# Measurement and Monte Carlo

## or how to make (and use) an optimally useful measurement

Jon Butterworth

University College London

MCnet school, Online/Dresden/Karlsruhe,

September 2021

*Thanks to Emily Nurse for the use of her slides

# Summary so far

- Introduction to MC event generators in data analysis
- How various particles are reconstructed in the data
- The importance of correcting for detector effects…
- …but of not extrapolating into unmeasured regions

# Correcting for acceptance affects

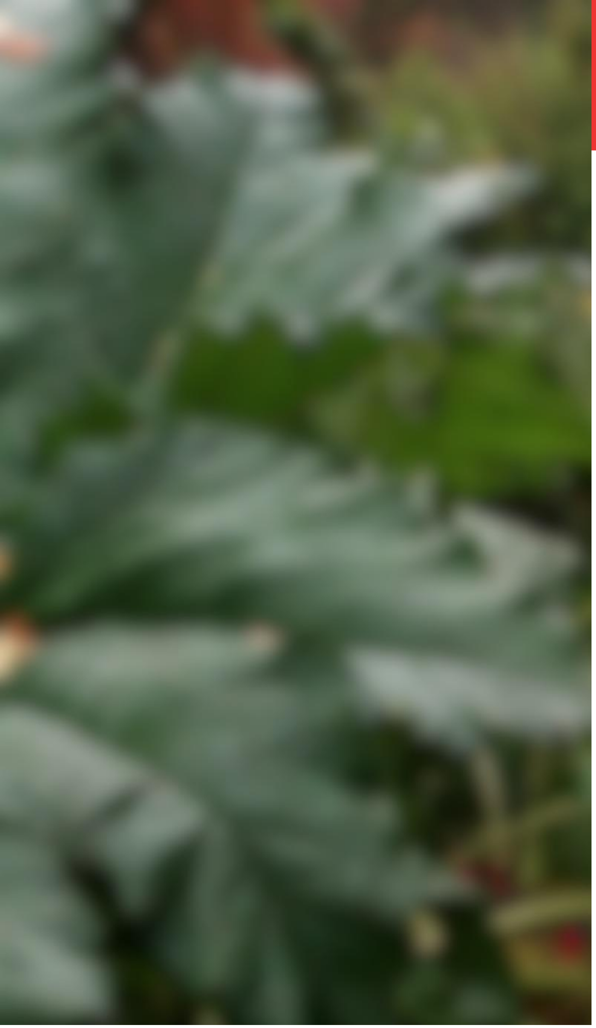
- AKA extrapolating outside the region we measure into full phase-space: e.g.
  - $p_T > 25$ GeV → $p_T > 0$ GeV
  - $|\eta| < 2.5$ → $|\eta| < \infty$
- Anyone can do this with their preferred SM prediction
  - no detector simulation needed (there's no detector!)
- But be careful! We do not measure this region!
- ***It is a bad idea to contaminate the precious data with the very theory we are trying to constrain!***

# Correcting for acceptance affects

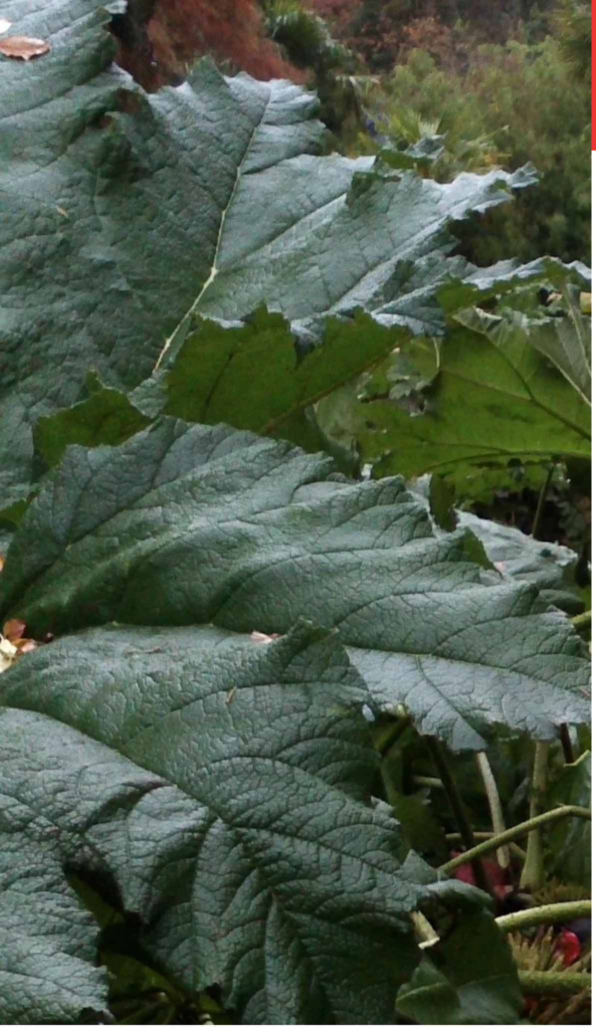
Example:
[Phys. Lett. B707 (2012) 459](Phys. Lett. B707 (2012) 459)

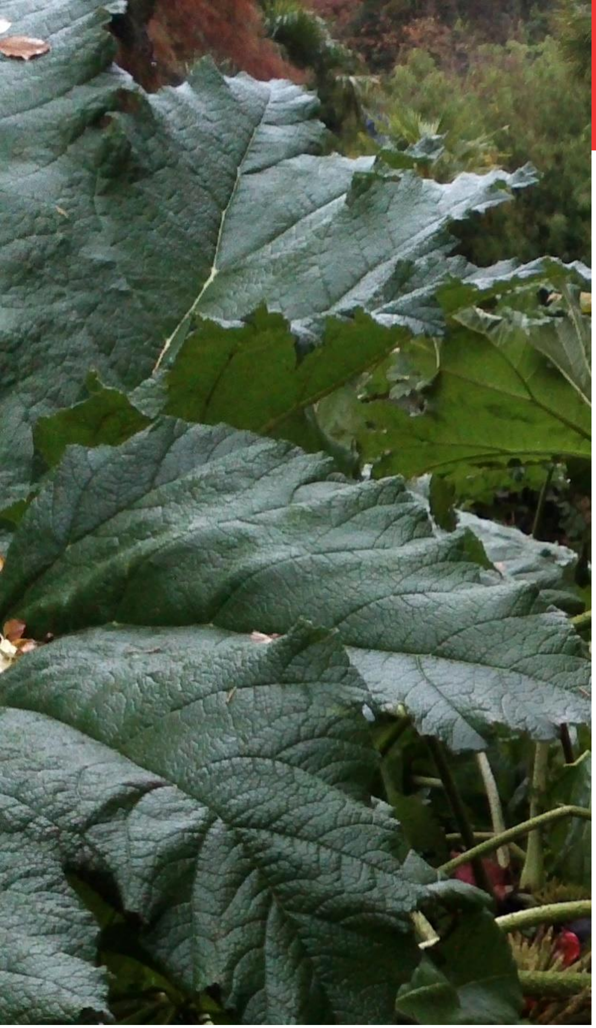
$$\sigma_{tt} = 177 \pm 25 \text{ pb}$$

- Run 1: Total $t\bar{t}$ cross-section reported
  - but the measurement is made in the dilepton decay channel with $p_T > 25$ GeV , $|\eta| < 2.5$ , and various cuts on $E_T^{miss}$, $H_T$, jets etc.
- Only 1.7% of $t\bar{t}$ events are used to measure the $t\bar{t}$ cross-section! 98.3% of events are *not "seen".*
- Some of this is detector inefficiencies, but a large amount is an extrapolation to a completely unmeasured region!



# Unfold





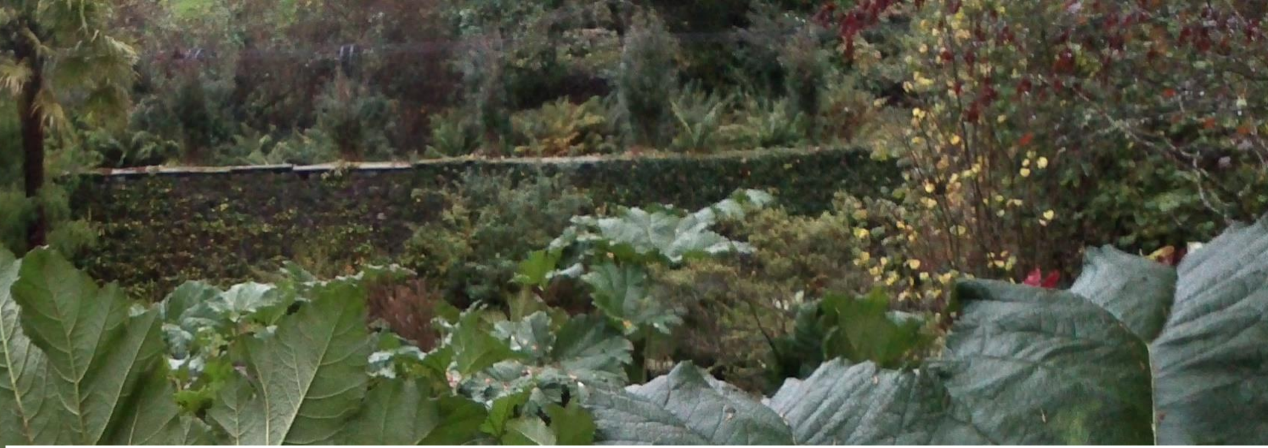
# Increase acceptance

# Increase acceptance

Extrapolate

But how reliably?

# Fiducial phase-space

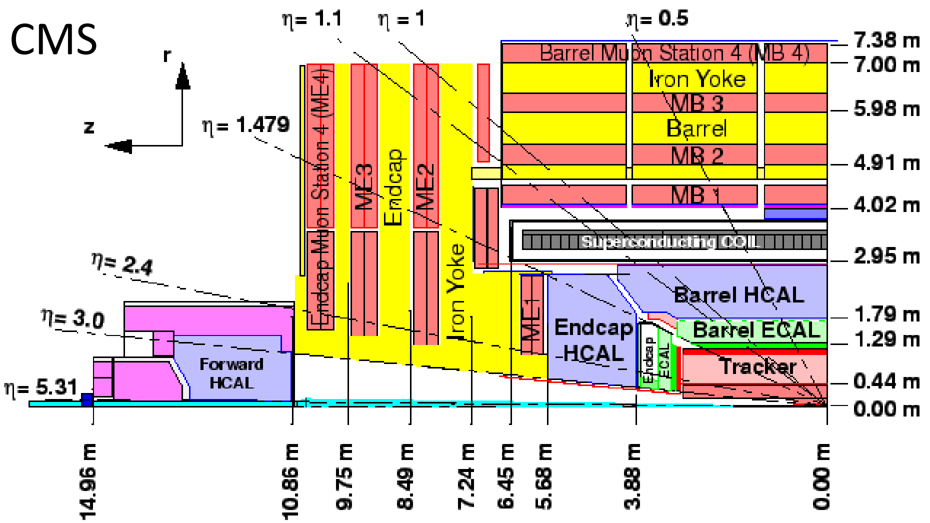



Inaccessible. Removed by kinematics cuts, and not part of the fiducial cross section

# Fiducial phase-space

Irrespective of detector efficiencies and resolution effects there are particular kinematic regions that *we just don't measure at all*.

We do not have $4\pi$ detectors and we can't go down to zero $p_T$!




A fiducial phase-space is a set of selection criteria that can be applied to **final-state "truth" particles**

e.g.: Select events with one (and only one) muon with $p_T$> 25 GeV, $|\eta|$<2.4 and $p_T^{miss}$ > 30 GeV.

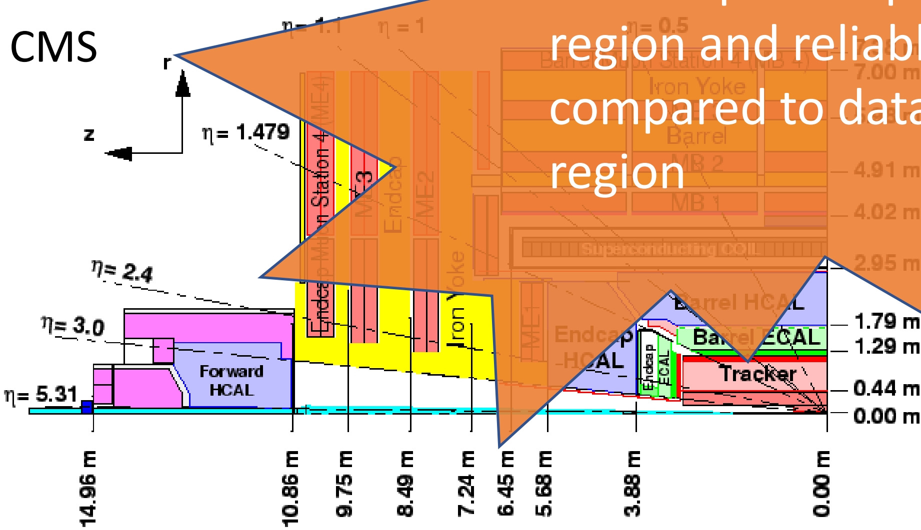
# Fiducial phase-space

Irrespective of detector efficiencies and resolution effects there are particular kinematic regions that *we just don't measure at all*.

We do not have $4\pi$ detectors and we can't go down to zero $p_T$!

Many (but not all) theoretical predictions can be defined in a fiducial phase-space region and reliably compared to data in this region

CMS




A fiducial phase-space is a set of selection criteria that can be applied to final-state "truth" particles

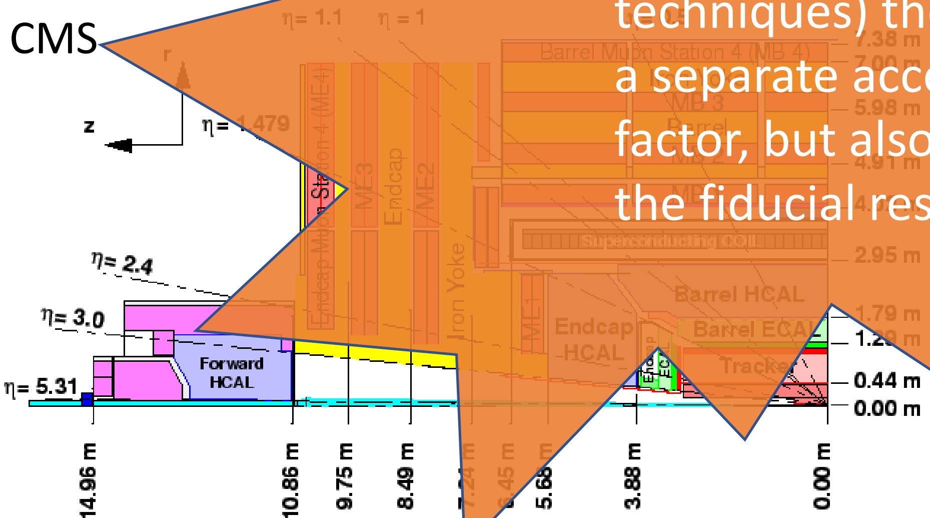
e.g.: Select events with one (and only one) muon with $p_T$> 25 GeV, $|\eta|$<2.4 and $p_T^{miss}$ > 30 GeV.

# Fiducial phase-space

Irrespective of detector efficiencies and resolution effects there are particular kinematic regions that *we just don't measure at all*.

We do not have $4\pi$ detectors and we can't go down to zero $p_T$!

CMS




If you want to compare to a theory prediction that cannot be calculated in a fiducial phase space (e.g. using resummation techniques) then provide a separate acceptance factor, but also publish the fiducial result!

A fiducial phase-space is a set of selection criteria that can be applied to final-state "truth" particles

e.g.: Select events with one (and only one) muon with $p_T$> 25 GeV, $|\eta|$<2.4 and $p_T^{miss}$ > 30 GeV.

# What is a final-state particle?

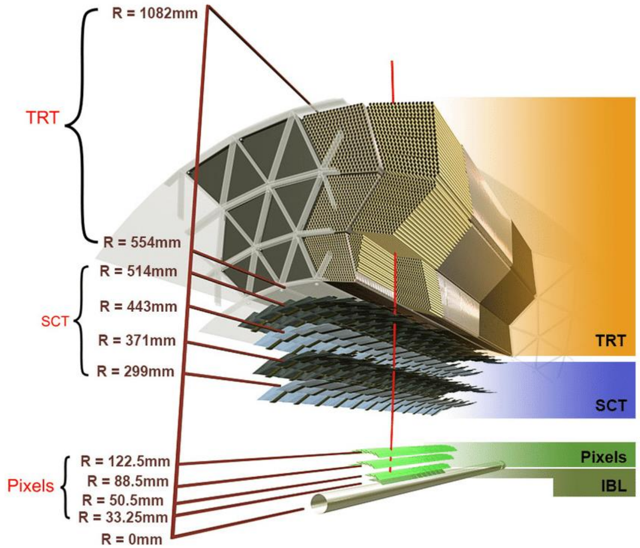
Lots of useful advice and discussion here: https://cds.cern.ch/record/2022743

$d = \tau_0 \gamma v = c\tau_0 p/m$

Recall:

- electrons: stable
- muons: "stable" ($\tau_0$ = 2.2ms, decays after ~1.2 km at 20 GeV)
- taus: unstable ($\tau_0$ = 0.3 ps, decays after about 1mm at 20 GeV)
- neutrinos: stable (but invisible)
- Quarks, gluons → hadrons: "stable" and unstable → jets
- photons: stable
- W,Z,H,top: unstable (and not uniquely defined)

Common choice : $\tau_0$ > 30 ps, after hadronization.



# What is a final-state particle?

Lots of useful advice and discussion here: https://cds.cern.ch/record/2022743

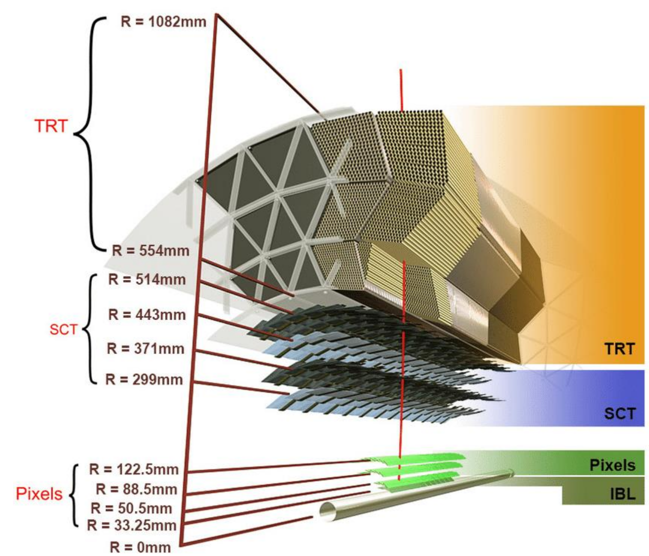
$d = \tau_0 \gamma v = c\tau_0 p/m$

Recall:

- electrons: stable
- muons: "stable" ($\tau_0$ = 2.2ms, decays after ~1.2 km at 20 GeV)
- taus: unstable ($\tau_0$ = 0.3 ps, decays after about 1mm at 20 GeV)
- neutrinos: stable (but invisible)
- Quarks, gluons $\rightarrow$ hadrons: "stable" and unstable $\rightarrow$ jets
- photons: stable
- W,Z,H,top: unstable (and not uniquely defined)

Common choice : $\tau_0$ > 30 ps, after hadronization.

| Hadron | [ps] | d @ 20 GeV | Classification |
|---|---|---|---|
| $\pi^{\pm}$ | 26,000 | 1 km | "stable" |
| $K_S$ | 90 | 1 m | "stable" |
| $B^0$ | 1.5 | 2 mm | unstable |
| $\pi^0$ | 8 x$10^{-5}$ | 3.6 m | unstable |

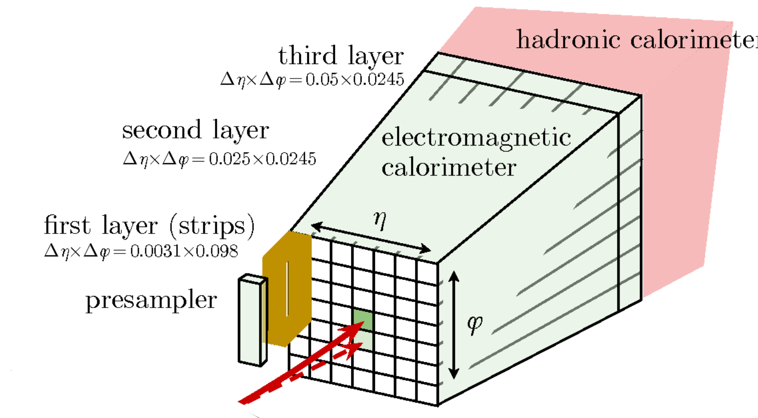


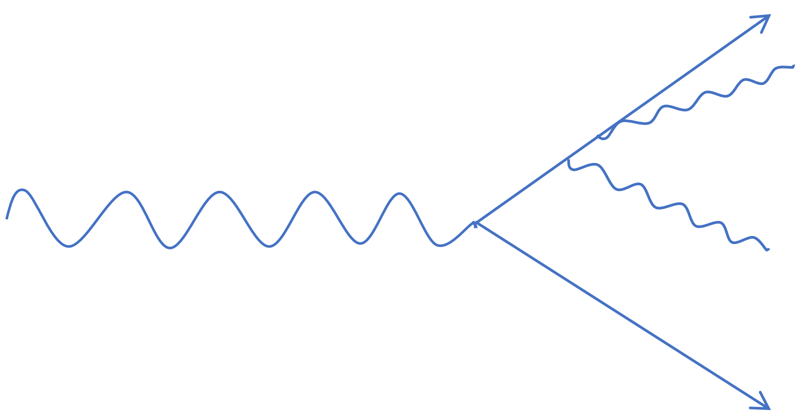
# What is a final-state electron/muon?

- Electrons/muons from hadron decays are typically removed in the data analysis by isolation cuts / fake removal
  - ✓ Can define "prompt leptons" to be "not-from-hadron decays" and only consider these : this is more robust and model-independent than asking that the lepton comes from a certain propagator in the hard process
  - ✓ Well defined in Rivet (see tutorial), but you may need to also implement it in your experiment's software
- Either define particle-level isolation, or correct for inefficiencies of these requirements
  - ➢ It might be worth reconsidering this in specific analyses where proximity to jets has a large effect on results, for example

# What is a final-state electron/muon?

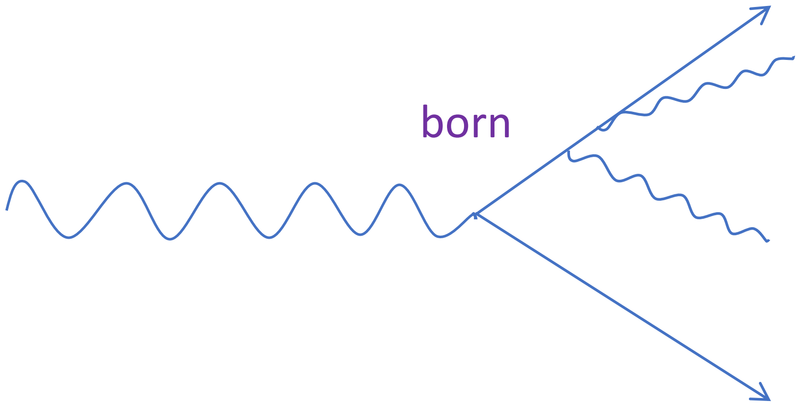
- Electrons and muons emit FSR photon radiation (and lots of it, especially in the collinear limit, especially for electrons).
  - For muons we measure the charged particle track, photon energy is not included
  - For electrons we cluster calorimeter cells and most collinear radiation will be included in the energy measurement



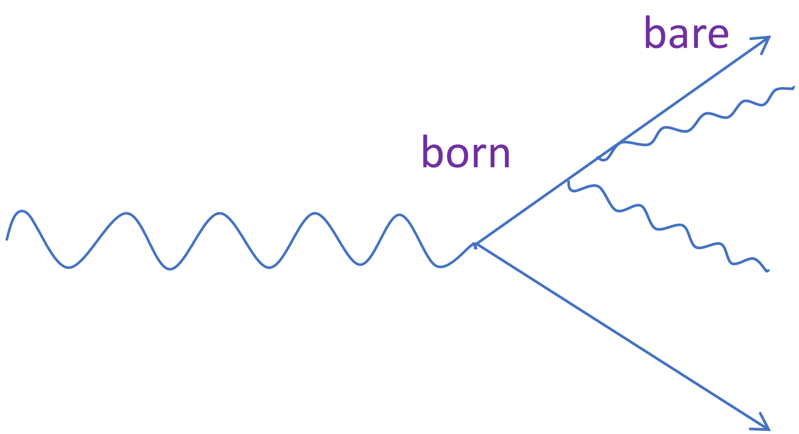
# What is a final-state electron/muon?

- Electrons and muons emit FSR photon radiation (and lots of it, especially in the collinear limit, especially for electrons).
  - For muons we measure the charged particle track, photon energy is not included
  - For electrons we cluster calorimeter cells and most collinear radiation will be included in the energy measurement
- We can define lepton momenta as:
  1. Born leptons – as if FSR never happened (not what we measure, not actually measureable…)



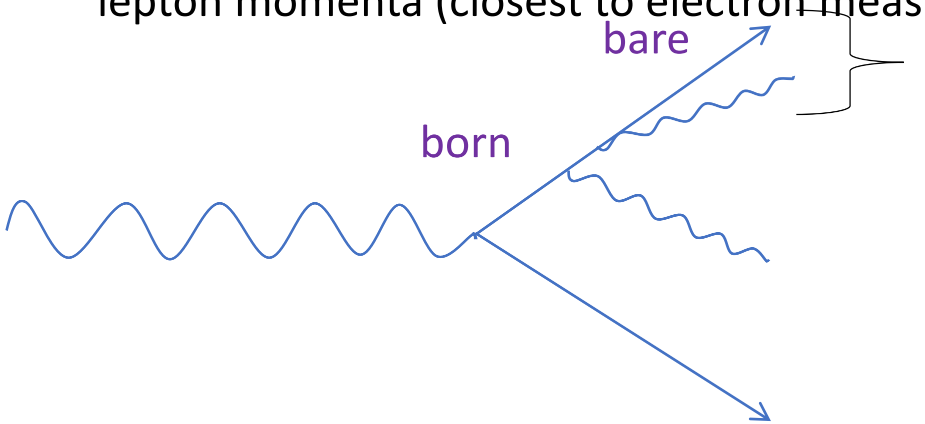
# What is a final-state electron/muon?

- Electrons and muons emit FSR photon radiation (and lots of it, especially in the collinear limit, especially for electrons).
  - For muons we measure the charged particle track, photon energy is not included
  - For electrons we cluster calorimeter cells and most collinear radiation will be included in the energy measurement
- We can define lepton momenta as:
  1. Born leptons – as if FSR never happened (not what we measure, not actually measureable…)
  2. Bare leptons – after all FSR (closest to muon measurement)



# What is a final-state electron/muon?

- Electrons and muons emit FSR photon radiation (and lots of it, especially in the collinear limit, especially for electrons).
  - For muons we measure the charged particle track, photon energy is not included
  - For electrons we cluster calorimeter cells and most collinear radiation will be included in the energy measurement
- We can define lepton momenta as:
  1. Born leptons – as if FSR never happened (not what we measure, not actually measureable…)
  2. Bare leptons – after all FSR (closest to muon measurement)
  3. Dressed leptons – with the momenta of close-by photons “clustered” into the lepton momenta (closest to electron measurement)




dressed : typically a $\Delta R < 0.1$ cone is used, but a jet algorithm may be better

# What is a final-state electron or muon?

- Electron and muon final states can be very different for bare leptons, but much closer for born and dressed leptons

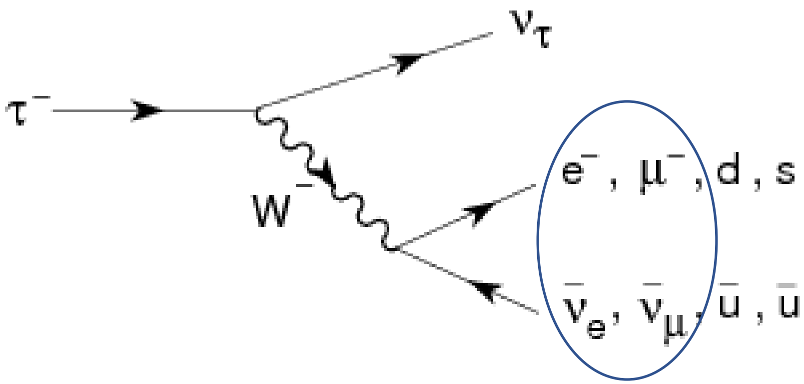
- It is often argued that dressed should be used for both to allow for *easy combination of final states.* Also bare versus dressed is much closer for muons than bare versus dressed for electrons

- Similarly, fiducial phase space cuts often harmonized for the two, requiring a small extrapolation in phase space for one

  - But electrons != muons
  - We may want to retain sensitivity to differences (cf LHCb…)
  - Perhaps it is better to measure both and publish correlations between uncertainties, and make choices that are best for each individual channel

# What is a final-state tau?

Recall: unstable (=0.1 mm

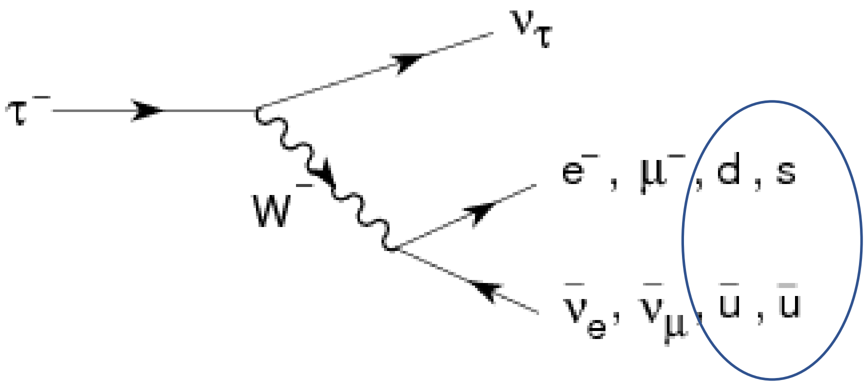



<u>Leptonic decays</u>

- The final state particles are electrons/muons and neutrinos
- Define fiducial phase-space with those (but we careful to check lepton efficiencies as e.g. impact parameter cuts can be less efficient for leptons from taus)

# What is a final-state tau?

Recall: unstable   (=0.1 mm



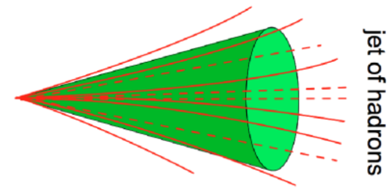

$\tau^\pm \rightarrow \pi^\pm \pi^0 \nu$

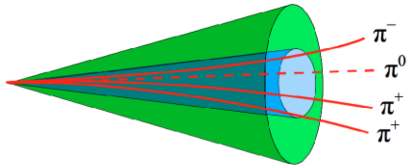
$\tau^\pm \rightarrow \pi^\pm \nu$

$\tau^\pm \rightarrow \pi^\pm \pi^0 \pi^0 \nu$

$\tau^\pm \rightarrow \pi^\pm \pi^\pm \pi^{\Box} \nu$

$\tau^\pm \rightarrow \pi^\pm \pi^\pm \pi^{\Box} \pi^0 \nu$



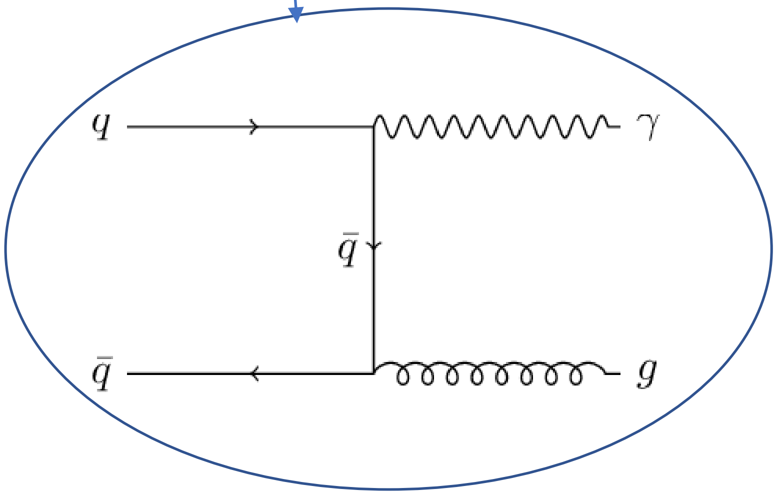



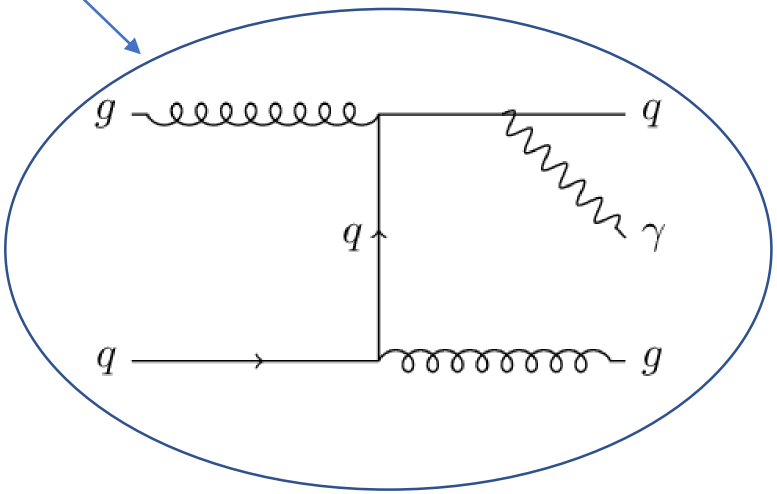

<u>Hadronic decays</u>

- Final state particles are hadrons (→jets) and neutrinos
- Such a definition alone is complicated due to the large number of hadrons not from taus
- Experimental cuts reject backgrounds based on features of the jets, which are hard to replicate at the particle-level
- In this case a compromise might be best: require a hadron in the jet to have come from a prompt tau (this is not quite “final-state based”)
- There is not much experience here and more detailed studies would be interesting

# What is a final-state photon?

- Analyses usually measure prompt, isolated photons
- Recall: Prompt means not-from-a-hadron-decay
- But photons can be further divided into those from the hard scatter and those from parton fragmentation




A particle-level isolation criteria is necessary to replicate the isolation applied at reco-level

Note in principle this could also be done for prompt leptons, but it is much less important

# What is a final-state neutrino?

Invisible in the detector and existence inferred by $p_T^{miss}$

Recall:

$$\mathbf{E}_T^{\text{miss}} = \underbrace{\underbrace{-\sum_{\substack{\text{selected}\\\text{electrons}}} \mathbf{p}_T^{e}}_{\mathbf{E}_T^{\text{miss},e}} \underbrace{-\sum_{\substack{\text{accepted}\\\text{photons}}} \mathbf{p}_T^{\gamma}}_{\mathbf{E}_T^{\text{miss},\gamma}} \underbrace{-\sum_{\substack{\text{accepted}\\\tau\text{-leptons}}} \mathbf{p}_T^{\tau_{\text{had}}}}_{\mathbf{E}_T^{\text{miss},\tau_{\text{had}}}} \underbrace{-\sum_{\substack{\text{selected}\\\text{muons}}} \mathbf{p}_T^{\mu}}_{\mathbf{E}_T^{\text{miss},\mu}} \underbrace{-\sum_{\substack{\text{accepted}\\\text{jets}}} \mathbf{p}_T^{\text{jet}}}_{\mathbf{E}_T^{\text{miss},\text{jet}}}}_{\text{hard term}} \underbrace{\underbrace{-\sum_{\substack{\text{unused}\\\text{tracks}}} \mathbf{p}_T^{\text{track}}}_{\mathbf{E}_T^{\text{miss},\text{soft}}}}_{\text{soft term}}$$

- Sometimes the momenta of (prompt?) invisible* particles are summed
- An alternative is to take – the sum of all the visible particles within detector acceptance, which is closer to what we measure but can be a bit complicated. E.g. what $p_T$ of hadrons are we actually sensitive to?

(More on this later)

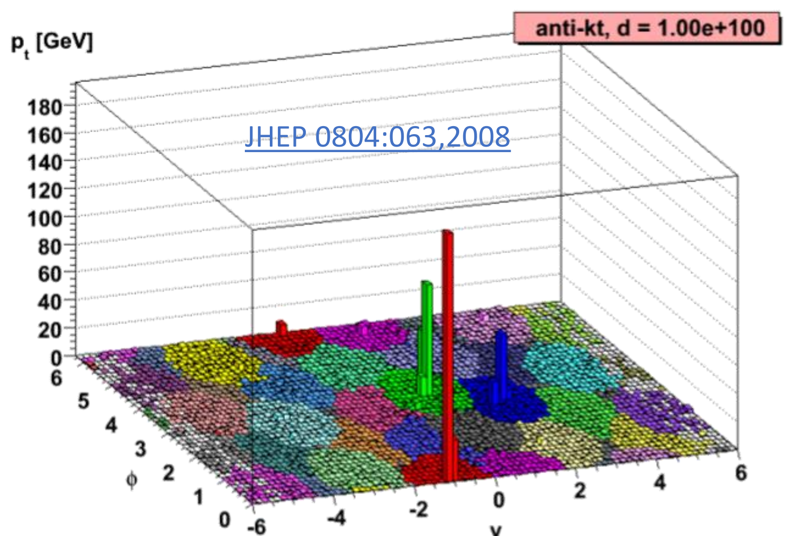
See also Rivet tutorial

*neutrinos are indistinguishable from BSM invisible particles

# What is a final-state parton?

- Partons radiate more partons which hadronize.
- Run a jet algorithm on the final-state particles
  - Form a list of particles (this would be clusters / tracks at reco-level)
  - Merge the smallest pair according to a "distance" parameter
  - Iterate
- Algorithms assign each hadron to a jet. The energy/momentum of the jet represents the energy/momentum of the parton from the hard scatter
- Think carefully about what is included as inputs: Muons? Neutrinos?

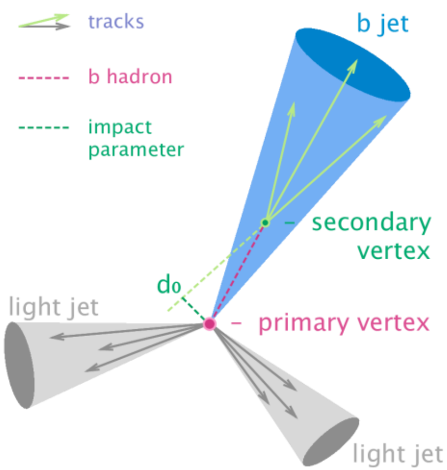
Note: Depending on the reconstruction code, an electron will often form a jet initially. We remove these jets using overlap removal at both reco- and truth-level (e.g. remove any jets with $\Delta R < 0.4$ from a prompt electron)




JHEP 0804:063,2008

# What is a final-state b-jet

- Recall decay length for a 20 GeV b-hadrons ~2 mm, they are therefore unstable and not included as final state particle
- However we select them experimentally by making displaced vertex selection cuts




- Common "compromise" is to associate the *non-final state b*-hadrons to jets.
- If a jet contains a b-hadron it is considered a particle-level b-jet

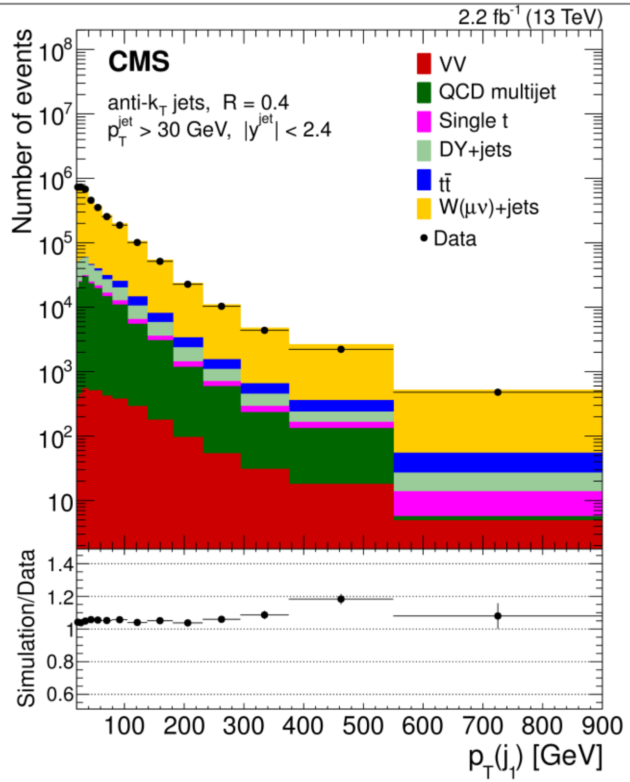
See Rivet tutorial for more details

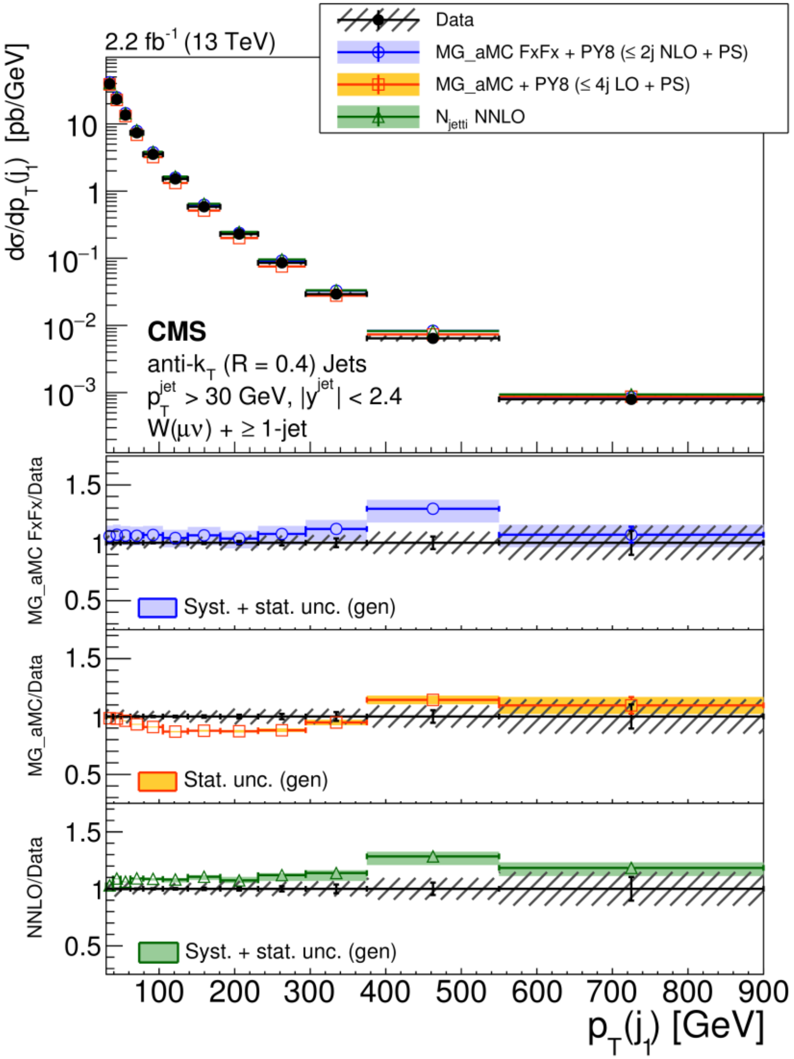
# Examples of data analysis

# Examples: CMS W+jets

Fiducial phase-space: (Follow data analysis cuts closely)

- One dressed ($\Delta R<0.1$) prompt muon with $p_T > 25$ GeV, $|\eta|<2.4$
- $m_T > 50$ GeV (using muon and prompt truth neutrino)
- Jets (exclude neutrinos and above muon): anti-$k_T$ (R=0.4) with $p_T>30$ GeV, $|y|<2.4$, and $\Delta R>0.4$ from the muon




Phys. Rev. D 96 (2017) 072005

Rivet: CMS_2017_I1610623

# Examples: CMS EWK W+dijet

arXiv:1903.04040 (Submitted to EPJC)

No Rivet routine

Data analysis cuts:

jet 1 $p_T$ > 50 GeV, jet 2 $p_T$ > 30 GeV

$m_{jj}$ > 200 GeV

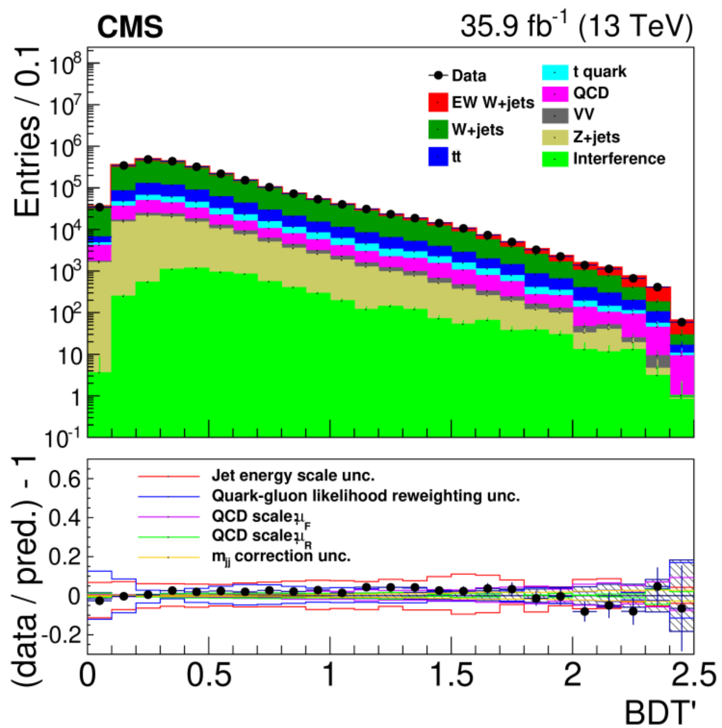
$p_T$ balance cut

$p_T$ lepton > 20 GeV, $|\eta|$ < 2.4

Fiducial phase-space:

$l\nu$ + *dijets* final state

$m_{jj}$ > 120 GeV and jet $p_T$ > 25 GeV

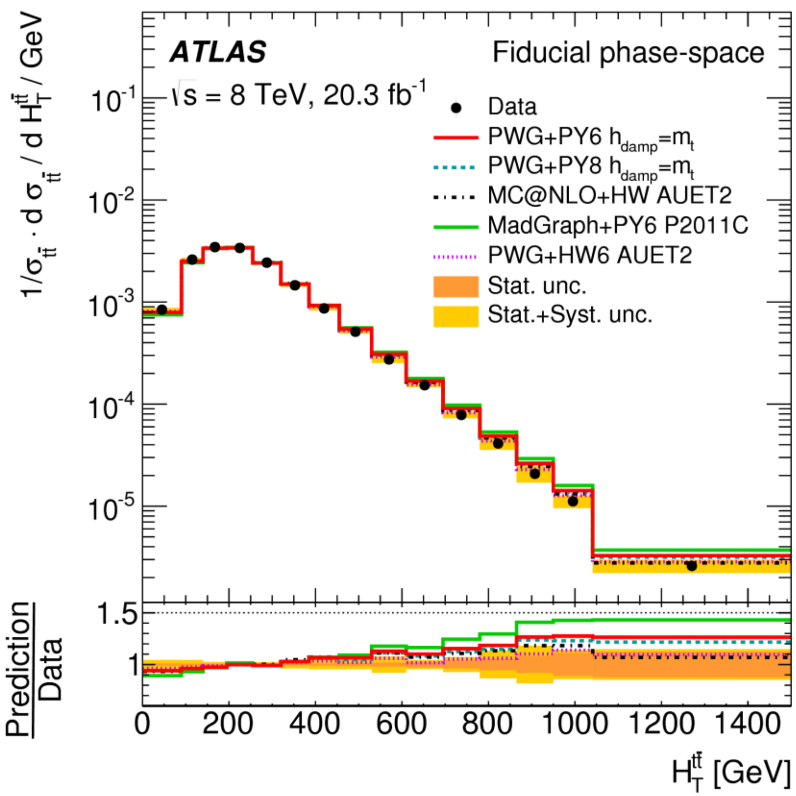



⬄☜⌖☎⌖𝓮𝓻𝓮𝓻➁🖬 6.23 ⌖ 0.12 (stat) ⌖ 0.61 (syst) pb

- Why such a large extrapolation?

# More recent top results

[Eur. Phys. J. C76 (2016) 538](#)
ATLAS_2015_I1404878




Eur. Phys. J. C 78 (2018) 487
DOI: 10.1140/epjc/s10052-018-5904-z
CERN-EP-2017-276
27th June 2018

**Measurement of the inclusive and fiducial $t\bar{t}$ production cross-sections in the lepton+jets channel in $pp$ collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector**

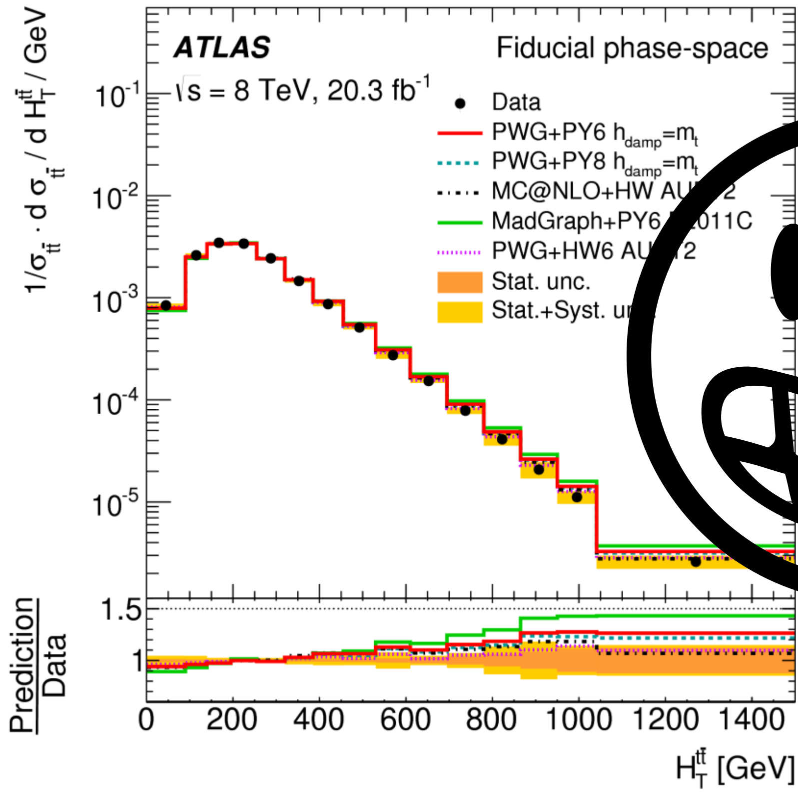
The ATLAS Collaboration

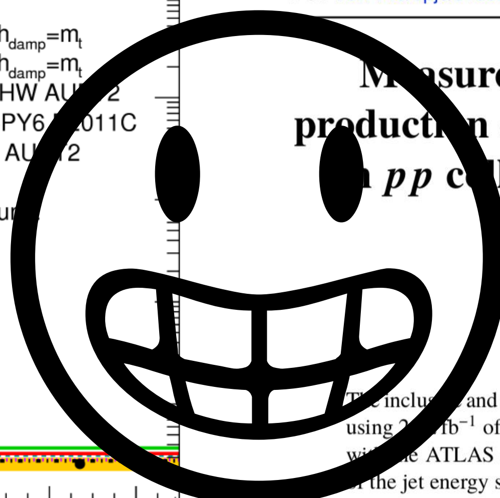
The inclusive and fiducial $t\bar{t}$ production cross-sections are measured in the lepton+jets channel using 20.2 fb$^{-1}$ of proton–proton collision data at a centre-of-mass energy of 8 TeV recorded with the ATLAS detector at the LHC. Major systematic uncertainties due to the modelling of the jet energy scale and $b$-tagging efficiency are constrained by separating selected events into three disjoint regions. In order to reduce systematic uncertainties in the most important background, the $W$+jets process is modelled using $Z$+jets events in a data-driven approach. The inclusive $t\bar{t}$ cross-section is measured with a precision of 5.7% to be $\sigma_{\text{inc}}(t\bar{t})$ = 248.3 ± 0.7 (stat.) ± 13.4 (syst.) ± 4.7 (lumi.) pb, assuming a top-quark mass of 172.5 GeV. The result is in agreement with the Standard Model prediction. The cross-section is also measured in a phase space close to that of the selected data. The fiducial cross-section is $\sigma_{\text{fid}}(t\bar{t})$ = 48.8 ± 0.1 (stat.) ± 2.0 (syst.) ± 0.9 (lumi.) pb with a precision of 4.5%.

# More recent top results

[Eur. Phys. J. C76 (2016) 538]

ATLAS_2015_I1404878




ATLAS EXPERIMENT

Eur. Phys. J. C 78 (2018) 487

DOI: 10.1140/epjc/s10052-018-5904-z

CERN-EP-2017-276

27th June 2018


## Measurement of the inclusive and fiducial $t\bar{t}$ production cross-sections in the lepton+jets channel in $pp$ collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector


The ATLAS Collaboration

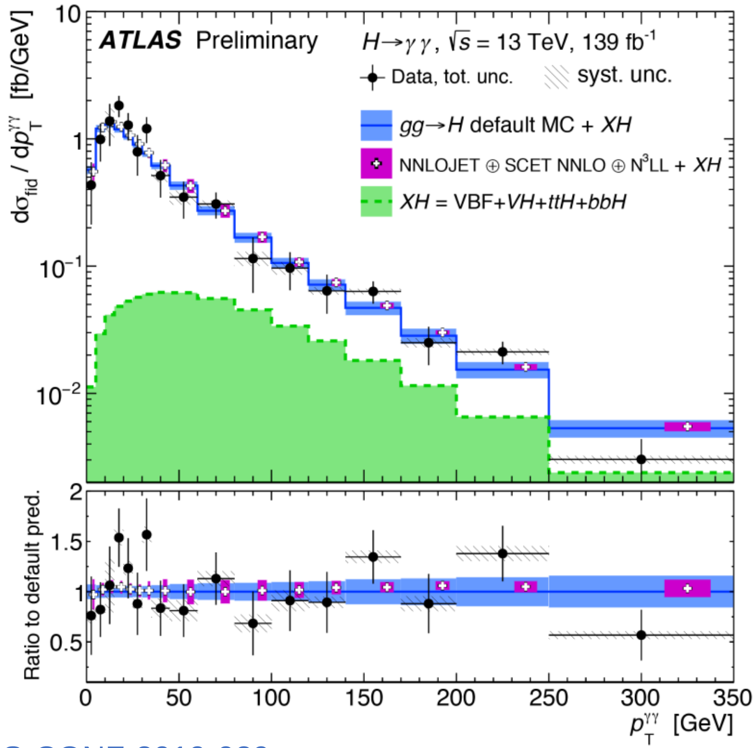


The inclusive and fiducial $t\bar{t}$ production cross-sections are measured in the lepton+jets channel using [illegible] fb$^{-1}$ of proton–proton collision data at a centre-of-mass energy of 8 TeV recorded with the ATLAS detector at the LHC. Major systematic uncertainties due to the modelling of the jet energy scale and $b$-tagging efficiency are constrained by separating selected events into three disjoint regions. In order to reduce systematic uncertainties in the most important background, the $W$+jets process is modelled using $Z$+jets events in a data-driven approach. The inclusive $t\bar{t}$ cross-section is measured with a precision of 5.7% to be $\sigma_{\rm inc}(t\bar{t})$ = 248.3 ± 0.7 (stat.) ± 13.4 (syst.) ± 4.7 (lumi.) pb, assuming a top-quark mass of 172.5 GeV. The result is in agreement with the Standard Model prediction. The cross-section is also measured in a phase space close to that of the selected data. The fiducial cross-section is $\sigma_{\rm fid}(t\bar{t})$ = 48.8 ± 0.1 (stat.) ± 2.0 (syst.) ± 0.9 (lumi.) pb with a precision of 4.5%.

# Higgs results

Table 2: Particle-level selections for the fiducial measurements. The photon isolation, $\sum p_{\mathrm{T}}^{i}/p_{\mathrm{T}}^{\gamma}$, is defined as the sum of the $p_{\mathrm{T}}$ of charged particles within $\Delta r < 0.2$ of the photon.

| Objects | Fiducial definition |
|---|---|
| Photons | $\lvert\eta\rvert < 2.37$ (excluding $1.37 < \lvert\eta\rvert < 1.52$), $\sum p_{\mathrm{T}}^{i}/p_{\mathrm{T}}^{\gamma} < 0.05$ |
| Jets | anti-$k_t$, $R = 0.4$, $p_{\mathrm{T}} > 30$ GeV, $\lvert y\rvert < 4.4$ |
| Diphoton | $N_\gamma \geq 2$, $105\,\mathrm{GeV} < m_{\gamma\gamma} < 160\,\mathrm{GeV}$, $p_{\mathrm{T}}^{\gamma_1}/m_{\gamma\gamma} > 0.35$, $p_{\mathrm{T}}^{\gamma_2}/m_{\gamma\gamma} > 0.25$ |

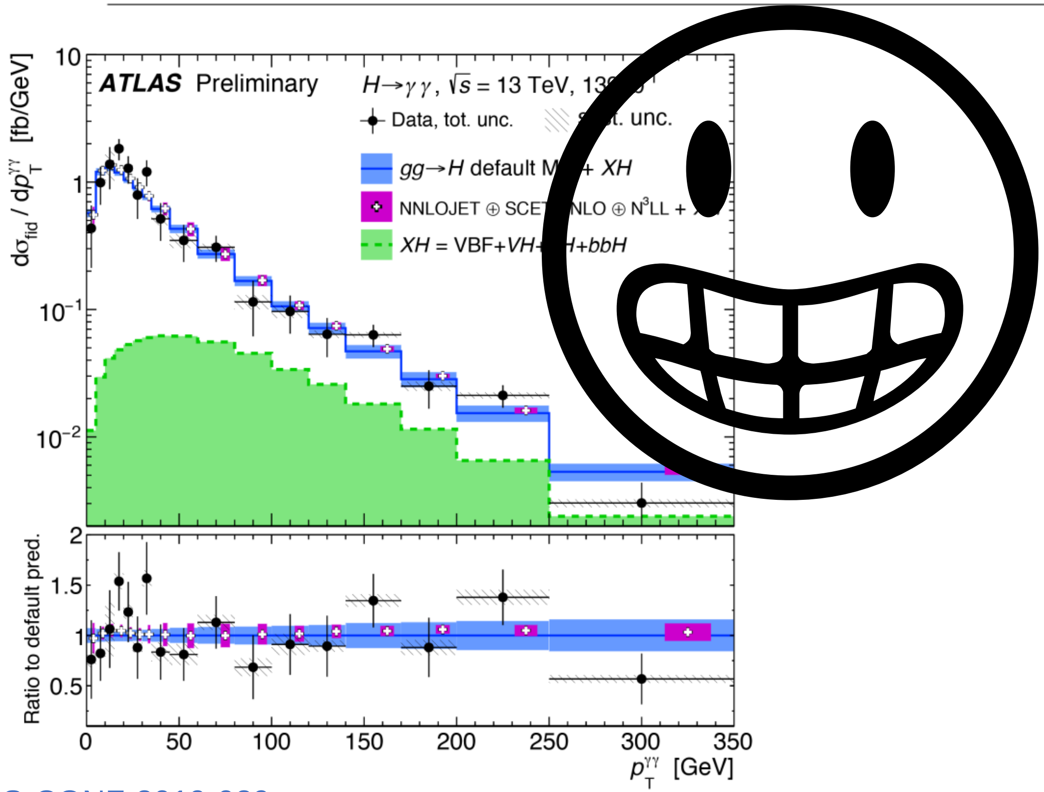



ATLAS-CONF-2019-029

# Higgs results

Table 2: Particle-level selections for the fiducial measurements. The photon isolation, $\sum p_T^i/p_T^\gamma$, is defined as the sum of the $p_T$ of charged particles within $\Delta r < 0.2$ of the photon.

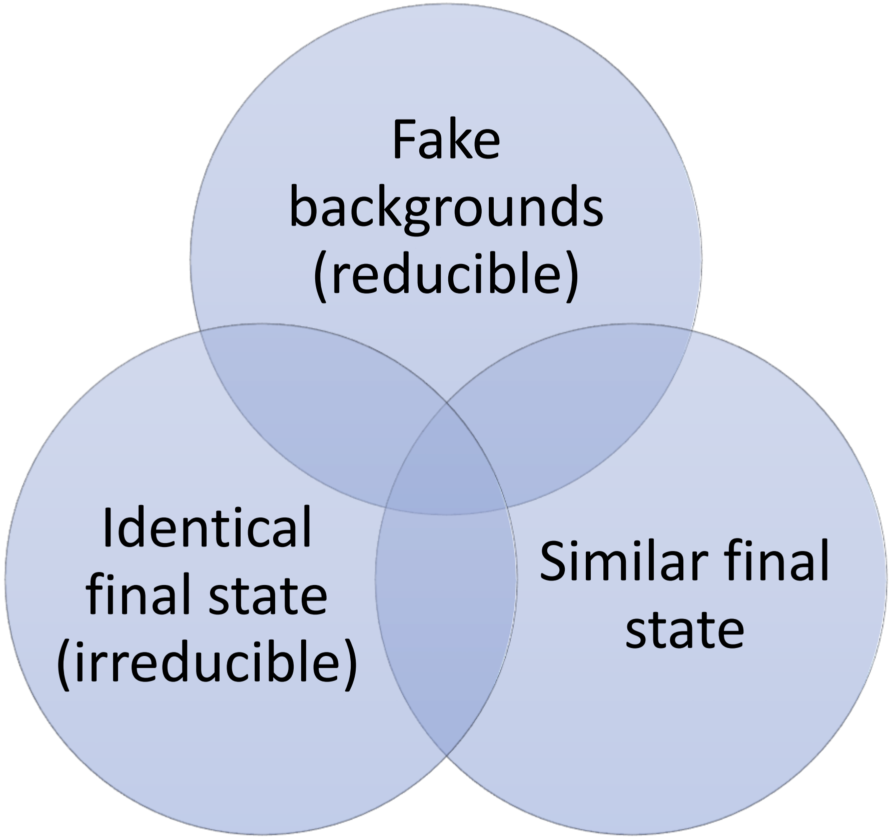
| Objects | Fiducial definition |
|---|---|
| Photons | $\|\eta\| < 2.37$ (excluding $1.37 < \|\eta\| < 1.52$), $\sum p_T^i/p_T^\gamma < 0.05$ |
| Jets | anti-$k_t$, $R = 0.4$, $p_T > 30$ GeV, $\|y\| < 4.4$ |
| Diphoton | $N_\gamma \geq 2$, $105\,\text{GeV} < m_{\gamma\gamma} < 160\,\text{GeV}$, $p_T^{\gamma_1}/m_{\gamma\gamma} > 0.35$, $p_T^{\gamma_2}/m_{\gamma\gamma} > 0.25$ |




ATLAS-CONF-2019-029

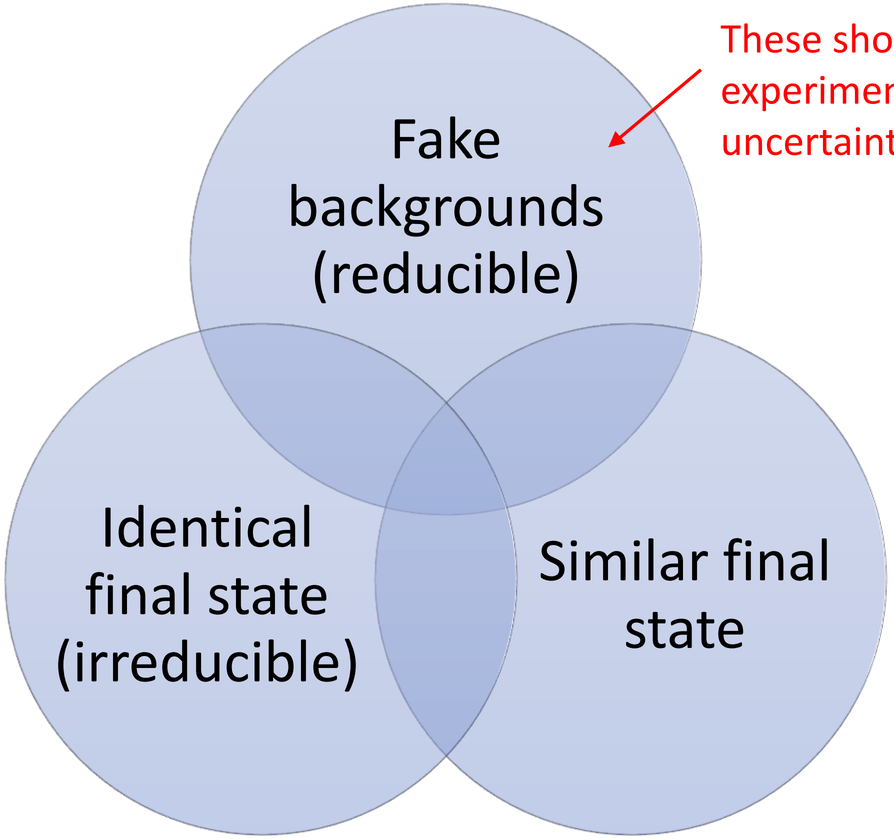
# Background subtraction (or not?)

# Background subtraction (or not?)



# Background subtraction (or not?)

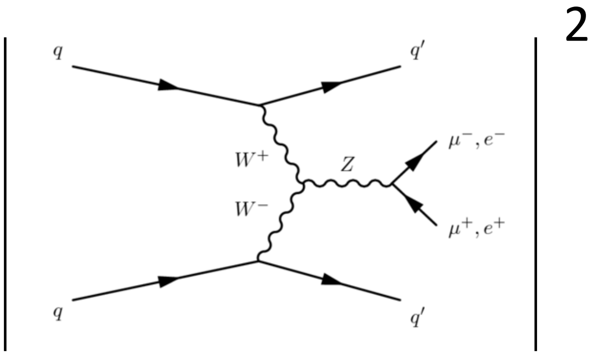
These should be subtracted by experimentalists and systematic uncertainties quantified

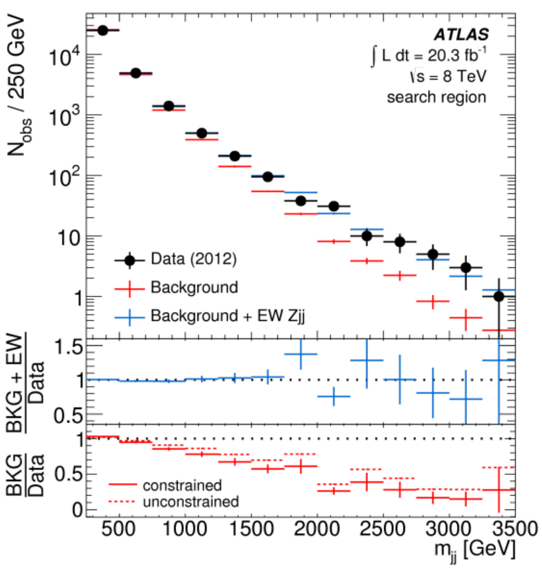


# Identical final-states

- Quantum mechanics tells us processes with identical final states will interfere and cannot be calculated separately
- Sometimes this is a huge effect and separating out diagrams breaks gauge invariance
- Other times the effect is quite small and attempts are made to isolate certain processes

# Identical final-states example: $l^+l^-$ VBF



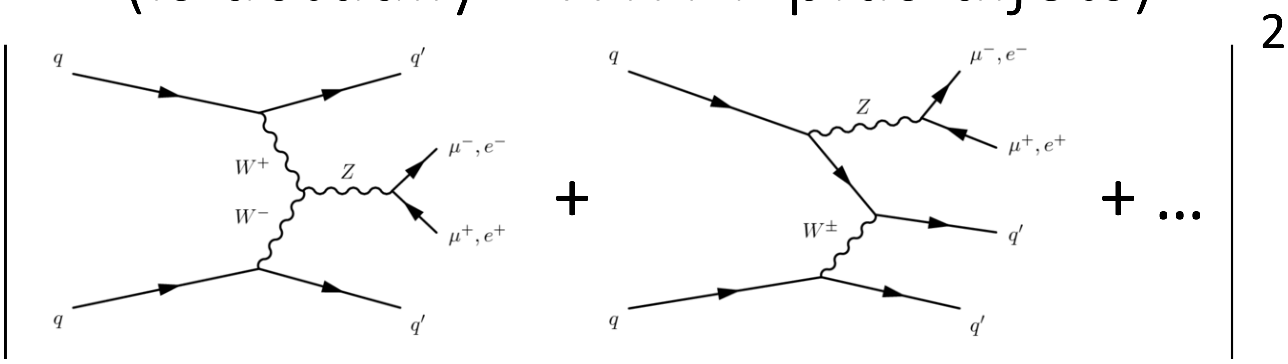



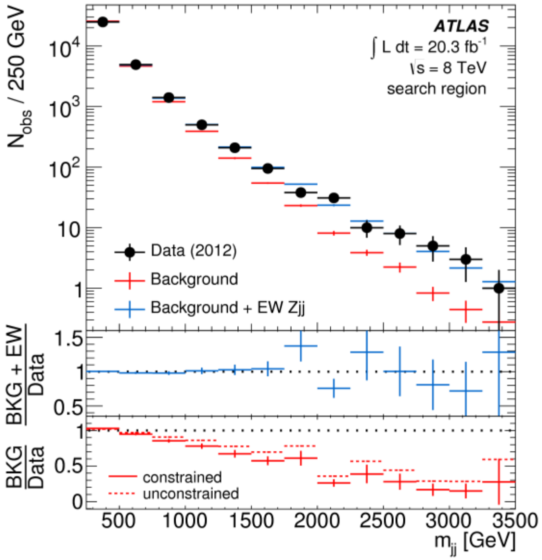

JHEP04(2014)031

Rivet: ATLAS_2014_I1279489

# Identical final-states example : $l^+l^-$ VBF

(is actually EWK $l^+l^-$ plus dijets)



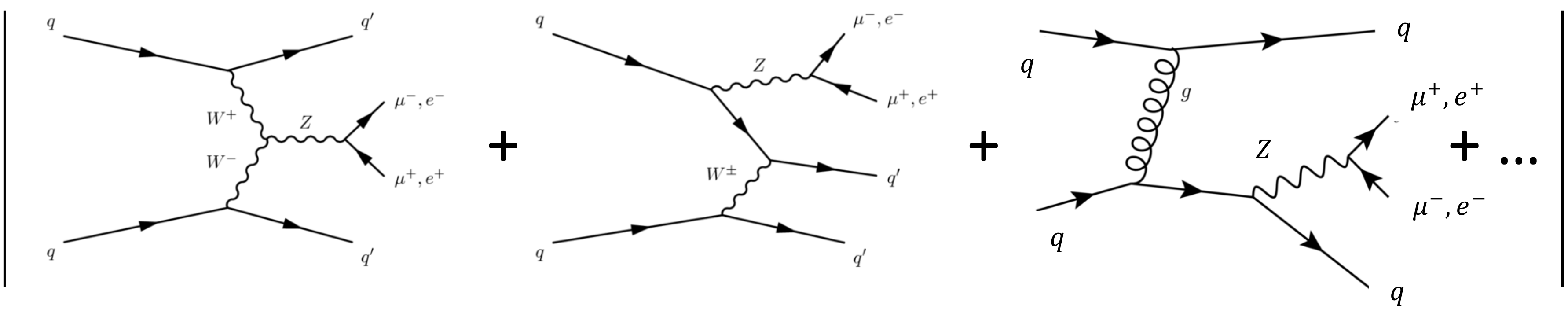

JHEP04(2014)031

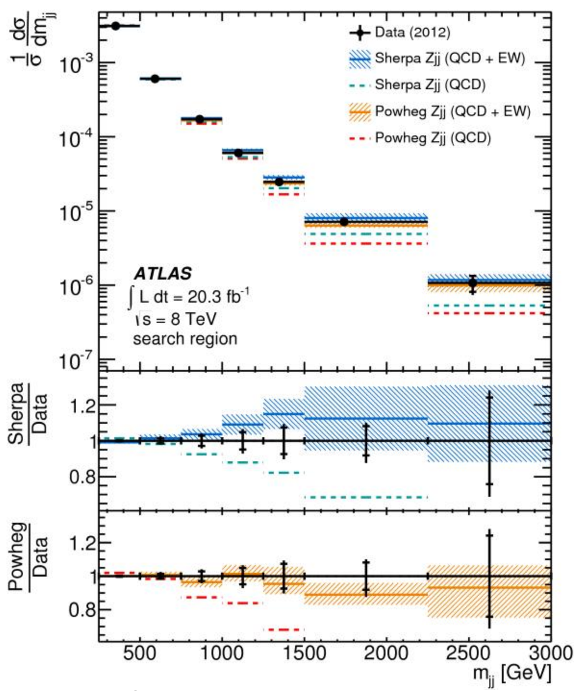
Rivet: ATLAS_2014_I1279489

"The VBF process cannot be isolated due to a large destructive interference with the electroweak Z-boson bremsstrahlung process."

# Identical final-states example : $l^+l^-$ VBF

## (is *really* actually $l^+l^-$ plus dijets)



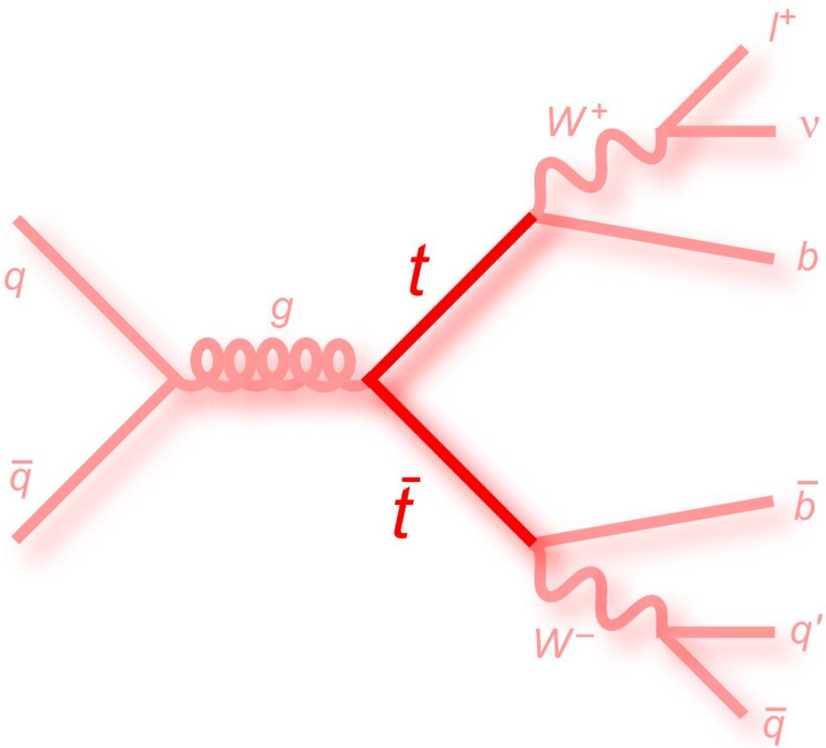




JHEP04(2014)031

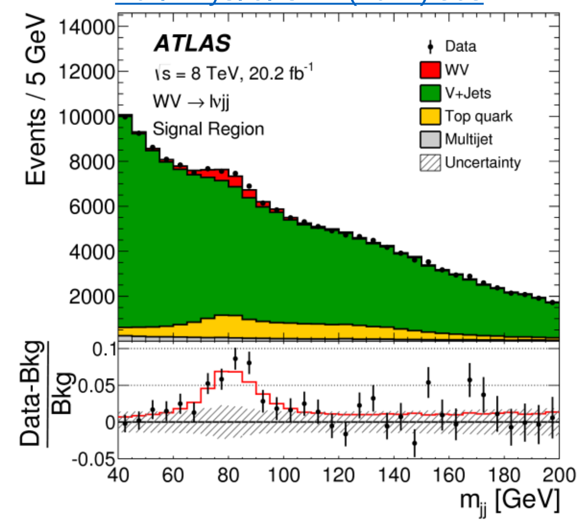
Rivet: ATLAS_2014_I1279489

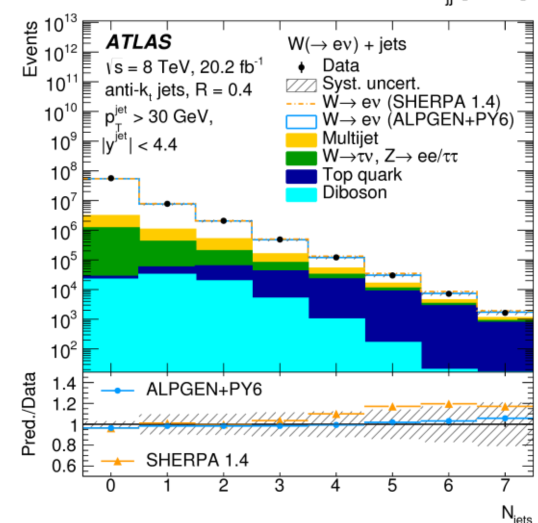
Its usually good to also include an inclusive measurement with no assumptions or subtractions made

# Example: ttbar is actually WW+jets is actually l+$E_T^{miss}$+jets



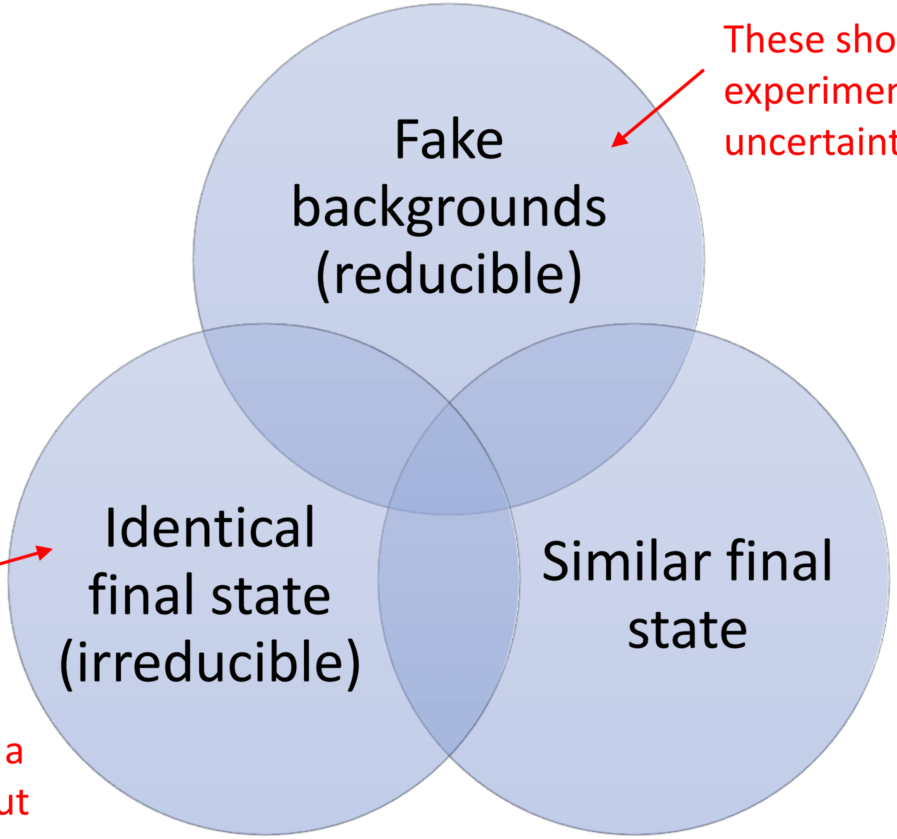

Eur. Phys. J. C 77 (2017) 563




JHEP 05 (2018) 077

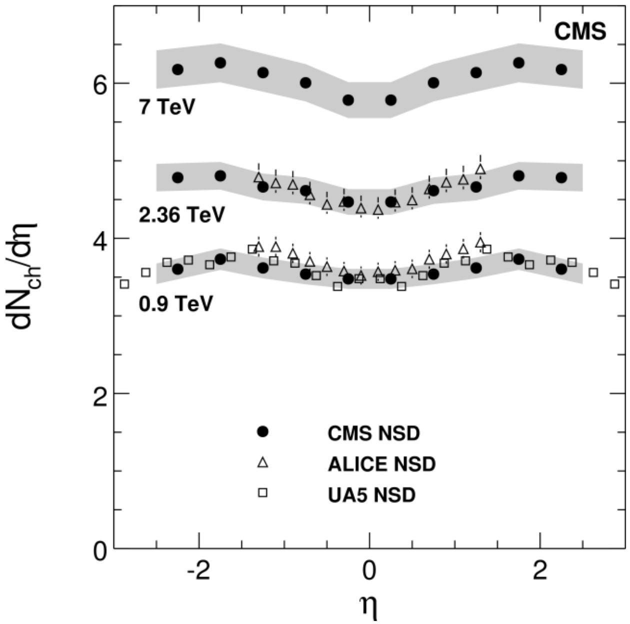
# Background subtraction (or not?)




These should be subtracted by experimentalists and systematic uncertainties quantified

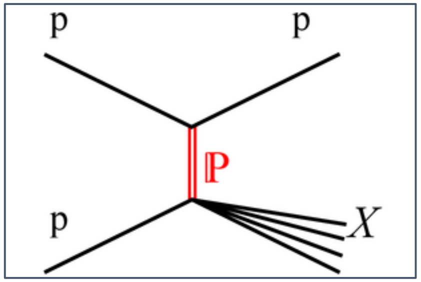
In general it is dangerous to isolate certain Feynman diagrams. In some cases it is a reasonable approximation but treat with caution and try to measure an inclusive observable too!

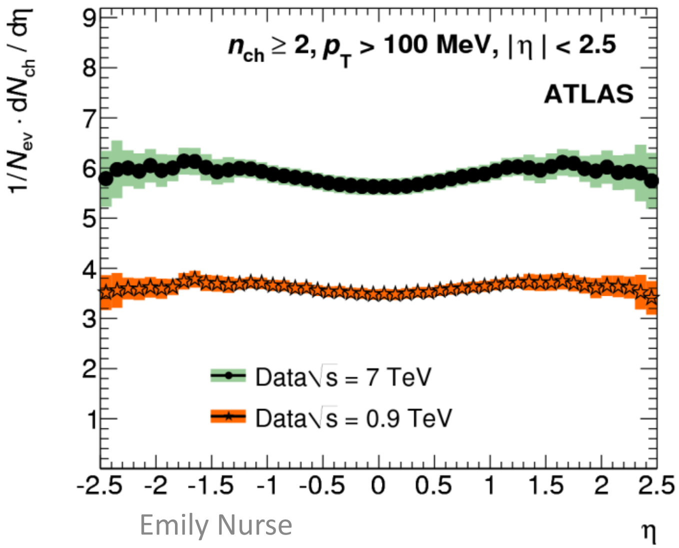
# Similar final-states example: Soft-QCD




Phys. Rev. Lett. 105 (2010) 022002
Rivet: CMS_2010_S8656010

Single Diffractive subtracted off

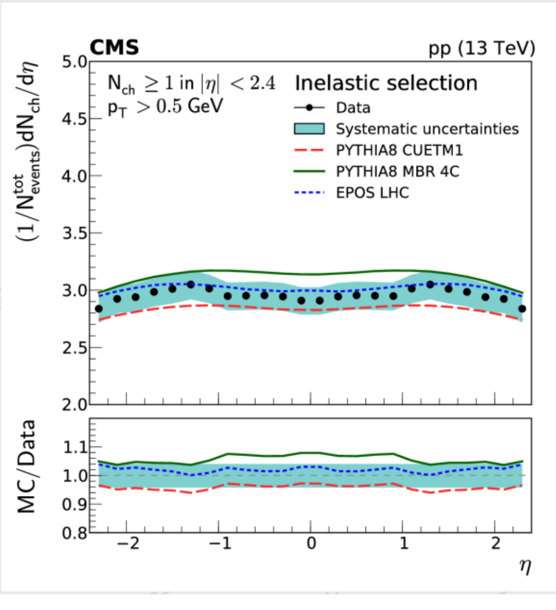



New J. Phys. 13 (2011) 053033
Rivet: ATLAS_2010_S8918562

Final-state particle definition

# Similar final-states example: Soft-QCD

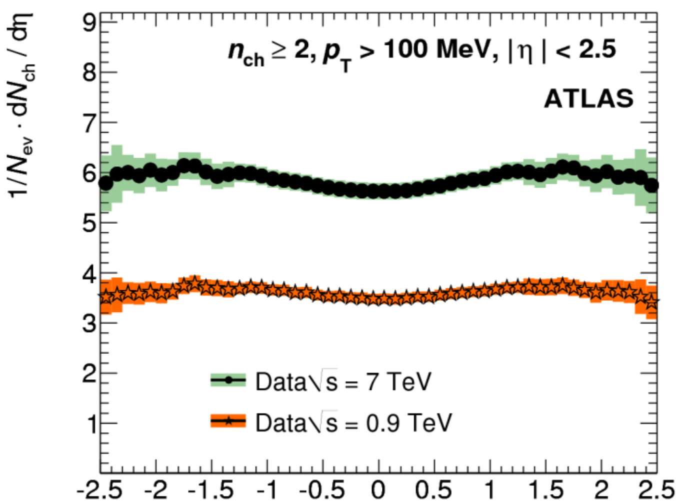



Eur. Phys. J. C 78 (2018) 697

Rivet: CMS_2018_I1680318

Final-state particle definition






New J. Phys. 13 (2011) 053033

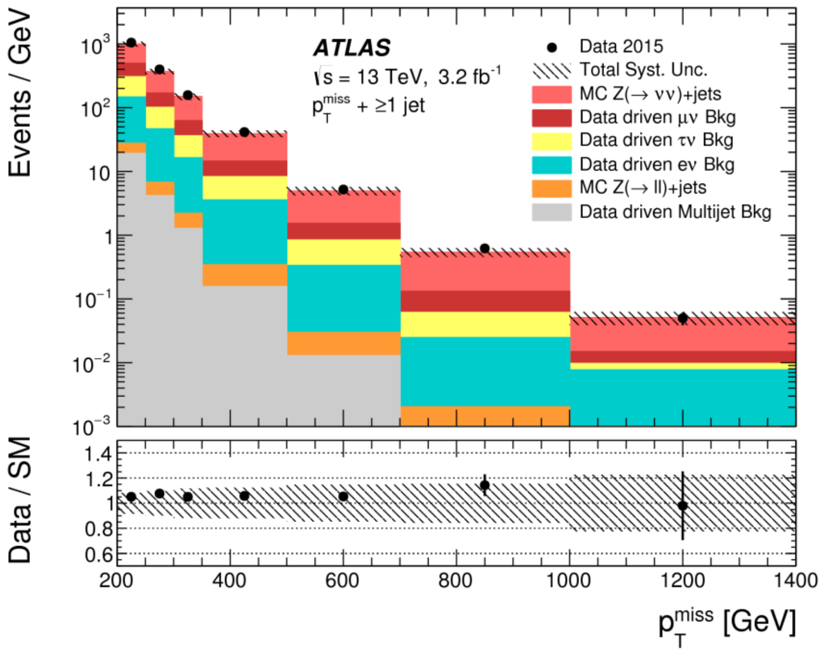
Rivet: ATLAS_2010_S8918562

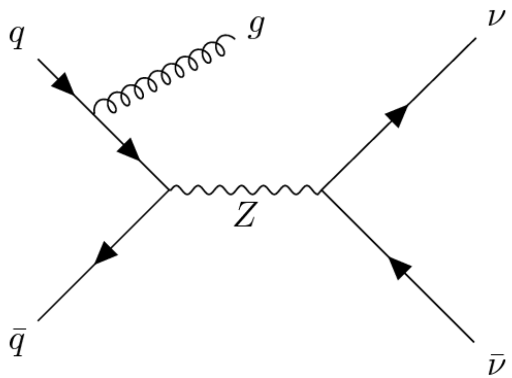
Final-state particle definition

# Similar final-states example: $p_T^{miss}$ + jets

[Eur. Phys. J. C 77 (2017) 765]

Rivet: ATLAS_2017_I1609448




Fiducial phase-space:

$p_T^{miss}$ + jet(s)

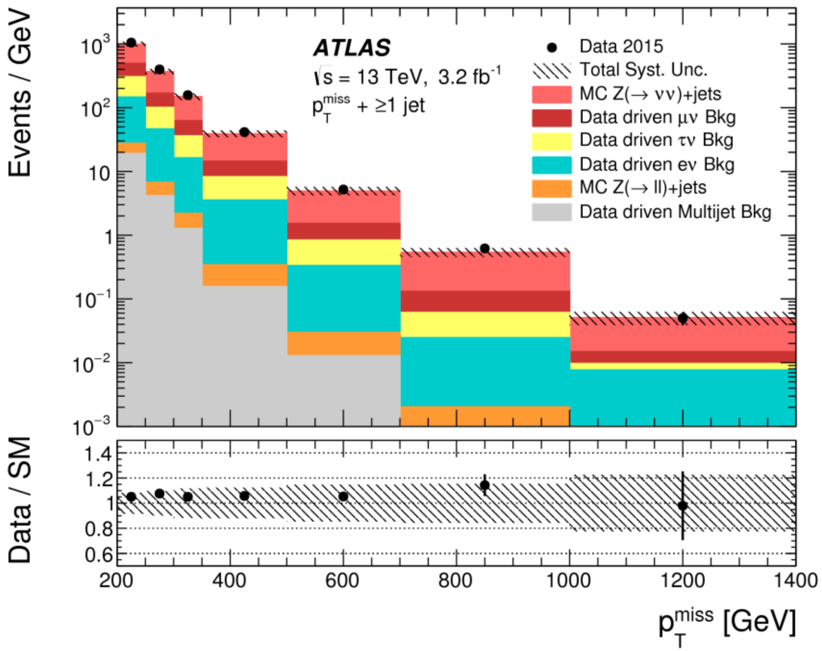
No charged leptons with $|\eta|$< 2.5, $p_T$ > 7 GeV

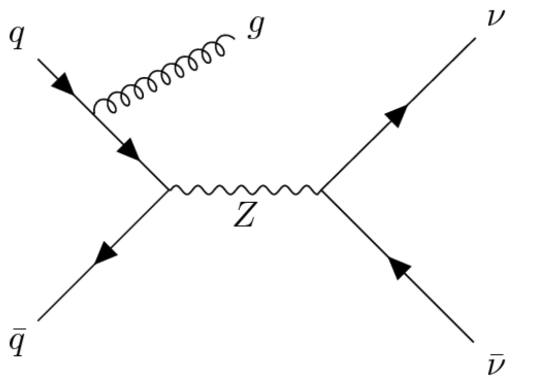
+ others….

# Similar final-states example: $p_T^{miss}$ + jets

Eur. Phys. J. C 77 (2017) 765

Rivet: ATLAS_2017_I1609448



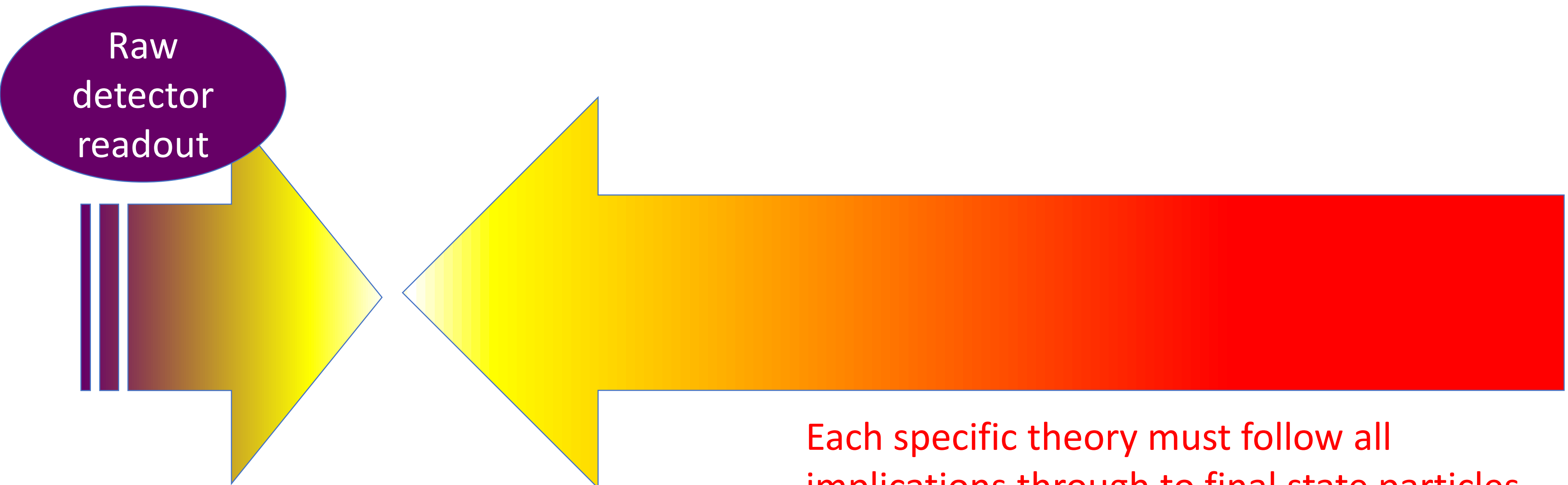




Fiducial phase-space:
$p_T^{miss}$ + jet(s)
No charged leptons with $|\eta|$< 2.5, $p_T$ > 7 GeV
+ others

W→l$\nu$ with "out of acceptance" leptons contribute ~ the same as Z→$\nu\nu$!

- In this paper: background determined using control regions+MC, and subtracted
- Perhaps these W's should be included as part of the "signal" definition?
  - This leaves the data uncontaminated and as close to "what we see" as possible.
  - Removes dependence on control regions and MC extrapolation between regions
- But be careful of fiducial phase-space definitions: e.g. out-of-acceptance muons should be included as *invisible* in a particle-level $p_T^{miss}$ definition!

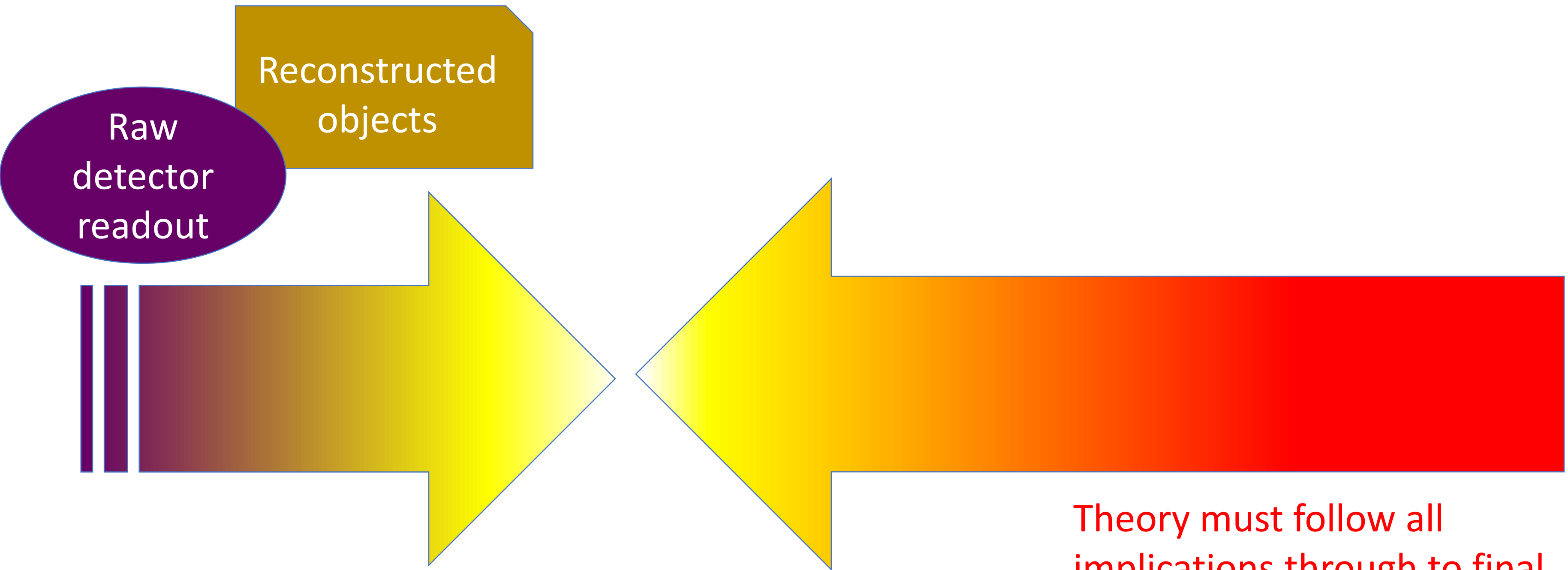
# Where to compare nature to our ideas?




Zero model dependence.

Each specific theory must follow all implications through to final state particles and full detector simulation, including specific run conditions and time-dependent calibrations.

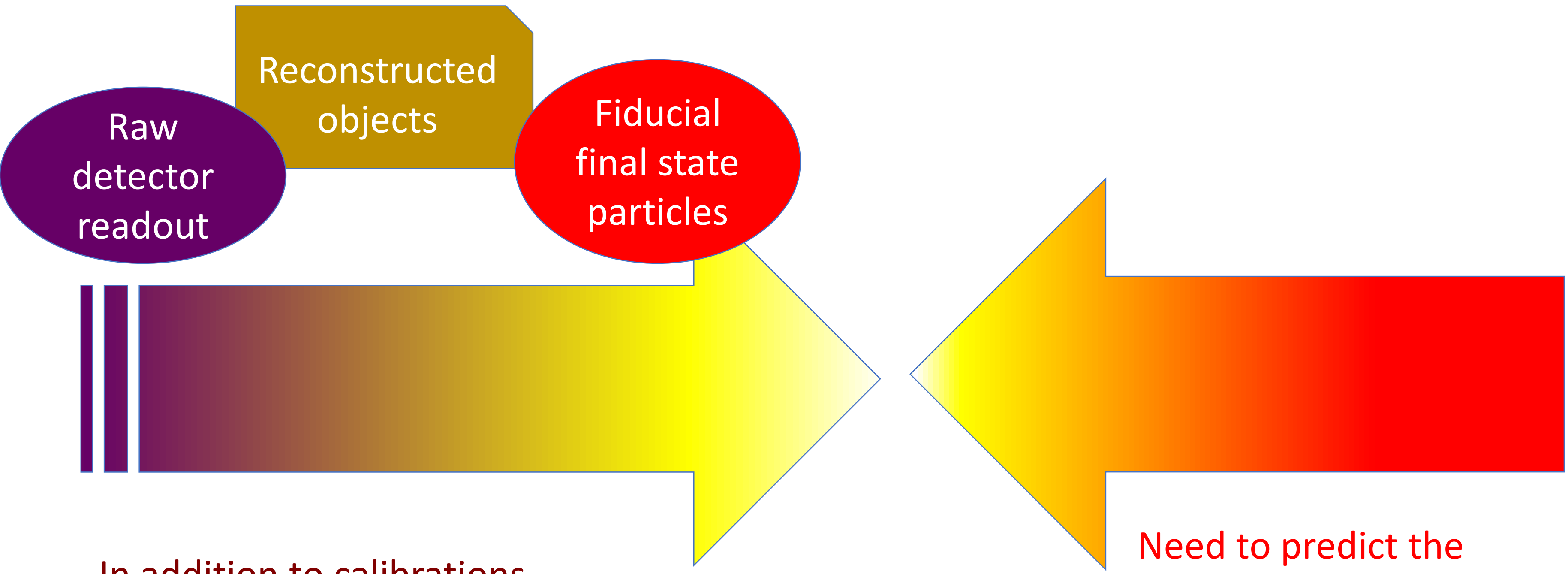
# Where to compare nature to our ideas?




Calibrations applied which may have some dependence on models, but minimal and dependence can be controlled.

Theory must follow all implications through to final state and at least some parameterised approximation of detector resolution and efficiency.

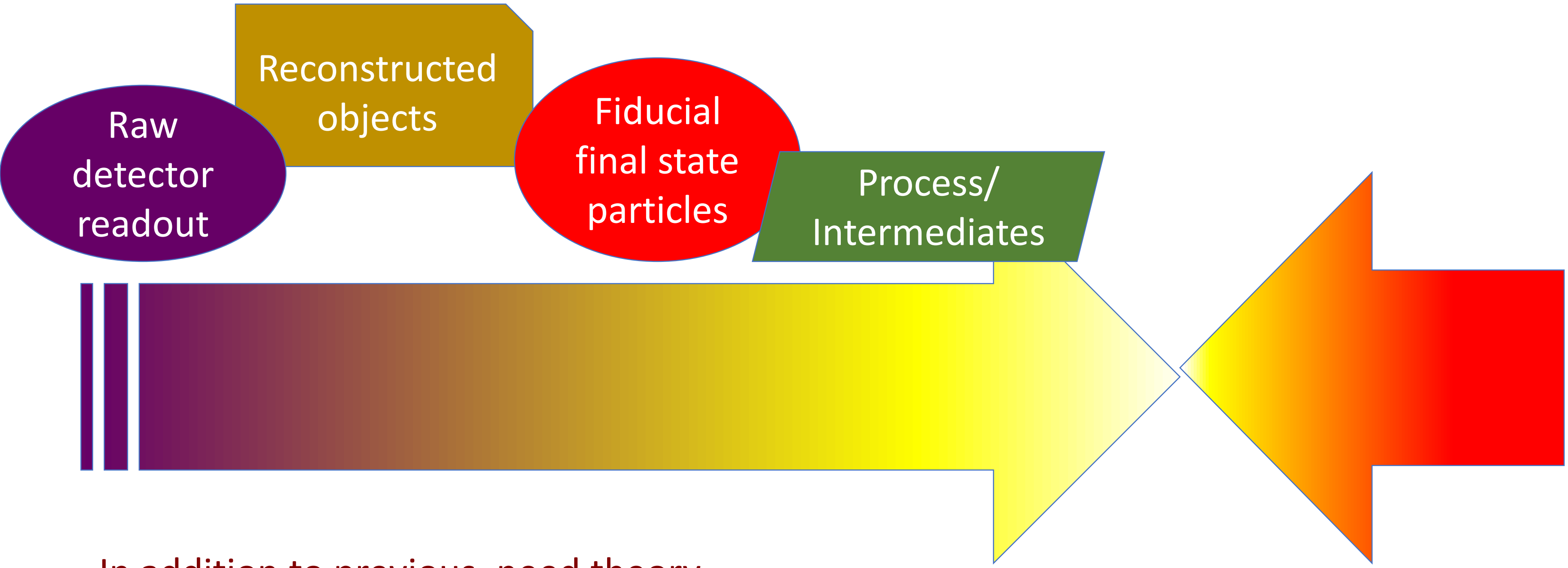
# Where to compare nature to our ideas?




In addition to calibrations, need unfolding for resolution and efficiency, though uncertainties can generally be controlled.

Need to predict the exclusive final state.

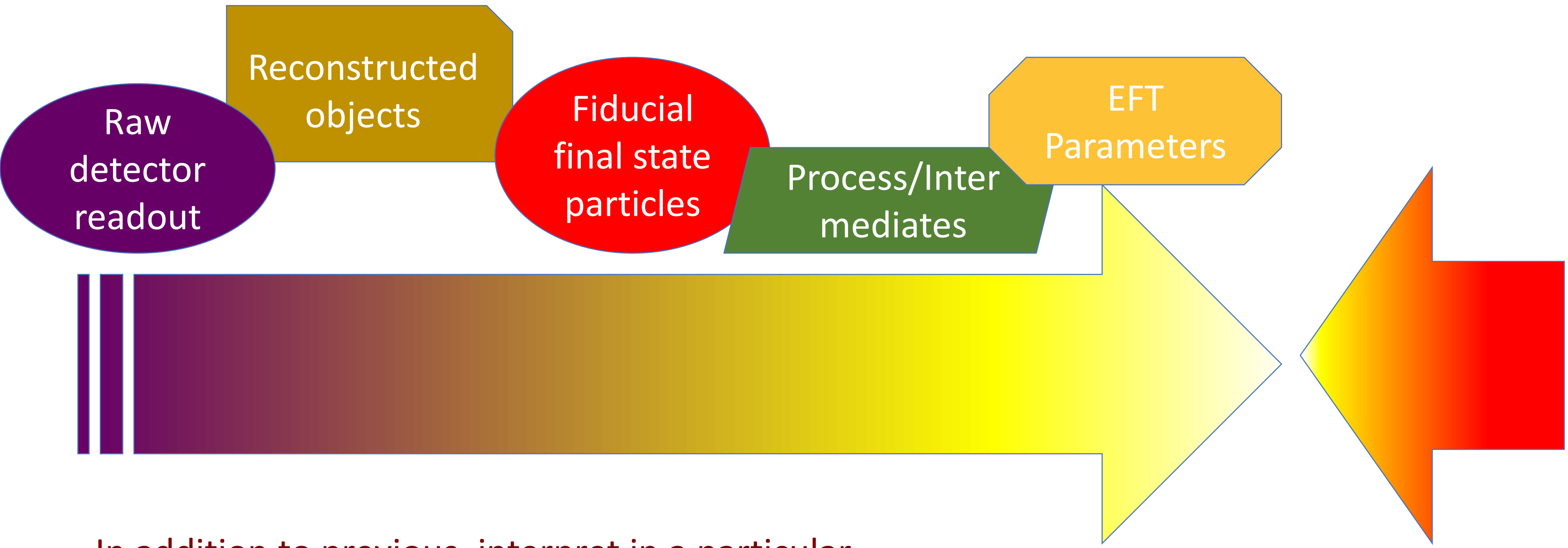
# Where to compare nature to our ideas?




In addition to previous, need theory extrapolations into unobserved regions, theory background subtractions, and corrections for soft/long distance physics.

Can integrate over inclusive phase spaces and ignore soft/long distance physics.

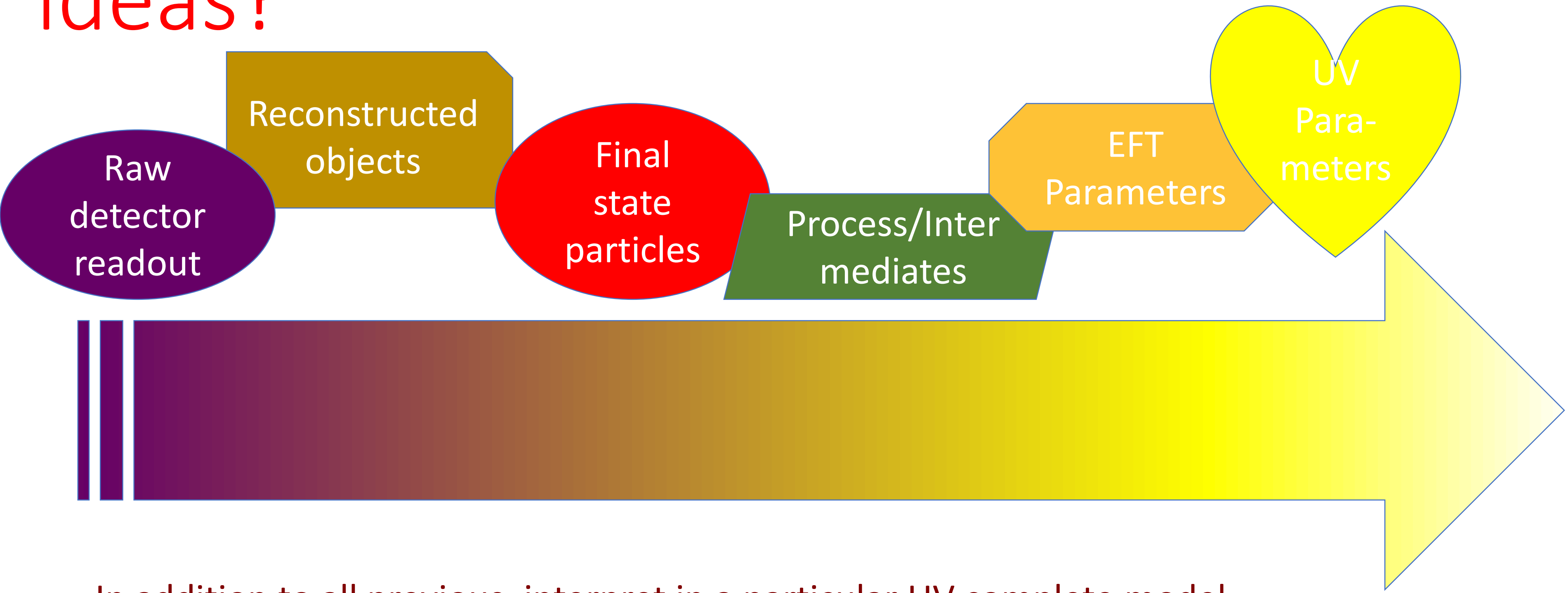
# Where to compare nature to our ideas?




In addition to previous, interpret in a particular (simplified?) model.

Need to think about running from high energies, but not much else…

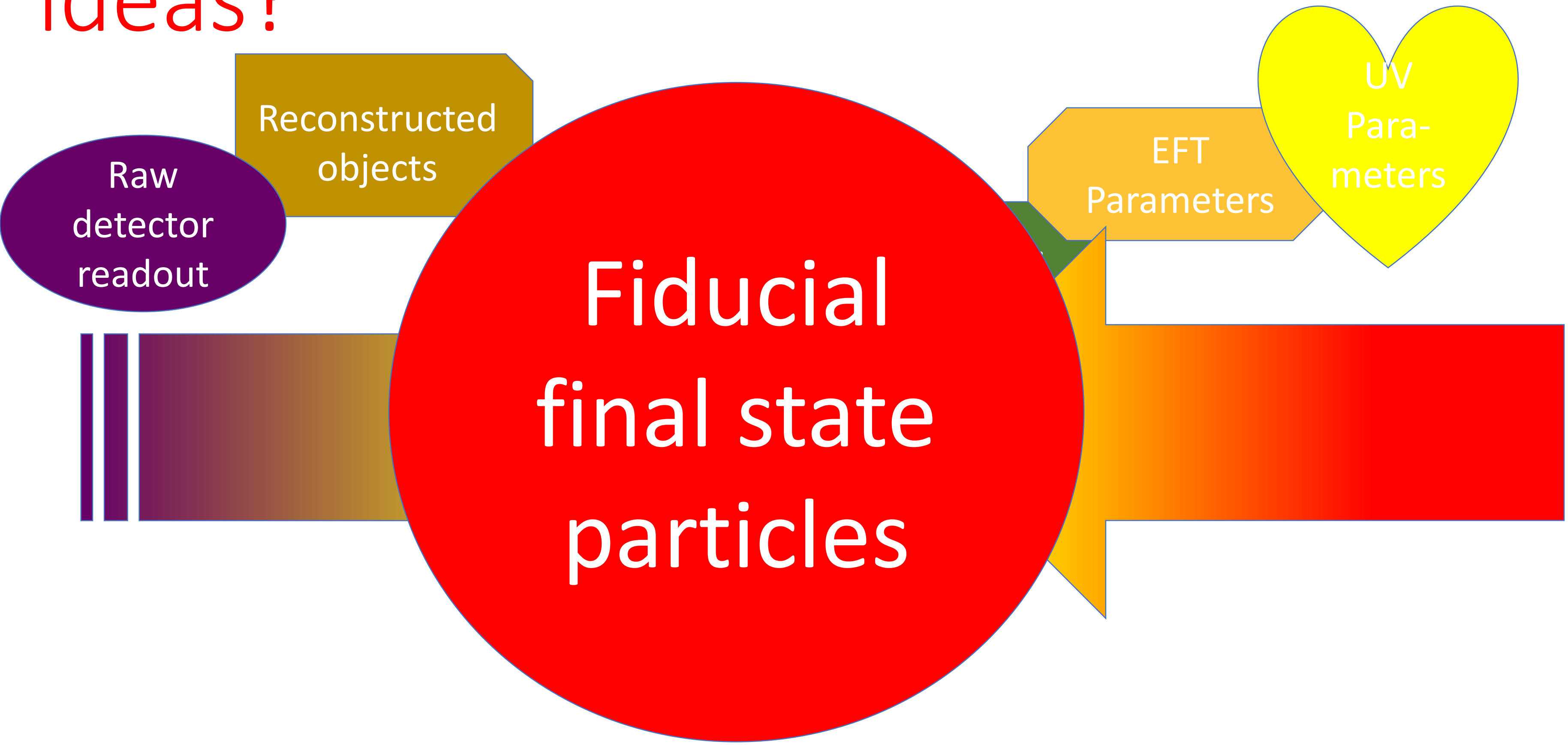
# Where to compare nature to our ideas?




In addition to all previous, interpret in a particular UV complete model.

Have a good idea, then play golf.

# Where to compare nature to our ideas?



# BSM searches : detector corrections

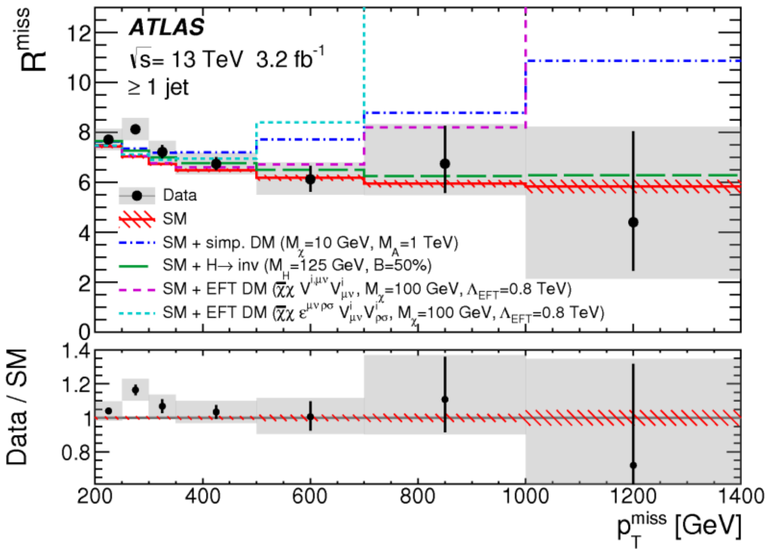
- Typically done at reco-level, the paper sets limits on parameters in a given model by comparing to reco-level MC predictions
- But data in a given analysis can be sensitive to many BSM theories, how to re-interpret these?
  - Many people working on how to reinterpret reco-level results, e.g. by using fast detector simulation (can be interfaced with Rivet)
  - Another option is to correct for detector effects and allow comparisons with “truth-level” predictions. Some sensitivity may be lost due to binning but much easier to reinterpret

Distinction between BSM search and SM measurement becomes blurred:
- We measure the data in certain final-states and compare to the best SM predictions.
- We should do this more in regions particularly sensitive to new physics
- Important to stick to the ”measuring a final-state” philosophy

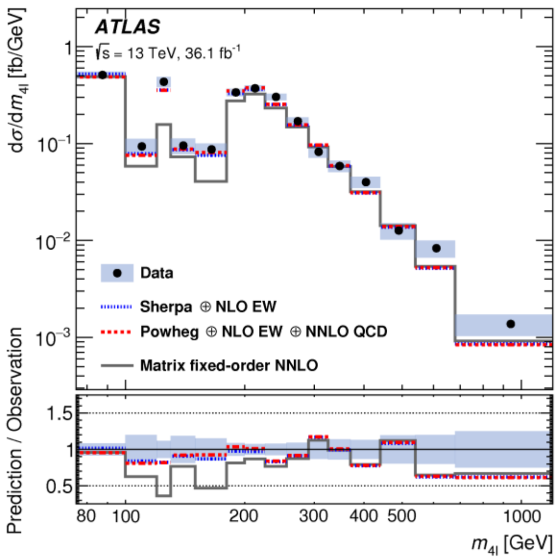
See Contur (https://contur.hepforge.org) and Thursday’s tutorial which uses all analyses in Rivet to constrain BSM parameter space.
Sometimes surprises occur and a certain model pops up in multiple final states we havn’t thought of yet.

# BSM searches : detector corrections

Eur. Phys. J. C 77 (2017) 765



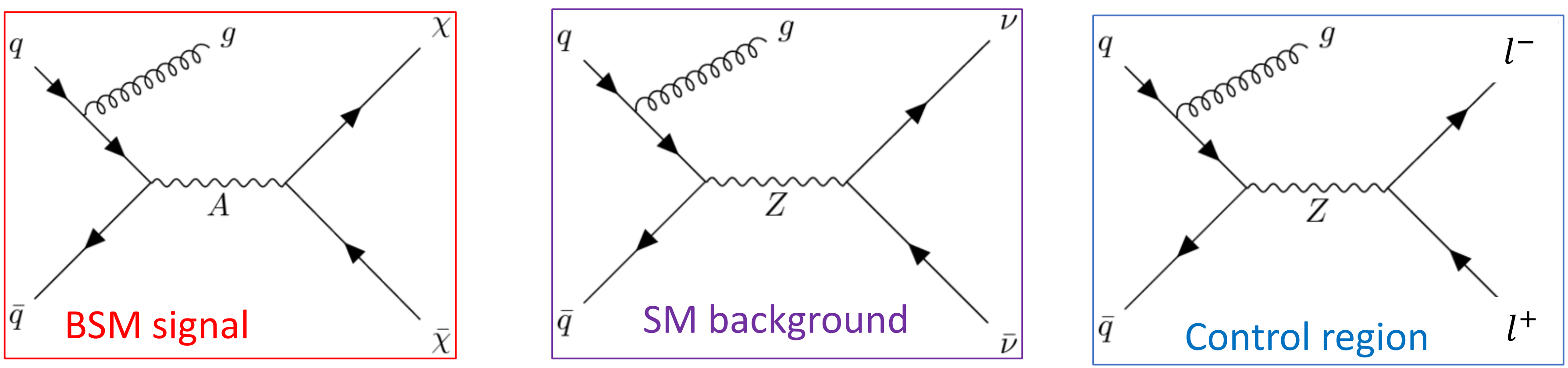

JHEP 04 (2019) 048




FYI: There are not many BSM motivated measurements like this, get involved!

# BSM searches: backgrounds

- Often backgrounds to BSM searches are predicted using constraints from “control regions”. These can be:
  - similar final states, or
  - the same final-state with different kinematic cuts
- This can be very useful, especially when modelling is bad, and can reduce systematic uncertainties a lot.




But it can limit re-interpretation, what if a BSM theory leads to final state particles in the control region too?

# BSM searches: backgrounds and unfolding

One possible solution:

- Unfold and publish the signal region and the control region with correlation information
- Control region constraints can then be made for models that allow it but not for others

These are all quite new ideas, lots of room for studies and analyses, get involved!

# Summary

- ✓ Correct (carefully) for detector effects (maybe even for BSM searches)
- ✓ Measure in your fiducial phase-space
- ✓ Think carefully about subtracting “backgrounds”
- ✓ Keep the data as clean and model independent as possible

# Summary

- ✓ Correct (carefully) for detector effects (maybe even for BSM searches)
- ✓ Measure in your fiducial phase-space
- ✓ Think carefully about subtracting “backgrounds”
- ✓ Keep the data as clean and model independent as possible

## And the rewards will follow