Searching for new physics at ATLAS

Rough guide to data analysis

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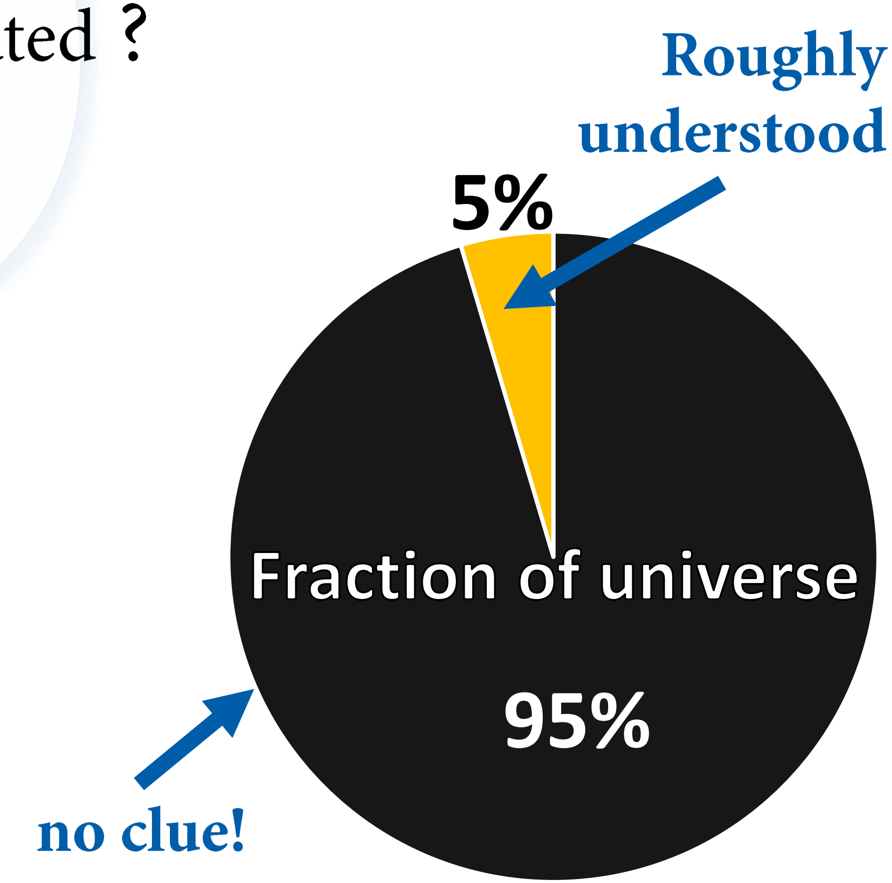
Overview

- LHC and ATLAS detector
- Physics objects
- Analysis – Boosted diboson search
- ~~Summary~~ Discussion

Particle physics – Why do we care?

- Ever wondered ..
  .. what am I and everything around me made of ?
  .. how was our universe created ?
  .. and what is it made of ?

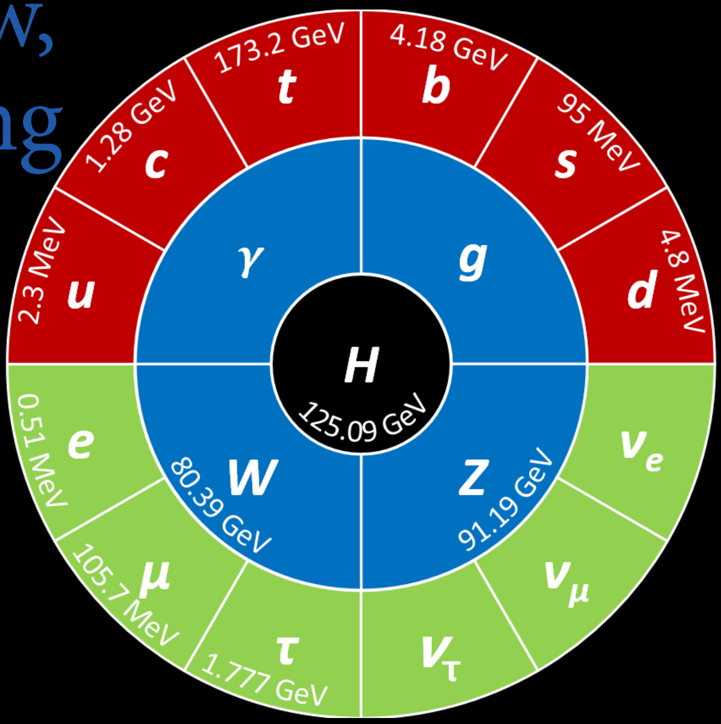
- We do!
  This is why we do particle physics.



Particle physics – Why do we care?

- What particles?

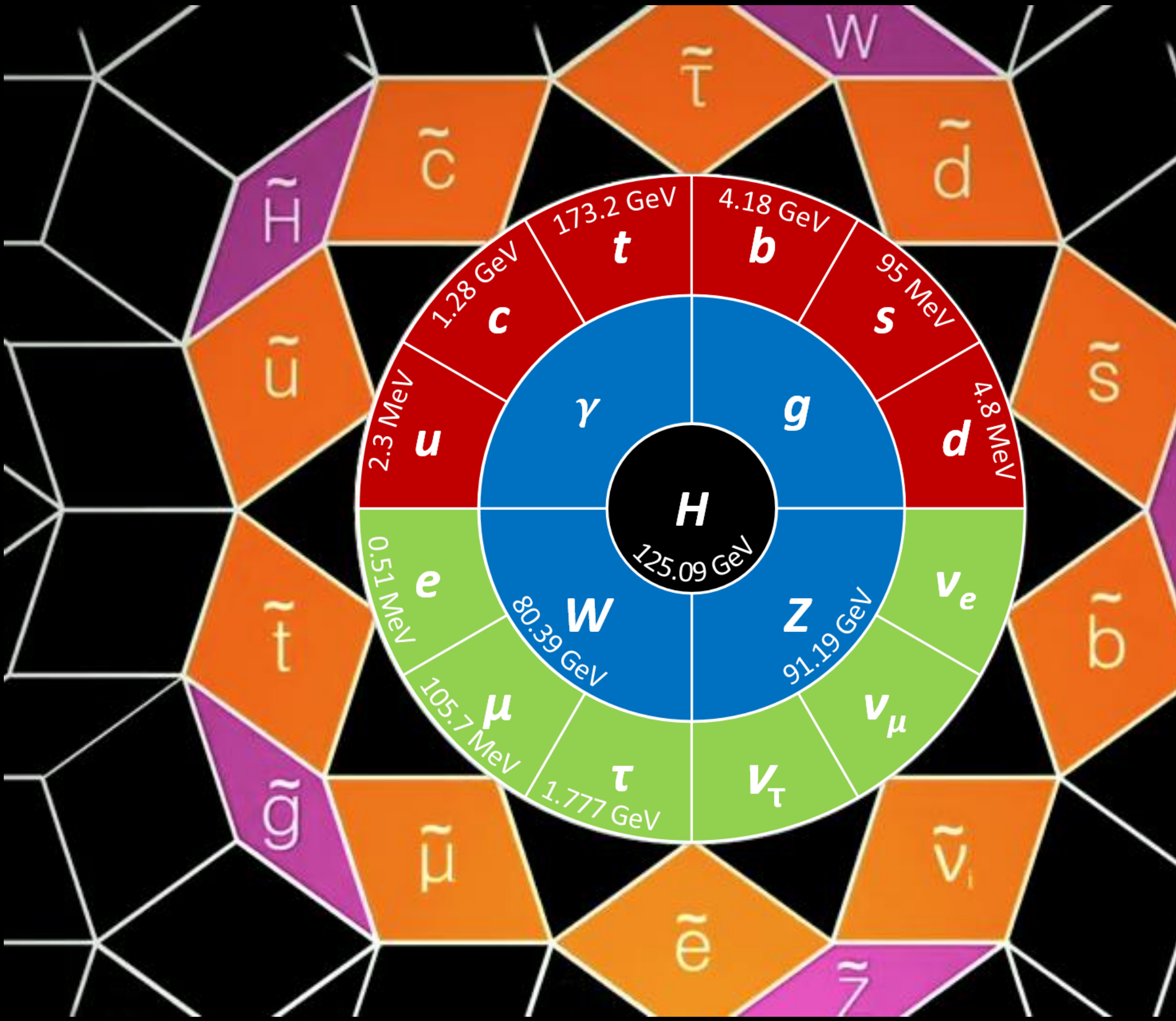
- These particles we know, and they are the building block of the 5%



Particle physics – Why do we care?

- What else could there be?

- Are these the 95% ?



Particle physics – Why do we care?

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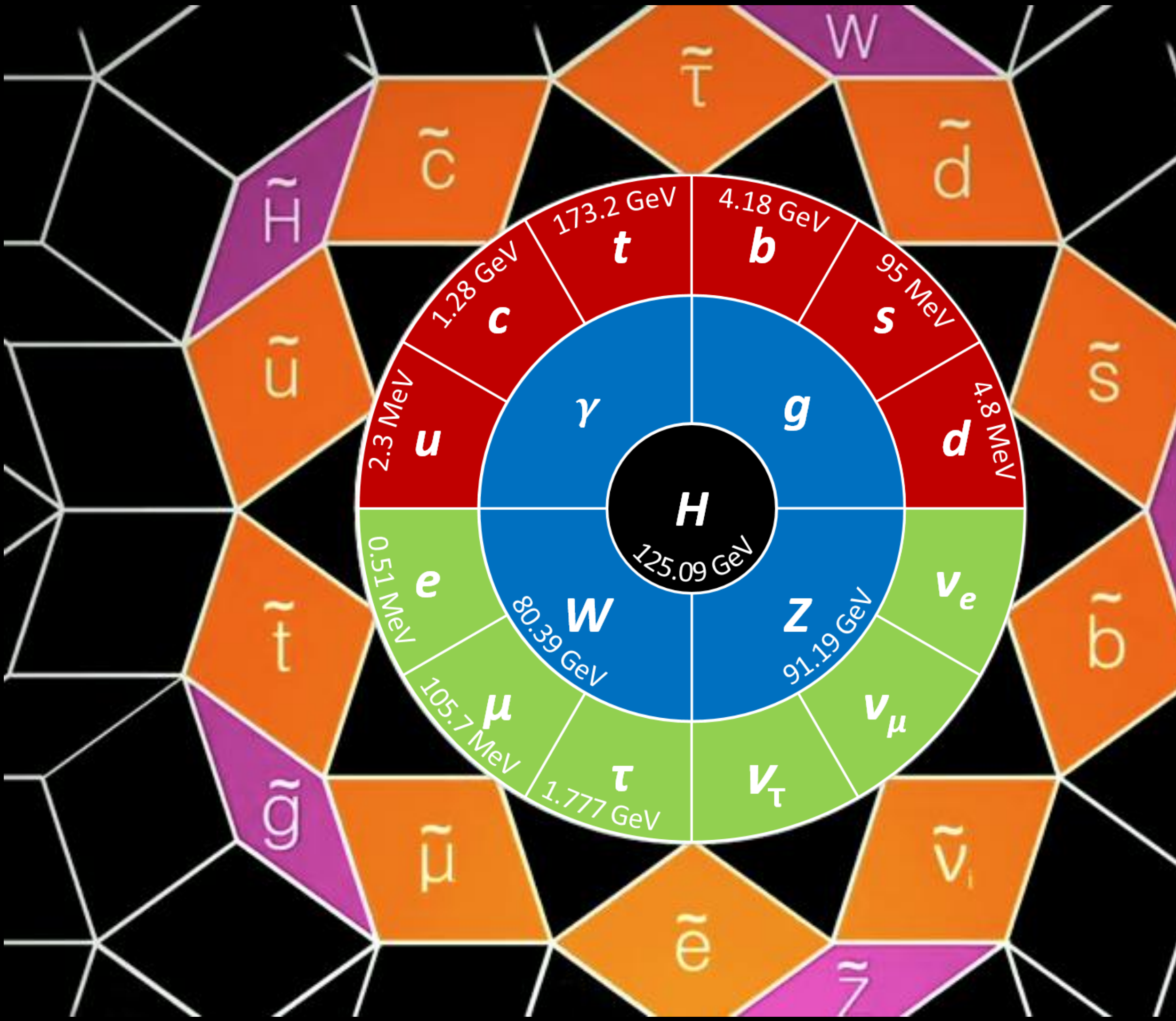
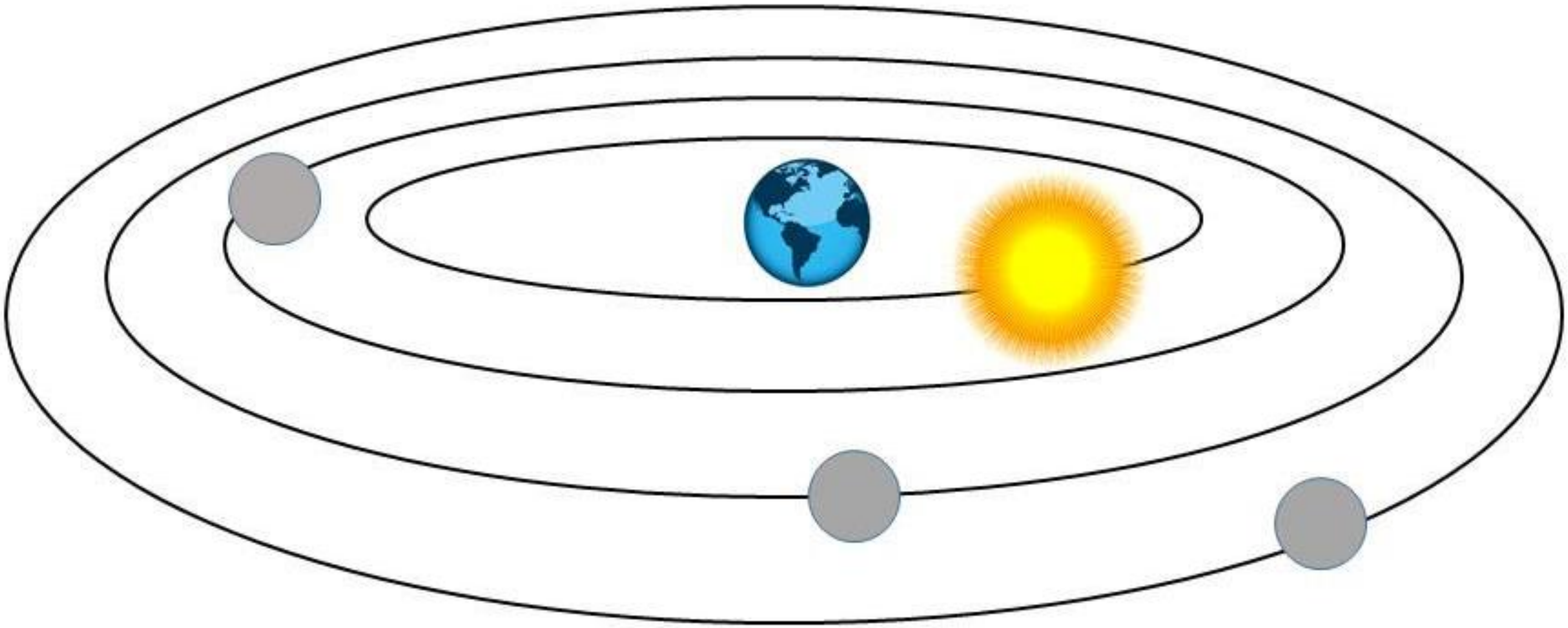


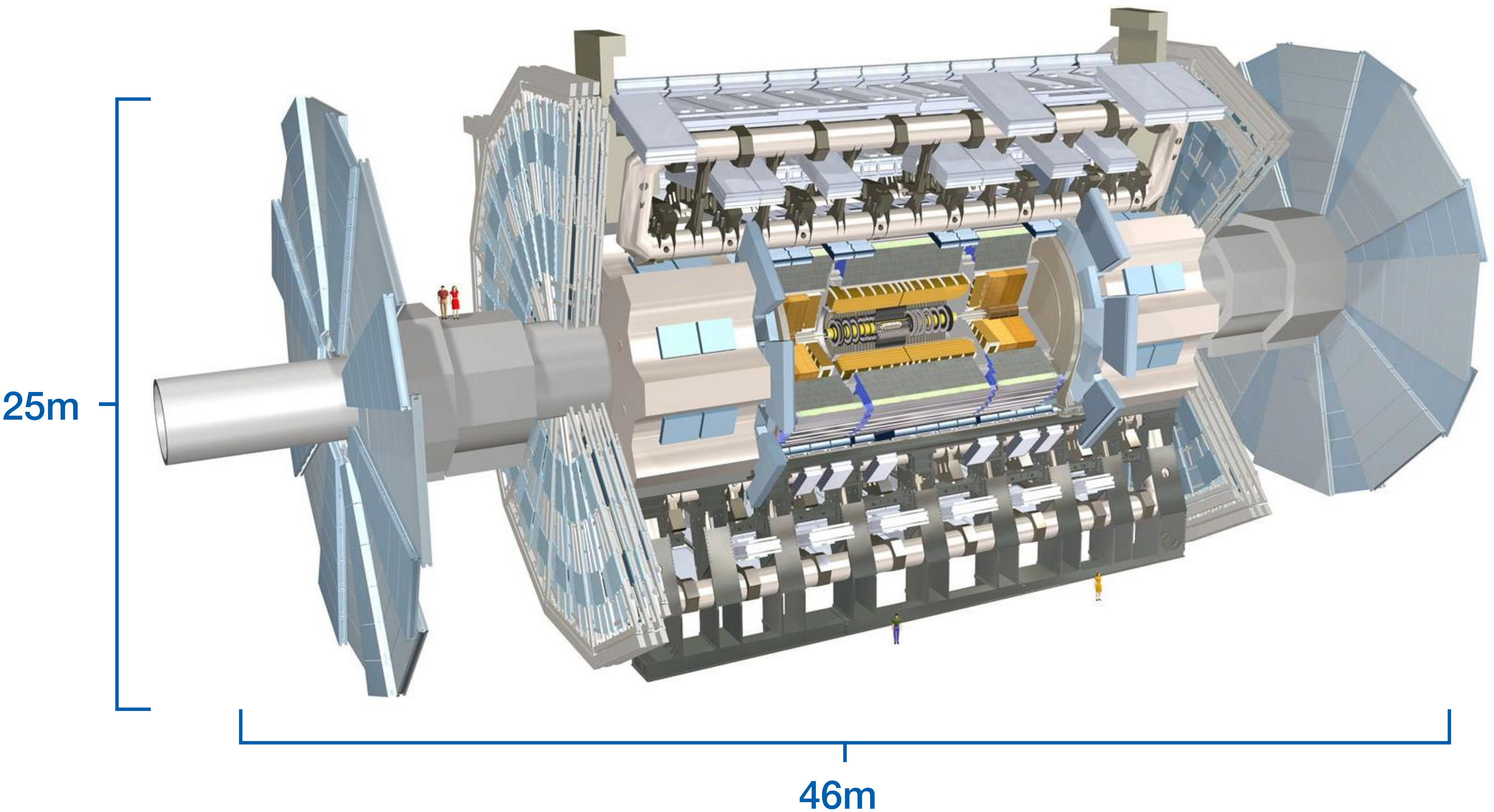
Particle physics – Why do we care?

- Sun goes around earth, earth around sun…
  sounds all the same to me.



Large Hadron Collider

ATLAS Detector

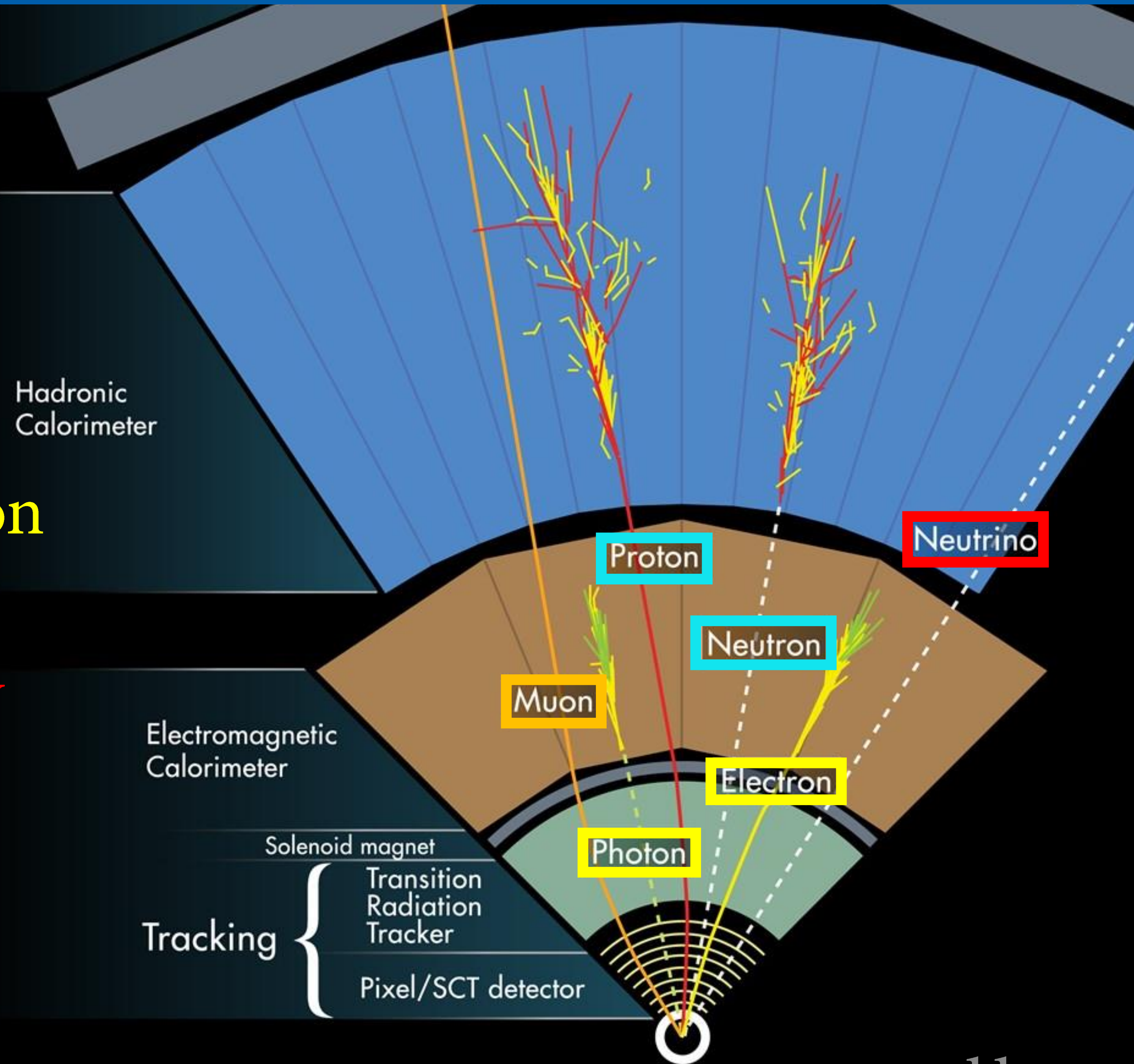


Physics Objects

ATLAS Detector & Objects

Physic objects:

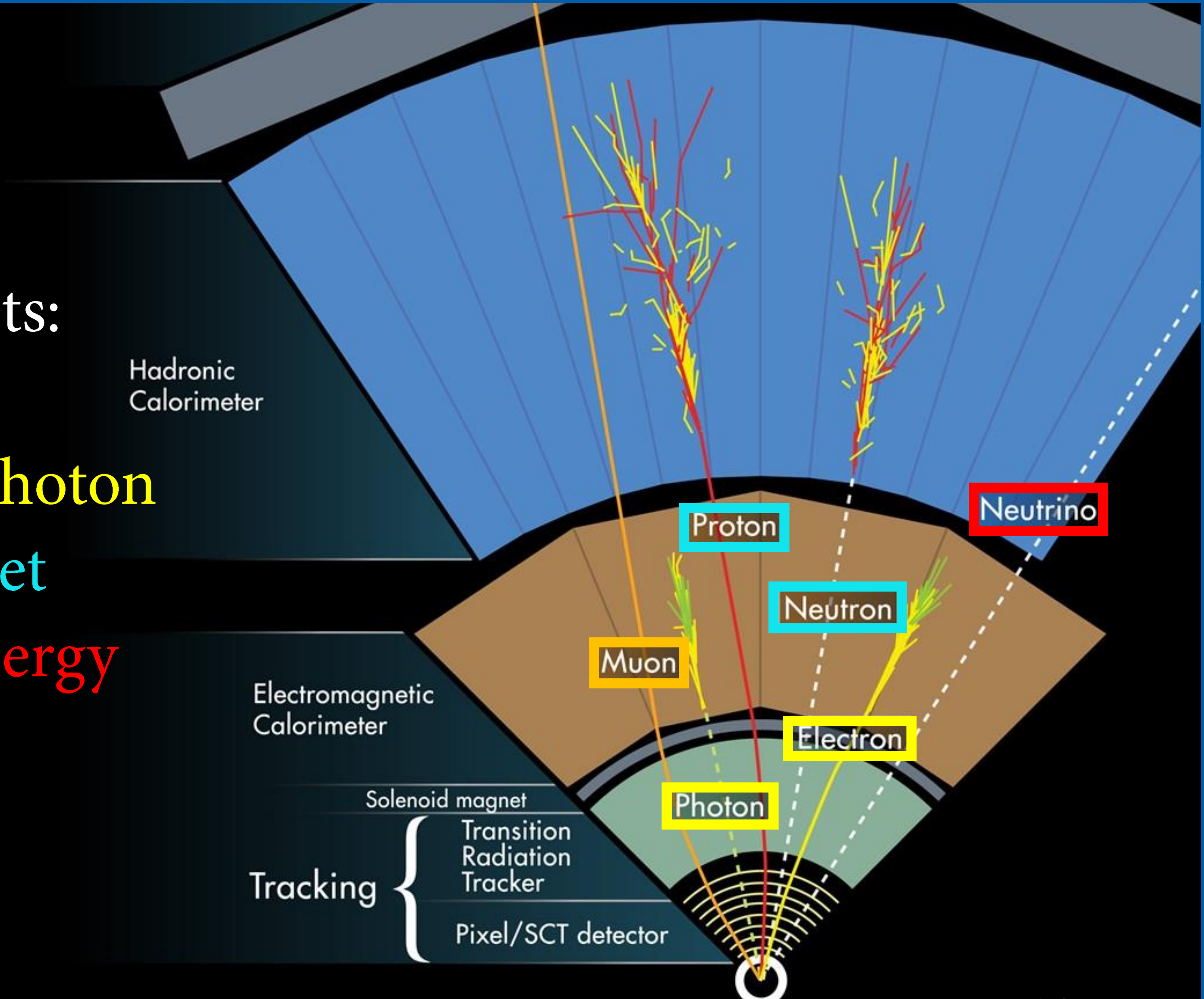
- Muon
- Electron/Photon
- Hadronic jet
- Missing energy



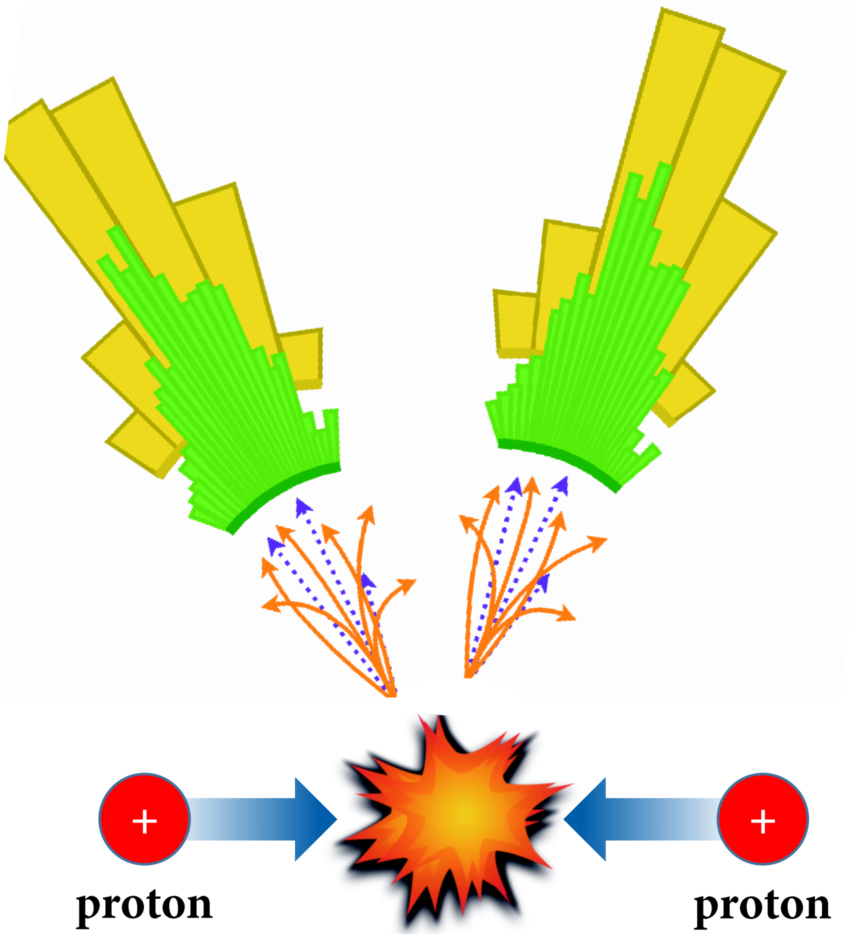
ATLAS Detector & Objects

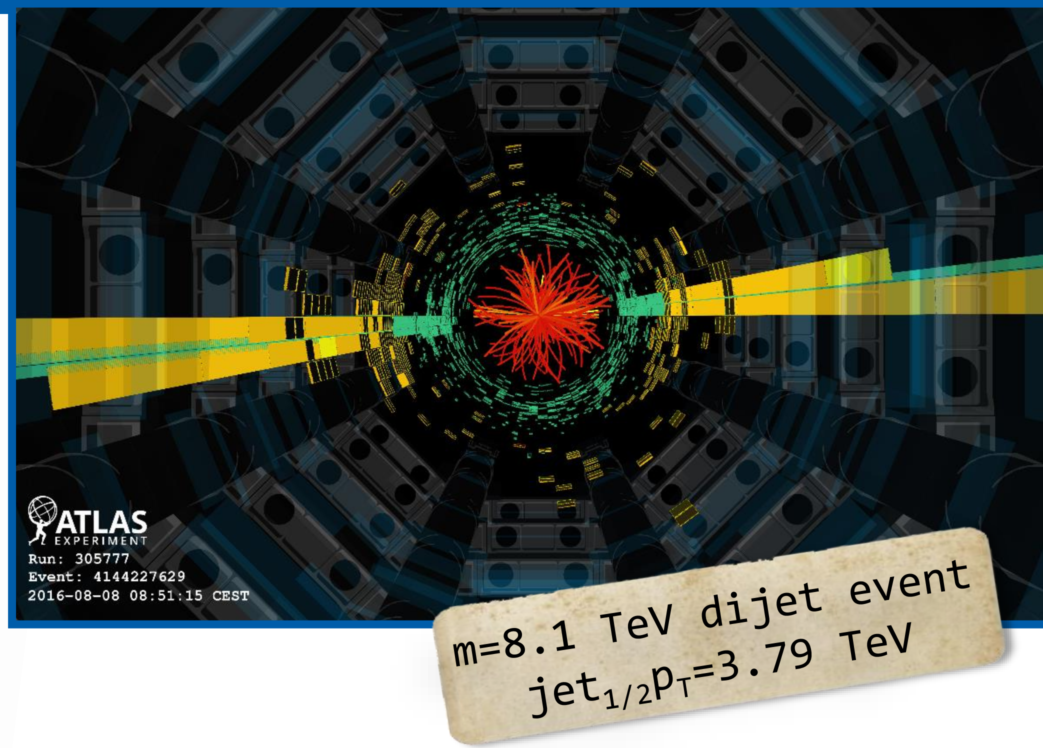
Physic objects:
- Muon
- Electron/Photon
- Hadronic jet
- Missing energy

Build from:
- Jets
- Tracks



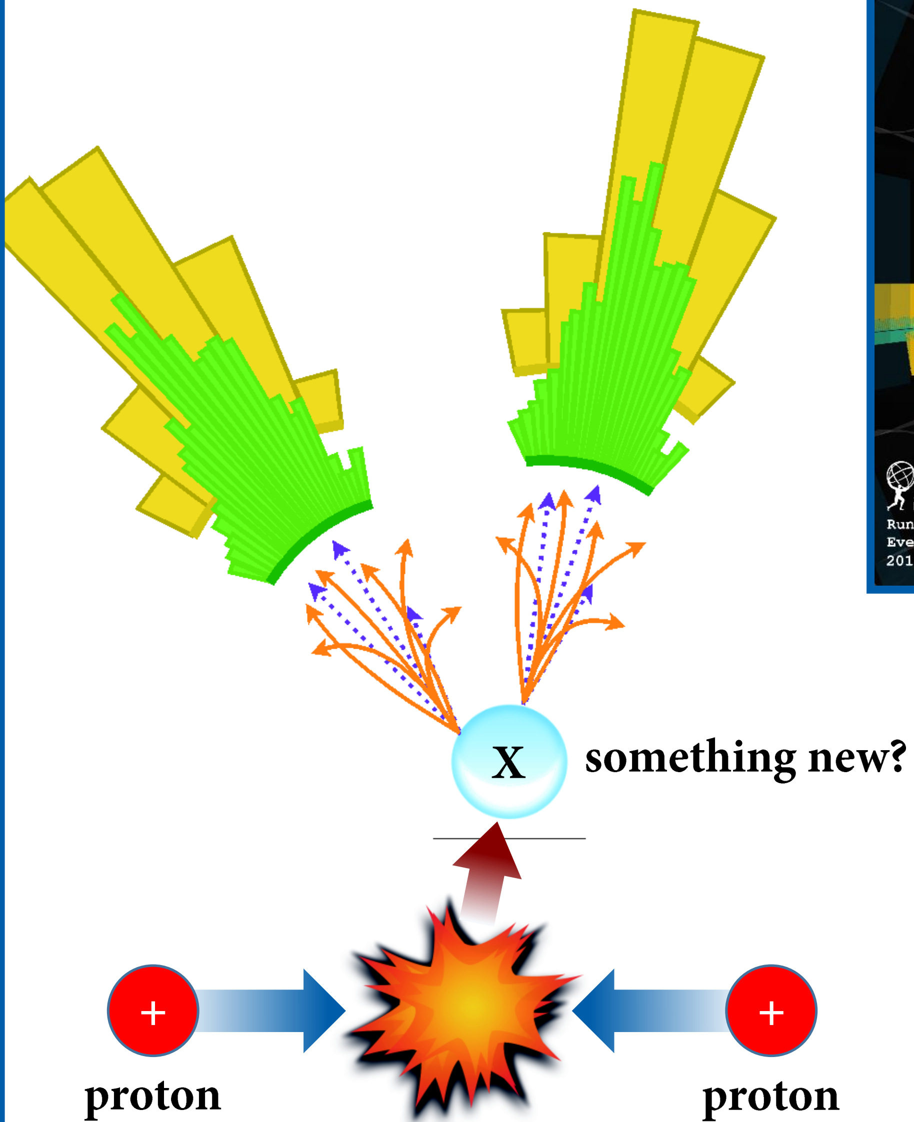
Energy Frontier: Jets

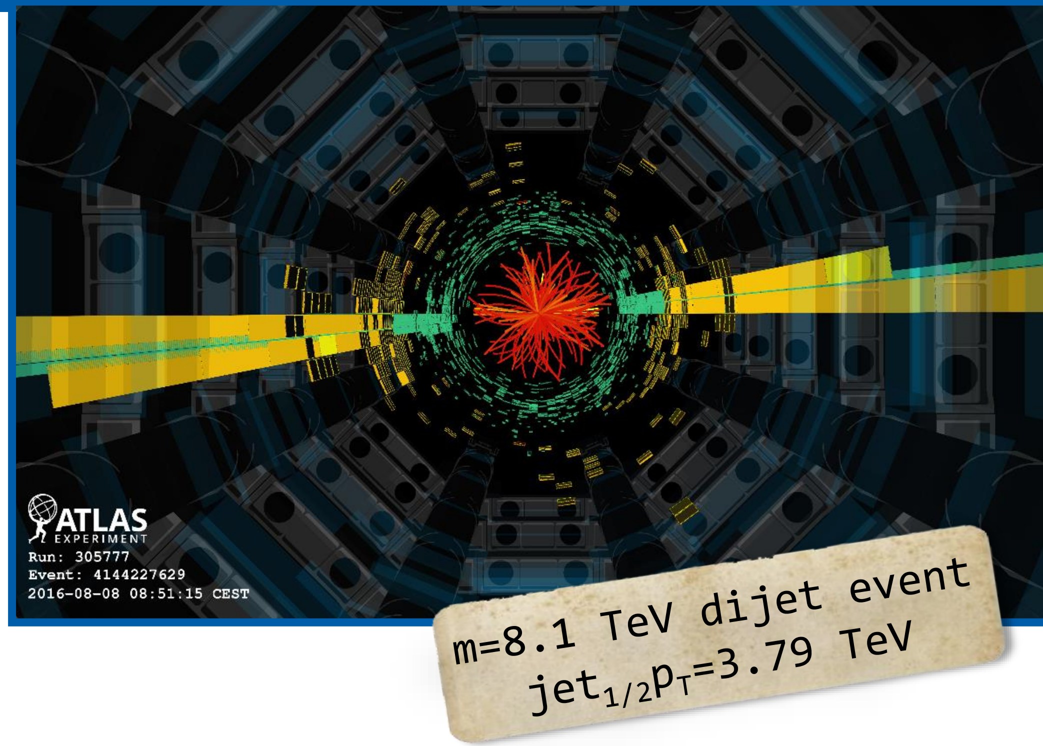




- **Newly opened energy regime: $\sqrt{s} = 13$ TeV.**

Energy Frontier: Jets

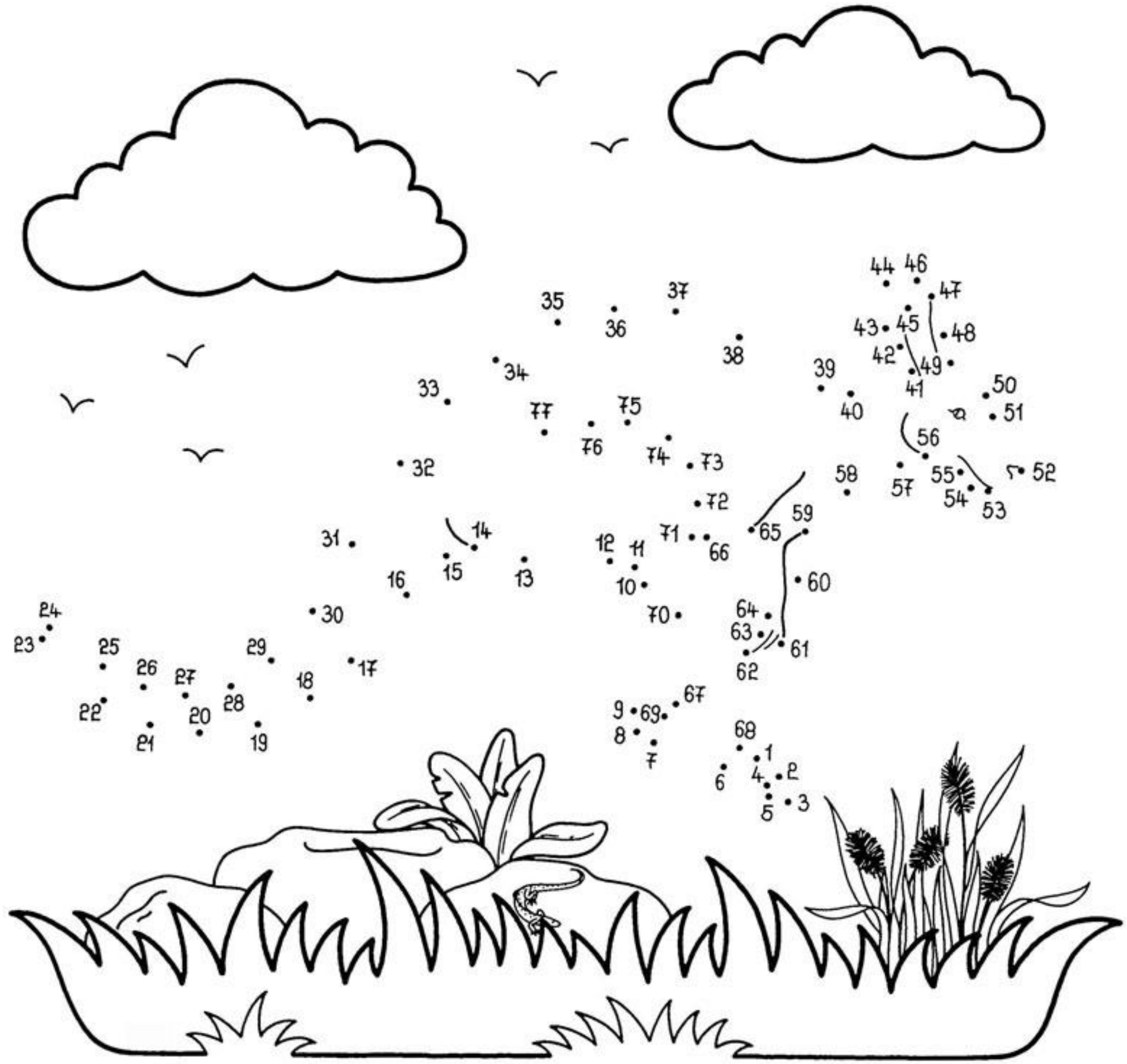




- **Newly opened energy regime: $\sqrt{s} = 13$ TeV.**

Track reconstruction - Concept

- Nowadays finding particle tracks is like this ..



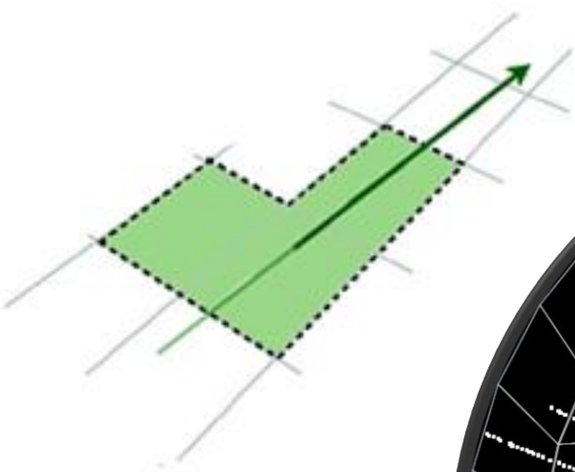
Track reconstruction - Concept

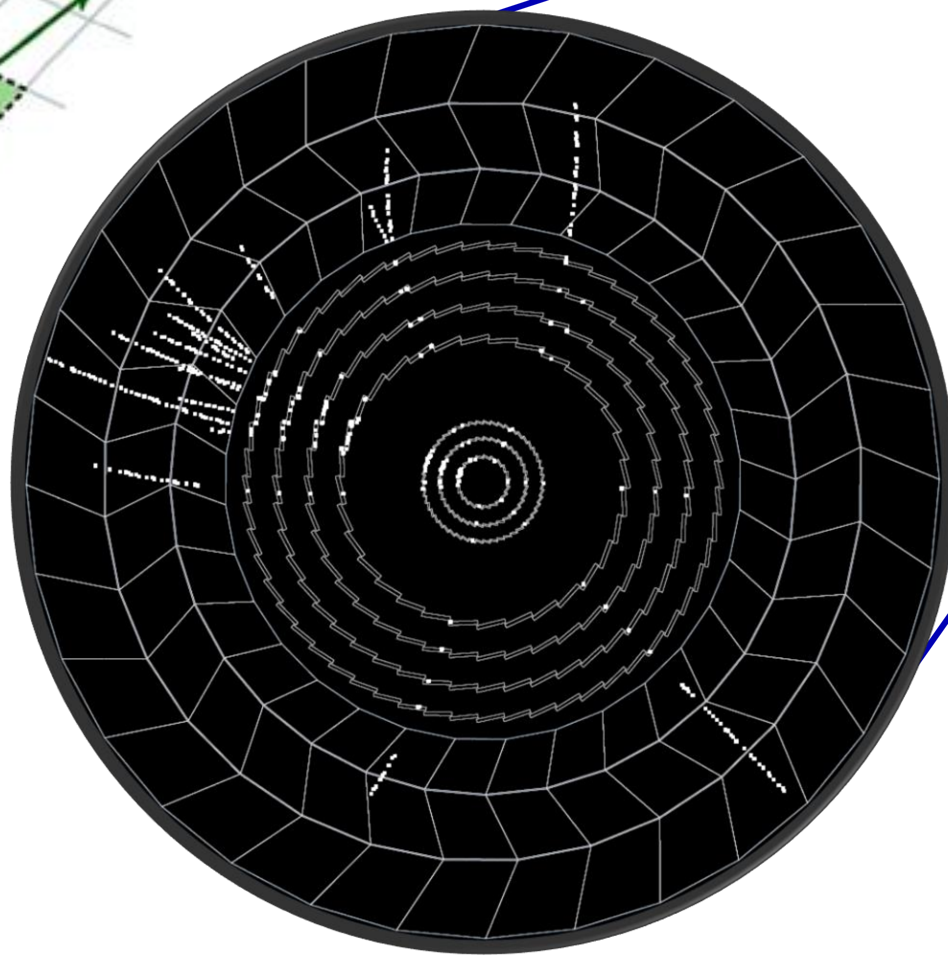
- Nowadays finding particle tracks is like this ..

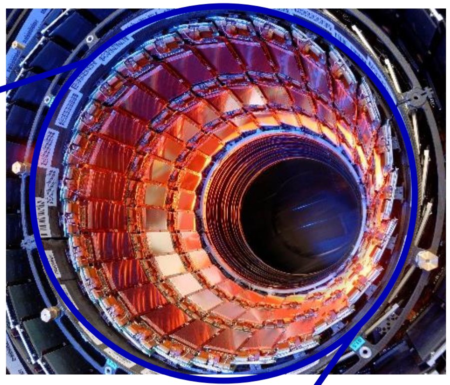
- But without the numbers!

Track reconstruction – Step by step

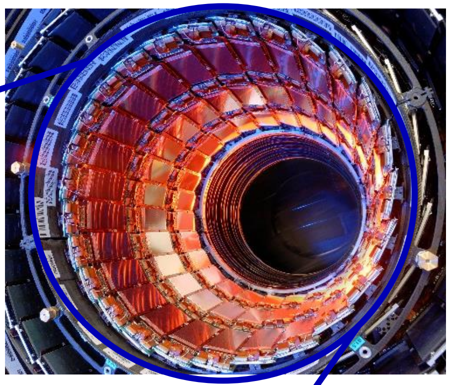
1. Register measurements (called **clusters**).

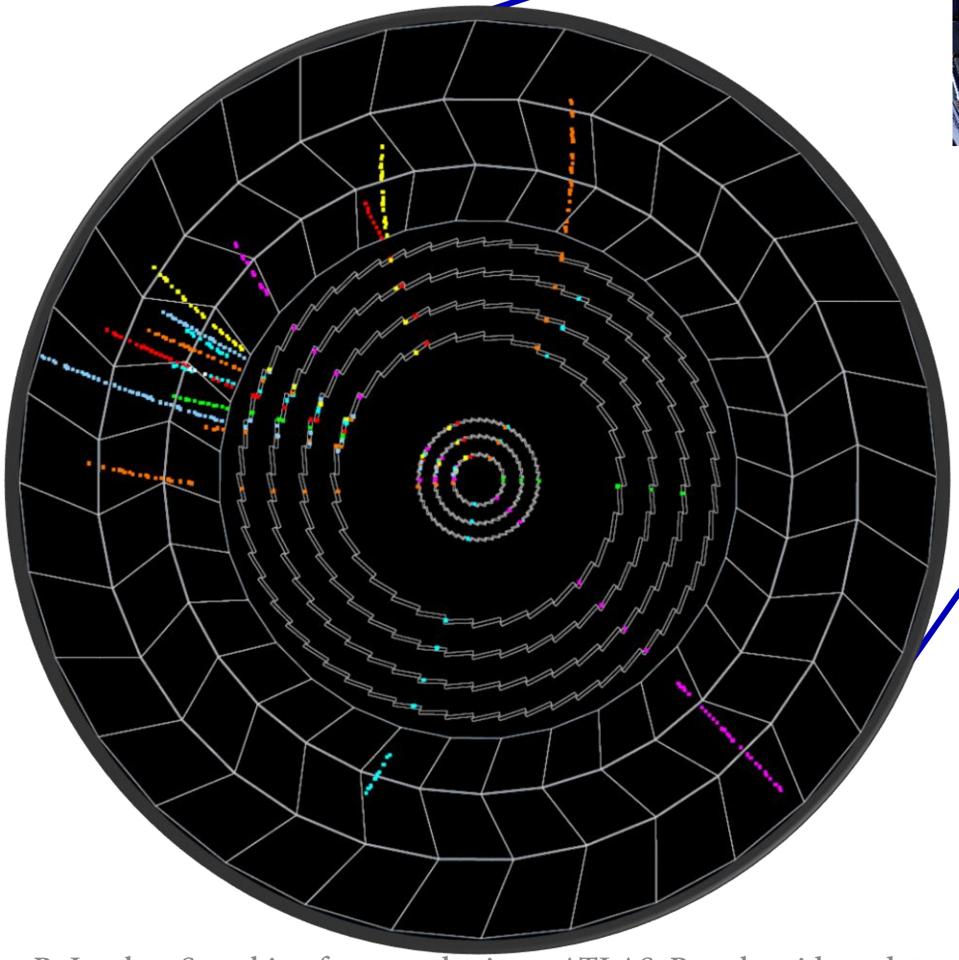






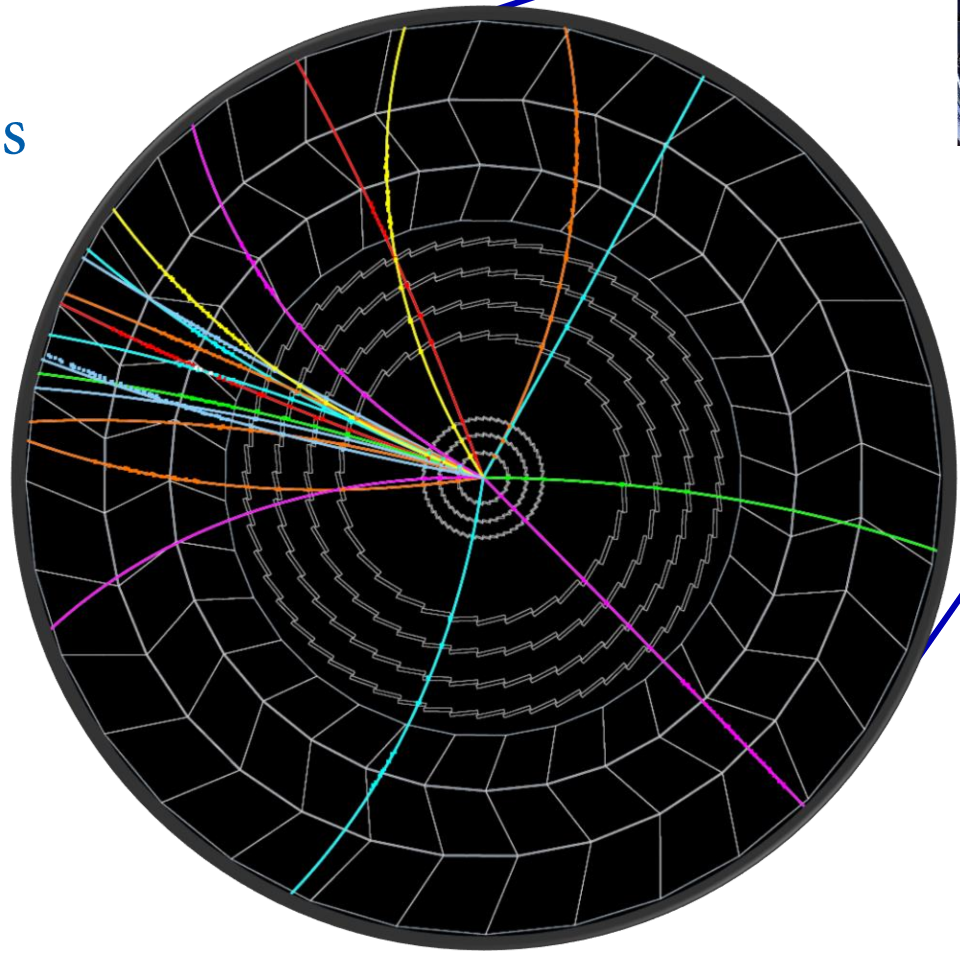
1. Register measurements (called **clusters**).
2. Associate clusters to particles' tracks.

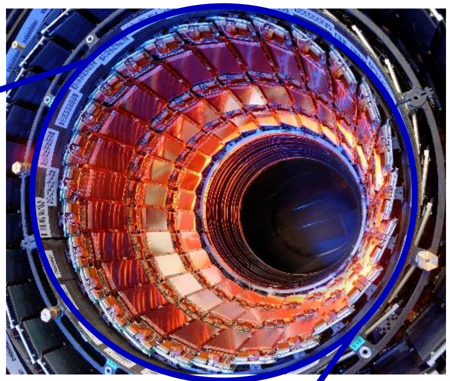




Track reconstruction – Step by step

1. Register measurements (called **clusters**).
2. Associate clusters to particles' tracks.
3. Fit particles trajectory.

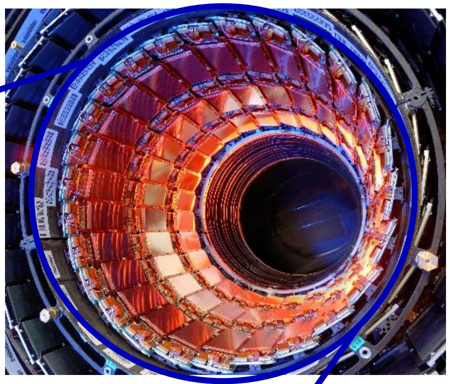


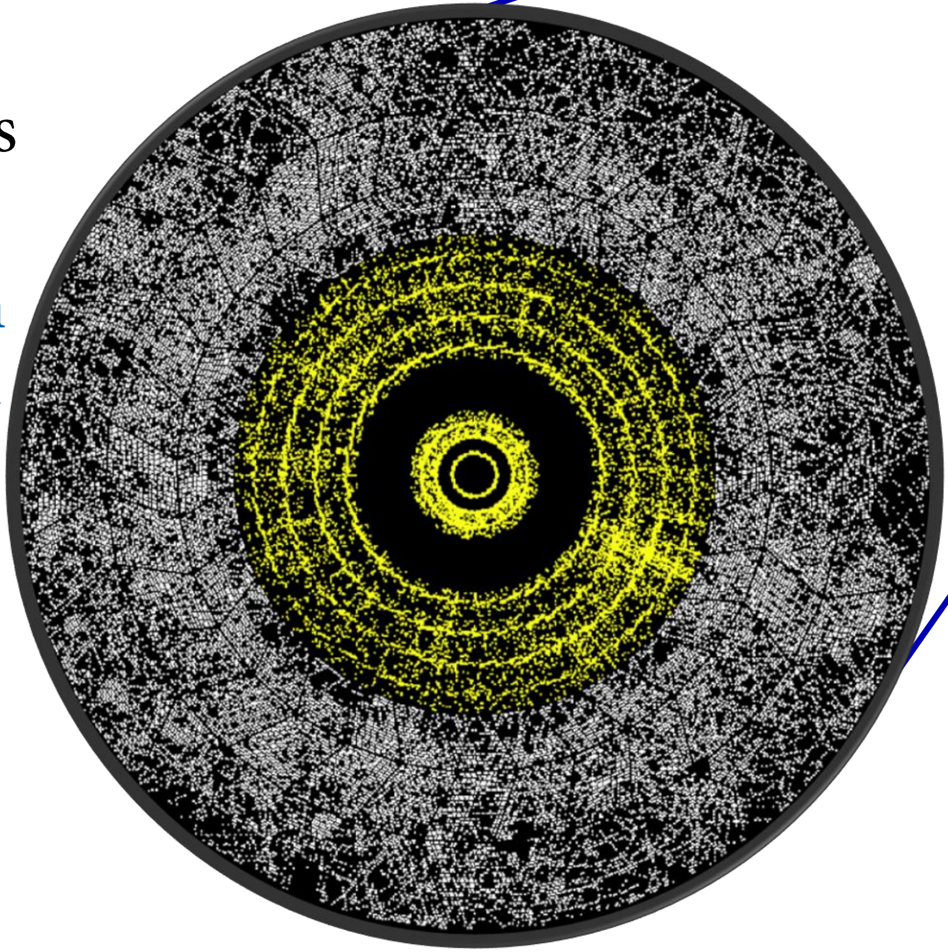


Track reconstruction – Step by step

1. Create measurements (called clusters).
2. Associate clusters to particles' tracks.
3. Fit particles trajectory.

How it looks in reality





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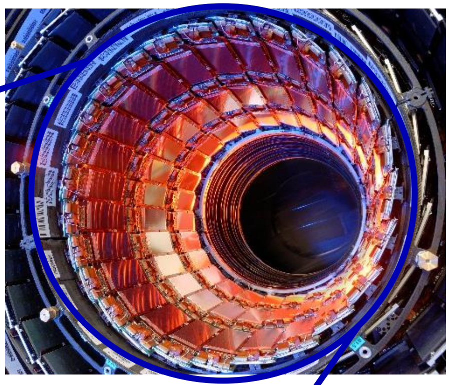
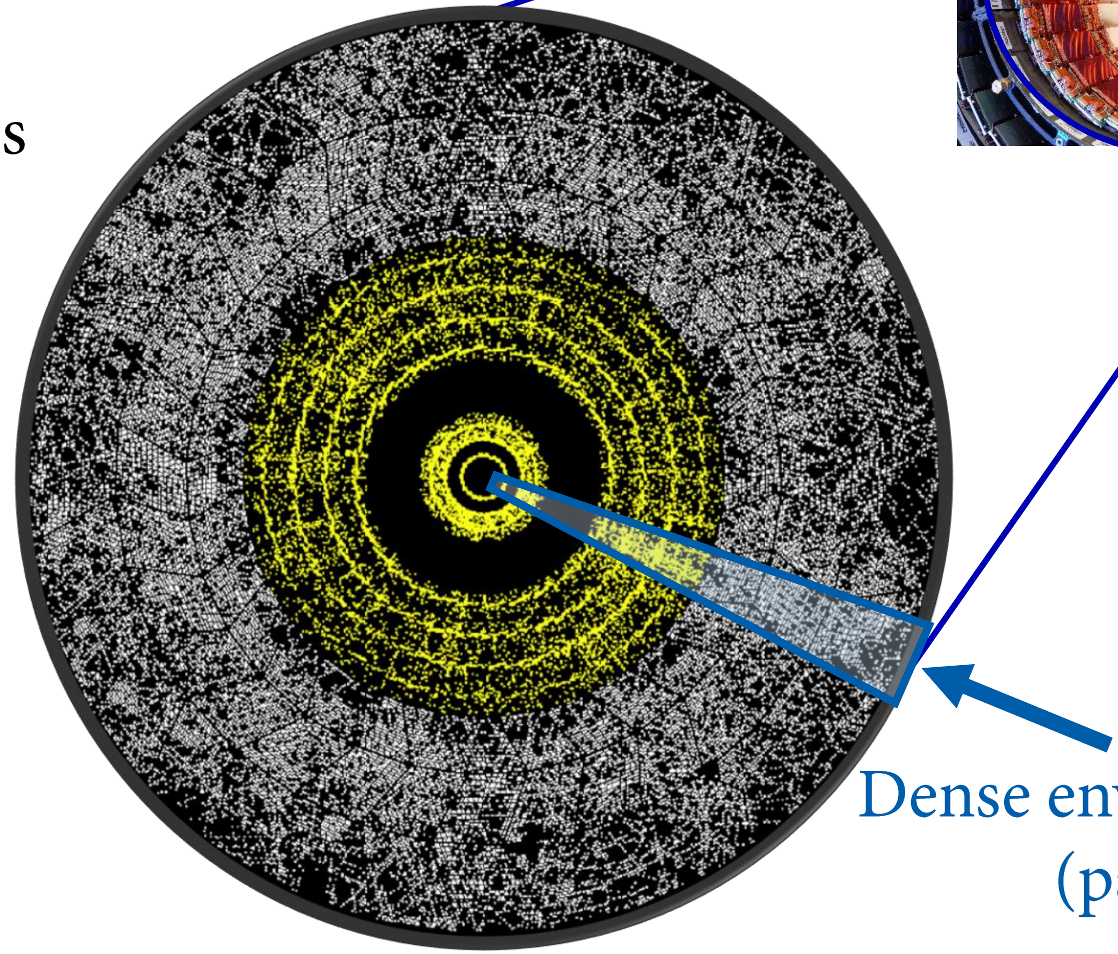




Dense environment (particle-jet)

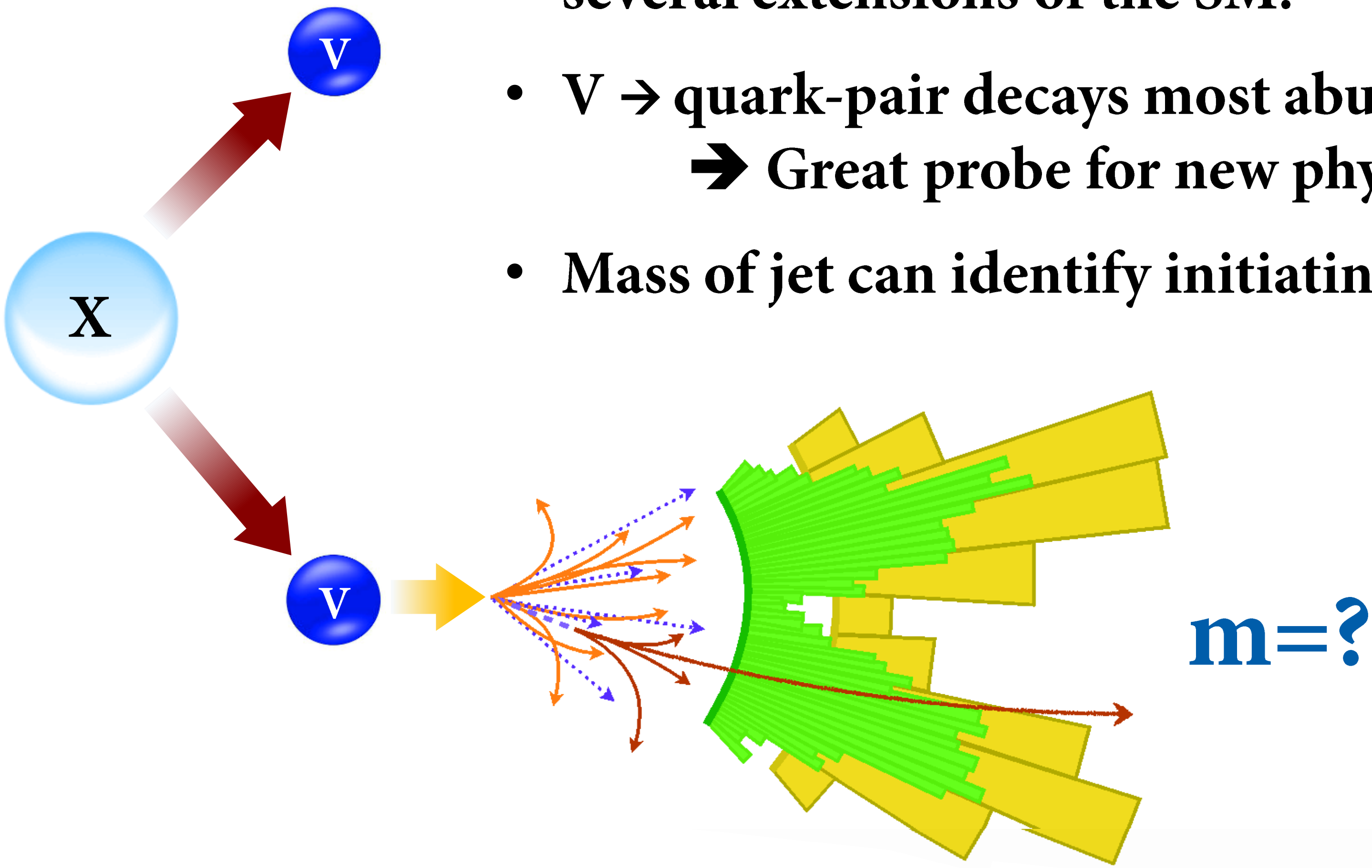
Example Analysis

Prerequisites for analysis

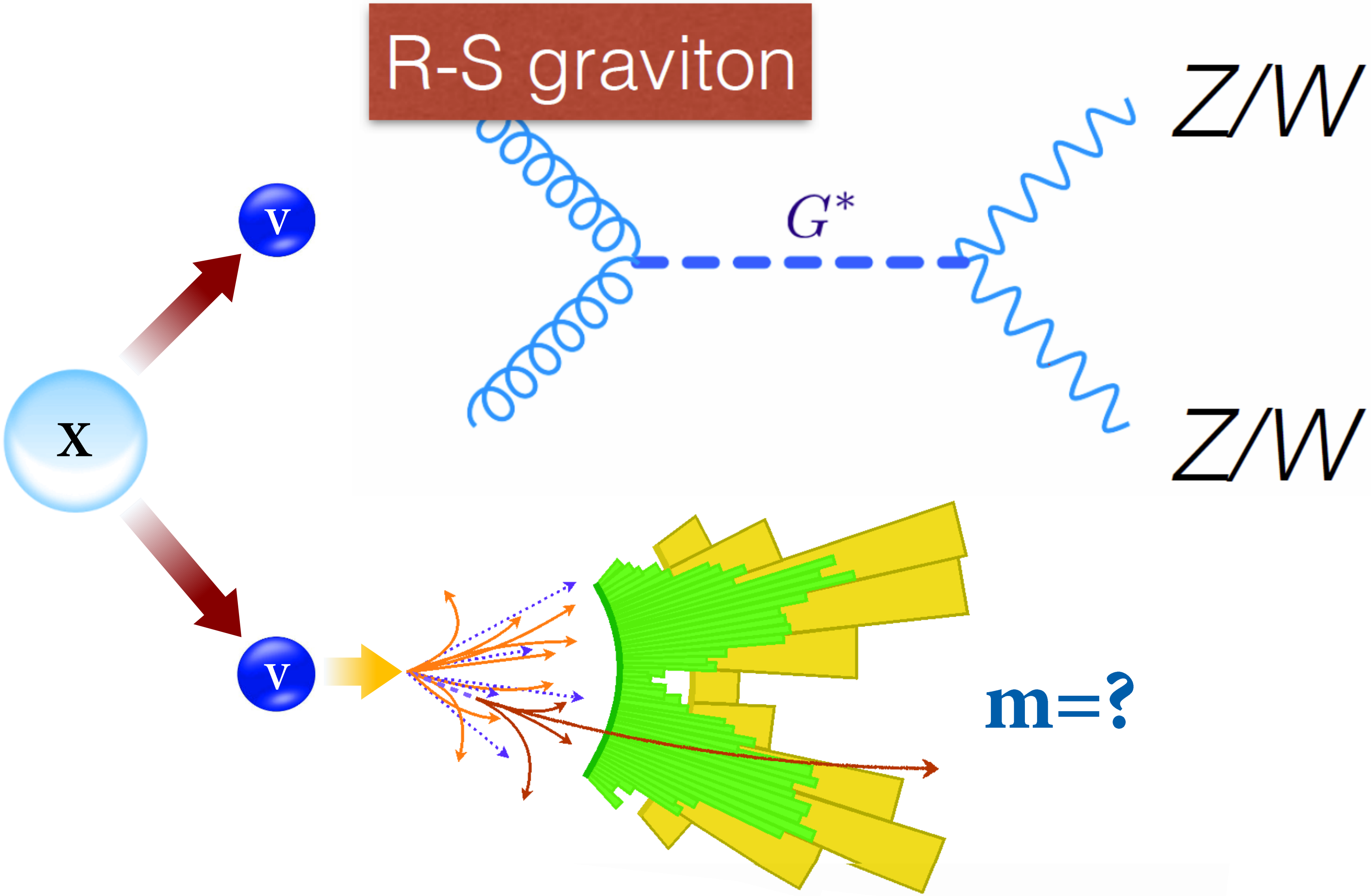
1. Collect data : Detector, trigger, DAQ
2. Reconstruction of physics objects
3. Simulation : Generate events, detector simulation

Boosted diboson search strategy

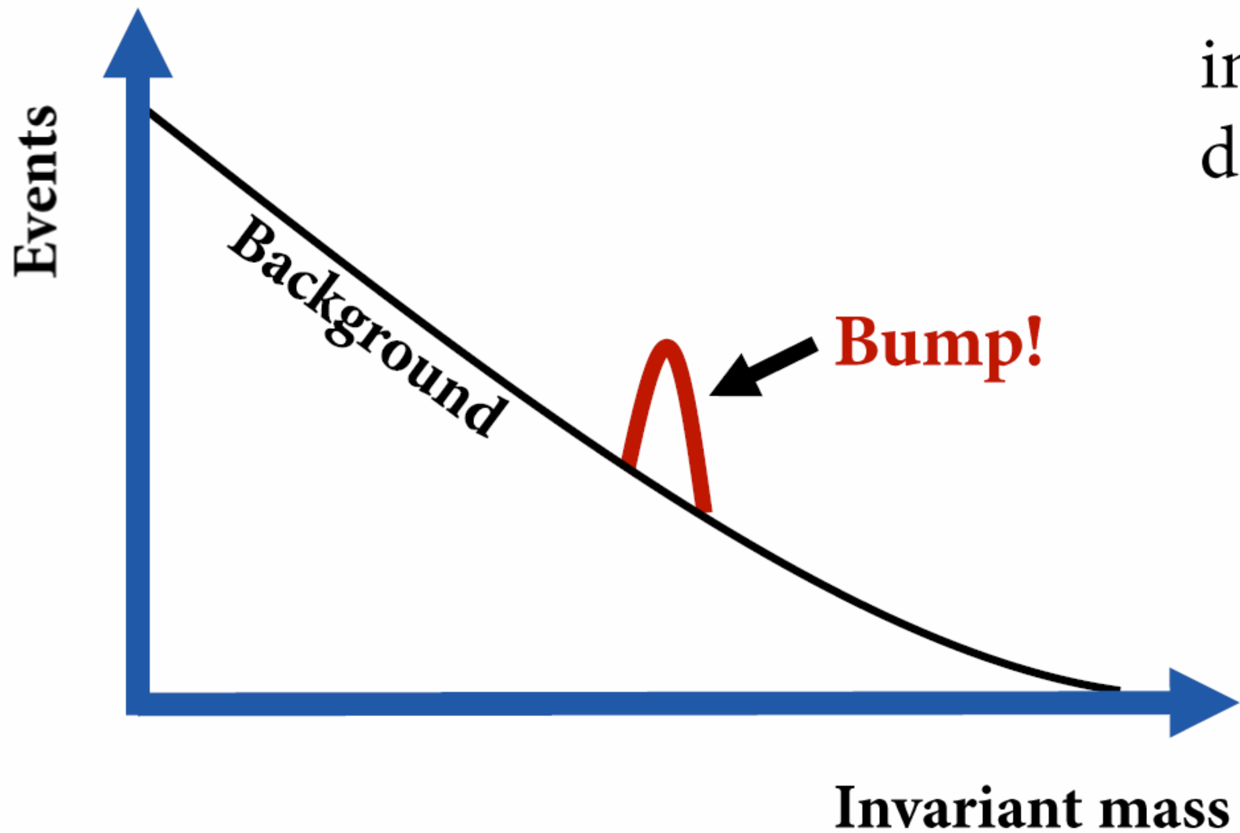
- Heavy (>1 TeV) resonances to pairs of vector bosons (V=W/Z) predicted by several extensions of the SM.
- V → quark-pair decays most abundant.
  ➔ Great probe for new physics!
- Mass of jet can identify initiating particle.



Boosted diboson search strategy



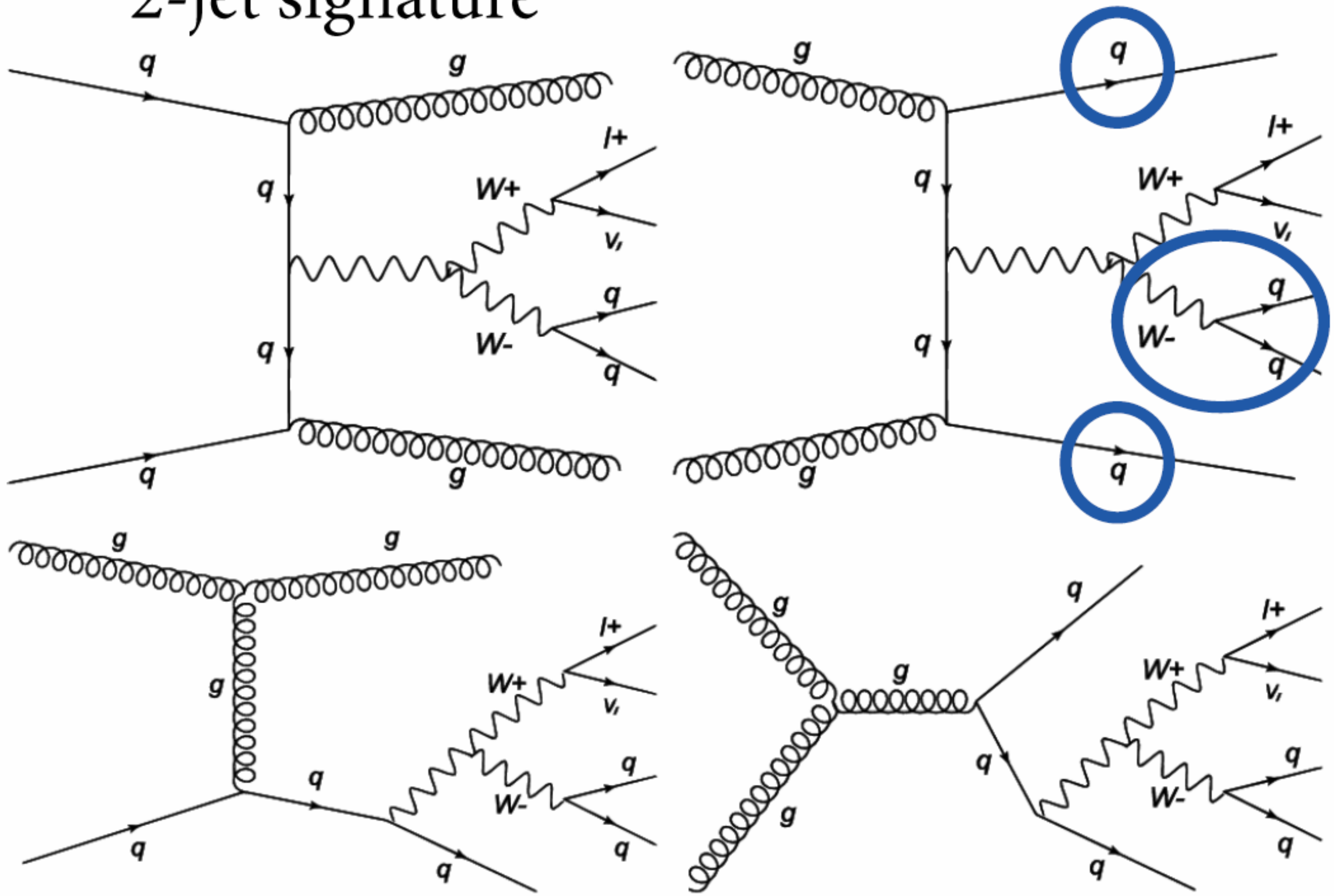
Boosted diboson search strategy



- Look for bump in steeply falling invariant mass distribution.

Main background:

- Standard model processes that can give the same 2-jet signature



Game of Chance

"Distinguishing the signal from the noise requires both scientific knowledge and self-knowledge: the serenity to accept the things we cannot predict, the courage to predict the things we can, and the wisdom to know the difference."
― Nate Silver, *The Signal and the Noise: Why So Many Predictions Fail - But Some Don't*

How to measure a cross-section

- Cross section $\sigma = \frac{N}{\mathcal{L}} \longrightarrow \sigma = \frac{N_{obs} - N_{bkg}}{\mathcal{L} \cdot \epsilon \cdot A \cdot \mathcal{B}}$

N(obs) = Observed number of events

N(bkg) = Estimated number of background

L = Integrated luminosity

ε = efficiency

A = acceptance

B= Branching ratio

How to measure a cross-section

- Cross section $$\sigma = \frac{N_{obs} - N_{bkg}}{\mathcal{L} \cdot \epsilon \cdot A \cdot \mathcal{B}}$$

N(obs) Direct from data

N(bkg) (from data and MC, most critical part of analysis)

L (Someone else calculates this!)

ε = efficiency (from Monte Carlo)

A = acceptance (from Monte Carlo)

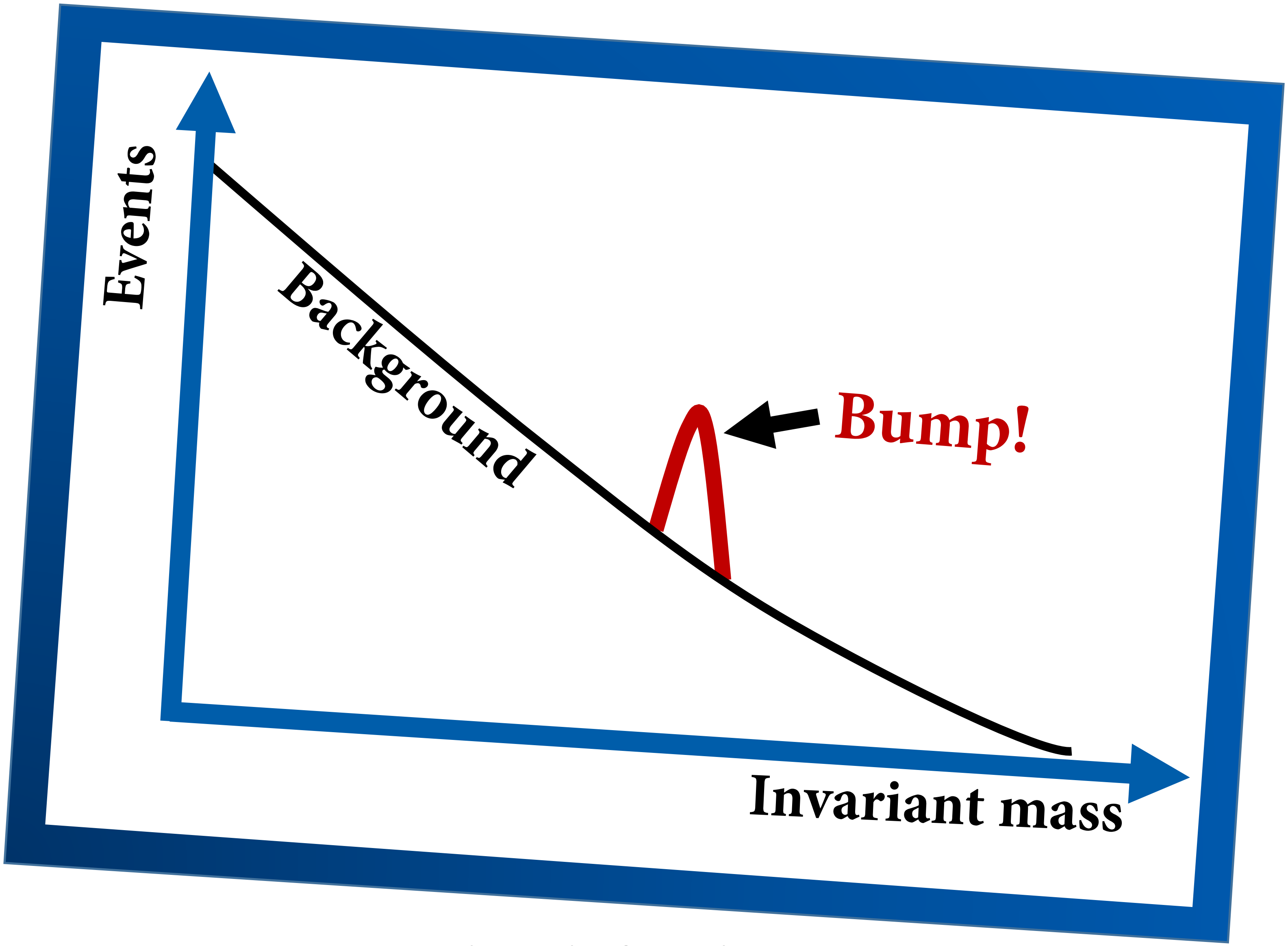
B = Branching ratio (from Particle data group)

Optimisation

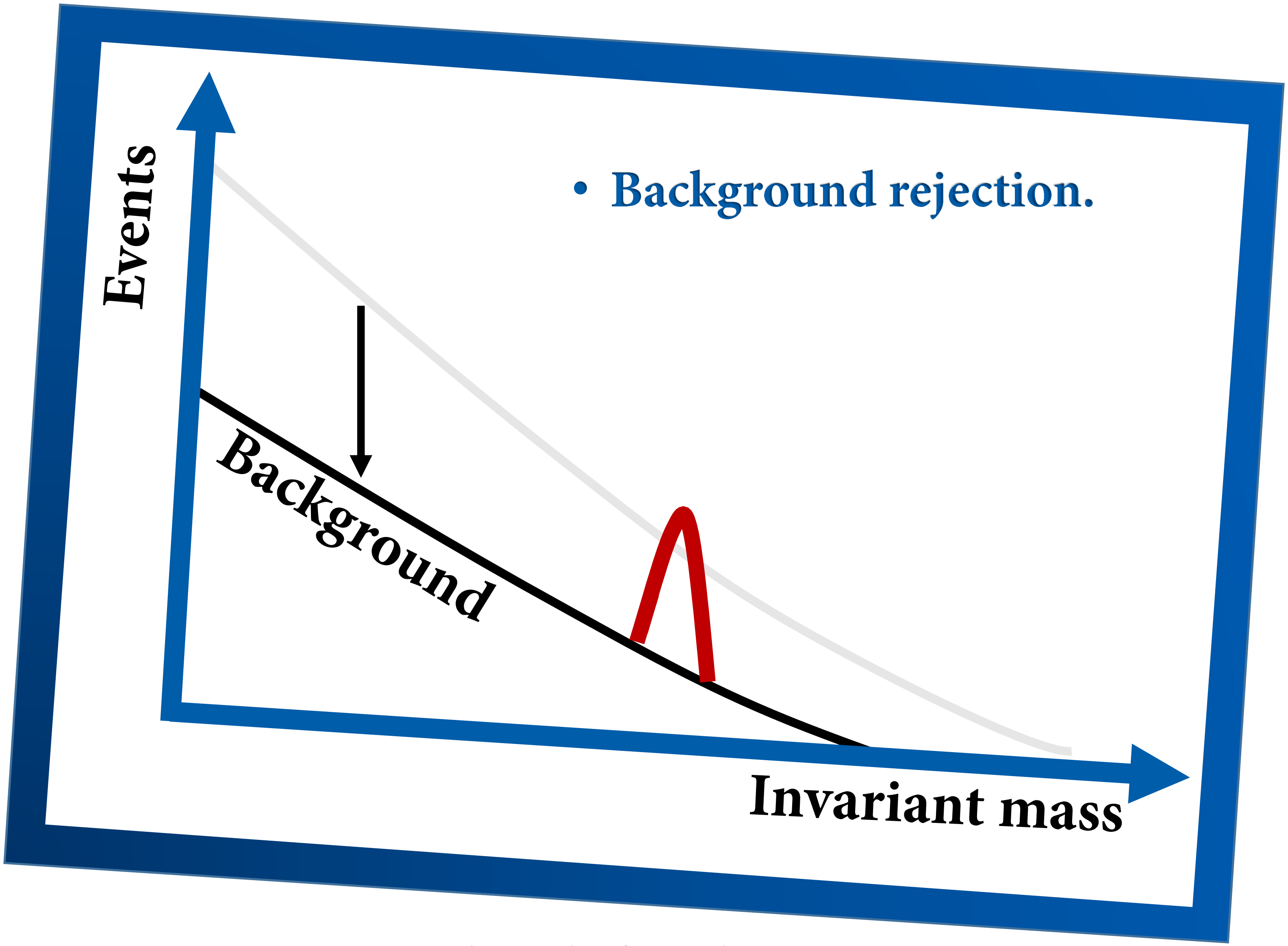
$$\sigma = \frac{N_{obs} - N_{bkg}}{\mathcal{L} \cdot \epsilon \cdot A \cdot \mathcal{B}}$$

- Minimise the uncertainty on σ!
- Maximise probability for signal detection, minimise probability for arriving at a fake signal detection.
- High signal to background : N(obs) >> N(bkd)
- High signal efficiency εA
- Reliable, robust method to determine N(bkg).
- Most important is the measurement of the uncertainty on N(bkg)
- Use Monte Carlo to help decide selection criteria that attempt to minimise the uncertainty on σ or significance of a discovery.

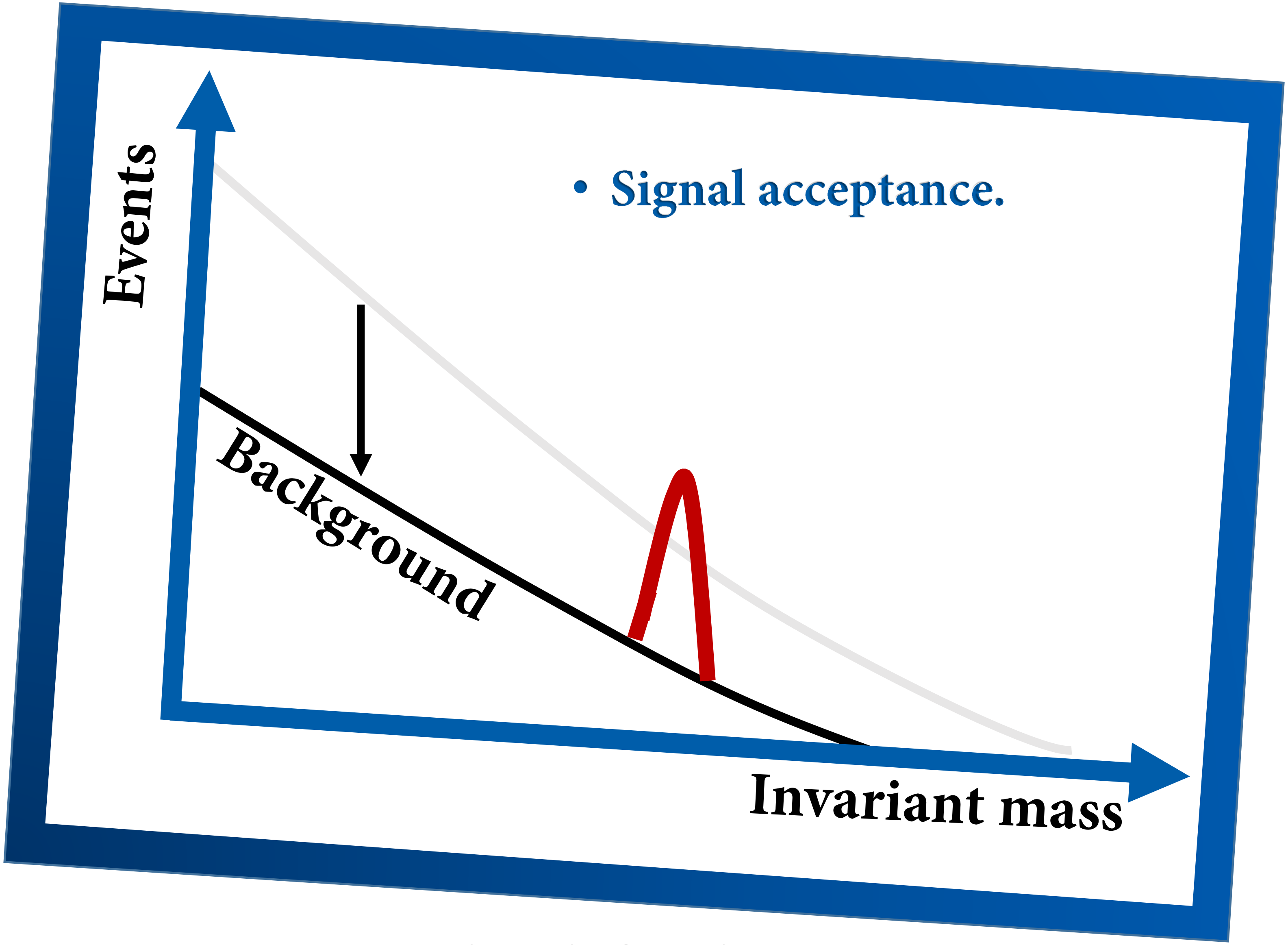
Optimisation



Optimisation



Optimisation



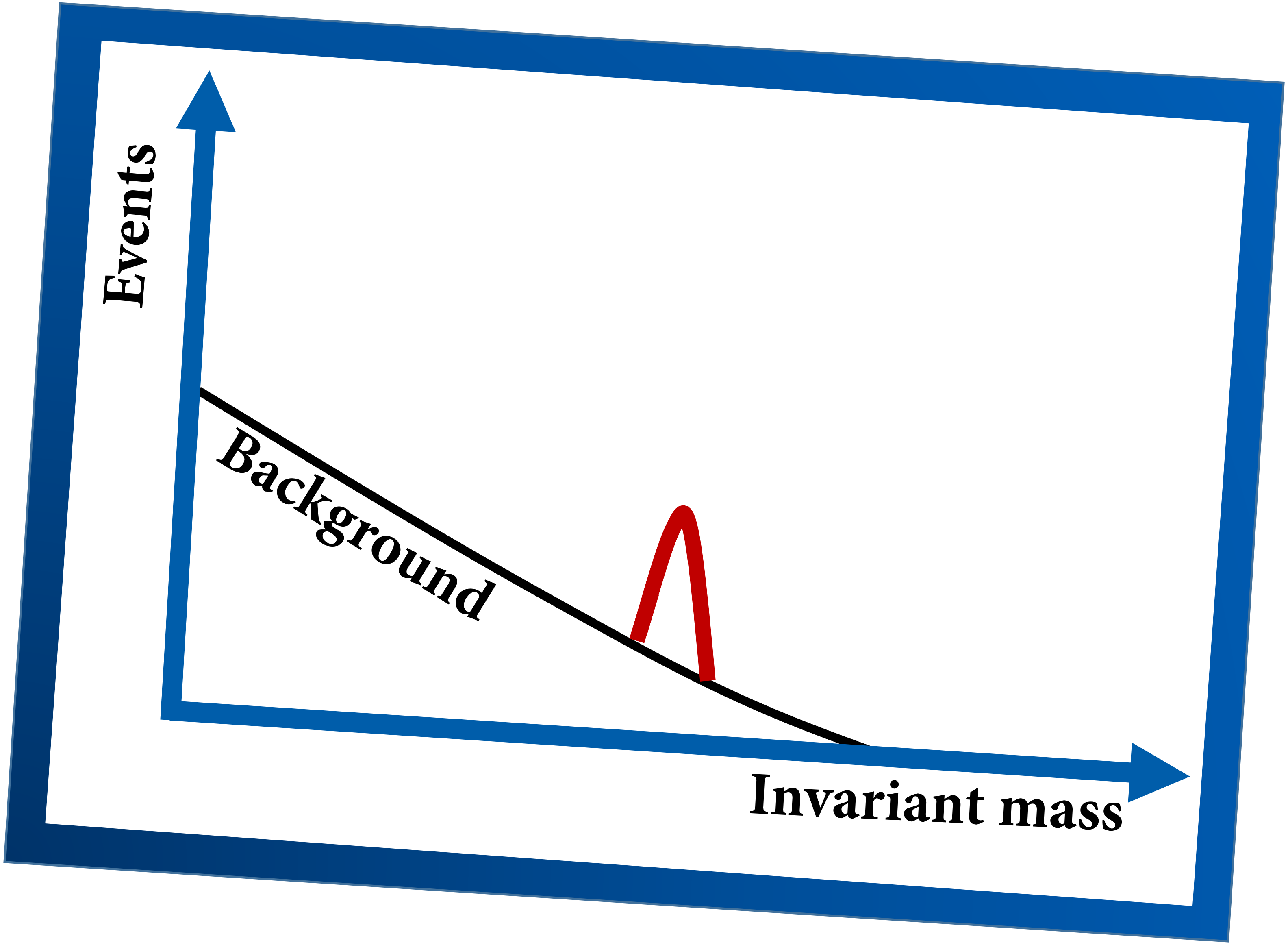
Statistical Uncertainties

- Arise from stochastic fluctuations arising from the fact that a measurement is based on a finite set of observations
- Repeated measurements will give a set of observations that will differ from each other.
- Statistical uncertainty is a measure of this variation
- Poisson fluctuations associated with random variations in the system one is examining

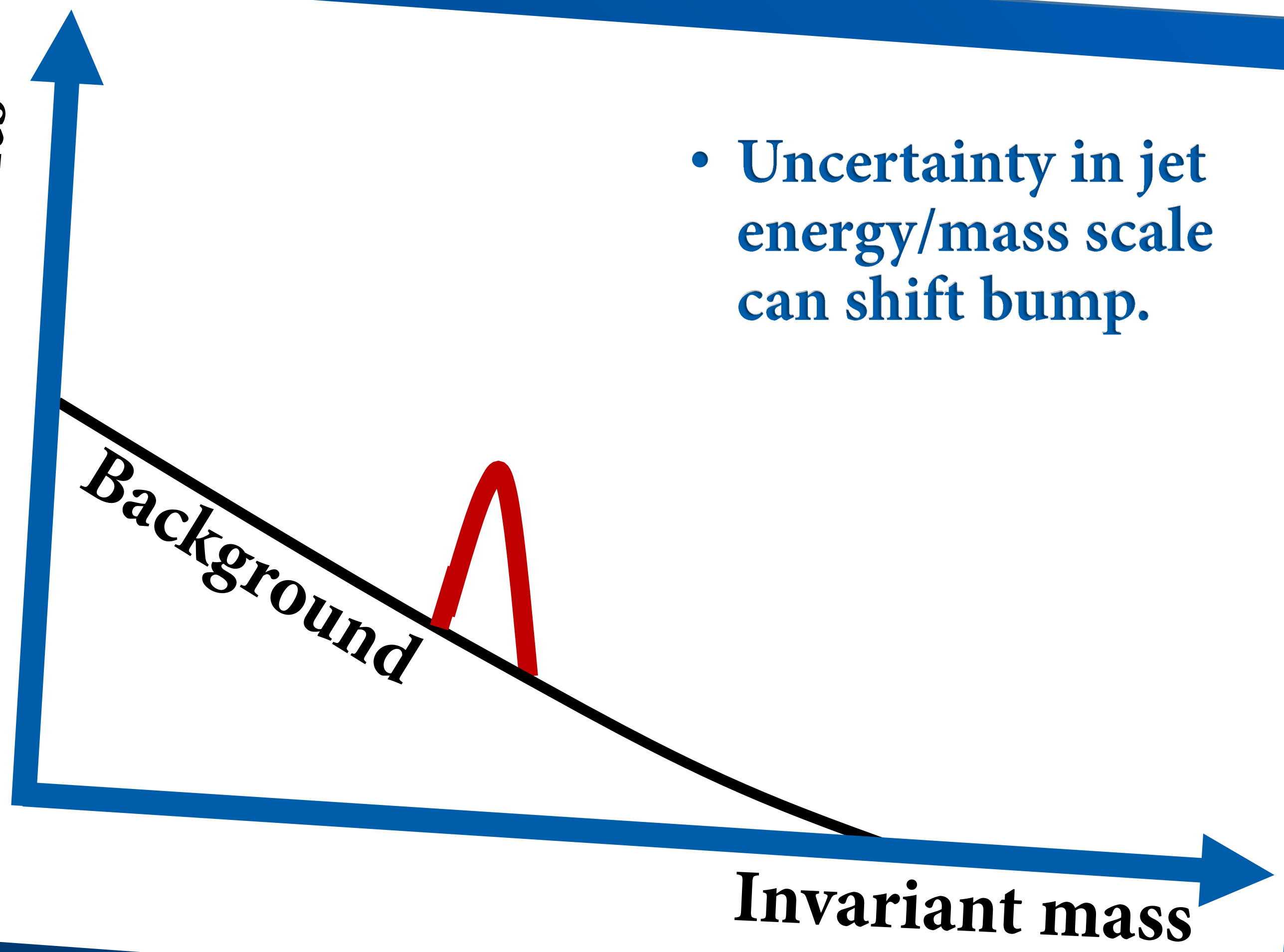
Systematic Uncertainties

- Arise from uncertainties associated with the measurement apparatus
- What are the assumptions underlying the measurement?
  - How accurate is the Monte Carlo Simulation?
  - Models for the signal and the background
  - E.g. acceptance, model parameters
  - What can we think of that has the potential to affect our measurement?

Systematic Uncertainties

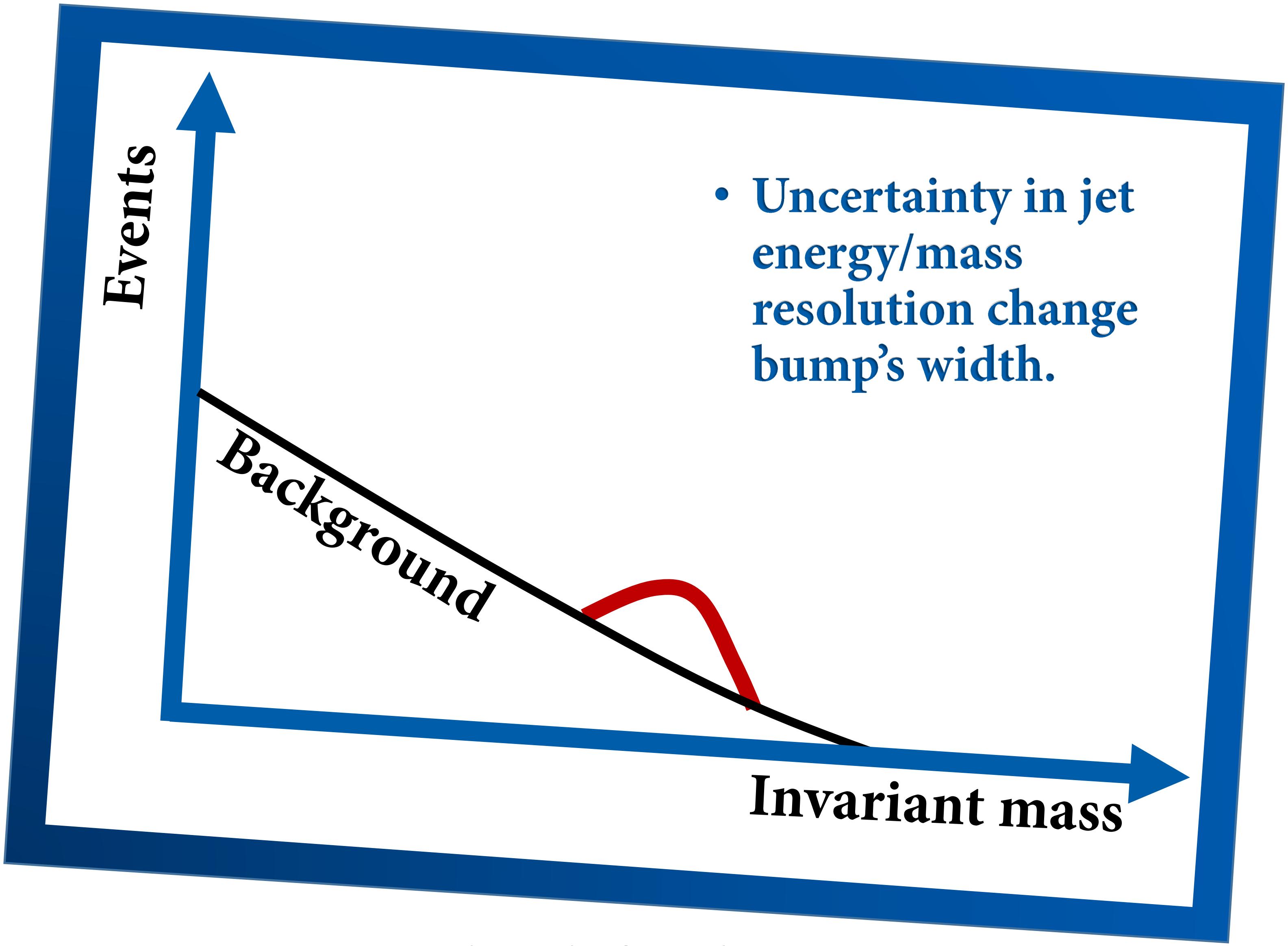


Systematic Uncertainties



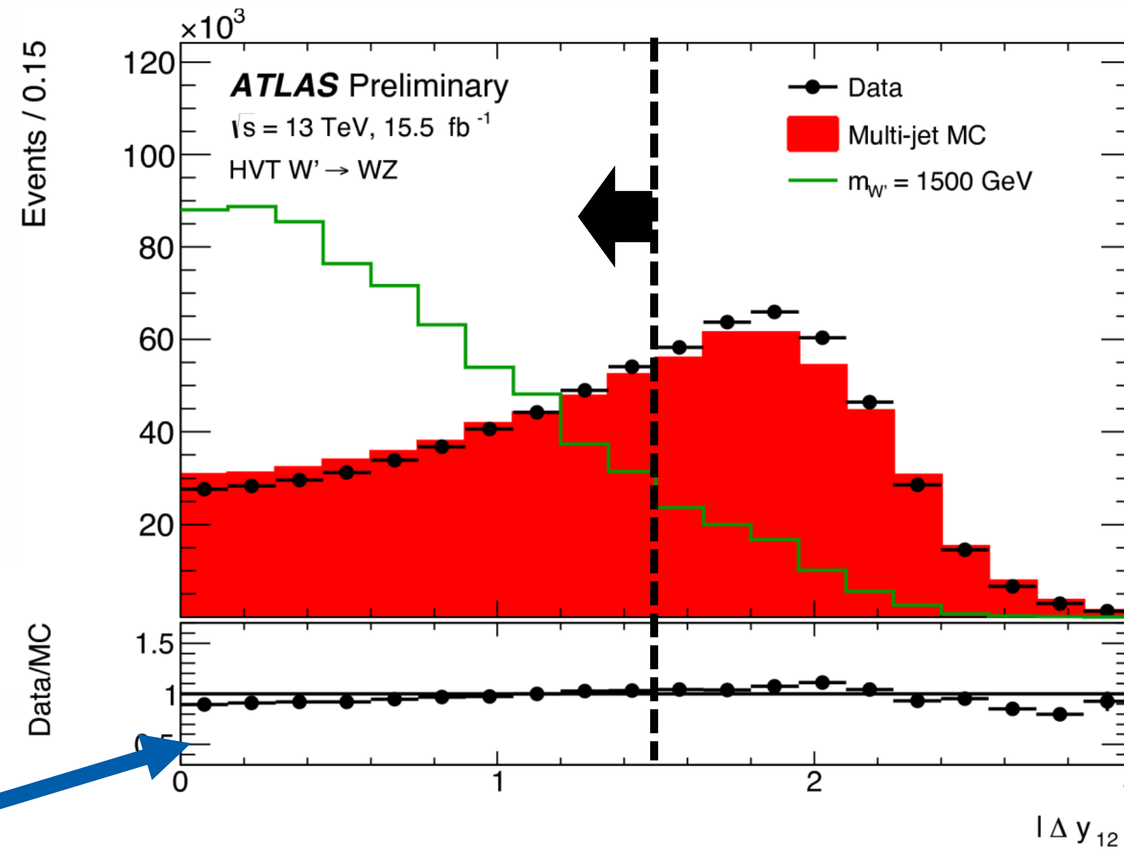
- Uncertainty in jet energy/mass scale can shift bump.

Systematic Uncertainties



Event Selection

- Try to maximize fraction of signal events versus background events.
- One example is the use of kinematic cuts.



Cut on separation of two jets in rapidity

Event Selection

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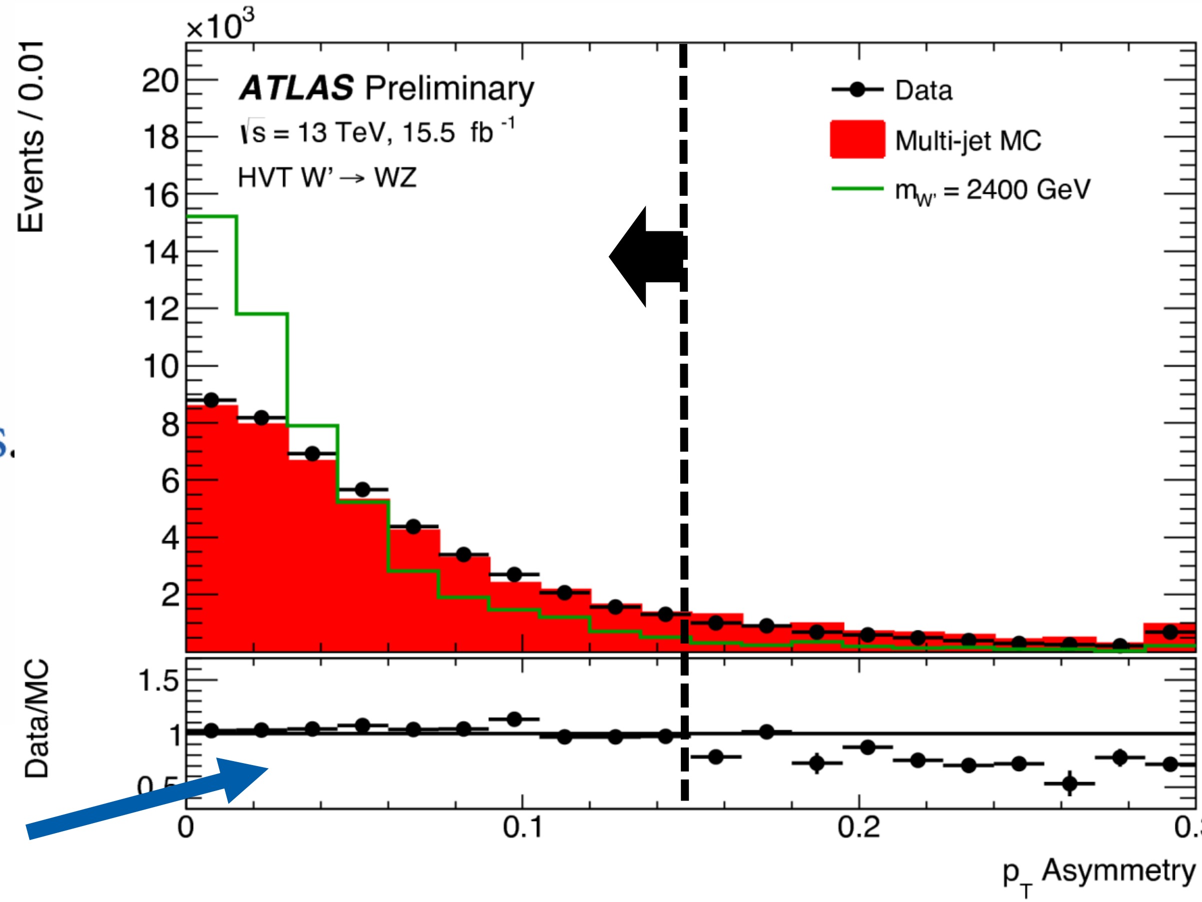
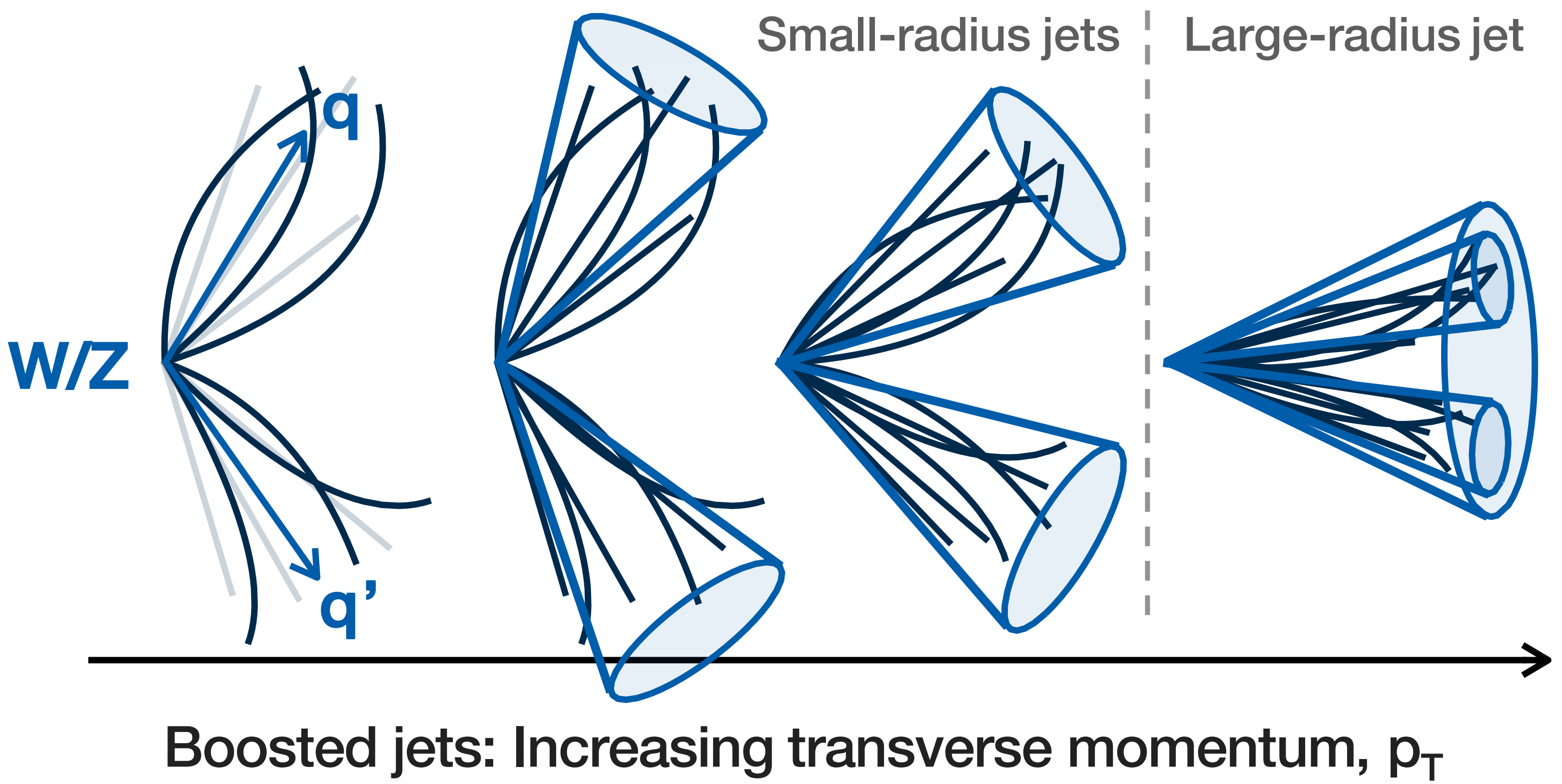


Cut on momentum asymmetry between two jets

Fatjets

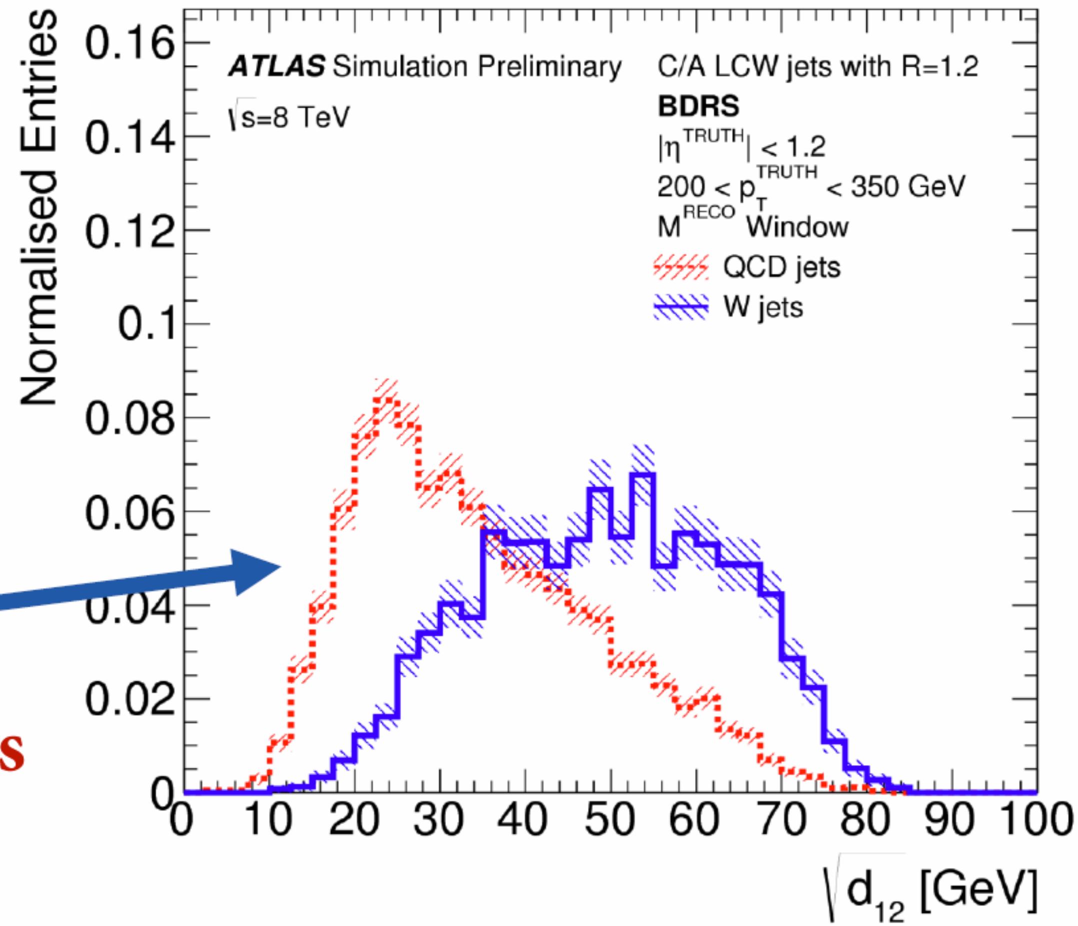


Small-radius jets
Large-radius jet
W/Z
q
q'
Boosted jets: Increasing transverse momentum, p_T

Boson tagging

- Utilize different properties of jets from W/Z-bosons with respect to the background to “tag” them.

Cut on jet substructure (calculated from energy distributions inside fatjet)



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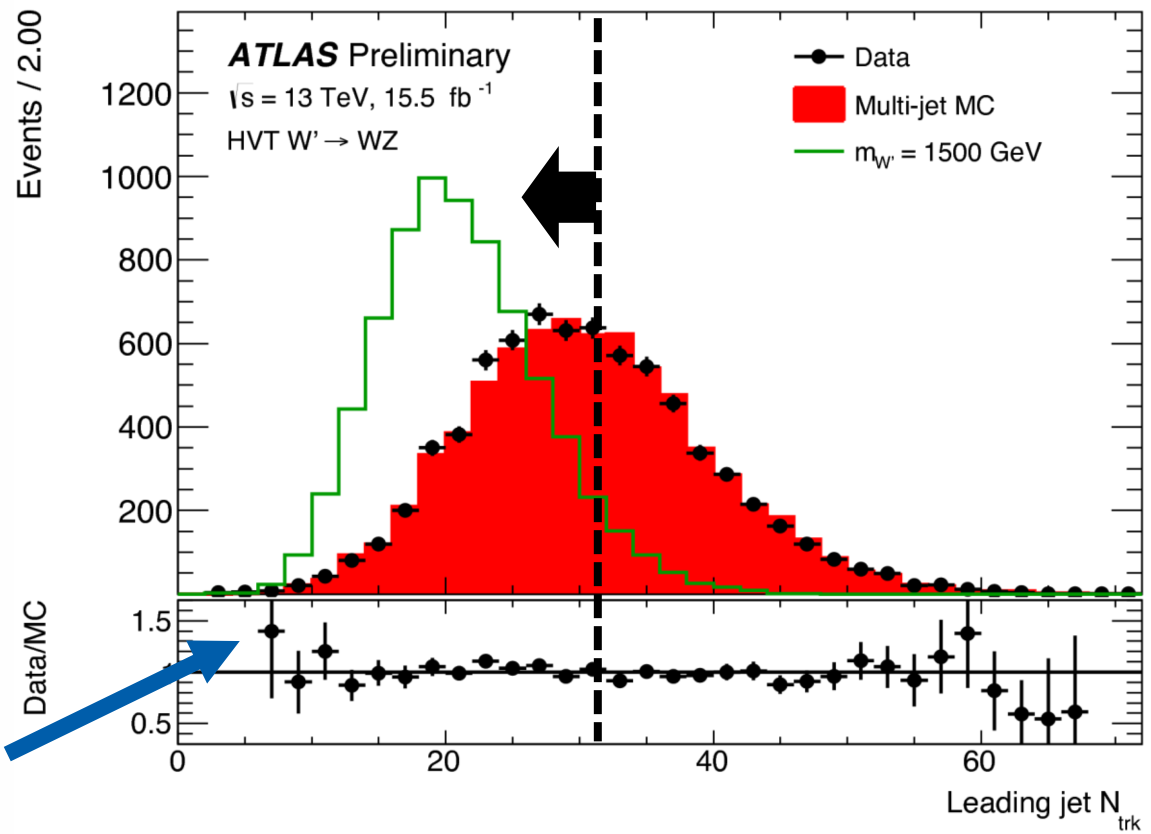
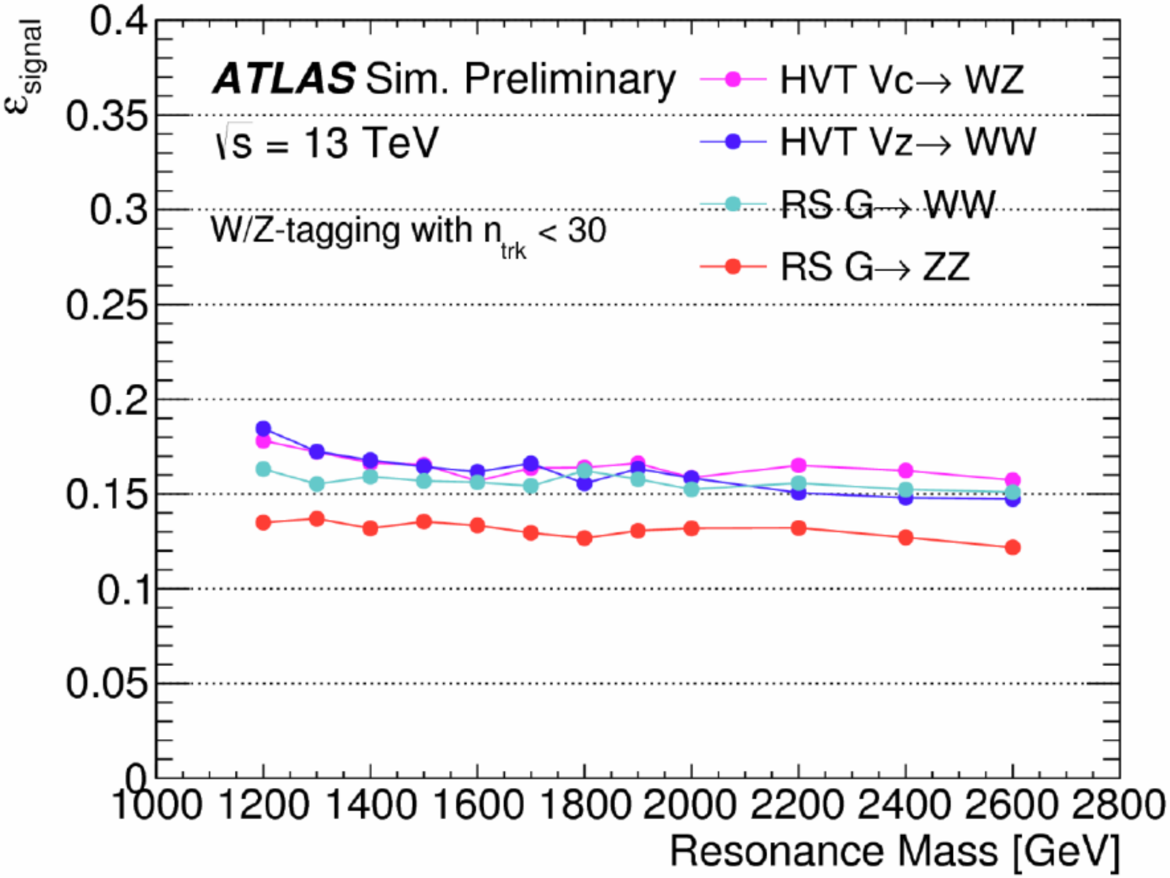


Cut on number of tracks in jet

- Selection on jet mass: require to be at W/Z mass!

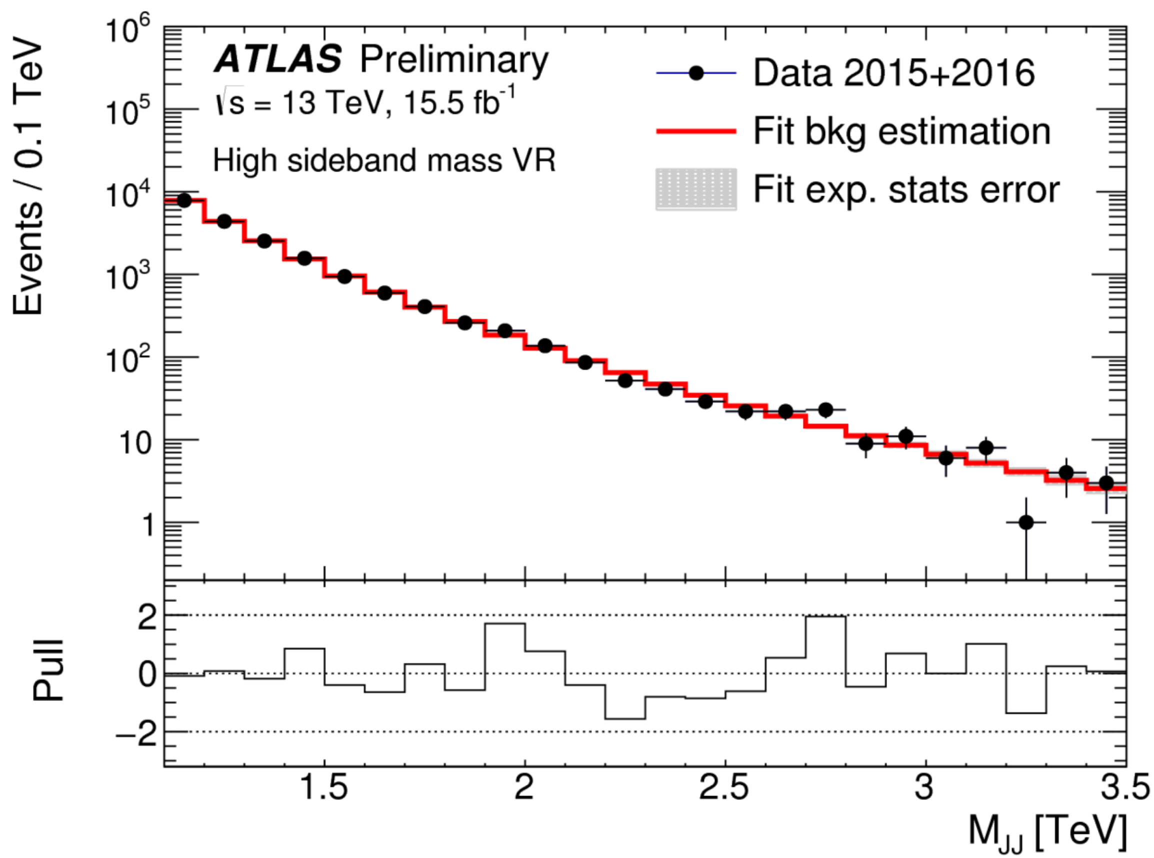
Signal efficiency

- After fixing selections of analysis, calculate expected signal efficiency and yield.



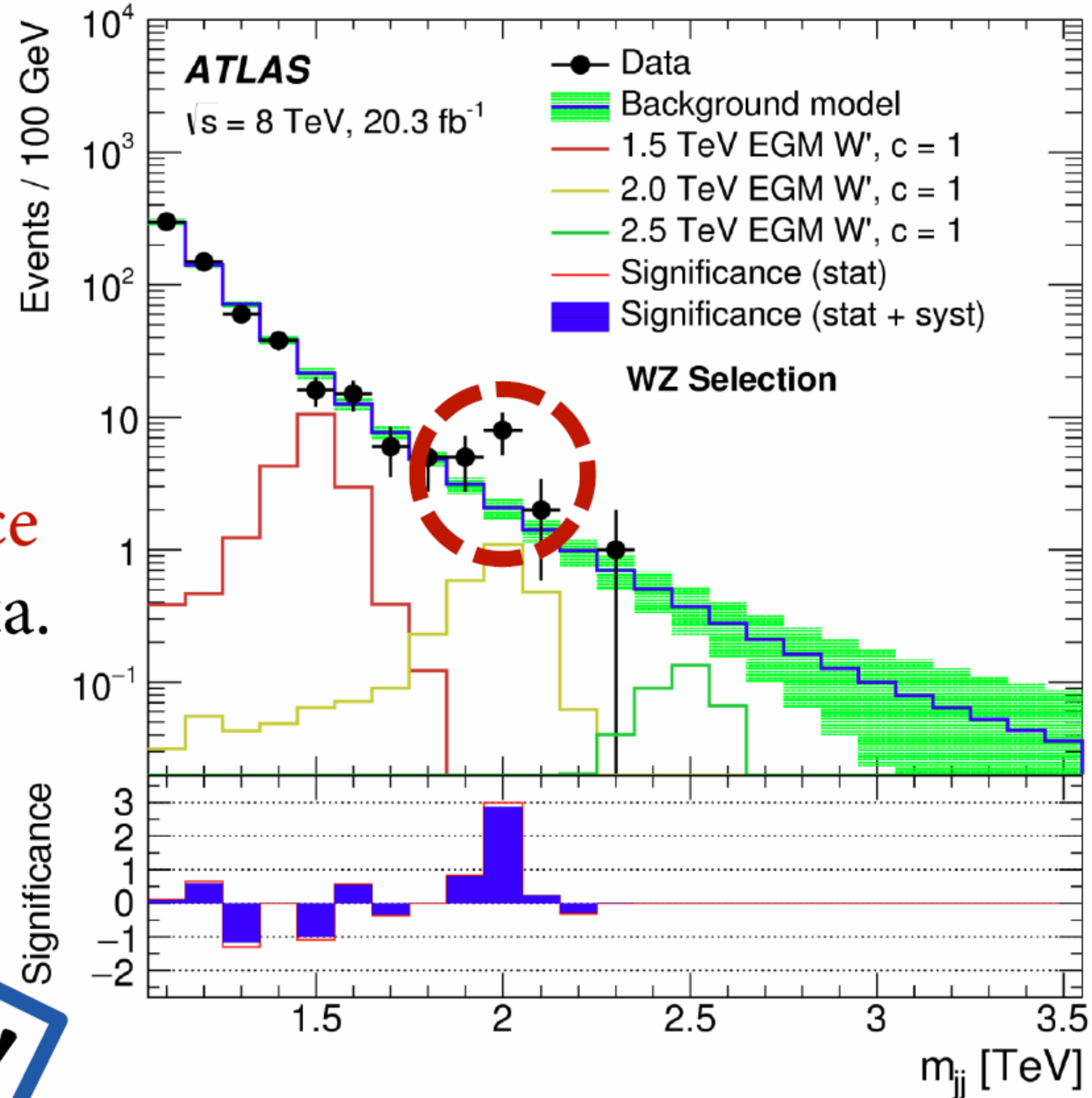
Control regions

- Before looking at the data, validate analysis in control regions (e.g. mass sidebands).
- Check that background is smoothly falling and not sculpted by selections.



Results!

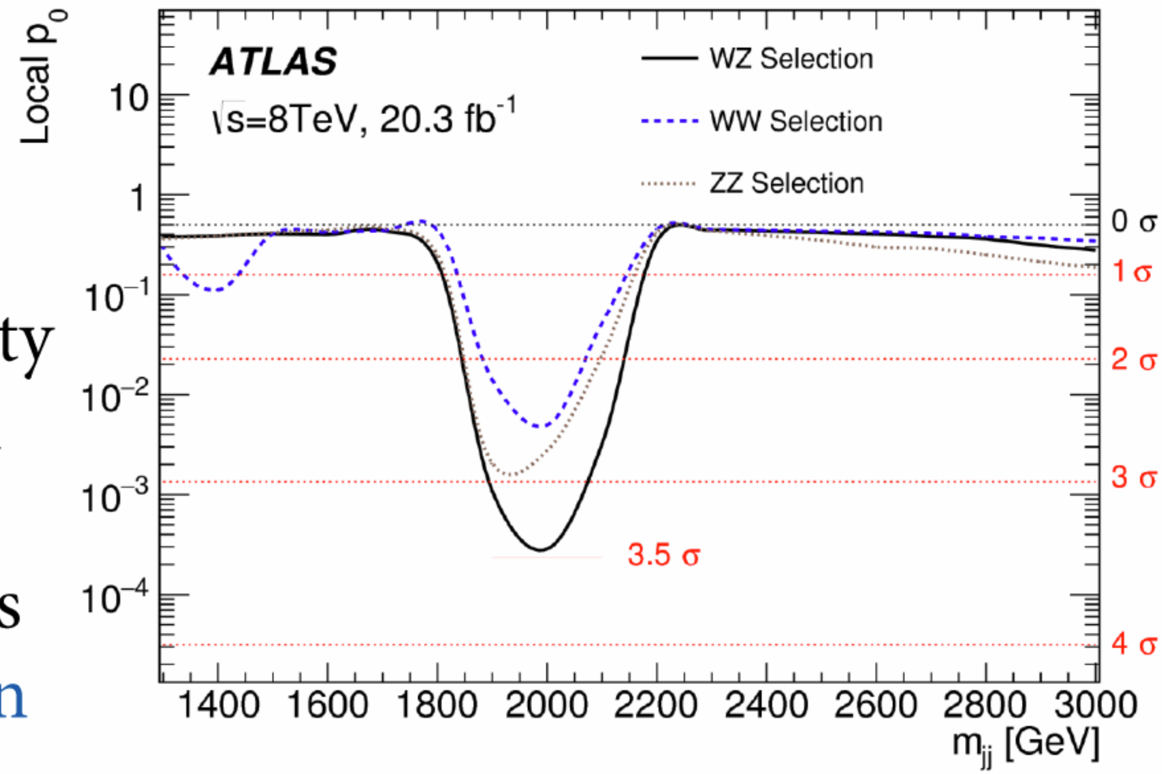
1. Finally, look at signal region
2. Fit background
3. Check for difference between fit and data.



Result from run 1!

Statistical treatment

- Estimate of p-value/significance of observed events, assuming probability density for random variable
- Assume: N_O follows Poisson distribution



- Poisson probability: $$\alpha = \sum_{n=N_o}^{\infty} \frac{\exp(-N_b)\,(N_b)^n}{n!}.$$

Statistical treatment

- Estimate of p-value/significance of ob
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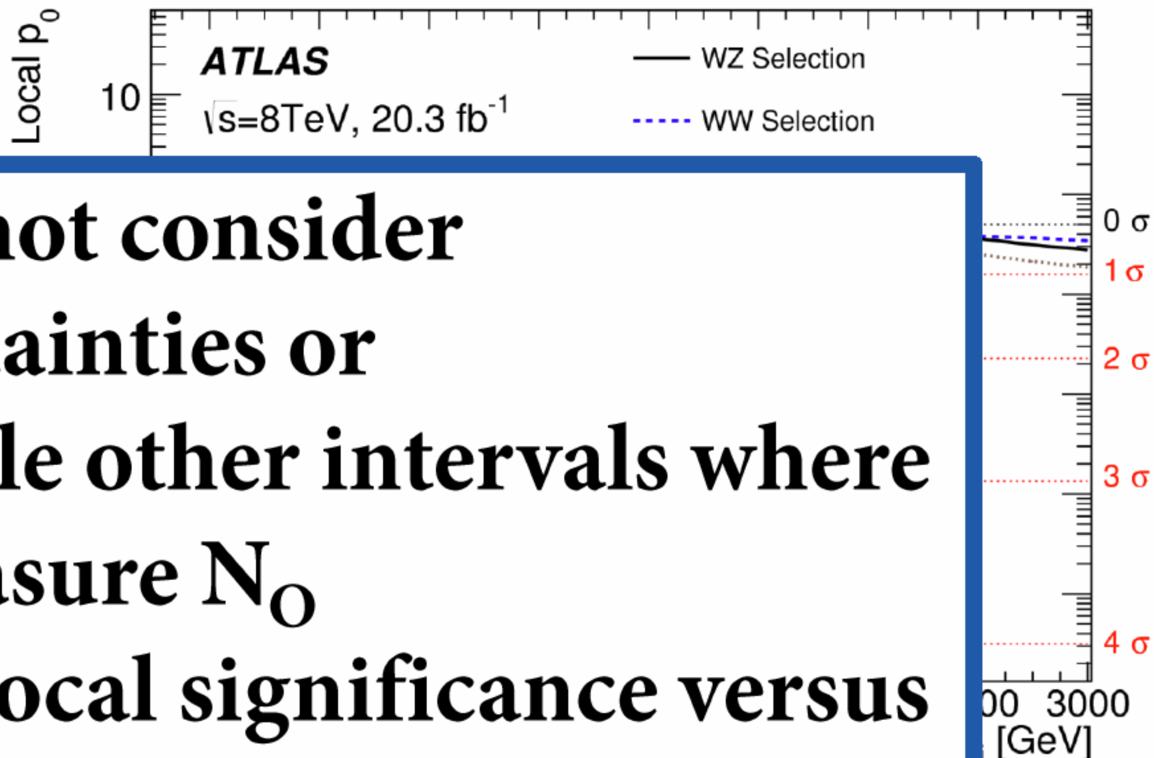


- Does not consider uncertainties or
- possible other intervals where to measure N_O

  → local significance versus global significance

- Poisson probability: $\alpha = \sum_{n=N_o} \frac{\exp(-N_b)\,(N_b)^n}{n!}.$

Statistical treatment

1-2σ

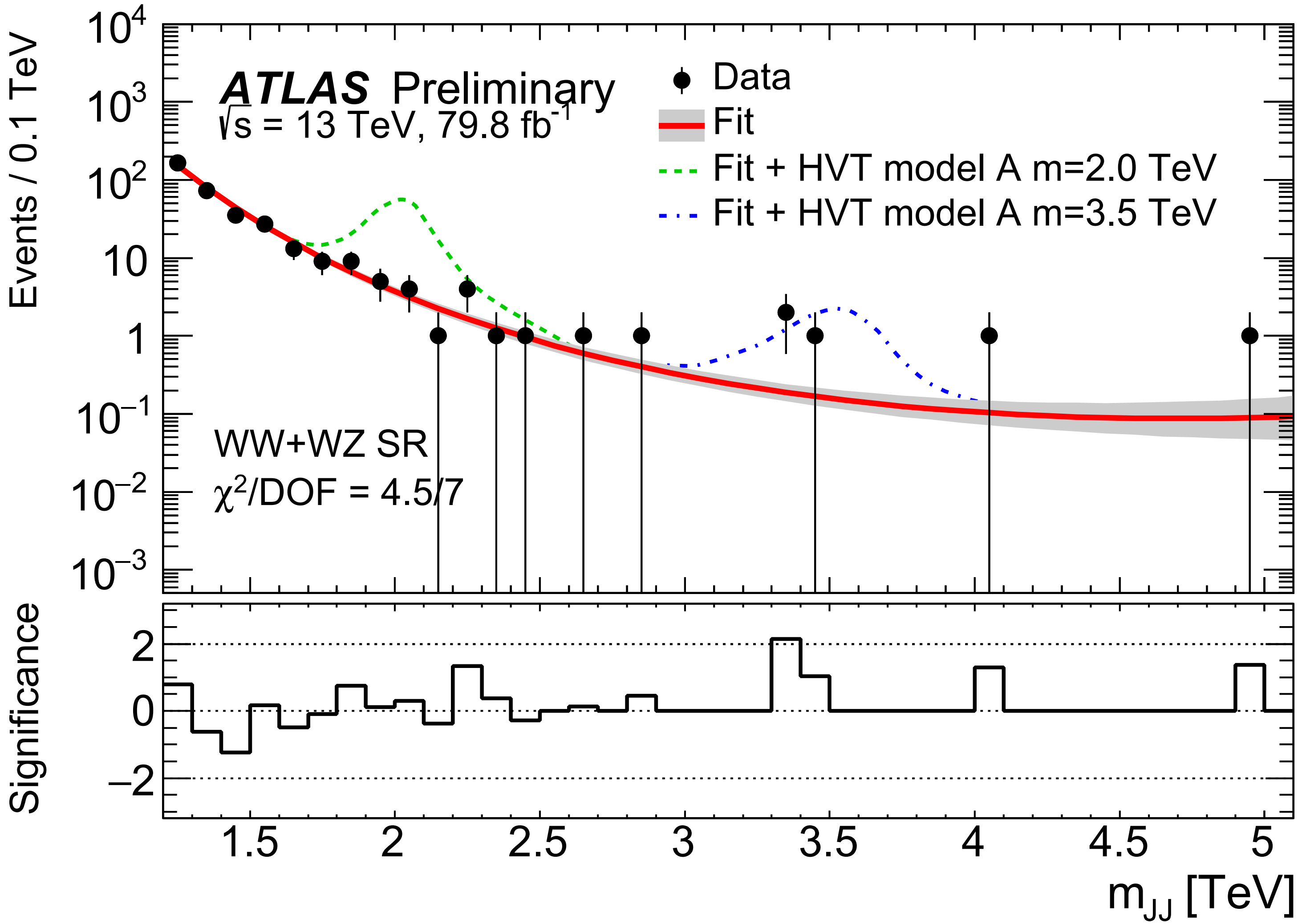
Statistical treatment

3σ

Statistical treatment

5σ

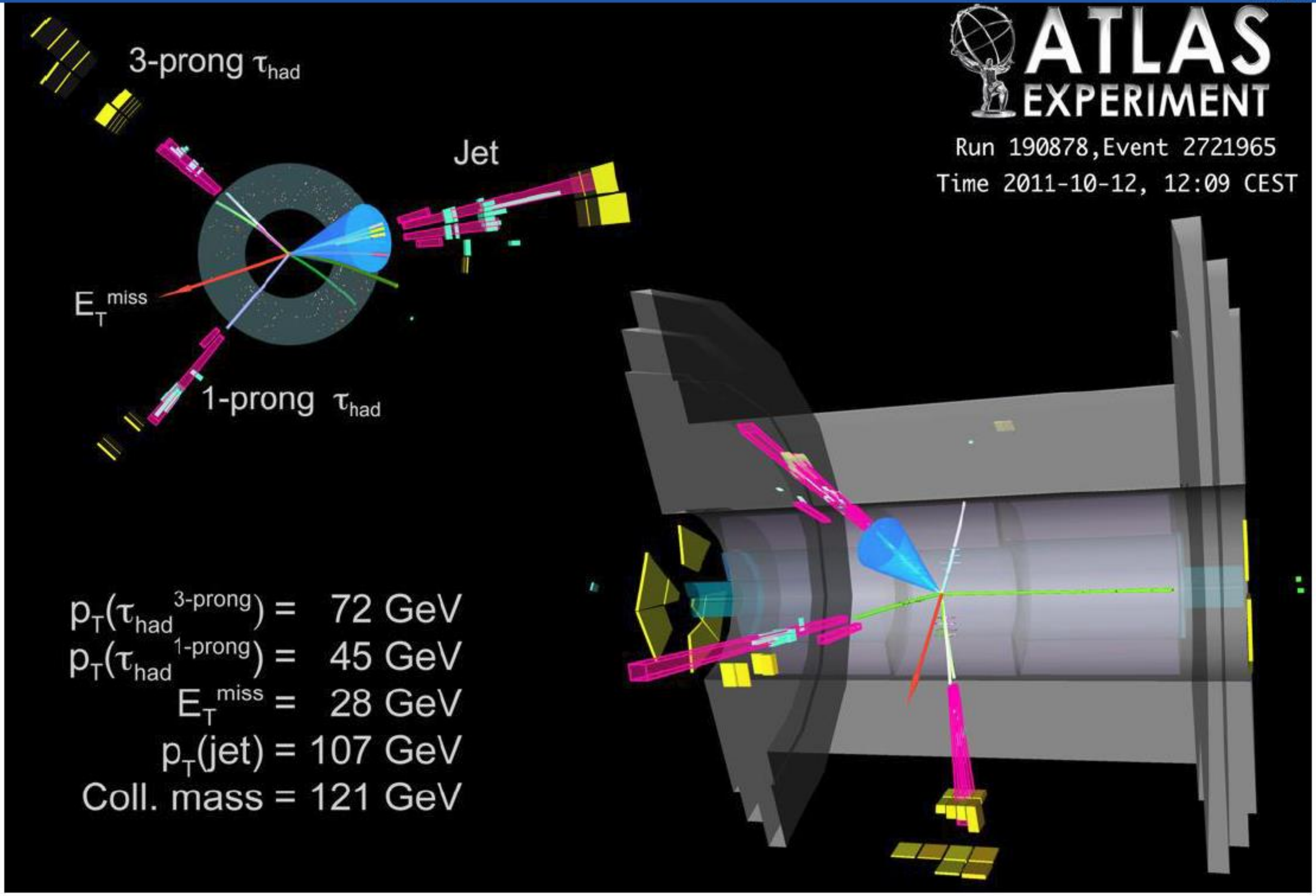
More Results!



Thank you – Discussion!

BACKUP

Taus



- Essentially thin jets $\tau^+ \to \pi^+ \nu_\tau \quad \tau^+ \to \pi^+ \pi^+ \pi^- \nu_\tau$