AI for software development

Tong Liu[1], Xuliang Zhu[2], Yue Sun[1], Shenchun Wang[1],

Zhiwen Tan, Bolun Zhang[1], Ke Li[1]

[1]IHEP

[2]SJTU

[3]LNU

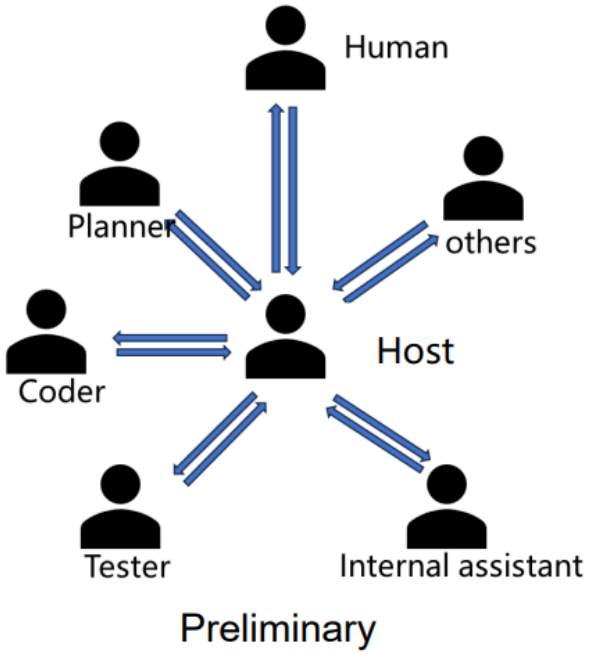
第二届粒子物理实验径迹重建研讨会 2nd workshop on Tracking in Particle Physics Experiments

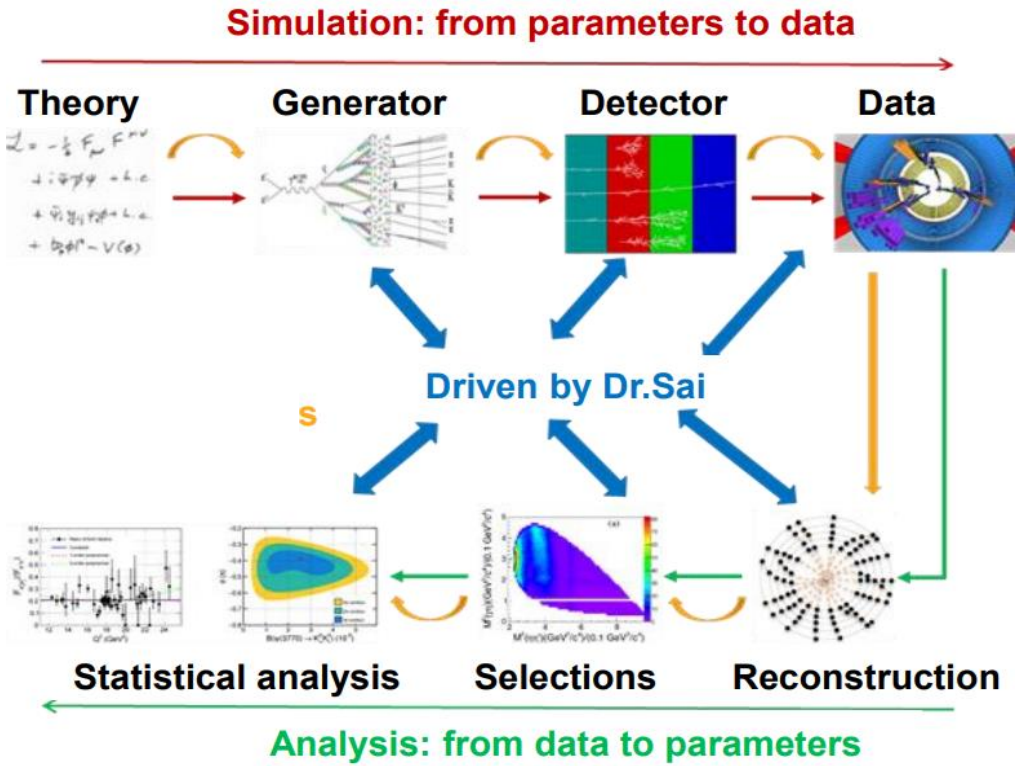
Outline

- Introduction
- Data set
- Current status
- Future
- Summary

Introduction

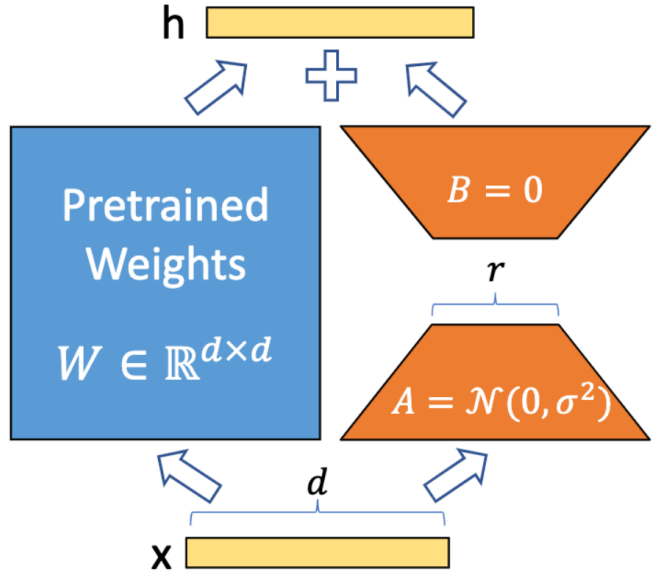
- Analysis of HEP is quite complex
  - Lots of scripts, checks, human-computer interactions
- Develop a AI system to speed up and simplify
  - Start from BESIII: Dr. Sai, a multi-agents system
  - Use LLM for text/code generation





Introduction

- As part of the auto-analysis, currently code generation is a big issue
  - ROOT code, BOSS code, …
  - To enhance code generation capabilities, perform a model fine-tuning
- We use LoRA (Low-Rank Adaptation) technology
  - An efficient technique for model fine-tuning, introduces low-rank matrices to reduce the number of parameters
  - Update the full (dxd) matrix → update A(dxr) and B(rxd)
  - Trainable parameters/full parameters = 0.01-1%
  - Performance close to the full-parameter fine-tuning



$$h = W_0 x + \Delta W x = W_0 x + BAx$$

Data set

- First focus on fit codes in CERNROOT frame: $ROOTSYS/tutorials/fit
  - The package only provide C code here
- Build training samples using deepseek-r1:671b
  - Read code, understand the functionality, remove comments
  - QA for the full code (~40 QA pairs)
  - QA for code blocks (~160 QA pairs)
  - Keep Q start with “使用CERNROOT框架” (“with CERNROOT frame”)
  - (next, generate more QA pairs with LLM)


```
 {
   "file": "line3Dfit.C",
   "comment": "使用CERNROOT框架，沿着一根三维直线产生散点数据，然后拟合得到这跟直线的参数。通过最小化每个点到直线的距离平方和来确定最佳拟合直线。将原始直线与拟合直线进行比较展示。",
   "code": "/// \\file\n/// \\ingroup tutorial_fit\n/// \\notebook\n/// Fitting of a TGraph2D with a 3D straight line\n///\n/// run this macro by doing:\n///\n/// ~~~{.cpp}\n/// root>.x line3Dfit.C+\n/// ~~~\n///\n/// \\macro_image\n/// \\macro_output\n/// \\macro_code\n///\n/// \\author Lorenzo Moneta\n\n#include <TMath.h>\n#include <TGraph2D.h>\n#include <TRandom2.h>\n#inclu
```


QA for the full code


```
 {
   "comment": "在CERNROOT框架中，定义三维直线参数方程，通过参数t生成坐标点(x,y,z)",
   "code": "void line(double t, const double *p, double &x, double &y, double &z) {\n   x = p[0] + p[1]*t;\n   y = p[2] + p[3]*t;\n   z = t;\n}"
 },
 {
   "comment": "在CERNROOT框架中，定义距离平方计算结构体，用于拟合过程中最小化点到直线的距离平方和",
   "code": "struct SumDistance2 {\n   TGraph2D *fGraph;\n\n   SumDistance2(TGraph2D *g) : fGraph(g) {}\n\n   double distance2(double x,double y,double z, const double *p) {\n      XYZVector xp(x,y,z);\n      XYZVector x0(p[0],
```


QA for code blocks

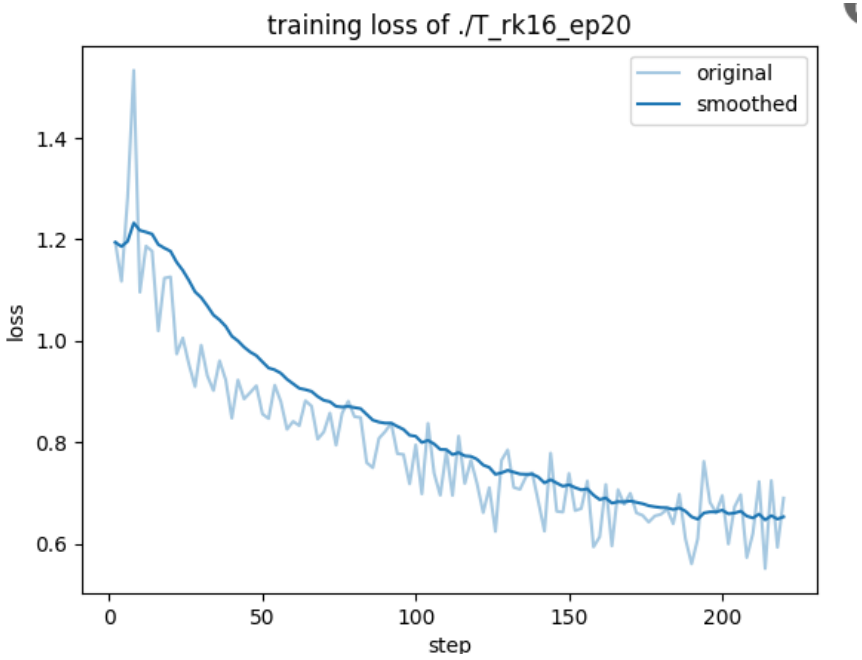
Data set

- Generate 10* code, calculate the number of times there are errors
- Test samples: a few commonly used fit tasks:
  - 1) 2D fit to 2D-Gaussian
  - 2) Linear+Gaussian, multi-range fit in sideband
  - 3) Fit to a TGraphAsymmErrors
  - 4) Fit and print C.L.s
  - 5) Simultaneous fit to sample1 (BG) and sample2 (BG+Sig)
  - 6) Fit to func⊗Gaussian

Target	Qwen2.5-7B	deepseek-r1:671b
1)	1/10	5/10
2)	2/10	3/10
3)	9/10	9/10
4)	9/10	7/10
5)	5/10	0/10
6)	10/10	6/10

Current status

- Fine-tuning with LLaMA-Factory
  - An open-source toolkit designed to simplify and accelerate the training, fine-tuning, and deployment of LLM
- Considering the current available data samples, we use Lora options:
  - Based on Qwen2.5-7B
  - Rank = 4, 8, 16
  - Epoch = 2, 5



Current status

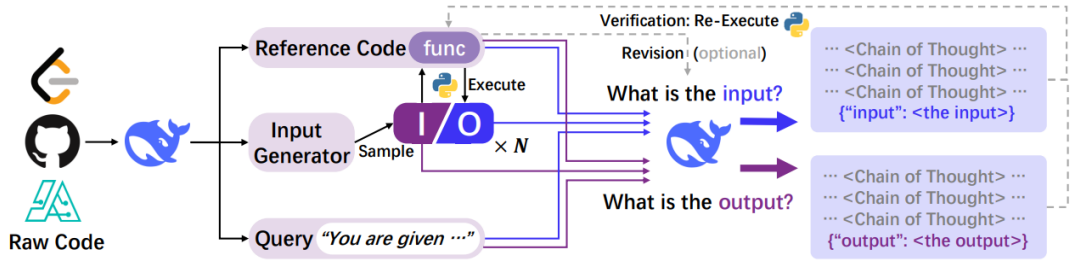
- Considering the current available data samples, we use Lora options:
  - Based on Qwen2.5-7B
  - Rank = 4, 8, 16
  - Epoch = 2, 5
- The model is improved after fine-tuning
  - Especially for complex tasks

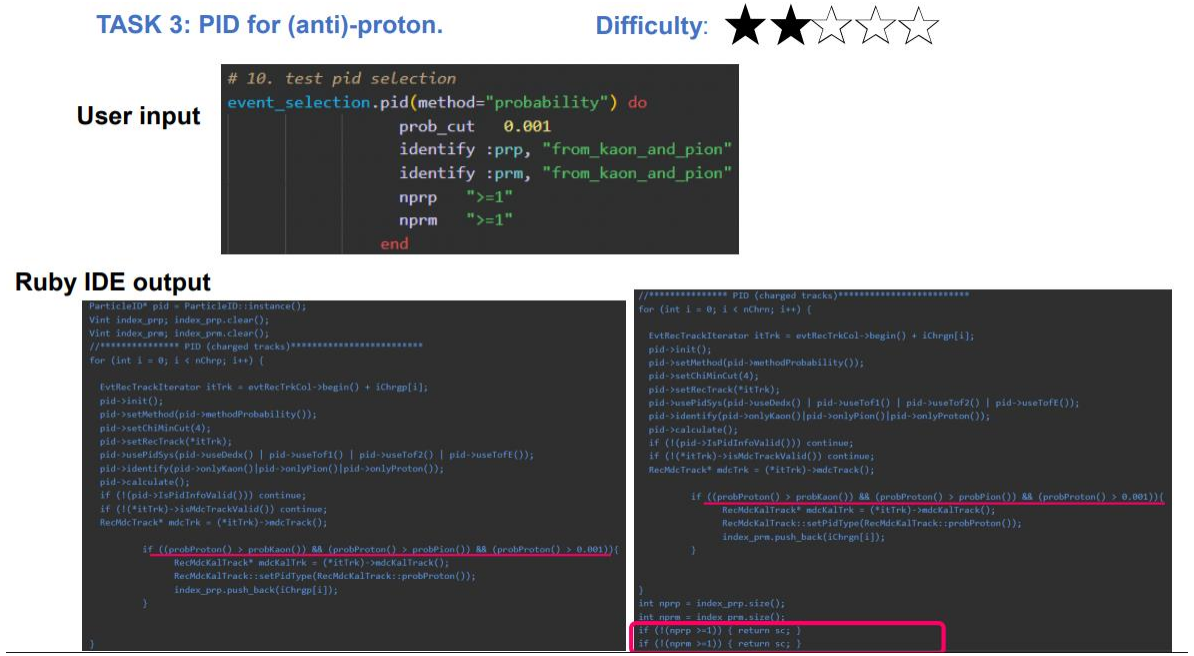
Target	Qwen2.5-7B	deepseek-r1:671b	rk4 ep2	rk4 ep5	rk8 ep2	rk8 ep5	rk16 ep2	rk16 ep5
1)	1/10	5/10	0/10	3/10	1/10	3/10	2/10	3/10
2)	2/10	3/10	4/10	1/10	4/10	2/10	4/10	6/10
3)	9/10	9/10	1/10	1/10	1/10	4/10	0/10	3/10
4)	9/10	7/10	10/10	7/10	6/10	6/10	8/10	8/10
5)	5/10	0/10	1/10	1/10	3/10	1/10	2/10	2/10
6)	10/10	6/10	4/10	8/10	7/10	8/10	3/10	4/10

Future

- CODEI/O, an approach to improve the reasoning abilities of LLMs by training them to predict code inputs and outputs in pure natural language Chain-of-Thought(CoTs)
- Domain Specific Language (DSL4BES)

[arXiv:2502.07316]





Summary

- Capabilities on code generation improves after fine-tuning
  - Optimize hyperparameters
  - There is limited tasks available, overfitting?
- We are working on generating more training samples
- Add other tasks like RooFit, BOSS code