquarks lead to baryon number violation.

The most prominent BNV process is proton decay.



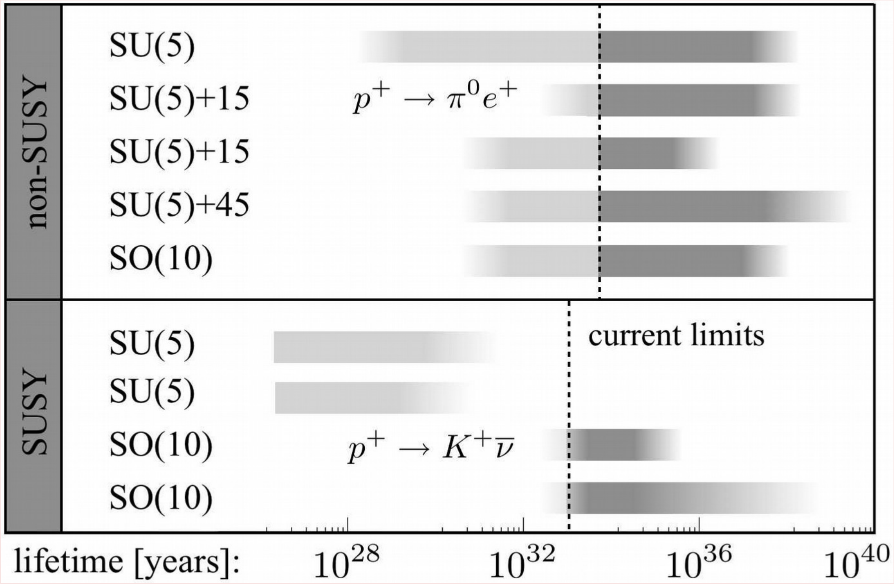
Under controle only recently

$$\Gamma(p \to \pi^0 e^+) \propto |\langle \text{hadr.} \rangle|^2 \times \frac{\alpha_G^2}{M_X^4} \times$$

$$\text{flavour} \times \text{eff. operator running}$$

Proton lifetime prediction in the non-SUSY minimal renormalizable SO(10) is robust with respect to the theoretical uncertainties.

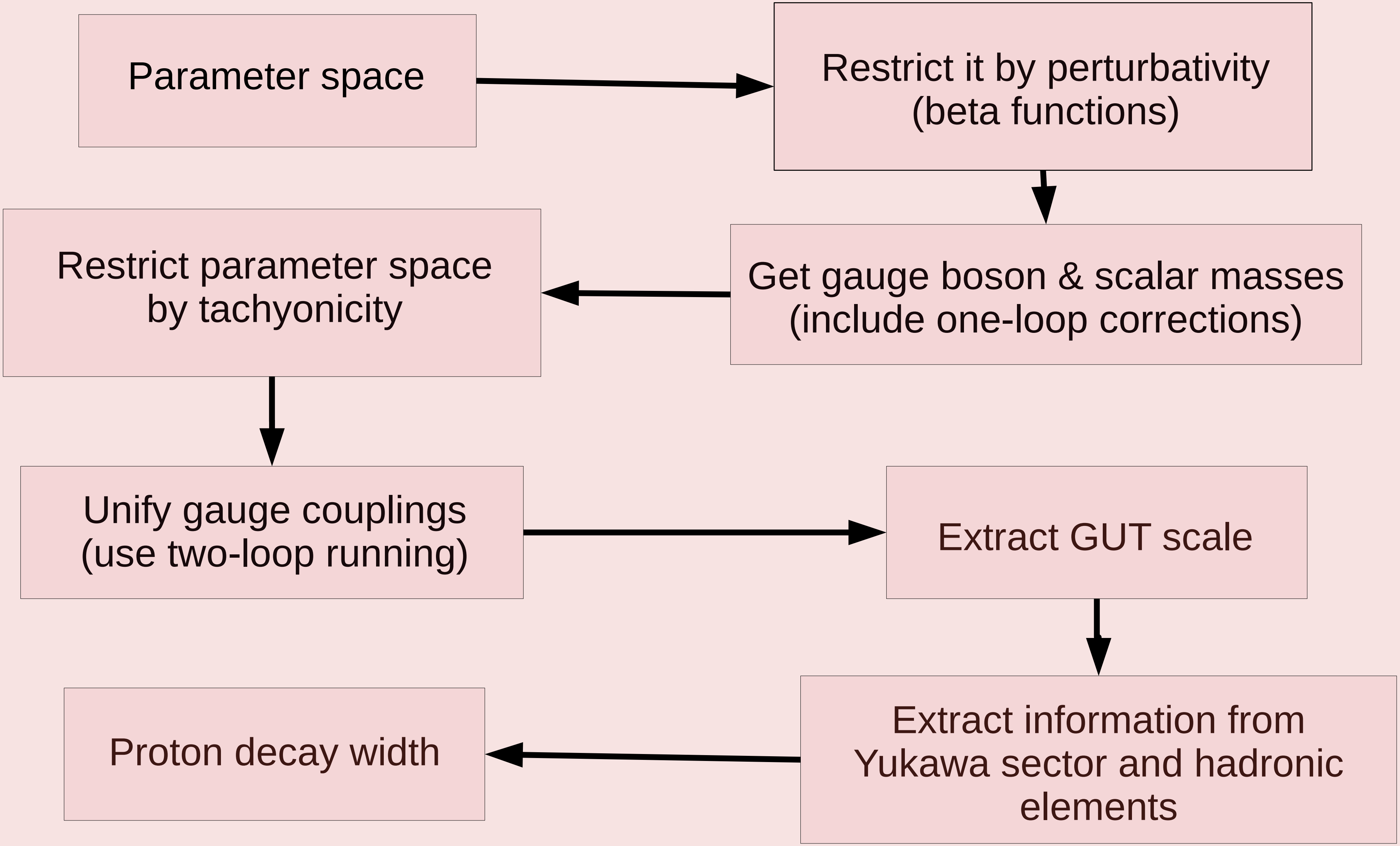
[Kolesova, Malinsky,Mede: AIP Conf. Proc. 2016]



[Kolesova, Malinsky: Proceedings ICHEP 2014]

Proton lifetime calculation

Proton decay cookbook



Parameter space

Restrict it by perturbativity (beta functions)

Get gauge boson & scalar masses (include one-loop corrections)

Restrict parameter space by tachyonicity

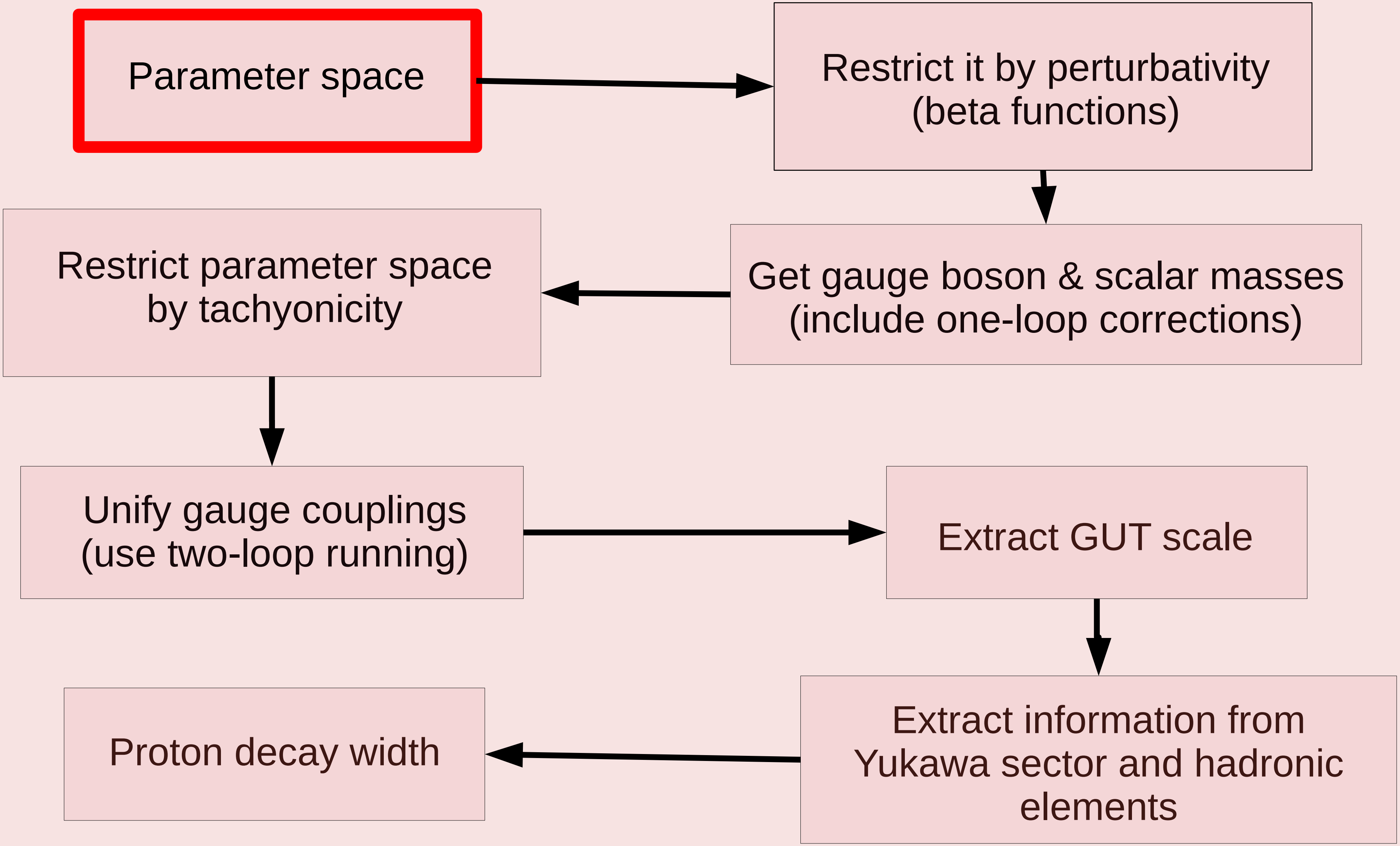
Unify gauge couplings (use two-loop running)

Extract GUT scale

Extract information from Yukawa sector and hadronic elements

Proton decay width

Proton decay cookbook



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Scalar potential

$$
\begin{aligned}
V_0(\phi_{45},\Sigma_{126},\Sigma^*_{126}) = & -\frac{\mu^2}{4}(\phi\phi)_0+\frac{a_0}{4}(\phi\phi)_0(\phi\phi)_0+\frac{a_2}{4}(\phi\phi)_2(\phi\phi)_2- \\
& -\frac{\nu^2}{5!}(\Sigma\Sigma^*)_0+\frac{\lambda_0}{(5!)^2}(\Sigma\Sigma^*)_0(\Sigma\Sigma^*)_0+\frac{\lambda_2}{(4!)^2}(\Sigma\Sigma^*)_2(\Sigma\Sigma^*)_2+ \\
& +\frac{\lambda_4}{(3!)^2(2!)^2}(\Sigma\Sigma^*)_4(\Sigma\Sigma^*)_4+\frac{\lambda'_4}{(3!)^2}(\Sigma\Sigma^*)_{4'}(\Sigma\Sigma^*)_{4'}+ \\
& +\frac{\eta_2}{(4!)^2}(\Sigma\Sigma)_2(\Sigma\Sigma)_2+\frac{\eta_2^*}{(4!)^2}(\Sigma^*\Sigma^*)_2(\Sigma^*\Sigma^*)_2+ \\
& +\frac{i\tau}{4!}(\phi)_2(\Sigma\Sigma^*)_2+\frac{\alpha}{2\cdot 5!}(\phi\phi)_0(\Sigma\Sigma^*)_0+\frac{\beta_4}{4\cdot 3!}(\phi\phi)_4(\Sigma\Sigma^*)_4+ \\
& +\frac{\beta'_4}{3!}(\phi\phi)'_4(\Sigma\Sigma^*)'_4+\frac{\gamma_2}{4!}(\phi\phi)_2(\Sigma\Sigma)_2+\frac{\gamma_2^*}{4!}(\phi\phi)_2(\Sigma^*\Sigma^*)_2
\end{aligned}
$$

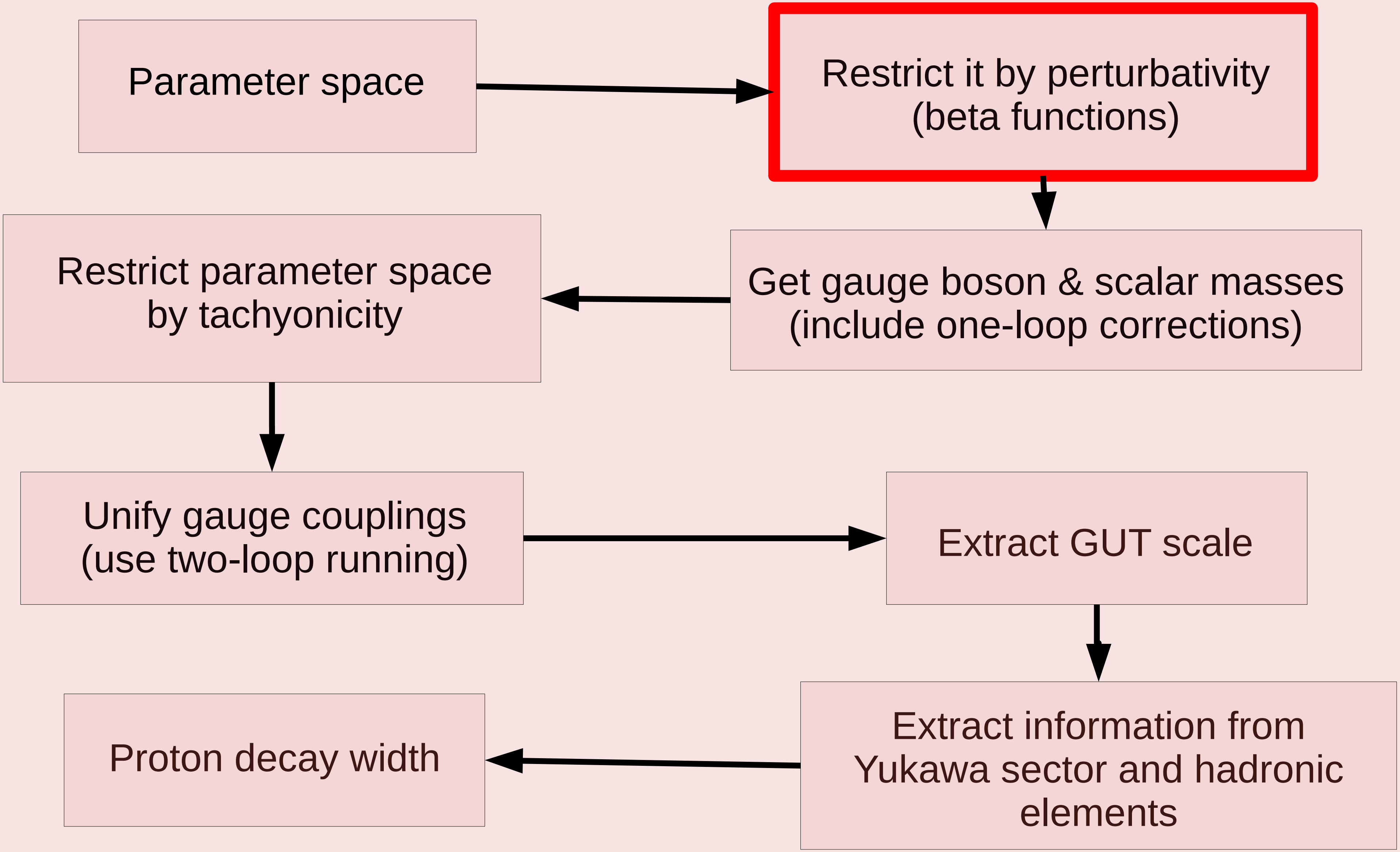
where $\{\mu,\nu,\tau\}\leftrightarrow \text{VEVs}\ \{\sigma,\underbrace{\omega_{BL},\omega_R}_{45_s\text{, GUT scale}}\}$ and gauge coupling g

126_s, seesaw scale

17 degrees of freedom

excluding Yukawa sector

Proton decay cookbook



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Perturbativity constraints

Vacuum stability:

- One-loop vacuum is not far from the tree-level vacuum (checked for different renorm. scales ← one-loop beta functions)
- Relation $\tau = P(\sigma, \omega_{BL}, \omega_R, \lambda) + Q(\lambda) \frac{\omega_{BL}\omega_R(\omega_{BL}+\omega_R)}{|\sigma|^2}$

$\leq \omega_{max}$

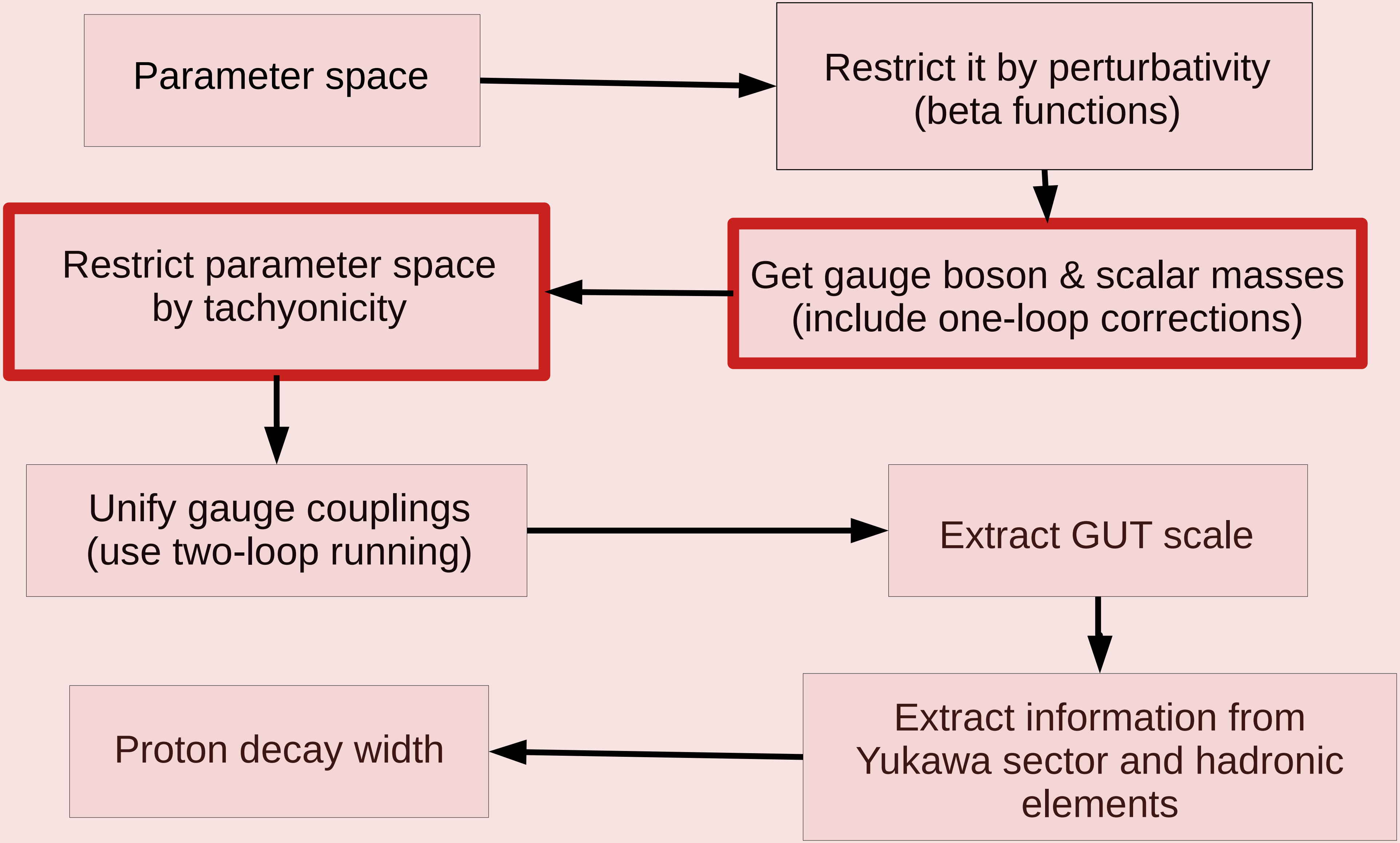
P,Q … polynomials

distinct cases: "almost one step breaking"
"(flipped) SU(5) iterm. stage"
"$SU(4)_c xSU(2)_L xU(1)_R$ iterm. stage"
"$SU(3)_c xSU(2)_L xSU(2)_R xU(1)_{B-L}$ interm. stage"

Mass stability:

- We require the maximal one-loop scalar mass correction to be smaller than the averaged tree-level mass

Proton decay cookbook



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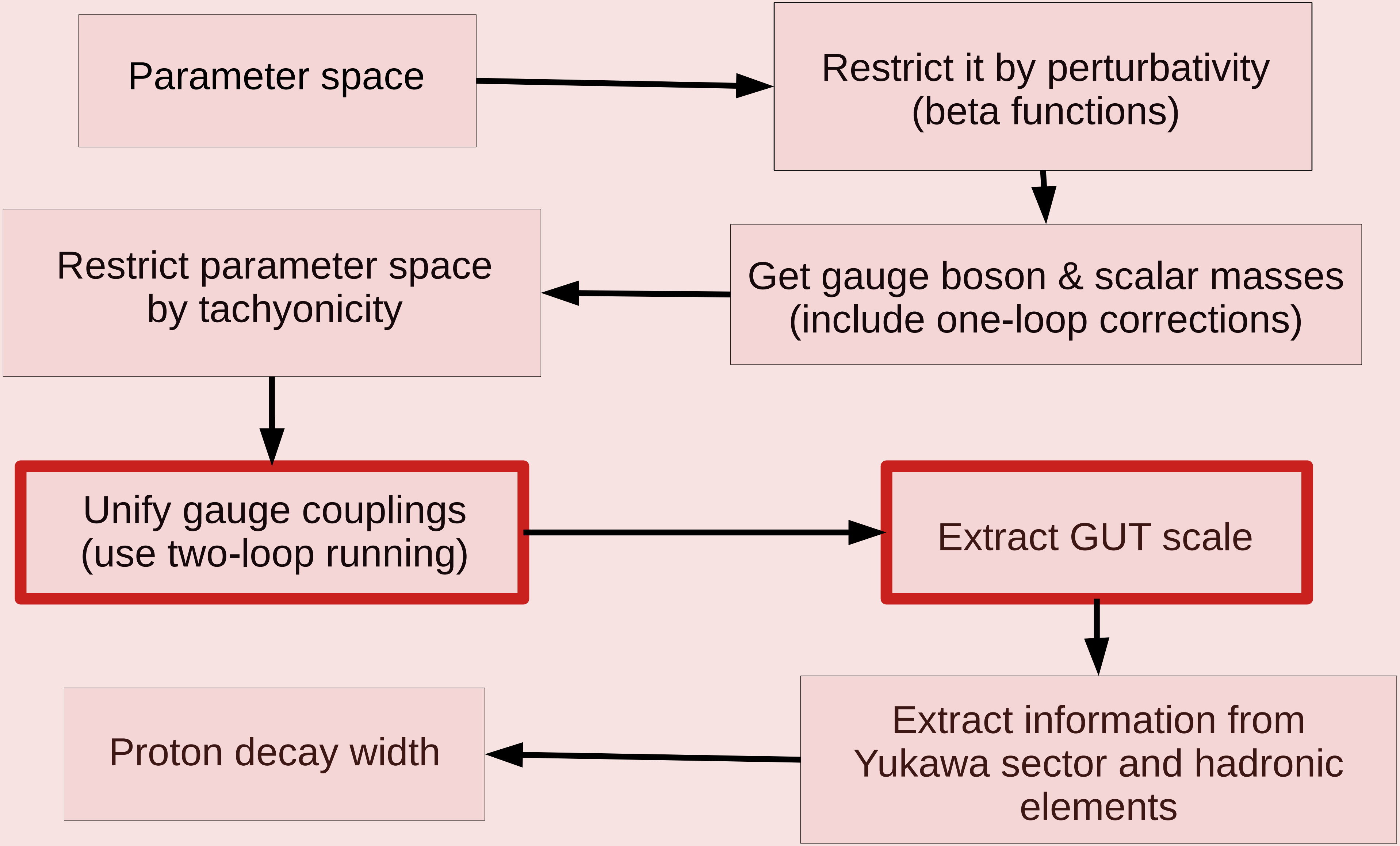
Tachyonicity constraints

The existence of non-tachyonic spectrum is the crucial requirement restricting viable parameter space. On top of that the realistic scenarios involve accidentally light pseudo-Goldstone scalars => one-loop calculations are necessary => inherently quantum model.

↓

Complete calculation of full one-loop effective scalar mass corrections is implemented.

Proton decay cookbook



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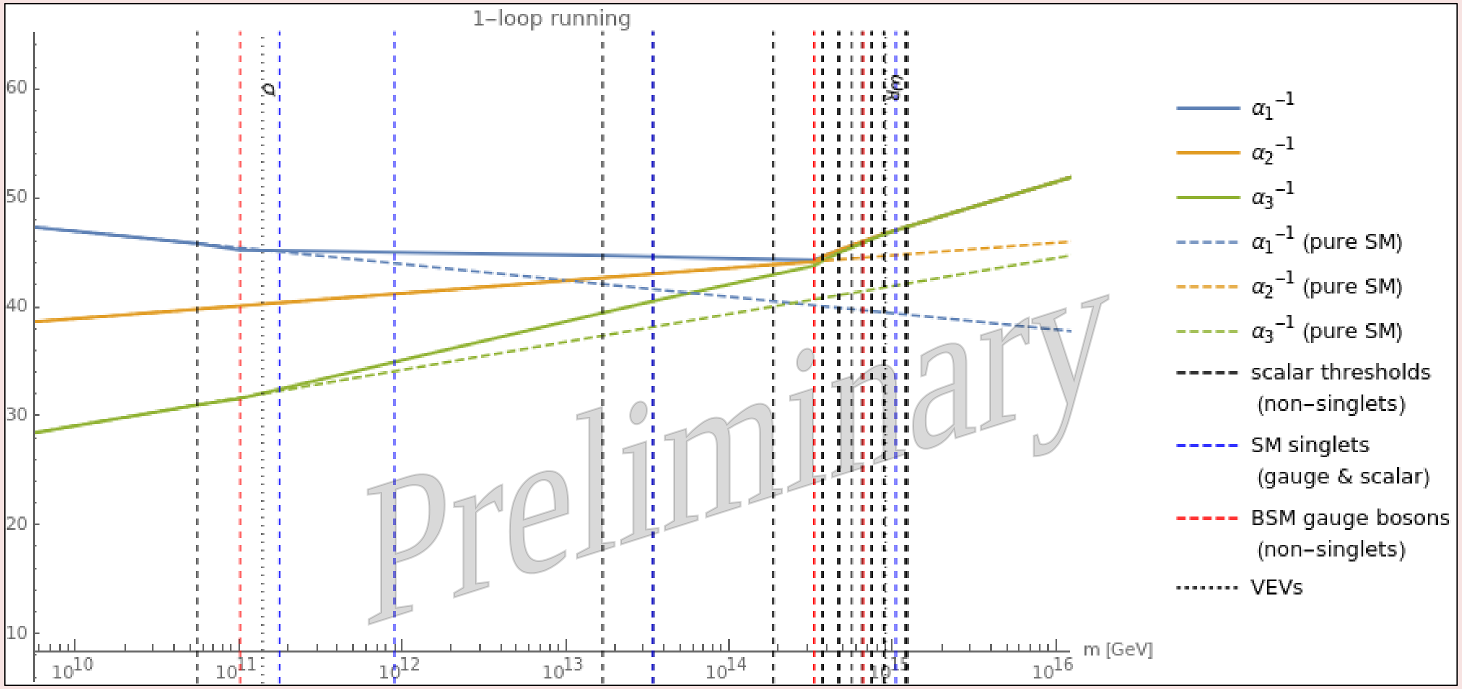
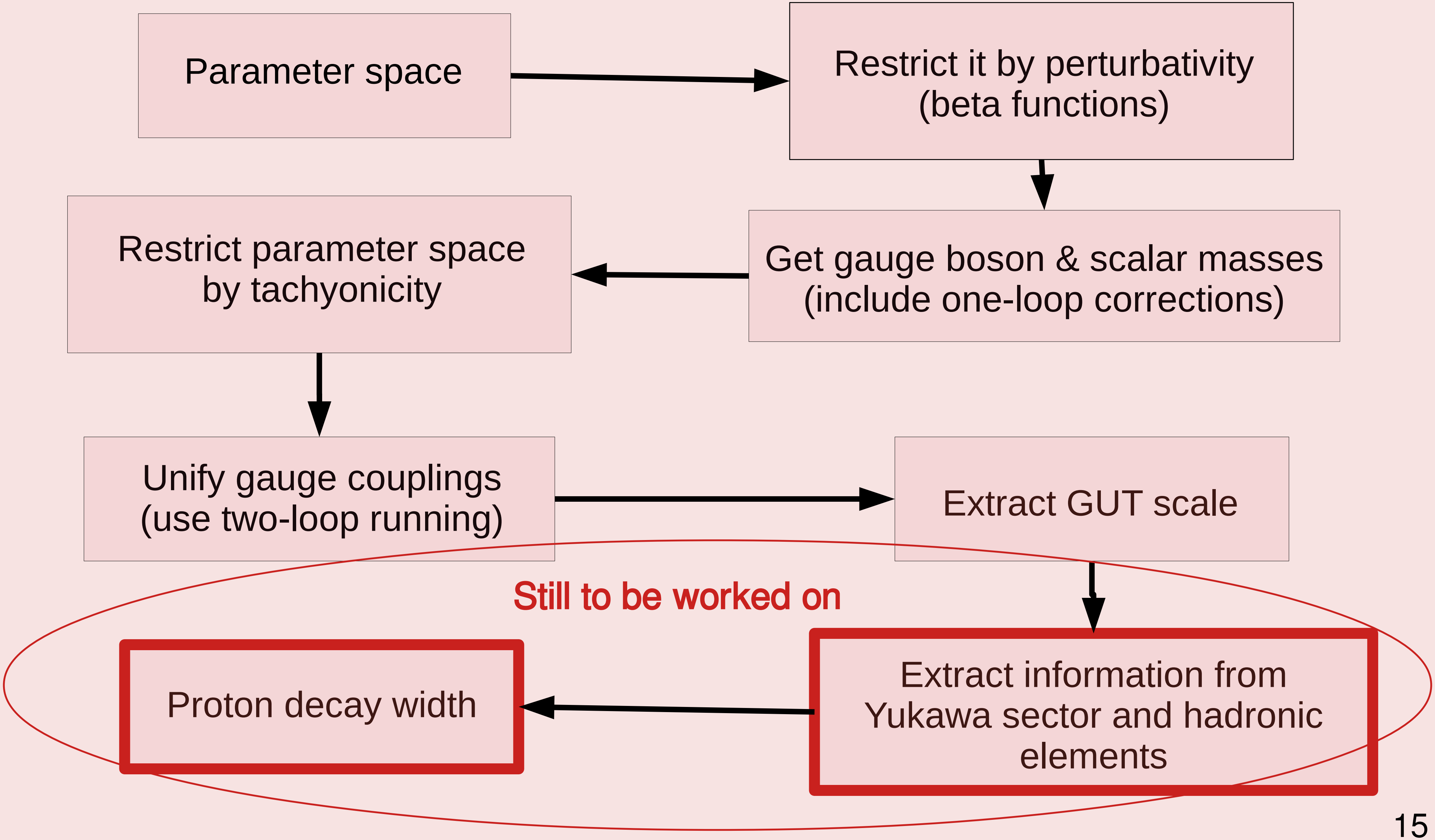
Gauge coupling unification

Robust proton lifetime estimate has to involve two-loop gauge coupling running calculation to extract the scale of unification. Successful unification also serves as a criterion to narrow down viable parameter space.



Proton decay cookbook



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Still to be worked on

Extract information from Yukawa sector and hadronic elements

Proton decay width

Summary

Minimal renormalizable non-SUSY **SO(10)**:

- Gauge bosons in 45_S
- All fermions from one generation (+ N_R) in 16_F
- Scalars in 45_S, 126_S (+ 10_S)

Proton lifetime estimate is robust with respect to theoretical uncertainties.

The **model analysis** involved:

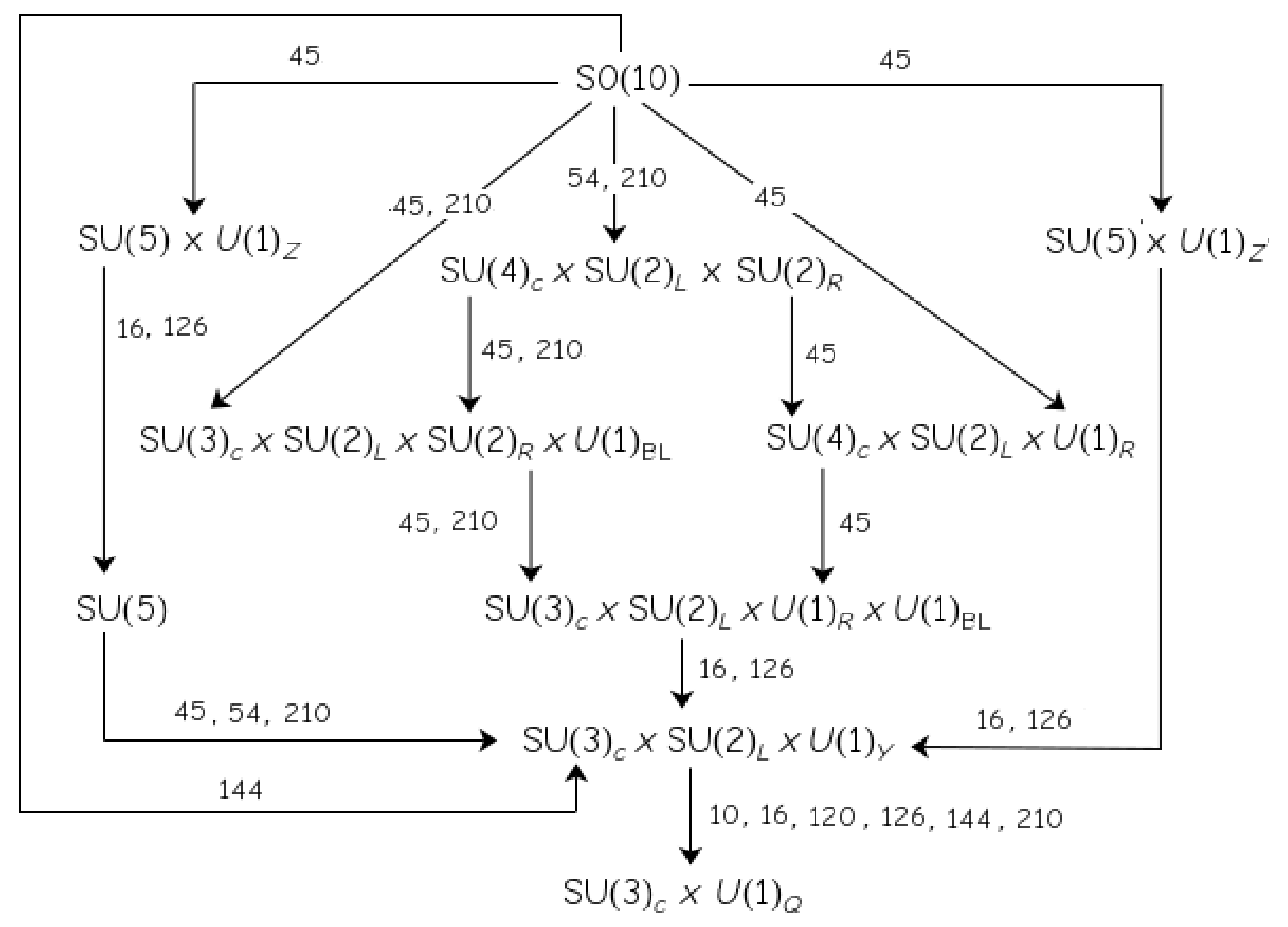
- Improved perturbativity considerations
- One-loop scalar masses calculation
- Two-loop gauge unification

Paper in preparation

Additional slides

SO(10) breaking chanes

(non-SUSY minimal renormalizable)



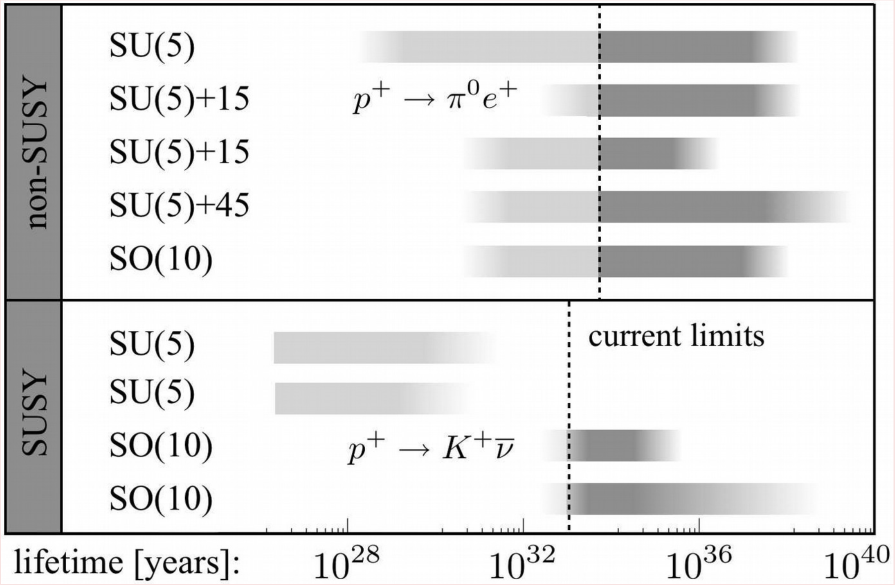
Theoretical uncertainties

Reducible:

- Finite order in perturbation theory

Irreducible:

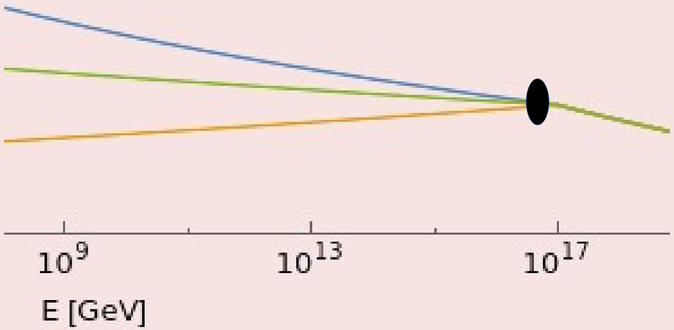
- Hadronic matric elements
- Planck scale physics (dim 5 operators)



[Kolesova, Malinsky: Porceedings ICHEP 2014]

$$\frac{c}{M_{Pl}} F^{\mu\nu}\Phi F_{\mu\nu} \to c\cancel{\frac{M_{GUT}}{M_{Pl}}} F^{\mu\nu}F_{\mu\nu}$$

SO(10)



$$\frac{c}{M_{Pl}} f_i f_j H\Phi \to c\frac{M_{GUT}}{M_{Pl}} f_i f_j H$$

Suppressed in SO(10)

[Kolesova, Malinsky: Phys.Rev.D 99 (2019)]

[Kolesova, Malinsky,Mede: AIP Conf.Proc. 1743 (2016)]