从拉格朗日量到排除线：

AI 智能体驱动的自动化对撞机唯象研究

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文章和作者

arXiv: 2603.14553

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An End-to-end Architecture for Collider Physics and Beyond

仇是 蔡则宇 卫家燊 李泽宇 殷艺轩

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总结和展望

哈佛物理教授疯了：我让AI写论文，结果两周干完博士一年工作！冲击顶刊

新智元 新智元 2026年3月24日 17:15 北京
标题已修改 441人 星标

新智元报道

编辑：Aeneas KingHZ

【新智元导读】哈佛物理学教授带AI读博，结果Claude 4.5在仅仅两周内，就产出一篇顶刊级论文，整个物理学圈都震了！而这个项目，人类博士生要干一年。科研的门槛，再次被击穿了……

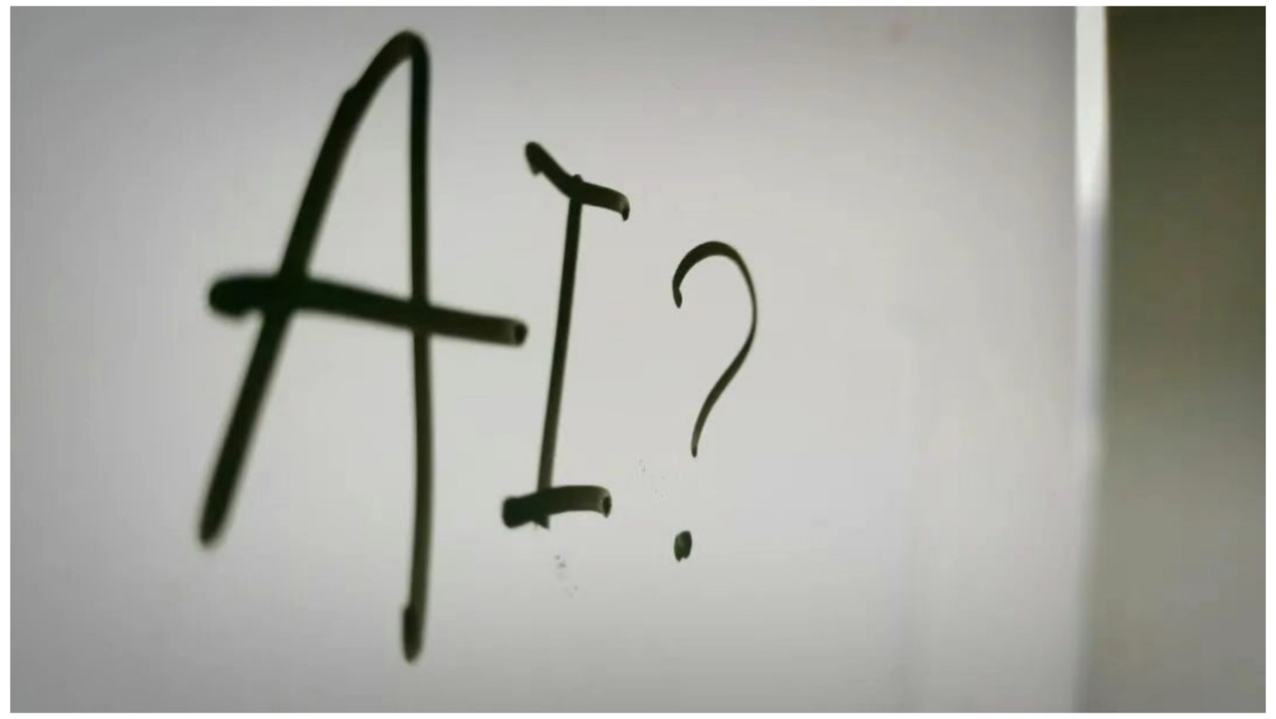
警惕你身边做AI for Science的人

知识分子 2026年3月20日 09:36 北京 898人
星标

以下文章来源于人工智能驱动材料计算，作者JinJ1N

人工智能驱动材料计算
笑一个吧，管他功成名就算不算目的

3.20 知识分子 The Intellectual



本报告也将通过ColliderAgent这个案例，从AI4Collider Physics的角度来部分回答这些问题！

AI Agent

1956 **1950–1980s 经典 AI 时代**
图灵测试、逻辑推理、专家系统，Agent = 感知-决策-执行

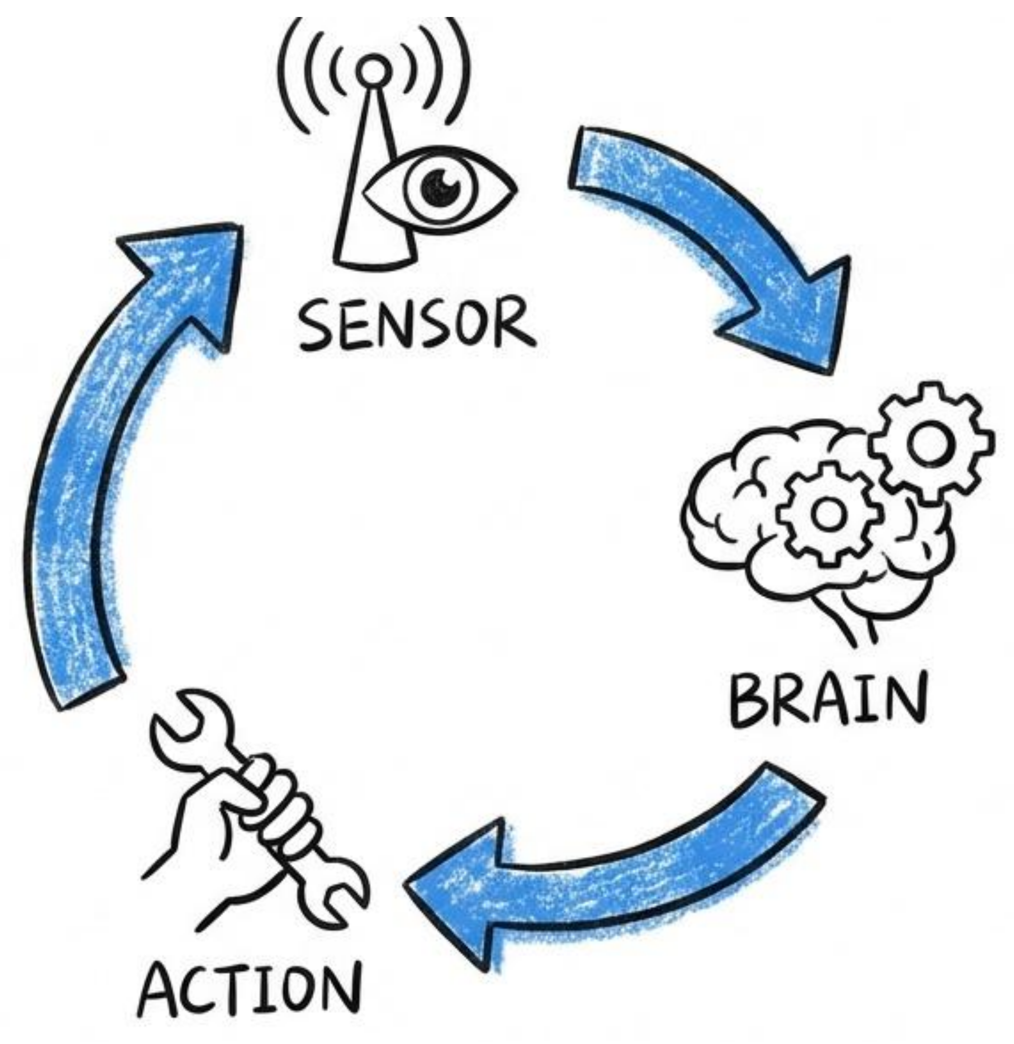
1987 **1980–1990s 符号 AI 与规划智能体**
STRIPS、BDI 模型（信念-愿望-意图），自动规划系统

1995 **1990s 多智能体系统（MAS）**
多个 Agent 协作、博弈论、强化学习初探

2015 **2010s 深度强化学习智能体**
DQN、AlphaGo，Agent 通过试错学习策略

2020 **2020–2022 LLM 驱动的智能体兴起**
GPT-3/4 等大模型具备推理能力，开始承担 Agent 角色

2022 **2022 ReAct 框架提出**
Yao et al.，将推理与行动结合，LLM Agent 的新范式



⟸ **LLM？**

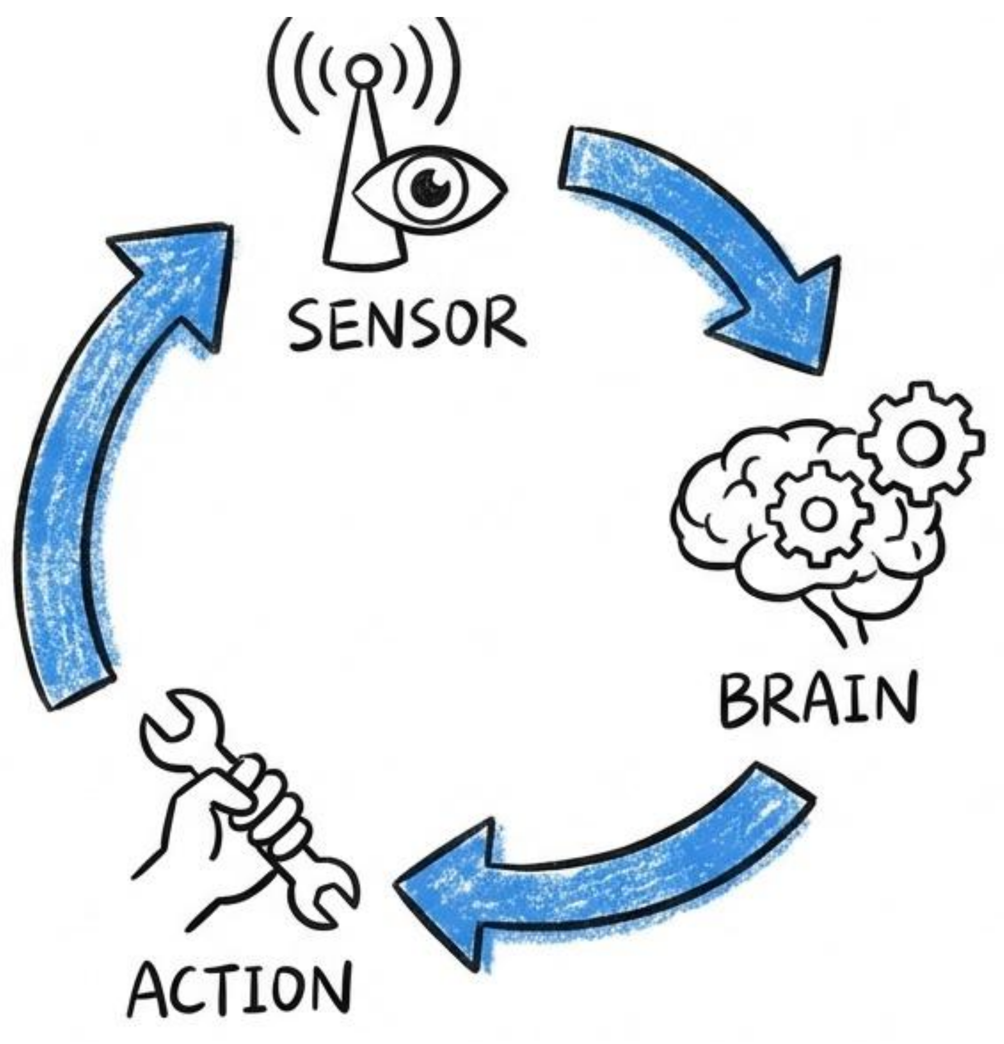
Russell & Norvig, *AIMA*：Agent是任何能够感知环境（使用传感器）并对其做出反应（使用执行器）的物体。

例如：带有摄像头和轮子的机器人，或者读取数据并提出建议的软件程序。

在AI时代，能否用LLM作为Agent的大脑?

AI Agent

- 2020.05 — RAG 论文发表（Lewis et al., Facebook AI） arXiv 2005.11401
- 2020.06 — GPT-3 发布（OpenAI） 175B参数，few-shot 学习能力
- 2022.01 — Chain-of-Thought 提示论文（Wei et al., Google） arXiv 2201.11903
- 2022.10 — LangChain 开源发布（Harrison Chase） 基于 GPT-3 completion API
- 2022.10 — ReAct 论文（Yao et al., Google/Princeton）
  推理+行动系统性结合，Thought→Action→Observation 循环
  纯文本格式约定实现工具调用，无需 Function Calling
- 2022.11 — ChatGPT 发布（OpenAI，2022年11月30日） 比 ReAct 晚 55 天
- 2023.01 — RAG 与 LLM 结合开始广泛普及 向量数据库 + LLM 成为标配
- 2023.06 — OpenAI Function Calling 发布（2023年6月） 结构化 JSON 工具调用



⟸ LLM ?

能否用LLM作为Agent的大脑?

不行（2020年，GPT-3发布）

- ▶ LLM缺乏推理能力：不知道要用什么工具来完成任务
- ▶ LLM没有工具调用能力：不会使用工具

但是，2022年被掩盖在ChatGPT光辉下的两项研究改变了这一事实：CoT和ReAct

AI Agent

- 2023.03 — **Cursor 正式发布（Anysphere）** AI 原生 IDE，VSCode fork
- 2024.11 — **MCP 发布（Anthropic）** Agent 工具/数据访问开放标准，解决 M×N 集成问题
- 2025.02 — **Claude 3.7 Sonnet + Claude Code（Anthropic）** 首个 Agent 优先模型，内置代码执行/文件读写能力
- 2025.03 — **OpenAI Agents SDK 发布** 轻量级多 Agent 框架，含 Handoffs / Guardrails
- 2025.04 — **Google ADK 发布** 企业级 Agent 框架，Google Cloud Next 发布
- 2025.04 — **OpenAI Codex CLI 发布** 终端编程 Agent，开源，o3/o4-mini 驱动
- 2025.05 — **Claude Opus 4 + Sonnet 4 发布（Anthropic）** 世界最佳编程模型
- 2025.10 — **Agent Skills 发布 beta（Anthropic）** 预封装能力模块：代码执行、文件读写、浏览器、记忆等
- 2025.11 — **Google Antigravity 发布（Google）** Agent-first IDE，Gemini 3 驱动，基于 Windsurf 技术

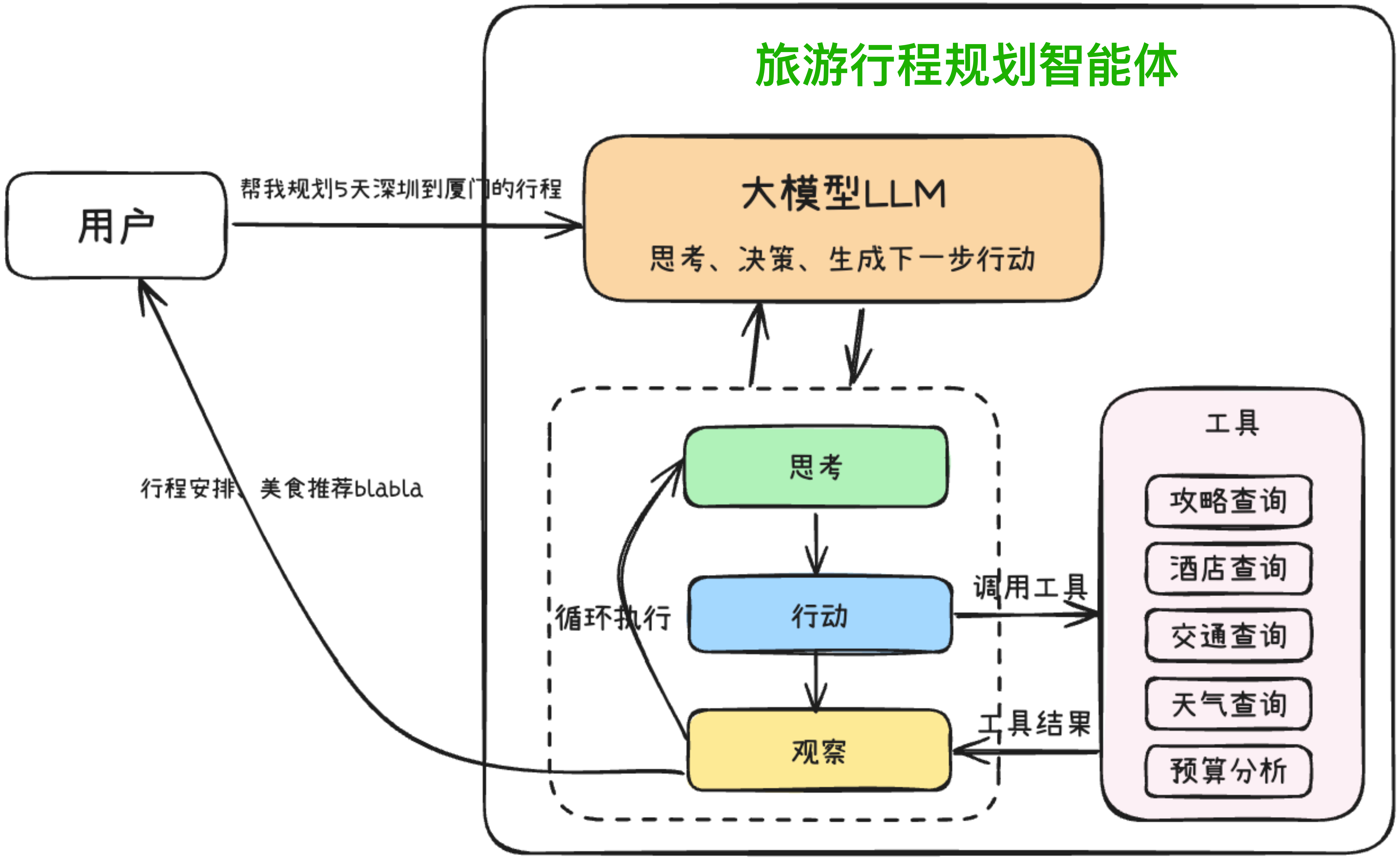
模型能力进一步提升：Claude Opus 4

工具调用进一步规范：MCP，Agent Skills

得益于这些进展，AI Agent开始从实验室逐渐向生产力转变，2025年也被称为“智能体元年”

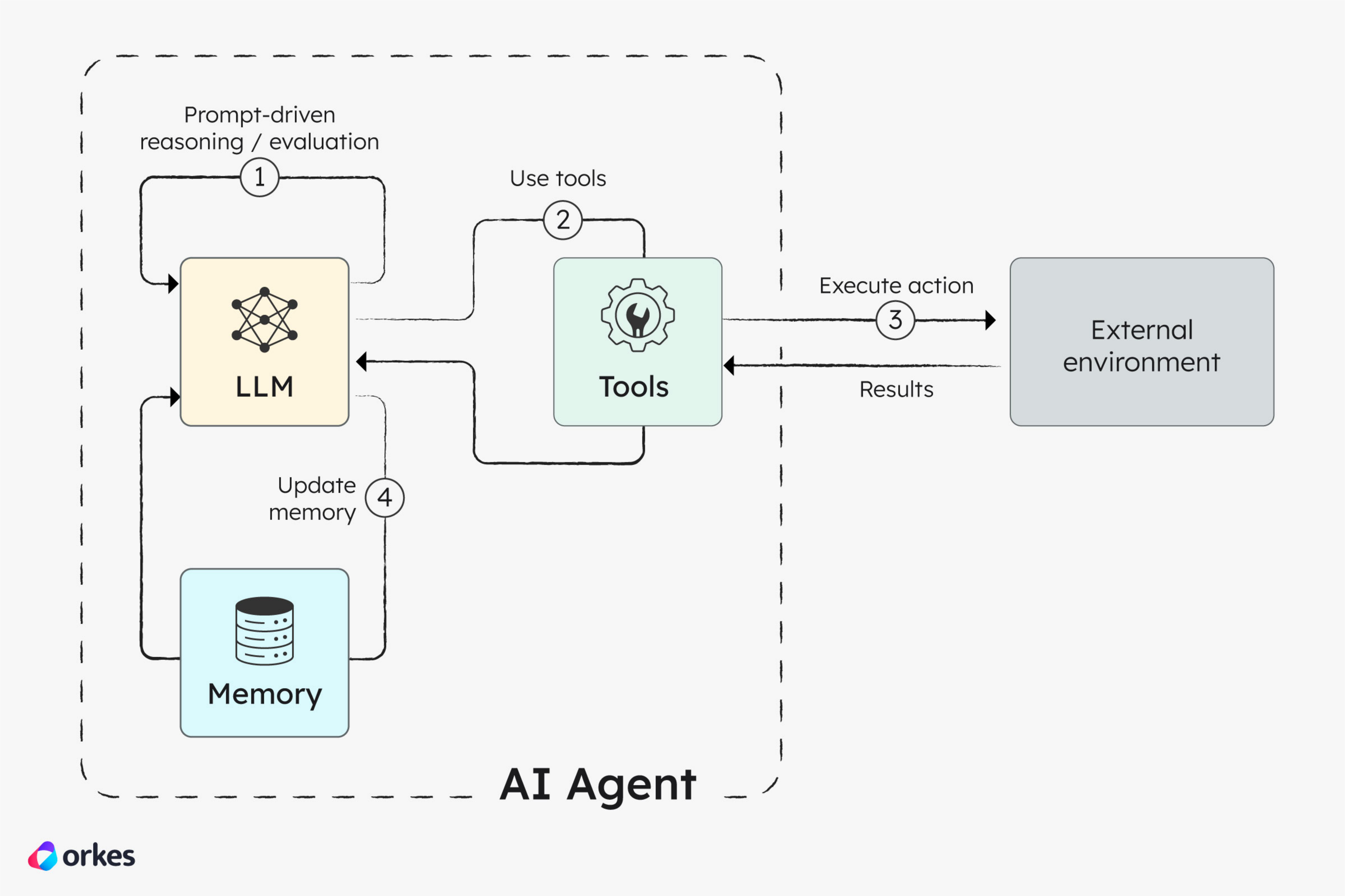
详见宋卓洋（LLM），仇是（Agent）的报告

典型的AI智能体



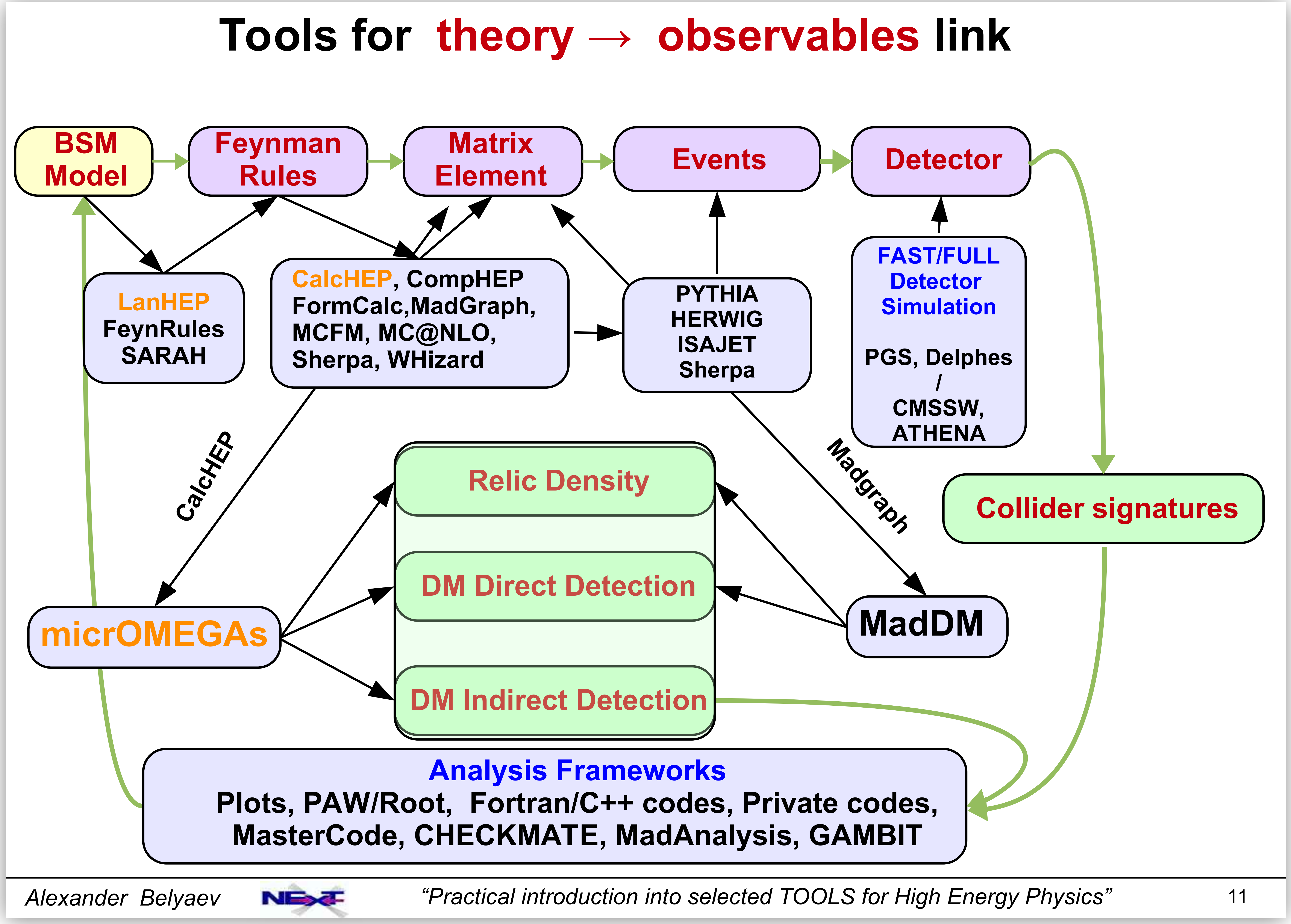
旅游行程规划智能体
用户
帮我规划5天深圳到厦门的行程
大模型LLM
思考、决策、生成下一步行动
思考
行动
观察
循环执行
调用工具
工具结果
工具
攻略查询
酒店查询
交通查询
天气查询
预算分析
行程安排、美食推荐blabla

典型的AI智能体



Prompt-driven
reasoning / evaluation
1
Use tools
2
Execute action
3
Results
Update
memory
4
LLM
Tools
External
environment
Memory
AI Agent
orkes

高能物理唯象领域的软件生态



对撞机物理、暗物质、新物理领域的程序包

- 高能物理领域有很多非常优秀的程序包 😀
- 形成了相对稳定的工作流 😀

- 不同程序包的代码约定/风格不一样，学起来很难 😭
- 安装时配置各类环境很烦。使用手册比较粗糙 😭

一线科研人员要花费大量时间学习相关程序包的功能和用法，而要知道程序包内部的运作方式、甚至隐藏的技巧更是难上加难）😭

能否自动化的运行整个工作流?
能否减少学习成本?

一些程序尝试自动化工作流的部分阶段、或针对特定唯象任务进行自动化:Checkmate, SARAH/SPheno, GAMBIT GUM

在AI时代，我们能不能做的更好？如何去做？

实现工作流的自动化
降低软件的学习成本
实现物理结果的可复现性

AI与高能物理软件生态的结合

现状：HEP程序包的差异极大，编程语言涵盖C、Fortran、Python、Mathematica，各程序的约定、输入输出的格式也各不相同

问题：如何用AI解决这些问题，并进一步的实现工作流的自动化?

我们发现HEP各类程序包有一个共性：可以通过少量的配置程序，或轻量级的代码来控制

MadGraph 脚本示例

```
import model sm
define l+ = e+ mu+
define l- = e- mu-
generate p p > l+ l-
output events/pp_ll_14tev
launch events/pp_ll_14tev
done
set nevents 50000
set ebeam1 6500
set ebeam2 6500
```

FeynRules 模型文件示例

```
LALP := Block[{mu, nu, rho, sigma},
  - gaZA * (1/2) * Eps[mu, nu, rho, sigma] * FS[Z, mu, nu] * FS[A, rho, sigma] *
  alp
  - gaZZ * (1/4) * Eps[mu, nu, rho, sigma] * FS[Z, mu, nu] * FS[Z, rho, sigma] *
  alp
  - gaWW * (1/2) * Eps[mu, nu, rho, sigma] * FS[W, mu, nu] * FS[Wbar, rho, sigma]
  * alp
];
```

解决方案：如果可以让LLM来写这些配置程序或轻量级代码，并调用相关程序来执行，就实现了我们的目的

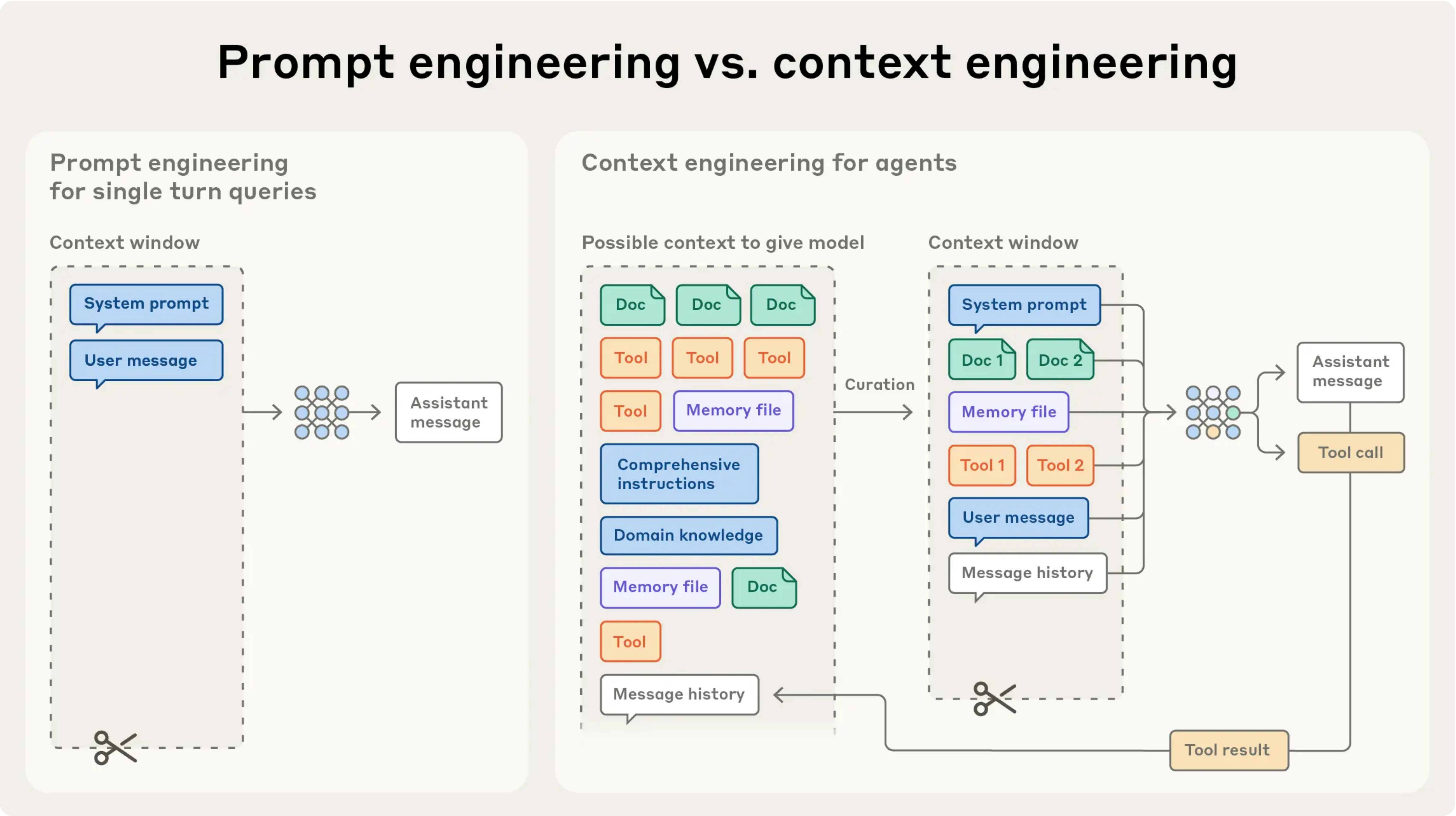
如何告诉LLM各类HEP程序包的使用方法?

1. 当前LLM已经具备了足够的编程能力
2. LLM的训练集中已经包含了部分HEP程序的手册和文档
3. 通过上下文工程来告诉LLM程序的执行步骤，关键的约定

Agent Skills

Context Engineering（上下文工程）

技术上：上下文工程 ≈ 混合了自然语言的编程



上下文工程：在与大型语言模型交互时，系统性地设计和管理输入上下文的技术与方法——让模型在每次推理时，拥有完成任务所需的"恰好合适"的信息

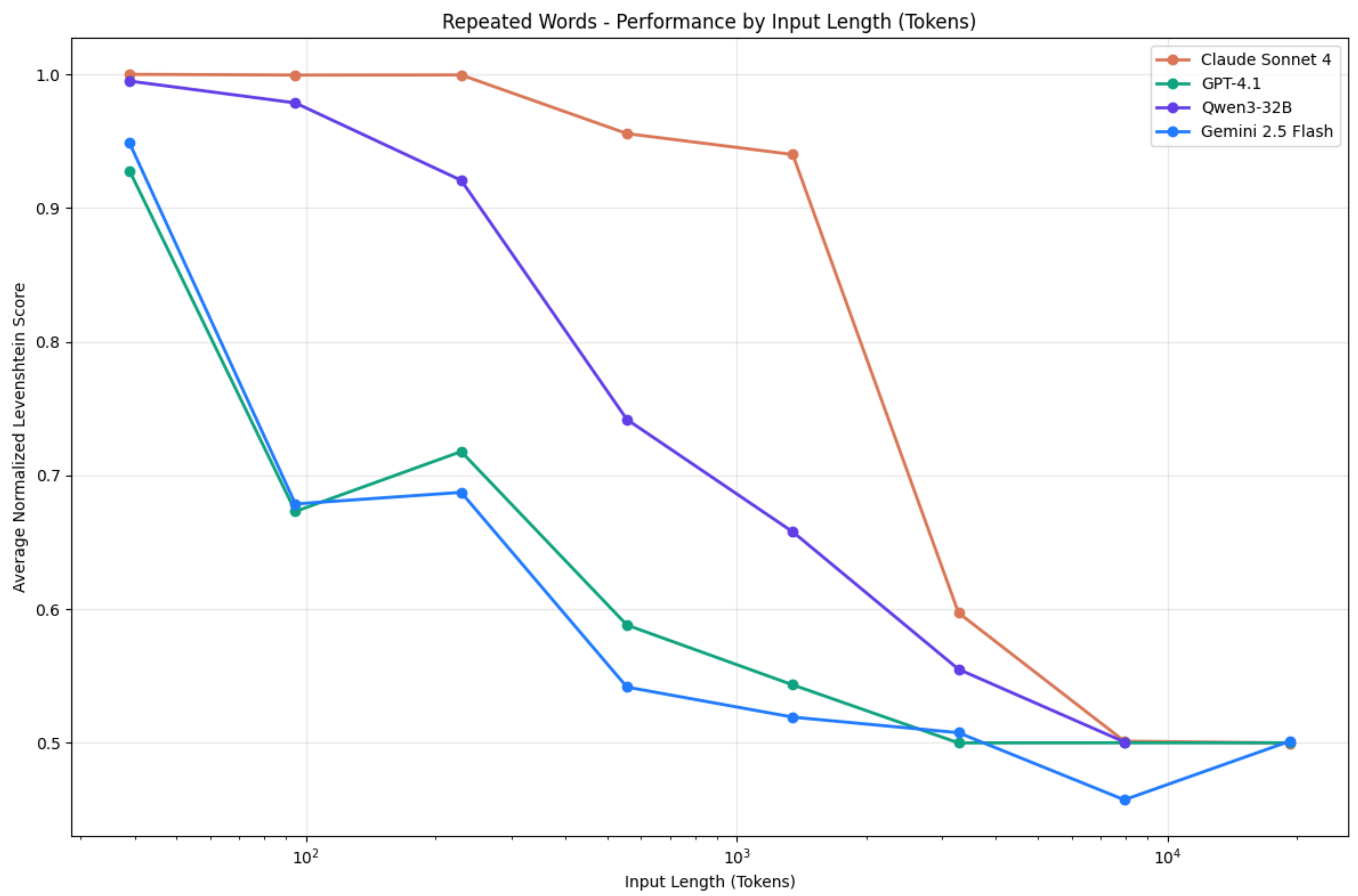
上下文空间

上下文空间是智能体的珍贵资源！

上下文腐化：模型的性能会随着输入长度的变化而发生显著变化

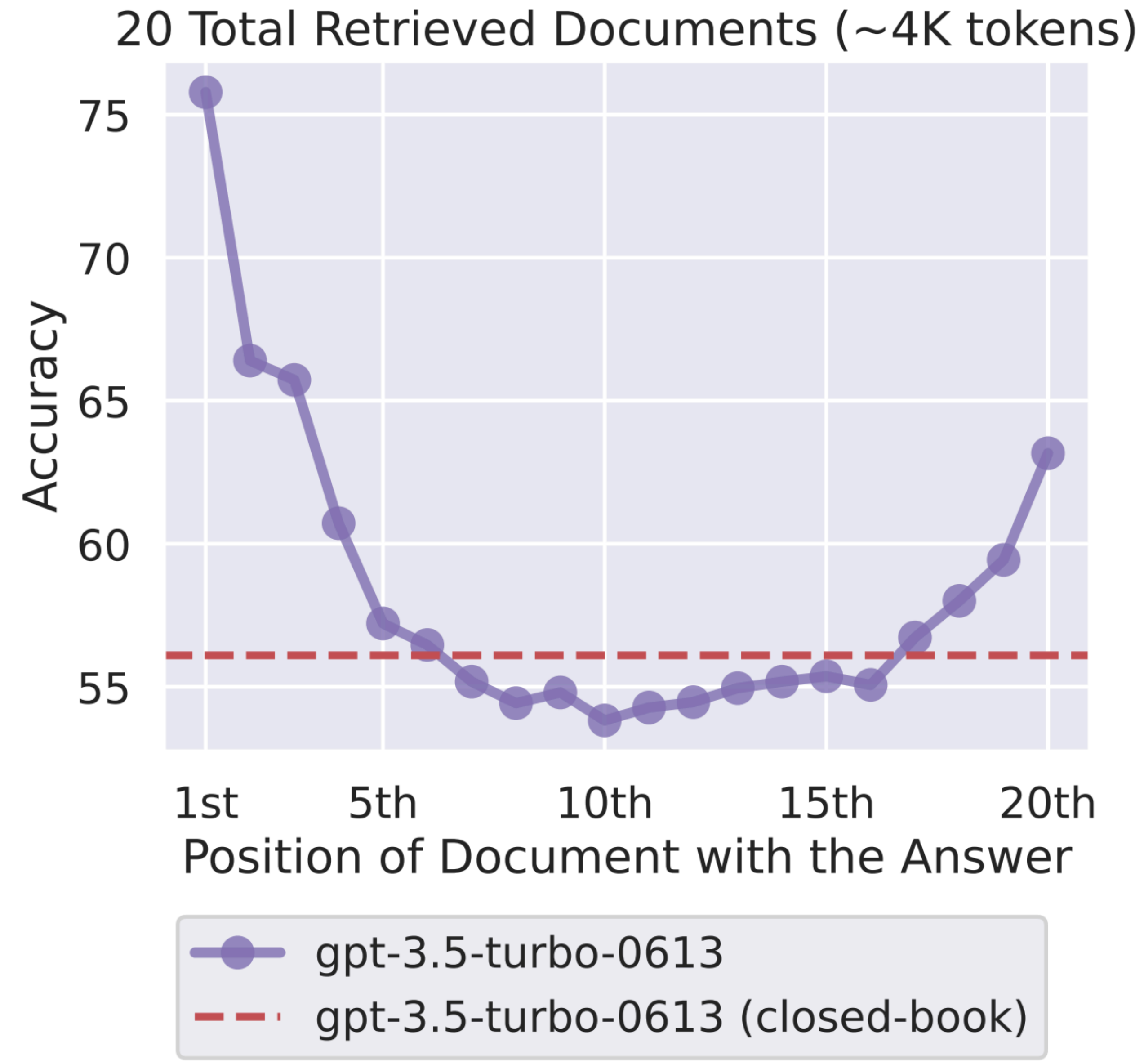
本质原因是当前LLM底层transformer架构的问题，这里不作深入探讨

2025 July https://www.trychroma.com/research/context-rot



Lost in the Middle: LLM对长文本信息的注意力是高度不均匀，开头和结尾处更高

N.F. Liu et al, 2307.03172



U型性能曲线

这些事情告诉我们，为了最大化的利用模型能力，通常只能使用最大上下文的10%～20%

如何在有限的上下文空间中，编排智能体的任务，工具的调用，是agent构建的核心！

特别是，对于复杂的任务，如何充分利用有限的上下文空间是非常具有挑战性的。

上下文工程与传统编程的区别

	传统编程	上下文工程
输入	精确	模糊
输出	确定	相对确定
长度	无限	有限
测试	单一模块/条件下 只需测试1次	单一模块/条件下 需要测试多次
编写方法	算法，规范	经验/测试
参考资料	丰富的开源程序，如 linux kernel	最好的全部闭源
看起来像	精心编写的代码	普通的文档

😀 **传统编程要求1个字母都不能输错**

😢 **LLM自身的特性，可通过上下文工程改善**

😭 **Claude Opus 4.6: 一百万上下文**
约等于500页PRD排版的论文，或者1本Peskin QFT

😭 **多进行非常多的测试，来判断实现效果，烧钱**

😢 **仅有一些经验性的方法（因而是各类Agent的护城河）**

😢 **如Claude Code闭源🤭，缺乏参考资料**

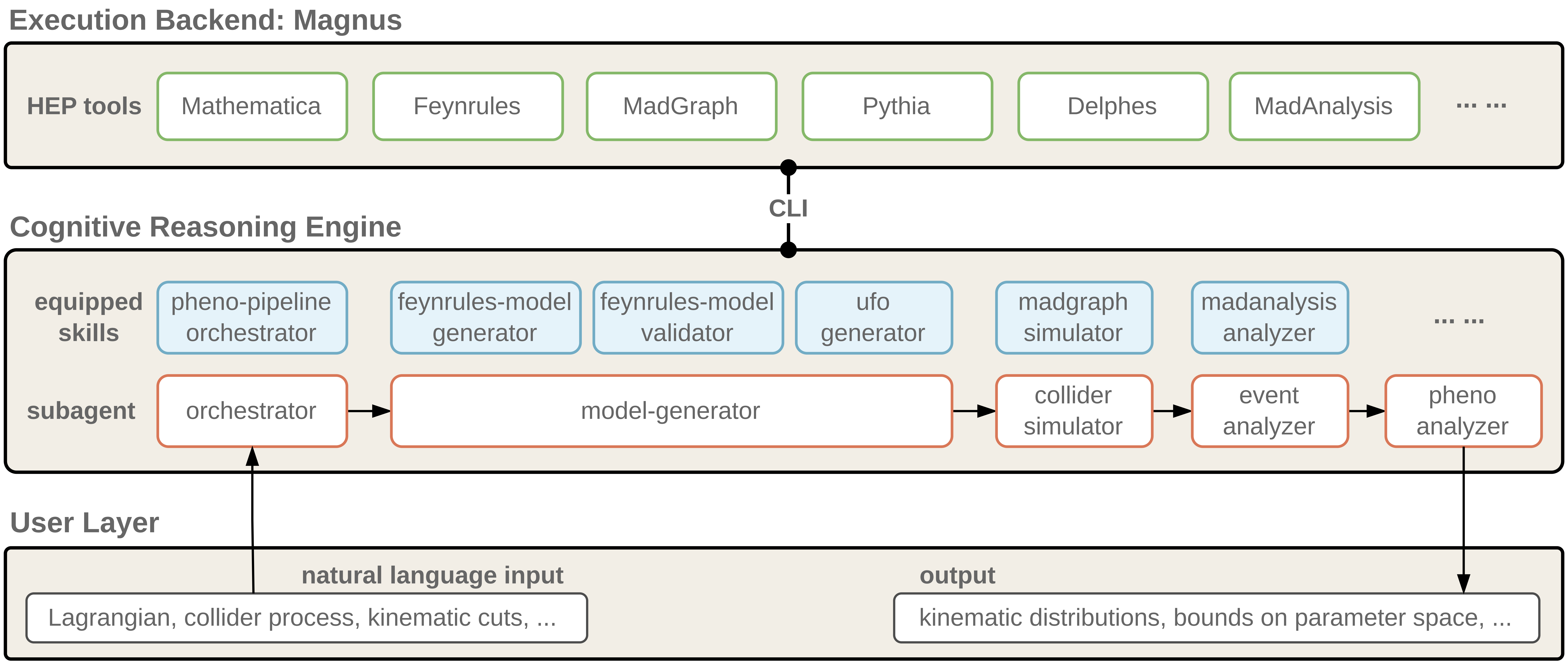
😢 **可能被误认为在写普通文档**

ColliderAgent

Hello-World Example

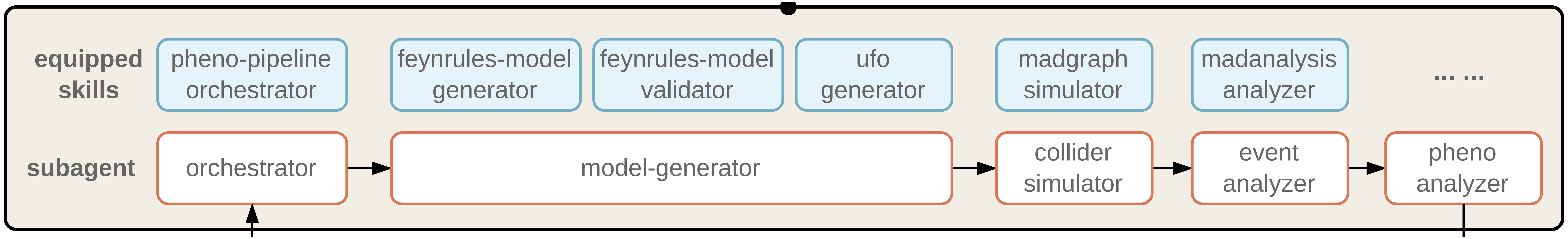
$pp \to \ell^+\ell^-$过程中轻子对的不变质量谱

智能体架构



基于Agent Skills **多智能体** **认知-执行解耦**

智能体架构：以Skills为基础



- Skills在提示词工程和工具调用的基础上引入了一种结构更完整的知识单元：它是一个可按需动态加载的模块化知识包，内部通常包含操作指令、工作流引导、可执行脚本、参考文档与元数据，并以一致、可复现的方式完成对应的专业化操作。这正与对撞机唯象研究的每个阶段相对应，例如从Lagrangian量到.fr模型文件：

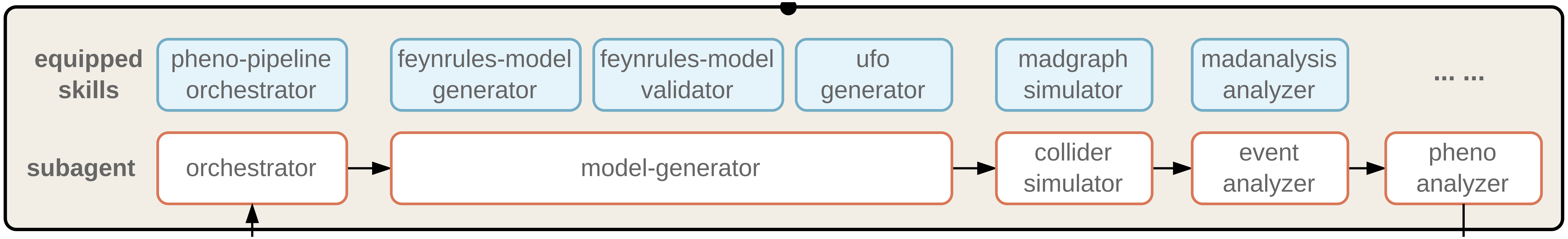
```
## Workflow

Work through these steps **one at a time**. Do not try to write the complete `.fr` file in one
shot — copy the skeleton first, then edit each section incrementally.

> ### Step 1: Analyze the Lagrangian…
> ### Step 2: Map Symbols to FeynRules Conventions…
> ### Step 3: Create the .fr file from the skeleton…
> ### Step 4: Define particle classes…
> ### Step 5: Define parameters…
> ### Step 6: Write the Lagrangian…
> ### Step 7: Validate…
```

```
### Step 5: Define parameters

Edit the `M$Parameters` section. For each new coupling constant:
- Set `ParameterType -> External` with `BlockName`, `OrderBlock`, `Value`
- Include `InteractionOrder -> {NP, 1}` for every new physics coupling (both External and Internal)
- Do **NOT** add Mass or Width symbols here — they are already defined by the particle class

For derived parameters, use `ParameterType -> Internal` with a `Value` expression.

See [references/feynrules_syntax.md](references/feynrules_syntax.md) section 6 for External/Internal parameter
examples, including mixing matrices with `Unitary -> True`.
```

Feynrules-model-generator的部分代码

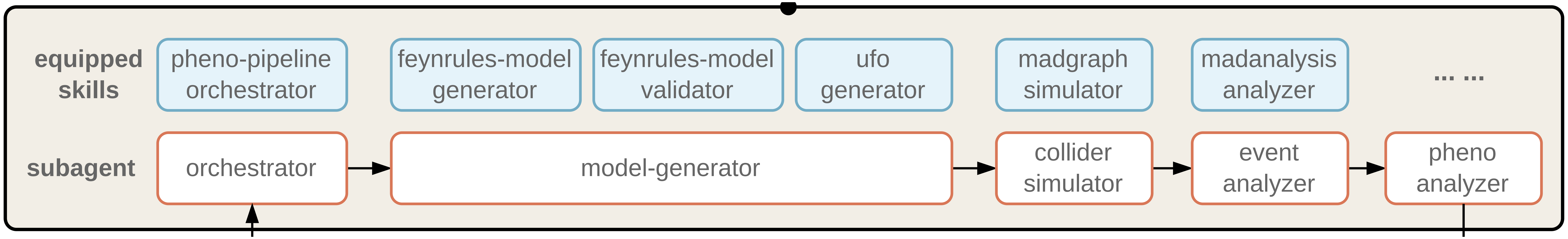
- Skills是通用的行业标准，可以在不同的Agent框架下无缝迁移
- Skills可以将唯象研究中的经验（包括一些非正式的、隐性的经验），转化为可存储、可版本管理、可跨项目共享、可持续改进的结构化知识资产。

智能体架构：以Skills为基础



pheno-pipeline-orchestrator	分解自然语言任务，组织端到端工作流
feynrules-model-generator	把自然语言（包括LaTeX）书写的Lagrangian转换为FeynRules的.fr模型文件
feynrules-validator	检验.fr模型文件：符号约定，FR内置的厄米性等自洽性检验，MadGraph预加载
ufo-generator	从.fr模型文件生成UFO模型文件
madgraph-simulator	编写、执行MadGraph脚本
madanalysis-analyzer	编写、执行MadAnalysis脚本（Normal Mode）
execution-summarizer	生成整个运行流程的总结，以及提示词和代码对应关系的总结。领域专家（或AI）可以便捷的知道ColliderAgent运行的细节，判断执行的对错。
reproduction-guide-generator	生成用于复现运行结果的全部必要脚本（包含.fr文件，.mg5, .ma5等），并生成bash一键运行脚本和复现指南。运行这个脚本后，可以自动化的重复所有的流程，最终复现结果。它保证了ColliderAgent结果的可复现性。
magnus-utility	负责与Magnus平台的作业提交、监控、重跑、结果回收与错误恢复等操作

智能体架构：multi-agent

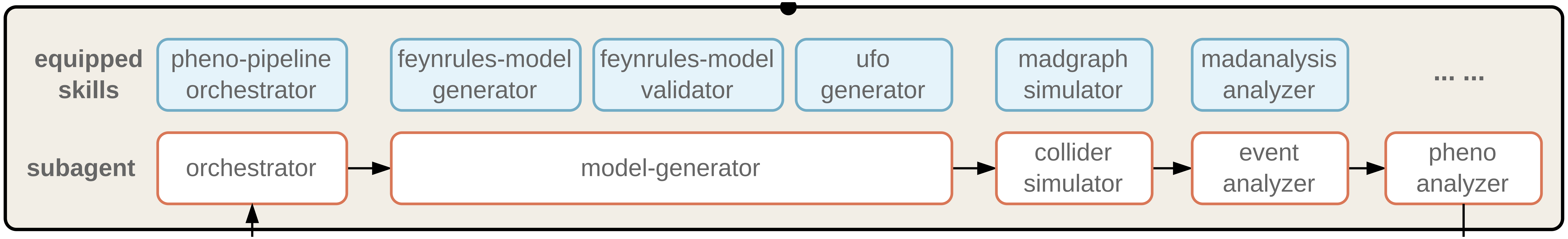


问题：对撞机唯象学的流程涵盖模型实现、事件生成、探测器模拟与末态统计分析等多个阶段。每个阶段的关注点、调用的工具以及所需的推理方式均存在显著差异。如果由单一智能体全程承担，在实践中容易导致两类问题：其一是**上下文积累引发的干扰**。模型实现阶段产生的大量技术细节会持续占据智能体的上下文窗口，在进行统计分析时形成无关信息的干扰，降低推理准确性；其二是**角色混淆导致的推理风格不稳定**。同一个智能体在不同阶段需要分别扮演理论建模者、软件工程师与数据分析师的角色，这种频繁切换会使其输出质量趋于不稳定。

解决： **多智能体**

优点： **子智能体只需维护与自身任务相关的上下文，信息负担显著降低，推理稳定性相应提升。**

智能体架构：multi-agent



多智能体 优点：子智能体只需维护与自身任务相关的上下文，信息负担显著降低，推理稳定性相应提升。

新的问题：**1）需要设计编排器来理解用户意图并分解任务。2）子智能体之间需要共享信息。**

解决方案：1）编排器通过pheno-pipeline-orchestrator Skills来分解任务；2）子智能体通过“双层通信”机制传递信息：subagent完成任务后生成包含此任务**全部信息的.md文件**，同时生成一份**精简版信息**并联同.md文件的路径传递给其它subagent。

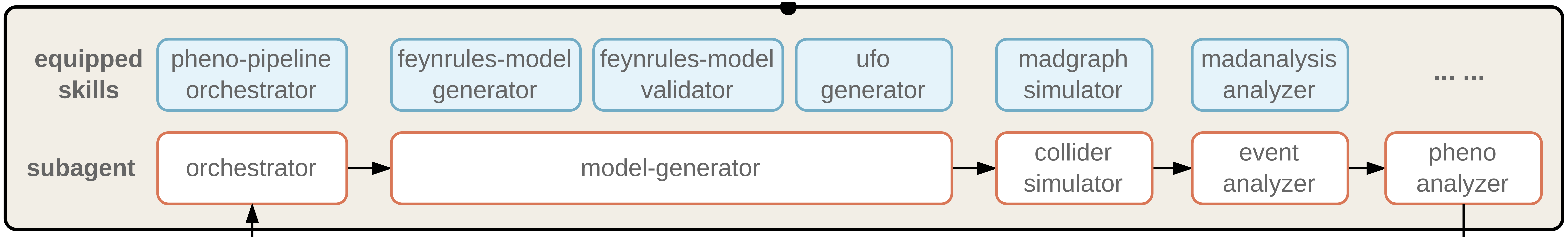
- progress
  - dy_ll_14tev
    - step1_feynrules.md
    - step2_madgraph.md
    - step3_madanalysis.md
    - step4_postprocessing.md
  - run_manifest.yaml

```
## File Paths

- **FeynRules model file**: `/Users/x/Project/agent/ALP_2_v4/ALP_bosonic.fr`
- **UFO model directory**: `/Users/x/Project/agent/ALP_2_v4/ALP_bosonic_UFO`
```

```
## BSM Parameters

| Parameter | Nature   | SLHA Block   | SLHA Code | Default Value | Description |
|-----------|----------|--------------|-----------|---------------|-------------|
| `fa`      | External | ALPINPUTS    | 1         | 1000 (GeV)    | ALP decay constant |
| `cWtil`   | External | ALPINPUTS    | 2         | 1             | Wilson coefficient for SU(2) operator |
| `Malp`    | External | MASS         | 9000005   | 0.001 (GeV)   | ALP mass |
| `gaZA`    | Internal | --           | --        | cWtil*sw/(cw*fa) | Effective ALP-Z-gamma coupling |
| `gaZZ`    | Internal | --           | --        | cWtil*(cw^4-sw^4)/(cw^2*fa) | Effective ALP-ZZ coupling |
| `gaWW`    | Internal | --           | --        | cWtil/fa      | Effective ALP-WW coupling |
```

step1_feynrules.md
中的部分内容

智能体架构：multi-agent



`orchestrator`	分解自然语言任务，组织端到端工作流
`model-generator`	把自然语言（包括LaTeX）书写的Lagrangian转换为FeynRules的.fr模型文件，并最终生成UFO模型文件，同时校验模型文件的正确性
`collider-simulator`	负责调用MadGraph生成parton–level事例，调用Pythia进行parton showering，调用Delphes进行探测器模拟
`madanalysis-analyzer`	调用MadAnalysis（normal mode）来执行事例分析
`pheno-analyzer`	利用LLM自身能力执行唯象分析任务，包括：profile–likelihood analysis等统计分析，参数空间扫描，画图等。

我们基于Claude Opus 4.6的测试表明：LLM可直接通过`Scikit-HEP`程序包`uproot`和`awkward`来读取LHE、LHCO和ROOT文件，并完成MadAnalysis expert-mode级别的事例筛选任务。

智能体架构：认知-执行解耦

详见蔡则宇的报告

ColliderAgent在系统层面引入了另一项关键设计，**认知–执行分离的双层解耦架构**：

- **认知层**由多智能体系统组成，负责科学任务的理解、分解、规划与结果判断
- **执行层**由统一的计算执行后端Magnus负责，处理作业的实际提交、运行监控与资源管理
- 两层之间通过清晰定义的**CLI**接口通信，互不渗透

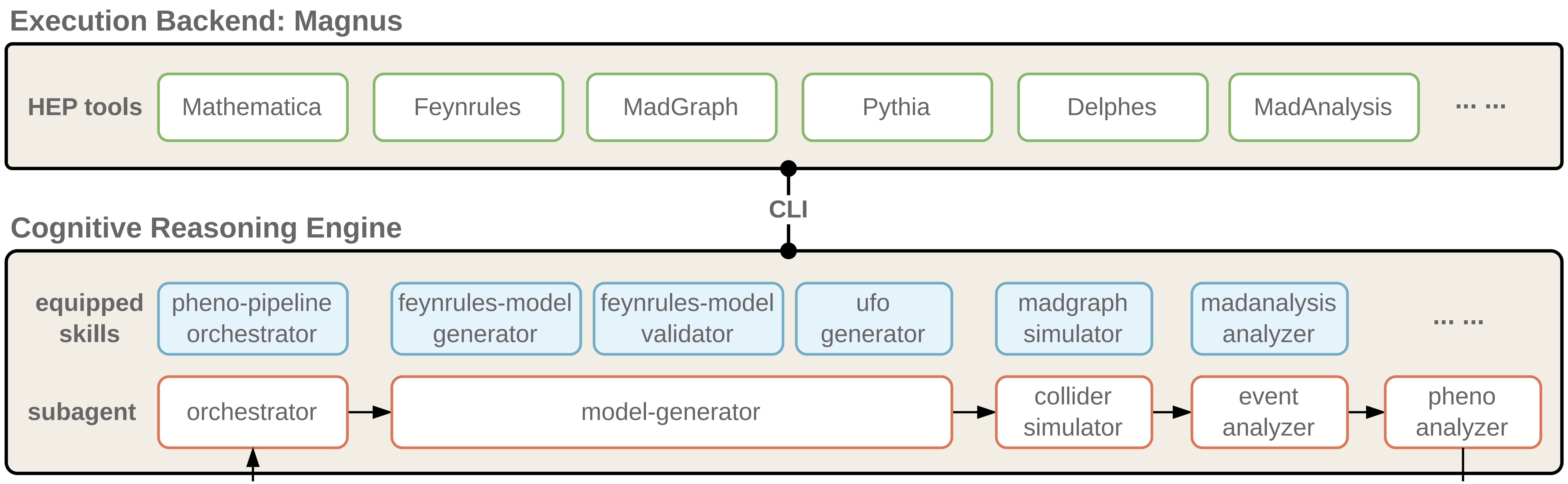
优点：

- 避免了科学逻辑与工程细节的耦合。研究者不再需要将大量精力消耗在配置环境、调试作业等非物理问题上
- 提升了系统的可移植性与可扩展性。例如，当工具链从MadGraph、Delphes扩展至其他（甚至HEP外的其它领域）软件时，也无需重新设计计算调度机制。

Magnus：**为AI时代设计的通用开源计算平台**

云原生、持续集成/持续交付的人机协作平台，构建高效工作流，沉淀科研蓝图与智能体技能

docker自动化部署
HPC部署（SLURM）



ColliderAgent能做什么？

下面我们通过经典论文的复现来看看ColliderAgent目前具备了哪些能力

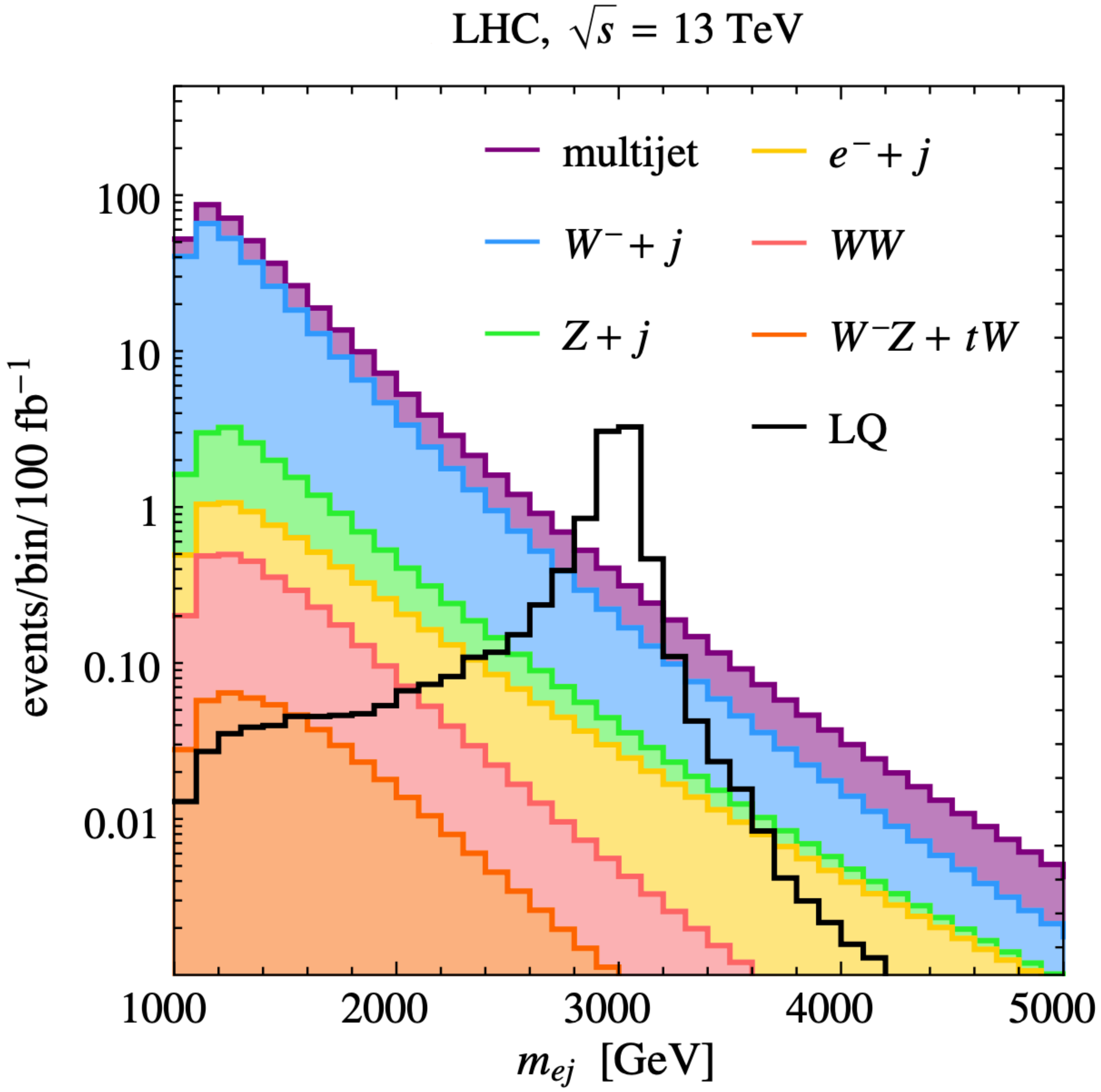
1. Single LQ production at the LHC

PHYSICAL REVIEW LETTERS **125,** 231804 (2020)

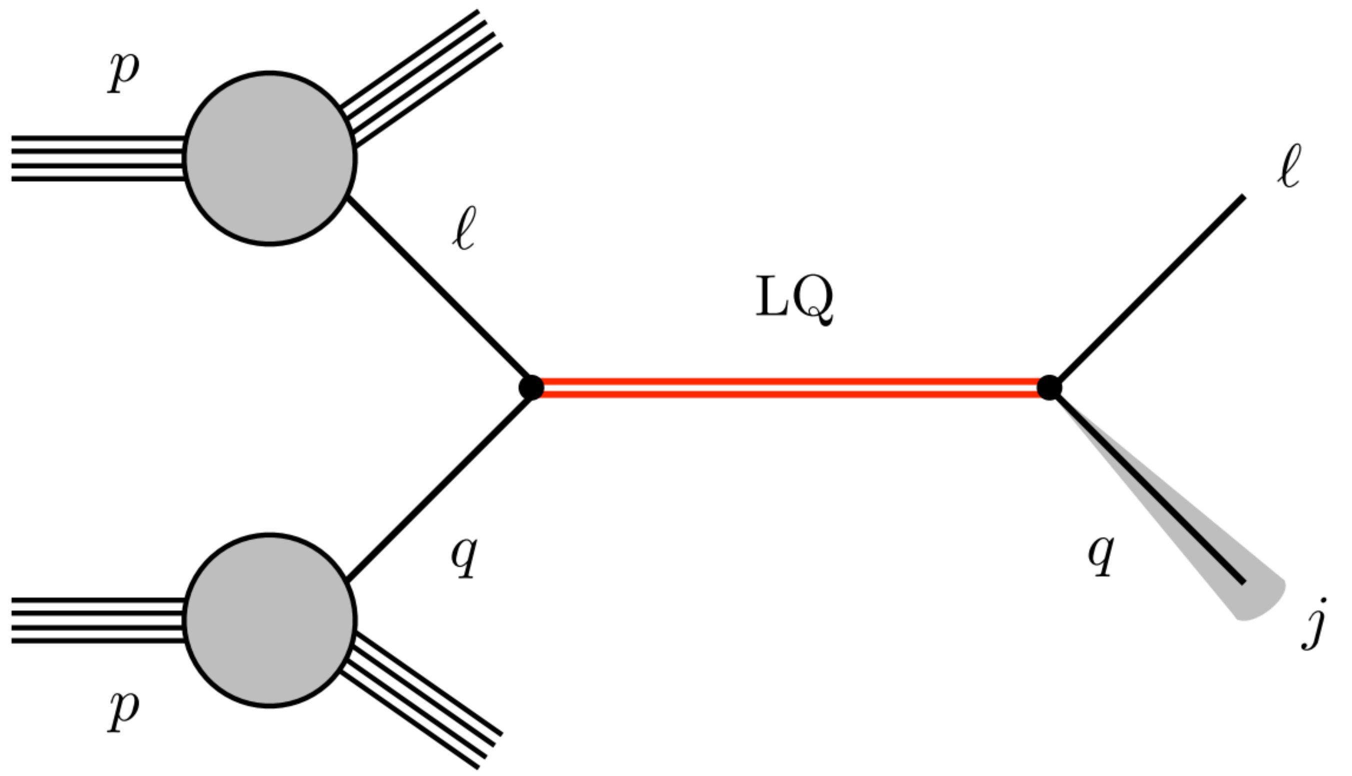
Lepton-Quark Collisions at the Large Hadron Collider

Luca Buonocore,[1,2,*] Ulrich Haisch,[3,†] Paolo Nason,[4,‡] Francesco Tramontano,[1,§] and Giulia Zanderighi[3,‖]
[1]*Dipartimento di Fisica, Università di Napoli Federico II and INFN, Sezione di Napoli, I-80126 Napoli, Italy*
[2]*Physik Institut, Universität Zürich, CH-8057 Zürich, Switzerland*
[3]*Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany*
[4]*Università di Milano-Bicocca and INFN, Sezione di Milano-Bicocca, Piazza della Scienza 3, 20126 Milano, Italy*

(Received 29 May 2020; revised 29 September 2020; accepted 9 November 2020; published 2 December 2020)



- **single leptoquark production by by picking a lepton from one beam and a quark from the other beam**
- **requiring the correct use of the LUXlep PDF set to account for leptons inside the proton.**



Since Pythia cannot handle incoming leptonic partons, the initial-state leptons in the LHE events should be replaced by photons before showering. The parton shower backward evolution of PYTHIA then produces only quarks from photon splitting, so after showering the simulation includes initial-state quarks instead of leptons.

1. Single LQ production at the LHC

1. Target

Considering the scalar leptoquark model described in this document, plot the m_{ej} distribution for the signal process.

---

2. Scalar Leptoquark Model

2.1 Lagrangian

$$\mathcal{L} = \lambda_{eu}\,\mathrm{LQ}_{eu}\,\bar{e}_R u_R^c + \text{h.c.}$$

where $\psi^c \equiv C\bar{\psi}^T$ with $C = i\gamma^2\gamma^0$ denotes the charge conjugation of ψ field. Note that the leptoquark LQ_{eu} couples to a lepton and a quark (no anti-particles). Here,

- LQ_{eu} is a scalar leptoquark. It is an $SU(2)_L$ singlet under the SM gauge group, carrying color triplet and electric charge $Q = -1/3$.
- λ_{eu} is the Yukawa coupling (real).

2.2 Parameters

The benchmark point for the signal:

- mass of LQ: $M_{\mathrm{LQ}} = 3000$ GeV
- total width of LQ: $\Gamma_{\mathrm{LQ}} = 60$ GeV
- $\lambda_{eu} = 1$

user prompt ≈ research note or paper

1. Single LQ production at the LHC

1. Target

3. Collider Simulation

3.1 Process

$$p\,p \to \mathrm{LQ} \to e\,j, \text{ mediated by the scalar leptoquark, without NWA approximation.}$$

Only consider contributions from the scalar leptoquark. Completely exclude all SM gauge bosons (Z, γ, $W^{\pm}$) and Higgs boson from all Feynman diagrams. Here, the underlying process is a lepton (e) from one proton PDF and a quark (u) from the other proton fusion to produce the LQ, which then decays back to $e + j$. This requires the LUXlep PDF, which provides lepton parton distribution functions inside the proton.

3.2 Collider simulation settings

- Collider: 13 TeV LHC
- Event number: 100000
- Parton shower: Pythia8
- Detector simulation: Delphes with ATLAS card (anti-k_T jets with $R = 0.4$)
- PDF: LUXlep; redefine the proton content to include leptons and the photon
- Generation-level cuts: $p_T(\ell, j) > 500$ GeV, $|\eta| < 2.5$
- Store the generated events in LHCO format

3.3 Pythia8 lepton-to-photon workaround

Pythia8 cannot backward-evolve leptons from proton PDFs. The correct steps are:

1. After MadGraph generates the LHE file, replace all initial-state leptons with photons in the LHE file.
2. Disable Pythia8's built-in event validity checks (charge/momentum conservation) so it accepts and showers the manually modified LHE file without rejecting it.
3. Perform shower and detector simulation.

user prompt ≈ research note or paper

1. Single LQ production at the LHC

1. Target

3. Collider Simulation

4. Numerical Analysis

4.1 Event selection
Read the reconstructed events from the Delphes output and apply the following selection cuts:

1. Electron: $p_T > 500$ GeV, $|\eta| < 2.5$
2. Jet: $p_T > 500$ GeV, $|\eta| < 2.5$ (anti-k_T, $R = 0.4$)
3. Missing transverse energy: $E_T^{\text{miss}} < 50$ GeV
4. Lepton veto: veto events with additional leptons ($|\eta| < 2.5$, $p_{T,\ell} > 7$ GeV)
5. Jet veto: veto events with additional subleading jets ($|\eta| < 2.5$, $p_{T,j} > 30$ GeV)

4.2 Signal histogram
Compute the invariant mass m_{ej} of the leading electron and leading jet for events passing all cuts.

- Bin the m_{ej} distribution in 100 GeV bins from 0 to 5000 GeV.
- Weight each event by $w = \sigma \times \mathcal{L}/N_{\text{gen}}$, where σ is the cross section, $\mathcal{L} = 100\ \text{fb}^{-1}$, and N_{gen} is the total number of generated events.

---

5. Plot Figure
Plot the signal m_{ej} distribution with solid black line.

1. After MadGraph generates the LHE file, replace all initial-state leptons with photons in the LHE file.
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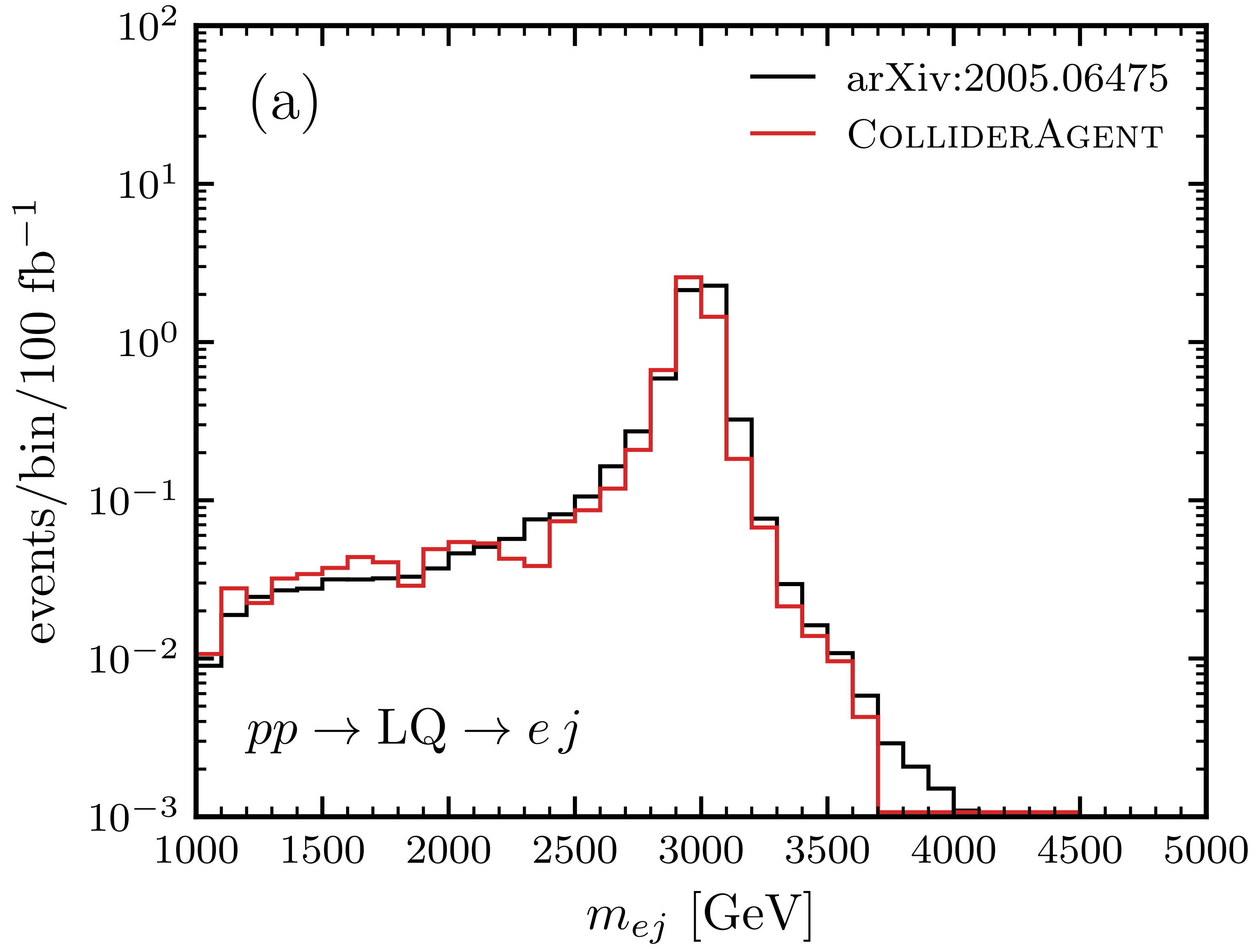

user prompt ≈ research note or paper

1. Single LQ production at the LHC

1. Target

3. Collider Simulation

4. Numerical Analysis

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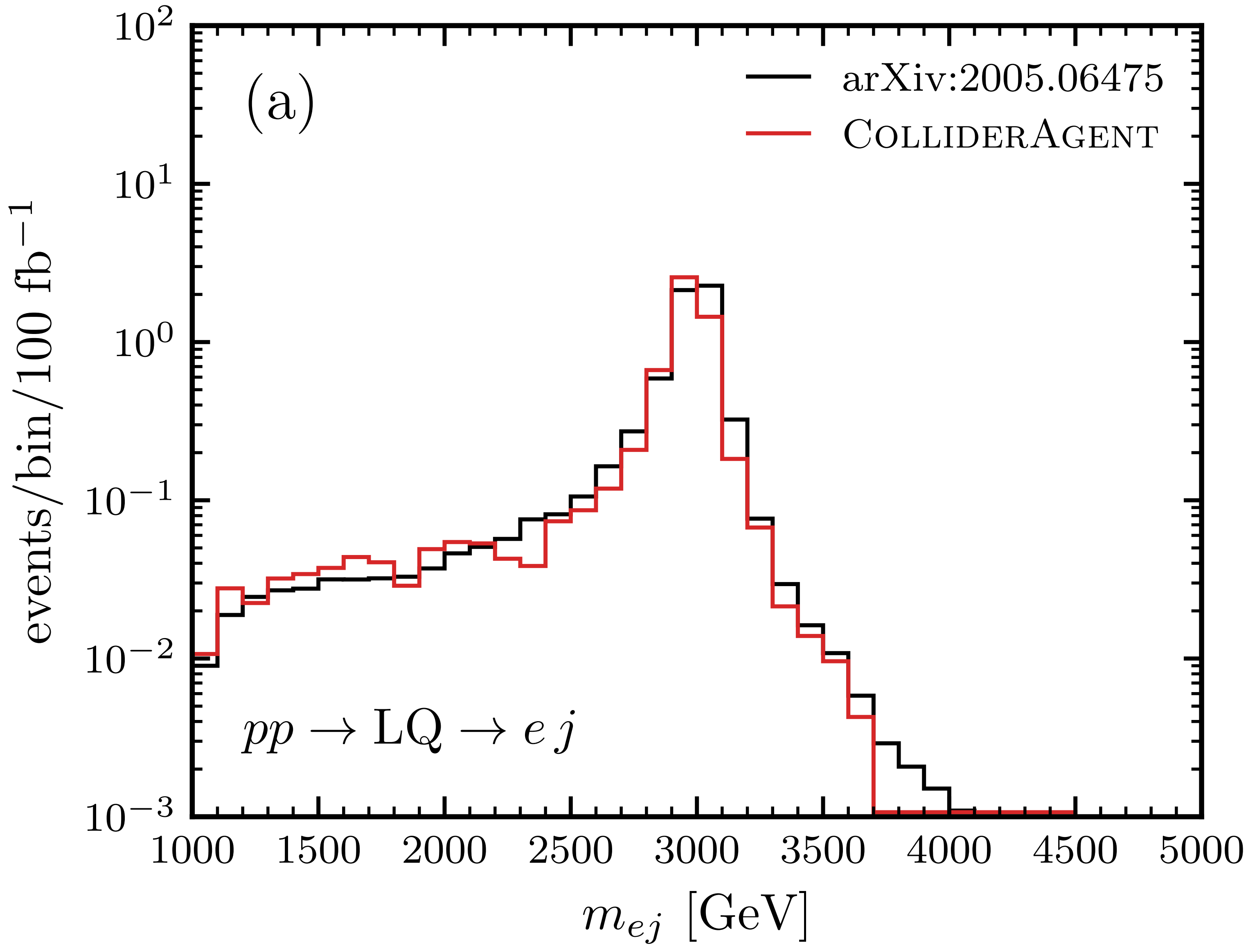


如果不放心的话，还可以

“请帮我验证arXiv: 2006.06477中的table 1”

user prompt ≈ research note or paper

SM cross section for lepton-lepton scattering at the LHC

	$e^+\mu^-$	$e^+\tau^-$	$\mu^+\tau^-$	e^+e^+	$\mu^+\mu^+$	$\tau^+\tau^+$
$\sigma_{13\text{TeV}}$ [fb]	$0.29^{+0.13}_{-0.10}$	$0.18^{+0.11}_{-0.08}$	$0.16^{+0.10}_{-0.07}$	$0.24^{+0.10}_{-0.08}$	$0.19^{+0.09}_{-0.07}$	$0.08^{+0.06}_{-0.04}$
$\sigma_{27\text{TeV}}$ [fb]	$0.53^{+0.25}_{-0.18}$	$0.34^{+0.21}_{-0.15}$	$0.30^{+0.19}_{-0.14}$	$0.440^{+0.19}_{-0.14}$	$0.34^{+0.16}_{-0.12}$	$0.14^{+0.12}_{-0.07}$

Buonocore, Nason, Tramontano, Zanderighi, 2005.06477

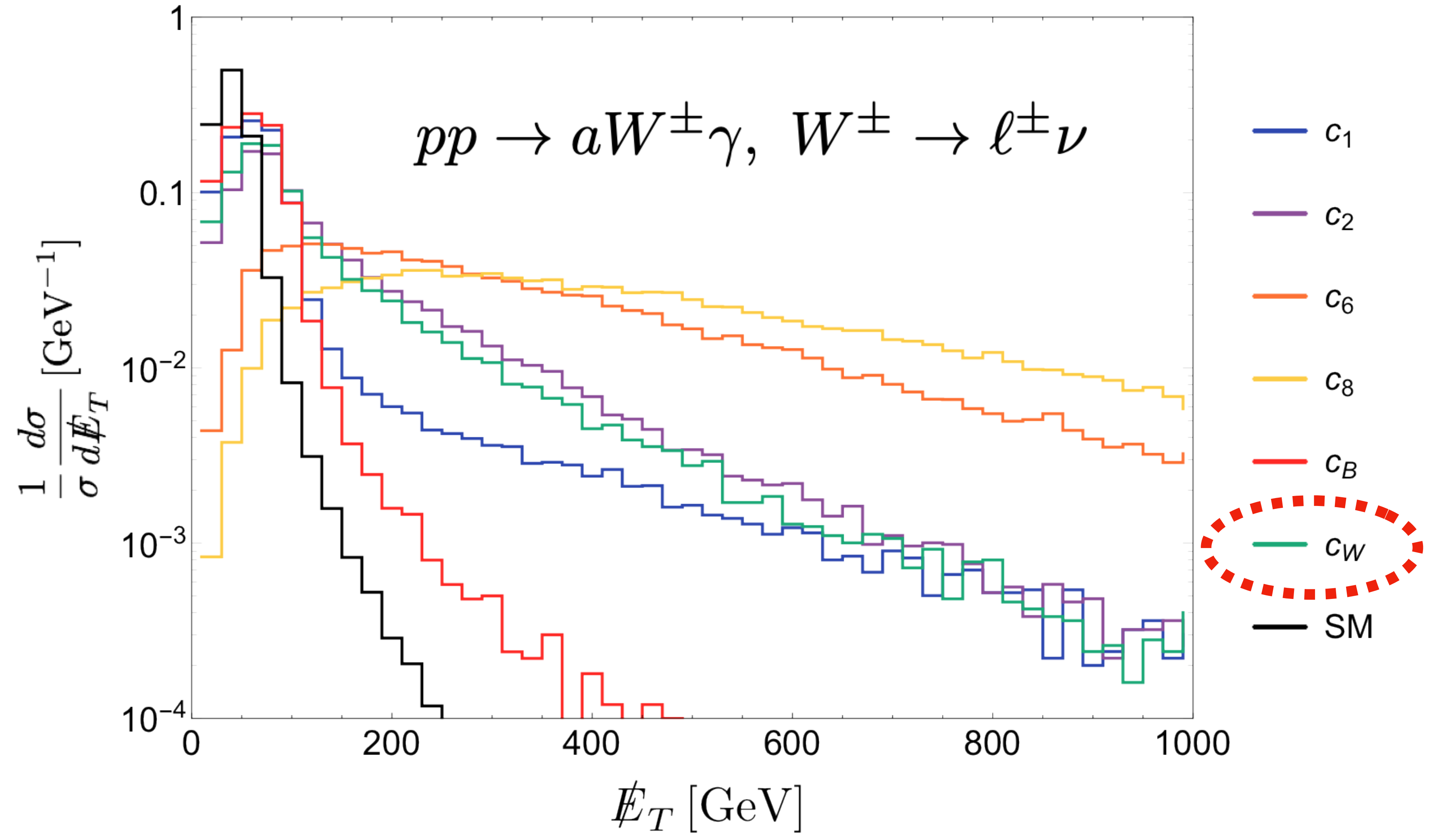
2. ALP production at the LHC in EFT

ALPs Effective Field Theory and Collider Signatures #1

I. Brivio (Bohr Inst. and Madrid, Autonoma U. and Madrid, IFT), M.B. Gavela (Madrid, Autonoma U. and Madrid, IFT), L. Merlo (Madrid, Autonoma U. and Madrid, IFT), K. Mimasu (Louvain U., CP3 and Sussex U.), J.M. No (King's Coll. London and Sussex U.) et al. (Jan 19, 2017)

Published in: *Eur.Phys.J.C* 77 (2017) 8, 572 • e-Print: 1701.05379 [hep-ph]

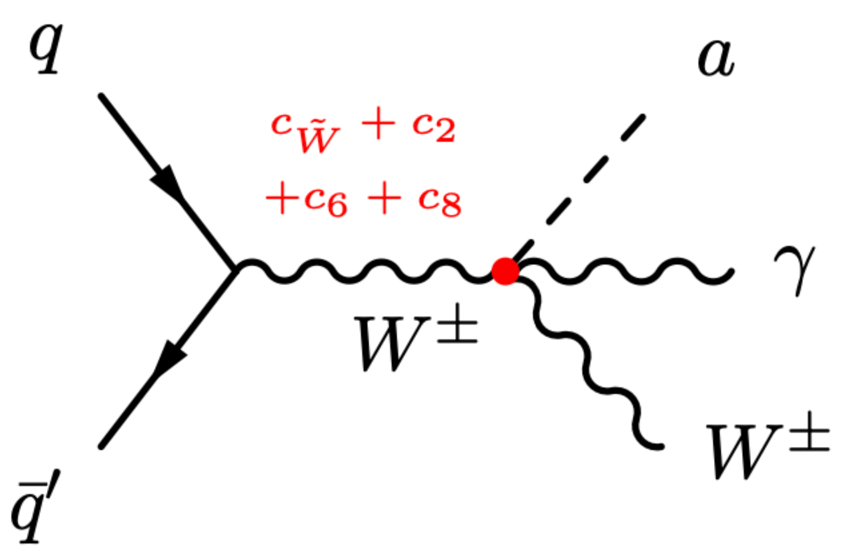
pdf DOI cite claim reference search 324 citations

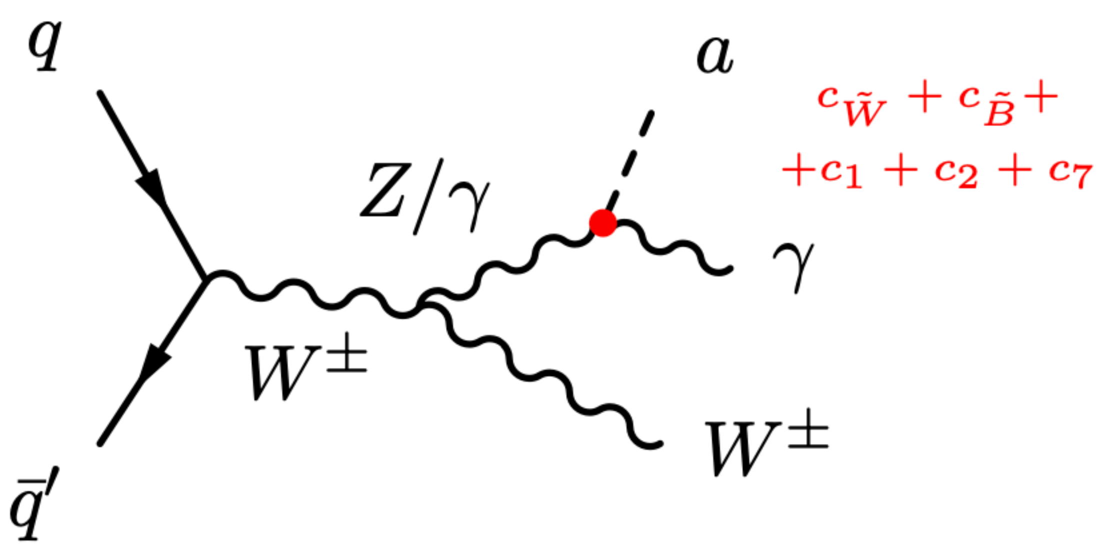


EW vertices induced by ALP EFT operators

$$\mathcal{A}_{\tilde{B}} = -B_{\mu\nu}\tilde{B}^{\mu\nu}\frac{a}{f_a} \qquad \mathcal{A}_{\tilde{W}} = -W^a_{\mu\nu}\tilde{W}^{a\mu\nu}\frac{a}{f_a}$$

$$c_{\tilde{B}} = -\tan^2\theta_W\, c_{\tilde{W}} \text{ so that } g_{a\gamma\gamma} = 0$$





2. ALP production at the LHC in EFT

1. Target

Considering the ALP EFT in this document, plot the normalized E_T^{miss} distribution for $pp \to a\,W^{\pm}\gamma$ ($W^{\pm} \to \ell^{\pm}\nu$) at $\sqrt{s} = 13$ TeV LHC.

---

2. ALP EFT

2.1 Lagrangian

The ALP bosonic EFT Lagrangian reads:

$$\delta\mathcal{L}_a^{\text{bosonic}} = c_{\tilde{W}}\mathcal{A}_{\tilde{W}} + c_{\tilde{B}}\mathcal{A}_{\tilde{B}}$$

where the operators are

$$\mathcal{A}_{\tilde{B}} = -B_{\mu\nu}\tilde{B}^{\mu\nu}\frac{a}{f_a}, \qquad \mathcal{A}_{\tilde{W}} = -W^a_{\mu\nu}\tilde{W}^{a\mu\nu}\frac{a}{f_a}.$$

Here,

- a is the ALP (axion-like particle), a pseudo-scalar singlet, with mass m_a.
- f_a is the ALP decay constant (dimension of mass).
- $B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$ is the $\mathrm{U}(1)_Y$ hypercharge field strength tensor.
- $W^a_{\mu\nu} = \partial_\mu W^a_\nu - \partial_\nu W^a_\mu + g\epsilon^{abc}W^b_\mu W^c_\nu$ is the $\mathrm{SU}(2)_L$ weak isospin field strength tensor ($a = 1, 2, 3$).
- $\tilde{B}^{\mu\nu} = \frac{1}{2}\epsilon^{\mu\nu\rho\sigma}B_{\rho\sigma}$, $\tilde{W}^{a\mu\nu} = \frac{1}{2}\epsilon^{\mu\nu\rho\sigma}W^a_{\rho\sigma}$ are the dual field strength tensors.
- $c_{\tilde{W}}, c_{\tilde{B}}$ are dimensionless Wilson coefficients. They satisfy the relation

  $$c_{\tilde{B}} = -\tan^2\theta_W \cdot c_{\tilde{W}}$$

  to enforce $g_{a\gamma\gamma} = 0$, where θ_W is the weak mixing angle.
- In the collider simulation, $f_a = 1000$ GeV and $m_a = 0.001$ GeV are chosen. So the free parameter is $c_{\tilde{W}}$.

2. ALP production at the LHC in EFT

1. Target

3. Collider Simulation

3.1 Process

$$pp \to a W^{\pm} \gamma, \qquad W^{\pm} \to \ell^{\pm} \nu$$

3.2 Collider Simulation Settings

- Collider: 13 TeV LHC
- Event number: 500,000
- Analysis level: Parton-level (no parton shower or detector simulation)
- PDF: nn23lo1
- $f_a = 1000$ GeV, $m_a = 0.001$ GeV, and $c_{\tilde{W}} = 1$

---

4. Numerical Analysis

4.1 Event Selection
Read the LHE events and apply the following selection cuts:

- photon: $p_T > 20$ GeV, $\eta < 2.5$
- lepton: $p_T > 20$ GeV, $\eta < 2.5$

4.2 Histogram and Normalization

- Histogram: $E_T^{\text{miss}} = |\vec{p}_T^{\,a} + \vec{p}_T^{\,\nu}|$, the vector sum of the transverse momenta of all invisible particles (ALP + neutrino).
- Binning: 50 bins, 0–1000 GeV

4.3 Plot Figure
Plot the histogram. The height of the histogram is the normalized events, which are defined as the ratio of the number of events in the bin to the total number of events.

2. ALP production at the LHC in EFT

1. Target

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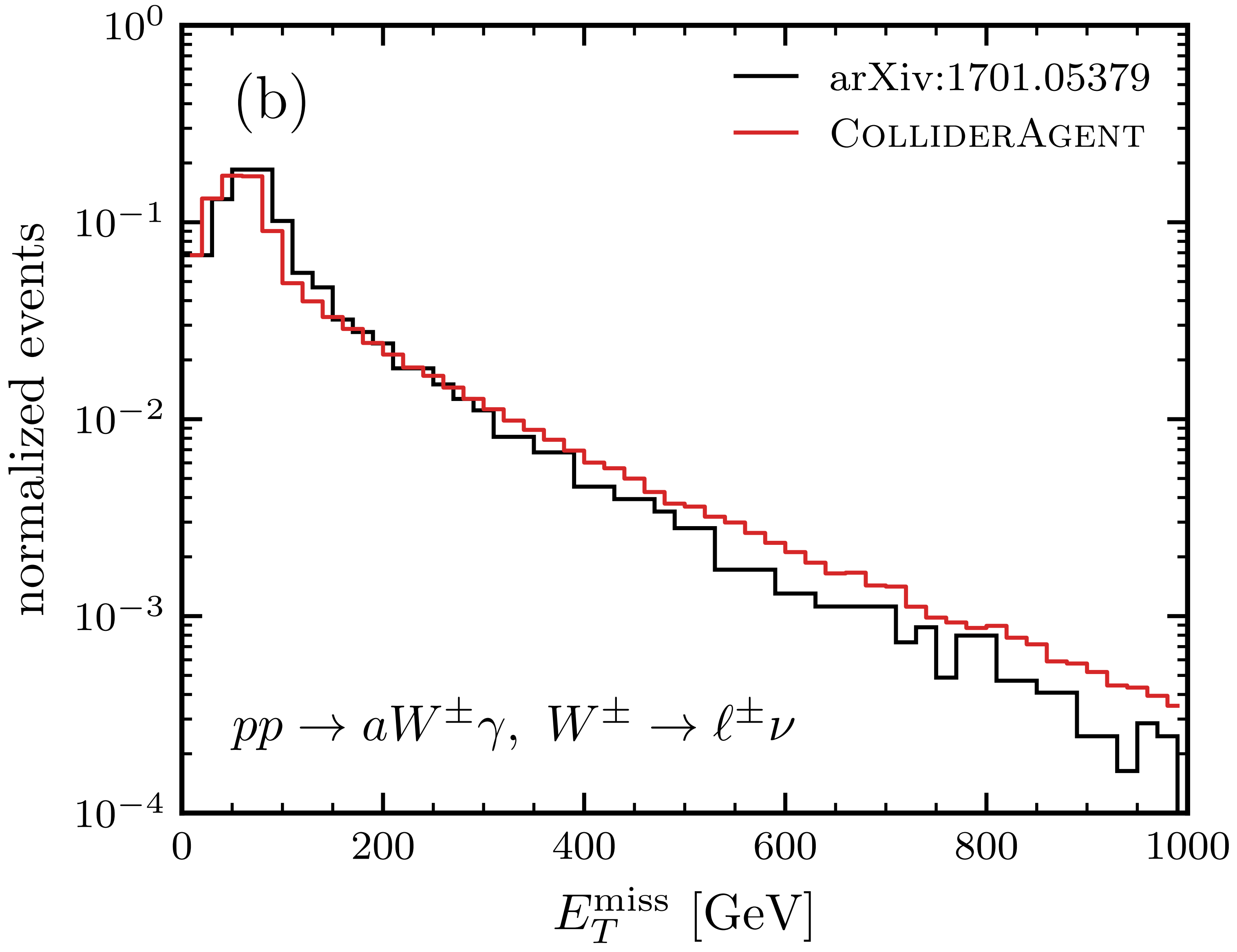


3. Constraints on U_1 LQ from LHC mono-τ search

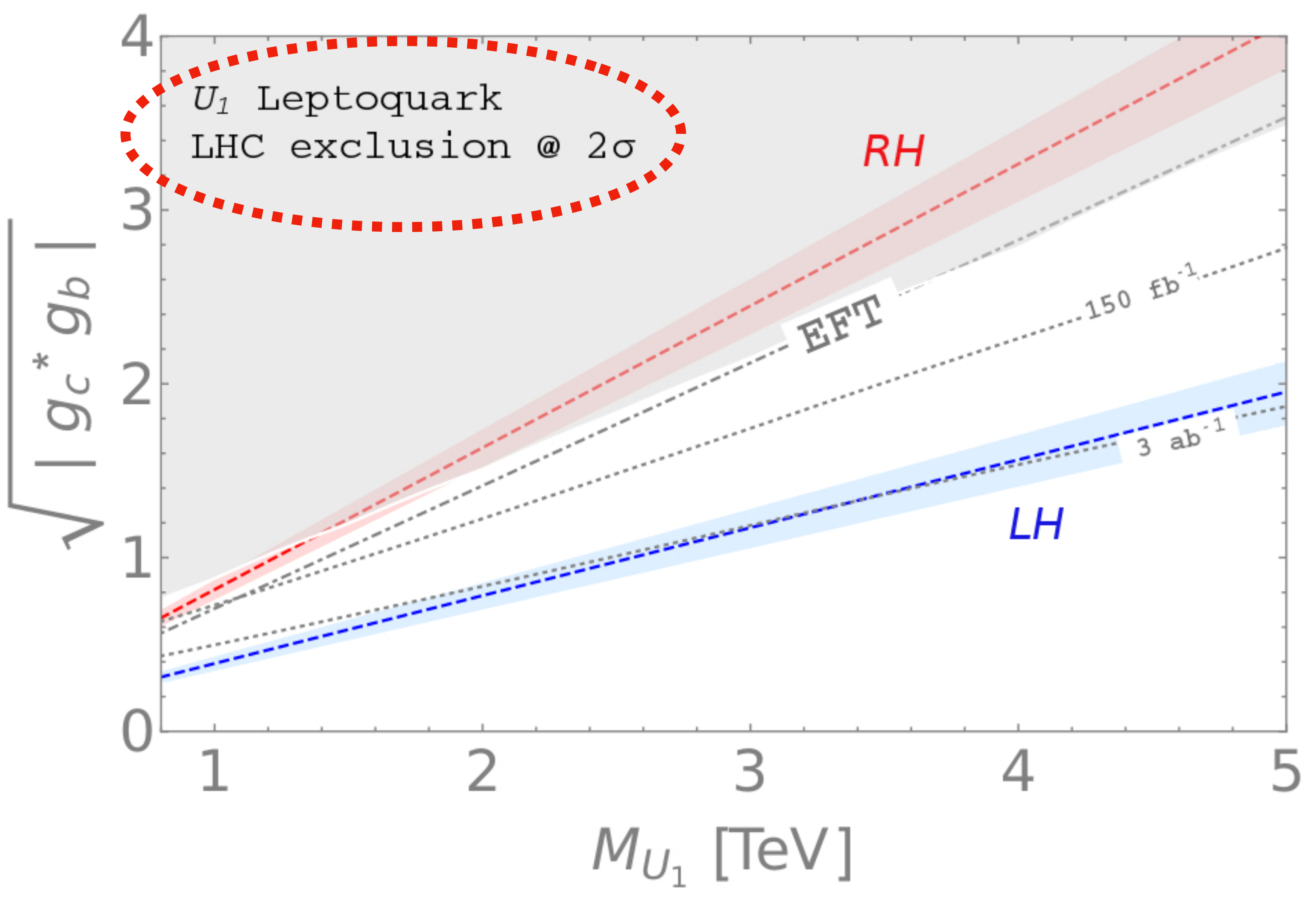
Mono-τ Signatures at the LHC Constrain Explanations of B-decay Anomalies

Admir Greljo (CERN), Jorge Martin Camalich (CERN and IAC, La Laguna and Laguna U., Tenerife), José David Ruiz-Álvarez (Antioquia U.)

Nov 19, 2018

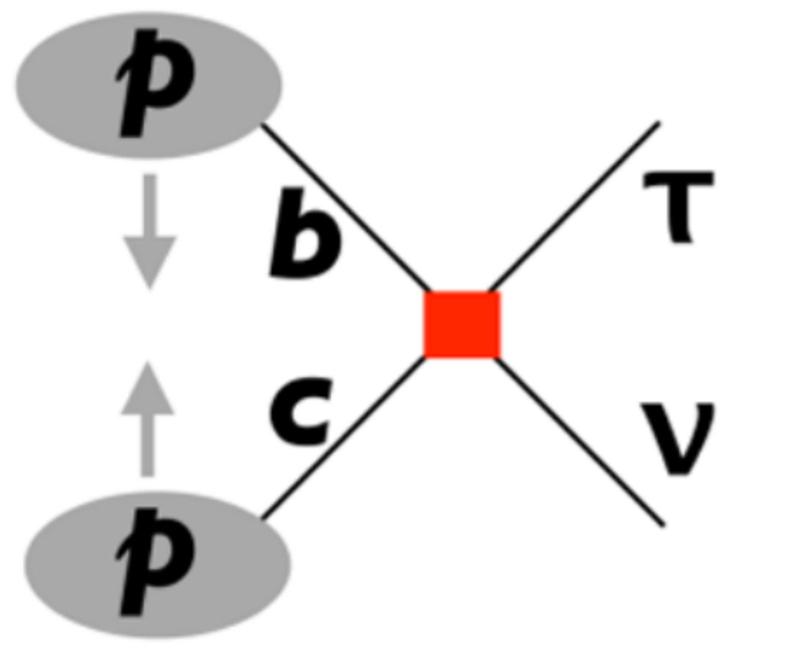
7 pages
Published in: *Phys.Rev.Lett.* 122 (2019) 13, 131803
Published: Apr 6, 2019
e-Print: 1811.07920 [hep-ph]
DOI: 10.1103/PhysRevLett.122.131803
View in: CERN Document Server, ADS Abstract Service

pdf cite claim reference search 135 citations



- **U_1 leptoquark model**

$$\mathcal{L}_{U_1} = -(D_\mu U_{1\nu} - D_\nu U_{1\mu})^\dagger (D^\mu U_1^\nu - D^\nu U_1^\mu) + M_{U_1}^2 \, U_{1\mu}^\dagger U_1^\mu + [g_c(\bar{c}\gamma^\mu P_L \nu_\tau)U_{1\mu}^\dagger + g_b(\bar{b}\gamma^\mu P_L \tau)U_{1\mu}^\dagger + \text{h.c.}]$$



- **full workflow, including event generation for the signal process pp → τν, showering and hadronization, detector simulation with ATLAS and CMS configurations, experiment-specific event selection, and the extraction of the exclusion contour by comparing the resulting signal templates with published LHC data in a profile-likelihood analysis.**

3. Constraints on U_1 LQ from LHC mono-τ search

1. Target

Considering the U_1 Leptoquark Model described in this document, plot the 2σ exclusion contour for the U_1 leptoquark in the $(\sqrt{|g_c^* g_b|},\, M_{U_1})$ plane, with some other lines and bands.

---

2. U_1 Leptoquark Model

In this section, the U_1 Leptoquark Model is introduced.

2.1 Lagrangian

$$\mathcal{L}_{U_1} = -(D_\mu U_{1\nu} - D_\nu U_{1\mu})^\dagger (D^\mu U_1^\nu - D^\nu U_1^\mu) + M_{U_1}^2\, U_{1\mu}^\dagger U_1^\mu + \left[g_c(\bar{c}\gamma^\mu P_L \nu_\tau)U_{1\mu}^\dagger + g_b(\bar{b}\gamma^\mu P_L \tau)U_{1\mu}^\dagger + \text{h.c.}\right]$$

Here,

- U_1 is a vector leptoquark beyond the SM. It is a new gauge boson carrying color triplet, $SU(2)_L$ singlet, and electric charge $Q = 2/3$.
- D_μ is the covariant derivative of the SM gauge fields.

2.2 Parameters

The free parameters are:

- M_{U_1} is the mass of U_1.
- g_c and g_b are the couplings of U_1 to c and b quarks, respectively. Both of them are real.

3. Constraints on U_1 LQ from LHC mono-τ search

1. Target

3. Collider Simulation

3.1 Process

$$pp \to \tau\nu$$

which is mediated by the U_1 vector leptoquark. Since the U_1 leptoquark couples to b and c quarks, the initial-state b and c partons from the proton PDF must be included.

3.2 Collider simulation settings
We have two runs. For each run,

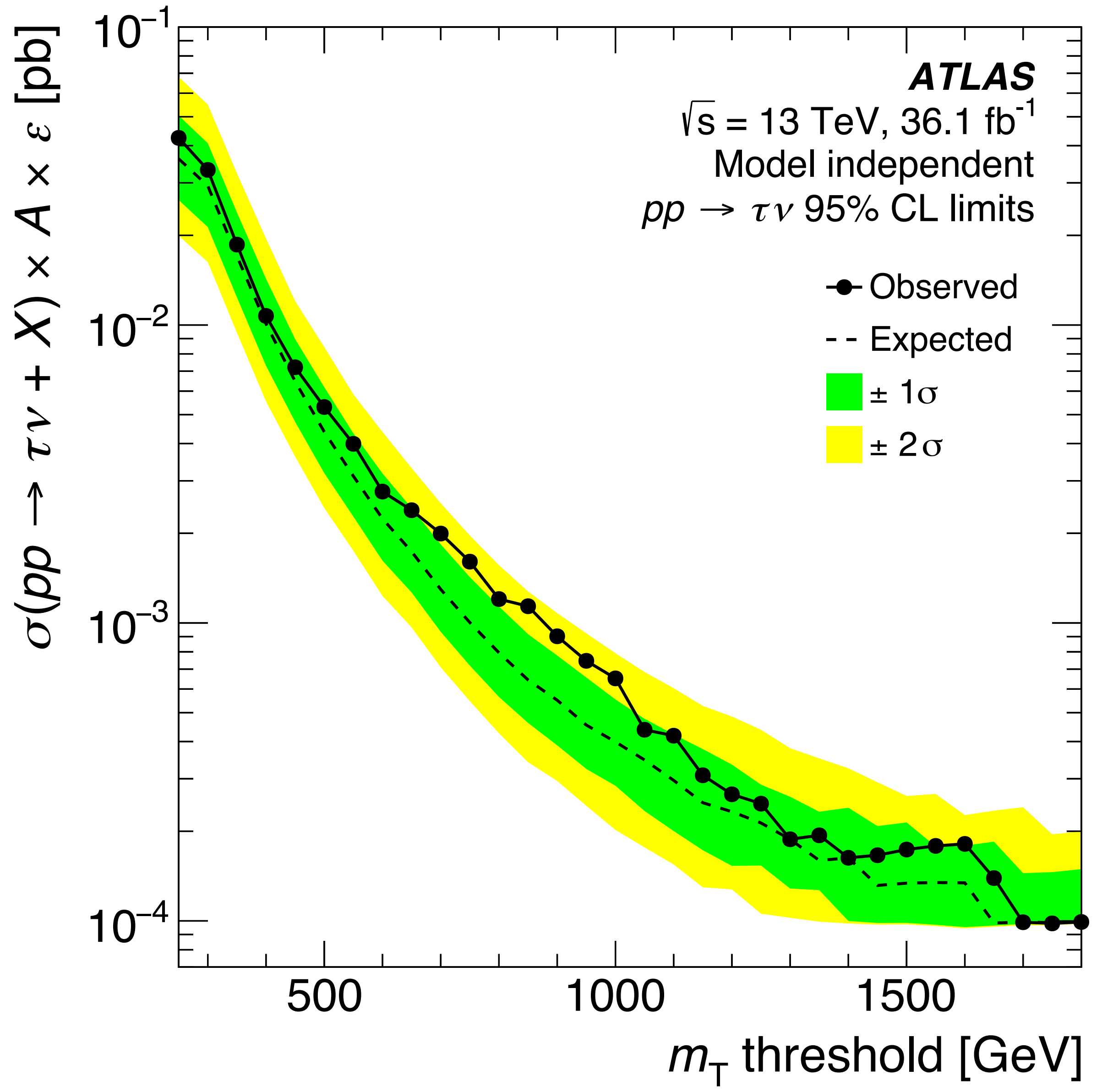
- collider: 13 TeV LHC
- event number: 10000
- parton shower: Pythia8
- perform mass scan for M_{U_1} masses: 750, 1000, 1250, 1500, 2000, 2500, 3000, 4000, 5000 GeV
- output format for reconstructed events: LHCO
- comment: decay width of LQ is not relevant, since only the t-channel contribution exists.

Run 1 (with ATLAS detector simulation):

- detector simulation: Delphes ATLAS card

Run 2 (with CMS detector simulation):

- detector simulation: Delphes CMS card



3. Constraints on U_1 LQ from LHC mono-τ search

1. Target

3. Collider Simulation

4 Numerical Analysis

4.1 Experimental data

Binned m_T distribution from ATLAS and CMS are given below.

ATLAS

- Stored as `analysis/hepdata/table1.yaml`
- 22 bins from 250 to 3200 GeV (log-spaced)
- Columns: observed events n_i, SM background b_i, symmetric error δb_i

CMS

The experimental data is given below:

m_T bin (GeV)	n_{obs}	b_{SM}	δb
320–500	1203	1243	160
500–1000	452	485	77
1000–3200	15	23.4	6.2

4.2 Simulated signal events

In this section, the expected signal events in each bin are calculated.

step 1: event selection

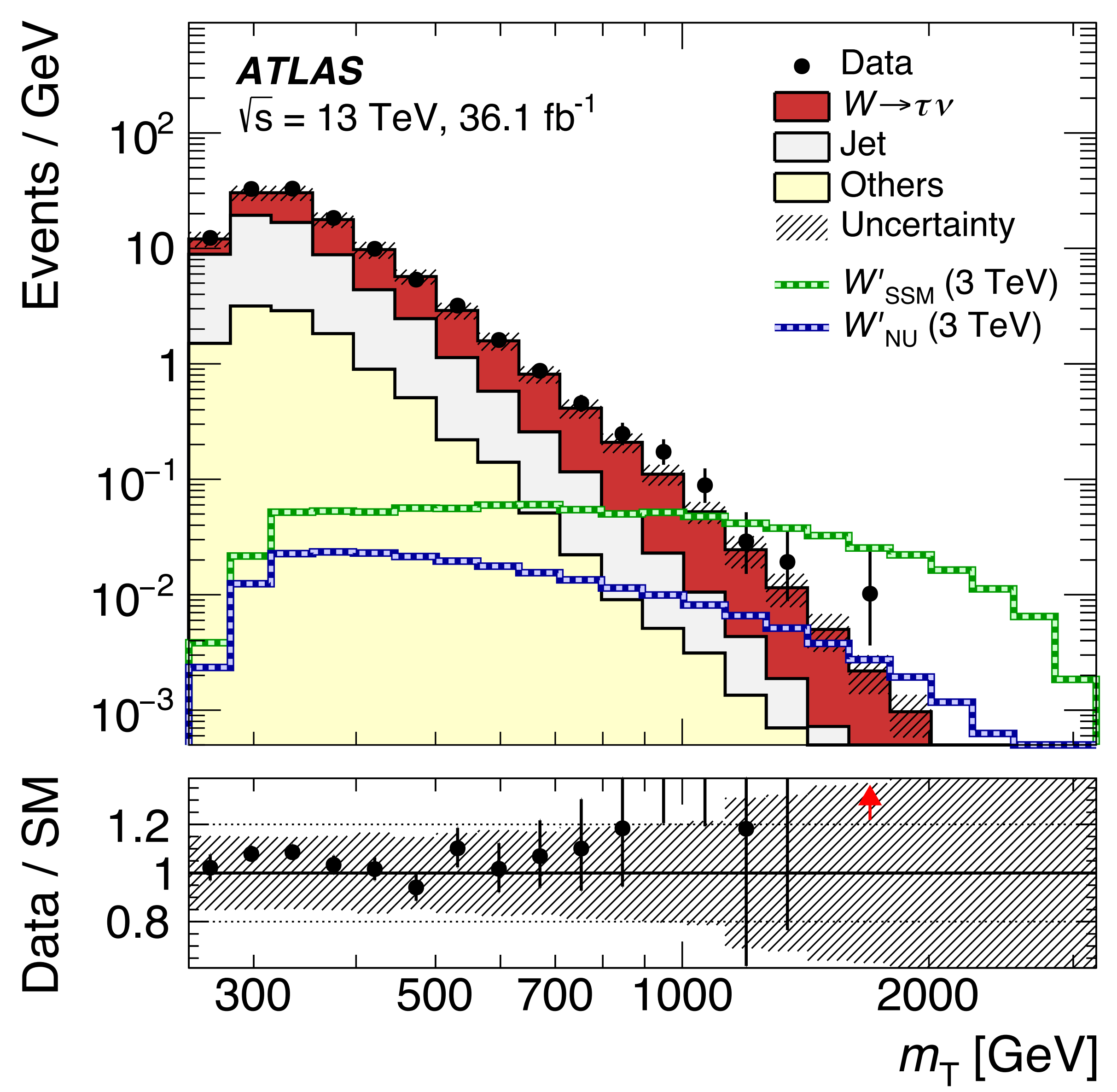
Read the reconstructed events from the simulation output and apply experiment-specific selections.

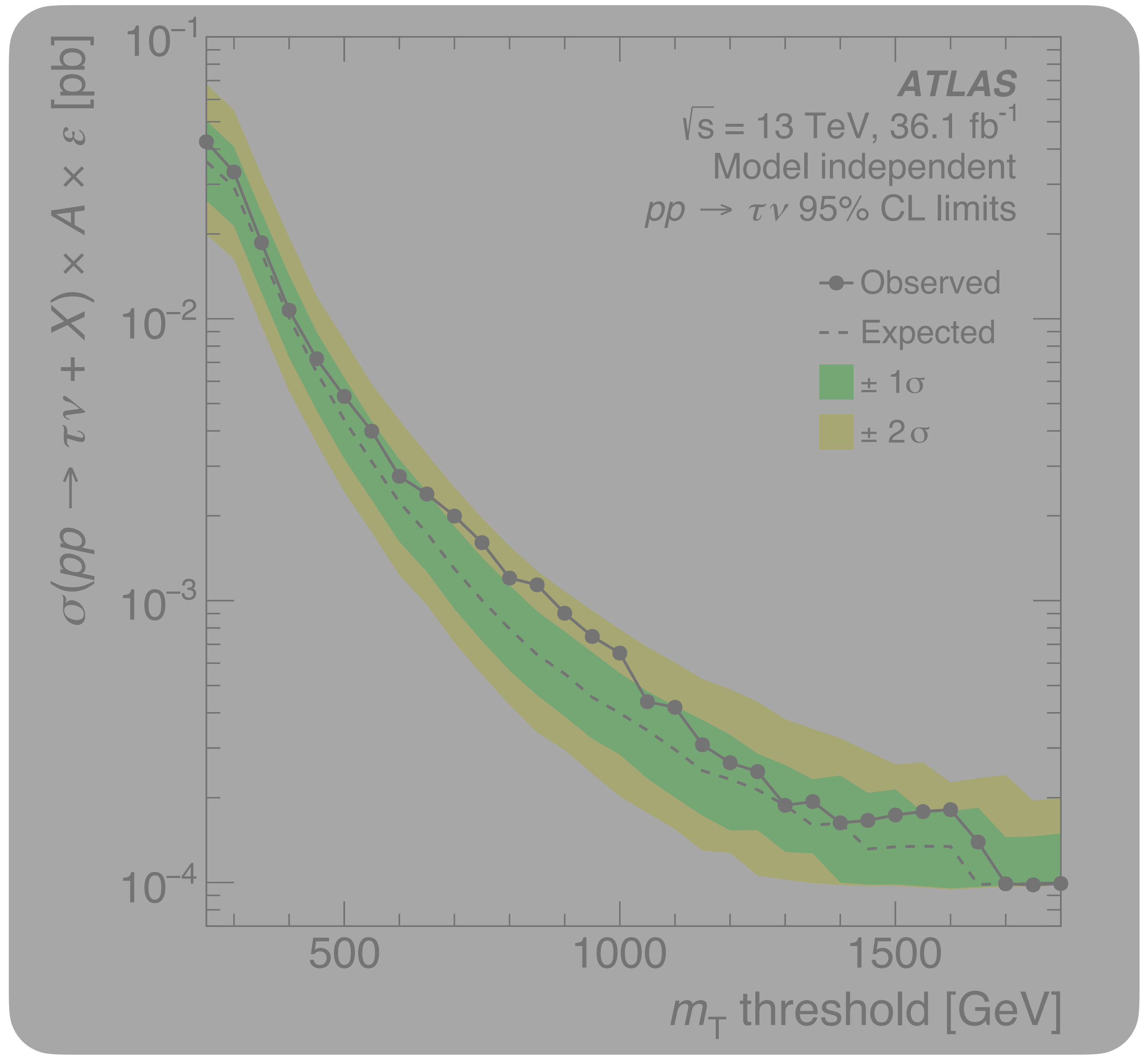
ATLAS selection

- Lepton veto: no electrons or muons
- ≥ 1 hadronic tau with $p_T > 80$ GeV, $|\eta| < 2.3$
- $E_T^{\text{miss}} > 150$ GeV
- $m_T > 250$ GeV, with $m_T = \sqrt{2p_T^\tau E_T^{\text{miss}}(1 - \cos\Delta\phi)}$

CMS selection

- Lepton veto: no electrons or muons
- ≥ 1 hadronic tau with $p_T > 80$ GeV, $|\eta| < 2.1$
- $E_T^{\text{miss}} > 200$ GeV





3. Constraints on U_1 LQ from LHC mono-τ search

1. Target

3. Collider Simulation

4 Numerical Analysis

step 2: signal template construction
For events passing selection, histogram m_T into ATLAS or CMS bins.

$$s_i^{(g=1)} = \frac{N_i^{\text{pass}}}{N_{\text{gen}}} \times \sigma(g=1) \times \mathcal{L}$$

where

- N_{gen} is the number of reconstructed events
- $\sigma(g=1)$ is the cross section at coupling $g=1$
- $\mathcal{L}$ is the luminosity (36.1 fb^{-1} ATLAS, 35.9 fb^{-1} CMS)

Signal scaling: $s_i(g) = g^4 s_i^{(g=1)}$

3.3 Profile likelihood analysis
For each bin,

$$-\ln L_i(\theta_i) = -\left[n_i \ln \mu_i - \mu_i\right] + \frac{1}{2}\frac{\theta_i^2}{(\delta_i/b_i)^2}$$

where

- n_i observed events
- b_i expected SM background
- δ_i systematic uncertainty
- θ_i nuisance parameter
- $s_i(g) = g^4 s_i^{(g=1)}$
- $\mu_i = b_i(1+\theta_i) + s_i$

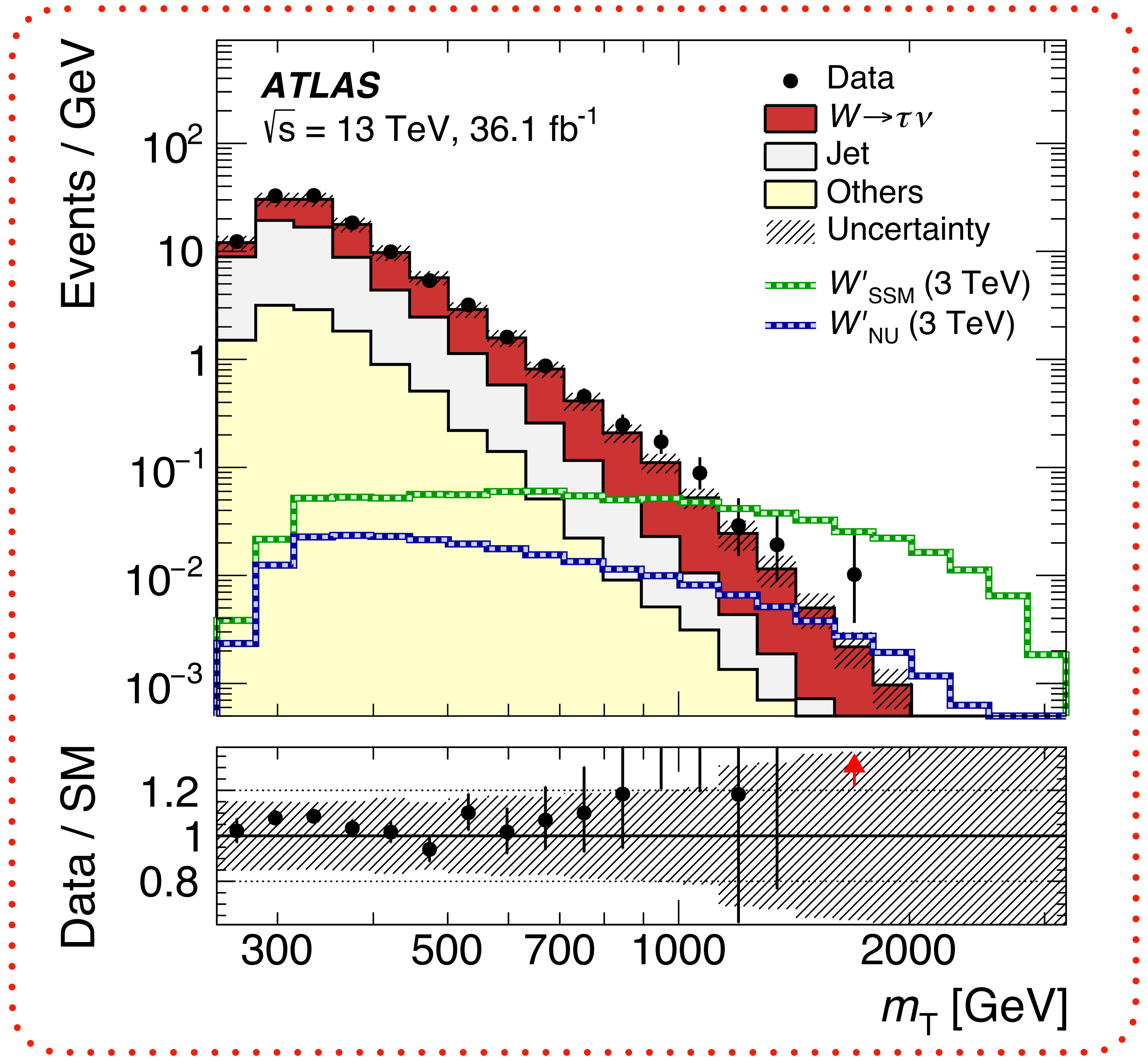
Procedure to find the 2σ exclusion contour
step 1 profiling: Minimize $-\ln L_i(\theta_i)$ numerically with constraint $\mu_i > 0$.

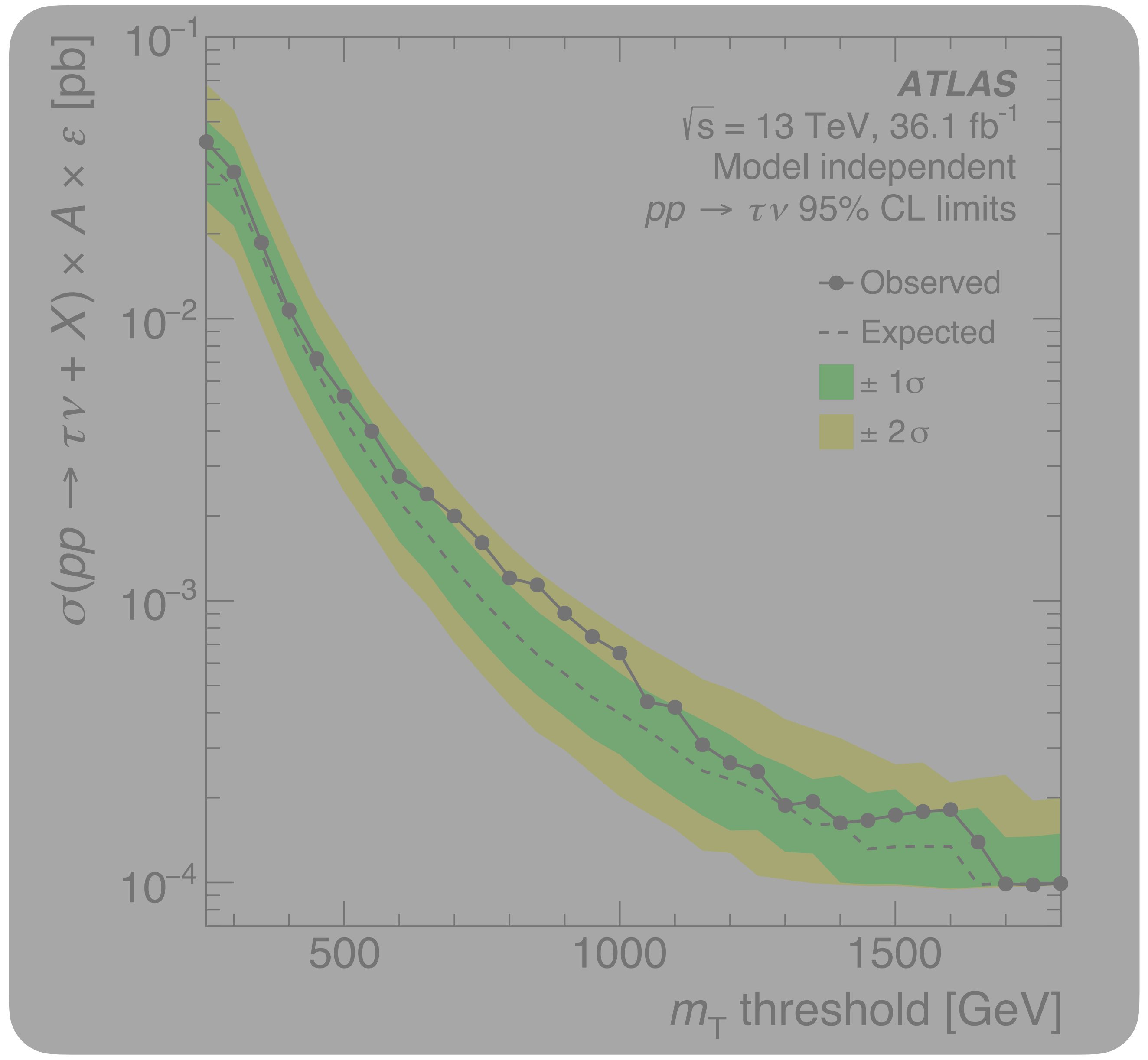
step 2 combine ATLAS + CMS Likelihood: $\ln \mathcal{L}_{\text{comb}} = \ln \mathcal{L}_{\text{ATLAS}} + \ln \mathcal{L}_{\text{CMS}}$

step 3 extract exclusion region:

1. Find best-fit $\hat{g}$
2. Find the exclusion curve by considering g_{excl} satisfying $-2\left[\ln \mathcal{L}(g_{\text{excl}}) - \ln \mathcal{L}(\hat{g})\right] = 4$

3.4 Plot Figure





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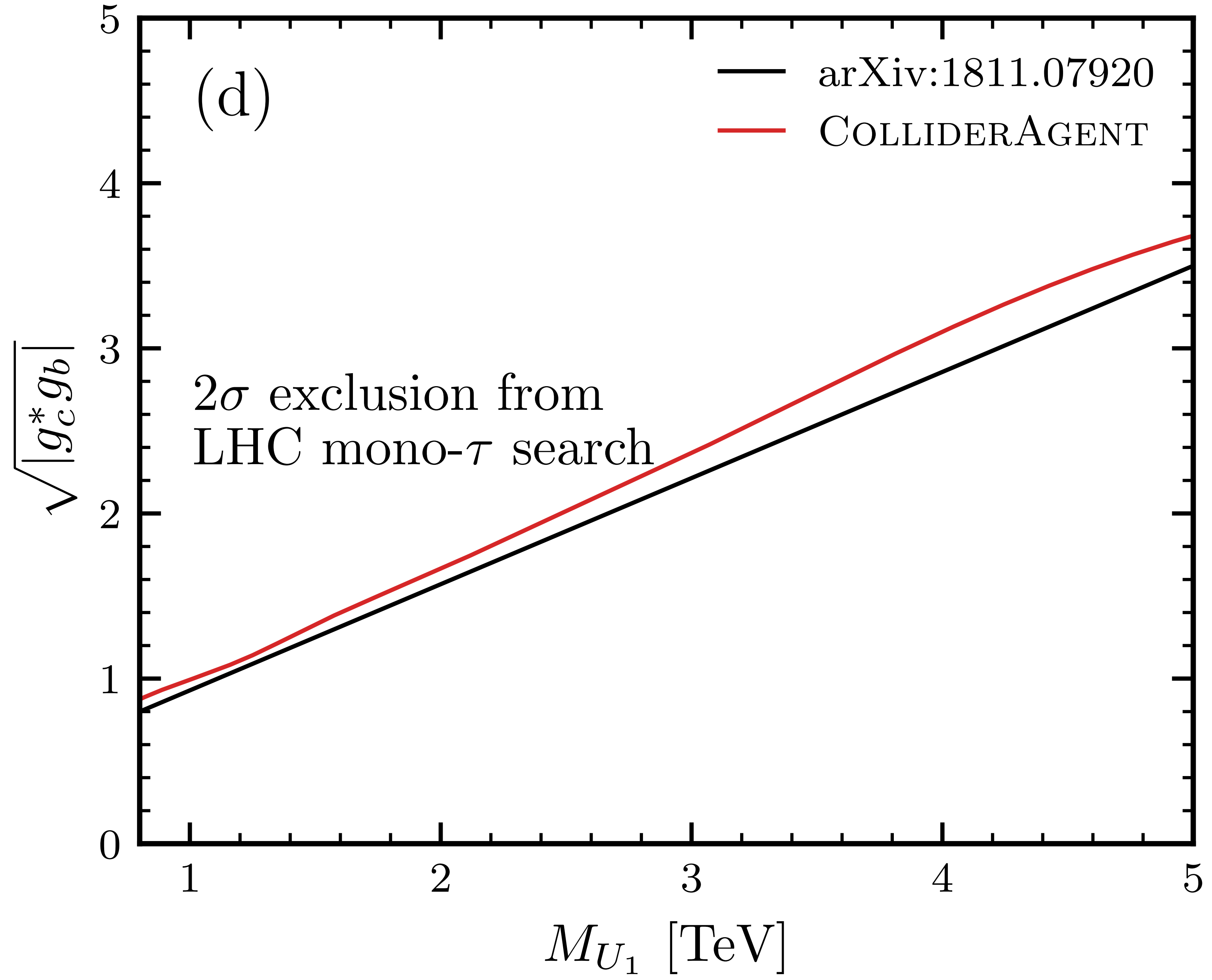
3.4 Plot Figure



4. Parameter scan in a minimal $U(1)_{B-L}$ model

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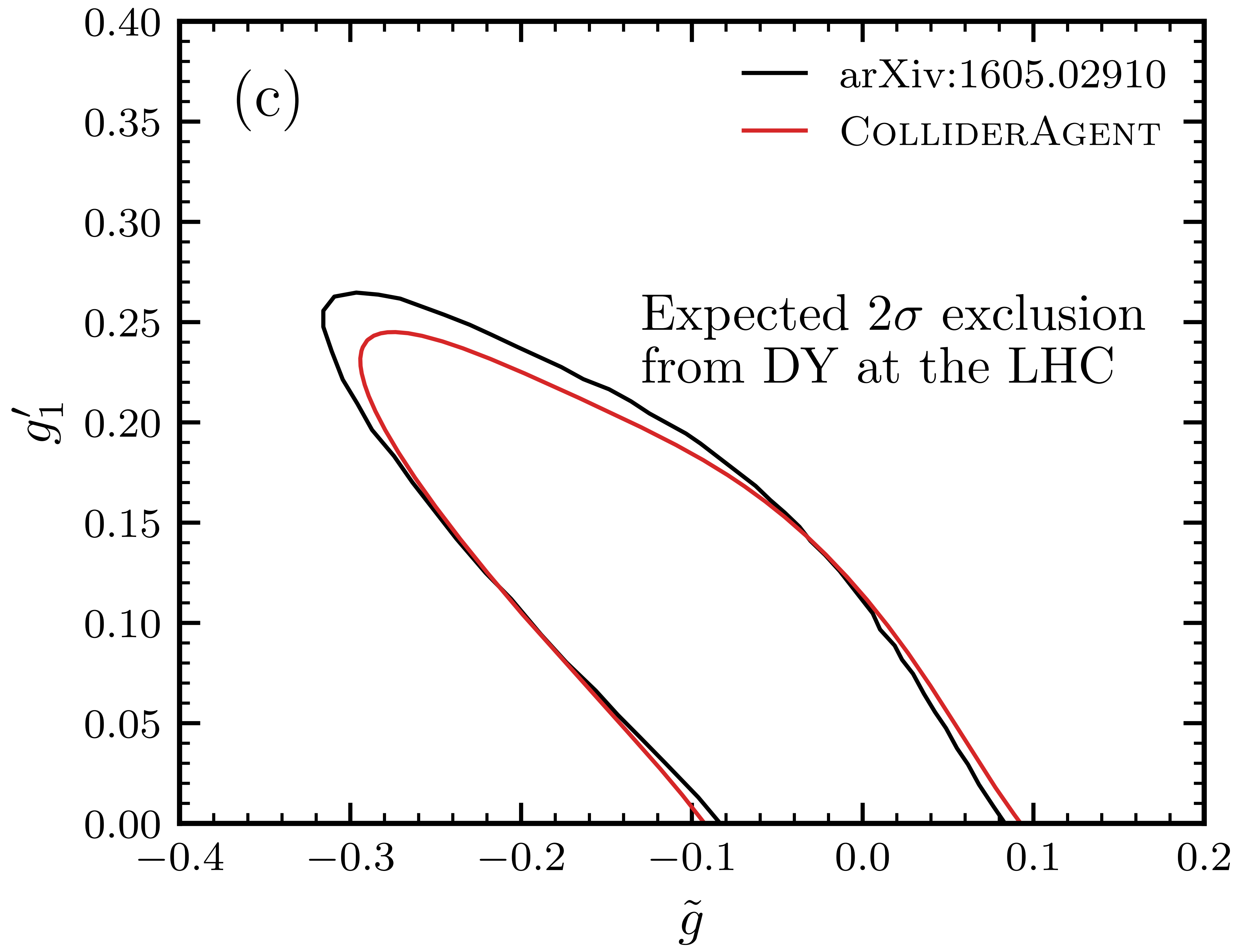
Z', Higgses and heavy neutrinos in $\mathrm{U}(1)'$ models: from the LHC to the GUT scale

Elena Accomando,[a] Claudio Corianò,[b,c] Luigi Delle Rose,[a] Juri Fiaschi,[a] Carlo Marzo[c] and Stefano Moretti[a]



Parameter Scan

Part of the Lagrangian

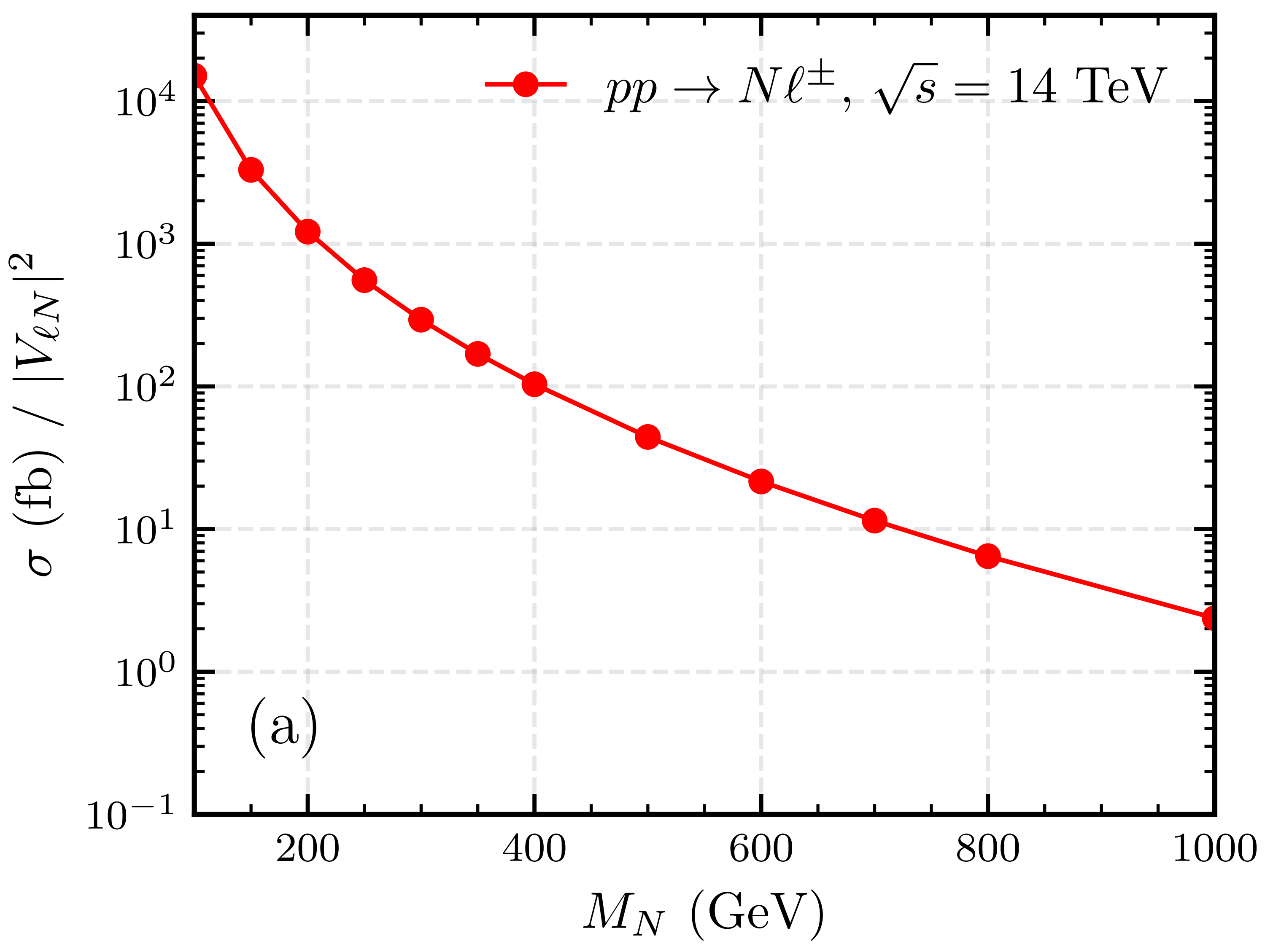
$$\mathcal{L}_{Z'ff} = \sum_f Z'_\mu \bar{f}\gamma^\mu (C_{f,L}P_L + C_{f,R}P_R) f$$

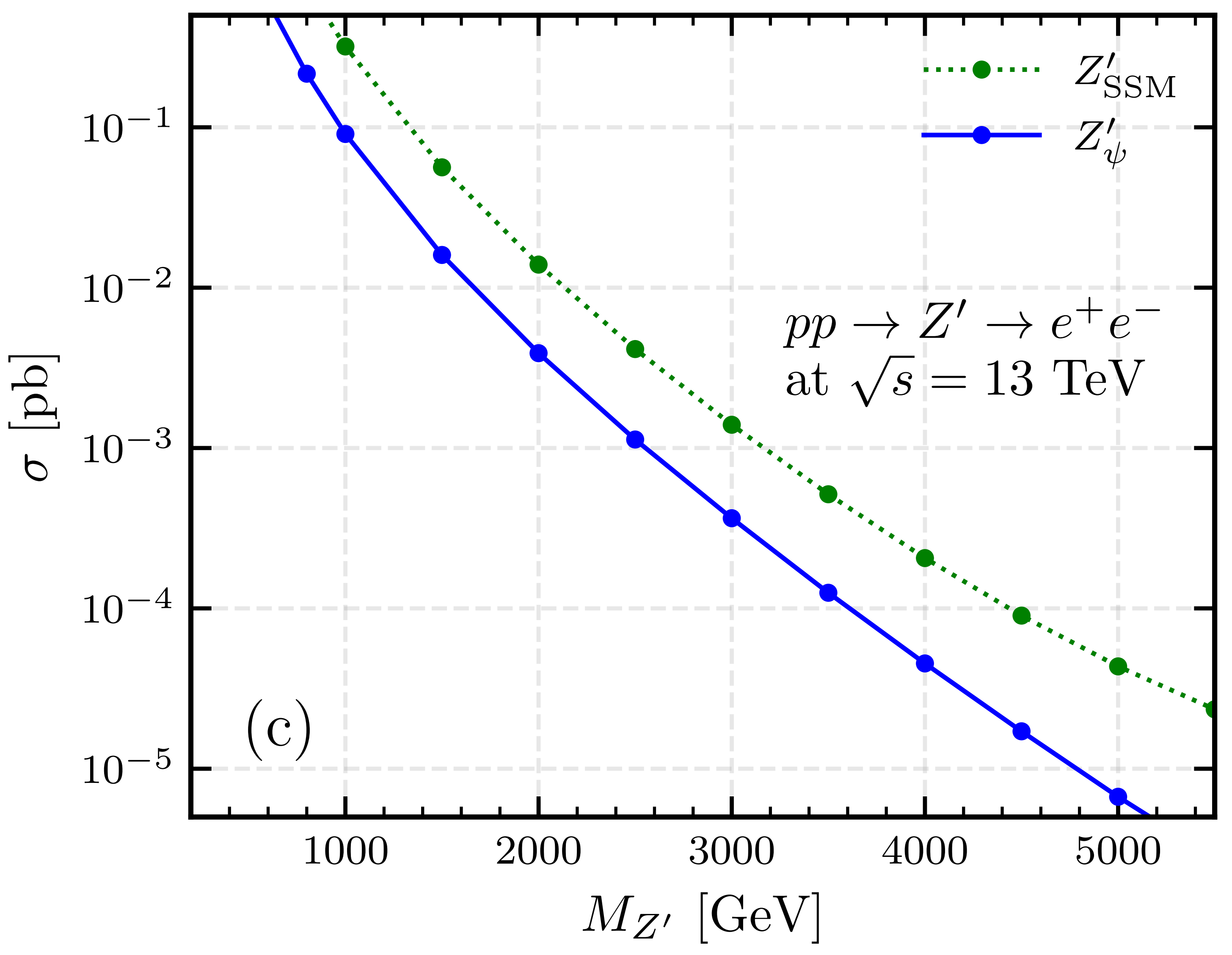
$$C_{f,L} = -e\frac{\sin\theta'}{\sin\theta_W \cos\theta_W}(T^3_f - \sin^2\theta_W Q_f) + (\tilde{g}Y_{f,L} + g'_1 z_f)\cos\theta'$$

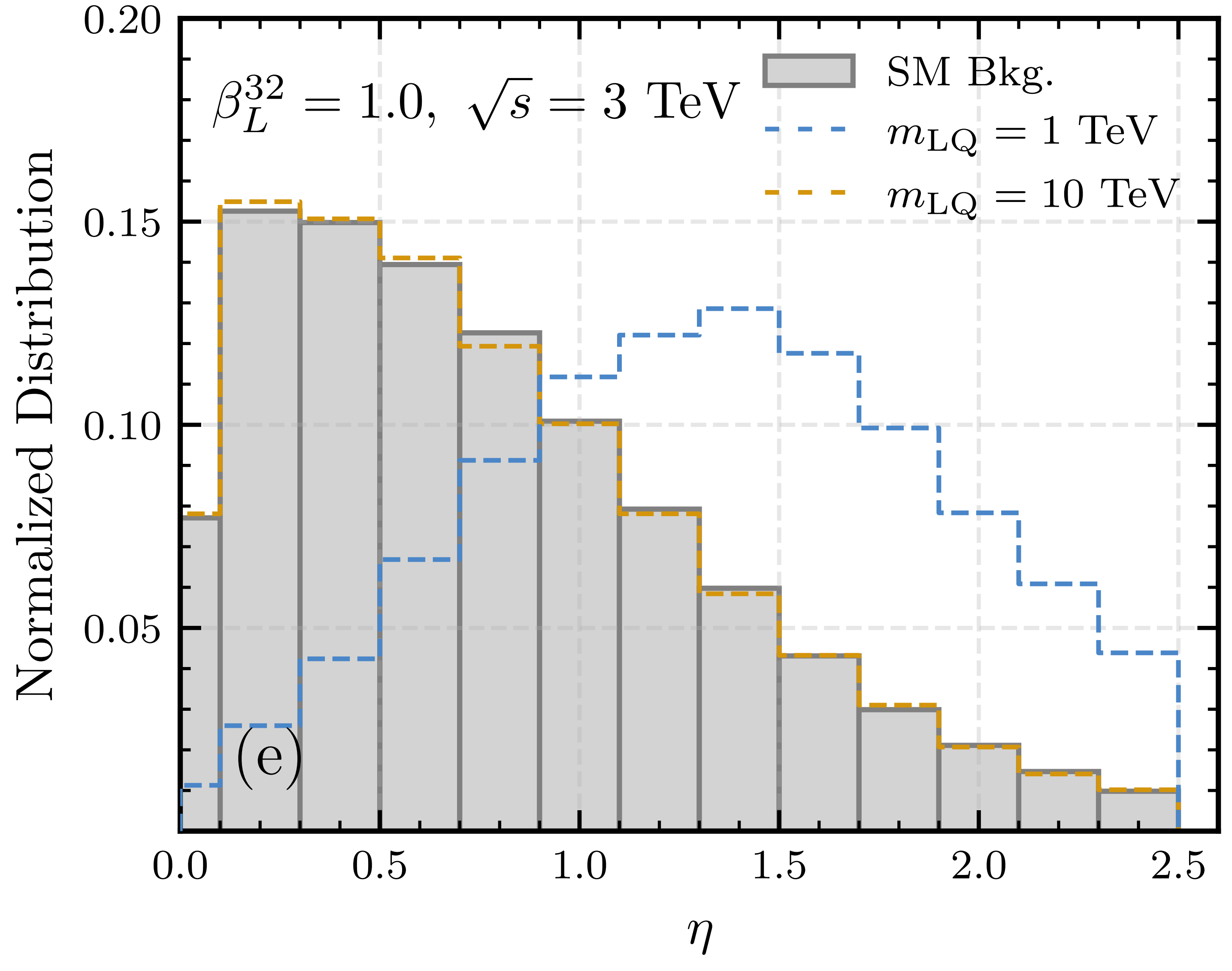
$$C_{f,R} = e\frac{\sin\theta_W \sin\theta'}{\cos\theta_W} Q_f + (\tilde{g}Y_{f,R} + g'_1 z_f)\cos\theta'$$

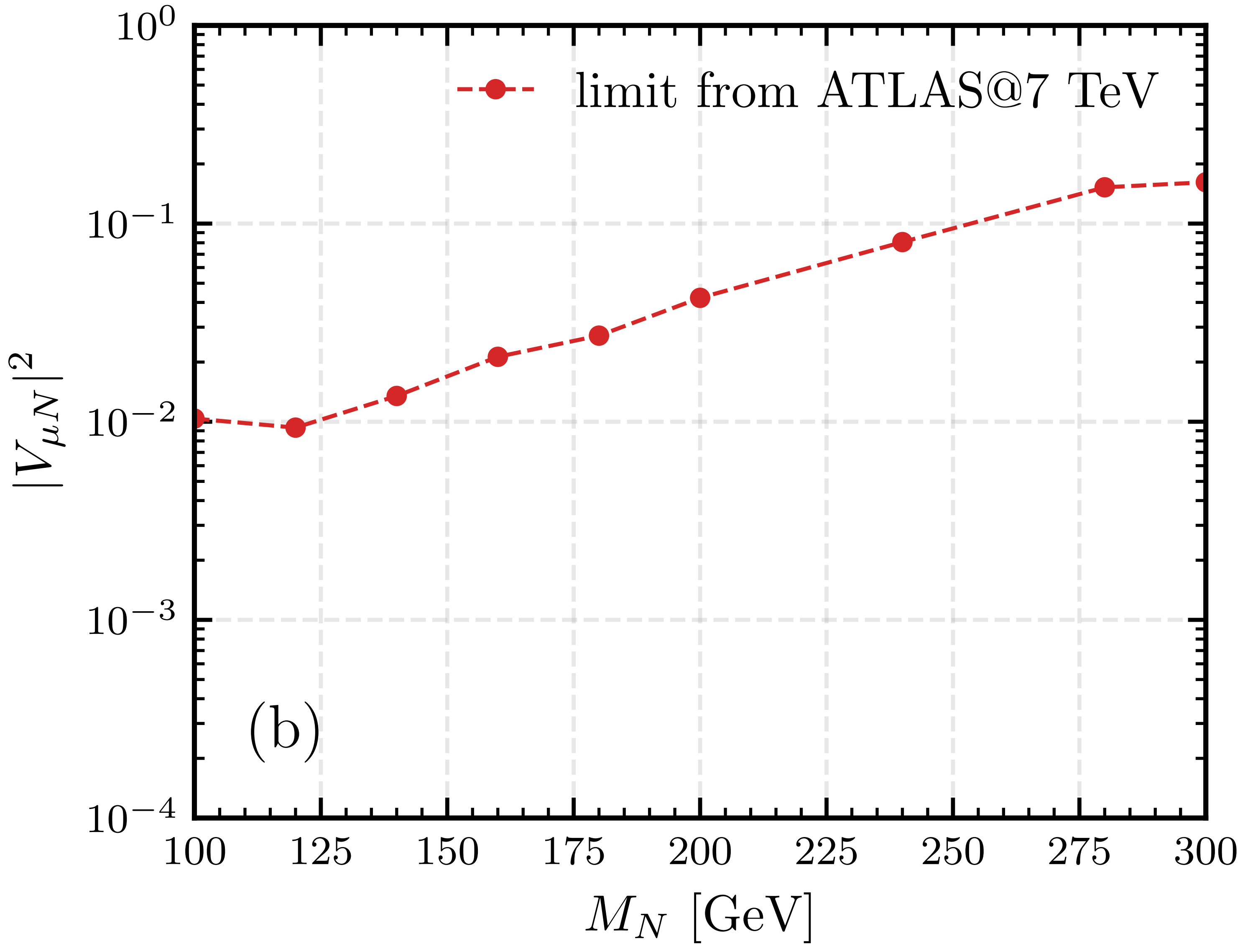
Other examples

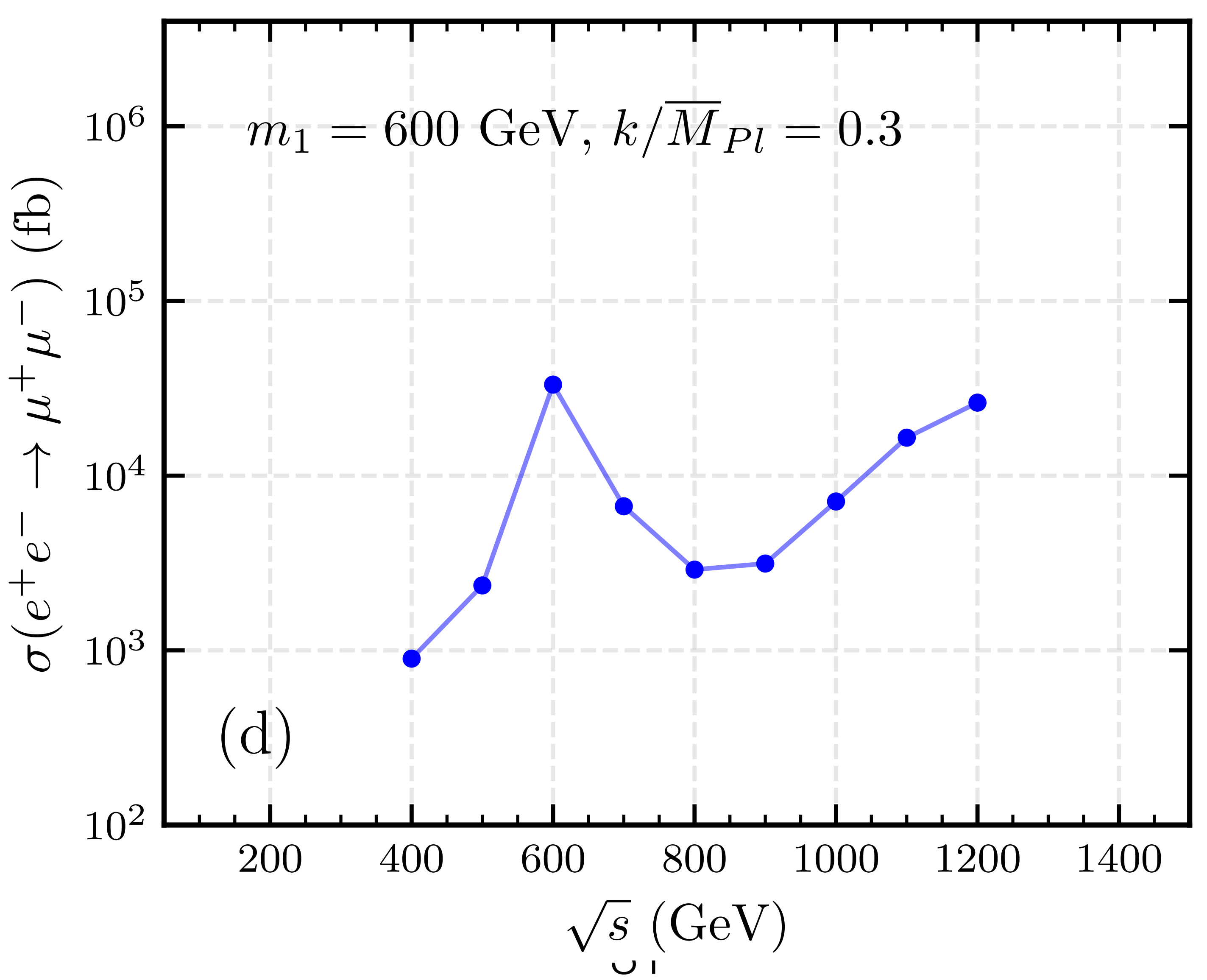
(a, b) P. S. B. Dev, A. Pilaftsis, and U.-k. Yang, arXiv: 1308.2209
(c) CMS, arXiv: 2103.02708
(d) H. Davoudiasl, J. L. Hewett, and T. G. Rizzo, hep-ph/9909255
(e, f) P. Asadi, R. Capdevilla, C. Cesarotti, and S. Homiller, arXiv: 2104.05720

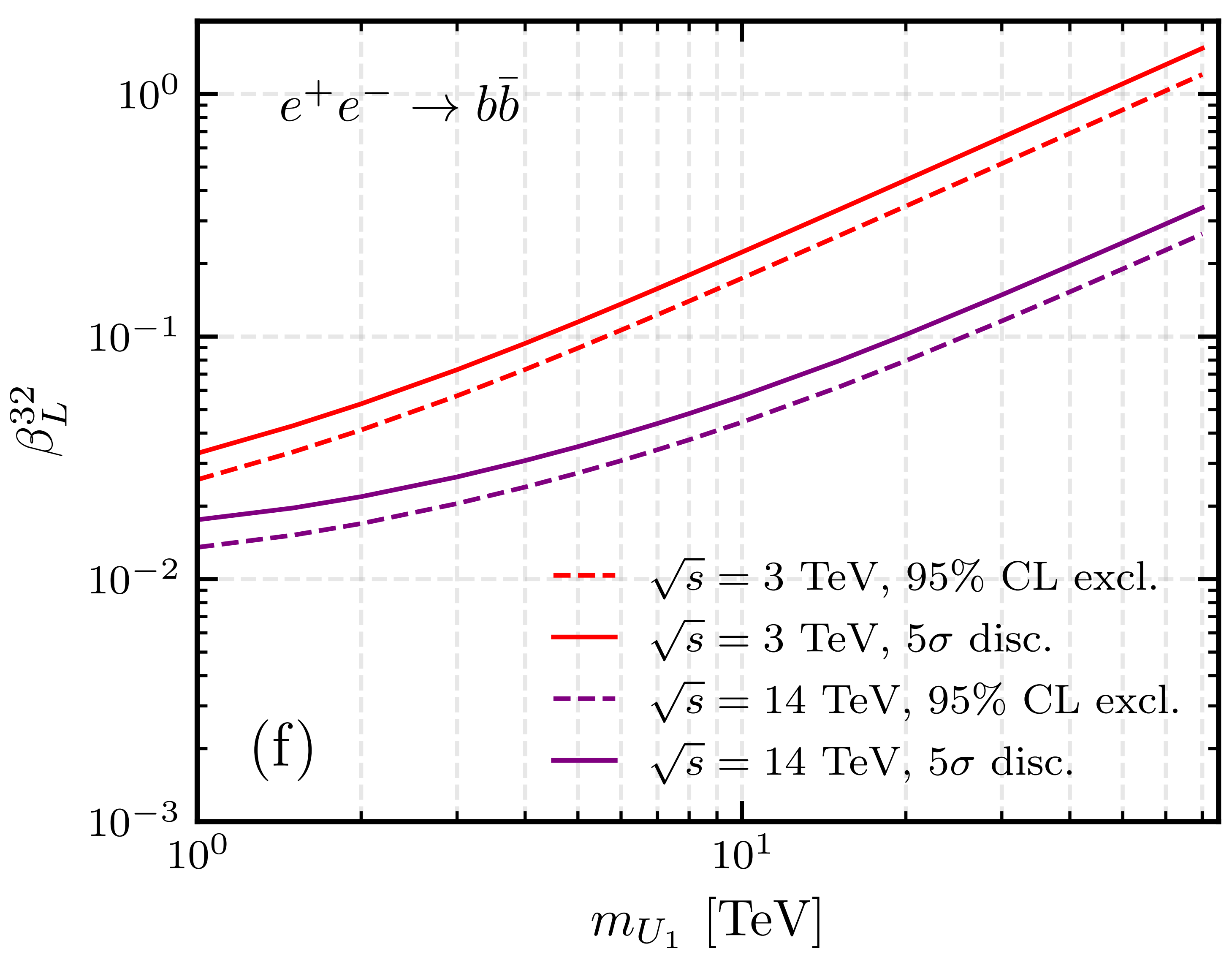












我们这套架构还能做什么？

- 暗物质：micrOMEGAs，DDCalc，DRAKE，……
- 味物理：MatchETE，MatchMakerEFT，DsixTools，Flavio，EOS，……
- 圈图计算：QGRAF，FIRE，KIRA，AMFlow，Libra，……
- 引力波：ELENA，CosmoTransitions，BSMPT，……

以及更一般的物理领域！

如果有好的想法也欢迎联系我们

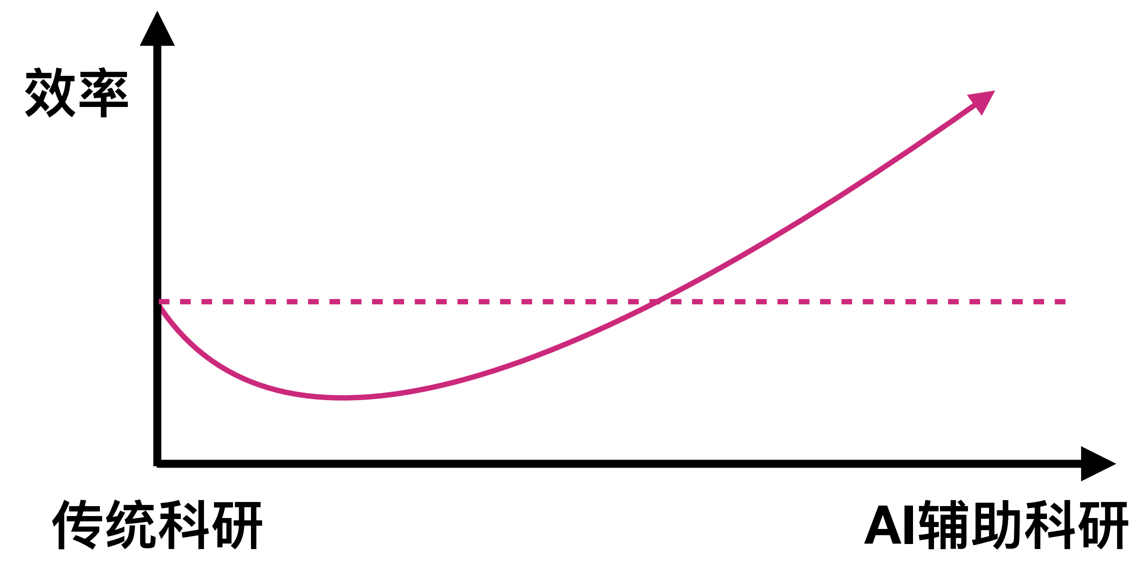
对撞机物理方面的其它相关研究

- **Tony Menzo, et al, 2512.15867**
- **Tilman Plehn, Daniel Schiller, Nikita Schmal, 2601.21015**
- **Prateek Agrawal, Nathaniel Craig, Amalia Madden, Inigo Valenzuela Lombera, 2603.22538**
- **parallel developments for agent for experiments**

总结与展望

ColliderAgent是首个仅依赖自然语言指令，即可从 Lagrangian 出发，自动推进至完整唯象学分析结果的自动化系统，成功实现了对 8 篇经典论文的端到端复现。它的智能体架构设计在其他物理领域也有巨大的应用潜力。

在目前的AI工具下，传统科研模式 ⟹ AI辅助科研 要经历一个适应过程，甚至开始时科研效率可能会下降，但经过适应期后效率会明显提高。



AI4Science何时落地（2026？ 2036？），以何种方式落地（AutoResearch？ Human in the Loop？），目前还不清楚。但从现在AI技术发展的角度来看，可以确定的是：AI4S是未来不可避免的趋势！

one more thing…

ColliderAgent

项目地址：https://github.com/HET-AGI/ColliderAgent

（安装方法，使用说明）

群聊: ColliderAgent 交流群

Multi-Agent + Skills: Claude Code
Skills: Cursor, CodeX, OpenCode, GitHub Copilot

谢谢大家！