

# The Case for Future Hadron Colliders From $b \rightarrow s\mu^+\mu^-$ Anomalies

**Tevong You**



[arXiv:1710.06363] B. C. Allanach, B. Gripaios, T.Y.

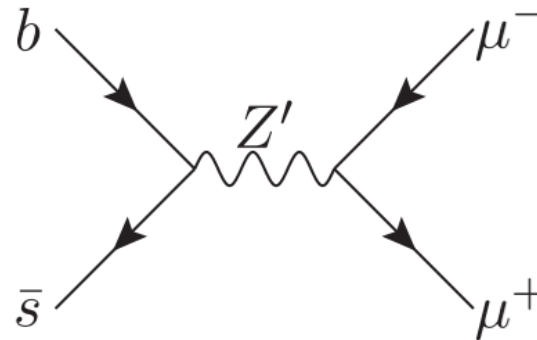
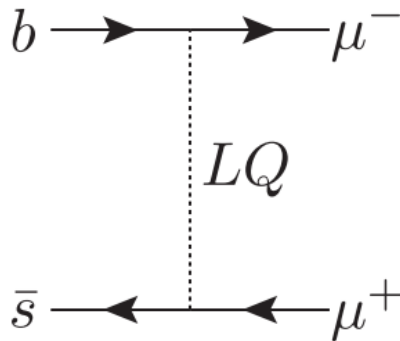
# Motivation

- If  $b \rightarrow s\mu^+\mu^-$  anomalies are confirmed, can we *definitely* discover directly the source (i.e. LQ/ $Z'$ ) at higher energies?

(80 TeV unitarity limit = **no general no-lose theorem** at FCC-hh)

Di Luzio, Nardecchia [1706.01868]

- Consider sensitivity to most **pessimistic** scenario: only include minimal couplings required to explain  $b \rightarrow s\mu^+\mu^-$  anomalies

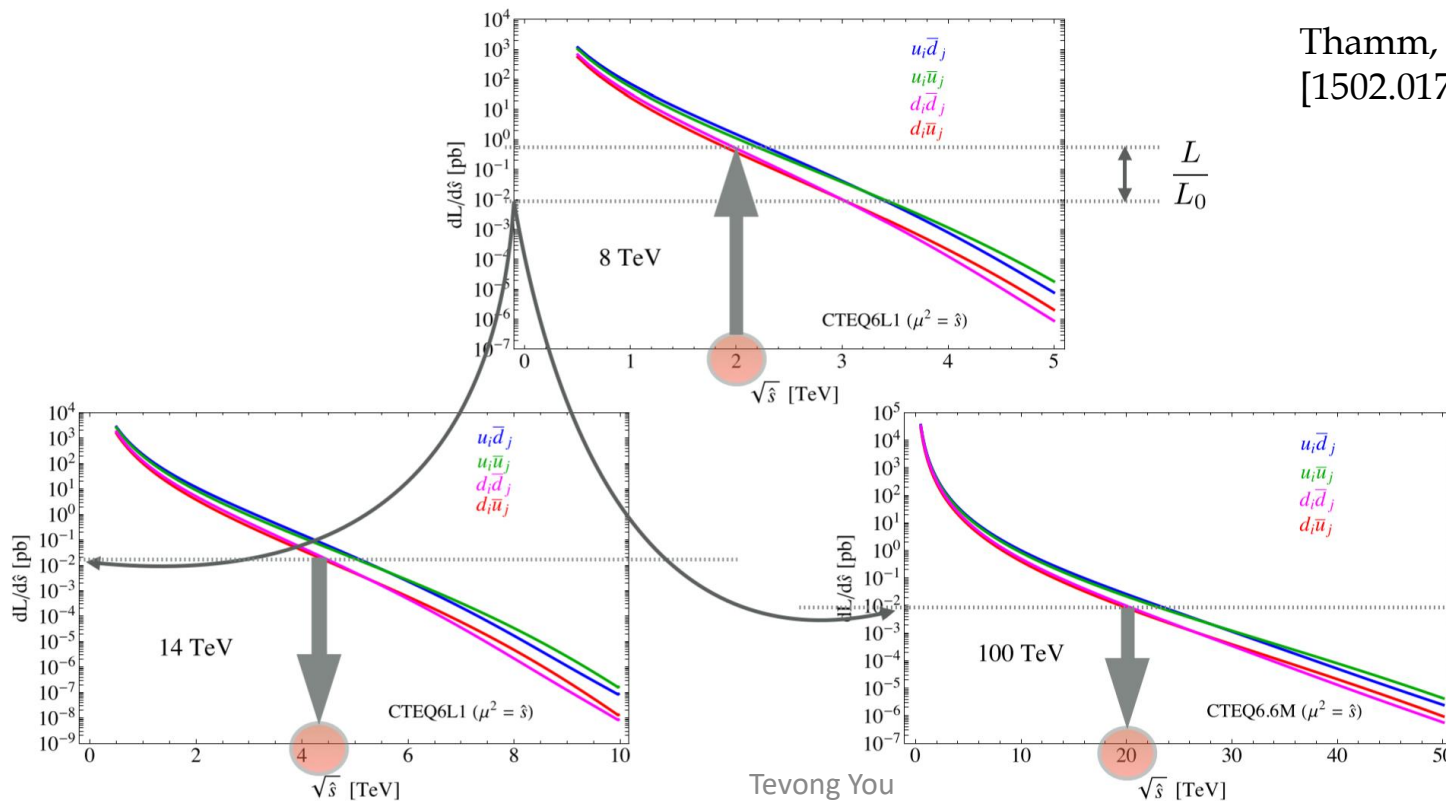


- More realistic models will only be *easier* to discover

# Extrapolation Method

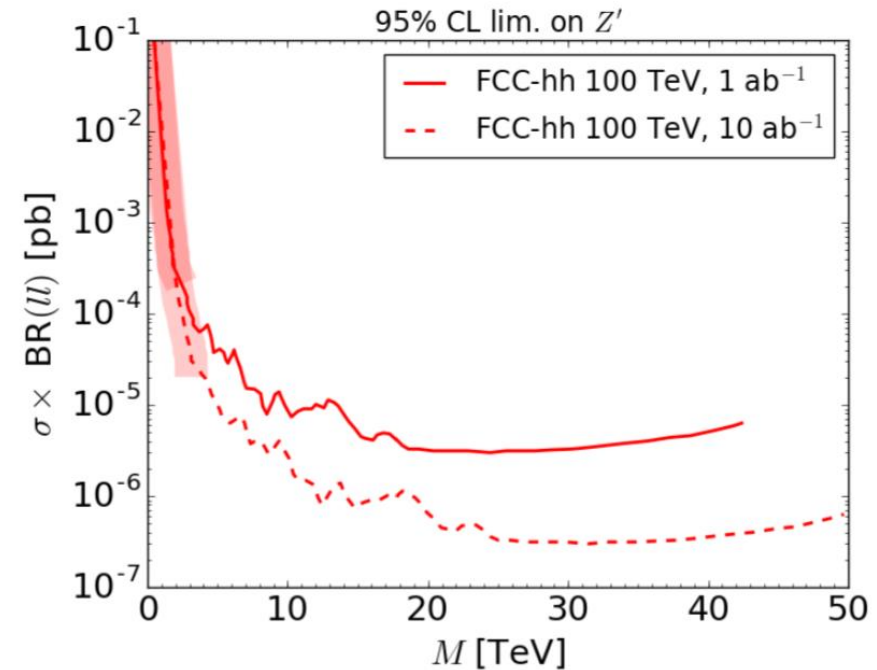
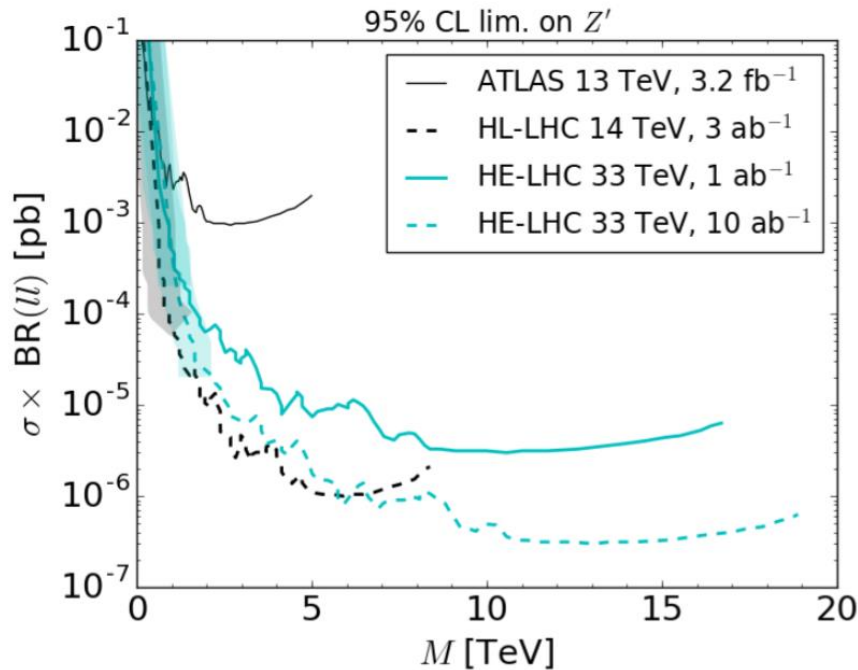
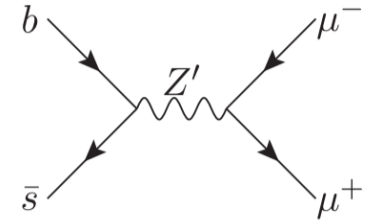
- 95% CL limit depends on number of bkg events
- For current limit at given mass, find equivalent mass at future collider with same number of bkg = same limit at equivalent mass

Thamm, Torre, Wulzer  
[1502.01701]



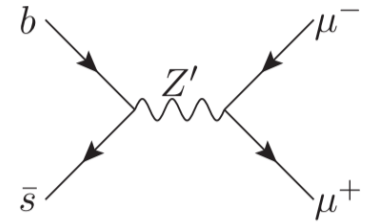
# Z' Sensitivity

- Extrapolate current 13 TeV di-muon search:

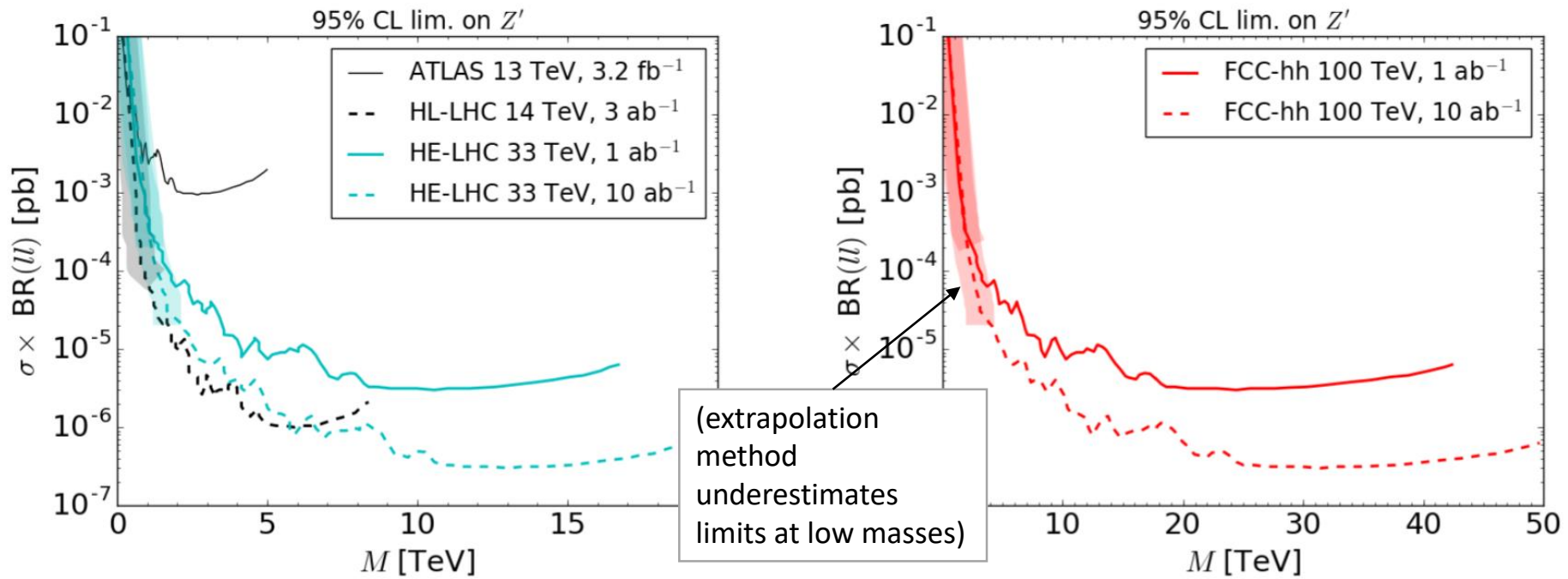


- Actual limits depend on  $Z'$  couplings in signal x-section

# Z' Sensitivity

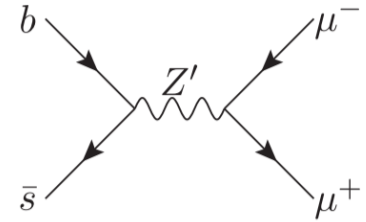


- Extrapolate current 13 TeV di-muon search:

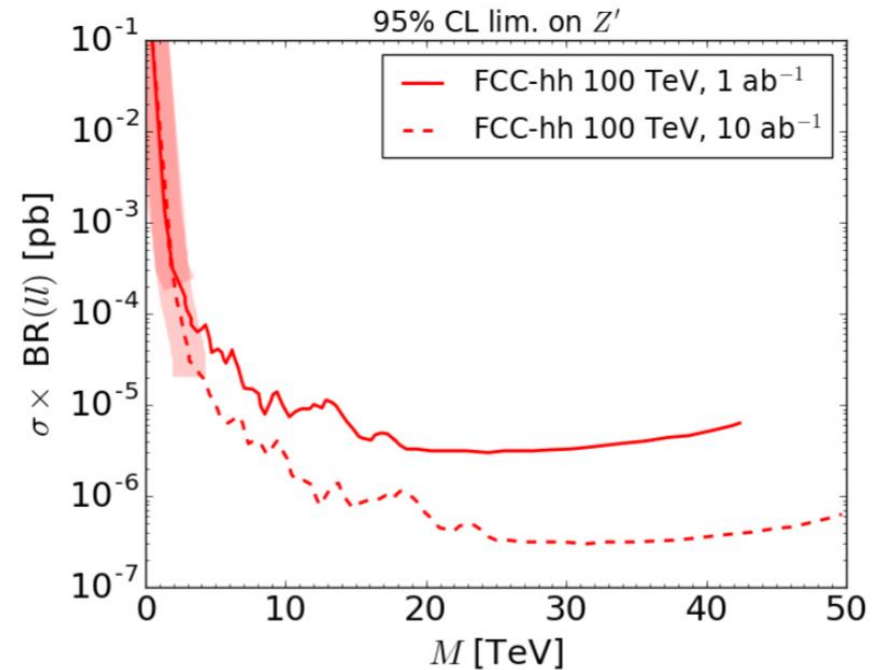
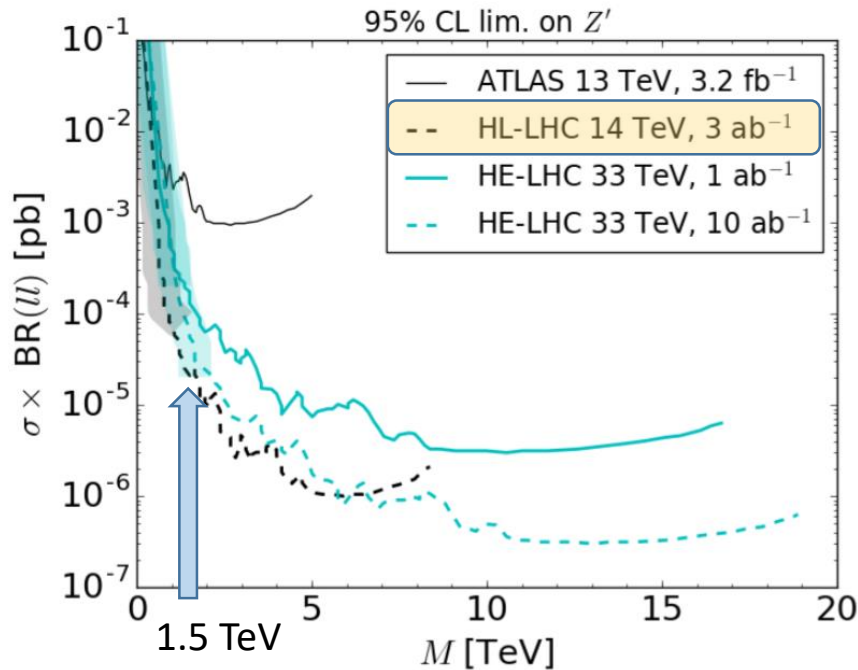


- Actual limits depend on Z' couplings in signal x-section

# Z' Sensitivity

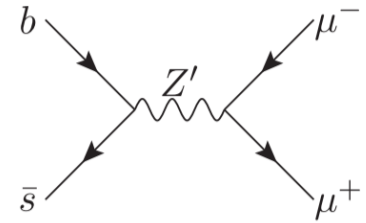


- Extrapolate current 13 TeV di-muon search:

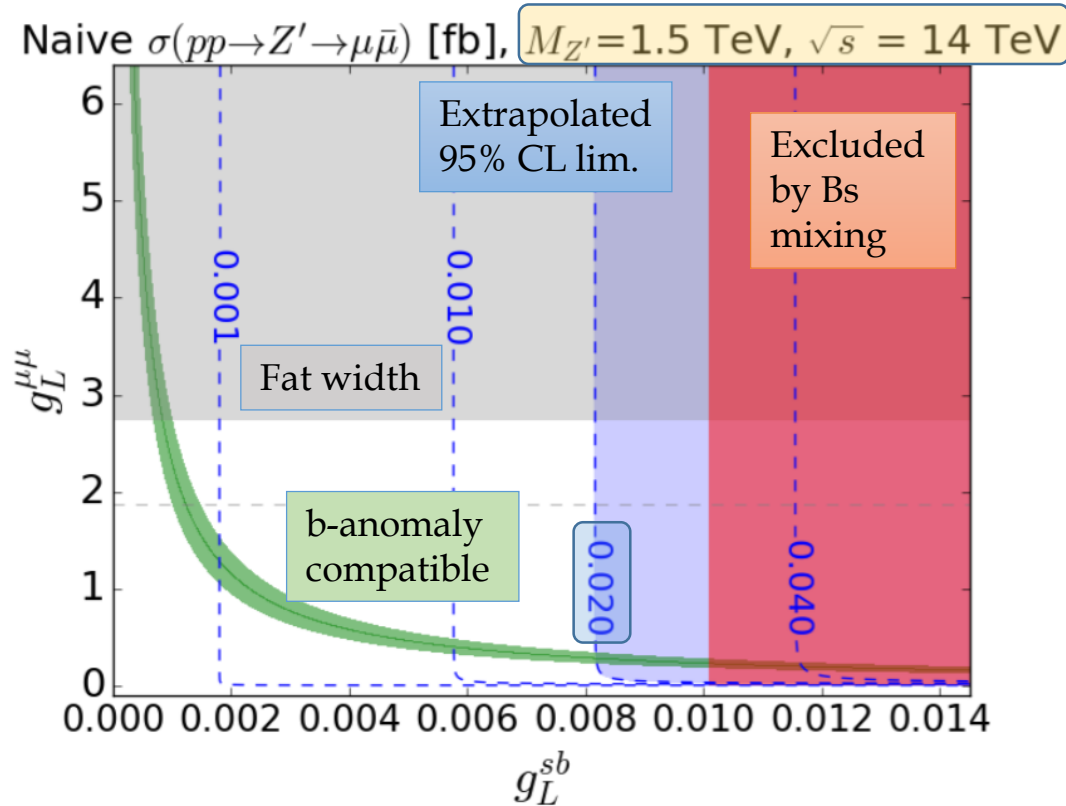


- Actual limits depend on  $Z'$  couplings in signal x-section

# Z' Sensitivity

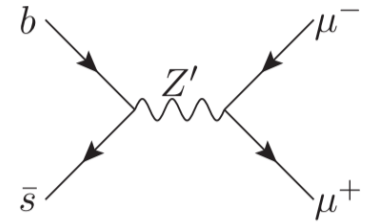


- Extrapolate current 13 TeV di-muon search:

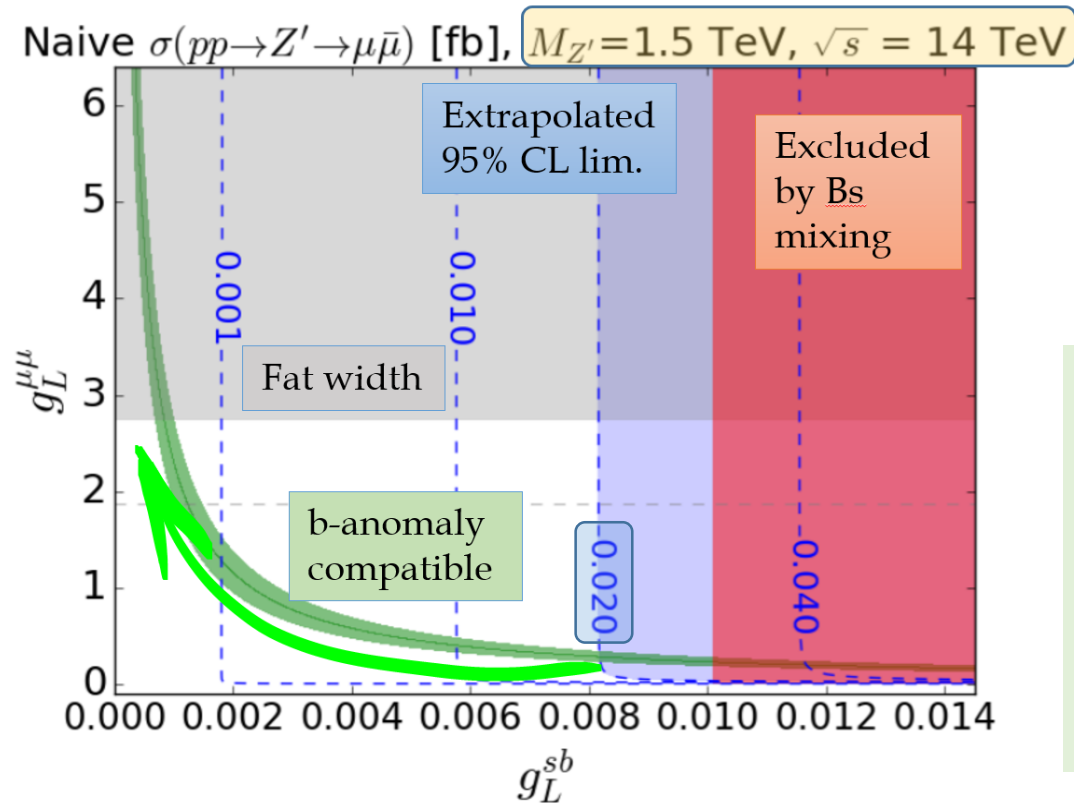


- Actual limits depend on Z' couplings in signal x-section

# Z' Sensitivity



- Extrapolate current 13 TeV di-muon search:

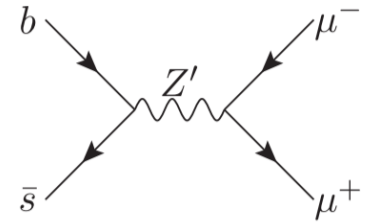


Summary of Z' coverage:  
For each  $M_{Z'}$ , plot vertically the anomaly-compatible region

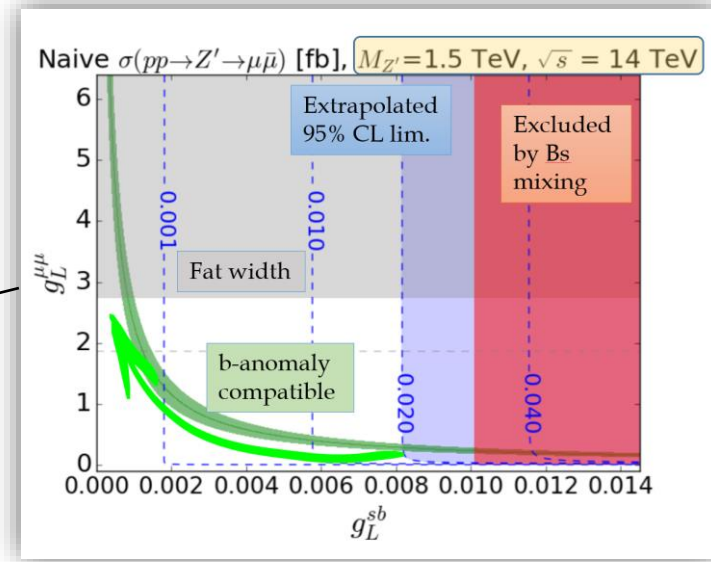
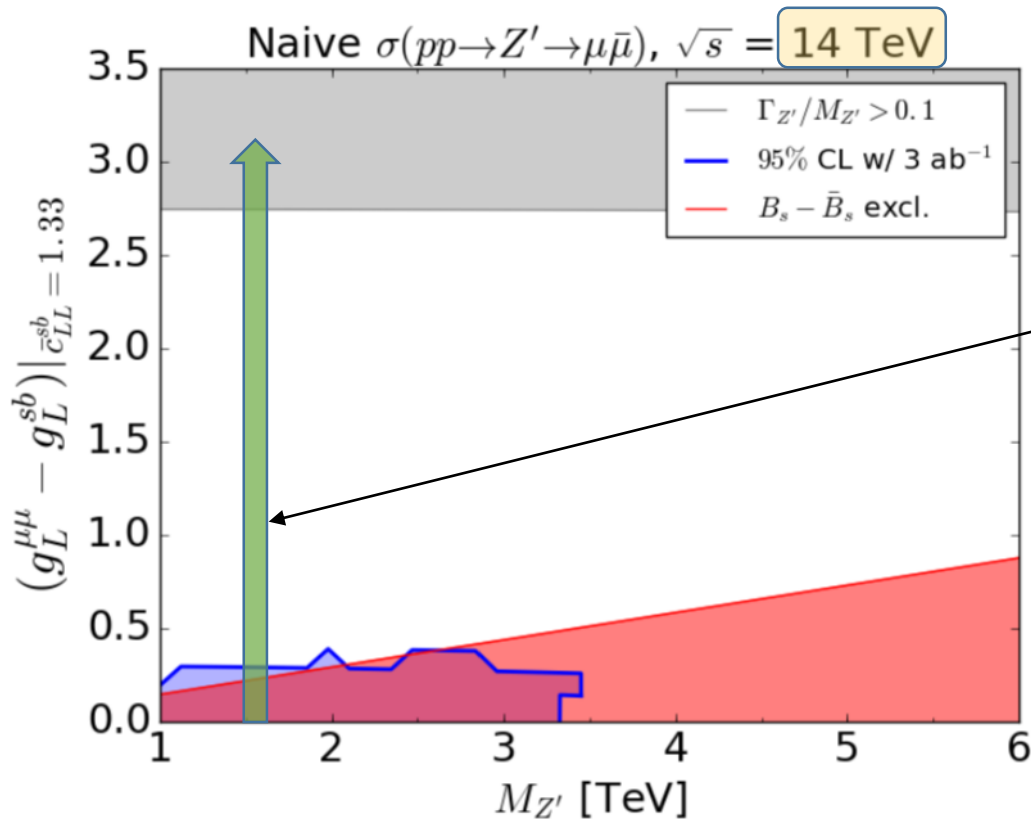
- Actual limits depend on Z' couplings in signal x-section



# Z' Sensitivity



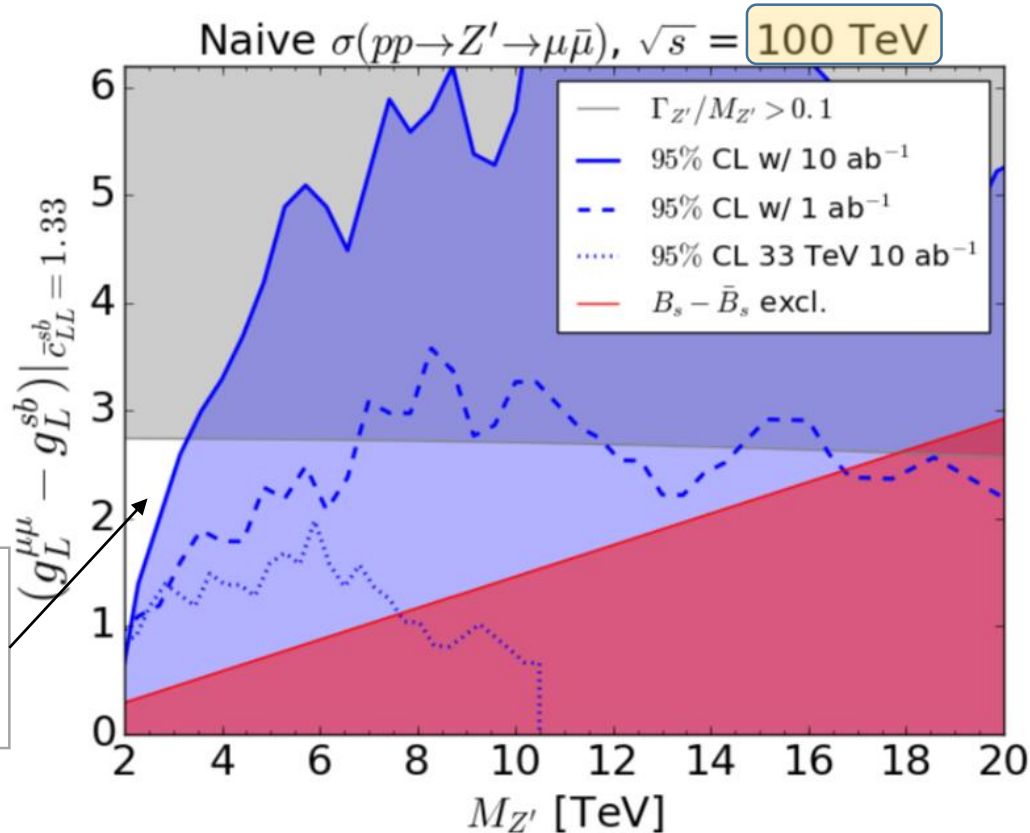
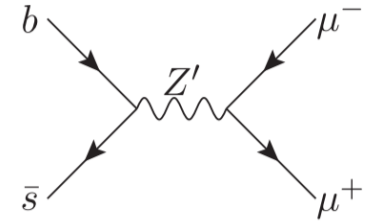
- Extrapolate current 13 TeV di-muon search:



- Actual limits depend on Z' couplings in signal x-section

# Z' Sensitivity

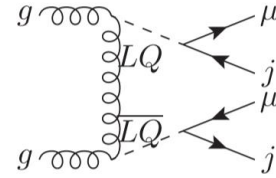
- Extrapolate current 13 TeV di-muon search:



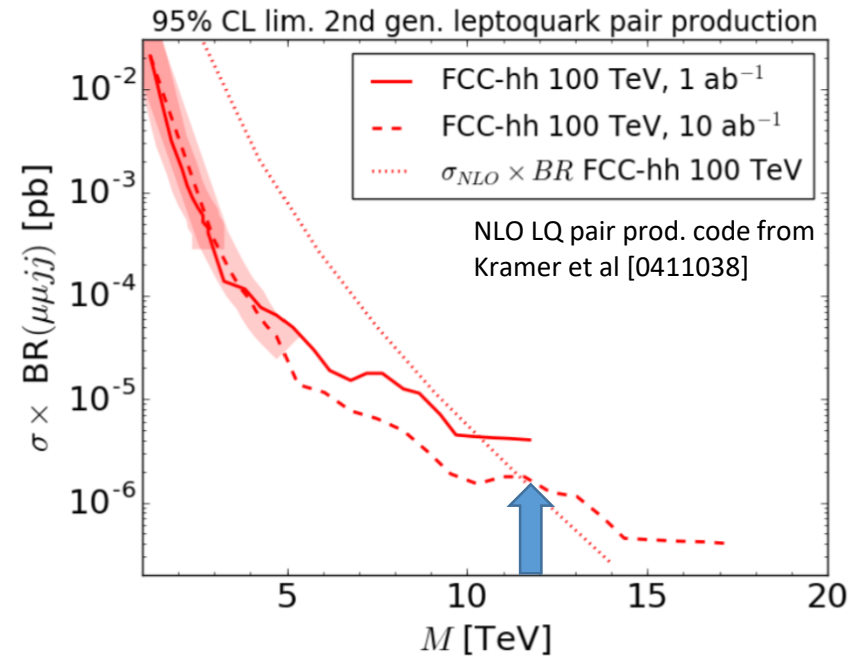
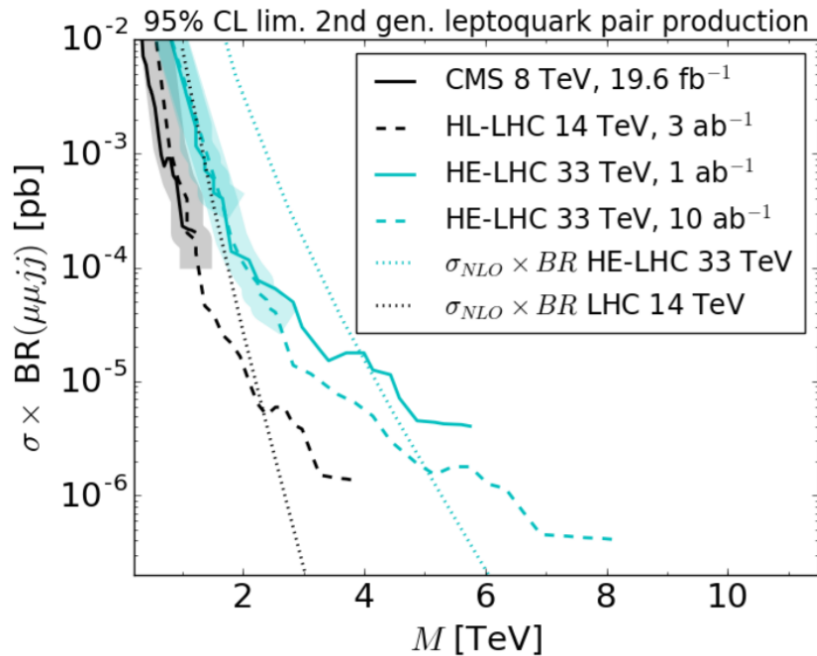
(extrapolation method underestimates limits at low masses)

- 100 TeV can cover **all** parameter space of most *pessimistic* scenario

# Leptoquark Sensitivity

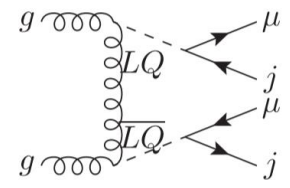


- Extrapolate current 8 TeV LQ di-muon+di-jet search:

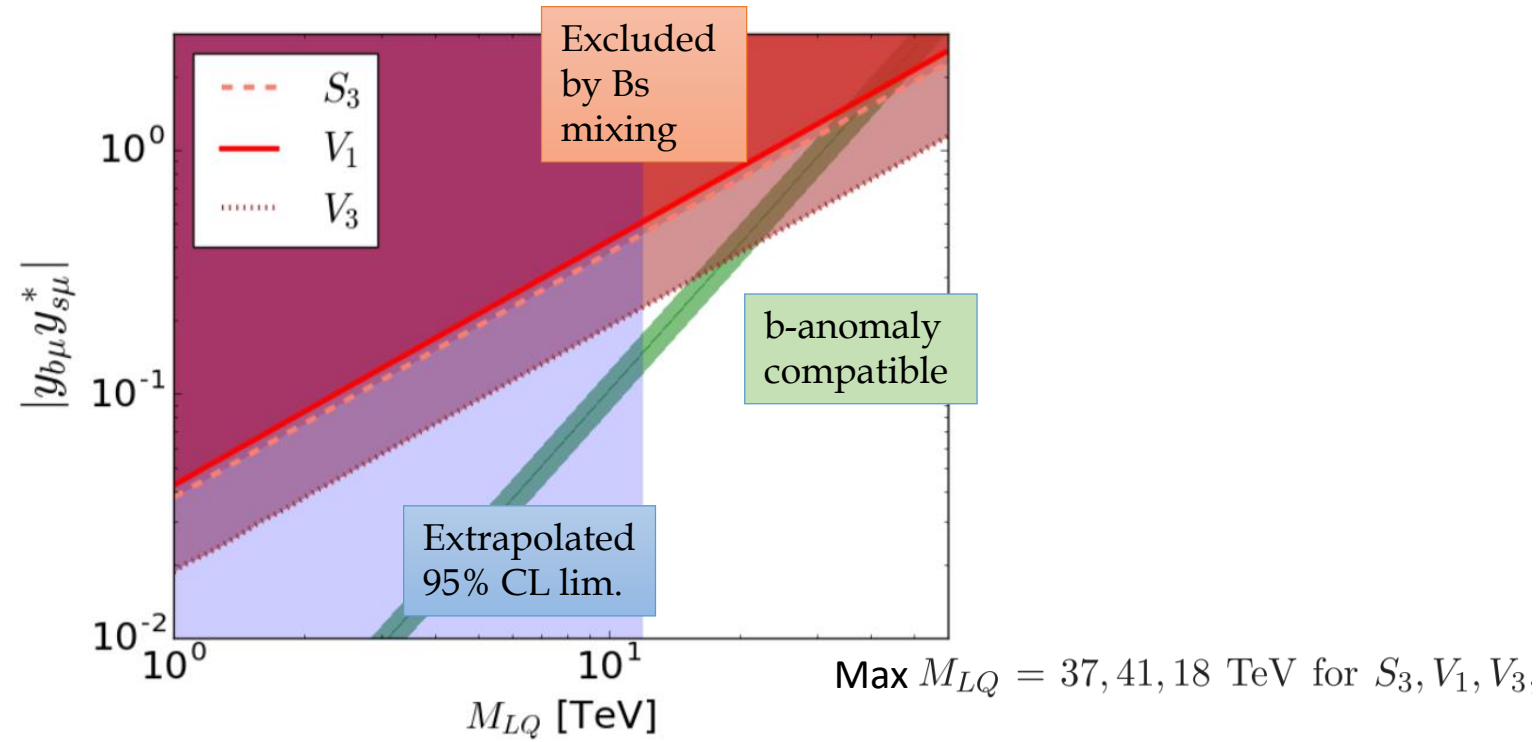


- Pair production for scalar LQ depends only on QCD coupling
- Upper limit from Bs mixing constraint

# Leptoquark Sensitivity



- Extrapolate current 8 TeV LQ di-muon+di-jet search:

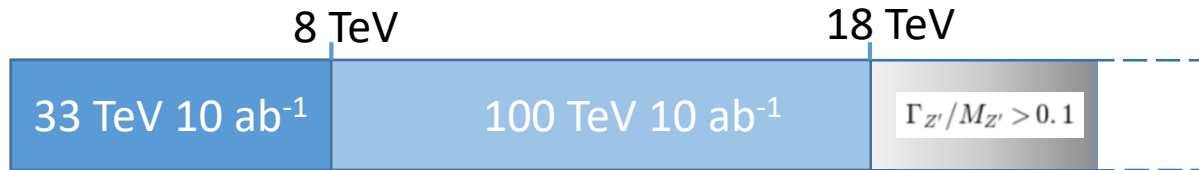


- Pair production for scalar LQ depends only on QCD coupling
- Upper limit from Bs mixing constraint

# Take-Home Message

n.b. Sensitivity for the most conservative and pessimistic scenario

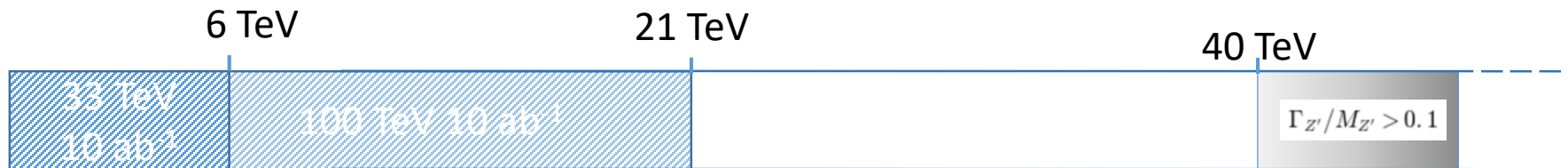
- Drell-Yan,  $p p \rightarrow Z' \rightarrow \mu^+ \mu^-$



- Pair production,  $p p \rightarrow LQ LQ \rightarrow \mu^+ \mu^- j j$



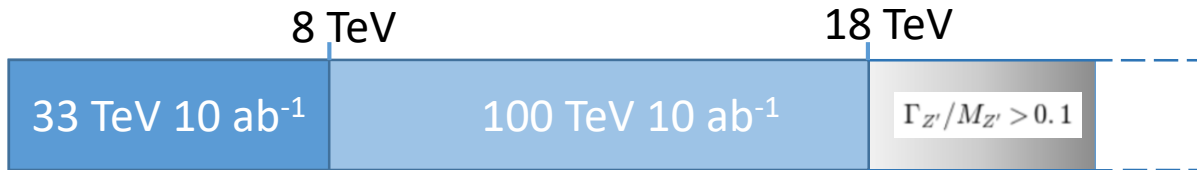
- Single production,  $p p \rightarrow LQ \rightarrow \mu^+ \mu^- j$



LQ coupling strength →

# Take-Home Message

- Drell-Yan,  $p p \rightarrow Z' \rightarrow \mu^+ \mu^-$



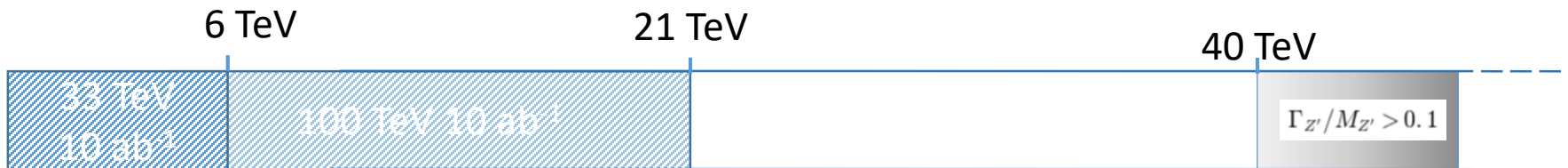
n.b. Sensitivity for the most conservative and pessimistic scenario

(for  $Z'$ , coupling only to  $b+s$  is **impossible**)

- Pair production,  $p p \rightarrow LQ LQ \rightarrow \mu^+ \mu^- j j$



- Single production,  $p p \rightarrow LQ \rightarrow \mu^+ \mu^- j$



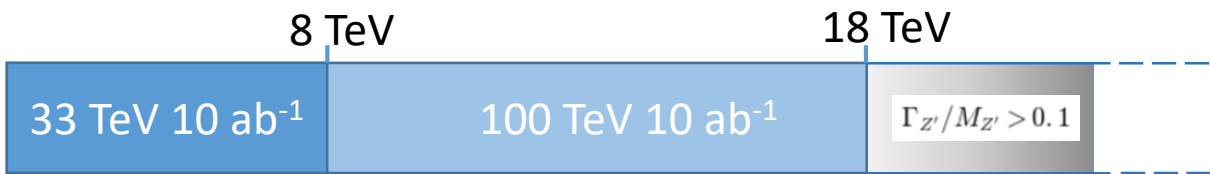
LQ coupling strength →

# Take-Home Message

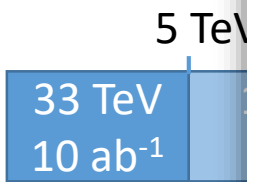
- Drell-Yan,  $pp \rightarrow Z' \rightarrow \mu^+ \mu^-$

n.b. Sensitivity for the most conservative and pessimistic scenario

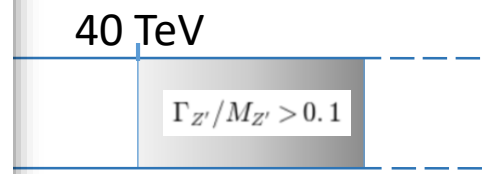
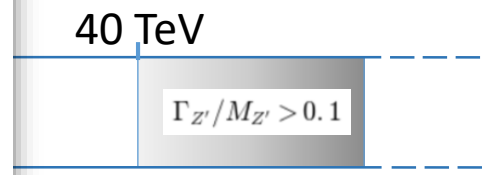
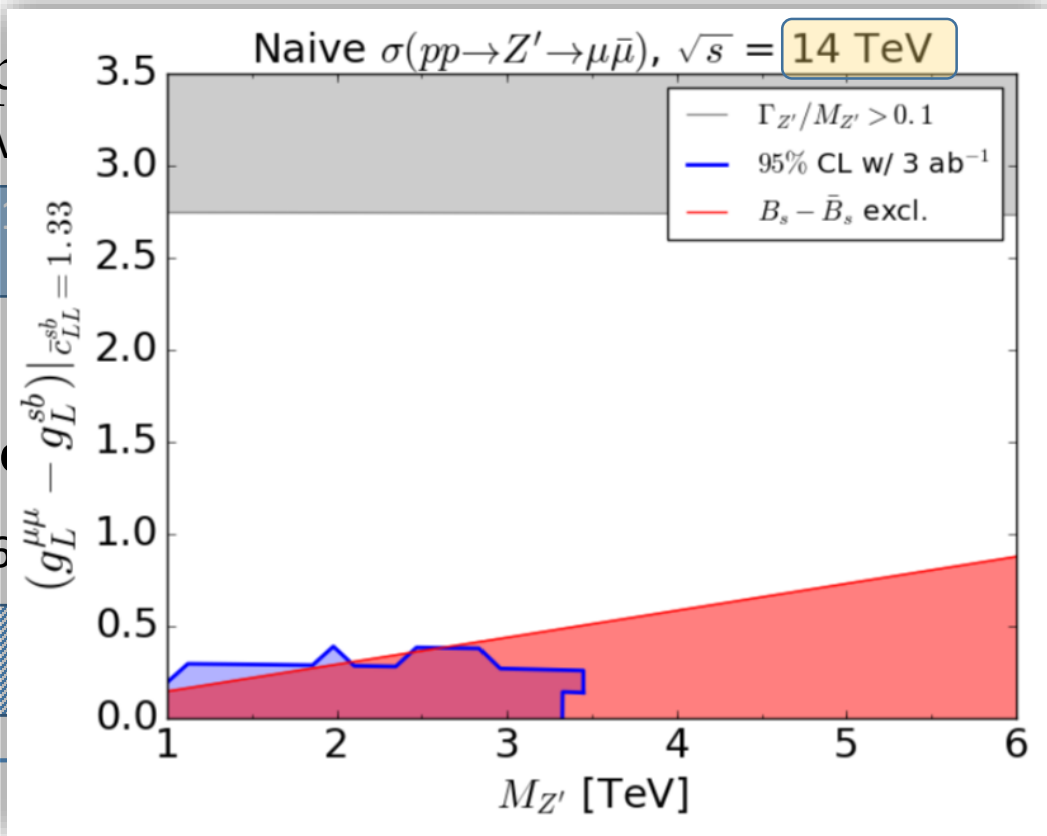
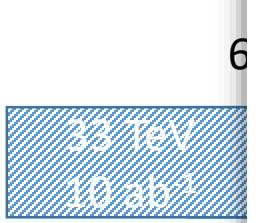
(for  $Z'$ , coupling only to  $b+s$  is **impossible**)



- Pair p

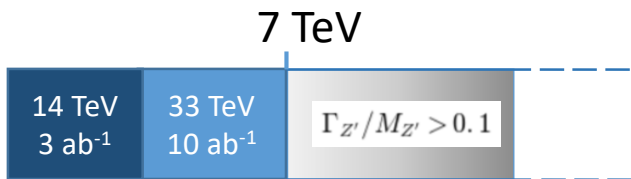


- Single



# Take-Home Message

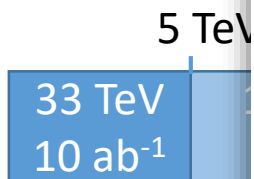
- Drell-Yan,  $pp \rightarrow Z' \rightarrow \mu^+ \mu^-$



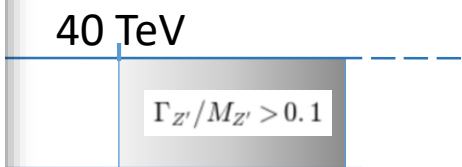
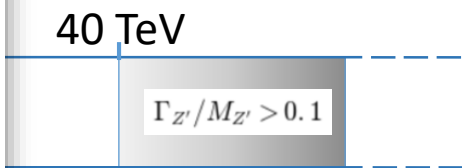
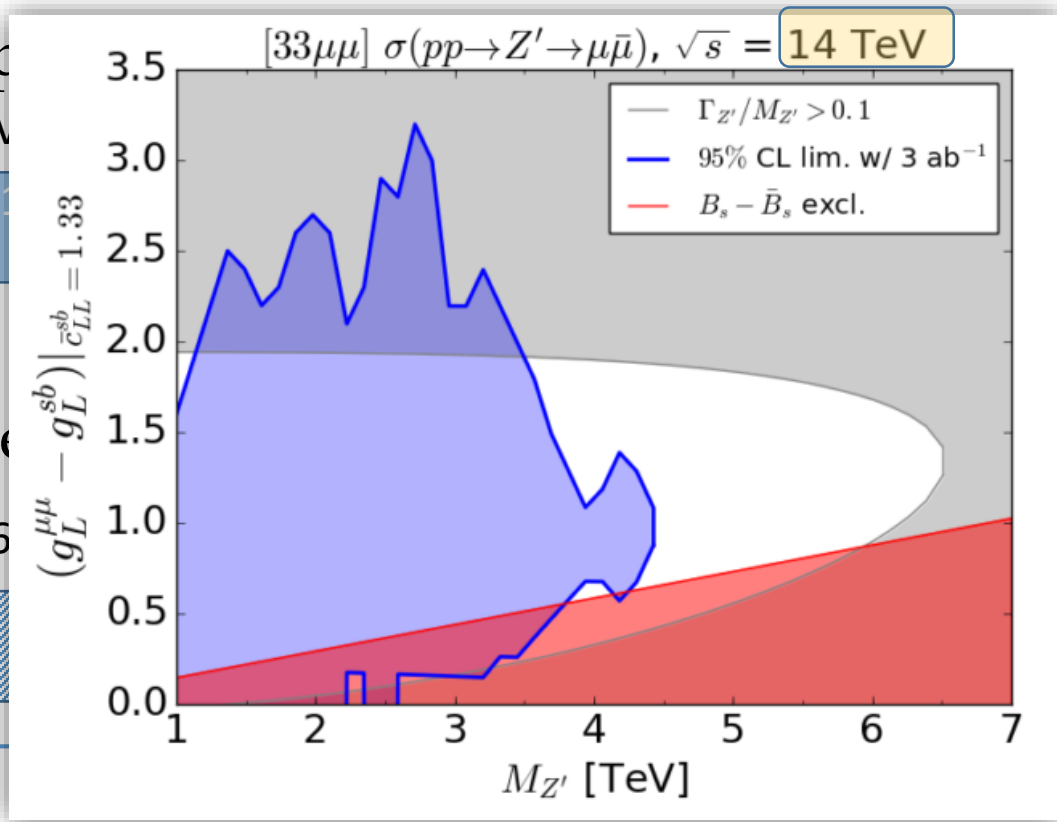
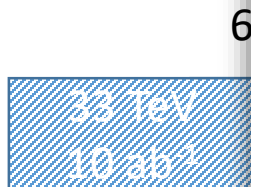
e.g. realistic model coupling to 3<sup>rd</sup> gen. quarks + CKM rotations

n.b. Sensitivity for the most conservative and pessimistic scenario  
 ( $Z'$ , coupling only to  $b+s$  is impossible)

- Pair p



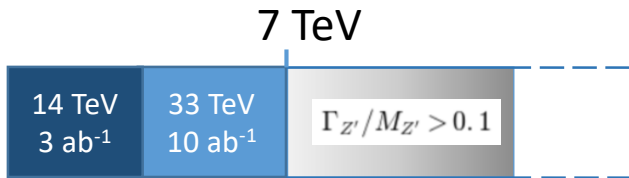
- Single





# Take-Home Message

- Drell-Yan,  $pp \rightarrow Z' \rightarrow \mu^+ \mu^-$

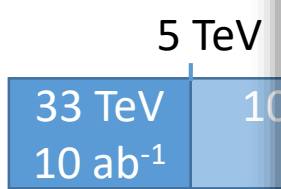


e.g. realistic model coupling to 3<sup>rd</sup> gen. quarks + CKM rotations

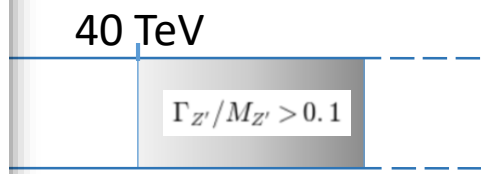
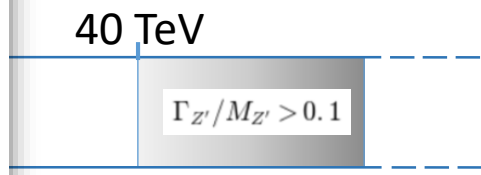
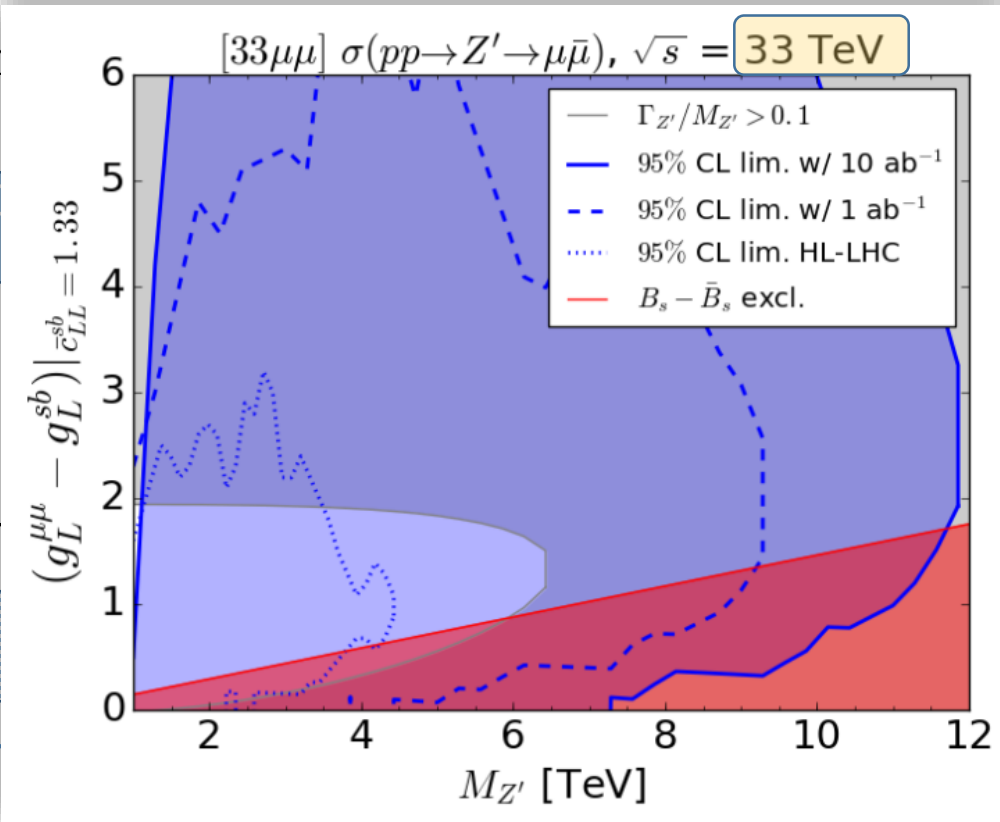
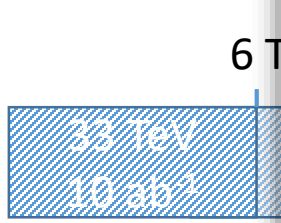
n.b. Sensitivity for the most conservative and pessimistic scenario

( $Z'$ , coupling only to  $b+s$  is impossible)

- Pair production



- Single production

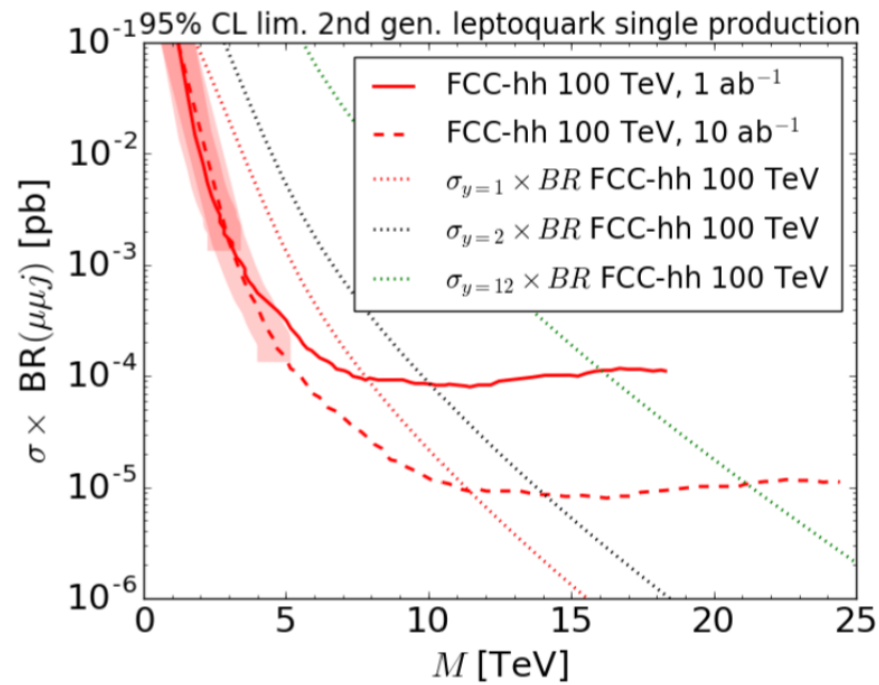
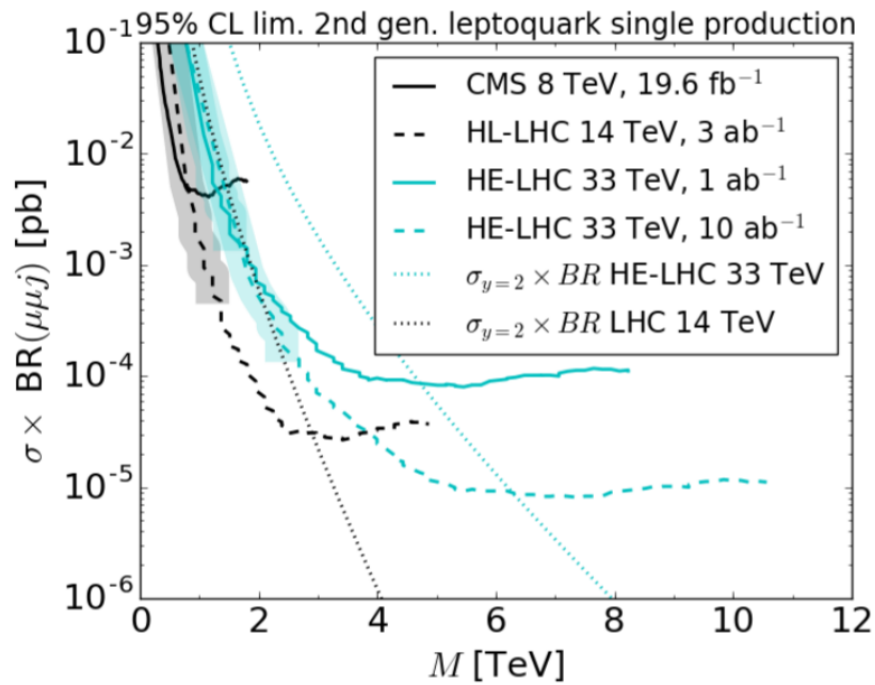
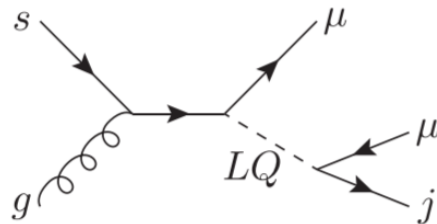


# Conclusion

- Complete coverage of  $Z'$  models at 100 TeV FCC-hh
- Contrived LQ models may still survive FCC-hh
- Future studies: consider backgrounds, other channels, more benchmark models, etc.
- Even if anomalies vanish, motivates **direct** discovery potential of future hadron colliders and **interplay** with **indirect** sensitivity from B physics

# Backup

# Leptoquark single production



# Extrapolation method

$$\sigma_B(M, s) \propto \sum_{i,j} \int_{M^2 - \Delta \hat{s}}^{M^2 + \Delta \hat{s}} d\hat{s} \frac{dL_{ij}}{d\hat{s}} \hat{\sigma}_{ij}(\hat{s}), \quad C_{ij} = \hat{s} \hat{\sigma}_{ij} \text{ is approximately constant.}$$

$$\propto \frac{\Delta \hat{s}}{M^2} \sum_{i,j} C_{ij} \frac{dL_{ij}}{d\hat{s}}(M, s)$$

$$L_0 \cdot \sum_{i,j} C_{ij} \frac{dL_{ij}}{d\hat{s}}(M_0, s_0) = L' \cdot \sum_{i,j} C_{ij} \frac{dL_{ij}}{d\hat{s}}(M', s')$$