南京大学
NANJING UNIVERSITY

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Recent Development on EXOTIC Searches at the LHC

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ATLAS EXPERIMENT

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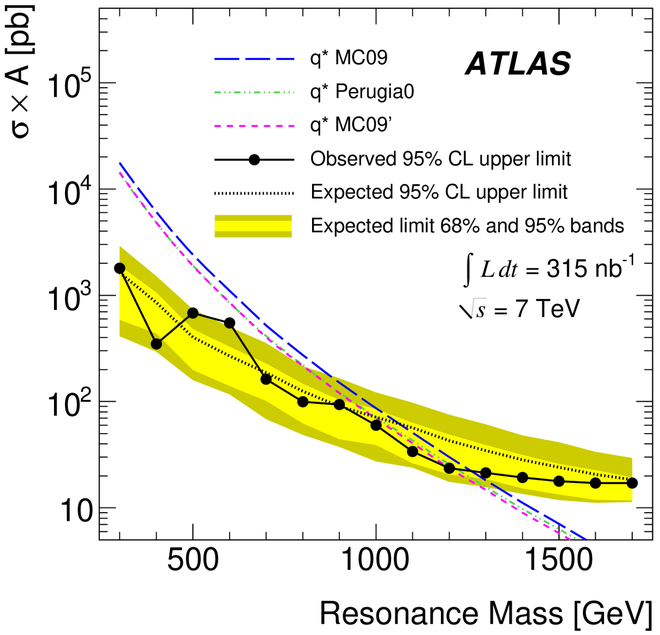
Historically, we consider non-SUSY BSM models EXOTIC

EXOTIC searches are more signature-based

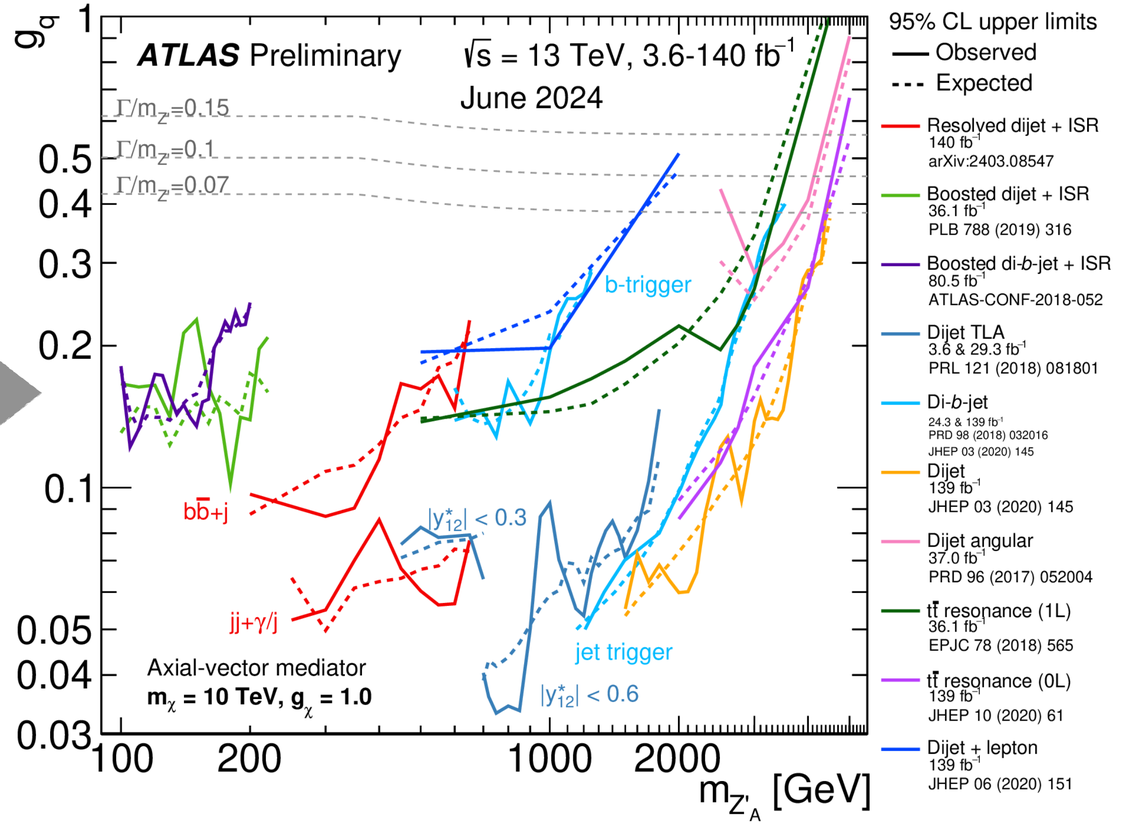
A Glance at the History

- First Run 2 ATLAS di-jet result



PhysRevLett.105.161801

- Latest ATLAS resonance summary plot



ATL-PHYS-PUB-2024-010

You May Assume:

LHC is a hadron collider with a CME of 13.6 TeV, so it is hard to look for low energy phenomena due to trigger limitation

It is hard to probe BSM models with subtle flavour structures as the LHC can only do b-jet and top tagging

The LHC is more suitable for prompt signatures, while the displaced or long-lived signatures are limited by reconstruction and trigger

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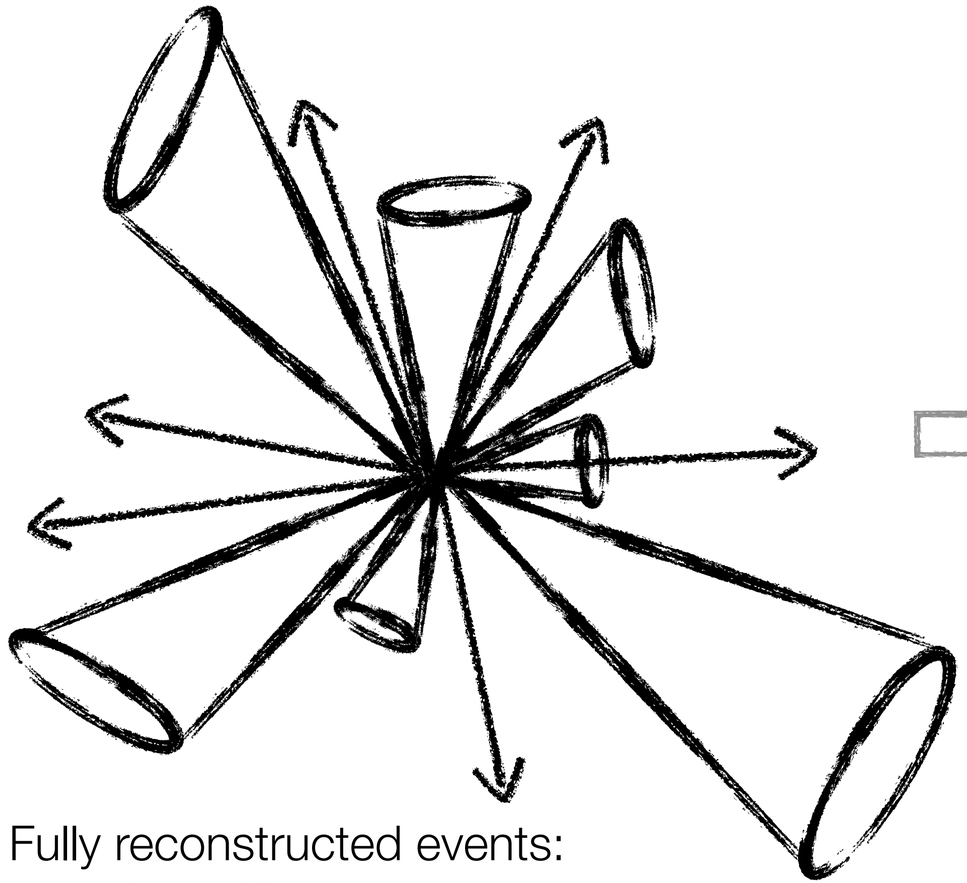
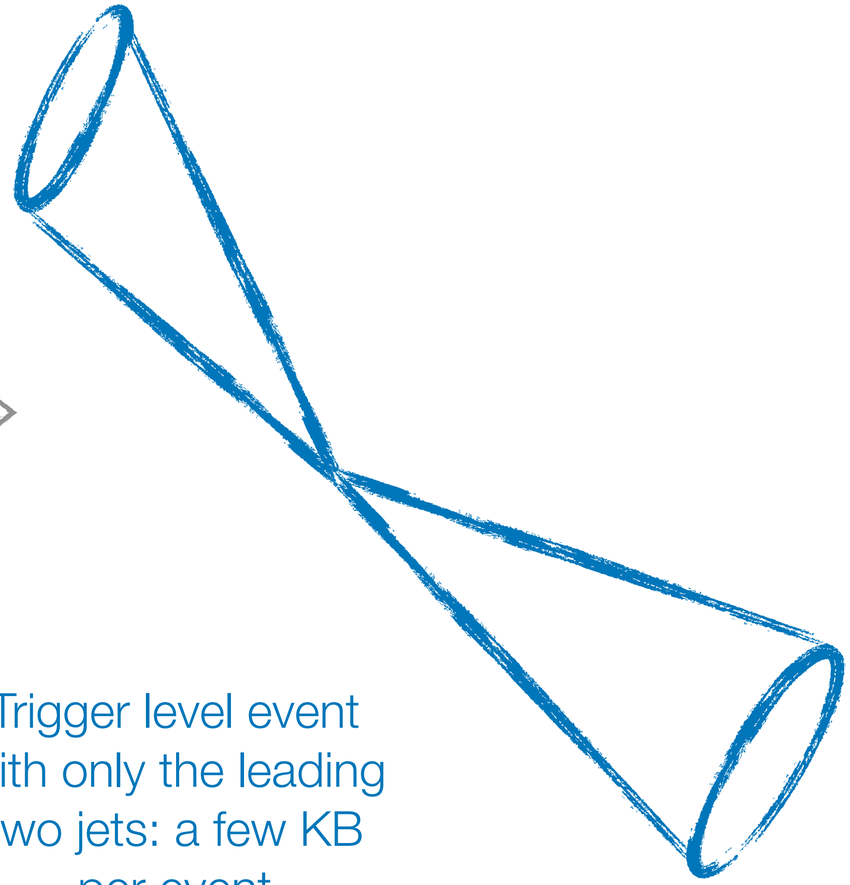
Trigger Level Analysis

- The triggering system is limited by the amount of data it can take every second
- If we only store the object at the trigger level, we can save a lot of space

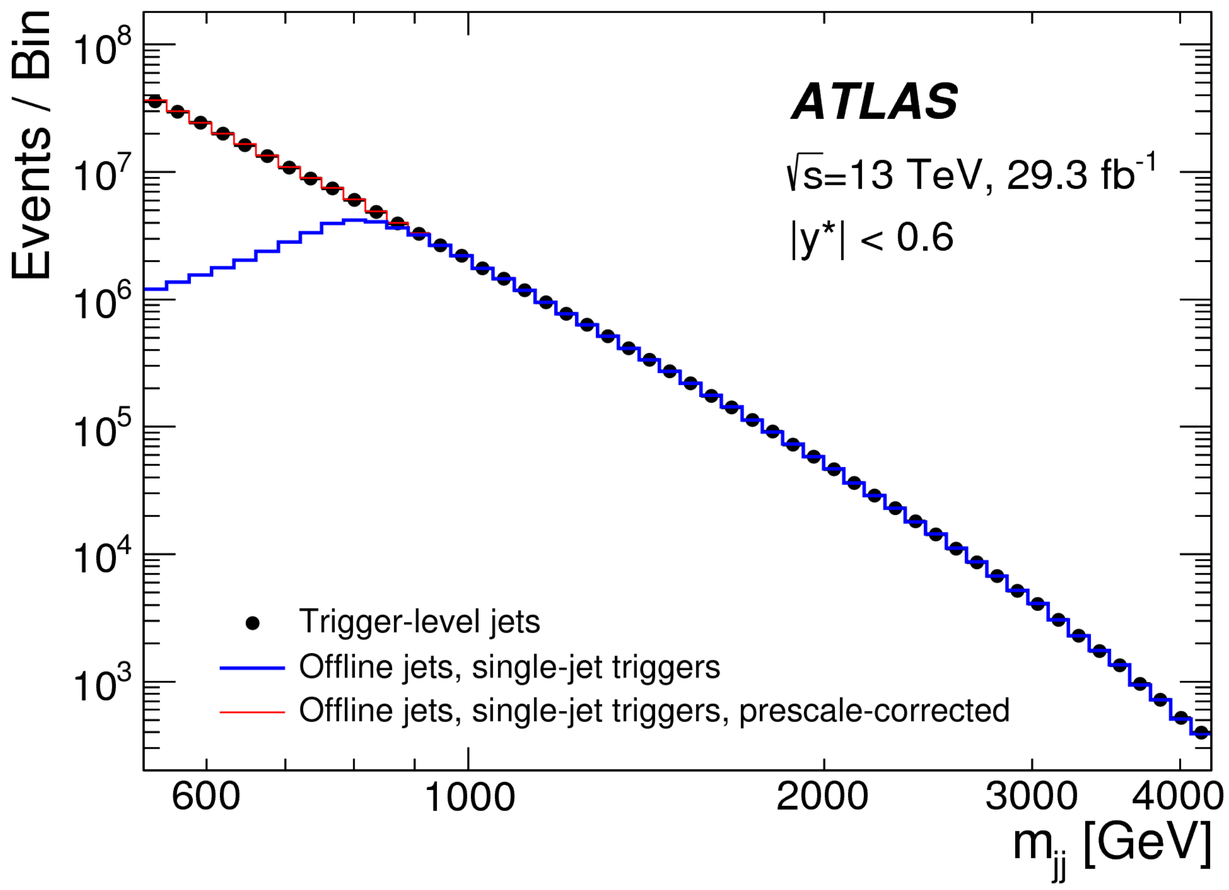


Fully reconstructed events:
a few MB per event



Trigger level event
with only the leading
two jets: a few KB
per event

Trigger Level Analysis



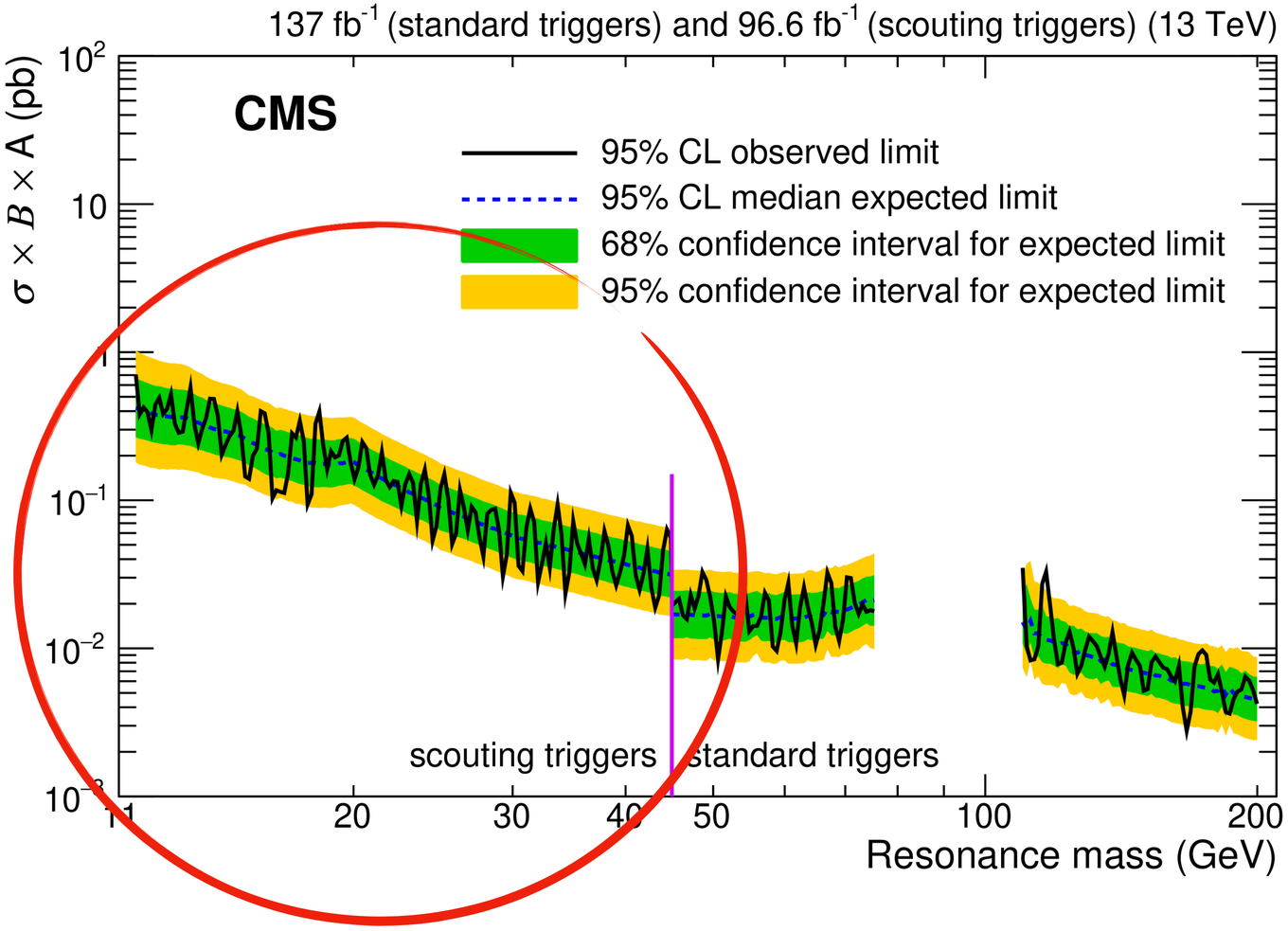
PhysRevLett.121.081801

Standard jet triggers can only collect events with mass larger than ~1 TeV.

Using the trigger level analysis techniques can bring it down to 500 GeV.

The same technology can be applied to other objects such as muons, photon, etc

Trigger Level Analysis

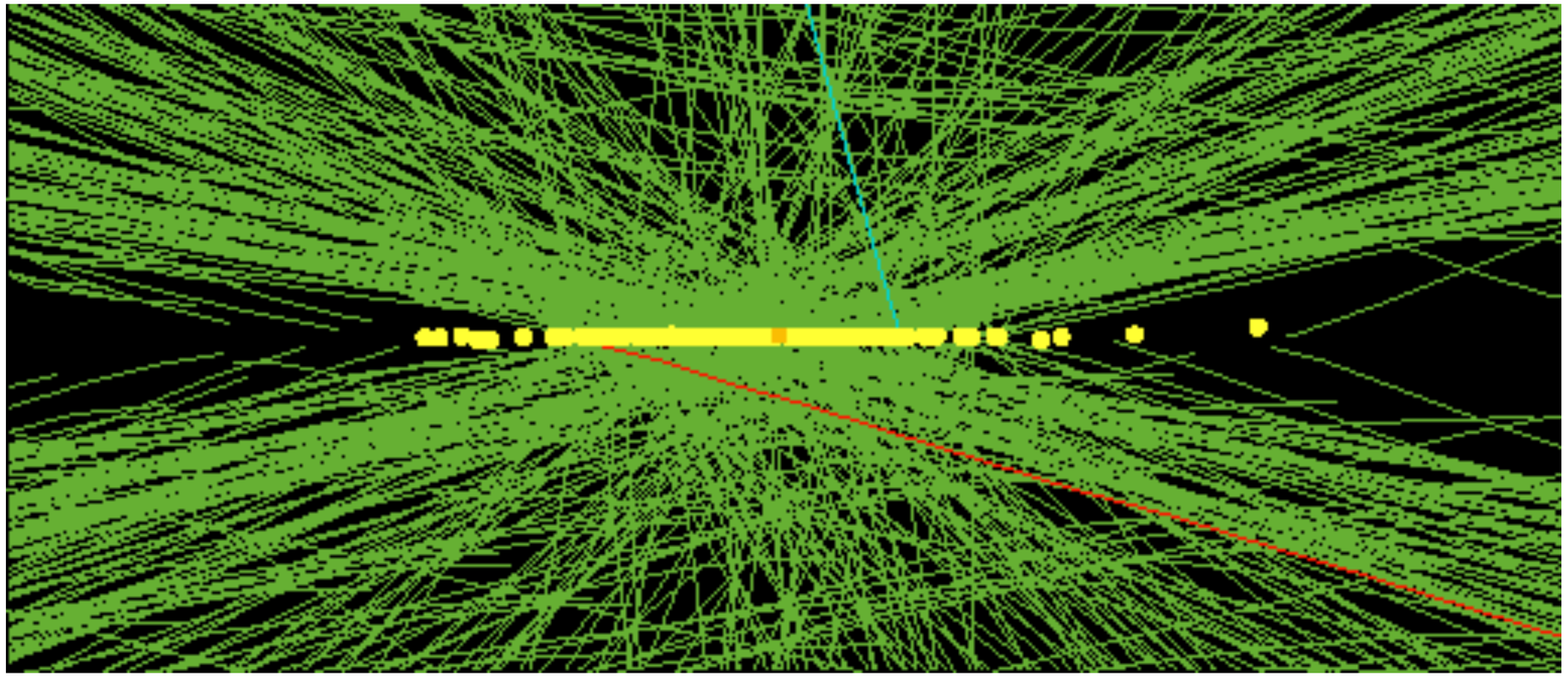


PhysRevLett.124.131802

Trigger level analysis (data-scouting techniques) allow to probe mass region down to ~10 GeV!

We can explore regions below the EWK scale at the LHC.

Use All Data

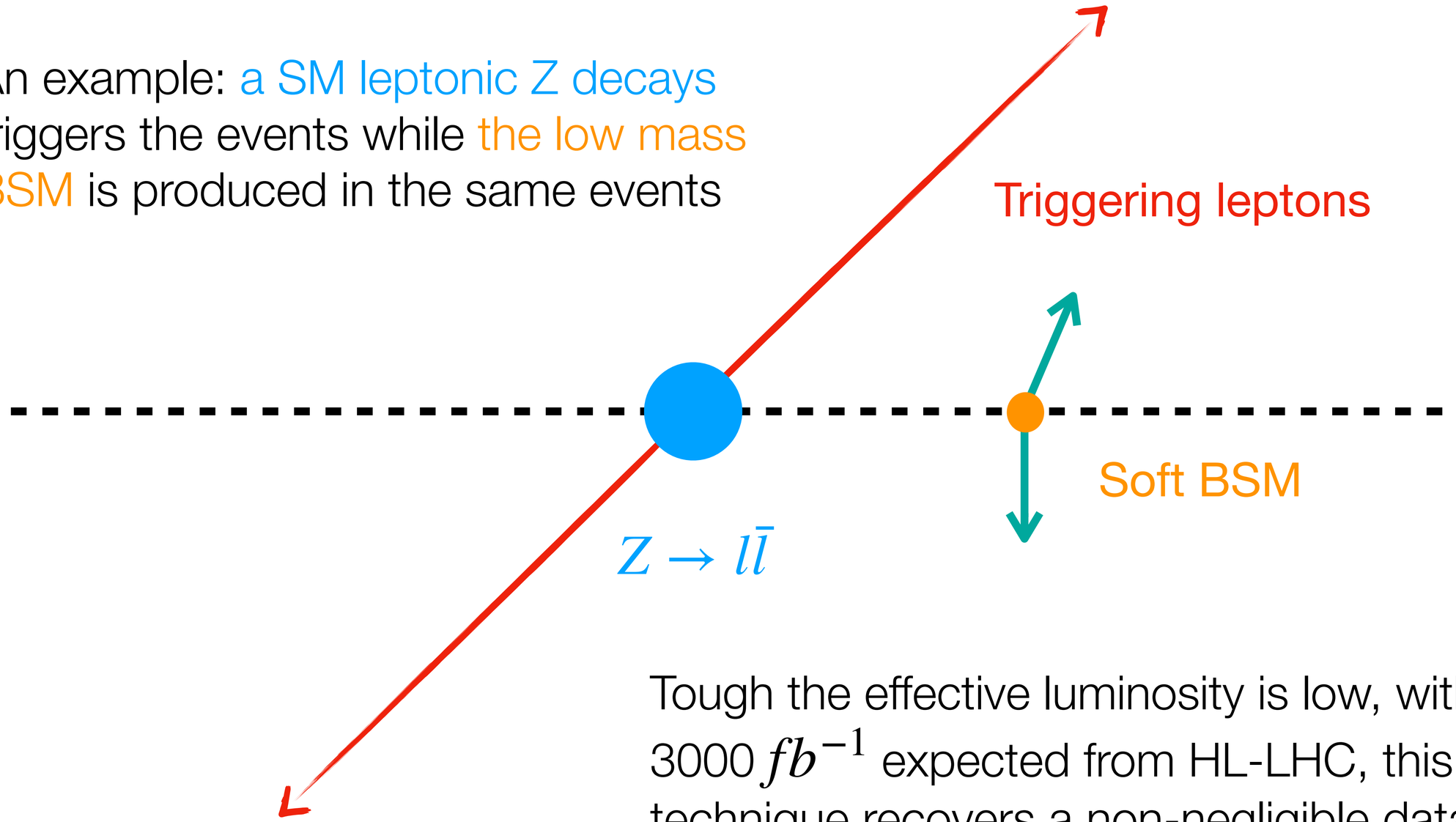


There can be up to ~100 events in one collision. Usually we only pick the most energetic one to analyze while the rest is considered as the “pile-up” events

But! New physics may appear in those “pile-up” events!

Use All Data

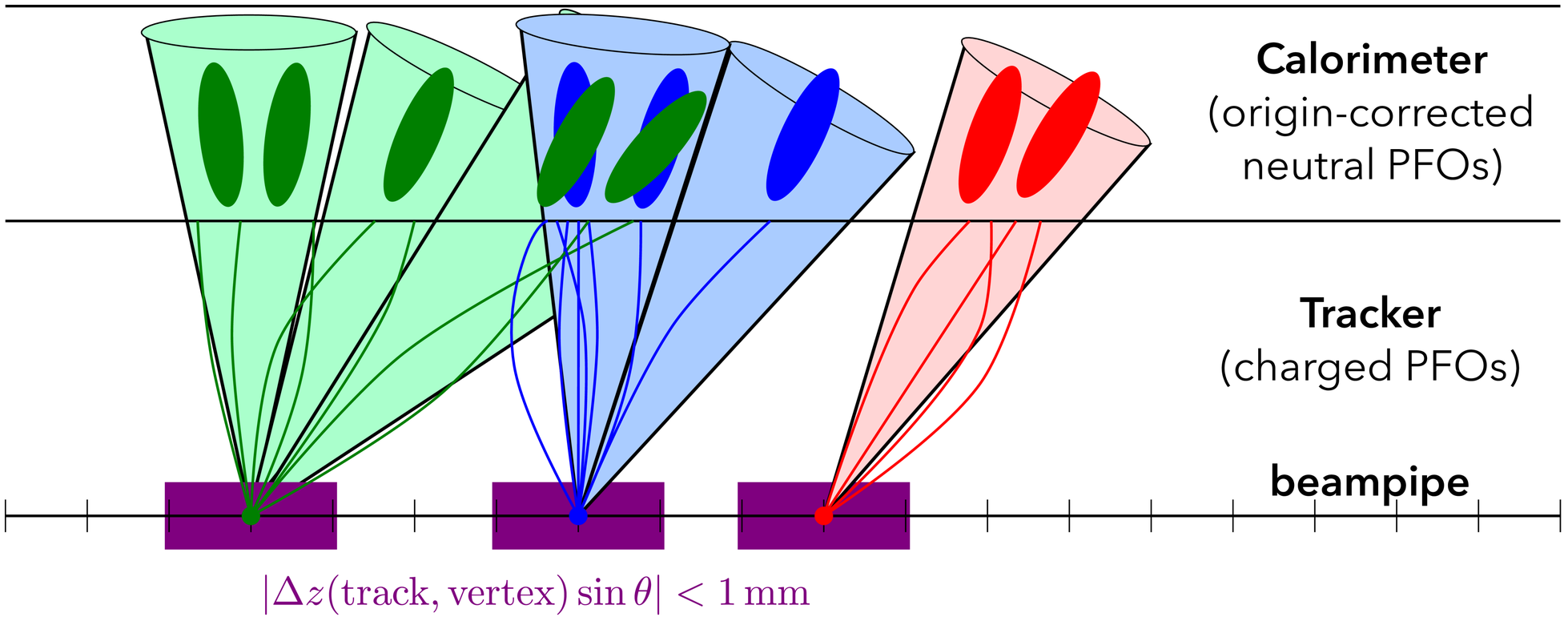
An example: a SM leptonic Z decays triggers the events while the low mass BSM is produced in the same events



Tough the effective luminosity is low, with 3000 fb^{-1} expected from HL-LHC, this technique recovers a non-negligible dataset

Analyzing Pile-up Data

JHEP12(2024)032



ATLAS has established a special jet reconstruction and calibration sequence, enabling the usage of those jets from pile-up events in physics analyses

It opens up a new avenue to look for BSM in the low energy regime

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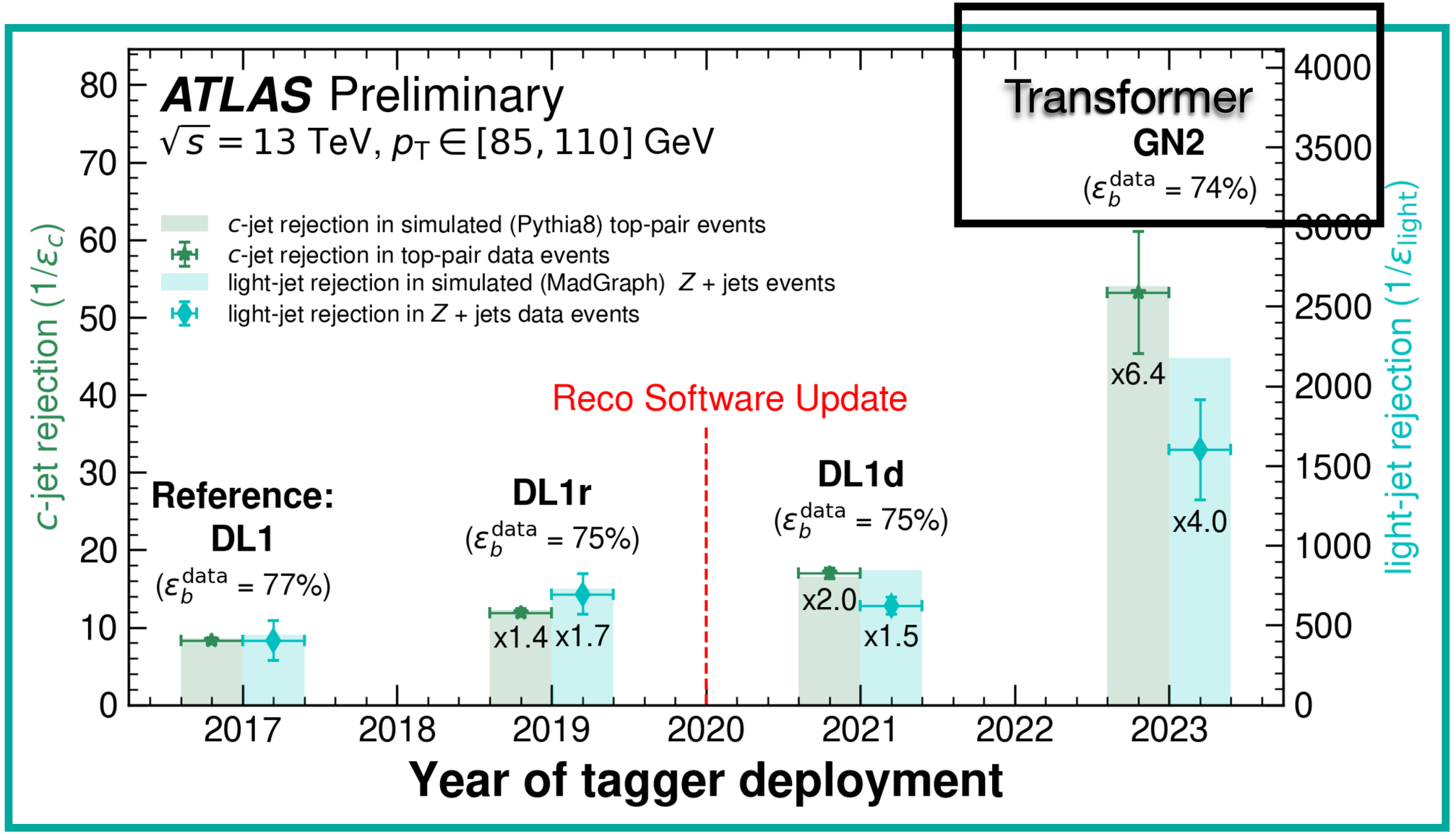
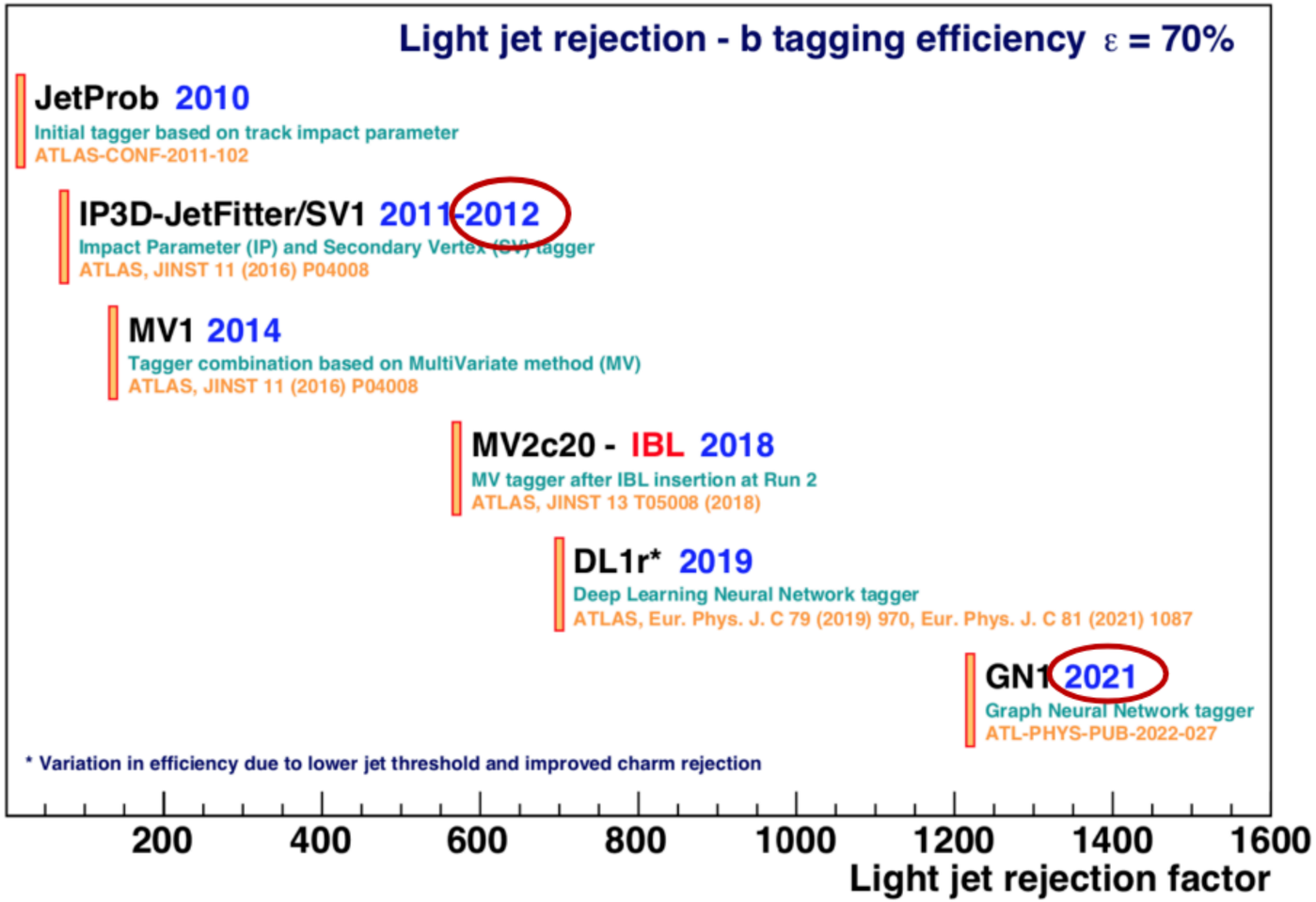
The LHC is more suitable for prompt signatures, while the displaced or long-lived signatures are limited by reconstruction and trigger

Learn the History of ML…in ATLAS FTAG



In Fabiola's Talk at the 10 Years Higgs Anniversary

Link to Fabiola's Slides



The b-jet tagging performance has been improved by a factor of $O(2)$ compared to Run 1!!

Back in the days we might have not expected to observe $H \to b\bar{b}$ that early

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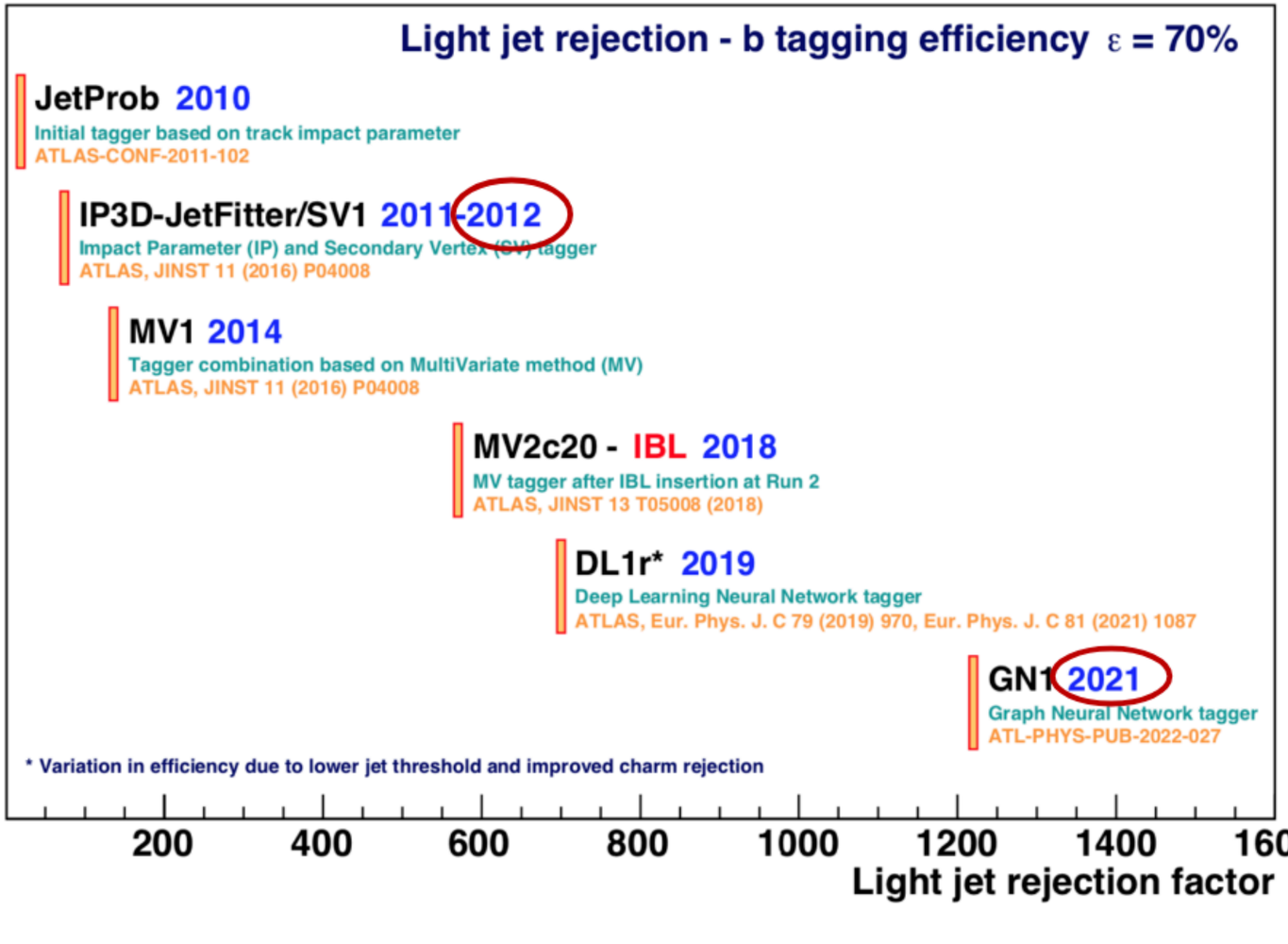


Sensitivity:

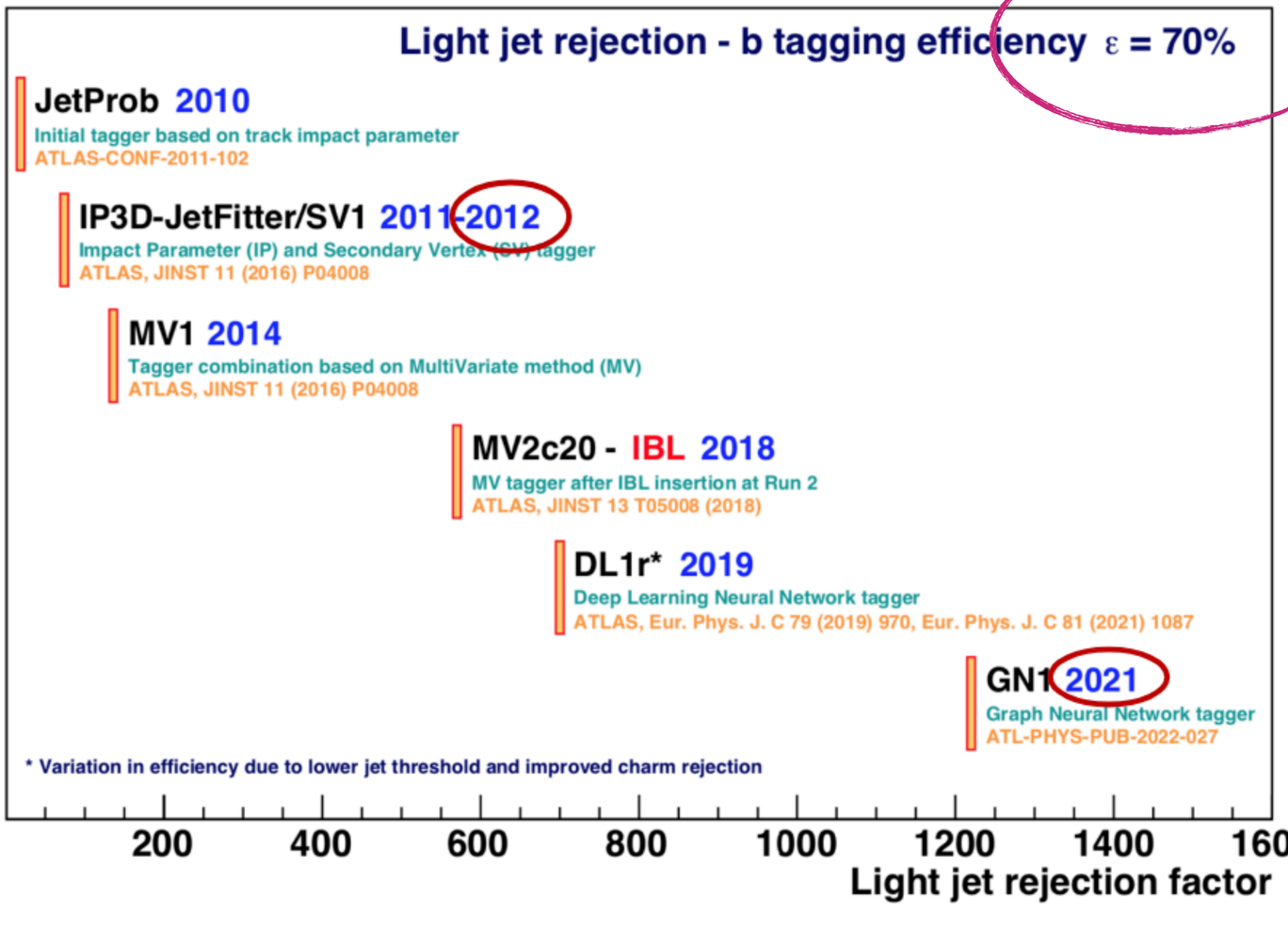
$$\frac{S}{\sqrt{B}} \approx \frac{\varepsilon_b}{\sqrt{\varepsilon_{non-b}}}\sqrt{t}$$

Sensitivity

Detector Operation Time

In Fabiola's Talk at the 10 Years Higgs Anniversary

Link to Fabiola's Slides



Sensitivity:

$$\frac{S}{\sqrt{B}} \approx \frac{\varepsilon_b}{\sqrt{\varepsilon_{non-b}}}\sqrt{t}$$

The ε_b is fixed to 70%

In Fabiola's Talk at the 10 Years Higgs Anniversary

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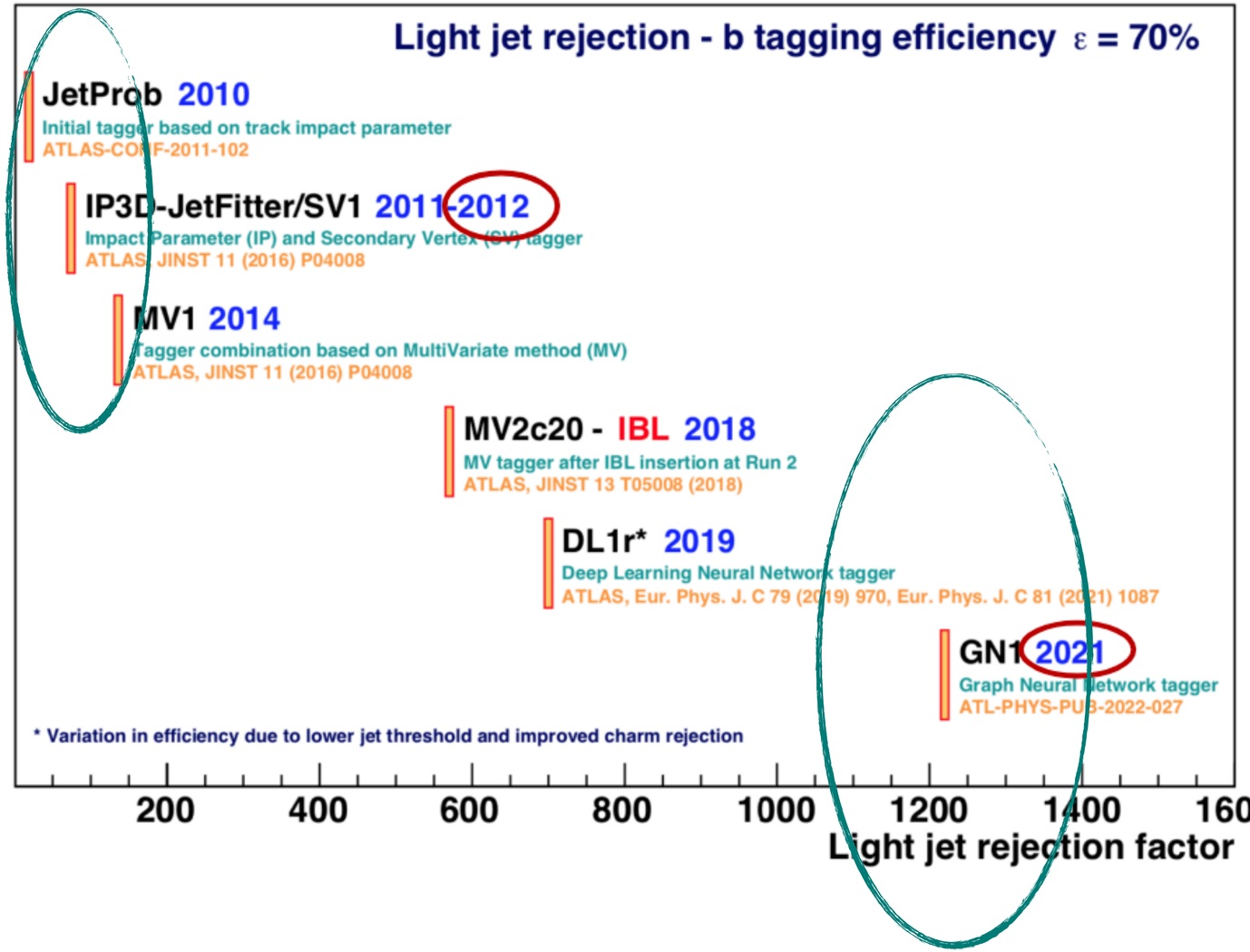
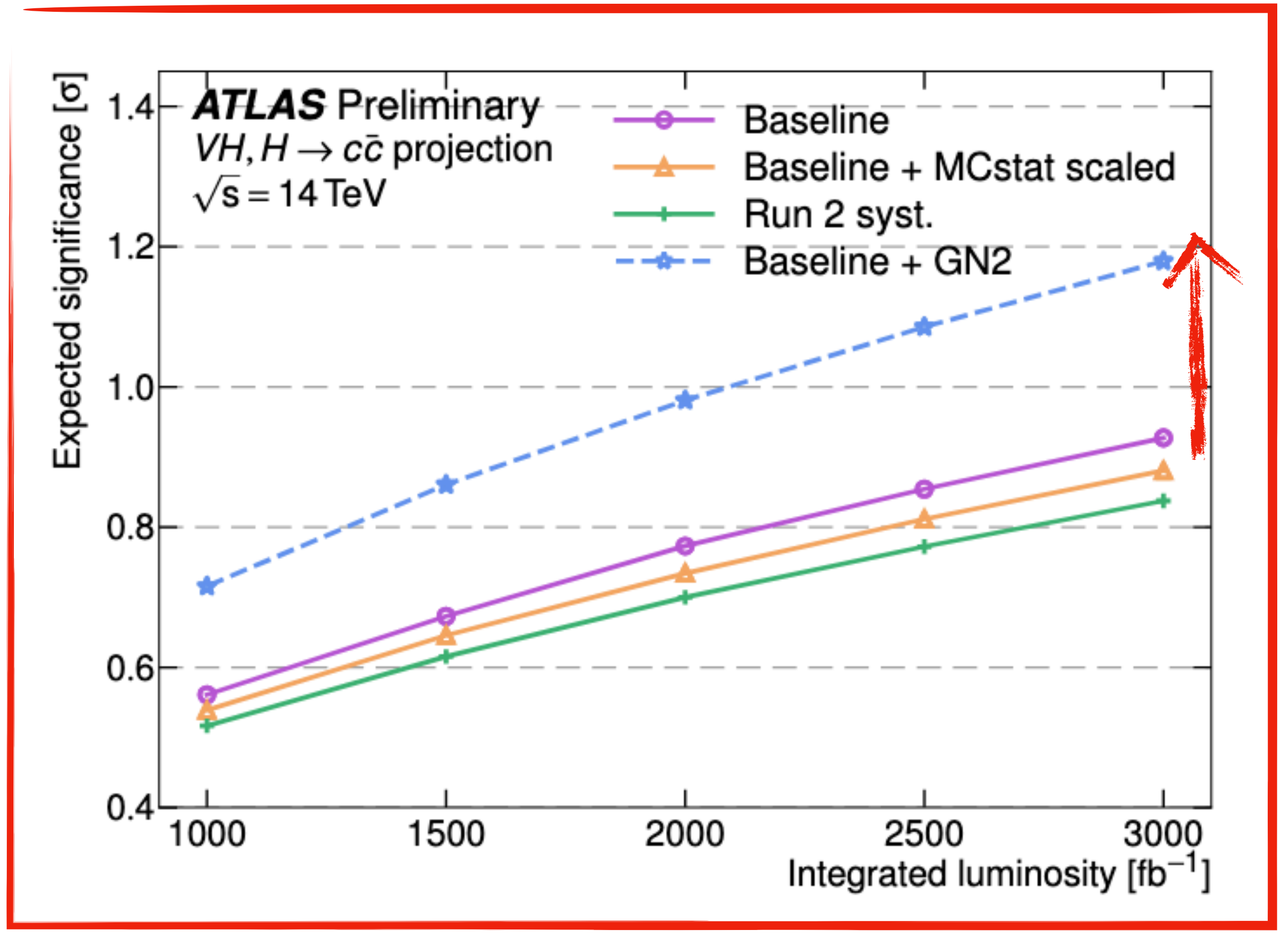


Sensitivity:

$$\frac{S}{\sqrt{B}} \approx \frac{\varepsilon_b}{\sqrt{\varepsilon_{non-b}}}\sqrt{t}$$

The ε_{non-b} is decreased by a factor of 100, which means we only need $10\,\%$ data to reach the same sensitivity!

HL-LHC Projections



ATL-PHYS-PUB-2025-012.pdf

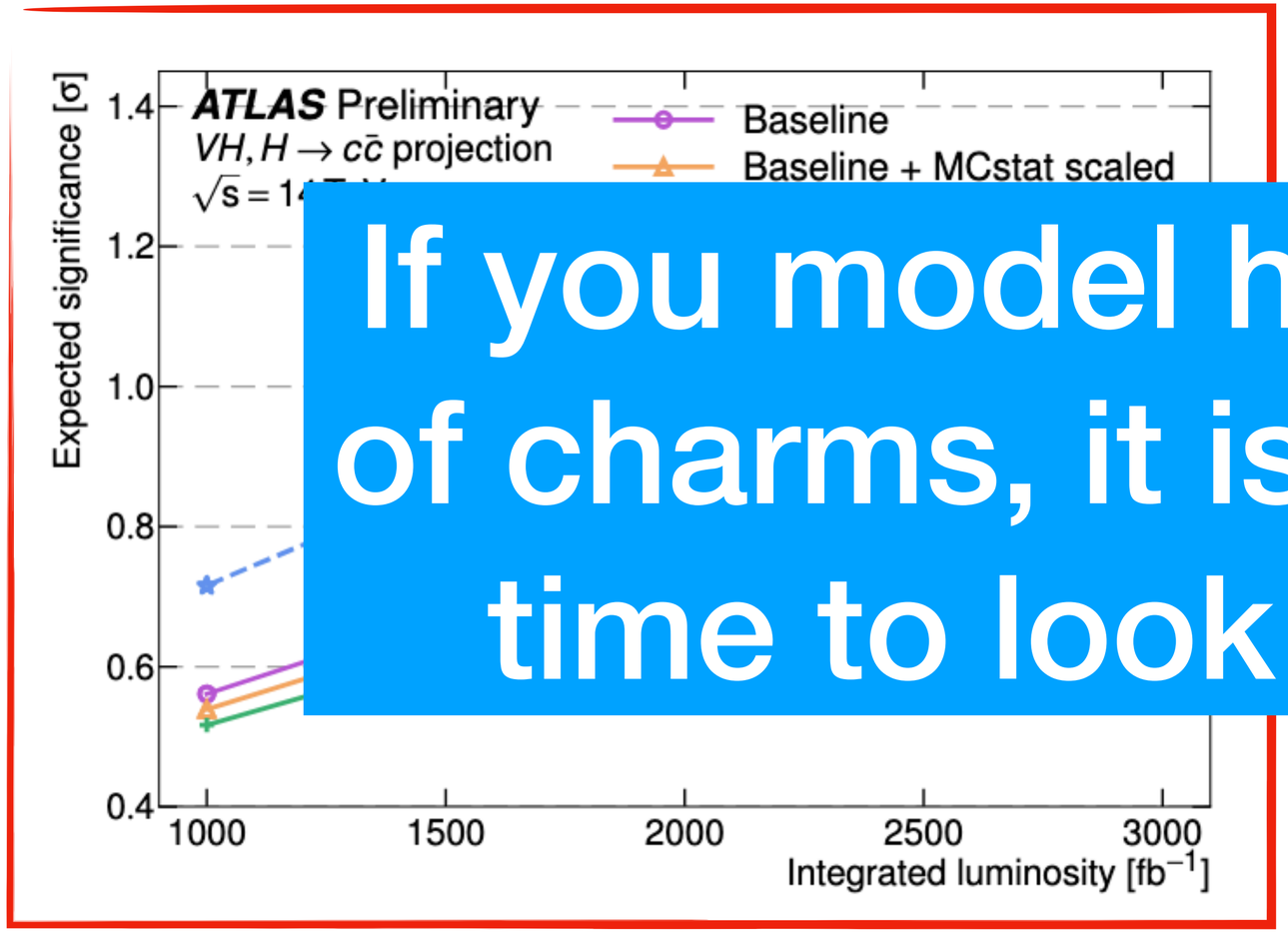
Applying the new transformer tagger:

A 50% improvement on the projected $H \to c\bar{c}$ sensitivity

Searches with charm quarks in the final states are expecting improvements as well

We only need half the data compared to the projection using the previous tagger

HL-LHC Projections



Applying the new transformer tagger:

If you model has a lot of charms, it is s good time to look for it!

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$c\bar{c}$ sensitivity

arm quarks in

e expecting

well

We only need half the data compared to the projection using the previous tagger

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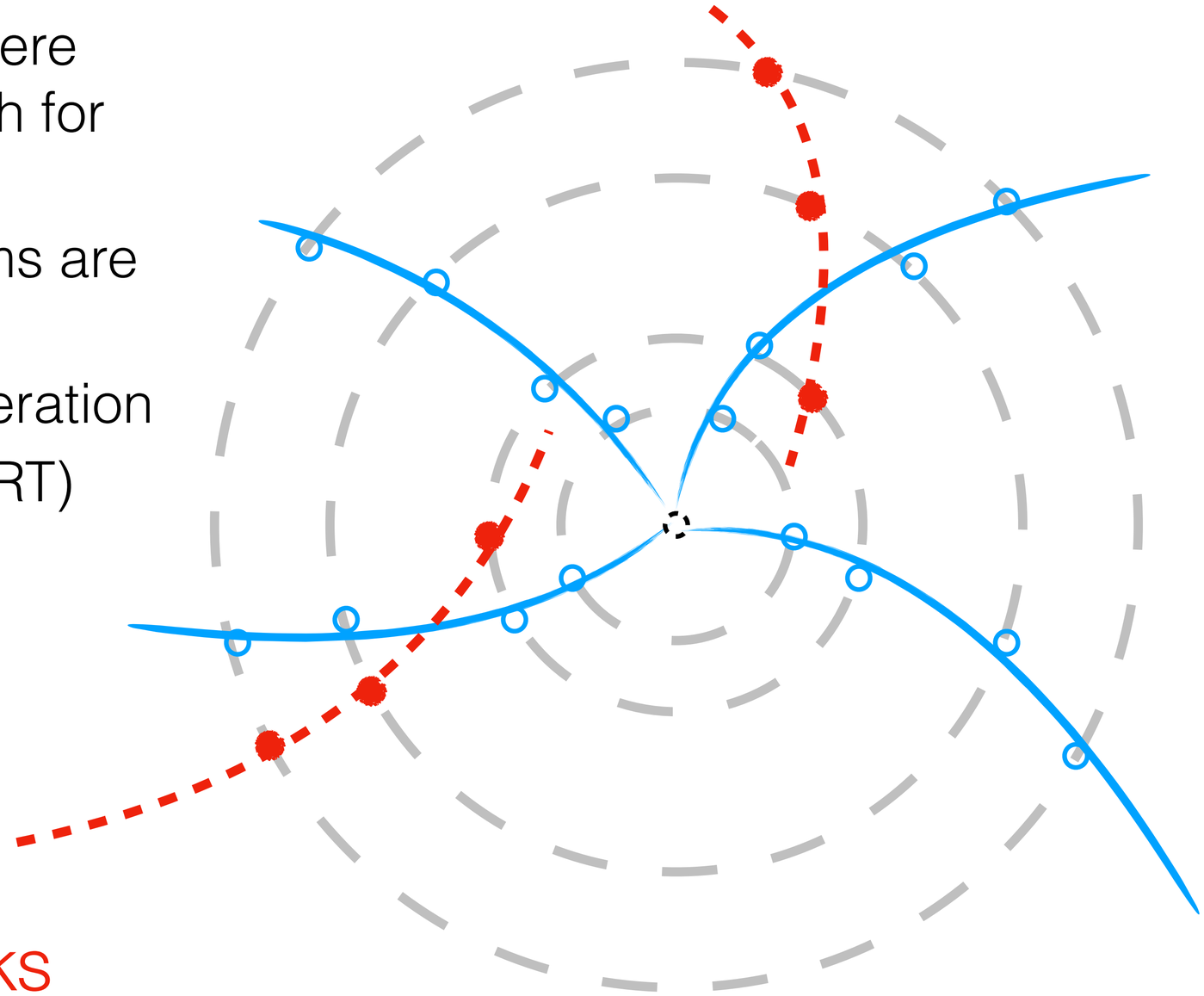
Large Radius Tracking

Eur. Phys. J. C 83 (2023) 1081

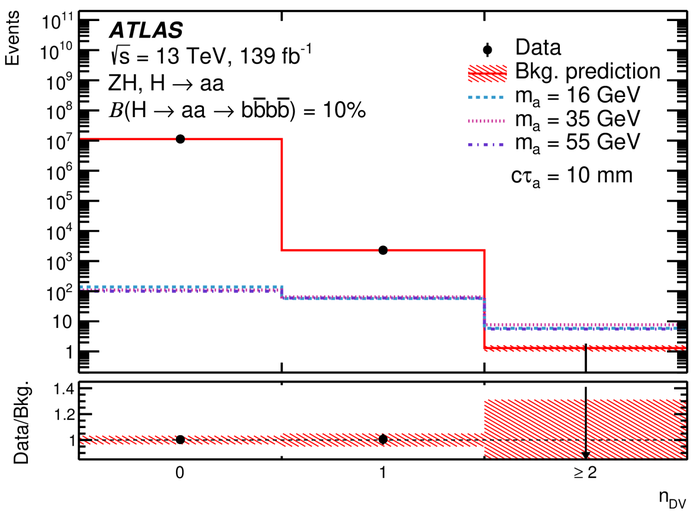
- Our detectors and algorithms were not designed originally to search for long-lived particles (LLPs)
- Special reconstruction algorithms are often needed
- ATLAS has a special tracking iteration
  - The Large Radius Tracking (LRT)



Prompt tracks

Displaced tracks

Higgs to Displaced Vertices

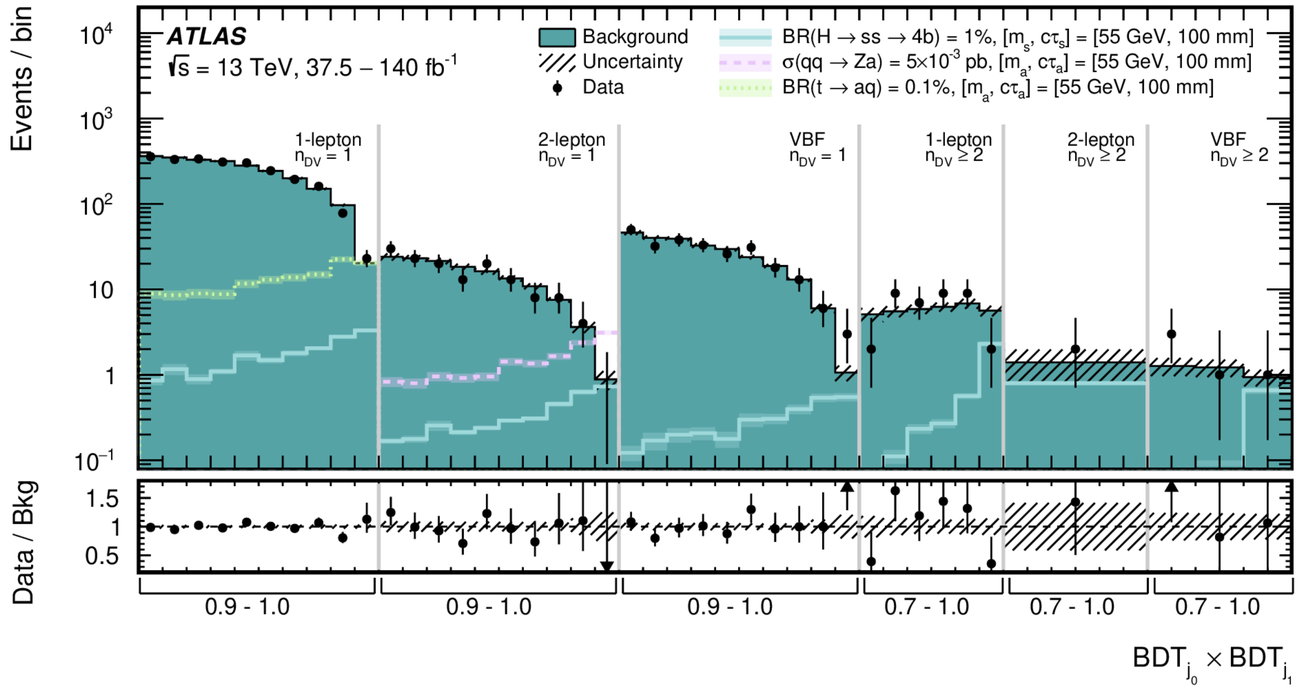


With the previous algorithm, we need to run a very cumbersome workflow. An analysis can only investigate a specific phase space a time

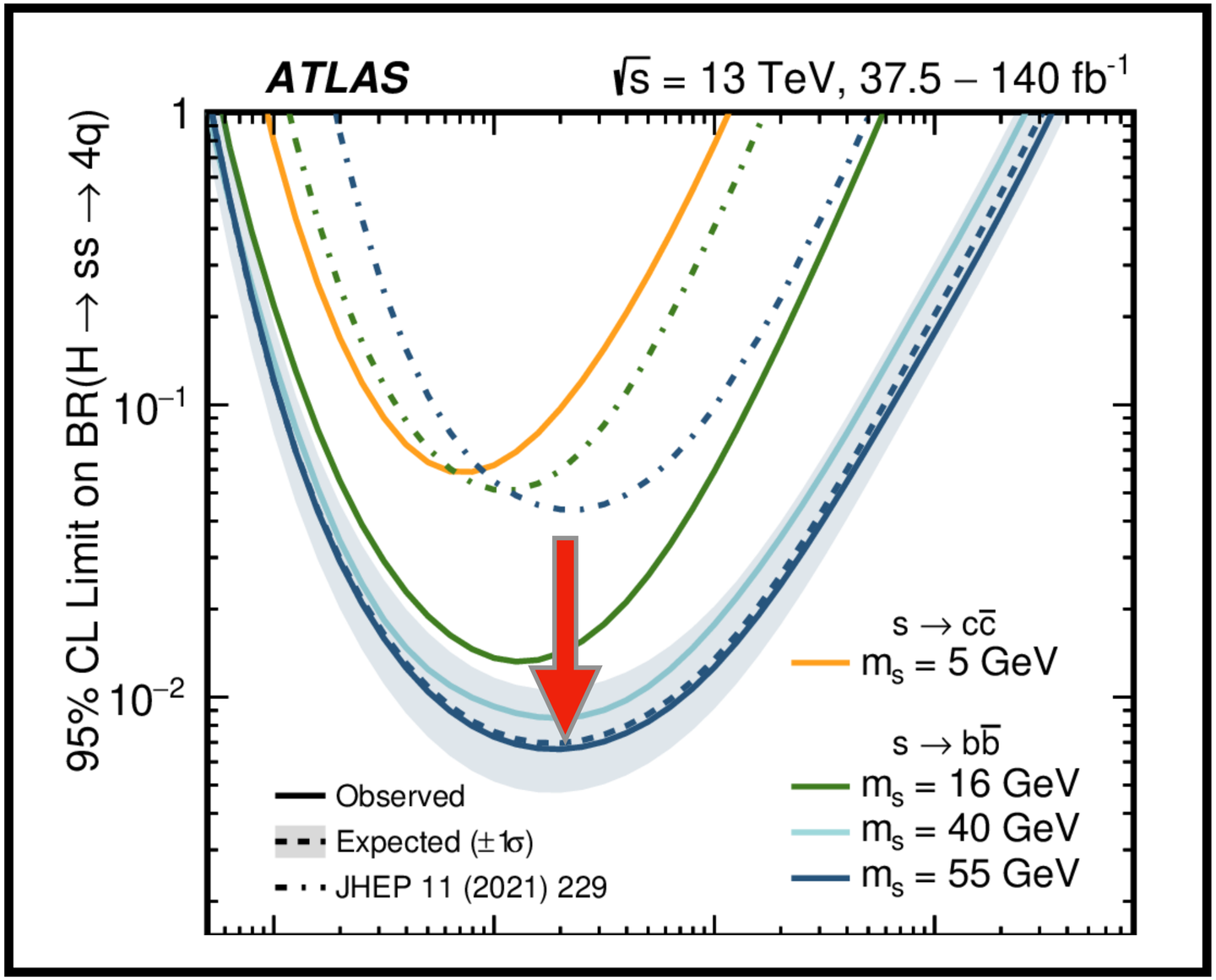
JHEP11(2021)229

The new algorithm has 10 times better signal to noise ratio, enabling more thorough exploration of the displaced vertices signatures

PhysRevLett.133.161803



The Impact



PRL Editor's Suggestion:

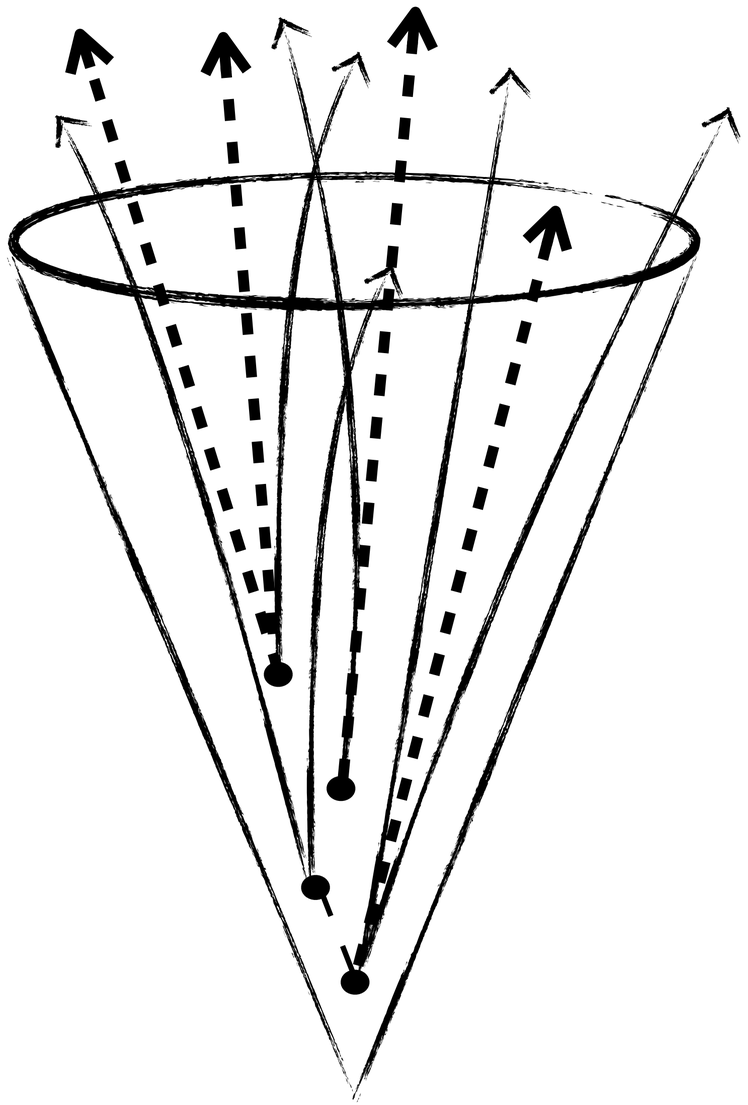
A search for long-lived particles at the LHC with a new scheme for reconstructing particle-tracks with significantly displaced vertices results in an order-of-magnitude improvement in constraints.

PhysRevLett.133.161803

You May Assume:

Your experimentalists friends are mighty magicians, and they can do anything

Dark Sector



The dark sector has started drawing more and more attention these days. It is an additional group analogous to QCD.

Very striking and challenging signatures in collider: **high multiplicity, missing energy, displaced vertices**….

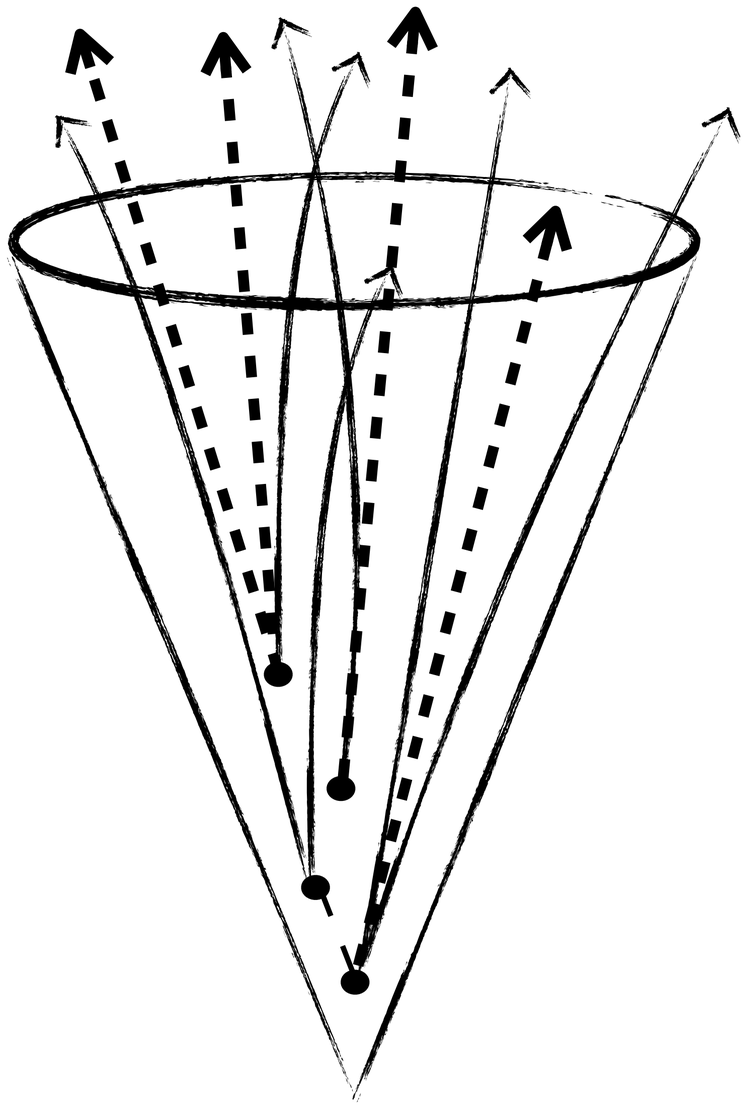
A very good candidate to combine all these nice developments: transformer architecture + displaced vertex

Results

ATLAS internal only at the moment

Stay tuned for LHCP

Dark Sector with ISR



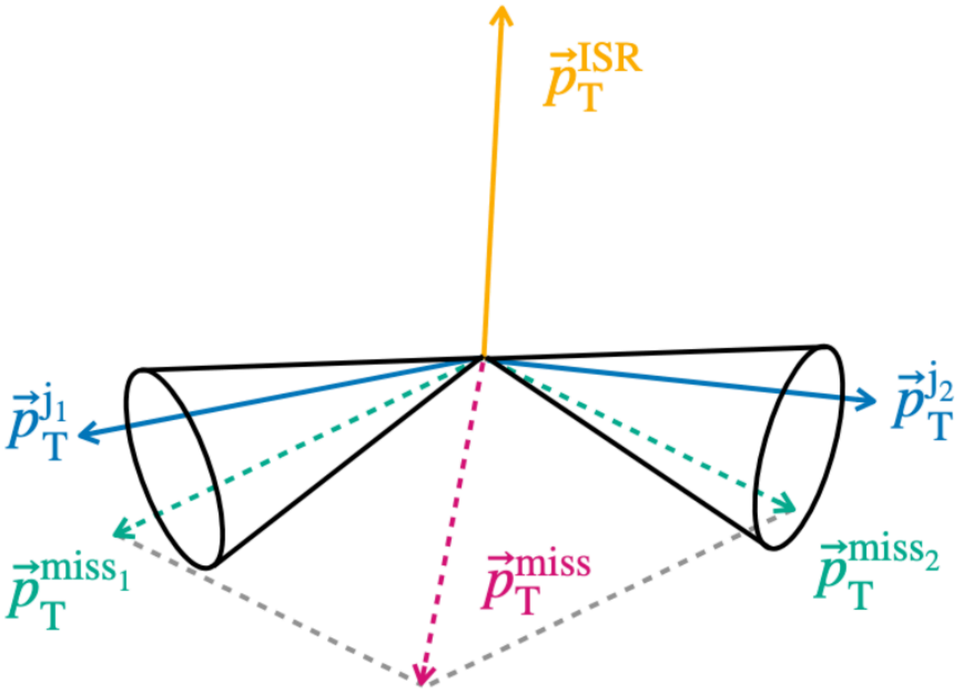
The invisible energy fraction of the jet, r_{inv}, is directly related with the dark shower model

Being able to reconstruct it allows to probe the physics model parameters better

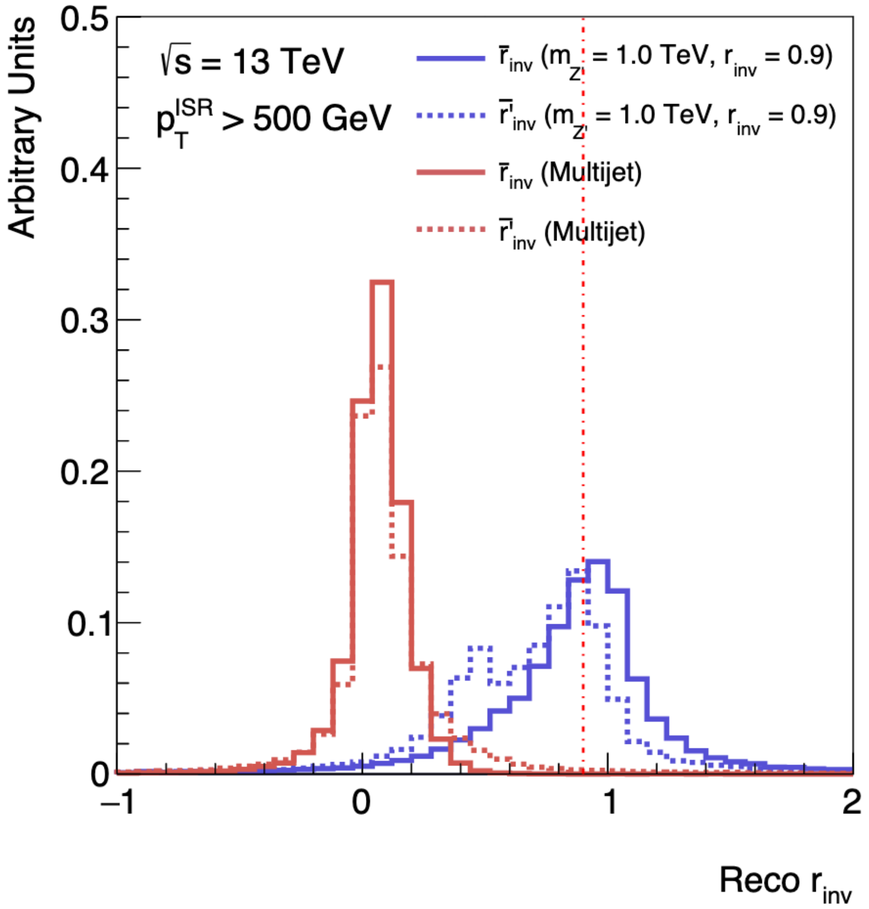
We found that with the help of an energetic ISR object, r_{inv} can be reconstructed via as simple decomposition method

BX. Liu, K. Pedro, JHEP12(2024)105

Dark Sector with ISR

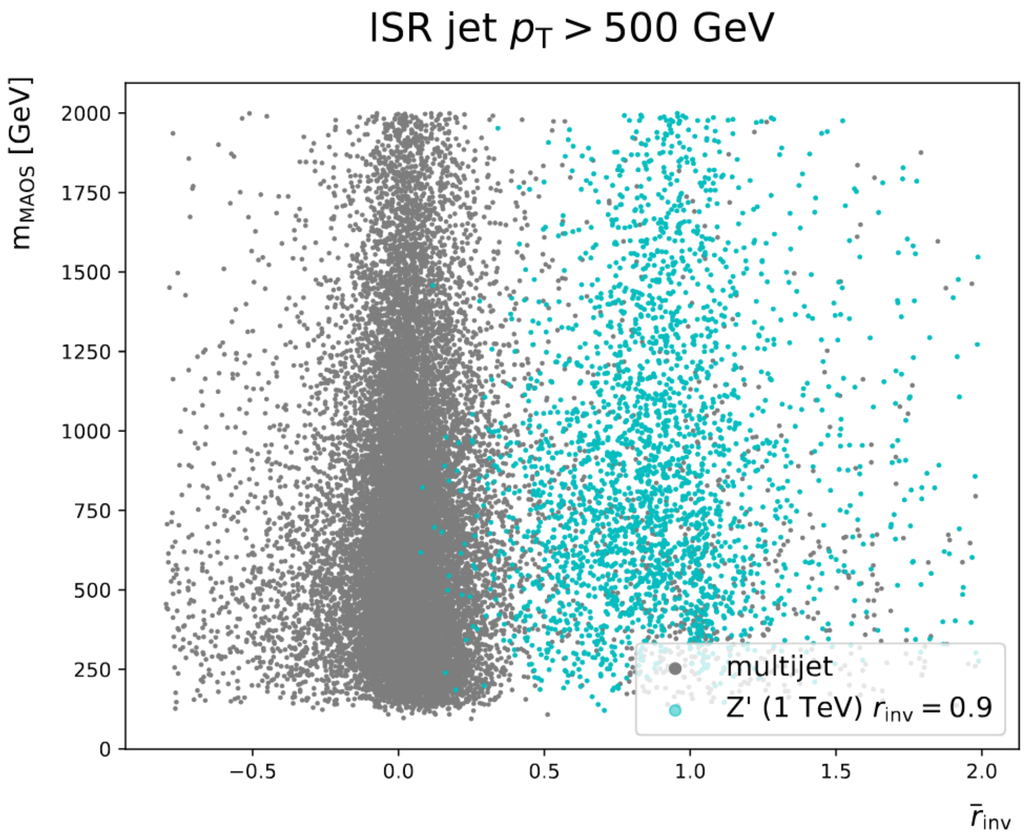


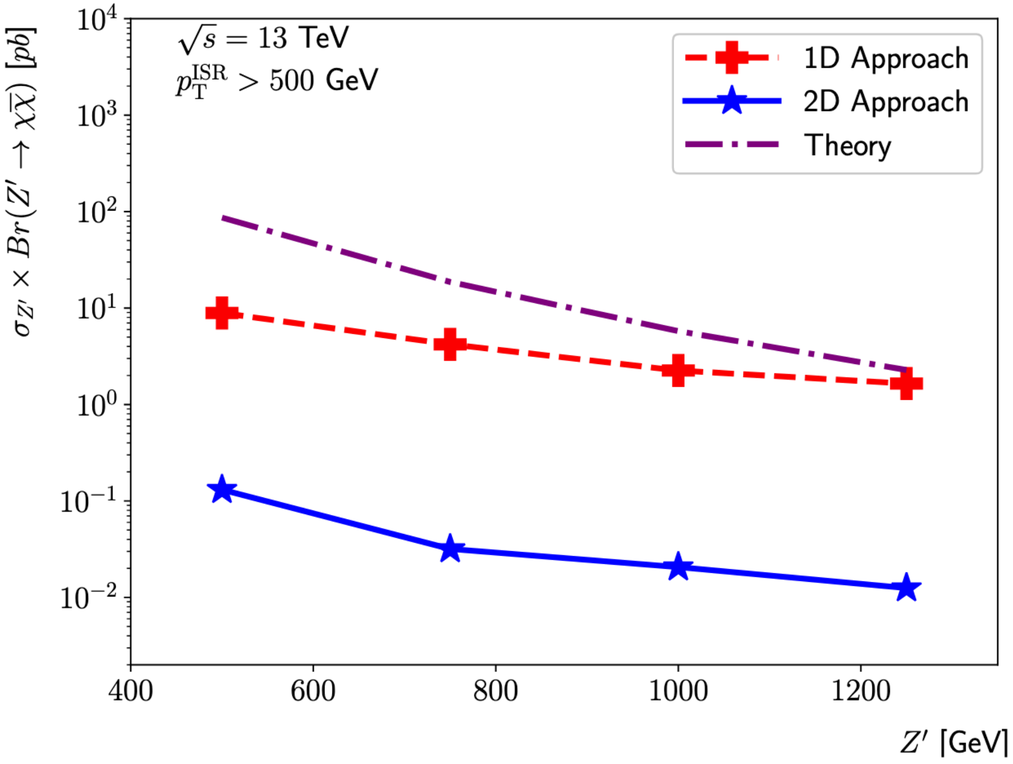
Decomposing the missing energy to the jet axes to approximate the invisible energy



It is able to reconstruct the r_{inv} parameter very precisely

Dark Sector with ISR





The signal is well separated from the background on the mass-r_{inv} 2D plane

The sensitivity is two orders of magnitudes larger compared to using mass variable only

The BSM discovery potential of the LHC is far from being exhausted!

Where is BSM?

It is in the data!

Thank You!