

AI Agents in the Making

Shaikh Saad



BRDA 2026, Belica in Medana
Oct 14–16, 2026

Outline

- Why Scientific AI Agents?
- Building Blocks of AI Agents

- bsm_agent:

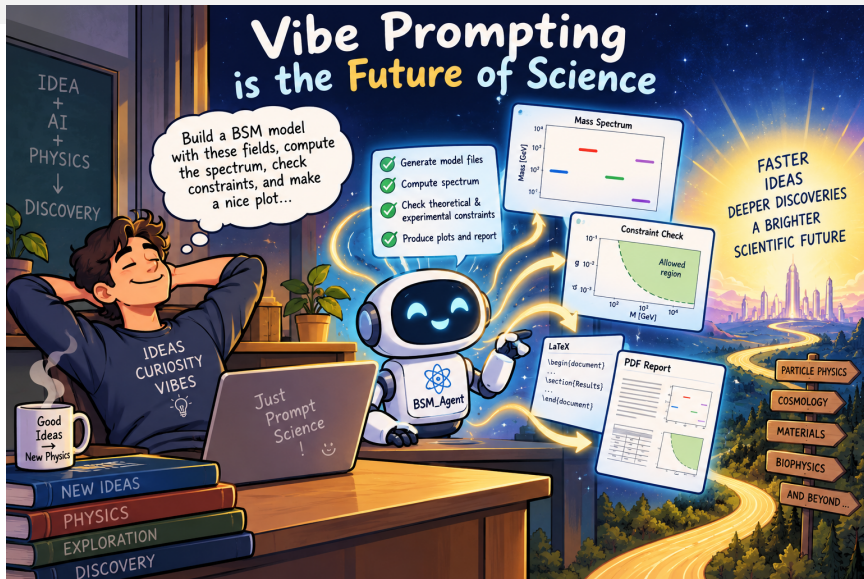
Saad 2026: <https://arxiv.org/abs/2606.21316>

extension in progress

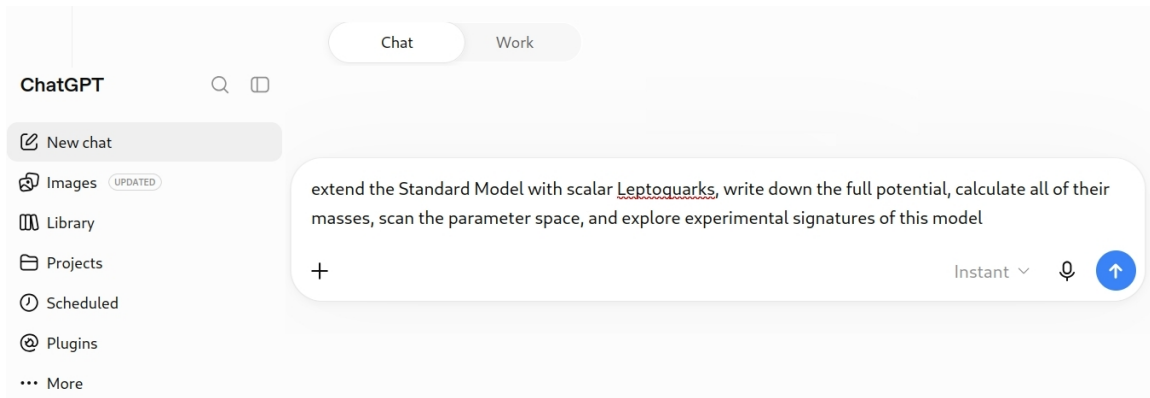
- proton_agent:

Saad 2026; arXiv: 2610:xxxxx

work in progress



Future of Science



- Reliability: *One must ensure its correctness*.

Why Build Scientific Agents?

General-purpose LLM

- Probabilistic, not inherently reproducible.
- Can hallucinate facts, numbers, or references.
- Lacks built-in scientific validation.

Scientific agent

- Uses the LLM to understand the request and explain the result.
- Delegates numerical and symbolic work to deterministic tools.
- Preserves tool outputs, artifacts, and provenance for audit.

Design principle: the model controls the workflow; verified tools establish the scientific facts.

bsm_agent: Model Building from Field Content

Large Language Model-Assisted Framework for BSM Model Building

Shaikh Saad

Jožef Stefan Institute, Jamova 39, P. O. Box 3000, SI-1001 Ljubljana, Slovenia

shaikh.saad@ijs.si

arXiv:2606.21316v1 [hep-ph] 19 Jun 2026

Abstract

Recent advances in artificial intelligence (AI), particularly large language models (LLMs), have created new opportunities for natural-language interaction with scientific software, but reliable theoretical model building still requires deterministic symbolic calculations. We present **bsm_agent**, an open-source symbolic framework for beyond the Standard Model (BSM) model building that combines a deterministic physics backend with an LLM chat interface. Starting from the SM field content and a user-specified set of additional scalars and/or fermions, the package constructs renormalizable Lagrangian, performs gauge-anomaly checks, expands operators into component fields, and derives electroweak symmetry breaking stationary conditions and tree-level mass matrices. The key novelty of the framework is that all of these tasks are performed automatically once the user specifies the quantum numbers of the new fields through a natural-language interface, eliminating the need for manual model construction. The symbolic calculations are performed entirely by the Python backend to ensure the correctness and reproducibility of the physics results; the LLM is used only as an orchestration layer that interprets natural-language requests, manages confirmation steps for ambiguous inputs, triggers backend tools, and formats report-ready summaries. The package supports three provider classes: local Ollama inference, remote self-hosted model servers accessed through the implemented remote provider interface, and commercial hosted APIs via OpenAI and Anthropic. This separation between conversational control and deterministic computation preserves reproducibility while making interactive BSM model construction substantially more convenient. [🔗 bsm_agent](#)

Saad 2026: <https://arxiv.org/abs/2606.21316> + extension in progress

bsm_agent

User>

build a model with five scalars: $(3,1,-1/3)$, $(3,1,-4/3)$, $(3,2,7/6)$, $(3,2,1/6)$, and $(3,3,-1/3)$

BSM_Agent>

The model is constructed. [1.8s]

bsm_agent

User>

describe the model

BSM_Agent>

Model: BSM

Field content:

- ϕ_1 is a scalar in $(3,1,-1/3)$: color triplet, weak singlet, hypercharge $-1/3$.
- ϕ_2 is a scalar in $(3,1,-4/3)$: color triplet, weak singlet, hypercharge $-4/3$.
- ϕ_3 is a scalar in $(3,2,7/6)$: color triplet, weak doublet, hypercharge $7/6$.
- ϕ_4 is a scalar in $(3,2,1/6)$: color triplet, weak doublet, hypercharge $1/6$.
- ϕ_5 is a scalar in $(3,3,-1/3)$: color triplet, weak triplet, hypercharge $-1/3$.

Interactions and consistency:

- Kinetic terms: 14
- Scalar potential: 73
- Yukawa: 14
- Mixed BSM interaction terms: 49
- Status: anomaly-free
- Anomaly summary: anomaly-free: $su3_cubic=0$, $su2_su2_u1=0$, $su3_su3_u1=0$, $u1_gravity=0$, $u1_cubic=0$

bsm_agent

User>

generate a pdf report for me

BSM_Agent>

Generated report for 'BSM' with field content $(3,1,-1/3)$, $(3,1,-4/3)$,
 $(3,2,7/6)$, $(3,2,1/6)$, $(3,3,-1/3)$.

TeX: /home/user/Downloads/bsm_agent/output/BSM.tex.

PDF: /home/user/Downloads/bsm_agent/output/BSM.pdf.

[1.2s]

Generated PDF>

BSM Field Content:

$$\phi_1 = \text{scalar } (3, 1, -1/3)$$

$$\phi_2 = \text{scalar } (3, 1, -4/3)$$

$$\phi_3 = \text{scalar } (3, 2, 7/6)$$

$$\phi_4 = \text{scalar } (3, 2, 1/6)$$

$$\phi_5 = \text{scalar } (3, 3, -1/3)$$

Anomaly Summary:

Anomalies: free.

→ 14 Yukawa terms

Generated PDF>

$$\begin{aligned}\mathcal{L}_Y = & Y_1 q q \phi_1 + Y_2 q q \phi_5 + Y_3 \phi_1^\dagger l q + Y_4 \phi_5^\dagger l q \\ & + Y_5 H^\dagger d^C q + Y_6 u^C q H + Y_7 \phi_3^\dagger e^C q + Y_8 d^C l \phi_4 \\ & + Y_9 u^C l \phi_3 + Y_{10} H^\dagger e^C l + Y_{11} \phi_1^\dagger d^C u^C + Y_{12} e^C d^C \phi_2 \\ & + Y_{13} \phi_2^\dagger u^C u^C + Y_{14} e^C u^C \phi_1 + \text{h.c.}\end{aligned}$$

→ 14 gauge kinetic terms:

Generated PDF>

$$\begin{aligned}\mathcal{L}_{\text{kin}} = & -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W_{\mu\nu}^a W^{a,\mu\nu} - \frac{1}{4} G_{\mu\nu}^A G^{A,\mu\nu} + (D_\mu q)^\dagger D^\mu q \\ & + (D_\mu l)^\dagger D^\mu l + (D_\mu d^C)^\dagger D^\mu d^C + (D_\mu u^C)^\dagger D^\mu u^C + (D_\mu e^C)^\dagger D^\mu e^C \\ & + (D_\mu H)^\dagger D^\mu H + (D_\mu \phi_1)^\dagger D^\mu \phi_1 + (D_\mu \phi_2)^\dagger D^\mu \phi_2 + (D_\mu \phi_3)^\dagger D^\mu \phi_3 \\ & + (D_\mu \phi_4)^\dagger D^\mu \phi_4 + (D_\mu \phi_5)^\dagger D^\mu \phi_5\end{aligned}$$

→ 73 terms in the scalar potential

Generated PDF >

$$\begin{aligned}
 V = & m_1^2 H H^\dagger + m_2^2 \phi_1 \phi_1^\dagger + m_3^2 \phi_2 \phi_2^\dagger + m_4^2 \phi_3 \phi_3^\dagger \\
 & + m_5^2 \phi_4 \phi_4^\dagger + m_6^2 \phi_5 \phi_5^\dagger + \left\{ \mu_7 H \phi_1 \phi_4^\dagger + \mu_8 H \phi_4^\dagger \phi_5 \right. \\
 & + \mu_9 \phi_1 \phi_4 \phi_4^\dagger + \mu_{10} \phi_2 \phi_3 \phi_4^\dagger + \text{h.c.} \left. \right\} + \lambda_{11} H H H^\dagger H^\dagger + \left\{ \lambda_{12} H H \phi_2 \phi_5^\dagger \right. \\
 & + \lambda_{13} H H \phi_3^\dagger \phi_4 + \text{h.c.} \left. \right\} + \lambda_{14} H H^\dagger \phi_1 \phi_1^\dagger + \left\{ \lambda_{15} H H^\dagger \phi_1 \phi_5^\dagger + \text{h.c.} \right\} + \lambda_{16} H H^\dagger \phi_2 \phi_2^\dagger \\
 & + \lambda_{17,c1} H H^\dagger \phi_3 \phi_3^\dagger + \lambda_{17,c2} H H^\dagger \phi_3 \phi_3^\dagger + \lambda_{19,c1} H H^\dagger \phi_4 \phi_4^\dagger + \lambda_{19,c2} H H^\dagger \phi_4 \phi_4^\dagger \\
 & + \lambda_{21,c1} H H^\dagger \phi_5 \phi_5^\dagger + \lambda_{21,c2} H H^\dagger \phi_5 \phi_5^\dagger + \left\{ \lambda_{23} H \phi_1 \phi_2 \phi_3 + \lambda_{24} H \phi_1 \phi_4 \phi_5 \right. \\
 & + \lambda_{25} H \phi_1^\dagger \phi_3^\dagger \phi_5^\dagger + \lambda_{26} H \phi_2 \phi_3 \phi_5 + \lambda_{27} H \phi_3^\dagger \phi_5^\dagger \phi_5^\dagger + \lambda_{28} H \phi_4 \phi_5 \phi_5 + \text{h.c.} \left. \right\} \\
 & + \lambda_{29} \phi_1 \phi_1 \phi_1^\dagger \phi_1^\dagger + \left\{ \lambda_{30} \phi_1 \phi_1 \phi_5^\dagger \phi_5^\dagger + \text{h.c.} \right\} + \lambda_{31,c1} \phi_1 \phi_1^\dagger \phi_2 \phi_2^\dagger + \lambda_{31,c2} \phi_1 \phi_1^\dagger \phi_2 \phi_2^\dagger \\
 & + \lambda_{33,c1} \phi_1 \phi_1^\dagger \phi_3 \phi_3^\dagger + \lambda_{33,c2} \phi_1 \phi_1^\dagger \phi_3 \phi_3^\dagger + \lambda_{35,c1} \phi_1 \phi_1^\dagger \phi_4 \phi_4^\dagger + \lambda_{35,c2} \phi_1 \phi_1^\dagger \phi_4 \phi_4^\dagger \\
 & + \lambda_{37,c1} \phi_1 \phi_1^\dagger \phi_5 \phi_5^\dagger + \lambda_{37,c2} \phi_1 \phi_1^\dagger \phi_5 \phi_5^\dagger + \dots
 \end{aligned}$$

→ 73 terms in the scalar potential

Generated PDF >

$$\begin{aligned}
 V = & \dots + \left\{ \lambda_{39,c1} \phi_1 \phi_2^\dagger \phi_3^\dagger \phi_4 + \lambda_{39,c2} \phi_1 \phi_2^\dagger \phi_3^\dagger \phi_4 \right. \\
 & + \lambda_{41,c1} \phi_1 \phi_3 \phi_3^\dagger \phi_5^\dagger + \lambda_{41,c2} \phi_1 \phi_3 \phi_3^\dagger \phi_5^\dagger + \lambda_{43,c1} \phi_1 \phi_4 \phi_4^\dagger \phi_5^\dagger + \lambda_{43,c2} \phi_1 \phi_4 \phi_4^\dagger \phi_5^\dagger \\
 & \left. + \lambda_{45} \phi_1 \phi_5 \phi_5^\dagger \phi_5^\dagger + \text{h.c.} \right\} + \lambda_{46} \phi_2 \phi_2 \phi_2^\dagger \phi_2^\dagger + \lambda_{47,c1} \phi_2 \phi_2^\dagger \phi_3 \phi_3^\dagger + \lambda_{47,c2} \phi_2 \phi_2^\dagger \phi_3 \phi_3^\dagger \\
 & + \lambda_{49,c1} \phi_2 \phi_2^\dagger \phi_4 \phi_4^\dagger + \lambda_{49,c2} \phi_2 \phi_2^\dagger \phi_4 \phi_4^\dagger + \lambda_{51,c1} \phi_2 \phi_2^\dagger \phi_5 \phi_5^\dagger + \lambda_{51,c2} \phi_2 \phi_2^\dagger \phi_5 \phi_5^\dagger \\
 & + \left\{ \lambda_{53,c1} \phi_2 \phi_3 \phi_4^\dagger \phi_5^\dagger + \lambda_{53,c2} \phi_2 \phi_3 \phi_4^\dagger \phi_5^\dagger + \text{h.c.} \right\} + \lambda_{55,c1} \phi_3 \phi_3 \phi_3^\dagger \phi_3^\dagger + \lambda_{55,c2} \phi_3 \phi_3 \phi_3^\dagger \phi_3^\dagger \\
 & + \lambda_{57,c1} \phi_3 \phi_3^\dagger \phi_4 \phi_4^\dagger + \lambda_{57,c2} \phi_3 \phi_3^\dagger \phi_4 \phi_4^\dagger + \lambda_{57,c3} \phi_3 \phi_3^\dagger \phi_4 \phi_4^\dagger + \lambda_{57,c4} \phi_3 \phi_3^\dagger \phi_4 \phi_4^\dagger \\
 & + \lambda_{61,c1} \phi_3 \phi_3^\dagger \phi_5 \phi_5^\dagger + \lambda_{61,c2} \phi_3 \phi_3^\dagger \phi_5 \phi_5^\dagger + \lambda_{61,c3} \phi_3 \phi_3^\dagger \phi_5 \phi_5^\dagger + \lambda_{61,c4} \phi_3 \phi_3^\dagger \phi_5 \phi_5^\dagger \\
 & + \lambda_{65,c1} \phi_4 \phi_4 \phi_4^\dagger \phi_4^\dagger + \lambda_{65,c2} \phi_4 \phi_4 \phi_4^\dagger \phi_4^\dagger + \lambda_{67,c1} \phi_4 \phi_4^\dagger \phi_5 \phi_5^\dagger + \lambda_{67,c2} \phi_4 \phi_4^\dagger \phi_5 \phi_5^\dagger \\
 & + \lambda_{67,c3} \phi_4 \phi_4^\dagger \phi_5 \phi_5^\dagger + \lambda_{67,c4} \phi_4 \phi_4^\dagger \phi_5 \phi_5^\dagger + \lambda_{71,c1} \phi_5 \phi_5 \phi_5^\dagger \phi_5^\dagger + \lambda_{71,c2} \phi_5 \phi_5 \phi_5^\dagger \phi_5^\dagger \\
 & + \lambda_{71,c3} \phi_5 \phi_5 \phi_5^\dagger \phi_5^\dagger
 \end{aligned}$$

bsm_agent

User>

expand the Lagrangian

BSM_Agent>

Generated report for 'SM+phi_1+phi_2+phi_3+phi_4+phi_5'
with field content (3,1,-1/3), (3,1,-4/3), (3,2,7/6), (3,2,1/6), (3,3,-1/3).
TeX: /home/user/Downloads/bsm_agent/output/SM_phi_1_phi_2_phi_3_phi_4_phi_5
.tex.
PDF: /home/user/Downloads/bsm_agent/output/SM_phi_1_phi_2_phi_3_phi_4_phi_5
.pdf.
[7.8s]

Generated PDF >

$$Y_4 \phi_5^\dagger l q + \text{h.c.} = Y_4 \left(\begin{aligned} & \phi_5^{+2/3, \bar{b}^\dagger} l^0 q_b^{+2/3} + \phi_5^{+2/3, \bar{g}^\dagger} l^0 q_g^{+2/3} \\ & + \phi_5^{+2/3, \bar{r}^\dagger} l^0 q_r^{+2/3} + \frac{\sqrt{2}}{2} \phi_5^{-1/3, \bar{b}^\dagger} l^- q_b^{+2/3} \\ & + \frac{\sqrt{2}}{2} \phi_5^{-1/3, \bar{b}^\dagger} l^0 q_b^{-1/3} + \frac{\sqrt{2}}{2} \phi_5^{-1/3, \bar{g}^\dagger} l^- q_g^{+2/3} \\ & + \frac{\sqrt{2}}{2} \phi_5^{-1/3, \bar{g}^\dagger} l^0 q_g^{-1/3} + \frac{\sqrt{2}}{2} \phi_5^{-1/3, \bar{r}^\dagger} l^- q_r^{+2/3} \\ & + \frac{\sqrt{2}}{2} \phi_5^{-1/3, \bar{r}^\dagger} l^0 q_r^{-1/3} + \phi_5^{-4/3, \bar{b}^\dagger} l^- q_b^{-1/3} \\ & + \phi_5^{-4/3, \bar{g}^\dagger} l^- q_g^{-1/3} + \phi_5^{-4/3, \bar{r}^\dagger} l^- q_r^{-1/3} \end{aligned} \right) + \text{h.c.}$$

Generated PDF>

$$\mu_8 H \phi_4^\dagger \phi_5 = \mu_8 \begin{pmatrix} -\sqrt{2} H^0 \phi_4^{+2/3, \bar{r}^\dagger} \phi_{5r}^{+2/3} - \sqrt{2} H^0 \phi_4^{+2/3, \bar{g}^\dagger} \phi_{5g}^{+2/3} \\ -\sqrt{2} H^0 \phi_4^{+2/3, \bar{b}^\dagger} \phi_{5b}^{+2/3} - H^0 \phi_4^{-1/3, \bar{r}^\dagger} \phi_{5r}^{-1/3} \\ -H^0 \phi_4^{-1/3, \bar{g}^\dagger} \phi_{5g}^{-1/3} - H^0 \phi_4^{-1/3, \bar{b}^\dagger} \phi_{5b}^{-1/3} \\ +H^+ \phi_4^{+2/3, \bar{r}^\dagger} \phi_{5r}^{-1/3} + H^+ \phi_4^{+2/3, \bar{g}^\dagger} \phi_{5g}^{-1/3} \\ +H^+ \phi_4^{+2/3, \bar{b}^\dagger} \phi_{5b}^{-1/3} + \sqrt{2} H^+ \phi_4^{-1/3, \bar{r}^\dagger} \phi_{5r}^{-4/3} \\ +\sqrt{2} H^+ \phi_4^{-1/3, \bar{g}^\dagger} \phi_{5g}^{-4/3} + \sqrt{2} H^+ \phi_4^{-1/3, \bar{b}^\dagger} \phi_{5b}^{-4/3} \end{pmatrix}$$

bsm_agent

User>

generate mass matrices

BSM_Agent>

Generated report for 'SM+phi_1+phi_2+phi_3+phi_4+phi_5'
 with field content (3,1,-1/3), (3,1,-4/3), (3,2,7/6), (3,2,1/6), (3,3,-1/3).
 TeX: /home/user/Downloads/bsm_agent/output/SM_phi_1_phi_2_phi_3_phi_4_phi_5.tex.
 PDF: /home/user/Downloads/bsm_agent/output/SM_phi_1_phi_2_phi_3_phi_4_phi_5.pdf.
 [22.9s]

Generated PDF>

$$M_{10}^2 [(\phi_3^{+2/3})^\dagger, (\phi_4^{+2/3})^\dagger, (\phi_5^{+2/3})^\dagger; \phi_3^{+2/3}, \phi_4^{+2/3}, \phi_5^{+2/3}] =$$

$$\begin{bmatrix} \frac{\lambda_{17,c1}v^2}{2} + m_4^2 & -\frac{\lambda_{13}v^2}{2} & 0 \\ -\frac{v^2\lambda_{13}}{2} & \frac{\lambda_{19,c2}v^2}{2} + m_5^2 & -\mu_8 v \\ 0 & -v\mu_8 & -\frac{\lambda_{21,c1}v^2}{2} + \lambda_{21,c2}v^2 + m_6^2 \end{bmatrix}$$

bsm_agent: Why is it Amazing?

- **Input:** specify the particle, e.g., scalar (1,3,1)
 - 👉 Unlike any other package, you don't need to input Lagrangian terms
- **deterministic tools:** *guarantees correctness*
 - 👉 Anomaly check
 - 👉 complete Lagrangian construction
 - 👉 Expand each term
 - 👉 EW symmetry breaking
 - 👉 Mass matrix
 - 👉 extensions in progress: phenomenology, parameter scans, ... theoretical sides

An Agent In a Nutshell

- Agents are independent systems that get things done for you.



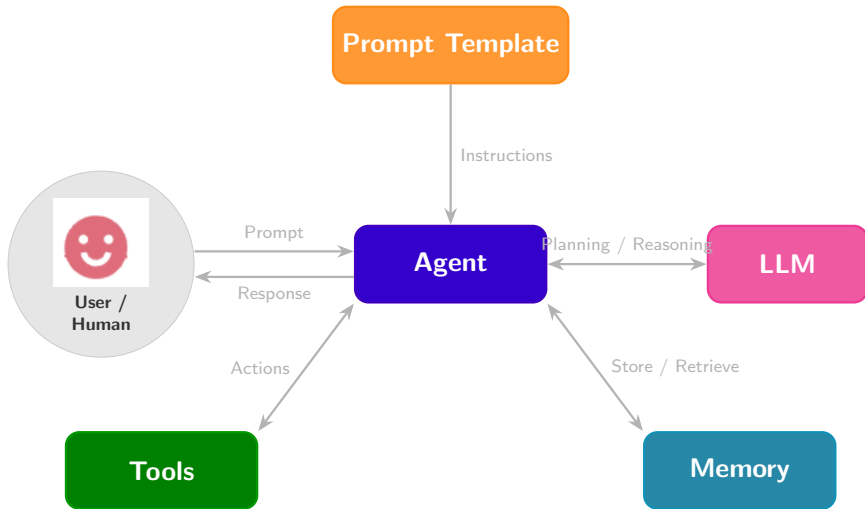
- **My LLM/Agent requirement:**

👉 User initiates a task; not autonomous.

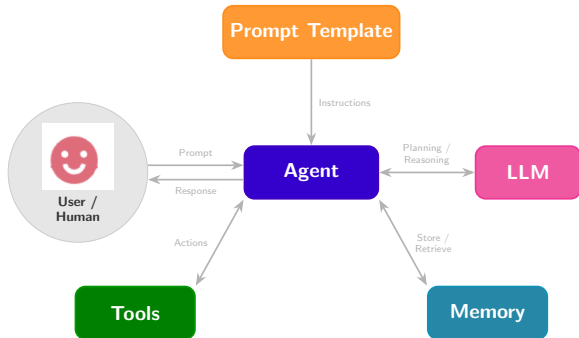
👉 **Open-source** LLMs (GPT/Qwen/Llama/...).

→ You can use OpenAI/Anthropic models via paid APIs.

Architecture



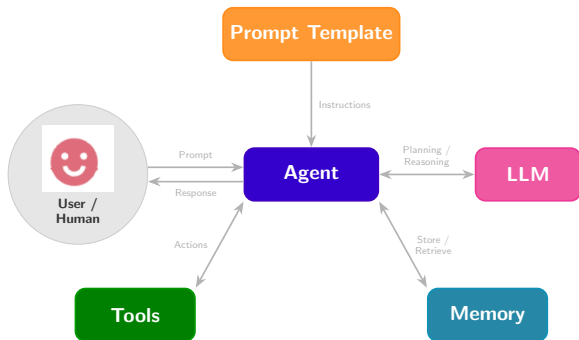
Architecture Components



- **LLM Brain**

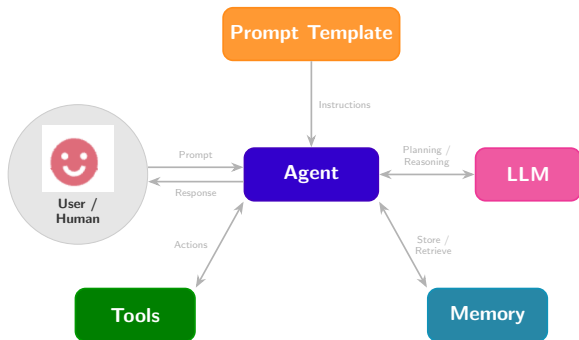
The central brain or reasoning engine.

Architecture Components



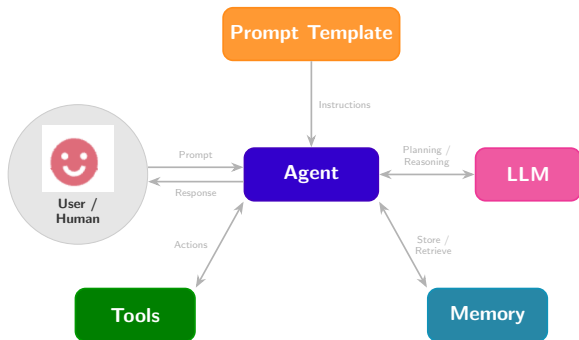
- **Prompt Template**
Sets the structural instructions and agent persona.

Architecture Components



- **Tool Integration**
Executes actions and gathers real-world context.

Architecture Components



- **Memory Store**
Retains historical logs and short/long-term context.

Prompting

ChatGPT

Where should we begin?

+ what is dark matter?



Prompting

Without Your Prompt (The Default ChatGPT)

"Dark matter is a mysterious substance that makes up about 85% of the matter in the universe. One exciting way physicists try to explain it is by adding a new, hypothetical particle to the Standard Model of particle physics.

Imagine a new 'scalar' particle, which is a type of particle similar to the Higgs boson. To make it a good dark matter candidate, this particle must be stable, meaning it doesn't decay into other things too quickly. It also shouldn't have an electric charge, otherwise, it would interact with light and wouldn't be 'dark.' Scientists often use math called a 'Lagrangian' to write down how this particle might interact with the Higgs boson..."

Prompting

"I am a postdoc-level particle physics model builder and phenomenologist. **Skip all introductory fluff, high-school analogies, and generic warnings about physics being complex. Provide highly technical answers, prioritize exact mathematical or Lagrangian definitions, cite specific experimental bounds (e.g., LHC, dark matter direct detection) where relevant, and explicitly state any assumptions or approximations being made.**"

Prompting

With Your Prompt (The Particle Physicist Persona)

To extend the Standard Model (SM) with a gauge-singlet scalar dark matter candidate (ϕ), we add a real scalar field that is odd under a discrete Z_2 symmetry ($\phi \rightarrow -\phi$) to ensure stability.

The most general renormalizable Lagrangian extension (the Higgs Portal model) is:

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{2} m_\phi^2 \phi^2 - \frac{\lambda_\phi}{4!} \phi^4 - \frac{\lambda_{h\phi}}{2} \phi^2 |H|^2$$

Phenomenological Implications & Constraints:

- **Relic Density:** The portal coupling $\lambda_{h\phi}$ dictates the thermal freeze-out via $\phi\phi \rightarrow H^* \rightarrow \text{SM particles}$. For a given mass m_ϕ , $\lambda_{h\phi}$ is strictly constrained to reproduce $\Omega_c h^2 \approx 0.12$.
- **Direct Detection:** The spin-independent elastic cross-section for ϕ -nucleon scattering via t-channel Higgs exchange is:

$$\sigma_{\text{SI}} = \frac{\lambda_{h\phi}^2 f_N^2 m_N^4}{4\pi m_h^4 (m_\phi + m_N)^2}$$

This is heavily constrained by current **LUX-ZEPLIN (LZ)** and **XENONnT** bounds, ruling out large regions of parameter space except near the Higgs resonance ($m_\phi \approx m_h/2$) or for heavy masses ($m_\phi > 1$ TeV).

- **Invisible Higgs Decays:** If $m_\phi < m_h/2$, the decay width $\Gamma(h \rightarrow \phi\phi)$ opens, restricted by the LHC bound of $\text{BR}(h \rightarrow \text{inv}) < 15\%$.

Prompt Engineering

→ The prompt controls behavior

- prompt engineering is what transforms a **generic model** into a structured, reliable agent architecture

→ How much prompt engineering is needed depends on how robust the model is

- **Task description:** the **role** you want the model to play
- **The task:** concrete **task** you want the model **to do**

→ It is an **iterative process**.

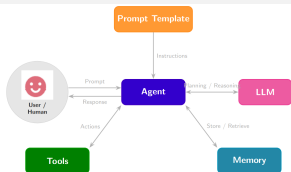
proton_agent

- proton_agent:

Saad 2026; arXiv: 2610:xxxxx work in progress (using: gpt-oss:20b)

- 👉 Derives RGE β -coefficients for various groups (1- and 2-loop)
- 👉 Generates RGE evolution plot for g_i
- 👉 Explains which fields are useful for coupling unification
- 👉 Computes proton decay lifetimes
- 👉 SUSY and Non-SUSY ($d = 5$ and $d = 6$)
- 👉 Performs scans, MCMC
- 👉 Generates lifetime plots
- 👉 Explains the results to the user
- 👉 Derives limits on masses based on experimental bounds

System Prompt



- **Role Play:** You are the **proton-decay specialist**, a tool-using assistant for proton-decay analysis.

- Tool policy: ...
- Model selection policy: ...
- Plot policy: ...
- Response policy/Output integrity: ...
- ...

*subject to extensive experimentation

Asking the LLM under consideration

oi Open WebUI

oi gpt-oss:20b

calculate proton decay for a GUT scale of 10^{16} GeV and unified coupling being 0.56

gpt-oss:20b— one of the best open-source LLMs. Requires~ 16 GM VRAM.

Asking the LLM under consideration

oi Open WebUI

oi gpt-oss:20b

calculate proton decay for a GUT scale of 10^{16} GeV and unified coupling being 0.56

oi gpt-oss:20b

Thought for 8 seconds ▾

Below is a quick estimate of the proton lifetime (in the simplest minimal-GUT picture) for a GUT scale $M_{GUT} = 10^{16}$ GeV and a unified gauge coupling $\alpha_{GUT} = 0.56$.

1. Rough formula for the proton lifetime

In a generic single-scale GUT the dominant dimension-6 operator mediating proton decay has the form

$$\mathcal{L}_{\text{eff}} \sim \frac{\alpha_{GUT}}{M_{GUT}^2} (\bar{q} \Gamma q) (\bar{l} \Gamma q) ,$$

so the partial width for a proton to decay is roughly

$$\Gamma_p \sim \frac{\alpha_{GUT}^2 m_p^5}{M_{GUT}^4} ,$$

where $m_p \approx 0.938$ GeV is the proton mass.

(The precise coefficient depends on the specific GUT model and hadronic matrix elements, but this gives the correct parametric dependence.)

The proton lifetime is the inverse of the width:

$$\tau_p \simeq \frac{1}{\Gamma_p} \approx \frac{M_{GUT}^4}{\alpha_{GUT}^2 m_p^5} .$$

Asking the LLM under consideration

2. Plugging in the numbers

SYMBOL	VALUE
M_{GUT}	10^{16} GeV
α_{GUT}	0.56
m_p	0.938 GeV

$$\begin{aligned}\tau_p &\approx \frac{(10^{16} \text{ GeV})^4}{(0.56)^2 (0.938 \text{ GeV})^5} \\ &\approx \frac{10^{64} \text{ GeV}^4}{0.3136 \text{ GeV}^5} \\ &\approx 3.19 \times 10^{63} \text{ GeV}^{-1}.\end{aligned}$$

Converting from the natural unit GeV^{-1} to seconds (using $1 \text{ GeV}^{-1} = 6.582 \times 10^{-25} \text{ s}$):

$$\tau_p \approx 3.19 \times 10^{63} \times 6.58 \times 10^{-25} \text{ s} \approx 2.1 \times 10^{39} \text{ s}.$$

Finally, in years ($1 \text{ yr} \approx 3.156 \times 10^7 \text{ s}$):

$$\tau_p \approx \frac{2.1 \times 10^{39} \text{ s}}{3.156 \times 10^7 \text{ s/yr}} \approx 6.7 \times 10^{31} \text{ yr.}$$

Check

- $\alpha = 0.56$

$$\tau_p \simeq \frac{M_{GUT}^4}{\alpha_{GUT}^2 m_p^5} \sim 9 \times 10^{32} yr \sim 10^{33} yr.$$

- $g = 0.56$

$$\tau_p \simeq \frac{16\pi^2 M_{GUT}^4}{g_{GUT}^4 m_p^5} \sim 5 \times 10^{35} yr.$$

Updated Information

Actual current bounds

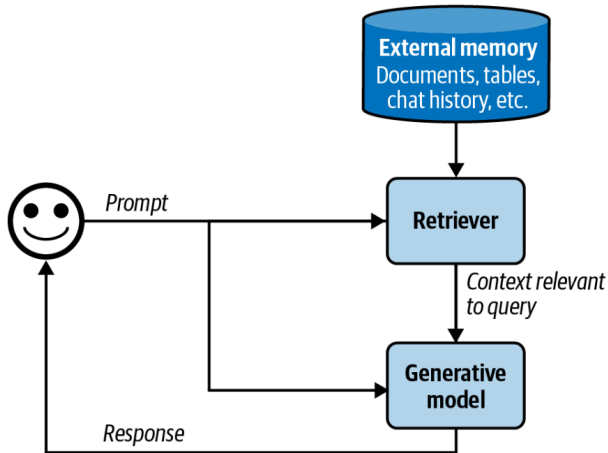
3. Comparison with experimental limits

CHANNEL	EXPERIMENTAL LOWER BOUND (YR)
$p \rightarrow \pi^0 e^+$	1.6×10^{34}
$p \rightarrow \pi^0 \mu^+$	1.3×10^{34}
$p \rightarrow K^0 e^+$	1.3×10^{33}
$p \rightarrow K^0 \mu^+$	1.3×10^{33}
$p \rightarrow \eta e^+$	1.0×10^{37}
$p \rightarrow \eta \mu^+$	1.0×10^{37}
$p \rightarrow \pi^+ \nu$	4.0×10^{32}
$p \rightarrow K^+ \nu$	7.0×10^{33}

2.4×10^{34}
1.6×10^{34}
1.1×10^{33}
3.6×10^{33}
1.0×10^{34}
4.7×10^{33}
3.9×10^{32}
6.6×10^{33}

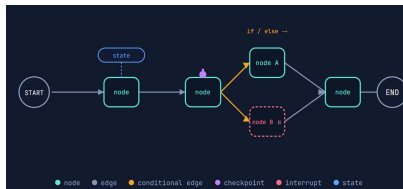
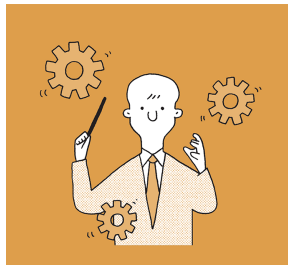
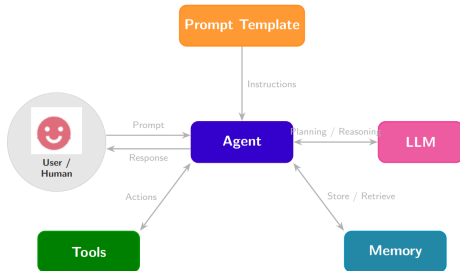
- Experimental bounds, Yukawas, Mixing matrices, Matrix elements, ...

Retrieval-Augmented Generation



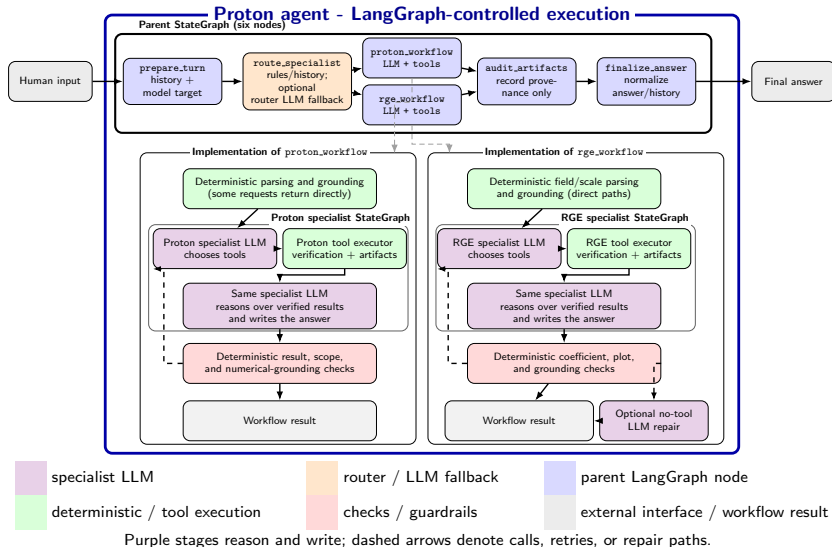
RAG grounds LLM responses in retrieved external information.

Workflow Orchestration



The LLM interprets, **LangGraph orchestrates**, and scientific tools compute.

Proton Agent: Architecture



proton_agent

User>

what are the new contributions to RGE beta coefficients if we add a scalar (1,3,0) to the Standard Model

Proton_Agent>

Gauge order: U1Y, SU2L, SU3C

Convention

$$\beta_i = \frac{g_i^3}{16\pi^2} b_i + \frac{g_i^3}{(16\pi^2)^2} \sum_j B_{ij} g_j^2.$$

All coefficients below are exact fractions; scalars are complex by default.

Standard Model coefficients

$$b_i^{\text{SM}} = \left(\frac{41}{10}, -\frac{19}{6}, -7 \right).$$

$$B_{ij}^{\text{SM}} = \begin{pmatrix} \frac{199}{50} & \frac{27}{10} & \frac{44}{5} \\ \frac{19}{10} & \frac{35}{6} & 12 \\ \frac{19}{10} & \frac{9}{2} & -26 \end{pmatrix}.$$

New contribution: S (1, 3, 0) — complex (default)

$$\Delta b_i = \left(0, \frac{2}{3}, 0 \right).$$

$$\Delta B_{ij} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \frac{56}{3} & 0 \\ 0 & 0 & 0 \end{pmatrix}.$$

proton_agent

User>

if this field, a real scalar (8,3,0), remains light, can it help with gauge coupling unification?

Proton_Agent>

Field contributions

- For the real scalar (8, 3, 0)

$$s_{12}^{(J)} = -\frac{8}{3}, \quad s_{23}^{(J)} = \frac{7}{6}.$$

SM-plus-field totals

- SM values: $s_{12}^{\text{SM}} = \frac{109}{15}$, $s_{23}^{\text{SM}} = \frac{23}{6}$.
- Adding the field's effect (with the field fully light, $r_J = 1$):

$$S_{12} = \frac{109}{15} - \frac{8}{3} = \frac{23}{5}, \quad S_{23} = \frac{23}{6} + \frac{7}{6} = 5.$$

Unification ratio

$$\frac{S_{23}}{S_{12}} = \frac{5}{23/5} = \frac{25}{23} \approx 1.087.$$

Interpretation

The field alone moves the ratio S_{23}/S_{12} toward the target value (the SM ratio is about 0.528, the target is about 0.718). However, when the field is kept light the ratio overshoots the target. Thus the field is directionally helpful but too strong if it remains fully light. To achieve the desired unification, the field would need to be heavier (reducing its weight r_J), or another field would have to compensate.

proton_agent

User>

if this real scalar (8,3,0) is not at the MZ scale, but somewhat heavy, what is the expected best scale for it to reside such that gauge coupling unification could be significantly improved?

Proton_Agent>

Best scale for the real scalar (8, 3, 0)

The single-field threshold analysis shows that the gauge-coupling ratios are moved toward the target value when the scalar is taken out of the running at a mass above the electroweak scale.

Solving the condition

$$\frac{S_{23}}{S_{12}} = \frac{0.717802056}{1}$$

for the threshold weight r_f (and hence for the mass M_f) gives

QUANTITY	VALUE
Field mass M_f	1.80×10^3 GeV (≈ 1.8 billion GeV)
Threshold weight r_f	0.449
Unification scale M_U	1.58×10^{15} GeV
Resulting ratio S_{23}/S_{12}	0.7170 (the target)

So, placing the scalar at roughly 1.8×10^3 GeV is the scale that most effectively improves gauge-coupling unification.

Why this scale works

- **Running contributions** – The scalar contributes $\Delta b_i = (0, 8/3, 3/2)$ to the beta-function coefficients.
 - Its presence from M_Z to M_U would keep the ratio S_{23}/S_{12} at the light-field value 1.087, far above the target.
 - Raising the mass reduces the effective weight r_f (the fraction of the energy range over which the field runs), thereby decreasing its influence on the running.
- **Threshold weight** – With $r_f \approx 0.45$, the scalar's effect is cut in half compared to being active from M_Z .
 - This brings the weighted sums S_{12} and S_{23} into the ratio required for unification.
- **Unification scale** – The resulting unification scale $M_U \approx 1.6 \times 10^{15}$ GeV is consistent with a typical grand-unification scenario and keeps the proton-decay predictions within experimental bounds.

Bottom line

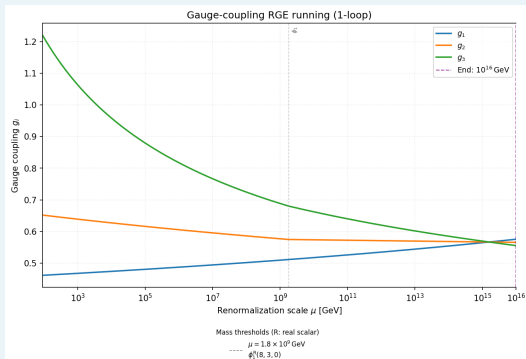
If the real scalar (8, 3, 0) is not at the electroweak scale but instead sits at a mass of about 1.8×10^3 GeV, its threshold effect will shift the gauge-coupling ratios to the target value and significantly improve unification. This is the optimal scale derived from the single-field threshold solution.

proton_agent

User>

make a plot of the gauge couplings within the Standard Model gauge group by keeping the real scalar (8,3,0) at 1.8e9 GeV

Proton_Agent>

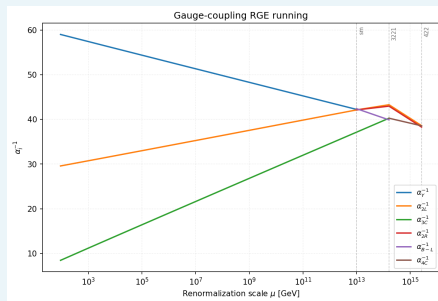


proton_agent

User>

Make a plot: run the Standard Model RGEs to $1e13$ GeV, where group is changed to left-right. At $1e13$ GeV, add scalars $(1,1,3,-2)+(1,2,2,0)$; run them up to $1.62339e14$ GeV. At $1.62339e14$ GeV, group is changed to Pati-Salam. At $1.62339e14$ GeV, add scalars $(15,2,2)+(10,3,1)+(10,1,3)+(15,1,1)$; run them to $2.66e15$ GeV. Use two-loop RGEs. plot inverse couplings.

Proton_Agent>



proton_agent

User>

an input file is given in input/example-SU5.txt, can you compute the proton lifetime; describe the results

Proton_Agent>

Non-supersymmetric SU(5) proton-decay prediction (file /input/example-SU5.txt)

QUANTITY	VALUE
GUT scale	$M_{GUT} = 5.25 \times 10^{13} \text{ GeV}$
Unified coupling	$g_{GUT} = 0.558$
Total proton lifetime	$\tau_p = 2.80 \times 10^{32} \text{ yr}$
Partial lifetimes (in years)	
$p \rightarrow \pi^0 e^+$	2.82×10^{34}
$p \rightarrow \pi^0 \mu^+$	1.79×10^{34}
$p \rightarrow K^0 e^+$	1.23×10^{33}
$p \rightarrow K^0 \mu^+$	4.14×10^{33}
$p \rightarrow \eta e^+$	2.96×10^{37}
$p \rightarrow \eta \mu^+$	1.89×10^{37}
$p \rightarrow \pi^+ \nu$	4.37×10^{32}
$p \rightarrow K^+ \nu$	7.41×10^{33}

Experimental status

- All predicted partial lifetimes exceed the current experimental lower bounds.
- The most constraining channel is $p \rightarrow \pi^+ \nu$ with a ratio 1.12.
- The model is **testable**: at least one channel ($p \rightarrow \pi^0 e^+$, $p \rightarrow \pi^0 \mu^+$, or $p \rightarrow K^+ \nu$) lies within the projected future sensitivity of upcoming experiments.

Experimental comparison

CHANNEL	CURRENT BOUND (YR)	PREDICTED LIFETIME (YR)	RATIO	PASSES CURRENT BOUND?	WITHIN FUTURE SENSITIVITY?
$p \rightarrow \pi^0 e^+$	2.4×10^{34}	2.815×10^{34}	1.17	✓	✓
$p \rightarrow \pi^0 \mu^+$	1.6×10^{34}	1.793×10^{34}	1.12	✓	✓
$p \rightarrow K^0 e^+$	1.1×10^{33}	1.233×10^{33}	1.12	✓	-
$p \rightarrow K^0 \mu^+$	3.6×10^{33}	4.135×10^{33}	1.15	✓	-
$p \rightarrow \eta e^+$	1.0×10^{34}	2.963×10^{37}	2963	✓	✗
$p \rightarrow \eta \mu^+$	4.7×10^{33}	1.887×10^{37}	4016	✓	✗
$p \rightarrow \pi^+ \nu$	3.9×10^{32}	4.366×10^{32}	1.12	✓	-
$p \rightarrow K^+ \nu$	6.6×10^{33}	7.408×10^{33}	1.12	✓	✓

All channels satisfy the present experimental lower limits; the most constraining ratio is 1.12 for $p \rightarrow \pi^+ \nu$. The point is classified as **testable** because at least one channel lies within a projected future sensitivity.

Key take-away

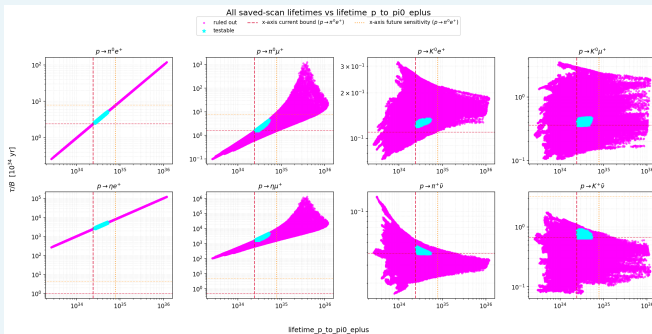
- The benchmark predicts a total proton lifetime of 2.8×10^{32} yr, comfortably above current limits.
- The dominant decay mode is $p \rightarrow \pi^+ \nu$ ($\approx 64\%$ of the total width).
- Several channels ($p \rightarrow \pi^0 e^+$, $p \rightarrow \pi^0 \mu^+$, $p \rightarrow K^+ \nu$) are within the reach of next-generation experiments, making this benchmark **testable**.

proton_agent

User>

starting from the input file input/nonsusy-SU5.txt, perform a mcmc, 100000 points. vary the flavor mixing parameters by 0.001 but by keeping the MGUT and gGUT fixed

Proton_Agent>



proton_agent

User>

an input file is given in input/example-SO10-susy.text, can you compute the proton lifetime

Proton_Agent>

```
proton-agent
Model / Scenario
SUSY SO10 proton-decay calculation performed on the benchmark file
/home/saad/Music/Files-02/AI-agent/proton_agent/input/example-SO10-susy.text.

Scalar inputs (GeV)
  *  $M_T = 1.0 \times 10^{17}$ 
  *  $m_{\tilde{W}} = 2000.0$ 
  *  $\mu = 1000.0$ 
  *  $m_{\tilde{g}} = 3500.0$ 
  *  $g_2 = 0.6374$ 
  *  $A_L = 0.4$ 
  *  $A_S = 1.0$ 
  *  $\tan \beta = 55.0$ 
  *  $\theta_u = 0.2$ 
  *  $\phi_u = 0.3$ 
  *  $\psi_u = 0.4$ 
  *  $\theta_d = 0.25$ 
  *  $\phi_d = 0.35$ 
  *  $\psi_d = 0.45$ 
  *  $v_L = 1.0 \times 10^{-11}$ 
  *  $v_R = 1.0 \times 10^{16}$ 
```

Predicted partial lifetimes (τ/B , years)

CHANNEL	T/B (YEARS)
$p \rightarrow \pi^+ \bar{\nu}$	6.19×10^{25}
$p \rightarrow K^+ \bar{\nu}$	6.69×10^{25}
$p \rightarrow \pi^0 e^+$	7.38×10^{27}
$p \rightarrow K^0 e^+$	2.61×10^{28}
$p \rightarrow \pi^0 \mu^+$	2.32×10^{27}
$p \rightarrow K^0 \mu^+$	9.60×10^{27}
total	3.14×10^{28}

Experimental comparison

- The most constraining channel is $p \rightarrow K^+ \bar{\nu}$, with a predicted lifetime 1.01×10^{-8} times the current experimental lower bound (6.6×10^{33} yr).
- All six channels examined lie below their respective current experimental limits; several are already within projected future sensitivities.

Overall classification
excluded.

proton_agent

User>

what to do to evade the bounds?

Proton_Agent>

oi proton-agent

Model: SUSY SO(10) with dressed dimension-five operators only.

Flavor structure: The Yukawa matrices $h, f, g, x, y, \tan\beta, \theta_u, \phi_u, \psi_u, \theta_d, \phi_d, \psi_d, v_L, v_R$ are held fixed.

Ways to increase the proton lifetime while keeping the flavor tensors unchanged

1. **Color-triplet mass M_T** –

The dimension-five operator amplitude is proportional to $1/M_T$.

Consequently the decay width scales as $1/M_T^2$ and the lifetime scales as M_T^2 .

Raising M_T with all other inputs fixed uniformly rescales every partial lifetime by the same factor M_T^2 , preserving the relative branching ratios of the included dimension-five contribution.

2. **Sfermion mass (represented by $m_{\tilde{q}} = m_{\tilde{q}(\text{deq})}$)** –

In the wino-dominated, heavy-degenerate limit the dressing amplitude is proportional to $M_{\tilde{W}}/m_{\tilde{q}}^2$.

Thus the decay rate scales as $M_{\tilde{W}}^2/m_{\tilde{q}}^4$.

Keeping the wino mass fixed, the lifetime grows as $m_{\tilde{q}}^4$.

This is a limiting approximation; the physical sfermion mass is not exactly $m_{\tilde{q}}$, but the trend is that a heavier sfermion spectrum suppresses the proton-decay rate.

These two directions—raising the color-triplet mass M_T and/or increasing the sfermion mass ($m_{\tilde{q}}$)—are the only adjustable parameters in the implemented SUSY SO(10) calculation that can help evade current proton-decay bounds while preserving the flavor structure.

proton_agent

User>

for this input file input/example-SO10-susy.txt, what is the minimum sfermion mass to satisfy the current experimental limits?

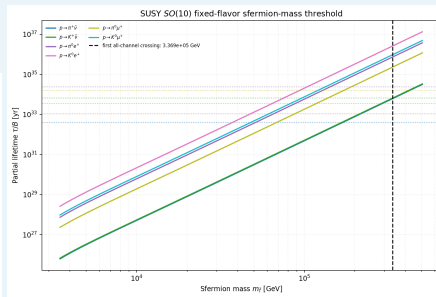
Proton_Agent>

or proton-agent

Minimum sfermion mass for the supplied SUSY SO(10) benchmark

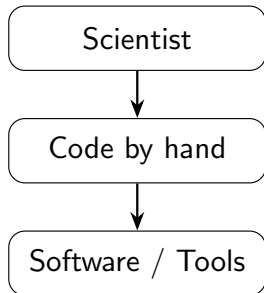
QUANTITY	VALUE
Minimum sfermion mass	3.3694×10^5 GeV
Classification at this mass	testable (passes current limits but lies within projected future sensitivity)
Most constraining channel	$p \rightarrow K^+ \bar{\nu}$
Bound ratio at the threshold	1.0000026 (just above the experimental limit)
Benchmark already excluded	No – the benchmark with the default sfermion mass (3.5 TeV) is excluded.

The scan was performed by varying only the sfermion mass while keeping all other benchmark parameters (M_T , $M_{H^\pm}$, μ , the Yukawa matrices, etc.) fixed. The adaptive grid found the first safe point at 3.3694×10^5 GeV. The corresponding partial lifetime for the $p \rightarrow K^+ \bar{\nu}$ mode just exceeds the current experimental bound, making the point testable with upcoming proton-decay experiments.

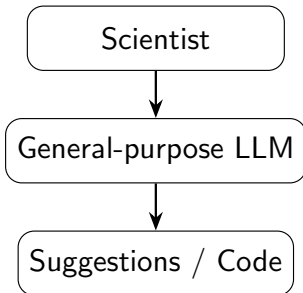


Scientific AI Agents: The Future Is Here

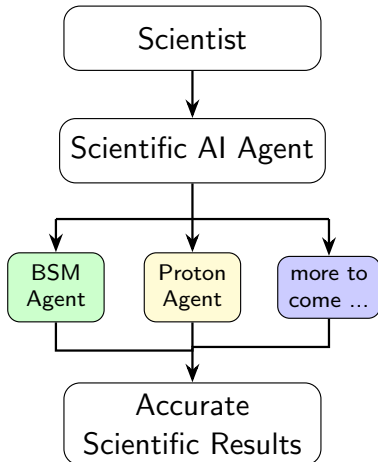
Past



Present



Emerging Future



THANK YOU!