RIGA TECHNICAL UNIVERSITY

Centre of High-Energy Physics and Accelerator Technologies

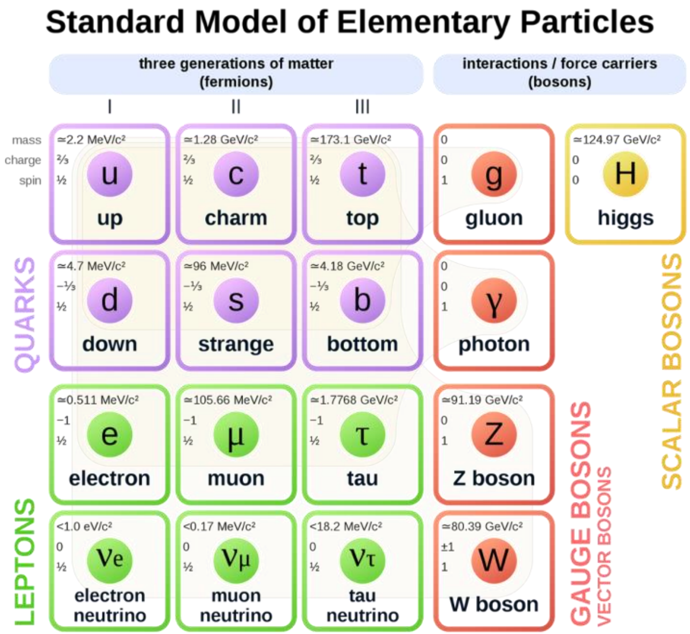
Top pair process simulation and jet energy studies

For 2nd CERN Baltic Conference

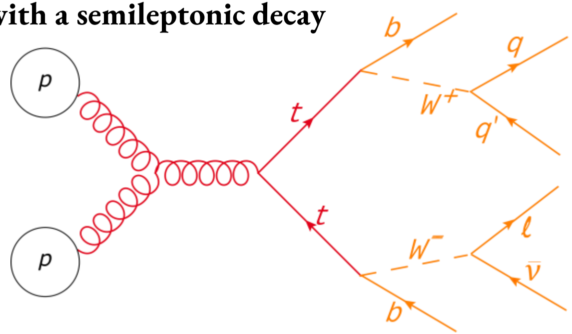
Kārlis Dreimanis, Markus Seidel, Andris Potrebko

11.10.2022

- Top quark – the heaviest elementary particle in the Standard model.
- Top-quark pair (ttbar, $t\bar{t}$) process – the most common process with top quarks.



Top-quark pair process with a semileptonic decay



- $t\bar{t}$ lepton+jets decay channel allows to measure the top quark mass separately from the anti-top quark.

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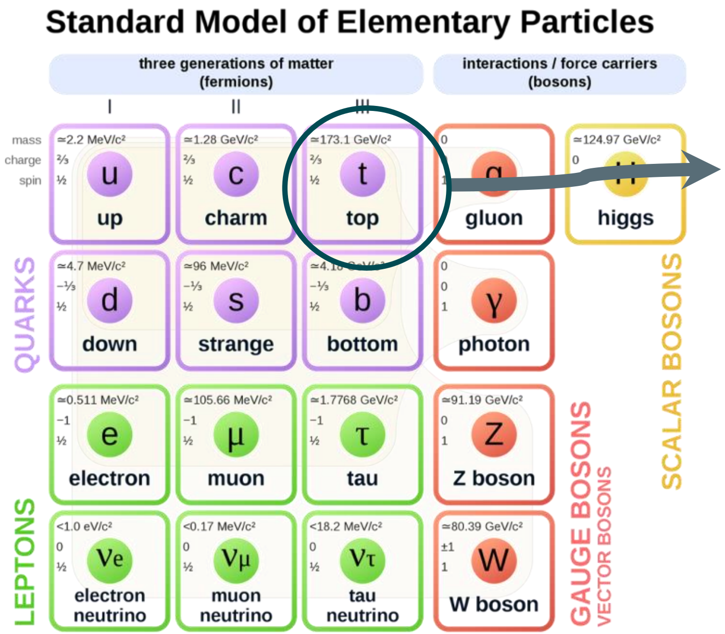

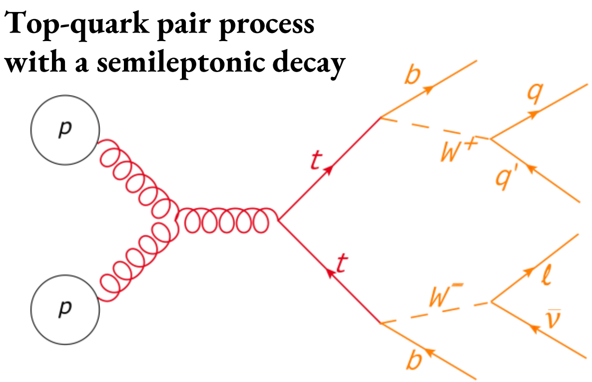

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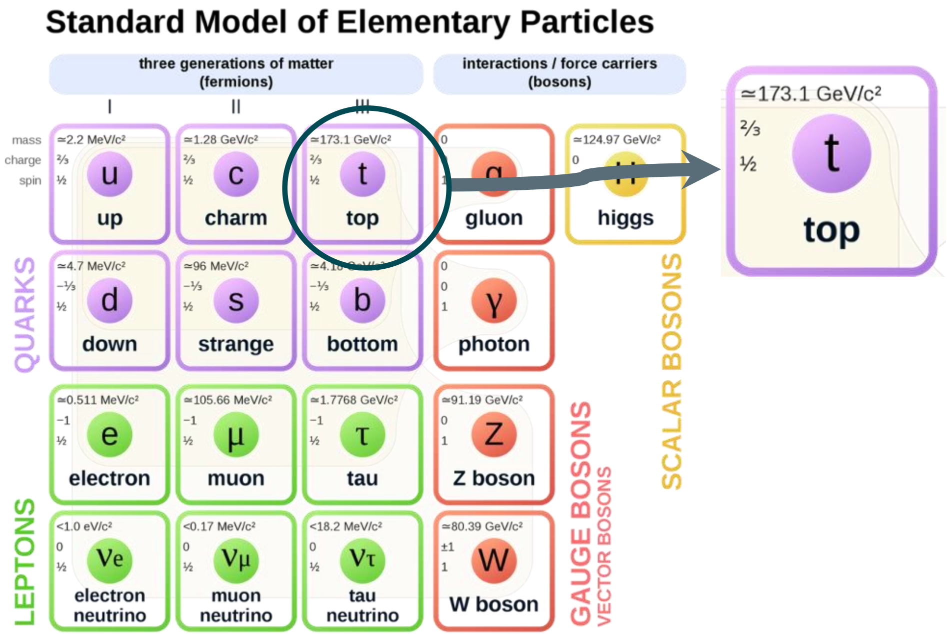

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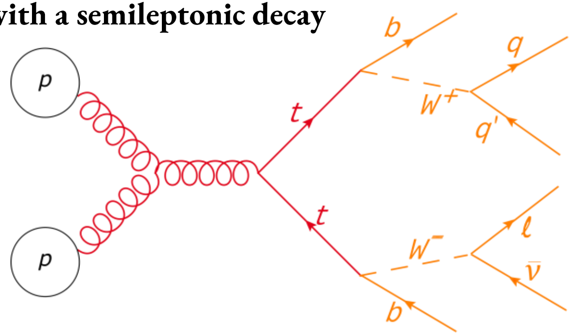

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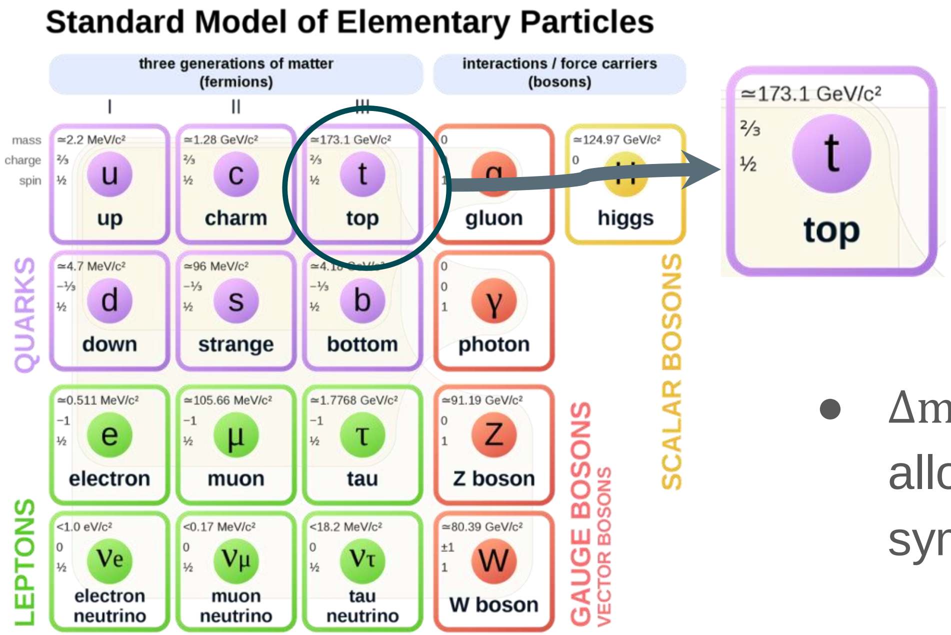

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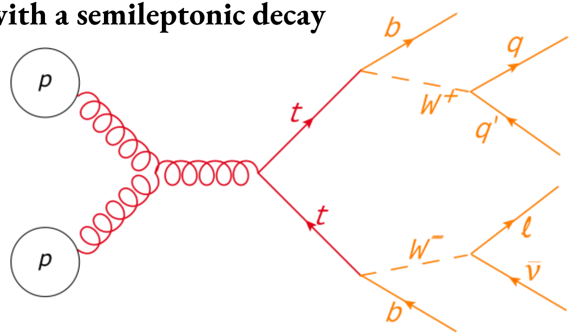
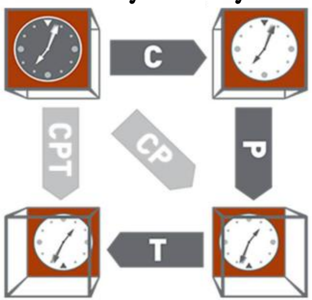


- $t\bar{t}$ lepton+jets decay channel allows to measure the top quark mass separately from the anti-top quark.

- $\Delta m_t = m_t - m_{\bar{t}}$ analysis allows to probe the CPT symmetry.

CMT symmetry



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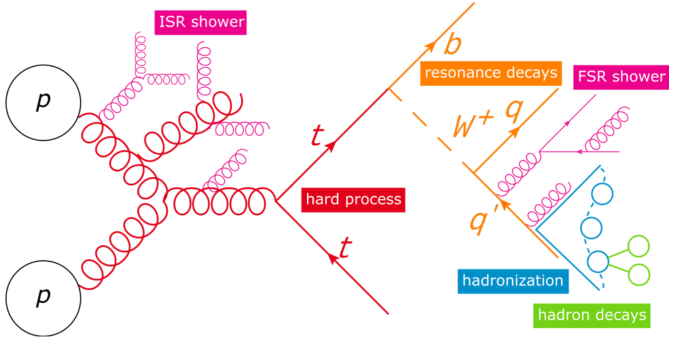
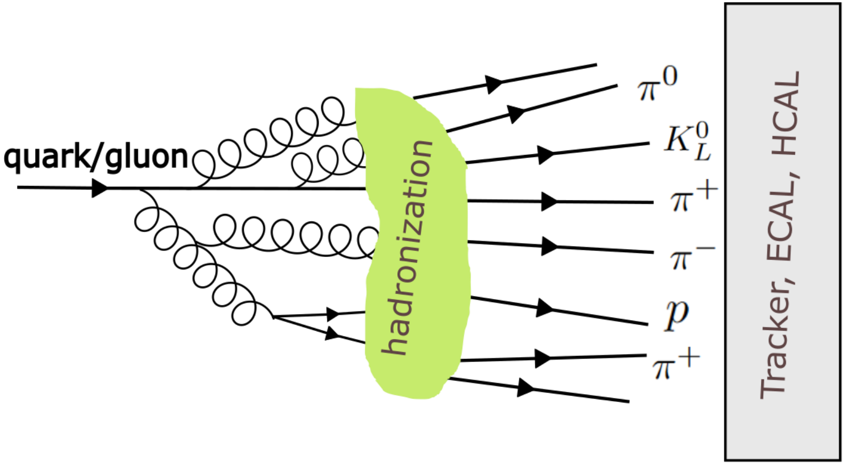
Outline of the presentation

1. Top pair event generation with Sherpa event generator

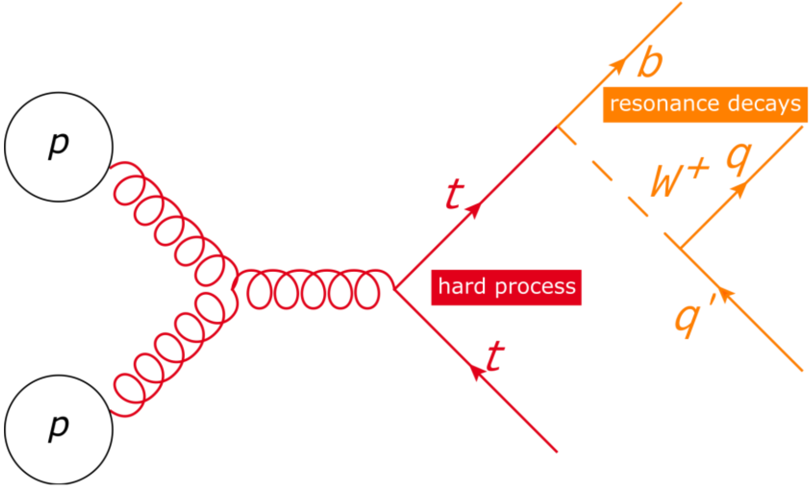


2. Jet Energy Correction studies



The complexity of generating a full physics event requires several general-purpose event generators for cross-validation:

Pythia | Herwig | Sherpa



Sherpa:

- Allows to switch between the Lund string model (Pythia) and cluster model (like Herwig) ⇒ opportunities for comparison.
- Allows to calculate $t\bar{t}$ together with many jets.

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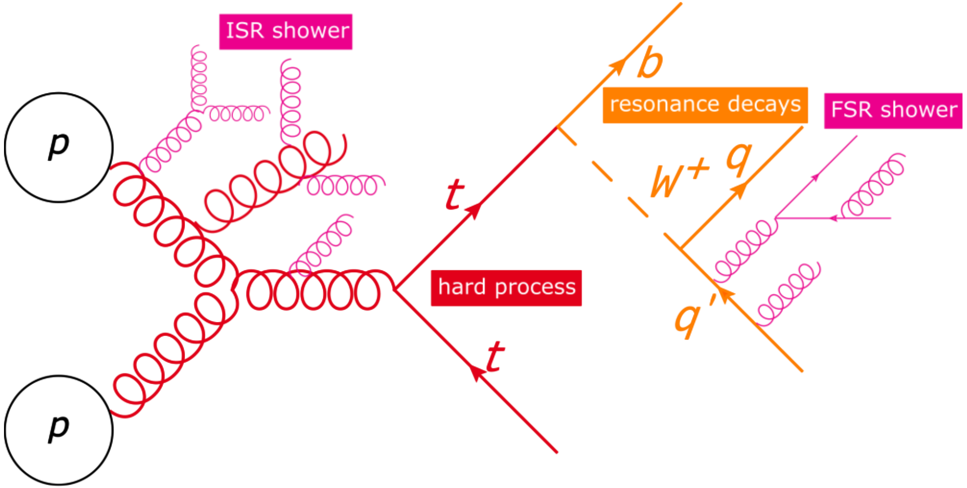

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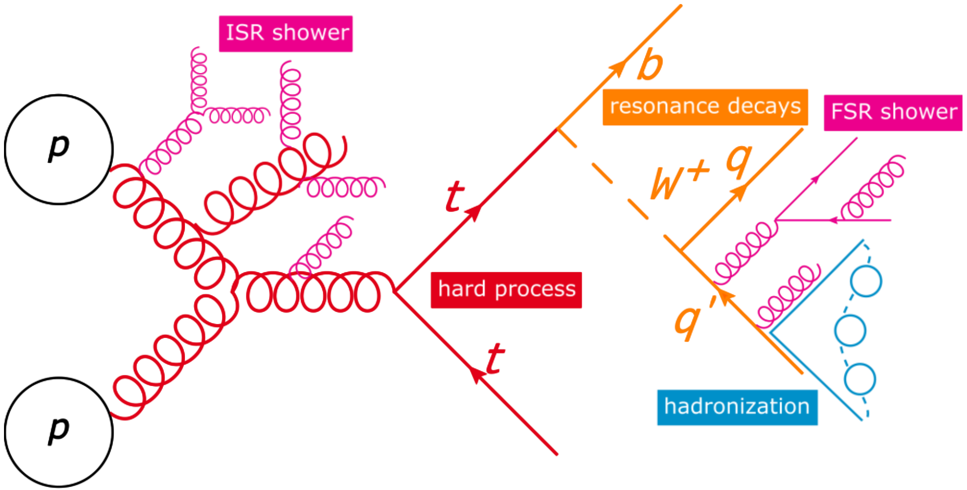

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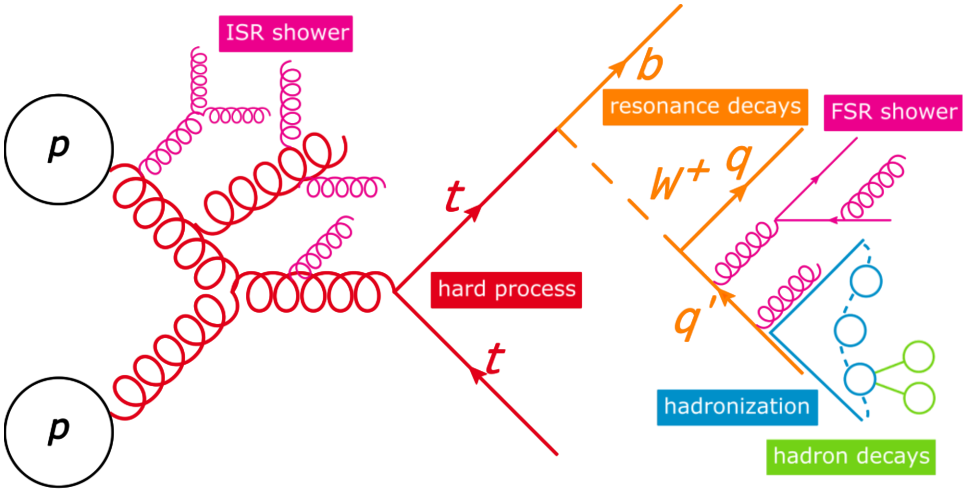

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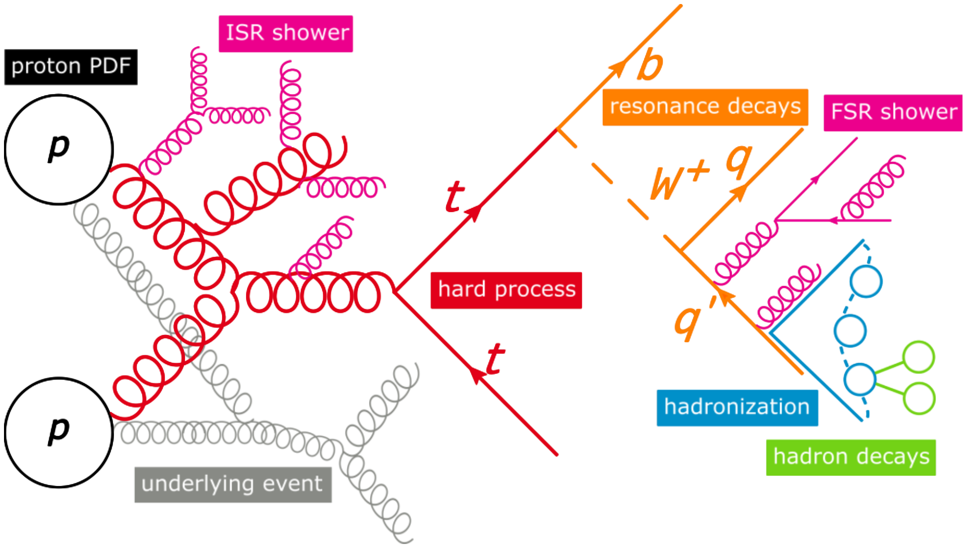

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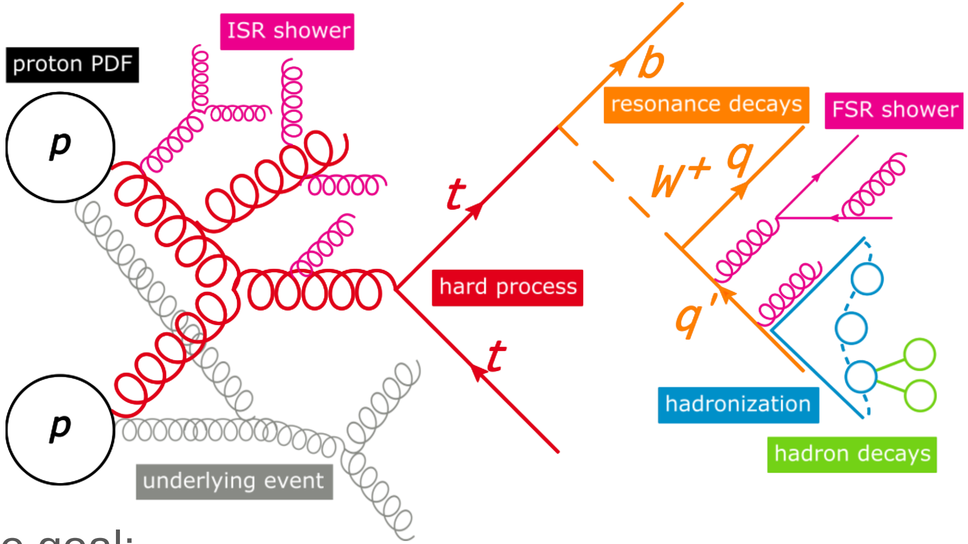

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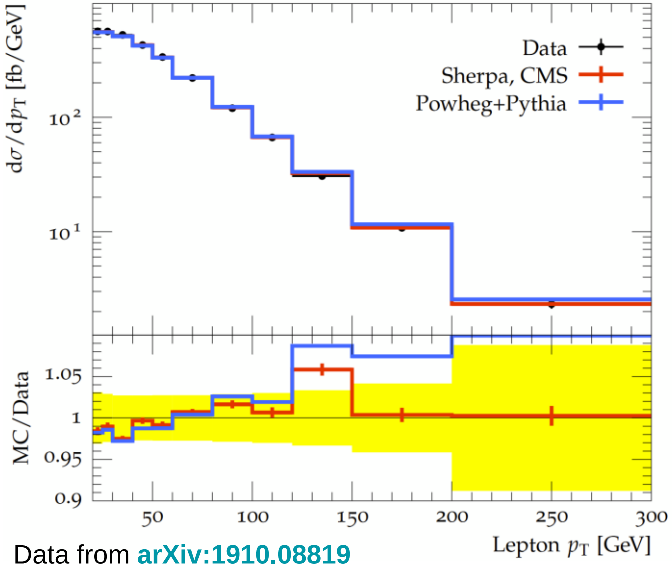
The goal:

- Generate and validate a new CMS Sherpa $t\bar{t}$ sample:
  a) Contribute to the CMS-ATLAS common sample ⇒ promote interexperimental collaboration.
  b) Study the impact of the choice of the hadronization model.

$t\bar{t}$ event simulation using Sherpa

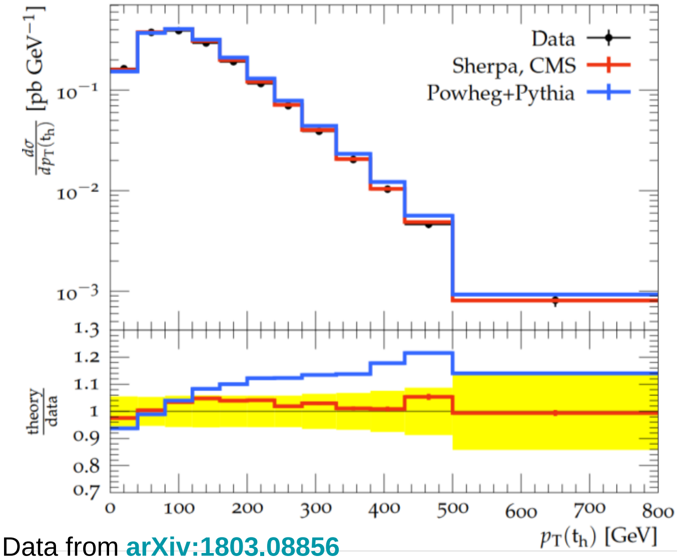
- Leptons — too hard in Pythia but good in Sherpa.
- Sherpa solves the known issue of hadronically decaying top being too hard in Powheg+Pythia.
- In full agreement with the ATLAS Sherpa sample (not on the plots).

Lepton transverse momentum, p_T, distribution in $t\bar{t}$ to two leptons decay channel



Data from arXiv:1910.08819

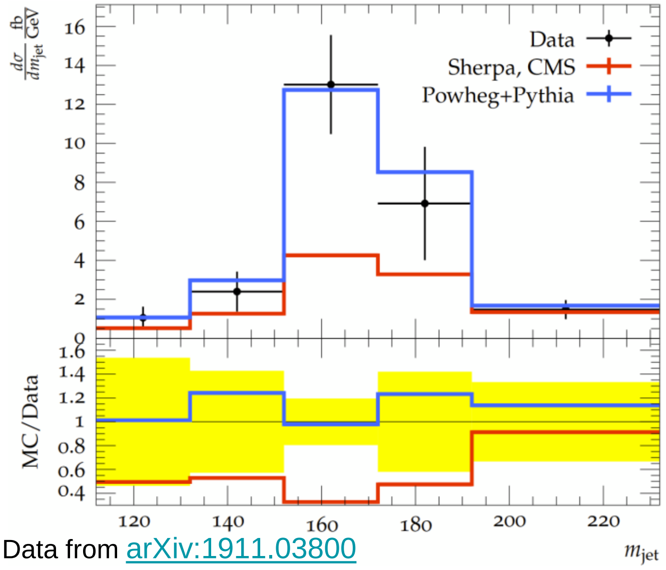
Hadronically decaying top p_T distribution In $t\bar{t}$ to lepton+jets decay channel



Data from arXiv:1803.08856

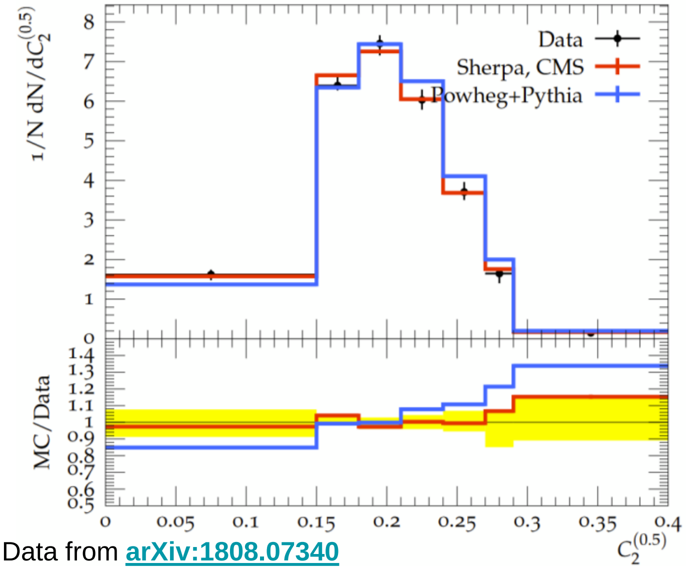
- Sherpa fails to describe the relatively rare boosted top quark events.
- The reason the disagreement in jet substructure can be explained by a different hadronization algorithm between Sherpa and Pythia (not on the plots).

Jet mass distribution in boosted top quark decays



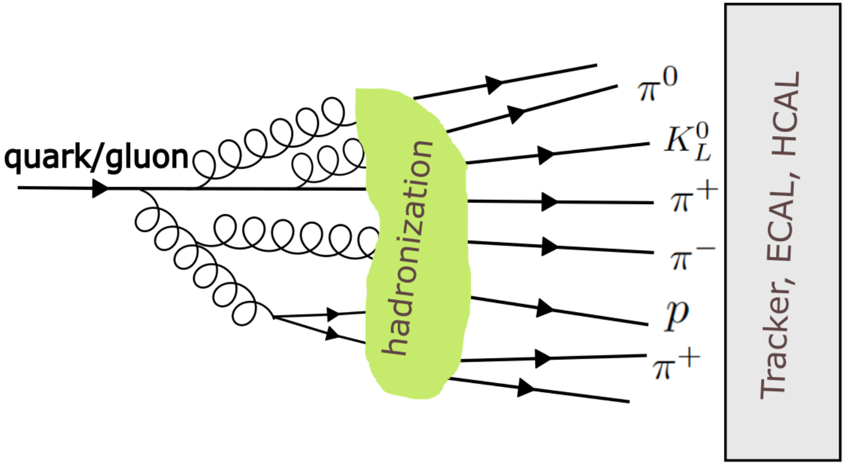
Data from arXiv:1911.03800

Distribution of N-point energy correlation double ratio in the lepton+jets channel

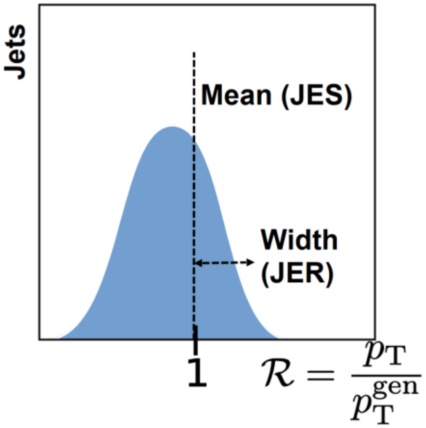


Data from arXiv:1808.07340

Jet energy correction studies



- Confinement: only particles in color singlet state observed in nature.
- Hadronization: (non-perturbative) formation of hadrons out of quarks and gluons.

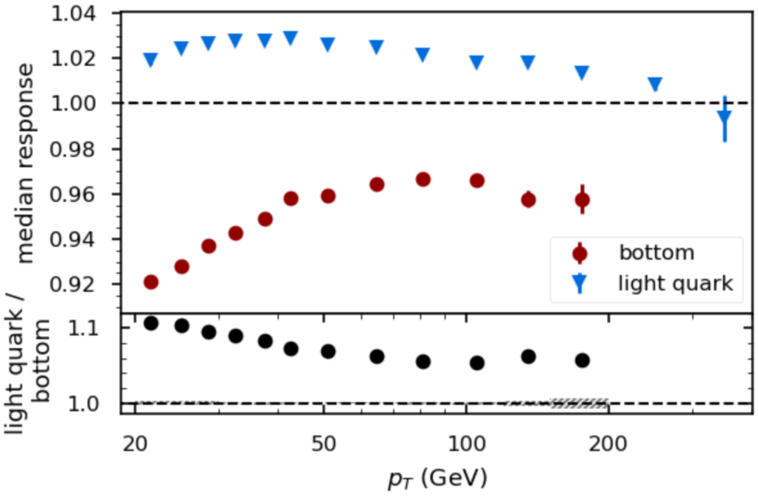


- Jet p_T response $R = \frac{\text{measured } p_T \text{ (detector simulation)}}{\text{true (generated) } p_T}$.
- General CMS strategy:
  - Apply inclusive (p_T, η) dependent corrections (L2L3) on MC and data
  - Residual corrections on data (L2L3Res)
  - Jet flavour uncertainty (last derived in 2014)

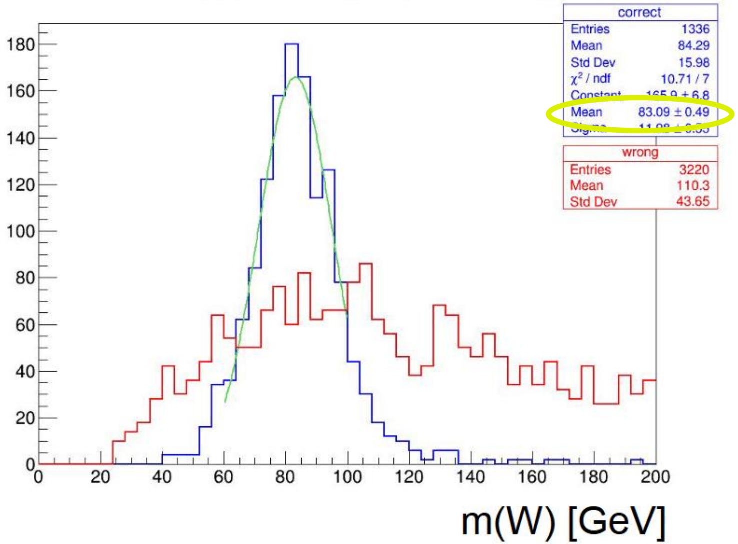
Jet energy correction studies

- Different flavour of the initial quark/gluon ⇒ different hadron content ⇒ different response.
- Flavour dependent (L5) correction last derived in 2014.

Median response for b-jets and light-jet in a $t\bar{t}$ sample



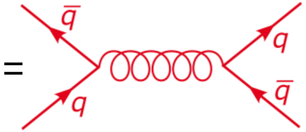
W mass peak shifted from 80 GeV to 84 GeV due to the high light jet response



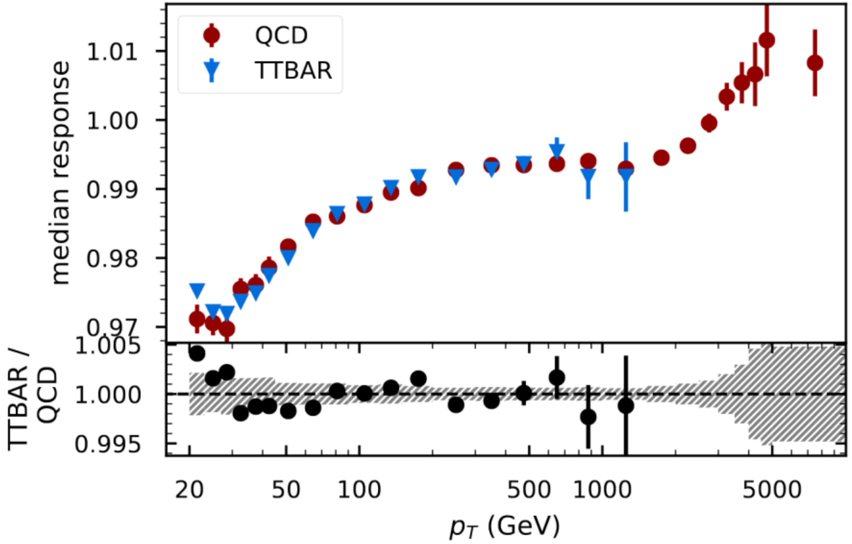
Jet energy correction studies

- Matching the reco jet with an ME particle (LHE particle) assigns jets from gluon splitting $g \to qq$ as gluons.
- Reduces the disagreement between QCD and TTBAR sample to under 0.1%.
- Agreement also in the light quark jet responses.

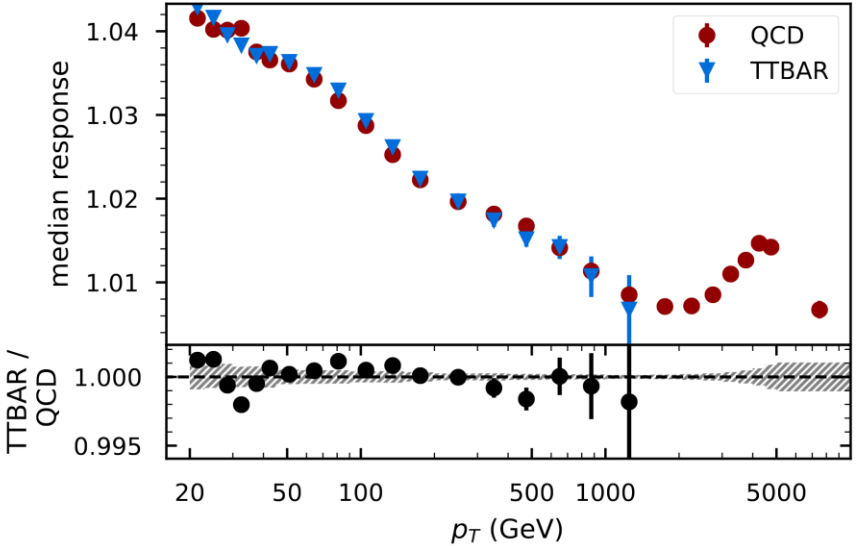
QCD ⇒ mostly dijet =



Jet energy responses for b-jet for a $t\bar{t}$ and QCD sample at *0<η<1.3*



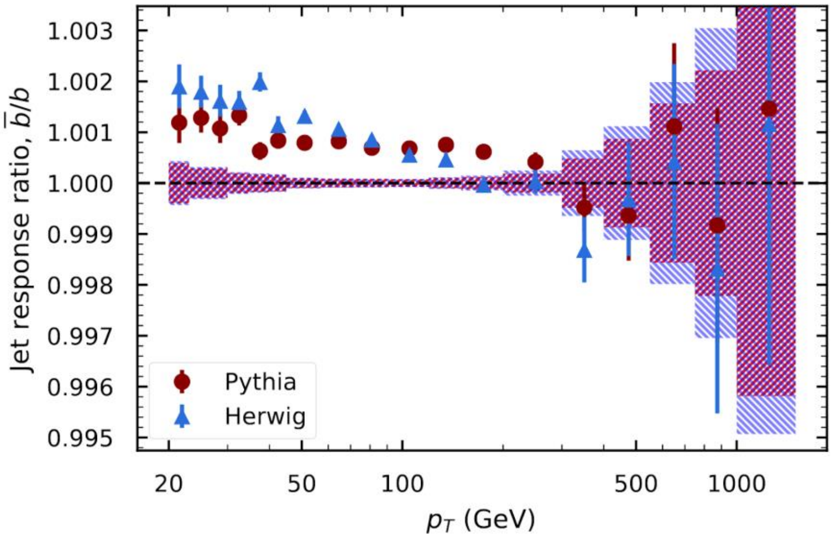
Jet energy responses for c-jet for a $t\bar{t}$ and QCD sample at *0<η<1.3*



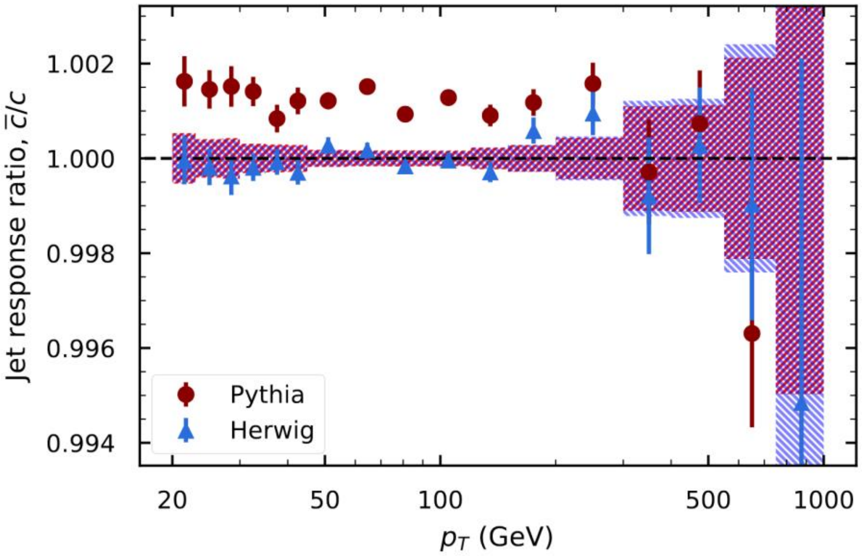
Anti-flavour and flavour jet response differences

- Pythia predicts a O(0.1%) larger response for anti-quark jets than for jets ⇒ anti-quark jets have a larger antiparticle content ⇒ anihilation.
- Herwig predicts such effect only for b-jets.
- Do generators represent the actual physics? ⇒ data driven techniques.

The ratio of jet energy responses for anti-b-jet and b-jet at $0<\eta<1.3$



The ratio of jet energy responses for anti-c-jet and c-jet at $0<\eta<1.3$



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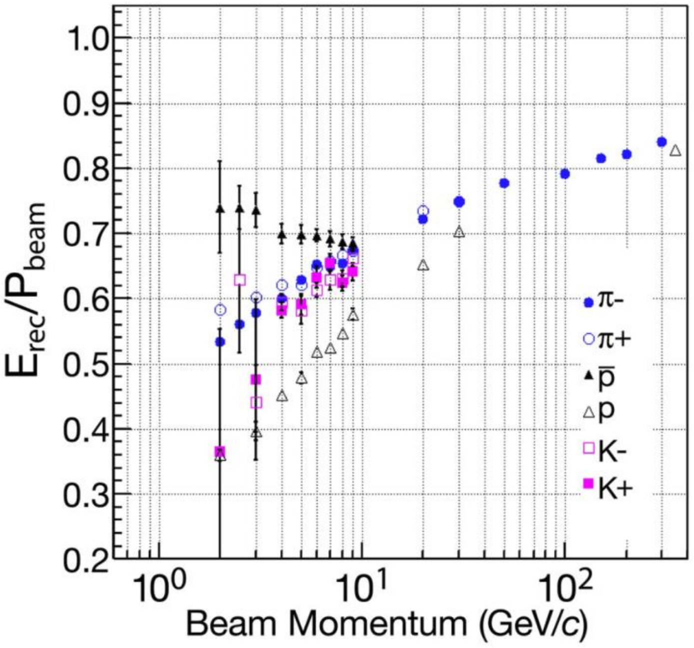


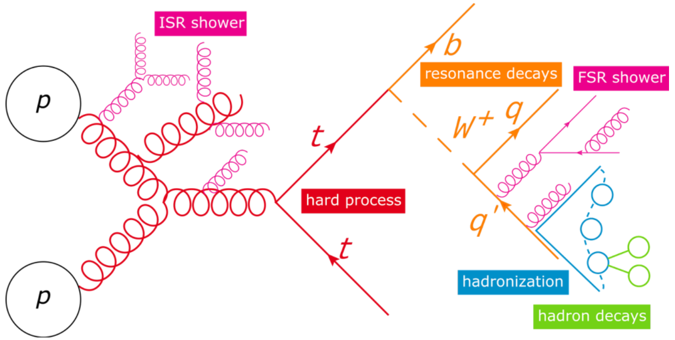
Source: FERMILAB-PUB-08-661-E-PPD

- ECAL+HCAL test beam data show higher response for anti-protons (π^+) than protons (π^-).

We plan to:

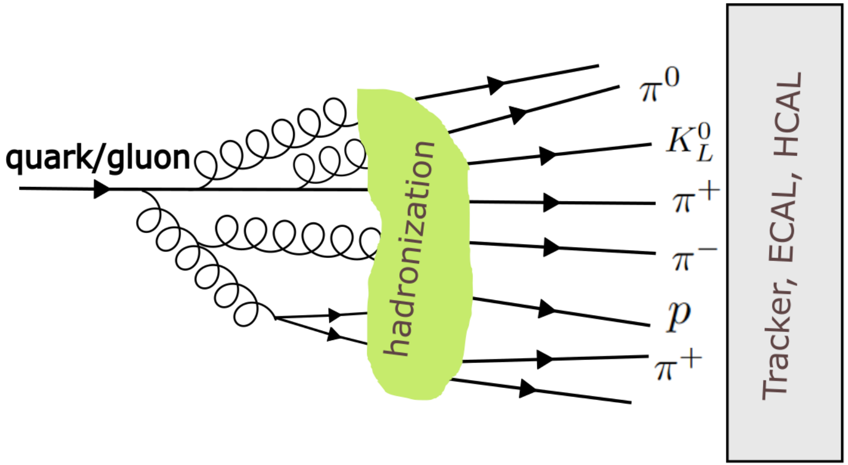
- Use the beam data to validate the GEANT 4 simulation.
- Verify with collision data using isolated pions at high energies.
- Checking tracking of positive and negative muons in Z decays.

1. Top pair event generation with Sherpa event generator

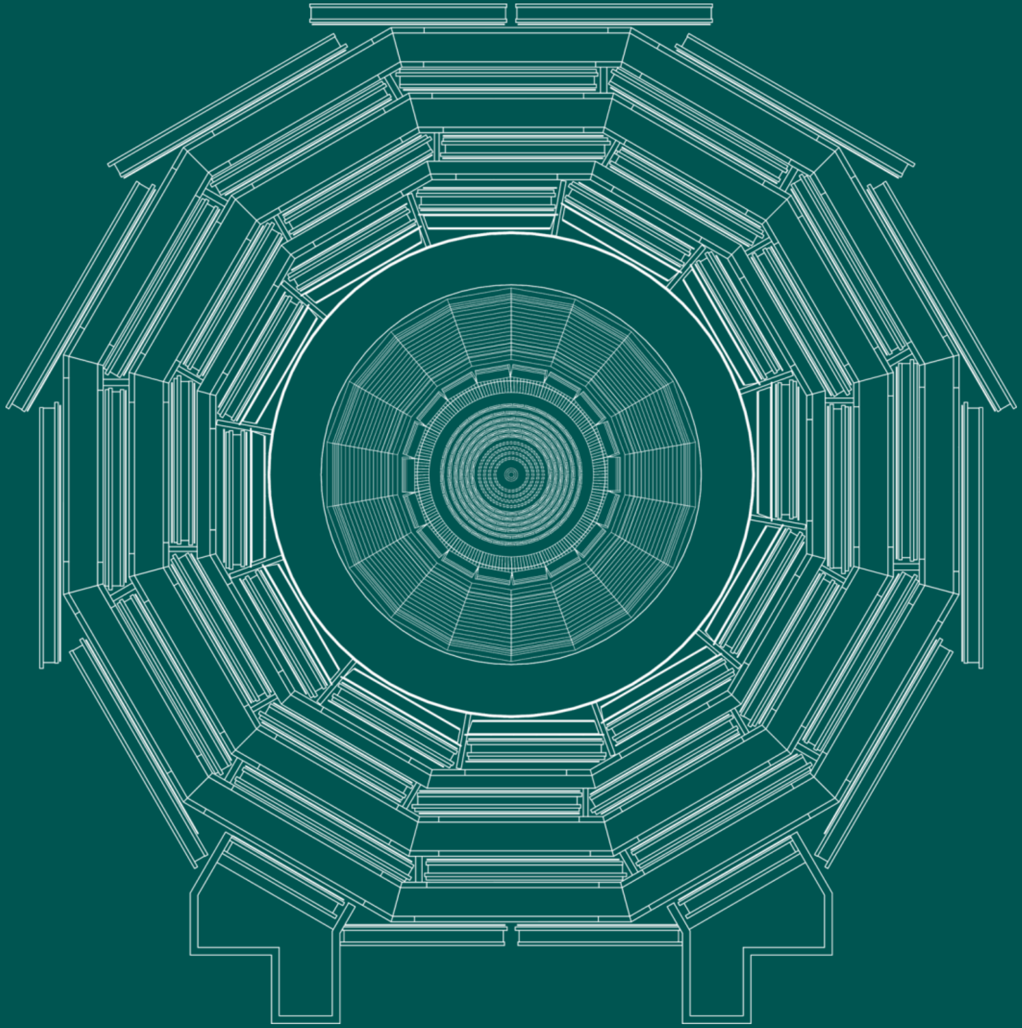


- A Sherpa $t\bar{t}$ sample generated and validated.
- A common CMS-ATLAS note to be published in the coming months.

2. Jet Energy Correction studies



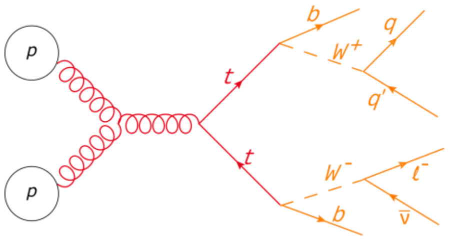
- Performing flavour-dependent jet energy correction studies.
- The first study of study quark vs antiquark jet response in CMS.



- Kinematic fit cannot be used for the mass difference measurement because of the $m_{t\ had} = m_{t\ lep}$ constraint.
- Replaced by a selection algorithm:
  - take events with 2 b-tagged (b) and 2 untagged jets (q)
  - assign untagged jets to W boson
  - combine b jets with the W boson and keep both possible solutions
  - add a W mass window

- Δm_t analysis requires determining the response differences between the quark jets and anti-quark jets in the detector.

Top-quark pair process with a semileptonic decay



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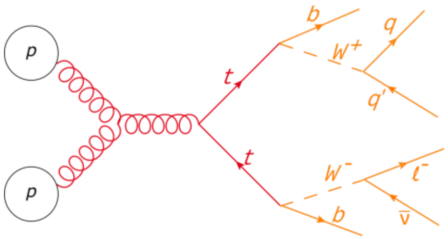
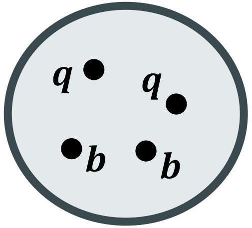


Event



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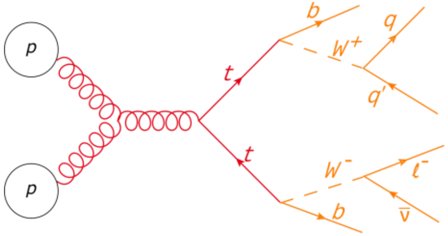

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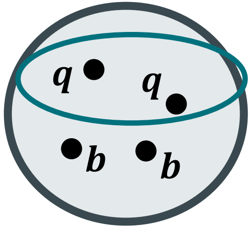

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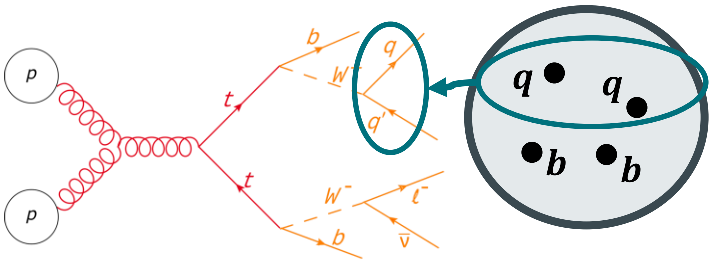

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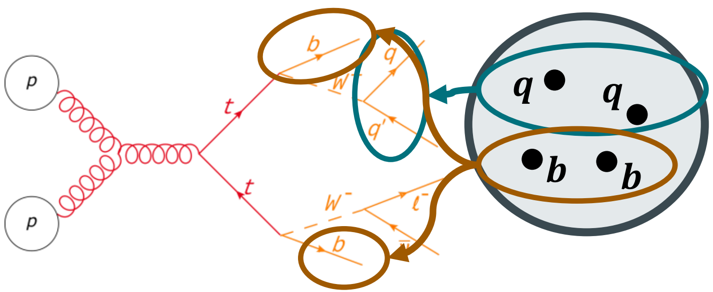

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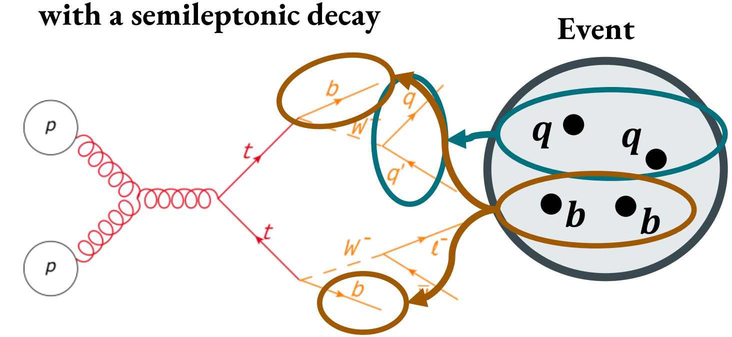

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