Higgs Decays to Long-Lived Particles at the Circular Electron Positron Collider

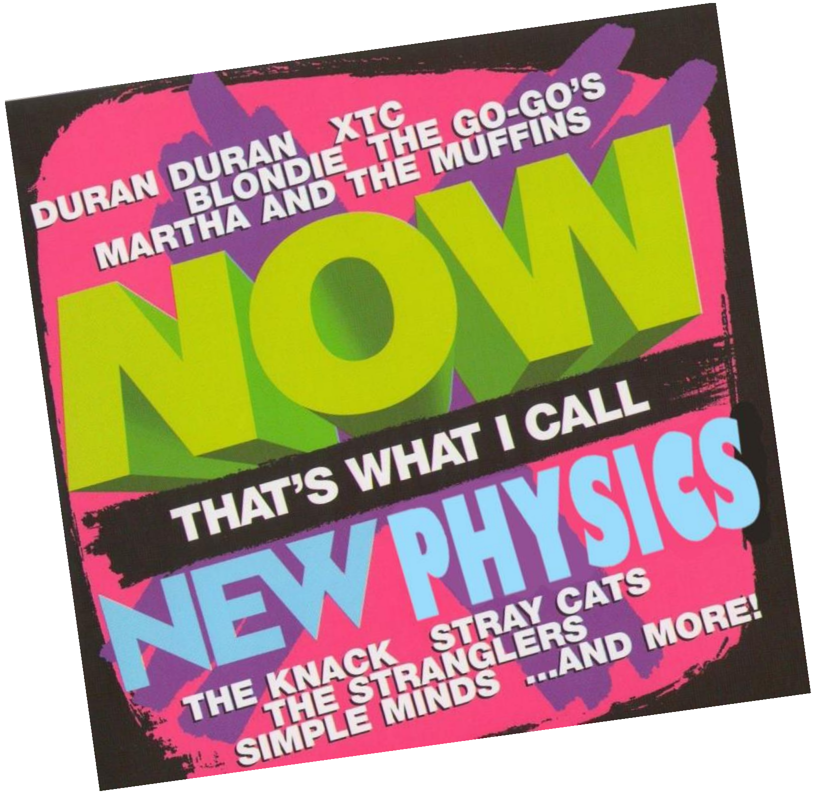
Seth Koren

UC Santa Barbara

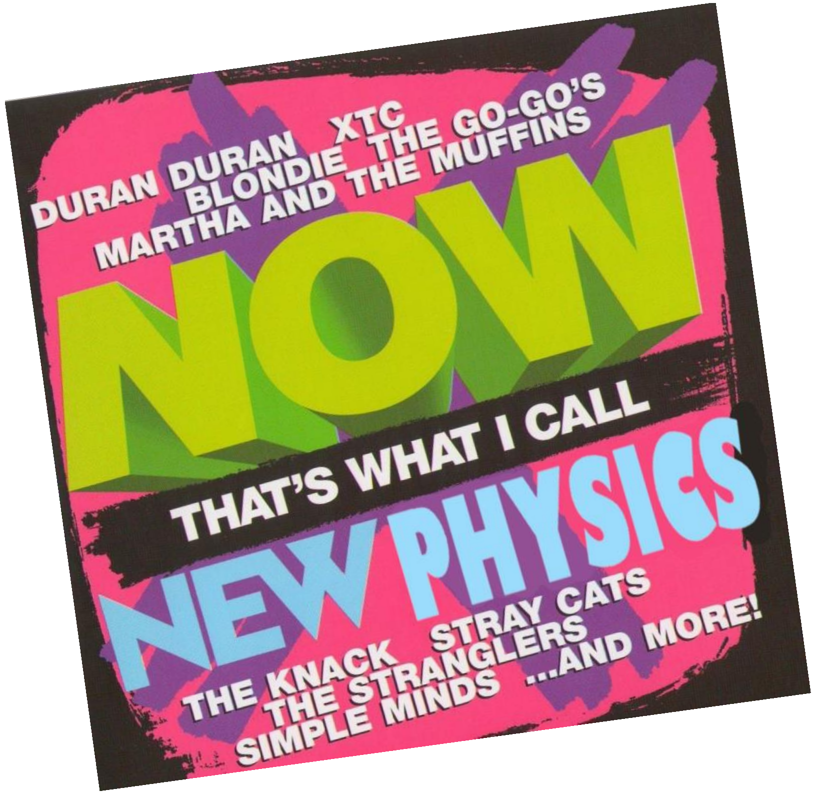
Work in progress with N. Craig and S. Alipour-Fard

Higgs

Higgs

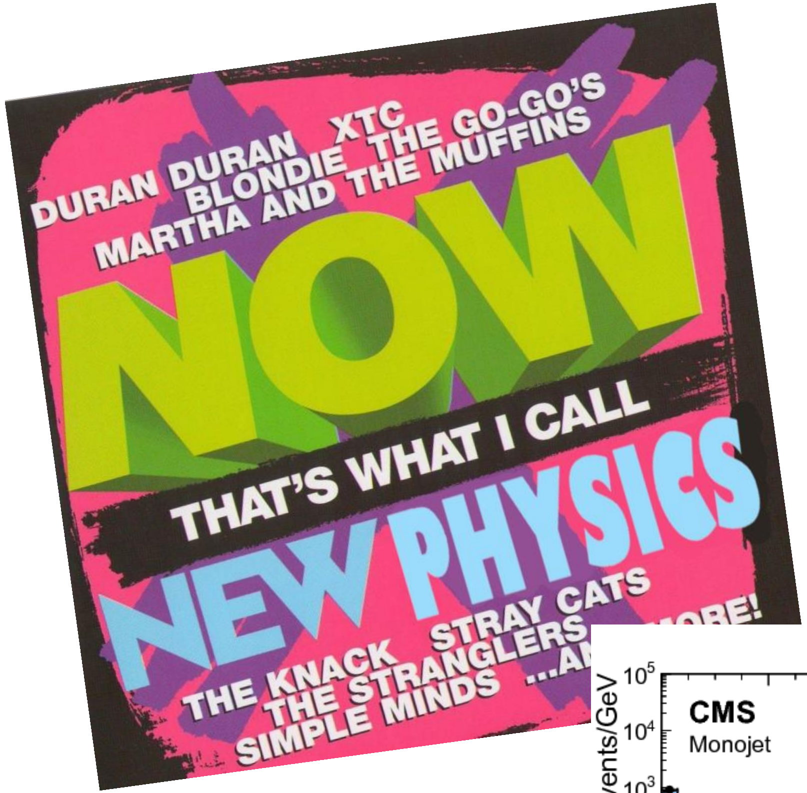

DURAN DURAN XTC
BLONDIE THE GO-GO'S
MARTHA AND THE MUFFINS
NOW
THAT'S WHAT I CALL
NEW PHYSICS
THE KNACK STRAY CATS
THE STRANGLERS
SIMPLE MINDS ...AND MORE!

Higgs



$$\mathcal{L} \supset |H|^2 \mathcal{O}_{\text{Dark}}$$

Higgs



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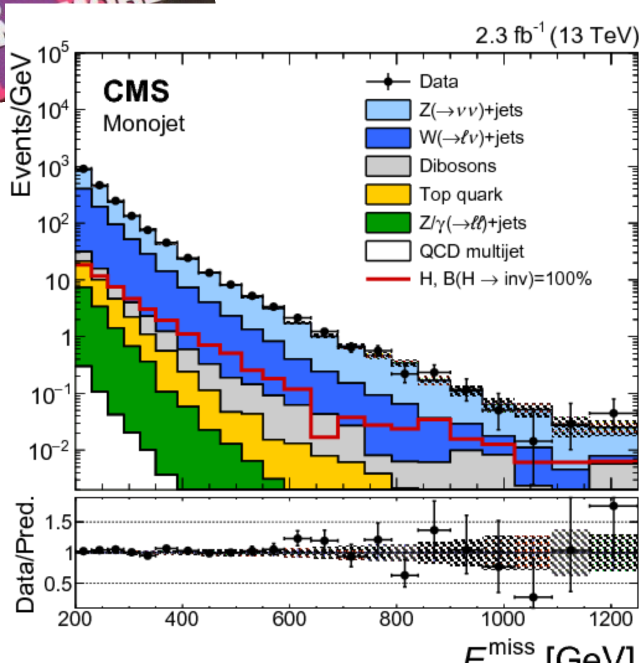
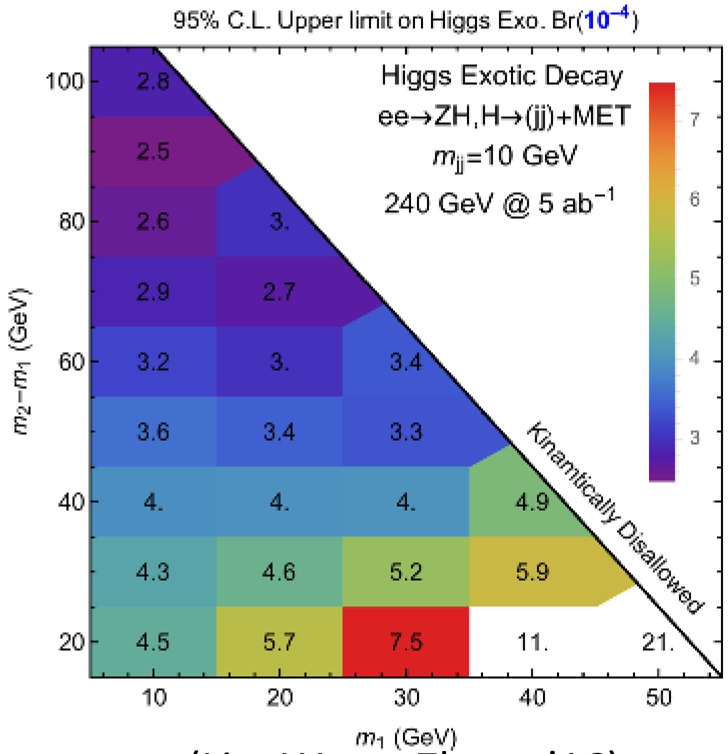


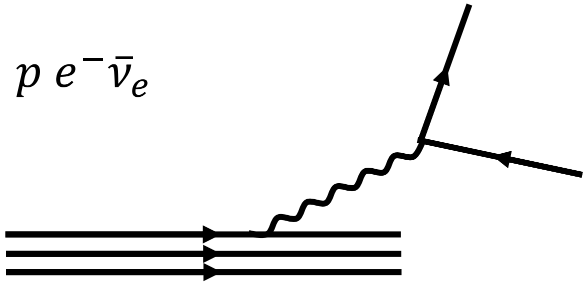


(Liu, Wang, Zhang '16)

Long-Lived Particles

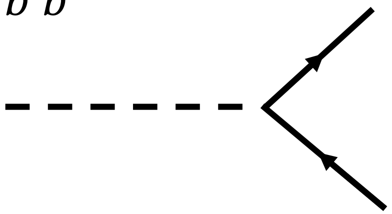
All over the SM!

$n \to p\, e^- \bar{\nu}_e$



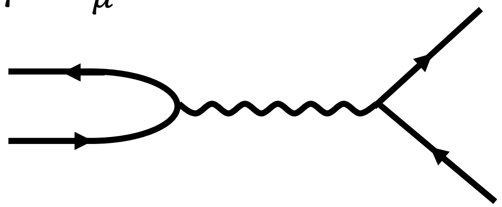
$$\Gamma \propto \left(m_p - m_n\right)^5$$

$h \to b\, \bar{b}$



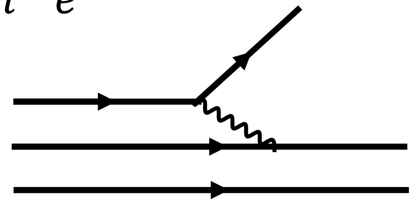
$$\Gamma \propto y_b^2$$

$\pi^+ \to \mu^+\, \nu_\mu$



$$\Gamma \propto \left(\frac{m_\pi}{m_W}\right)^4$$

$p \to \pi^0\, e^+$



$$\Gamma \propto \left(\frac{m_p}{m_{GUT}}\right)^4$$

See MATHUSLA Physics Case 1806.07396 for thorough discussion of well-motivated BSM analogues

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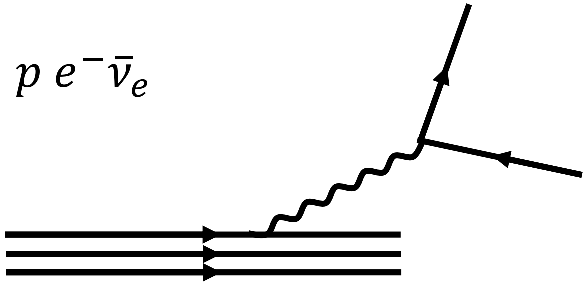

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Small Splitting

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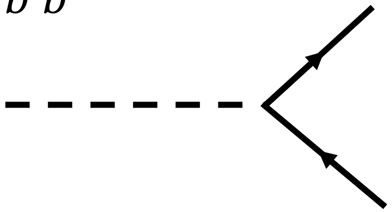

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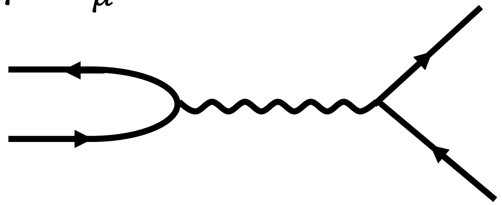

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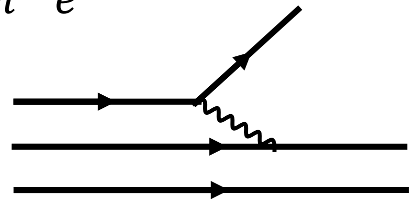

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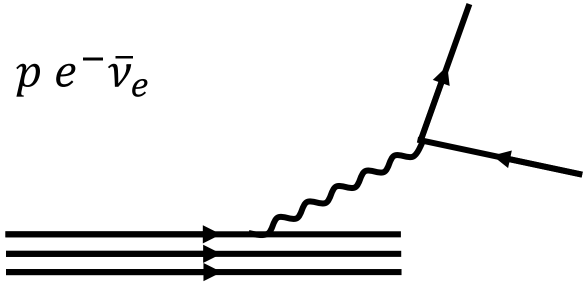

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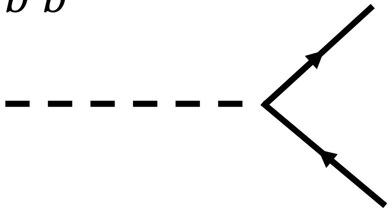

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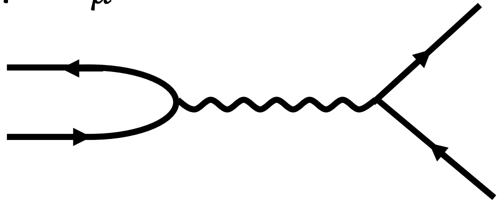

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Off-Shell Decay

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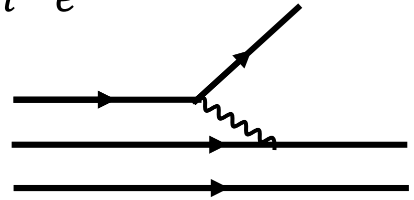

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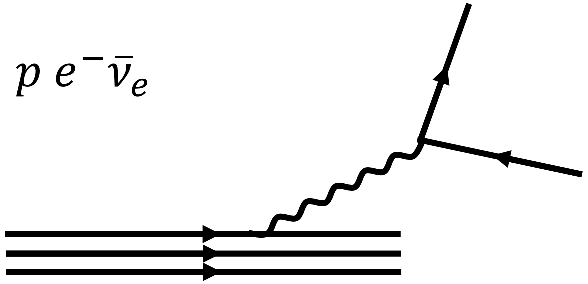

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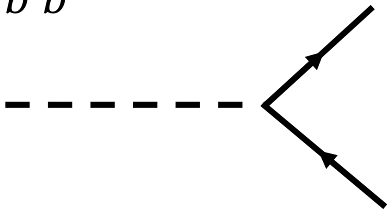

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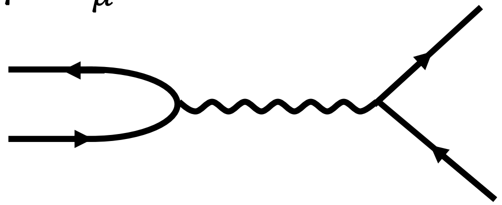

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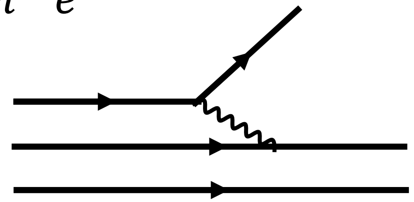

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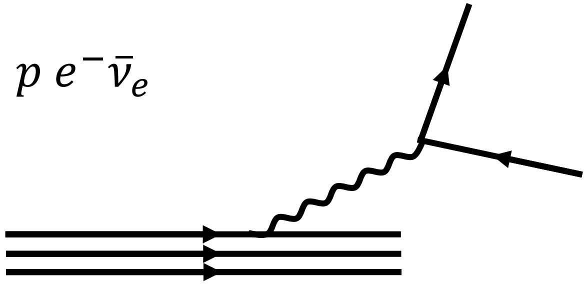

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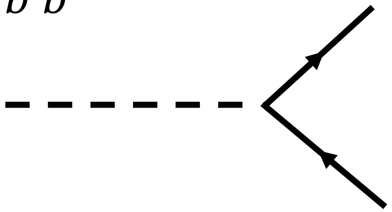

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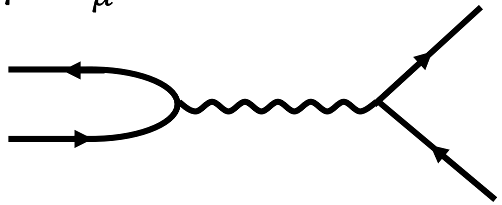

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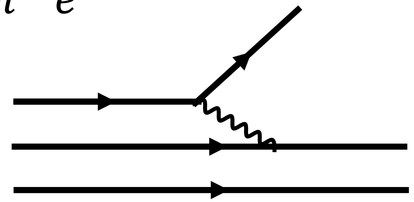

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Approximate(?) Symmetry

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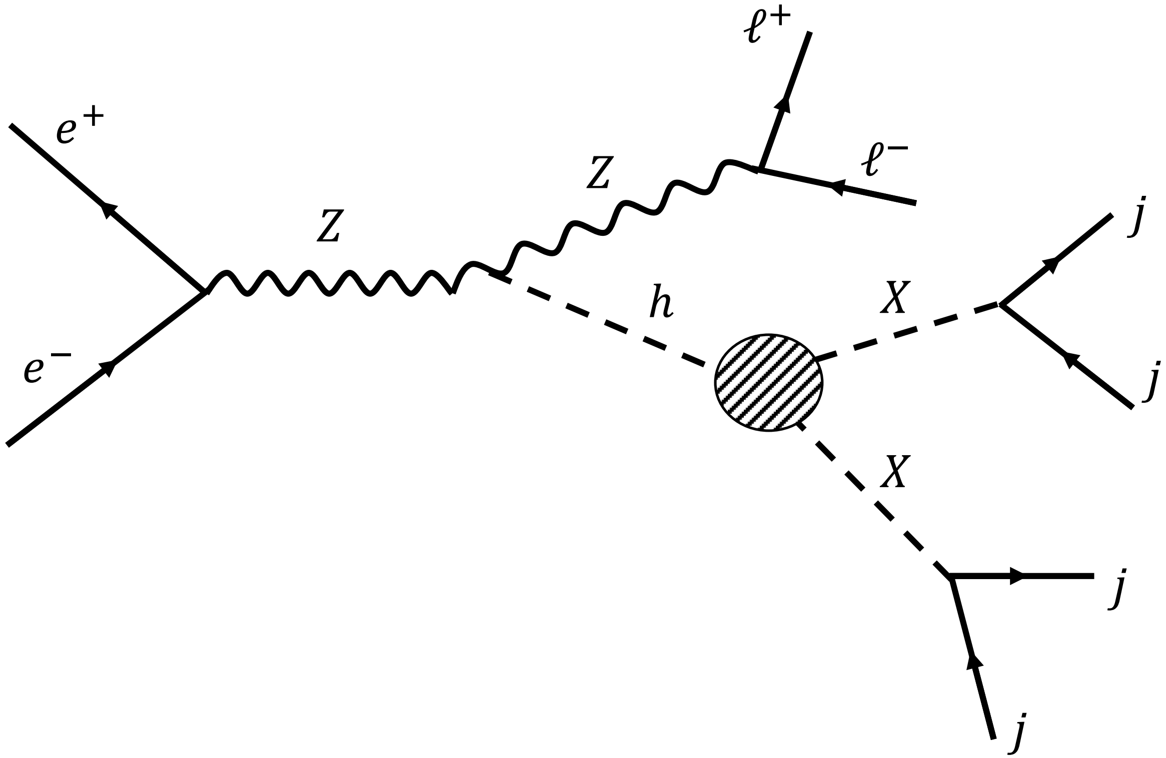
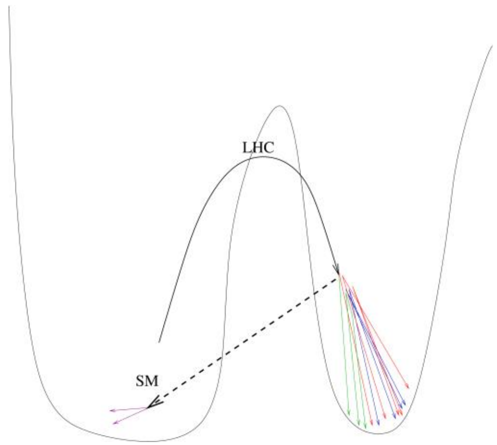
Exotic Higgs Decays Signal Model



Generally, a Higgs portal
`Hidden Valley‘ scenario (Strassler, Zurek ‘06)

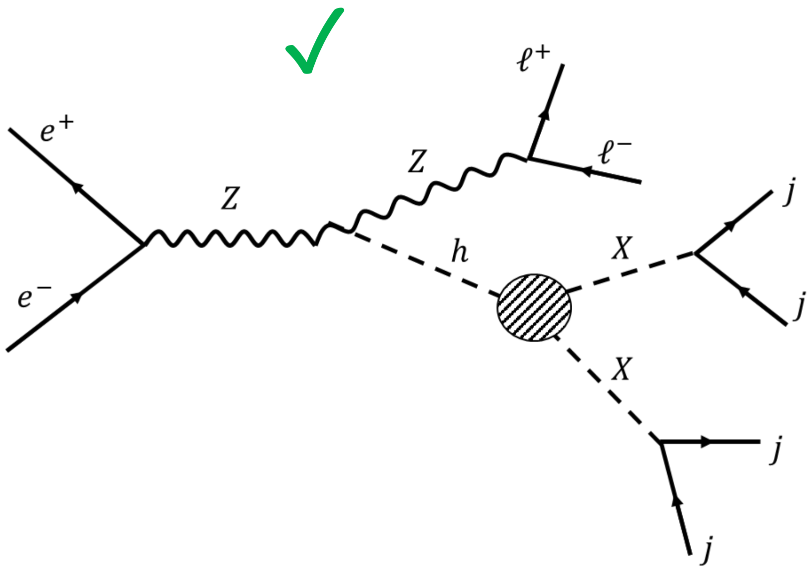


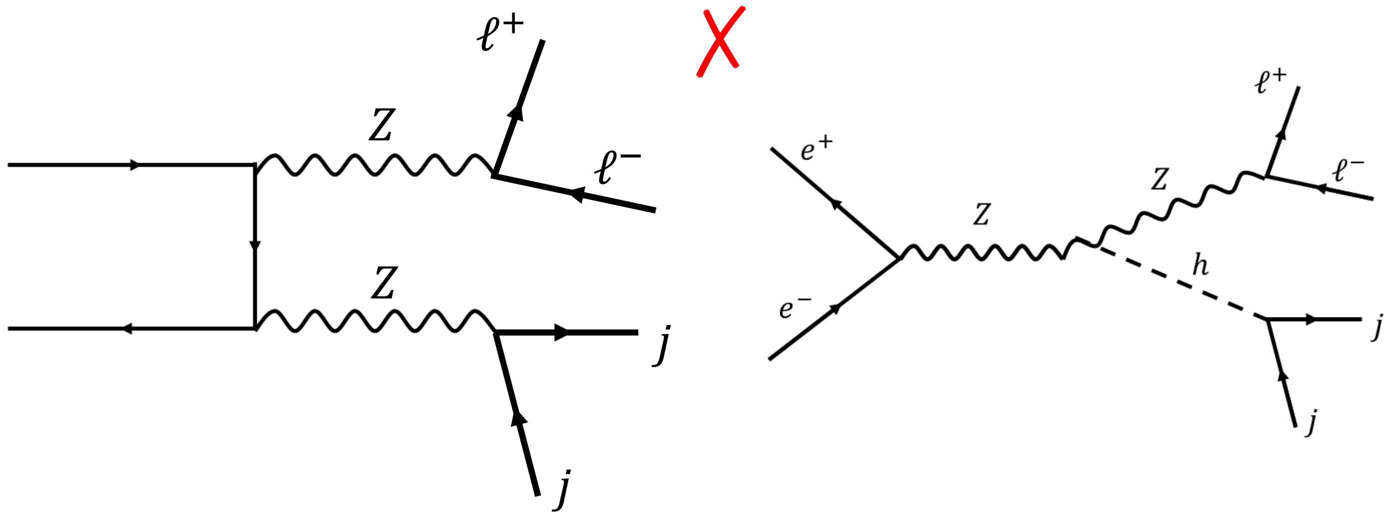
(Strassler ‘08)

E.g. Fraternal Twin Higgs with $X = 0^{++}$ glueball
(Craig, Katz, Strassler, Sundrum ‘15)

For faithful forecasting we have to account for backgrounds and efficiency!

Backgrounds and Analysis



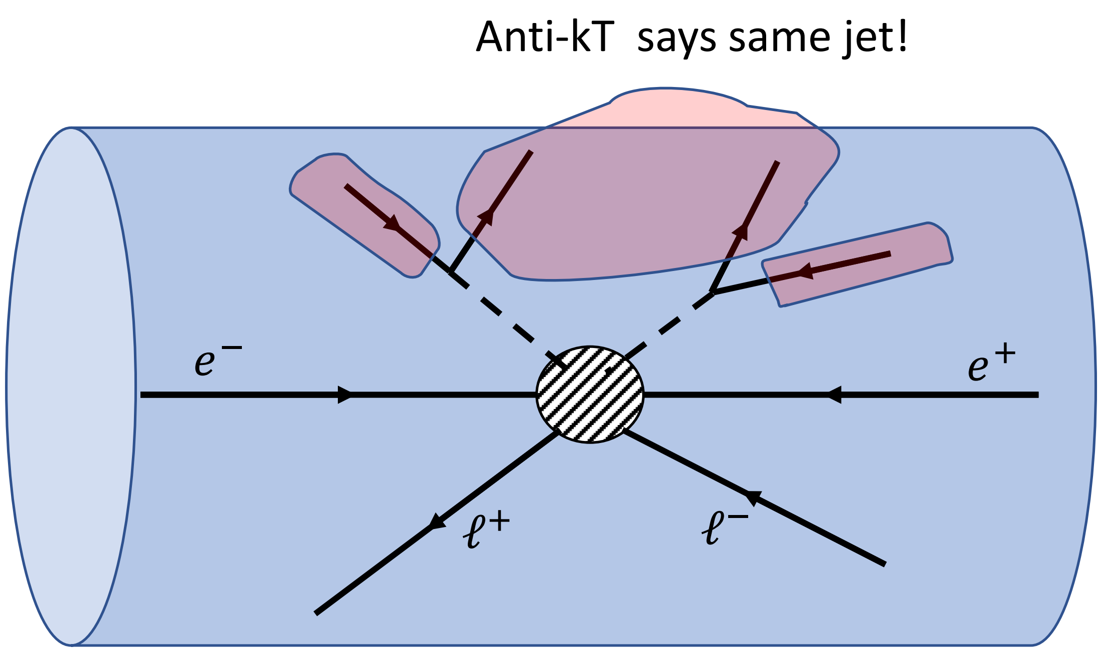


`Prompt'/Standard cuts
- Lepton invariant mass
- Recoil mass

But displaced vertices are exotic, striking signatures of new physics! Utilize them!
Strategies:
- Displaced dijet invariant mass
- Locate displaced secondary vertices
- Remove SM long-lived hadron background

Displaced Jets!?

Standard jet algorithms in Delphes perform badly on displaced jets



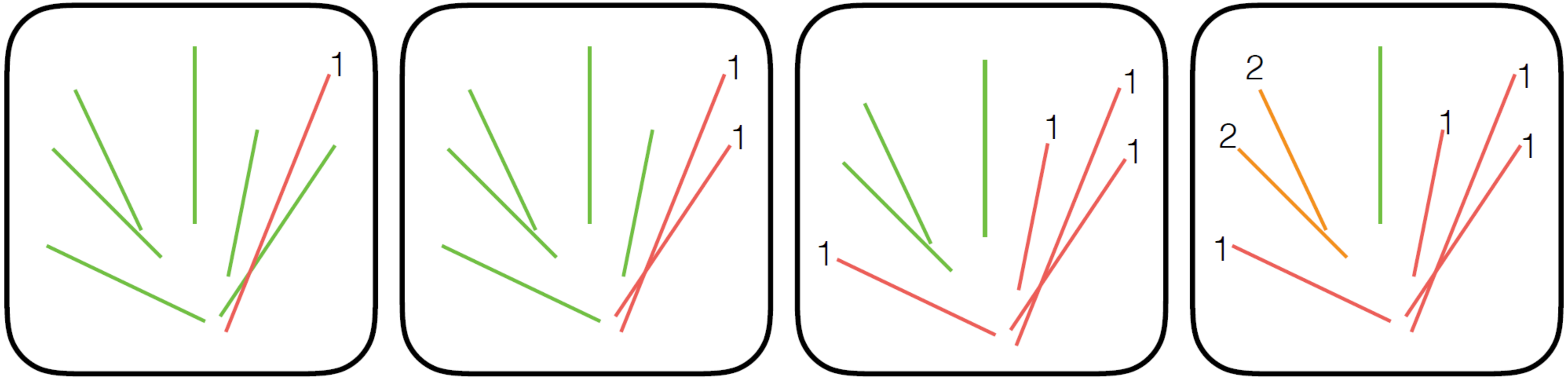
This poses a challenge for faithful simulation and forecasting

Future: Particle-flow algorithm?
Providing guidance to Delphes?
Machine learning?!

For now: Avoid dealing directly with jets and make use of secondary vertex identification.

Secondary Vertex Identification

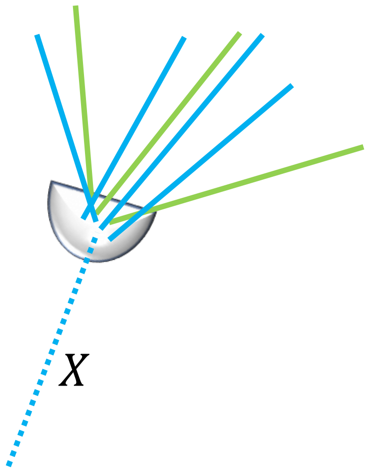
Perform depth-first `clustering' of particles to form candidate vertices



Secondary vertex then identified as displaced cluster ($> 10\ \mu m$) closest to beamline

~~Dijet~~ Cluster Invariant Mass

Can’t faithfully construct jet objects, so instead make use of our clustering algorithm

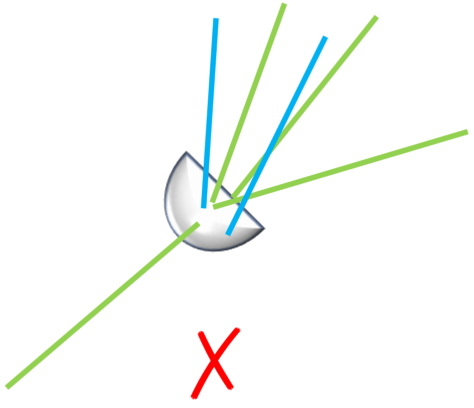


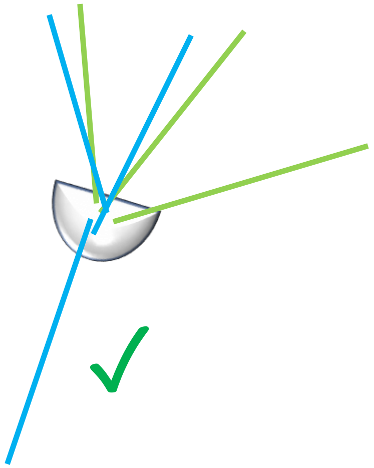
$$\left(\sum_{i\in\text{Cluster}} p_i\right)^2 = m_X^2$$

Apply `smearing’ to account for dijet resolution, then require $m_{cluster} \leq m_h/2$

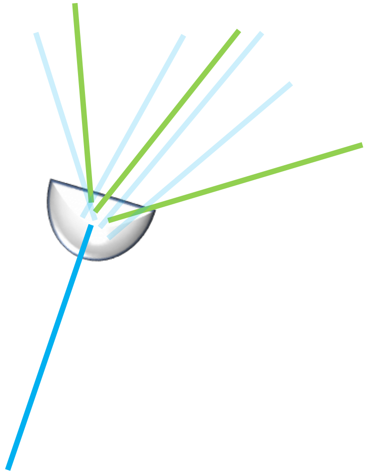
Removing Long-Lived Hadrons

Cut on `pointer tracks' from PV to cluster





For long-lived neutral hadrons use invariant mass of charged tracks in cluster



Require

$$\left(\sum_{\substack{i\in\text{Cluster}\\ i\text{ Charged}}} p_i\right)^2 \geq 6\text{ GeV}$$

Preliminary Results

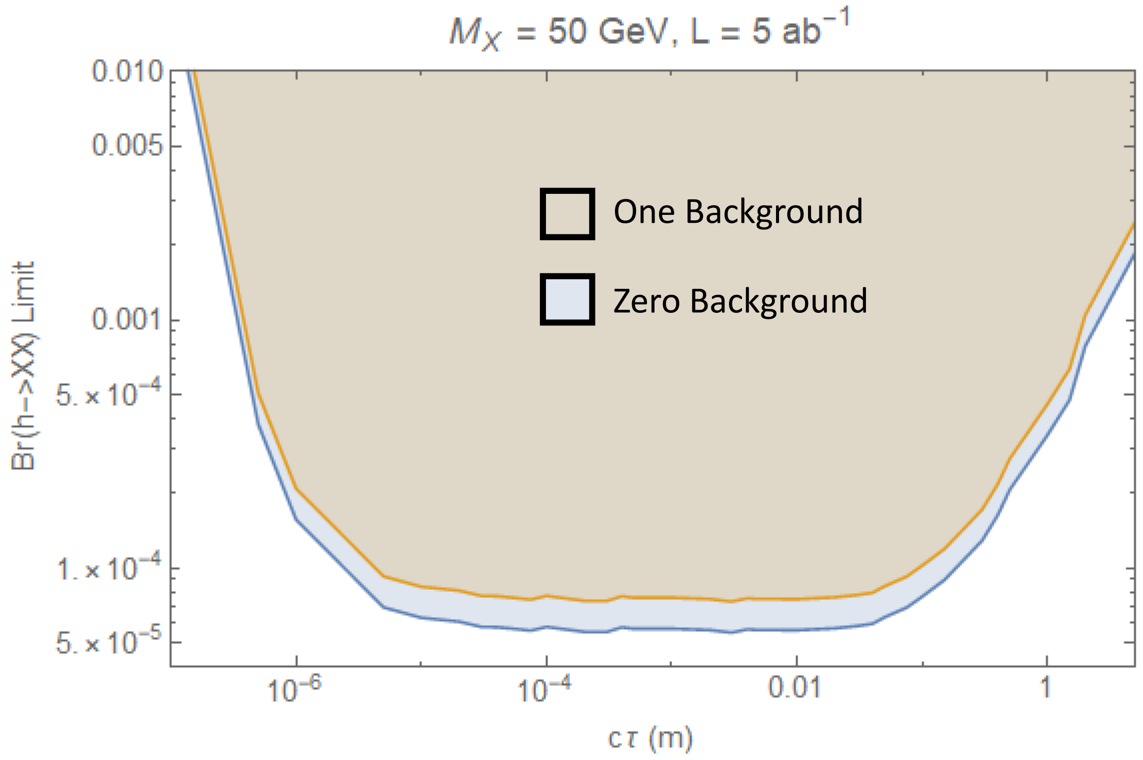
Acceptance x Efficiency

$\boldsymbol{M_X = 50\ \mathrm{GeV}}$

	$ZH \to (\ell\ell)(j\,j)$	$ZZ \to (\ell\ell)(j\,j)$	$c\tau = 10\ \mathrm{mm}$	$c\tau = 10\ \mathrm{cm}$	$c\tau = 10\ \mathrm{m}$
$M_{\ell\ell}$	0.968	0.997	0.961	0.964	0.960
m_{recoil}	0.942	0.001	0.951	0.954	0.951
Displaced Cluster	0.942	0.001	0.951	0.954	0.201
Charged Invt Mass	0.001	0	0.939	0.940	0.180
\`Dijet' Invt Mass	0.001	0	0.910	0.911	0.162
Pointer Track	0	0	0.907	0.911	0.160

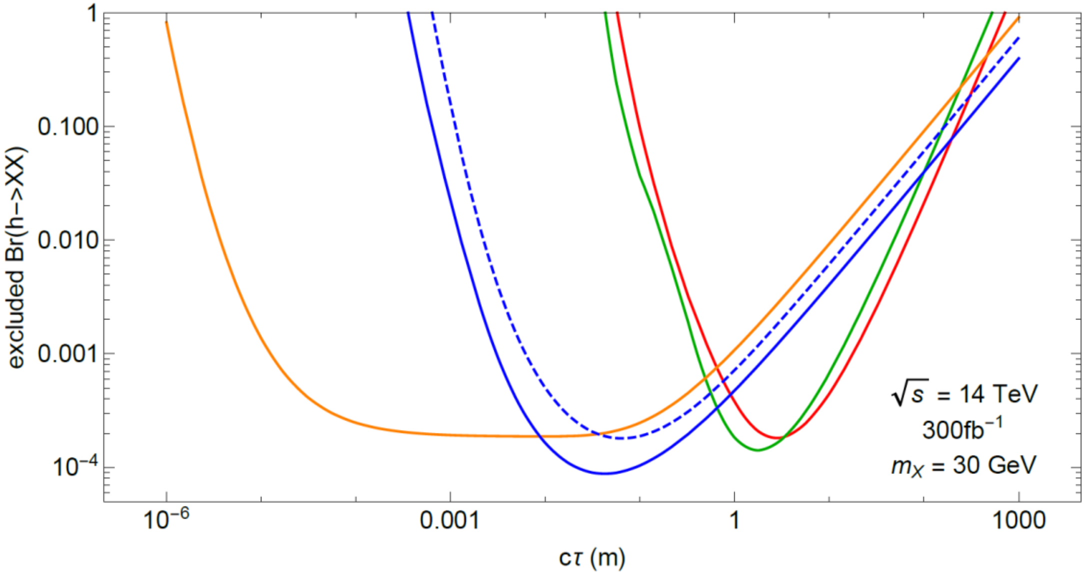
Comparison with LHC

This work



No official projections (yet) for LHC14, just theory estimates

(Curtin & Verhaaren, `15)



(See also Csaki, Kuflik, Lombardo, Slone `15)

LHC produces more total Higgses, but CEPC has better impact parameter resolution, better vertex reconstruction, and cleaner environment.

Conclusions

- Exotic Higgs Decays to LLPs are a well-motivated place to look for new physics and probe Higgs properties
- Forecasting sensitivity with displaced vertices is difficult, and requires further concerted effort from the community
- Now is the time for this work so we can inform detector design
- CEPC can improve on the LHC in searching for such rare decays