

Can we definitely discover the source of $B \rightarrow K^{(*)} \mu^+ \mu^-$ anomalies at future colliders?

Tevong You



With B. C. Allanach, B. Gripaios [JHEP, arXiv:1710.06363]

oasis

Definitely Maybe



oasis

Definitely Maybe



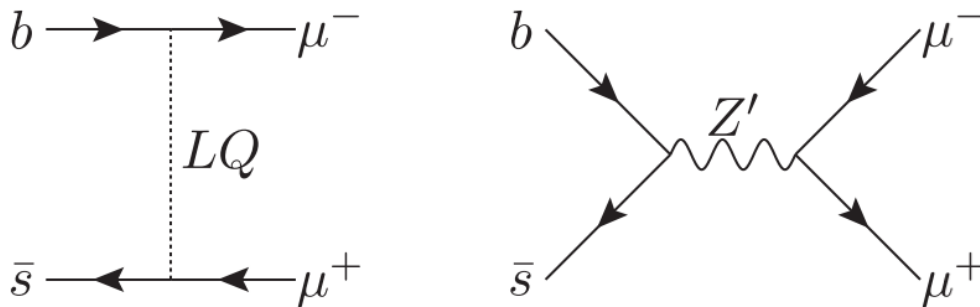
Motivation

- Assume $b \rightarrow s\mu^+\mu^-$ anomalies are confirmed at **high significance** in individual measurements, and by **independent** experiments
- Underlying new physics the main case for going to **higher energies** – but how high is enough for a reasonable guarantee of discovery (i.e. LQ/ Z')?

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

Di Luzio, Nardecchia [1706.01868]

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

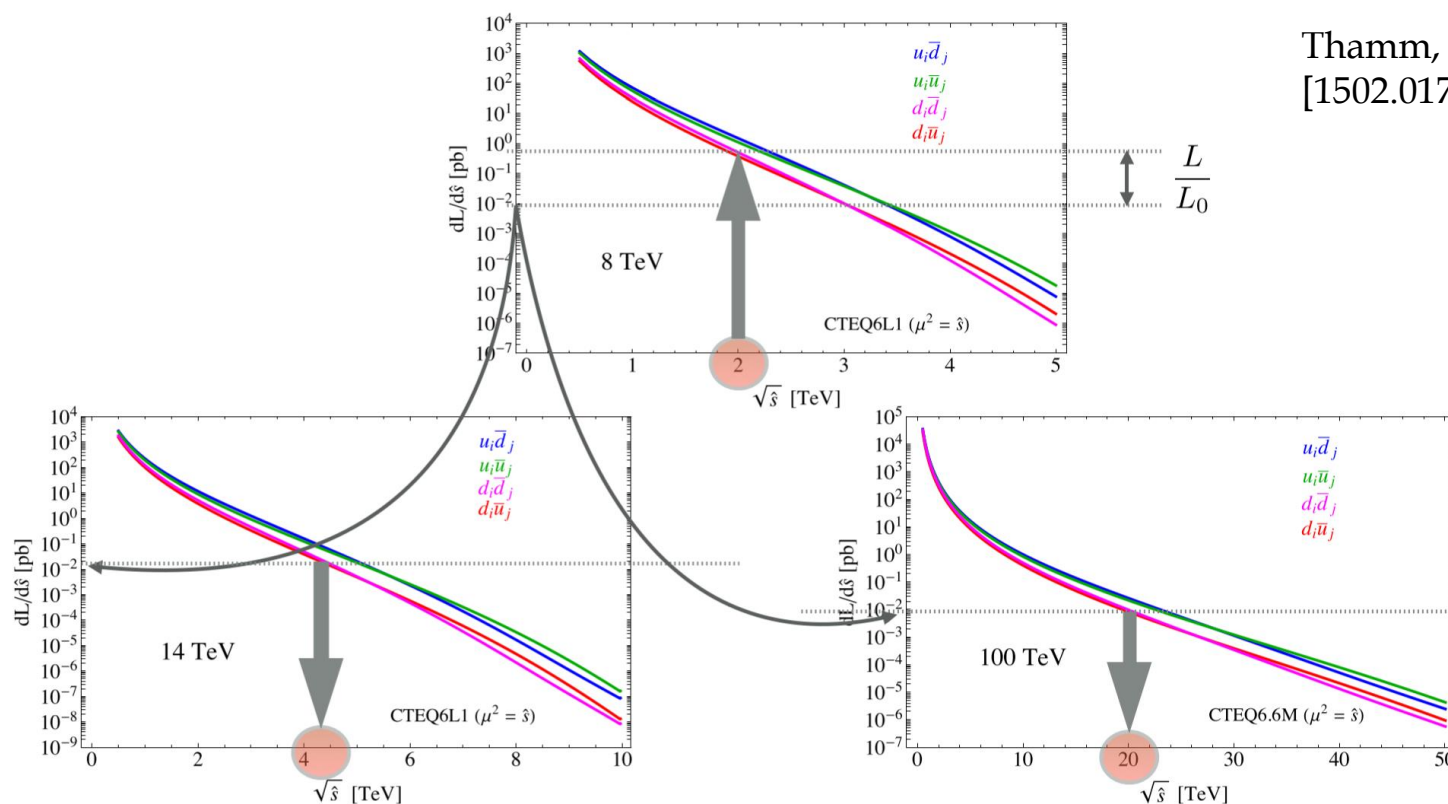


- Useful benchmark, more realistic models will typically be *easier* to discover

Extrapolation Method

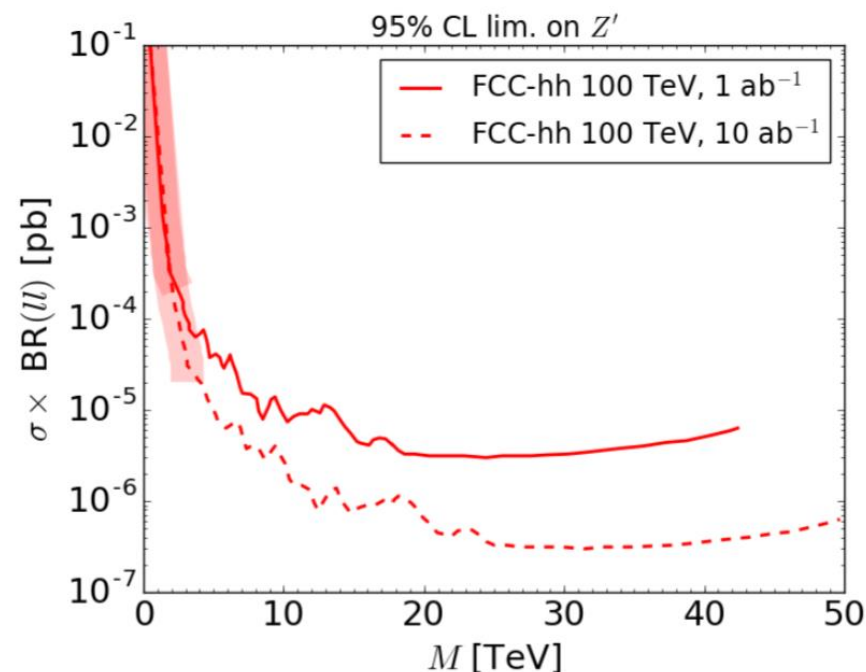
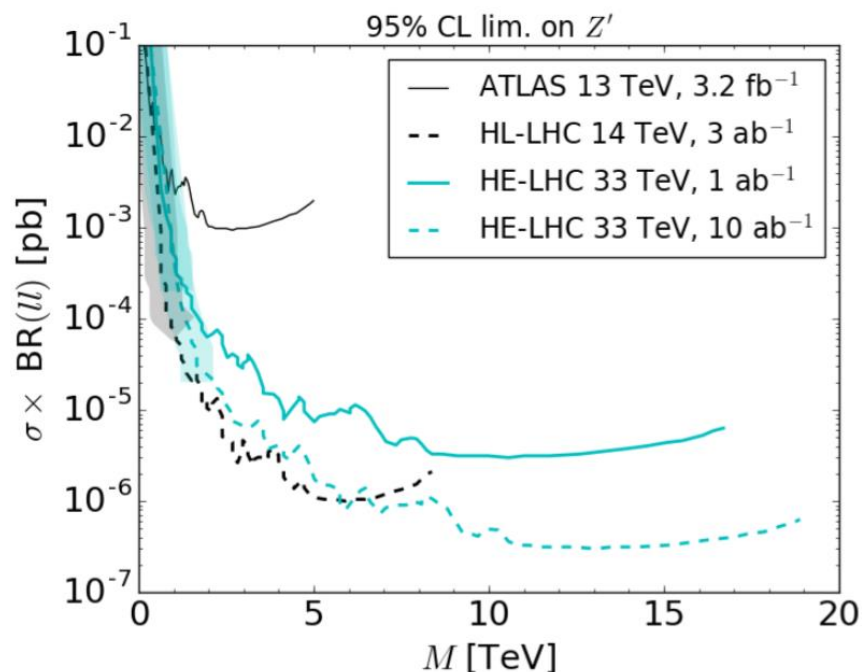
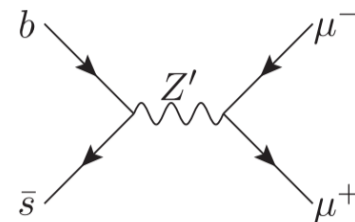
- 95% CL limit depends on number of background events
- For current limit at given mass, find equivalent mass at future collider with same number of background = same limit at equivalent mass

Thamm, Torre, Wulzer
[1502.01701]



Z' Sensitivity

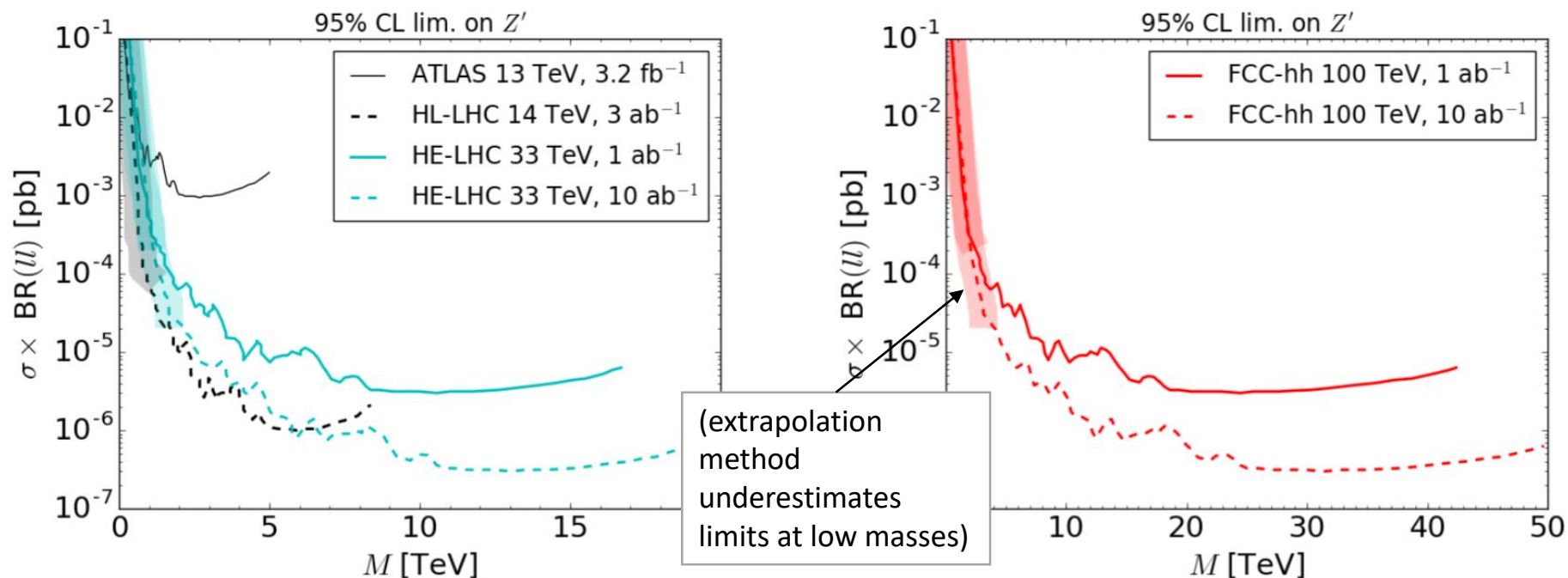
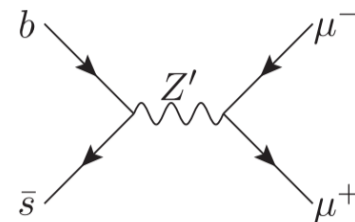
- Extrapolate current 13 TeV di-muon search:



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

Z' Sensitivity

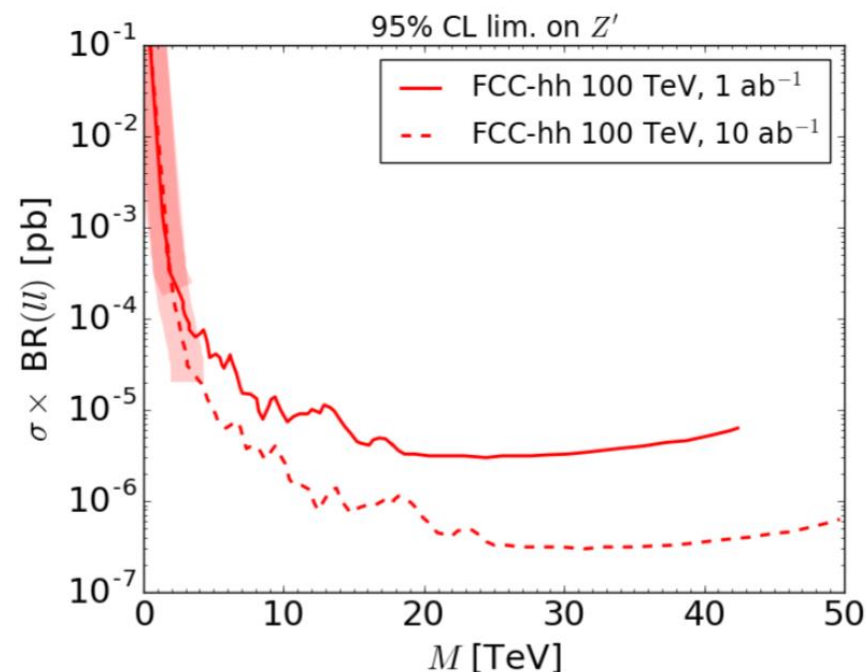
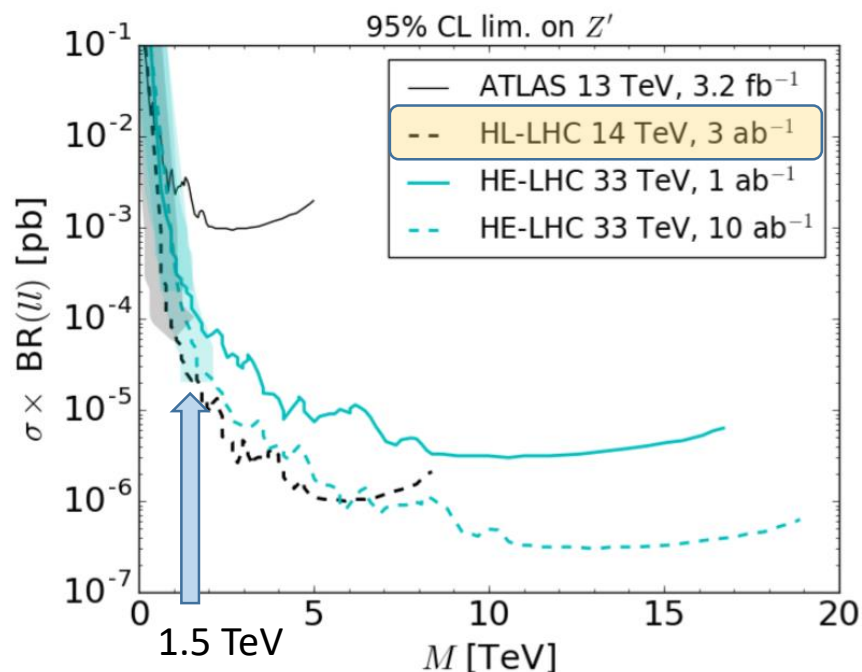
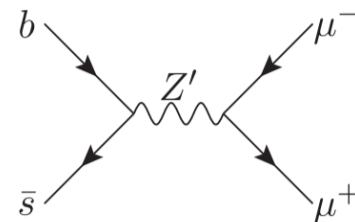
- Extrapolate current 13 TeV di-muon search:



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

Z' Sensitivity

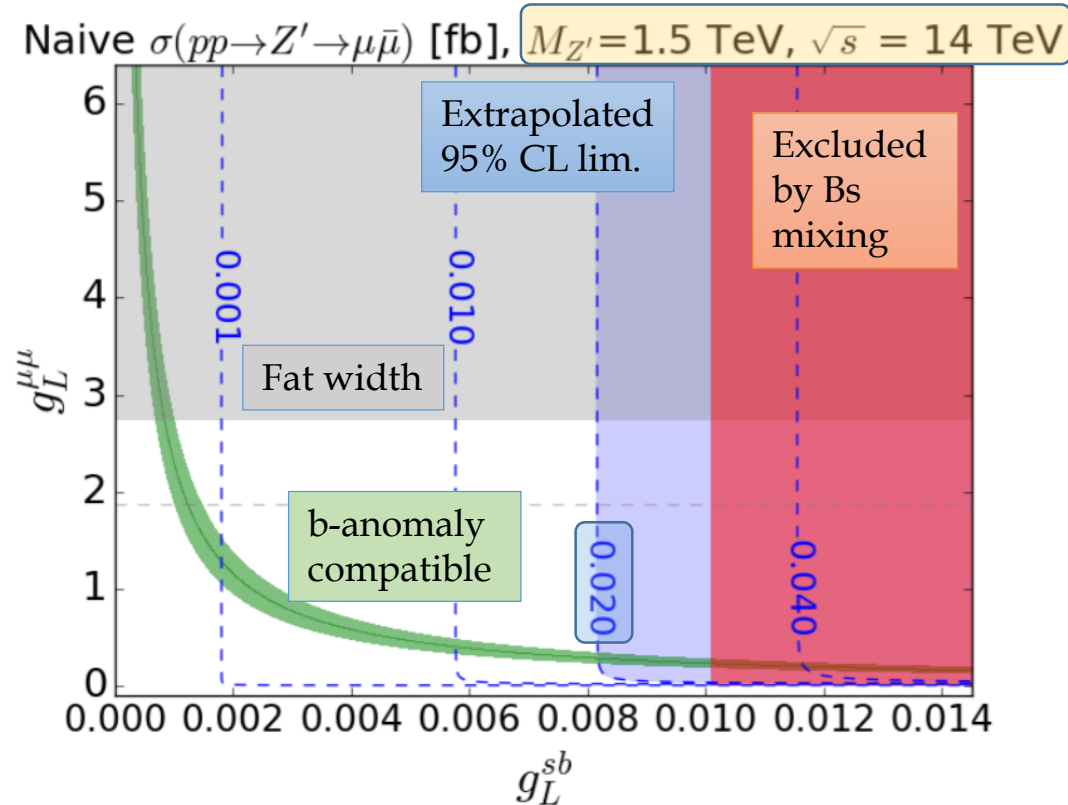
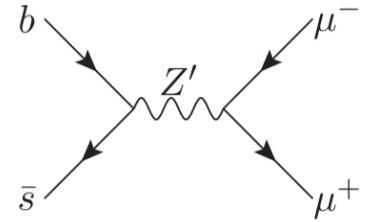
- Extrapolate current 13 TeV di-muon search:



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

Z' Sensitivity

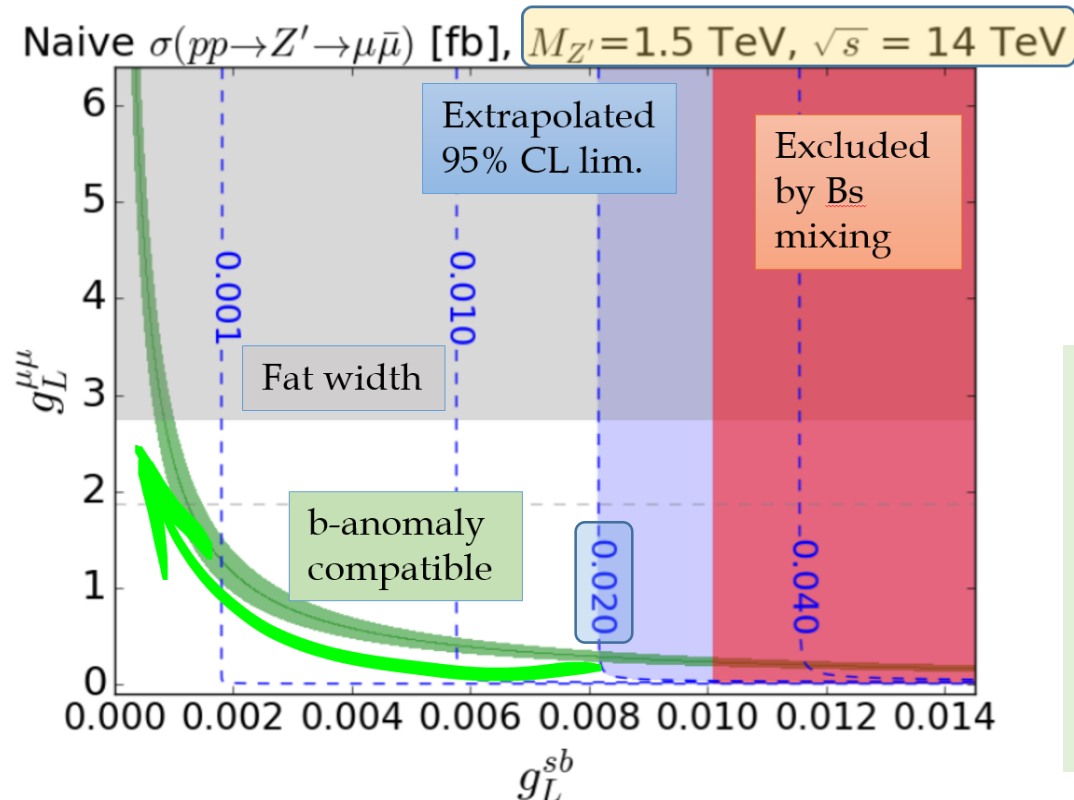
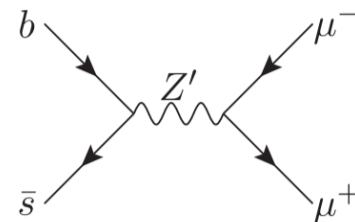
- Extrapolate current 13 TeV di-muon search:



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

Z' Sensitivity

- Extrapolate current 13 TeV di-muon search:

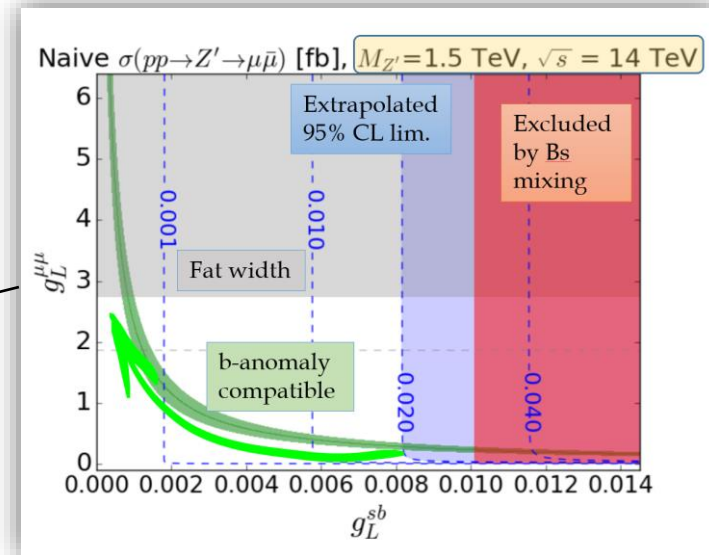
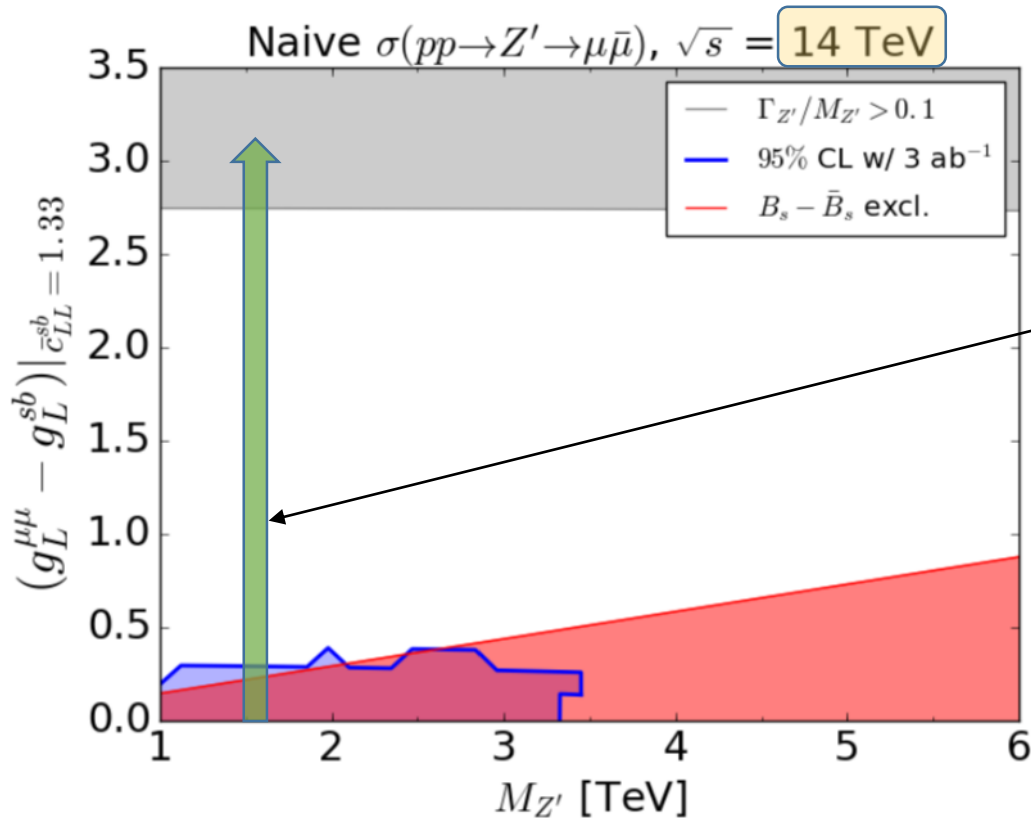
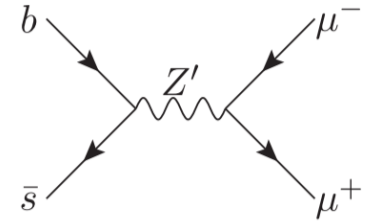


Summary of Z' coverage:
For each $M_{Z'}$, plot vertically the anomaly-compatible region

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

Z' Sensitivity

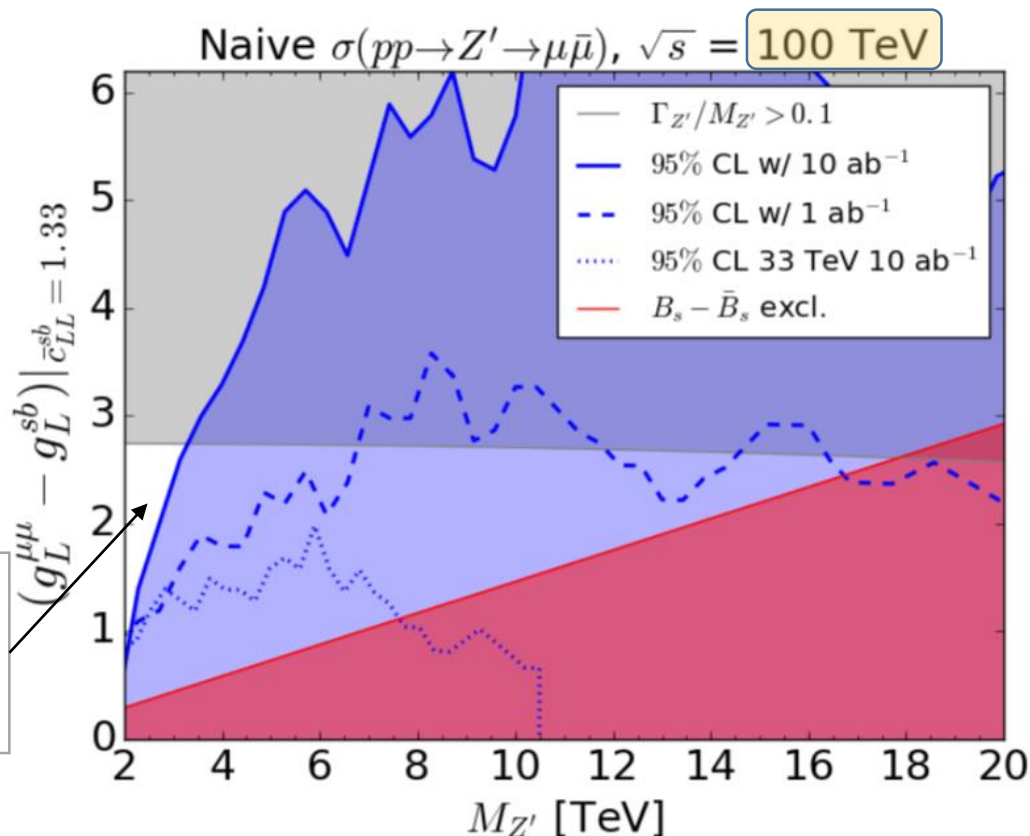
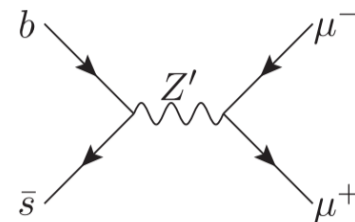
- Extrapolate current 13 TeV di-muon search:



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

Z' Sensitivity

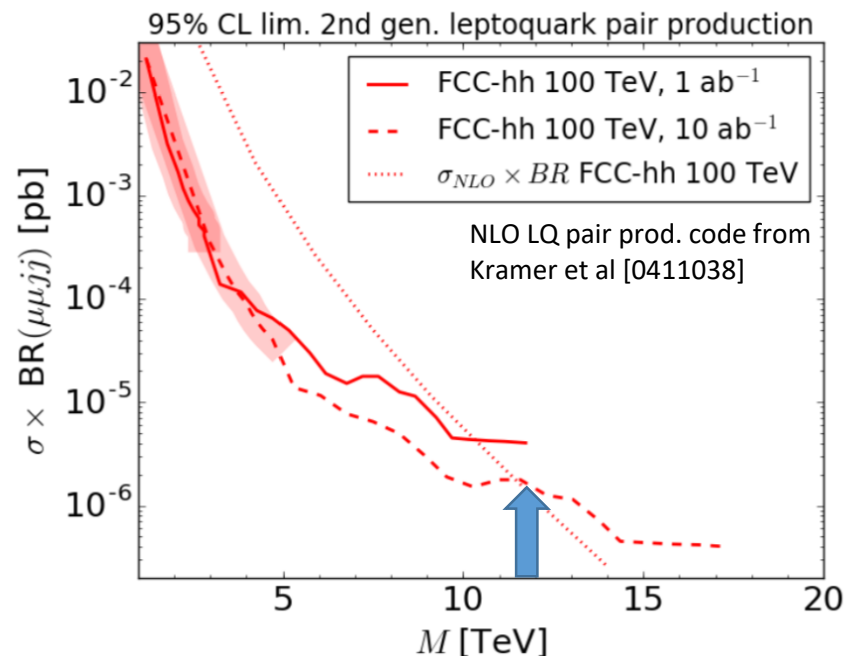
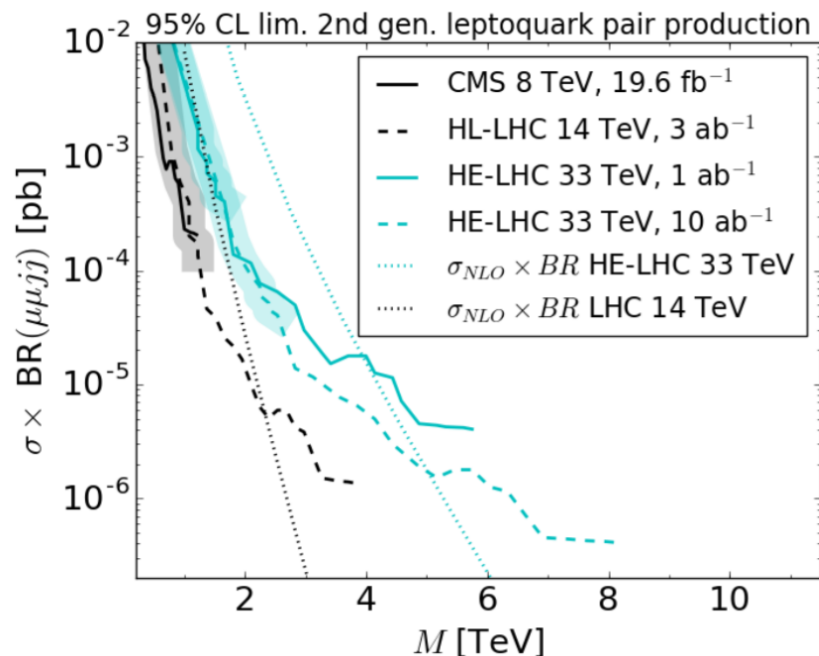
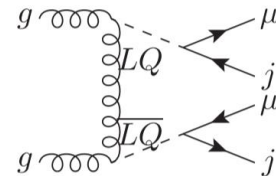
- Extrapolate current 13 TeV di-muon search:



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

Leptoquark Sensitivity

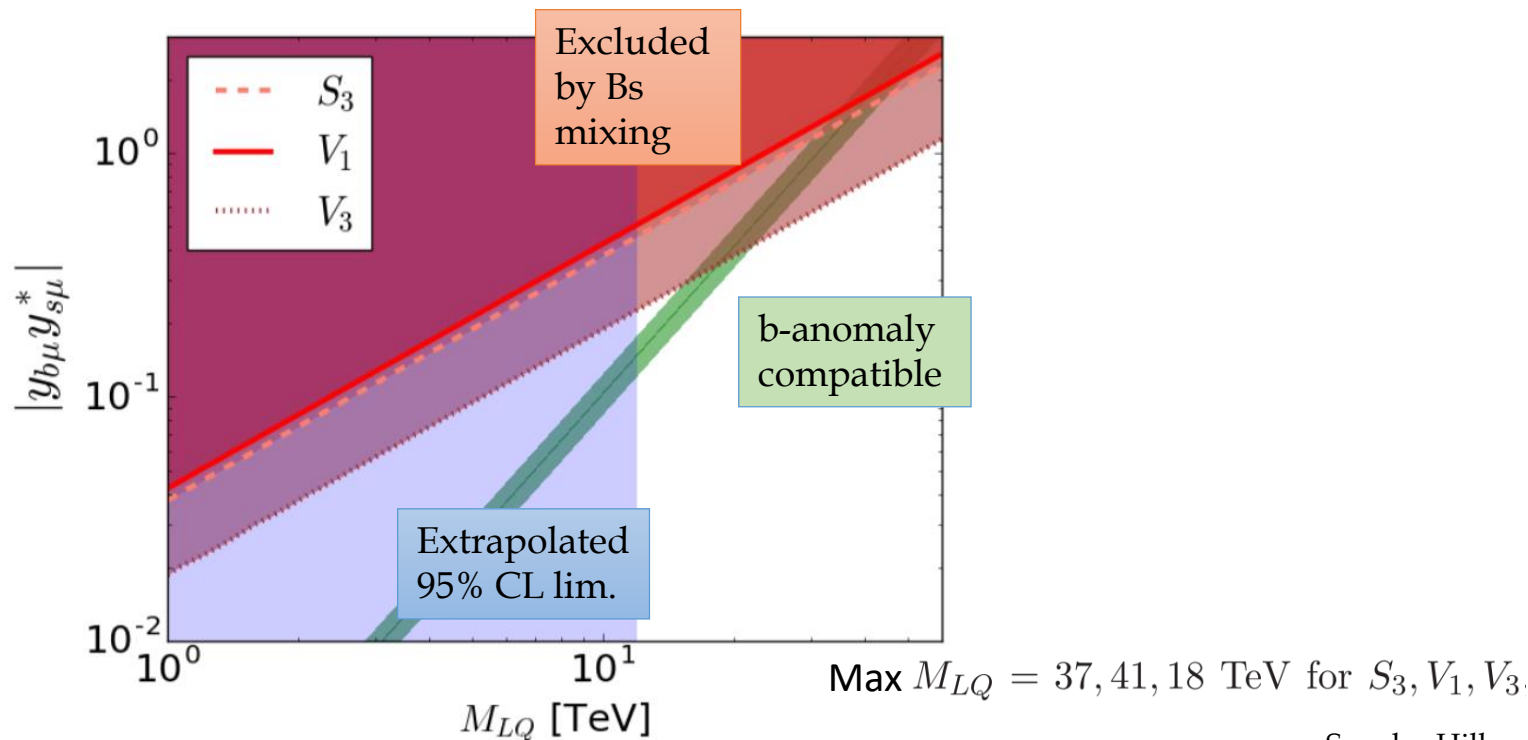
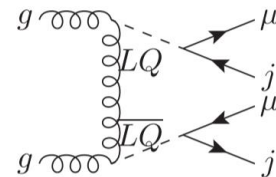
- Extrapolate current 8 TeV LQ di-muon+di-jet search:



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

Leptoquark Sensitivity

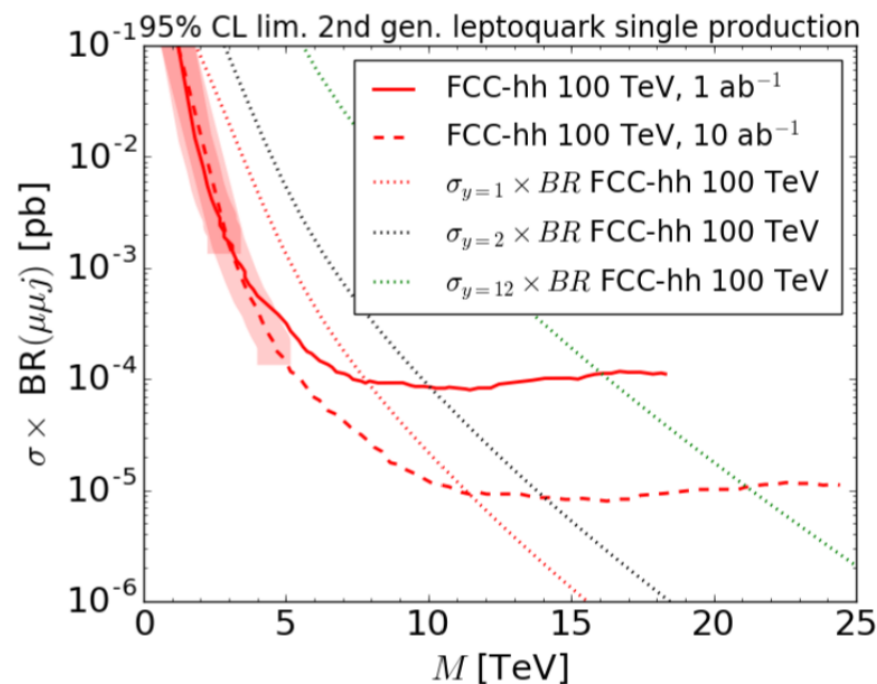
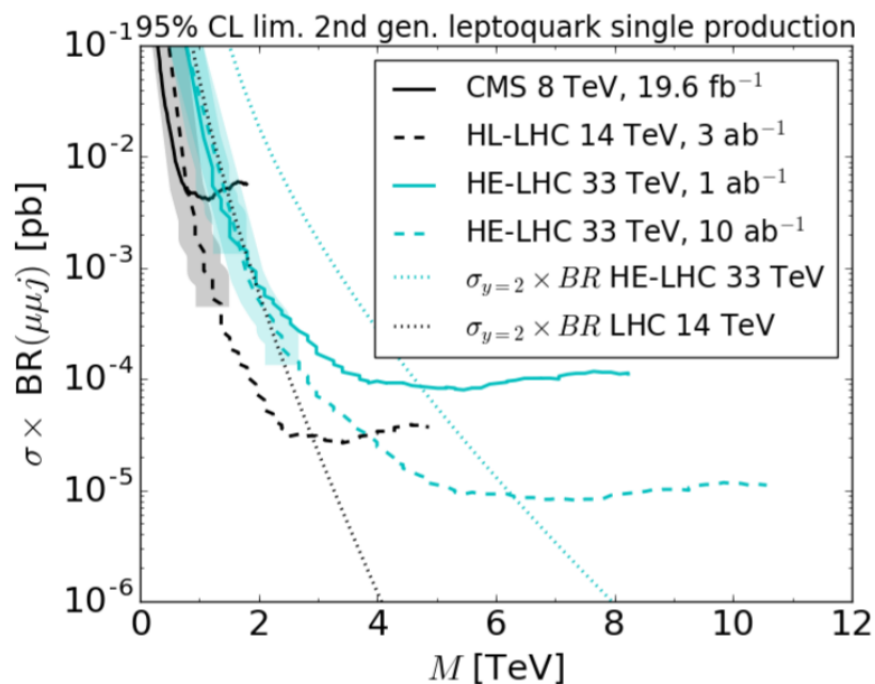
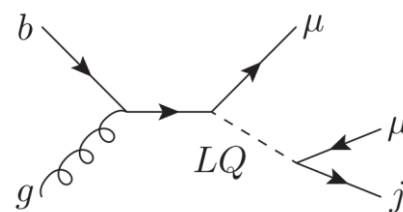
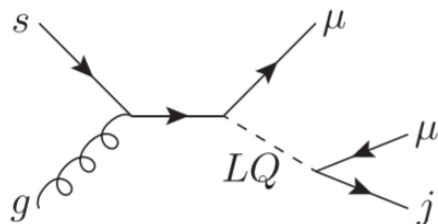
- Extrapolate current 8 TeV LQ di-muon+di-jet search:



See also Hiller
& Nisandzic,
1704.05444

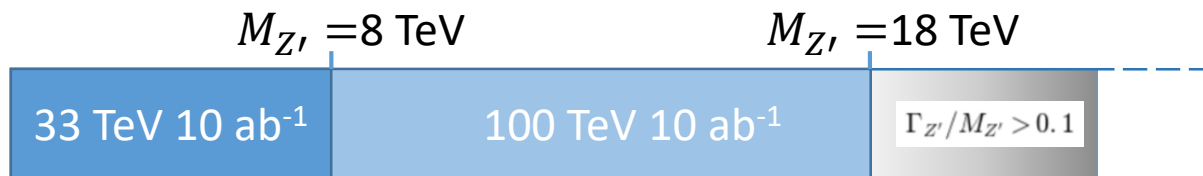
- Pair production for scalar LQ depends only on QCD coupling
- Upper limit from B_s mixing constraint

Leptoquark single production



Take-Home Message

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

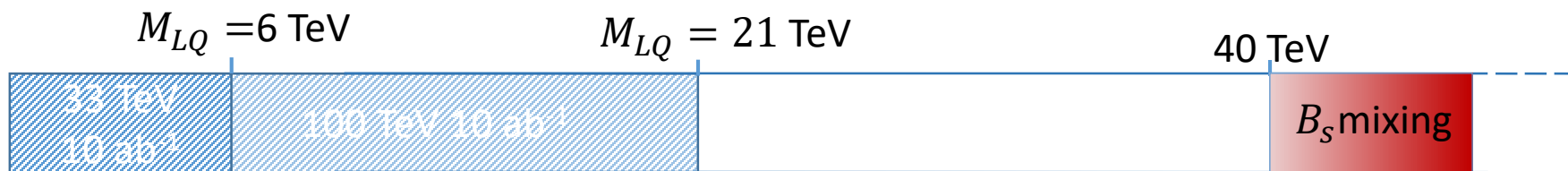


n.b. Sensitivity for
the most
*conservative and
pessimistic scenario*

- 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 \rightarrow

Take-Home Message

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



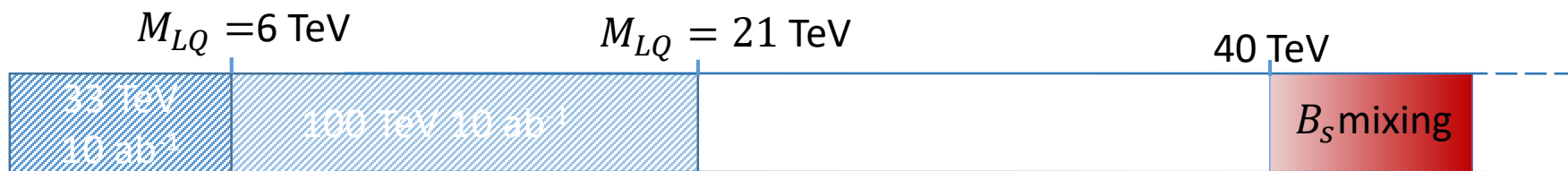
n.b. Sensitivity for
the most
conservative and
pessimistic scenario

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

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



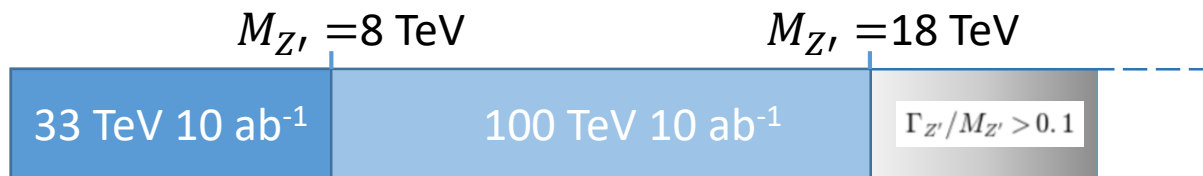
- Single production, $p p \rightarrow LQ \rightarrow \mu^+ \mu^- j$



LQ coupling strength \rightarrow

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 p

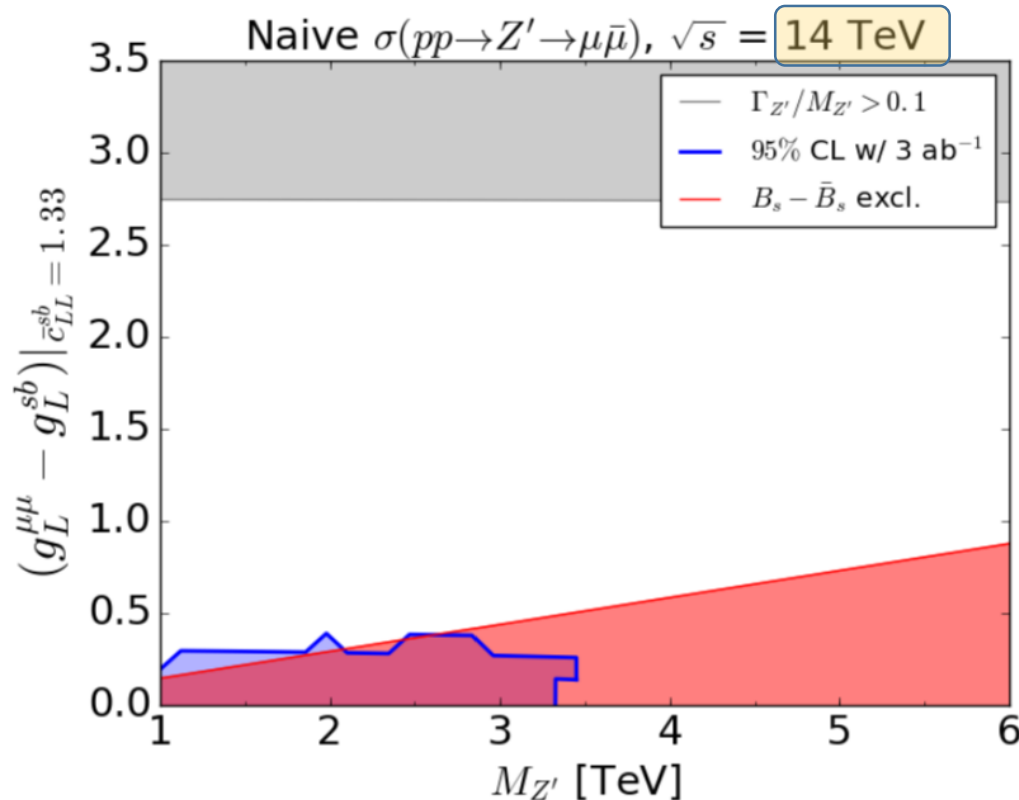
$M_{LQ} = 5$

33 TeV
10 ab^{-1}

- Single

M_{LQ}

33 TeV
10 ab^{-1}



40 TeV

B_s mixing

40 TeV

B_s mixing

Take-Home Message

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

$$M_{Z'} = 7 \text{ TeV}$$

14 TeV
3 ab⁻¹

33 TeV
10 ab⁻¹

$$\Gamma_{Z'}/M_{Z'} > 0.1$$

e.g. realistic model
coupling to 3rd gen.
quarks + CKM
rotations

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

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

- Pair p

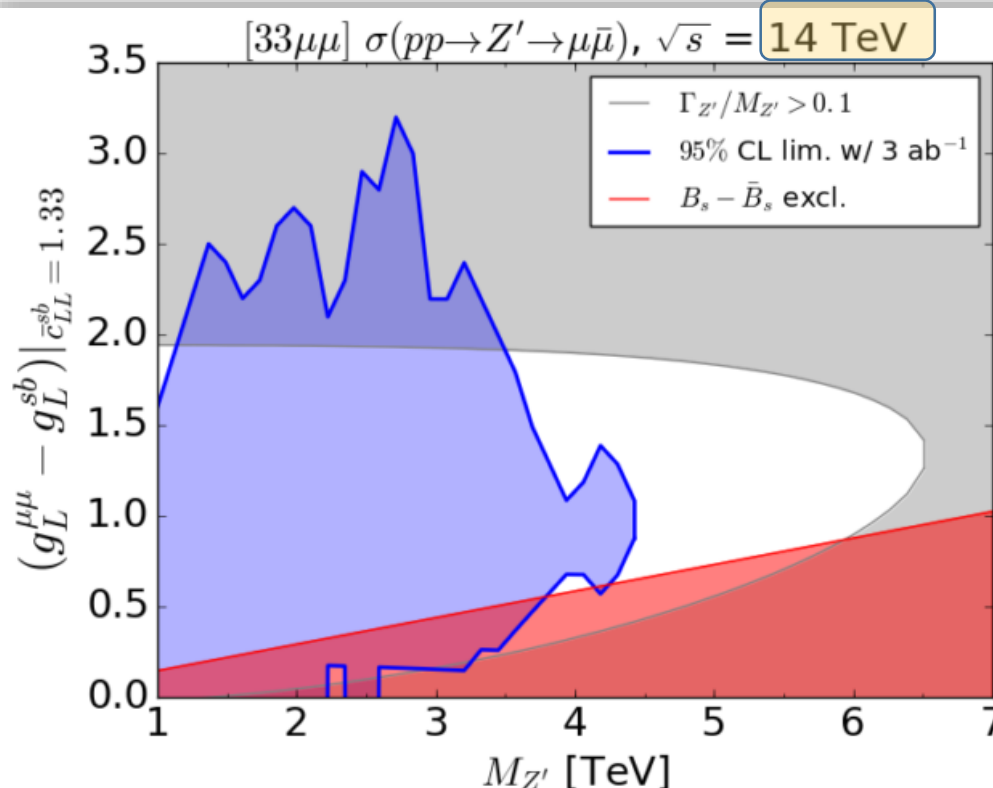
$$M_{LQ} = 5$$

33 TeV
10 ab⁻¹

- Single

$$M_{LQ}$$

33 TeV
10 ab⁻¹



40 TeV

B_s mixing

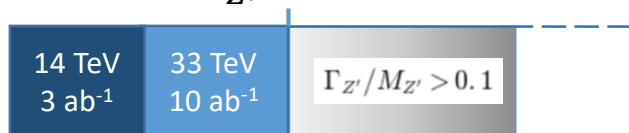
40 TeV

B_s mixing

Take-Home Message

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

$$M_{Z'} = 7 \text{ TeV}$$



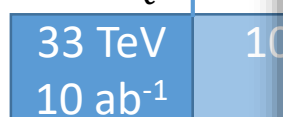
e.g. realistic model
coupling to 3rd gen.
quarks + CKM
rotations

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

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

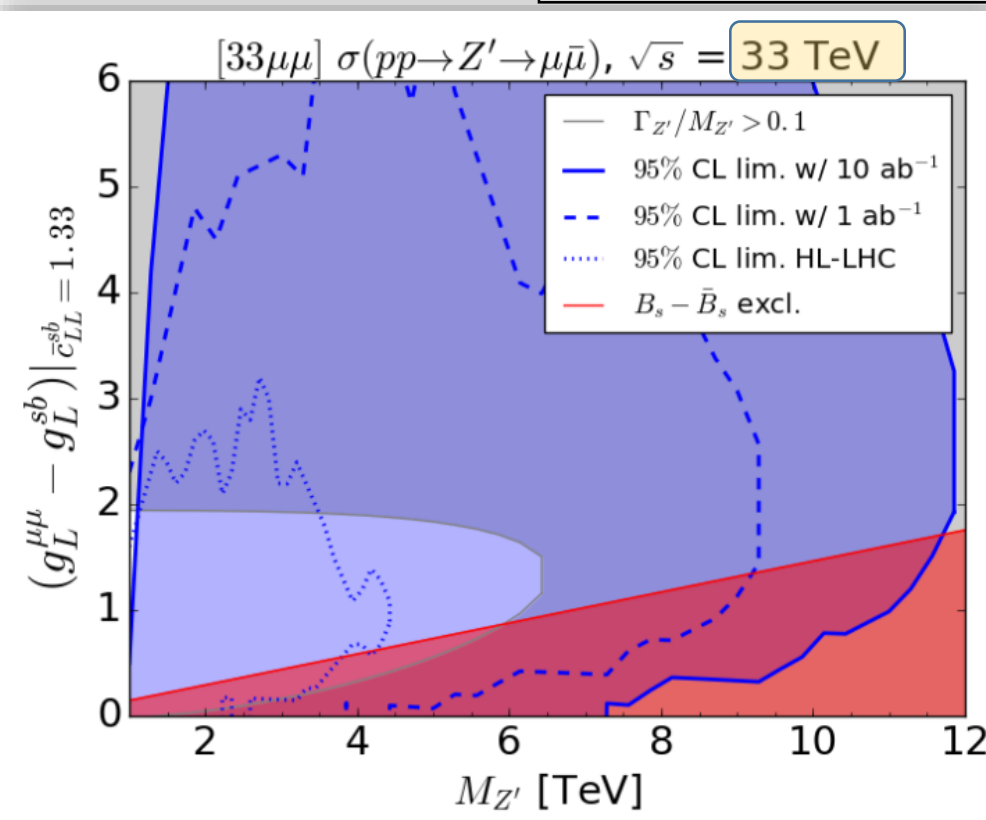
- Pair production

$$M_{LQ} = 5 \text{ TeV}$$



- Single production

$$M_{LQ} =$$



40 TeV

B_s mixing

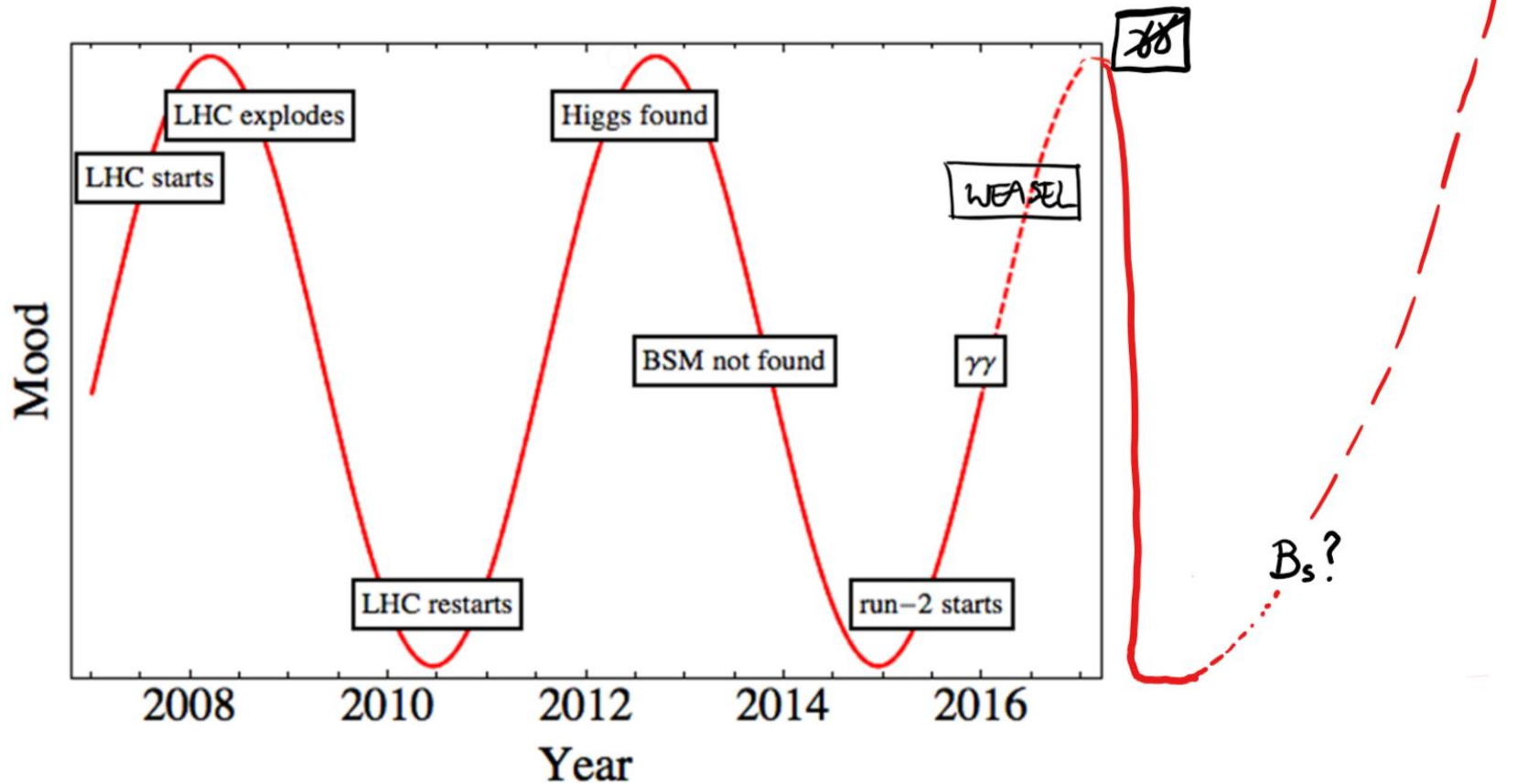
40 TeV

B_s mixing

Conclusion

- Complete coverage of narrow 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

Conclusion



<http://resonaances.blogspot.com.es/2016/01/do-or-die-year.html>

Backup

Extrapolation method

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

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

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