The ALP search with NeuralRinger ATLAS experiment

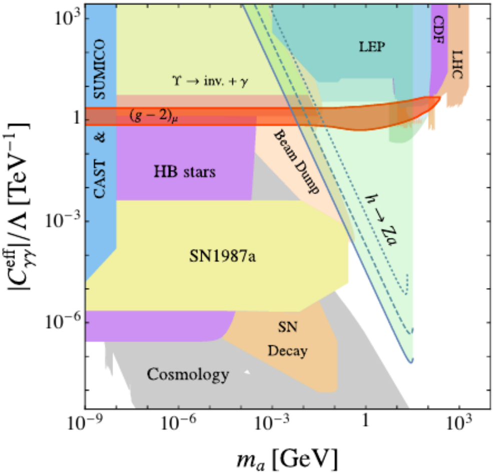
Yara do Amaral Coutinho[a], Luiz Balabram[a], Artur Cordeiro Oudot Choi[b], Mateus Hufnagel[c], Mikola Khandoga[b], Bertrand Laforge[b], Jose Ocariz[b]
[a]Universidade Federal do Rio de Janeiro,
[b]LPNHE, Sorbonne Université, Université de Paris,
[c]Universidade Federal de Juiz de Fora

Axion-like particles (ALP) search

- ALP is inspired by the QCD axion associated with the breaking of the Peccei-Quinn symmetry;
- ALP (pseudoscalar) is a possible DM candidate;
- Suggested in many BSM scenarios, unrelated to the strong CP problem (exception $m_a \propto f_\pi m_\pi / f_a$);
- For ALP, f_a and m_a are independent parameters;
- $(g-2)_\mu$ anomaly $\rightarrow$ the ALP contribution solves the discrepancy between the SM prediction and the measurement of the muon magnetic momentum (Muon $g-2$ experiment);
- $h \rightarrow a + a$, $h \rightarrow Z + a$ ($\mathcal{L}_{eff}$)
- Cosmology/Astrophysics experiments propose the ALP search;
- LHC physics programm, the precision measurements and "searches" are mandatory.

The search of the ALP - parameter space ($m_a \times C_{\gamma\gamma}$)

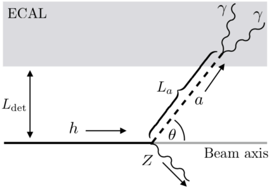
$$h \to Z(\ell^+\ell^-) + a(\gamma\gamma) \qquad \mathrm{a} = \mathrm{ALP}, \ell^\pm = e^\pm, \mu^\pm.$$

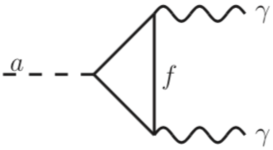


Bauer M. et al., JHEP 12 (2017) 044. Light green → reach of LHC Run 2 with $L_{int} = 300\ \mathrm{fb}^{-1}$ (three values for $|C_{Zh}|/\Lambda$)

Inside detector

- ALPs with small masses and/or very low couplings, present a secondary vertex (displaced vertex). The decay length can be macroscopic, a fraction of them decays inside the detector.





$$\Gamma(a \to \gamma\gamma) = \frac{4\pi\alpha^2 m_a^3}{\Lambda^2}|C_{\gamma\gamma}^{eff}|^2$$

Bauer M. et al., hep-ph 1708.00443

Egamma objects

- Photons and electrons are reconstructed from energy deposits in the EM calorimeter & tracks in the ID;
- After the reconstruction of an energy cluster in the EM calorimeter, a selection is applied based on tracks, information from different layers of the EM calorimeter and leakage in the TileCal;
- This procedure allows to recognize origin of the energy deposit: e^-/γ;
- A sliding window with certain size is used to scan the EM looking for cluster "seeds" (clustering algorithm) with $E_t > 2.5$ GeV;
- Track reconstruction with two sub-steps (algorithm);
- So, e^-/γ candidate reconstruction (cluster seeds & track);
- ID algorithm to identify e^-;
- Photon ID based on cuts on discriminant variables (lateral and longitudinal shower development) in EM calorimeter & leakage to the TileCal.

Strategies for egamma objects

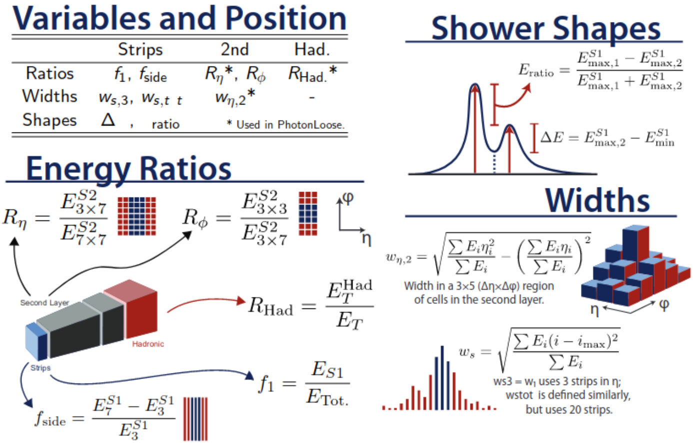
- Shower shape variables;
- NeuralRings;
- R_p mapping;
- Quarter rings and strips.

Cross-talk (XT) mitigation in the EM Calorimeter using Deep Learning

- Electrical connections lead to cross-talk (resistive, capacitive and indutive);
- The cross-talk distorts the signal and degrades the energy and time reconstruction;
- Also alters shower shapes complicating particle ID.

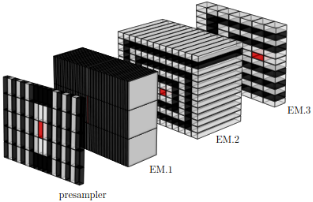
Shower shape variables (identify photons)

They are based on energy deposits in each of the EM calorimeter cells, discriminanting photon candidates from QCD jets. Eur. Phys. J. C 79 (2019) 205, CERN-EP-2018-216

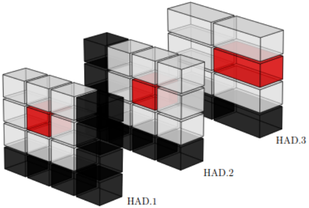


NeuralRinger

Built using all calorimeter layers centered on cluster barycenter. Each ring is the collection of cells around the previous one; ring variable sums E_t of all cells comprised in a ring. ATLAS Note, ANA-TRIG-2021-01-INT1



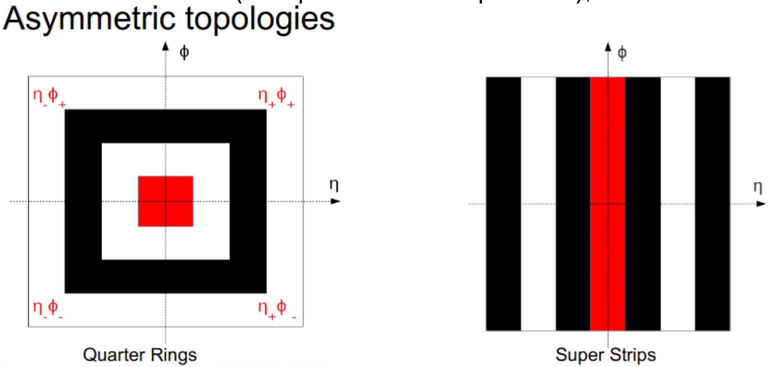
(a) Eletromagnetic calorimeter cells within the ringer reconstruction window.



(b) Hadronic calorimeter cells within the ringer reconstruction window.

Quarter Rings and Strips

The topologies increase the mapping granularity to capture asymetric information from showers (one photon $\times$ two photons);



- R_p (effective shower width), is a discriminant quantity that may be useful for electron detection;
- Weighing the ring-shaped signals as a function of the energy and distance of the rings from the center.

Jets in general

- Jet is defined in terms of the energy deposited in calorimeter cells & identified by a jet algorithm;

Jet algorithms,

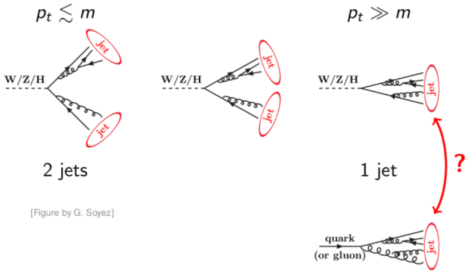
1. The sequential clustering algorithms: kt, anti-kt, Cambridge/Aachen,
2. The seedless infrared safe cone (SIScone).

The jet reconstruction algorithms should be free of divergences (collinear and infrared), so the resulting hard jets are not substantially affected by the small-angle (collinear) and soft splittings that occur in a parton shower, which ensures that one obtains finite results at every order in perturbation theory.

In many cases, a jet is formed from several objects and one can try to reconstitute these objects

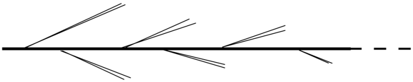
Jets in general

- Kind of jets: single photons (jets dominated by single photons), photon-jets (collinear photons), single electrons (jets dominated by single electrons), electron-jets (collinear electrons) and QCD-jets;
- If a di-photon system (ALP) is highly collimated → it fakes single photon. The challenge is the separation of single photon from "photon-jets".



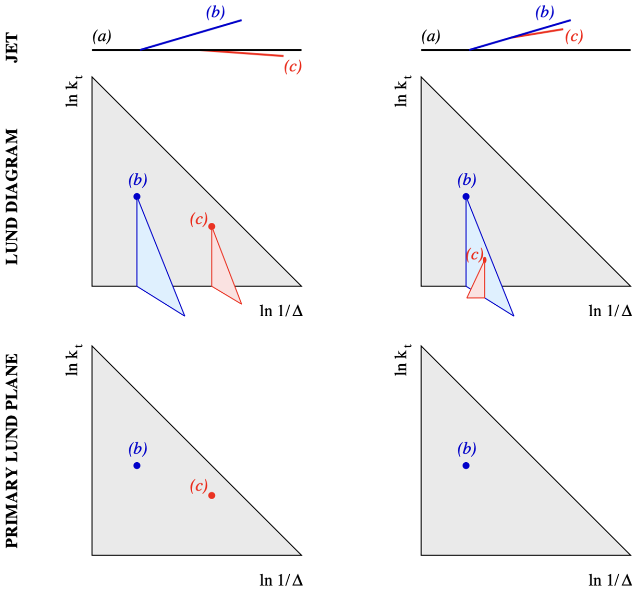
Lund Jet Plane (LJP)

- The jet substructure observables can help to distinguish between different origins of jets: decay of a boosted W/Z/H boson versus those from quarks and gluons jets;
- Lund Jet Plane is created for individual jets through repeated Cambridge/Aachen declustering;
- Lund Jet Plane: the phase space of all emissions can be described by two variables (transverse momentum k_t and the angle of any given emission with respect to its emitter Δ), is mapped in a triangle.



jet core with emitted particles

Lund Jet Plane representation

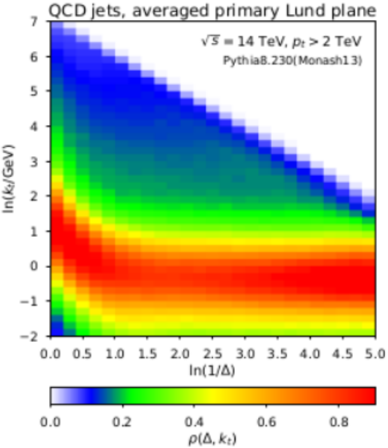


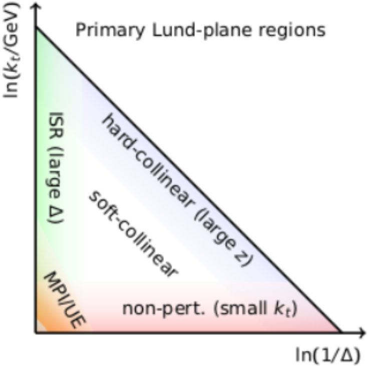
Building the primary Lund Jet Plane of a jet

- The declustering variables are $\ln \Delta$ and $\ln k_t$ (definition of the LJP)
- Each point of the LJP has a set of coordinates $\ln \Delta$ and $\ln k_t$ (the full set of primary branchings),
- Following the lower p_t branch at each declustering, we create secondary, tertiary, etc., Lund planes (or triangles), i.e. one for each emission, giving the full Lund diagram as in the middle row of Fig. 1.
- In some papers the main focus is the primary LJP;
- The omission of secondary and tertiary splittings leads to a loss of information;

Frédéric A. Dreyer, Gavin P. Salam, Grégory Soyez. JHEP 12 (2018) 064; Simne Marzani, Grégory Soyez. and Michael Spannowsky, Looking Inside Jets - An Introduction to Jet Substructure and Boosted-object Phenomenology, Lecture Notes in Physics (2019) volume 958; Andrew Lifson, Gavin P. Salam and Grégory Soyez. JHEP 10 (2020) 170; Frédéric A. Dreyer and Huilin Qu, JHEP 03 (2021) 052 -LundNet (jet tagging).

Different regions of the LJP

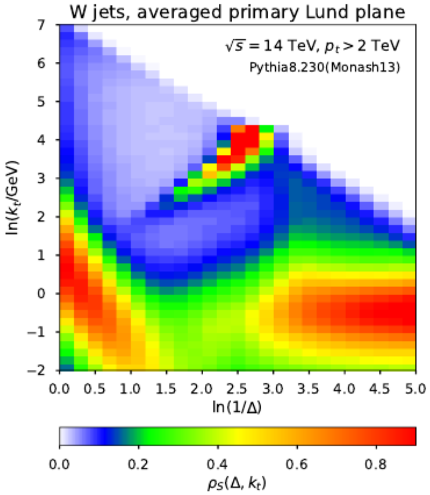




Frédéric A. Dreyer, Gavin P. Salam, Grégory Soyez. JHEP 12 (2018) 064

Boosted-W tagging

$(\ln 1/\Delta, \ln k_t/\mathrm{GeV}) = (2.5, 4)$ and reduction red area $\rightarrow$ W mass



Ongoing activites (Run III, HL-LHC)

- Implementing and improving cells selection algorithm based on jets in the region of interest;
- Starting process of building and adding relevant Ringer variables: rings, quarter rings, strips (separation γ/π^0);
- Prepare code to survey the triggers fired by collimated di-photons;
- Develop a dedicated HLT Ringer algorithm optimized for the identification of collimated di-photons;
- Usage of asymmetric rings (calibration using asymmetric shower measurements);
- New involvement to the boosted di-photon analysis team: Romain Van Den Broucke;
- Development of Athena tool to aid the energy reconstruction and cross-talk studies (improvement the discrimination for highly collimated showers inside the ATLAS calorimeters);
- Data conversion from Athena Framework to a dataset which can be used for ML studies including jets and particle discrimination.

Ongoing activites (Run III, HL-LHC)

- Production of the samples (private) in order to obtain the validation plots exploring the phenomenology of the process (models, couplings, mass points, Madgraph, ...), triggers one- and di-photon;
- Try to propose LJP for QED jets (declustering);
- Define "new" QED variables instead QCD ones (shape of the plane);
- Can we think in QED jet substructure?
- This application can help to find a way to distinguish the origin of (any) jet/shower (egamma objects/QCD jets and so on...).