Searching for Hidden Valleys at the LHC

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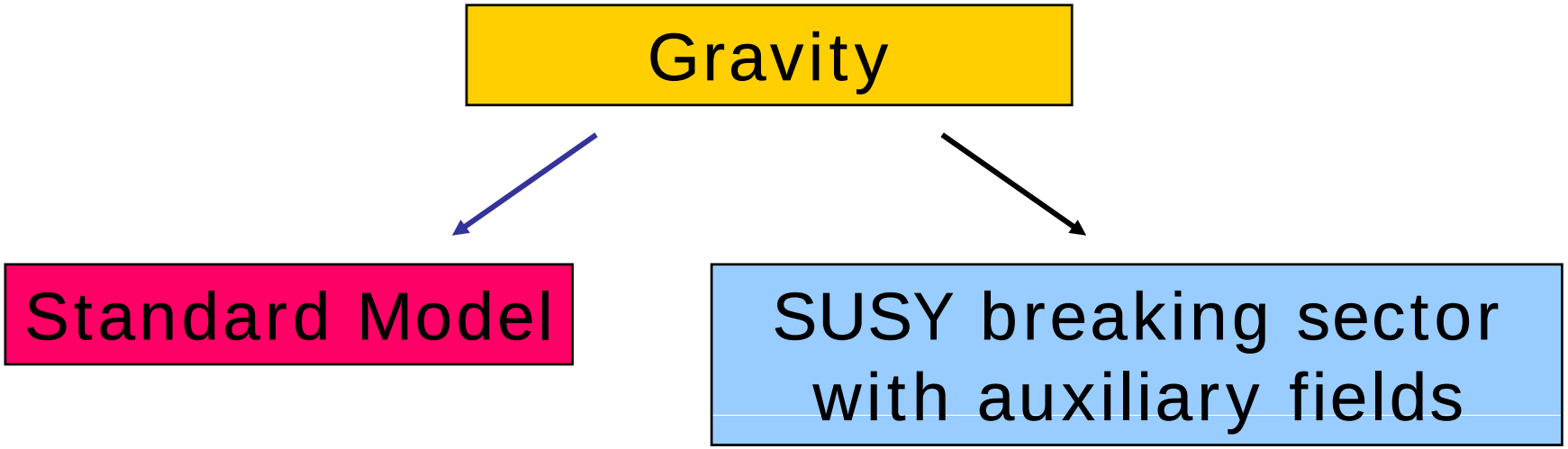
Strassler and KZ, **hep-ph/0604261**, **hep-ph/0605193**

Han, Si, KZ, in progress

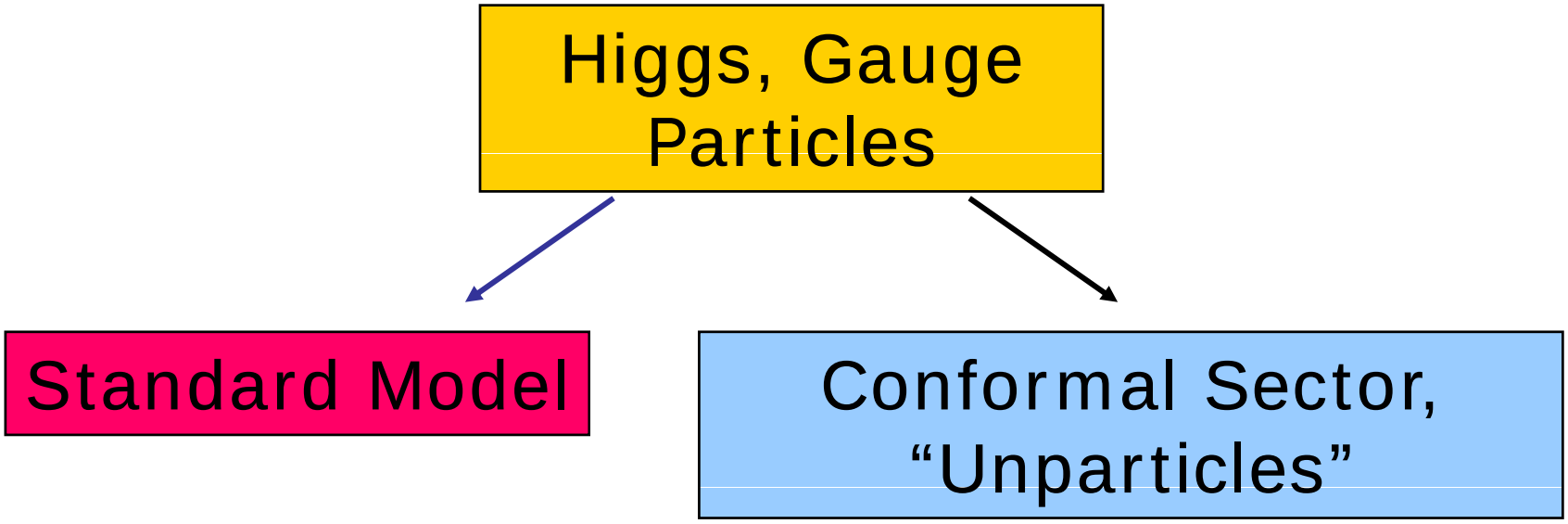
A hidden valley: what is it?

Generic structure of hidden sectors:

Examples of hidden sectors: Gravity mediation



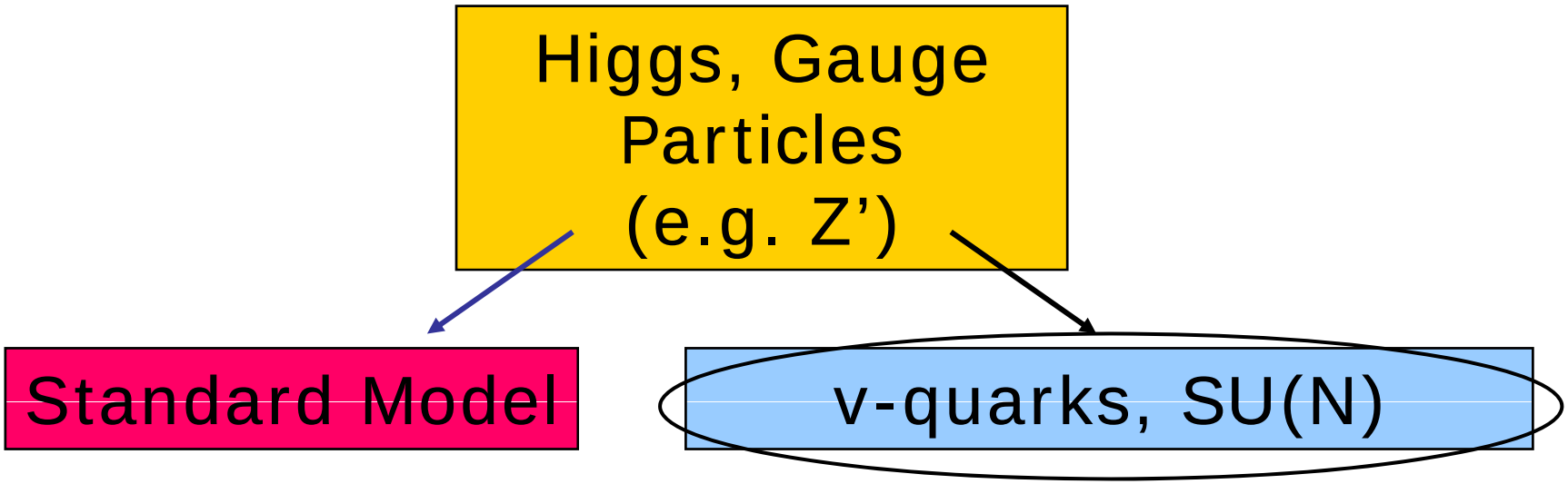
Examples of hidden sectors: Unparticles



$$\frac{1}{M_U^k} O_{SM} O_{BZ}$$

Georgi PRL98:221601,2007

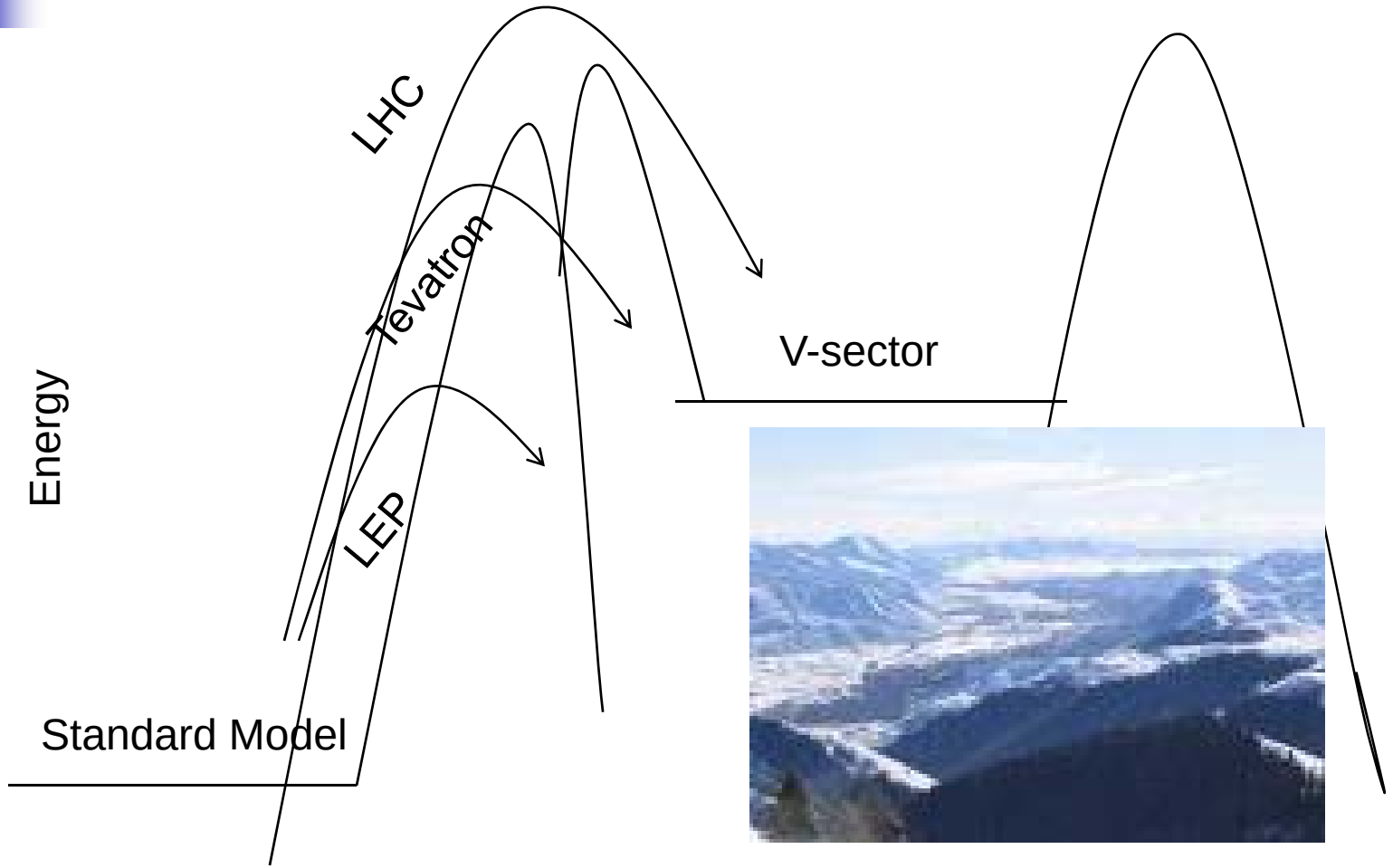
A hidden valley: what is it?



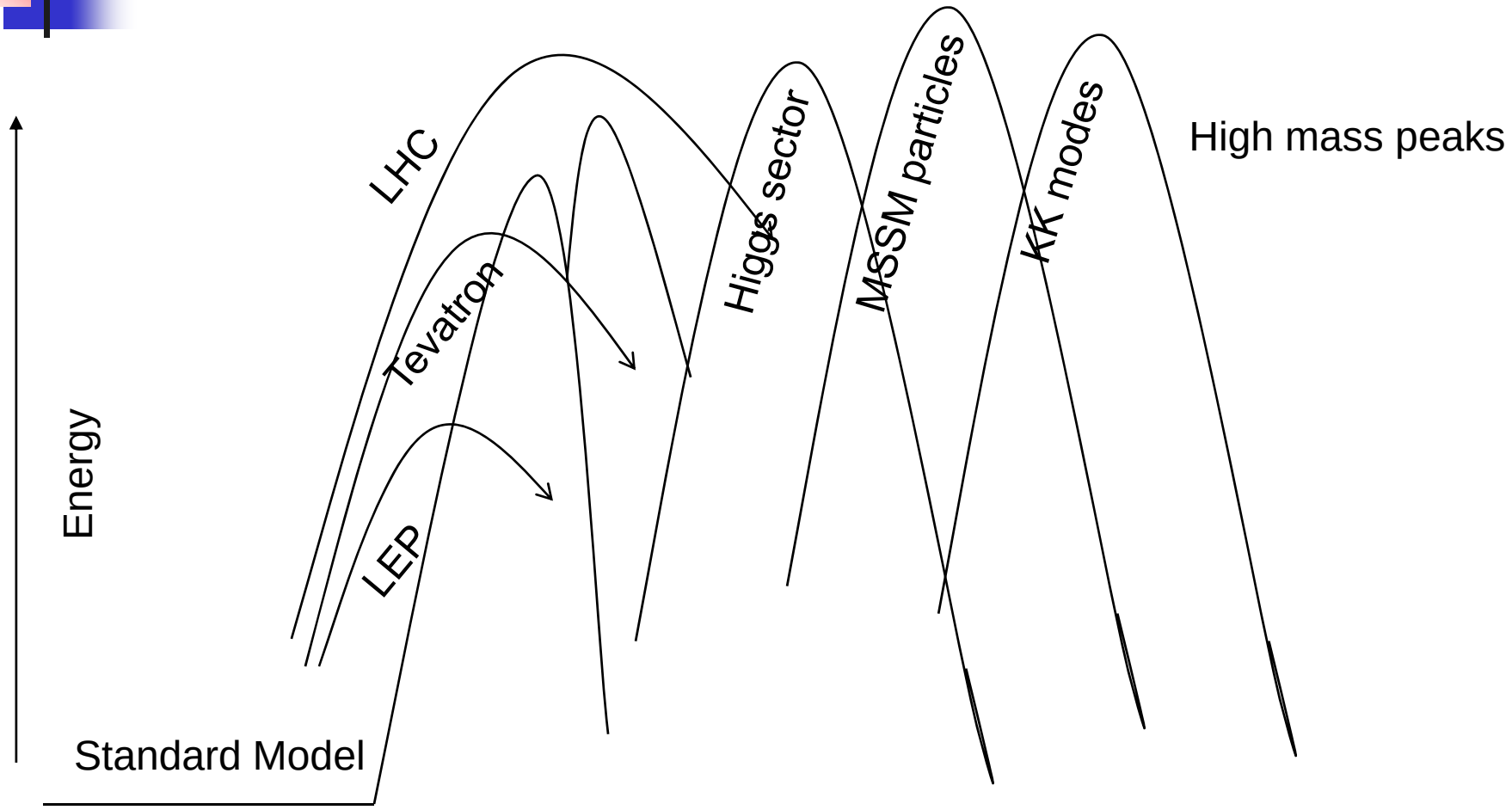
$$\frac{1}{M_U^k} O_{SM} O_{SU(N)}$$

- Confining gauge group binds v-quarks
- Confinement scale and quarks masses are *low*

Imagery

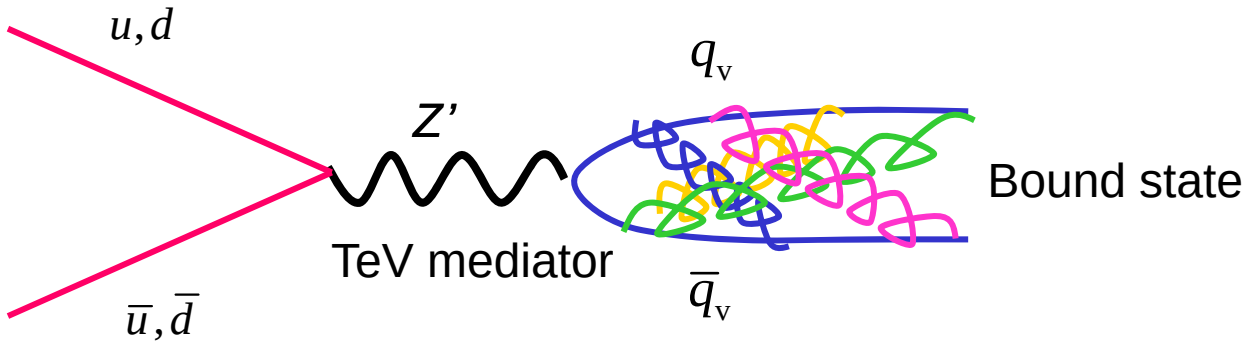


As opposed to:

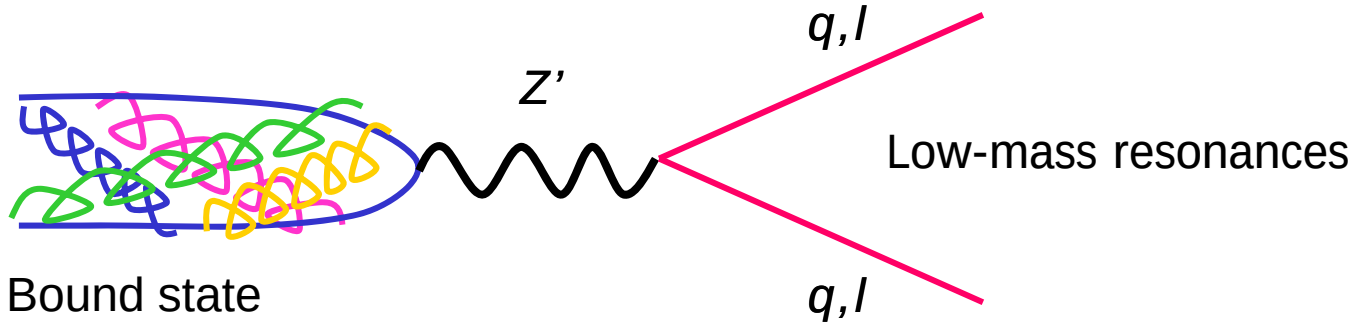


Novel phenomenology

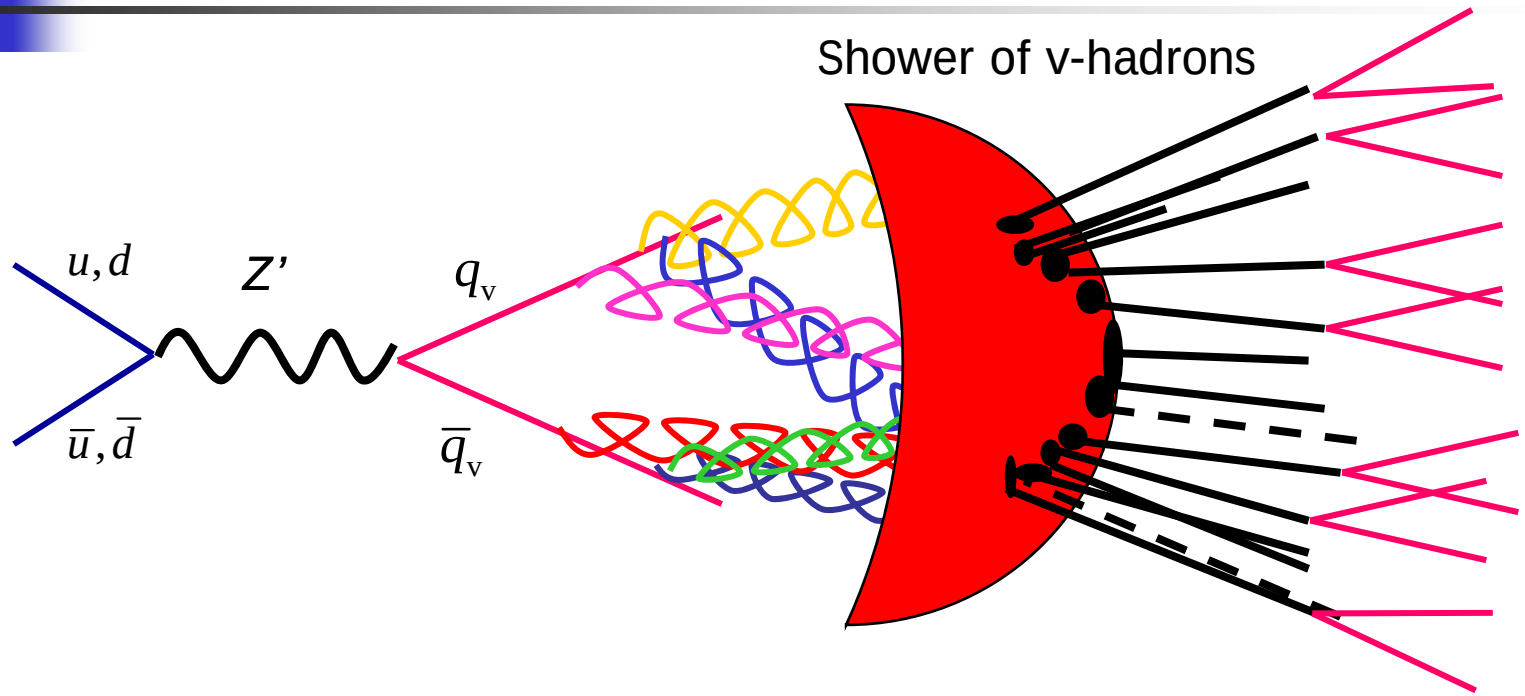
- Production of *low mass* bound states at LHC



- Decay to SM neutral pairs of leptons, quarks



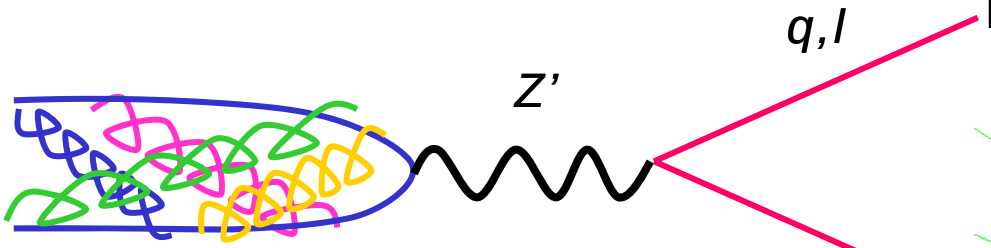
Production



Each pair reconstructs to low mass v-hadron

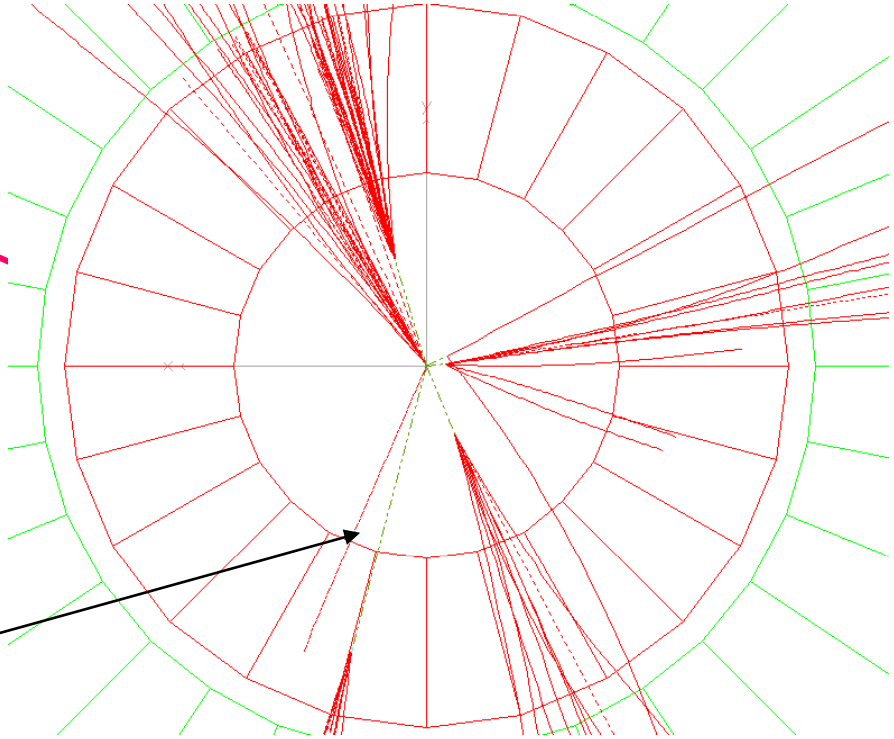
Reconstruct entire event to Z' resonance

V-hadron decays



$$\ell_{\eta_v \to b\bar{b}} \sim 4\ \text{cm} \frac{(20\ \text{GeV})^7}{f_{\eta_v}^2 m_{\eta_v}^5} \left(\frac{m_{Z'}/g'}{10\ \text{TeV}} \right)^4$$

Image courtesy of Rome/Seattle ATLAS working group on displaced decays



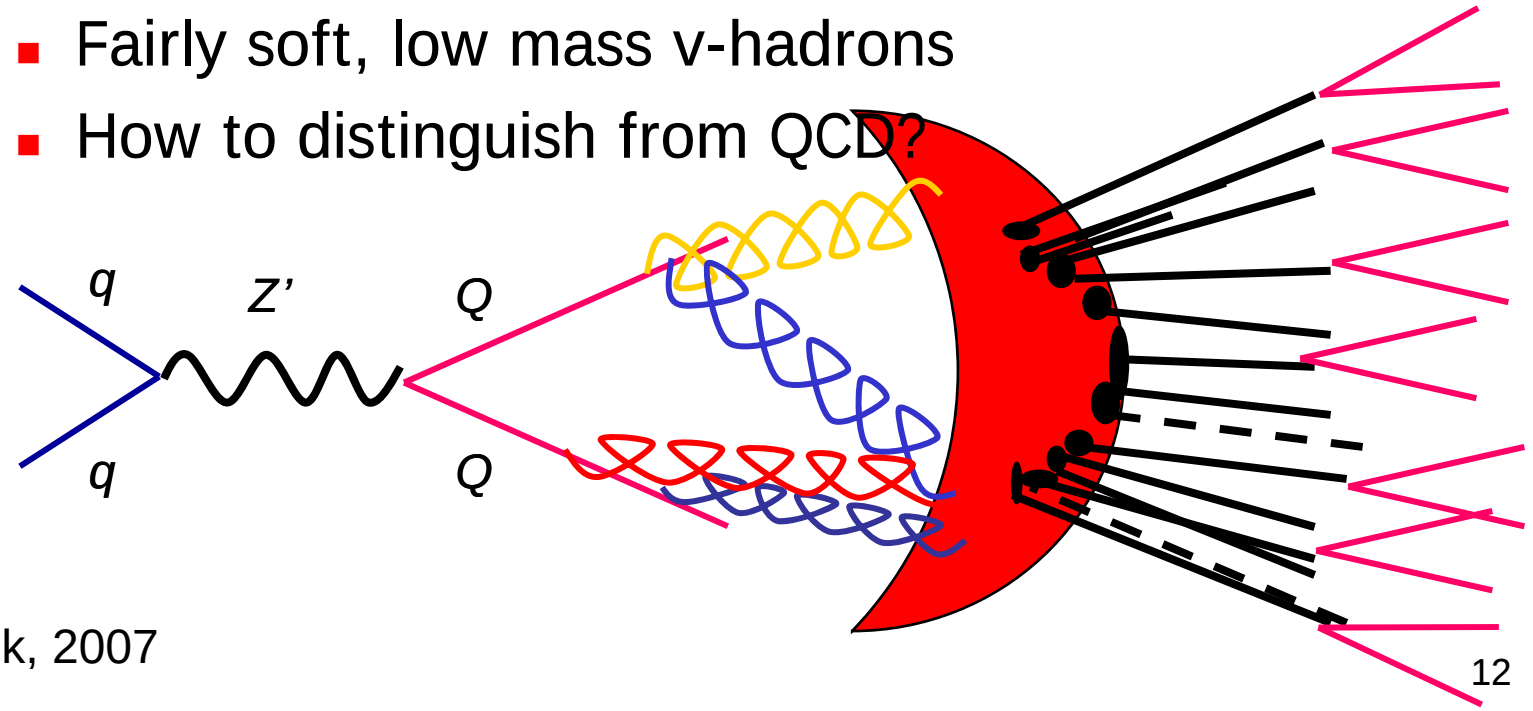
Displaced vertices

Looking for displaced vertices

- Previously, there was no *generalized* displaced vertex search
  - "Experimentalists are used to looking for displaced vertices"
    - True, but not
    - B-tagging looks for mm displaced vertex
    - Displaced vertices not typical of b's are rejected, as they are usually cosmic rays
    - Most usual BSM candidates have prompt decays
      - Notable exceptions: SuperWIMPs, gluinos in split SUSY
  - Atlas Working Group to change level II triggers

But if no displaced vertex?

- Challenges:
  - High multiplicities
    - (Lots of stuff in the event)
  - Fairly soft, low mass v-hadrons
  - How to distinguish from QCD?



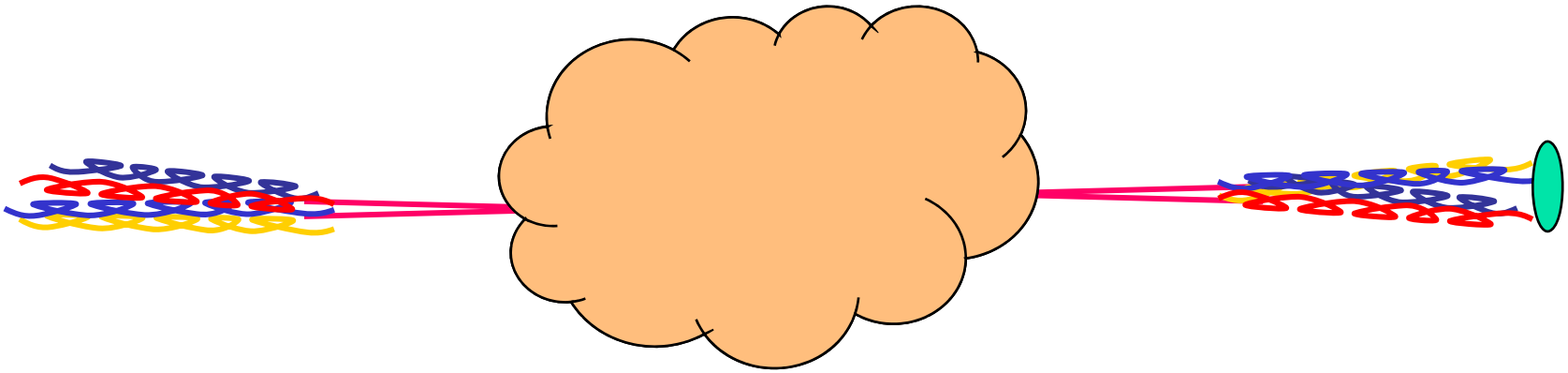
Han, Si, Zurek, 2007

Use typical energy scales

- Low mass v-hadrons $m_{\text{vh}} < 20\ \text{GeV}$
  - Use displaced vertex

$$\ell_{\eta_v \to b\bar{b}} \sim 4\ \text{cm} \frac{(20\ \text{GeV})^7}{f_{\eta_v}^2 m_{\eta_v}^5} \left(\frac{m_{Z'}/g'}{10\ \text{TeV}} \right)^4$$

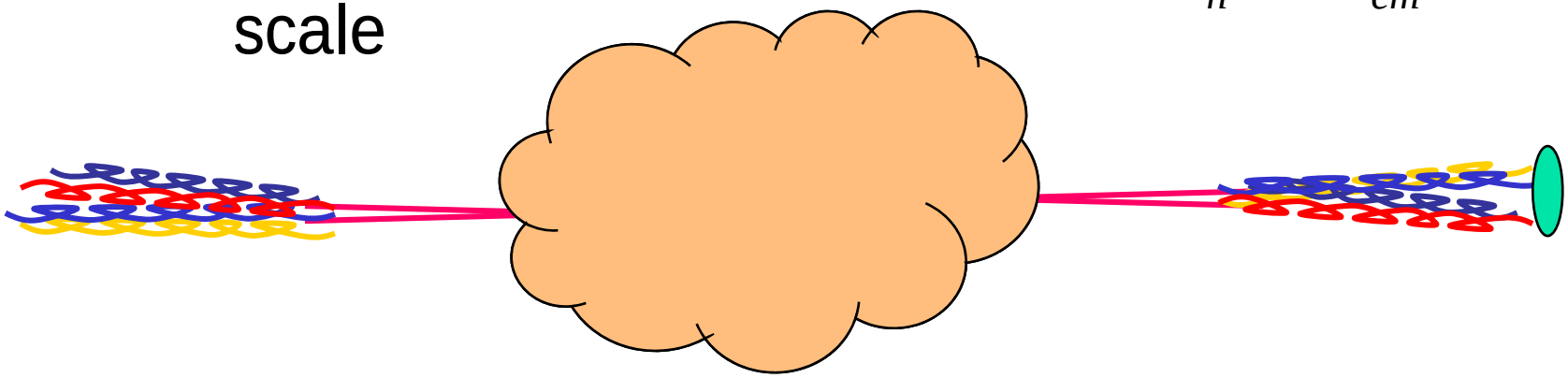
- Higher mass v-hadrons $m_{\text{vh}} > 20\ \text{GeV}$
  - Shape of event set by confinement scale



Use Typical Energy Scales

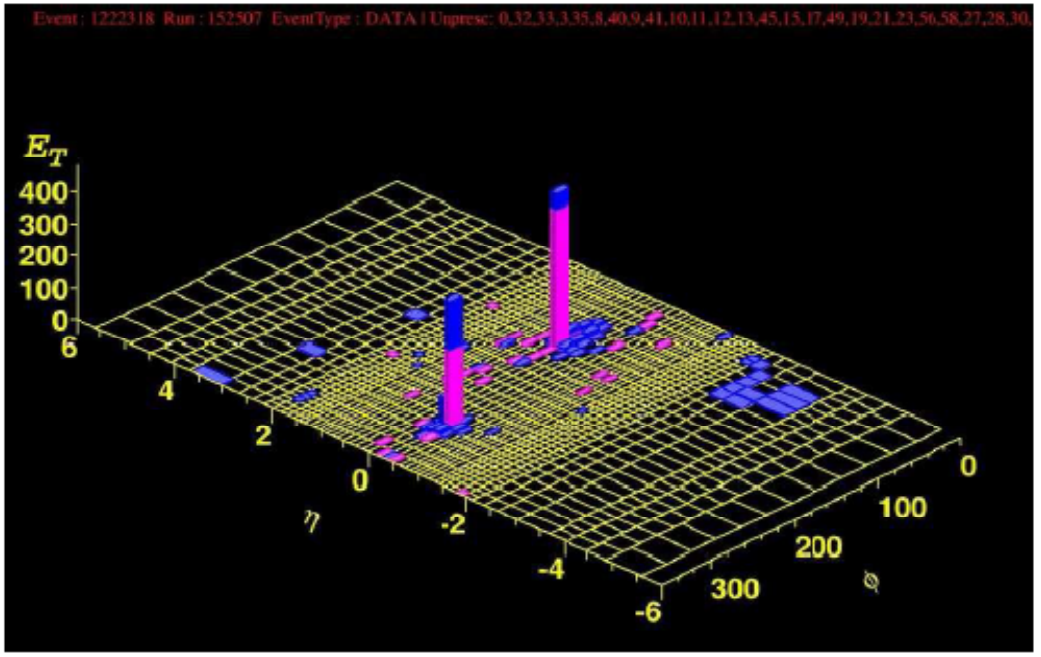
- Shape of event set by confinement scale

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

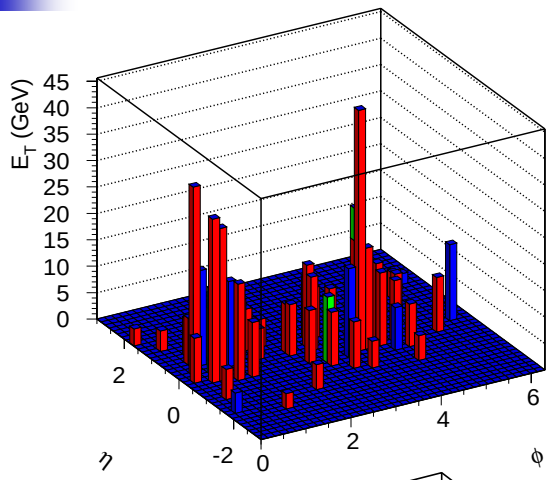


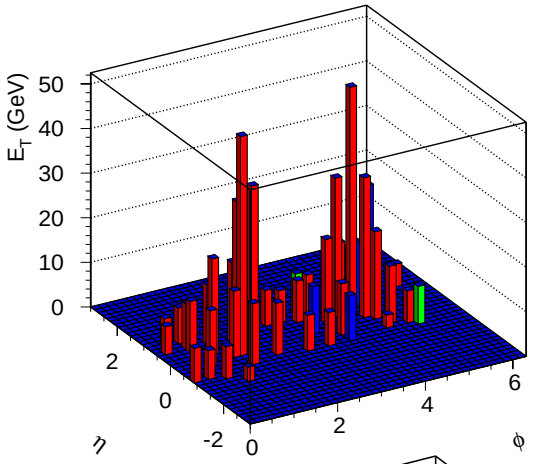
- Light quark jets $p_\perp \sim \Lambda_{QCD} \sim 1\ \text{GeVish}$
- Hidden valley jets $p_\perp \sim \Lambda_v > 20\ \text{GeV}$

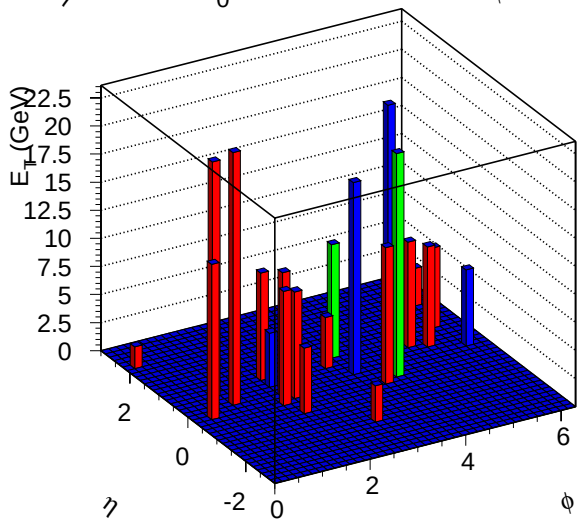
Lego Plot View

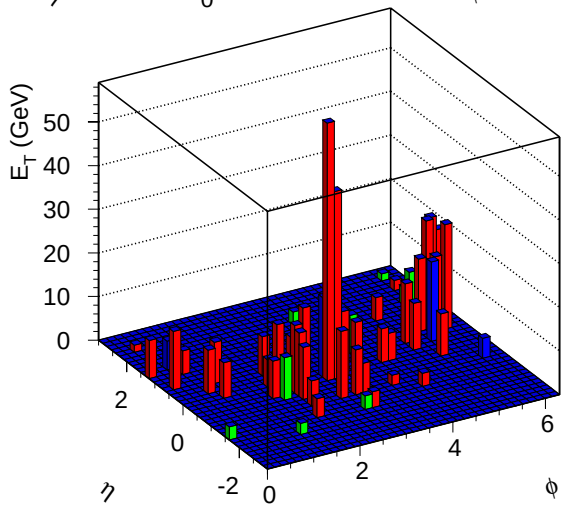


Contrast Hidden Valley Events





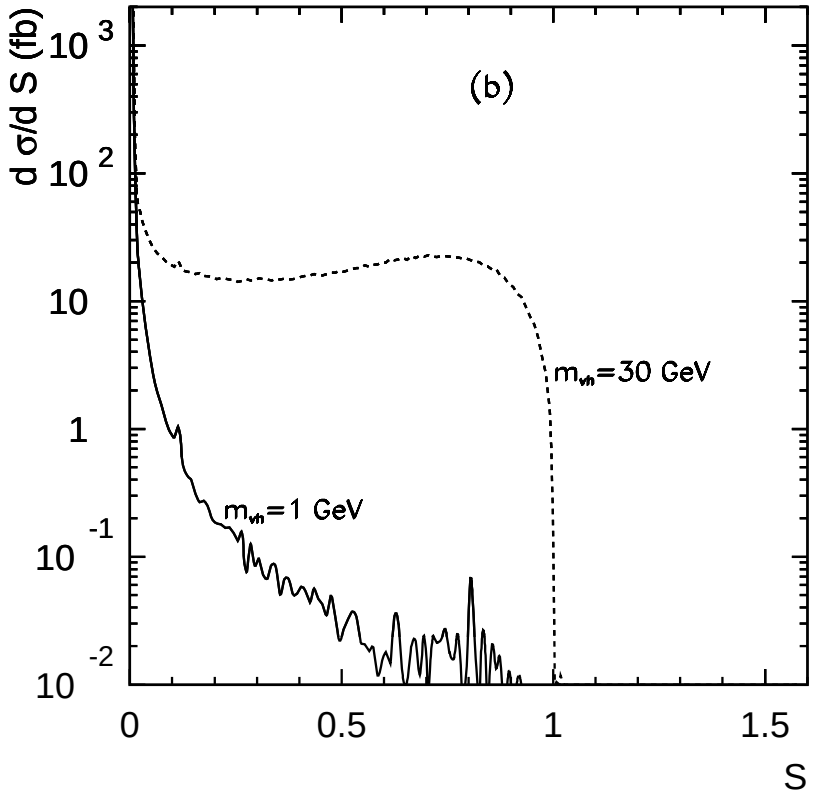


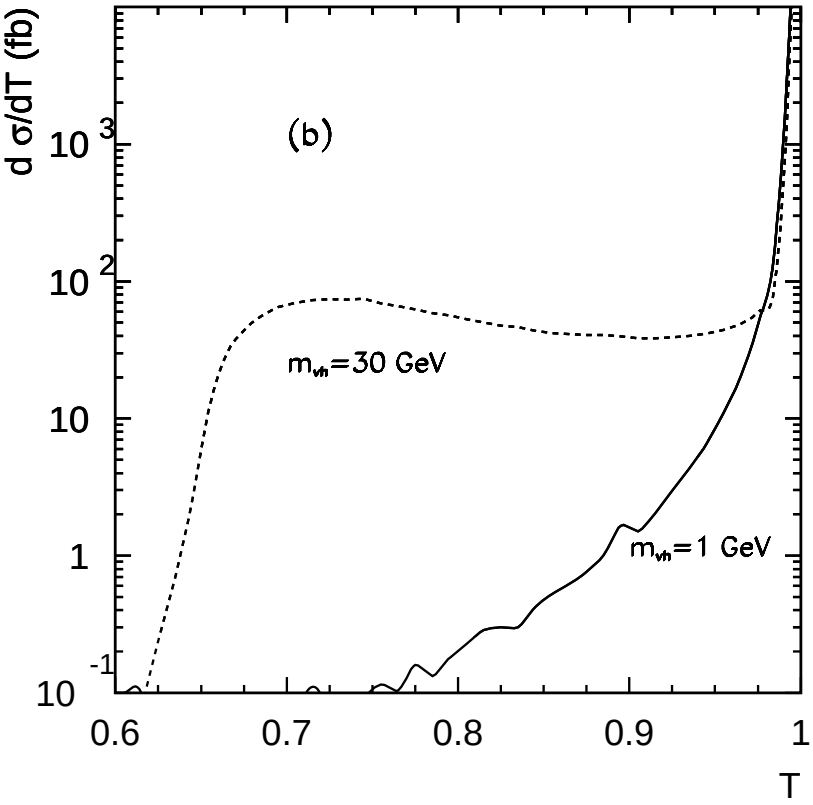


Use different energy scales

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

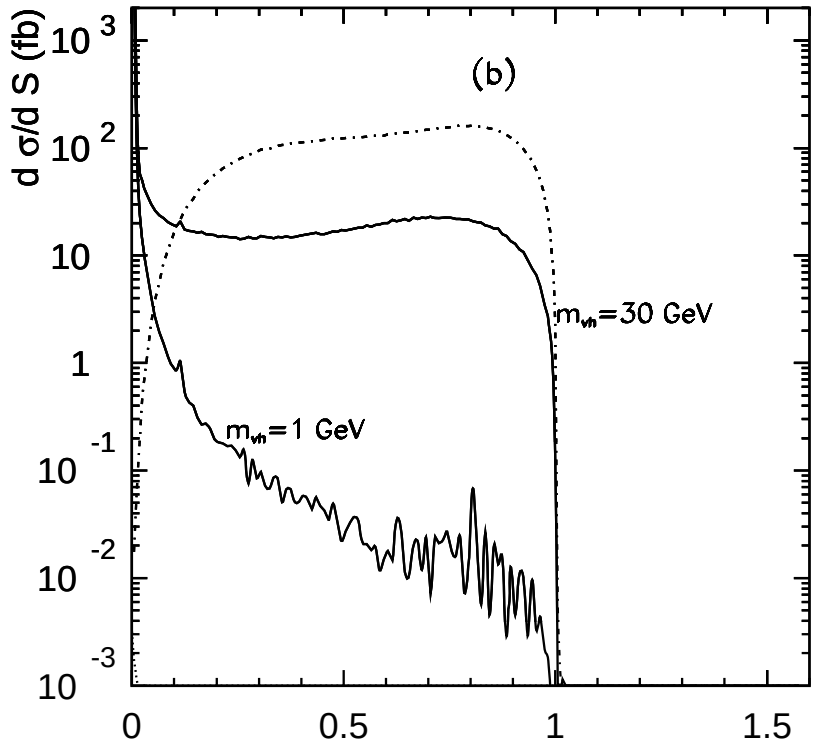
Sphericity and Thrust

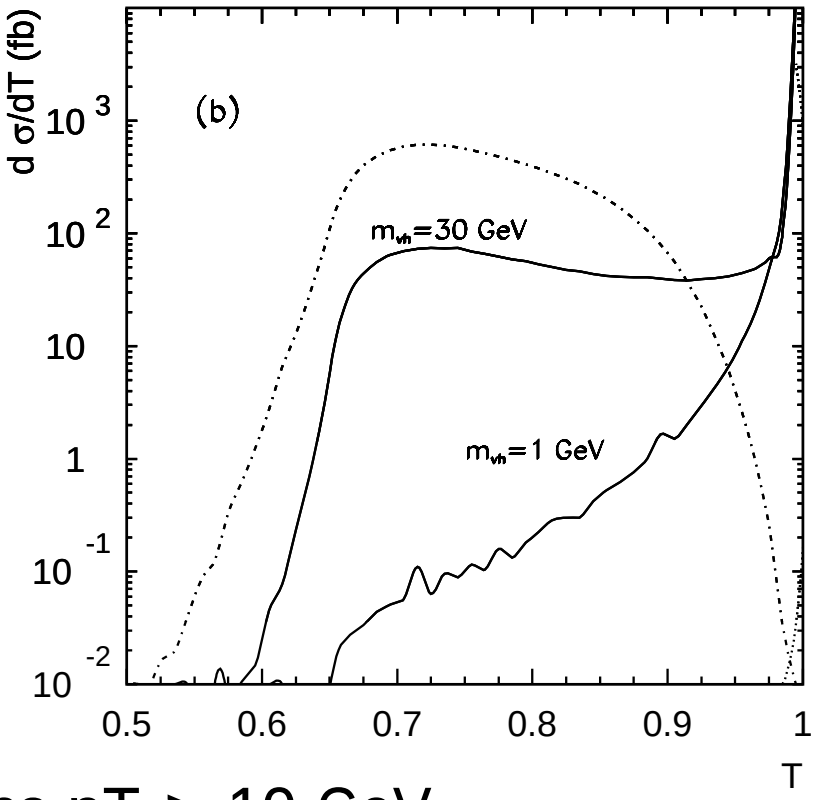




No cuts

Sphericity and Thrust





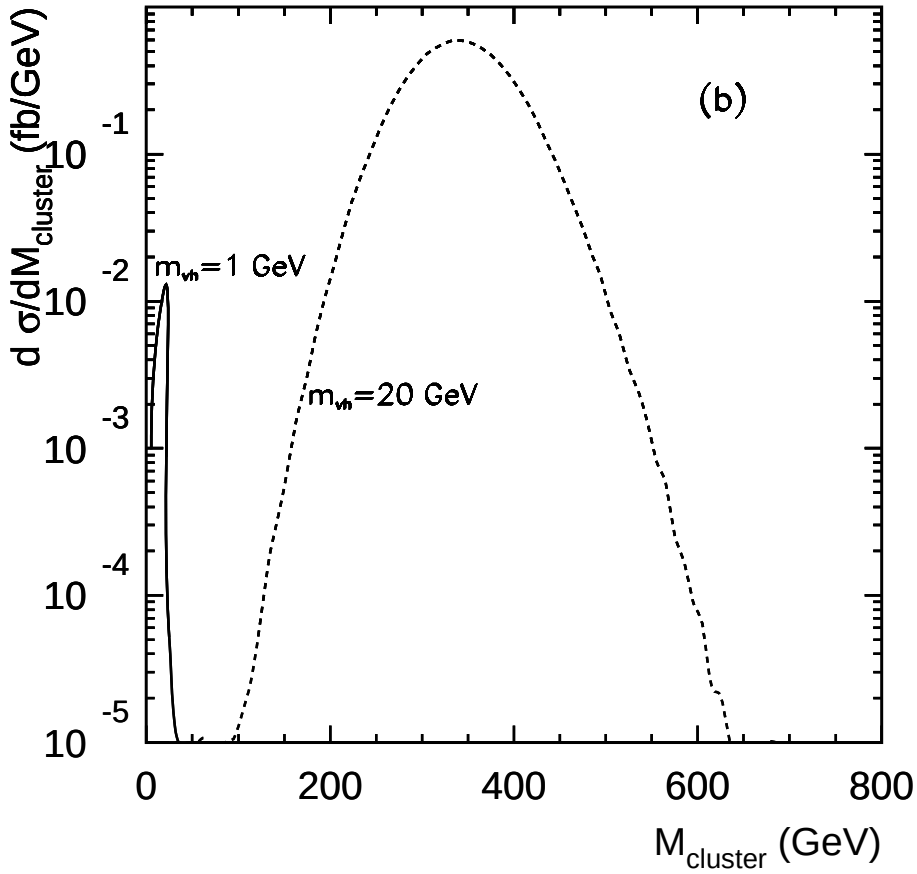
Trigger: 2 leptons pT > 10 GeV

Particle Acceptance: pT > 3 GeV

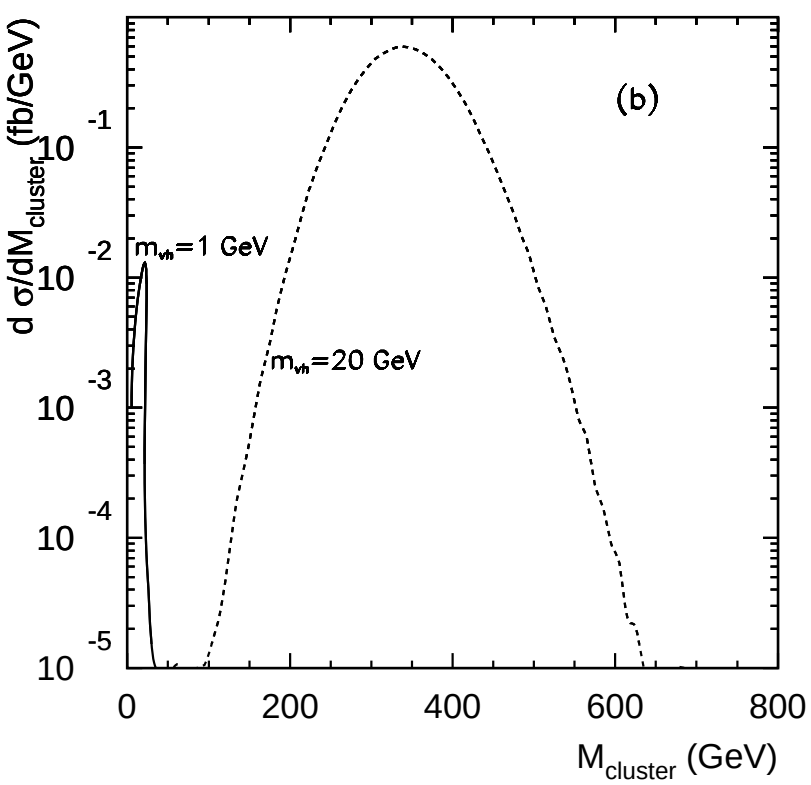
Best measure: invariant mass of cluster

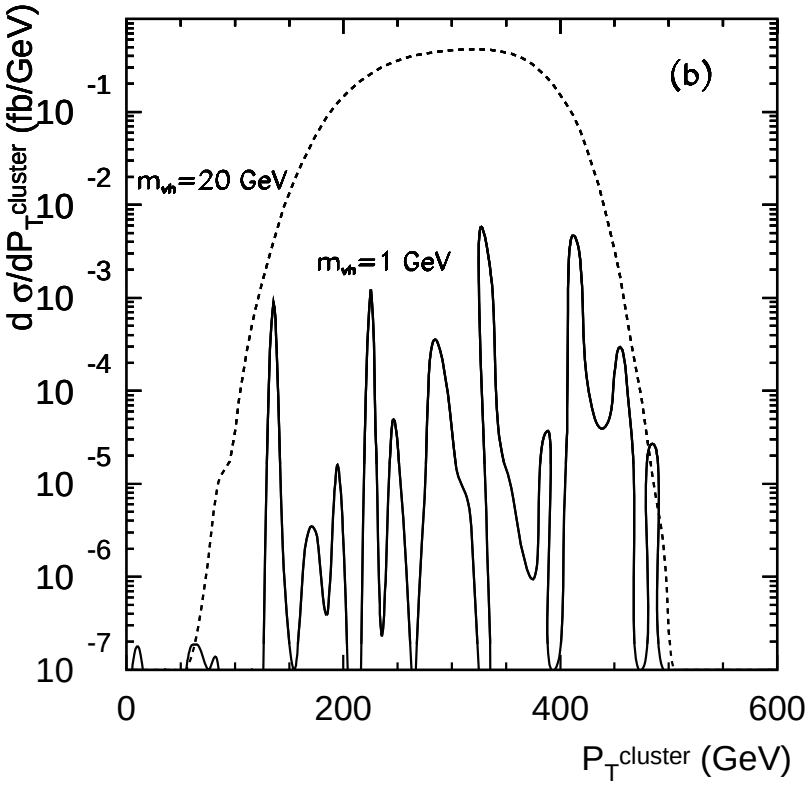
$$m_{clus}^2 = \left(\sum E_i\right)^2 - \left(\sum \vec{p}_i\right)^2$$

Highly collinear → low invariant mass



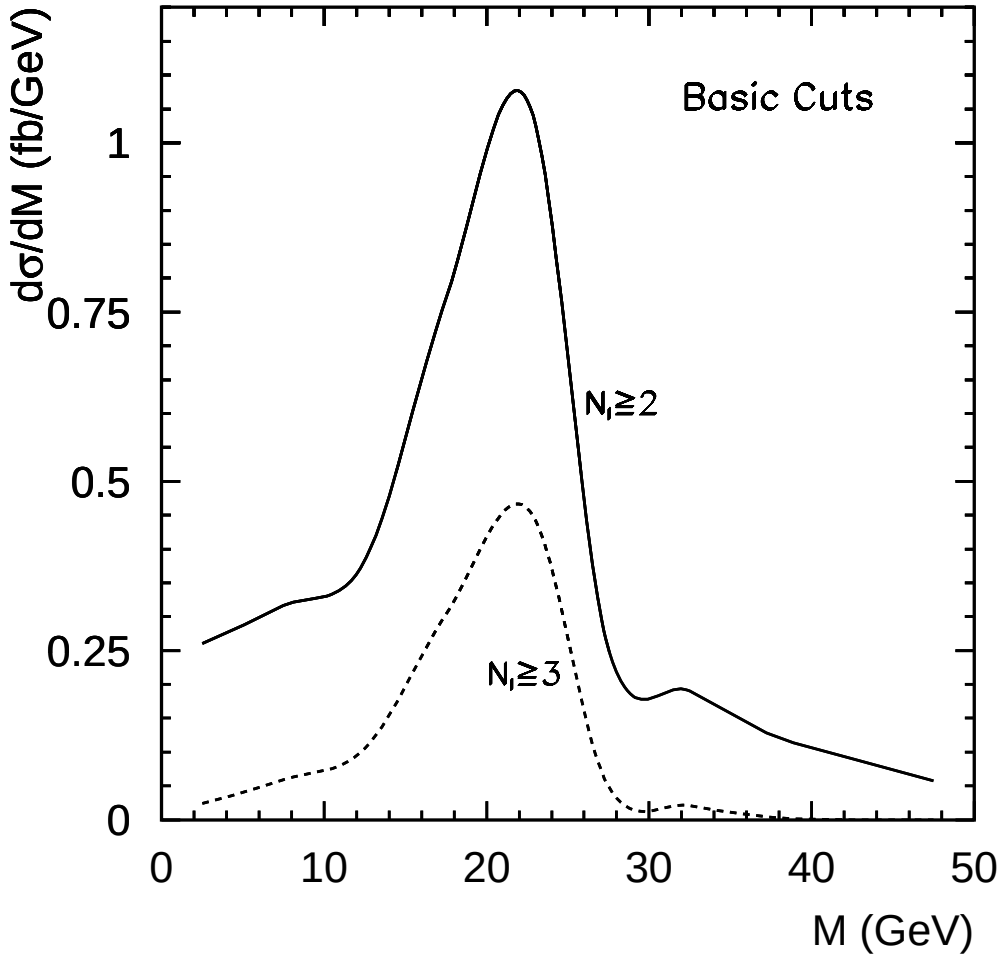
Invariant Mass

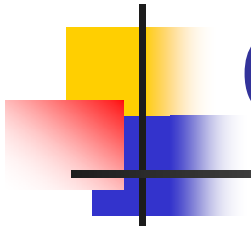




Implement cut: $m_{cluster} > 20\% \, p_T^{cluster}$

Reconstruct resonance





Conclusions

- Hidden valleys yield novel phenomenology, consistent with broad class of models
  - Displaced vertices (requires work on triggers)
  - Multiple high pT (>10 GeV) leptons
  - Leptons may be isolated
  - Events are more spherical...
  - and have higher cluster invariant mass
  - In short: they look very different from the SM and from any other new physics model