Higgs decaying to lepton jets

Jure Zupan
SISSA & Josef Stefan Inst. & Univ. of Ljubljana

based on work with Falkowski, Ruderman, Volansky (1002.2952)

THE AIMS OF THIS TALK

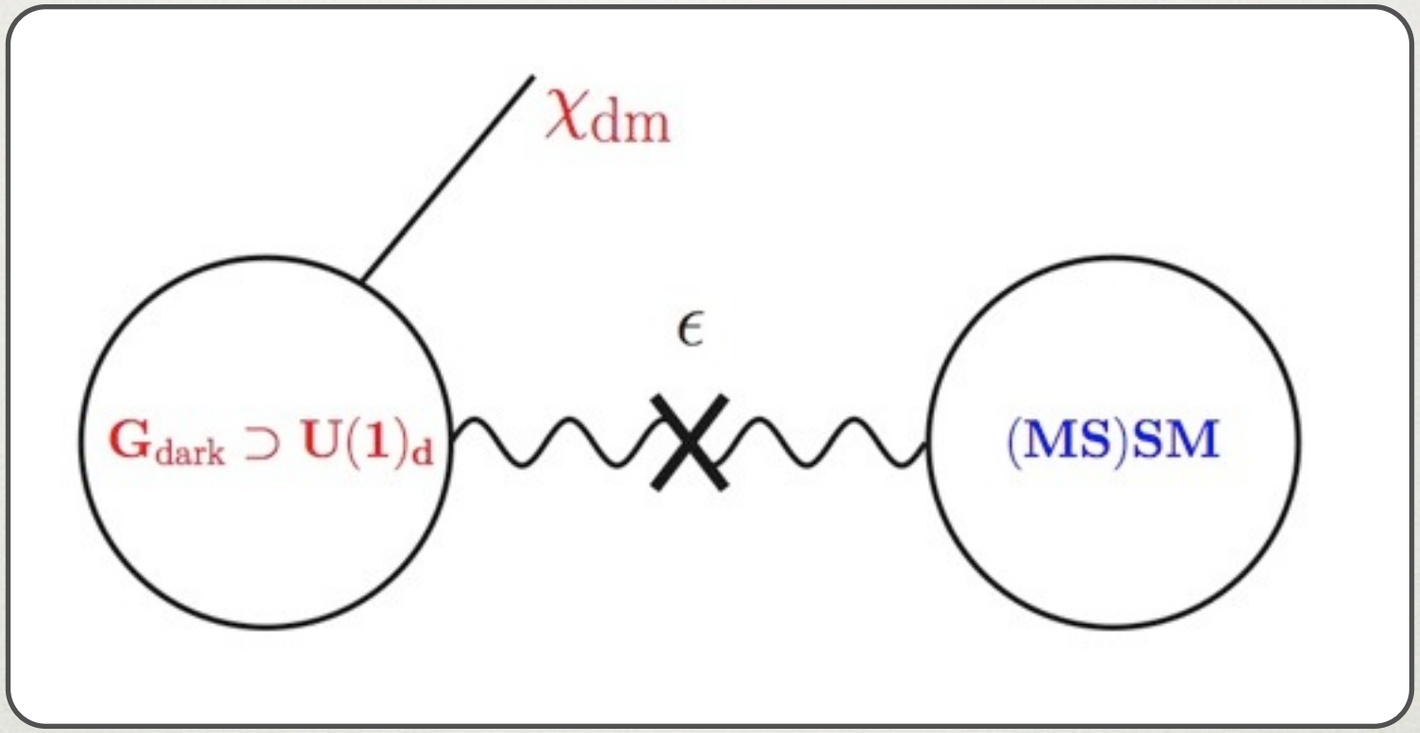
- *h→lepton jets* can alleviate little hierarchy problem (lower higgs mass)
- build / show benchmark models
- how to find them at LHC, Tevatron, LEP?

NECESSARY INGREDIENTS

- higgs couples to hidden sector (directly or indirectly) and $h \to hidden$ dominates
  - not unlikely, given $y_b \sim 0.02$
- a nontrivial light hidden/dark sector
  - why not? visible sector is also complicated
- mixing between visible and dark sectors
  - so that it can decay back to visible sector

GENERAL SETUP

- our models supersymmetric



- G_{dark} is broken at GeV (we will use $G_{dark}=U(1)_d$)
- the cross-talk is done through kinetic mixing

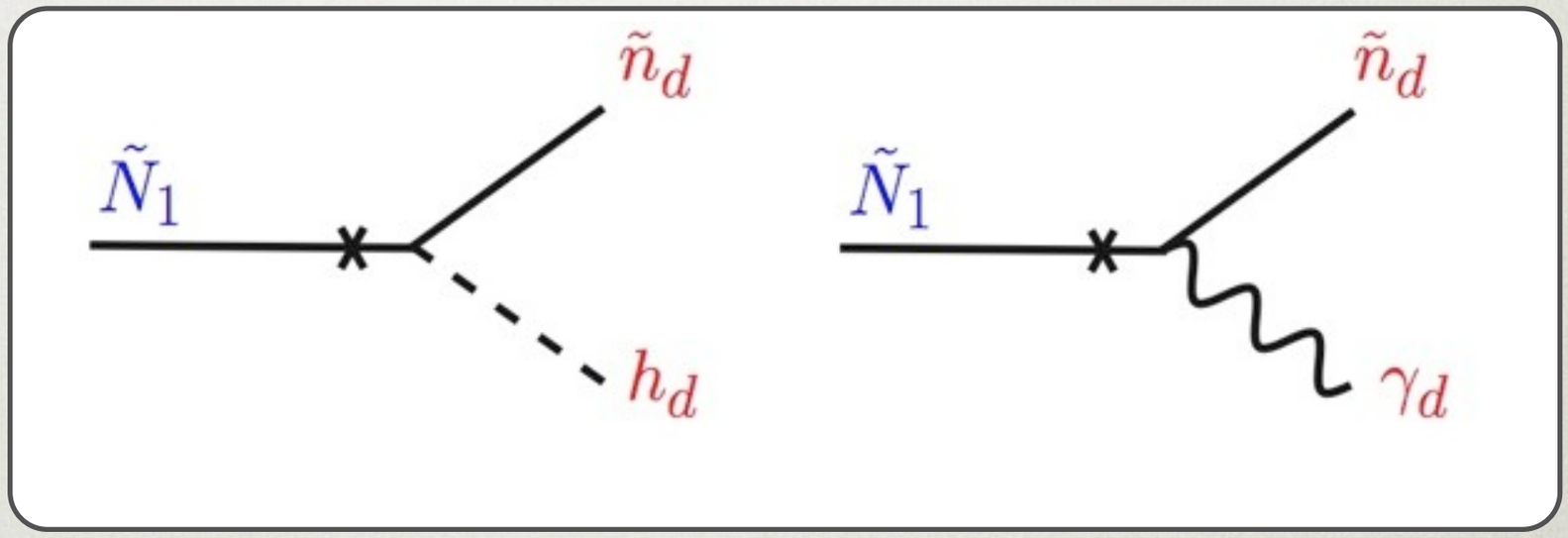
$$\mathcal{L} \supset \frac{\epsilon}{2} b_{\mu\nu} B^{\mu\nu} \qquad \epsilon \lesssim 10^{-3}$$

DECAYING TO HIDDEN SECTOR

- in our models no direct higgs- hidden/dark sector coupling
- dark sector couples to neutral particles in (N)MSSM
- three choices
  - neutralino portal
  - sneutrino portal
  - singlet portal

NEUTRALINO PORTAL

- susy ⇒ kin. mix. also in gaugino sector
- MSSM neutralinos can decay to hidden sector



- need to make sure $Br(Z \to 2\tilde{N}_1) < 10^{-3}$
  - possible, if neutralino mostly bino

SAMPLE DECAY

- results in many leptons and MET

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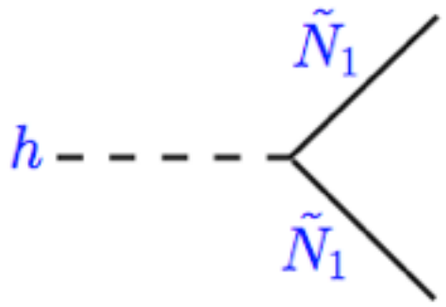

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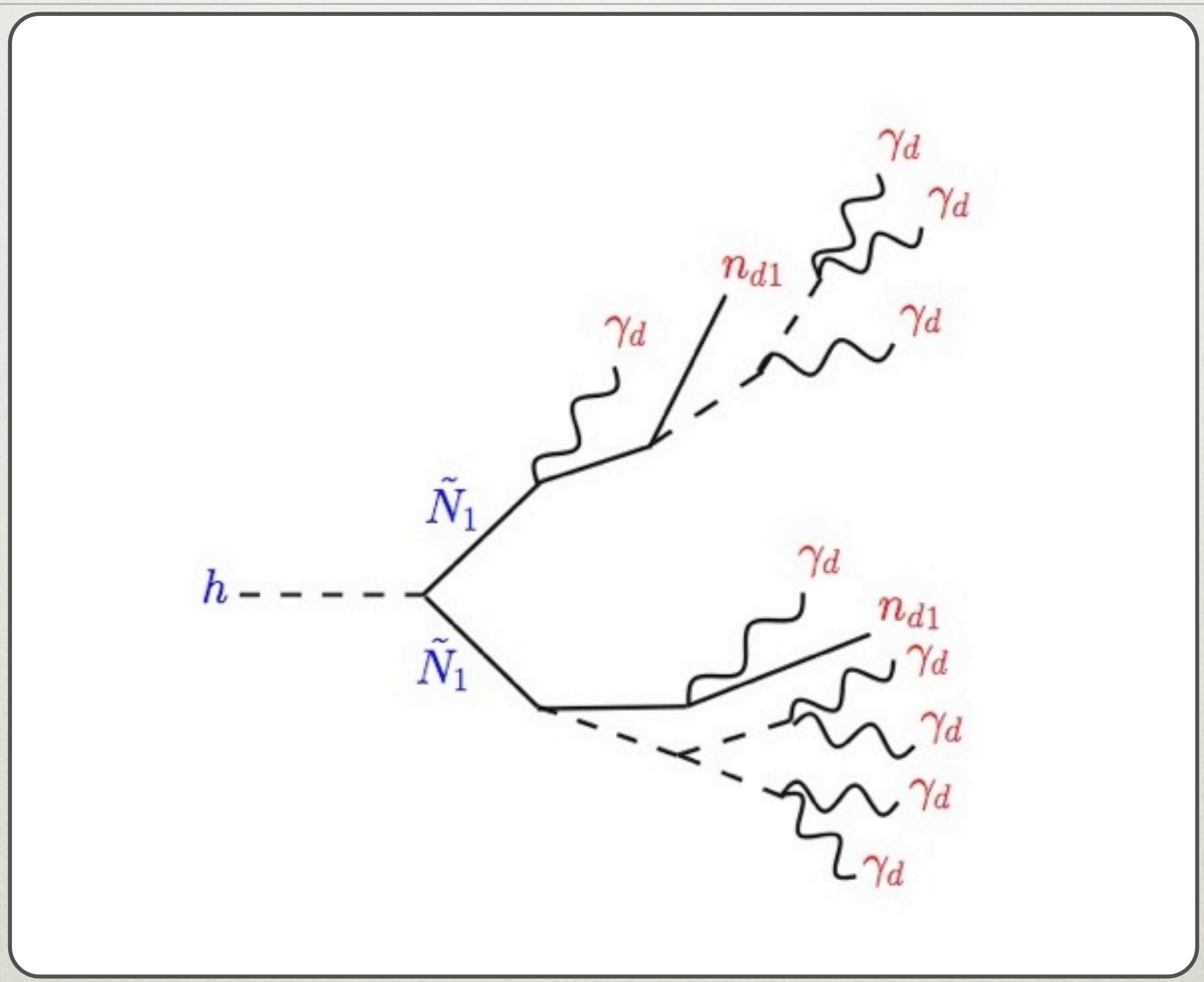

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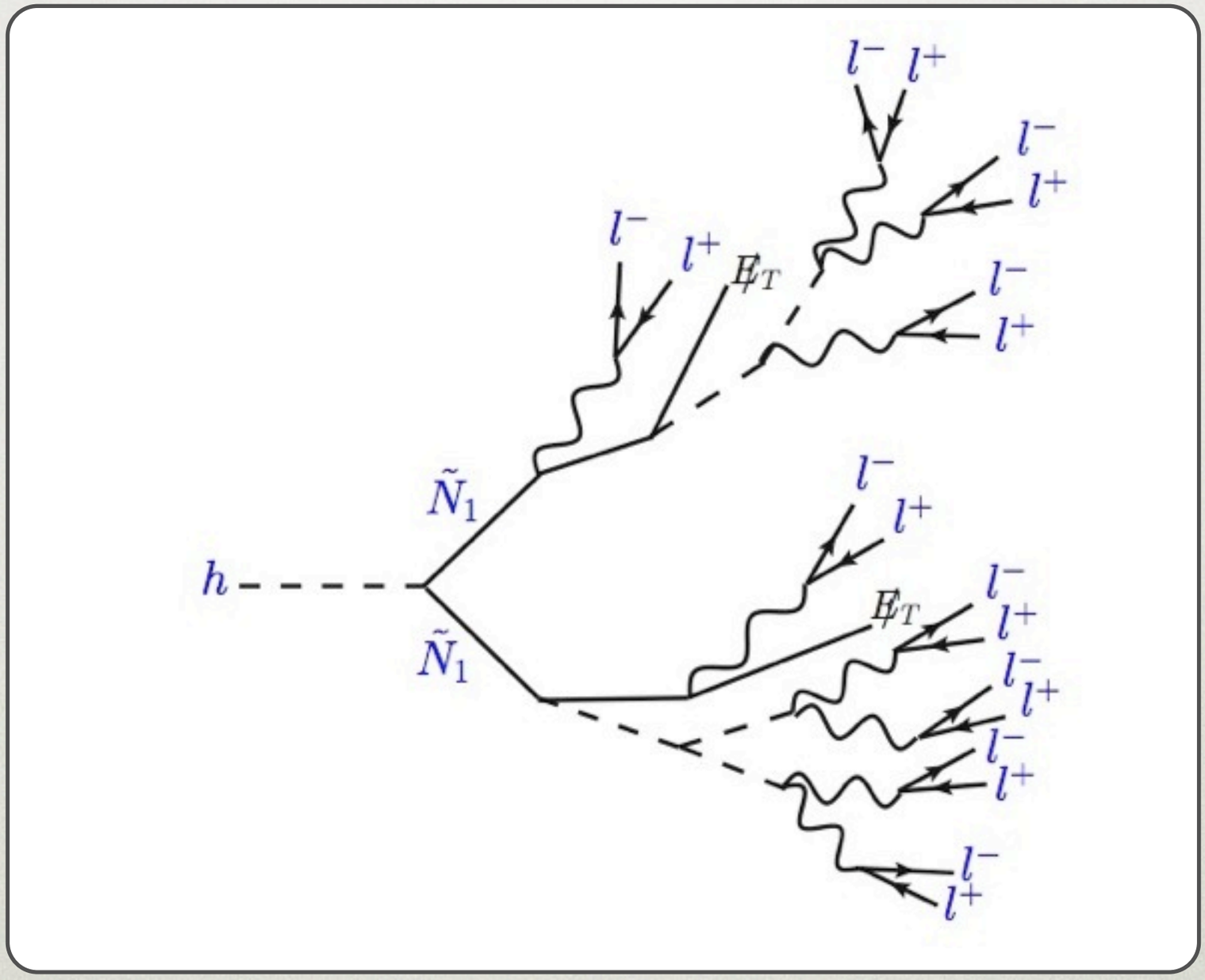

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SNEUTRINO AND SINGLET PORTALS

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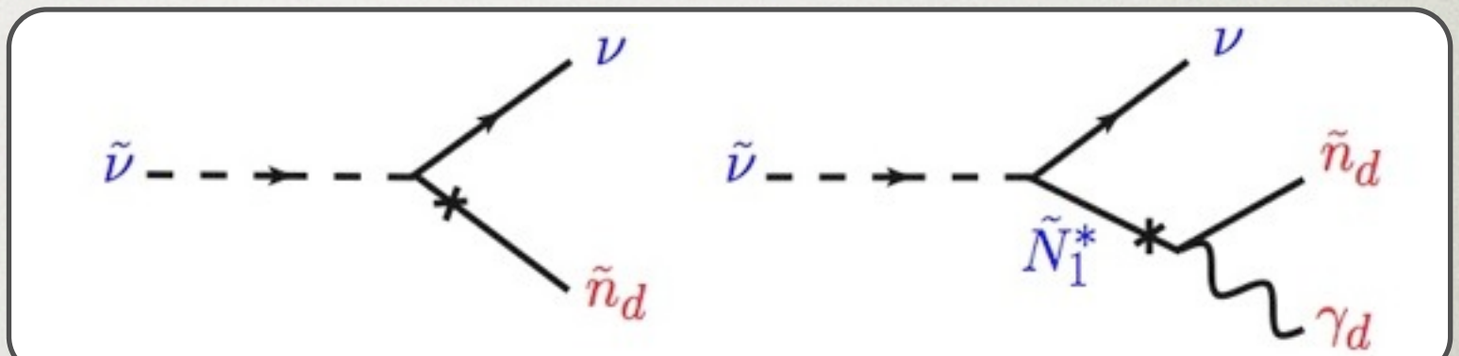
- **sneutrino portal:** higgs-snu-snu coupling from D terms, is large
  - LEP1: Z should not decay to it ⇒

$m_Z < 2m_{\tilde{\nu}} < m_h$



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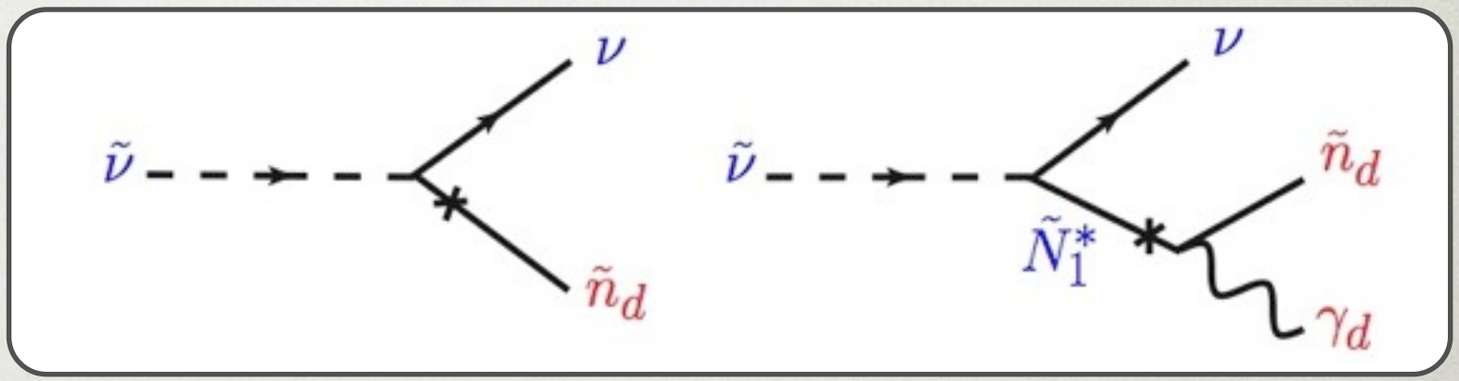
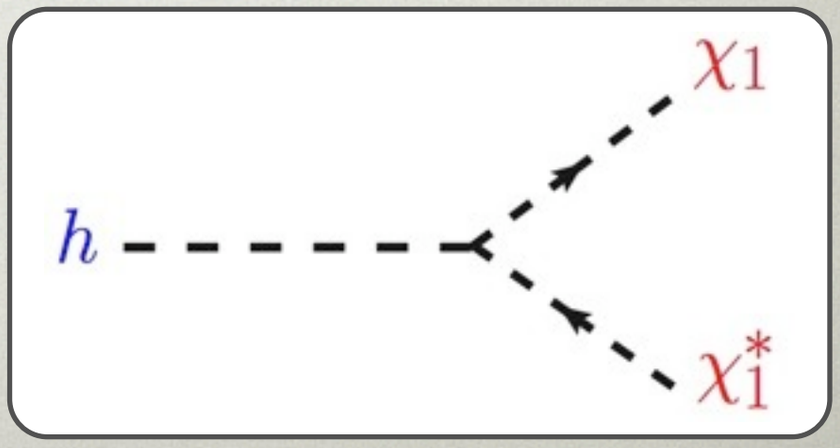


- **singlet portal:** NMSSM+two chiral fields with hidden $U(1)_d$ charges ±2

$$W \supset S H_u H_d + S \chi\bar{\chi} + \chi\bar{h}^2 + \bar{\chi}h^2$$



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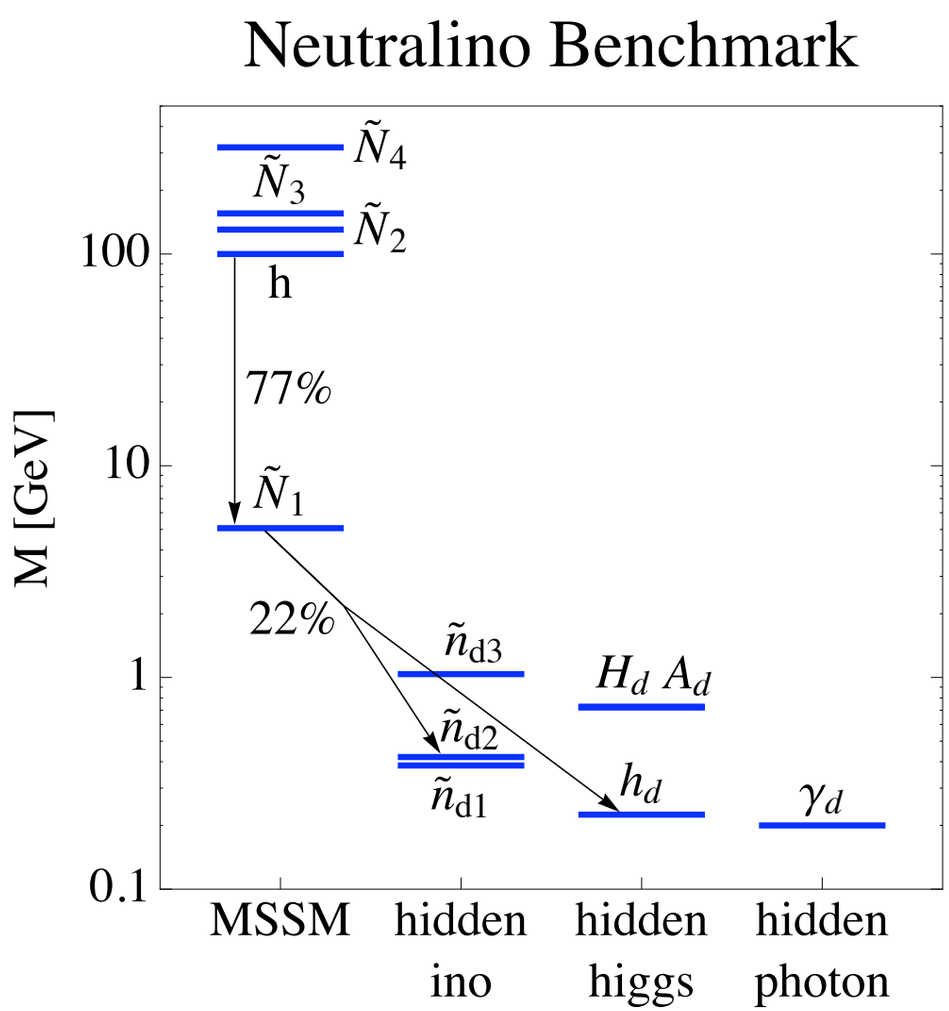

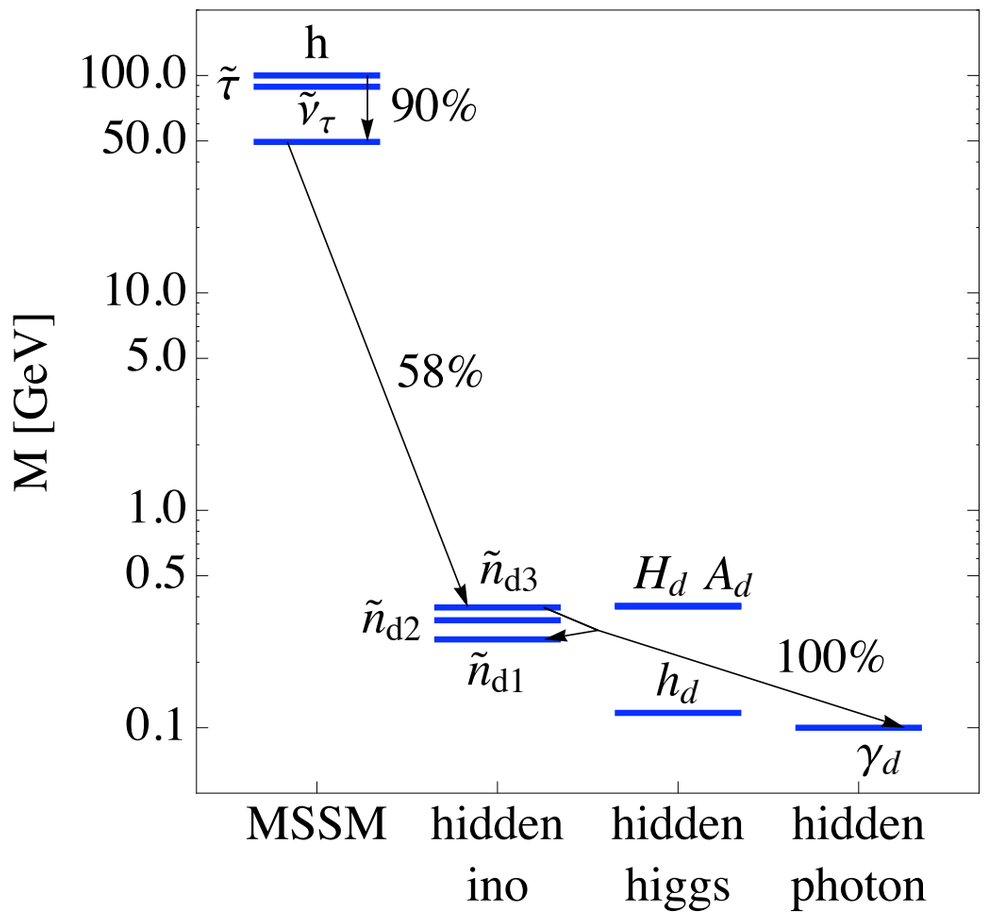

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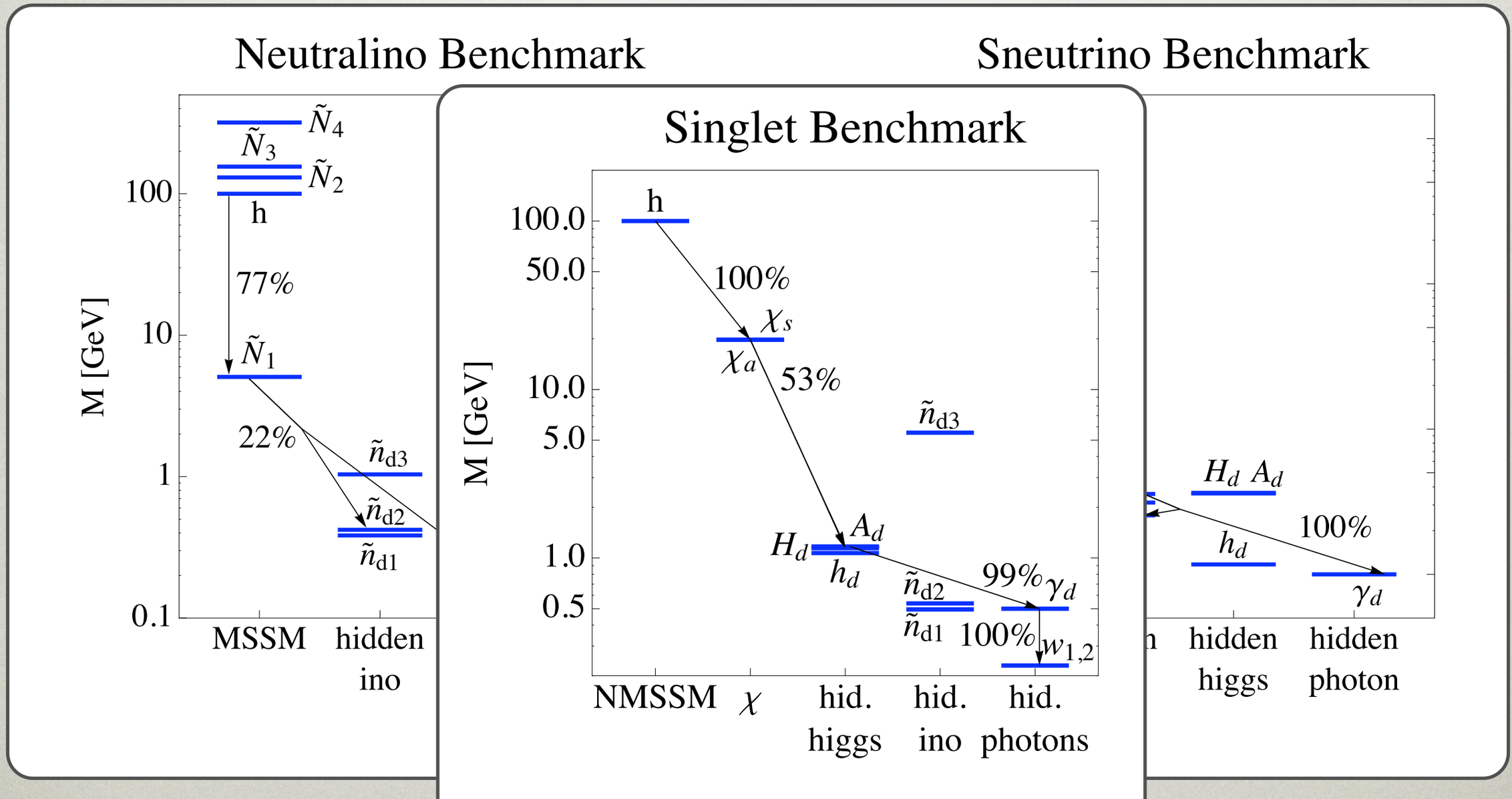

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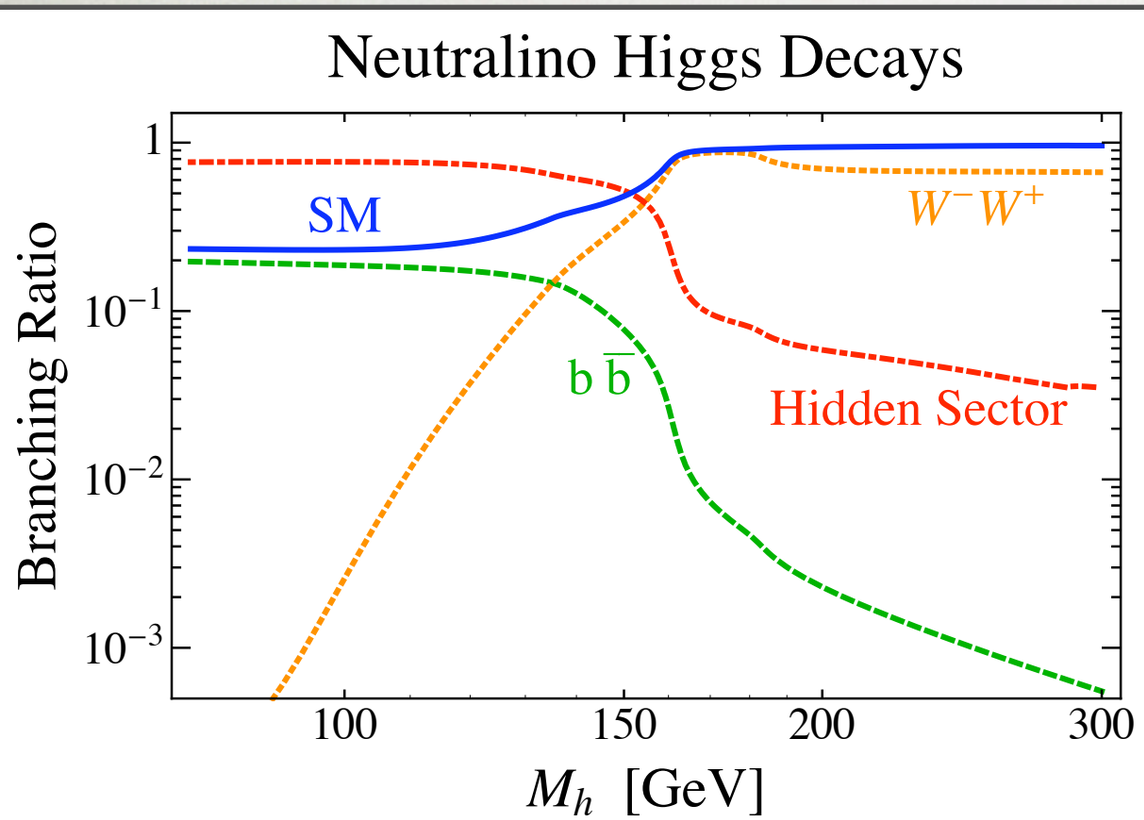

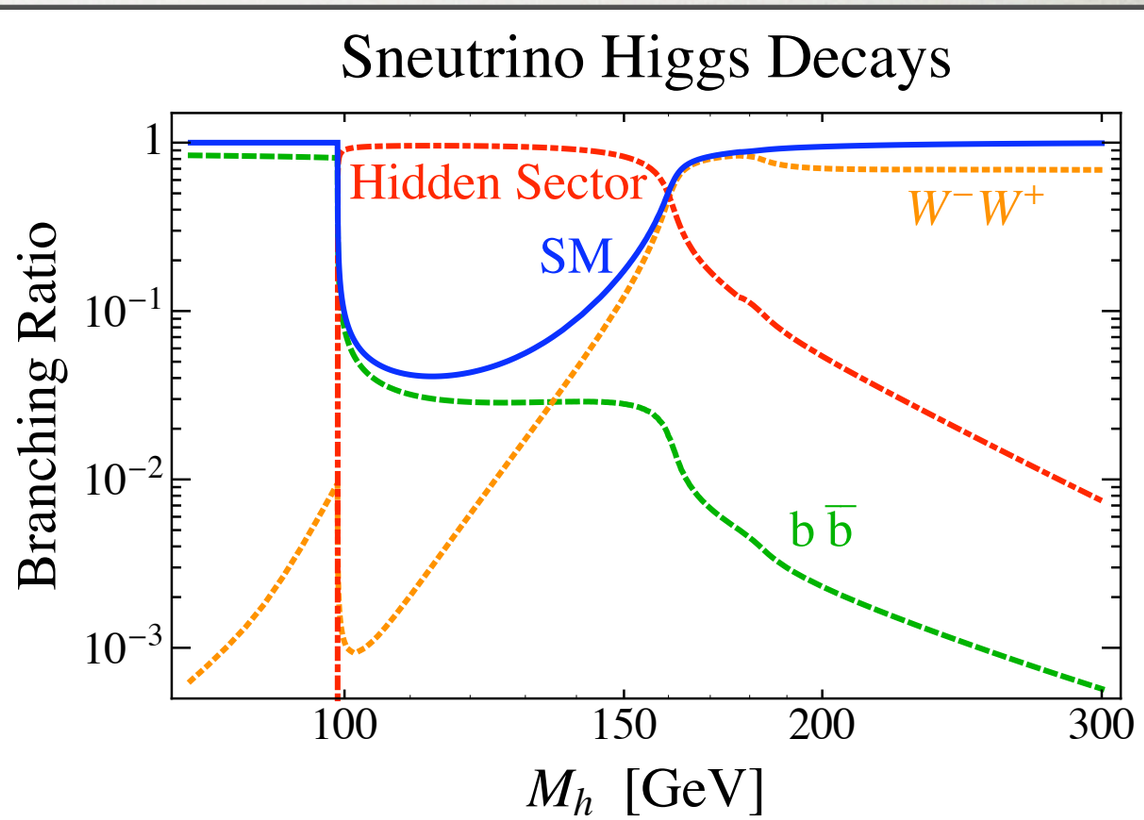

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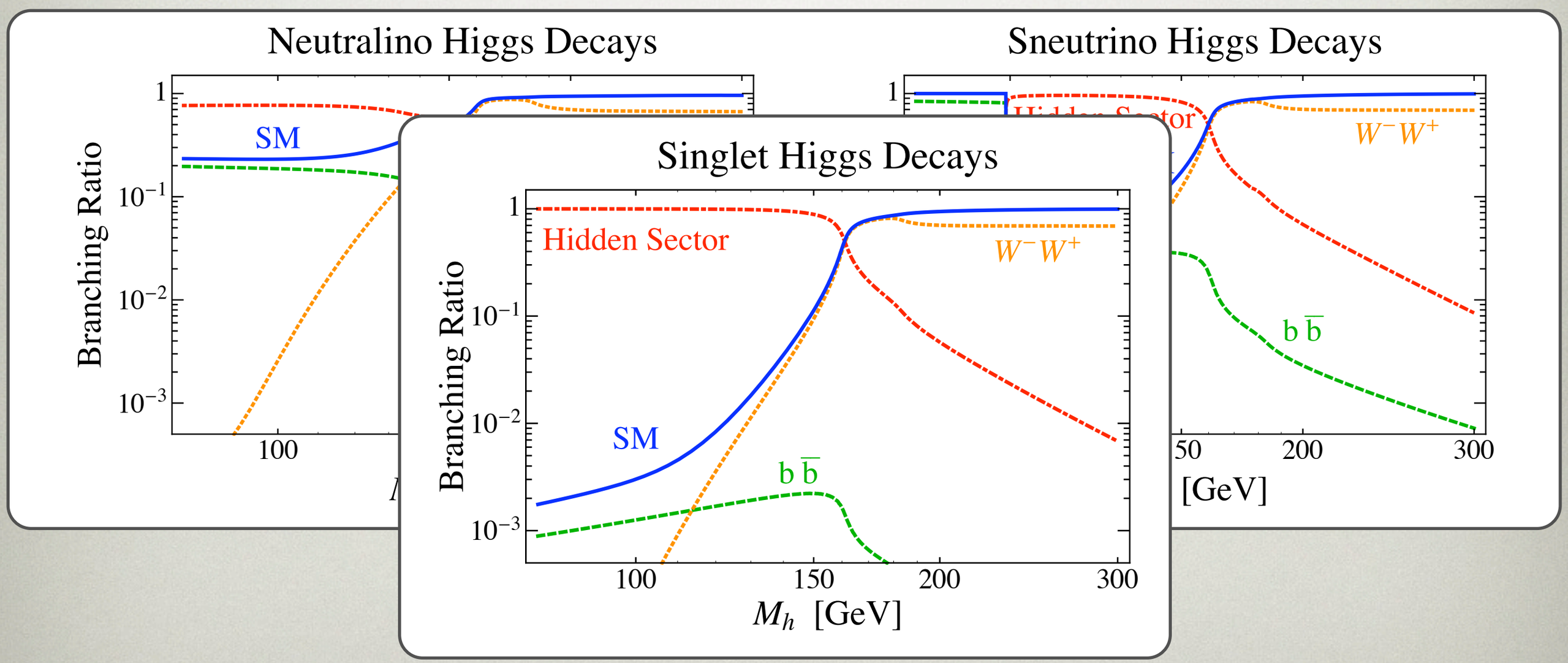

BENCHMARK MODELS

- we choose three benchmarks
- take m_h=100 GeV
- test against LEP-1, LEP-2, Tevatron searches
- before any cuts one has
  - O(100 higgs evnts/exp) @ LEP-2
  - O(10^4 higgs evnts/exp) @ Tevatron

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Many events, so isn't this excluded trivially?!

on

CAN LEPTON JETS REALLY HIDE THE HIGGS?

- O(100) higgses/exp @ LEP-2:
  - preliminary selection cuts reduce this by ~order of magnitude
  - often hadronic events identified by charged tracks ⇒ hidden in hadronic bckg.
  - need dedicated searches

CAN LEPTON JETS REALLY HIDE THE HIGGS?

- O(10^4 events) @ Tevatron
  - large QCD bckg., cannot search 'by eye'
  - still, there are many leptons...
  - but Tevatron searches require them to be isolated
  - in lepton jets this not true
  - need dedicated searches

LEPTON JET MONTE CARLO

- we simulated *h→lepton jets* at LEP and Tevatron using Monte Carlo
  - `Madgraph` for higgs production and decay
  - `Bridge` for cascade decays
  - `SlowJet` (our Mathematica code) for event analysis
- this is "theorists simulation": no detector effects, to get precise limits this would be needed

RELEVANT EXPERIMENTAL SEARCHES

RE

LEP-1 searches

Search	Ref.	Obs.	Bckg.	Neutr.	Sneutr.	Singlet	Max.
Monojets	[42]	3	2.8	< 1	0	0	6.6
Acoplanar	[41]	0	0.2	< 1	0	0	3.8

LEP-2 searches

Search	Ref.	Obs.	Bckg.	Neutr.	Sneutr.	Singlet	Max.
$H \to 4\tau$	[12]	2	5.09	1	**15**	1	5.0
$H \to \not{E}$	[36]	8	11	2	5	3	7.5
$H \to WW^*2c$	[52]	0	0.3	2	< 1	2	3.8
$H \to WW^*2t$	[52]	1	1.2	1	1	3	5.0
6l	[55]	1	1.1	< 1	4	< 1	5.0
$2j + \not{E}$ (OPAL)	[56]	13	19.8	8	**35**	7	7.8
$2j + \not{E}$ (ALEPH)	[57]	19	15.9	7	3	1	14.5
$2j + 2l + \not{E}$	[57]	5	3	2	4	5	9.0

Tevatron searches

Search	Ref.	Obs.	Bckg.	Neutr.	Sneutr.	Singlet	Max.
Dark photon	[59]	7	8	~ 1	< 1	< 1	7.9
$H \to 4\mu$	[60]	2	2.2	0	0	2	5.8
Unified 3l	[44]	1	1.47	< 1	< 1	< 1	3.7
Low p_T 3l	[45]	1	0.4	< 1	< 1	< 1	5.4
Like-sign 2l	[43]	13	7.8	1	< 1	< 1	14.7

RELEVANT EXPERIMENTAL SEARCHES

- sneutrino benchmark is excluded by LEP-2
  - the recent ALEPH $h \to 4\tau$
  - and OPAL 2j+MET
- other two benchmarks survive
- of course these are just benchmarks
- the higgs→lepton jets framework is more general

GENERAL FEATURES

- constraints are in general avoided, if higgs decay has
  - two-jet topology (higgs decays to two lepton jets)
  - high lepton multiplicity (at least 4 leptons per lepton jet)
  - all electron or very high multiplicity

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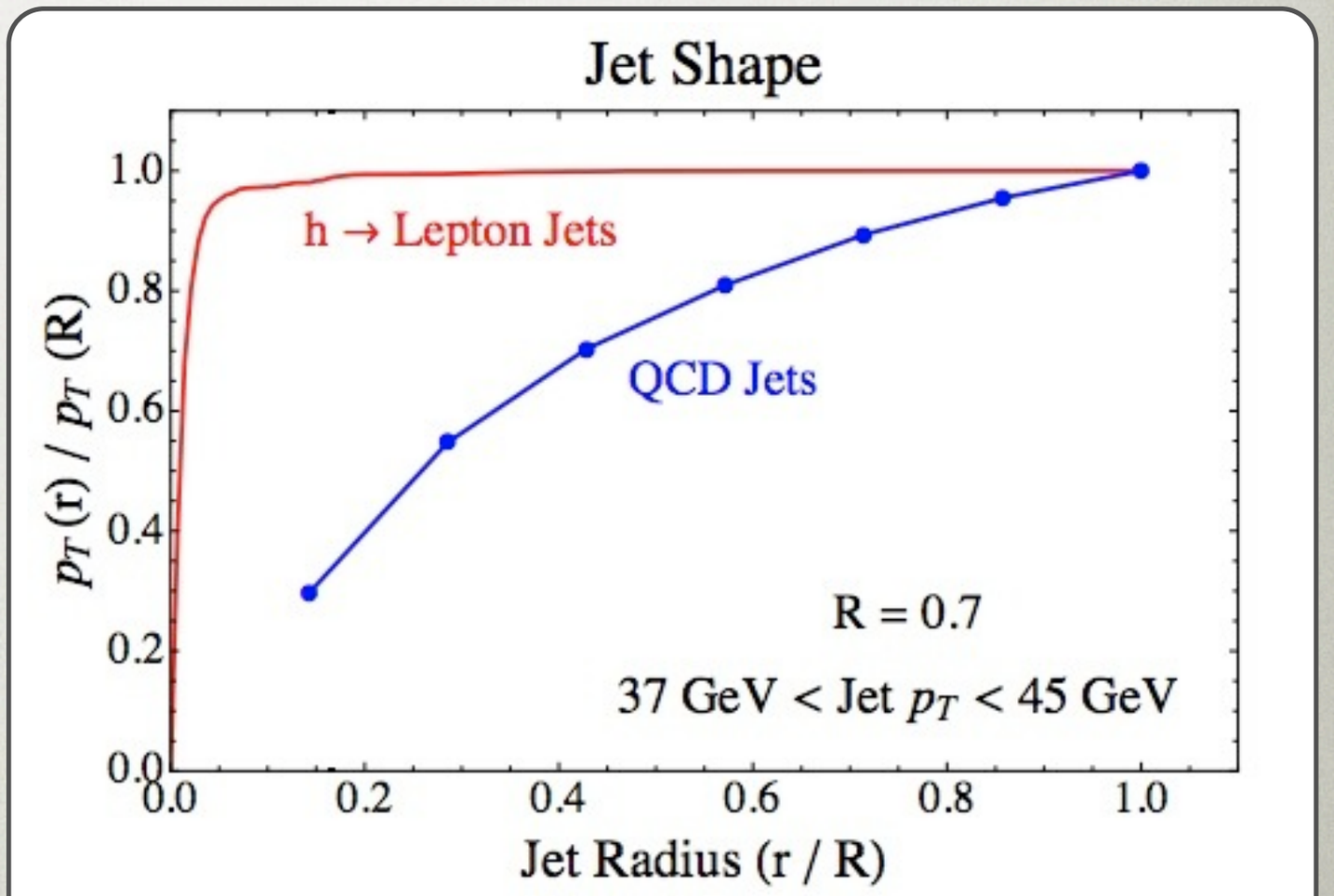

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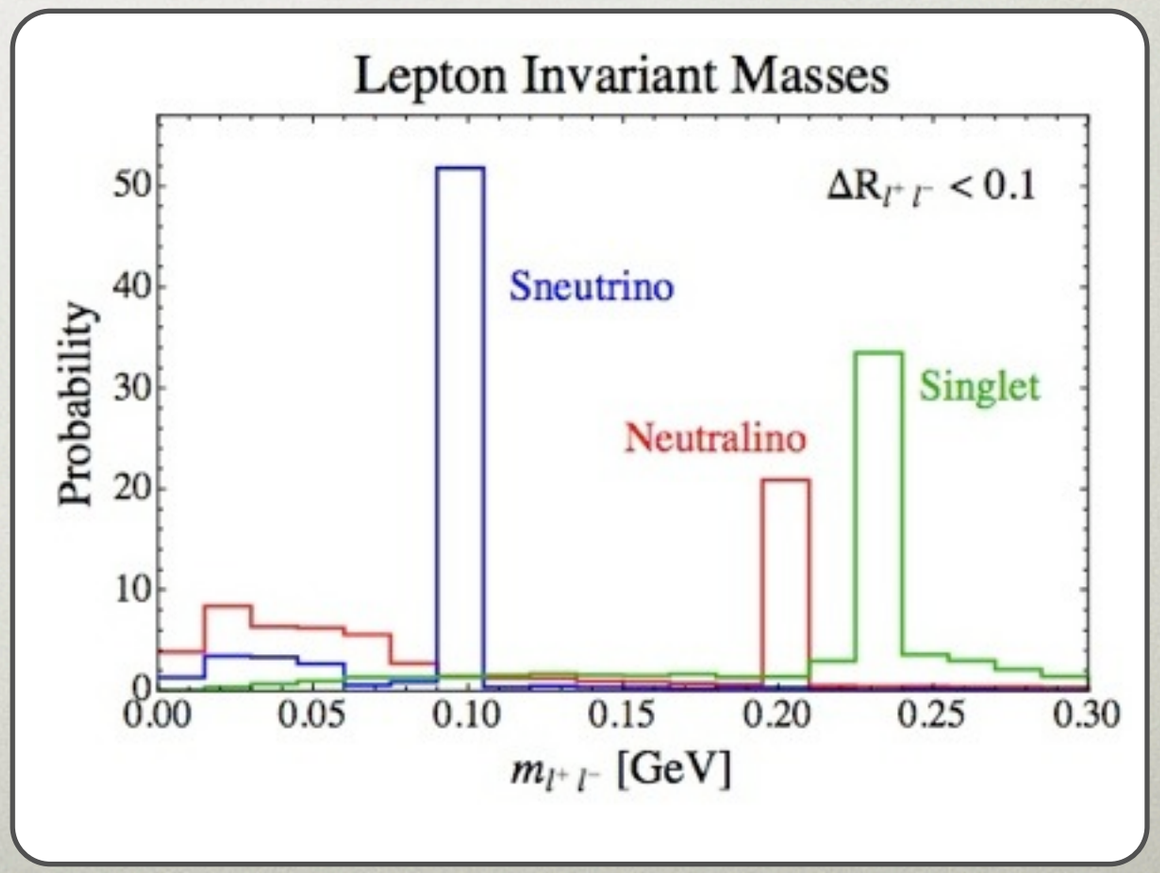
- lepton pair invariant mass



POSSIBLE SEARCH STRATEGIES

- hadronic energy deposition E_{had}/E_{em}
- event shapes (lepton jets much more collim. than QCD jets)
- lepton pair invariant mass
- allow for many leptons in jets
  - use other variables to control bckg

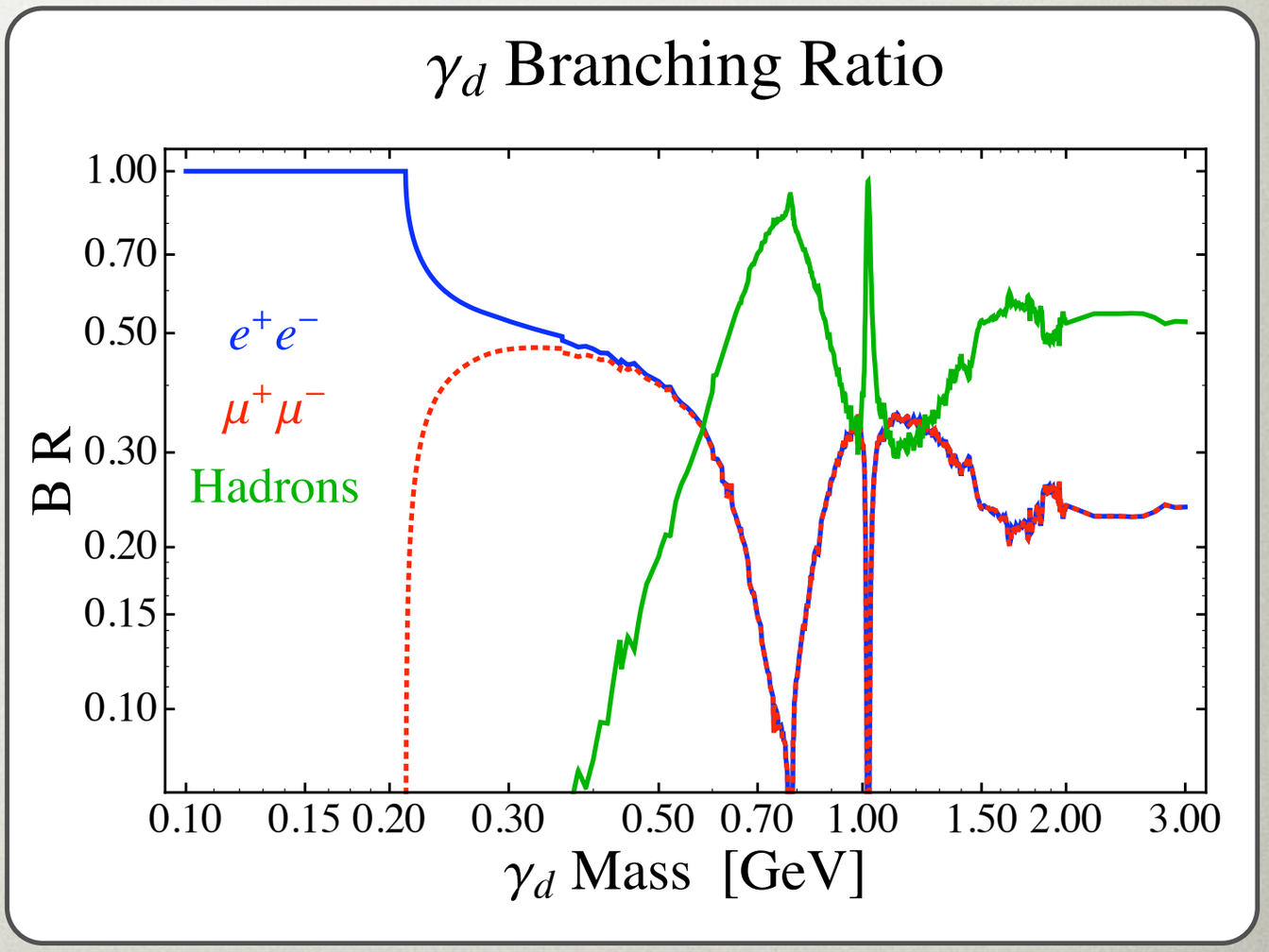
CONCLUSIONS

- *h→lepton jets* can alleviate little hierarchy (lower higgs mass)
  - models + exp. signatures/constraints
- how to find them at LHC, Tevatron, LEP?
  - need to go looking

BACKUP SLIDES

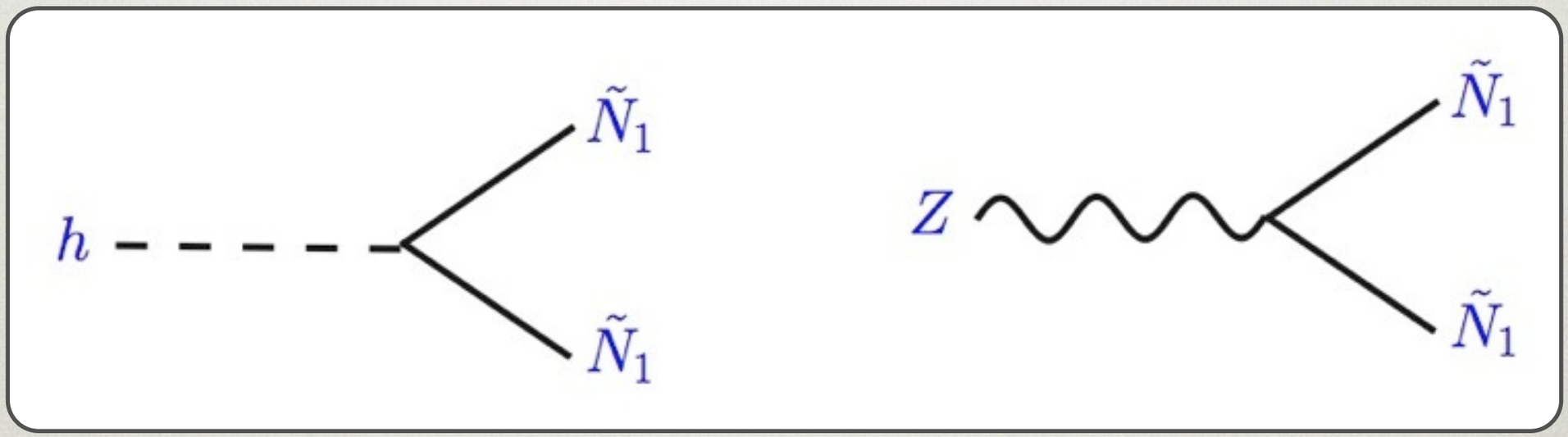
ARRIVING FROM HIDDEN SECTOR

- dark photon couples to EM current $\epsilon b_\mu J^\mu_{EM}$
- Br's of light photon to visible are fixed
- for low enough dark photon mass, it only decays to leptons



NEUTRALINO PORTAL

- higgs decays to pair of MSSM neutralinos, $h \to 2\tilde{N}_1$, if $2m_{\tilde{N}_1} < m_h$
- for $2m_{\tilde{N}_1} < m_Z$ Z also decays to $\tilde{N}_1$
  - consistent with LEP1, if $Br(Z \to 2\tilde{N}_1) < 10^{-3}$



- possible, if neutralino mostly bino, since then

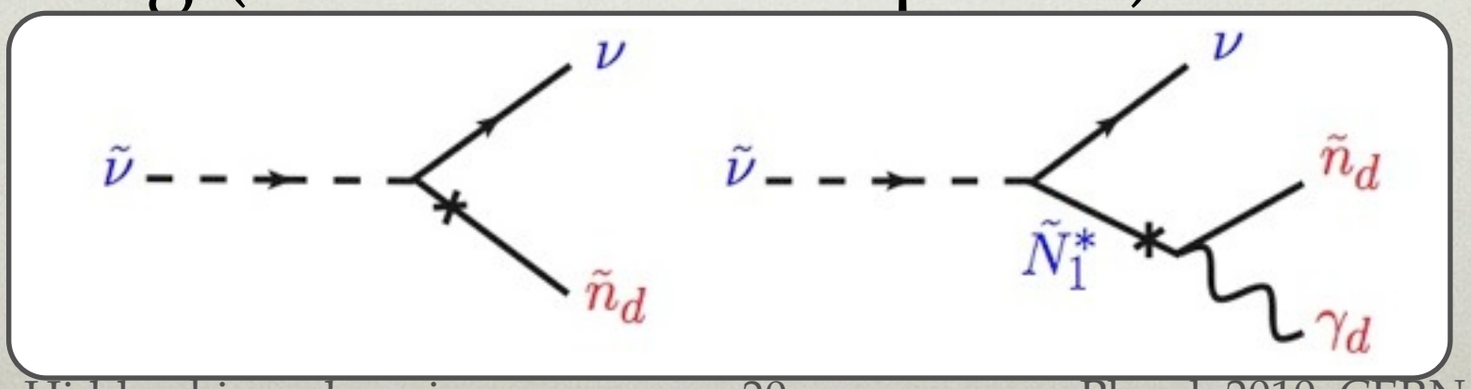
$$Br(Z \to 2\tilde{N}_1) \propto (\theta_{\tilde{N}_1 \tilde{H}})^4 \qquad Br(h \to 2\tilde{N}_1) \propto (\theta_{\tilde{N}_1 \tilde{H}})^2$$

SNEUTRINO PORTAL

- higgs-snu-snu coupling from D terms, is large

$$D_1 = \frac{g_1}{2}\left(|H_u|^2 - |H_d|^2 - |\tilde{\nu}_i|^2 + ...\right)$$
$$D_2^a = \frac{g_2}{2}\left(H_u T^a H_u^* + H_d T^a H_d^* + \tilde{L}_i T^a \tilde{L}_i^*\right)$$
$$V \supset \frac{1}{2}D_1^2 + \frac{1}{2}D_2^2$$

- LEP1: Z should not decay to it $\Rightarrow\ m_Z < 2m_{\tilde{\nu}} < m_h$
- $h \to \tilde{\nu}\tilde{\nu}$ dominates over h→bb
- the decay to hidden sector is from kinetic mixing (as in neutralino portal)



EXPERIMENTAL OBSERVABLES

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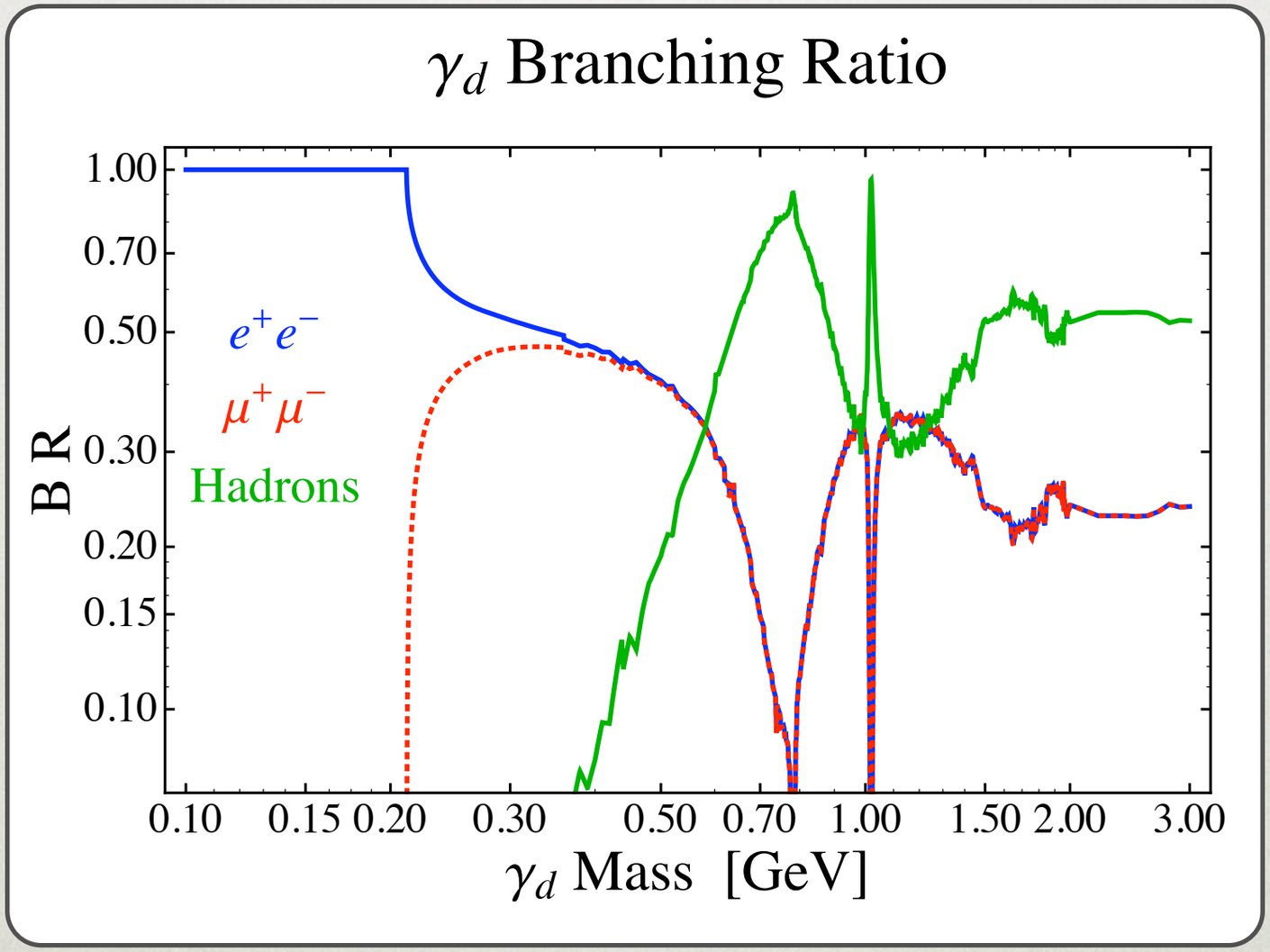
- visible final states: electrons vs. muons



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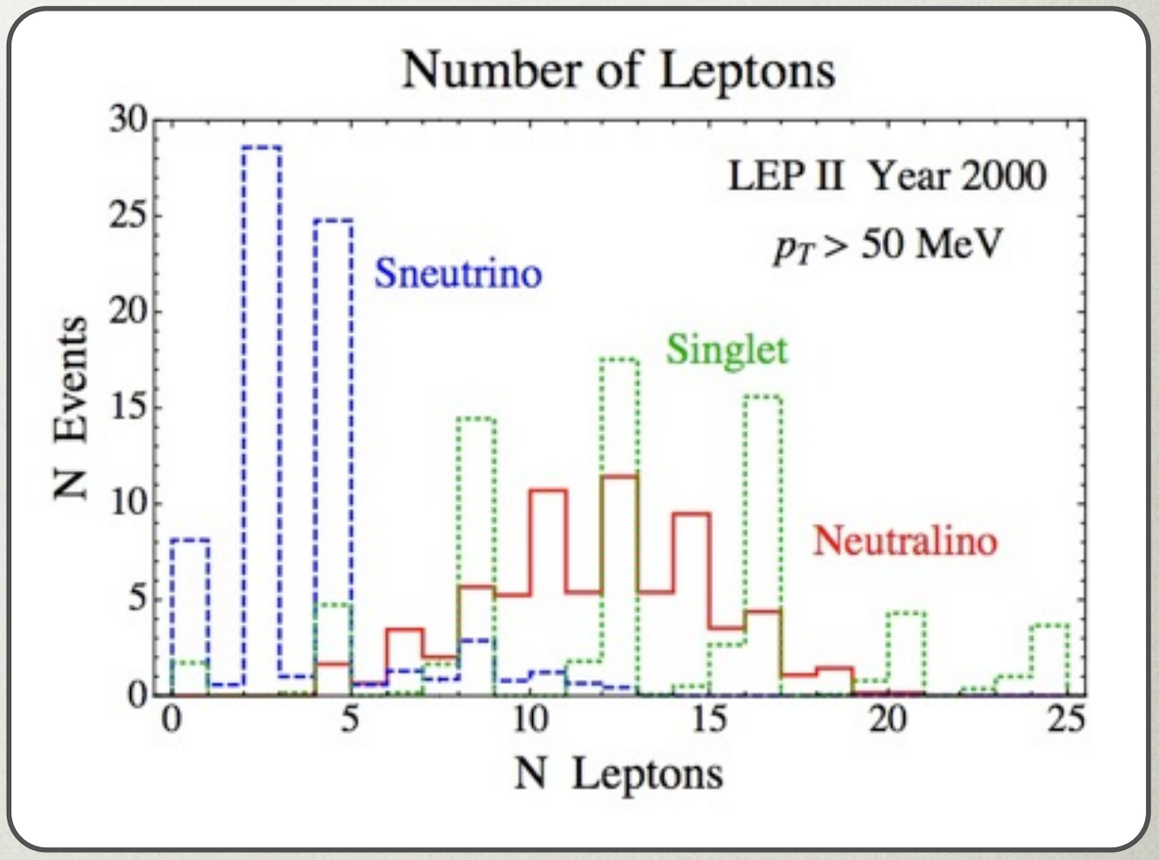

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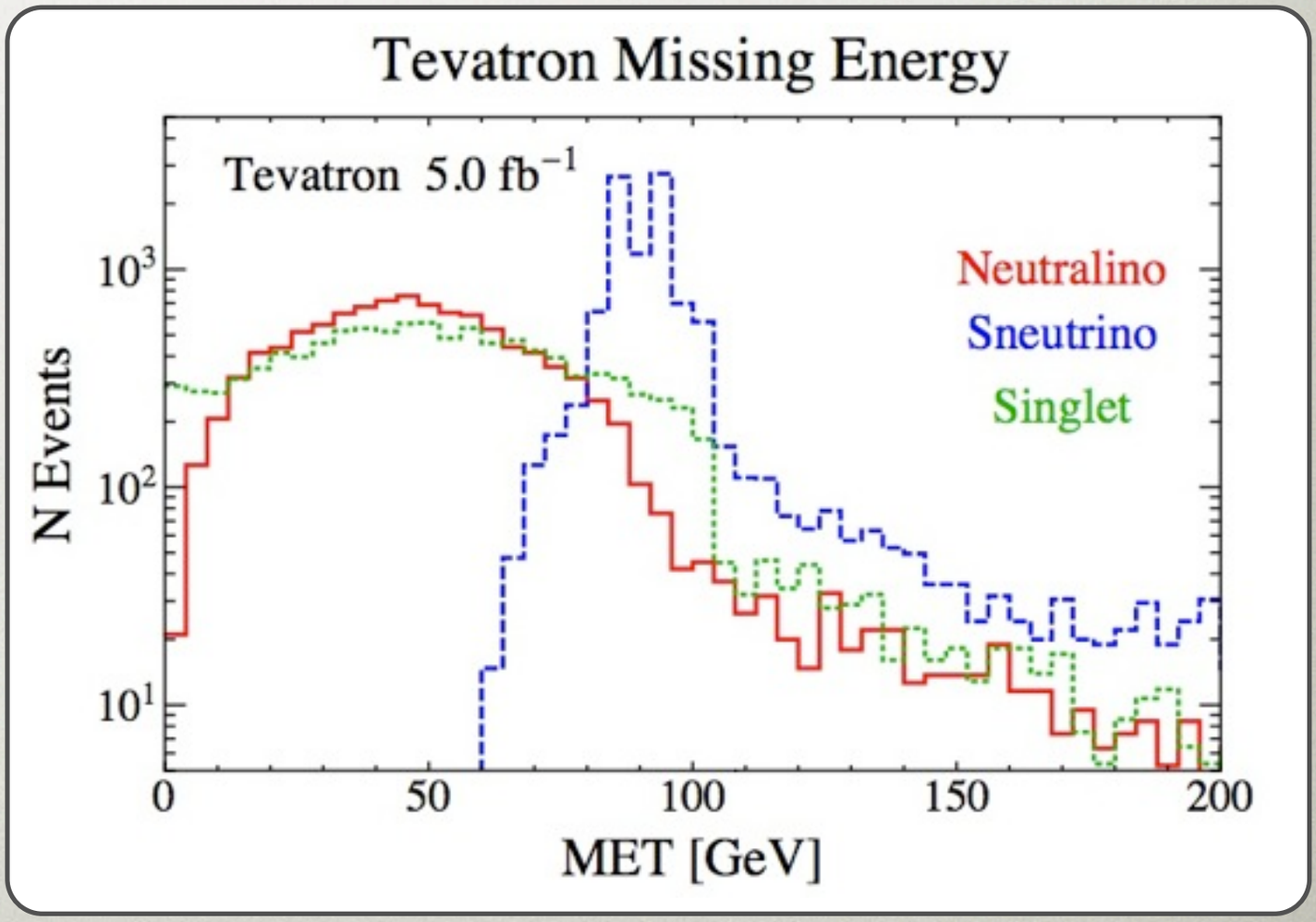

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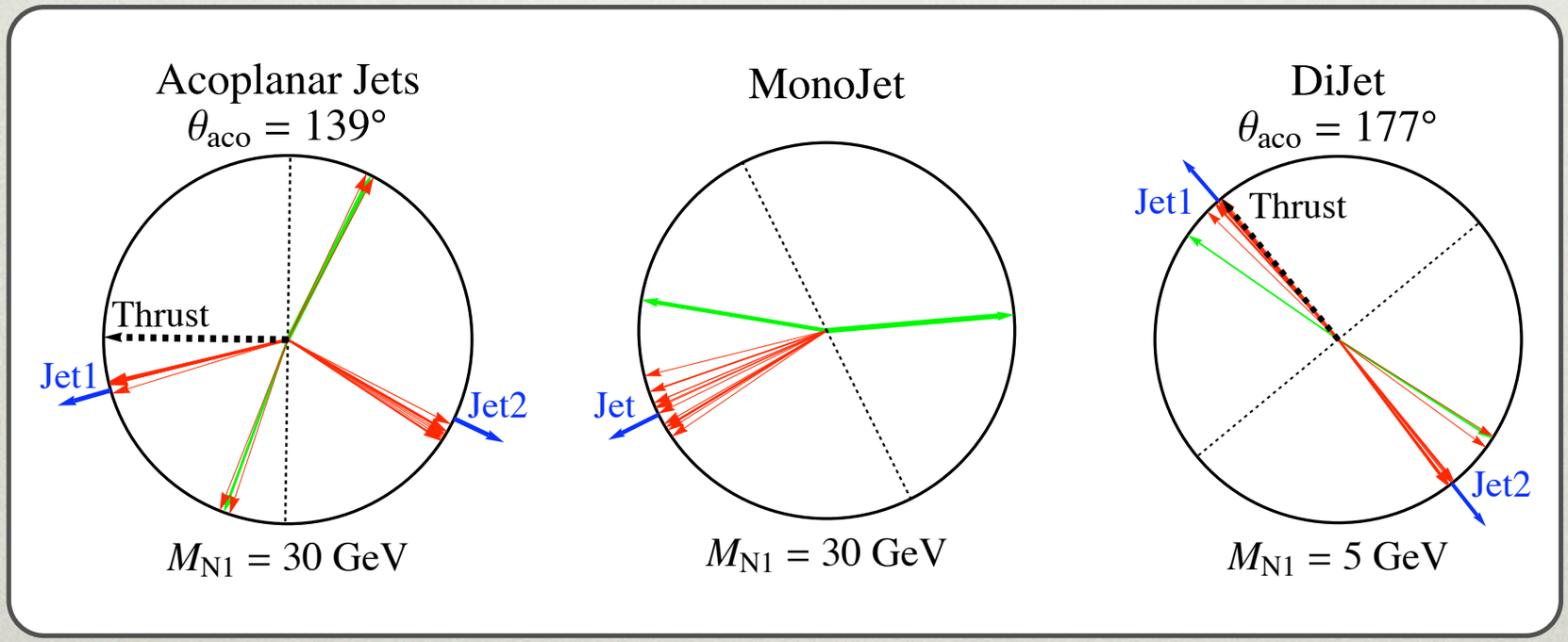

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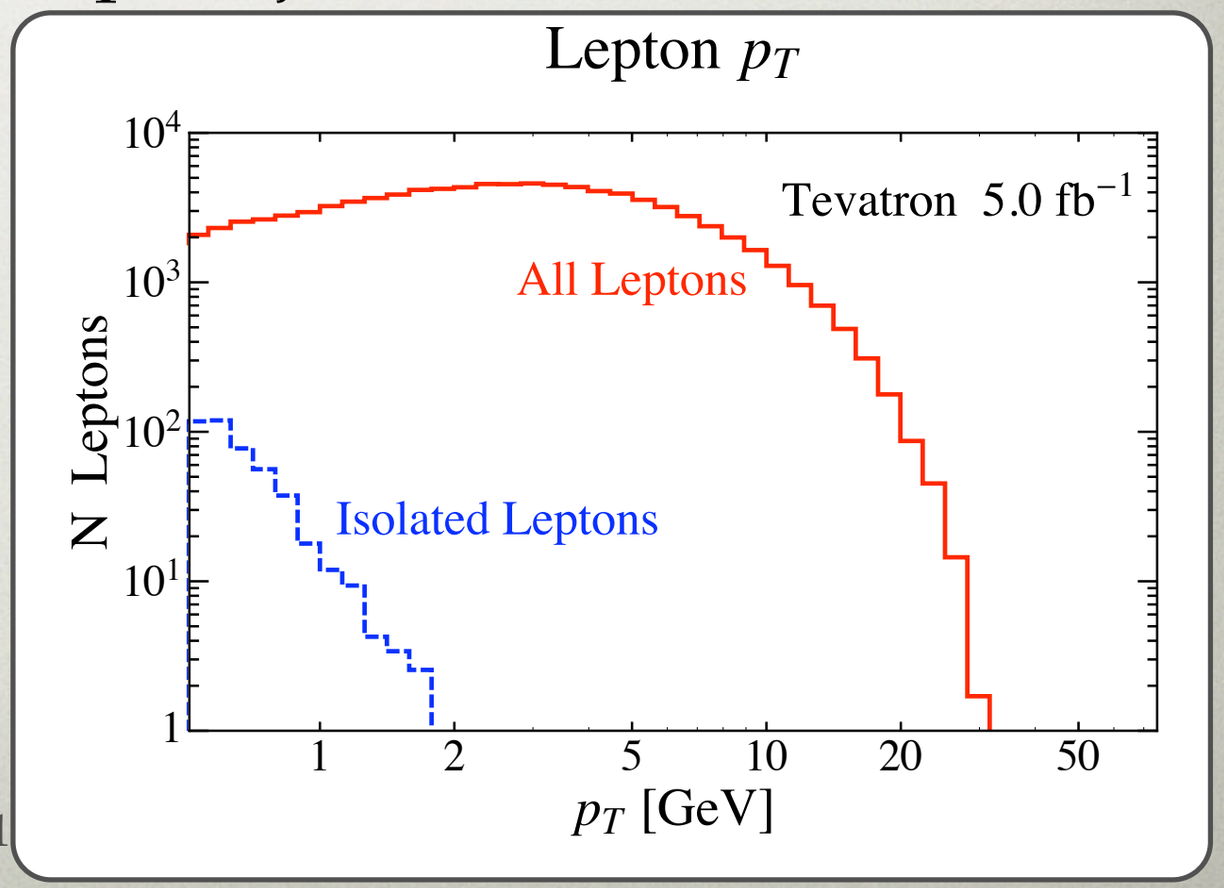
- event topology:number of lepton jets and distr.
- lepton isolation



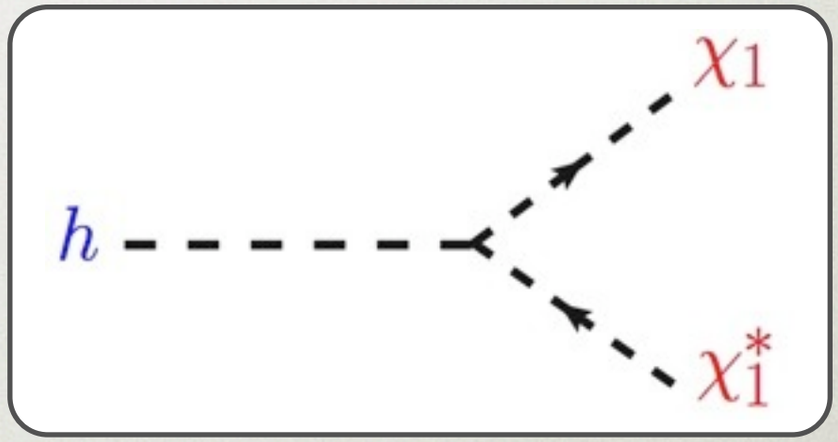
SINGLET PORTAL

- NMSSM+two chiral fields $\chi, \bar{\chi}$ with hidden $U(1)_d$ charges ± 2

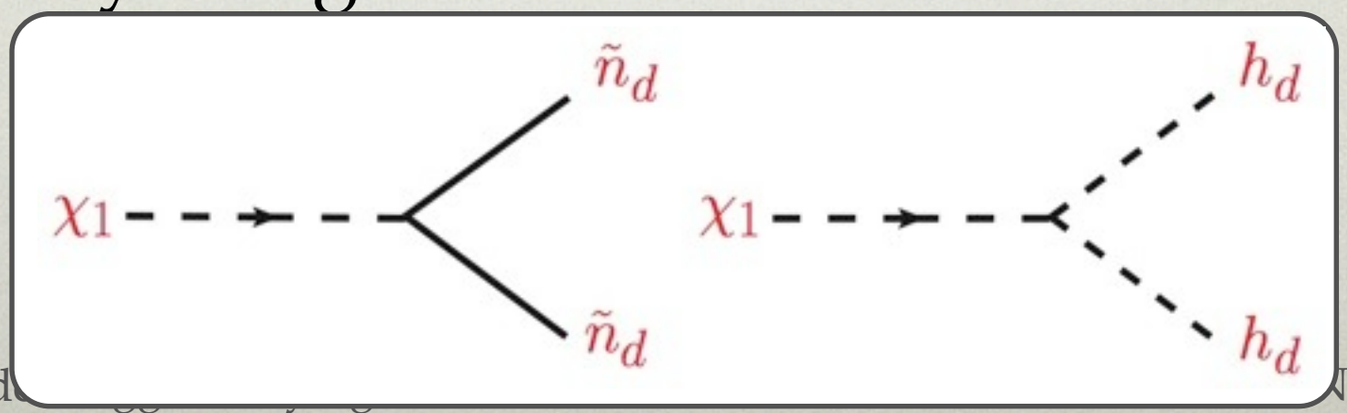
$$W \supset S H_u H_d + S \chi\bar{\chi} + \chi \bar{h}^2 + \bar{\chi} h^2$$

- $\chi, \bar{\chi}$ obtain weak scale masses from S vev
- higgs decays through F-term of a singlet

$$V \supset |F_S|^2 = |H_u H_d + \chi\bar{\chi}|^2$$



- χ's decay to lighter hidden sector states



DECAYING TO HIDDEN SECTOR

- kinetic mixing: $\epsilon b_\mu J^\mu_{EM}$
  - Br of dark photon fixed by kinematics
- we focus on scenario where
  - hidden sector naturally light ~500 MeV- few GeV
  - decays are almost exclusively leptonic

CASCADES

- *h→ many body final states* can naturally arise from
  - h→ hidden sector
  - cascade in hidden sector
  - then decay back to visible sector
- will use susy in the following
  - not necessary ingredient, framework much more general

LEPTON JETS

- *lepton jets:* high multiplicity clusters of boosted, collimated leptons
- lepton jets, if $m_{\gamma d} < 2m_{\pi}$
- mass gap between higgs and its decay products (to obtain boost)