

Breakdown of the Narrow Width Approximation in BSM Physics

- ▶ Assumptions and Definition
- ▶ Effective Branching Ratio
- ▶ Cascade 'Super - Enhancement'
- ▶ Left-Right Asymmetry
- ▶ Conclusions

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May 8, 2007

hep-ph/0703058

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Narrow Width Approximation

- Assumptions:

- Separability of the Propagator

→ Resonant Diagrams Only

- Massless Final State $m \ll M$

- $\sqrt{\hat{s}} - m \gg \Gamma$

- $\Gamma \ll M$

- $R = \frac{\sigma_{OFS}}{\sigma_{NWA}} \sim \log(s), \log(m)$

- Violations typically vary with $\frac{m}{M}$

- $(R - 1) \sim \mathcal{O}\left(\text{many} \times \frac{\Gamma}{M}\right)$ even for moderate

$$\begin{aligned}
 & \int_{q_{\min}^2}^{q_{\max}^2} dq^2 \left| \frac{1}{q^2 - m^2 + im\Gamma} \right|^2 \\
 &= \int_{q_{\min}^2 - m^2}^{q_{\max}^2 - m^2} \left\{ \frac{dx}{x^2 + (m\Gamma)^2} \right\} \\
 &\stackrel{||}{=} \int_{-m^2}^{s - m^2} \left\{ \begin{array}{l} q_{\max}^2 \rightarrow s \\ q_{\min}^2 \rightarrow 0 \end{array} \right\} \\
 &\approx \int_{-\infty}^{\infty} \left\{ \begin{array}{l} s \rightarrow \infty \\ m^2 \rightarrow \infty \end{array} \right\} = \frac{\pi}{m\Gamma}
 \end{aligned}$$

Effective Branching Ratio

$$BR = \frac{\sigma_{NWA}}{\sigma_{2 \rightarrow 2}} \rightarrow BR_{naive} = \frac{\sigma_{OFS}}{\sigma_{2 \rightarrow 2}}$$

- Proper: $BR_{eff} = \frac{\sigma_{OFS}}{\sigma_{Tot}}$
- Assume only 1 decay violates NWA

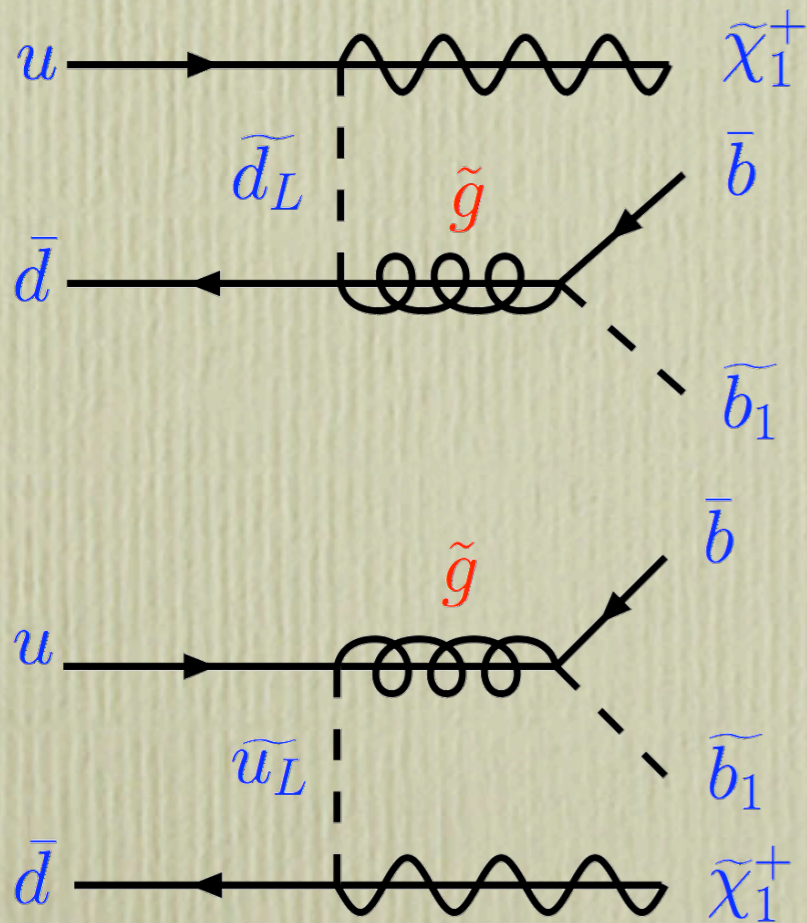
$$BR_{eff} = \frac{\sigma_{OFS}}{\sigma_{OFS} + \left(\frac{\Gamma_i}{\Gamma_i + \Gamma_b} \times \sigma_{2 \rightarrow 2} \right)}$$

- If $R \sim 1$, $BR_{eff} \approx BR_{naive}$

$$\frac{BR_{eff}}{BR_{naive}} \text{ near } 1 \text{ if:}$$

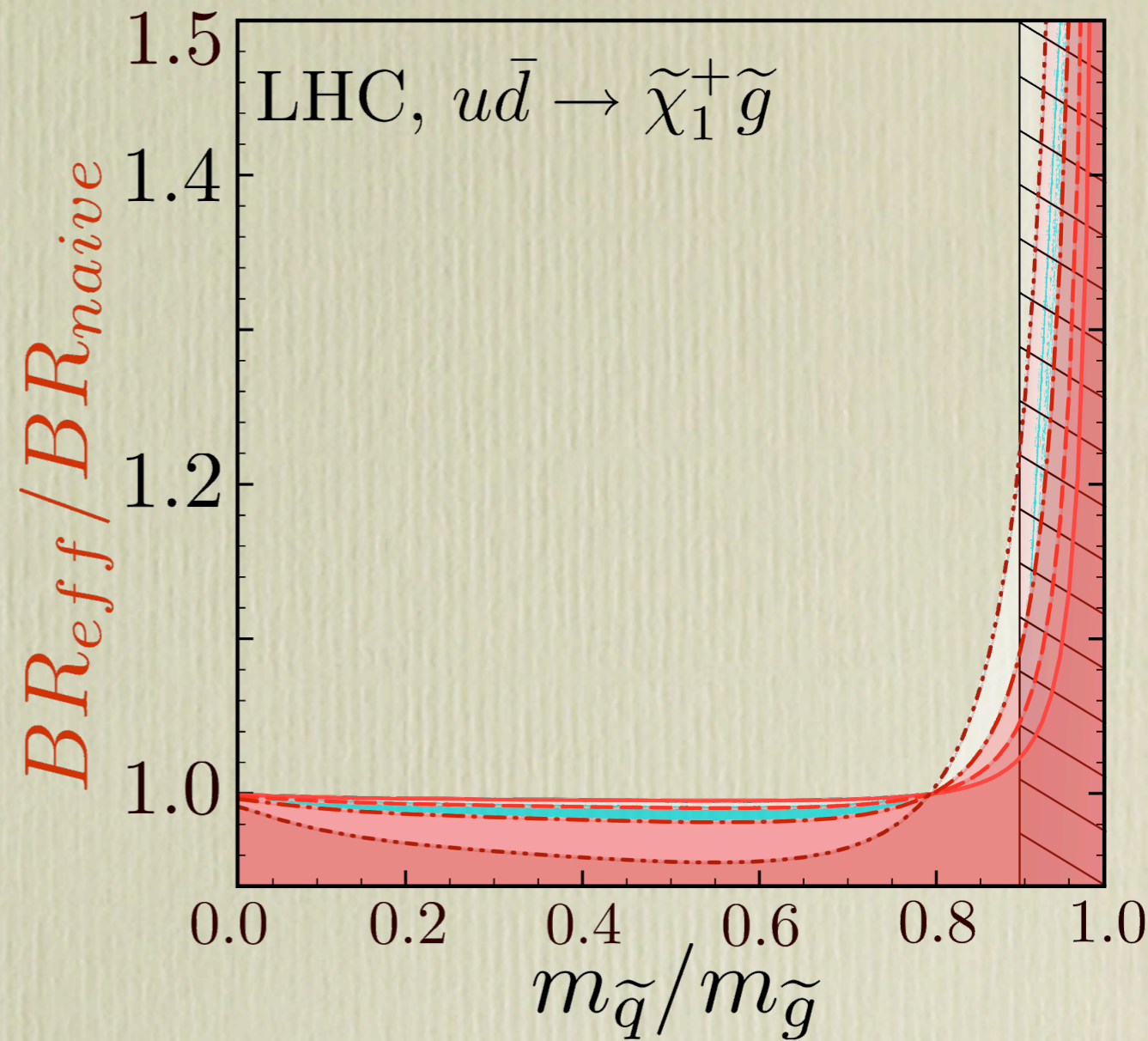
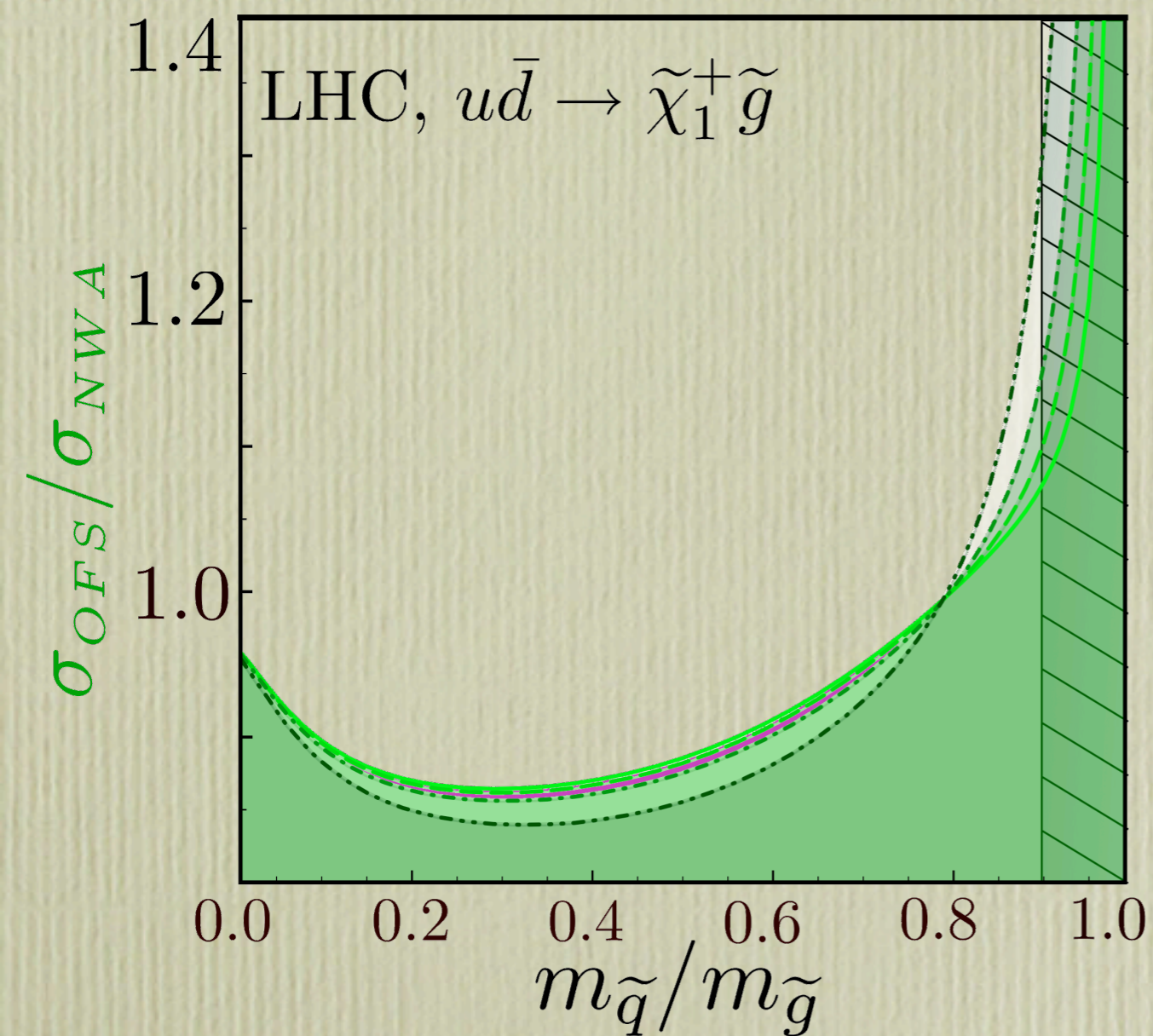
- A rare decay mode has $\frac{m}{M} \sim 1$

- Common b.c. PS suppresses $\frac{m}{M} \sim 1$ modes



- Scan over $\frac{m}{M}$ Compare w/ **R**

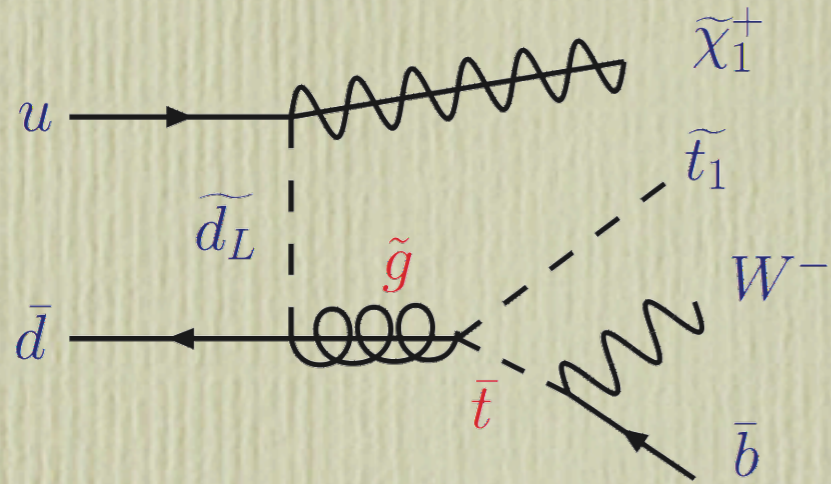
- Assume 1st 2 generations of squark degenerate



- Shaded region = SPS points

- Decay/Cascade Tools (e.g. SDECAY, PYTHIA..) ignore this

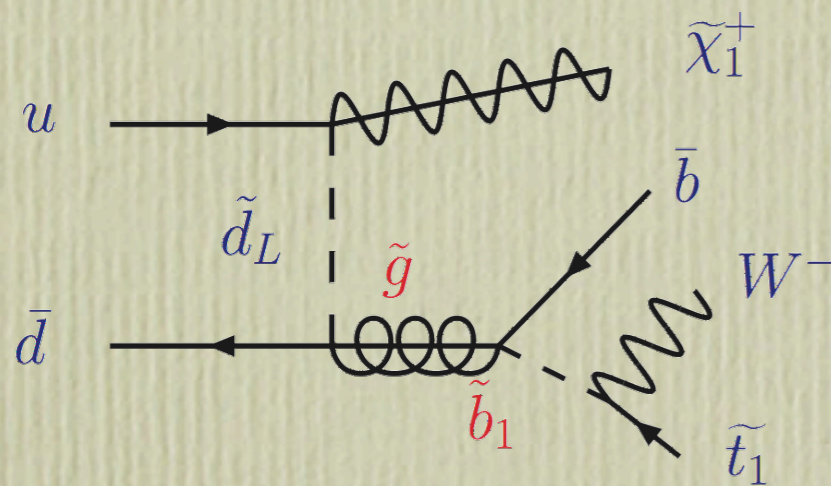
Multiple Successive Decays



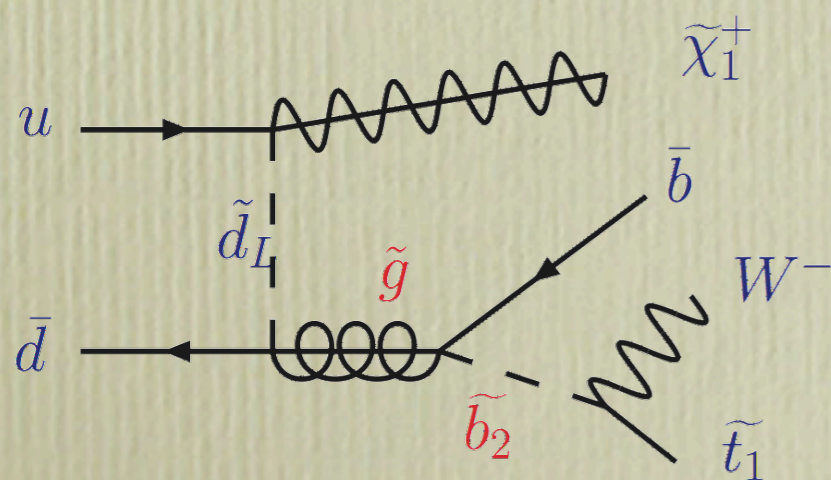
- Real processes cascade

- Multiple Breit-Wigners

- How does this change things?

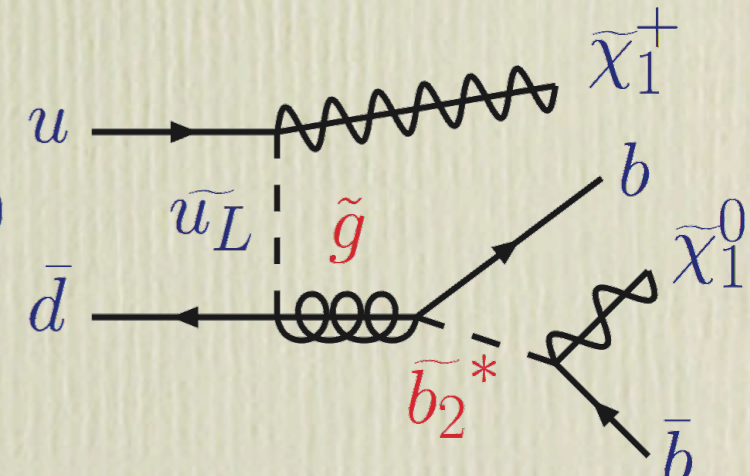
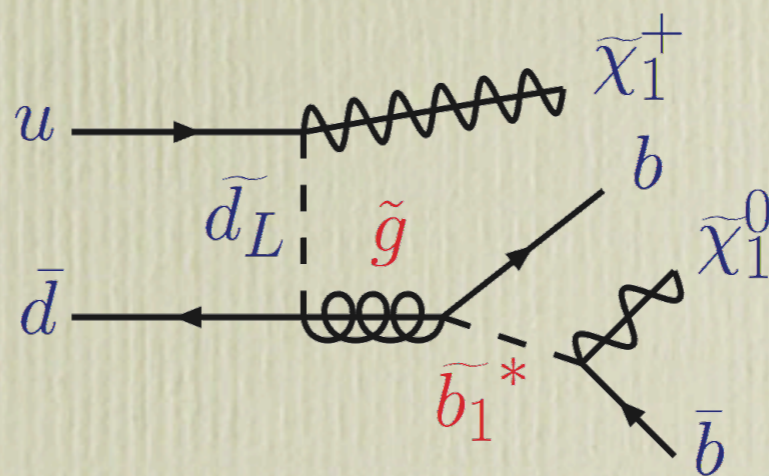


- When? Need multiple degeneracies?

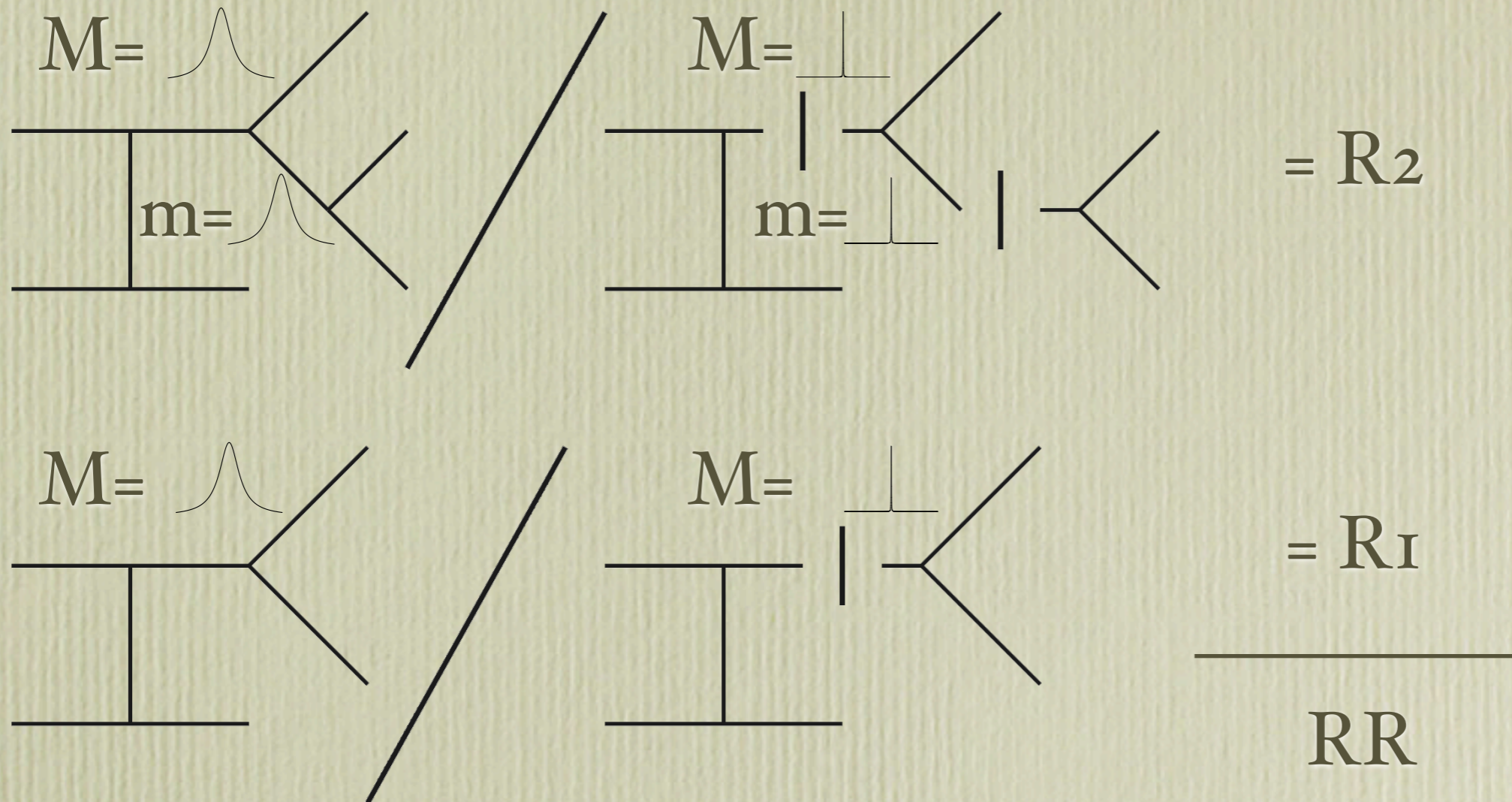


SSV

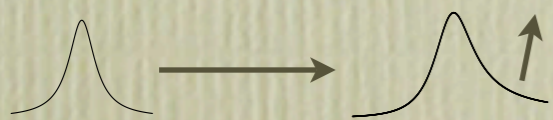
SFF



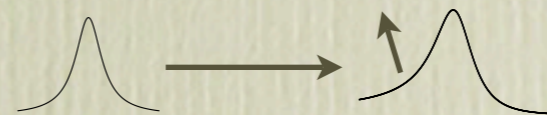
“Super-Enhancement”: Origin



If $R_1 > 1$ and m can vary:



If $\frac{m}{M} \rightarrow 1$ and m can vary,

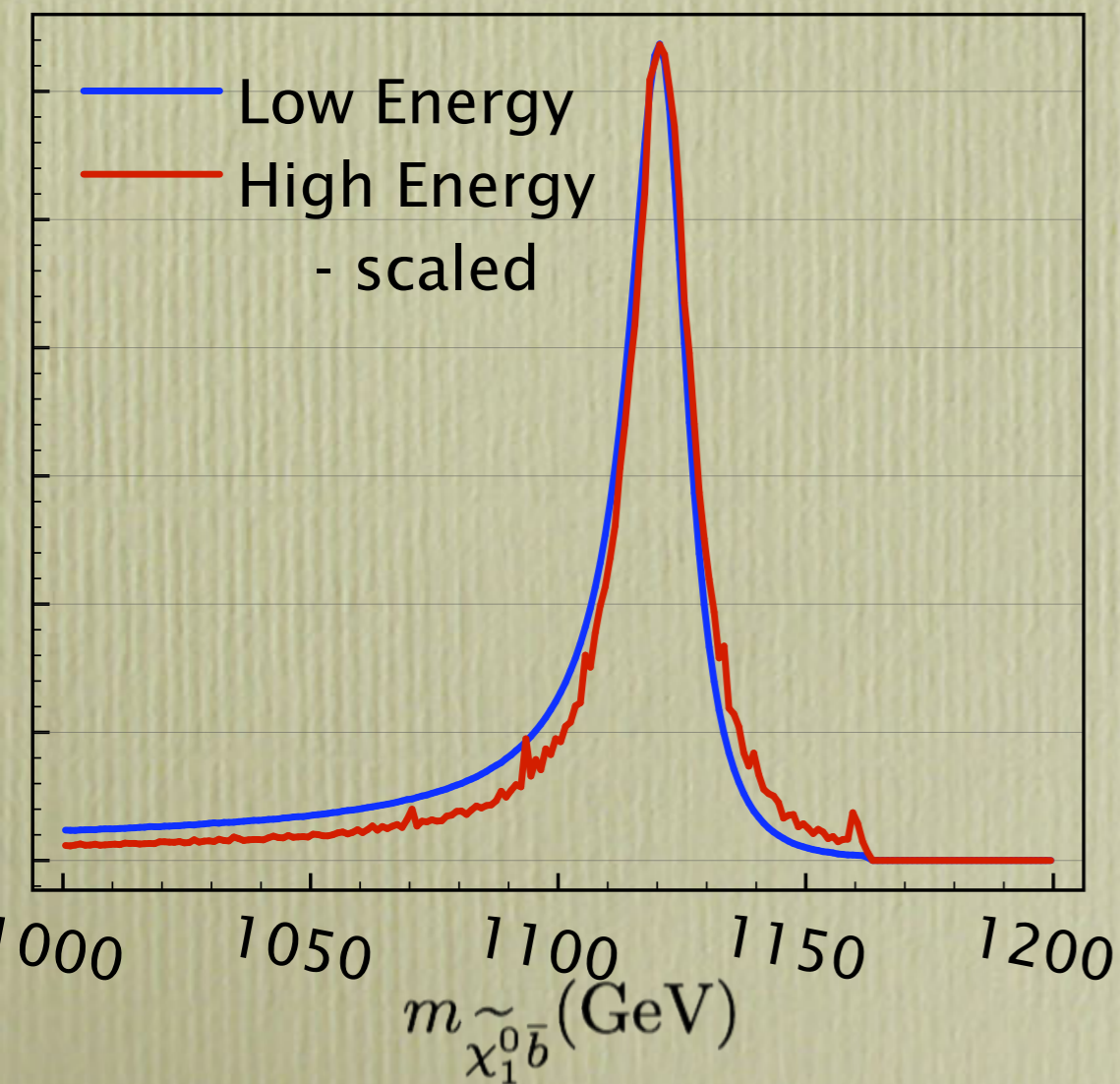
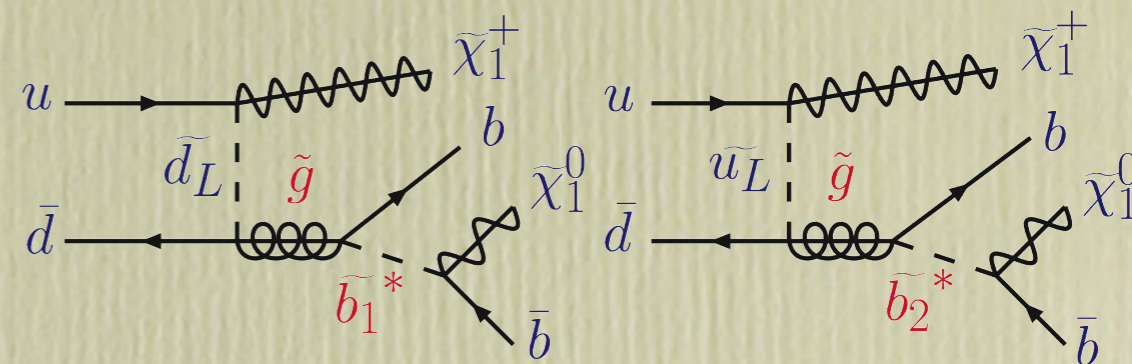


- OFS enhancement enhances high tail, PS suppression kills it

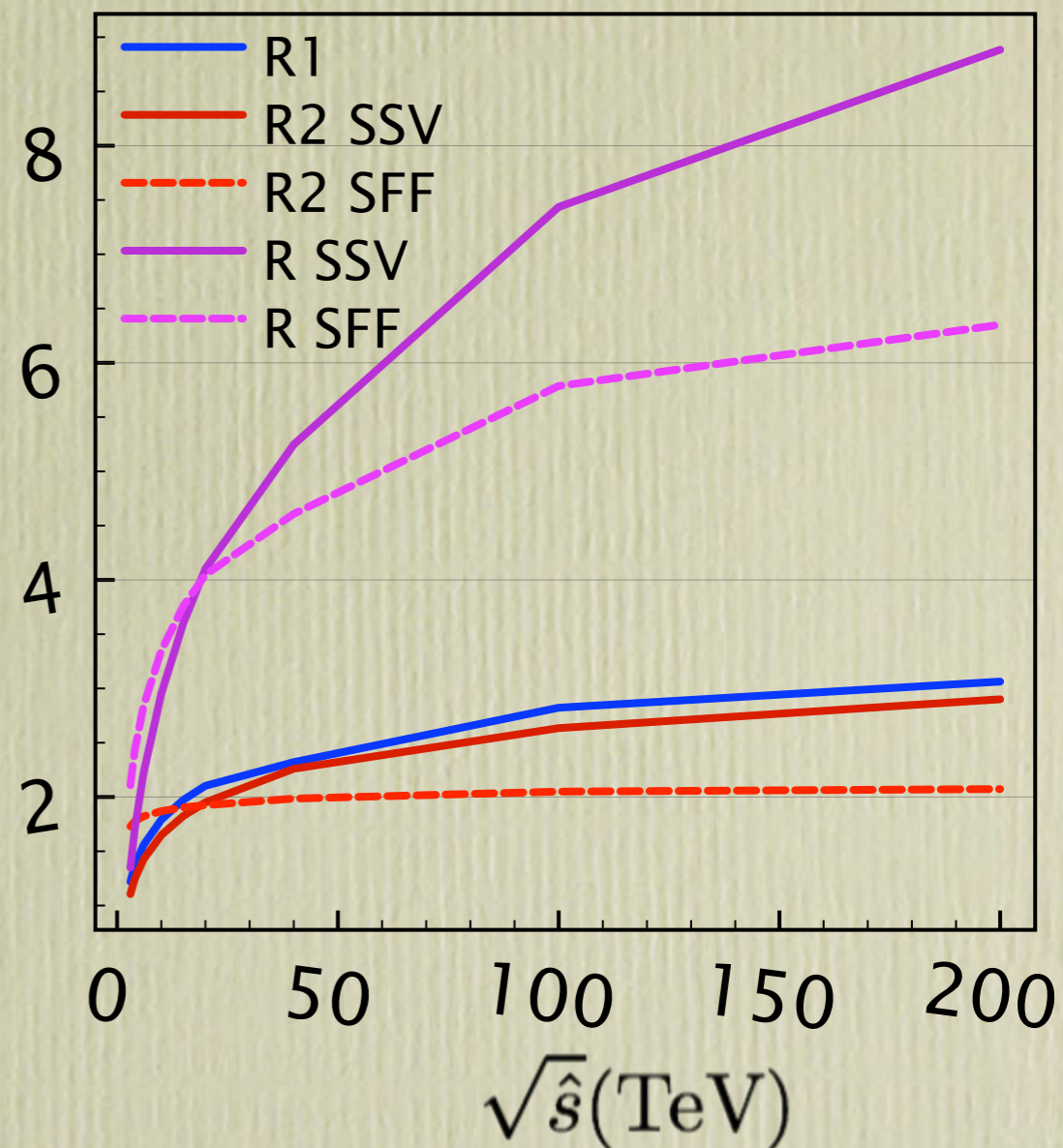
Energy Dependence

PRELIMINARY

<i>Process@LHC</i>	<i>R</i>	$\frac{BR_{eff}}{BR_{naive}}$
	1-level	1.16
<i>SSV</i>	2-level	3.36
<i>SFF</i>	2-level	1.04

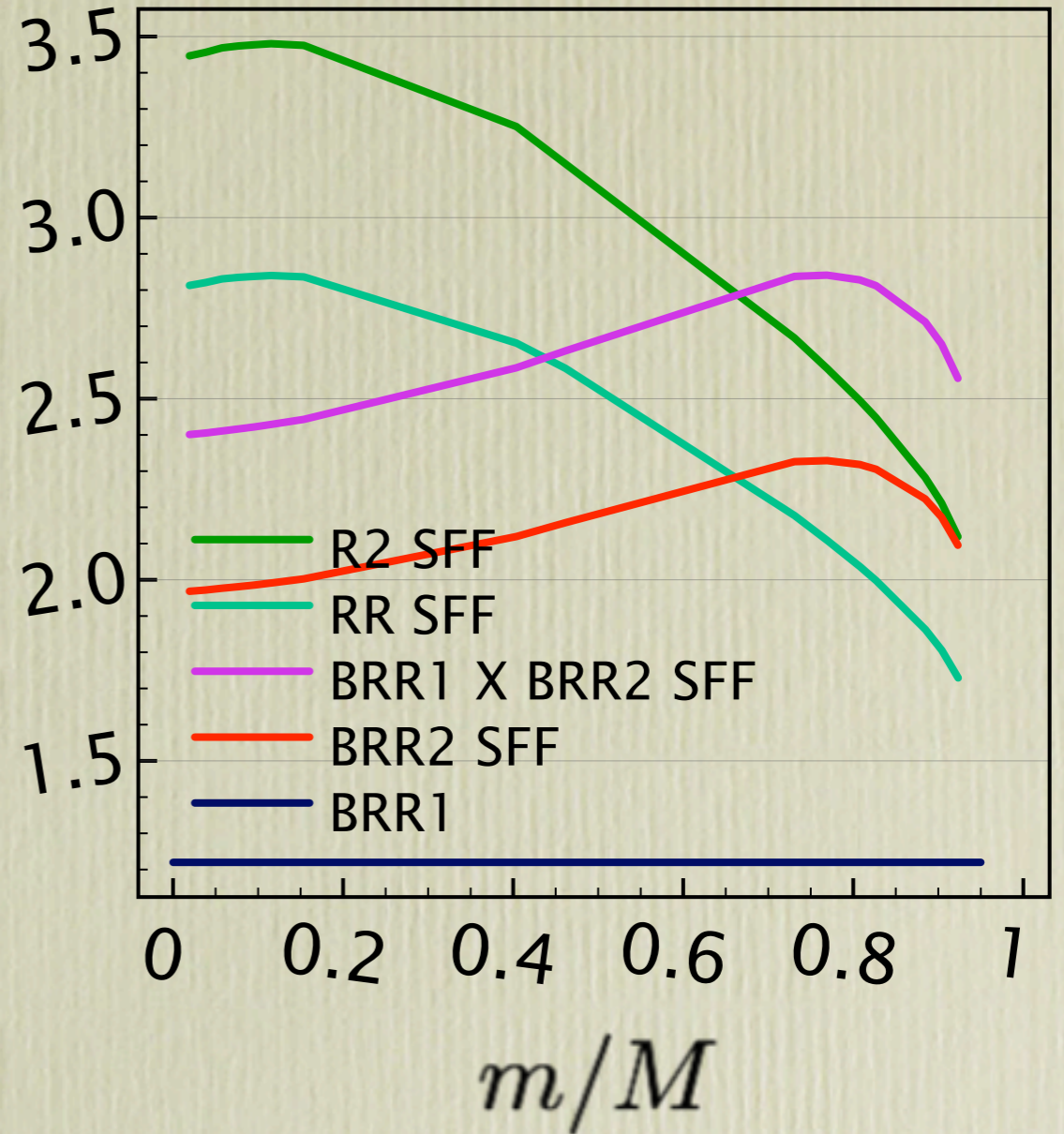
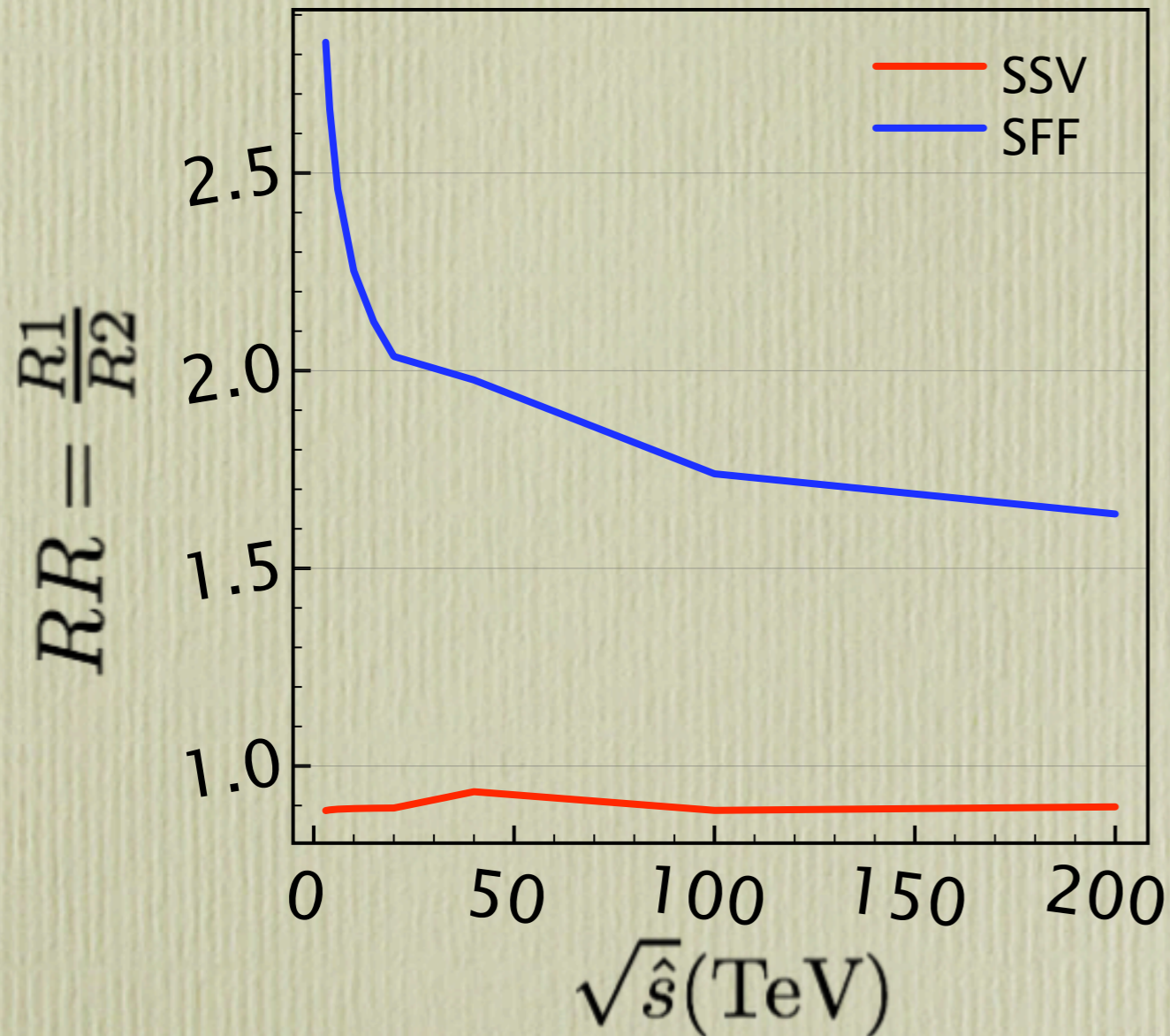


R



“Super-Enhancement”: Behavior

PRELIMINARY



- For large $\frac{m}{M}$, 2nd decay suppresses R

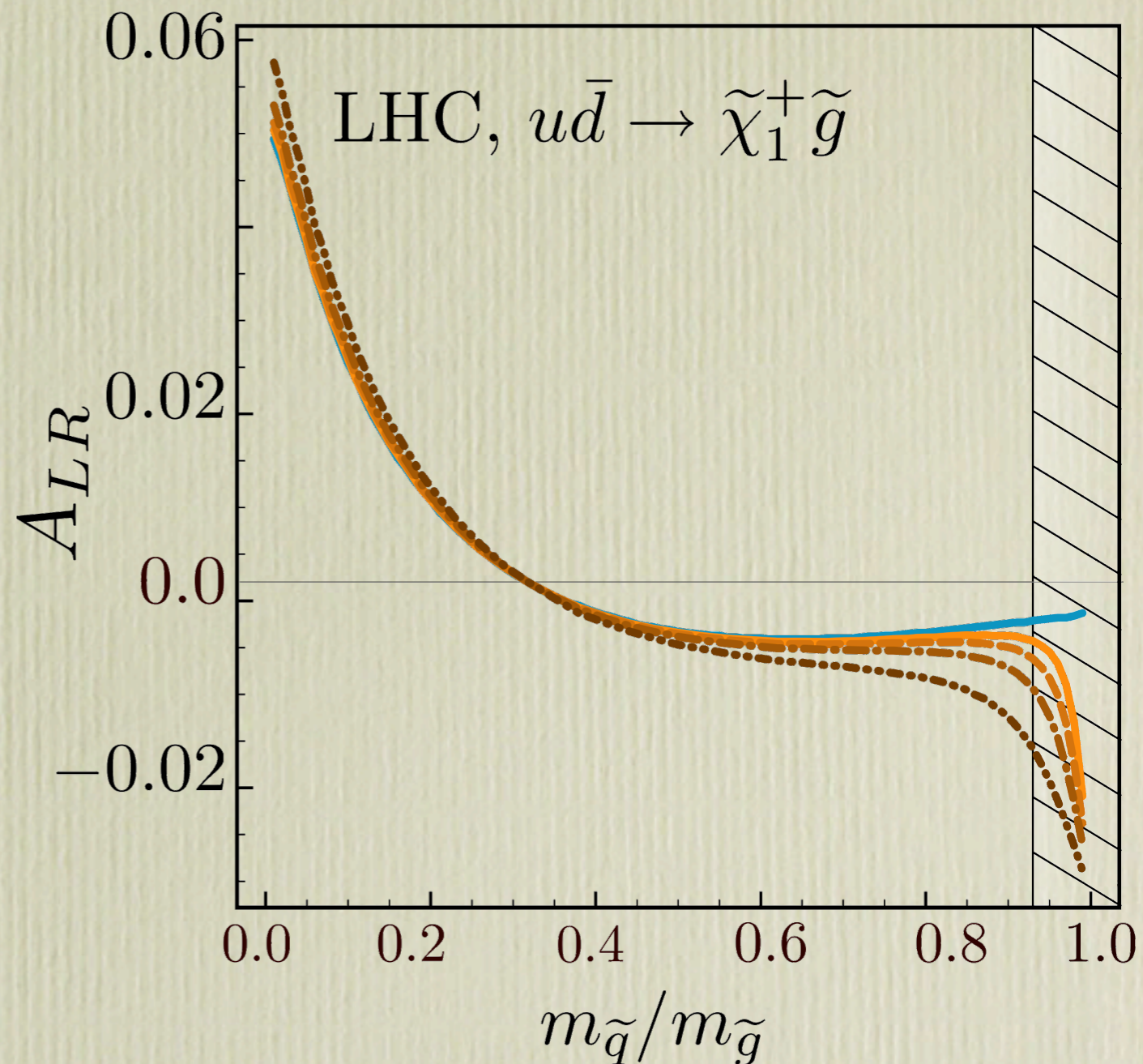
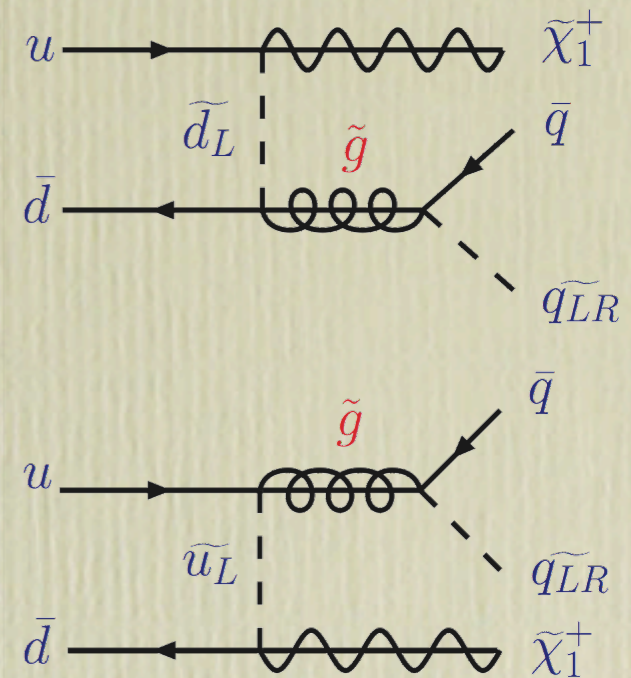
$$BRR = \frac{BR_{eff}}{BR_{naive}}$$

Left-Right Asymmetry

- $\sigma_{2 \rightarrow 2} \times BR$ is helicity-neutral
- Chargino chooses left coupling
- Helicity pref carried through
- Gluino mass can flip, but doesn't equalize

$$A_{LR} = \frac{\frac{\sigma_{\sim} - \sigma_{\sim}}{q_L} \frac{q_R}{q_L + \sigma_{\sim}}}{\frac{\sigma_{\sim} + \sigma_{\sim}}{q_L} \frac{q_R}{q_L + \sigma_{\sim}}}$$

- $\frac{m}{M} < .3$ (light squark) disfavored
- $\frac{m}{M} > .8$ effect may be observable



Conclusions

- NWA often dramatically invalid in BSM physics
- Modified BRs could confuse Model ID
- Large effects from successive decays
- Cannot parametrize effect of additional decays
- Left-Right Asymmetry could confuse coupling measurement / Model ID
- Cannot trust NWA with massive spectra.