CIPANP - Physics at High Energies

Rapporteur Summary

Kirtimaan Mohan (Michigan State U.) & Lisa Everett (Wisconsin), Josh Isaacson (FNAL), Laura Jeanty (Oregon) CIPANP JUNE 2025 Madison, Wisconsin

CIPANP – Physics at High Energy Themes

- Current colliders (LHC)
 - SM
 - Higgs measurements
 - W-boson mass measurements
 - New proton PDFs data and techniques
 - First collider neutrino cross-section measurements
 - BSM
 - SMEFT updates to theory and experimental searches
 - Searches for resonances, LLPs, specific models, exotic scenarios
 - New searches proposed for LHC
 - Significant advances to theory and experiment with Machine Learning
- Future colliders (Muon collider)
 - Detector R&D
 - New Searches suggested and explored



Standard Model



Recent highlights in the Standard Model and Higgs Results from the LHC (Alexander Khanov, Oklahoma State University)

- Topics covered in this talk
 - Higgs boson production cross-section with constraints on SMEFT coefficients
 - ggF +VBF $(H \rightarrow WW^*)$
 - VH $(H \rightarrow WW^*)$
 - Differential cross-section combination with constraints on coupling modifiers
 - Higgs boson mass and width in $H \rightarrow ZZ^*$ and $H \rightarrow WW^*$
 - di-Higgs production $(H \rightarrow bb \gamma \gamma)$ with constraints on Higgs trilinear coupling
 - jet cross-section and substructure many jet observables measured- test of QCD!
 - physics with same-sign WW pairs
 - Evidence for Longitudinal W boson pair scattering test of SM!
 - First dedicated Z mass (Z $\rightarrow \mu\mu$) measurement at LHC
 - SMEFT interpretations and constraints on Wilson coefficients

m_H=125.04±0.11(stat)±0.05(syst) GeV

Focus talk on recent Higgs measurements from ATLAS

Production cross sections:

 $H \rightarrow ZZ^* \rightarrow 4\ell \underline{\text{ATLAS-CONF-2025-002}}$ $VH, H \rightarrow WW^* \underline{\text{HIGG-2023-09}}$ $(ggF + VBF)H \rightarrow WW^* \underline{\text{HIGP-2024-07}}$

Width measurements:

 $H^* \to WW \to \ell \nu \ell \nu \ \underline{\text{HIGP-2024-05}}$









(Lucrezia Boccardo, Genova)

W Mass from ATLAS

(Hugo Beauchamin, Tufts)



nD

(combined fit)

also dijet data, but don't

know how to

combine with inclusive jets

(officially)

Global QCD analyses

Preliminary

Towards new CTEQ (CT25) PDFs

NNLO fits with new data (nD) from LHC at 8 and 13 TeV

 χ^2/N_{pt} for CT18A + new data (vs. CT18A at right) NNLO fits; 68% CL (fits with 1 new process, **ID** Experimental data set N_{pt} CT25prel CT18A 'nProcces') **Drell-Yan pair production** $2.37^{+1.30}_{-0.68}$ $3.56\substack{+2.26\\-1.65}$ 211 ATLAS 8 TeV W 22 $2.10^{+2.20}_{-0.38}$ $2.13\substack{+3.46 \\ -0.30}$ 12212 CMS 13 TeV Z $1.14^{+0.10}_{-0.04}$ $1.21\substack{+0.32 \\ -0.15}$ 188 214 ATLAS 8 TeV Z 3D nDY $0.74_{-0.08}^{+0.31}$ $0.70^{+0.2}_{-0.0}$ 215 ATLAS 5.02 TeV W,Z 27 $1.47\substack{+0.43\\-0.38}$ 217 LHCb 8 TeV W 14 $1.06^{+0.76}_{-0.28}$ $1.29^{+0.95}_{-0.44}$ 16218 LHCb 13 TeV Z 13 TeV $t\bar{t}$ production $1.07\substack{+0.08\\-0.05}$ $1.07\substack{+0.12\\-0.07}$ 12521ATLAS all-hadronic $y_{t\bar{t}}$ $1.10\substack{+0.56\\-0.40}$ $1.13\substack{+0.85\\-0.53}$ CMS dilepton $y_{t\bar{t}}$ 10528nTT $1.38^{+0.65}_{-0.40}$ $1.44_{-0.56}^{+0.89}$ CMS lepton+jet $m_{t\bar{t}}$ 15581 $0.94\substack{+0.13\\-0.11}$ $0.94\substack{+0.28\\-0.09}$ ATLAS lepton+jet $m_{t\bar{t}} + y_{t\bar{t}} + y_{t\bar{t}}^B + H_T^{t\bar{t}}$ 34587**Inclusive** jet production $1.54_{-0.06}^{+0.09}$ $1.57^{+0.12}_{-0.07}$ ATLAS 8 IncJet 553171 $1.25\substack{+0.07 \\ -0.03}$ $1.26\substack{+0.08\\-0.04}$ ATLAS 13 IncJet 554177nIncJet $1.11_{-0.09}^{+0.13}$ $1.10\substack{+0.21\\-0.10}$ 555CMS 13 IncJet 78

Important updates for precision measurements at the LHC

776 new data points from DY, $t\bar{t}$ and jets for CT25

High Energy Neutrinos at Colliders



Dennis Soldin, U. of Utah

Looking to the future (Run4)



- Pseudorapidities: $\eta \gtrsim 7.5$
- Four proposed experiments:
 - ► <u>FASER2</u>
 - Magnetic tracking spectrometer (search for light and weakly-interacting states)
 - <u>FASER $\nu 2$ </u>
 - Emulsion detector (detection of TeV neutrinos)
 - ► <u>FLArE</u>
 - ▶ 10-ton noble liquid fine-grained TPC (detection of neutrinos and light dark matter)
 - FORMOSA
 - ► Scintillating bars (detection of millicharged particles)

Proposal for medium-baseline detectors



Beyond Standard Model



Recent highlights in BSM searches from the LHC Shivani Lomte (UW-Madison)

- Topics covered
 - Dark Matter Searches
 - DM+ pencil Jet
 - Mono Higgs
 - Dark Higgs ٠
 - Resonances ٠
 - Diboson resonances
 - Dijet resonances
 - $H \rightarrow aa \rightarrow 4\tau$
 - γH and γZ
 - Low mass (60 GeV) data scouting ٠
 - SUSY •
 - **Direct Slepton production**
 - Electroweakinos
 - Searches via boosted objects
 - Exotic/Unconventional Signatures
 - Semi-visible jets ٠
 - **Emerging Jets**

Overview: selective list of recent BSM results at LHC

- 1. Heavy H_{γ} and Z_{γ} resonances with bb
- Exotic Higgs decay to 4 tau final state
- Anomaly detection for di-jet resonance search RATLAS arXiv:2502.09770 3.
- **Direct slepton production** 4.
 - Electroweakinos production **CMS-PAS-SUS-24-003**,
- Comprehensive search with boosted objects 6
- DM+pencil jet
- Mono-Higgs(bb)
- DM with dark Higgs \rightarrow bb 9
- 10. Semi-visible jets
- Emerging jets 11.
- 12. Resonance search using Scouting data 🎬 CMS-PAS-EXO-24-012

- CMS-PAS-B2G-24-007 PATLAS arXiv:2503.05463 QATLAS arXiv:2503.17186 CMS-PAS-SUS-24-012. CMS-PAS-EXO-23-017 CMS-PAS-SUS-23-014
 - CMS-PAS-SUS-23-017
 - CMS-PAS-SUS-23-017
- Phys.Rev.Lett. 134 (2025) 12. 121801
- arXiv:2505.01634
- ATLAS arXiv:2505.02429

This talk

Sara Khaled, NYU

CERN-EP-2025-060

Search for $t\overline{t}$ + pseudoscalar($a \rightarrow b\overline{b}$)

Signal and Background Reconstruction with Neural Networks + BDT

Assume BR(a-> $b\bar{b}$)=100%.

 $g_t \ge 1$ excluded for all masses.

 $g_t \ge 0.5$ excluded from 50-80 GeV.



$$\mathcal{L} = -\frac{g_t y_t}{\sqrt{2}} a \,\overline{t} \, i\gamma^5 t - \frac{g_b y_b}{\sqrt{2}} a \,\overline{b} \, i\gamma^5 b$$



Long-lived neutral particles decaying into the ATLAS muon spectrometer



- Strongest sensitivity to very long-lived signals (cτ>~10m) by searching for displaced vertices in the muon spectrometer
- Several ongoing studies to improve sensitivity towards Run-3.



Spencer Klein, LBNL



CMS g_{ar} (TeV⁻¹) 10 BaBa LEP I and II CDF LHC (pp) 10⁻¹ (10.4 (10.4 (1.0) 10^{-2} o[®] 0.2 10-3 0.1 10-4 0.05 5 6 7 8 10 m_a (GeV) 10-5 10⁻³ 10^{-2} 10-1 10 10³ m_a (GeV) 22 CMS, arXiv:2412.15413

Constraints on BSM Phenomenology with Light-by-Light Scattering in Heavy ion collisions at LHC

- Light-by-light scattering observed and consistent with the SM
- Constraints on BSM via:
 - charged particles in loops
 - axion like particles.

New Vector Like Quark Searches proposed using same sign leptons



T-channel Dark Matter searches at the LHC

Kirtimaan Mohan, MSU





Classification of t-channel Dark Matter models from the LHC Dark Matter Working Group. (arXiv: 2504.10597)

Interesting physics with non-perturbative effects and bound states.

2504.16700

Symmetry restoring finite counterterms of SMEFT four-fermion operator insertions at one-loop

SMEFT (Standard Model Effective Field Theory):

parametrization of heavy NP obeying local symmetries

theoretical consistency: operator renormalization, finite one-loop matching,...

Here: one step to higher order calculations -

finite renormalization to restore gauged symmetries at one-loop



finite counterterms needed for four-fermion operator (contact) insertions



Machine Learning

Recent advances in ML for Physics Analysis at CMS

(Raghav Kansal, Caltech/FNAL)

MLG-23-005

POIs

 $\min\left(-\log\left(\mathcal{L}\right)\right)$

MLG-23-003

ABCDisCo method

 $r_s \pm \Delta r_s$

Histogram

 $D_H \subseteq \mathbb{N}^{h \times l}$

 $\hat{\mathbf{y}} \to H(\hat{\mathbf{y}})$

 $\min(\Delta i)$

BTV-22-001





Recent advances in ML for Physics Analysis at ATLAS

(Nicholas Luongo, ANL)

GN2: state-of-the-art ATLAS flavor-tagging ATLAS, 2306.04415 algorithm with neural network architecture



CWoLa (Classification Without Labels) ATLAS, 2505.09770

Search for narrow-width resonance decaying to two large-R jets using background estimation and weakly-supervised classifier

Unsupervised 2-body Anomaly Detection: <u>Phys. Rev. Lett. 132 (2024) 081801</u> resonance in 2-body jet + X final states

Emerging jets: ATLAS, 2505.02429

Example: dark sector paradigm, Z' mediator



Jet classification from transformer architecture inspired by GN2

Semi-visible jets: ATLAS, 2505.01634

train fully supervised Particle Flow Net (PFN) classifier semi-supervised anomaly detection (ANTELOPE)

Neural Simulation-Based Inference (NSBI):

Rep. Prog. Phys. 88 (2025) 067801

physics parameter estimation using learned, high-dimensional likelihood ratios

Studying Hadronization with ML and the Road to "differentiable" Pythia (MLHAD) Stephen Mrenna, Fermilab

- Characterizing the hadronization of parton showers using the HOMER method: [arXiv:2503.05667]
- Towards a data-driven model of hadronization using normalizing flows: (MAGIC) doi:10.21468/SciPostPhys.17.2.045 [arXiv:2311.09296]



Muon Collider



https://home.cern/science/accelerators/muon-collider

Physics at High Energies: summary

Detector R&D for a 10 TeV Muon Collider

Many detector challenges for high energy muon collider Ex: large beam induced background (BIB)

Overview of one possible detector design: MAIA (Muon Accelerator Instrumented Apparatus)

Evolution of 3 TeV CLIC detector:

BIB shielding

solenoid inside calorimeters, reoptimized tracker, incr. cal. depth

Detector performance evaluated w/single particle samples tracker, EM/hadronic calorimeters, radiation damage,...

Studies of more complex object reconstruction underway Lots more work to do!





2502.00181

(Benjamin Rosser, U. Chicago)

Fermion portal dark matter at a muon collider

(Pouv	/a A	sadi,	Oreg	(on)
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f	Q	u	d	e	L
SM Charges	(3,2,1/6)	(3,1,2/3)	(3,1,-1/3)	(1,1,-1)	(1,2,-1/2)





2312.03826, 2412.14235

Searches for ϕ in the freeze-in limit at a 10 TeV MuC:

cut-and-count analysis:

signal: dijet/dilepton + MET

µ parton PDF should be included for meaningful predictions!



benchmarks: O(100%) sys. tolerable



Electroweak Observables in Neutrino-Electron Scattering at a TeV Muon Storage Ring

Elastic neutrino-electron scattering as neutrino microscope

Concept: companion neutrino detector near the muon collider / muon storage ring



precision access to running of weak mixing angle, neutrino weak couplings, flavor dependent-couplings... possibility of electroweak observables of <1% precision with neutrino scattering! 2505.00152

Outlook

- Lots of great progress!
- Lots of great innovation!
- More data is coming!
- More results and innovation imminent!

INTERSECTIONS - CIPANP 2025

