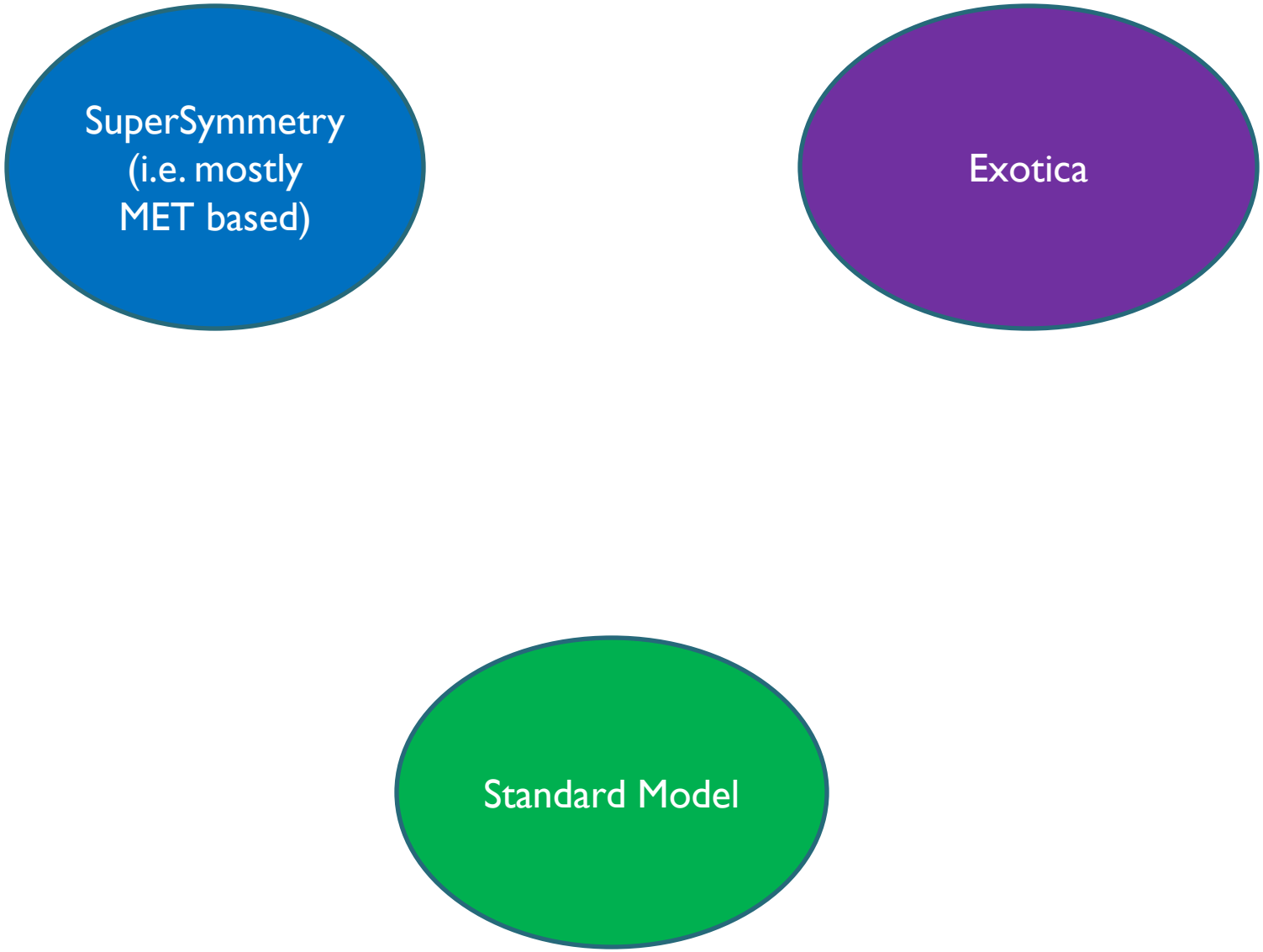
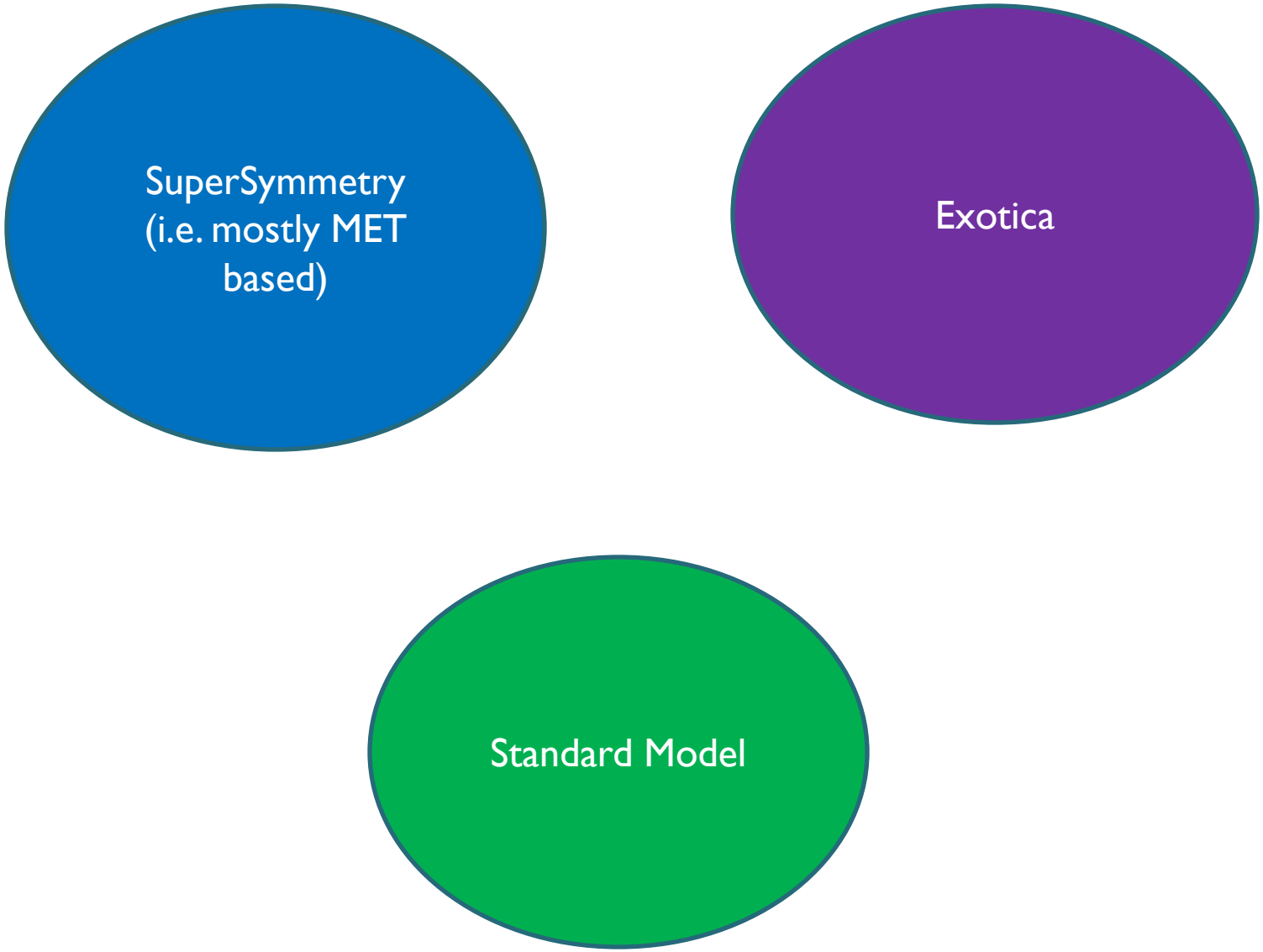
A Theorist's View of Exotica Searches

(A few selected topics)

Matt Strassler


SuperSymmetry
(i.e. mostly
MET based)
Exotica
Standard Model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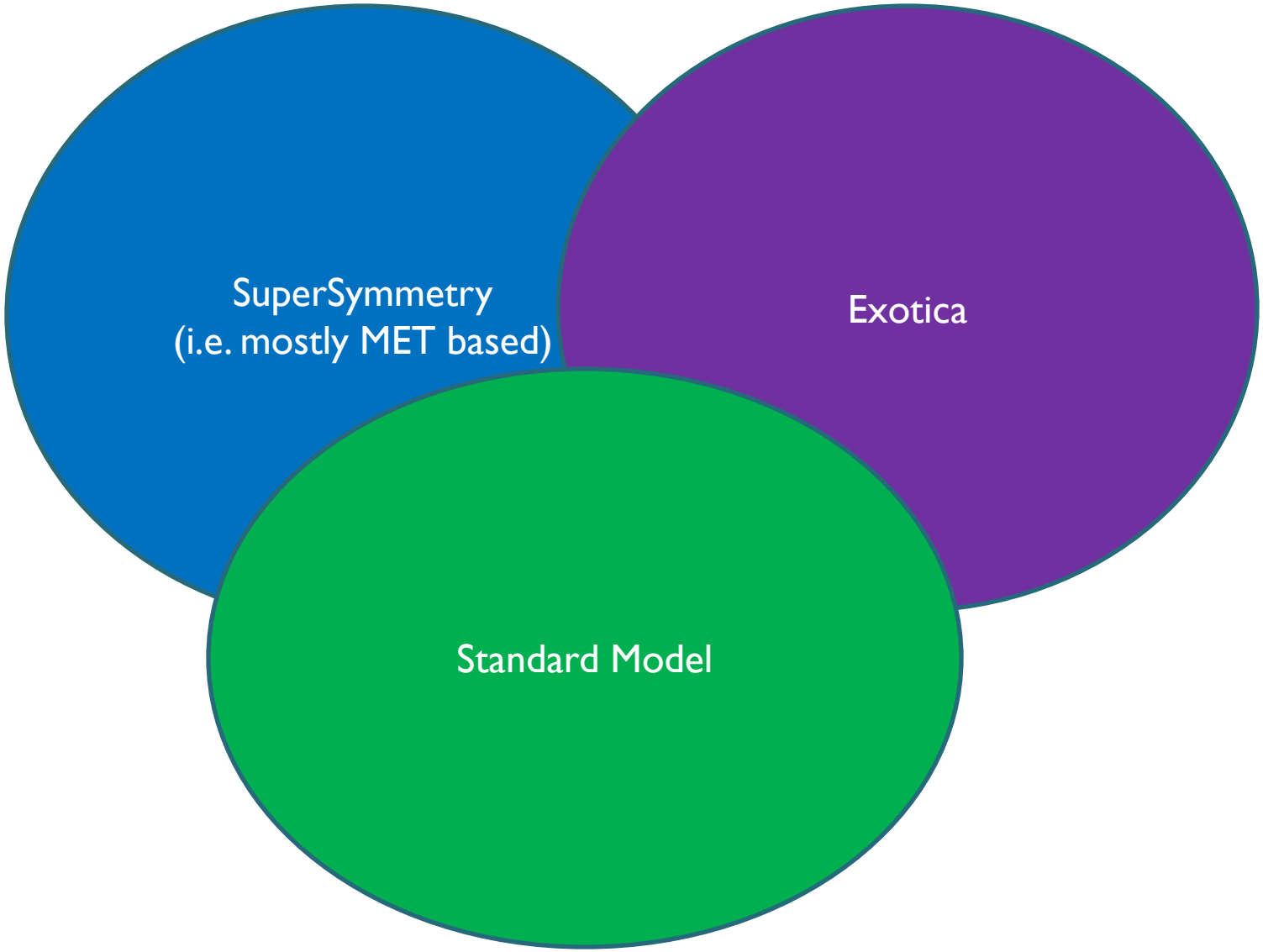
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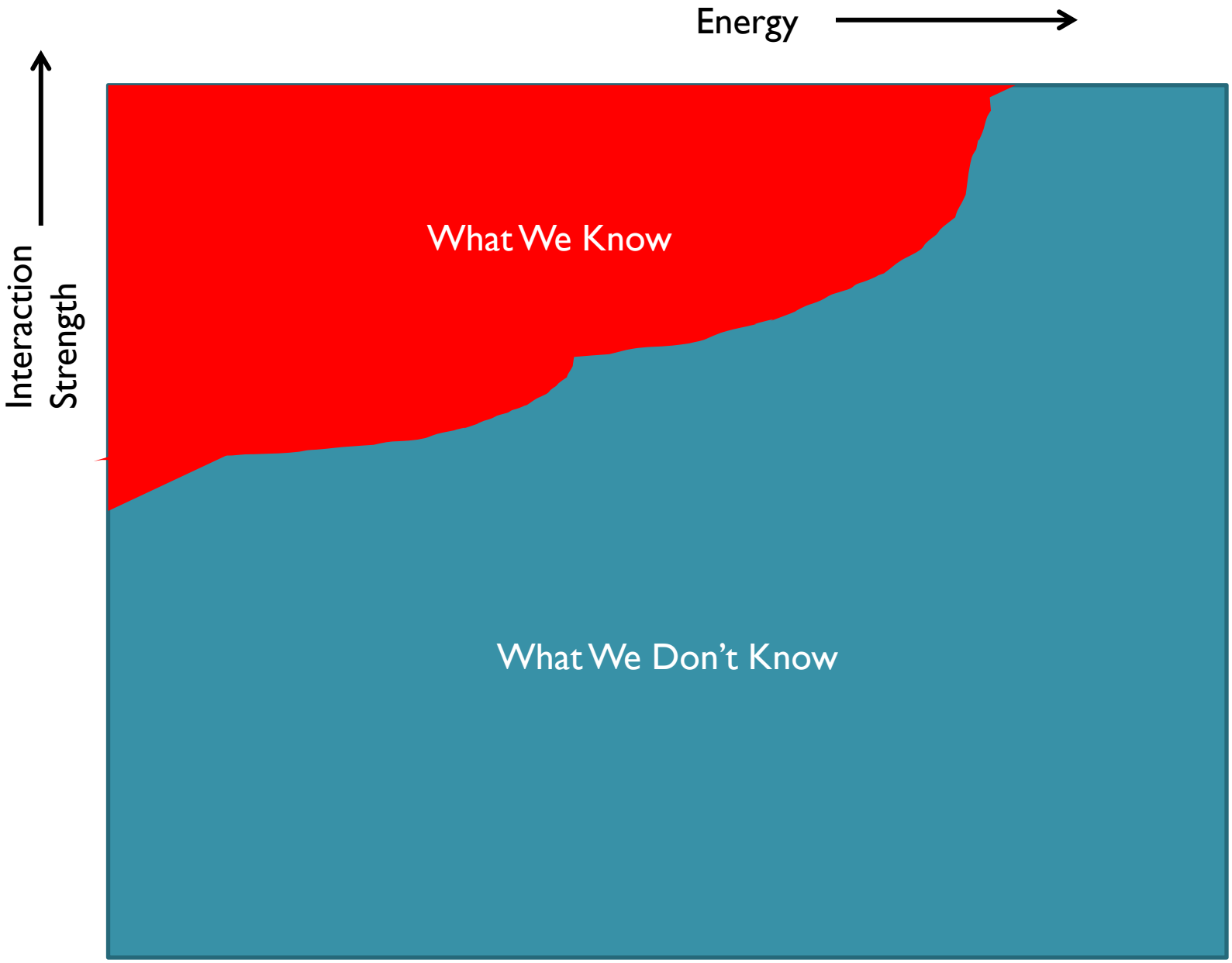
Let's Remember What We Know

(Not as much as we tend to think…!)


Energy
Interaction Strength
What We Know
What We Don't Know

Low-Mass Particles Still Possible

- Colored Particles are limited by Tevatron/LHC
  - If small color charge, spin and nasty decays, still ~200 GeV
    - *Gaps?!*
- Electrically Charged/Color-Neutral limited by LEP
  - Still 100 GeV limits (sometimes even less)
- Electrically and Color-Neutral particles
  - Practically speaking, NO LIMITS on mass
  - Small coupling: ➔ tiny direct production, yet decay in detector
    - Including below the Z mass, down to 1 GeV and beyond
  - Observe at LHC mainly in decay of a heavier particle
    - e.g. H, LSP,/LKP/LTP, top, Z

"Hidden Valley"
Strassler & Zurek 2006

From Easy to Hard

- Dramatic Breakdown in QFT
- Sharp Resonance with SM-like Couplings
- Rich Spectrum of Colored Particles:
  - S/B >> 1 typically, accessible to model-indp. broad searches

- Gluinos and other particles with exotic color charge
  - S/B > 1 for most decay modes

- Fermion Top-Prime (assuming dominant decay mode)
  - S/B ~ 1 [i.e. σ(top') ~ σ (top) at fixed s-hat]
  - Need to model t versus t' carefully to make S >> B

- Scalar Top-Squark (assuming dominant decay mode)
- Electroweak Production
  - S/B << 1 [i.e. σ(s-top) ~ σ (top) at fixed s-hat]

Cut Hard and Count

- In many cases very hard cuts are used to get good S/B
- Consequent low sensitivity to signals with S~B or less
- But using MC to get better determination of B
  - Can relax cuts and let in more S
  - Can use new kinematic handles to cut or fit with more efficiency
  - Can add new samples previously viewed as unusable
- Need to move away from data-overdriven

Requires coordination of search groups with SM group and theorists

Search Strategies

- Broad "Easy" Model-Independent High Mass Searches
  - Narrow resonances on smooth distributions (mostly tails)
  - Excesses on High-Energy Tails
  - More?

S/B >> 1 expected
Low-Mass/Energy Fits Extrapolated

- Highly Targeted Searches for Low-Mass Phenomena
  - Top partners (specific model or 100% Br to particular final state)
  - Higgs

S/B ~ 1 , < 1 , even << 1
Careful Background Modeling (mix data/MC driven)
Optimized for Signal Sensitivity

- Areas to Fill In During 2012-2014
  - Moderately Targeted, But Still Rather Model-Independent
  - S/B ~ 1 or < 1 even on tails – can hide in today's control samples

"Easy" Things Remaining

- Low-Mass Medium-Rate Dilepton or Diphoton Resonances
  - Maybe not visible in inclusive searches
    - Require high H_T, high p_T, high multiplicity?
    - Loosen isolation requirements? (e.g. lepton-jets, photon-jets)
  - Some limits from non-observation in non-dedicated searches
    - But what limits? What holes remain?
      - Information & coherence lacking (benchmarks?)
- Same for endpoints/edges

"Easy" Things Remaining

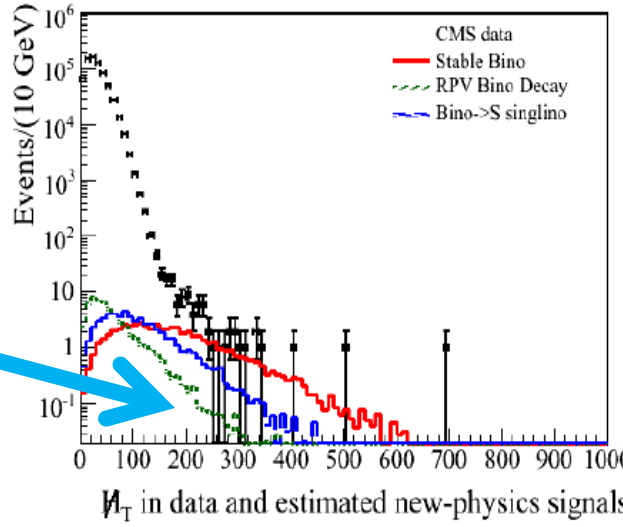
- High-Multiplicity High-S_T High-Rate signals
  - But below black hole rates/energies
  - SUSY models with extra cascades
    - RPViolating, or RPConserving with Hidden Valley/Stealth
  - Compositeness Models with decays to top + jets

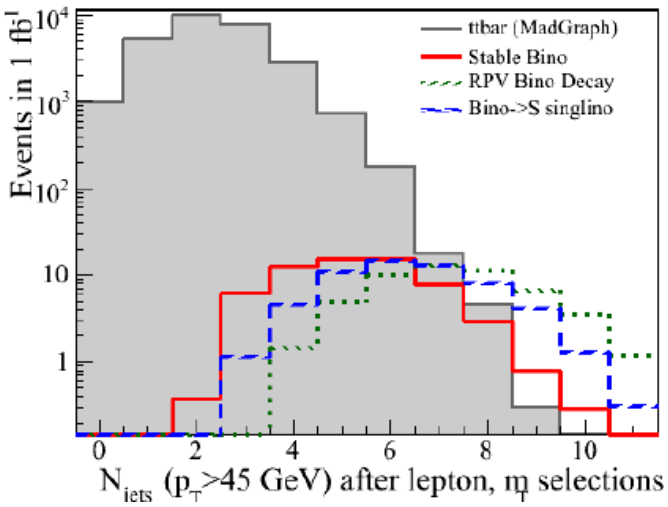
- Strategy: Rare object(s) + many jets
  - Cf. Theorists: Lepton + Many Jets search [background: top]
  - Cf. ATLAS: MET + Many Jets search [background: QCD, W/Z+jets]
  - Cf. CMS: Photon + Many Jets search [background: QCD, inclu γ]

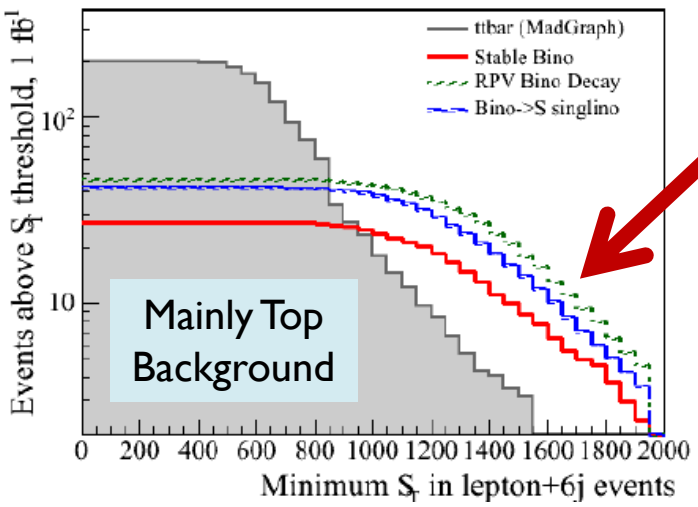
  - Require many jets, limited MET; look at S_T tail for excess
  - Increase sensitivity through better modeling of backgrounds
    - Cross-checks from kinematics, b-tagging

Rare Object + Many Jets

- Lepton + many jets Lisanti, MJS, Schuster, Toro 2011
  - No MET cut (just MT>30 to reduce fakes)
  - Background dominated by top pairs
- Reduced MET and M_T for
  - SUSY
    - R-Parity Violation, GMSB, Singlets with R-Parity Conserved
  - Top-Prime → Top + Jets







Robust High-S_T Tail

Rare Object + Ma[illegible]ets

Cf. New CMS Photon + Multi-Jet HV/"Stealth SUSY" Search

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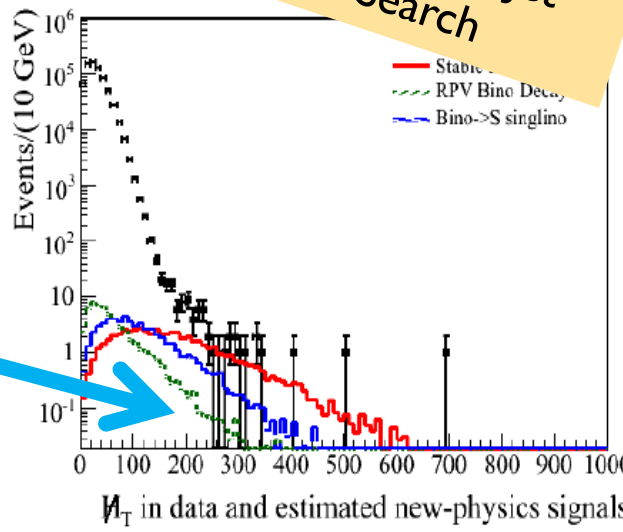

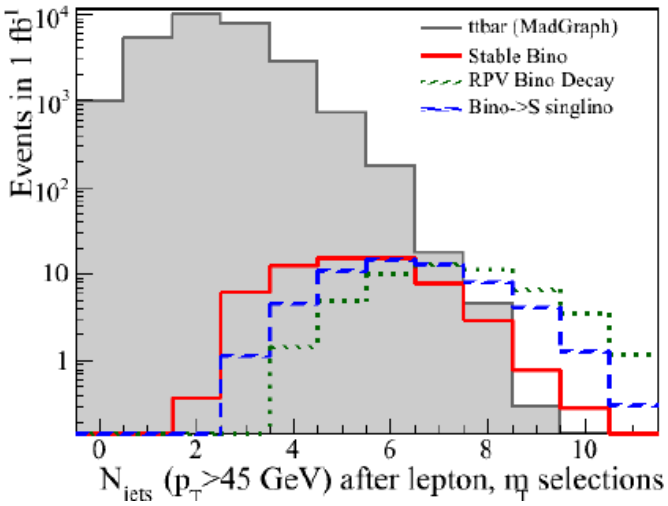

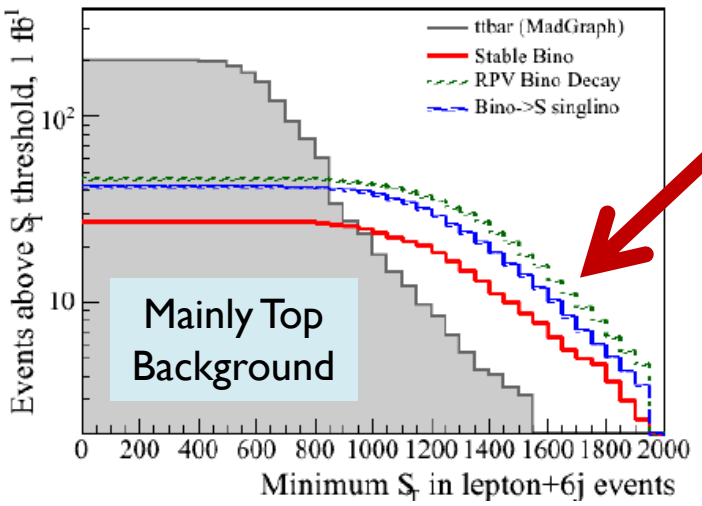

Robust High-S_T Tail

Exhaustive Top-Prime

- In pairs – or if heavy, perhaps singly too
- Decaying to
  - bW, tZ, tH
  - t+MET
  - t g, t γ
  - tX, X a singlet decaying to jj (others?)
- Crucial to start combining channels
  - Allow that the t' decays differently from the t'bar
  - Combine the matrix of final states
    - Start with just two dominant decays A,B? (AA + AB + BB)
- Must get backgrounds under even better MC control

Exotica in Top or Bottom + Jets

- Motivated by top A_{FB}
  - Precise measurements of top + jets kinematics & b-tags
- Motivated by dark matter
  - Exotic top decays – a challenge

These again require precision top physics

Other Resonances

- Targeted
  - Top squark → dijets or jet + lepton (RPV)
  - Colored Scalar → t + j (A_{FB}^{tt})
- Less Targeted
  - Ultra-weakly interacting, or X-onium states (low rate and low mass)
  - Pairs of resonances
  - New boosted objects → Resonances in fat-jets with substructure

Flavor Structure and/or Violation

- H → tau mu (or even Z?)
- t → c H, c Z, c g

- SUSY models with large flavor non-degeneracies
  - Production rates dramatically altered
    - squark-squark, squark-gluon production reduced
  - Single top + jets, possibly +MET
  - Sources of correlated OS mu + e, or mu + tau, or e + tau
    - E.g. edges or endpoints

Cf. A. Weiler talk
Implications Workshop
@ CERN

Exotic H Production

- Exotic Production can't be 100 pb but perhaps a few pb

- How can we organize studies? Find H_{SM}–Free Zones?
  - Check H at high pT, high S_T, high MET, high multiplicity
  - H with jets that aren't from gg, VBF, Vh or tth
    - t → c H

- Two H's at a time?
    - H → h h, or SUSY with NLSP → h LSP, or LSP → gravitino h, or…
  - γ γ b b (double resonance)
  - γ γ + lepton
  - Dileptons (SF and OF) (inclu hadronic taus) plus b's
  - >2 leptons

Exotic H Decays

- Non SM decays may easily be Br ~10%, 1%, 0.1%
  - Recall 500,000 H_{SM} at CMS in 2012!!!

- Remember:
  - There can be very light neutral particles
    - These could be very hard to produce, but decay within detector
  - Light H very sensitive to new interactions

- Easily leads to new H decays
  - Invisible (i.e. MET) Shrock 83
  - Mostly Invisible (i.e., soft particles + MET)
  - Two or more non-QCD-like jets (e.g. lepton jets, light pseudoscalars)
  - Four-body (typically in paired resonances)
    - 2 quark pairs; lepton pair + quark pair ; photon pair + gluon pair
  - Four-body + MET
  - Six-body (e.g. two leptons + quark recoiling against three quarks)
  - Long-lived Particles (2 or more)
  - Etc., Etc., Etc.

Dermisek & Gunion 04
Chang, Fox, & Weiner 05
Strassler & Zurek 06
Carpenter, Kaplan & Rhee 06

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Worry: Higgs lies at the edge of trigger's knife; will the trigger even fire? Answer: **Not always** (cf. MJS trigger study)

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Answer: **Not always** (cf. MJS trigger study)

Worry: Would improved triggering actually allow any interesting analyses?
Answer: **Sometimes** (cf. analysis study by Katz, Shelton, Volansky, MJS, Curtin, Essig, …)

MJS assisting CMS-Imperial (Buchmueller, Brooke, Tapper, …)

CMS Inclusive VBF Data Parking

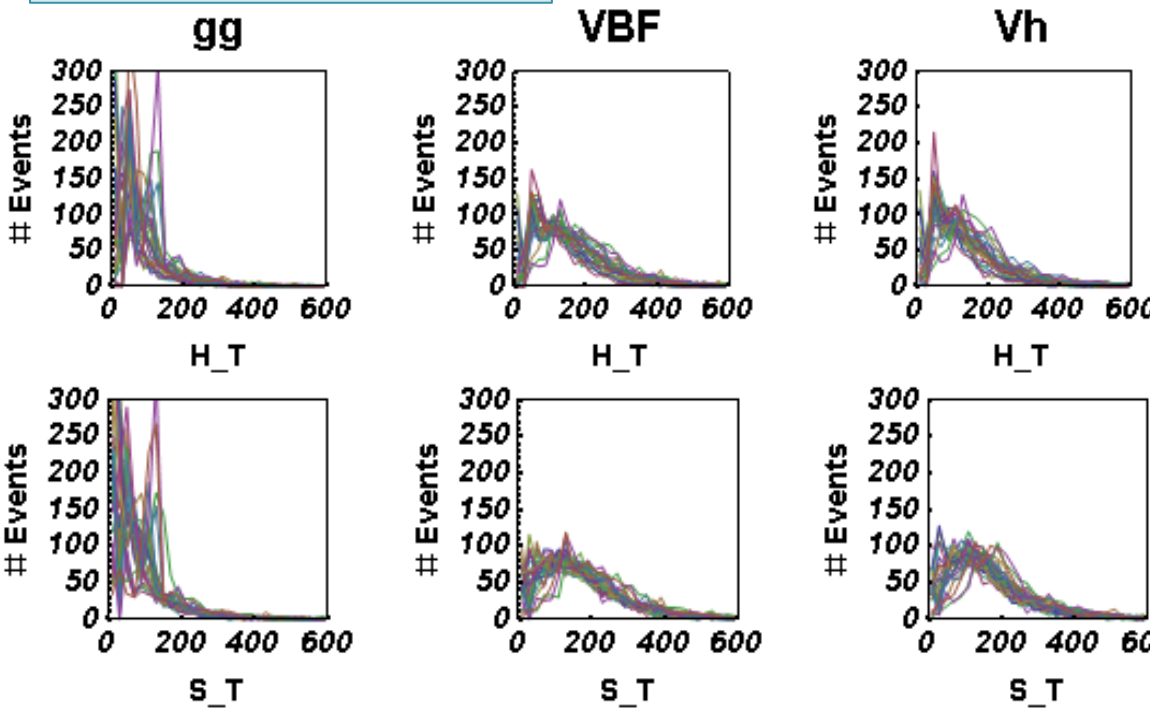
H decays ➔ S_T ~ 100-150 GeV

- S_T = H_T + MET,
- H_T = sum scalar pT of all central objects

In VBF, S_T larger since

- pT of H increased
- Typically a VBF jet is central

HT and ST distributions for many Higgs decay modes show rough universality



- Strategy
  - L1: Require S_T (actually H_T or MET) >100 GeV
  - HLT: Require 2 VBF-like jets; > 10% efficiency
  - Double or more the ``fallback'' events

Question: add semi-exclusive triggers relying on the Higgs decay products?

Exotic Objects (H ExoDKs, SUSY with low MET, etc.)

- Long-Lived Particles
  - Many final states, lifetimes, subtleties
  - Triggering is a huge issue! So is analysis of course.

- Clustered Objects (e.g. lepton-jets) Arkani-Hamed&Weiner 09 Many authors (inclu Wacker, Yavin,)
  - New Boosted Particles – only produced this way
  - Isolation issues in triggering

- Quirks of all shapes and sizes
  - Weird tracks (triggering issue)
  - Weird underlying event (triggering issue?)

Unique triggering [urgent!!!] and analysis issues:

- discussion coming up that focuses on these objects

What should theorists do…

- With extra month we really need focus on triggers
  - Possible trigger strategies
  - Analysis studies to allow prioritization of triggering & analysis

- What are strategies for searching for
  - Exotic H production
  - Production of unknown low-mass resonances

Conclusions: Some Bullet Points

- The Obvious Must-Do's
  - Natural stuff that hides because of reduced/no MET
  - Top partners (e.g. stops, top-primes)
  - H/W/Z partners (e.g. electroweak-inos, KK partners)
  - Everything H (production/decay, expected/unexpected)
- Fishing In a Very, Very Big Sea of the Unknown
  - Resonances with unusual final states
  - Boosted
  - Lightweight
  - Long-lived
  - Flavor-violating or non-universal
  - Etc. Etc. Etc. Etc.

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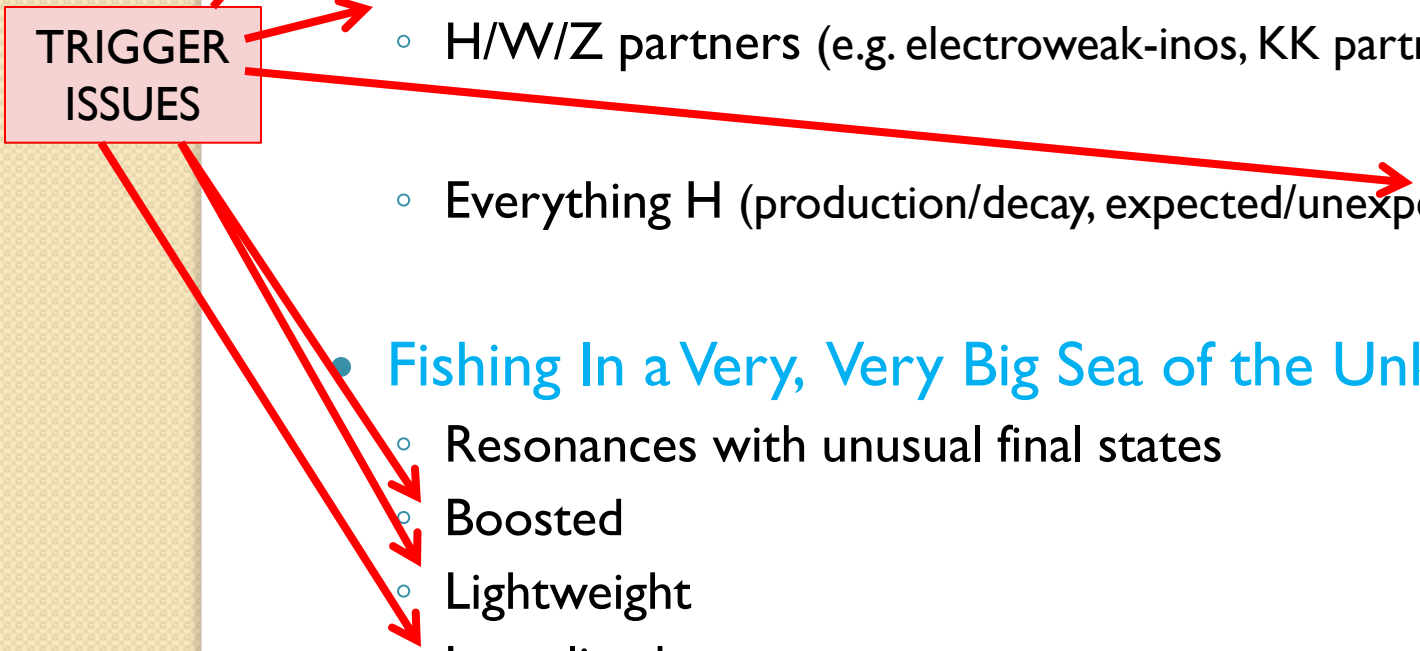

Backup

My [Mostly Naïve] Suggestions

- Cross-Links Between Search Groups, SM Group Needed
  - Improved SM Measurements will underpin less-targeted searches
  - Such searches are fundamentally SM Null Tests
- Theory Needs to Be Put to Work
  - Monte Carlo programs work well
  - More reliance on MC, less on data-driven may be safe
    - Especially since we are not at the end of the data stream!
  - Safe techniques need to be developed (ratios, good kinematics, …)
    - Bring MC/QCD/EW theorists into the SM measurements
  - Maybe start with top and with diboson (+ 0,1,2 jets)?
- Compare 7/8/14 TeV; detector effects, backgrounds, signals differ
    - Mangano & Rojo
- Benchmarks: Do Not Let Them Limit Results Unnecessarily

Broad Resonances

- To see a broad resonance on a falling distribution is tough
- Need to predict background distribution rather than fit it
  - Theory MC to predict the physics curve
  - Other data or detector MC to predict the efficiency corrections?
- Additional benefits for narrow resonances at low rate
- Ambiguities can be settled with 7/8/14 TeV comparisons

Harder but Important in 2012-13

- Low Mass, Low Cross-Section Resonances
  - Maybe only observable in associated production, or in pairs
- Broad resonances
  - Precise (or monotonically uncertain) predictions of falling distributions?

- Electroweak Production
  - Includes charginos, neutralinos, sleptons; many other possibilities

- Non-Standard Model Higgs
  - New Scalar States (possibly very low cross-section)
  - New Production Modes
  - New Decay Modes (possibly rare – recall 10^6 Higgses)

- Rare W, Z, t decays (?)
  - LHC has the most of each of these [but trigger issues]

Simple Searches for H ExoDK

- On edge of existing H search
  - H → X X → two dilepton pairs
  - H → X X → dilepton pair + quark pair (possibly b's)

- Why wouldn't first be found in existing search?
  - Kinematic cuts inappropriate
  - Isolation requirements too tight
  - Background estimates too high

- Why might the second escape?
  - Requirement of near-on-shell Z in leptons or in jets
  - Isolation requirements too tight
  - No one looking for dilepton resonance in this channel

Other Searches for H ExoDK

- Slightly more subtle
  - H → X X → two diphoton pairs
  - H → X X → diphoton pair + gluon pair
- Why wouldn't first be found already?
  - Kinematic cuts inappropriate
  - Isolation requirements too tight
  - Trigger
- Why might the second escape?
  - Lots of fake background at low invt mass for photons
  - Isolation requirements too tight
  - No one looking for diphoton resonance requiring the jets

Hard Searches for H ExoDK

- Hard:
  - H → X X → tau pair + b pair
  - H → X X → (lepton-pair + MET) + (3 jets)
  - H → X X → (photon+MET) + (photon+MET)

- MET, no dilepton/diphoton resonance ➔ no mass peaks

- Backgrounds challenging
- Trigger challenging
  - Fallback: WH/ZH where W or Z decays leptonically
  - Improvement: Dump VBF-candidate events to data parking
    - (factor of 2 – 3 ?)