Hidden Valleys
and
Jet Substructure

Matt Strassler
Rutgers University

MJS and Zurek 2006
MJS 2006-2008
Mrenna,Skands, MJS

Hidden Valley Review

MJS + Zurek 06

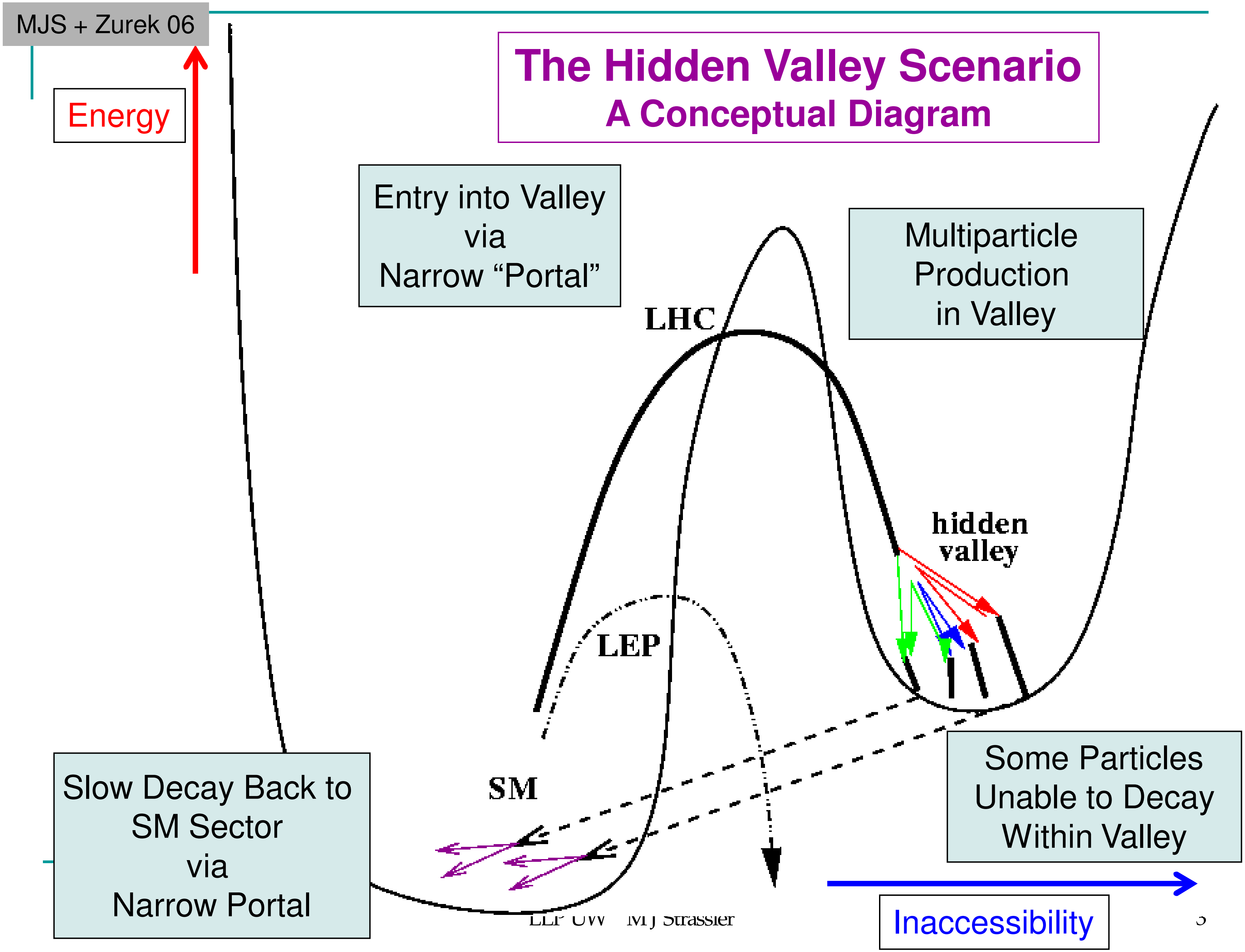
We have very few limits on light particles that interact weakly with SM

- no precision contraints
- moderate LEP constraints
- weak cosmological/astrophysical constraints

Is it possible that an entire sector of such particles awaits us?

- Such sectors arise in many attempts to build MSSM in string thy
- Dark matter may arise from such sectors
  - See Hooper & Zurek 08, Arkani-Hamed & Weiner 08
- Very natural in extra-dimensional models

If the interactions in the new sector are not trivial, then a vast and complex array of phenomenological signatures becomes possible


MJS + Zurek 06
The Hidden Valley Scenario
A Conceptual Diagram
Energy
Entry into Valley
via
Narrow “Portal”
LHC
Multiparticle
Production
in Valley
hidden
valley
LEP
SM
Slow Decay Back to
SM Sector
via
Narrow Portal
Some Particles
Unable to Decay
Within Valley
Inaccessibility

General Predictions of HV Scenario

hep-ph/0604261

- New neutral resonances
  - Maybe 1, maybe 10 new resonances to find
  - Many possible decay modes
    - Pairs of SM particles (quarks, leptons, gluons all possible; b quarks common)
    - Triplets, quartets of SM particles…
  - Often boosted in production; jet substructure key observable

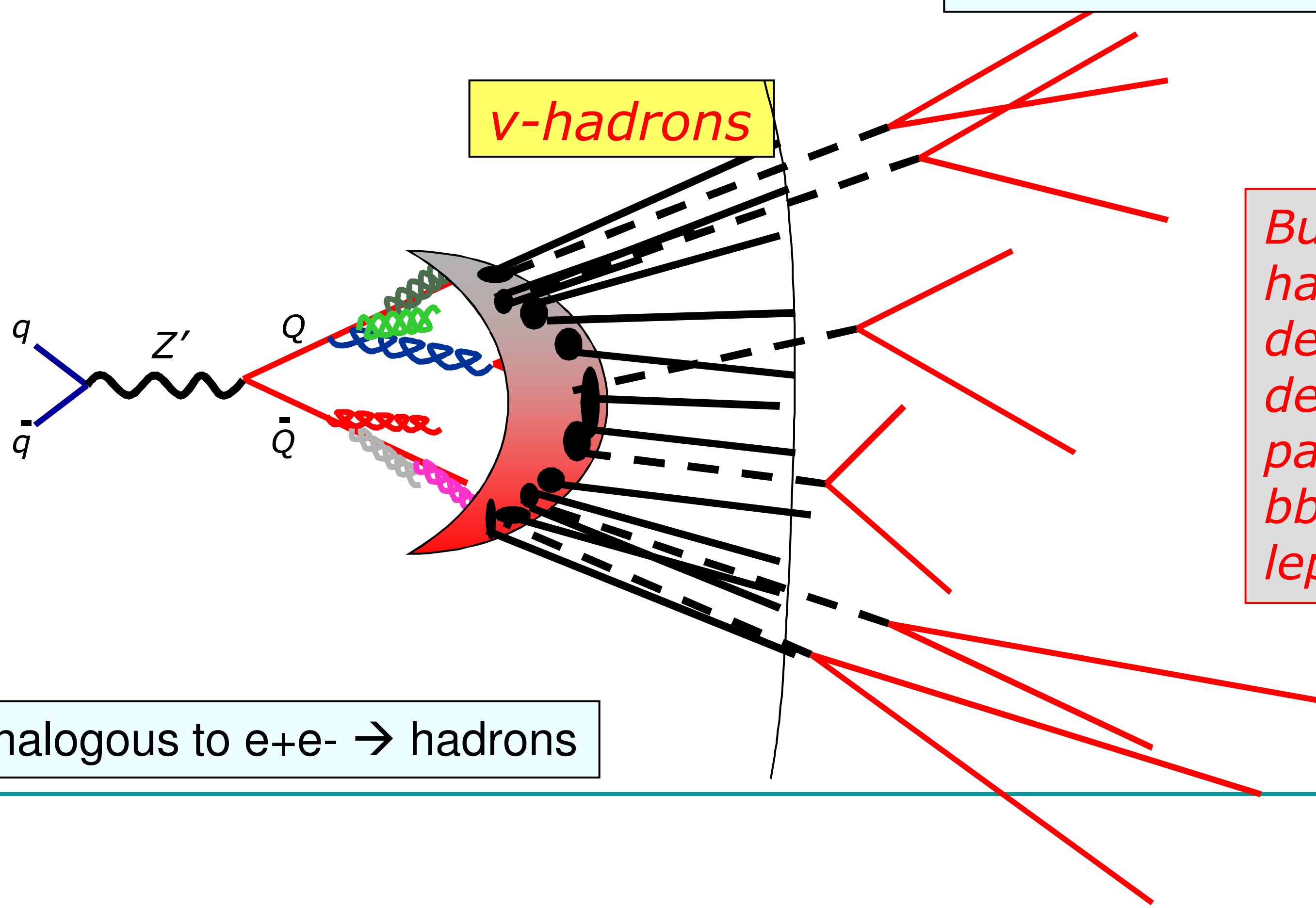
- Long-lived resonances
  - Often large missing energy
  - Displaced vertices common (possibly 1 or 2, possibly >10 per event)
    - … in any part of the detector
    - Great opportunity for LHCb if rates high
    - Problem for ATLAS/CMS trigger if event energy is low

- Multiparticle production with unusual clustering
  - Exceptionally busy final states possible
    - 6-20 quarks/leptons typical in certain processes
    - up to 60 quarks/leptons/gluons in some cases
  - Breakdown of correspondence of measured jets to partons
  - Very large fluctuations in appearance of events

- All figures below made with
  - HVMC 0.4 (MJS 2006; reorganized Pythia)
  - HVMC 1.0 (Mrenna, Skands & MJS 2007; Pythia-based)
- Event display (MJS homegrown – no magnetic field)
  - shows end-on tracker and calorimeter energy
  - gray/black hadron tracks, green/blue lepton tracks
  - red/purple photon/neutral hadron deposition in cal.
  - orange blocks show total cal deposition in azimuthal angle
- Calorimeter resolution 0.1 x 0.1, no smearing

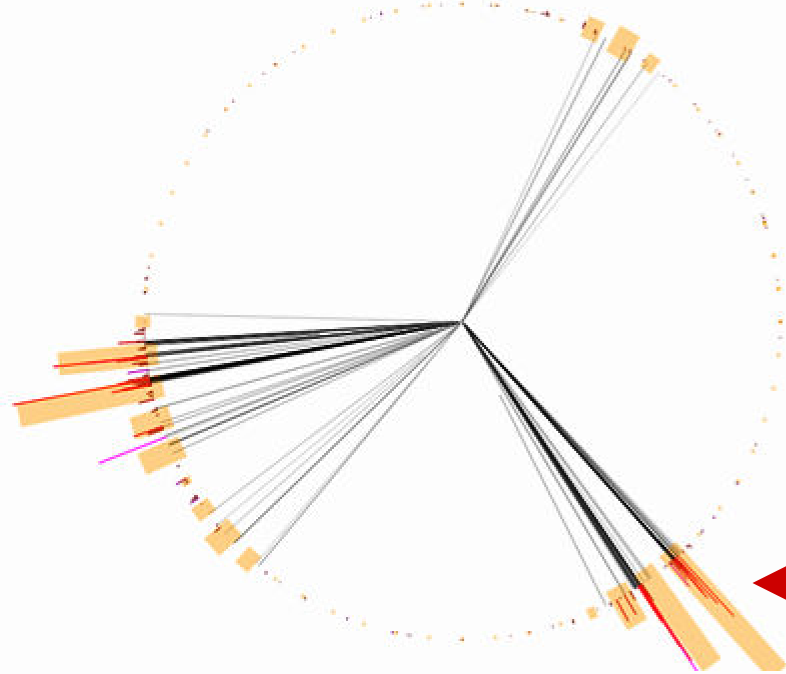
$q\bar{q} \rightarrow Q\bar{Q}$: An illustrative example

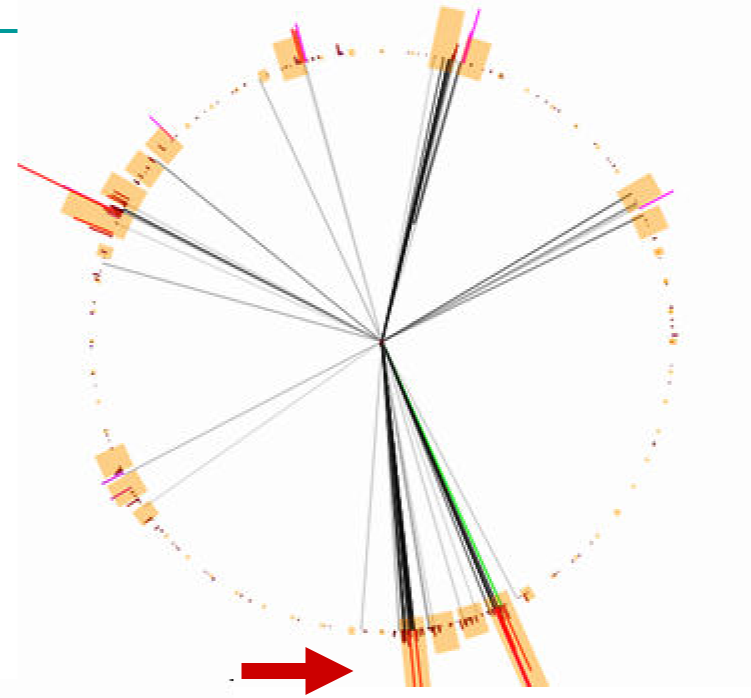
Some v-hadrons may be (meta)stable and therefore invisible



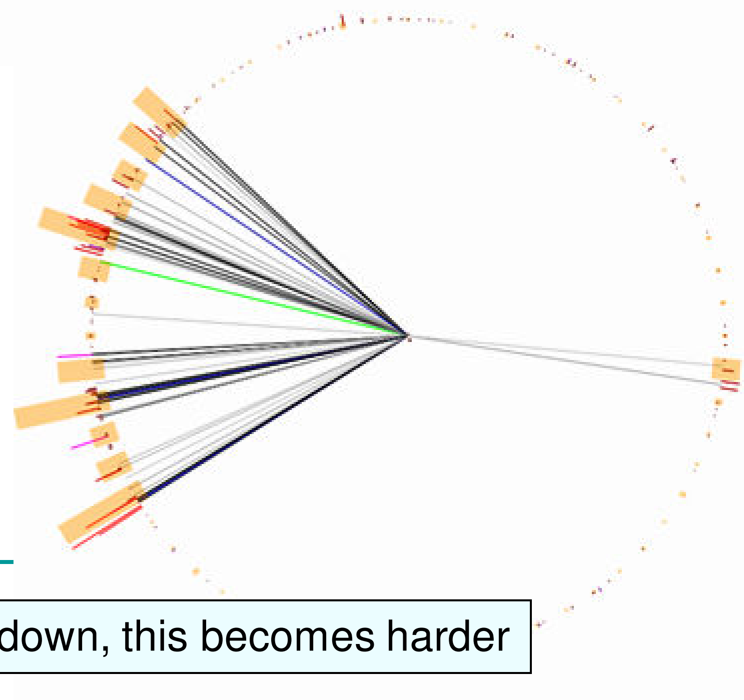
But some v-hadrons may decay in the detector to visible particles, such as bb pairs, qq pairs, leptons etc.

Analogous to e+e- → hadrons





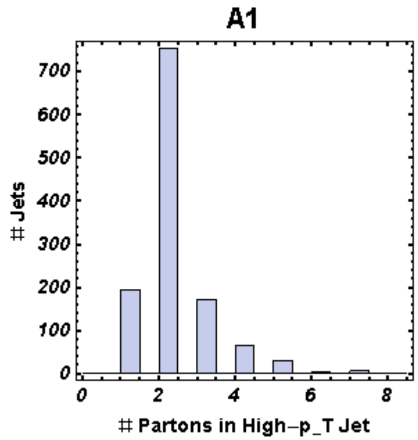
Z’ → v-hadrons
Average: 3 b’s
Max: 12 b’s

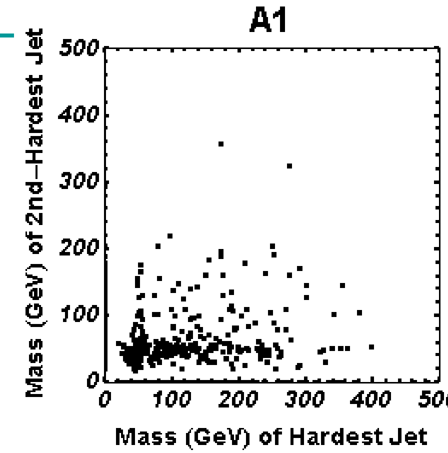


MJS 2008

Z’ mass = 3.2 TeV
v-pi mass = 200 GeV
Flavor-off-diagonal
v-pions stable

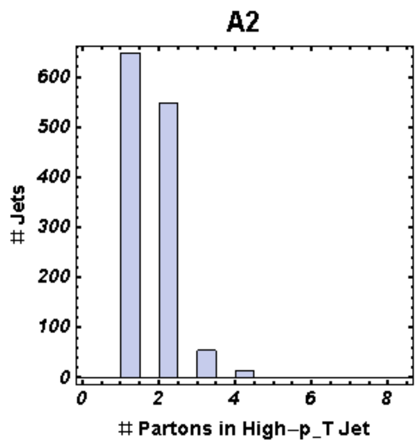
As the mass goes down, this becomes harder

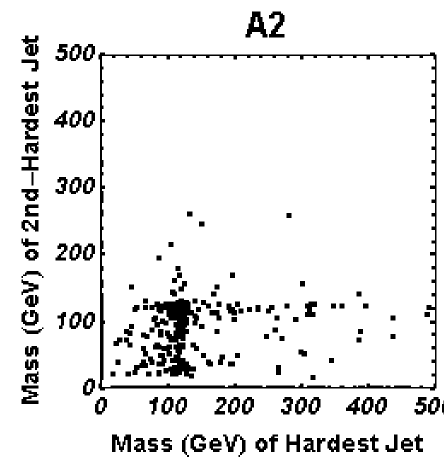




The hardest jets typically contain two or more quarks

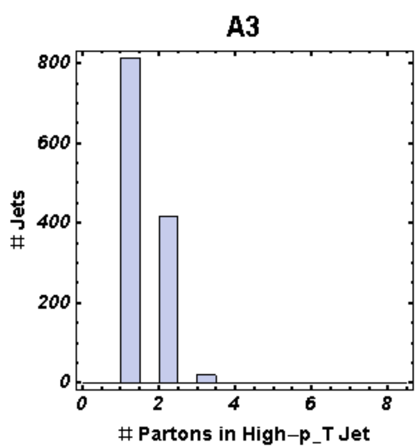
3 cases shown have
Z' mass = 3.2 TeV
v-hadron mass = 50, 120, 200 GeV

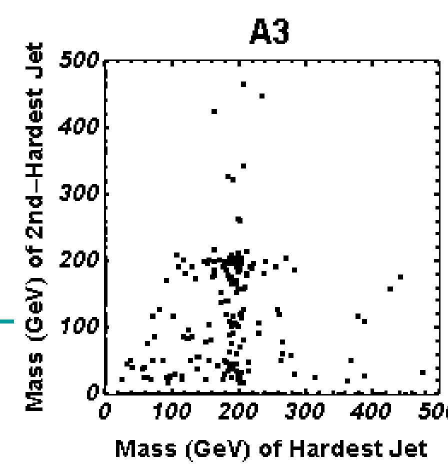




LEFT: # hard partons per cone jet with Delta R = 0.4, pt > 200 GeV

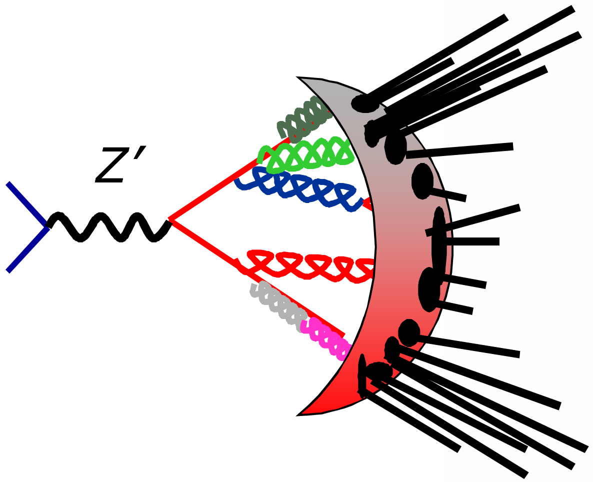
RIGHT: invariant masses of two highest pT cone jets with Delta R = 0.7, other criteria

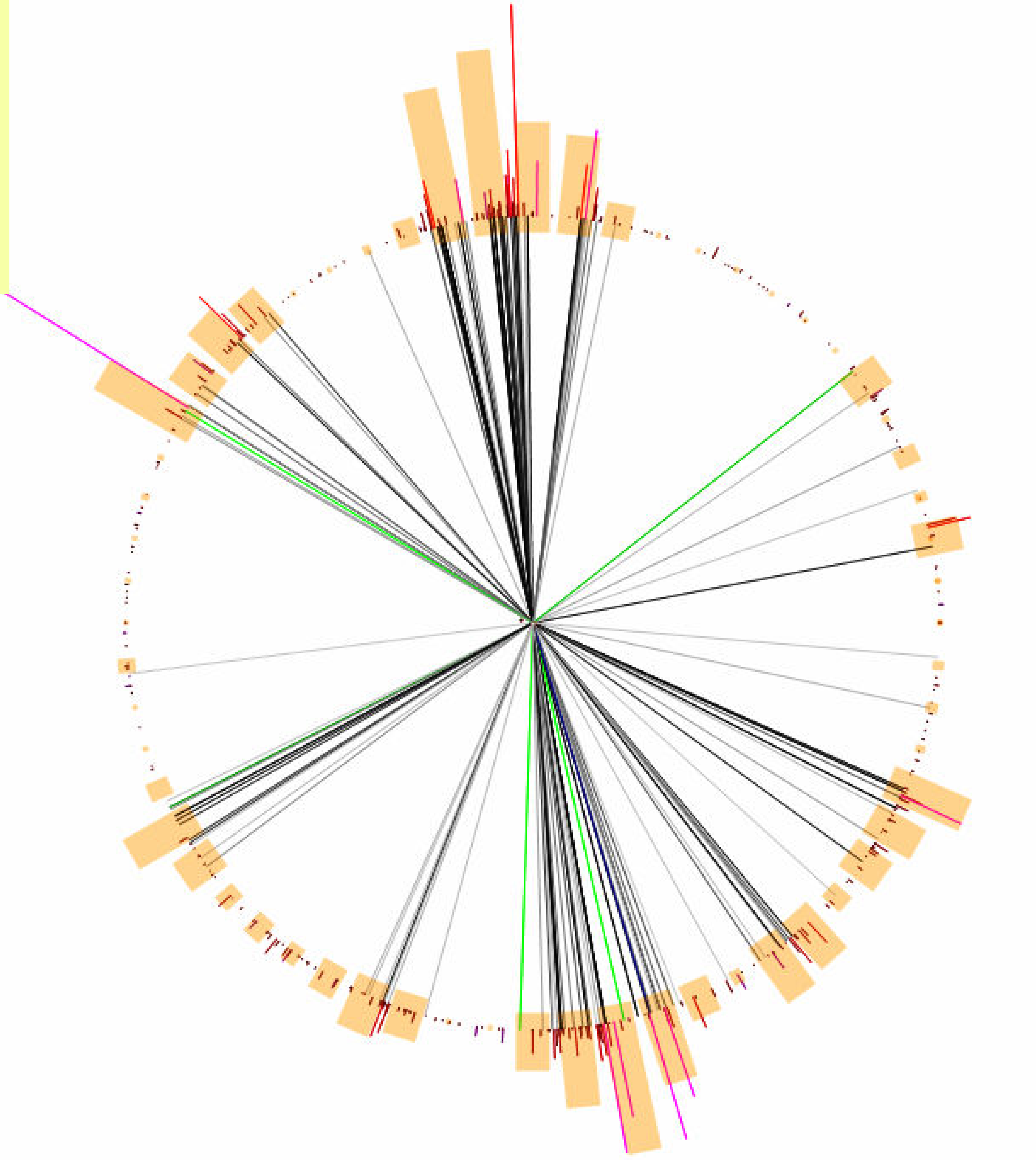




MJS 2008
HVMC 0.4

UV Weak-Coupling
(small anom dims)
~ 10 v-hadrons
Some hard, some soft
~ of order 20 quarks/leptons
of widely varying pT



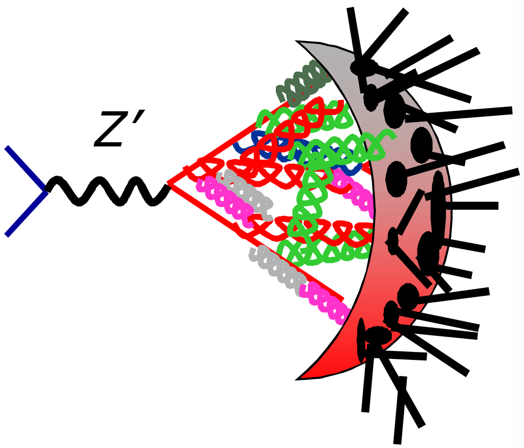


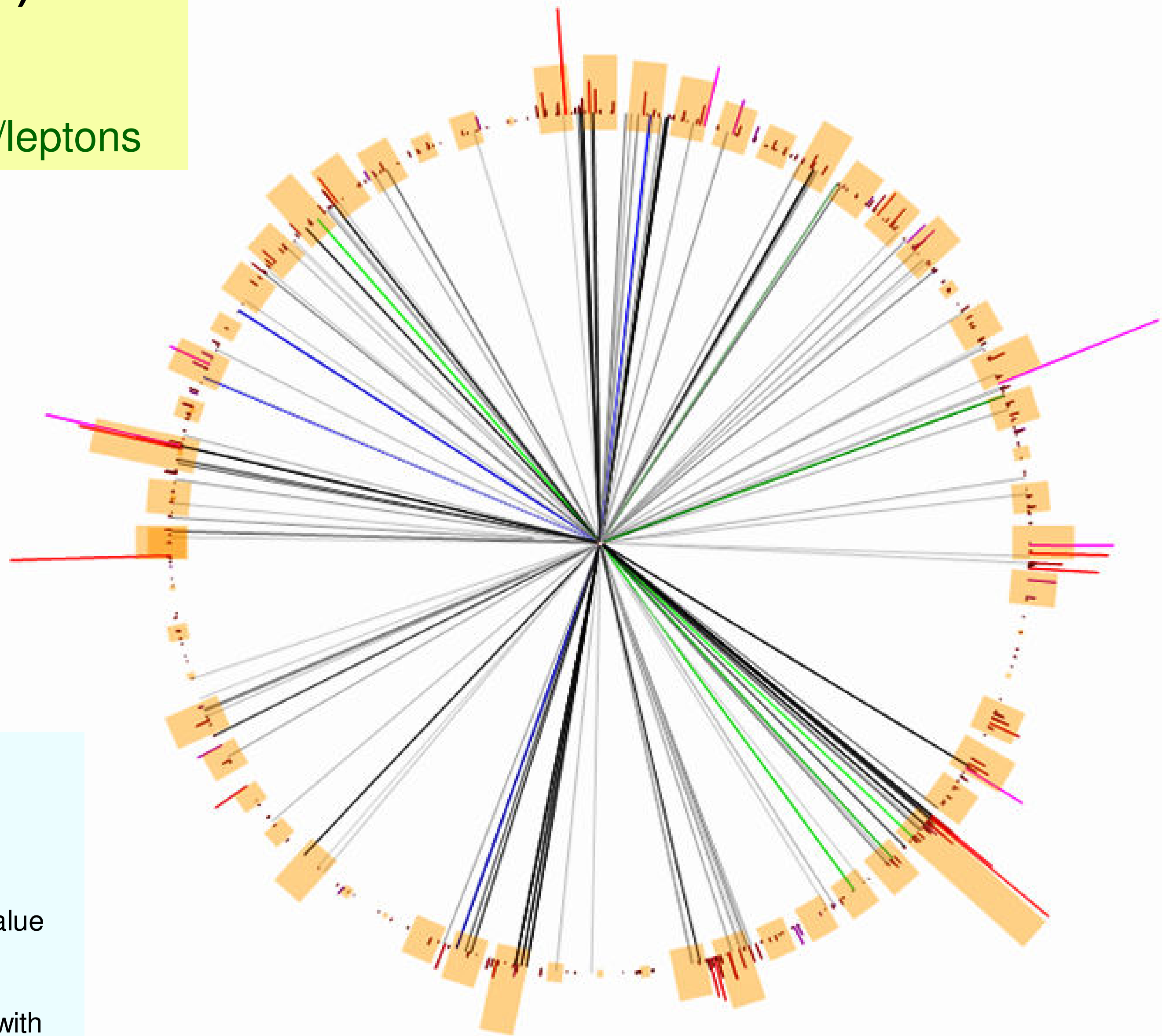
UV Strong-Coupling Fixed Point (large anom dims)

~ 30 v-hadrons

Softer v-hadrons

~ 50-60 soft SM quarks/leptons

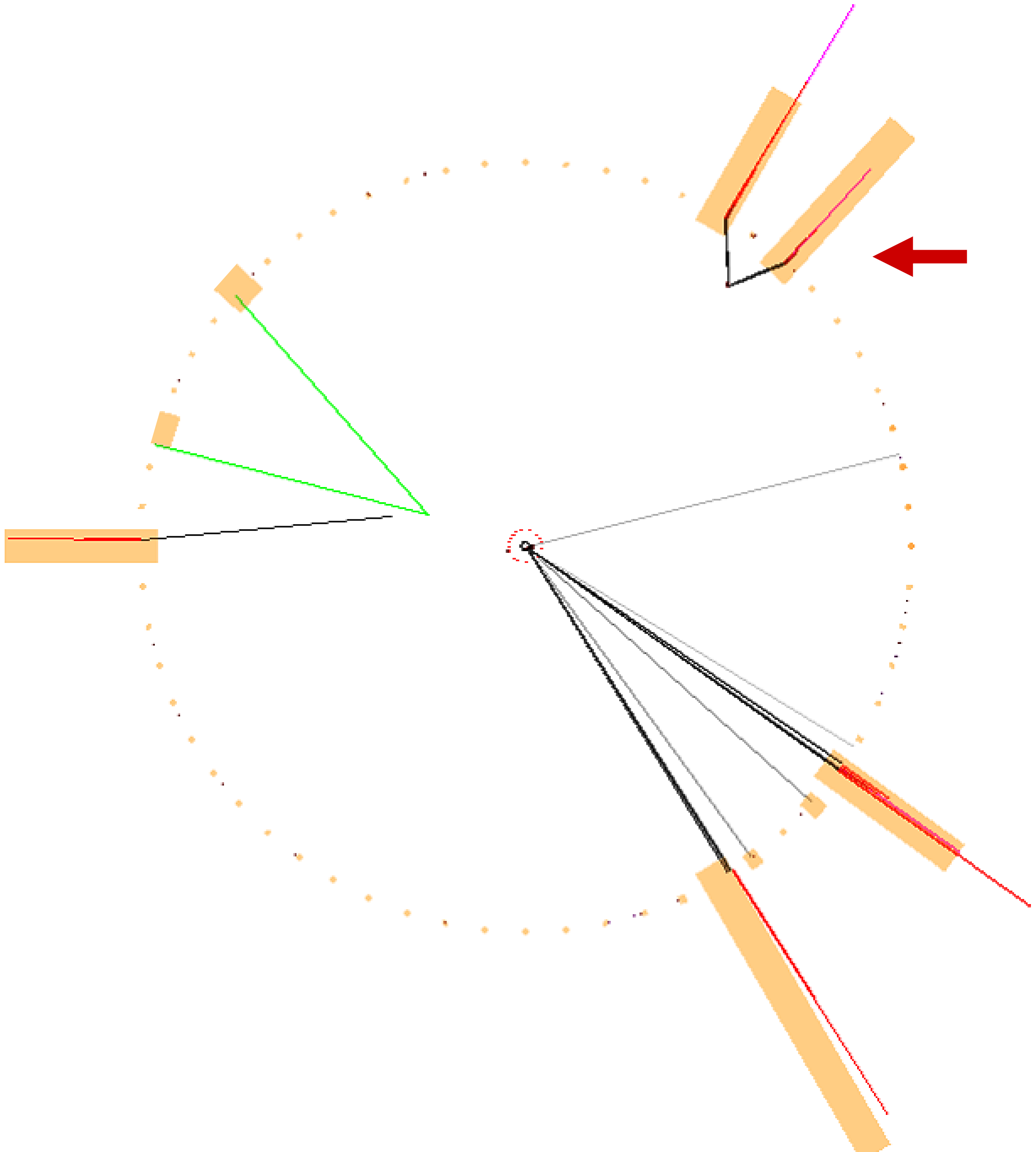




Educated guesswork!

Crude and uncontrolled simulation

- Fix α in HV Monte Carlo 0.5 at large value
  - This increases collinear splitting
- Check that nothing awful happens
- Check answer is physically consistent with my expectation



Summary and Outlook

- Hidden Valley scenario:
  - Hidden ("dark") sector with mass gap, accessible at LHC
- Hidden Valleys commonly predict (any or all of)
  - Boosted particles decaying to 2 or more partons
  - Events with high multiplicity of hard partons
  - Long-lived particles

    Any of these can give unusual substructure to jets
- Modern substructure methods (>2007) have not yet been applied
- Questions for discussion
  - Jet substructure as a trigger criterion? Needs to be very fast
  - How to maximally exploit the various angular and energy resolutions of the tracker, ECAL and HCAL?