SEARCHING FOR HIDDEN VALLEYS

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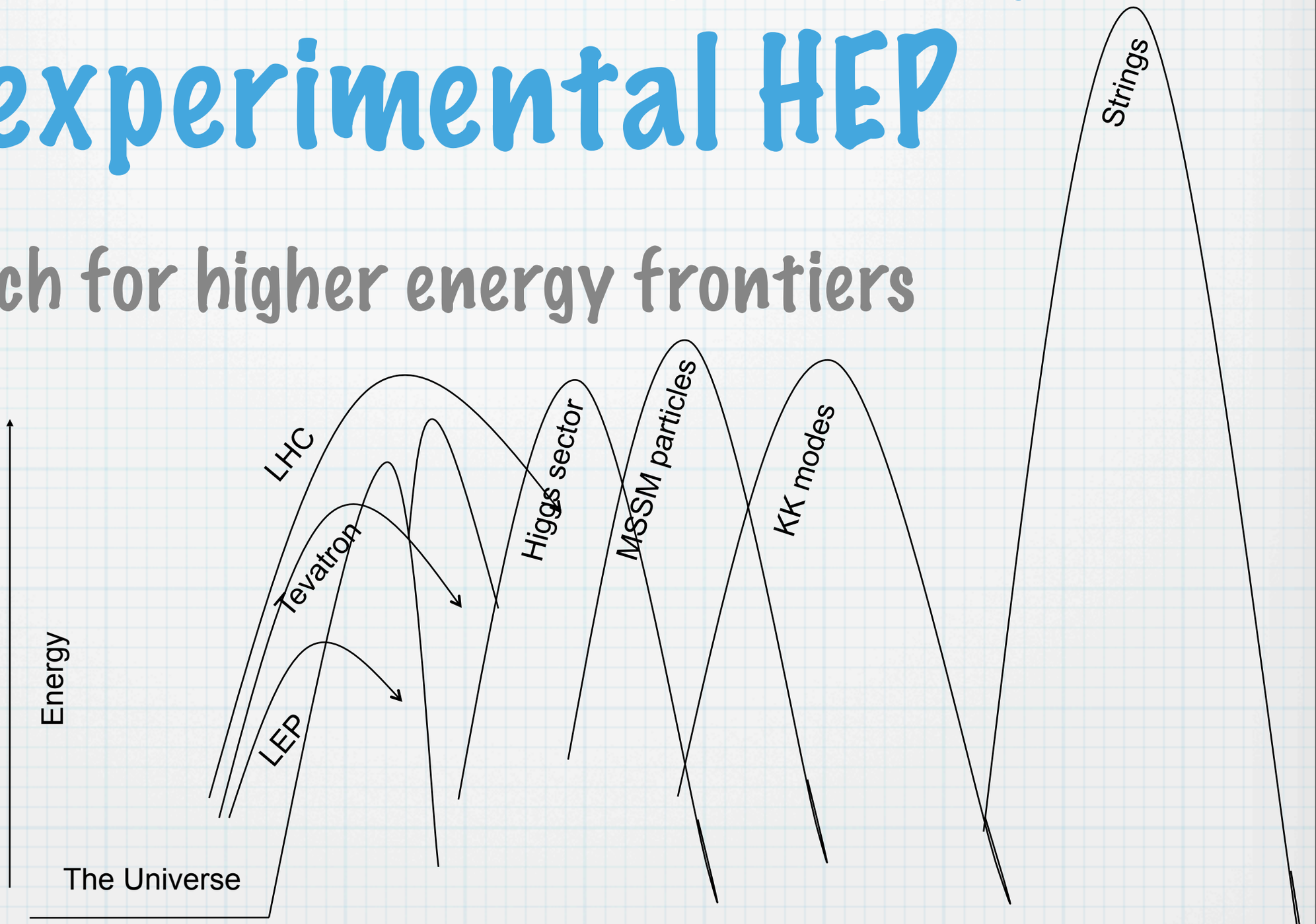
ASPEN WINTER CONFERENCE

Summary

- Hidden valleys
  - What are they? (Strassler, KZ 2006)
    - Low mass hidden sectors connected to SM through higher dim ops
  - Why are they interesting and experimentally relevant?
  - Search techniques, challenges (Han, Si, KZ, Strassler 2007)

Focus of theoretical and experimental HEP

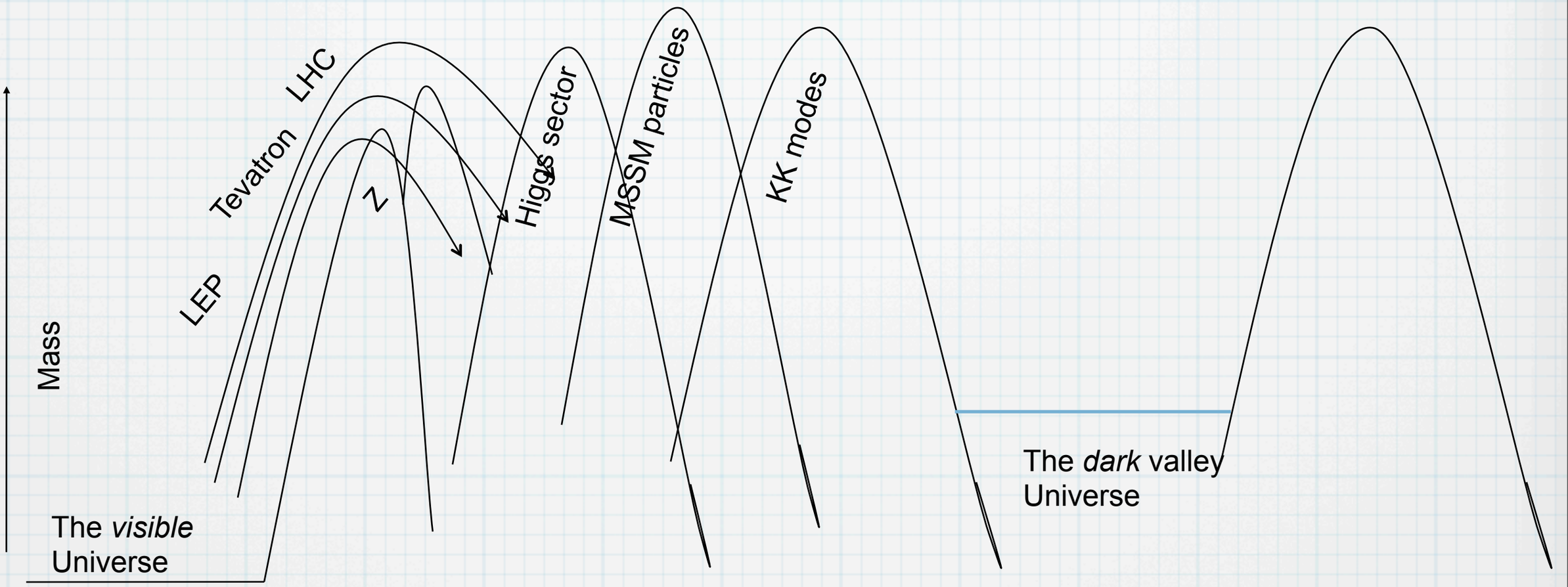
* Reach for higher energy frontiers



Focus on high mass phenomena

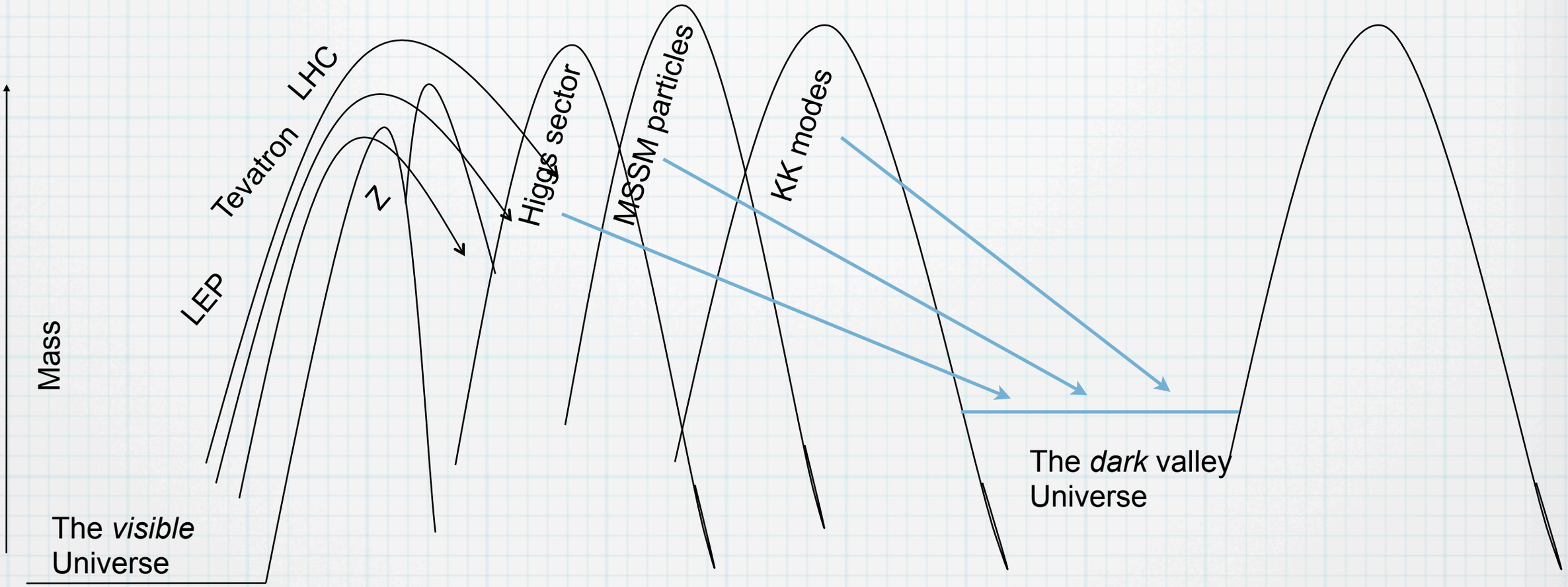
* Theory: solutions to the hierarchy problem
  * Extensions of the Higgs sector
  * SUSY
  * Technicolor
  * Extra dimensions (large or warped)
  * Little Higgs
  * Extra Z'
* Hundreds of GeV to TeV scale particles

TeV scale physics + (plus)



- May be light valley particles (low elevation of valley floor)
- Next valley must be hidden (neutral under SM gauge groups)
- But charged under high mass mediator

TeV scale physics + (plus)



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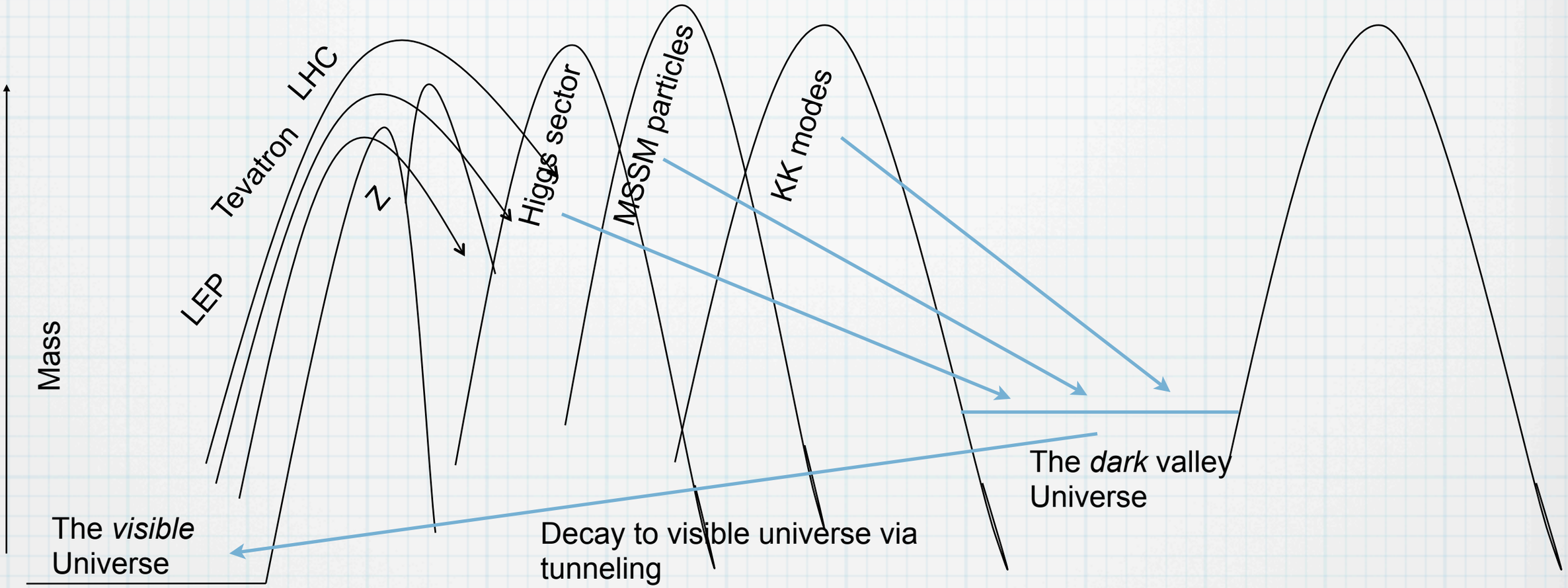

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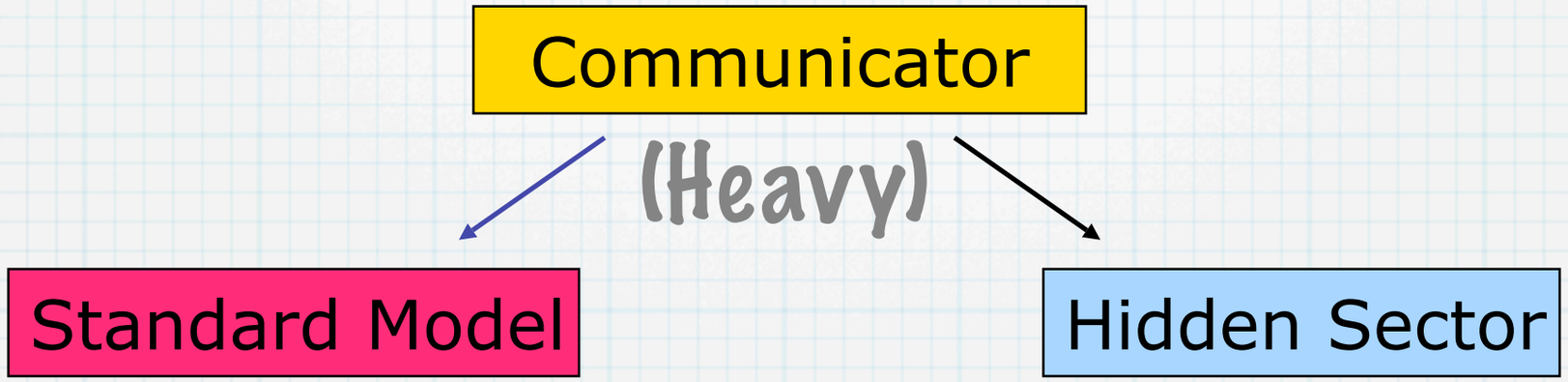
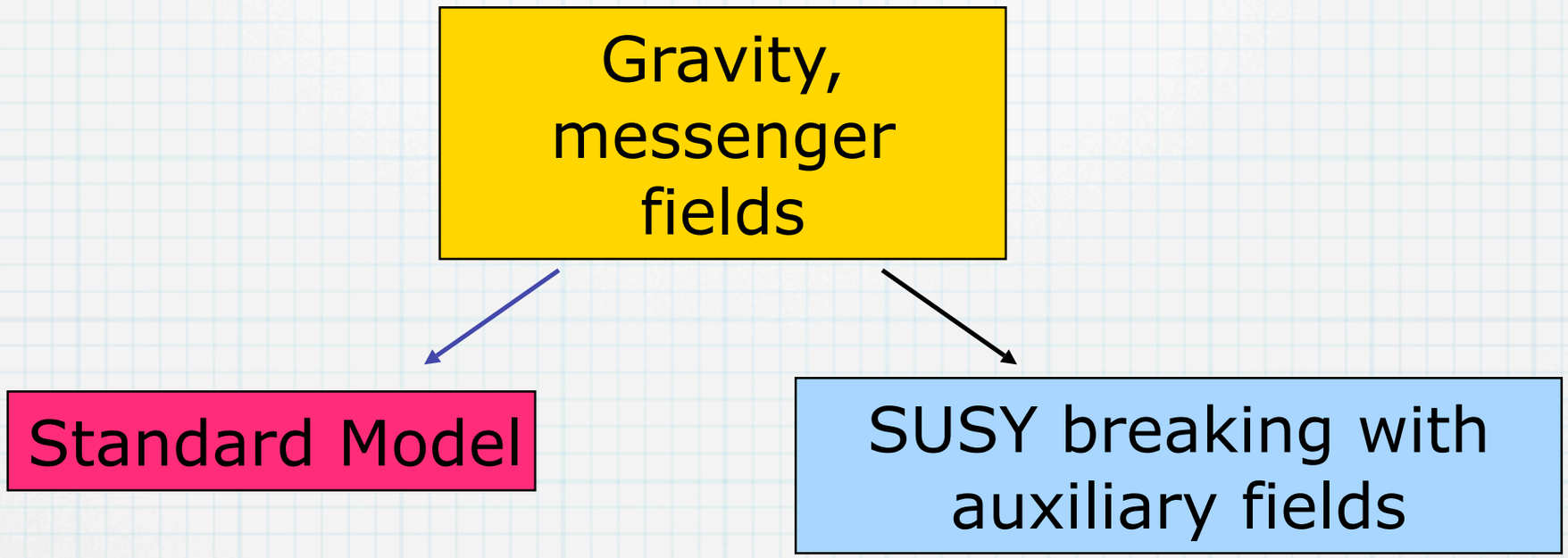
Schematic



$$\frac{\mathcal{O}_{SM}\mathcal{O}_{HV}}{M^k}$$

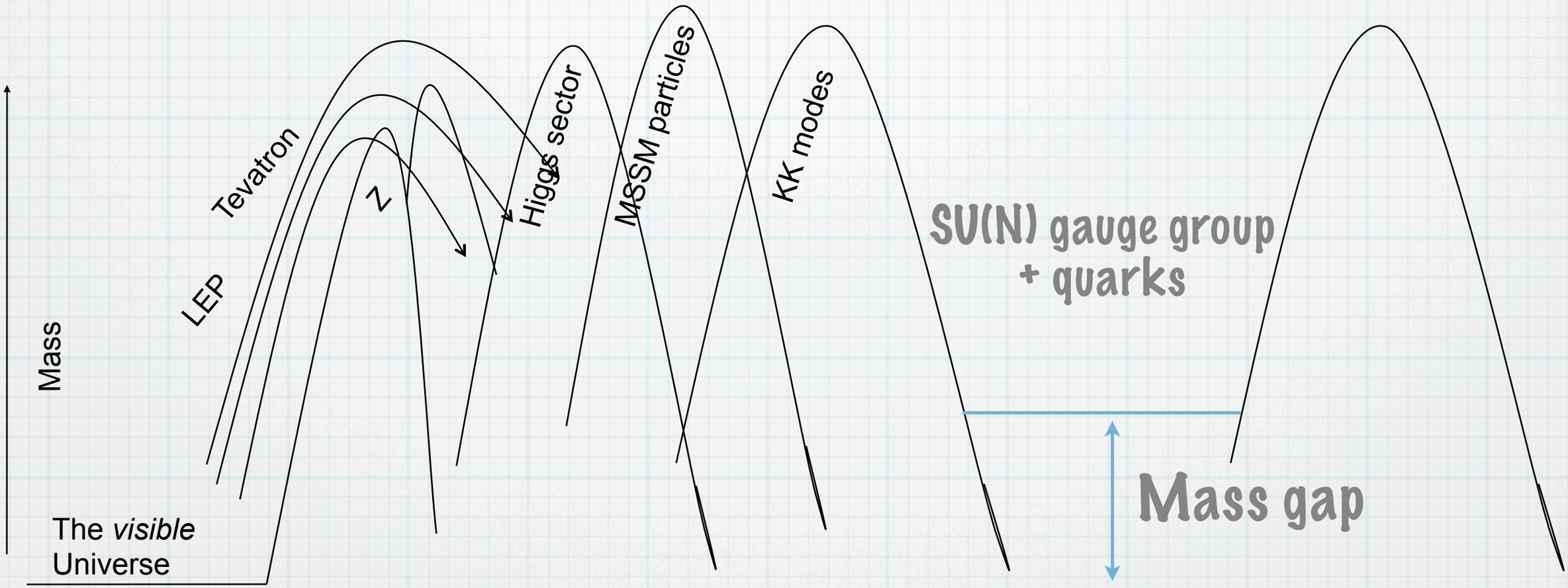
Schematic



(Heavy)
No SM charges

New feature:
Hidden sector is light!
(masses of particles in HV << 1 TeV)

What is in the hidden valley?

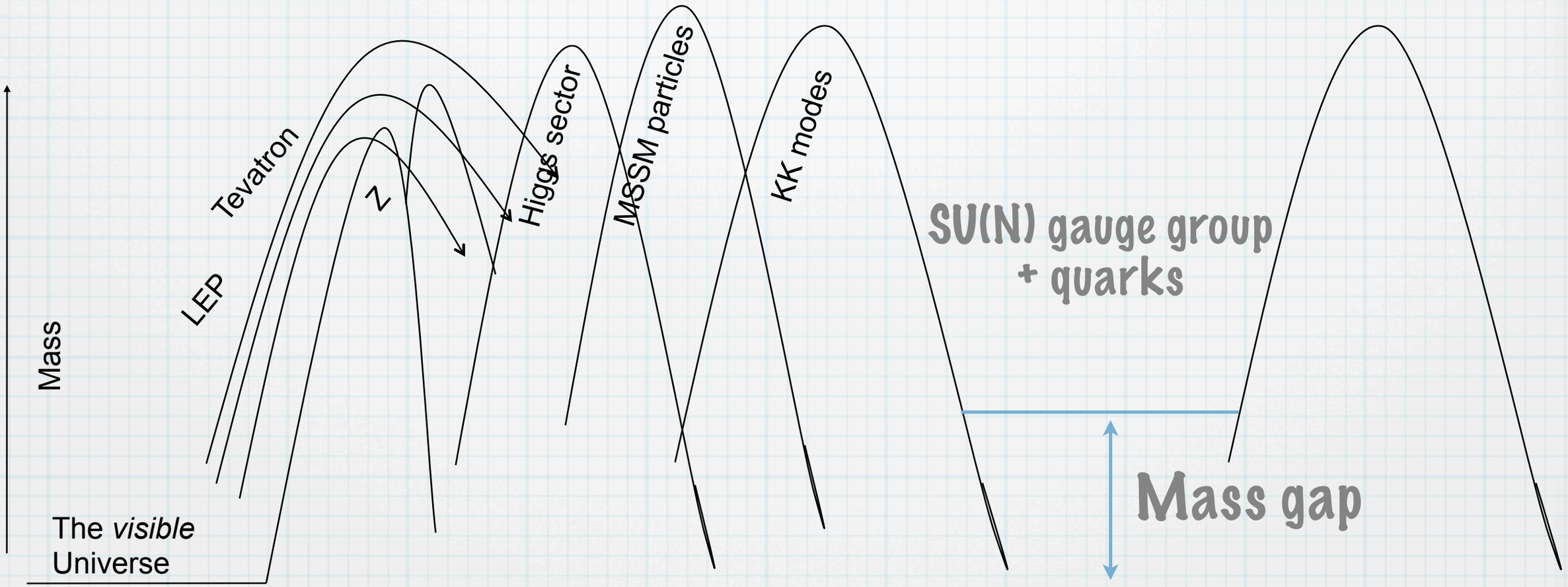


Confinement sets height of valley floor

π_v stable DOF

$m_{\pi_v}^2 \sim \hat{\Lambda} m_v$

What is in the hidden valley?

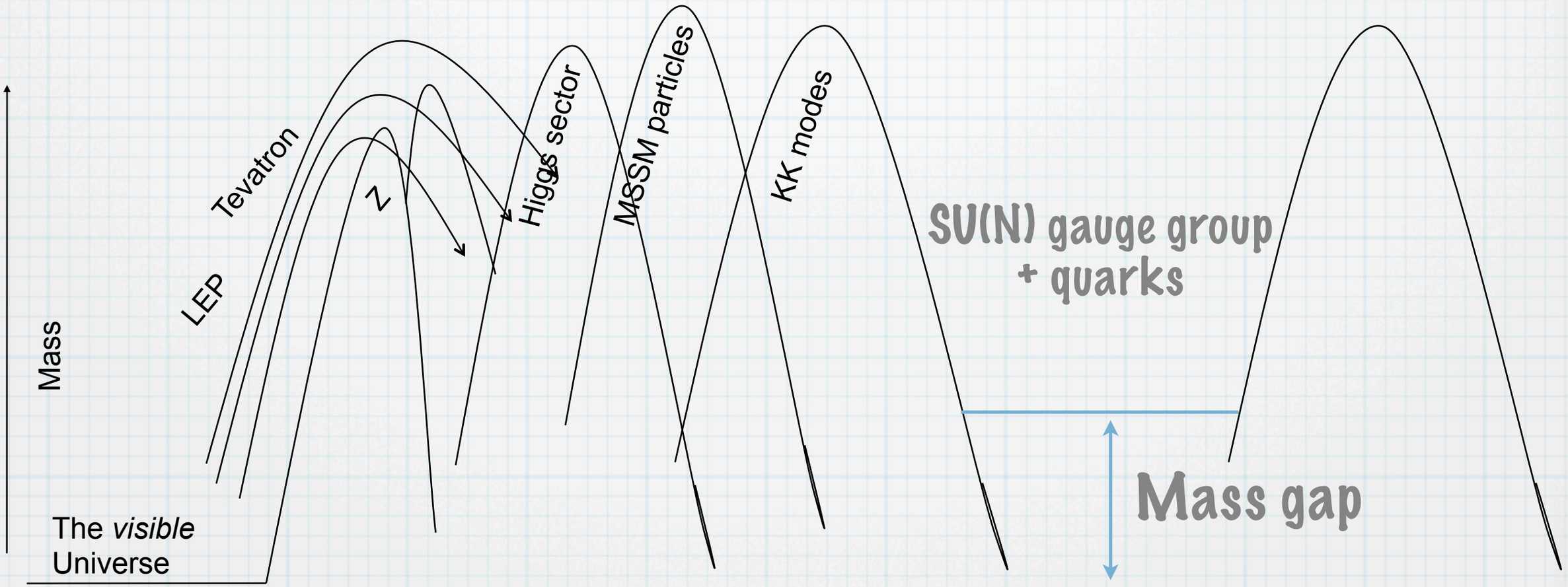


Many theories with this structure:

QCD-like theory with F flavors and N colors
QCD-like theory with only heavy quarks
QCD-like theory with adjoint quarks
Pure glue theory
UV-fixed point = confining
N=4 SUSY Conformal
RS throat

Seiberg duality cascade
KS throat
Remnant from SUSY breaking
Partially higgsed SU(N) theory
Banks-Zaks sector
Unparticles

What's in the hidden valley?



Mass gap -->0, integrate out heavy quarks, approx. unparticle

Phenomenology of the hidden valley

* Depends on the content of the hidden sector
  * How many quarks? Lighter or heavier than confinement scale? Scale of confinement?
* Depends on the mediator (dim of operator)
  * Higgs? Z'? KK mode? Messenger fermion?
  * Decay modes (which SM particles?)
  * Lifetimes (may be long)

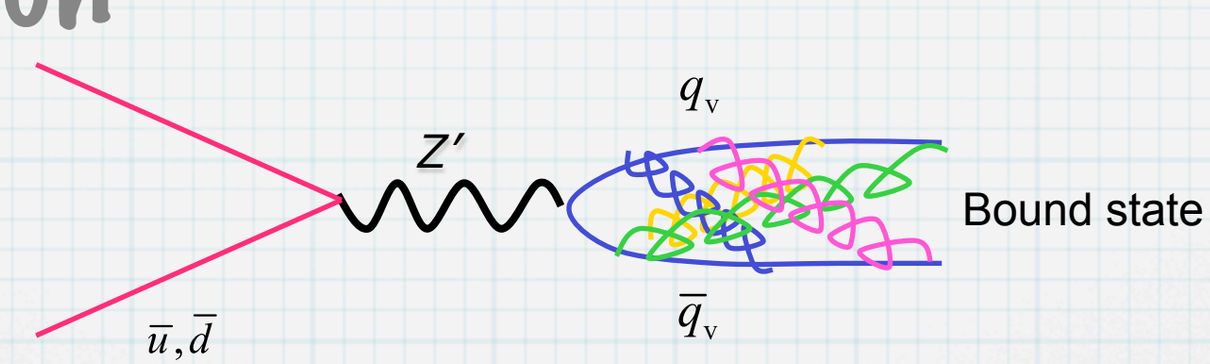
Models with a mass gap

* Most important features
  * Total CM energy of event is high
    * Produce (heavy) mediator on shell
    * Helps with backgrounds enormously!
  * Low mass resonance (J/psi in high Ecm event)

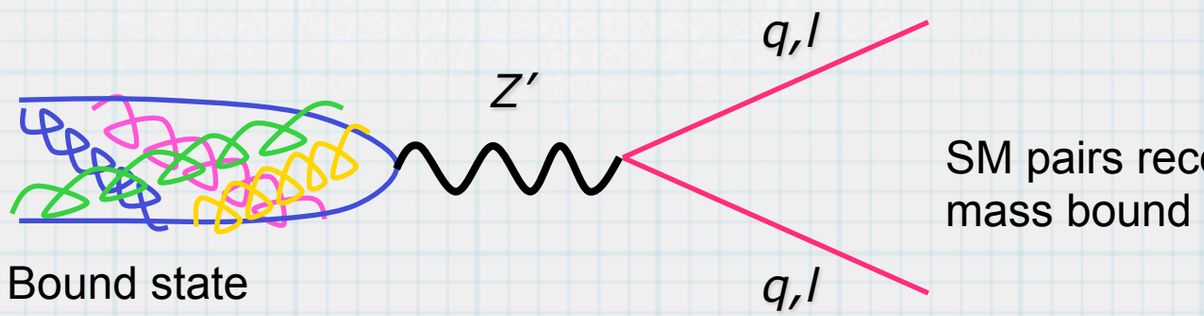
$$\rho \to \mu^+\mu^-, \mathrm{b\bar{b}}$$

A concrete example

* Z′ mediator
* SU(N) gauge theory with 1 light quark
* Production



* Decay



$\rho_v(1^-)$ decays democratically to all flavors q, l
$\eta_v(0^-)$ decays predominantly to heavy flavor

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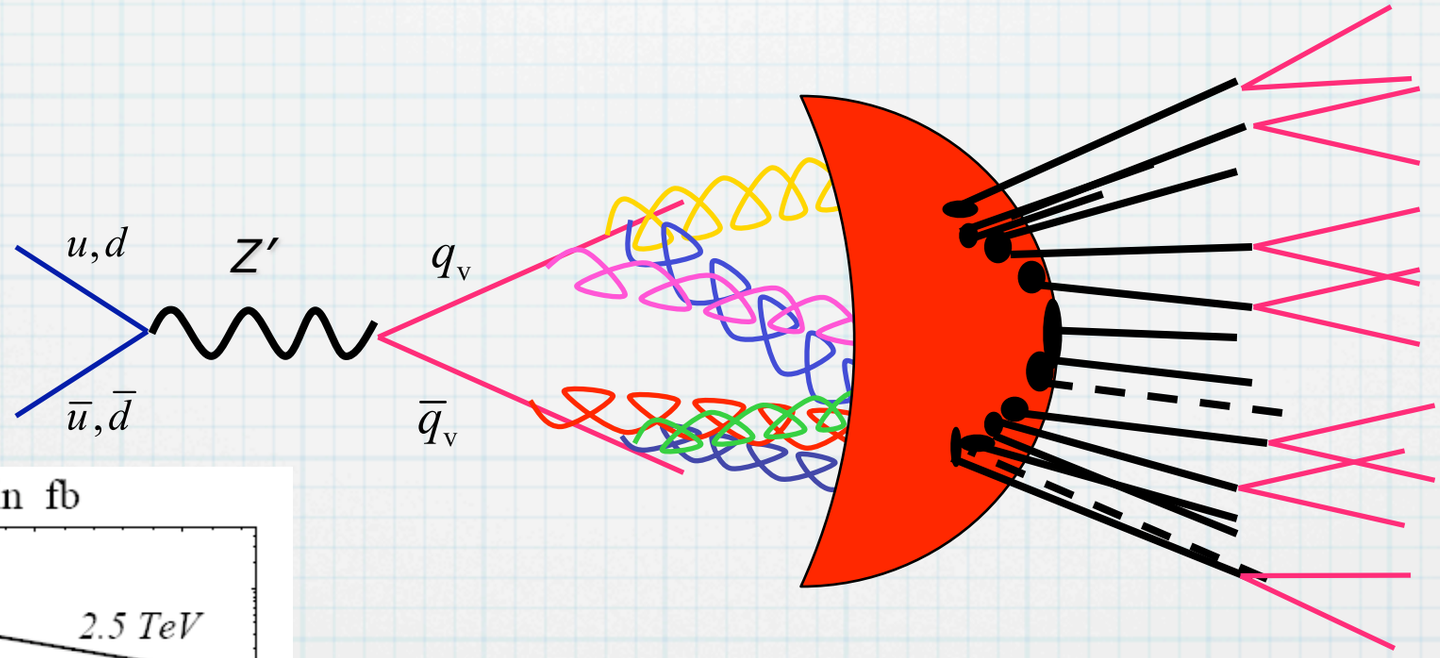

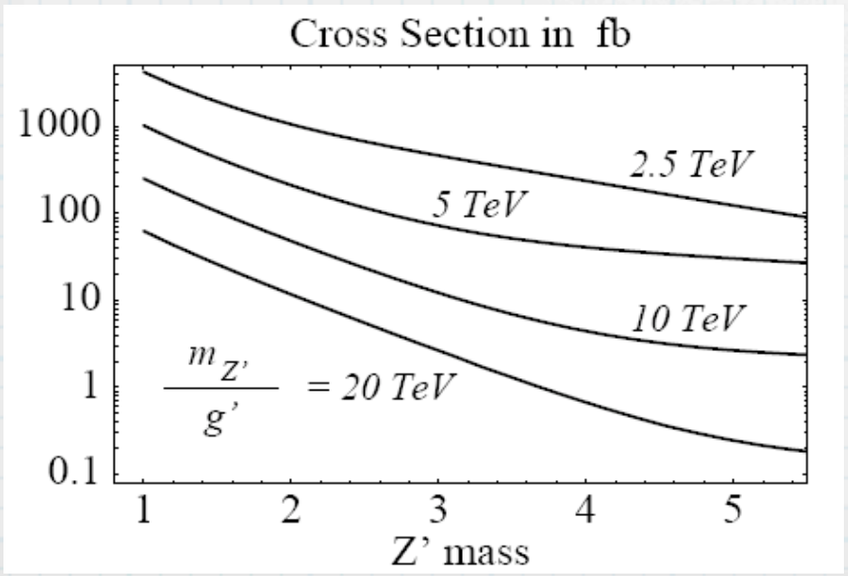

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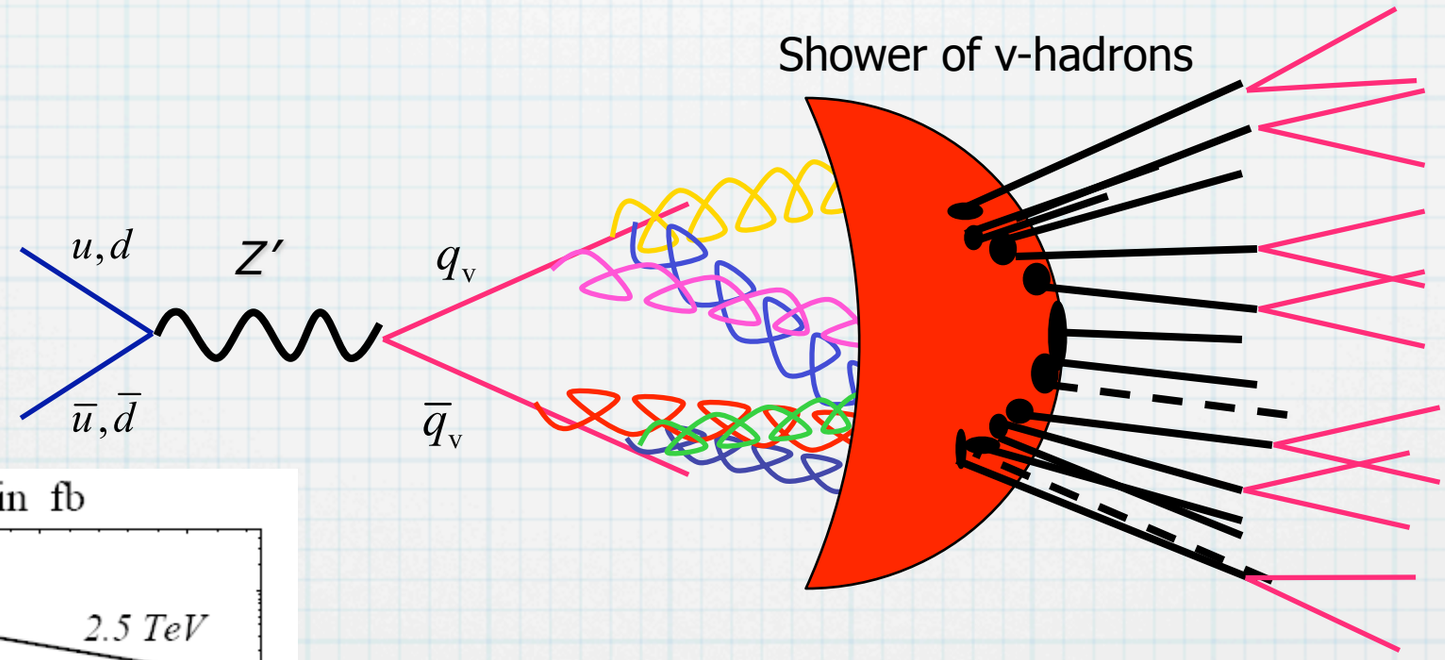

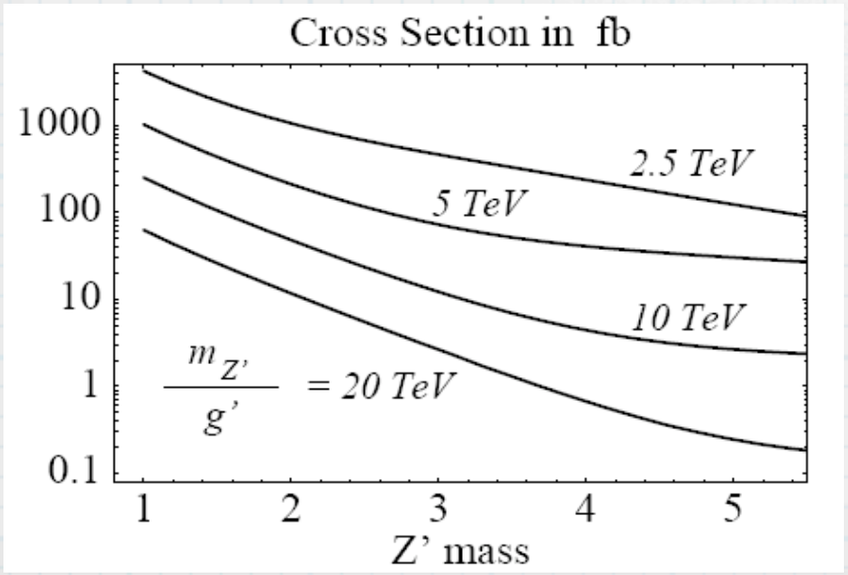

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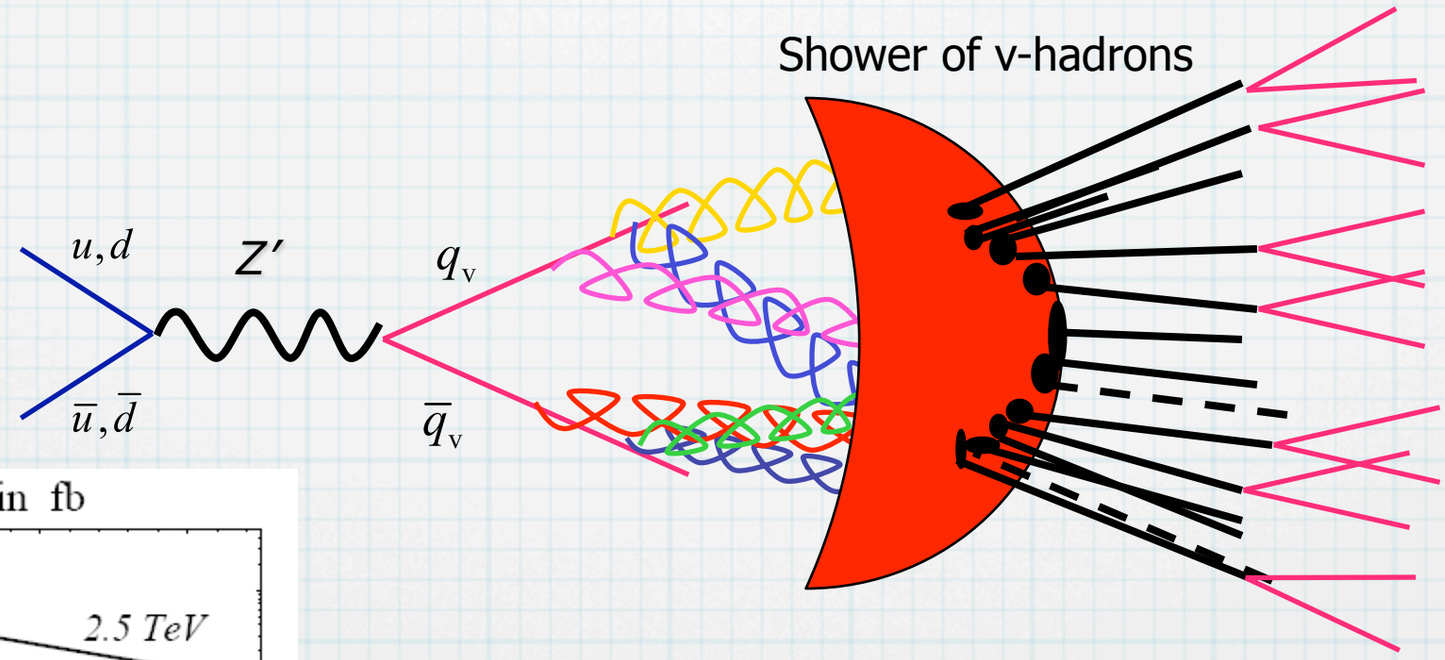
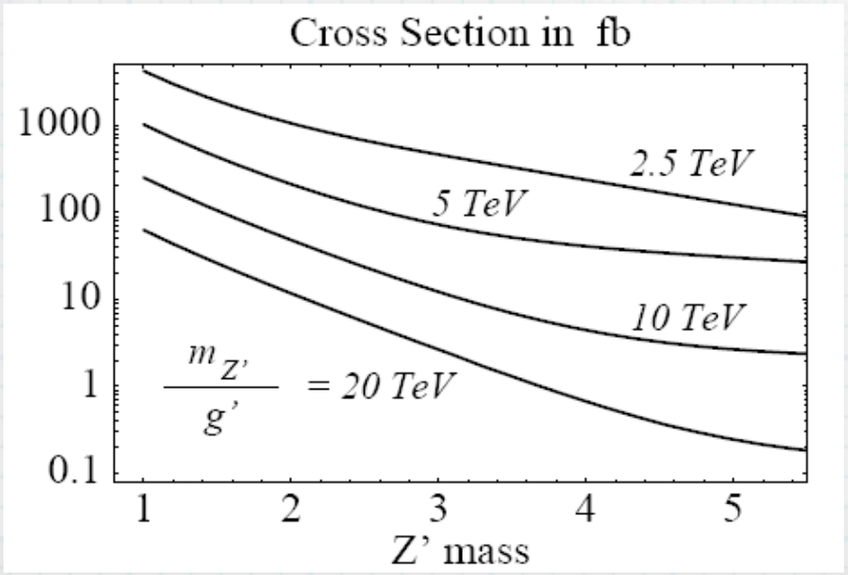


Each pair reconstructs to low mass v-hadron



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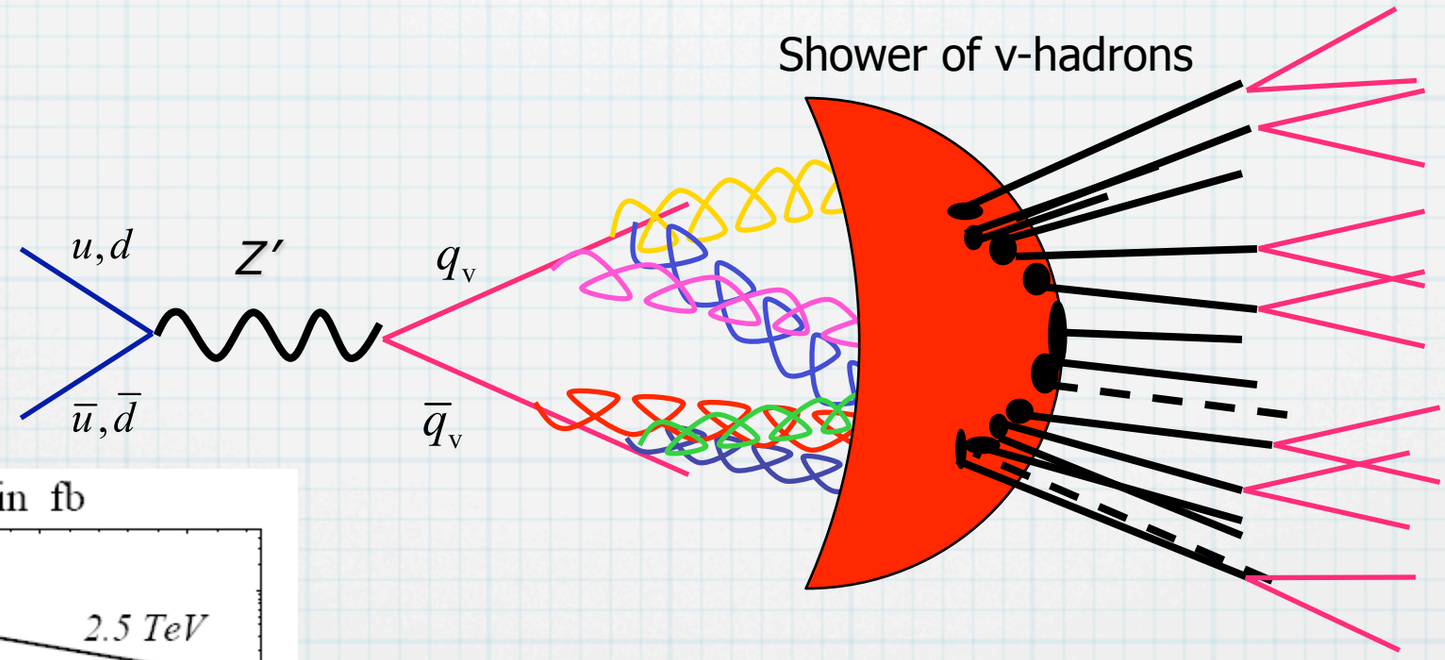
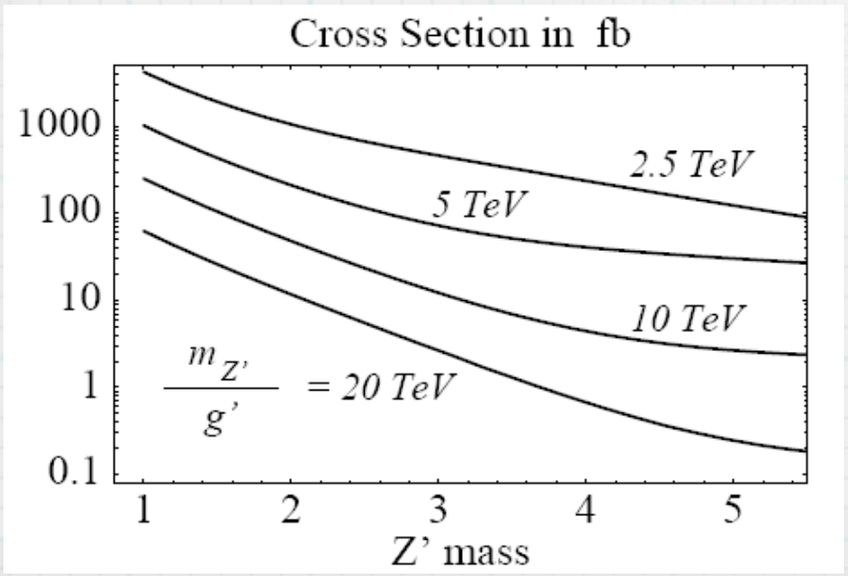


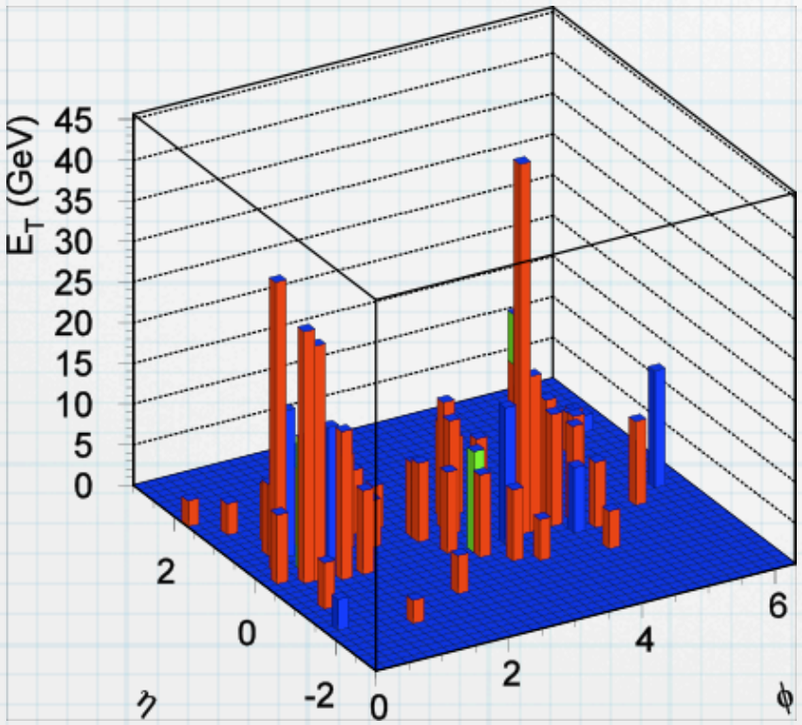


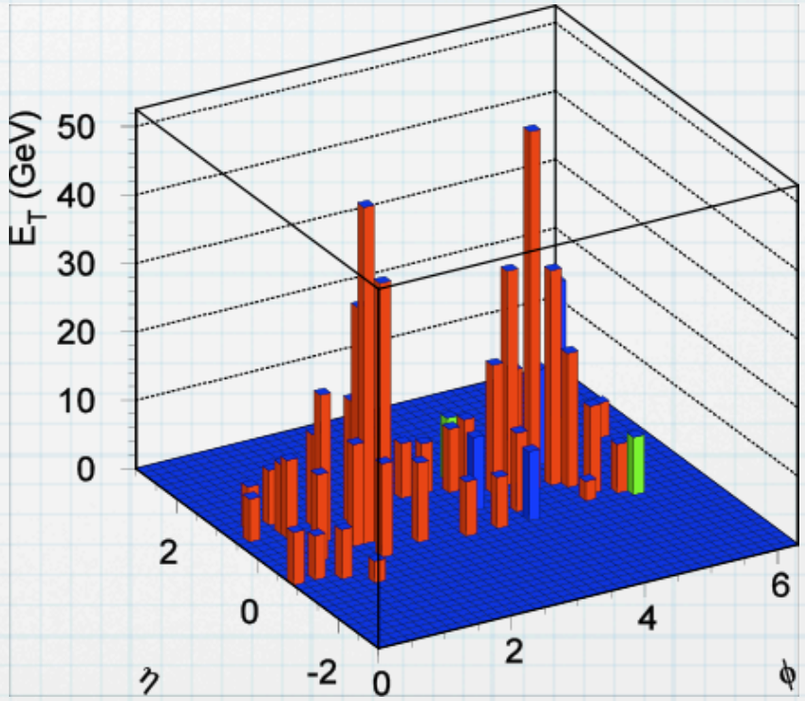
Each pair reconstructs to low mass v-hadron

Reconstruct entire event to Z' resonance

A concrete example

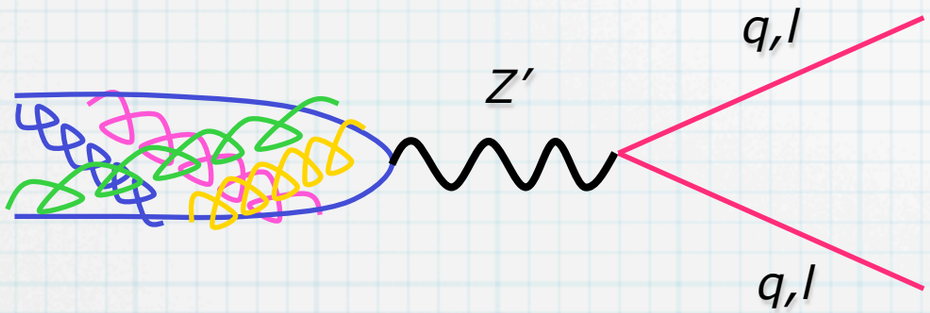
* Z' mediator
* SU(N) gauge theory with 1 light quark





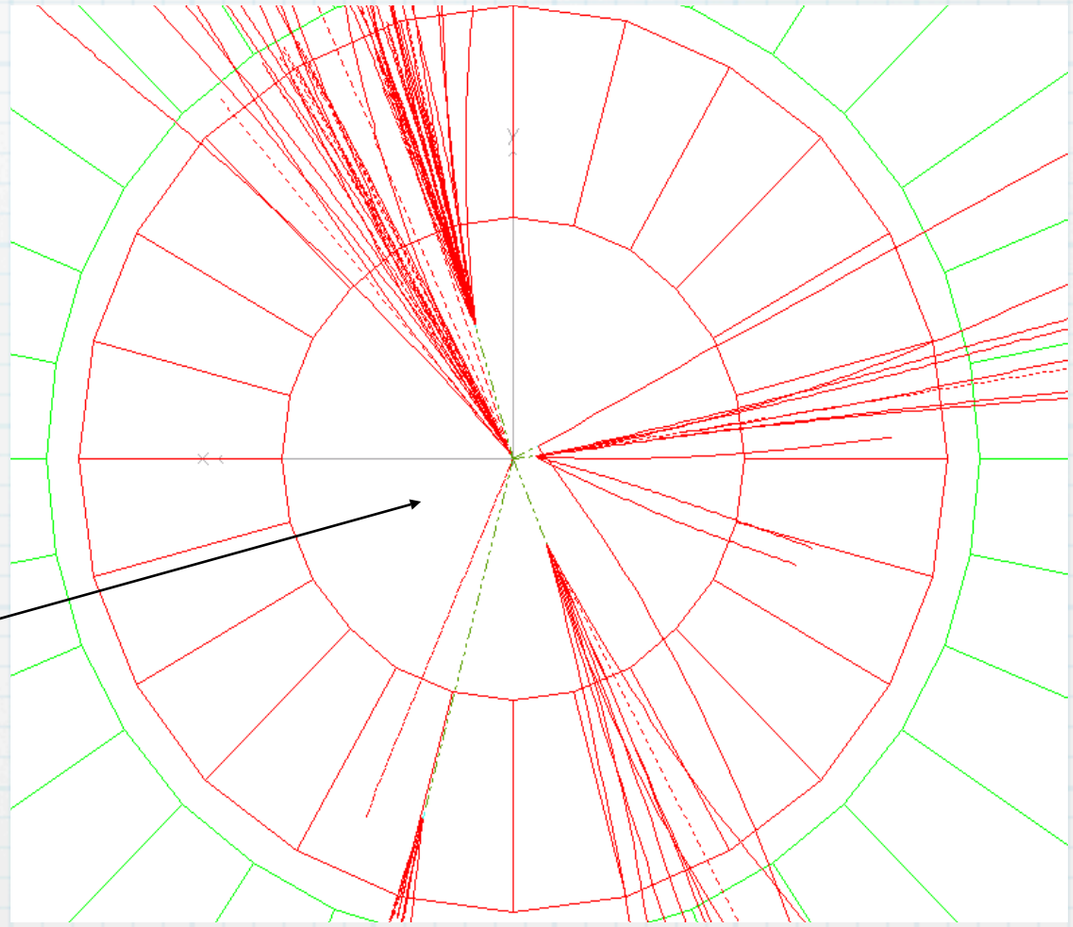
Han, Si, KZ, Strassler 2007

Event topology



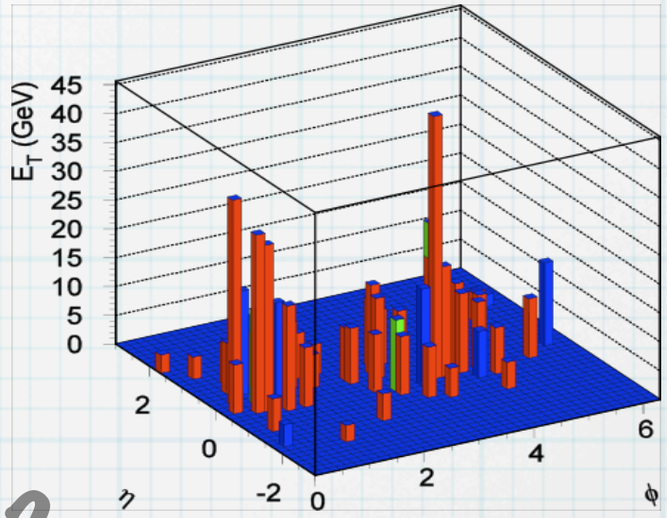
$$\ell_{\eta_v \to b\bar{b}} \sim 4 \text{ cm} \frac{(20 \text{ GeV})^7}{f_{\eta_v}^2 m_{\eta_v}^5} \left(\frac{m_{Z'}/g'}{10 \text{ TeV}} \right)^4$$

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

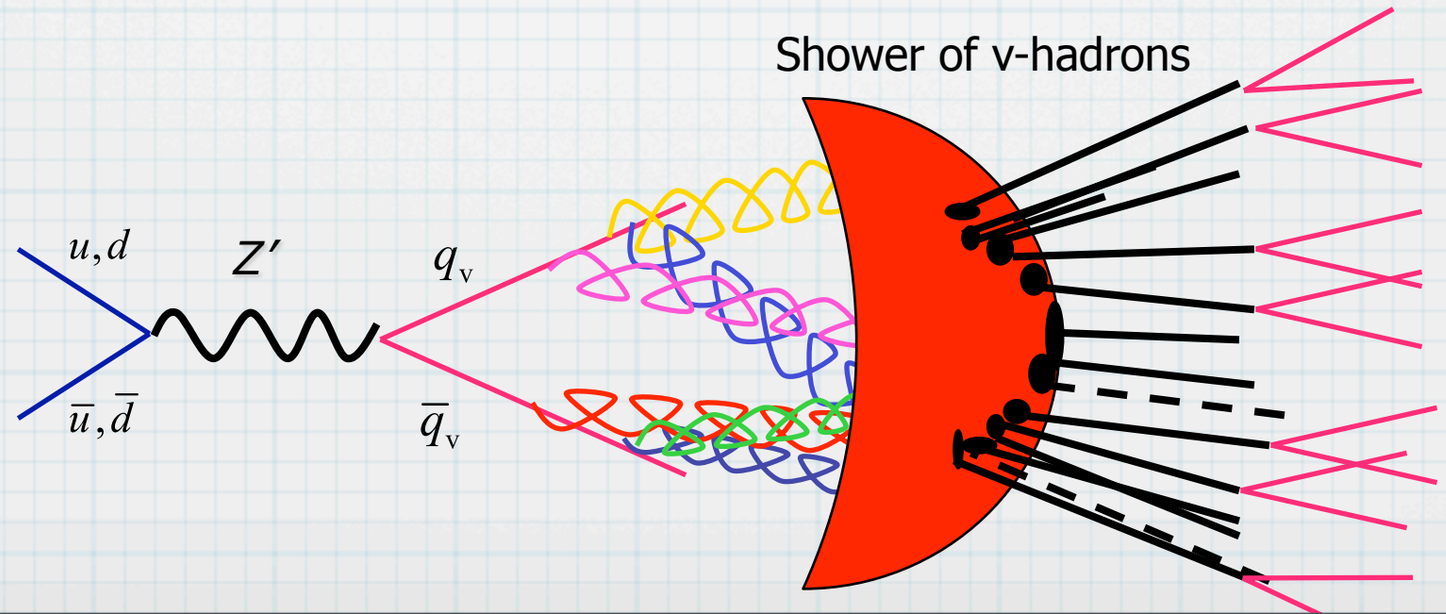


If no displaced vertex

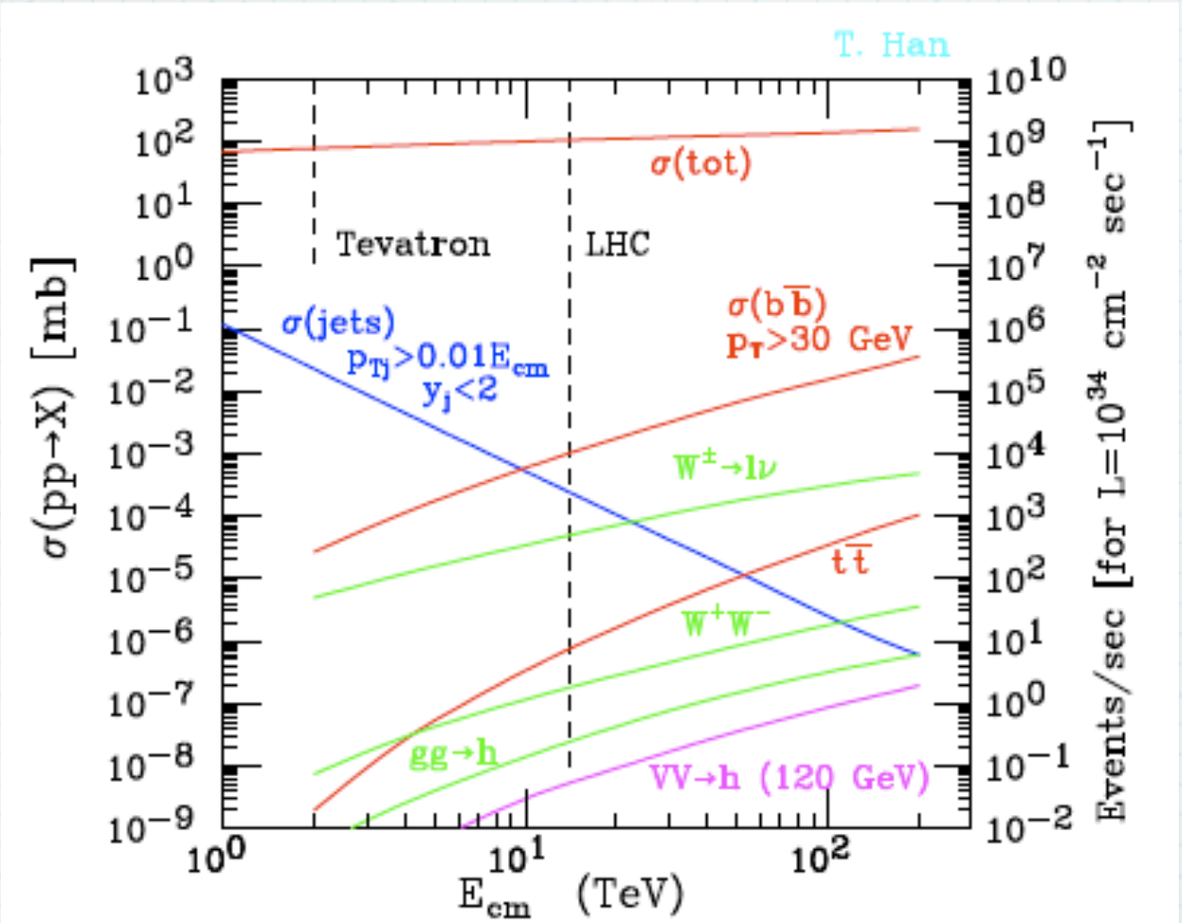
$$\ell_{\eta_v \to b\bar{b}} \sim 4 \text{ cm} \frac{(20 \text{ GeV})^7}{f_{\eta_v}^2 m_{\eta_v}^5} \left(\frac{m_{Z'}/g'}{10 \text{ TeV}} \right)^4$$

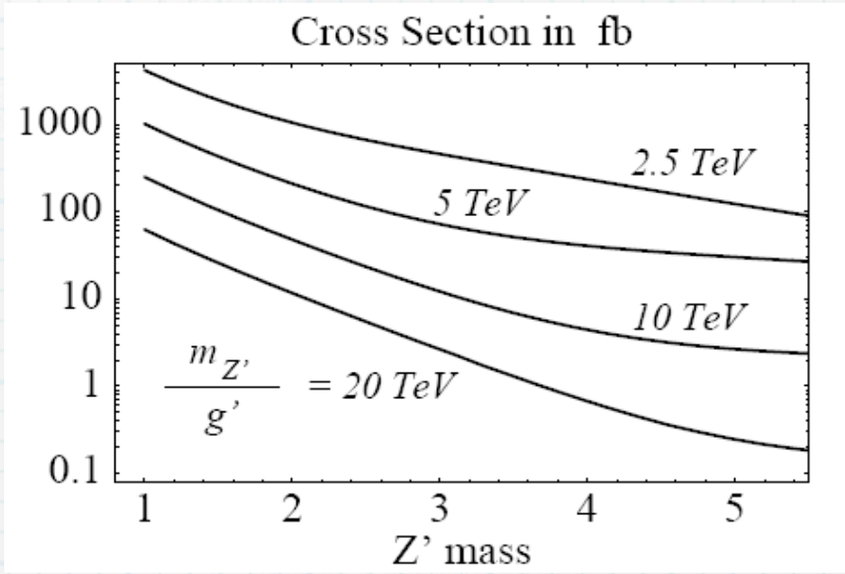


* High multiplicities
* Low mass stuff in event
* How to distinguish from QCD?



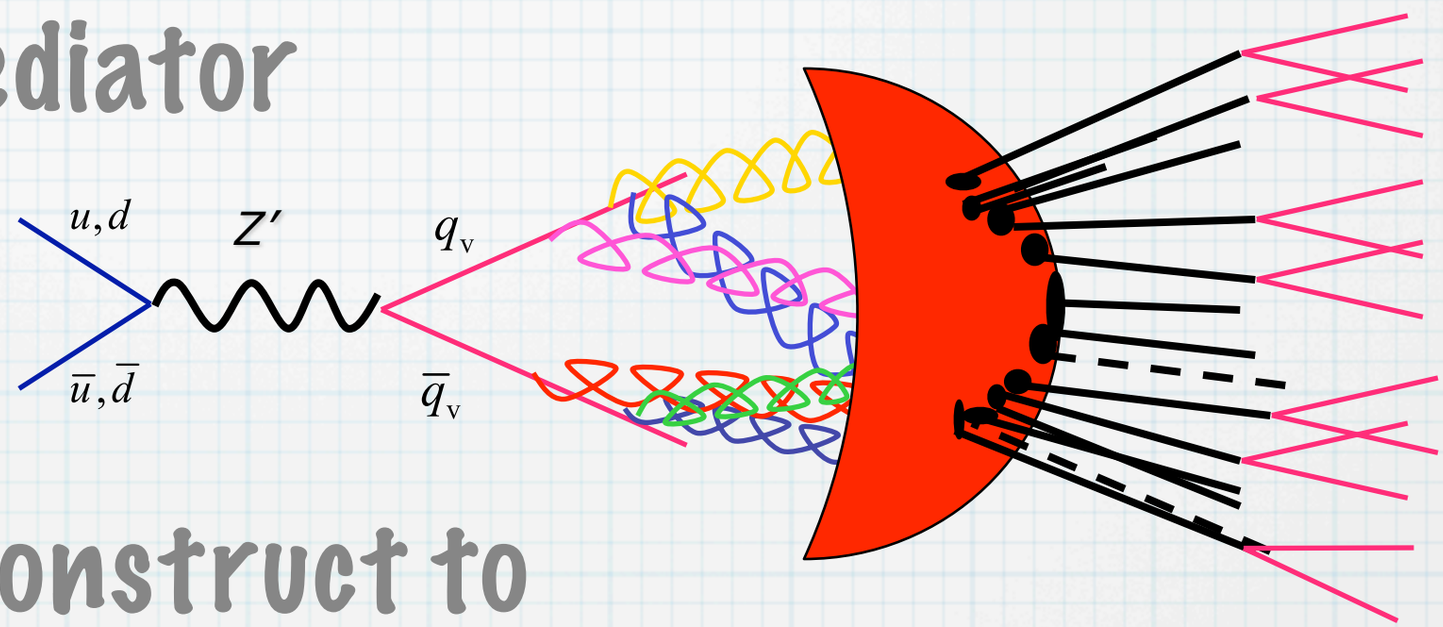
Search methods and backgrounds





Handles

* Resonant mediator production
  * Z'/Z



* SM pairs reconstruct to very narrow resonance (analogue of J/psi)
* Event shape variables

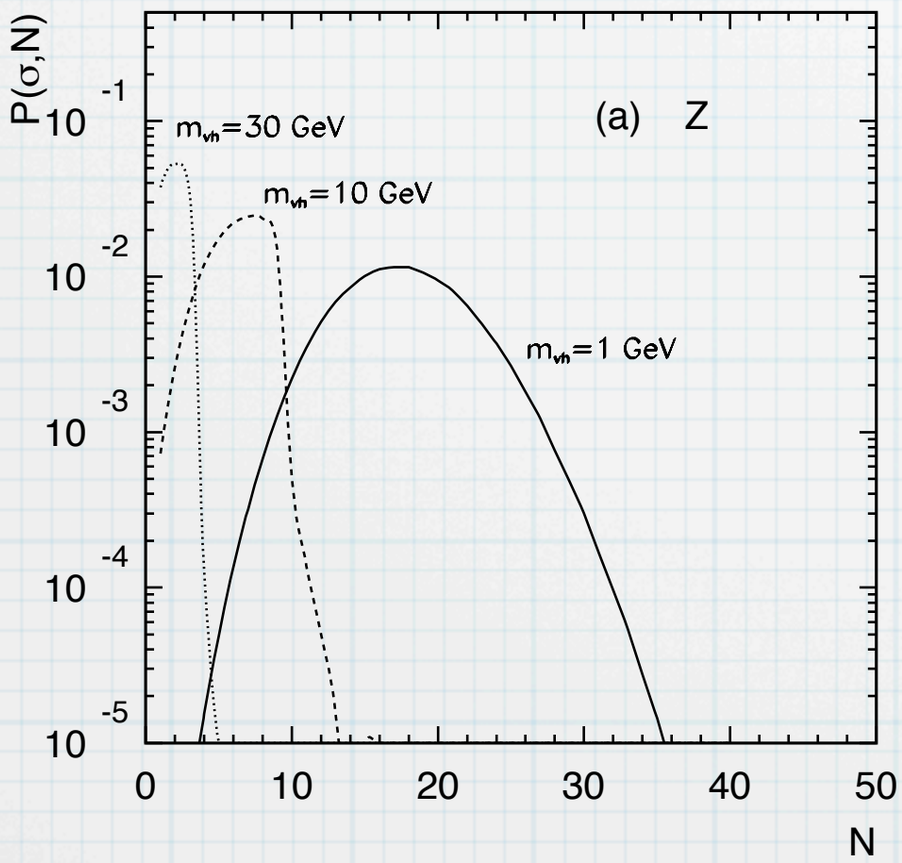
Search methods

* Ecm (Z')
* Multiplicity
* Hard muons (two, pT > 10 GeV)
* Event shape (sphericity and thrust)
* Cluster mass
* Narrow! low mass resonance

* All backgrounds
* Drell-Yan + jets (1 nb)
* Soft QCD (light quarks--pions)
* Harder QCD (heavy quarks--c,b) (microb)
* tops, soft QCD, DY + jets
* Everything

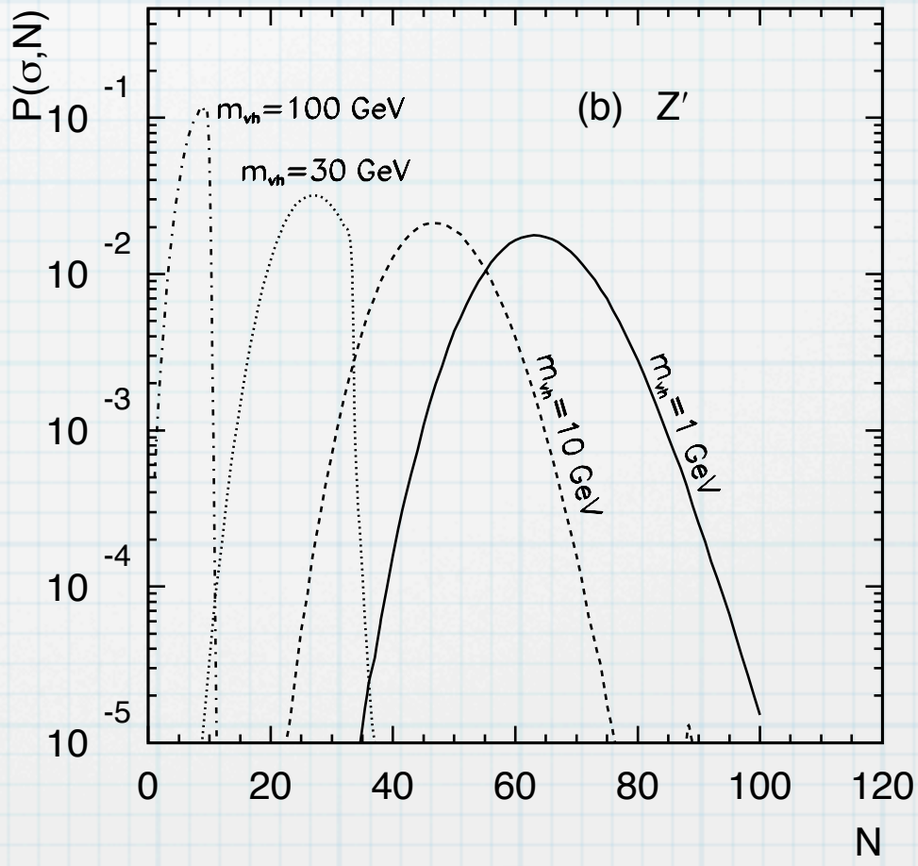
Multiplicity

Z mediator



$$m_Z - 50\ \text{GeV} < \sqrt{\hat{s}} < m_Z + 50\ \text{GeV}$$

Z' mediator



$$m_{Z'} - 100\ \text{GeV} < \sqrt{\hat{s}} < m_{Z'} + 100\ \text{GeV}$$

Two hard muons

* Help with soft QCD background
  * 2 with pT > 10 GeV
  * Z mediator $\sigma(Z) = 125\ \text{fb} \rightarrow 0.7\ \text{fb}$
  * Z' mediator $\sigma(Z') = 370\ \text{fb} \rightarrow 120\ \text{fb}$
* --> Z mediator difficult; focus on Z'

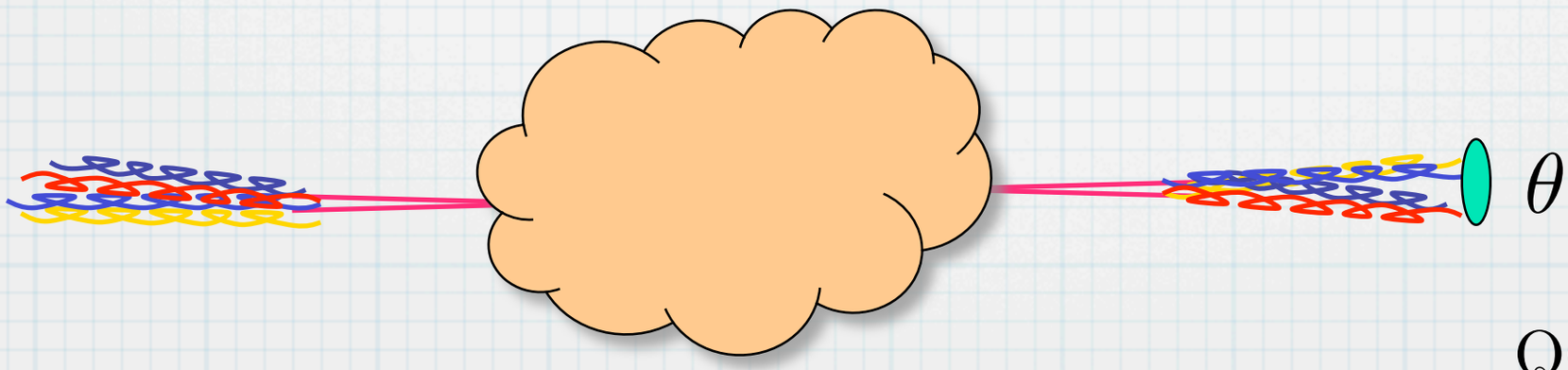
Event shape variables

* Low mass v-hadron likely to escape the detector or leave displaced vertex

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

* Higher mass v-hadron has different shape

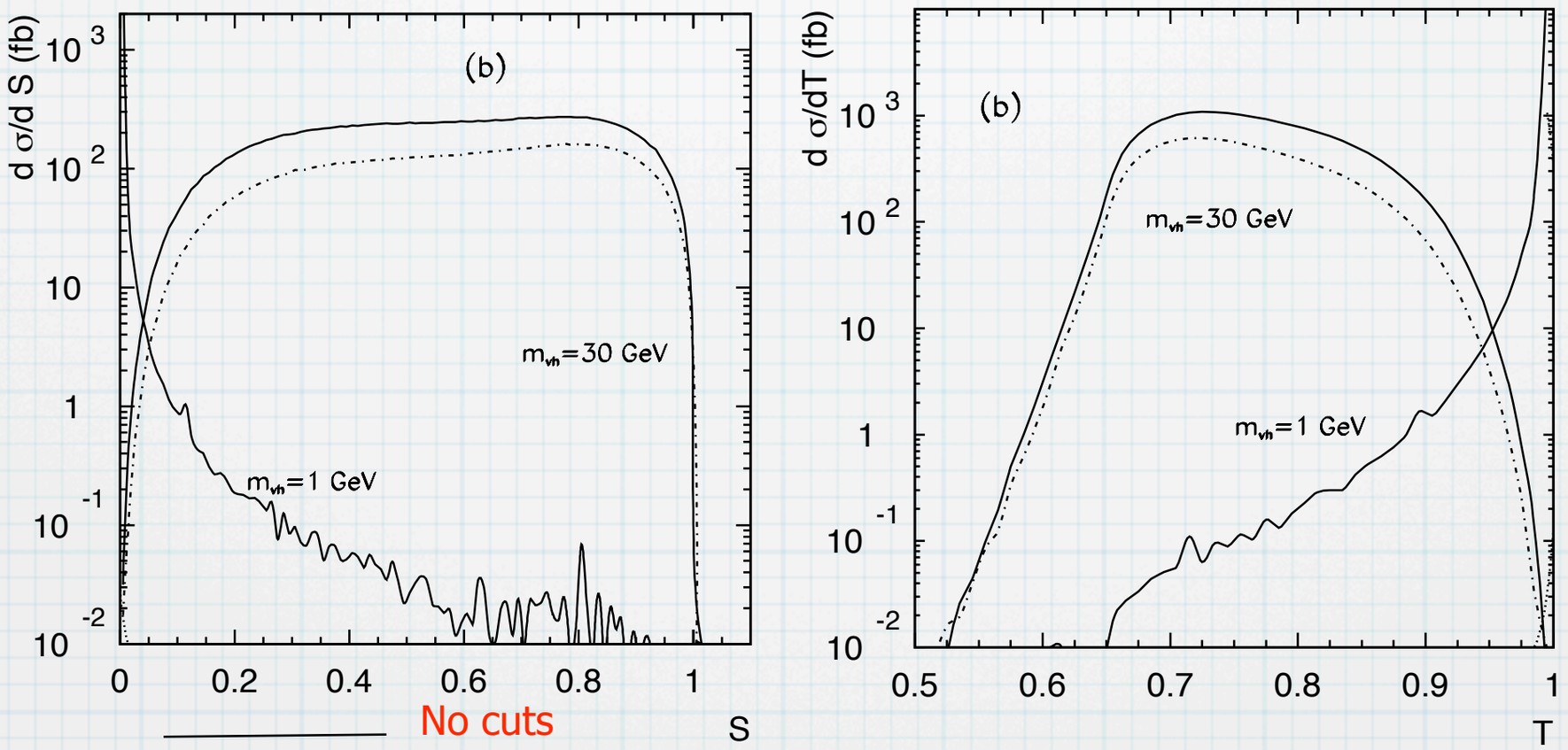
$$\theta \sim \frac{m_h}{E_{jet}}$$



QCD $m_h \sim 1$ GeV

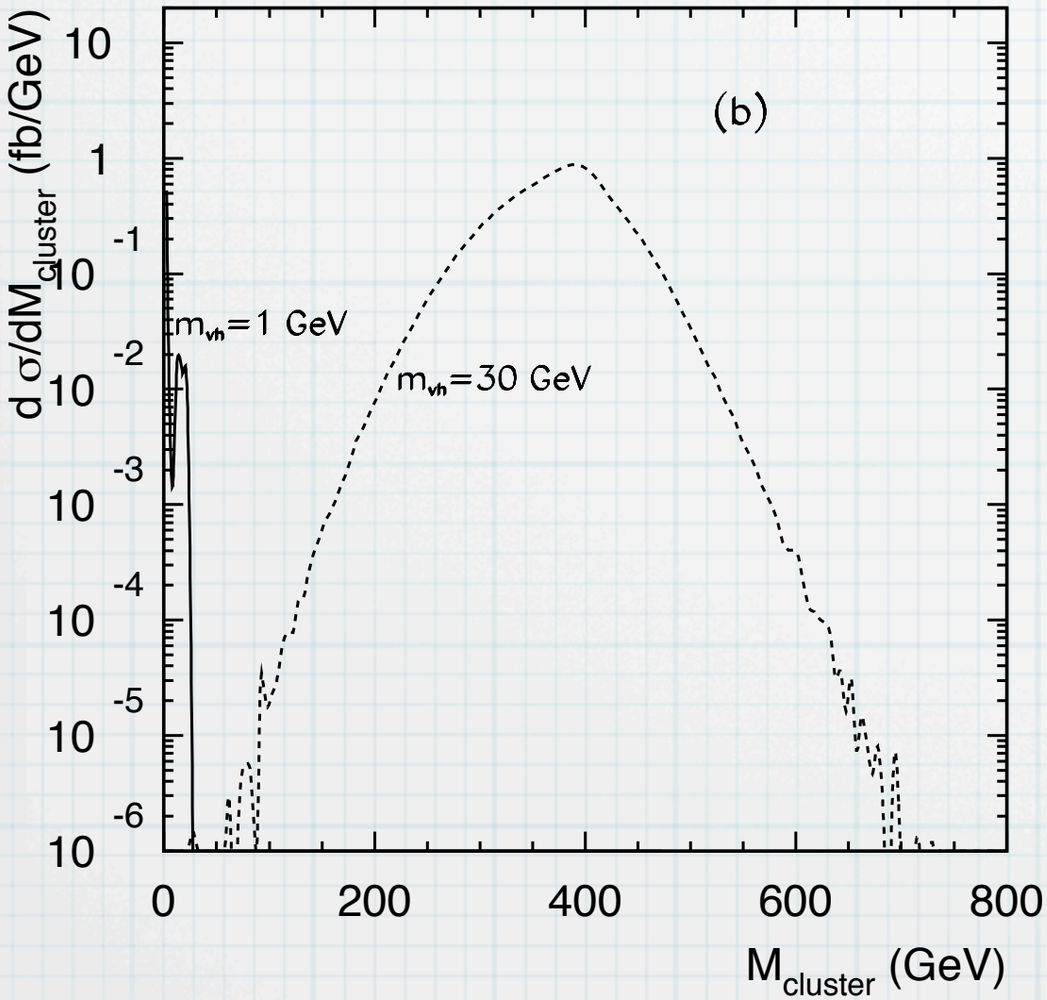
Theorist's event shape: sphericity and thrust

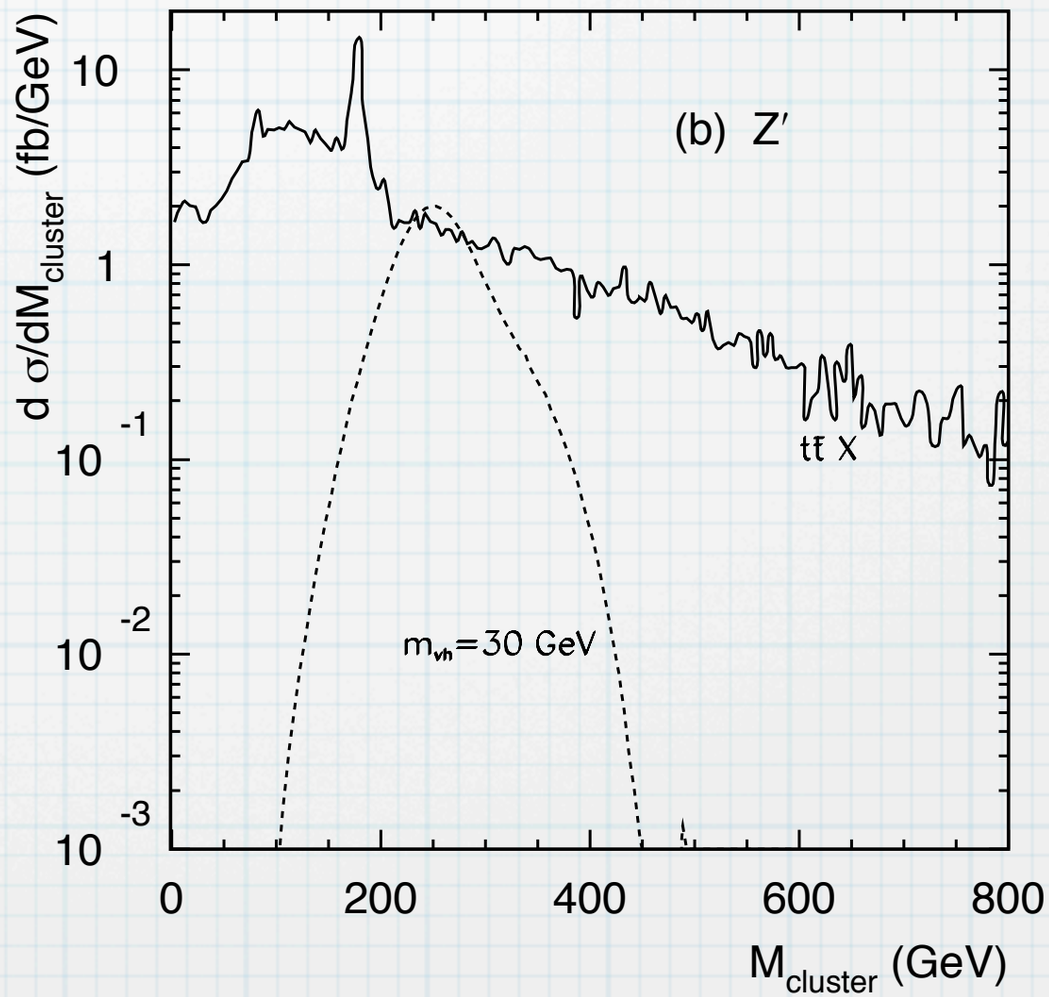
Z' mediator



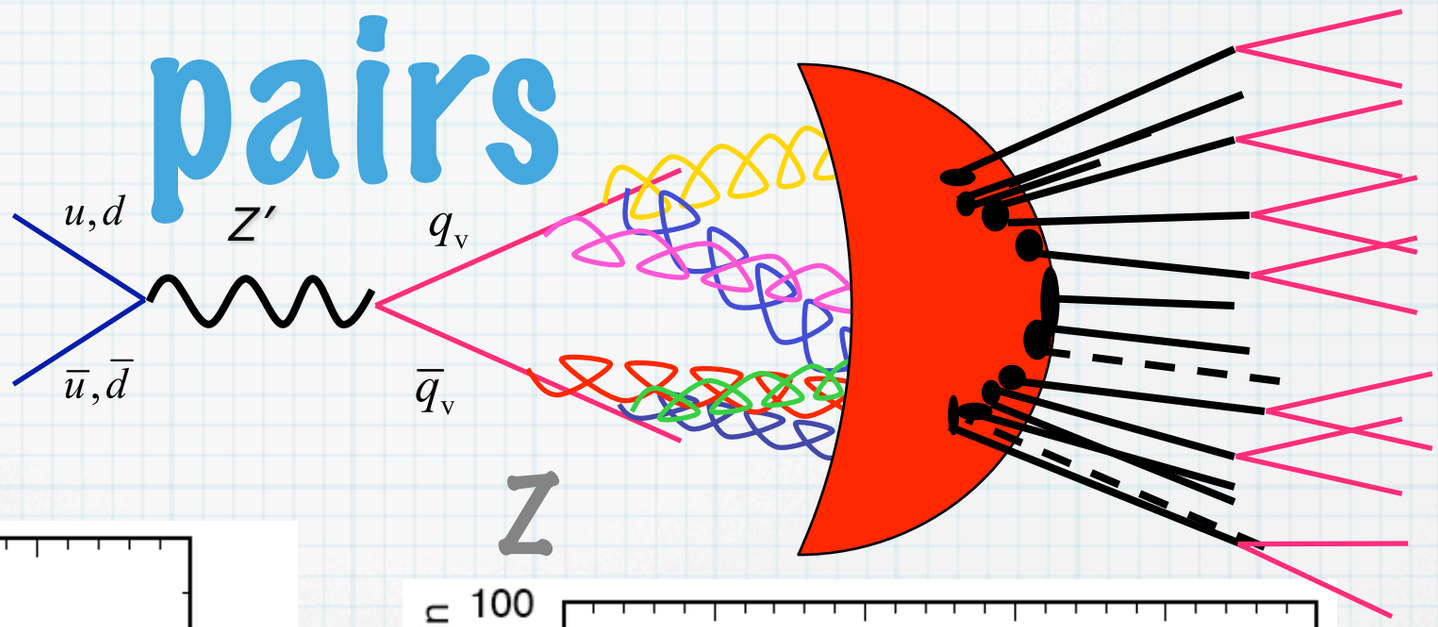
Cluster mass for tops

Z′ mediator

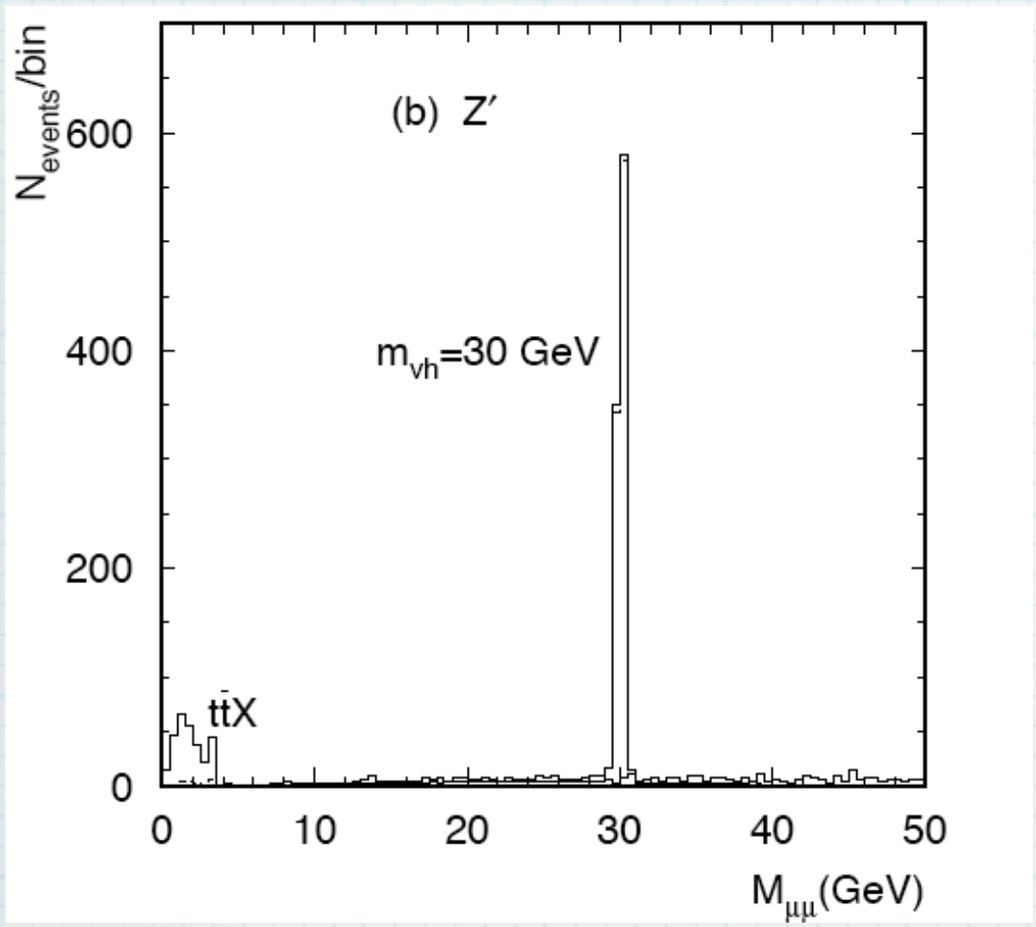




Narrow peak in muon pairs

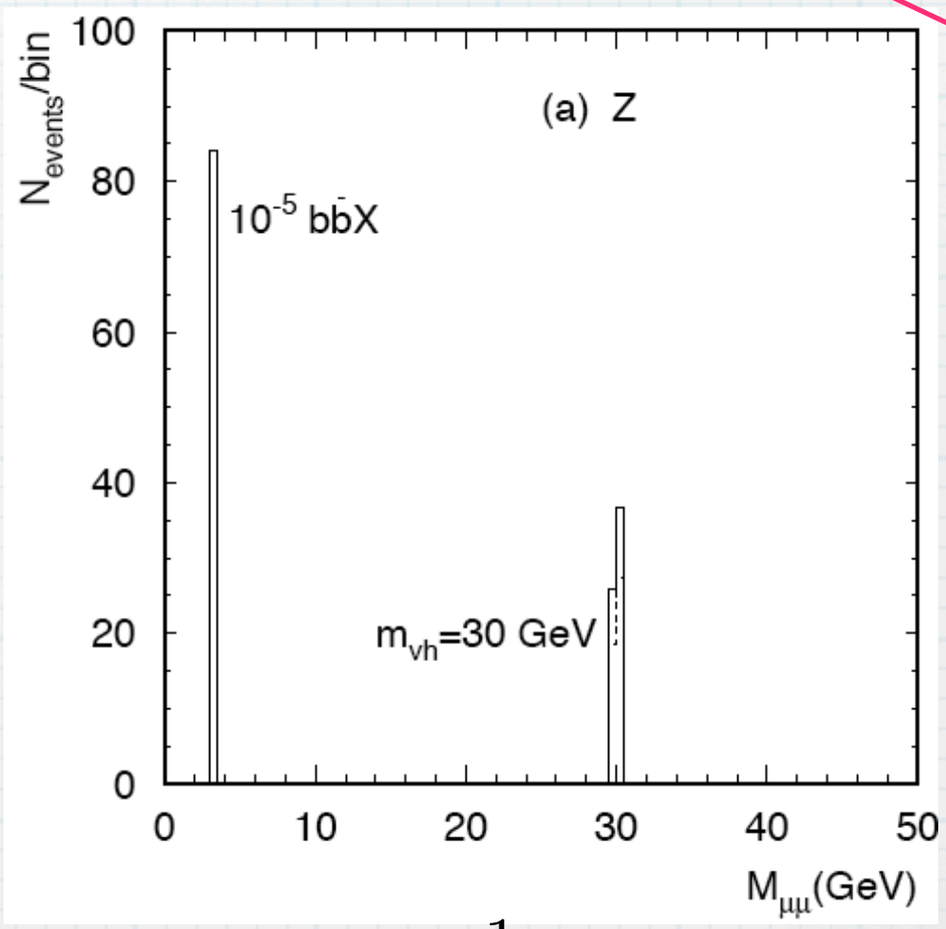


Z′



100 fb^{-1} of data

Z



10 fb^{-1} of data

Summary

* Low mass hidden sectors can appear in many extensions of the SM
* Qualitatively different phenomenology--perhaps displaced vertex
* Look for narrow low mass resonances from high energy events
* Round events with high cluster mass; pairs of muons reconstructing to light resonance. High multiplicities.