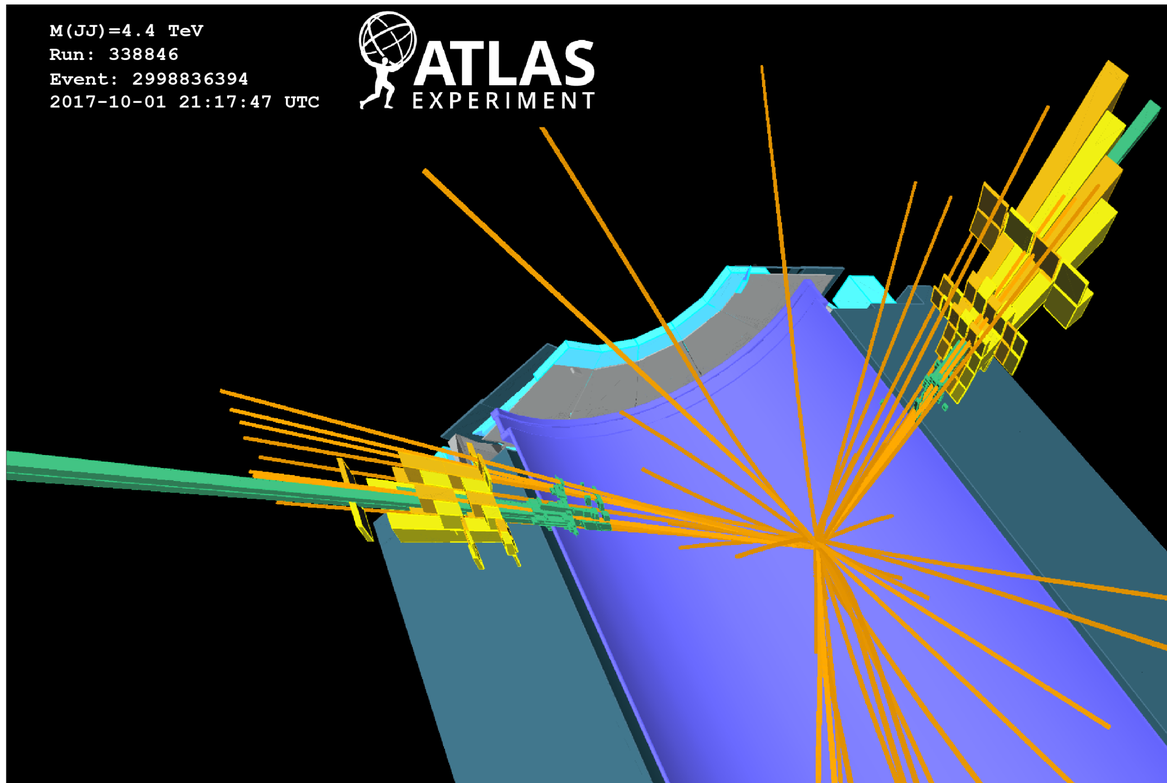
Searching for new physics using W & Z bosons

Dylan van Arneman

NNV (astro)particle physics fall meeting
November 2023



University of Amsterdam
Institute of Physics

Overview

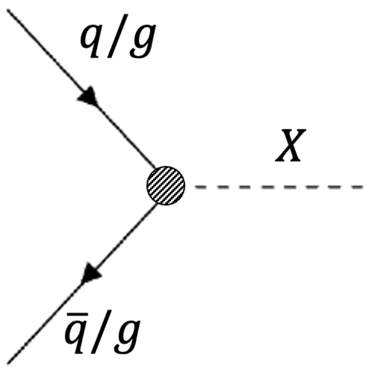
Two main parts:

- General introduction and overview of the analysis
- My main contribution: the background estimation

Part I: Resonance search overview

Heavy resonance searches

- Searching for the resonant production of some new heavy (~TeV) particle



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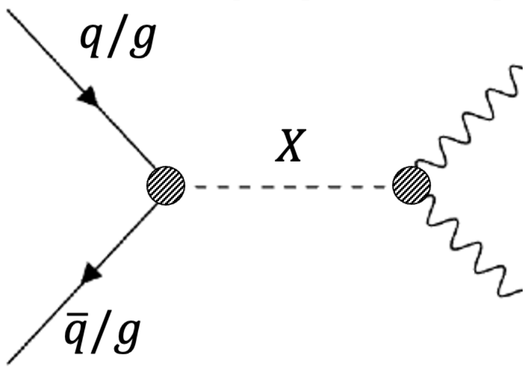

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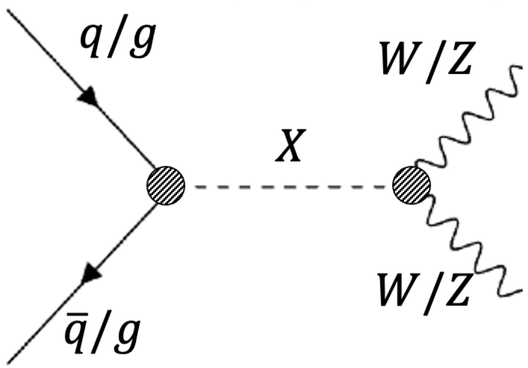

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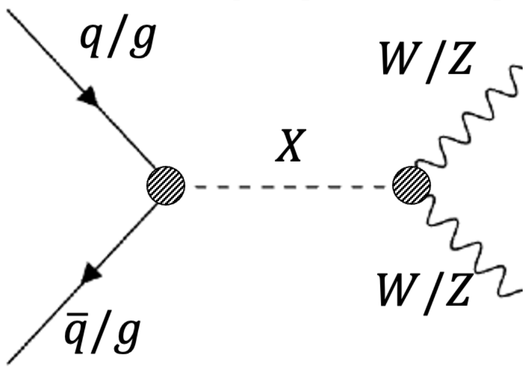

Why dibosons?

- As spin-1 particles, pairs of EW bosons have a wide range of possible interactions
  - ➡ Pairs of V-bosons can interact with new particle *X* of spin-0 (Radion), spin-1 (HVT) or spin-2 (RS Graviton)

Diboson searches

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- I study the *fully hadronic* channel
  - ➡ Jargon: "jet" → a quark or gluon that hadronizes into a cone of more hadrons

Diboson searches: fully hadronic

Why a fully hadronic final state?

- Want to study diboson interactions at the highest possible energy scale
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W → $q\bar{q}$ 67.6%
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Major challenge:

- Lots of *QCD multijet* background in this channel

Jets coming from different (SM) processes

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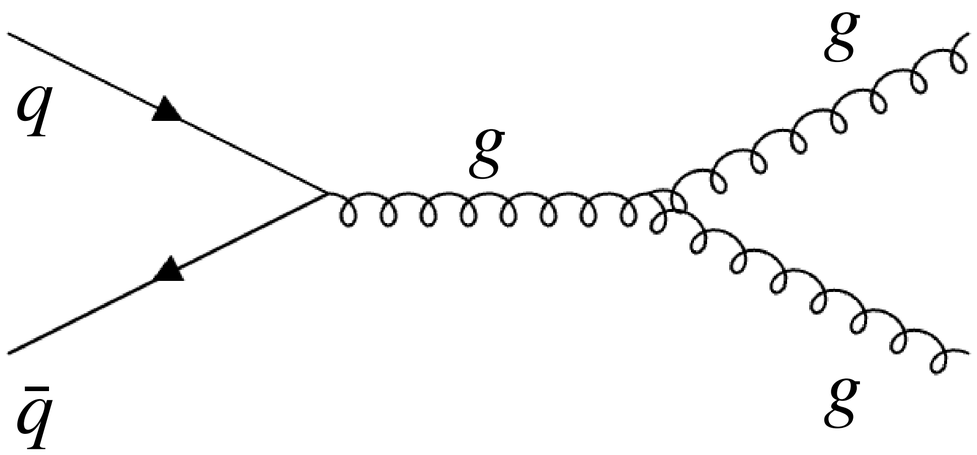
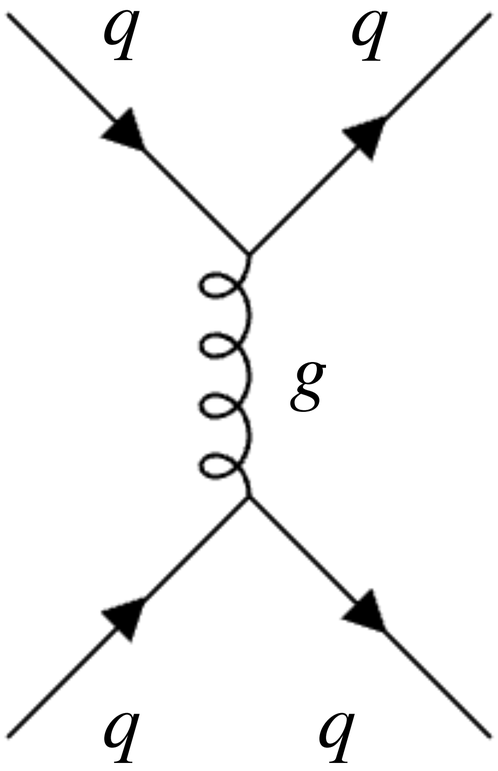
- Two examples:





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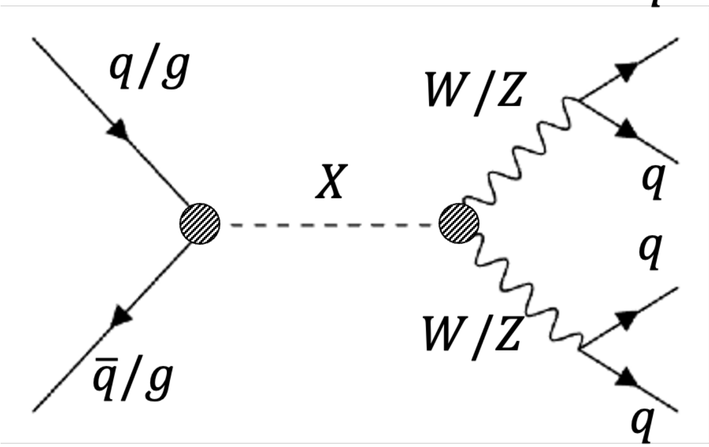
NOT INTERESTING
(for us 😊)

Diboson searches: fully hadronic

- The signal: some heavy particle *X* decays into *two V-bosons* which each decay into a pair of quarks



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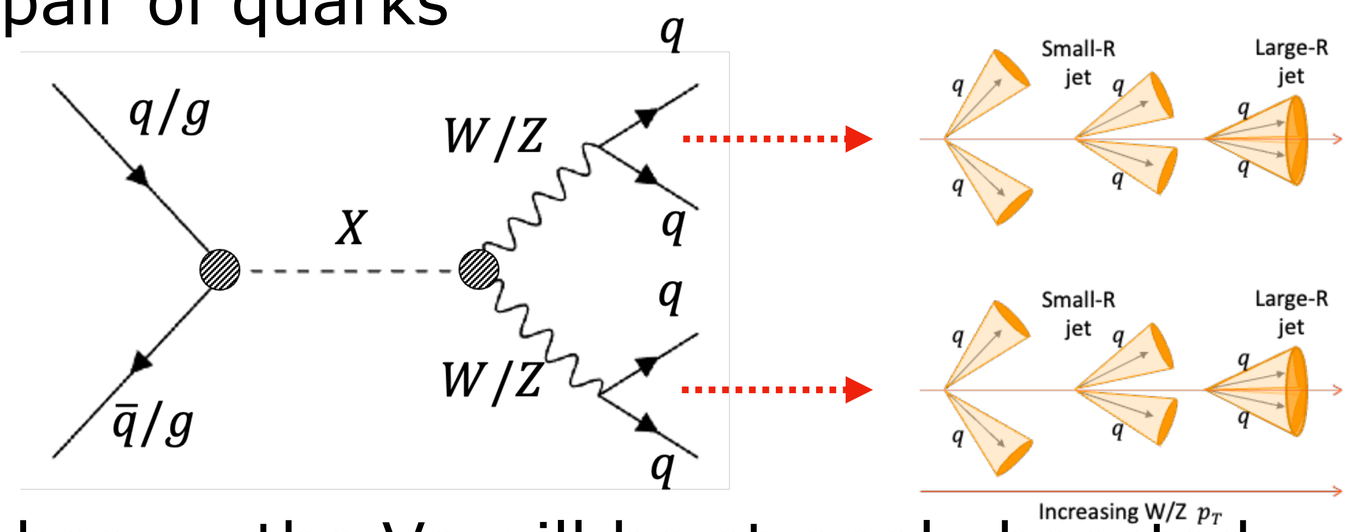
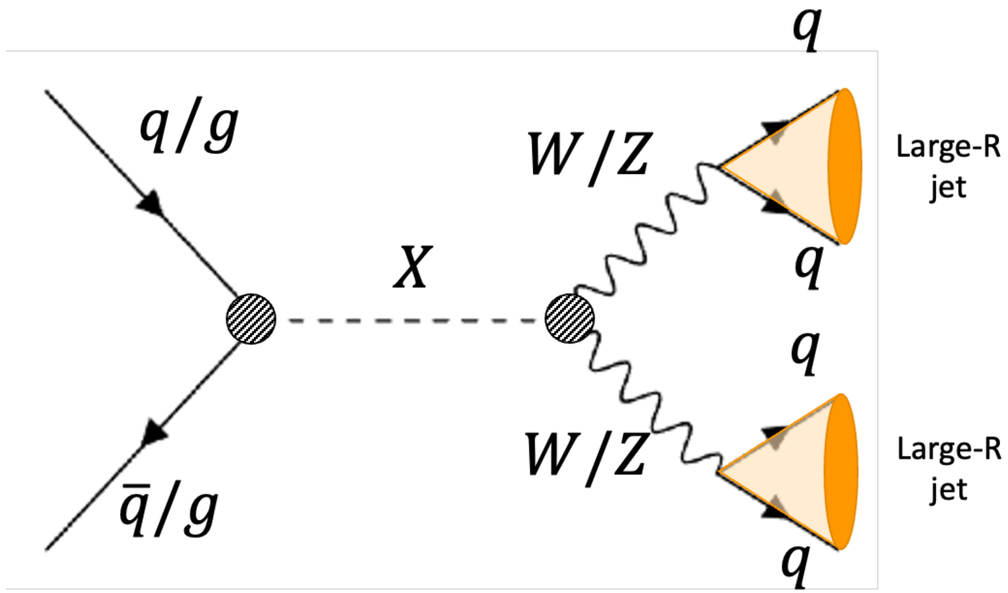


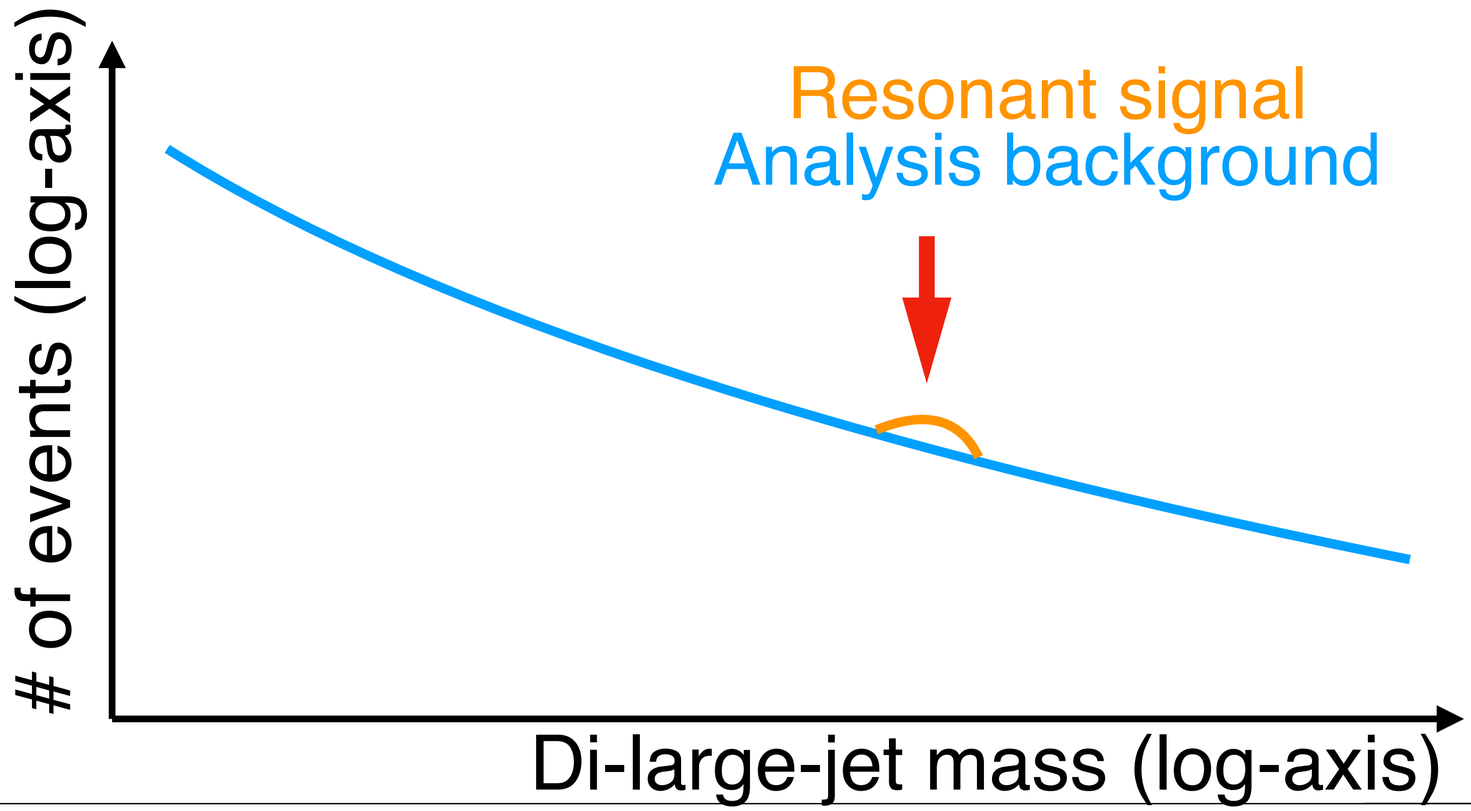
Since *X* is so heavy, the Vs will be strongly boosted

➡ Ultimately forming two *large-R jets* in total

Diboson searches: fully hadronic

- The signal: some heavy particle *X* decays into *two V-bosons* which decay into **two of large-R jets**
- What we want to see: two large-R jets with a combined invariant mass 2 - 6 TeV





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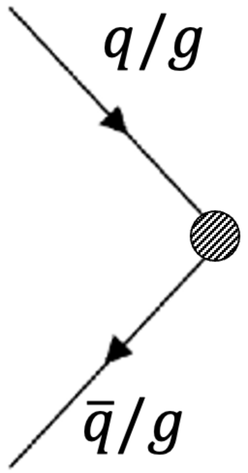

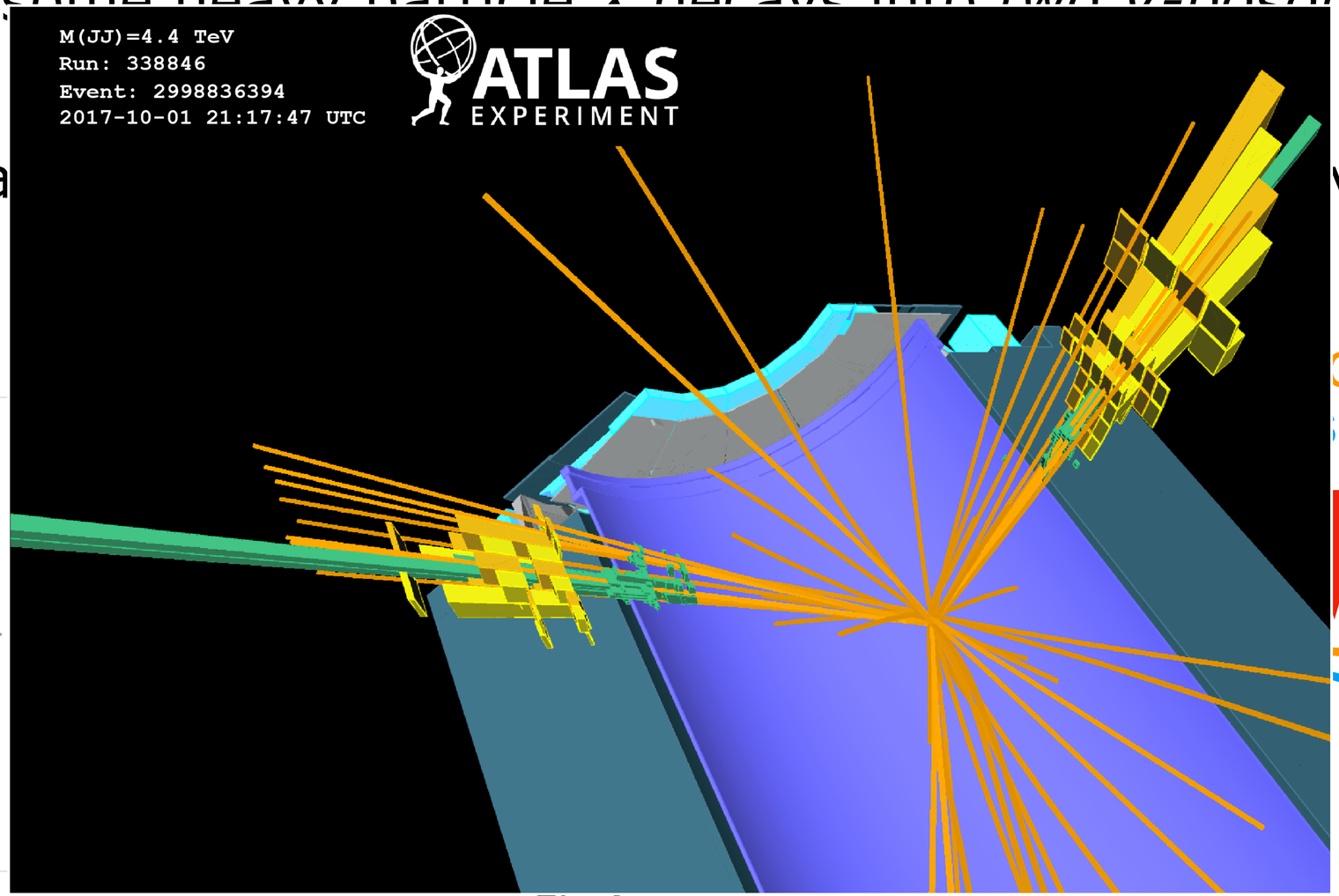

onant signal
is background

Di-large-jet mass (log-axis)

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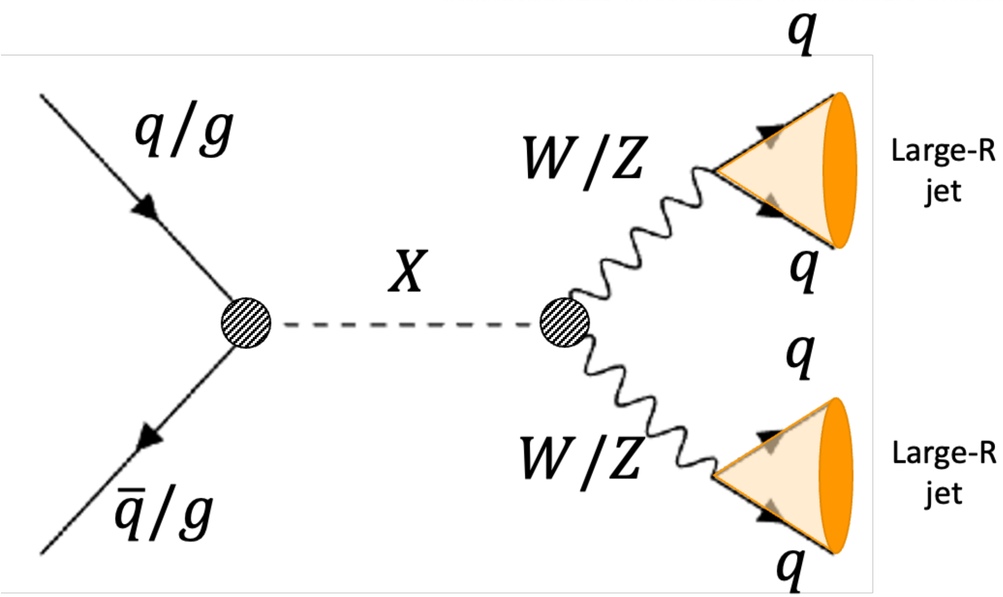
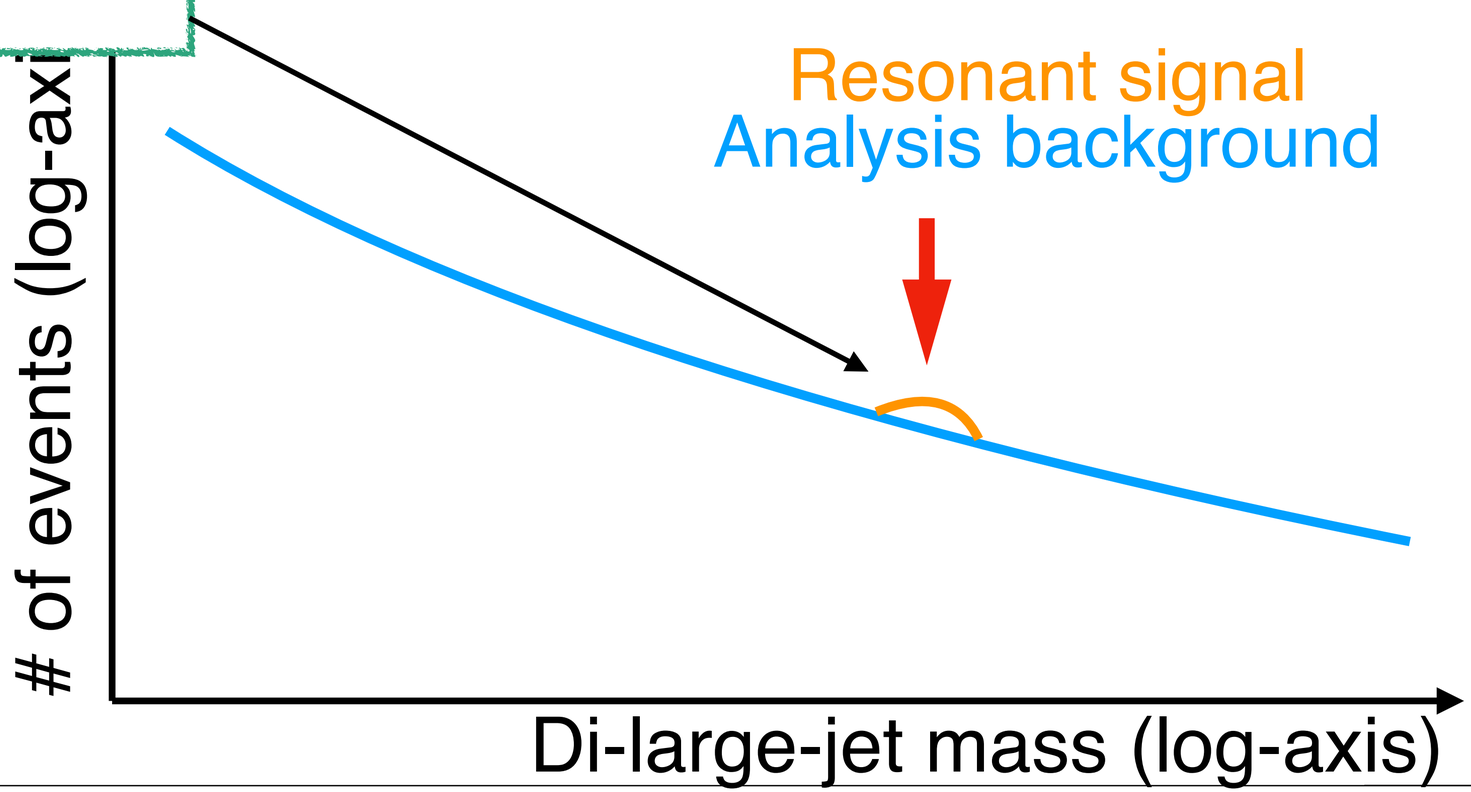
Expect the signal to look like a resonance peak





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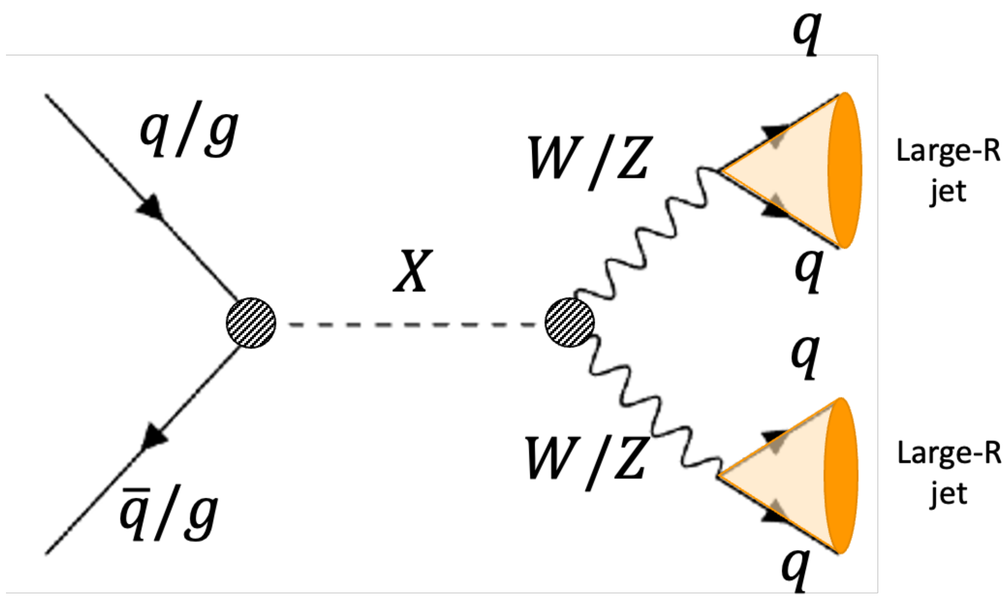

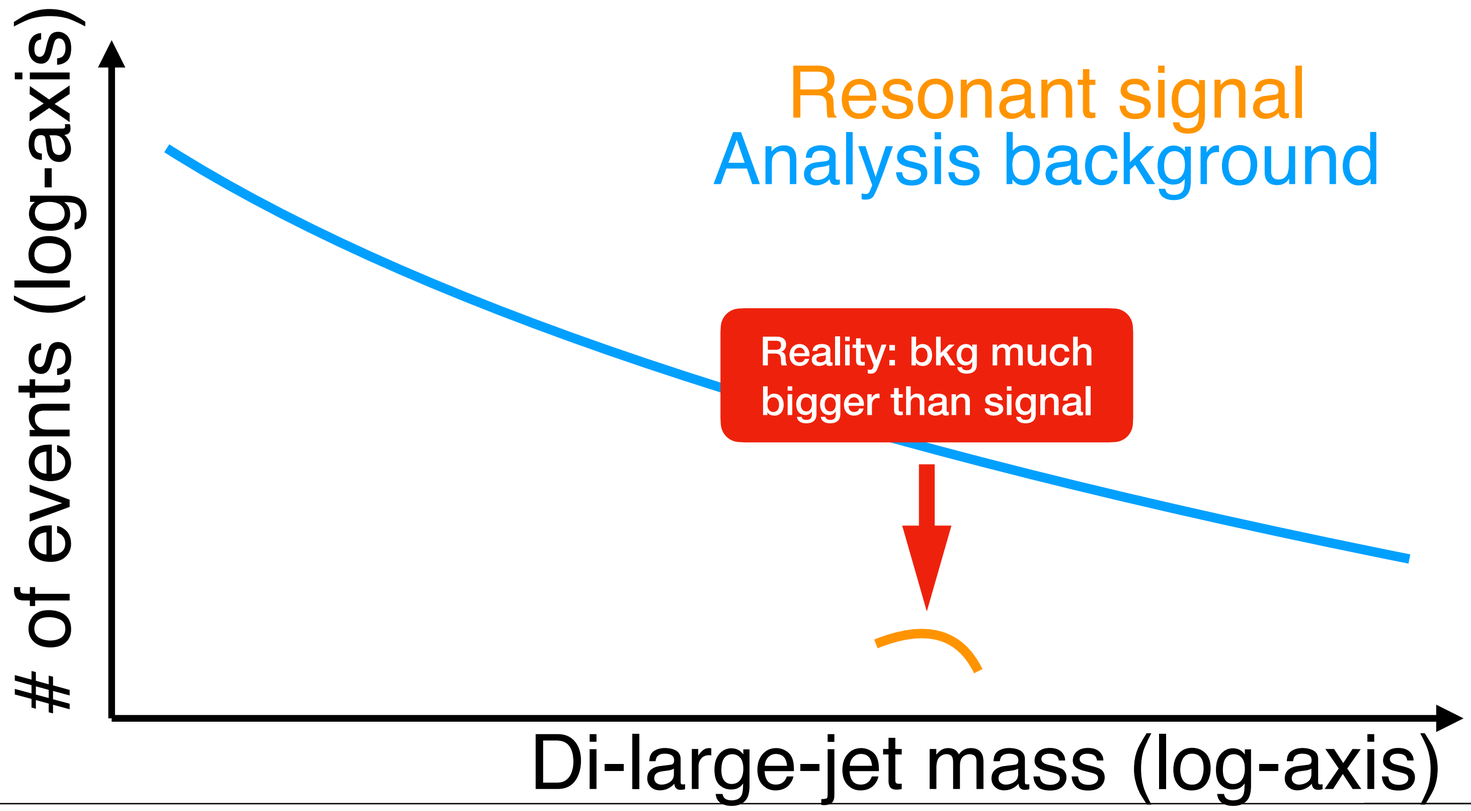

Diboson searches: major challenge

Plot: PUB-2021-03

- Since we are working with a fully hadronic final state, standard model QCD background is dominant
  - ➡ The cross section of proton-proton -> 2 jets is **3 orders of magnitude** bigger than proton-proton -> 2 V
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  - ➡ Need to find some way to keep our bkg under control

Part II (a): Estimating the QCD background

Background estimation

- Since high-energy QCD is non-perturbative, it is very difficult to predict and model
- Typically there are two options: *MC simulations* or *data driven*
  - ➡ Not possible to do MC simulations for QCD
  - ➡ A data driven method is much more reliable for QCD

Data driven: ABCD Method

- Idea: estimate background contribution in **signal region** by looking at **control regions**

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Intermezzo: Signal & Control regions

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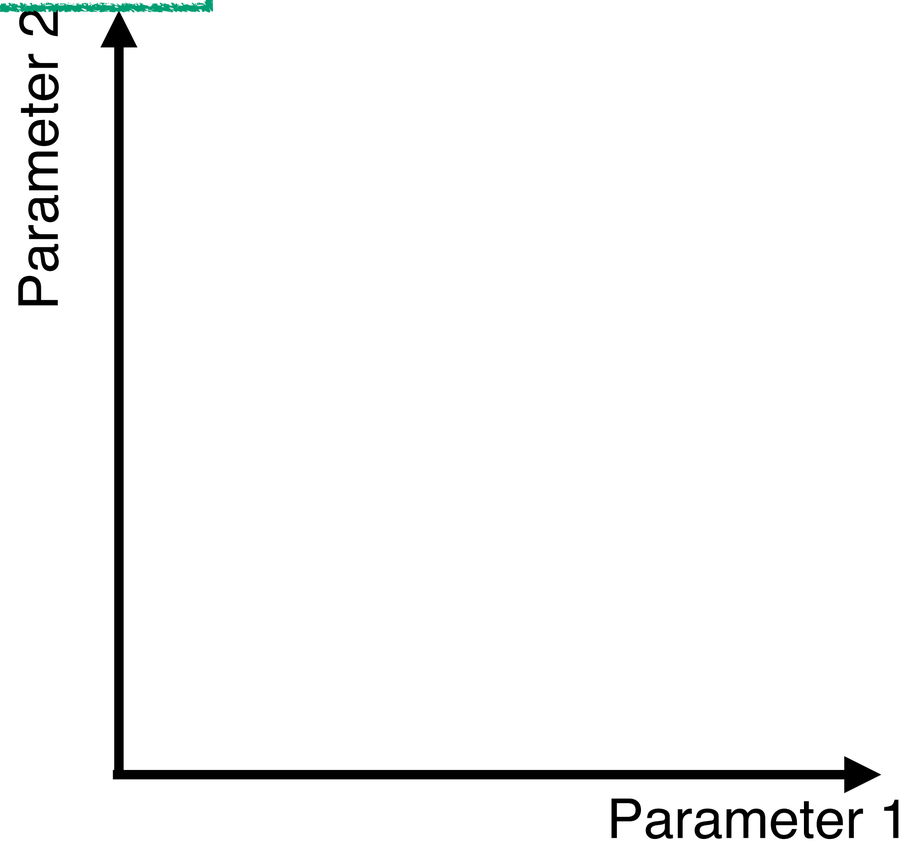

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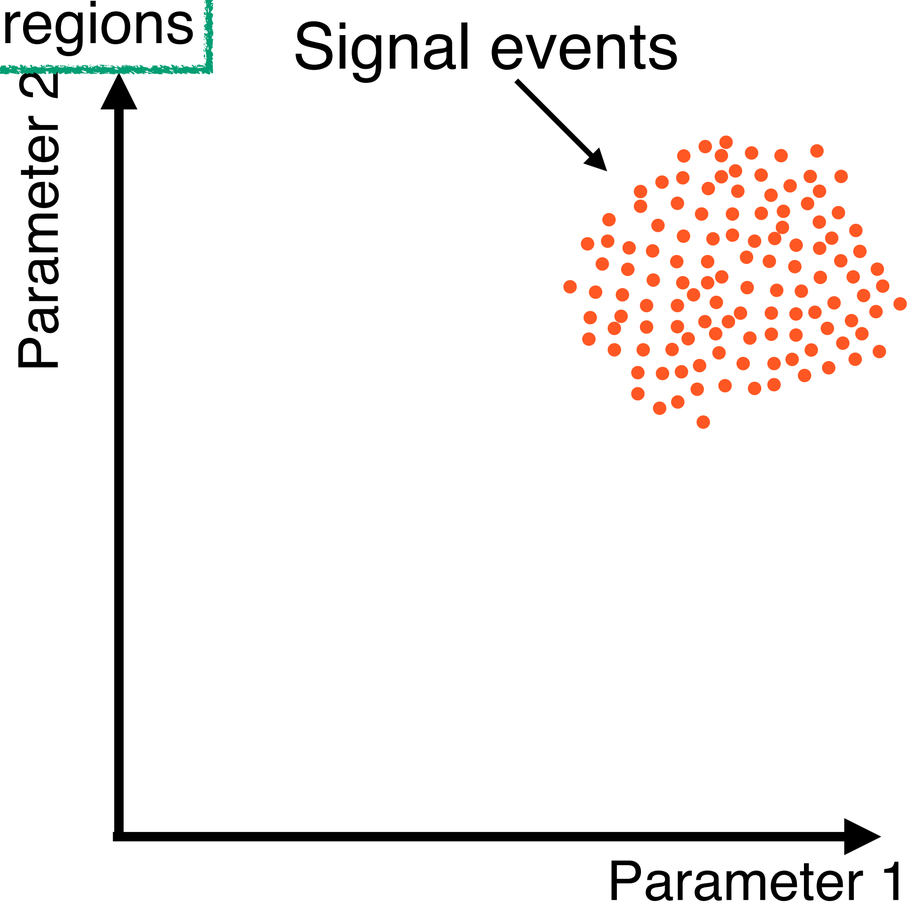

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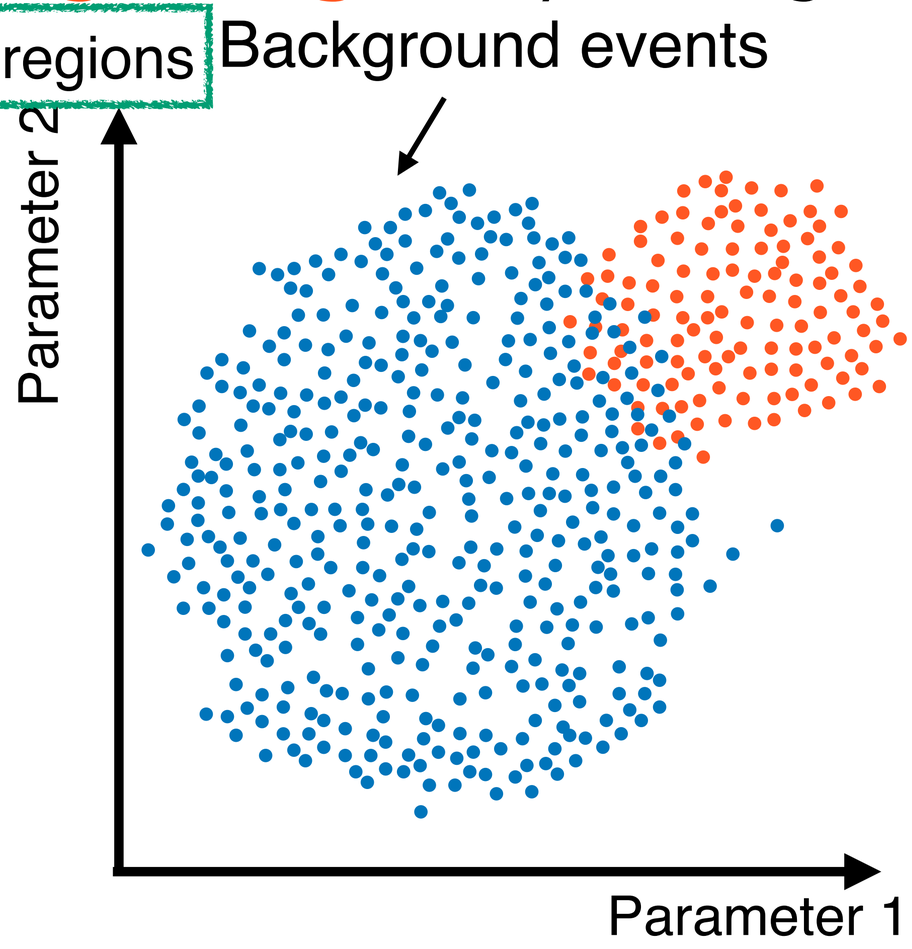

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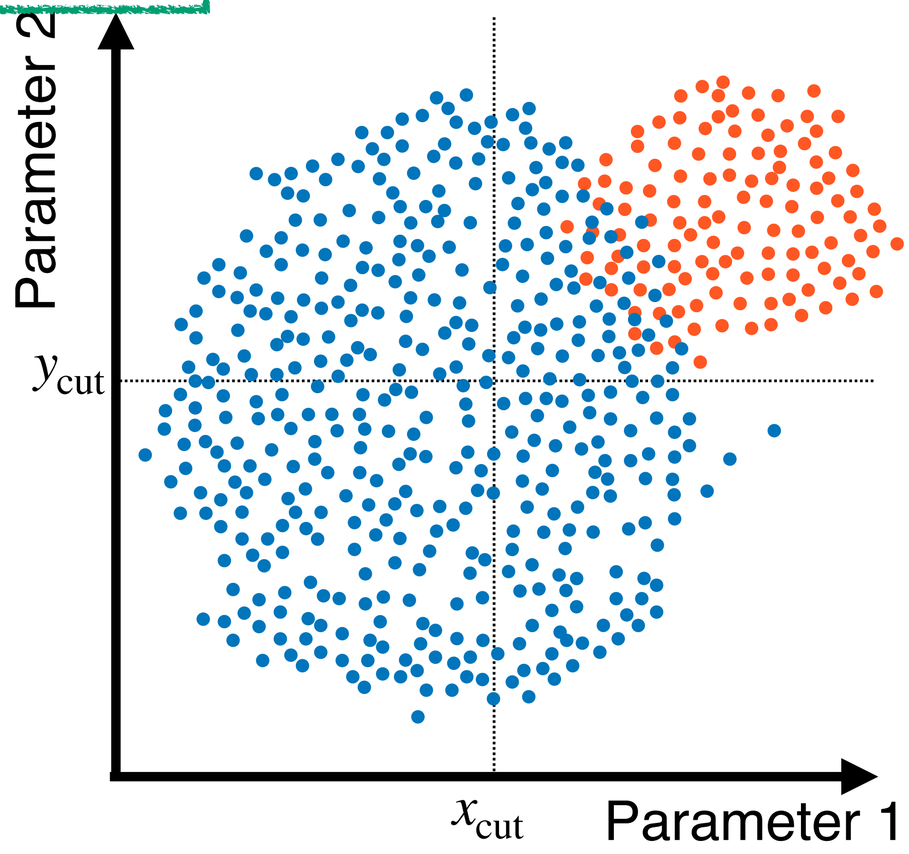

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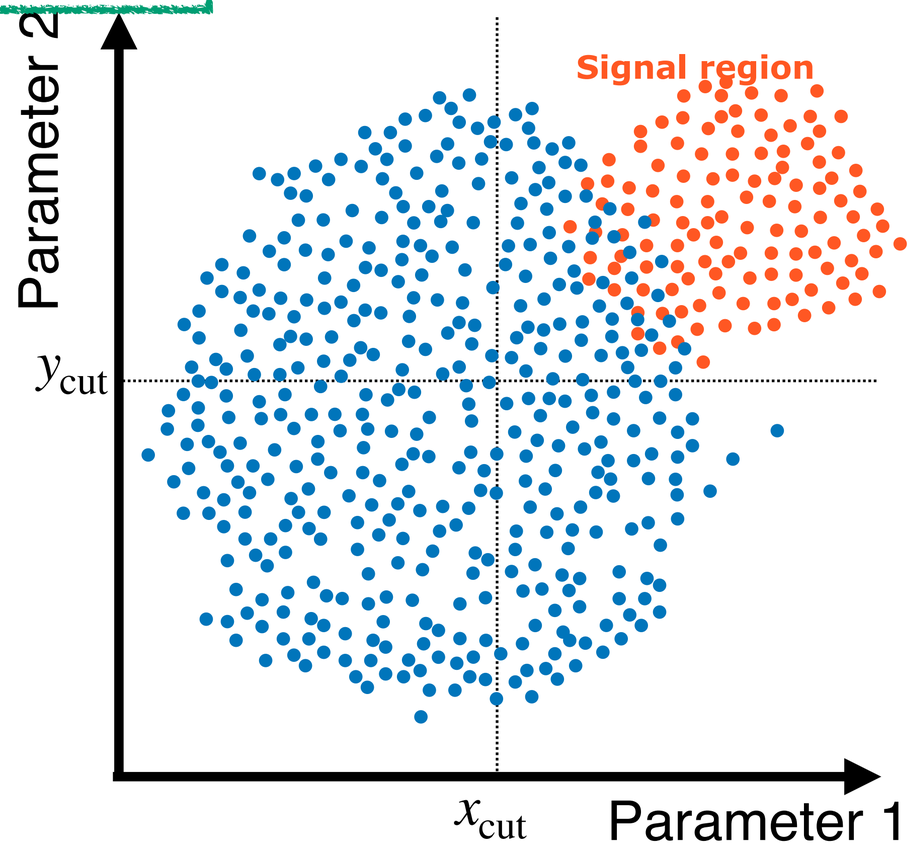

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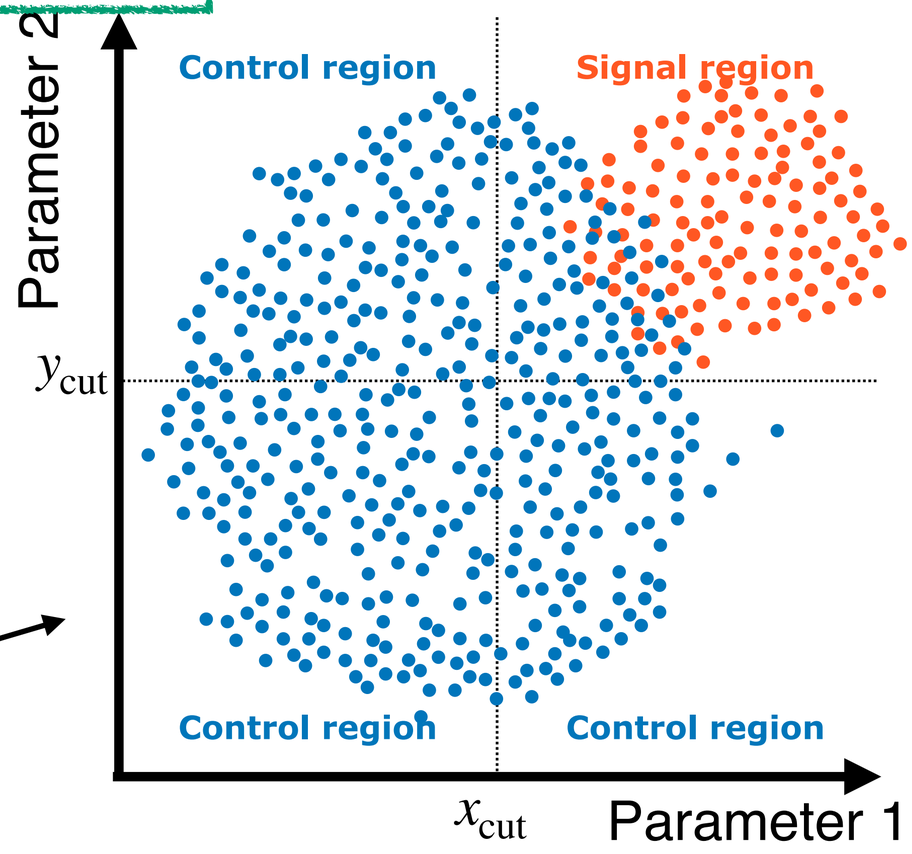

Ideal scenario where you know exactly what each event is

Data driven: ABCD Method

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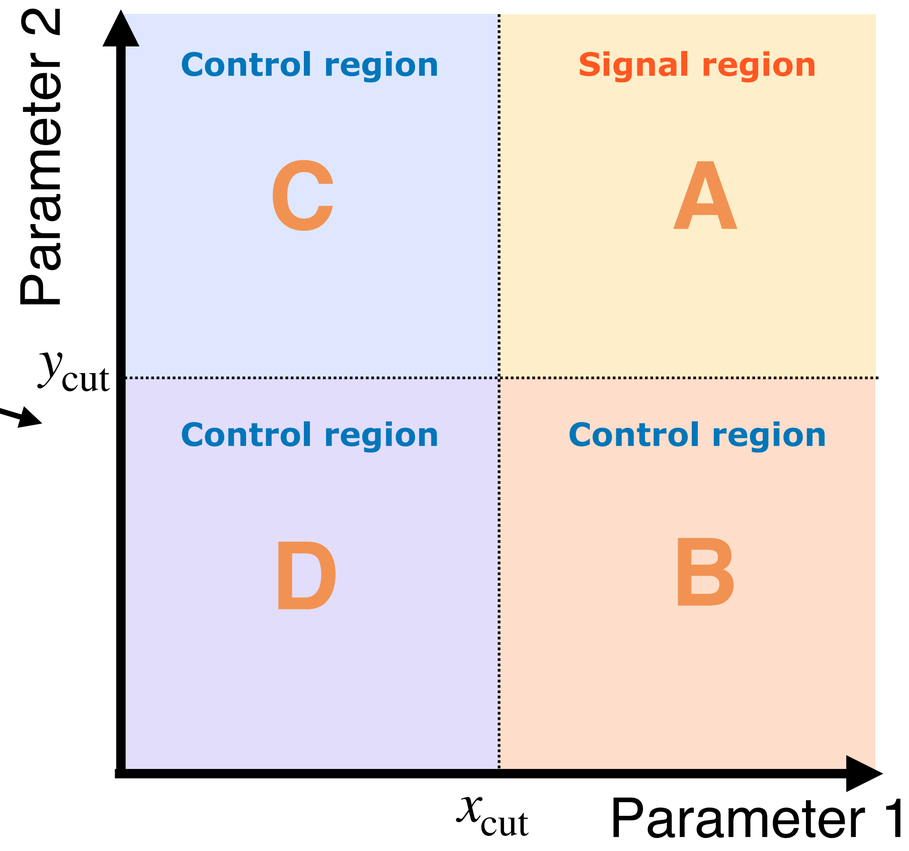
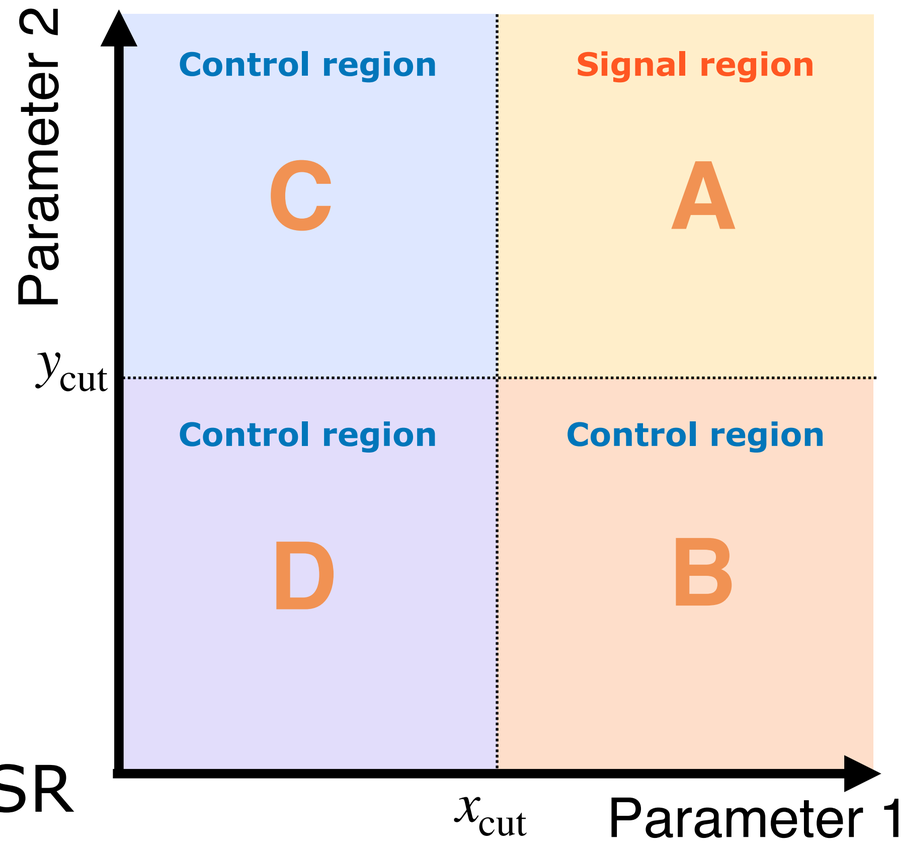
What do you do if you don't know whether an event is signal or background?



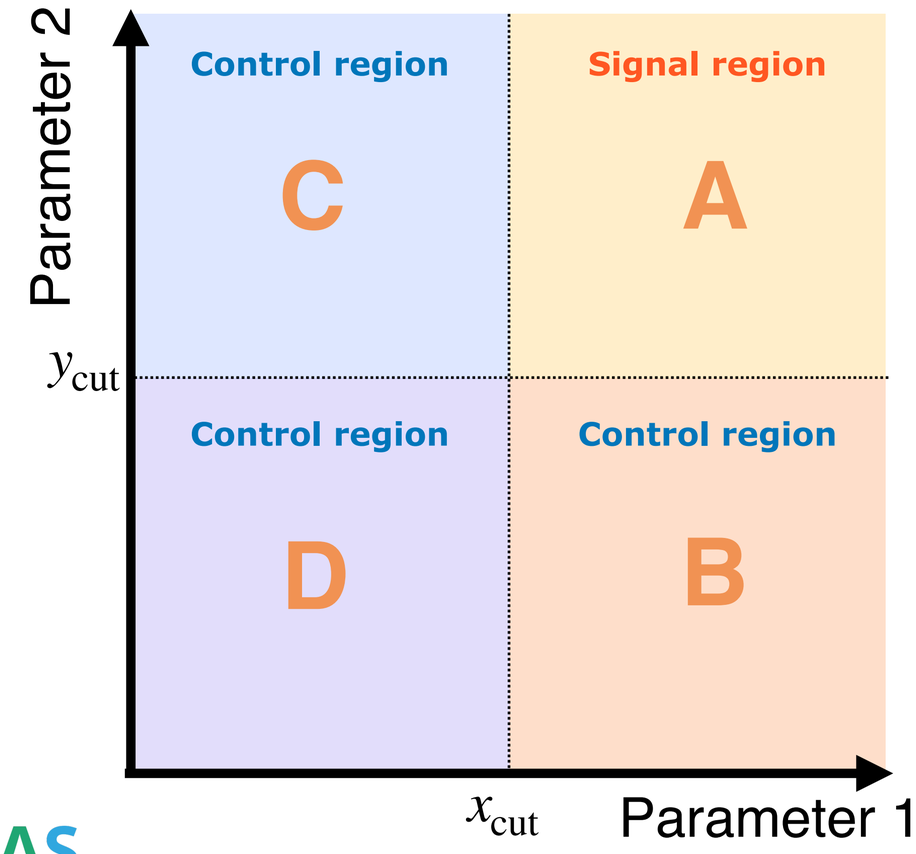
Data driven: ABCD Method

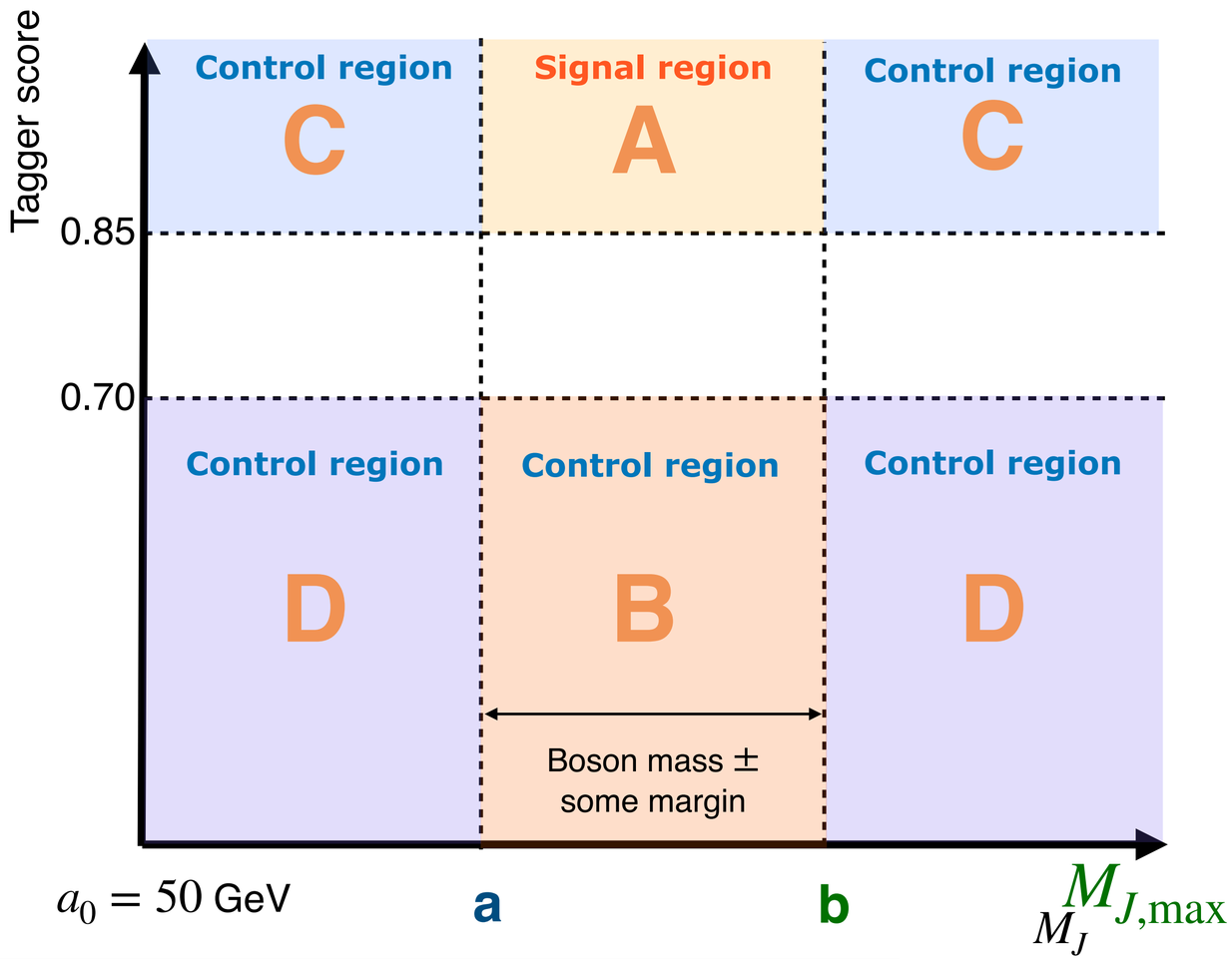
- Idea: estimate background contribution in **signal region** by looking at **control regions**
- If the parameters chosen for the y- & x-axis are **not correlated**, *and* if your **signal region is well defined** You can say:
  - ➡ $\frac{A}{B} = \frac{C}{D}$ (For # background events)
  - ➡ $A = B \times \frac{C}{D}$
  - ➡ Now you can estimate # bkg events in SR by only looking at control regions



ABCD Method: Our Case

- $A = B \times \frac{C}{D}$, where A, B, C & D are the #bkg events within the specific regions





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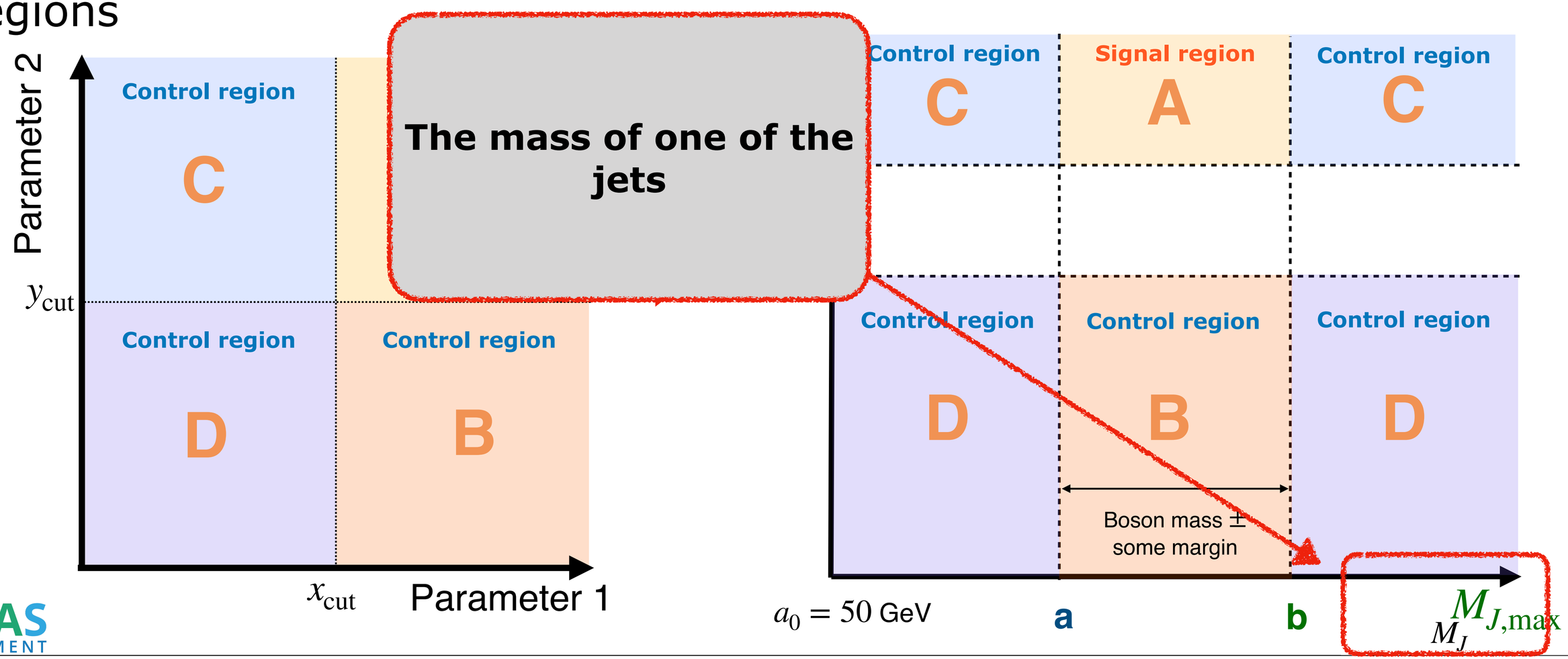

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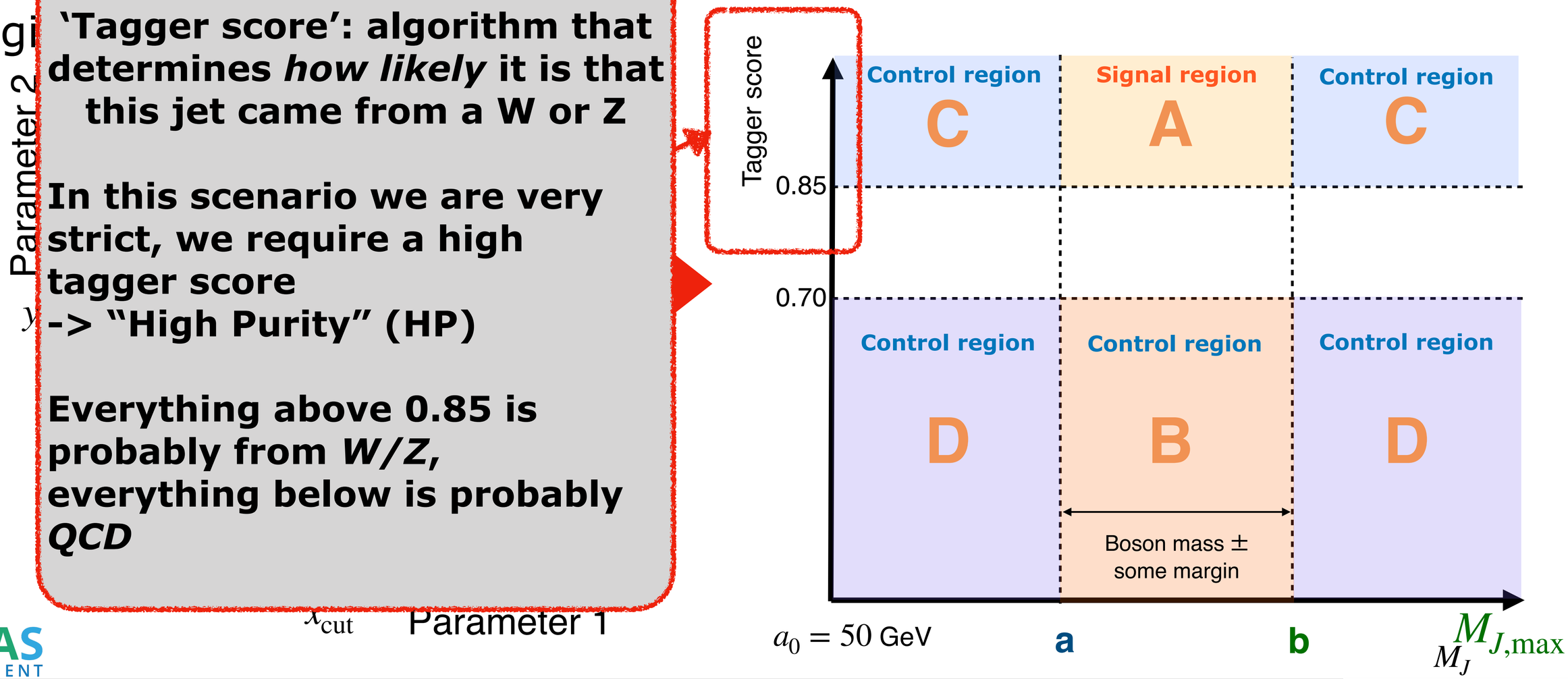
'Tagger score': algorithm that determines *how likely* it is that this jet came from a W or Z

In this scenario we are very strict, we require a high tagger score -> "High Purity" (HP)

Everything above 0.85 is probably from *W/Z*, everything below is probably *QCD*



ABCD Method: Our Case

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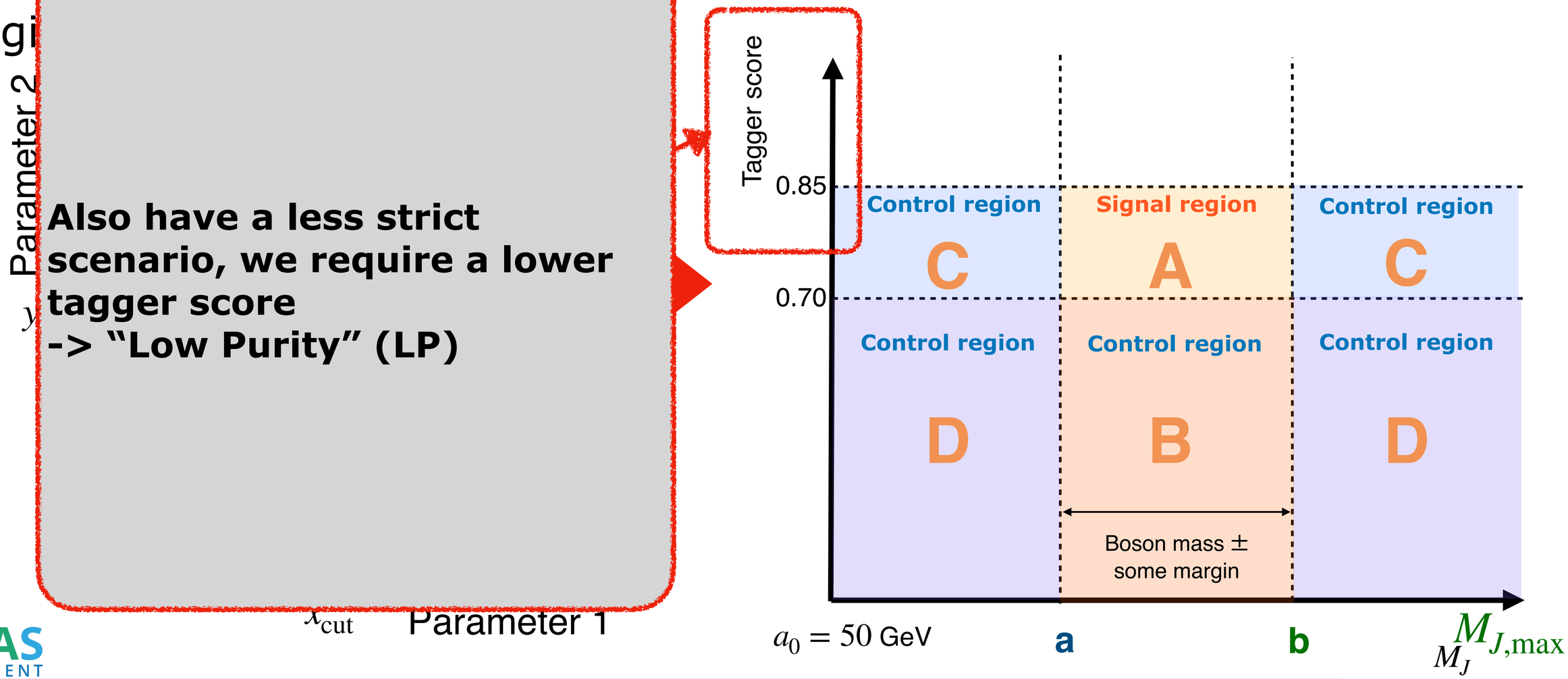
Also have a less strict scenario, we require a lower tagger score
-> "Low Purity" (LP)



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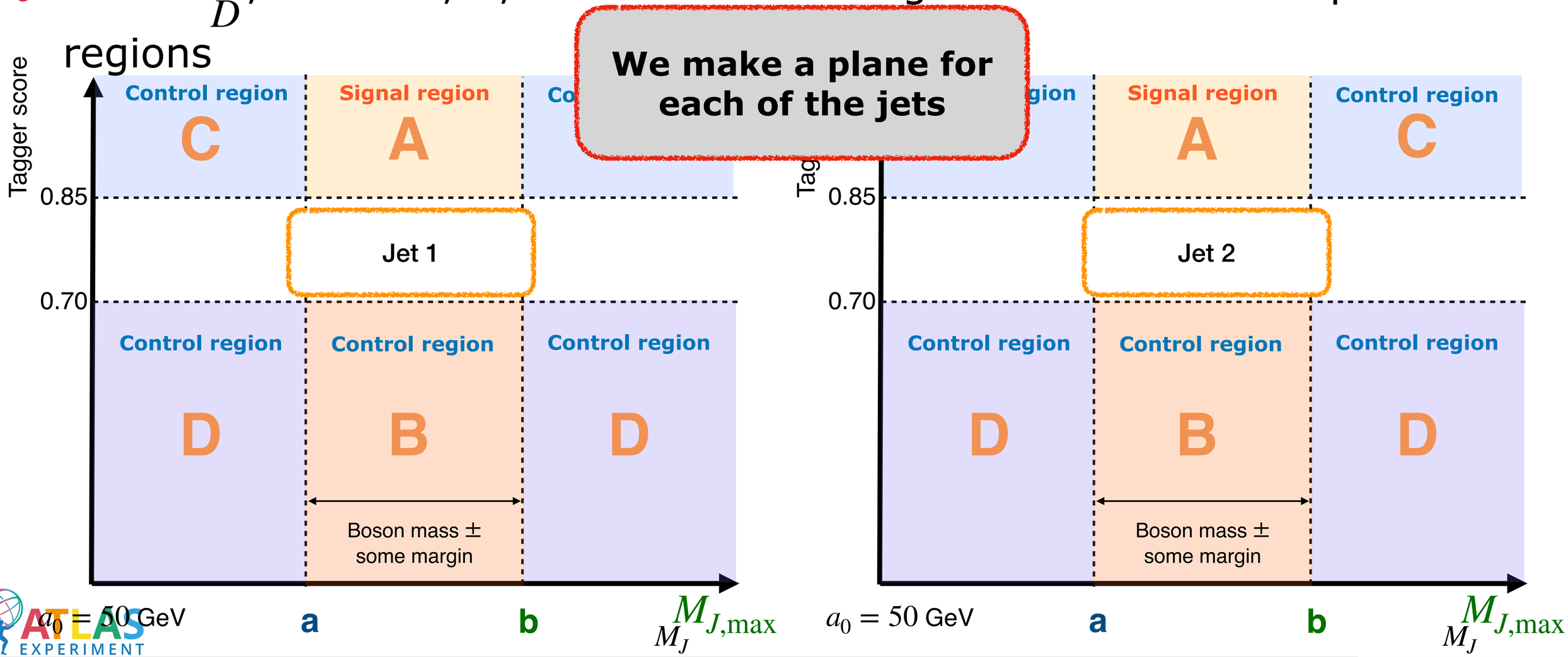

Part II (b): Final Estimate

Final QCD Estimate

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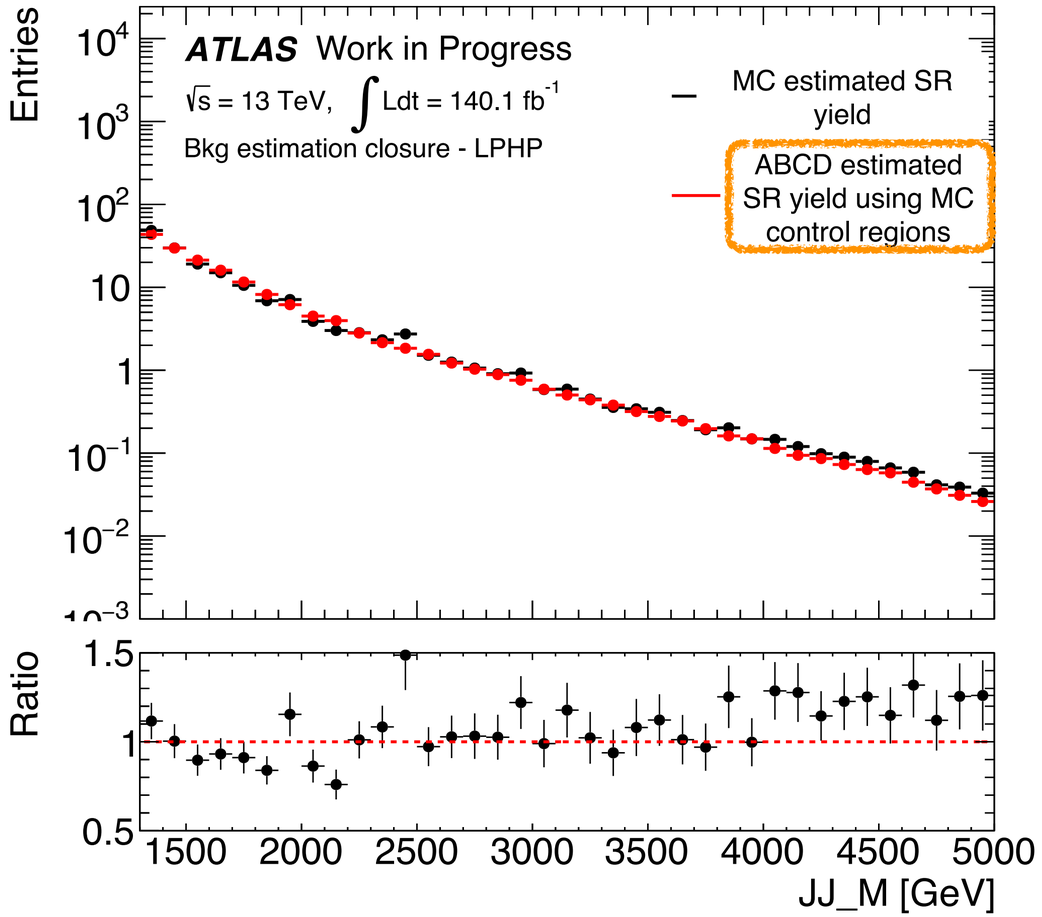
- First try out the method on MC simulations to see if it delivers consistent results:
  - ➡ Use MC control regions as input for ABCD (and see if it returns the same SR output as 'raw' MC)
  - ➡ Consistency check



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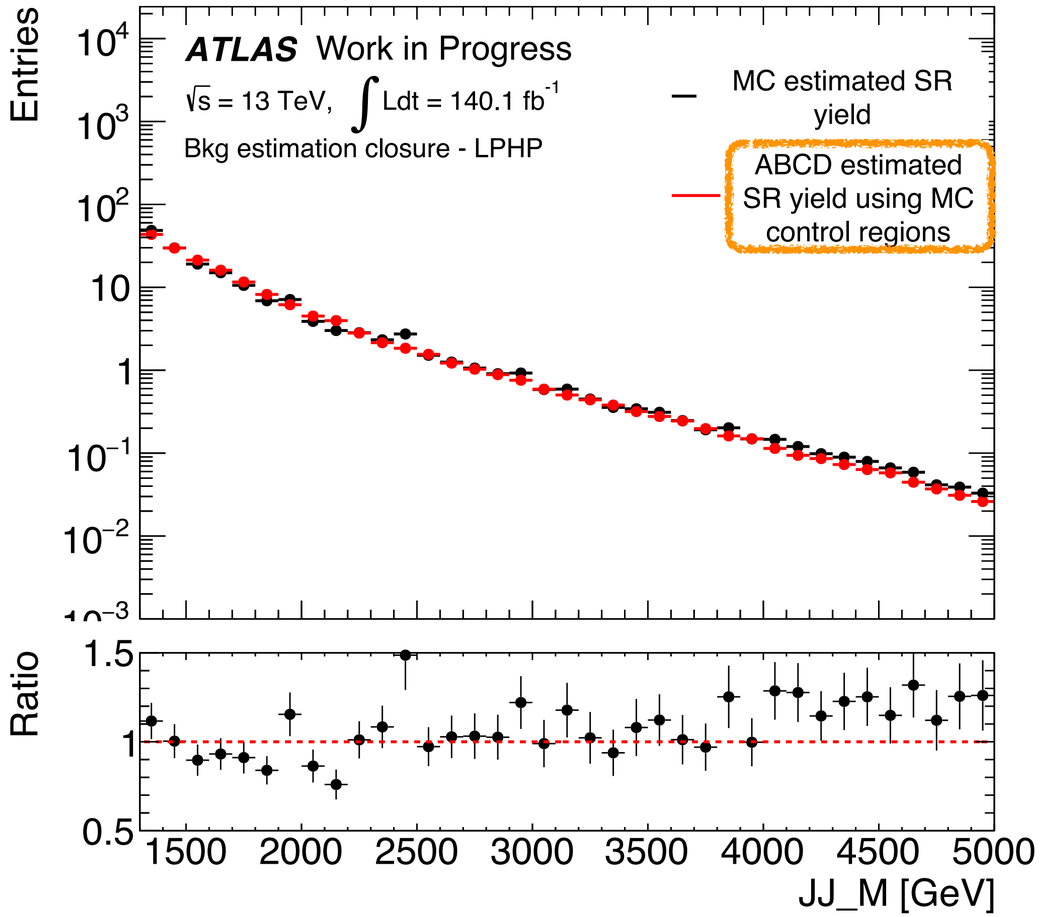
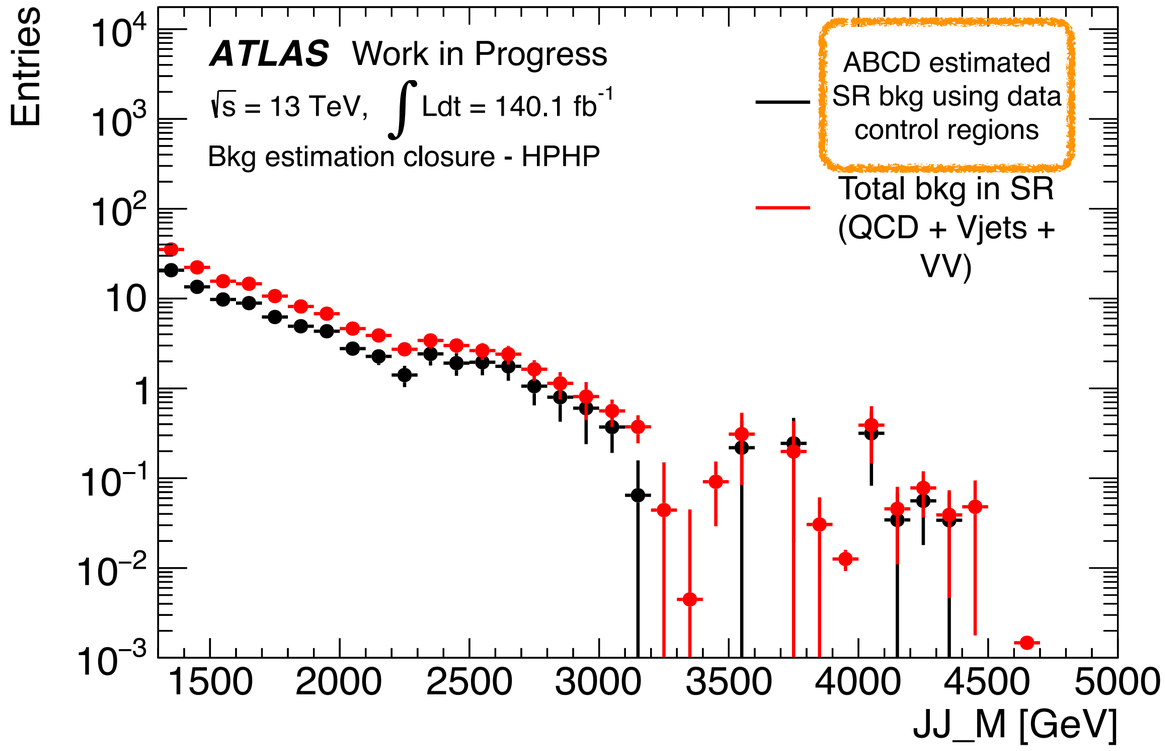
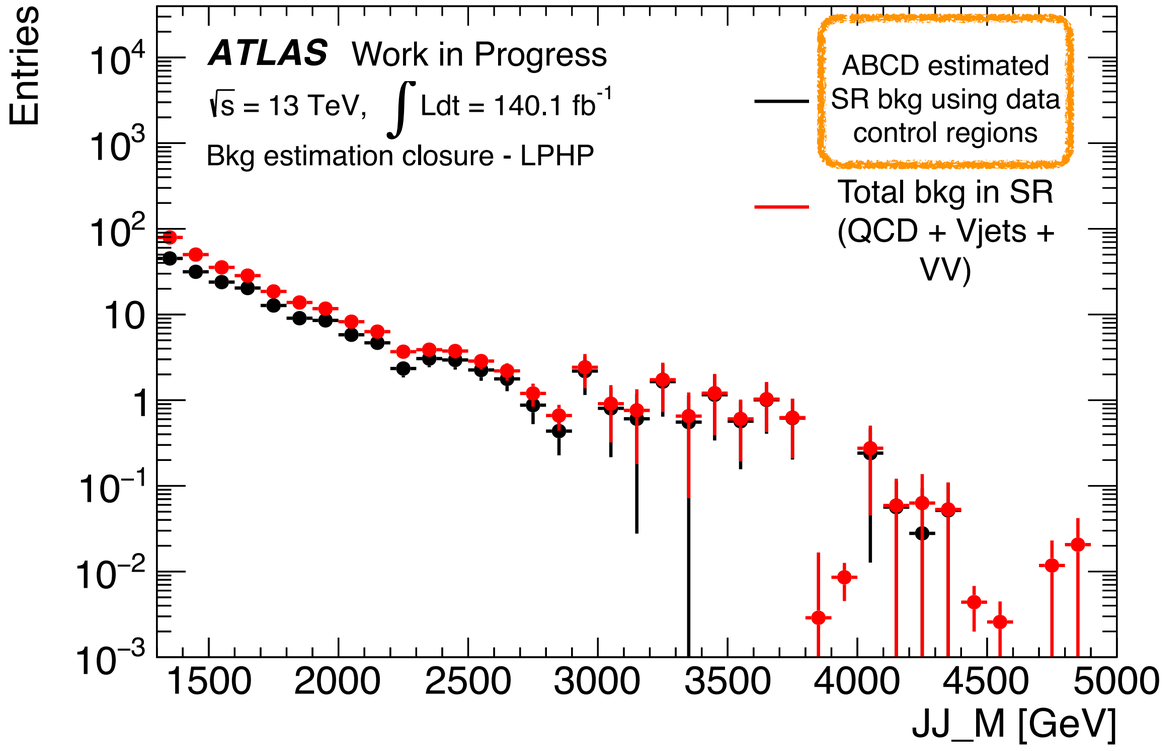
  - ➡ Consistency check
- We find good agreement between MC and ABCD ✅



Final QCD Estimate

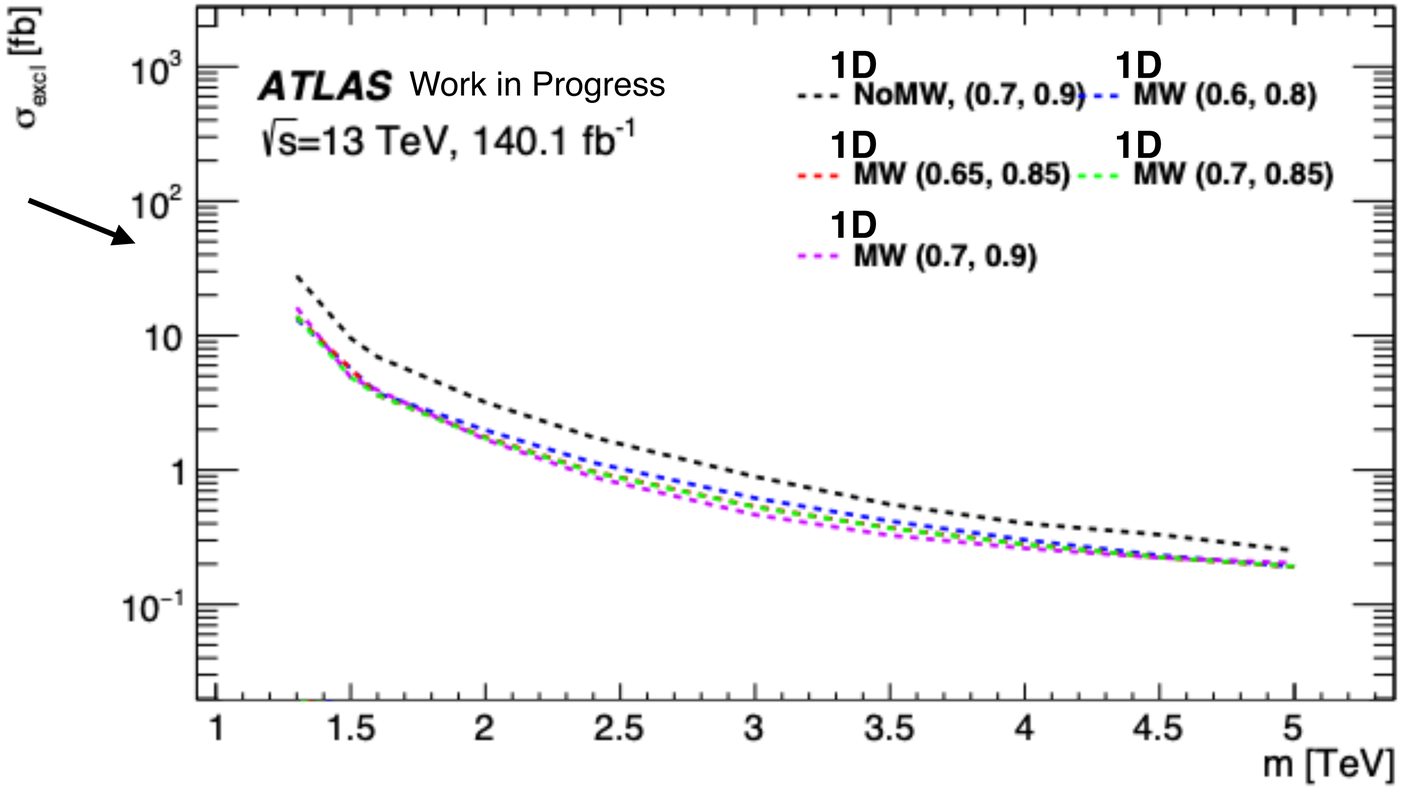
- Now apply the method on data





Expected sensitivity

- Given this background estimate, these are the cross sections we can probe
  - ➡ Might be sensitive to BSM signal?
  - ➡ Have to look at data!



Summary & Conclusion

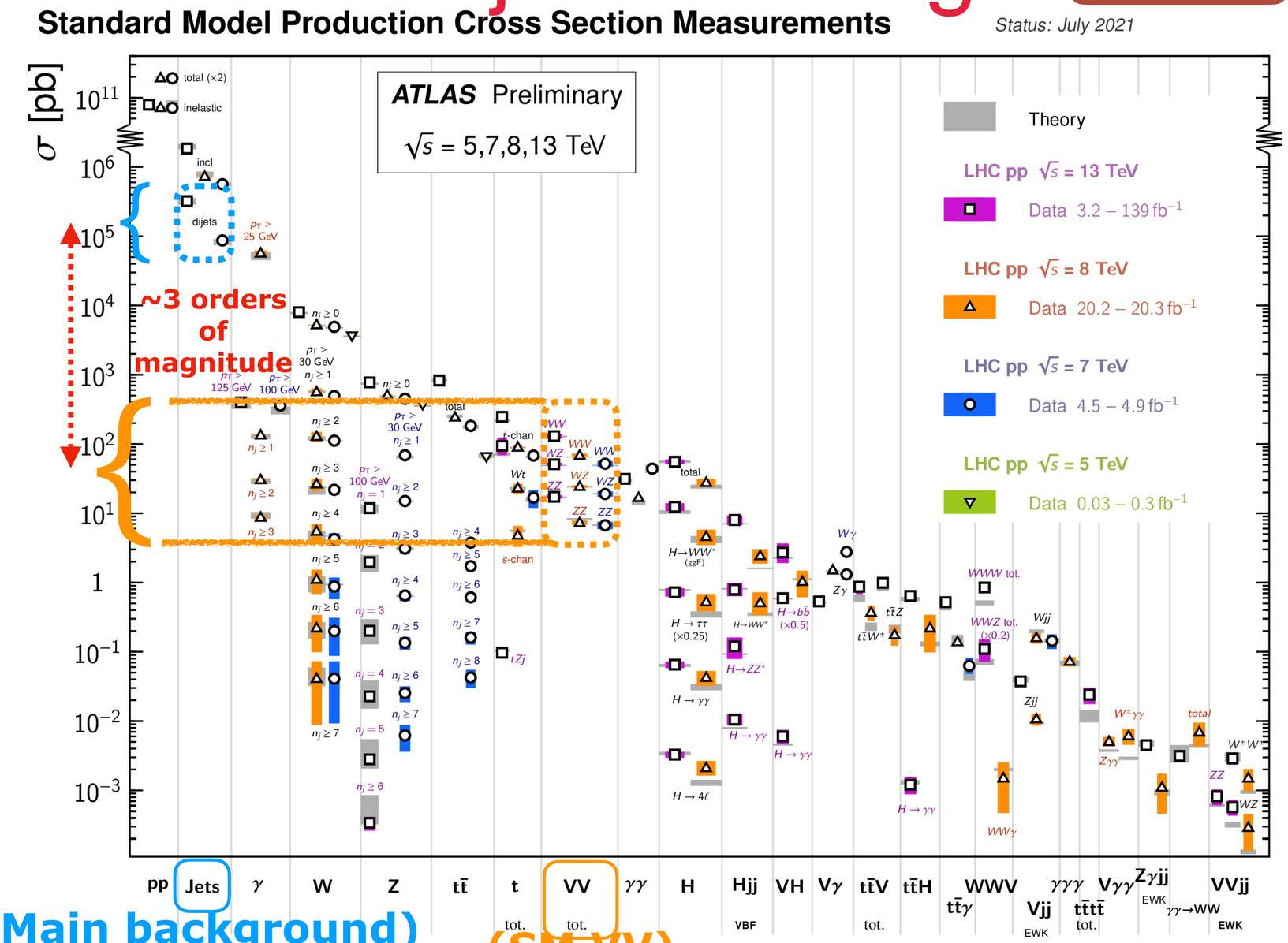
- W/Z bosons good probe for new physics
- Overcome QCD hurdle by using ABCD method
- Now that we have our background fully under control we can move onto the next steps
  - ➡ Move towards unblinding (i.e. look at data in the signal region, compare with bkg to see if there is any new physics)

Backup

Diboson searches: major challenge

Plot: PUB-2021-03

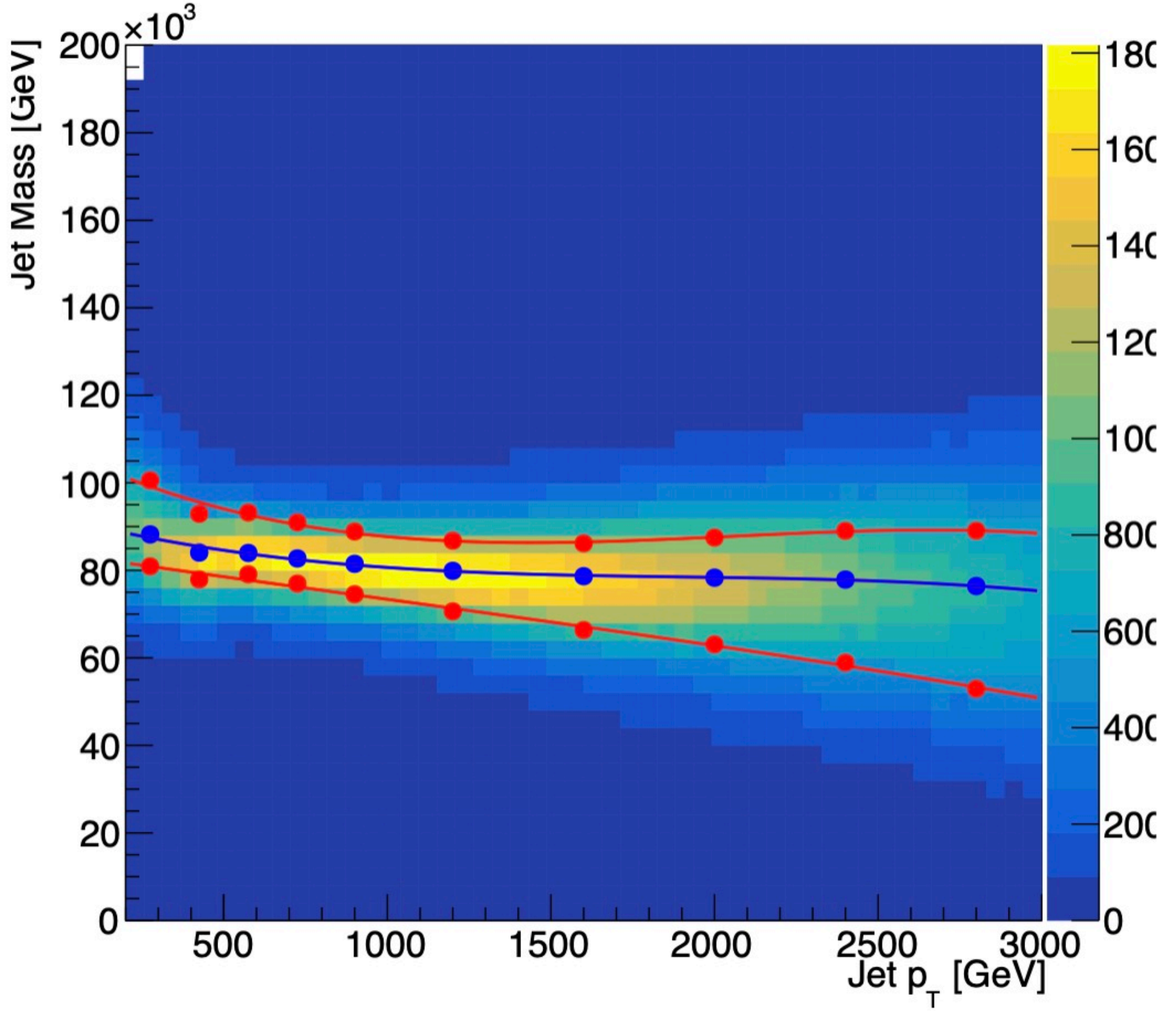
- Since we are working with a fully hadronic final state, QCD background is dominant
  - ➡ Need to find some way to keep our bkg under control

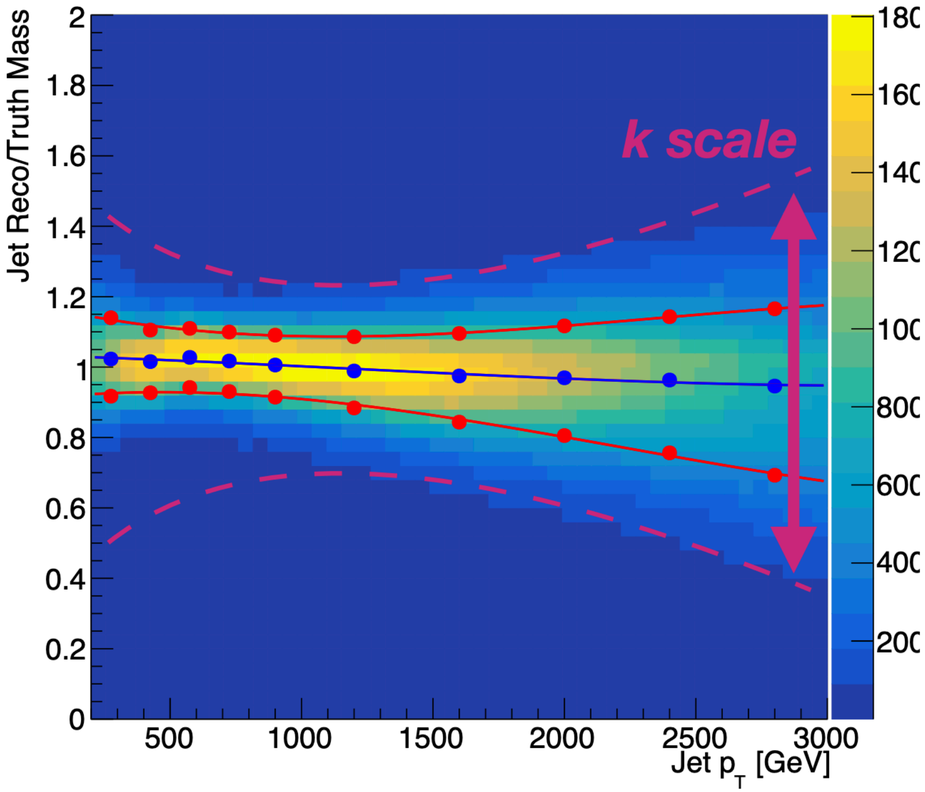


Background ABCD setup

Strategy 1006		Jet 1	Jet 2
HPHP			
	A	HP, MW	HP, MW
	B	QCD, MW	HP, MW
	C	HP, LSB || HP, HSB	HP, MW
	D	QCD, LSB || QCD, HSB	HP, MW
HPLP			
	A	HP, MW	LP, MW
	B	HP, MW	QCD, MW
	C	HP, MW	LP, LSB || LP, HSB
	D	HP, MW	QCD, LSB || QCD, HSB
LPHP			
	A	LP, MW	HP, MW
	B	QCD, MW	HP, MW
	C	LP, LSB || LP, HSB	HP, MW
	D	QCD, LSB || QCD, HSB	HP, MW

Mass Window


Jet Mass [GeV]
×10^3
Jet p_T [GeV]


Jet Reco/Truth Mass
k scale
Jet p_T [GeV]

Input for tagger algorithm

- Low-level: jet constituents
- High-level: jet variables (ntracks, energy distribution within the jet, other jet substructure variables)
- Jet mass
- Output: mass decorrelated score

CMS result

2210.00043

- Our results are not public yet, but CMS has released theirs
  - ➡ They find a 3.6σ local excess at 2.1 TeV and 2.9 TeV (2.3σ global)
  - ➡ Good motivation to keep looking at this channel!