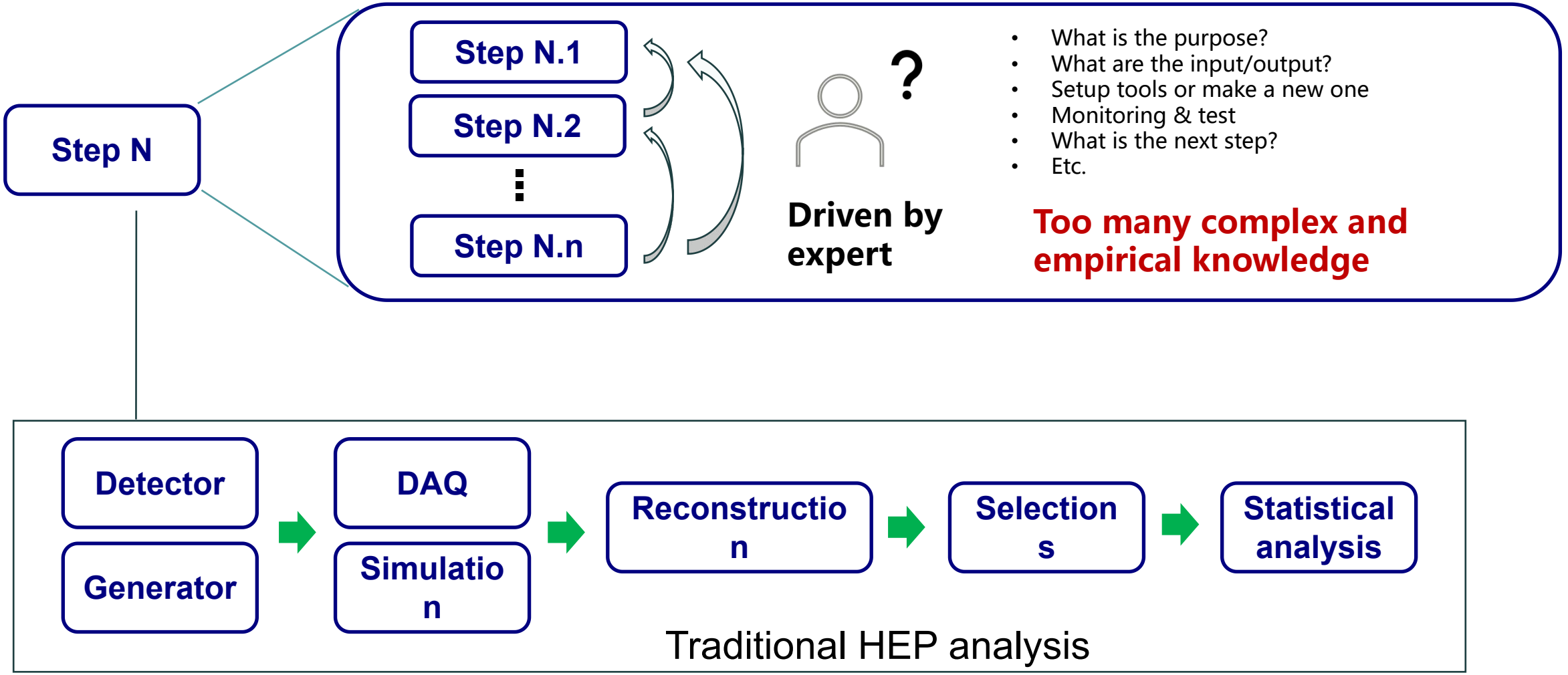
Towards automatic discovery: how can DrSai help on XYZ studies

Tong Liu for the DrSai group

Outline

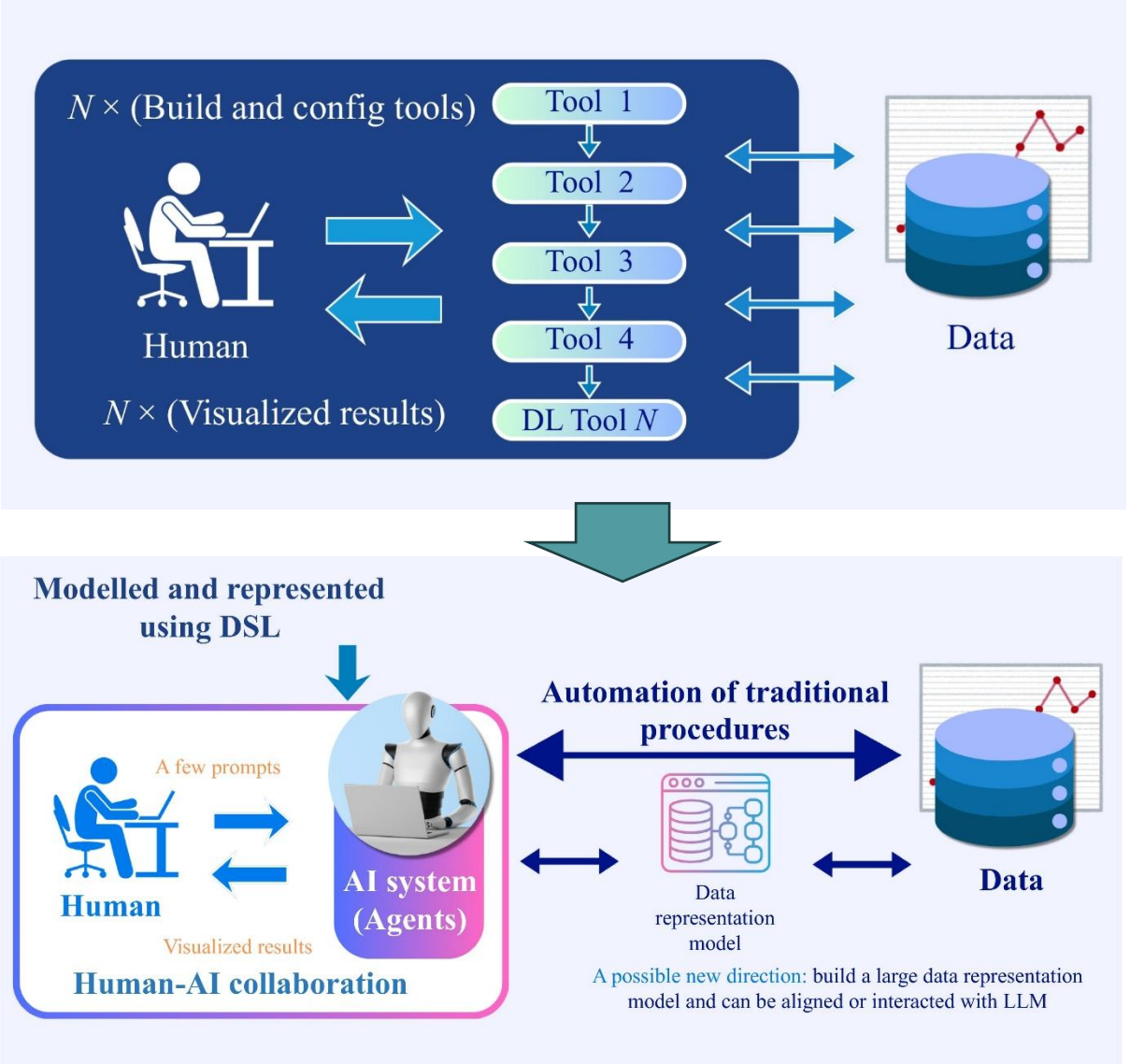
- Motivation
- History and Status of DrSai
- The first analysis with DrSai:
  - Exclusive R value measurement at 1.9 GeV
- Summary and outlook

Motivation


Step N
Step N.1
Step N.2
Step N.n
?
Driven by expert
What is the purpose?
What are the input/output?
Setup tools or make a new one
Monitoring & test
What is the next step?
Etc.
Too many complex and empirical knowledge
Detector
Generator
DAQ
Simulation
Reconstruction
Selections
Statistical analysis
Traditional HEP analysis

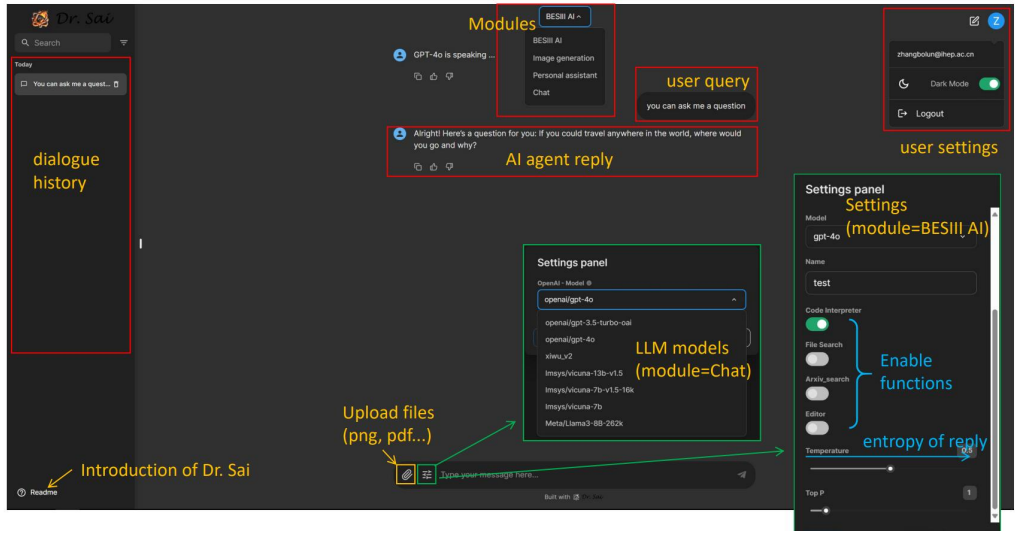
Motivation

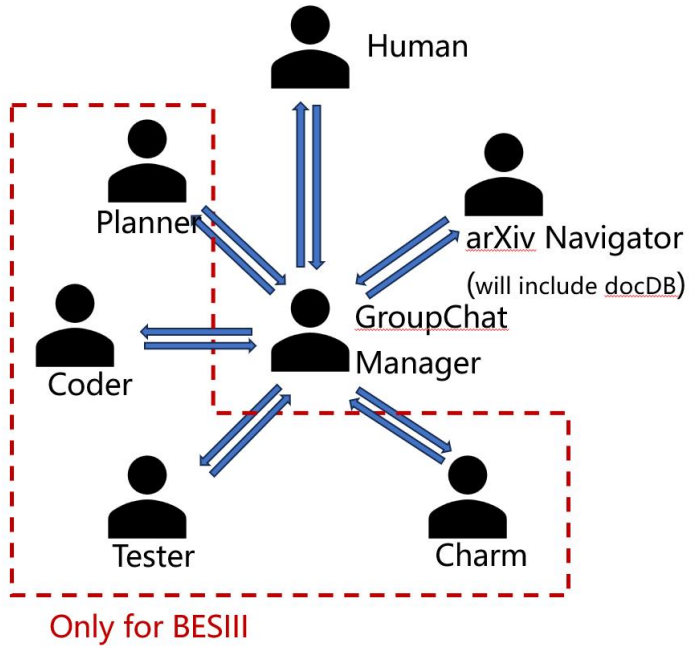
- LLM is smart enough to build an AI partner for experts
  - The AI partner designs and conducts the entire workflow based on human commands and feedback.
  - Human-AI collaboration, free humans from repetitive work
  - Make analysis more efficient



History of DrSai v1

- Developed based on open-source multi-agents framework: AutoGen.
- Deploy workers to wrap-up the tools
- Tested LLMs on intent understanding, orchestration, tool invocation, etc.
- Verified feasibility

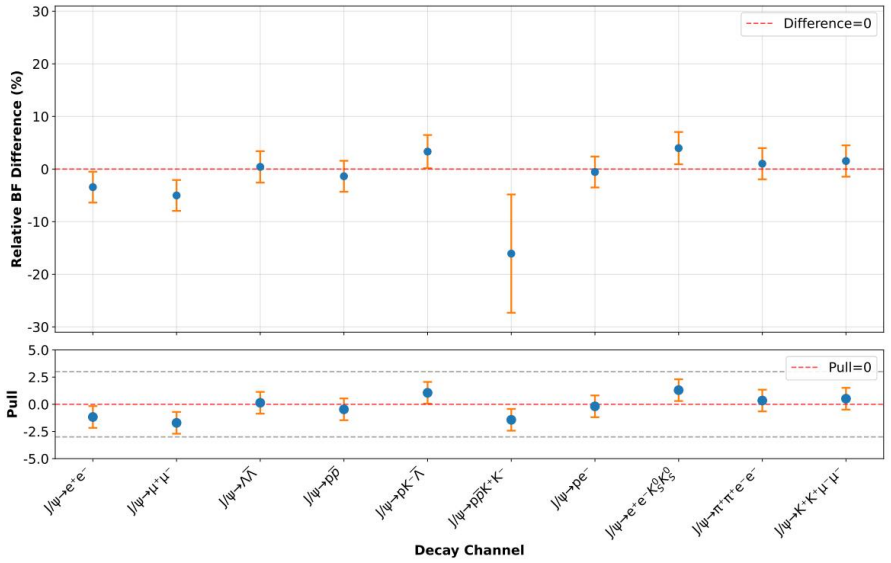


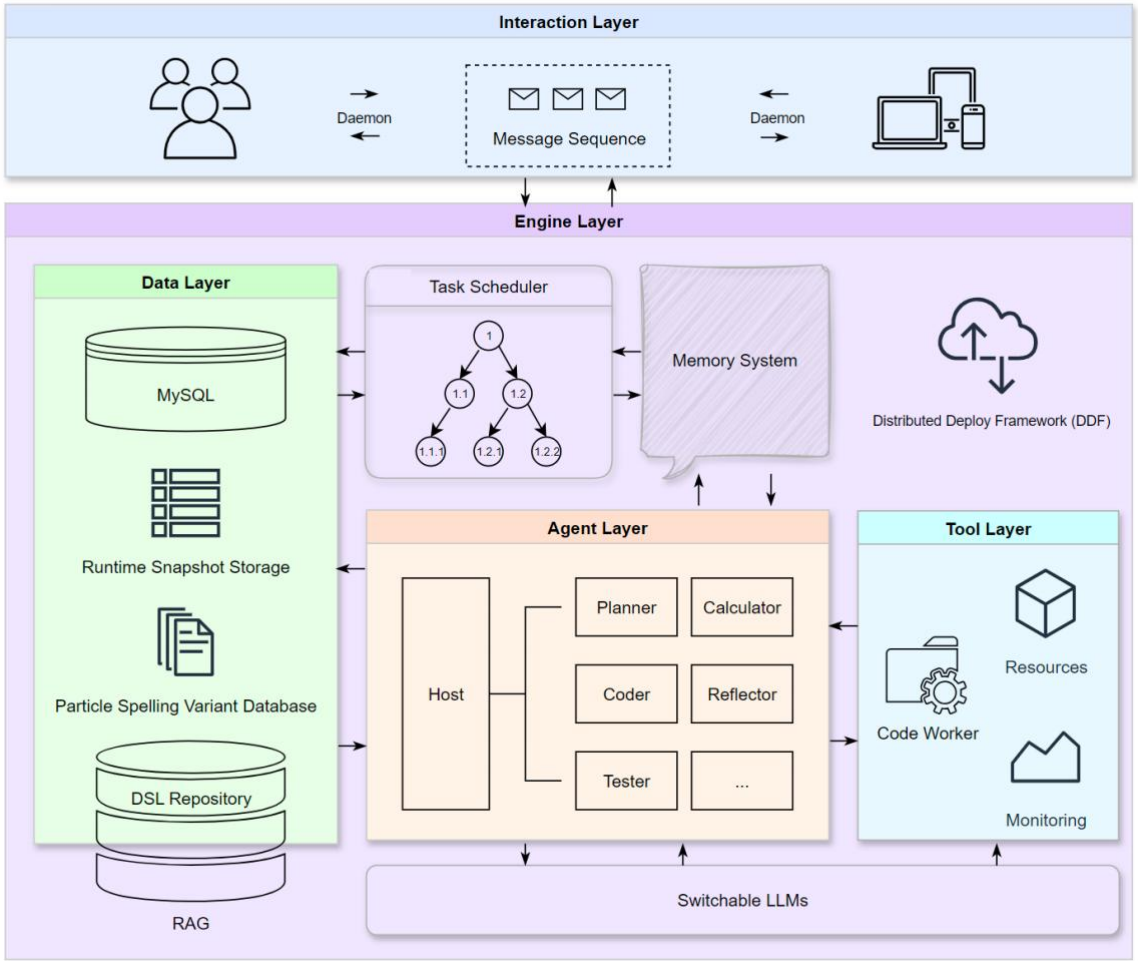


More details in [the talk at ICHEP2024]

History of DrSai v2

- Make BESIII analysis agent-based
  - Based on AutoGen framework
- Analysis represented via DSL (preliminary)
- Validated by re-measuring J/ψ BFs
  - Good consistency with input





arXiv:2604.22541

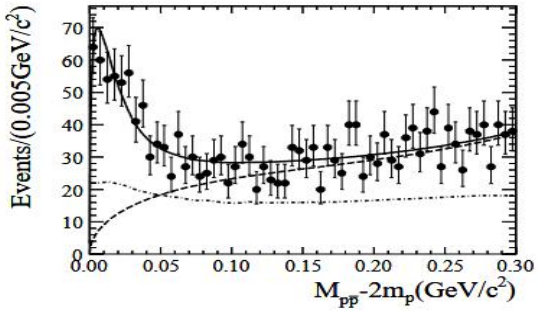
Now we release DrSai v3

- https://code.ihep.ac.cn/liutong2016/DrSai_v3
- Industrial AI is developing fast, and works well
  - Domain-specific agents seems no further necessary for HEP
  - **Drsai_v3: General-purpose Agent + skills**
    - Skill: turns AI's understanding into actionable, reusable capabilities.
    - Portable: not tied to any framework or base model
    - By default we use claude code + deepseek-v4-pro
    - Maintainable: fix or debug through human-agent interaction
    - Modular: each skill is replaceable

Updates on DrSai v3

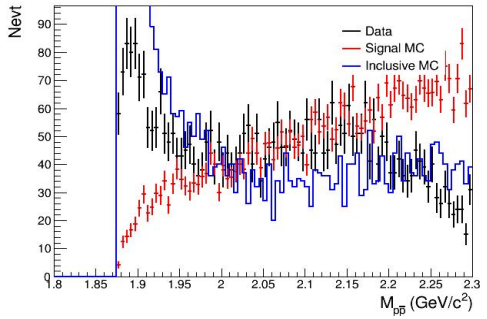
- Based on AutoGen → **General-purpose** Agent + S**kills**
- **Skills: modular and reusable, knowing how to do something, not just knowing about it**
- Use **DSLs** to represent the analysis pipeline
  - A **DSL-yaml** as work "note", updated as the work proceeds
  - A **DSL-ruby** (HepScript) for more stable coding and help users check/confirm code logic
- **GraphRAG**: improve code generation
  - Take each class/package as a node
  - Define edges - contains, extends, depends
- **Agentic RAG**: knowledge from previous work → strategy for new work
  - Previous works are chunked by physical meaning

CPC **34**, 421 (2010)



DrSai

arXiv:2605.01423



DrSai

Updates on DrSai v3

- DSL-yaml as work "note": represent the analysis pipeline
  - Use existing work to extract knowledge for preliminary DSL-yaml generation
  - YAML format, parsed by LLM, high readability
  - Interactive work, revisable at any time (manually or via LLM).
  - Finally obtain "note" that contain all the information of this analysis
    - Write MEMO automatically

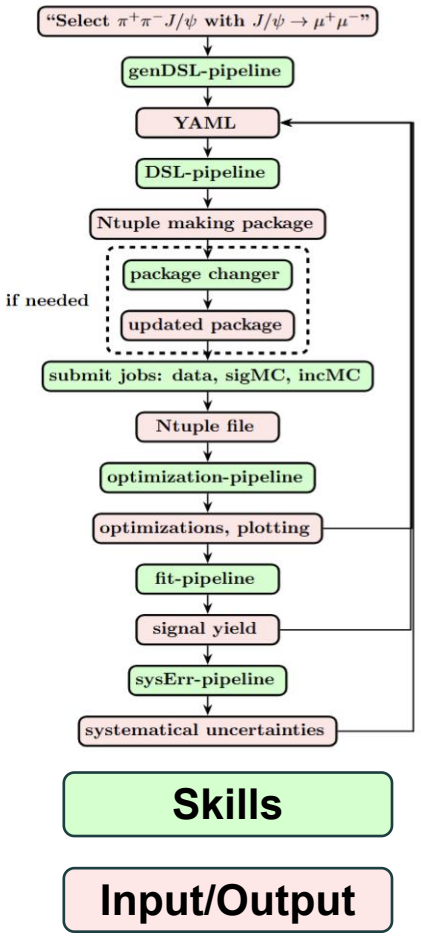
Start a new analysis using DrSai v3

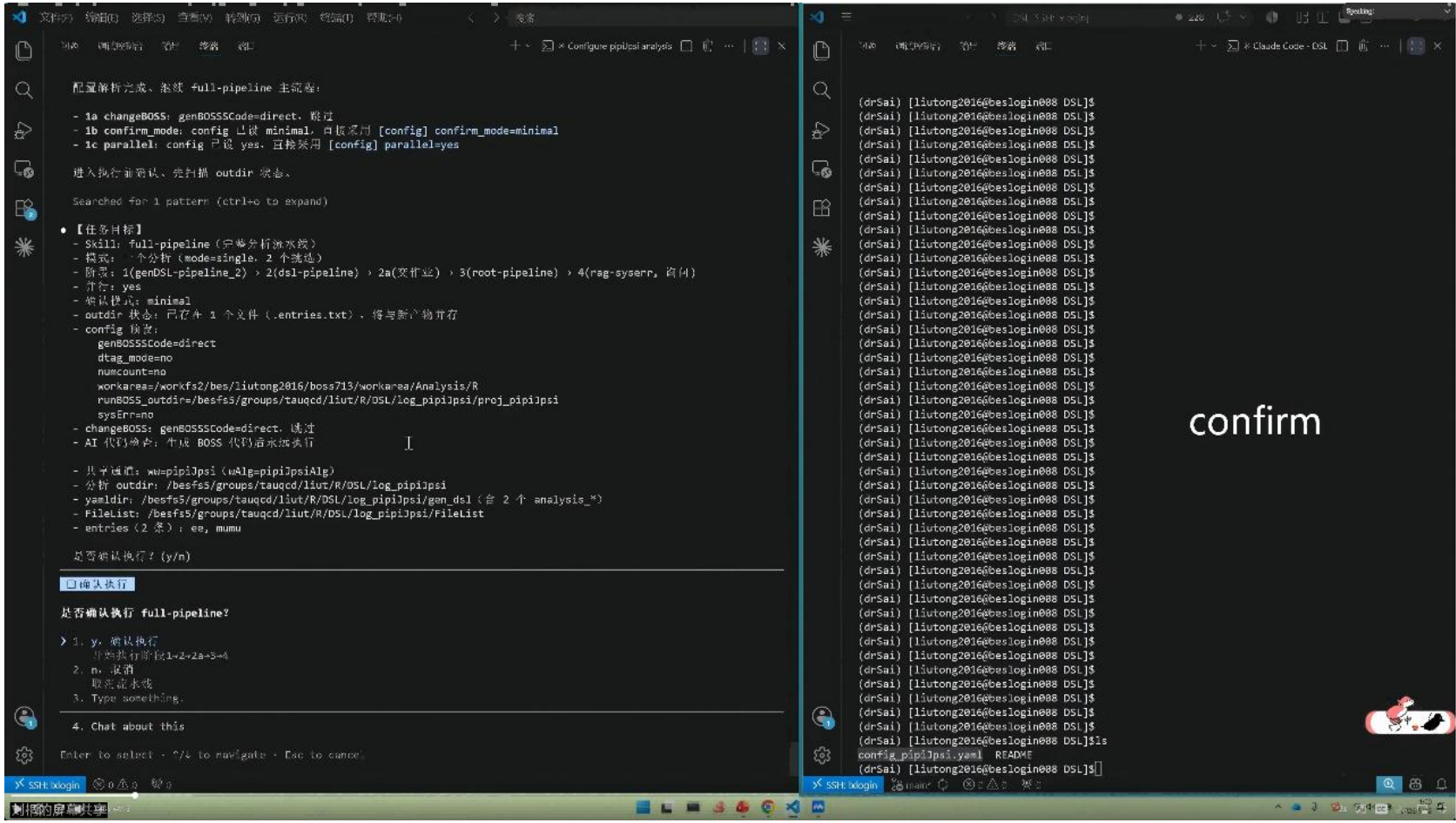
- Say “analysis with DrSai, see config.yaml”
  - A yaml-like style configuration
  - Or generate config.yaml via human-AI interaction
- config.yaml contains:
  - Directories
  - Confirmation
  - subAgents-parallel
  - sysErr estimation
  - BOSS package generation
  - Physical processes
  - Samples (data, incMC, list)

```yaml
# ========== Global Fields ==========

outdir: ./logR              # directory for analysis output.
runBOSS_outdir: ./logR/proj  # directory for BOSS job projects. omitted → interaction
workarea: /workfs2/bes/liutong2016/boss713/workarea/Analysis/R  # BOSS package workarea. omitted → interaction

confirm_mode: minimal           # detailed (ask at every step) | minimal (interact only for required items)
parallel: yes                   # yes | no. Whether to enable parallel agent execution.

# If both yes, LLM will combine the outputs
sysErr: yes                     # yes | no. Whether to generate systematic error code via RAG
sysErr-ruby: yes                # yes | no. Use the systematic error analysis benchmark developed for HepScript

genBOSSCode: direct     # ruby | direct. BOSS code generation method.
                        # ruby   – generate BOSS code via Ruby/HepScript
                        # direct – generate directly

# ========== entries Mode and Entries ==========

mode: single                    # single | multi
                                #   single – one analysis
                                #   multi  – multiple independent analyses

ww: Rvalue              # Optional. Valid only when mode=single and entries≥2
                        # Ignored in other modes (multi / single+entries=1)

entries:
  # Format per line: process   threshold_cut=<GeV>   description
  # - process        – channel name / algorithm base name, used for subdirectory and analysis package naming.
  # - threshold_cut  – energy threshold for KKMC+BesEvtGen (GeV). If missing, full-pipeline will interactively p
rompt at load time (default 3.0).
  # - description    – brief description of the analysis procedure: final-state particles, etc.
  - "bhabha   threshold_cut=0.001022   select e+e- at 1.9 GeV"
  - "dimu     threshold_cut=0.2113     select mu+mu- at 1.9 GeV"
  - "pipi     threshold_cut=0.280      select pi+pi- at 1.9 GeV"
  - "pipipi0  threshold_cut=0.415      select pi+pi-pi0, pi0->gamma gamma at 1.9 GeV"
```

Eg: rediscovery of $Z_c(3900)$ in $e^+e^- \to \pi^+\pi^- J/\psi$

- A demo with DrSai_v3.0.0, Continuously updated





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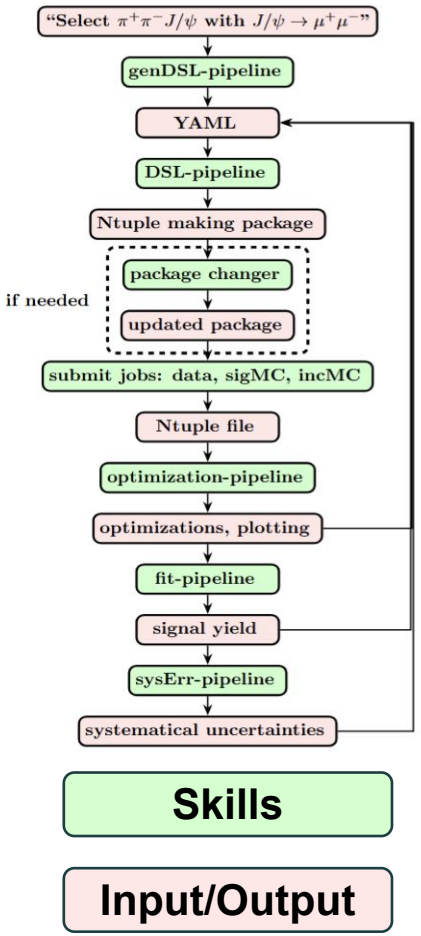

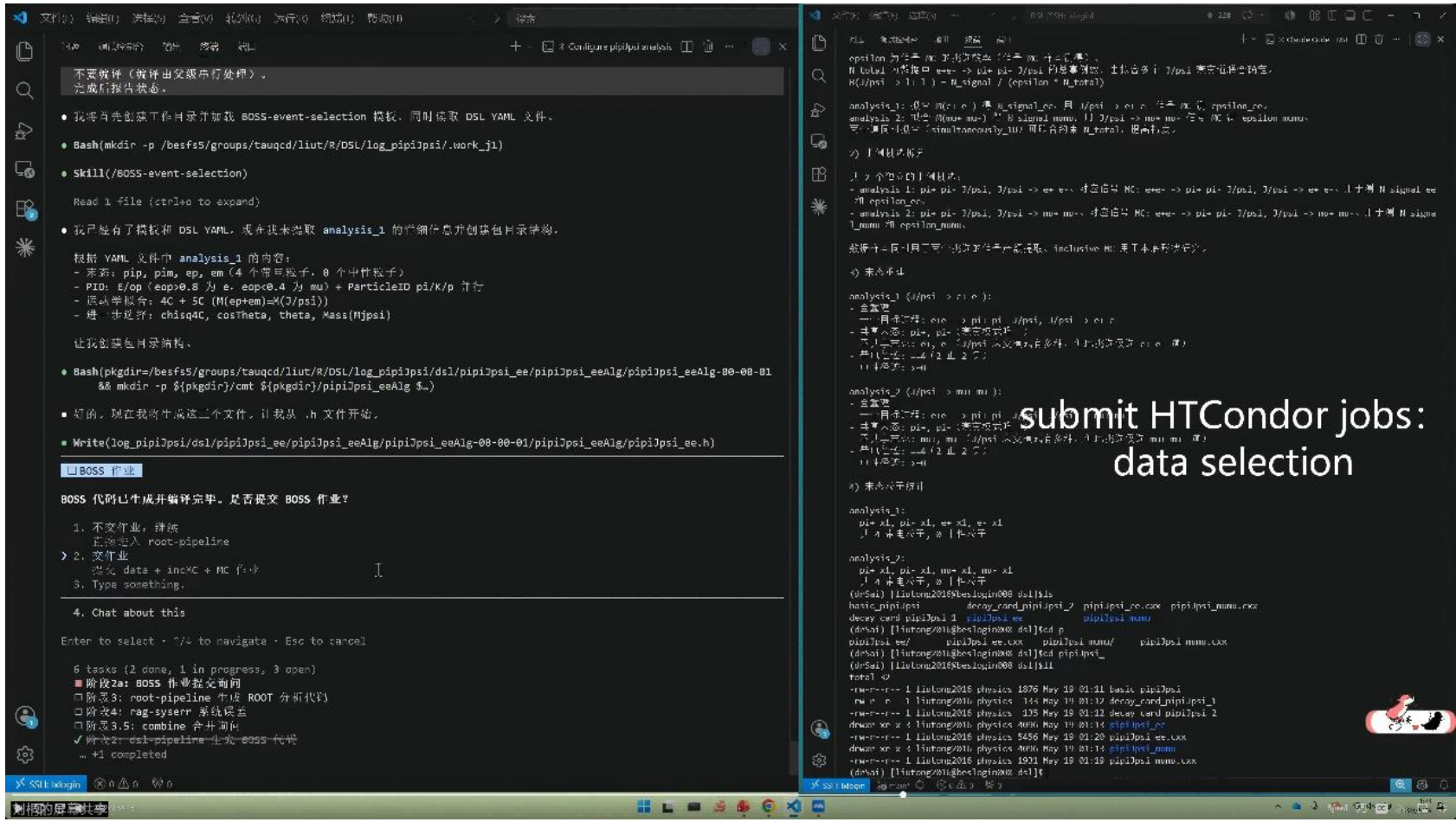

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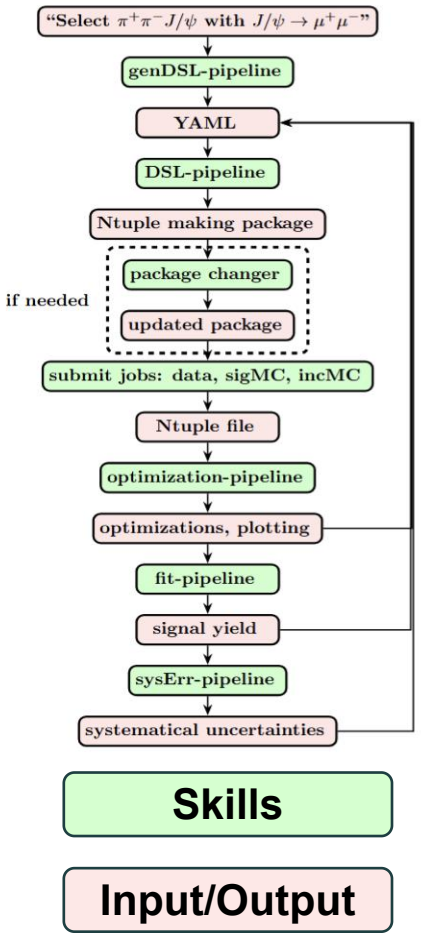

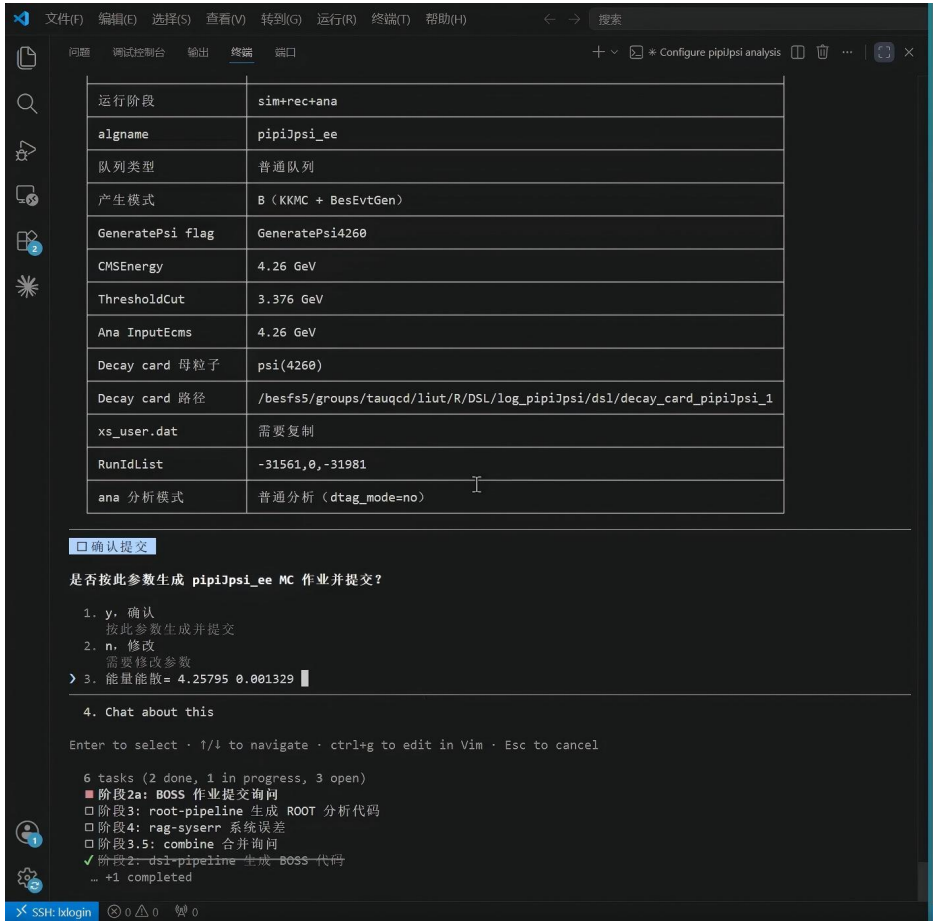

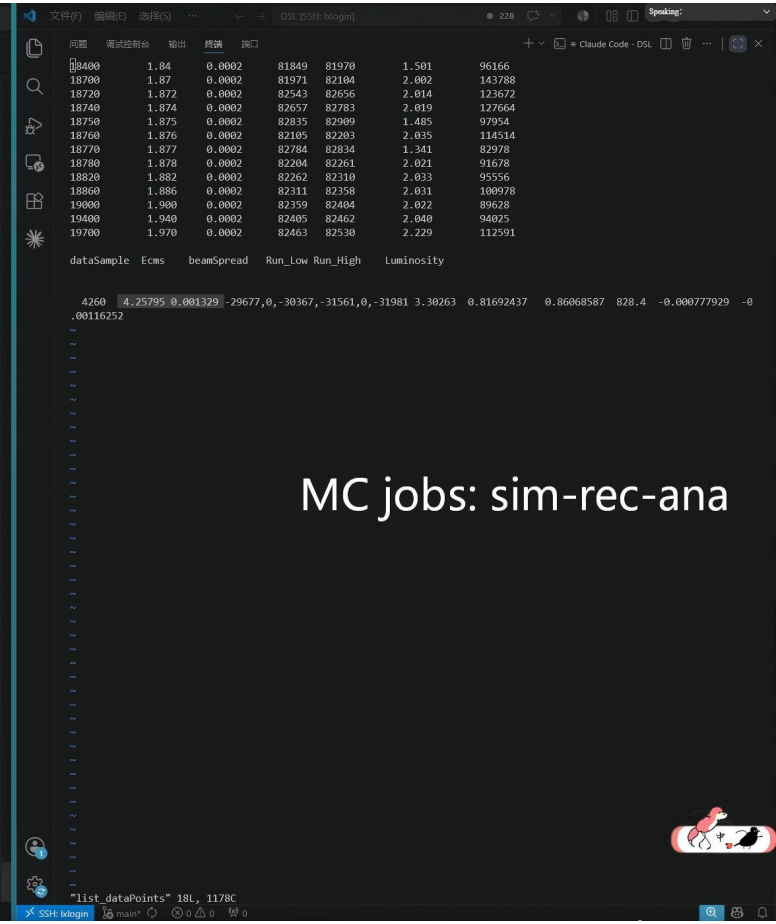

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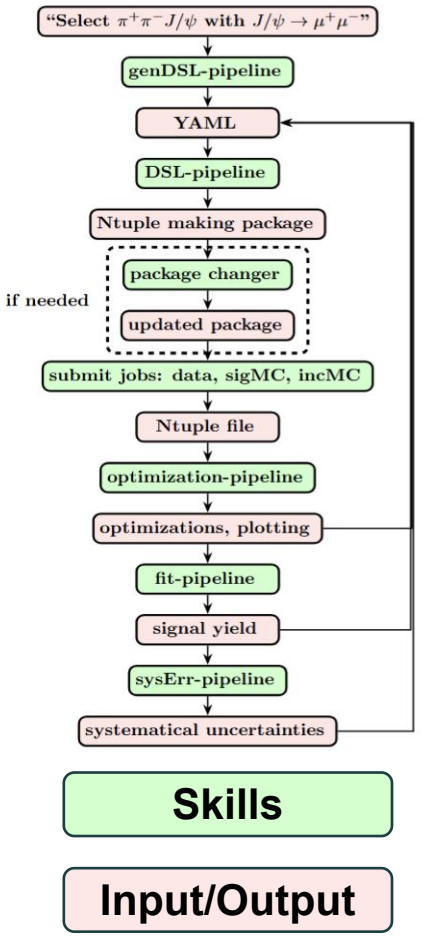

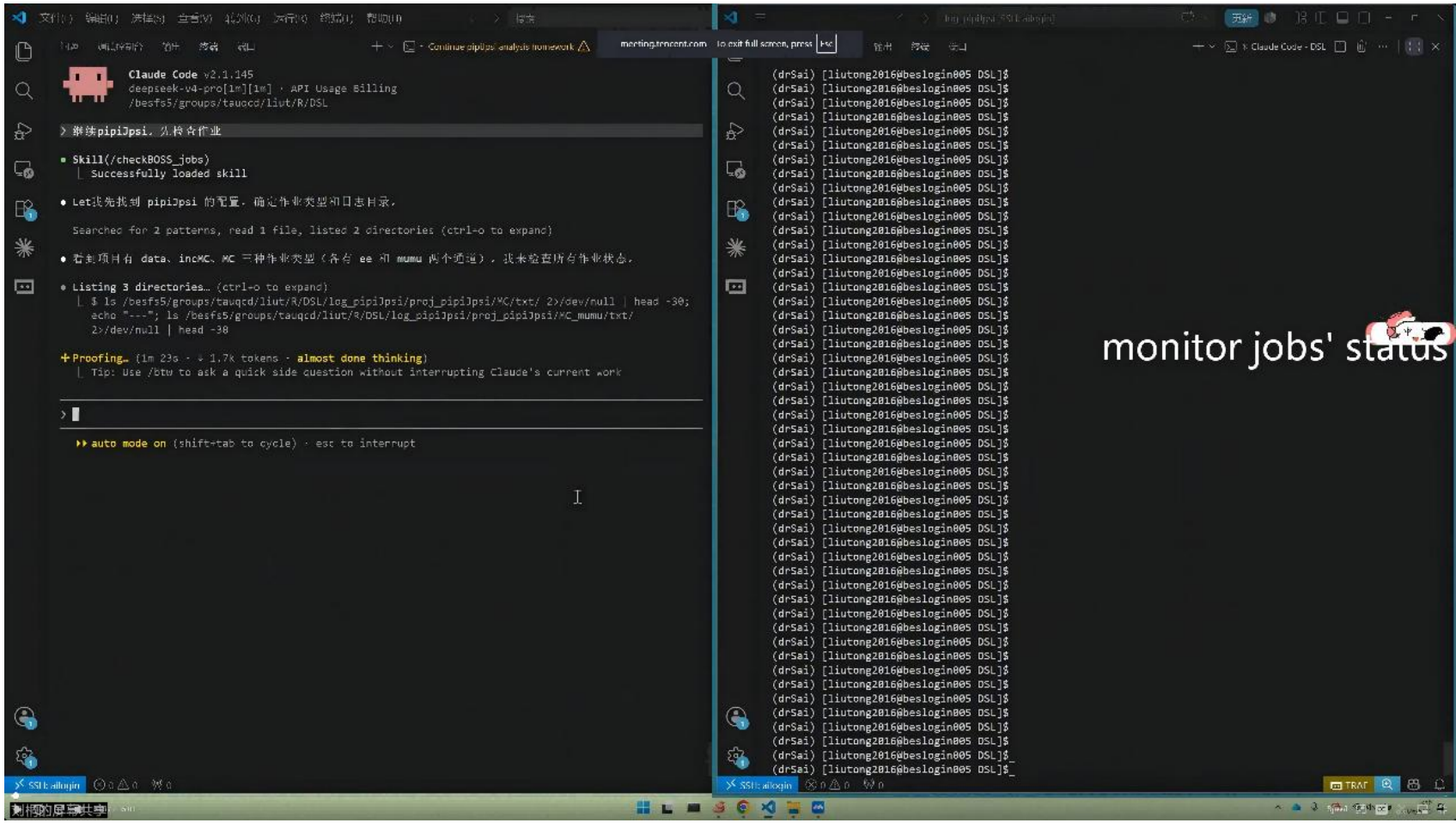

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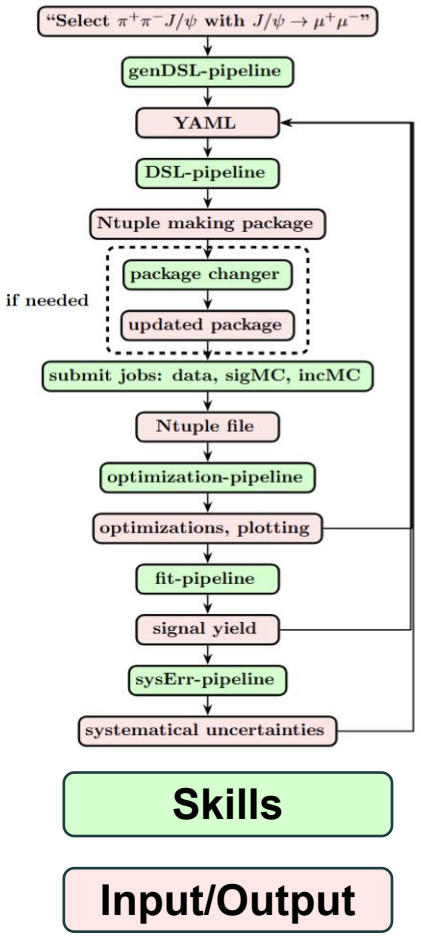

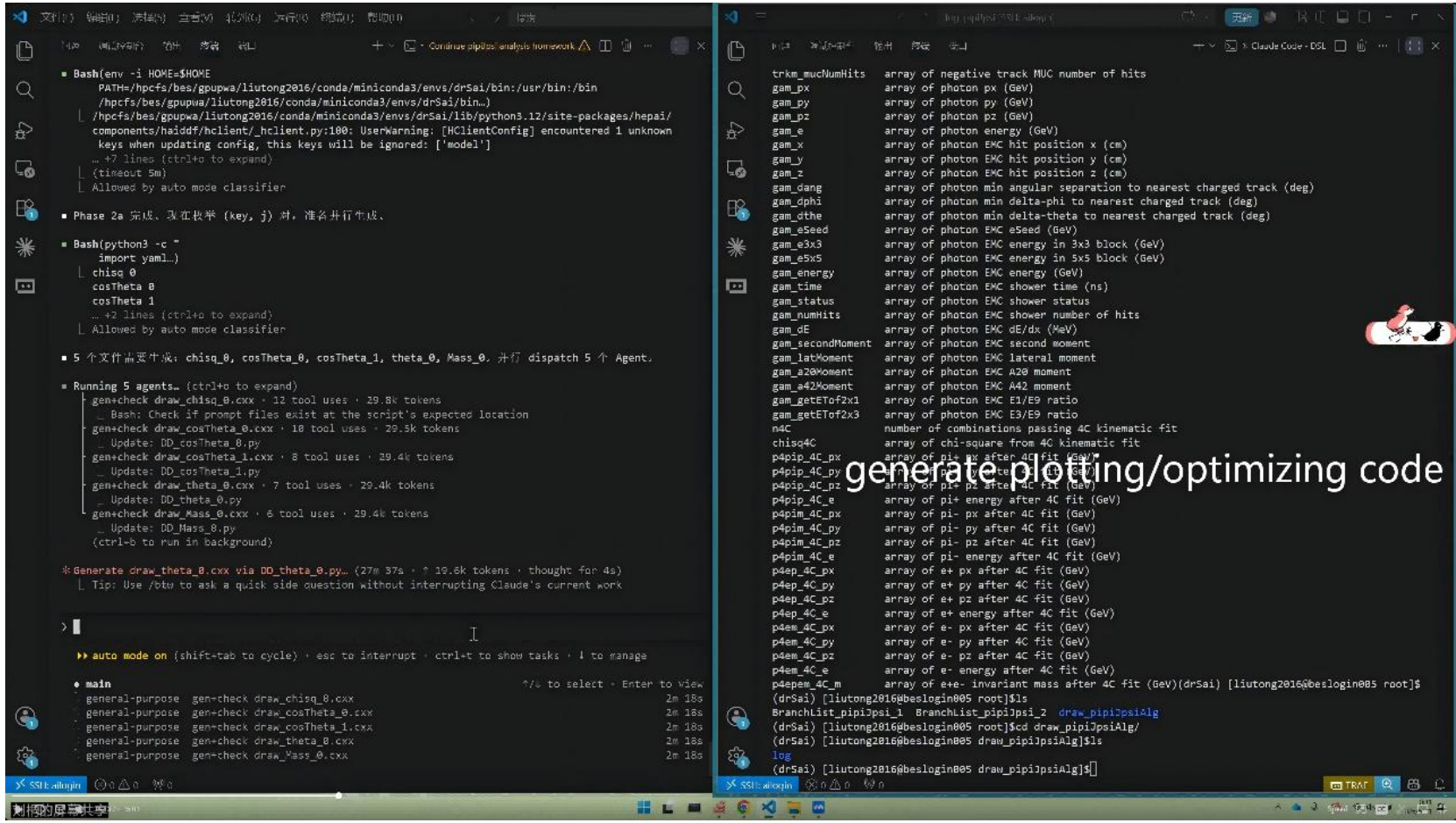

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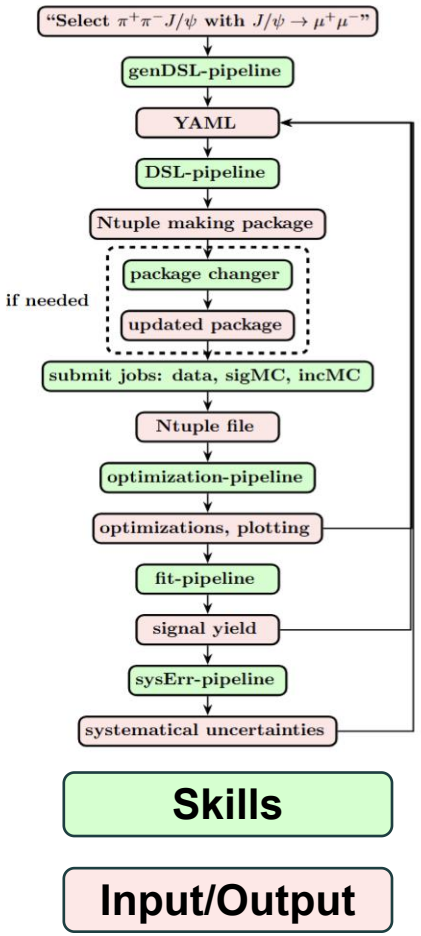

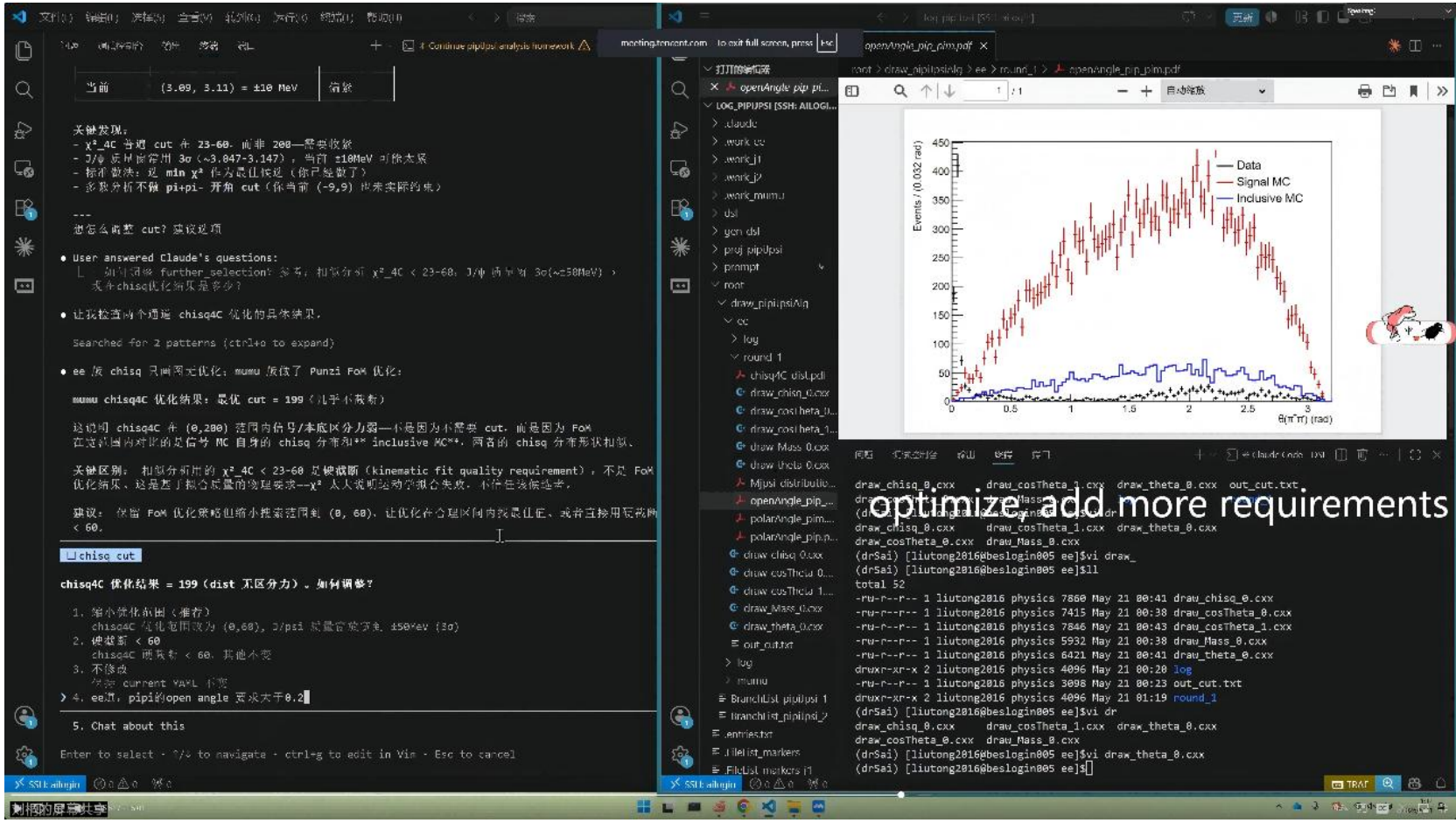

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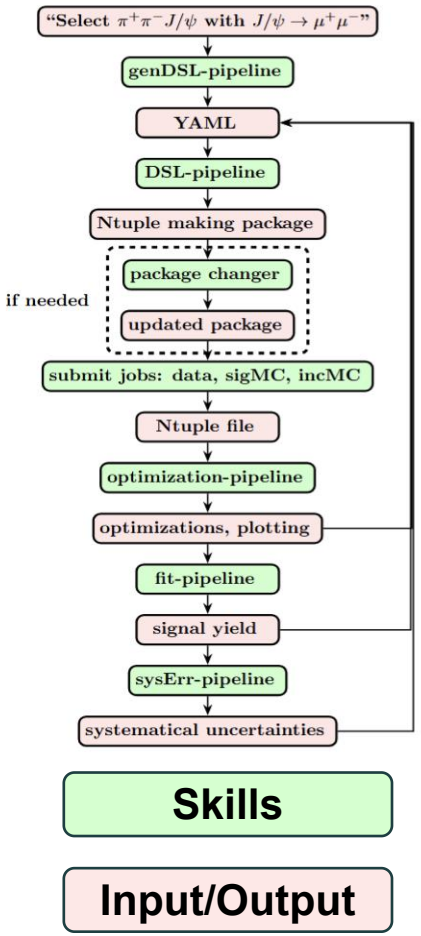

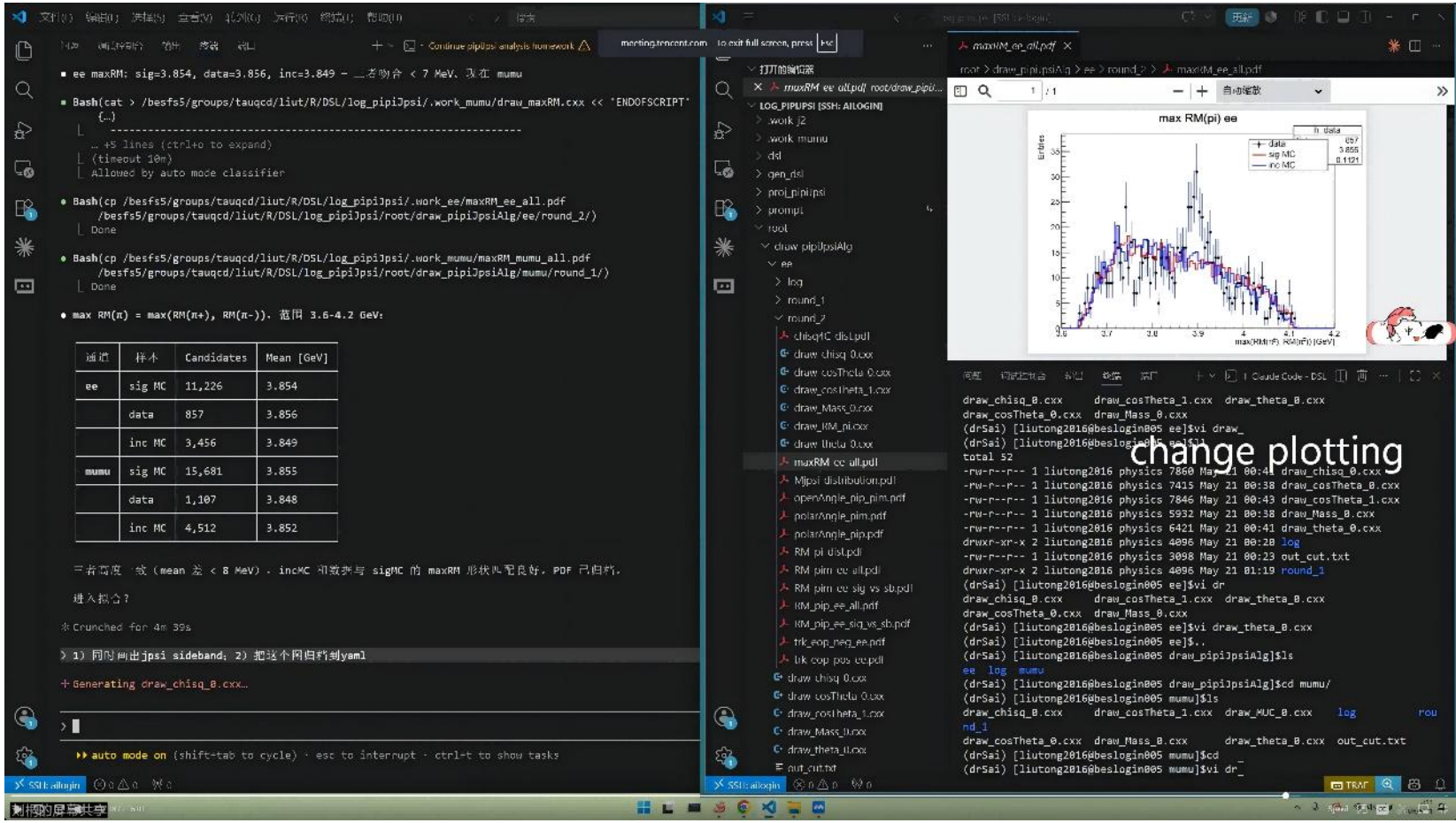

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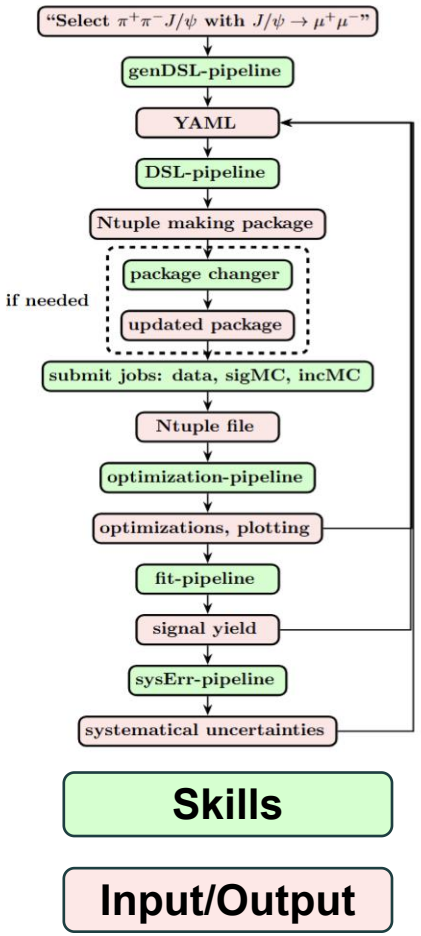

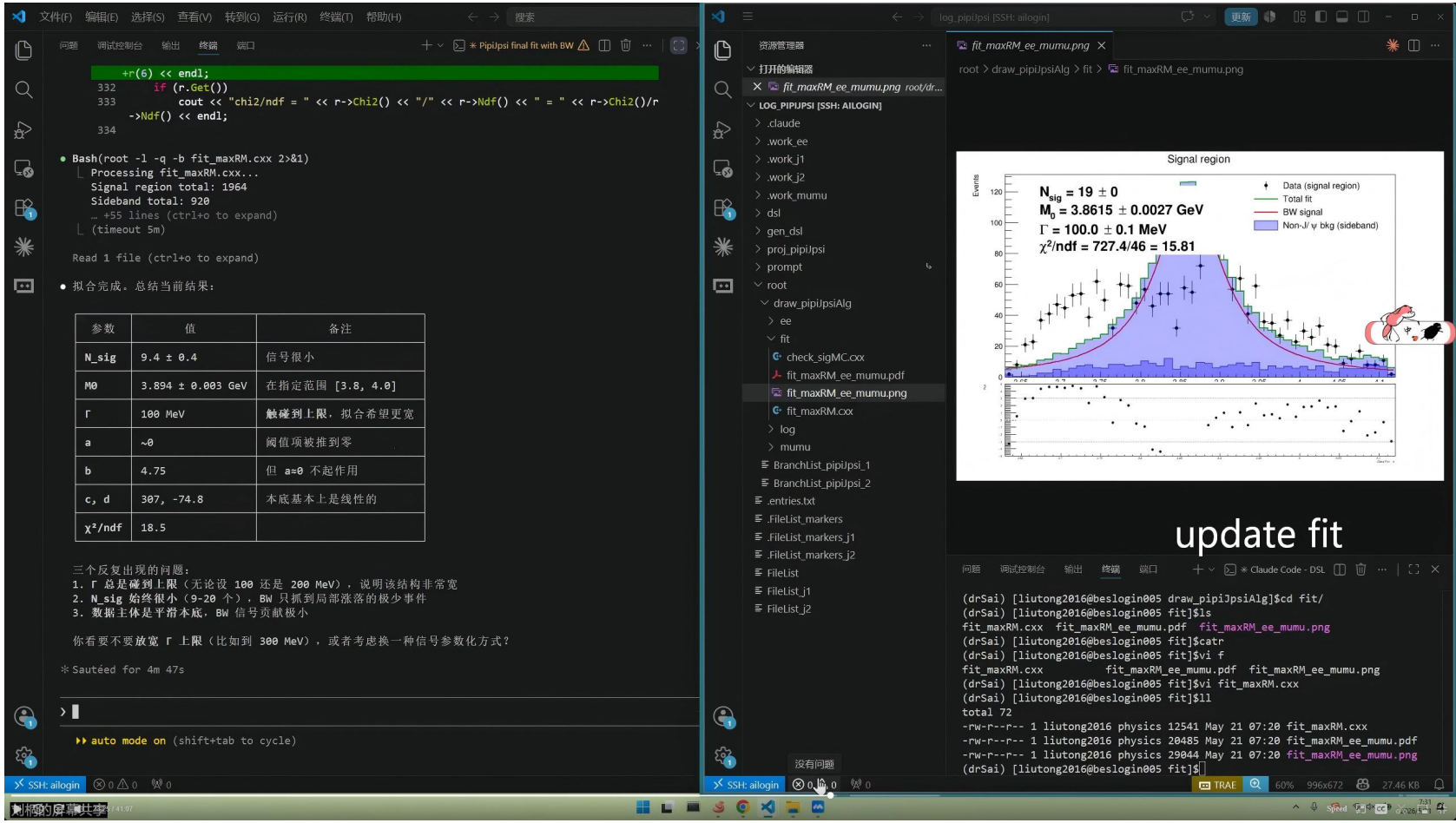

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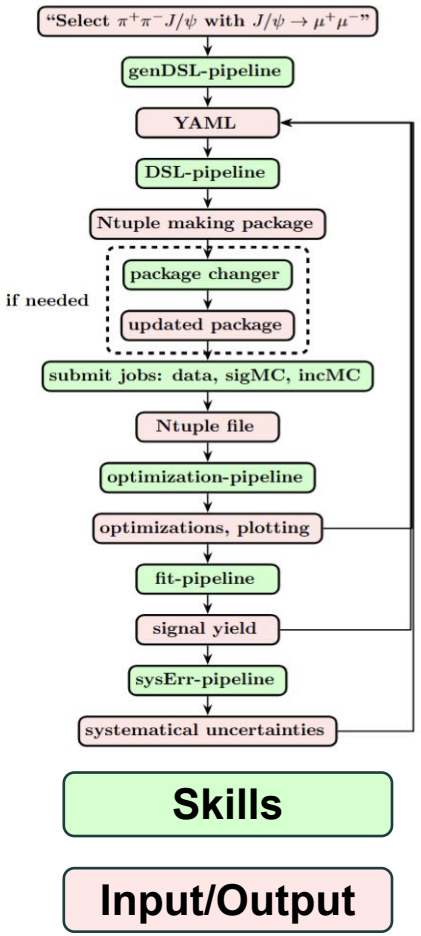

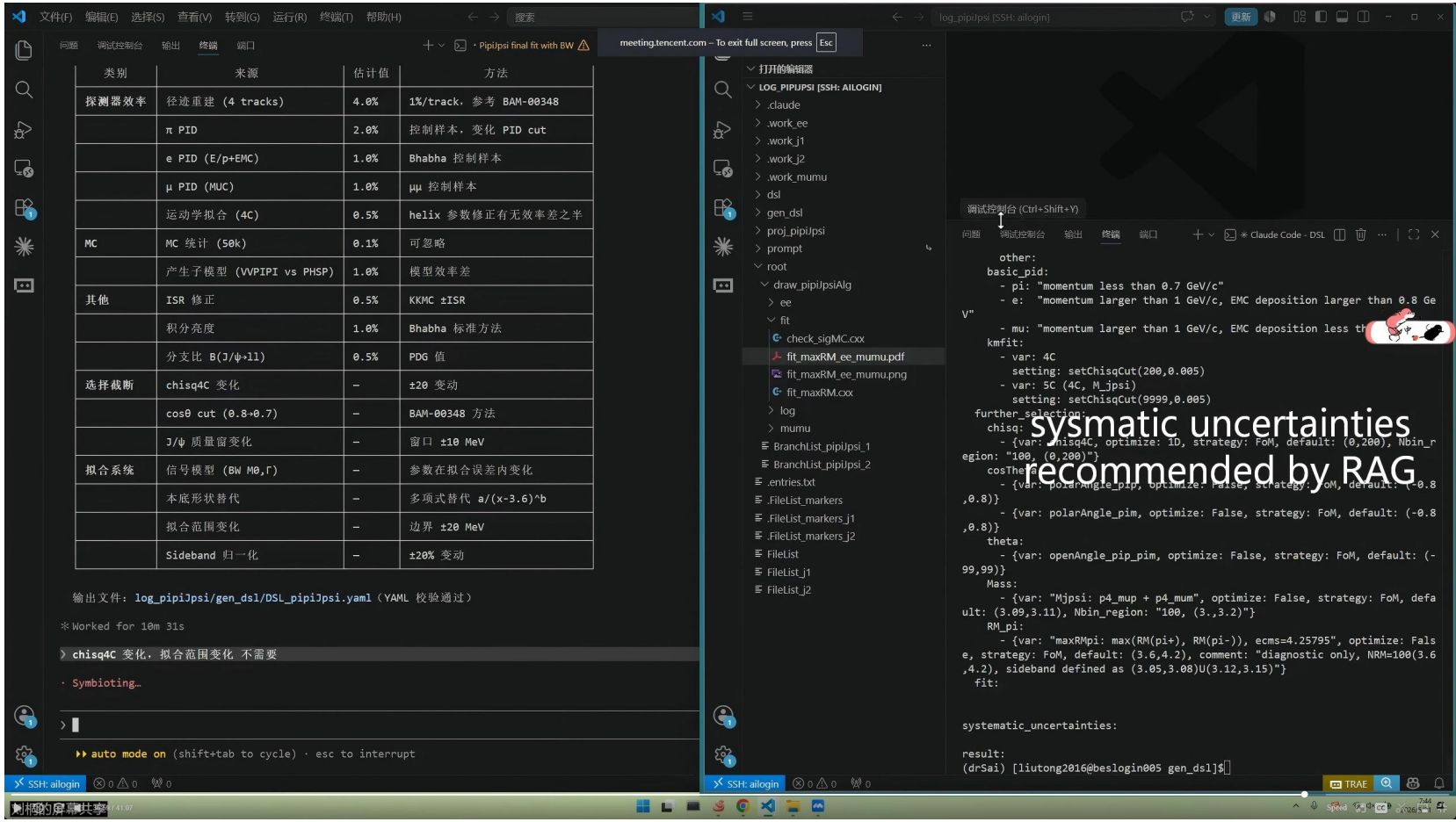

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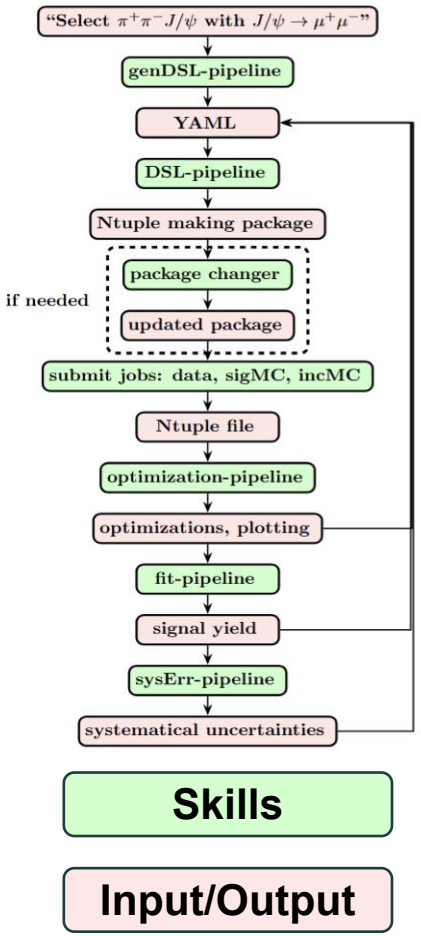
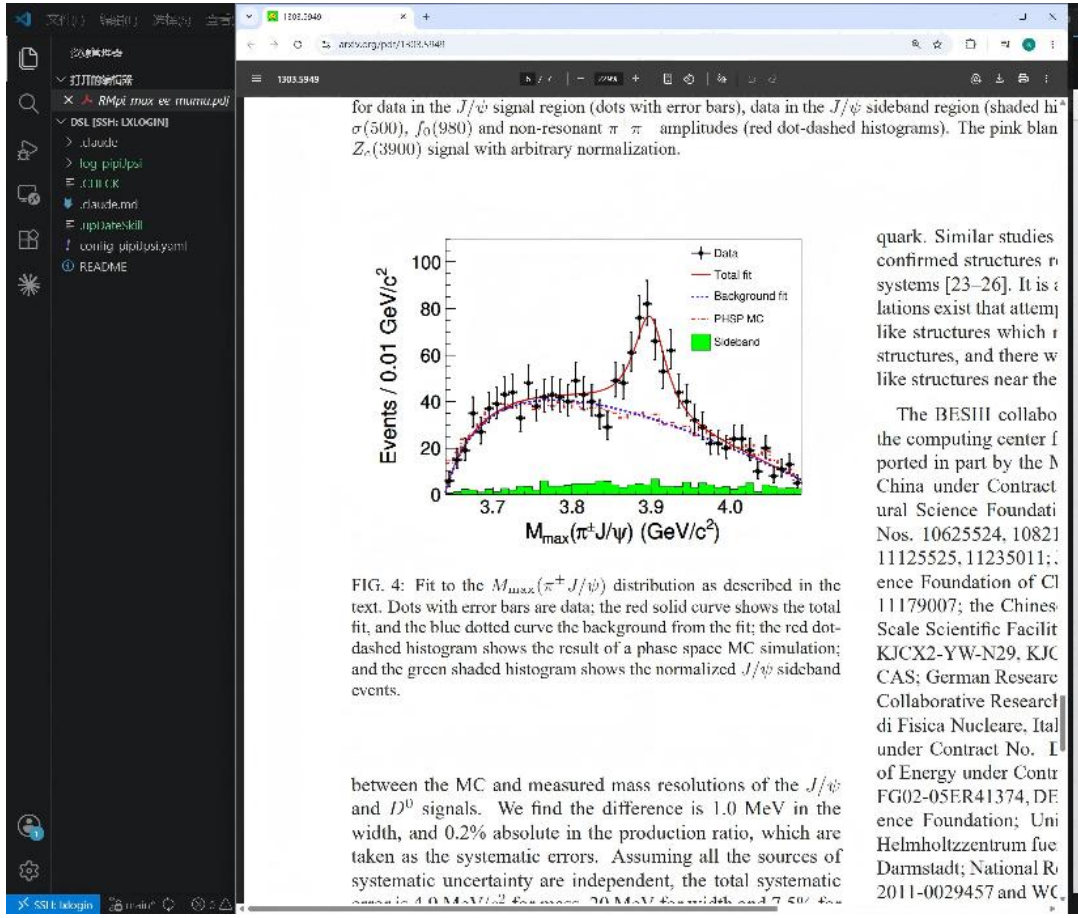
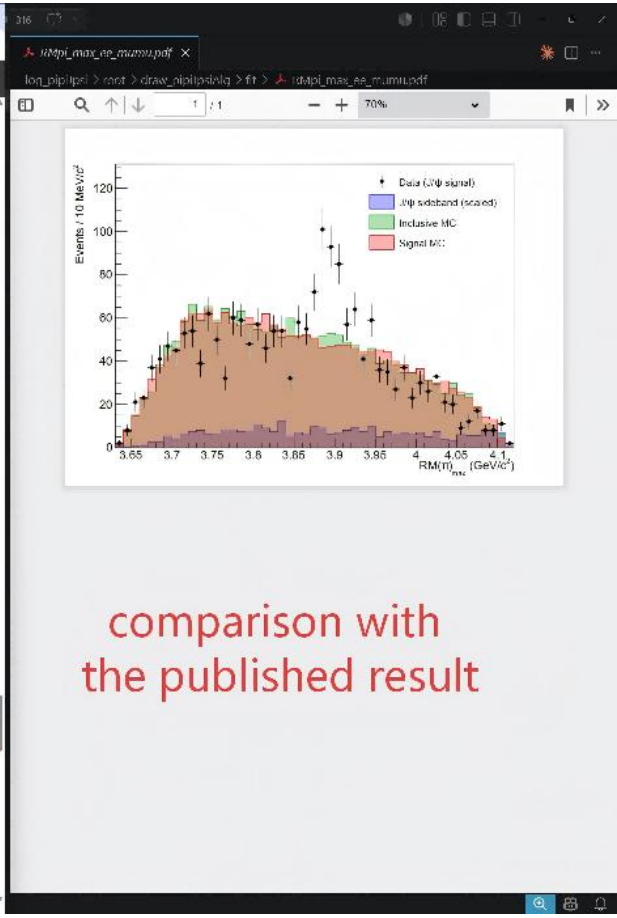
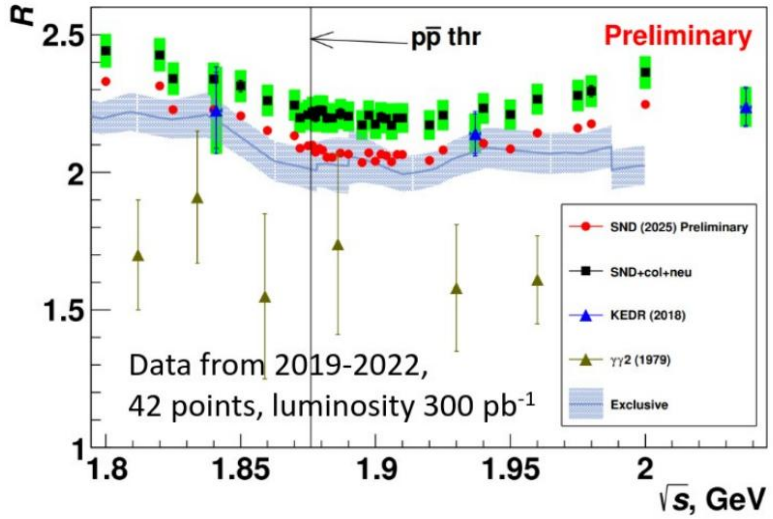






The first analysis with DrSai: R@1.9 GeV

- Exclusive R value measurements at 1.9 GeV
  - Difference between inclusive and exclusive results



Recent results from the SND experiment

Signature	Final states (preliminary, published)
2 charged	$\pi^+\pi^-, K^+K^-, K_SK_L, p\bar{p}$
2 charged + γ's	$\pi^+\pi^-\gamma, \pi^+\pi^-\pi^0, \pi^+\pi^-\eta, K^+K^-\pi^0, K^+K^-\eta, K_SK_L\pi^0, K_SK_L\eta, \pi^+\pi^-\pi^0\eta, \pi^+\pi^-2\pi^0, \pi^+\pi^-3\pi^0, \pi^+\pi^-4\pi^0$
4 charged	$\pi^+\pi^-\pi^+\pi^-, K^+K^-\pi^+\pi^-, K_SK^\pm\pi^\mp, K_SK_L\pi^+\pi^-, K_SK_S\pi^+\pi^-$
4 charged + γ's	$\pi^+\pi^-\pi^+\pi^-\pi^0, \pi^+\pi^-\eta, \pi^+\pi^-\omega, \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0, K^+K^-\eta, K^+K^-\omega$
6 charged	$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-, K_SK^\pm\pi^\mp\pi^+\pi^-, K_SK_S\pi^+\pi^-$
6 charged + γ's	$3(\pi^+\pi^-)\pi^0$
Neutral	$\pi^0\gamma, \eta\gamma, \pi^0\pi^0\gamma, \pi^0\eta\gamma, \pi^0\pi^0\pi^0\gamma, \pi^0\pi^0\eta\gamma$
Other	$n\bar{n}, \pi^0e^+e^-, \eta e^+e^-$
Rare decays	$\eta', D^*(2007)^0$, $f_1(1285)$

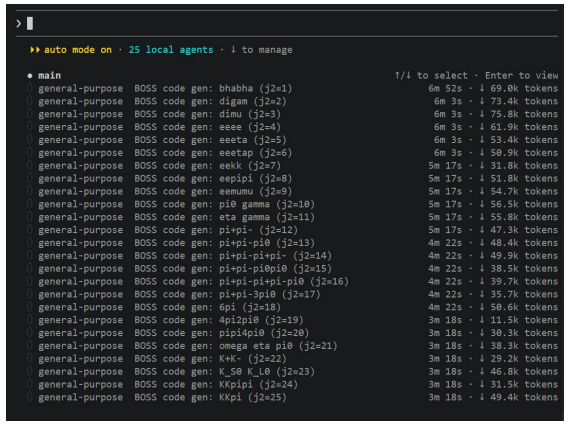
CMD-3 analysis

PRD **97**, 114025 (2018)

Channel	This work (KNT18)	HLMNT11 [9]	Difference
Chiral perturbation theory (ChPT) threshold contributions			
$\pi^0\gamma$	0.12 ± 0.01	0.12 ± 0.01	0.00
$\pi^+\pi^-$	0.87 ± 0.02	0.87 ± 0.02	0.00
$\pi^+\pi^-\pi^0$	0.01 ± 0.00	0.01 ± 0.00	0.00
$\eta\gamma$	0.00 ± 0.00	0.00 ± 0.00	0.00
Data based channels ($\sqrt{s} \leq 2$ GeV)			
$\pi^0\gamma$	4.46 ± 0.10	4.54 ± 0.14	-0.08
$\pi^+\pi^-$	502.99 ± 1.97	505.77 ± 3.09	-2.78
$\pi^+\pi^-\pi^0$	47.82 ± 0.89	47.51 ± 0.99	0.31
$\pi^+\pi^-\pi^+\pi^-$	15.17 ± 0.21	14.65 ± 0.47	0.52
$\pi^+\pi^-\pi^0\pi^0$	19.80 ± 0.79	20.37 ± 1.26	-0.57
$(2\pi^+2\pi^-\pi^0)_{\text{no }\eta}$	1.08 ± 0.10	1.20 ± 0.10	-0.12
$3\pi^+3\pi^-$	0.28 ± 0.02	0.28 ± 0.02	0.00
$(2\pi^+2\pi^-2\pi^0)_{\text{no }\eta\omega}$	1.60 ± 0.20	1.80 ± 0.24	-0.20
K^+K^-	23.05 ± 0.22	22.15 ± 0.46	0.90
$K_S^0K_L^0$	13.05 ± 0.19	13.33 ± 0.16	-0.28
$KK\pi$	2.80 ± 0.12	2.77 ± 0.15	0.03
$KK2\pi$	2.42 ± 0.09	3.31 ± 0.58	-0.89
$\eta\gamma$	0.70 ± 0.02	0.69 ± 0.02	0.01
$\eta\pi^+\pi^-$	1.32 ± 0.06	0.98 ± 0.24	0.34
$(\eta\pi^+\pi^-\pi^0)_{\text{no }\omega}$	0.63 ± 0.15	-	0.63
$\eta2\pi^+2\pi^-$	0.11 ± 0.02	0.11 ± 0.02	0.00
$\eta\omega$	0.31 ± 0.03	0.42 ± 0.07	-0.11
$\omega(\to \pi^0\gamma)\pi^0$	0.88 ± 0.02	0.77 ± 0.03	0.11
$\eta\phi$	0.45 ± 0.04	0.46 ± 0.03	-0.01
$\phi \to$ unaccounted	0.04 ± 0.04	0.04 ± 0.04	0.00
$\eta\omega\pi^0$	0.42 ± 0.10	-	0.42
$\eta(\to \text{npp})K\bar{K}_{\text{no }\phi\to KK}$	0.01 ± 0.01	-	0.01
$p\bar{p}$	0.07 ± 0.00	0.06 ± 0.00	0.01
$n\bar{n}$	0.06 ± 0.01	0.07 ± 0.02	-0.01
Estimated contributions ($\sqrt{s} \leq 2$ GeV)			
$(\pi^+\pi^-3\pi^0)_{\text{no }\eta}$	0.53 ± 0.05	0.60 ± 0.05	-0.07
$(\pi^+\pi^-4\pi^0)_{\text{no }\eta}$	0.25 ± 0.25	0.28 ± 0.28	-0.03
$KK3\pi$	0.08 ± 0.03	0.08 ± 0.04	0.00
$\omega(\to \text{npp})2\pi$	0.10 ± 0.02	0.11 ± 0.02	-0.01
$\omega(\to \text{npp})3\pi$	0.20 ± 0.04	0.22 ± 0.04	-0.02
$\omega(\to \text{npp})KK$	0.01 ± 0.00	0.01 ± 0.00	0.00
$\eta\pi^+\pi^-2\pi^0$	0.11 ± 0.05	0.11 ± 0.06	0.00

The first analysis with DrSai: R@1.9 GeV

- Exclusive R value measurements at 1.9 GeV
  - Difference between inclusive and exclusive results
- Neglect small processes, still >30 channels, an excellent scenario for DrSai
  - Codes are generated with subAgents simultaneously
  - Strategies are suggested by RAG
  - Only human-AI interaction, no manual coding!



nCharge=0	
$\gamma\pi^0$	
$\gamma\eta$	

nCharge=2	
$\pi^+\pi^-$	
$\pi^+\pi^-\pi^0$	BAM-546
$\pi^+\pi^-2\pi^0$	
$\pi^+\pi^-3\pi^0$	
$\pi^+\pi^-4\pi^0$	
$\pi^+\pi^-\eta$	
$\omega\eta\pi^0$	BAM-00672
K^+K^-	
$K^+K^-\pi^0$	BAM-376, BAM-655
$K^+K^-\pi^0\pi^0$	BAM-229, BAM-346
$K^+K^-\pi^0\pi^0\pi^0$	$KK3\pi$~0.08
$K^+K^-\eta$	$\phi\eta$ dom.
$K_S^0K_L^0$	
$K_S^0K_L^0\pi^0$	BAM-376, BAM-655
$K_S^0K_L^0\pi^0\pi^0$	
$K_S^0K_L^0\pi^0\pi^0\pi^0$	$KK3\pi$~0.08
$K_S^0K_L^0\eta$	

nCharge=4	
$2(\pi^+\pi^-)$	
$2(\pi^+\pi^-)\pi^0$	BAM-416, BAM-596
$2(\pi^+\pi^-)2\pi^0$	
$2(\pi^+\pi^-)3\pi^0$	
$2(\pi^+\pi^-)\eta$	~0.11
$K^+K^-\pi^+\pi^-$	BAM-229, BAM-346
$K^+K^-\pi^+\pi^-\pi^0$	$KK3\pi$~0.08
$K^+K^-\pi^+\pi^-\pi^0\pi^0$	<$3(\pi^+\pi^-)$~0.28
$K^+K^-\pi^+\pi^-\pi^0\pi^0\pi^0$	<$3(\pi^+\pi^-)$~0.28
$K^+K^-\pi^+\pi^-\eta$	<0.11 ?
$K_S^0K^\pm\pi^\mp$	BAM-376, BAM-655
$K_S^0K^\pm\pi^\mp\pi^0$	
$K_S^0K^\pm\pi^\mp\pi^0\pi^0$	$KK3\pi$~0.08
$K_S^0K^\pm\pi^\mp\pi^0\pi^0\pi^0$	<$3(\pi^+\pi^-)$~0.28
$K_S^0K^\pm\pi^\mp\eta$	
$K_S^0K_L^0\pi^+\pi^-$	
$K_S^0K_L^0\pi^+\pi^-\pi^0$	$KK3\pi$~0.08
$K_S^0K_L^0\pi^+\pi^-\pi^0\pi^0$	<0.08
$K_S^0K_L^0\pi^+\pi^-\pi^0\pi^0\pi^0$	<0.08
$K_S^0K_L^0\pi^+\pi^-\eta$	<0.11 ?

nCharge=6	
$3(\pi^+\pi^-)$	~0.28
$3(\pi^+\pi^-)\pi^0$	
$3(\pi^+\pi^-)\eta$	<<$2(\pi^+\pi^-)\eta$~0.11
$K^+K^-2(\pi^+\pi^-)$	<<$3(\pi^+\pi^-)$~0.28
$K^+K^-2(\pi^+\pi^-)\pi^0$	<<$3(\pi^+\pi^-)$~0.28
$K^+K^-2(\pi^+\pi^-)\boldsymbol{\eta}$	<<$2(\pi^+\pi^-)\eta$~0.11
$K_S^0K^\pm\pi^\mp\pi^+\pi^-$	$KK3\pi$~0.08
$K_S^0K^\pm\pi^\mp\pi^+\pi^-\pi^0$	<0.08
$K_S^0K^\pm\pi^\mp\pi^+\pi^-\eta$	<0.08
$K_S^0K_L^0\pi^+\pi^-\pi^+\pi^-$	<<$3(\pi^+\pi^-)$~0.28
$K_S^0K_L^0\pi^+\pi^-\pi^+\pi^-\pi^0$	<<$3(\pi^+\pi^-)$~0.28
$K_S^0K_L^0\pi^+\pi^-\pi^+\pi^-\eta$	<<$2(\pi^+\pi^-)\eta$~0.11

The first analysis with DrSai: R@1.9 GeV

- Exclusive R value measurements at 1.9 GeV
  - $R = \sigma^{had}/\sigma^{\mu\mu} = \Sigma R^c$
  - $\sigma^{had} = \Sigma\sigma^c, R^c = \sigma^c/\sigma^{\mu\mu}$
- For each exclusive selection:
  - $N_{ob,i} = \Sigma N^c_{ob,i} = L\Sigma\epsilon^c_i\sigma^c$
  - Select all exclusive channels simultaneously, consider cross feed natually !

$N^c_{ob,i}$ and cross-feed ϵ^c_i

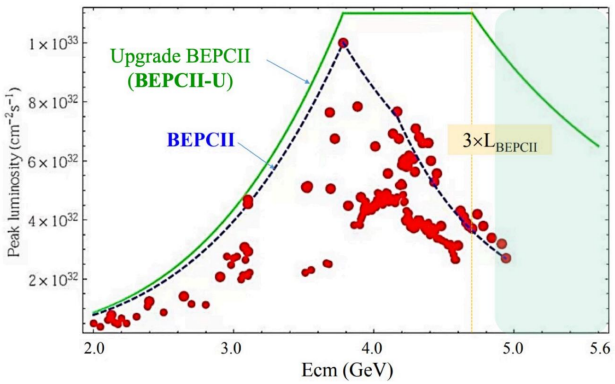
过程	信号MC效率	cross feed 前三个（算法:误挑率% 绝对数）
dimu	83.44%	KpKm:90.78%(90,780) · pippim:85.44%(85,441) · KpKmpi0:0.49%(492)
gammapi0	66.91%	gammaeta:5.92%(5,920) · KpKm:1.91%(1,907) · pippim:1.75%(1,750)
gammaeta	57.16%	gammapi0:9.27%(9,268) · KpKm:2.01%(2,012) · pippim:1.86%(1,859)
KpKm	84.03%	dimu:21.29%(21,291) · KpKmpi0:5.54%(5,544) · KpKm2pi0:0.39%(390)
KpKmeta	16.87%	KpKm:47.81%(47,814) · KpKmpi0:24.65%(24,649) · KpKm2pi0:8.74%(8,744)
KSKL	55.35%	KpKm:34.67%(34,666) · pippim:34.15%(34,149) · KSKLpi0:8.52%(8,515)
KSKLpi0	34.20%	KSKL:46.18%(46,183) · KpKm:36.08%(36,082) · pippim:35.85%(35,847)
KSKL2pi0	27.74%	KSKLpi0:39.69%(39,686) · KSKL:38.66%(38,664) · KpKm:37.47%(37,472)
KSKLeta	18.46%	KSKL:39.49%(39,488) · KpKm:38.70%(38,697) · pippim:38.49%(38,490)
4pi	56.16%	KpKm:4.94%(4,937) · pippim:4.85%(4,847) ·

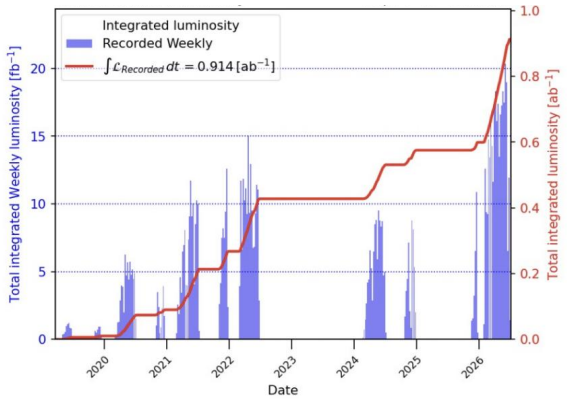
isospin sym.

R value

DrSai for charmonium(-like) study

- Fully automatically repetition with a complete DSL
  - No human-AI interaction
  - repeat/update analysis with BESIII's upcoming XYZ-scan points, BelleII's increased statistics ...

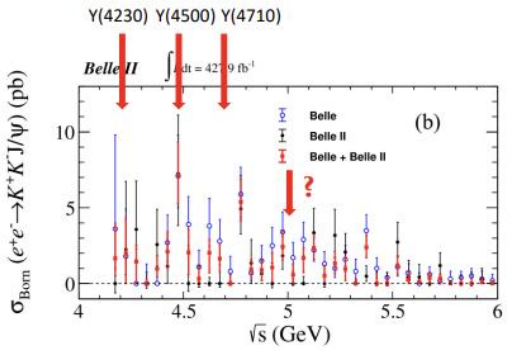


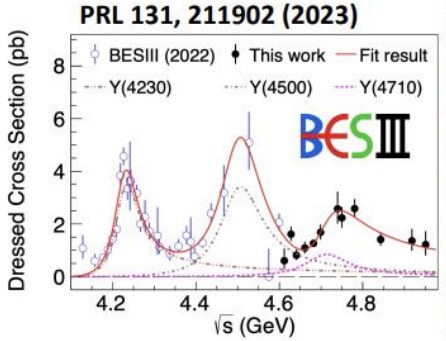


(from Sen Jia's talk)

PRD 113, 112010 (2026)

$e^+e^- \to K^+K^-J/\psi$ via ISR:

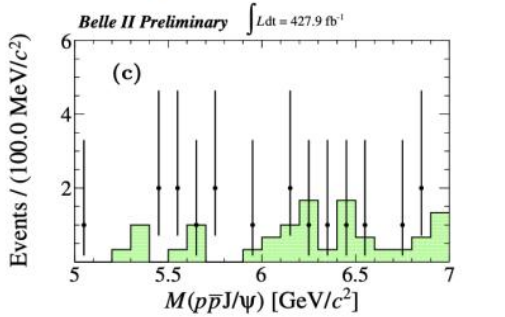


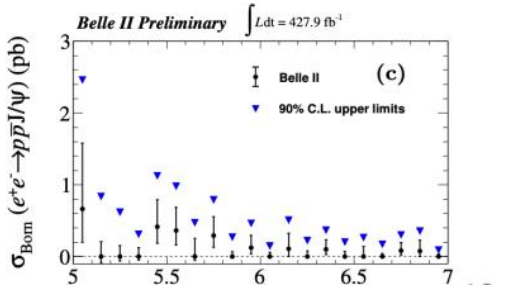


- **No clear signals were observed at Belle II.**
- **More data are needed.**

$e^+e^- \to p\bar{p}J/\psi$ via ISR:

The cross section for $e^+e^- \to P_c\bar{p}$ is estimated to be $\lesssim \mathcal{O}(0.1$ pb) [PLB 872 (2026) 140007].

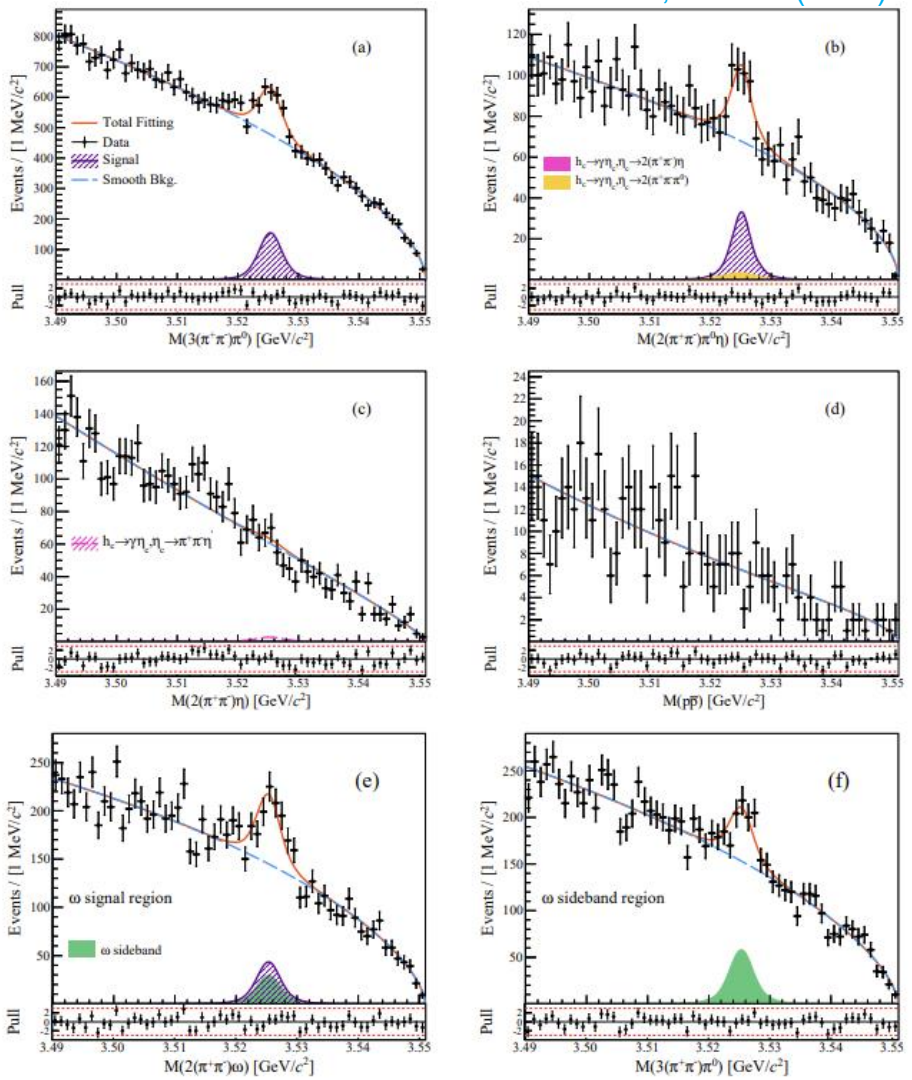




DrSai for charmonium(-like) study

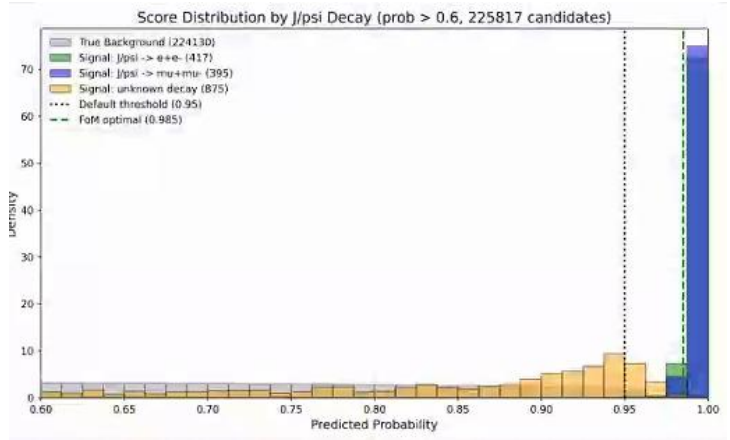
- A set of exclusive analyses, to search for unknown decay modes, and to improve the precision up to the current experimental sensitivity limits.
  - $\mathrm{Br}(h_c \to \text{light hadrons})$ to be $(8.8 \pm 0.8)\%$ and $(48 \pm 7)\%$ with the perturbative QCD(PQCD) and non-relativistic QCD (NRQCD) [PRD **65**, 094024 (2002)]
  - $\mathrm{Br}(h_c \to \mathrm{ggg}) = 57\%$ based on QCD calculations [PRD **66**, 014012 (2002)]

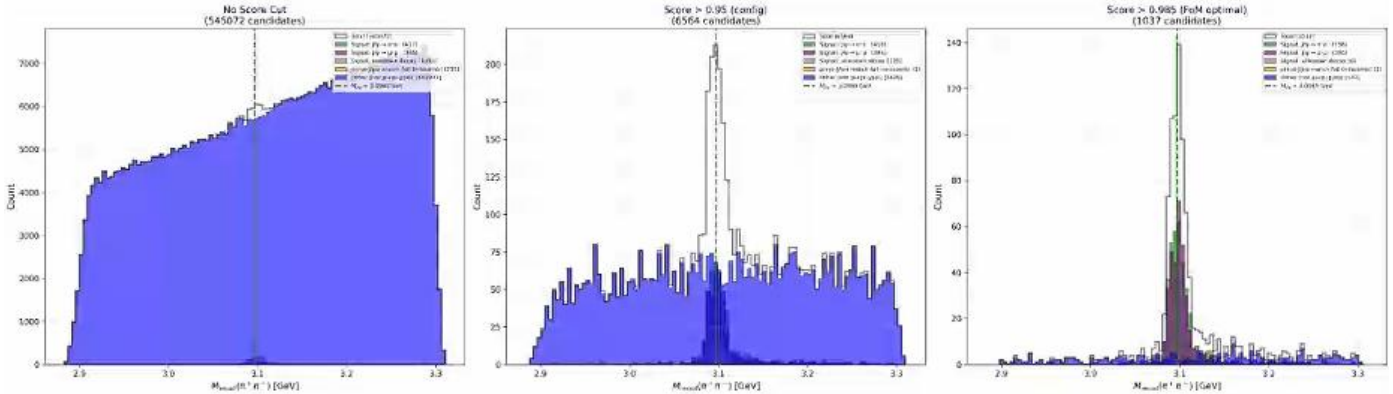
PRD **109**, 072018 (2024)



DrSai for charmonium(-like) study

- More complex jobs:
  - PWA
    - With amplitudes written with AI
    - Based on available PWA packages
  - Build ML-based selection, no need of the knowladge of ML
    - Build user-friendly skills
    - To improve efficiencies of $J/\psi, \eta_c$ …





$e^+e^- \to \pi^+\pi^- J/\psi$ training

Summary & Outlook

- We release DrSai v3: General-purpose Agent+DSL+Skills+RAG
  - https://code.ihep.ac.cn/liutong2016/DrSai_v3
- Training: May@IHEP, Aug.@Shenzhen
- AI partner and agent-based analysis is being realized today
  - Only human-AI interaction, no manual coding
    - Fully automatically repetition
    - Developing agents to replace more human-AI interactions.
  - 10~30 CNY per channel (deepseek-v4-pro)
  - Ability is tested, the first analysis is ongoing

Thank you!