Higgs Decaying to Lepton Jets

Nov. 2010

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UCB

Based on:

A. Falkowski, J. Ruderman, TV, J. Zupan [arXiv:1002.2952].
A. Falkowski, J. Ruderman, TV, J. Zupan [arXiv:1007.3496].

Where is the Higgs?

- The mass of the SM Higgs is constrained by LEP, $m_h \gtrsim 114.4$ GeV.
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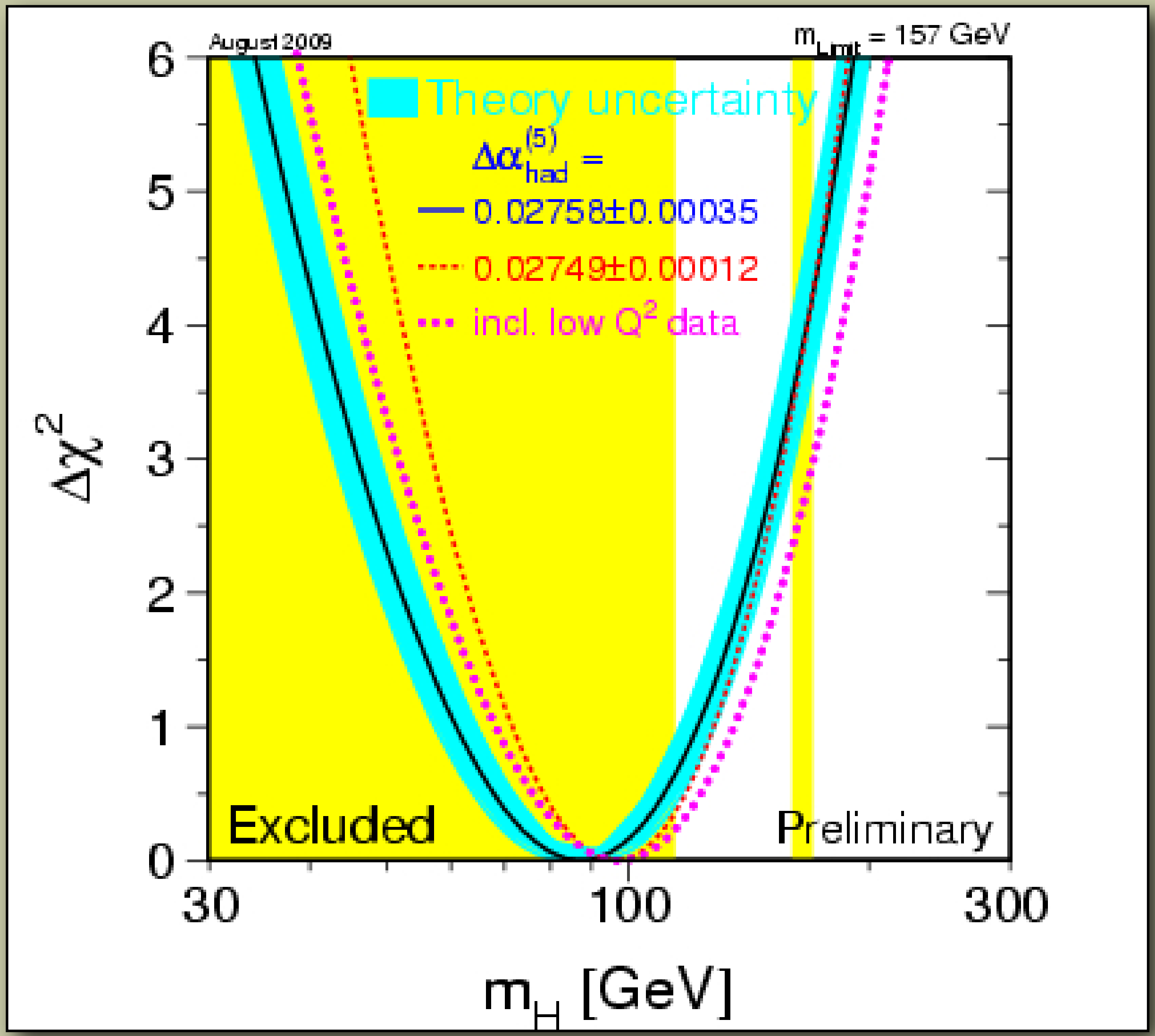

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  - Theoretical: Little hierarchy (in theories such as MSSM, $m_h \sim m_Z$).

$$\delta m_h^2 = \frac{3}{4\pi^2} y_t^2 m_t^2 \ln \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}$$

$$\delta m_{H_u}^2 = -\frac{3}{4\pi^2} y_t^2 m_{\tilde{t}}^2 \ln \frac{M}{m_{\tilde{t}}}$$

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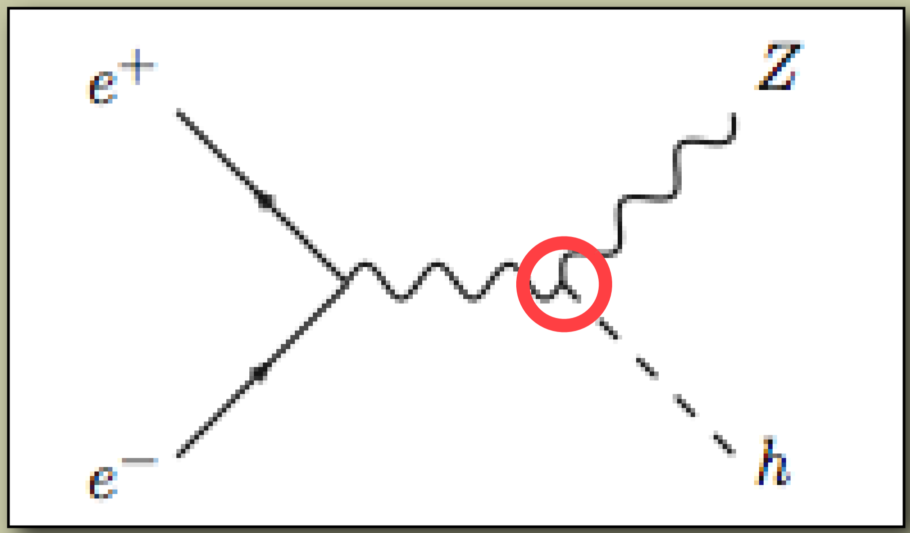
- In fact, there are good reasons to consider models where the Higgs is below this bound:
  - Experimental: Electroweak precision measurements.
  - Theoretical: Little hierarchy (in theories such as MSSM, $m_h \sim m_Z$).
  - Interesting! New ideas and phenomenology that may show up regardless of the Higgs mass.

Is the Higgs hidden?

It is possible that the Higgs is lighter than 114 GeV?

- Option I: Higgs coupling to Z boson is suppressed so it was not produced at LEP.



Is the Higgs hidden?

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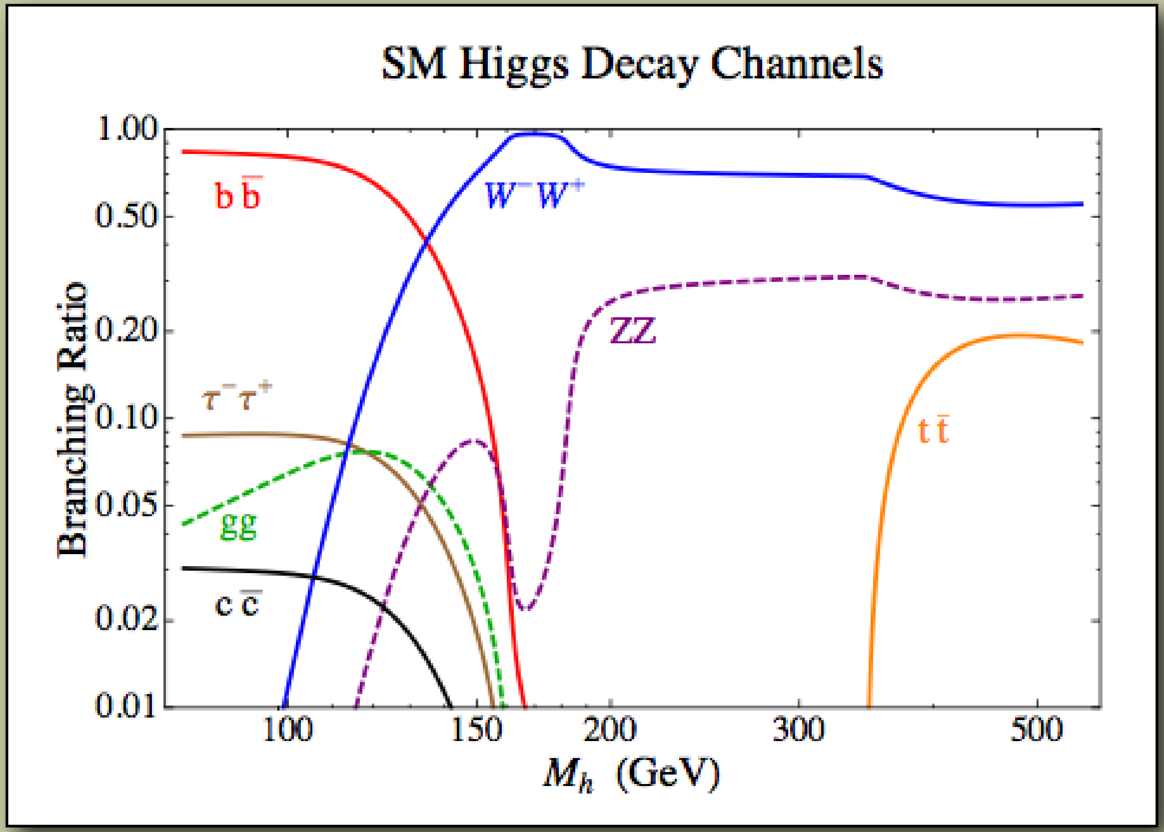
- Option I: Higgs coupling to Z boson is suppressed so it was not produced at LEP.
- Option II: The Higgs decays in a non-standard manner.

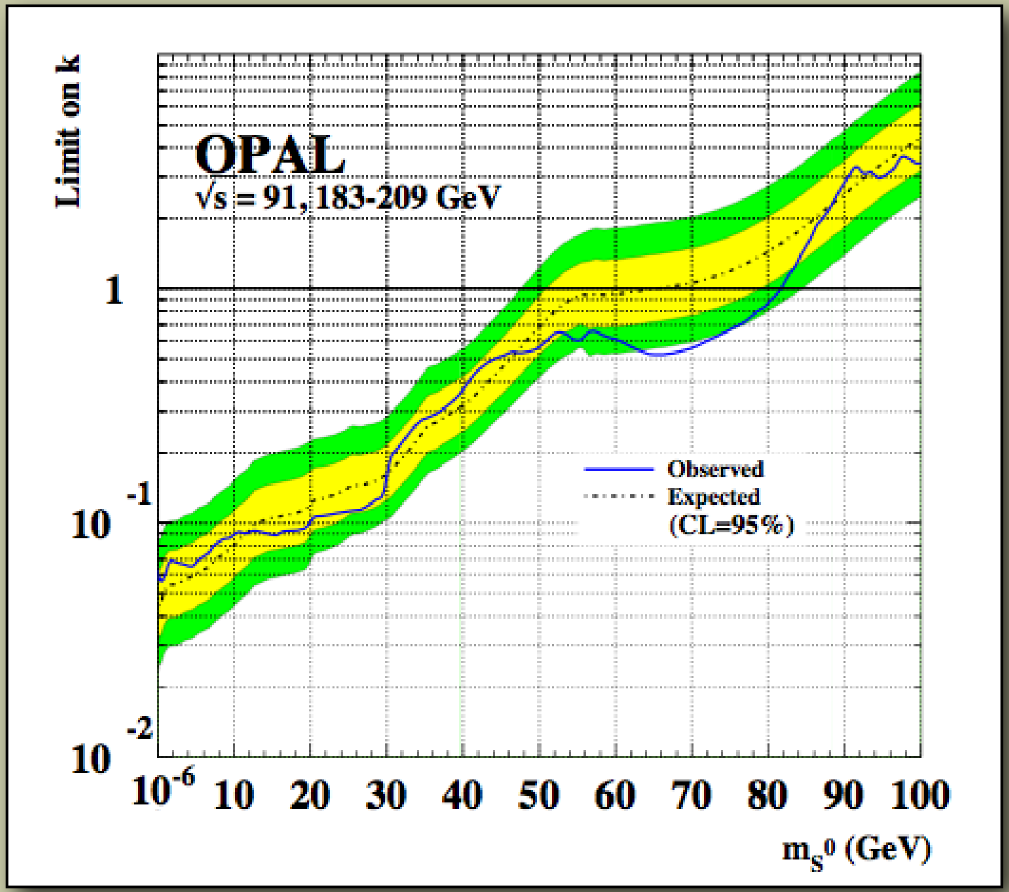


Hidden Higgs: It has been copiously produced at LEP and the Tevatron but has evaded detection due to non-standard decays.

LEP Constraints

- LEP has many searches and many model-dependent constraints.
- There are three general results to keep in mind:

  1. OPAL model independent: $m_h > 82$ GeV



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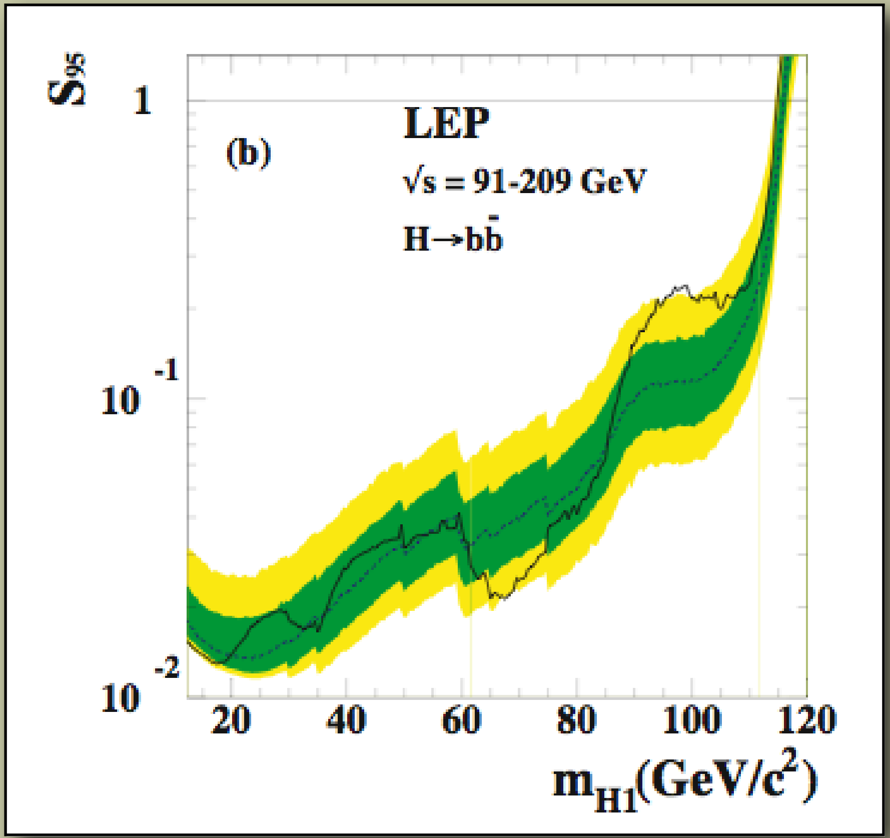

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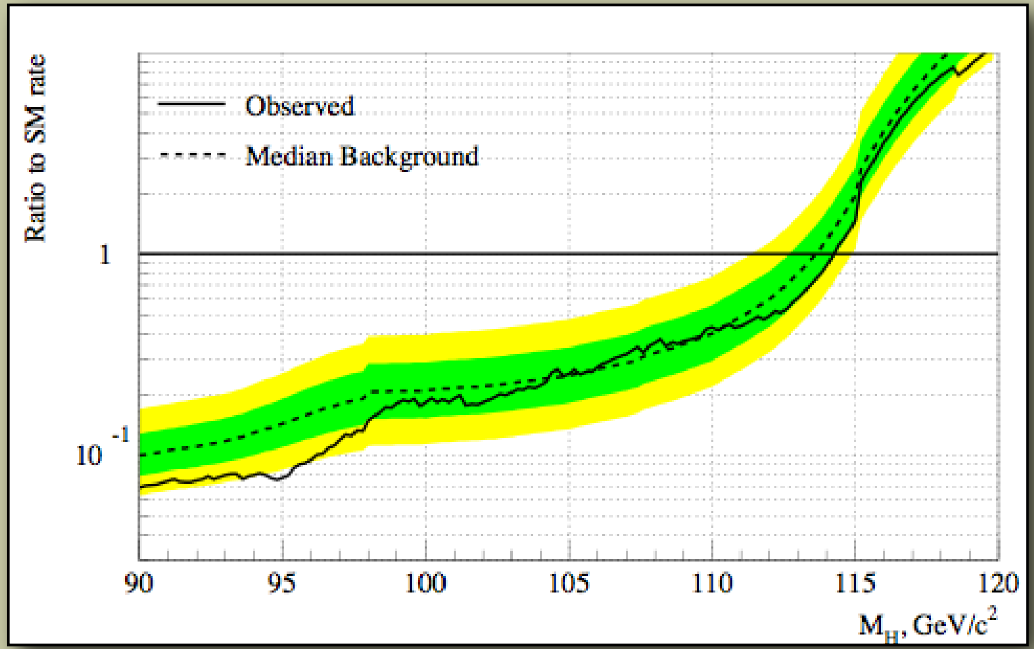
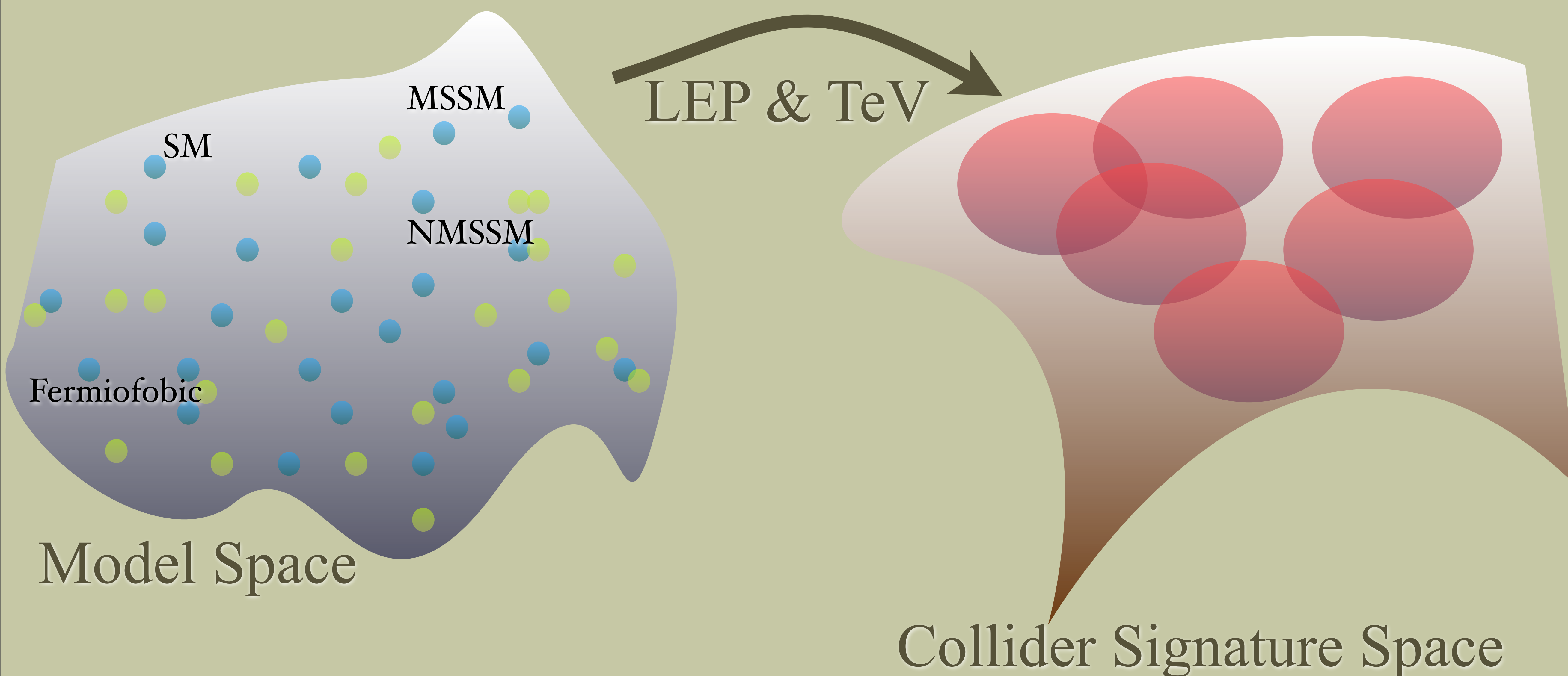
     Can be interpreted as $BR(h \to b\bar{b}) \lesssim 20\%$ for $m_h = 100$ GeV.
  3. Invisible Higgs: $m_h > 115$ GeV.
     Can be interpreted as $BR(h \to \not{E}) \leq 15\%$.



What About Other Final States?

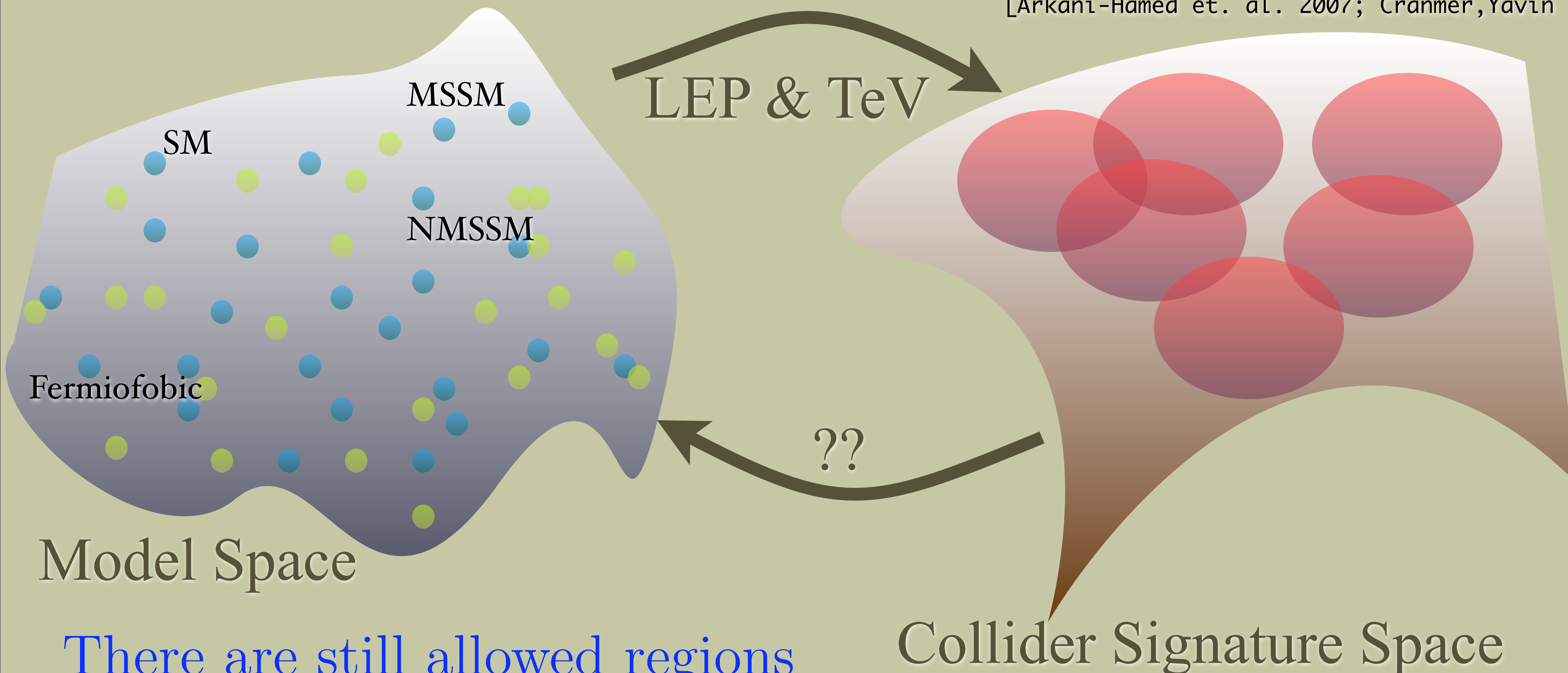
- 2-body final states are strongly constrained.
- Other final states and topologies have been searched for model-dependently.
- Even without dedicated searches, various topologies are constrained.



What About Other Final States?

- It is in many cases hard to know which model is excluded and to what extent.
- The inverse problem is tedious and hard.
- This problem will soon reappear with LHC data and should be addressed.

[Arkani-Hamed et. al. 2007; Cranmer,Yavin 2010]



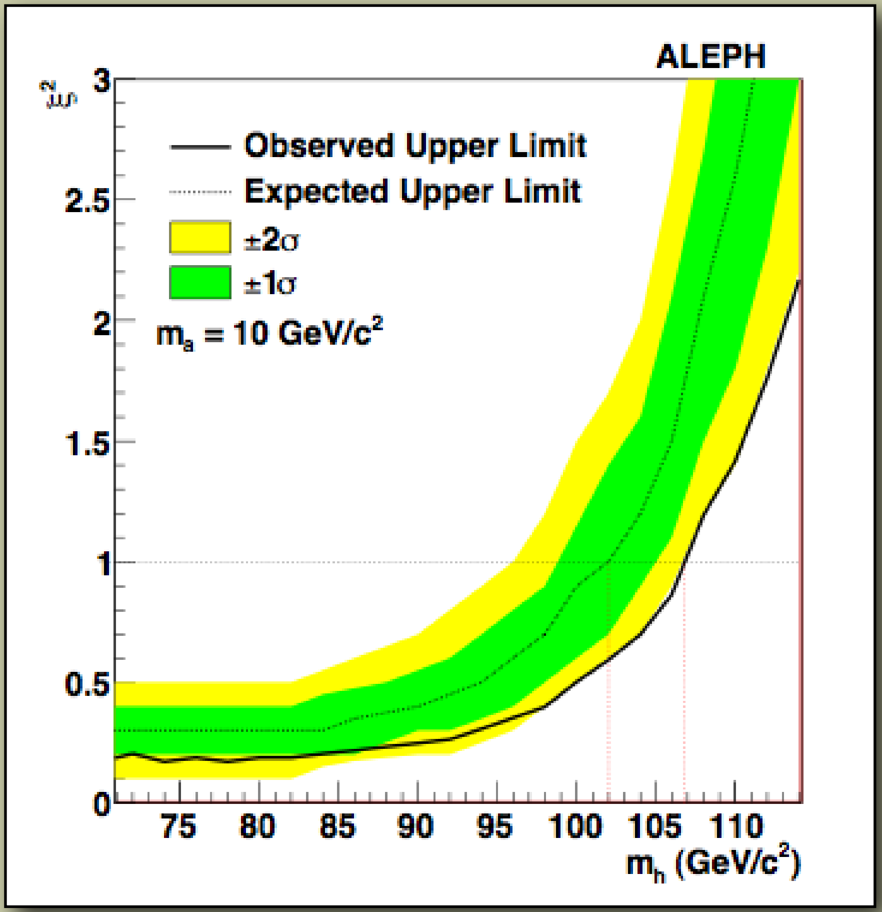
There are still allowed regions in signature space!

Hidden Higgs Scenarios

- The most studied scenario is the NMSSM with light CP-odd Higgs, $h \rightarrow AA \rightarrow 4\tau$.

  [Dermisek, Gunion 2004; Chang et al.,2006]

- Very recently ALEPH data was revisited. New limit: $m_h \gtrsim 107$ GeV



[Cranmer et al. 2010]

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- Other interesting proposals:

  – RPV MSSM: $h \rightarrow 6j$. [Carpenter, Kaplan, Rhee, 2006]

  – Buried Higgs: $h \rightarrow 4j$. [Bellazzini, Csaki, Falkowski, Weiler, 2009]

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Today we study a new possibility: $h \to$ Lepton Jets

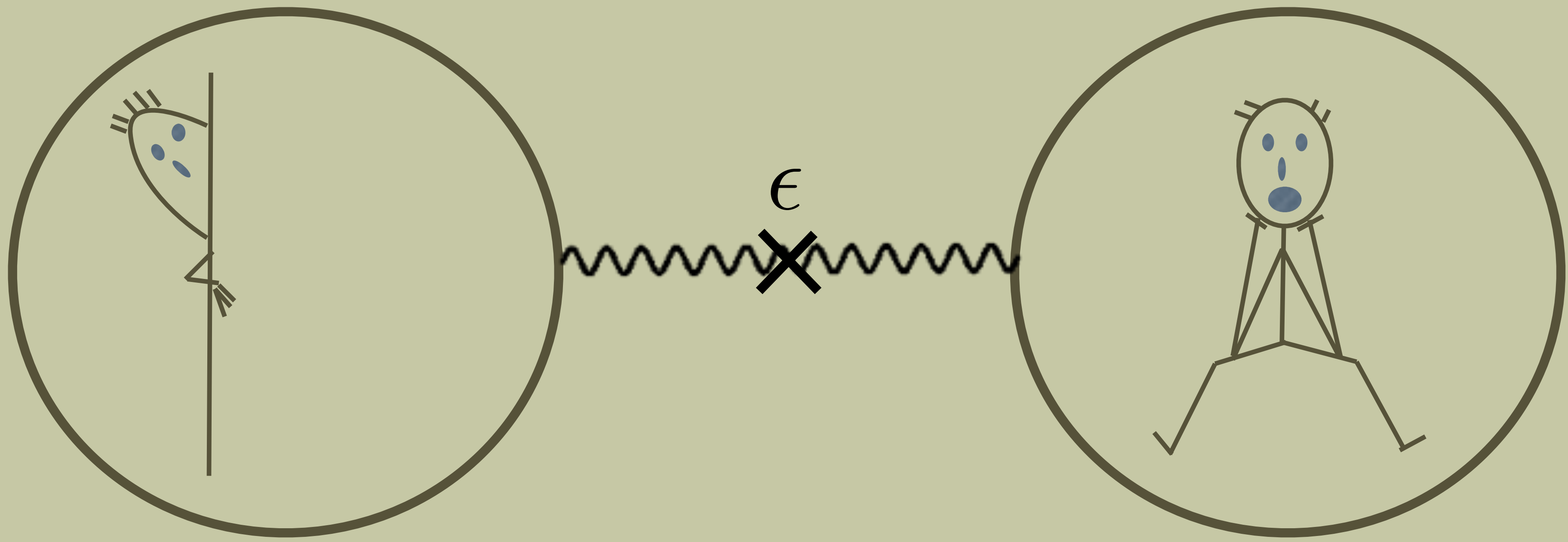
- We work in the supersymmetric framework: We consider the possibility of also hiding SUSY.

Outline

- Theory:
  - Framework: Low-Scale Hidden Sectors
  - Higgs Decay Channels
- Phenomenology:
  - Collider Signatures
  - Experimental Constraints
- Search Strategies
- Conclusions

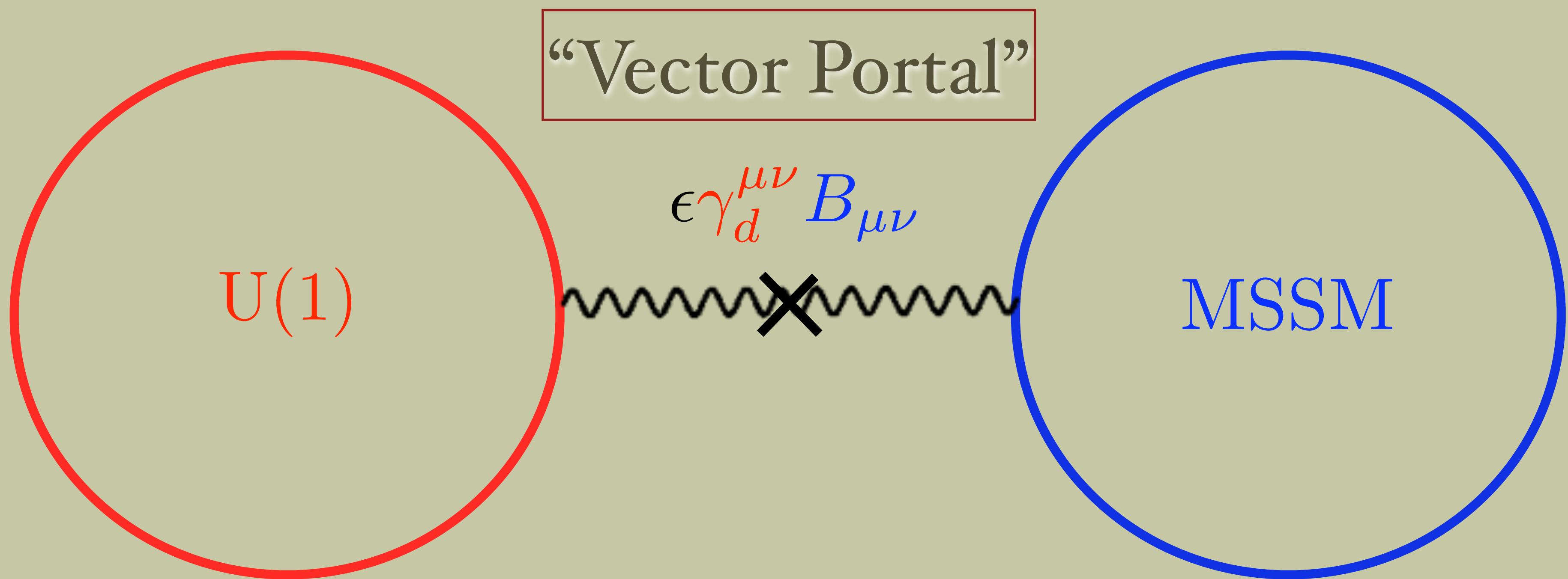
Framework:
Low Scale Hidden Sectors

A Hidden Sector



- A simple and plausible extension of the SM.
- Mixing can be naturally generated at high scale, $\epsilon \lesssim 10^{-3}$.
- Motivation:
  - String theory constructions.
  - New phenomenology (hidden valleys). [Strassler, Zurek, 2006]
  - Cosmic Ray anomalies.

A Hidden Sector



- We work in the supersymmetric framework.
- The simplest case: $U(1)'$, is already rich enough!
- Easy to generalize to other portals or gauge groups.
- the Lagrangian:

$$\mathcal{L}_{mix} = \underbrace{\frac{1}{2}\epsilon\, \gamma_d^{\mu\nu} B^{\mu\nu}}_{\text{Gauge}} \underbrace{- i\epsilon\, \tilde{\gamma}_d^\dagger \bar{\sigma}^\mu \partial_\mu \tilde{B} + i\epsilon\, \tilde{B}^\dagger \bar{\sigma}^\mu \partial_\mu \tilde{\gamma}_d}_{\text{Gaugino}}$$

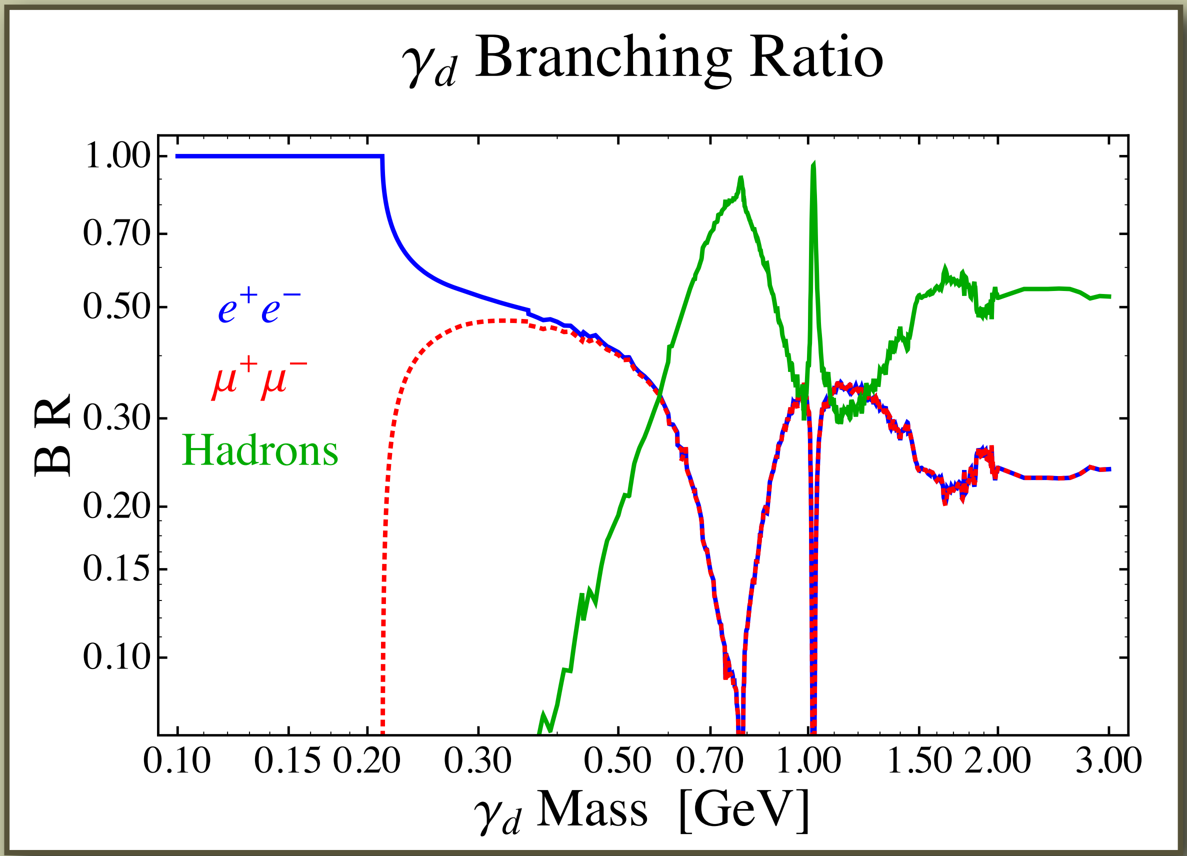
Gauge Kinetic Mixing

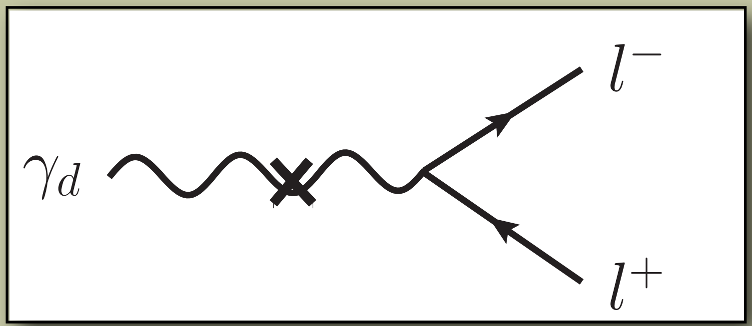
- Mixing can be removed:

$$A_\mu \to A_\mu + \epsilon \cos\theta_W \gamma_{d\mu}$$

$$A_\mu J^\mu_{\rm SM} \to A_\mu J^\mu_{\rm SM} + \epsilon \cos\theta_W \gamma_{d\mu} J^\mu_{\rm SM}$$

- Therefore the SM fields are millicharges under the new photon.
- Consequently the hidden photon can decay to kinematically available SM fermions.





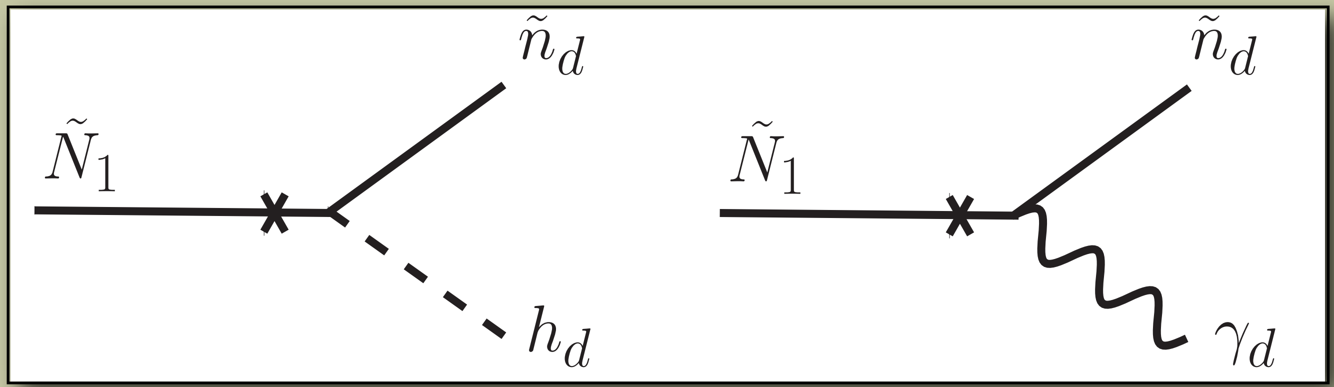
Gauge Kinetic Mixing

- Similar shift removes Gaugino mixing:

$$\tilde{\gamma}_d \to \tilde{\gamma}_d + \epsilon\,\tilde{B}$$

$$\tilde{\gamma}_d \tilde{J}_{\rm hid} \to \tilde{\gamma}_d \tilde{J}_{\rm hid} + \epsilon \tilde{B}\,\tilde{J}_{\rm hid} \qquad \tilde{J}_{\rm hid} = \sum_i q_i h_d^{i\dagger} \tilde{h}_d^i$$

- The lightest visible neutralino (LVSP) can therefore decay into the hidden sector!



- The lifetime of both the γ_d and $\tilde{N}_1$ is controlled by ϵ.
- Here we consider prompt decays ($\epsilon \sim 10^{-3-4}$). The case of displaced vertices is under study. [Graesser, Ruderman, Surujon, TV, in progress]

Hidden Particle Content

- There are (obviously) no constraints on the particle content in the hidden sector.
- Minimal content: in order to break the $U(1)'$ we minimally need two Higgs chiral superfield, $h_\pm$.
- Minimal spectrum:
  - One massive photon, γ_d.
  - Three hidden neutralinos $\tilde{n}_d^i$ (mixtures of the hidden gaugino and Higgsinos).
  - Three hidden scalars, h_d^i: h_d, H_d, A_d.
- All particles are assume to have masses of order $0.1 - 1$ GeV.

The minimal model is already rich enough to hide the Higgs!

Higgs Decay Channels

Neutralino Channel

- In principle, there is no model-independent bound on the mass of the LVSP neutralino.

- Coupling to Higgs arises from $h - \tilde{h} - \tilde{B}/\tilde{W}$:

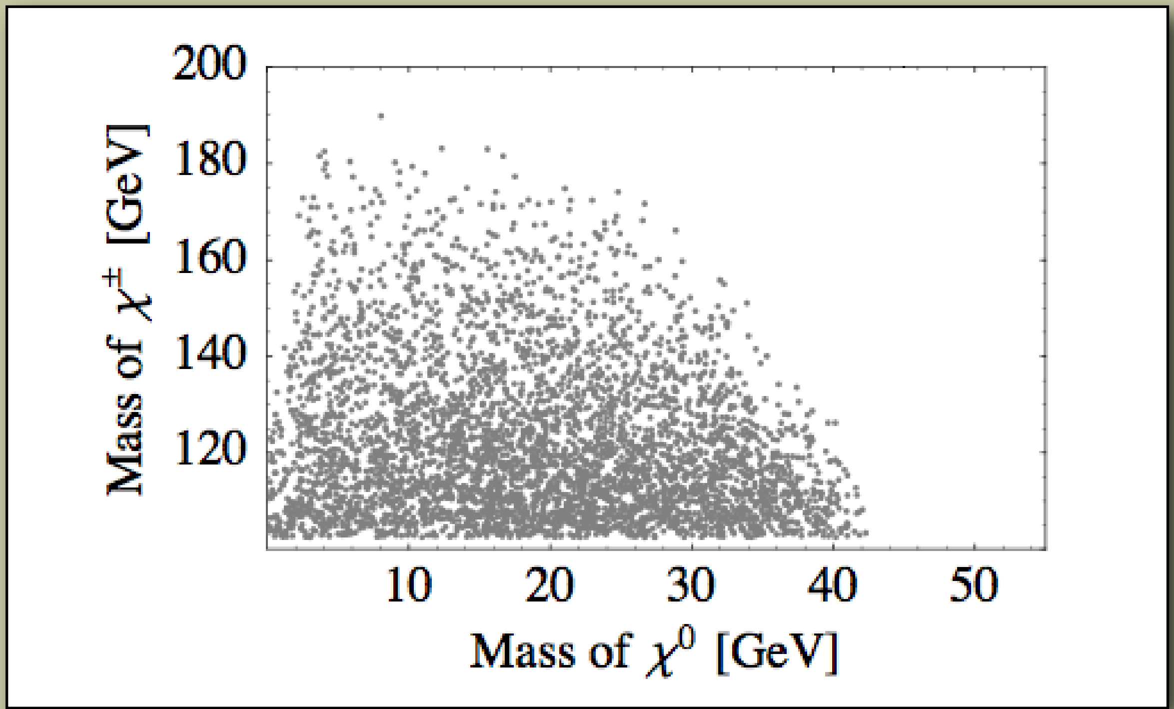
$$g_{h11} h \tilde{N}_1 \tilde{N}_1 \qquad\qquad \Gamma(h \to \tilde{N}_1 \tilde{N}_1) = \frac{g_{h11}^2 m_h}{4\pi} \left(1 - 4\frac{\tilde{m}_{N1}^2}{m_h^2}\right)^{3/2}$$

- $\tilde{N}_1$ must therefore be a mixture:

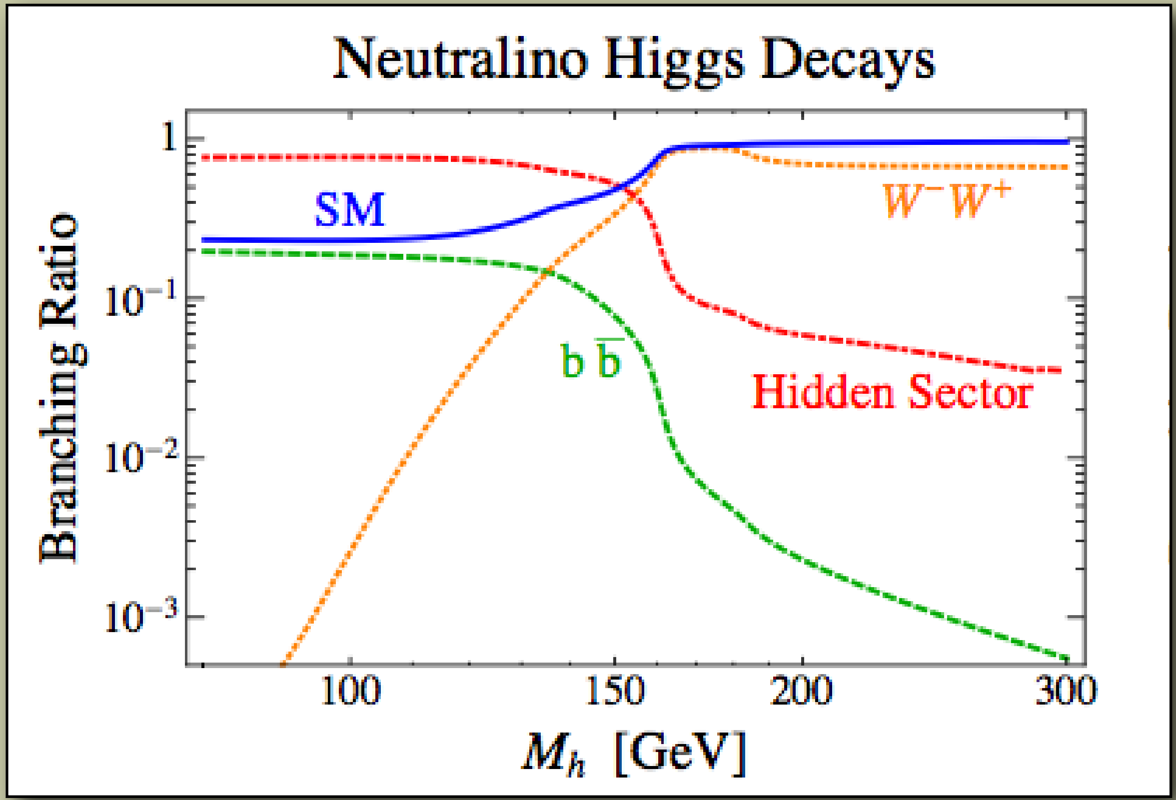
$\tilde{N}_1$

- There is therefore a possible tension with Chargino constraints.

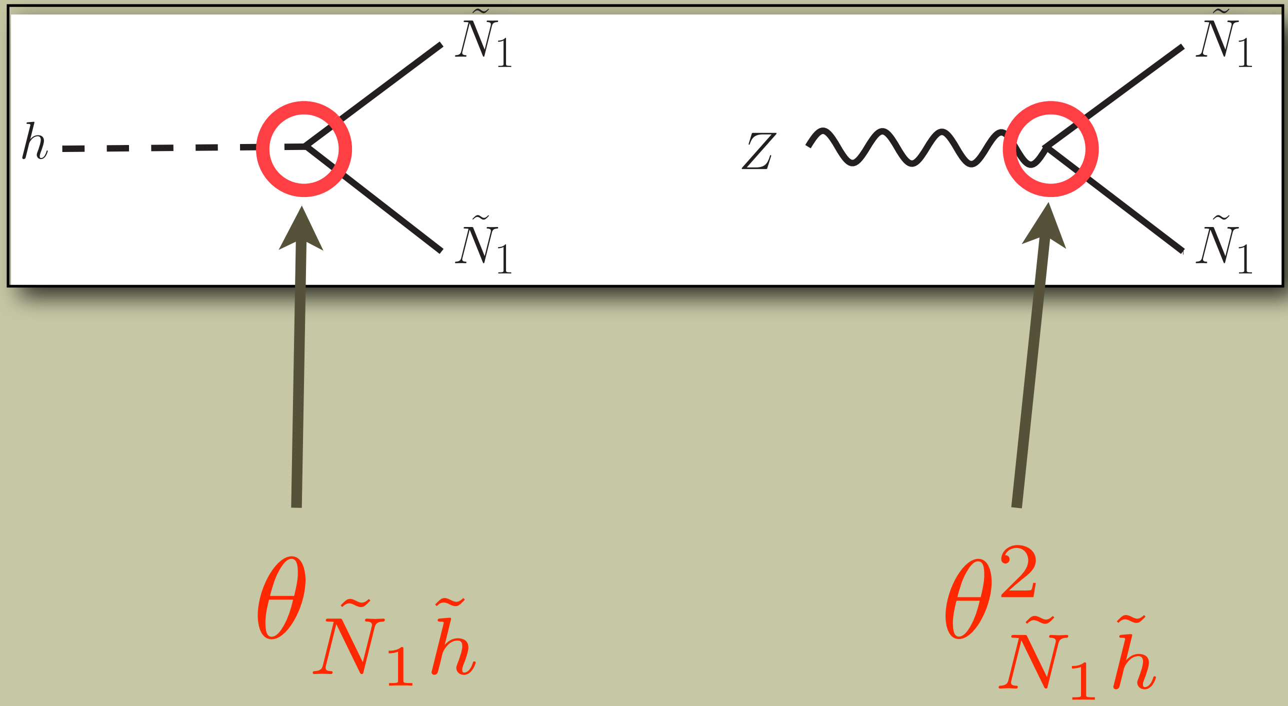
Neutralino Channel



[Carpenter, Kaplan, Rhee, 2007]



- Chargino bound can be satisfied.
- Implies Z can also decay to $\tilde{N}_1$.

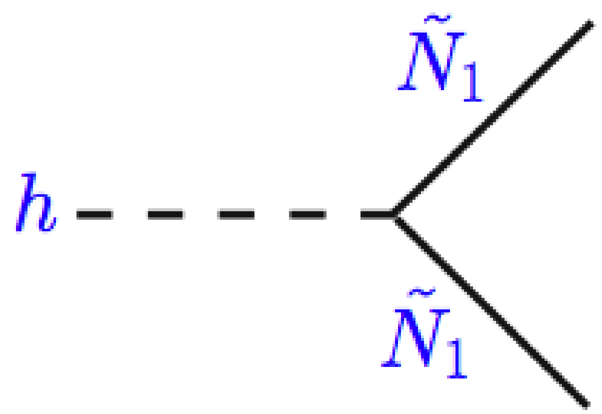


- Z-width constraint is satisfied
- Typical values to be used:

$$m_{\tilde{N}_1} \lesssim 10 \text{ GeV}$$

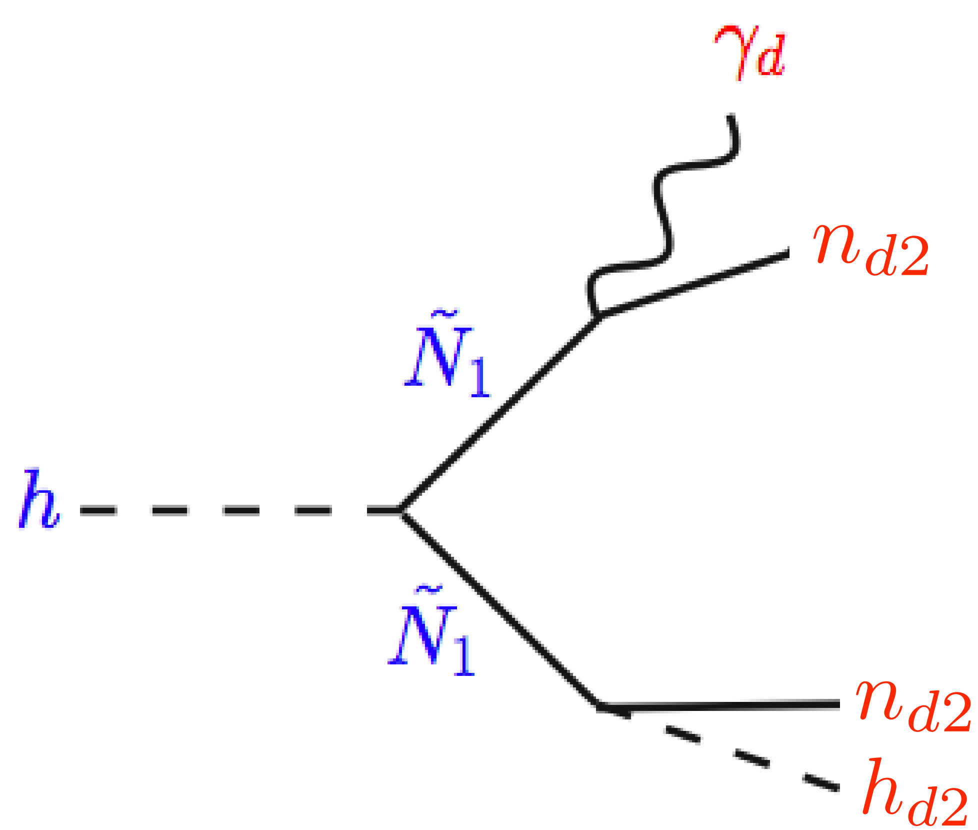
Example: Lepton Jet Topology

Higgs decays...



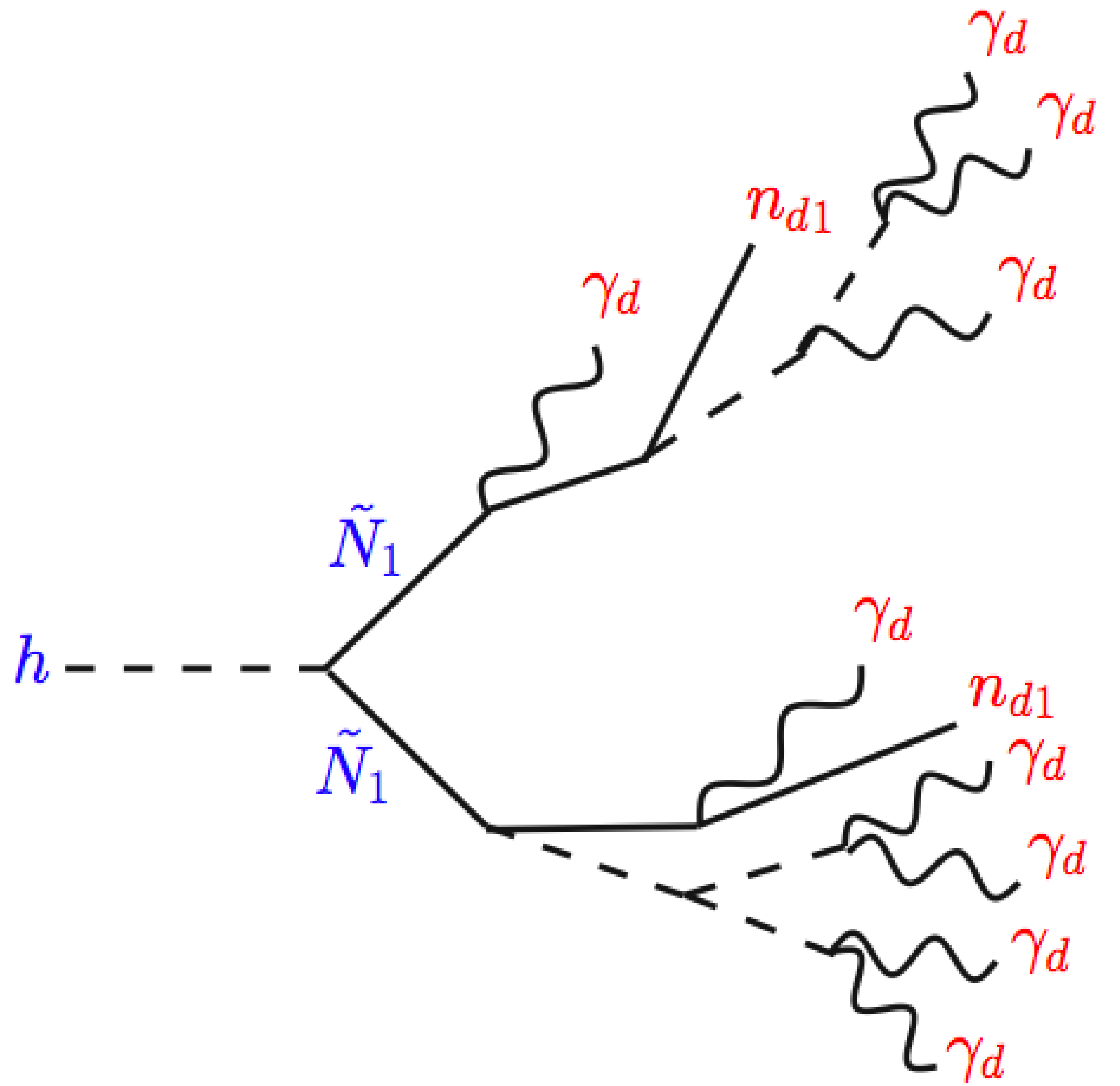
Example: Lepton Jet Topology

Into the Hidden Sector...



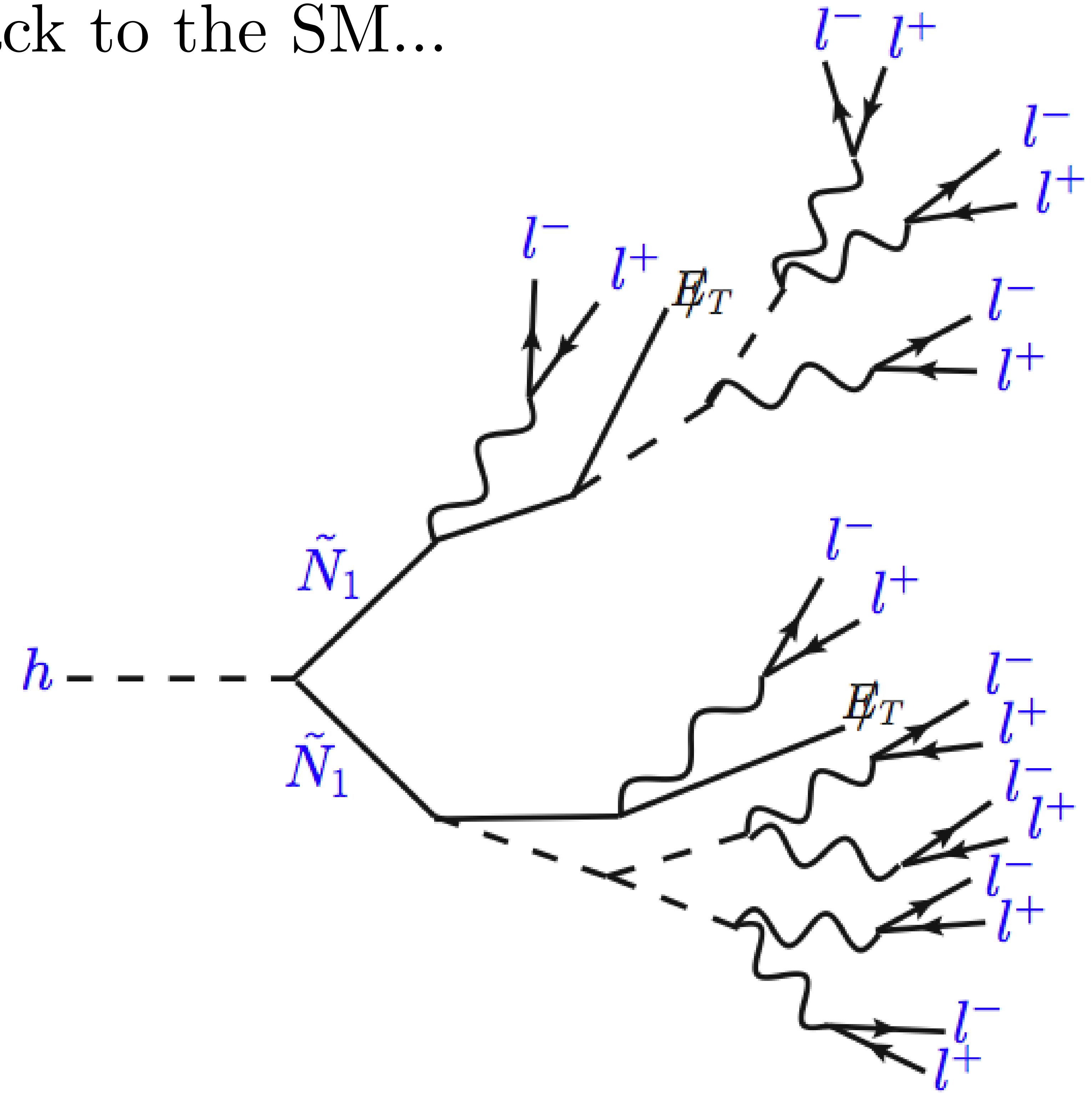
Example: Lepton Jet Topology

Hidden cascade...

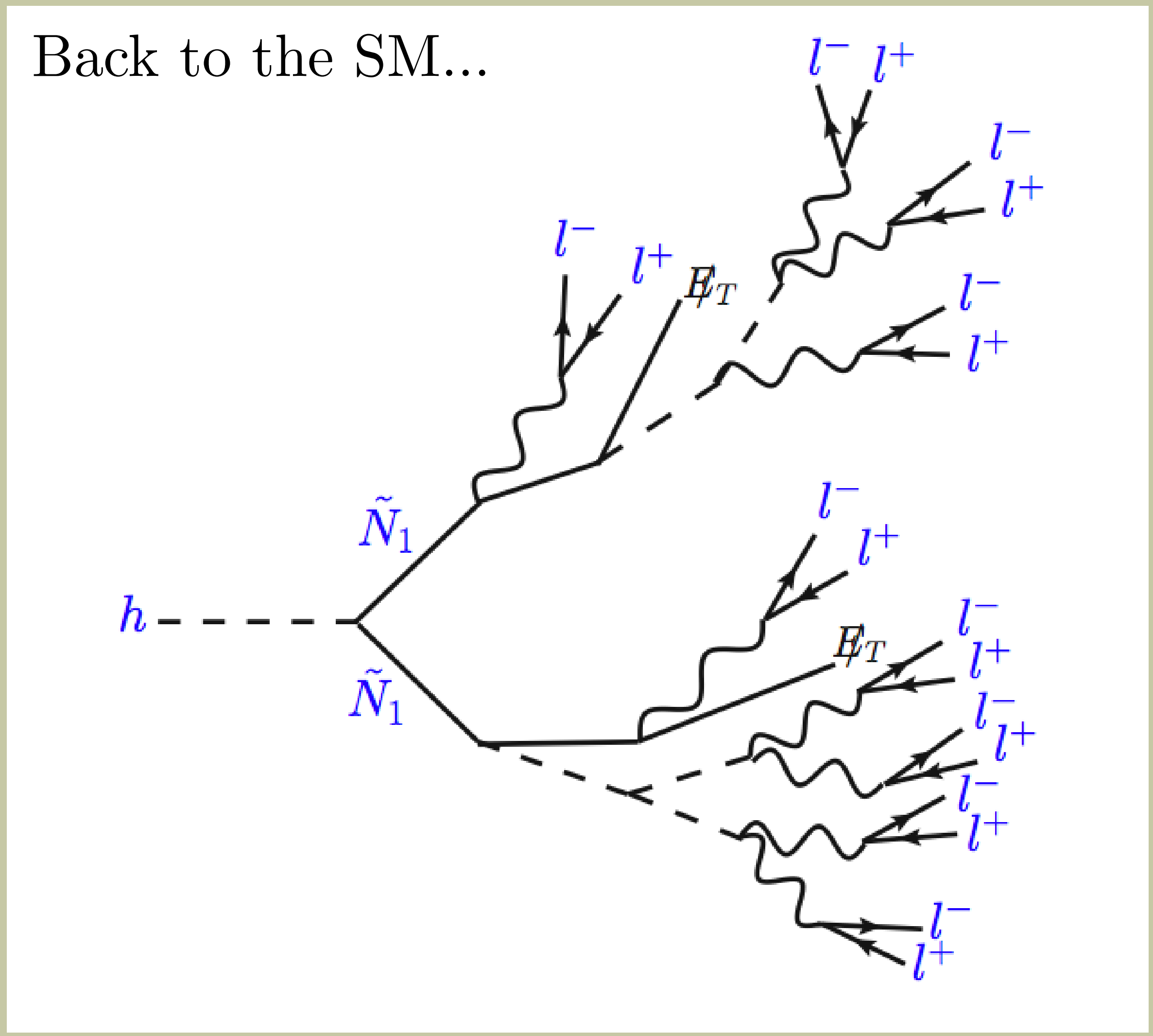


Example: Lepton Jet Topology

Back to the SM...



Example: Lepton Jet Topology



The final states are high-multiplicity clusters of boosted and collimated leptons:

Lepton Jets

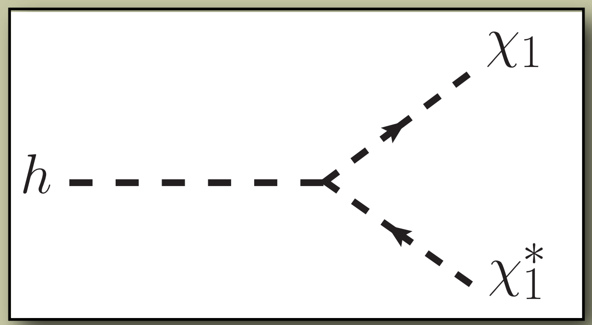
[Arkani-Hamed, Weiner; Cheung, et al.; , Baumgart, et al.]

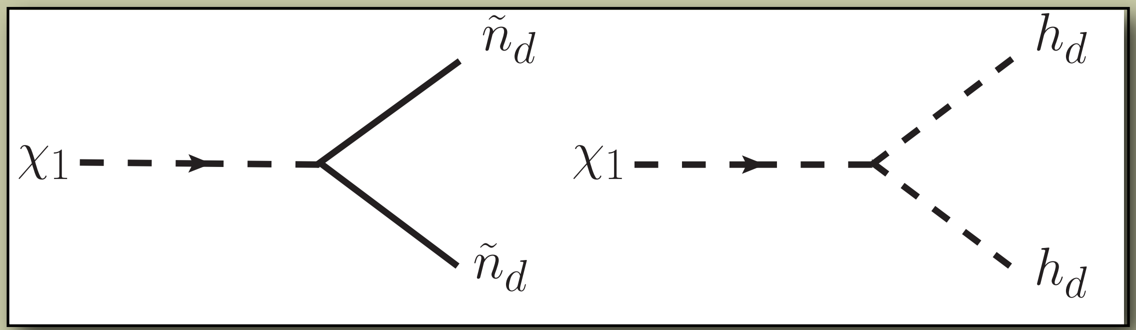
Singlet Channel

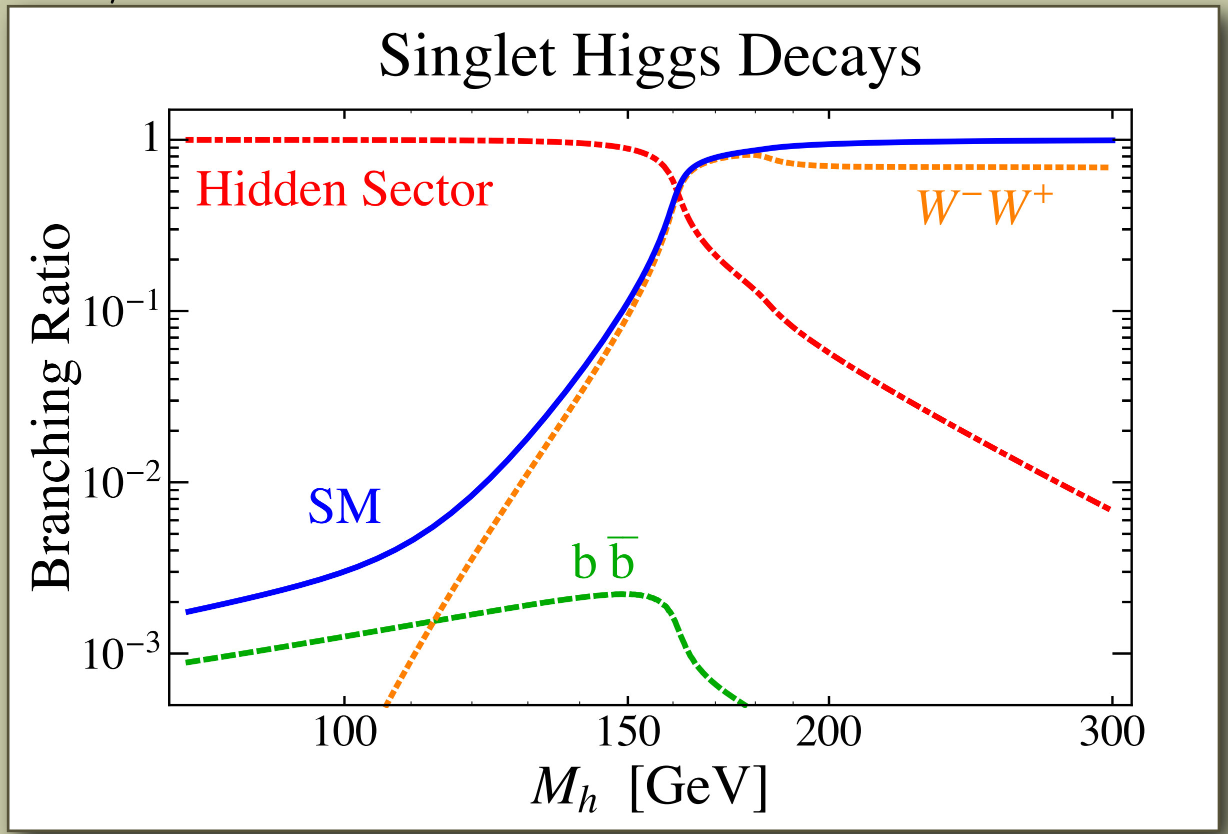
- Distinct decay modes occur through coupling to singlets. For example:

$$W_{\rm singlet} = S\,(y\,\chi\,\bar{\chi} + \lambda\,H_u H_d) + \kappa_1\,\bar{\chi}\,h_1^2 + \kappa_2\,\chi\,h_2^2\,.$$

- This is a simple extension of the NMSSM.
- Couplings allow the Higgs to decay to χ with $\mathcal{O}(1)$ BR, independently of the NMSSM spectrum.
- χ subsequently cascades in the hidden sector.
- Final states of Higgs decays are leptons + $\not{E}_T$.



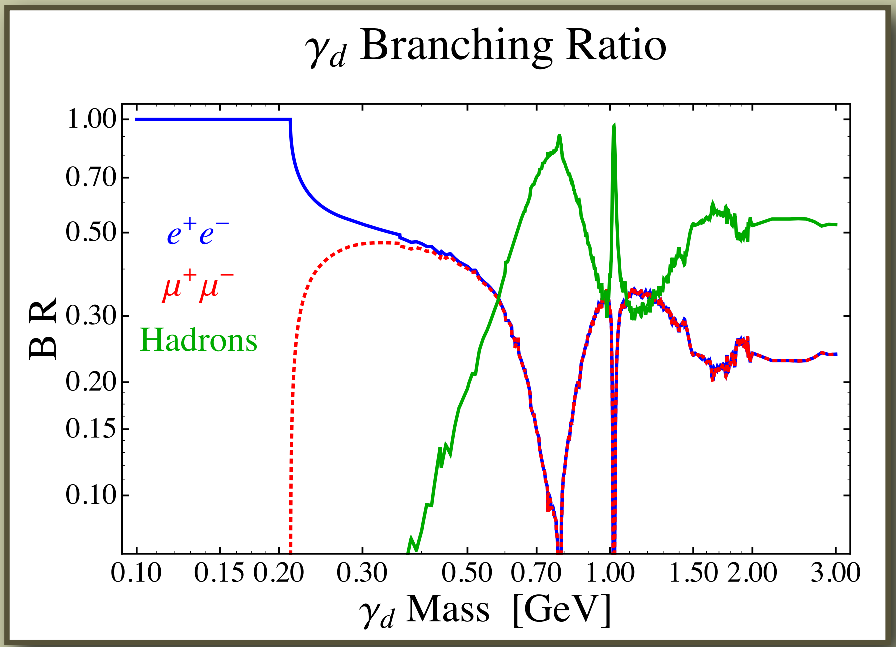




Constraining Collider Signatures

Collider Signatures

- The complete "inverse problem" of mapping the viable region in observable space is hard.
- Here we study a region which is expected to be relatively unconstrained (with no dedicated searches): lepton jets.
- We identify the following observables relevant for LEP and Tevatron searches:
  - Visible Final States: Electrons vs. Muons
    - The mass of the hidden photon is the only parameter.
    - Branching fractions are controlled by m_{γ_d}



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  - Visible Final States: Electrons vs. Muons
  - Lepton Multiplicity
    - Extremely sensitive to he hidden spectrum.
    - Since $\tilde{B} \to \tilde{h}_i h_i$, the mass of the hidden higginos control length of the cascade.
    - Spectrum of hidden Higgses also matter.
    - Non-abelian gauge group and showering in hidden sector can increase multiplicity.
    - Multiplicity can range from $0 - \mathcal{O}(100)$

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- We identify the following observables relevant for LEP and Tevatron searches:
  - Visible Final States: Electrons vs. Muons
  - Lepton Multiplicity
  - Missing Energy
    - Very sensitive to hidden spectrum.
    - Can have many hidden collider-stable particles.

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  - Missing Energy
  - Event Topology
    - Characterized by number of lepton jets.
    - Depends on the spectrum and first steps of the cascade.

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  - Lepton Multiplicity
  - Missing Energy
  - Event Topology
  - Lepton Isolation
  - Jet Shape
  - Displaced Vertices

Methodology

- To study our signal $h \to$ Lepton Jets and identify the viable regions in signature space, we simulate benchmark models:
  - Higgs production and decay using `Madgraph`.
  - Hidden sector cascade using `BRIDGE`.
  - Event analysis using our own Mathematica package, `Slowjet`.
- No hidden sector showering is taken into account.
- No detector simulation.
- A more comprehensive study must be made with experimentalists using full detector simulation. Without it lepton id and nearby tracks reconstruction may be wrong.

LEP

LEP-1

- Roughly 2×10^7 Z bosons were produced at LEP-1. Thus as many as 10^4 neutralinos and lepton jets may have been produced.
- This is in contrast to the direct coupling of the Z to the hidden sector, which is suppressed by ϵ.
- LEP-1 is therefore a great place to look for a signal and to constrain the Lepton Jet scenario.

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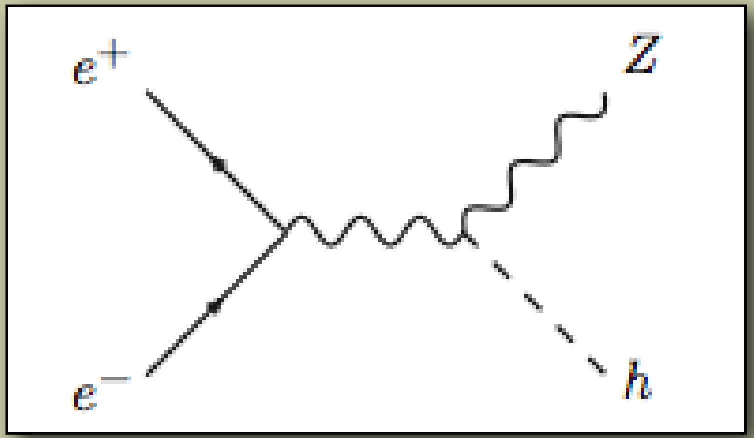
LEP-2

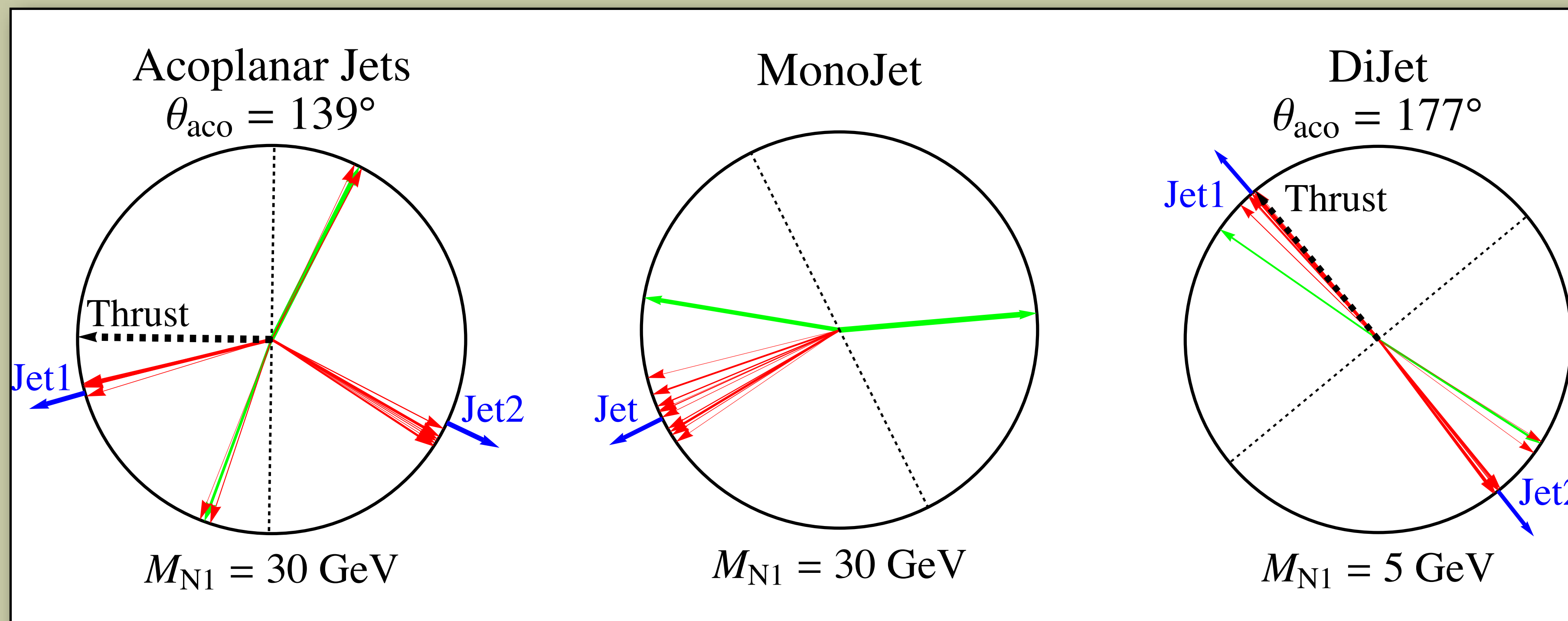


- The Higgs is produced through Higgstrahlung.
- LEP-2 collected $\sim 700\ \text{pb}^{-1}$ at $\sqrt{s} = 183 - 209$ GeV per experiment.
- For a 100 GeV Higgs, the production cross-sction is $\sim 0.3 - 0.4$ pb.
- Thus $\sim$ 130 Higgs events would have been produced at LEP-2. This is enough to place stringent constraints on Higgs physics.

LEP-1: Monojets and Acoplanar Jets

- LEP-1 searched for $e^+e^- \to (H \to \text{jets})(Z^* \to \nu\bar{\nu})$ by looking for Acoplanar jets and Monojets.

$$T = \max_n \frac{\sum_i |\mathbf{p_i} \cdot \mathbf{n}|}{\sum_i |\mathbf{p_i}|}$$

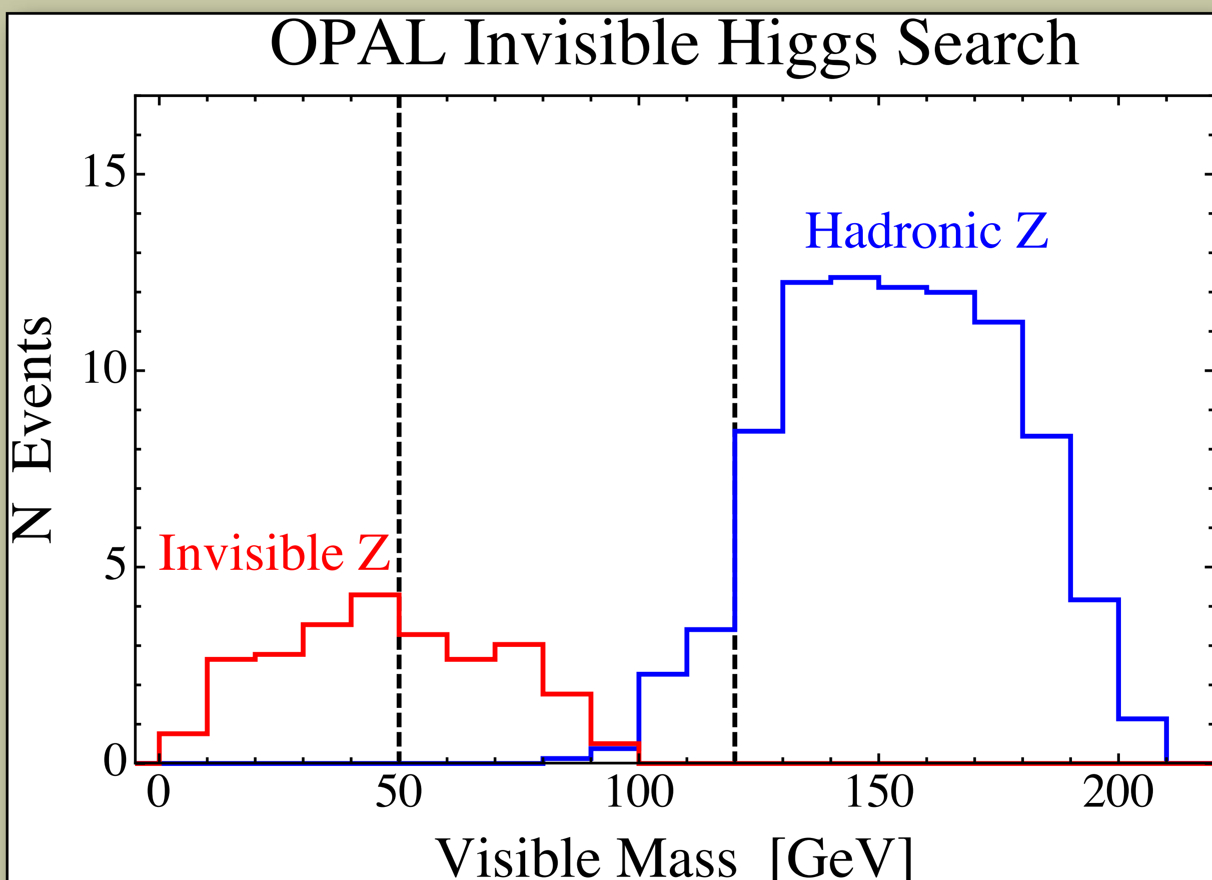


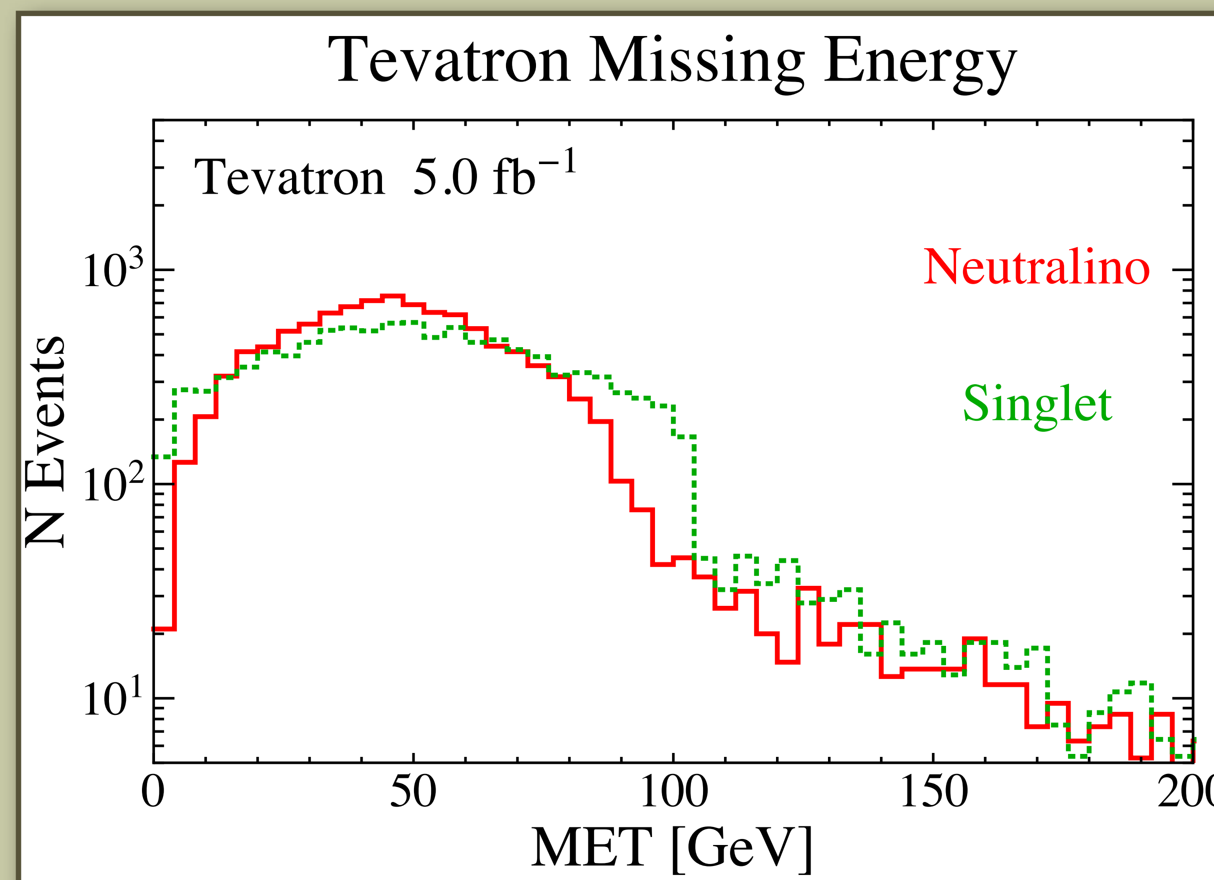
- As a consequence, $BR(Z \to\neq 2 \text{ jets}) \lesssim 10^{-6}$
- Therefore:
  - $BR(\tilde{N}_1 \to \text{Invisible}) \lesssim 10^{-3}$
  - 2-jet topology is obtained with $m_{\tilde{N}_1} \ll m_Z/2$.

2-jet topology and large multiplicity is required

LEP-2: Invisible Higgs

- Searches for Zh with $h \to \not{E}$ have been performed by all collaborations.
- OPAL search is most dangerous due to large Z window: 50 GeV $< M_{\rm vis} <$ 120 GeV.
- Therefore events with 50 GeV $< m_h <$ 120 GeV where ($h \to$ visible) and ($Z \to \nu\bar{\nu}$) are caught.





Higgs must decay to some but not too much $\not{E}$

LEP-2: Higgs to WW*

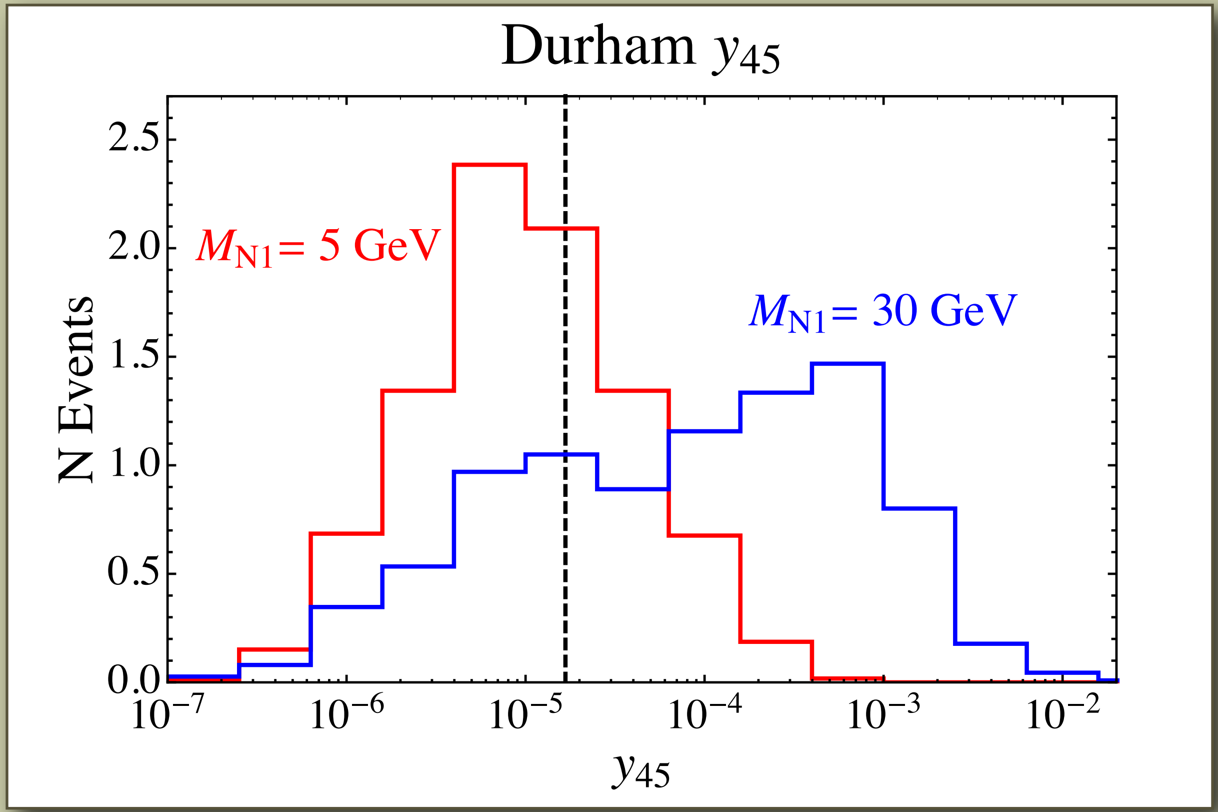
- ALEPH searched for $h \to WW^*$ in the context of fermiophobic Higgs models.
- W decays to leptons and missing energy makes this search relevant
- In fact, this search is dangerous to most models: includes many topologies.
- Most relevant topology, $ZWW^* \to l^+l^-l\nu q\bar{q}$: **2 hard leptons + softer lepton + $\geq$ 2 tracks.**
- Very low SM background.
- Sensitive to lepton jets + leptonic Z.

Class and topology	Targeted Channel	(BR)
1: Fully-Hadronic	**No leptonic decay**	**(0.422)**
1a: 6 jets	$q\bar{q}\,q\bar{q}\,q\bar{q}$	(0.328)
1b: 4 jets and E_{miss}	$\nu\bar{\nu}\,q\bar{q}\,q\bar{q}$	(0.094)
2: Two-Hard-Leptons	**Z leptonic decays**	**(0.054)**
2a: plus jets	$\ell^+\ell^-\,q\bar{q}\,q\bar{q}$	(0.032)
2t: plus jets and E_{miss}	$\ell^+\ell^-\,\tau\nu\,q\bar{q}$	(0.003)
2b: plus jets and 1 soft lepton	$\ell^+\ell^-\,q\bar{q}\,\ell\nu$	(0.010)
2c: plus jets and 1 hard lepton	$\ell^+\ell^-\,\ell\nu\,q\bar{q}$	(0.007)
2d: plus 1 hard lepton and 1 track	$\ell^+\ell^-\,\ell\nu\,\ell\nu$	(0.003)
3: One-Hard-Lepton (and E_{miss})	**W leptonic decays**	**(0.171)**
3a: plus jets	$q\bar{q}\,\ell\nu\,q\bar{q}$	(0.101)
3b: plus jets and 1 soft lepton	$q\bar{q}\,\ell\nu\,\ell\nu$	(0.031)
3c: plus 1 track and M_{miss}	$\nu\bar{\nu}\,\ell\nu\,\ell\nu$	(0.029)
3d: plus jets and M_{miss}	$\nu\bar{\nu}\,\ell\nu\,q\bar{q}$	(0.008)
4: One-Soft-Lepton	**W* leptonic decays**	**(0.130)**
4a: plus jets	$q\bar{q}\,q\bar{q}\,\ell\nu$	(0.101)
4b: plus jets and M_{miss}	$\nu\bar{\nu}\,q\bar{q}\,\ell\nu$	(0.029)

LEP-2: Higgs to WW*

- To reduce WW background they select events with at least 5 well separated objects.
- Using Durham, they take $y_{45} > 2 \times 10^{-5}$,

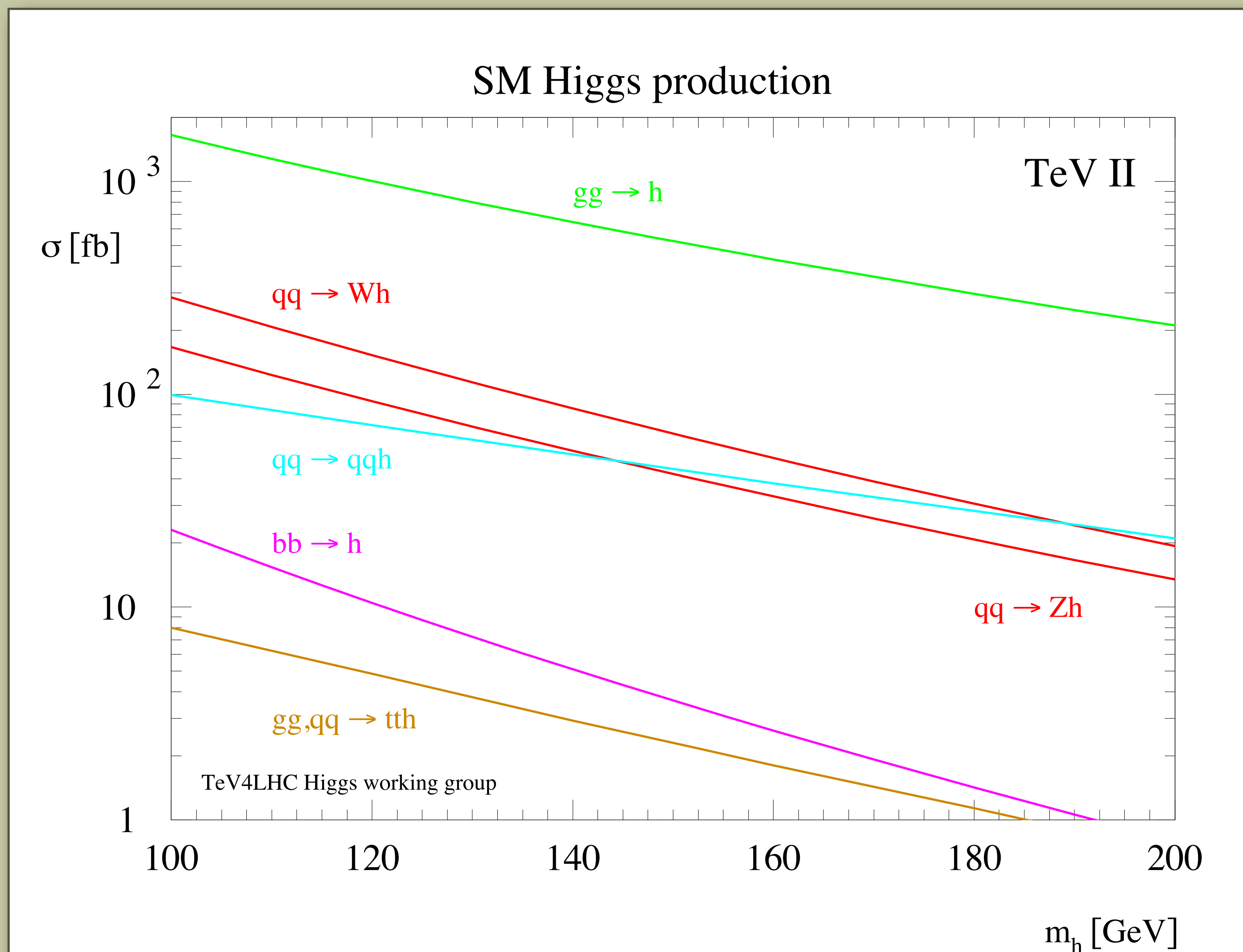
$$y_{ij} = \frac{2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{E_{\text{vis}}^2}$$



Signal must therefore be of 2-jet topology.

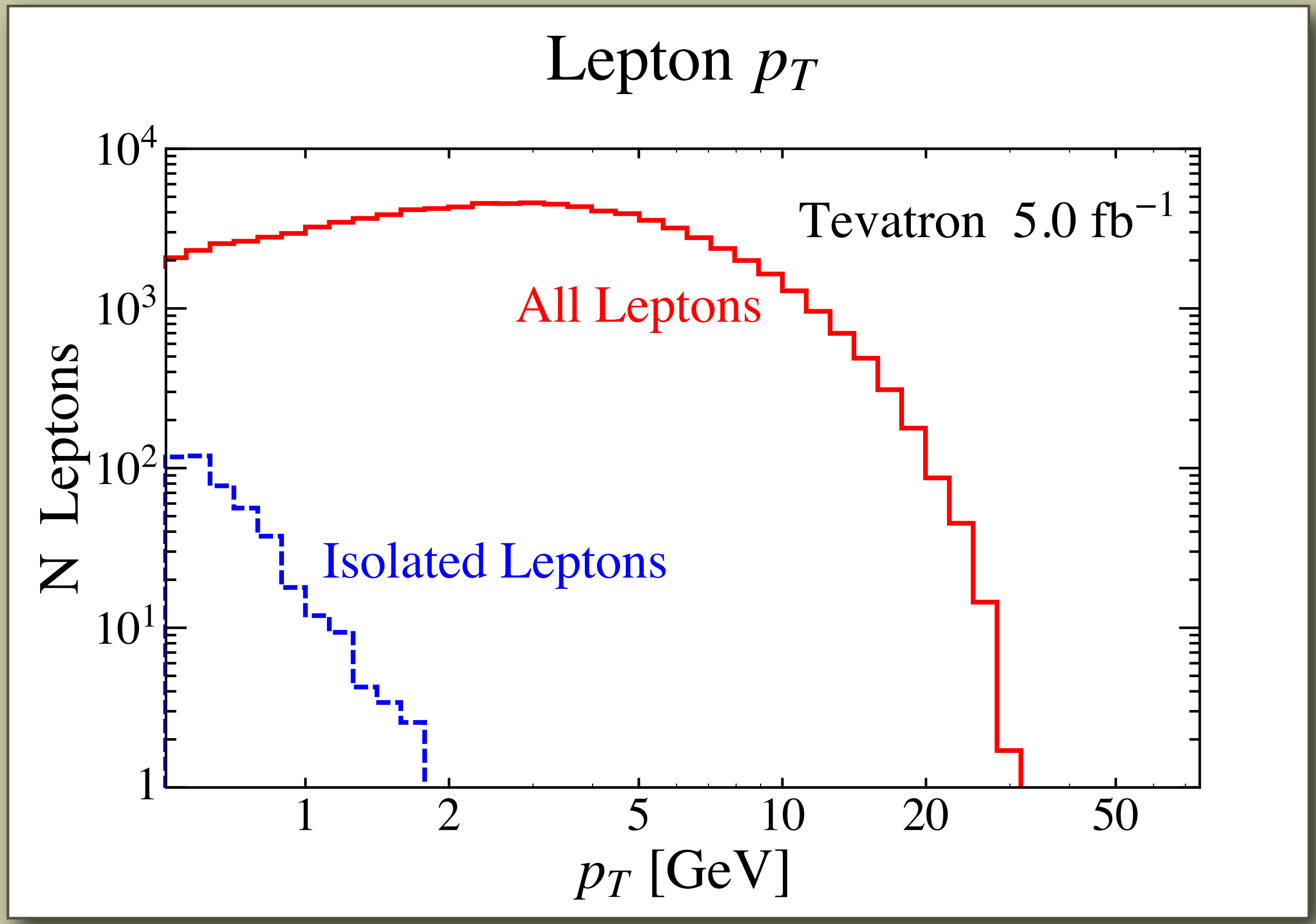
Tevatron

- The Tevatron experiments search for lepton jets in a noisier hadronic environment.
- Nonetheless, due to the large Higgs production cross-section (2 pb) and the high luminosity ($\sim 4-5\ \mathrm{fb}^{-1}$), discovery may be within reach with possibly many light Higgs-to-lepton jets events already on tape.



Tevatron: Trileptons

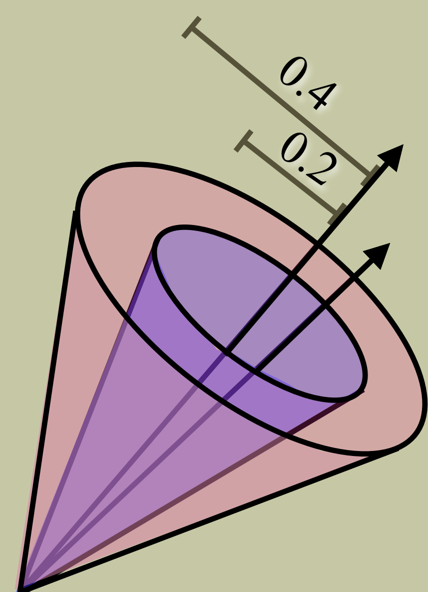
- Trilepton searches require (relatively) hard and isolated leptons ($\Delta R < 0.4$).
- Large lepton multiplicity evades such searches.

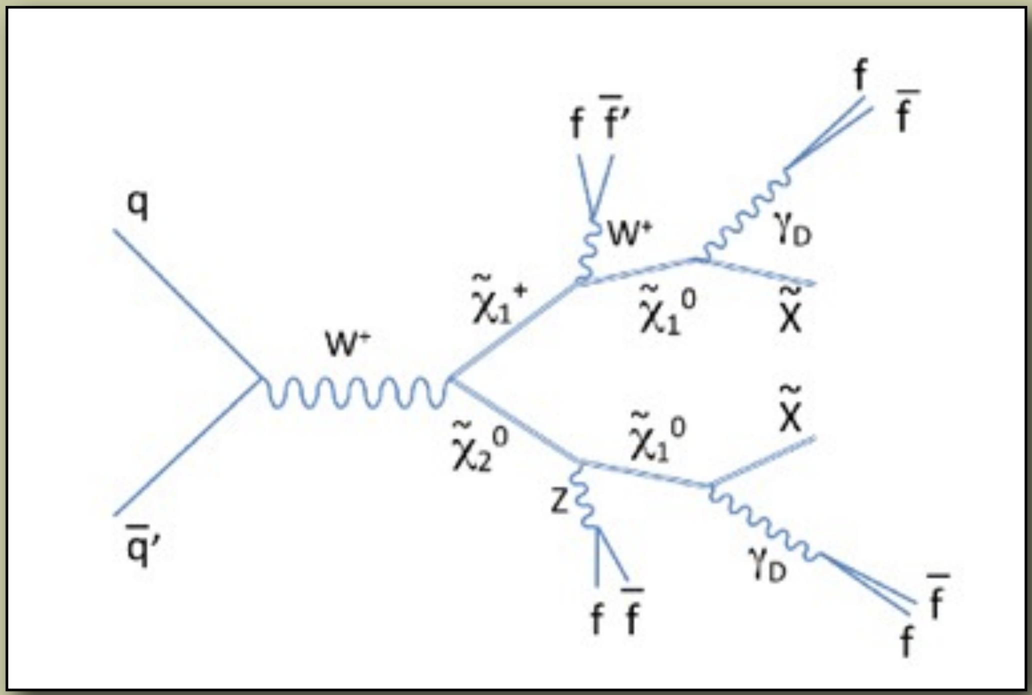


Leptons must not be isolated (large multiplicities)

Tevatron: Dark Photon Search

- Very recently, D0 performed an inclusive search for two LJs + MET.
- Look for $\Delta R < 0.2$ clusters, containing an electron or muon of $p_T > 10$ GeV and at least one OS companion track of $p_T > 4$ GeV.
- Jets are required to be isolated in an annulus: $0.2 < \Delta R < 0.4$.
- D0 search sensitive to narrow LJs with low multiplicities.





Lepton jets must be relatively wide or soft (large multipliciites)

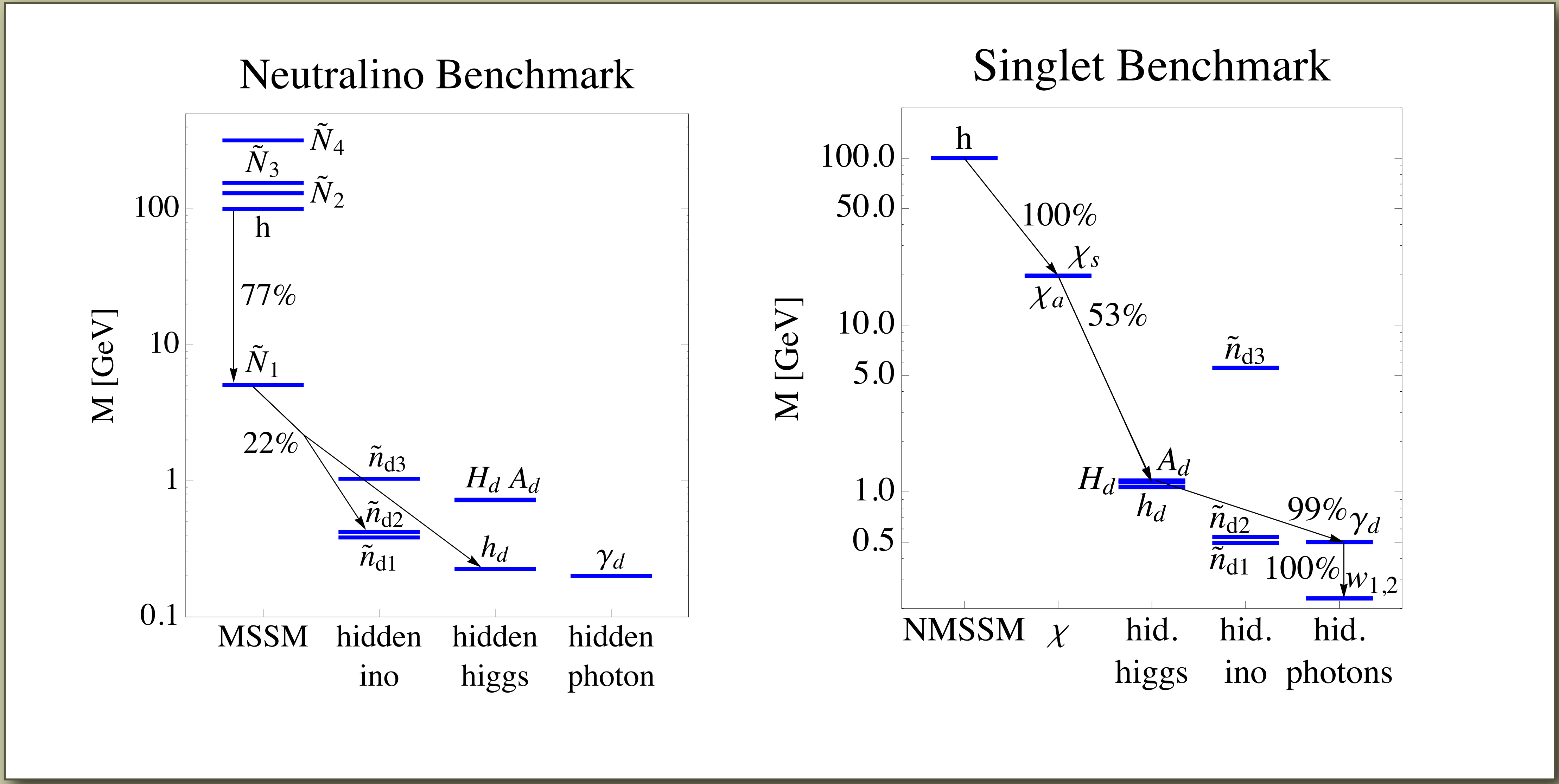
Collider Signatures: Summary

• Visible Final States: Electrons vs. Muons	Both can be accommodated
• Lepton Multiplicity	Large ($\gtrsim 6$)
• Missing Energy	Some is required ($\mathcal{O}(50)$ GeV)
• Event Topology	2-jet topology
• Lepton Isolation	No hard isolated leptons
• Jet Shape	Not too narrow ($R > 0.2$)
• Displaced Vertices	In progress..

Benchmark Models

Benchmark Models

- It is intriguing that (almost) minimal models are sufficient to reproduce the required allowed region.
- Singlet benchmark model has electron and muon final states. Neutralino benchmark model has only electron final states.



Benchmark Models

- To explore a wide range of LJ signatures, we use effective "simplified" models.
- We assume an N-step cascade.
- Tunable parameters:
  - Number of cascade steps (multiplitcity and p_T).
  - Hidden particle masses (number and width of LJs).
  - BR of last step into SM vs. hidden particle (amount of missing energy).

Discovering Lepton Jets

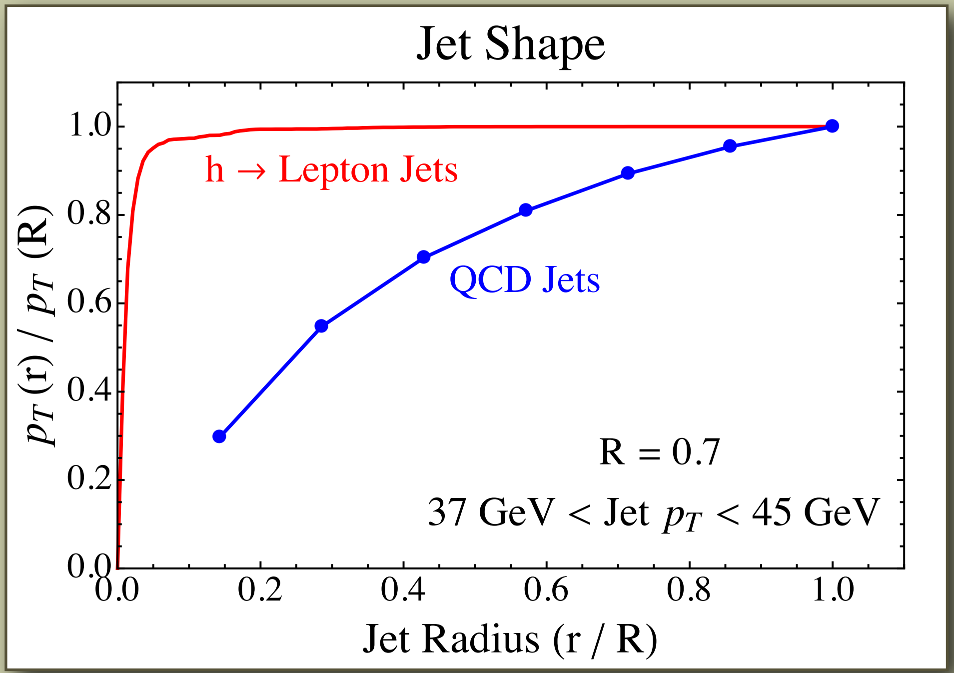
Can We Find the Hidden Higgs?

- There could be as many as 10^4 Higgs and lepton jet events at LEP-1 and the Tevatron. On the order of ~ 100 events at LEP-2 and more than 3.5×10^4 events at the 1 fb^{-1} LHC data.
- With dedicated searches it should therefore be simple to find such a Higgs at any of these experiments.
- Goal: Differentiate between the lepton 2-jet topology from the SM QCD background.

Can We Find the Hidden Higgs?

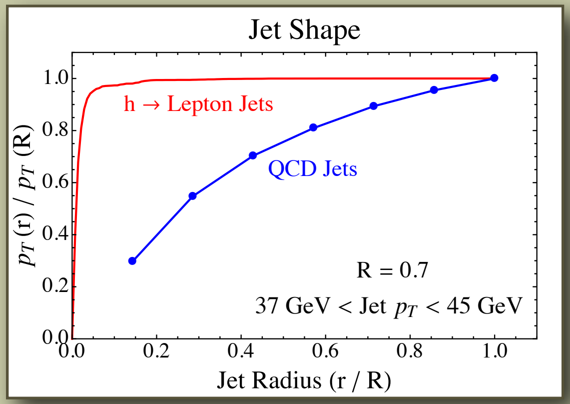
Some possibly useful observables:

- Jet Shape [$m_{N_1} \ll m_h$ and weakly coupled hidden sector]



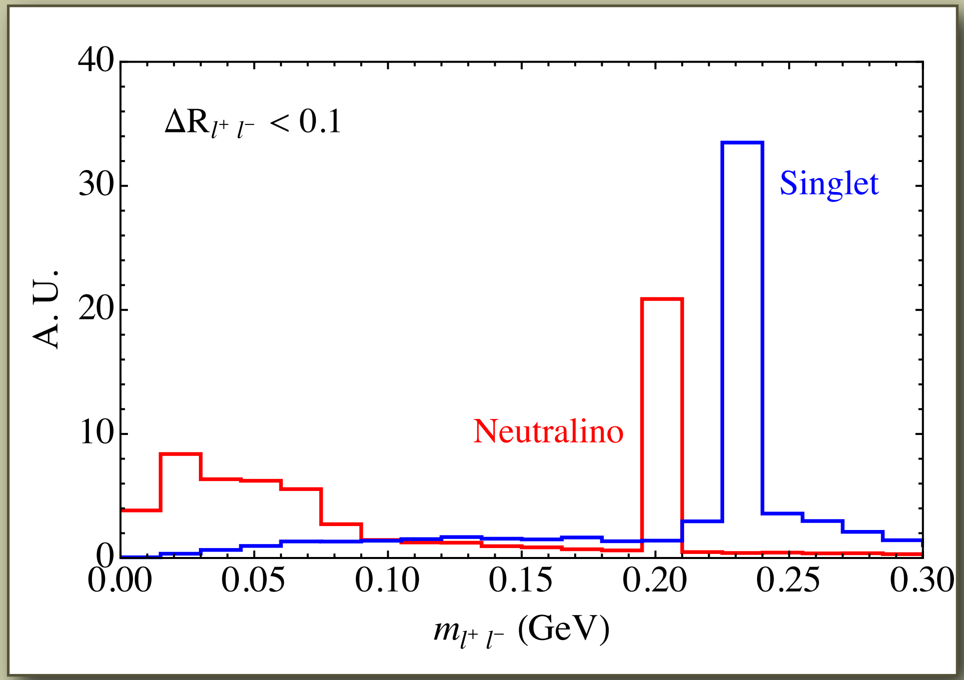
Can We Find the Hidden Higgs?

Some possibly useful observables:



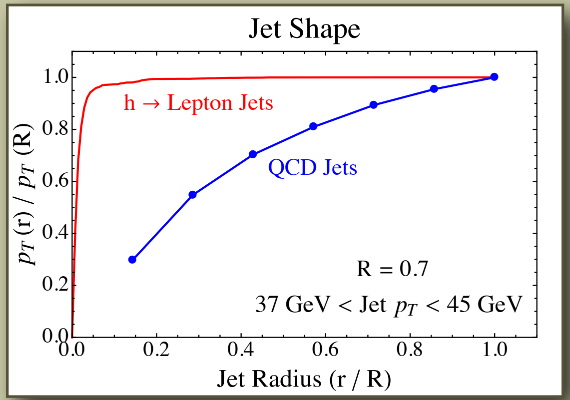
- Jet Shape [$m_{N_1} \ll m_h$ and weakly coupled hidden sector]

- Lepton invariant mass [Depends on hidden sector spectrum]

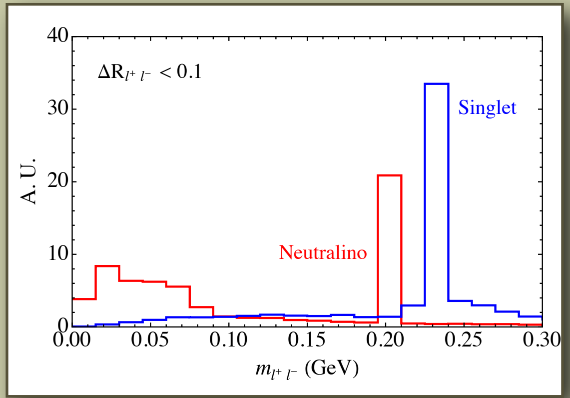


Can We Find the Hidden Higgs?

Some possibly useful observables:



- Jet Shape [$m_{N_1} \ll m_h$ and weakly coupled hidden sector]



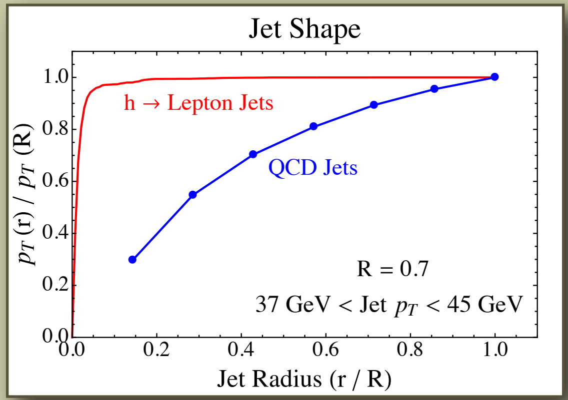
- Lepton invariant mass [Depends on hidden sector spectrum]

- Ecal/Hcal ratio [Assuming electronic jets]

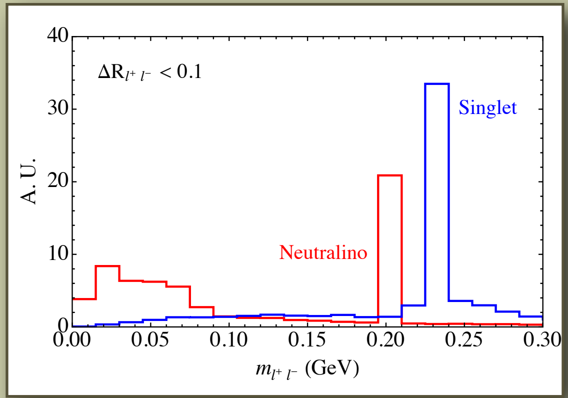
Background rejection of few $\times 10^{-3}$ per jet.

Can We Find the Hidden Higgs?

Some possibly useful observables:



- Jet Shape [$m_{N_1} \ll m_h$ and weakly coupled hidden sector]



- Lepton invariant mass [Depends on hidden sector spectrum]
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Background rejection of few $\times 10^{-3}$ per jet.

QCD vs. Electron Jets

- Closely spaced leptons do not satisfy usual isolation criteria and will not reconstruct as leptons.
- We therefore use:
  - EM Fraction (EMF): $\frac{E_{\rm EM}}{E_{\rm Total}}$
  - Charge Ratio (CR): $\frac{\sum p_T}{E_{\rm EM,T}}$
- For LJs we expect: EMF $\sim$ CR $\sim$ 1
- Background consists mostly of $\pi^{\pm}$ (EMF $\ll$ 1) and photons from π^0 (EMF $\sim$ 1). Precise jet composition fluctuates highly.
- EMF distribution further broadens by fluctuations of EM and Hadronic cascade and detector smearing.
- High EMF tail of QCD is due to high photon content, so CR $<$ 1.

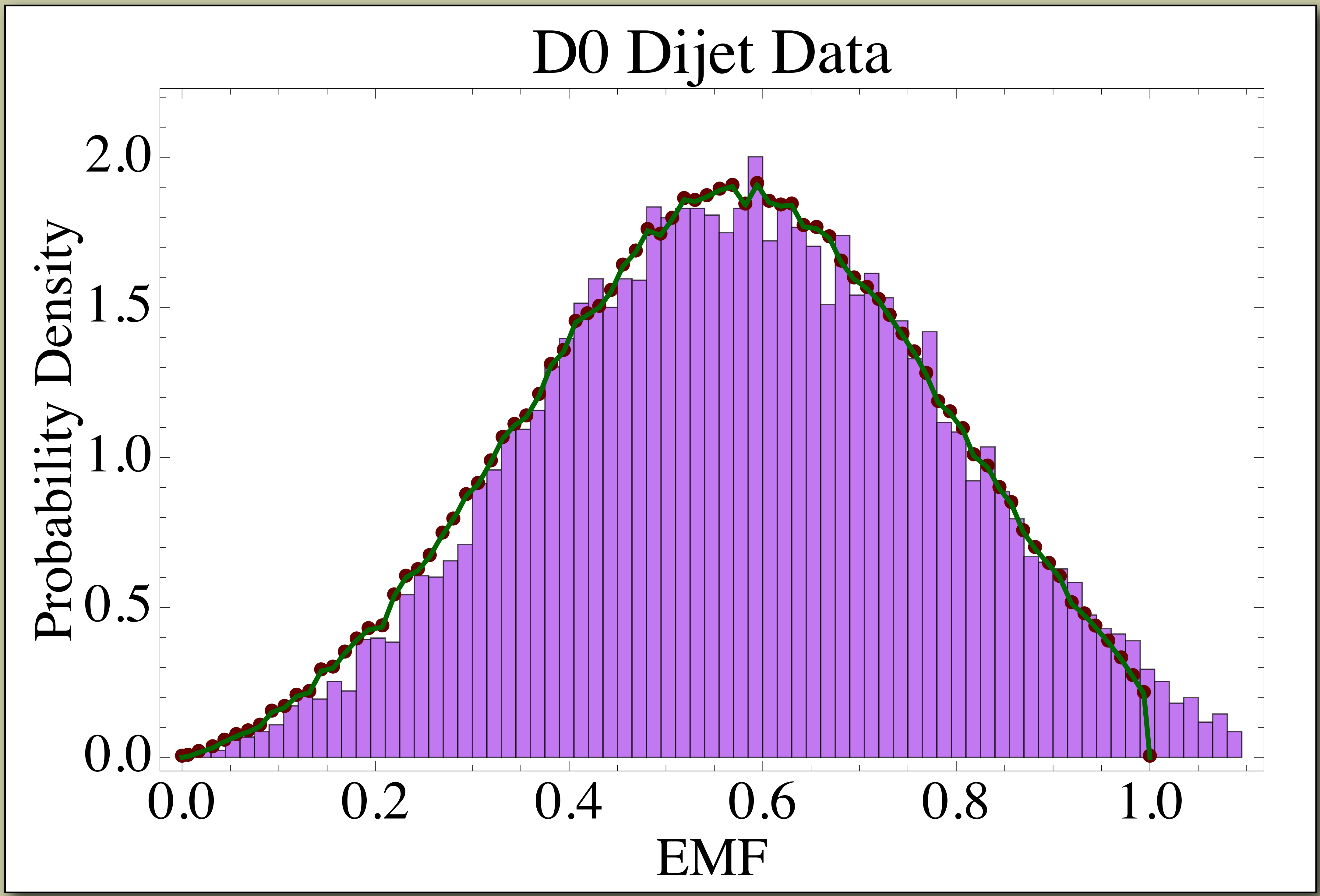
Analysis

- Higgs production through gluon fusion is overwhelmed by dijet background.
- We concentrate on leptonic Z/W + 2 LJs.
- Main background: Z/W + jj
- Study: D0 and ATLAS.
- Divide search into
  1. Kinematic cuts that target Z/W+h
  2. EMF and CR that target LJs (not necessarily through Higgs production).

Methodology

- Background and signal simulated using usual MC chain:
  - Parton level: `MadGraphv4` and `BRIDGE`.
  - Shower and hadronization: `Pythia 6.4.21` (including multiple interactions and pileup).
  - Cross-sections normalized using to NLO with `MCFM`.
  - Detector simulation, `PGS4`, tuned for D0 and ATLAS.
- `PGS` is too simplistic for simulating EMF and CR.
- We use a fast calorimeter MC, taking into account parametrization for EM and hadronic showers tuned for D0 and ATLAS.
- Allow fluctuations of all parameter, taking into account non-compensating effects (e/h) and detector smearing.
- Simulation is tuned to D0 and ATLAS using dijet EMF data.

Fast Calorimeter Tuning



Analysis: Kinematic Cuts

- Exactly two jets:

$$p_T(j) > 15 \text{ GeV} \qquad \Delta R_{j_1,j_2} > 0.7$$

$$|\eta| < 1.1 \quad 1.5 < |\eta| < 2.5 \qquad |\eta| < 2$$

(D0) (ATLAS)

- Z+h: 2 opposite sign same flavor isolated leptons ($l = e, \mu$):

$$p_T(l) > 10 \text{ GeV} \qquad |m(l^+l^-) - m_Z| < 10 \text{ GeV}$$

- W+h: 1 lepton and missing p_T:

$$p_T(l) > 20 \text{ GeV} \qquad p_{T,\text{miss}} > 20 \text{ GeV}$$

- $N^j_{\text{trk}} > 4$ (to cut down photon conversions in tracker).

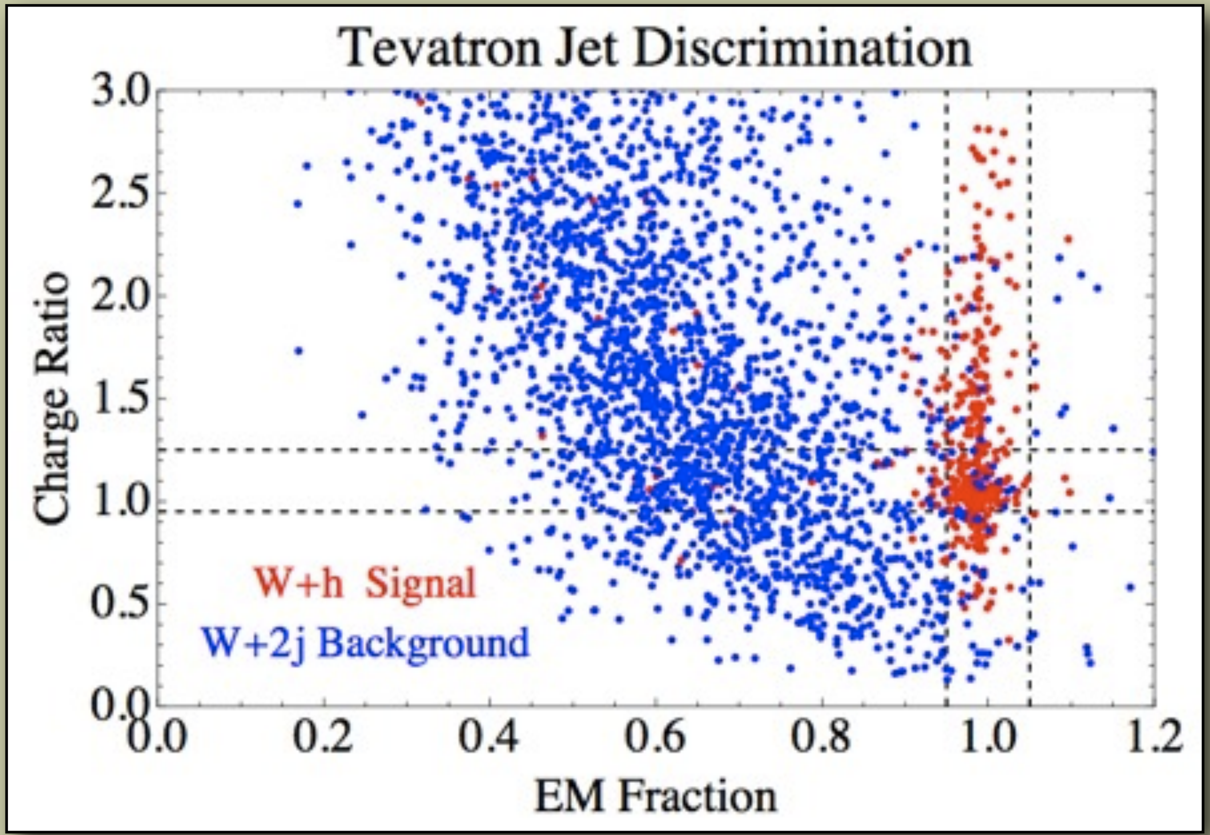
Analysis: EMF & CR

- EMF: different cuts due to detector efficiencies

$0.95 < \text{EMF} < 1.05$	$0.99 < \text{EMF} < 1$
(D0)	(ATLAS)

- CR cut different for Z/W due to smaller Z cross-section

$0.9 < \text{CR} < 1.9$	$0.95 < \text{CR} < 1.25$
(Z+h)	(W+h)

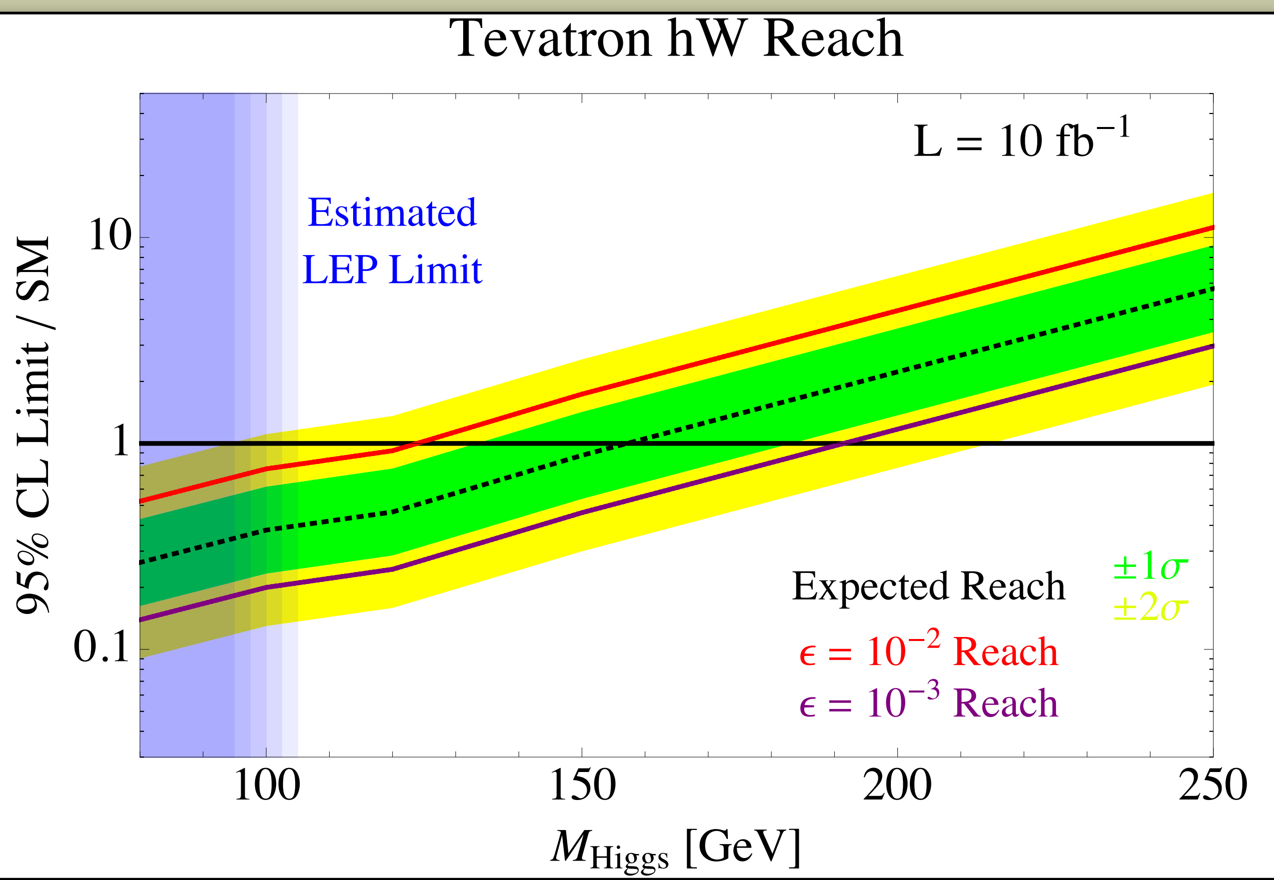


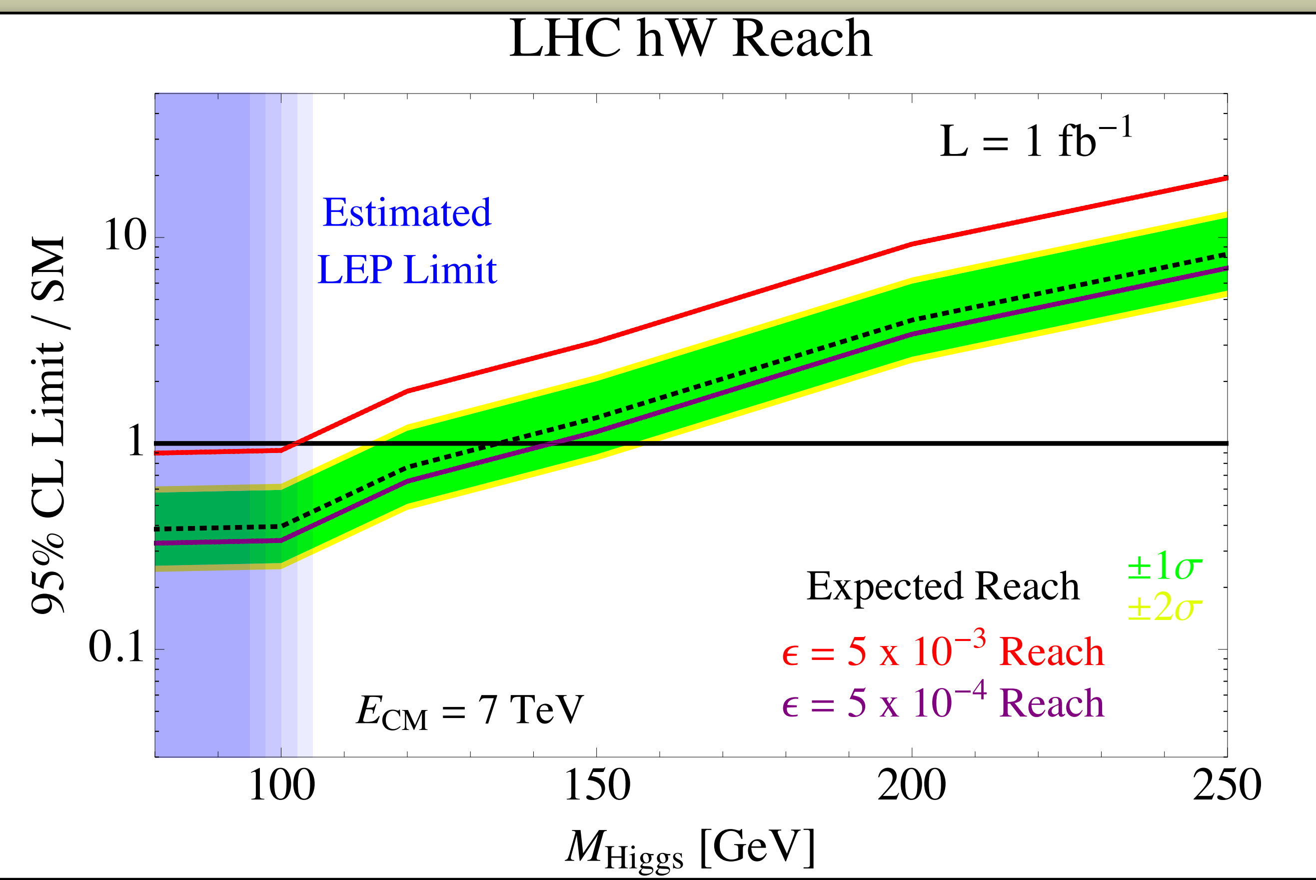
Search Efficiency

$m_h = 120$ GeV		$W+h$		$Z+h$	
		Signal(Eff.)	Bckg.	Signal(Eff.)	Bckg.
Tevatron	Kinematic	87 (18%)	4.4×10^5	10.6 (18%)	2.8×10^4
(10 fb^{-1})	EMF+CR	14.4 (3%)	5.9	3.5 (6%)	1.4
LHC	Kinematic	35 (17%)	4.9×10^5	5.2 (25%)	3.6×10^4
(1 fb^{-1})	EMF+CR	4.9 (2%)	0.7	1.5 (7%)	0.7

TABLE I: The number of signal and background events for the $W+h$ and $Z+h$ channels, with $m_h = 120$ GeV, at the Tevatron and LHC. Event counts are shown after the cuts of Eqs. (1) - (3) and requiring at least 4 tracks per jet (Kinematic), and also after including the cuts on electromagnetic fraction and charge ratio (EMF+CR).

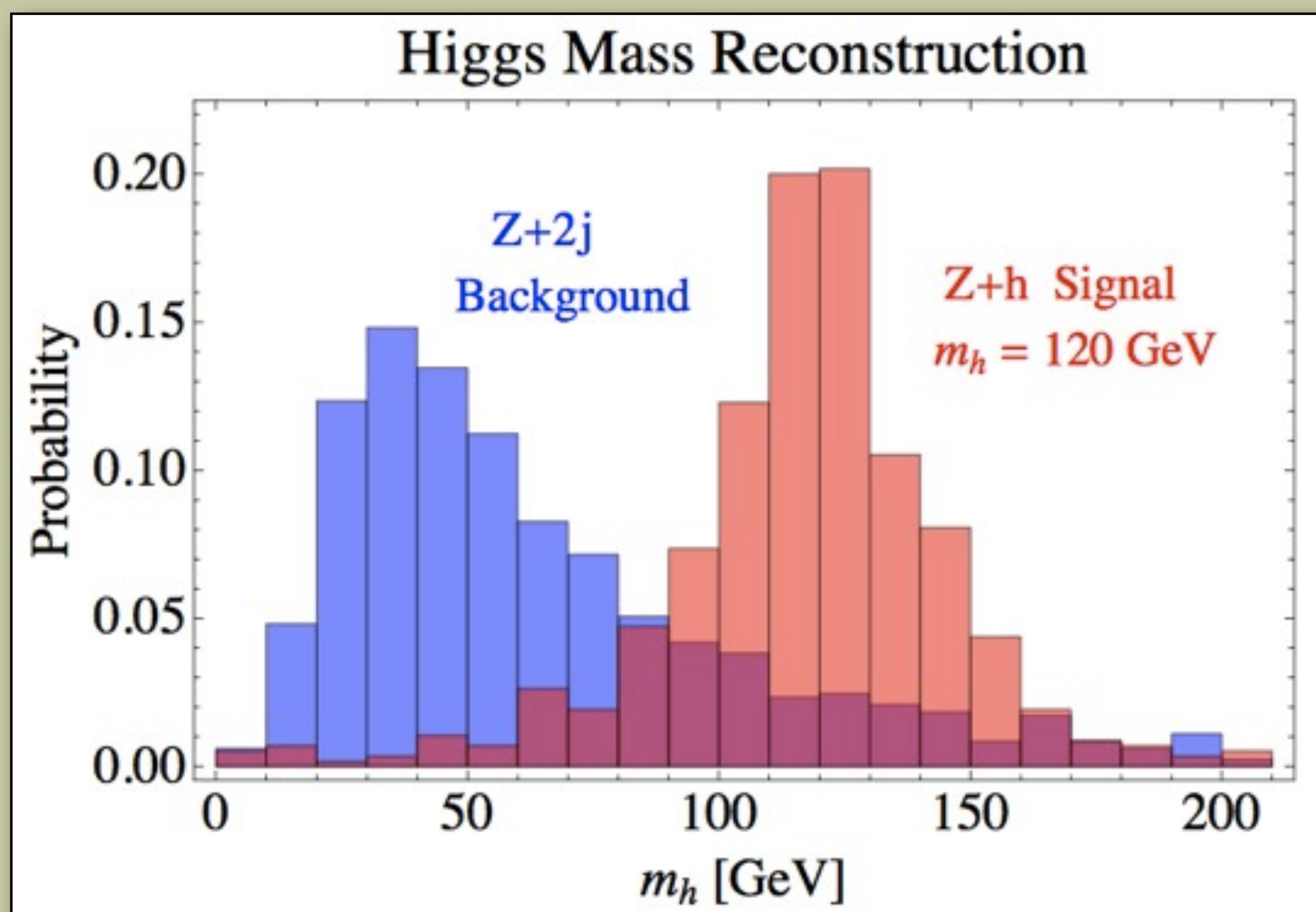
Discovery Reach





Higgs Mass Reconstruction

- MET is aligned with LJ direction.
- Two unknowns can be recovered from momentum conservation, so Higgs mass can be reconstructed in Z+h channel.
- Probably need more than 1 fb^{-1} or light Higgs.



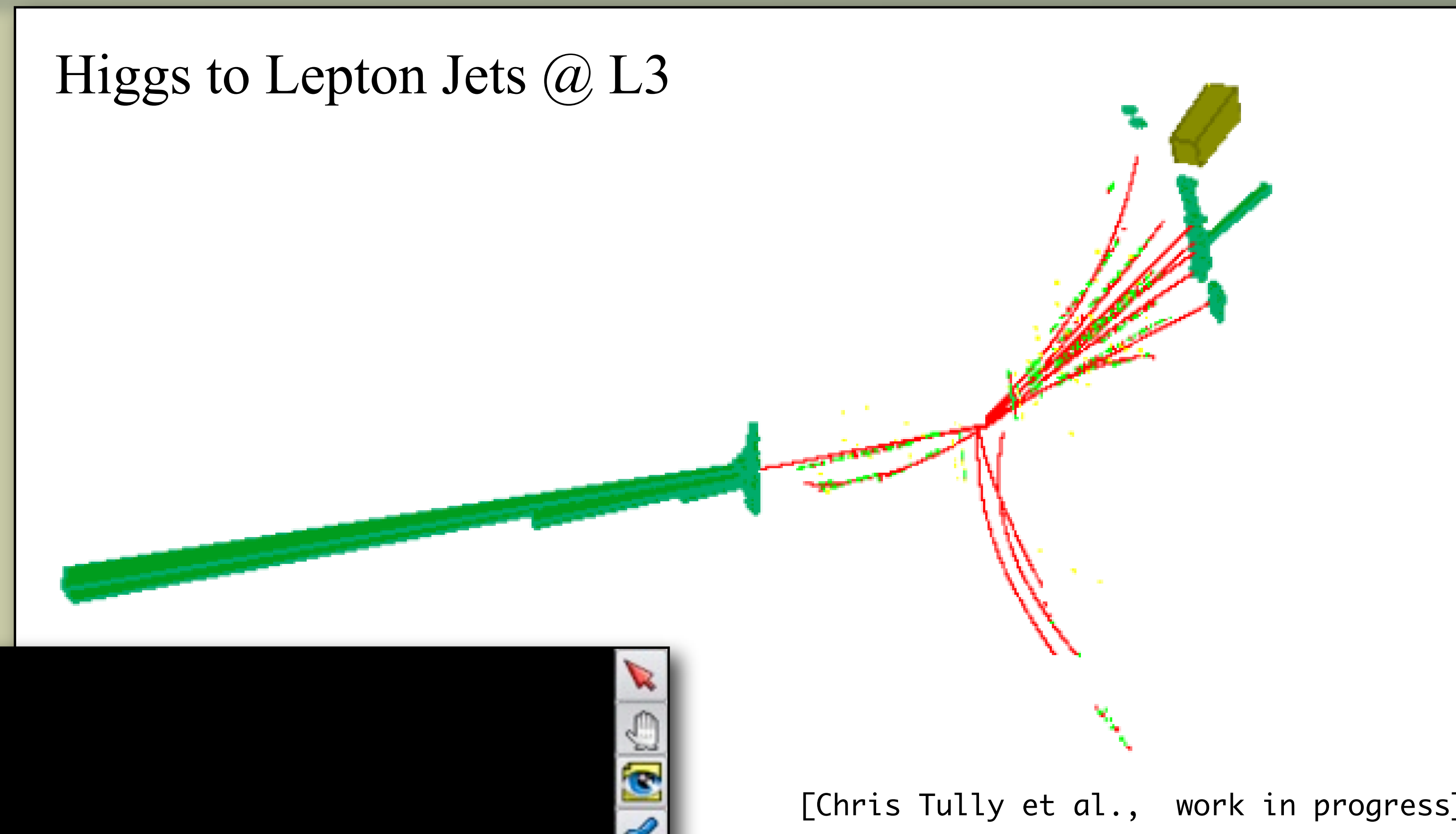
Conclusions

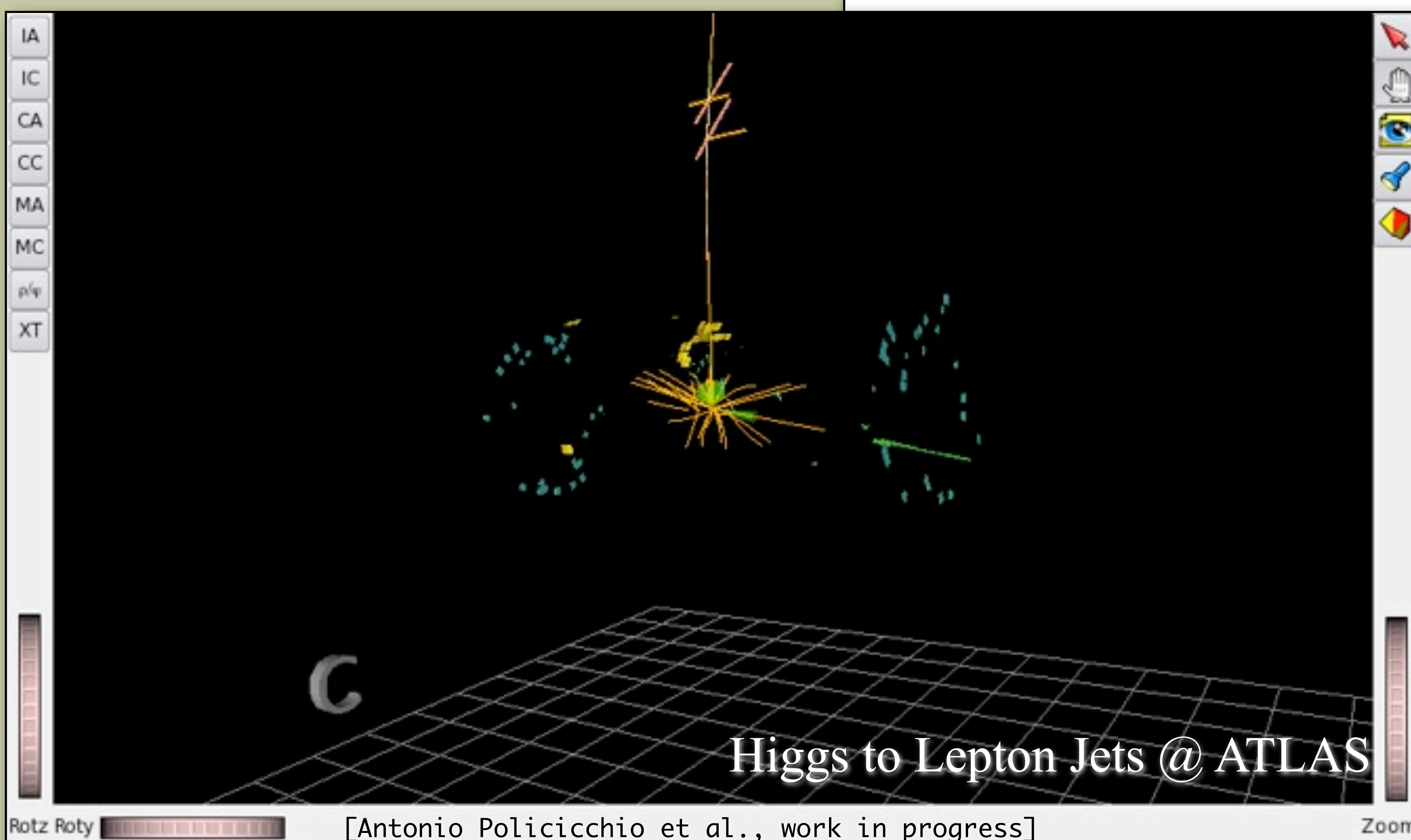
- Despite the many searches at LEP and the Tevatron, it is still possible that the Higgs was missed (10^4 events!!).
- Such a possibility is intriguing and is motivated both theoretically and experimentally.
- Phenomenology is interesting even if the Higgs is not hidden, in which case, similar studies are required for LHC physics.
- Search strategies have been demonstrated to be efficient with high mass reach.
- A systematic approach to constrain the signature space is require, especially at the LHC era.

Ongoing Experimental Effort..

- L3 search for $H \to$ LJs (Princeton).
- CMS search for $H \to$ LJs (Princeton).
- CMS search for prompt and displaced muonic LJs (Princeton).
- CMS search for hardronic LJ production (Rutgers)
- ATLAS search for hardronic LJ production (..).
- ATLAS triggering on displaced LJs (Seattle).
- CDF search for $H \to$ LJs (..).
- D0 search for $H \to$ LJs (Rutgers).
- ...

An Answer Soon??





Extras

Efficiencies

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

Table 1: A compilation of relevant searches for constraining the Higgs-to-lepton jet events.