The status of alignment models at the LHC era (2012)

Gilad Perez

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Gedalia, Mannelli & GP (10);
Gedalia, Kamenik, Ligeti & GP (12)
Mahbubani, Papucci, GP, Ruderman & Weiler, in prep';
Kadosh, Paradisi & GP, in progress;
Grossman, Kagan, Ligeti, GP & Petrov, in prep'.

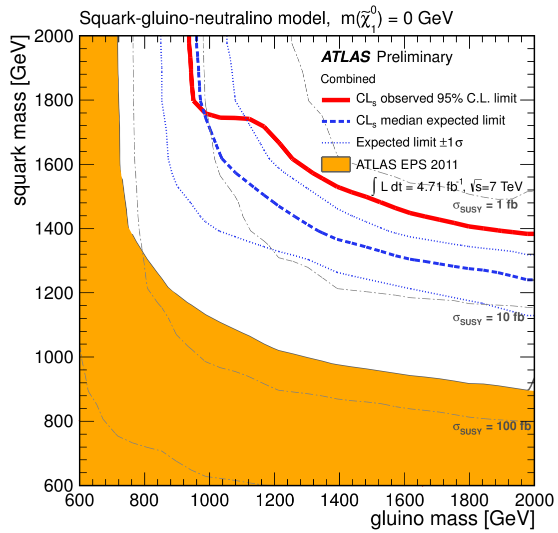
Johns Hopkins 36th Workshop
Latest News on Fermi scale from LHC & DM searches

The Galileo Galilei Institute

Prologue, current status of Supersymmetry

Putting stops aside, what are the bounds on first 2-generation "light" squarks?

Bounds from ATLAS & CMS:



Light squarks > 1.4 TeV?

See later: this bound is prejudiced, relaxing assumption may open window to SUSY & non-trivial flavor info'.

Outline

- Introduction, importance of uFCNC.
- Alignment & CP violation (CPV) in D mixing.
- New robust bound on standard model (SM) D mixing absorptive CPV & dark photon/hidden valley models.
- Non-degenerate light (burried) squark @ the LHC.
- Conclusions.

Effective Field Theory (EFT) Model independent approach

microscopic dynamics above few *x 100* GeV is unknown.

Can parameterize our ignorance by set of higher dim' operators suppressed by the scale of new physics (NP).

$$\mathcal{H}_{\rm eff}^{\Delta S,C,B=2} = \sum_{i=1}^{5} \left(O_i^{sd}/\Lambda^2 + O_i^{cu}/\Lambda^2 + O_i^{b,sd}/\Lambda^2 \right)$$

(see e.g.: UTFit, 0707.03535)

$$Q_1^{q_iq_j} = \bar{q}^\alpha_{jL}\gamma_\mu q^\alpha_{iL}\bar{q}^\beta_{jL}\gamma^\mu q^\beta_{iL}\,, \quad Q_3^{q_iq_j} = \bar{q}^\alpha_{jR}q^\beta_{iL}\bar{q}^\beta_{jR}q^\alpha_{iL}\,, \quad Q_5^{q_iq_j} = \bar{q}^\alpha_{jR}q^\beta_{iL}\bar{q}^\beta_{jL}q^\alpha_{iR}\,.$$

$$Q_2^{q_iq_j} = \bar{q}^\alpha_{jR}q^\alpha_{iL}\bar{q}^\beta_{jR}q^\beta_{iL}\,, \quad Q_4^{q_iq_j} = \bar{q}^\alpha_{jR}q^\alpha_{iL}\bar{q}^\beta_{jL}q^\beta_{iR}\,,$$

Almost any NP model can be described at low *E* by this set of operators (above Op' are most dangerous & yet clean).

$\Delta F = 2$ status

Isidori, Nir & GP (10)

Operator	Bounds on Λ in TeV ($c_{ij}=1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.1×10^2		7.6×10^{-5}		Δm_{B_s}
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		1.3×10^{-5}		Δm_{B_s}
$(\bar{t}_L \gamma^\mu u_L)^2$					sign t's

Probably bound already exists due to LHCb, CMS indep' confirmation?

Adding Leptons?

Operator	Bounds on Λ in TeV ($c_{ij}=1$) Re	Bounds on Λ in TeV ($c_{ij}=1$) Im	Bounds on c_{ij} ($\Lambda = 1$ TeV) Re	Bounds on c_{ij} ($\Lambda = 1$ TeV) Im	Observables
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$(\bar{t}_L\gamma^\mu u_L)^2$					same sign t's

$\bar{L}_i\sigma^{\mu\nu}e_{Rj}HF_{\mu\nu}$	1.7×10^4			$Br\,(\mu\to e\gamma)$
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$(\bar{\mu}\gamma^\mu P_L e)\,(\bar{u}\gamma_\mu P_L u)$	1.9×10^2			$\frac{\sigma(\mu^- Ti\to e^- Ti)}{\sigma(\mu^- Ti\to capture)}$

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$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		[illegible]		[illegible]
$(\bar{t}_L \gamma^\mu u_L)^2$			[illegible]		[illegible]

Very very strong ...

Operator	Bounds on Λ			Observables
$\bar{L}_i \sigma^{\mu\nu} e_{Rj} H F_{\mu\nu}$	1.7×10^4			$Br\,(\mu \to e\gamma)$
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$(\bar{\mu}\gamma^\mu P_L e)\,(\bar{u}\gamma_\mu P_L u)$	1.9×10^2			$\frac{\sigma(\mu^- Ti \to e^- Ti)}{\sigma(\mu^- Ti \to capture)}$

What do we conclude ?

- SM mechanism to induce flavor & CPV is successful.

The Nobel Prize in Physics

© The Nobel Foundation Photo: U. Montan

Makoto Kobayashi

© The Nobel Foundation Photo: U. Montan

Toshihide Maskawa

$\Delta F = 2$ status

Isidori, Nir & GP, Ann. Rev. Nucl. Part. Sci. (10)

Operator	Bounds on Λ in TeV ($c_{ij}=1$) Re	Bounds on Λ in TeV ($c_{ij}=1$) Im	Bounds on c_{ij} ($\Lambda = 1$ TeV) Re	Bounds on c_{ij} ($\Lambda = 1$ TeV) Im	Observables
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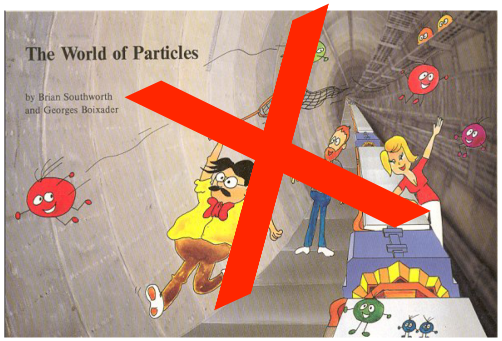
$(\bar{t}_L\gamma^\mu u_L)^2$					

- Bounds are too strong to allow for NP to be directly probed.



- Hint for underlying structure of microscopic laws of nature.

Alternatively, assume $1\mathrm{TeV}$ & bound coefficients

$$\mathcal{L}_{\Delta F=2} = \frac{z_{sd}}{(1\,\mathrm{TeV})^2}(\overline{d_L}\gamma_\mu s_L)^2 + \frac{z_{cu}}{(1\,\mathrm{TeV})^2}(\overline{c_L}\gamma_\mu u_L)^2$$
$$+ \frac{z_{sd}^4}{(1\,\mathrm{TeV})^2}(\overline{d_L}s_R)(\overline{d_R}s_L) + \frac{z_{cu}^4}{(1\,\mathrm{TeV})^2}(\overline{u_L}c_R)(\overline{u_R}c_L).$$

$$\mathcal{I}m(z_{sd}, z_{sd}^4) \lesssim (3.4\times 10^{-9}, 2.6\times 10^{-11})\,(\Lambda_{\mathrm{NP}}/\mathrm{TeV})^2,$$

$$\mathcal{I}m(z_{cu}, z_{cu}^4) \lesssim (1.0\times 10^{-7}, 1.1\times 10^{-8})\,(\Lambda_{\mathrm{NP}}/\mathrm{TeV})^2,$$

recent, will be further improved

Flavor structure of TeV NP is highly non-generic!

What kind of NP survives?

- Flavor blind/universal NP, for sure, but very restrictive.

  (spoiled by RGE)

- NP flavor structure is controlled by SM one, effective minimal flavor violation (MFV) => more exciting than naively guessed

- Maybe NP is anarchic but aligned. Nir-Seiberg (92).

The importance of up-type FCNC

What if down/lepton alignment is at work ?

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The importance of up-type FCNC

What if down/lepton alignment is at work ?

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$\cancel{(\bar{s}_R\, d_L)(\bar{s}_L d_R)}$	$\cancel{1.8\times10^4}$	$\cancel{3.2\times10^5}$	$\cancel{6.9\times10^{-9}}$	$\cancel{2.6\times10^{-11}}$	$\cancel{\Delta m_K;\ \epsilon_K}$
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$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	$\Delta m_D;\ \lvert q/p\rvert,\phi_D$
$\cancel{(\bar{b}_L\gamma^\mu d_L)^2}$	$\cancel{5.1\times10^2}$	$\cancel{9.3\times10^2}$	$\cancel{3.3\times10^{-6}}$	$\cancel{1.0\times10^{-6}}$	$\cancel{\Delta m_{B_d};\ S_{\psi K_S}}$
$\cancel{(\bar{b}_R\, d_L)(\bar{b}_L d_R)}$	$\cancel{1.9\times10^3}$	$\cancel{3.6\times10^3}$	$\cancel{5.6\times10^{-7}}$	$\cancel{1.7\times10^{-7}}$	$\cancel{\Delta m_{B_d};\ S_{\psi K_S}}$
$\cancel{(\bar{b}_L\gamma^\mu s_L)^2}$	$\cancel{1.1\times10^2}$		$\cancel{7.6\times10^{-5}}$		$\cancel{\Delta m_{B_s}}$
$\cancel{(\bar{b}_R\, s_L)(\bar{b}_L s_R)}$	$\cancel{3.7\times10^2}$		$\cancel{1.3\times10^{-5}}$		$\cancel{\Delta m_{B_s}}$
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$\cancel{\bar{L}_i\sigma^{\mu\nu} e_{Rj} F_{\mu\nu}}$	$\cancel{1.7\times10^4}$				$\cancel{Br\,(\mu\to e\gamma)}$
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$(s_L\gamma^\mu d_L)$ [illegible]	[illegible]	1.6×10^{4}	9.0×10^{-7}	[illegible]	[illegible]
[illegible]	1.8×10^{4}	3.2×10^{5}	6.9×10^{-9}	[illegible]	[illegible]
$(\bar c_L\gamma^\mu u_L)^2$	1.2×10^{3}	2.9×10^{3}	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar c_R\, u_L)(\bar c_L u_R)$	[illegible]	[illegible]	[illegible]	$\times10^{-8}$	Δm_D; $\lvert q/p\rvert, \phi_D$
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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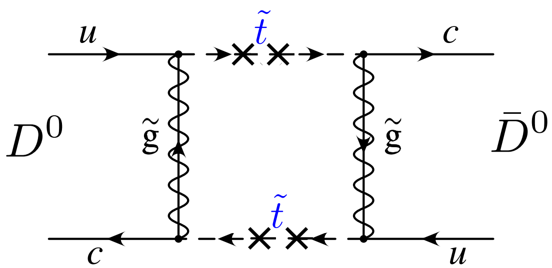
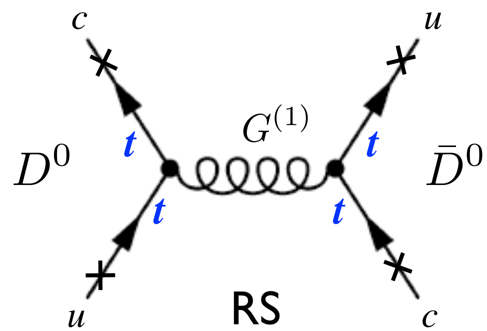
uFCNC remove immunities

uFCNC data, a crucial test of NP structure

- General: dominant NP constraints coming from extended strong sector, need not "talk" to down & charged lepton sector:



SUSY



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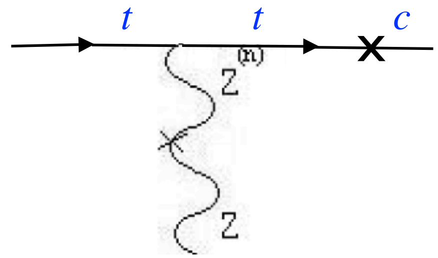
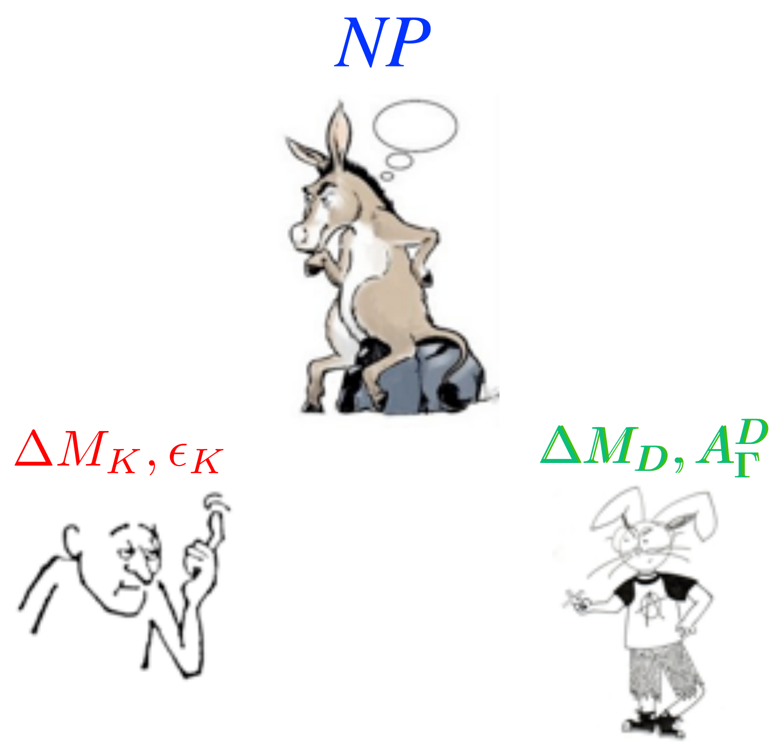


- Down & lepton flavor violation maybe removed via alignment, anarchic NP is diagonal in down/ charged-lepton mass basis.



[Nir & Seiberg (93);
Crappy: Fitzpatrick, GP & Randall (08);
Csaki, GP, Surujon, & Weiler (09)].

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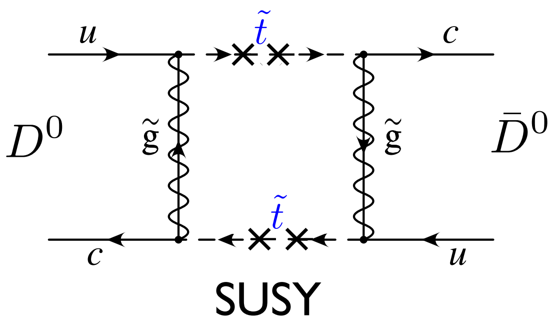

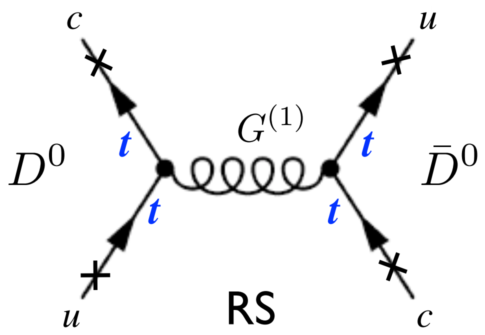

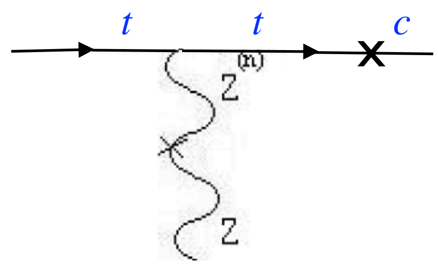

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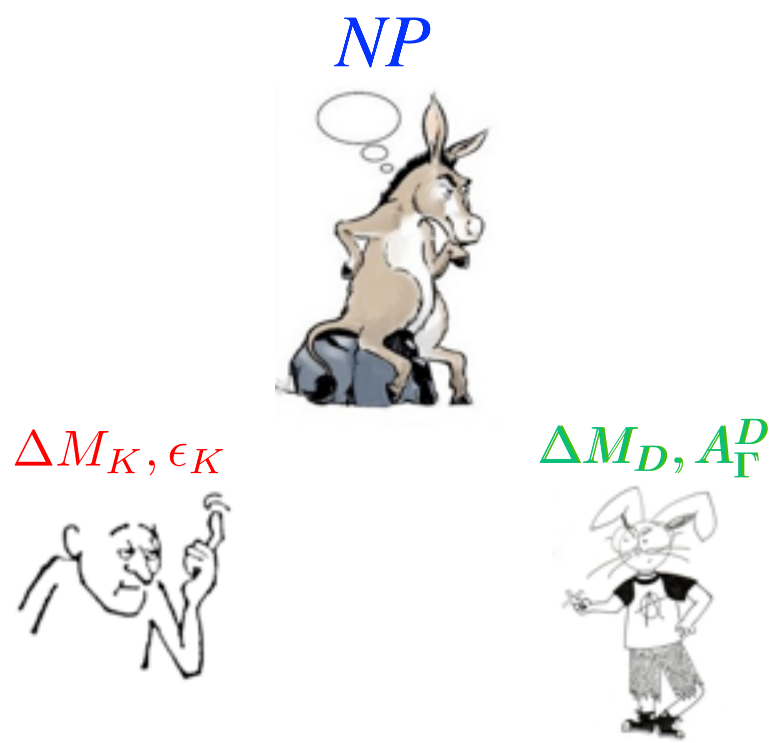

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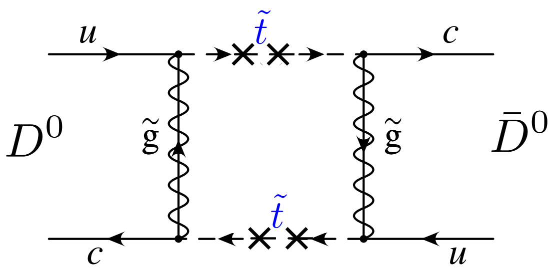

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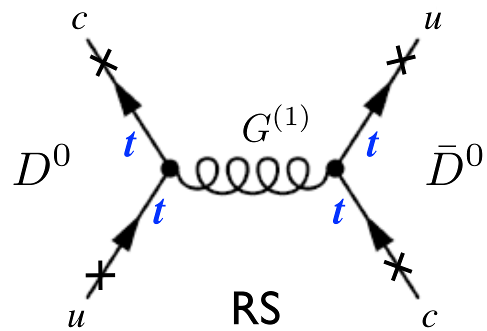

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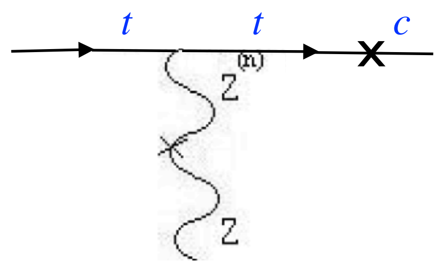

NP

$\Delta M_K, \epsilon_K$

$\Delta M_D, A_\Gamma^D$

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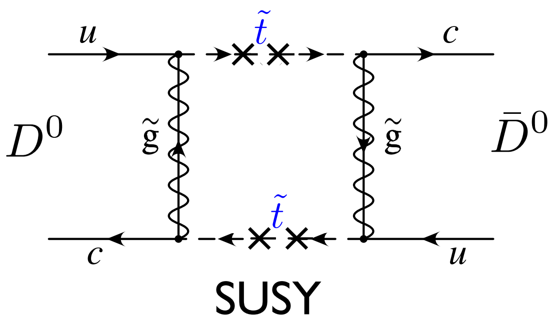
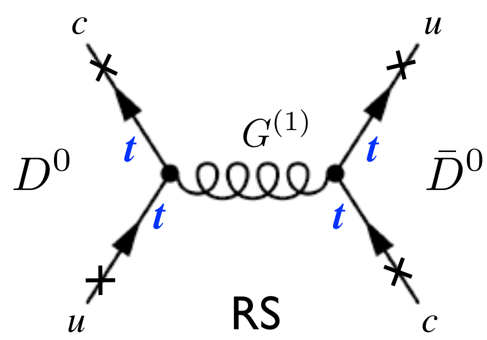
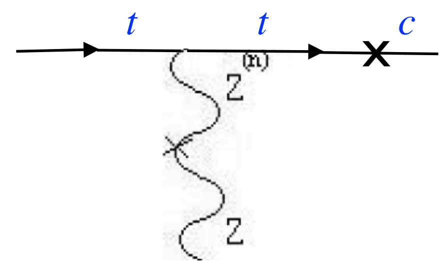
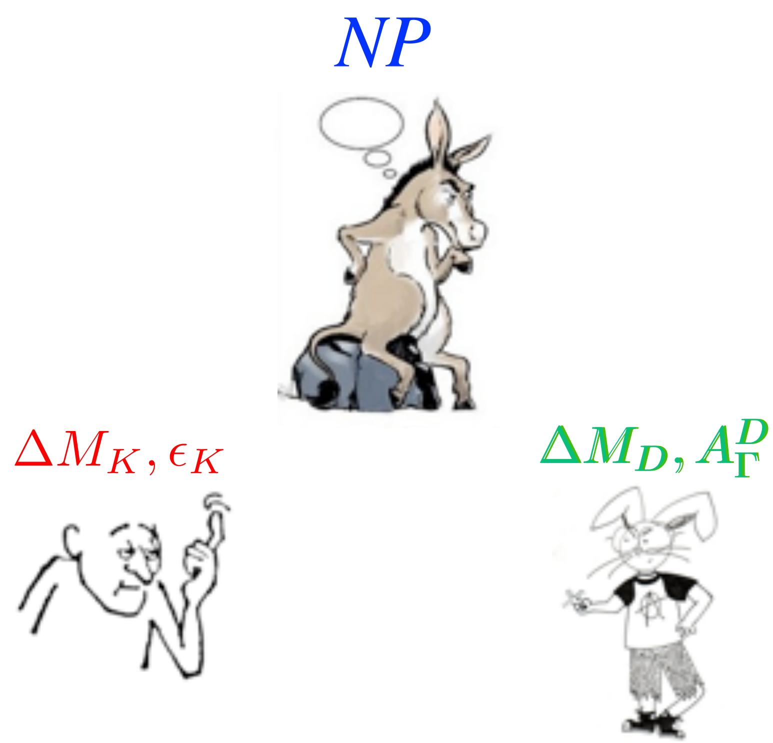






- Down & lepton flavor violation maybe removed via alignment, anarchic NP is diagonal in down/ charged-lepton mass basis.



[Nir & Seiberg (93);
Crappy: Fitzpatrick, GP & Randall (08);
Csaki, GP, Surujon, & Weiler (09)].

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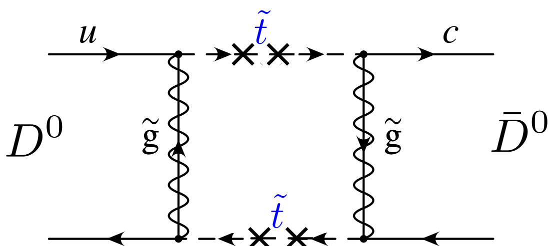
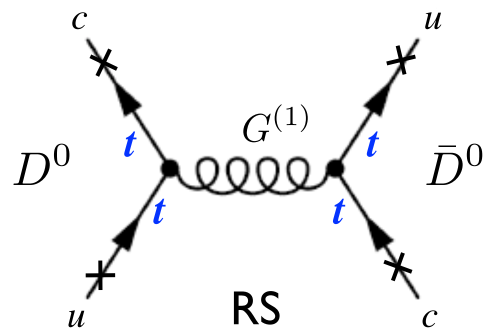
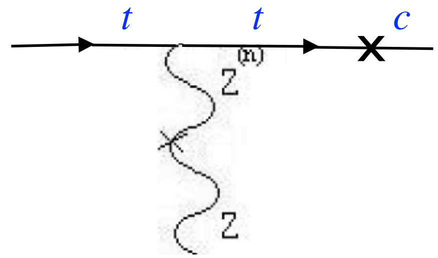


SUSY



RS



NP

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[Nir & Seiberg (93);
Crappy: Fitzpatrick, GP & Randall (08);
Csaki, GP, Surujon, & Weiler (09)].

$\Delta M_K, \epsilon_K$

$\Delta M_D, A_\Gamma^D$

Aligning away NP & the power of the D system

The bounds from $z^4_{sd,cu}$ are much more severe.

However, $z^4_{sd} \subset (1, \mathbf{8}, 1, \mathbf{8})$, $z^4_{cu} \subset (\mathbf{8}, 1, \mathbf{8}, 1)$

Have singlet part which can be aligned with SM, $Y_U^\dagger Y_U$, $Y_D^\dagger Y_D$.

On the other hand assuming $SU(2)_L$ $z_{sd,cu}$ expected to have a common origin, z_Q .

Cannot align z_Q simultaneously with both $Y_U Y_U^\dagger$ & $Y_D Y_D^\dagger$.

Nir (07); Blum, Grossman, Nir, GP (09)

Combining $K-\bar{K}$ & $D-\bar{D}$ mixing to constrain NP flavor structure

Two generation covariant description

Gedalia, Mannelli & GP (10);

Assuming $SU(2)_L$: $\frac{1}{\Lambda_{\rm NP}^2}(\overline{Q_{Li}}(X_Q)_{ij}\gamma_\mu Q_{Lj})(\overline{Q_{Li}}(X_Q)_{ij}\gamma^\mu Q_{Lj})$,

X_Q is 2x2 Hermitian matrix, can be described as a vector in SU(2) 3D flavor space.

$$|\vec{A}| \equiv \sqrt{\frac{1}{2}{\rm tr}(A^2)}\,, \quad \vec{A}\cdot\vec{B} \equiv \frac{1}{2}{\rm tr}(A\,B)\,, \quad \vec{A}\times\vec{B} \equiv -\frac{i}{2}\,[A,B]\ ,$$

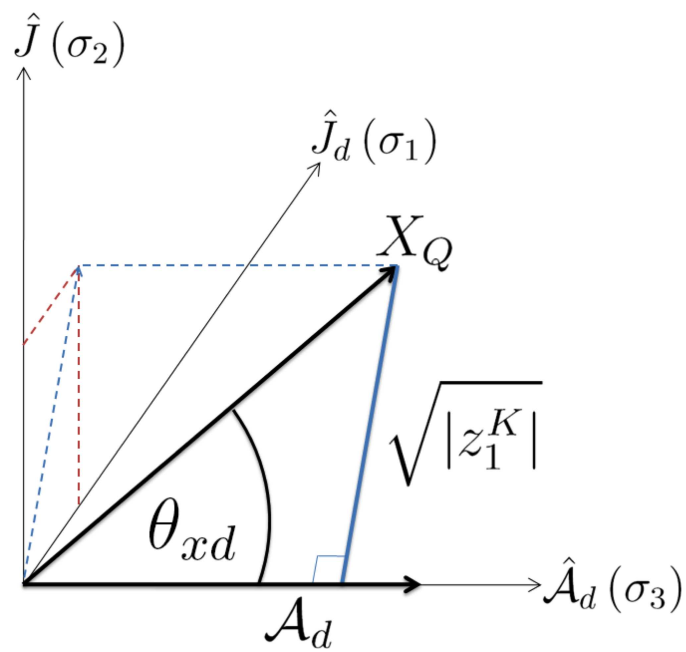
$$\cos(\theta_{AB}) \equiv \frac{\vec{A}\cdot\vec{B}}{|\vec{A}||\vec{B}|} = \frac{{\rm tr}(A\,B)}{\sqrt{{\rm tr}(A^2){\rm tr}(B^2)}}\,.$$

Space can be span via SM Yukawas (useful for CPV, see later):

$$\mathcal{A}_u \equiv (Y_u Y_u^\dagger)_{\not{\rm tr}} \quad \mathcal{A}_d \equiv (Y_d Y_d^\dagger)_{\not{\rm tr}}$$

Two generation covariance description, cont’

$$\hat{\mathcal{A}}_{u,d} \equiv \frac{\mathcal{A}_{u,d}}{|\mathcal{A}_{u,d}|}\,, \qquad \hat{J} \equiv \frac{\mathcal{A}_d \times \mathcal{A}_u}{|\mathcal{A}_d \times \mathcal{A}_u|}\,, \qquad \hat{J}_{u,d} \equiv \hat{\mathcal{A}}_{u,d} \times \hat{J}\,.$$



: The contribution of X_Q to $K^0 - \overline{K^0}$ mixing, Δm_K, given by the solid blue line. In the down mass basis, $\hat{\mathcal{A}}_d$ corresponds to σ_3, $\hat{J}$ is σ_2 and $\hat{J}_d$ is σ_1.

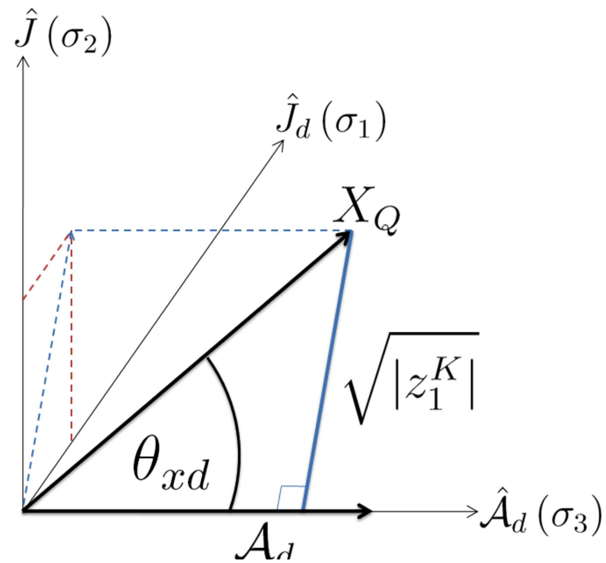
Assuming $SU(2)_L$: $\quad \frac{1}{\Lambda^2_{\rm NP}}(\overline{Q_{Li}}(X_Q)_{ij}\gamma_\mu Q_{Lj})(\overline{Q_{Li}}(X_Q)_{ij}\gamma^\mu Q_{Lj}),$

Special role of "CPV" direction

Notice that:

A 2-gen' case, 3 adjoints yield CPV: $J = \mathrm{Tr}\left\{X\left[Y_D Y_D^\dagger, Y_U Y_U^\dagger\right]\right\}$

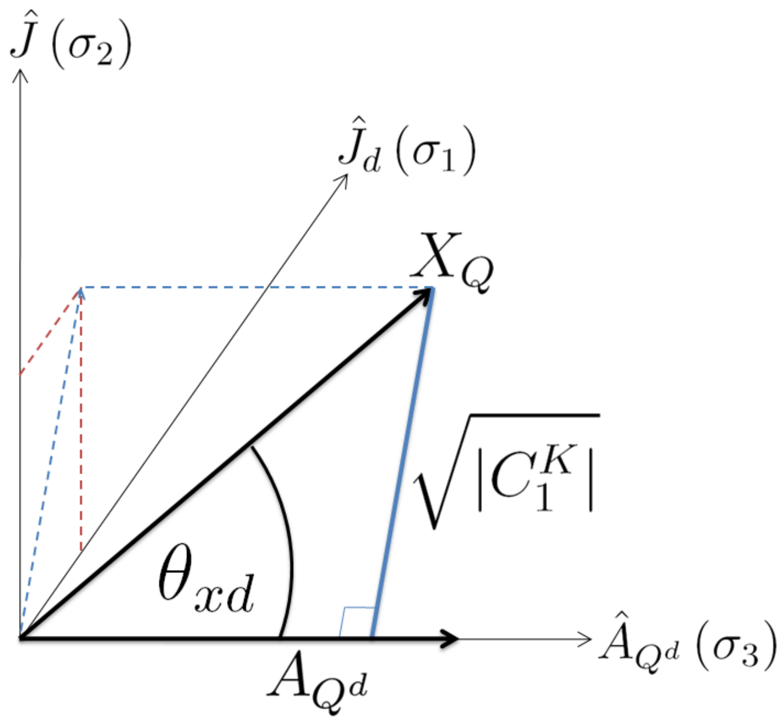
Projection of X_Q onto $\hat{J}$ is measuring the physical CPV phase.



Adding constraints from CPV

$$\frac{C_1}{\Lambda_{\rm NP}^2} O_1 = \frac{1}{\Lambda_{\rm NP}^2} \left[\overline{Q}_i (X_Q)_{ij} \gamma_\mu Q_j\right] \left[\overline{Q}_i (X_Q)_{ij} \gamma^\mu Q_j\right] ,$$

$$\left| C_1^{D,K} \right| = \left| X_Q \times \hat{A}_{Q^u, Q^d} \right|^2 \qquad \text{(Sorry } \mathcal{A}_{u,d} \equiv A_{Q^u,Q^d})$$



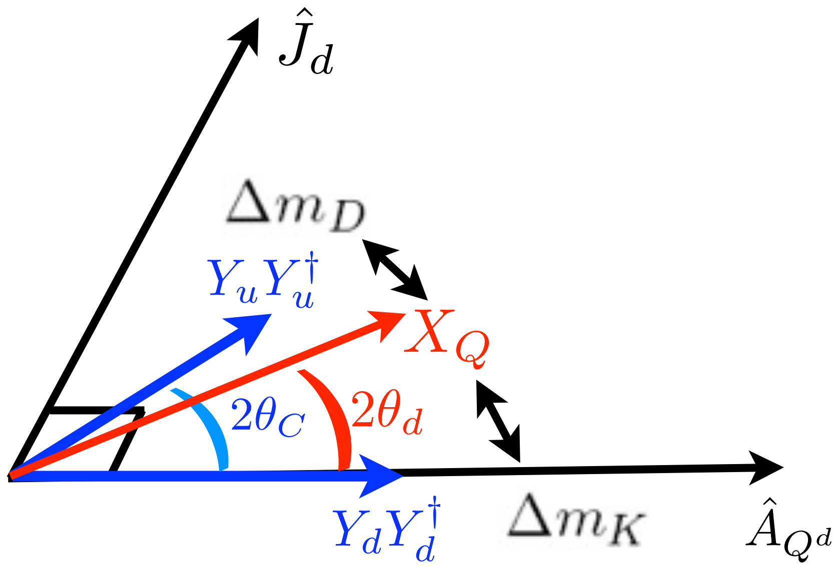
$$\mathrm{Im}\left(C_1^{K,D}\right) = 2\left(X_Q \cdot \hat{J}\right)\left(X_Q \cdot \hat{J}_{u,d}\right) .$$

Finding the weakest robust bound, no CPV

$$C_1^K = L^2\left[\left(X^J\right)^2 + \left(X^{J_d}\right)^2\right]\,,$$

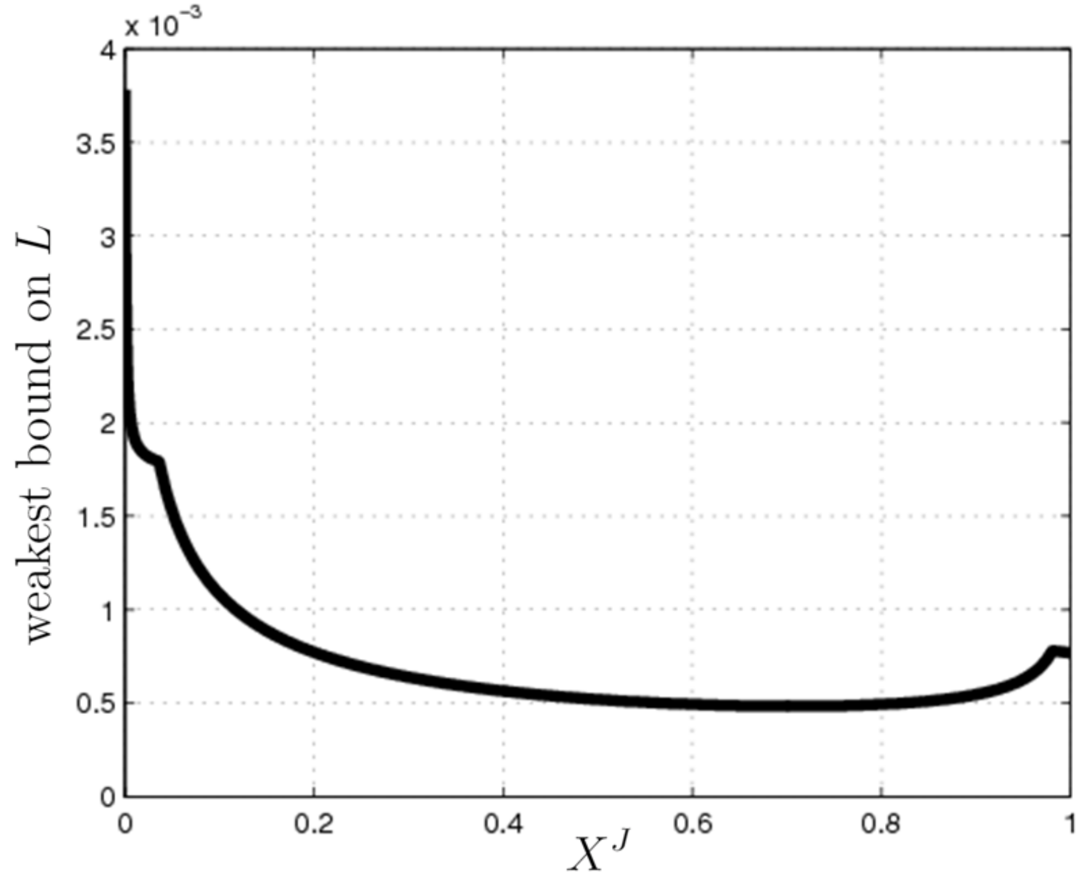
$$C_1^D = \frac{L^2}{2}\left[2\left(X^J\right)^2 + \left(X^d\right)^2 + \left(X^{J_d}\right)^2 + \left(\left(X^{J_d}\right)^2 - \left(X^d\right)^2\right)\cos(4\theta_{\mathrm{C}}) + 2X^dX^{J_d}\sin(4\theta_{\mathrm{C}})\right]\,.$$

$L = |X_Q| = \left(X_Q^2 - X_Q^1\right)/2\,,$ *a flavor diagonal quantity.*



Finding the weakest robust bound, with CPV

$$L \leq \frac{3.4 \times 10^{-4}}{\left[(X^J)^2 - (X^J)^4\right]^{1/4}} \left(\frac{\Lambda_{\rm NP}}{1\,{\rm TeV}}\right)$$



Blum-Grossman-Nir-Perez (09)

The weakest upper bound on L coming from flavor and CPV in the K and D systems, as a function of the CP violating parameter X^J, assuming $\Lambda_{\rm NP} = 1$ TeV.

SUSY implications, naively looks like alignment is dead!!

What is X_Q in the SUSY case?

$$\frac{m_{\tilde{Q}_2} - m_{\tilde{Q}_1}}{m_{\tilde{Q}_2} + m_{\tilde{Q}_1}} \leq \begin{cases} 0.034 & \text{maximal phases} \\ 0.27 & \text{vanishing phases} \end{cases}$$

(squark doublets, 1TeV)

Blum-Grossman-Nir-Perez (09)

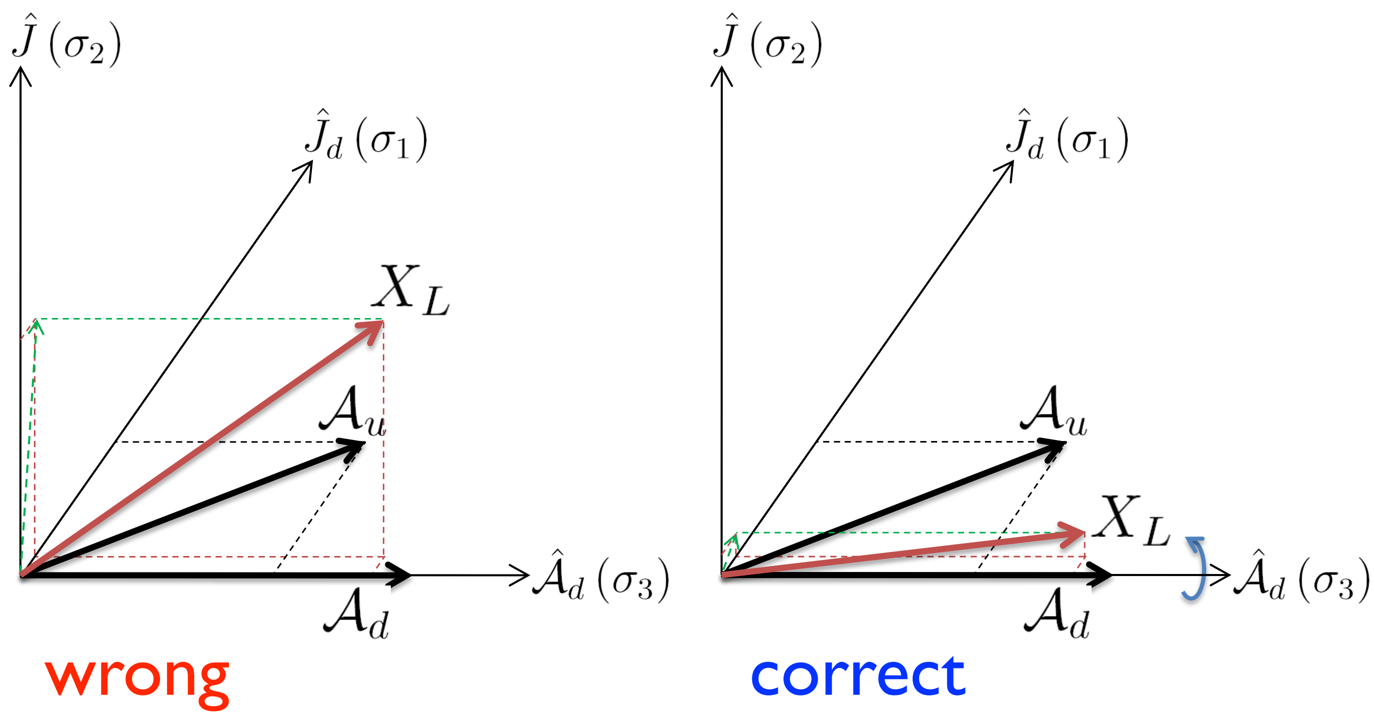
With phases, first 2 gen' squark need to have almost equal masses.

Looks like squark anarchy/alignment is dead!

However ...

How do successful alignment models look like?

- The maximal phase case does not correspond to an alignment model.
- Alignment makes both real and imaginary parts small.



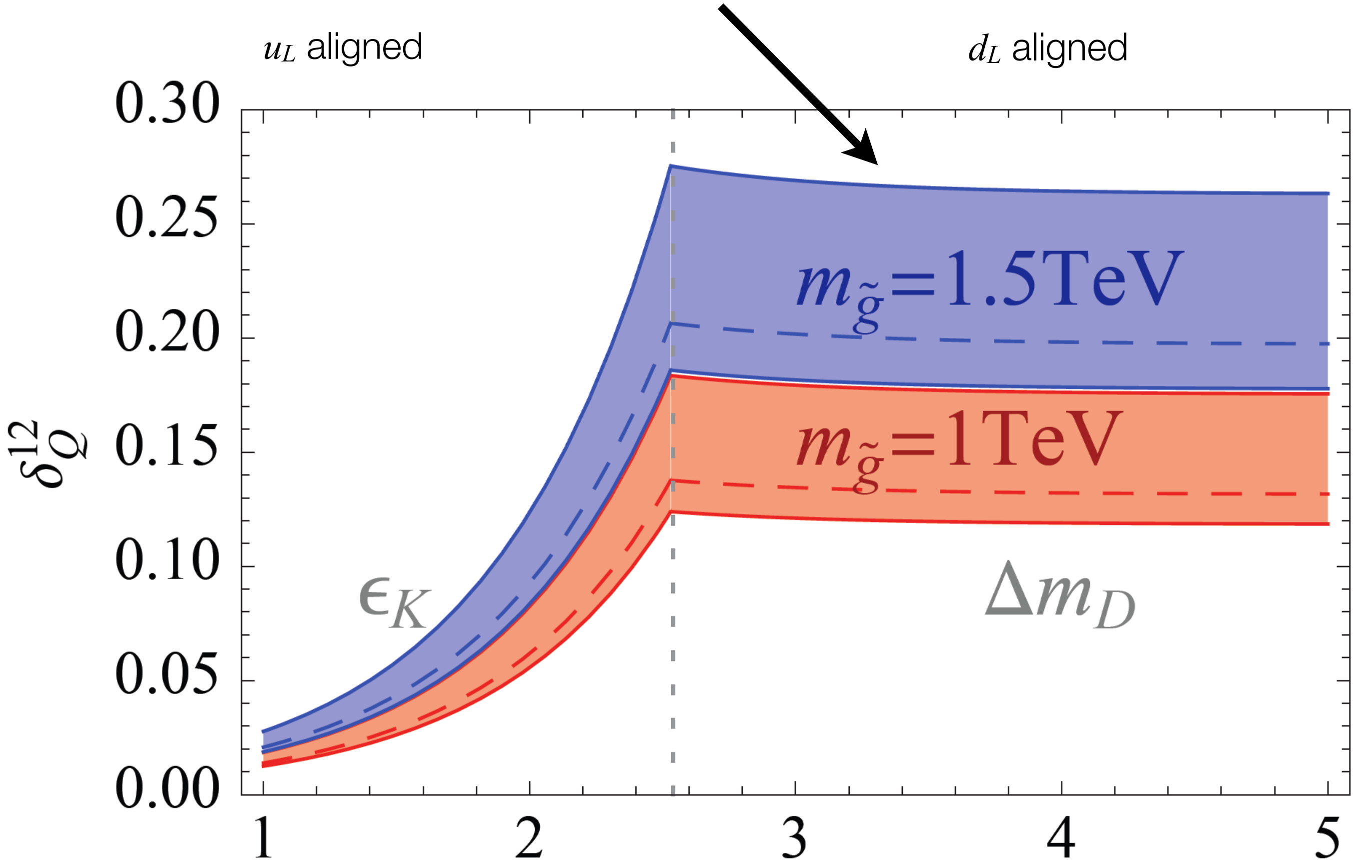
Imaginary part is universal => successful alignment models => small physical CP phase!

Gedalia, Kamenik, Ligeti & GP (12)

CP conserving constraints count => weaker degeneracy

Gedalia, Kamenik, Ligeti & GP (12)

$\delta_Q^{12} \lesssim 0.3$



$$\delta_Q^{12} \equiv \frac{m_{\tilde{Q}_2} - m_{\tilde{Q}_1}}{m_{\tilde{Q}_2} + m_{\tilde{Q}_1}}$$

- No strong degeneracy required!
- Ex.: $m_{\tilde{g}}$=1.3 TeV, $m_{\tilde{Q}_2}$ =550 GeV, $m_{\tilde{Q}_1}$ =950 GeV

(non) Degeneracy of Squarks

- No strong degeneracy required!
- Ex.: $m_{\tilde{g}}$=1.3 TeV, $m_{\tilde{Q}_1}$=550 GeV, $m_{\tilde{Q}_2}$=950 GeV
- This can be generated by*: Dine, Kagan & Samuel (90); Nir & Raz (02).
  - Anarchy at the SUSY breaking mediation scale
  - SUSY renormalization group flow to the TeV scale
  - Can lead to modest level of degeneracy

Back to $D - \bar{D}$ mixing

ד

δ

Δ

Two questions on CPV in D mixing (3 slides)

- So within successful alignment models can we say something generic on CPV in D mixing? (& how to go beyond LO in δ_Q^{12})

Kadosh, Paradisi & GP, in progress.

- Can we robustly bound the SM CPV in D mixing?

Grossman, Kagan, Ligeti, GP & Petrov, in prep'.

Alignment: upper bound on CPV in D mixing

Kadosh, Paradisi & GP, in progress.

- In complete alignment limit no CPV: $[\tilde{m}_Q^2, Y_d Y_d^\dagger] = 0$
- Min' alignment with Y_d just to saturate $\epsilon_K, \Delta m_D$: (switching to MIA)

$$\epsilon_K \propto \Im\left(\delta^d_{LL}\right)_{12} \Re\left(\delta^d_{LL}\right)_{12}, \quad \text{in alignment: } \Im\left(\delta^d_{LL}\right)_{12} \sim \Re\left(\delta^d_{LL}\right)_{12} \equiv \delta_{\epsilon_K} \sim 1\%$$

$$\Downarrow$$

$$\text{Im part of } D-\bar{D} \propto 2\lambda_{\rm C}\, \delta_Q^{12}\, \Im\left(\delta^d_{LL}\right)_{12} \approx 2\lambda_{\rm C}\, \delta_Q^{12}\, \delta_{\epsilon_K}$$

$$\Delta m_D \propto 4\lambda_{\rm C}^2 \left(\delta_Q^{12}\right)^2 \qquad \text{(both for } 2\lambda_{\rm C}\delta_Q^{12} \gg \delta_{\epsilon_K})$$

$$\Downarrow$$

$$\text{CPV in } D-\bar{D}: \ \delta_{\epsilon_K}/2\lambda_{\rm C}\, \delta_Q^{12} \lesssim 10\% \times \left(0.3/\delta_Q^{12}\right)$$

LHCb soon (HCP?) will start testing alignment paradigm!
ATLAS+CMS implications discussed below.

SM: upper bound on absorptive CPV in D mixing

Grossman, Kagan, Ligeti, GP & Petrov, in prep'.

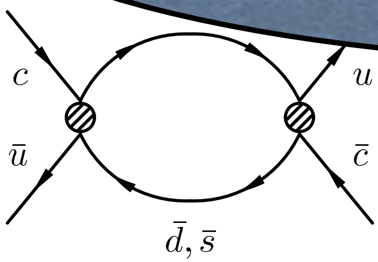
$$\langle D^0|\mathcal{H}|\overline{D}^0\rangle = M_{12} + \frac{i}{2}\Gamma_{12}\,. \qquad |D_{1,2}\rangle \quad p|D^0\rangle \pm q|\overline{D}^0\rangle.$$

preliminary

$$m \equiv \frac{m_1+m_2}{2}, \qquad \Gamma \equiv \frac{\Gamma_1+\Gamma_2}{2}, \qquad x = (0.63^{+0.19} \quad 10^{-2} \quad y = (0.75 \pm 0.12) \times 10^{-2}$$

$$x \equiv \frac{m_2 - m_1}{\Gamma},$$

absorptive = related to on-shell states



(neglecting b a sec' a sec')

Γ_{xy} in the OPE picture

$$\phi_{12}^{\Gamma} \equiv \mathrm{Im}\left(\frac{\delta\Gamma_{12}}{\Gamma_{12}^{0}}\right) = \frac{1}{2}\arg\left[\frac{\Gamma_{12}}{\Gamma_{12}^{*}}\left(\frac{A_f}{\overline{A}_f}\right)^2\right]$$

$$\phi_{12}^{\Gamma} = 2\,|\lambda_b\lambda_s|\,\sin\gamma\,\frac{\Gamma_{sd}}{\Gamma_{12}^{0}}\,\frac{\Gamma_{sd}-\Gamma_{dd}}{\Gamma_{sd}} + O(\lambda_b^2),$$

$$|\phi_{12}^{\Gamma}| = 0.008 \;\times\; y_{sd} \;\times\; |\epsilon_d^{\Gamma}|\,, \qquad \epsilon_d^{\Gamma} \equiv \frac{\Gamma_{dd}-\Gamma_{sd}}{\Gamma_{sd}}, \qquad \mathrm{SU(3)\ breaking}\ \epsilon_d^{\Gamma} \lesssim 1 \qquad y_{xy} \equiv |\Gamma_{xy}/\Gamma|\,,$$

Unitarity: $y_{sd} \leq 1 \quad \Rightarrow \quad \boxed{|\phi_{12}^{\Gamma}| \lesssim 0.008 \times |\epsilon_d^{\Gamma}|}.$

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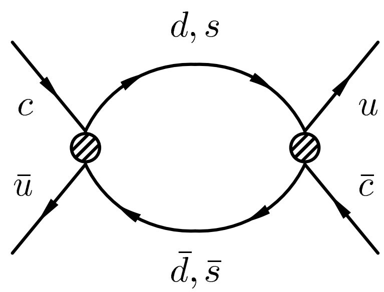
$$x \equiv \frac{m_2-m_1}{\Gamma}, \qquad y \equiv \frac{\Gamma_2-\Gamma_1}{2\Gamma}. \qquad |q/p| = 0.91^{+0.18}_{-0.16}\,, \qquad \phi = -0.18 \pm 0.16\,.$$

$$\Gamma_{12}^0 = -\left(\lambda_s^2\,\Gamma_{ss} + 2\lambda_s\lambda_d\,\Gamma_{sd} + \lambda_d^2\,\Gamma_{dd}\right), \qquad \text{where} \quad \lambda_p = V_{cp}V_{up}^*$$



Γ_{xy} in the OPE picture

(neglecting b a sec' a sec')

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Unitarity: $y_{sd} \leq 1$ $\Rightarrow$ $\boxed{|\phi_{12}^{\Gamma}| \lesssim 0.008 \times |\epsilon_d^{\Gamma}|}$.

D mixing absorptive CPV, measured? affected by NP?

Grossman, Kagan, Ligeti, GP & Petrov, in prep'.

preliminary

- ϕ & ϕ_{12}^{Γ}: quasi-universal CP phases, related to final states without CP in decay, $\left|\frac{\bar{A}_f}{A_f}\right| \simeq 1$

$$\left|\frac{q}{p}\right|^2 e^{-2i\phi} = \frac{(x_{12}/y_{12})\, e^{-i\phi_{12}} - i}{(x_{12}/y_{12})\, e^{i\phi_{12}} - i} e^{-2i\phi_{12}^{\Gamma}}$$

$y_{12} \equiv \frac{|\Gamma_{12}|}{\Gamma}\,,\quad x_{12} \equiv \frac{2|M_{12}|}{\Gamma}\,,\quad \phi_{12} \equiv \arg\left(\frac{M_{12}}{\Gamma_{12}}\right)$

- Modified model indep' bound:

Ligeti, Papucci & GP; Grossman, Nir & GP; Kagan-Sokoloff.

$$\tan(\phi - \phi_{12}^{\Gamma}) = -A_m x/y$$

$A_m = (|q/p|^2 - 1)/(|q/p|^2 + 1)$

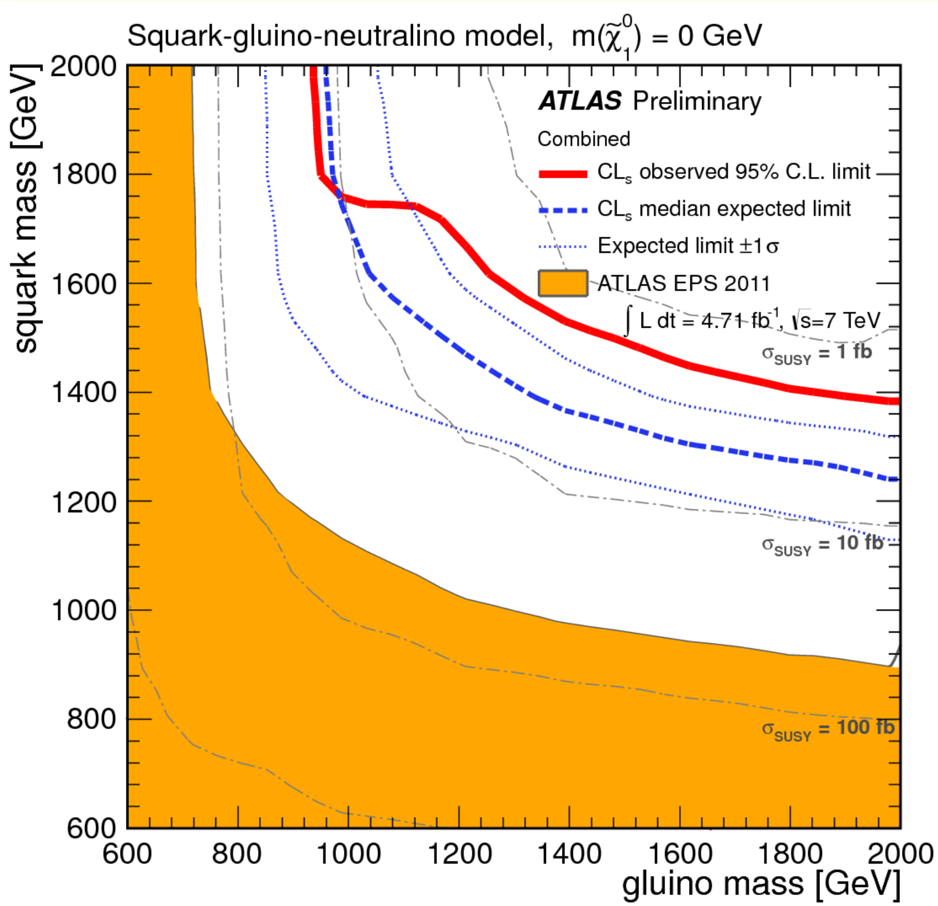
LHCb precisely measure x, y, ϕ, A_m & test for presence of ϕ_{12}^{Γ}

- CPV light hidden sector that couples to D & decay to SM => quasi universal absorptive phase, can be observed as above.

However is this consistence with the LHC data??

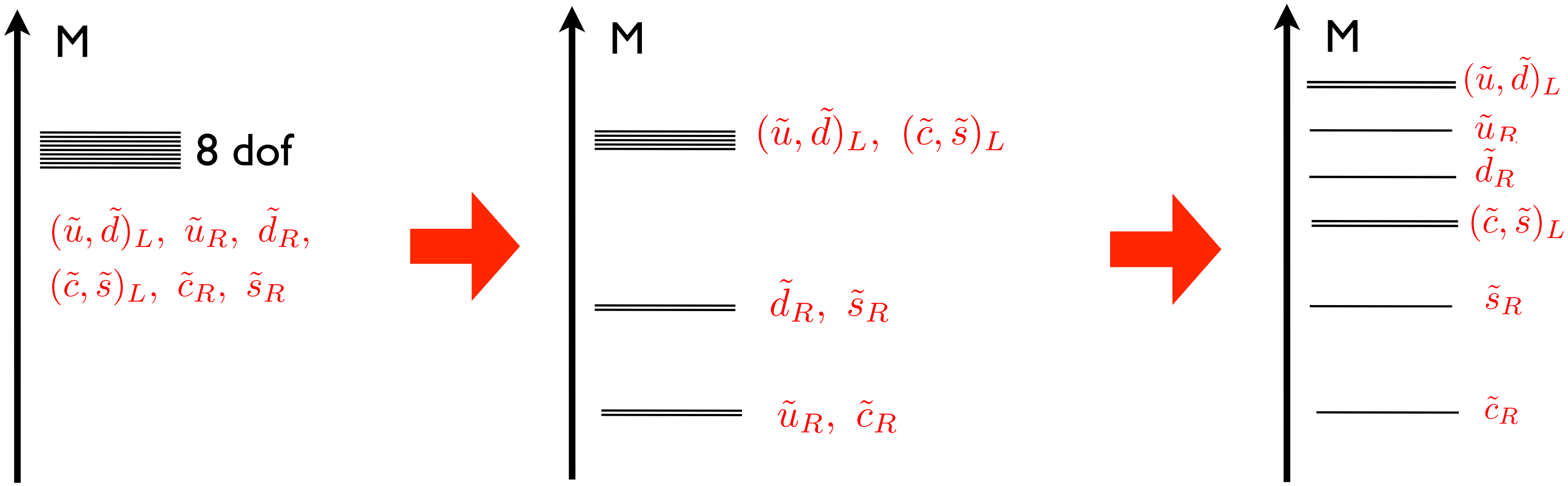
Mahbubani, Papucci, GP, Ruderman & Weiler, to appear.

$$m_{\tilde{g}} = 1.3\,\mathrm{TeV},\, m_{\tilde{Q}_1} = 550\,\mathrm{GeV},\, m_{\tilde{Q}_2} = 950\,\mathrm{GeV}$$



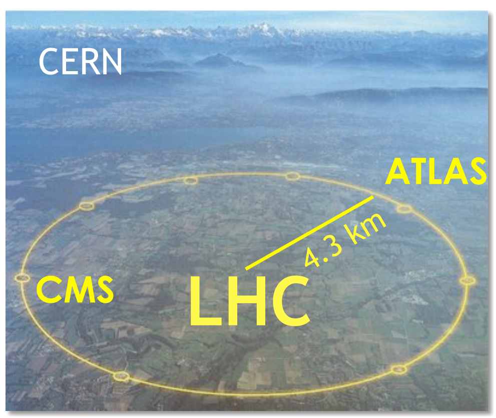
What if the first 2 generation squark are not degenerate?

Mahbubani, Papucci, GP, Ruderman & Weiler, to appear.



Everything degenerate — Split, but MFV — Anarchy!

??



??

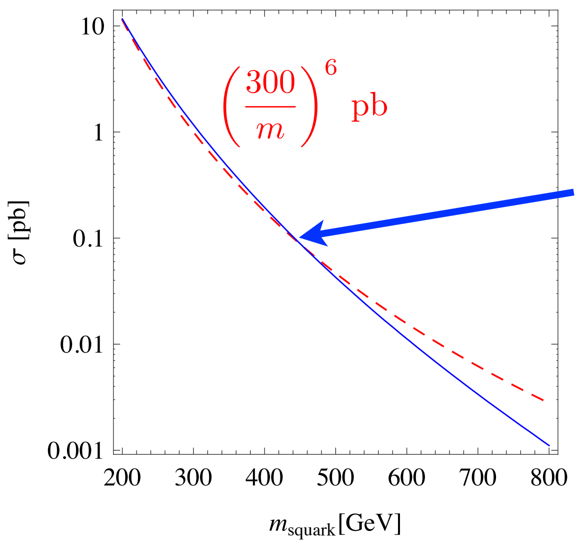
Limits affected by:

- squark multiplicity
- signal efficiencies
- PDFs

How do limits change?

Cross-sections vs. mass

$$\sigma(pp \to \tilde{u}_R \tilde{u}_R^*) \propto \frac{1}{m^6}$$ (roughly)



NLO xsec (Prospino)

(gluino decoupled)

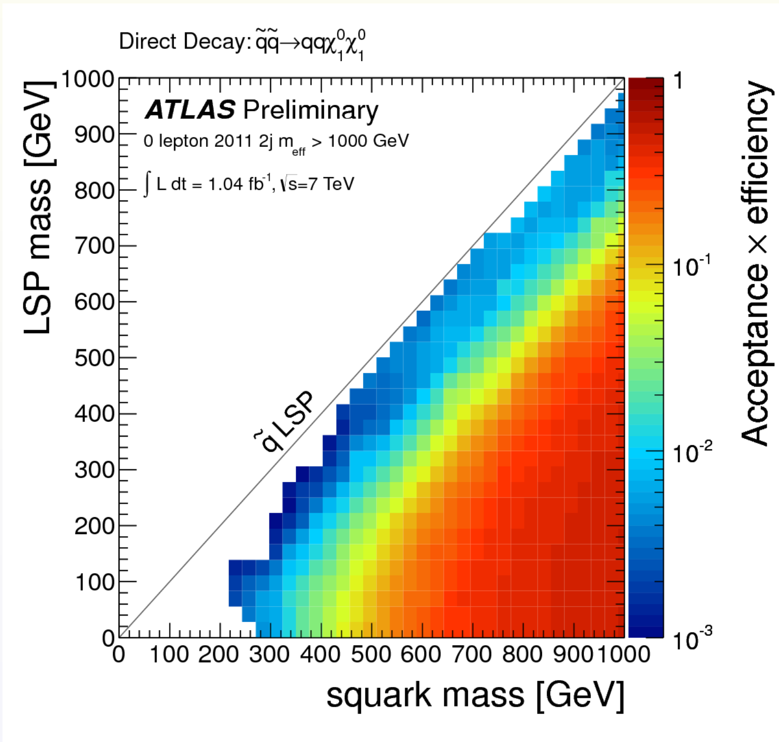
$$8/m^6 = 6/m_H^6 + 2/m_L^6$$

$$(m_L/m_H) = (1/4)^{1/6} \sim 0.8$$

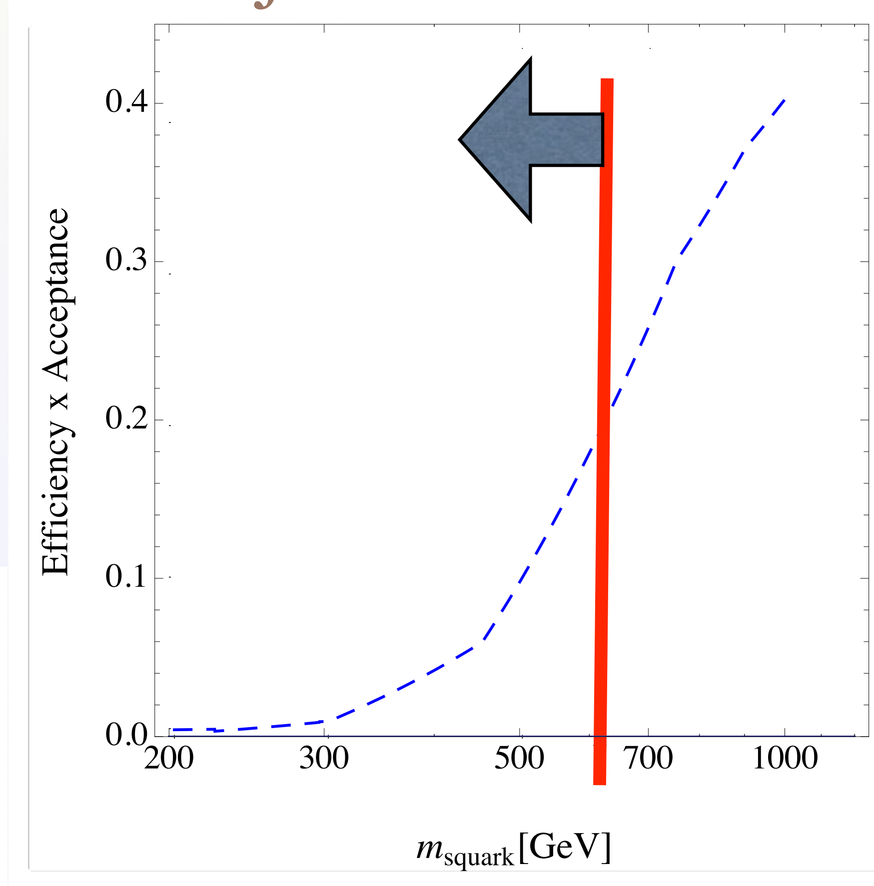
Efficiencies

Signal efficiency falls very rapidly with decreasing squark mass

Below $\sim$ 600 GeV $\epsilon\sigma = 1$

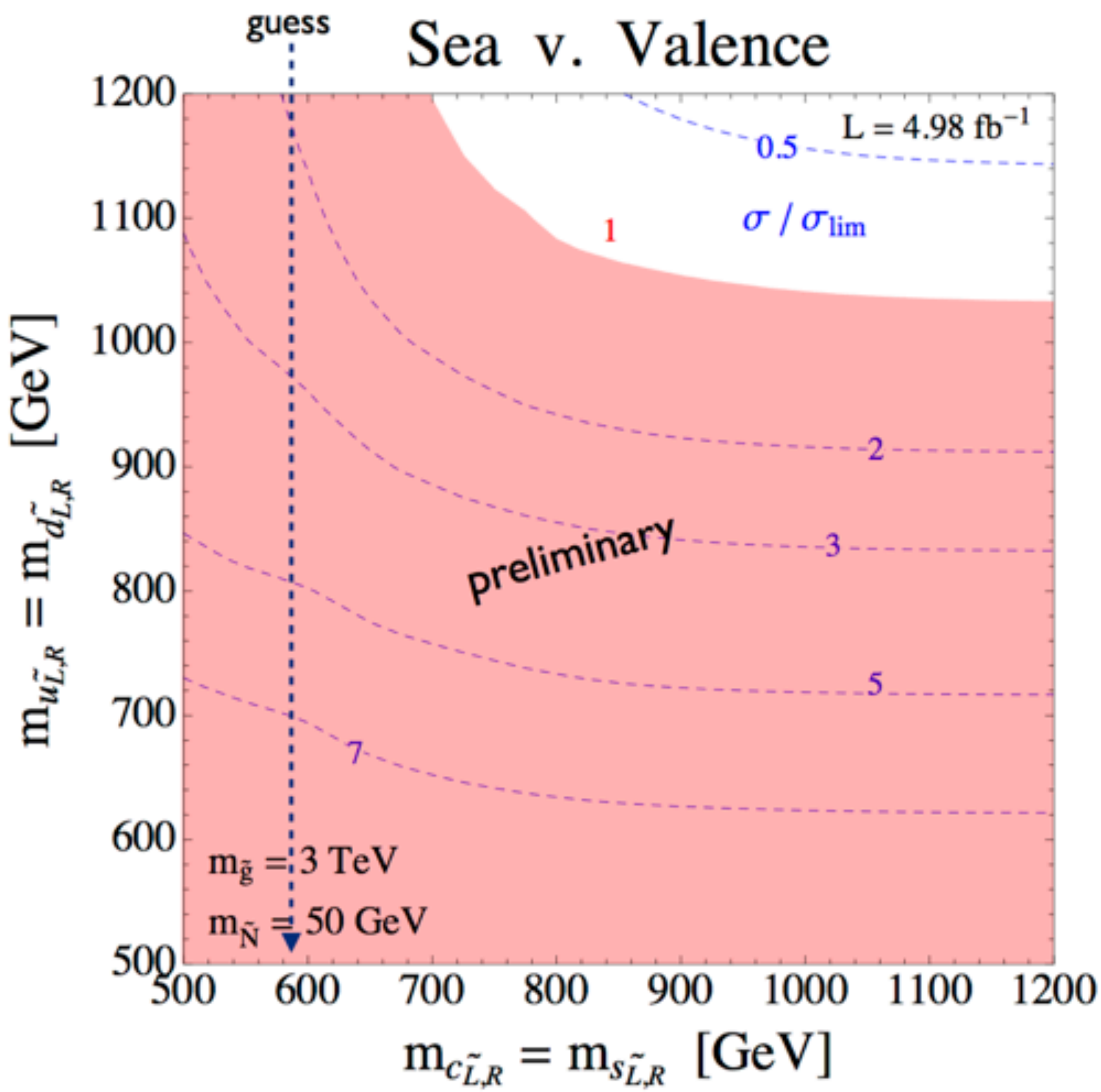


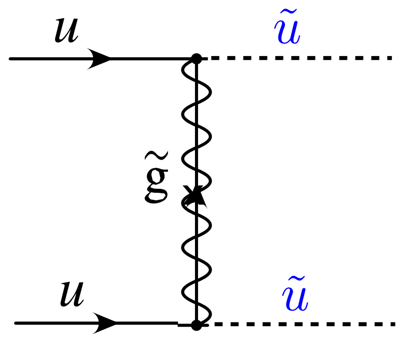
ATLAS 1/fb,
2jet M_{eff}>1TeV



meff is the scalar sum of transverse momenta of the leading N jets with E^{miss}.

In fact, all 4 flavor "sea" squarks can be rather light!





Conclusions

- Minimalism: up flavor & CPV might hold the key.

- Alignment: non degeneracy is viable: testable at LHC(b).

- SM: new (*preliminary*) robust bound on absorptive D-D CPV; sensitive to "dark photon / hidden valley" models.
  (The holy grail being the dispersive remains unconstrained)

- Light (non-"sups") squarks maybe buried (regardless of alignment).