

LHCP Boston 2024

The 12th Large Hadron Collider Physics Annual Conference

June 3-7, 2024 @ Northeastern University

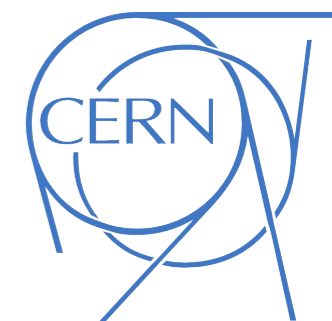
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Photo credit: Alina Mak



Poster Awards

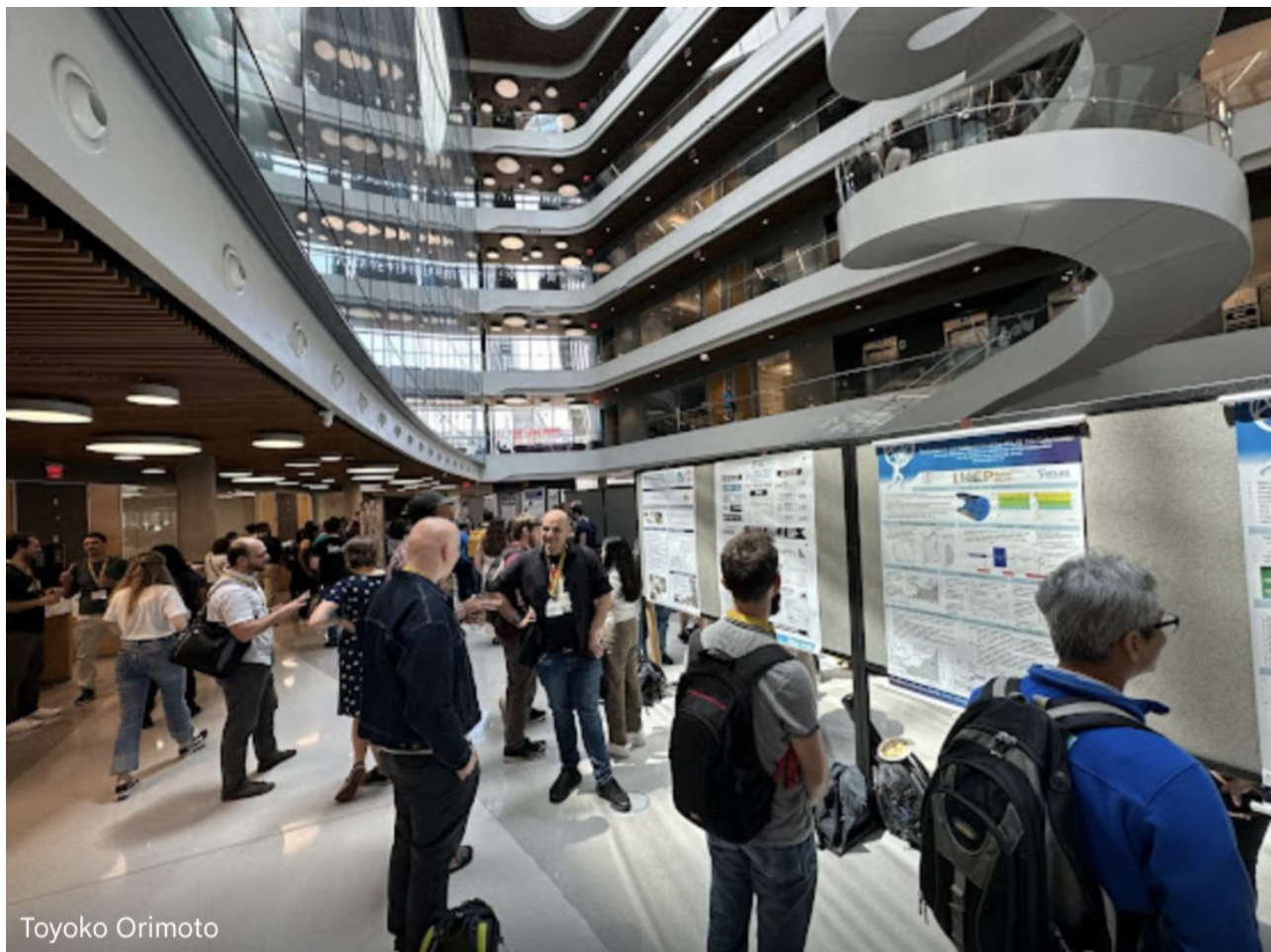
Sarah Demers, Yale University
*Chair of the LHCP2024 Poster
Award Committee
Conference Co-Chair*



First, some thanks!

- **Thank you** to the local organizers who put the poster session together, with special thanks to Darien Wood
- **Thank you** to IUPAP for the Conference sponsorship that enabled us to give out awards.
- **Thank you** to the team of judges
 - Marina Artuso, Andrea Beraudo, Stefania Bufalino, Rebeca Gonzalez Suarez, Laura Havener, Larry Lee, Ian Moulton, & Matt Reece
- **Thank you** to the poster presenters for engaging presentations of wonderful work
- **Thank you** to all for engaging with the posters





Toyoko Orimoto

We had almost 100 posters spanning many topics.

Judges were looking for well-crafted posters and for clear and engaging presentations.

The quality of posters and presentations was so high that it was very difficult to choose our five winners!

BSM (1 TeV)	22
BSM (Feebly Inter. Particles)	6
Electroweak Physics	4
Higgs Physics	8
Top Physics	2
Flavour Physics	2
QCD Physics	3
Heavy Ion Physics	4
Performance & Upgrade Tools	15
Upgrades	18
Future Prospects	5
Outreach, Diversity, Inclusion	8



Toyoko Orimoto

Carrying the trigger “menu” analogy to a flawless conclusion, this poster wowed the judges not only with its creative layout, but it also served as excellent support for a great overview of the ATLAS Run 3 Trigger system by Marco!

THE ATLAS RUN 3 TRIGGER MENU

MARCO MONTELLA [1]
ON BEHALF OF THE ATLAS TRIGGER GROUP

OUR SIGNATURES

ELECTRONS 270 HZ

MUONS 290 HZ

TAUS 160 HZ

JETS & MET 630 HZ

ABOUT US

ATLAS runs a two-level triggering strategy:

- L1** → Hardware-based, coarse reconstruction, total accepted rate is 90-100 kHz
- HLT** → Software-based, reconstruction precision approaching offline reconstruction

The Trigger Menu is limited by:

- L1 RATE** → Constrained by dead time impacts the range of physics accessible
- HLT CPU** → Limits the execution rate of high-precision reconstruction algorithms
- TO CPU** → Limits the data volume that can be reconstructed promptly for endpoint analysis

L1/HLT limitations scale with luminosity:

- END OF FILL** → Enhance signatures limited by L1 rate and/or HLT rate & CPU

OUR STREAMS

MAIN
For prompt reconstruction
Rate limited by L1, CPU & TO Resources 1.7 KHZ

DELAYED Hadronic B-Physics
Delayed Processing when TO CPU available 900 HZ

TRIGGER-LEVEL ANALYSIS (TLA) Jets, Photons, b-tag
Reduced event content, HLT Objects only. Minimal burden on bandwidth 5+ KHZ

PARTIAL EVENT BUILDING (PEB) Jets, Photons, B-tag
Regional data around near physics objects identified by trigger 0.5 KHZ

Specialty TRIGGERS

EMERGING JETS	10 HZ	DISAPPEARING TRACK	4 HZ	HEAVY IONS: RUN 2 THRESHOLDS PRESERVED!
HIGHLY IONIZING TRACK	5 HZ	DISPLACED OBJECTS	40 HZ	
ISOLATED TRACK	1 HZ	PARTIAL EVENT BUILDING	200 HZ	

CHEF'S NOTES

AN UPGRADED SYSTEM

Meeting the challenges of higher luminosity & beam intensity:

L1

- NEW DIGITIZED LAR CALORIMETER READOUT** → x10 Calo Granularity!
- NEW L1CALO FEATURE EXTRACTORS:**
 - eFEX** → High granularity EM & Tau core reconstruction
 - jFEX** → L1 Jet & hadronic Tau shower isolation
 - gFEX** → Coarser granularity for large-scale reconstruction (large-R jets, MET)
- OVERHAULED MUON TRIGGER:** → NSW + New EndCap Processor
- RENEWED L1TOPO** → New logic for input data from Phase-1 FEXes

HLT

- TRACKING IMPROVEMENTS:**
 - LARGE RADIUS** → High efficiency reconstruction for LLP signatures
- FULL SCAN TRACKING+VERTEXING FOR HLT JETS:**
 - Particle Flow Reconstruction
 - High Performance Flavour Tagging
- 'REAL TIME ANALYSIS':**
 - MULTI-OBJECT TLA** → Combined signatures (e.g. Photon +Jets)
 - PARTIAL EVENT BUILDING** → Regional data around near physics objects identified by trigger

ELECTRONS & MUONS THE STAPLES

NEW & IMPROVED IN '22

Run 3 Entrées

LRT & B-TAGGING AND MUCH MORE!

CERTIFIED PERFORMANCE!

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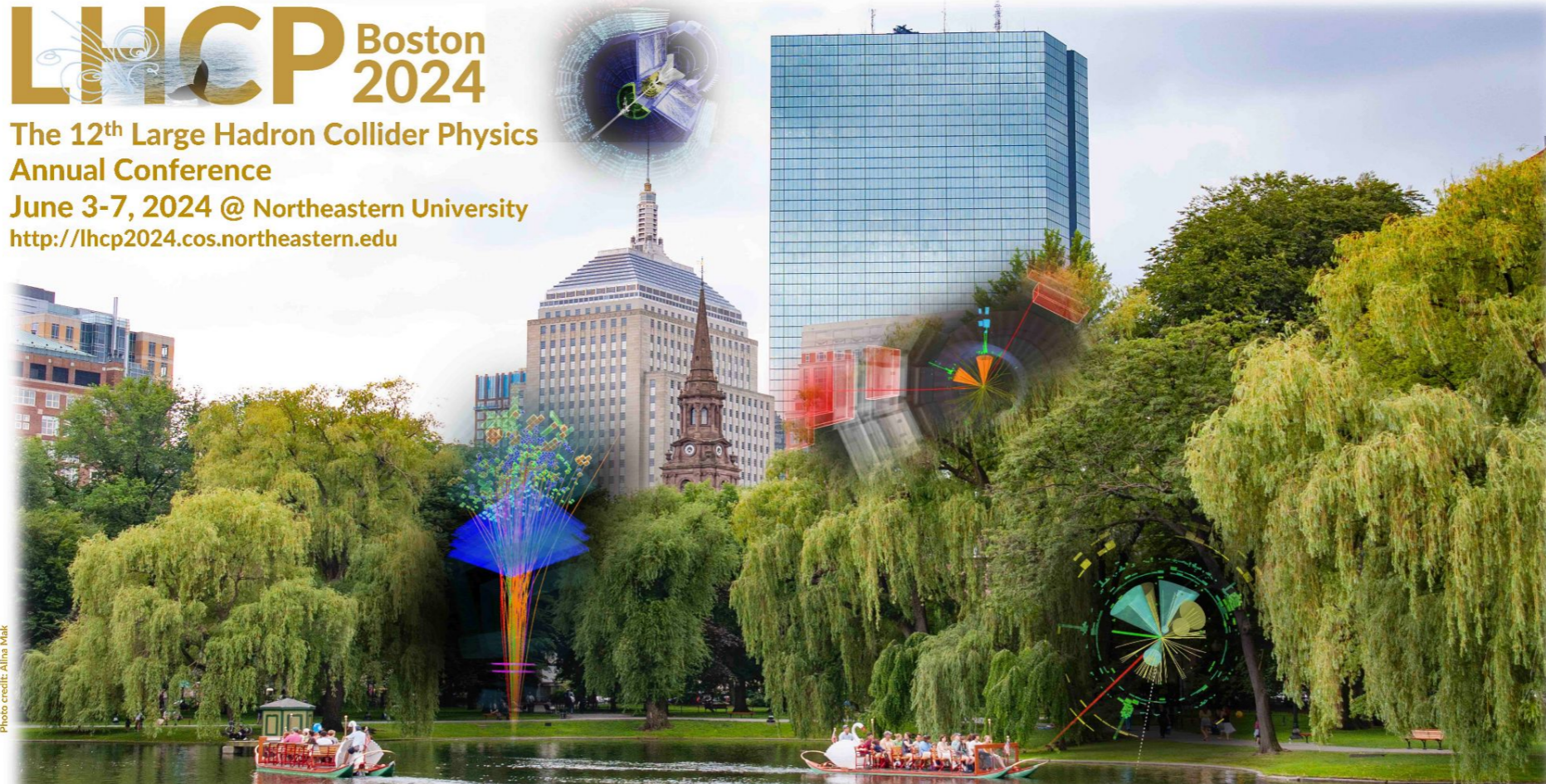
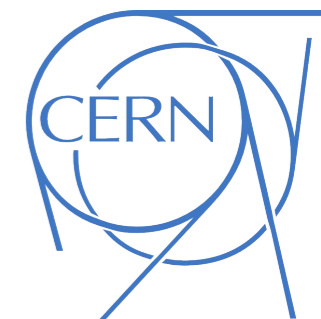


Photo credit: Allina Mak

Marco Montella, Ohio State University

For the poster entitled:

"ATLAS Trigger Menu in Run 3"



Shahram Rahatlou
Chair of the LHCP2024
International Advisory
Committee

7 June 2024

Sarah Demers
Chair of the LHCP2024
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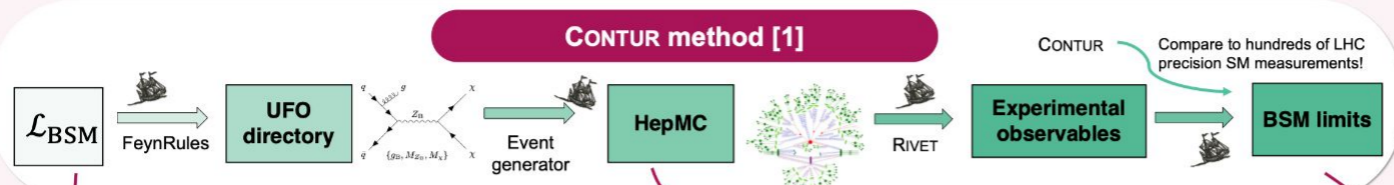
Dark Matter from Anomaly Cancellation at the LHC

Submitted to Physical Review D, arXiv: 2405.03749

Jon Butterworth¹, Hridoy Debnath², Pavel Fileviez Pérez², Yoran Yeh¹

¹ Department of Physics and Astronomy, University College London, UK

² Physics Department and Center for Education and Research in Cosmology and Astrophysics (CERCA), Case Western Reserve University, USA



Theory and motivation

- Promote **global baryon number** to **local gauge symmetry** [2]: $\mathcal{G}_{SM} \otimes U(1)_B$
- New particles from anomaly cancellation:**
 - Leptophobic Z_B gauge boson
 - New Higgs boson h_B (mixes with SM Higgs via θ_B)
 - Stable Majorana dark matter (DM) candidate χ
 - Upper-bound of symmetry breaking at $\mathcal{O}(\text{TeV})$ → Test theory at (HL-)LHC!

Phenomenology

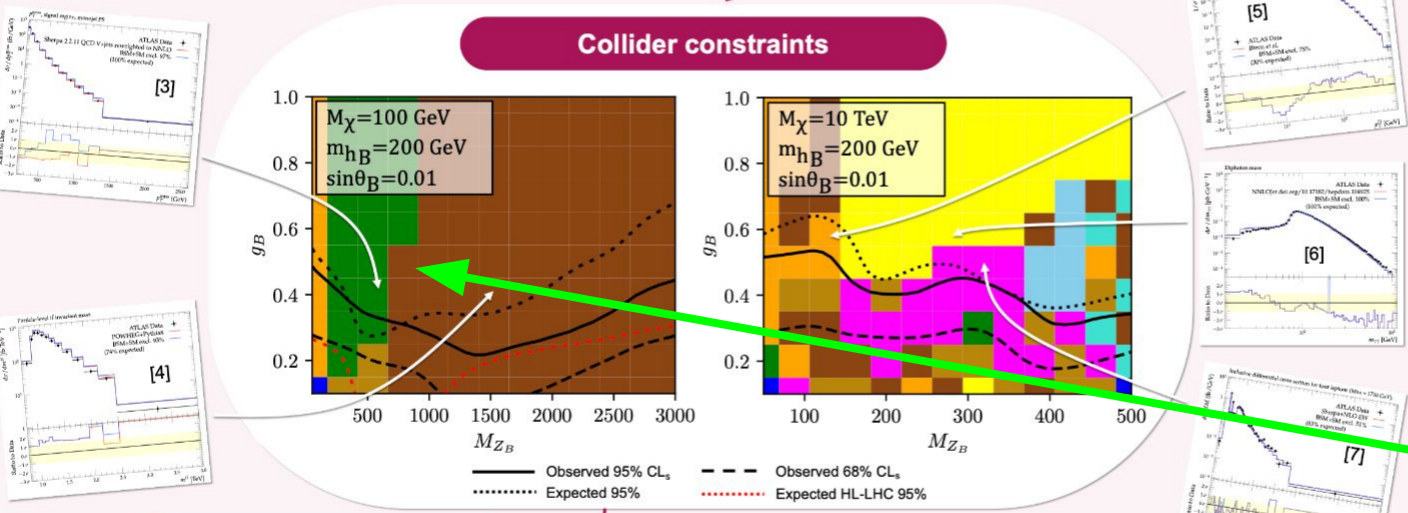
Relevant parameters: $M_{Z_B}, M_\chi, M_{h_B}, g_B, \theta_B$

Distinct signatures at LHC from heavy decays:

- $Z_B^{(*)} \rightarrow q\bar{q}, \chi\chi$
- $h_B \rightarrow \gamma\gamma, WW, ZZ, hh, Z_B Z_B$

"Cucuyo-Higgs"

Collider constraints



Dark Matter constraints

- Constraints from Dark Matter relic density
- Perturbativity bound
- Direct detection limits

Future prospects

- i) well motivated, anomaly free theory ii) with a DM candidate iii) close to the EW scale
- Compatible with current collider, direct detection and DM limits
- Estimated sensitivity clearly shows potential to probe it at HL-LHC!
- Look out for e.g. $p_T^{miss} + jets$, h_B decays, $\bar{t}t$, or **more exotic signatures!**

Who doesn't want to see their analysis have a second life by feeding into other searches and constraints? This clear poster tells an interesting story that not only highlights LHC measurements, but also pulls in direct detection dark matter experiments.

(Yoran's analysis is in green...)

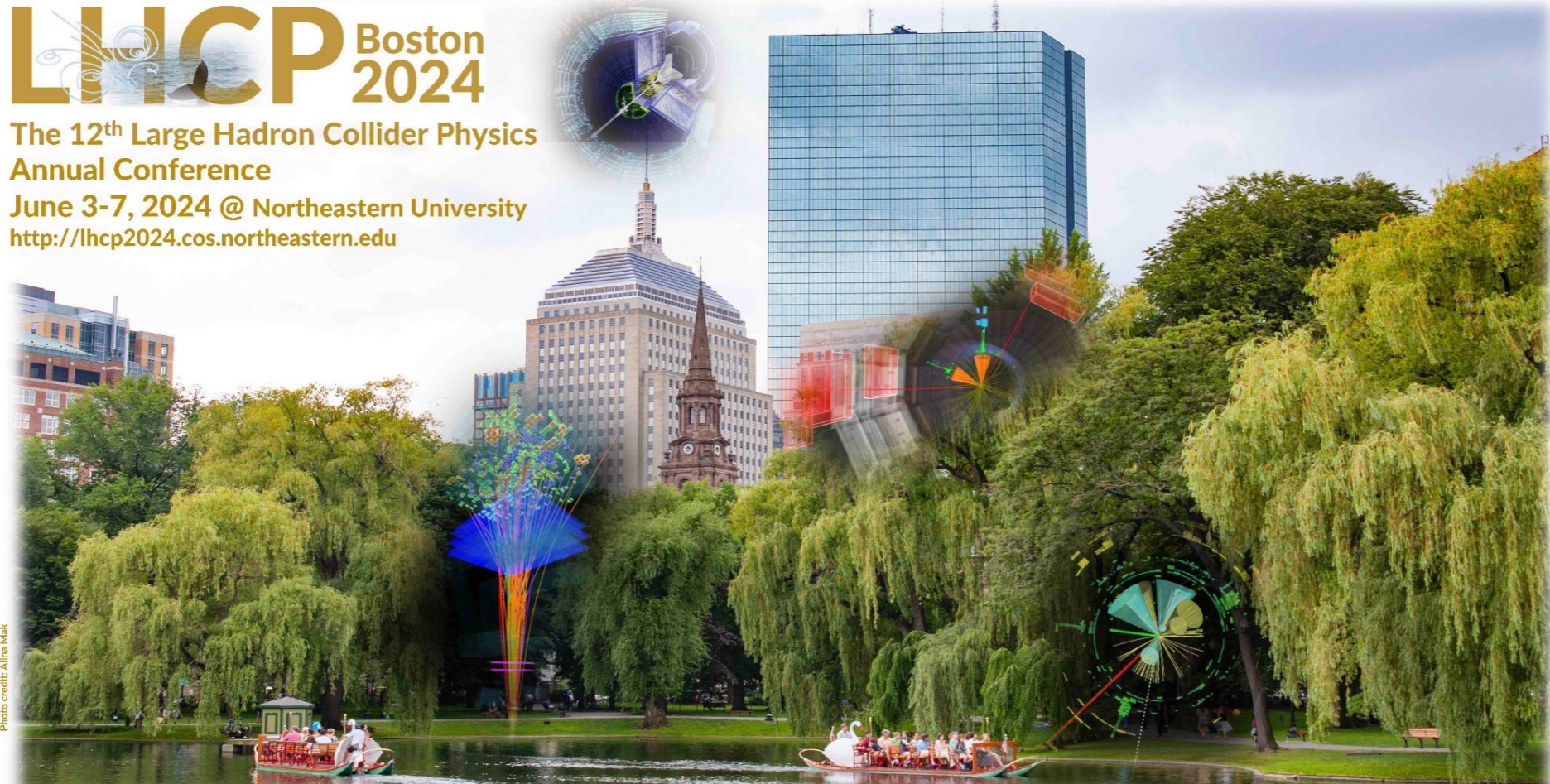
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Yoran Yeh, University College London



For the poster entitled:

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Hannah Bossi (MIT), Arjun Kudinor (Cambridge), Ian Moutl (Yale), Daniel Pablos (Santiago), Krishna Rajagopal (MIT)

This poster's display of the beauty and challenge of heavy ion collisions was expertly explained. A wonderful combination of theory and experiment!

Motivation

Quark Gluon Plasma (QGP) → strongly coupled liquid of deconfined partons.
 Jets & jet substructure → useful probe of vacuum QCD and of the QGP.
 Jets & jet substructure modification in medium → probe interaction with medium.
 Energy Correlators probe *shape* of energy flow in vacuum. In the presence of a medium, it probes the *shape of the medium response via energy flow.*

Jets and the QGP

Jets produced during the initial hard scattering traverse the QGP. Medium evolution is imprinted on jets!

Jets & their substructure are modified in medium [1]

Medium Response (Strong Coupling Limit): Wake

Impact of medium on jet: AdS/CFT Drag, "Jet Energy Loss", Drag Force

Impact of jet on medium: Negative Wake, Wake, "Medium Response", Hydrodynamic Wake

For details, see [2]

*Schematic in position space

Energy Correlators in Vacuum

$$ENC(R_L) = \left(\prod_{k=1}^N \int d\Omega_{\vec{n}_k} \right) \delta(R_L - \Delta \hat{R}_L) \cdot \frac{1}{(E_{jet})^{(n^*N)}} (\mathcal{E}^n(\vec{n}_1) \mathcal{E}^n(\vec{n}_2) \dots \mathcal{E}^n(\vec{n}_N))$$

Projected Correlators

QCD angular ordering!

Hybrid model, vacuum Hadrons, n = 1.0 Full anti-k jets, R = 0.8

- 40 < p_T < 100 GeV/c
- 100 < p_T < 200 GeV/c
- 200 < p_T < 300 GeV/c
- 300 < p_T < 400 GeV/c
- 400 < p_T < 500 GeV/c
- 500 < p_T < 1000 GeV/c

3-point correlator (EEEEC)

Configurations: Equilateral Flat Isosceles

Collinear singularity of vacuum QCD!

Collinear Singularity

Hydro, Vacuum n = 1.0, 0.8 < R_L < 0.7 Full anti-k jets, R = 0.8 140 GeV/c < p_{T, jet} < 160 GeV/c

Full anti-k jets, R = 0.8 140 GeV/c < p_{T, jet} < 160 GeV/c

$$\phi = \arcsin \sqrt{1 - \frac{(R_L - R_M)^2}{R_S^2}} \quad \xi = \frac{R_S}{R_M}$$

EEEEC sensitivity to the Wake

√s = 5.02 TeV
 Jet Radius = 0.8

Ratio with vacuum shows **significant enhancement in the equilateral region - effect of the wake!**

Pb-Pb Vacuum

Sensitivity to medium response: EEC & E3C

Normalized EEC vs R_L

Normalized E3C vs R_L

Hybrid Model (Inclusive Sample) Hadrons, n = 1 Full anti-k jets, R = 0.8 260 GeV/c < p_{T, jet} < 360 GeV/c

- Vacuum Jet
- Jet + wake
- Jet + no wake

Wake appears at large R_L

Ratio with vacuum correlations of different contributions:

Jet-Jet-Wake, Jet-Wake-Wake, Wake-Wake-Wake

Sensitivity to medium response: E3C/EEC

Deviations from vacuum scaling – Wake effects!

Ratios-robust to detector effects minimize uncorrelated background

γ-tagged jets show similar behavior!

Evolution of medium effect with R_L

γ-tagged jets: 140 GeV/c < p_T^{jet} < 200 GeV/c p_{T, min}^{jet} > 40 GeV/c

Effect of the **wake** is prominent at **larger values of R_L**

0.4 < R_L < 0.5, 0.5 < R_L < 0.6, 0.6 < R_L < 0.7

γ-tagged jets mitigate selection bias – wake effect is larger!

Summary:

- Energy Correlators are sensitive to medium effects such as the wake.
- Higher point correlators highlight the shape of the medium response.

[1] <https://arxiv.org/pdf/2110.14490>
 [2] <https://arxiv.org/pdf/1405.3864>

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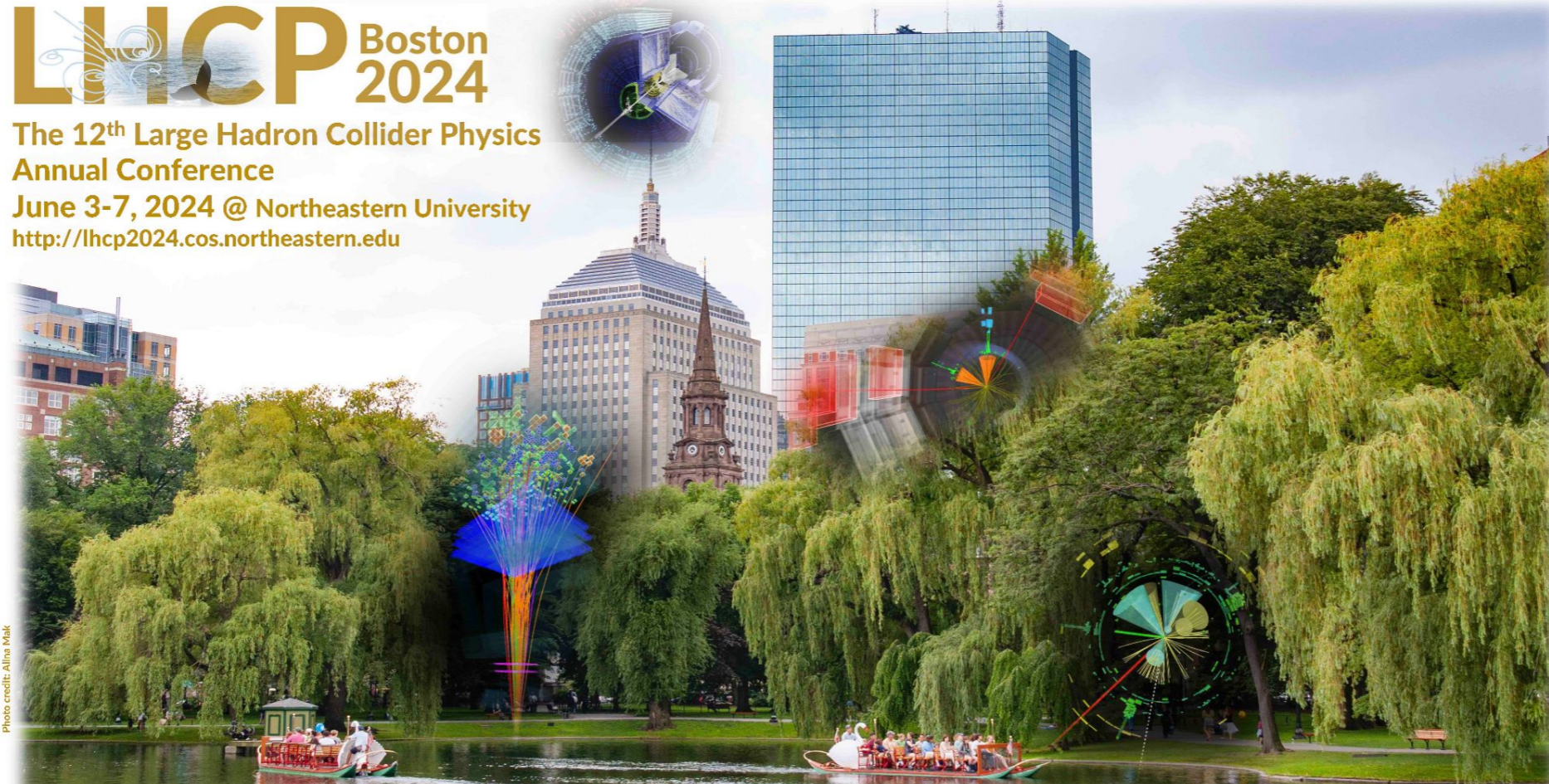
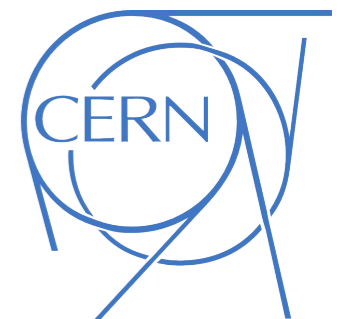


Photo credit: Allina Mak

Ananya Rai, Yale University

For the poster entitled:

"Imaging the Wake of a Jet with Energy Correlators"



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Precision Alignment of the CMS Electromagnetic Calorimeter

Curt Thoreson, on behalf of the CMS Collaboration

Northeastern University: LHCP 2024 Boston: 12th Large Hadron Collider Physics Conference



ECAL Must Provide

- Fast and efficient readout for online selection
- High resolution of the measured energy and position of reconstructed particles

ECAL PbWO₄ Crystals & Readout Technology

- Homogenous medium
- Fast light emission: ~80% in 25 ns
- Small radiation length: $X_0 = 0.89$ cm
- Small Molière radius: $R_M = 2.10$ cm
- Reasonable radiation resistance
- Avalanche Photodiodes and Vacuum Phototriodes convert scintillation light from crystals into an electronic pulse in the EB and EE, respectively

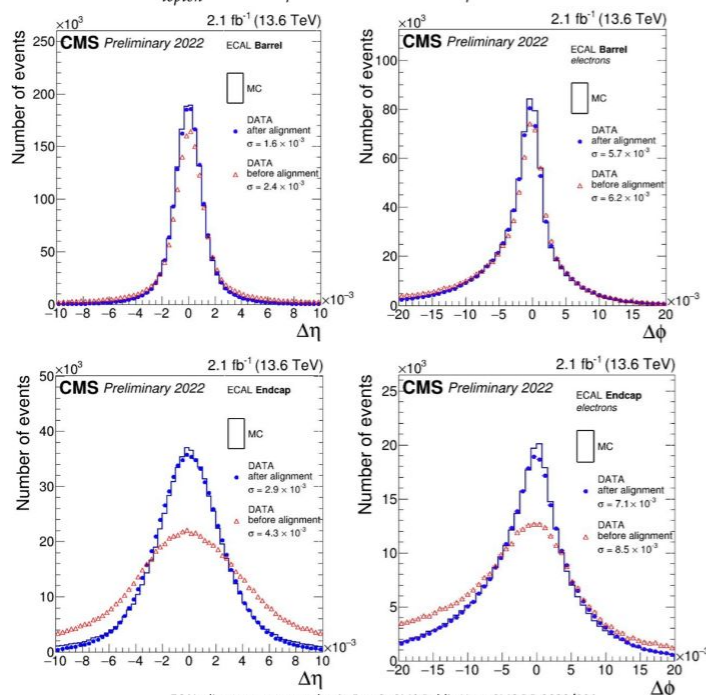
Why We Need ECAL Alignment

- The primary function of ECAL is to measure precisely the energy/position of electrons and photons
- Precise alignment ensures that the energy deposits reconstructed in the ECAL match accurately with the particle tracks
- Accurate alignment allows for more precise determination of the momentum direction of particles
- Proper alignment is crucial for precisely reconstructing the vertex of diphoton events, thus accurately identifying the origin of particle interactions
- Misalignment blurs the boundaries between neighboring crystals, causing difficulty to separate showers and correctly identify particles

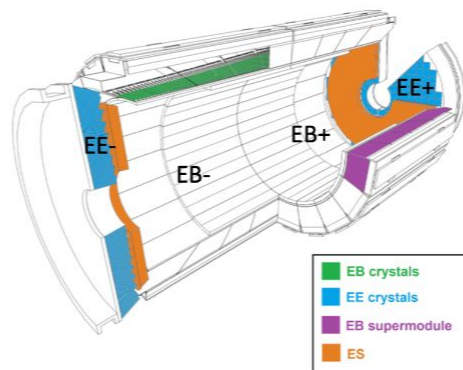
Alignment Procedure

- Relative alignment of the ECAL crystals and tracker, measured using low bremsstrahlung electrons from $Z \rightarrow ee$ events
- Angular distance between extrapolated track and cluster position is minimized for both e^- and e^+ using MC simulations
- The minimization is performed for each supermodule and Dee with respect to the MC simulation expectation values
- Plots show residual difference in $\Delta\eta$ and $\Delta\phi$ of the ECAL supercluster and the extrapolated track position. Relative ECAL-track precision of 3×10^{-3} in η units and 7.1×10^{-3} mrad in ϕ achieved in EE
- Meets the ECAL requirements for electron identification of 4×10^{-3} $\Delta\eta$ and 20 mrad in $\Delta\phi$ between the position extrapolated from the tracker and the position reconstructed in ECAL

$$\chi^2_{\pm} = \sum_{lepton} \frac{(\Delta\phi - \langle\Delta\phi_{\pm}^{MC}\rangle)^2}{\epsilon_{\phi}^2} + \frac{(\Delta\eta - \langle\Delta\eta^{MC}\rangle)^2}{\epsilon_{\eta}^2}$$



ECAL alignment w.r.t. tracker in Run 3, CMS Public Note CMS DP-2023/001



ECAL Barrel 61,200 crystals
 ECAL Endcap 14,648 crystals
 Preshower 137,200 Pb/Si strips

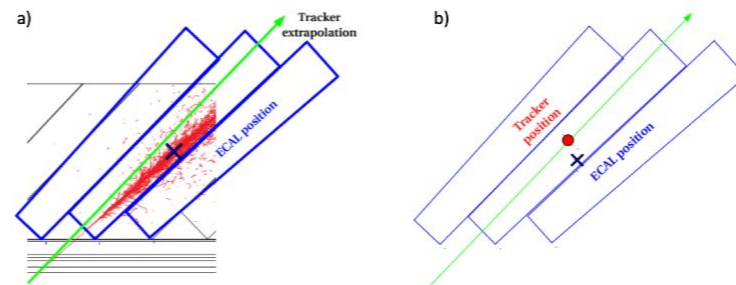


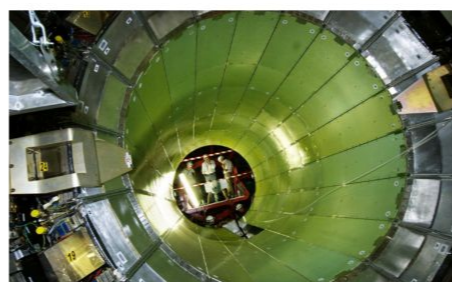
Figure (a) is the position reconstructed by ECAL and Figure (b) is the position extrapolated from the tracker

ECAL Geometry

- The CMS ECAL is comprised of two sections, the barrel (EB) and the endcaps (EE)
- The CMS EB is made of 61,200 PbWO₄ crystals which are divided in 36 identical substructures called Supermodules.
- Each of the two CMS EE is composed of 7,324 PbWO₄ crystals divided into two substructures called Dees
- Each of the two CMS ES is comprised of a plane of lead followed by 68,600 Si strips

Tracker Geometry

- The CMS Tracker is composed of multiple layers of Si sensors which are located in the volume between the ECAL and beam pipe
- The CMS Tracker provides precise measurement of charged particles' trajectory as they pass through the detector



Insertion of the last EB+ SM in 2007



EB Crystal with APD

“Precision” and “Alignment”, two words that are a personality litmus test, either striking fear or sparking excitement. Regardless, this kind of critical work lays the foundation for the kind of precision physics measurements that the LHC is becoming famous for.

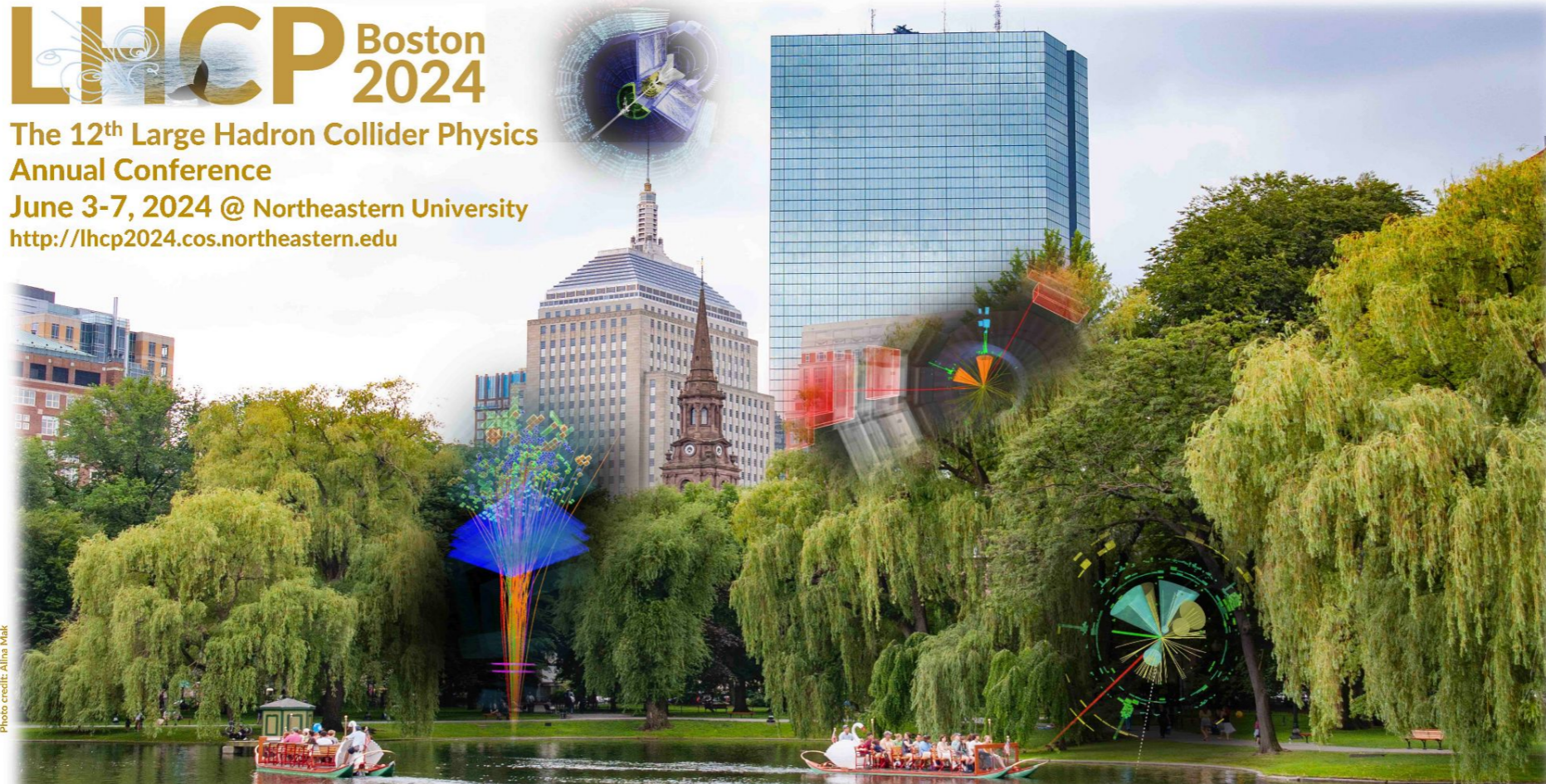
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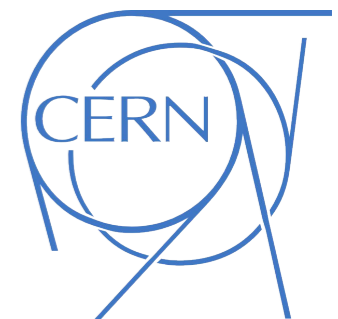


Cort Thoreson, Northeastern University



For the poster entitled:

"Precision Alignment of the CMS Electromagnetic Calorimeter"



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To be uploaded!

The judge was so impressed with the energy and clarity of this presentation that they were still advocating for this poster to be chosen for an award even after it was... We are are excited about the LHCb SciFi upgrade!

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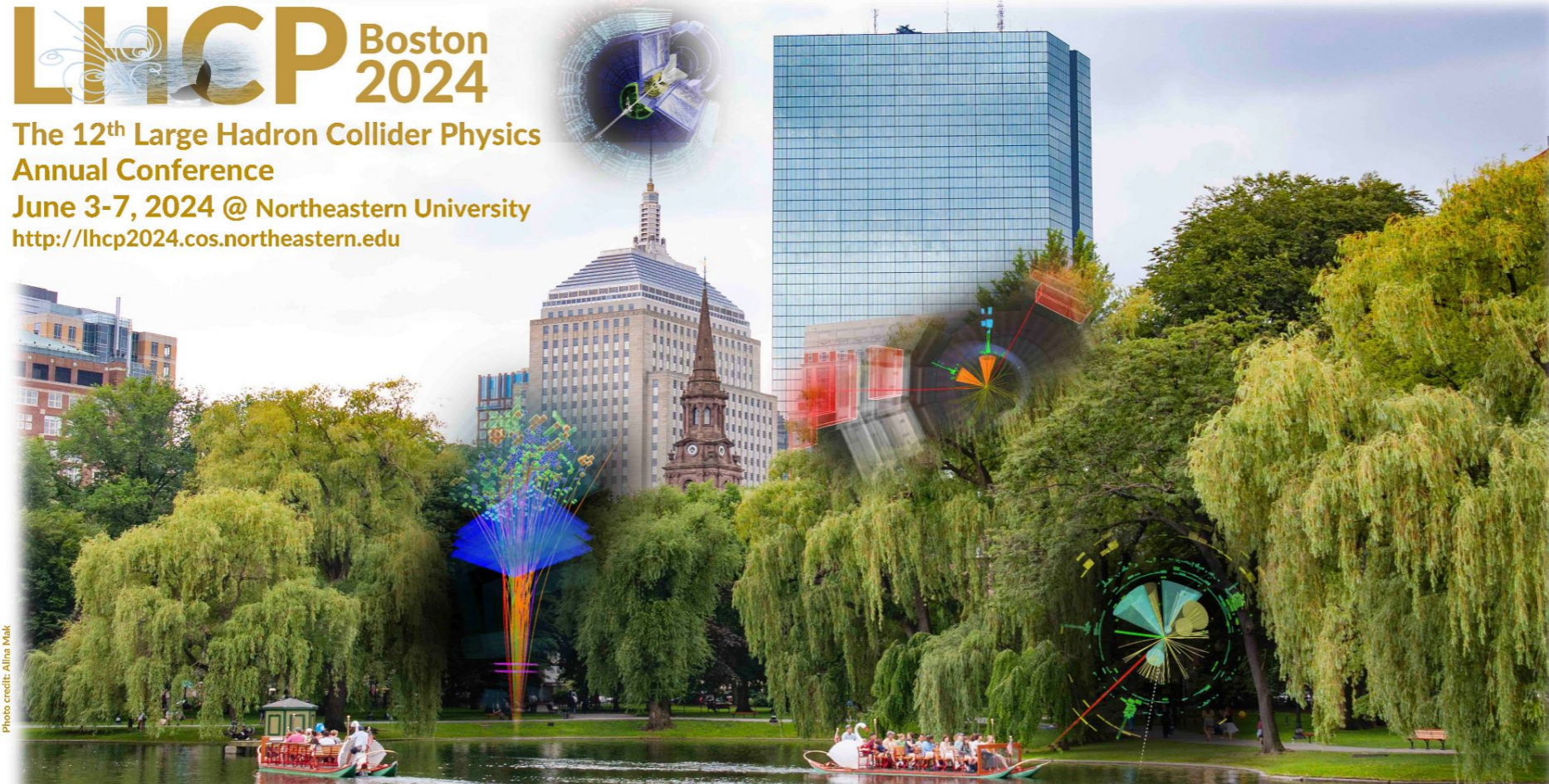
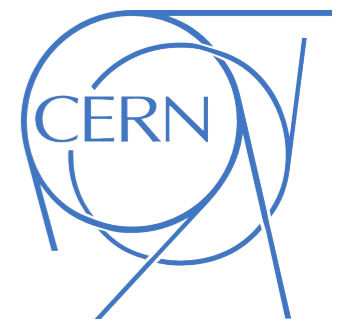


Photo credit: Allina Mak

Carina Trippi, La Salle, Ramon Llull University

For the poster entitled:

"LHCb SciFi Tracker and Future Upgrades"



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