Top partners/ vector-like quarks

G.Cacciapaglia (IPNL)

@ XXVIII Rencontres de Blois

What is a VLQ?

- Left and Right-handed have the same (gauge) interactions

- Gauge invariant Dirac mass

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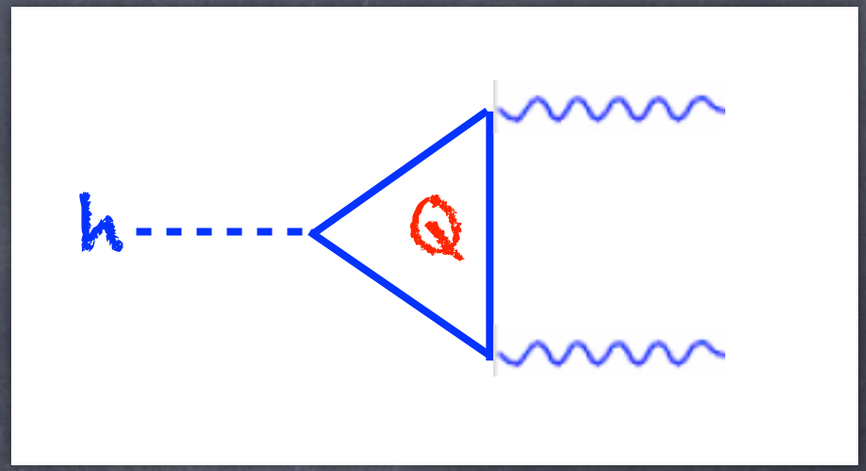
What role in BSM?

- Loop-coupling enhancers



$$\mathcal{A} \sim y_Q \frac{v}{M_Q}$$

decoupling limit exists
large couplings are needed

What is a VLQ?

- Left and Right-handed have the same (gauge) interactions

- Gauge invariant Dirac mass

What role in BSM?

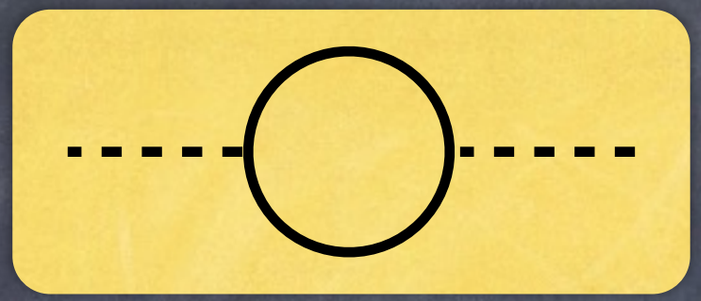
- Loop-coupling enhancers
- same-spin Top partners in Naturalness

Little Higgs, pNGB Higgs, ...
(COMPOSITENESS)

?

Contribute to
the Higgs potential → Light???

Anatomy of the potential

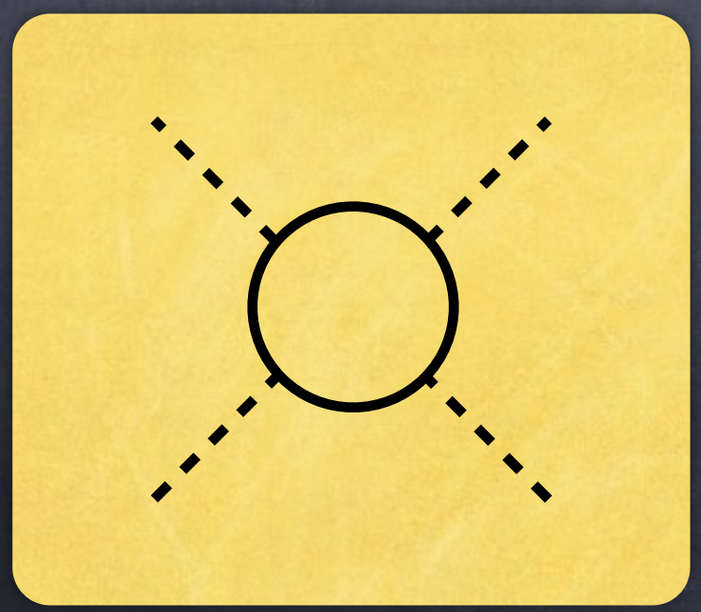


$$\delta m_h^2 \sim \frac{y^2}{16\pi^2}(4\pi f)^2 \sim y^2 f^2$$

compositeness scale

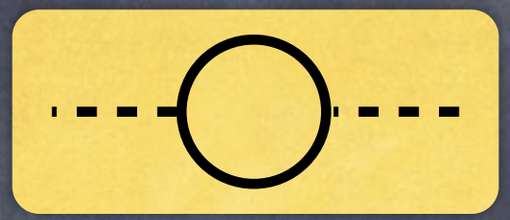
$\Lambda \sim 4\pi f$

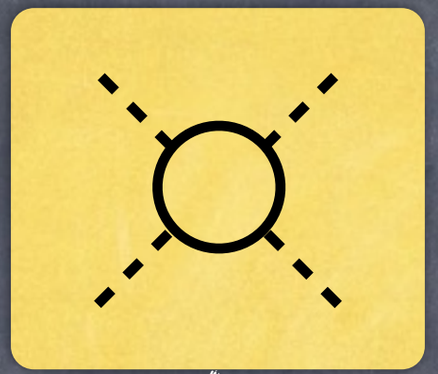
Strong dynamics estimate



$$\delta\lambda \sim \frac{y^4}{16\pi^2}\log\Lambda$$

Anatomy of the potential

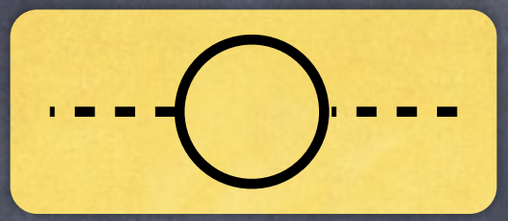


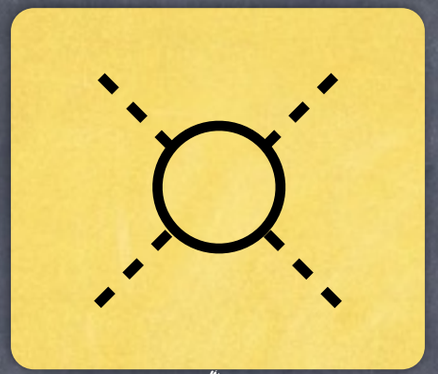


$$\sin\theta \sim \frac{v}{f}$$

$$V \sim \alpha \sin^2\theta + \beta \sin^4\theta$$

Anatomy of the potential



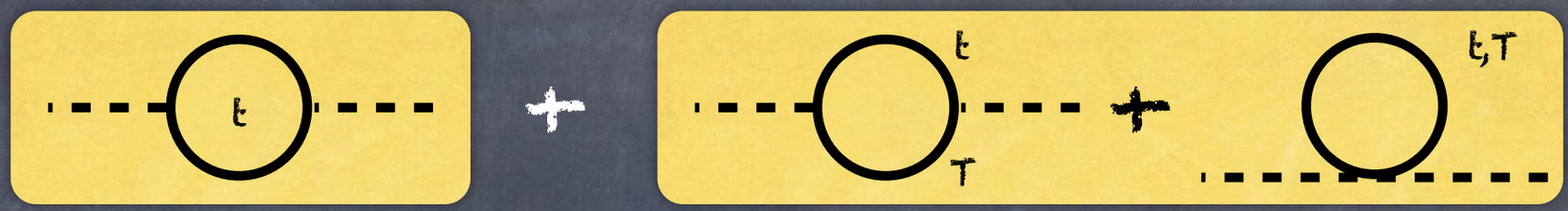


$$\sin\theta \sim \frac{v}{f}$$

$$V \sim \alpha \sin^2\theta + \beta \sin^4\theta$$

Minimum: $\theta \sim \frac{\pi}{2} \qquad (v = f)$

Anatomy of the potential



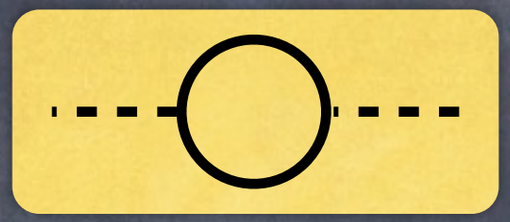
$$\sin\theta \sim \frac{v}{f}$$

$$V \sim \alpha \sin^2\theta + \beta \sin^4\theta$$

$$\alpha < \beta$$

Minimum: $\theta \sim \epsilon \quad (v \ll f)$

Anatomy of the potential



Mass of the underlying fermions

$\sin\theta \sim \frac{v}{f}$

$$V \sim \alpha \sin^2\theta + \gamma \cos\theta$$

$$\alpha \sim \gamma$$

Minimum: $\theta \sim \epsilon \quad (v \ll f)$

Possible!

Anatomy of the potential

- Light top partners are NOT the only way to stabilise the Composite Higgs
- Why do we need them?

The hot potato: flavour!

G.C., H.Cai, T.Flacke, S.J.Lee, A.Parolini, H.Serodio
1501.03818

See also:
O.Matsedonskyi 1411.4638
G.Panico, A.Pomarol 1603.06609

100.000 TeV — $\Lambda_{\rm flavour}$ — Light flavours

near-conformal dynamics

10 TeV — $\Lambda \sim 4\pi f$ — Vectors

1 TeV — f — Condensation scale (extra pions)

} + top partners

100 GeV — $v_{\rm SM} \sim f \sin\theta$ — EWSB

750 di-photon: see talk by T. Flacke

The hot potato: flavour!

SM quarks (3) VLQs (3)

$$M_{\rm up} = \left(\begin{array}{ccc|ccc} & & & 0 & 0 & 0 \\ & m^{\alpha\beta}_{\rm UV}\,\epsilon & & 0 & 0 & 0 \\ & & & Y_{LQ} & Y_{LX}\,\epsilon^2 & -Y_{L\tilde{T}}\,\epsilon \\ \hline 0 & 0 & Y_{RQ}\,\epsilon & M_4 & 0 & 0 \\ 0 & 0 & -Y_{RX}\,\epsilon & 0 & M_4 & 0 \\ 0 & 0 & Y_{R\tilde{T}} & 0 & 0 & M_1 \end{array} \right)$$

$$\epsilon \sim \frac{v}{f}$$

- Mixing is chiral!
- Couplings to light generations can be sizeable!
- Important consequence for single production!

VLQ @NLO_QCD

Similar to: M.Buchkremer, G.C., A.Deandrea, L.Panizzi 1305.4172

$$
\begin{aligned}
\mathcal{L}_{\text{eff}} &= \frac{\sqrt{2}g}{2}\left[\bar{Y}\not{W}\left(\kappa_L^Y P_L+\kappa_R^Y P_R\right)d+\bar{B}\not{W}\left(\kappa_L^B P_L+\kappa_R^B P_R\right)u\right.\\
&+ \left.\bar{T}\not{W}\left(\kappa_L^T P_L+\kappa_R^T P_R\right)d+\bar{X}\not{W}\left(\kappa_L^X P_L+\kappa_R^X P_R\right)u\right]\\
&+ \frac{g}{2c_W}\left[\bar{B}\not{Z}\left(\tilde{\kappa}_L^B P_L+\tilde{\kappa}_R^B P_R\right)d+\bar{T}\not{Z}\left(\tilde{\kappa}_L^T P_L+\tilde{\kappa}_R^T P_R\right)u\right]\\
&- h\left[\bar{B}\left(\hat{\kappa}_L^B P_L+\hat{\kappa}_R^B P_R\right)d+\bar{T}\left(\hat{\kappa}_L^T P_L+\hat{\kappa}_R^T P_R\right)u\right]+\text{h.c.}\,,
\end{aligned}
$$

$T \to 2/3$

$B \to -1/3$

$X \to 5/3$

$Y \to -4/3$

$\kappa \sim \tilde{\kappa} \sim u \qquad \hat{\kappa} \sim u\,\dfrac{M_Q}{v}$

u = generic mixing angle

$u_L \ll u_R \quad \text{or} \quad u_R \ll u_L$

FeynRules + NLOCT
MadGraph5_AMC@NLO

Work in progress with B.Fuks, H.S.Shao and H.Cai, A.Carvalho, A.Deandrea, T.Flacke, D.Majumder

Preliminary results:
single + 1 jet

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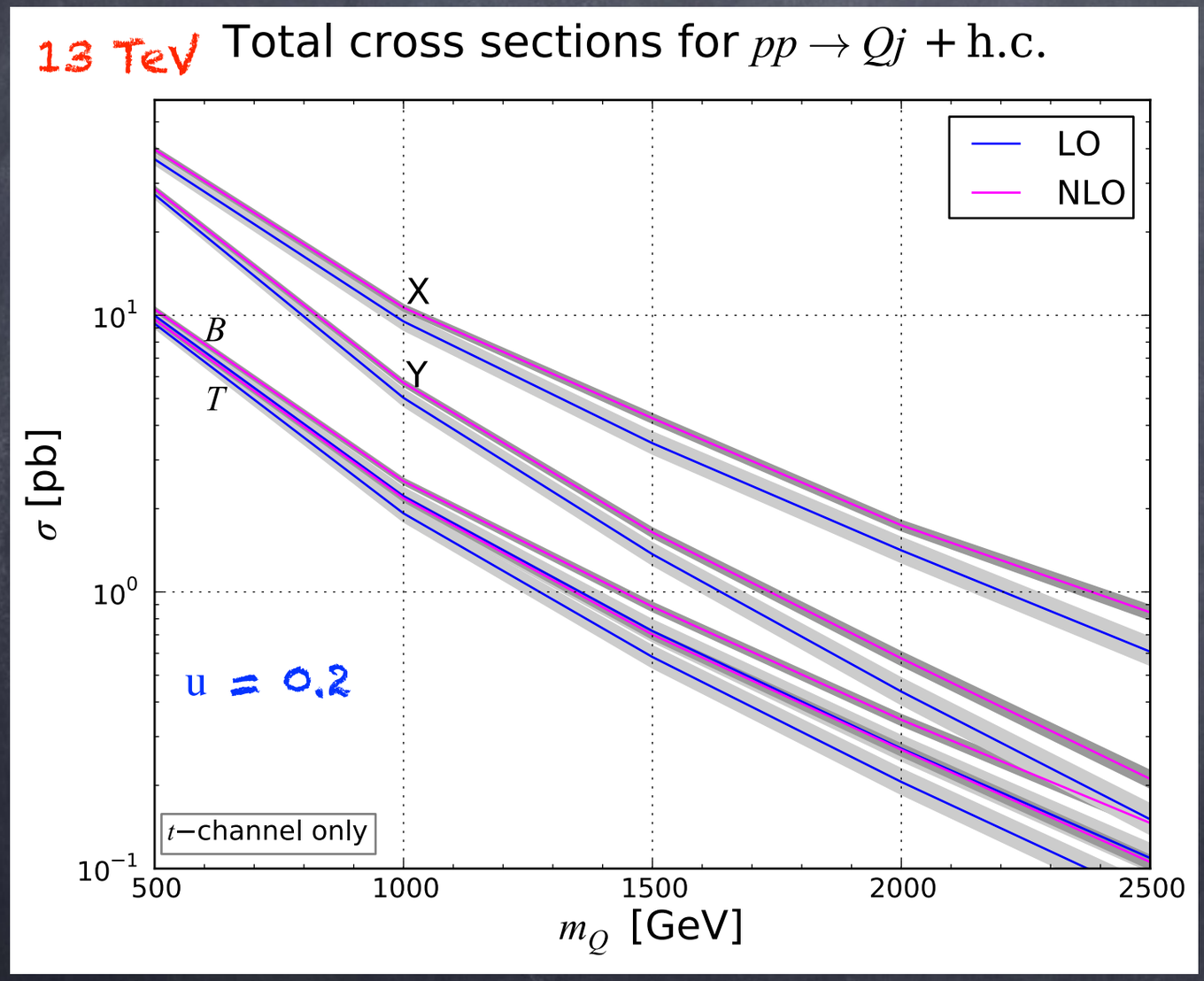

- Strongly reduced errors (scale variation)
- Enhancement at high masses!
- Distributions?

Preliminary results: pair production

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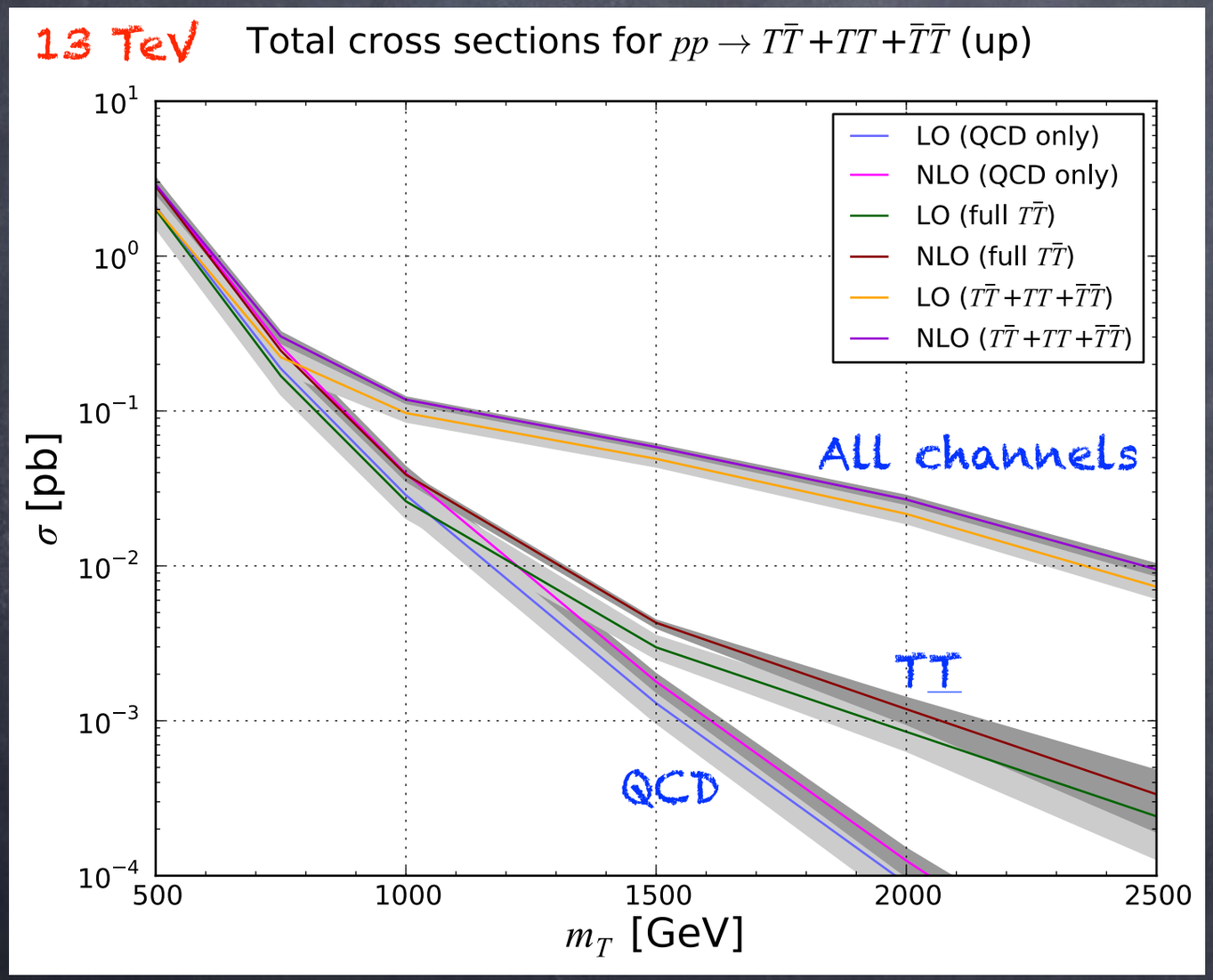
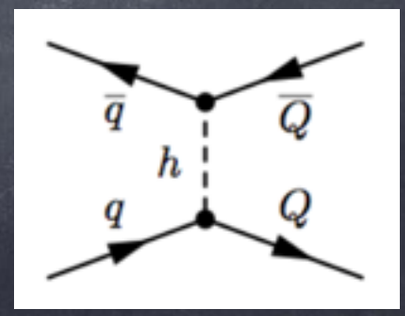


- EW pair production can dominate for valence quarks!
- Sensitivity to high masses!



Preliminary results:
di-Higgs production

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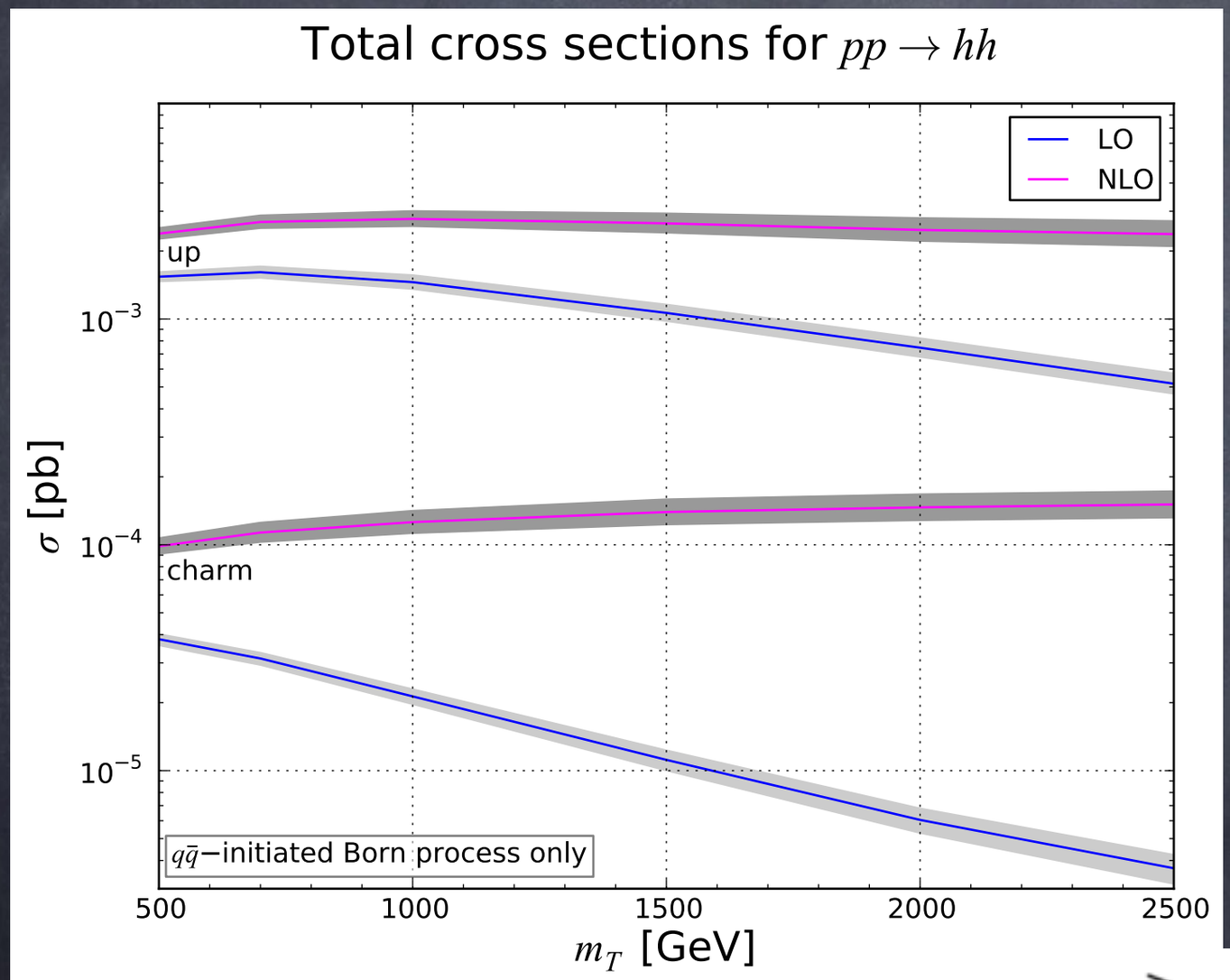
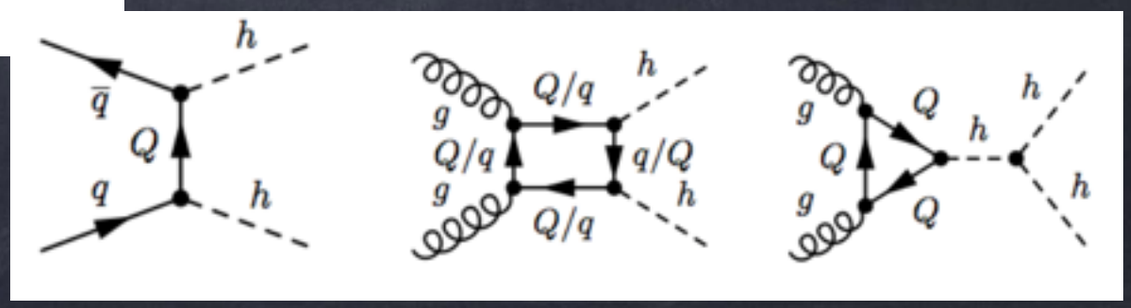


- t-channel in double-Higgs production
- box and triangle included @ NLO
- HUGE k-factors due to additional glu-initiated processes

$$ug \to hhu$$

$$\hat{\kappa} \sim u \, \frac{M_Q}{v}$$



Summary

- VLQ are interesting objects to look for @ LHC
- aka top-partners: not a must in natural theories! (they may be as heavy as 10 TeV)
- Flavour: couplings to light generations may be sizeable (NLO_QCD needed!)
- Non standard decays: DM, other (light) composite scalars, ...