


LARGE N, DISORDER AND MIMESIS



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Confronting Naturalness: from LHC to Future Colliders - DESY - April 2018



LARGE N MIMESIS AT THE LHC

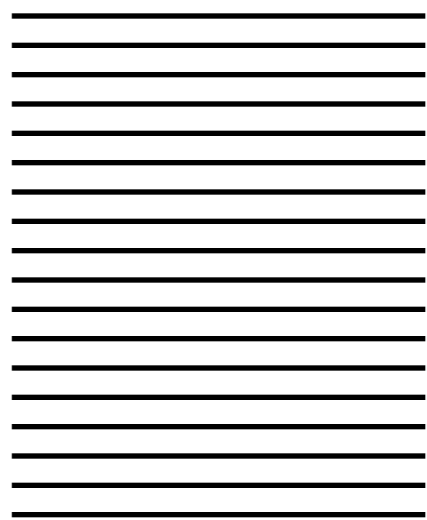
w/ M. Low

w/ T. Cohen,
M. Low

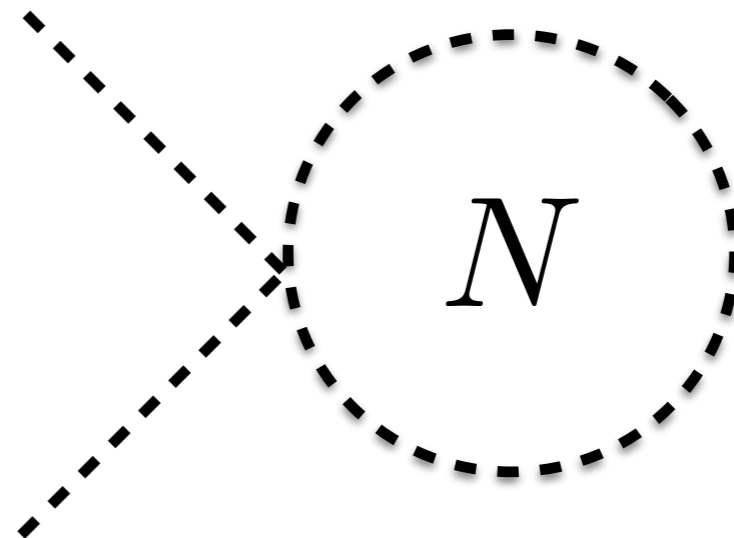
LARGE N DARK MATTER

LARGE N BASICS

$$\lambda |H|^2 \sum_{i=1}^N \phi_i^2$$



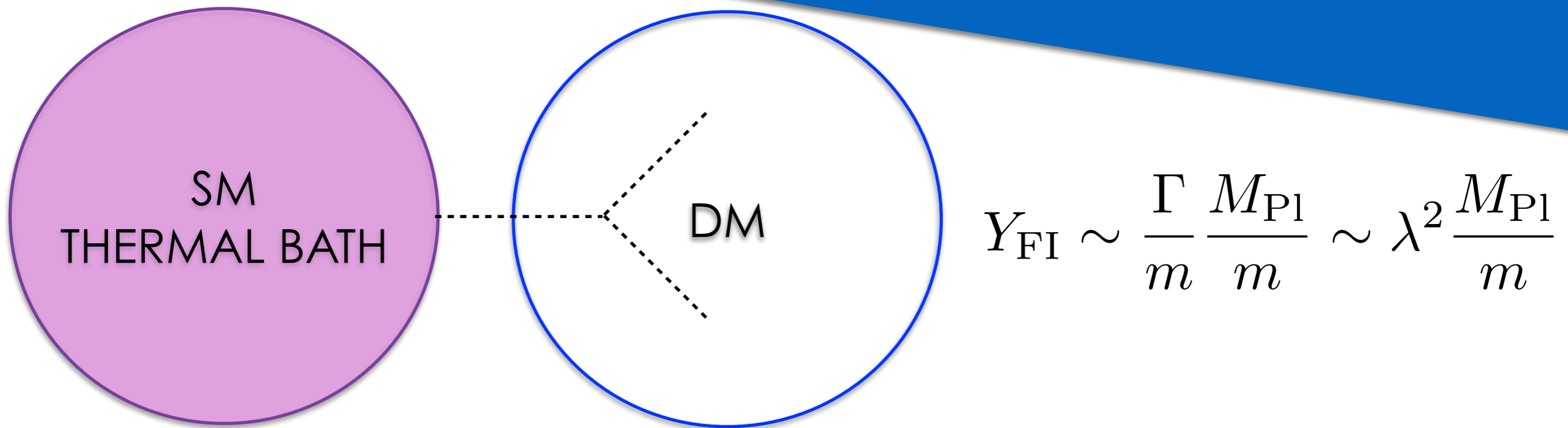
ϕ_i



PERTURBATIVITY

$$\lambda \sim \frac{1}{N}$$

LARGE N DARK MATTER

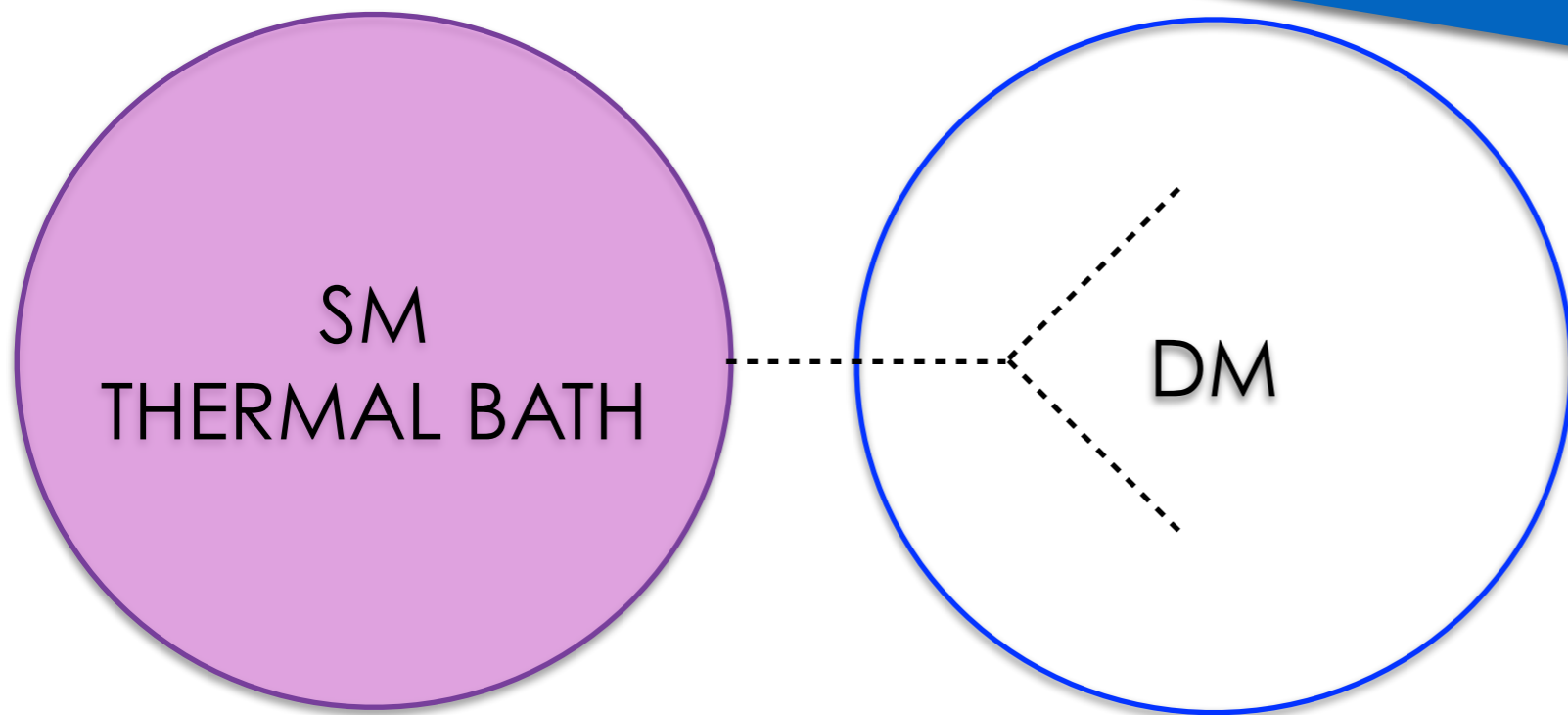


OBSERVATION

$$\lambda \sim \frac{v}{M_{\text{Pl}}} \sim \frac{1}{\sqrt{N}}$$

TEMPTING
SPECULATION

LARGE N DARK MATTER



“DIAGONAL” DECAYS

$$Y_{FI} \sim N \frac{\Gamma}{m} \frac{M_{\text{Pl}}}{m} \sim N \lambda^2 \frac{M_{\text{Pl}}}{m}$$

$$\lambda \sim \frac{1}{N}$$

$$N \sim \frac{M_{\text{Pl}}^2}{v^2}$$

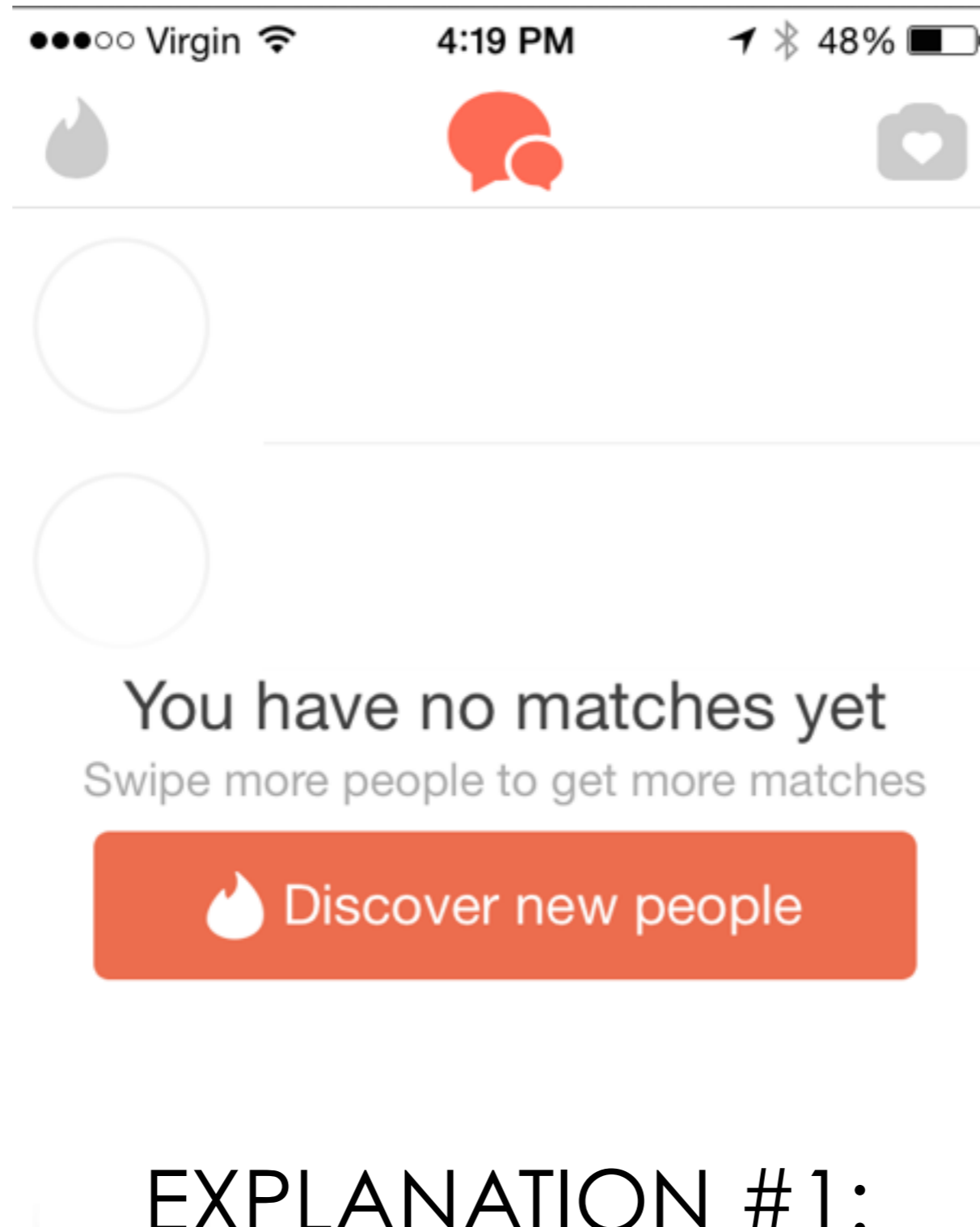
$$\Lambda_G \sim v$$

NO HIERARCHY PROBLEM
(BUT MANY OTHER ISSUES)

WITHOUT SQUIGGLES

$$\Lambda_G \gtrsim 10^5 \text{ TeV}$$

WHY HAVE WE SEEN
NOTHING SO FAR?




EXPLANATION #1:
THERE IS NOTHING TO SEE


It's a Match!

You and Allison have liked each other.



 Send a Message


 Keep Playing


 Tell your friends


Match!

You have liked each other.



 Send a Message


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
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
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
 Keep Playing


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
Match!

You have liked each other.



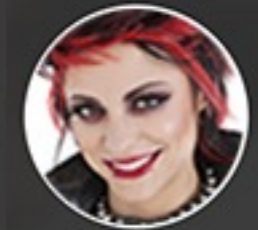
 Send a Message


 Keep Playing

 Tell your friends

Match!

You have liked each other.



 Send a Message

 Keep Playing

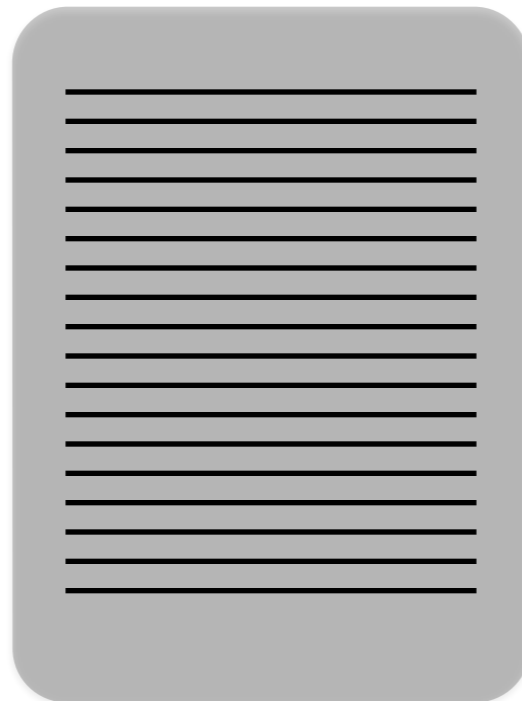
 Tell your friends

EXPLANATION #2:

THERE ARE TOO MANY NEW PARTICLES

LARGE N CONSEQUENCES

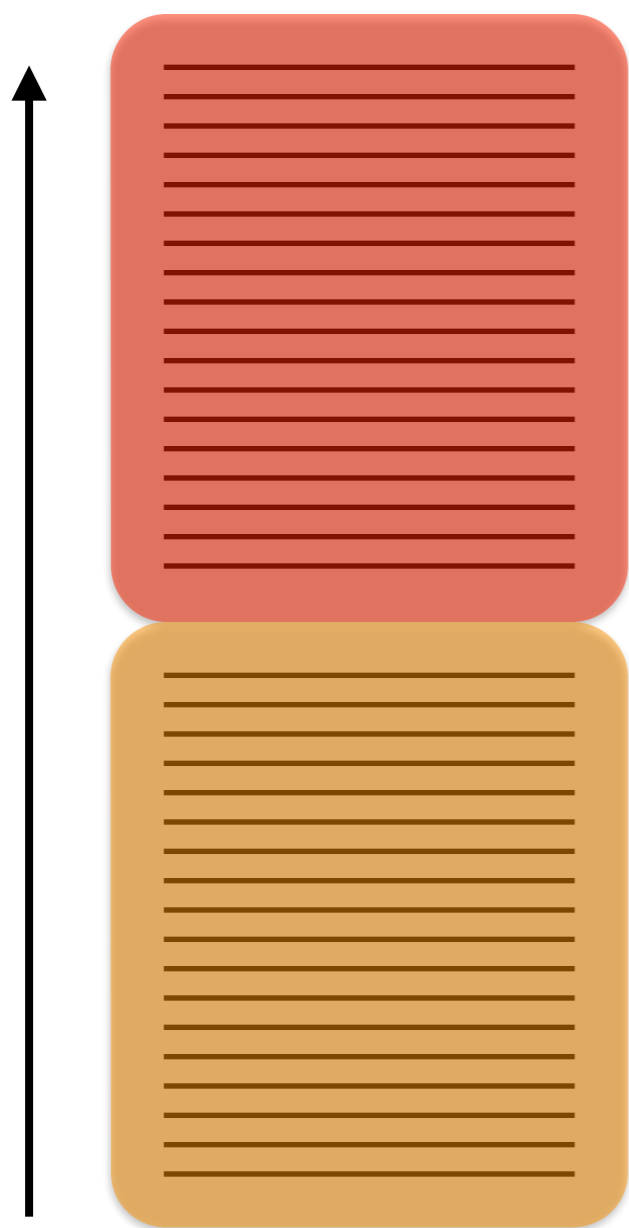
OUT OF REACH



$$\sigma \sim \frac{1}{N}$$

LARGE N CONSEQUENCES

INCREASING MASS



LONG DECAY CHAIN,
LOW PT FINAL OBJECTS,
LOW VISIBLE ENERGY

=

MISSED BY CURRENT
TRIGGERS

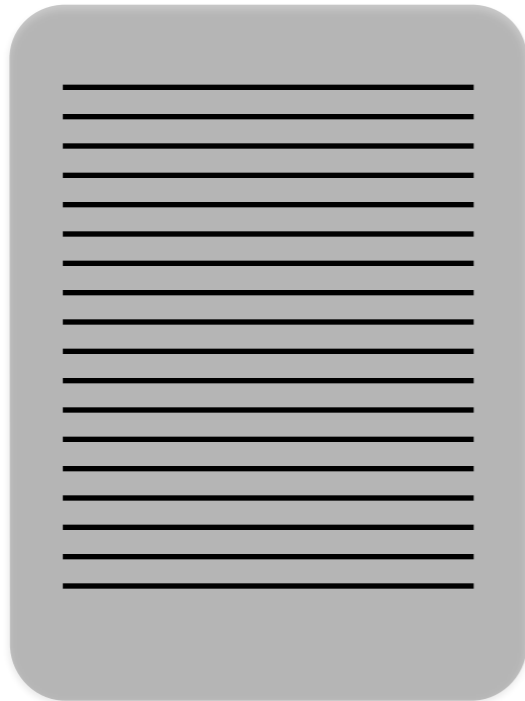
SHORT DECAY CHAIN,
SMALL MASS

=

TOO MUCH
BACKGROUND OR
"UNTRIGGERABLE"

A TOY EXAMPLE

OUT OF REACH



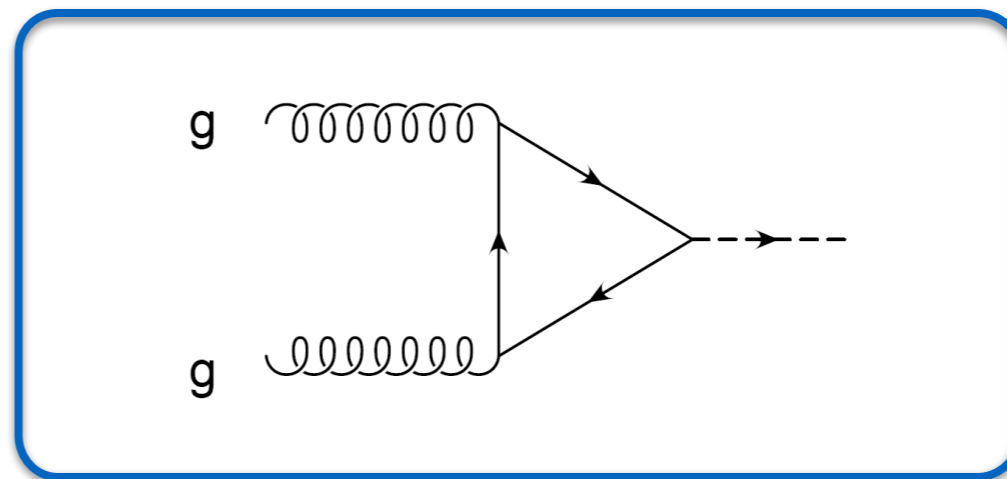
$$\phi_2 \quad \underline{350 \text{ GeV}}$$

$$\phi_1 \quad \underline{300 \text{ GeV}}$$

$$-\mathcal{L} \supset m\phi_2^\dagger\phi_1^2 + \epsilon m(\phi_1 + \phi_2)|H|^2 + \text{h.c.}$$

$$\epsilon \sim \frac{1}{N} \ll 1$$

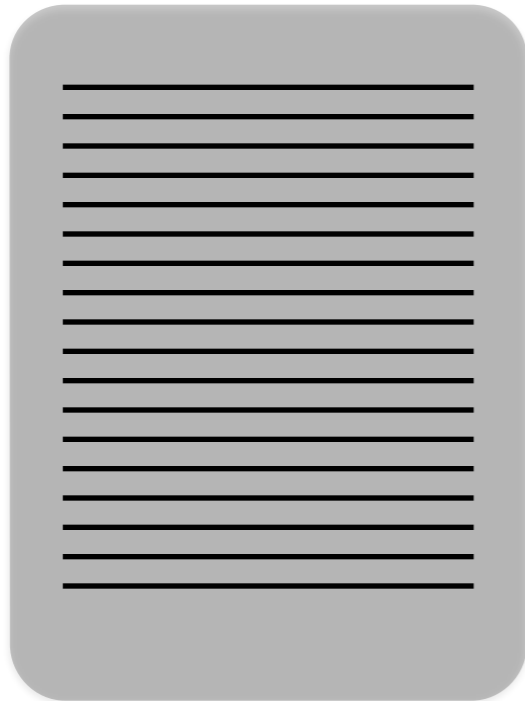
PRODUCTION



$$\phi_2 \approx 100 \text{ events}$$

A TOY EXAMPLE

OUT OF REACH



$$\phi_2 \quad \underline{350 \text{ GeV}}$$

$$\phi_1 \quad \underline{300 \text{ GeV}}$$

$$-\mathcal{L} \supset m\phi_2^\dagger\phi_1^2 + \epsilon m(\phi_1 + \phi_2)|H|^2 + \text{h.c.}$$

$$\epsilon \sim \frac{1}{N} \ll 1$$

DECAY

$$\phi_2 \rightarrow \phi_1\phi_1^* \rightarrow hh\bar{b}b$$

$$\phi_1 \rightarrow hh$$



A DISORDERED NEW SECTOR

A DISORDERED NEW SECTOR

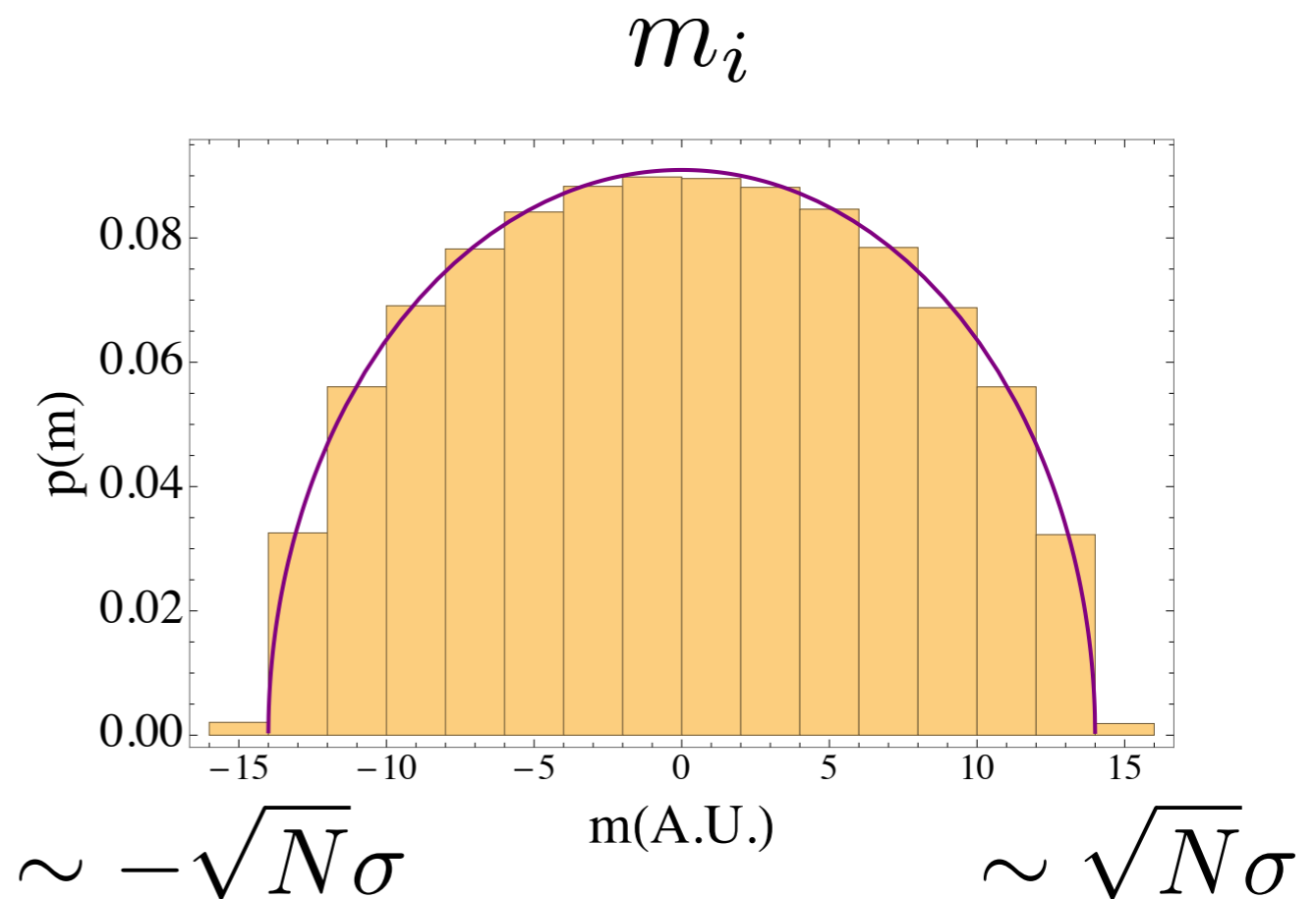
TODAY WE FOCUS ON A SPECIAL, BUT REASONABLE POSSIBILITY. MANY PHENO EXPLORATIONS ARE POSSIBLE!

REAL AND SYMMETRIC $N \times N$

$$\begin{pmatrix} \omega_{11} & \omega_{12} & \dots & \dots \\ \omega_{21} & \omega_{22} & \dots & \dots \\ \dots & \dots & \omega_{33} & \dots \\ & & & \dots \end{pmatrix}$$

$$p(\omega) \propto e^{-(\omega - \mu)^2 / 2\sigma^2}$$

$$\omega_{ij} = \omega_{ji}$$

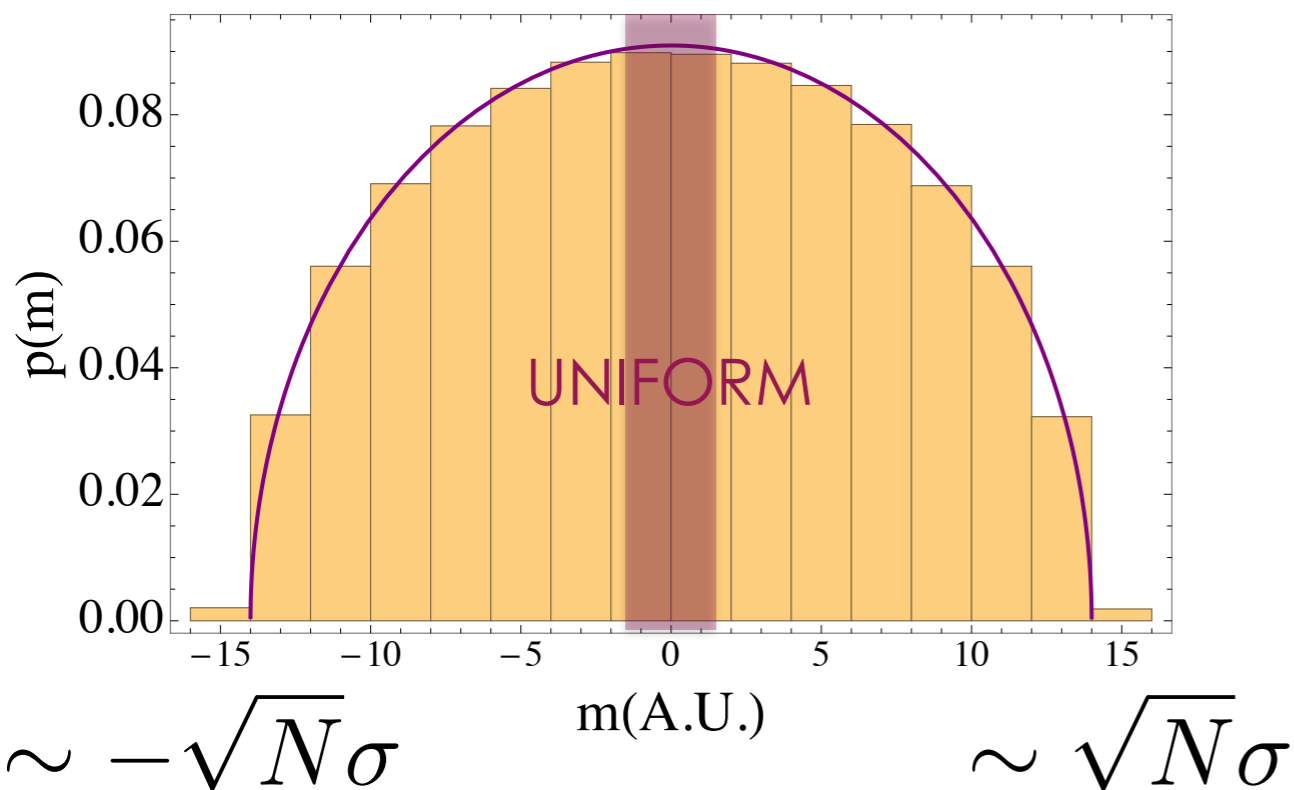


EIGENVALUES

A DISORDERED NEW SECTOR

TODAY WE FOCUS ON A SPECIAL, BUT REASONABLE POSSIBILITY. MANY PHENO EXPLORATIONS ARE POSSIBLE!

REAL AND SYMMETRIC $N \times N$



$$p(\omega) \propto e^{-(\omega - \mu)^2 / 2\sigma^2}$$

- THE MEAN DOES NOT MATTER [GOLDSTONES OF $SO(N)/SO(N-1)$]
- EVEN IF THE DISTRIBUTION IS NOT SYMMETRIC THE EIGENVALUES ARE STILL CENTERED AROUND ZERO

TODAY'S MODEL

$$-\mathcal{L} \supset \sum_{\alpha=1}^N \frac{m_{\alpha}^2}{2} \phi_{\alpha}^2 + \sum_{\alpha, \beta, \gamma, \delta=1}^N \lambda_{\alpha\beta\gamma\delta} \phi_{\alpha} \phi_{\beta} \phi_{\gamma} \phi_{\delta}$$

$$-\mathcal{L} \supset |H|^2 \sum_{\alpha, \beta=1}^N \lambda_{H\alpha\beta} \phi_{\alpha} \phi_{\beta}$$

$$m_{\alpha} \in [m_1, m_2]$$

UNIFORMLY DISTRIBUTED

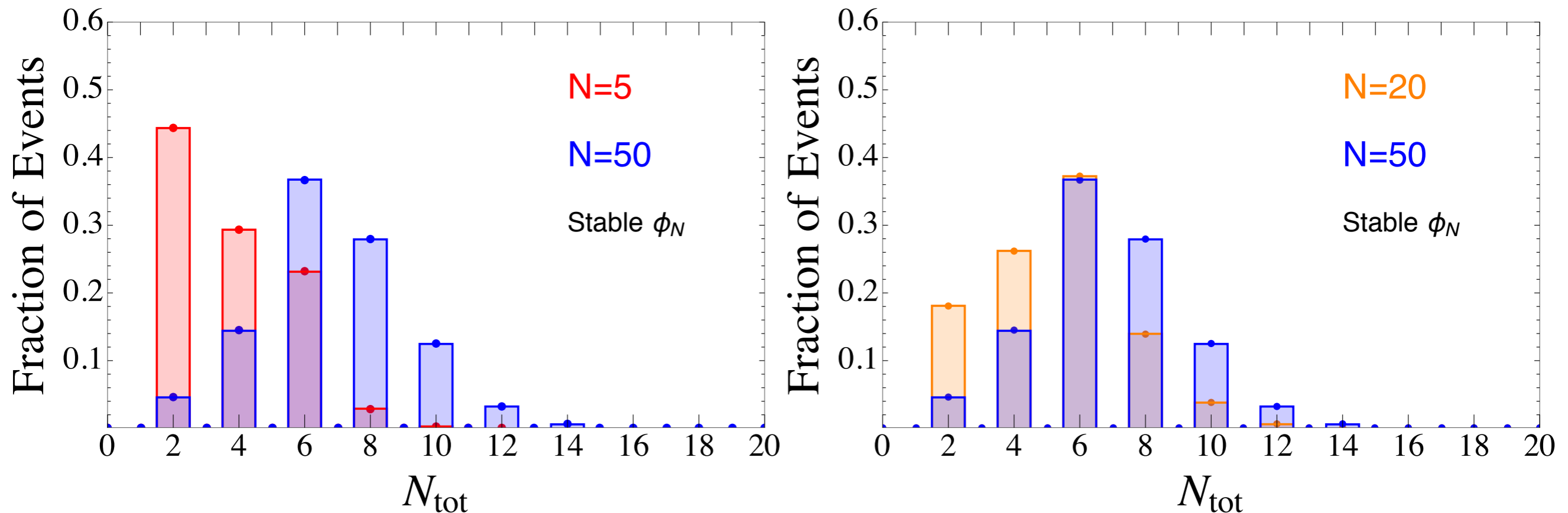
$$\lambda_{\alpha\beta\gamma\delta} = \frac{1}{N}, \quad \forall (\alpha, \beta, \gamma, \delta)$$

FOR SIMPLICITY

PARTICLE MULTIPLICITIES

$$N_{\text{tot}} = b, c, \mu, s, W, Z, g, \gamma, \phi_N$$

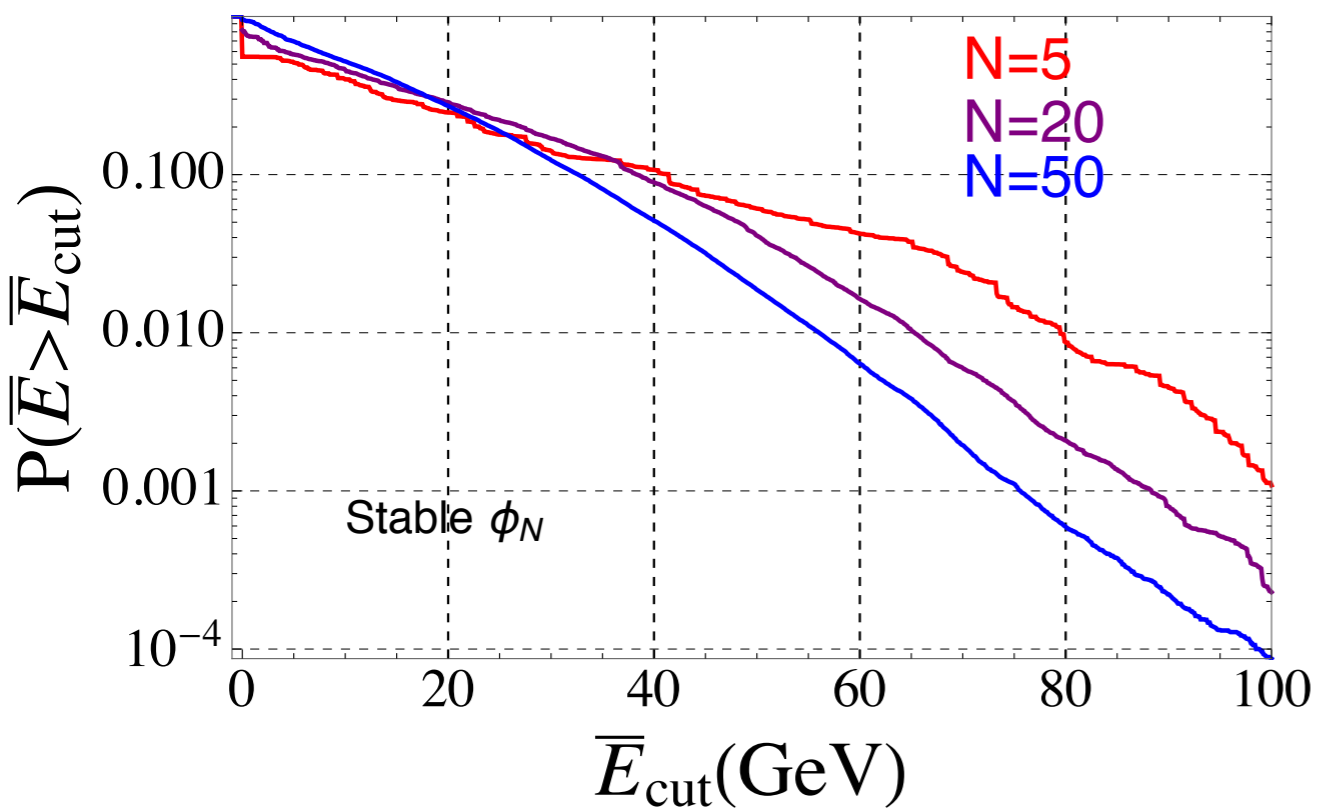
$$m_\alpha \in [100, 600]$$



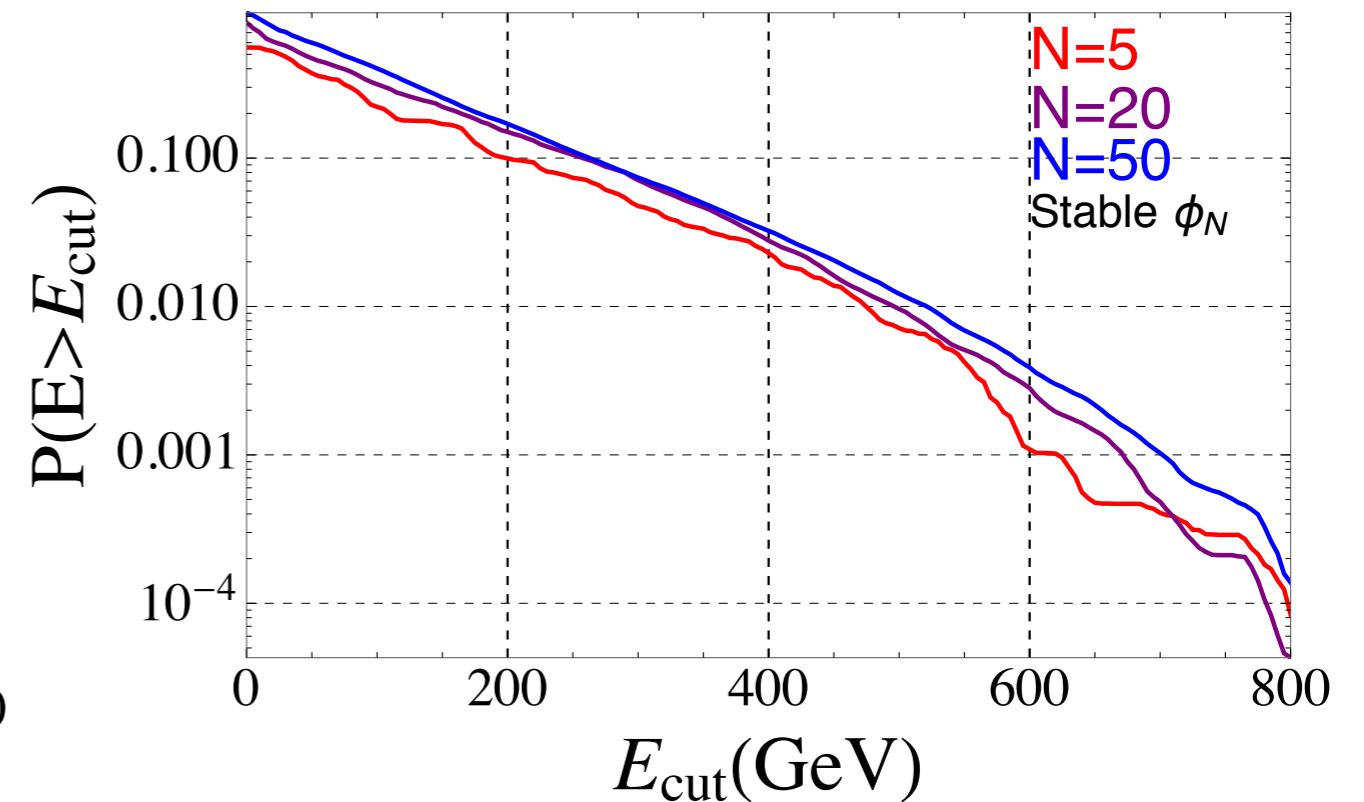
N.B. ALMOST ONLY JETS AND B-JETS
(EVENTS WITH TAU'S AND W'S <10%)

FINAL STATE ENERGIES

AVERAGE VISIBLE ENERGY
PER PARTICLE



TOTAL VISIBLE ENERGY
IN THE EVENT

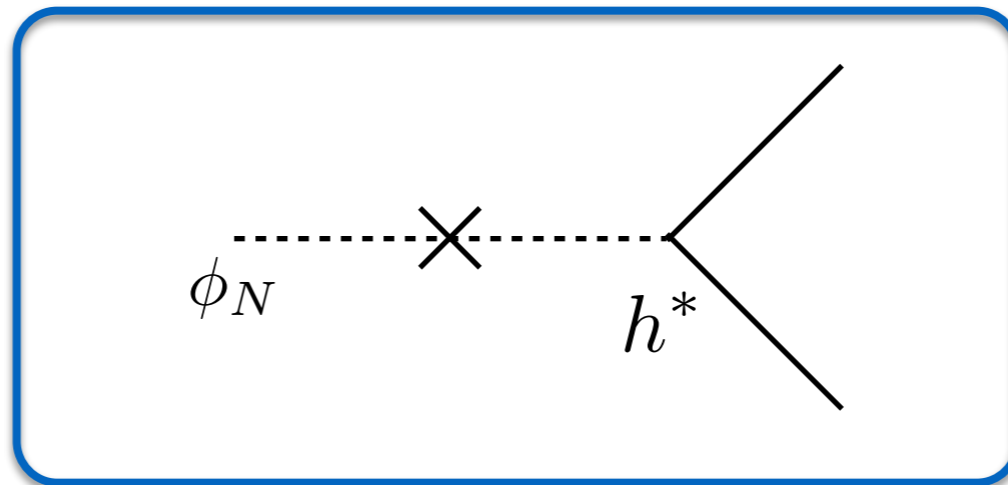


N.B. THERE ARE ALWAYS TWO INVISIBLE PARTICLES

MAKE IT UNSTABLE

$$-\mathcal{L} \supset a_H \sum_{\alpha=1}^N \phi_{\alpha} |H|^2$$

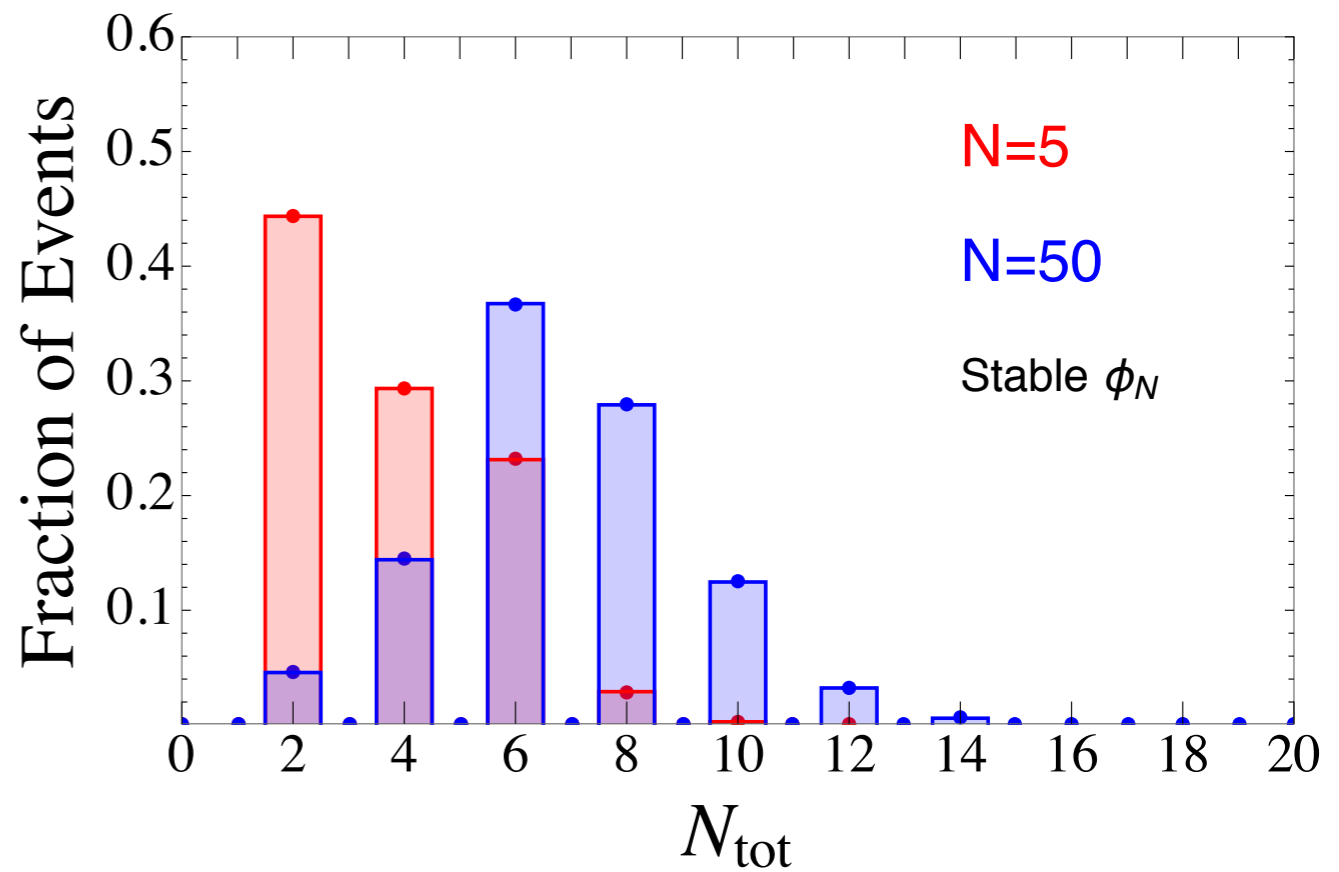
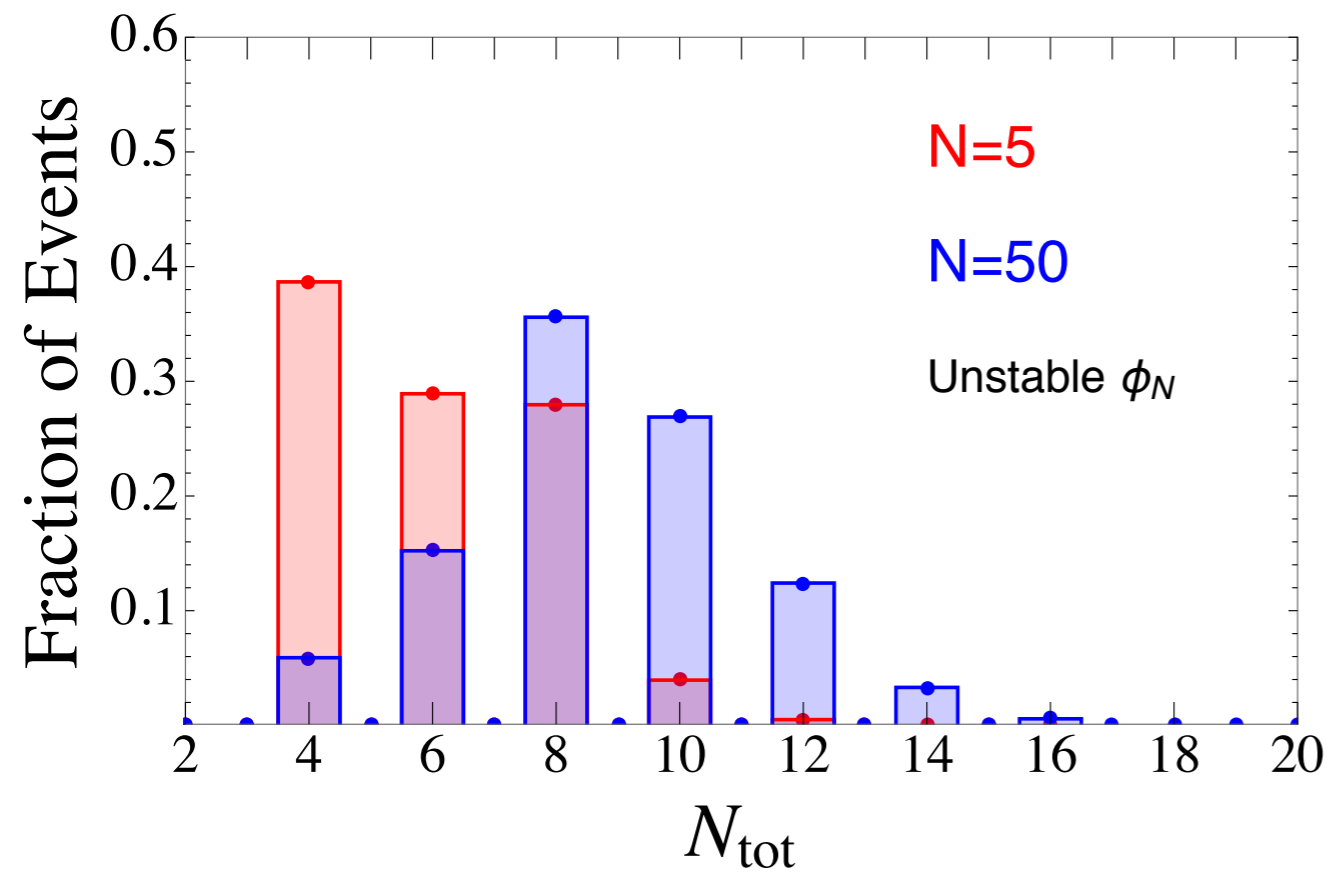
$$a_H \ll \lambda_H v \sim \lambda_{\alpha\beta\gamma\delta} v$$



THE LIGHTEST NEW STATE CAN DECAY

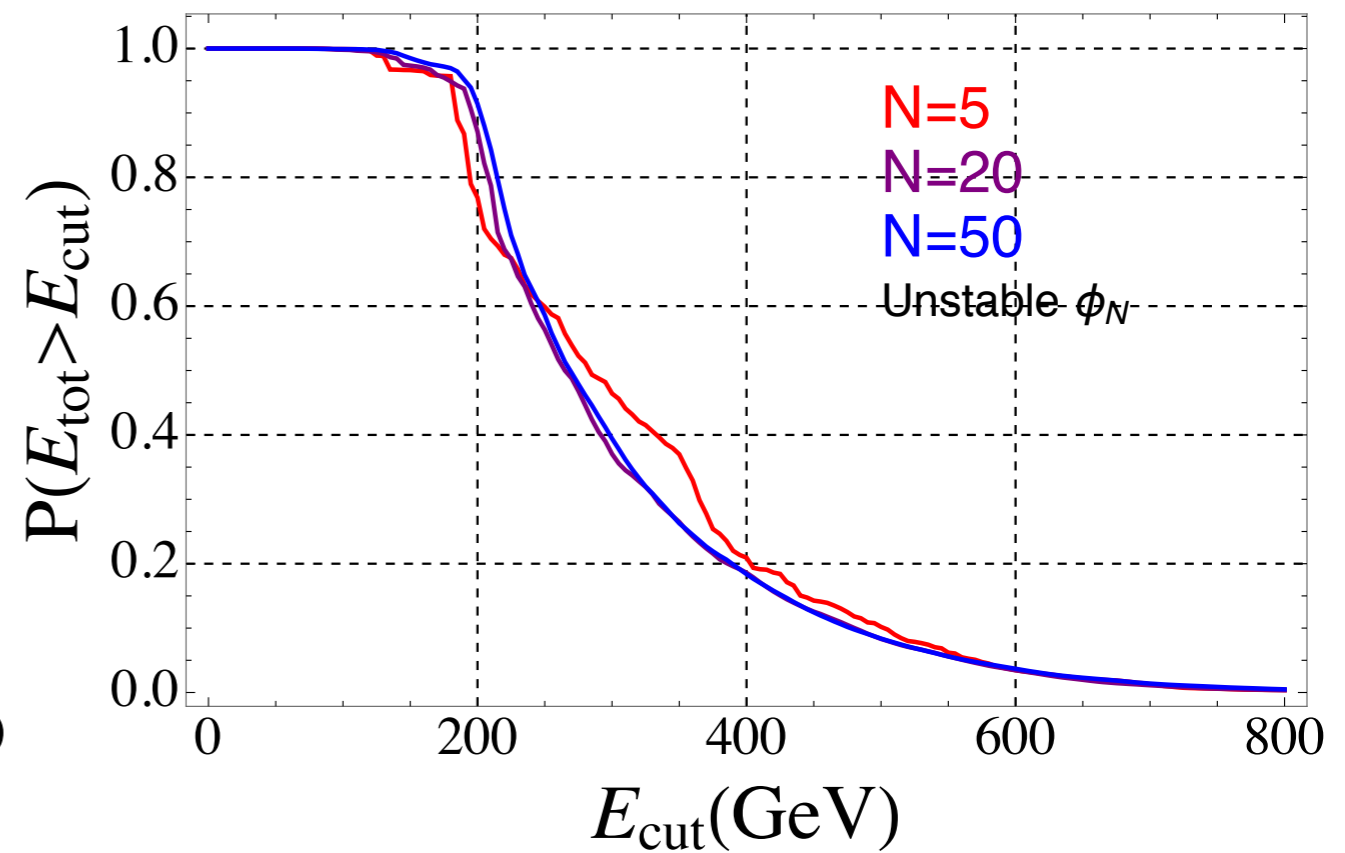
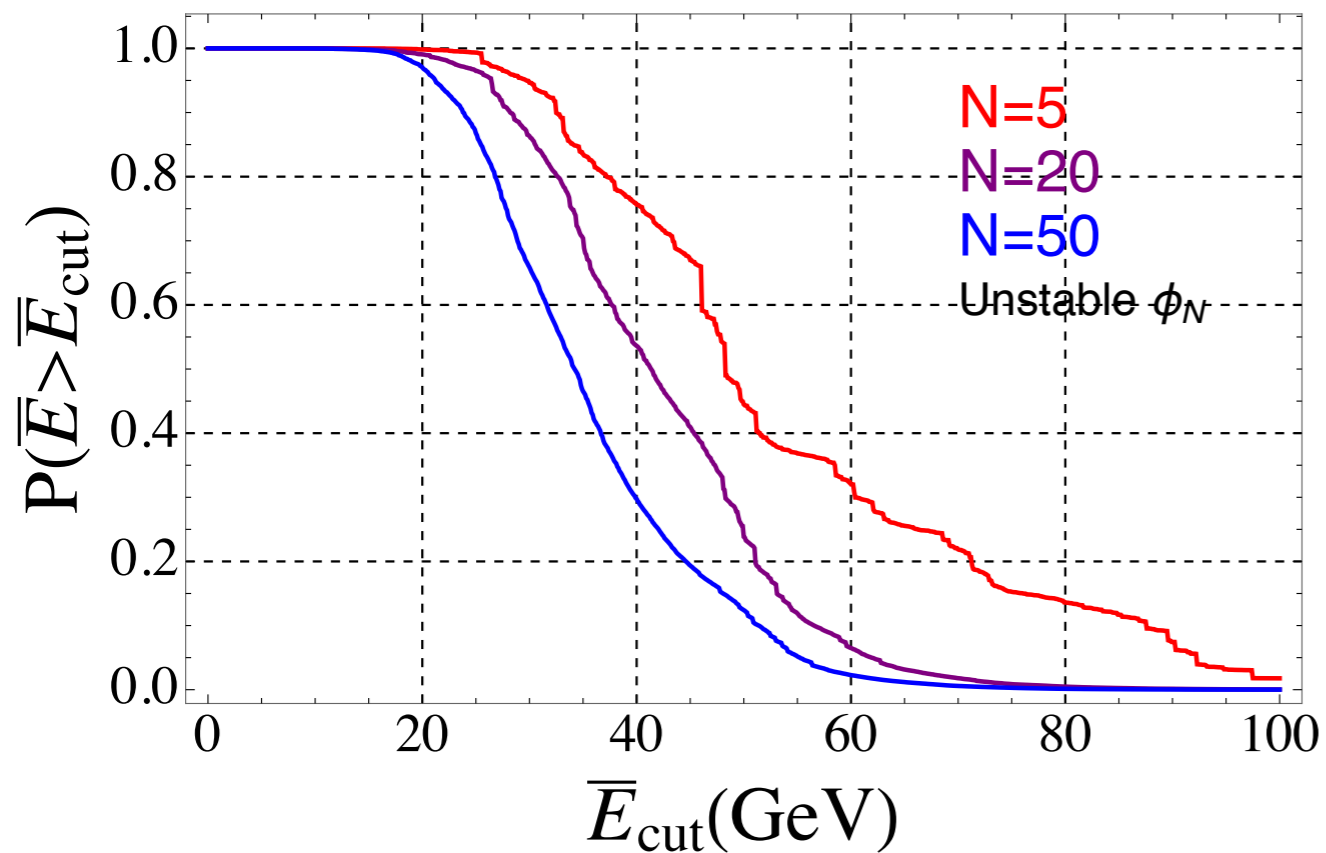
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FINAL STATE ENERGIES

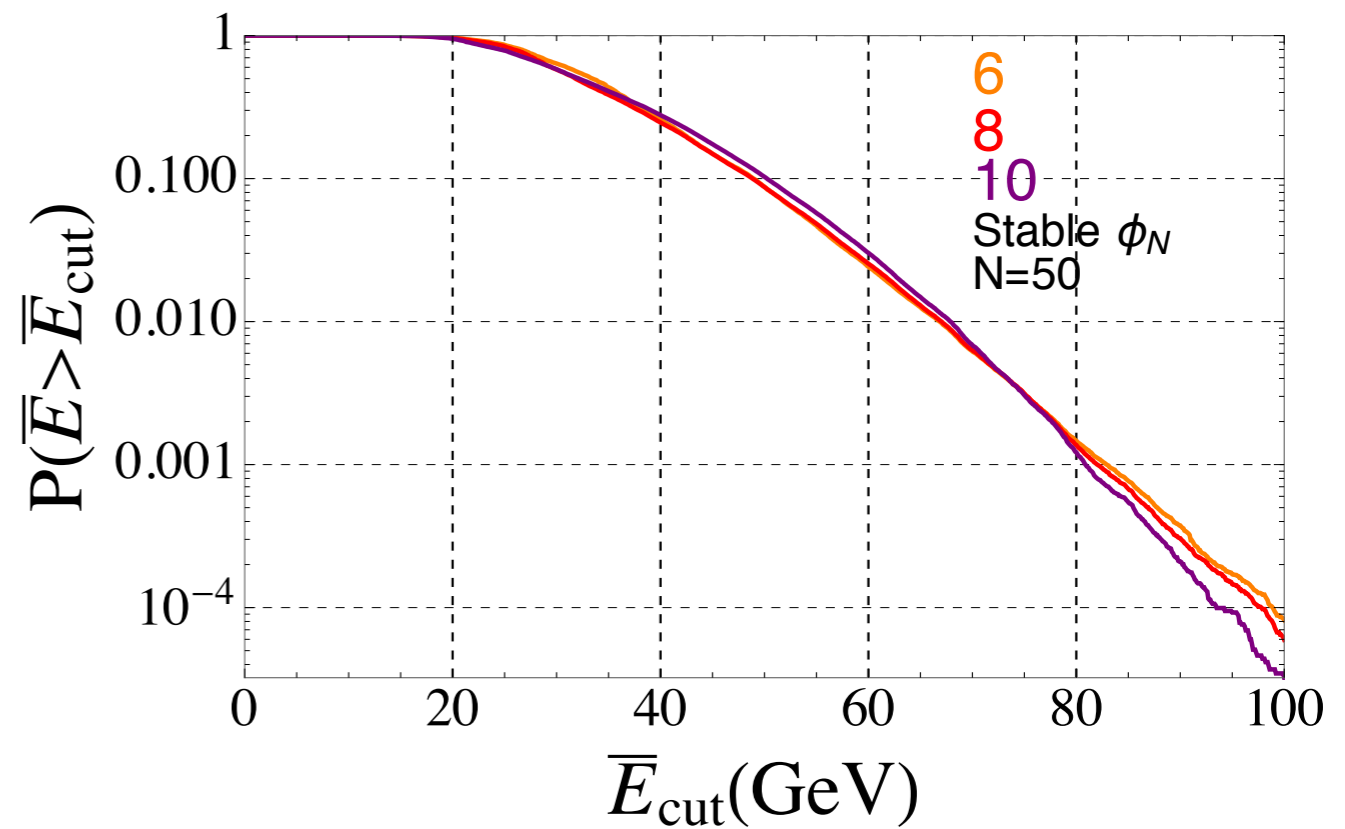
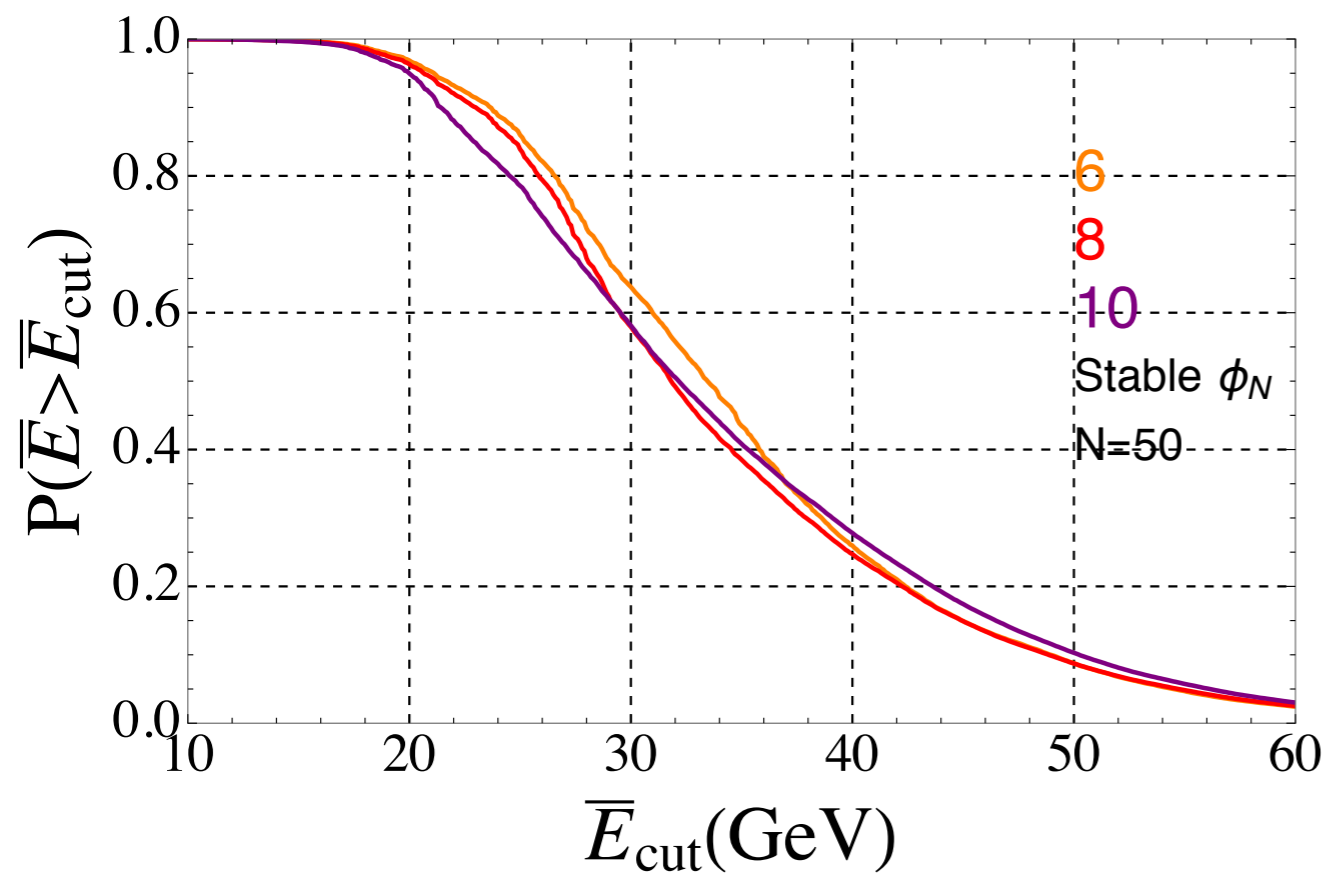
AVERAGE VISIBLE ENERGY
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TOTAL VISIBLE ENERGY
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FINAL STATE ENERGIES

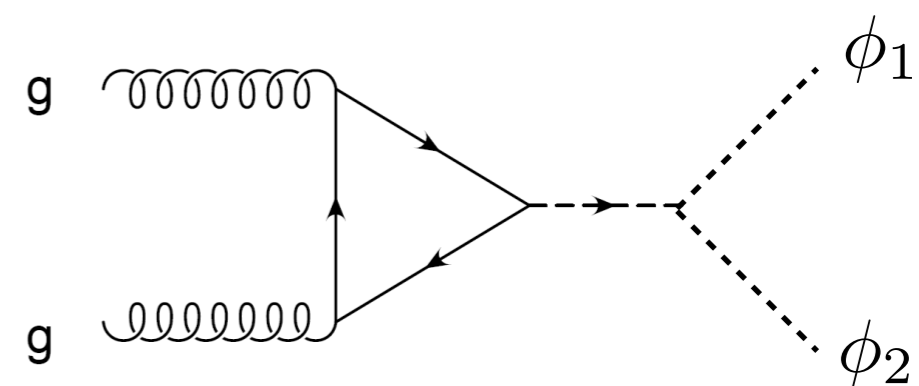
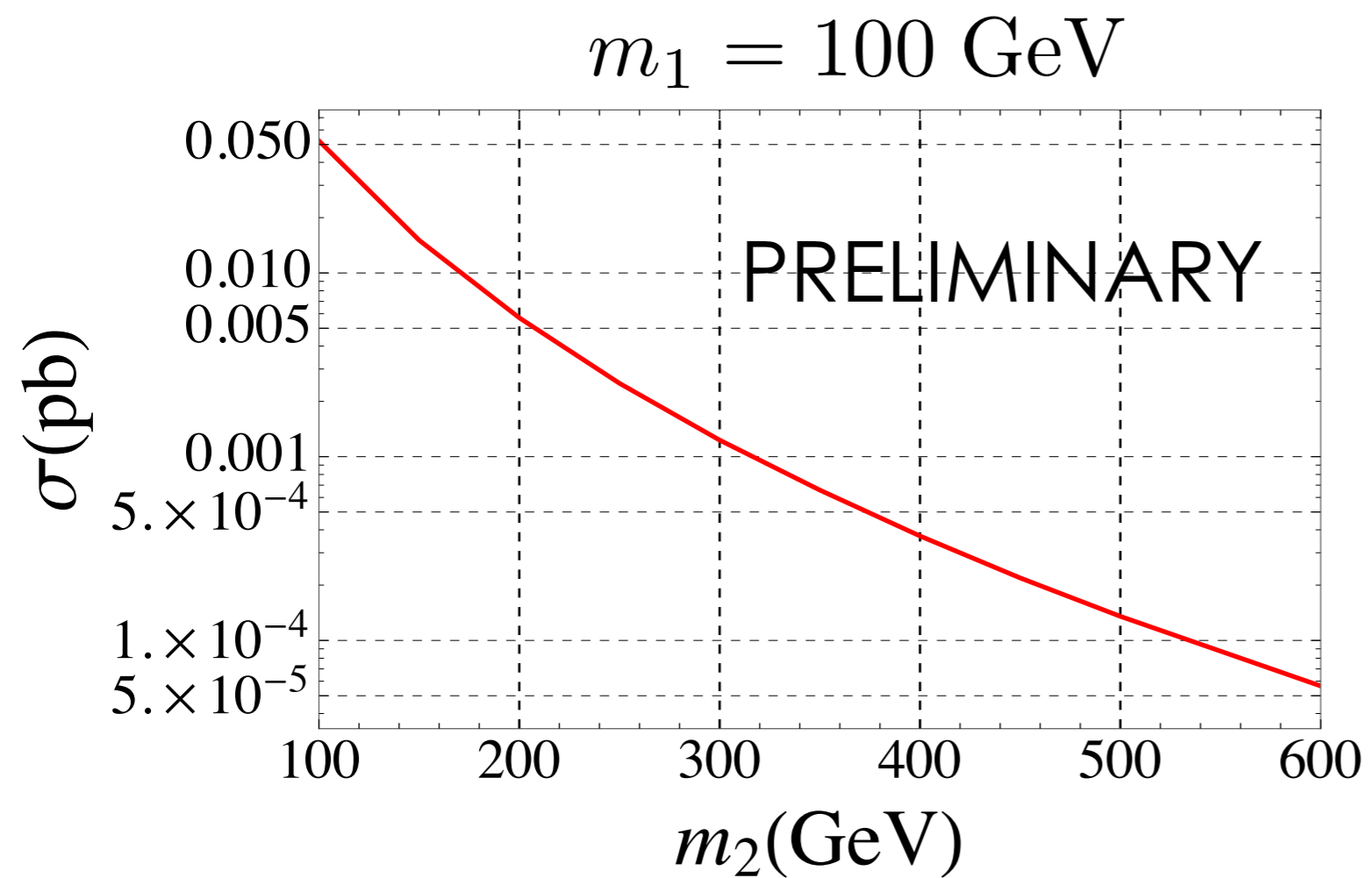
AVERAGE VISIBLE ENERGY PER PARTICLE
HIGH MULTIPLICITY EVENTS



OUTLOOK

- NEW SECTORS WITH MANY NEW PARTICLES ARE A REALISTIC POSSIBILITY WITH A PLAUSIBLE TOP-DOWN MOTIVATION FROM THEORIES WITH EXTRA DIMENSIONS, INCLUDING STRING THEORY
- A LARGE NUMBER OF NEW PARTICLES DOES NOT NECESSARILY MAKE NEW PHYSICS EASIER TO DETECT, ESPECIALLY GIVEN THE CURRENT BIAS IN THE TRIGGER TABLES TOWARDS HIGH ENERGY EVENTS
- DISORDER AND HIGH MULTIPLICITIES HAVE NOT BEEN EXPLORED MUCH AT THE WEAK SCALE, BUT THEY CAN GIVE RISE TO INTERESTING NEW PHENOMENA (MAYBE A WAY TOWARDS ANSWERING THE QUESTIONS THAT WE TRULY CARE ABOUT?)

PAIR PRODUCTION CROSS SECTION

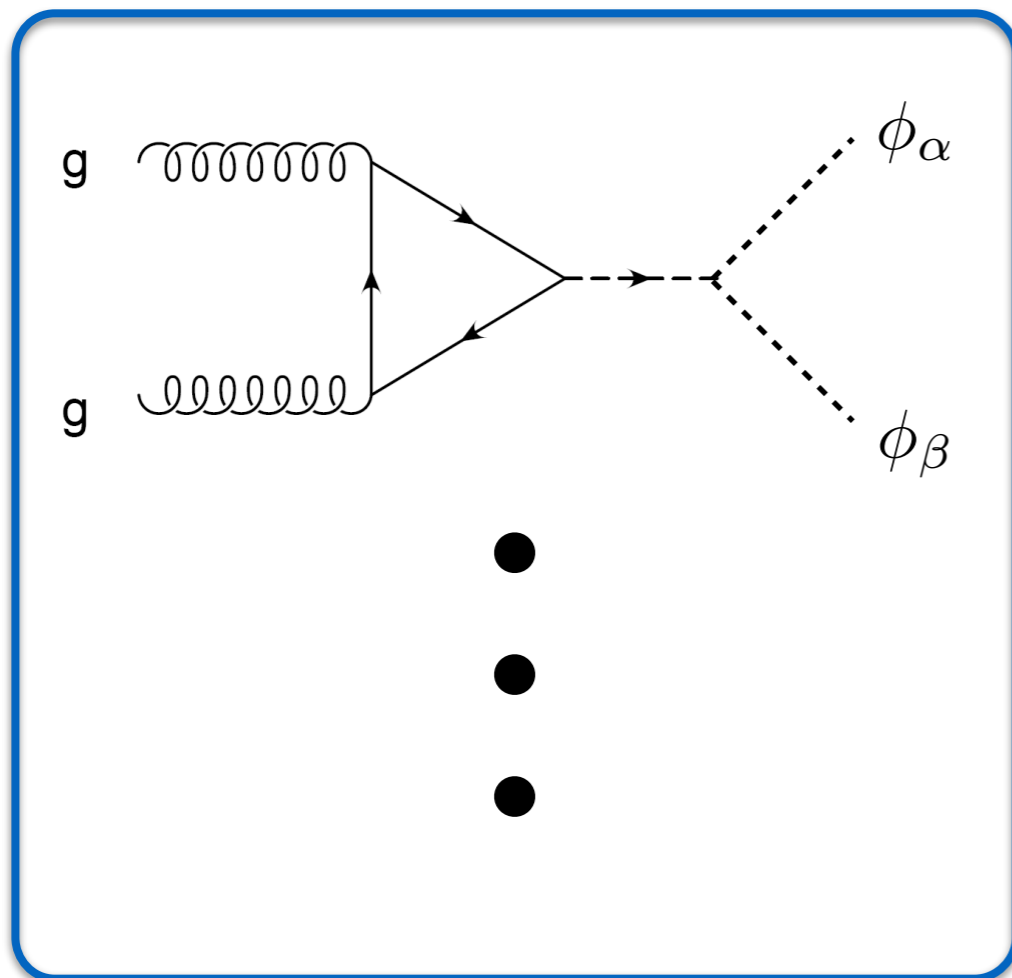


TODAY'S MODEL

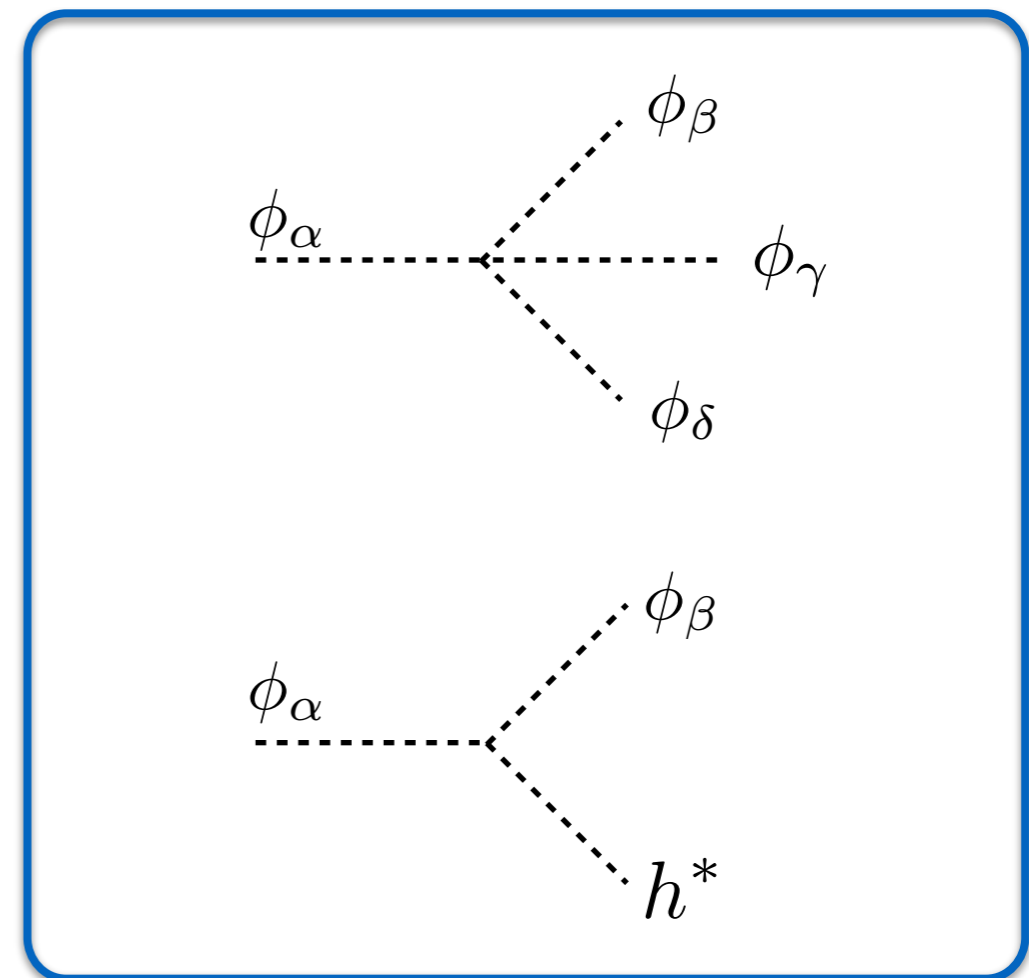
$$-\mathcal{L} \supset |H|^2 \sum_{\alpha, \beta=1}^N \lambda_{H\alpha\beta} \phi_\alpha \phi_\beta$$

$$\lambda_H \sim \frac{1}{N} \sim \lambda_{\alpha\beta\gamma\delta}$$

PRODUCTION



DECAYS

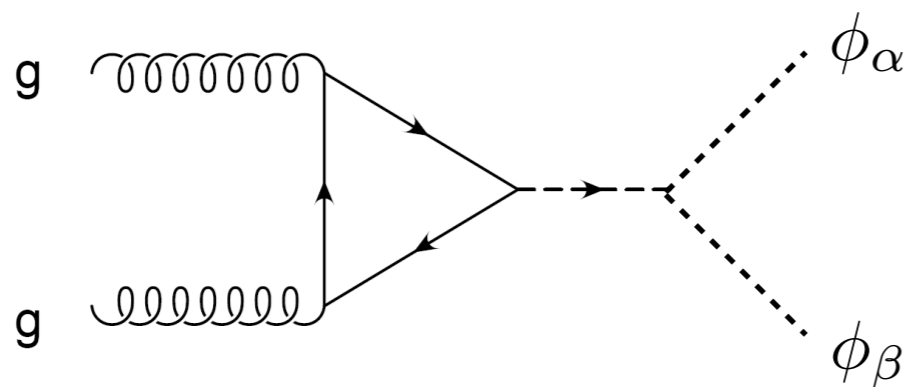


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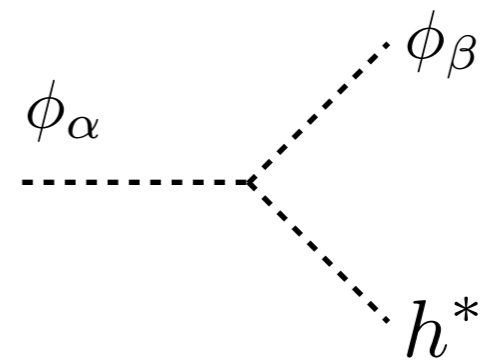
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PRODUCTION

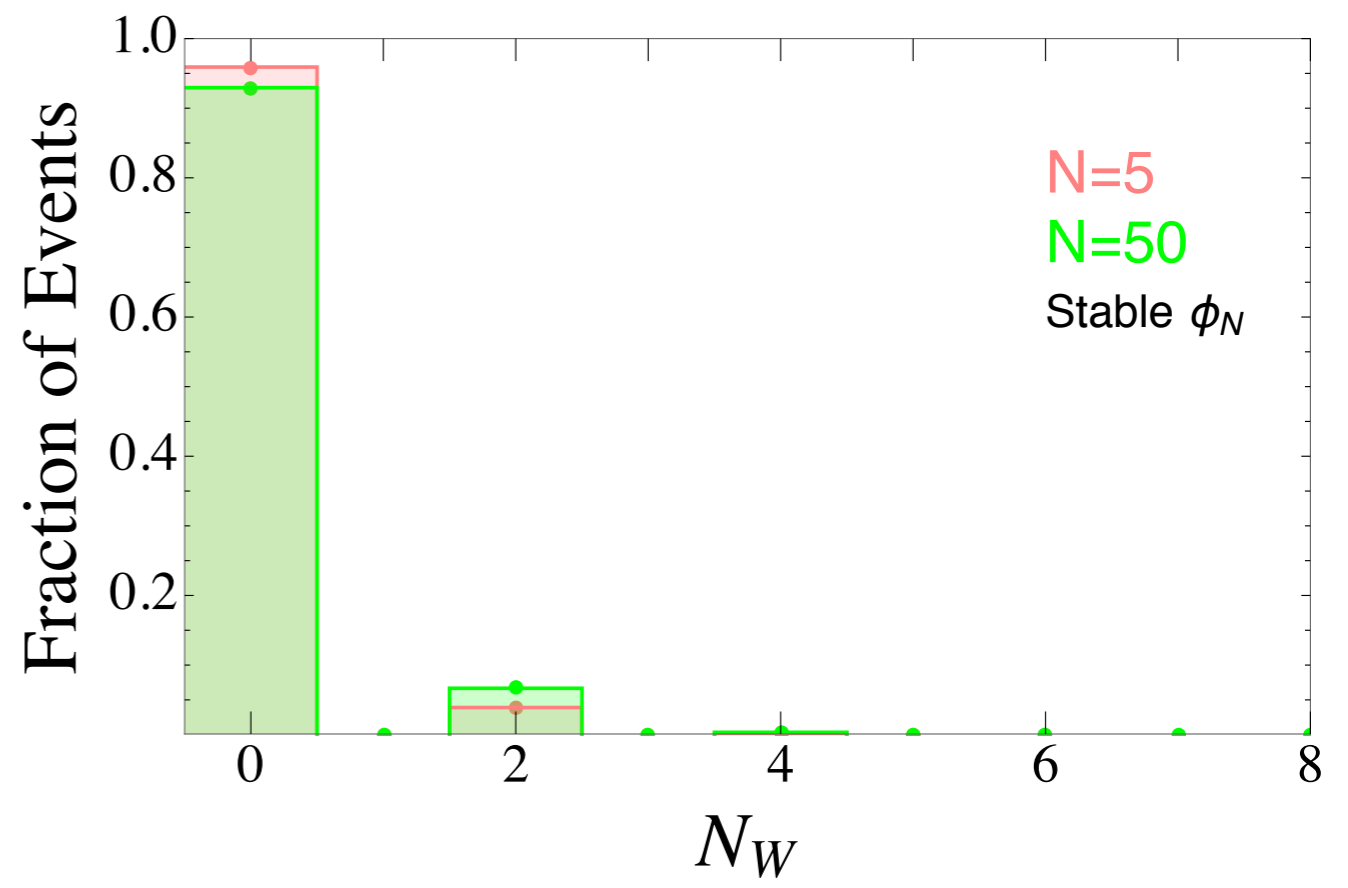
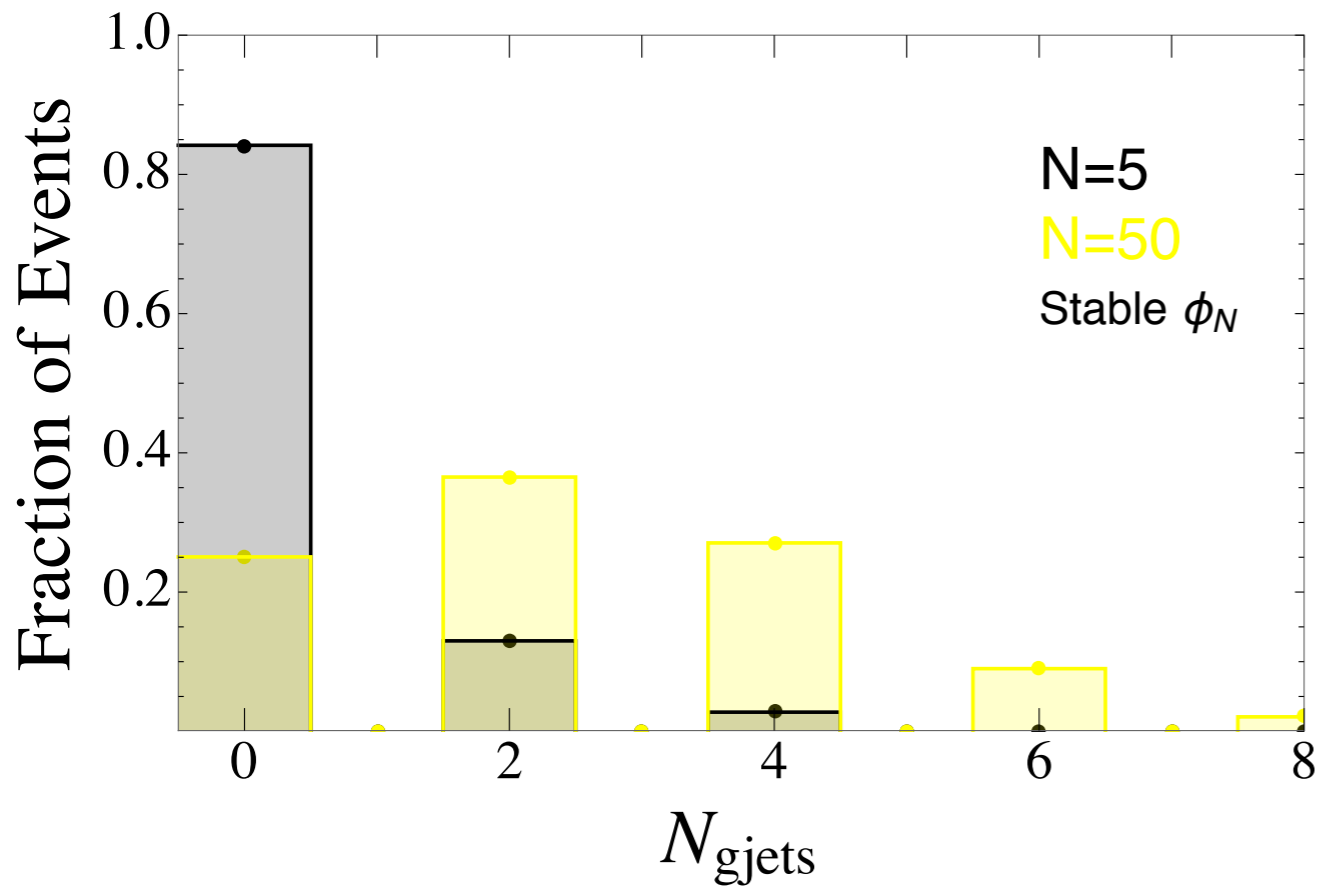
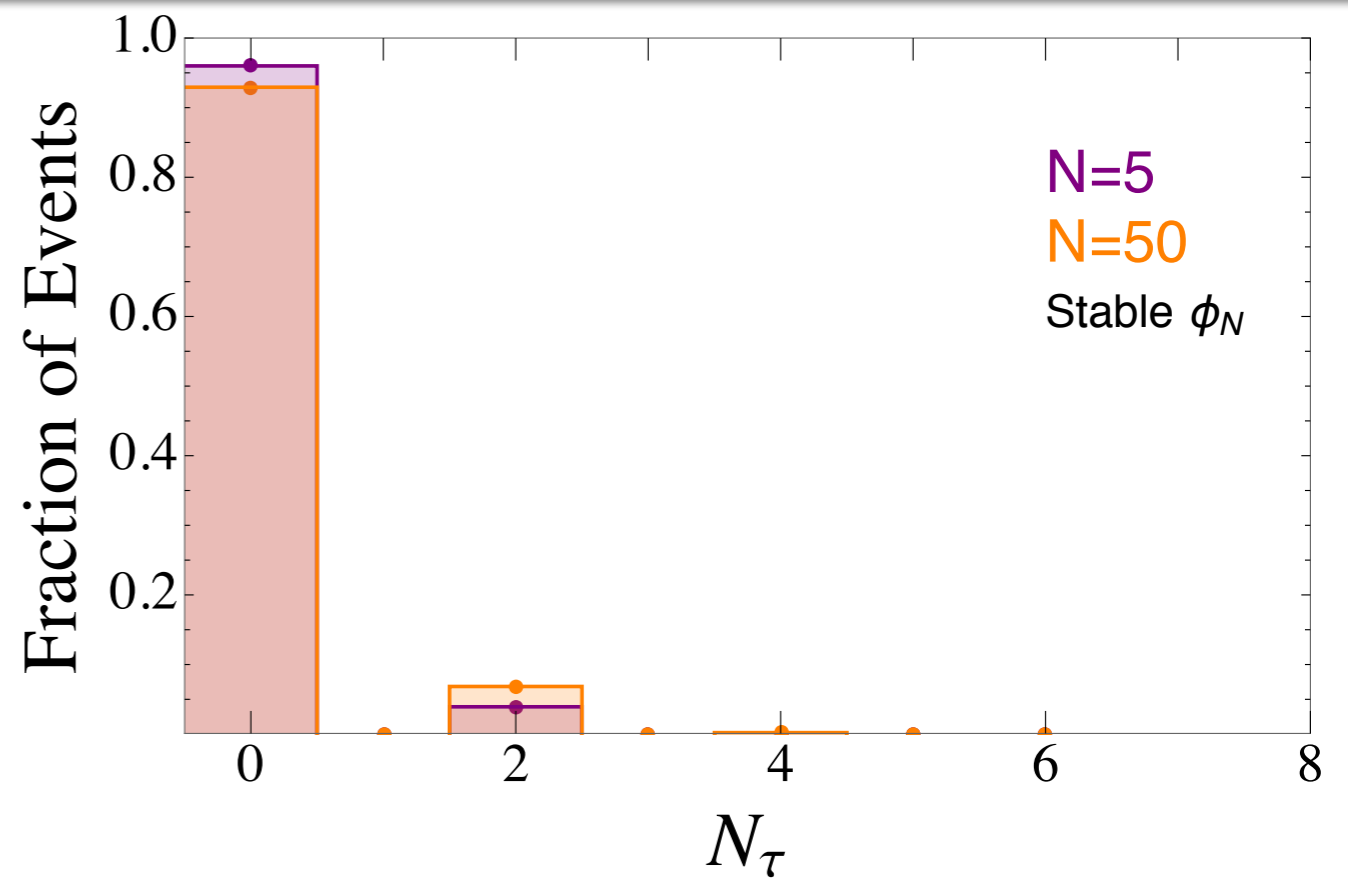
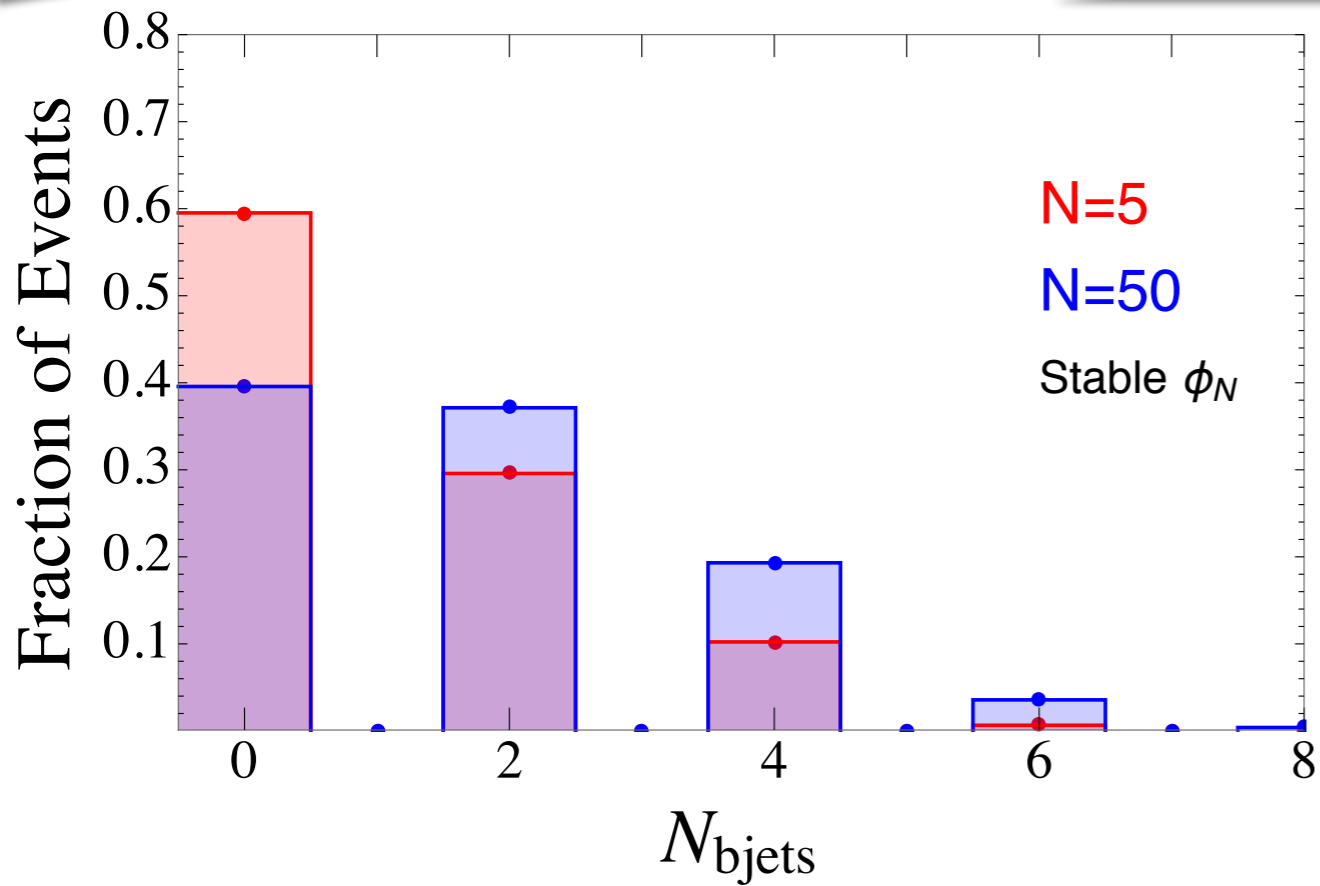


DECAYS

THE LIGHTEST NEW SCALAR IS STABLE



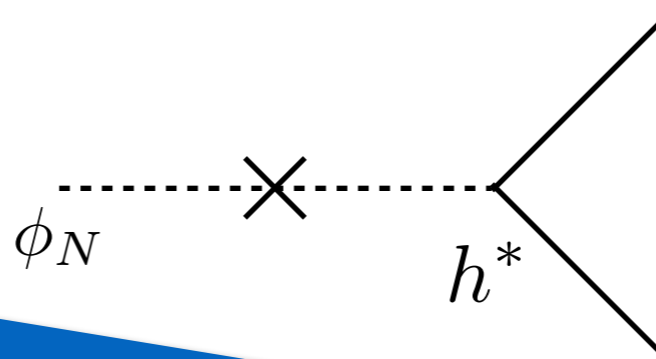
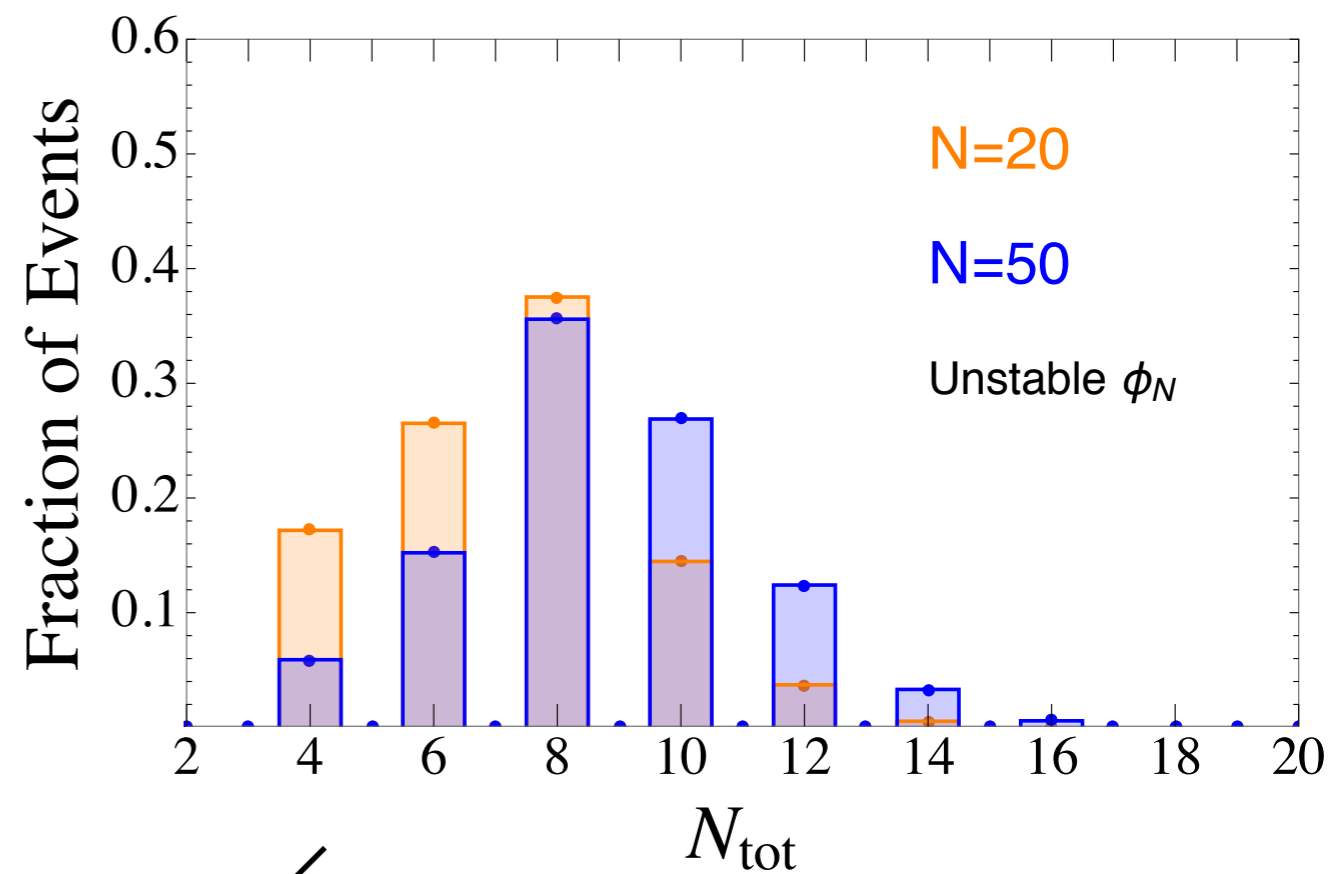
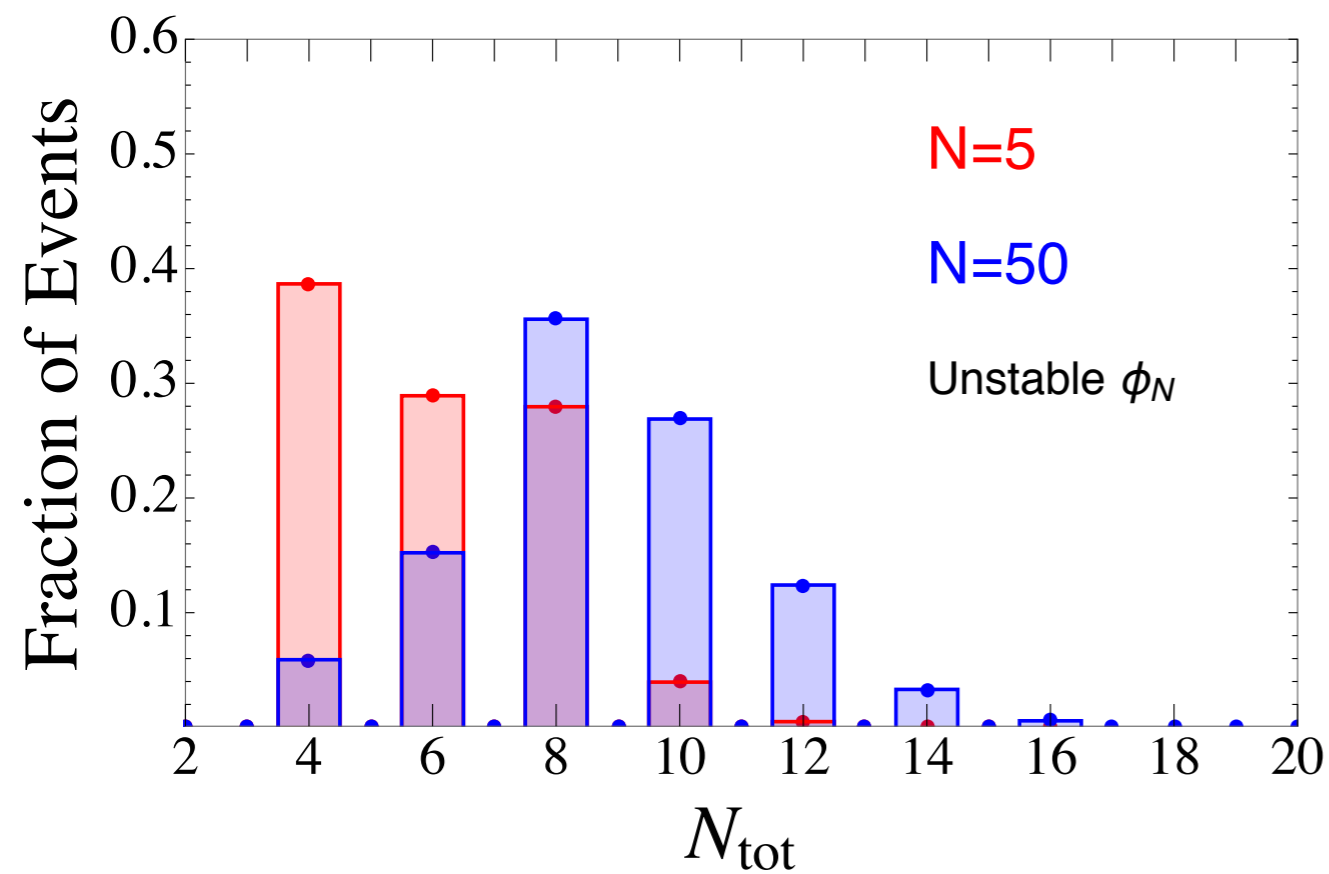
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FINAL STATE PARTICLES

