Searching for new physics with ATLAS
Rough guide to data analysis

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Teacher Program - 16th July 2019

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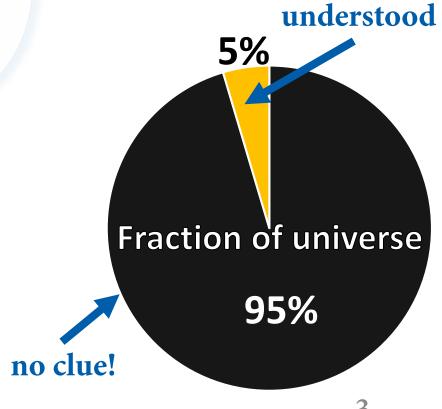- **Analysis – Boosted diboson search**
- ~~**Summary**~~ **Discussion**

- Ever wondered ..

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

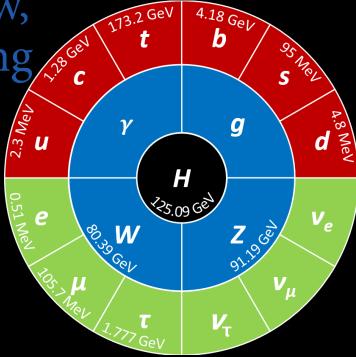 .. how was our universe created ?

  .. and what is it made of ?

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

Roughly understood

5%

Fraction of universe

95%

no clue!
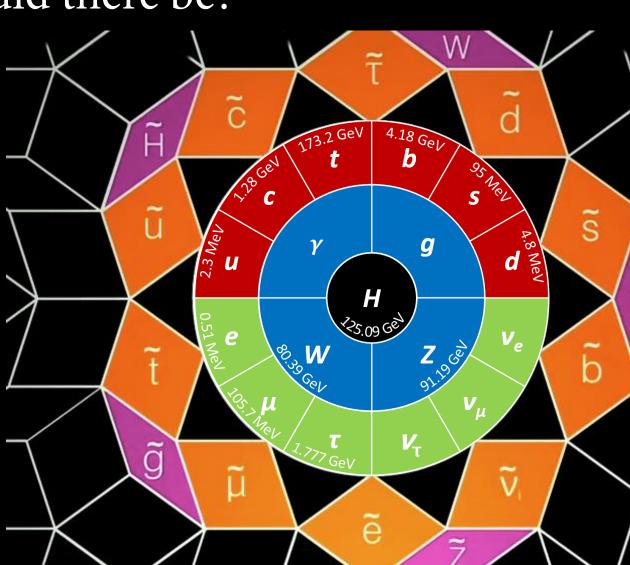
- What particles?

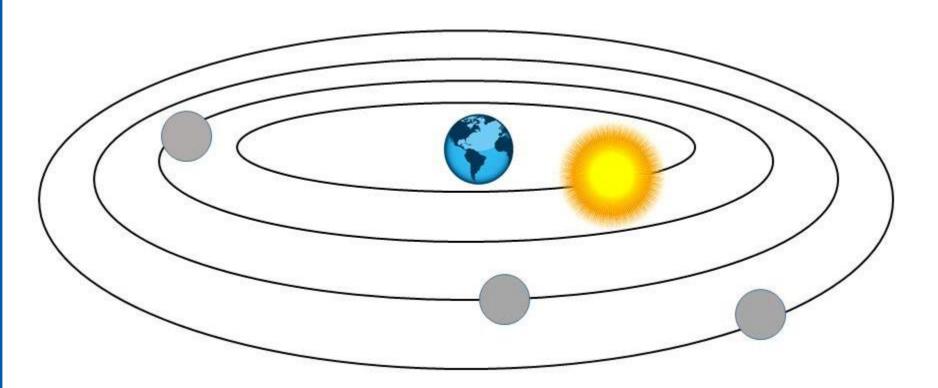- These particles we know, and they are the building block of the 5%

- What else could there be?

- Are these the 95% ?

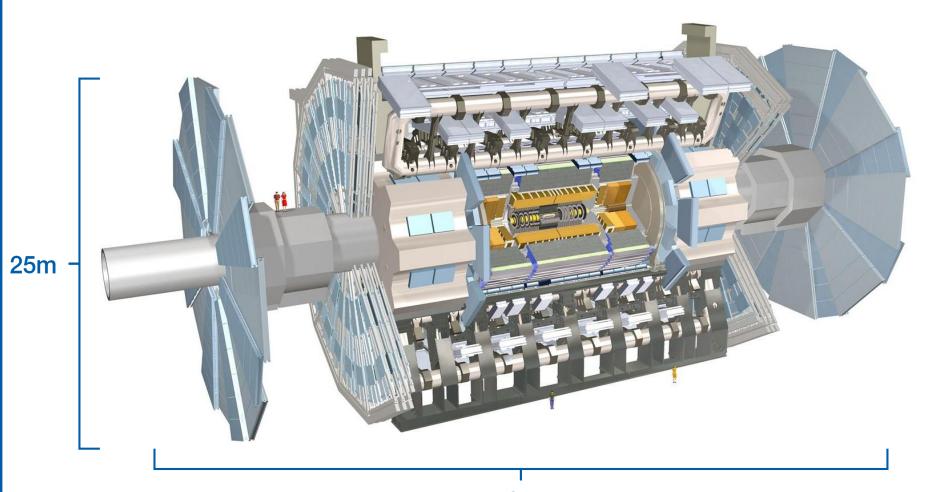- Sun goes around earth, earth around sun…
  sounds all the same to me.

Large Hadron Collider

CMS

LHCb

ALICE

ATLAS

My apartment

25m

46m

Physics Objects

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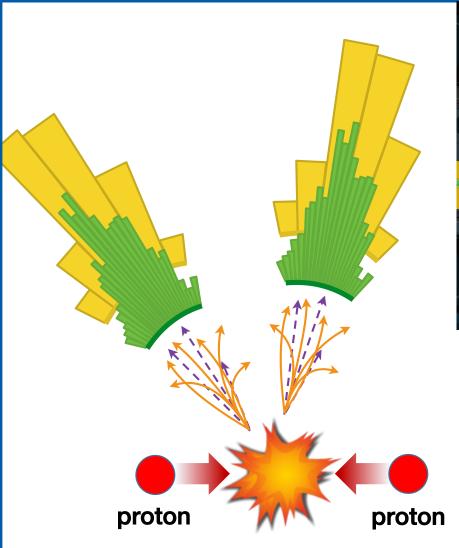
Hadronic Calorimeter

Electromagnetic Calorimeter

Solenoid magnet

Tracking {
Transition Radiation Tracker
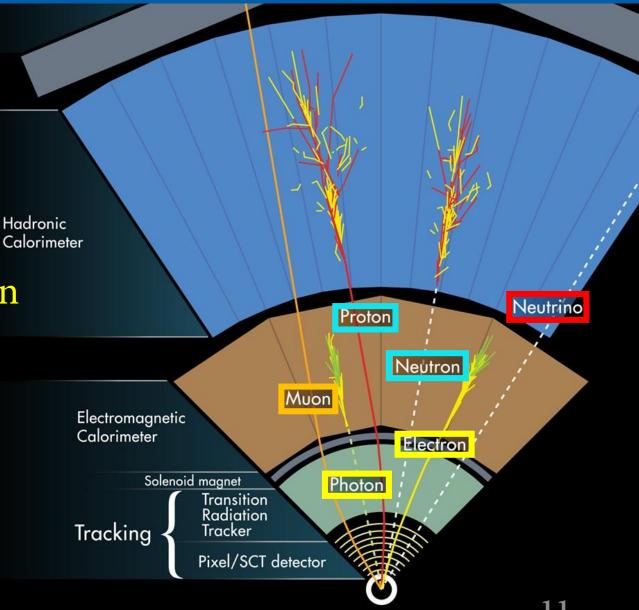Pixel/SCT detector
}

Proton

Neutron

Muon

Electron

Photon

Neutrino

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

Build from:
- Jets
- Tracks
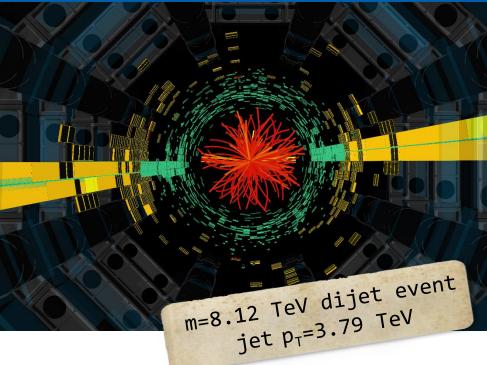
Hadronic Calorimeter

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Transition Radiation Tracker

Tracking

Pixel/SCT detector

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m=8.12 TeV dijet event
jet p_T=3.79 TeV

- **Newly opened energy regime: $\sqrt{s} = 13$ TeV.**
- **Invariant mass**
$$m = \sqrt{\left(\sum E\right)^2 - \left\|\sum p\right\|^2}.$$

something new? X

proton   proton

m=8.12 TeV dijet event
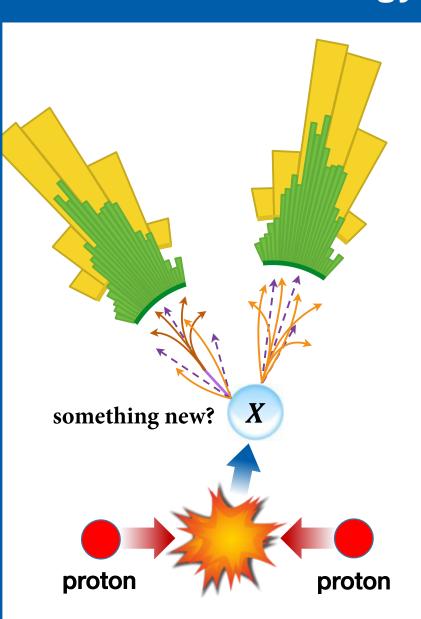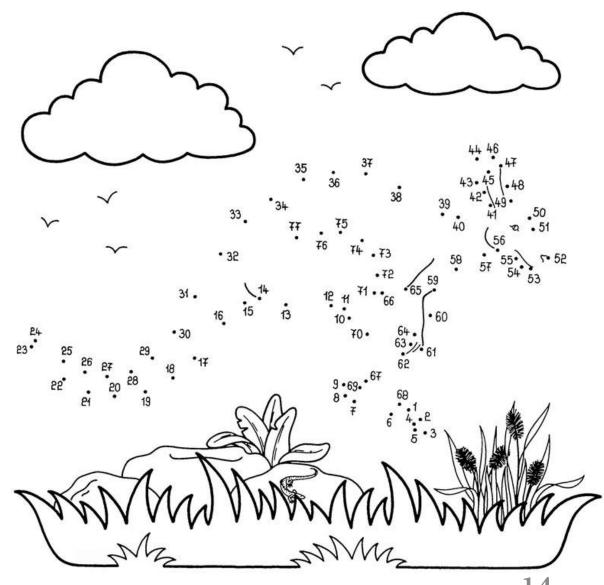jet p_T=3.79 TeV

- **Newly opened energy regime: $\sqrt{s} = 13$ TeV.**
- **Invariant mass**
  $$m = \sqrt{(\sum E)^2 - \|\sum p\|^2}.$$

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- Nowadays finding particle tracks is like this ..

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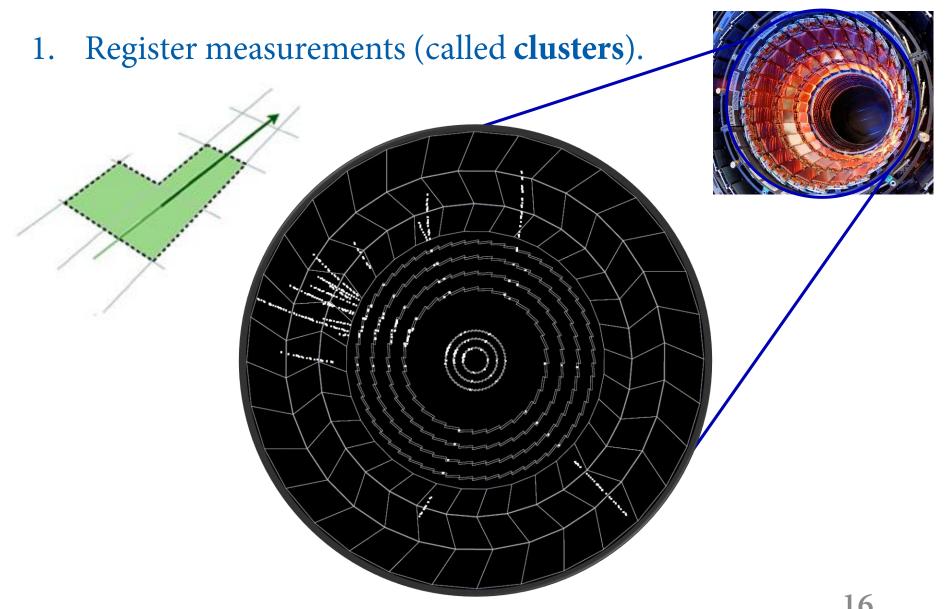
- Nowadays finding particle tracks is like this ..

- But without the numbers!
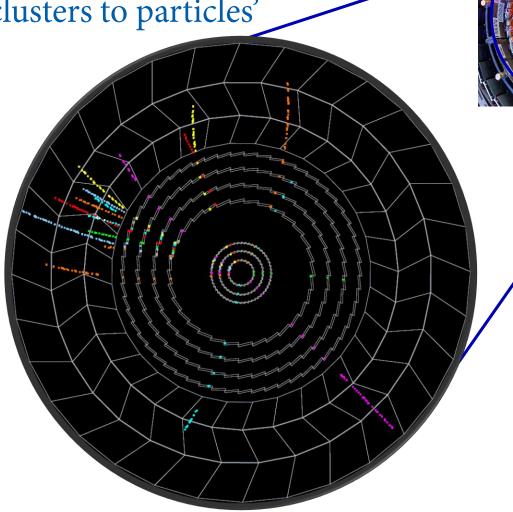
1. Register measurements (called **clusters**).

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2. Associate clusters to particles' tracks.

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3. Fit particles trajectory.

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How it looks in reality →
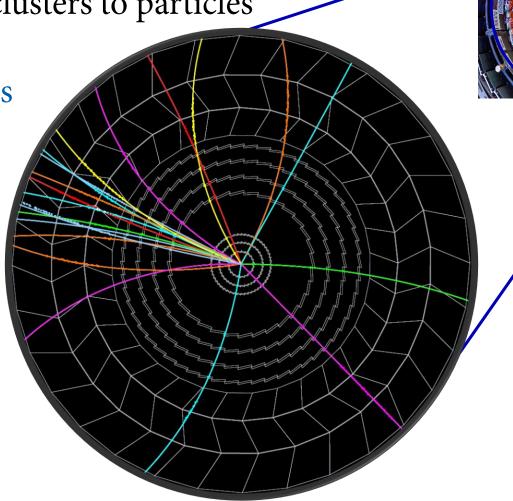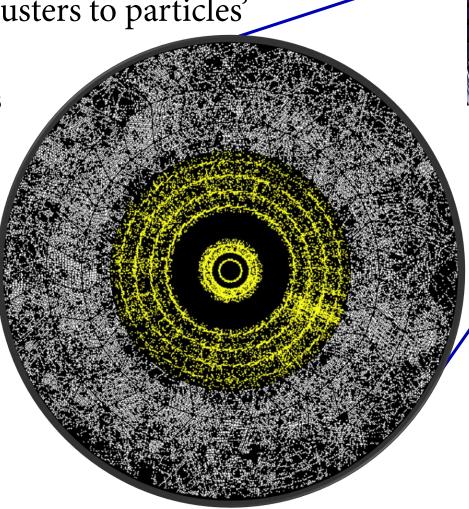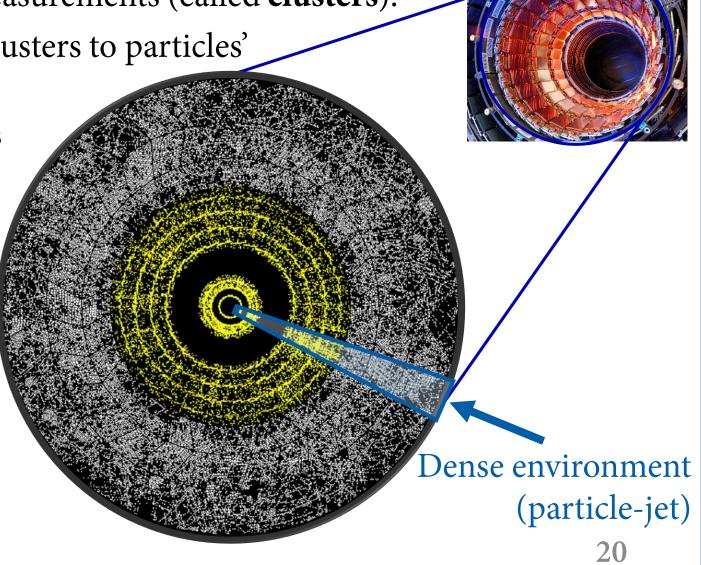
1. Register measurements (called **clusters**).

2. Associate clusters to particles' tracks.

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Dense environment (particle-jet)
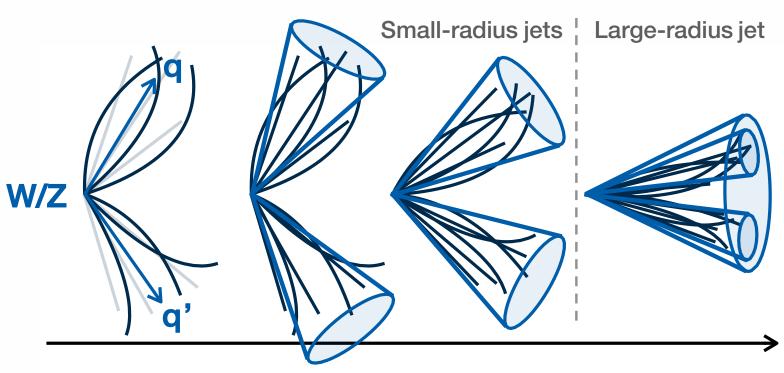
Example Analysis

1. Collect data : Detector, trigger, DAQ

2. Reconstruction of physics objects

3. Simulation : Generate events, detector simulation

Fatjets

Small-radius jets | Large-radius jet

W/Z q q'
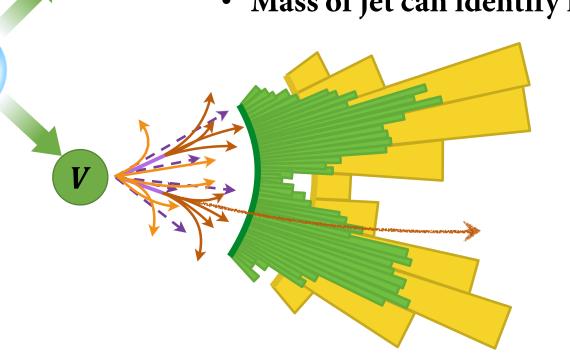
Boosted jets: Increasing transverse momentum, p_T

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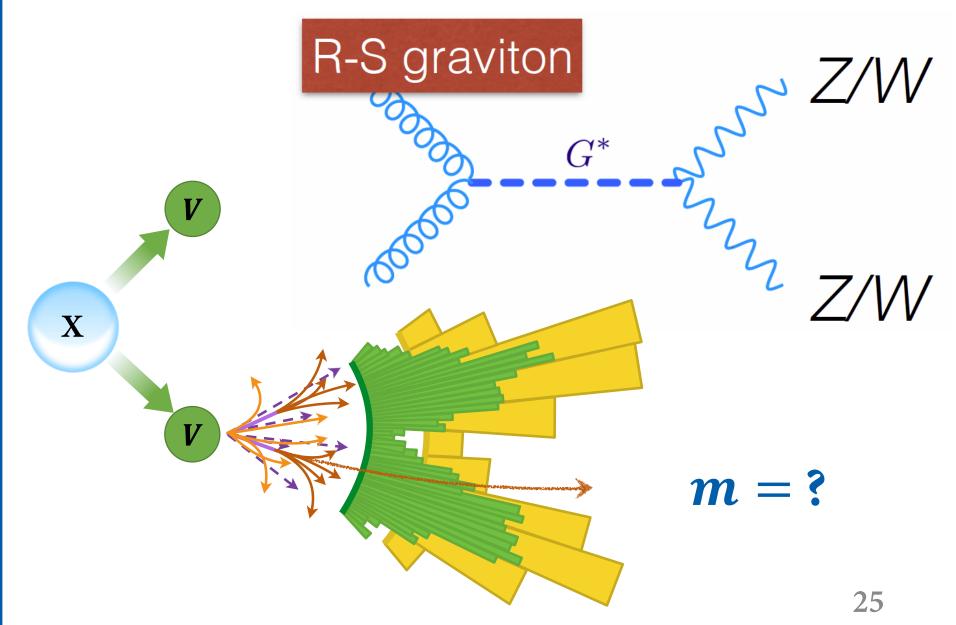
- **Heavy (>1 TeV) resonances to pairs of vector bosons ($V = W/Z$) predicted by several extensions of the SM.**

- **$V \rightarrow$ quark-pair decays most abundant.**
  ➔ Great probe for new physics!

- **Mass of jet can identify initiating particle.**

$$m = ?$$

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R-S graviton

Z/W

G^*

Z/W

V

X

V

$m = ?$

R-S graviton

G^*

Z/W

Z/W

V

X

$m = ?$
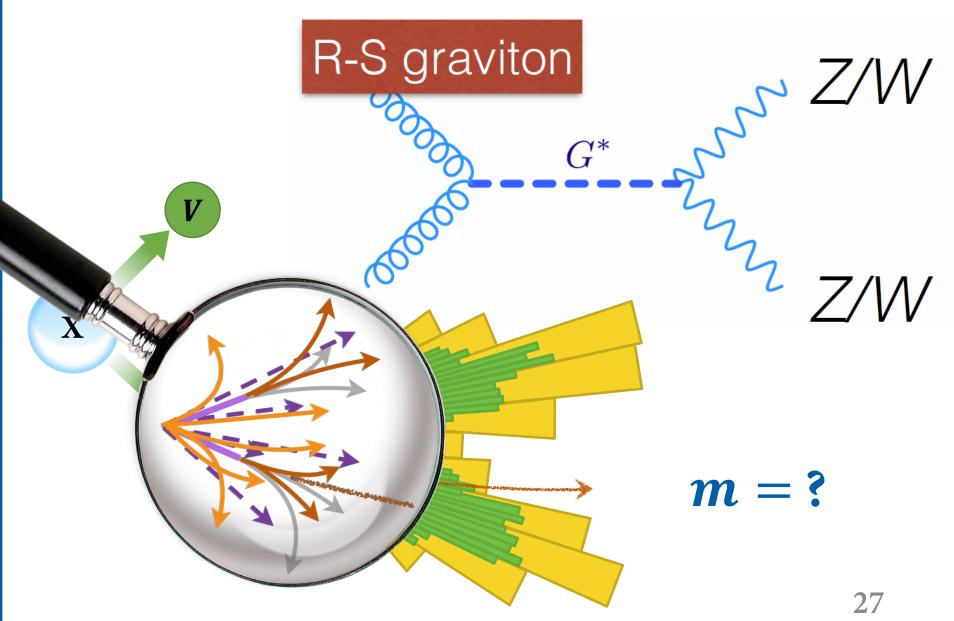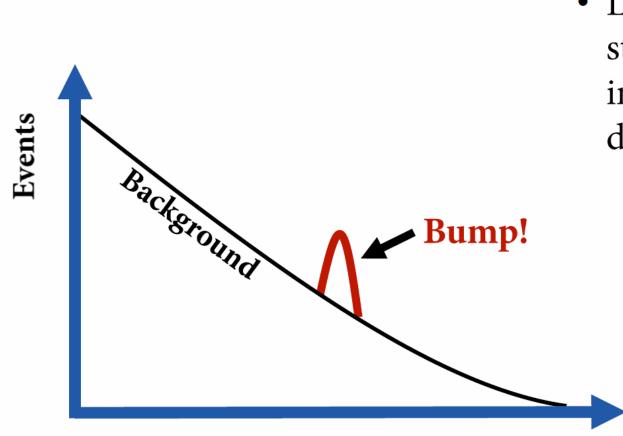
Boosted diboson search strategy
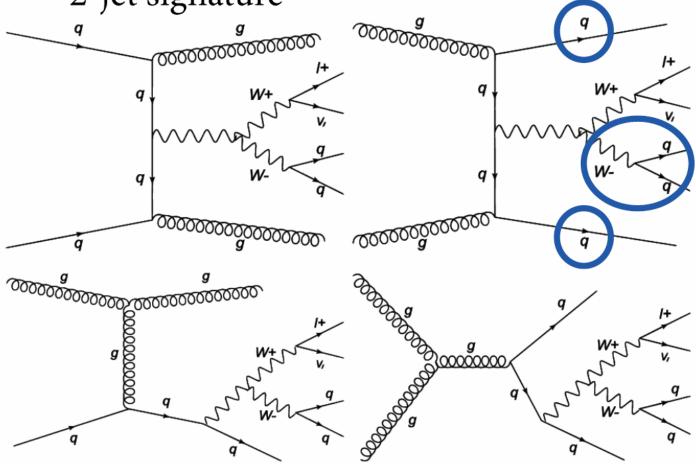
- Look for bump in steeply falling invariant mass distribution.

Invariant mass$= \sqrt{(\sum E)^2 - \|\sum p\|^2}$

Main background:

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

How to measure a cross-section

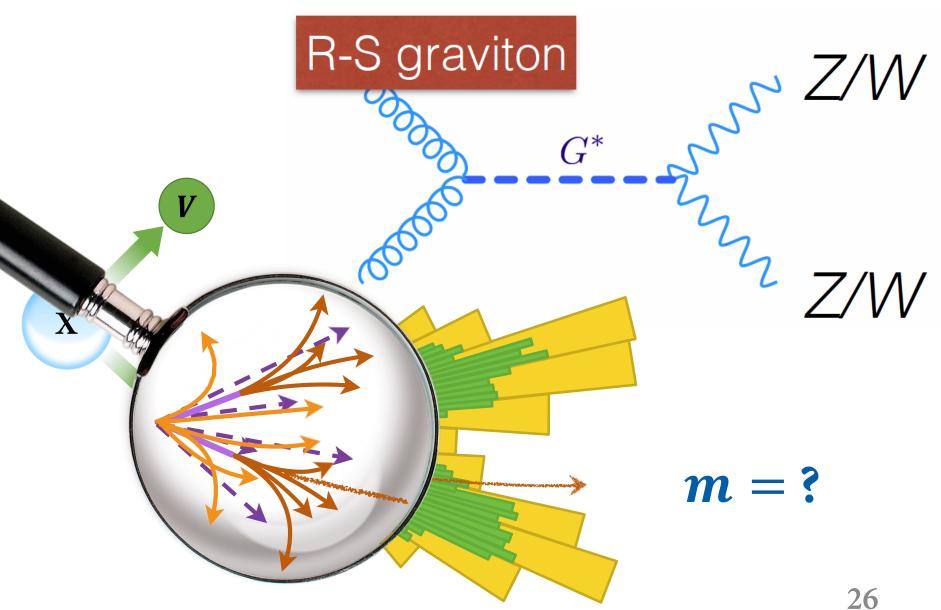- Cross section $$\sigma = \frac{N}{\mathcal{L}} \longrightarrow \sigma = \frac{N_{obs} - N_{bkg}}{\mathcal{L} \cdot \epsilon \cdot A \cdot \mathcal{B}}$$

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)
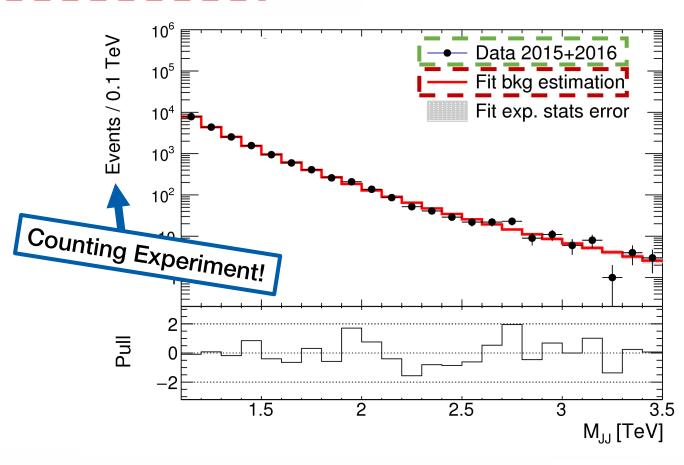
How to measure a cross-section

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

Counting Experiment!

Legend:
- Data 2015+2016
- Fit bkg estimation
- Fit exp. stats error
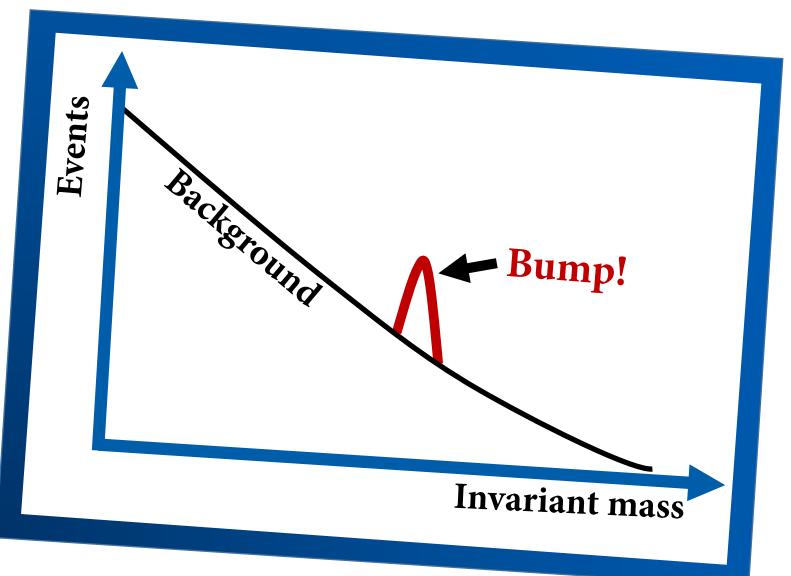
Axes: Events / 0.1 TeV, Pull, M_{JJ} [TeV]
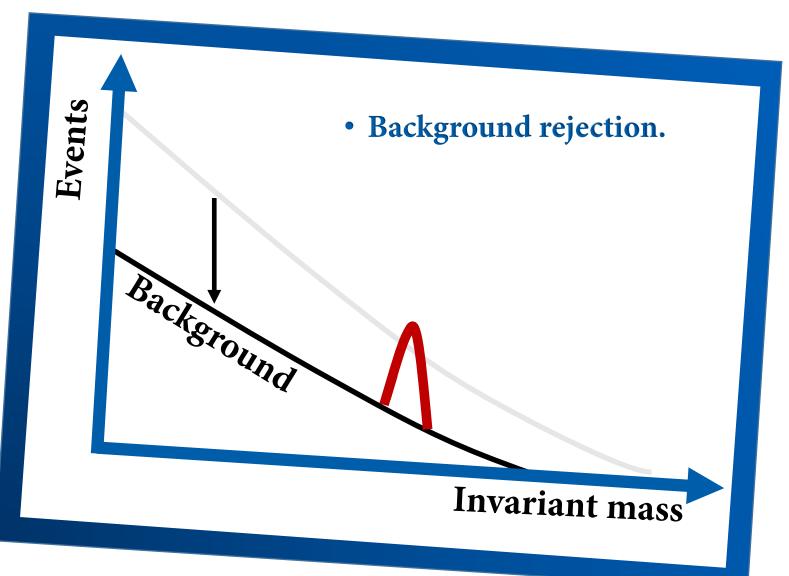
$$\sigma = \frac{N_{obs} - N_{bkg}}{\mathcal{L} \cdot \epsilon \cdot A \cdot \mathcal{B}}$$

- 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.

- **Background rejection.**

- **Signal acceptance.**

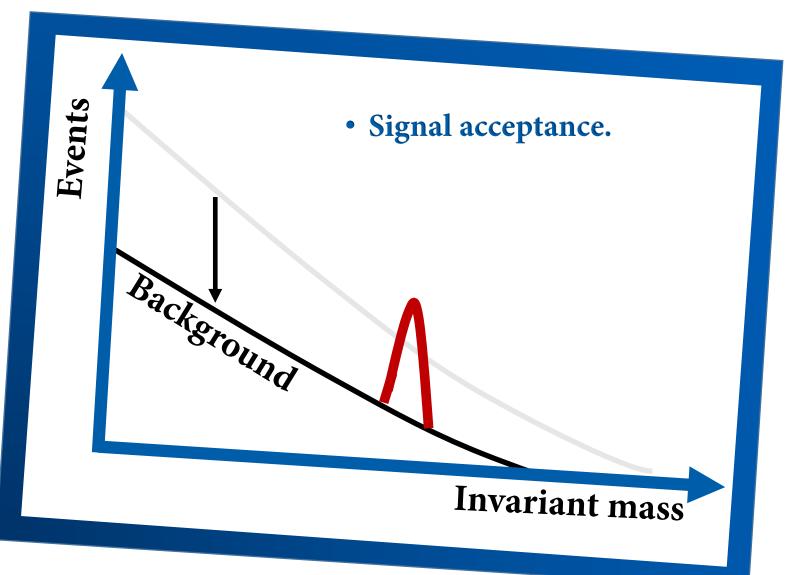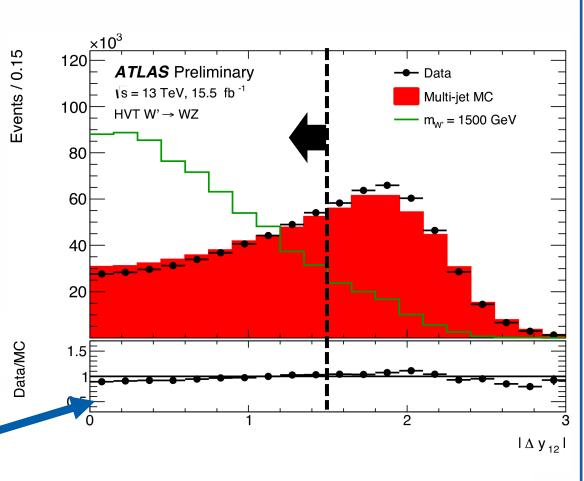- Try to **maximize fraction of signal events versus background** events.
- One example is the use of **kinematic cuts**.

Cut on separation of two jets in rapidity
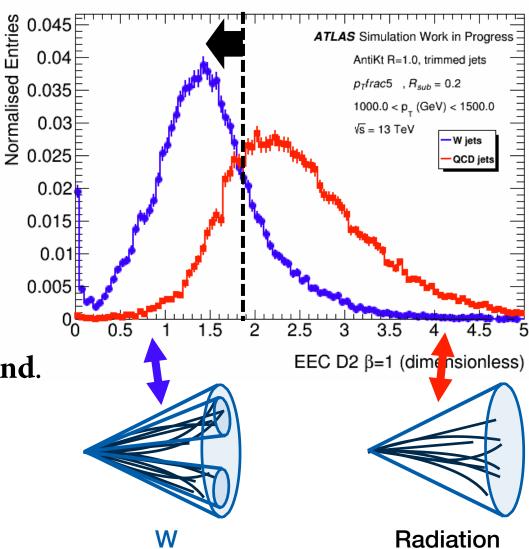
- Utilize different properties of jets from W/Z-bosons with respect to the background to "tag" them.
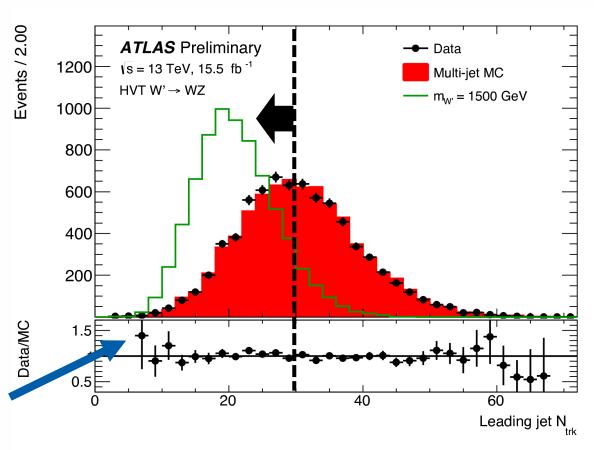
- „2-prong" for **signal**, „1-prong" for **background**.

ATLAS Simulation Work in Progress
AntiKt R=1.0, trimmed jets
$p_T frac5$, $R_{sub} = 0.2$
$1000.0 < p_T$ (GeV) < 1500.0
$\sqrt{s} = 13$ TeV

W jets
QCD jets

EEC D2 β=1 (dimensionless)

W

Radiation

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

Cut on number of tracks in jet
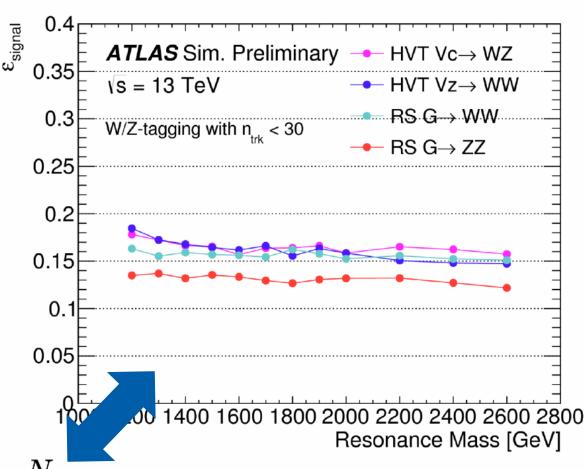
- Selection on jet mass: require to be at W/Z mass!

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

$$\varepsilon \cdot A = \frac{N_{Selected}}{N_{All}}$$

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

ATLAS Sim. Preliminary
$\sqrt{s}$ = 13 TeV
W/Z-tagging with $n_{trk} < 30$

— HVT Vc → WZ
— HVT Vz → WW
— RS G → WW
— RS G → ZZ

ε_{signal} vs Resonance Mass [GeV]

- **Fit background using parametric function:** $\dfrac{dn}{dx} = p_1(1-x)^{p_2 - \xi p_3} x^{-p_3}$

  $x = \dfrac{m_{JJ}}{13\,\text{TeV}}$, ξ decorrelation factor

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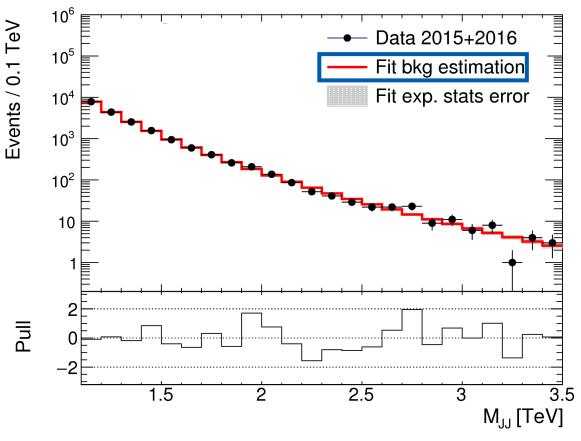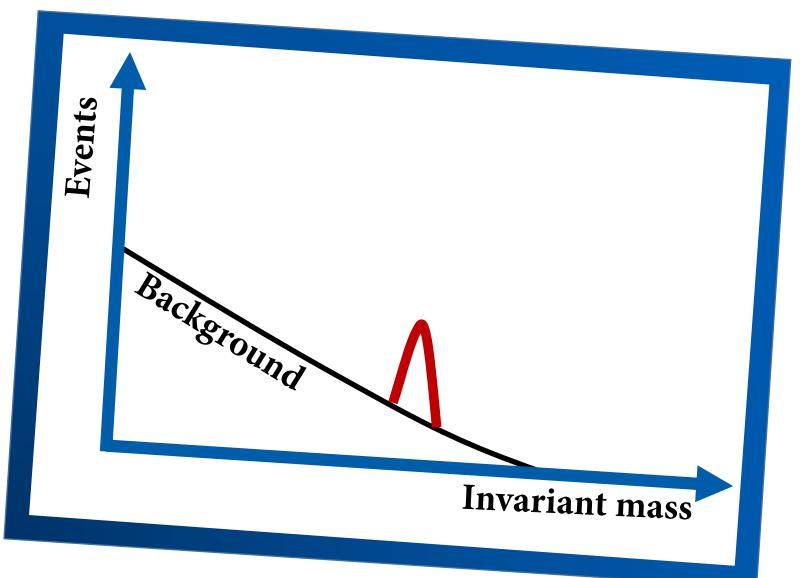
Statistical Uncertainties

- 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
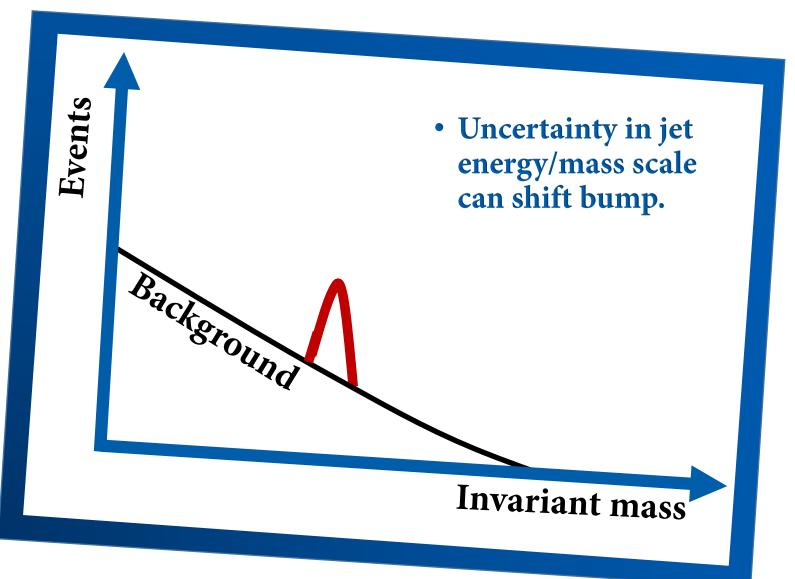
- Arise from uncertainties associated with the measurement apparatus

- 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?

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

Events

Background

Invariant mass

- **Uncertainty in jet energy/mass resolution change bump's width.**
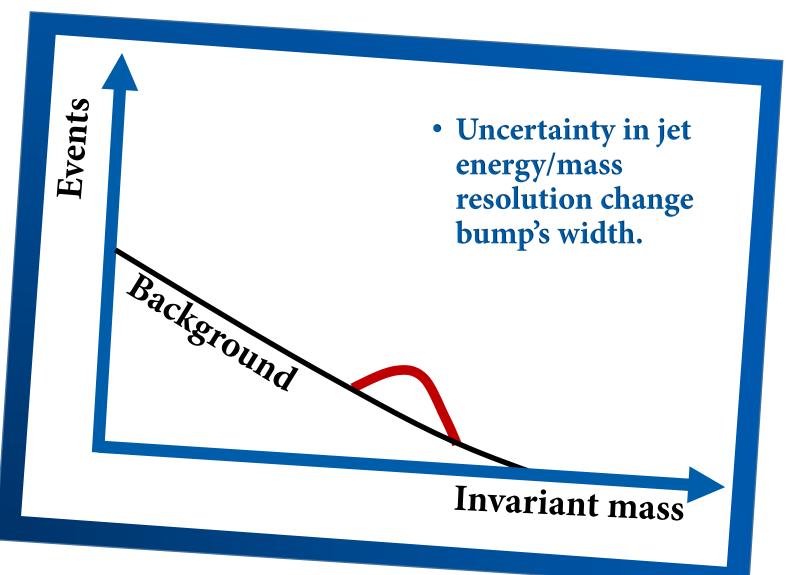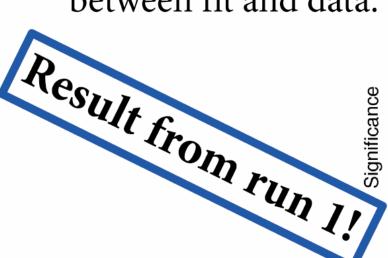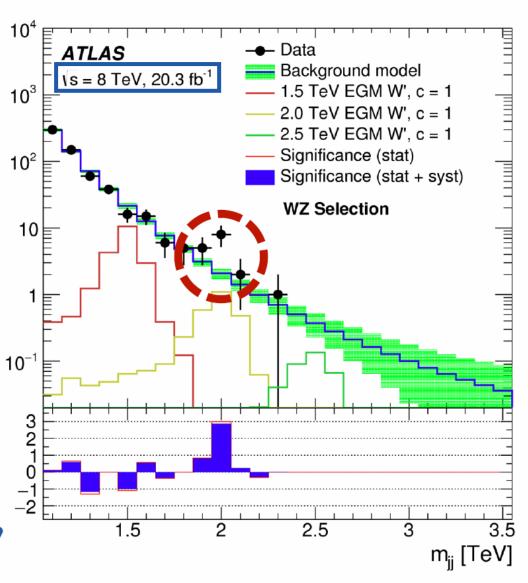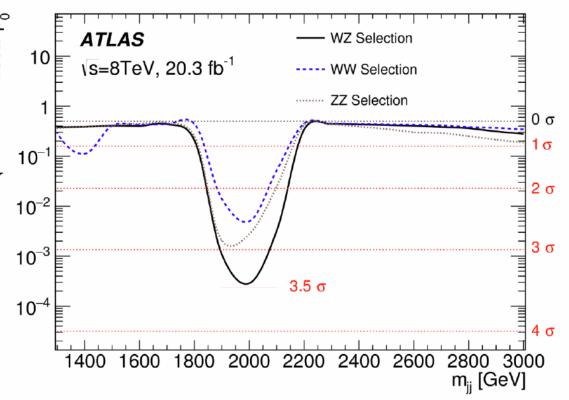
1. Finally, look at signal region

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

ATLAS
$\sqrt{s}$=8TeV, 20.3 fb^{-1}

— WZ Selection
-- WW Selection
⋯ ZZ Selection

Local p_0

3.5 σ

m_{jj} [GeV]

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

- Estimate of p-value/significance of ob... assu... dens... varia...

- Assu... Poiss...

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

- **Does not consider uncertainties or**

- **possible other intervals where to measure N_O**

→ **local significance versus global significance**

Local p_0

ATLAS
$\sqrt{s}=8\text{TeV}, 20.3\text{ fb}^{-1}$

— WZ Selection

···· WW Selection

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0 σ
1 σ
2 σ
3 σ
4 σ

00 3000
[GeV]

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$$1\text{-}2\sigma$$

Statistical treatment

$$3\sigma$$

5σ
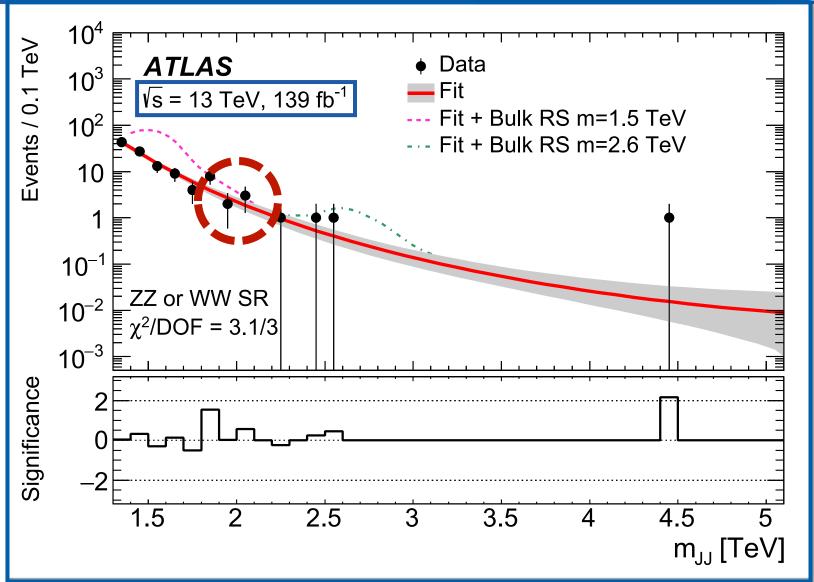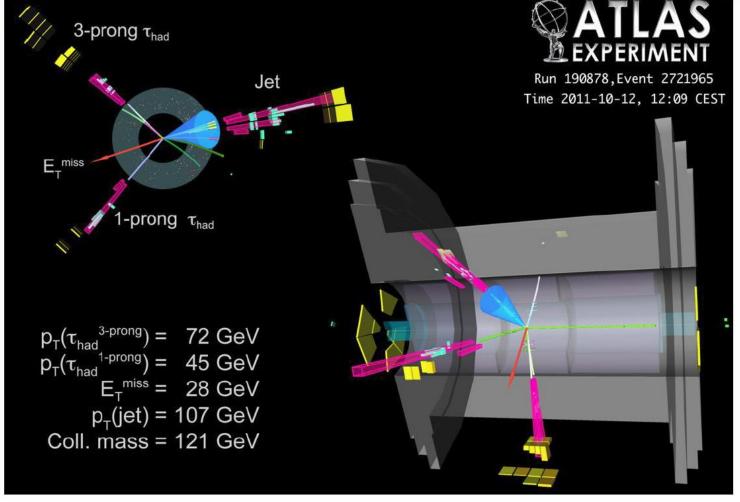
Thank you – Discussion!

BACKUP

3-prong τ_{had}

Jet

ATLAS EXPERIMENT

Run 190878, Event 2721965
Time 2011-10-12, 12:09 CEST

E_T^{miss}

1-prong τ_{had}

$p_T(\tau_{had}^{3\text{-}prong}) = 72$ GeV
$p_T(\tau_{had}^{1\text{-}prong}) = 45$ GeV
$E_T^{miss} = 28$ GeV
$p_T(jet) = 107$ GeV
Coll. mass = 121 GeV

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