Searching for hidden valleys without displaced vertices

- Whether or not a displaced vertex is present is highly model dependent
  - Depends on v-hadron mass
  - Depends on mediator mass
  - Depends on size of dimensionless coupling
  - Depends on quantum numbers of v-hadron
    - e.g. pseudoscalar or vector state

$$\Gamma \sim \frac{m_{vh}^{2(D-4)+1}}{\Lambda_M^{2(D-4)}}$$

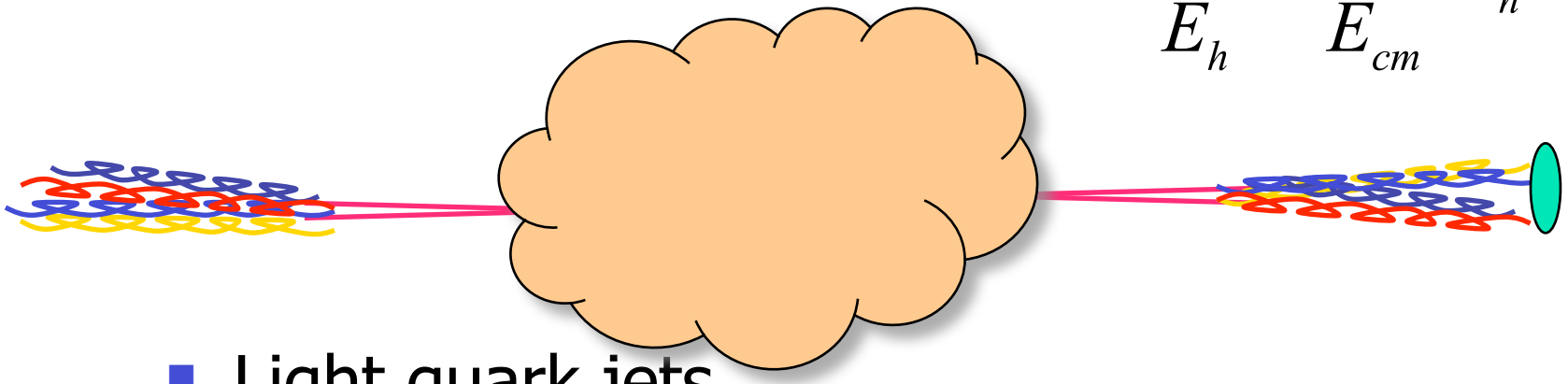
For example

- Z’ mediator, one light v-quark
- Low mass v-hadrons $m_{\text{vh}} < 20\ \text{GeV}$
  - Use displaced vertex $\ell_{\eta_v \to b\bar{b}} \sim 4\ \text{cm} \frac{(20\ \text{GeV})^7}{f_{\eta_v}^2 m_{\eta_v}^5} \left(\frac{m_{Z'}/g'}{10\ \text{TeV}} \right)^4$
- Higher mass v-hadrons $m_{\text{vh}} > 20\ \text{GeV}$
  - Shape of event set by v-hadron mass

Other handles? Event shapes

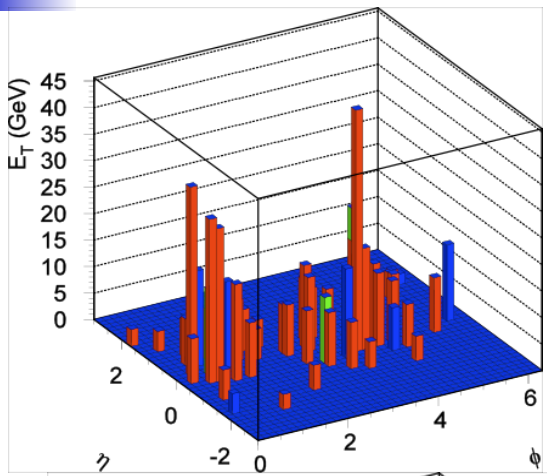
- Shape of event set by v-hadron mass

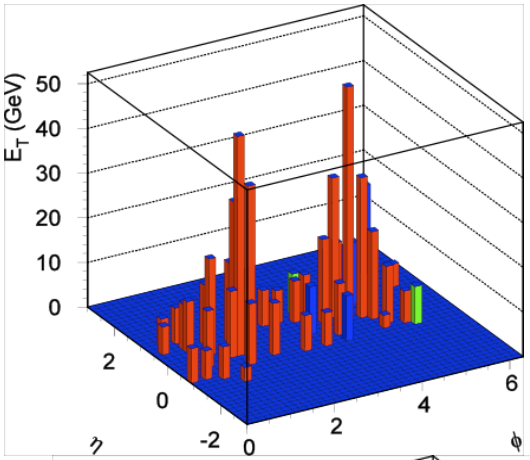
$$\theta \sim \frac{p_\perp}{E_h} \sim \frac{p_\perp}{E_{cm}} N_h$$

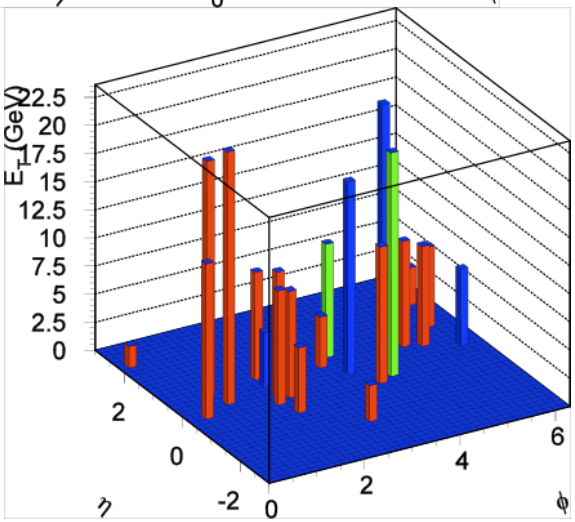


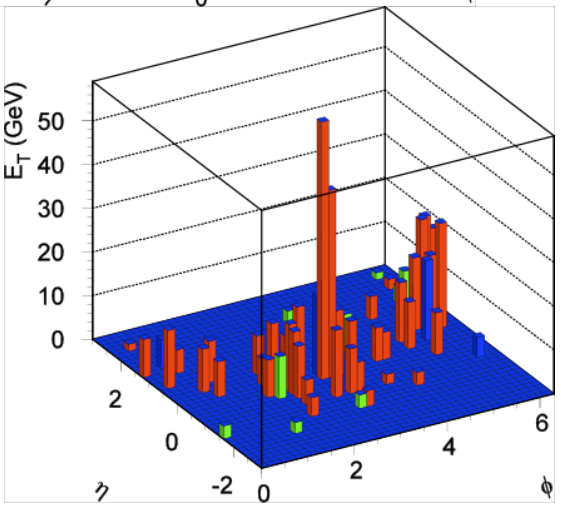
- Light quark jets
- vs. Hidden valley jets--larger opening angles due to higher mass v-hadrons

Contrast Hidden Valley Events



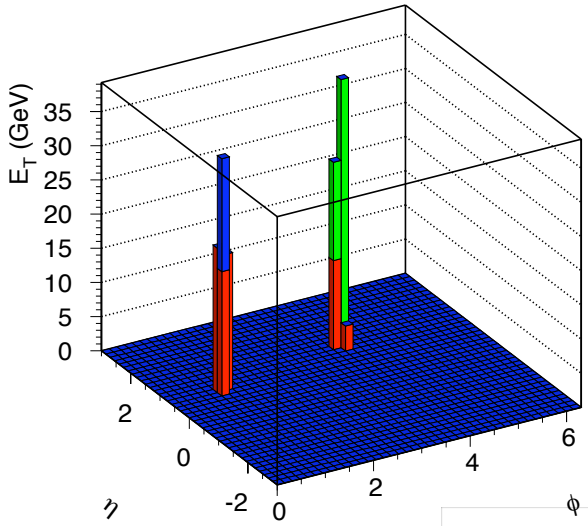




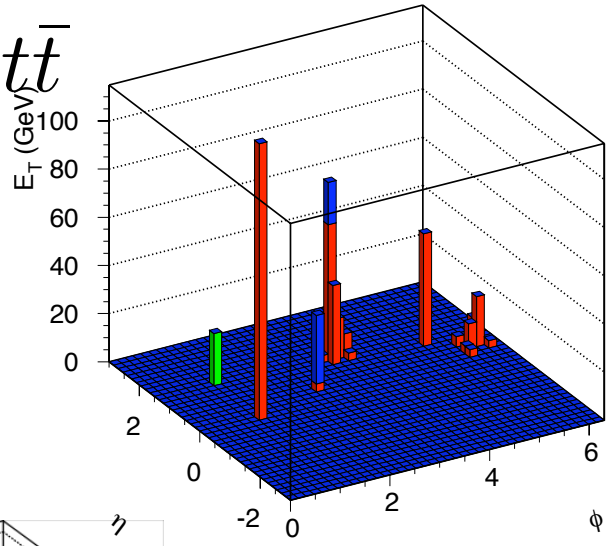


Contrast against standard model backgrounds

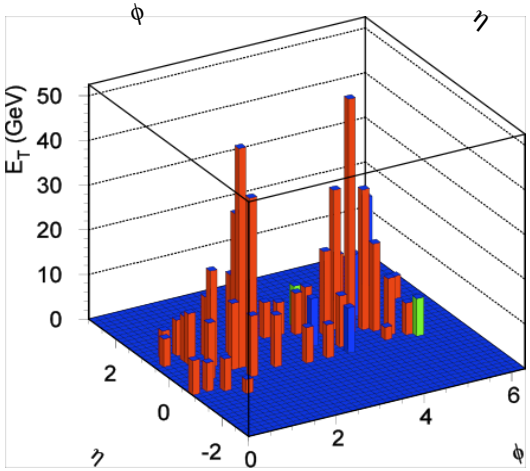
$b\bar{b}$



$t\bar{t}$



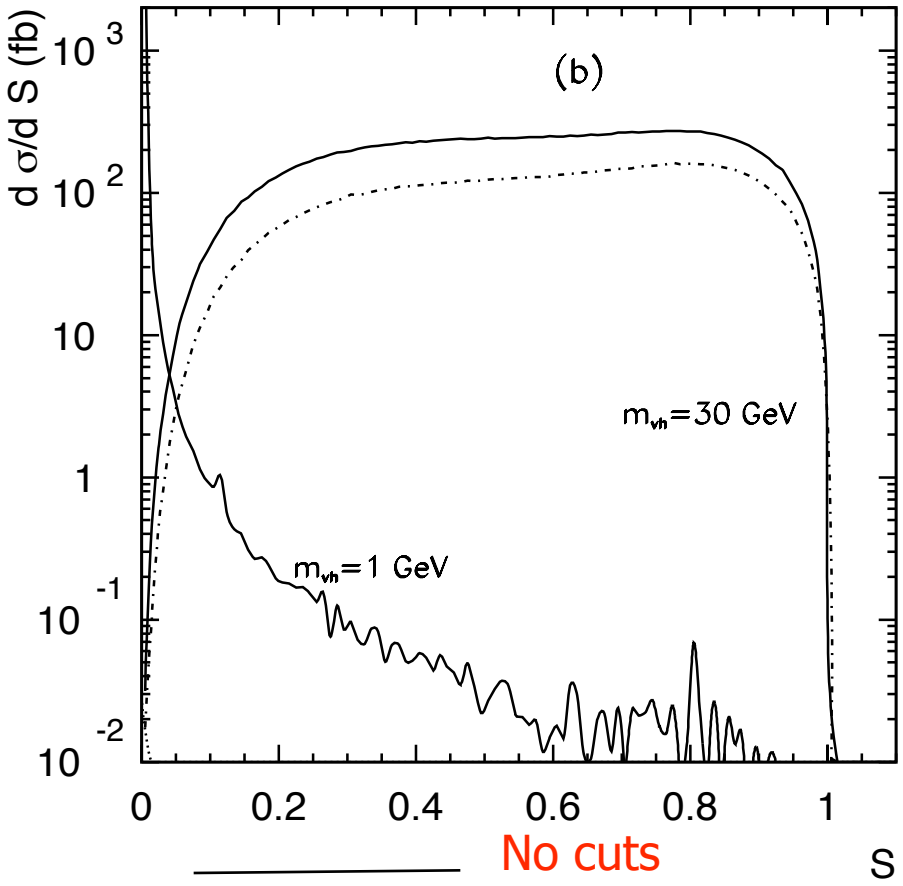
Hidden valley

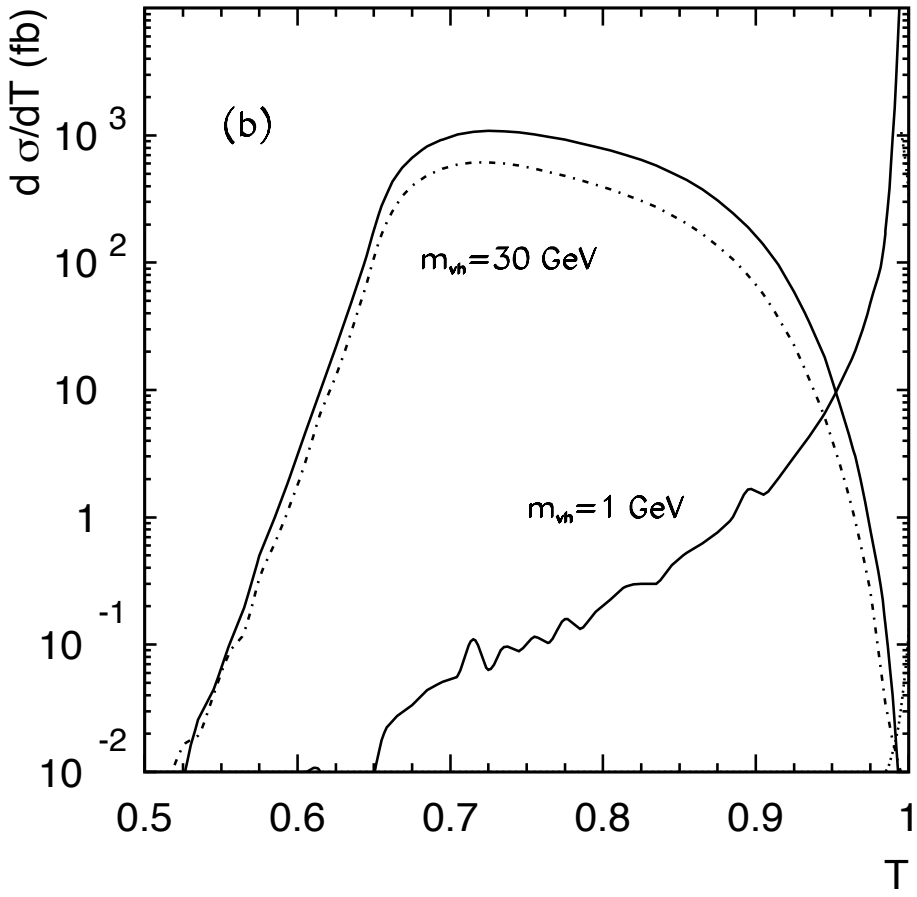


Use different energy scales

- Basic trigger on events
  - 2 muons, pT > 10 GeV
- Additional cuts to remove QCD background
  - Multiplicity
  - Thrust
  - Sphericity
  - Separation of leptons
  - Cluster invariant mass

Sphericity and Thrust

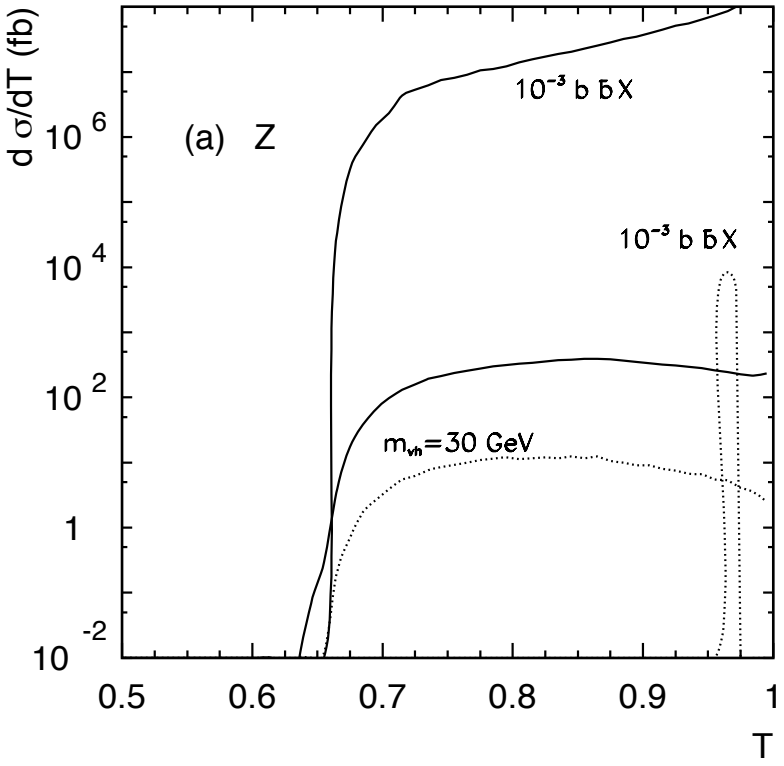


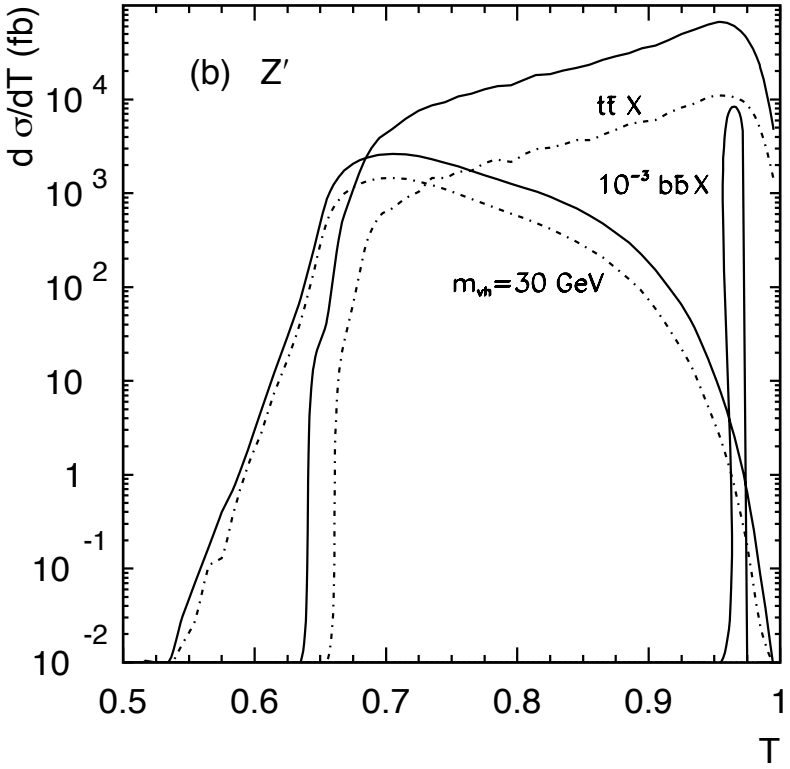


No cuts

Two muon trigger, pT > 10 GeV

With SM backgrounds



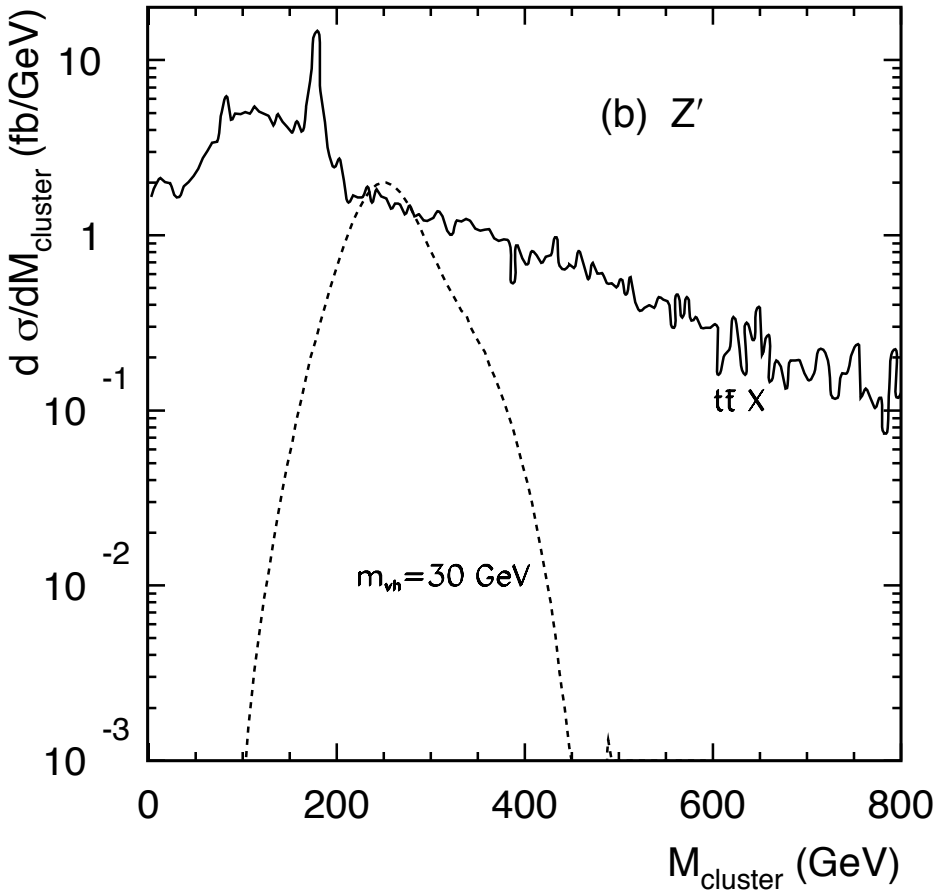


No cuts

Two muon trigger, pT > 10 GeV

Kill b background with T < 0.95 cut

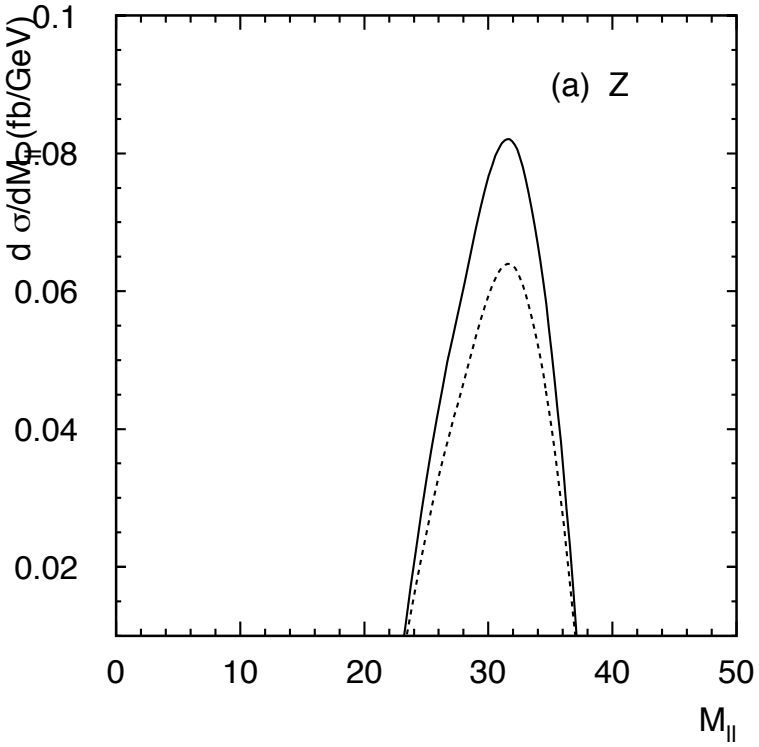
Cluster mass

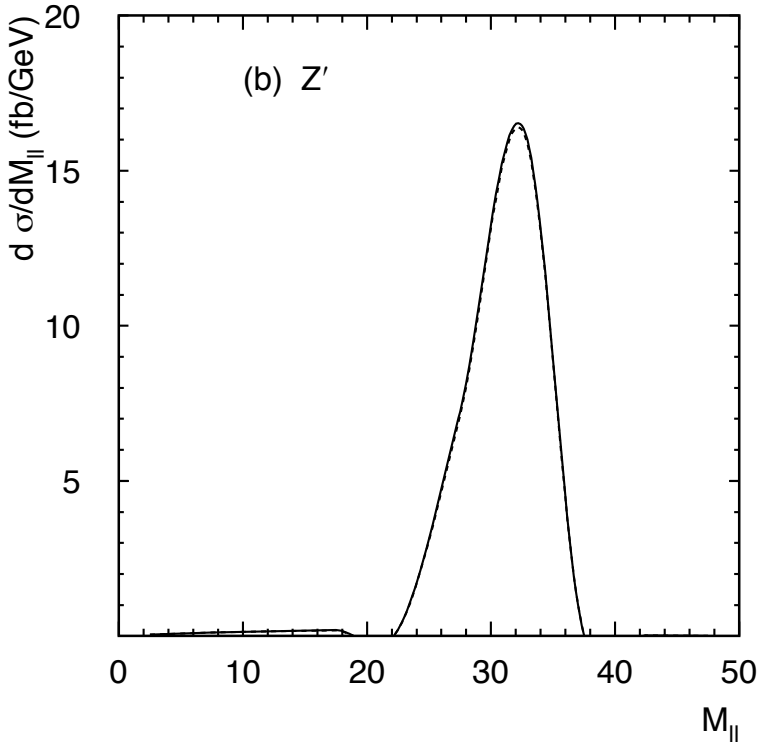


Further remove t background with cluster cut

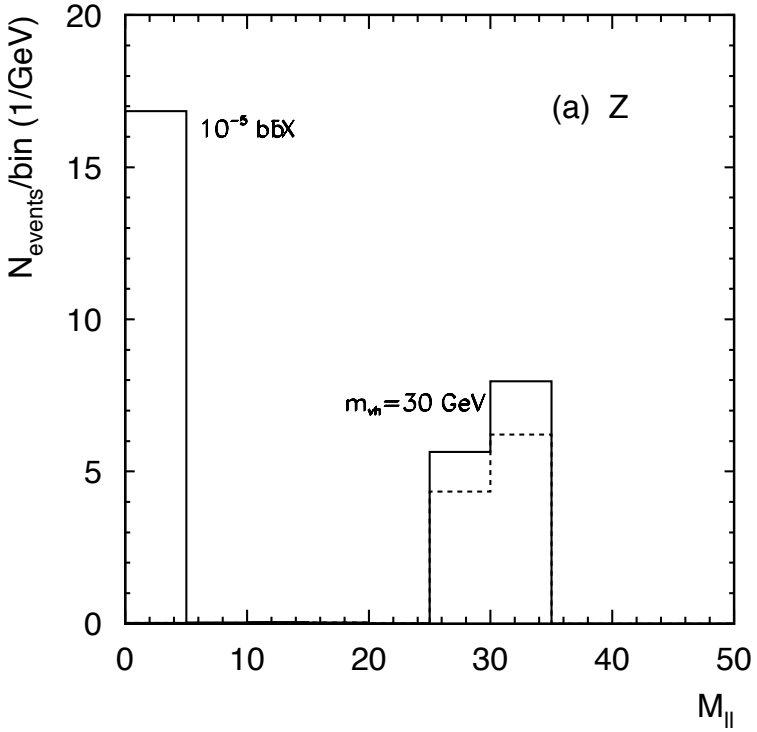
$$m_{cluster} > 200 \text{ GeV}$$

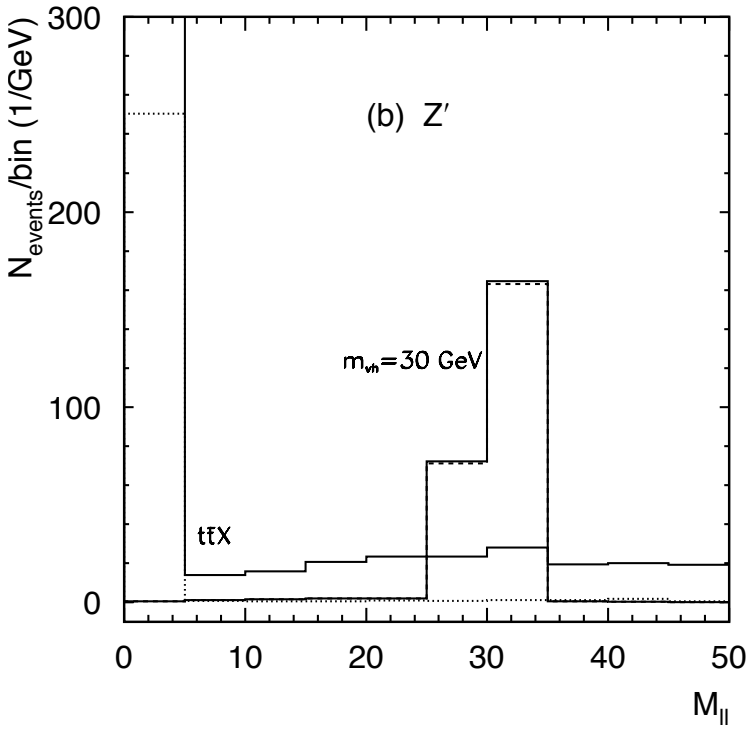
Reconstruct resonance



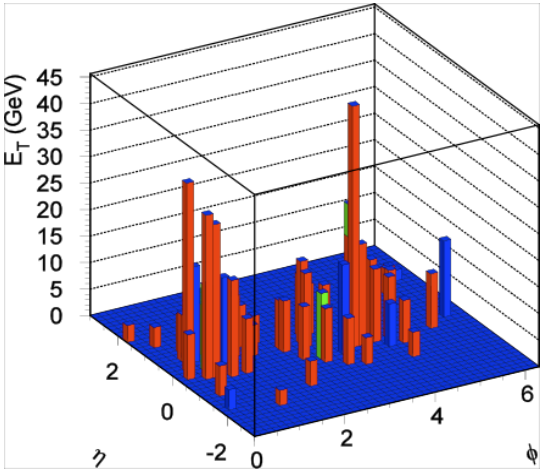


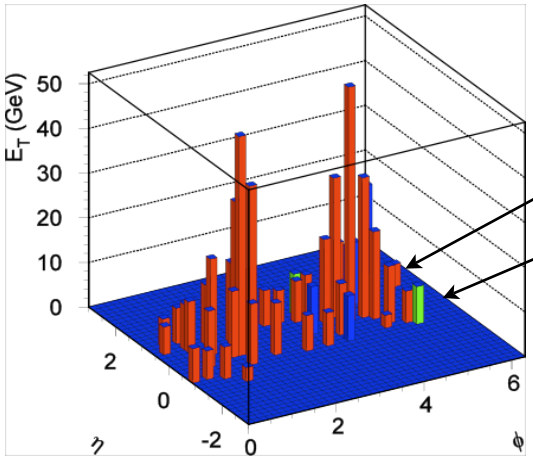
Reconstruct resonance





Isolated leptons

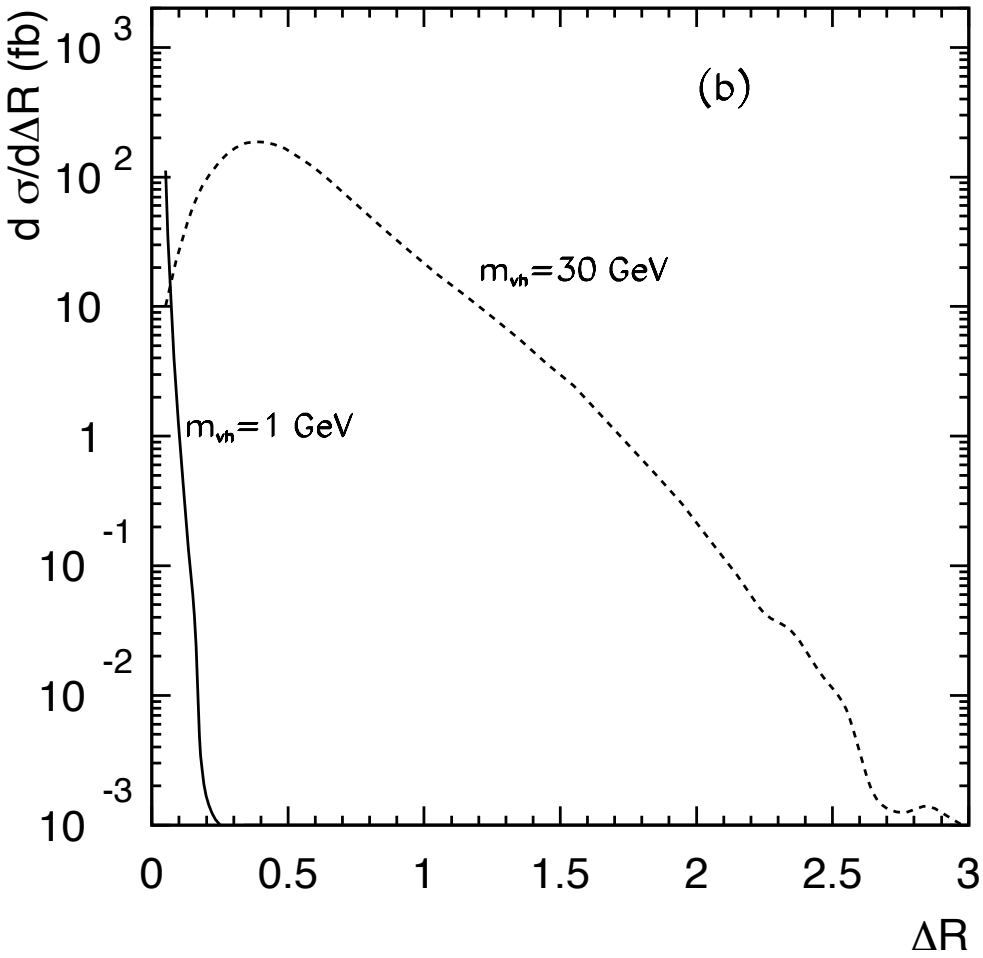




ΔR

Separation between most isolated lepton and nearest non-leptonic neighbor

Isolated leptons



Separation between most isolated lepton and nearest non-leptonic neighbor

Implement cut $\Delta R > 0.3$