LHC Implications of WIMP Dark Matter and Grand Unification

Can Kilic, K. K., Takemichi Okui: Phys.Rev. D83 (2011) 015006

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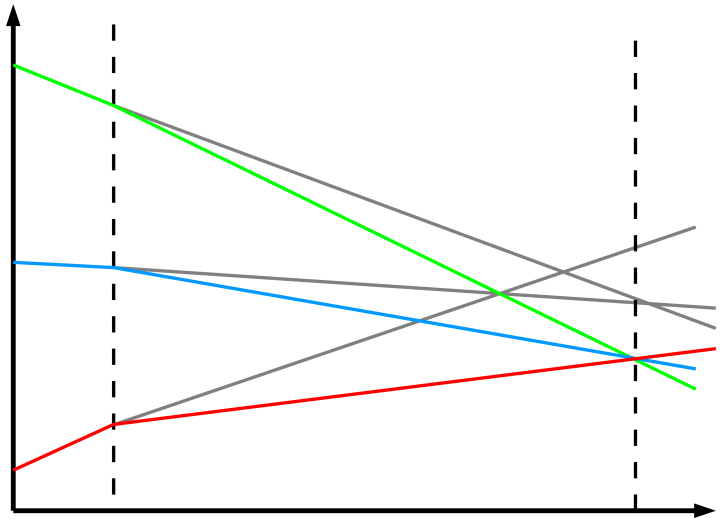
Florida State University

SUSY '11

August 29, 2011

Unification



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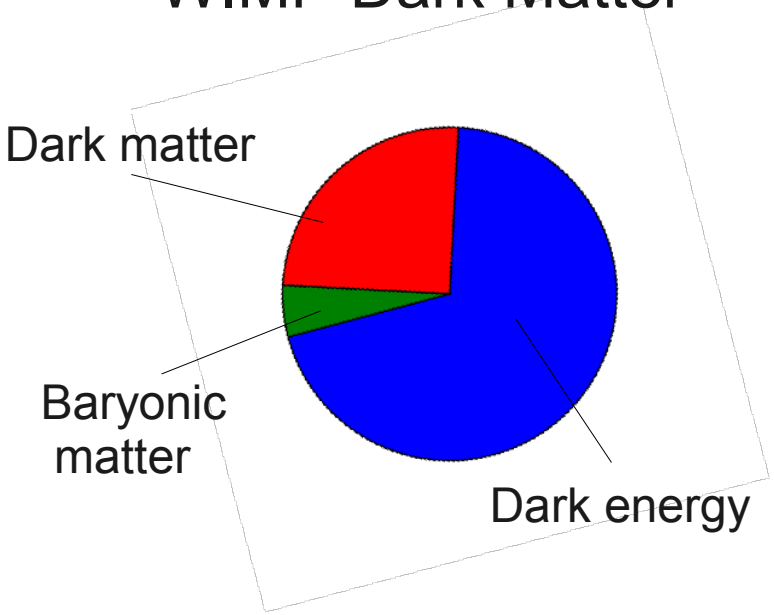
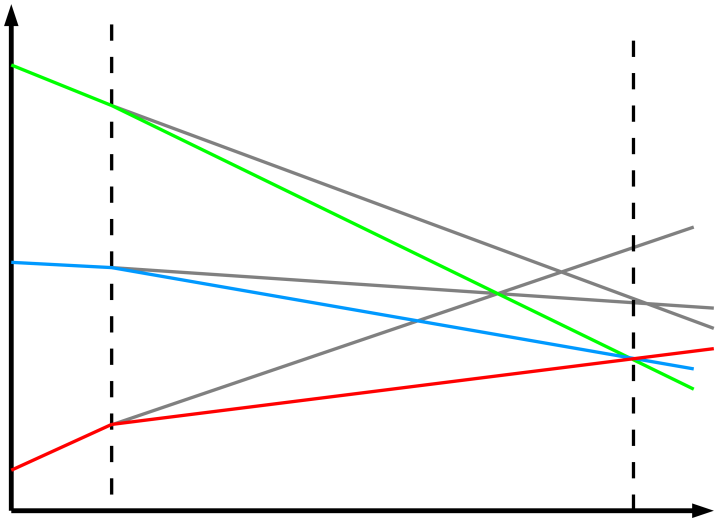
WIMP Dark Matter



Unification



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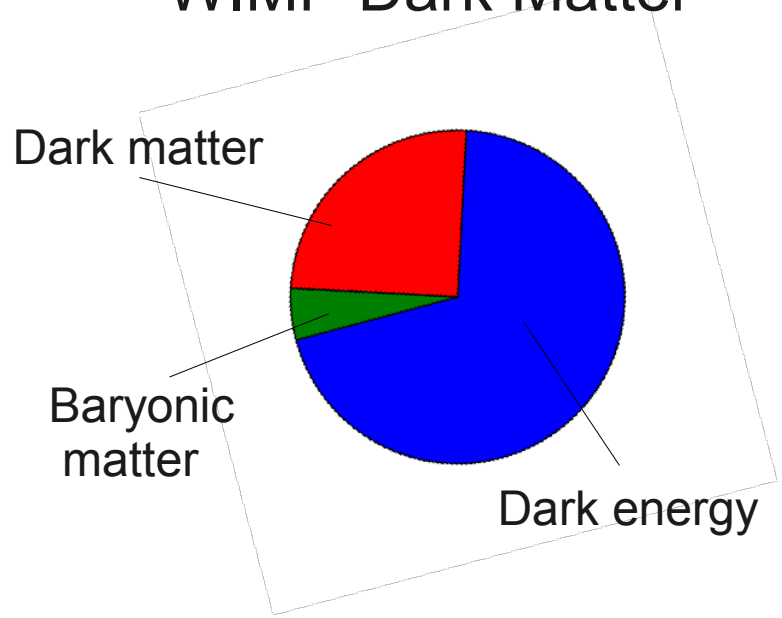


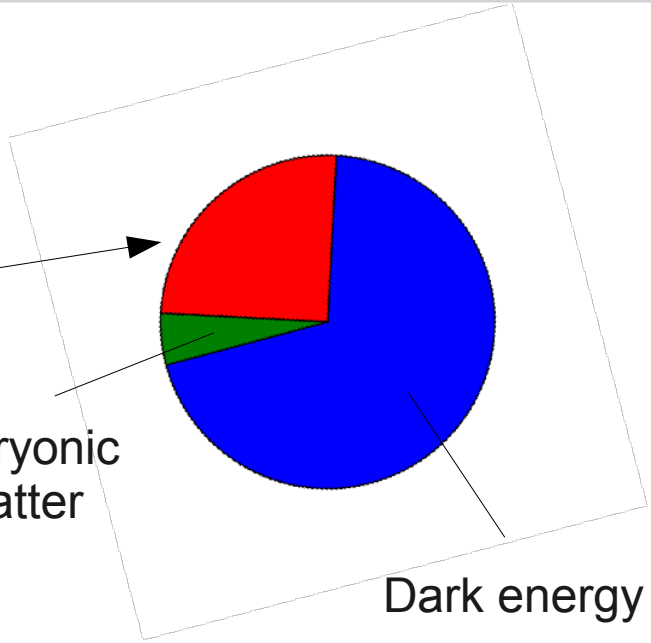
→ LHC signals ?

New Physics at the TeV scale ?

→ Hierarchy Problem

→ WIMP Dark matter

- Evidence of new Physics
- Maybe a WIMP with TeV scale mass



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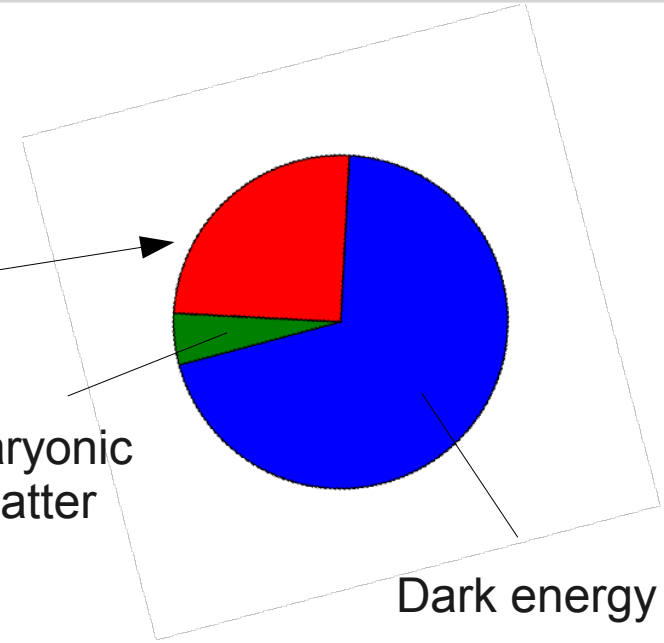
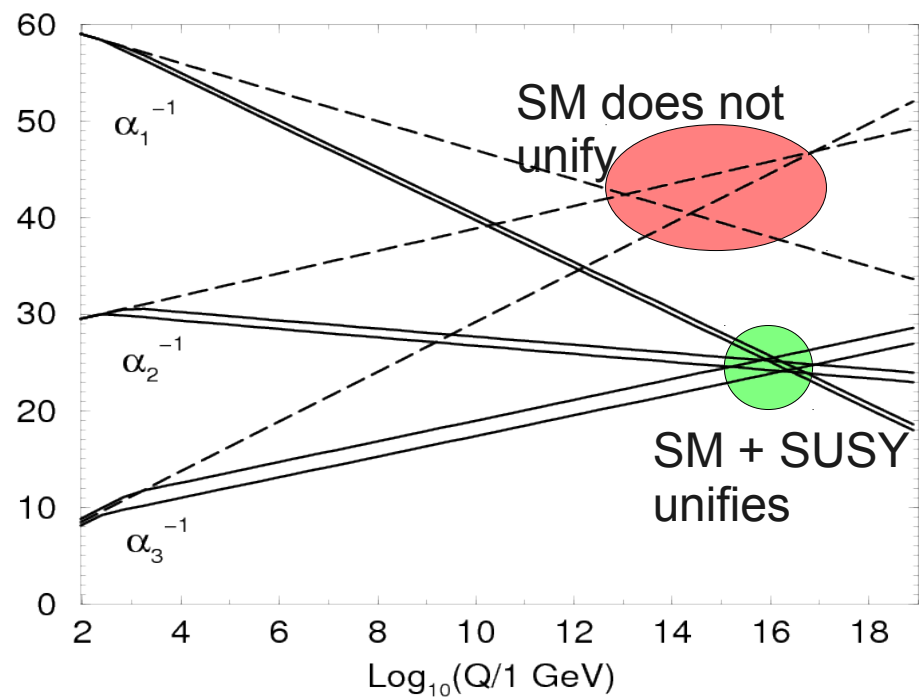


Unification

$$SU(5) \supset \begin{pmatrix} SU(3)_{1/3} & \\ & SU(2)_{-1/2} \end{pmatrix}$$

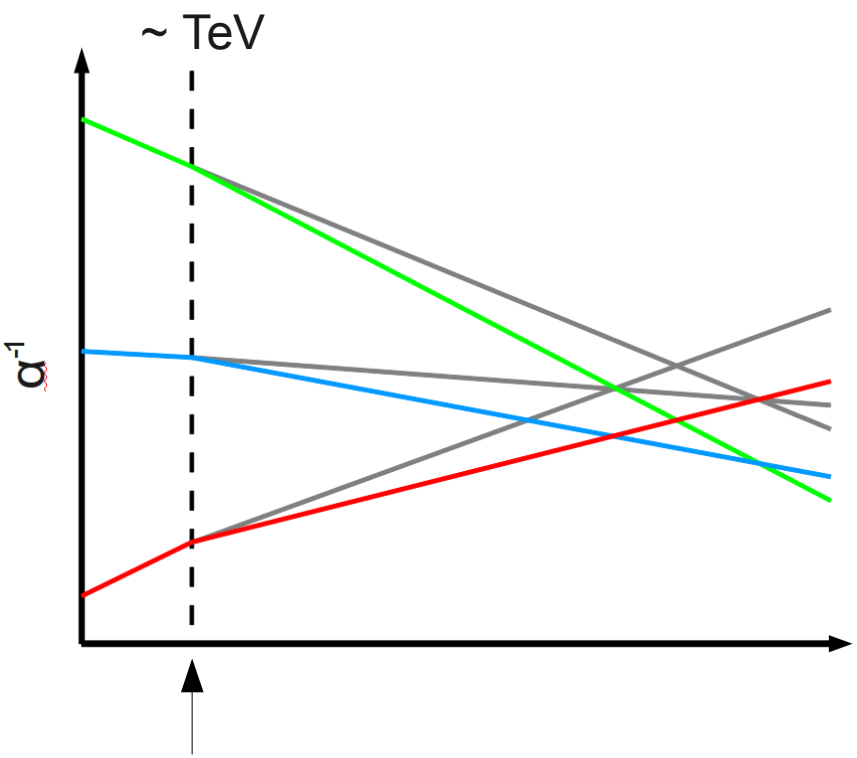
SM in $\bar{5}$, 10 of $SU(5)$



Martin: hep-ph 9709356

Search for simple models with WIMP DM + Unification:

SM + WIMP DM



Dark matter WIMP

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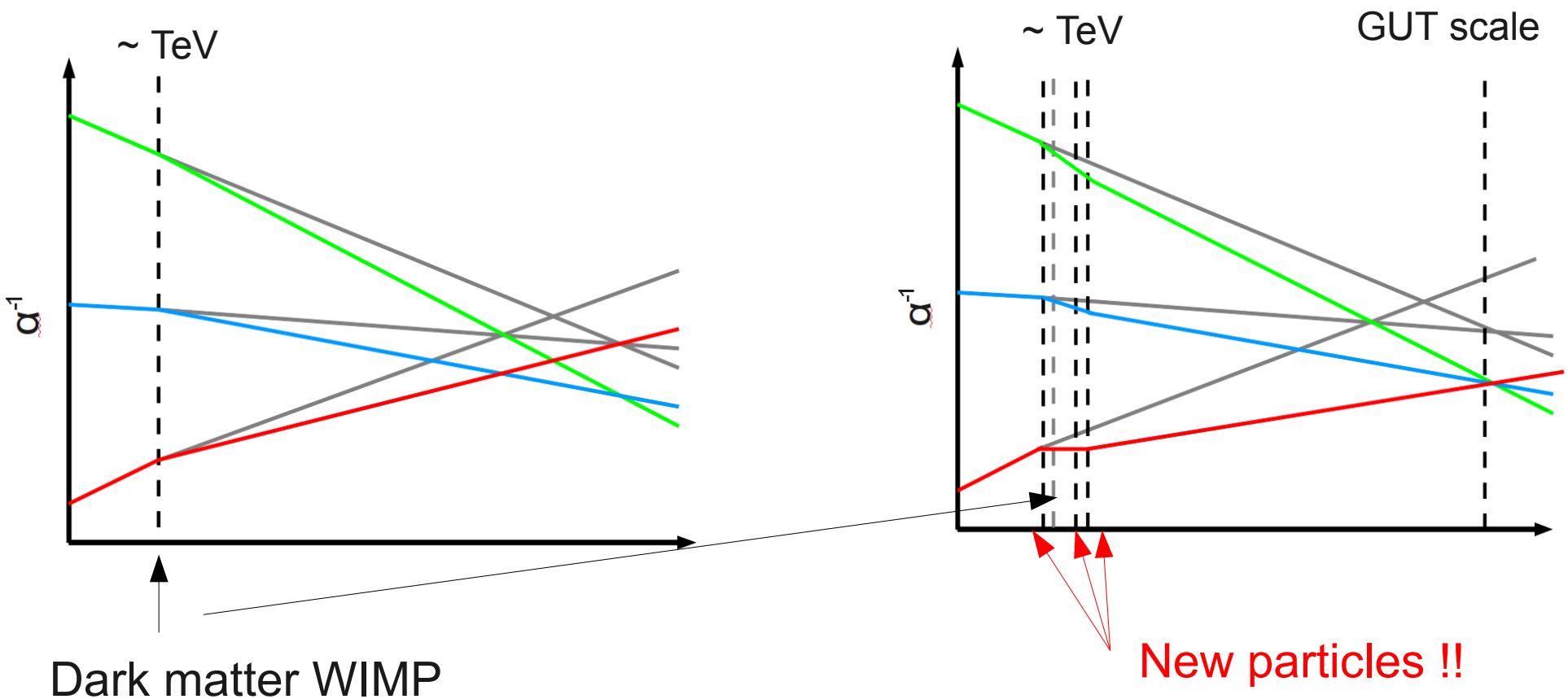
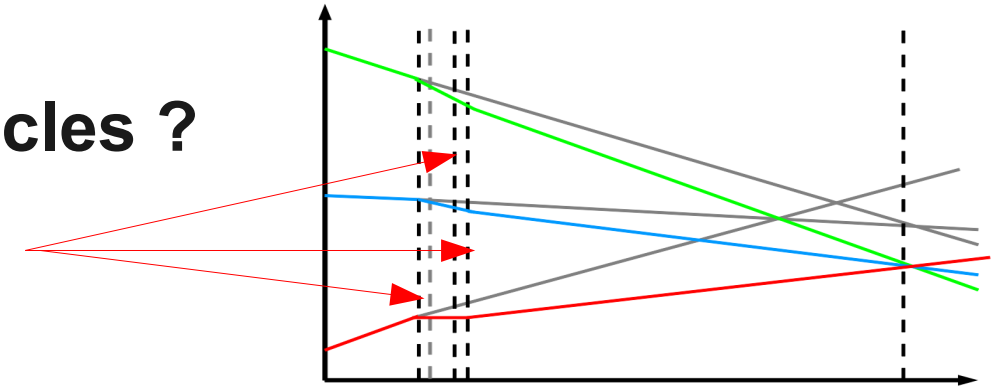


→ Which new particles?
→ Possible new signals for LHC ??

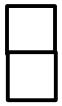
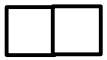
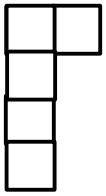
Which new particles ?

???



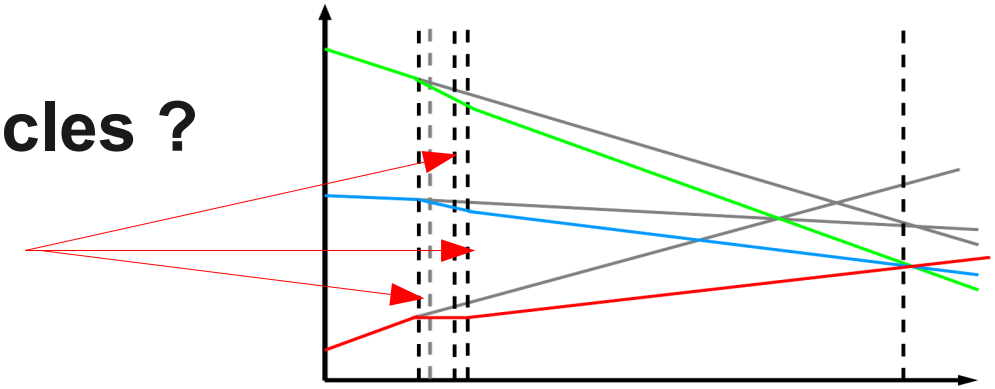
Assumptions:

- Simple multiplets of SU(5):

5  10  15  24 (adjoint)  ↔ 10 particle species

Which new particles ?

???



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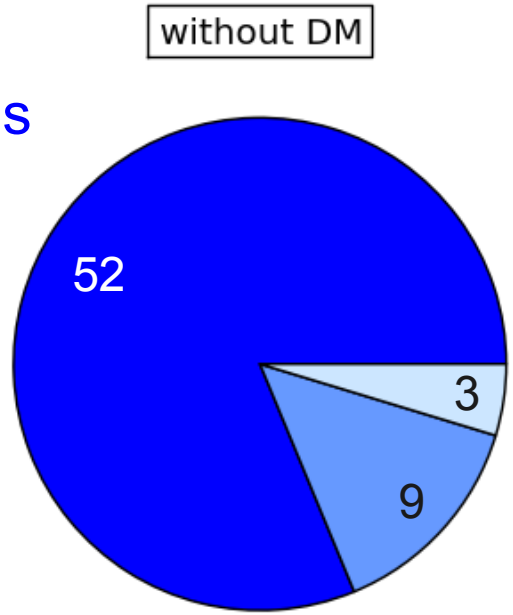
- Simple multiplets of SU(5):

5 $\square$ 10 $\begin{smallmatrix}\square\\\square\end{smallmatrix}$ 15 $\square\square$ 24 (adjoint) $\begin{smallmatrix}\square&\square\\\square&\\\square&\\\square&\end{smallmatrix}$ $\leftrightarrow$ 10 particle species

- $(\mathbf{1},\mathbf{3})_0$ (from 24) serves as WIMP DM
- new scale to be ~TeV, as dictated by WIMP miracle
- Vectorlike fermions
- No more than 3 species with max. 3 generations each

Results: unifying models

64 models



Colored new particles	yes	yes	—
new particles with Yukawa couplings to SM: $\lambda_i H d_i^c X$	yes	—	—

Results: unifying models

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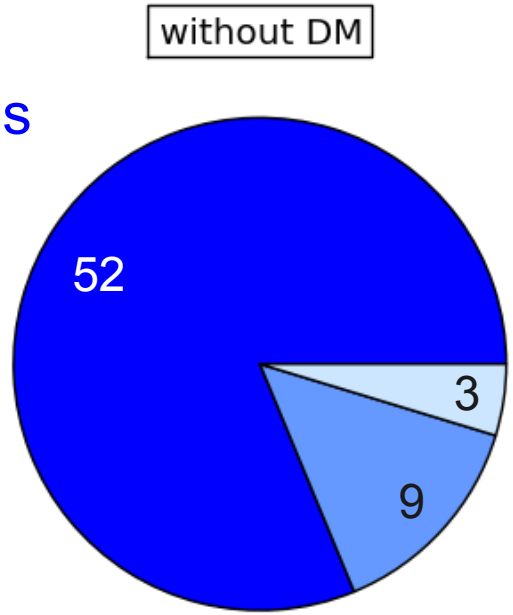
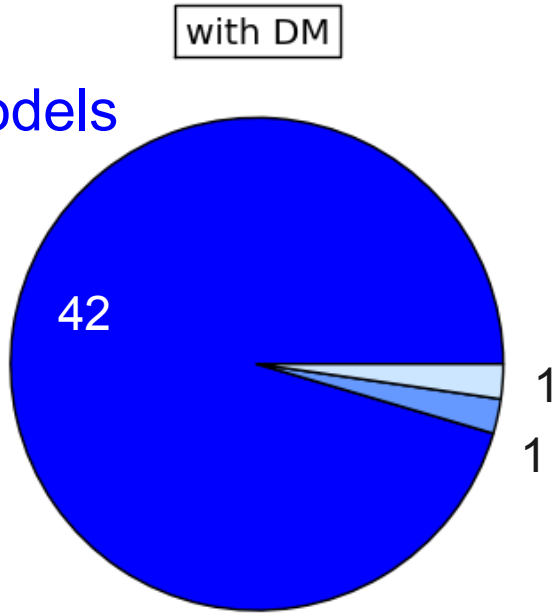


44 models



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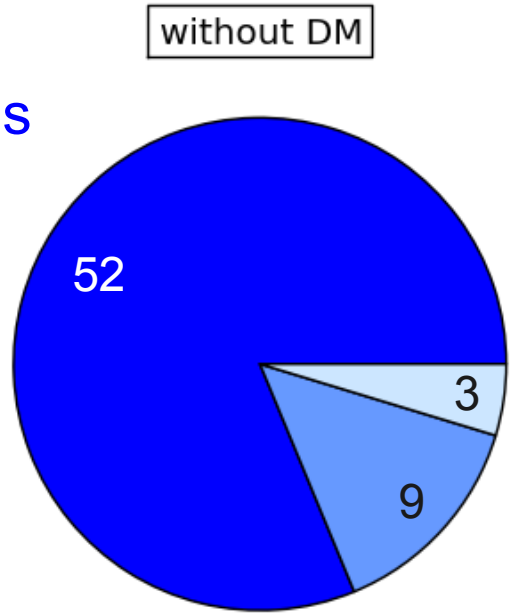

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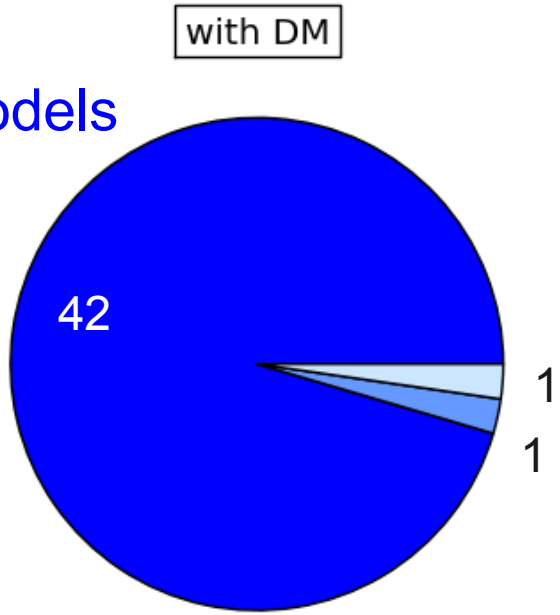


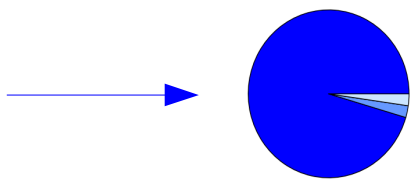
Combining Unification & WIMP DM exhibits strong phenomenological trend

Colored new particles	yes	yes	—
new particles with Yukawa couplings to SM: $\lambda_i H d_i^c X$	yes	—	—

Benchmark

$$\text{SM} + \begin{cases} \text{DM } (1,\mathbf{3})_0 \quad m = 2.7 \text{ TeV} \\ 2 \text{ Generations of } (X + X^c) \text{ where } X \sim (\mathbf{3},\mathbf{2})_{-5/6} \end{cases}$$

- Coupling to the SM: $\lambda_{ia} H d_i^c X_a$
- Representative for 42 of 44 models



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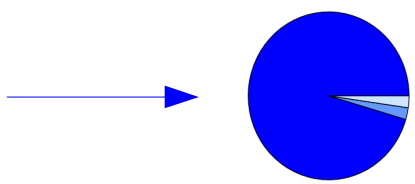
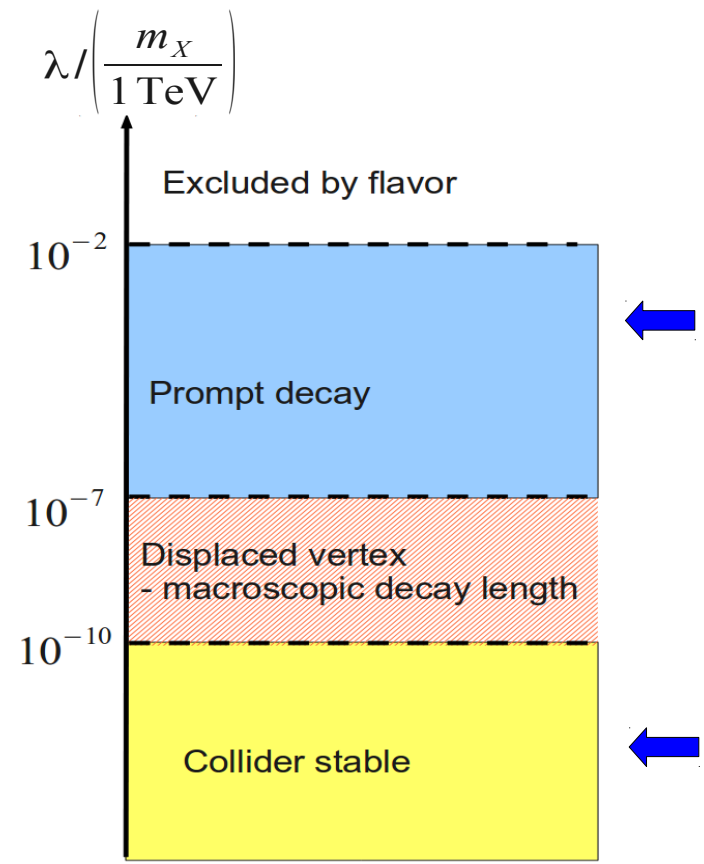
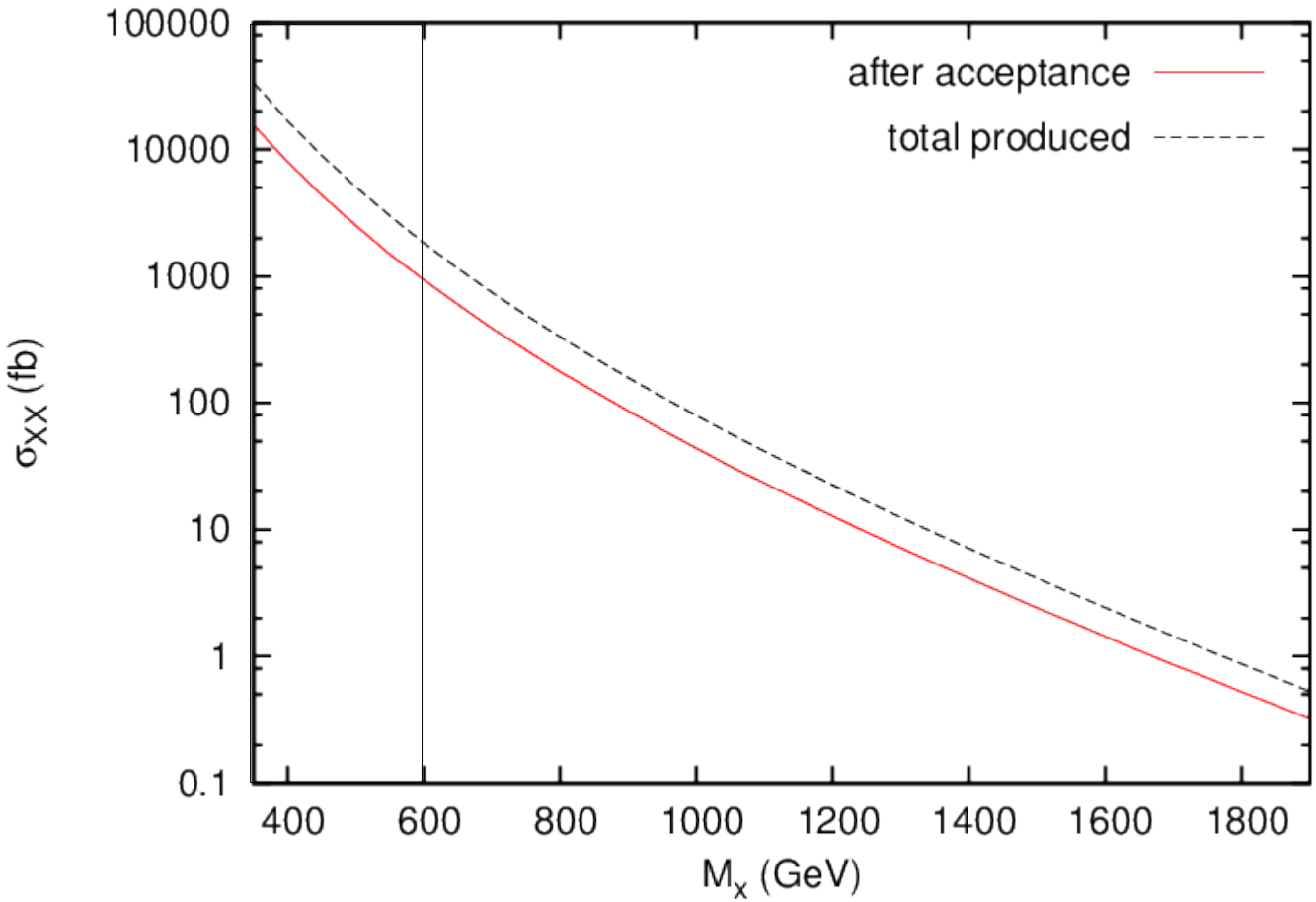


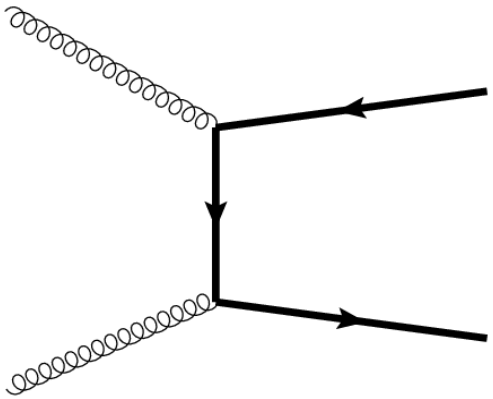
- No assumptions about Yukawa matrices → Flavor bounds from analysis of eff. Operators
- lightest generation of X dominates the collider signal



R-hadrons: Results

With the full LHC (14 TeV, 10 fb^{-1})



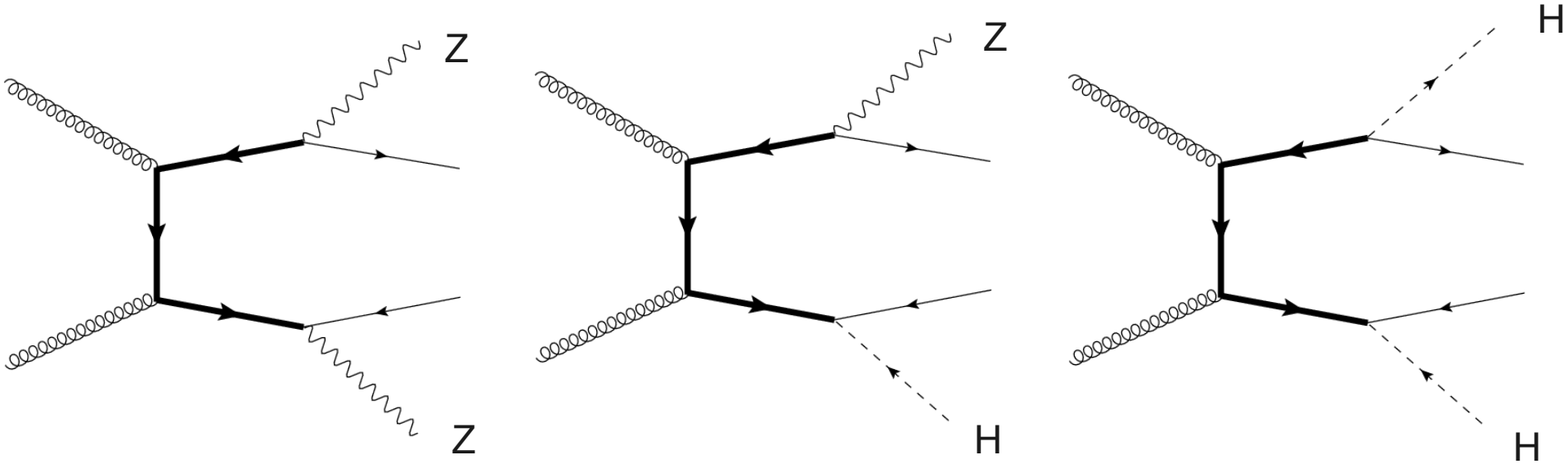


Exclusion limit from R-hadron search: mX ≥ 600 GeV (CMS PAS EXO-11-022)

Prompt decay

Excluded WZ/ZZ searches: mX ≥ 400 GeV
[CMS PAS EWK-11-019] [ATLAS-CONF-2011-107]

Signal: X decay to W/Z/H+jets



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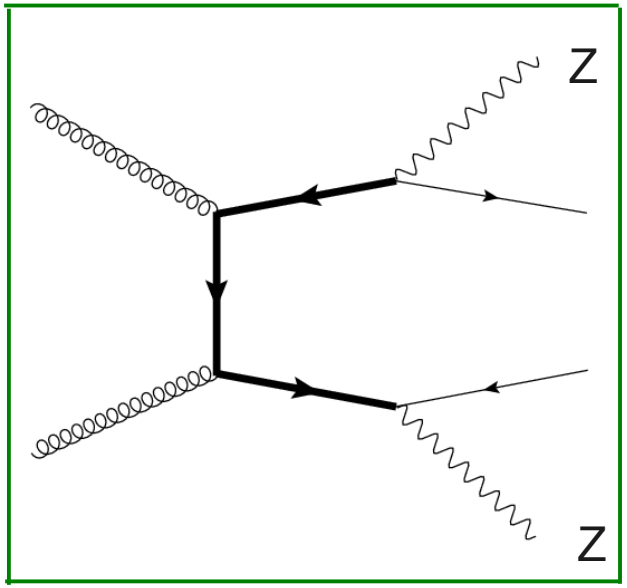

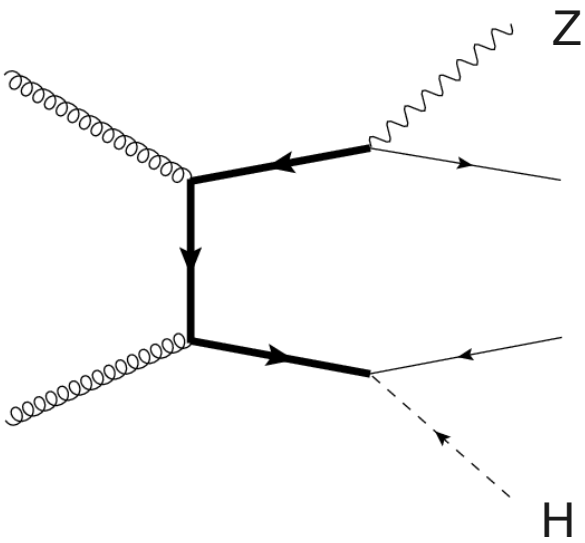

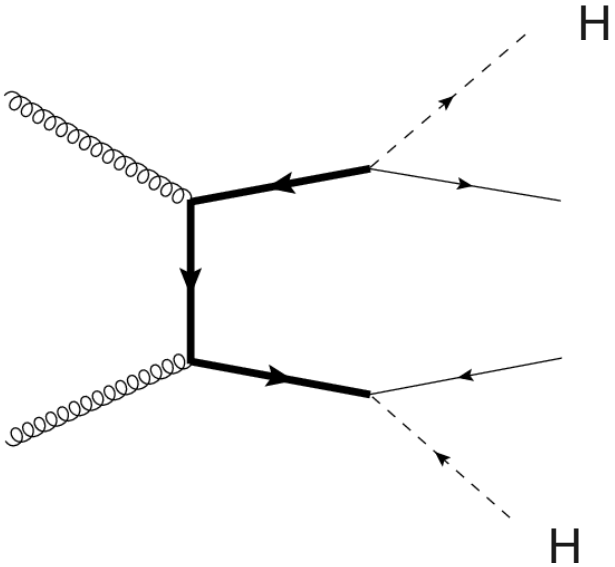

Program:

(1) Identify X in leptonic Z decays

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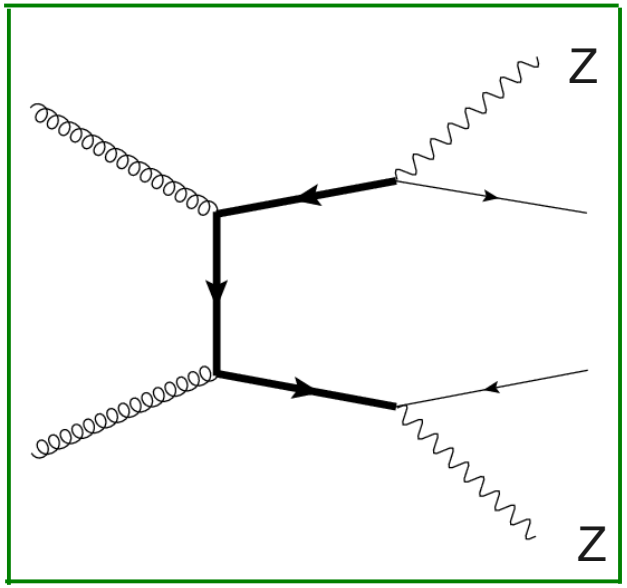
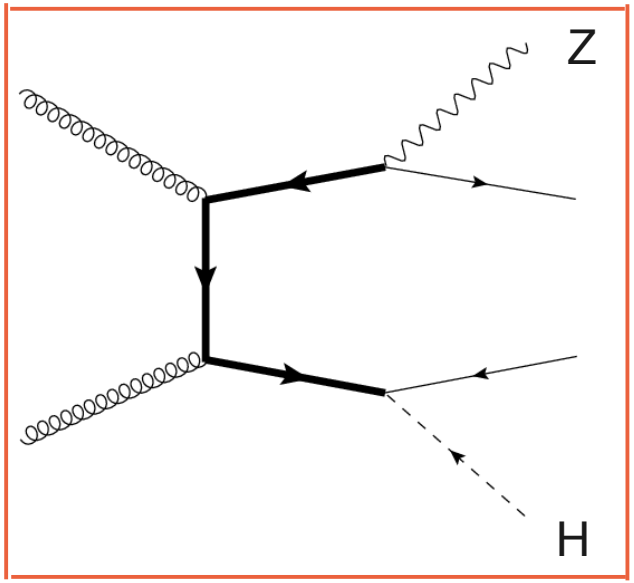
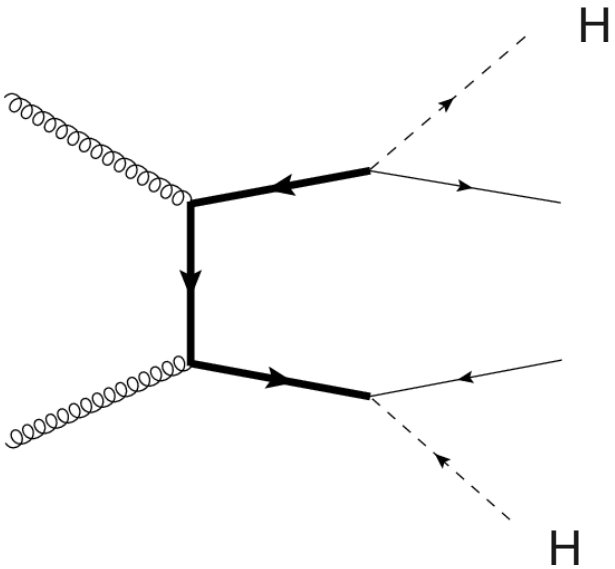






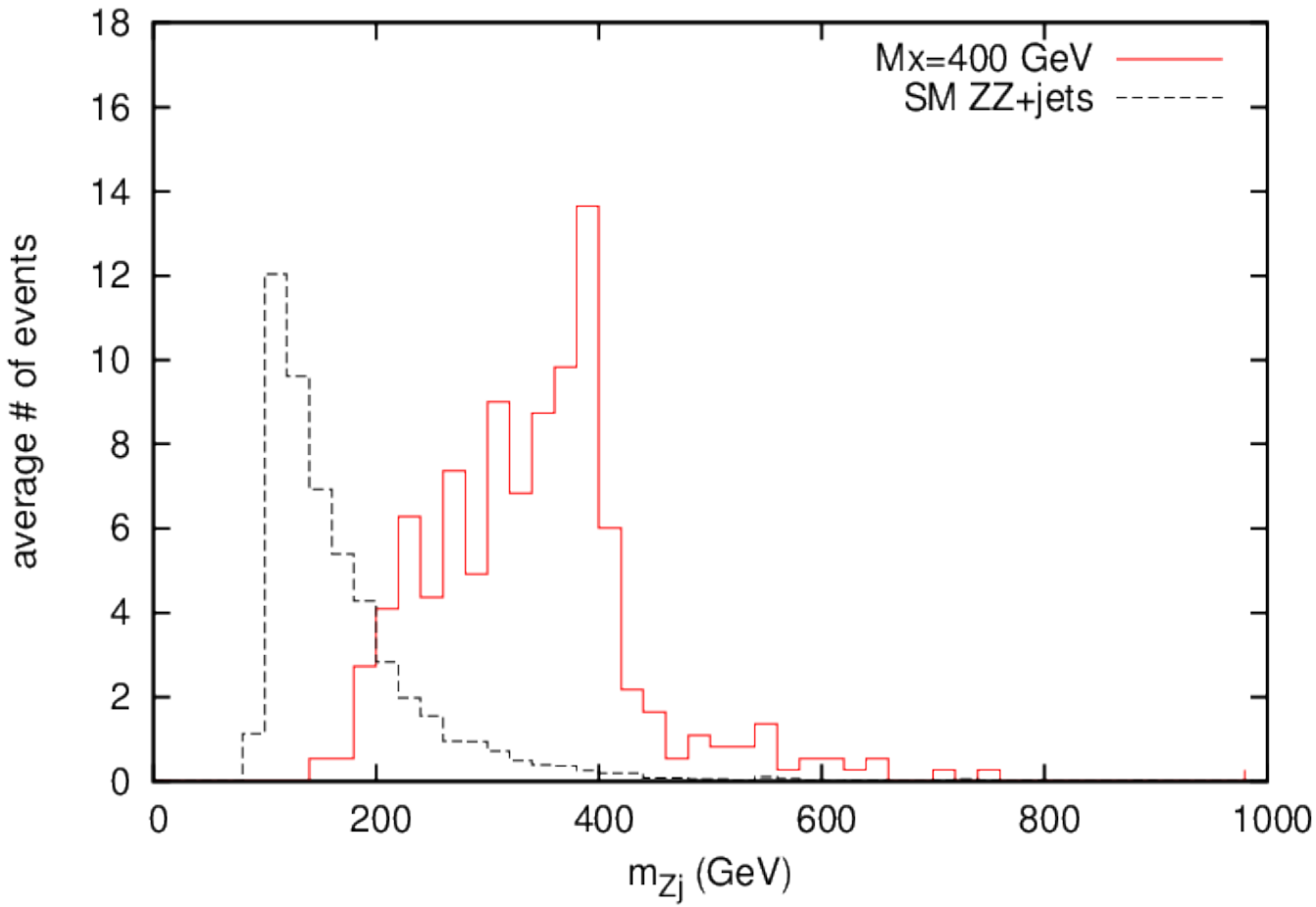
Program:

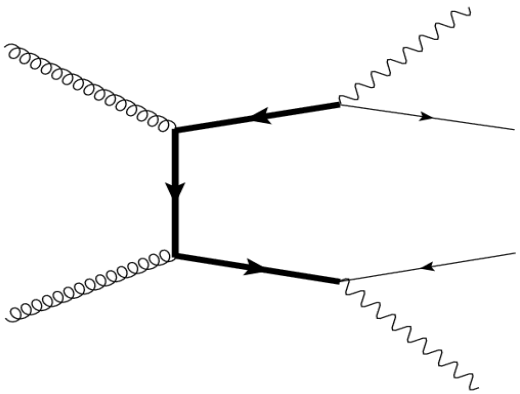
(1) Identify X in leptonic Z decays

(2) Discovering the Higgs produced in X decays

Prompt decay: Results I

(1) Identify X in leptonic Z decays





14 TeV, 10 fb^{-1}

Prompt decay: Results I

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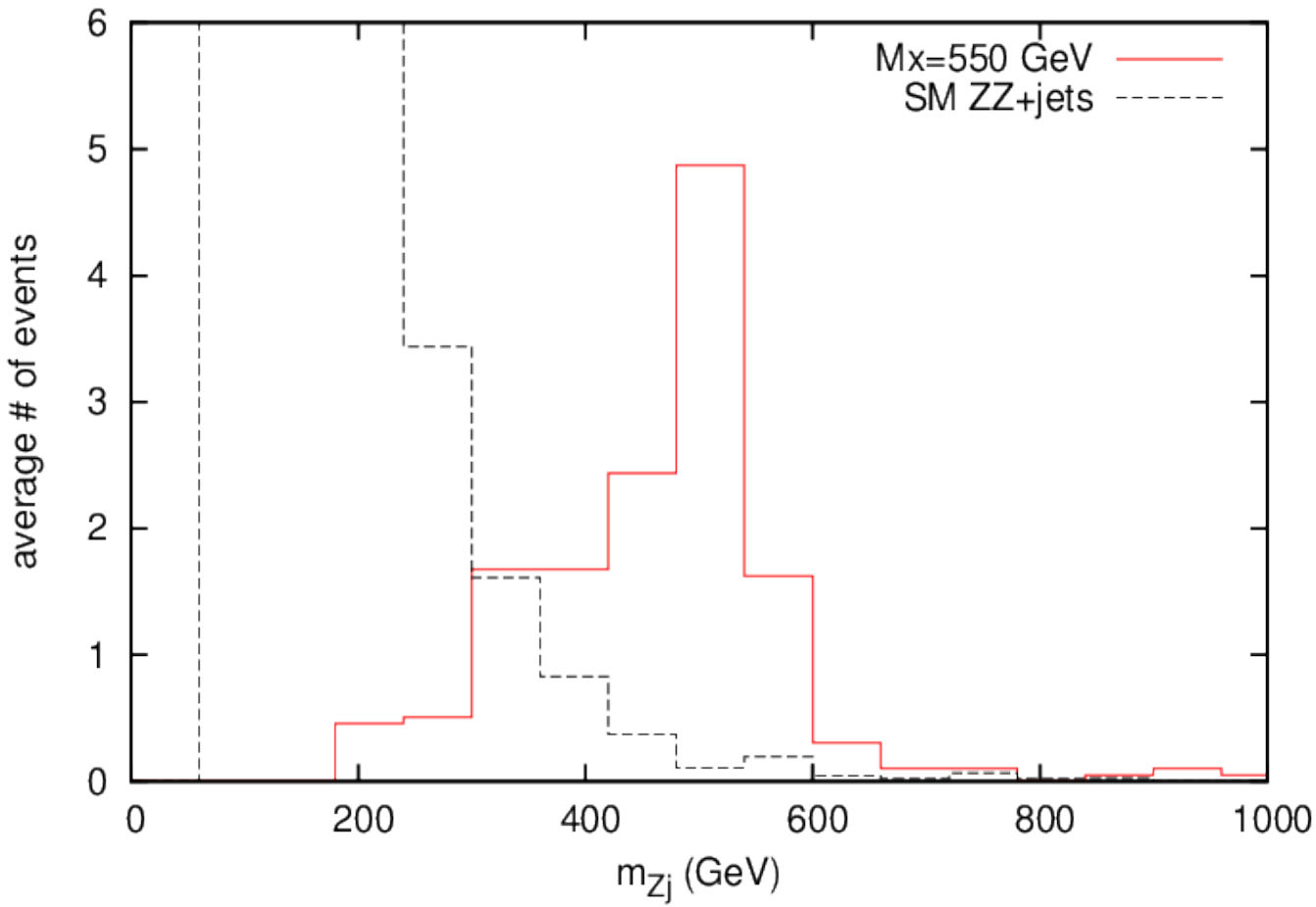

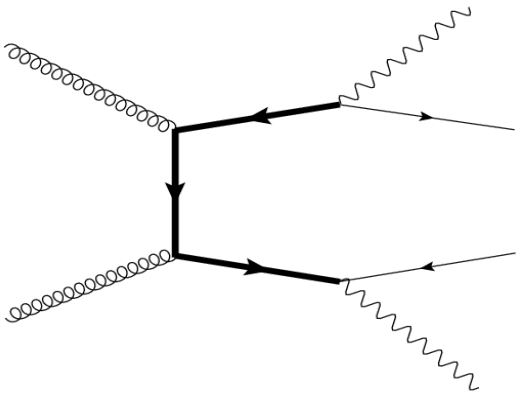

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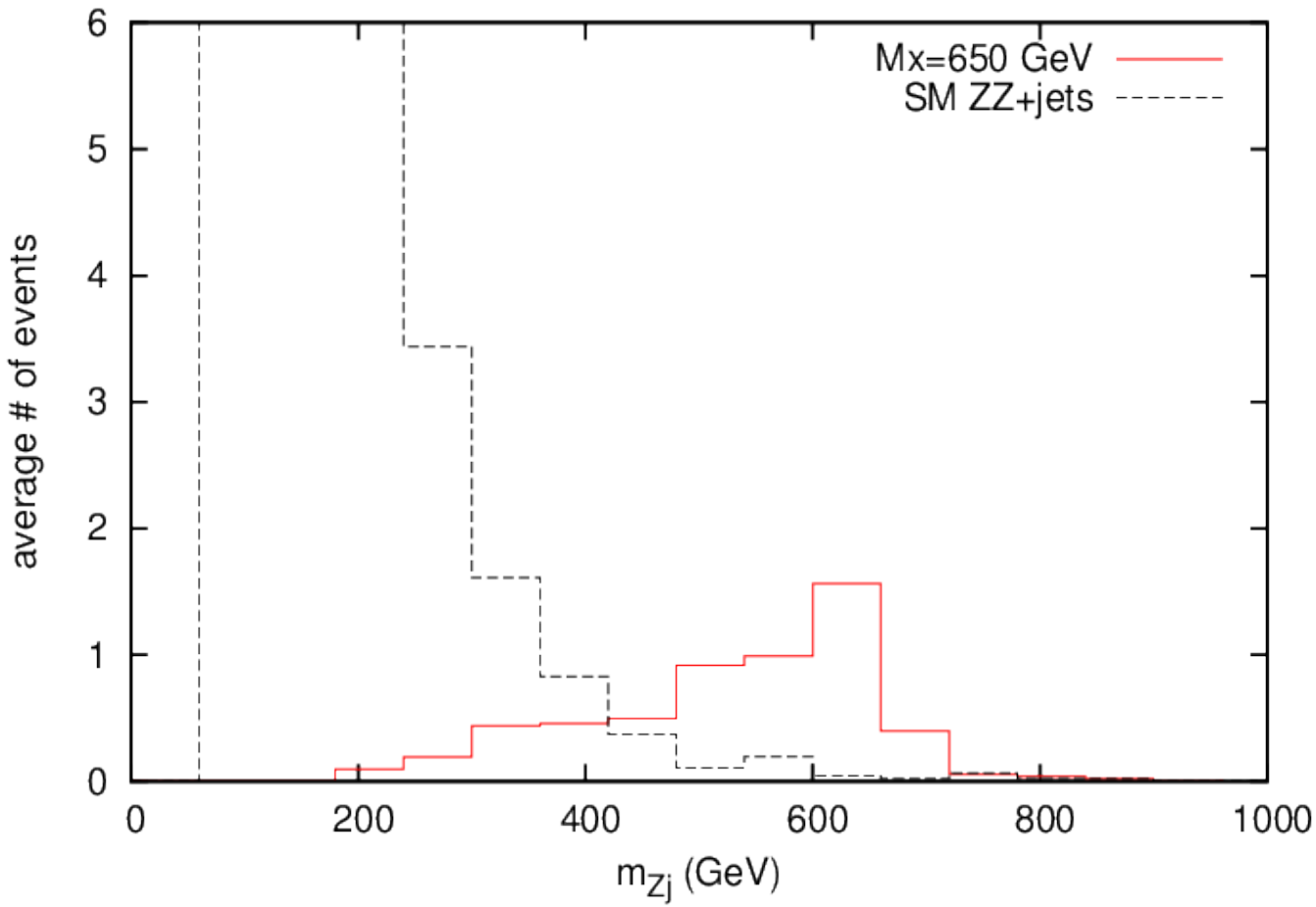
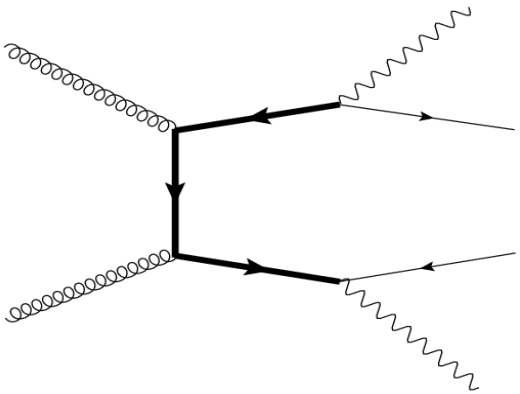
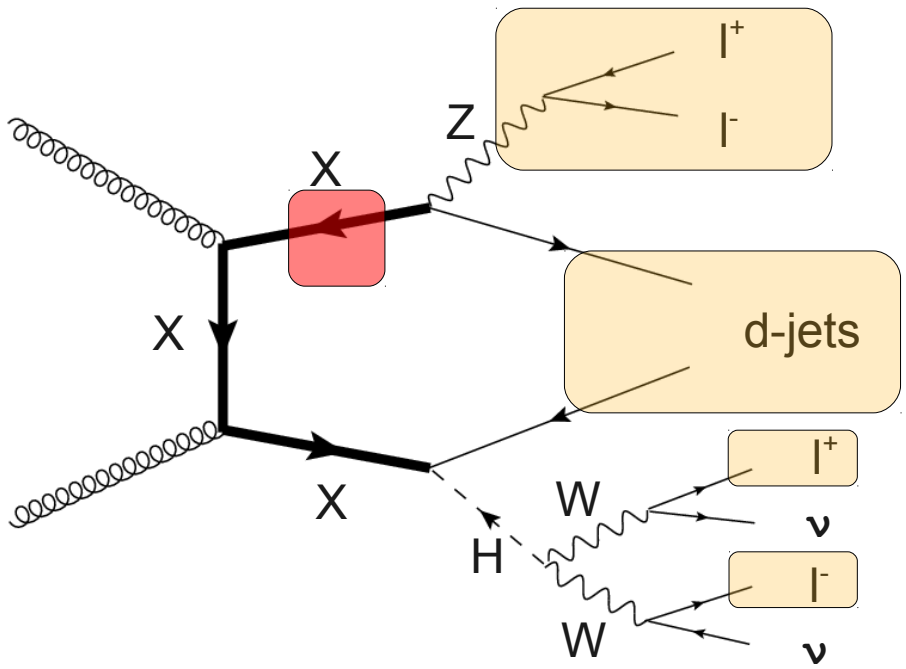




14 TeV, 10 fb^{-1}

(2) Discovering the Higgs produced in X decays (m_H=220 GeV)



Event selection

4 leptons, exactly 1 Z candidate, 2 jets

Z candidate + 1 jet with inv. mass=mX ± 90 GeV

SM background: $t\,\bar{t}\,Z$

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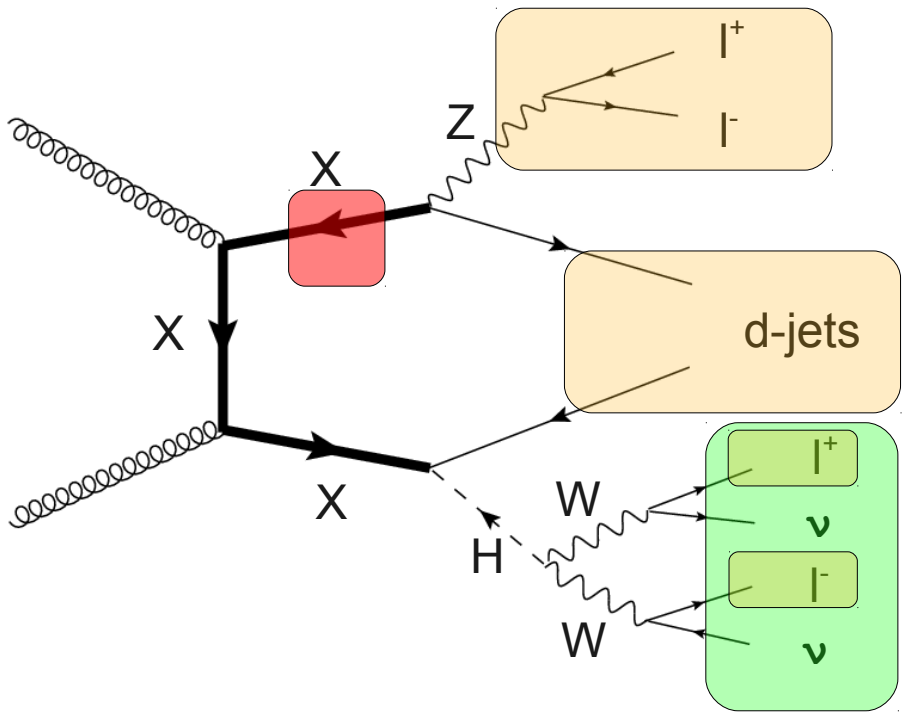

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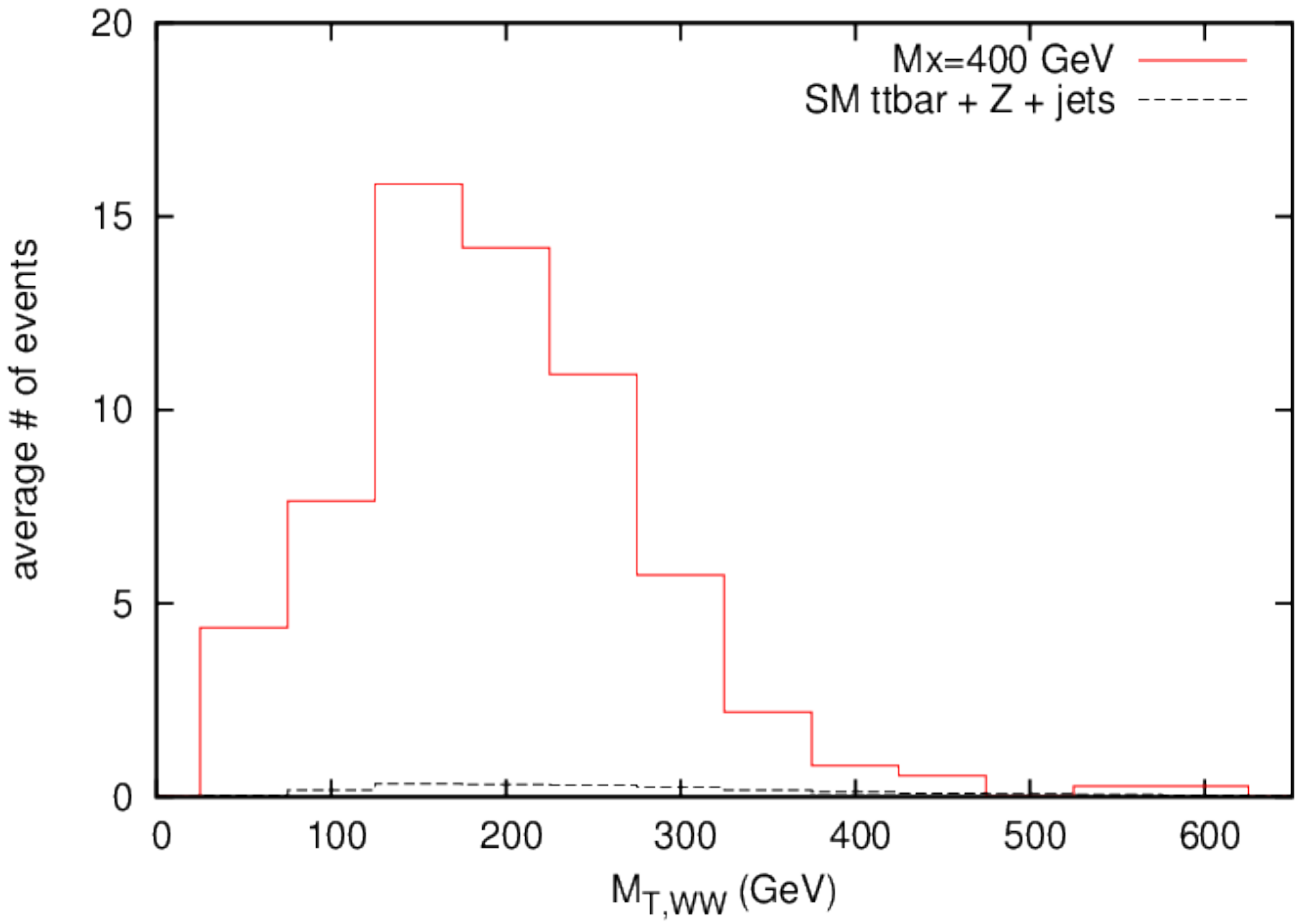
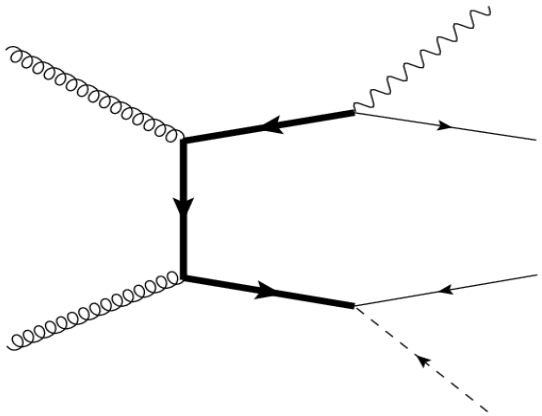
Transverse mass variable

$$M^2_{T,WW} = (E_{T,l^+l^-} + E_{T,\nu\bar{\nu}})^2 - (\vec{p}_{T,l^+l^-} + \vec{p}_{T,\mathrm{miss}})^2 \qquad E^2_{T,\nu\bar{\nu}} = \vec{p}^{\,2}_{T,\mathrm{miss}} + m^2_{l^+l^-}$$

Prompt decay: Results II

(2) Discovering the Higgs produced in X decays





14 TeV, 10 fb^{-1}

Prompt decay: Results II

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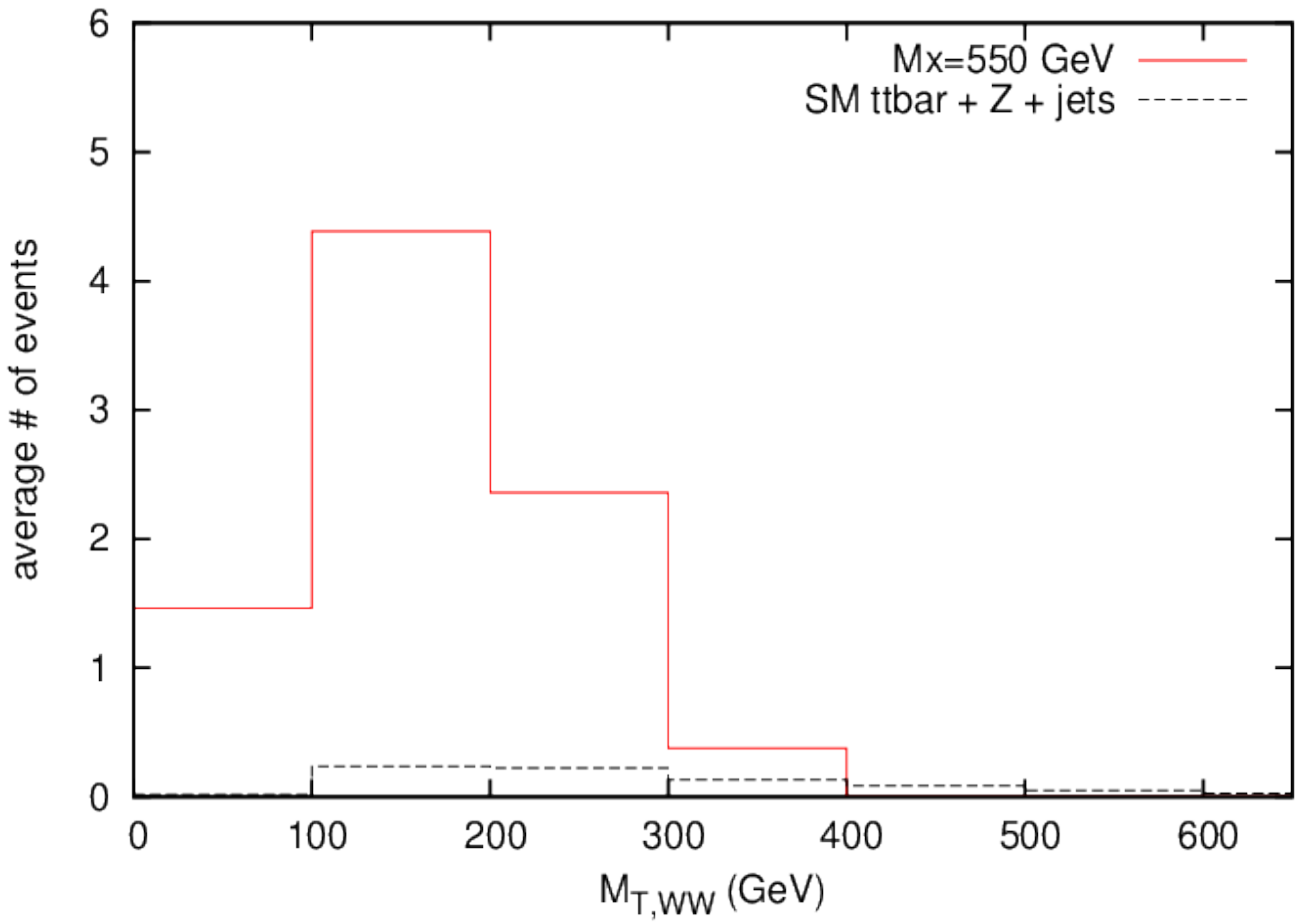
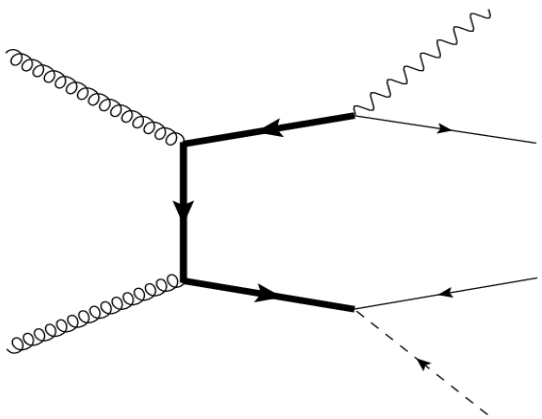
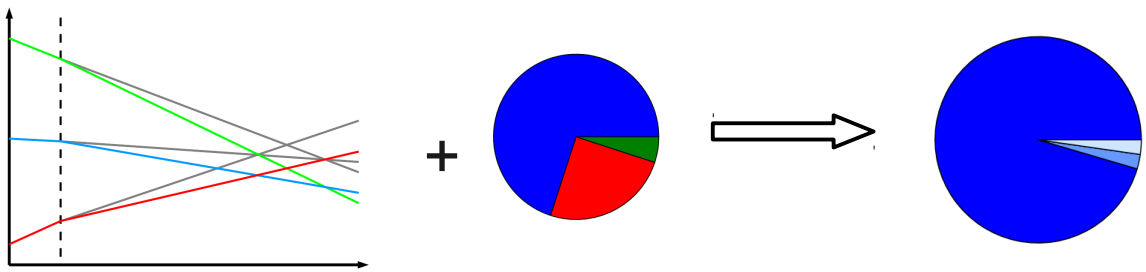




14 TeV, 10 fb^{-1}

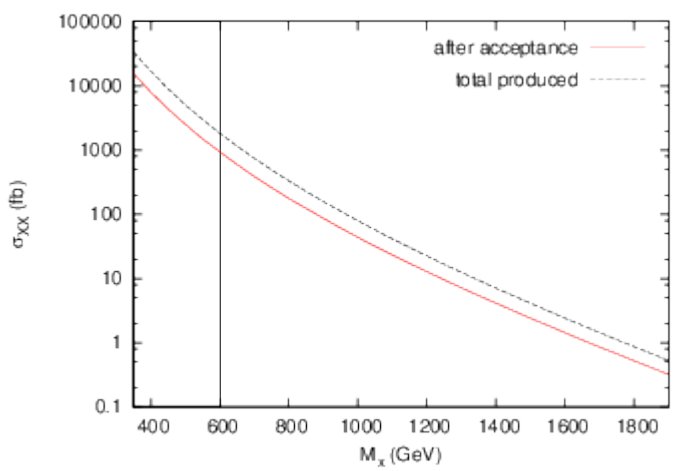
Conclusion

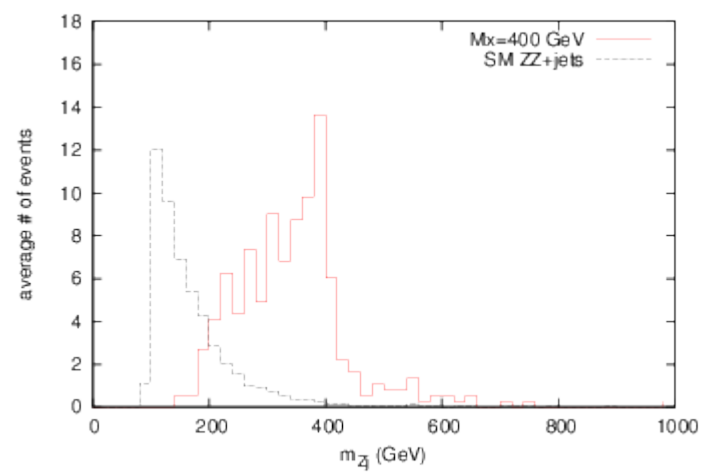
Unification + WIMP DM ⇨ new colored particles w/ coupling to SM Higgs+quark



a single benchmark model covers almost all models

Promising discovery potential for both R-hadron / prompt decay case !!





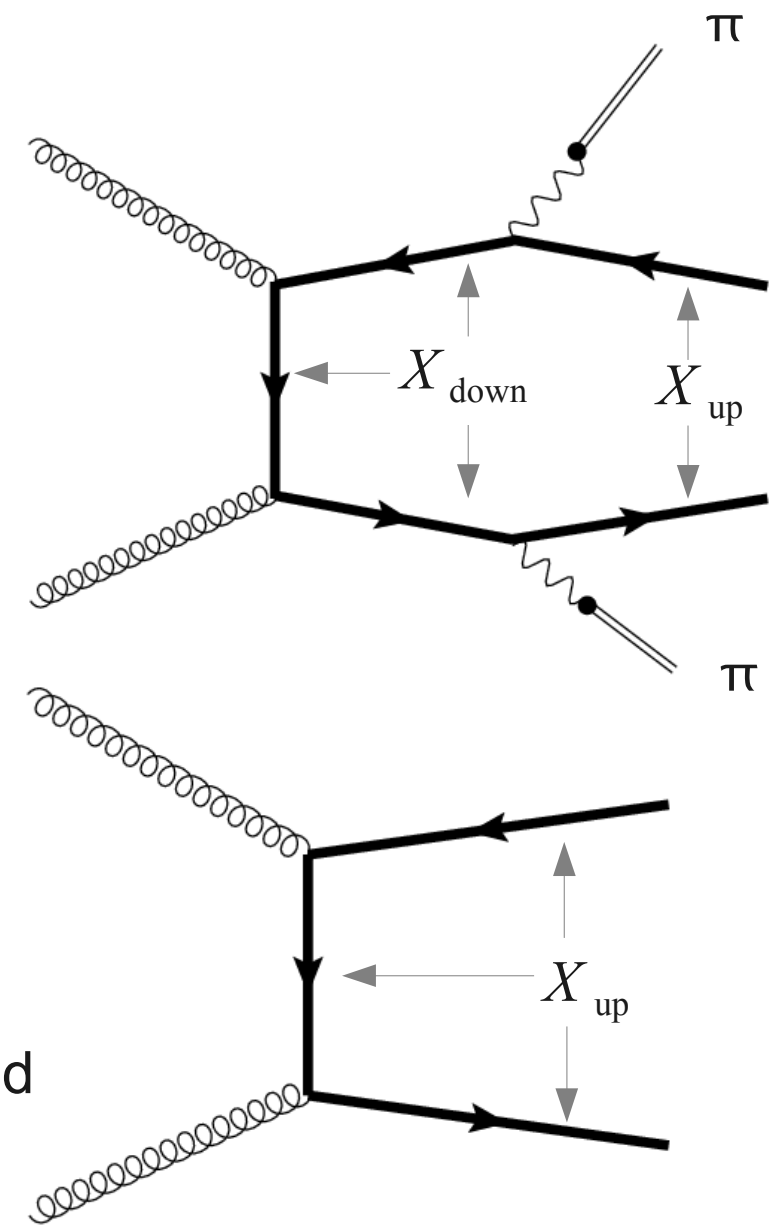
Thank you!

R-hadrons

$$X = \begin{pmatrix} X_{\text{up}} \\ X_{\text{down}} \end{pmatrix} \xrightarrow{\text{EWSB}} m_{X\,\text{down}} = m_{X\,\text{up}} + 0.60\,\text{GeV}$$

$$X_{\text{down}} \to X_{\text{up}} + \pi$$

Effectively: only stable X_{up} (charge -⅓)

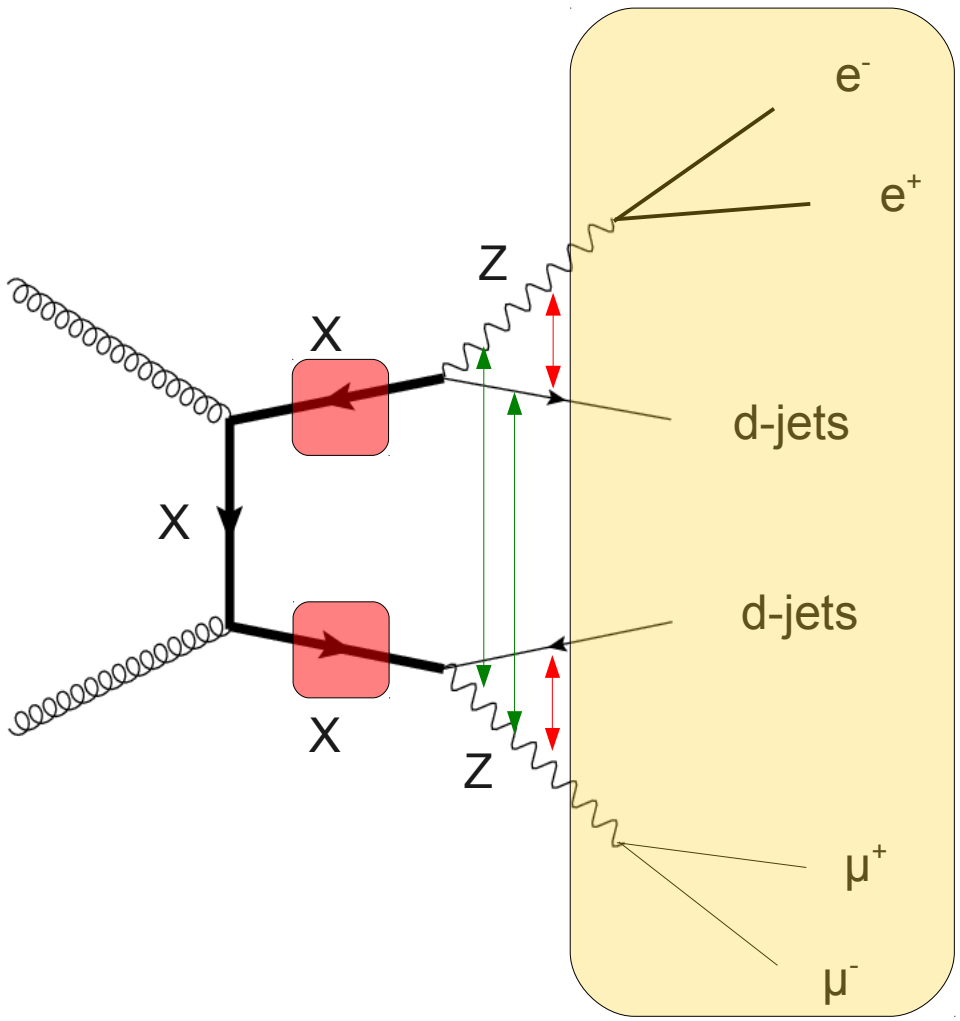


X form color-neutral bound states with light quarks → R-hadrons

- (anti-)baryons $Xqq\,(\bar{X}\,\bar{q}\,\bar{q})$
- mesons $X\,\bar{q}\,(\bar{X}\,q)$

} 50% charged

(1) Identify X in leptonic Z decays

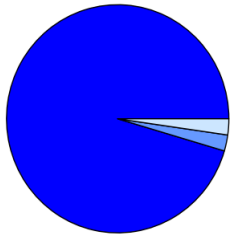


Event analysis

- Select events with 2 leptonic Z candidates and 2 jets
- pair Z candidates with the hardest jets
- keep pairing with inv. masses closest to each other → mX

SM background: ZZ+jets

Outlook



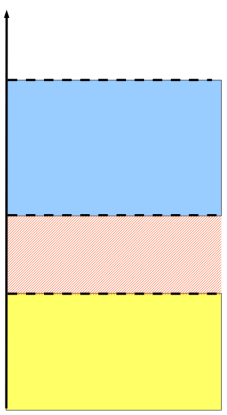
$X \sim (\mathbf{3},\mathbf{2})_{-5/6}$ $\lambda H d^c X$ ⇦ analyzed

$U \sim (\mathbf{3},1)_{2/3}$ $\lambda H U^c q$

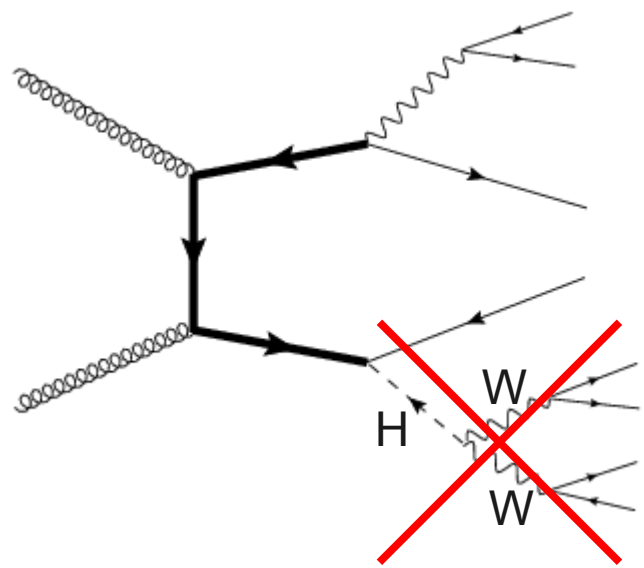
$D \sim (\mathbf{3},1)_{-1/3}$ $\lambda \tilde{H} D^c q$

$Q \sim (\mathbf{3},\mathbf{2})_{1/6}$ $\lambda_d \tilde{H} d^c Q$ $\lambda_u H u^c Q$

} Additional decays to tops

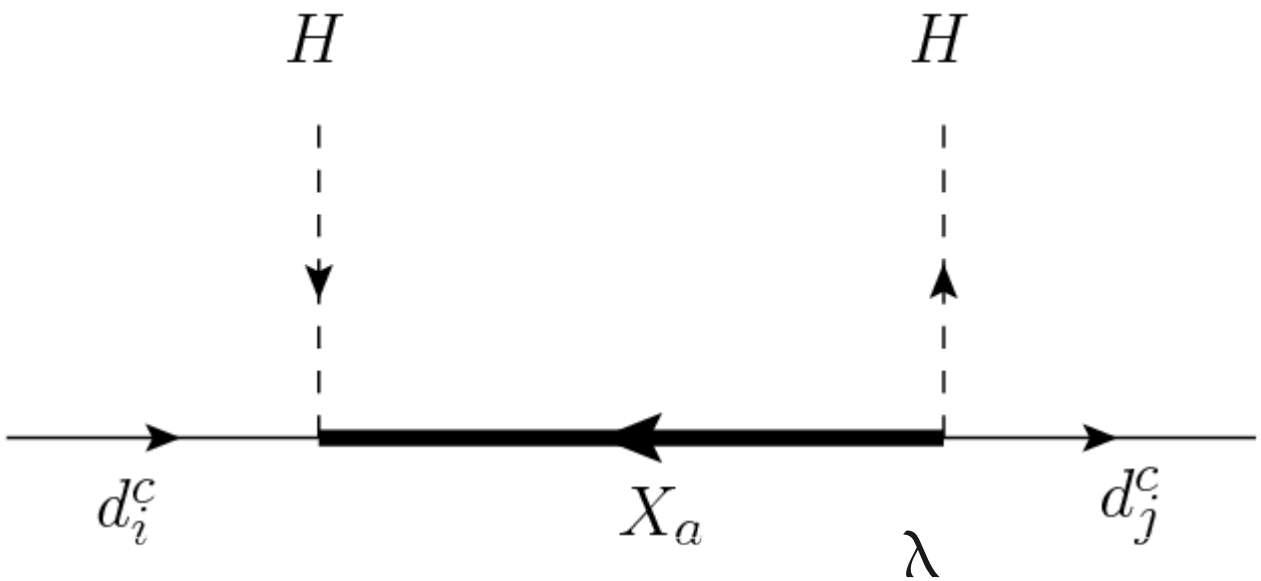


⇦ Intermediate λ range: macroscopic decay length



Higgs factory case for mH < 160 GeV

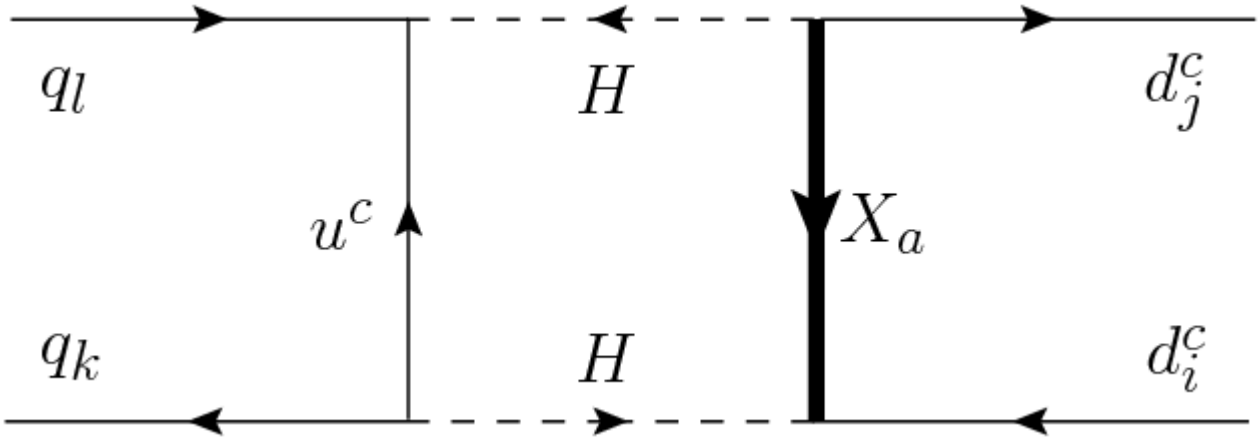
Jet substructure (talk by Tuhin Roy)



$$\sim \sum_{a\,i\,j} \frac{\lambda_{ia}\lambda_{aj}}{m_{Xa}^2} d_i^c \sigma^\mu \bar{d}_j^c (H^\dagger \overleftrightarrow{D}_\mu H)$$

Contributions to $Zb\bar{b}$ and 4-fermion-Operators

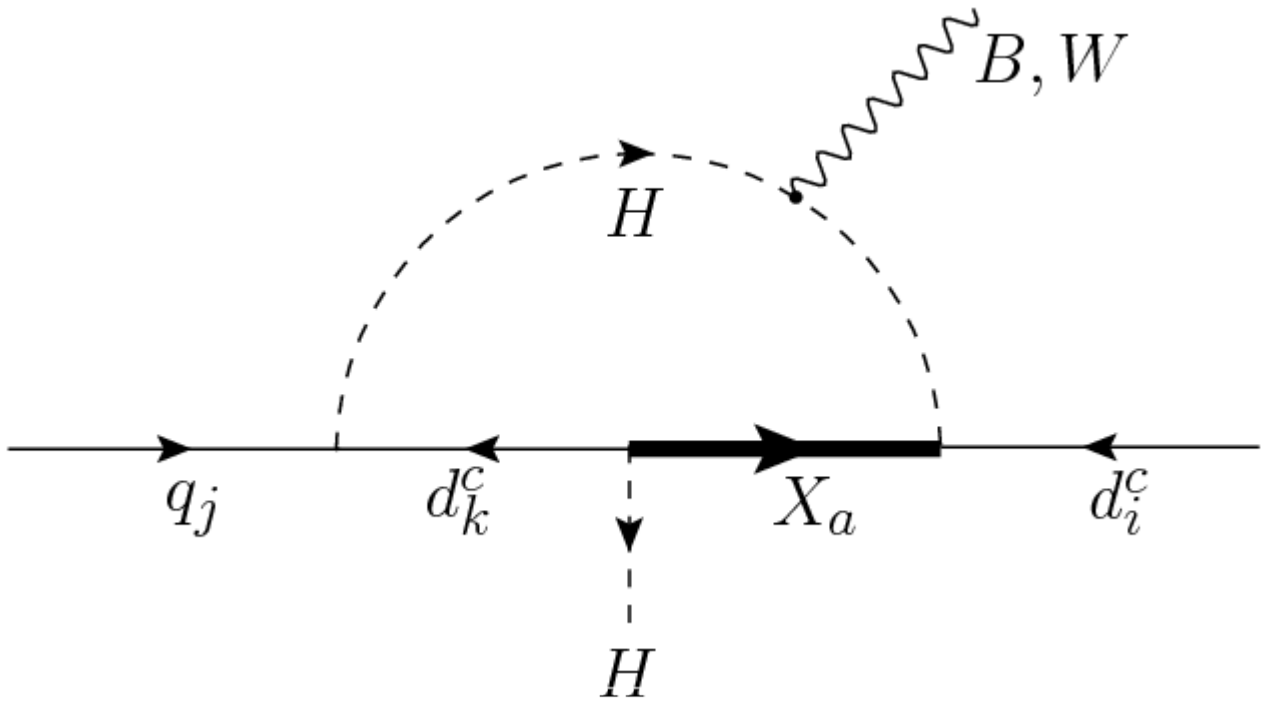
$$\lambda \leq 10^{-2}\sqrt{\frac{m_x}{1\,\mathrm{TeV}}}$$



$$\sim \frac{1}{16\pi^2} \sum_{aijkl} \frac{\lambda_{ia} \lambda_{aj}^{\dagger} (y_u y_u^{\dagger})_{kl}}{m_X^2} (d_i^c \sigma_\mu \bar{d}_j^c)(\bar{q}_k \bar{\sigma}^\mu q_l)$$

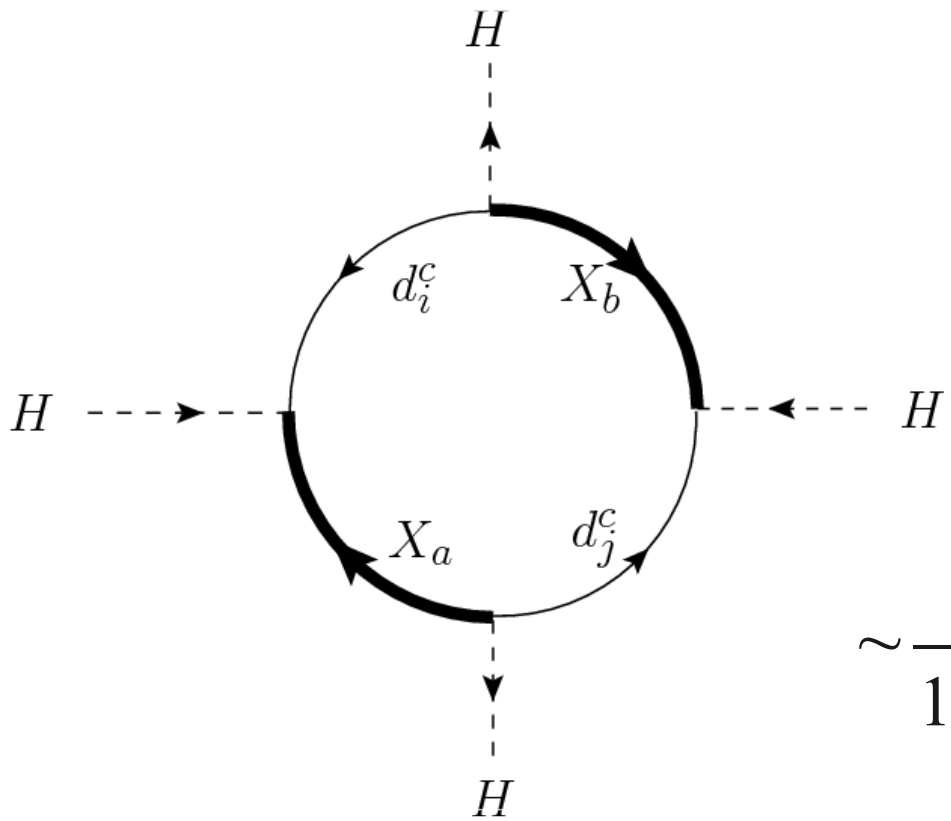
K- Kbar oscillations

$$\lambda \leq 10^{-2} \frac{m_X}{1\,\mathrm{TeV}}$$



$$\sim \frac{g_F}{16\pi^2} \sum \frac{\lambda_{ia} \lambda^{\dagger}_{ak} (y_d)_k}{m_X^2} H^{\dagger} d_i^c \bar{\sigma}^{\mu\nu} F_{\mu\nu} q_j$$

Contributions to B →sγ $\lambda \leq 10^{-1} \frac{m_X}{1\,\mathrm{TeV}}$



Contribution to the rho-parameter

$$\sim \frac{\lambda^2}{16\pi^2 m_X^2}(H^\dagger D_\mu H)(H^\dagger D^\mu H)$$

$$\lambda \leq \sqrt{\frac{m_X}{1\,\mathrm{TeV}}}$$