GLUINOS LIGHTER THAN S-QUARKS AND DETECTION AT LHC

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OUTLINE

- Motivation
- Typical mass ranges considered
- Importance of limits from Kaon Physics
- Relevance at the LHC
- Recapitulation

MOTIVATION

- Test Family SUSY Models with definite signatures at the LHC $m_{\tilde{g}} \sim O(1)\ \mathrm{TeV}$ $m_{\tilde{f}} \sim O(10)\ \mathrm{TeV}$
- FS could solve flavour and CP problems so models with underlying supergravity at High-Scale may be not that ugly with light gluinos and heavy scalars.
- Reassess the importance of getting limits of SUSY models using the Kaon sector at NLO QCD, despite the uncertainties in the SM determination.
- Interesting LHC phenomenology (gluino decays)

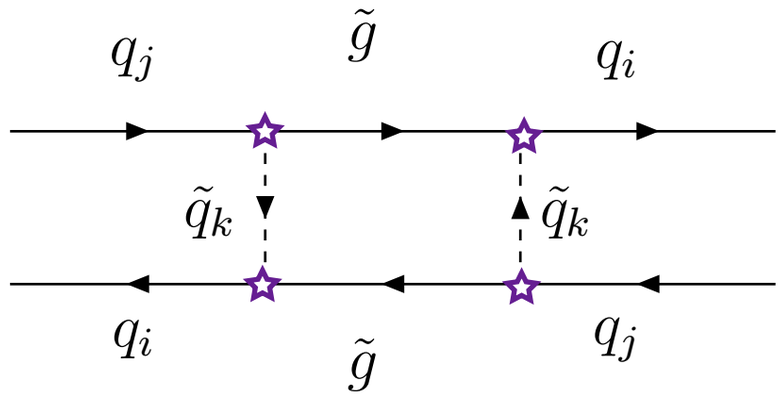
TYPICAL MASS RANGES CONSIDERED

- Why?

$$m_{\tilde{g}} \sim O(1)\ \mathrm{TeV} \qquad m_{\tilde{f}} \leq O(10)\ \mathrm{TeV}$$

  - FCNC controlled by gluino exchanges → easier to pin-down flavour structures: need to worry just about kaon sector

$\Delta F = 2$



  - If $m_{\tilde{f}} > O(10)\ \mathrm{TeV}$ it gets difficult to probe flavour structures

- As it happens often in PP similar features have been considered with other motivations

- Gaugino Anomaly Mediation Symmetry Breaking

$$M_i, \quad m_0 \approx 0 \approx A_0$$

- G2-MSSM models

$$M_i = f_{3/2} m_{3/2} (1 + \Delta_i) \approx 0.1 m_0, \quad m_0 \approx A_0 = m_{3/2}$$

- U(2)-FS SUSY models (achieving orders of magnitude splitting among first two heavier scalar generations and a lighter one)

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Somewhat heavier $m_{\tilde{f}}$ than what we want

In our set ups we are interested in the case of three scalar families of the same order

References

- Gaugino Anomaly Mediation Symmetry Breaking

RANDALL & SUNDRUM, NUCL. PHYS. B557, 79, (1999)
GIUDICE, LUTY, MURAYAMA & RATTAZZI, JHEP 12, 027 (1998)
BAER, DE ALWIS, GIVENS, RAJAGOPALAN, SUMMY 1002.4633

- G2-MSSM models

ACHARYA & DENEF, VALANDRO, JHEP 0506 TH/0502060

ACHARYA, BOBKOV, KANE, KUMAR, SHAO PRD 76, TH/0701034

ACHARYA, BOBKOV, KANE, KUMAR, VAMAN PRL 97, TH/0606262

ACHARYA & BOBKOV, 0810.3285...

- U(2)-FS SUSY models (achieving orders of magnitude splitting among first two heavier scalar generations and a lighter one)

BARBIERI, ISIDORI, JONES-PÉREZ, LODONE,STRAUB.
1105.2296

Our scenario

[Kersten & L.V-S in prep.]

High Scale

- Gaugino masses $m_{3/2}\ k_a(1+\Delta_a),$ $\boxed{M_2 > M_1, M_3,}$ $k_a < 1$
- Scalar masses $m_{3/2} \leq O(10)\ \text{TeV}$
- Trilinear masses $m_{3/2}$

Necessary to achieve a good value of m_h

- $\tan\beta$ small

EW Scale

$$\boxed{m_{\tilde{f}_2} \approx m_{\tilde{f}_3} \sim 2m_{\tilde{f}_1}} \sim O(m_{3/2})$$

$$900\text{GeV} < m_{\tilde{g}} < 1800\text{GeV}$$

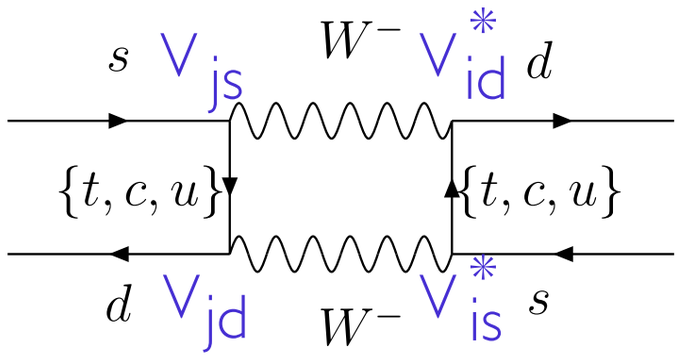
$$4 < \tan\beta < 20$$

Where could it be found?

- Effective supergravity scenarios coming from string compactifications where the overall modulus, and not the dilaton, gives the main contribution to gaugino masses

IMPORTANCE OF LIMITS FROM KAON PHYSICS

SM



$$\epsilon = \frac{\exp(i\pi/4)}{\sqrt{2}} \frac{\mathrm{Im}\langle K^0|H_{\rm eff}^{\Delta S=2}|\bar{K}^0\rangle}{\Delta m_K} = \frac{A\left(K_L \to (\pi\pi)_{I=0}\right)}{A\left(K_S \to (\pi\pi)_{I=0}\right)}$$

$$A_{0,2}e^{i\delta_{0,2}} = \langle \pi\pi(0,2)|\mathcal{H}_{\Delta F=1}|K'\rangle$$

$$\epsilon' = \frac{e^{i\pi/4}}{\sqrt{2}} \frac{1}{\mathrm{Re}A_0} \left(\mathrm{Im}A_2 - \frac{\mathrm{Re}A_0}{\mathrm{Re}A_2}\mathrm{Im}A_0\right)$$

$$\mathrm{Im}\langle K^0|H_{\rm eff}^{\Delta S=2}|\bar{K}^0\rangle \quad \propto \quad \sum_{i,j} V_{js}V^*_{id}V_{jd}V^*_{is}\ S\left(\frac{m_i^2}{M_W^2}, \frac{m_j^2}{M_W^2}\right)$$

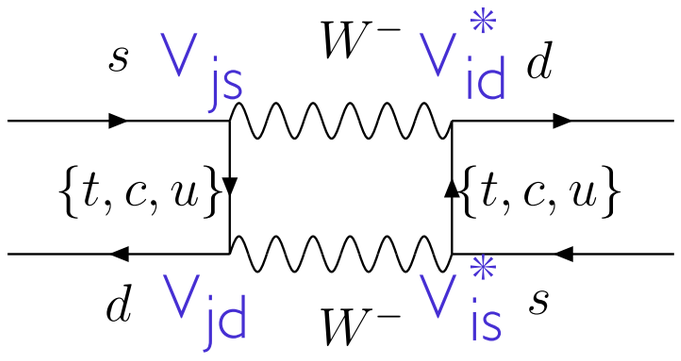
$$\epsilon = (2.228 \pm 0.011) \times 10^{-3} \times e^{i43.5\pm0.7\ ^o}$$
$$|\epsilon^{NNLO}| = (1.90 \pm 0.26) \times 10^{-3}$$
$$\Delta m_K^{\rm SD} = (3.1 \pm 1.2) \times 10^{-15}\ \mathrm{GeV}.$$

$$0 < \mathrm{Re}(\epsilon'/\epsilon)_{SM} < 3.3 \times 10^{-3}$$

$$\mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right)_{exp} = (1.65 \pm 0.26) \times 10^{-3}$$

[Brod, Gorbahn, 1007.0684]

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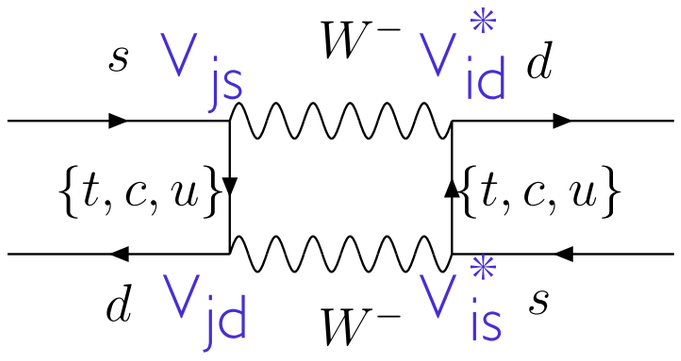
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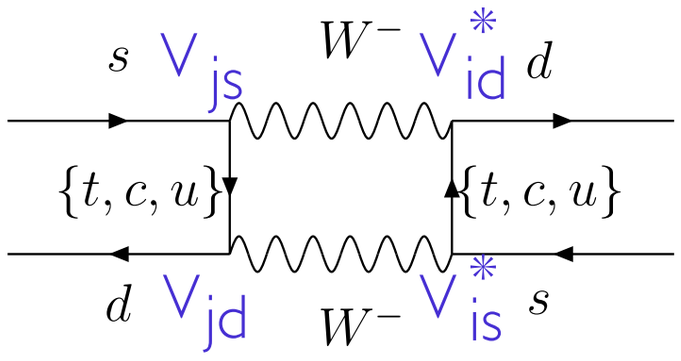
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Very large hadronic uncertainties but in some SUSY models, contributions could be fairly large

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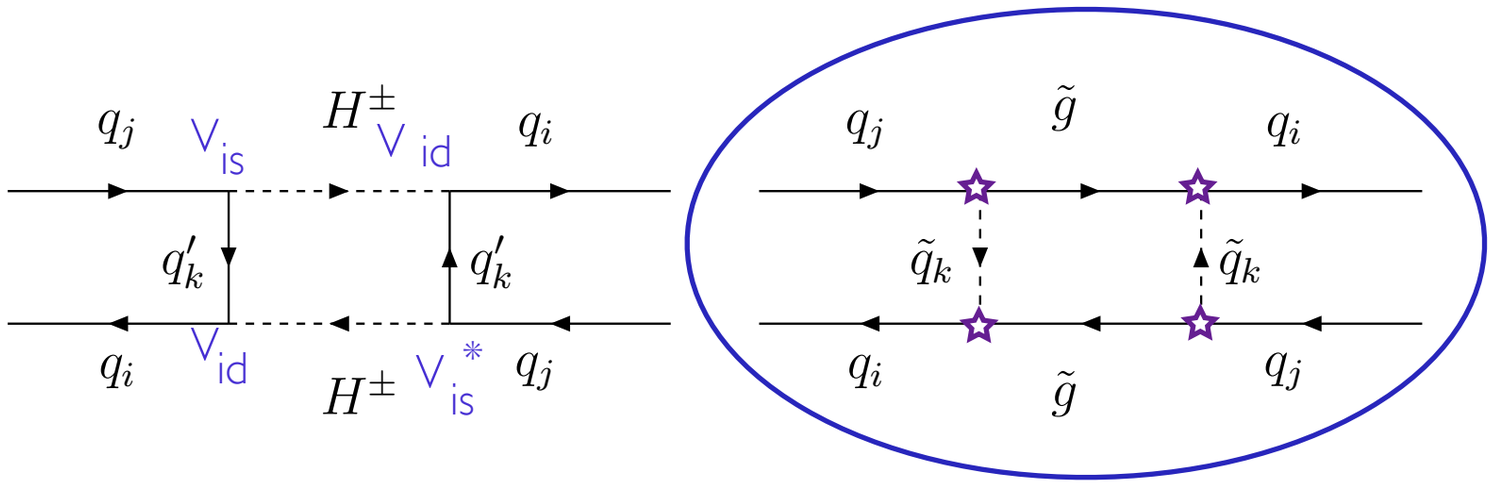
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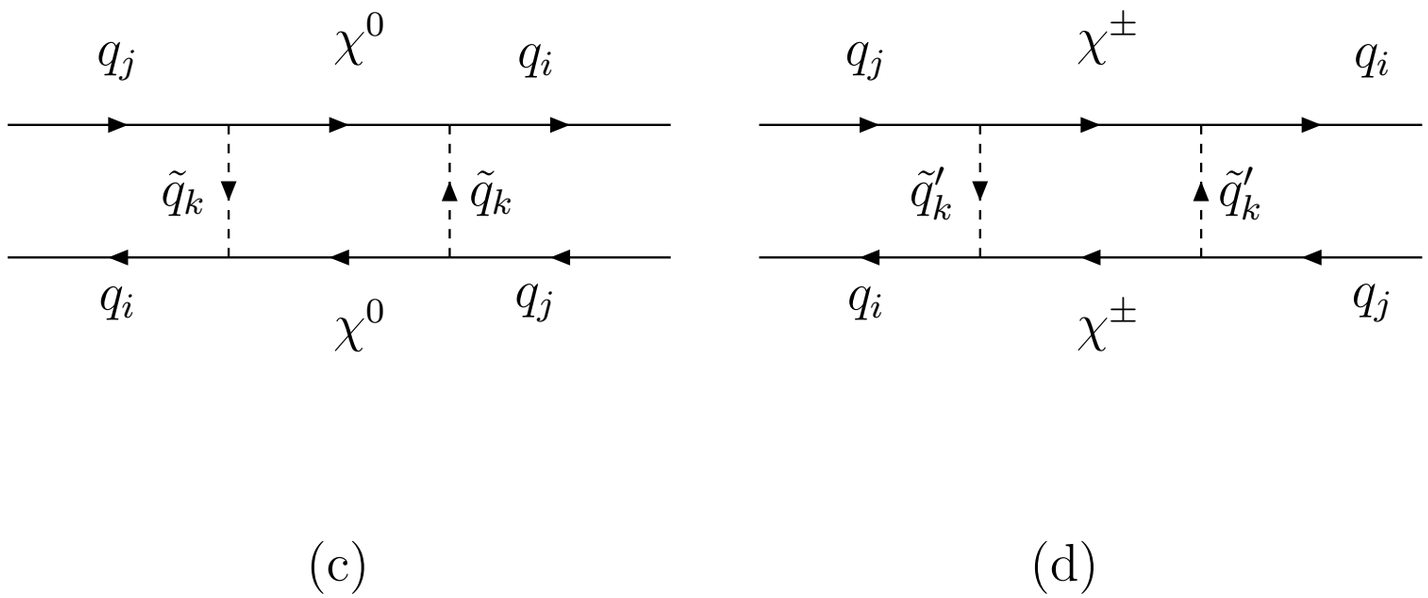
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Very large hadronic uncertainties but in some SUSY models, contributions could be fairly large

- As it is well known SUSY has plenty of CP violation sources so contributions to Δm_K, ε and ε′ can be huge.



q={s,d}



- Given the uncertainties *, is there a point in using Δm_K ε and ε′ as constraints for the models under consideration?
- Yes, because of the sensitivity of these parameters to physics BSM

Arkani-Hamed & Murayama ph/9703259
Arkani-Hamed, Dimopolous, Giudice & Romanino ph/0409232
Giudice, Nardecchia & Romanino ph/040932
Kadota, Kane, Kersten and L. V-S. 1107.3105

SUSY contribution can go well beyond experimental limits

*Hadronic, long distance, experimental determination of CKM parameters, etc.

- Limits on $\sqrt{\mathrm{Re}(\delta^d_{12})^2_{AB}}$ from

$$\boxed{\Delta m_K = 2\mathrm{Re}\,\langle K^0|H^{\Delta S=2}_{\mathrm{eff}}|\overline{K}^0\rangle} = \frac{G_F^2 f_K^2 m_K B_K}{6\pi^2}\mathrm{Re}[X],$$

$$X = \left[(V^*_{td}V_{ts})^2 S(x_t)\eta_{tt} + (V^*_{cd}V_{cs})^2 S(x_c)\eta_{cc} + 2(V^*_{cd}V_{cs})(V^*_{td}V_{ts})S(x_t,x_c)\eta_{tc} + C_{\tilde{g}}S(x_{\tilde{g}})\right]$$

- Limits on $\sqrt{\mathrm{Im}(\delta^d_{12})^2_{AB}}$ from

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- Limits on $\sqrt{\mathrm{Im}(\delta^d_{12})^2_{LR}}$ and $\mathrm{Im}(\delta^d_{12})^2_{RL}$ from $\mathrm{Re}(\epsilon'/\epsilon)$

LIMITS FROM $\Delta m_K = 2\mathrm{Re}\,\langle K^0|H_{\mathrm{eff}}^{\Delta S=2}|\overline{K}^0\rangle$

- Importance of NLO QCD Corrections

$$(\mathcal{M}^2_{\tilde{f}})_{ij} = \begin{bmatrix} M^2_{LL} & M^{2\dagger}_{LR} \\ M^2_{LR} & M^2_{RR} \end{bmatrix}_{ij}$$

$$(\delta^d_{\mathrm{XY}})_{ij} = \frac{(\hat{m}^2_{\tilde{d}\mathrm{XY}})_{ij}}{\sqrt{(\hat{m}^2_{\tilde{d}\mathrm{XY}})_{ii}(\hat{m}^2_{\tilde{d}\mathrm{XY}})_{jj}}}$$

$$= \begin{bmatrix} (M^2_{\tilde{Q}})_{ij} + (M^2_f)_{ij} + D^f_L & -(a_{f\,ij}v_f + \mu^* \tan^p\beta (M_f)_{ij}) \\ -(a^*_{f\,ij}v_f + \mu \tan^p\beta (M^*_f)_{ij}) & (M^2_{\tilde{f}_R})_{ij} + (M^2_f)_{ij} + D^f_R \end{bmatrix}$$

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$$(\delta^d_{LR})_{12} = \frac{-(\mu \tan\beta m_{f_{12}} + a_{12}v_d)}{\sqrt{(\hat{m}^2_{\tilde{d}})_{11}\hat{m}^2_{\tilde{d}})_{22}}} = \frac{A_{\tilde{d}}(m_s, m_b)\epsilon^r}{\sqrt{(\hat{m}^2_{\tilde{d}})_{11}(\hat{m}^2_{\tilde{d}})_{22}}} \sim \frac{(m_s, m_b)\epsilon^r}{f m_{3/2}} \sim 10^{-2}$$

LIMITS FROM $\Delta m_K = 2\mathrm{Re}\,\langle K^0|H_{\mathrm{eff}}^{\Delta S=2}|\overline{K}^0\rangle$

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Test FS

LIMITS FROM $\Delta m_K = 2\mathrm{Re}\,\langle K^0|H_{\mathrm{eff}}^{\Delta S=2}|\overline{K}^0\rangle$

- Importance of NLO QCD Corrections

$$\mathcal{H}^{\Delta F=2} = \sum_i^5 C_i O_i + \sum_i^3 C_i \tilde{O}_i,$$

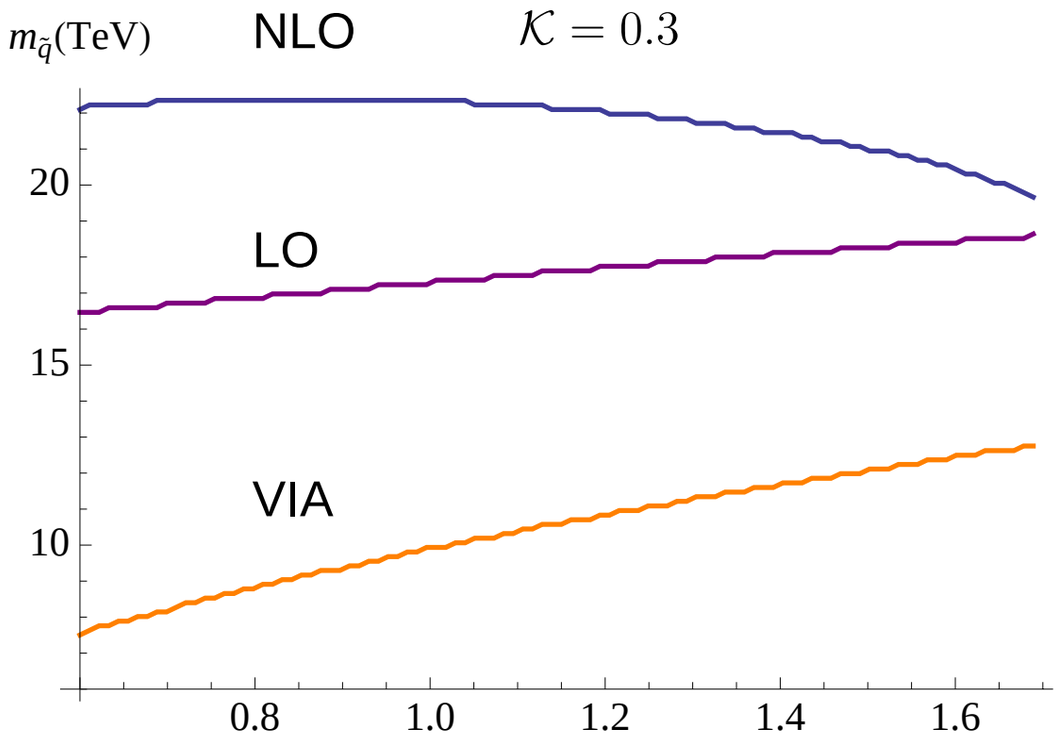
$f(m_{\tilde{g}}^2/m_{\tilde{d}}^2)$

	$(\delta_{12}^d)_{LL}$	$(\delta_{12}^d)_{LR}$	$(\delta_{12}^d)_{RL}$	$(\delta_{12}^d)_{RR}$
I	$\mathcal{K}$	0	0	0
II	0	$\mathcal{K}$	0	0
III	$\mathcal{K}$	0	0	$\mathcal{K}$
IV	0	$\mathcal{K}$	$\mathcal{K}$	0

$$m_{\tilde{d}} \longrightarrow m_{\tilde{g}} \longrightarrow m_t \ldots \longrightarrow 2\mathrm{GeV}$$

LIMITS FROM $\Delta m_K = 2\mathrm{Re}\,\langle K^0|H_{\mathrm{eff}}^{\Delta S=2}|\overline{K}^0\rangle$

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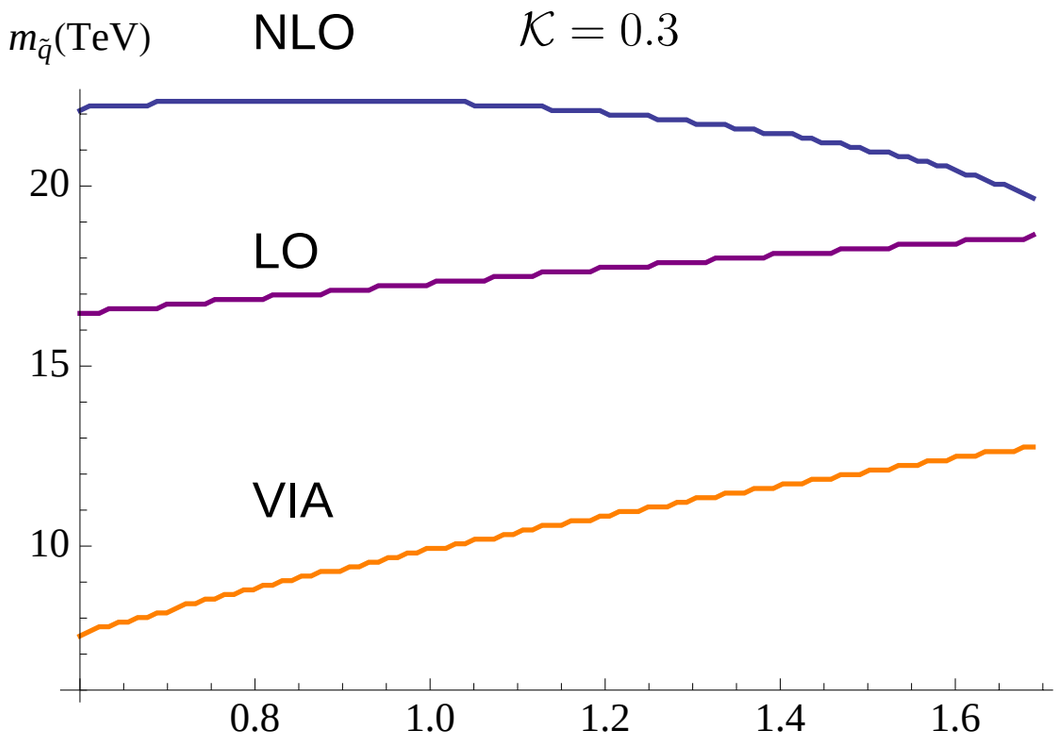
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IV	0	$\mathcal{K}$	$\mathcal{K}$	0

$$\langle K^0|Q_1|\bar{K}^0\rangle_{VIA} = \frac{1}{3}M_K f_K^2$$

$$\langle K^0|Q_1(\mu)|\bar{K}^0\rangle = \frac{1}{3}M_K f_K^2 B_1(\mu)$$

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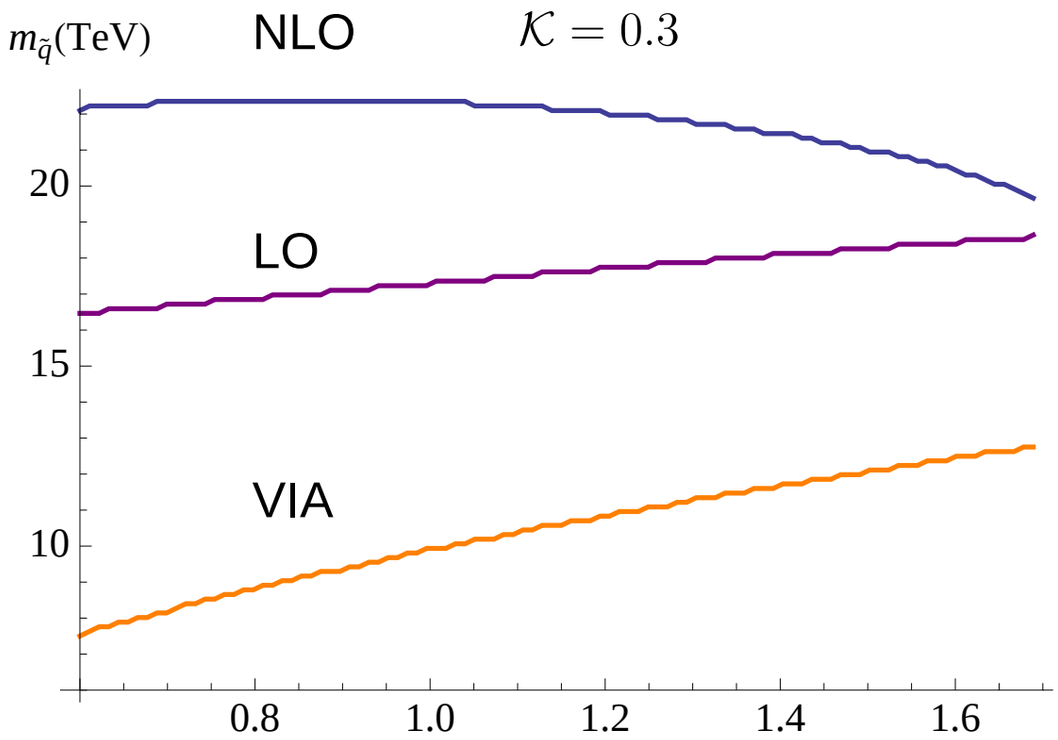
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Somewhat similar to Bagger, Matchev, Zhang ph/9707225

Contino & Scimeni ph/9809437

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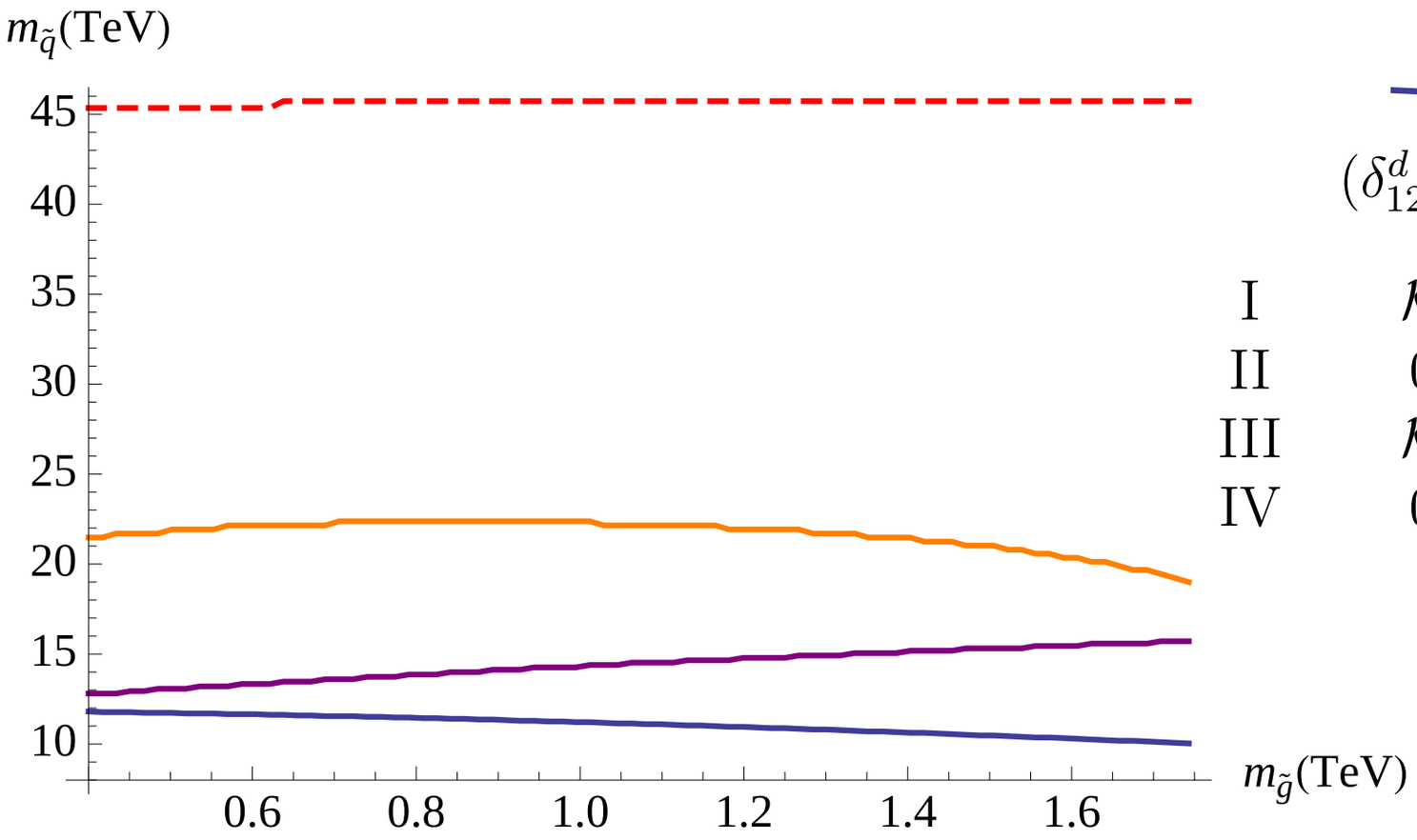
Somewhat similar to Bagger, Matchev, Zhang ph/9707225 VIA

Contino & Scimeni ph/9809437

Here two heavy generations

O(10)> a lighter one

• At NLO



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III	$\mathcal{K}$	0	0	$\mathcal{K}$
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Extreme value $\mathcal{K} = 0.3$

• At NLO

$m_{\tilde{q}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{LL}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{LR}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{RL}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{RR}}$
5 TeV	0.2	$1. \times 10^{-1}$	$1. \times 10^{-2}$	$2. \times 10^{-1}$
10 TeV	0.5	0.5	$1. \times 10^{-1}$	$1. \times 10^{-1}$

Table 1: Limits on $\mathrm{Re}(\delta^d_{12})_{AB}$ with $m_{\tilde{g}} = 900$ GeV.

- At NLO

$m_{\tilde{q}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{LL}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{LR}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{RL}}$	$\sqrt{\mathrm{Re}(\delta^d_{12})^2_{RR}}$
5 TeV	0.2	$1. \times 10^{-1}$	$1. \times 10^{-2}$	$2. \times 10^{-1}$
10 TeV	0.5	0.5	$1. \times 10^{-1}$	$1. \times 10^{-1}$

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Partial answer for FS models

$$(\delta^d_{LR})_{12} \sim \frac{(m_s, m_b)\epsilon^r}{f m_{3/2}} \sim 10^{-2}$$

Tipycally

Abelian

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Tipycally

Abelian

Non-Abelian

LIMITS FROM $\mathrm{Im}\,\langle K^0|H_{\rm eff}^{\Delta S=2}|\overline{K}^0\rangle$

$m_{\tilde{q}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{LL}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{LR}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{RL}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{RR}}$
2 TeV	$6.\times 10^{-3}$	$3.\times 10^{-3}$	$4.\times 10^{-4}$	$6.\times 10^{-4}$
5 TeV	$2.\times 10^{-3}$	$9.\times 10^{-3}$	$8.\times 10^{-4}$	$2.\times 10^{-3}$
10 TeV	$3.\times 10^{-3}$	$3.\times 10^{-3}$	$2.\times 10^{-3}$	$4.\times 10^{-3}$

Table 2: Limits on $\mathrm{Im}(\delta^d_{12})_{AB}$ with $m_{\tilde{g}} = 900$ GeV.

LIMITS FROM $\mathrm{Im}\,\langle K^0|H_{\rm eff}^{\Delta S=2}|\overline{K}^0\rangle$

$m_{\tilde{q}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{LL}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{LR}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{RL}}$	$\sqrt{\mathrm{Im}(\delta^d_{12})^2_{RR}}$
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Table 2: Limits on $\mathrm{Im}(\delta^d_{12})_{AB}$ with $m_{\tilde{g}} = 900$ GeV.

Here: Model dependent answer to FS because of the phases in A terms

RELEVANCE AT THE LHC

$$pp \to \quad \tilde{g}\tilde{g}, \quad \tilde{\chi}_1^0\tilde{\chi}_1^\pm, \quad \tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$$

- Typical decays

Primary

$$\begin{aligned}
\tilde{g} \quad &\to \quad \tilde{\chi}_2^0 \; t\bar{t} \\
&\to \quad \tilde{\chi}_1^0 \; b\bar{b} \\
&\to \quad \tilde{\chi}_1^0 \; q\bar{q} \\
&\to \quad \left(\tilde{\chi}_1^- \bar{d}u + h.c.\right)
\end{aligned}$$

Secondary

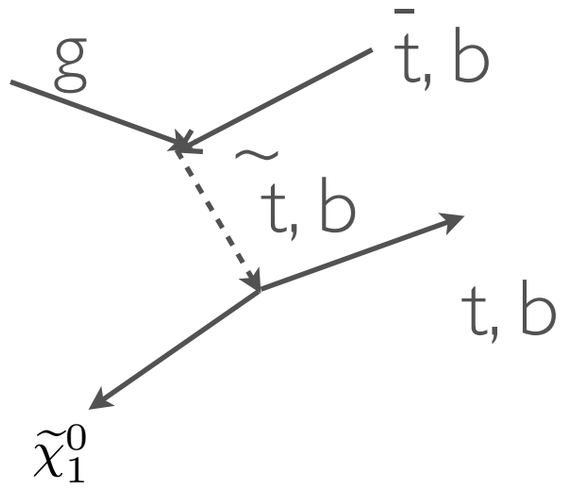
$$\begin{aligned}
\tilde{\chi}_2^0 \;&\to\; \chi_1^\pm W^* \;\to\; \chi_1^\pm \ell\nu_\ell, \quad \chi_1^\pm qq' \\
\chi_1^\pm \;&\to\; \chi_1^0 \ell\nu_\ell, \quad \chi_1^0 qq'
\end{aligned}$$

$$pp \to \quad \tilde{g}\tilde{g}, \quad \tilde{\chi}_1^0\tilde{\chi}_1^\pm, \quad \tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$$

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\end{aligned}$$

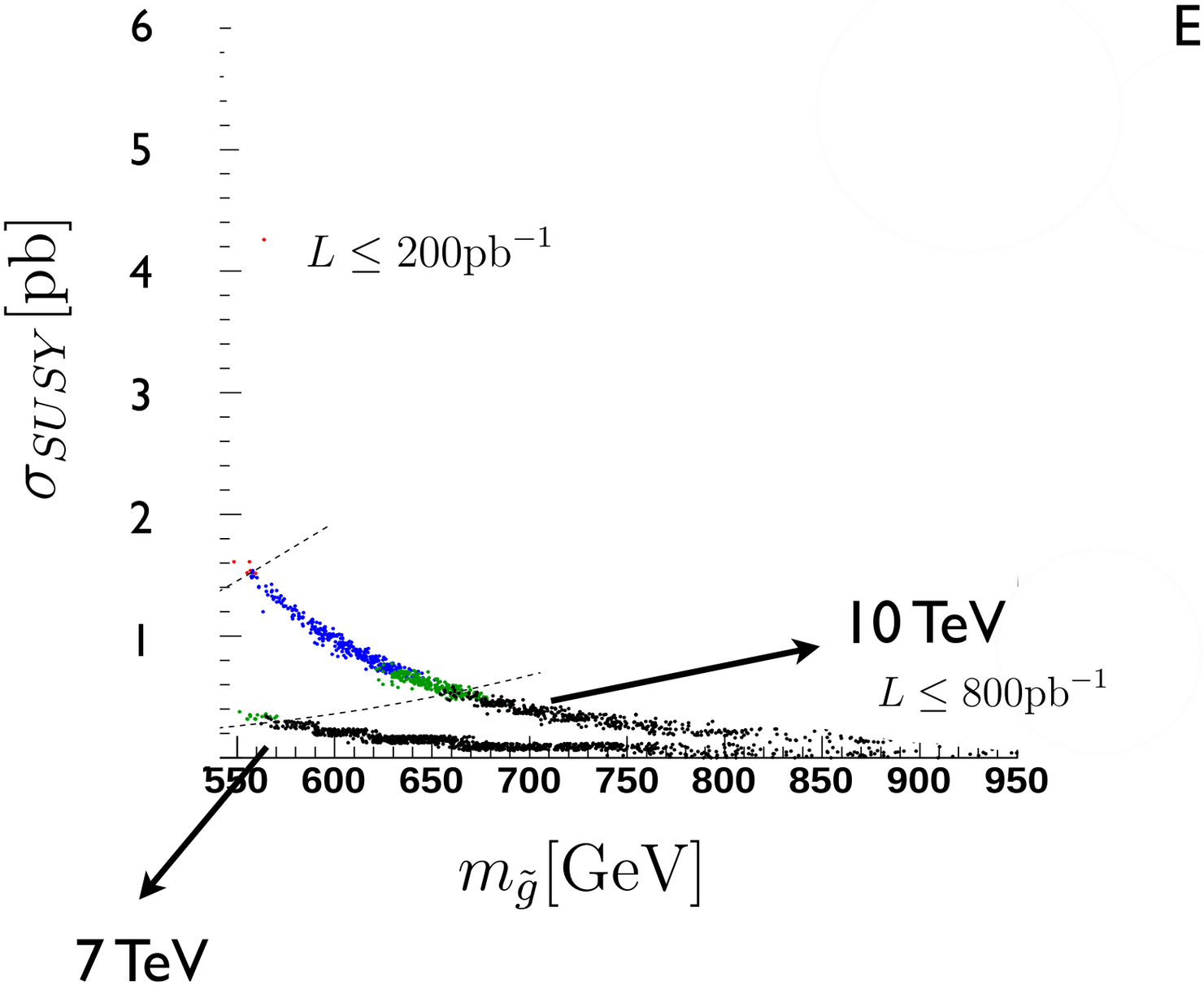


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\chi_1^\pm &\to \tilde{\chi}_1^0 \to \chi_1^0 \ell\nu_\ell, \quad \chi_1^0 qq'
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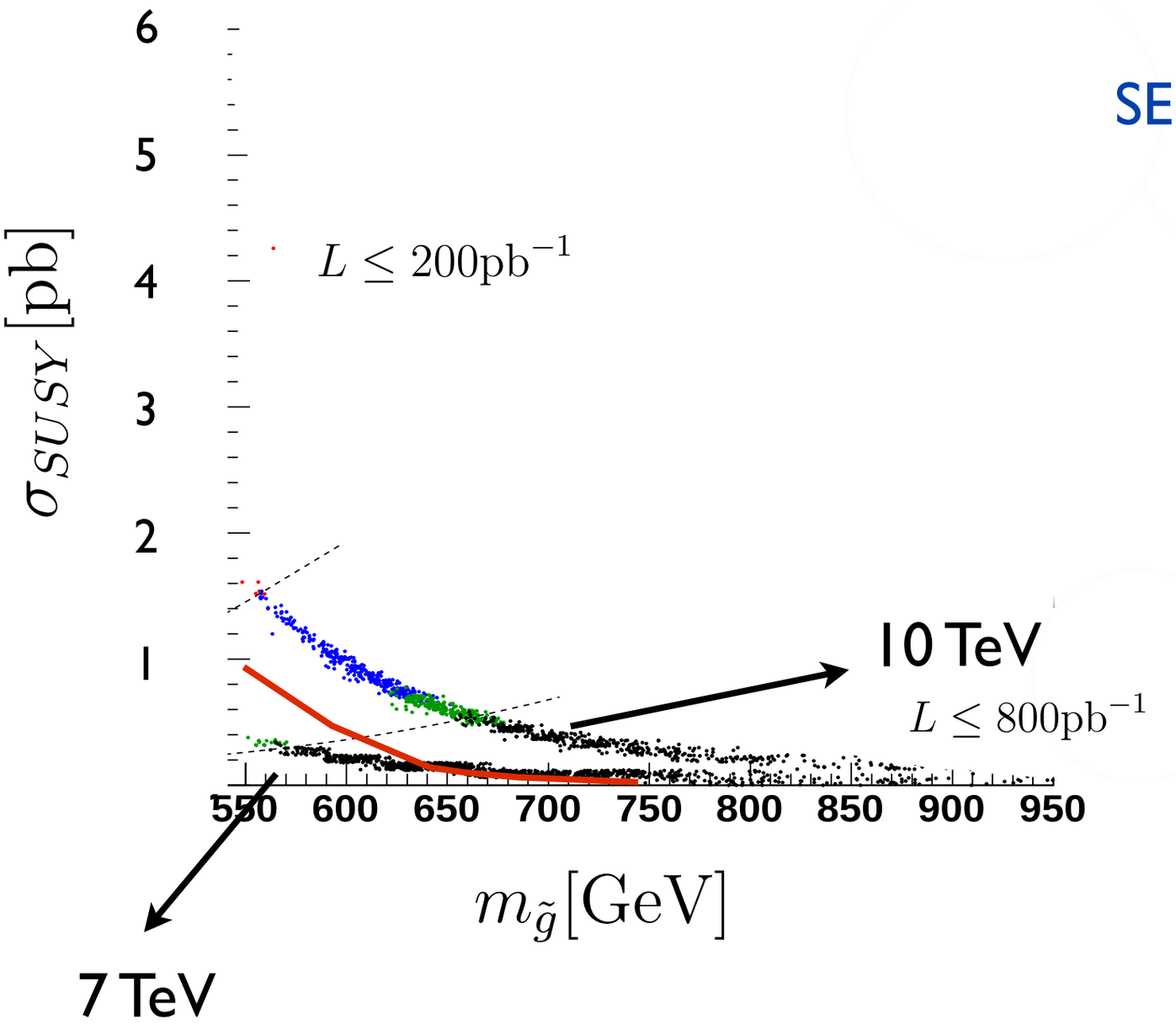
Pre-LHC

E CUT 200 GeV



Feldman, Kane, Lu & Nelson, 1002.2430 (G2-MSSM)

LHC (ATLAS SEARCHES)



SEE M D JØRGENSEN TALK

- Depending on $\Delta m_\chi = \chi^\pm - \chi^0$

Could be degenerated, depends on the $M_2 - M_1$ splitting

$$\chi^\pm \rightarrow \chi^0 \pi^\pm$$

Soft pions

displaced vertex

$$\Delta_\chi \leq m_\pi \rightarrow 10 \text{ m}$$
$$\Delta_\chi \gtrsim m_\pi \rightarrow 0.1 \text{ m}$$

CHEN C.-H., DREES & GUNION 9607421
BUCKLEY, RANDALL & SHUVE, 0909.4549

CDF dedicated study

In the models at hand one needs to first detect gluinos and then track down the chargino decays

RECAP

- LHC is already setting limits on models with light gluinos and heavy squarks
- In this work, we wanted to understand still the Flavour Problem with out too many complications
- Stressed the importance of QCD corrections in the Kaon sector ⟶
  - Ready to set limits on $m_{\tilde{d}}$ and FS parameters