Boosted $H \to b\bar{b}$ tagging in ATLAS

Yajun HE[1]
[1]LPNHE, Paris

JRJC-La Rochelle-10/2021

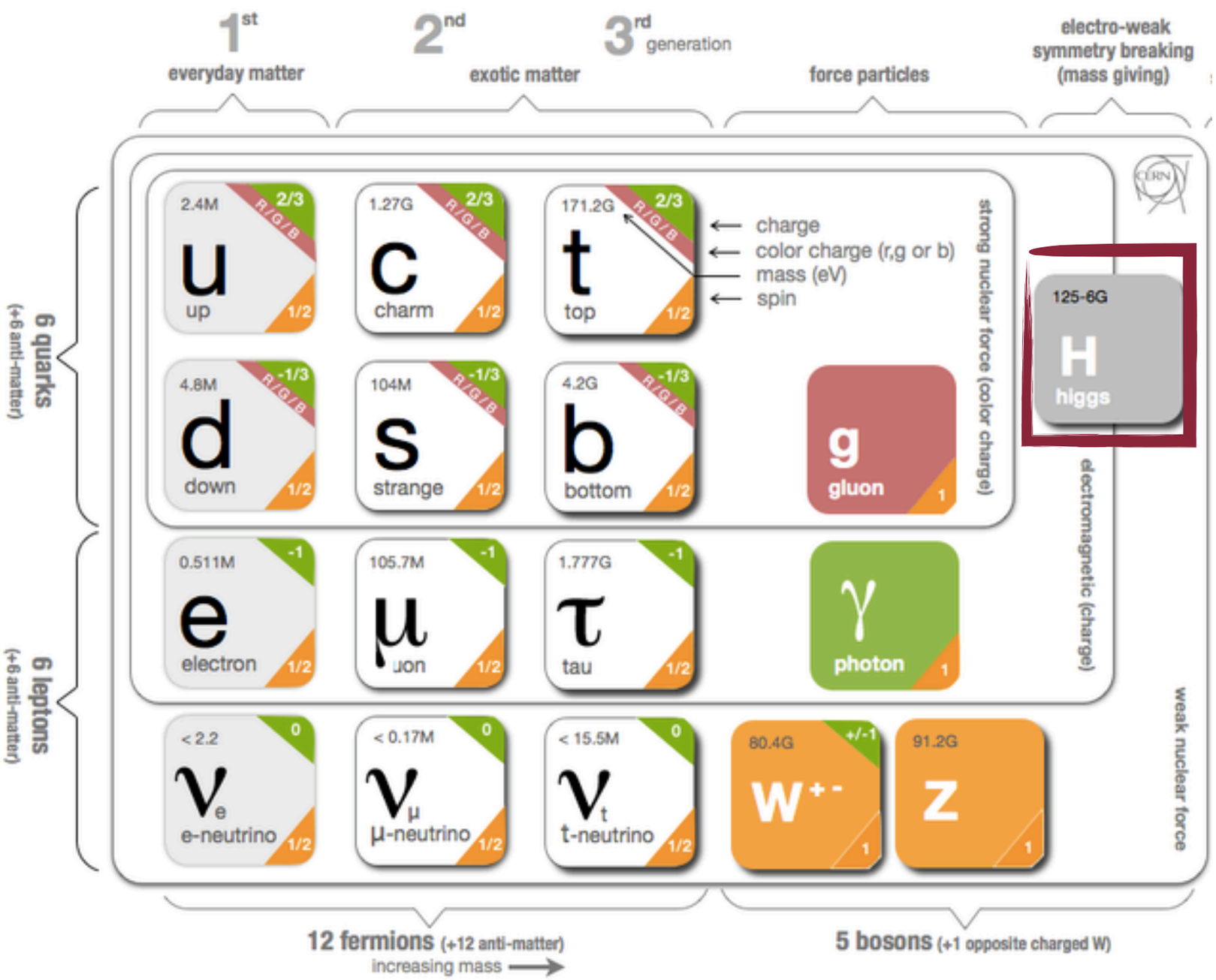
Outline

- Why we're interested in boosted Higgs boson (H) and $H \to b\bar{b}$?
- What are the current techniques to identify boosted $H \to b\bar{b}$ events in ATLAS?
- How to apply the techniques into physics analyses?
- What will the future look like?

Question 1

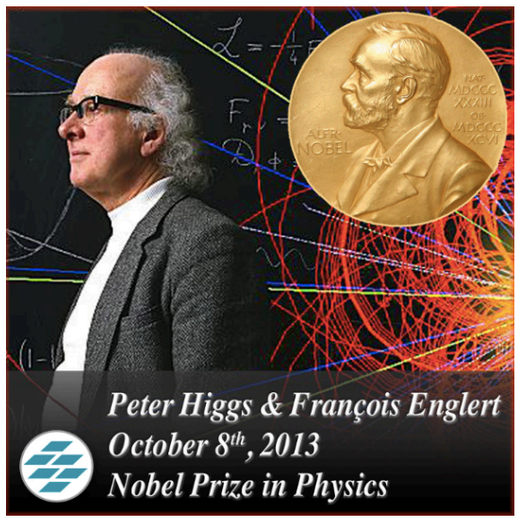
- **Why we're interested in boosted Higgs boson (H) and $H \to b\bar{b}$?**
- What are the current techniques to identify boosted $H \to b\bar{b}$ events in ATLAS?
- How to apply the techniques into physics analyses?
- What will the future look like?

Higgs boson giving mass

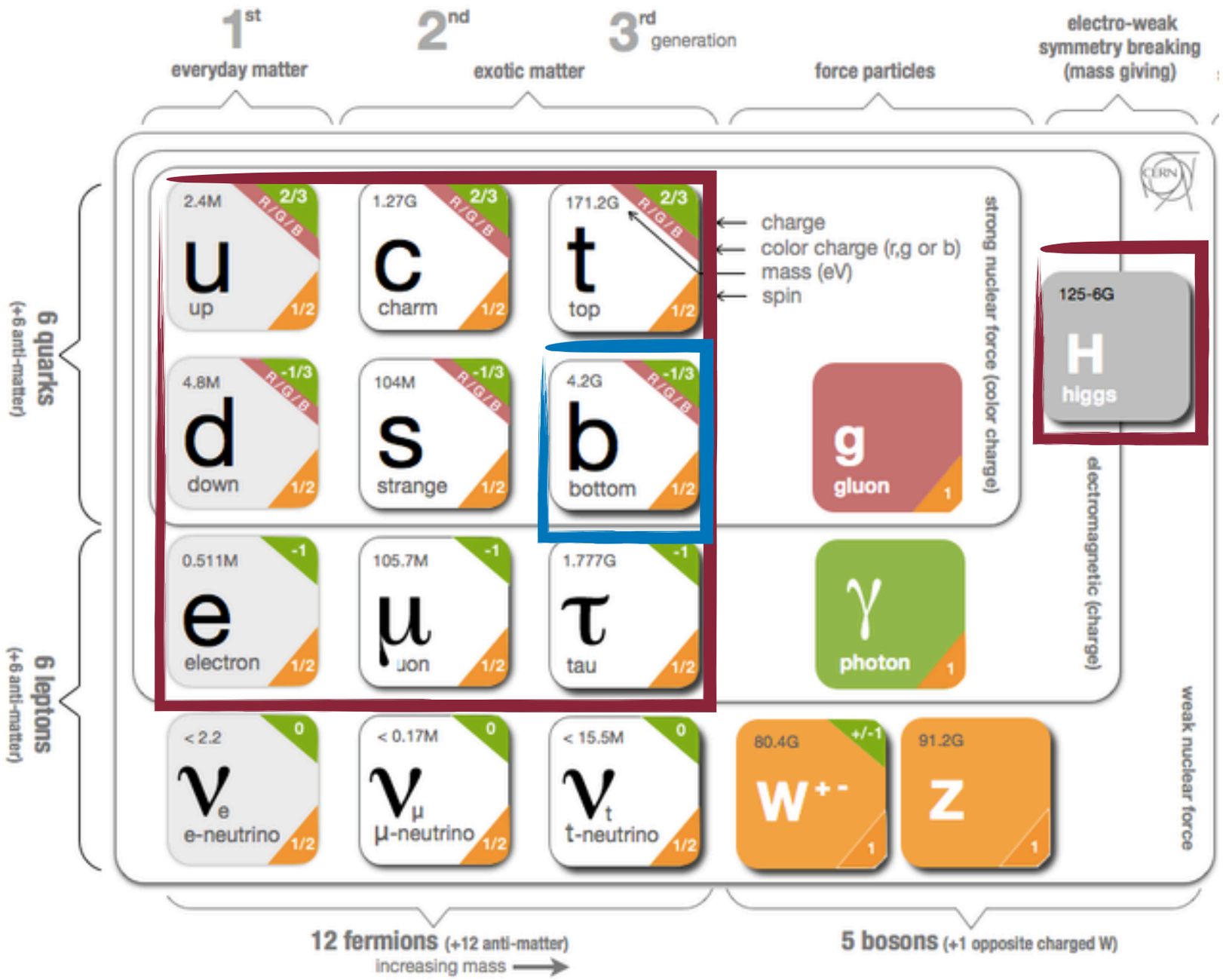


- Mass is inertial for elementary particles ($E = mc^2$) and is given to particles through their interactions with the Higgs field in Standard Model (SM).

Discovery of Higgs at 2012
Phys.Lett. B716 (2012) 1-29



Higgs boson giving mass



- Higgs fields provides mass to charged fermions via Yukawa interactions, with strength proportional to their mass.

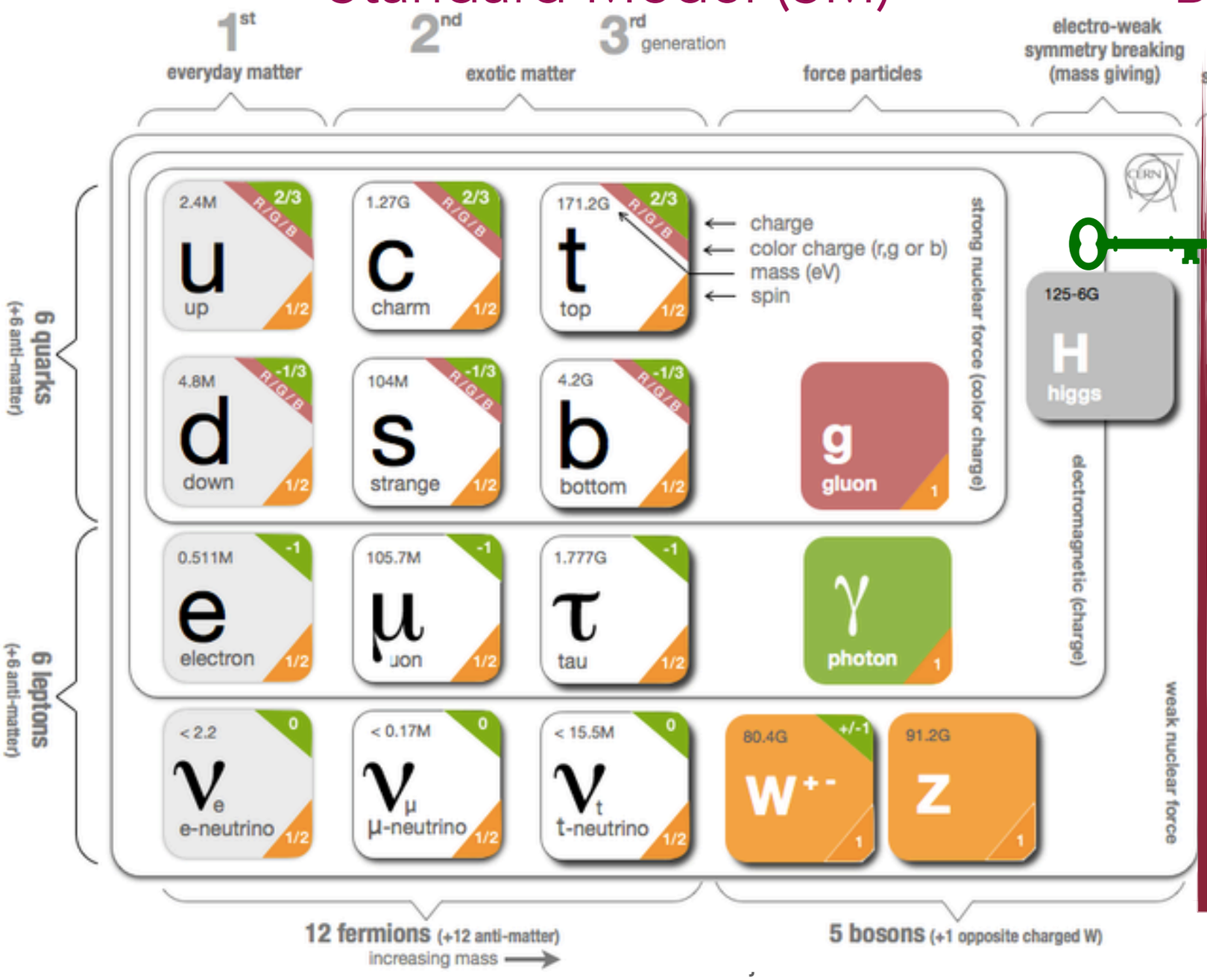
First observation of $H \to b\bar{b}$ at 2018

Phys. Lett. B 786 (2018) 59

Higgs boson: one key for new physics

- Many phenomena can not be explained within Standard Model like gravity, dark matter …

Standard Model (SM)



Beyond Standard Model (BSM)

Direct searches

(Test BSM models directly)

Indirect searches

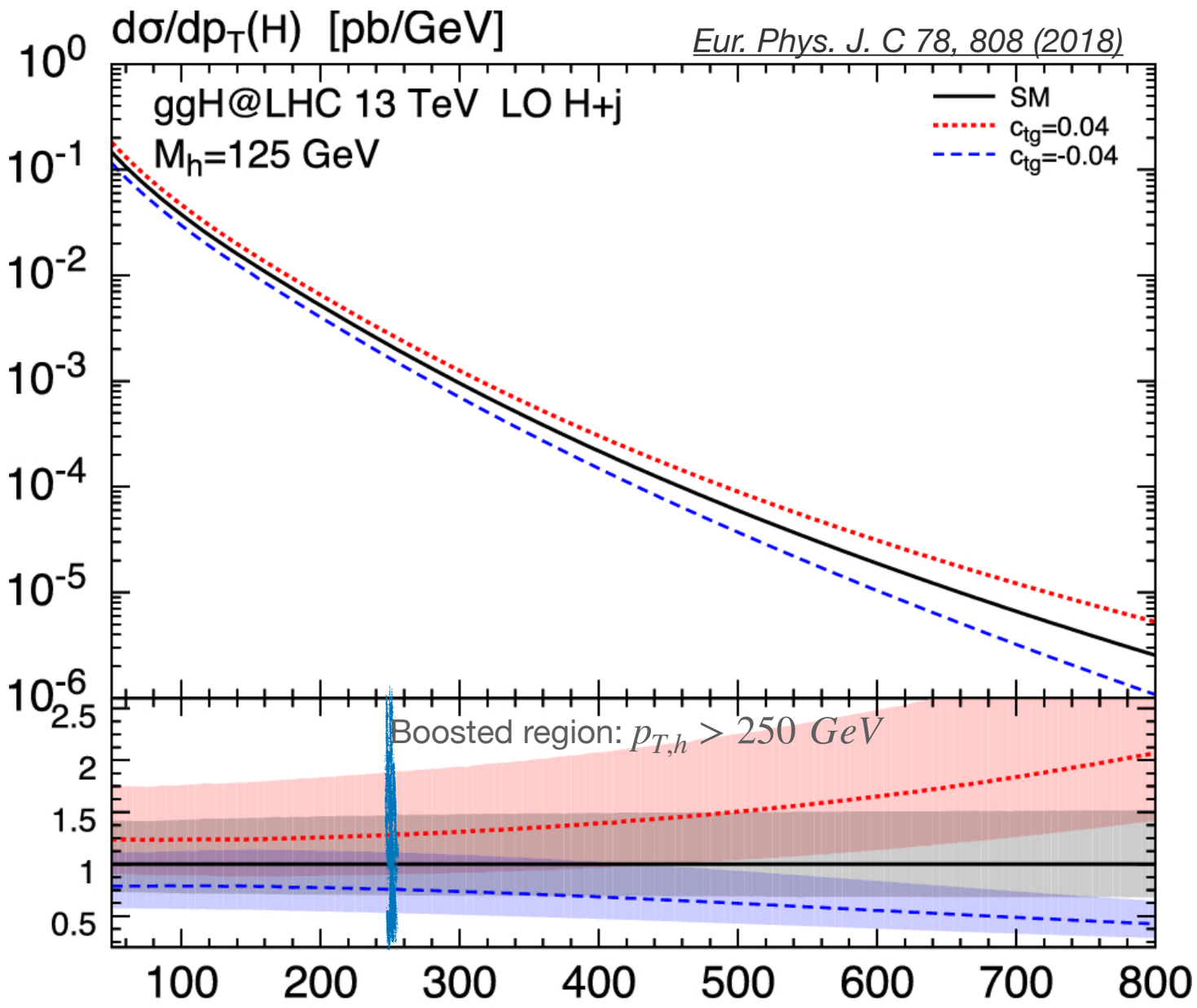
(Precise measurement of SM Higgs properties and compare with SM prediction)

graviton

gravitational force

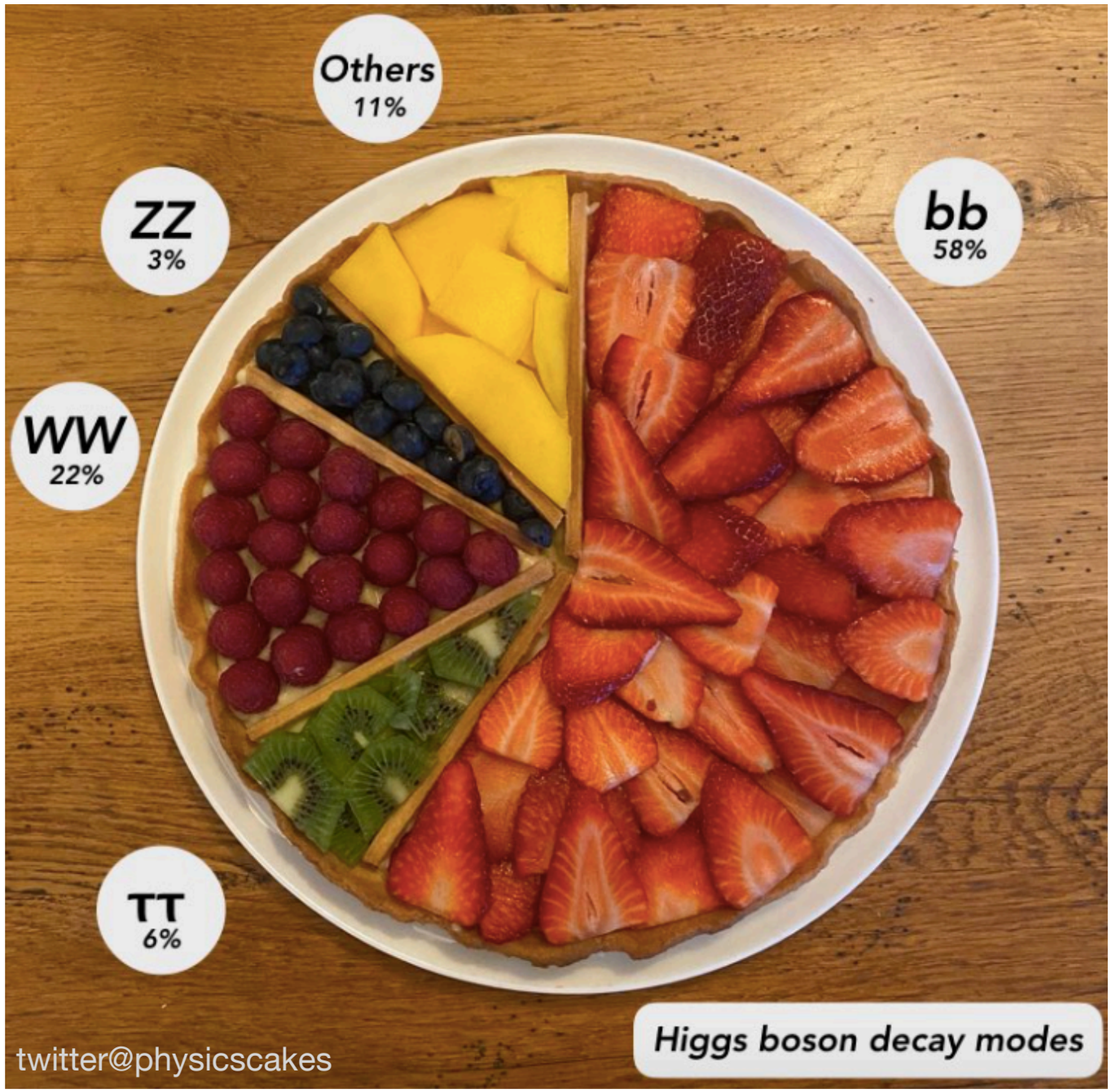
Boosted Higgs bosons

- Can improve the sensitivity of SM Higgs measurements.
- Can be used as a tool to search new physics.



The largest BR in H decay: $H \to b\bar{b}$

- Branching Ratio (BR): fraction of particles decaying to an individual mode



Question 2

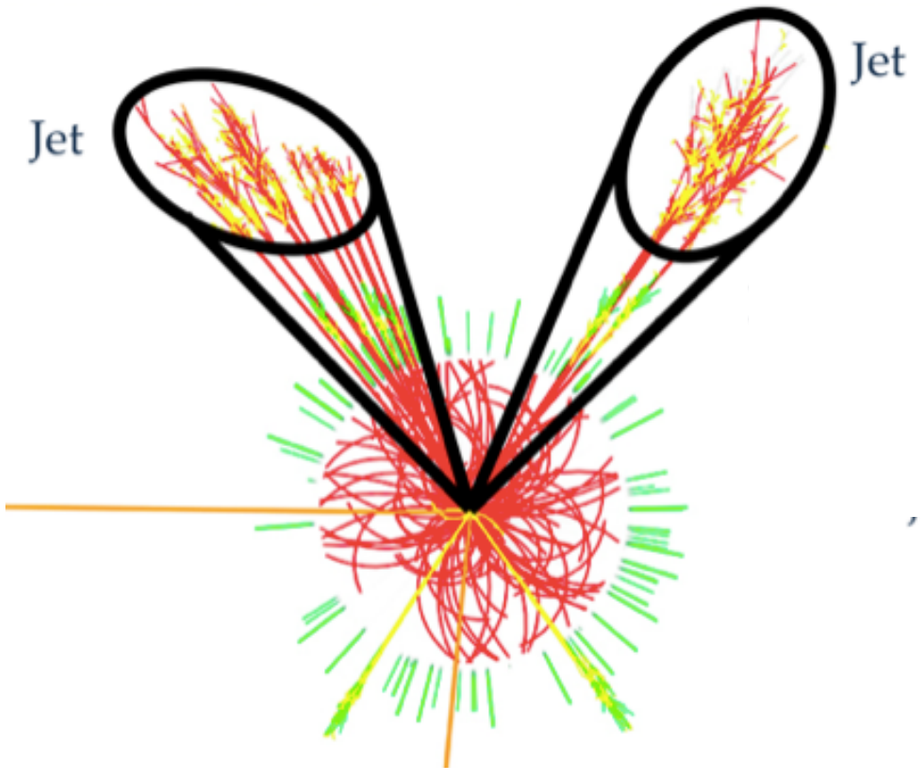
- Why we're interested in boosted Higgs boson (H) and $H \to b\bar{b}$?

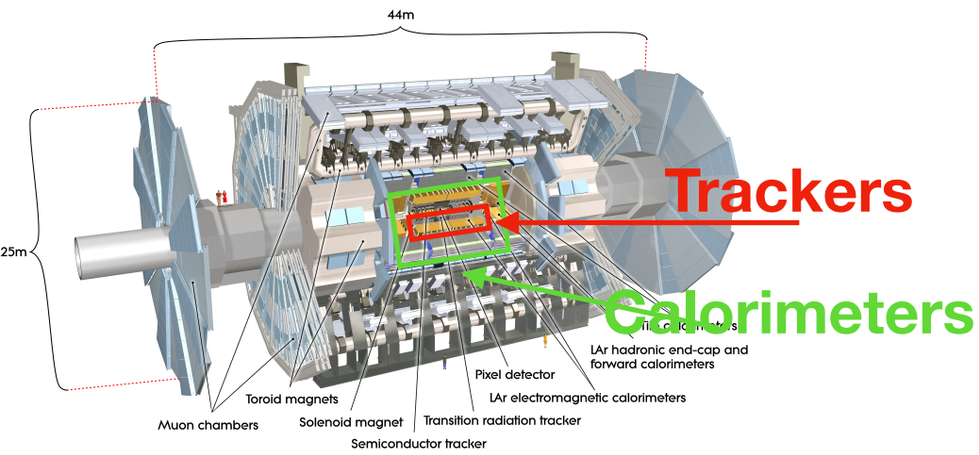
- **What are the current techniques to identify boosted $H \to b\bar{b}$ events in ATLAS?**

- How to apply the techniques into physics analyses?

- What will the future look like?

Jet: Proxy to the quarks/gluons



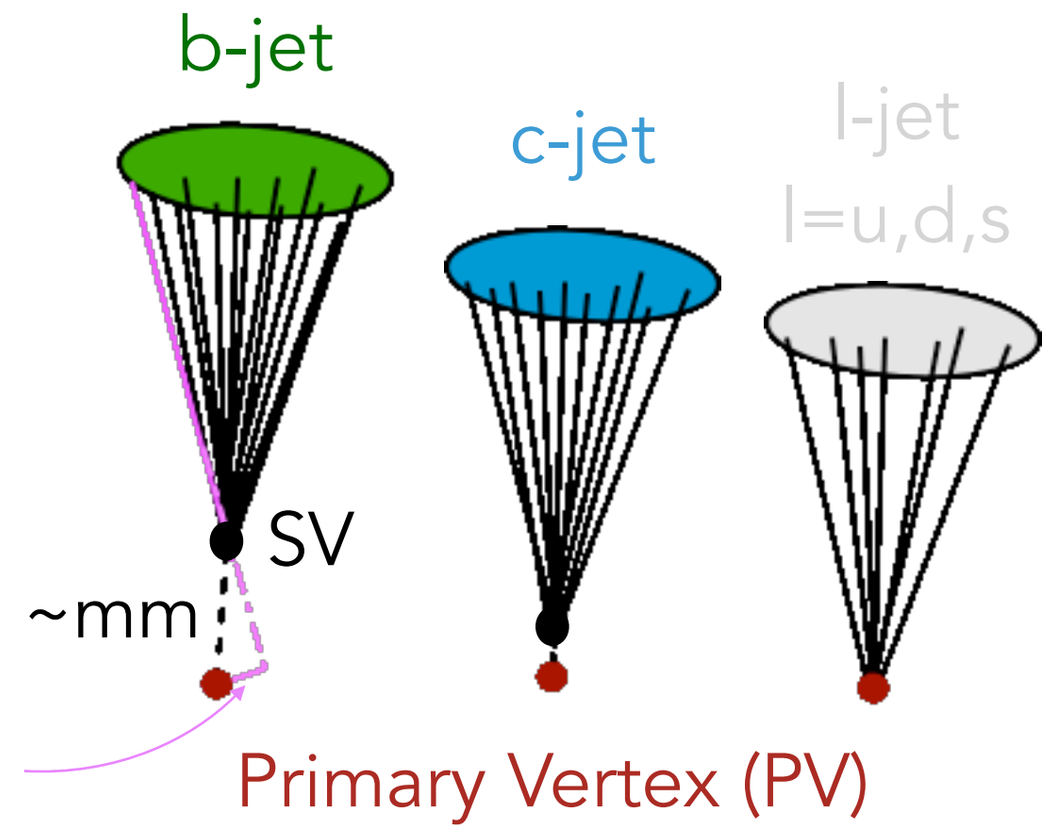


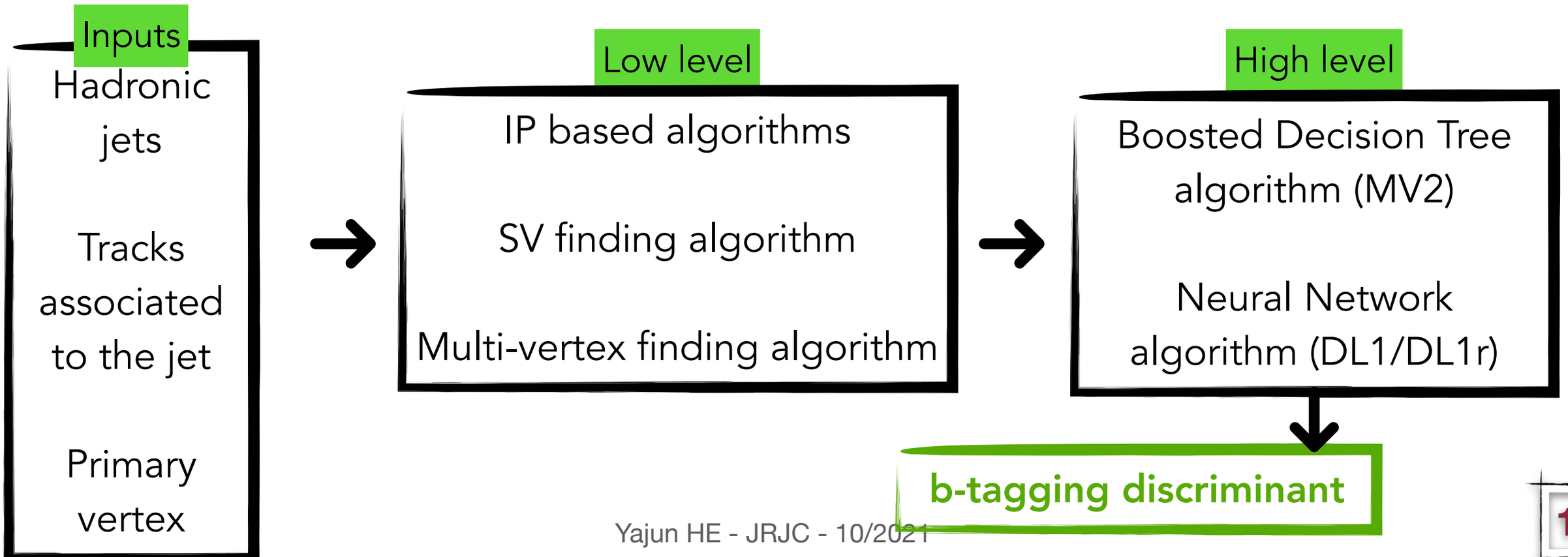
- Quarks can not be measured directly.
- Jet is a stream of particles produced from quarks or gluons.
- Jets are reconstructed using informations from trackers and calorimeters.

We're interested in **b-jets** instead of b-quarks.

b-jet and b-tagging

- Secondary Vertex (SV) measurable due to longer lifetime (~ps/~mm)
- High decay product multiplicity due to large mass (4.2 GeV)





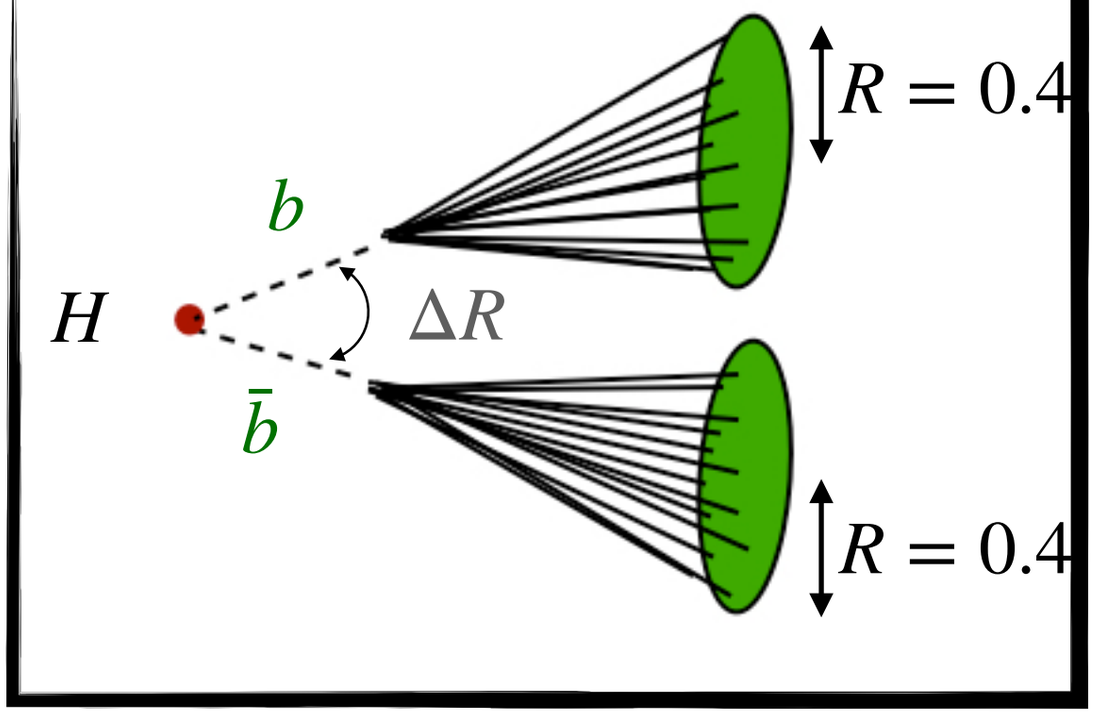
Boosted $H \to b\bar{b}$ tagging

Double b-tagging method

$$\Delta R(b,\bar{b}) \simeq \frac{2m_H}{p_T}$$

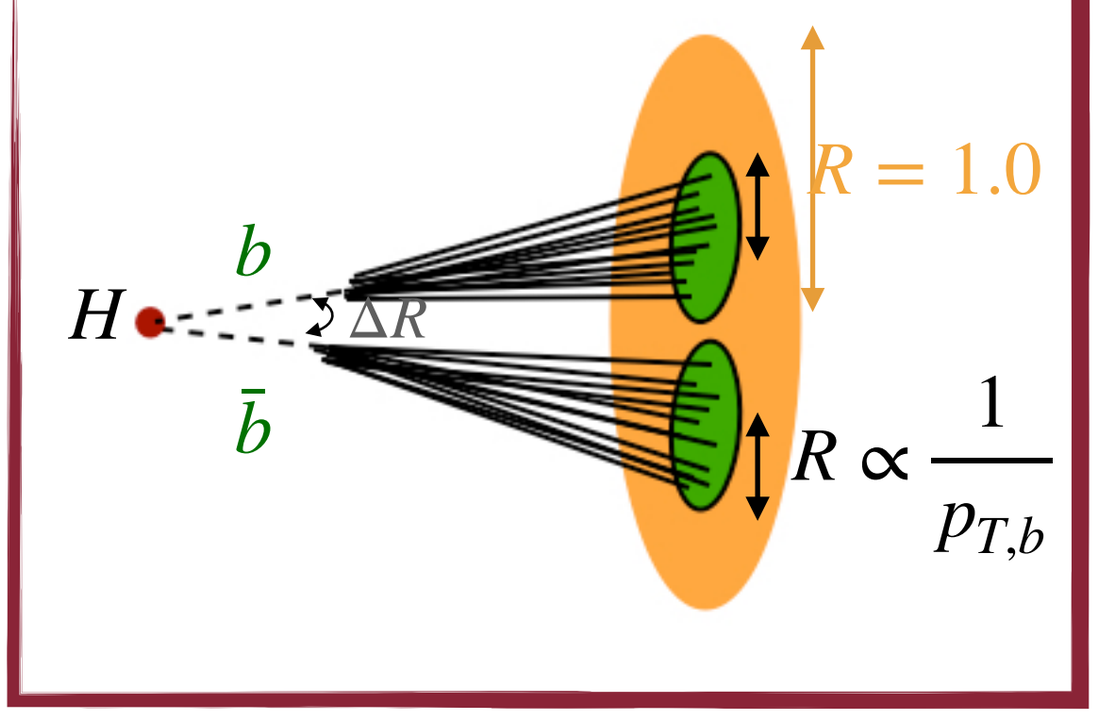
At low energy regimes

Resolved $H \to b\bar{b}$



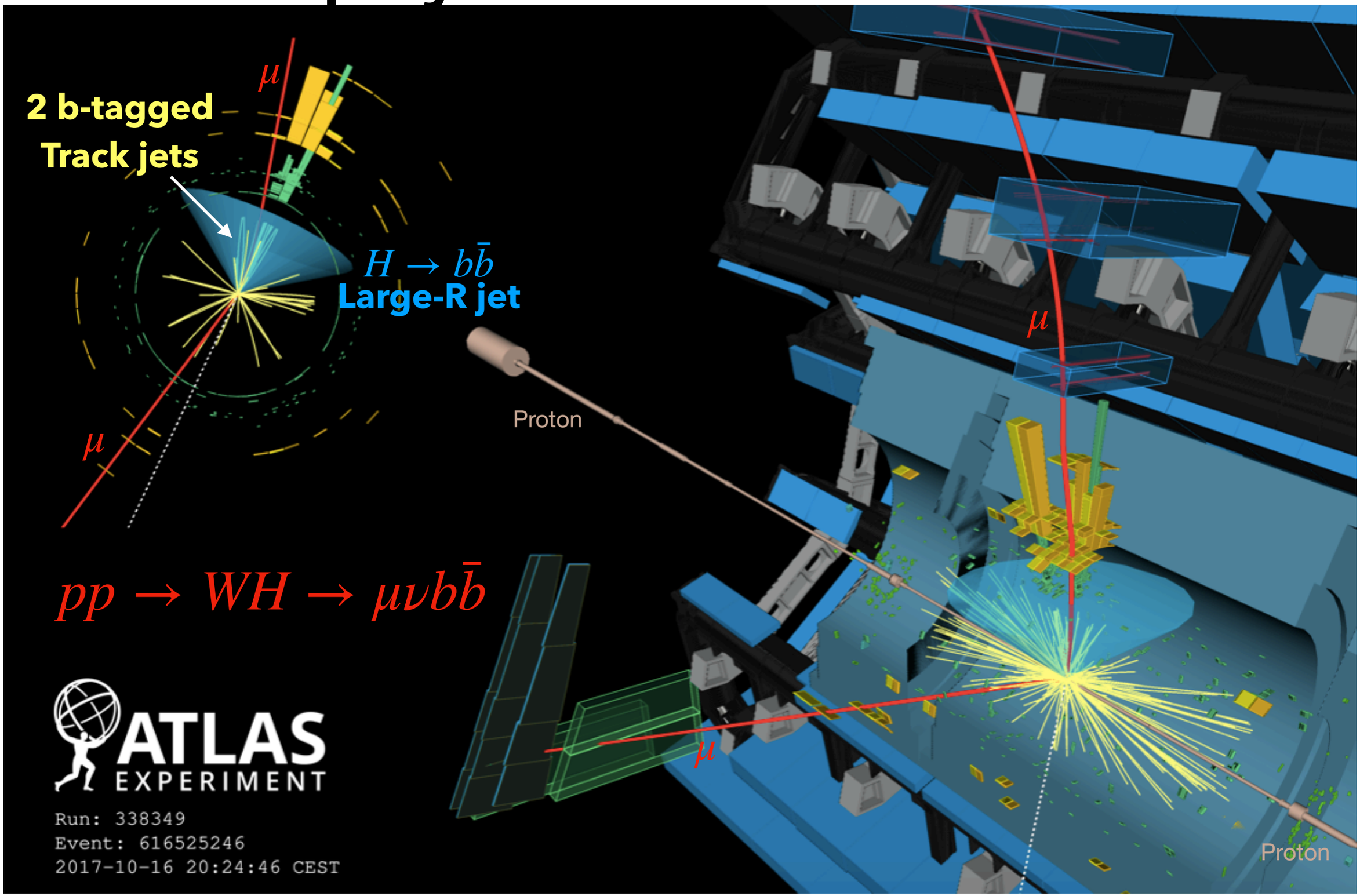
At high energy regimes

Boosted $H \to b\bar{b}$



The large-R jets with 2 b-tagged associated variable radius (VR) track jets are identified as boosted $H \to b\bar{b}$.

Event display of boosted $H \to b\bar{b}$

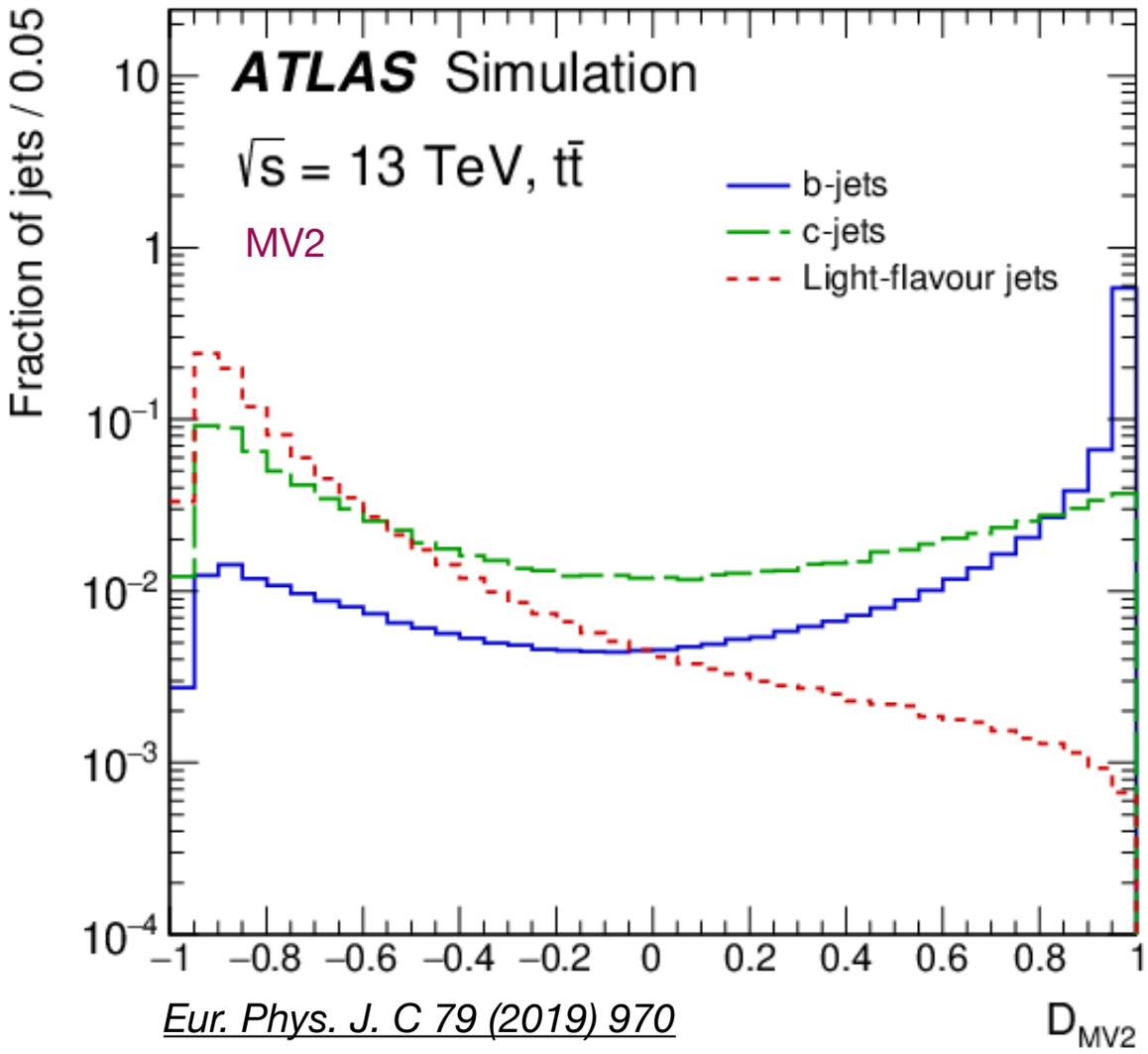


ATLAS-PHOTO-2020-006

Question 3

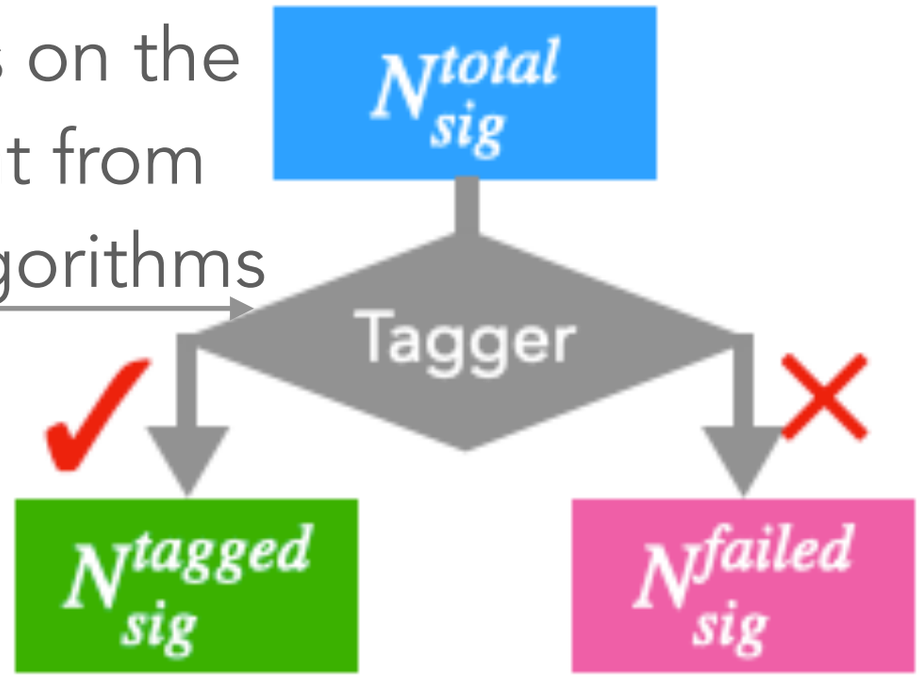
- Why we're interested in boosted Higgs boson (H) and $H \to b\bar{b}$?
- What are the current techniques to identify boosted $H \to b\bar{b}$ events in ATLAS?
- **How to apply the techniques into physics analyses?**
- What will the future look like?

Work point definition



Eur. Phys. J. C 79 (2019) 970

Choose cuts on the discriminant from high level algorithms



Signal tagging efficiency $\epsilon = \frac{N^{tagged}_{sig}}{N^{total}_{sig}}$

Calibration

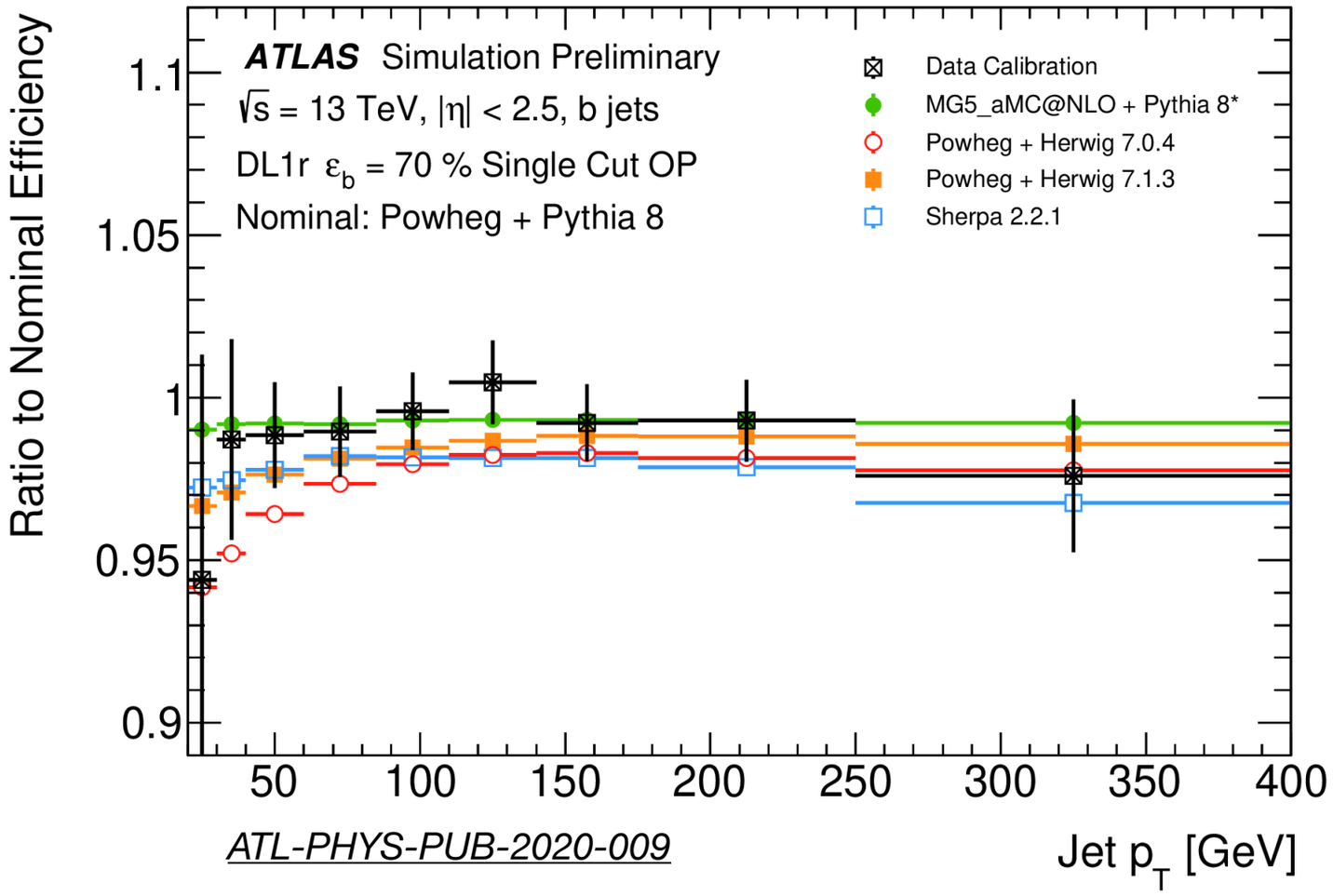
- Taggers developed using specific (nominal) Monte-Carlo (MC) simulations which may have different performance with MCs used in physic analyses and which can not fully describe data.

- MC-to-MC scale factors:

$$\epsilon_{alt.MC}/\epsilon_{nom.MC}$$

- Data-to-MC scale factors:

$$\epsilon_{data}/\epsilon_{nom.MC}$$



Usage in ATLAS analysis

Smoothing

↓

Extrapolation to high p_T jets

↓

Generator dependencies

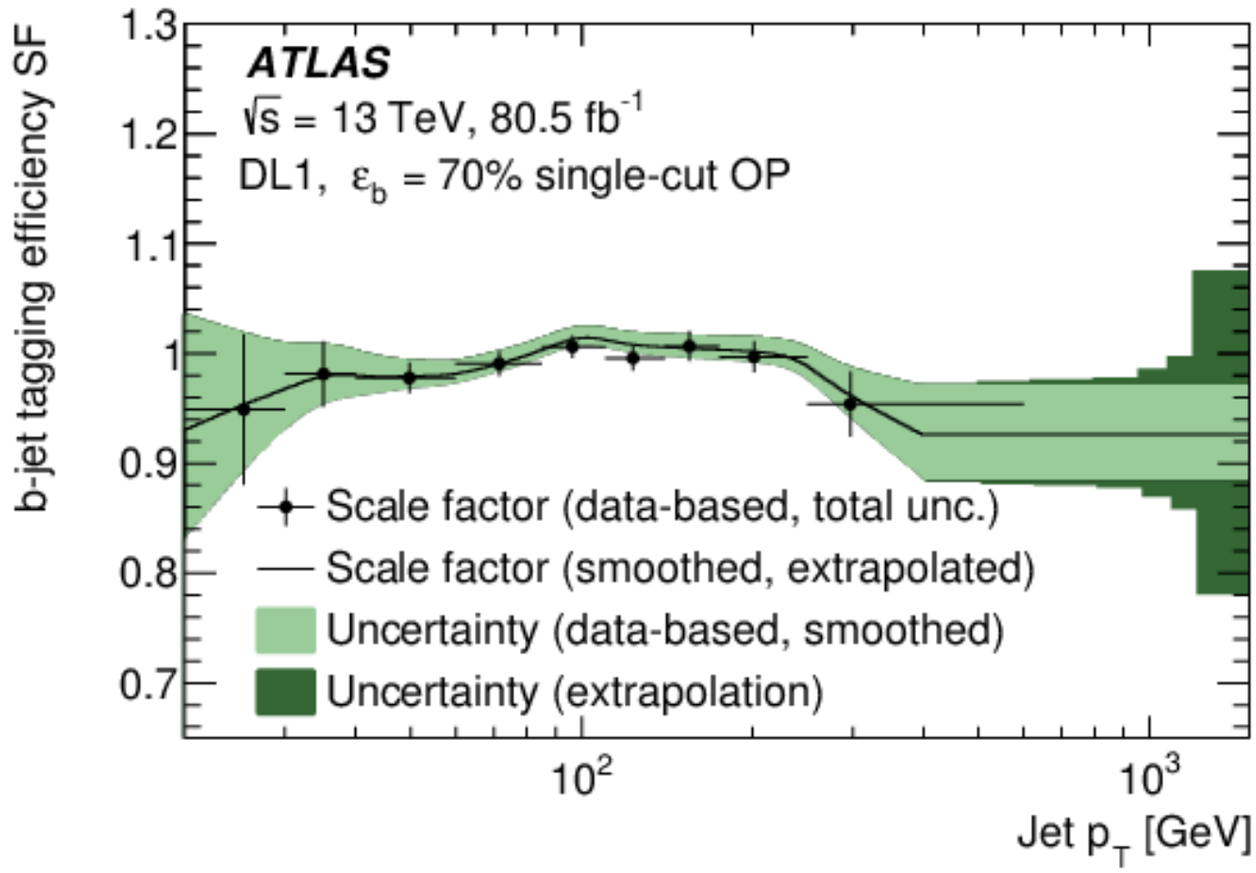
↓

Eigenvalue decomposition to reduce # of syst.

↓

Applied weight to simulated events

Eur. Phys. J. C 79 (2019) 970



$$SF = \frac{SF_{\text{data-MC}}(p_T, \eta\,..)}{SF_{\text{MC-MC}}(p_T, \eta\,..)}$$

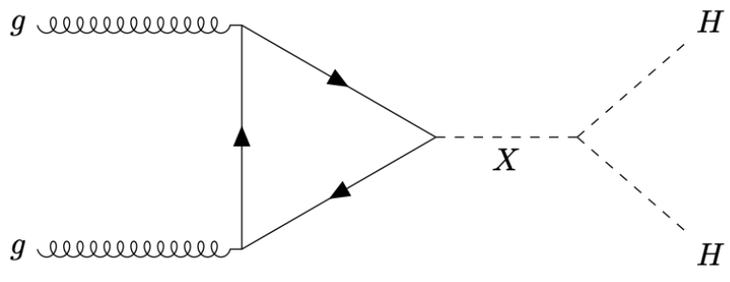
For tagged jets: $w_{jet} = SF(p_T, \eta\,..)$

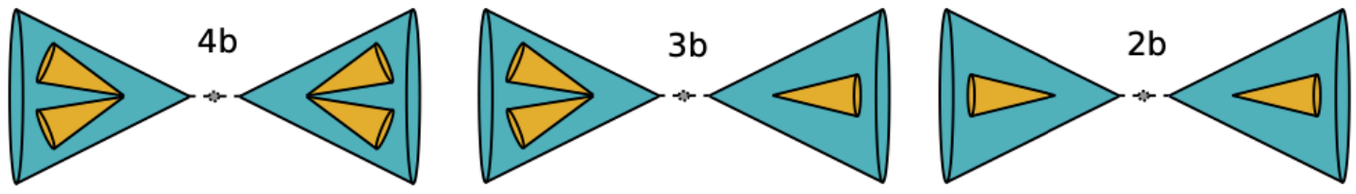
For untagged jets: $w_{jet} = \frac{1-\epsilon_{data}}{1-\epsilon_{MC}} = \frac{1-SF\times\epsilon_{MC}}{1-\epsilon_{MC}}$

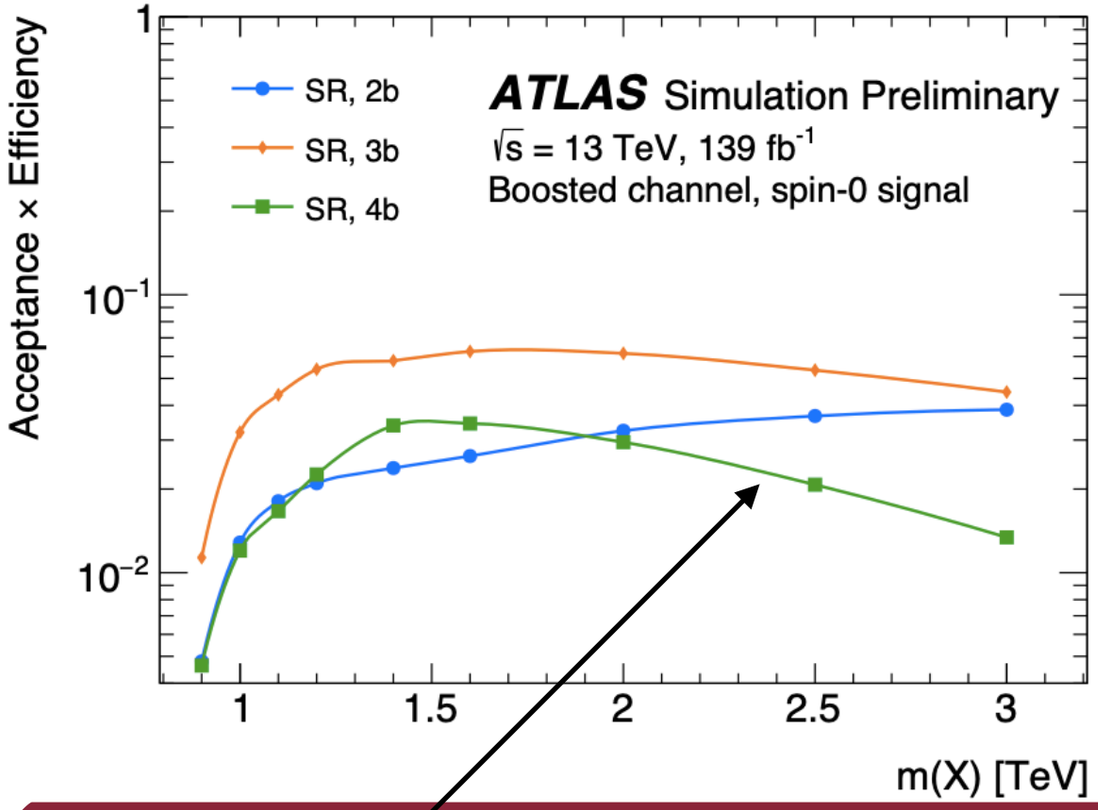
Example of direct NP searches

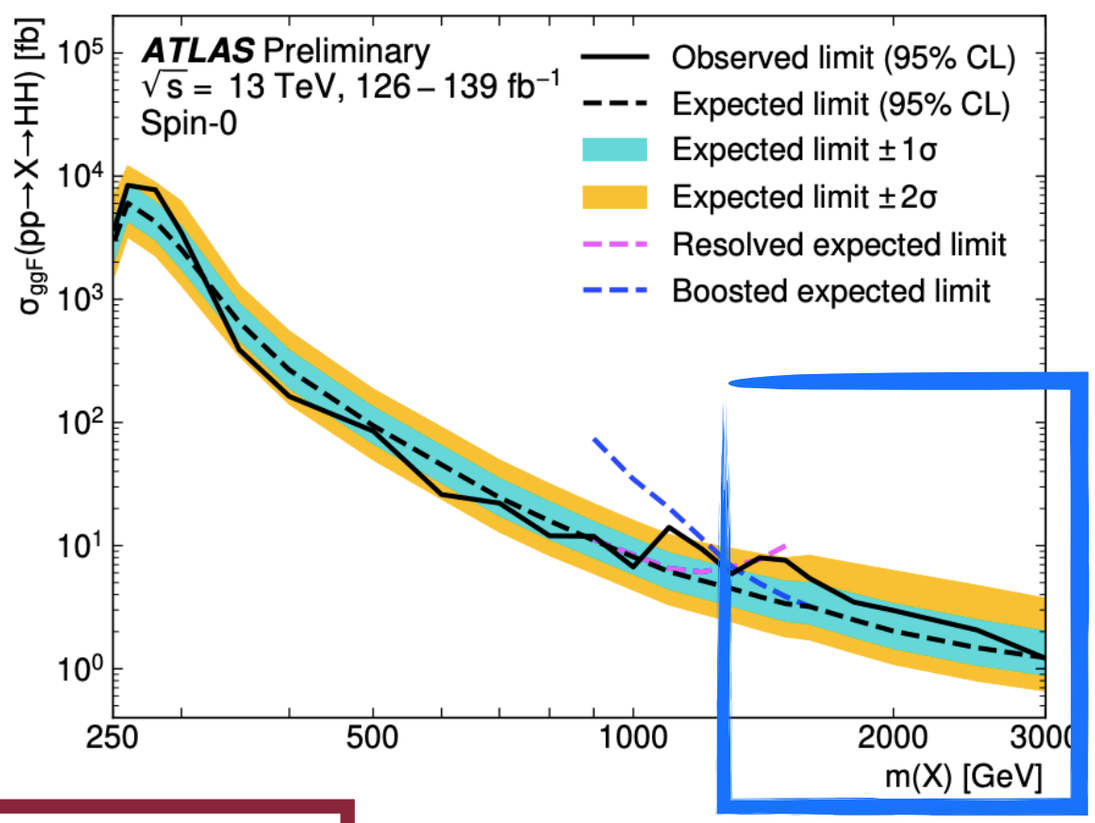
Searches for heavy resonance decaying to HH via $b\bar{b}b\bar{b}$

ATLAS-CONF-2021-035









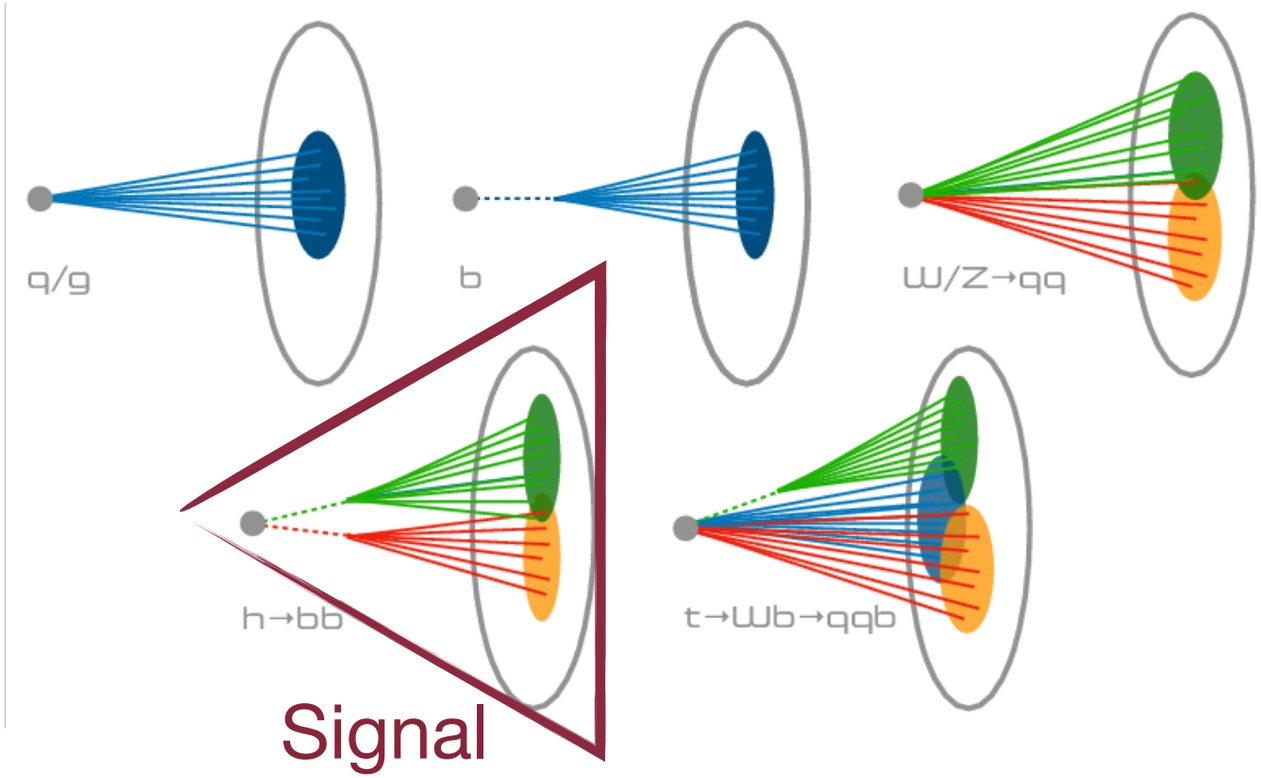
Degradation of 2b tagging method at very high energy

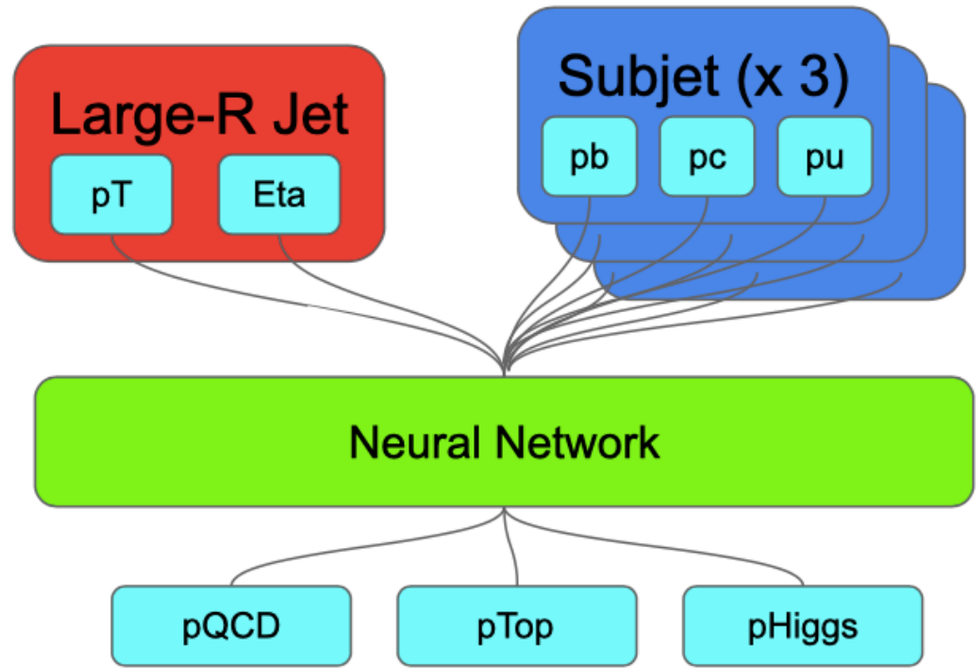
Question 4

- Why we're interested in boosted Higgs boson (H) and $H \to b\bar{b}$?
- What are the current techniques to identify boosted $H \to b\bar{b}$ events in ATLAS?
- How to apply the techniques into physics analyses?
- **What will the future look like?**

New $X \to b\bar{b}$ tagger

Instead of tagging b-jets, let's tag the $H \to b\bar{b}$ jets.



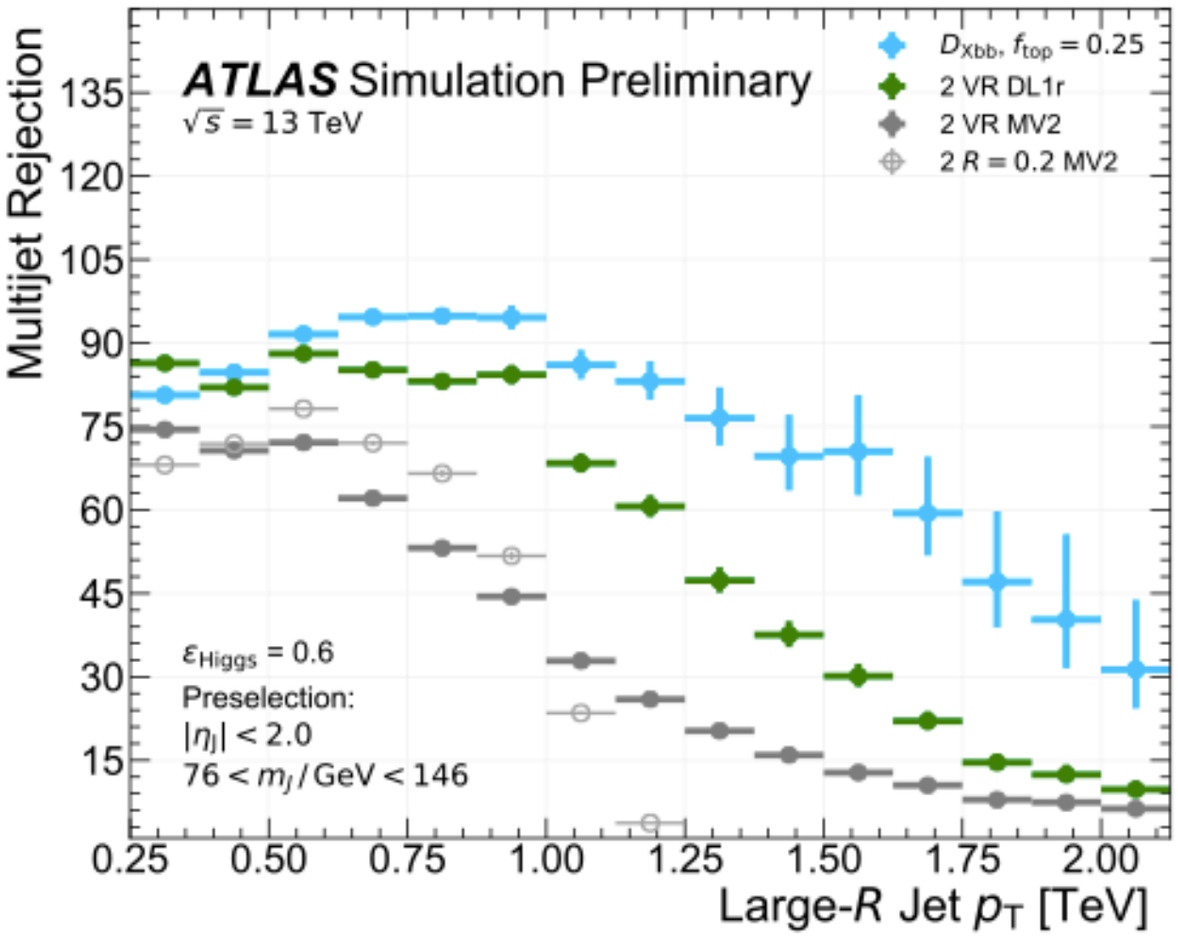


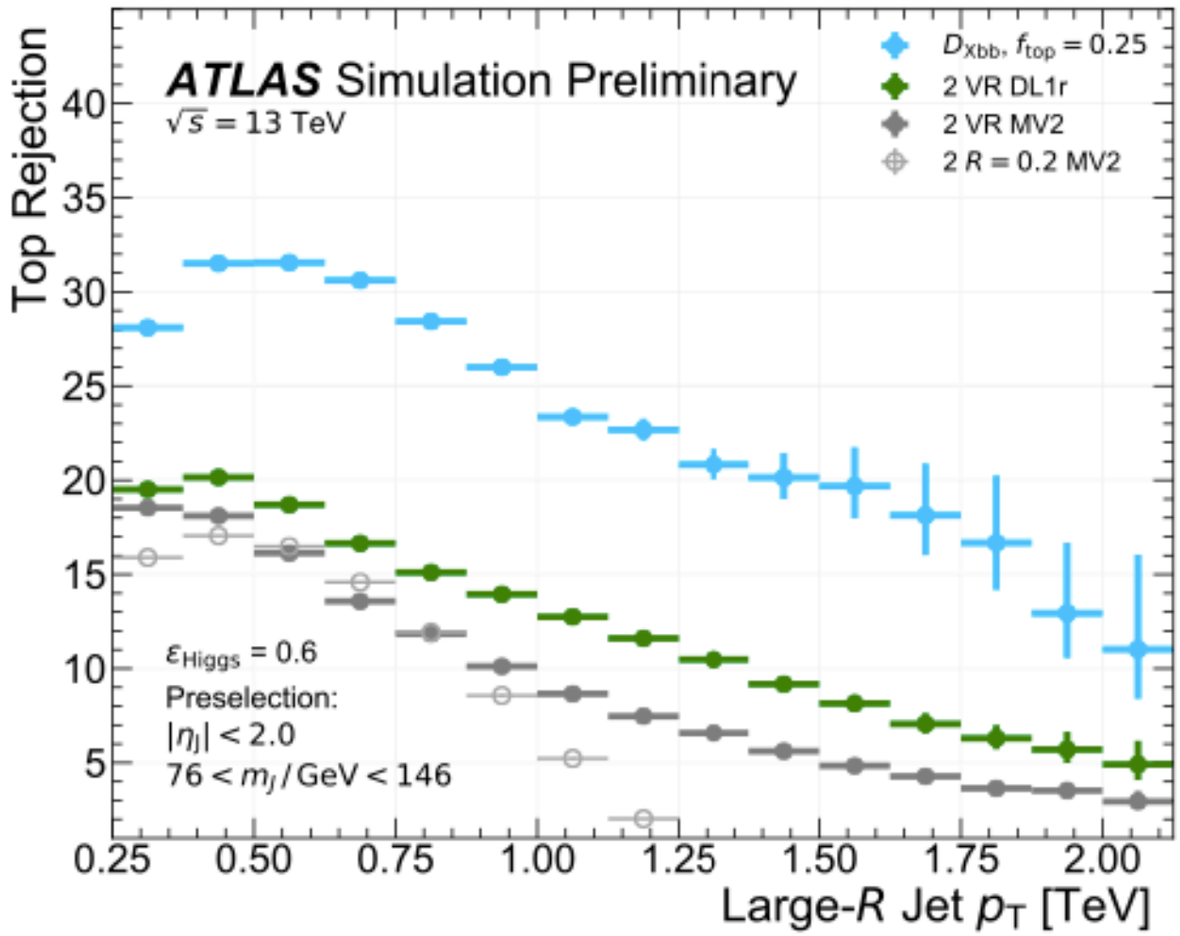
Discriminant used to define work points

$$D_{Xbb} = \ln \frac{p_{Higgs}}{f_{top} \cdot p_{top} + (1 - f_{top}) \cdot p_{multijet}}$$

New $X \to b\bar{b}$ tagger

ATL-PHY-PUB-2020-019





$X \to b\bar{b}$ tagger shows more powerful background rejection at higher p_T.

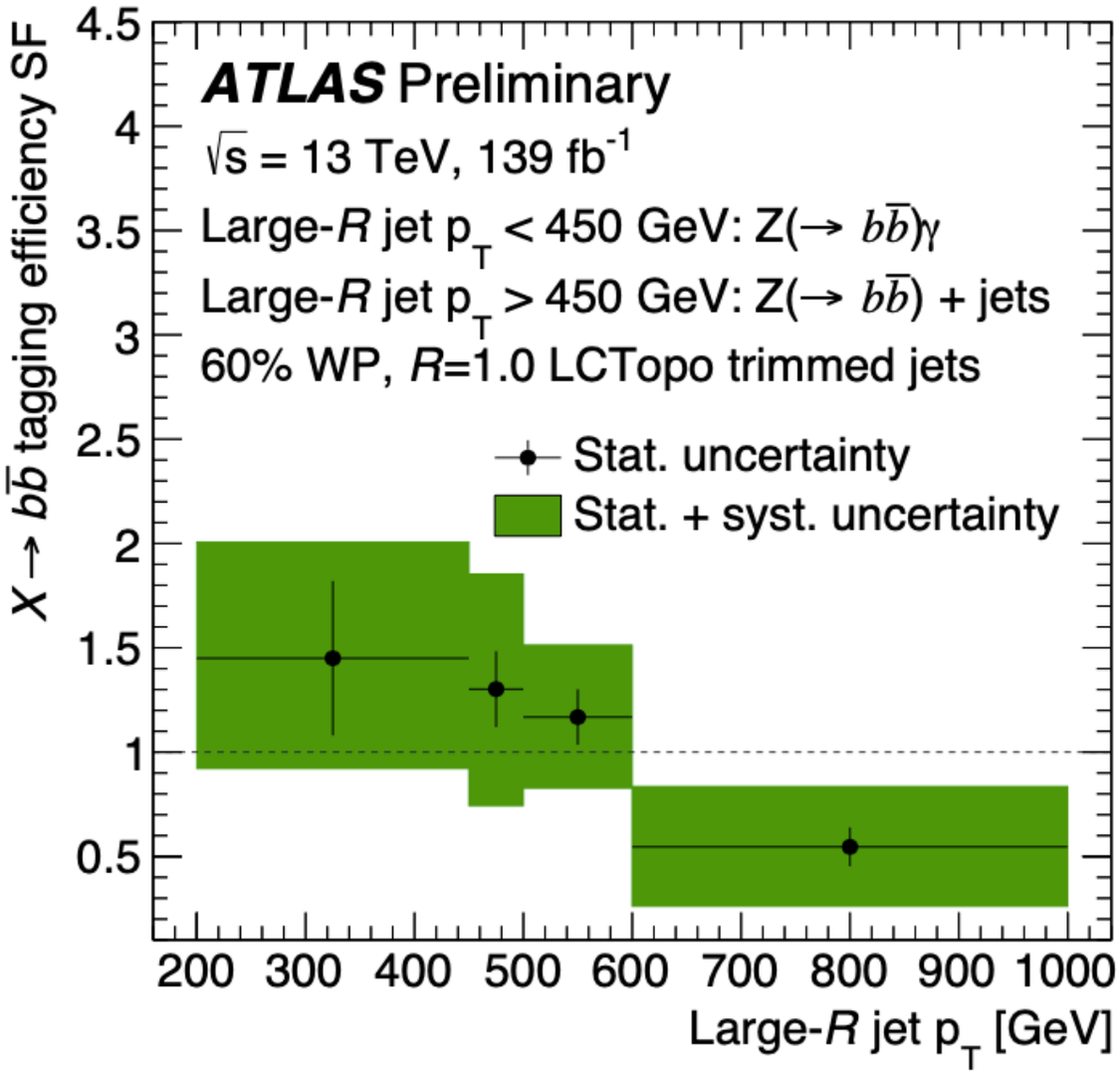
Signal efficiency calibration

First calibration results!!!!!

$Z(\rightarrow b\bar{b})\gamma$ and $Z(\rightarrow b\bar{b}) + jets$ methods

- $Z \rightarrow b\bar{b}$ similar to $H \rightarrow b\bar{b}$ topology
- Important contribution of $Z \rightarrow b\bar{b}$ in analyses using $H \rightarrow b\bar{b}$
- Calibration using large-R jets having ≥2 ghost-associated VR track jets (different from 2b-tagging!!!)
- p_T -dependent calibration: 200-450 GeV ($Z\gamma$), 450-1000 GeV ($Z + jets$)

ATL-PHYS-PUB-2021-035



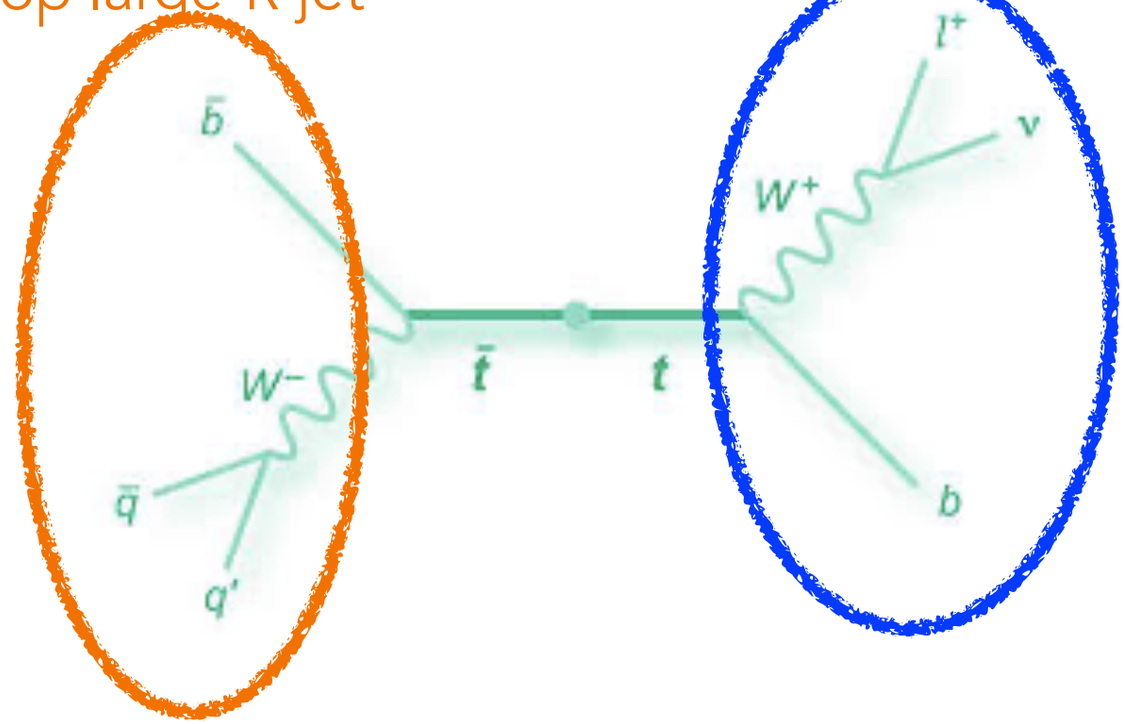
Mis-tag rate calibration

First calibration results!!!!!

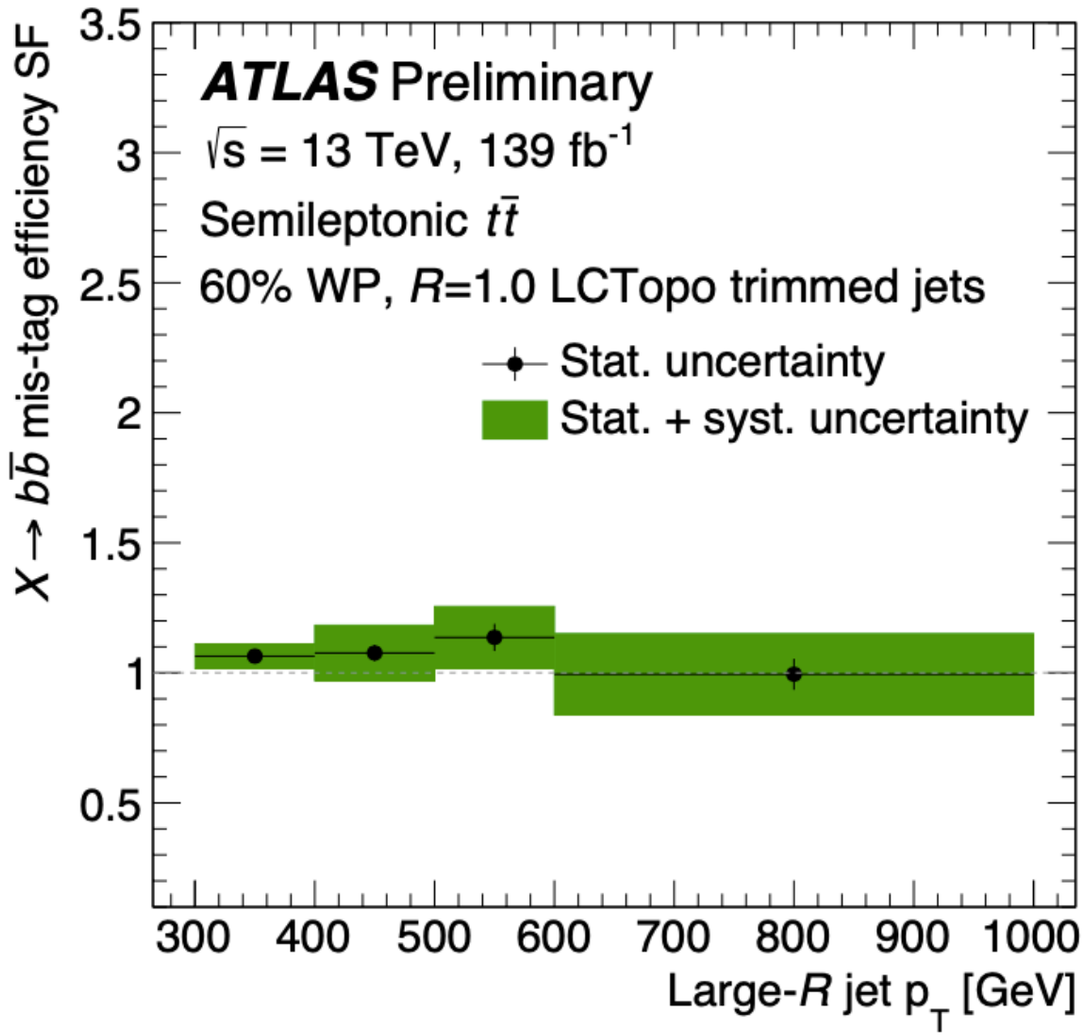
Top mis-tag rate calibration

To construct the top large-R jet

To tag the event



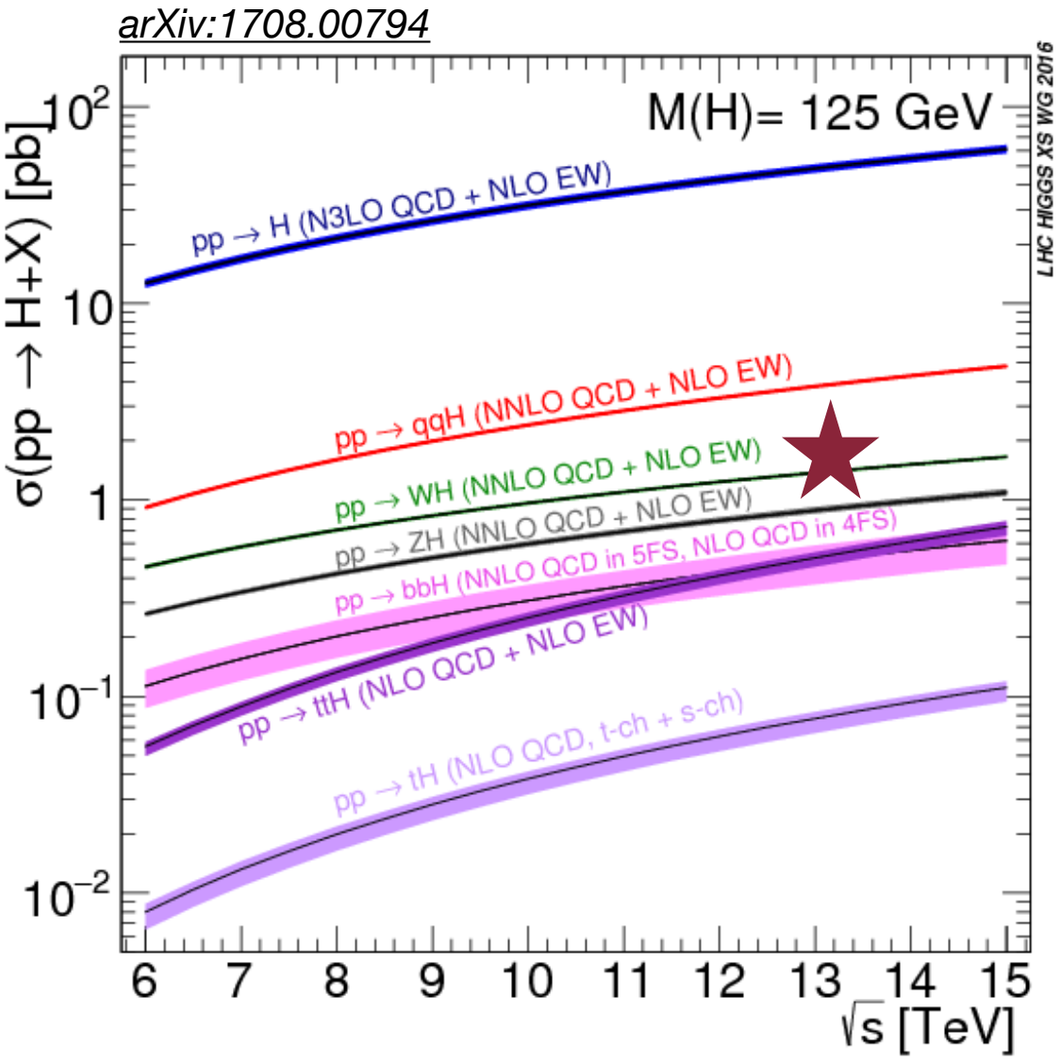
ATL-PHYS-PUB-2021-035



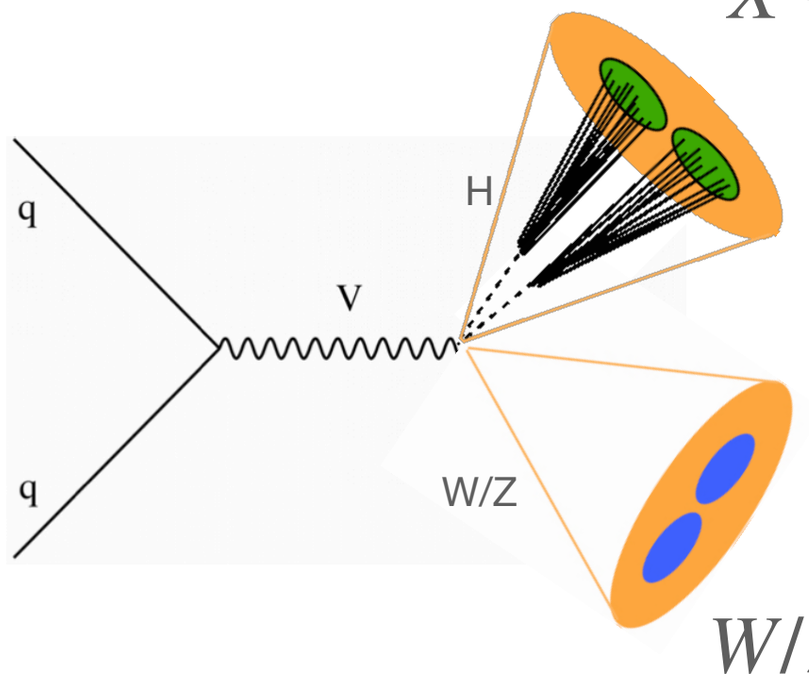
QCD mis-tag rate calibration: studies using $g \to b\bar{b}$ events

Application

Production of Higgs associated with a vector boson (VH)
(First study of VH full hadronic ongoing)



$X \to b\bar{b}$ tagger



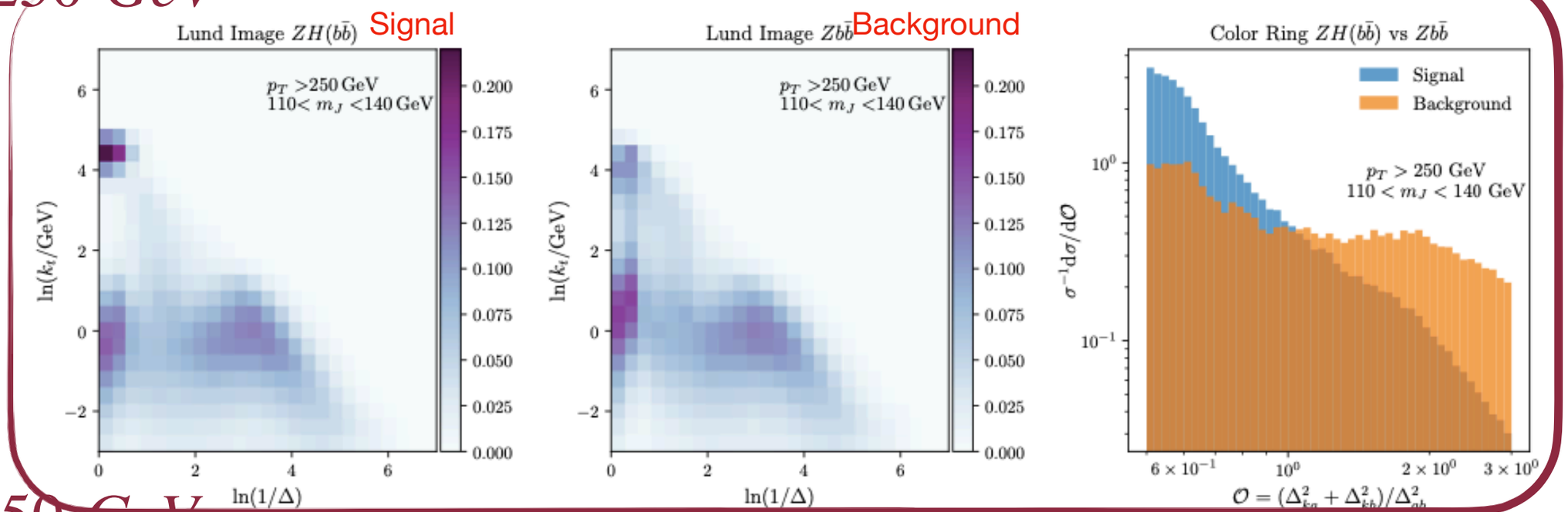
$W/Z \to qq$ tagger

New ideas

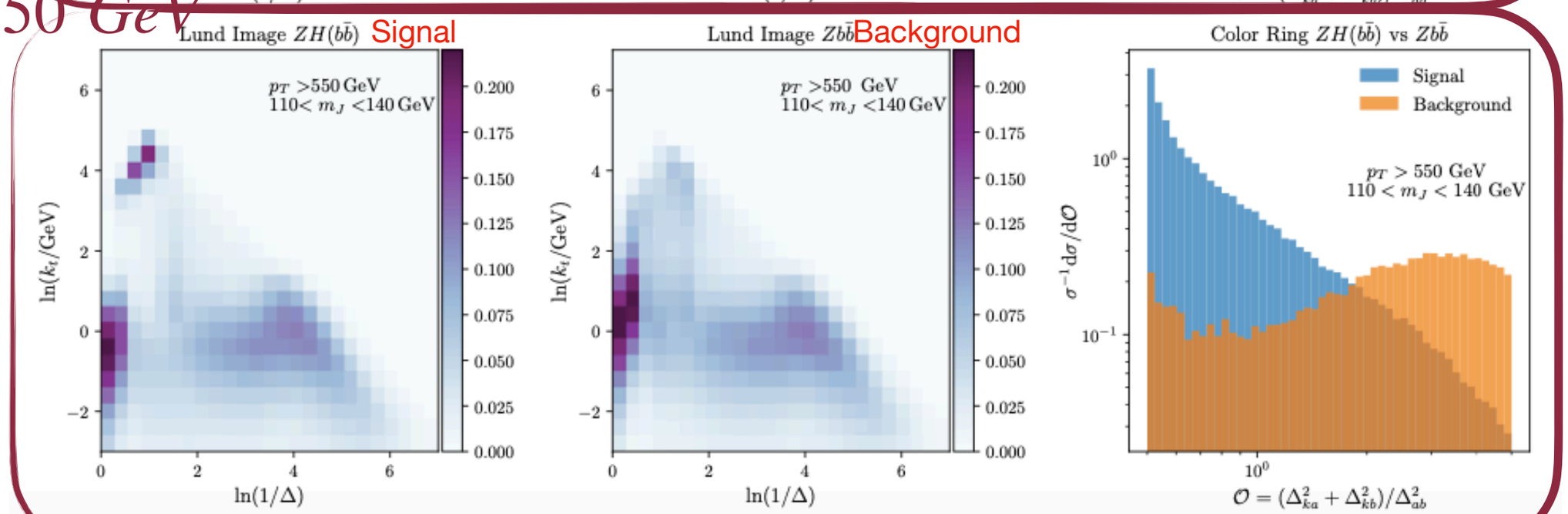
Boosted Higgs tagging with Lund jet plane and color ring

arXiv:2105.03989

$p_T > 250\ GeV$



$p_T > 550\ GeV$



Summary

- Boosted $H \to b\bar{b}$ tagging is an essential topic for physics analyses.

- Double b-tagging method has been used in most of analyses in ATLAS and lots of interesting results have been produced.

- Boosted $X \to bb$ tagger is newly developed and starts to shine. Our team's work on calibration make it useful in physics analyses. We're looking forward to its performance in current (future) researches.

- New ideas and new techniques show promising future for physics at higher energy frontier in future ATLAS and LHC.