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 ..

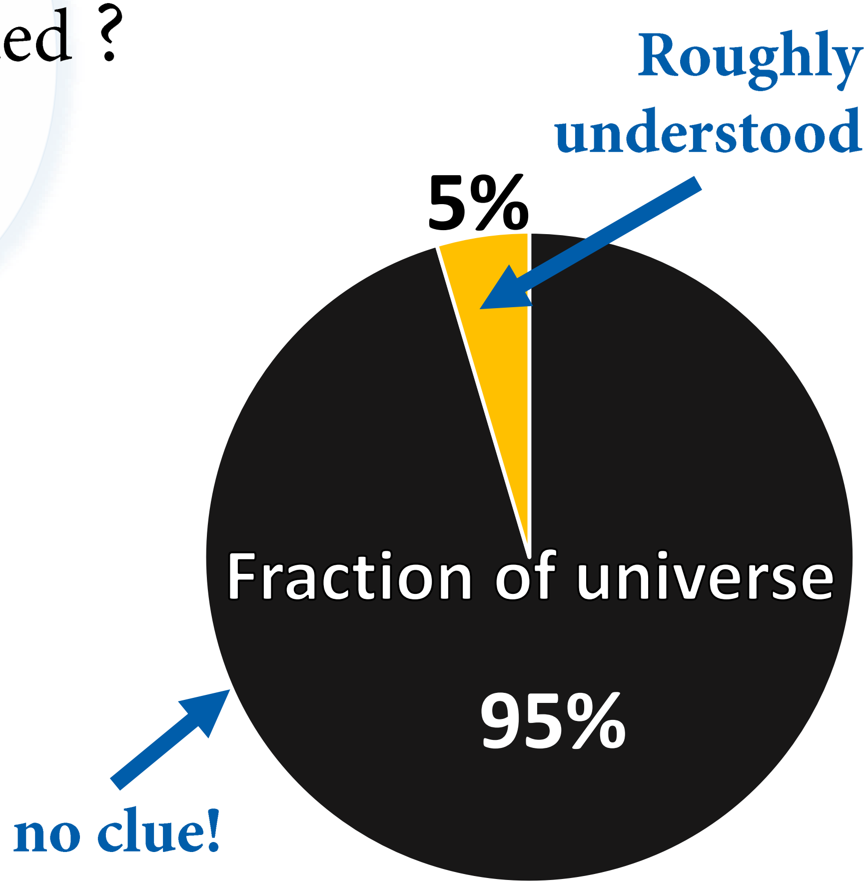
  .. what am I and everything around me made of ?

  .. how was our universe created ?

  .. and what is it made of ?

- We do!

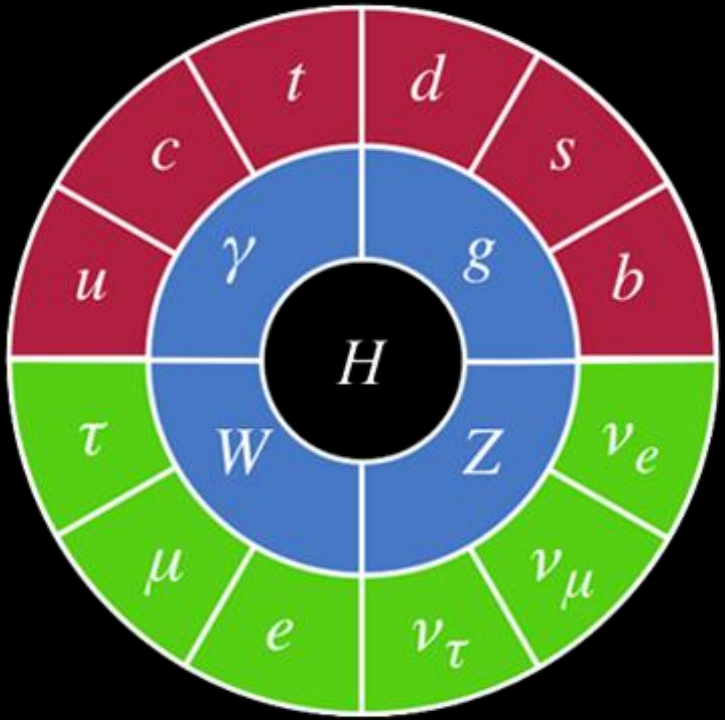
  This is why we do particle physics.



Particle physics – Why do we care?

- What particles ?

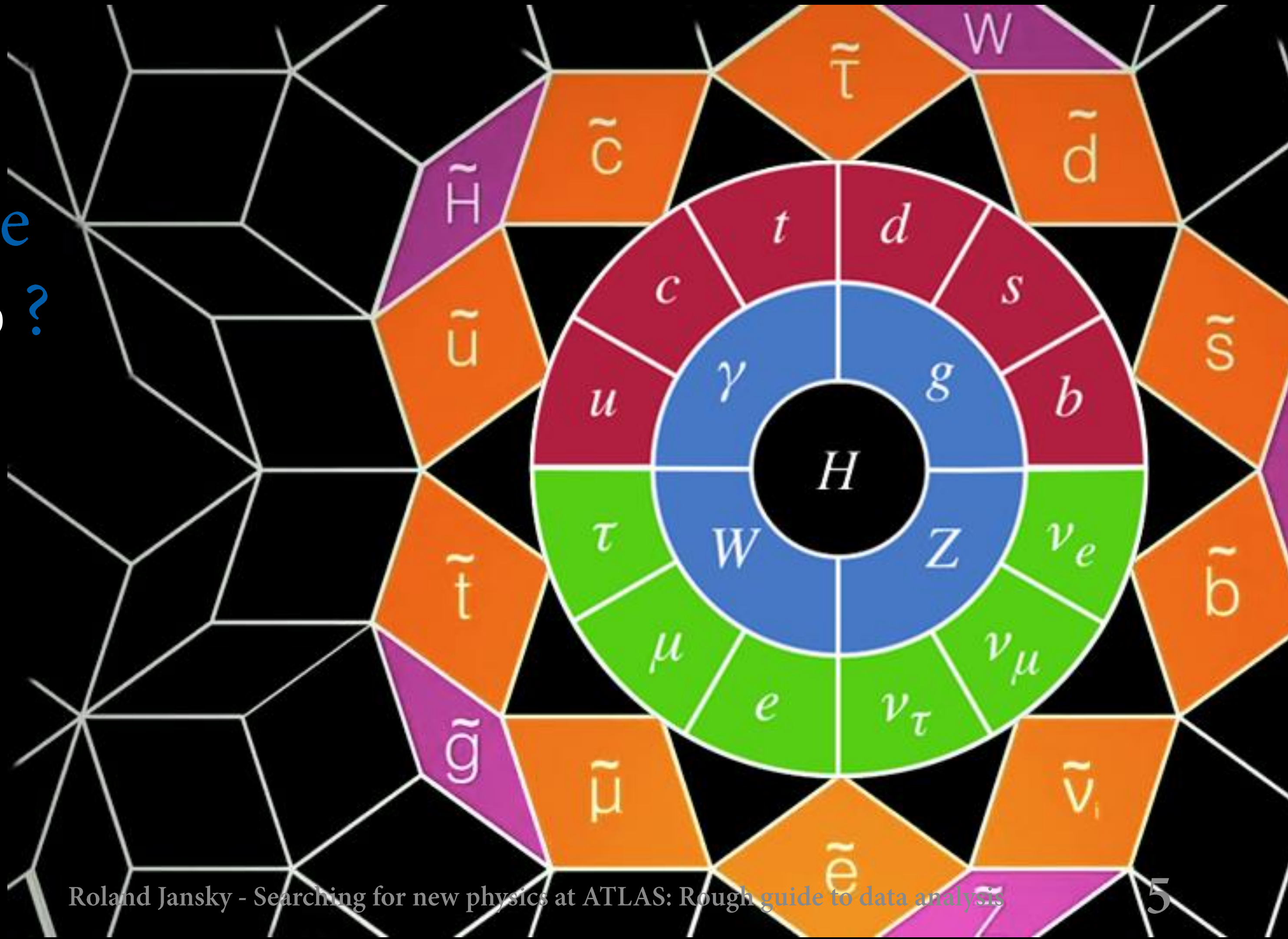
- These particles we know, and they are the building blocks of the 5%



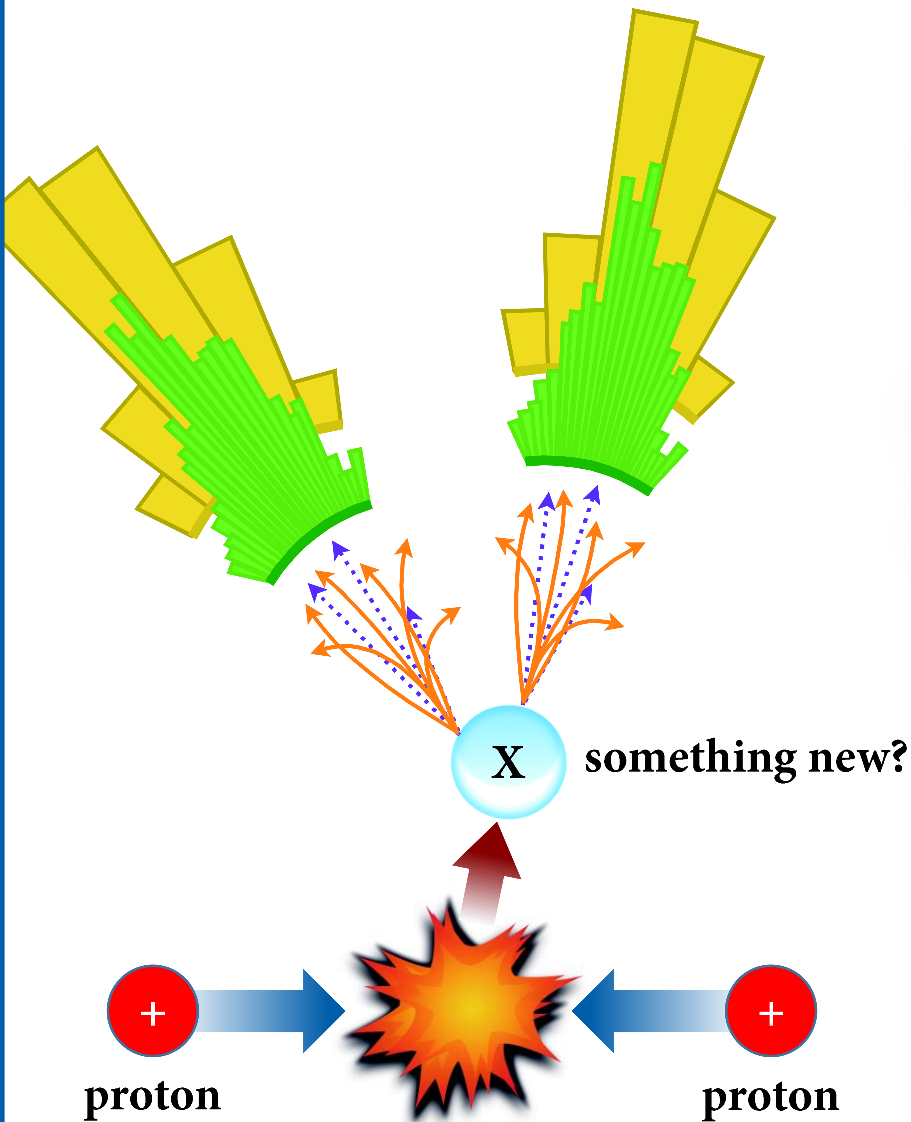
Particle physics – Why do we care?

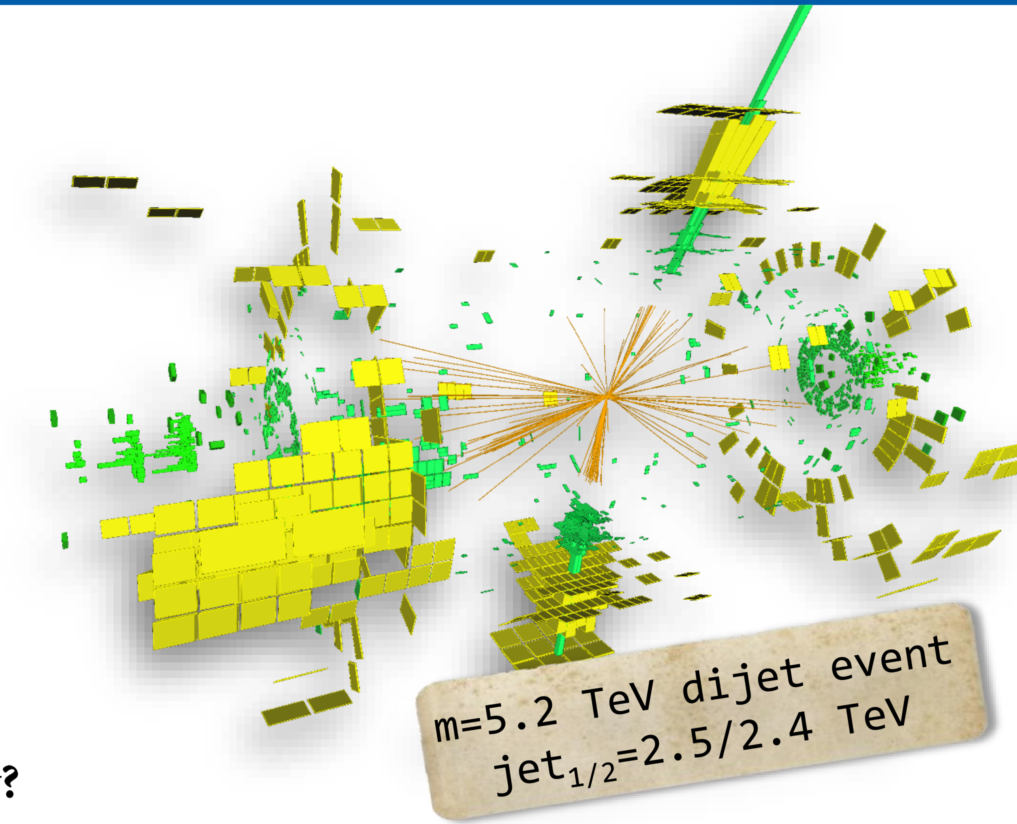
- What else could be there ?

- Are these the 95% ?



Energy Frontier: Jets



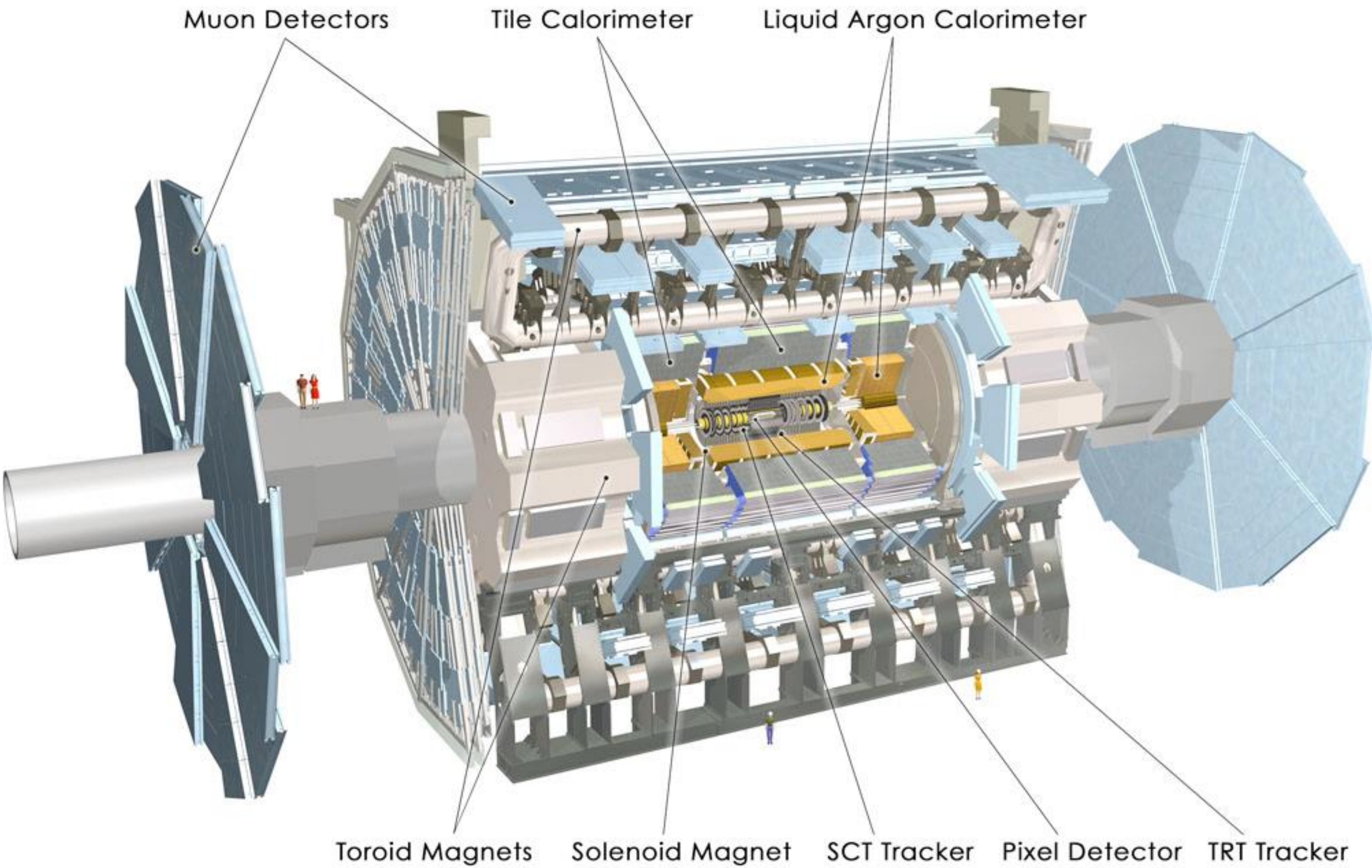


LHC - Large Hadron Collider

<u>Superconducting Accelerator and Collider</u>

Tunnel: 27 km long : 4m diameter :1232 Dipoles : 8 Tesla Field : Temp ~ 1.9 K

ATLAS (Hermetic) detector

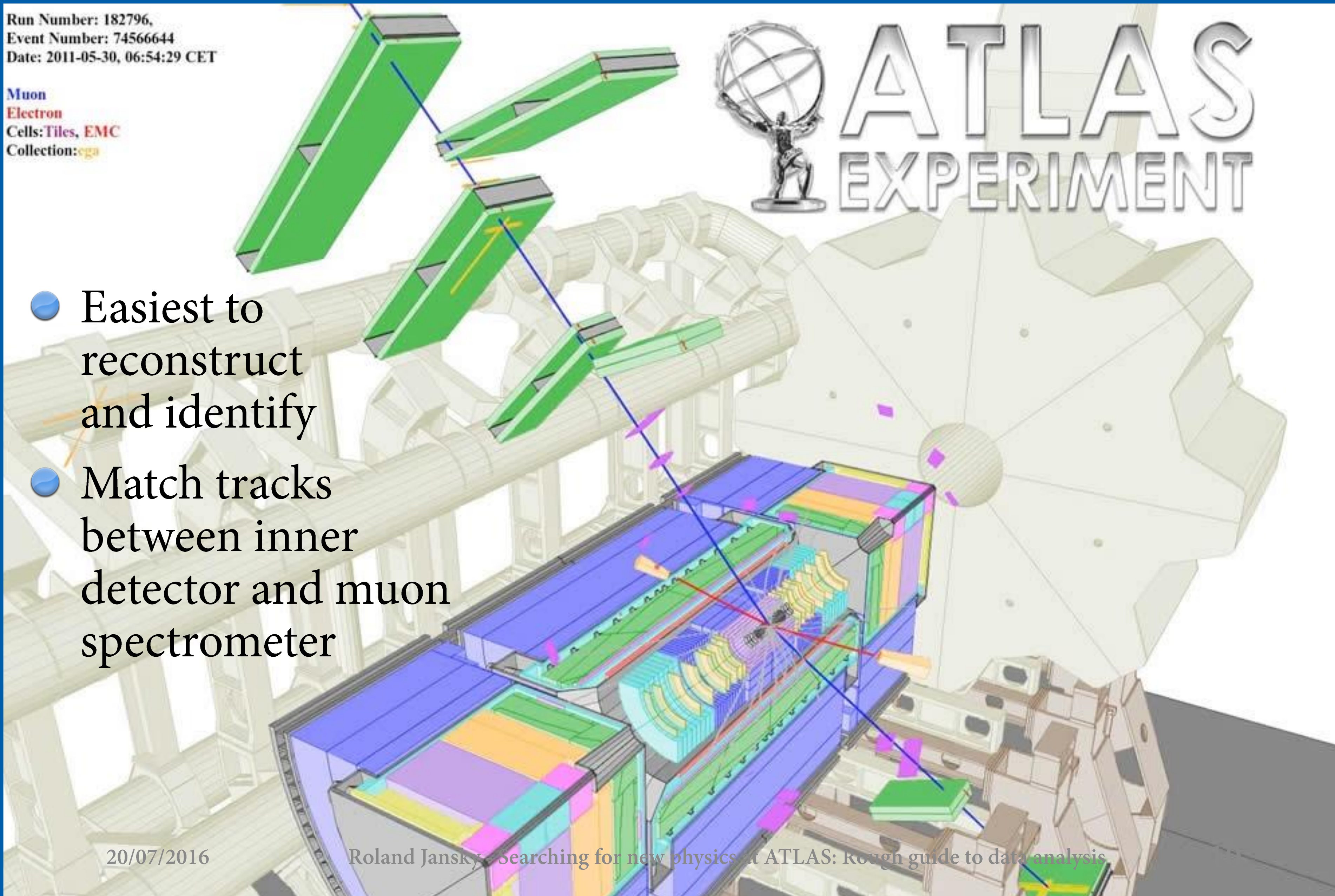


Analysis objects

- List of objects needed for analysis
  - Leptons
    - *muons, electrons, taus*
  - Photons
  - Hadronic jets
  - Energy sums
    - *Missing transverse energy*

- Measure p_T, E_T, η and φ of objects

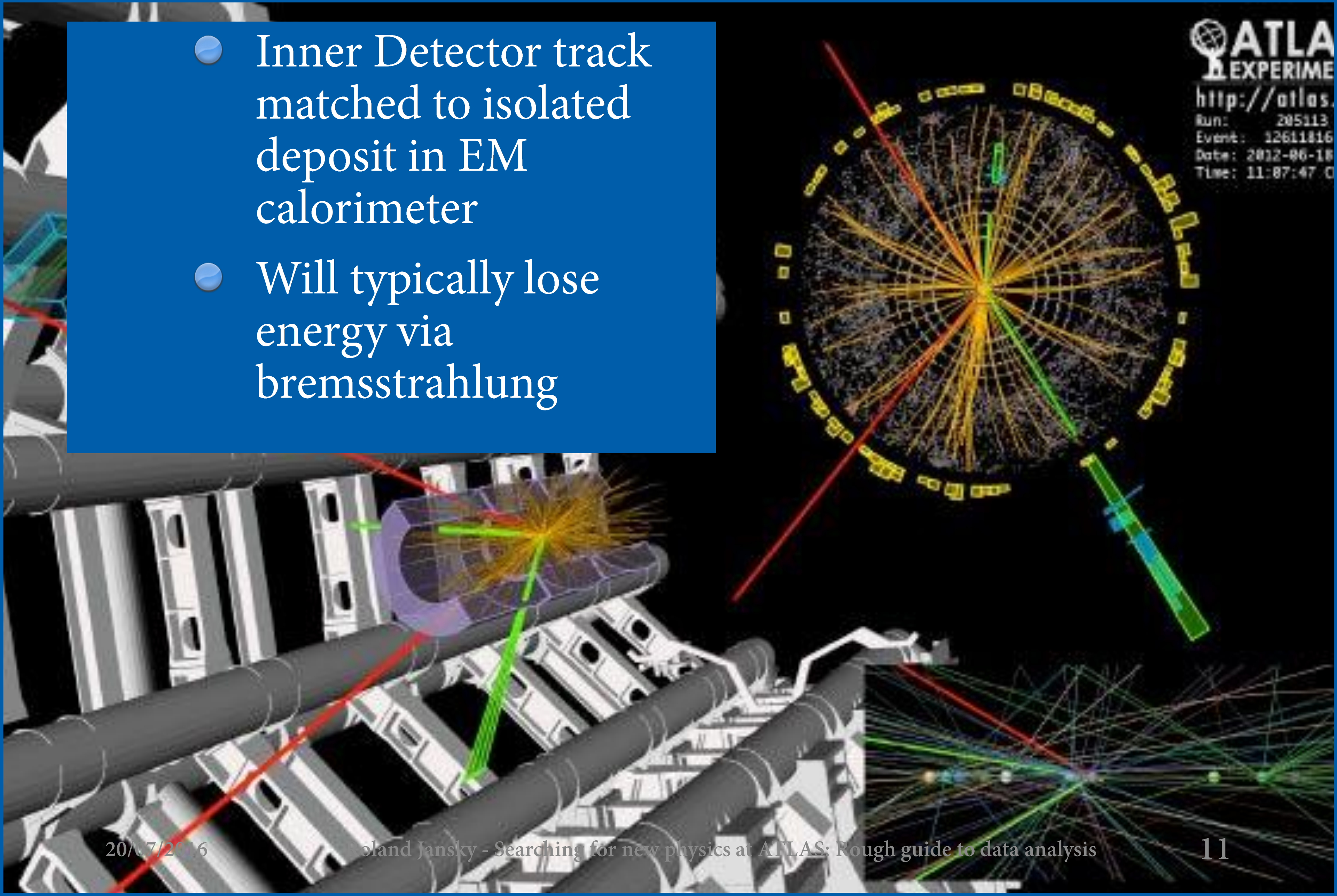
Muons



- Easiest to reconstruct and identify
- Match tracks between inner detector and muon spectrometer

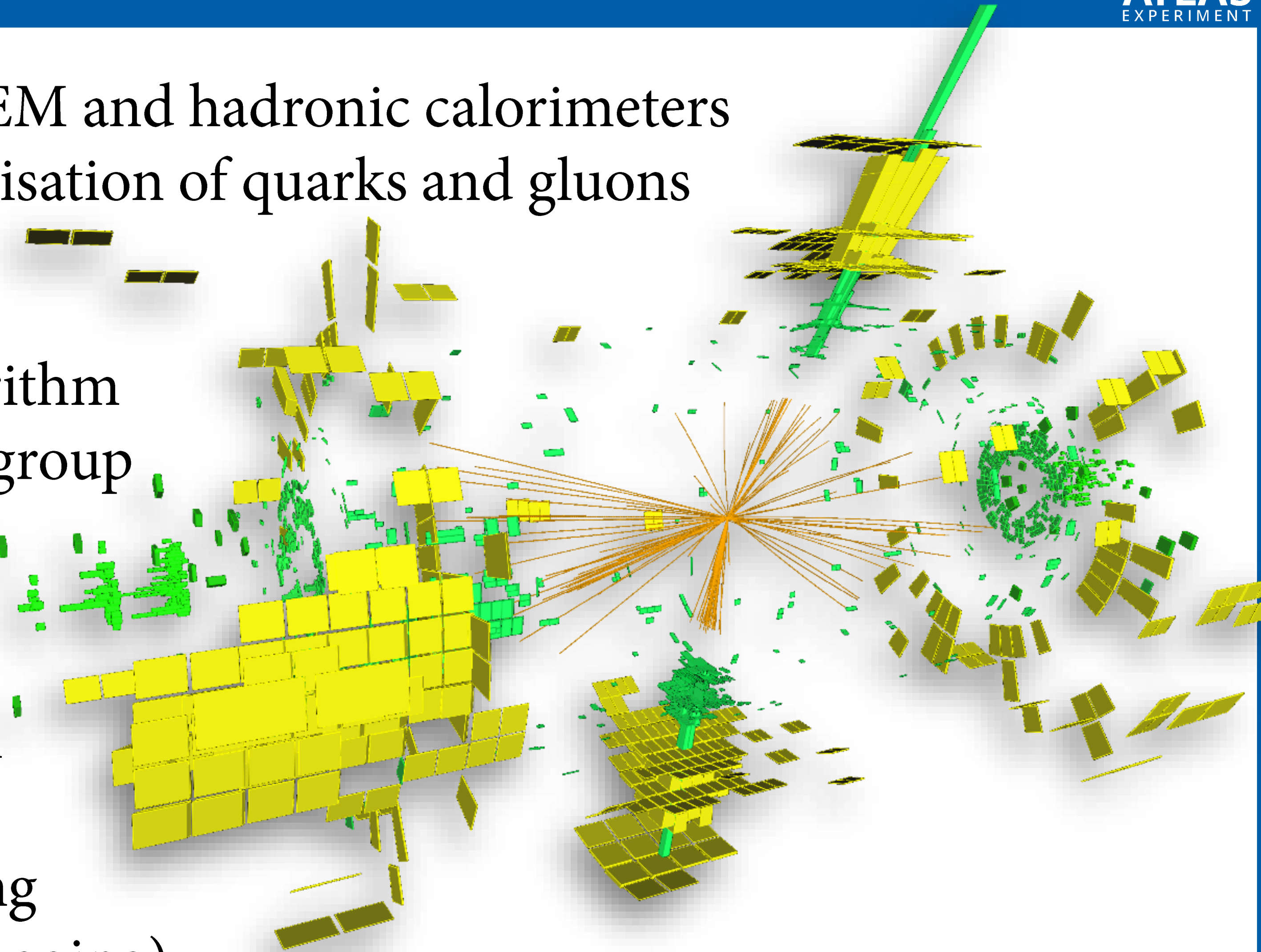
Electrons

- Inner Detector track matched to isolated deposit in EM calorimeter
- Will typically lose energy via bremsstrahlung

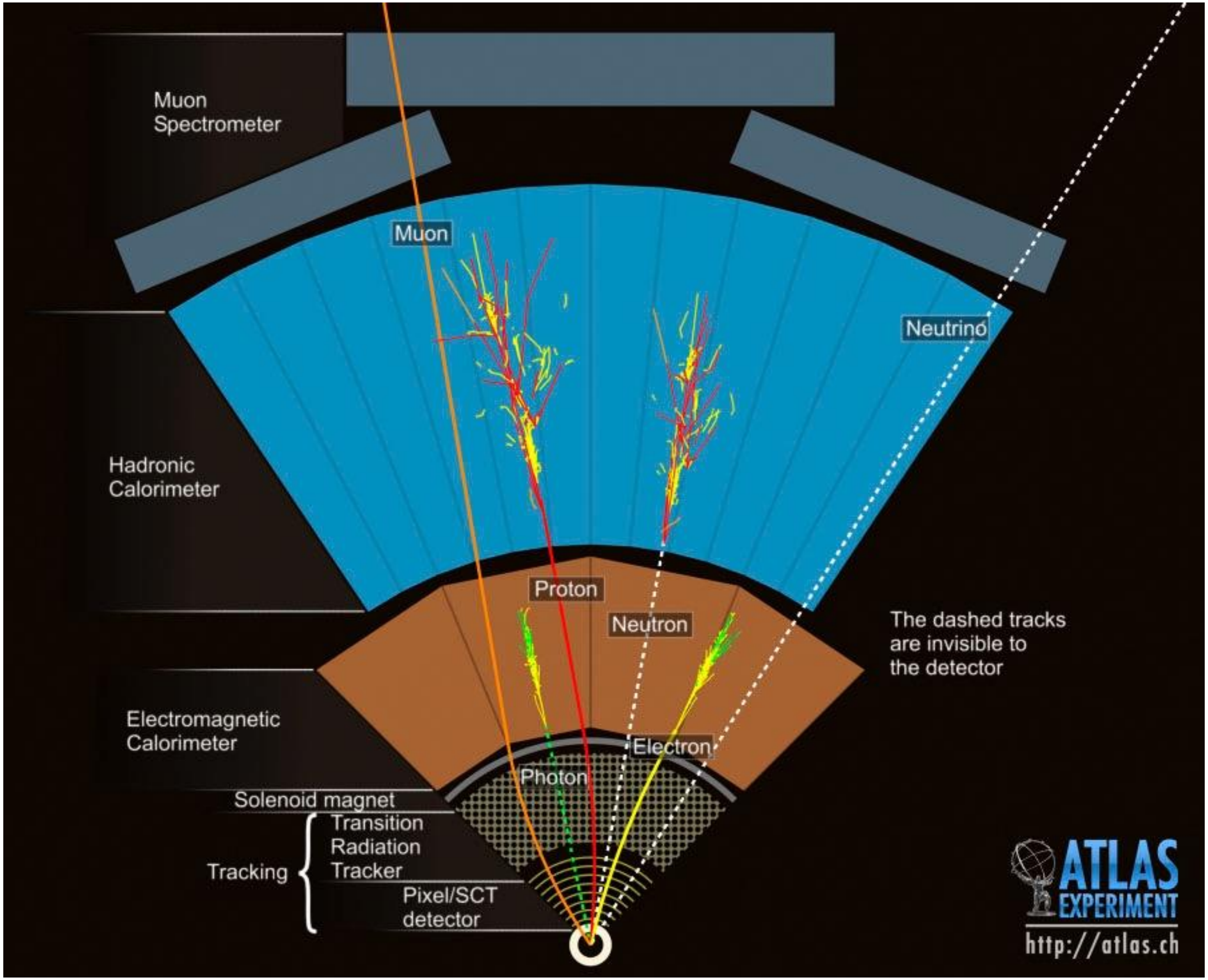


Hadronic jets

- Deposits in EM and hadronic calorimeters from hadronisation of quarks and gluons (partons)
- Cluster algorithm (anti-k_T) to group deposits
- bottom and charm quark jets have distinguishing features (b-tagging)

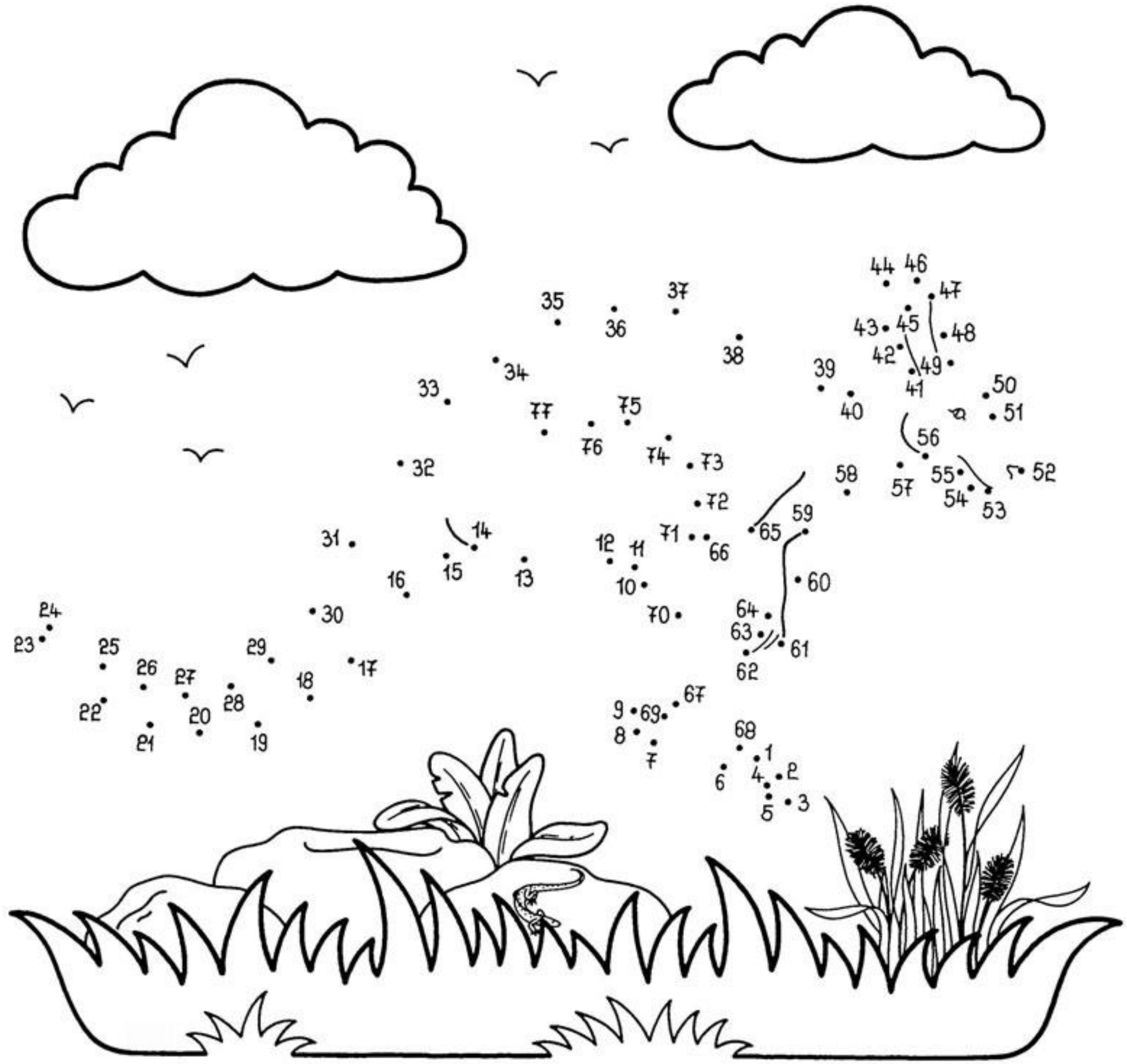


ATLAS detector Wedge



Track reconstruction - Concept

- Nowadays finding particle tracks is like this ..



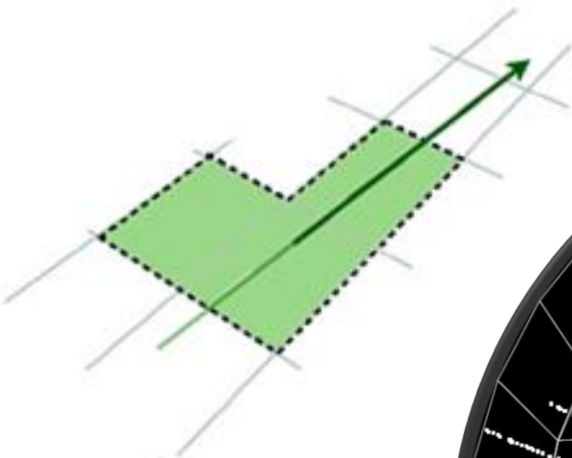
Track reconstruction - Concept

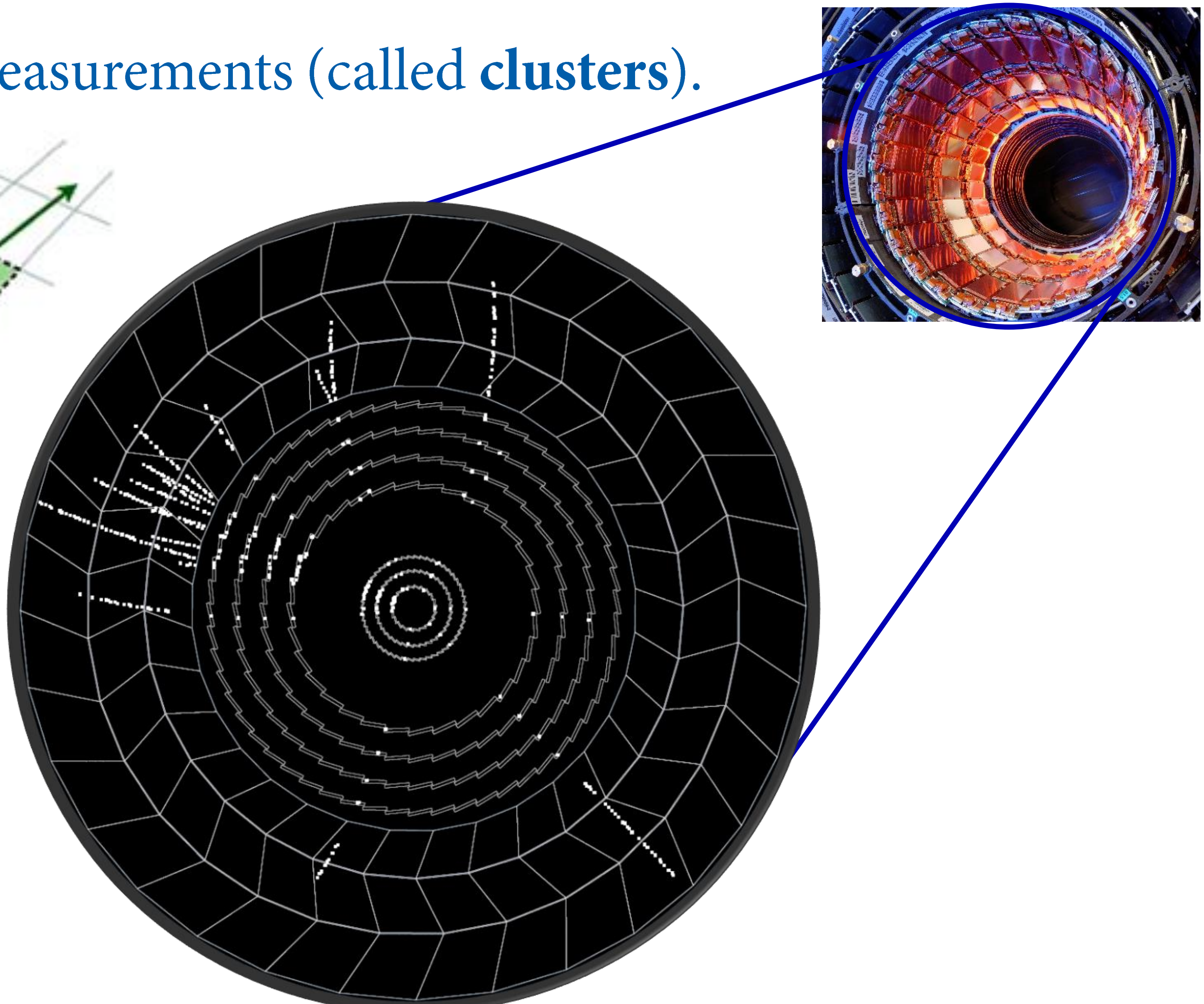
- Nowadays finding particle tracks is like this ..

- But without the numbers!

Track reconstruction – Step by step

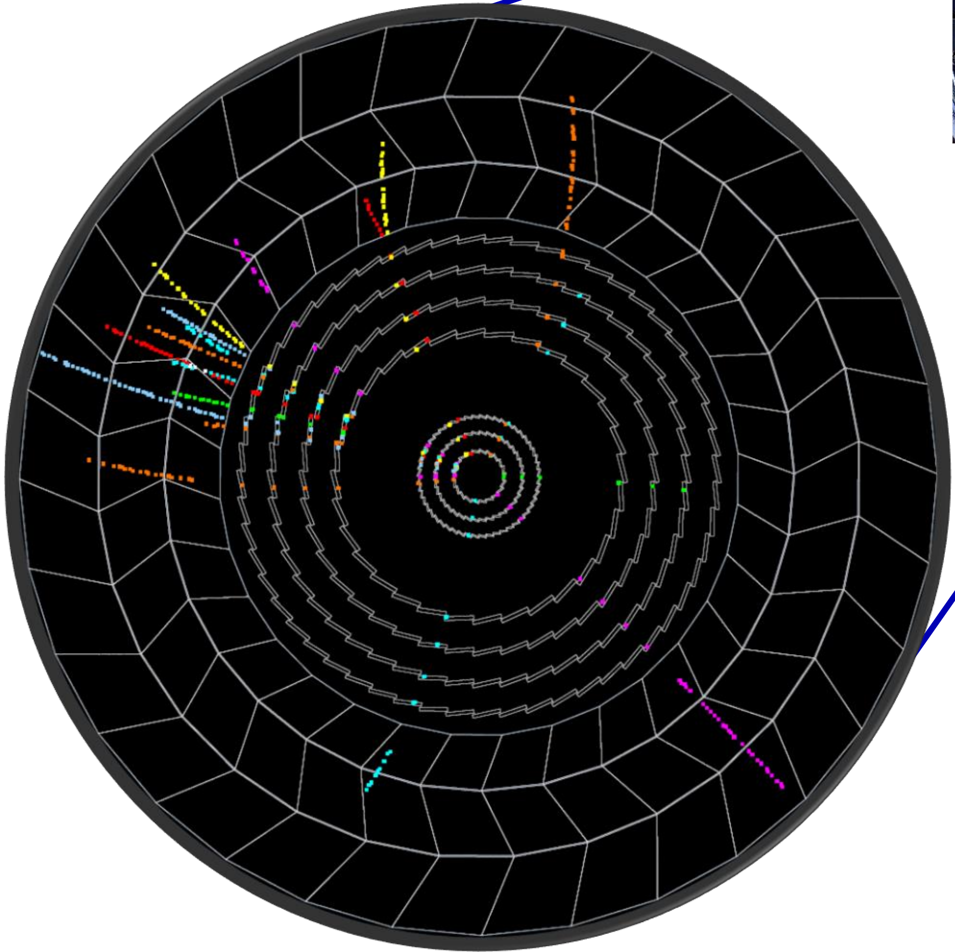
1. Register measurements (called **clusters**).

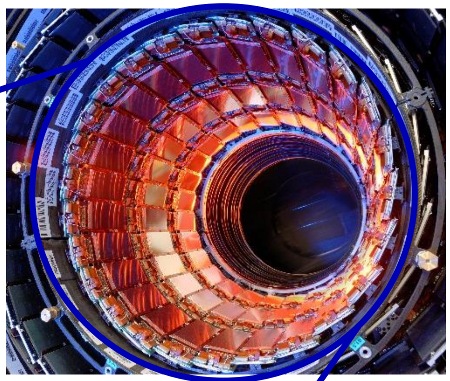




Track reconstruction – Step by step

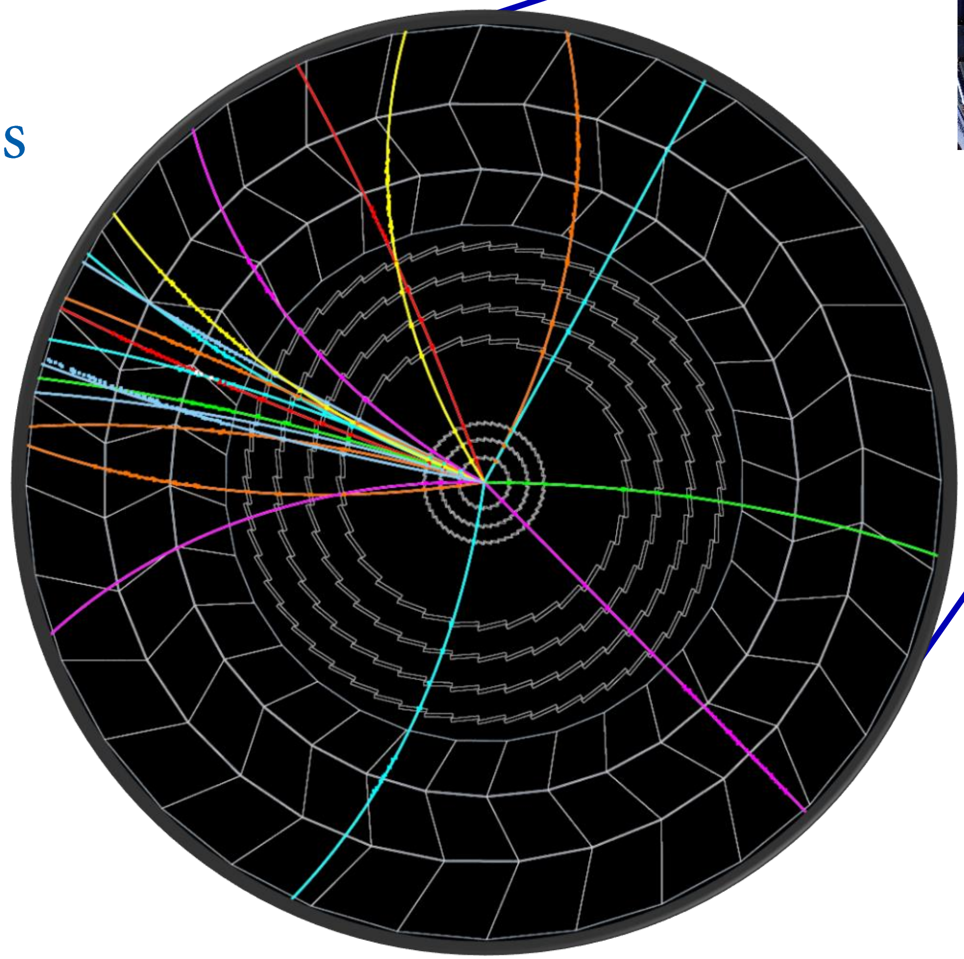
1. Register measurements (called **clusters**).
2. Associate clusters to particles' tracks.

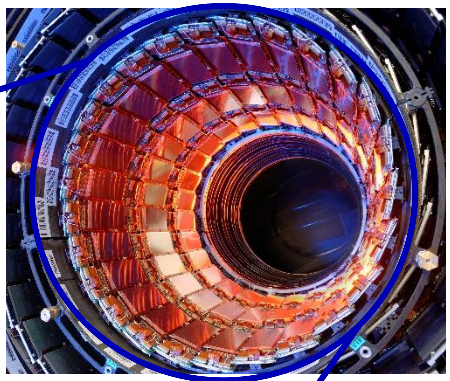




Track reconstruction – Step by step

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

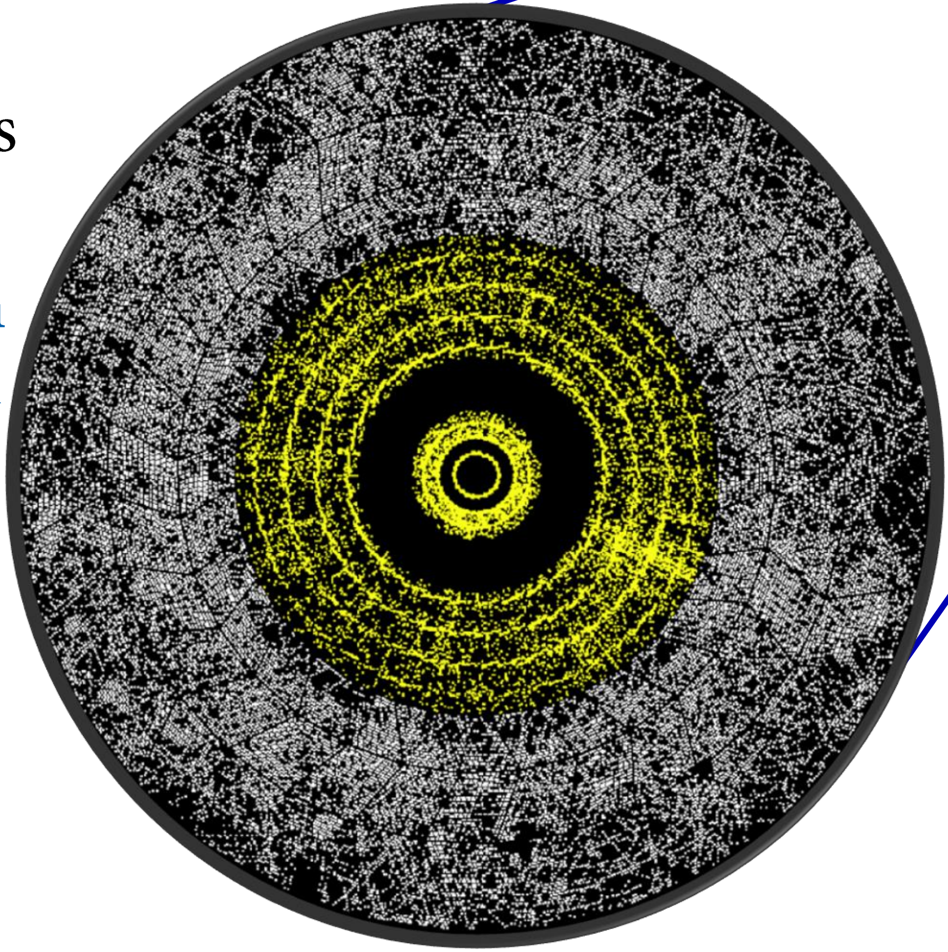


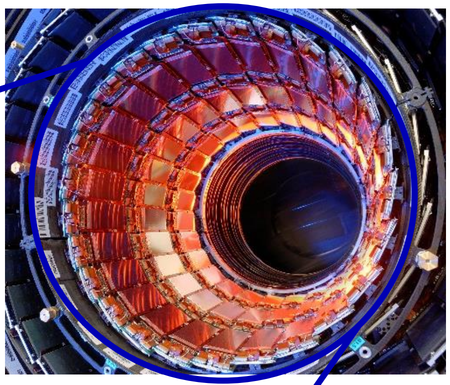


Track reconstruction – Step by step

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

How it looks in reality



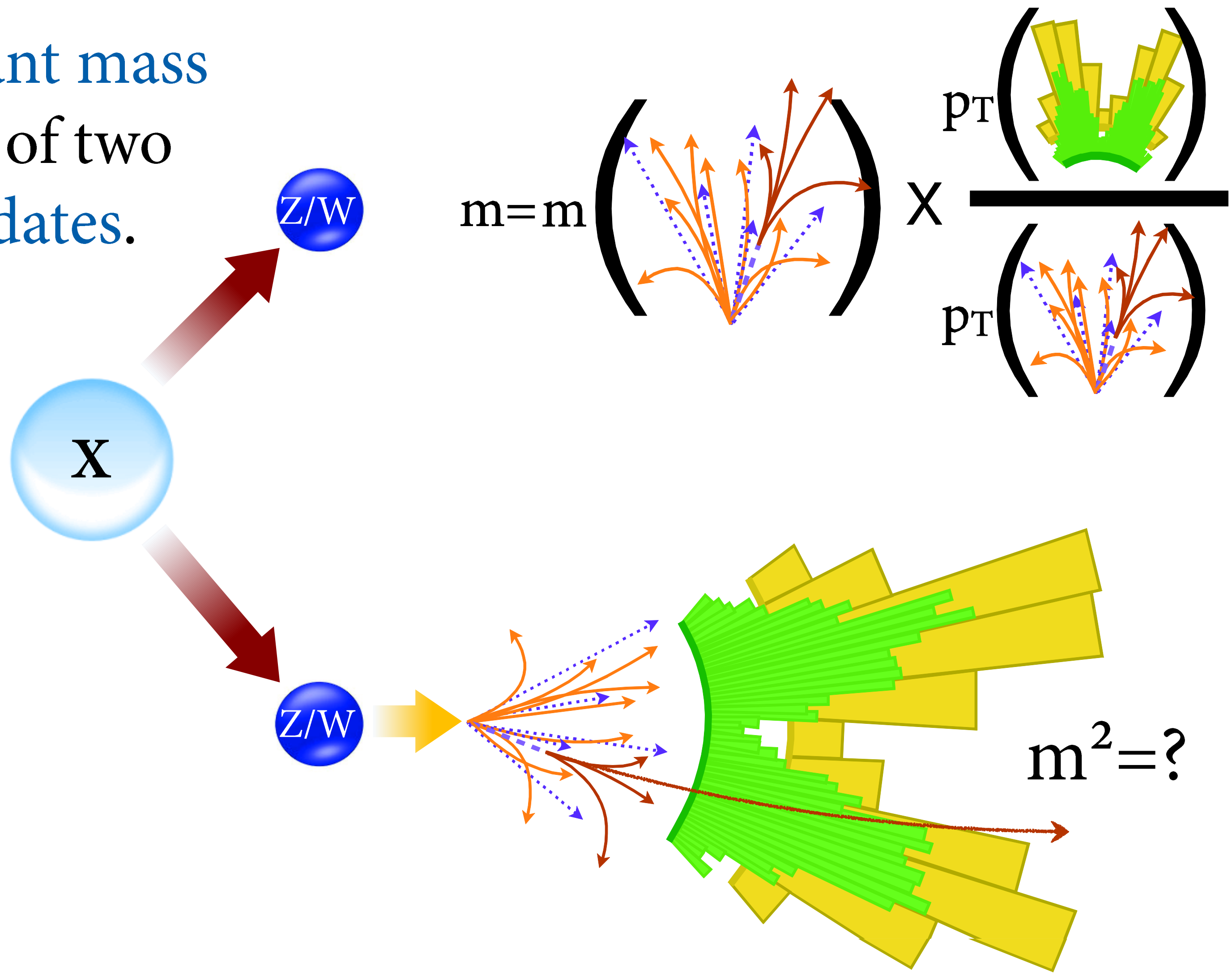


Prerequisites for analysis

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

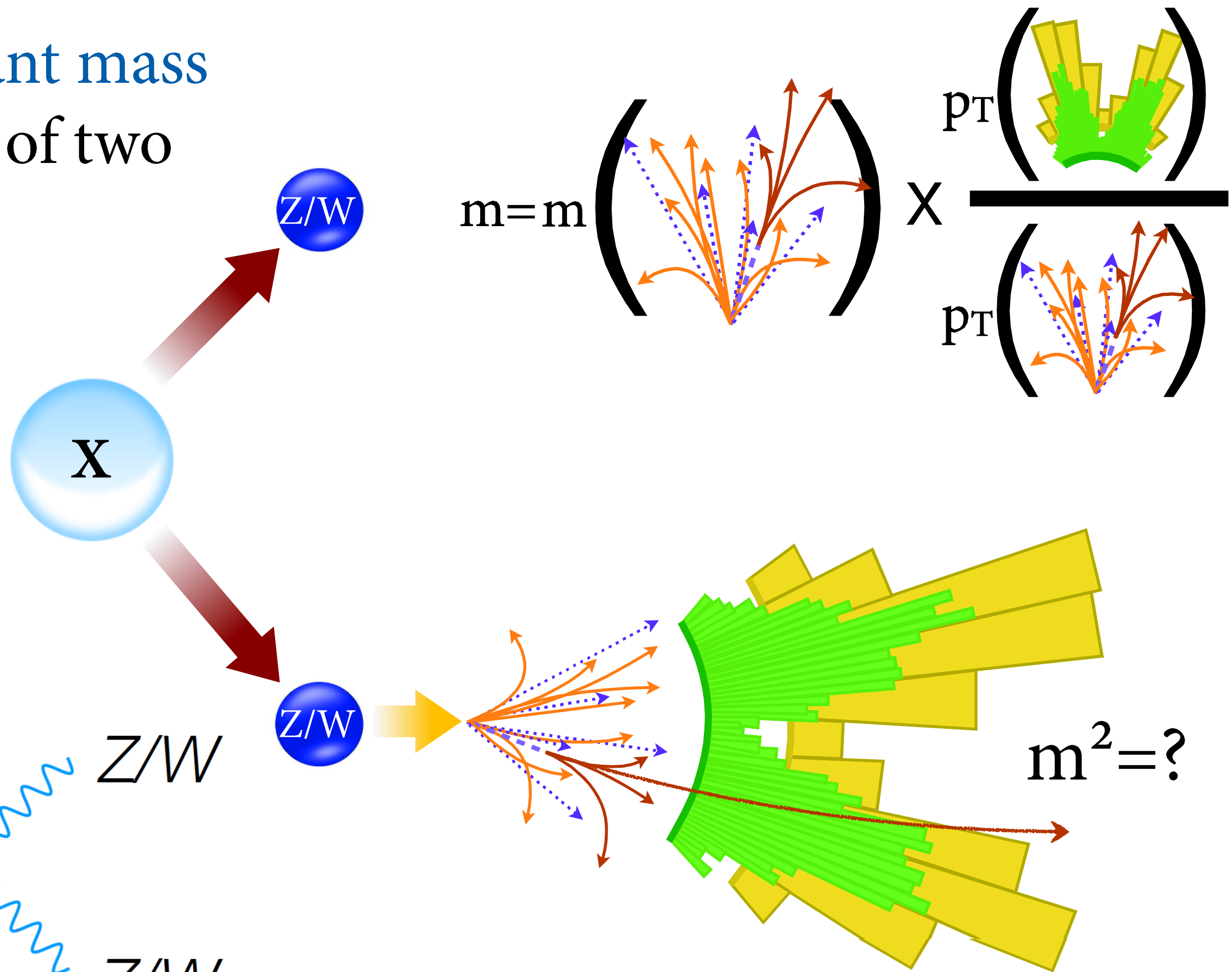
Boosted diboson search strategy

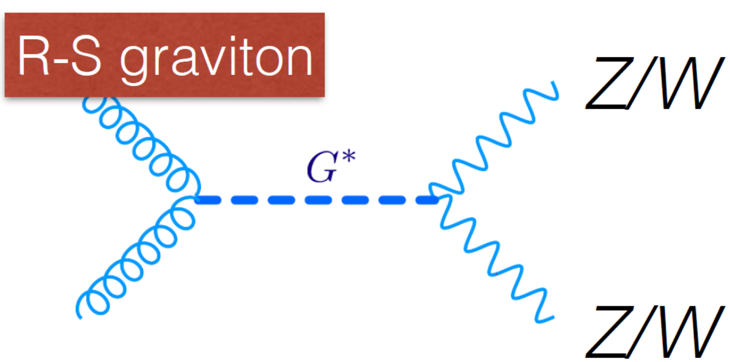
- Build invariant mass from system of two boson candidates.



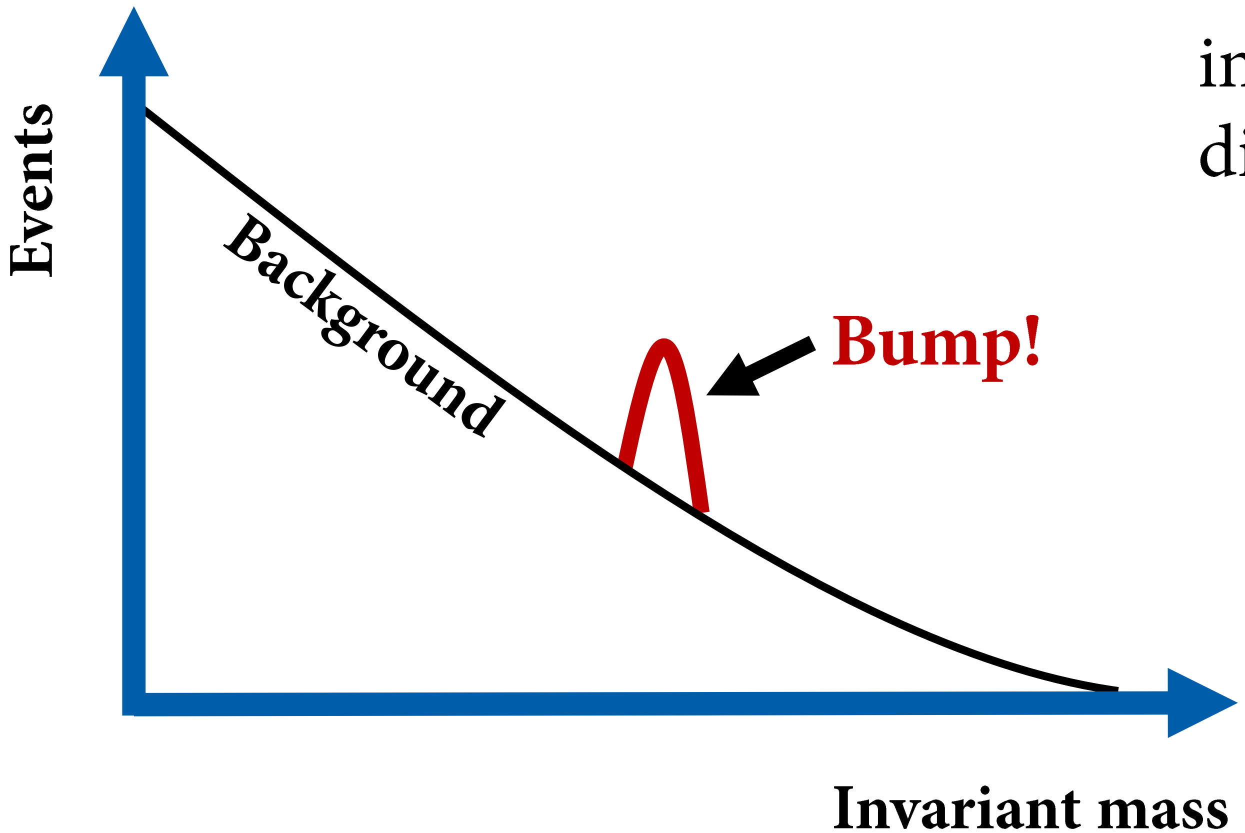
Boosted diboson search strategy

- Build invariant mass from system of two (boson) jet candidates.





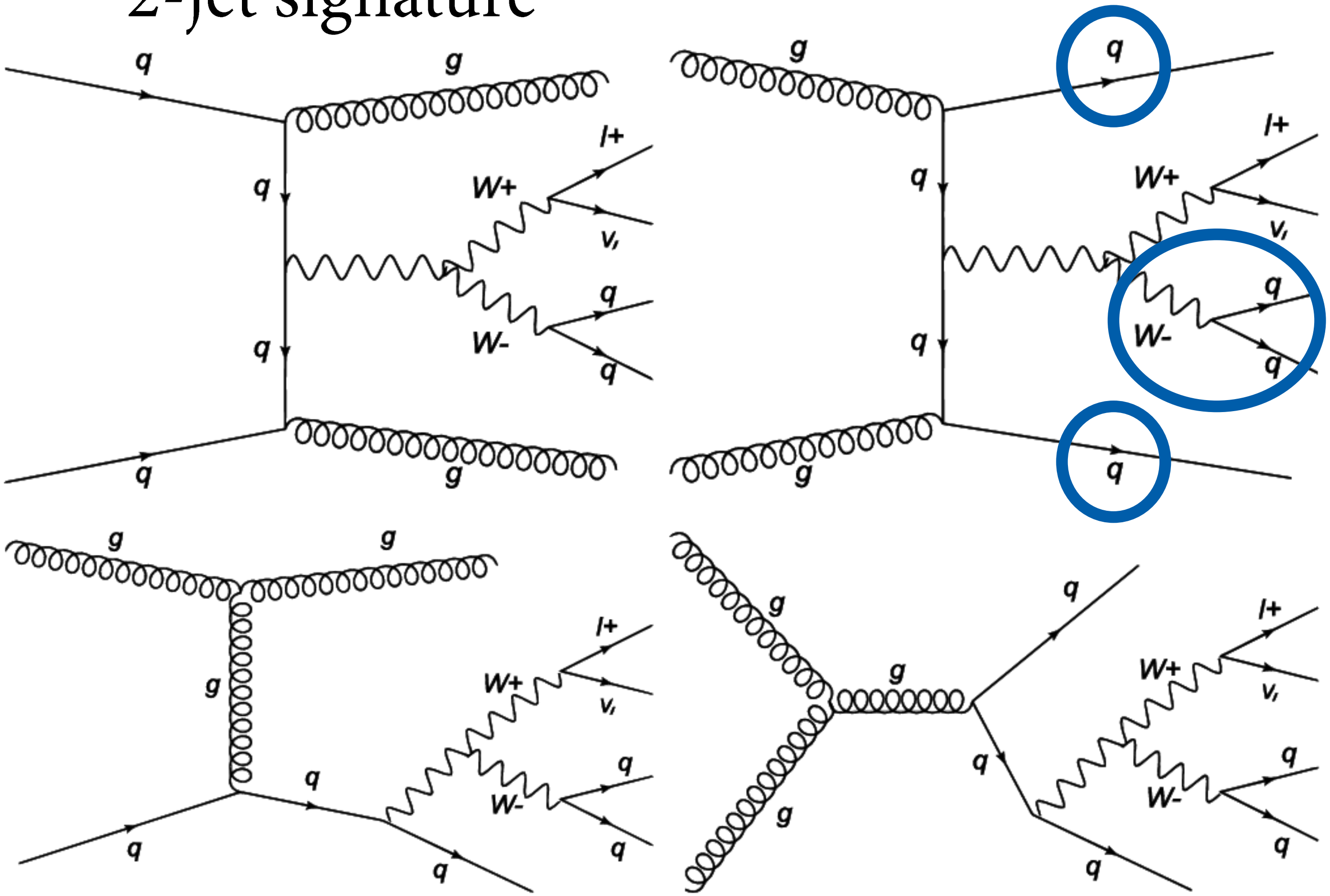
Boosted diboson search strategy



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

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)

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?

Summary

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

N(obs) Statistical uncertainty

N(bkg) Systematic uncertainty

L Systematic uncertainty

ε Systematic uncertainty

A Systematic uncertainty

B Systematic uncertainty

Optimisation

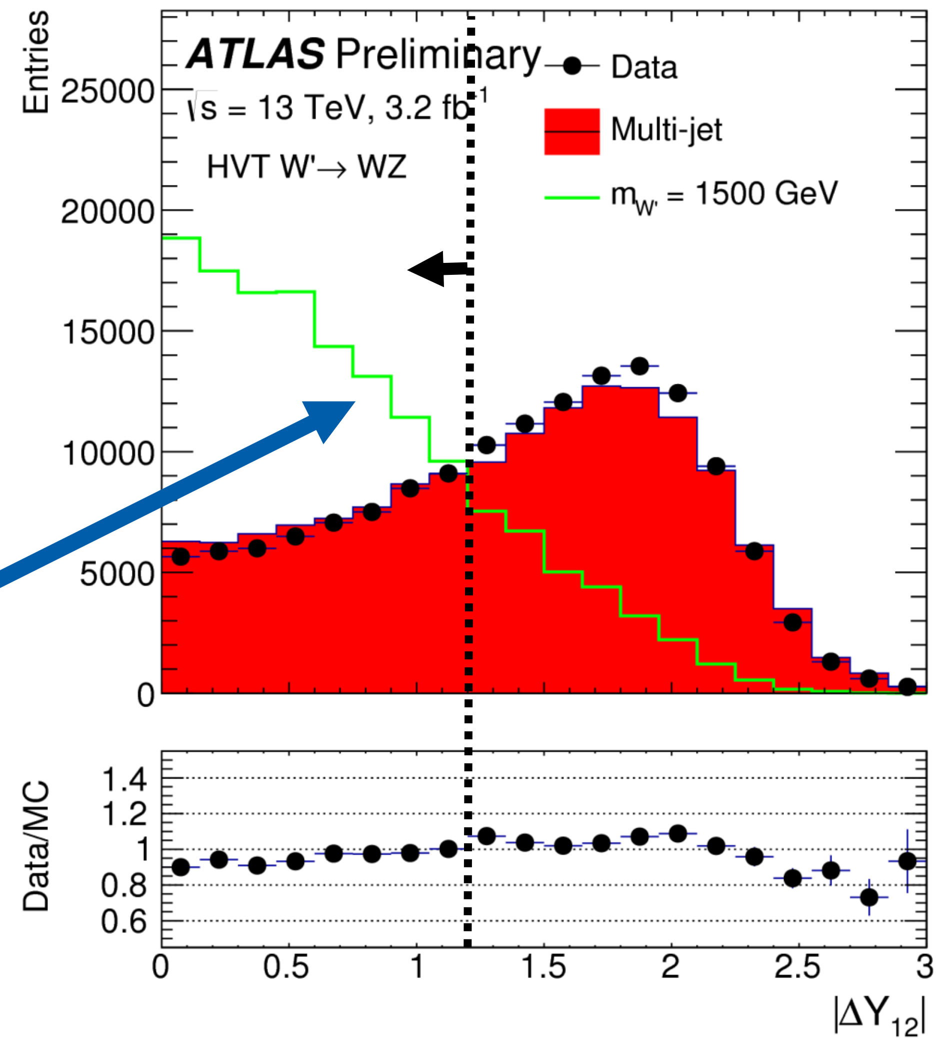
$$\sigma = \frac{N_{obs} - N_{bkg}}{\mathcal{L} \cdot \epsilon \cdot A \cdot \mathcal{B}}$$

- 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.

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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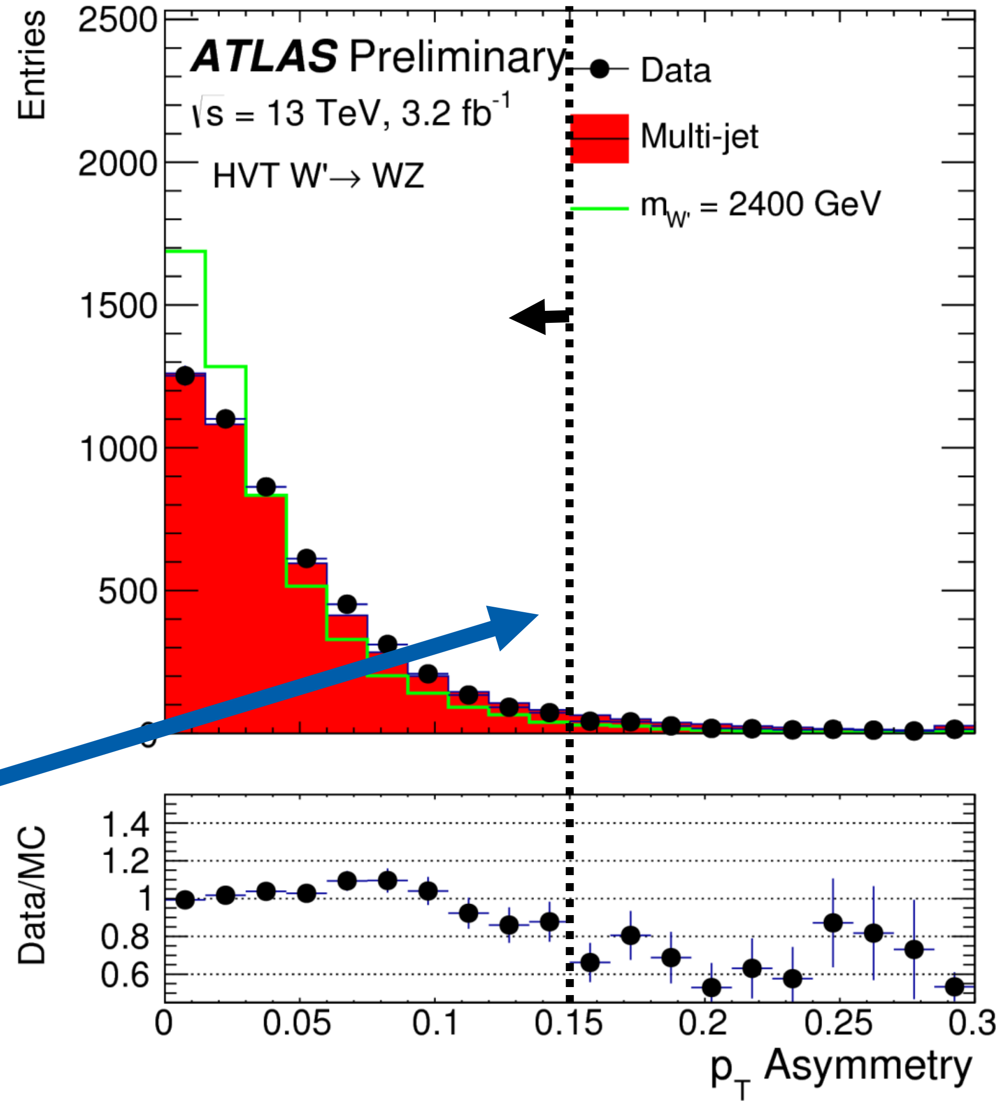
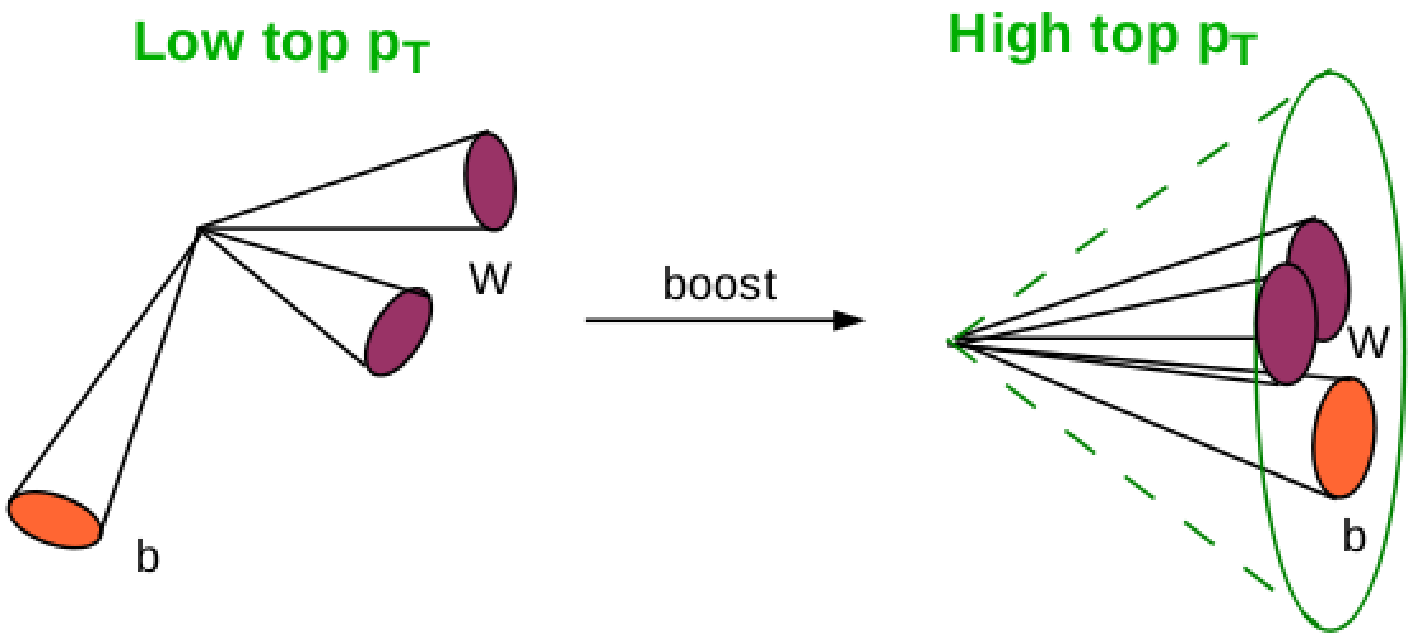


Cut on momentum asymmetry between two jets

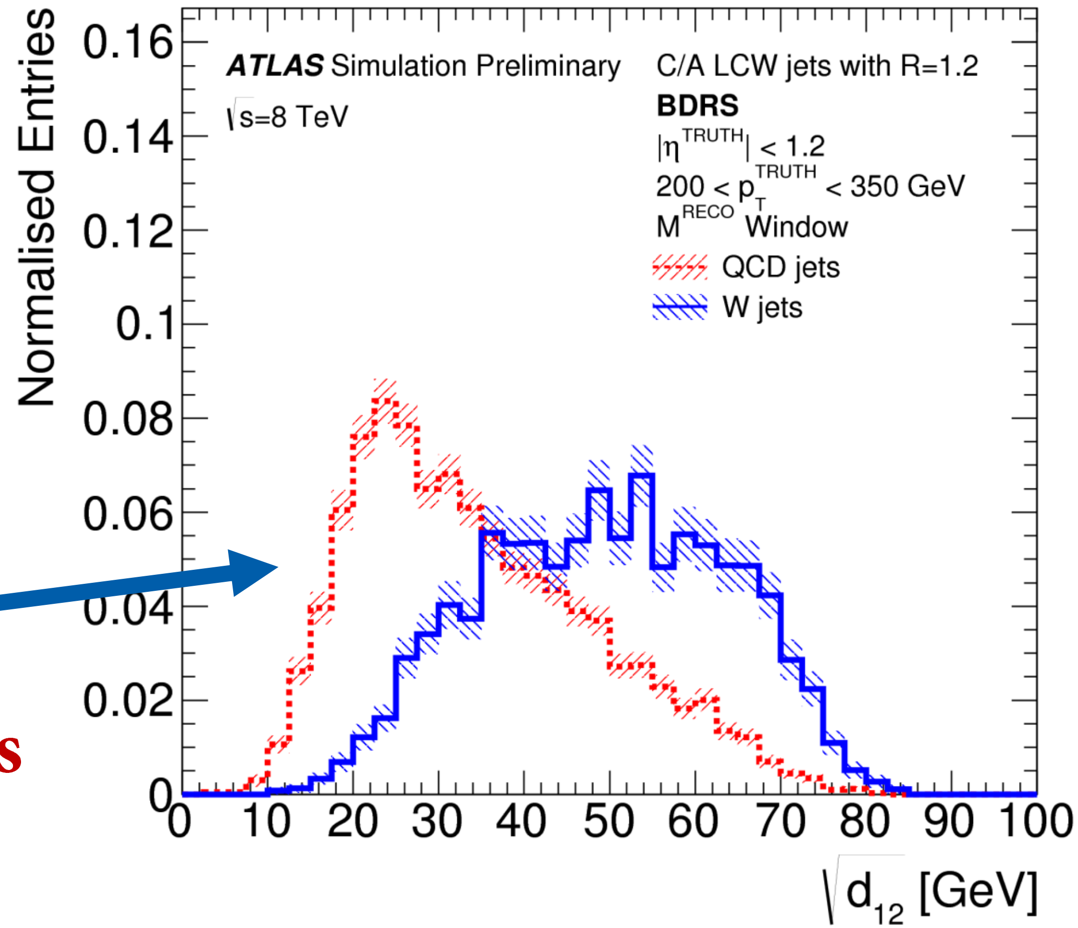
Fatjets



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)



Boson tagging

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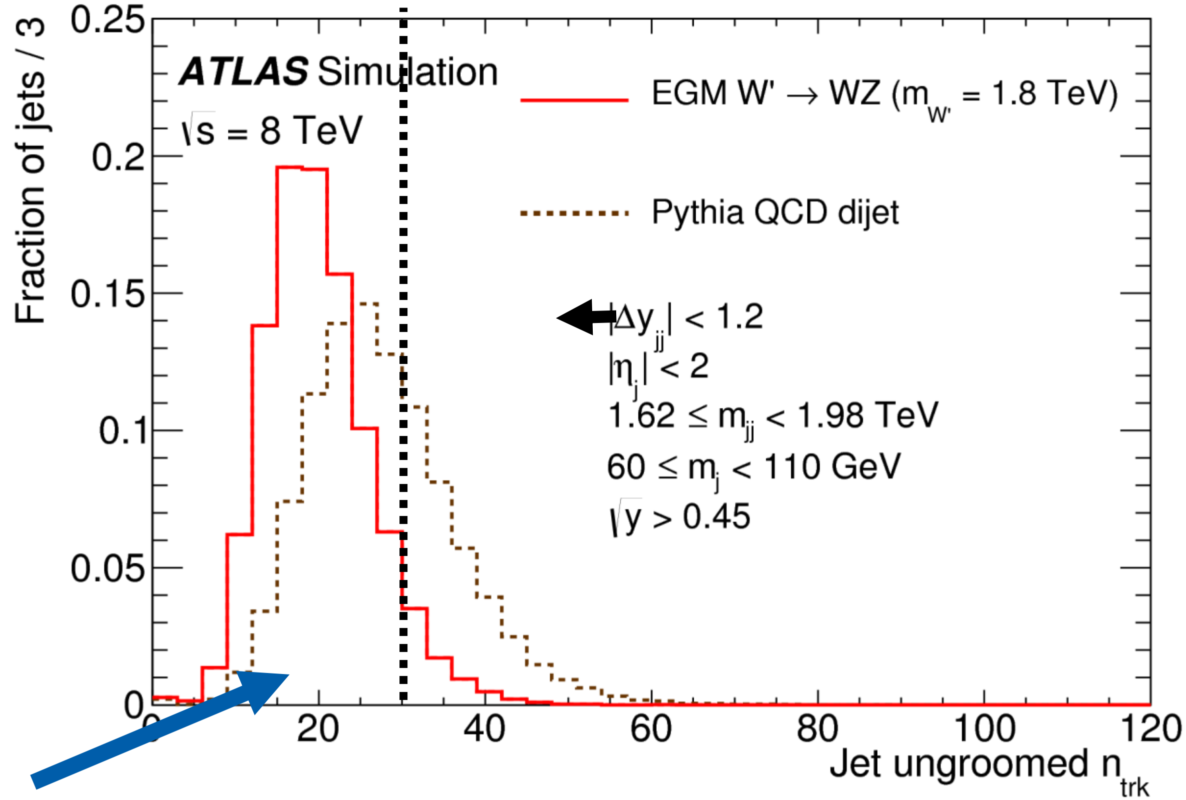
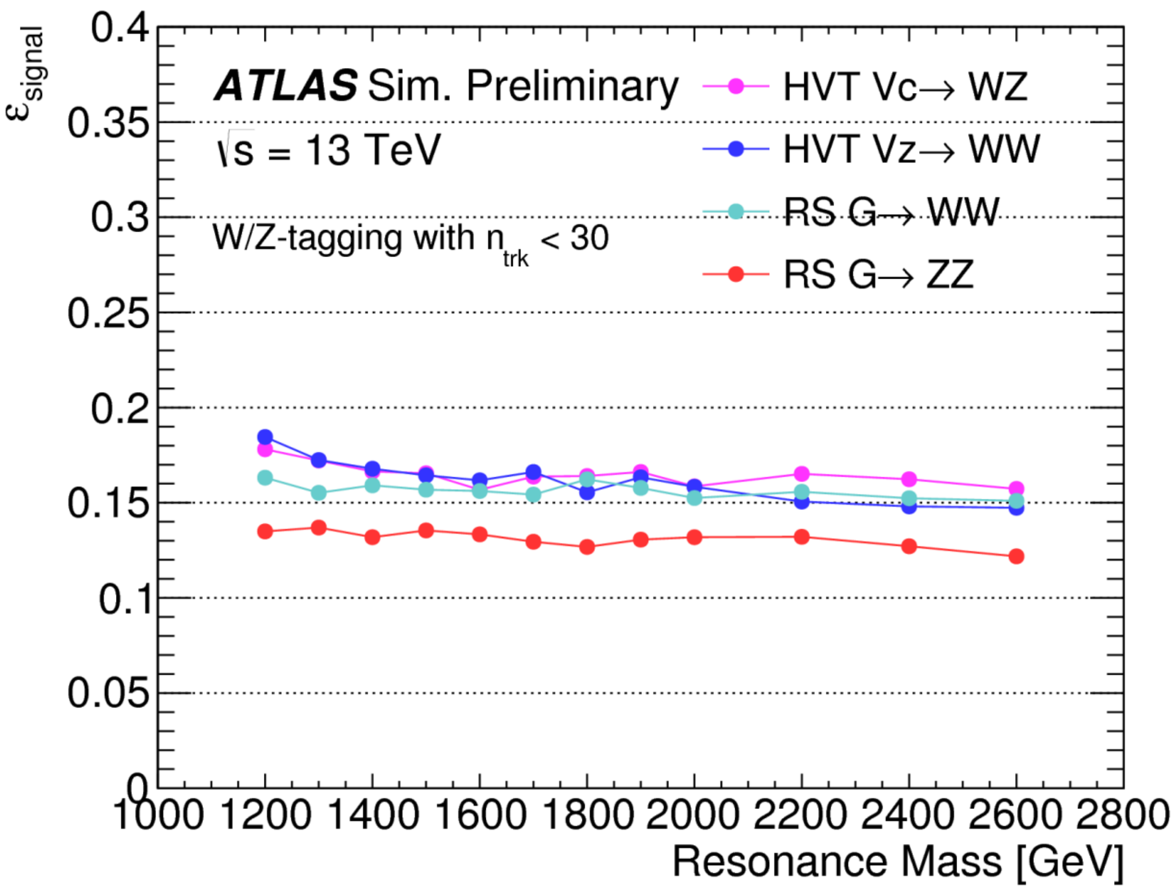


Cut on number of tracks in jet

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

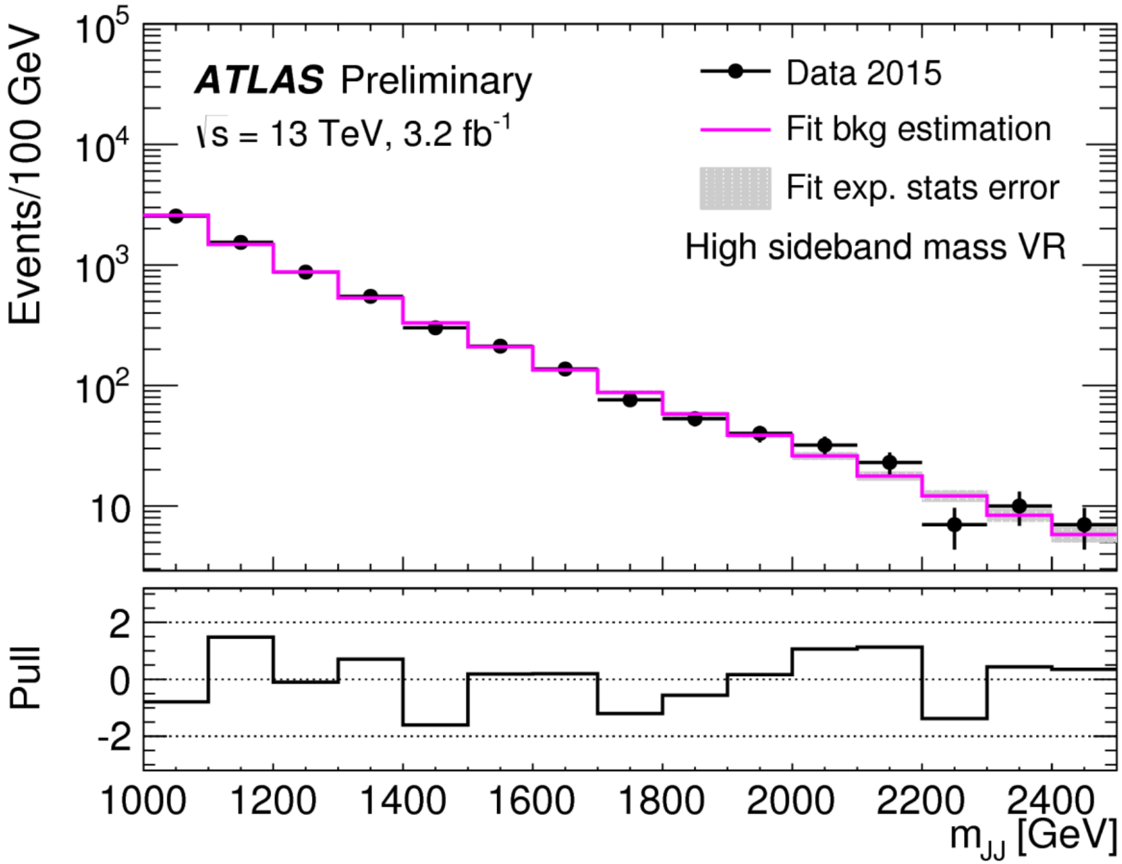
Signal efficiency

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



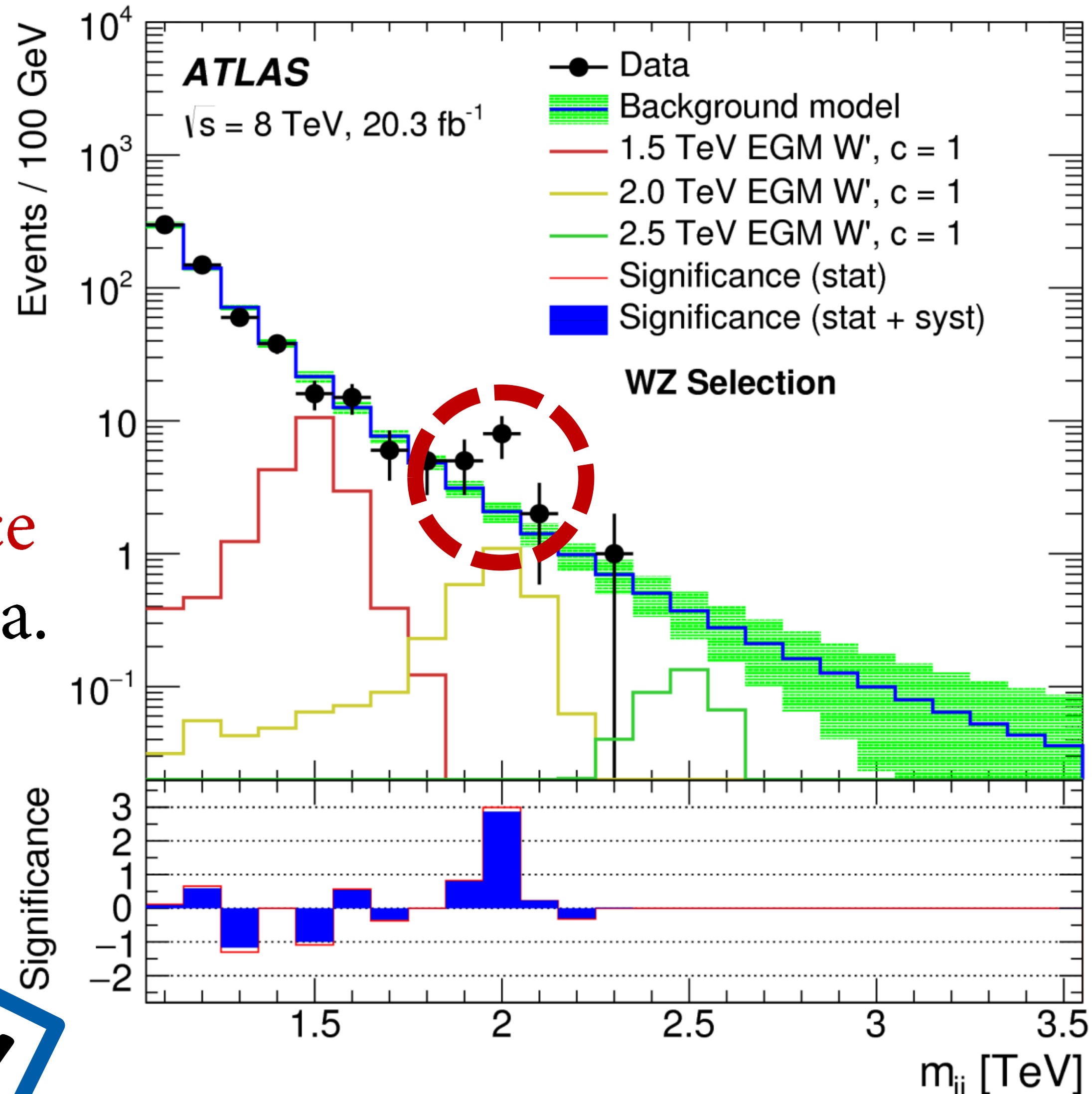
Control regions

- 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!

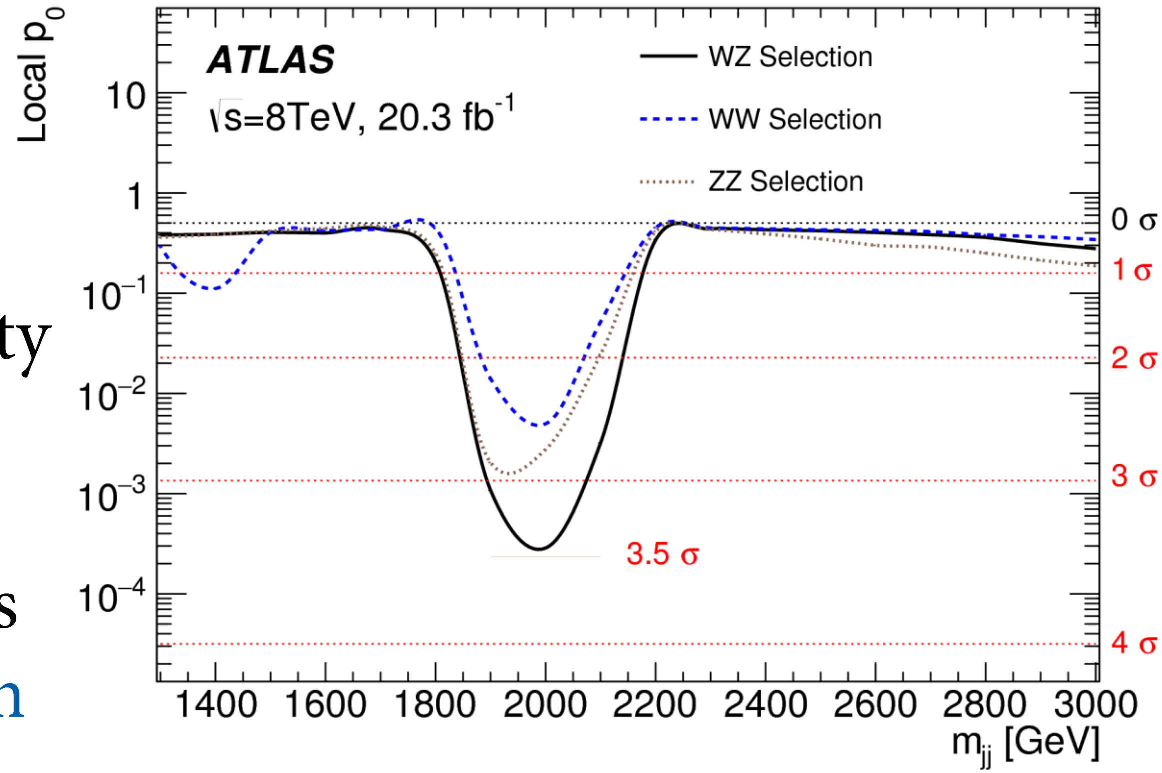
1. Finally, look at signal region
2. Fit background
3. Check for difference between fit and data.



Result from run 1!

Statistical treatment

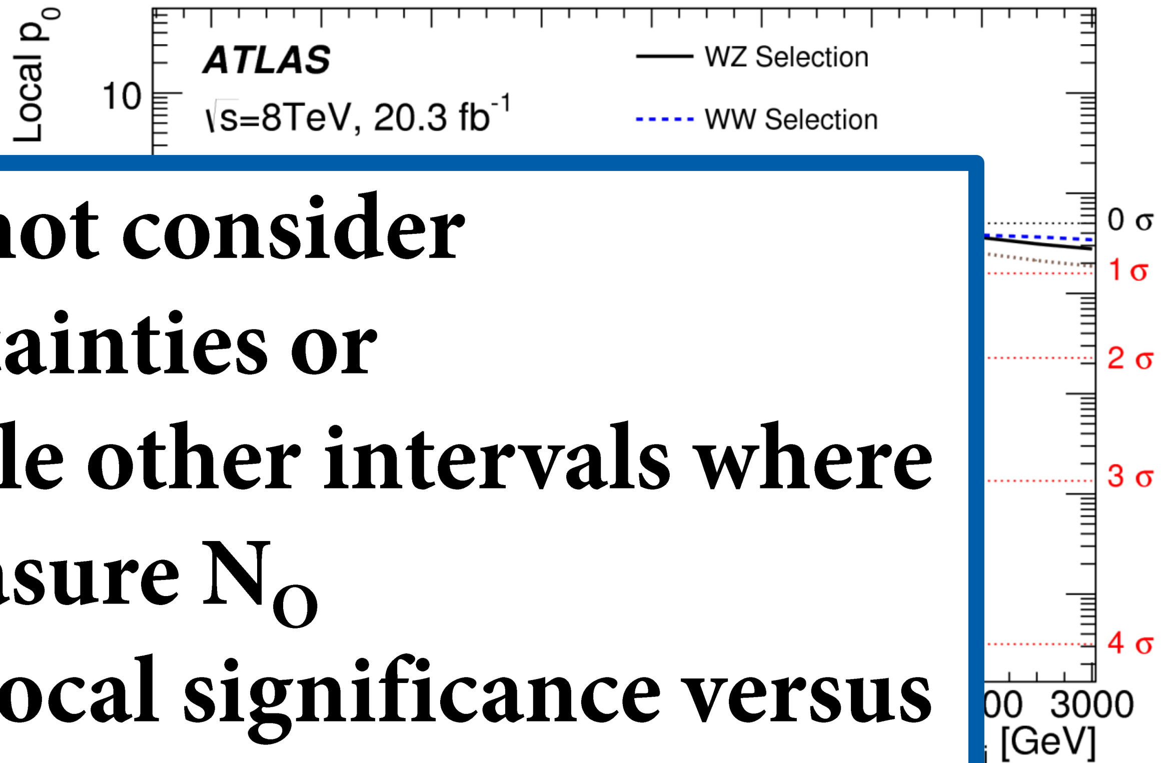
- Estimate of p-value/significance of observed events, assuming probability density for random variable
- Assume: N_O follows Poisson distribution



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

Statistical treatment

- Estimate of p-value/significance of ob… assu… dens… varia…
- Assu… Poiss…



- 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

$1\text{-}2\sigma$

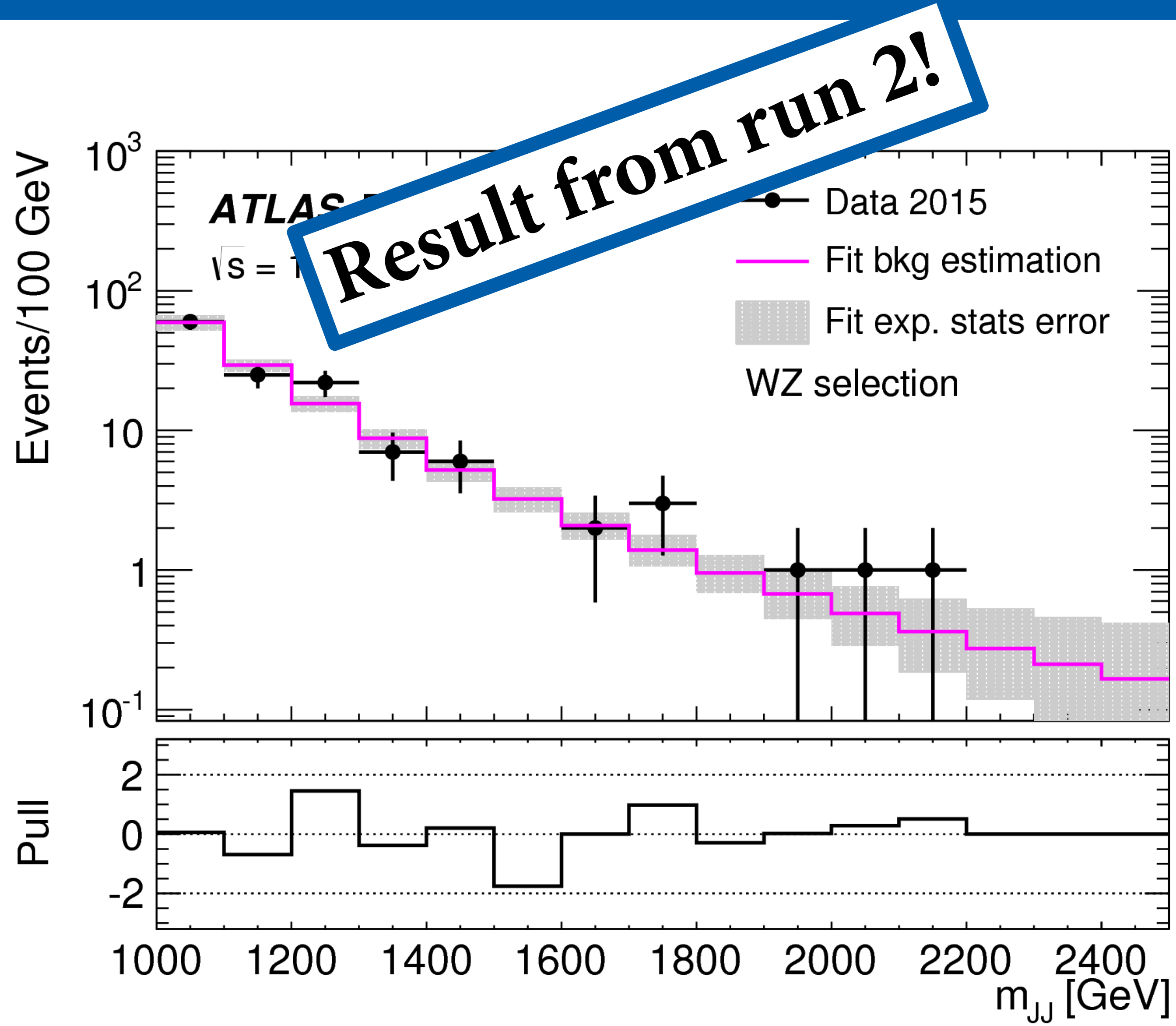
Statistical treatment

3σ

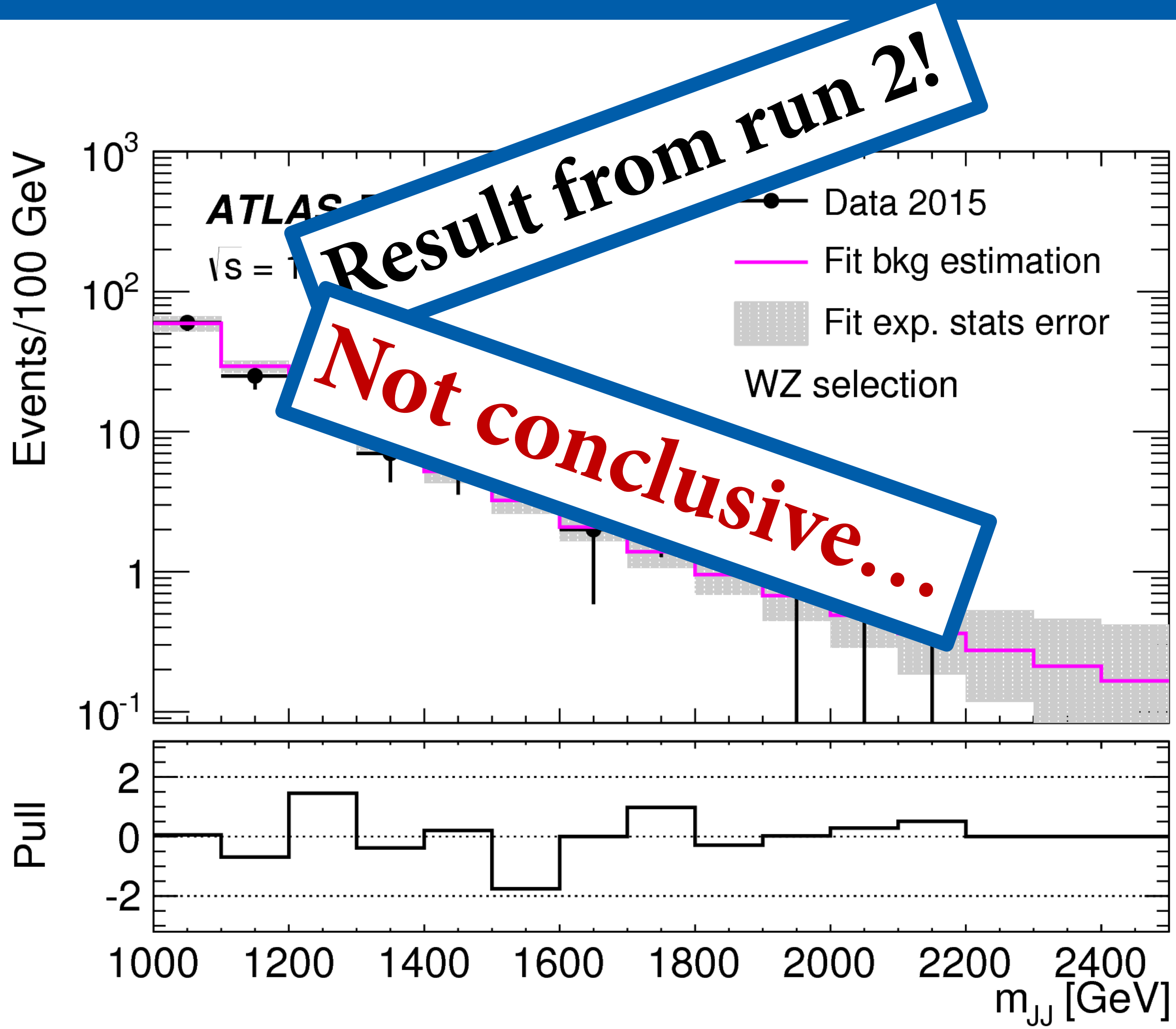
Statistical treatment

5σ

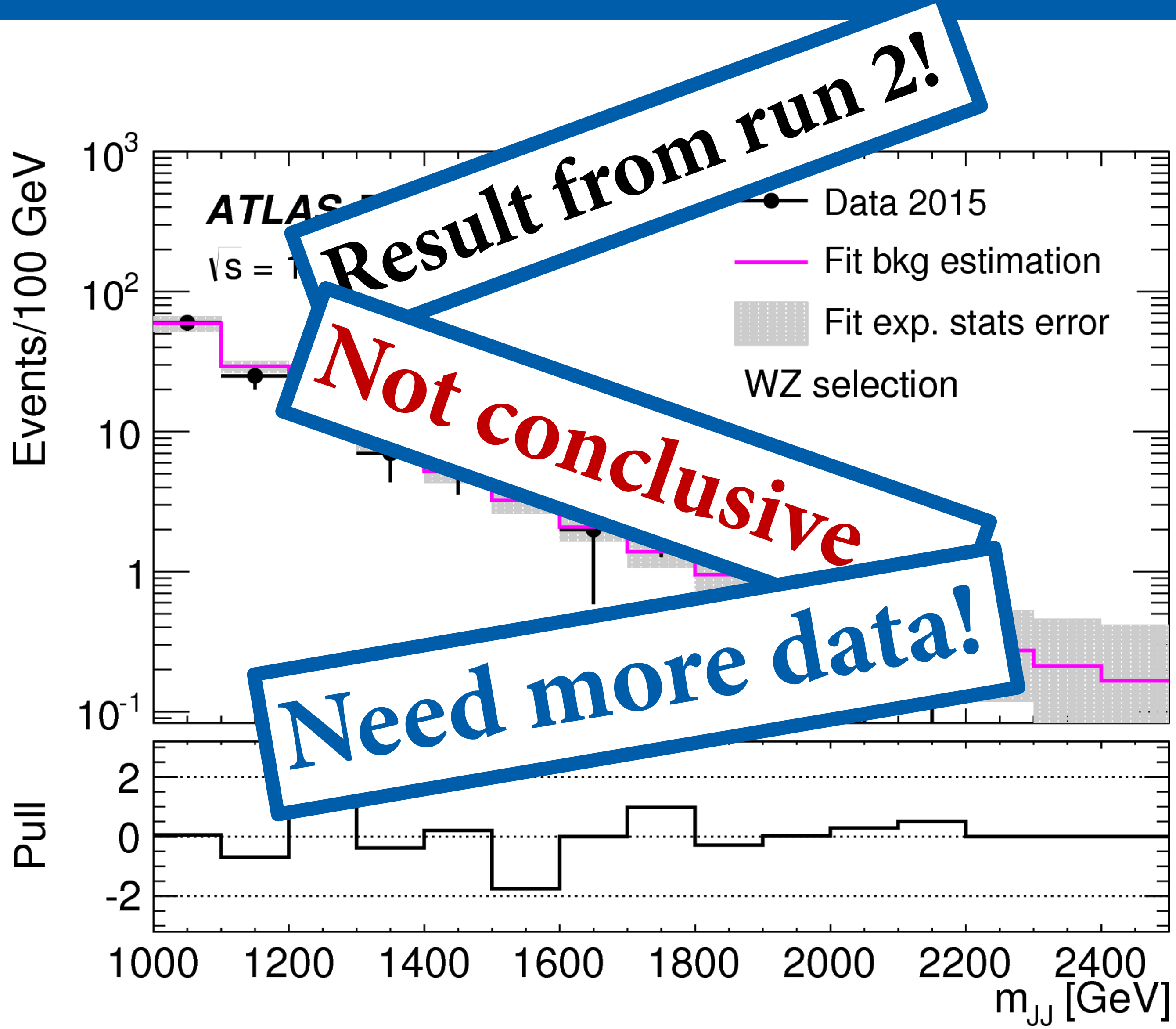
More Results!



More Results!



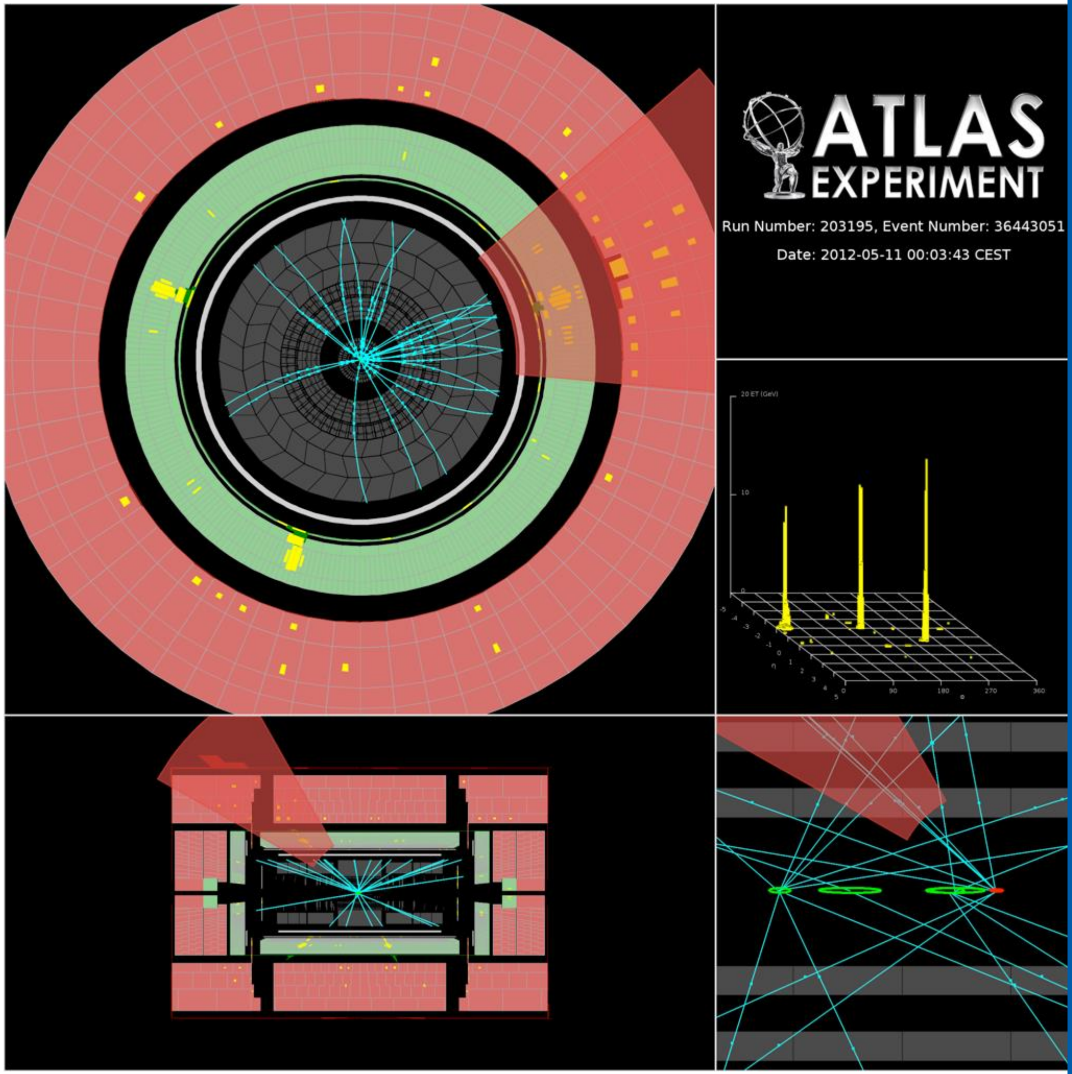
More Results!



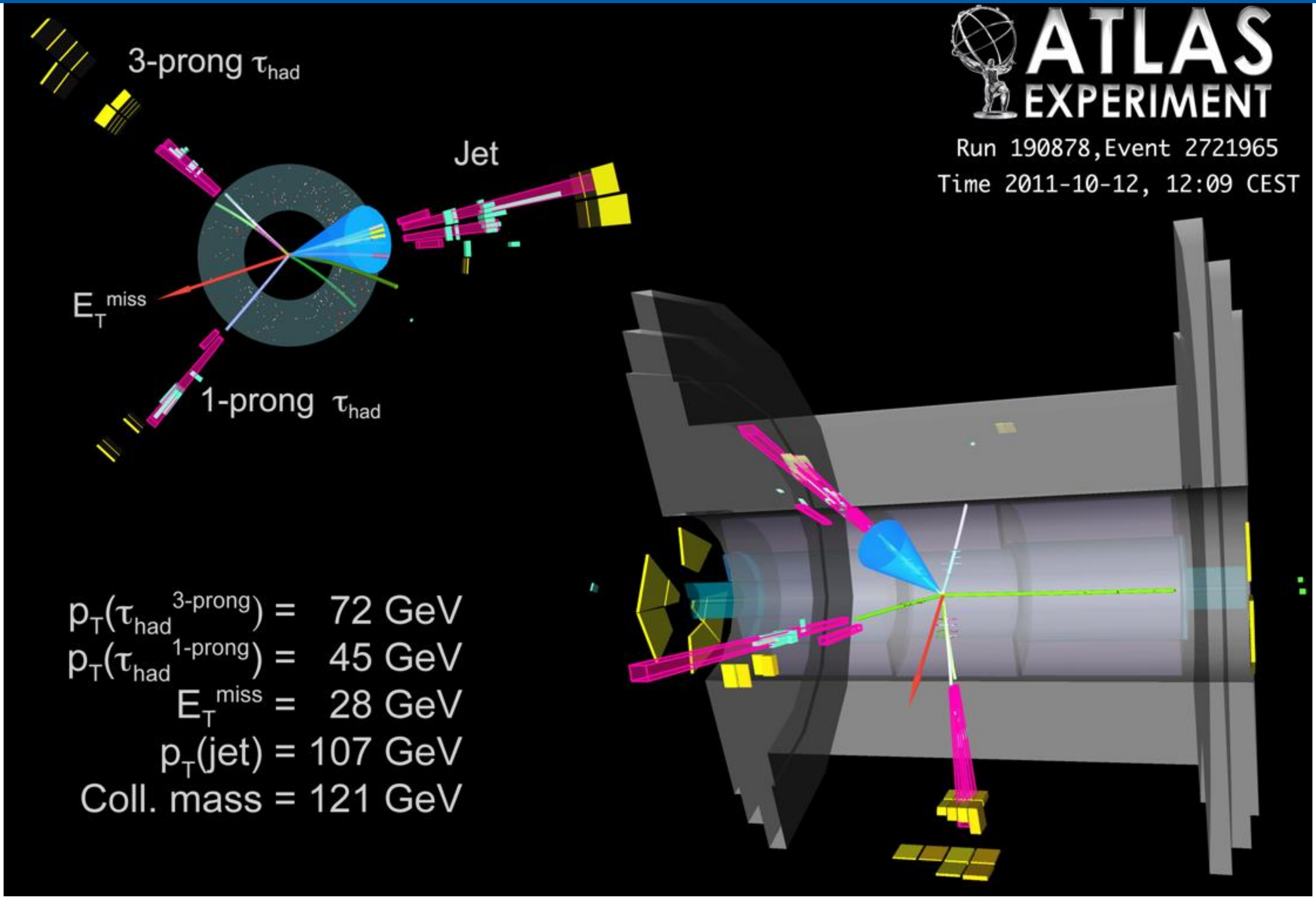
BACKUP

Photons

- Isolated EM deposit with no matching track in inner detector
- Different shower shape to an electron



Taus



- Essentially thin jets $\tau^+ \rightarrow \pi^+ \nu_\tau$ $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu_\tau$

Missing transverse energy

- Negative of vector sum of all energy deposits in the event projected onto the transverse plane